Relativistic Nuclear Physics

Basic Facility Nuclotron and its Development

03-1-0979-92/2005

Priority of the project:	1
Status:	Realization

Development of the Nuclotron Accelerator Complex

Leader from JINR: A. Kovalenko

Participating countries and international organizations: JINR, Bulgaria, Germany, Romania, Russia, Slovak Republic, Sweden, the USA, Finland

The Nuclotron accelerator complex at LHE is the basic facility of JINR for generation of proton, polarized deuteron (also neutron/proton) and multicharged ion (nuclear) beams in the energy range up to 6 GeV/u. General view of the facility is shown in Fig.1.

The Nuclotron was built during 1987–1992. This accelerator is based on the unique technology of superconducting magnetic system, which was proposed and investigated at the Laboratory. All design, tests and assembling work were carried out at LHE. Mechanical production of the structural cryomagnetic elements was done by the JINR workshops.

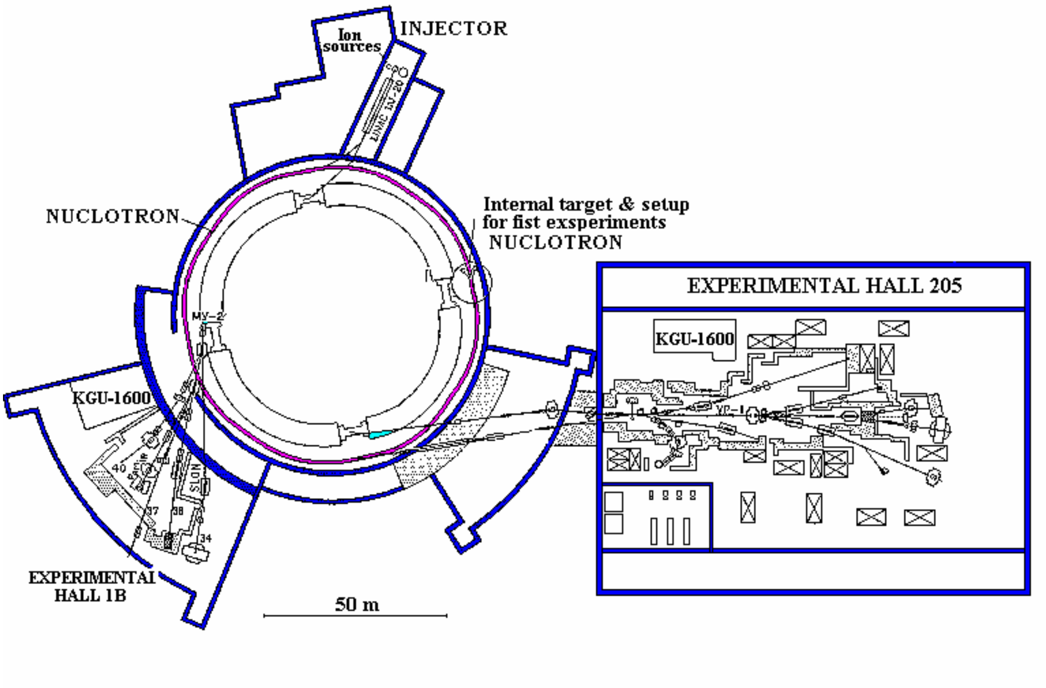


Fig.1. The Nuclotron accelerator complex

The main goals

Providing polarized deuteron beams at the Nuclotron with intensities up to 10^9pps. Extension of heavy ion beams available for physics experiments up to Xe. Development of new superconducting magnets for rapid cycling heavy-ion synchrotrons and beam transport channels. Construction of prototype magnets for the booster rings. Work on the replacement of conventional magnets by superconducting ones along the beam line VP1.

Experiments and Facilities at Nuclotron

03-1-0983-92/2004

Priority of the project: 1

Status: Data taking

Investigation of Multiple Processes in Nucleus–Nucleus Collision in 4π Geometry, Development of the SPHERE Experimental Facility

Leader from JINR: A. Malakhov

Participating countries and international organizations: Azerbaijan, Armenia, Belarus, Bulgaria CERN, Czech Republic, Japan, Kazakhstan, Mongolia, Poland, Romania, Russia, Slovak Republic, Ukraine, Uzbekistan

The main goal of the project is to construct the SPHERE experimental facility for an investigation of relativistic nucleus fragmentation in geometry closed to 4π using the LHE accelerator complex.
The SPHERE spectrometer is aimed at high intensity nuclear beams accelerated by the Nuclotron. The primary beam intensity will be up to 10^8–10^9 s^{-1} for the study of multiple cumulative hadron production and up to 10^{11} s^{-1} for the muon pair production study.

A general layout of the spectrometer is shown in the Fig.1. Functionally, the spectrometer consists of three parts:

- Central detector aimed at identification of fragmentation products of the target nucleus.
- Forward detector covering the fragmentation region of the projectile nucleus.
- Target and hadron absorber for muon experiments.

The strategy is to make experiments using the prepared detector subsystem. Based on this strategy the experimental results shown below have been obtained.

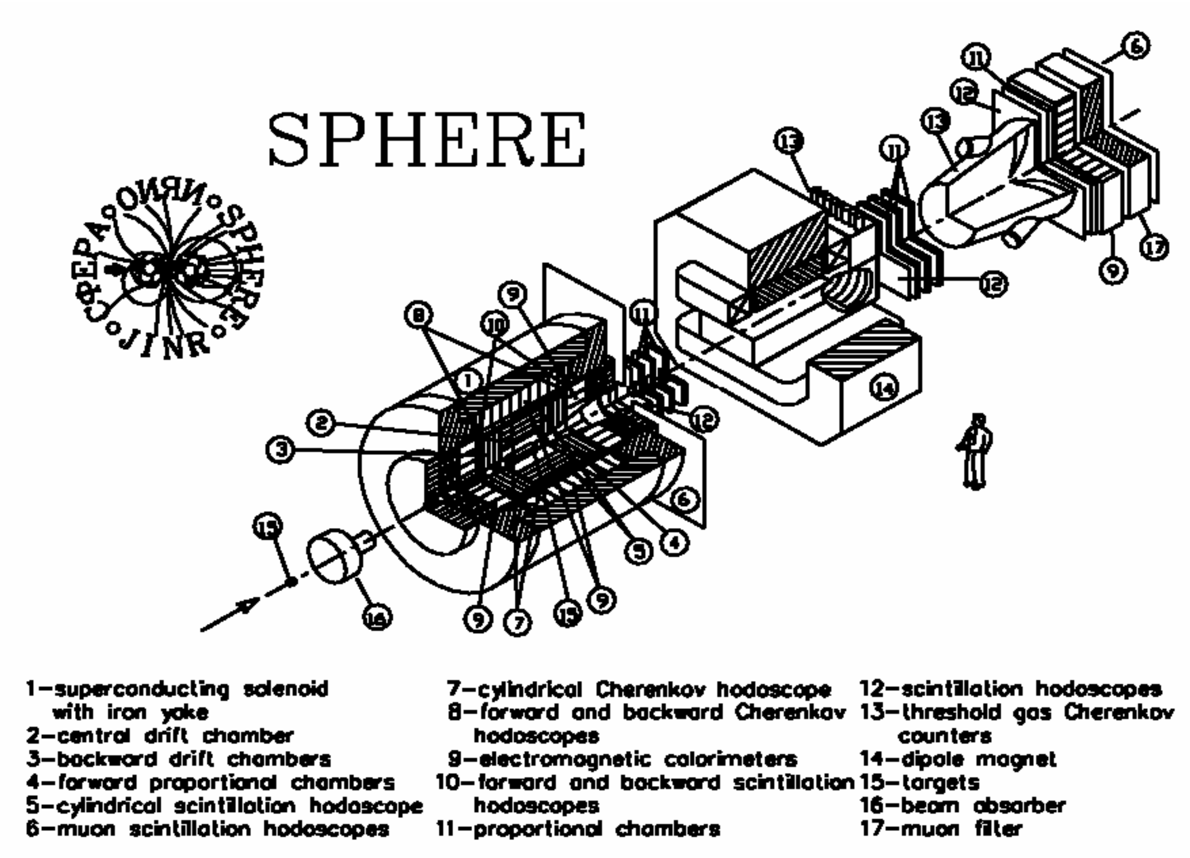


Fig.1. General layout of the SPHERE experimental facility

The Research Program

1. Multiple cumulative particle production in 4π geometry:

- Reactions of multiple cumulative particle production with special attention paid to:
- vector meson production in cumulative region;
- search for quark exotic states;
- study of dynamic correlation.
- Spin effects critical for theoretical model approval.
- Lepton pair productions since it bear information about internal nuclear structure.

2. Investigation of tensor analyzing power for cumulative hadron production.

3. Investigation of nucleus excitation in charge exchange reactions.

4. Hypernucleus investigation program:

- mean lifetime ${}^{3}_{\Lambda}H$, ${}^{4}_{\Lambda}H$ and ${}^{6}_{\Lambda}He$;
- binding energy of hypernuclei ${}^{3}_{\Lambda}H$ and ${}^{6}_{\Lambda}He$ and their Coulomb dissociation.

5. Search for η−nuclei.

6. Investigation of pion production:

- process of pion production by pions on nuclei;
- single and double charge exchange reactions on nuclei;
- few nucleon systems;

7. Experiments on the Nuclotron internal target:

- investigation of the interaction of η−mesons with nucleons and nuclei;
- study of subthreshold production of ρ, ω, φ, η, K mesons and lepton pairs in nucleus-nucleus collision;
- study of narrow two-proton correlation;
- investigation of double cumulative effect.

8. Search for exotic nuclei such as ^{10}He, ^{15}B, ^{22}O, ^{23}Na.

03-0-0941-91/2006		Priority of the project: 1
		Status: Data taking

Investigation of Charge-Exchange Processes in the Deuteron-Proton Collisions (Project STRELA)

Leader from JINR: V. Glagolev, N. Piskunov

Participating countries and international organizations: Bulgaria, JINR, Poland, Russia, Slovak Republic.

An experiment is proposed to study the spin dependent part of the nucleon scattering amplitude in the $np \to pn$ charge exchange process at the Nuclotron deuteron beams. The two-proton production cross section at small momentum transfers in the dp interactions is planned to measure in the range of the deuteron momentum from 3.0 GeV/c to 4.0 GeV/c. The experimental equipment includes the liquid hydrogen target, analysing magnet, scintillation and Cherenkov counters, drift tubes. The selection of events with two protons having momentum near to half of momenta impinging deuteron is made. Differential cross section of charge-exchange reaction on deuteron near t=0 determining a spin-dependent part of amplitude np→pn scattering is measured. Layout of the experimental setup is shown in a Fig.1.

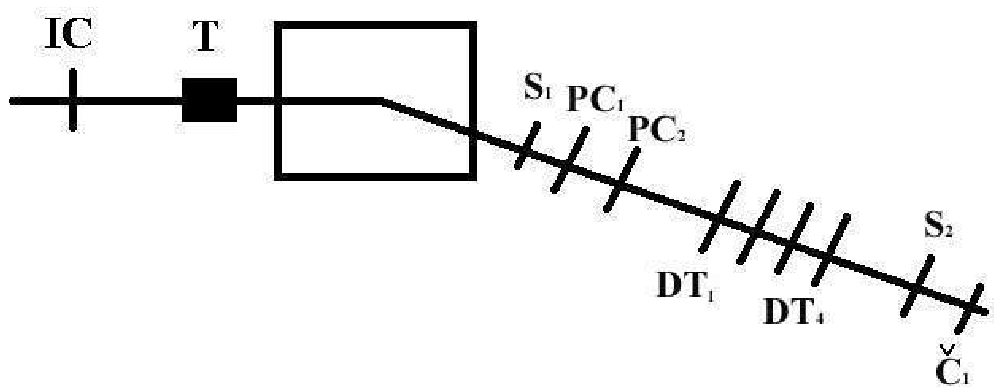


Fig.1

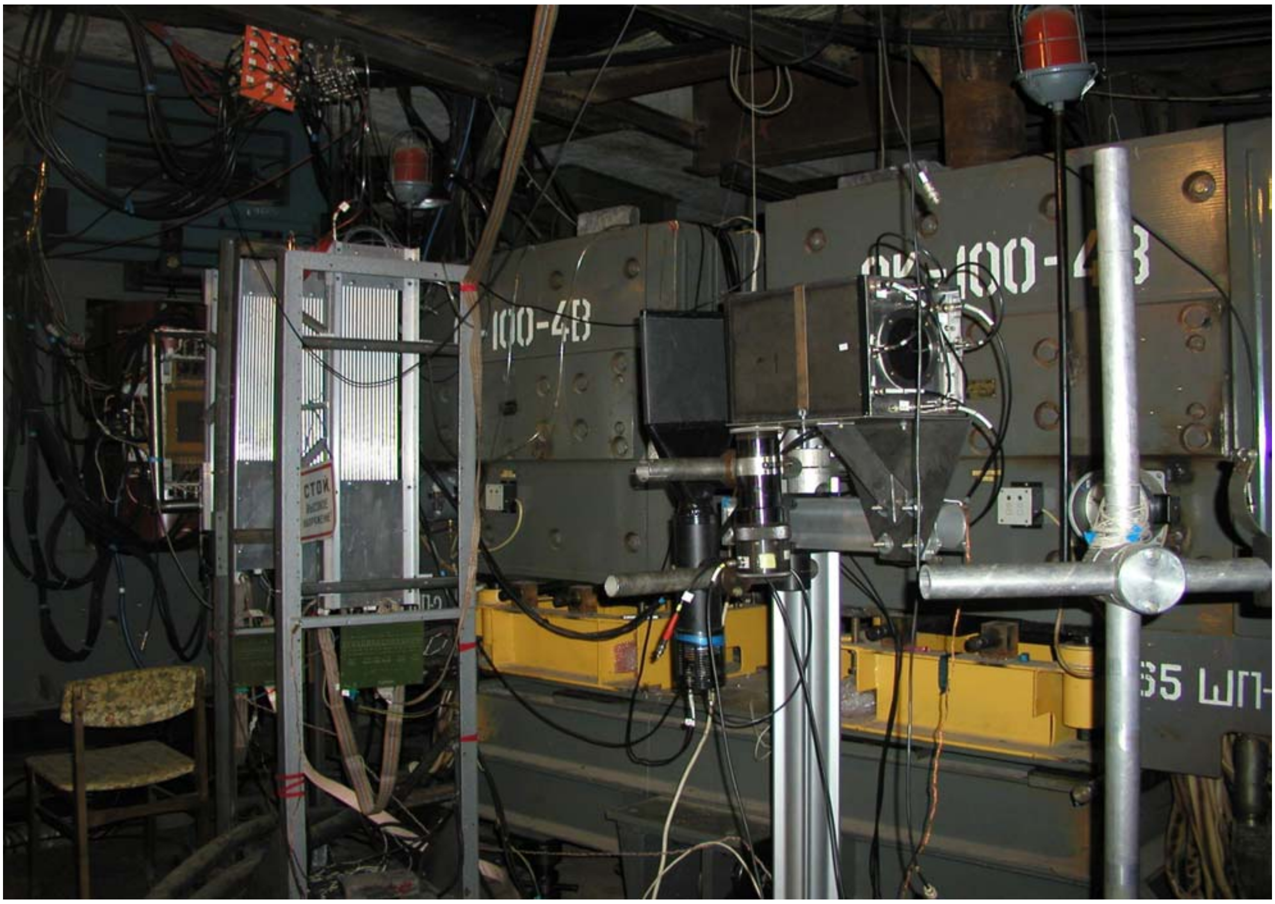


Fig.2. Photo of the setup Strela from the side of drift tubes.

03-0-0941-91/2006

Priority of the project:	1
Status:	Completed

Investigation of Polarization Phenomena and Nuclear Reactions with the Medium Resolution Spectrometer (Project MRS)

Leader from JINR: N. Piskunov

Participating countries and international organizations: Bulgaria, JINR, Russia, Slovak Republic, the USA, Ukraine.

It is proposed to use the Medium Resolution Spectrometer (LAMPF, Los Alamos, USA) at the accelerator complex of the Laboratory of High Energies of JINR (Dubna, RUSSIA). This possibility arised after signing by representatives on March, 13th, 1997 the AGREEMENT on the Scientific Collaboration among Los Alamos National Laboratory, Los Alamos, NM, USA, the Institute for Nuclear Research of the Russian Academy of Science, Moscow, Russia and the Joint Institute for Nuclear Research, Dubna, Russia. Due to the agreement the MRS is available for experiments at the Laboratory of High Energies for 5 year period with additional prolongation.

Installation of this spectrometer opens new opportunities for the LHE research program in relativistic nuclear physics and particle physics in the "transition mode" region using various nuclear beams as well as polarized deuteron and nucleon beams up to momenta of 6 GeV/c per nucleon. Common utilisation with the polarized proton target (ANL–Saclay–JINR) opens unique opportunities for studies of spin effects in this energy region.

Physical motivation

Problems of understanding the nature of confinement in strong interactions, origin of nucleon spin and QCD vacuum structure pertain to the most fundamental problems of the modern nuclear and particle physics. The progress in solving these problems is based on the intense experimental and theoretical studies of processes occurring at distances from the confinement radius, where nonperturbative effects dominate, up to those, where the perturbative QCD begins to be valid, i.e. in the so-called "transition region". Polarization phenomena in strong interactions are one of the most informative sources of information about physics of the "transition region".

The first part of the program includes experiments with MRS as the main detector; for some of the experiments simple detectors must be added and this part of the program can be started immediately after the installation of MRS in LHE (the "first generation" experiments). The second part contains experiments studying various multi-particle correlations, and MRS will be used as one arm of multi-arm setup (the "second generation" experiments).

Description and main parameters of the MRS spectrometer

The MRS spectrometer consists of three basic elements: a quadrupole which mainly focuses in the transverse (horizontal) direction, a dipole that bends the central ray 33^o upwards, and a second dipole that bends the central ray 15^o downwards which leaves an overall bend angle of only 18^o, see Fig 1 and Table 1. Since the quadrupole focuses in horizontal direction, it is mainly responsible for the large horizontal acceptance (±60 mrad) of MRS. Both edge angles of the first dipole are slanted by 41^o and provide radial focusing at the entrance as well at the exit. The curvature of the entrance edges introduces sextupole corrections to the system. The second dipole is quite short, bends in the reverse direction, and has rotated and curved edges at both the entrance and the exit. This dipole, roughly triangular in shape, acts primarily as a quadrupole doublet. The entrance edge focuses radially while exit edges focus transversely.

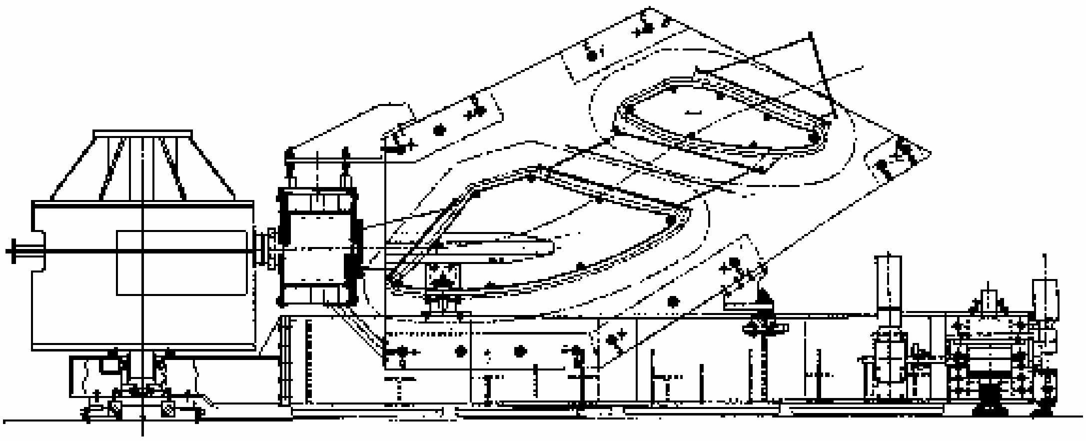


Fig.1. Side view of the MRS spectrometer

Table 1: **Main parameters of the MRS**

1.	**Overall dimensions (length, width, height), m**	**9.25 * 4.0 * 5.5**
2.	**Optical configuration**	$QD\vec{D}$
3.	**Momentum range, GeV/c**	**0.2–1.8**
4.	**Nominal momentum (B=17 kG), GeV/c**	**1.5**
5.	**Momentum acceptance, $\Delta p/p$, %**	**$\pm$ 20**
6.	**Momentum resolution, $\delta p/p$. %**	**0.08 – 0.2**
7.	**Solid angle, msr**	**7 – 9**
8.	**Horizontal acceptance angles, mr**	**$\pm$ 60**
9.	**Vertical acceptance angles, mr**	**$\pm$ 40**
10.	**Total weight, tons**	**118**
11.	**Electrical power consumption, kW**	**350**
12.	**Voltage, V (consumption, kW)**	
	Q	**123 (100)**
	D	**204 (161)**
	$\vec{D}$	**127 (89)**
13.	**Water flow, l/min**	**460**

03-0-0941-91/2006

Priority of the project:	1
Status:	Preparation

Measurement of Spin Correlation in Backward Elastic *dp* Scattering (Project BES)

Leader from JINR: I. Sitnik

Participating countries and international organizations: Bulgaria, JINR, Russia, Czech Republic, Slovak Republic, Ukraine, the USA.

The physics goal is to measure the spin correlation parameter CNNOO in backward elastic *dp* scattering (BES) when both the initial deuteron and a proton have a transversal (parallel or antiparallel) polarization. Such an observable of this reaction has never been measured.

This reaction is usually considered as a one-neutron-exchange (ONE) process, which is a particular case of IA. In this approach, the deuteron is considered as two nucleons in the S- and D-states. The obtained data do not support such a simple picture. To clear up the situation, the measurement of new polarization observables is necessary. To reconstruct all of 4 complex amplitudes decribing BES, no less than 7 polarization observables must be measured.

The observable CNNOO, suggested to be measured is most sensitive to possible additional P-waves in the deuteron, Such components are inevitable when a relativistic description of the deuteron is used; they also emerge in the models based on quark counting when the 6-q states are projected on such two-nucleon systems as NN*.

To study all BES aspects, the activity of our collaboration is directed to extending this program. As the next step after this experiment, the measurement of polarization transfer from deuteron to deuteron is under development. The measurement of polarization transfer from proton to proton is approved at COSY (spokesman C. Pedrisat). The measurement of tensor-vector asymmetry, which is sensitive to the imaginary parts of the scattering amplitudes is studied as a possible task for Dubna or COSY.

Research Program

To realize the experiment, a new spectrometer (NS) should be made near the Polarized Proton Target installed at the Dubna Synchrophasotron-Nuclotron. The system PPT+NS is implied as a multitask one.

The conditions of the experiment allow us to use the region of primary beam momenta of 2.0–6.5 GeV/c. This corresponds to internal momenta of 0.33–0.85 GeV/c in the deuteron.

Measurements of 10 points with error bars of about ±0.03 inside this region are being planned. The following parameters of the setup are assumed: the solid angle is 10^{-2}rad, the momentum resolution is 1%, and the time of flight resolution is better than Ins. A detailed description of the suggested experiment is given in ref.

03-0-0941-91/2006

Priority of the project:	1
Status:	Data taking

Determination of Spin-Dependent Elastic np Forward Scattering Amplitudes over 1.2–3.7 GeV Reaction: Measurments of the $\Delta\sigma_{L,T}$(np) and A_{ookk}(np) and A_{oonn}(np) — Total np Cross Section Differences and Spin-Correlation Parameters from np→pn Scattering (Project DELTA-SIGMA)

Leader from JINR: V. Sharov, L. Strunov

Participating countries and international organizations: Bulgaria, CERN, Czech Republic, JINR, Russia, France, Ukraine

The $\Delta\sigma_L$(np) and $\Delta\sigma_T$(np) are the differences in *np* total cross sections for antiparallel and parallel beam and target polarizations, oriented longitudinally (L) or transversely (T) with respect to the beam direction. Transmission measurements over 1.2–3.7 GeV of the energy dependences of $\Delta\sigma_L$(np) and $\Delta\sigma_T$(np) have been proposed and started in Dubna in collaboration with the groups from FSU, France and the U.S.

The main aim of these experiments is to extend studies of the nucleon-nucleon (NN) interaction over a new higher energy region of free polarized neutron beams, provided at present only by the JINR LHE accelerator.

Measurements of the $\Delta\sigma_L$(np) and $\Delta\sigma_T$(np) at the same energies allow a direct determination of the imaginary parts of the *np* forward scattering amplitudes. The energy points in which the $\Delta\sigma_{L,T}$(np) are to be measured have to be chosen near those where the $\Delta\sigma_{L,T}$(np) results already exist. It is suitable to deduce a $\Delta\sigma_{L,T}$(I=0) — isoscalar part of the $\Delta\sigma_{L,T}$(NN), using both the measured $\Delta\sigma_{L,T}$(np) values and significantly large set of $\Delta\sigma_{L,T}$(pp) (isospin I=1) existing data. $\Delta\sigma_{L,T}$(np) obtained data can be also used for a verification of predictions of some modern dynamic models of strong interaction and in a future phase-shift analysis (PSA) over this energy range.

To perform the proposed $\Delta\sigma_{L,T}$(np) measurements int Dubna, a large reconstructed Argonne-Saclay polarized proton target (PPT), the new polarized neutron beam lines with suitable parameters, the modern set of neutron detectors with corresponding electronics and data acquisition system, and other needed equipment were prepared, tuned, and tested. A scheme of the Delta-Sigma set-up is shown in Fig.1.

The free polarized neutron beam is produced by break-up at 0°of vector polarized deuterons, accelerated and extracted at the Synchrophasotron of the JINR LHE. The neutron beam energy can be varied over a range of 1.2–3.7 GeV with a momentum spread of FWHM ≅ 5%. An intensity of the prepared neutron beam is at present ~ $2\cdot10^6$ n/cycle. The size of beam spot at the PPT placing is ≅30 mm in diameter. The L/T-polarization of neutron beam is $\vec{P}_n \cong 0.53$.

The dimensions of the frozen-spin polarized proton target are 200 mm long and 30 mm in diameter. The proton polarization at the PPT is $\vec{P}_p \cong 0.7$–0.8.

The research program

Taking into account the present economic situation, the experimental program can be completed up to 2004 using the intense polarized beams from the Synchrophasotron and Nuclotron. The planned measurements are as follows:

1) To complete the measurements of the $\Delta\sigma_L$(np) energy dependence one needs to measure the $\Delta\sigma_L$(np) values at 1.4, 1.6, 2.0 and 3.17 GeV with a statistical accuracy better than 1 mb. The request of run-time for these measurements is about 10 days.

2) The measurements of the energy dependence of the $\Delta\sigma_T(np)$ with transverse polarized beam neutrons and target protons. These measurements will be carried out at the energy points where the $\Delta\sigma_L(np)$ were measured. The run-time request for the $\Delta\sigma_T(np)$ measurements with statistical accuracy about 1 mb is about 30 days.

The simultaneous with $\Delta\sigma_L(np)$ and $\Delta\sigma_T(np)$ measurements of spin correlation parameters in the np backward elastic scattering are in preparing to study the real parts of the NN elastic scattering amplitudes together with imaginary ones.

Expenses from the JINR budget are mainly needed to prepare and carry out the Delta-Sigma setup runs — 40 days using L,T polarized beams of the LHE JINR accelerating complex. The set-up is built thanks mainly to the external support and was successfully tested during the 2 short $\Delta\sigma_L(np)$ runs jointly with the PPT.

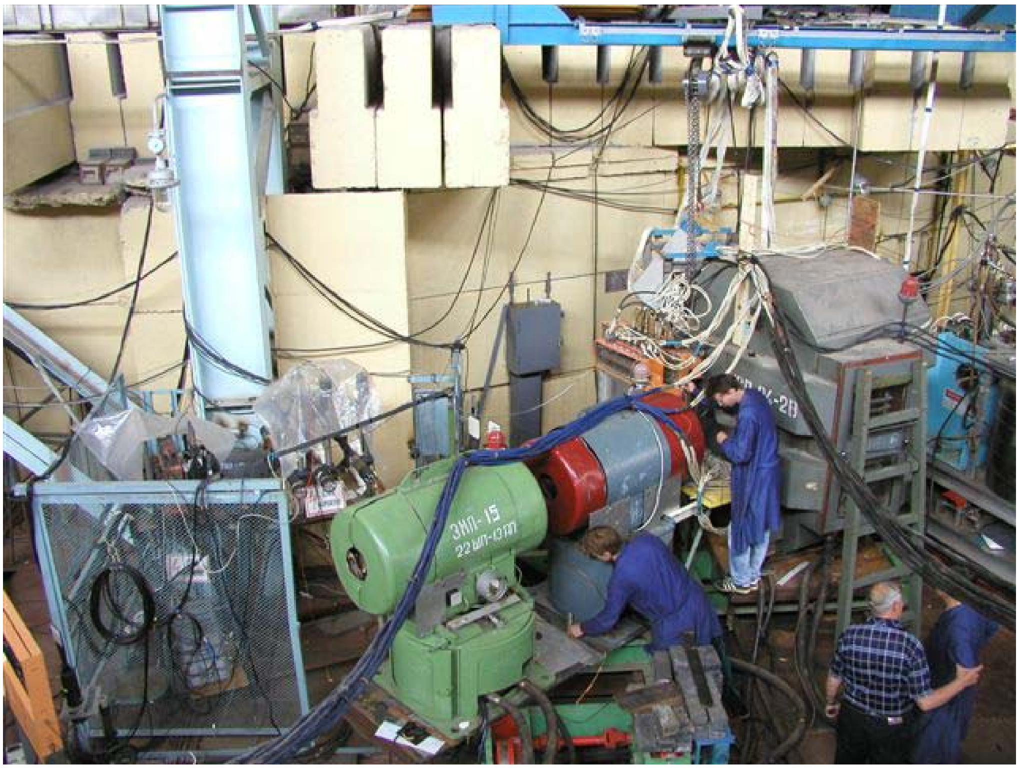


Fig.1

03-0-0941-91/2006

Priority of the project:	1
Status:	Data taking

Measurement of Polarization Transfer from d to p in the Reaction $^{12}C(\vec{d},\vec{p})X$ at Internal Momenta of 0.6–0.8 GeV/c (Project KAPPA)

Leader from JINR: I. Sitnik

Participating countries and international organizations: JINR, Bulgaria, France, the USA

We plan to measure the polarization transfer coefficient from deuteron to proton in the reaction $^{12}C(\vec{d}, \vec{p})X$. The vector polarized deuteron beam will be varied from 7.0 to 6.6 GeV/c while beam line for secondary will be adjusted for protons of 5.5 GeV/c. The corresponding interval of internal momenta k will be varied from 0.6 up to 0.8 GeV/c. The present experiment will allow to extend the existing set of data on polarization transfer, which is restricted now by values k =0.58 GeV/c.

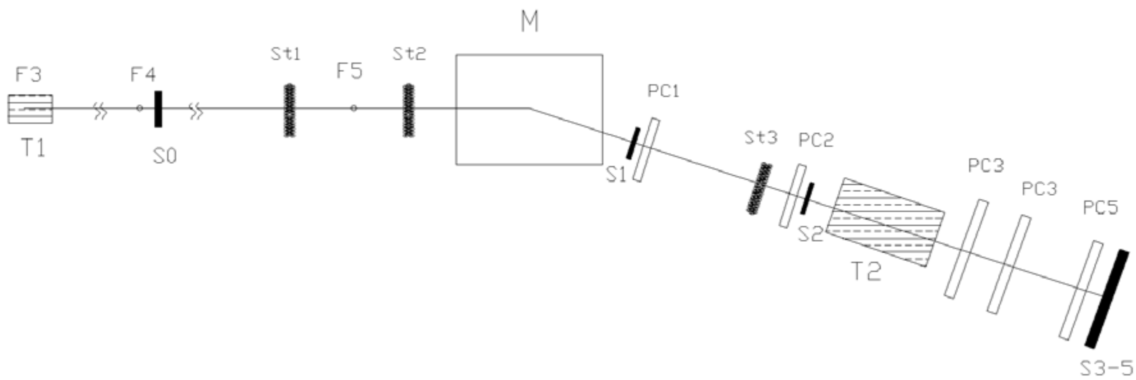


Fig.1. Experimental setup. S_i — scintillation counters; PC_i — proportional chambers; St_i — straws; M — magnet; T_i — targets.

Deuteron breakup reactions using either hadronic or leptonic probes, together with backward elastic *pd*- and elastic *ed* scattering, are good tools to investigate the deuteron structure. The elastic *ed* form factors are connected to the deuteron wave function by a Fourier integral; in contrast, both in backward elastic *pd* and in the deuteron breakup reactions, the observable is directly connected with the argument of the wave function, at least within the framework of the Impulse Approximation (IA). Hence, one expects breakup data and backward elastic *pd* to provide a more sensitive tool to investigate the deuteron structure than elastic ed data.

It is of course well known that the IA description of both breakup and backward elastic processes is valid only at small internal momenta of the deuteron constituents (proton and neutron). At higher momenta theoretical difficulties emerge, and a commonly accepted description of these reactions still does not exist.

The T_{20} observable was measured by several groups in Dubna up to internal momenta $k \cong 1$ GeV/c. The deviation of data from the IA calculations in the vicinity of $k = 0.3$ GeV/c was explained by Lykasov for the expense of the reaction mechanism with Δ-isobar in the intermediate state, but unexpected negative asymptotic could not find an explanation for a long time. The difficulty to describer the breakup process at high internal momenta is connected first of all with the fact that the theory of relativistic bound states still does not exist. Only recently the completely covariant description of the deuteron was formulated. But this theory is not commonly accepted. A more or less fair attempt to fit T_{20} data on the base of rescattering effects was done by Kobuskin. The corresponding prediction for k is suggested.

One can see that the polarization transfer κ was measured only up to $k = 0.58$ GeV/c. The matter is that the acceptance of polarimeters used in these experiments was not enough to measure data at higher internal momenta for a reasonable beam time.

Extension of measurement of k up to k =0.8 GeV/c will allow us:

- to obtain new information in the region where a good description of process can be achieved only on the basis of a correct theory of relativistic bound states;
- to evaluate the scale of violation of the IA approach in the region of $0.58<k<0.8$ GeV/c; c) to check several models, which describe fairly the behavior of T_{20} in this region.

The experimental setup is shown in fig. 1. It is a modification of POMME, created at Saclay (France) and is successfully time-tested in many experiments at the Saturne-2 accelerator. Proportional chambers upstream the 60 cm CH_2 target (13·13cm) are from the ALPHA spectrometer. Rear proportional chambers (50·50cm) are from POMME (former front chambers). Wires spaced 2 mm are in all chambers. Straws have a space resolution better then 0.1 mm. They are created at the William and Mary College (Williamsburg, USA) and were used at experiment 305 at Saclay.

The angular and momentum acceptances of the beam transport line (from F_3 up to F_5) are about $\Delta\Omega=10^{-4}$ srad and $\Delta p/p$=3%, respectively. The polarimeter angular acceptance and momentum resolution respectively incident to T_2 particles are $\theta<15°$ and $\Delta p/p<0.2\%$, respectively.

Vector polarized deuterons will be accelerated from the Synchrophasotron accelerator in the energy range 6.6–7.0 GeV/c. The intensity of the primary beam is $2\cdot10^9$ particles per beam spill.

The polarized protons are produced by fragmentation of the polarized deuteron beam on a 20 cm thick carbon target F_3. The beam transport line is 60 m long. Two dipoles (not shown in fig.) separate the break up protons at zero angle from the deuteron beam. The beam line will be adjusted to keep 5.5 GeV/c for secondary protons incident on the polarimeter target. The different values of internal momenta will be set by the variation of primary deuteron beam momentum. The polarization of the secondary proton beam will be measured by the polarimeter, which will be previously calibrated at p_p=5.5 GeV/c.

The suggestion to cover the region of 0.6–0.8 GeV/c in measurement of k is based on the new polarimeter much higher acceptance (2π geometry) than was used in previous measurements.

The expected numbers of protons incident on the polarimeter target were calculated using cross section data for the ^{12}C(d, p)X reaction. The error bars/time were calculated on the proceedings from the preliminary data on analyzing power of the $p+CH_2$ reaction at 5.4 GeV/c. These data are obtained at the Synchrophasotron (June 2001) using a new polarimeter (without straws).

The main difficulty in this experiment is to separate desirable protons from deuterons with same momenta on the level of the fast trigger. The expected ratio at highest internal momenta (k =0.790 GeV/c) is about 2 orders in favor of deuterons. To separate deuterons and protons we assume to update the existing TOF system (40 m base between S_0 and S_2 counters, 5ns between deuterons and protons at 5.5 GeV/c). It is worth to mark that the suppression by the fast trigger of protons (in small part) is admittable, because the exact value of cross section in the first target is not a subject of interest.

03-1-0983-92/2004

Priority of the project:	1
Status:	Data taking

Investigation of Hypernuclei and Δ, N — Isobar Behavior in Nuclear Matter (Project GIBS)

Leader from JINR: J. Lukstins

Participating countries and international organizations: JINR, Czech Republic, Kazakhstan, Russia, Ukraine

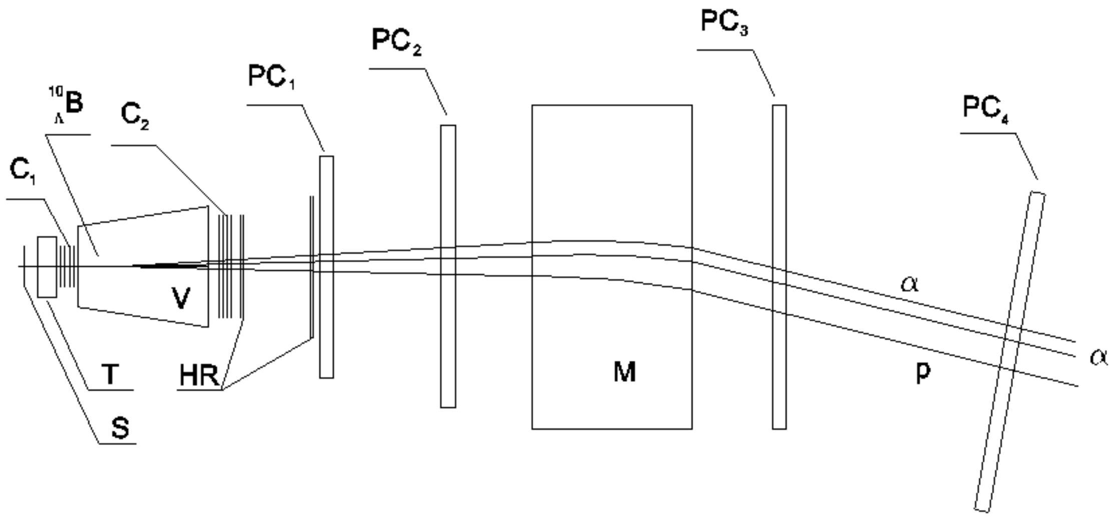


Fig.1. SPHERE spectrometer modified to investigate the nonmesonic decay of $^{10}{}_{\Lambda}B$ produced in the Nuclotron carbon beam. S — the beam control counters; T — target; $C_{1,2}$ — the trigger Cherenkov counters; V — vacuum decay volume; HR — high resolution detectors; M — magnet; $PC_{1\text{-}4}$ —proportional chambers.

The goal of the proposal is to obtain data for the theory considering interactions of strange particles and isobars with nuclear matter.

The experiments with nuclei containing hyperon or isobar probe will be performed to reach these goals. The study of particle spectra in charge exchange reactions $A(t,^3He)$ and investigation of hypernuclei are the experiments of this type.

The goal of our charge exchange experiment is to search for any unknown or poorly investigated reaction channels and measure the probability of the investigated processes. The data significant for the theory will be obtained in the result of this research.

Hypernuclear experiments at the Nuclotron will provide a significant contribution in solving the problem in general because the binding energy of weakly bound hypernuclei and the lifetime of light hypernuclei will be measured with an accuracy inaccessible in other laboratories. Investigation of the partial widths of the nonmesonic $^{10}{}_{\Lambda}B$ decays offers a unique possibility to obtain the weak ΛN interaction matrix elements.

In all the proposed experiments the approach was chosen allowing us to minimize background, systematic errors, efficiency and acceptance corrections, and etc. The new experiments are the natural continuation of our previous experiments completed with good results, for example, due to 4π geometry allowing us to register pions in a kinematic region inaccessible in other experiments or due to the absence of systematic errors or background in the lifetime measurements for hypernuclei.

Investigation of charge exchange reactions

Investigations of charge exchange reactions performed in Dubna as well as in France and Japan have shown that the excitation of Delta-isobar Δ(1232) plays a significant role in the reactions and that the properties of delta excited on free nucleons and in nuclear matter are rather different. Effects like de-excitation of Delta via the non-mesonic channel $\Delta N \rightarrow NN$ (absorption of virtual pions) or collective effects associated with Δ-hole propagation were supposed to explain these features. One of the by-products of theoretical studies of this reaction was the finding of coherent pion production as a relevant channel.

Two approaches will be used by the project: a study of the simplest reaction $p(t,{}^{3}He)$ and a 4π geometry experiment with a streamer chamber where secondary particles are registered in all kinematic regions.

Hypernuclear programme

There are three main goals in our hypernuclear experiments: a) to measure the binding energy of lightest hypernucleus — hypertriton with an accuracy of several times better than the measured one up to now, b) to measure the lifetimes of the light hypernuclei with an error of 2–3% and c) to investigate nonmesonic decay channels of medium hypernuclei.

Experimental facilities and carrying out of the experiments

Two experimental facilities will be used.

1) The streamer chamber (GIBS facility) will be used as a 4π vertex detector to register and investigate all charged particles produced in charge–exchange reactions. The filmless readout based on 3 CCD TV cameras was designed and tested in the period of two years with a special test streamer chamber. Computer codes for data processing are ready.

2) The SPHERE facility with a trigger and time-of-flight system from GIBS. Commission of the proportional chambers in 2003 is in progress. The large chambers to be installed beyond the analyzing magnet will be used for the NIS project too and the significant part of preparation procedures is carried out by the NIS team.

It should be noted that all estimations of the conditions of our experiments are based not only on the calculations but also on the data obtained in our previous experiments. For example, the cross sections of charge–exchange reactions and hypernuclear production measured in our experiments are used in the estimations of efficiency, which has also been tested experimentally.

The background is low or negligible in all our experiments (for example, there is no background for hypernuclear decays in the vacuum volume) but one should take into account the background triggers. However, the fraction of the events discriminated by the trigger can be varied in wide limits that was found in the previous experiments, however, some problems are expected for nonmesonic decays. A common feature of all the suggested experiments is a rather low beam intensity (10^6 nuclei/s) that is why the probability to organize the hypernuclear experiments simultaneously with others is high enough. Approximately 250–300 hours per year of the Nuclotron run time is necessary to perform the proposed programme. However, one should note that the energy of the Nuclotron beam should be more than 4 GeV per nucleon and the spill time should be equal or exceed 10 s.

Since the hypernuclear research programme was suggested to perform in the period till 2006 it is clear that it will be delayed because the Nuclotron progress is slower than estimated in the Programme and with lower funds. Indeed, one can expect the 4–6 GeV Nuclotron beams in 2004 or later in spite of optimistic 2003. That is why only 24 hours of the Nuclotron carbon beam was used in 2003 to investigate the properties of the thin Cherenkov counters.

03-1-0983-92/2004

Priority of the project:	1
Status:	Data taking

Spin Effects at Meson Production of Polarized Nuclei (Project PIKASO)

Leader from JINR: L. Zolin

Participating countries and international organizations: JINR, Bulgaria, Japan

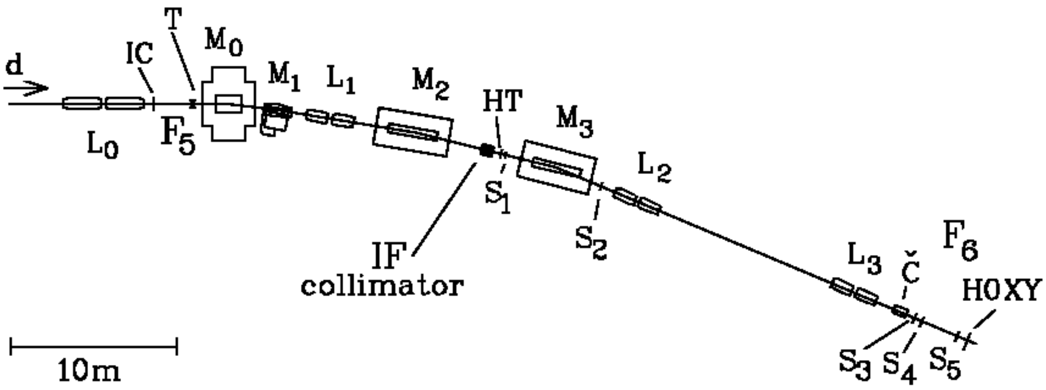


Fig. The focusing spectrometer at beam line "4B" in experimental hall of accelerator complex of LHE. M_i — dipole magnets; L_i — quadrupole lenses; T — target; IC — ionization chamber; S_i, C — scintillation and Cherenkov counters; HT, $HOXY$ — scintillation hodoscopes; F_5, IF, F_6 — target, intermediate and final focuses of the spectrometer.

Motivation

Continuation of spin effect study at fragmentation of polarized deuterons into pions and kaons is proposed. Main attention should be paid to the behaviour of spin observables at π, K-meson production with momenta close to kinematic limit when hadrons are produced on strongly correlated nucleon pair, i.e. in the region of deuteron core. Dominating of D-state in the deuteron core region is supposed to cause notable spin effects in those reactions.

Previous study of reaction $\vec{d}\,A\to\pi X$ confirmed that the large D-state effects take place at fragmentation of tensor polarized deuterons into cumulative pions. However, the behaviour of tensor analyzing power A_{yy} in $\vec{d}\,A\to\pi X$ contradicts to IA-calculations based on the standard DWF. It cannot be explained with the hypothesis of the direct mechanism of pion production by high momentum nucleon component in the deuteron. One can conclude that a meson cloud of the deuteron core can not be reduced to superposition of meson clouds of quasi-free nucleons. Thus, substantially new information about features of meson component at short internucleonic distances in nuclei can be obtained.

The purpose of the new project is:

- to perform study of the tensor analyzing power in the reaction of $\vec{d}\,A\to\pi X$ to evaluate an energy dependence $A_{yy}(E_d)$ and a transverse momentum dependence $A_{yy}(P_T)$. Study of tensor analyzing power of reaction $\vec{d}\,A\to\pi X$ in broadened ranges of x_c and P_T seems to be exceptionally important. That permits to clarify relation of the large spin effects revealed in this reaction and mechanisms governing short-range NN-interactions in the bound two-nucleon system — the deuteron;

- to investigate the tensor analyzing power at fragmentation of tensor polarized deuterons into kaons $\vec{d}\,A \to K^{+}X$. It was pointed out repeatedly that cumulative kaons can makes a source of information about strange quark sea in the fluctons (multiquark configurations in nuclei). In the framework of meson-exchange models, data of deuteron fragmentation into cumulative kaons can be used to extract information about correlation of spin state of the deuteron with probability of hidden strangeness exchange between nucleons at overlap of their wave functions (the deuteron core region).

The new data of spin-dependent observables can be used for a more profound study of structure of meson exchange and quark exchange currents at short range *NN*-interactions.

Experimental facility

Proposed measurements can be preformed by means of the focusing spectrometer at beam line "4B" used in the previous experiments. Additional financial support is required to keep the detector system of spectrometer in the course of work, to upgrade the data acquisition system and to provide with momentum magnetic control at the final focus of the spectrometer. Particle selection is based on the time of-flight technique. Cherenkov counters with gas and aerogel radiators should be used additionally at operation with a positive secondary particle beam.

Required time for operation with polarized deuteron beam

The experiment is planned for 4 years with data taking for reaction $\vec{d}\,A \to \pi X$ at the 1-st two-year stage using extracted deuteron beam from the LHE 10 GeV accelerator (Phase A); study of reaction $\vec{d}\,A \to KX$ is supposed to be performed at the 2-nd stage with the use of polarized deuterons extracted from the new LHE accelerator Nuclotron (Phase B).

The measurements are to be performed with tensor polarized deuterons of momentum from 4.5 to 9 GeV/c at cycling change of the polarization sign (+,–,0). It is planned to perform the measurements with the beryllium target (29 g/cm^2) only. Required time of data taking is estimated proceeding from beam intensity of $2\cdot10^9$ polarized deuterons in acceleration cycle (10 s) and polarization level of $p_{zz}^{\pm}=0.70$.

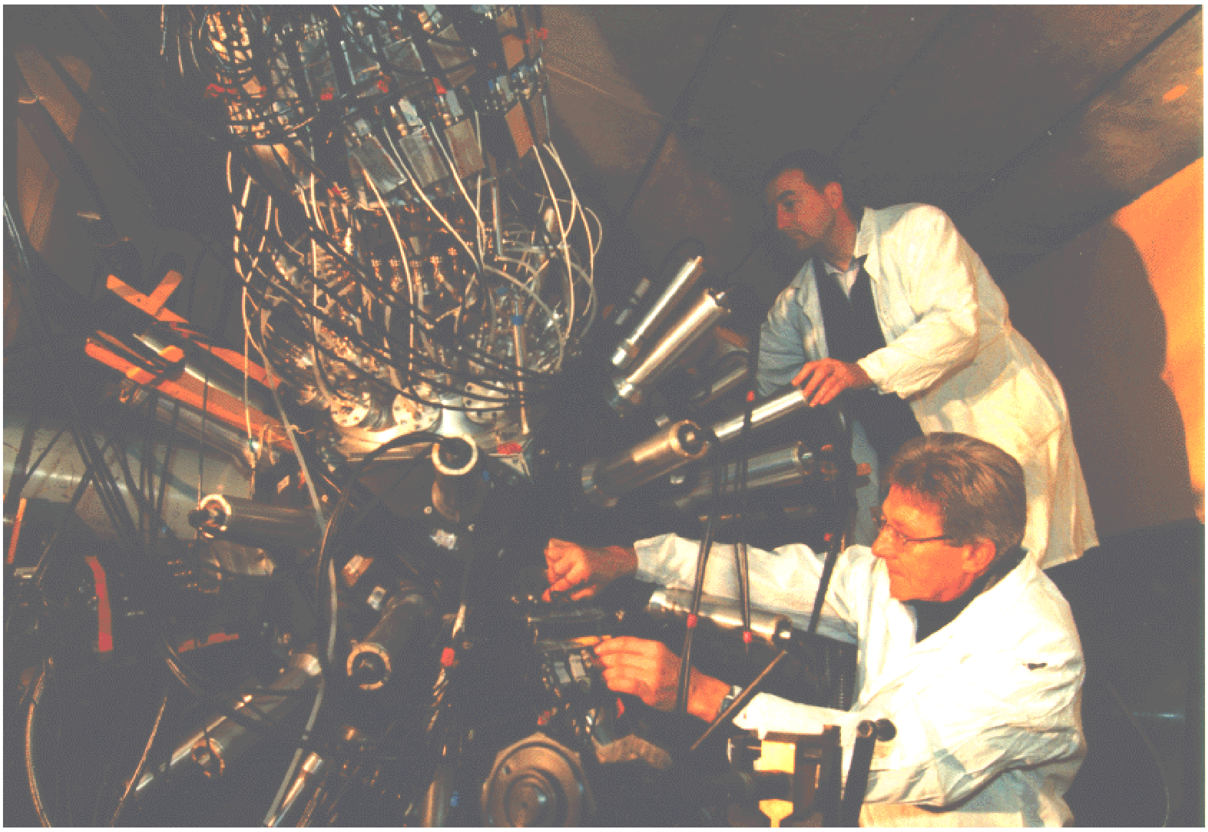
03-1-0983-92/2004

Priority of the project:	1
Status:	Data taking

Thermal Multifragmentation Induced by Light Relativistic Ions and Nuclear Phase Transitions (Project FASA)

Leader from JINR: V. Karnaukhov

Participating countries and international organizations: Germany, JINR, Poland, Russia, the USA



The scientific goal of the Project is investigating the nuclear equation of the state at the reduced densities and the temperatures below the critical one T_c (for the "liquid-gas" phase transition). Thermal multifragmentation is adequate to that. This is a *new multi-body* decay process of the hot target spectator with the copious emission of the intermediate mass fragments (IMF, $2<Z<20$). It is the main decay channel of very excited nuclei. It was shown that the break up density is $\rho_b \approx 0.3\ \rho_0$ and the temperature is (5–7) MeV. These findings correspond to the onset of the multifragmentation of nucleus entering the phase coexistence (spinodal) region. Due to the density fluctuations, a homogeneous system converts into a mixed phase, consisting of the charged droplets (IMF's) surrounded by the nuclear gas. This is a *nuclear fog*, which explodes because of the Coulomb repulsion. So, the thermal multifragmentation is in fact the nuclear *liguid-fog* phase transition. The critical temperature for the *liquid-gas* phase transition is estimated by analysis of the IMF charge distribution: T_c=(17±2) MeV.

These studies will be continued. We have well prepared the Program of the further investigations. It includes the study of the evolution of the reaction mechanism with increasing the projectile mass (from *p* up to Ne), measuring the expansion time of the hot nucleus and various fragment correlations. As a result, the nature of the collective flow observed for the beams heavier than He will be established; new information on the nuclear liquid-fog and liquid-gas phase transitions will be obtained as well as new data about the space configuration of the system at the break-up moment. Investigation of the expansion dynamics of hot nucleus driven by thermal pressure promises to get the unique information on the nuclear rigidity at the temperature 5–7 MeV. The limits of the statistical interpretation of the multifragmentation will be explored. Generally, better understanding the multifragmentation phenomenon will be achieved.

We use the modified 4π-setup FASA, installed on the Nuclotron beam. This device includes 30 telescopes dE(gas)-E(Si) and a fragment multiplicity detector, composed by 64 thin CsI(Tl) scintillators. The total number of electronic channels is 205. Upgrading the FASA setup is planned.

03-1-0983-92/2004

Priority of the project: 2

Status: Preparation

Design of Data Acquisition Multiprocessor Systems for the Experimental Setups and Diagnostic Systems of the LHE Accelerator Center (Project “ELECTRONICA”)

Leader from JINR: V. Smirnov

Participating countries and international organizations: JINR, Bulgaria

Introduction

The experimental research currently being carried out in relativistic nuclear physics focuses on the study of processes, which occur with very low probability against the background of processes more probable by several orders of magnitude. This determines the volume of the electronic apparatus, which is needed to organize the data-acquisition (DAQ) systems. These systems are based on nuclear electronics modules, computing devices, including computers and computing modules realized in some standard (CAMAC, VME, FASTBUS, etc.), and also computer interfaces. The biggest part of experimental installations of the Laboratory of High Energies is designed to conduct experimental studies at the LHE accelerator center. But the systems of the LHE accelerator center also need some patterns of high-performance unique diagnostics, control and front-end electronics. And all of them contain some multiprocessor data acquisition systems and use real-time application programs. So, the design of new modules and systems will be directed to increase the number of channels and the speed of event registration, and to use some specialized hardware on primary event selection and data processing in real time.

The realization of the design program assumes the usage of the latest achievements in the field of semi-conductor technology, large-scale integration chips, programmable matrices and microprocessors. The requirements of the DAQ systems, which are prepared for experimental research at the LHE accelerator complex, determine all characteristics of the developed equipment. Applied software works within the framework of operational real time systems (UNIX-like) for the multiprocessor DAQ systems. The developments are the following:

- to create some prototypes of front-end electronics for primary processing (data filtering, data compression and correction, pedestal subtraction, etc.);
- to create some prototypes of logic, processor, interface and network modules for multi-channel multiprocessor data acquisition systems on the basis of modern electronic standards and the latest achievements in the field of semiconductor technology;
- to develop basic parts of the data acquisition system;
- to create real-time software for the multiprocessor systems using modern operating systems;
- to create some elements of diagnostic and control systems at the LHE accelerator center.

Main results

The working program of the Scientific Department of Physical Research Automation (SDPRA) is concentrated on design of data acquisition multiprocessor systems. These systems intend for the experimental setups and diagnostic systems of the Synchrophasotron-Nuclotron accelerator complex, as well as of other accelerators at CERN (SPS, LHC), BNL (RHIC), GSI (SIS) and at CELSIUS storage ring in Uppsala (Sweden).

The systems are made, and their operation is maintained. The first one is <u>the internal target station of the Nuclotron.</u> The system on the basis of several vacuum electron multipliers provides the measuring of the intensity of nuclear beams in the Nuclotron chamber. One of these systems is the polarimeter which provides taking and presentation of data obtained from the devices which measure beam polarization (see Fig.). Data acquisition system on the CAMAC controller basis with an embedded processor for the LU-20 polarimeter setup. (Its successful operation during the accelerator runs is maintained).

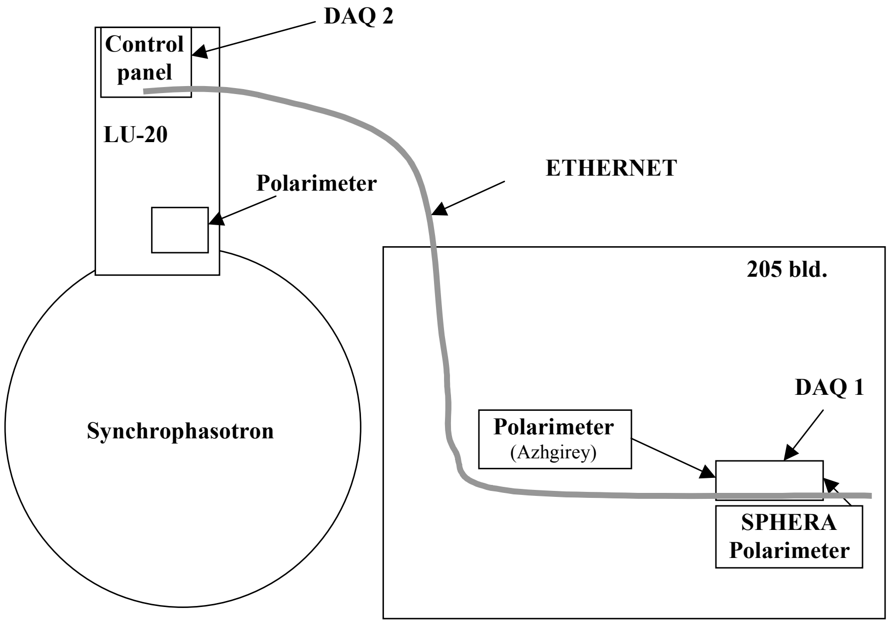


Fig.

A number of data acquisition systems to take data from the SPHERE, ALFA, STRELA, MARUSIA and DELTA setups are prepared. One of them is the new multiprocessor data acquisition system (hardware and software design) for the SPHERE setup. Another one is the trigger and data acquisition system for the STRELA setup (hardware and software design). Next one is the new multiprocessor data acquisition system and software for the ALFA setup (hardware and software design). Data acquisition system on the basis of a CAMAC crate controller with an embedded PC for the MARUSIA setup is prepared.

During last three years the engineers of SDPRA designed more than ten types of universal electronic modules in CAMAC, VME and standards specified by the user for almost all the experimental setups at LHE (SPHERE, DELTA, INESS-ALFA, STRELA, DELTA-SIGMA, DISK, MARUSIA, STAR, PHENIX], WASA-PROMICE, ENERGIA et al.).

The engineers of SDPRA provide common service for the Laboratory. Regular competent consulting service on the use of the most advanced domestic and foreign means of nuclear electronics in CAMAC, VME and FASTBUS standards and some elements of IBM PC hardware and software is supported. During last three years about 120 electronic modules in CAMAC, VME and standards specified by the user for the Laboratory setups (Nuclotron, SPHERE, DELTA, INESS-ALFA, STRELA, DELTA-SIGMA, DISK, MARUSIA, NA-45 (CERN), STAR (RHIC), WASA-PROMICE (Uppsala), CMS (CERN), ENERGIA et al.) were prepared.

03-1-0983-92/2004	Priority of the project: 2
	Status: Preparation

Modelling of the Electronuclear Method of Energy Production and Study of Radioactive Waste Transmutation Using a Proton Beam of the JINR Synchrophasotron / Nuclotron "ENERGY+TRANSMUTATION"

Leader from JINR: M. Krivopustov

Participating countries and international organizations: Australia, Belarus, China, Germany, Greece, Mongolia, Czech Republic, India, Poland, Russia, Romania, France, Ukraine, the USA

The concept of construction of hybrid electronuclear systems, combining a proton accelerator, a heavy element target (tungsten, lead, bismuth) to generate intensive neutron fluxes and fissile target surroundings, is standing out among several approaches to solve the problem of nuclear energy development prospects, its economic competitiveness and ecological Safety including waste fuel utilization.

Since the establishment of the JINR in 1956, this theme has been of fundamental importance in research activities of its Laboratories. The following was performed in this field:

- studies of neutron multiplication in extended blocks of heavy elements in the beams from the synchrocyclotron and synchrophasotron;
- studies of radioactive waste transmutation in the fields of electronuclear neutrons;
- computer simulation of processes in electronuclear systems;
- efforts aimed at developing intermediate energy accelerators to study the electronuclear method of energy production.

The main aim of research of the electronuclear method with the program of the proposed project «Energy +Transmutation» at the accelerator complex of the Laboratory of High Energies, JINR for the next three years is to make investigations using a fissile blanket instead of a large lead target to obtain data on nuclear processes in hybrid installations under irradiation with relativistic ion beams and to study radioactive wastes for the development of practical recommendations of choosing the parameters of an electronuclear transmuter prototype.

The project and experimental program are aimed at:

- determining optimum parameters of the multi-purpose electronuclear assembly;
- obtaining data on heat generation and the power amplification coefficient, energy costs of neutron generation, neutron balance and spectrum;
- measuring neutron flux characteristics of the uranium-lead target depending on the type and energy of ion beam, isotope composition of the blanket and target-converter;
- obtaining experimental data on the effectiveness of transmutation of long-lived radioactive wastes (actinides and fission products) required to develop an electronuclear transmuter prototype of radioactive wastes (isotopes of iodine, uranium, neptunium, americium, curium and plutonium including weapon grade plutonium) on a semi-industrial scale;
- obtaining information necessary for testing and improving computing methods and programs to simulate electronuclear processes.

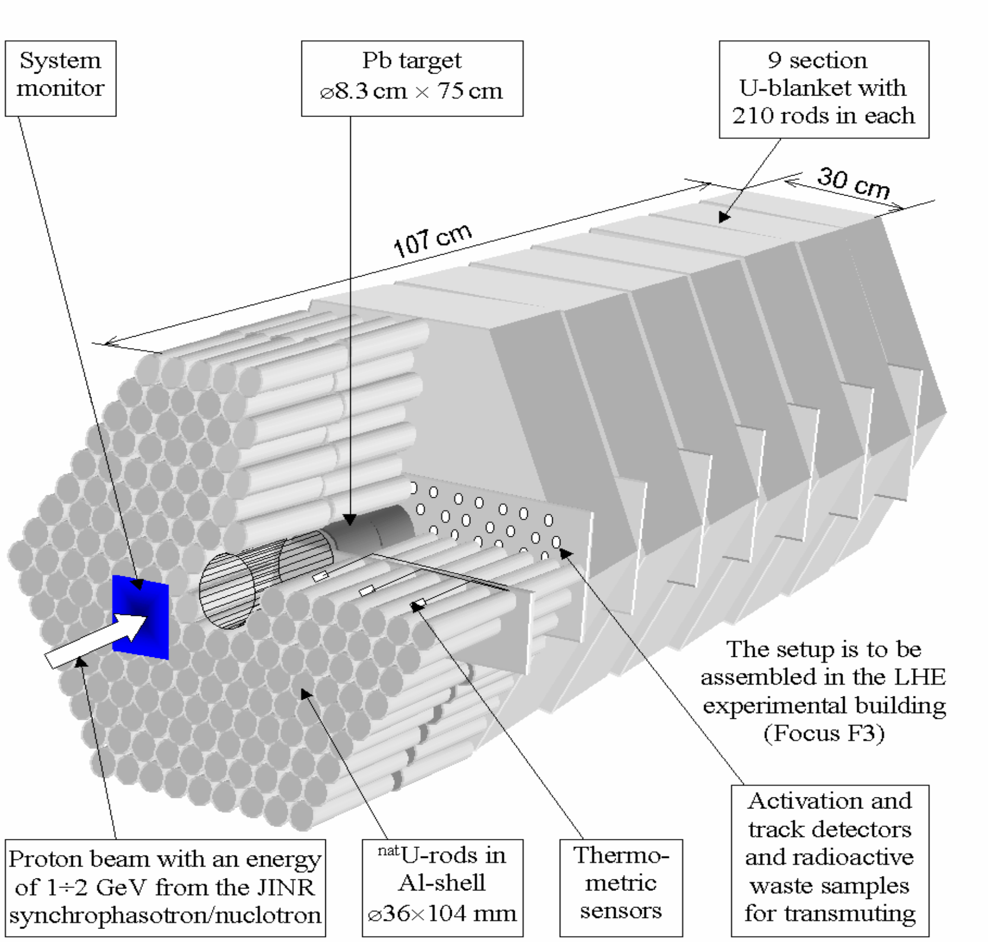


Fig. Setup “ENERGY+TRANSMUTATION”

03-1-1011-95/2005

Priority of the project: 1

Status: Data taking

Study of Cumulative Particle Production and Structure of the Lightest Nuclei in Experiments with Polarized and Unpolarized Beams (Project DISK)

Leader from JINR: Yu. Panebratsev

Participating countries and international organizations: Armenia, Azerbaijan, Czech Republic, JINR, Romania, Russia, Serbia and Montenegro, the USA

Main goal of experiments at DISC is study of the extreme state of nuclear matter using polarized and nonpolarized beams and targets. The nonperturbative QCD is at the moment the greatest challenge to all of us. Several new phenomena were found in experiments with nuclei.

The cumulative effect have regarded it as a signal that in nuclei there are non-nucleon or quark-gluon configurations, whose structure greatly differs from that of free nucleons. The Color Transparency (CT) is an effect of suppression of nuclear shadowing of hard reactions, closely related to the color screening. The CT data of the carbon nucleus in the *C(p,2p)* quasielastic scattering process near 90° *pp* center of mass (c.m.) have shown a surprising beam momentum dependence in 6–12 GeV region.

The Nuclotron is presently the only machine dedicated for experiments with a fixed target and beams of protons (up to 12GeV/c), nuclei (up to 6 GeV/c per nucleon) and opportunity to operate with high-intensity proton beams (up to $5\cdot10^{11}$ particles per cycle), as well as polarized deuteron, neuteron and proton beams. Unique cryogenic H, D, He targets are available for DISK experiment too.

Using these advantages we are going to investigate:

- The cumulative production of K^+- and K^--mesons on the lightest nuclei of deuterium and helium for which the experimental difficulty arises from a small production cross section.
- The vector and the tensor analyzing powers of inclusive particles in collisions of polarized beams with various targets at the high p_T and in the cumulative region with the DISK setup. Mechanisms of particle production in this kinematical region are not well understood and directly connect with our understanding of the internal structure of the nuclear; moreover, while the deuteron is the simplest nuclear system, questions still remain about it structure at short distances <1 *fm,* where nucleons are overlapped and therefore one can expect the manifestation of the non-nucleon degrees of freedom in the deuteron wave function. The polarization adds new physical parameters which can help us to made more clear separation between the different models.
- The Color Transparency effect in detail will be examined with polarized beams and different targets.

For carrying out of these researches it is necessary to made upgrade the DISK installation. Basic elements of upgrade should become creation of magnetic spectrometers allowing to detect charged particles with a momentum up to 7 GeV/c with accuracy of ~1%, creation of tracker and new trigger systems.

03-1-1010-99/2005

Priority of the project:	1
Status:	Preparation

Investigation of the Transition Mode (Transition from Nucleon to Quark-Gluon Degrees of Freedom in Nuclei) on the Basis of the Experimental Study of Hadron Production in Relativistic Nuclear Collisions (Project MARUSYA)

Leader from JINR: A. Baldin

Participating countries and international organizations: Bulgaria, Czech Republic, Georgia, JINR, Russia, Ukraine

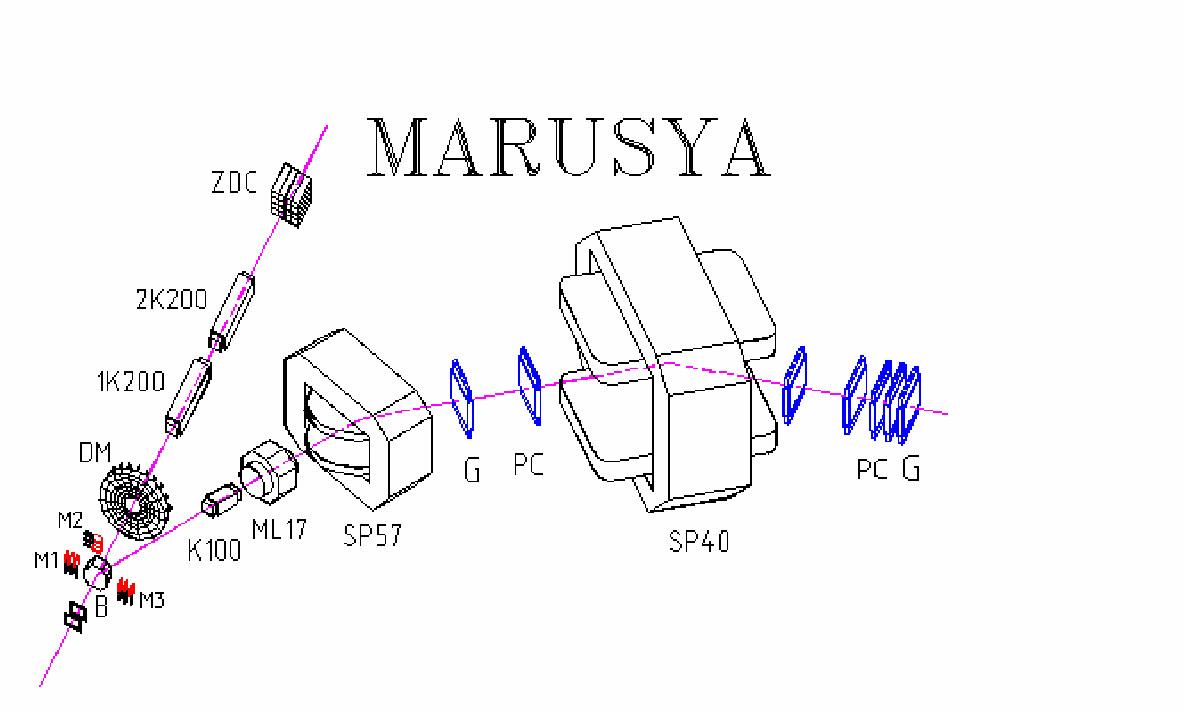


Fig.1. M1-M3 — The beam monitoring system consists of three scintillation telescopes located around the target at 90° angles. Also the information on the extracted beam intensity will be obtained by an ionisation chamber placed on the beam axes in front of the target. K100, ML17 — Magnetic lenses. SP57,SP40 — Dipole magnets. B — The small size barrel system located around the target which provides the trigger from the interaction in the target. PC — Proportional chambers. G — Scintillator hodoscopes. DM — Multiplicity detector. ZDC — Zero degree hadronic calorimeter.

Among the fundamental problems of modern nuclear physics and particle physics there are problems of the confinement in strong interactions, the origin of the spin of a nucleon, the structure of the vacuum in QCD.

One of the perspective trends of research of these problems is the study of the transition mode from nucleon to quark-gluon degrees of freedom of nuclear matter at the LHE accelerator complex NUCLOTRON.

nvestigations of the cumulative and deep subthreshold hadron production carried out up to 400 GeV showed that the transition mode corresponds to the energy of relativistic nuclei from hundreds of MeV to about 10 GeV/nucleon.

Asymptotic characteristics of cumulative particle production, anomalous large emission of strange particles and antiprotons, enhanced A dependences were observed in a wide energy range of 1 to 200 GeV/nucleon at the JINR synchrophasotron, BEVALAC (Berkeley), the ITEP accelerator, AGS (Brookhaven), SPS (CERN) etc.

The novelty of the proposed research is the investigation of rare subthreshold and cumulative processes taking into account the polarization of colliding objects, the extraction of events by the degree of centrality and reaction plane on the basis of additional measurements of multiplicity and the identification of the part of the nuclear fragment not participating in an interaction.

The interest in investigations of the antiprotons and K^- production is due to their antiquark content, which allows the creation of these particles only via the hadronization of the "sea" quarks. The production of antiprotons studied at the AGS accelerator at 13.6 GeV/nucleon show an essential dependence of invariant cross-sections on the centrality (selection of the events on multiplicity). In the transition mode there is practically no such kind of measurements.

The investigation of the spin phenomena in the transition mode is just now beginning. Measurements of structure functions, asymmetries, vector and tensor analysing power performed on beams of polarized leptons e,μ, protons and deuterons show the limited character of the application of the perturbative QCD methods for the description of the spin effects. In the framework of the QCD vacuum model as a liquid of instantons it is possible to give a qualitative explanation of the spin and flavour effects in hadron processes. These effects should manifest them selves quite clearly in the transition mode energy range.

Measurements of single spin asymmetries in the reactions $\uparrow d+A \rightarrow \pi^{\pm}, K^{\pm}, p^{\pm} + \ldots$, with simultaneous measurements of centrality and the reaction plane will provide new information on the spin structure of the deuteron. One of the predictions is the change of the sign of asymmetry during the transition from a non-cumulative region to the cumulative one.

Investigation of the A dependence of single spin asymmetries in $\uparrow d+A$ interactions is important for the study of the role of nuclear matter on the mechanism of the particle production taking into account spin degrees of freedom.

Presently there is no complete theory of polarization phenomena in hadron-nuclear interactions. Because of this, qualitative estimation of polarization effects versus the energy, momentum transfer and the type of studied particles will give the possibility of a critical analysis of different theoretical approaches.

The physics program proposed for the investigated range of the energy of nuclear collisions (2–6 GeV/nucleon) also implies the study of the nuclear matter phenomena at a high baryon density and relatively low temperature. These phenomena are planned to study via "side-splash" and "squeeze-out" effects, i.e. effects depending on the mass of an emitted fragment. These experiments were performed at energies of about 1 GeV/nucleon and their interpretation in the framework of thermodynamical approach allowed us to determine the ratio of the energy of "the squeezing" to the "thermal" energy.

For the investigation of the physics problems mentioned, we propose to carry out:

1. Measurements of the cross-sections of the deuterons, kaons, pions, antiprotons and nuclear fragments production versus:

- types of beam nuclei and target nuclei (p - U);
- energy of beam nuclei (2–6 GeV/nucleon);
- momenta of detected particles (0.3–2.0 GeV/c);
- angle of particle production (20°–90°);
- direction of polaization of beam particles;

2. Under the conditions of item 1, simultaneous measurements of multiplicity and centrality at a Zero Degree Hadronic Calorimeter placed behind the target.

3. Detection of two particles belonging to one event in the aperture of a magnetic spectrometer with their identification and under conditions of item 2.

The experimental setup is placed in experimental building 205of LHE. It consists of a magnetic channel, a system of beam diagnostics and monitoring, beam counters, spectrometric detectors, multiwire proportional chambers, a threshold Cherenkov counter, a multyplicity detector, a zero degree hadronic calorimeter, an electronics and data acquisition system, a graphic representation and data analysis apparatus and a target device. The main parameters of the spectrometer are:
acceptance 50–80 mstr.%;
momentum resolution $\Delta P/P \sim 0.5\%$.

The particle identification will be provided via time-of-flight measurements, ΔE-TOF analysis, fast particle rejection by Cerenkov counters, momentum measurements by means of multiwire proportional chambers.

03-1-0983-92/2004

Priority of the project:	1
Status:	Preparation

Light Nuclei Structure Investigation at LHE-JINR and RIKEN (Project LNS)

Leader from JINR: V. Ladygin

Participating countries and international organizations: JINR, Bulgaria, Romania, Russia, Slovak Republic

The majority of modern theoretical nucleon-nucleon (NN) potentials (eg. CD Bonn, Argonne AV18, Nijmegen I and II) describe the existing NN data with an unmatched accuracy, manifested by a χ^2/data point close 1. Three-nucleon (3N) system is the simplest non-trivial enviroment in which the quality of the various NN interaction models in the presence of additional nucleons can be tested. Development of rigorous techniques of solving Faddeev equations for the 3N system enables to compare the predictions of different NN interaction models with the experimental data on a new level of accuracy. On the other hand, the nuclear medium renormalization effects, parametrized in the form of a 3N- potential, can be also exactly included into the calculations.

The idea of LNS- project is to extend the measurements of different observables in the processes involving 3-nucleon systems in new energy and angular domain, where Faddeev techniques is still working, and hence, the comparison of the experiment and theory can be made with a high level of accuracy. The main goal of the proposed experimental program is to extract the information on the spin part of the 3NF.

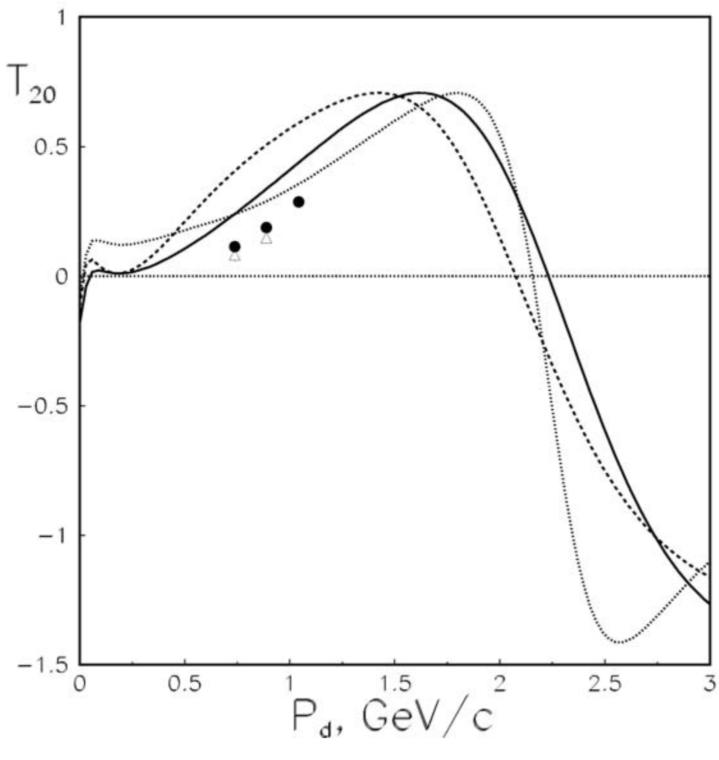


Fig.1. Energy dependence of the tensor analyzing power T_{20} in the dd→^{3}Hen (filled circles) and dd→^{3}Hp (open symbols) reactions. Curves are the calculations using different ^{3}He wave functions.

The experimental program of LNS-project includes 3 different experiments:

- measurements of the cross section, vector A_y, tensor A_{yy} and A_{xx} analyzing powers in dp-elastic scattering between 300 and 500 MeV of the deuteron kinetic energy;
- measurements of the cross section, vector A_y and tensor A_{yy} analyzing powers in dp-breakup between 300 and 500 MeV in different configuration (complanar, space star etc. geometries);
- measurements of the tensor analyzing powers in the $dd \to {}^3He n$ and $dd \to {}^3H p$ reactions up to 270 MeV.

The first two experiments are planned to be performed using unpolarized and polarized deuteron beam of the NUCLOTRON and the Internal Target Station (ITS), the third one was performed at RARF, RIKEN, Japan.

The results on the energy dependence of the tensor analyzing power T_{20} in the $dd \to {}^3He n$ and $dd \to {}^3H p$ in collinear geometry are shown in Fig.1. The curves are the calculations using different ${}^3He$ wave functions. The strong sensitivity to the spin structure of ${}^3He$ is observed. The analysis of the data on the tensor analyzing powers A_{yy}, A_{xx} and A_{xz} at 200 and 270 MeV is in progress.

The preparation of the experiments on the study of the polarization observables in the dp-elastic scattering and dp breakup at the Internal Target Station at the Nuclotron is started.

The detection of the elastic events will be done by 4 pairs of the detectors, each of them detects proton and deuteron in coincidence. Four pairs of the detectors will be placed symmetrically in the directions of azimuthal angles left, right, up, and down. A lead block will be placed in front of the scintillator to degrade the kinetic energy of the scattered particles so that their energy loss in the plastic scintillator will be maximized.

Deuteron breakup, $dp \to ppn$, will be investigated by measuring the energies of both protons. Two counters with 1 cm and 20 cm scintillators will be used to measure energy losses and total energy, respectively. The opening angle of each detector is 2° in the laboratory frame. At least 4 ΔE-E counters will be used to detect two protons from $dp \to ppn$ reaction to increase the statistics.

The optimization of the setup detection system has been performed for both experiments at ITS. The manufacture of the scintillation detectors, high voltage system, mechanics and registration electronics is in progress.

The first data are expected in 2004.

03-1-0983-92/2004

Priority of the project:	1
Status:	Preparation

Probing Short-Range Spin Structure of Deuteron with Polarized Deuteron Beam and Polarized ^{3}He Target (Project PHe3)

Leader from JINR: V. Ladygin

Participating countries and international organizations: JINR, Bulgaria, Romania, Russia, Slovak Republic, Japan.

The goal of the PHe3-project is to measure the polarization observables for the ^{3}He(d, p)^{4}He reaction at T_d= 1.0–1.75GeV by using polarized deuteron beam from the Nuclotron at LHE–JINR. This experiment is the continuation of the investigations performed at RIKEN, Japan, at intermediate energies. The main goal of the experiment is to obtain high precision polarization data in the energy region, where the contribution from the deuteron D-state is expected to reach a maximum in one-nucleon exchange approximation and to obtain new information on the strange structure observed in the behaviour of the tensor analyzing power T_{20} in the dp- backward elastic scattering. These data will help to understand the short-range spin structure of deuteron and effects of non-nucleonic degrees of freedom.

The measurements of the tensor analyzing power T_{20} and polarization correlation $C_{y,y}$ will be carried out separately. The first experiment uses the cryogenic ^{3}He gas target, while the latter one uses the spin-exchange type polarized ^{3}He target.

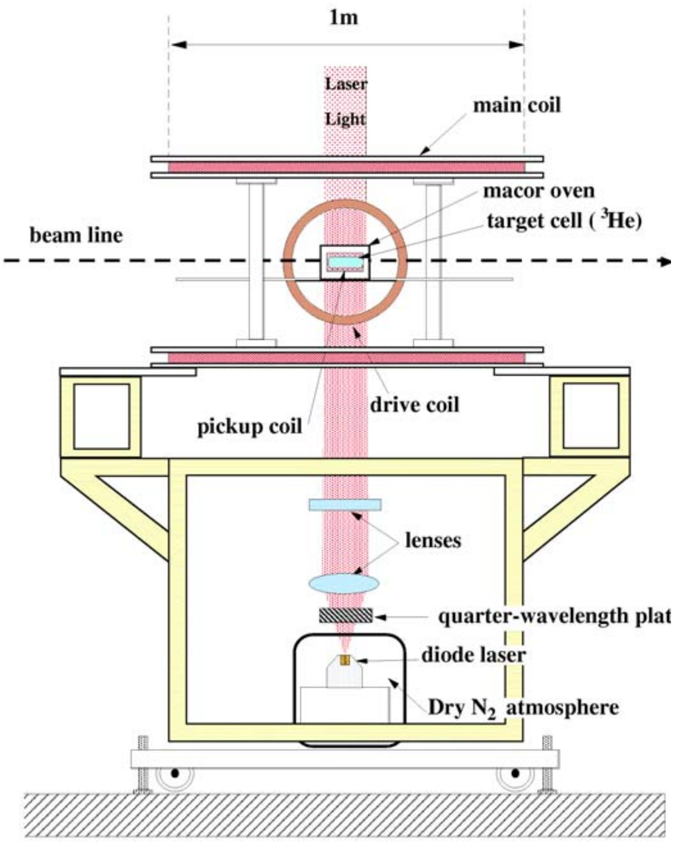


Fig.1. Schematic view of the spin-exchange type polarized ^{3}He target.

In the polarization correlation measurement, the spin-exchange type polarized 3He target developed at RIKEN will be used (see Fig.1). The size of target cell is 5cm in diameter and 30cm in length along the beam path. Maximum target polarization obtained so far is 25%, but the work on the increasing of the polarization value is in progress now.

The T_{20} is planned to be measured at 4 energies between 1.0 and 1.75 GeV, while the spin-correlation parameter $C_{y,y}$ at 3 energies only. The expected statistics for both observables and their combination $C_{//}$ are shown by the open symbols in Fig.2 as functions of the incident deuteron energy.

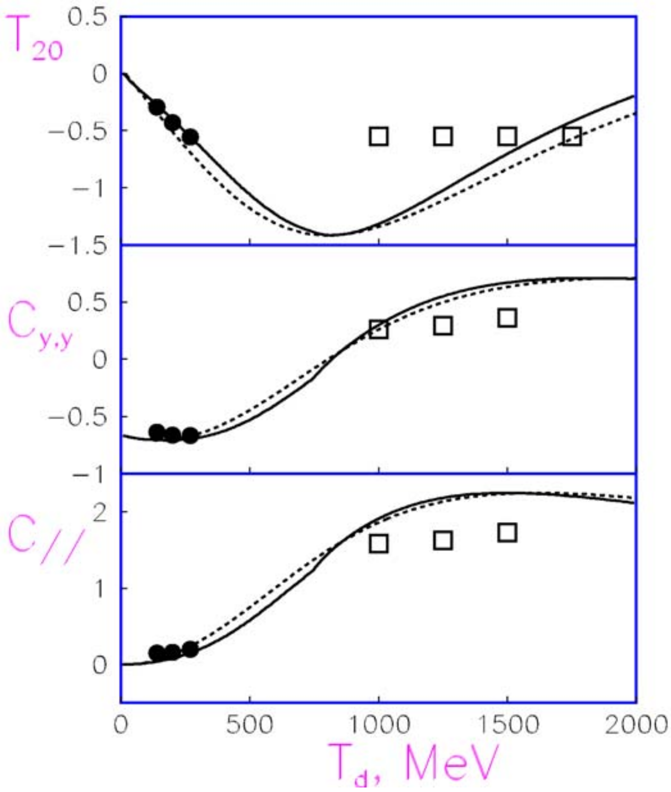


Fig.2. Tensor analyzing power T_{20}, vector polarization correlation coefficient $C_{y,y}$ and $C_{//}$ for the $^3He(d, p)^4He$ reaction at T_d=140, 200, and 270MeV obtained at RIKEN shown by the full symbols. The open symbols are the points to be measured within PHe3-project with the expected statistics.

Tensor analyzing power T_{20}, vector polarization correlation coefficient $C_{y,y}$ and $C_{//}$ measured at RIKEN at 140–270 MeV are shown by the solid circles in Fig.2. The dashed and solid lines represent one-nucleon exchange calculations without and taking into account the Fermi motion in the target nucleus, respectively. Since both predictions do not differ significantly, one can conclude that the $^3He(d,p)^4He$ can be a good probe to the high-momentum spin structure of deuteron.

The $^3He(d, p)^4He$ reaction will be identified by means of the measurements of the momentum and the time-of-flight of the proton. For these purposes, the magnetic spectrometer with the scintillation counters and drift chambers will be used. The apparatus for the experiment is in preparation now.

03-1-1033-2000/2005

Priority of the project:	2
Status:	Data taking

Project Experiment "Leading Particles"

Leader from JINR: L. Sarycheva

Participating countries and international organizations: JINR, Czech Republic, Germany, Russia, Switzerland

In the framework of the programme of the investigation of interaction of polarized protons with nuclei we propose the experimental investigation of single-spin asymmetries of polarized proton scattering on intranuclear nucleons to be compared with the analogous characteristics for the scattering on free nucleons in the region of energies 1–4 GeV. The main subject of measurements is vector analyzing power (a.p.) $A(\theta)$, determined as normalized on $\vec{P}$ left-right asymmetry $\sigma(\vartheta,\theta) = \sigma_0(\theta)(1+A(\theta)(\vec{P}\cdot\vec{n}))$.The comparison of this value is for the scattering on the free and intranuclear nucleons the parameter R of the reduction of a.p. for the scattering on any intranuclear nucleon, or for the scattering on intranuclear proton only.

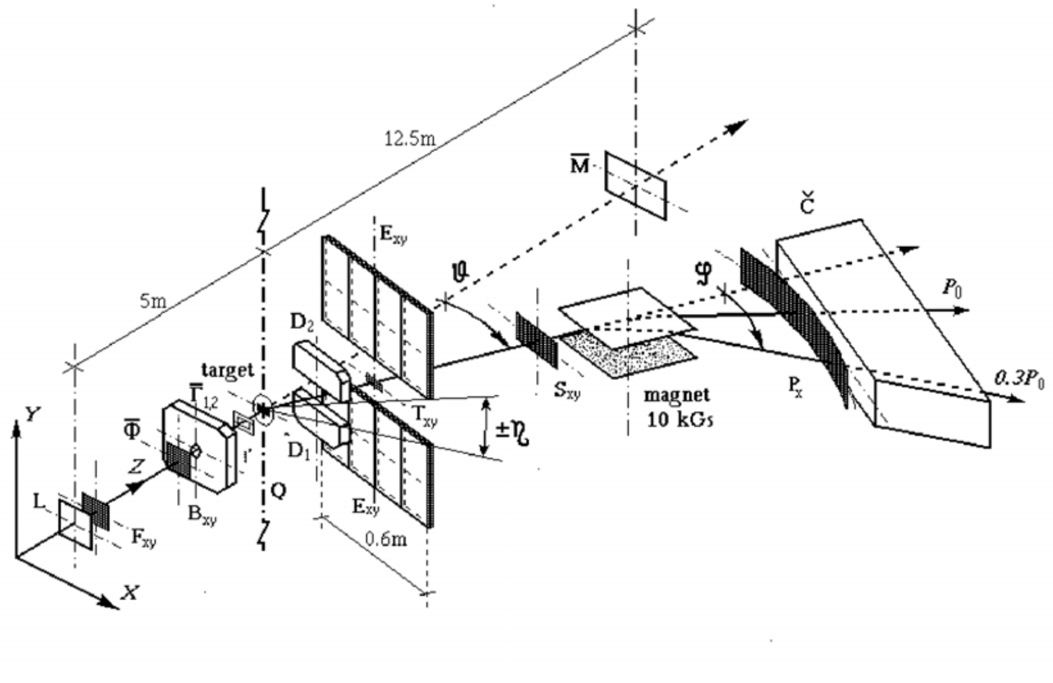


Fig. SMS MSU-SPHERE setup.

In the experiment, the first case corresponds to the measurement of the proton-carbon scattering a.p. at the detection of the quasielastic channel by the magnetic analysis of the scattered particle momentum, but without any separation of the proton-proton or proton-neutron interaction. The compilation of the mentioned data is shown on the Fig.1 by open symbols and an estimation of the asymptotic behaviour (R(T)→0.96) is shown by the dashed line. The second case corresponds to the proton-carbon a.p. measurement at the detection of the recoil proton. This measurement under the spectrometric selection of quasielastic kinematic region was carried out at KEK. There was the analogous measurement at SATURNE II accelerator, but without any analysis of the momenta, so this data for the quasielastic scattering could be significantly distorted by the undetected contribution of the inelastic channels. To be included in the world data compilation, this data were model–dependently corrected under strong supposition, that a.p. of the inelastic channel of proton-carbon scattering is close to zero at these energies. The behaviour of the R for proton-proton quasielastic scattering is shown on the Fig.1 by closed symbols and interpolated by the solid line (R(T)→0.67). Therefore the a.p. of the scattering on the intranuclear protons looks significantly reduced, and one can assume the different reduction of the a.p. for intranuclear protons and neutrons. One can show that this phenomena cannot be explained by the Fermi-motion effects. The other possible reasons are:

- relativistic effects for bound state of target nucleon;
- nucleon clusterization in nuclei;
- excitation of non-nucleon degrees of freedom.

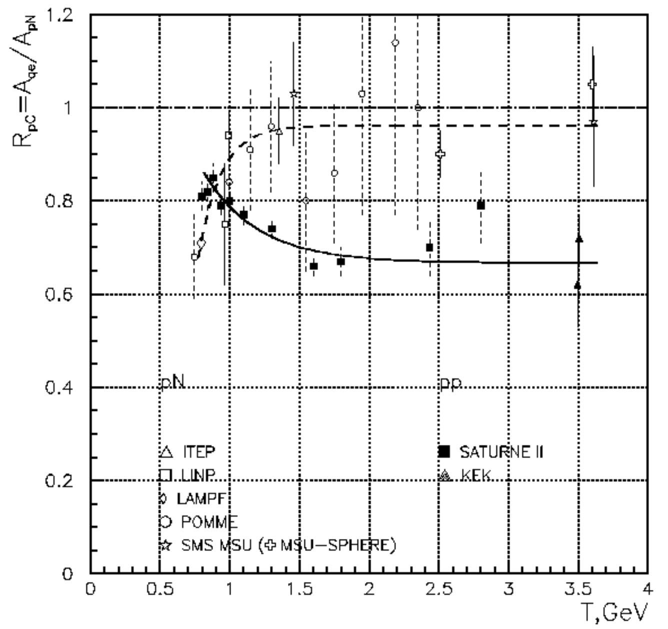


Fig.1. Compilation of the experimental data for $R_{pN} = A_{qe}/A_{pN}$ and $R_{pp} = A^{p}_{qe}/A_{pp}$ measurements. Data of the model dependent software analysis are marked by dashed error bars. Presented experiment data are shown by open crosses.

To investigate the suggested phenomenon, the joint "SMS MSU — SPHERE" experiment was proposed. For the conditions of LHE synchrophasotron the principal methods of the experiment with the polarized proton beam was tested in the previous experiments at the SMS MSU set up. The first run of the new experiment was carried out in June, 2000 and devoted to the test of the methodic and preliminary measurements of the investigated reactions.

In the first run the a.p. of quasielastic scattering was measured at 2.51 and 3.60 GeV for proton-nucleon scattering in the reactions $p\uparrow + C^{12} \rightarrow p_L + p(n)_R + X$ and $d\uparrow + C^{12} \rightarrow p_L + p(n)_R + X$ (scattering angles are 9.0° and 6.7°, scattered proton momenta are 3.20 and 4.36 GeV/c correspondingly).

Preliminary data of quasielastic scattering are in the agreement with the assumed tendency in the behaviour of the R_{pN} for arbitrary scattering on the intranuclear proton or neutron (see Fig.1). The second part of the experiment has to be devoted to the simultaneous measurement of the channels of *pp* and *pN* quasielastic scattering, and this measurement will permit to resolve the main question of the project: to confirm or to reject the existence of the phenomenon.

Also during the reported period the model-theoretical investigation of the one of the possible reasons of a.p. reduction based on the relativistic impulse approximation (RIA) has been carried out. There is an indication of the a.p. reduction increasing at the increasing of the transverse momentum square. But the existing data do permit to make definite conclusion about the considered phenomenon. Obviously, it is necessary to carry out the experiment to measure both R_{pp} and R_{pN} at the same experimental conditions for few values of transverse momentum. The most convenient energy for critical test is T=2.5 GeV, and it is necessary to understand the nature of the effect. So this measurement is planned to be done in 2003–2004 in the frame of this experiment.

Therefore, the main reason to ask for the prolongation of the project is the real possibility to complete the announced investigation without significant expenses and using existing experimental equipment. As a result, the principally new data about nuclear spin effects will be obtained being important for both spin physics of high energies and methods of nuclear polarimetry.

03-1-1033-2000/2005

Priority of the project:	2

Status: Data analysis

Project SPIN

Leader from JINR: M. Finger

Participating countries and international organizations: Czech Republic, Germany, France, Russia, Switzerland.

Study of spin effects in neutron-proton interactions at intermediate energies at PSI

Two experiments have been realized at Paul Scherrer Institute:
R-87-12 Measurements of Spin Observables in Neutron-Proton Elastic Scattering.
R-95-08 Spin Dependence of Pion Production in Neutron-Proton Collisions.

Experimental set-up for elastic scattering experiment

Two experimental layouts were installed one behind the other on the neutron beam line. The beam polarization $\vec{P}_B$ was oriented along the base vectors $\vec{n}$, $\vec{s}$ and $\vec{k}$. The first layout uses a frozen spin polarized proton target (PPT) of a volume 4·4·4 cm^3. PPT was polarized at 2.5 T and operated at 0.5 T–0.8 T holding magnetic field. Its temperature of ~50 mK was obtained by the ^{3}He–^{4}He dilution refrigerator. An average $|P_T|$ was $\cong$ 70% and the relaxation time reached more than 1000 hours. The $\vec{P}_T$ orientations along the same base vectors were available. Scattered neutrons were detected by a~neutron counter hodoscope, the recoil proton polarization was measured by a carbon polarimeter containing MWPCs. The spin observables were measured at kinetic energies from 230 to 590 MeV over the angular range $60° < \theta_{CM} < 160°$. The second layout used LH_2 target and measured the polarization transfer observables at energies 210–590 MeV over the range $150° < \theta_{CM} < 180°$.

Experimental set-up for inelastic scattering experiment

The experimental layout uses a~liquid hydrogen target with the window to match the 45° emission cone. A large solid angle detector consisted of:
- the tracking drift chamber stack (DCS);
- the trigger hodoscope (TH);
- the large drift chambers (LDC) and
- the large time-of-flight wall (LTOFW). For a complete kinematical reconstruction all the reaction products emitted in a forward cone of 45° were detected.

The reconstruction of charged outgoing particles relied mainly on DCS. The TH allowed to distinguish elastic and inelastic events. Using LDC an unambiguous determination of tracks in space was possible. The LTOFW measurements for the secondary particles imposed additional constraints on the reconstructed kinematics.

Low-temperature nuclear orientation

Introduction

The method of nuclear orientation (NO) is based on the interaction of the nuclear electromagnetic moments with the electromagnetic fields which results the orientation of the with ensemble of nuclear spins, if the temperature of the ensemble is sufficiently low, i.e. much lower than 1 K. Principially it is possible to produce the electromagnetic field required for NO in laboratory, however, much stronger fields often are experienced by nuclei from the unpaired electrons in atomic shells or from the localized environments of solid phase. This type of interaction is known as hyperfine interaction or, if we consider the atomic shells, as hyperfine structure. Thus, the low-temperature NO introduces the physical direction where the nuclear, atomic and solid state physics and the technology of low temperature are crossing among themselves. From the experimental point of view the low-temperature NO is very complicated, however, the results which may be obtained are very significant as the NO allows one to solve directly many problems of the enumerated physical branches and also gives possibility to study some properties of fundamental interactions as, for instance, the violation of the space parity or time invariance in nuclear conversion processes.

We remind here the final expressions of the NO theory and their generalization which we made for the case of γ radiation deexcited the level populated from any number of initially oriented states. These expressions will show the possibilities and also restrictions of the low-temperature NO which shall be illustrated by our experimental and theoretical results (see references bellow).

The developed theory of the low-temperature nuclear orientation (LTNO) for the description, analysis and interpretation of the experiments is probably one of the most worked out and graceful theories of nuclear phenomena and is based on the general principles of symmetry: space rotation and space reflection.

Directional distribution of γ rays following the decay of nuclei oriented at temperature T is written as, see, for instance, "The Electromagnetic Interaction in Nuclear Spectroscopy", ed. W.D.Hamilton (North-Holland, Amsterdam, 1975),

$$W(\Theta,T) = \Sigma_{\lambda\ even} B_\lambda\ (I,T)\ U_\lambda\ A_\lambda\ E_\lambda\ G_\lambda\ Q_\lambda\ P_\lambda\ (\cos\Theta),$$

where Θ is the angle between the directions of the emitted radiations and external magnetic field B_{ext}.

Future development

It is clear from the facts given above that the on-line experimental facility (SPIN-2) needs to be supplemented the with existing off-line facility (SPIN-1). We have a beam of the monoisotopic nuclei, but we need a new refrigerator and so on. The on-line experiment was planned as having a facility with implantation into cold matrix, i.e. the NO measurement of isotopes usible half-lives up to $T_{1/2}$ >1s would be possible. The limits put the spin-lattice relaxation time. With the ferromagnetic matrixes, the half-lives of 1–100s would be possible to measure. The laser induced orientation would decrease the half-life limit up to $T_{1/2}$ >1ns.

However, there are possibilities to do even more with the off-line SPIN-1 facility. For instance:

- Measurements of the β and α radiations and coincidences from oriented nuclei.
- The fission of oriented nuclei to study the parity violation which was predicted theoretically (Novosibirsk) to have higher effect at least by an order of magnitude than with γ radiation, which was already measured.
- Laser spectroscopy with oriented nuclei.
- New regions of deformation below A=100.
- The new plasma ion source for mass-separator is under construction. It opens new possibilities to study (i) the end of the A~180 deformed nuclei region and the transition $\subset \supset \rightarrow$ O. This end seems to be not so sharp as in the A~150 region. There is no proper study of this problem yet. (ii) The nuclei around the Pb with the doubly closed shells and (iii) the transuranium elements which are produced in very small quantities.

03-1-0940-91/2005

Priority of the project:	1
Status:	Data taking

Investigation of Secondary Particle Generation and Neutron Yields from Extended Targets in Nuclear Interactions. Study of Transmutation of Nuclear Waste from Nuclear Power Plants. (Project GAMMA-2)

Leader from JINR: V. Golovatyuk

Participating countries and international organizations: Belarus, Czech Republic, Georgia, Germany, JINR, Poland, Romania, Russia.

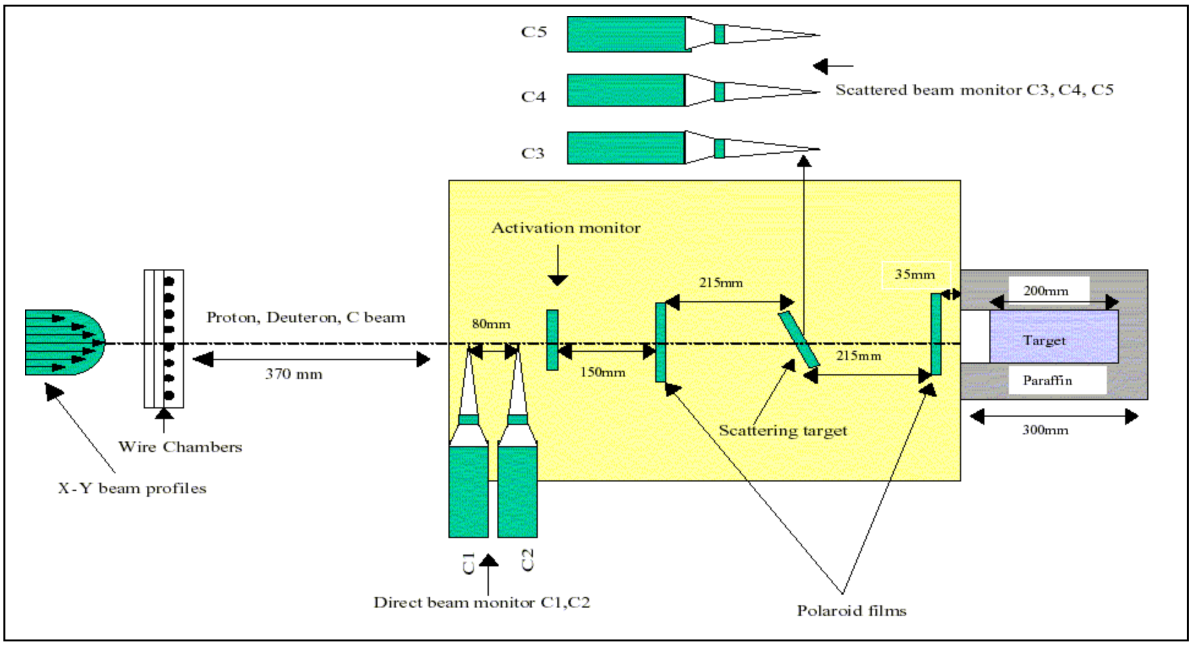


Fig.

The aim of the project is an experimental study of energy and space distribution of secondary particles produced in the extended lead target (GAMMA-2 facility), measurements of transmutation reaction cross sections for components of spent nuclear fuel in the field of secondary neutrons, as well as investigation of residual nuclei formation in thin targets of transuranic isotopes in nuclear interactions using the LHE Nuclotron proton beams with energies 1–5 GeV.

The GAMMA-2 experimental setup consists of 8 cm ∅ Pb-target of 20 cm long and surrounded by 6 cm thick paraffin moderator placed at the F3N focus of the JINR LHE Nuclotron (see Figure). Activation samples are placed onto the outer surface of the moderator, and after the irradiation are transported to radiochemical units and counted on the HPGe γ-detectors with high registration efficiency and energy resolution.

In our experiments with transmutation samples we determine B-parameter (specific reaction rate) which is defined as the ratio of the number of the nuclei produced in the reaction channel under study N_{at} to the sample weight in grams m and the number of the protons hit the target N_p:

$$B = \frac{N_{at}}{m \cdot N_p} \qquad [\text{proton}^{-1} \cdot \text{gram}^{-1}]$$

The list of the reactions in the transmutation samples whose reaction rates (B) are studied at the GAMMA-2 facility is given below:

$$^{139}\mathrm{La}(n,\gamma)^{140}\mathrm{La}\xrightarrow[t_{1/2}=40.2h]{\beta^-}{}^{140}\mathrm{Ce}\ (\mathrm{stable})$$

$$^{129}\mathrm{I}\,(n,\gamma)^{130}\mathrm{I}\xrightarrow[t_{1/2}=12.4d]{\beta^-}{}^{130}\mathrm{Xe(stable)}$$

$$^{237}\mathrm{Np}(n,\gamma)^{238}\mathrm{Np}\xrightarrow[t_{1/2}=2.12d]{\beta^-}{}^{238}\mathrm{Pu}\xrightarrow[t_{1/2}=88yr]{\beta^-}$$

$$^{239}\mathrm{Pu}\ (\mathrm{n},f)\rightarrow \text{fission fragments}$$

Although they are geometry dependent, these B-factors can be compared with nuclear reaction/transport model predictions. Besides transuranic isotopes ^{139}La having high cross section for thermal neutrons, is used in our experiments to substitute highly radioactive isotopes. Secondary neutron fields are measured with sets of activation threshold detectors.

During the last years B-values of ^{139}La(n, γ)^{140}La, ^{129}I(n, γ)^{130}I, ^{237}Np(n, γ)^{238}Np, and ^{239}Pu(n, f) reactions were measured in the energy range 0.53–4.15 GeV. Among the most promising results is shape of the energy dependence of ^{139}La(n, γ)^{140}La reaction rate which changes with energy increase very slightly. The observed effect can be explained by suggesting that the spatial distribution of the thermal part of the neutron spectrum on the surface of the moderator does not change significantly with the energy of protons. Transmutation efficiency (B/E_p) in the reactions ^{139}La(n, γ)^{140}La, ^{129}I(n, γ)^{130}I, and ^{237}Np(n, γ)^{238}Np has been established for the whole energy range as presented above. On its basis we declare that it decreases with energy of the initial proton beam, and maximum of this dependence is located between 0.5 and 1 GeV. This result has practical use for planning lead-based targets for the future electronuclear systems.

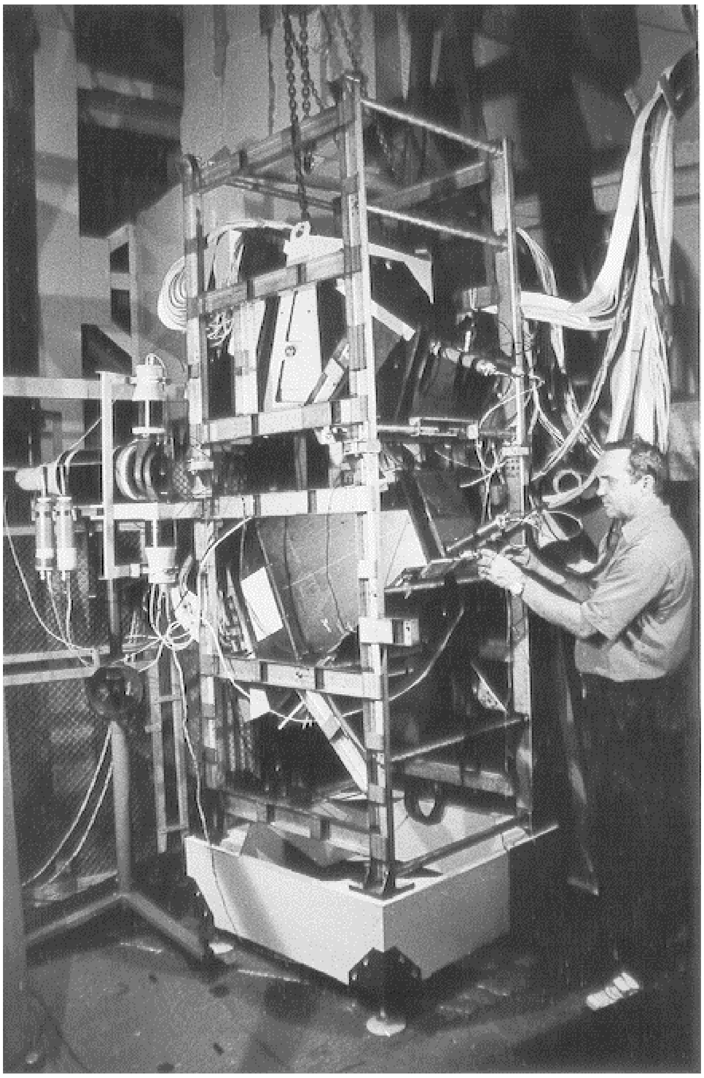
03-1-0983-92/2004

Priority of the project:	1
Status:	Data taking

Study of Nucleon Structure at η Meson Production in Polarized Nucleons Collisions at Energies 1200–1400 MeV (Project DELTA-2)

Leader from JINR: V. Krasnov

Participating countries and international organizations: Russia, Slovak Republic.



A general view of installation for neutral meson detection at the polarized article beam in 205 LHE experimental hall.

To study neutral meson production with polarized nucleons at LHE JINR, the DELTA spectrometer has been designed and completely assembled. In principle, the setup ensures a high-resolution and high-aperture detection of π^0- and η - mesons for an energy of 300 MeV (for π^0) or 30–40 MeV (for η) and above, π^+-mesons over an energy region of 30–150 MeV, K^+-mesons and protons within 70–320 MeV, deuterons within 150–600 MeV. These are the following main units: a 300 — channel γ,e-Cherenkov spectrometer consisting of two blocks each based on 150 lead-glass prisms, a 14 — layer scintillation telescope of detectors based on opto-fiber plates and used to identify charged particles and to measure their energy by the method of repeated ionization loss measurements. The first physics program, a description of the detectors, characteristics and preliminary results of the first beam trun are presented.

Introduction

Recent advances in accelerator and beam-target technology at JINR have opened up new possibilities for nuclear physics. Using slowly extracted polarized deuterons, available at the Synchrophasotron-Nuclotron accelerator complex of the Laboratory of High Energies JINR, polarized quasi-monochromatic neutrons of momenta from 1.1 to 4.5 GeV/c were generated. The momentum spread of the neutrons is 5% (FWHM). The mean value for neutron beam polarization $|P_B(n)| = 0.535 \pm 0.009$. In addition, for the JINR physics program, the Argonne-Saclay frozen spin proton polarized target (used initially in the E704 experiment at FERMILAB) was updated and installed on the LHE polarized neutron beam line. The target material is 1.2-propanediol $C_3H_6(OH)_2$ and contains $9 \cdot 10^{23}$/cm^2 polarized hydrogen atoms approximately. The maximum value of proton polarization was 0.842. The first measurements on the polarized beam-target complex were carried out, and the results of the neutron-proton total cross section difference $\Delta\sigma_L$ were obtained.

The physics program of measurements on the new DELTA setup includes a search for the polarization phenomena of π^0- and η-meson production in *NN* collisions with polarized nucleons (with probable deuteron production in the final state) at energies up to 2.5 GeV. The spin, parity and G-parity of π°- and η-mesons as, members of the pseudoscalar meson nonet are identical.

Properties of π^0- and η-mesons

	π^0	η
J^{PC}	0^{-+}	0^{-+}
(I,I_3)	(1,0)	(0,0)
Quark w.f.	$(u\bar{u} - d\bar{d})/\sqrt{2}$	$(u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}$
Mass	134.9 MeV	548.8 MeV
Mean life	$0.83\cdot10^{-16}$ sec	$0.75\cdot10^{-18}$ sec
2γ decay fraction	98.8%	39%

A major difference between the η- and π^0-meson is in their isospin and quark wave function: in addition to the $\bar{u}u$ and $\bar{d}d$ components, η also contains a $\bar{s}s$ pair, reflecting a relatively large mass of η. Another attractive feature of the η-meson is a selective excitation of the $N^*(1535)$ S_{11}-resonance in ηN interaction (nearby the production threshold). The η-meson also decays into two photons with a large fraction (39%) similar to the π^0-meson which decays predominantly into two photons. To study π^0- and η-production with polarized nucleons at the LHE JINR, the DELTA lead-glass Cherenkov spectrometer has been designed to determine the energies and exit angles of incident γ-quanta after meson decay in the studied target.

Setup of the experiment

We are planning to perform an experiment at the LHE JINR Dubna Polarization Complex based on the polarized deuterons accelerated by the Synchrophasotron-Nuclotron and the ANL–Saclay–LHE polarized proton target (PPT). A free polarized proton and neutron beam of momenta from 1.1 to 4.5 GeV/c and an intensity of up to 10^7 particles per accelerator cycle is produced by breaking up polarized deuterons on a carbon-beryllium target [1]. The momentum spread of neutrons is 5% (FWHM), and the mean value for beam polarization is $|P_B(n)| = 0.54$. The PPT, containing main parts of the Saclay-Argonne frozen spin proton polarized target, has been updated (superconducting polarizing solenoid and spin holding coils) at the LHE JINR. The target made of $C_3H_6(OH)_2$ -material contains approximately $9\cdot10^{23}/cm^2$ polarized hydrogen atoms. The maximum values of proton polarization are 0.842 and -0.906 for positive and negative polarizations, respectively, and the nuclear spin relaxation time in the frozen spin mode is over 1000 hours.

The experimental setup "DELTA", used to study the particle production process, basically mesons, in nucleon -nucleon interactions at intermediate energies from hundreds MeV to 6–7 GeV, has been constructed. The setup ensures a high-resolution and a high-aperture detection of π^0- and η-mesons with an energy of 300 MeV and over, π^+-mesons within an energy region of 30–150 MeV, K^+ -mesons and protons within 70–320 MeV, deuterons within 150–600 MeV. The setup was completely assembled. At the present time, it is being adjusted and prepared for electron beam calibration at the Synchrophasotron (Laboratory of High Energies, Joint Institute for Nuclear Research). These are the following main units: a 300-channel γ,e-Cherenkov spectrometer consisting of two blocks (CH1 and CH2) each based on 150 lead-glass prisms, a 14 — layer scintillation telescope of detectors (ST) based on opto-fiber plates and used to identify charged particles and to measure their energy by the method of repeated ionization loss measurements. The Cherenkov spectrometer and scintillation telescope are fixed inside some mechanical systems which allows one to move them and to adjust their position. These systems are mounted directly in the beam area and allow the detectors to be rotated in the vertical and horizontal planes independently and relative to the target center. A remote computer controls the movements of the detectors.

03-0-0941-91/2006

Priority of the project:	1

Status:

Movable Polarized Target (Project MPT)

Leader from JINR: E. Matyushevsky, N. Borisov

Participating countries and international organizations: JINR, Russia, Ukraine, France.

The accelerator complex of the JINR has become a unique facility to provide 3–12 GeV/c polarized deuteron beams with hi intensity and good polarization. It is possible to obtain quasi-monoenergetic polarized neutron and proton beams using a break-up of accelerated polarized deuterons. To get full benefit of this opportunity, the experiments with polarized beams must be performed in conjunction with a polarized proton or deuteron target. To produce in the shortest possible time a working combination of a polarized beam and polarized target, it was agreed to use, after reconstruction, the Saclay-Argonne frozen spin proton polarized target which was built and used initially in the E704 experiment at FERMILAB.

First experiments consisted in the measurement of the spin-dependent neutron-proton total cross section differences $\Delta\sigma_L$ for antiparallel and parallel beam and target polarizations, oriented longitudinally to the beam direction. Early in 1995, three $\Delta\sigma_L$ (np) data points were successfully measured at neutron beam energies 1.19, 2.49 and 3.65 GeV. In 1997, the values of $\Delta\sigma_L$ (np) were measured at 1.59, 1.79 and 2.20 GeV. A fast decrease of $\Delta\sigma_L$ (np) with increasing energy above 1.1 GeV was established. The results were compared with dynamic model predictions and the phase shift analysis fits. The $\Delta\sigma_L$ quantities for isosinglet state I=0 were deduced from the measured values of $\Delta\sigma_L$ (np) and known $\Delta\sigma_L$ (pp). Further $\Delta\sigma_L$ (np) measurements and new $\Delta\sigma_T$ (np) data with transverse target polarization over a kinetic energy region above 1.1 GeV are planned (Project "Measurements of the energy behaviours of spin-dependent differences of the JINR LHE polarized n beams and p target" (DELTA-SIGMA)).

The transverse target polarization is also demanded for another proposed experimental Project "Measurement of spin-spin correlation in elastic pp scattering near 90° (pp-singlet)". For this experiment, a polarized proton beam with a kinetic energy from 2.6 to 3.5 GeV will be used. Using the world data on the differential cross sections, the modulus of the spin-singlet amplitude of the elastic pp scattering will be found at each energy and its energy dependence will be studied in detail. The experiment should also answer a question if there is a resonant structure in $^1D_2$ partial wave of the elastic pp scattering or not. It will contribute to the world NN database for the direct reconstruction of the proton-proton amplitude at energies of several GeV. The data in this energy range will be obtained at the first time. All present time, the acceleration complex of LHE JINR is the only place in the world where such measurements can be performed.

For the purpose of the physics program in Dubna the Saclay-Argonne target has been reassembled and upgraded adding missing parts. A new quality was given to the target assembly during this reconstruction — transportability from one experimental area to another. This is a "movable" polarized target (MPT) concept. It means that all the major parts of the target assembly disposed closely to the beam line are mounted on two separate decks which can be moved as blocks in and out of the beam, and also between various accelerators. These decks may be translated on high precision rails fixed on a main frame. During the experiment, the working target may be moved in or out of the beam line within some minutes without interference with the polarized or frozen mode in progress. Between experiments, transportation to another area does not need disassembly of the equipped decks. The dimension of the decks with their equipment corresponds to dimension of a standard sea container.

Larger of two decks contains the $^3He/^4He$ dilution refrigerator with a horizontal axis mounted on a 1.5 tons concrete cube, a 30 l service helium dewar of the refrigerator, a 1000 l supply helium dewar and a ^3He circulation system. The pumping system consisting of one Gerauer roots pump (PRW-3600) 3600 m^3/h and two Leybold pumps (WS-1000 and WS-250) with pumping speeds 1000 m^3/h and 250 m^3/h mounted on a compact stage and placed onto the deck using pneumatic dampers for vibration isolation. The pumping system is connected to the dilution refrigerator through about 1.5 m piece of 200 mm diameter stainless steel tube with bellows inserts. A polarizing superconducting solenoid, its 300 l service helium dewar and power supply are mounted on a smaller deck.

A remote control of the entire operation of the MPT is achieved from the control room. It contains an operating vacuum, ^3He and ^4He systems, an interlock system, a microwave system and an NMR system. A new effective cleaning system for ^3He has been built containing liquid nitrogen cooled charcoal traps and warm silicagel traps.

The microwave system intended for proton polarization build-up consists of a microwave source, a waveguide and a power supply. A diffraction radiation generator with 4 mm wavelength is used as the microwave source. The waveguide consists of warm and cold parts. The warm part contains a directed brancher intended to measure the frequency, an electronic attenuator and a wavemode transformer. The microwave power comes to the refrigerator in H01 mode. The cold part of the waveguide inside the refrigerator was left unchanged.

1,2-propanediol with a paramagnetic Cr(V) impurity having a spin concentration of $1.5 \cdot 10^{20}$ cm^{-3} was used as a target material. A load of 140 cm^3 of propanedoil beads in a plastic container having 200 mm length and 30 mm diameter was placed inside the dilution refrigerator.

The target polarization measurements were carried out using a computer controlled NMR system. Maximum values of proton polarization obtained were 80 and 85% for positive and negative polarizations, respectively. A duration of one run at a given sign of target polarization was about 12 h. Polarization degradation during this period was insignificant since the nuclear spin relaxation time in a frozen mode (at a temperature 50 mK and a magnetic field 2.5 T) is over 1000 h.

The purpose of this project is an upgrade of the Movable Polarized Target. This includes the installation into MPT new holding field system. The magnetic system creating a transverse holding field is formed with two superconducting coils located in separate cryostats. The design of the current leads into the cryostat makes the holding system universal and permit to create not only the vertical as well as horizontal transverse holding field but the longitudinal one with a larger aperture.

03-0-0941-91/2006

Priority of the project:	1
Status:	Preparation

Measurement of spin-spin correlation in elastic *pp* scattering near 90 degree (Project SINGLET)

Leader from JINR: E. Strokovsky

Participating countries and international organizations: Russia, France.

The "SINGLET" project is aimed to experimental determination of characteristics of the nucleon-nucleon interaction in the "transition" energy region and a search for exotic nucleon-nucleon states.

The particular goal of this experiment is the measurement of the energy dependence of the spin-spin correlation parameter A_{oonn} of the elastic proton-proton scattering (Fig.1), making use of the polarized proton beam of kinetic energy from 2.6 to 3.5 GeV and "transversally" polarized proton target. The measurements must be performed with two opposite orientations of spins of the beam and the target in the angular interval of about 10º around θ_{cm}=90º at several values of the initial energy in that interval.

The two-arm scintillation spectrometer (Fig.2) will detect both final state protons from the elastic *pp* scattering in coincidences. Making use of the data to be obtained and the world data on the differential cross sections, the modulus of the spin-singlet amplitude of the elastic *pp* scattering will be found at each energy and its energy dependence will be studied in detail. The separation of the module of spin-singlet scattering amplitude from the spin-triplet one (which is dominant) exploits the fact that at 90º$_{CM}$ the analysing powers $A_{oono} = A_{ooon} = 0$ and the module squared of the spin-singlet scattering amplitude is proportional to $(1 - A_{oonn})$, while the module of spin-triplet amplitude is proportional to $(1 + A_{oonn})$ because the sum of $|a|^2 + |d|^2 + |e|^2 = \frac{1}{2}\frac{d\sigma}{d\Omega}\cdot(1 + A_{oonn})$ is pure spin triplet (a(90º$_{CM}$) = 0).Thus a question about a possible resonance-like character of the energy dependence of this amplitude in the vicinity of T_{kin} 2.8 GeV (Fig.3), as has been indicated in SATURNE-II NN-experiment, will be resolved.

Fig.1. The world data on A_{oonn}

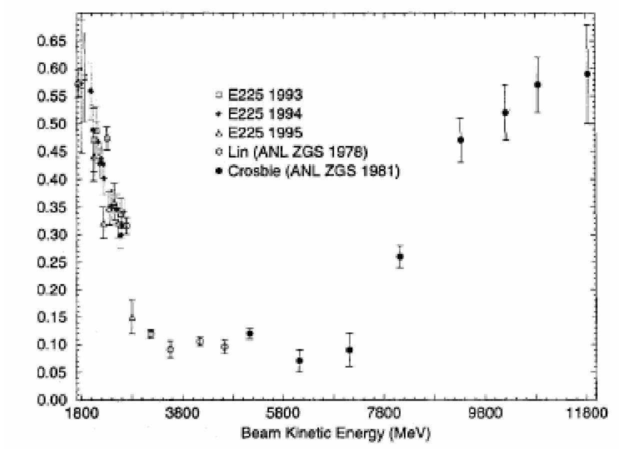
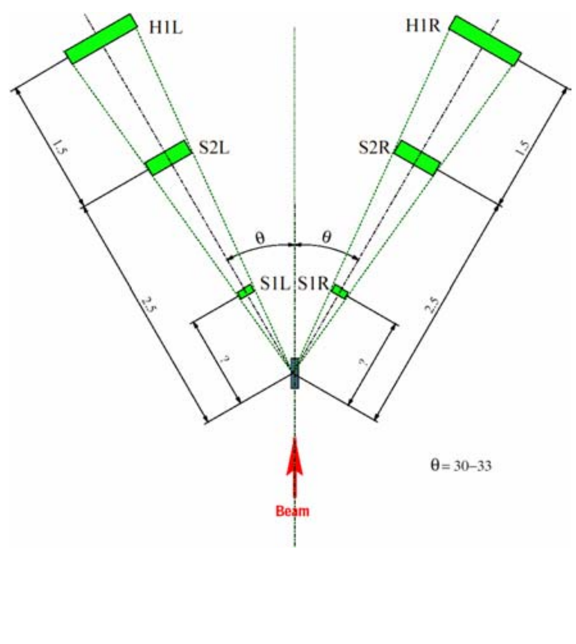


Fig.2. The spectrometer layout.



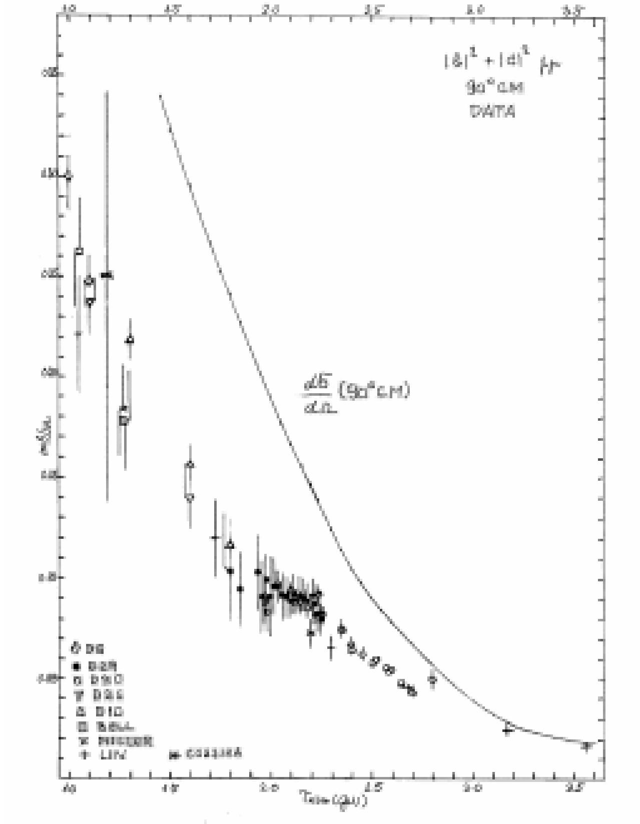


Fig.3. Energy dependence of the module of the singlet amplitude squared up to 3.5 GeV.

The experiment should also answer a question whether there is a resonance structure in $^1D_2$ partial wave of the elastic pp scattering or not. It will contribute to the world *NN* database for the direct reconstruction of the proton-proton amplitude at energies of several GeV. The planned data will be obtained at first time in this energy range. At present time, the acceleration complex of LHE JINR is the only place in the world where such measurements can be performed.

03-0-0941-91/2006

Priority of the project:	1
Status:	Data taking

Measurement of analyzing powers for the reaction p+CH_2 at polarized proton momentum 3–6 GeV/c (Project ALPOM)

Leader from JINR: N. Piskunov

Participating countries and international organizations: France, the USA, Slovak Republic, JINR.

As all fundamental interactions are spin-dependent, the knowledge of polarization observables is essential for the understanding of the structure of hadrons and for disentangling the reaction mechanism in nuclear reactions. The polarization of intermediate energy protons (i.e. in the range from a few hundreds MeV to a few GeV) is generally measured with full azimuthal acceptance focal plane polarimeters; they measure the angular distribution of a charged particle issued from an inclusive reaction, usually the scattering from a carbon target. The availability of high luminosity polarized electron beams opens up the possibility to develop the experimental study of spin degrees of freedom in hadron physics, at intermediate energy. In particular a recent experiment at the Thomas Jefferson National Accelerator Laboratory, through the measurement of the recoil proton polarization in the elastic scattering of longitudinally polarized electrons on a proton target, showed that the ratio of the electromagnetic form factors of the proton, electric and magnetic, GEp=GMp, decreases monotonically with increasing four momentum transfer squared, Q^2, starting at about 0.8 GeV^2 and up to 5.6 GeV^2 , which corresponds to proton momenta up to 3.8 GeV/c. The extension of this measurement to larger momenta requires the construction of a new polarimeter which will measure the polarization of recoil protons up to momenta of 5.7 GeV/c. Polarization experiments are, in general, time consuming. Therefore a thorough optimization of the characteristics of the polarimeter is desired. This requires a careful study of the analyzing reaction, which has to have large yield and large analyzing powers. An optimization of the nature and the thickness of the polarimeter analyzer target as well as of the geometry of the detection system is required. Complete angular distributions for the carbon analyzing power exist for values of proton momenta p p between 0.644 and 1.92 GeV/c and between 1.75 and 3.2 GeV/c, using the direct polarized proton beam of the Saturne accelerator in Saclay, and for dierent thicknesses of the target. There are also data for different carbon target thickness, performed at ITEP in Moscow between 1.35 and 2.02 GeV/c. Data on a 100 cm thick CH_2 target are available from Jlab, with polarized protons issued from ~ep elastic scattering; there are also data at two angles at 4.45 GeV/c for a CH_2 target. Analyzing powers on a thin proton target are also available. The largest momentum for which the analyzing powers are known for *pp* scattering is 10 GeV/c. The knowledge of A_y to the highest momentum of the proposed experiment is highly desirable to help planning the experiment. Such calibration has become possible at the Joint Institute for Nuclear Research (JINR) — Laboratory of High Energy (LHE) accelerator complex where a polarized proton beam is available up to *pp* =5.5 GeV/c.

During the realization of the proposal the POMME polarimeter, which has been widely used at Saclay, was transported to Dubna and used as a part of the detection system of the ALPHA spectrometer. A schematic view of the detection is shown in Fig.1.

The incident protons were detected by proportional chambers PC1, PC2 (ALPHA) with sensitive area 12·12 cm^2. The three wire chambers PC3-PC5 (POMME) with sensitive area 48·48 cm^2 were used to detect the trajectory of the charged particle after the scattering on the CH_2 analyzer. Each chamber has a x- and a y-plane and wire spacing of 2 mm. The plane angular resolution achieved with this polarimeter was 2.6 mrad.

The trigger was defined by the coincidence of signals from scintillation counters S1 and S2 of a diameter of 48 mm. In order to improve data acquisition system a new module was developed, it allows us to increase number of recorded events up to 4800 per beam spill.

During two beam runs at the Synchrophasotron we measured the analyzing power for the inclusive reaction p+CH_2 $\rightarrow$ one charged particle +X, at proton momenta of 3.8, 4.5 and 5.3 GeV/c, for different thicknesses of the CH_2 target, and at proton momentum 1.75 GeV/c, with a 37.5 g/cm^2 thick target.

To continue this project to higher proton momenta we are going to change the small proportional chambers to planes of drift tubes. These tubes are the contribution to the proposal from the American side of the collaboration. After this improvement the polarimeter can be installed at any place in the experimental area and used in other experiments, for example, the measurement of the transfer polarization coefficient in deuteron fragmentation. The drift tubes were successfully checked during the June 2003 run.

The collaboration is going to continue the measurements of the analyzing powers for the reaction p+CH_2 (C) at polarized proton momentum up to 6.5 GeV/c using the polarized deuteron beam at the Nuclotron. No such measurements have ever been reported; such a database is generally of great interest; in particular it may support further investigations of the proton form factors to Q^2 values larger than 10 GeV^2 at JLab.

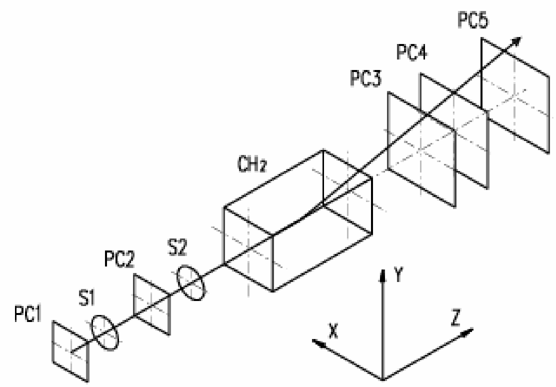
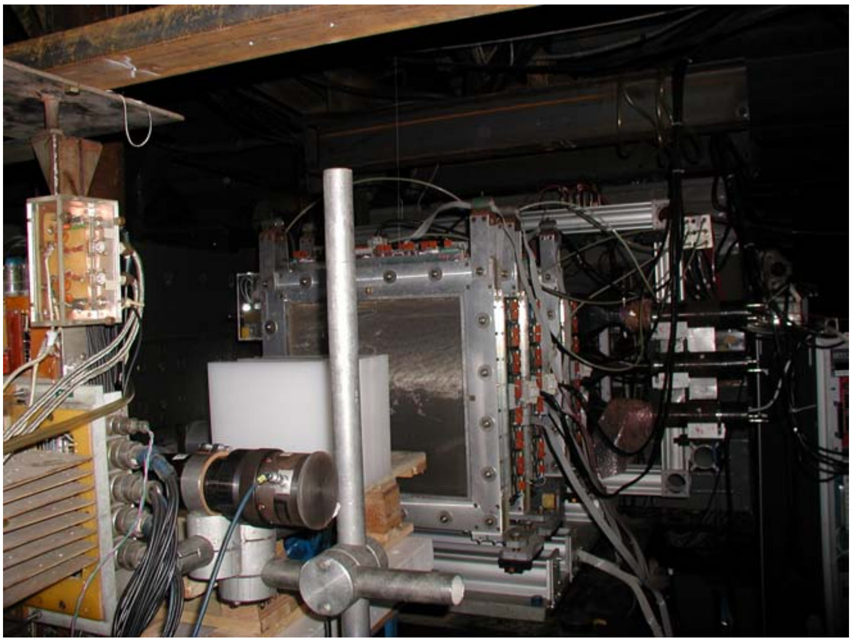


Fig.1. Schematic view of the setup. Si — scintillator counters, PCi — proportional chambers, CH2 target.



03-1-0983-92/2004	Priority of the project: 1
	Status: Data taking

Project BECQUEREL

Leader from JINR: P. Zarubin

Participating countries and international organizations: Armenia, Bulgaria, Kazakhstan, Slovak Republic, Russia.

The project is aimed on nuclear clustering studies on the grounds of the observations of interactions of light nuclei with an initial energy above 1·A GeV in nuclear emulsions. Thank to the best spatial resolution and the full solid angle acceptance provided by nuclear emulsions, such an approach allows one to obtain unique observations reflecting cluster-like features in light nuclear structures.

This research is important for the physics of few body nuclear systems and the related problems of nucleosynthesis. The obtained and expected results are illustrated with characteristic and evident images obtained by means of a microscope equipped with a CCD camera and can be found on the web site http://becquerel.lhe.jinr.ru.

The explorations are provided with the primary and secondary beams of the JINR Nuclotron. Investigations are carried out for He, Be, B, C, and N isotopes.

Early performed emulsion exposures in relativistic beams of ^{22}Ne, ^{24}Mg, ^{28}Si, and ^{32}S nuclei provide grounds for search of phase transition of these nuclei in Bose condensate of dilute α-particle gas-like systems.

Research program

The BECQUEREL Project (**Be**ryllium (**B**oron) **C**lustering **Que**st in **Rel**ativistic Multifragmentation) is oriented toward emulsion expositions by light stable and radioactive nuclei with energy of the order of few GeV per nucleon in the JINR Nuclotron beams. Observations of the fragmentation of light relativistic nuclei open up new opportunities to explore highly excited nuclear states near multiparticle decay thresholds. Our interest in such states is motivated by their predicted properties as loosely bound systems with spatial spread significantly exceeding the fragment sizes. Natural components of such states are the lightest nuclei having no excited states below particle decay thresholds, i. e. deuterons, tritons, ^{3}He, and ^{4}He nuclei.

A principal experimental task consists in provision of a complete spectroscopy of final fragments — observation of dissociation events, determination of various channel probabilities (branchings), and fragment identification and velocity measurement. Multiple track detection is performed in BR-2 emulsion layers measuring $100{\cdot}200{\cdot}0.5$ mm^3. The layers are assembled in few cm thick stacks. The stacks are exposed to a beam in the longitudinal direction. They provide multiple track visualization over the total solid angle with spatial resolution of about 0.5 micron. Their sensitivity extends from slow fragments down to relativistic single charged particles. A mean range of light relativistic nuclei in emulsion is defined by the cross section of their inelastic interaction with emulsion nuclei. It varies from 14 cm for ^{6}Li nuclei to 9 cm for ^{24}Mg.

Advantages of an emulsion technique are exploited most completely in the study of peripheral fragmentation of light stable and neutron deficient nuclei. Visual scanning is concentrated on the events with a total charge transfer of an incoming nucleus to secondary particles in a narrow fragmentation cone. Emulsion nucleus fragmentation and meson production become reduced or even suppressed in this way. Such events amount to a few percent of the total number of inelastic events. In practice, this approach allows one to accumulate statistics of a few tens of peripheral events, which is sufficient for a reliable determination of dominating dissociation channels. Earlier, a role of channels ^{6}Li$\to$^{4}He^{2}H, ^{12}C$\to$3^{4}He, and ^{16}O$\to$4^{4}He was explored.

At present an analogous search of effects of a deuteron and triton clustering is in progress for exposures with $^{6}He(^{4}He)$, ^{7}Li (^{3}H-^{4}He), $^{10,11}B$($^{2,3}H$-^{4}He-^{4}He), and ^{14}N (^{2}H-^{4}He-^{4}He-^{4}He).

^{3}He clustering manifests in decays of light neutron deficient nuclei. Our aim is to clarify a role of ^{3}He clustering in forthcoming exposures with ^{7}Be ($^{4,3}He$-^{3}He), ^{8}B ($^{1,2}H$-$^{4,3}He$-^{3}He), ^{9}Be (^{4}He-^{4}He), ^{9}C (^{3}He-^{3}He-^{3}He), ^{10}C (^{3}He-^{3}He-^{4}He), and ^{11}C (^{3}He-^{4}He-^{4}He).

A complete spectroscopy of few body decays of highly excited nuclei allows one to search for the Efimov excited states in nuclear systems. The Efimov effect is the remarkable theoretical observation that the number of bound states for three particles interacting via s-wave short range potentials may grow to infinity, as the pair interaction are just about to bind two particles. The Efimov states are loosely bound and their wave functions extend far beyond those of the remaining two particles. Search for analogs of such states on nuclear scale is of interest since they can play a role of intermediate states ("waiting stations") due to dramatically reduced Coulomb repulsion for nuclear fusions in stellar media.

Other intriguing conjecture is that $n\alpha$ nuclei near the $n\alpha$ particle decay threshold can constitute a loosely bound dilute gas forming a Bose condensate. Its major signature is multi α particle decays with a narrowed distribution of relative velocities. Search for such states on the nuclear scale is of interest since they can play a role of intermediate states ("waiting stations") for a stellar nuclear fusion due to reduced Coulomb repulsion.

Universality of a coherent dissociation mechanism enables us to search for such events in emulsions already irradiated by ^{22}Ne, ^{24}Mg, ^{28}Si, and ^{32}S nuclei at 4.5A GeV/c in order to study multiple fragment decays. Verifcation of a hypothesis about the phase transition of light nuclei from a ground state to multiparticle one via a Bose condensate is one of intriguing perspectives of this research.

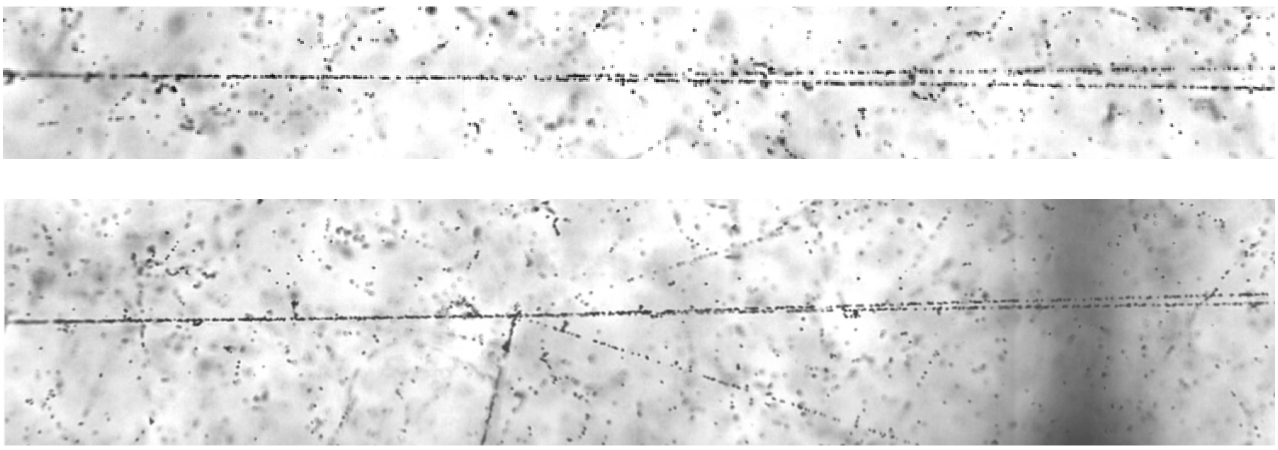


Photo. Examples of peripheral dissociation of 1.23A GeV ^{7}Be nuclei into pairs of He nuclei. Upper photo: dissociation without target nucleus excitation and produced charged mesons. Lower photo: dissociation accompanied by a target fragment and a meson like pair.

03-1-0983-92/2004

Priority of the project: 1

Status: Data analysis

Project SCAN-2

Leader from JINR: S. Afanasiev

Participating countries and international organizations: JINR, Romania.

The backward elastic pd scattering pd→dp the triangle diagram of one-pion exchange with the subprocess pp→dp$^+$ considerably contributes in the Δ-region. This mechanism describes well the energy dependence of the pd→ dp cross section at Θ*=180° and, in addition, explains the qualitative agreement between the proton vector analyzing power A_y from pp→dp$^+$ and pd→dp, observed in the Δ-region. If one assumes that the triangle diagram with one-pion exchange dominates in the break-up pd→(pn)p at large scattering angles, one would expect in this reaction a similar s/t ratio of a few percent, as observed in pp→pnp$^+$. For the Δ-mechanism of the pd→pnp reaction, which dominates the one-pion exchange triangle diagram, the product of spin and isospin factors yields a s/t ratio of 1/27. In contrast, one should expect a higher s/t ratio of about 1/3 for the one-nucleon exchange mechanism of the deuteron breakup. It was suggested in different references to directly measure the singlet channel in the reaction pd→(pp)(0°)+n(180°) with a pp pair of low relative energy E_{pp}=0–5 MeV emitted in forward direction and a neutron going backward. Due to a considerable suppression of the Δ-mechanism in this reaction other mechanisms, more sensitive to the short-range structure of the deuteron, are expected to become important.

The formation of a singlet $(NN)_S$ pair in $^1S_0$ state is the most interesting process. As is well known, because of the change of the isospin of the NN pair in the process d + N ↔N + $(NN)_S$, the balance between the ONE, Δ, and SS mechanisms can be considerably different from that in purely elastic pd→pd scattering.

The mechanism of three-baron resonances, which appeared in the analysis of dp backward elastic scattering is not considered here, since there are so far no experimental data on the reactions under considerations. At small relative energies in the NN pair, E_{NN}<3 MeV, the final pp state is dominated by $^1S_0$ wave.

The research program

In the SCAN-2 project we proposed a experimental study the process of dp backward inelastic scattering d+p→(pp)+n where the two nucleons in the final NN pair have almost parallel and almost equal momenta in the backward direction, and the third nucleon is emitted into the forward hemisphere. When the energy of the relative motion in the NN pair is small, E_{NN}<3 MeV, the kinematics of these processes is very similar to the kinematics of dp backward elastic scattering.

In our project we have proposed to select reaction d+p→(pp)+n detecting processes where only two slowly protons produced.

This measurement was been proposed for installation on nuclotron beam and we have planed to measure as cross section reaction as T_{20} using a polarise neuteron beam. For realisation this measurement was assembled a spectrometer next configuration Fig.1.

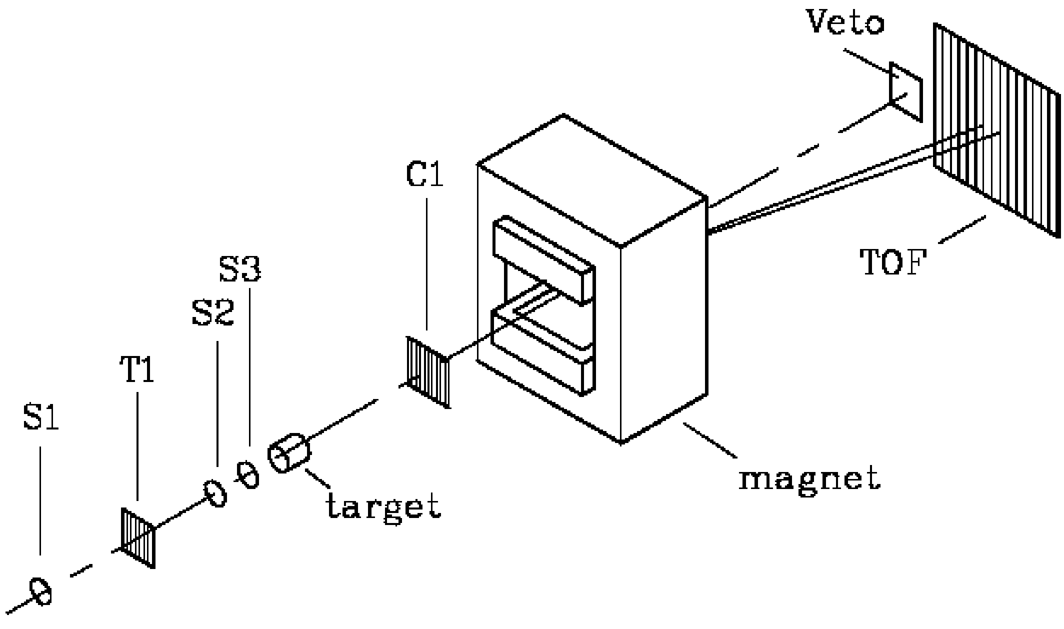


Fig.1. Current setup of SCAN-2 experiment.

As es this project was been arranged for polarized beam of nuclotron we where needed an information on beam polarization in nuclotron. The panned intensity was low and that was no setup for this measurement. For solving this problem we propose to use internal beam and the monitors of SCAN spectrometer. This setup is shown in Fig.2.

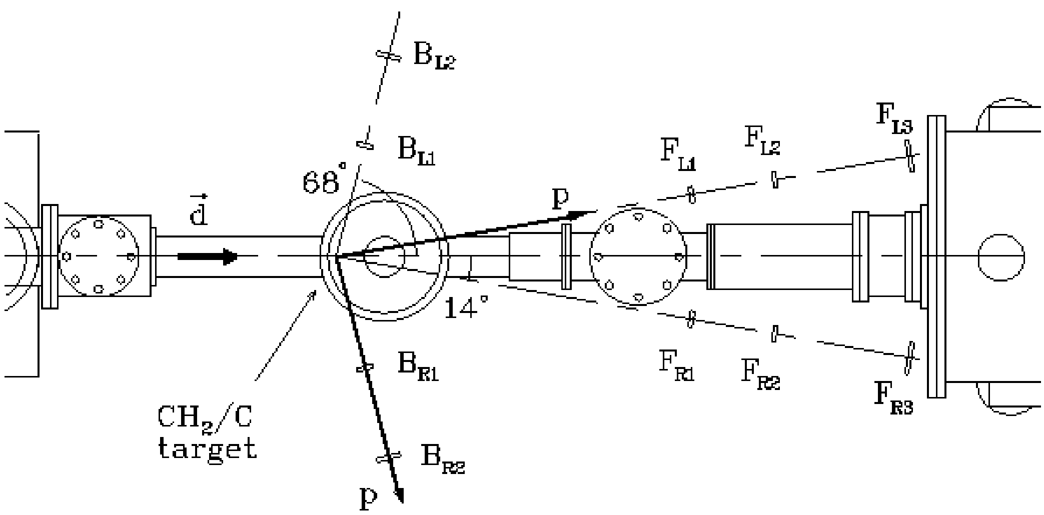


Fig.2. Setup of the polarimeter.

During 2003 operation year was been collected data for two proton formation at two deuteron momentum 3.0 GeV/c and 3.5 GeV/c. We have not enough time to make full analyze and project was been extended for 2004 year.

In the next year we are planing to finish analysis of the data and to make assembled polarimeter as permanent setup of nuclotron.

03-0-1008-95/2005

Priority of the project:	1
Status:	In-progress

Theoretical and Experimental Research in Electronuclear Method of Energy Production and Radioactive Waste Transmutation

Leader from JINR: A. Sissakian, I. Puzynin, S. Tachanowski, I. Shelayev

Participating countries and international organizations: Belarus, Czech Republic, France, Germany, India, JINR, Mongolia, Poland, Russia, Spain, Sweden, Ukraine.

This theme is aimed at carrying out research on relativistic nuclear physics and accelerator facilities required for the development of the electronuclear method of energy production and radioactive waste transmutation. The main purpose is to carry out experimental work on the DLNP 660 MeV phasotron and a sub-critical assembly with a thermal neutron spectrum and a booster sub-critical system controlled by the neutron generator ($1.5 \cdot 10^{12}$ n/s) in the National Academy of Sciences of Belarus (Minsk).

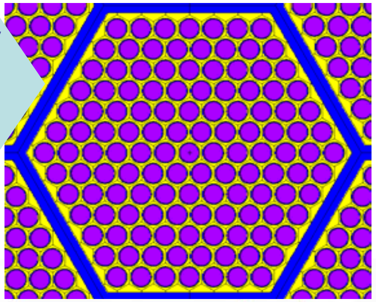
The theme combines and coordinates the research under way at 5 JINR laboratories and a number of JINR Member State institutes. JINR has got the major scientific and technical basis and unique experimental possibilities for such investigations. The results in this research area have received high estimates at international conferences in 1996–2003. The theme practically implements the results of fundamental research under way at JINR. The project “SAD” is being worked out for creation of a 20 KwT electronuclear installation on the basis of the DLNP 660 MeV phasotron, a sub-critical assembly with MOX fuel, and a sub-critical assembly with a thermal neutron spectrum with 10% enriched Uranium, as well as a booster sub-critical system comprising a fast zone (36–90% enriched Uranium and a leaden decelerator) and a thermal zone (10% enriched Uranium and a polyethylene decelerator) controlled by a neutron generator operating in continuous and pulsed modes.

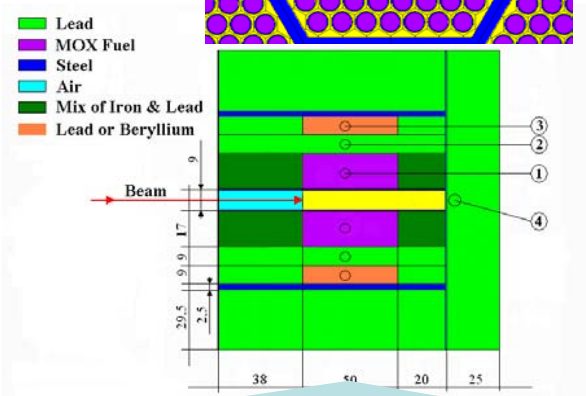
Upon completion of the theme, the following results are expected:

- Measuring the activity of isotopes generated in various targets (Pb, Pb-Bi) exposed to 660 MeV protons. Measurement of the dose around the targets using dosimeters of various types;
- Measurement of time characteristics of the density distribution of the neutron flux in a sub-critical system with a thermal spectrum (YALINA) controlled by a pulsing proton beam (without a fissionable material). Processing of experimental data obtained on the DLNP 660 MeV phasotron and the sub-critical assembly of the NAS of Belarus;
- Simulation of parameters of sub-critical assemblies in combination with a proton accelerator (PA) and a neutron generator (NG) with the purpose of optimization of the SAD structure and composition. Numerical analysis of the SAD parameters. Estimation of the parameters of targets–converters, spatial and energy distribution of neutron fields in SAD devices, including estimation of the influence of sizes of the primary target and its arrangement in the SAD volume, composition and geometry of SAD on the characteristics of the installation. Calculations: a) the energy release in constructional devices of SAD, b) neutron transport with the purpose of optimization of planned experiments and determination of neutron fields distribution in experimental channels, c) determination of dependence of the effective neutron multiplication coefficient K_{eff} on modification of the SAD construction, d) radiation shielding of the installation in the direction of the proton beam penetration, estimation of the ionizing radiation around the SAD. Estimation of the kinetic characteristics of SAD on the basis of calculating the time oscillations K_{eff} in various operating modes of the installation. Preparation of cross-sections and carrying out calculations of the induced activity in the SAD components and radiation shielding.

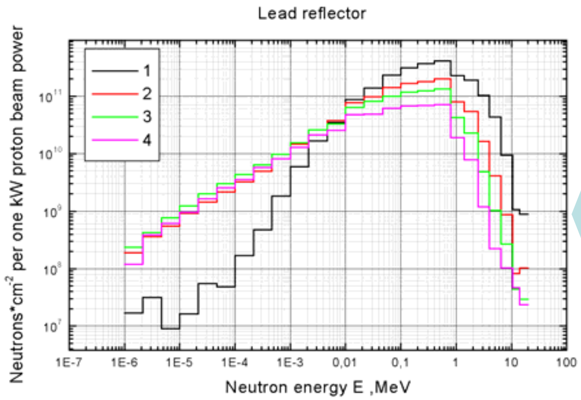
Monte Carlo Modeling of a Subcritical Assembly Driven with the Existing 660 MEV JINR Protons Accelerator

Geometry of Fuel Batch

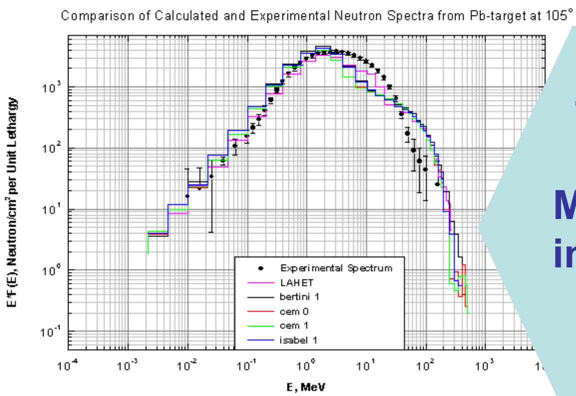




Model of SAD for 9cm Target Diameter and for Fuel with 27% PuO_2



Neutron spectra calculated at volumes 1,2,3 and 4



Results of the Neutron Spectrum Measurements in Comparison with the Computer Simulations

JINR’s Participation in Experiments at CERN

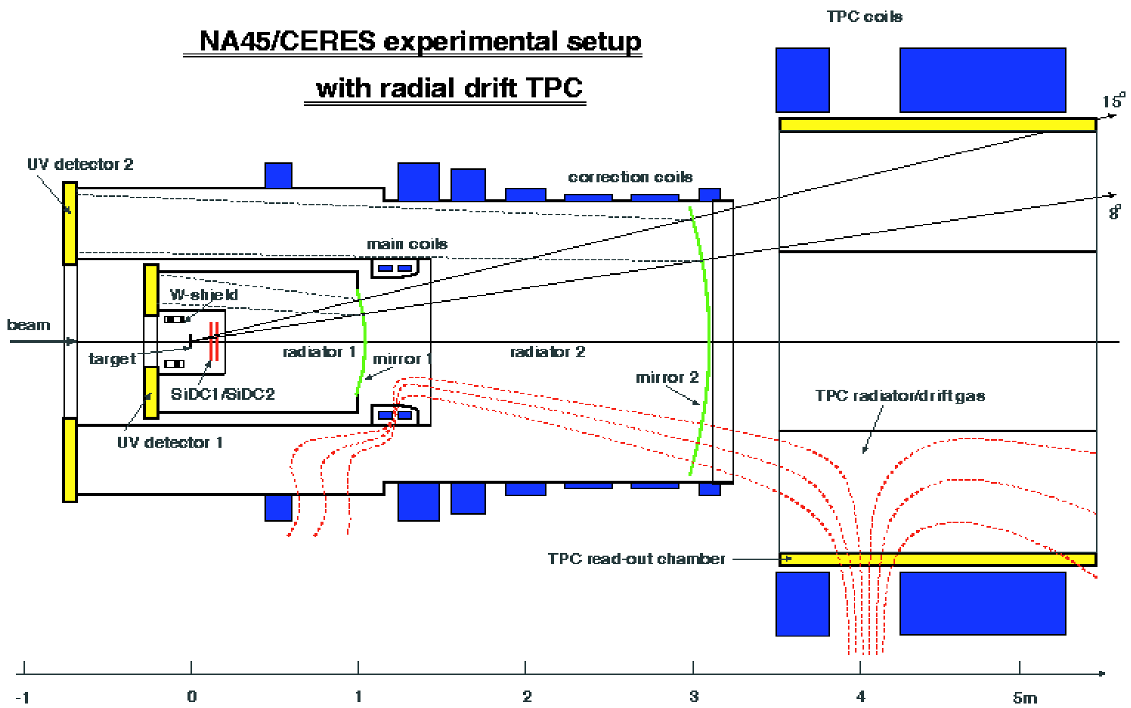
03-1-1011-95/2005

Priority of the project:	1
Status:	Data taking

Electron — Pair and Photon Production in pp, p-A and AA Collisions CERES/NA45 experiment

Leader from JINR: Yu. Panebratsev

Participating countries and international organizations: CERN, Czech Republic, Germany, Italy, Israel, the USA, JINR, CERES collaboration.



CERES is an experiment dedicated to the measurement of electron-positron pairs and direct photons produced in hadron and nuclear collisions, at CERN SPS energies. Its main goal is to study systematically the pair continuum in the mass region from 50 MeV/c² up to ~2 GeV/c², and the vector mesons ρ/ω and Φ. Due to the absence of final state interactions, these observables are considered as unique probes of the dynamics of ultrarelativistic heavy-ion collisions, and in particular of the hot early stages where a quark-gluon plasma is expected to be formed.

CERES has started the measurement of low-mass electron pairs in 160 GeV/nucleon Pb-Au collisions at central rapidities in a wide multiplicity range. This work is the continuation of our systematic studies on pair production in p-Be, p-Au and S-Au interactions. The motivation for this effort derives from a new source of low-mass dileptons recently observed in S-Au collisions.

In 1997–1998 upgrade of the CERES set-up with the addition of a TPC downstream of the present double RICH spectrometer was made. The main purpose was to improve the spectrometer mass resolution down to the level of the natural width of the ω thereby allowing, in addition to the continuum measurement, precision spectroscopy of the vector meson resonances ρ, ω, Φ.

The addition of the TPC improves substantially the hadron capability of the CERES spectrometer. This allowed for a systematic investigation of hadronic observables around midrapidity. The recent back-to-back correlation analysis of the charged hadrons and high-p_t pions with taking into account flow (v_2) and HBT corrections shows the significant contribution of non-flow component possibly originating from the semi-hard processes. The centrality dependent HBT analysis at different energies shows that thermal pion freeze-out occurs at constant mean free path $\lambda_f \sim 1.0$ fm that implies a significant opaqueness of the pion source. These studies are exceptionally interesting now as RHIC has claimed the discovery of jet-quenching phenomenon at the region of pQCD applicability. A study of elliptic flow fluctuations is feasible and might give insight to new dynamical phenomena at the earliest stages of the collision.

Mass production of 31M, triggering on the most central 8% of the geometrical cross section, Pb+Au events at 158A GeV has been completed in 2003.

Analysis of 31M Pb+Au events at 40, 80 and 158A GeV and reconstruction of e^+e^- — pair effective mass spectrum, with resolution compared with natural width of the φ-meson, and hadronic observations will be main goal for CERES collaboration in 2003–2006.

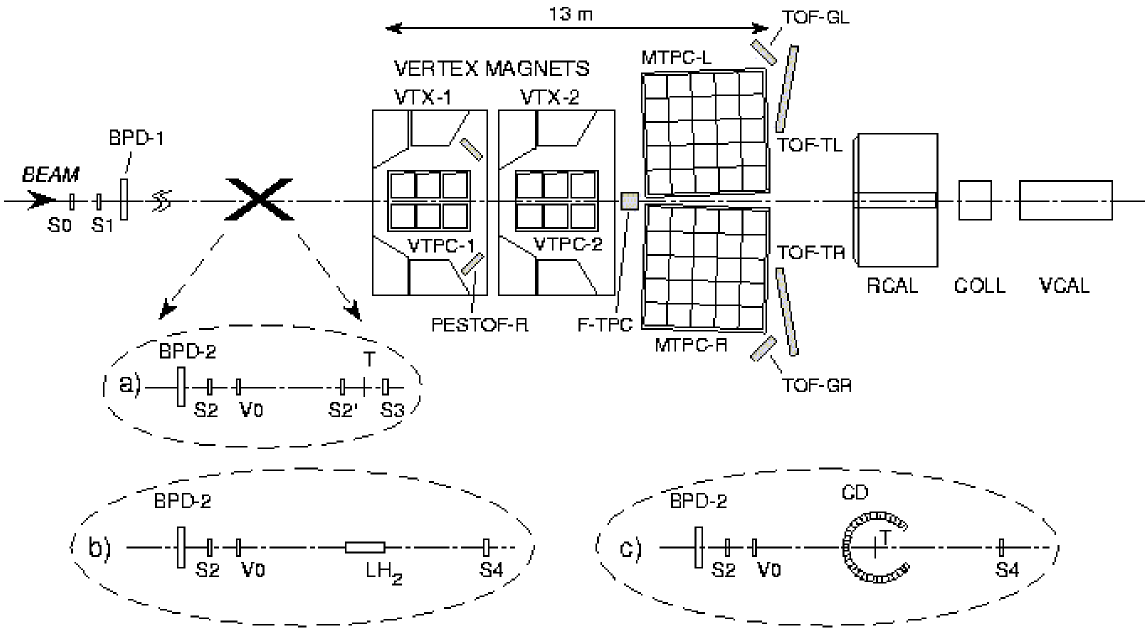
03-1-0983-92/2004

Priority of the project:	1
Status:	Data taking

Large Acceptance Hadron Detector for an Investigation of Pb-Induced Reactions at the CERN SPS (Project NA49)

Leader from JINR: G. Melkumov

Participating countries and international organizations: Australia, CERN, Croatia, Germany, Greece, Hungary, Poland, Russia, Slovak Republic, France, the USA, the UK.



The NA49 experiment is being performed to search for the phase transition from hadrons to deconfined quarks and gluons in Pb+Pb collisions at the SPS predicted by Lattice QCD. Such reactions provide the largest energy density of a collision system for a controlled study at the laboratory. The NA49 was optimized to study hadronic observables in strong interactions of nucleons and nuclei, with a specific aim at obtaining large acceptance for momentum reconstruction and for the identification of most produced particles.

JINR has been taking an active part in the NA49 since 1995. A 900-channel Time-of-Flight (TOF) detector is the main contribution of Dubna to the experiment. In this activity, the Dubna group has focussed on the design and construction, the maintenance and running of the whole TOF system on the beam, as well as on its callibration and test, and finally, on data taking and analysis.

Experiment

The experimental NA49 setup comprises four Time Projection Chambers (TPC) for tracking and energy loss measurements; four Time-of-Flight (TOF) walls; an array of PesTOF counters for additional particle identification; calorimetry for neutral particle detection and triggering; a system of beam detectors.

Two medium size TPCs (VTPC-1/2) are located inside the Vertex-Magnets (VTX-1/2) with up to 1.5T field strengths each. Two large size TPCs (MTPC-L/R) are positioned downstream the magnet for high-precision dE/dx measurements and acceptance coverage in the forward direction.

The TOF scintillator systems supply an additional particle identification in the region of minimum ionization. A Ring Calorimeter (RCAL) offers a photon and neutral particle measurement as well as a transverse energy determination over the full azimuth. A Veto Calorimeter (VCAL) covering an extreme forward direction is used for central event triggering in Pb+Pb interactions.

The position and direction of each beam particle is measured by a system of proportional chambers with cathode readout (BPD-1.2.3). Metal foil targets are used for Pb+Pb and p+A running (fig.1a and c). A liquid hydrogen target is available for p+p running (fig.1b). The acceptance coverage amounts to about 80% of all charged particles. For central Pb+Pb interactions, this means that 1200 produced charged particles are detected out of about 1500.

Research program

The status and future program of the NA49 experiment were submitted to the SPS Committee in Addenda 2 and 3 to Proposal SPSLC/P264.

This report advocates a comprehensive and consistent study of hadronic interactions with the NA49 detector, ranging from elementary hadron + nucleon processes via hadron + nucleus interactions with controlled centrality to heavy ion collisions at a variety of nuclear masses and energies.

Primary items of the NA49 experimental program are the following:

- to obtain more statistics for Pb+Pb collisions at 158 A*GeV as needed for rare processes requiring clean TOF identification, such as PHI, λ (1520) and KK, pp interferometry;
- to study Pb+Pb collisions at lower beam energies (40 A*GeV and 80 A*GeV) in order to establish the collision energy dependence of QGP signals and to locate the QGP phase transition potentially;
- to study collisions of lighter ions (C+C and Si+Si and Ag+Ag) in order to investigate how the properties of matter depend on the size of colliding objects (the level of equilibration, creation of QGP);
- to continue the investigation of proton(meson)-nucleon and nucleus reactions with sufficient statistics for relating to nucleus-nucleus collisions and for studying soft hadronic phenomena in a simpler environment.

03-1-0001-2000/2005

Priority of the project: 1

Status: Realization

ALICE: Participation of the Joint Institute for Nuclear Research in the ALICE Experiment at the CERN LHC

Leader from JINR: A. Vodopianov

Participating countries and international organizations: Georgia, JINR, Russia, Romania and ALICE collaboration.

ALICE (A Large Ion Collider Experiment) is a dedicated heavy-ion experiment and its prime goal is the study of Pb-Pb interactions at LHC at a center-of-mass energy of about 5.5 TeV/nucleon to establish and analyze the existence of QCD bulk matter and the Quark Gluon Plasma (QGP). The aim is to study the physics of strongly interacting matter at extreme energy densities, where the formation of a new phase of matter, the quark-gluon plasma, is expected. The existence of such a phase and its properties are a key issue in QCD for the understanding of confinement and chiral-symmetry restoration. For this purpose, we intend to carry out a comprehensive study of the hadrons, electrons, muons and photons produced in the collision of heavy nuclei.

The ALICE Collaboration presently consists of about 750 physicists from 79 institutions. The ALICE experiment will be ready to take data at the start up date of LHC in July 2005. The JINR involvement in the ALICE project is devoted to four major directions: physics study and simulation; design and construction of the large dipole magnet; design and construction of subsystems for the particle identification; development of the software for the simulation of the inner tracking system, for the pattern recognition and track reconstruction.

Physics study and simulation

In order to attain the main goal of the ALICE collaboration, a number of various observable have to be obtained and learned in the following main directions of physics investigations: global event features (particle and transverse-energy flows, the shape and structure of rapidity distributions) transverse momentum spectra (large event-by-event fluctuations, the spectra peculiarities related to the ‘jet quenching’) flavor composition (strangeness and charm enhancement) vector meson characteristics (mass, width and decay pattern changeable of lighter (ρ, ω, ϕ) ones, suppression of the heavy quarkonia resonances (J/ψ, ψ', Υ, Υ', Υ'') production) correlation and fluctuation (multi particle correlation, CENTAURO events, Bose-Einstein correlation) prompt photons (the thermal radiation from QGP and mixed phase).

The Dubna group main activity relates to the vector meson physics and Bose-Einstein correlation. In order to check the possibility to observe ρ, ω, ϕ decays to e^+e^- -pairs and $\phi \to K^+K^-$ decays the simulation has been done for the Pb-Pb central events taking into account the detectors resolution and tracking and particle identification efficiencies. It has been shown that it will be possible to determine the signals over the background for all considered resonance decay modes. Accuracies of the determination of the resonance mass positions are of the order of a few percent. Besides, in case of $\phi \to K^+K^-$ decay the resonance can be width–extracted from a fit procedure of the signal shape with the accuracy of the order of a few percents also. The simulation of Pb-Pb VENUS events with Bose-Einstein correlation including has shown that the corresponding interferometric radii at LHC energy would be rather large — about 15–20 fm. Besides, a new possibility to determine a time order of different particles (K^+, K^-, π^+, π^-, p) emission at very short time scale of several fm/c was shown from nonidentical particles correlation analysis. In particular, this effect could be useful to indicate the formation of QGP.

Warm Dipole Magnet for the Muon Arm Spectrometer

The large conventional dipole magnet is a major part of the ALICE forward muon spectrometer. The magnet will be designed and constructed at JINR as a joint effort of JINR and CERN. The proposed dipole magnet has the central field of 0.7 T, the field integral of 3.0 T·m and the aperture of 9°. The magnet has the length of 5 m and the largest inner diameter of 4.1 m. The coil is made from a hollow aluminum conductor of 50·50 mm^2. Its weight is about 30 ton. The weight of the iron yoke is about 800 tons. The coil will be flat wounded and then bent to quasi-cylindrical shape.

Particle Identification System

JINR team involved into the particle identification in the ALICE detector via the Transition Radiation Detector for electron identification and Time-of-Flight array based on the Resistive Plate Chambers for hadron identification. Main tasks are development of the prototypes and the production of the detectors.

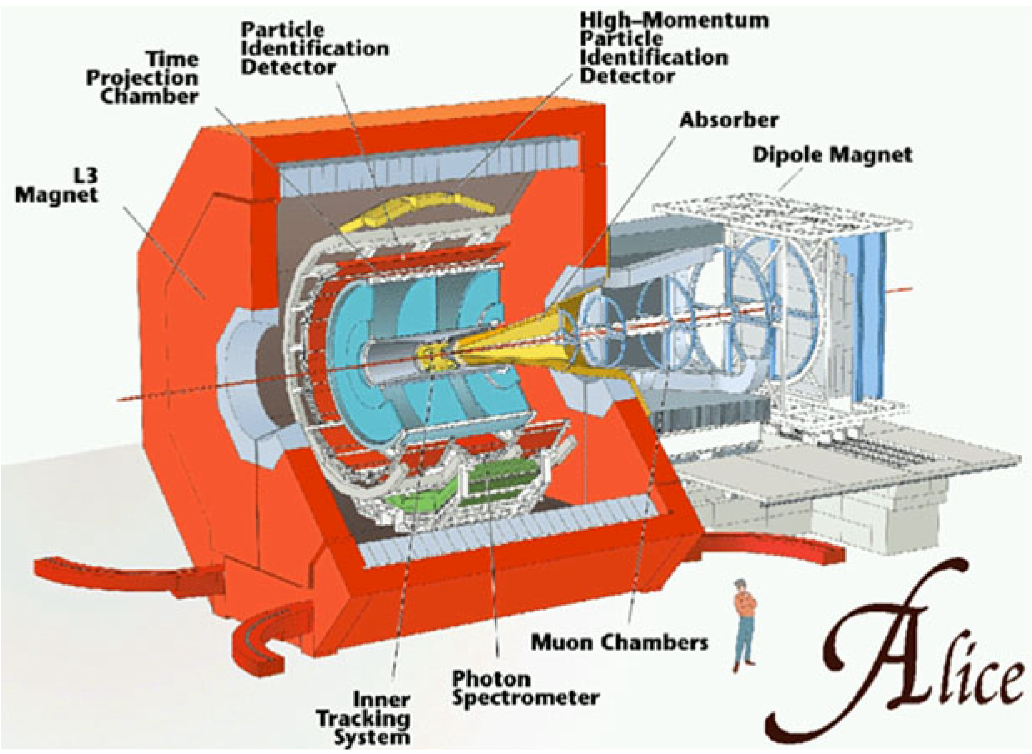
Software development

To simulate the silicon Inner Tracking System (vertex detector) a GEANT-based program for a "realistic" simulation of different types (pixel, drift, double-sided microstrip) silicon detectors was created in Dubna. Such detail as electron and hole drift and diffusion, electronics response and noise influence and also the real detector geometry was taken into account. The main results are the following:

- the created charge is distributed through one or several cells in dependence of the detector type and direction (cluster creation);
- the spatial precisions for the pixel, drift, strip detector are obtained;
- the particle identification power is shown;
- all parameters are adequate to the detector performance.

Two different tracking programs were created in Dubna based in Kalman filtering and Neural Networks algorithms respectively. The following main results have been obtained for the ITS+TPC detectors:

- the tracking efficiency varies from 90% to 50% versus P_t;
- the mean angular resolutions are 1.5–2.0 mrad, the mean momentum resolution is less than 2% and correspondent resolutions for impact parameters in transverse and longitudinal directions equaled to 40 microns and 90 microns;
- the tracking efficiency and the resolutions are adequate to physics performances in ALICE.



JINR's Participation in Experiments at BNL

03-1-0983-92/2004

Priority of the project: 1

Status: Data taking

High pt Upgrade for PHENIX
"UP Dubna Project" Dubna Participation

Leader from JINR: A. Litvinenko

Participating countries and international organizations: JINR, Japan, the USA.

In order to enhance particle identification (PID) capability of PHENIX, installation of aerogel counters are proposed. Although much larger coverage of aerogel counters would enhance physics capability, here we propose aerogel counter at limited coverage (~ 2x2 m^2 with, 200 segmentations) as a first step. This aerogel counter will be installed on the West Arm of PHENIX (see Fig.1). Together with TOF and RICH counters, this additional aerogel counter provides the particle identification of π/K/p up to 10 GeV/c.

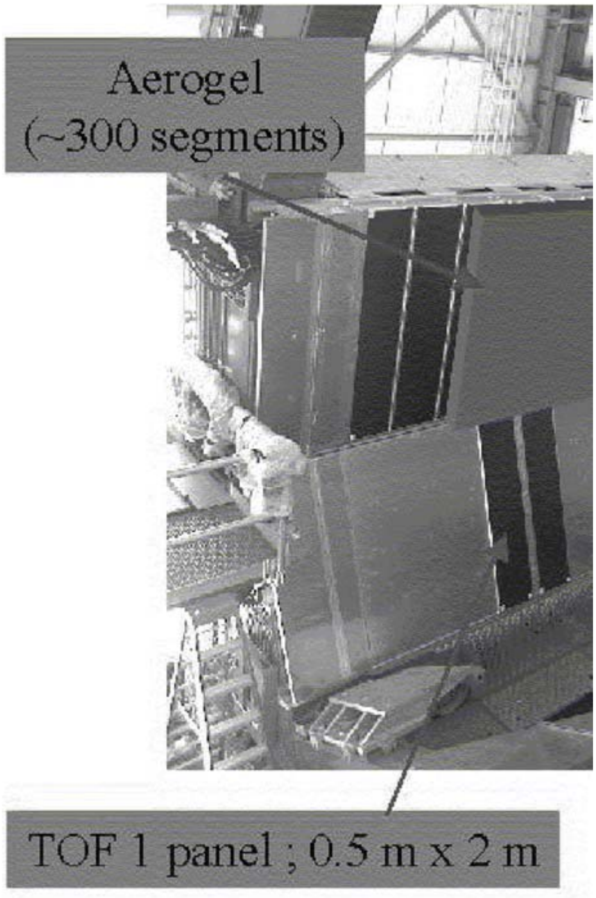


Fig.1. The view of aerogel counter wall at PHENIX experiment setup.

The High pt Upgrades project is aimed to improve particle identification (PID) for PHENIX (The Pioneering High Energy Nuclear Interacting Experiment). The PHENIX (see http://www.phenix.bnl.gov/) is one of the four experiments situated at the Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) (see http://www.bnl.gov/RHIC/).

Polarized protons and nuclei as heavy as gold (Au) are accelerated at RHIC to energies of $\sqrt{S_{NN}}$=200 GeV per nucleon-nucleon pair.

The main goals of Spin Physics at PHENIX are to study spin structure of the nucleon (gluon helicity distribution DG, anti-quark helicity distribution Dqi, quark transversity distribution DTqi) and Test of Symmetry (Transverse spin effects).

The heavy nuclei programs of the all RHIC experiments are first of all oriented on the search of quark-gluon plasma (QGP) creation in heavy nuclei collisions. The PHENIX experiment is designed to investigate nuclear collisions with a wide variety of probes, focusing primarily on those produced in the early stages of the collision.

To make a more definite conclusion from high p_T suppression it is natural to extend the PID towards higher momentum. It has to be done by taking into account the following condition: the possibility of existed PHENIX PID capability has to be used; the free space for the proposed detector system on PHENIX set-up should be found; \item the material amount in detector system to be installed should be minimized in order to avoid the background of the detected system situated behind the proposed detectors; reasonable price and time of construction.

These conditions were satisfied in "High pt project at RHIC-PHENIX experiment" (see tt http://alice-france.in2p3.fr/qm2002/) It was proposed in this project that Aerogel Cherenkov counters will be installed on the West Arm of PHENIX setup.

The specifics "High pt project at RHIC-PHENIX experiment" is the necessity to have good enough granularity (high multiplicity in the central Au-Au at RIHC energies); necessity to use low refraction index (n=1.007); necessity to cover large (at about $2\cdot 2$ m^2) area.

Timetable and milestones in the future are listed below:

- Mechanical: Completion of simulation study, Oct., 2002. Prototype production for KEK test and RUN3, Nov., 2002. Beam test of final prototype, Dec., 2002. Installation of a few cells to the West Arm, Jan.–Feb., 2003. Partial purchase of PMT's and aerogel, Mar., 2003. Mechanical design of the main frame on the carrier, summer 2003. Final decision on the design, Jul., 2003. Start of mass production of cells, Aug., 2003. Start of partial installation, fall-winter, 2003. All system ready by mid-2004.
- Electronics(PMT bleeder, preamp and calibration system): Prototype design of bleeder and preamp, Nov., 2002. Evaluation of bleeder and preamp prototype, Dec., 2002. Production of final bleeder and preamp, Feb., 2003. Start mass production of bleeder & preamp, Mar., 2003. Setup testbench for PMT, bleeder and preamp tests, Mar., 2003. Decision on calibration system (LED), Mar., 2003. Complete, 1=3 of bleeder/preamp/LED production, summer, 2003. All system ready by mid-2004.
- Front-End and trigger Electronics: Design the FEE (minor modification to RICH FEE), Feb., 2003. FEE Prototype production, Apr., 2003. FEE production, fall, 2003. Trigger circuit design, Jun., 2003. All system ready by mid-2004.

03-1-1011-95/2005

Priority of the project:	1

Status: Data taking

Project STAR

Leader from JINR: Yu. Panebratsev

Participating countries and international organizations: Germany, Czech Republic, JINR, Russia, France, the USA and STAR collaboration.

Scientific programme

The STAR project involves the investigations of nuclear interactions and polarized protons at the relativistic heavy ion collider (RHIC). Particularly, it is assumed to investigate spin effects in polarized proton-proton collisions.

Main results and plans

The first 3 runs in STAR have been an outstanding success producing a wealth of results and new physics; even so, the most important achievements are still goals. The next 1–2 years will be extremely exciting.

The data on high pt suppression and correlations support the conclusion that we have produced a medium that: is dense, is dissipative (very strong interacting). We need: extended Au-Au run needed to address several important probes that need large data sets (e.g., pT-dependence of suppression; J/ψ, υ, open charm, heavy baryon/meson flow); also, species and energy scans to map the evolution of key observables.

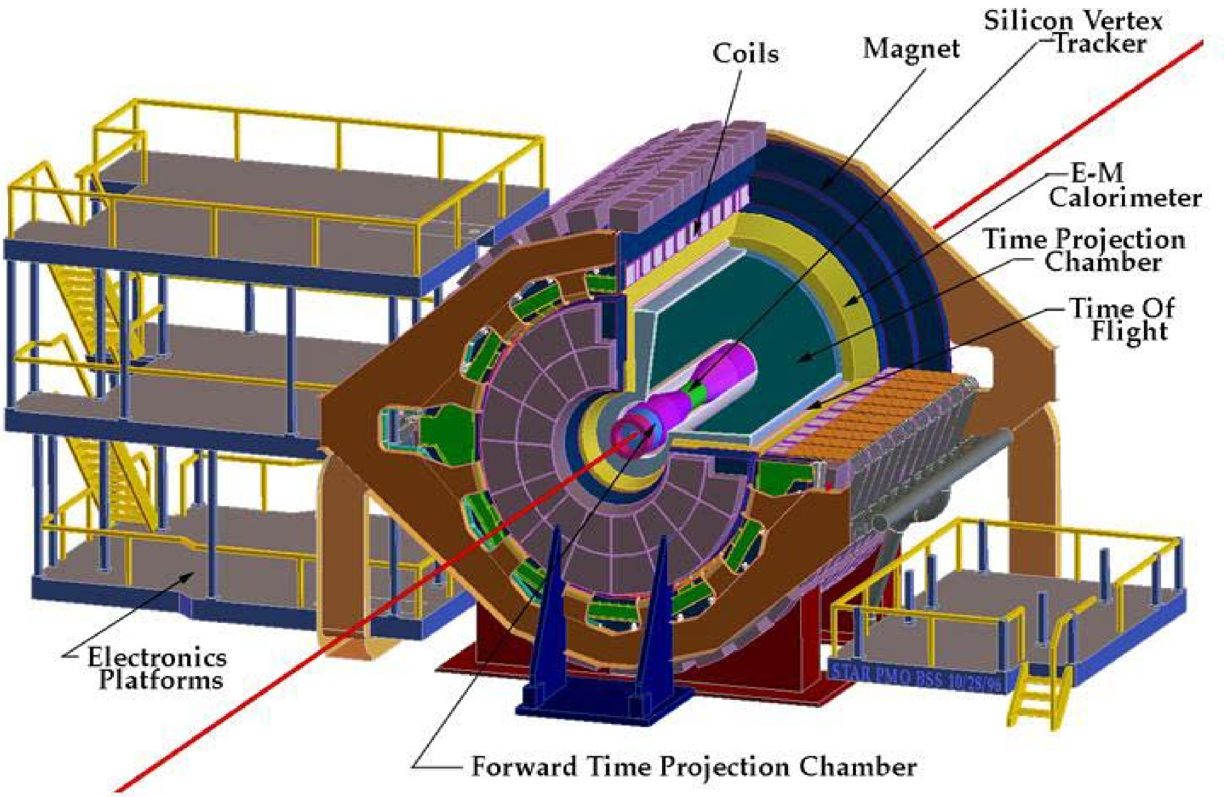
The highest priority scientifically for the coming runs is to go as far as possible to determine the properties of the qualitatively new, dissipative medium discovered in central Au+Au collisions at RHIC, and to study how these may change at a lower energy.

Continued progress on the RHIC spin physics program in the near-term is critical. A realistic plan which accomplishes sustained progress and allows sufficient running time to develop luminosity even in a constant effort scenario**.**

STAR is now on a path to RHIC II. The strategy is to extend the scientific reach of the detector, maintaining the core capability of STAR to provide nearly complete event characterization over a wide range of central rapidity. Upgrades will be staged in such a way as to allow a vigorous physics program between now and 2010.

According MOU between LHE-JINR Dubna, STAR Group and STAR Endcap EMC Collaboration Project Management at Indiana University members of the LHE STAR group at JINR participate in many aspects of the EEMC project collaboration and particularly in aspects of the design, construction, testing, installation and operation of the EEMC in STAR. These jobs will be finished to 2005.

The STAR Detector at RHIC



JINR's Participation in Experiments at GSI

03-1-1020-95/2005

Priority of the project:	1
Status:	Preparation

High Acceptance Di — Electron Spectrometer (Project HADES)

Leader from JINR: Yu. Zanevsky

Participating countries and international organizations: Czech Republic, Germany, Italy, Hungary, JINR, Poland, Russia, Sweden.

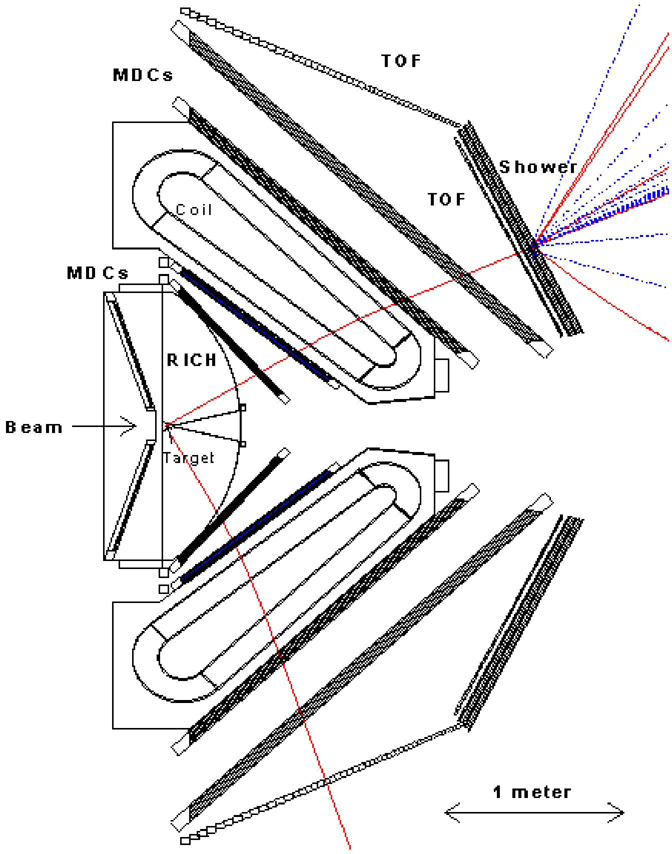


Fig. Schematic cross section of HADES spectrometer. MDC — low mass multilayer drift chamber

The physics goal of the HADES collaboration is to investigate in-medium modifications of light vector mesons (ρ, ω, φ), as well as to study dilepton continuum below the ρ/ω — region in hot and dense hadronic matter. Attractive extensions of this program include the investigation of ρ/ω interference and the measurement of electromagnetic formfactors of baryons and neutral mesons via dilepton and Dalitz decays, respectively. The HADES detector is specially designed to provide an excellent mass resolution and a very large acceptance for comprehensive studies of the behaviour of ρ,ω and φ mesons in a nuclear medium.

HADES is designed to measure the dilepton yield at invariant masses below 1 GeV/c^2 in π - nucleus, p - nucleus and heavy nucleus - nucleus collisions. The detector has a geometric acceptance of almost 50% for $e^+ e^-$ pairs and a mass resolution of 0.8% for ρ and ω mesons. Presently, the HADES collaboration consists of about 100 physicists from 19 institutes and 9 countries. JINR responsibilities are concentrated on the following: full responsibility for the design of a system of six Multilayer Drift Chambers (MDC, plane — II), carrying out R&D on analogue readout electronics for all Macs (plane I–IV, totally 24 modules), preparation of software for fast finding and reconstructing charged particle tracks in the MDC system and participation in data analysis.

The Research Program

The physics program of HADES is rather broad and includes the study of lepton pair emission in relativistic heavy ion collisions, dilepton production in elementary reactions and experiments aimed at studying the structure of hadrons:

- Investigation of properties of dense and hot nuclear matter in heavy ion collisions at SIS (up to 2 AGev):
  - investigation of in-medium modifications of light vector mesons' (ρ, ω, φ) properties (masses, widths). The spectrometer HADES has a geometric acceptance of almost 50% for electron pairs and a mass resolution of 0.8% in the ρ/ω region;
  - investigation of dilepton continuum below the ρ/ω - region.
- Investigation of ρ/ω interference and measurement of electromagnetic form-factors of baryons and neutral mesons via dilepton and Dalitz decays, respectively.
- Study of dilepton productions with pion and proton beams.

JINR's Participation in Experiment at CELSIUS

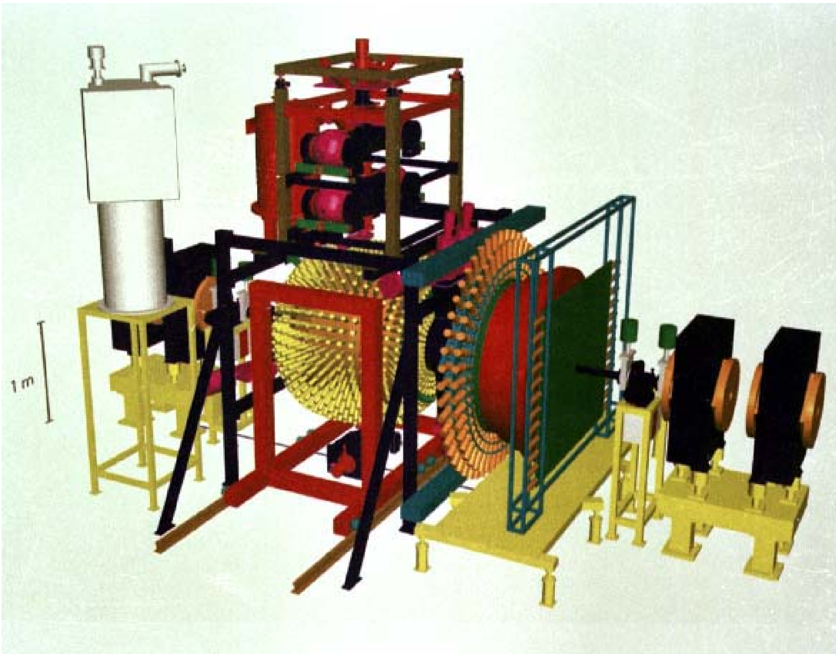
03-1-0994-92/2005

Priority of the project:	2
Status:	Preparation

Studies of the Threshold Production and Rare Decays of Light Mesons (Project WASA)

Leader from JINR: B. Morozov

Participating countries and international organizations: Germany, Japan, JINR, Poland, Russia, Sweden, the USA.



The WASA project is aimed at further studies of the threshold production of light mesons and at new research of rare decays of neutral mesons produced in p-p and p-d reactions. Of interest are π° and η decays but other mesons such as ω, $\eta^/$ and ϕ may be studied providing the CELSIUS maximum energy increases. The goal is to produce and measure 10^{10} ηs and $10^{11}\pi^\circ$s per year. The expected results of the research in rare decays of π° and η will contribute to the test of the Standard Model fundamental predictions, to the predictions of the Chiral Perturbation theory (ChPT) and the Nambu–Jona–Lazinio model, to a precise finding of correct parameters of the models (C and CP invariance, mass difference of light quarks etc.). The studies of bremsstrahlung, production of light mesons in proton-nucleon scattering near the energy threshold will profit by the close to 4π acceptance. It will offer unprecedented possibilities of detailed investigations of kinematic distributions. Near the threshold, the production cross section is sensitive to details of the nucleon-nucleon interaction and to the meson-nucleon interaction. The WASA detector system is well suited to measure reactions with neutral mesons in the final state also for two-pion production studies.

The WASA detector is designed to:

- handle luminosities of about 10^{32} cm^{-2} s^{-1} , using frozen droplets (pellets) of H_2 and D_2 as targets, in a coasting beam of about 10^{10} protons;
- measure charged particles and photons over a solid angle close to 4π with a high accuracy in energy, charge and track coordinates;
- minimize the photon conversion probability in the target, in the beam tube and in the vertex detector;
- provide a fast trigger for the selection of rare events.

The central detector (CD) covers almost 4π steradians and includes a CsI calorimeter (SEC) and a magnetic spectrometer part with an extremely thin-walled (0.18 rad. lengths) superconducting solenoid (SCS). Within the magnet, there is a track detector (MDC) surrounded by a plastic scintillator barrel (PSB). The MDC is a cylindrical chamber of the straw type with 1738 straws arranged in 17 stereolayers surrounding a scattering beryllium (0.0034 rad. lengths) chamber. The CD allows highly efficient measurements of both charged particles and photons. To measure charged particles emitted at angles from 4 to 18 degrees, a forward detector (FD) is used (calorimeter, tracker and trigger). Very-near-threshold measurements of meson production using forward going recoils in pd and dd reactions are possible owing to a small-angle tagging spectrometer (TS), for which the quadrupoles and first bending magnets downstream the target are used as components (e.g., helium recoils at threshold for η-production in the pd reaction that can be used for η tagging).

Presently, the CELSIUS/WASA Collaboration consists of about 80 physicists from 14 institutions and 5 countries. JINR responsibilities are concentrated in the following WASA detector subsystems: full responsibility for the development, construction and test of the central Mini-Drift Chamber system (MDC), Tagging Spectrometer (TS), readout electronics for the MDC and TS, readout PM tubes and a high voltage system for the CD. The JINR physicists are responsible for the CD track recognition and also participate in the development of data acquisition and trigger systems and in the data analysis.

The Research Program

Some initial studies with the WASA 4π-setup are the following:

Subject	Main reaction	Outcome of the experiment
η neutral decays	$pp \to pp\eta$ $\eta \to \gamma\gamma$ $\eta \to 3\pi^\circ$ $\eta \to \pi^\circ\gamma\gamma$	Production kinematics details C breaking $\eta \to 3\gamma$ Check ChPT
η charged decays	$pp \to pp\eta$ $\eta \to \pi^\circ\pi^+\pi^-$ $\eta \to \pi^+\pi^-\gamma$ $\eta \to e^+e^-\gamma$	Double Dalitz and rate of $\pi^\circ e^+e^-$ and e^+e^- decays $\pi^+\pi^-$ asymmetries Dalitz decay formfactor, production of prompt e^+e^-
π° decays	$pp \to pp\pi^\circ$ $\pi^\circ \to e^+e^-\gamma$	Double Dalitz and e^+e^- decays Dalitz decay formfactor, production of prompt e^+e^-
Quasi-free η production in pn	$pd \to n_{spect}\,pp\eta$ $pd \to p_{spect}\,d\eta$ $pd \to p_{spect}\,pn\eta$	Production kinematics and threshold cross section Test high rate d tagging in FD and TS
2-pion production	$pN \to pN\ 2\pi$ $d\ 2\pi$	Details of production kinematics
Production of heavier mesons	$pd \to pd\eta^/$ $^3He\ \eta^/$	$\eta^/$ (and other heavier mesons) studies
in breaking	$dd \to {}^4He\ \eta$	Excitation function at threshold Isospin breaking $dd \to {}^4He\ \pi^\circ$ around η threshold

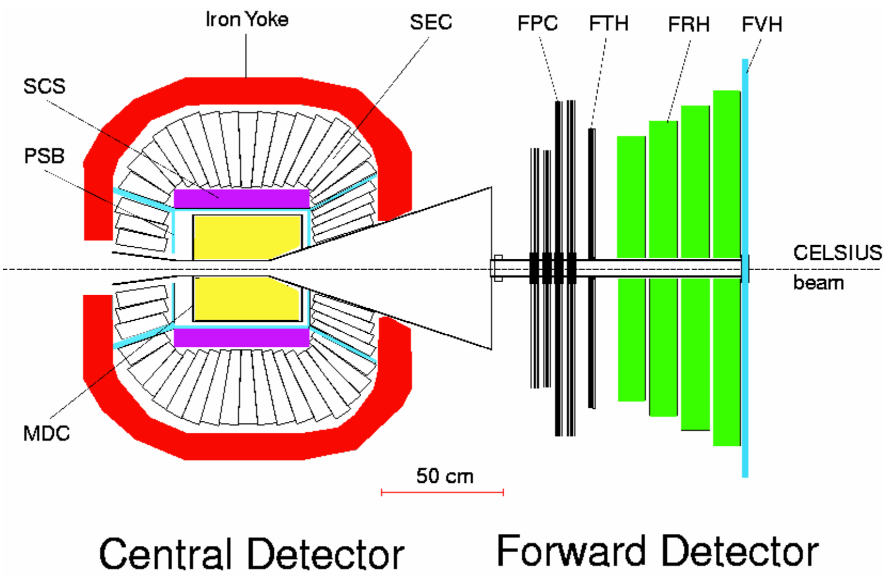


Fig. Layout of the WASA 4π-setup. MDC — Mini-Drift Chamber; SCS — Superconducting Solenoid; PSB — Plastic Scintillator Barrel; SEC — CsI (Na) Electromagnetic Calorimeter; FPC — Proportional Counter Straw Chamber (Tracker); FTH — Forward Trigger Hodoscope; FRH — Forward Range Hodoscope; FVH — Forward Veto Hodoscope.