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TRITONS FOR THE STUDY OF THE CHARGE-EXCHANGE REACTIONS WITH THE LHE STREAMER CHAMBER: STATUS AND SOME POSSIBILITIES

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The 6 and 9 GeV/c secondary tritons, produced in the $^4He + A \to {}^3H + X$ reaction, were used to study the charge-exchange reactions using a streamer chamber in magnetic field. The triton formation schemes, the beam parameters achieved as well as a way to reduce the beam momentum spread are given in the paper.

The investigation has been performed at the Laboratory of High Energies, JINR.

Тритоны для исследования реакций перезарядки при помощи стримерной камеры ЛВЭ: состояние и некоторые возможности

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Вторичные тритоны с импульсом 6 и 9 ГэВ/с, образующиеся в реакции $^4He + A \to$ $\to {}^3H + X$, использовались для исследования реакций перезарядки при помощи стримерной камеры в магнитном поле. В работе описываются схемы формирования тритонов, полученные параметры пучков, а также вариант уменьшения импульсного разброса.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. The phenomena of relativistic nuclear physics are the main subject of research at the Laboratory of High Energies (LHE). In this context, the nucleus-nucleus charge exchange reactions significantly attract attention as they have manifested specifically nuclear features unusual to the nucleon-nucleon interaction. The phenomena of the nuclear Δ-peak shifting and broadening compared to the reactions on protons, firstly discovered and studied at the Laboratory on ^{3}He beams [1], then were acknowledged in experiments with various projectiles and targets carried out both in Dubna and in other accelerator centres (e.g., see the review in [2]). At the LHE, further advance in the investigation was achieved in exclusive experiments using as projectiles the ^{7}Li and ^{3}H nuclei [3]. Tritons as the simplest nuclei are well theoretically tractable. But beside this fact, one of the most significant reasons to carry out experiments on tritium beams is the opportunity to obtain data on the $n(^3He, t)$ reaction, needed for building up a theory of charge-exchange reaction, studying the isotopically

conjugate $p(t, {}^3He)$ one. Such experiments are scheduled for a new facility design in cooperation of the SPHERE, DELTA and GIBS collaborations [4]. A set of methodical advantages of experiments on triton beams should also be mentioned. The ^3He nuclei produced have a favorable for the magnetic analysis p/z ratio and are easily detected among other single charged particles due to the fourfold ionization density. Decays of the corresponding Δ-isobar yield negative pions which are also easy identified among positive particles.

In principle, beams of relativistic tritium nuclei could be got by immediate (from an ion source) triton acceleration using the facilities which allow one to accelerate nuclei with $z/A = 1/3$. The obvious advantages of the beams would be good geometric parameters, high intensity and low momentum spread (10^{-3}—10^{-4}). However, this way encounters serious technical problems due to the high ($\sim 10^4$ Ci/g) specific activity of tritium. An alternative approach is the generation of tritons as secondary particles as a result of interaction of some primary beam with a target. The most efficient and at the same time simple variant can be realized on the basis of the relativistic α-particle stripping reaction $^4He + A \rightarrow {}^3H + X$. The reaction cross section (25–70 mb for light target nuclei [5], [6]) causes a yield, at an optimal target thickness, up to 5 tritium nuclei per hundred incident ^4He nuclei. As the beam momentum rises, the angular spread of the stripping tritons linearly decreases, the yield at zero degree quadratically increases and the momentum spread tends to a constant value of several per cent. The latter, however, is an unacceptably large value for some physical tasks. Mention, that the charge exchange reaction $^3He + A \rightarrow {}^3H + X$ on its own can also serve as a triton source. Though its cross section [3], [6] is lower by an order of magnitude than that for the $^4He + A \rightarrow {}^3H + X$ reaction, it can provide beams of ^3H nuclei with the highest energy for a given accelerator: due to the corresponding Z/A ratios at fixed accelerator field, the momenta of the tritium nuclei immediately accelerated, produced by ^4He stripping and by ^3He charge exchange, relate to each other as $\frac{2}{3} : 1 : \simeq \frac{3}{2}$.

2. At the accelerator facility of the Laboratory of High Energies [7] the method of accelerated ^4He nuclei stripping was used to form relativistic tritium beams. An α-particle beam accelerated in the Synchrophasotron was slowly extracted out of the accelerator and thrown on a target placed at the joining point of the extraction system and the beam line transporting particles to experimental set-ups — the F3 focus (Fig.1). The main parameters of the beam are given in the Table.

Table. The ^4He beam parameters

Momentum range	$\simeq$ 3—18 GeV/c
Intensity per cycle*	$5 \cdot 10^{10}$
Cycle frequency	0.12 Hz
Extraction time	0.5 s
Beam size (σ_{hor})*	2—4 mm
Beam divergency ($\sigma_{\theta_{hor}}$)*	4—6 mrad

* at $P \geq P_{max}/2$

Tritons and other secondary particles produced due to the interaction of ^4He nuclei with the target ones were captured at 0° by the head

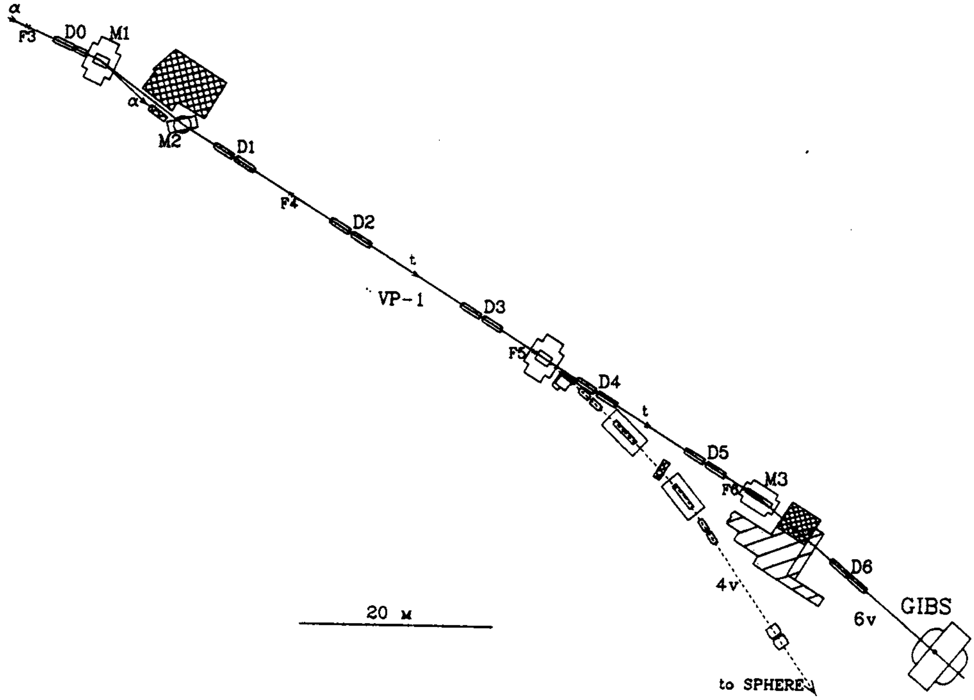

Fig.1. Layout of the VP-1 & 6V beam lines used to form tritium beams

doublet D0 of the VP-1 beam line. The whole line was tuned on transport of particles having charge $z = 1$ and momentum $p = \frac{3}{4} p_{\alpha}$. Primary α particles which did not participate in the interaction as well as secondaries with a magnetic rigidity differing from the nominal one by more than 5% were swept off the line passed the D0 doublet and the first bending magnet M1 and were absorbed in a shield between the experimental halls (partially marked as hatched areas between M1 and D1 in Fig.1). The shield provided sufficiently strong suppression of a background arising from primary beam absorption. The background conditions allowed one to place, when needed, detectors even at the F4 focus area without subjecting them to an essential additional load.

Complete tritium beam forming was carried out through entire traces of the VP-1 & 6V magnetic channels of a common length of more than 110 m including three bending magnets M1, M2, M3 and seven quadrupole lens doublets D0—D6. According to an optical scheme, we are referring to in what follows as the standard one, the VP-1 lenses are grouped in three quartets with FD-DF polarity alternation in the horizontal plane. The beam crossovers are formed at the F4, F5, F6 points area. The second and third doublets operate in regimes close to the symmetrically mirror-like one. The D6 doublet transfers an image from F6 to a set-up target. Beam envelopes for this optical scheme are shown in Fig.2. The standard regime and a short distance, 3.2 m, from the point (F3) location of a triton generating target to the head doublet (D0) entrance provide good transmission of the channel.

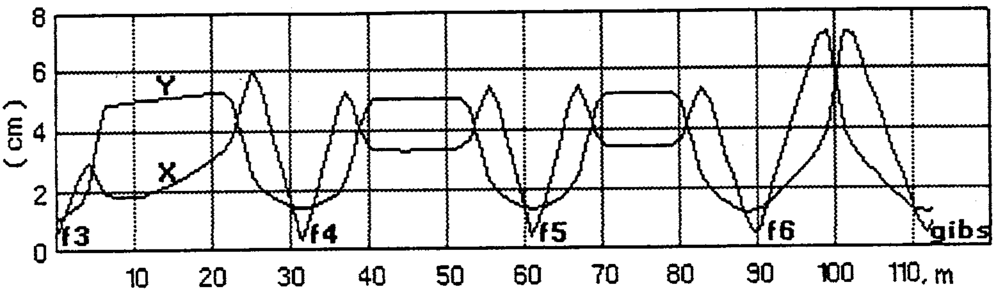

Fig.2. Beam envelopes (2σ) for the standard regime of the VP-1 & 6V beam lines in a horizontal (X) and a vertical (Y) planes ($\varepsilon_x \simeq \varepsilon_y = 40\pi$ mm·mrad, $\delta_p = 0$)

The calculated angular acceptance of the configuration is $\Delta\Omega = \Delta\theta_x \Delta\theta_y \simeq 50$ mrad·18 mrad = = 0.9 msr. As an illustration, we give data on 6 GeV/c triton intensity, obtained under the conditions close to those described above:

- primary beam — 8 GeV/c α particles, 10^9 per cycle,
- target — polystyrene, 5 g/cm^2,
- tritium nuclei intensity at the line end — $5 \cdot 10^5$ per cycle.

Purity of the beam was specially tested and the admixtures were found to be not larger than 1-2%, which could be explained by the ^{3}H fragmentation in air at the line end. The beam profiles from four profilemeters placed along the beam trace are shown in Fig.3. Third and fourth distribution pairs correspond to a separate triton beam. The profilemeters were multiwire chambers operating in the current regime and having a low sensitivity threshold on beam intensity about 10^6 single charged particles per second. The distributions correspond to the standard line regime which was used only at the beginning stage of beam

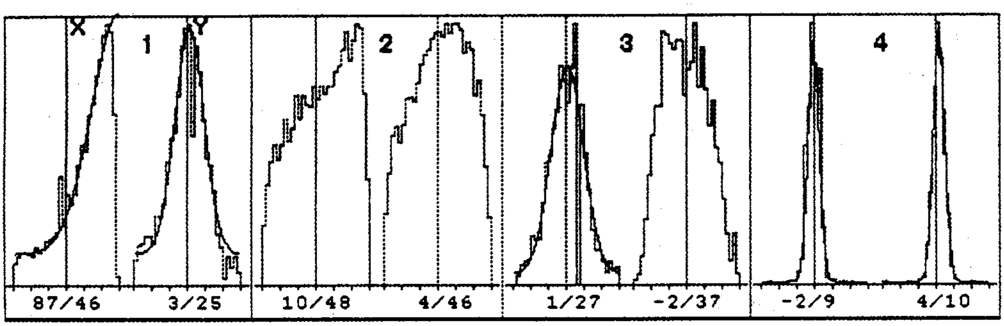

Fig.3. The tritium beam forming: the distributions on coordinates in a horizontal (X) and a vertical (Y) planes at $P_{^3H} = 6$ GeV/c. 1 — after the M1 magnet («tail» of primary α-particle beam), 2,3 — at the D1, D3 doublet entrances, 4 — at the F6 focus. The numbers under the histograms are mean value/r.m.s. deviation, mm. The smooth curves are the Gaussian fitted

tuning. Then it was needed to reduce beam intensity by a factor of 10—30: optimal intensity for operation of the GIBS spectrometer (a streamer chamber in magnetic field) is several tens of thousands per cycle. Intensity reduction of an extracted primary α-particle beam would be undesirable as would lead to deterioration of extraction stability all the more when a structureless extraction was used (that is, extraction at accelerator RF switched off). Then the following trick was used: current in the first lens (F_{hor}) of the D2 doublet was strongly decreased. This caused strong beam defocusing and led to losses at the entrance of the next doublet which, in turn, was adjusted to new source positions. The magnitude of the losses and, correspondingly, the intensity of the beam passed are directly connected with the current in the second lens (D_{hor}) of the D2 doublet. Varying the current in the lens, we have had the opportunity to do this immediately in the set-up control room, made it possible to perform fine tuning of the intensity to a desirable level and, practically, did not require tuning of the downbeam channel elements.

3. As it has been mentioned above, the disavantage of secondary tritium beams produced immediately from a target is a momentum spread. Its value for the α-particle stripping reaction is defined by the proton r.m.s. momentum inside the ^{4}He nucleus and is given sufficiently accurately by the relations

$$\sigma_{P_{\rm lab}} = \gamma_0 \sigma_{p^*}, \quad \delta_{P_{\rm lab}} = \frac{\sigma_{P_{\rm lab}}}{P_{\rm lab}} = \frac{\sigma_{p^*}}{\beta_0 M_t},$$

where β_0 and γ_0 are the velocity and the Lorentz-factor of an incident α particle in the laboratory frame, $M_t = 2.809$ GeV/c^2 is the triton mass. The experimental data [5] or the model [8] give $\sigma_{p^*} = 160$—200 MeV/c. This defines a 6—8 % initial momentum spread for a 9 GeV/c triton beam. There are no special built-in collimators in the VP-1 & 6V channels as their main goal is transportation of monochromatic extracted beams. When secondary beams are formed, momentum selection takes place on the magnetic element aperture. Calculations carried out by means of simulation of individual ray passages through the system, the details of which are suggested to be described in a separate paper, show that for the standard regime the σ_P/P is about 5 % at the D1 doublet entrance and gradually decreases down to 1.8—2.3 % at the 6V line end. It should be emphasized that the beam defocusing in the middle of the VP-1 channel described above did not lead to noticeable changing in the momentum bandwidth.

The momentum spread of a few per cent is too large for a set of tasks. One of the available approaches, allowing to compensate the disadvantage, is the time of light (TOF) tagging. This method was realized in a 6 GeV/c triton beam run [9]. The first TOF detector was placed at the F4 focus, the second one — at the GIBS set-up. Such counter positions defined a flight base of $L = 77$ m. With the flight base and the proper time resolution $\sigma_t = 0.1$ ns the momentum resolution $\delta_P \simeq \beta_0 \gamma_0^2 (\sigma_t c)/L \simeq 0.2$ % was provided. The measured momentum spread was 1.8—2.0 % (110—120 MeV/c) which corroborates the calculation results.

However, if an effect studied strongly depends on energy and both the beam run time and the data acquisition speed are limited, beams with lower momentum spread are needed. To reveal a possibility to select a more narrow momentum interval in the frame of the existing mangetic line structure the line resolving properties were analysed as a function of gradients and the coordinate along the line. The usual definition of resolving power — the ratio of linear dispersion (d) to the image size $R = \left|\frac{d}{M\Delta X_0}\right|$ (*M* is magnification, Δx_0 is a source size) — relates to a focal plane. To describe the resolving properties along an entire beam path we considered the ratio of linear dispersion to linear envelope of a pattern monochromatic beam as a momentum resolution measure. Somewhat arbitrarily, the pattern beam parameters were taken close to ones of a beam slowly extracted from the Synchrophasotron at the maximum momentum. The following initial values of 2σ-envelopes were used: in a horizontal plane — 5 mm × 8 mrad, in a vertical one — 10 mm × 4 mrad ($\varepsilon_x \simeq \varepsilon_y = 40\pi$ mm·mrad, $\delta_p = 0$). The linear envelopes in figures of the paper are drawn for these data. A scheme of searching for a region for momentum gap extracting looked as follows. Firstly, extremums of the resolving power as a function of the lens gradients were searched for taking into account the element aperture constraints and restricting extremum positions by the F4—F6 focus areas. The latter is connected with the accessibility of these places for additional collimators or detectors. Then passage of a particle ensemble through the magnetic line structure was simulated and the $f(x, \delta_p)$ distributions in the vicinities of the extremum points found were considered. Finally, a restricting interval $x_1 \le x \le x_2$ (or

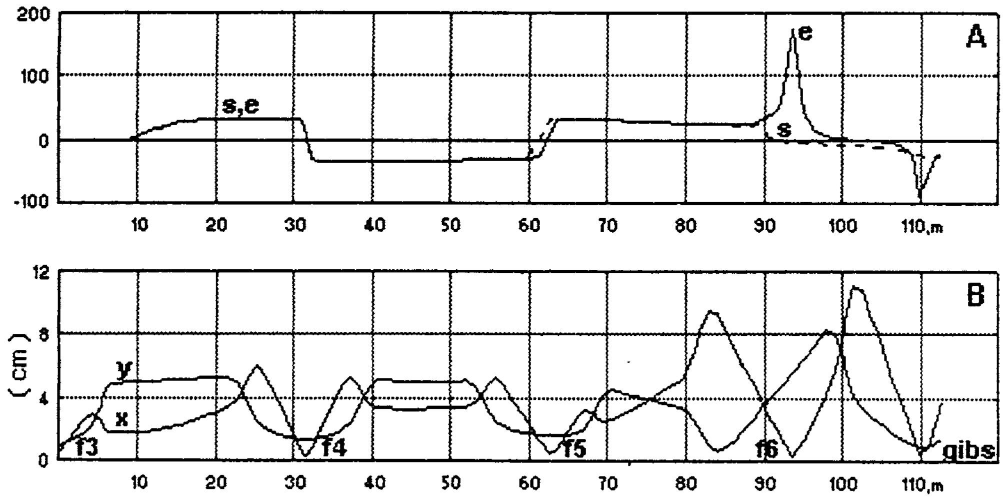

Fig.4. A: the resolving functions (see in the text) for the standard (s) and enhanced (e) resolution regimes along the VP-1 & 6V lines. B: beam envelopes in a horizontal (X) and a vertical (Y) planes for the (e) case

several) was specified and the momentum spread over the sampling of particles reaching the line end was calculated.

The dependencies of the resolving power along the VP-1 and 6V lines for the standard (s) regime and for an enhanced (e) resolution variant are shown in Fig.4A and the liner beam envelopes of the (e) case are shown in Fig.4B. Taking into account beam cut-off by the 50×50 mm^2 TOF counters placed at the F4 focus and at the GIBS set-up ($z_1 = 31.6$ m, $z_2 = 108.8$ m) and the 60×30 mm^2 one before the streamer chamber target ($z_3 = 110.8$ m) the following data were obtained from the calculations:

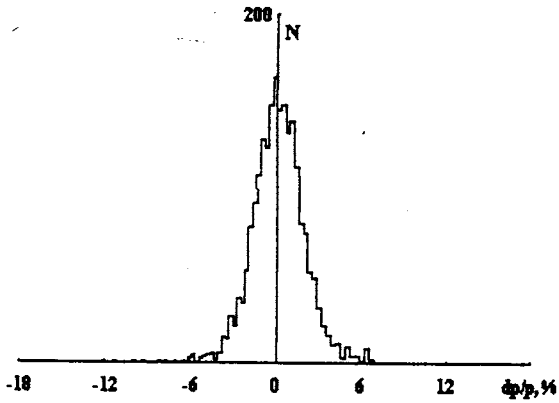

Fig.5. A momentum distribution of the 6 GeV/c tritium beam (from a TOF spectrum)

- $\delta_p \simeq 1.9$ % for the standard regime (compare with the momentum distribution in Fig.5),
- $\delta_p \simeq 0.7$ % for the enhanced resolution regime if an additional collimating slit (1 cm) is placed at the $z_{slit} = 94$ m; the channel throughput in the case is as large as 15 % of the previous item which is exceedingly enough to provide working intensity ($\simeq 5 \cdot 10^4$ per cycle) at the set-up.

The maximal triton momentum available in the line is $P_{max} \simeq 11$ GeV/c which is limited by the M1, M3 bending magnets. More sophisticated solutions providing still lower momentum spreads as well as numerical data on the beam line regimes are described in [10].

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References

1. Ableev V.G. et al. — JETP Lett., 1984, v.40, p.763.
2. Strokovsky E.A., Gareev F.A., Ratis Yu.L. — Part. & Nucl., 1993, v.24, p.603.
3. Avramenko S.A. et al. — JETP Lett., 1992, v.55, p.707.
4. Afanasiev S.V. et al. — JINR Rapid Comm., 1995, 1[69]-95, p.47.
5. Abdurakhimov A.U. et al. — JINR, E1-12730, Dubna, 1979.

6. Glagolev V.V. et al. — Z. Phys., 1993, v.C60, p.421.
7. Issinsky I.B. et al. — Acta Physica Polonica B, 1994, v.25, p.673.
8. Czyz W., Lesniak L. — Phys. Lett., 1967, v.B24, p.227.
9. Avramenko S.A., Belikov U.A. et al. — JINR, P1-96-281, Dubna, 1996.
10. Kirillov A.D. et al. — JINR, P13-97-344, Dubna, 1997.

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