Physics program of the JINR group in the BES-III experiment

A. Zhemchugov

JINR Scientific Council, 102nd session

28 September 2007

Outline

- The BEPCII/BESIII project
- Physics program of the BESIII experiment
- Principal physics goals of the JINR group

The BES-III Collaboration

China: Anhui Uni, CCAST, Guangxi Normal Uni, Guangxi Uni, GUCAS, Henan Normal Uni, Huazhong Normal Uni, Hunan Uni, **IHEP**, Liaoning Uni, Nanjing Normal Uni, Nanjing Uni, Nankai Uni, Peking Uni, USTC, Shanxi Uni, Sichuan Uni, Shandong Uni, Sun Yat-sen Uni, Tsinghua Uni, Wuhan Uni, Zhejiang Uni, Zhengzhou Uni

USA: University of Hawaii, University of Washington

Japan: Tokyo University

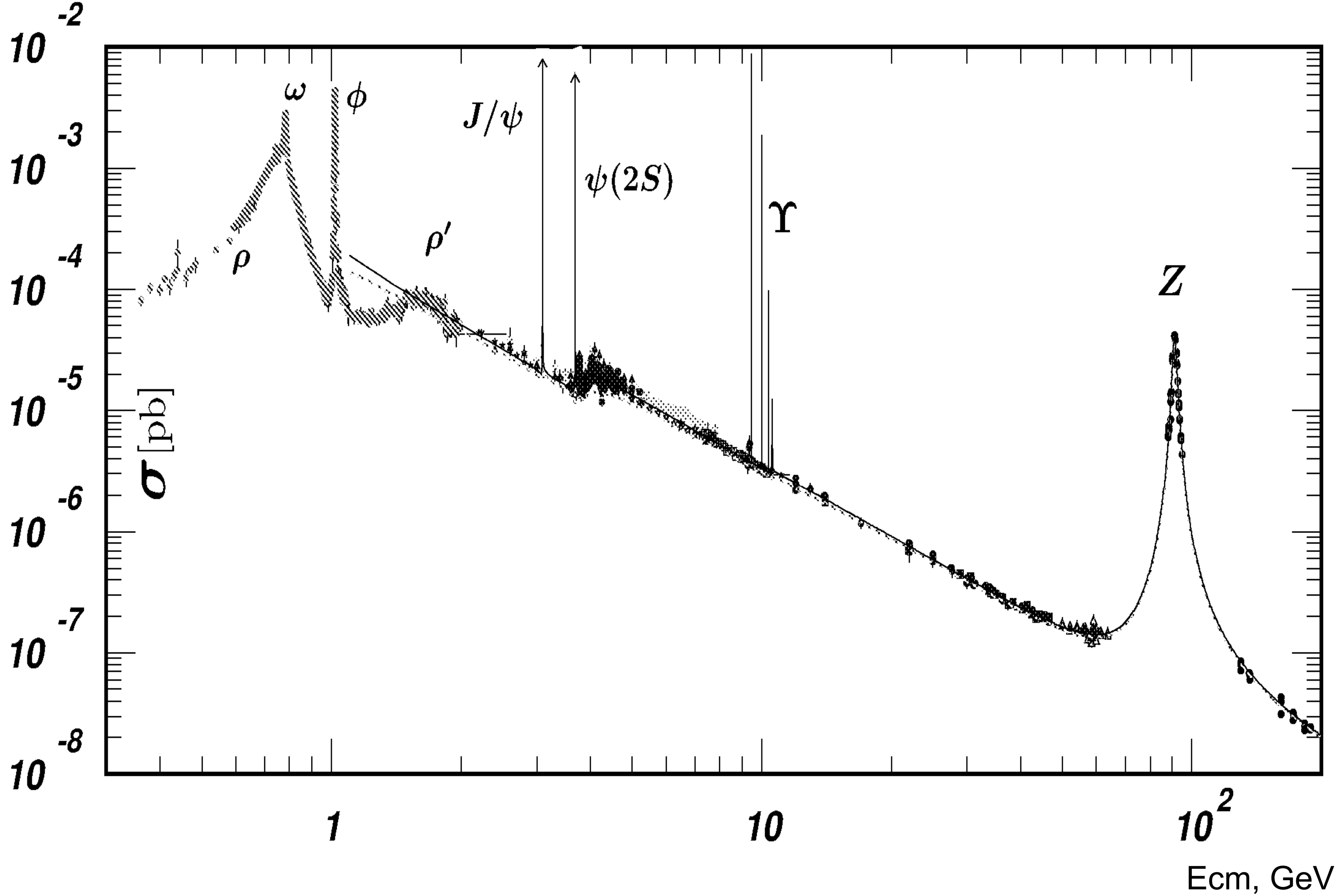
Joint Institute for Nuclear Research

Germany: Bochum Uni, GSI Darmstadt, Giessen Uni

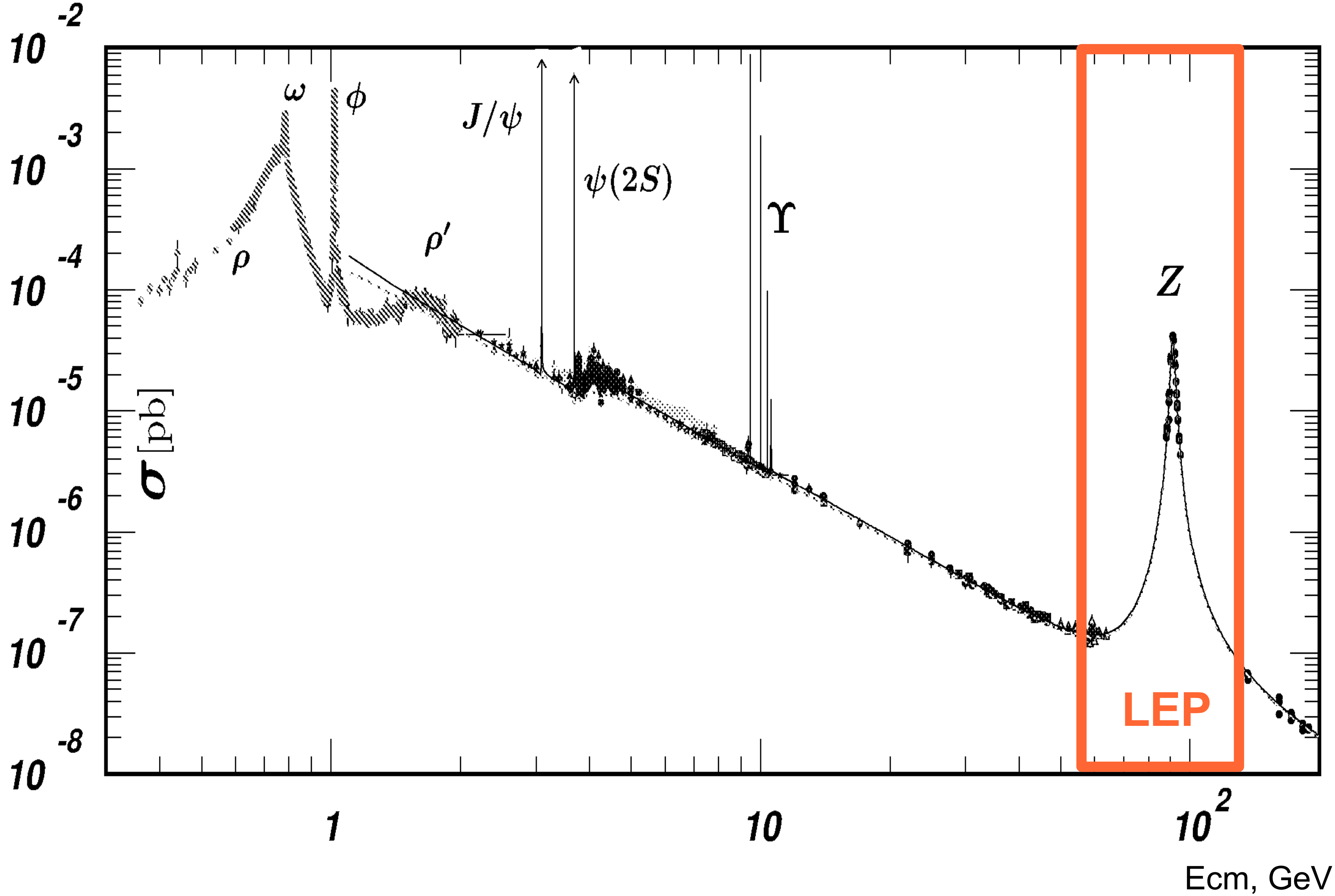
The JINR group in BES-III

DLNP A.B. Arbuzov, D.Yu. Bardin, I.R. Boyko, G.A. Chelkov, D.V. Dedovich, M.I. Gostkin, S.A. Grishin, A.V. Guskov, L.V. Kalinovskaya, Yu.A. Nefedov, L.A. Rumyantsev, <u>A.S. Zhemchugov</u>, V.V. Zhuravlov

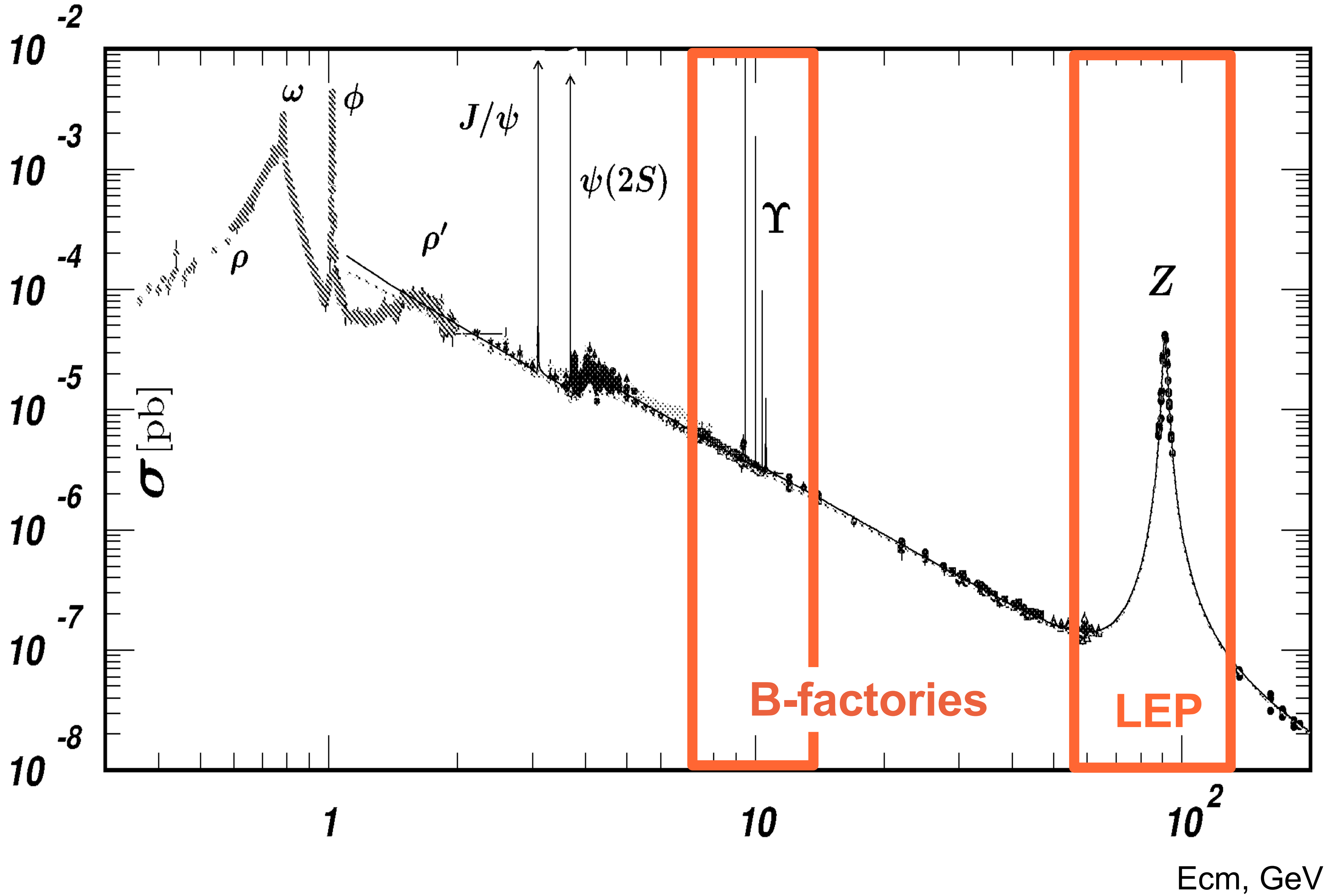
BLTP I.V. Anikin, V.V. Bytyev, E.A. Kuraev, E.S. Shcherbakova, O.V. Teryaev



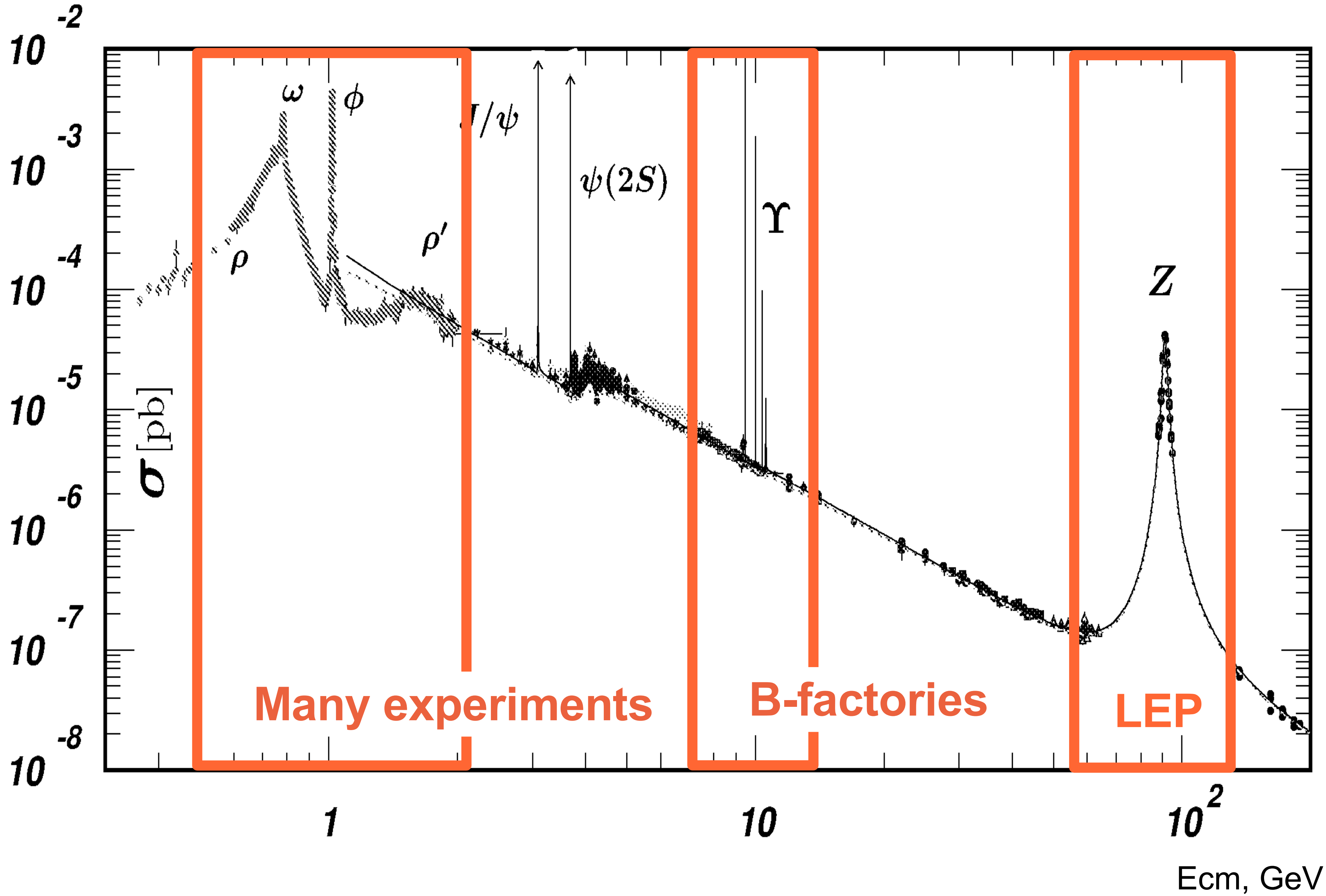
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
σ [pb]
ω
ϕ
J/ψ
$\psi(2S)$
Υ
ρ
ρ'
Z
1
10
10^2
Ecm, GeV



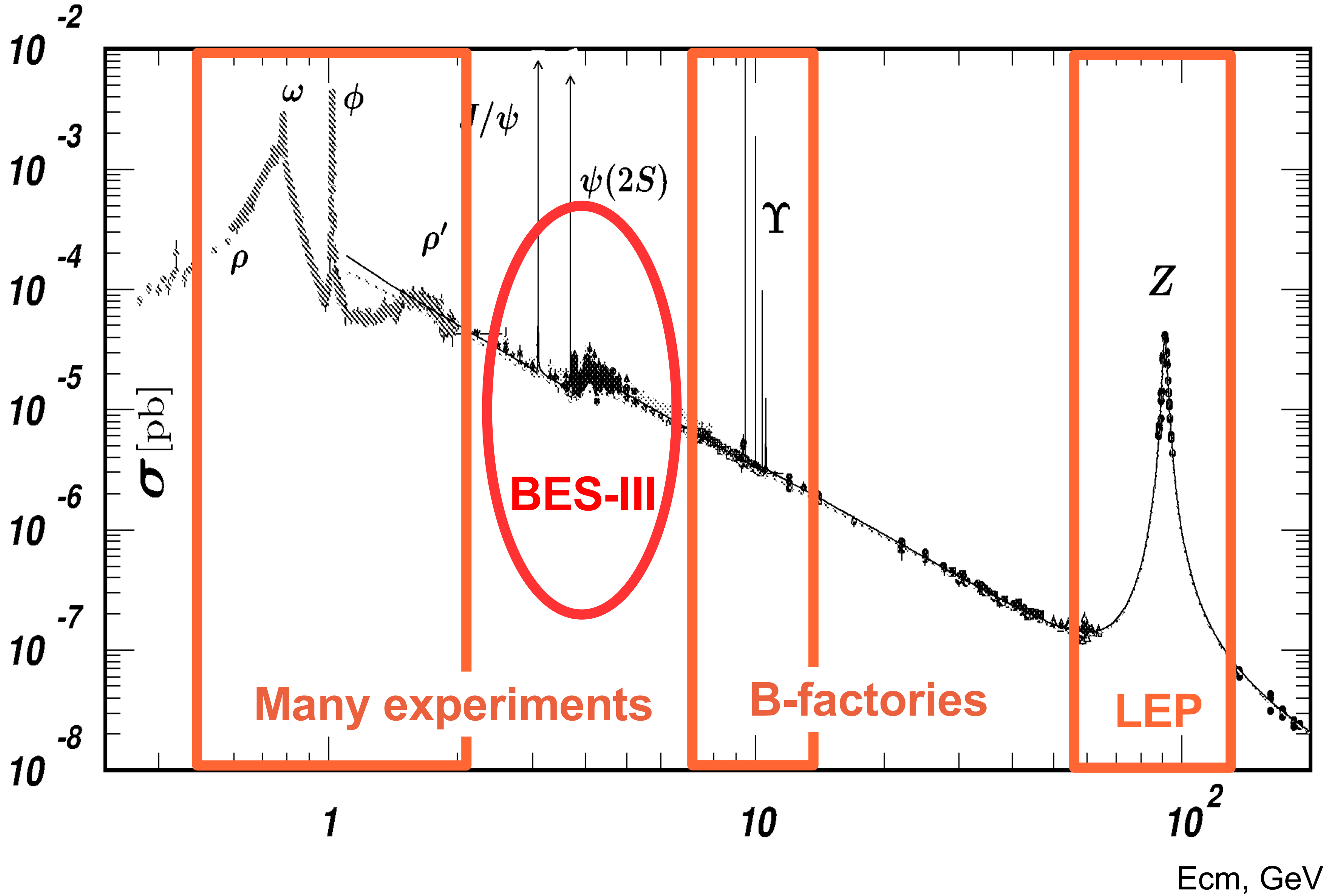
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
σ [pb]
ω
ϕ
J/ψ
$\psi(2S)$
Υ
ρ
ρ'
Z
LEP
1
10
10^2
Ecm, GeV



10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
σ [pb]
ω
ϕ
J/ψ
$\psi(2S)$
Υ
ρ
ρ'
Z
B-factories
LEP
1
10
10^{2}
Ecm, GeV

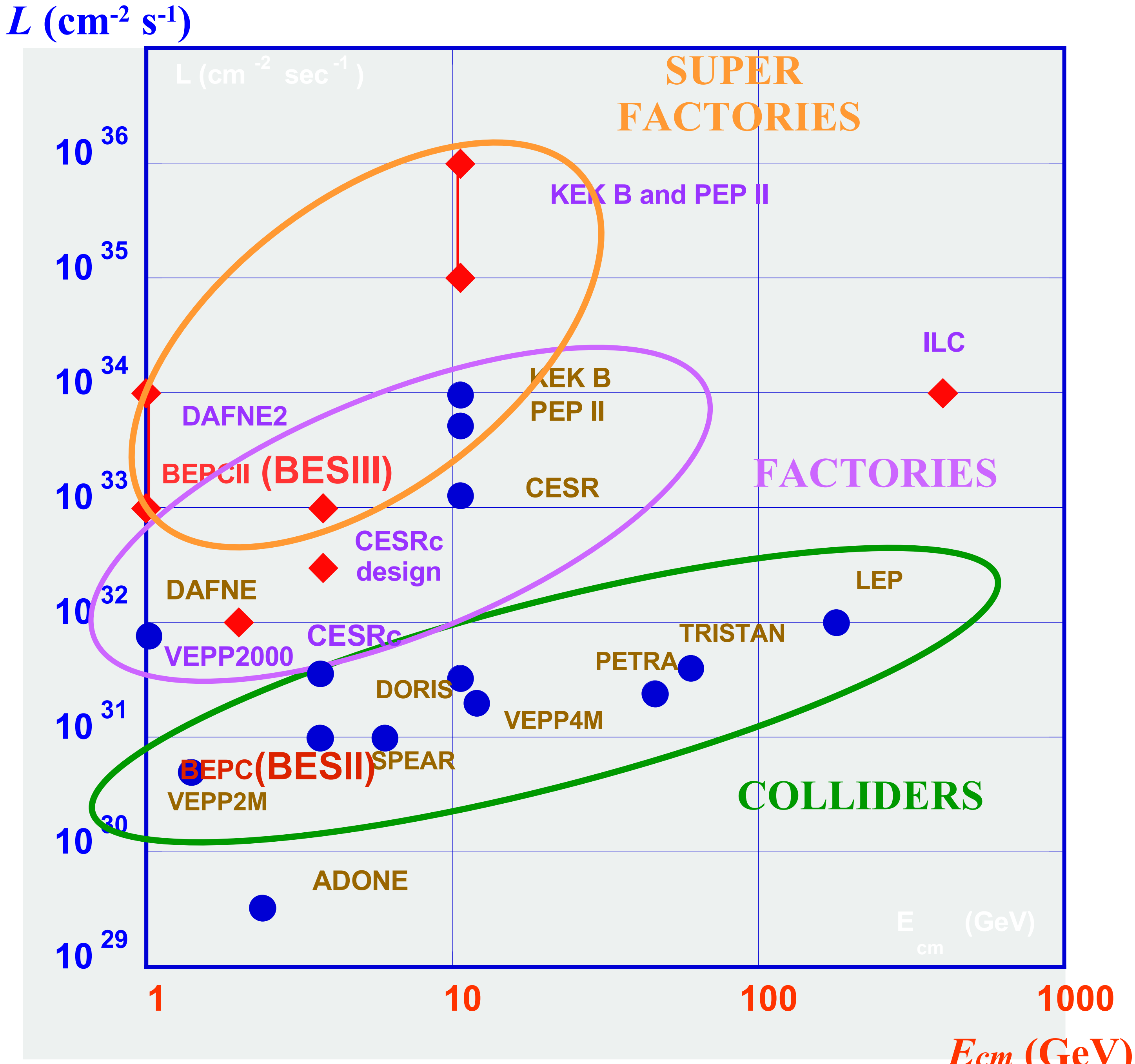


10 -2
10 -3
10 -4
10 -5
10 -6
10 -7
10 -8
σ [pb]
ω
φ
J/ψ
ψ(2S)
ρ
ρ′
ϒ
Z
Many experiments
B-factories
LEP
1
10
10 2
Ecm, GeV



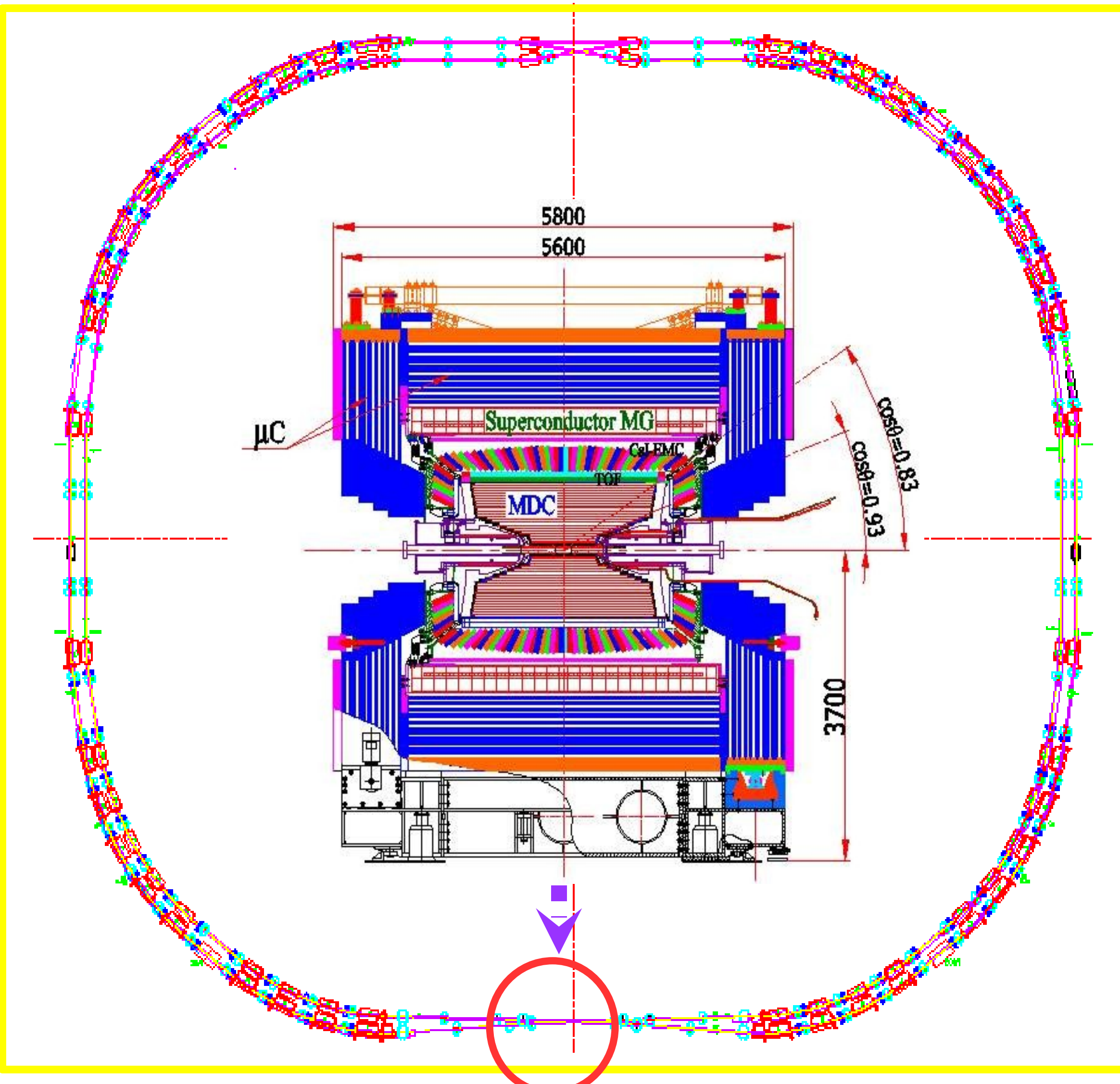
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
σ [pb]
ω
ϕ
J/ψ
$\psi(2S)$
ρ
ρ'
Υ
Z
BES-III
Many experiments
B-factories
LEP
1
10
10^2
Ecm, GeV

Evolution of e⁺-e⁻ colliders



Orig. C. Biscari, 2003

The BEPCII/BESIII Project



- Luminosity

  10^{33} cm^{-2} s^{-1} @1.89GeV

  0.6×10^{33} cm^{-2} s^{-1} @1.55GeV

- 0.6×10^{33} cm^{-2} s^{-1} @ 2.1GeV

The project timeline

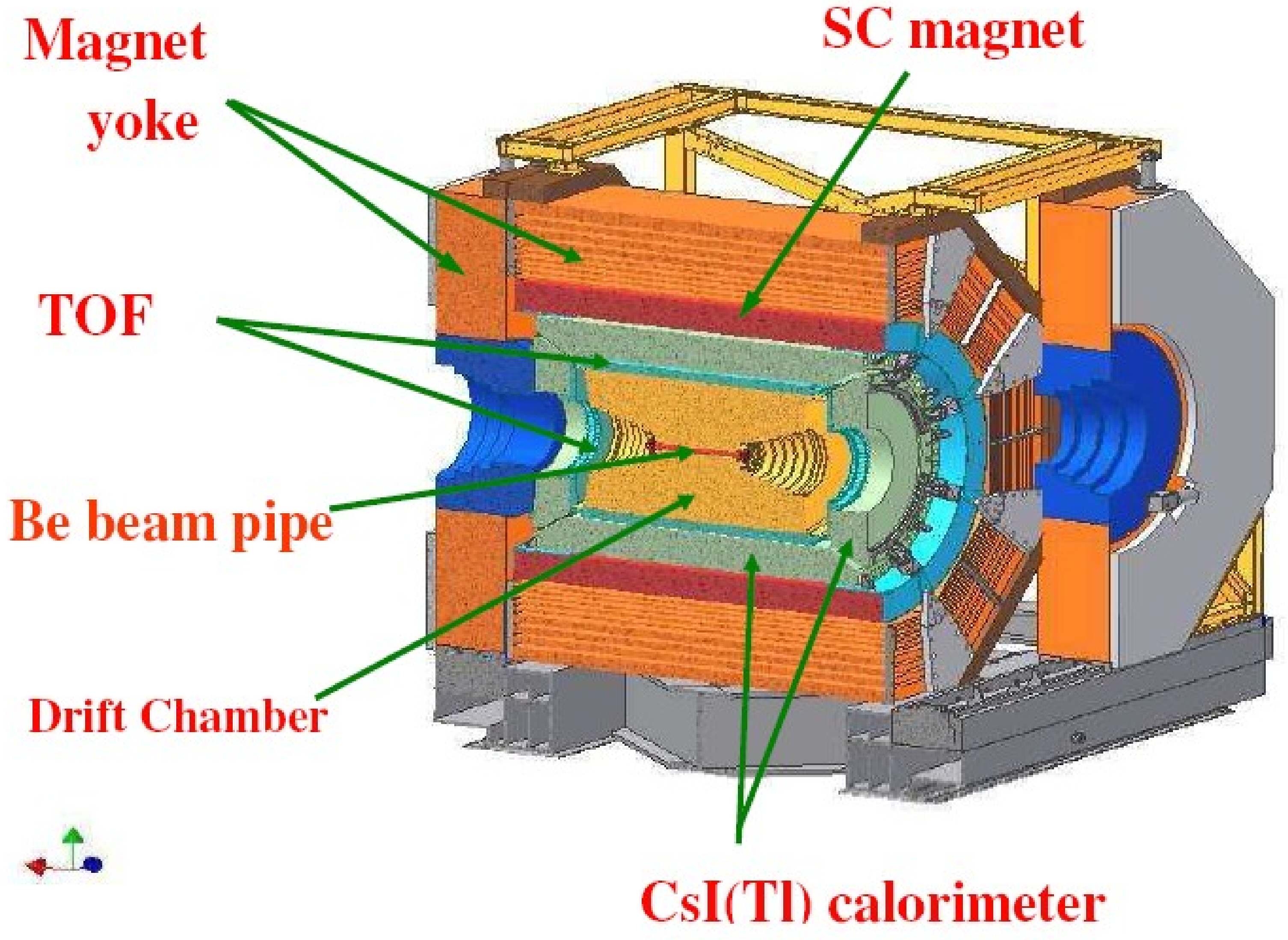
- Linac installation 2004
- Ring installation 2005
- The detector installation 2006
- BEPCII/BESIII commissioning

  autumn 2007
- Start of data taking (cosmics)

  january 2008
- Start of data taking (physics)

  august 2008

The BES-III detector



Detector properties

Subdetector	BESIII	BESII	CLEOc
MDC	σ_{xy} = 130 um	250 um	90 um
	$\Delta P/P$ = 0.5% @ 1GeV	2.4%@1GeV	0.5% @ 1GeV
	dE/dx resolution 6-7 %	8.5%	6 %
EMC	$\Delta E/E$ = 2.5% @ 1 GeV $\Delta\theta$ ~5mrad @ 1 GeV	20%@1GeV 25mrad @1GeV	2%
TOF	σ_T: barrel:100 ps end-cap:110 ps	180 ps barrel 350 ps endcap	RICH
Muon Identifier	9 layers	3 layers	----
Magnet	1.0 Tl	0.4 Tl	1.0 Tl

Event statistics

	Center-of-Mass Energy (GeV)	Peak luminosity ($10^{33}cm^{-2}c^{-1}$)	Physics cross-section (nb)	Expected number of events per year
J/ψ	3.097	0.6	~3400	1.0×10^{10}
τ+τ-	3.67	1.0	~2.4	1.2×10^{7}
ψ(2S)	3.686	1.0	~640	3.0×10^{9}
DD	3.770	1.0	~5	2.5×10^{7}
D_sD_s	4.030	0.6	~0.32	1.0×10^{6}
	4.140	0.6	~0.67	2.0×10^{6}

Physics program

- Study of electroweak interactions and precise tests of the Standard Model
- Study of strong interactions and precise tests of QCD
- Charmonium physics
- Charmed meson physics
- Light hadron spectroscopy
- τ physics
- Search for New Physics in the J/ψ and D meson decays

BES-III Principal Measurement Targets

- Leptonic charm decays $D \to l\upsilon$ and $D_S \to l\upsilon$
  - Decay constant f_D and f_{Ds} can be directly measured with accuracy ~3%
- Semileptonic charm decays
  - CKM matrix elements Vcd and Vcs can be measured with 1% accuracy
- Hadronic decays of charmed mesons
  - measurement of branching fraction with few percent accuracy (current knowledge is up to 25%)
- Rare and CP-violating decays. DDbar-mixing
- Charmonium study and QCD tests
- R-ratio measurement $\left(R = \frac{\sigma_0(e^+e^- \to hadrons)}{\sigma_0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma_0^{had}(s)}{\sigma_0^{\mu\mu}(s)} \right)$
  - BESII improved R precision in the range 2-5 GeV by a factor of 10. BESIII can do 2-3 times better
- Light hadron spectroscopy
  - careful study of $f_0(1500)$, $f_0(1710)$, $\xi(2230)$... Glueball search
- τ mass measurement near threshold

Physics program of the JINR group

- τ physics (I.Boyko, G.Chelkov, D.Dedovich,V.Zhuravlov)
  - *Study of Lorentz structure of the weak charged current*
  - *Measurement of spectral functions in the hadronic τ decays*
- Measurement of the fragmentation functions (N.Skachkov, E.Kuraev, O. Teryaev, I. Anikin)
- Dalitz analysis of η_c decay into 3P state (D.Dedovich, S.Grishin, Yu.Nefedov)
- Measurement of branchings and polarization for η_c, χ_c,$D^0 \to V_1 V_2$ decays (D.Dedovich, S.Grishin)
- Two-photon physics (V.Bytev, A.Zhemchugov)

Study of Lorentz structure of the weak charged current (1)

- In general case, the tau decay can be caused by different types of interaction: scalar, vector, tensor, left-handed, right-handed
- These possibilities are parameterized in terms of Michel parameters ($\rho, \eta, \xi, \xi\delta$), which were extensively studied at LEP and CLEO (including the JINR group at DELPHI).
- The JINR-DELPHI group has also proposed an extension of the Michel parametrization, an anomalous tensor interaction which requires derivatives in the Lagrangian. Such possibility was never considered before.
- The anomalous tensor interaction was measured in DELPHI (together with the "standard" Michel parameters), but with a large statistical error and only under the assumption that the "standard" Michel parameters take exactly the Standard Model values

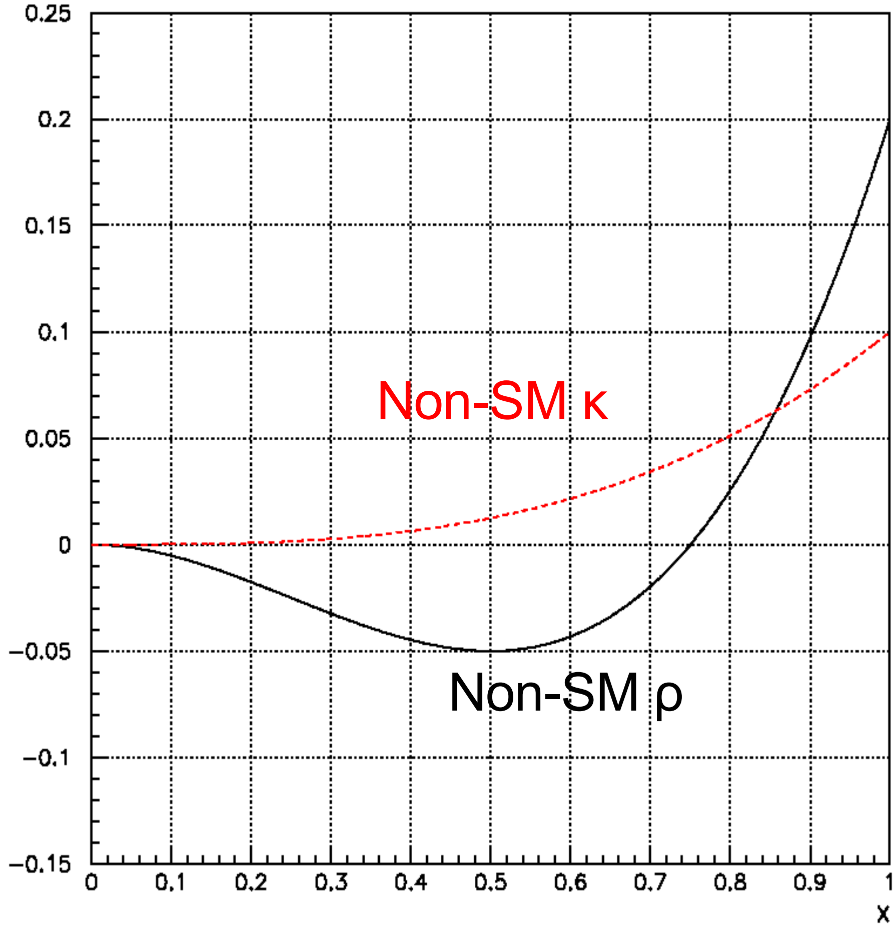
Study of Lorentz structure of the weak charged current (2)

- Both the Michel parameters and the constant of the anomalous tensor interaction can be measured from the energy spectrum of the tau decay:

$$d\Gamma/dx \sim x^2(3(1-x)+\rho(8x/3-2)+\kappa x)$$

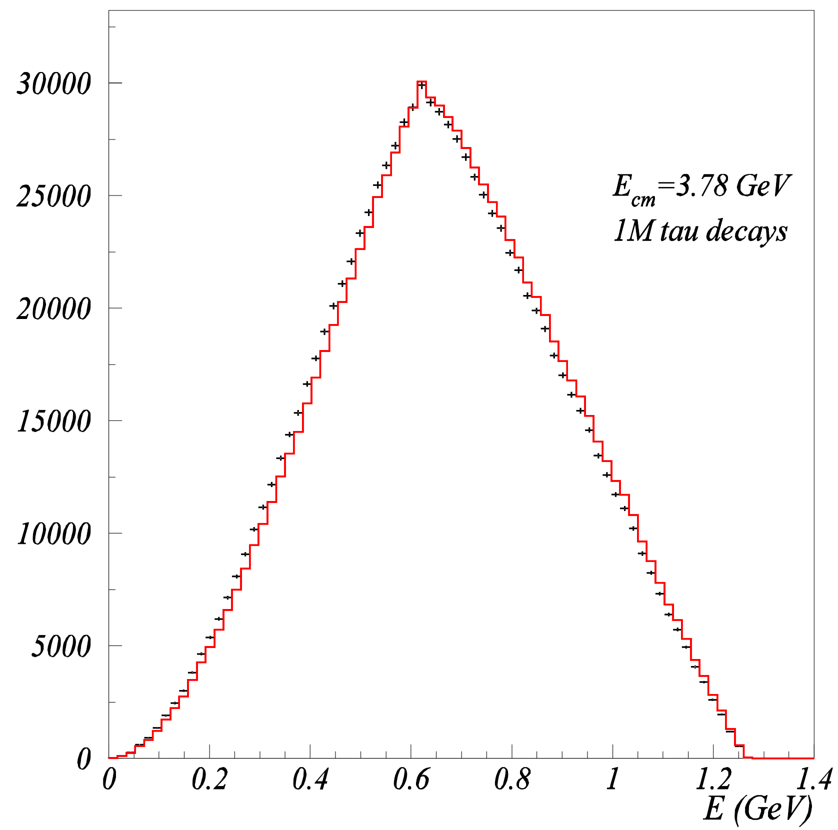
- Here x=E/Emax is the normalized energy of the tau decay product
- The non-SM values of the Michel parameters and of the tensor interaction result in different distortions of the spectrum, which allows a simultaneous measurement of both (provided the statistics is sufficient)

Distortions of the energy spectrum

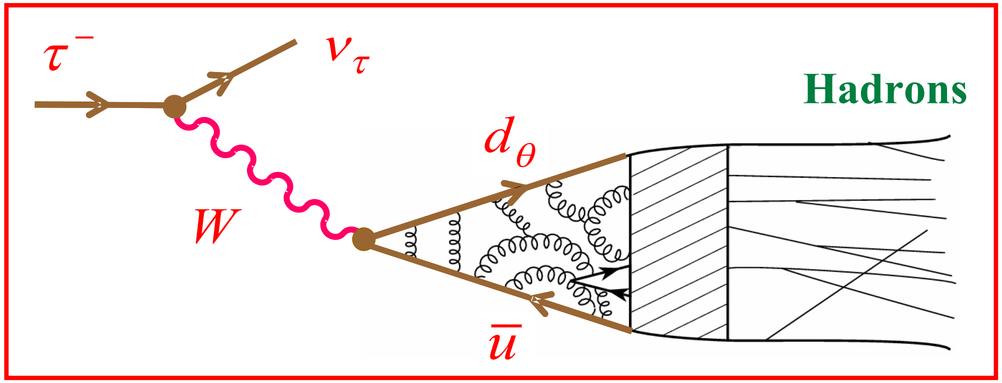


Study of Lorentz structure of the weak charged current (3)

- Preliminary Monte-Carlo studies show that the BESIII statistics and the detector performance are sufficient to improve the precision of the current results by a significant factor:
  - ρ : by factor of 2
  - η : by factor of 5
  - κ : by factor of 10
- The large statistics also makes it possible to measure all parameters simultaneously, without assumption that all other parameters take the SM values



Hadronic τ decays & spectral functions (1)



$$v_1(s)/a_1(s) = \frac{m_\tau^2}{6\,|V_{\rm CKM}|^2\,S_{\rm EW}}\,\frac{\mathcal{B}(\tau^- \to V^-/A^-\,\nu_\tau)}{\mathcal{B}(\tau^- \to e^-\,\overline{\nu}_e\nu_\tau)} \times \frac{dN_{V/A}}{N_{V/A}\,ds}\left[\left(1-\frac{s}{m_\tau^2}\right)^2\left(1+\frac{2s}{m_\tau^2}\right)\right]^{-1},$$

$$a_0(s) = \frac{m_\tau^2}{6\,|V_{\rm CKM}|^2\,S_{\rm EW}}\,\frac{\mathcal{B}(\tau^- \to \pi^-(K^-)\,\nu_\tau)}{\mathcal{B}(\tau^- \to e^-\,\overline{\nu}_e\nu_\tau)}\,\frac{dN_A}{N_A\,ds}\left(1-\frac{s}{m_\tau^2}\right)^{-2},$$

Hadronic τ decays & spectral functions (2)

One can use spectral functions to calculate hadronic vacuum polarization function

$$\begin{aligned}\Pi^{\mu\nu}_{ij,U}(q) &\equiv i\int d^4x\, e^{iqx}\,\langle 0|T(U^{\mu}_{ij}(x)U^{\nu}_{ij}(0)^{\dagger})|0\rangle \\ &= \left(-g^{\mu\nu}q^2 + q^{\mu}q^{\nu}\right)\,\Pi^{(1)}_{ij,U}(q^2) + q^{\mu}q^{\nu}\,\Pi^{(0)}_{ij,U}(q^2)\end{aligned}$$

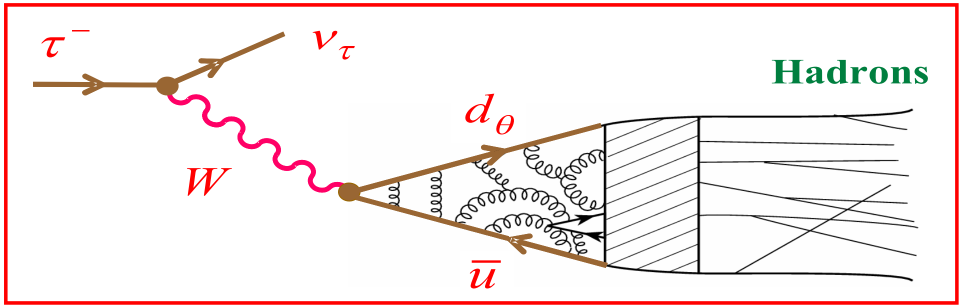
$$\mathrm{Im}\Pi^{(1)}_{\bar{u}d(s),V/A}(s) = \frac{1}{2\pi}v_1/a_1(s)\ , \qquad \mathrm{Im}\Pi^{(0)}_{\bar{u}d(s),A}(s) = \frac{1}{2\pi}a_0(s)$$

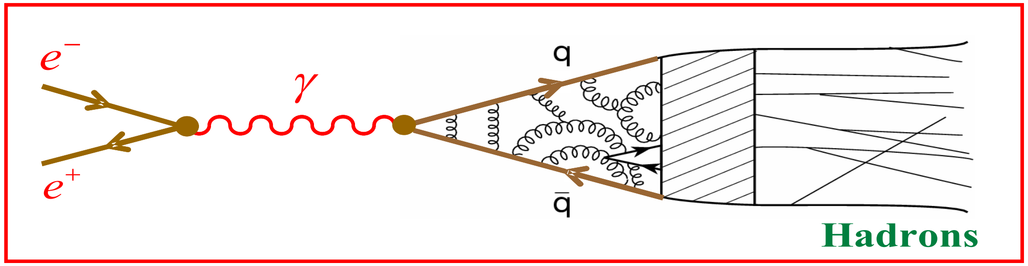
$$\Pi^{(J)}_{ij,U}(q^2) = \frac{1}{\pi}\int_0^{\infty} ds\,\frac{\mathrm{Im}\Pi^{(J)}_{ij,U}(s)}{s - q^2 - i\varepsilon}$$

Hadronic τ decays & spectral functions. Comparison with e^+e^- data (1)

$$\tau^- \to \nu_\tau \, H^-$$

$$\left\langle H^- \middle| \bar{d}_\theta \, \gamma^\mu (1-\gamma_5) u \middle| 0 \right\rangle$$





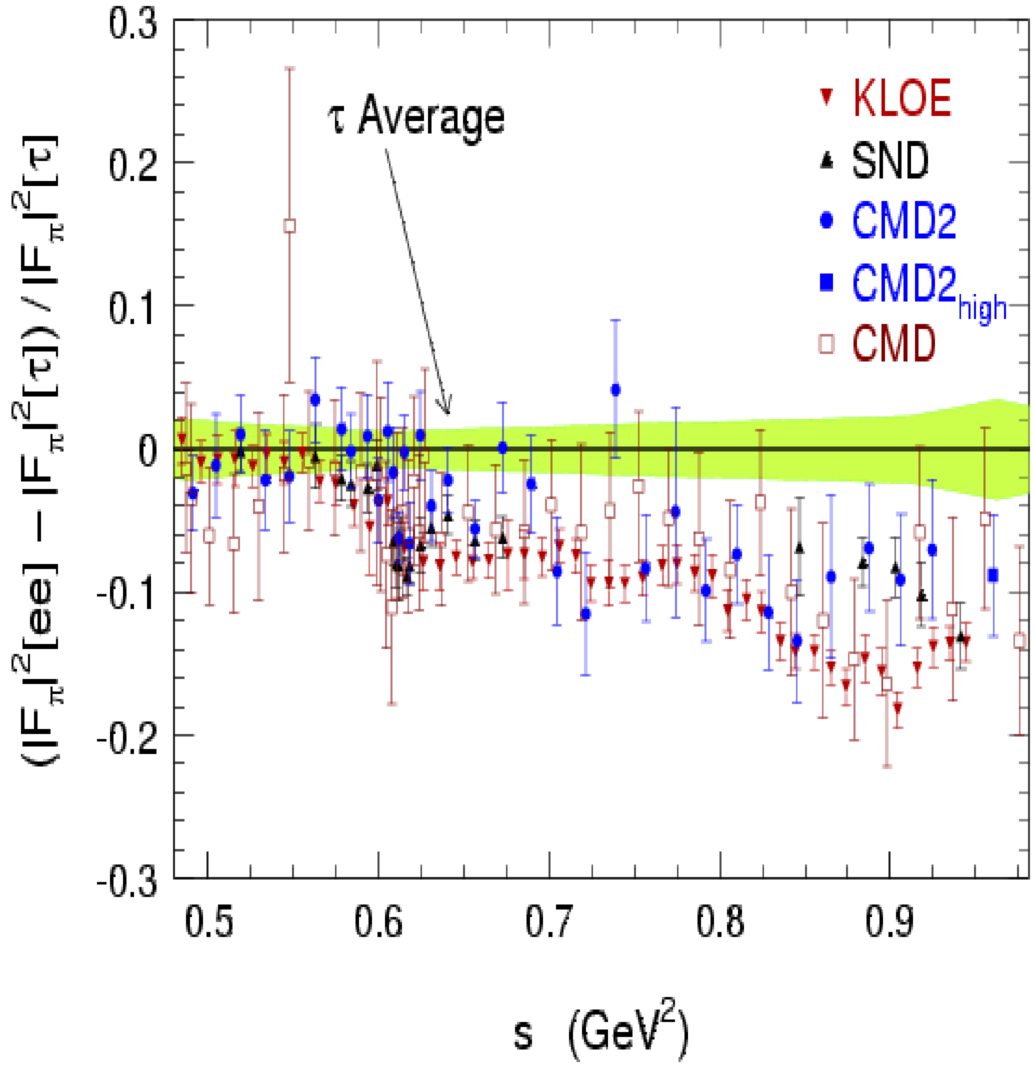
$$e^+e^- \to H^0$$

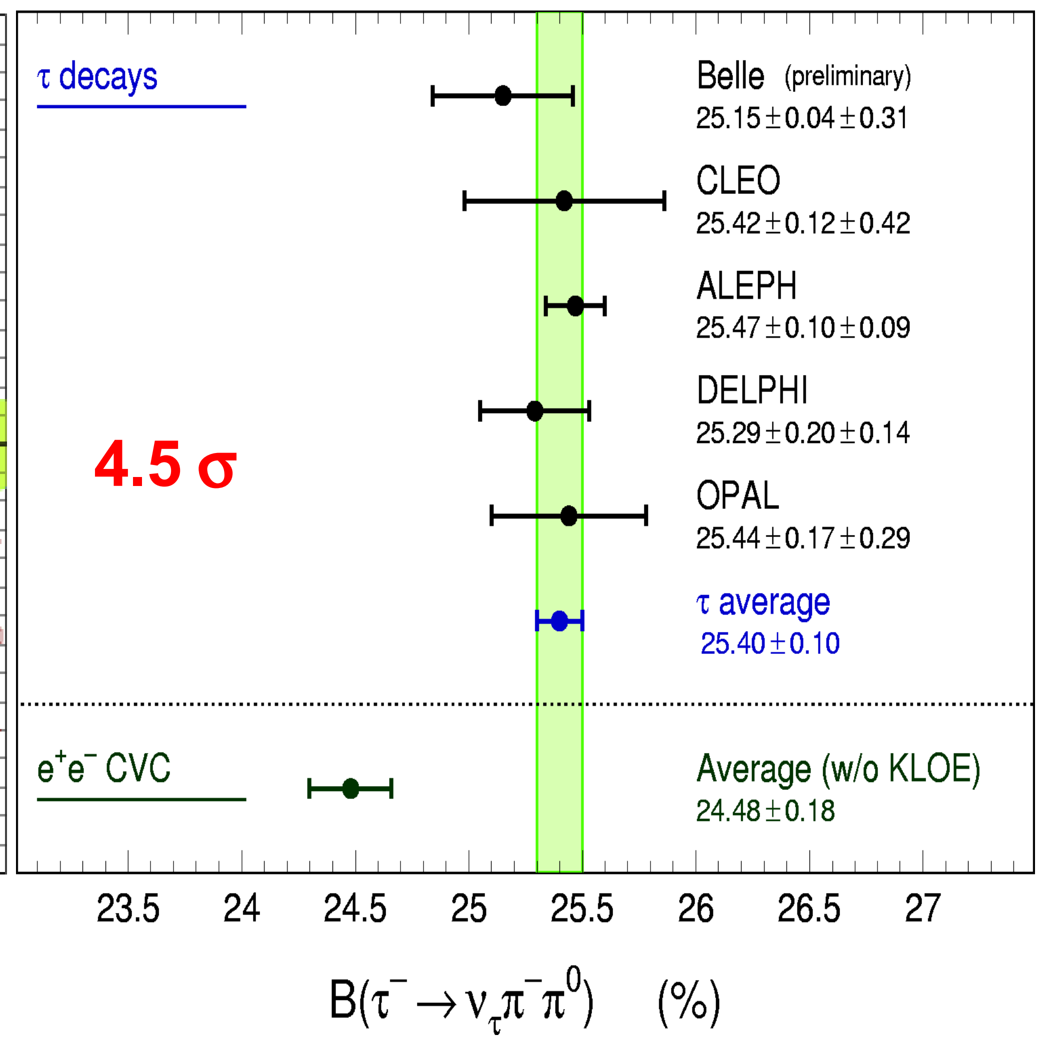
$$\left\langle H^0 \right| \qquad \bar{q} \, \gamma^\mu q \left| 0 \right\rangle$$

Assuming CVC :

$$\sigma^{I=1}_{e^+e^- \to X^0}(s) = \frac{4\pi\alpha^2}{s} v_{1,\, X^-}(s)$$

Hadronic τ decays & spectral functions. Comparison with e^+e^- data (2)





Measurement of fragmentation functions at BESIII (1)

- Fragmentation functions – important non-perturbative QCD inputs.
- Similar to parton distributions – but much less known
- Fragmentation functions were measured at LEP at Z^0 peak (DELPHI, OPAL, ALEPH, L3) and at DESY (TASSO, MARKII, and other collab.)
- BESIII gives an opportunity to study them in single inclusive annihilation *for free!*
- We plan to perform at BESIII energies the analysis analogous to that was done at DELPHI by Dubna physisists *(N.Skachkov, O.Smirnova, L.Tkachev et al., "Measurement of quark and guon fragmentation functions at Z0 hadronic decays, Eur.Phys.J. C6 (1999) 19-33.)*

Measurement of fragmentation functions at BESIII (2)

QCD fragmentation functions $D^h_{q(g)}(X_p,Q^2)$, $X_p=2P_h/Q$ (where P_h is the hadron momentum, Q is the e^+e^- CMS energy), describe the transition of the produced quarks (q) and gluons (g) to the final state hadrons (h).

One can measure longitudinal, transverse and asymmetric fragmentation functions

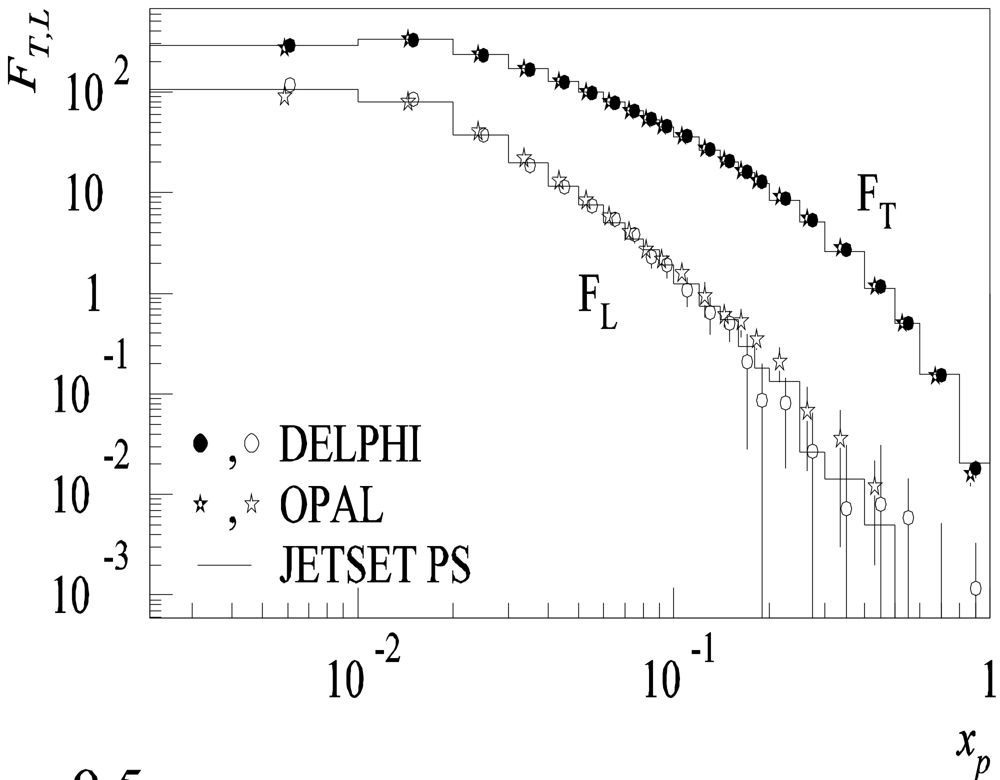
$$F_K(x_p) = (1/\sigma_{tot})(d\sigma_K^{ch}/dx_p) \quad ,K=L,T,A,$$

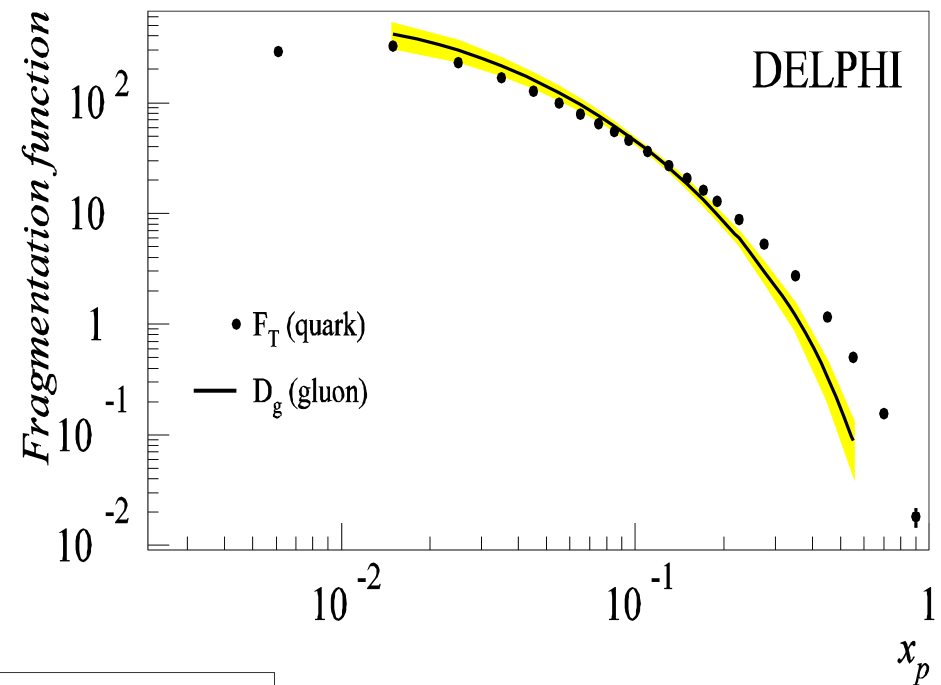
measuring the $e^+e^- \to h + X$ production cross-sections:

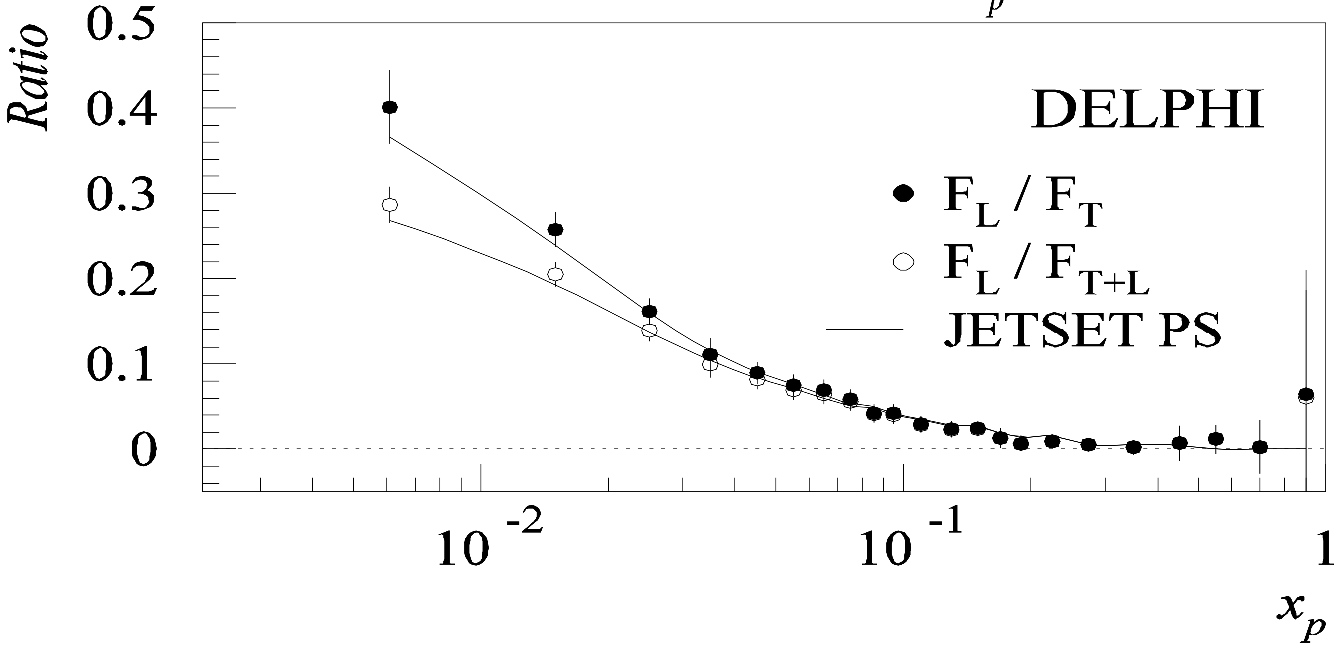
$$\frac{d^2\sigma^h}{dx_p\, d\cos\theta} = \frac{3}{8}(1+\cos^2\theta)\frac{d\sigma_T^h}{dx_p} + \frac{3}{4}\sin^2\theta\frac{d\sigma_L^h}{dx_p} + \frac{3}{4}\cos\theta\frac{d\sigma_A^h}{dx_p},$$

Overall charged hadron differential cross-sections should be measured

DELPHI results







We can repeat these measurements at BESIII:

- different CMS energy
- c-quark component
- test of scaling

Study of hadronic decay of scalar charmed mesons (VV and 3P mode)

η_c decay modes (PDG):

$\eta'(958)\pi\pi$	$(4.1 \pm 1.7)\ \%$		1321
$\rho\rho$	$(2.0 \pm 0.7)\ \%$		1273
$K^*(892)^0 K^- \pi^+ +$ c.c.	$(2.0 \pm 0.7)\ \%$		1276
$K^*(892)\overline{K}^*(892)$	$(9.2 \pm 3.4) \times 10^{-3}$		1194
$K^{*0}\overline{K}^{*0}\pi^+\pi^-$	$(1.5 \pm 0.8)\ \%$		1071
$\phi K^+ K^-$	$(2.9 \pm 1.4) \times 10^{-3}$		1102
$\phi\phi$	$(2.7 \pm 0.9) \times 10^{-3}$		1087
$\phi 2(\pi^+\pi^-)$	$< 4.7 \times 10^{-3}$	90%	1249
$a_0(980)\pi$	$< 2\ \%$	90%	1324
$a_2(1320)\pi$	$< 2\ \%$	90%	1194
$K^*(892)\overline{K} +$ c.c.	$< 1.28\ \%$	90%	1308
$f_2(1270)\eta$	$< 1.1\ \%$	90%	1143
$\omega\omega$	$< 3.1 \times 10^{-3}$	90%	1268
$\omega\phi$	$< 1.7 \times 10^{-3}$	90%	1183
$f_2(1270) f_2(1270)$	$(1.0 {}^{+0.4}_{-0.5})\ \%$		771

Decays into stable hadrons

$K\overline{K}\pi$	$(7.0 \pm 1.2)\ \%$		1379
$\eta\pi\pi$	$(4.9 \pm 1.8)\ \%$		1427
$\pi^+\pi^- K^+ K^-$	$(1.5 \pm 0.6)\ \%$		1343
$K^+ K^- 2(\pi^+\pi^-)$	$(10 \pm 4) \times 10^{-3}$		1252
$2(K^+ K^-)$	$(1.5 \pm 0.7) \times 10^{-3}$		1053
$2(\pi^+\pi^-)$	$(1.20 \pm 0.30)\ \%$		1457
$3(\pi^+\pi^-)$	$(2.0 \pm 0.7)\ \%$		1405
$p\overline{p}$	$(1.3 \pm 0.4) \times 10^{-3}$		1158

IN TOTAL: <30%

Measurement of branchings is crucial for correct simulation of decays

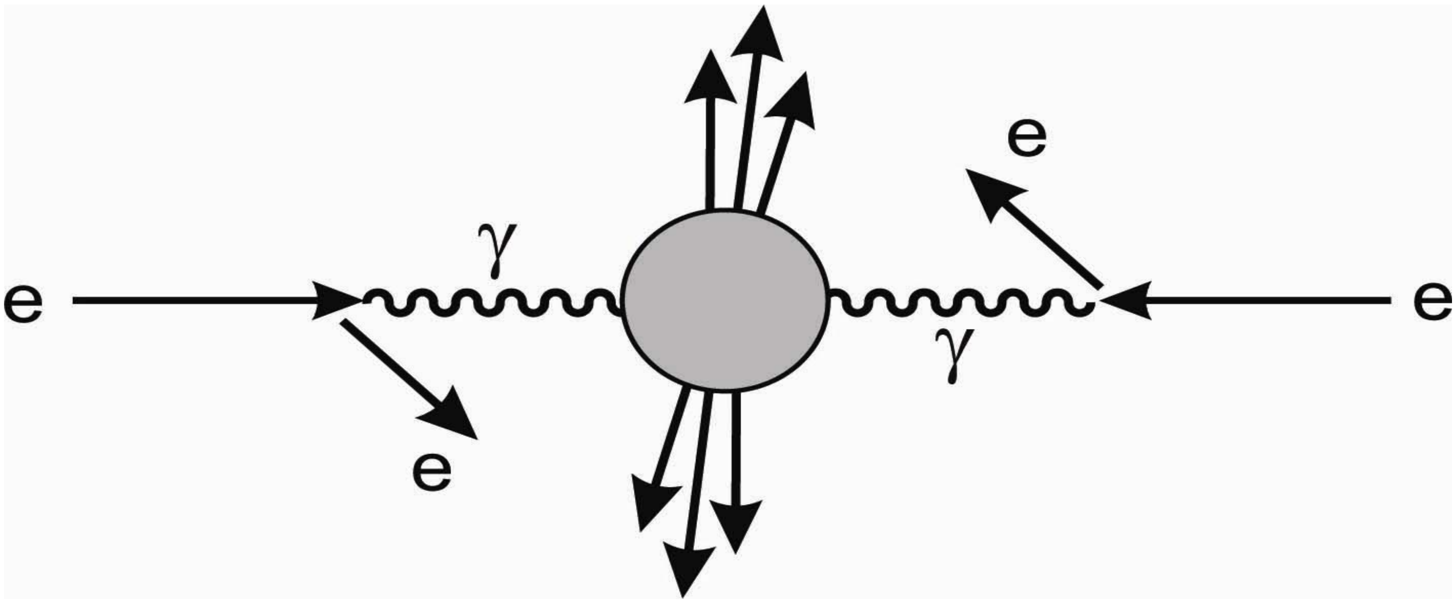
Dalitz analysis of scalar charmonium decay into 3P state

- 3P final state is ~ 40% of known decay mode for η_c and χ_{c0} , while theory predicts 2-body decay dominance
- Known, well-tagged initial 0^{-+} state is the nice place to study light scalar mesons (like a_0,f_0) and to search for exotics.
- Even if one cannot resolve close resonances, the results will be very important for the following full PWA analysis (selection, coupling with different final state, etc)
- Simple & reliable technique – results can be obtained fast, with clear systematics. Very attractive short-term goal for the BES-III start-up.

Measurement of branching and polarization for η_c, χ_c, $D^0 \rightarrow V_1 V_2$ decays

- Polarization affects strongly the momentum spectra and angular distributions of decay products, and must be obtained to measure branching correctly
- η_c decay (with known polarization) can be used to check systematics for later analyses of charmonium and D^0 decays. Significant deviation from the SM prediction will be a clear evidence of new physics
- Contribution of CP-even and CP-odd final states can be measured in D^0 decays for CP violation study.

Two photon physics



$$e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-X$$

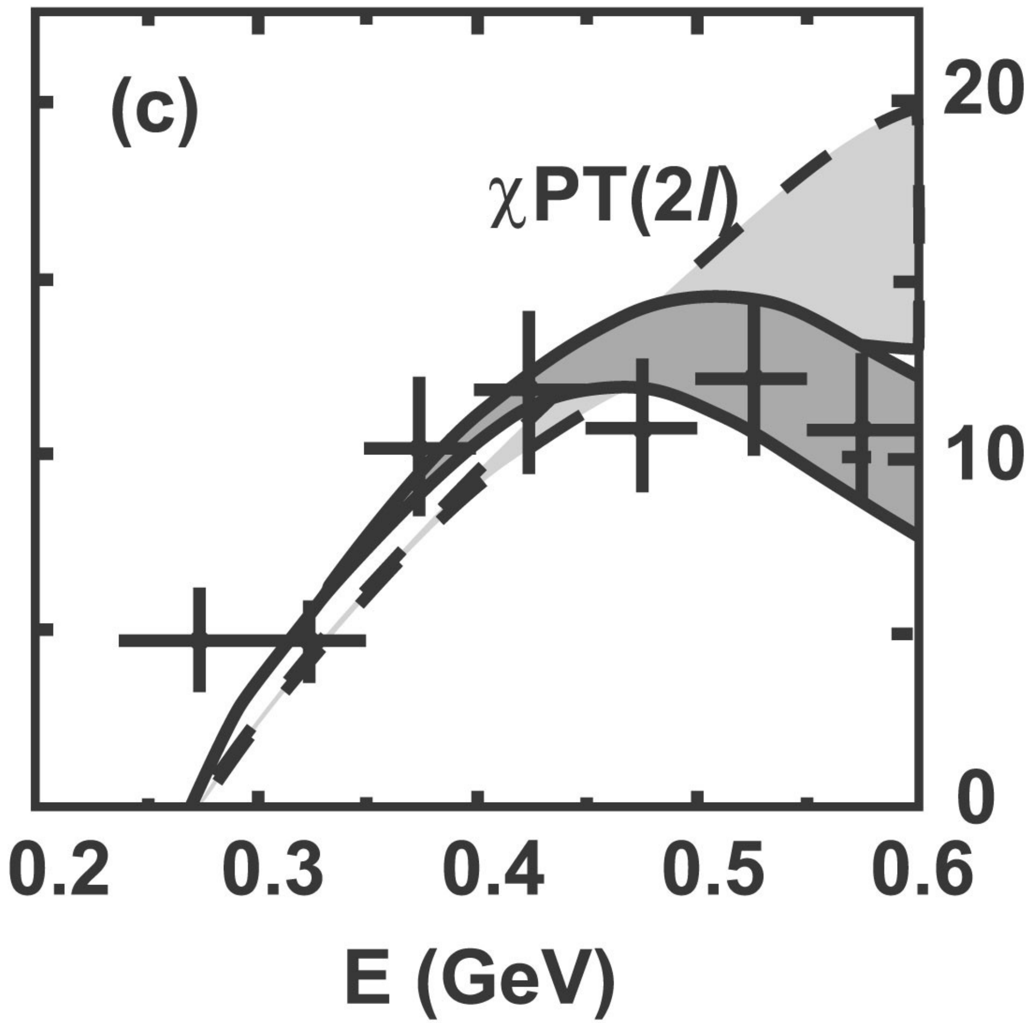
X – muons, electrons, hadrons

- electron and positron radiate photons in beam direction
- bulk of radiated photons are almost real
- the main process in consideration $\gamma\gamma \to \mathbf{X}$
- "no tag", "single tag" and "double tag" measurements

Hot topics in two-photon physics

- $\pi^0\pi^0$ production (test of ChPT)
- $\Gamma_{\gamma\gamma}$ of $a_0(980)$ and $f_0(980)$ is poorly known (about 30%)
- η and η' width to $\gamma\gamma$
- Photon-pion transition form factor in single tag experiment

$\pi^0\pi^0$ production as test of ChPT



M.R. Pennington hep-ph/0511146

Theoretical prediction for

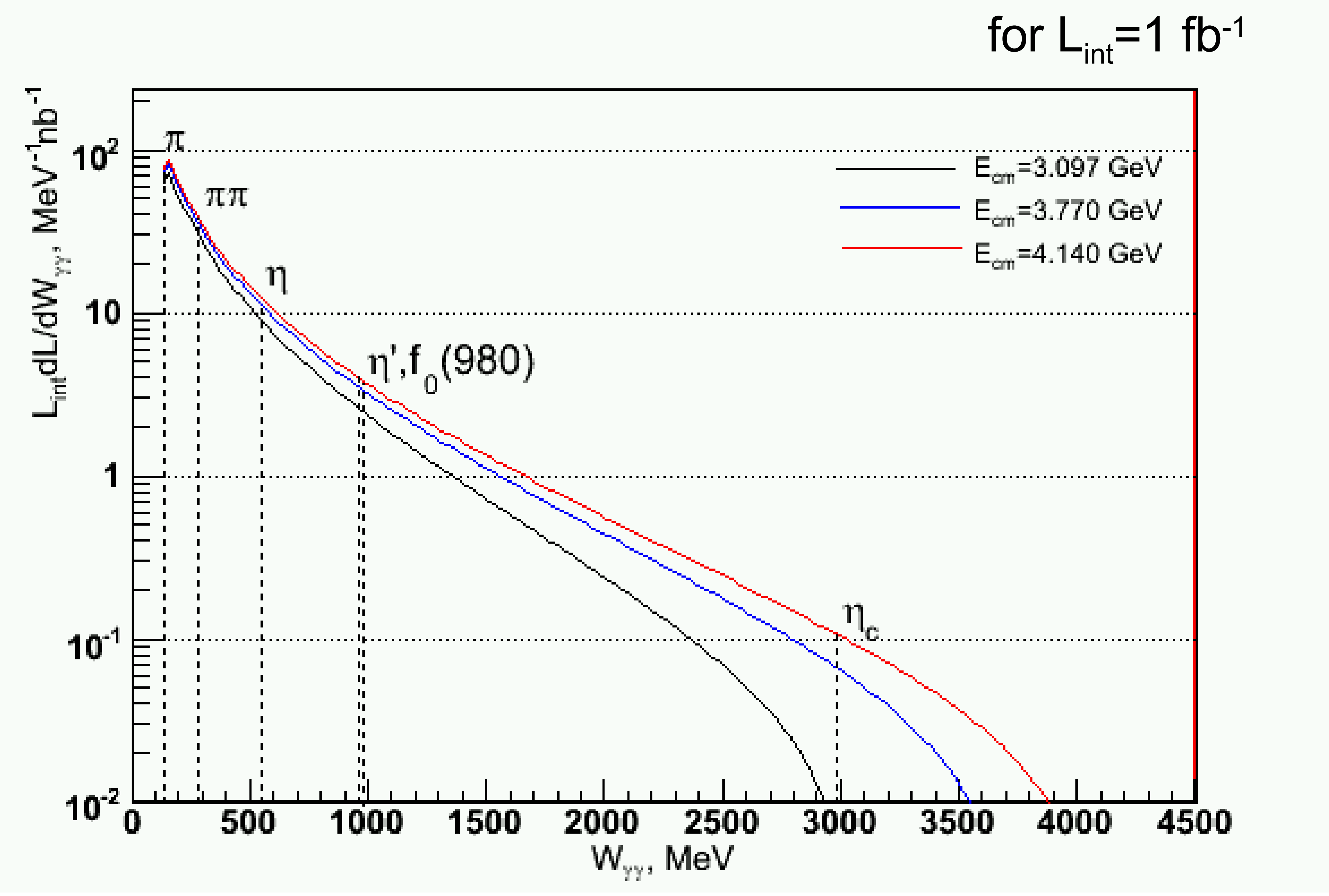
$$\gamma\gamma \to \pi^0\pi^0$$

in 1- and 2- loop approximation in ChPT

The only data available from Crystal Ball Coll.

The BES III could provide an independent measurement and important test of ChPT

Two photon luminosity



Event rate estimation

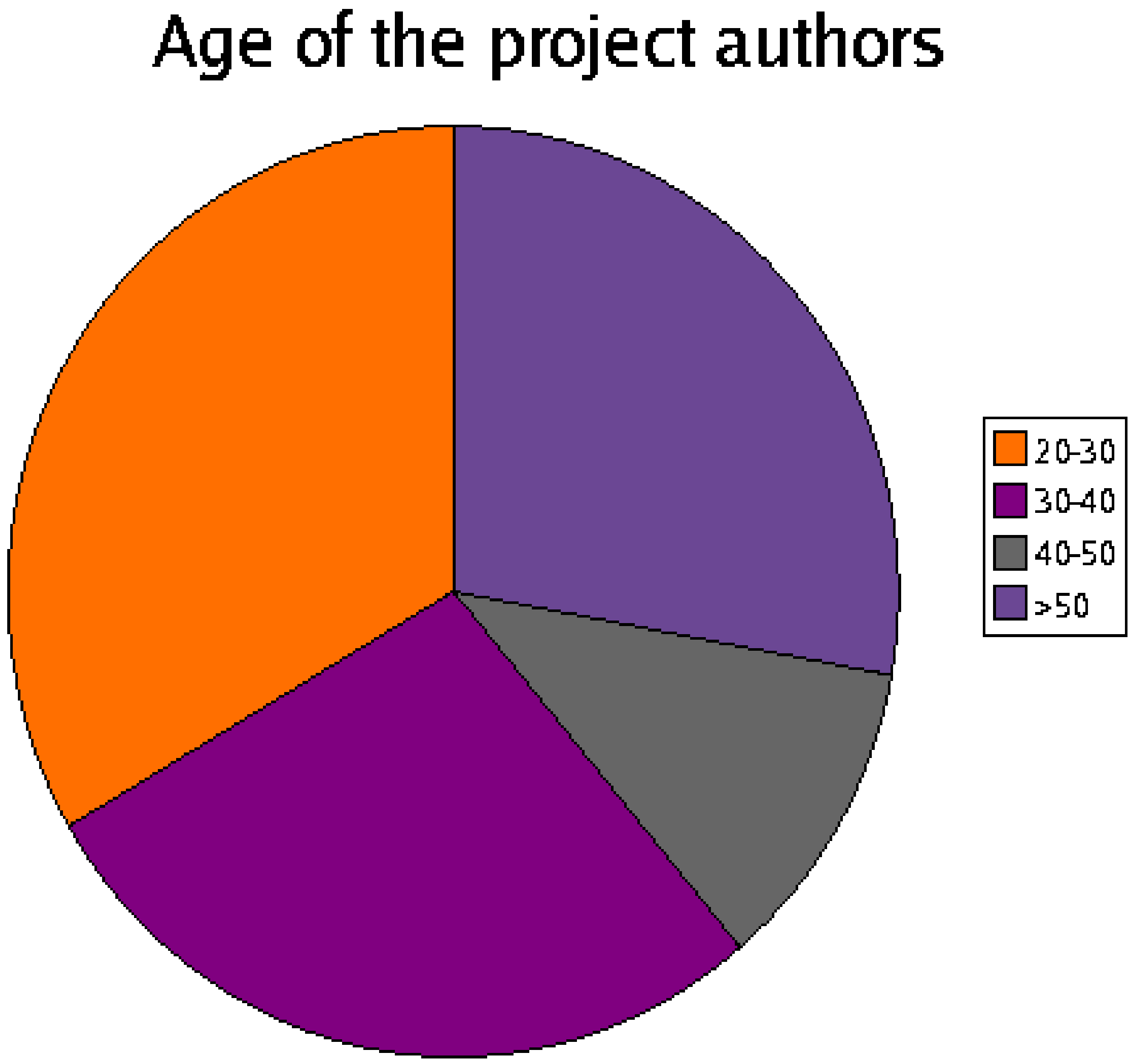
E_{cm} = 3.77 GeV L_{int} = 5 fb^{-1}

Mode	Total cross-section [nb]	No tag $\times 10^6$	Single tag $\times 10^3$	Double tag
$\pi^+\pi^-$	2.38	11.9	236.5	5860
$\pi^0\pi^0$	0.062	0.31	25.5	885
π^0	0.67	3.35	7.85	90
η	0.24	1.20	32.8	490
η'	0.37	1.85	113.0	2255
$a_0(980)$	0.33	1.65	7.87	990
$f_0(980)$	0.046	0.23	9.5	140
η_c	0.0016	0.008	1.9	225

Summary

- The BESIII experiment will start data taking in 2008, and it will stay the world leading experiment in the τ-charm domain at least until 2015, when FAIR starts
- The JINR group physics program is based both on the experience gained in DELPHI and strong theoretical support from BLTP
- Our physics program covers wide range of topics, from tau physics to study of charmed mesons decays and two-photon reactions. Both short-term and long-term topics are present
- We have a clear working program and an exciting time in front of us!

backup slides


Age of the project authors
20-30
30-40
40-50
>50

Measurement of branchings and polarization for η_c, χ_c, $D^0 \to VV$ decays

η_c decays:

- Branching measurements
- Study of systematic for polarization measurements

χ_c decays:

- Branching and polarization measurements

D^0 decays:

- Branching & polarization measurements
- Measurements of CP-even and CP-odd contribution into D0 decay final states. Search for CP violation in D0 decays

LO QCD formula for connection of F_L with F_T and gluon fragmentation function

$$
\begin{aligned}
F_L(x_p) &= \frac{\alpha_s^{LO}(M_Z)}{2\pi} C_F \int\limits_{x_p}^{1} \frac{F_T(z)}{z} dz \\
&+ \frac{2\alpha_s^{LO}(M_Z)}{\pi} C_F \int\limits_{x_p}^{1} \left(\frac{z}{x_p} - 1 \right) D_g(z) \frac{dz}{z} + \mathcal{O}(\alpha_s^2)
\end{aligned}
$$

For $\tau \rightarrow l\upsilon\upsilon$

$$\mathcal{M} = \frac{4G_F}{\sqrt{2}} \sum_{\gamma=S,V,T} \sum_{i,j=L,R} g_{ij}^{\gamma} \langle \bar{\ell}_i | \Gamma^{\gamma} | \nu_\ell \rangle \langle \overline{\nu}_\tau | \Gamma_\gamma | \tau_j \rangle,$$

Michel parametrization:

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_\ell} = h_0(x_\ell) + \eta h_\eta(x_\ell) + \rho h_\rho(x_\ell) - P_\tau \left[\xi h_\xi(x_\ell) + \xi\delta h_{\xi\delta}(x_\ell) \right],$$