News from e+e- colliders in Novosibirsk

E.Solodov

(CMD-3 collaboration)

Budker Institute of Nuclear Physics,
SB RAS, Novosibirsk, Russia

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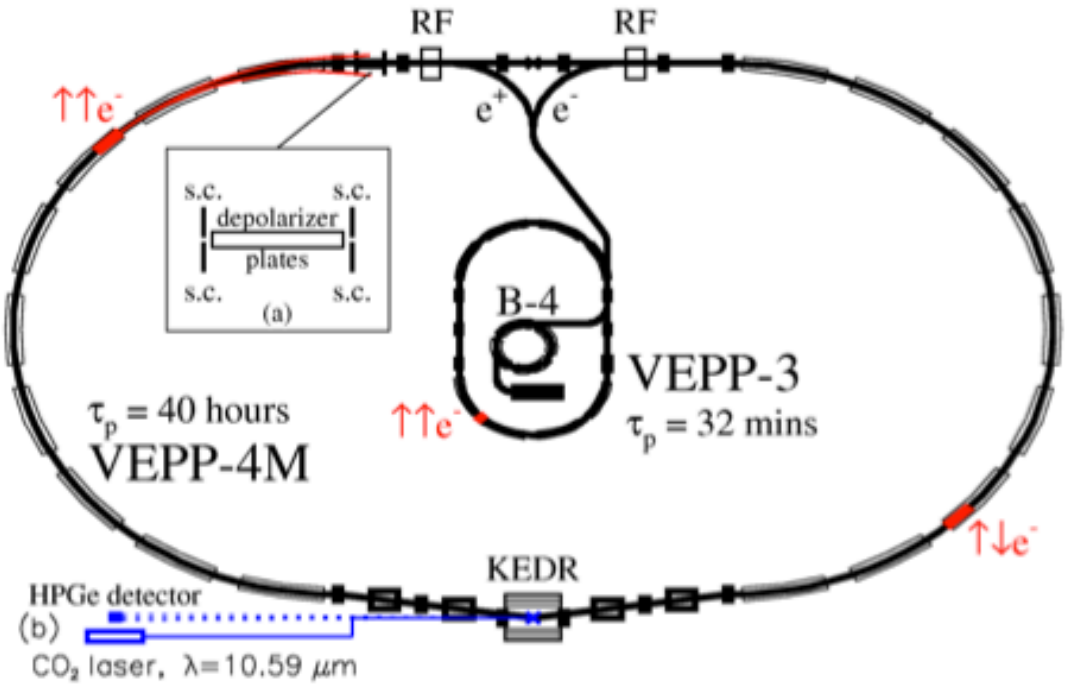
OUTLINE

1 – VEPP4M – latest measurements, plans
2 - VEPP-2000 collider, motivation, performance
4 - SND and CMD-3 detectors, physics runs
5 – Results
6 – Plans

VEPP-4M



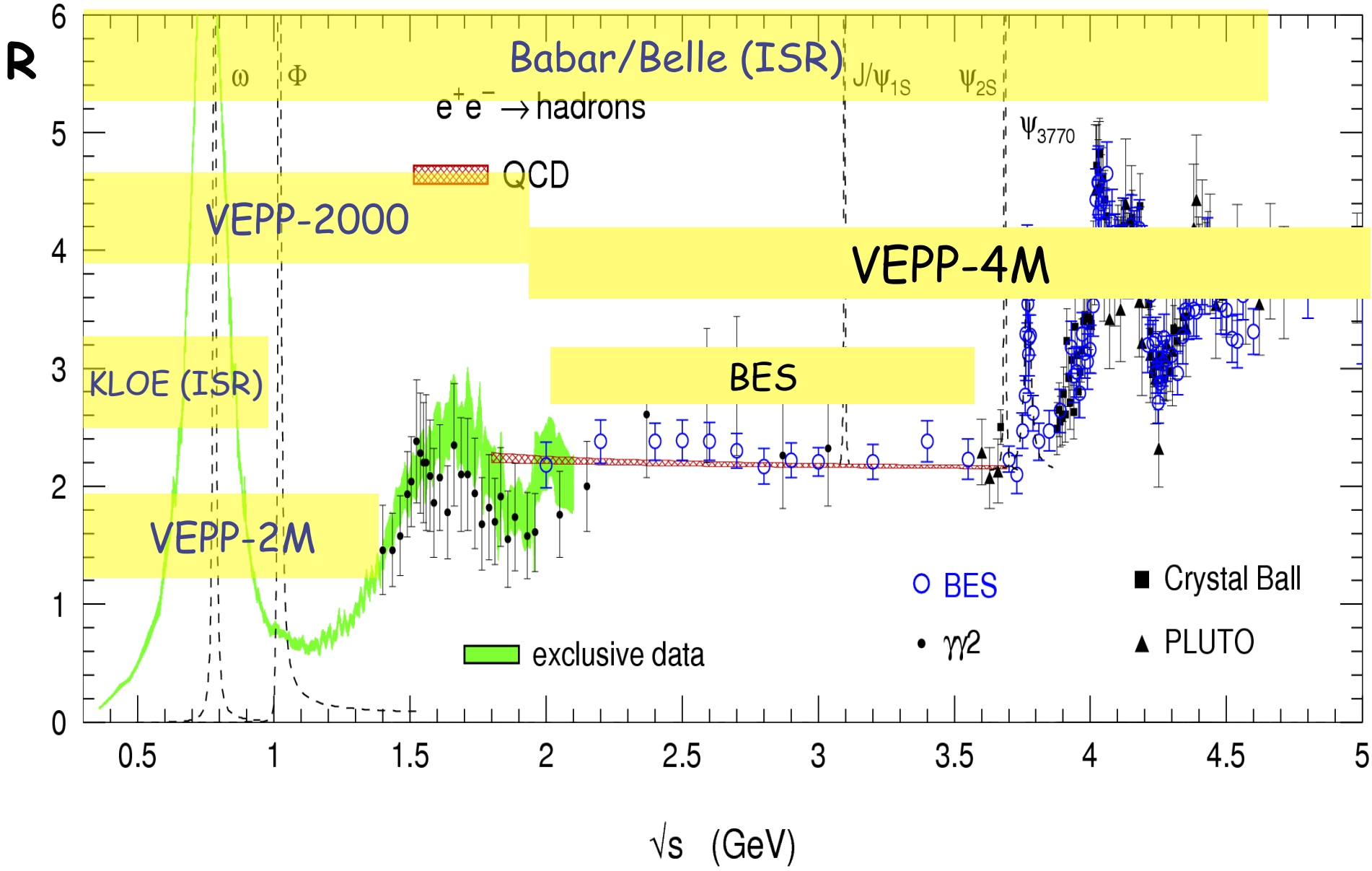
Beam energy $1 \div 5$ GeV
Number of bunches 2×2

$E = 1.5$ GeV $\quad 10^{30}$ cm^{-2} c^{-1}

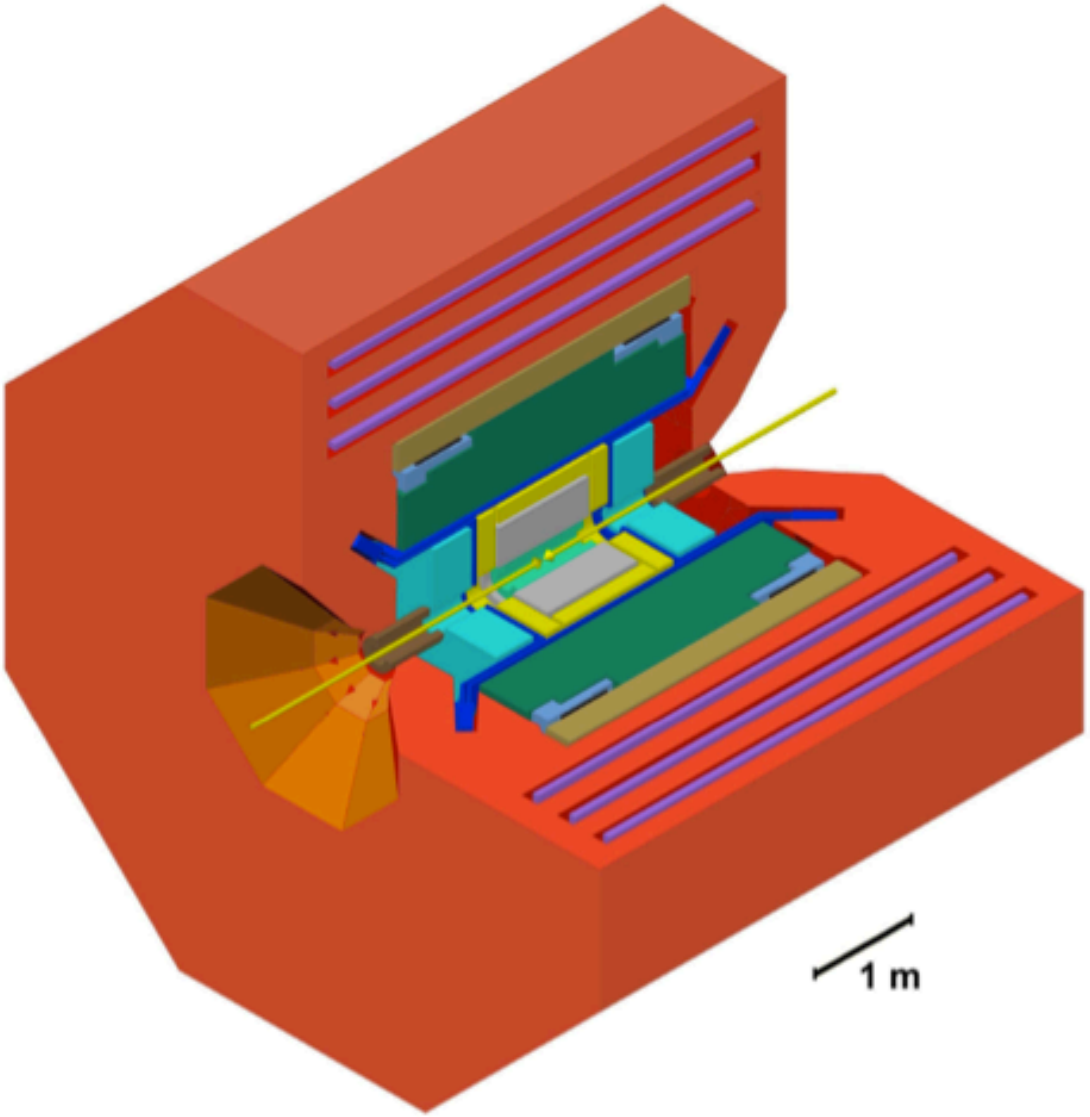
Energy determination

- Resonant depolarization technique:
  Energy interpolation accuracy $10 \div 30$ keV
- Infra-red light Compton backscattering :
  Systematic uncertainty is about 70 keV

R(s) measurements at low s



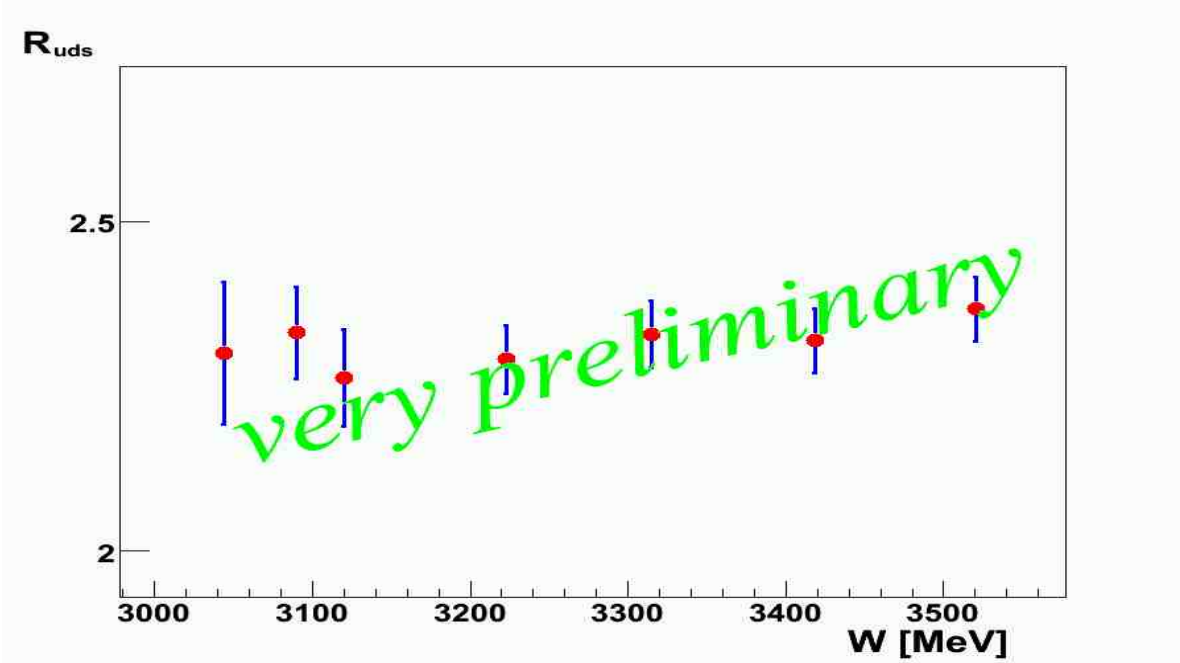
KEDR



- Vertex detector
- Drift chamber
- Aerogel threshold counters
- ToF counters
- Lkr calorimeter
- Superconducting coil
- Yoke
- Muon chambers
- CsI calorimeter
- Compensating solenoid

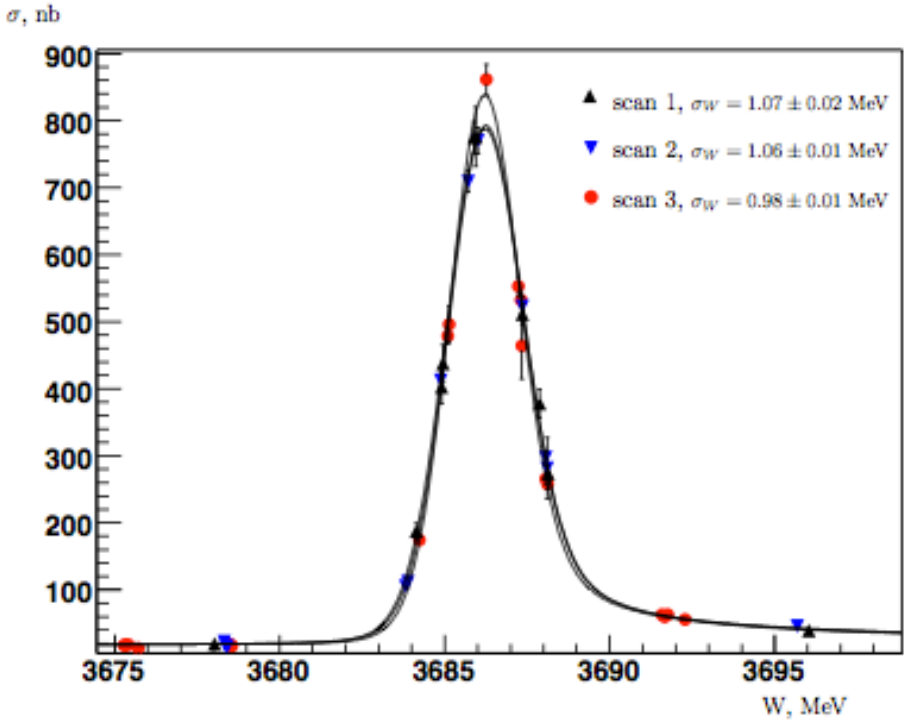
KEDR Status and plans

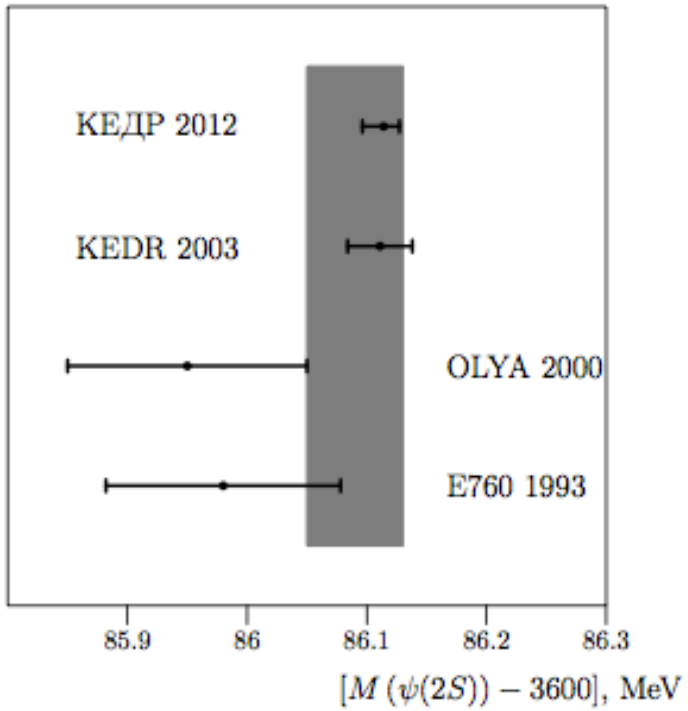
1. ~2 pb-1 collected in range of 2E= 1.9 – 3.7 GeV with step ~100 MeV.
2. Data analysis in process, preliminary results in range of 2E=3.1-3.5 GeV are presented in figure below (stat. errors only).



3. In this year we plan to take 2 pb-1 additional statistics for the energy range 2E=3.1-3.7 GeV, to get 1.5% statistical error in each data point. Machine and detector are in preparation to scan energy up to 2E = 8 GeV (and later to 10 GeV).
4. Double tag system for scattered e+ and e- is ready for $\gamma\gamma$ physics

Measurement of $\psi(2S)$ parameters





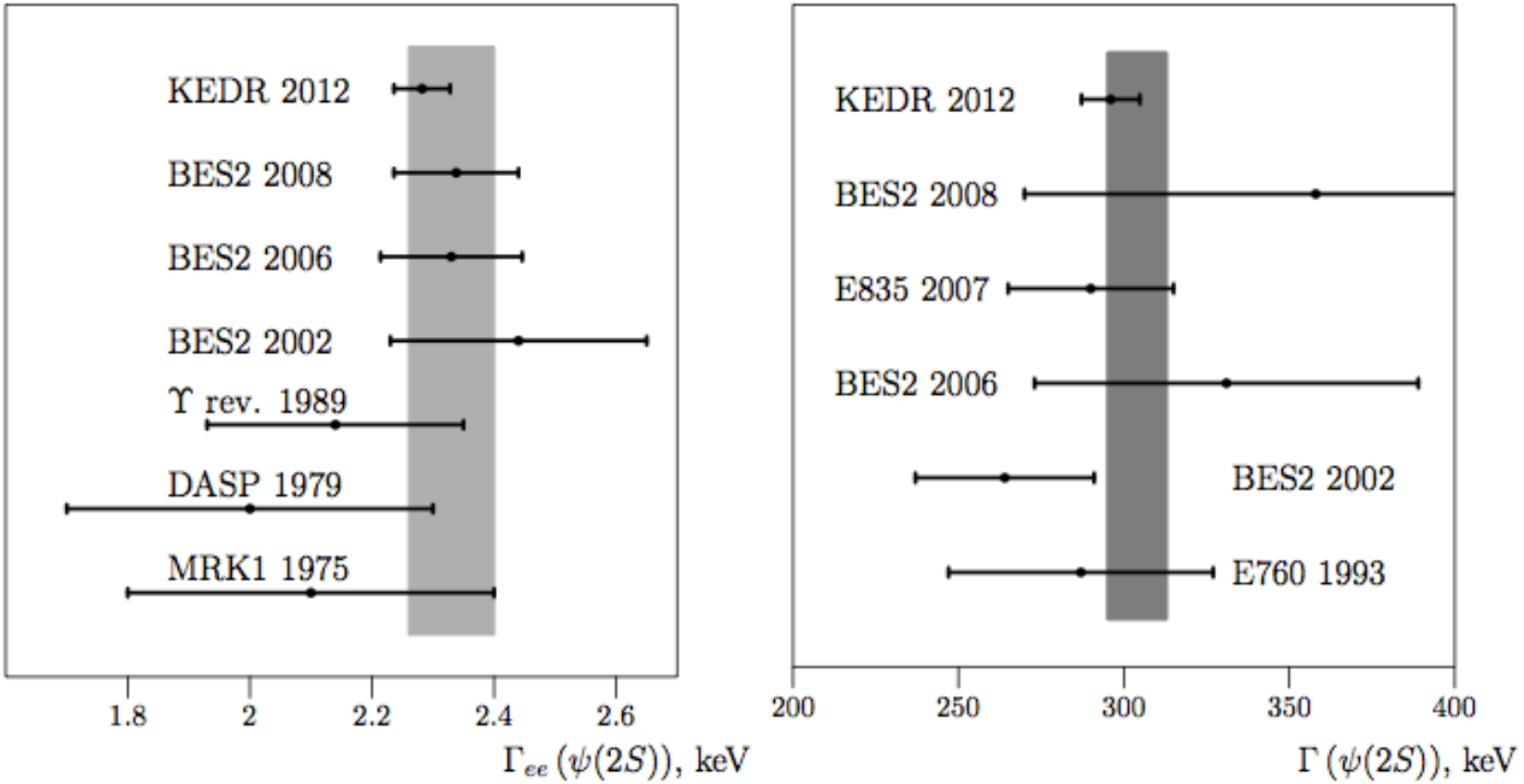
Scans 2004, 2006 $\int \mathcal{L}dt \simeq 0.6$ pb^{-1}.

$$M = 3686.114 \pm 0.007 \pm 0.011\,^{+0.002}_{-0.012}\ \text{MeV}$$

$$\Gamma_{ee} \times \mathcal{B}_{hadrons} = 2.233 \pm 0.015 \pm 0.037 \pm 0.020\ \text{keV}$$

Phys. Lett. B 711 (2012), 280-291

Results for $\psi(2S)$

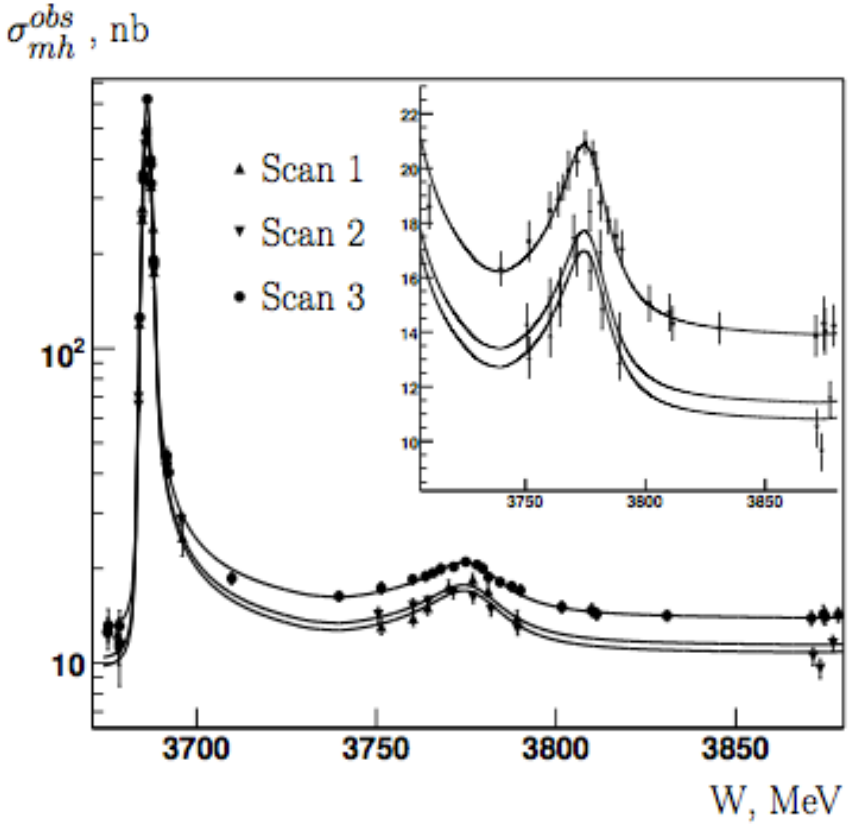


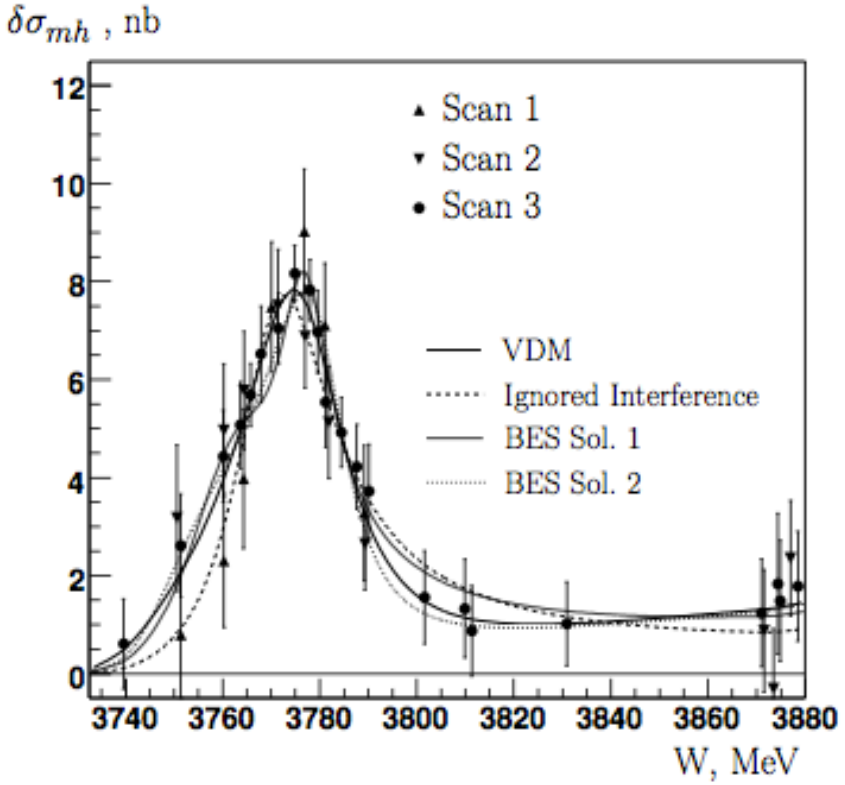
Using $\mathcal{B}^{PDG}_{hadrons} = 0.9785 \pm 0.0013$ and $\mathcal{B}^{PDG}_{ee} = 0.00772 \pm 0.00017$

$$\Gamma_{ee} = 2.282 \pm 0.015 \pm 0.038 \pm 0.021\,\text{keV}$$

$$\Gamma = 296 \pm 2 \pm 8 \pm 3\,\text{keV}$$

Measurement of $\psi(3770)$ parameters



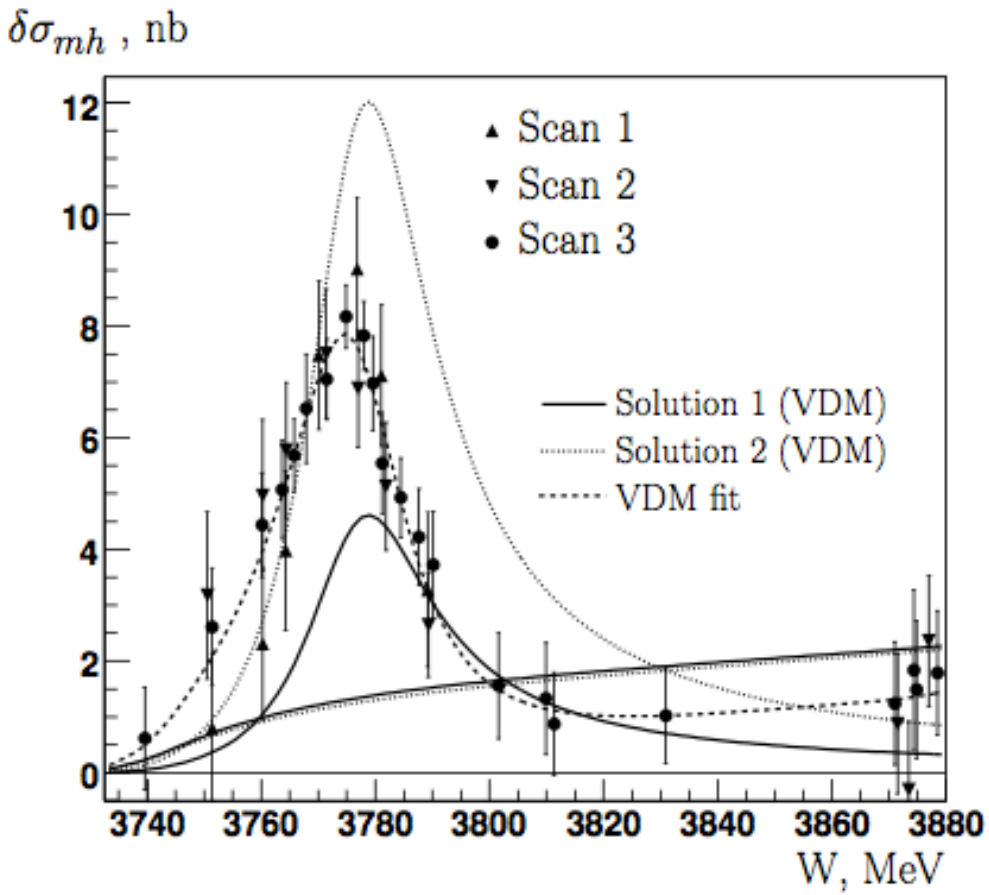


$$M = 3779.2\ ^{+1.8}_{-1.7}\ ^{+0.5}_{-0.7}\ ^{+0.3}_{-0.3}\ \text{MeV}$$

$$\Gamma = \quad 24.9\ ^{+4.6}_{-4.0}\ ^{+0.5}_{-0.6}\ ^{+0.2}_{-0.9}\ \text{MeV}$$

Phys. Lett. B 711 (2012), 292-300

Ambiguity of $\psi(3770)$ resonance parameters

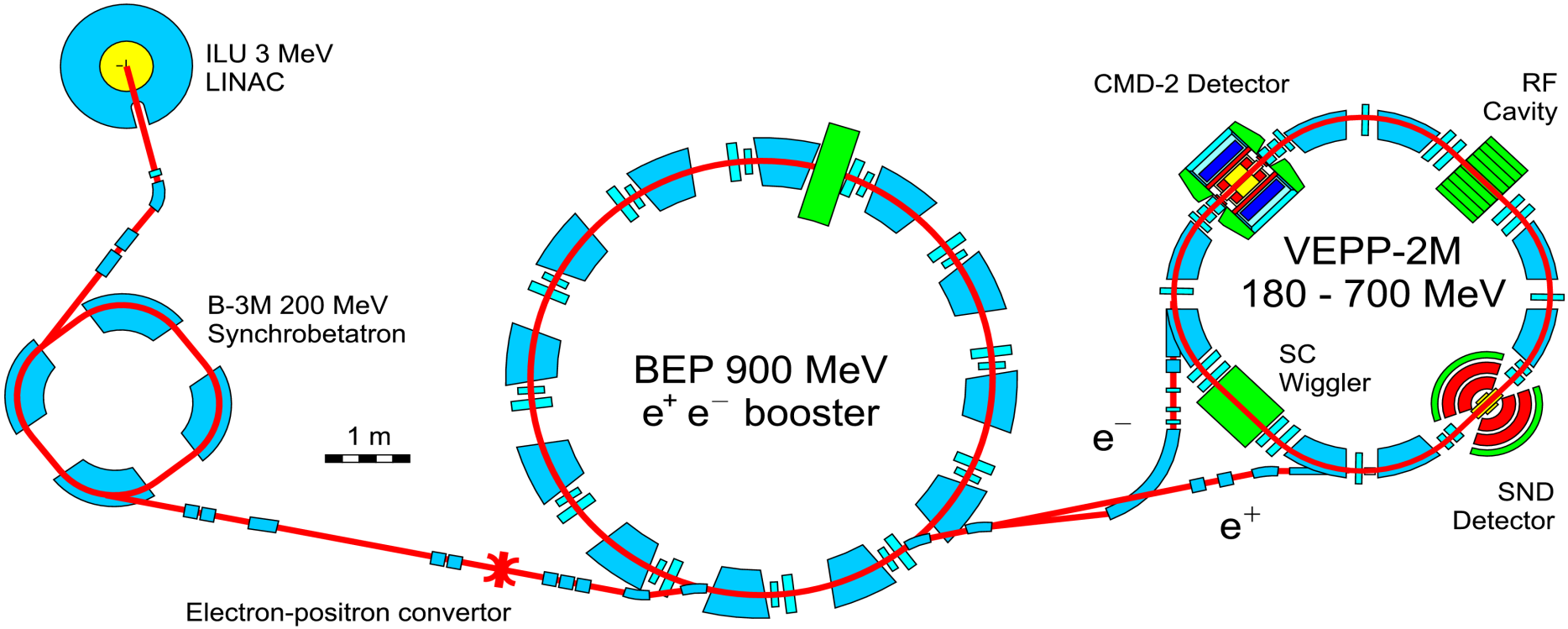


(1) $\Gamma_{ee} = 154\,^{+79}_{-58}\,^{+17}_{-9}\,^{+13}_{-25}$ eV

(2) $\Gamma_{ee} = 414\,^{+72}_{-80}\,^{+24}_{-26}\,^{+90}_{-10}$ eV

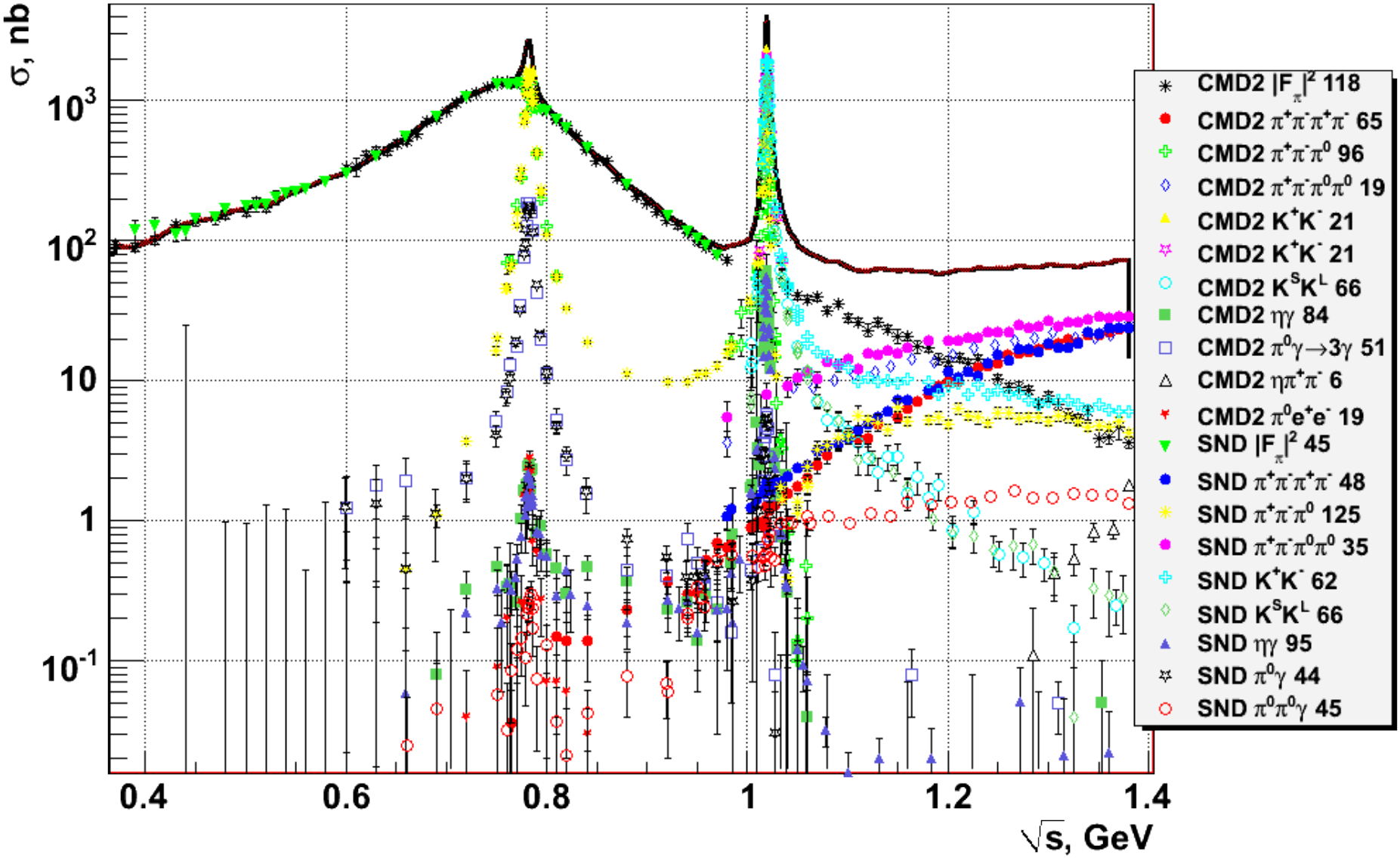
VEPP-2M collider complex

(1974-2000)



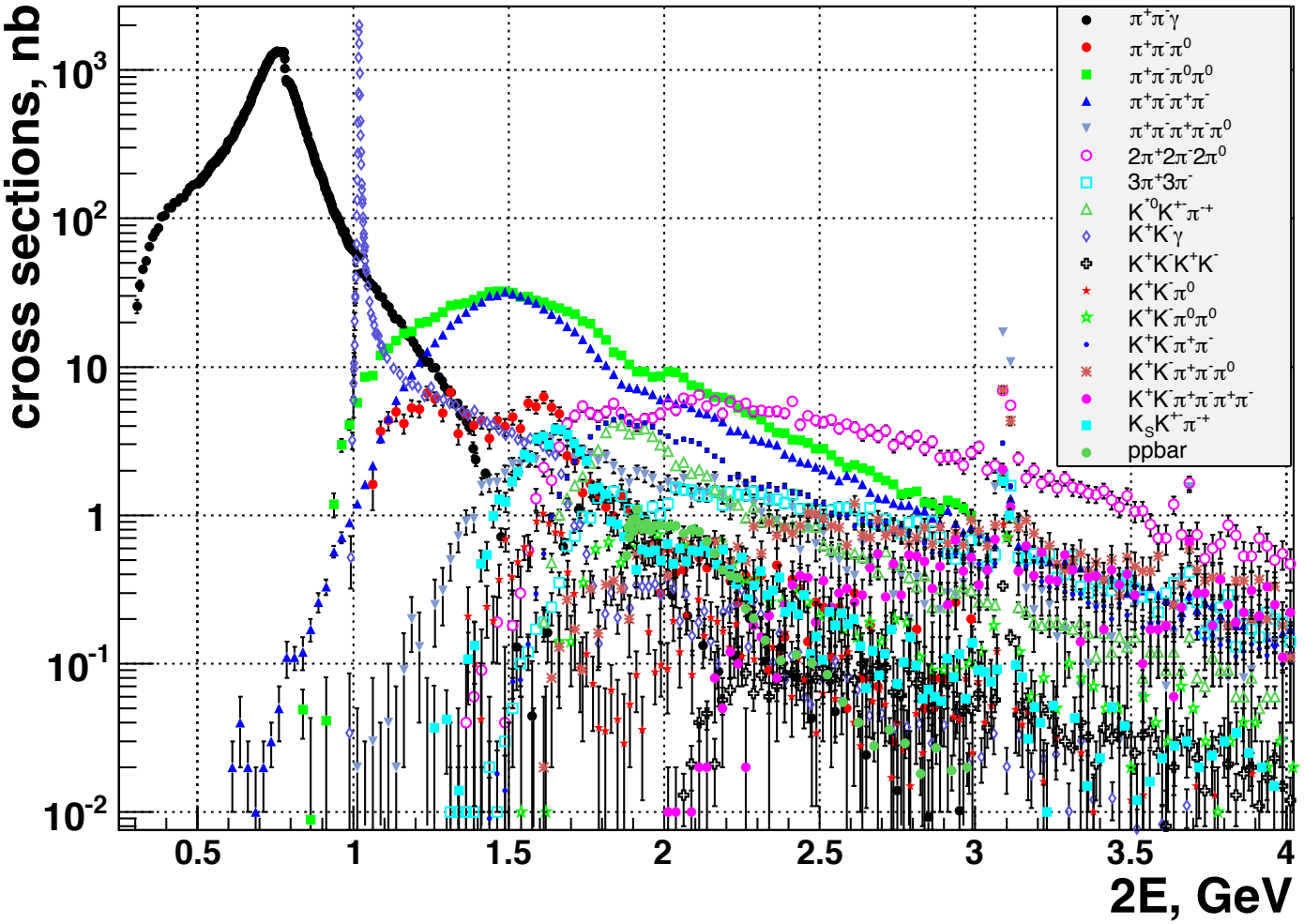
- High luminosity: $L=5\times10^{30}cm^{-2}s^{-1}$:
- Radiative polarization
- Spin precession frequency measurements
- $\rho, \omega, \varphi, K^{\pm}, K^{0}$ mass measurements
- e^+e^- anomalous magnetic moment comparison (10^{-11})

Overview of VEPP-2M results



1-5% systematic error for major channels

More BaBar data are available



1-5% systematic errors

to obtain R in the energy range 1-2 GeV the processes

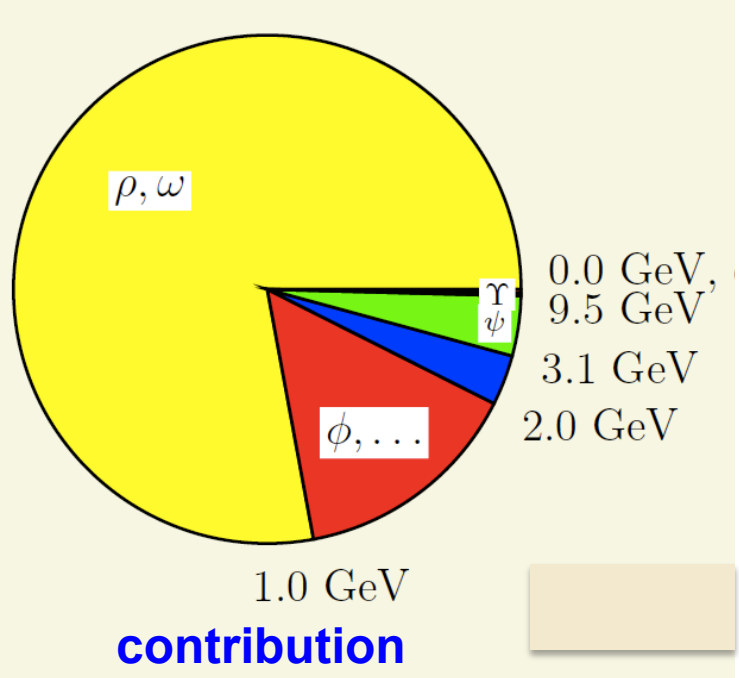
$\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^-, K_SK_L, $K_SK_L\pi\pi$, $K_SK^+\,\pi^-\pi^0$

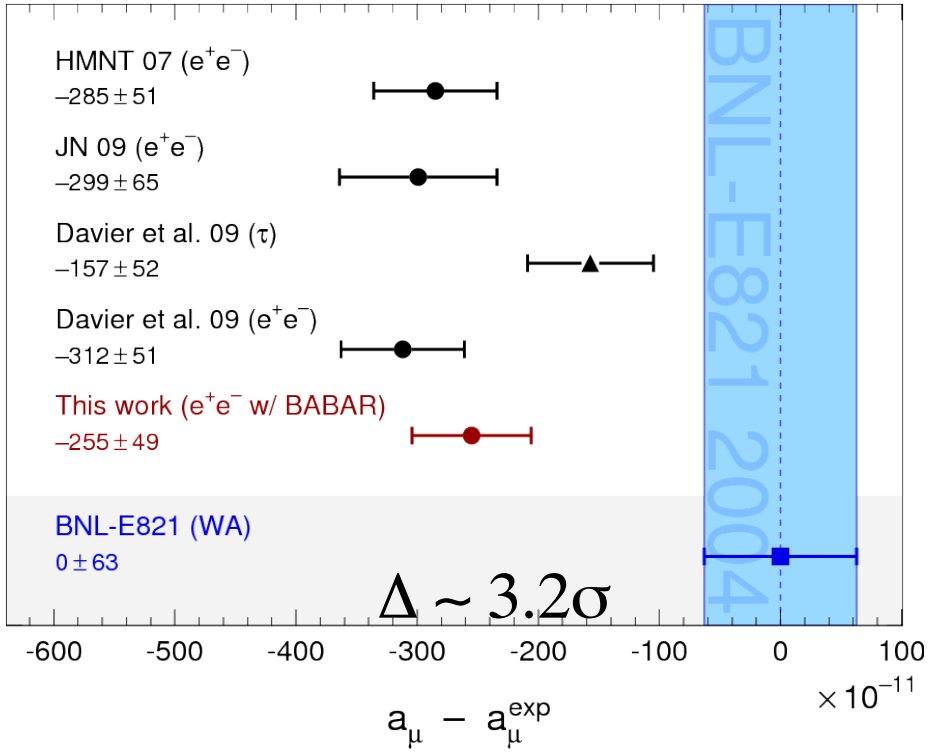
remain to be measured

See talk by A. Hafner

Hadronic contribution to muon g-2

$$a_\mu(\text{had}) = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} \frac{ds}{s^2} K(s) \left(\frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}\right)$$



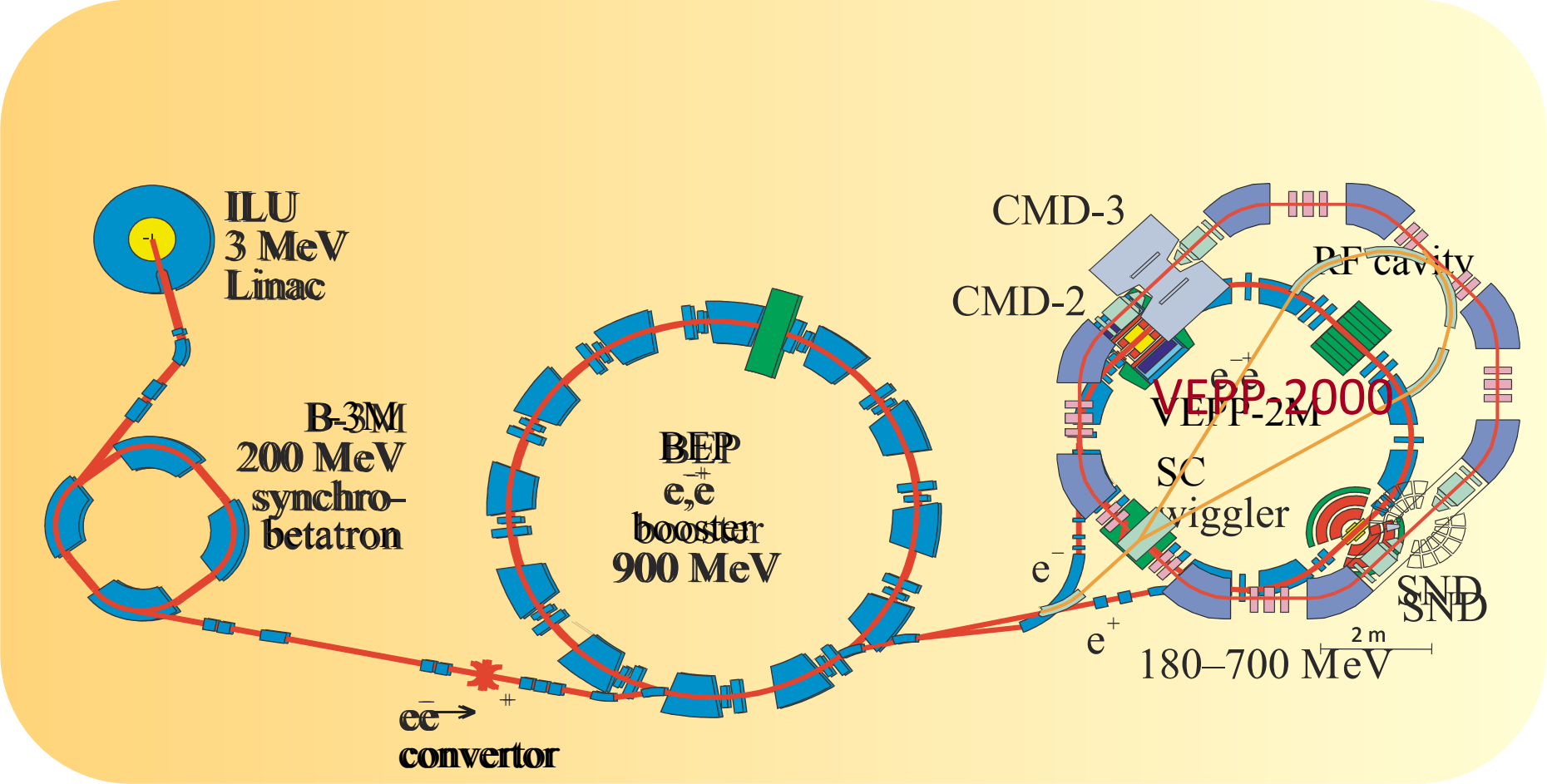


Error dominated by the E<2 GeV region

-- VEPP-2M, BaBar, KLOE significantly reduced errors
– Additional KLOE data (?)
– BaBar will provide more multihadrons, perhaps Belle
– < 1% systematic error for most of the channels is needed!

VEPP-2M → VEPP-2000

(2000-2007)



- E ≈ 1 GeV (per beam)
- L ≈ 1×10^{32} cm^{-2} sec^{-1} (1×1 bunch)

Increasing of Luminosity

- Number of bunches (i.e. collision frequency)
- Bunch-by-bunch luminosity

$$L = \frac{\pi\gamma^2 \xi_x \xi_y \varepsilon_x f}{r_e^2 \beta_y^*}\left(1+\frac{\sigma_y}{\sigma_x}\right)^2$$

Round Beams:

$$L = \frac{4\pi\gamma^2 \xi^2 \varepsilon f}{r_e^2 \beta^*}$$

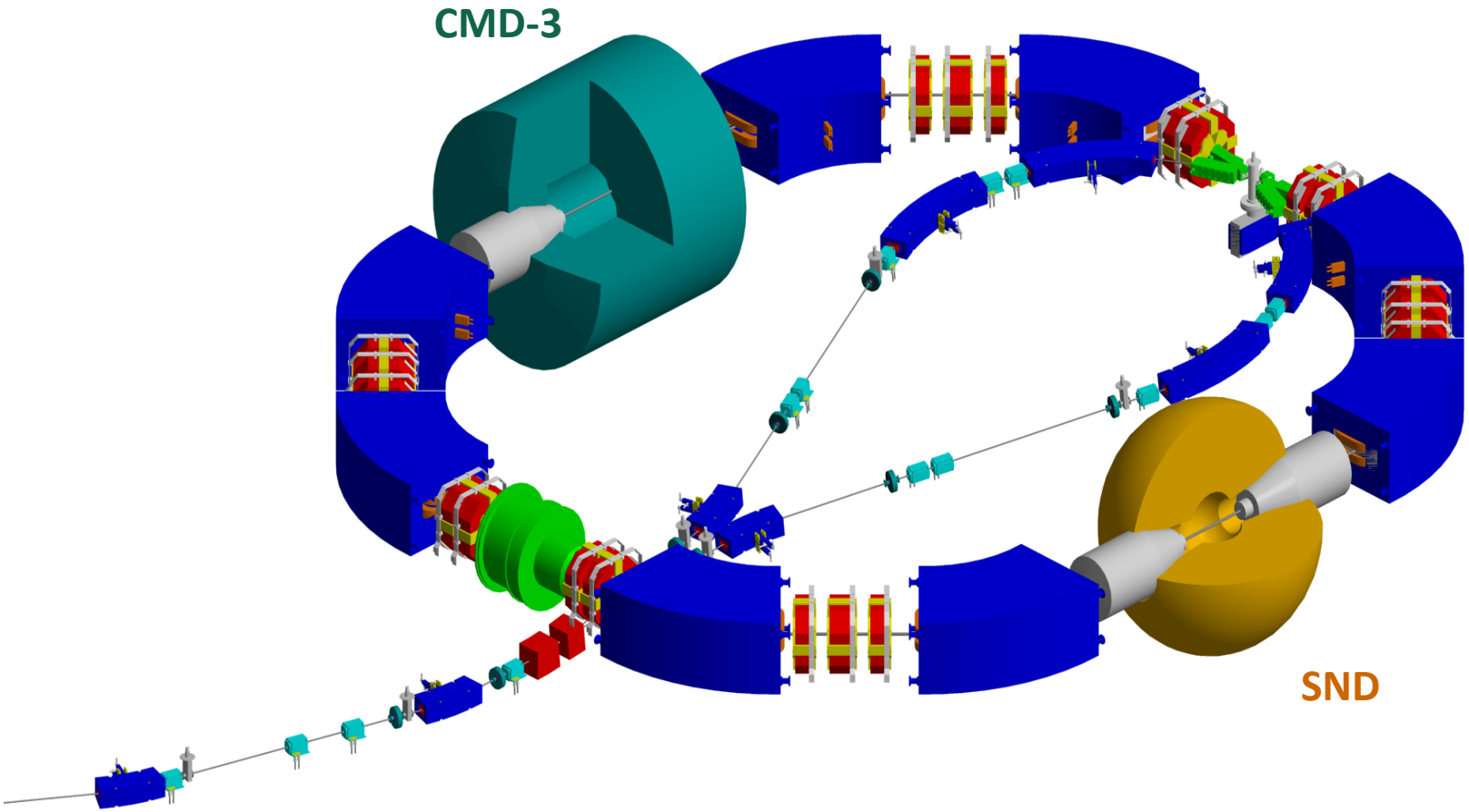
✓Geometric factor (gain=4)
✓Beam-beam limit enhancement (gain~4)
✓IBS for low energy? worth life time!

(V.V.Danilov et al., EPAC'96, Barcelona, p.1149, (1996))

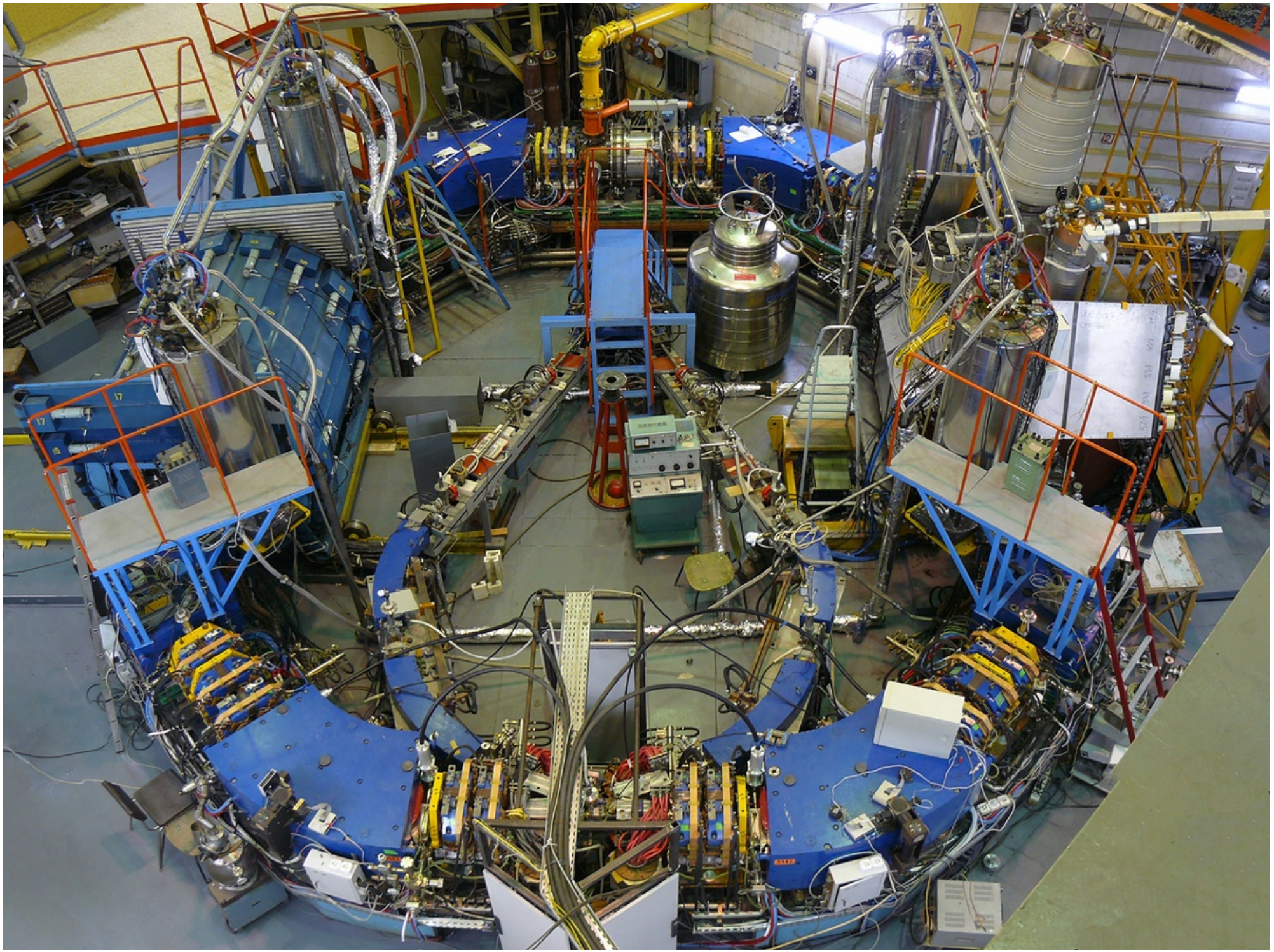
$$\xi_{x,y} \geq 0.1$$

VEPP-2000

Integrated luminosity ~ 100 pb^{-1} per detector/year

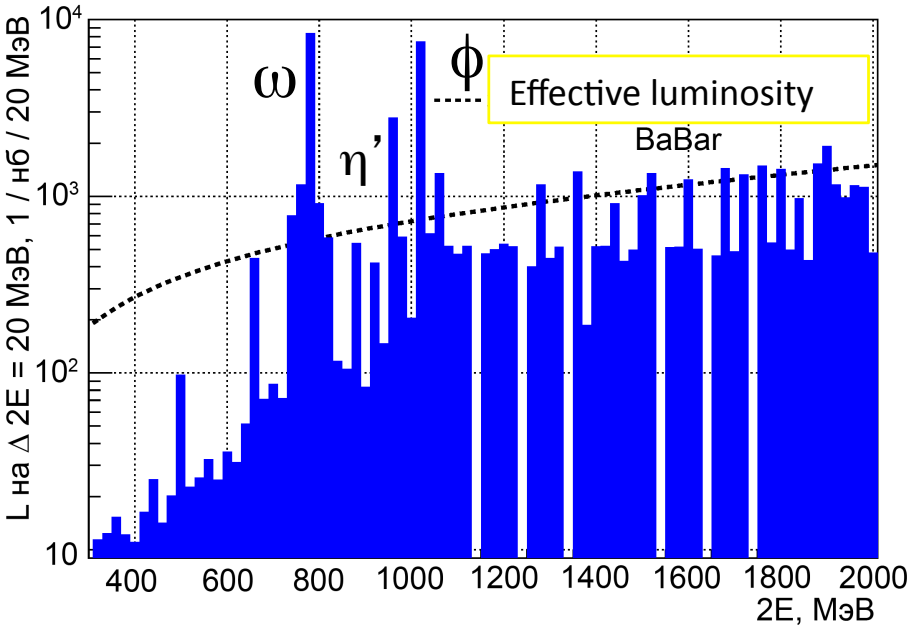


Total integrated luminosity with all detectors on VEPP-2M ~ 70 pb^{-1}



Experiments at VEPP-2000

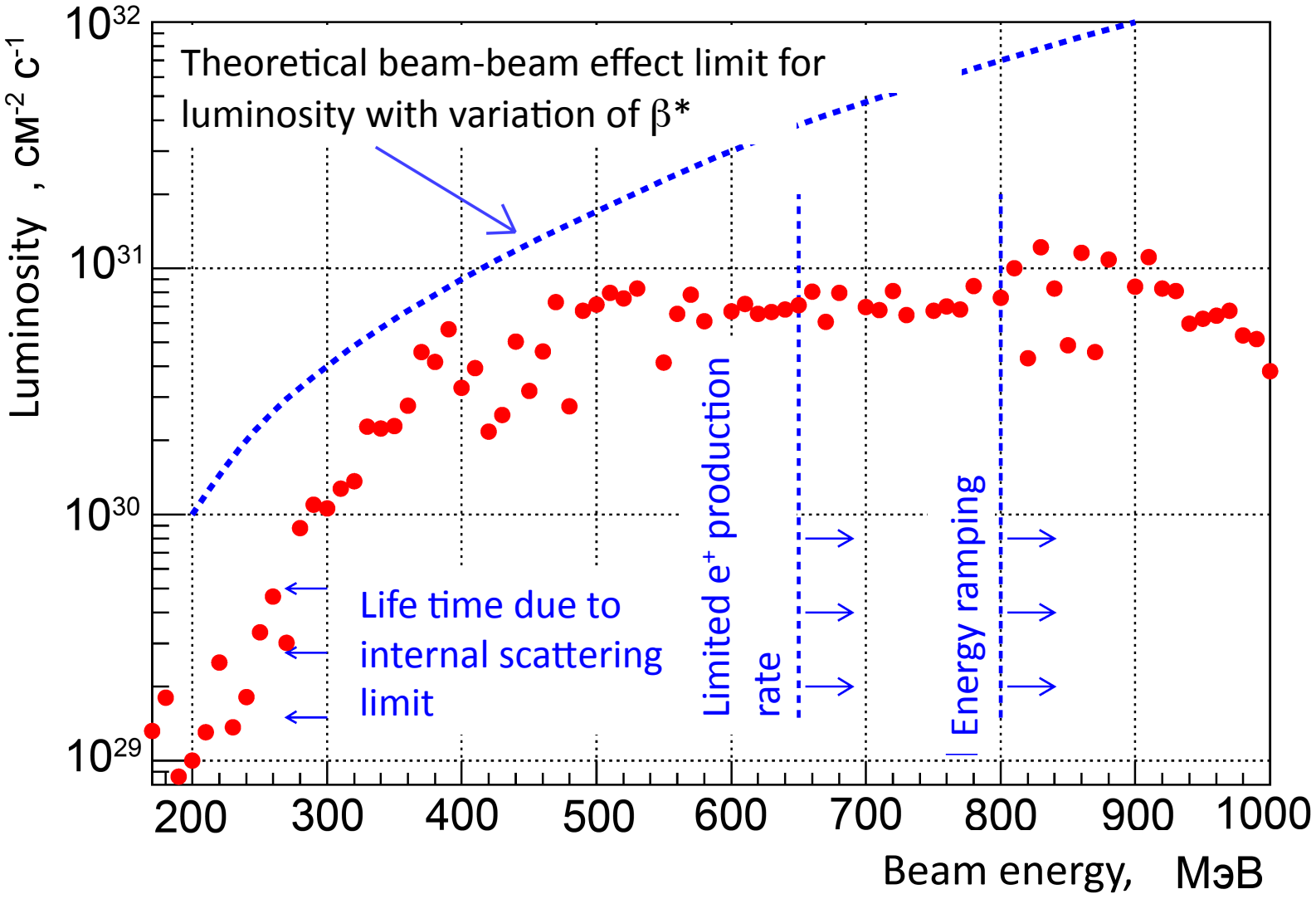
	Energy Region, GeV	Energy step, MeV	Integrated luminosity, pb^{-1} (per detector)
scan2010	1.1-1.9	100	5
scan2011	1.05-2.0	25	25
scan2012	1.4-2.0	10	15
scan2013	0.32-1.05	5-10	25



L ~ 60 pb^{-1} / detector (all seasons)

8.3 pb^{-1}	ω - region
9.4 pb^{-1}	< 1 GeV (excluding ω)
8.4 pb^{-1}	φ - region
34.5 pb^{-1}	> 1.04 GeV

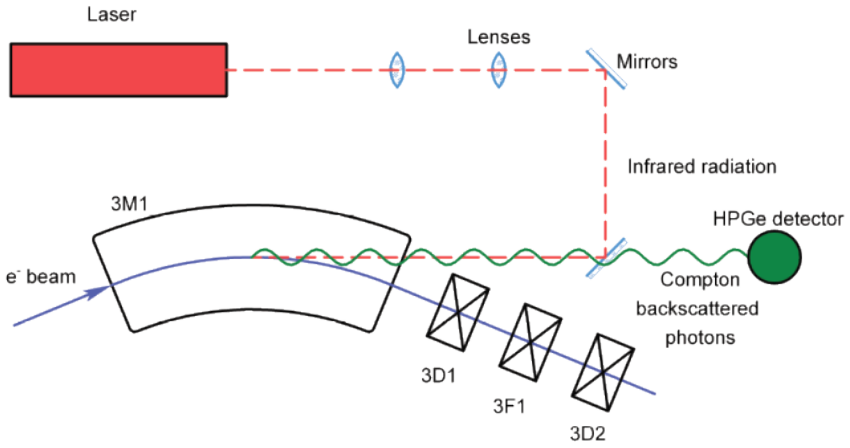
Luminosity for the «round beams»

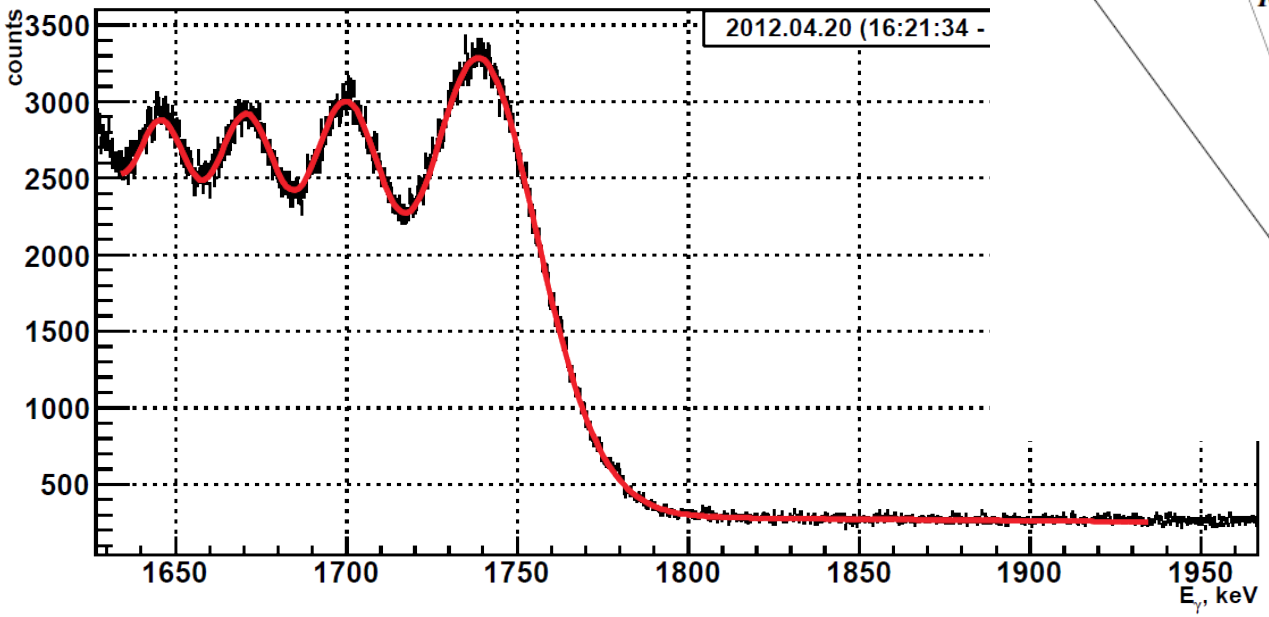


Dots are average luminosity for 10% of best runs of CMD-3 data

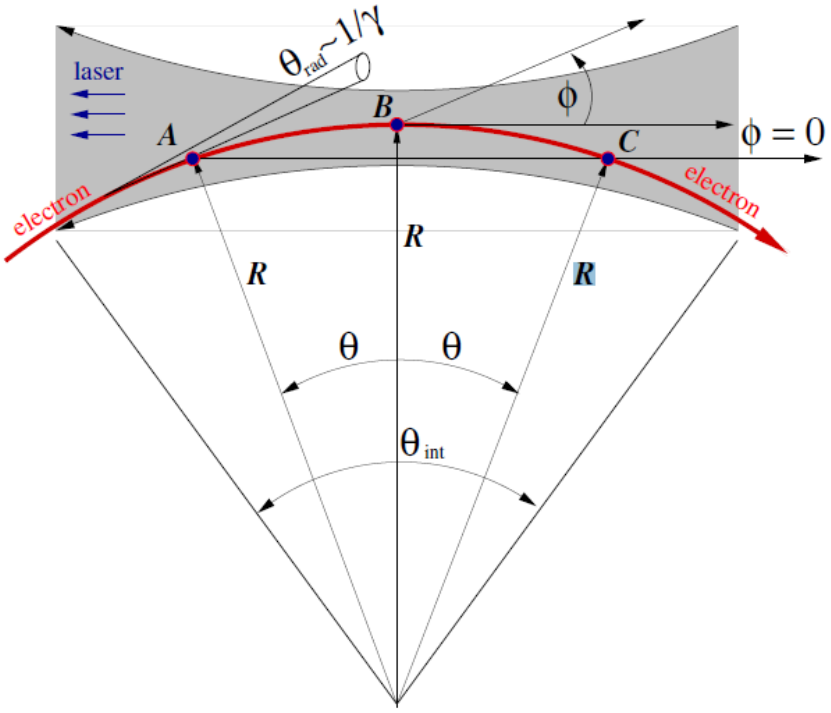
Beam energy measurement at VEPP-2000

(back scattering laser light)





Radiation from points A and C at
$\phi = 0$ interfier



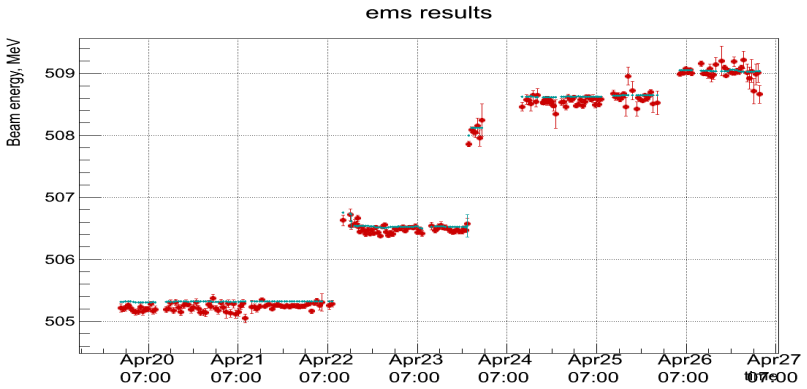
E = 993.662 ± 0.016 МэВ

M.N. Achasov et al. arXiv:1211.0103v1 [physics.acc-ph] 1 Nov 2012

Beam energy measurement at VEPP-2000

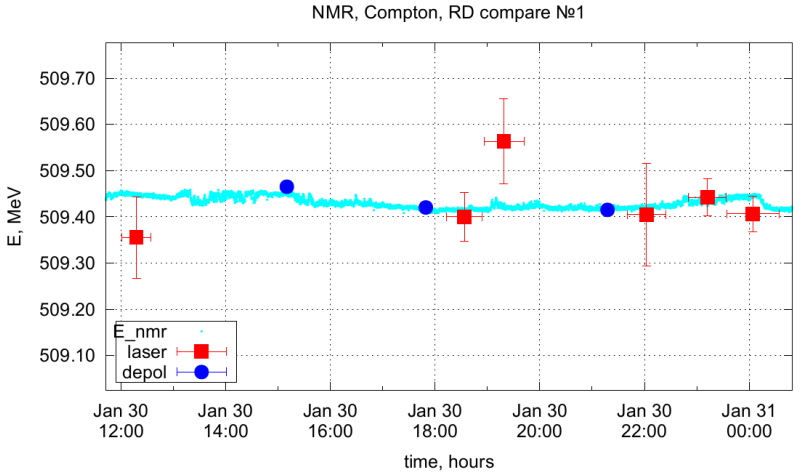
- Magnetic field control in bending magnets
  - 8x2 NMR probes, continuous control
  - Absolute calibration using:

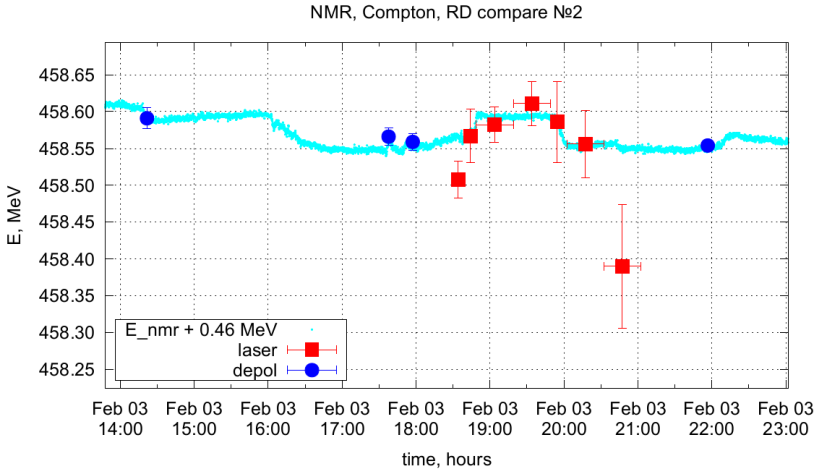
    ϕ-meson (1019.455 ± 0.020 МэВ), ω-meson (782.65 ± 0.12 МэВ).
- Measurement of photon energy from back scattering laser light
  - Installed in 2012.
  - Needs beam current (20 мА), ~20-50 keV accuracy in 10
  - Energy control during data taking.



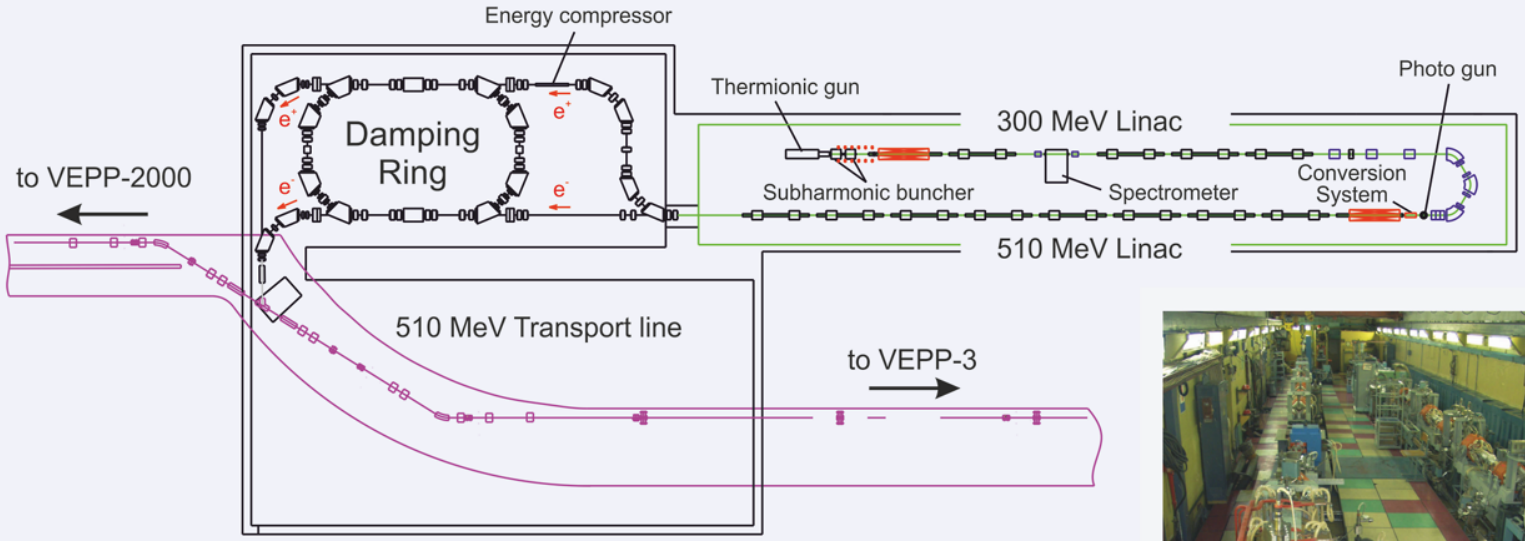
- Resonance depolarization method
  - Very high accuracy ($\delta E/E < 10^{-5}$).
  - Special configuration of VEPP-2000: “warm” optics without CMD-3 field.

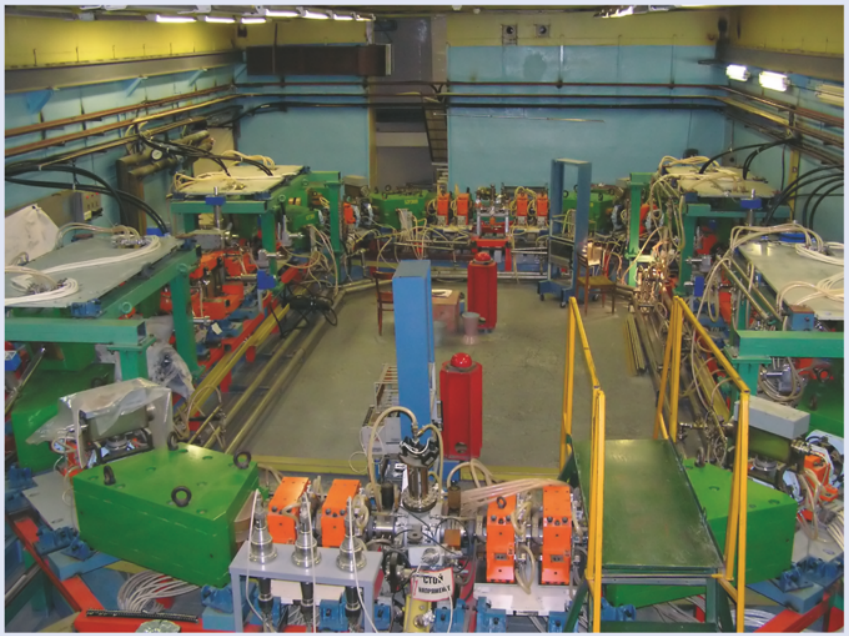
Methods comparison:

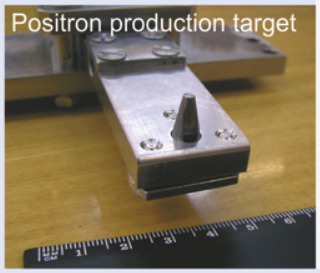




VEPP-5 INJECTION COMPLEX





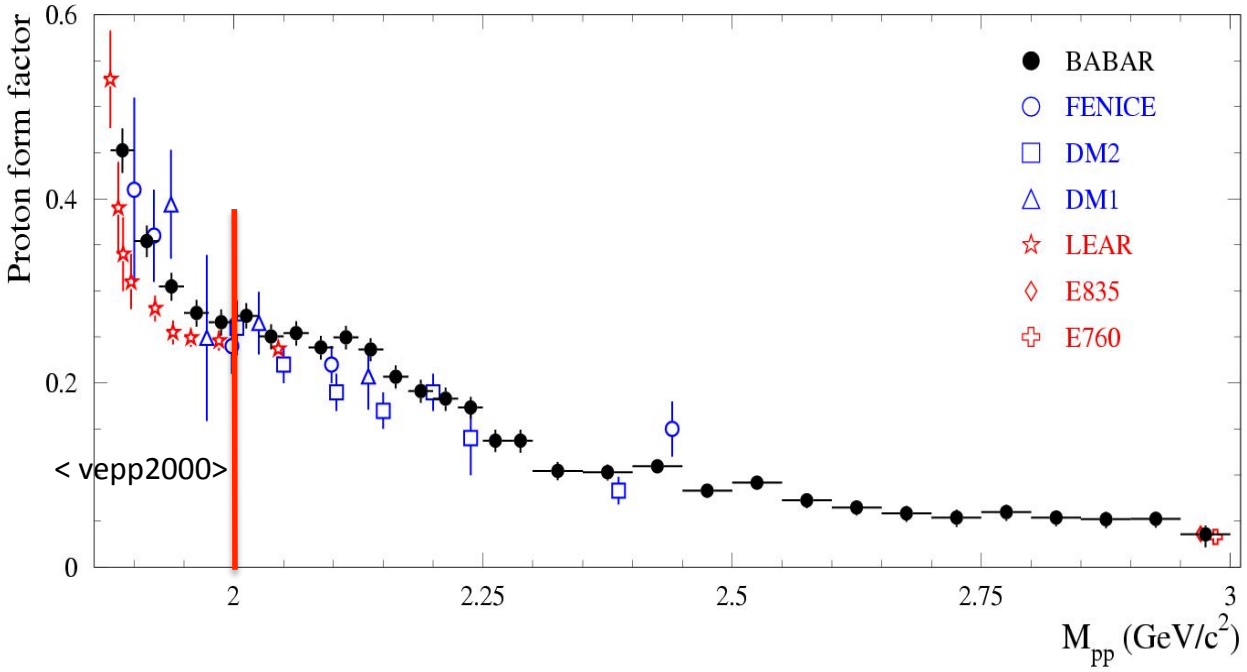


Parameters at E_{beam} = 510 MeV

Number of electrons per bunch	$2 \cdot 10^{10}$
Number of positrons per bunch	$2 \cdot 10^{10}$
Repetition rate	1 Hz
Electron bunch energy spread	0.07%
Positron bunch energy spread	0.07%
Vertical emittance	$5 \cdot 10^{-9}$ m·rad
Horizontal emittance	$23 \cdot 10^{-9}$ m·rad

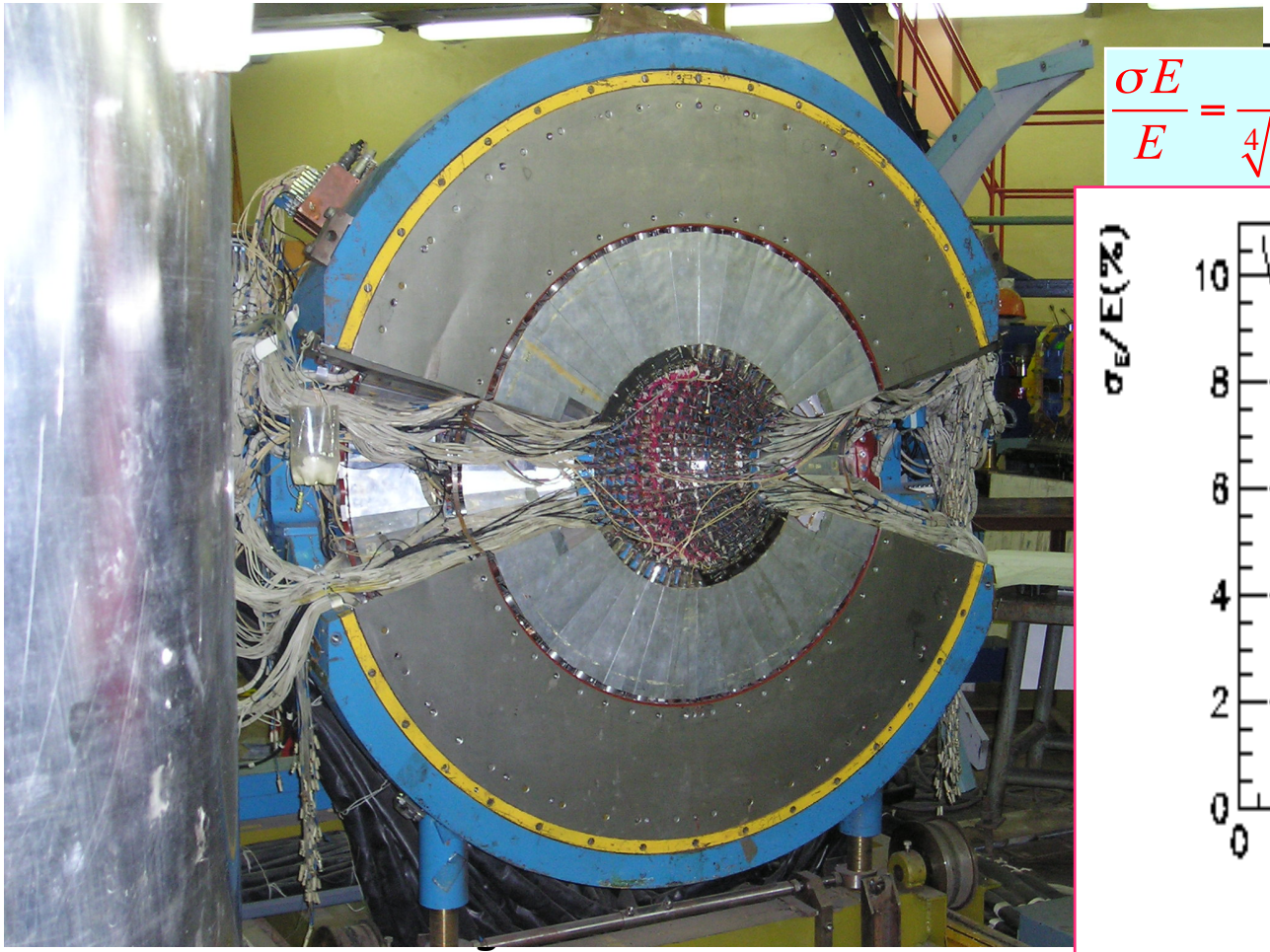
Physics program at VEPP-2000

1. Precise measurement of the quantity
   $R=\sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ – GOAL <1% systematic for major channels
2. Study of hadronic ch
   $e^+e^- \to$ 2h, 3h, 4h …, h
3. Study of 'excited' ve
4. CVC tests: compariso
   cross section with τ-
5. Study of nucleon-ant
   nucleon electromagne
   search for NNbar re
6. Hadron production in
   (ISR) processes
7. Two photon physics
8. Test of the QED high order processes 2->4,5



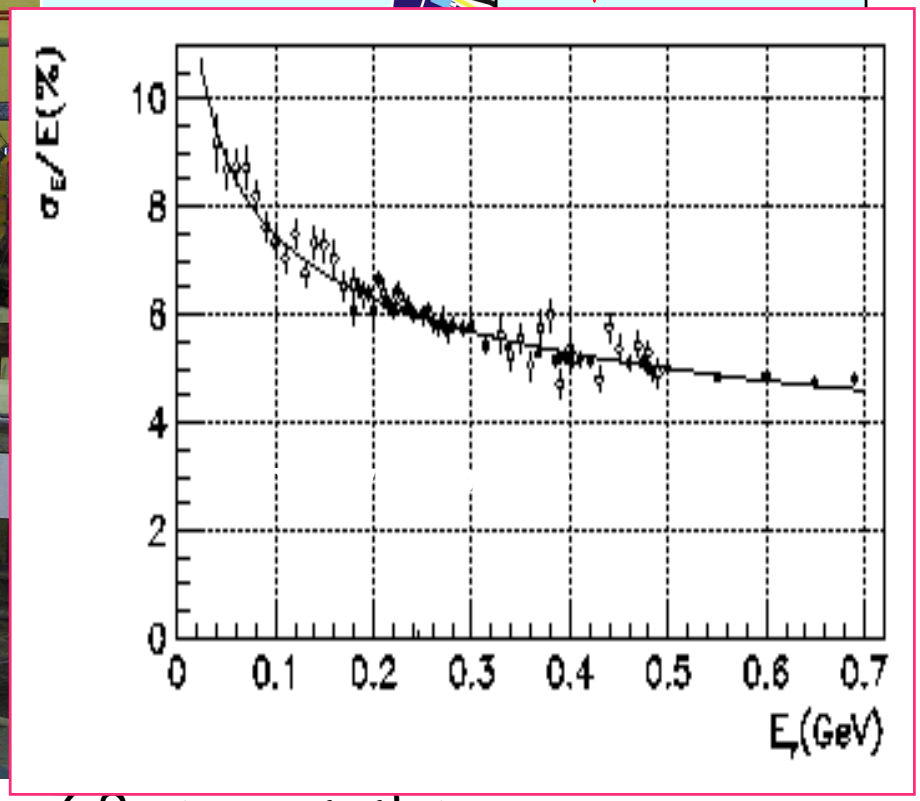
Two detectors have been build for the study

Spherical Neutral Detector

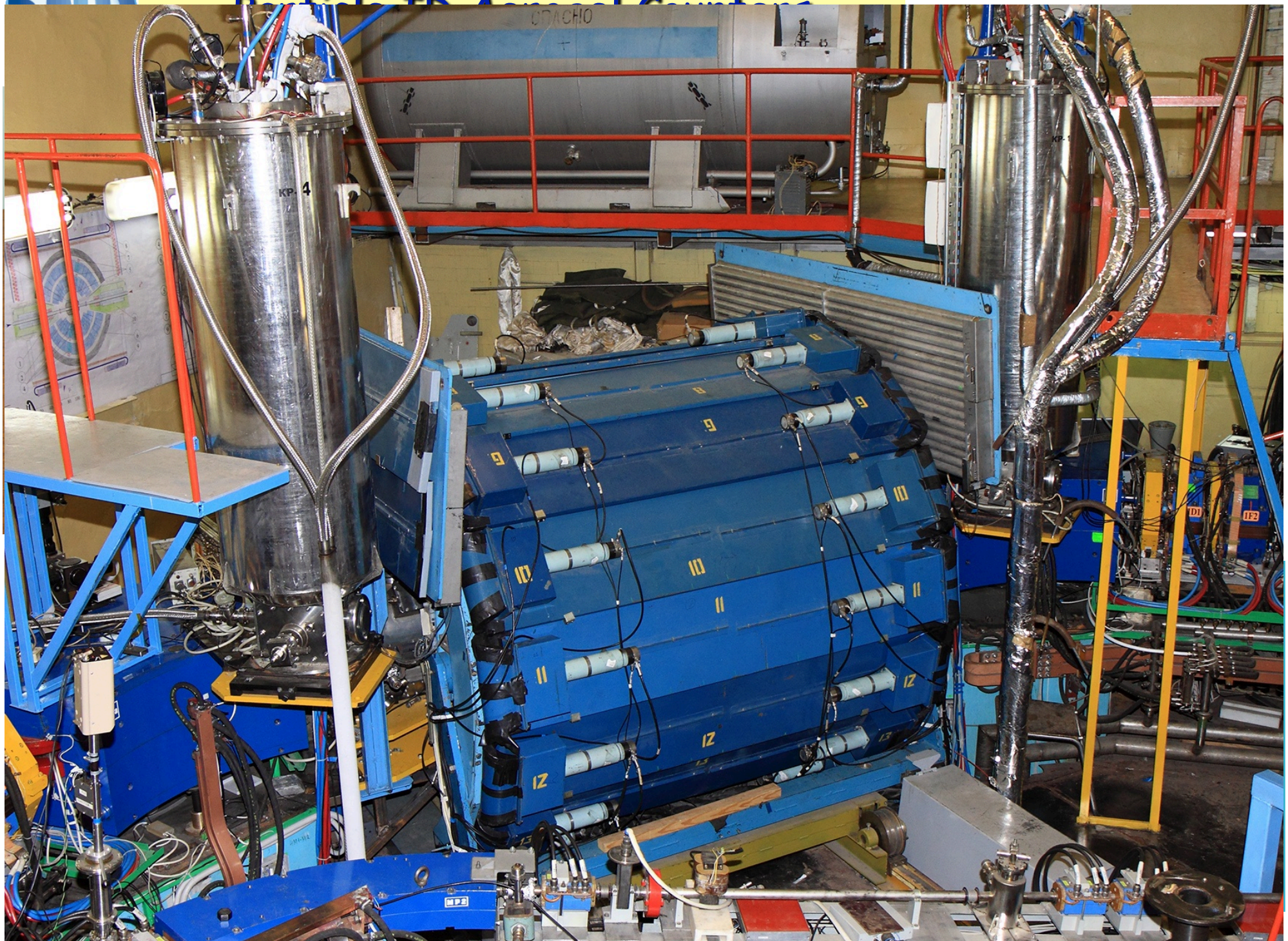


$$\frac{\sigma E}{E} = \frac{4.2\%}{\sqrt[4]{E(GeV)}}$$

$$\sigma_\phi = \frac{0.82^0}{\sqrt{E(GeV)}} \oplus 0.63^0$$



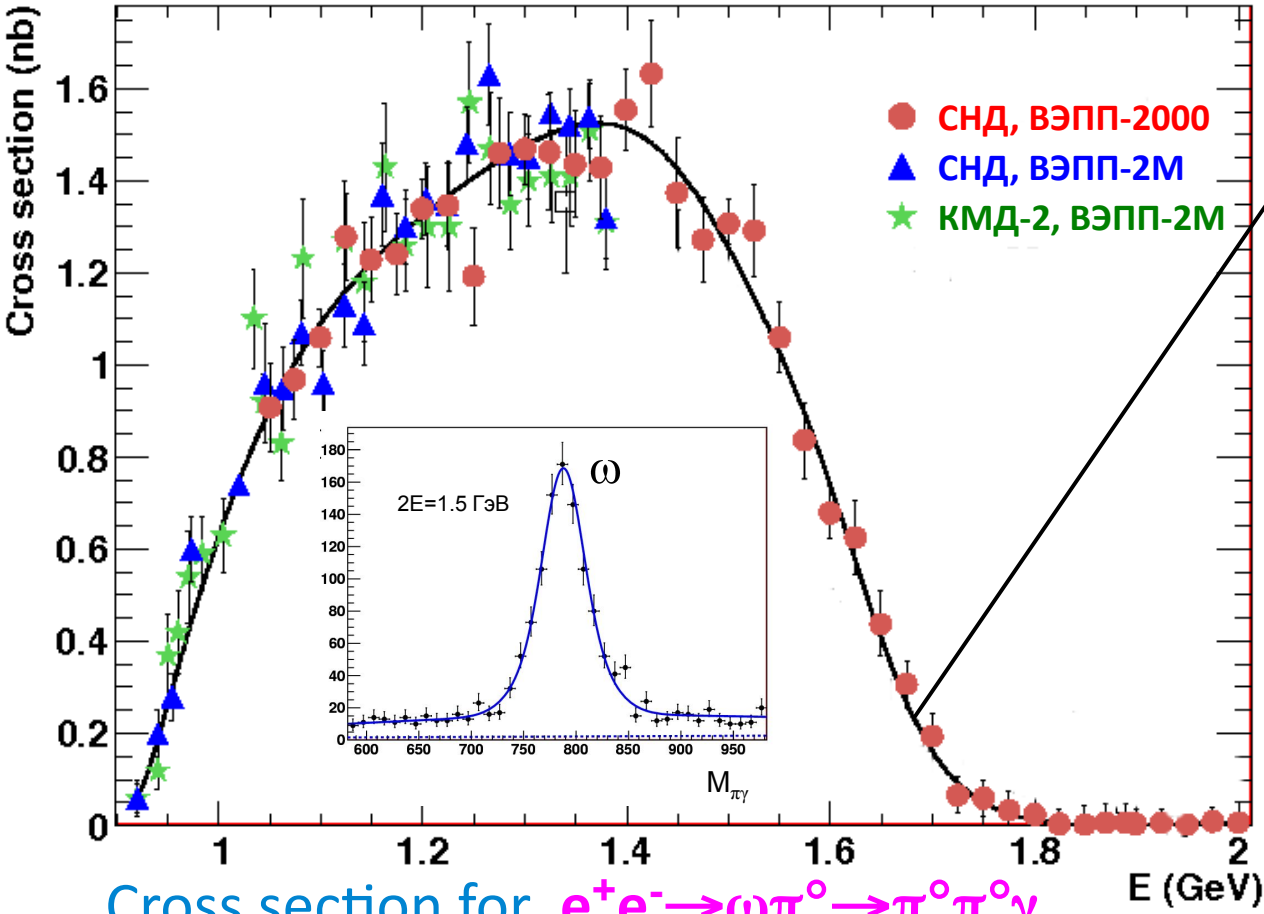
vacuum phototriodes, 6 – absorber, 7-9 – muon system,
10 – VEPP-2000 phocusing solenoid


KP-4
LP2
TD1
TF2

$e^+e^- \to \omega\pi^\circ \to \pi^\circ\pi^\circ\gamma$ for Ec.m. = 1,05 – 2,00 ГэВ.

Analysis completed. Published:

M.N. Achasov, et al., «Study of $e^+e^- \to \omega\pi^\circ \to \pi^\circ\pi^\circ\gamma$ in the energy range **1.05 – 2.00** GeV with SND», *Phys.Rev. **D**88 (2013) 054013.*



Cross section for $e^+e^- \to \omega\pi^\circ \to \pi^\circ\pi^\circ\gamma$.

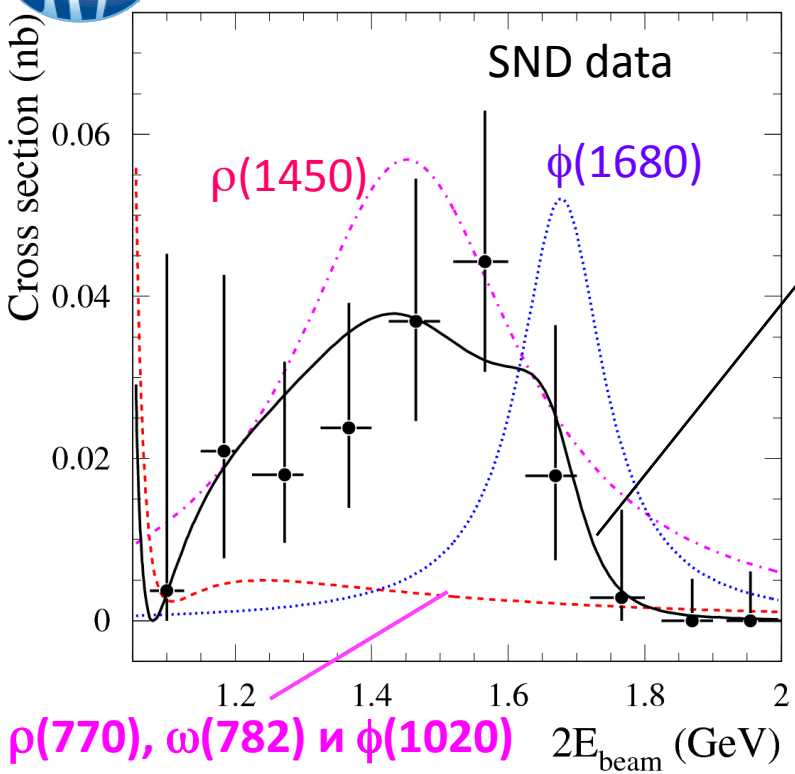
Sum of ρ, ρ', ρ'' with interference

Plan to study:

$e^+e^- \to S\gamma \to \pi^\circ\pi^\circ\gamma$, где

$S = f_0(600), f_0(980), f_0(1350), f_2(1270)$

$e^+e^- \to \eta\gamma$ for $\sqrt{s}$ = 1,07 – 2,00 ГэВ.



Sum of ρ(770), ω(782), ϕ(1020) and ρ(1450) и ϕ(1680) with interference

About 30 events ηγ above 1,15 GeV, can only be explained by **ρ(1450) and ϕ(1680) mesons**.

It is first observation of radiative decays of ρ(1450) and ϕ(1680) mesons

Peak cross sections

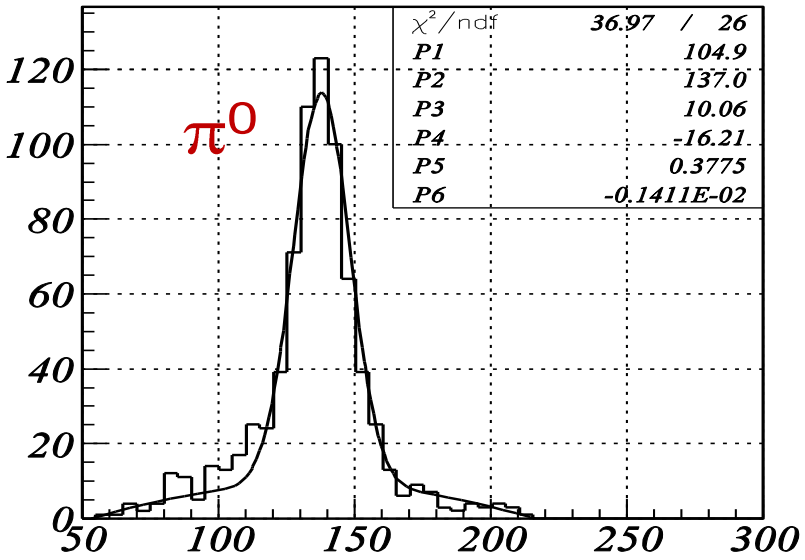
$\sigma(e^+e^- \to \rho(1450) \to \eta\gamma)$=57±10±7 pb и $\sigma(e^+e^- \to \phi(1680) \to \eta\gamma)$=52±17±15 pb

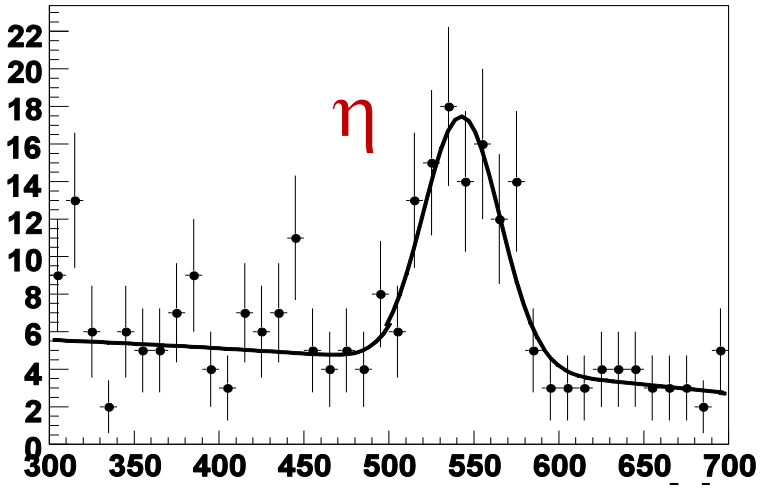
are much larger of theoretical predictions from quark model:
about 15 pb for ρ(1450) and **about 10 pb** for ϕ(1680).

Paper has been sent to the journal

Plan to study the process $e^+e^- \to \eta'\gamma$.

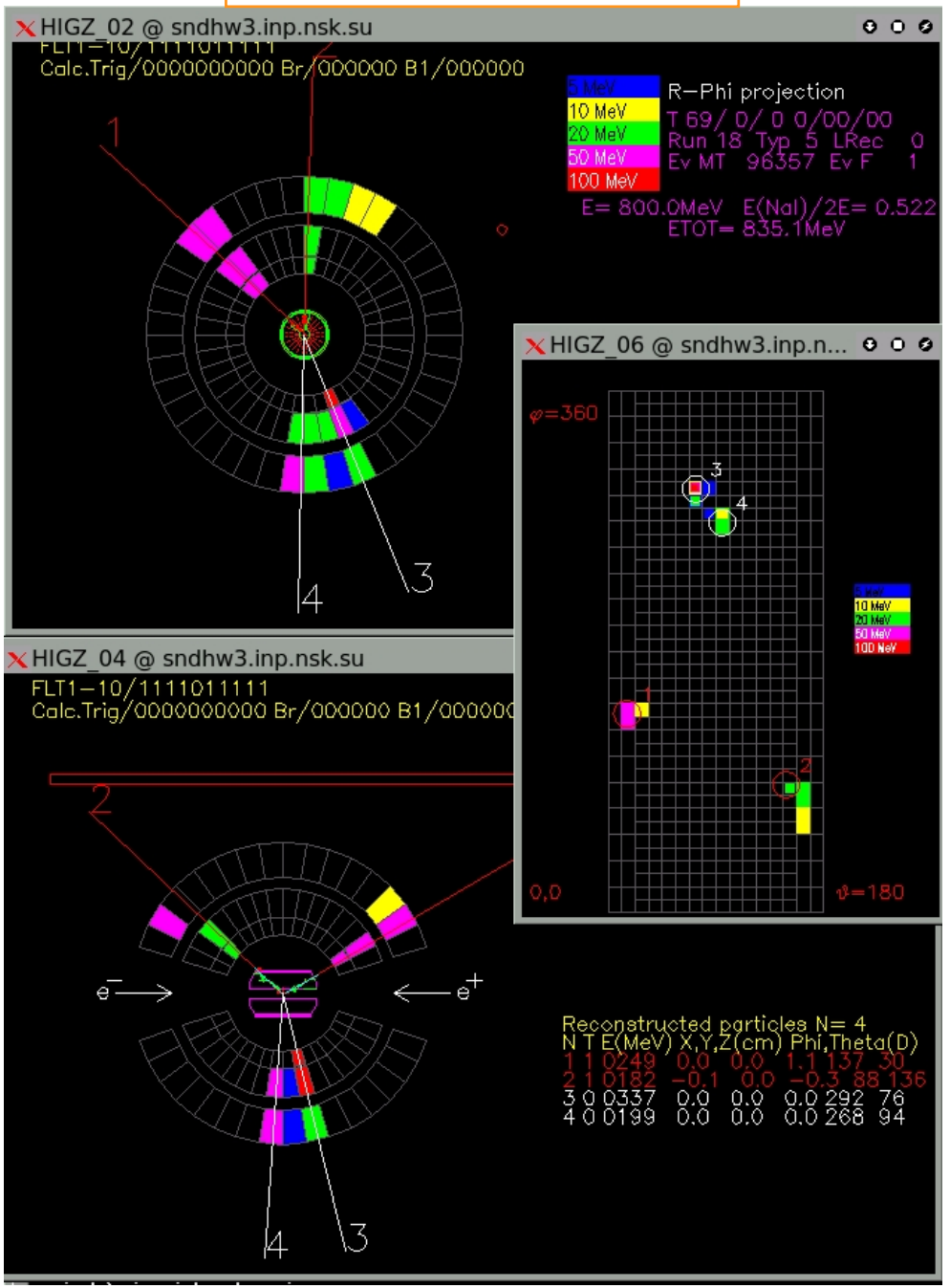
$e^+e^- \to \pi^+\pi^-\pi^0, \pi^+\pi^-\eta$





$M_{\gamma\gamma}$, MeV

$e^+e^- \to \pi^+\pi^-\gamma\gamma$ **event**

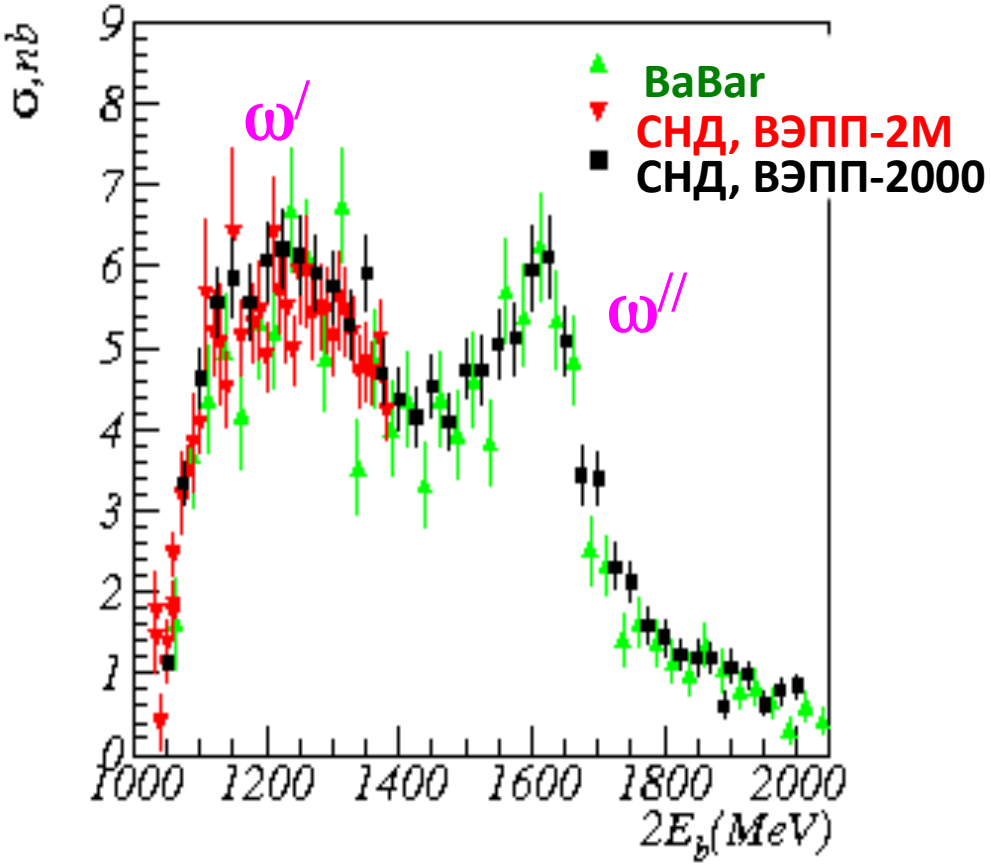


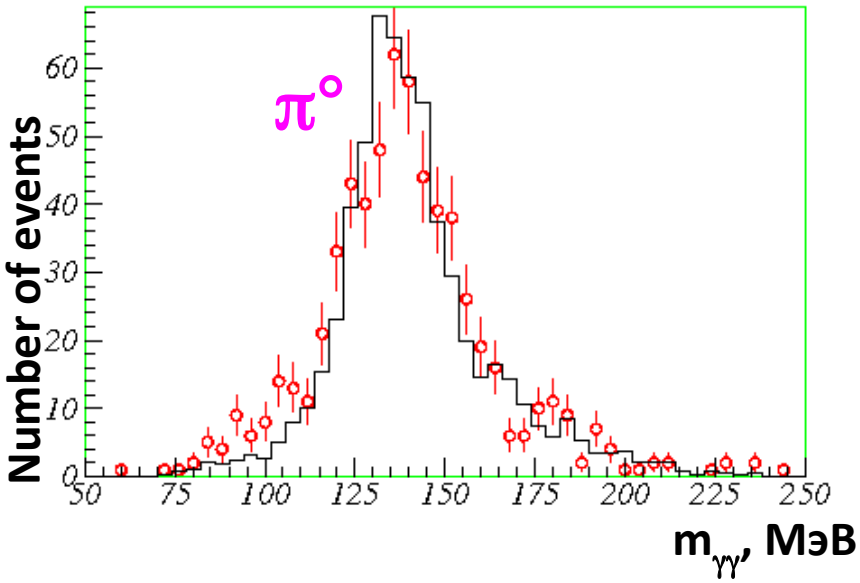
$e^+e^- \to \pi^+\pi^-\pi^\circ$ for $\sqrt{s}$ = 1,05 – 2,00 GeV.

Two intermediate states:

- $e^+e^- \to \omega, \phi, \omega', \omega'' \to \rho\pi \to \pi^+\pi^-\pi^\circ$ (dominant).
- $e^+e^- \to \rho, \rho', \rho'' \to \omega\pi^\circ \to \pi^+\pi^-\pi^\circ$.

- Based on detection of $\pi^+\pi^-\gamma\gamma$
- Selections use kinematic fit.

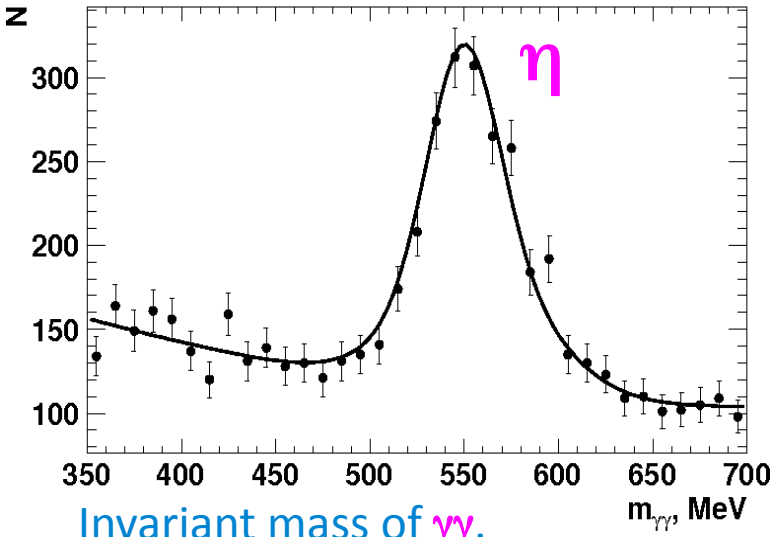




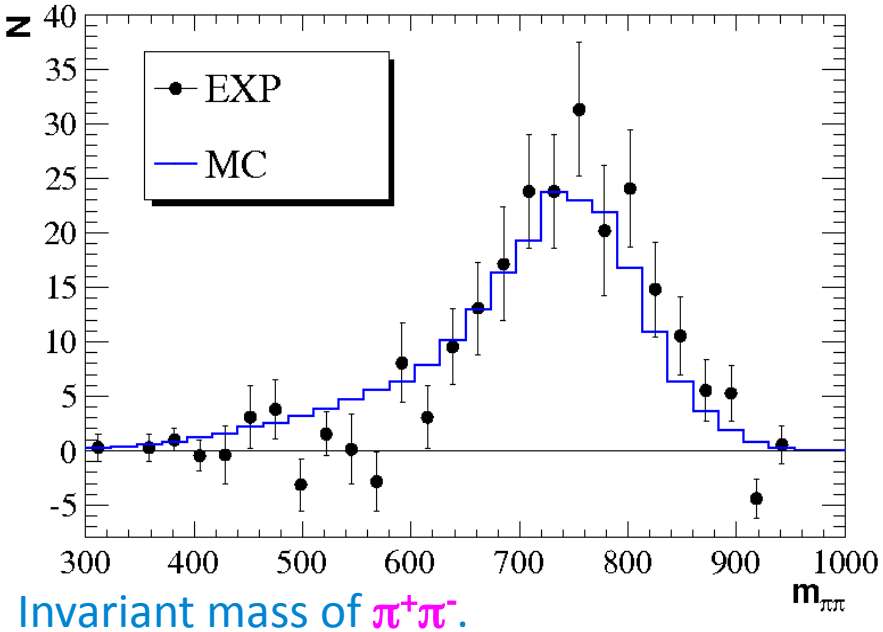
Cross section for $e^+e^- \to \pi^+\pi^-\pi^\circ$.

$e^+e^- \to \pi^+\pi^-\eta$ for $\sqrt{s}$ = 1,08 – 2,00 GeV.

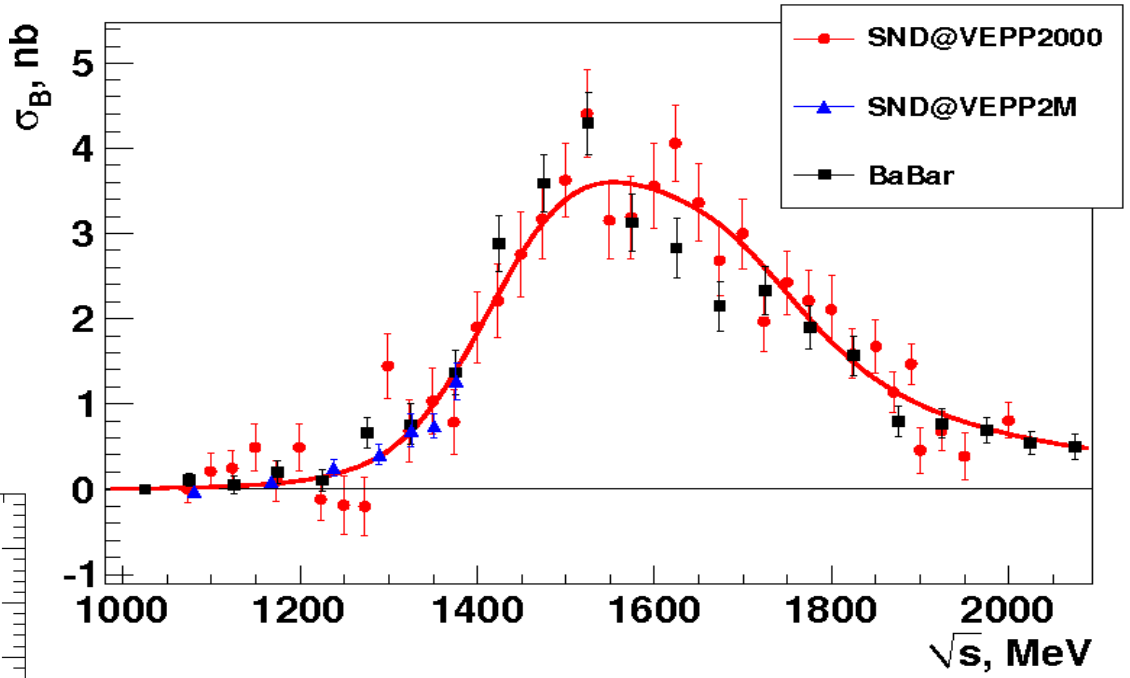
Detection of $\pi^+\pi^-\gamma\gamma$.
Kinematic fit is used.



Invariant mass of $\gamma\gamma$.



Invariant mass of $\pi^+\pi^-$.



Cross section for $e^+e^- \to \pi^+\pi^-\eta$. Line is sum of ρ, ρ', ρ''.

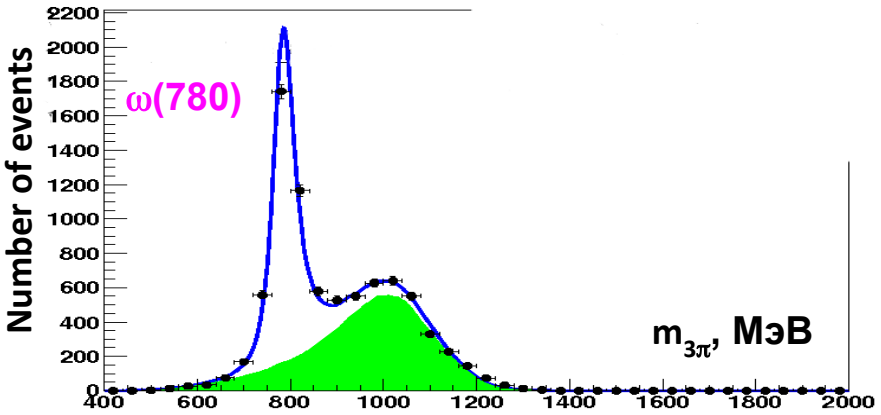
From $\pi^+\pi^-$ masses $e^+e^- \to \rho\eta \to \pi^+\pi^-\eta$ process is dominant

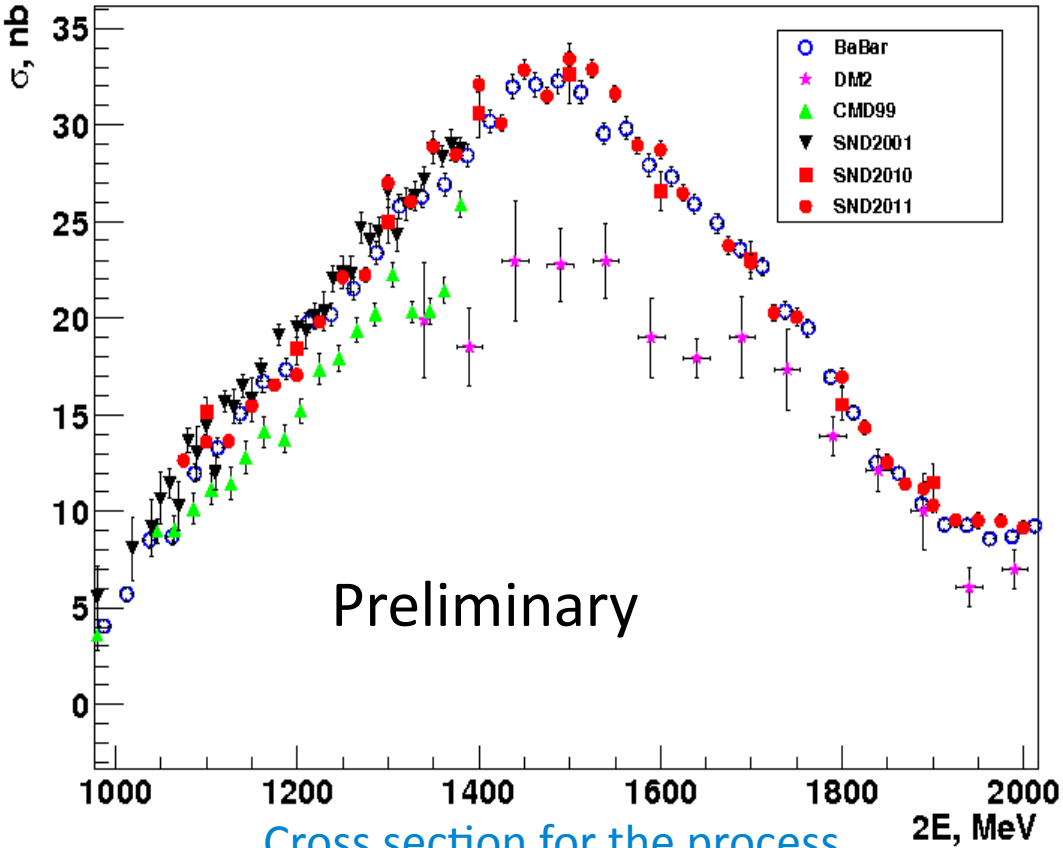
$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ for $\sqrt{s}$ = 1,05 – 2,00 GeV.

Intermediate states:

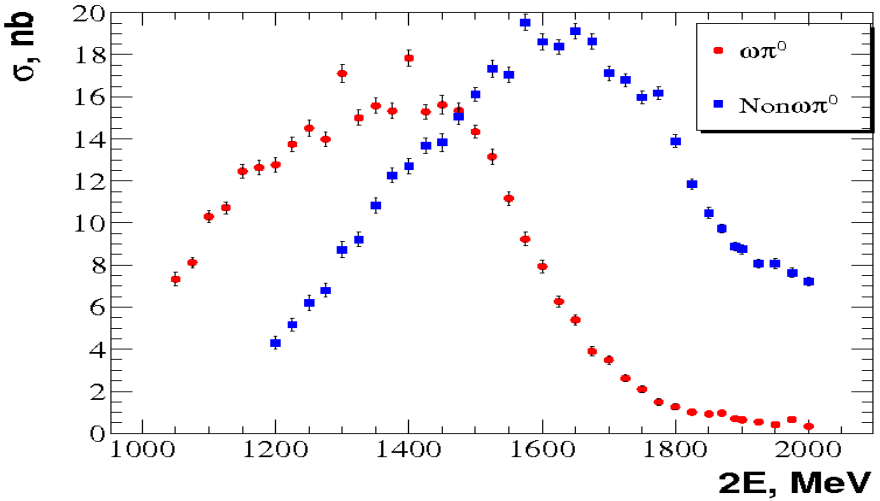
- $e^+e^- \to \rho, \rho', \rho'' \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$,
- $e^+e^- \to \rho, \rho', \rho'' \to a_1(1260)\pi^\pm \to \rho^\pm\pi^0\pi^\pm \to \pi^+\pi^-\pi^0\pi^0$,
- $e^+e^- \to \rho, \rho', \rho'' \to \rho^+\rho^- \to \pi^+\pi^-\pi^0\pi^0$,
- $e^+e^- \to \rho, \rho', \rho'' \to f_0(980)\rho^0 \to \pi^+\pi^-\pi^0\pi^0$.

Detection of $\pi^+\pi^-\gamma\gamma\gamma\gamma$ events. Plus kinematic fit in $\pi^+\pi^-\pi^0\pi^0$ hypothesis



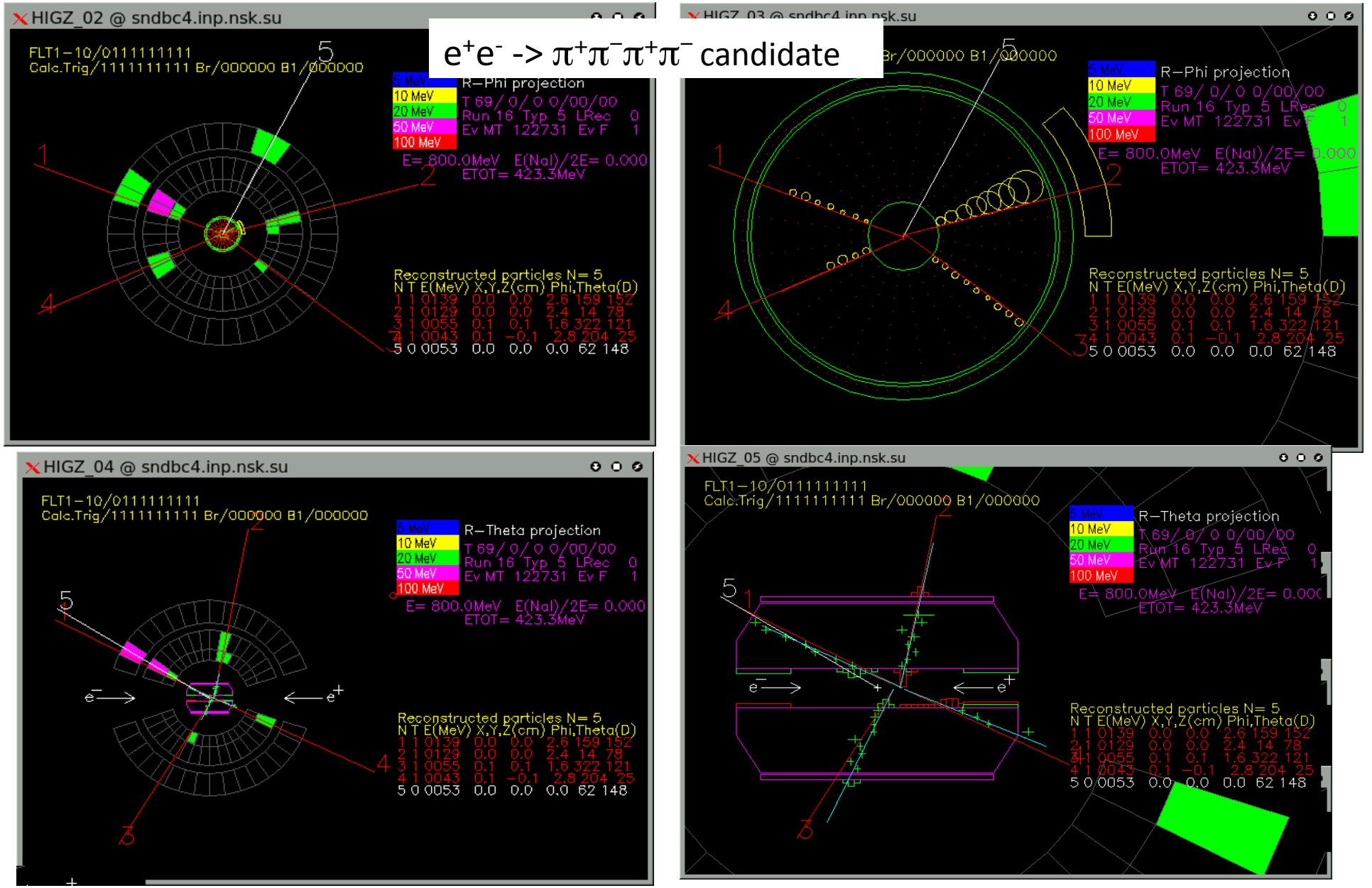


Cross section for the process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$



Expect ~ 3% systematic uncertainties

$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$

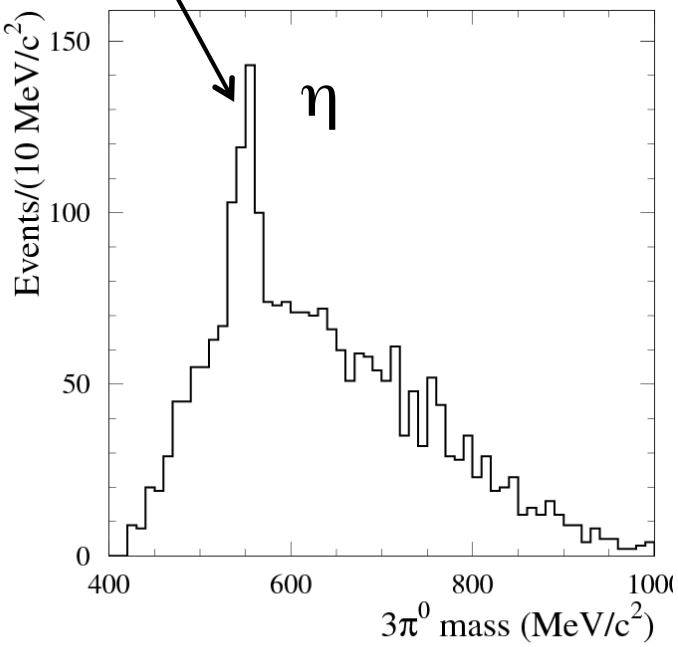


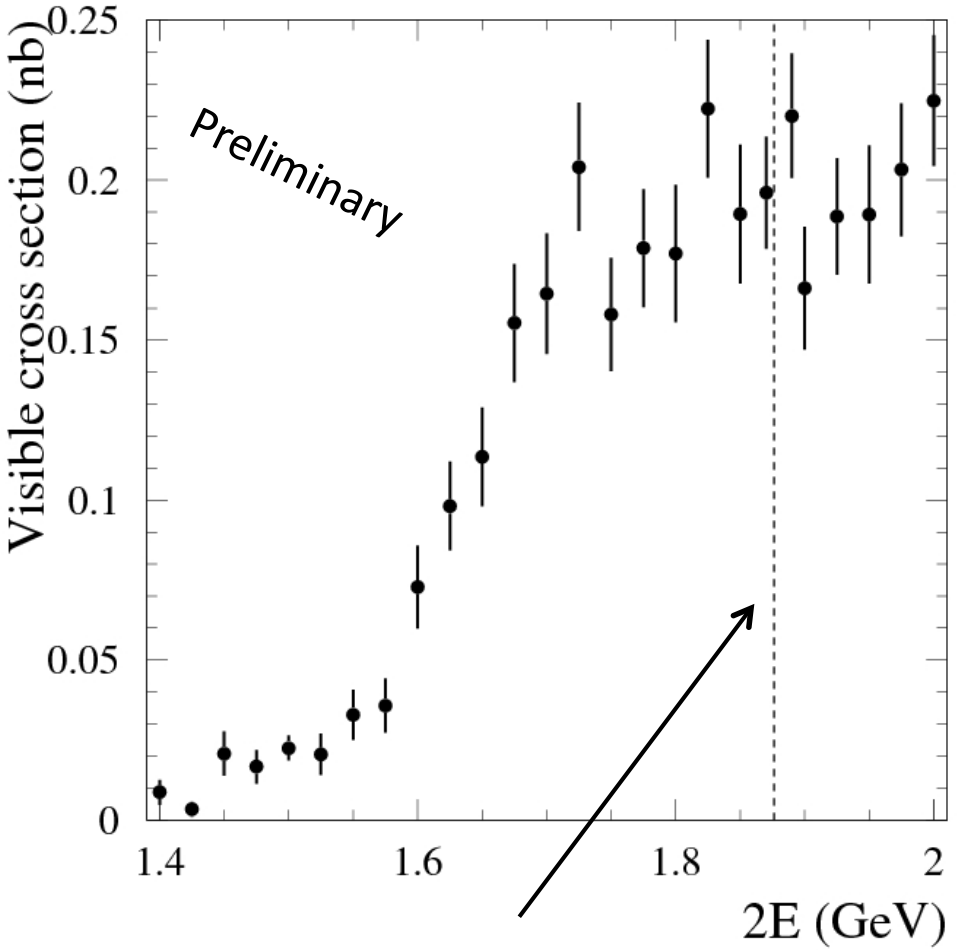
$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ candidate

$e^+e^- \to \pi^+\pi^-\pi^0\pi^0\pi^0\pi^0 \to \pi^+\pi^- 8\gamma$

scan 2011

$e^+e^- \to \pi^+\pi^-\pi^0\eta$ ($\omega\eta$,$\phi\eta$)





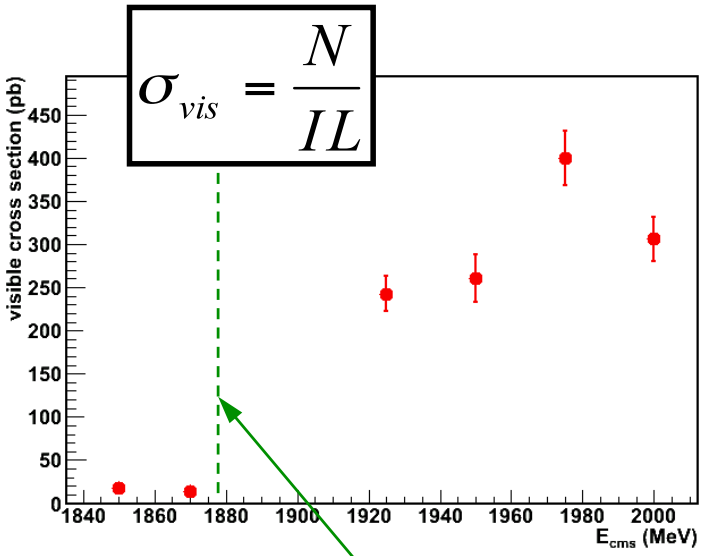
p bar-p threshold

First observation !

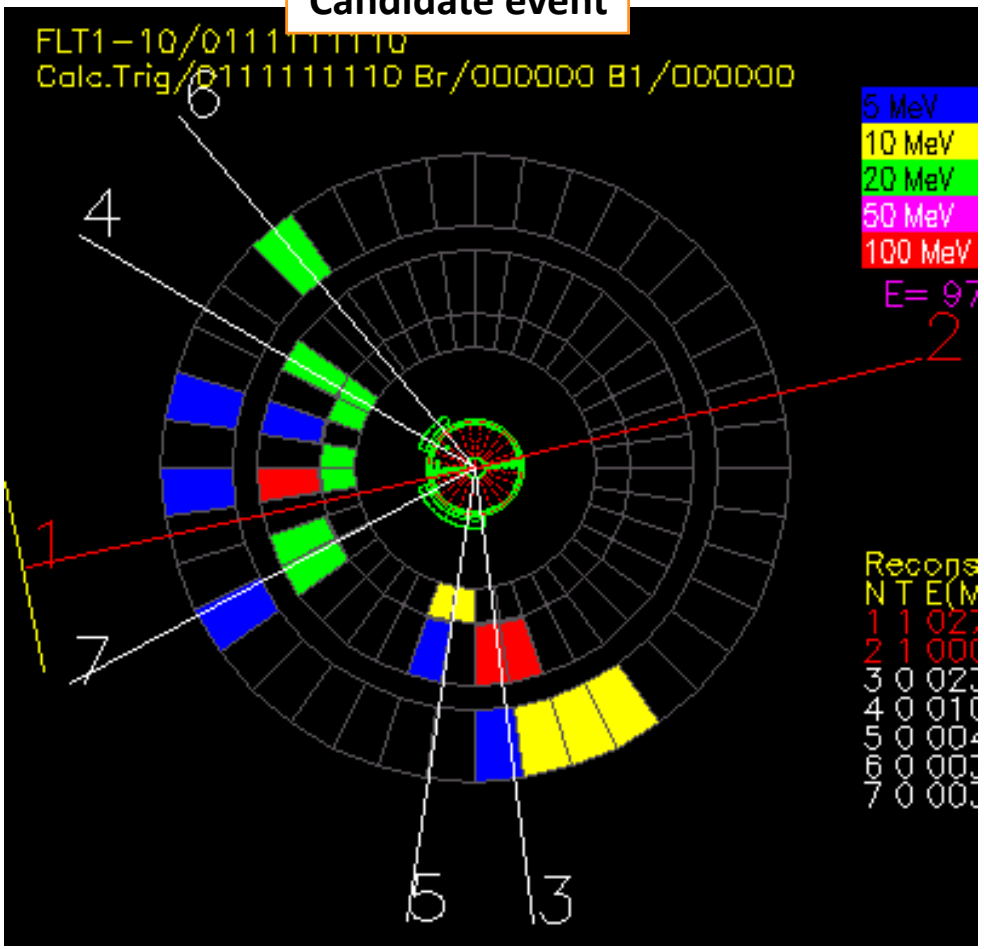
$e^+e^- \rightarrow$ p pbar

Selection:

- ✓ 2 collinear tracks with large dE/dx,
- ✓ energy deposition >650 МэВ
- ✓ no clusters on one of the track

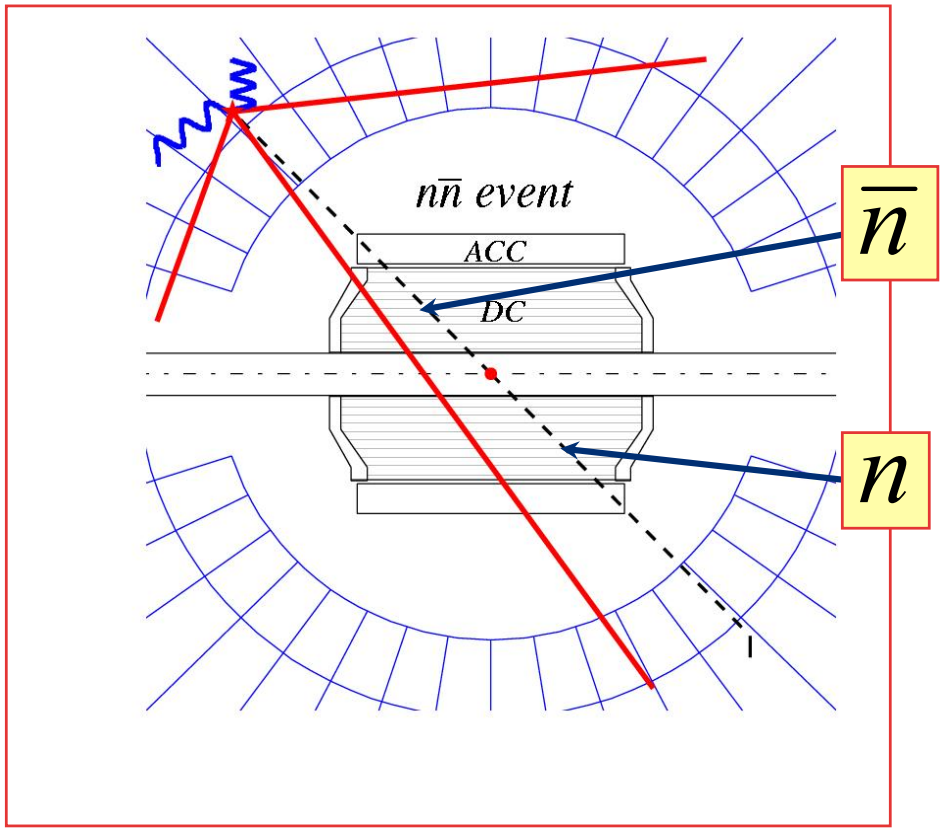


Candidate event



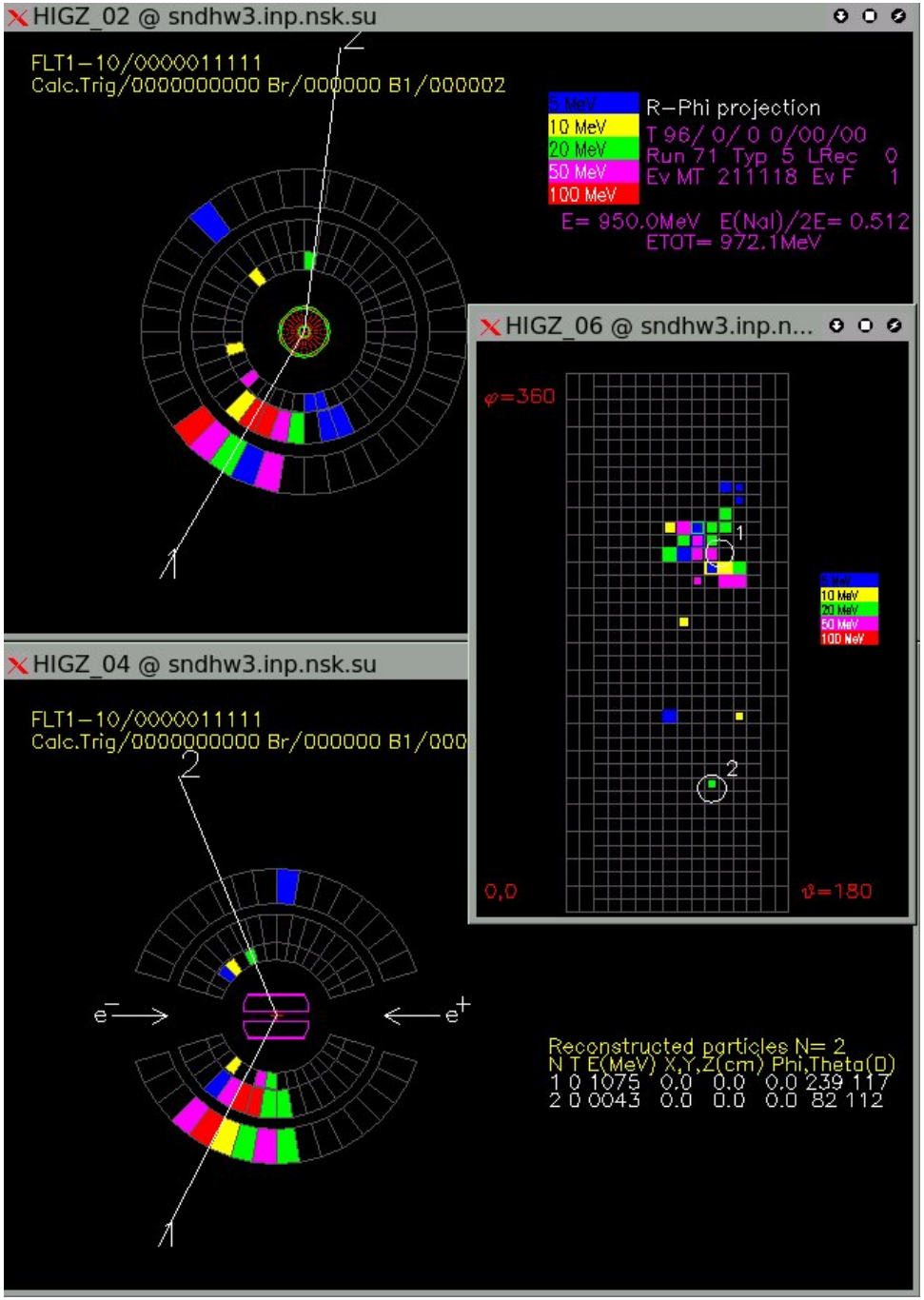
$e^+e^- \to n\bar{n}$

Event topology

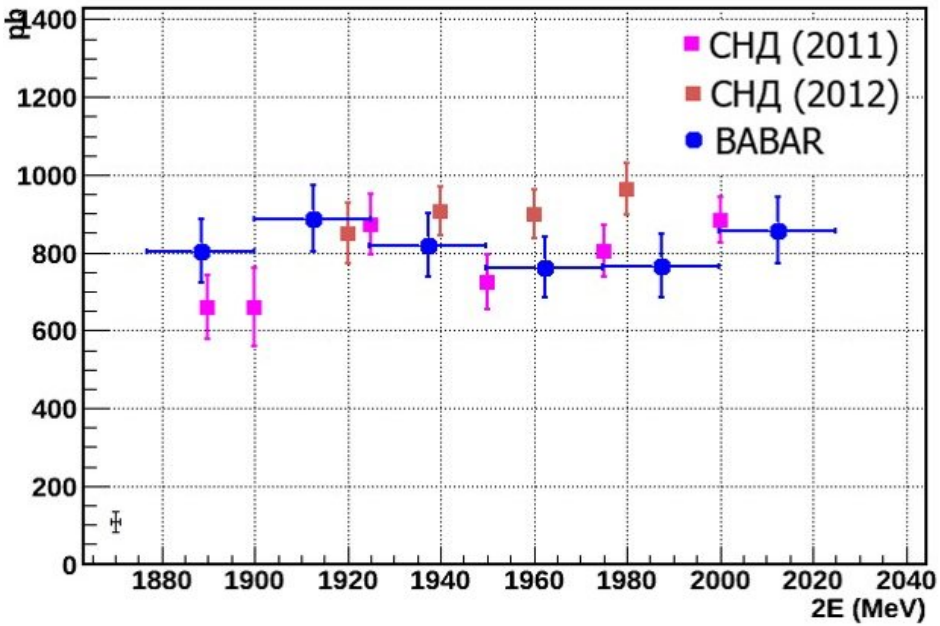


Even signature:

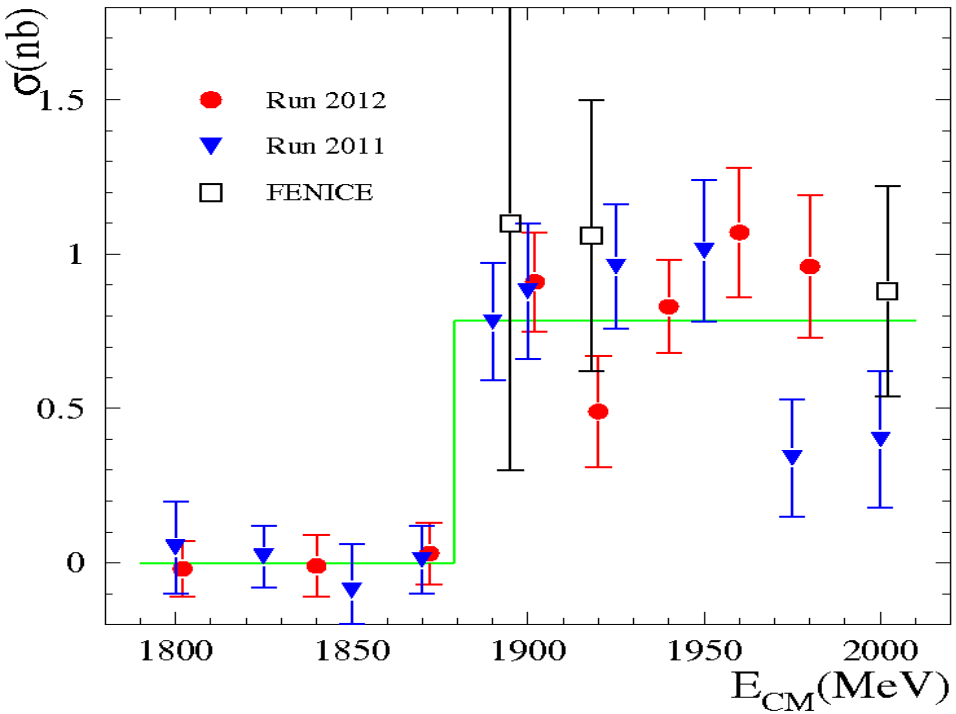
- no signal from neutron
- “star” from anti-neutron



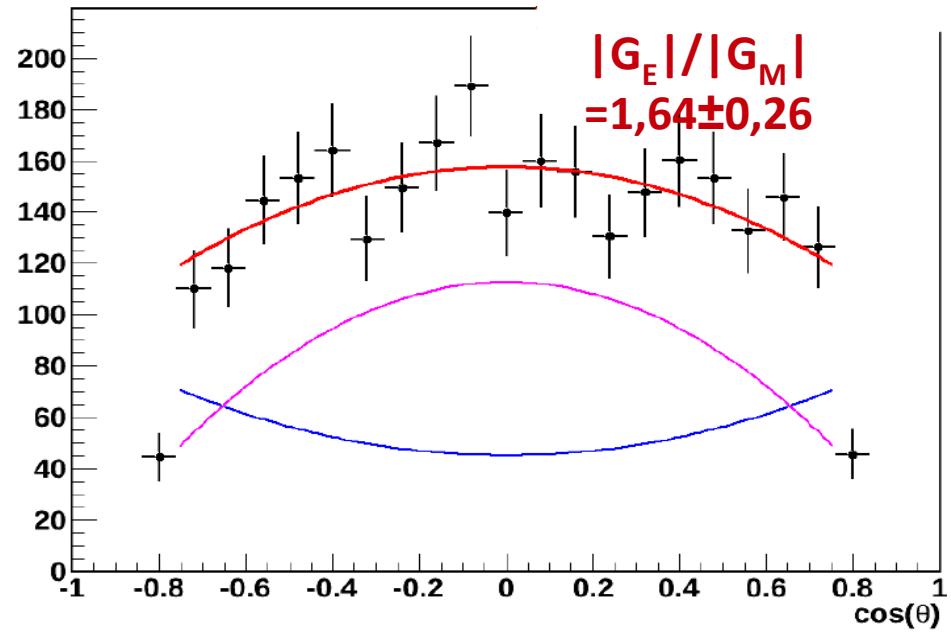
Cross section for $e^+e^-\to pp$.

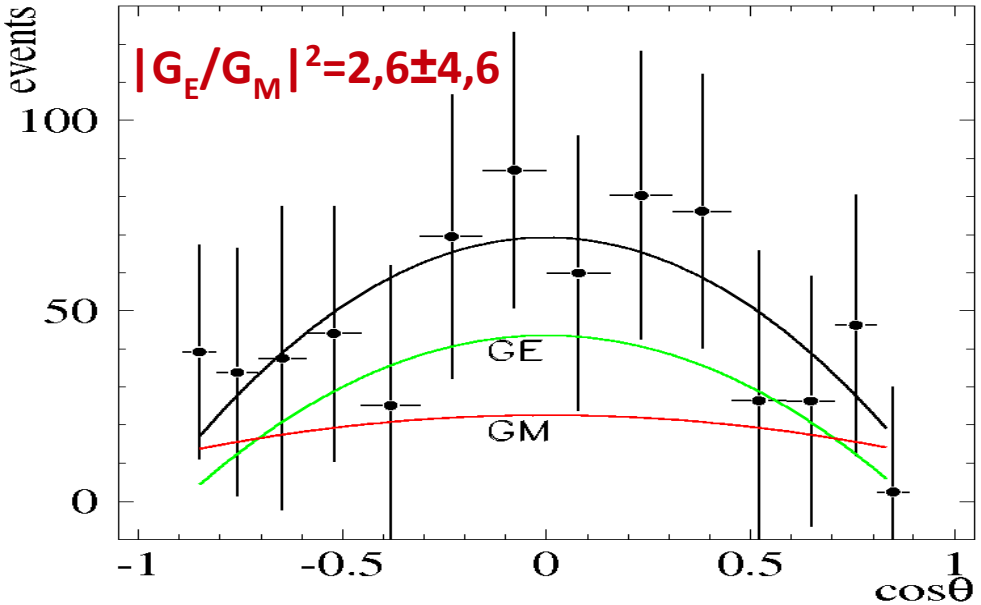


Cross section for $e^+e^-\to nn$.



Distribution for **cosθ** for $e^+e^-\to pp$ events

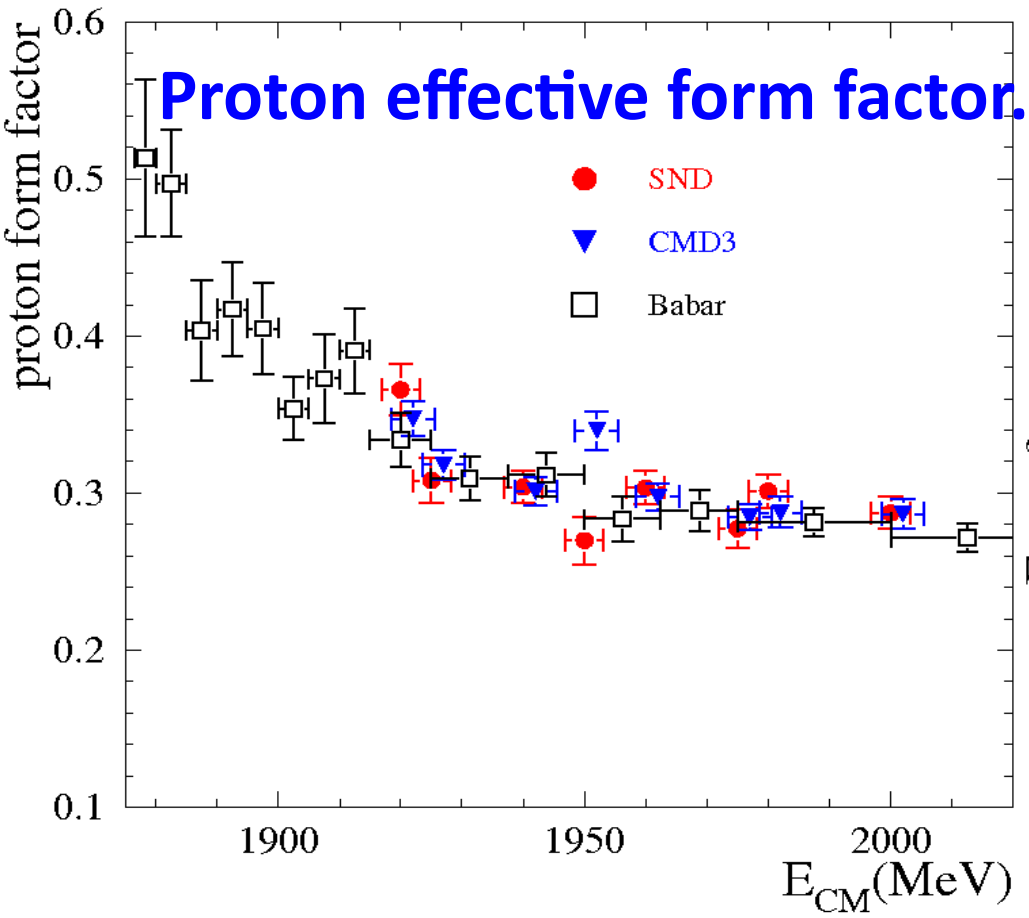




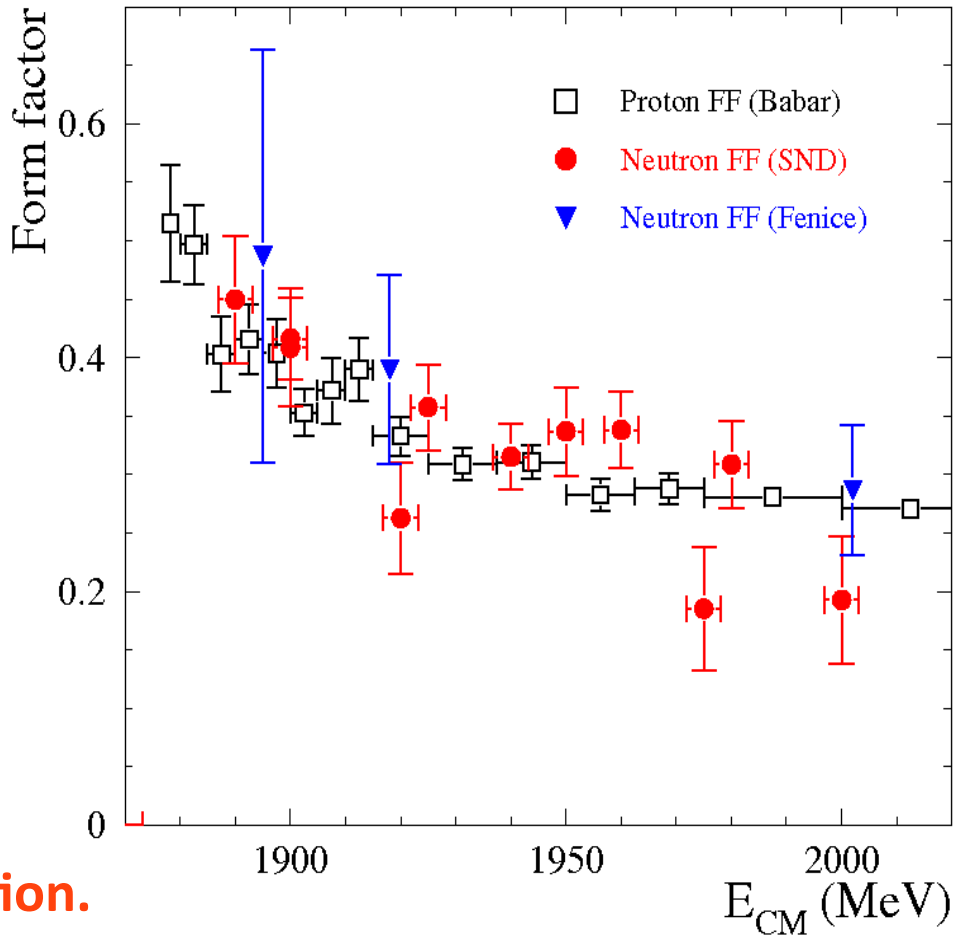
Distribution for **cosθ** for $e^+e^-\to nn$ events

$e^+e^- \to NN$

Proton effective form factor.



Effective form form factor for neutron and proton.

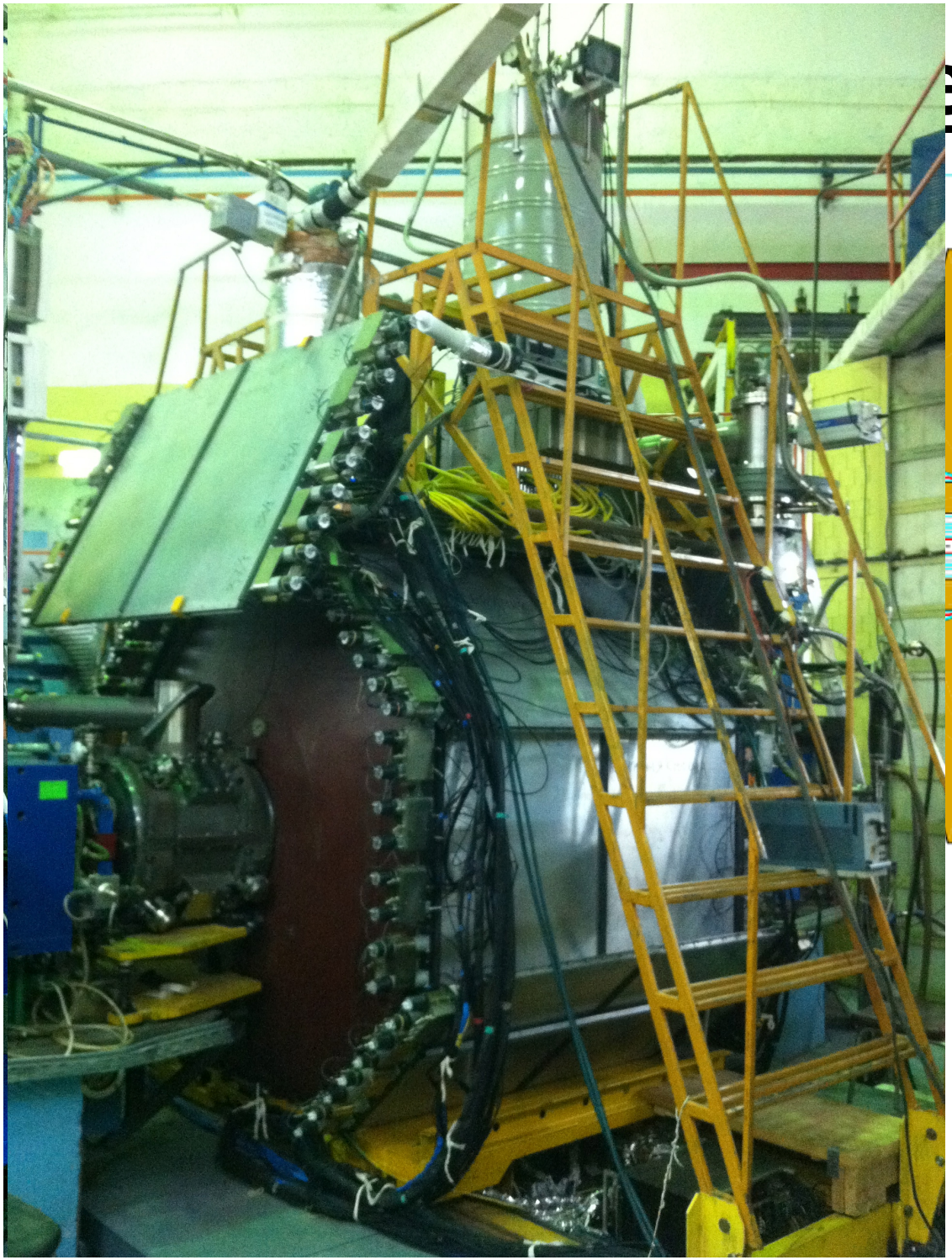


Journal article for $e^+e^- \to nn$ is in preparation.

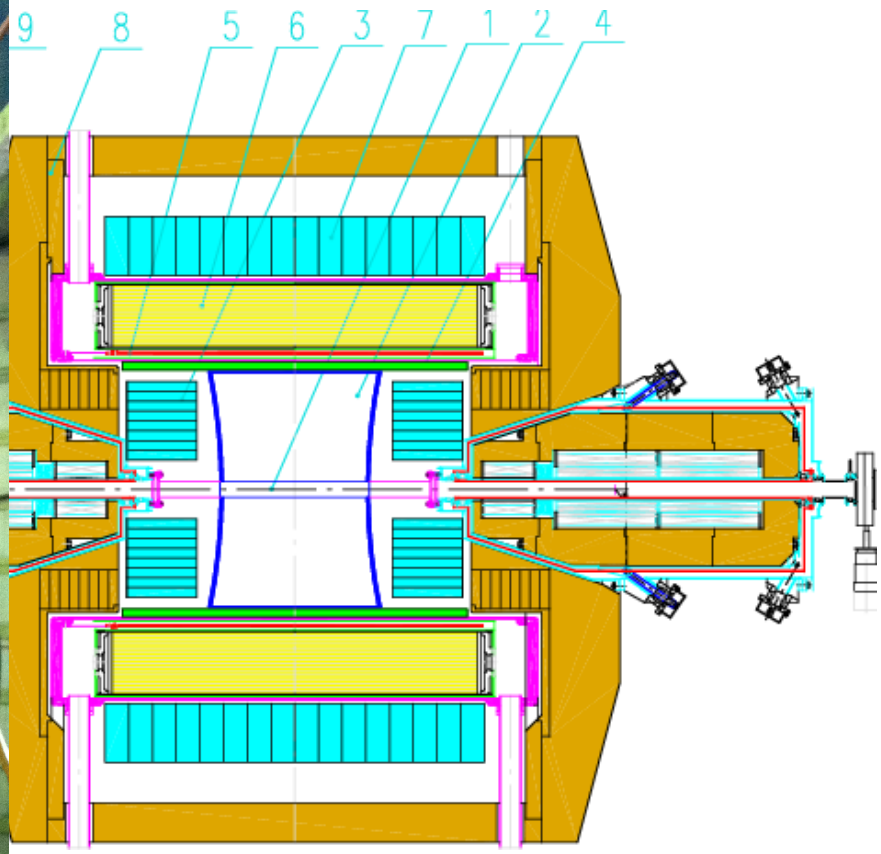
Conclusions & Plans for SND

1. **The data taking runs have been performed with SND at VEPP-2000 in the range 0.32 – 2.0 GeV with ~ 70 inv. pb**
2. **Preliminary results on hadron cross sections have been obtained**

   ($e^+e^- \to \omega\pi^0$, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0\pi^0$, $\eta\pi^+\pi^-$, ppbar, nnbar)
3. **To analyze the full recorded statistics**
4. **To upgrade the SND electronics and reconstruction procedure**
5. **To continue data taking runs**



etic Detector-3

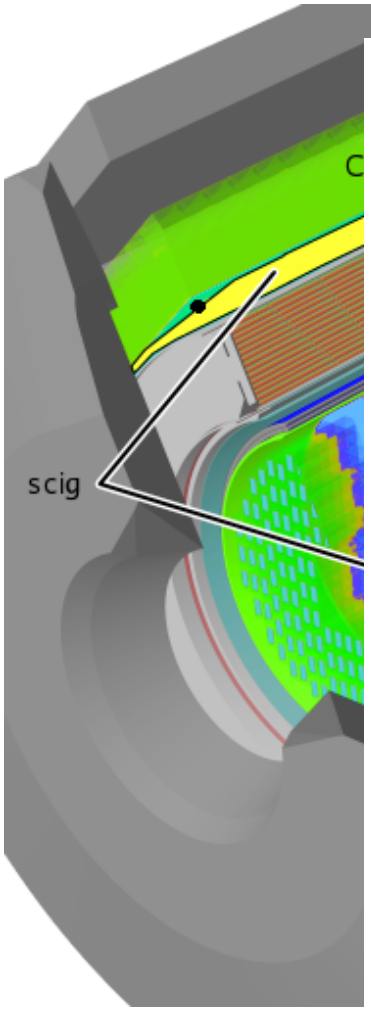


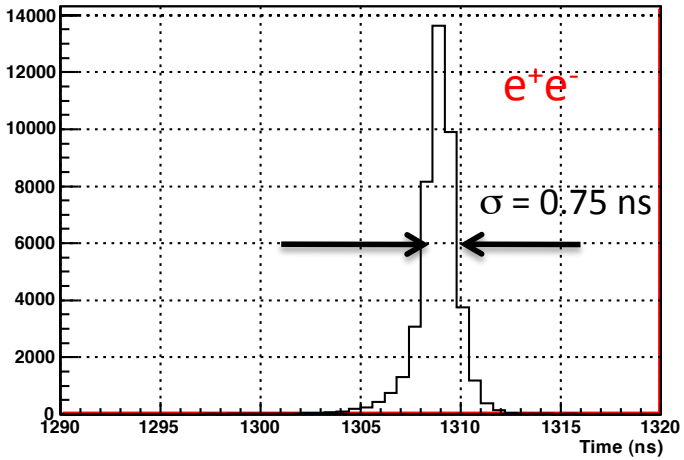
6 – electromagnetic calorimeter LXe
7 – electromagnetic calorimeter CsI
8 – yoke
9 – VEPP-2000 solenoid

Calorimeter LXe

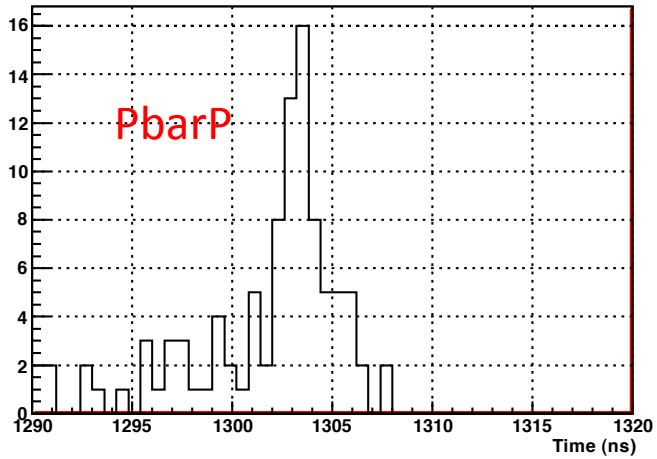
tons)

Particle ID: Timing Counter (SCiG)



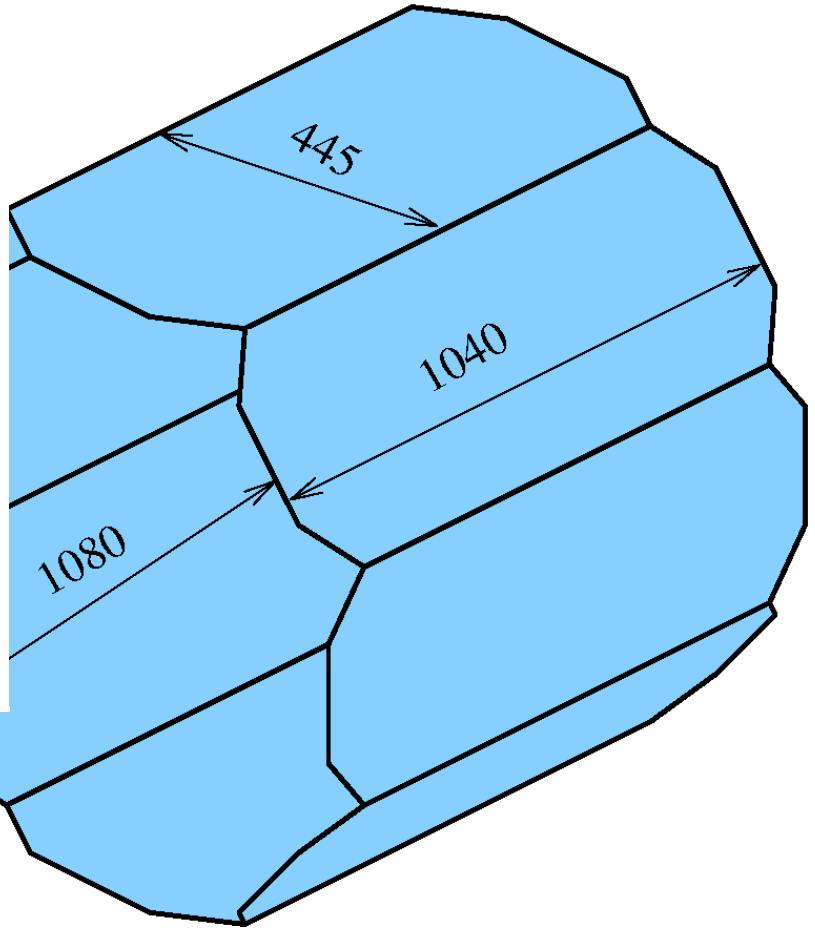


Ec.m. =1.925 GeV

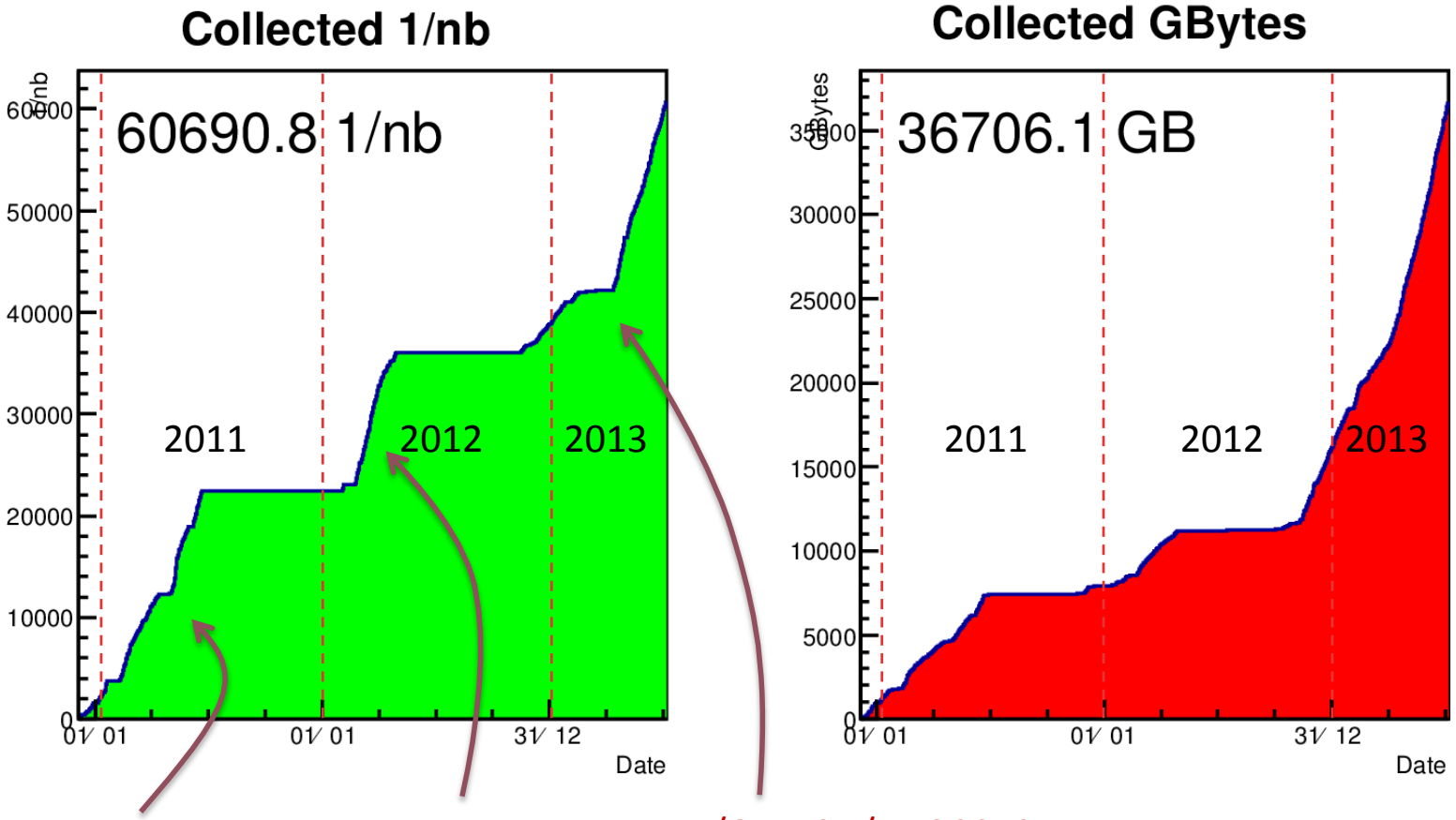


Antineutron identification

$^{+}e^{-} \rightarrow n\ n\ bar$



Data taking history

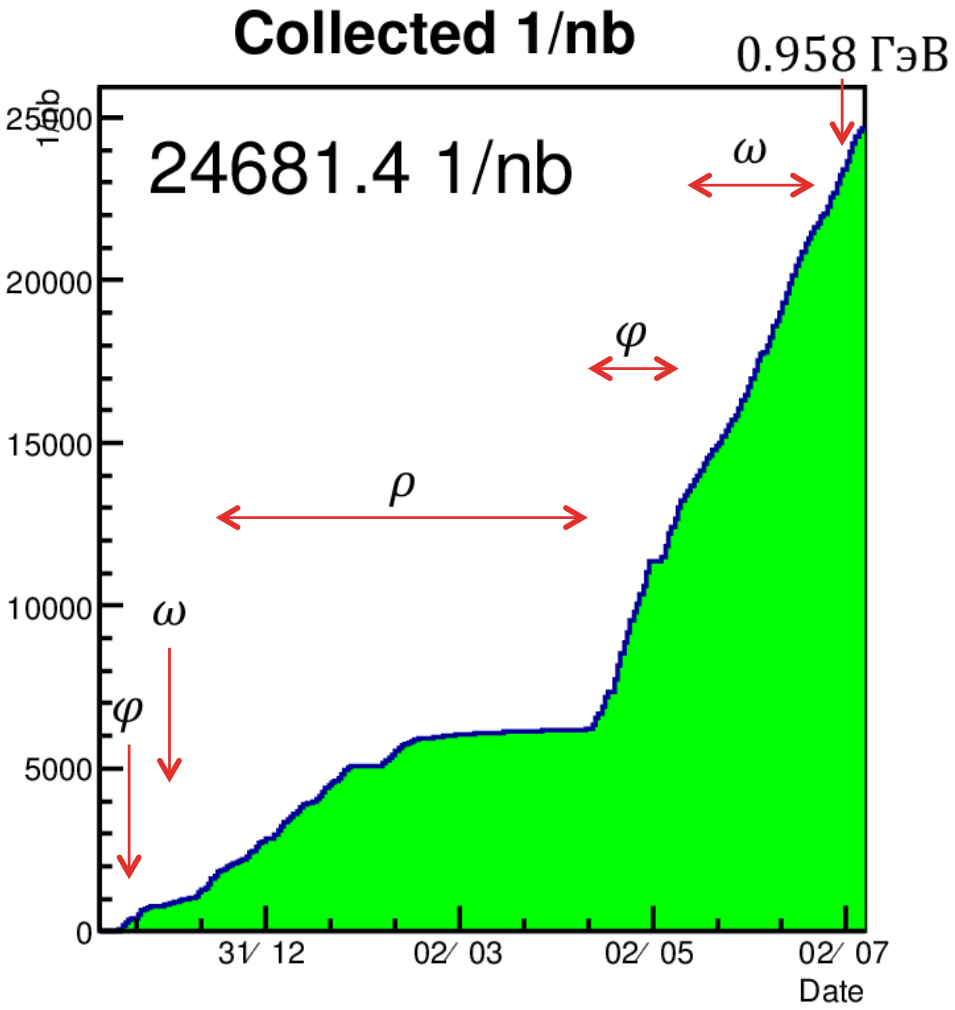


HIGH2011
12.2010-06.2011
22 1/пб

HIGH2012
02.2012-04.2012
14 1/пб

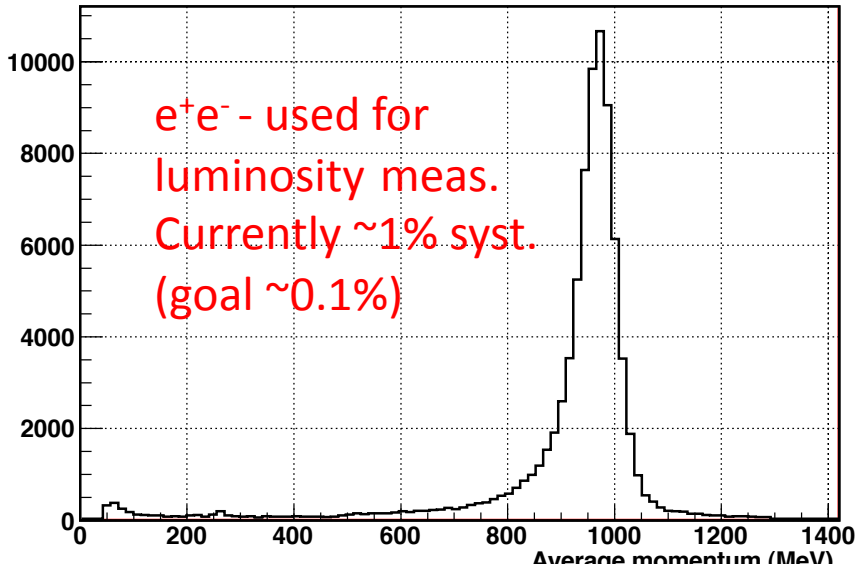
PHI/OMEGA/RHO2013
11.2012-06.2013
25 1/пб

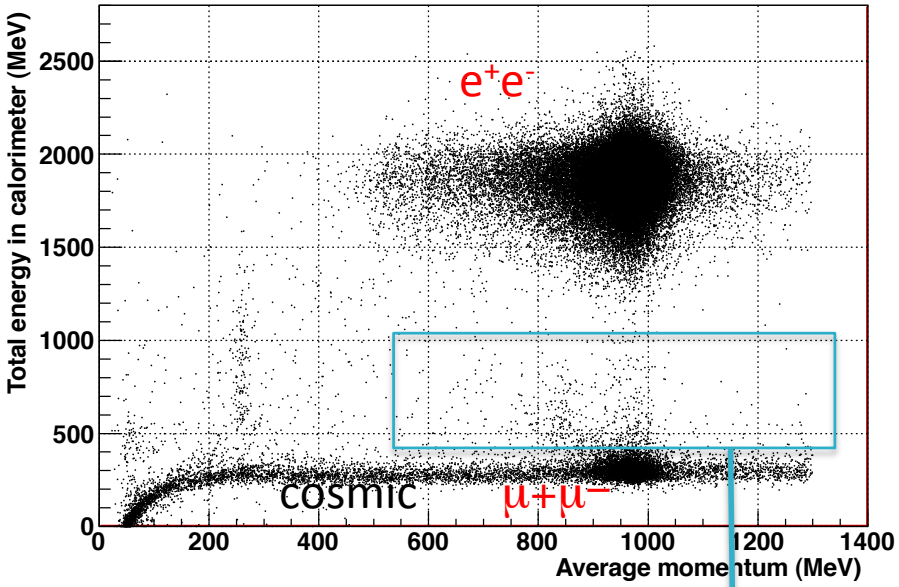
last scan in 2013

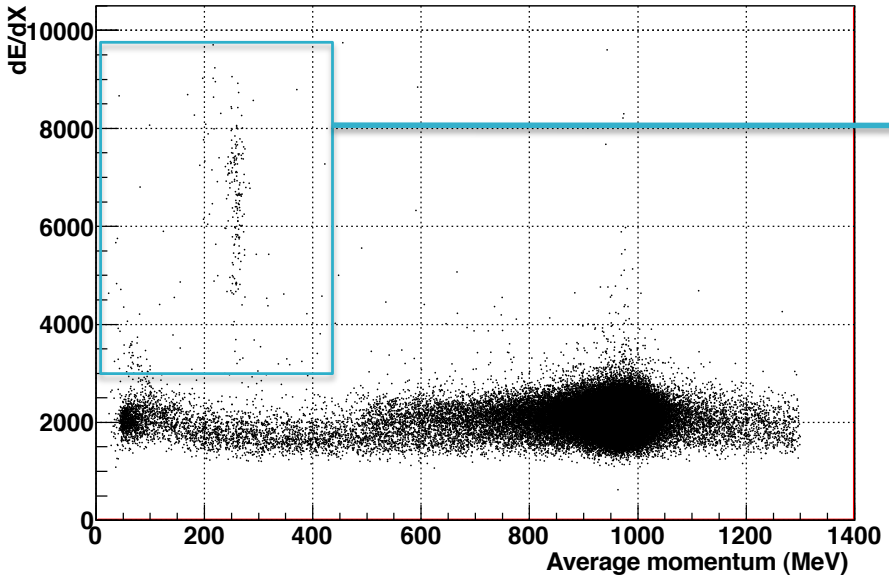


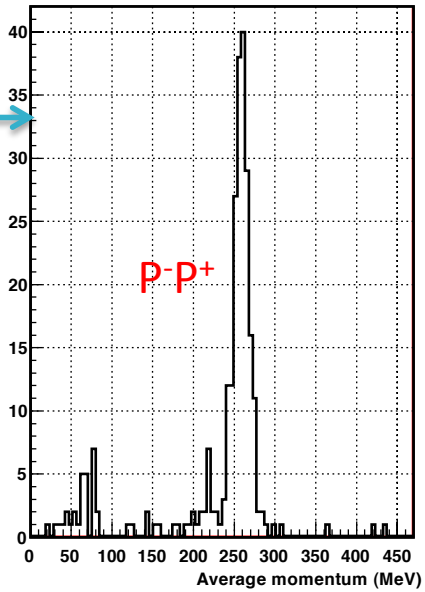
φ	9.11.2012 23.11.2012	0.68 пб$^{-1}$
ω	23.11.2012 04.12.2012	0.23 пб$^{-1}$
ρ (<1 ГэВ)	04.12.2012 17.04.2013	6.2 пб$^{-1}$
φ	17.04.2013 12.05.2013	6.2 пб$^{-1}$
ω	12.05.2013 25.06.2013	8.6 пб$^{-1}$
0.958 ГэВ	25.06.2013 07.07.2013	2.7 пб$^{-1}$

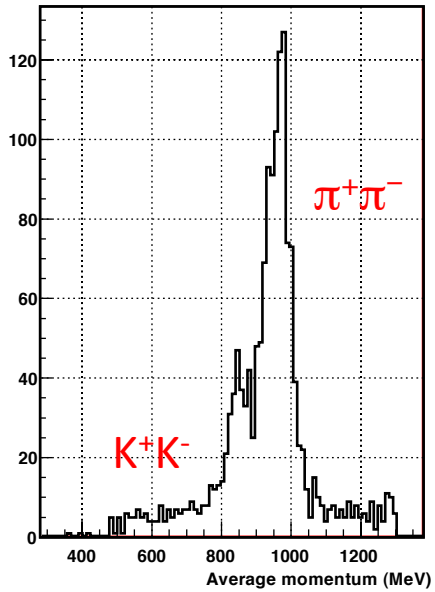
Collinear events in CMD-3 ($E_{c.m.}$ = 1.95 GeV)











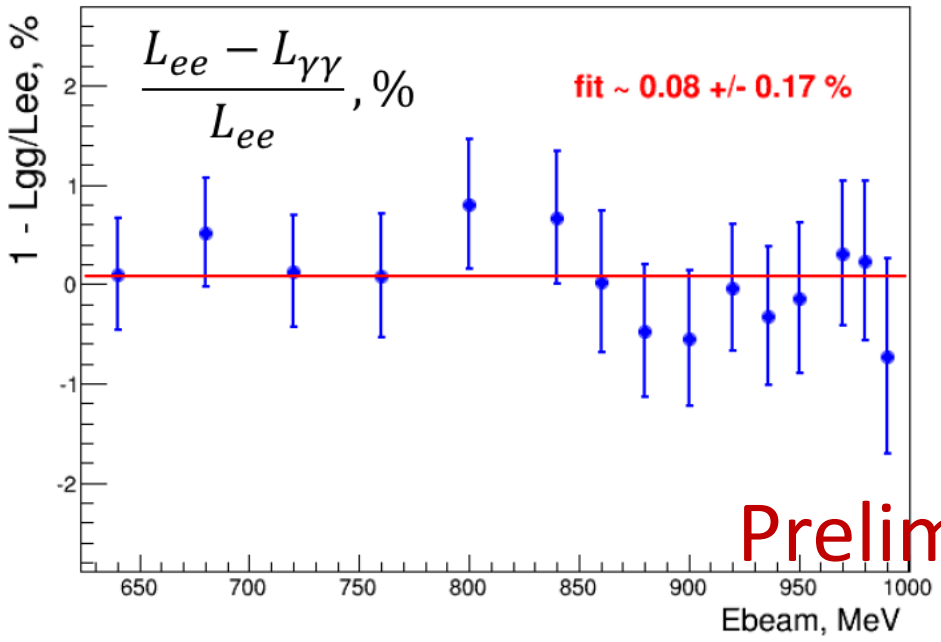
We plan precision measurements of the e^+e^- -> P^-P^+, K^+K^-, $\pi^+\pi^-$ processes in all energy range

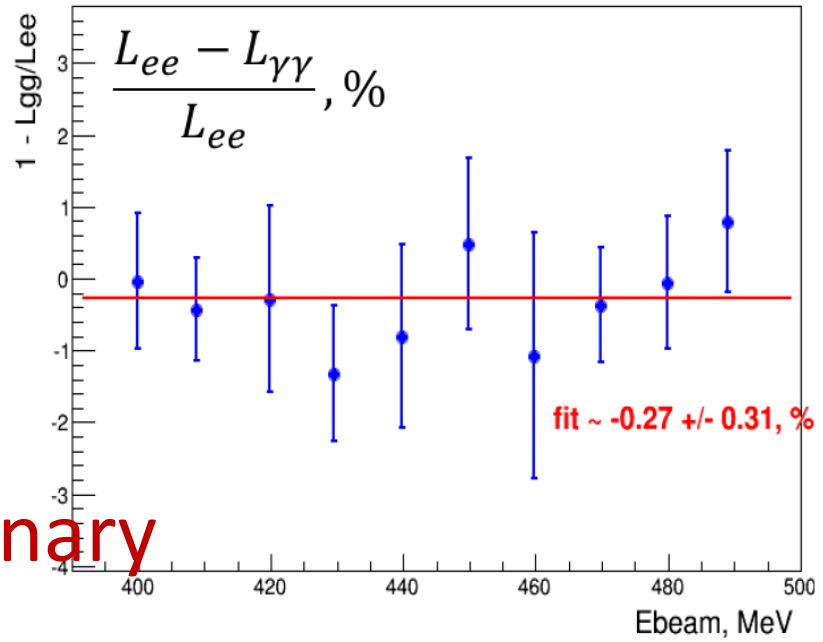
Luminosity measurement

We use two processes to measure luminosity: $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$

Very different detection, trigger, reconstruction

We have good overall agreement





Preliminary

$e^+e^- \to \pi^+\pi^-$

One of the most important result expecting from CMD-3 and SND

Largest contribution to (g-2) calculation

$$\delta a_\mu(BNL) = 0.54\ ppm$$
$$\delta a_\mu(theory) = 0.42\ ppm$$

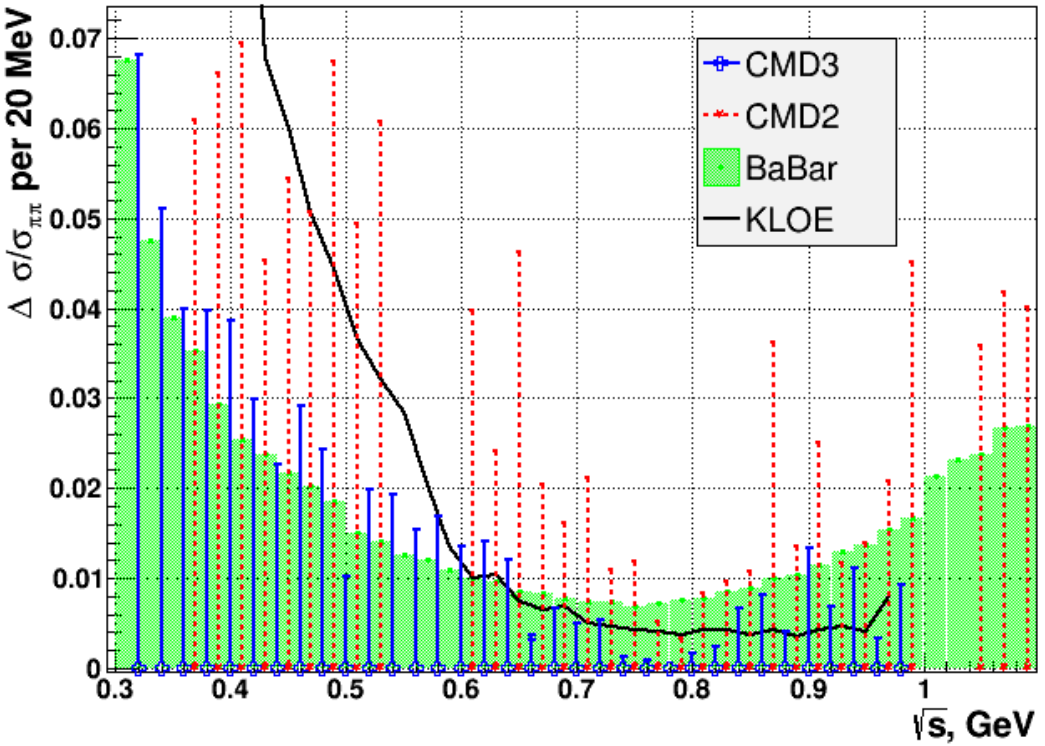
2π contribute $0.27\ ppm$

$$\Delta a_\mu(exp - th) = 3.3 \div 3.6\ \sigma$$

FermiLab experiment (2016-2020):

$$\delta a_\mu(FNAL) = 0.15\ ppm$$

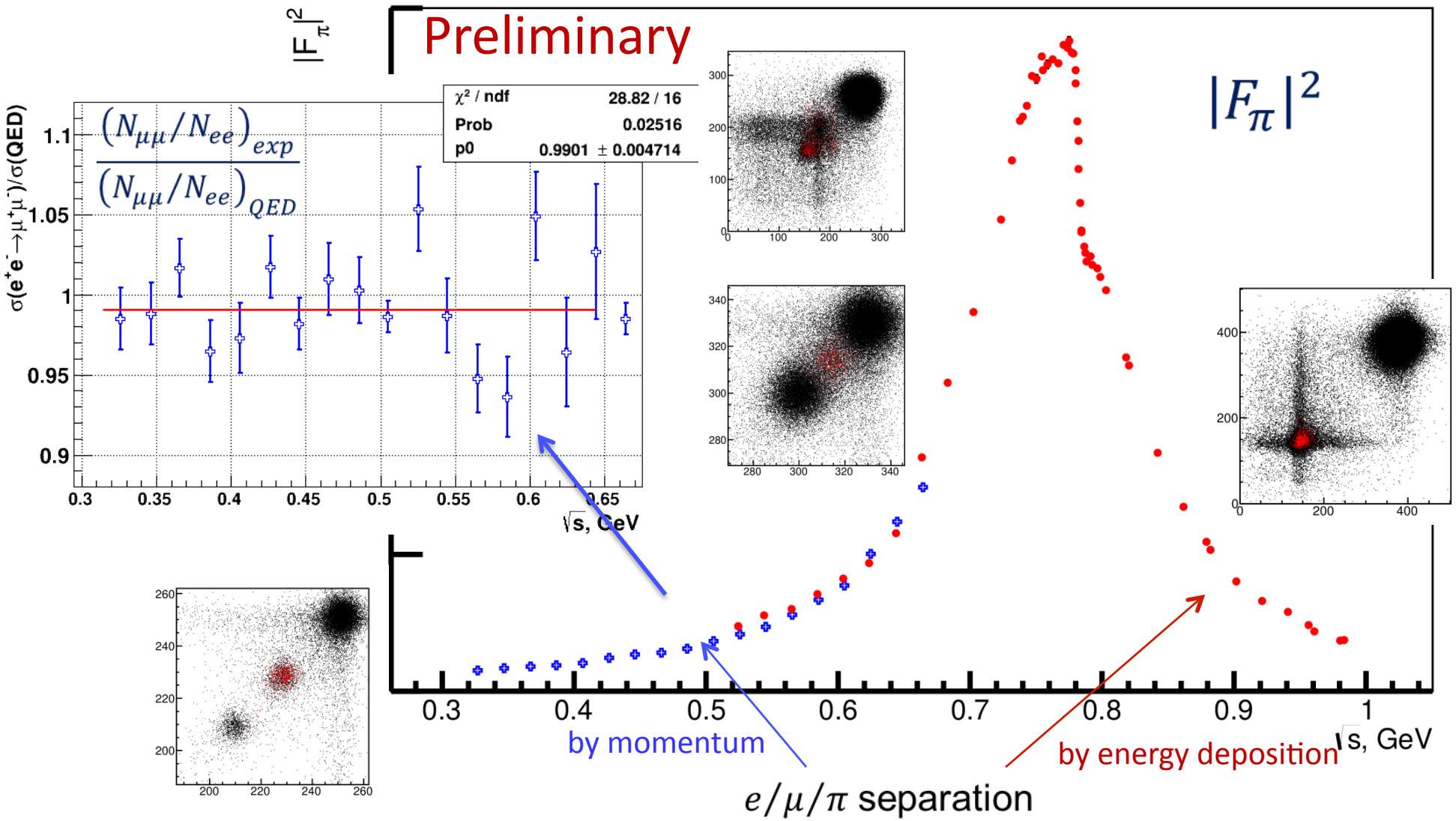
Expected statistical uncertainties



Our goal is to reach systematic uncertainties at the level of 0.35%

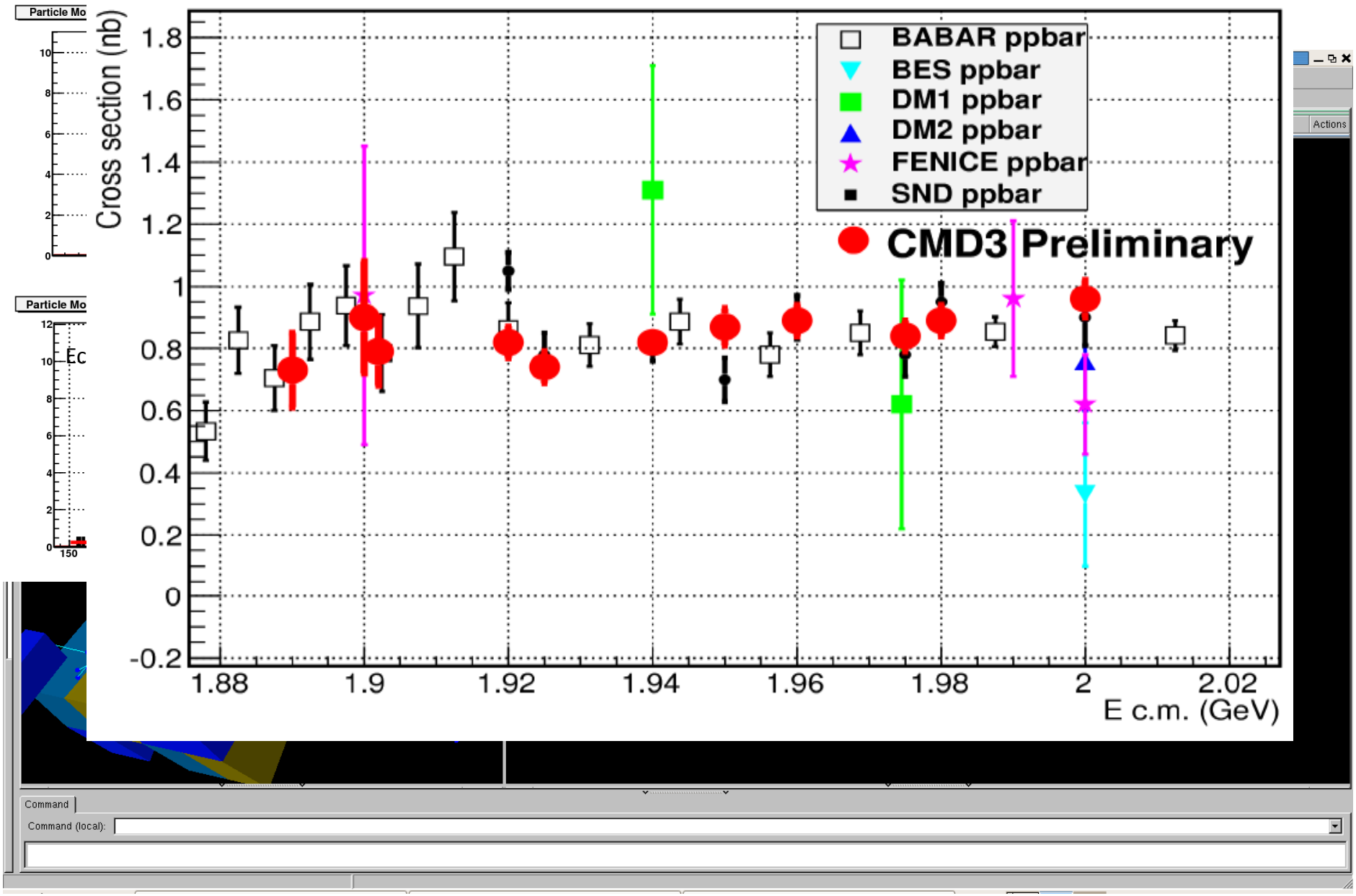
We expect systematic accuracy for 2013 data comparable with other data

$e^+e^- \to \pi^+\pi^-$


Preliminary
$|F_\pi|^2$
$\frac{(N_{\mu\mu}/N_{ee})_{exp}}{(N_{\mu\mu}/N_{ee})_{QED}}$
χ^2 / ndf 28.82 / 16
Prob 0.02516
p0 0.9901 ± 0.004714
$\sigma(e^+e^-\to\mu^+\mu^-)/\sigma(QED)$
$\sqrt{s}$, GeV
$|F_\pi|^2$
by momentum
by energy deposition
$e/\mu/\pi$ separation
$\sqrt{s}$, GeV

Preliminary results for the e^+e^- -> PbarP study (1)

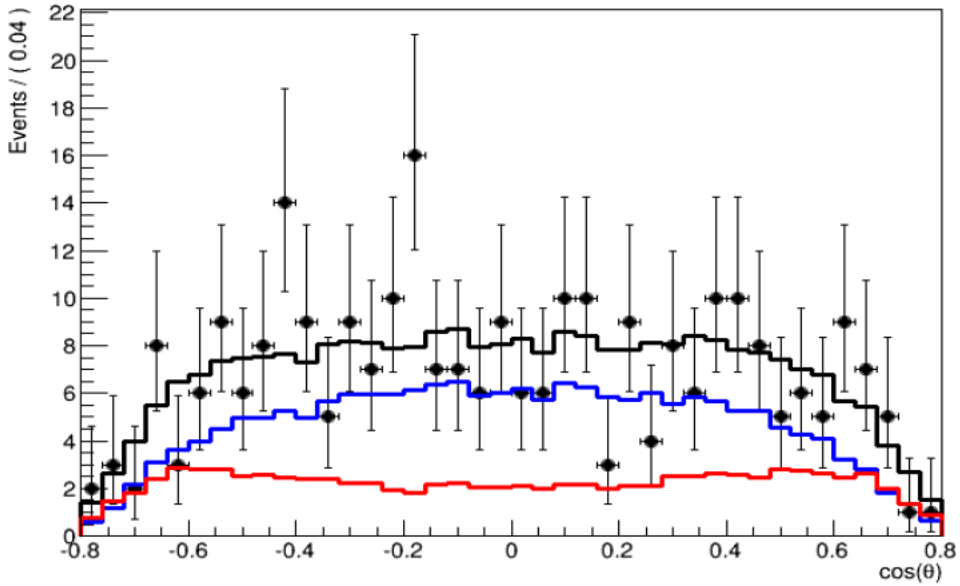
Number of

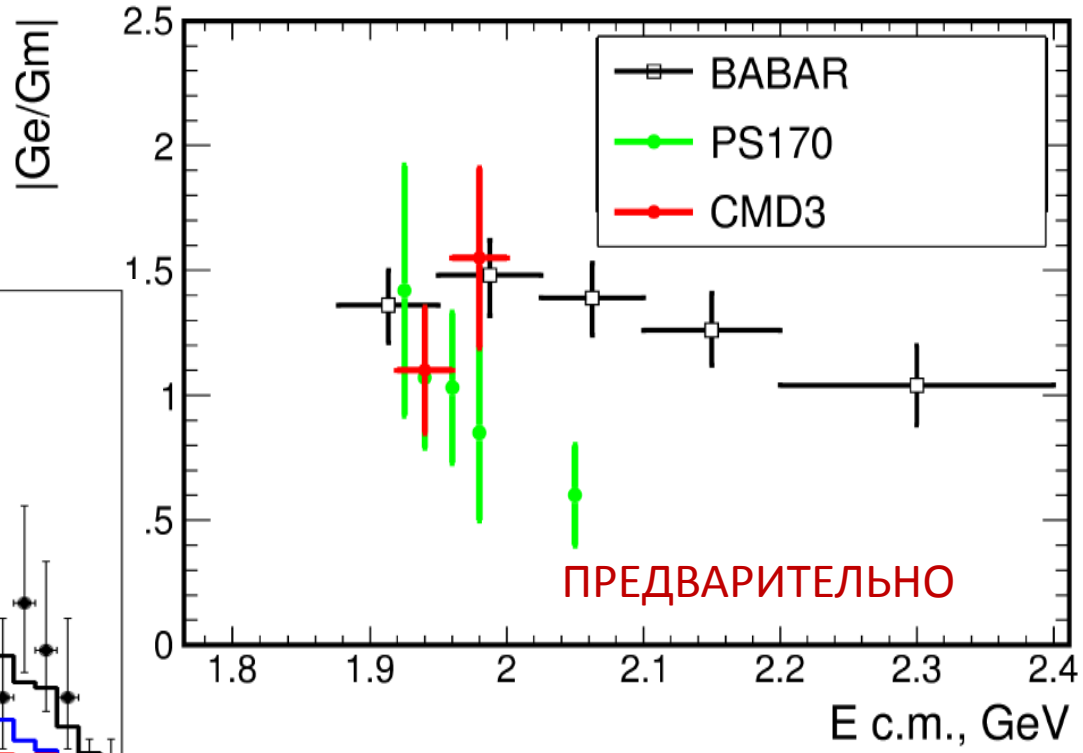


Preliminary results for the e^+e^- -> PbarP study (2)

Angular distribution gives information for the |GE/GM| ratio:

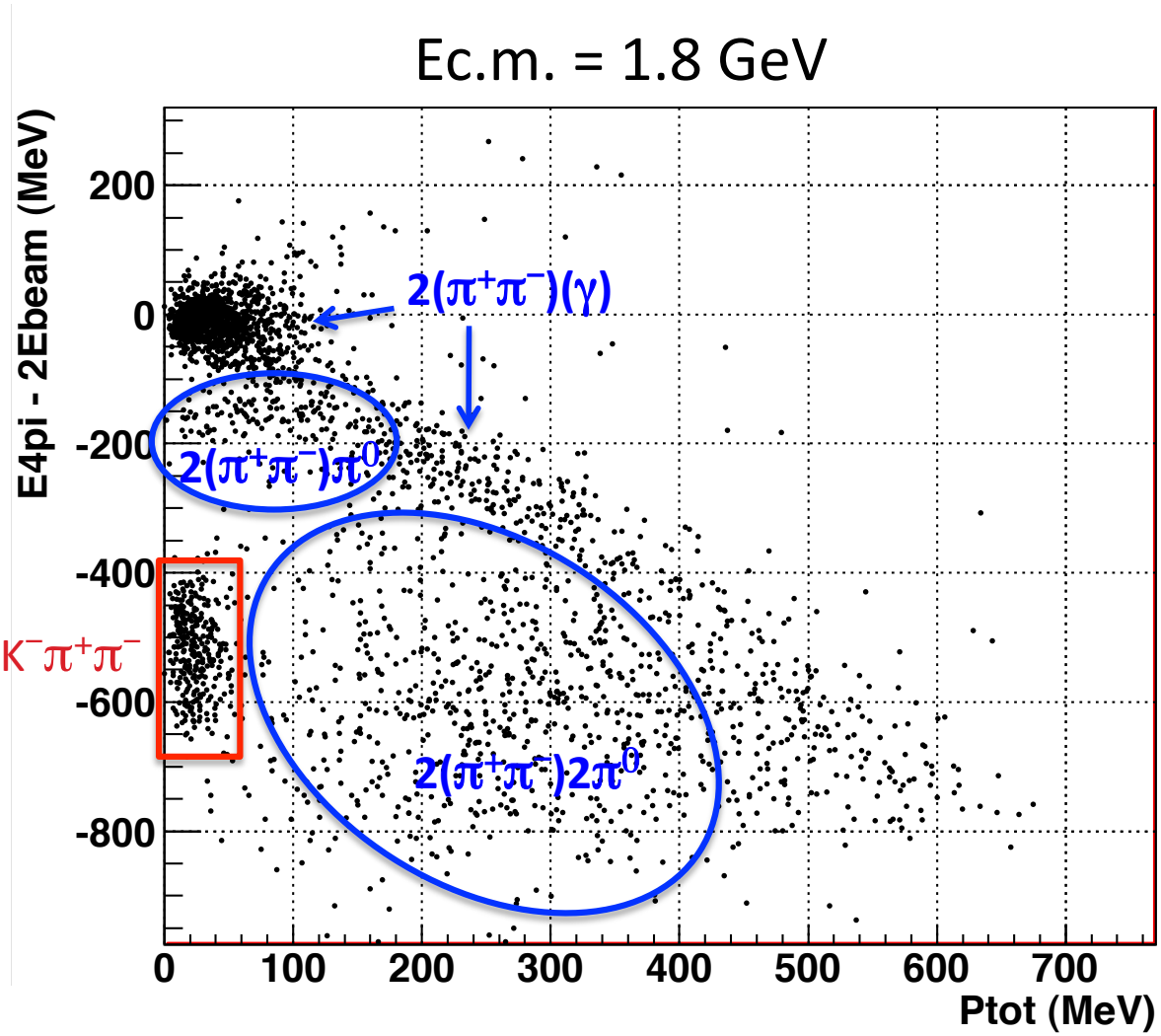
$$|G_E|^2 \leftrightarrow \sin^2\Theta$$
$$|G_M|^2 \leftrightarrow (1+\cos^2\Theta)$$

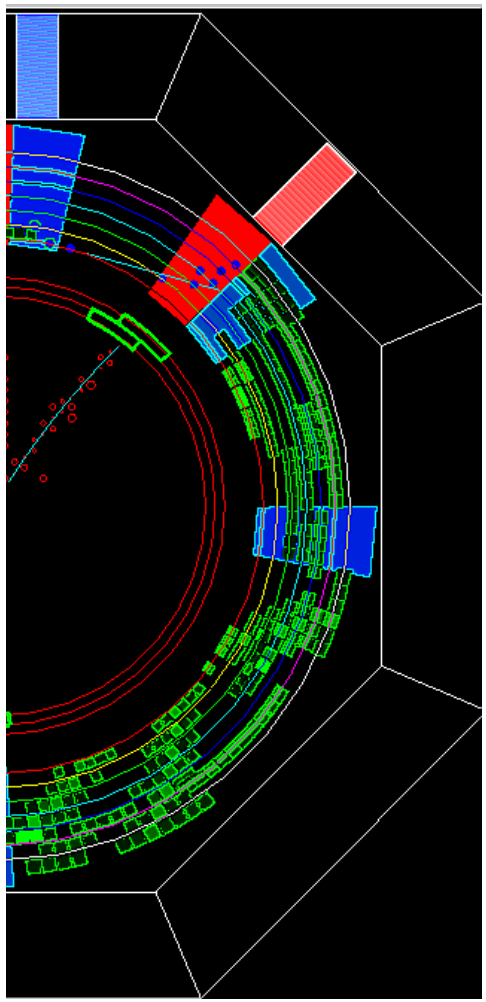




We need more than factor of 10 in statistic

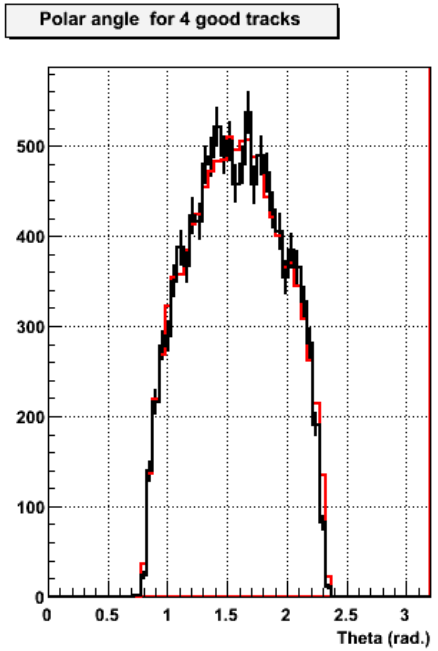
Example of e^+e^- -> 4 charged tracks in CMD-3

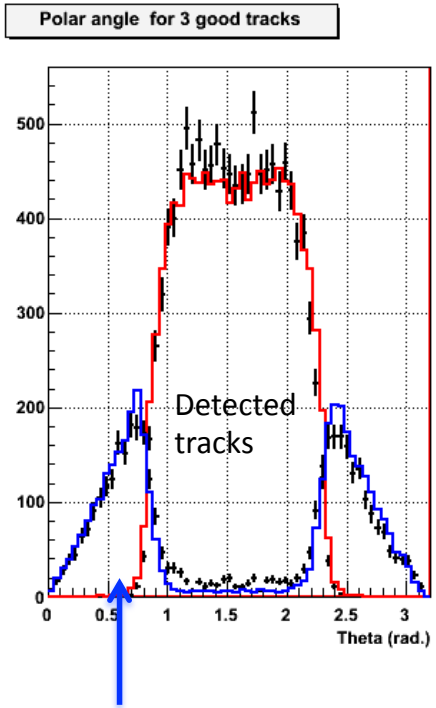


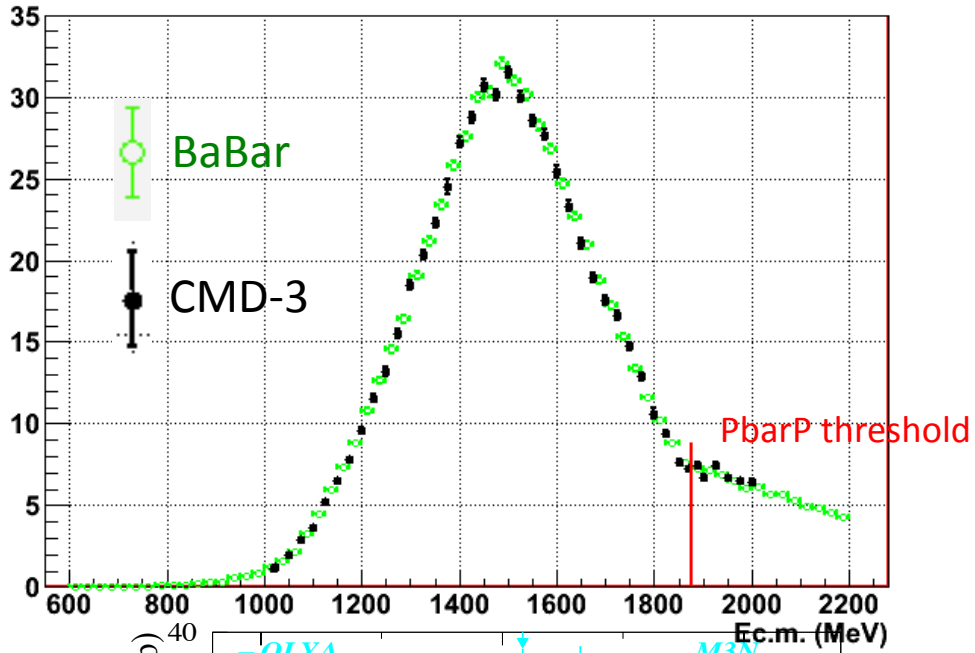


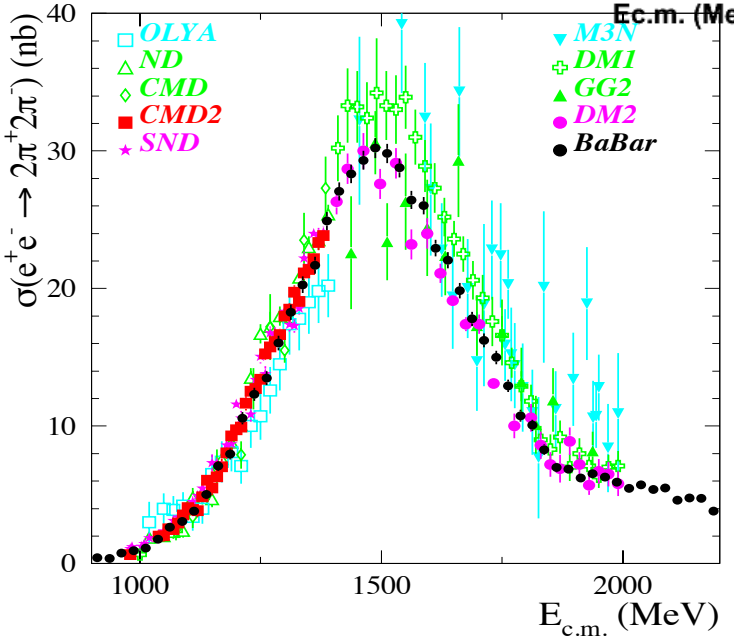
Preliminary results for the e^+e^- -> $2(\pi^+\pi^-)$ study

We have relatively clean selection of 4 and 3 charged pions





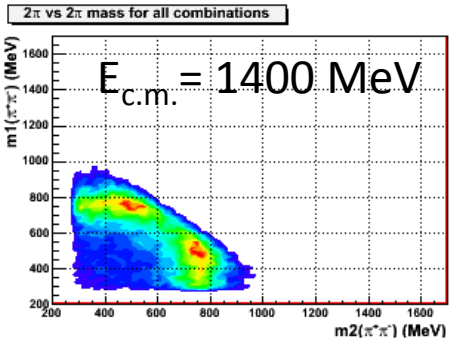


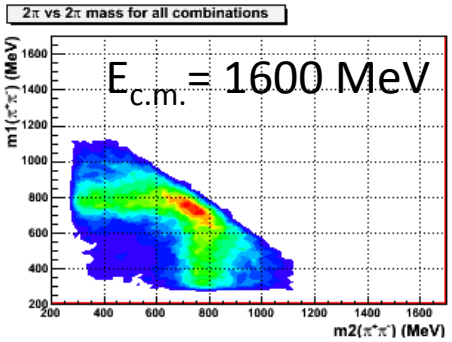


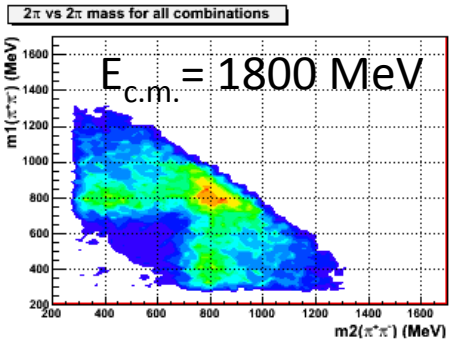
Statistical errors are at the level of 1-2% per point.
Systematical errors are under investigation.

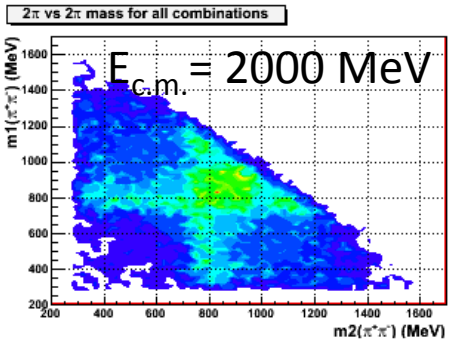
Preliminary study of the $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ process

Preliminary mass distributions study:

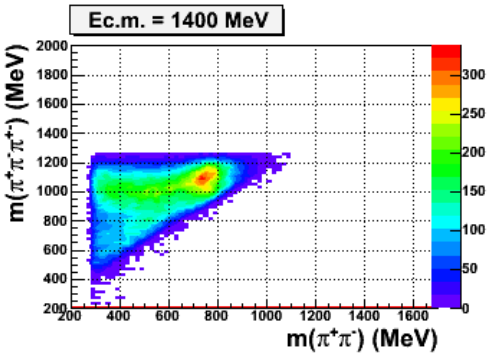


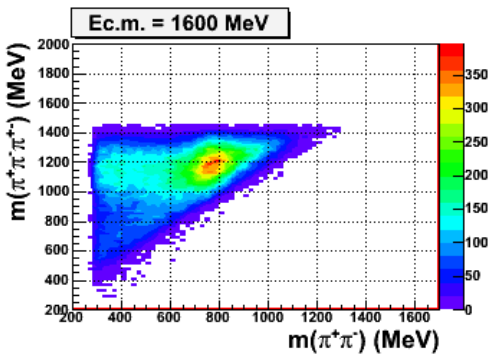




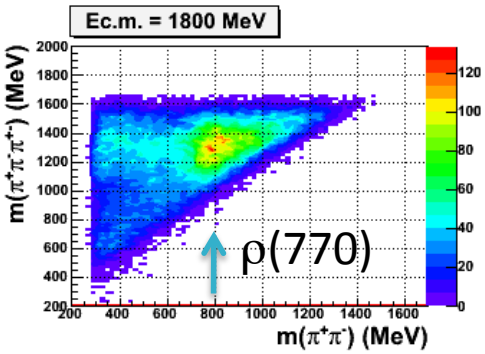


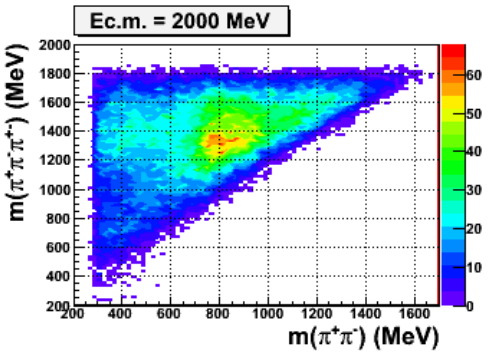
We confirm $a_1(1260)\pi$ dominance. Some other states ($\rho(770)f_0(600)$, $\rho(770)f_0(980)$) are seen, but small.





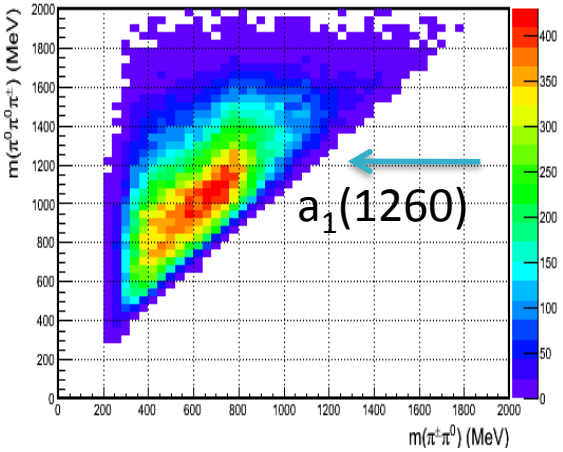
$a_1(1260)$, $a_2(1320)$?

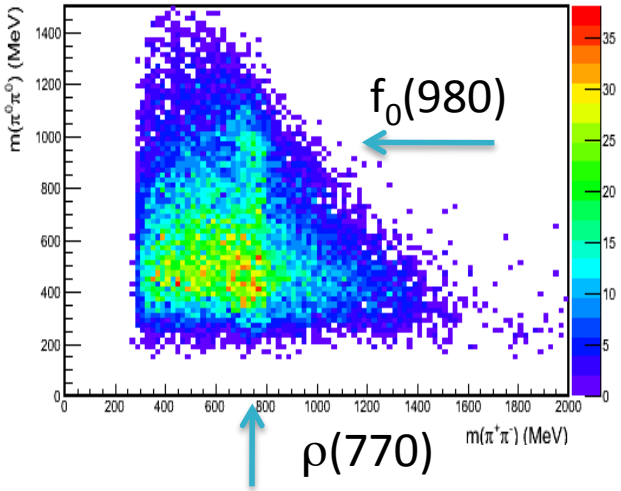


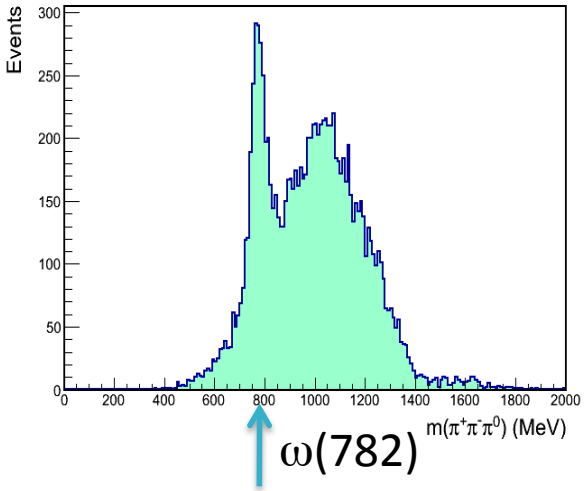


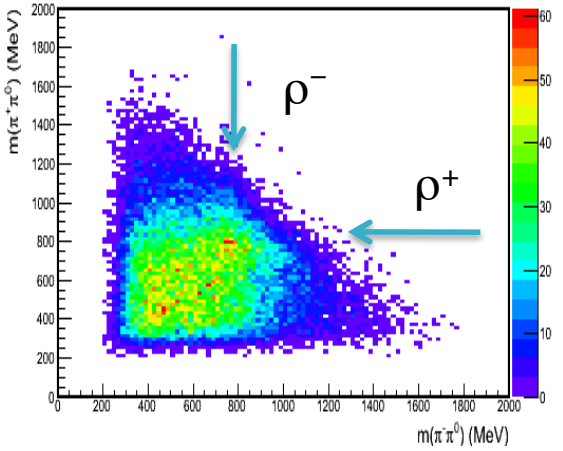
Preliminary study of the $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ process

Looking for two π^0 in addition to two charged tracks. The π^0 efficiency is under investigation.
Preliminary mass distributions study:

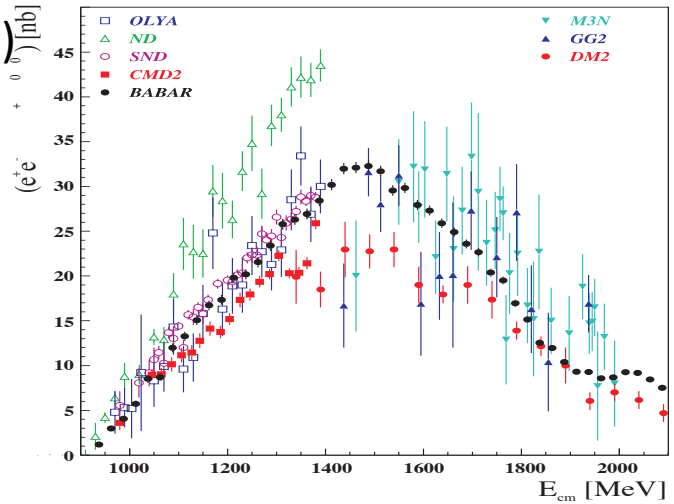








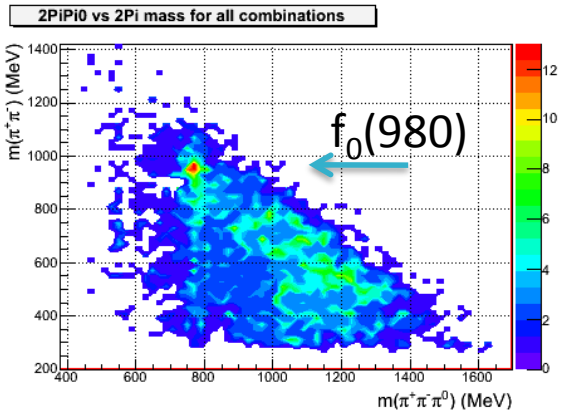
In addition to dominant $\omega\pi^0$ and $a_1\pi$ we see
$\rho^+\rho^-$, $\rho(770)f_0(600)$?, $\rho(770)f_0(980)$?

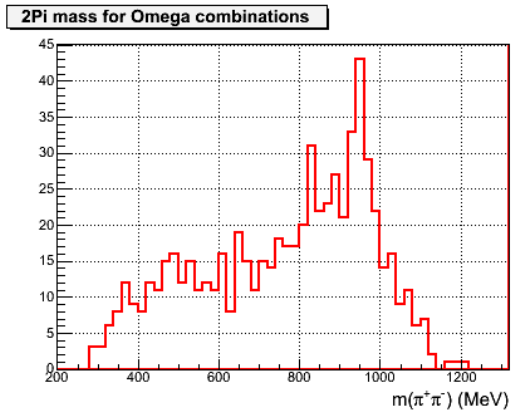


We have statistical errors at the level of 1-2% per point.
Systematical errors are under investigation.

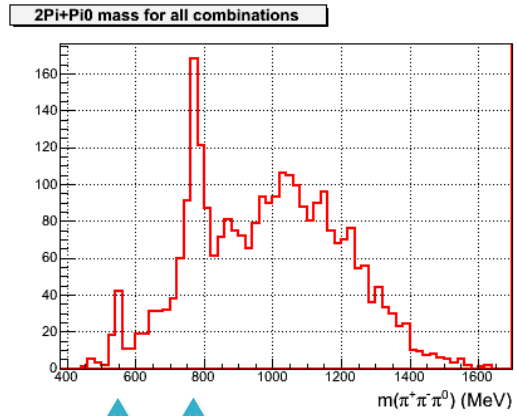
First look to the e^+e^- -> $2(\pi^+\pi^-)\pi^0$ process

We look for the π^0 in addition to four "good" tracks satisfying energy-momentum conservation

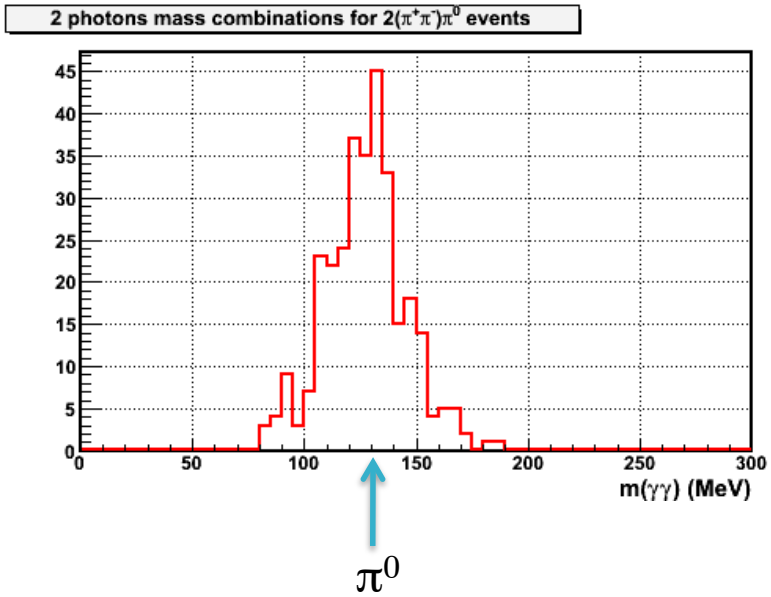




Example of $\omega f_0(980)$ signal
In $\omega\pi^+\pi^-$ final state.



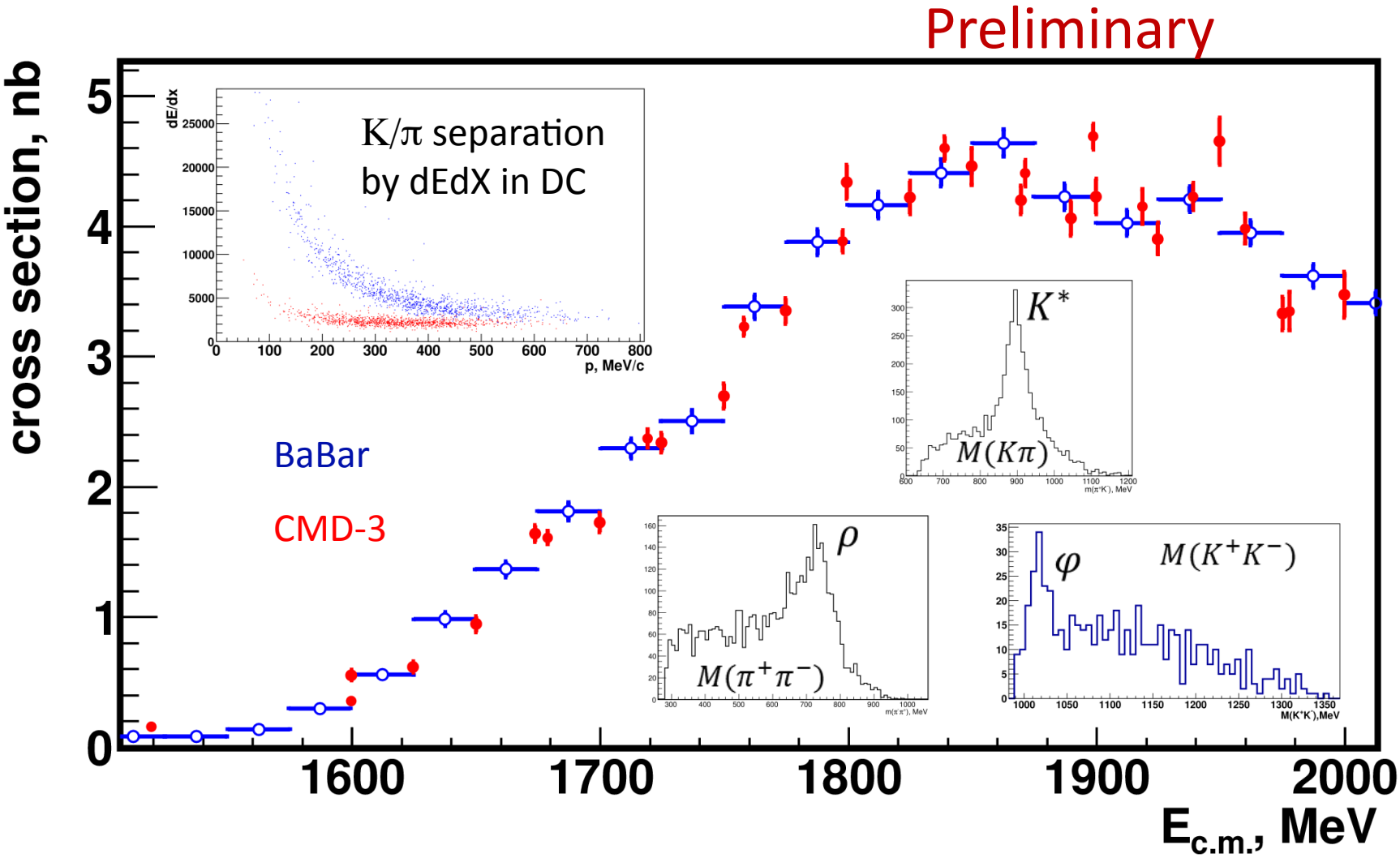
$\eta(545)$ $\omega(782)$



π^0

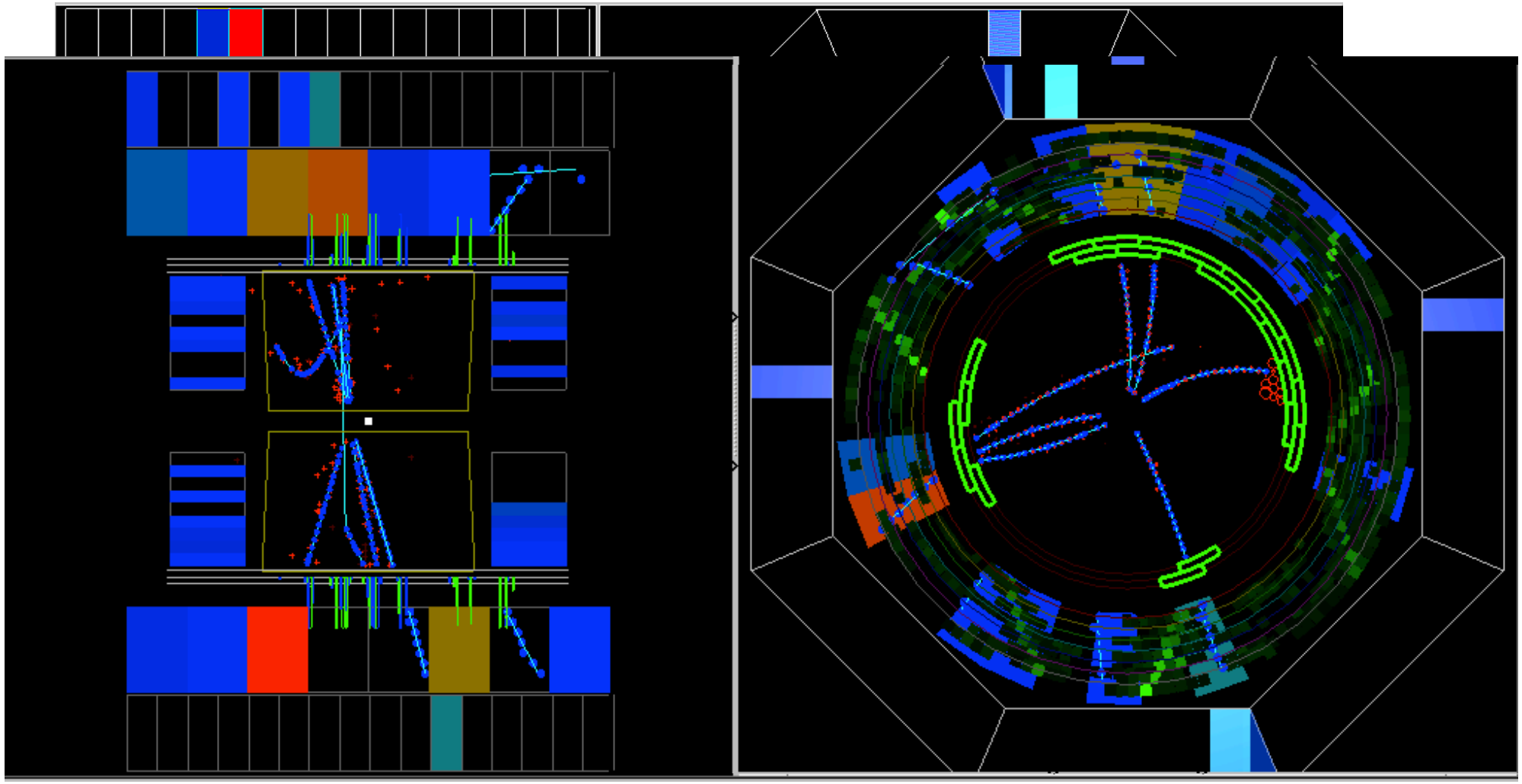
Detailed analysis is coming….

Results for the e^+e^- -> $K^+K^-\pi^+\pi^-$ study

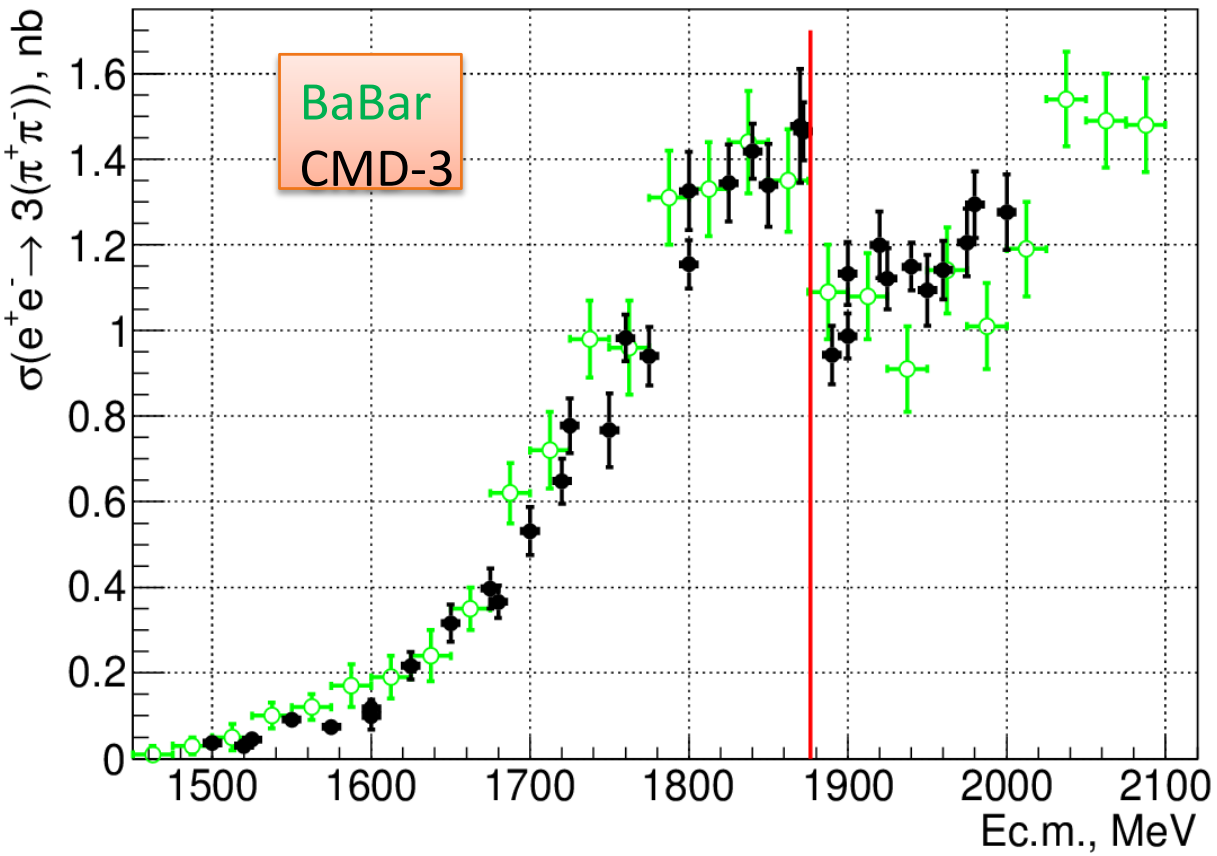


Analysis is close to publication

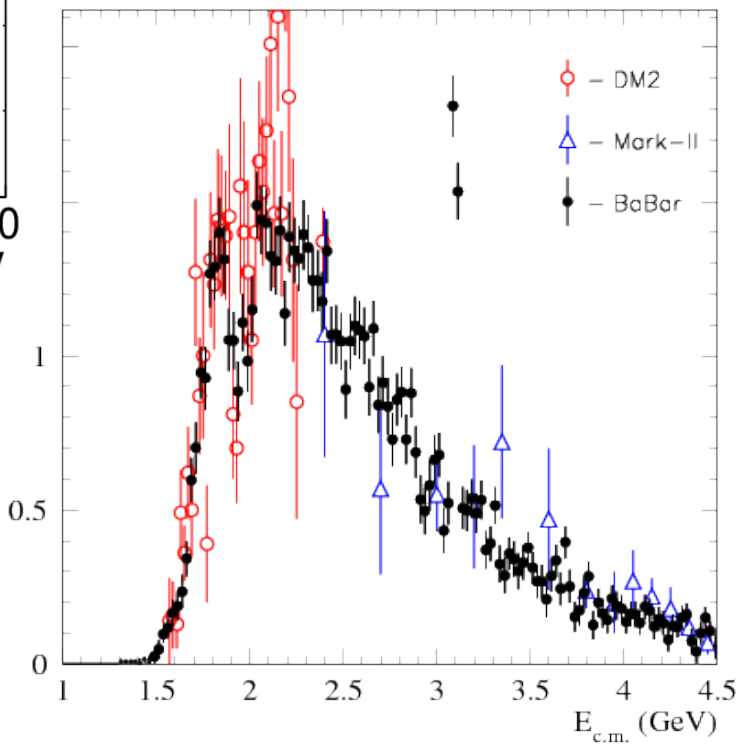
Example of e^+e^- -> $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ from CMD-3



Results for the e^+e^- -> $3(\pi^+\pi^-)$ study



Other data for e^+e^- -> $3(\pi^+\pi^-)$



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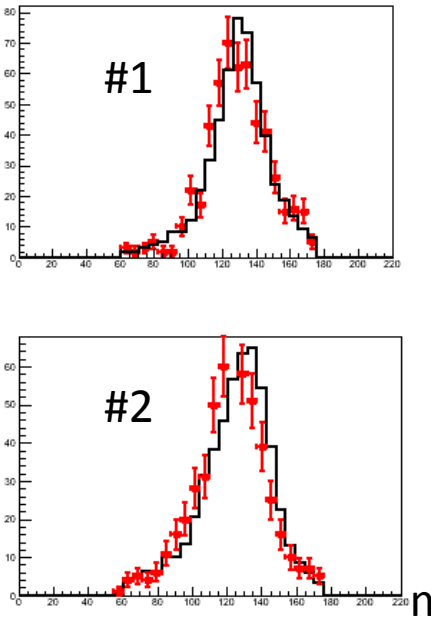
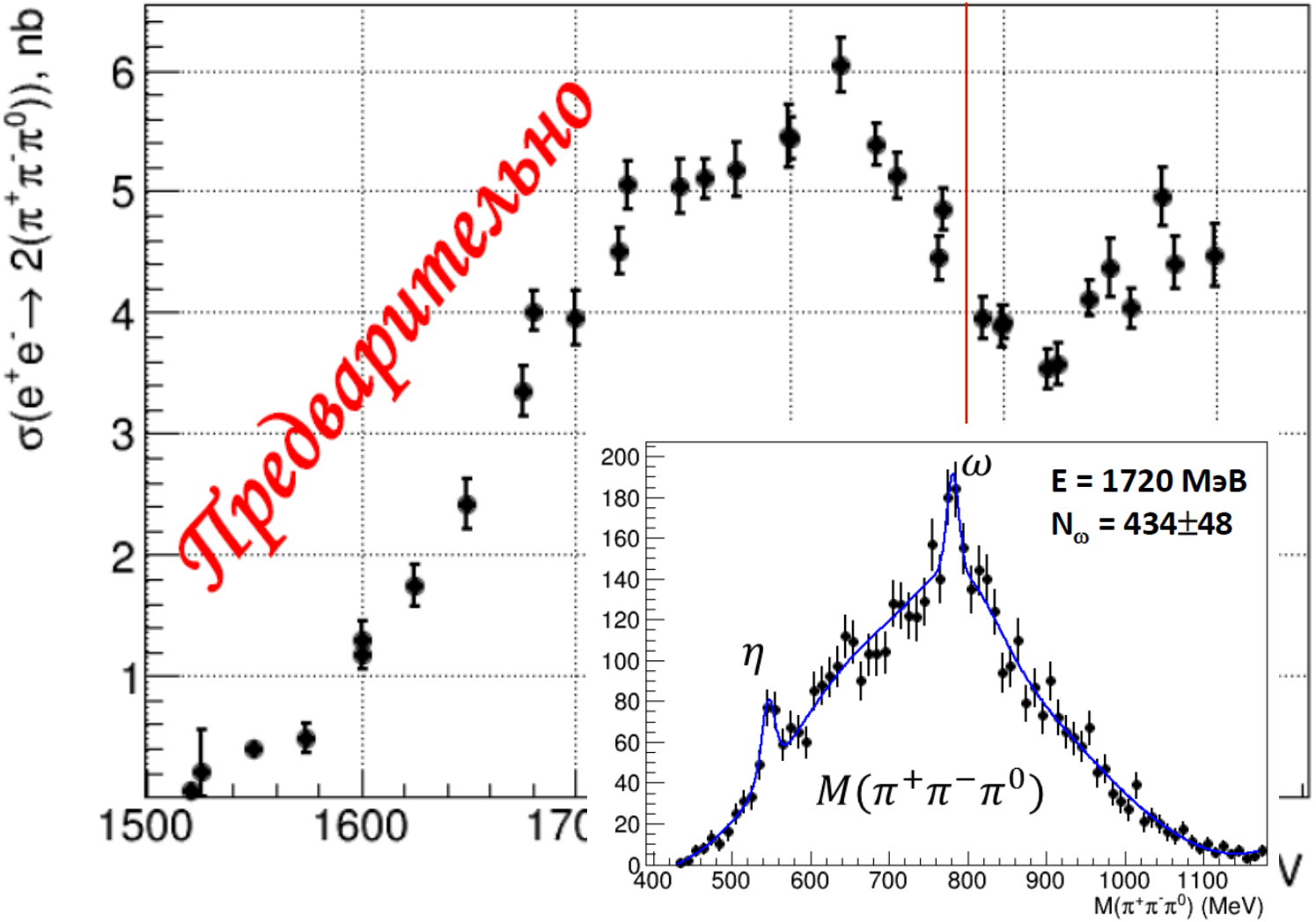
Preliminary results for the e^+e^- -> $2(\pi^+\pi^-\pi^0)$ study

We have relatively clean selection of 2 and 1 π^0 in addition to four charged tracks





$\omega\eta$, $\phi\eta$, $\rho 4\pi$ intermediate states are seen, systematic errors are under study.

More details in P.Lukin talk

Summary

- VEPP-4M and KEDR detector continue deliver precision measurements. R-scans up to 8-10 GeV have been planned. Double tag $\gamma\gamma$ physics is in preparation
- New generation of detectors, CMD-3 and SND, perfectly matches the rich physics potential of VEPP-2000.
- $L \sim 2 \times 10^{31}$ $cm^{-1}sec^{-2}$ has been reached so far – positrons limited. About 60 bp^{-1} per detector have been collected.
- "Unlimited" positron source is in preparation. Hope for X10 in luminosity and statistic.
- Both detectors are upgrading to accept higher luminosity.
- First results are published, many preliminary results are in preparation for publications.
- Upgraded machine and detectors plan to start working with beams at the end of 2014.