HADRONIC CROSS SECTION MEASUREMENT AT CMD3

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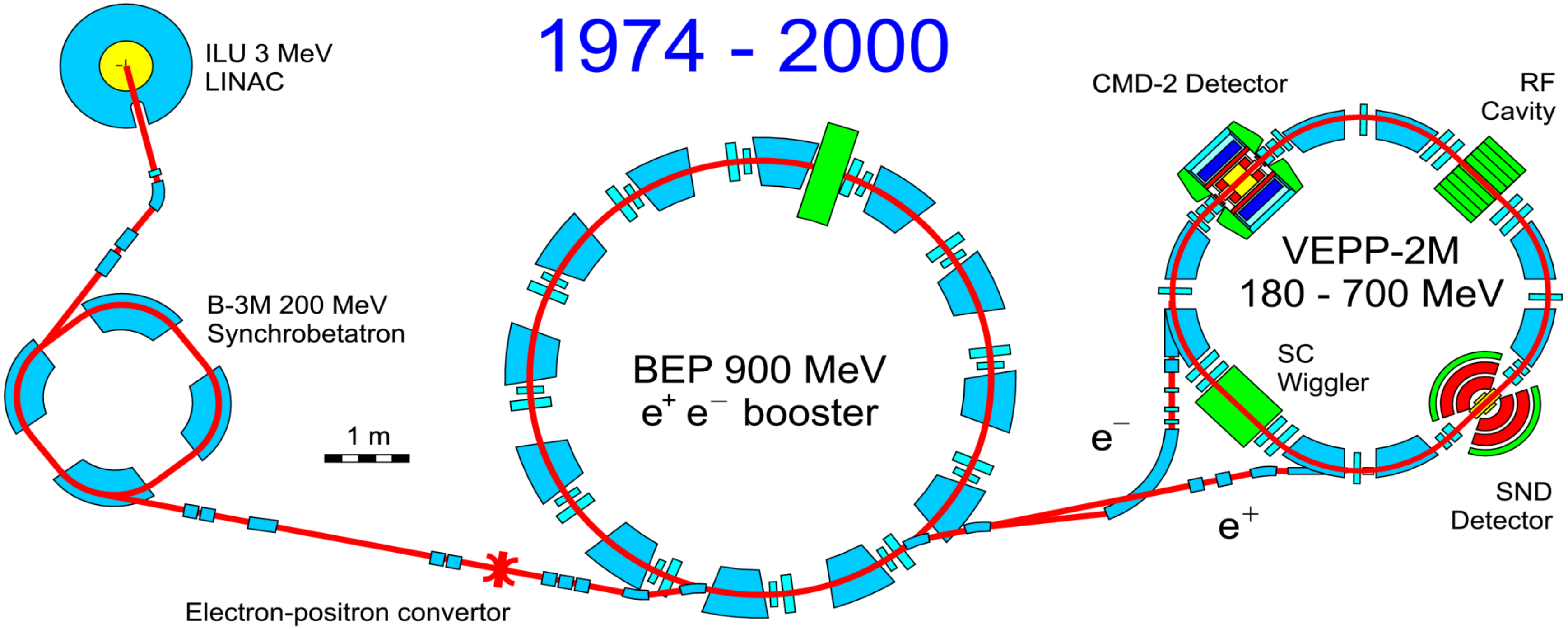
Outline

- VEPP-2000
- Detector CMD-3
- Pion form factor
- Multihadron final states
- Proton form factor

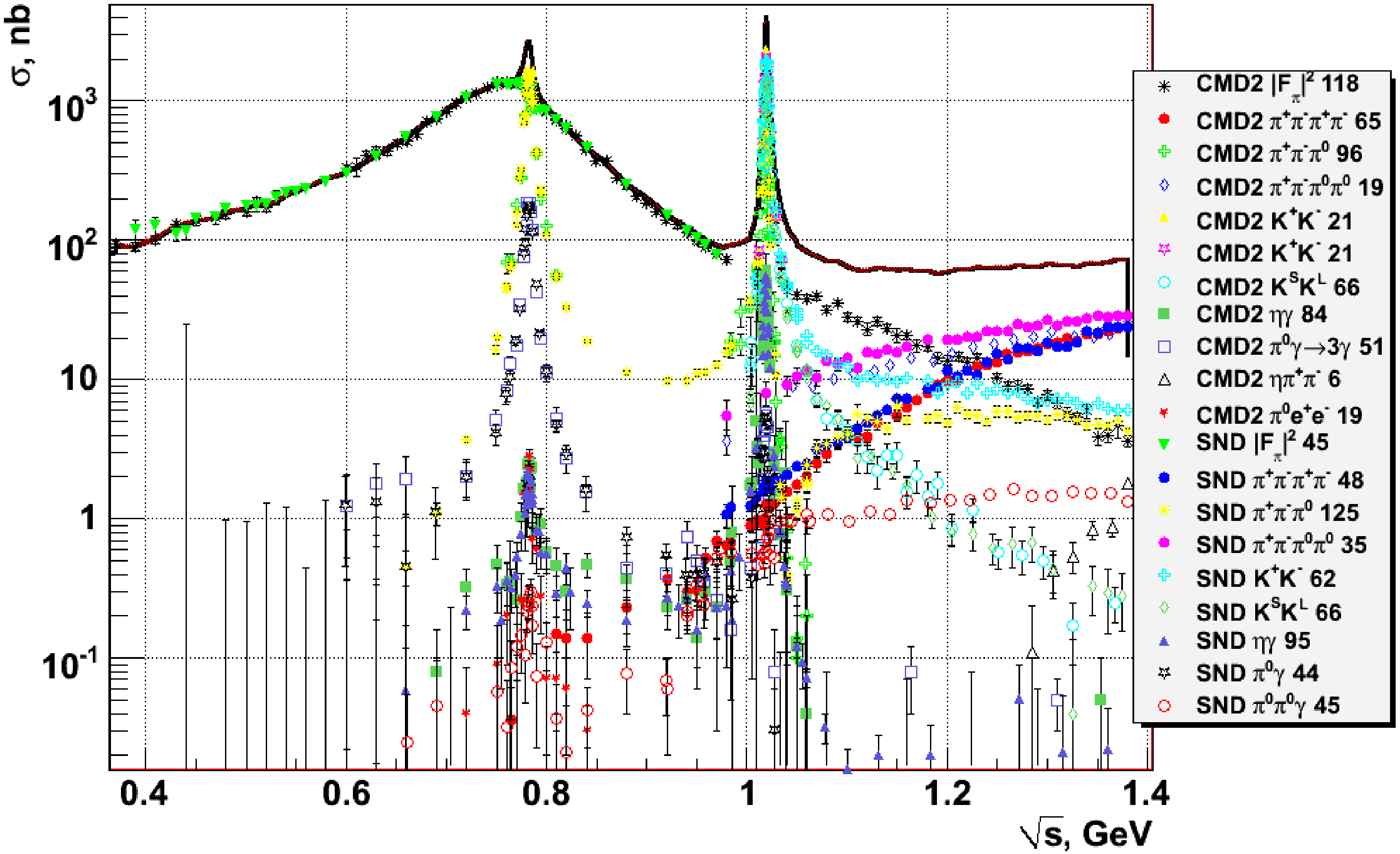
There was VEPP-2M



Energy range: 0.36 – 1.4 GeV

Luminosity up to $5*10^{30}$ 1/cm^{2}s

Cross-section measurements at VEPP-2M

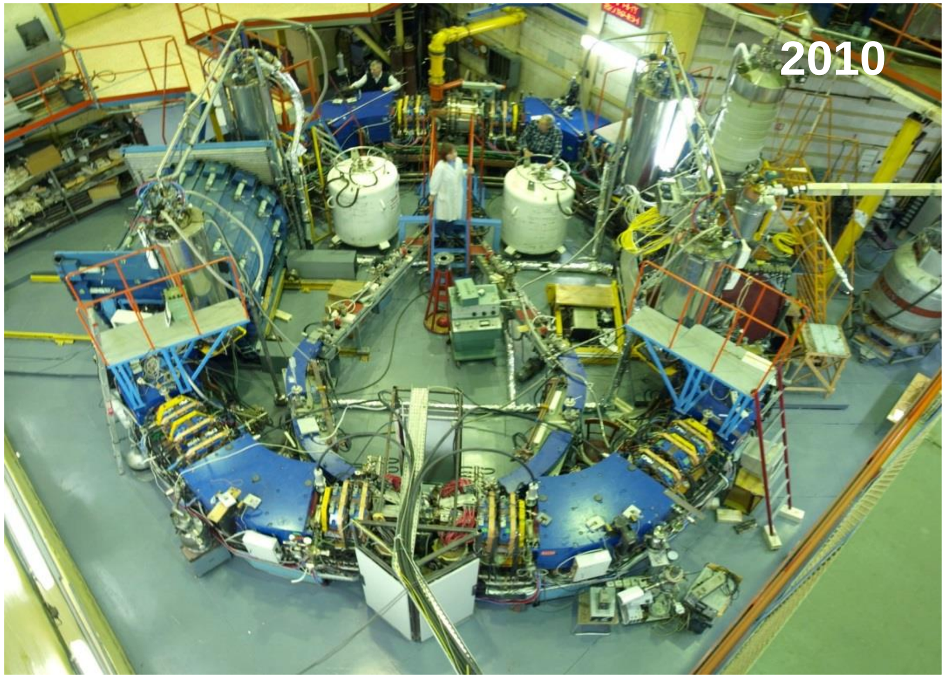


Hadronic cross-section measurements with precision from <1% to ~5%

From VEPP-2M to VEPP-2000

2001 VEPP-2M decommissioned

2010 first engineering run at VEPP-2000 collider with 2 new detectors: CMD-3 and SND

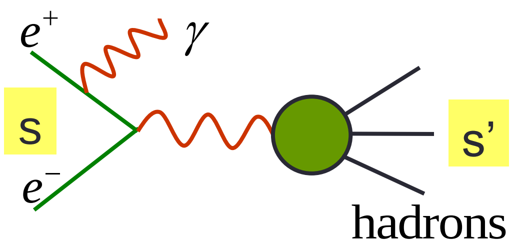


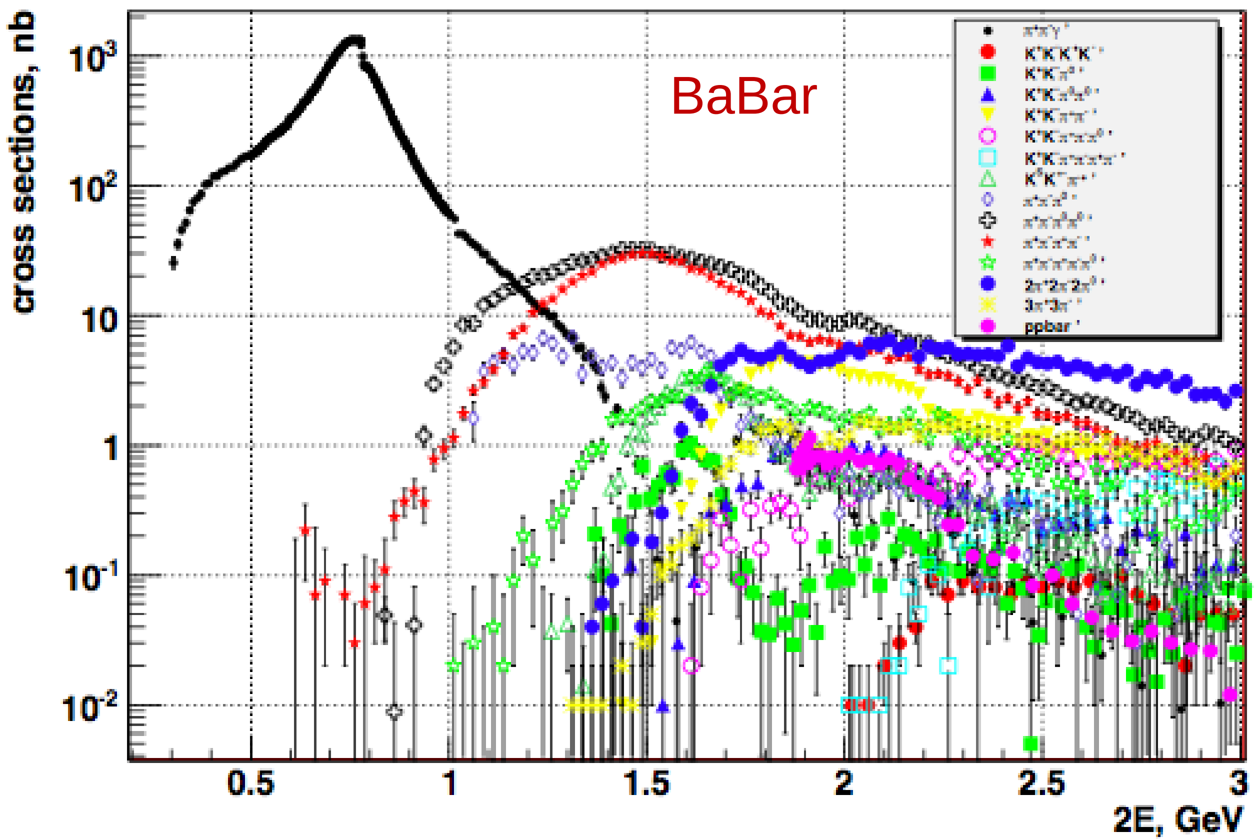
Main VEPP-2000 advantages:
- maximum energy up to 2 GeV
- higher luminosity

Meanwhile

New approach to measurement of the hadronic cross-sections was fully developed over last decade: ISR (Initial State Radiation), mainly by BaBar and KLOE.

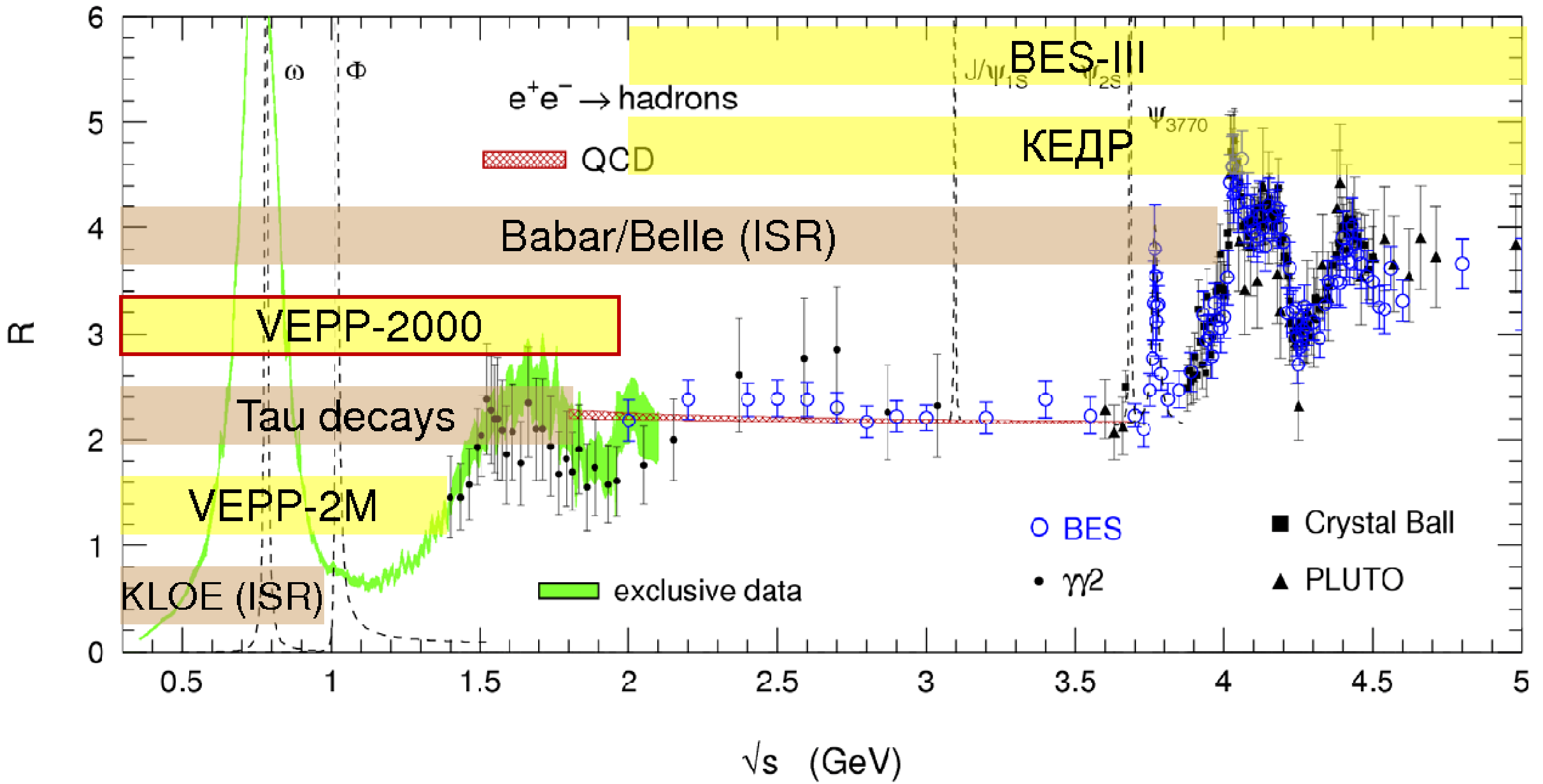
$$d\sigma(e^+e^- \rightarrow \text{hadrons} + \gamma) = H(Q^2, \theta_\gamma) \cdot d\sigma(e^+e^- \rightarrow \text{hadrons})$$



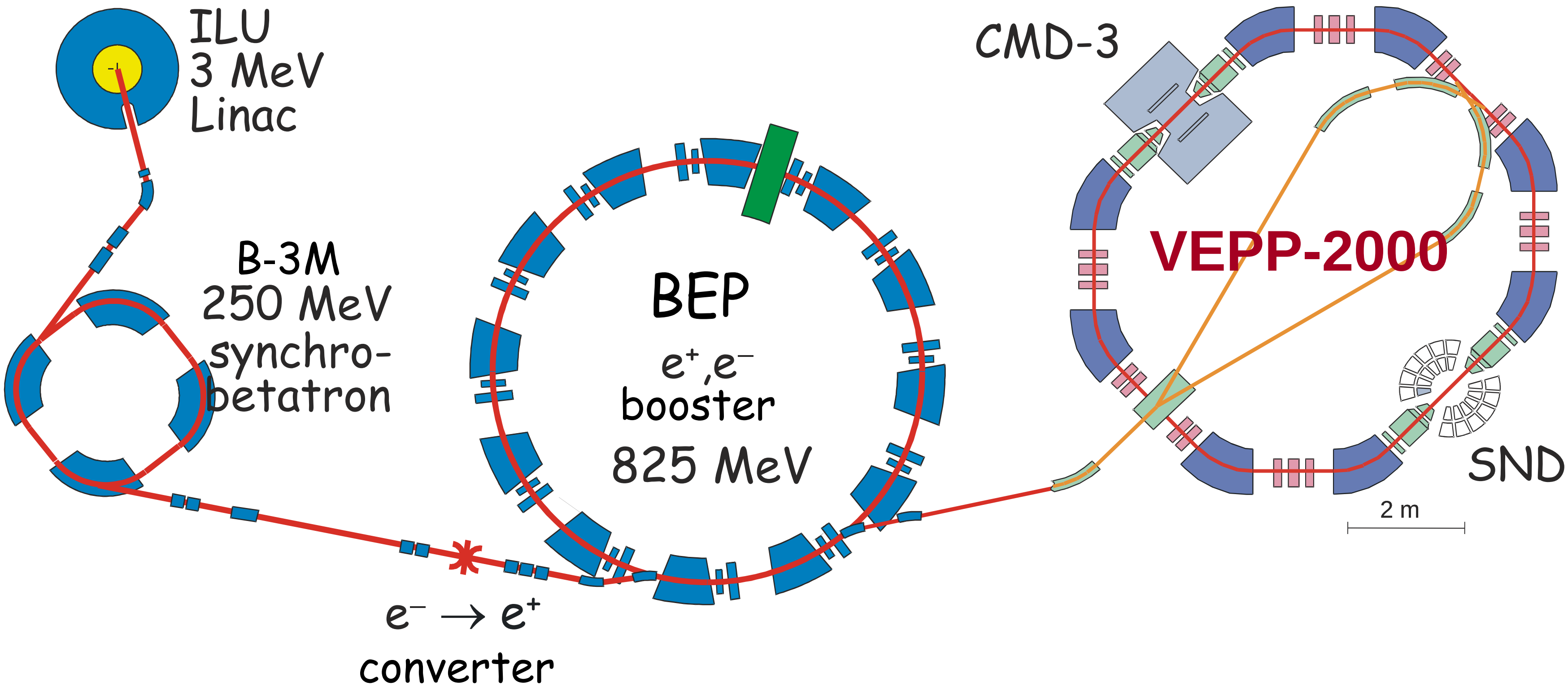


Main idea: cross-section is measured in the wide energy range, using events with hard photon, emitted by initial particles.

VEPP-2000 and the world



VEPP-2000



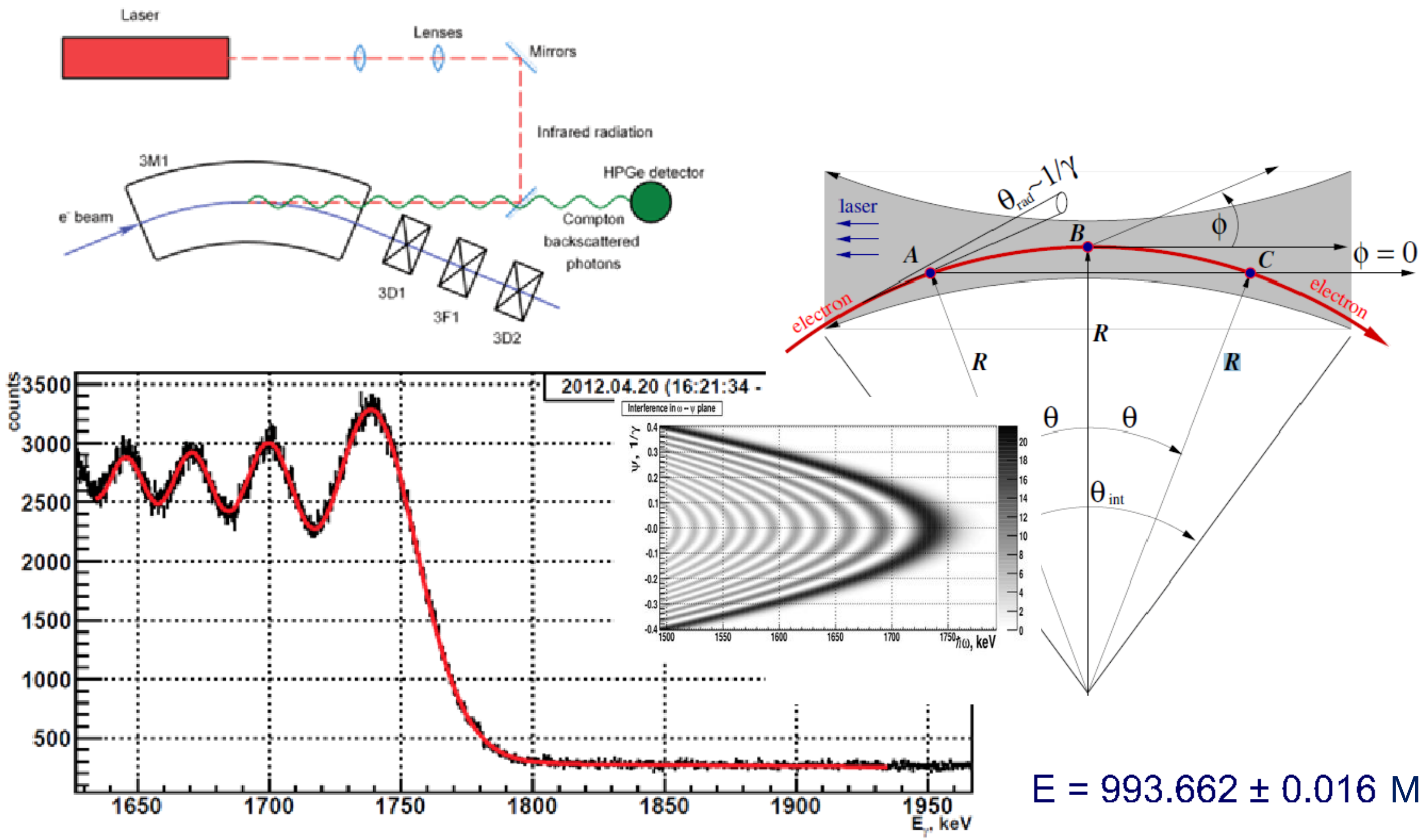
Maximum c.m. energy is 2 GeV, project luminosity is $L = 10^{32} 1/cm^2 s$ at $\sqrt{s} = 2$ GeV

Unique optics, “round beams”, allows to reach higher luminosity

Experiments with two detectors, CMD-3 and SND, started by the end of 2010

Energy measurement

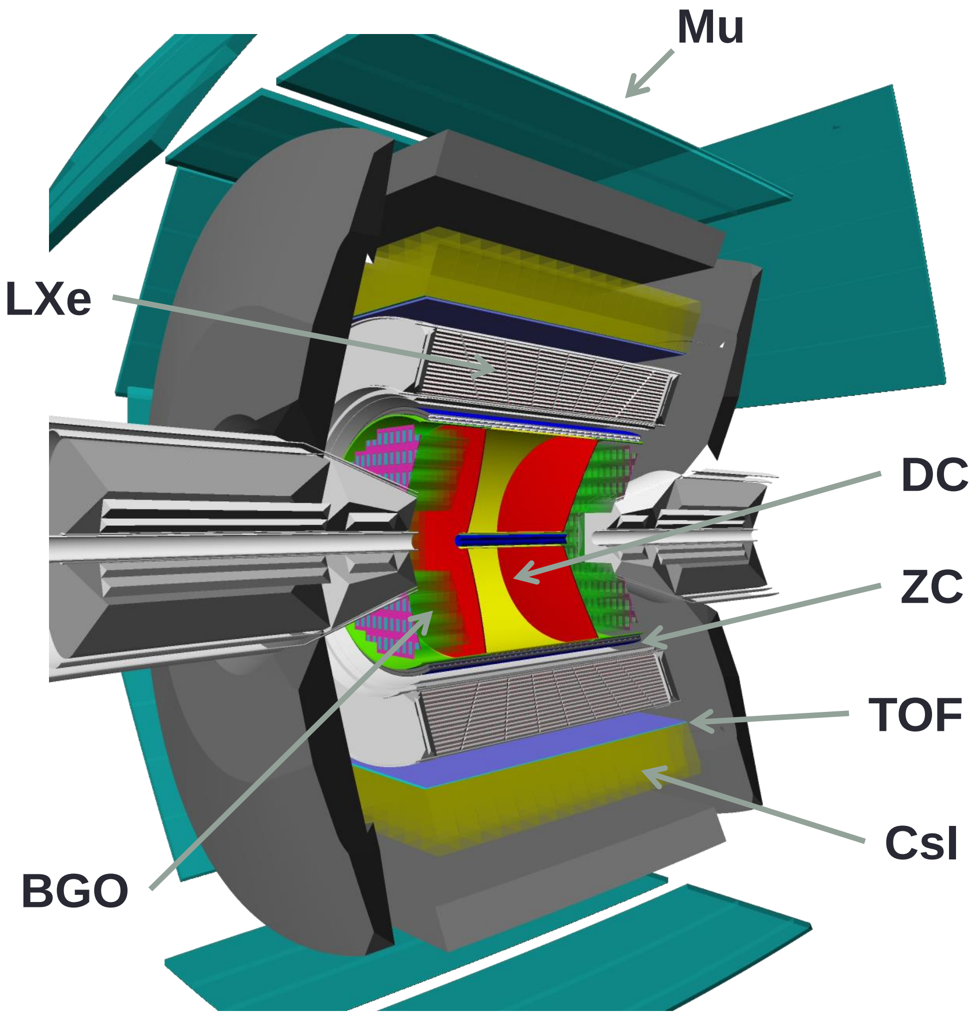
Starting from 2012, energy is monitored continuously using compton backscattering

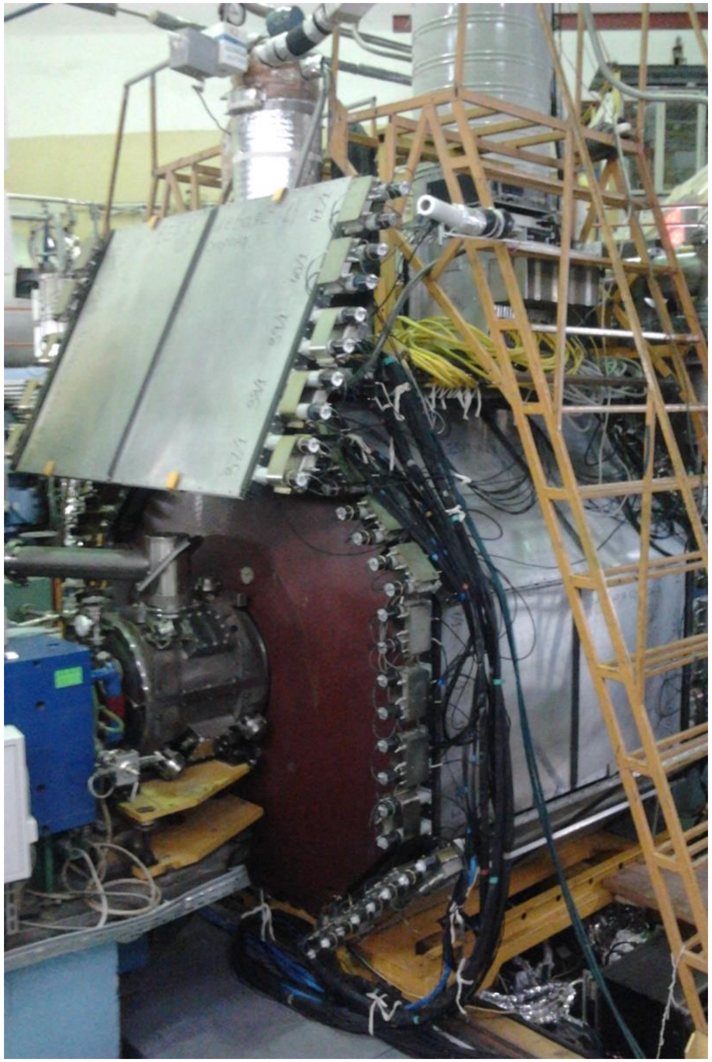


E = 993.662 ± 0.016 MeV

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

Detector CMD-3

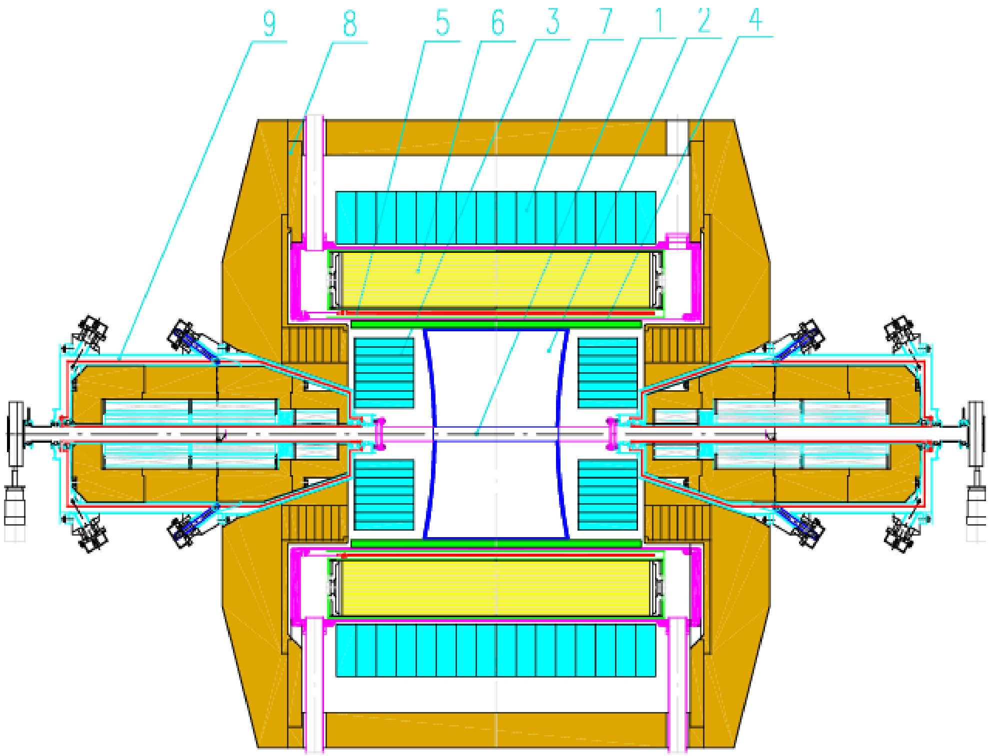




CMD-3 vs CMD-2

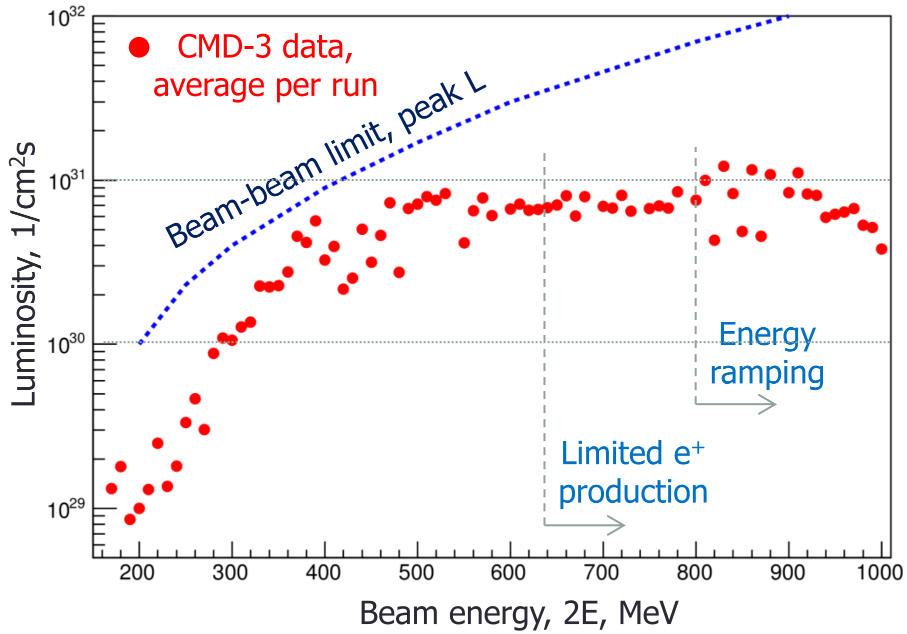
CMD-3 advantages compared to its predecessor CMD-2:

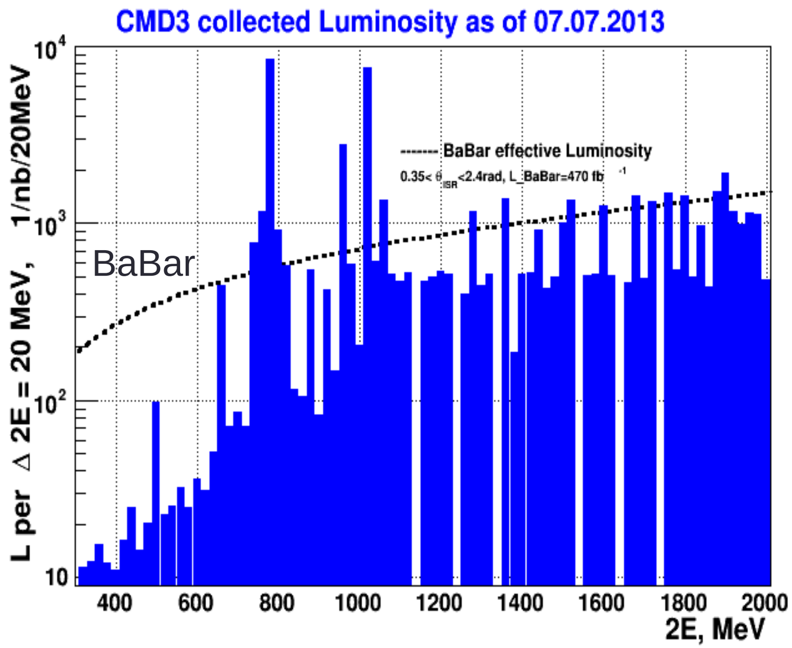
- new drift chamber with two times better resolution, higher B field
  better tracking
  better momentum resolution
- thicker barrel calorimeter ($8.3X_0 \rightarrow 13.4\ X_0$)
  better particle separation
- LXe calorimeter
  measurement of conversion point for γ's
  measurement of shower profile
- TOF system
  particle id (mainly p, n)



1 – IP, 2 – drift chamber, 3 – BGO (680 crystals), 4 – Z–chamber, 5 – SC solenoid, 6 – LXe (400 liters), 7 – CsI (1152 crystals), 8 – magnet yoke, 9 – ring solenoids, not shown – muon range system and TOF system

Collected luminosity





Currently the luminosity is limited by a deficit of positrons (from $E > 650$ MeV) and limited energy of the booster (from $E > 825$ MeV).

After upgrade in 2013-2014 we expect luminosity increase by up to factor 10 at maximum energy.

About 60 pb-1 collected per detector

$\omega(782)$	$8.3\ 1/pb$
$2E < 1$ GeV (except ω)	$9.4\ 1/pb$
$\varphi(1019)$	$8.4\ 1/pb$
$2E > 1.04$ GeV	$34.5\ 1/pb$

Physics program

1. Precision measurement of $R = \sigma(e^+e^- \to hadrons)/\,\sigma(e^+e^- \to \mu^+\mu^-)$
   exclusive approach, up to <1% for major modes
2. Study of hadronic final states:
   $$e^+e^- \to 2h, 3h, 4h, \ldots \quad h = \pi, K, \eta$$
3. Study of vector mesons and theirs excitations:
   $$\rho', \rho'', \omega', \varphi', \ldots$$
4. Comparison of cross-sections $e^+e^- \to hadrons\ (T = 1)$ with spectral functions of τ-decays
5. Study of nucleon electromagnetic formfactor at threshold
   $$e^+e^- \to p\bar{p}, n\bar{n}$$
6. Measurement of the cross-sections using ISR
7. Study of higher order QED processes

Overall, we plan to collect $0.5 \div 1$ 1/fb

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

The most challenging channel at CMD-3, because of the high precision.

Reasons to measure pion form factor yet again:

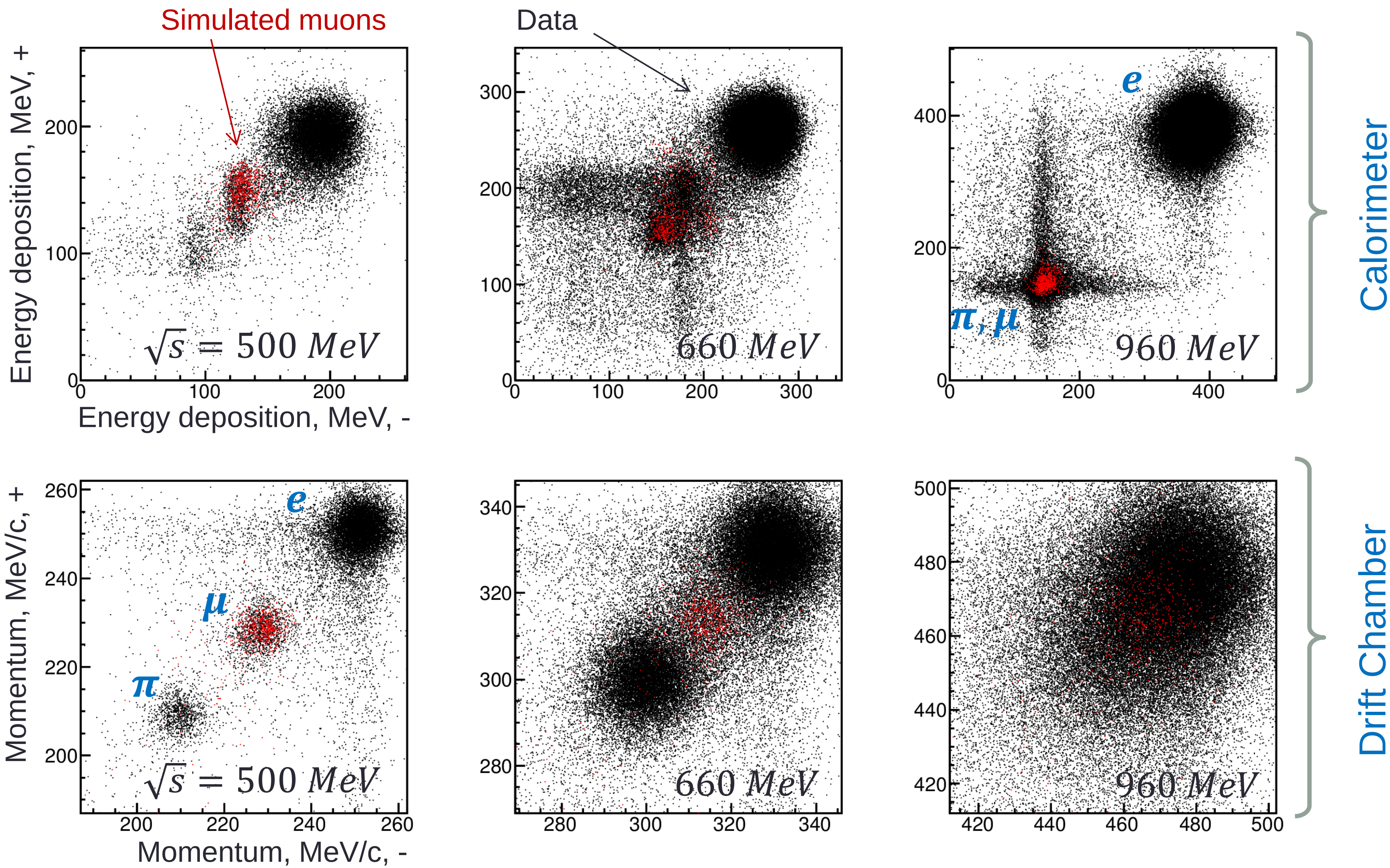
1. In units of hadronic contribution to $(g-2)_\mu$:
   $\delta a_\mu^{HVP} = 0.6\%, \quad \Delta a_\mu(\text{exp} - \text{theory}) \approx 4.0\% \pm 1.1\%$
   $\sigma(e^+e^- \to \pi^+\pi^-)$ attributes to 73% of a_μ^{HVP} and to 0.45% to δa_μ^{HVP}.
2. New experiment at FNAL is expected to measure $(g-2)_\mu$ to 0.25%
3. There is good overall agreement between KLOE, BABAR, CMD-2 and SND, but there are local disagreements.

CMD-3 goal: measure $\sigma(e^+e^- \to \pi^+\pi^-)$ with systematic accuracy of 0.3% and negligible statistical errors.

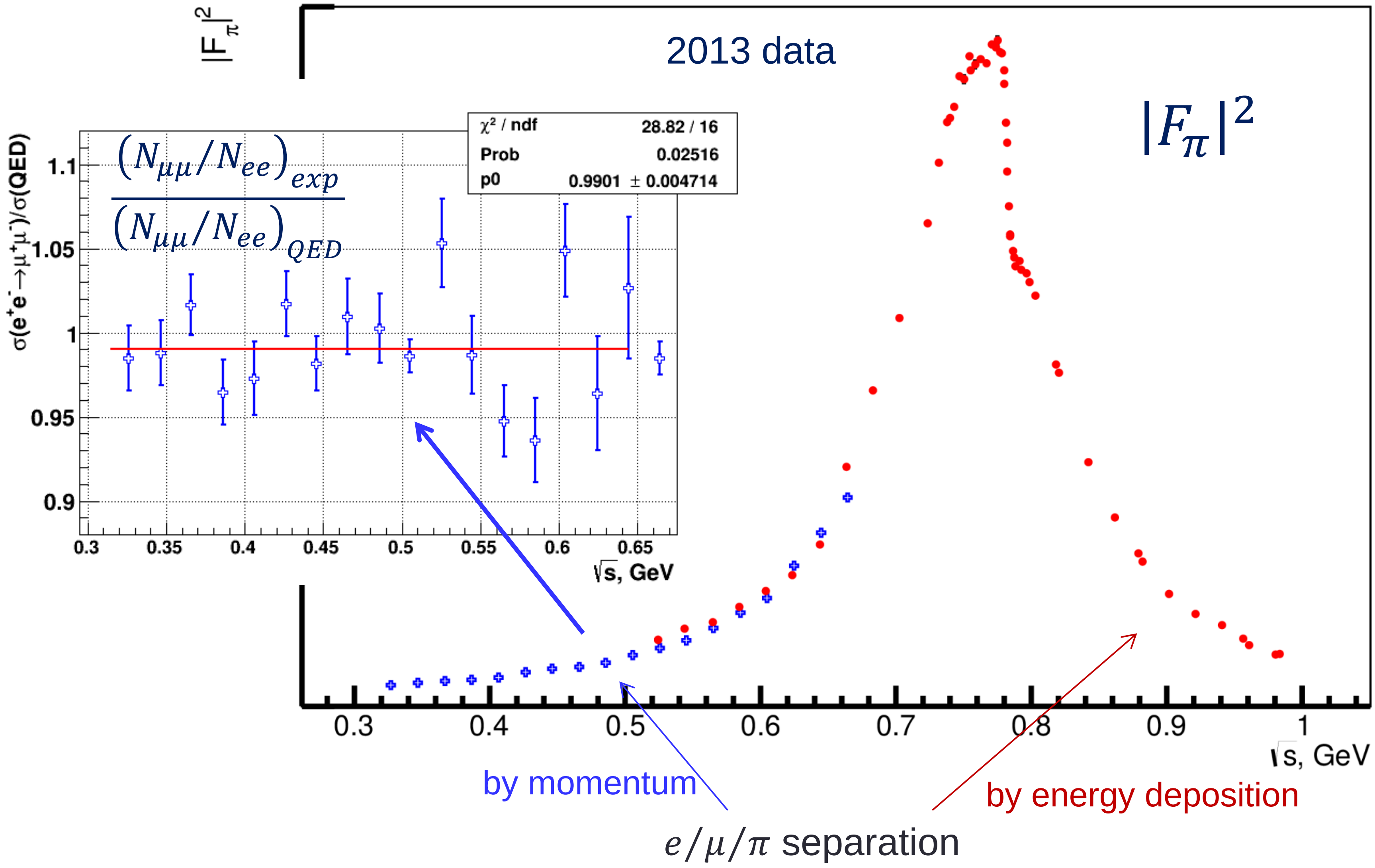
Means to improve systematics:

- Better $e/\mu/\pi$ separation – thick multilayer calorimeter, high resolution DC
- Continuous beam energy monitoring
- High statistics – allows to see systematic effects

$e^+e^- \to \pi^+\pi^-$: e, μ, π separation



$e^+e^- \to \pi^+\pi^-$: very preliminary results



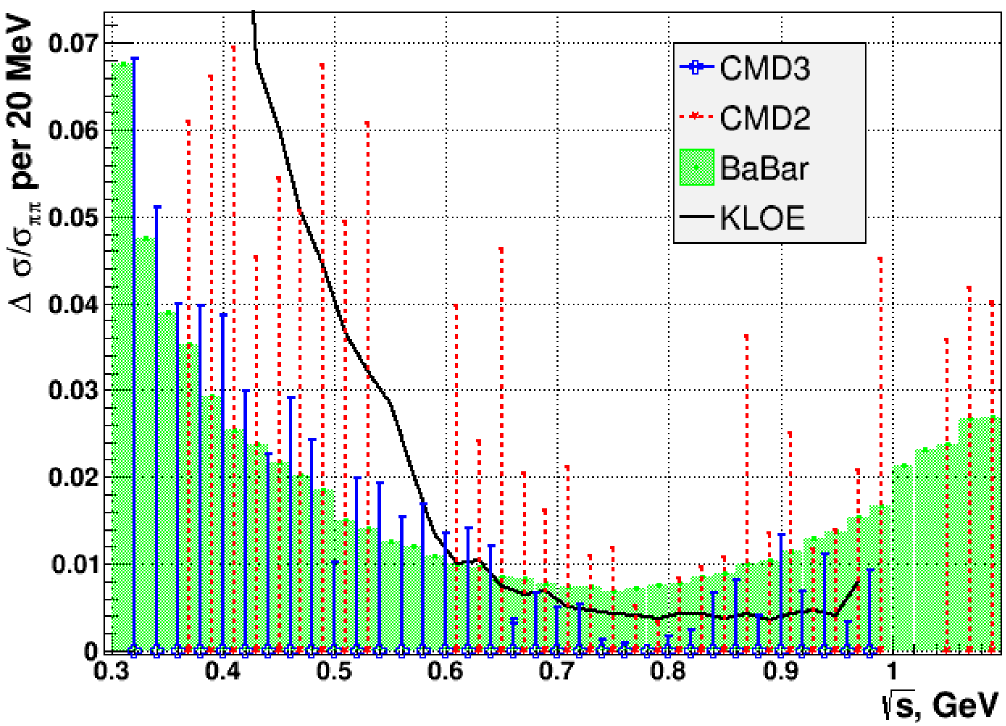
$e^+e^- \to \pi^+\pi^-$: statistics and systematics

Main sources of systematics:

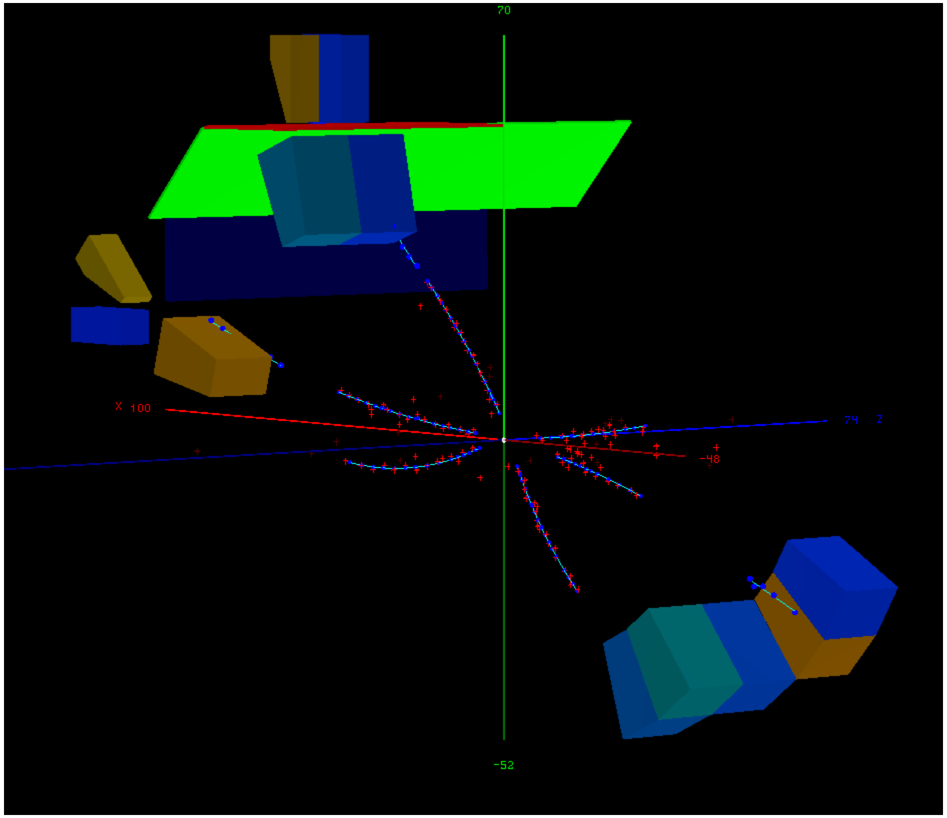
- $e/\mu/\pi$ separation – 0.2%
  multiple ways to get detector response from data itself
- fiducial volume – 0.1%
  2 independent systems, which can be used to determine fiducial volume
- beam energy – 0.1%
  constant monitoring with Compton backscattering
- radiative corrections – 0.1%
  proof from data

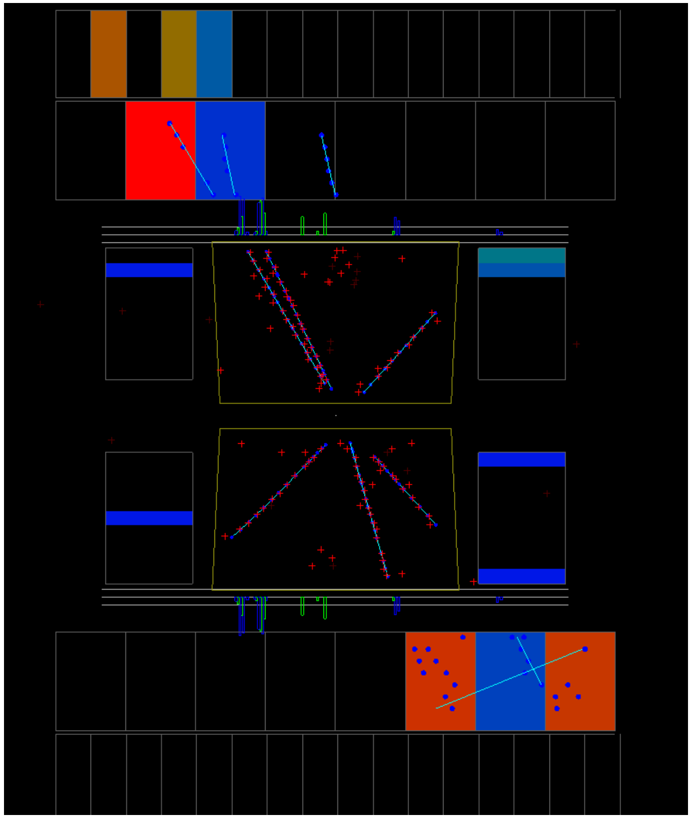
Many systematic studies rely on high statistics

Expected statistical error for 2013 data



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



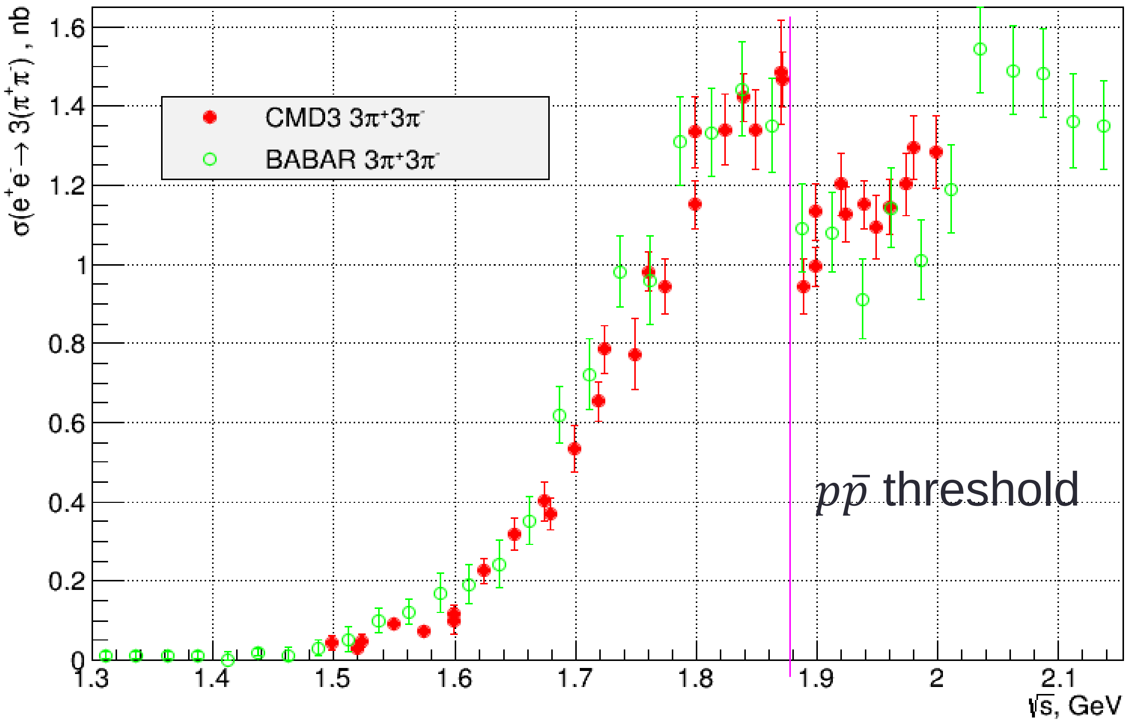


$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$

First result, published by CMD-3:
Phys.Lett. B723 (2013) 82-89

Based on about 22 1/pb, 8000 events selected

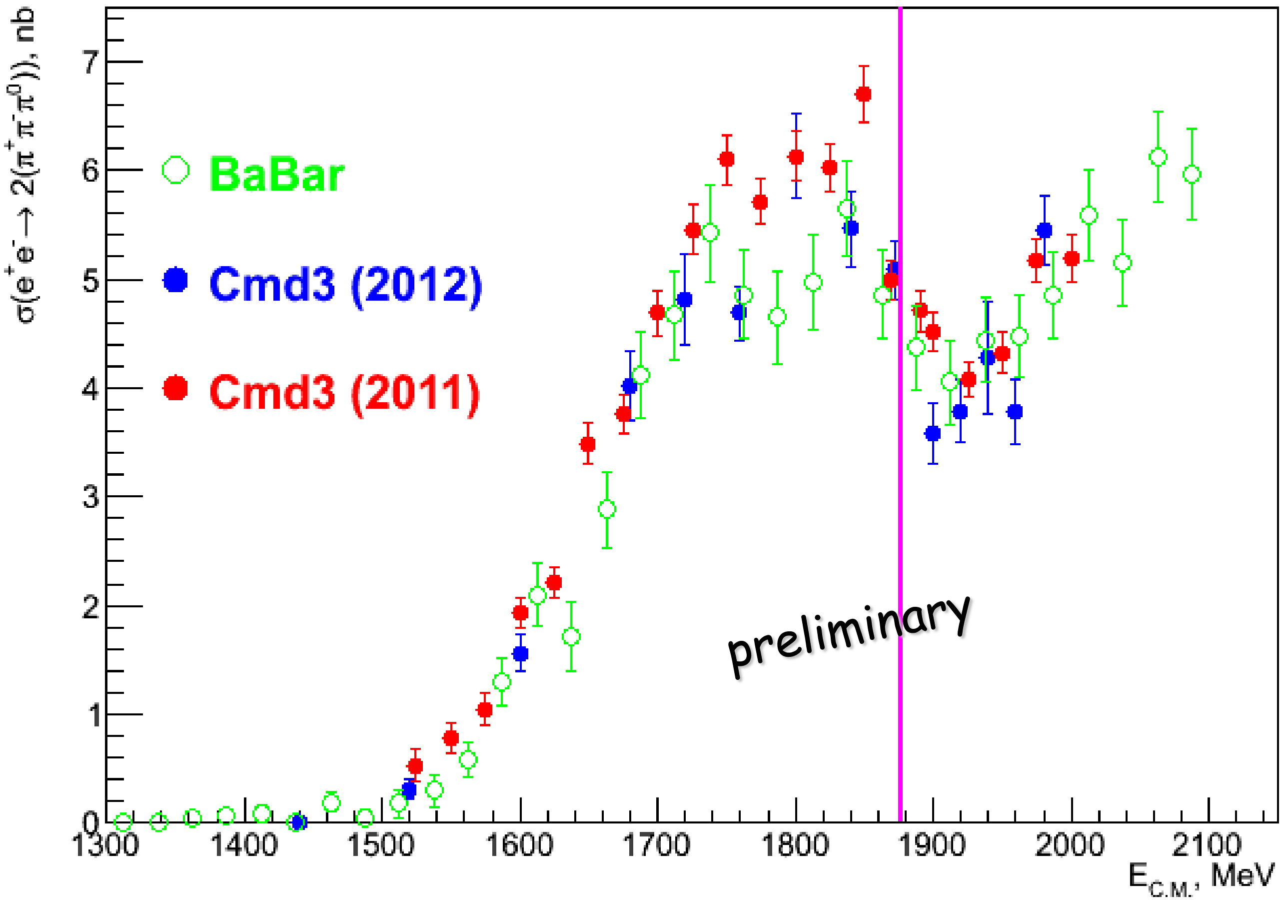
Systematic error is 6%, main source is model dependence, will be reduced with more statistics



Preliminary studies of dynamics:

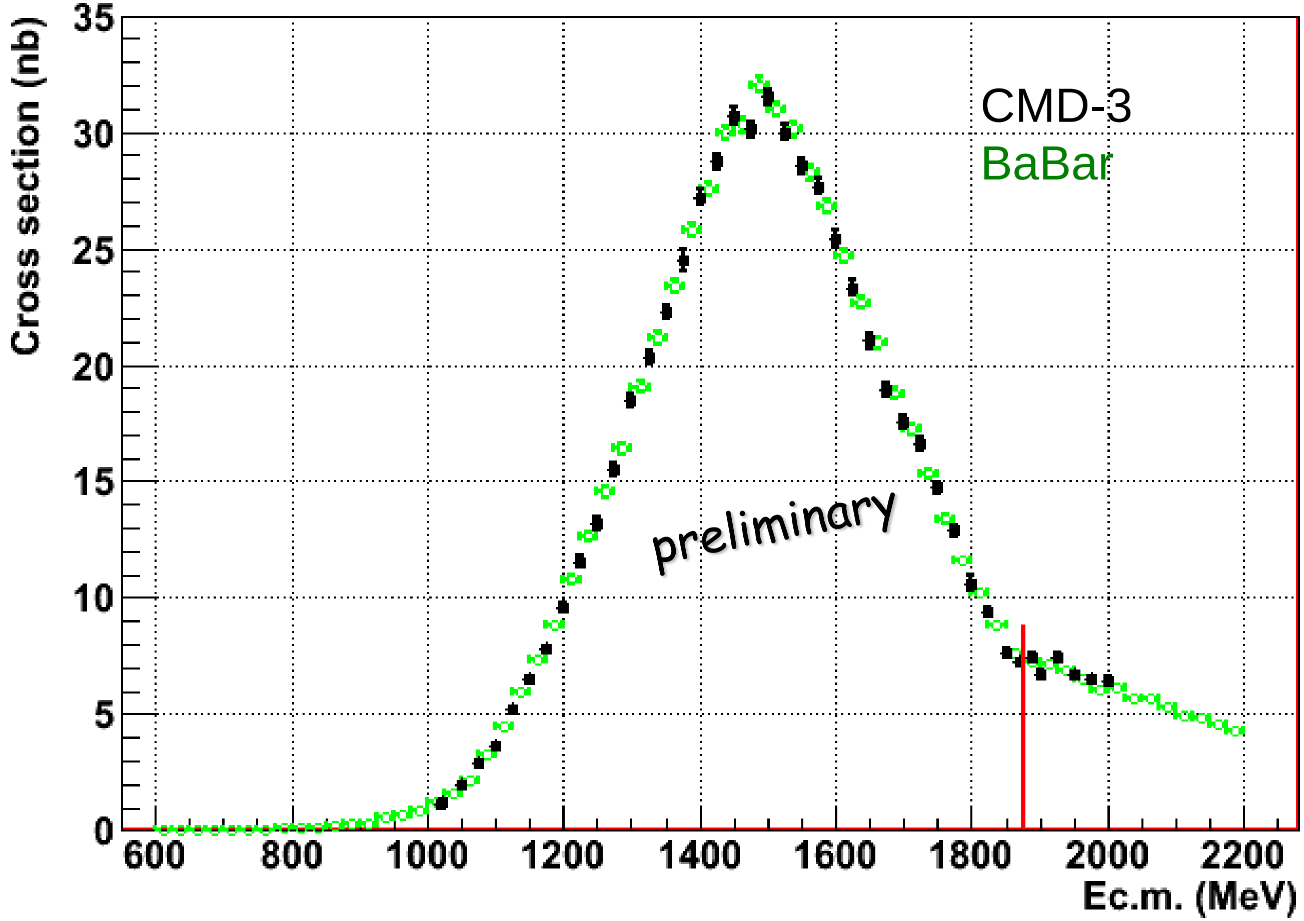
- Main production mode: $\rho(770) + 4\pi$ (phase space or f_0(1370))
- Hint of energy dependent dynamics in 1.7-1.9 GeV energy range

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



Ongoing analysis, $\omega\eta$, $\varphi\eta$ intermediate states are seen

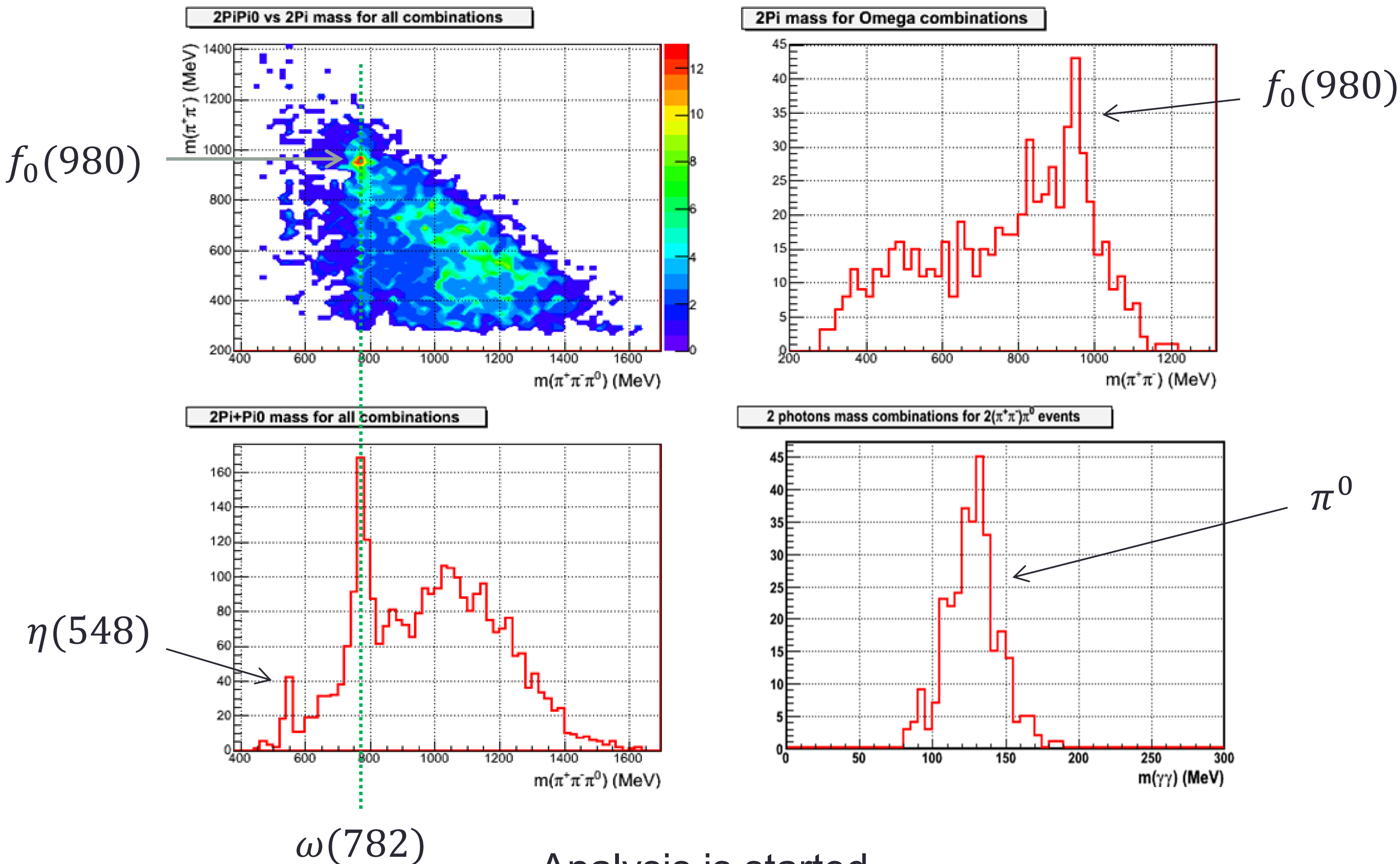
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$



Statistical errors 1-2% per point, systematics under study

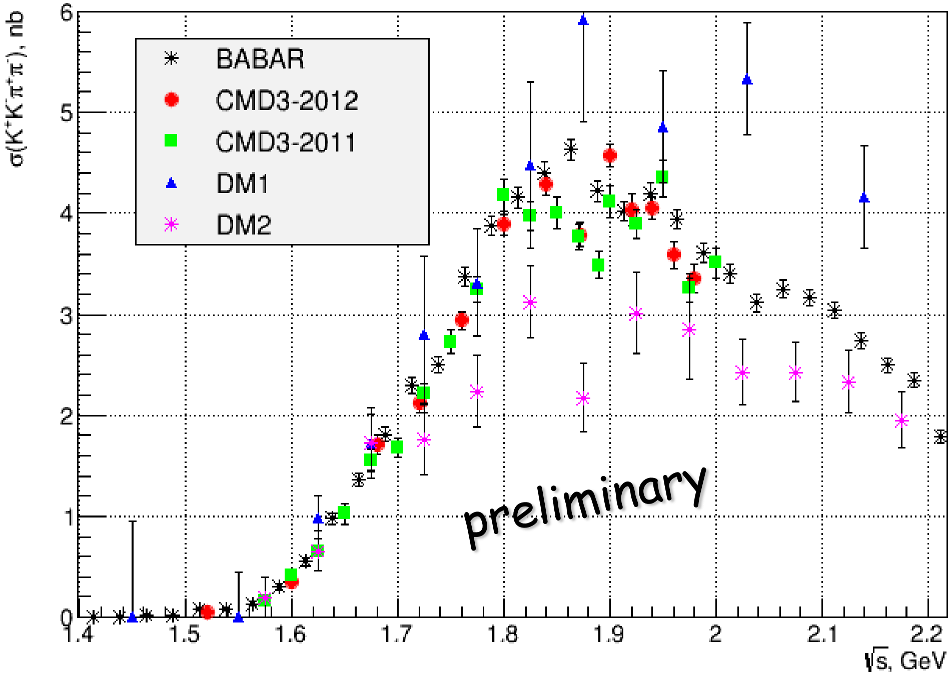
Dynamics: confirm $a_1(1260)\pi$ dominance, $\rho f_0(600)$, $\rho f_0(980)$ are seen

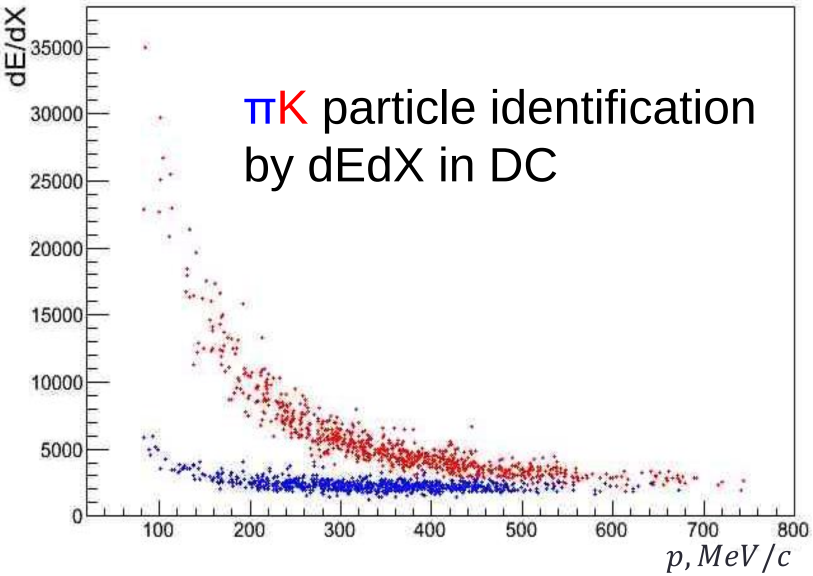
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$: first look

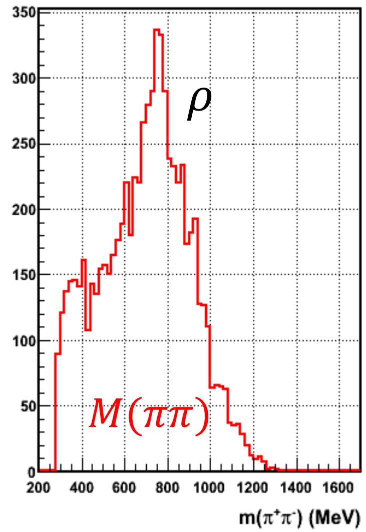


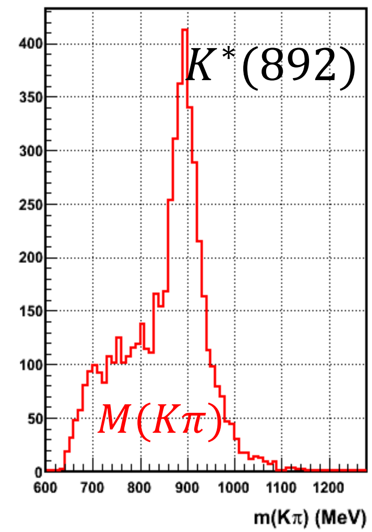
Analysis is started…

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









Seen many intermediate states:

$K_1(1270)K \rightarrow K^*(892)K\pi$

$K_1(1400)K \rightarrow K^*(892)K\pi$

$K_1(1270)K \rightarrow \rho KK$

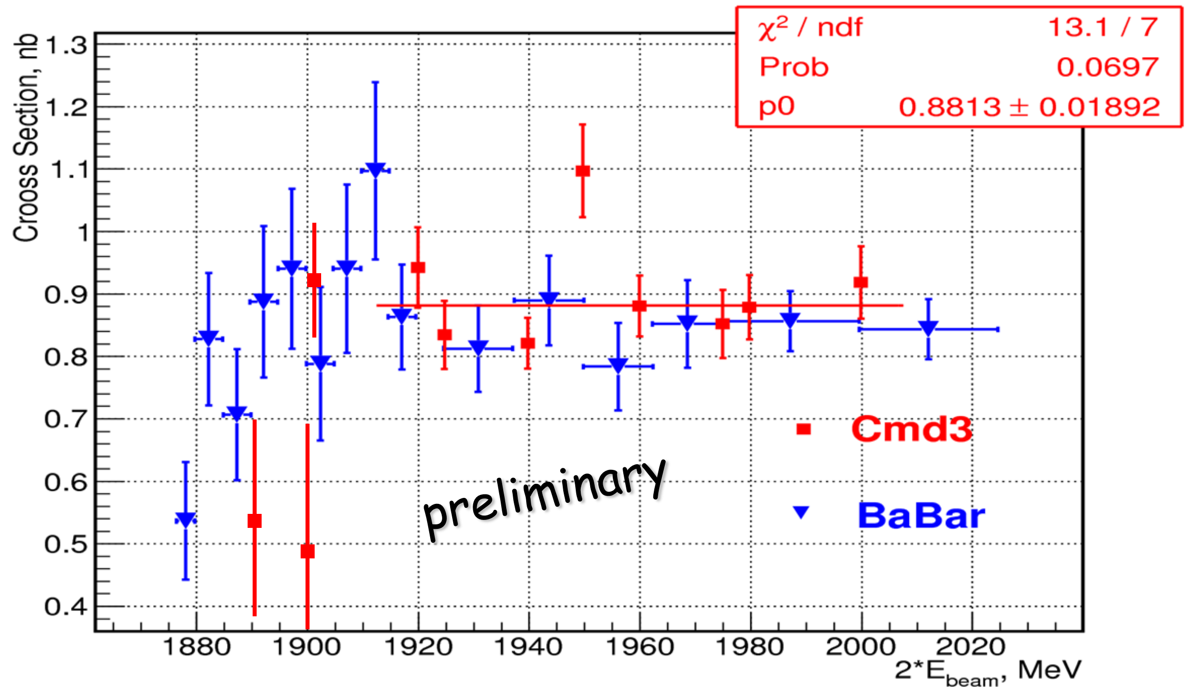
$K^*(892)K^*(892), \varphi\pi\pi$

There is dedicated poster presentation

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

Antiprotons identified by large dE/dx and by secondary particles.

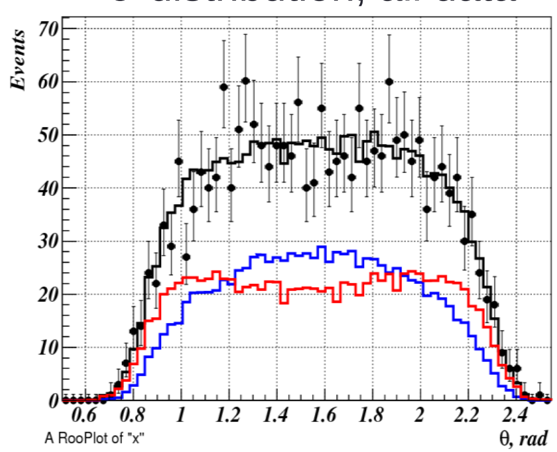
There is dedicated poster presentation.



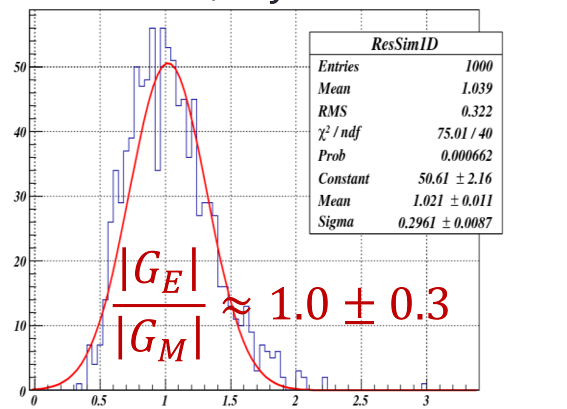
Angular distribution allows to extract $|G_E|^2$ and $|G_M|^2$:

$$|G_E|^2 \propto (1 - \cos^2\Theta)$$
$$|G_M|^2 \propto (1 + \cos^2\Theta)$$

Θ-distribution, all data



Stat.error, toy simulation



Need much more statistics!

Conclusion

- VEPP-2000 successfully started operation
- In 2011-2013 large amount of data collected in the whole energy range, exceeding total integral of VEPP-2M
- CMD-3 detector shows good performance
- Data analysis is ongoing, the first result is published
- We expect to produce new precise measurements of hadron production
- VEPP-2000 upgrade is upcoming, big boost in luminosity at high energies is expected