MEASUREMENT OF HADRONIC CROSS-SECTIONS AT VEPP-2000

Ivan Logashenko

on behalf of CMD-3 and SND collaborations

Budker Institute of Nuclear Physics
Novosibirsk State University

ICHEP 2016, August 3-10, 2016

$\sigma(e^+e^- \to hadrons)$ and the hadronic contribution to a_μ

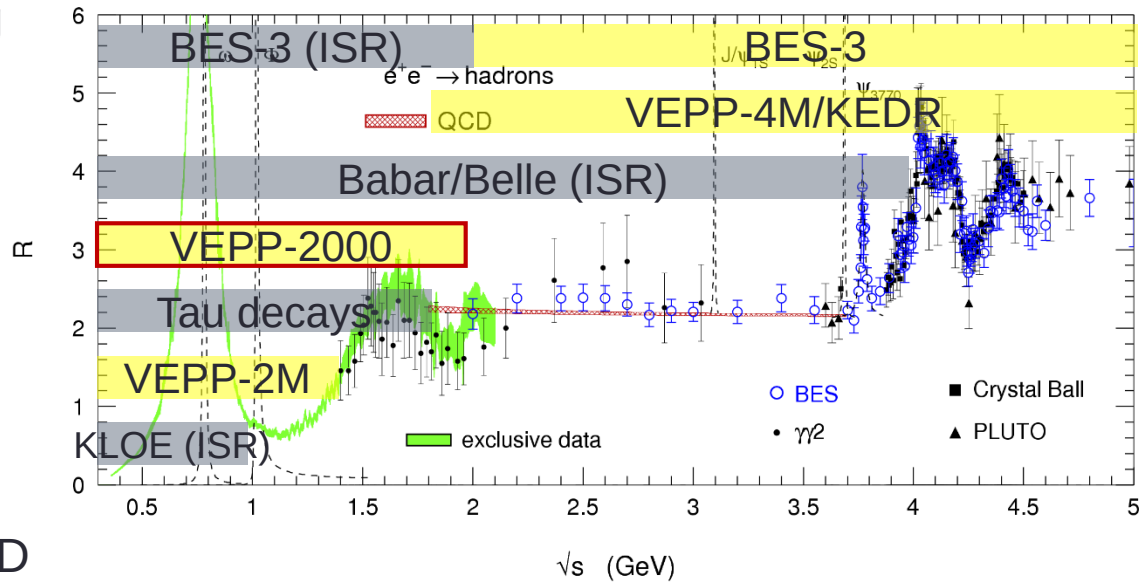
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

So far, the hadronic contribution to a_μ is calculated by integrating experimental cross-section $\sigma(e^+e^- \to hadrons)$.

Weighting function $\sim 1/s$, therefore lower energies contribute the most.

Many sources of data:

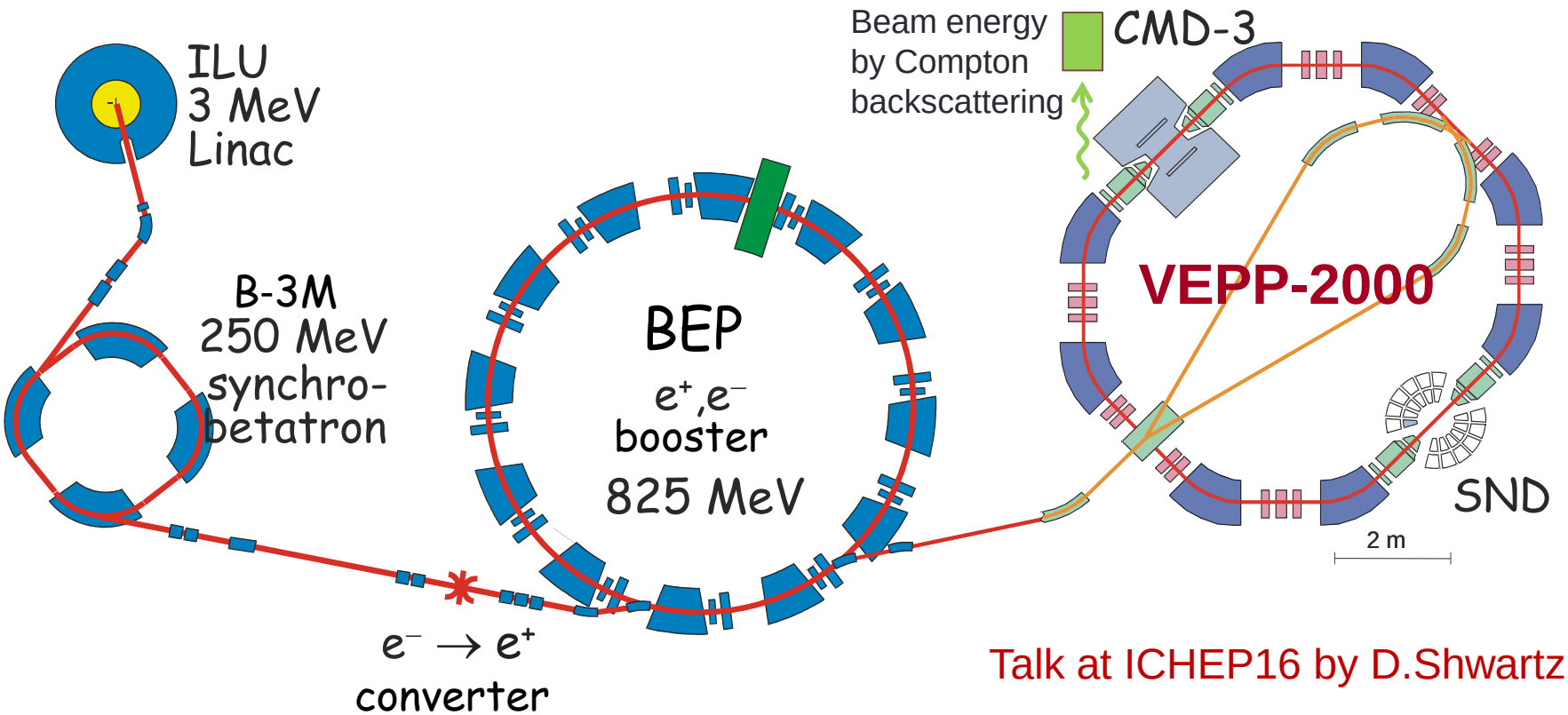
- Novosibirsk: CMD-2 and SND (VEPP-2M), CMD-3 and SND (VEPP-2000)
- Factories: Babar, KLOE
- BES-III, KEDR



$\Delta a_\mu(exp - th) = (287 \pm 80) \cdot 10^{-11}$ (DHMZ'12) corresponds to $(4.15 \pm 1.15)\% \cdot a_\mu^{had,LO}$

FNAL expected precision of 140 ppb corresponds to $0.25\% \cdot a_\mu^{had,LO}$

VEPP-2000 (2010-2013)

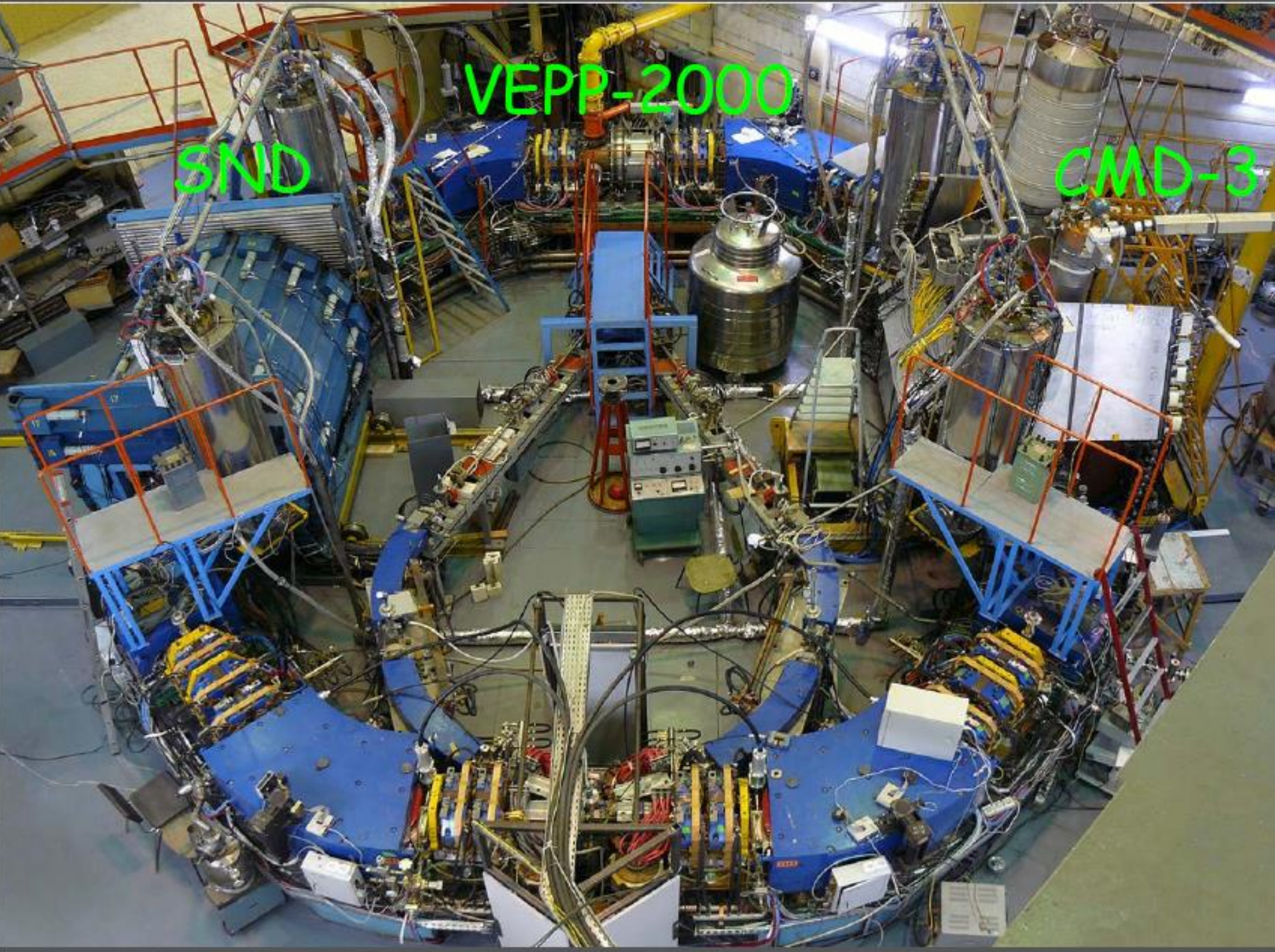


Talk at ICHEP16 by D.Shwartz

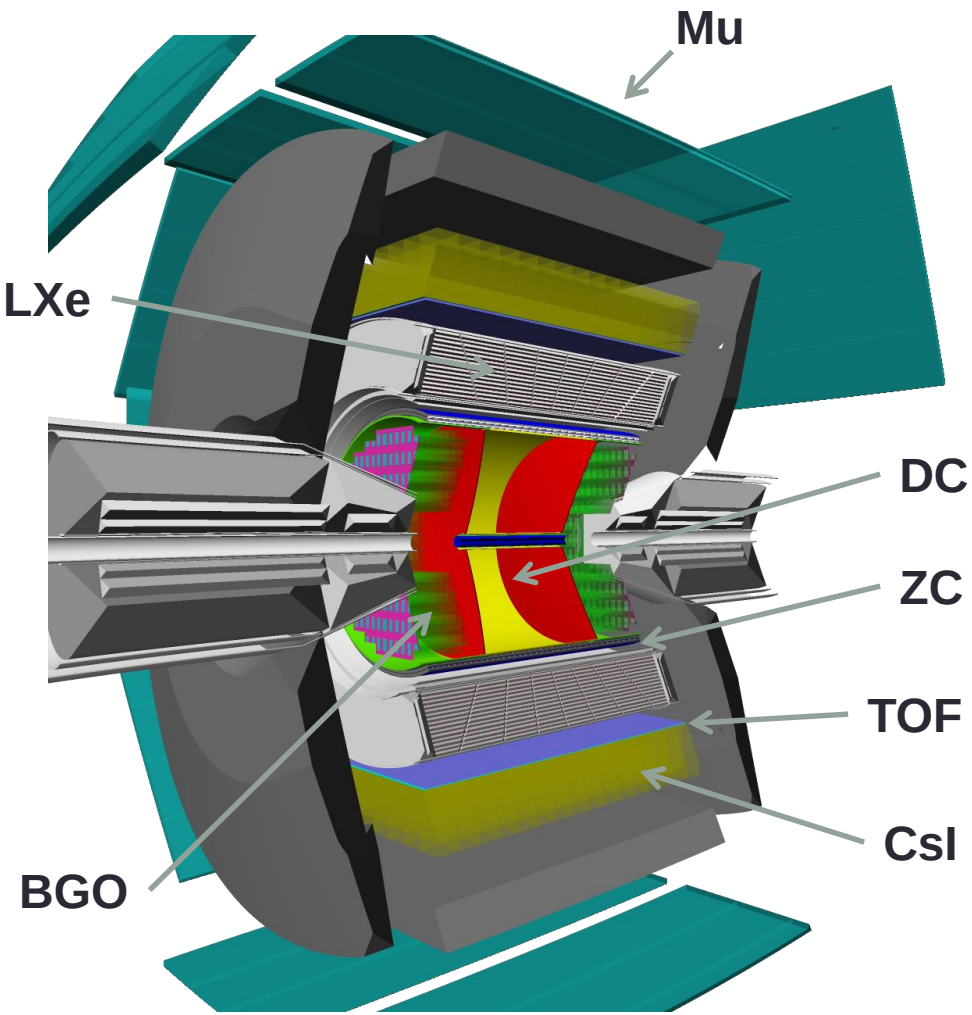
C.m. energy range is 0.32-2.0 GeV; unique optics – “round beams”

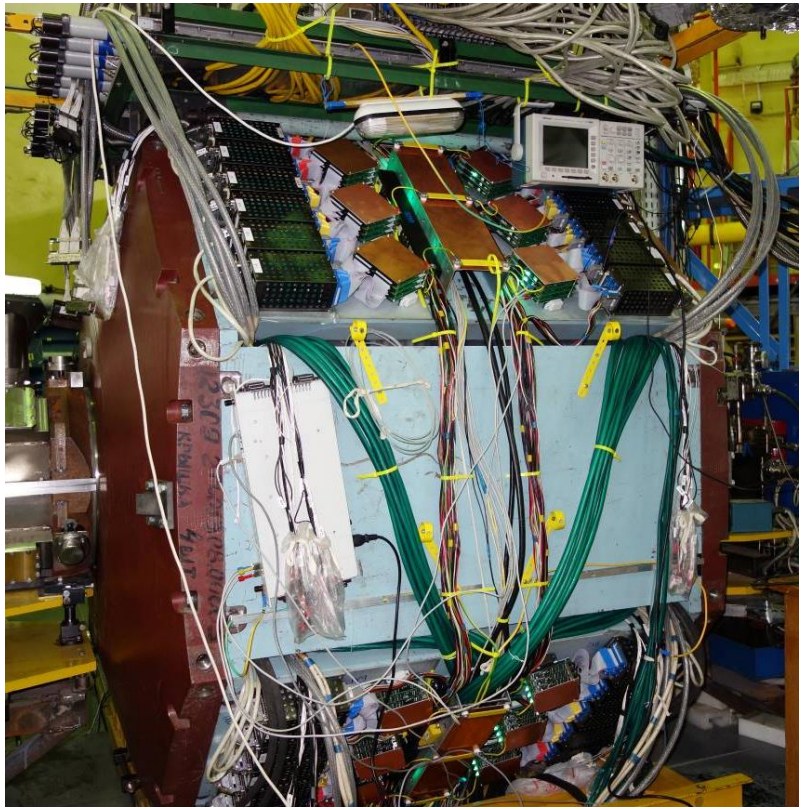
Design luminosity is $L = 10^{32} 1/cm^2 s$ @ $\sqrt{s} = 2$ GeV

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


VEPP-2000
SND
CMD-3

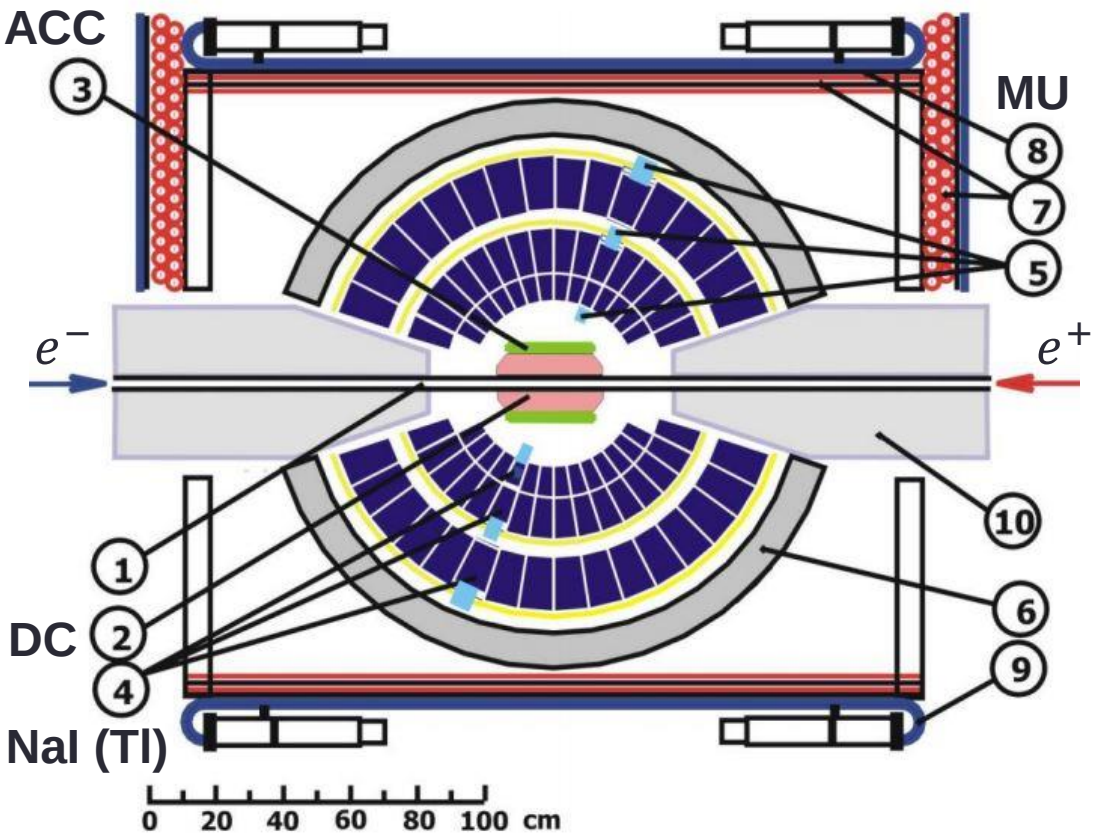
Detector CMD-3



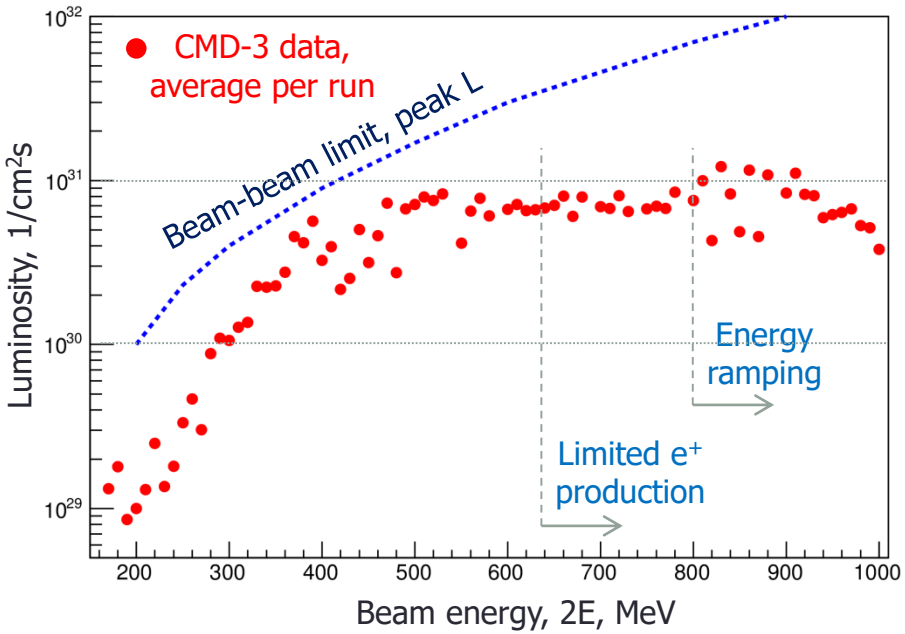


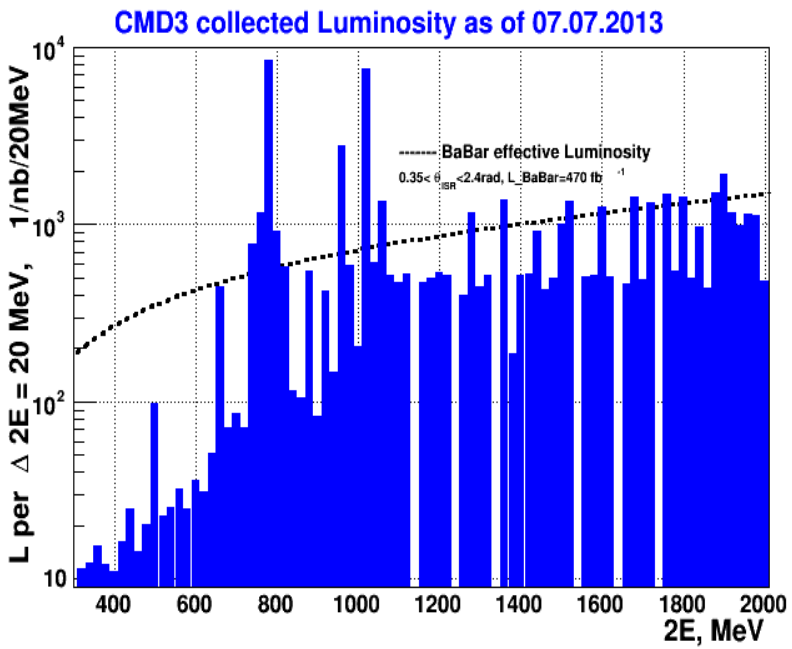
1.3 T magnetic field
Tracking: $\sigma_{R\varphi} \sim 100\ \mu, \sigma_z \sim 2$ mm
Combined EM calorimeter (LXE, CsI, BGO), $\sigma_E \sim 3\% - 8\%$

Detector SND



Collected luminosity (CMD-3)





The luminosity was limited by a deficit of positrons and limited energy of the booster.

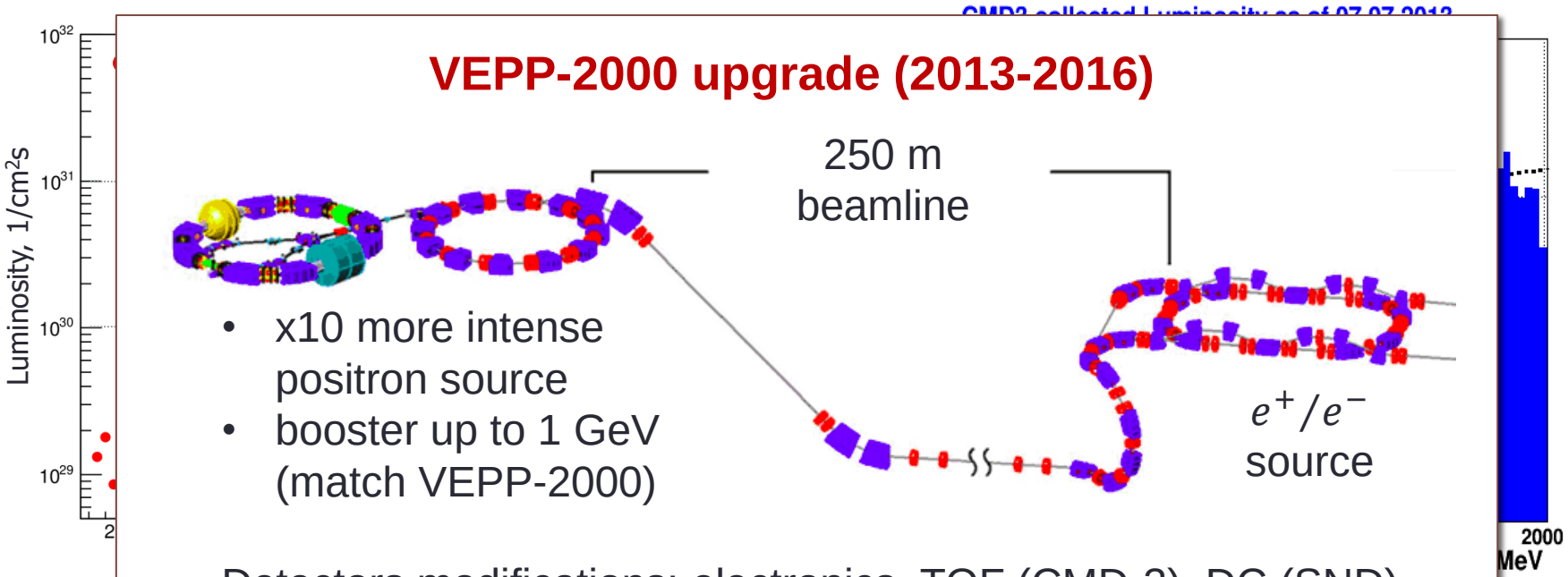
The VEPP-2000 upgrade has started in 2013.

After upgrade we expect to reach the project luminosity.

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	$34.5\ 1/pb$

Collected luminosity (CMD-3)



VEPP-2000 upgrade (2013-2016)

250 m beamline

- x10 more intense positron source
- booster up to 1 GeV (match VEPP-2000)

e^+/e^- source

Detectors modifications: electronics, TOF (CMD-3), DC (SND)

Restart of data taking by the end of 2016

The
positr

The VEPP-2000 upgrade has started in 2013.

After upgrade we expect to reach the project luminosity.

$\omega(782)$	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 $1/pb$

Exclusive channels under analysis

At VEPP-2000 we do exclusive measurement of $\sigma(e^+e^- \to hadrons)$.

- 2 charged

$$e^+e^- \to \pi^+\pi^-, K^+K^-, K_SK_L, p\overline{p}$$

- 2 charged + γ's

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

- 4 charged

$$e^+e^- \to \pi^+\pi^-\pi^+\pi^-, K^+K^-\pi^+\pi^-, K_SK^*$$

- 4 charged + γ's

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

- 6 charged

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

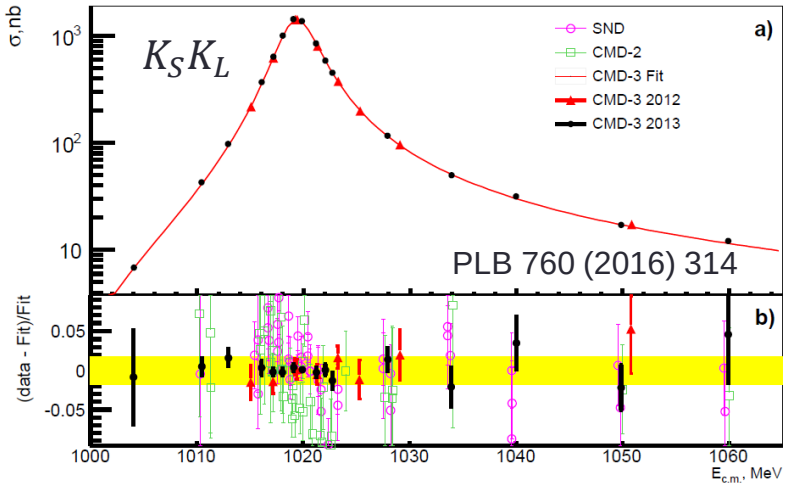
- γ's only

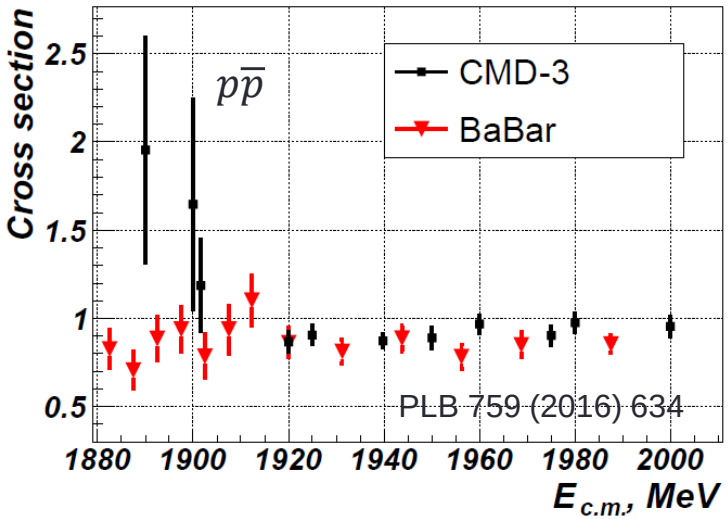
$$e^+e^- \to \pi^0\gamma, \eta\gamma, \pi^0\pi^0\gamma, \pi^0\eta\gamma, \pi^0\pi^0\pi^0\gamma, \pi^0\pi^0\eta\gamma$$

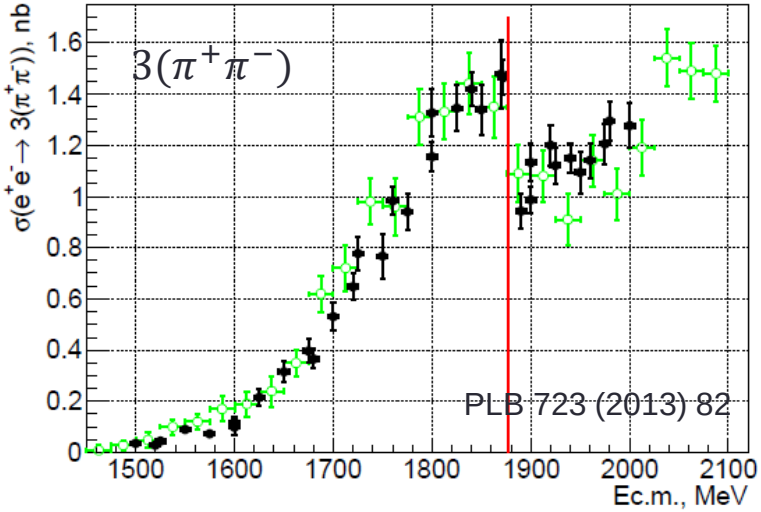
- other

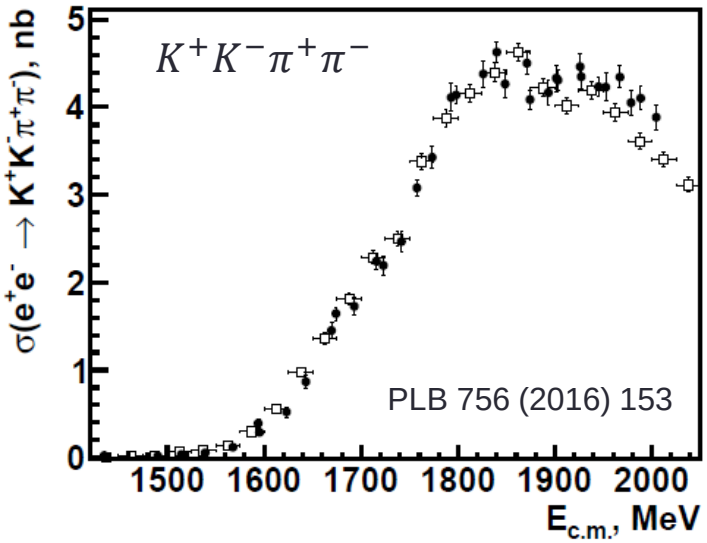
$$e^+e^- \to n\overline{n}, \pi^0e^+e^-, \eta e^+e^-$$

Published results from 2011-2013: CMD-3

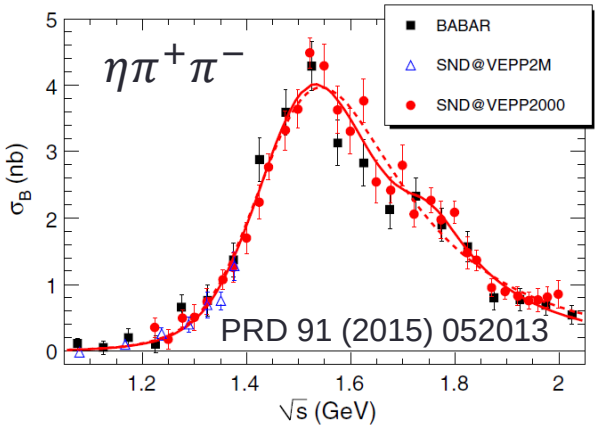


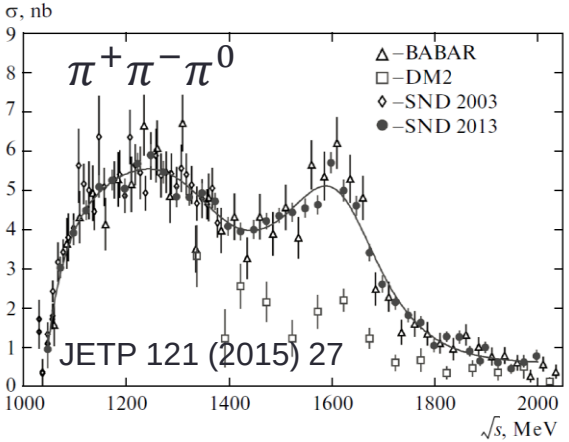


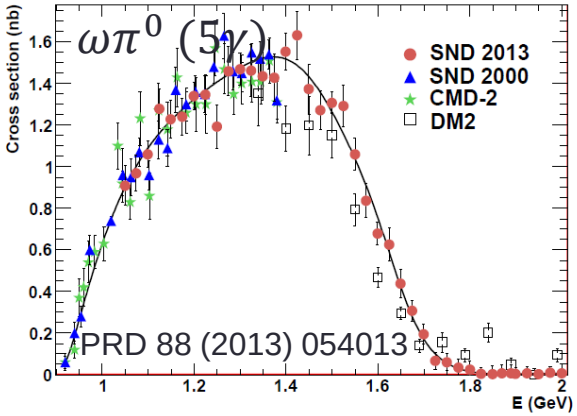


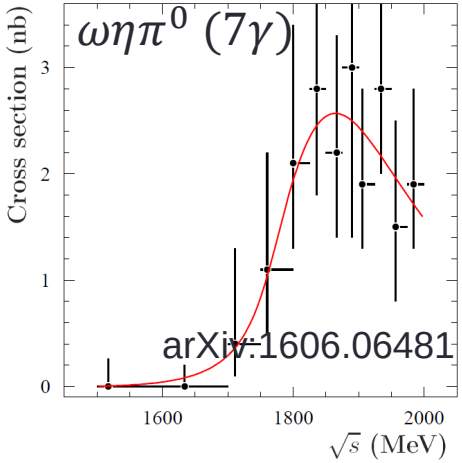


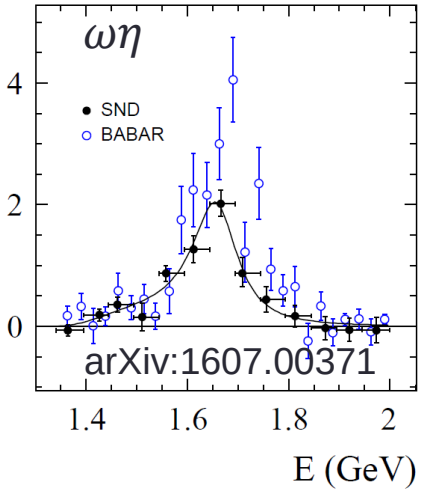
Published results from 2011-2013: SND

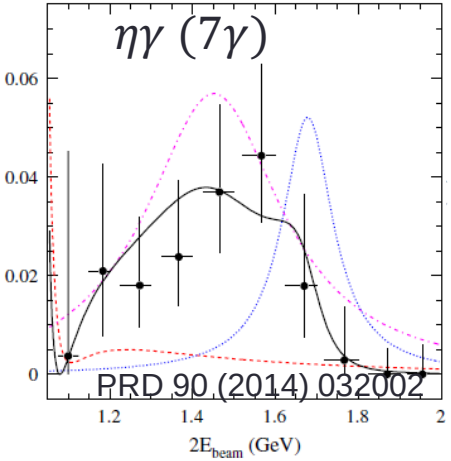


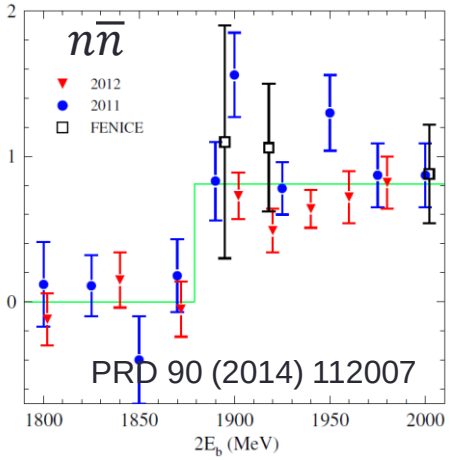




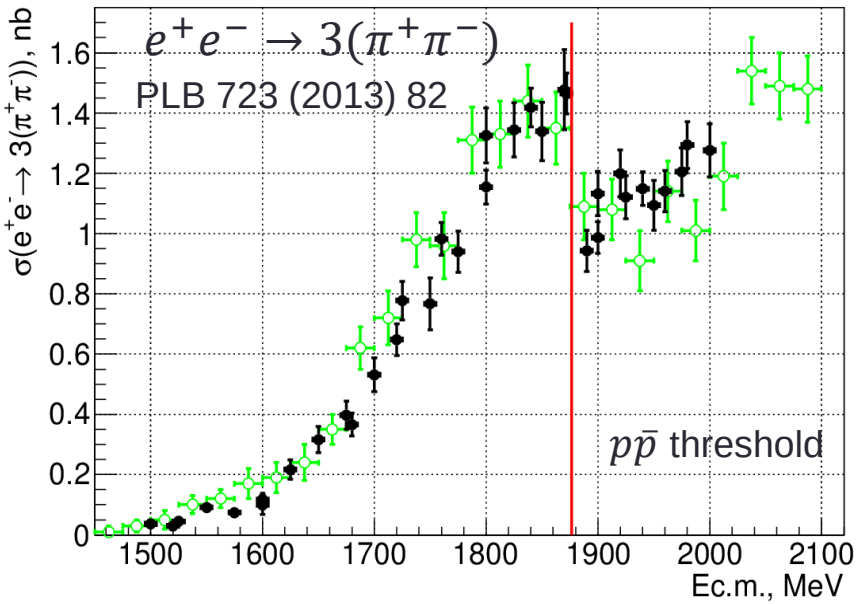


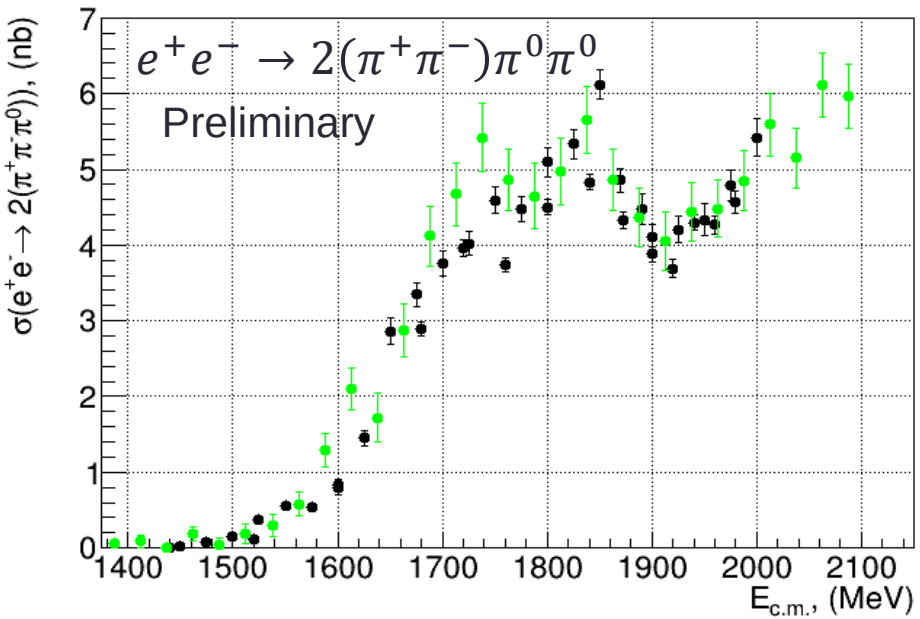






$e^+e^- \to 6\pi$ @CMD-3





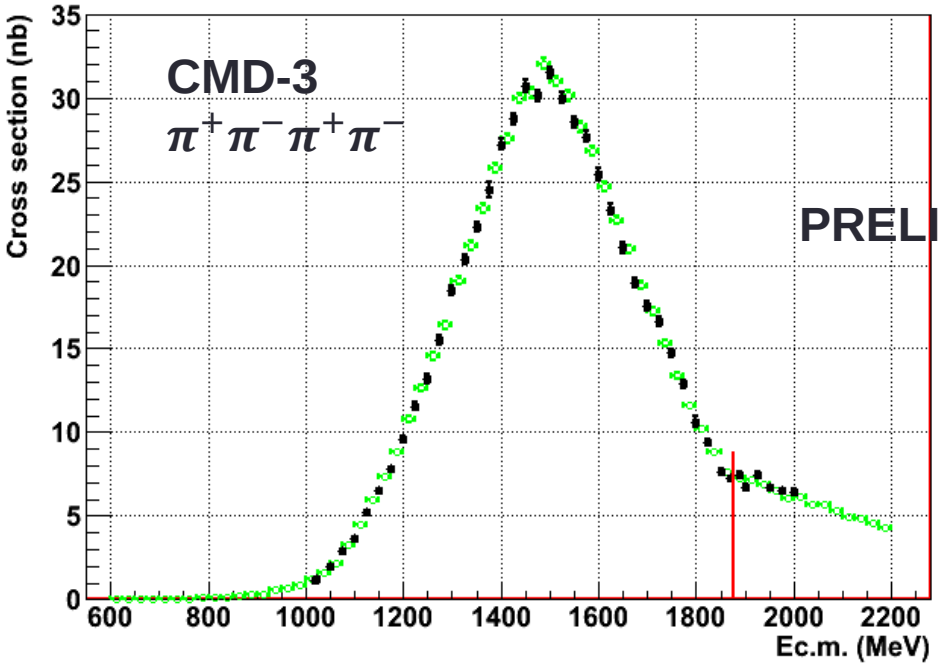
Preliminary studies of dynamics of $e^+e^- \to 3(\pi^+\pi^-)$:

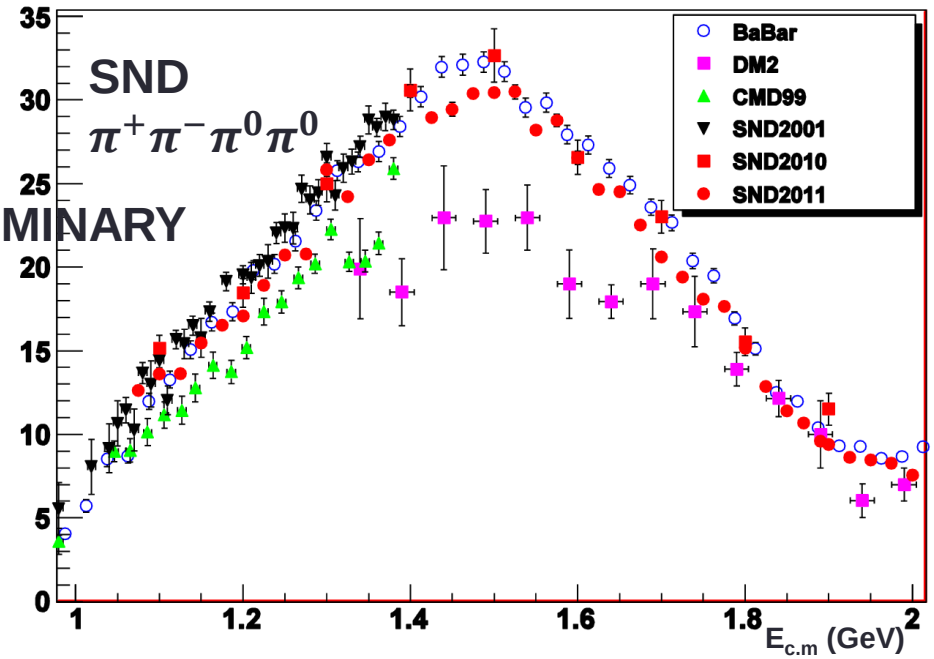
- Main production mode: $\rho(770) + 4\pi$ (phase space or $f_0(1370)$)
- Hint of energy dependent dynamics in 1.7-1.9 GeV energy range

Possible contributions to $e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0$:

$\rho(4\pi)$, ρf_0, ρa_0, $\omega(3\pi)$, $\eta(3\pi)$, $\omega\eta$

Preliminary: $e^+e^- \to 4\pi$

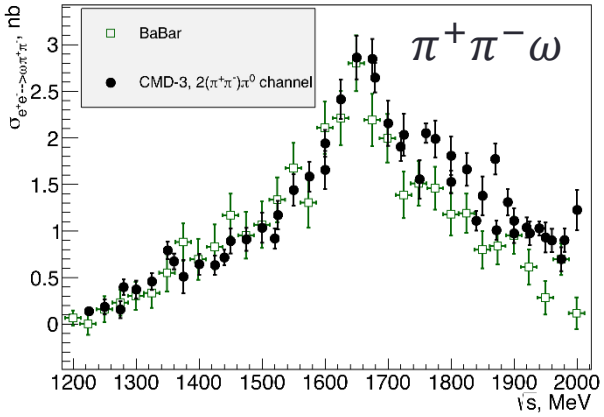


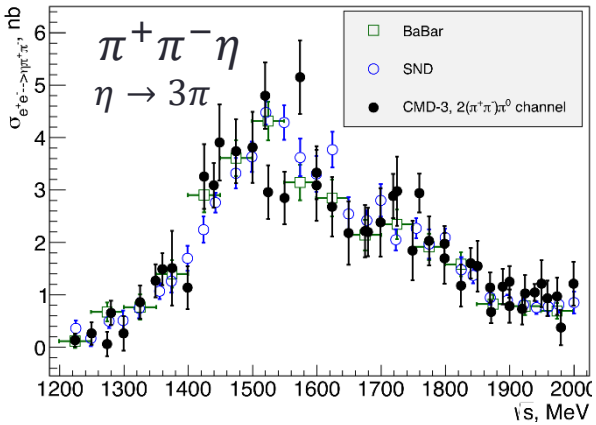


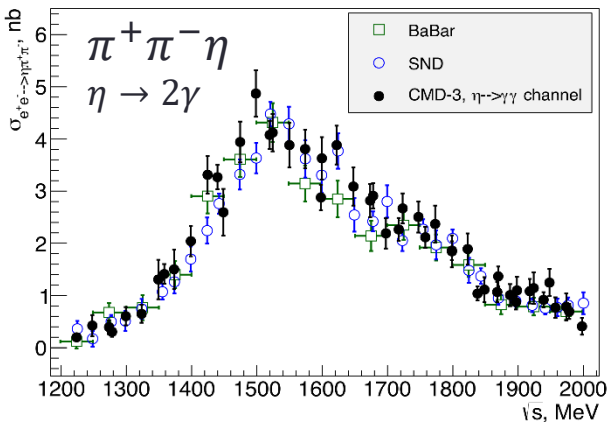
Dominant channels above φ meson. Need to measure these channels to a few %.

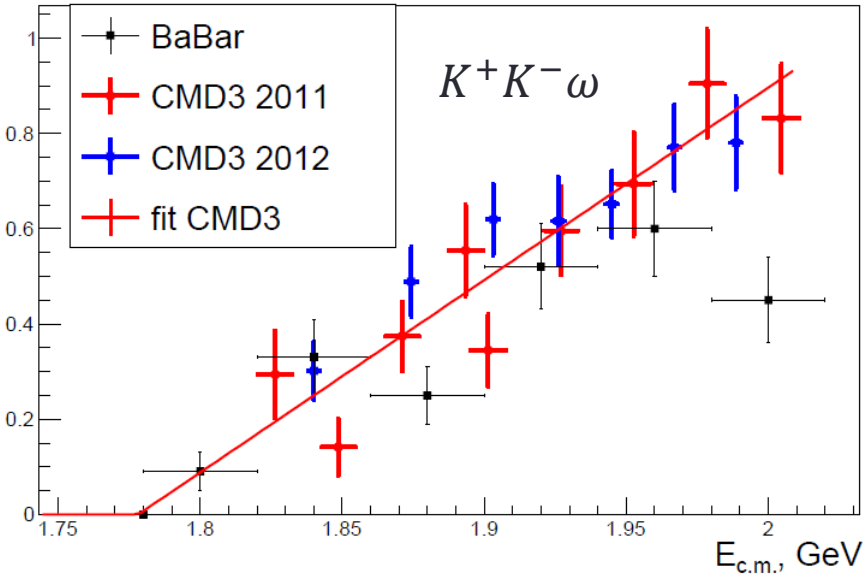
The dominant source of systematic error is the model uncertainty. Detailed understanding of dynamics ($\omega\pi^0, a_1\pi, a_2\pi, \rho f_0, \ldots$) in necessary to reach precision.

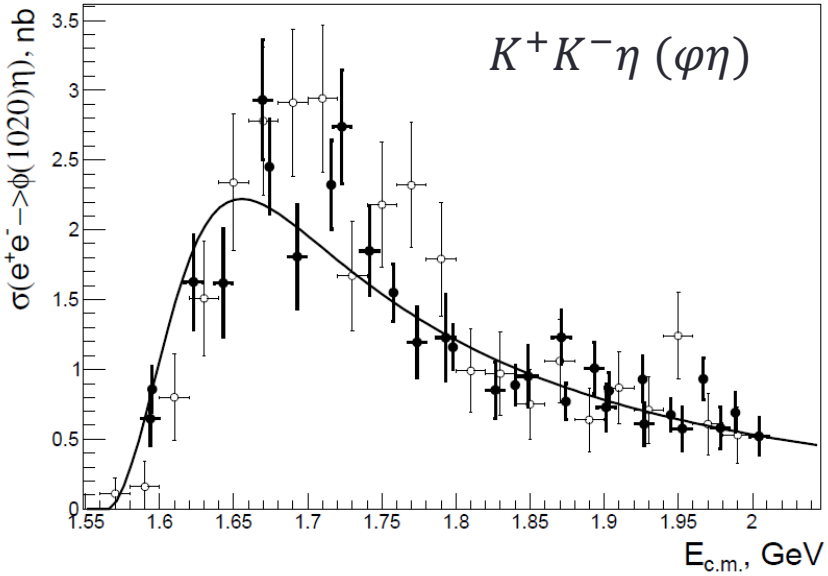
CMD-3 preliminary: $\pi^+\pi^-(\omega,\eta), K^+K^-(\omega,\eta)$



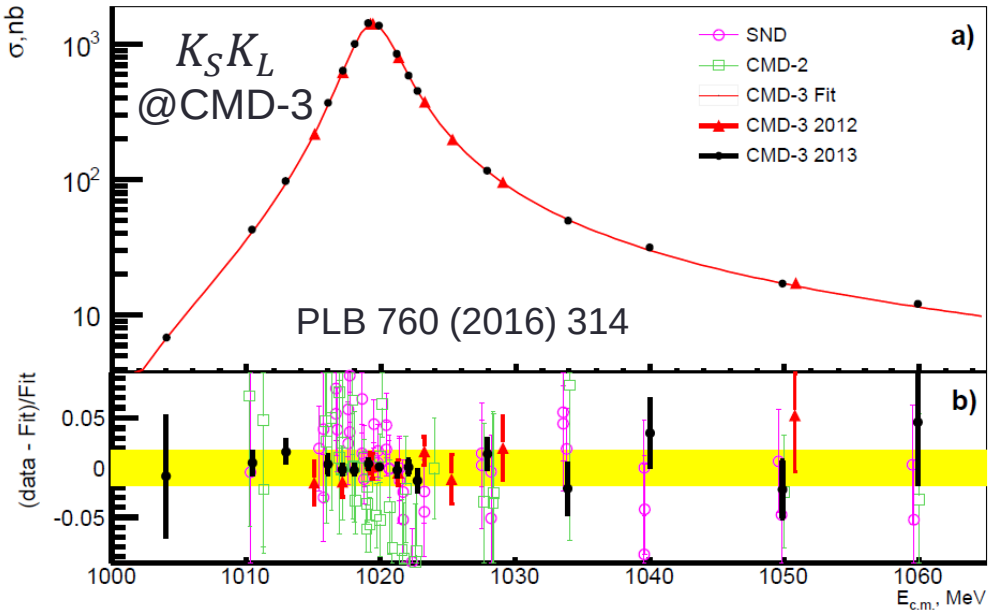


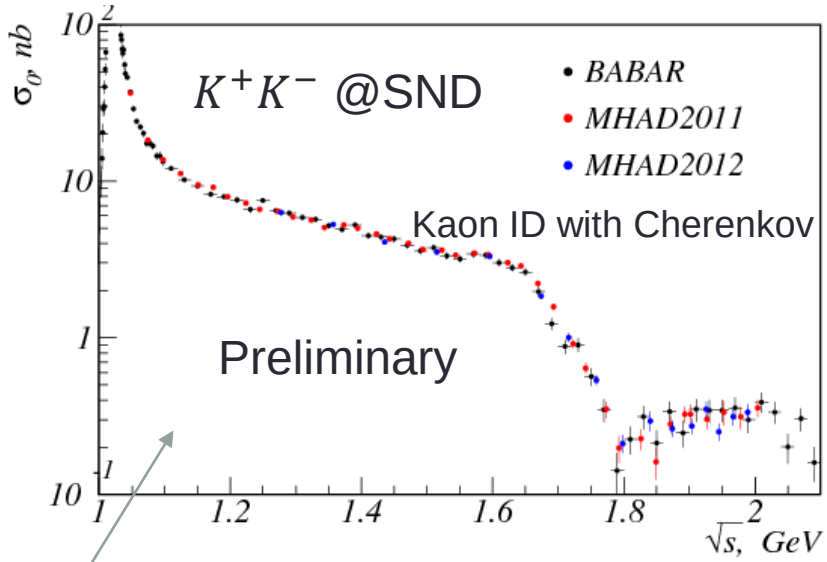


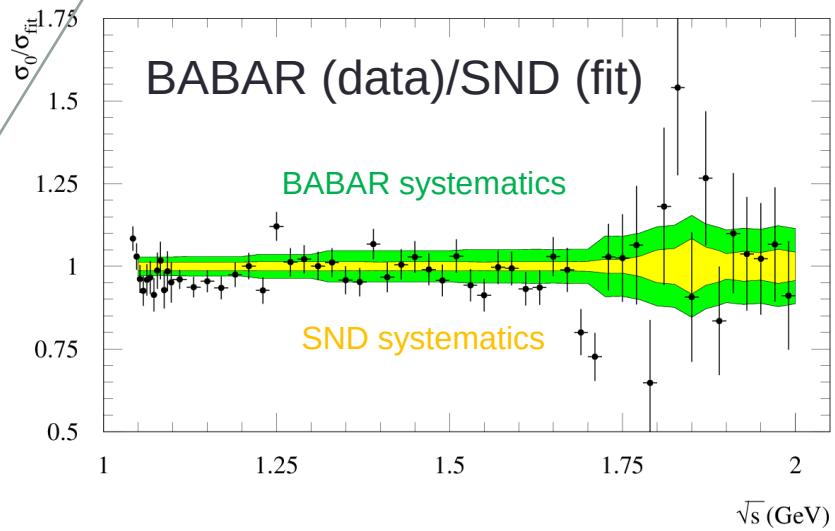




$K_S K_L$ @CMD3 and K^+K^- @SND



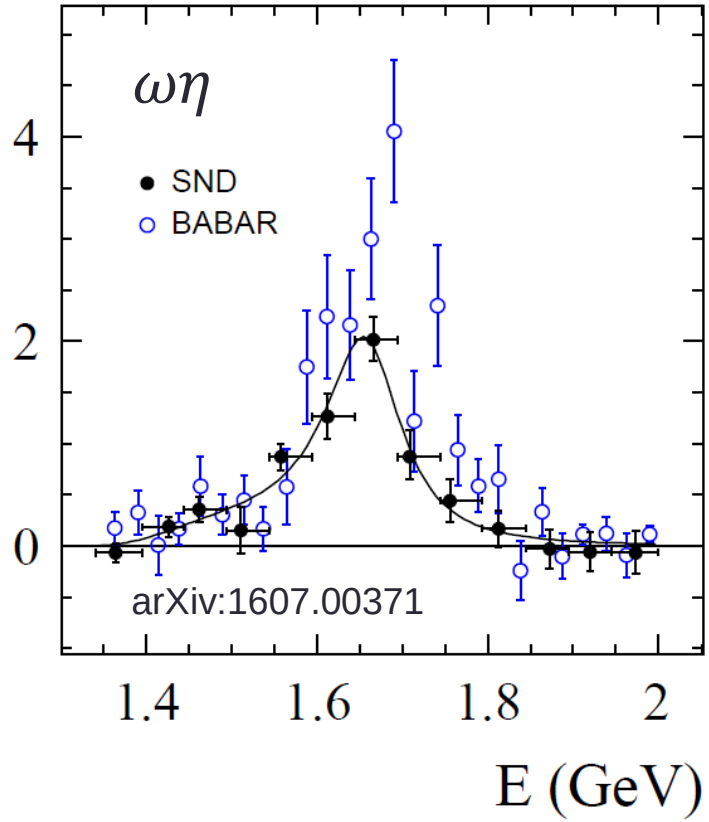


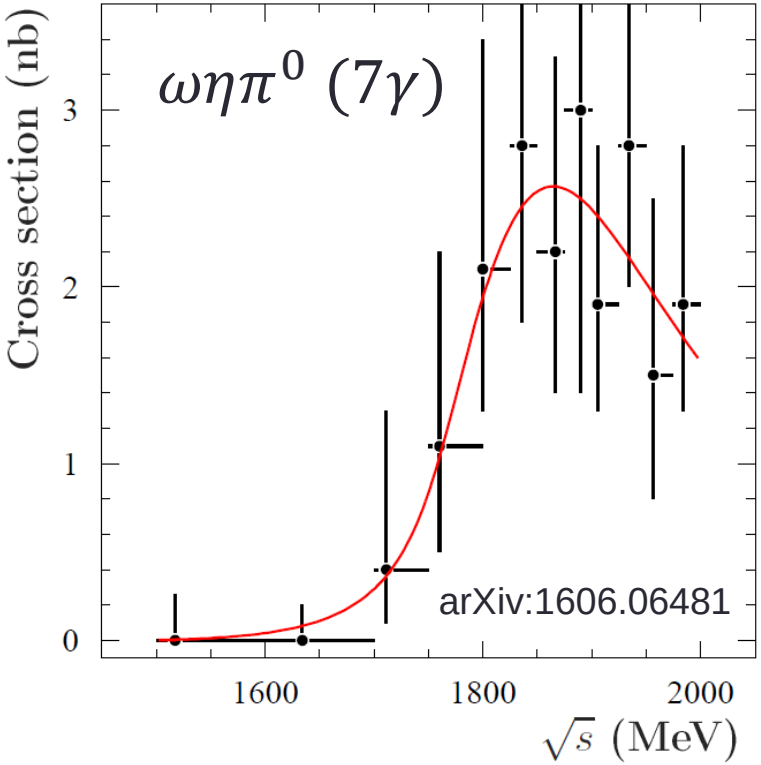


Recent result from CMD-3: $K_S K_L$ at φ
Best systematic precision (1.8%)
K^+K^- is under internal review

Preliminary result on K^+K^- from SND
Good kaon ID using aerogel Cherenkov

New results from SND: $\omega\eta, \omega\eta\pi^0$

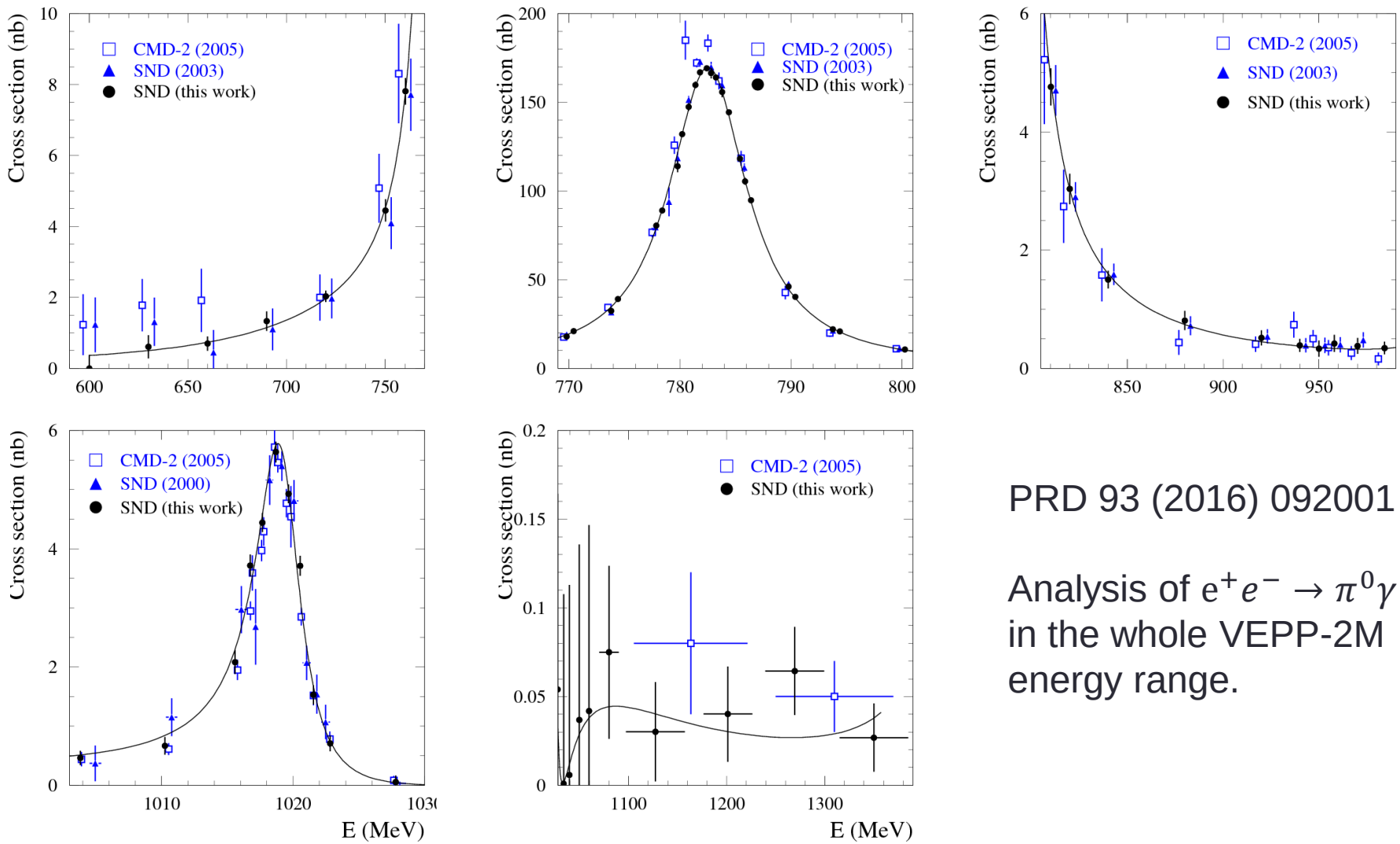




Part of $\pi^+\pi^-\pi^0\eta$ (under analysis).
Other contributions: $\phi\eta$, $a_0\rho$, structureless
There is difference between SND and BABAR

Analyzed in 7γ channel
First measurement
Consistent with $\rho(1700) \to \omega a_0$

VEPP-2M is still alive: $\pi^0\gamma$ @SND



PRD 93 (2016) 092001

Analysis of $e^+e^- \to \pi^0\gamma$ in the whole VEPP-2M energy range.

Dominant channel: $e^+e^- \to \pi^+\pi^-$ @CMD-3

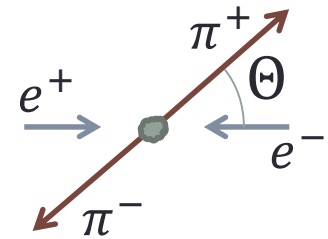
Very simple, but the most challenging channel due to high precision requirement.

Crucial pieces of analysis:

- $e/\mu/\pi$ separation
- precise fiducial volume
- radiative corrections

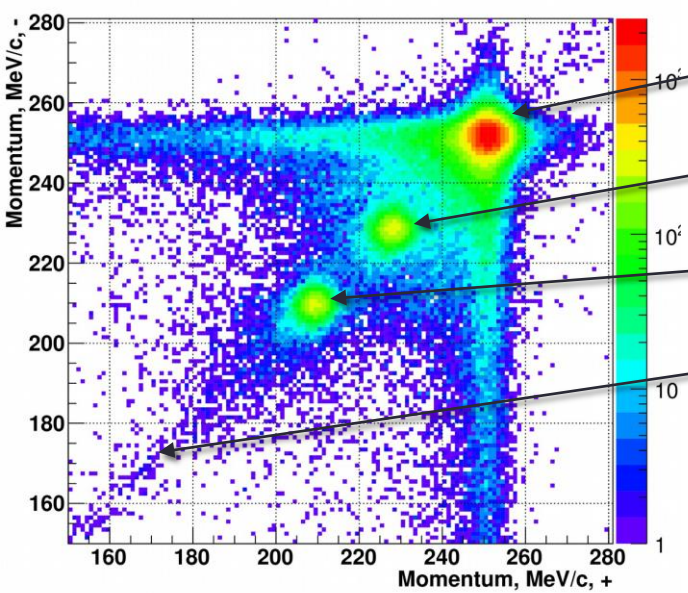
CMD-3: events separation either by momentum or by energy deposition

"Cleaner" momentum approach can be used up to $\sqrt{s} \approx 0.9$ GeV (0.6 GeV at VEPP-2M)



Main background: $e^+e^- \to e^+e^-, \mu^+\mu^-$

P^- vs P^+ @$\sqrt{s} = 0.5$ GeV



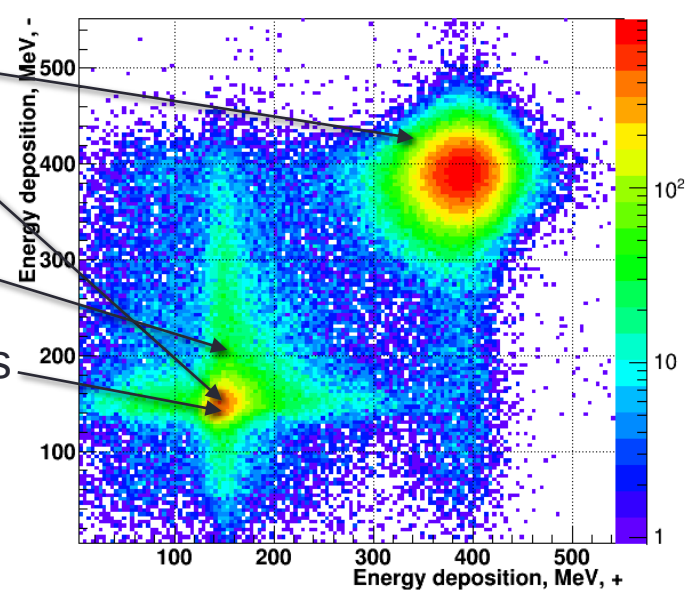
e^+e^-

$\mu^+\mu^-$

$\pi^+\pi^-$

cosmics

E^- vs E^+ @$\sqrt{s} = 0.92$ GeV



$e^+e^- \to \pi^+\pi^-$: radiative corrections

Measurement of $e^+e^- \to \pi^+\pi^-$ requires high precision calculation of radiative corrections.

Several MC generators available with 0.1-0.5% precision.

CMD-3: MCGPJ generator (0.2%)

- 1 real γ + γ jets along all particles

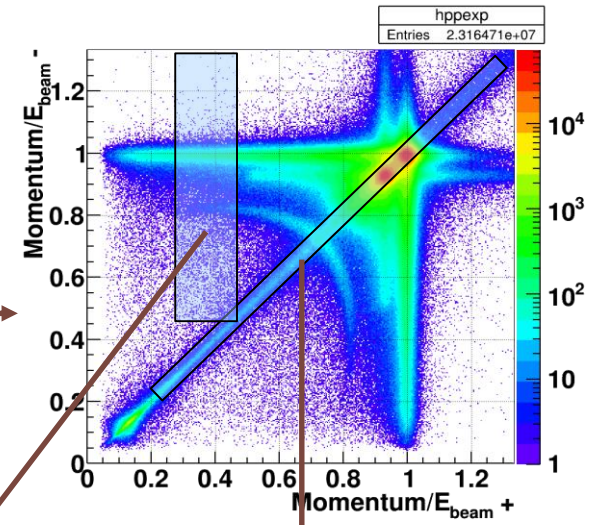
With high statistics we can compare experimental spectra with theoretical.

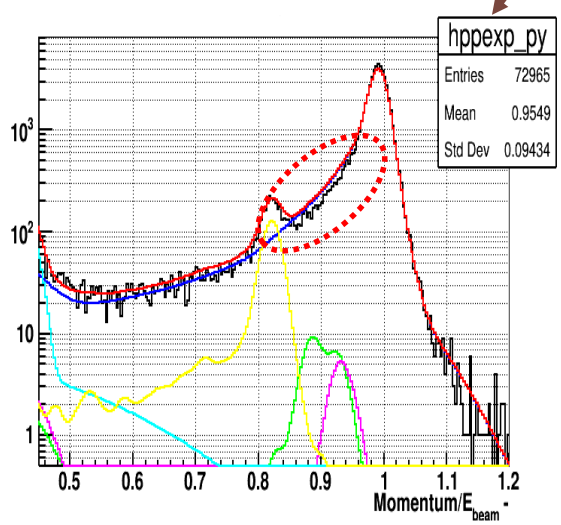
Some discrepancies observed in tails of e^+e^- spectra (not in integral), percent-level effect on event separation by P.

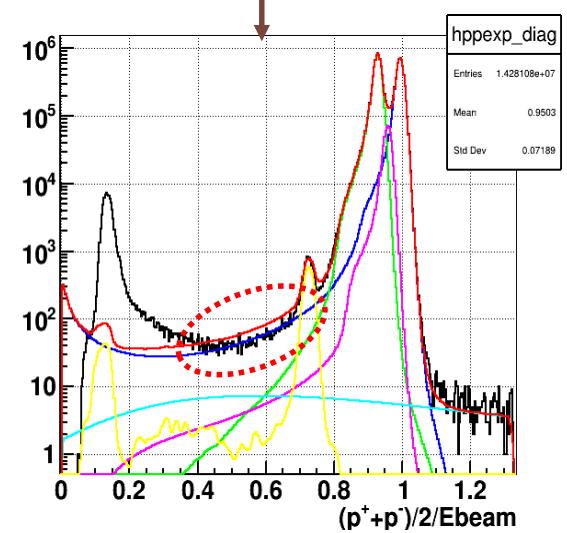
The source of the discrepancy is understood, now upgrading MCGPJ.

$\frac{P^-}{E_b}$ vs $\frac{P^+}{E_b}$

All 2013 data
$2 \cdot 10^7$ events





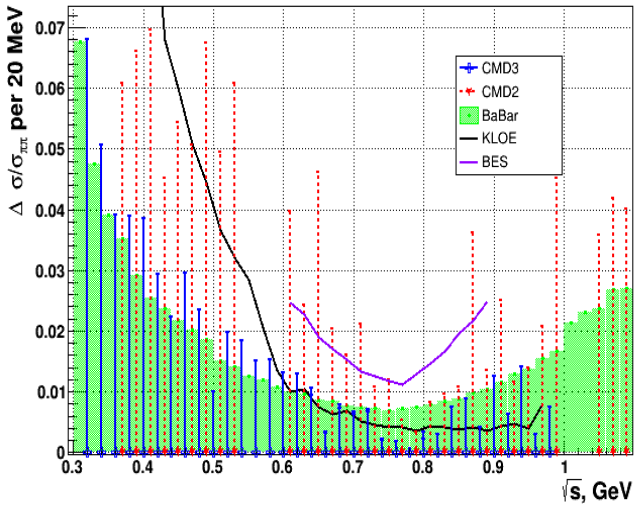


$e^+e^- \to \pi^+\pi^-$: statistics and systematics

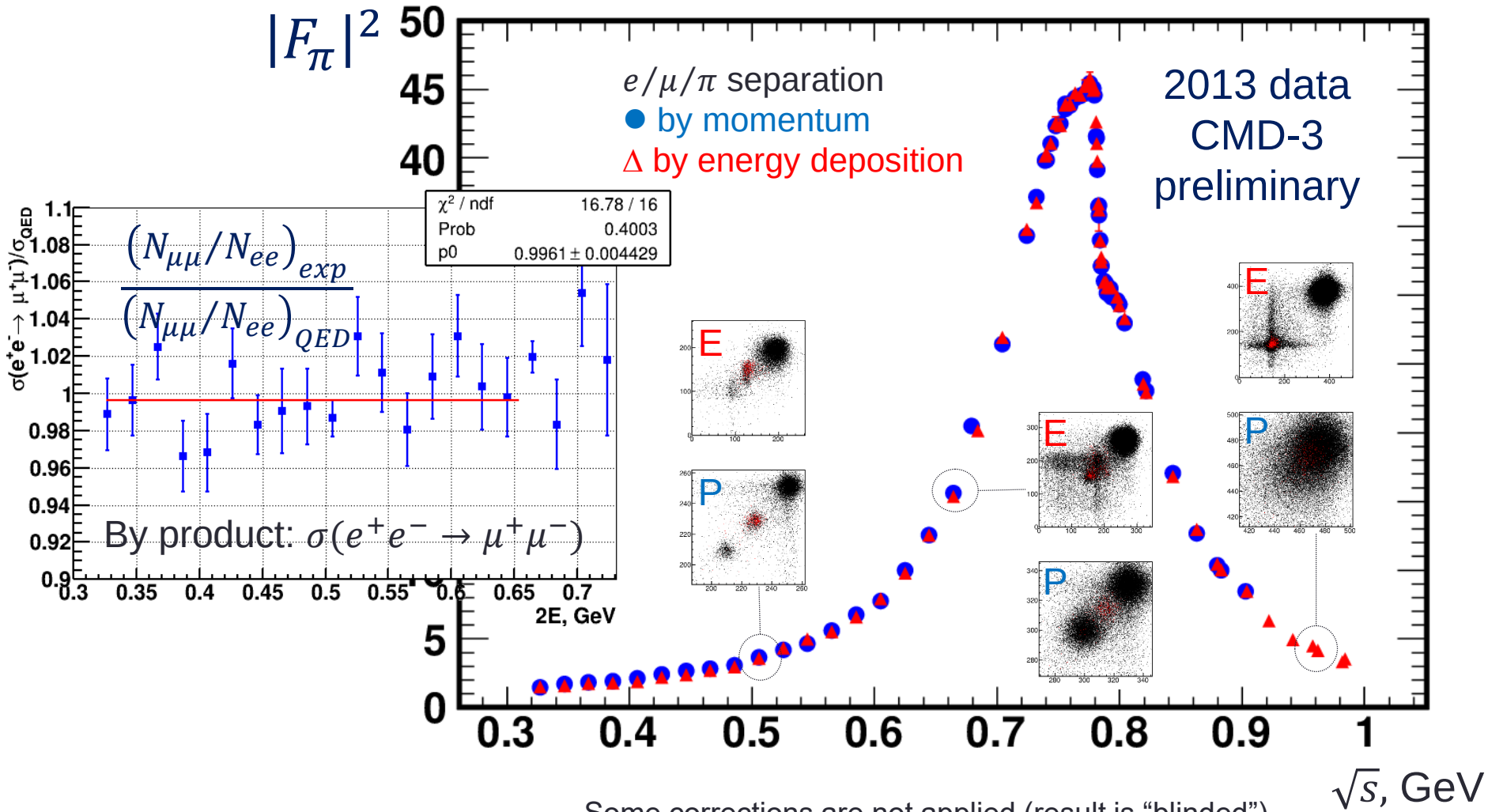
Source	Syst. Now (goal)	Comment
$e/\mu/\pi$ separation	0.5-1.5% (0.2%)	comparison of two methods; correlated to r.c.
fiducial volume	0.3-0.5% (0.1%)	two independent measurements; angular distribution
beam energy	0.1% (0.1%)	continuous monitoring via Compton
radiative corrections	0.2% (0.1%)	working on improving MCGPJ
Detection efficiencies	0.5-1.5% (0.1%)	mainly at lowest energies due to pion decays; working on studying decay events

- For most sources of systematics there is clear way how to bring it down
- For 2013 data we aim at sub-% accuracy
- Statistical accuracy matches or better the current world-best

Statistical accuracy of 2013 data



$e^+e^- \to \pi^+\pi^-$: CMD-3 preliminary results



Some corrections are not applied (result is “blinded”)

Conclusion

- In 2011-2013 CMD-3 and SND have collected 60-70 1/pb per detector in the whole energy range $0.32 \leq \sqrt{s} \leq 2.0$ GeV, available at VEPP-2000. Collected integral is similar to the total integral available before.
- Data analysis of exclusive modes of $e^+e^- \rightarrow hadrons$ is in progress. Many results have been published.
- In 2013-2016 the collider has been upgraded. We plan to finish commissioning this year.
- We plan to resume data taking by the end of 2016 with the ultimate goal of collecting O(1) 1/fb below 2 GeV