CMD-3 EXPERIMENT OVERVIEW

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

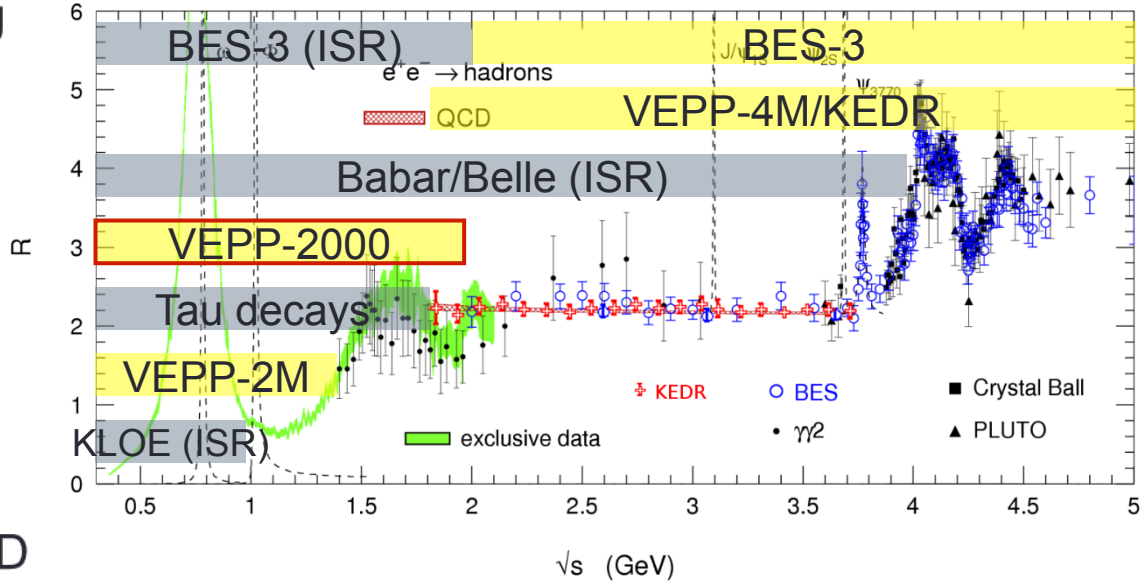
So far, the hadronic contribution to $a_\mu$is calculated by integrating experimental cross-section $\sigma(e^+e^- \to hadrons)$.

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

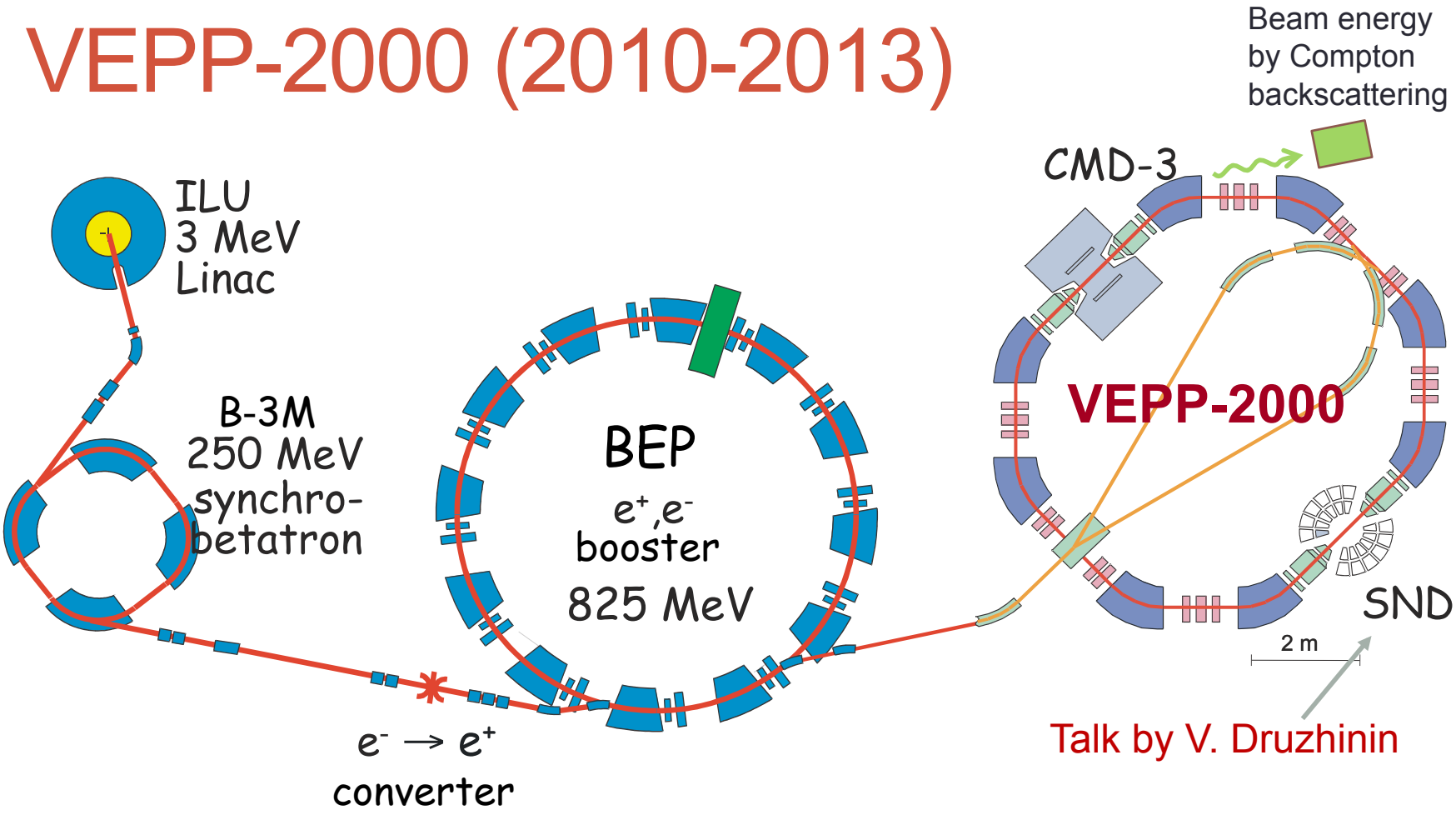
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



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

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

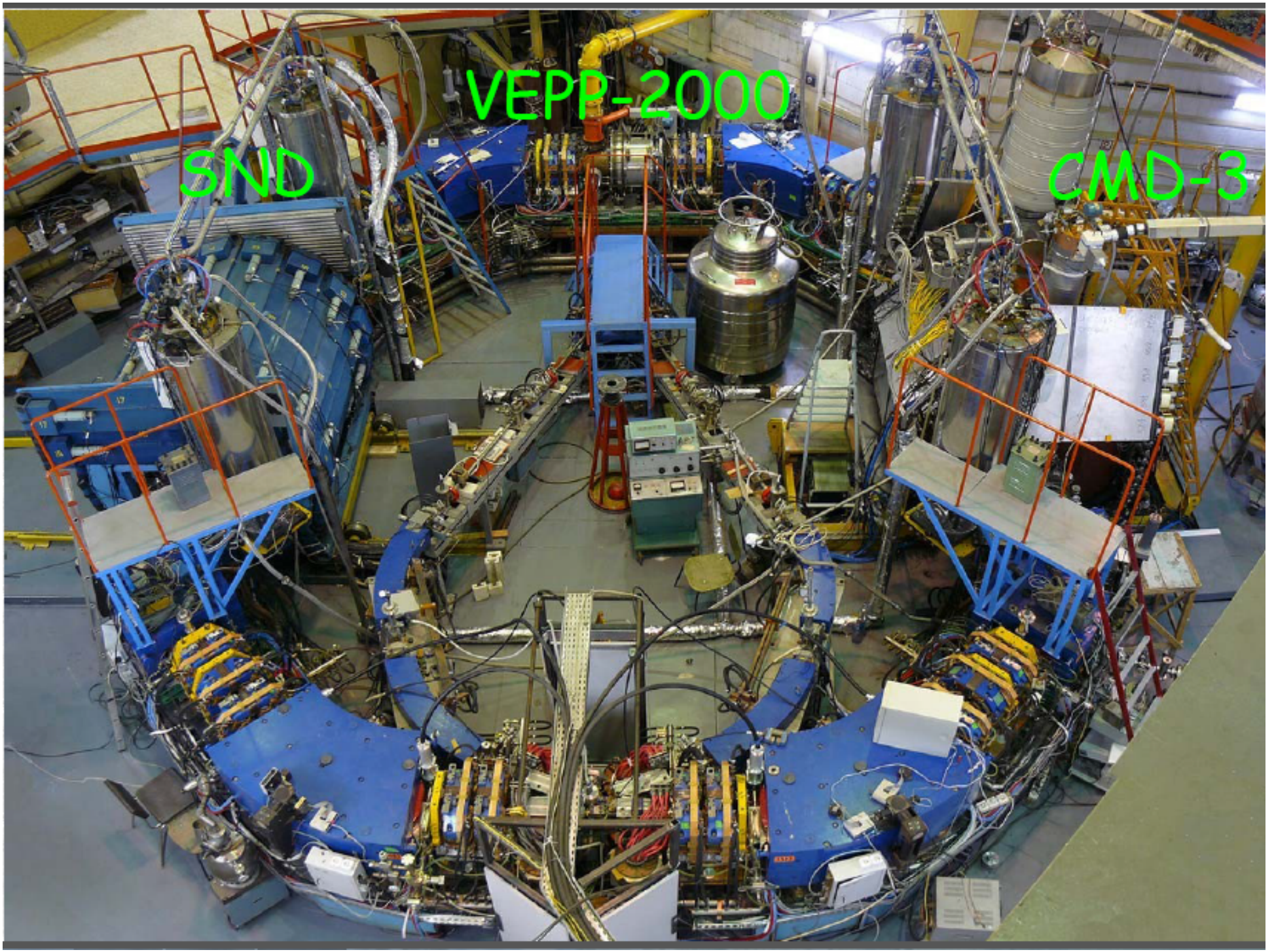
VEPP-2000 (2010-2013)



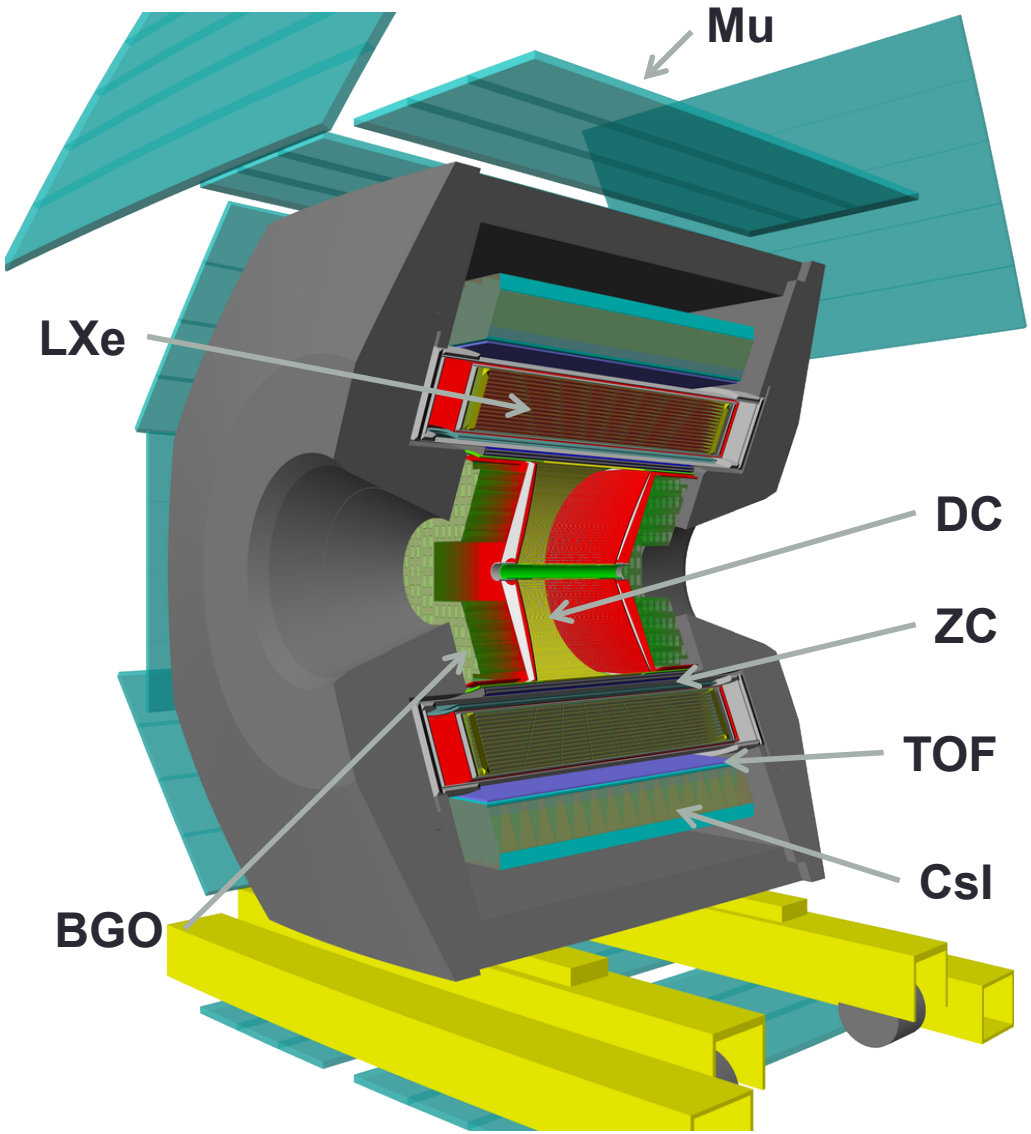
C.m. energy range is 0.32-2.0 GeV; unique optics – “round beams”

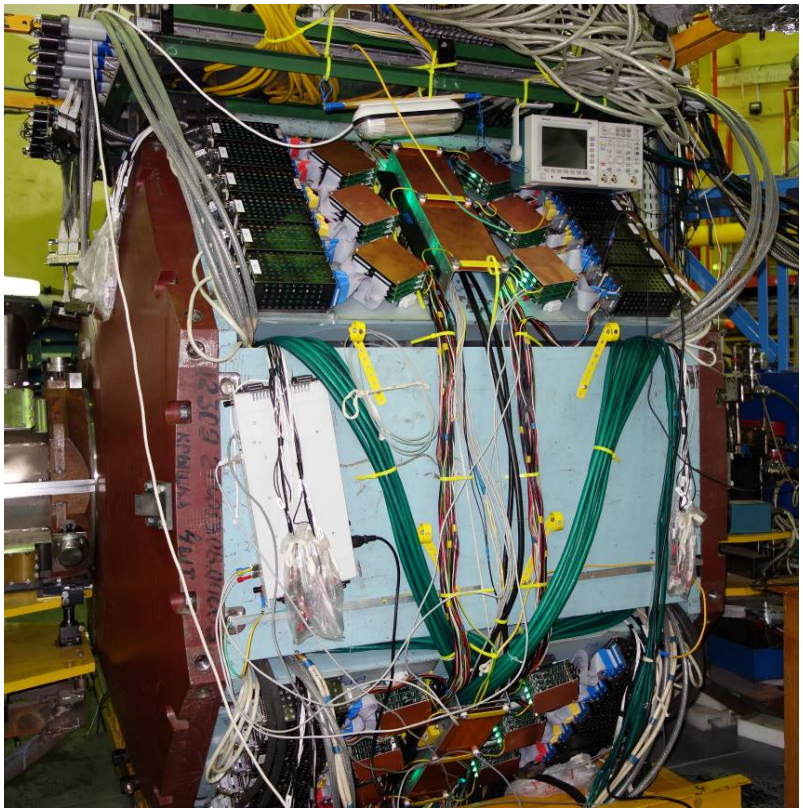
Design luminosity is $L = 10^{32} 1/cm^2 s$ @ $\sqrt{s} = 2$ GeV

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

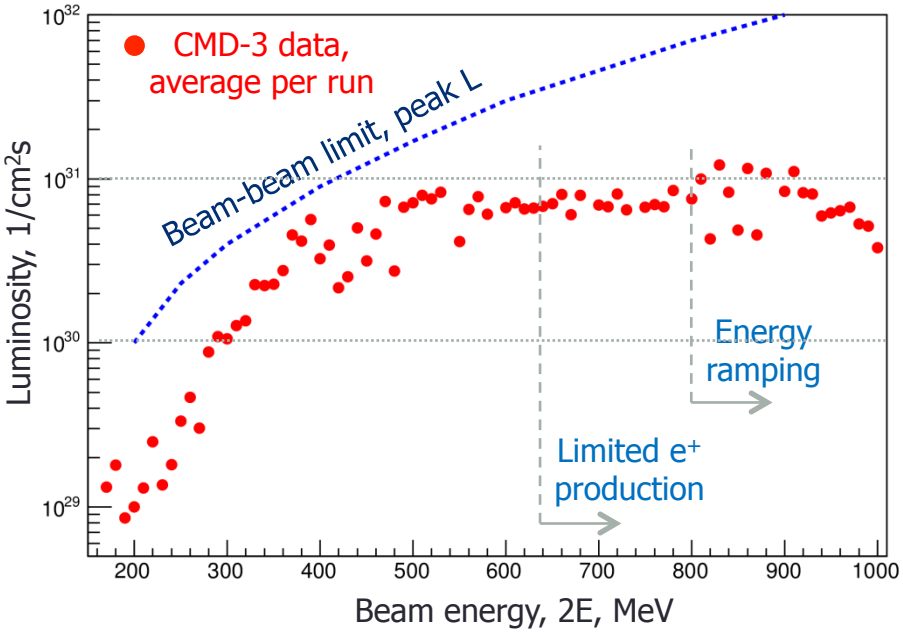

VEPP-2000
SND
CMD-3

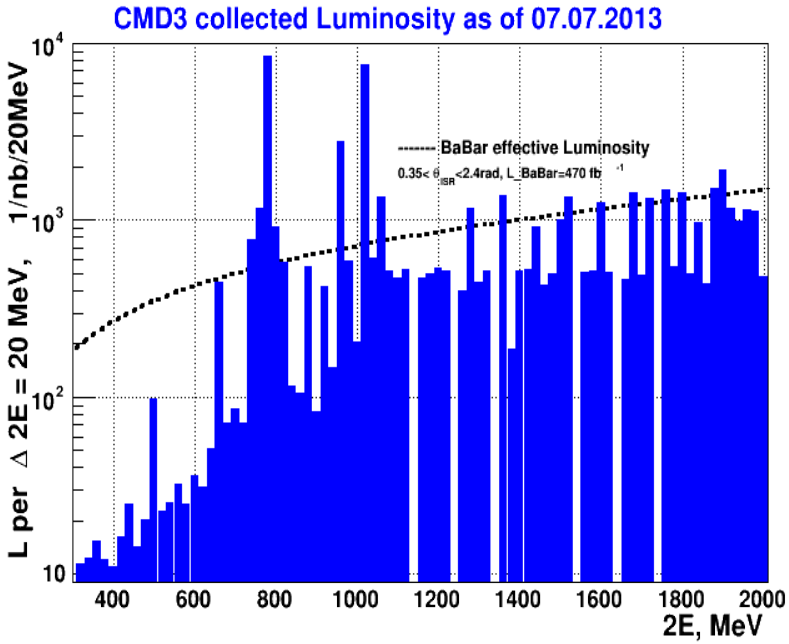
Detector CMD-3





Collected luminosity in 2011-2013





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

The VEPP-2000 upgrade has started in 2013.

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	$34.5\ 1/pb$

Exclusive channels $e^+e^- \to hadrons$

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

- 2 charged

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

- 2 charged + γ's

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

- 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

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

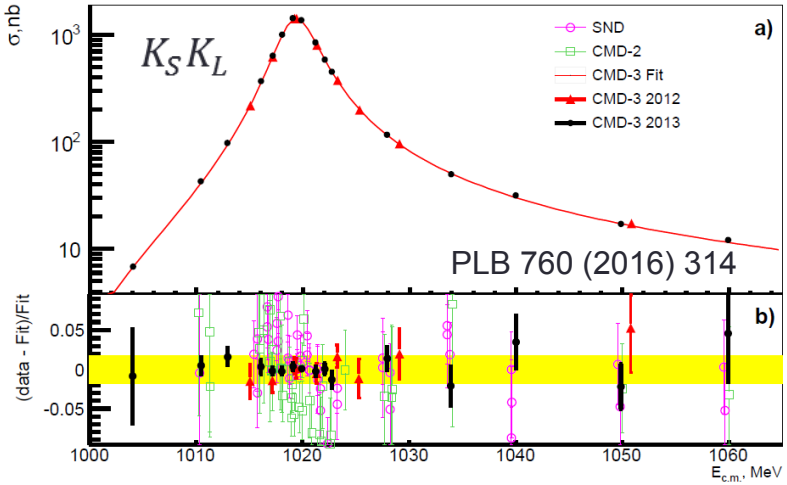
- γ's only

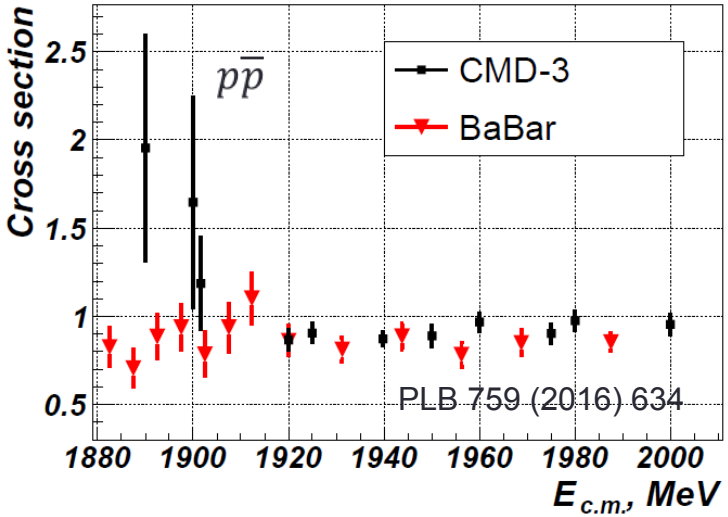
$$e^+e^- \to \pi^0\gamma, \eta\gamma, \pi^0\pi^0\gamma, \pi^0\eta\gamma, \pi^0\pi^0\pi^0\gamma, \pi^0\pi^0\eta\gamma$$

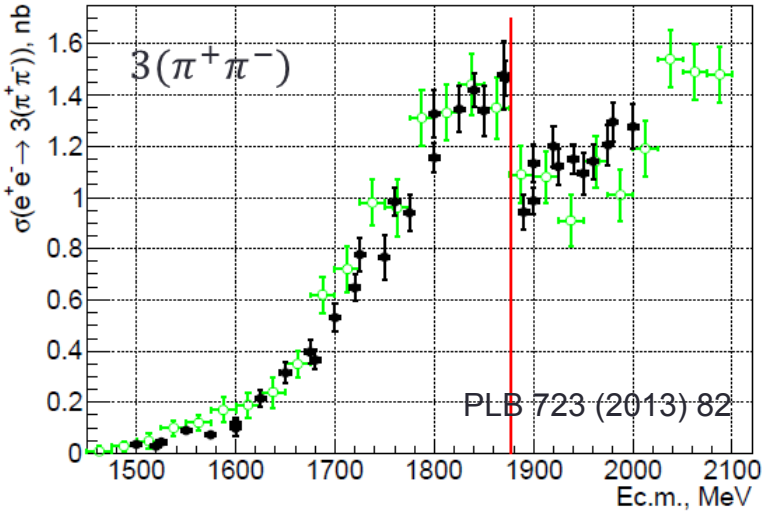
- other

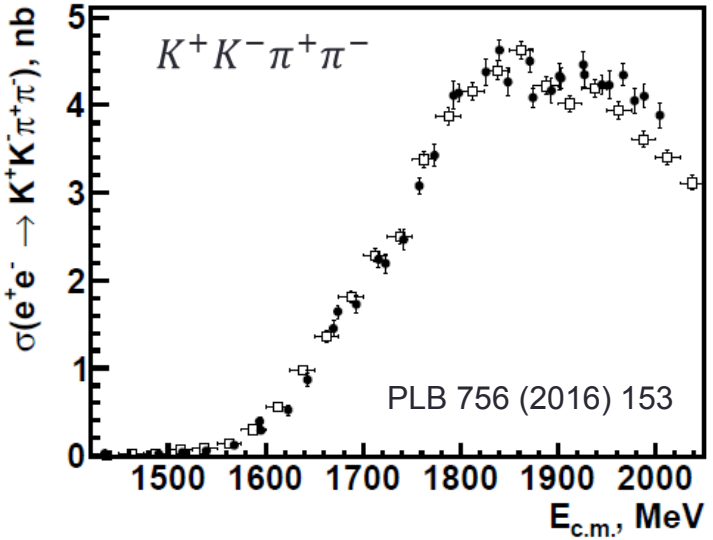
$$e^+e^- \to n\bar{n}, \pi^0e^+e^-, \eta e^+e^-$$

Published results from 2011-2013: CMD-3

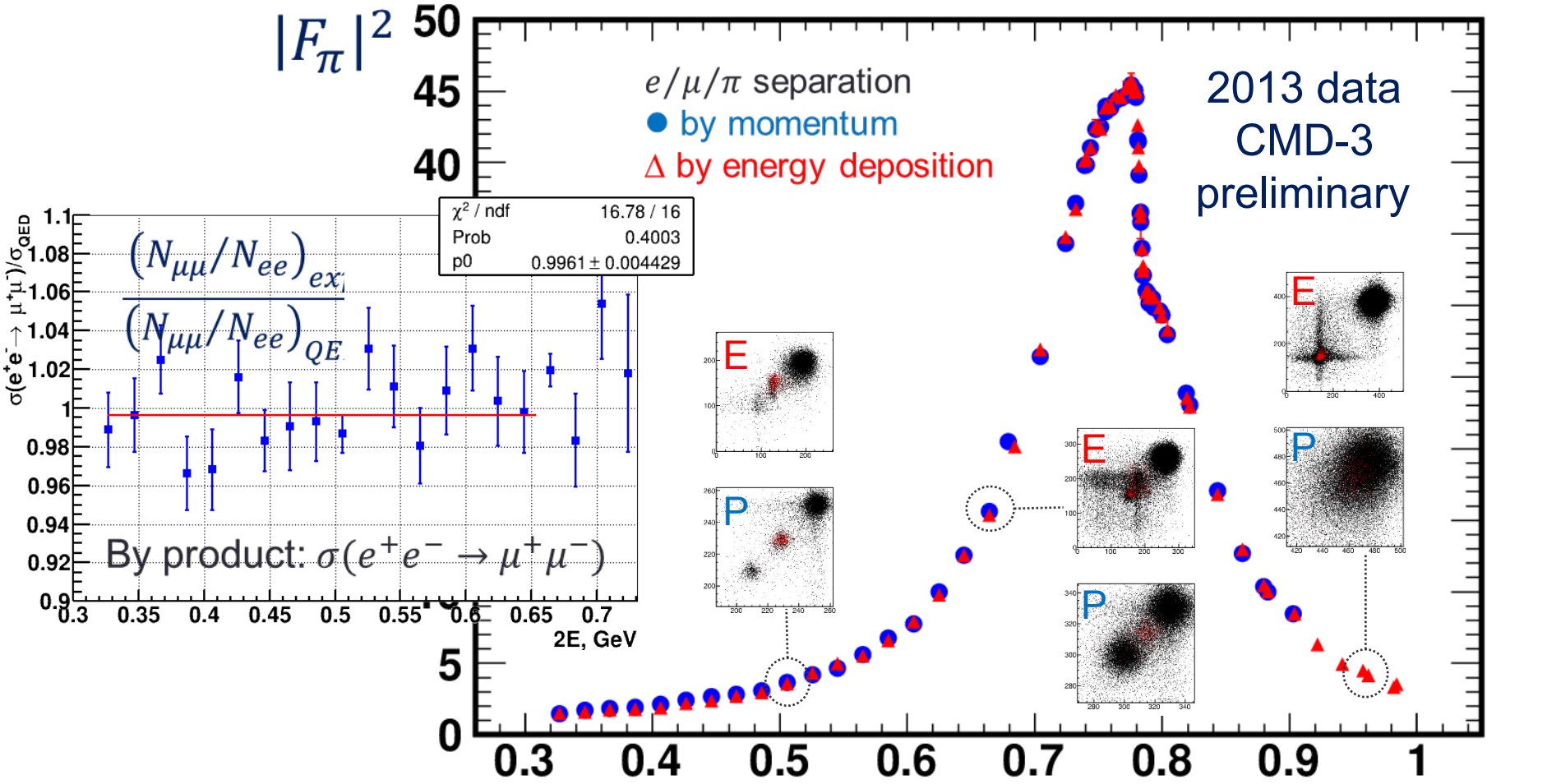








Dominant channel: $e^+e^- \to \pi^+\pi^-$



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

Dominant channel: $e^+e^- \to \pi^+\pi^-$

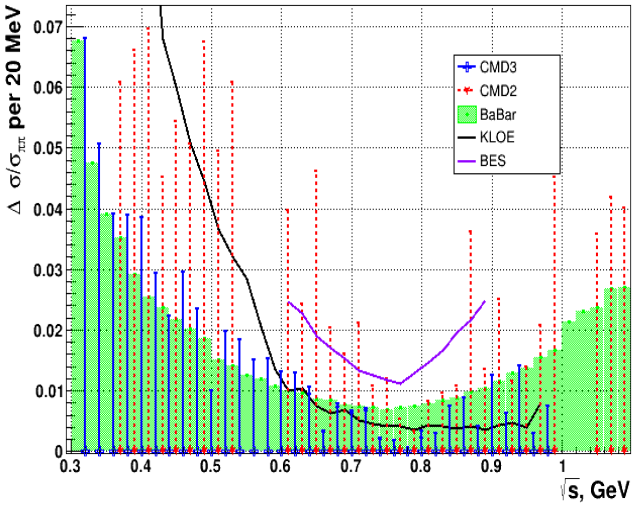
- Energy range below φ was scanned in 2013. Data analysis is in progress.
- Energy range above φ was scanned in 2011-2012. Data analysis for $\pi^+\pi^-$ havn't started yet. There are known problems with data, which will limit precision, e.g. the beam energy was measured only for subset of energy points.

Current estimate of the systematic error:

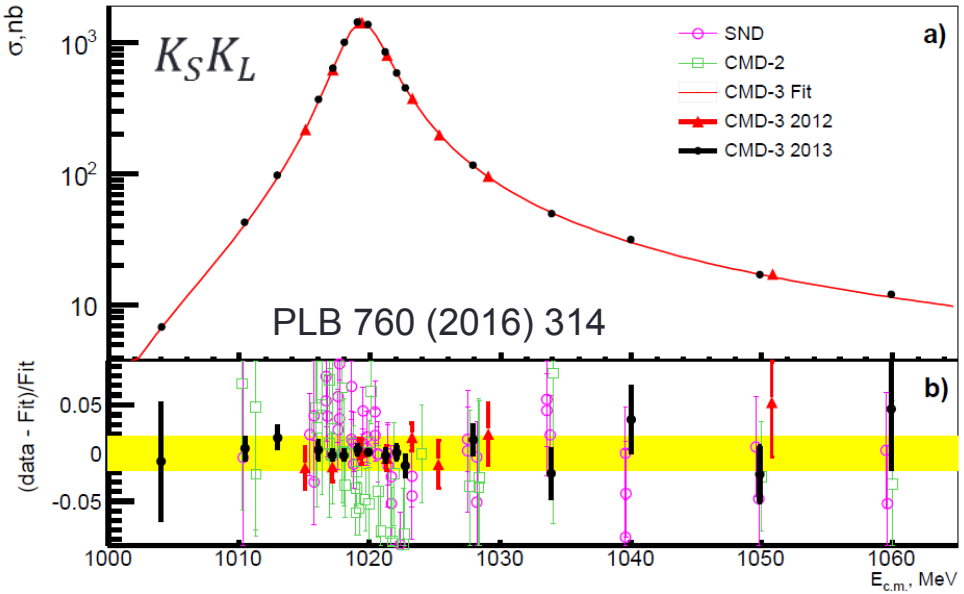
~< 1% for momentum separation
~1.5-2% for energy deposition

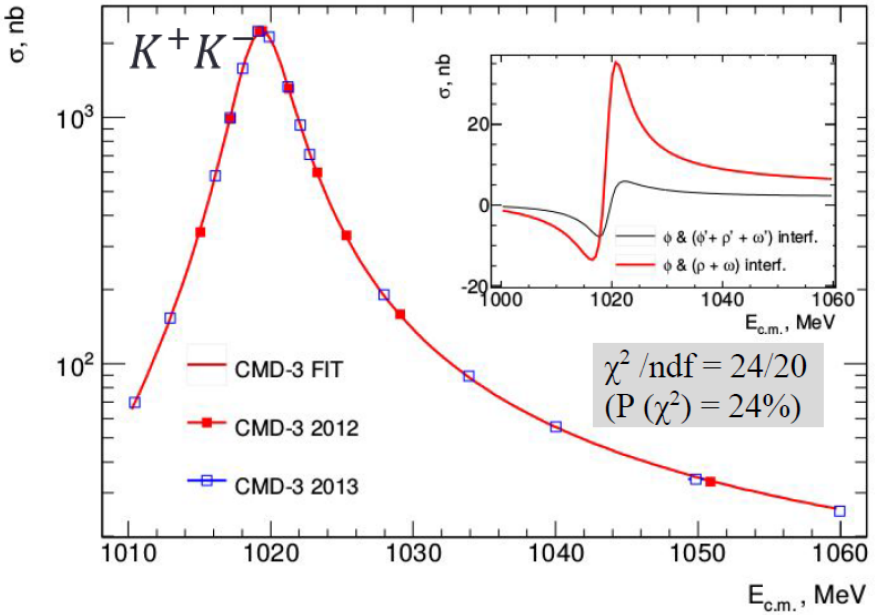
Open the box when both methods <1%
Hopefully later this year

Statistical accuracy of 2013 data



$K_S K_L$ and K^+K^- @$\varphi(1020)$

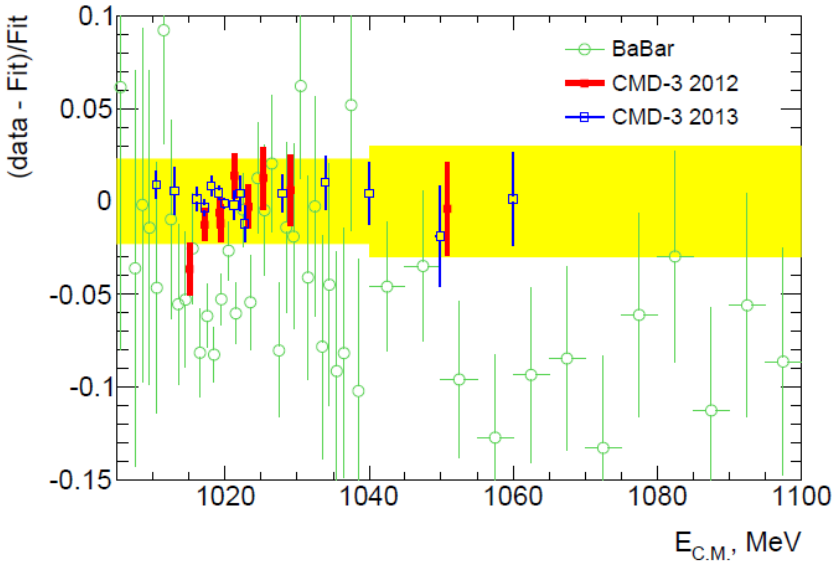


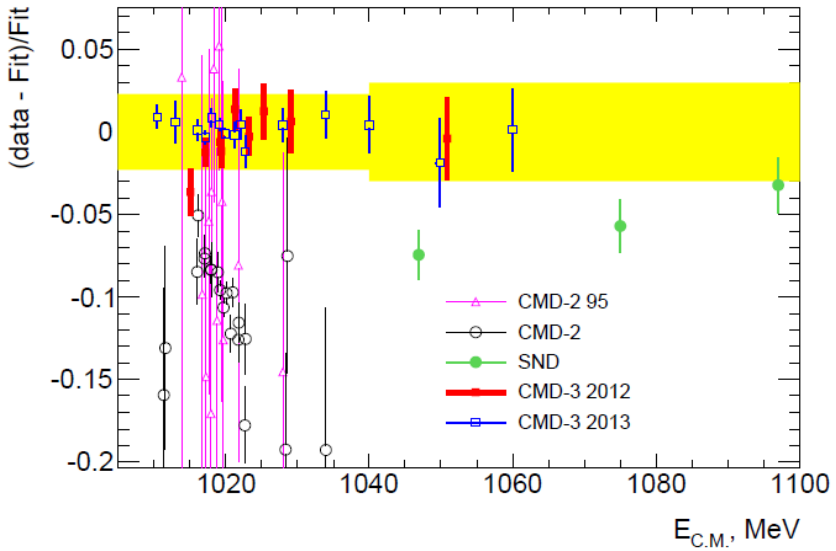


Recent result from CMD-3:

- $K_S K_L$ at φ, systematic precision 1.8%
- K^+K^- at φ, systematic precision 2.5% (under internal review)

K^+K^-: comparison with other measurements





K_SK_L at φ is consistent between different experiments, but there is discrepancy in K^+K^- channel.

New CMD-3 K^+K^- cross-section is above CMD-2 and BaBar, but is consisteny with isospin symmetry:

$$R = \frac{g_{\varphi K^+K^-}}{g_{\varphi K_S K_L}\sqrt{Z(m_\varphi)}} = 0.990 \pm 0.017$$

- $R_{SND} = 0.92 \pm 0.03 (2.6\sigma)$
- $R_{CMD-2} = 0.943 \pm 0.013 (4.4\sigma)$
- $R_{BaBar} = 0.972 \pm 0.017 (1.5\sigma)$

$K_S K_L$ and K^+K^-: $\rho - \varphi$ interference

$\rho - \varphi$ interference can be directly observed:

$$R_{c/n} = \sigma(e^+e^- \to K^+K^-) \times \frac{p^3_{K^0}(s)}{p^3_{K^\pm}(s)} \times \frac{1}{Z(s)} - \delta \times \sigma(e^+e^- \to K_S K_L)$$

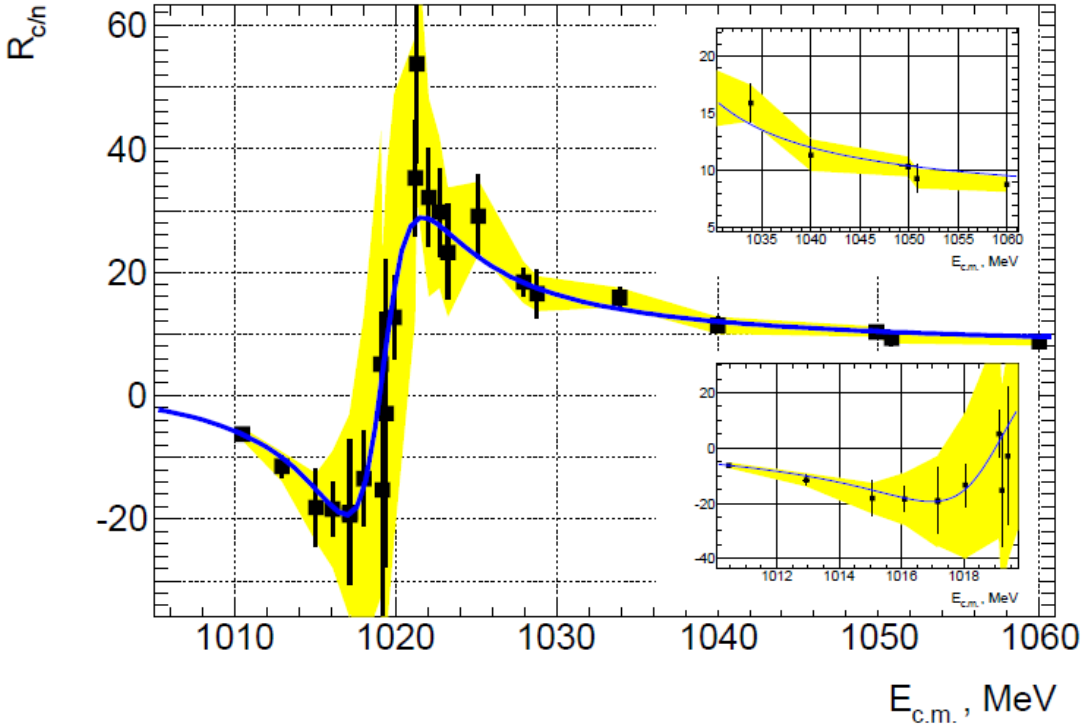
- $r_{\rho,\omega} = 0.91 \pm 0.04$

  deviation of SU(3) relations

  $g_{\omega K^+K^-} = g_{\rho K^+K^-} = -g_{\varphi K^+K^-}/\sqrt{2}$

- $\delta = 0.989 \pm 0.003$

  test of systematic errors

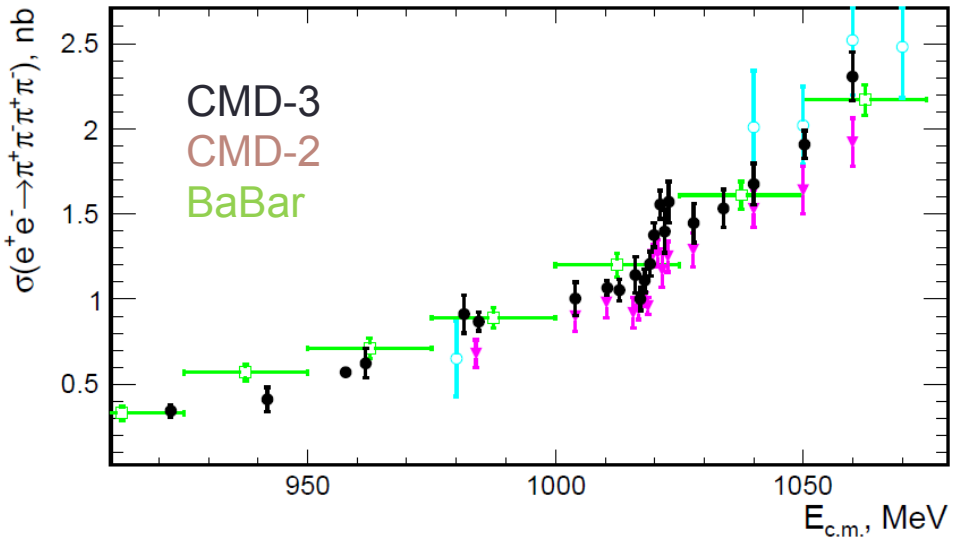


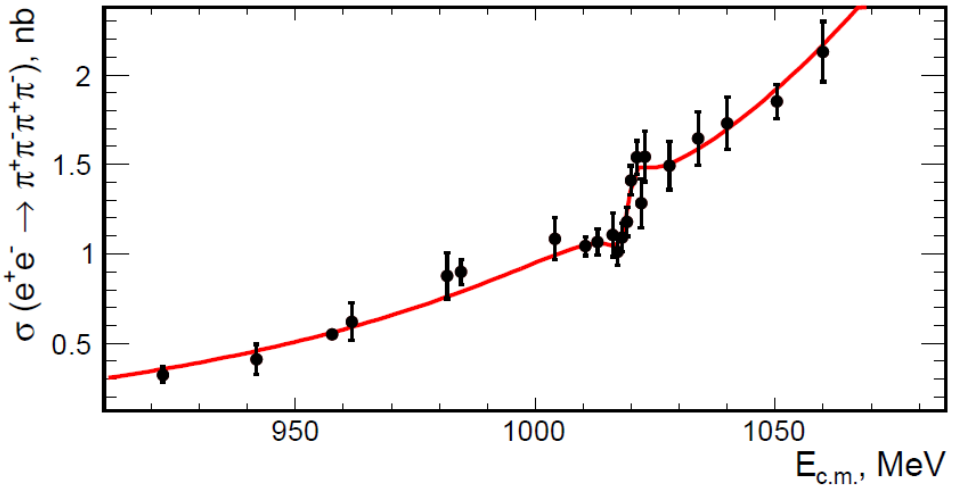
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ @$\varphi(1020)$

PLB 768 (2017) 345-350

2011-2013 data, 10 1/pb
systematic error 3.5%

$$B\left(\varphi \to 2(\pi^+\pi^-)\right) = (6.5 \pm 2.7 \pm 1.6) \times 10^{-6}$$

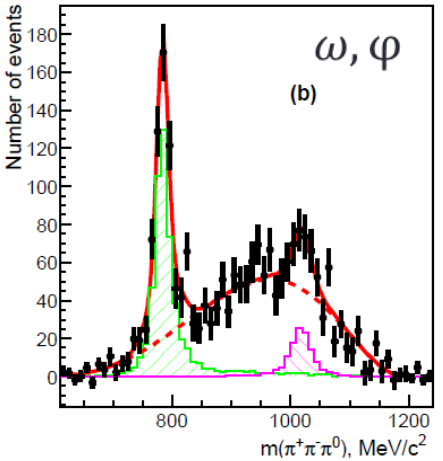


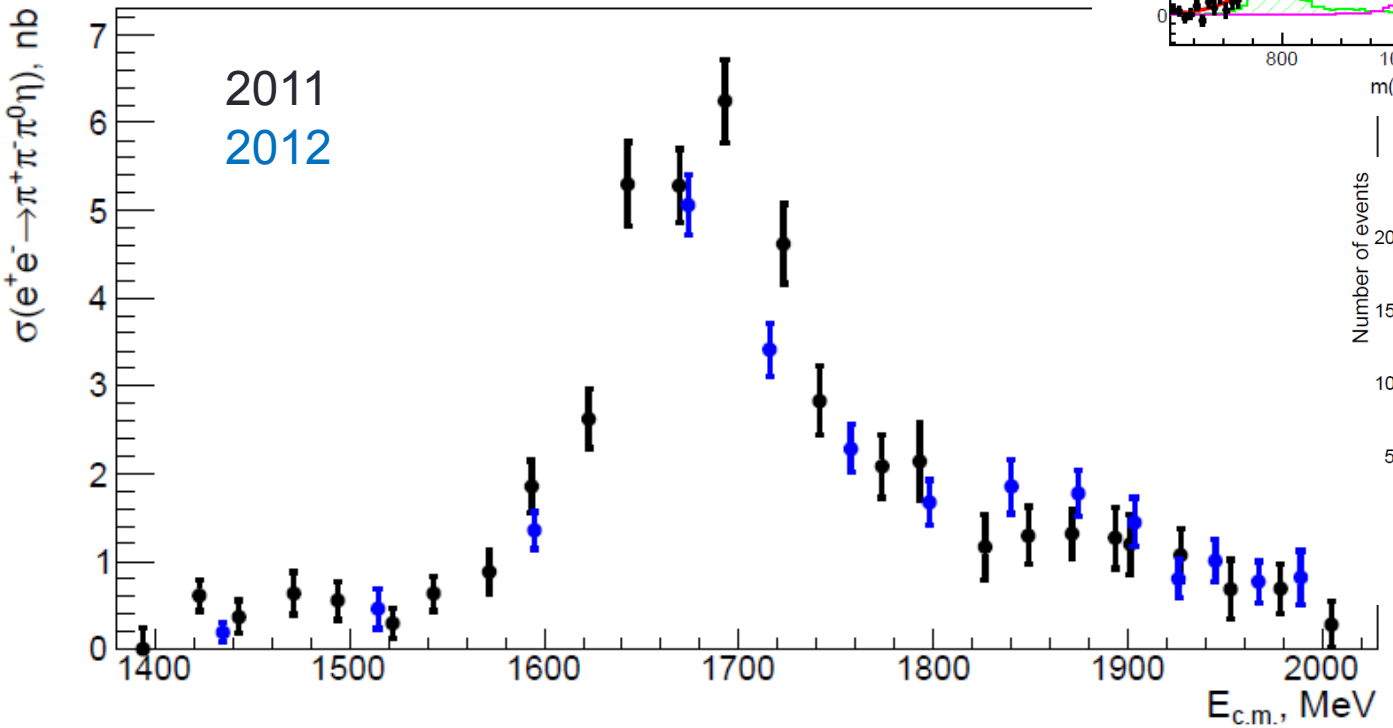


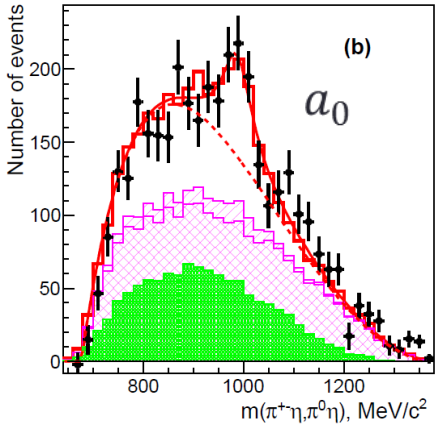
$e^+e^- \to \pi^+\pi^-\pi^0\eta$

First measurement of total $e^+e^- \to \pi^+\pi^-\pi^0\eta$ cross section. Systematic error is 15%.

https://arxiv.org/abs/1706.06267v1





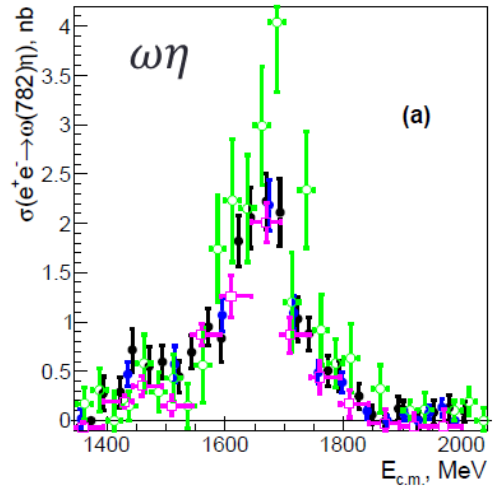


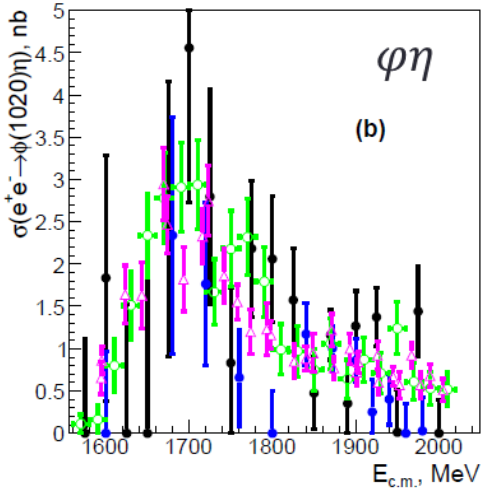
Dynamics of $e^+e^- \to \pi^+\pi^-\pi^0\eta$

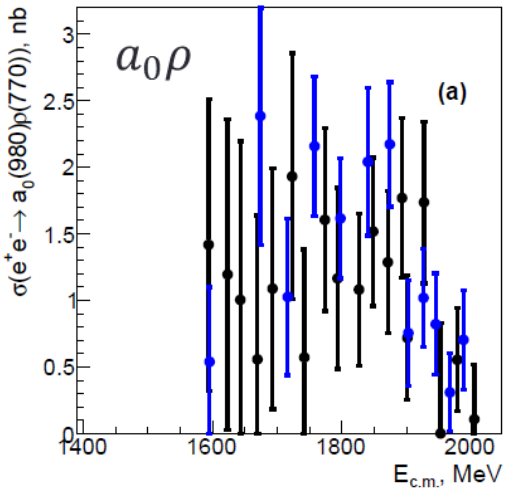
At “low” energies dominated by
$e^+e^- \to \omega\eta, \varphi\eta$

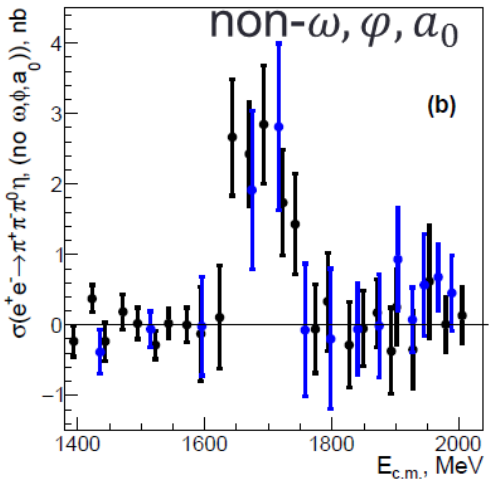
At “high” energies dominated by
$e^+e^- \to a_0(980)\rho$

We see non-ω, φ, a_0 contribution
Possible mechanism:
$e^+e^- \to \omega(1650) \to$
$\rho(1450,1700)\pi \to \rho(770)\eta\pi$

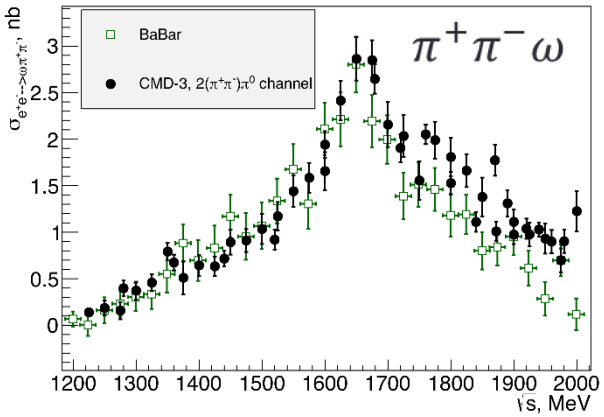


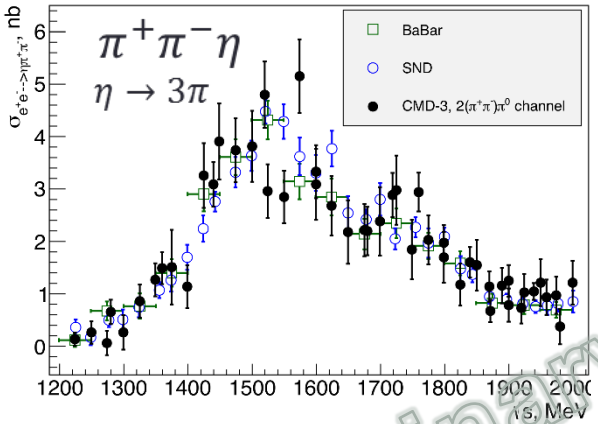


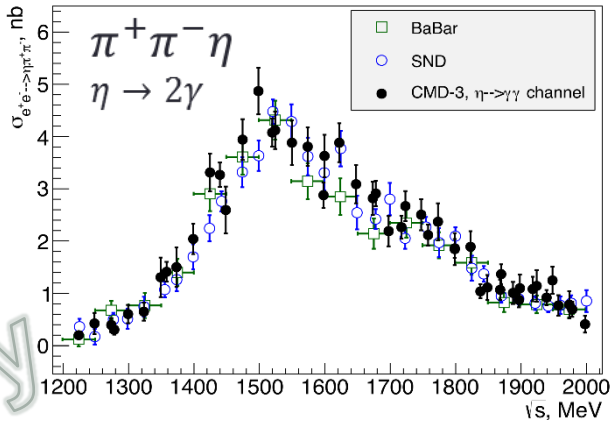


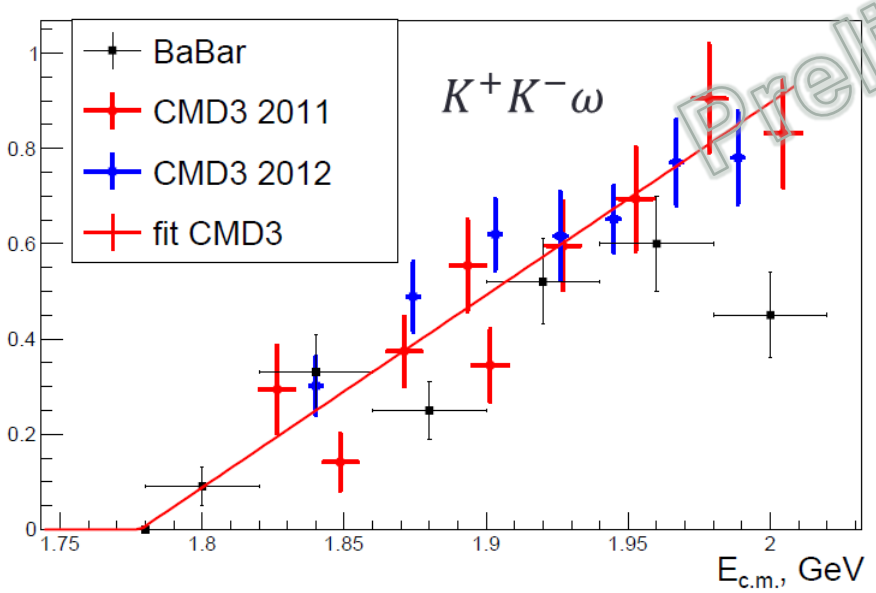


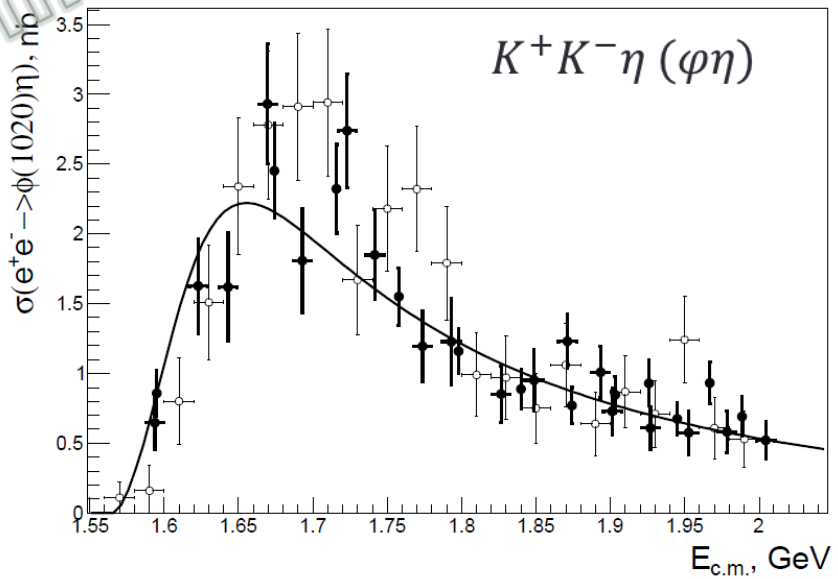
CMD-3 preliminary: $\pi^+\pi^-(\omega,\eta), K^+K^-(\omega,\eta)$





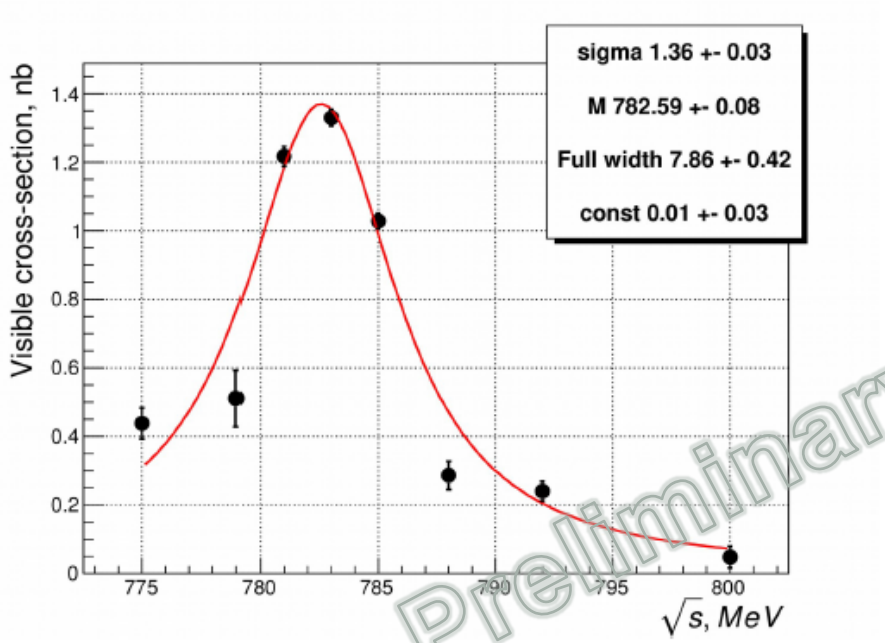






$\omega \to \pi^o e^+ e^-$

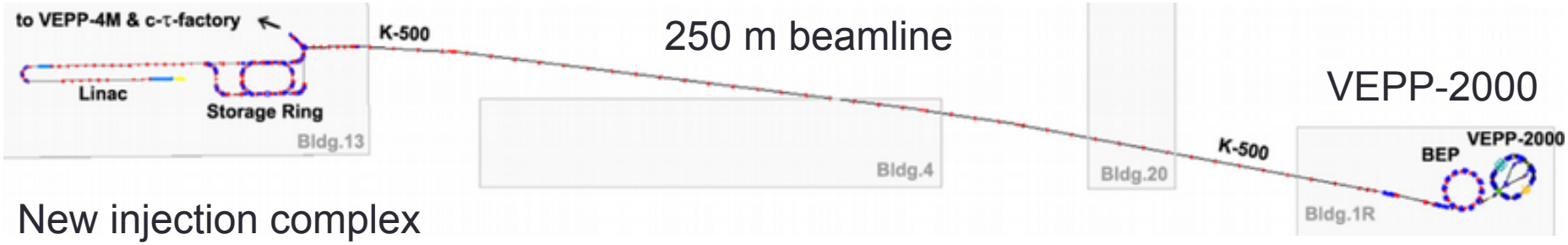
- Motivation: study of the internal structure of the vector mesons (transition form factor).
- $\pi^0 \to \gamma\gamma$.
- $\pi^+\pi^-\pi^0$: opening angle between tracks, kinematic of the decay, recoil mass of photon pairs.
- $\pi^0\gamma$: The method for $\pi^0 e^+e^-$ and $\pi^0\gamma$ (with conversion γ on material of the detector) separation is based on information from drift chamber and uses a neural network.



Visible cross section of the signal process is fitted with a Breit–Wigner distribution.

- 1339 events of decay were selected (The amount of statistic 8 1/pb);
- Current value $Br(\omega \to \pi^0 e^+e^-) = (8{,}15 \pm 0{,}18)\cdot 10^{-4}$ (stat.) (the contributions of $\omega \to \pi^+\pi^-\pi^0$, $\omega \to \pi^0\gamma$ were not taken into account)[1].

VEPP-2000 upgrade (2013-2016)



Collider upgrades:

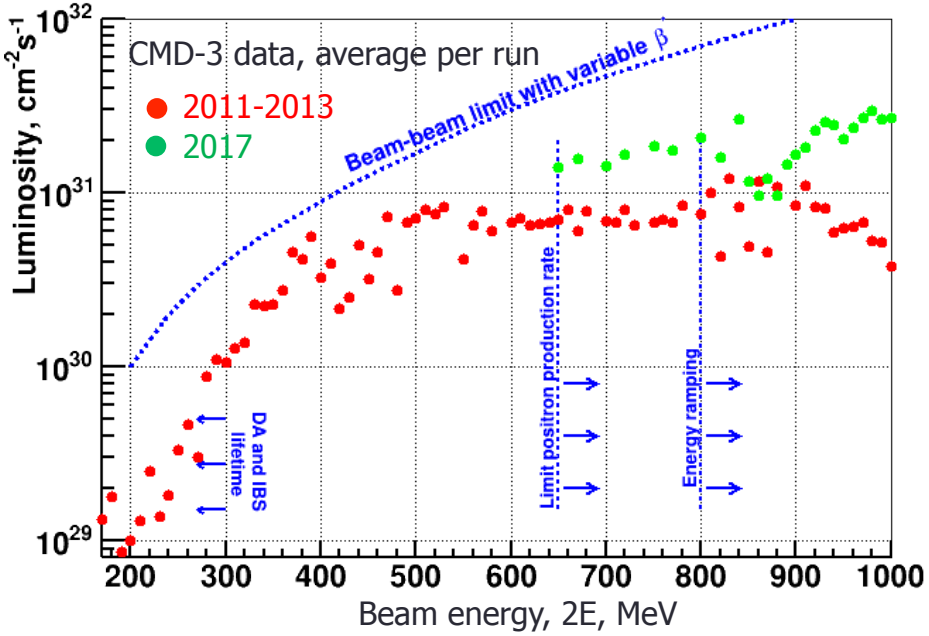
- x10 more intense positron source
- booster up to 1 GeV (match VEPP-2000)

CMD-3 upgrades:

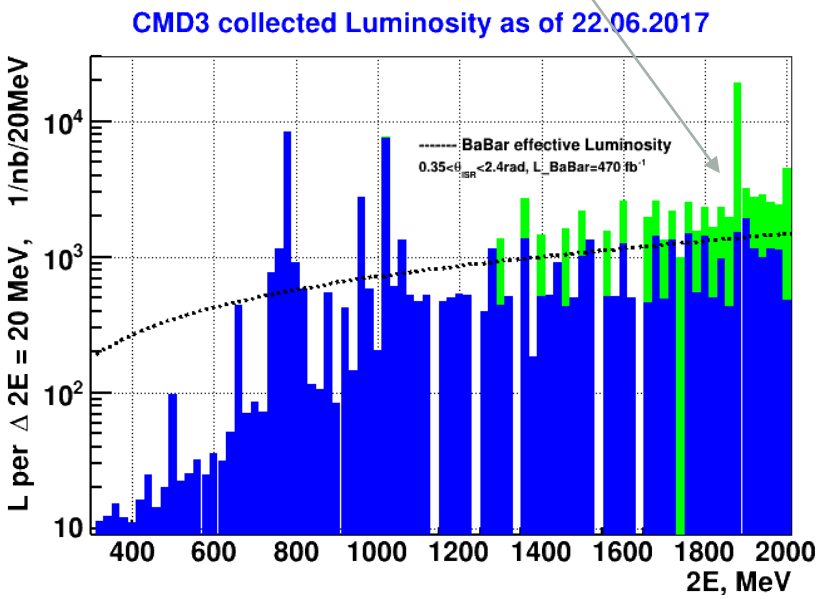
- New electronics for Lxe calorimeter
- New TOF system
- DAQ and electronics upgrades

Detectors resumed data taking by the end of 2016

2017 data taking



CMD-3
26/01-20/06/2017



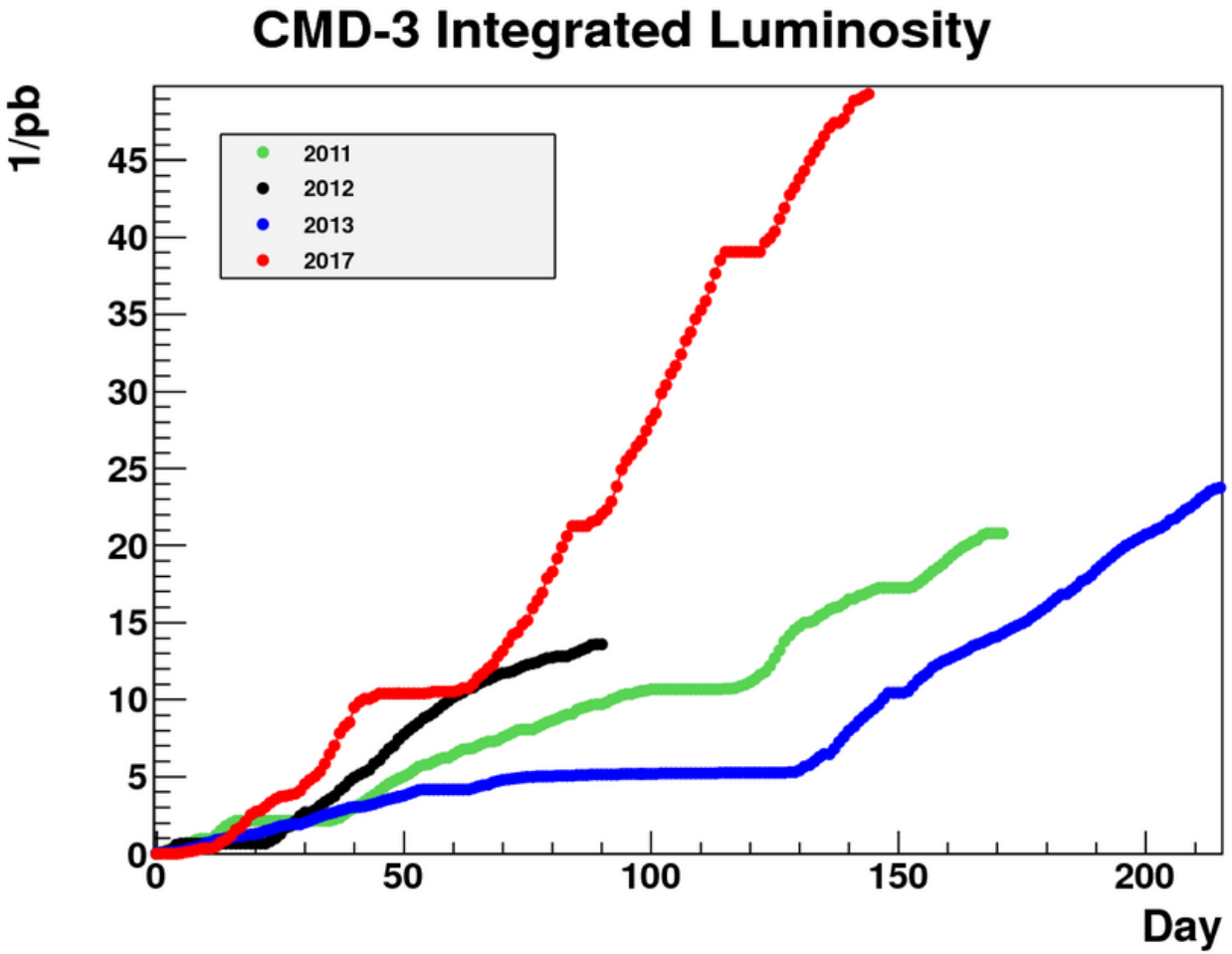
In 2017: big improvement in luminosity at high energy, still way to go

Collected data at “high” energies

About 50 pb^{-1} collected

$2.007\ \mathrm{GeV}\ (e^+e^- \to D^{0*})$	$4\ \ 1/pb$
$p\bar{p}$ and $n\bar{n}$ threshold	$14\ \ 1/pb$
Overall:	
$1.28 - 2.007\ \mathrm{GeV}$	$50\ \ 1/pb$

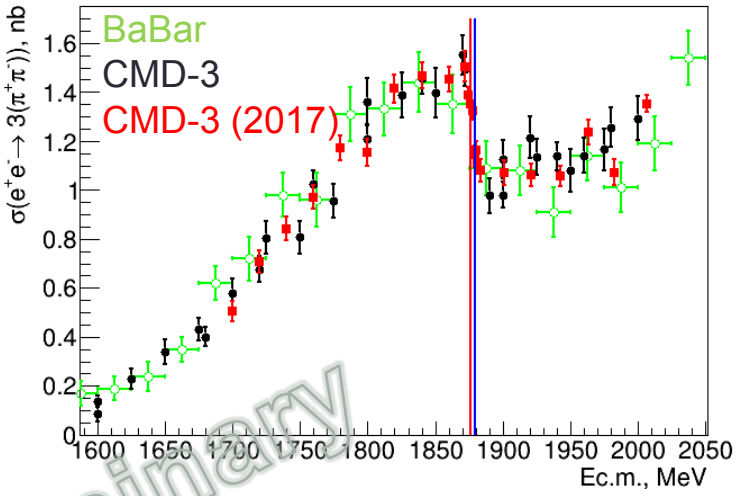
Overview of CMD-3 data taking runs

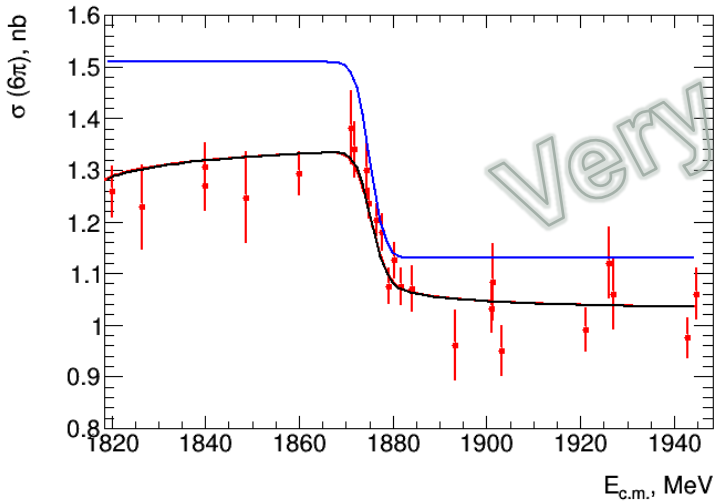


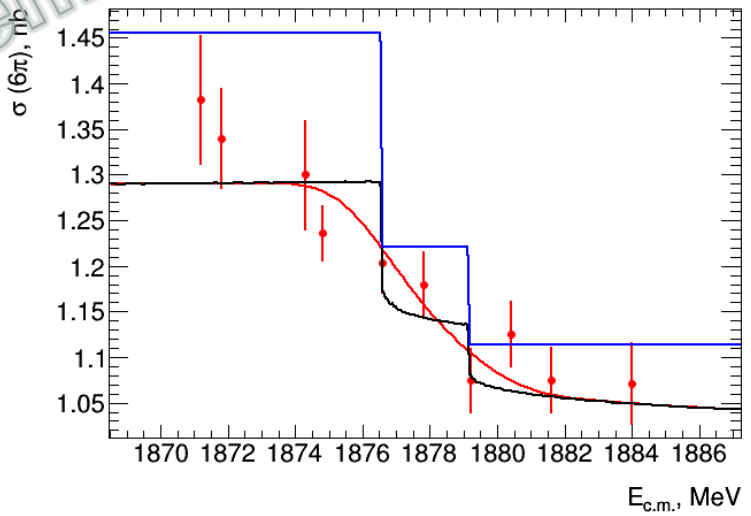
2017: $e^+e^- \to 3(\pi^+\pi^-)$ at $N\bar{N}$ threshold

In 2017, CMD-3 collected 13 1/pb in the narrow energy range around $N\bar{N}$ threshold
Very first look at the data:

- the sharp drop in cs is confirmed
- can be described as single transition at $(m_p + m_n)/2$ with ~2.5 MeV width
- or as two narrow transitions at m_p or m_n (consistent with only beam energy spread, $\sigma_{2E} \approx 1.2$ MeV)







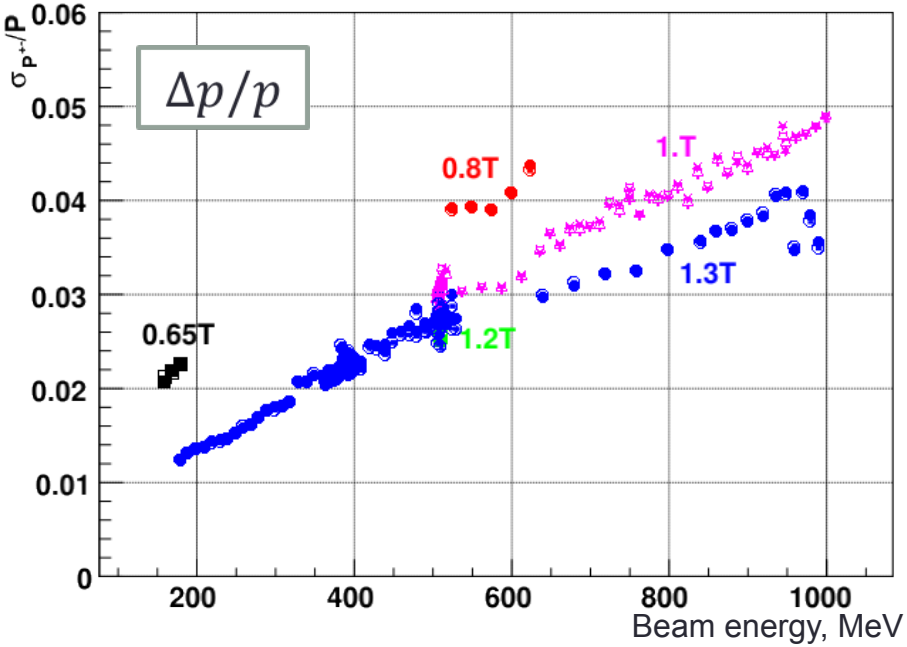
Very preliminary

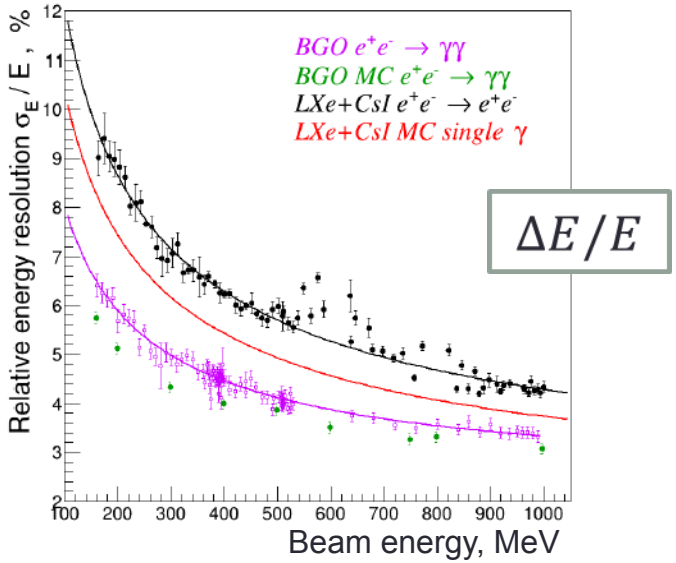
Conclusion

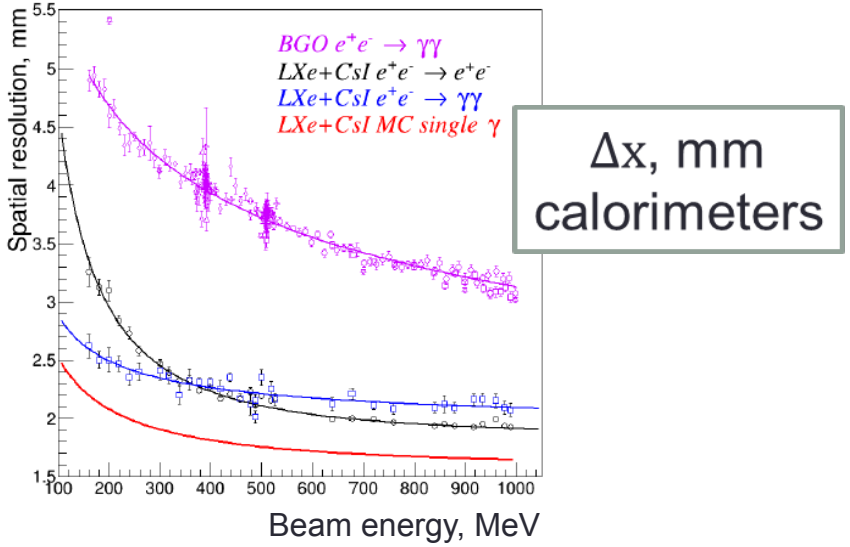
- In 2011-2013 CMD-3 has collected 60 1/pb in the whole energy range $0.32 \leq \sqrt{s} \leq 2.0$ GeV, available at VEPP-2000.
- Data analysis of exclusive modes of $e^+e^- \to hadrons$ is in progress. Many results have been published.
- In 2013-2016 the collider and the CMD-3 detector have been upgraded.
- The data taking was resumed in 2017. About 50 1/pb were collected over 5 months in the energy range above 1.28 GeV.

CMD-3 Performance (2011-2013)

- 1.0-1.3 T magnetic field
- Tracking: $\sigma_{R\varphi} \sim 100\ \mu, \sigma_z \sim 2-3$ mm
- Combined EM calorimeter (LXE, CsI, BGO), 13.5 X_0
  - $\sigma_E/E \sim 3\% - 10\%$
  - $\sigma_\Theta \sim 5$ mrad

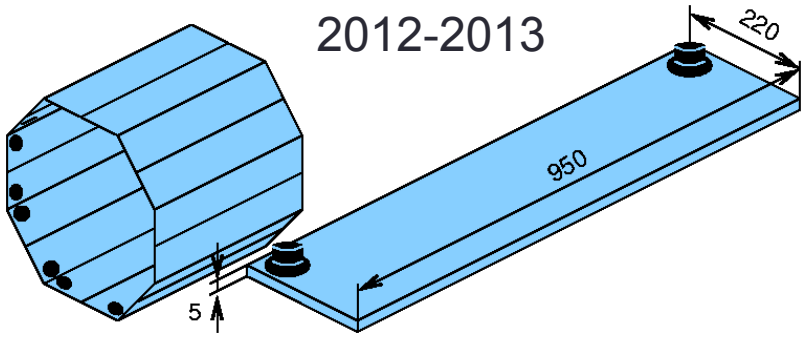




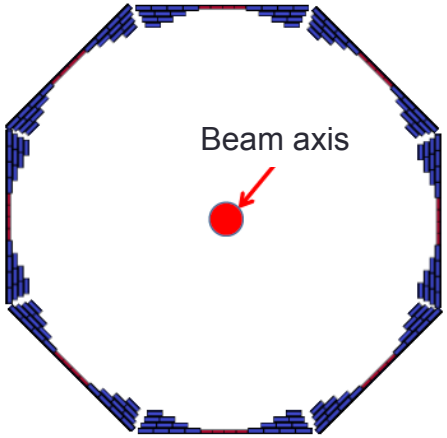


New TOF system

"Old" TOF
2012-2013

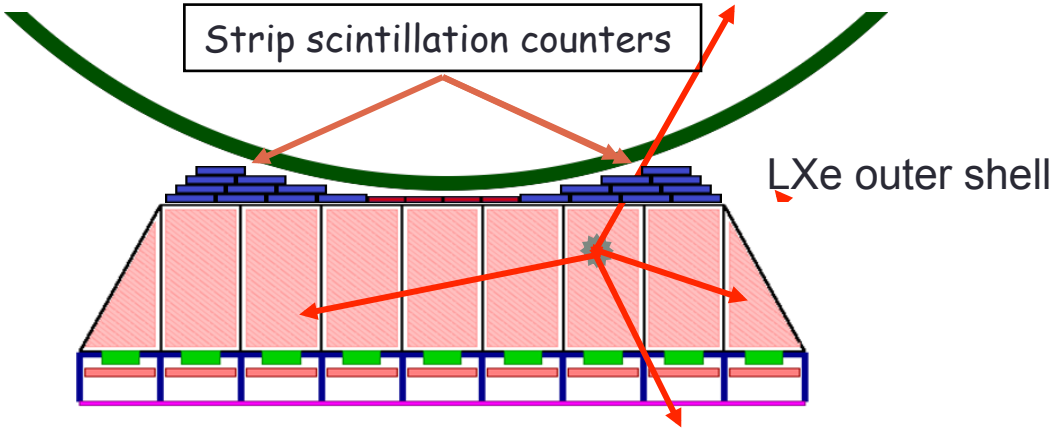


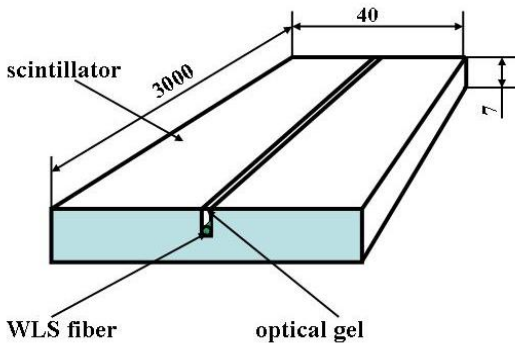
"New" TOF (2017-)



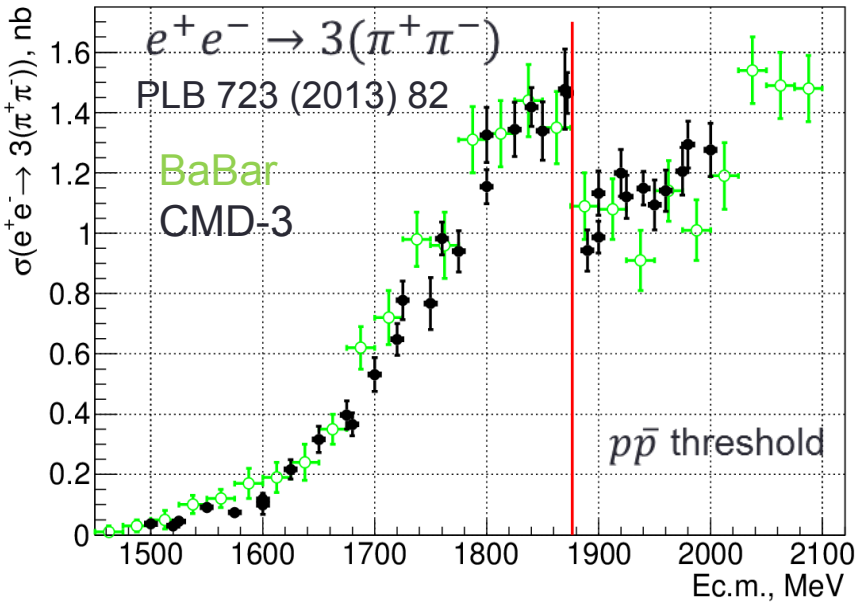
In 2013-2016 the TOF system was completely replaced

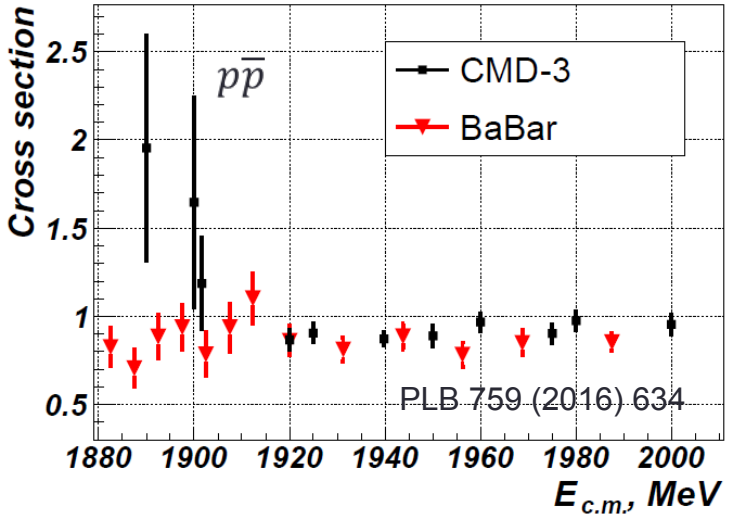
- More granulated (16 counters → 175 counters)
- 0.8 ns resolution per counter





$R(s)$ at $N\bar{N}$ threshold



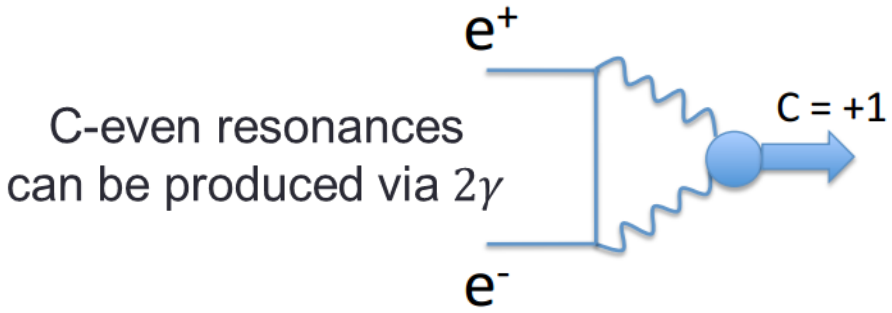


One of first results from CMD-3:

- Sudden drop of $e^+e^- \to 3(\pi^+\pi^-)$ cross section at $N\bar{N}$ threshold
- Confirmed, that $p\bar{p}$ production cross section increases quickly at threshold
- Preliminary studies of dynamics of $e^+e^- \to 3(\pi^+\pi^-)$, hint of energy dependent dynamics in 1.7-1.9 GeV energy range

Search for e+e- → η'(958)

Phys.Lett. B740 (2015) 273-277



C-even resonances can be produced via 2γ

Theory: assuming real γ

$$B(\eta' \to e^+e^-) = 3.7 \cdot 10^{-11}$$

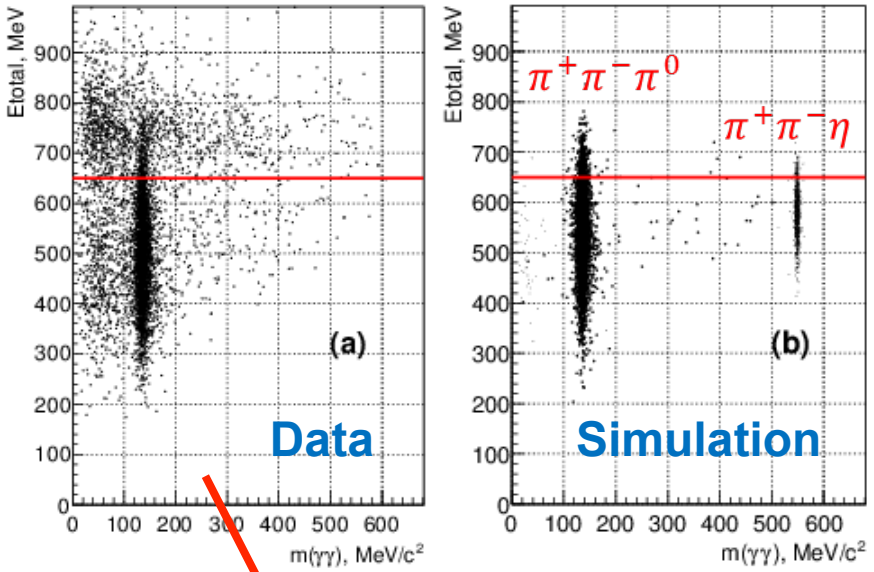
γ virtuality and transition form factor can enhance it

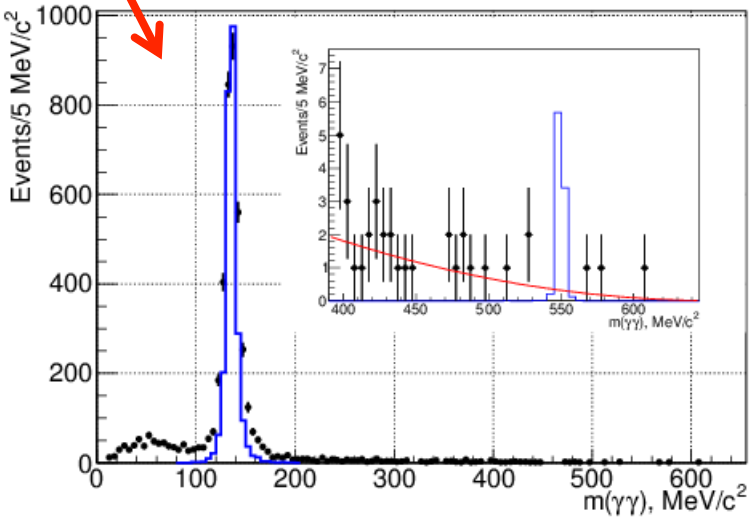
New limit:

$B(\eta' \to e^+e^-) < 5.6 \times 10^{-9}$ (90%CL) - SND+CMD-3

Dedicated data taking at $\sqrt{s} = M_{\eta'}$

Continuous beam energy monitoring is crucial

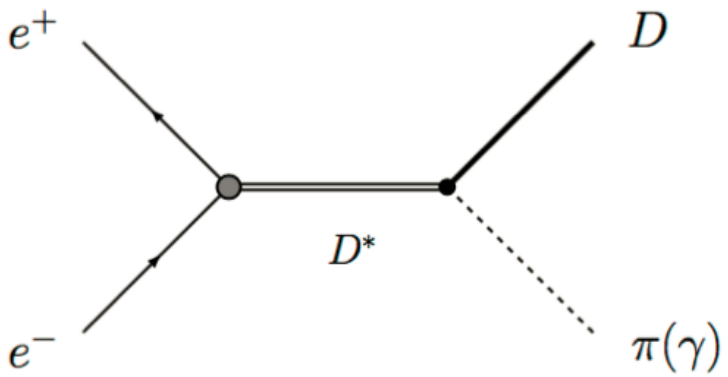




Search for FCNC process: $e^+e^- \to D^{*0}$

Talk by Alexey Petrov (WSU) at ICHEP'16 and JHEP 1511 (2015) 142

$$\sigma(e^+e^- \to D\pi)_{\sqrt{s}\simeq m_{D^*}} \equiv \sigma_{D^*}(s) = \frac{12\pi}{m_{D^*}^2}\,\mathcal{B}_{D^*\to e^+e^-}\mathcal{B}_{D^*\to D\pi}\,\frac{m_{D^*}^2\Gamma_0^2}{(s-m_{D^*}^2)^2+m_{D^*}^2\Gamma_0^2}$$



Estimated sensitivity:

$$B_{D^*\to e^+e^-} \geq \frac{4\times 10^{-10}}{\varepsilon\int Ldt\,[pb^{-1}]} \times \frac{\sigma_{2E}}{\Gamma_{D^*}\,[60\,keV]}$$

Standard Model:

$$B_{D^*\to e^+e^-} \approx (0.1 \div 7)\times 10^{-19}$$

Example of New Physics contribution:

$$B^{Z'}_{D^*\to e^+e^-} < 2.5\times 10^{-11}$$

In 2017 CMD-3 collected 4 pb^{-1} at 2007 MeV with $\sigma_{2E} \approx 2$ MeV