CMD-3 OVERVIEW

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on behalf of CMD-3 collaboration

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

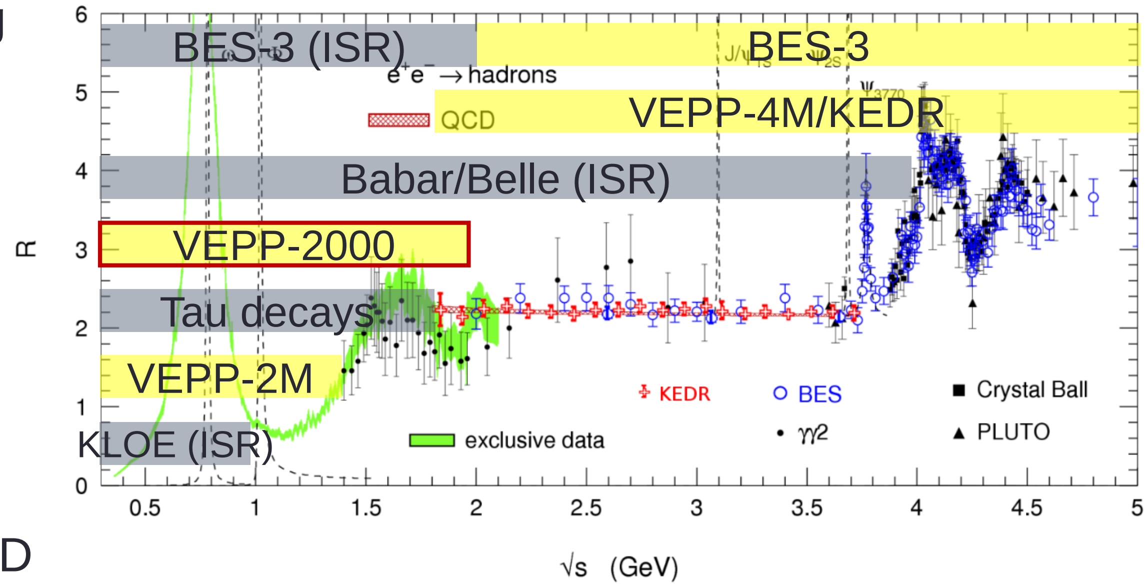
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

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



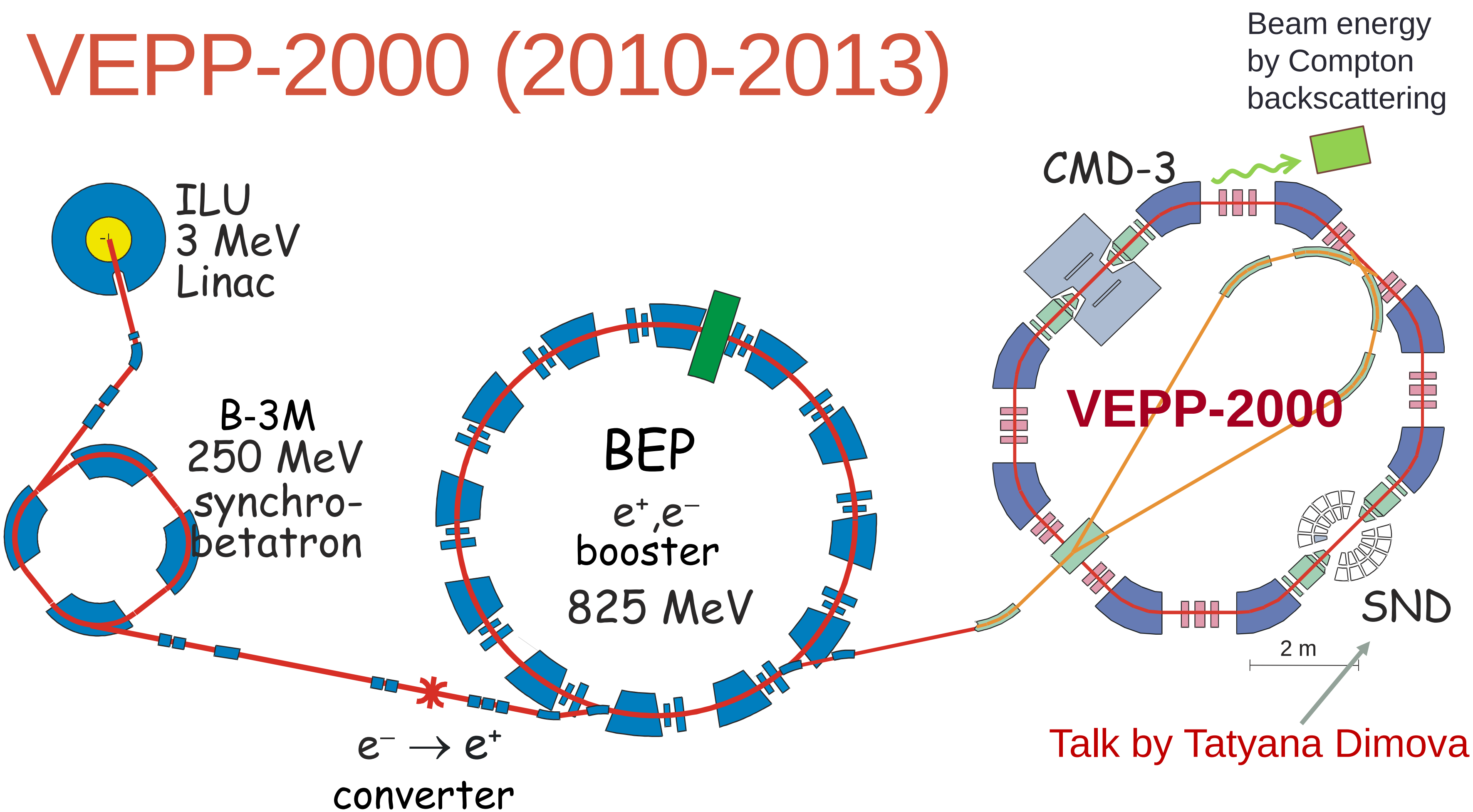
$$\Delta a_\mu(exp - th) = (287 \pm 80) \cdot 10^{-11}$$ (DHMZ'12)

corresponds to

$$(4.15 \pm 1.15)\% \cdot a_\mu^{had,LO}$$

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

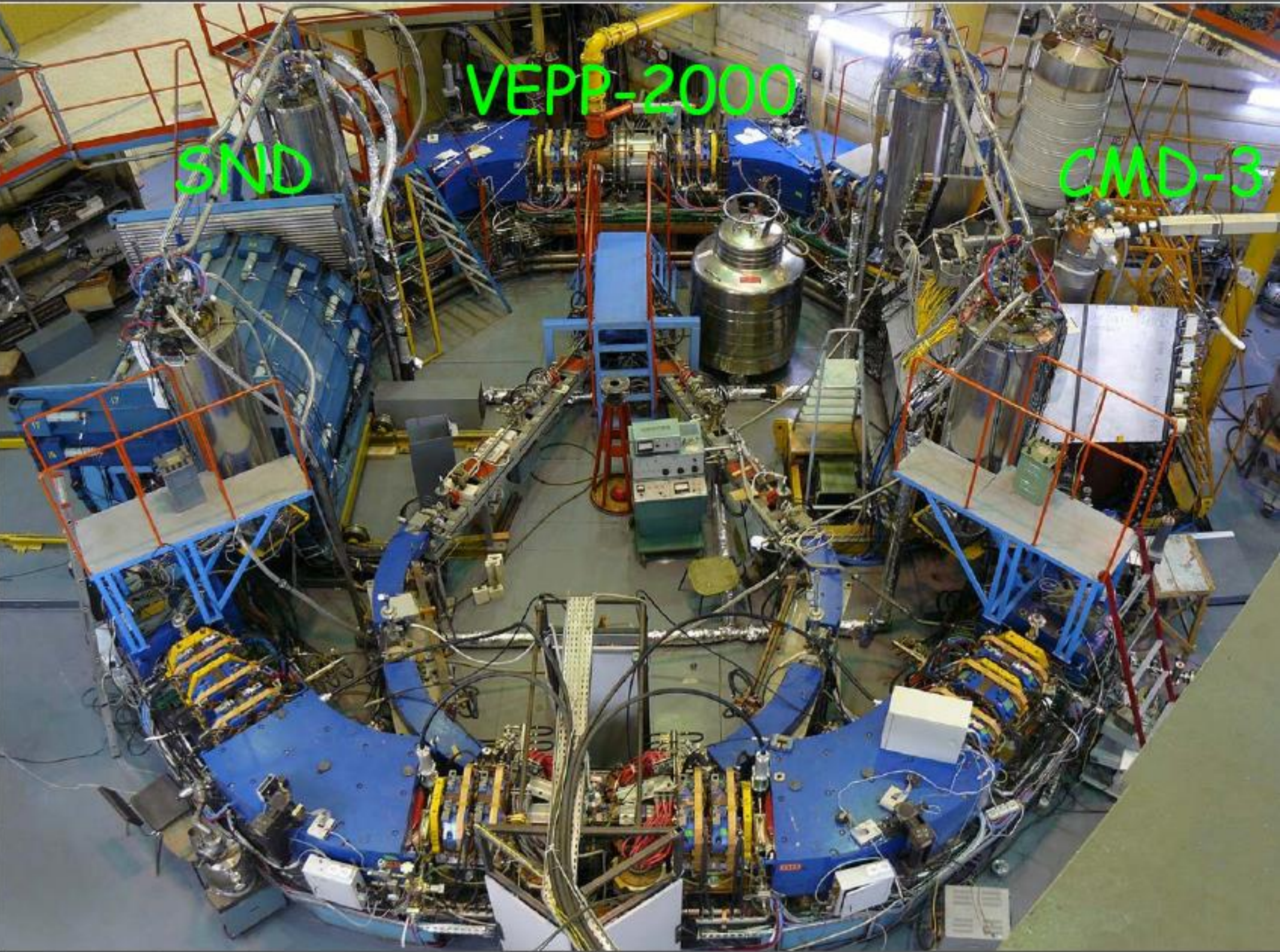
VEPP-2000 (2010-2013)



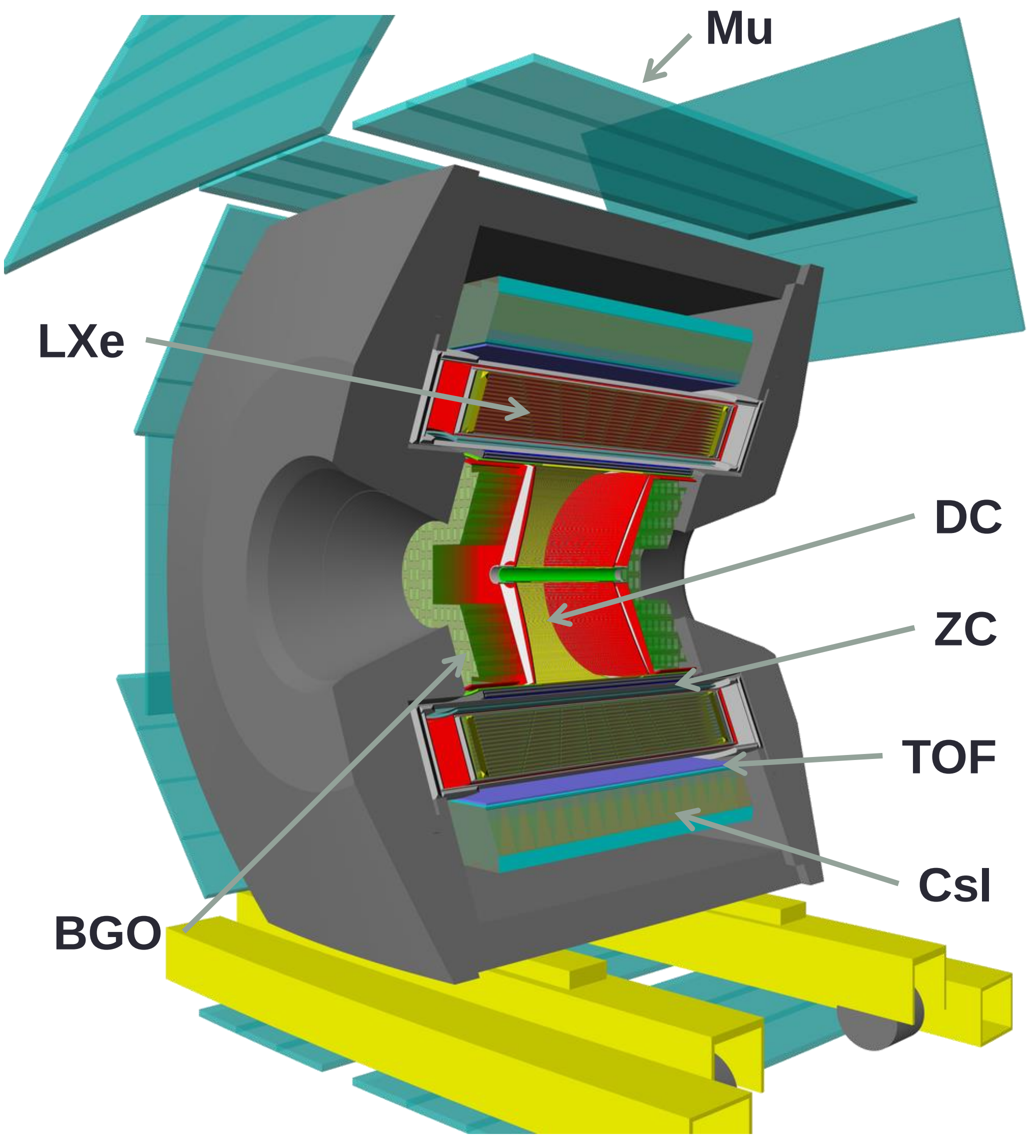
C.m. energy range is 0.32-2.0 GeV; unique optics – “round beams”

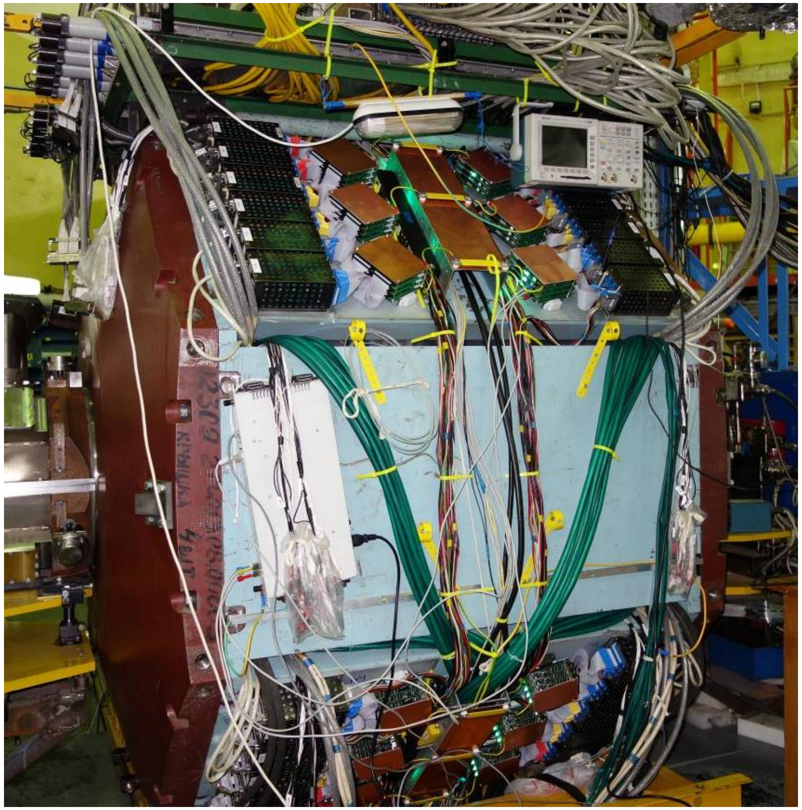
Design luminosity is $L = 10^{32} 1/cm^2 s$ @ $\sqrt{s} = 2$ GeV

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


VEPP-2000
SND
CMD-3

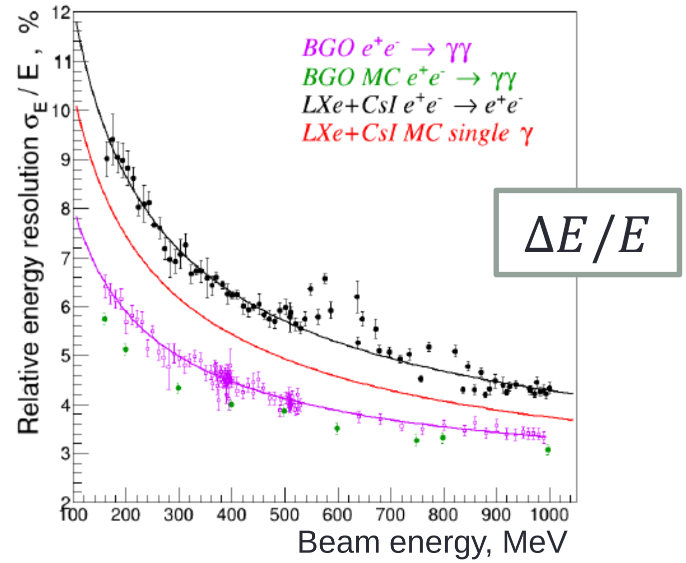
Detector CMD-3

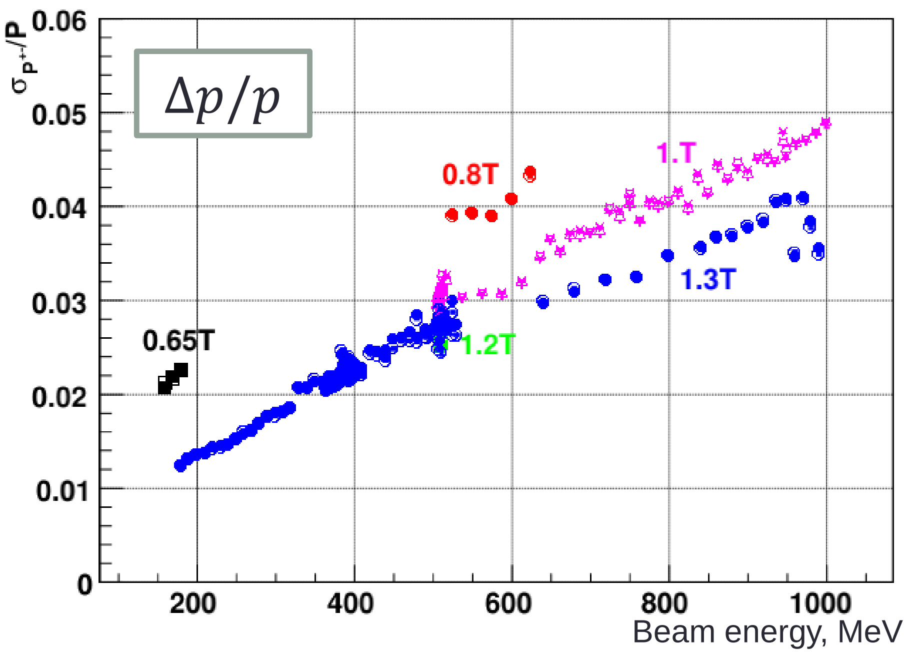


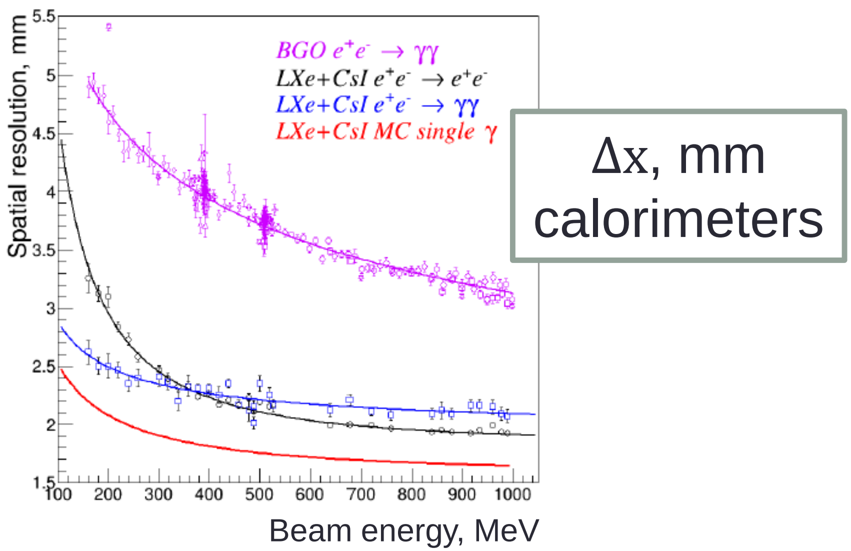


CMD-3 Performance (2011-2013)

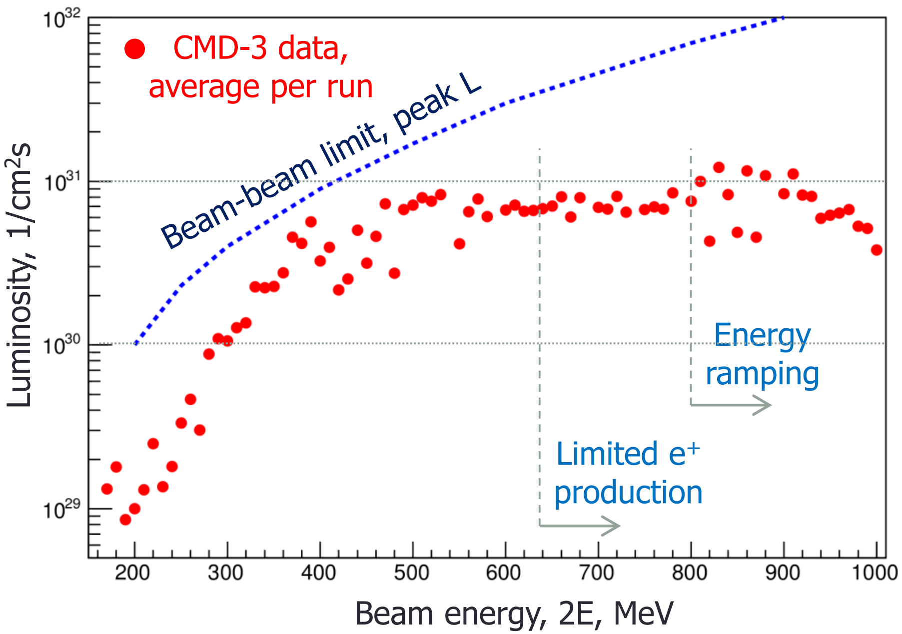
- 1.0-1.3 T magnetic field
- Tracking: $\sigma_{R\varphi} \sim 100\ \mu, \sigma_z \sim 2-3$ mm
- Combined EM calorimeter (LXE, CsI, BGO), 13.5 X_0
  - ➢ $\sigma_E/E \sim 3\% - 10\%$
  - ➢ $\sigma_\Theta \sim 5$ mrad

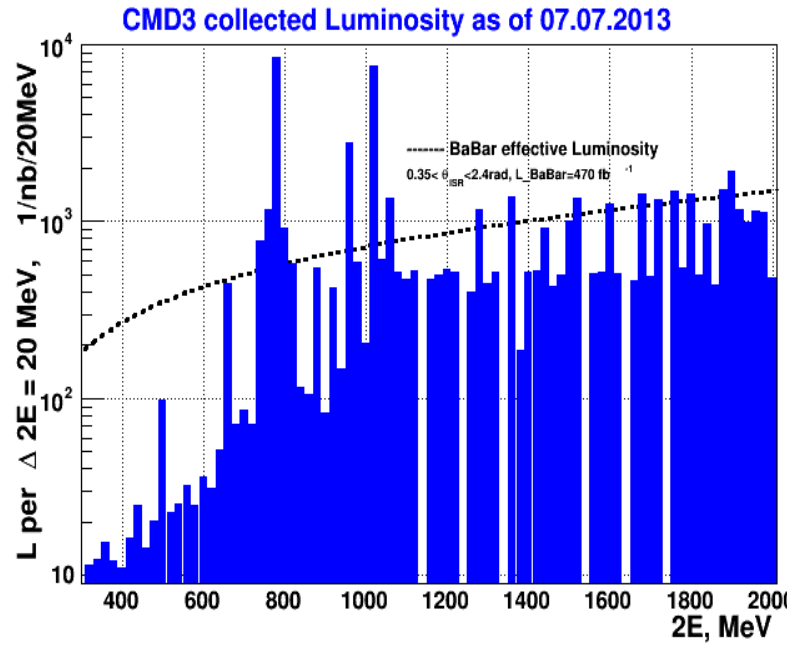






Collected luminosity in 2011-2013





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	$34.5\ \ 1/pb$

VEPP-2000 upgrade (2013-2016)

Collider upgrades:

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

CMD-3 upgrades:

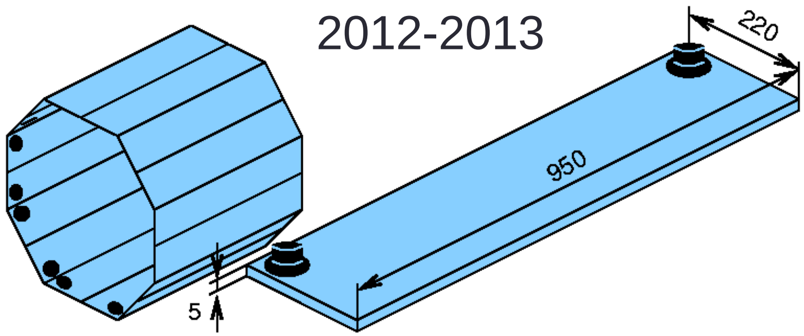
- New electronics for Lxe calorimeter
- New TOF system
- DAQ and electronics upgrades

Detectors resumed data taking by the end of 2016

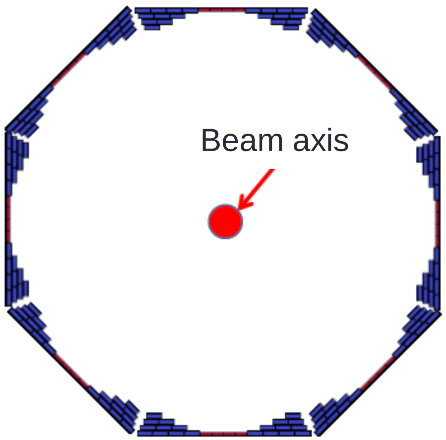
Talk by Dmitry SHWARTZ on Thursday

New TOF system

“Old” TOF
2012-2013

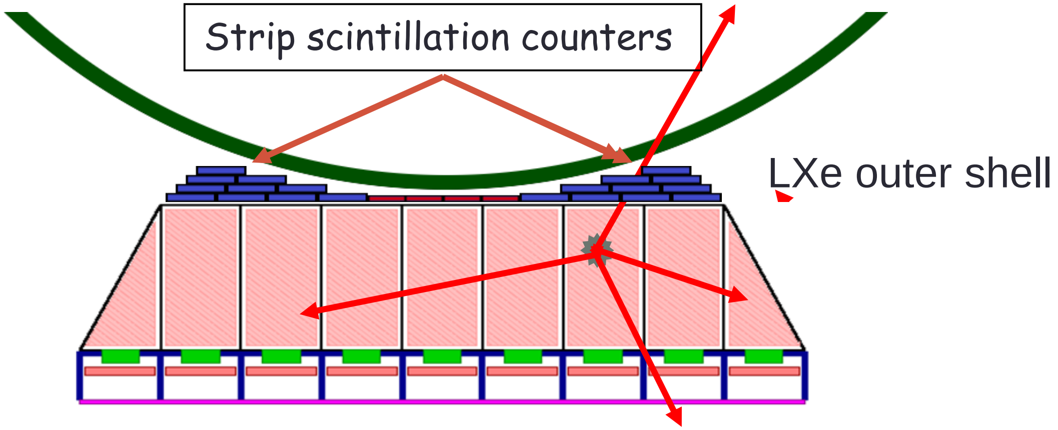


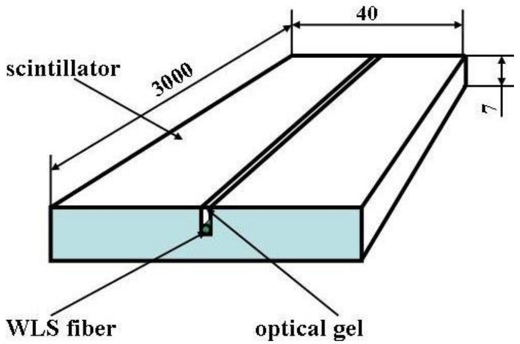
“New” TOF (2017-)



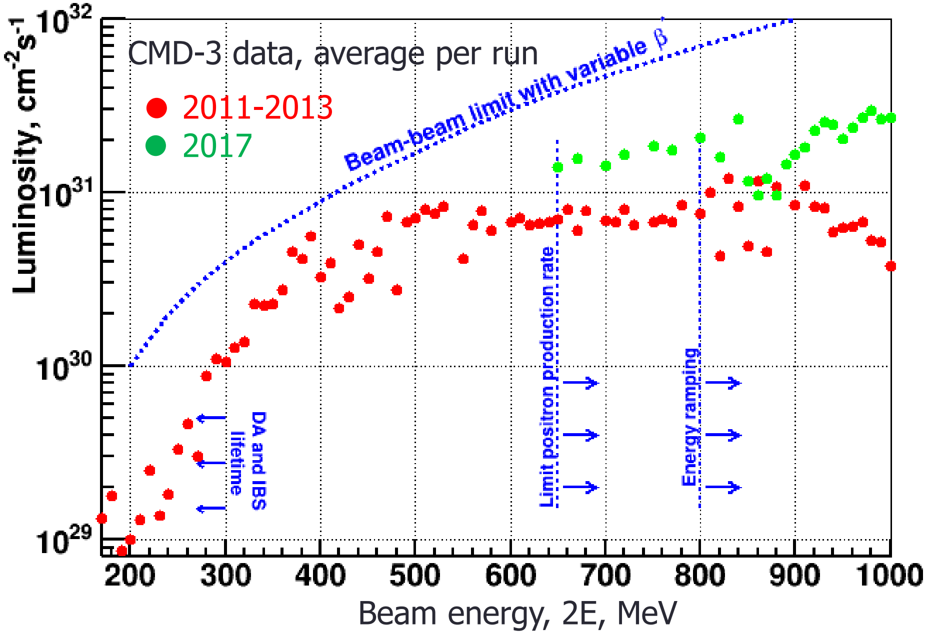
In 2013-2016 the TOF system was completely replaced

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

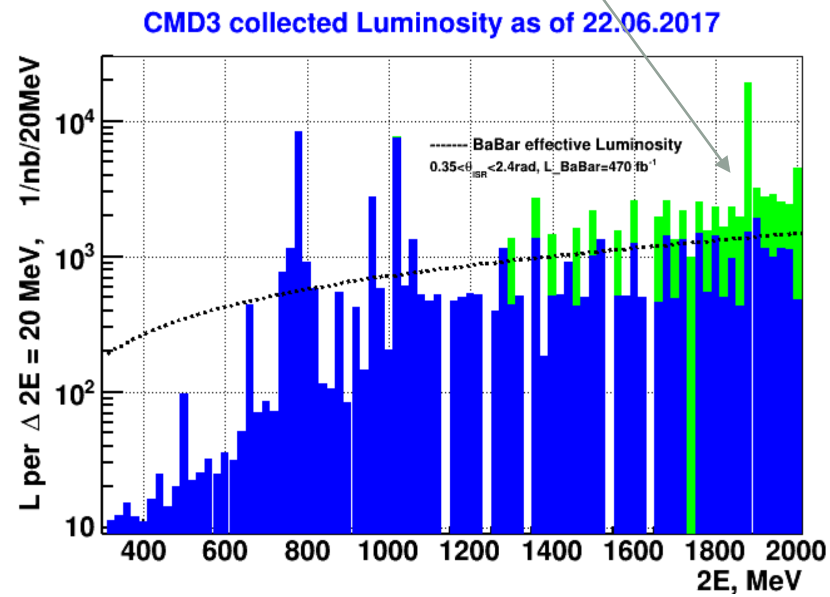




2017 data taking



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



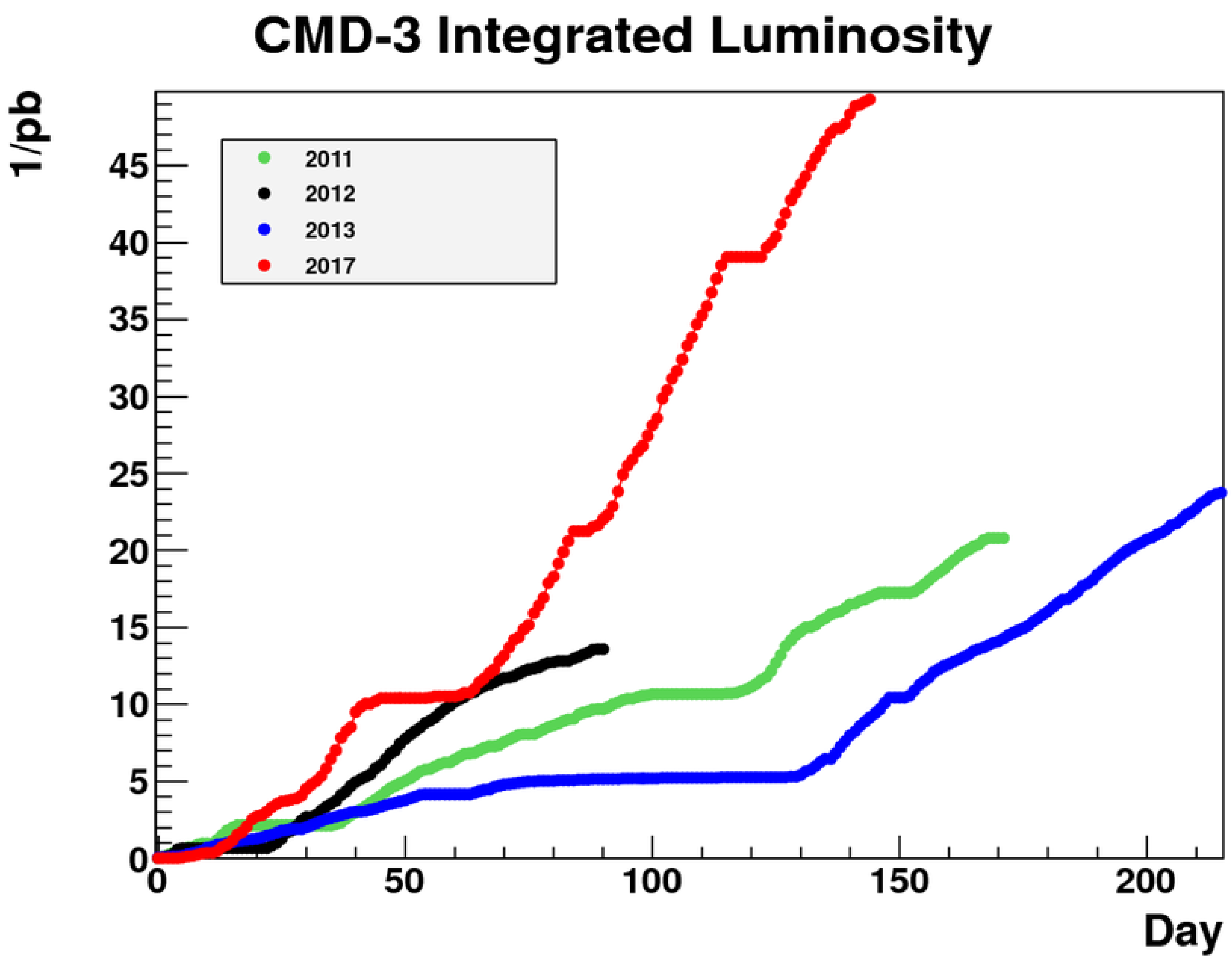
In 2017: big improvement in luminosity at high energy, still way to go

Collected data at “high” energies

About 50 pb^{-1} collected

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

Overview of CMD-3 data taking runs



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

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

- 2 charged

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

- 2 charged + γ's

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

- 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

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

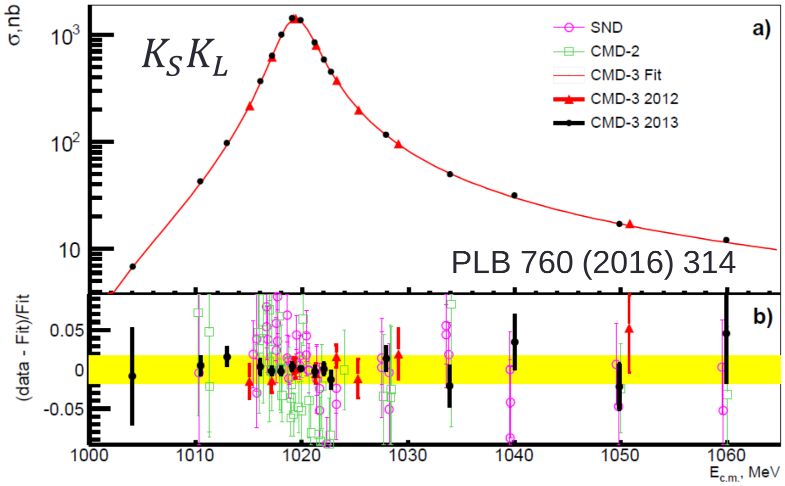
- γ's only

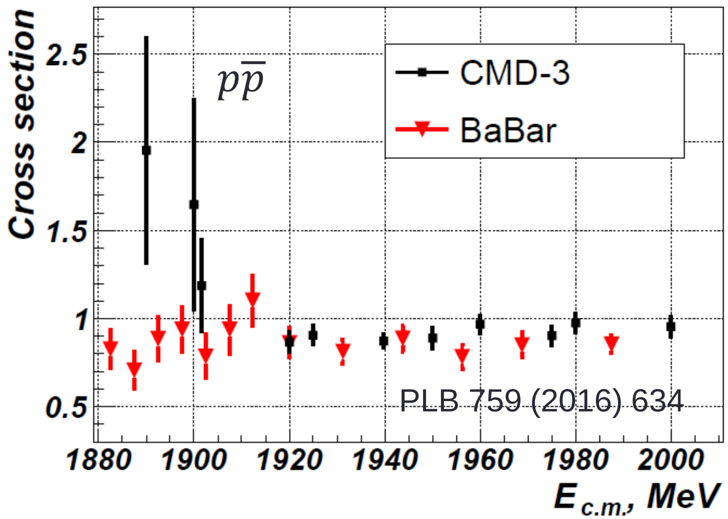
$$e^+e^- \to \pi^0\gamma, \eta\gamma, \pi^0\pi^0\gamma, \pi^0\eta\gamma, \pi^0\pi^0\pi^0\gamma, \pi^0\pi^0\eta\gamma$$

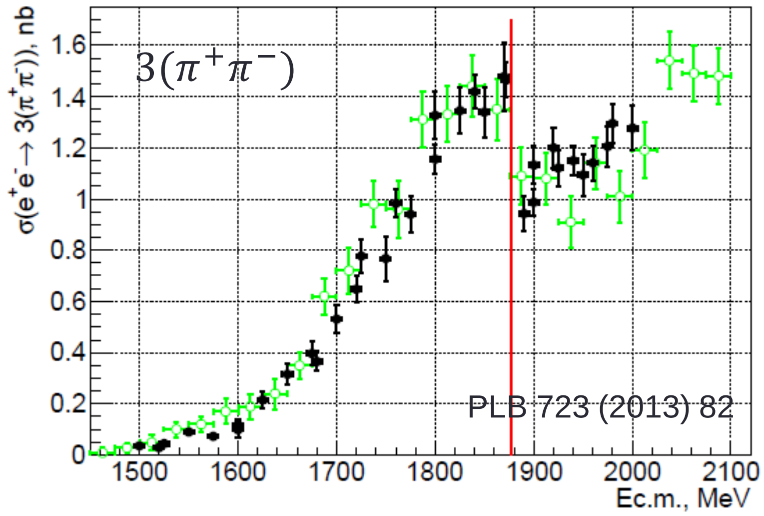
- other

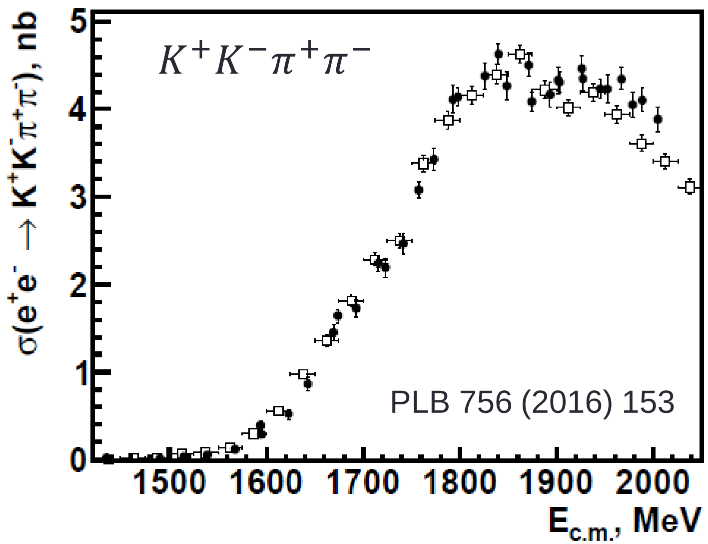
$$e^+e^- \to n\overline{n}, \pi^0e^+e^-, \eta e^+e^-$$

Published results from 2011-2013: CMD-3







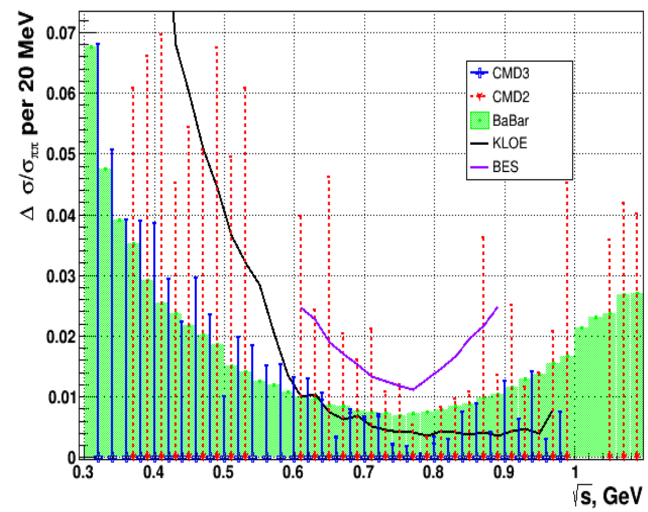


Dominant channel: $e^+e^- \to \pi^+\pi^-$

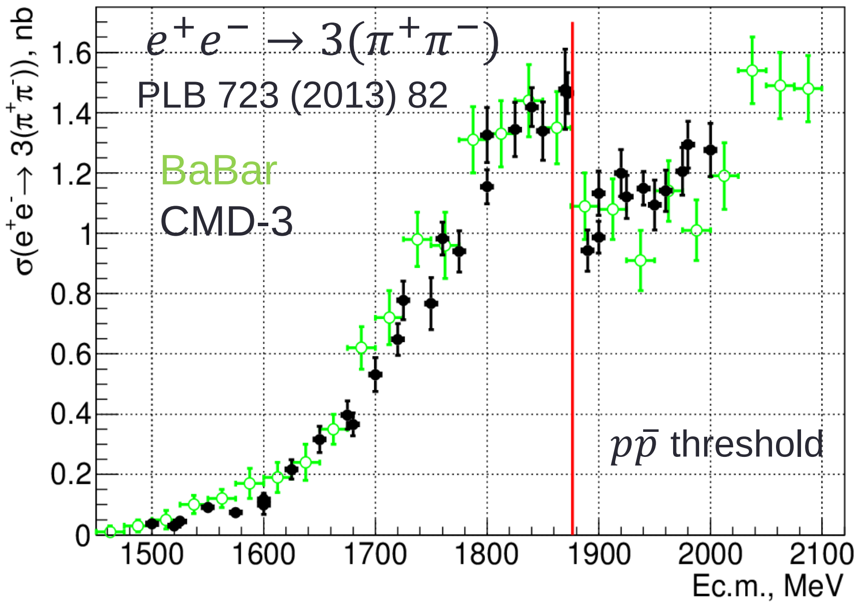
- Energy range below φ was scanned in 2013. Data analysis is in progress.
- Energy range above φ was scanned in 2011-2012. Data analysis for $\pi^+\pi^-$ havn't started yet. There are known problems with data, which will limit precision, e.g. the beam energy was measured only for subset of energy points.

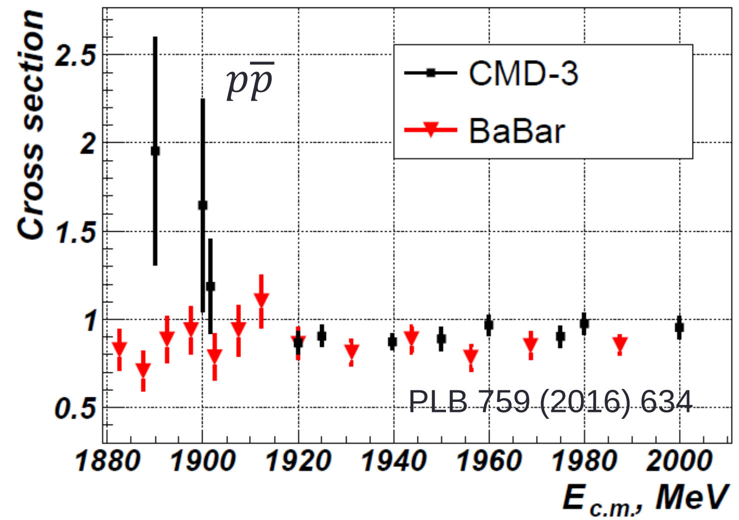
Talk by Fedor Ignatov on Monday

Statistical accuracy of 2013 data



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





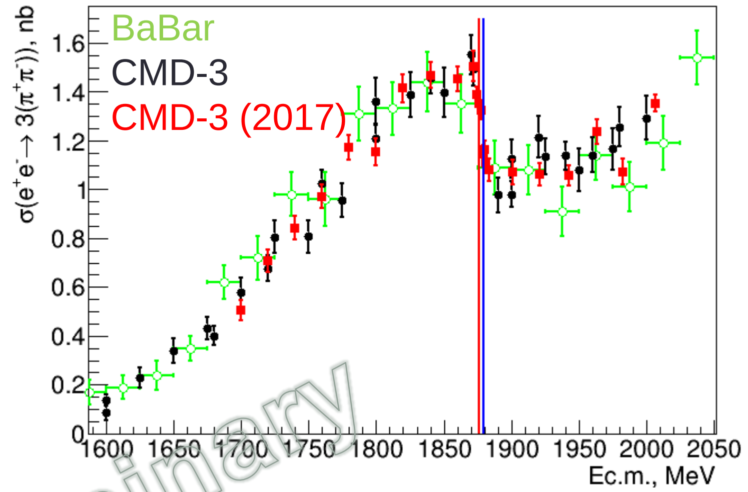
One of first results from CMD-3:

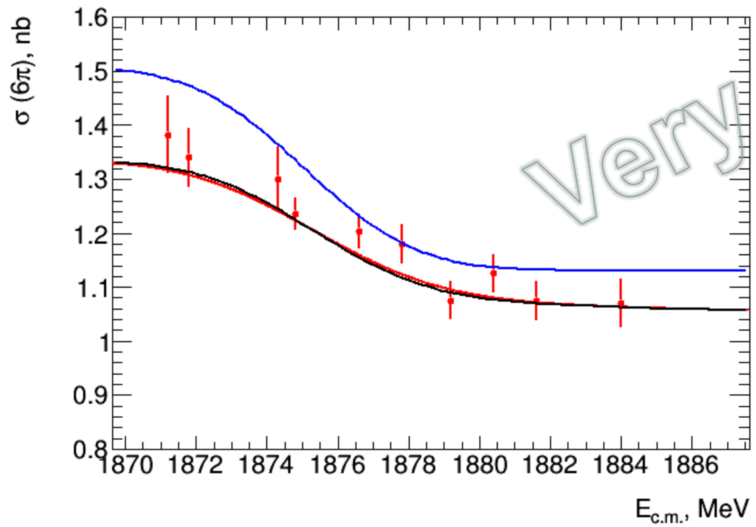
- Sudden drop of $e^+e^- \to 3(\pi^+\pi^-)$ cross section at $N\bar{N}$ threshold
- Confirmed, that $p\bar{p}$ production cross section increases quickly at threshold
- Preliminary studies of dynamics of $e^+e^- \to 3(\pi^+\pi^-)$, hint of energy dependent dynamics in 1.7-1.9 GeV energy range

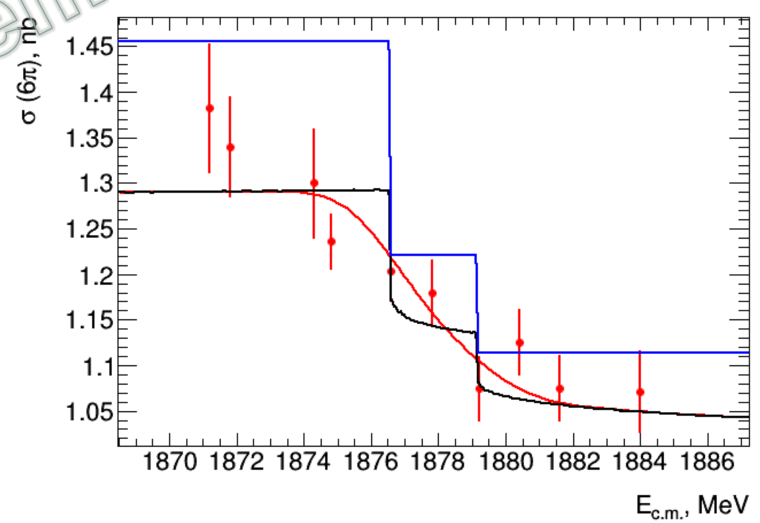
2017: $e^+e^- \to 3(\pi^+\pi^-)$ at $N\bar{N}$ threshold

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)

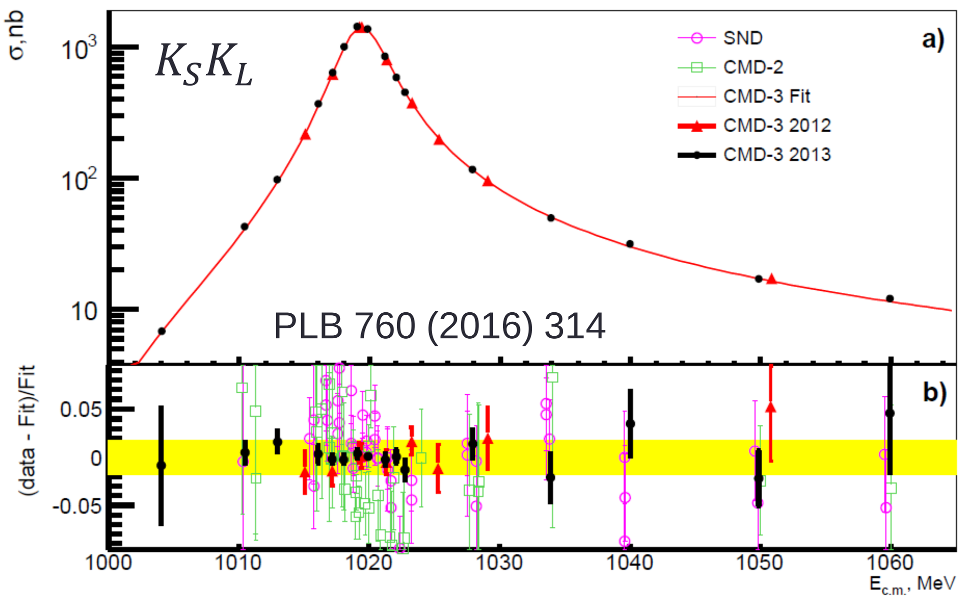


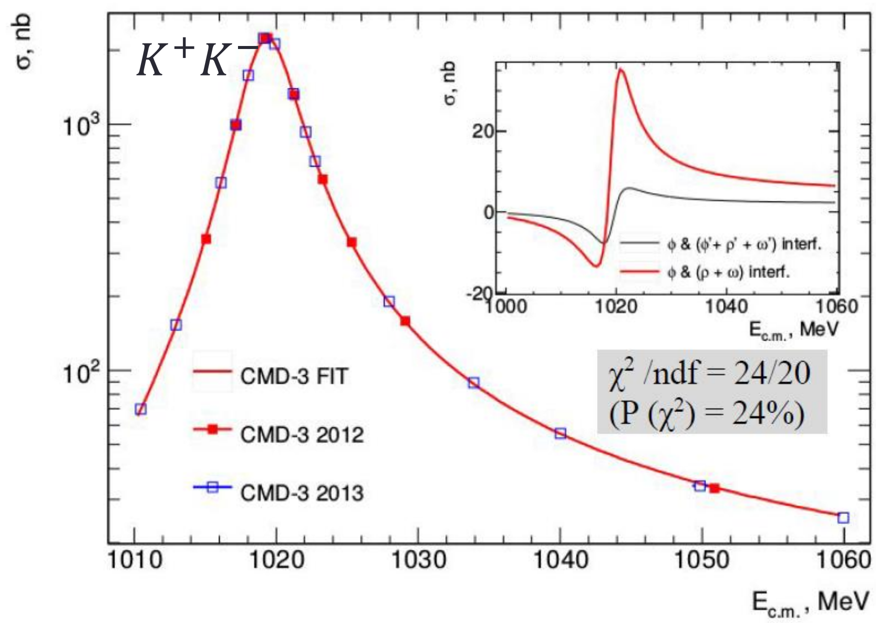




Very preliminary

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

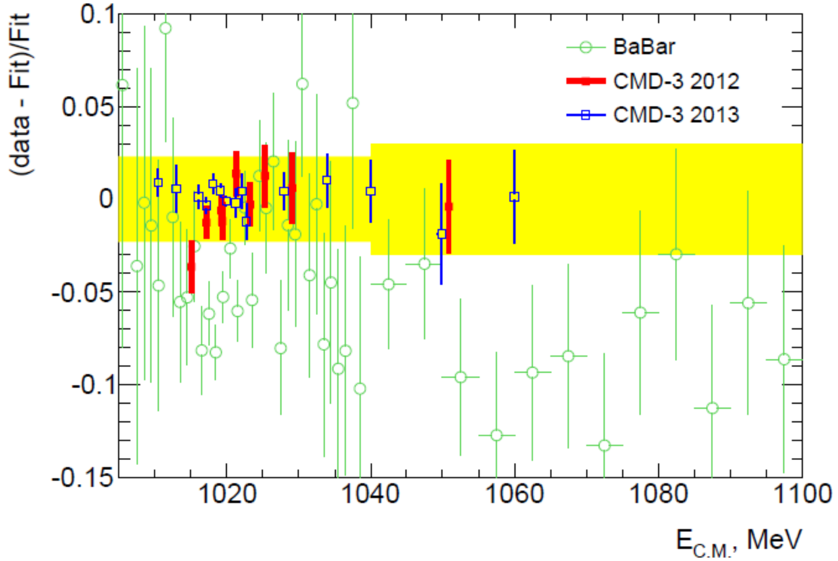


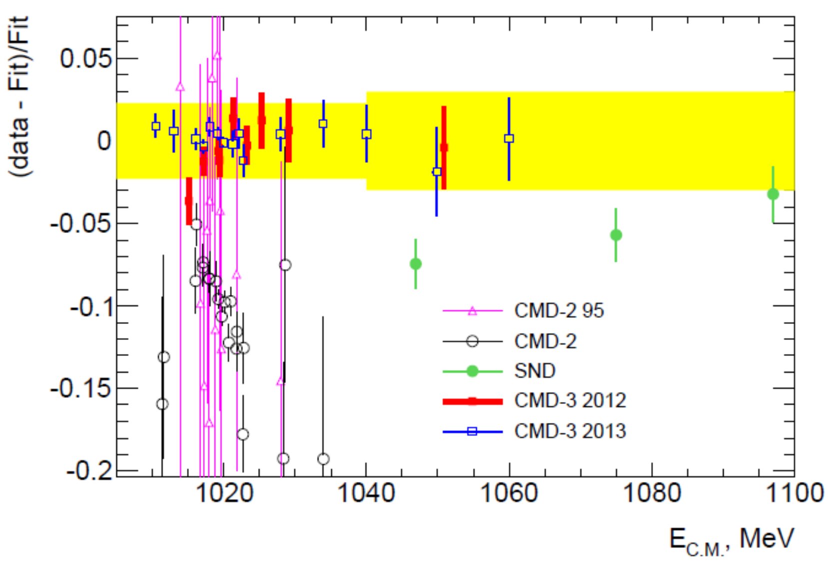


Recent result from CMD-3:

- $K_S K_L$ 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:

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

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

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

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

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

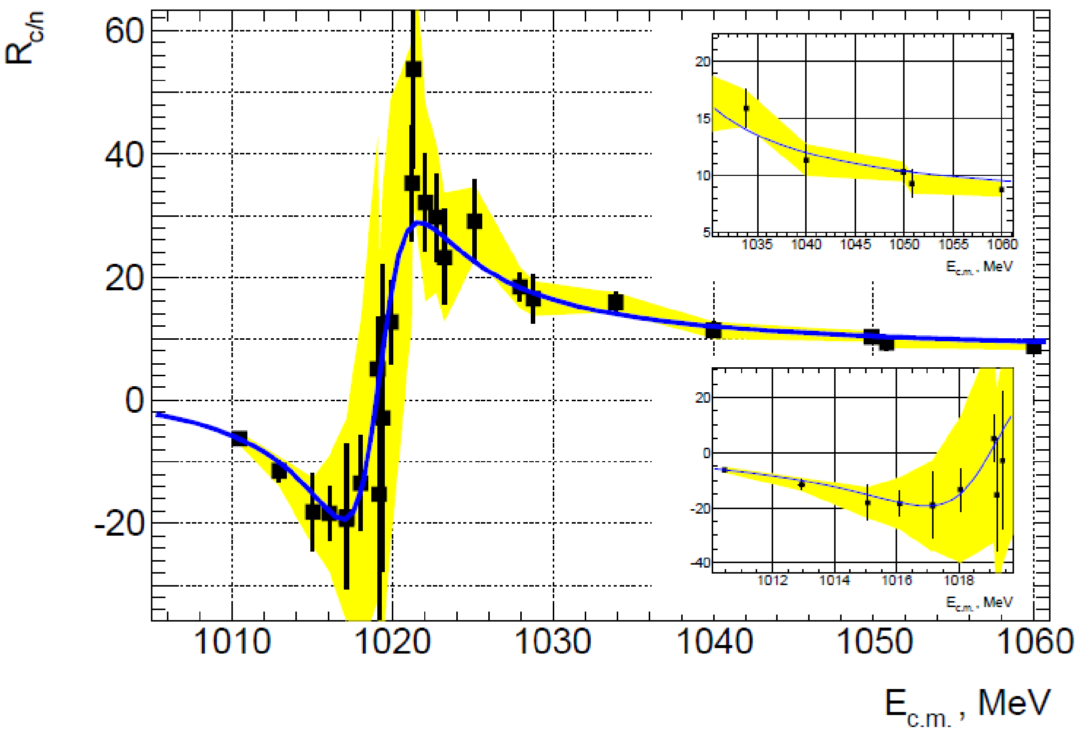
- $r_{\rho,\omega} = 0.91 \pm 0.04$

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

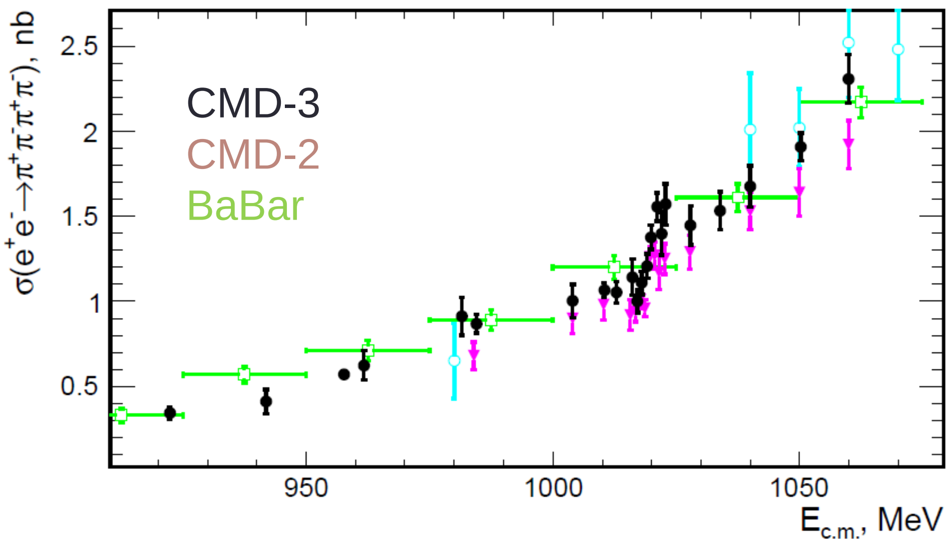


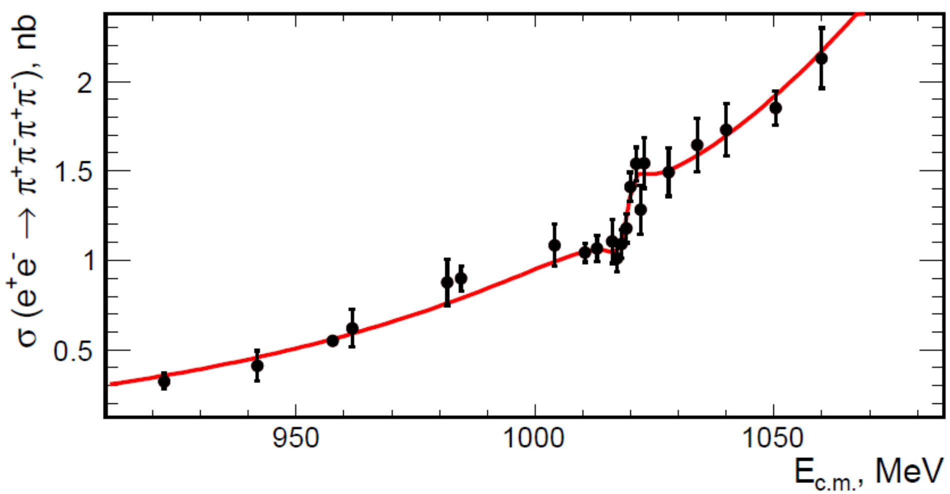
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ @$\varphi(1020)$

PLB 768 (2017) 345-350

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

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

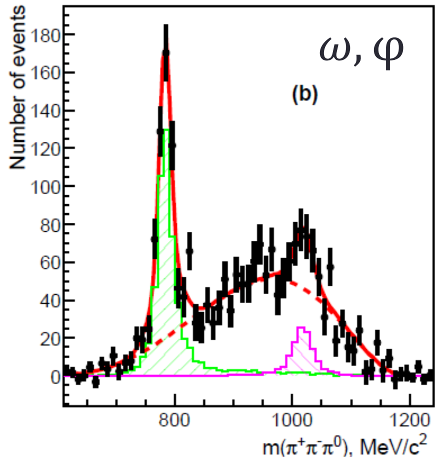


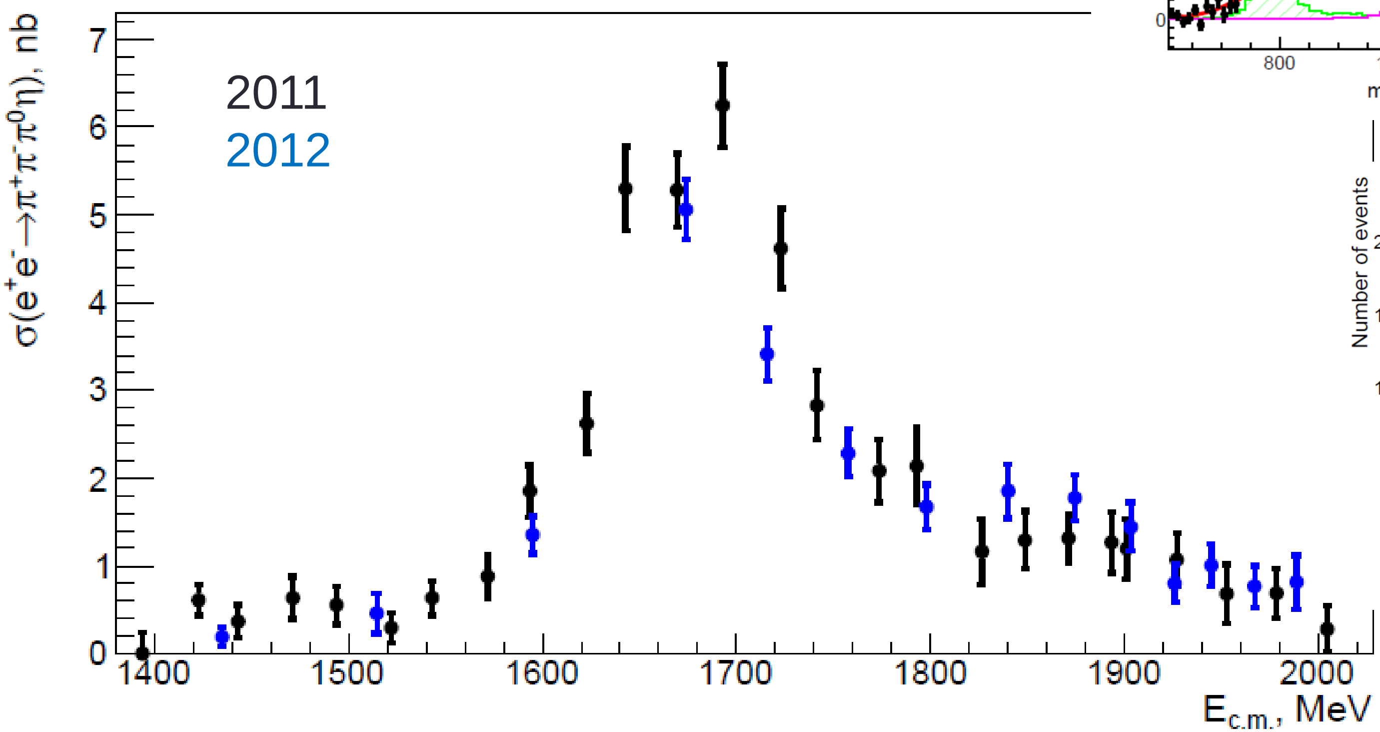


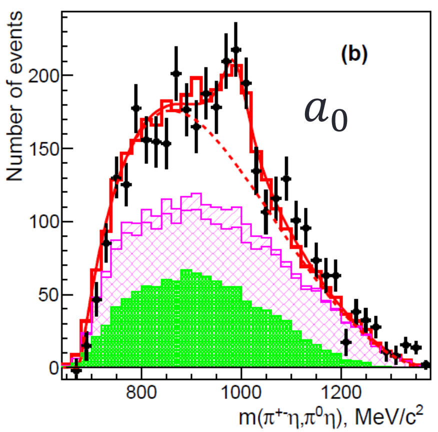
$e^+e^- \to \pi^+\pi^-\pi^0\eta$

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

$$e^+e^- \to \omega\eta, \varphi\eta$$

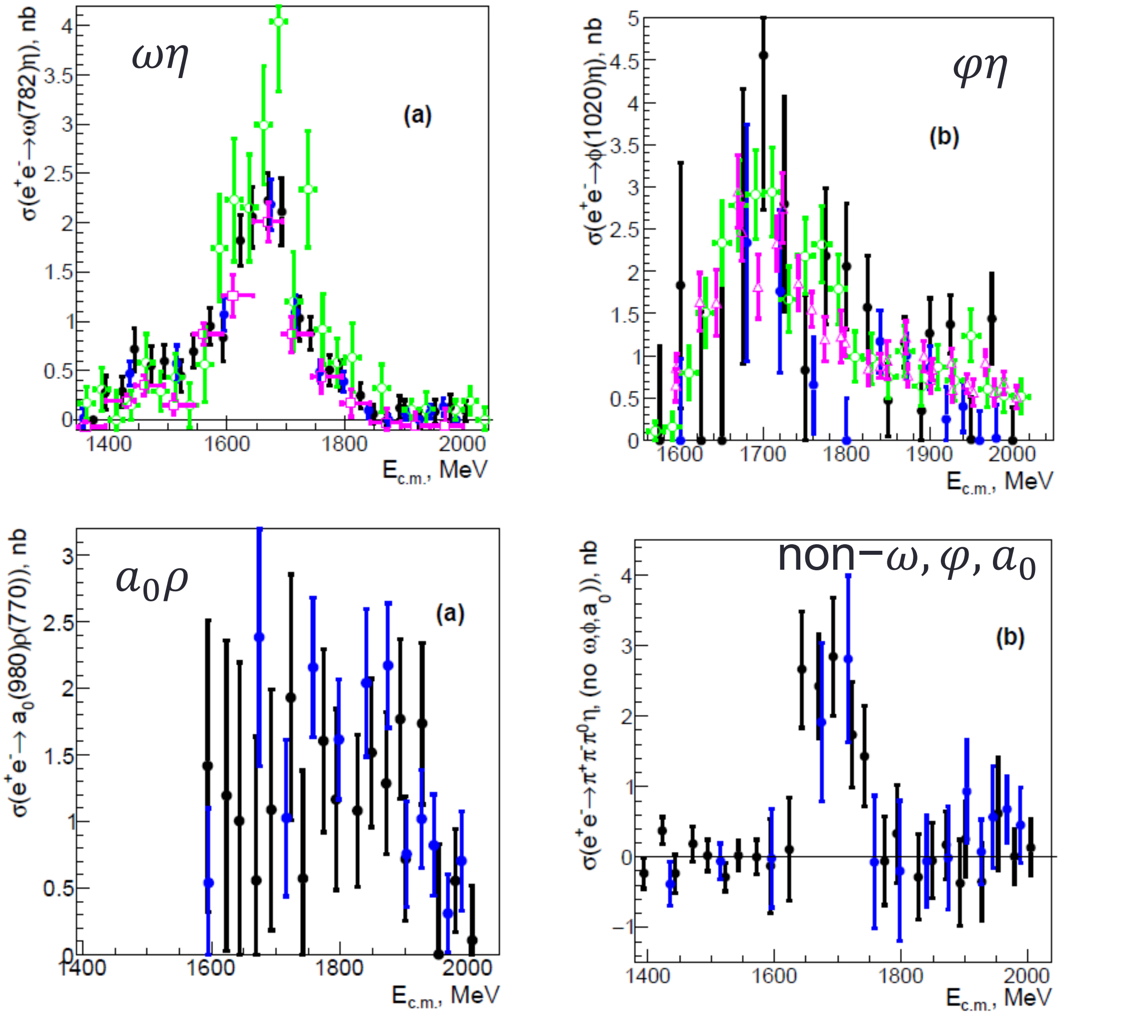
At “high” energies dominated by

$$e^+e^- \to a_0(980)\rho$$

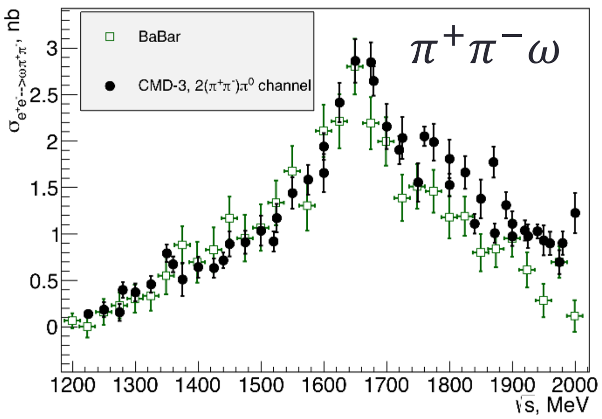
We see non-ω, φ, a_0 contribution

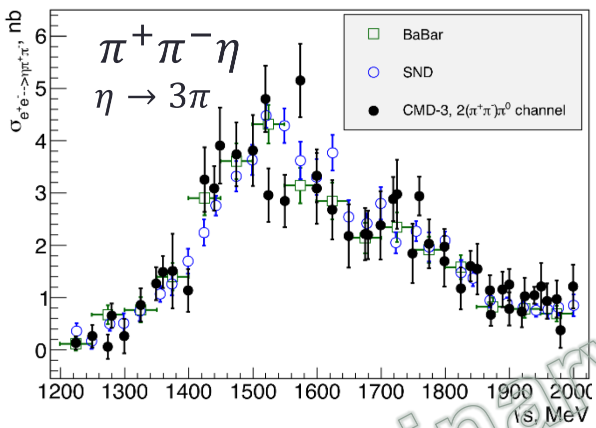
Possible mechanism:

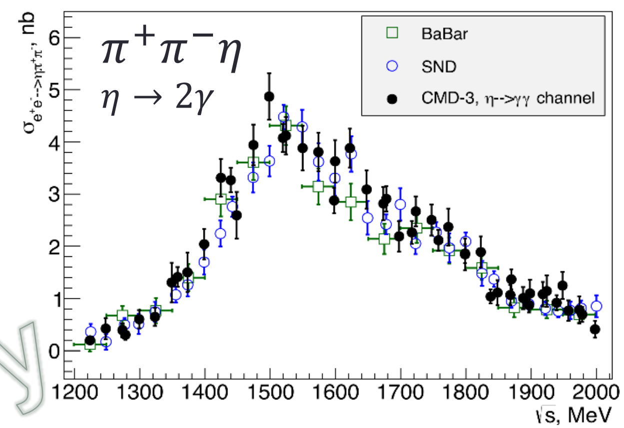
$$e^+e^- \to \omega(1650) \to \rho(1450{,}1700)\pi \to \rho(770)\eta\pi$$

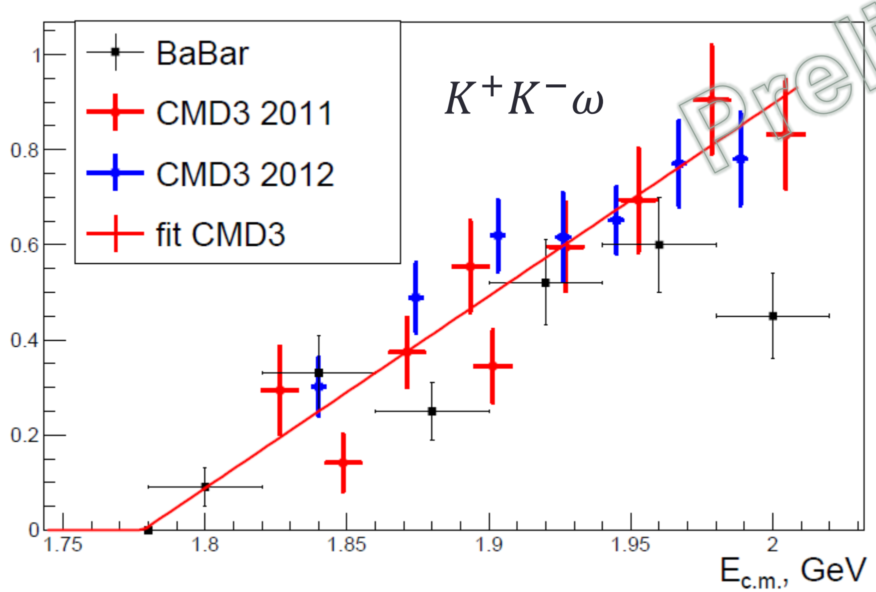


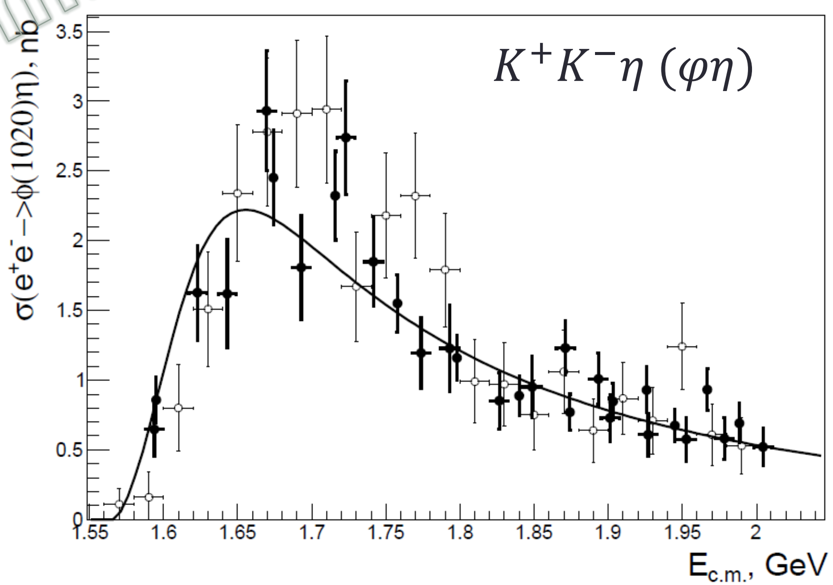
CMD-3 preliminary: $\pi^+\pi^-(\omega,\eta), K^+K^-(\omega,\eta)$





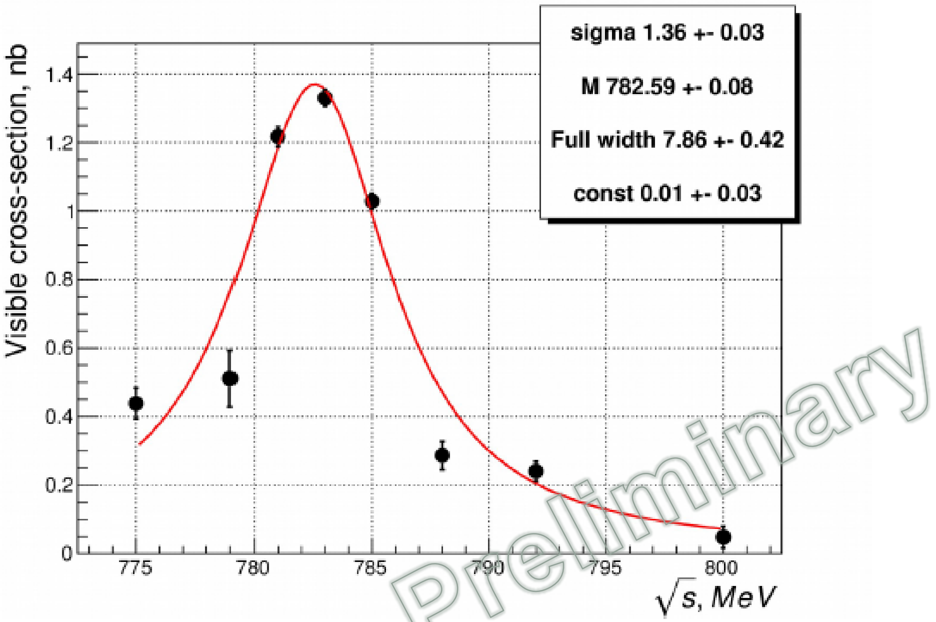






$\omega \to \pi^o e^+ e^-$

- 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.



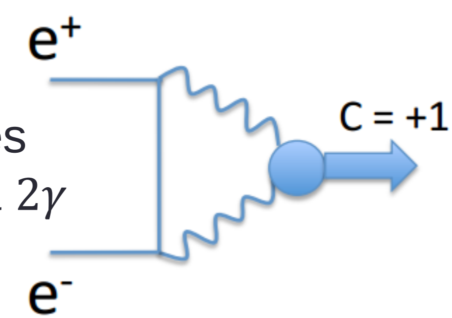
Visible cross section of the signal process is fitted with a Breit–Wigner distribution.

- 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).

Search for $e^+e^- \to \eta'(958)$ at CMD-3

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

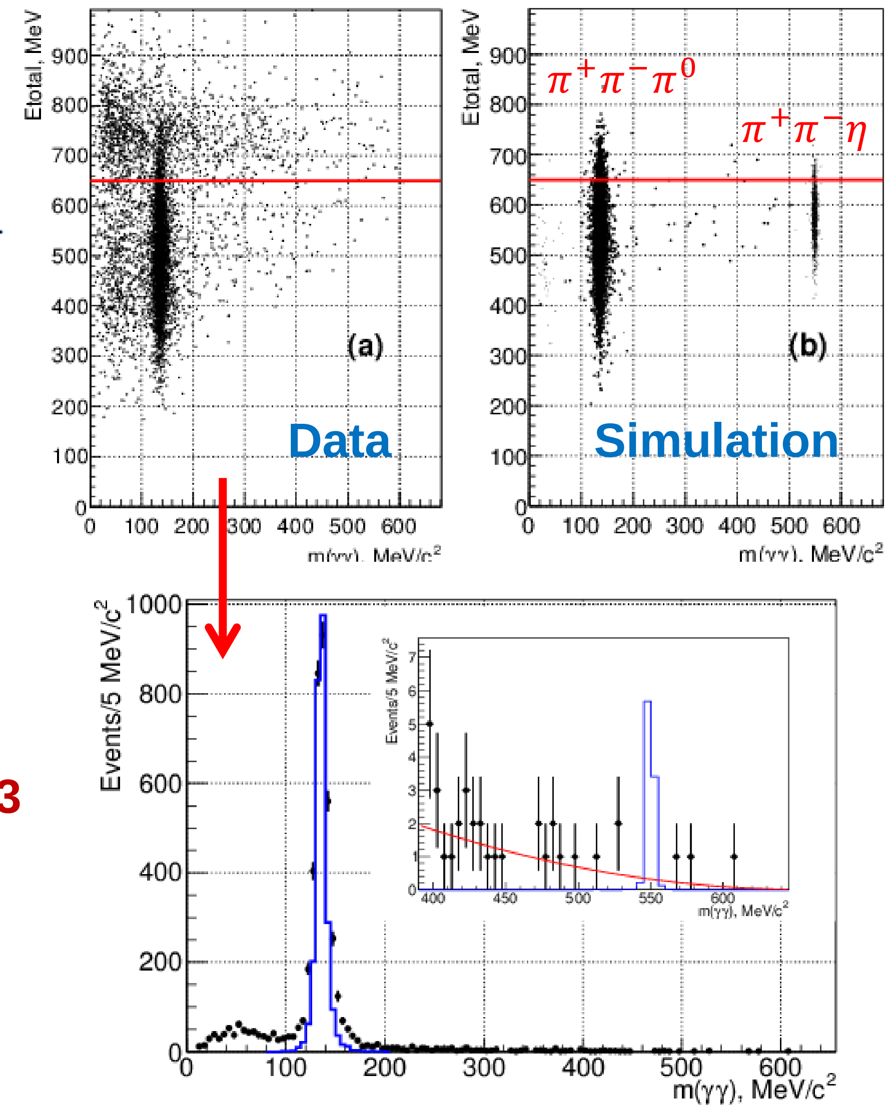
New limit:

$B(\eta' \to e^+e^-) < 1.2 \cdot 10^{-8}\ (90\%CL)$ **CMD3**

$B(\eta' \to e^+e^-) < 2.1 \cdot 10^{-7}\ (90\%CL)$ **ND**

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

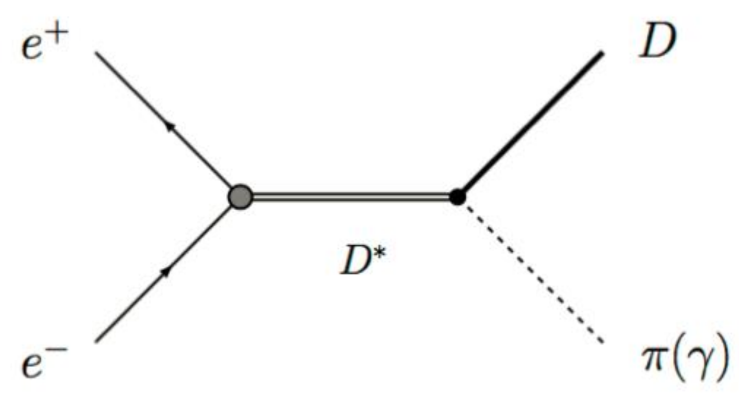
Continuous beam energy monitoring is crucial



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

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.