NEWS FROM CMD-3, SND EXPERIMENTS AT VEPP2000

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on behalf of CMD-3 and SND collaborations

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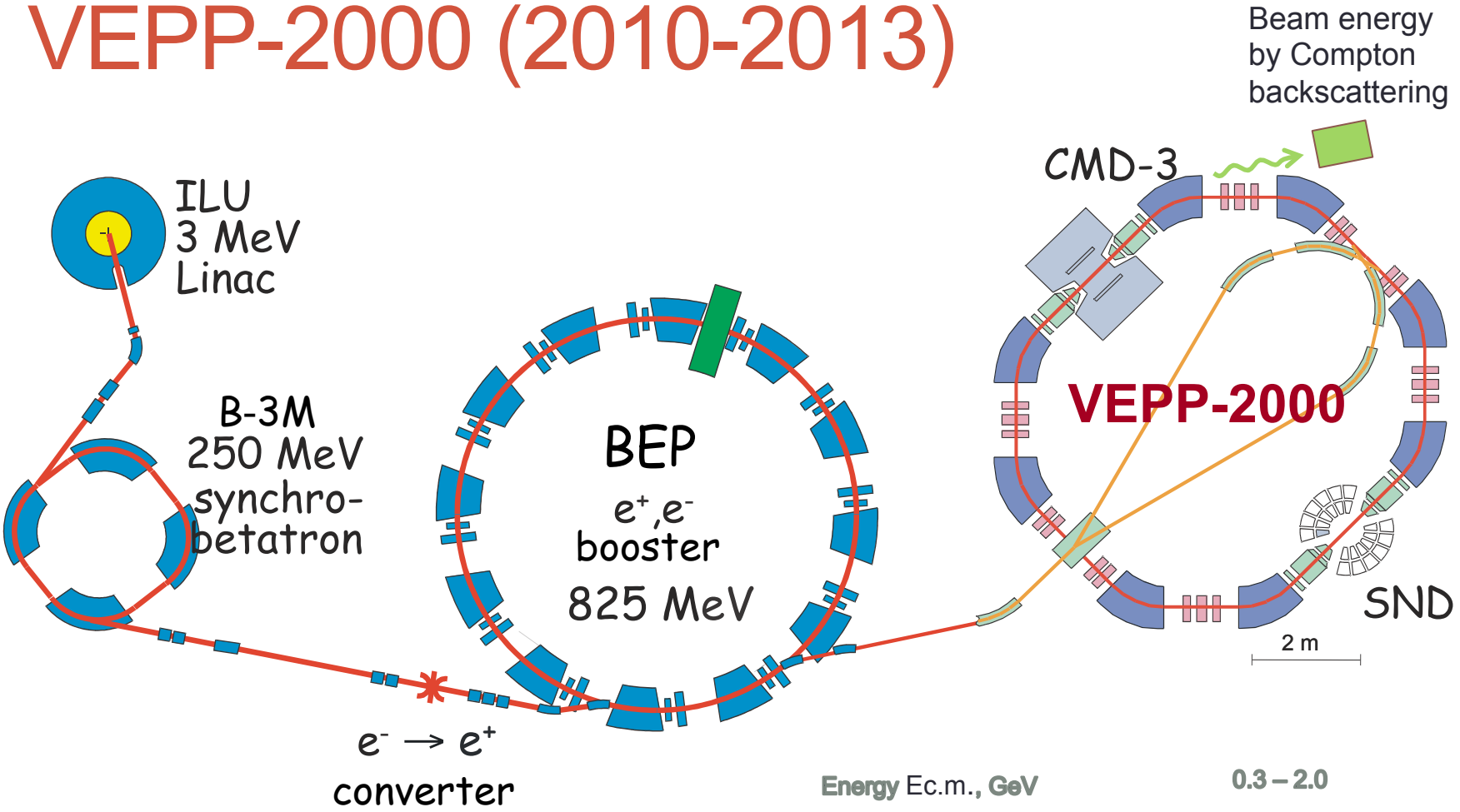
June 2018

VEPP-2000 (2010-2013)

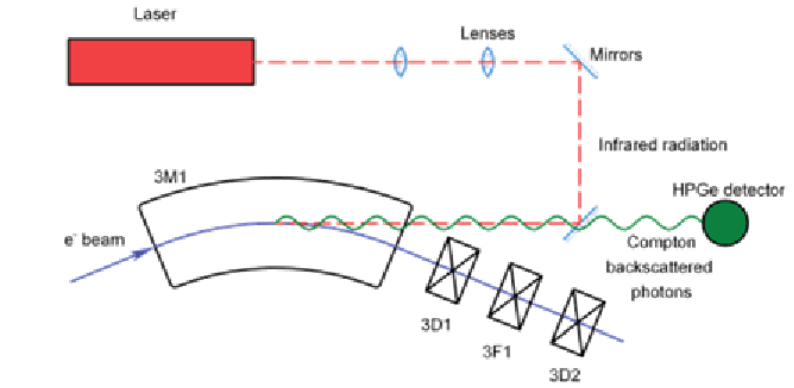


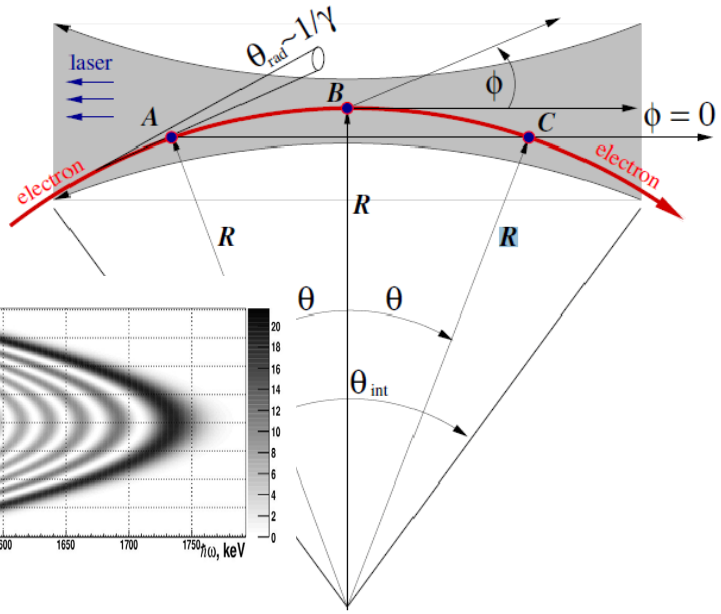
During 2010-2013 the luminosity was limited by shortage of positrons

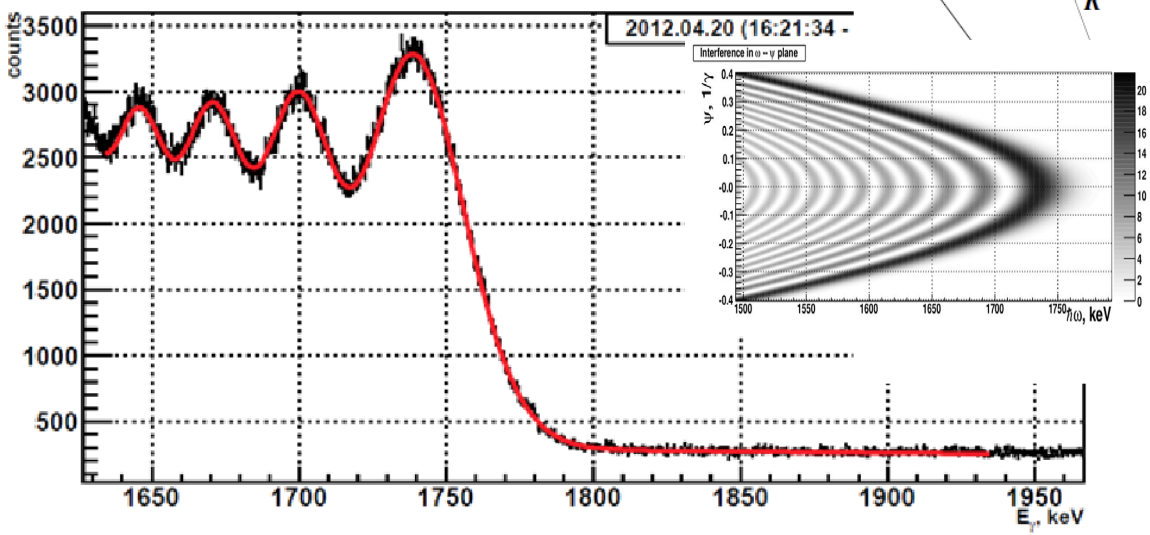
Energy Ec.m., GeV	0.3 – 2.0
Circumference, m	24.4
Beam optics	round
Positron source	converter $e^- \rightarrow e^+$
Luminosity (at 2 GeV), $cm^{-2}\ sec^{-1}$	1×10^{32} (project) 2×10^{31} (achieved)

Energy measurement

Starting from 2012, energy is monitored continuously using Compton backscattering

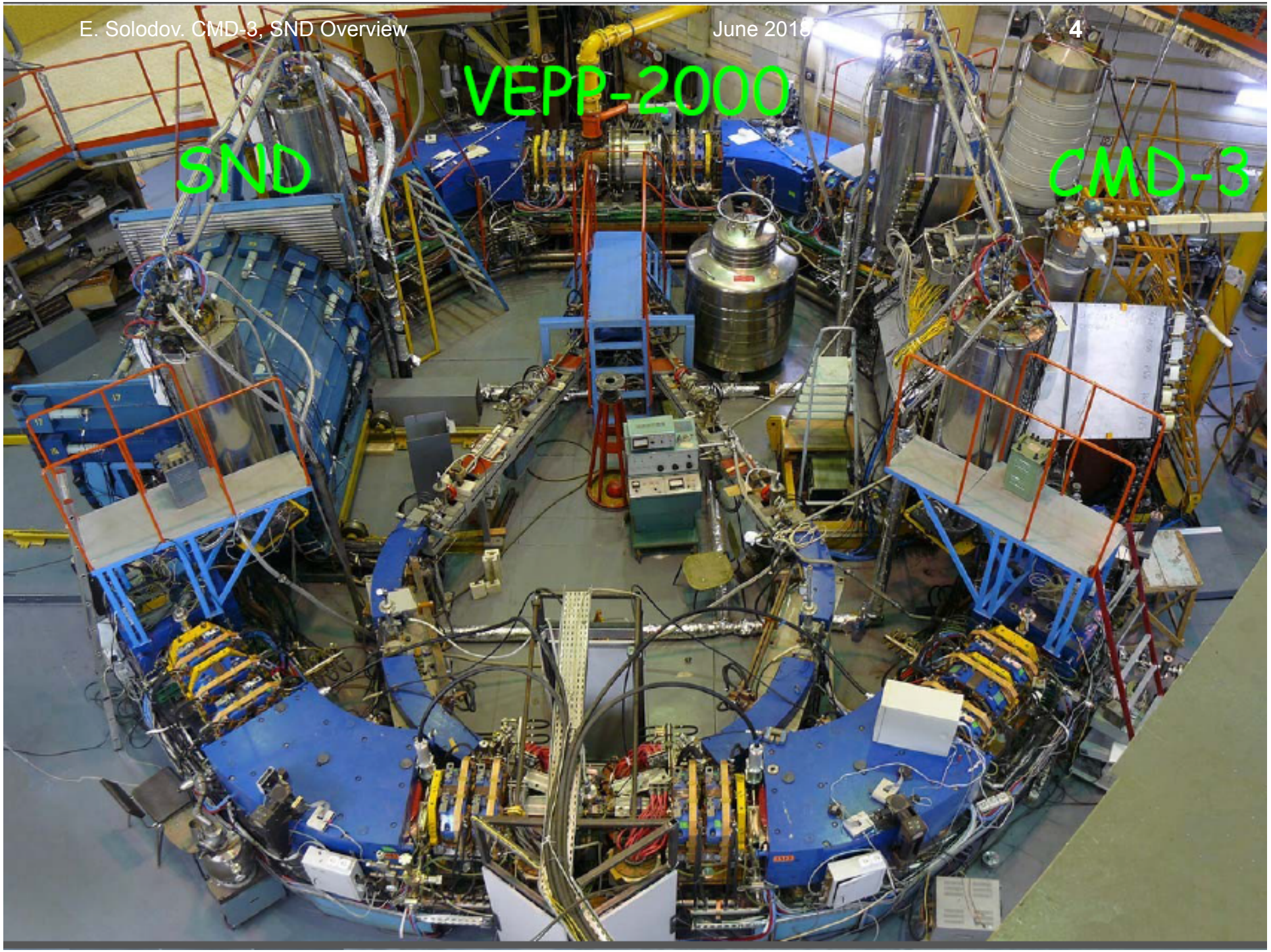






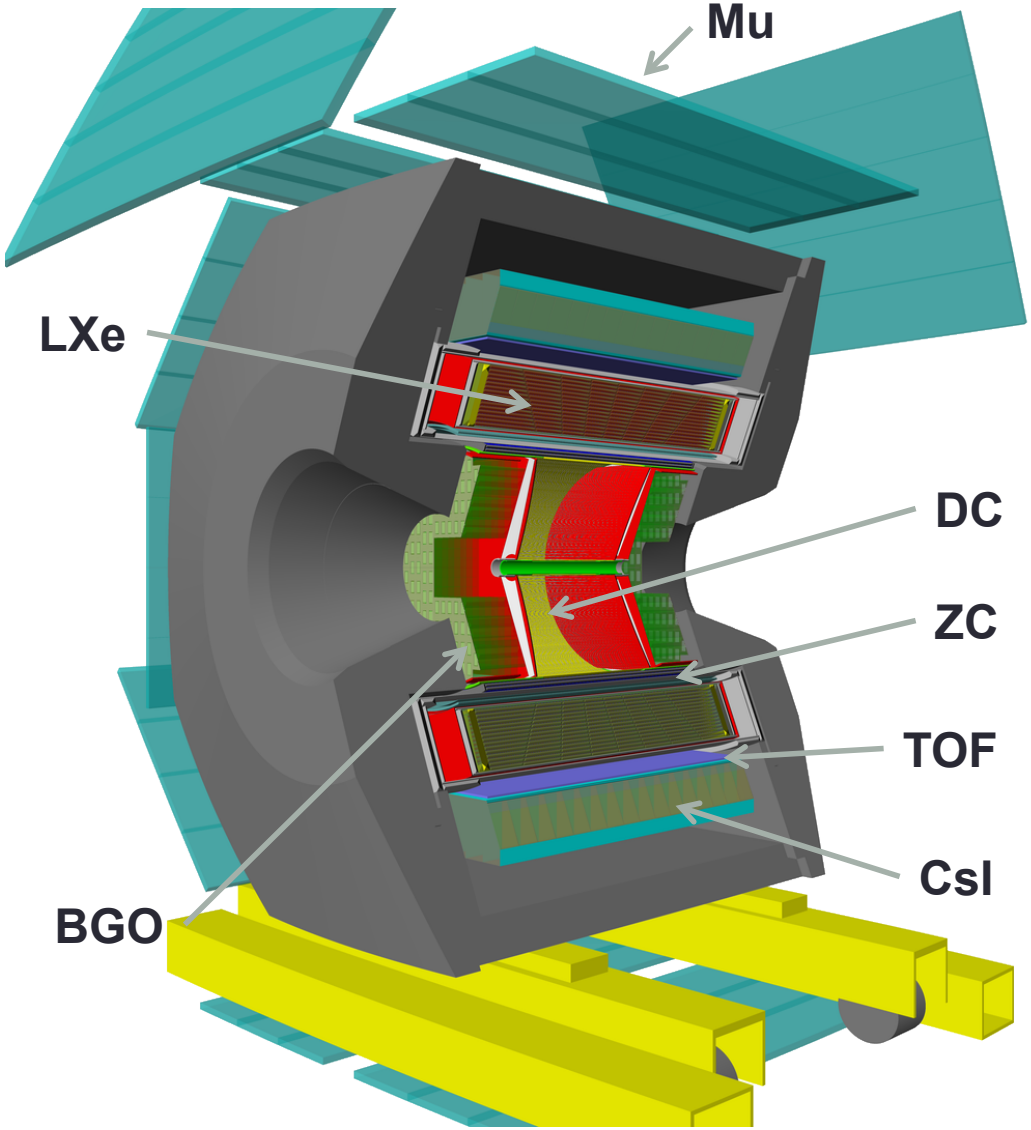
E = 993.662 ± 0.016 MeV

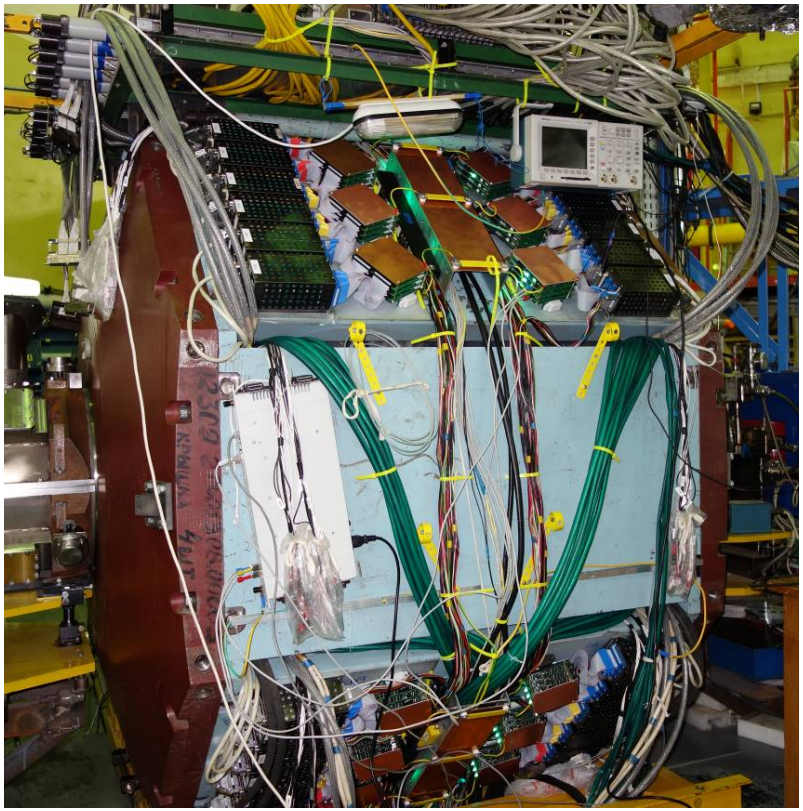
M.N. Achasov et al. arXiv:1211.0103v1 [physics.acc-ph] 1 Nov 2012


VEPP-2000
SND
CMD-3

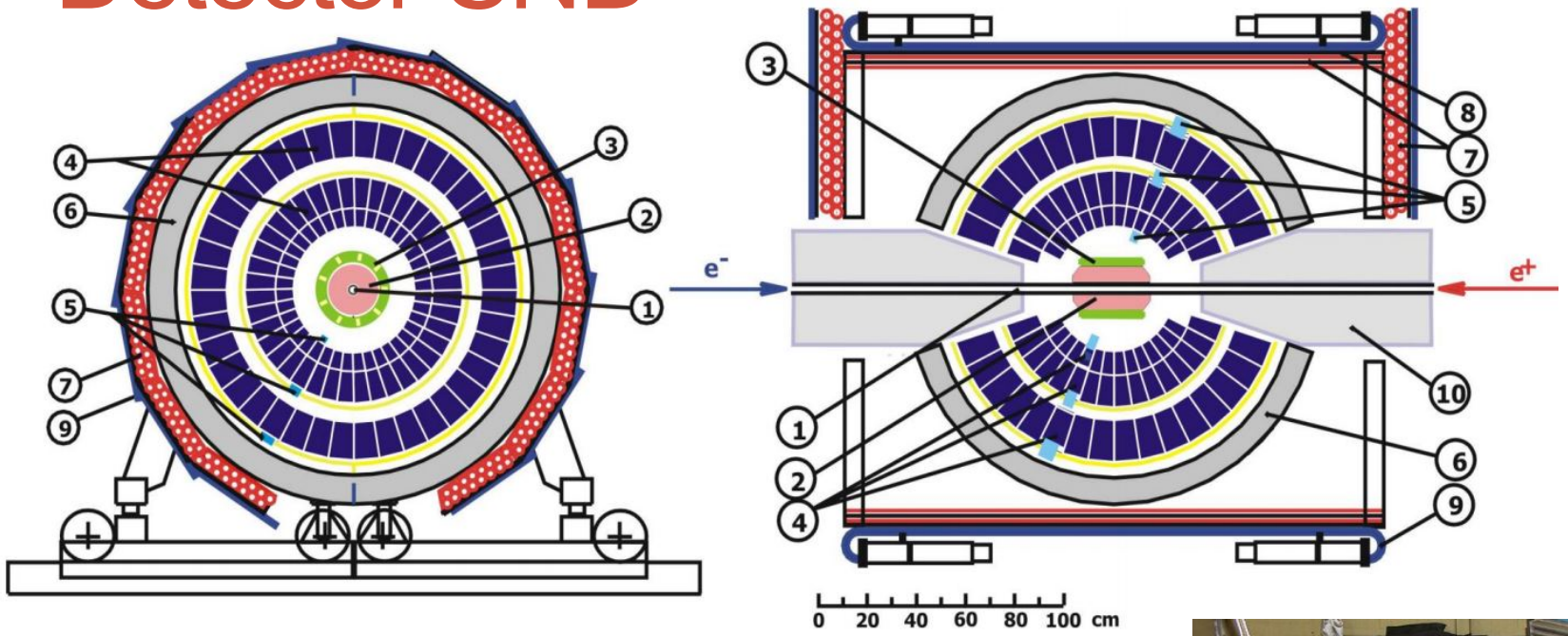
Detector CMD-3

General purpose magnetic detector
With excellent tracking and calorimeter

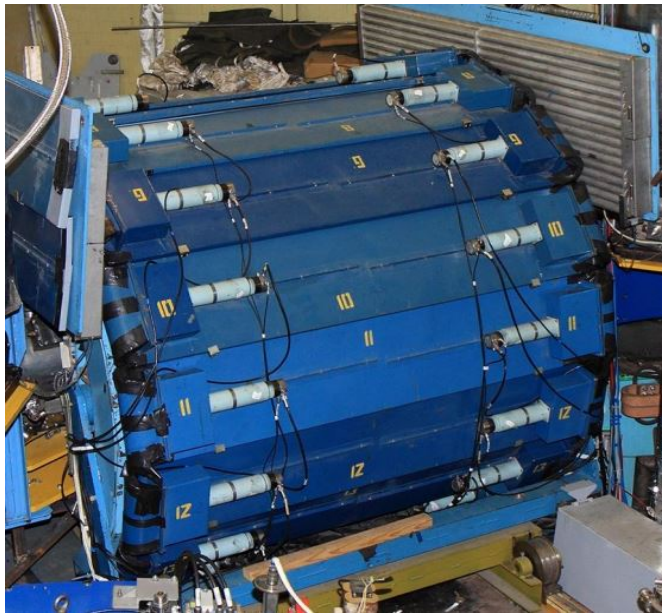




Detector SND

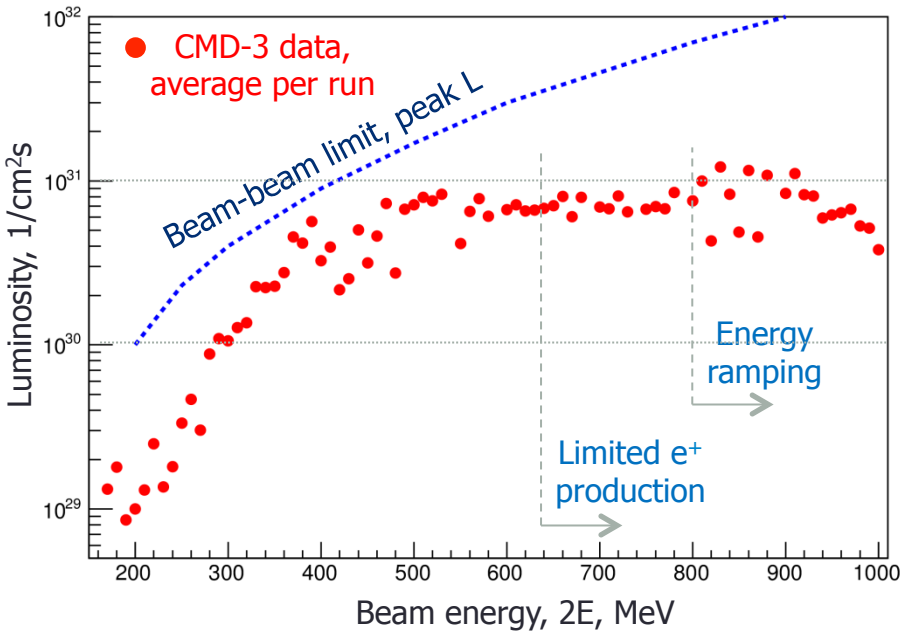


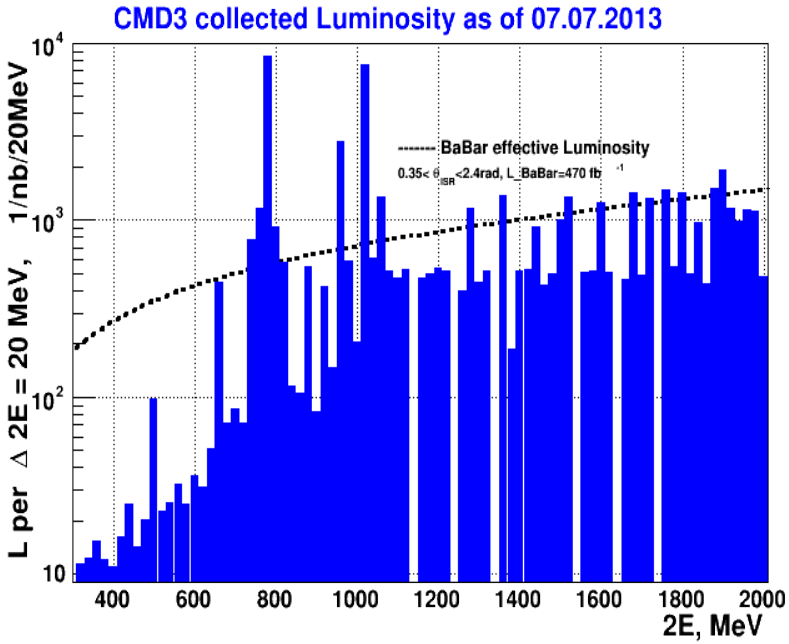
1 – vacuum chamber, 2 – tracking DC,
3 – aerogel n=1.13, 1.05 4 – NaI(Tl) crystals,
5 – phototriodes, 6 – absorber, 7–9 – muon detector, 10 – SC solenoids



High-resolution NaI calorimeter with excellent tracking and PID

Collected luminosity in 2011-2013





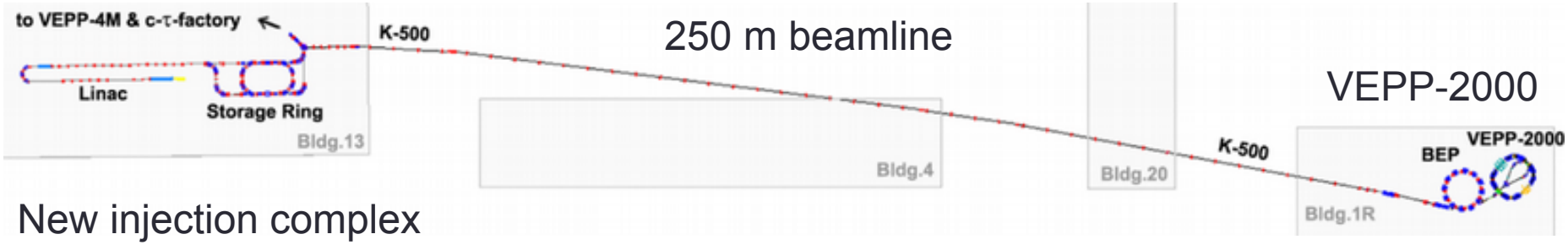
The luminosity was limited by a deficit of positrons and limited energy of the booster.

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)



New injection complex

Collider upgrades:

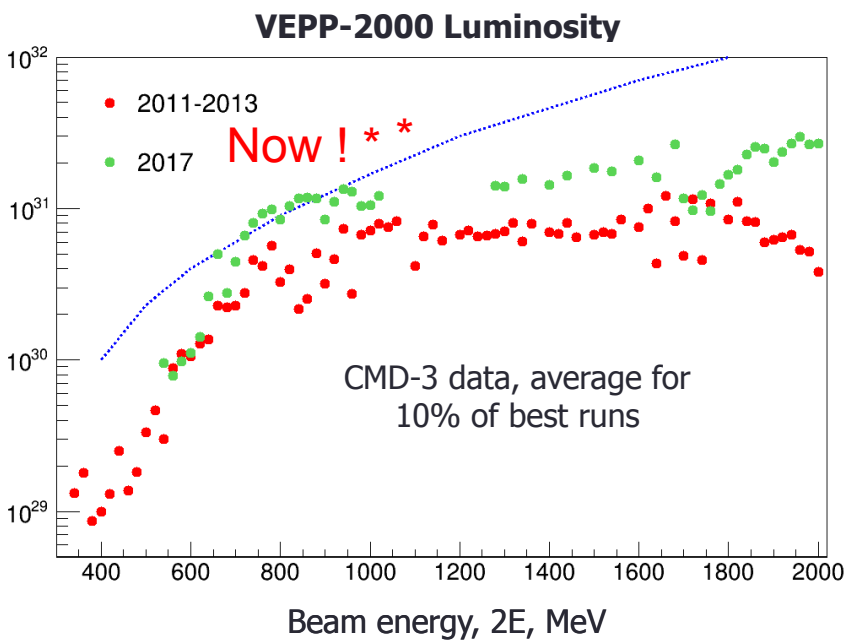
- x10 more intense positron source
- booster up to 1 GeV (match VEPP-2000)

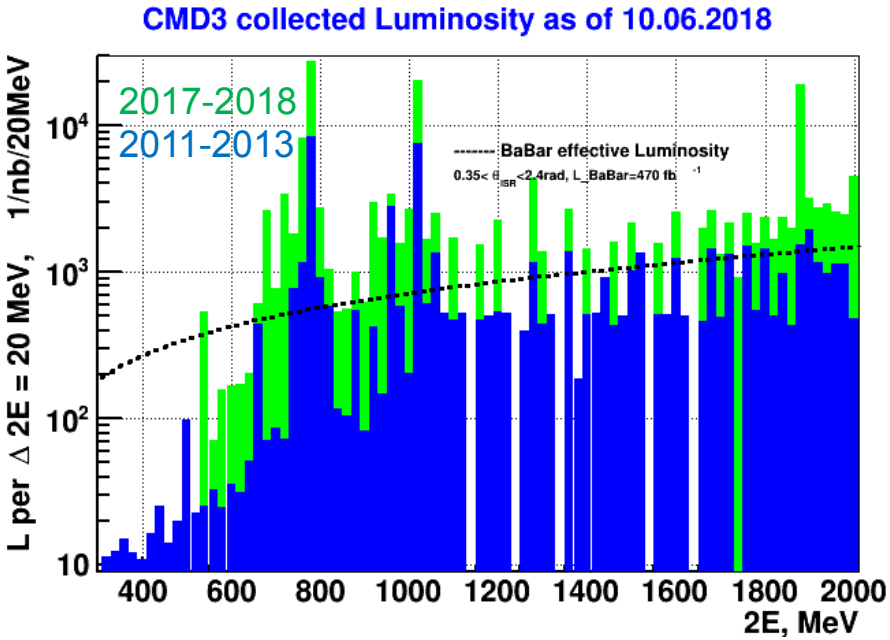
CMD-3 upgrades:

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

Detectors resumed data taking by the end of 2016

2017-2018 data taking



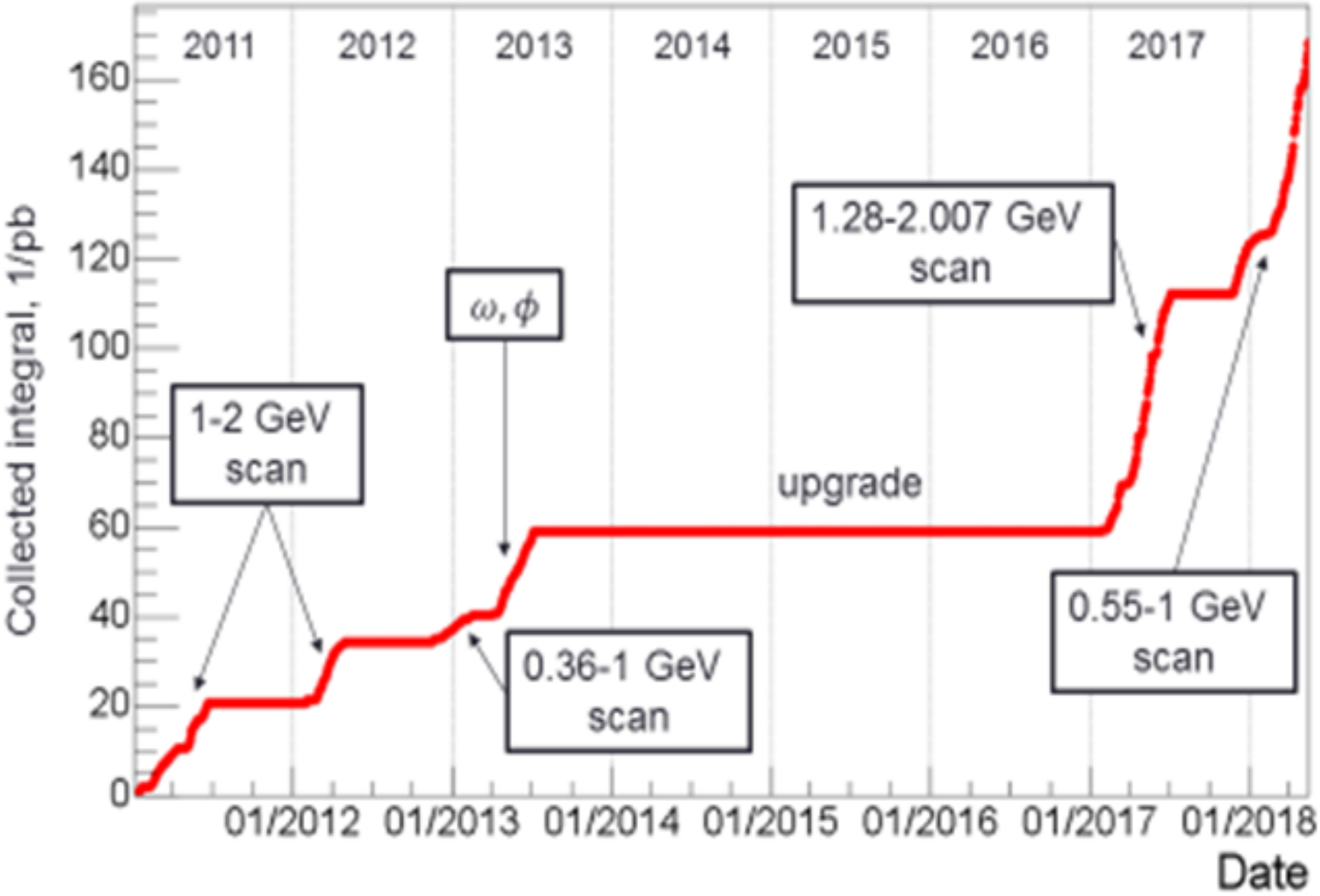


In 2017: big improvement in luminosity, still way to go.

$4*10^{31}$ at E = 550 MeV has been achieved!

Below 1 GeV – 2017-2018:
66 pb^{-1}

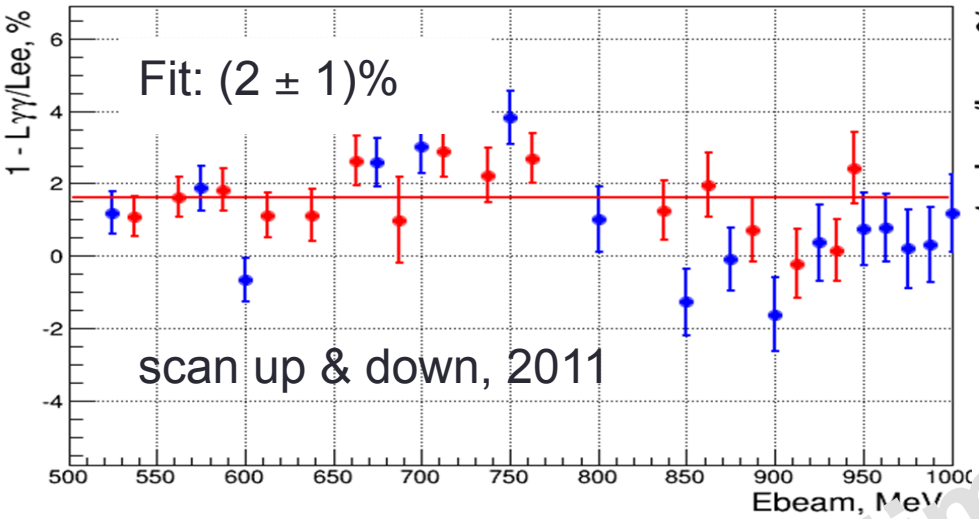
Above 1 GeV: ~50 pb^{-1} collected	
D0(2007)*	4 pb-1
and pp, nn threshold	14 pb-1

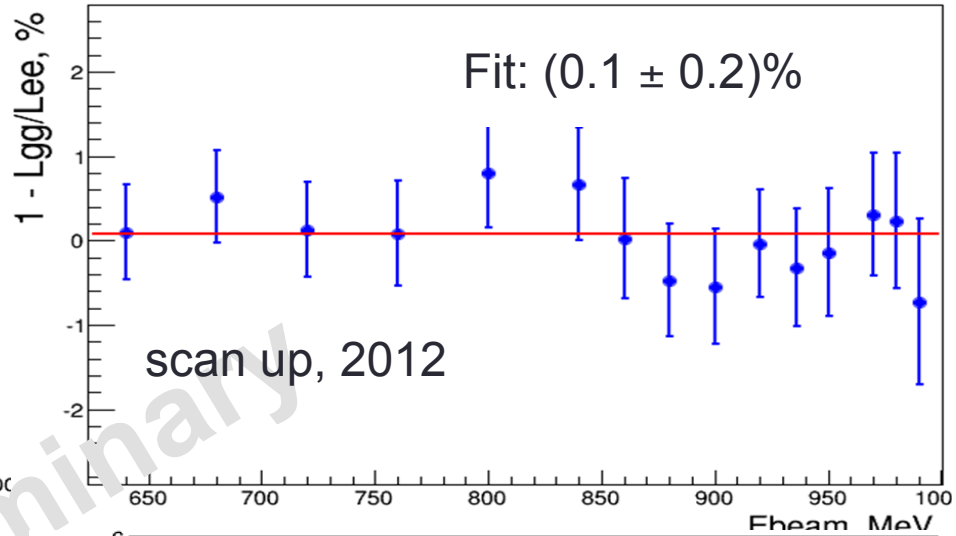

2011
2012
2013
2014
2015
2016
2017
160
140
120
100
80
60
40
20
0
Collected integral, 1/pb
1-2 GeV scan
ω, ϕ
0.36-1 GeV scan
upgrade
1.28-2.007 GeV scan
0.55-1 GeV scan
01/2012
01/2013
01/2014
01/2015
01/2016
01/2017
01/2018
Date

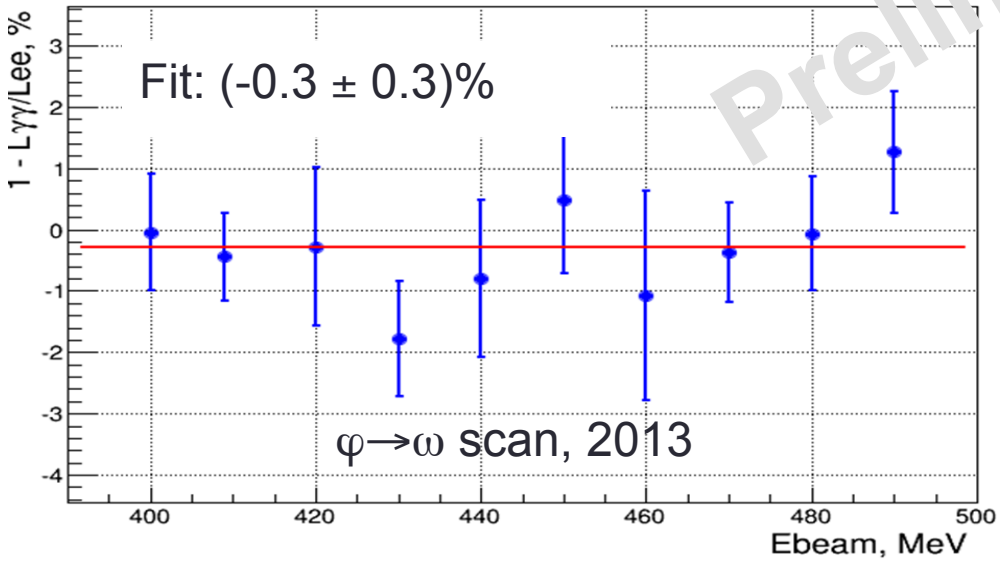
At VEPP2000 - we do exclusive measurements of e^+e^- -> hadrons and study production dynamics.

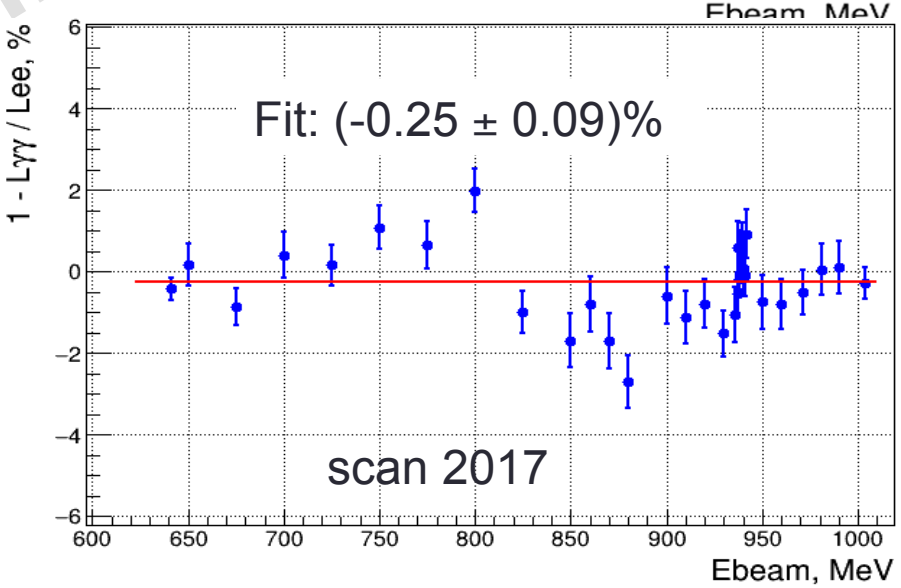
Luminosity determination

Overall runs systematic uncertainty is about 1%

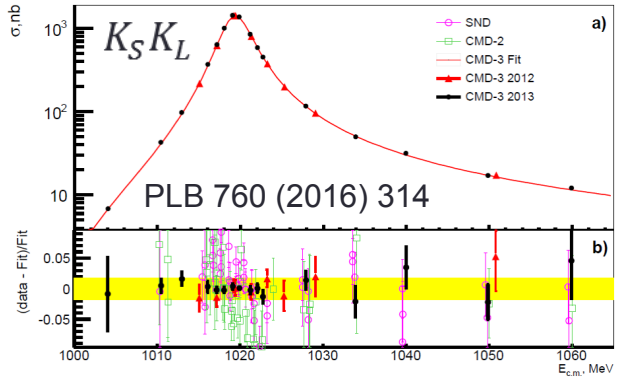


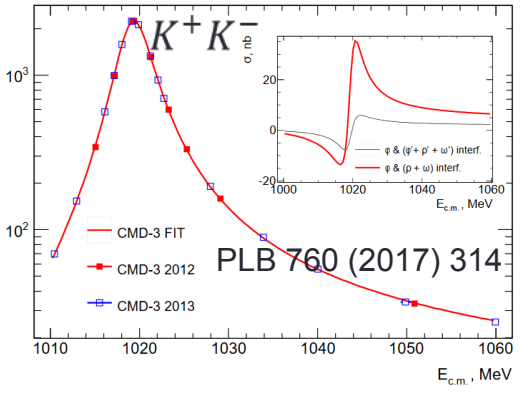


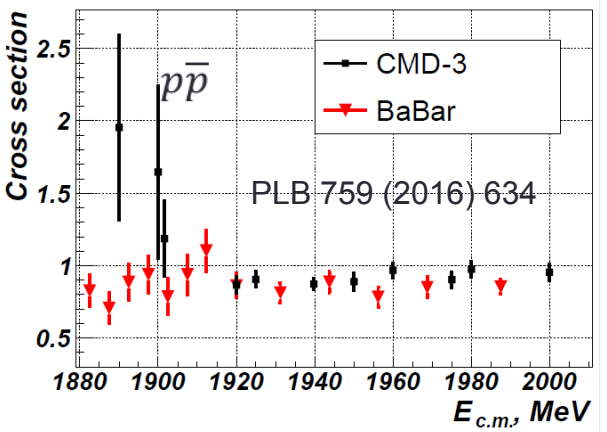


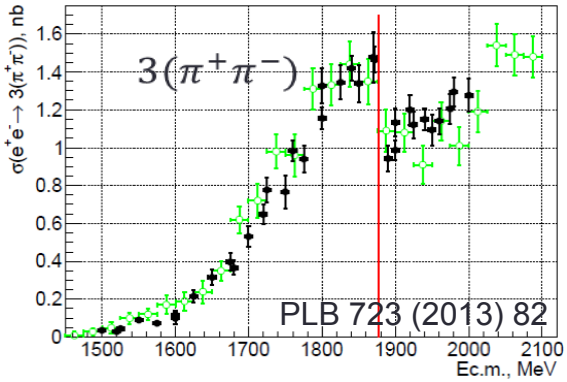


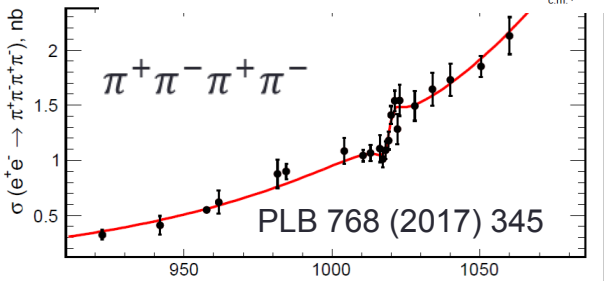
CMD-3 published results from 2011-2013

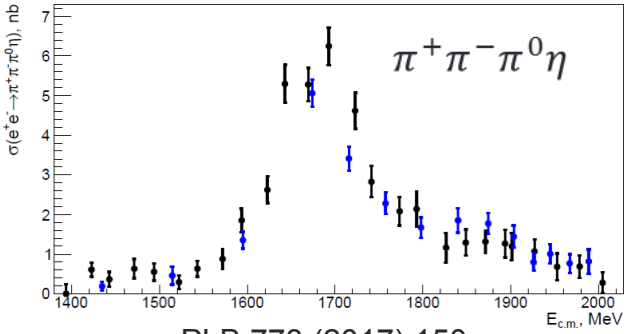


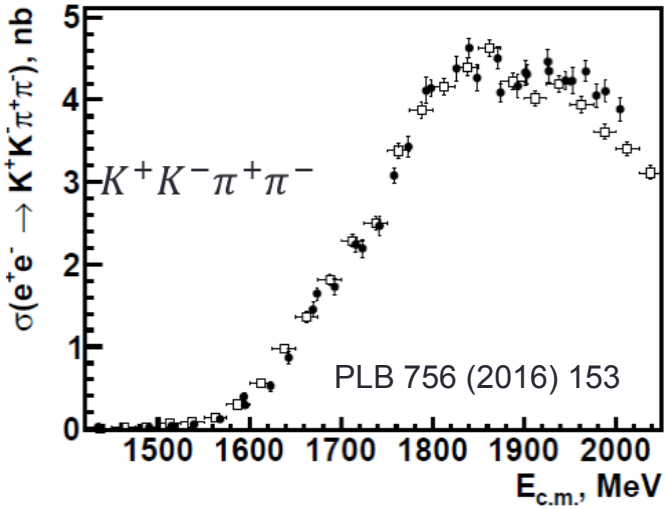








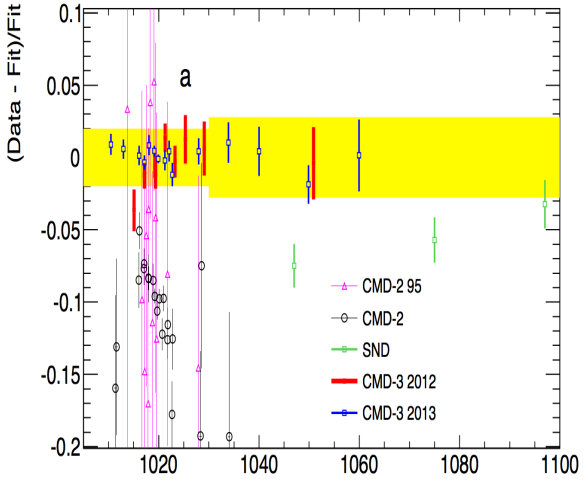


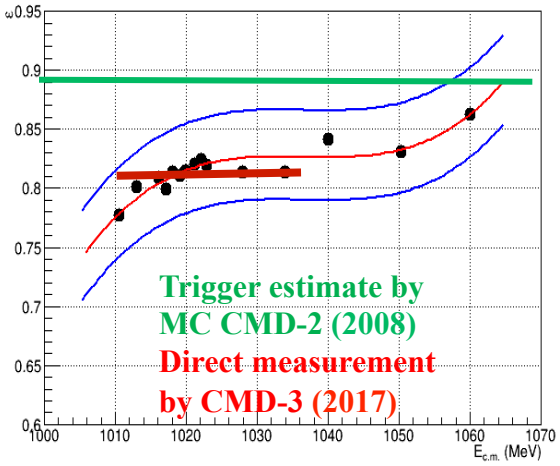


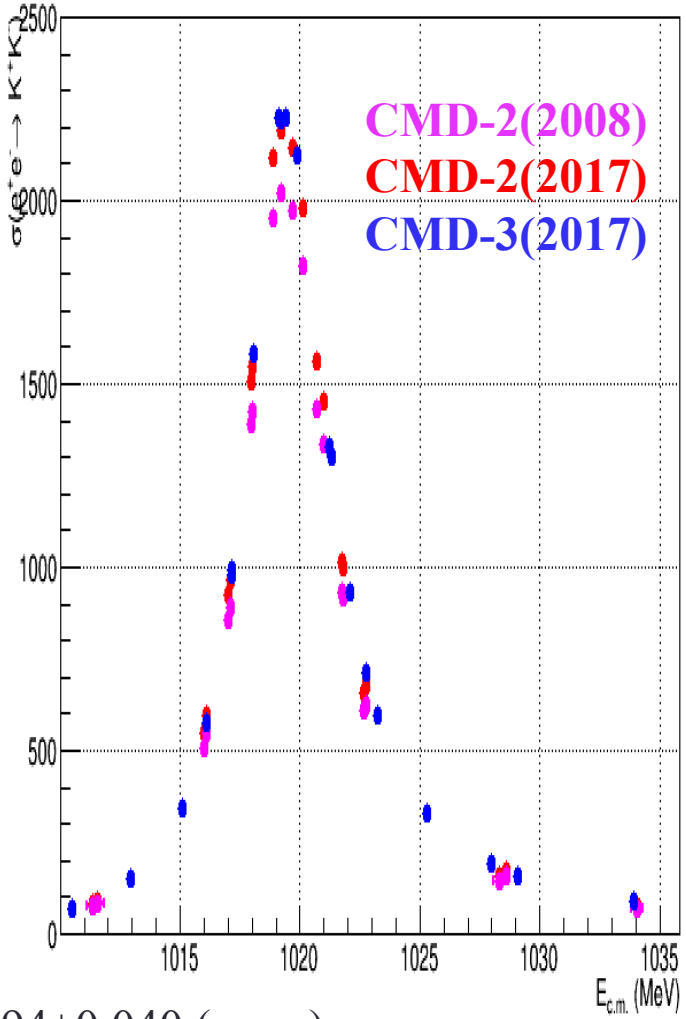
Intermediate structures are studying in every final state

Correction to K^+K^- at ϕ

- We observe large discrepancy between CMD-2 and CMD-3 data.
- CMD-2 has trigger DC+Z-chamber+CsI calorimeter energy deposition – no cross check! Kaons stop in first wall and only decays and interactions provide trigger.
- CMD-3 has only DC hits in trigger, but all information from Z-chamber(the same!) and calorimeter.
- We can directly measure trigger efficiency of CMD-2.
- Corrected data should be published soon





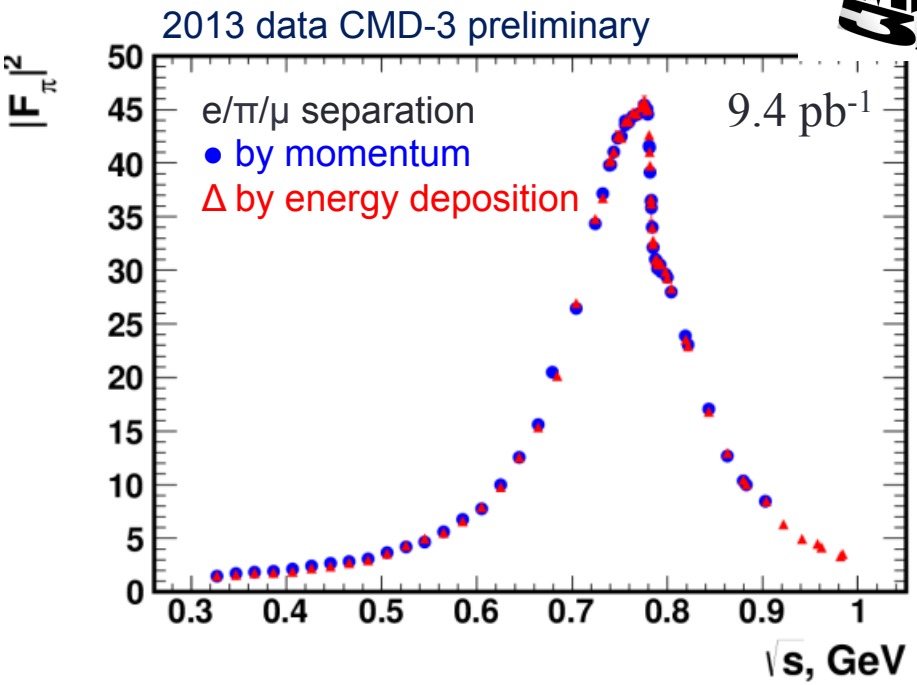


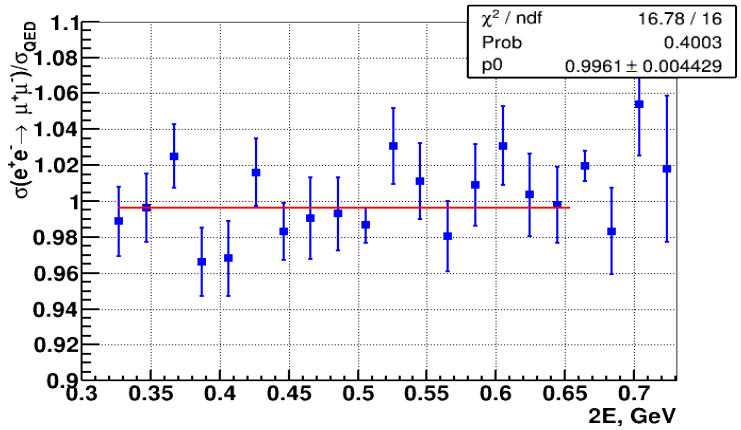
Trigger correction $(1+\delta)_{trig} = 1.094 \pm 0.040$ (сист.)

Cross check for Bhabha events $\varepsilon_{trig} = 0.9949 \pm 0.0001$

Dominant channel e^+e^- -> $\pi^+\pi^-$

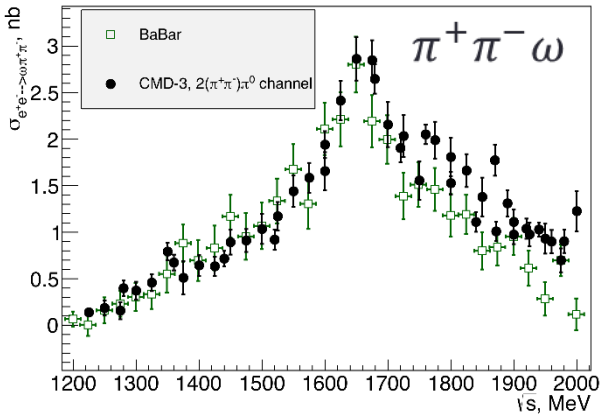
Source	Goal	Current estimation
Radiative Correction	0.2%	0.2% (cross-section) 0.0-0.4% (mom.sep.)
Event separation	0.2%	0.1-0.5% (mom. sep.) ~1.5% (energy sep.)
Fiducial volume	0.1%	ok
Beam energy	0.1%	ok
Pion corrections (decay, nucl.int.)	0.1%	0.1% -nucl. int. 0.6-0.3% decays at low energies
Combined	0.33%	0.4-0.9% (mom.sep.) 1.5% (energy sep.)

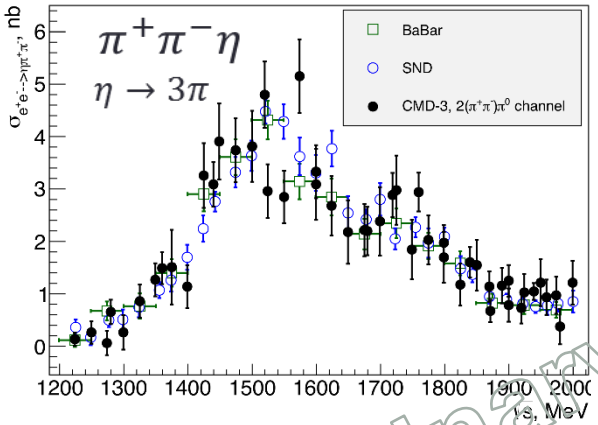


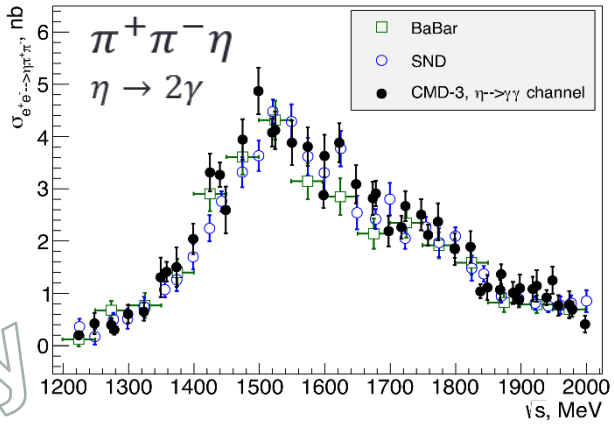


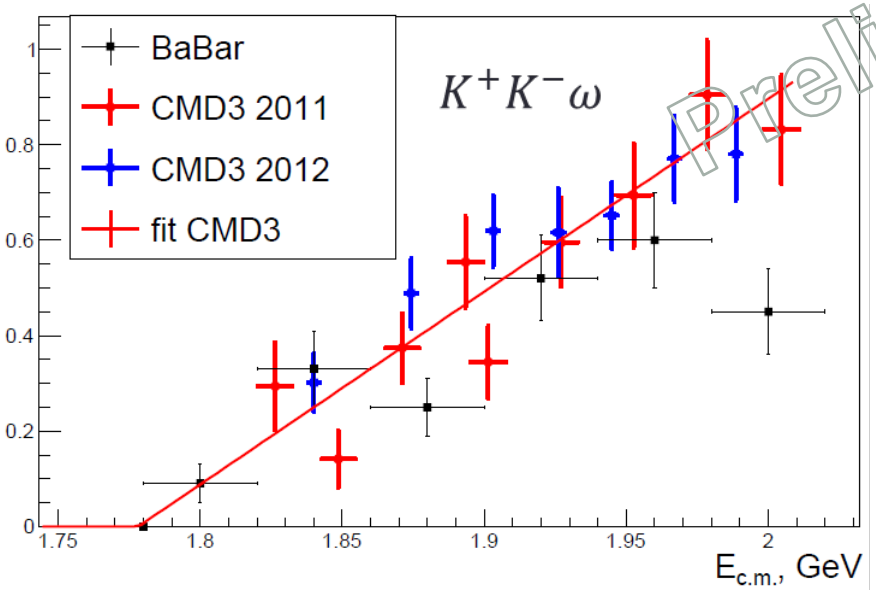
Some corrections are not applied (result is still “blinded”)
Hope to finalize it later this year

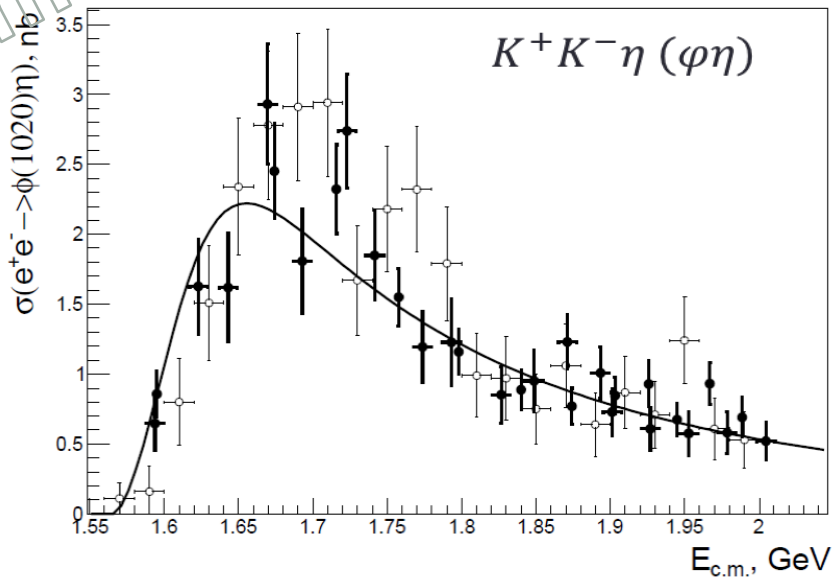
CMD-3 preliminary: $\pi^+\pi^-(\omega,\eta), K^+K^-(\omega,\eta)$





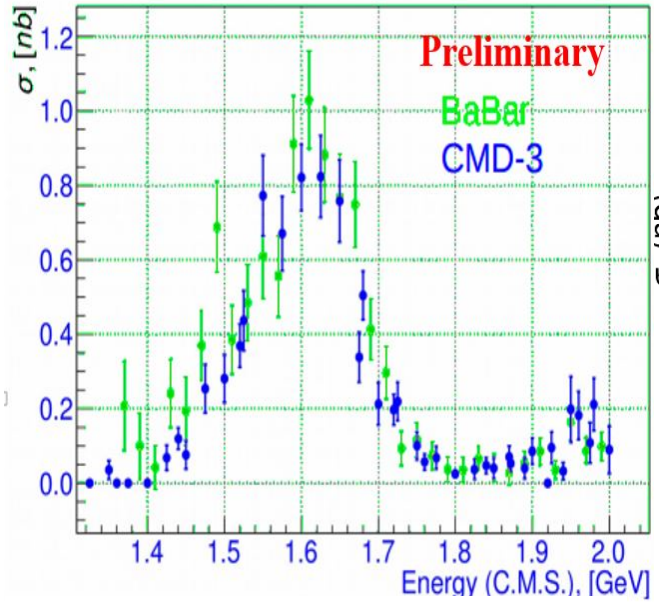


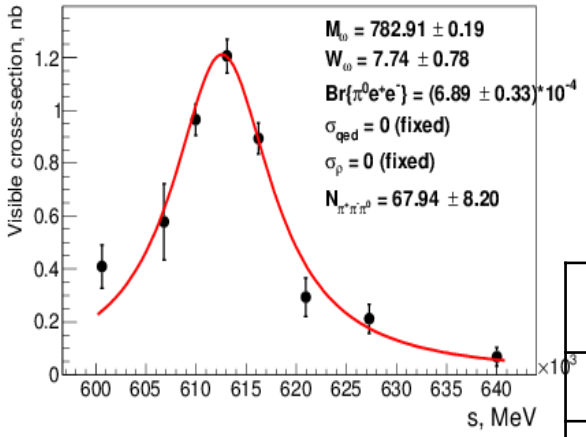




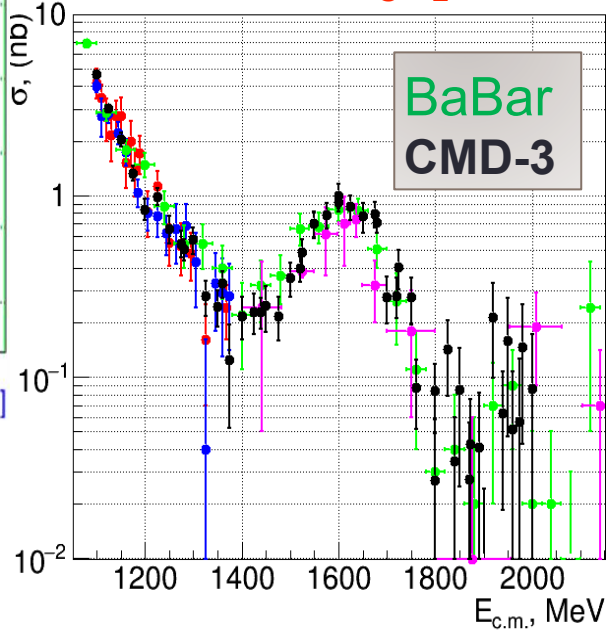
More preliminary CMD-3 results

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

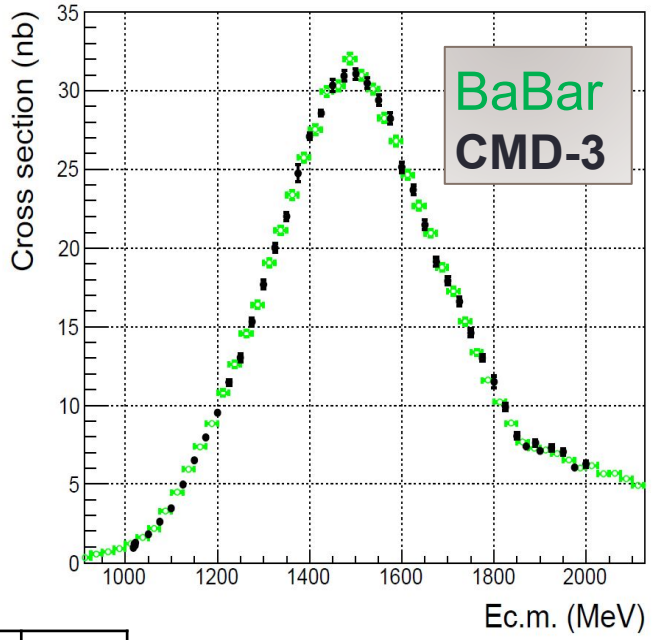




$e^+e^- \to K_SK_L$



$e^+e^- \to 2(\pi^+\pi^-)$

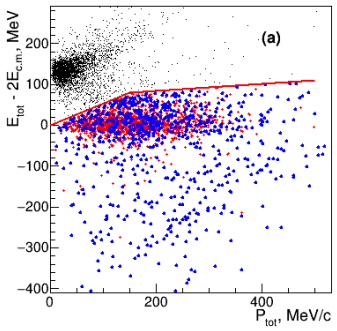


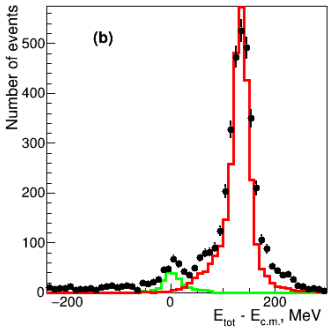
Experiment	Br(ω → $\pi^0e^+e^-$)	events	data, pb^{-1}
CMD-2	(8.19±0,71±0.62)∗10^{-4}	230	3.3
SND	(7.61±0,53±0.64)∗10^{-4}	613	9.8
CMD-3	(6.90±0.33)∗10^{-4}	1169	8

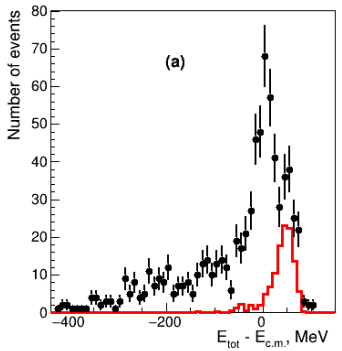
Analysis in progress
Publications are in preparations

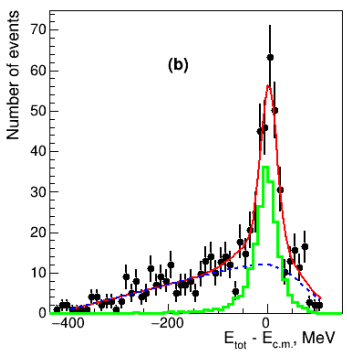
NEW! e^+e^- -> $3(\pi^+\pi^-)\pi^0$

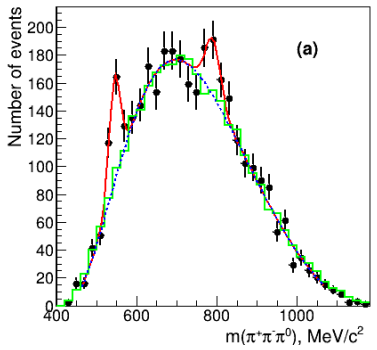
Based on 56 pb^{-1} in 1600-2000 MeV

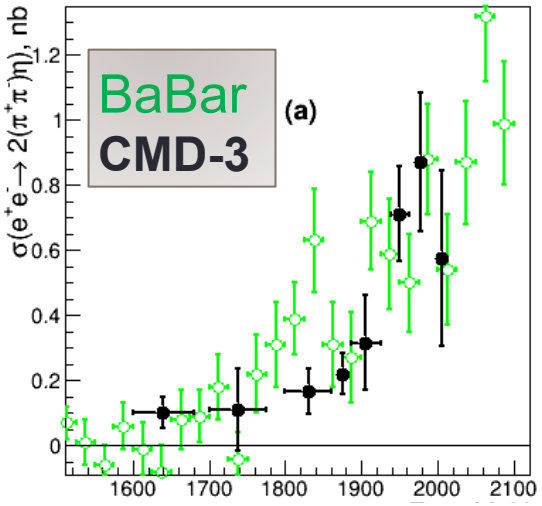


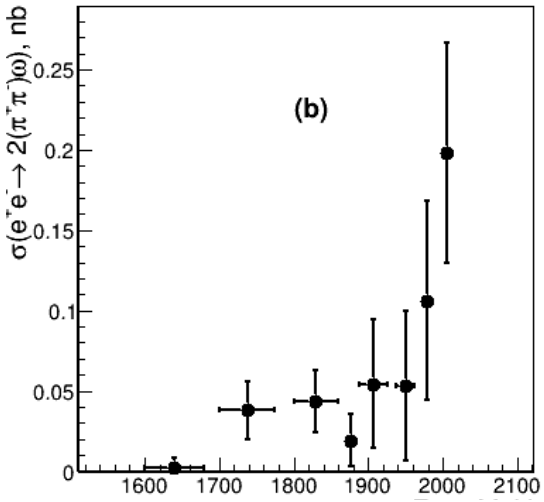


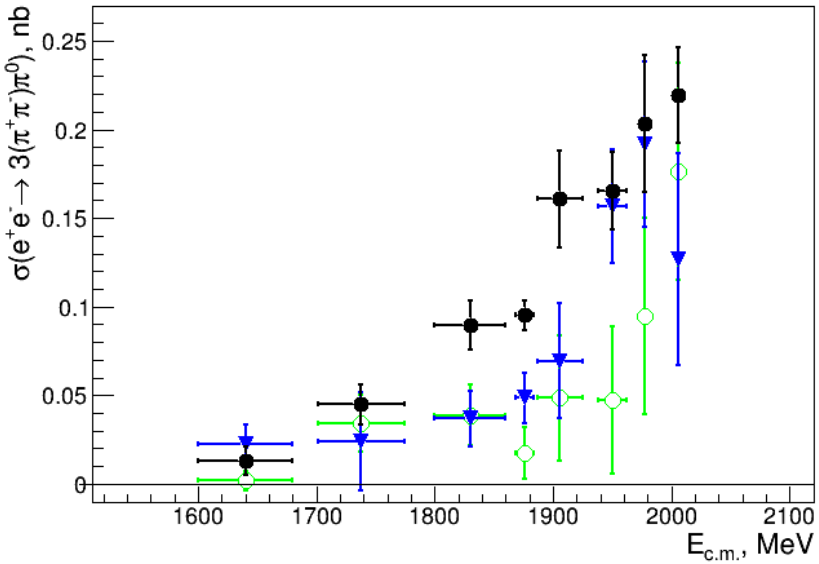












Dominated by

$\omega 4\pi$

$\eta 4\pi$

Publications are in preparations

SND@VEPP-2000 summary of results, (journal articles)

Published:

1. e+e- → $\pi^0\pi^0\gamma$, Ph.Rev.D, (2013,2016)
2. e+e- → nn, Phys.Rev.D,(2014)
3. e+e- → NN-6π, JETP Lett.,(2014)
4. e+e- → $\eta\gamma$, Phys.Rev.D,(2014)
5. e+e- → η', Phys.Rev.D,(2015)
6. e+e- → $\eta\pi^+\pi^-$, Phys.Rev.D,(2015)
7. e+e- → $\pi^+\pi^-\pi^0$, JETP,(2015)

Published, cont'd :

8. e+e- → η, JETP Lett.,(2015)
9. e+e- → K^+K^-, Phys.Rev.D,(2016)
10. e+e- → $\omega\eta\pi^0$, Phys.Rev.D,(2016)
11. e+e- → $\omega\eta$, Phys.Rev.D,(2016)
12. e+e- → $\pi^0\gamma$, Phys.Rev.D,(2016)
13. e+e- →NN-nπ, Phys.At.Nucl, (2017)

In print:

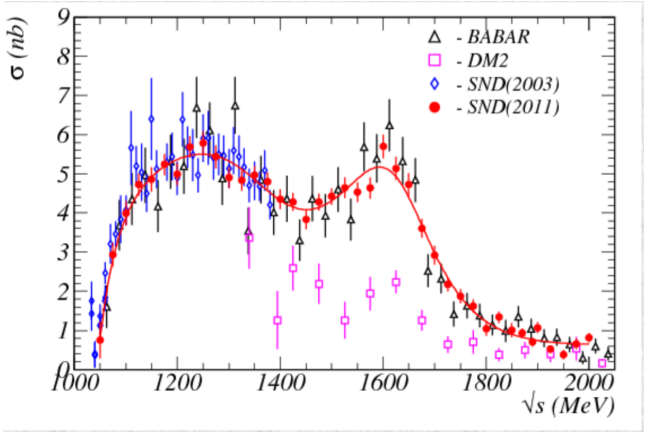
1. e+e- → $K_SK_L\pi^0$, Phys.Rev.D,
2. e+e- → $\eta\pi^+\pi^-$, Phys.Rev.D,
3. e+e- → ηK^+K^-, JETP,

In analysis:

1. e+e- → $\pi^+\pi^-$,
2. e+e- → $\eta\pi^0\pi^+\pi^-$,
3. e+e- → $\pi^+\pi^-\pi^0\pi^0$,
4. e+e- → $K^+K^-\pi^0$,
5. e+e- → $\omega\pi^0\pi^0$,
6. e+e- → 6π

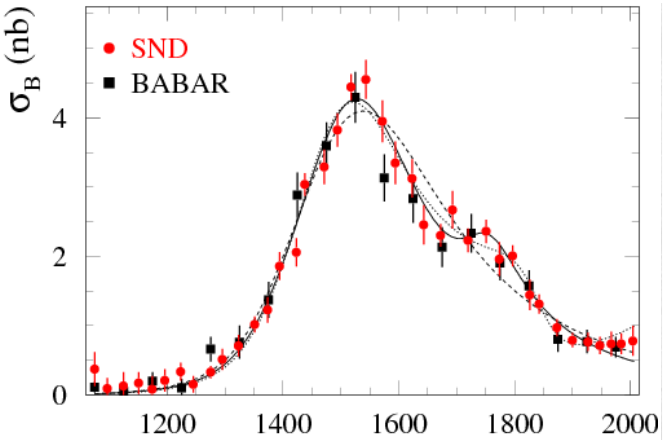
Some SND results overview

e+e−→π+π−π0



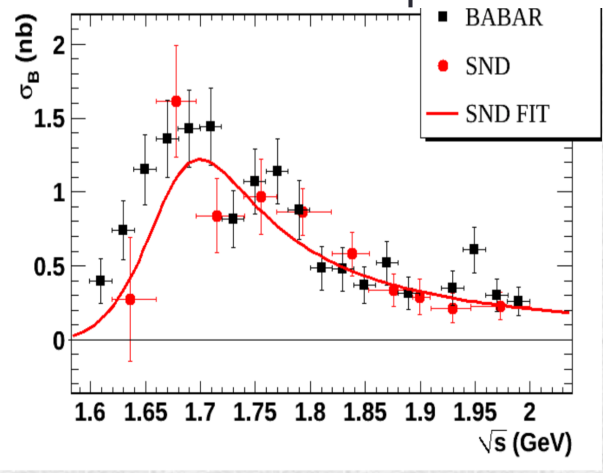
J.Exp.Theor.Phys. 121 (2015) 1.

e+ e−→π+π−η

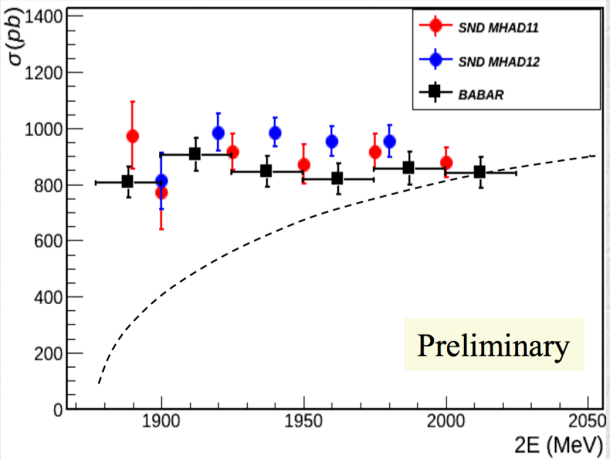


Phys. Rev. D 91, 052013 (2015)

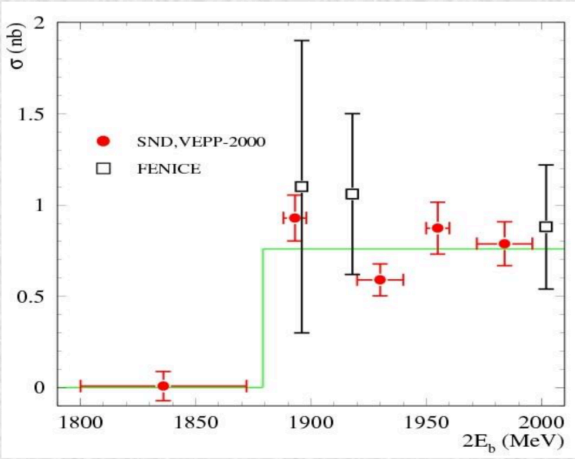
e+ e−→K+ K−η



$e^+e^- \to$ p anti-p

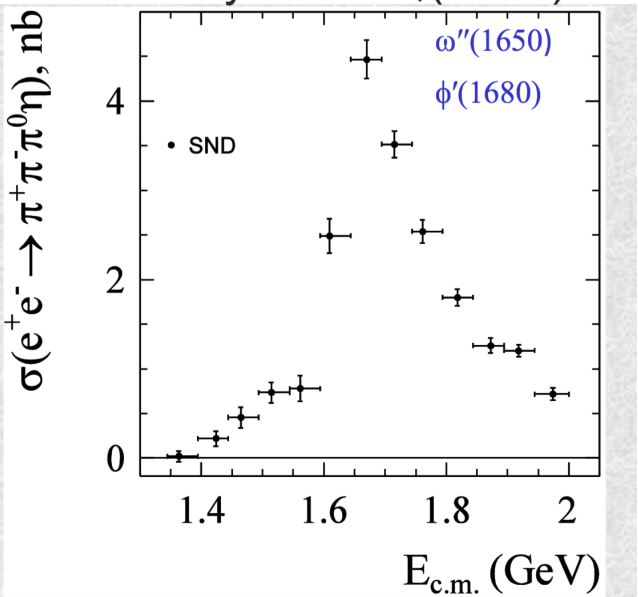


$e^+e^- \to$ n anti-n



Phys.Rev.D,(2014)

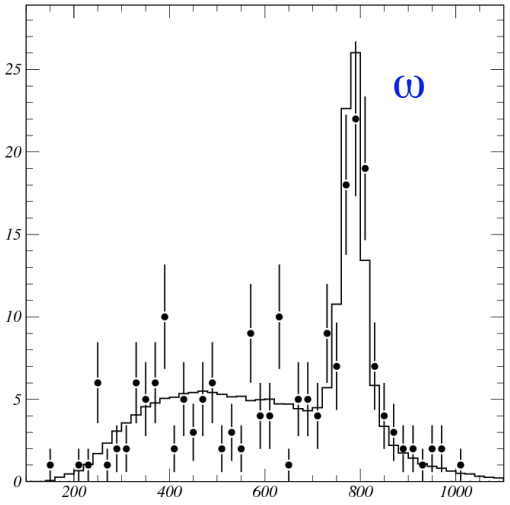
Phys.Rev.D,(2016)



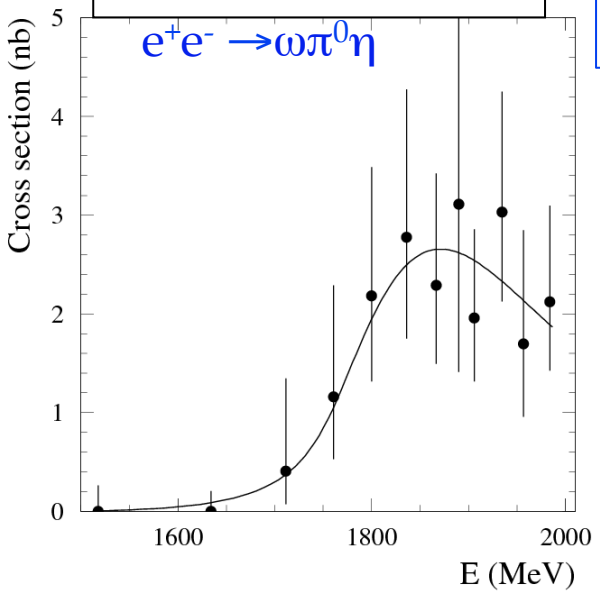
$e^+e^- \to \omega\pi^0\eta$, Phys. Rev. D 94,032010 (2016)

7 photon final state

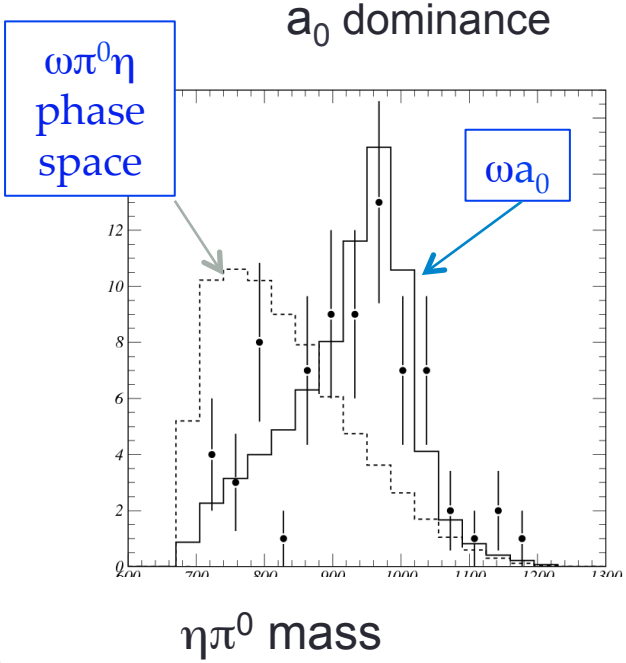
$e^+e^- \to \pi^0\pi^0\eta\gamma \to 7\gamma$



Cross section:
~ 5% of hadr. cross sect.
at 1.8-2.0 GeV



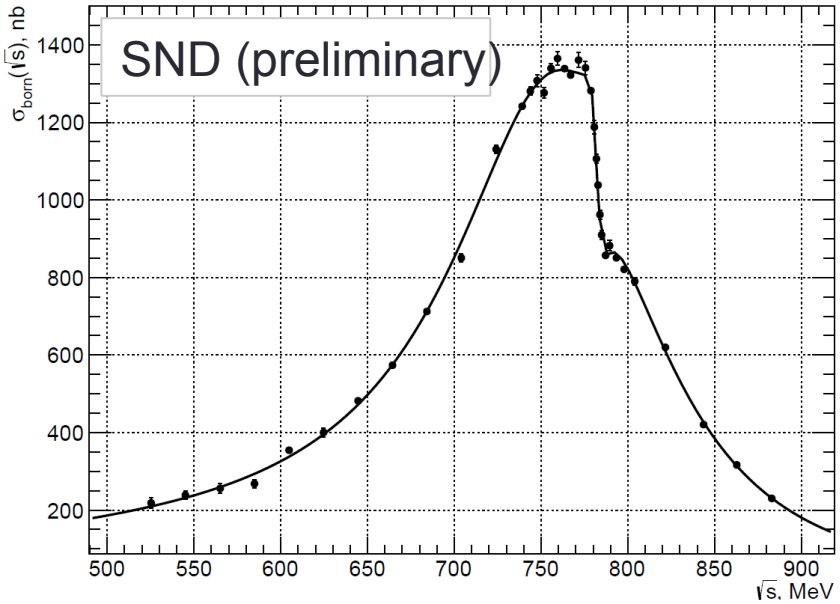
a_0 dominance

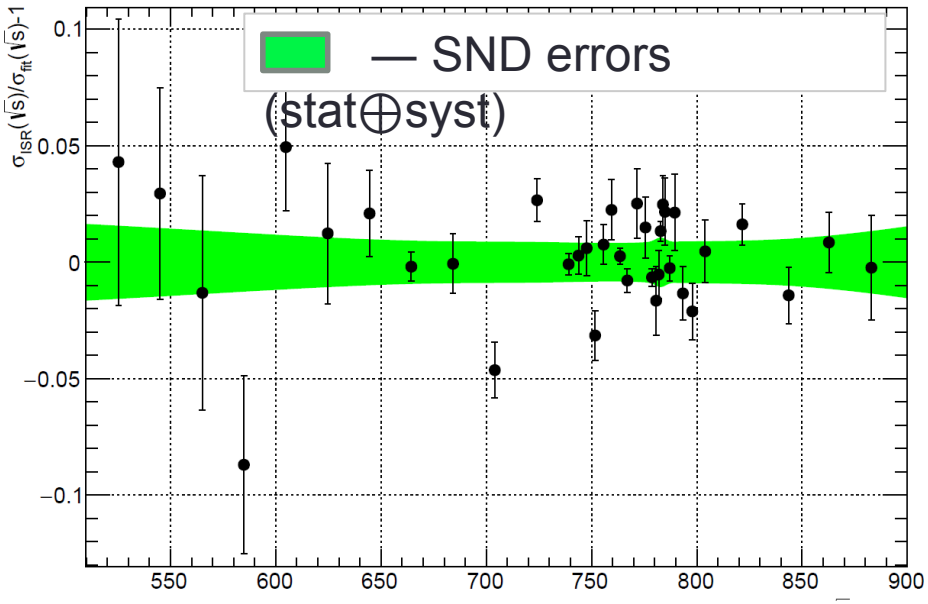


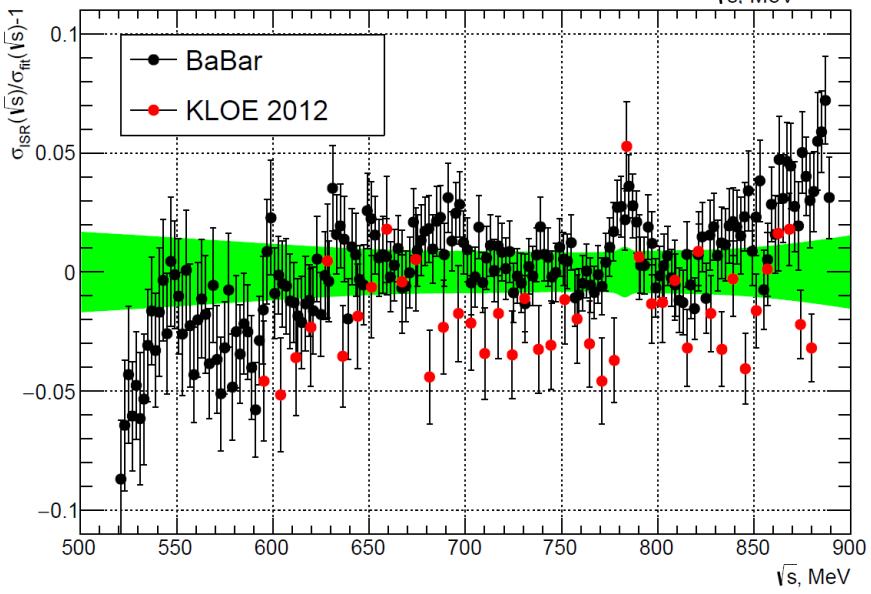
- First measurement of the $e^+e^- \to \omega\pi^0\eta$ cross section.
- The dominant mechanism is $\omega a_0(980)$.
- The cross section is about 2.5 nb, 5% of the total hadronic cross section

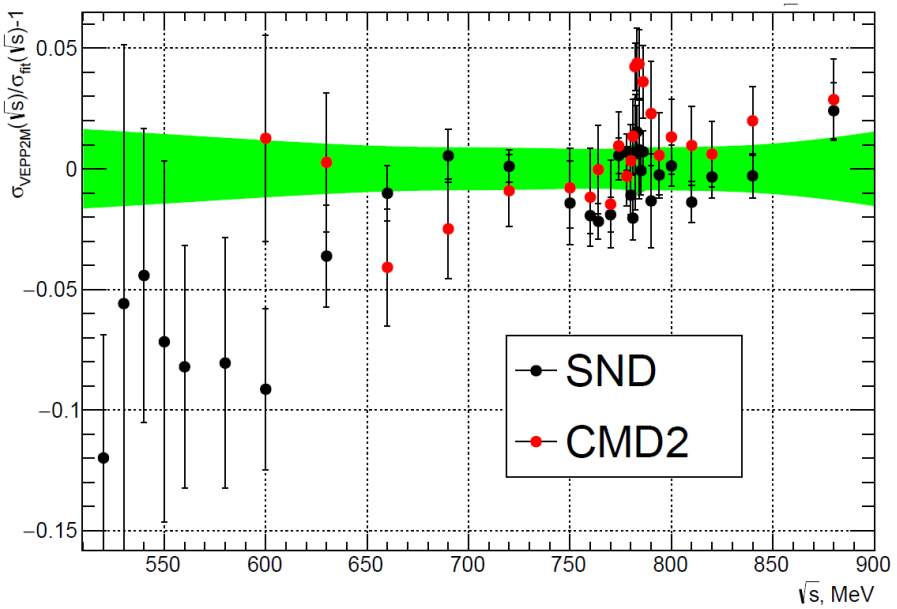
Intermediate structures are studying in every final state

e^+e^- -> $\pi^+\pi^-$ SND (preliminary)



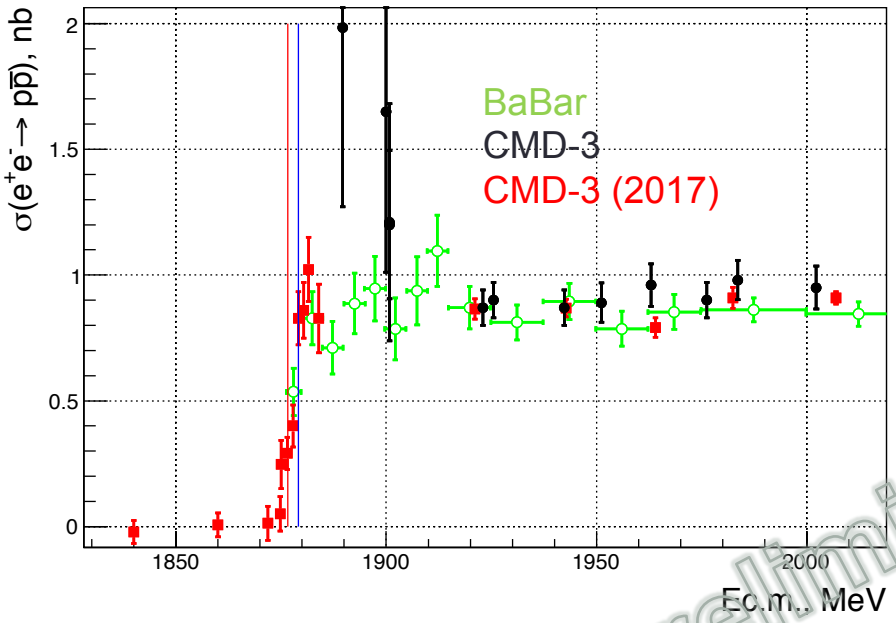






2017: e^+e^- -> pp at NN threshold

In 2017 CMD-3 and SND has performed the scan at the NNbar threshold with a step smaller than c.m. machine energy spread (1.2 MeV). The e+e- -> ppbar cross section demonstrate exponentially fast rising in about 1 MeV interval.



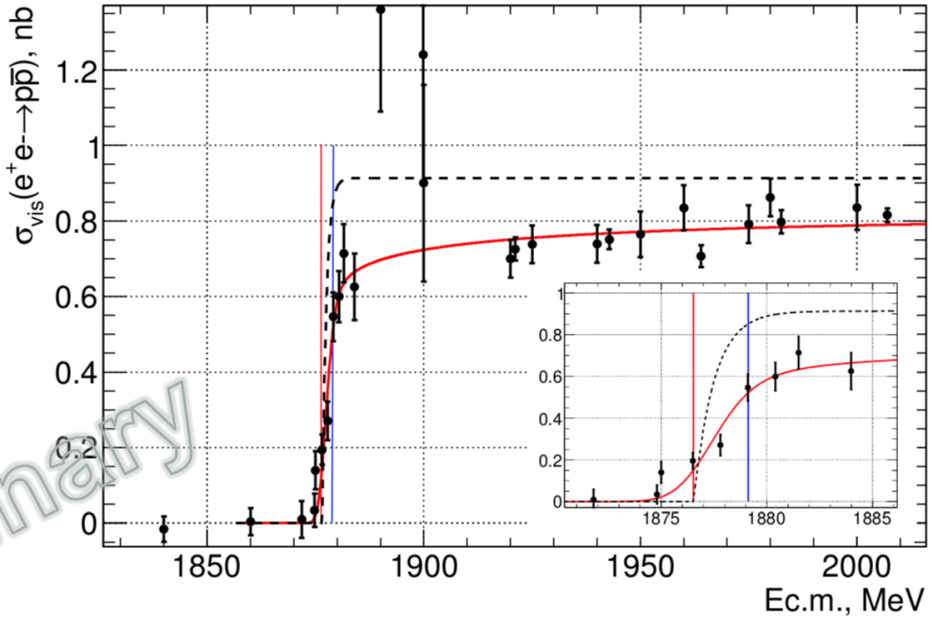


Figure 2: The $e^+e^- \to p\bar{p}$ visible cross section measured with the CMD-3 detector. Solid curve shows a fit with Gaussian-rised Born cross section (dashed curve) convoluted with 1.2 MeV energy spread and radiation function. The vertical lines show the $p\bar{p}$ and $n\bar{n}$ thresholds.

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

CMD-3 has confirmed fast drop of the cross section, and new scan shows the scale of the drop consistent with ppbar cross section rise ~1 MeV.

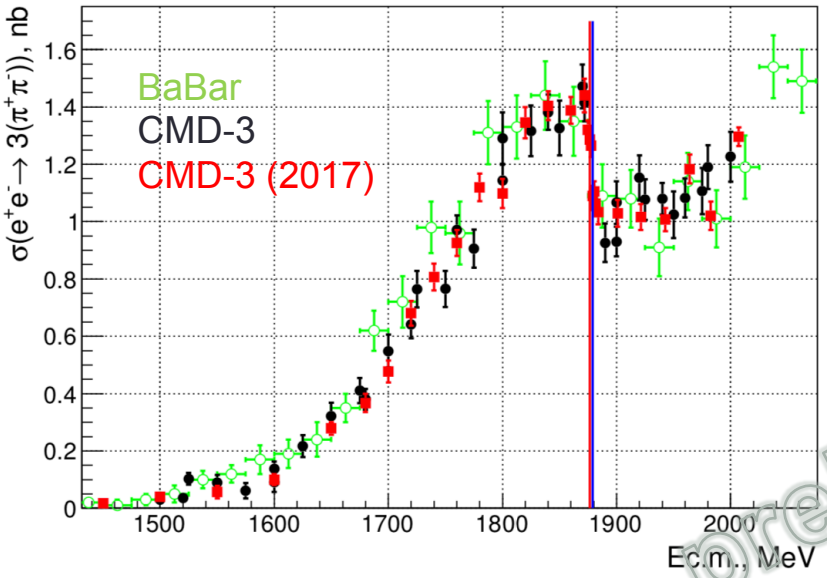


Figure 1: The $e^+e^- \to 3(\pi^+\pi^-)$ cross section measured with the CMD-3 detector at VEPP-2000 in 2017 run (squares). The results of previous CMD-3 measurements [6] are shown by dots, when BaBar measurement [4] are shown by open circles. The lines show the $p\bar{p}$ and $n\bar{n}$ thresholds.

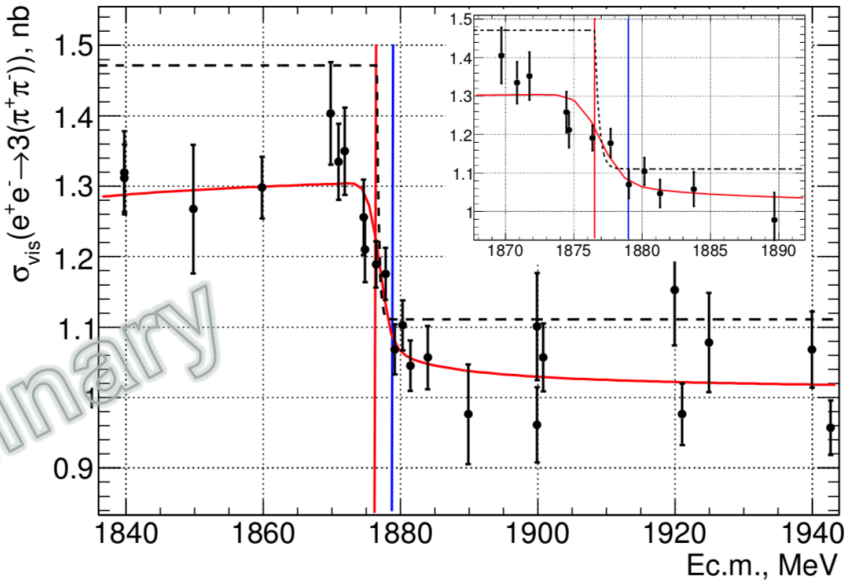


Figure 3: The $e^+e^- \to 3(\pi^+\pi^-)$ visible cross section measured with the CMD-3 detector. Solid curve shows fit with Born cross section (dashed curve) convoluted with 1.2 MeV energy spread and radiation function. The vertical lines show the $p\bar{p}$ and $n\bar{n}$ thresholds.

No indication of NNbar threshold in the e^+e^- -> $2(\pi+\pi-)$ reaction!

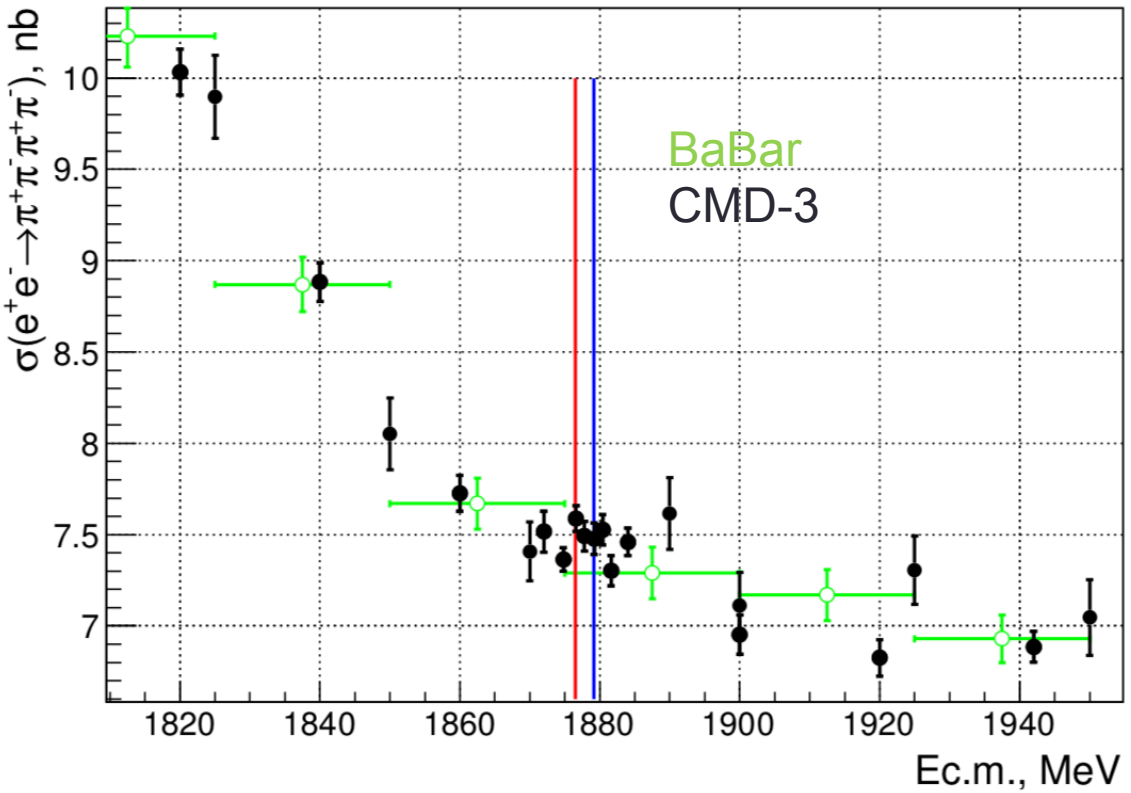
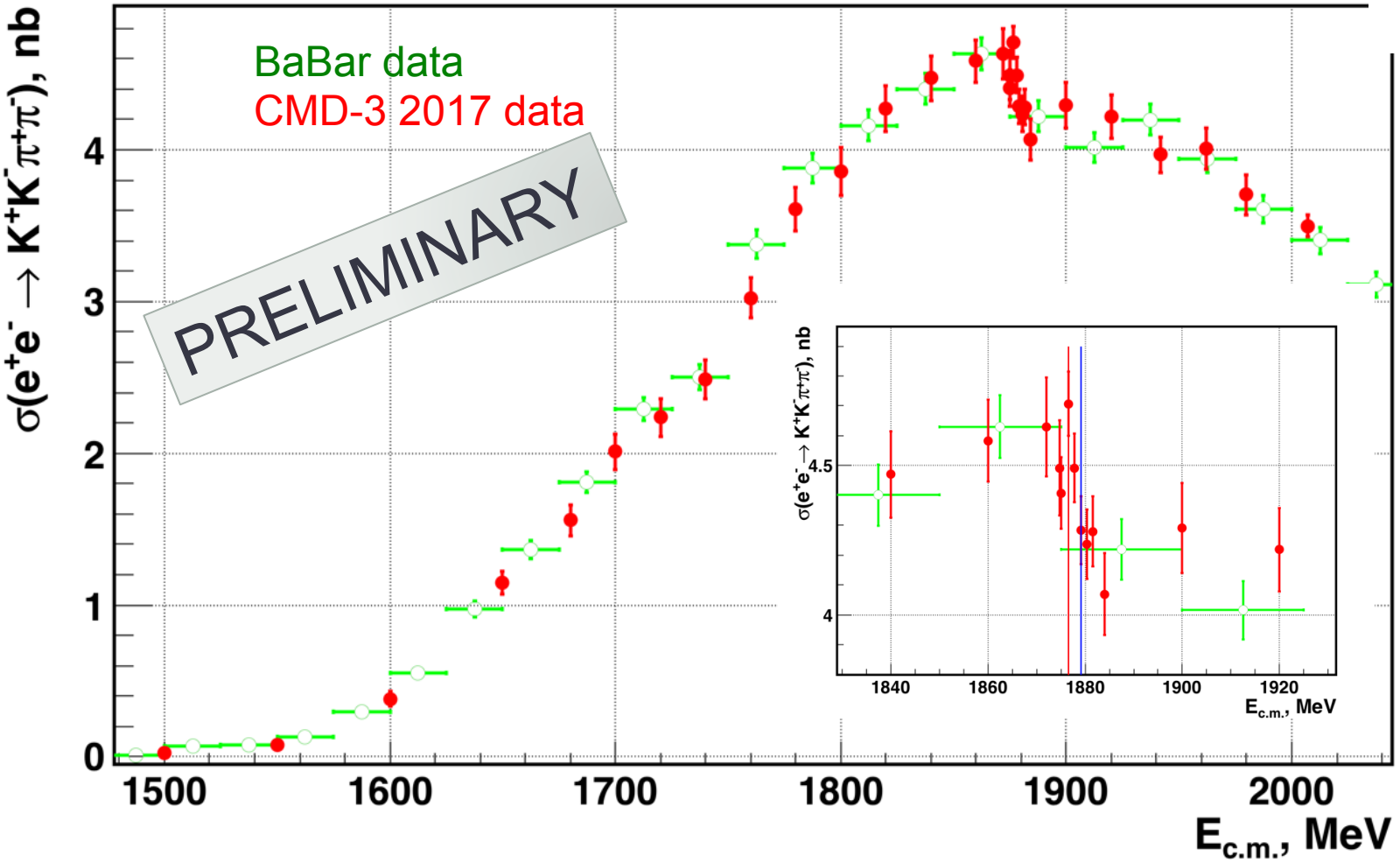


Figure 4: The $e^+e^- \to 2(\pi^+\pi^-)$ cross section measured with the CMD-3 detector. Lines show the $p\bar{p}$ and $n\bar{n}$ thresholds.

We continue search for the NNbar threshold indication in other multi-hadron reactions

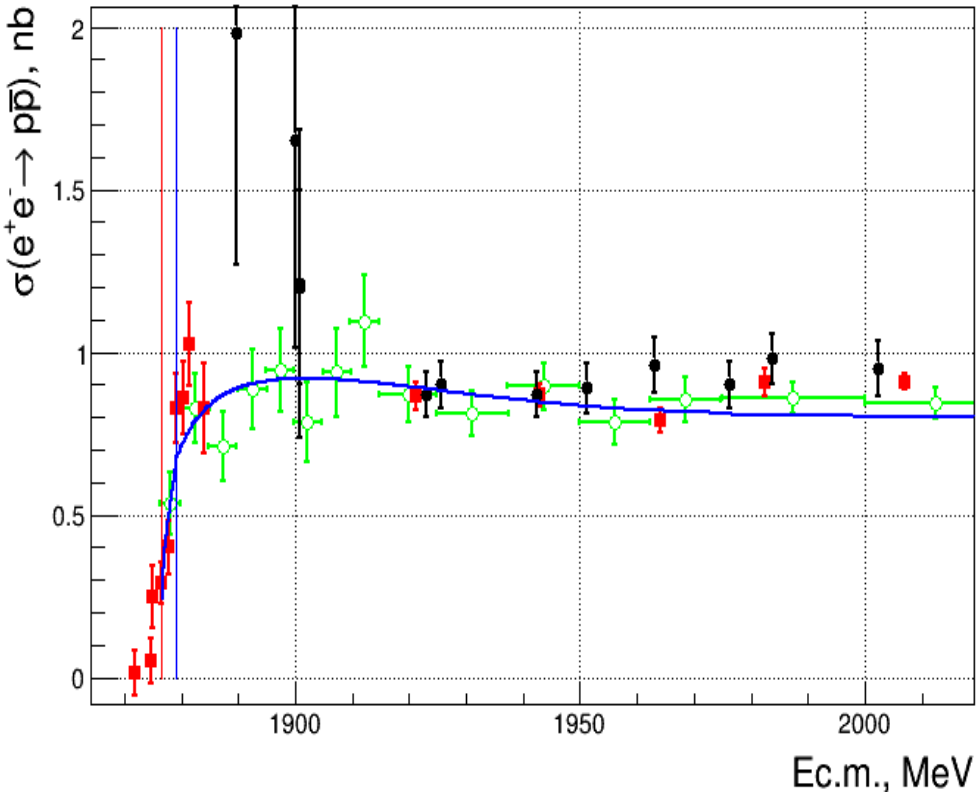
NEW! Structure in e^+e^- -> $K^+K^-\pi^+\pi^-$

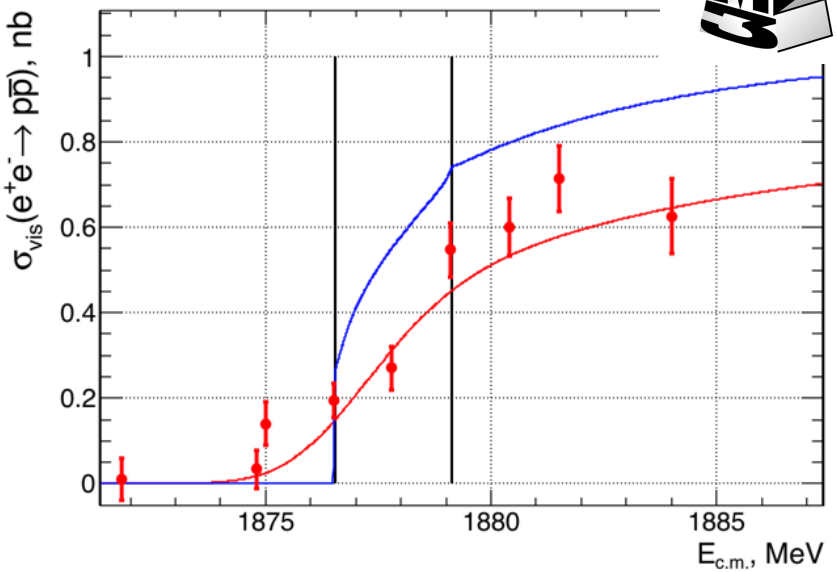


One more channel, where NN threshold structure has been observed!

Milstein-Salnikov prediction (fit?)

Theoretical calculation well describes the experimental data for ppbar production in e+e-

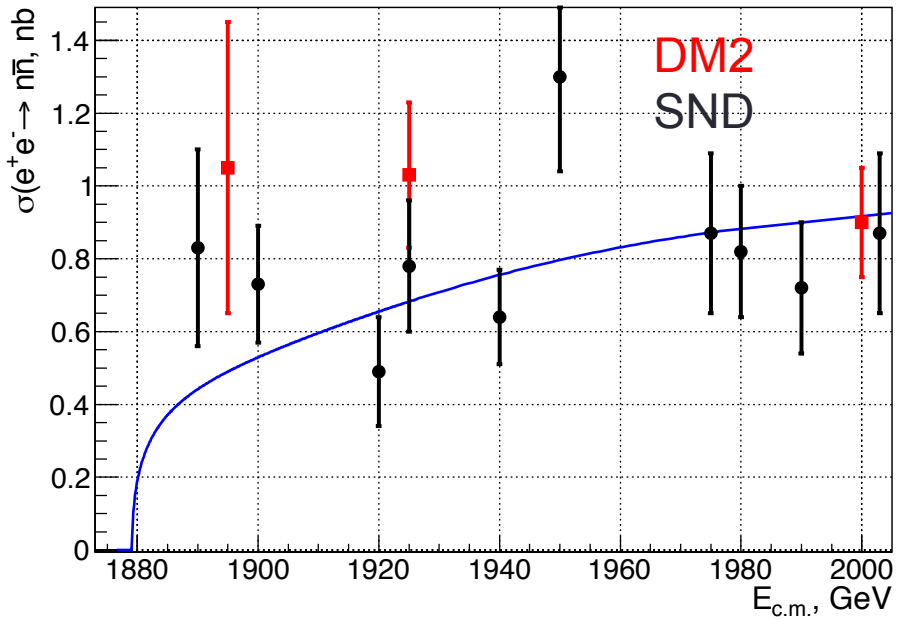




Using predicted shape convoluted with radiative effects and beam energy spread we fit visible XS:
Good agreement in shape
– theoretical prediction should be increased by 10% to fit our 2017 data
Note NON-ZERO XS at the threshold.

Milstein-Salnikov prediction (fit?)

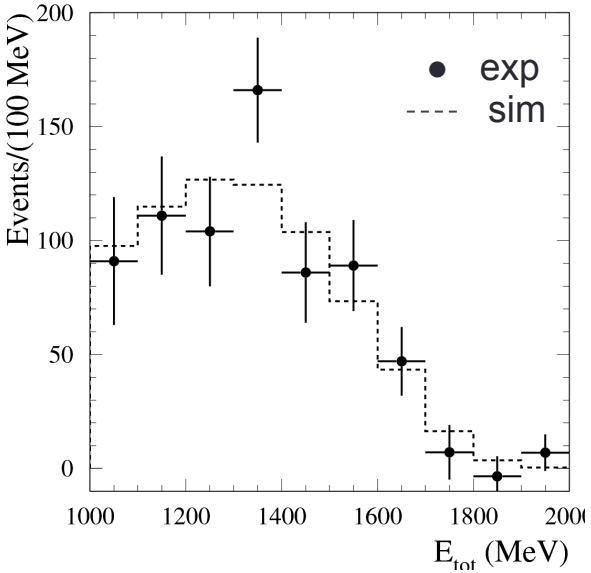
Theoretical calculation not so well describes the experimental data for nnbar production in e+e-, but not in contradiction.

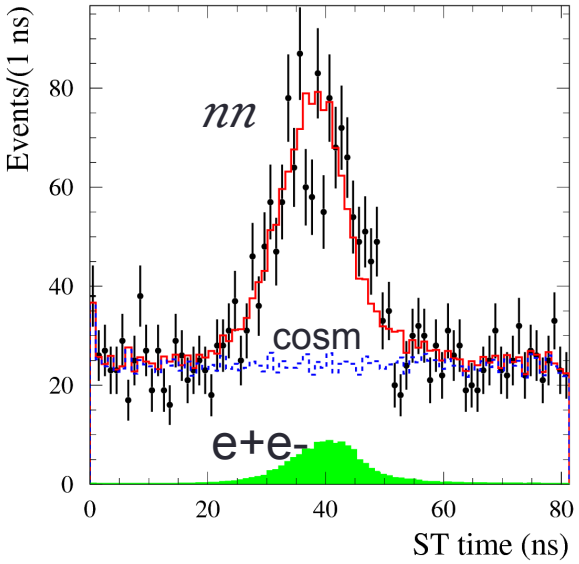


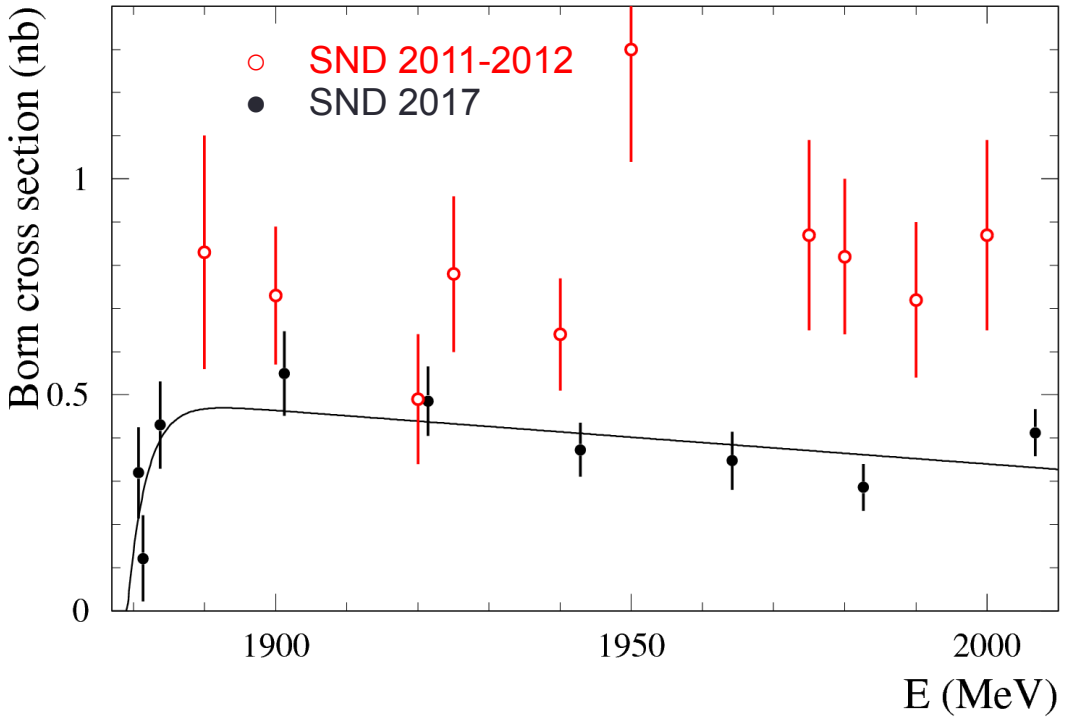
We are eagerly wait for the result of nnbar analysis from SND and CMD-3 at the threshold

Should be later this year.

e+e- -> nn SND (preliminary)







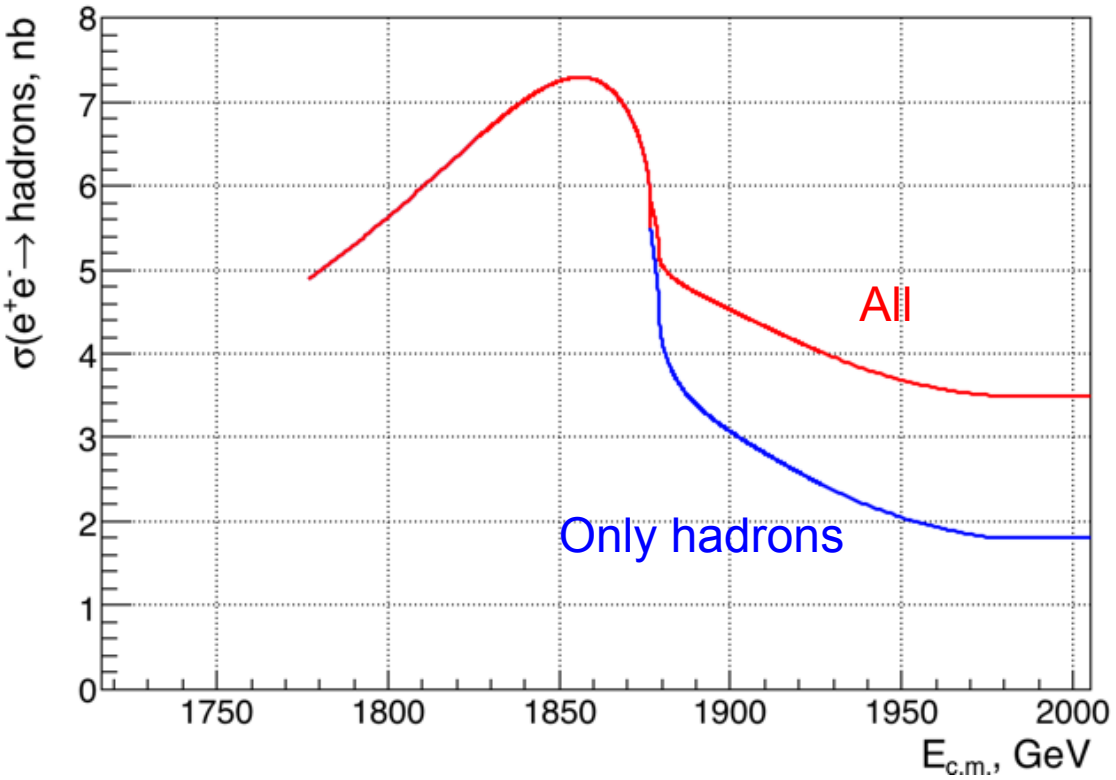
The difference:

-- incorrect nn simulation
-- beam background
-- cosmic background

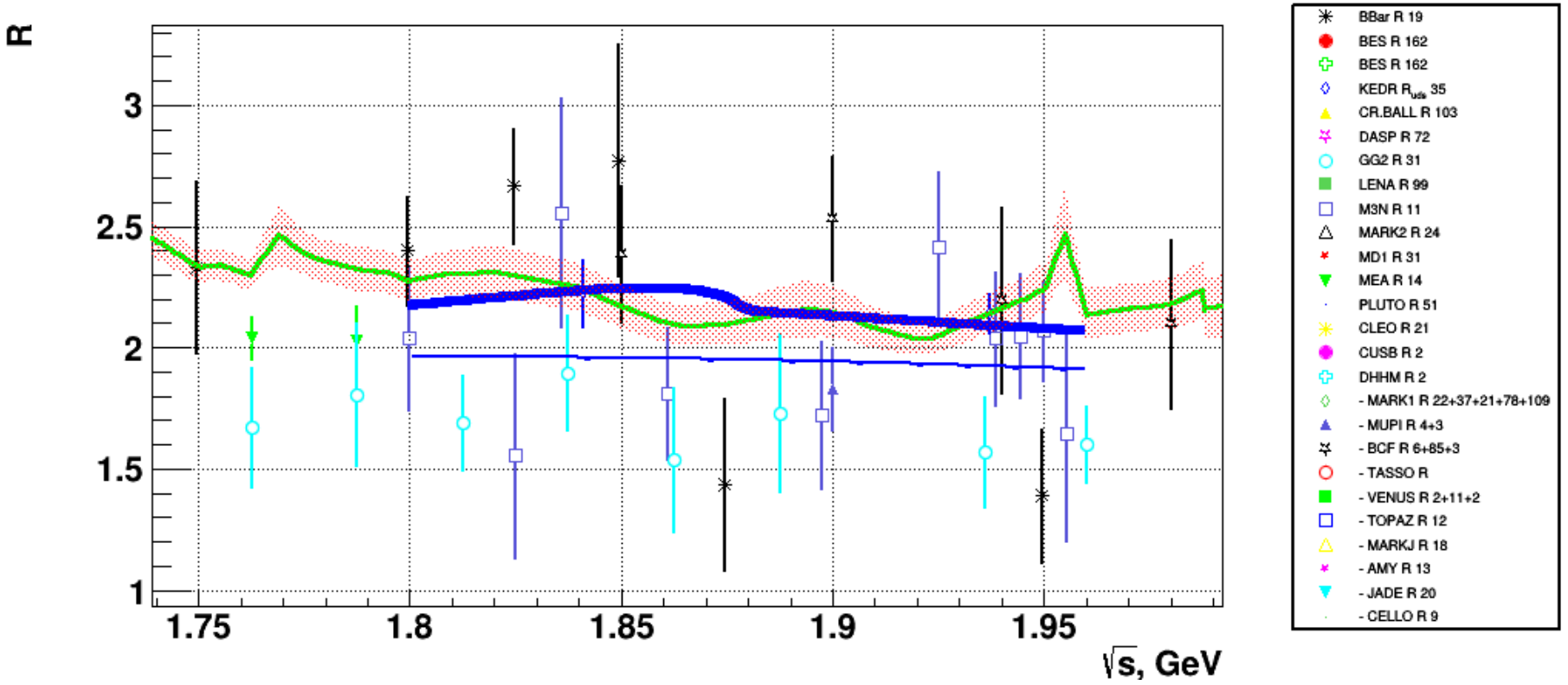
Systematic uncertainty ~20%, mainly due to MC

Milstein-Salnikov prediction

Large contribution to total hadronic cross section!!: 7 nb to ~40 nb total



Present accuracy in R is too poor



Green line and band – sum of exclusive channels
Points – inclusive measurements
Blue line(s) – Milstein-Salnikov prediction – about 15% of total XS is due to NN interaction !?

Conclusion

• The goal of two experiments CMD-3 and SND at VEPP2000 is to provide exclusive measurement of e+e- -> hadrons reactions in the energy range 0.32 – 2.0 GeV

• In 2011-2013 both detectors have collected about 60 pb^{-1} each in the whole 0.32 – 2.0 GeV energy range, available at VEPP2000

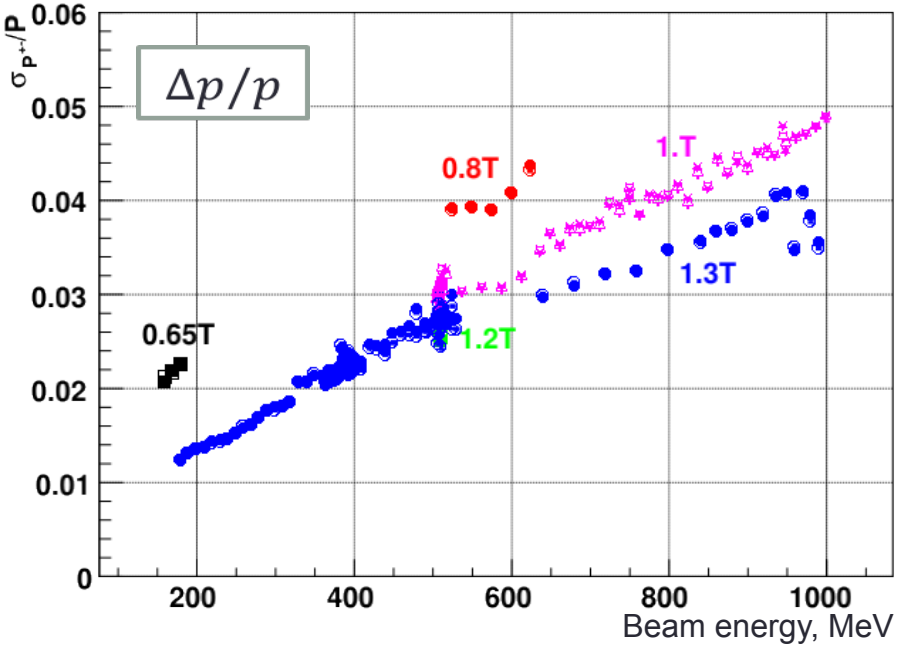
• During 2014-2016 machine and detectors have been upgraded and at the end of 2016 detectors resumed data taking

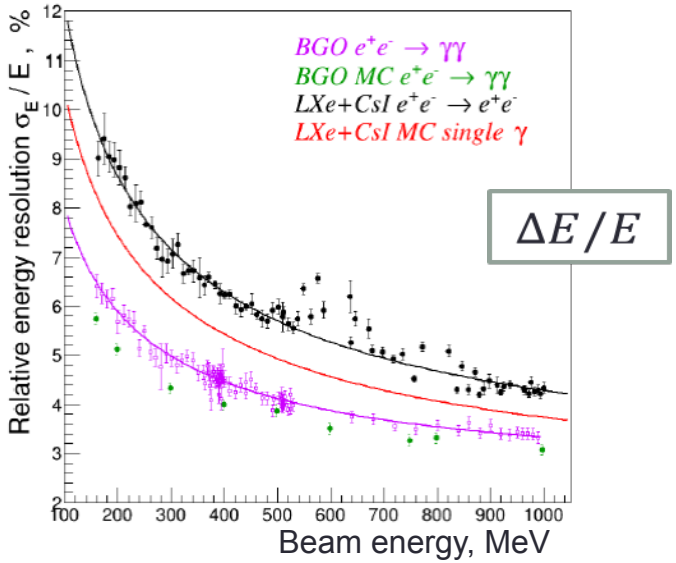
• In 2017 both detectors have collected 50 pb^{-1} in 5 months with c.m. energy scan from 1.68 to 2.0 GeV. At the end of 2017, beggining of 2018 - 66 pb^{-1} have been collected in 0.55-1.0 GeV

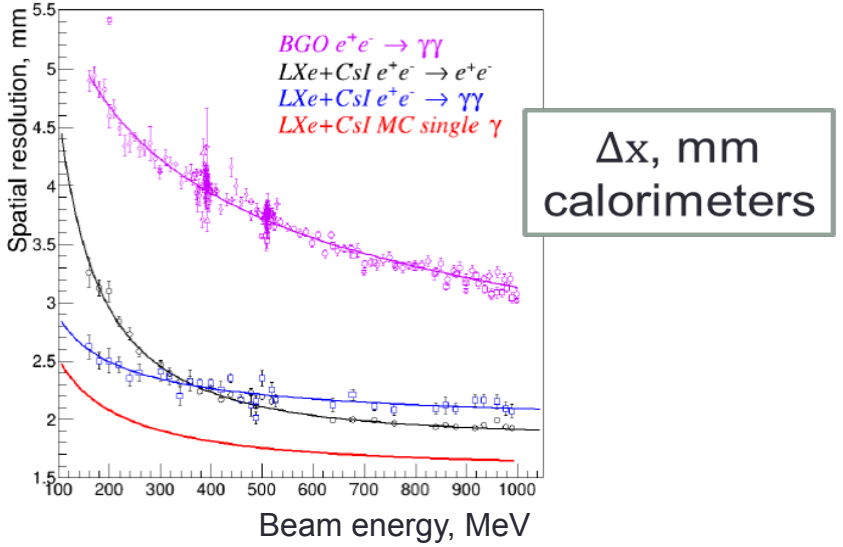
• Many analyses have been published. Many more are in the line.

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

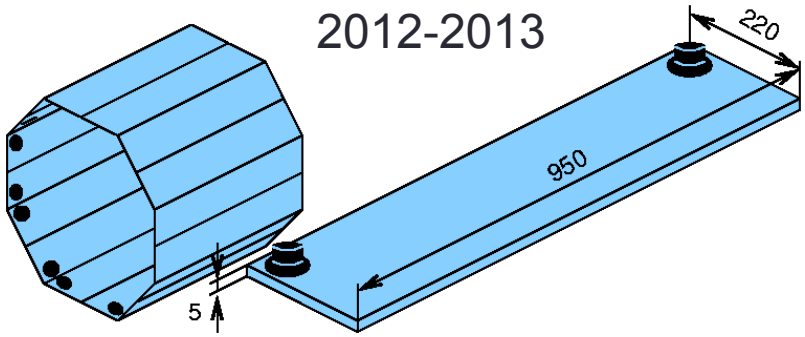




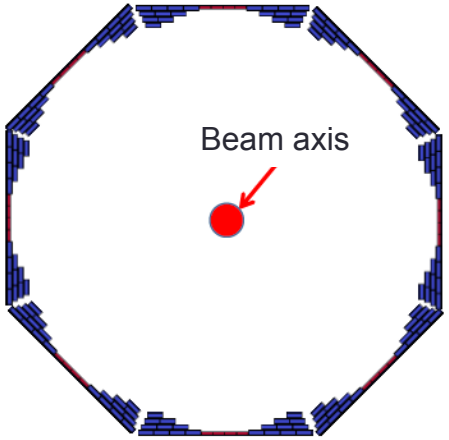


New TOF system

"Old" TOF
2012-2013

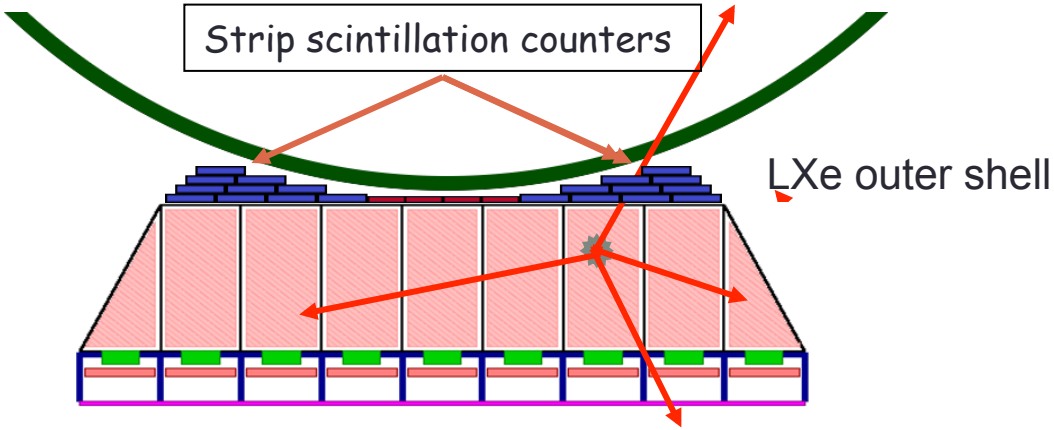


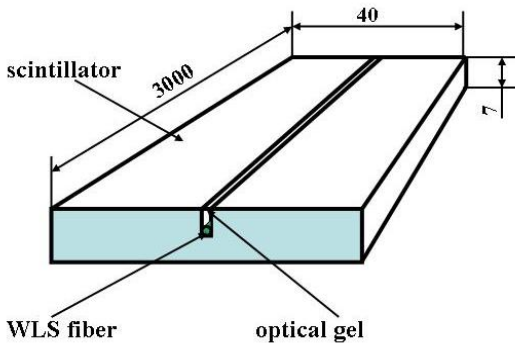
"New" TOF (2017-)



In 2013-2016 the TOF system was completely replaced

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





Search for e+e- → η'(958)

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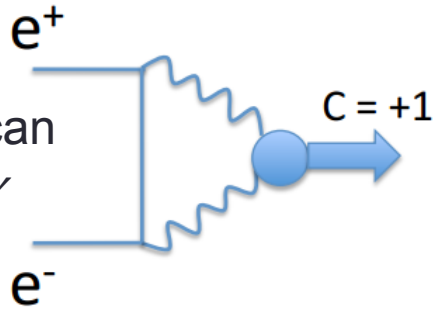

C-even resonances can be produced via 2γ

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