

Analysis of Novosibirsk Data

Simon Eidelman

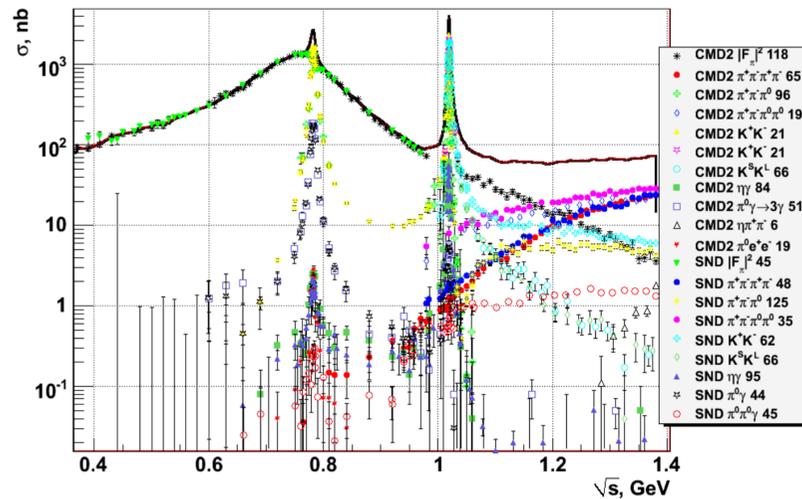
Budker Institute of Nuclear Physics SB RAS
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Novosibirsk, Russia

(on behalf of CMD-3, SND and KEDR Collaborations)

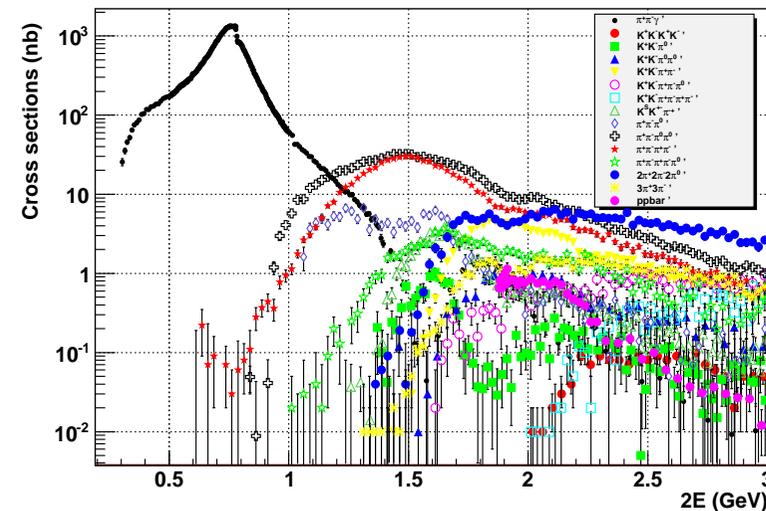
Outline

1. Results from CMD-3 and SND at VEPP-2000
2. Results from KEDR at VEPP-4M
3. Future and prospects

Status of Exclusive Measurements after VEPP-2M



Scan at CMD-2/SND below 1.4 GeV

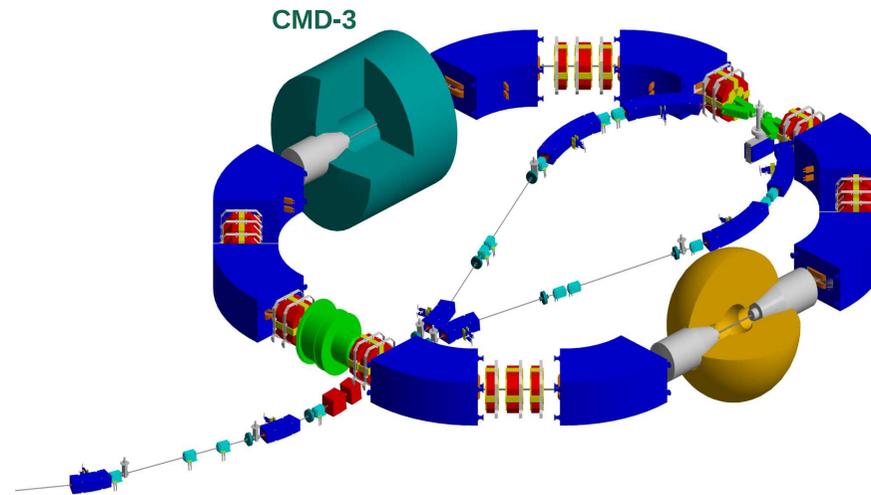


ISR at BaBar up to 3 GeV

Current ISR players are BaBar, KLOE-2 and BESIII with BelleII in the future

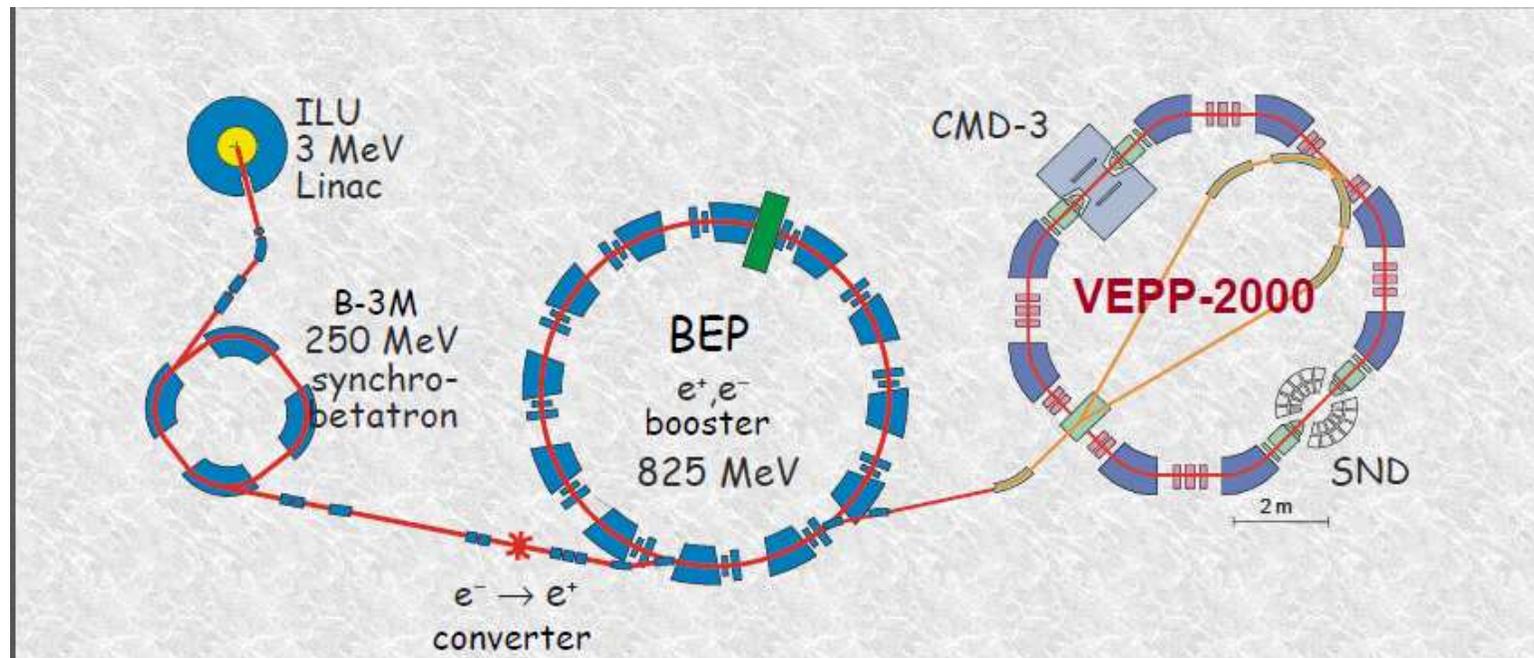
72% of $a_{\mu}^{\text{LO,HVP}}$ from $e^+e^- \rightarrow \pi^+\pi^-$, more than 90% from below 2 GeV

VEPP-2000 – I



Collider	Operation	\sqrt{s} , MeV	\mathcal{L} , $10^{30} \text{cm}^{-2} \text{s}^{-1}$
VEPP-2M	1975-2000	[360,1400]	3
VEPP-2000	2010-	$[2m_\pi, 2000]$	100

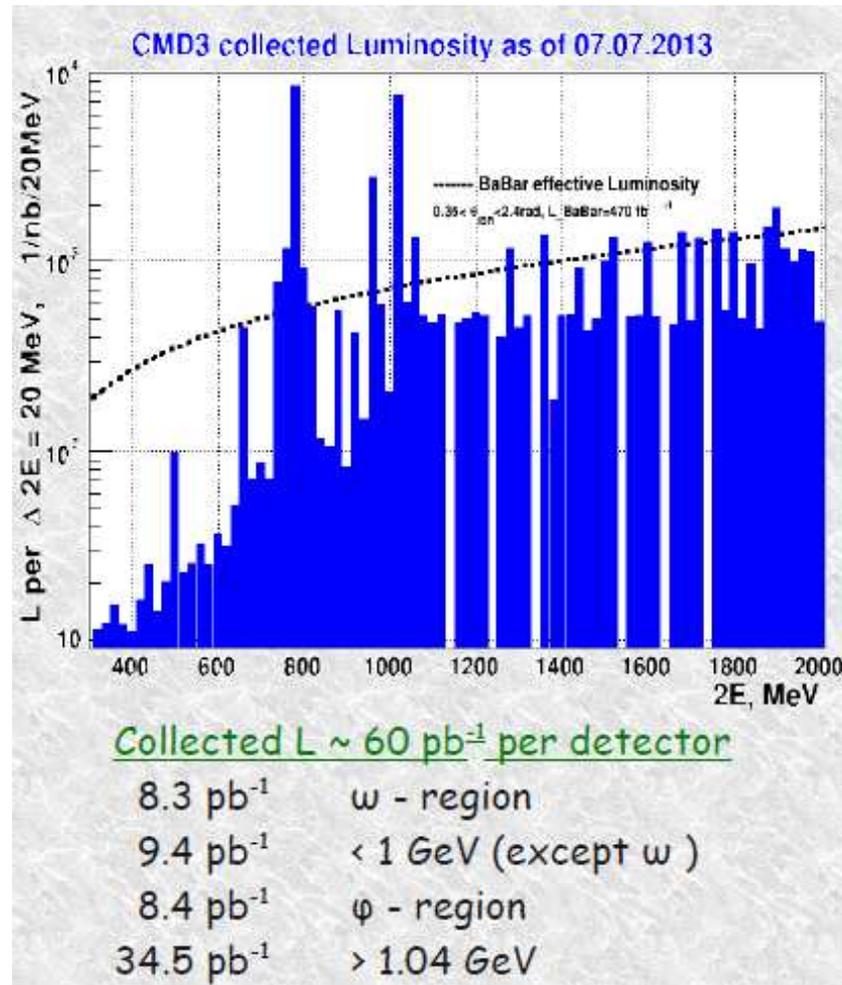
VEPP-2000 – II



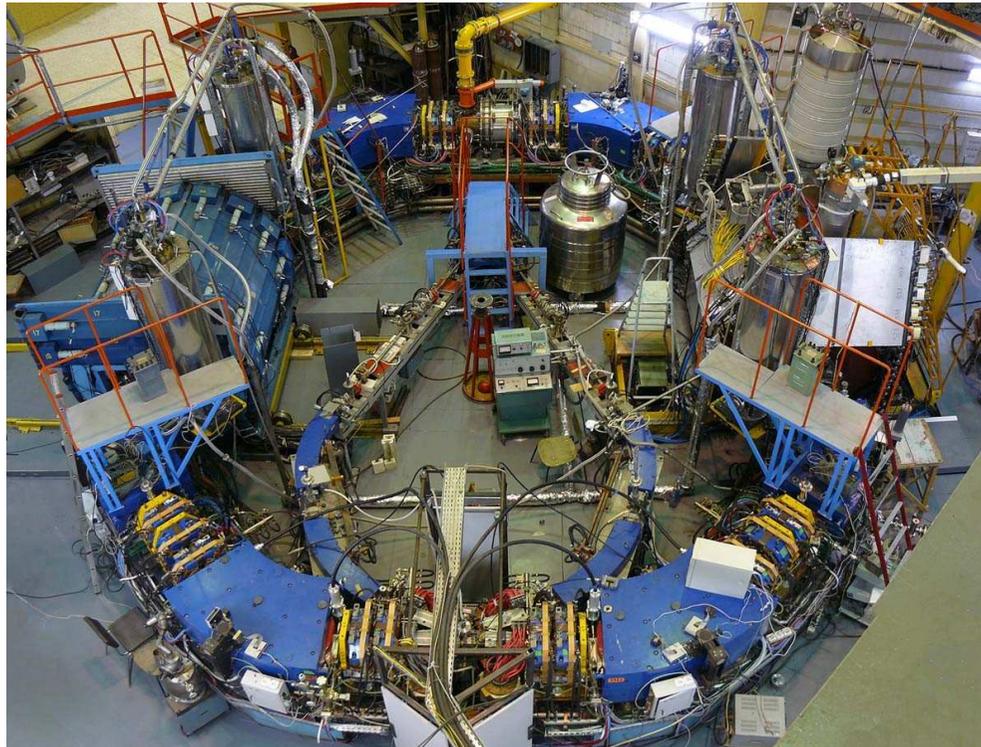
New optics with round beams \Rightarrow higher luminosity,
precise beam energy measurement using LCBS

In 2013-2015 the complex was upgraded to increase the booster
energy to 1 GeV and commission the new injection complex

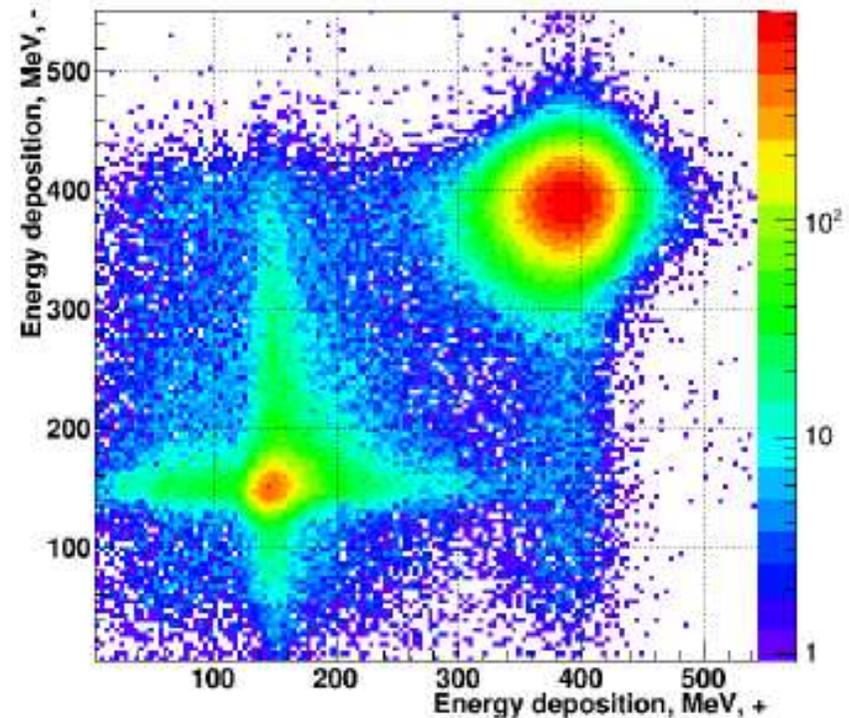
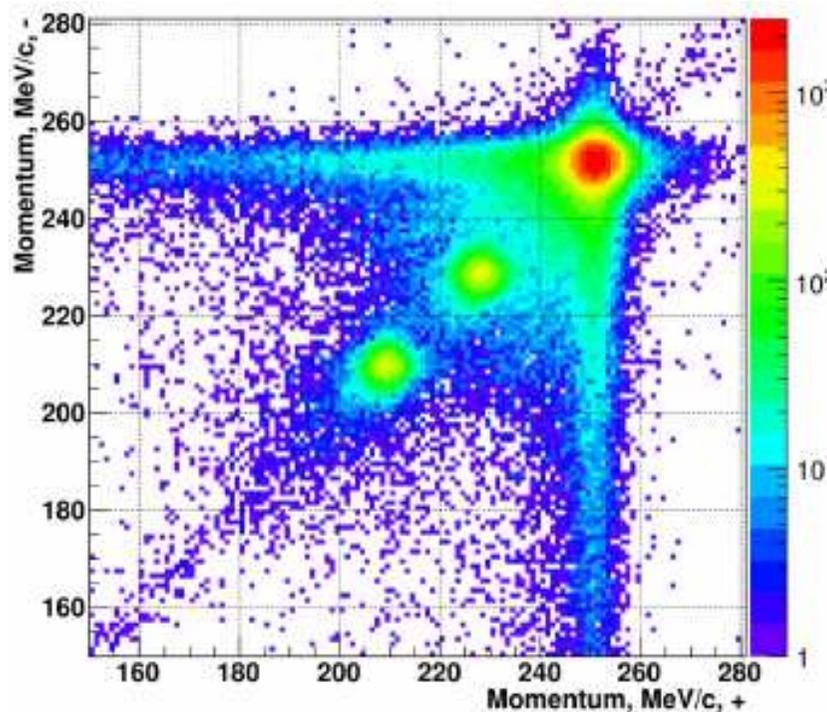
Data Taking at VEPP-2000 in 2011-2013



VEPP-2000 and Detectors

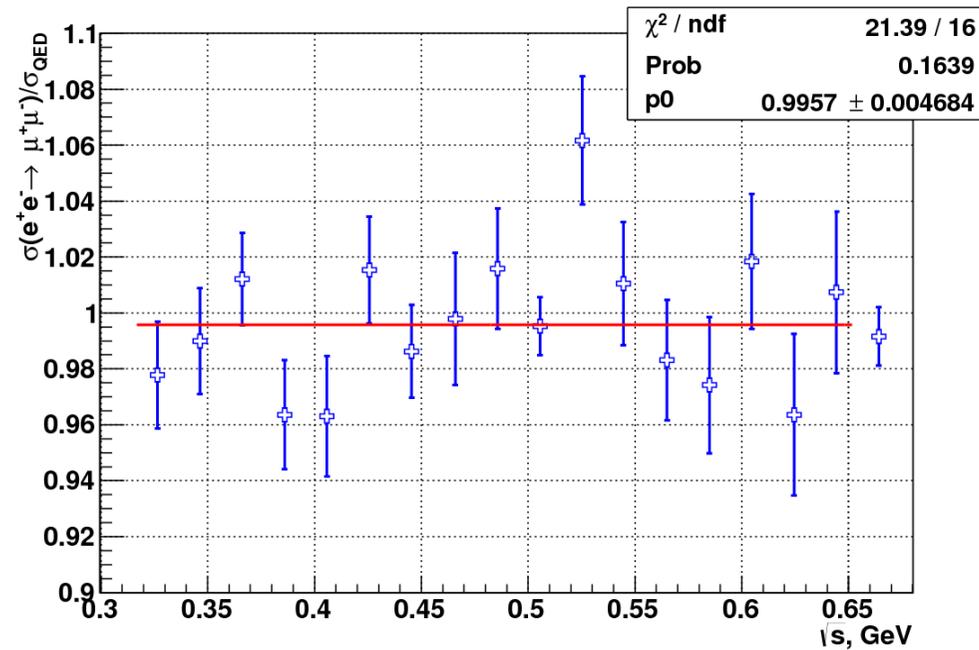


Two detectors - CMD-3 and SND

$$e^+e^- \rightarrow \pi^+\pi^- \text{ at CMD-3 - I}$$


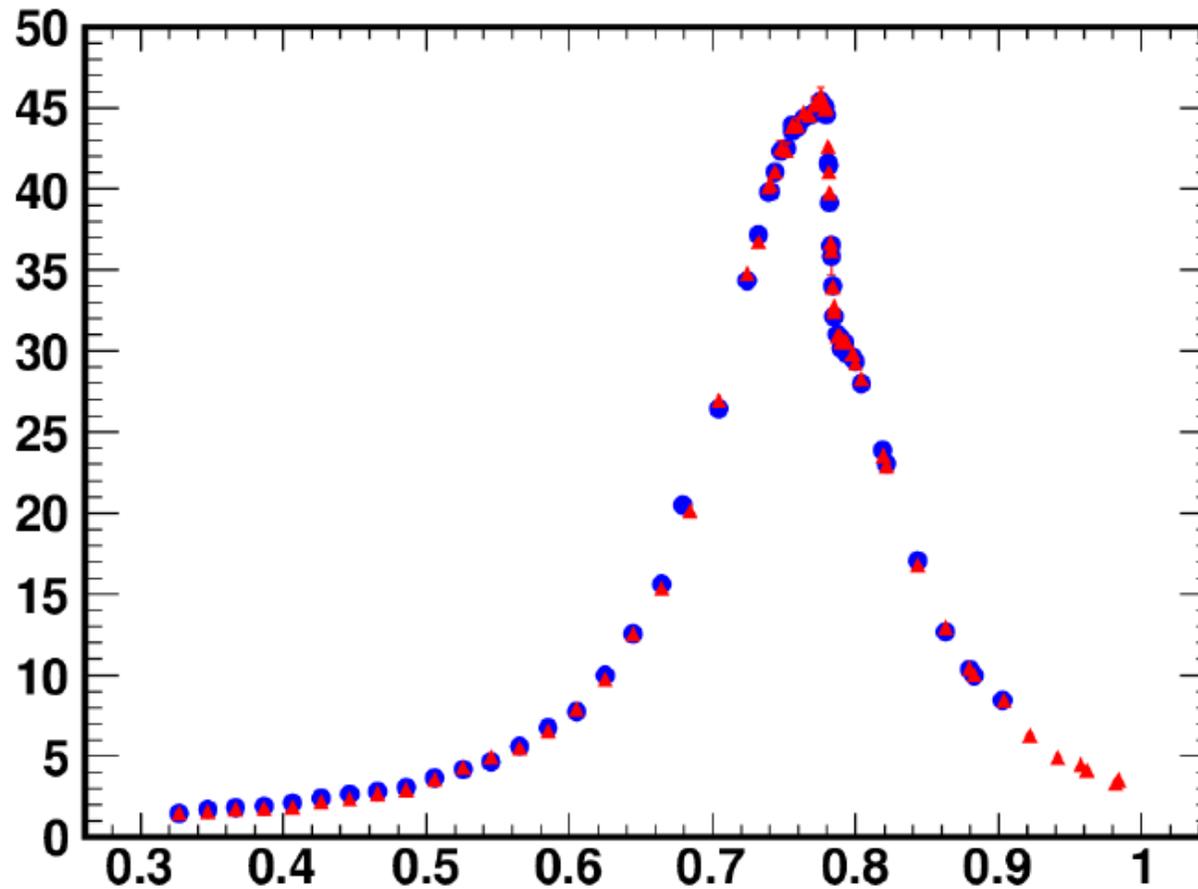
Identification below 900 MeV - by DC with separation of $\mu^+\mu^-$

At higher energy - by energy deposition in calorimeters

$$e^+e^- \rightarrow \pi^+\pi^- \text{ at CMD-3 - II}$$


Muon separation, $N_{\pi\pi}$ and $N_{\mu\mu}$

Direct cross check of rad. corrections with $\pi^+\pi^-\gamma$

$$e^+e^- \rightarrow \pi^+\pi^- \text{ at CMD-3 - III}$$


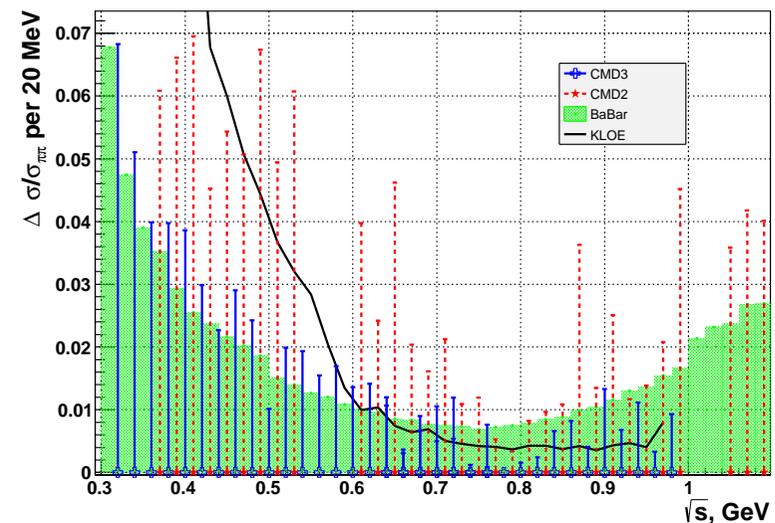
Systematic error: goal 0.35% at the ρ (BaBar achieved 0.5%)

I. Logashenko, ICHEP-2016

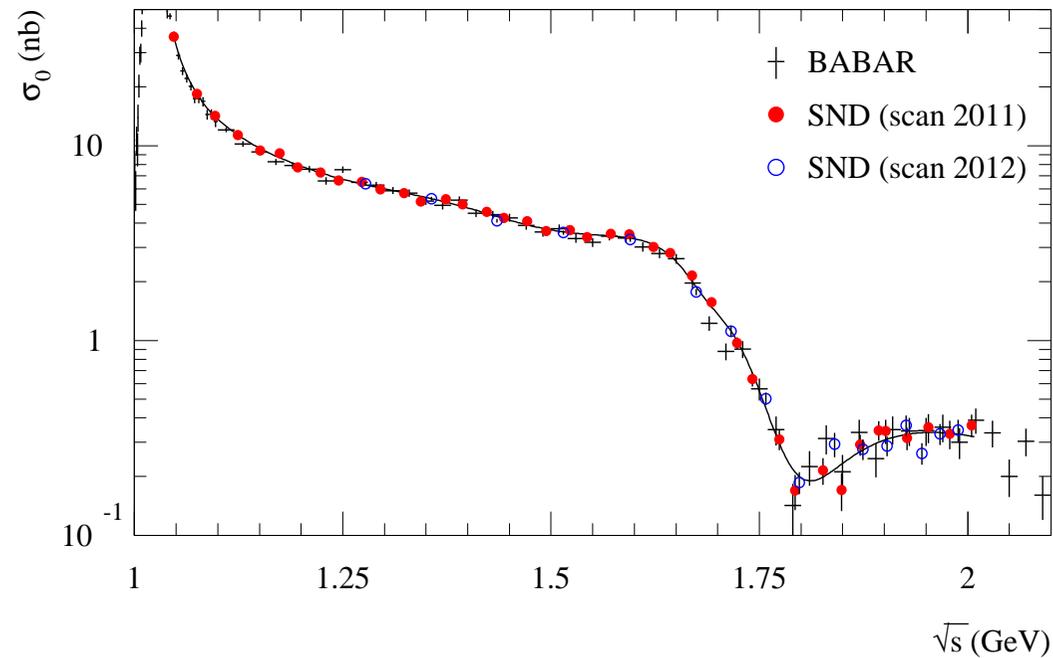
$$e^+e^- \rightarrow \pi^+\pi^- \text{ at CMD-3 - IV}$$

Expected systematics

$e/\mu/\pi$ separation	0.2
Fiducial volume	0.1
Beam Energy	0.1
Rad. corrections	0.1
Det. efficiency	0.1
Total	0.35



Statistics not worse than at BaBar

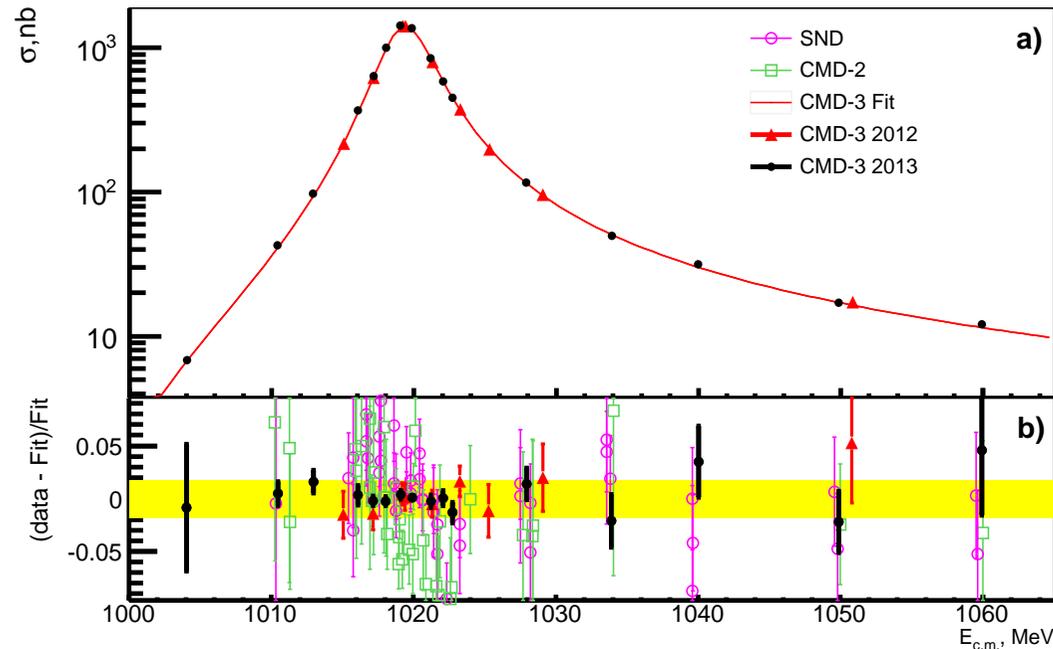
$e^+e^- \rightarrow K^+K^-$ at SND

SND agrees with BaBar and has better precision,
systematics: (1.4-1.7)% below 1.8 GeV, (4.3-4.4)% above 1.8 GeV

Disagreement with SND at VEPP-2M and DM2 is confirmed

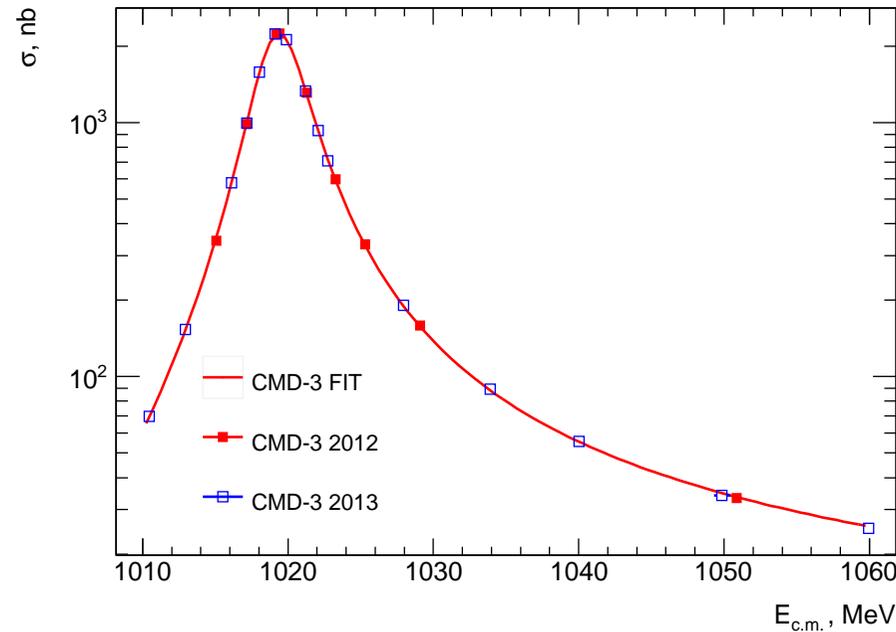
M.N. Achasov et al., Phys. Rev. 94 (2016) 092002

$$e^+e^- \rightarrow \phi \rightarrow K_S^0 K_L^0 \text{ at CMD-3}$$



The most precise measurement of the cross section
based on 6.5×10^5 events, 1.8% systematic uncertainty

E.A. Kozyrev et al., Phys. Lett. B760 (2016) 314

$$e^+e^- \rightarrow \phi \rightarrow K^+K^- \text{ at CMD-3}$$


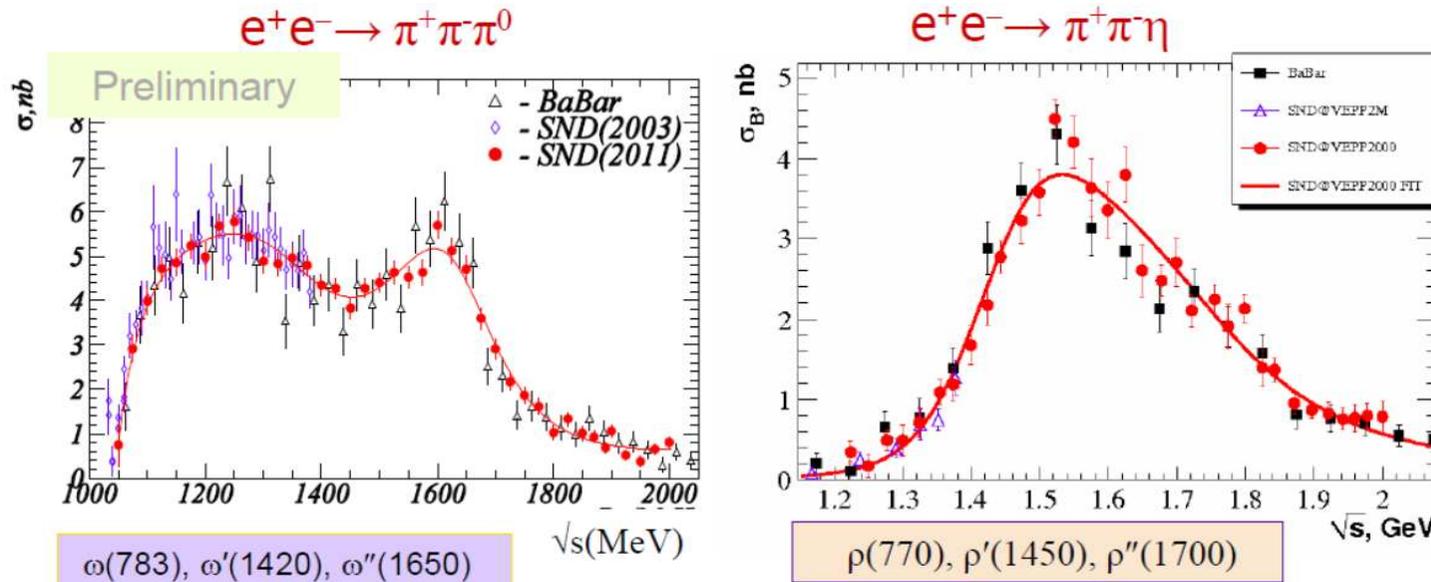
The most precise measurement of the cross section based on 1.6×10^6 events, 2% systematic uncertainty

$\Gamma_{\phi \rightarrow ee} \mathcal{B}_{\phi \rightarrow K^+K^-}$ is larger than at BaBar by 1.8σ ,

$\mathcal{B}_{\phi \rightarrow ee} \mathcal{B}_{\phi \rightarrow K^+K^-}$ is larger than PDG by 2.7σ

E.A. Kozyrev et al., to be published in Phys.Lett.B

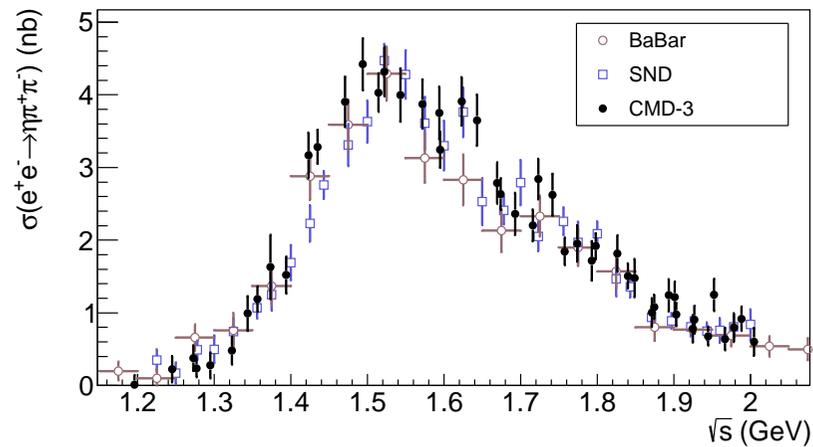
$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ and $e^+e^- \rightarrow \pi^+\pi^-\eta$ at SND



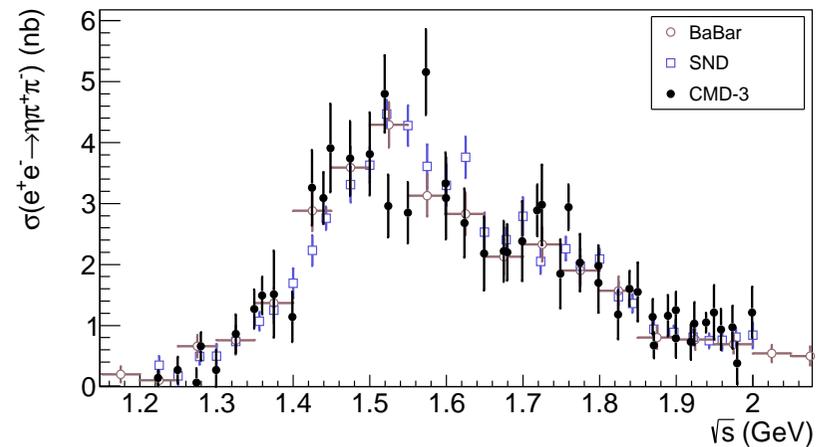
At each \sqrt{s} full information on invariant masses

$\pi^+\pi^-\pi^0$: V. Aulchenko et al., JETP 121 (2015) 34,

$\pi^+\pi^-\eta$: V. Aulchenko et al., Phys. Rev. D 91 (2015) 052013

$$e^+e^- \rightarrow \pi^+\pi^-\eta \text{ at CMD-3}$$


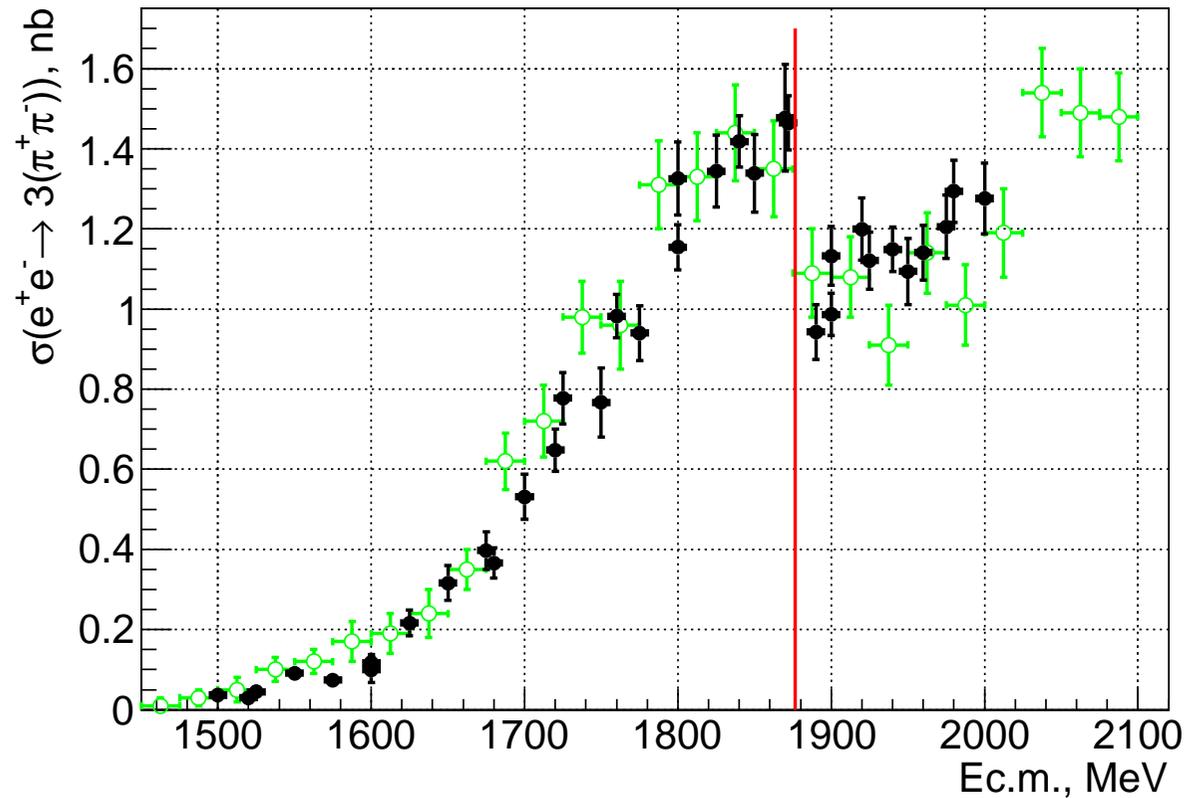
$\eta \rightarrow 2\gamma$, ~ 6800 events, 6% syst.



$\eta \rightarrow \pi^+\pi^-\pi^0$, ~ 4000 events, 10% syst.

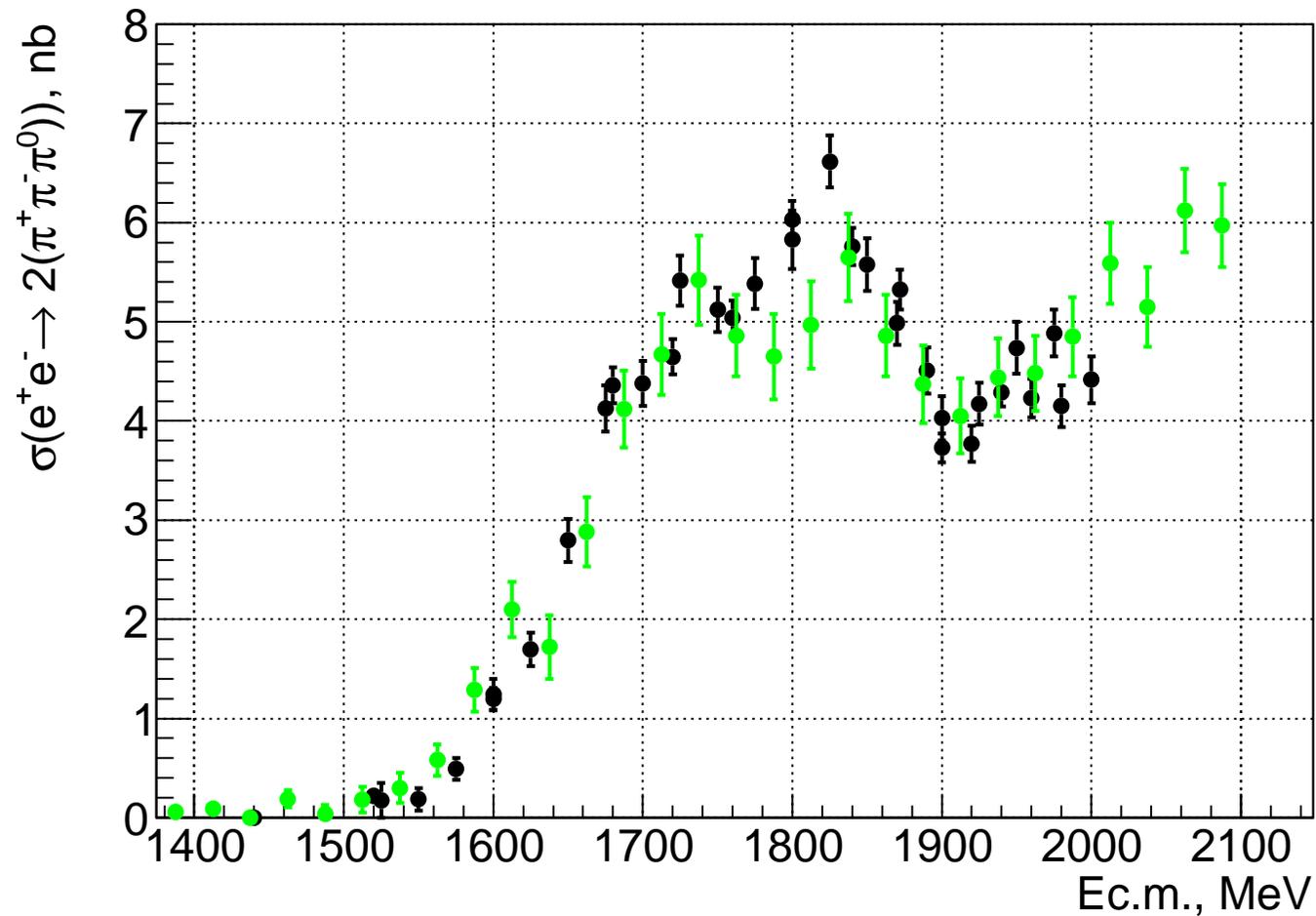
CMD-3 - Preliminary

Will we unambiguously observe the $\rho(1700)$?

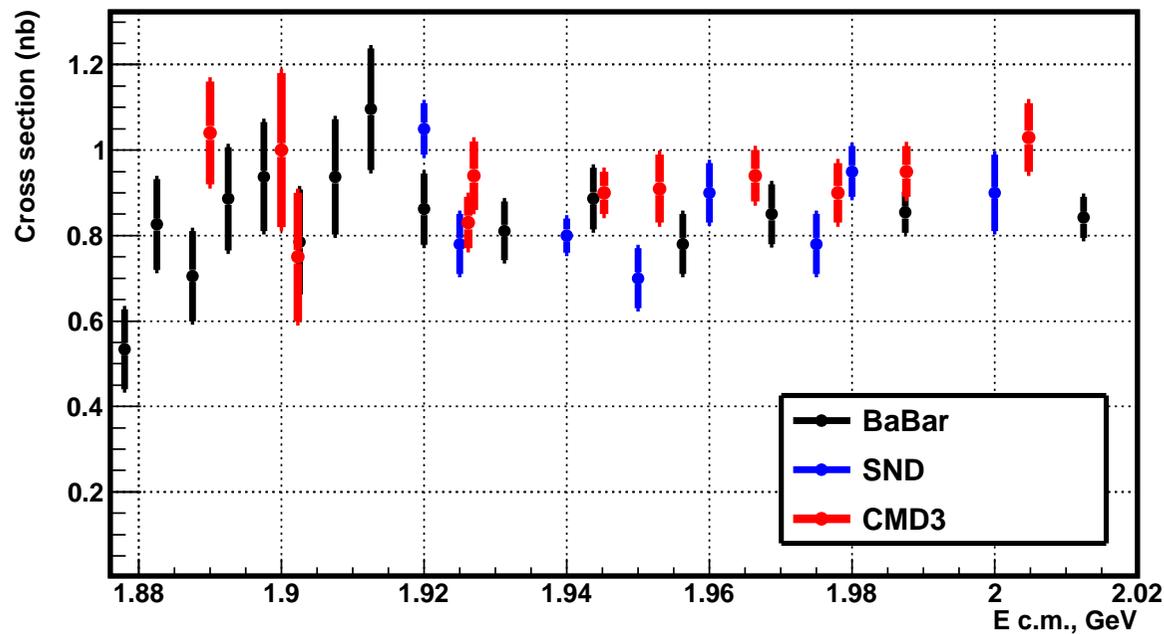
$$e^+e^- \rightarrow 3\pi^+3\pi^- \text{ at CMD-3}$$


The dip structure near $N\bar{N}$ threshold is confirmed

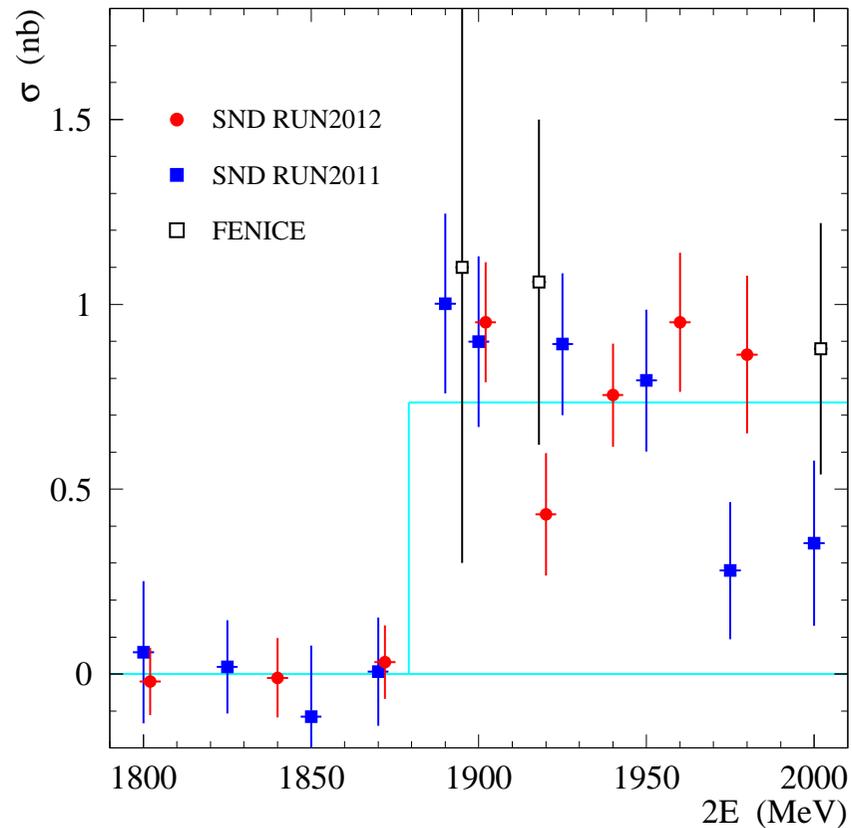
R.R. Akhmetshin et al., Phys. Lett. B 723 (2013) 82

$$e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0 \text{ at CMD-3}$$


The dip structure near $N\bar{N}$ threshold also seen

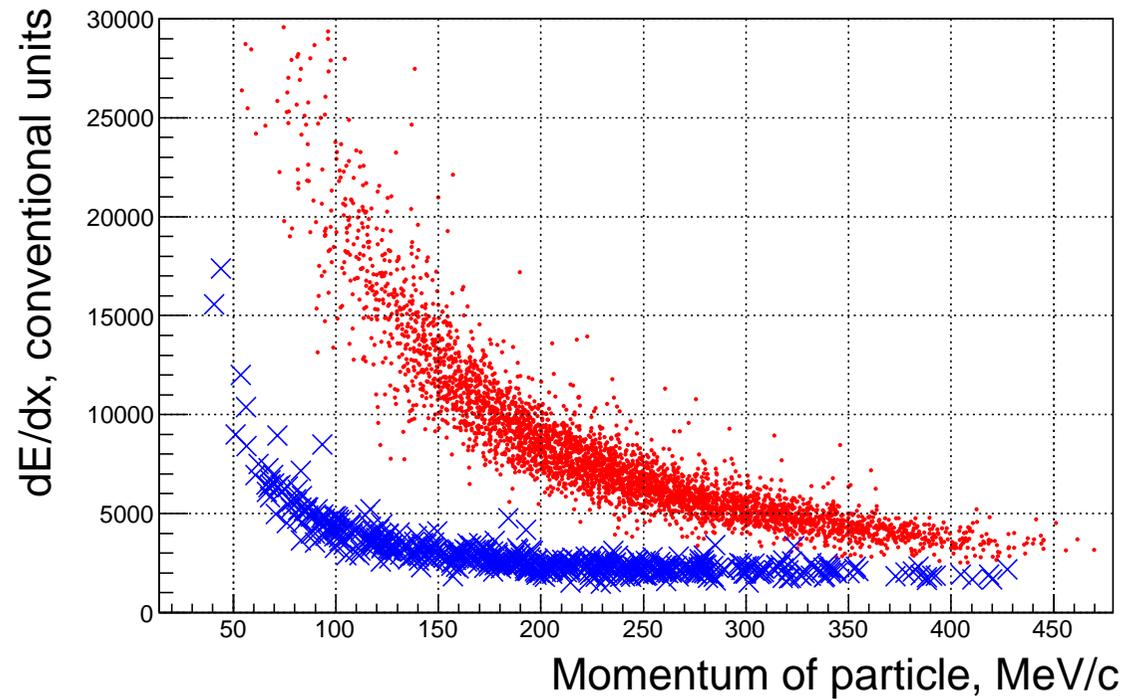
$p\bar{p}$ Production at VEPP-2000

In addition to cross sections, first attempts of measuring f/f made
R.R. Akhmetshin et al., Phys. Lett. B759 (2016) 634

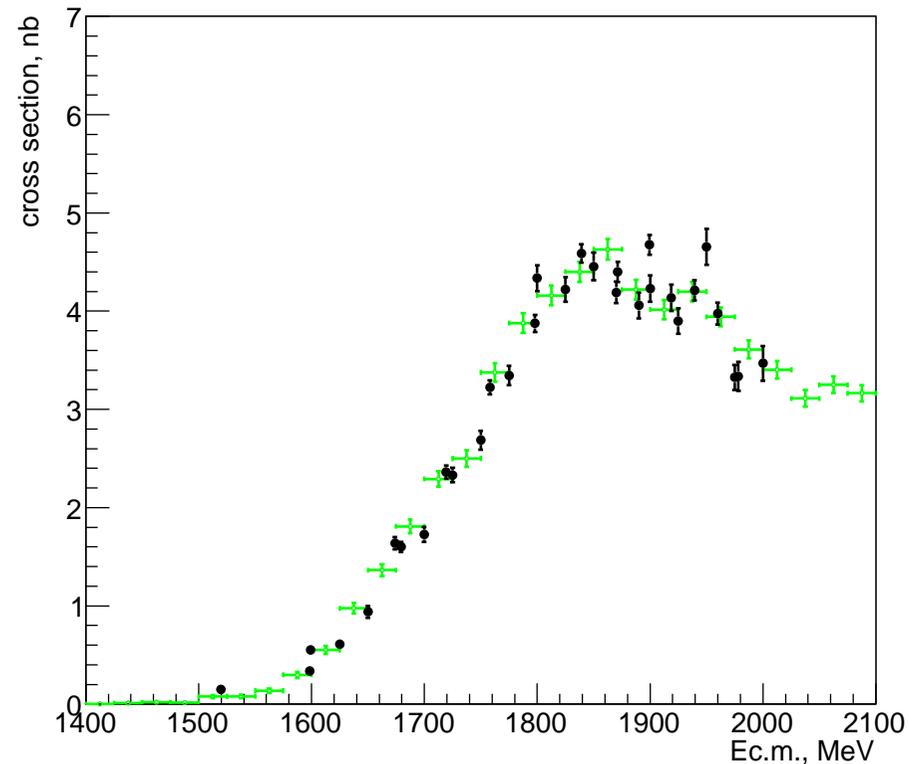
$e^+e^- \rightarrow n\bar{n}$ at SND

The first and more precise measurement after FENICE
M.N. Achasov et al., Phys. Rev. D 90 (2014) 112007

Multibody Final States with Charged Kaons



Ionization losses in DC (dE/dx) provide good K/π separation

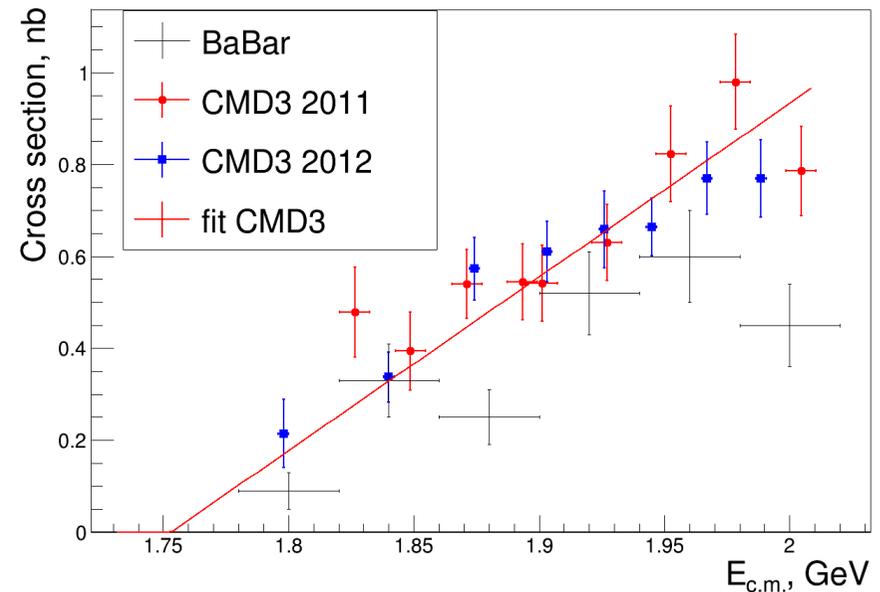
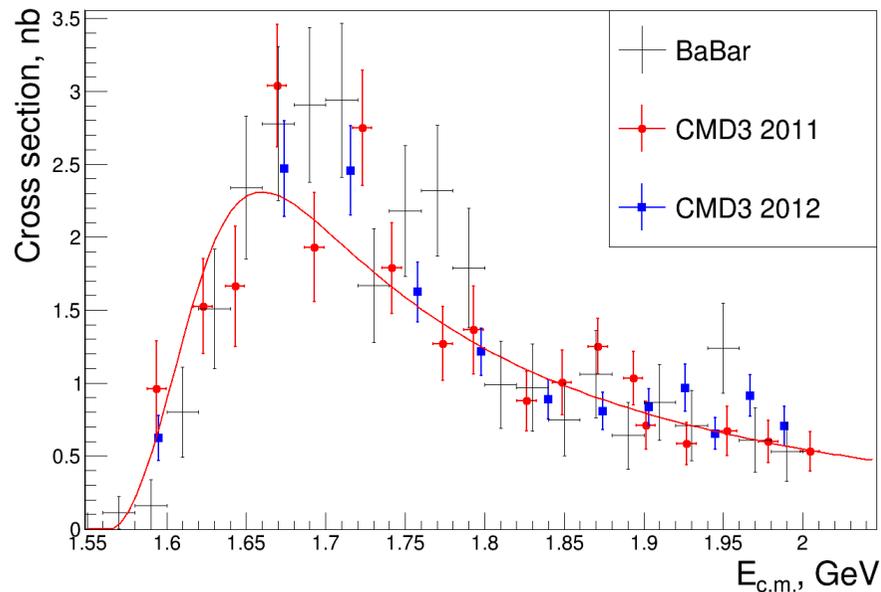
$$e^+e^- \rightarrow K^+K^-\pi^+\pi^- \text{ at CMD-3}$$


From more than 10000 events many different mechanisms seen:
 $K_1(1270)\bar{K} \rightarrow K\bar{K}\rho$, $K^*(892)\bar{K}\pi$, $K_1(1400)\bar{K} \rightarrow K^*(892)\bar{K}\pi$, $\phi\pi^+\pi^-$

R.R. Akhmetshin et al., Phys. Lett. B 756 (2016) 153

$$e^+e^- \rightarrow K^+K^-\eta \text{ and } e^+e^- \rightarrow K^+K^-\omega \text{ at CMD-3}$$

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

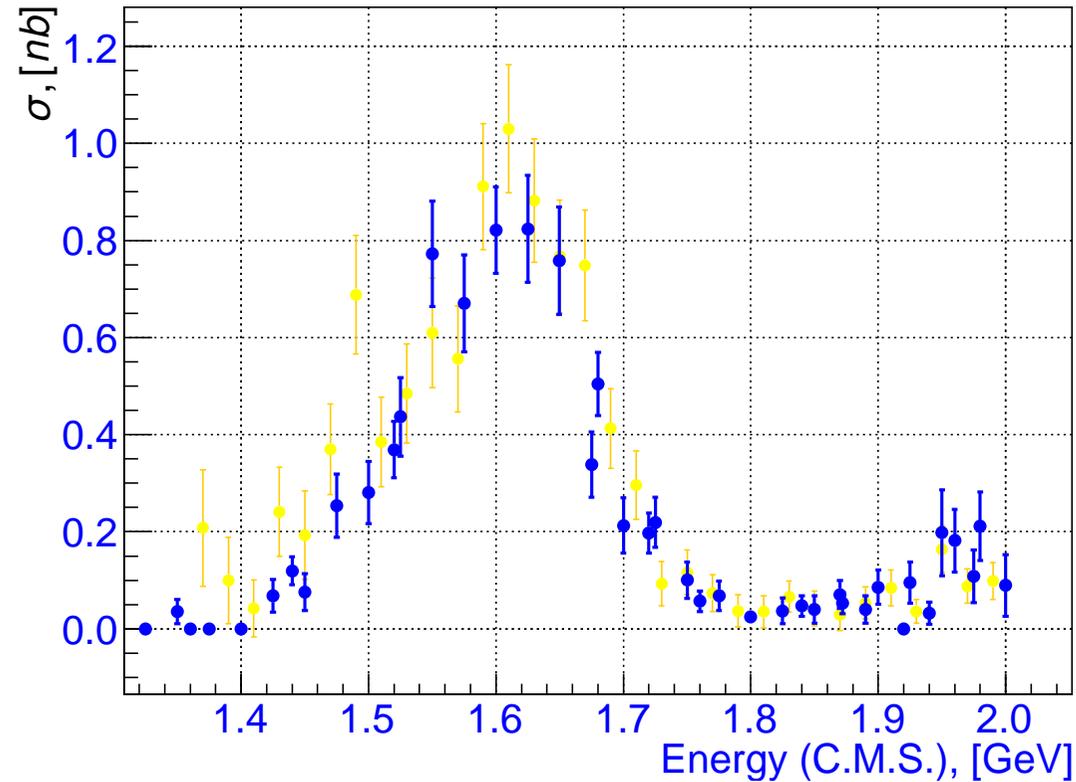
$$e^+e^- \rightarrow K^+K^-\omega$$


1371 events, 6% systematics, $\phi\eta$ only

1016 events, 6% systematics

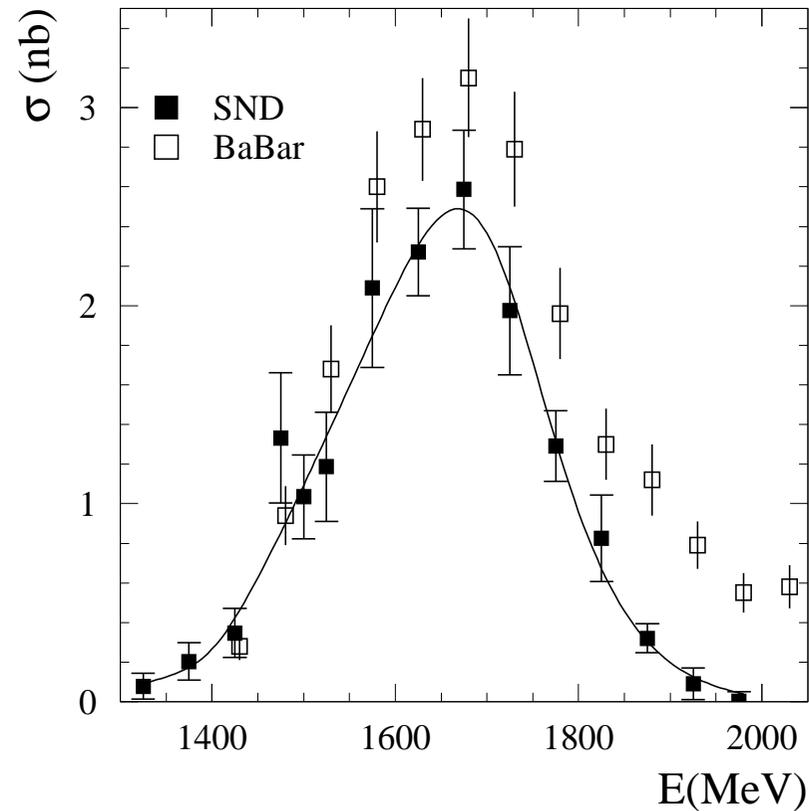
The cross sections are consistent with and more precise than BaBar

$$e^+e^- \rightarrow K^+K^-\pi^0 \text{ at CMD-3}$$



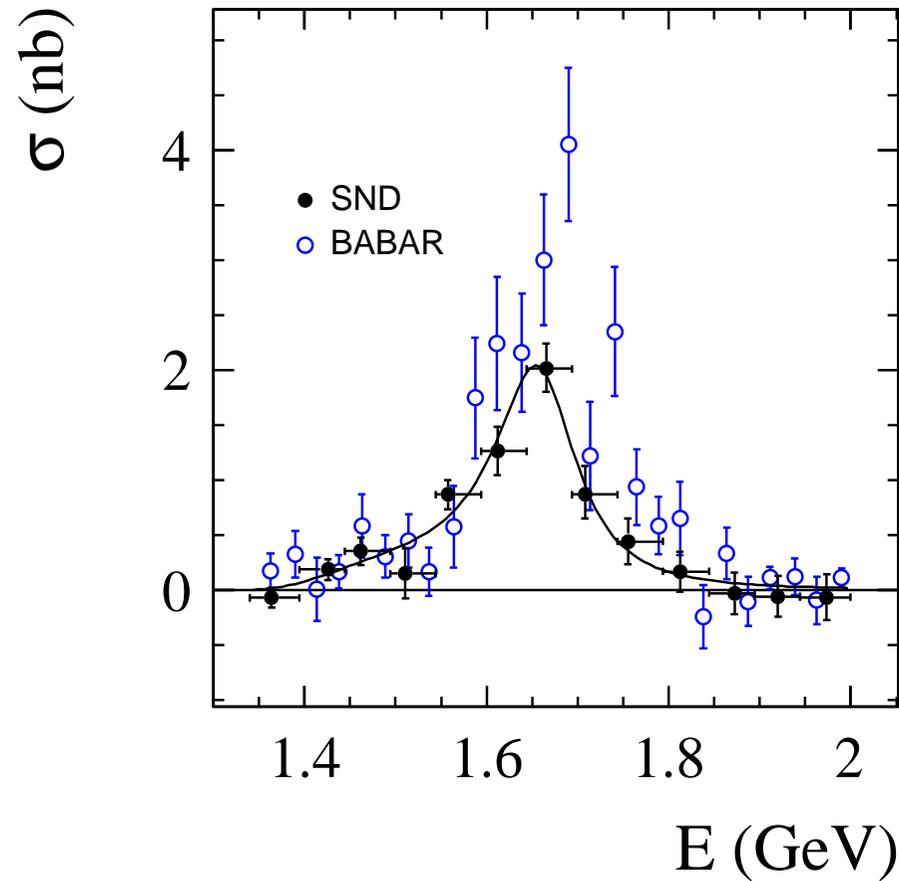
From 600 events the $\phi\pi^0$ and $K^{*\pm}(892)K^\mp$ mechanisms seen
The cross section is consistent with and more precise than BaBar

$$e^+e^- \rightarrow K_S^0 K_L^0 \pi^0 \text{ at SND}$$



~ 700 events selected

Significant disagreement with BaBar above 1.6 GeV

$e^+e^- \rightarrow \omega\eta$ at SND

850 $\pi^+\pi^-\pi^0\eta$ events, significant disagreement with BaBar above 1.6 GeV

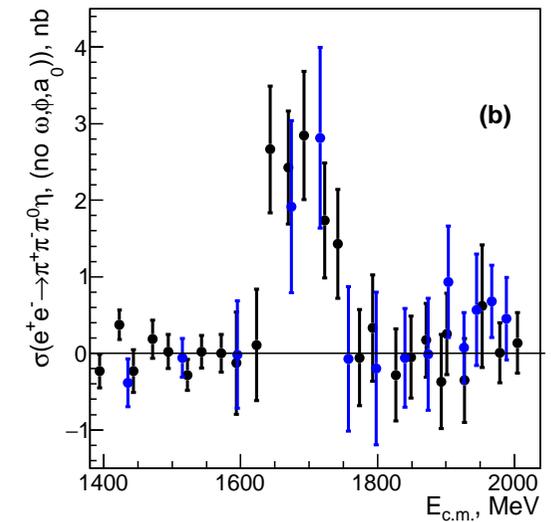
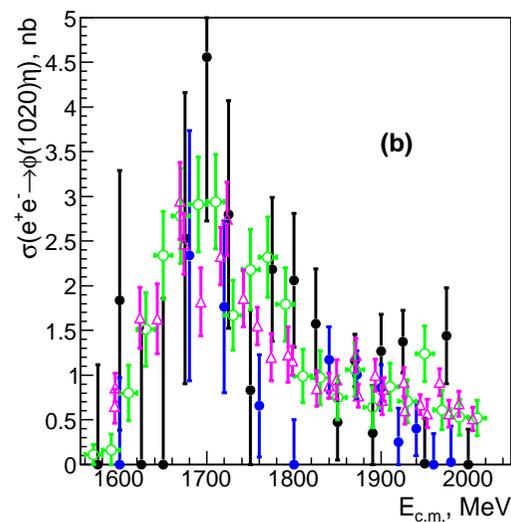
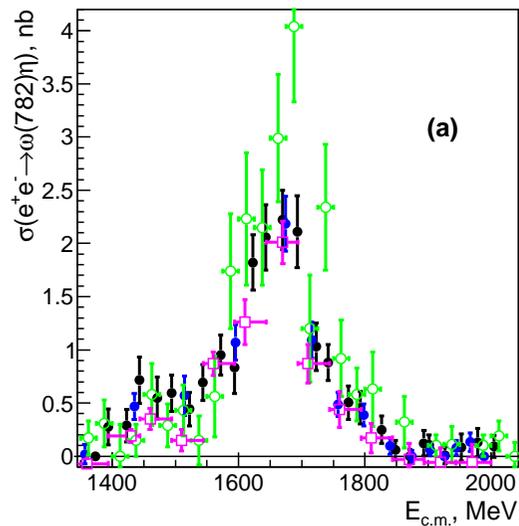
M.N. Achasov et al., Phys. Rev. D94 (2016) 092002

$$e^+e^- \rightarrow \eta\pi^+\pi^-\pi^0 \text{ at CMD-3 - I}$$

$$e^+e^- \rightarrow \omega\eta$$

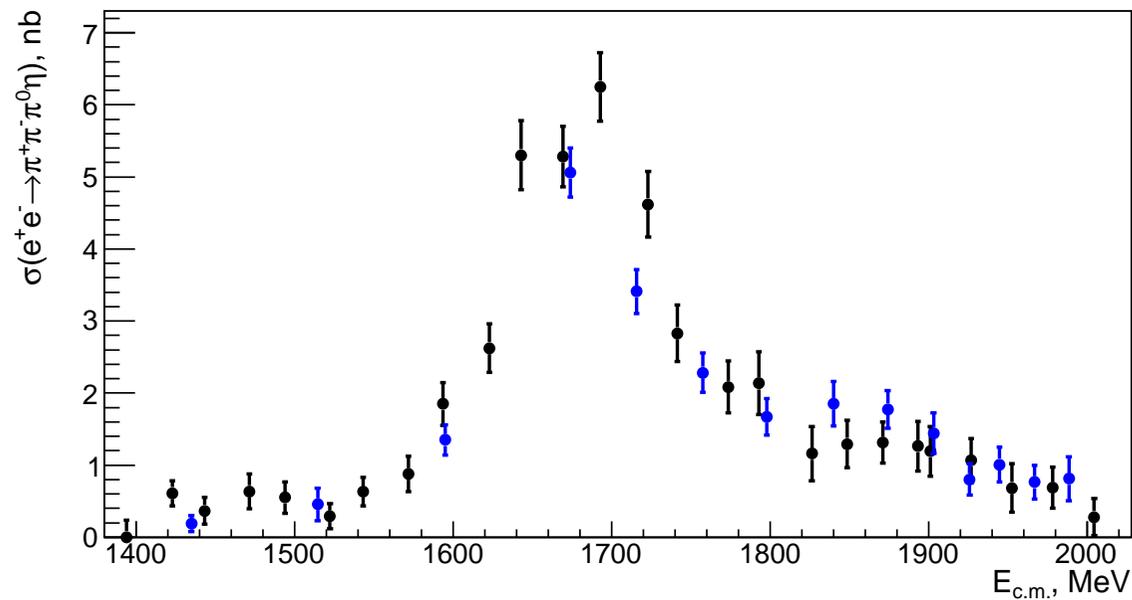
$$e^+e^- \rightarrow \phi\eta$$

$$e^+e^- \rightarrow \text{other states}$$

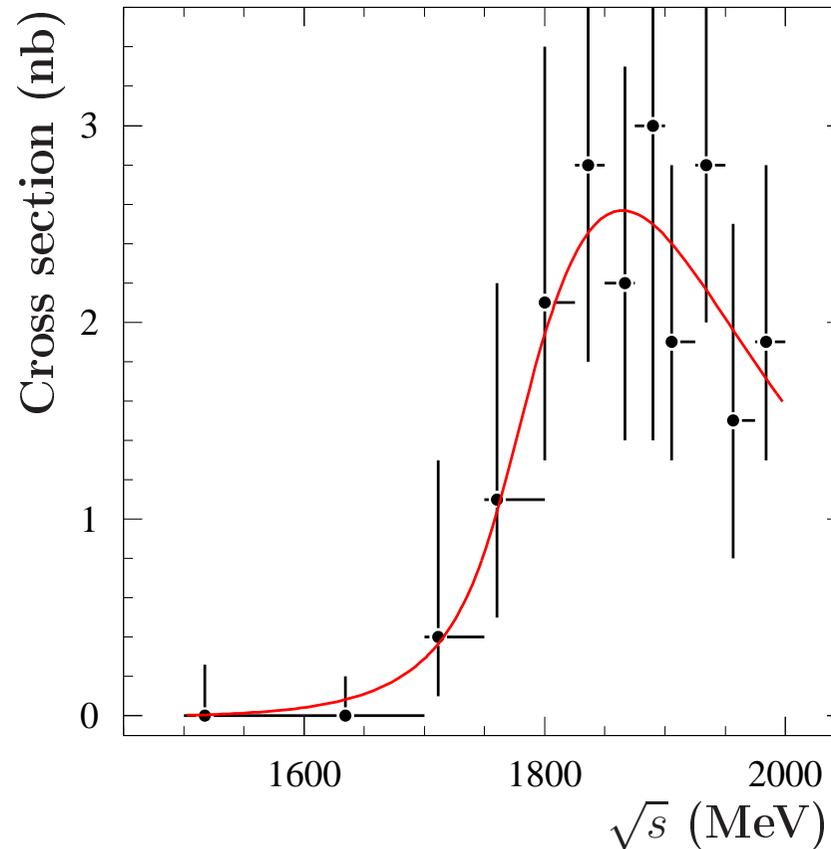


At low energies $\omega\eta$ and $\phi\eta$, at higher - $a_0(980)\rho$ dominate

$$e^+e^- \rightarrow \eta\pi^+\pi^-\pi^0 \text{ at CMD-3 - II}$$



About 2800 events selected. Using some average efficiency for 4 different channels the cross section is obtained for the first time

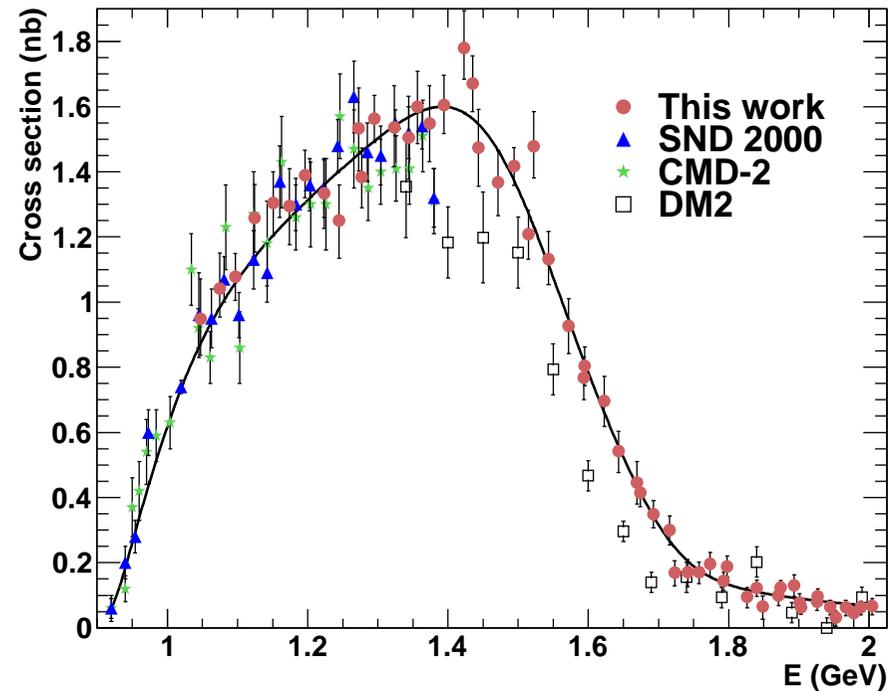
$$e^+e^- \rightarrow \omega\eta\pi^0 \text{ at SND}$$


First ever observation with 62 $\pi^0\pi^0\gamma\eta$ events

The $\omega a_0(980)$ mechanism dominates

M.N. Achasov et al., Phys. Rev. D94 (2016) 032010

$$e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma \text{ at SND - I}$$

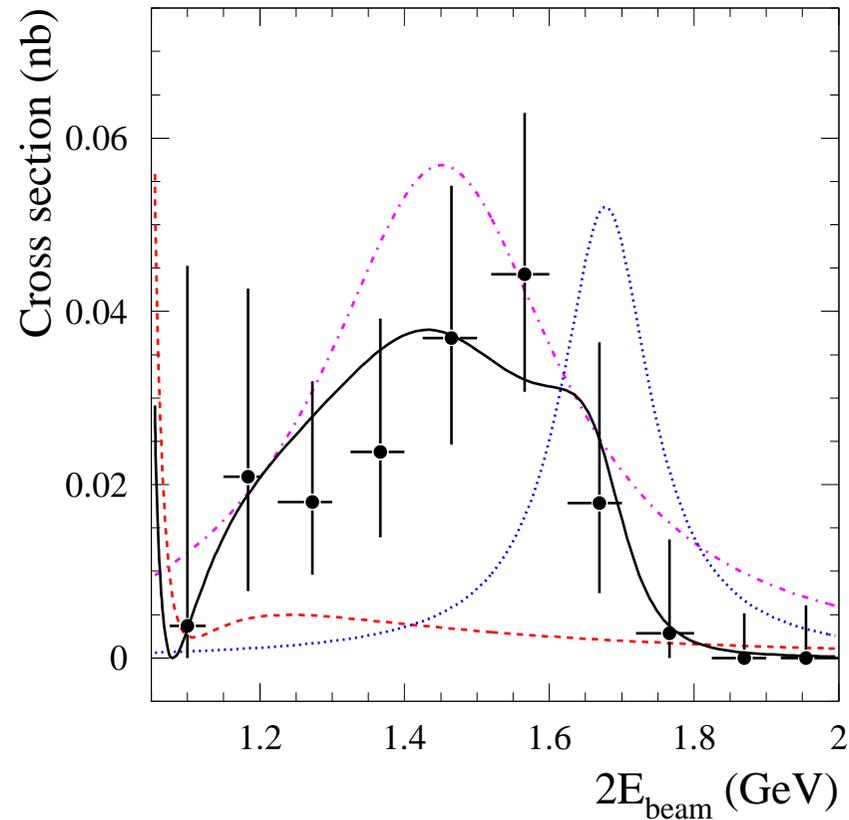


10.2k 5γ events, the systematic uncertainty varying from 2.7% to 5.2%

CVC test with $\mathcal{B}(\tau^- \rightarrow \omega\pi^- \nu_\tau)$: $(1.87 \pm 0.02 \pm 0.07)\%_{\text{CVC}}$ $(1.95 \pm 0.06)\%_{\text{WA16}}$

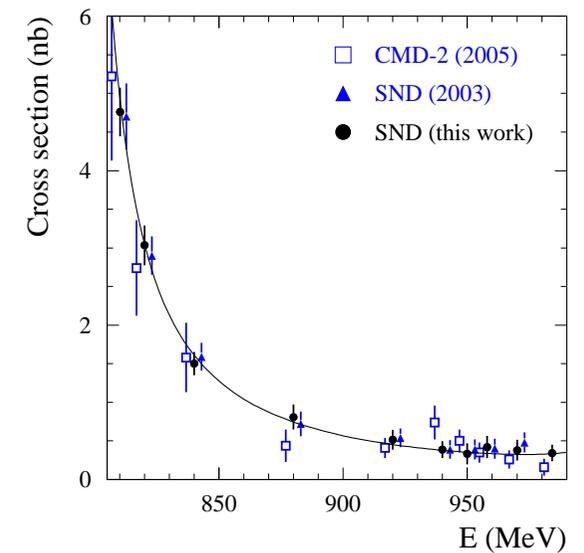
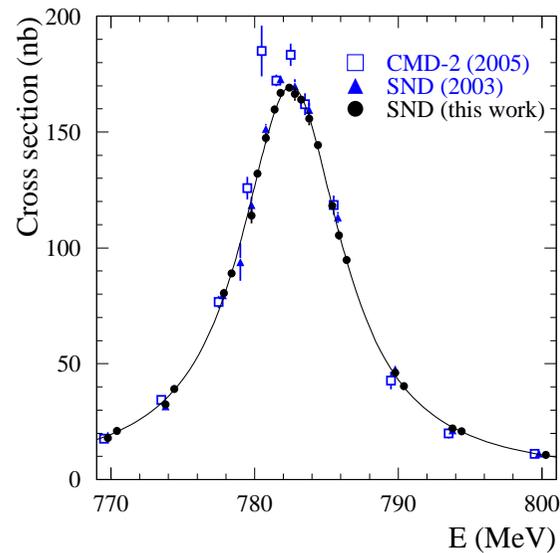
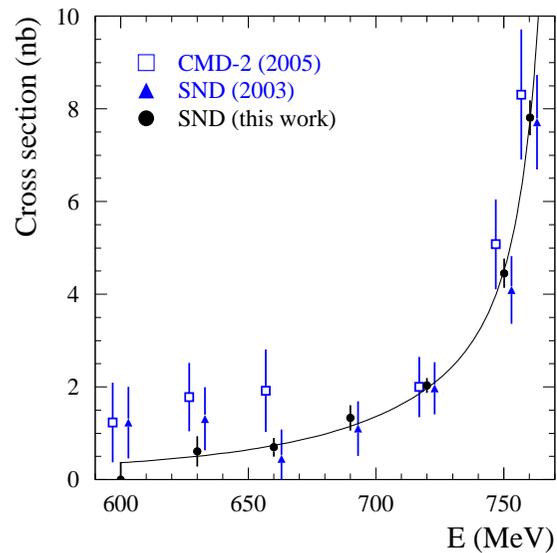
M.N. Achasov et al., Phys. Rev. D94 (2016) 112001

$$e^+e^- \rightarrow \eta\gamma \text{ at SND}$$



The first measurement of radiative decays above 1.4 GeV

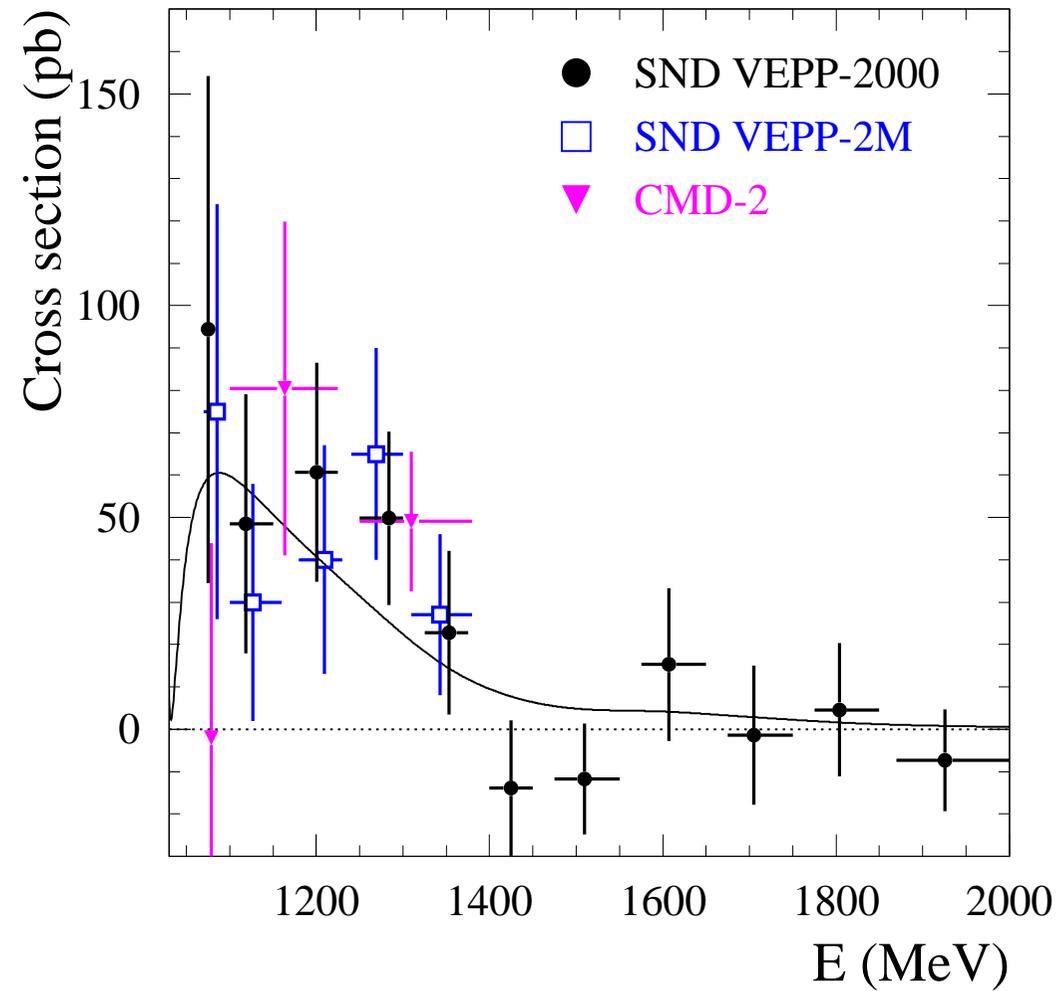
M.N. Achasov et al., Phys. Rev. D 90 (2014) 032002

$$e^+e^- \rightarrow \pi^0\gamma \text{ at SND at VEPP-2M}$$


The most precise measurement below 1.4 GeV

SND points seem to be below CMD-2

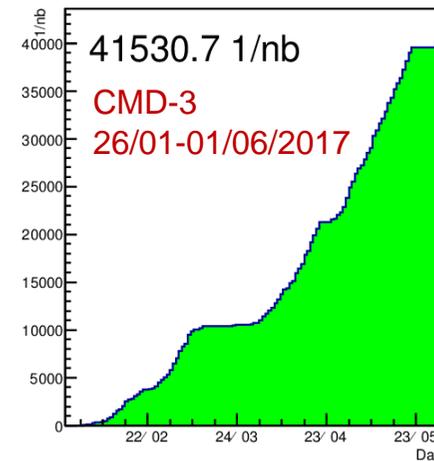
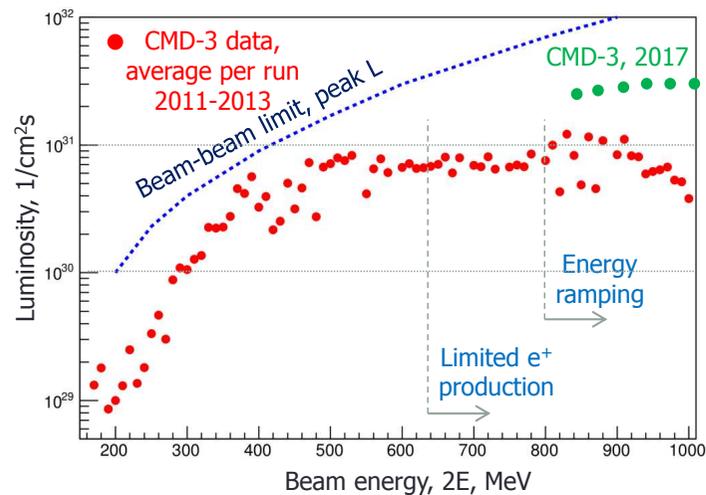
M.N. Achasov et al., Phys. Rev. D 93 (2016) 092001

$e^+e^- \rightarrow \pi^0\gamma$ at SND at VEPP-2000

VEPP-2000 Upgrade – I

1

2017 data taking



In 2011-2013, the luminosity was limited by a deficit of positrons (from $E > 650$ MeV) and limited energy of the booster (from $E > 825$ MeV).

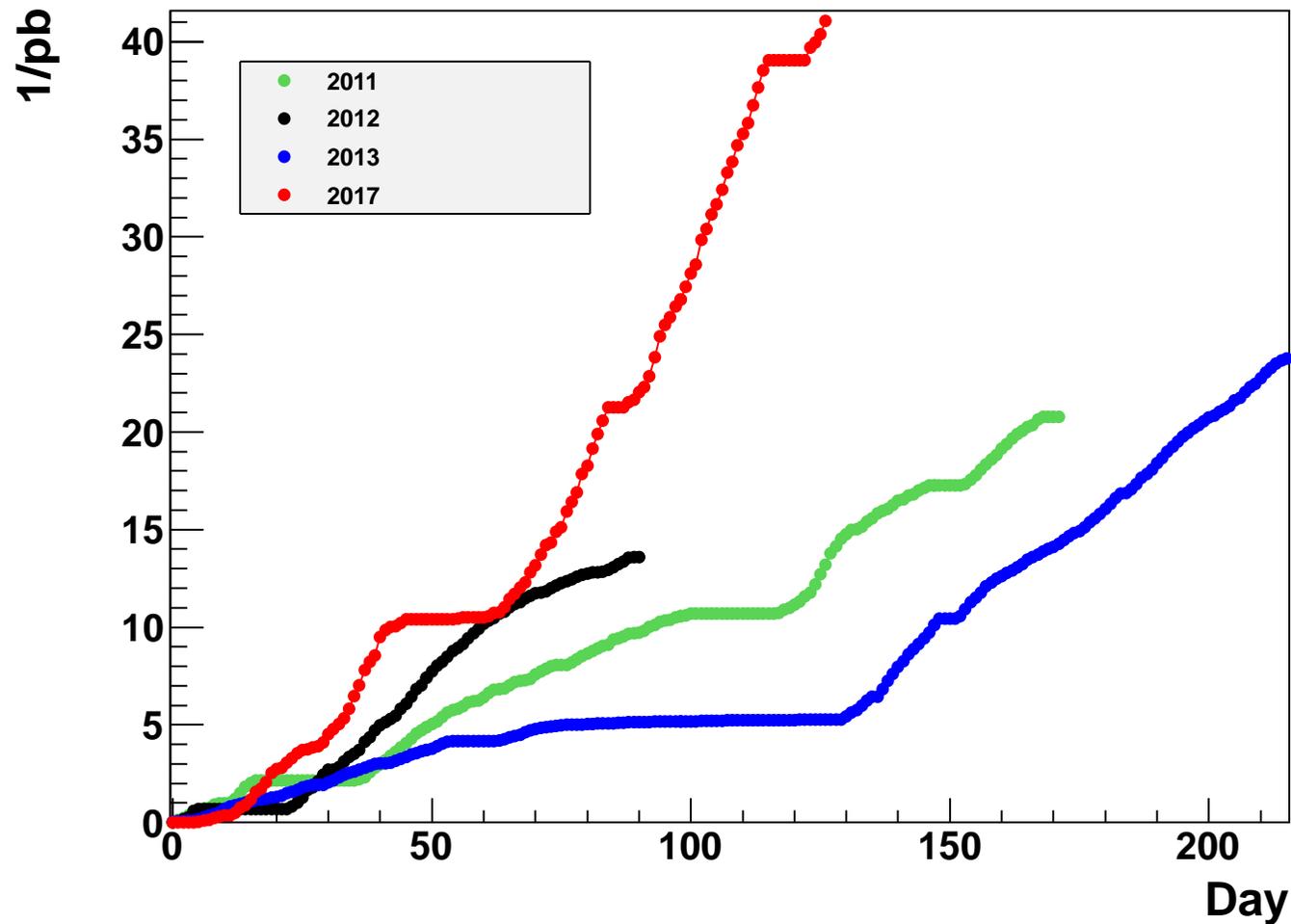
In 2017: big improvement in luminosity at high energy, still way to go

About 40 pb-1 collected

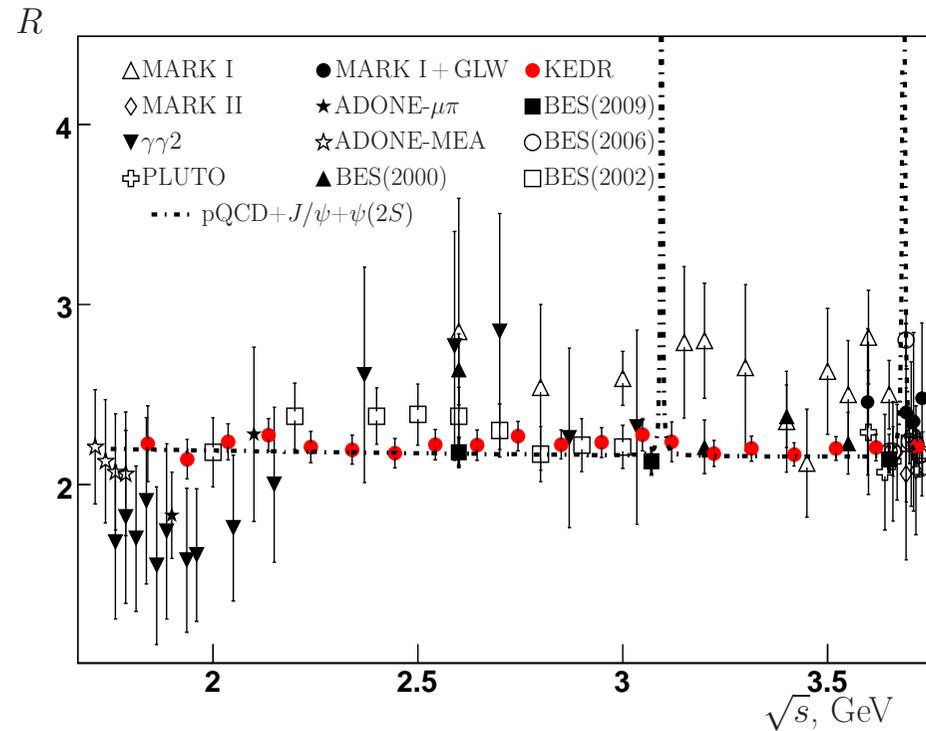
2.007 GeV ($e^+e^- \rightarrow D^{0*}$)	4 $1/\text{pb}$
$p\bar{p}$ and $n\bar{n}$ threshold	14 $1/\text{pb}$
Overall:	
1.65 – 2.007 GeV	41.5 $1/\text{pb}$

VEPP-2000 Upgrade – II

CMD-3 Integrated Luminosity



R Measurement between 1.84 and 3.72 GeV at KEDR – I



\sqrt{s} , GeV	N	δ_{tot} , %	δ_{syst} , %	Reference
1.84-3.05	13	3.9	2.4	Phys.Lett. B775 (2017) 174
3.12-3.72	7	3.3	2.1	Phys.Lett. B753 (2016) 533

R Measurement between 1.84 and 3.72 GeV at KEDR – II

\sqrt{s} , GeV	\bar{R}	R_{pQCD}
1.84-3.05	$2.209 \pm 0.020 \pm 0.046$	2.18 ± 0.02
3.12-3.72	$2.189 \pm 0.022 \pm 0.042$	2.16 ± 0.01

Using $\alpha_s(m_\tau) = 0.333 \pm 0.013$ from hadronic τ decays

- R at KEDR from 1.8 to 2 GeV can be compared to the sum of CMD-3 σ 's
- New precise measurement of $\Gamma_{ee}\mathcal{B}_{\text{had}}$ at J/ψ
- New precise measurement of $\Gamma_{ee}\mathcal{B}_{\mu\mu}$ at $\psi(2S)$

Future

- Two new measurements of a_μ are expected in 3-5 years improving the uncertainty a factor of 4 each
- What is expected for the HVP from $e^+e^- \rightarrow$ hadrons?
Progress in low energy e^+e^- annihilation expected from VEPP-2000 scans, from ISR with KLOE-2, BESIII, BaBar and BelleII
- New exciting approaches:
C.M. Carloni Calame et al., Phys. Lett. B 746 (2015) 325, from $\alpha(t)$ in the spacelike region of Bhabha
G. Abbiendi et al., Eur. Phys. J. C77 (2017) 139, from $\alpha(t)$ in the spacelike region of $\mu e \rightarrow \mu e$

Conclusions

- VEPP-2000 is running smoothly with CMD-3 and SND at $0.32 < \sqrt{s} < 2.00$ GeV, the achieved accuracy is comparable or better than in ISR measurements, sometimes disagreement with ISR and old results seen
- The goals are 0.35%(0.5%) for $\pi^+\pi^-$ and 3% for multibody modes
- Below 2 GeV progress (a factor of 2-3) expected in exclusive σ 's due to scans in Novosibirsk and ISR from KLOE-2, BaBar, BESIII and BelleII
- Various high-statistics experiments will substantially improve the accuracy of vacuum polarization calculations for $(g_\mu - 2)/2$
- Higher statistics ($\sim 1\text{fb}^{-1}$) \Rightarrow a detailed study of dynamics, thus a study of mesons with various quantum numbers
- Good prospects for a study of transition form factors and hLbL
- Meanwhile a $(3.5 - 4.0)\sigma$ deviation of a_μ^{SM} from a_μ^{exp} persists:
New Physics or various experimental and interpretation errors?