Measurement of hadronic cross sections of e^+e^- annihilation at the VEPP-2000 collider in Novosibirsk

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on behalf of CMD-3 and SND collaborations

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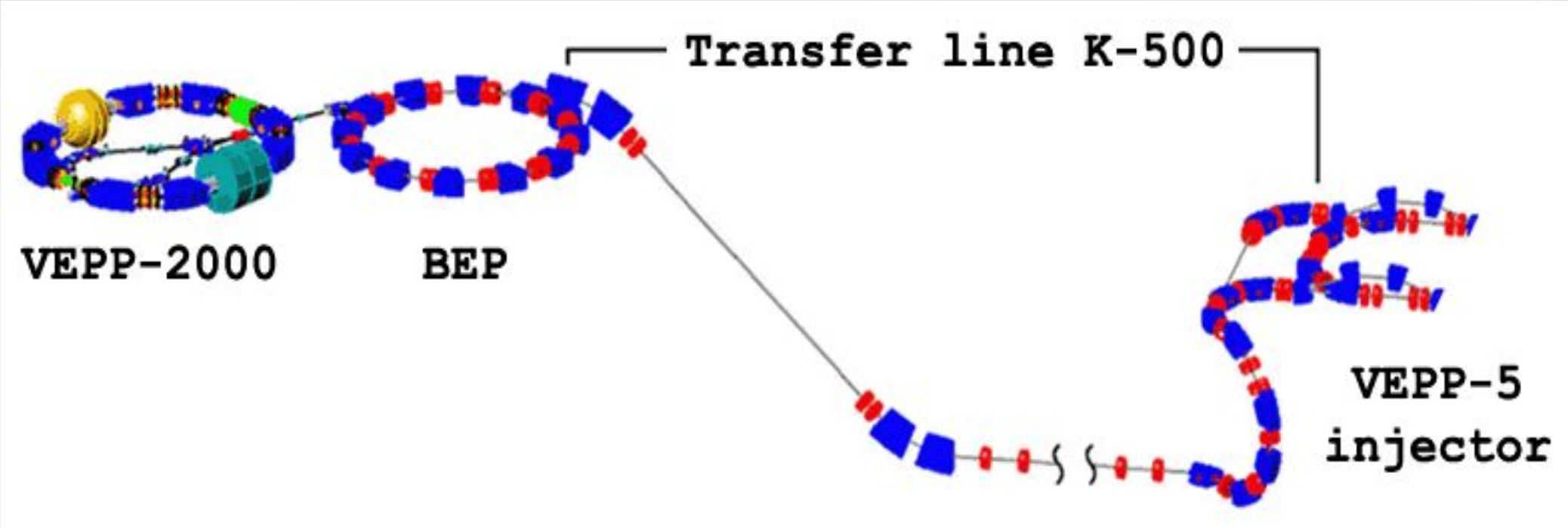
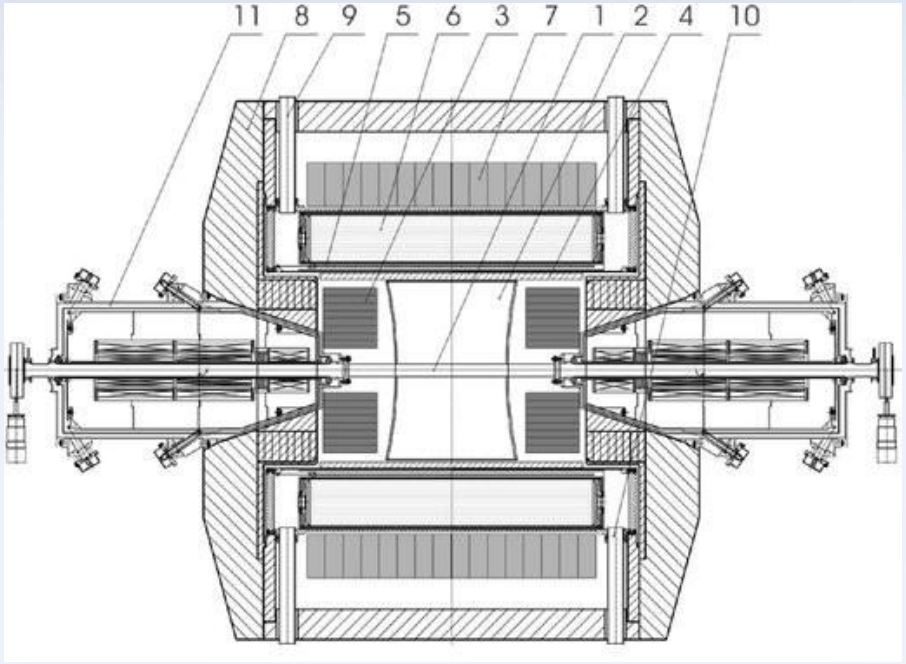
VEPP-2000 e^+e^- collider



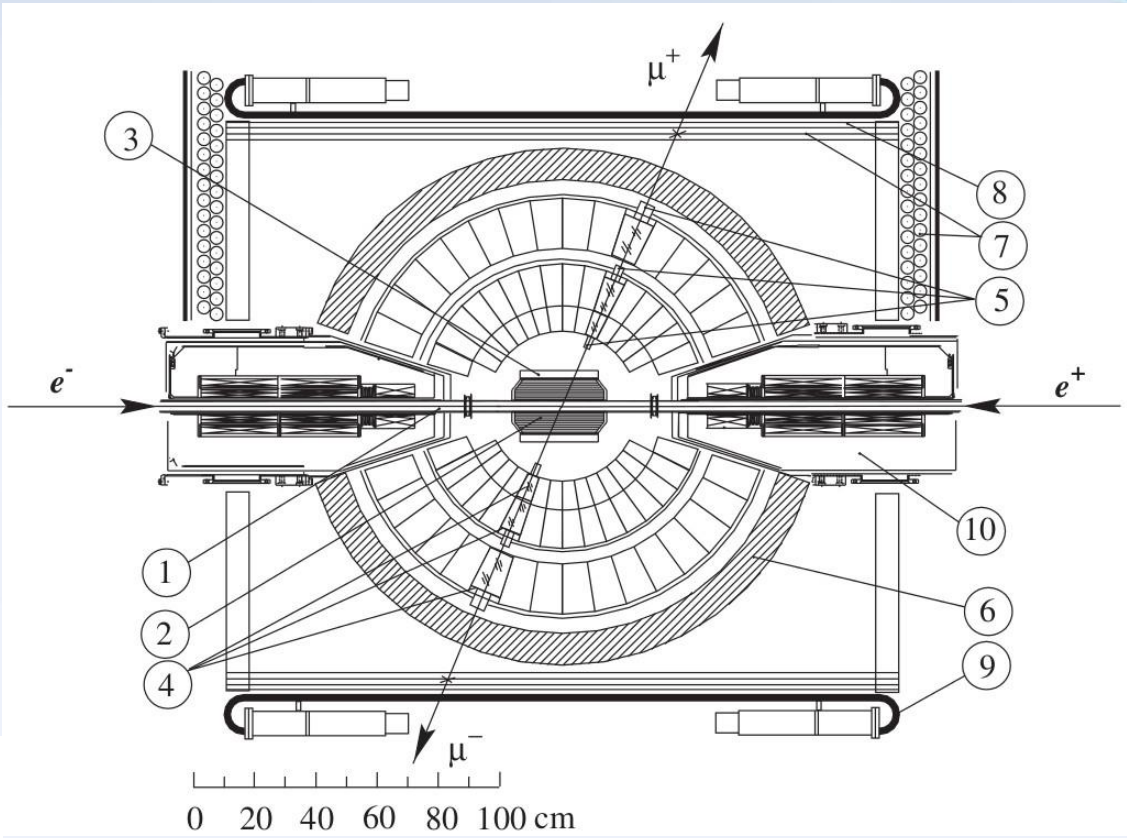
VEPP-2000 parameters:

- c.m. energy E=0.3-2.0 GeV
- circumference – 24.4 m
- round beam optics
- Luminosity at E=1.8 GeV
  1×10^{32} cm^{-2} sec^{-1} (project)
  4×10^{31} cm^{-2} sec^{-1} (achieved)
- Two detectors: SND and CMD-3

CMD-3 and SND detectors



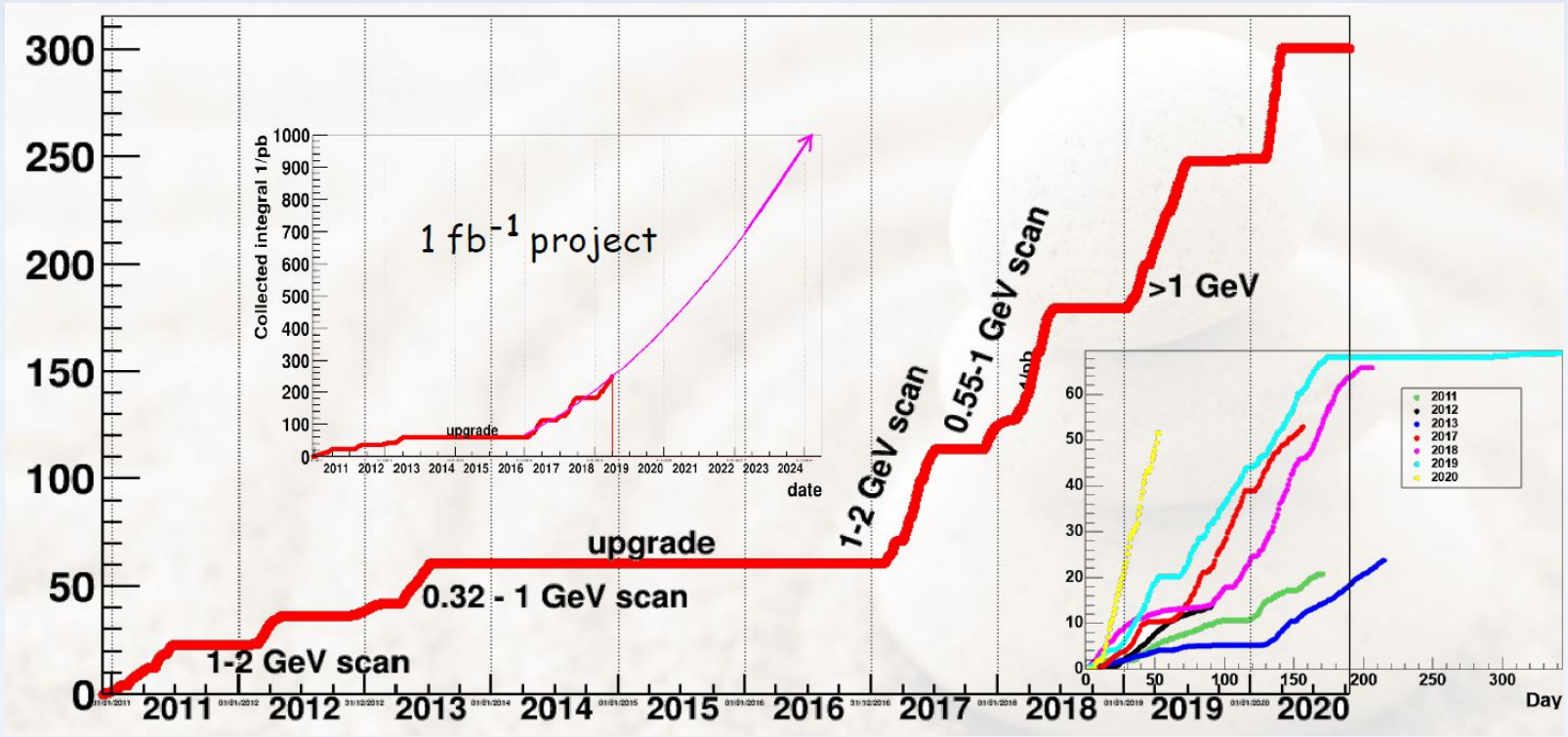
Cryogenic Magnetic Detector:
1 – beam pipe, 2 – drift chamber, 3 – BGO calorimeter , 4 – Z-chamber, 5 – focusing solenoids, 6 – LXe calorimeter, 7 – CsI calorimeter, 8 – yoke, 9 – LHe supply, 10 – vacuum pumpdown, 11 – magnetic lenses



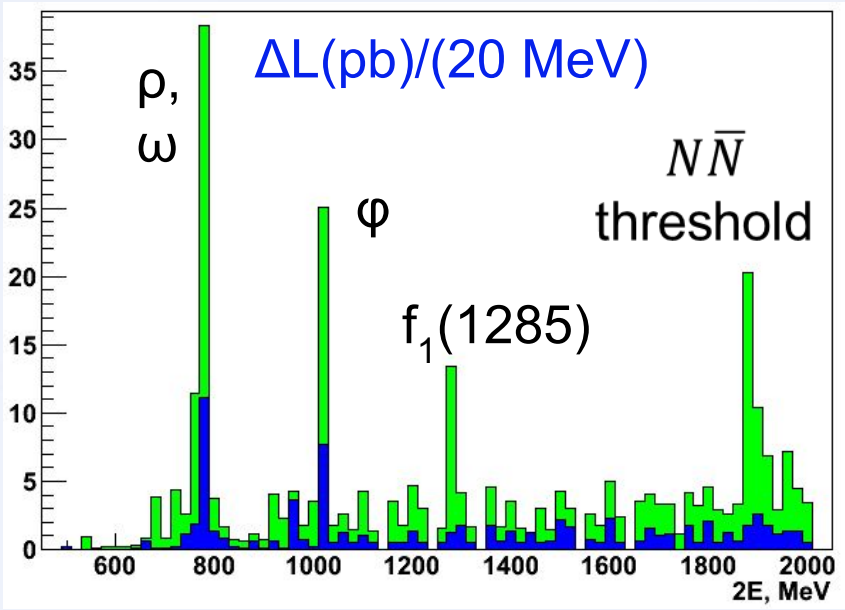
Spherical Neutral Detector:
1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counter, 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids

Experiments at VEPP-2000

Luminosity collection history

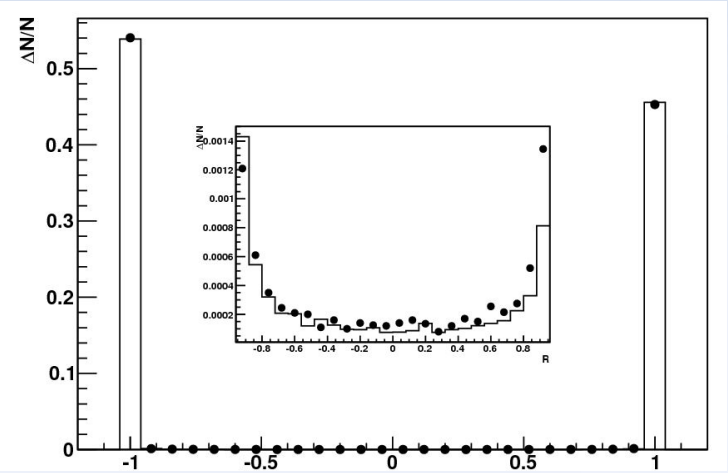


Collected luminosity



	Below φ	Near φ	Above φ	Total
IL, pb^{-1}	77	31	209	317
E_{cm}, GeV	0.30-0.97	0.98-1.05	1.05-2.00	0.30-2.00

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

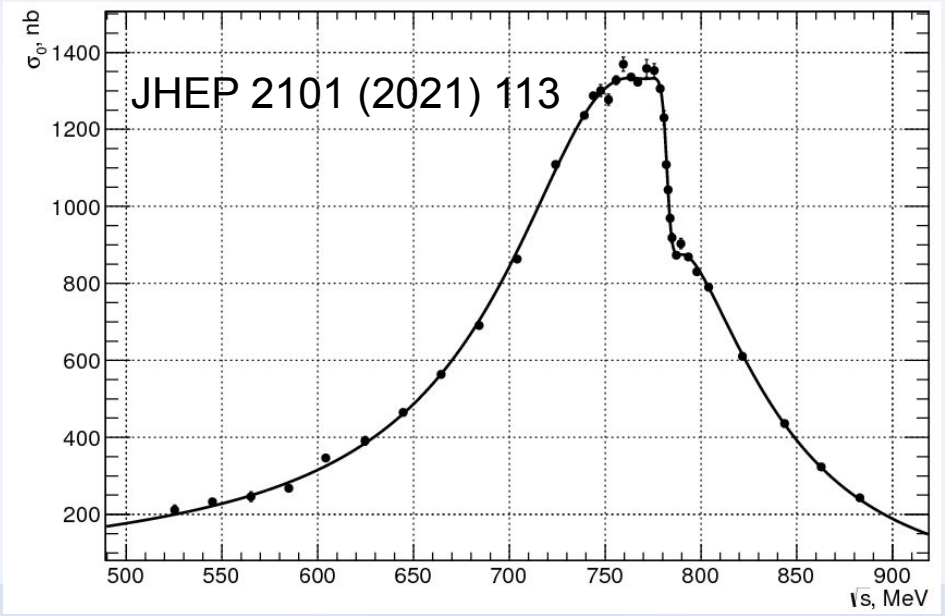


Systematic uncertainty of the cross section (%)

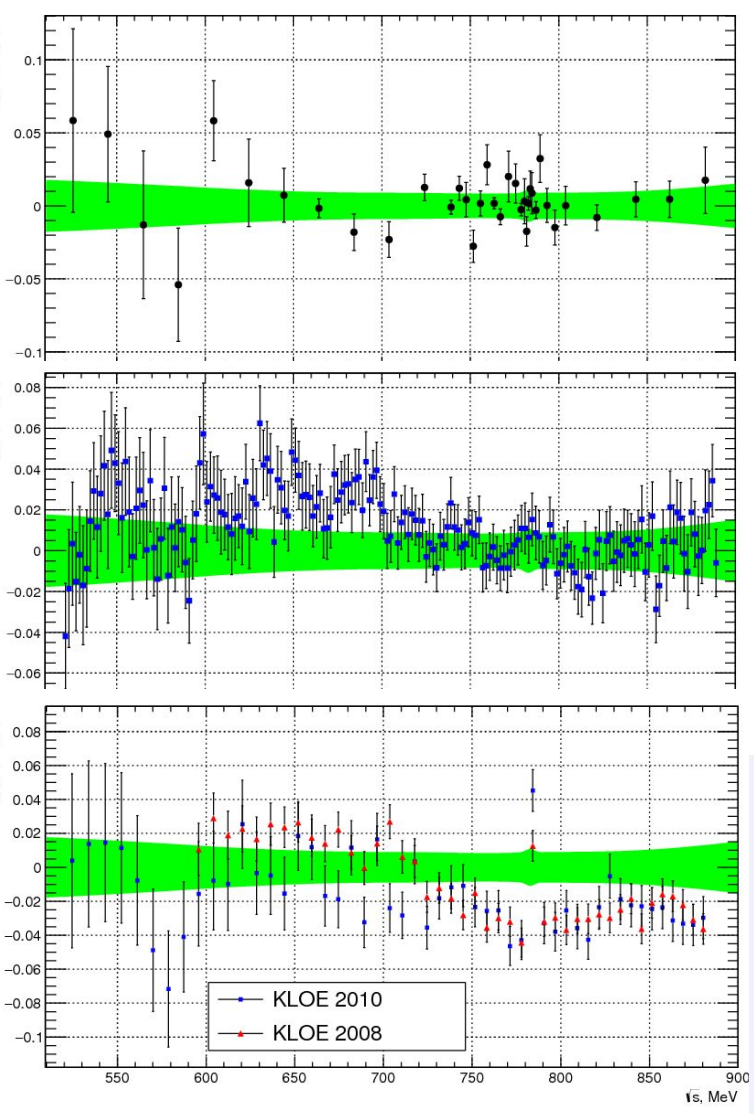
Source	< 0.6 GeV	0.6 - 0.9 GeV
Trigger	0.5	0.5
Selection criteria	0.6	0.6
e/π/μ separation	0.5	0.1
Nucl. interaction	0.2	0.2
Theory	0.2	0.2
Total	**0.9**	**0.8**

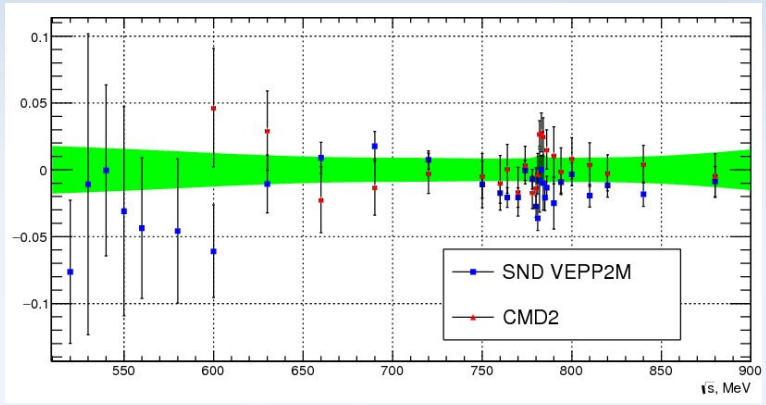
The analysis is based on 4.7 pb^{-1} data (1/10 full SND data set) recorded in 2013

	SND @VEPP-2000	SND @ VEPP-2M	PDG
M_ρ, MeV	775.3±0.5±0.6	775.6±0.4±0.5	775.3±0.3
Γ_ρ, MeV	145.6±0.6±0.8	146.1±0.8±1.5	147.8±0.9
$B_{\rho ee}\times 10^5$	4.89±0.02±0.04	4.88±0.02±0.06	4.72±0.05
$B_{\omega\pi\pi}$, %	1.77±0.08±0.02	1.66±0.08±0.05	1.53±0.06



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

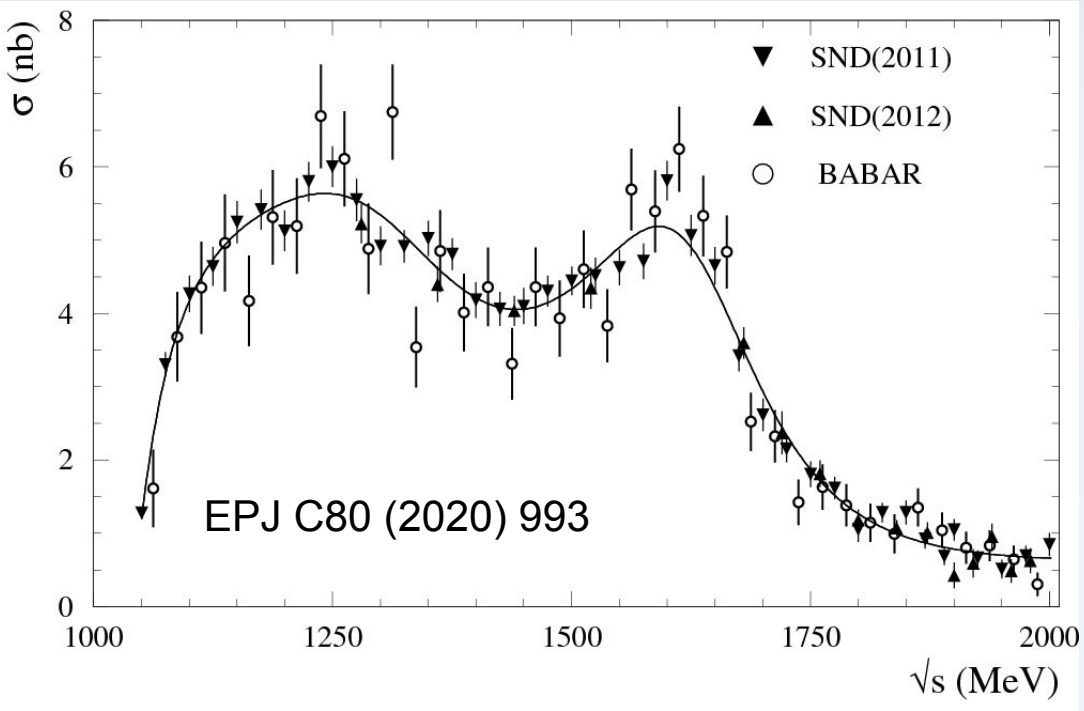




$$0.53 < \sqrt{s} < 0.88 \text{ GeV}$$

	$a_\mu \times 10^{10}$
SND @ VEPP-2000	409.79 ± 1.44 ± 3.87
SND @ VEPP-2M	406.47 ± 1.74 ± 5.28
BABAR	413.58 ± 2.04 ± 2.29
KLOE	403.39 ± 0.72 ± 2.50

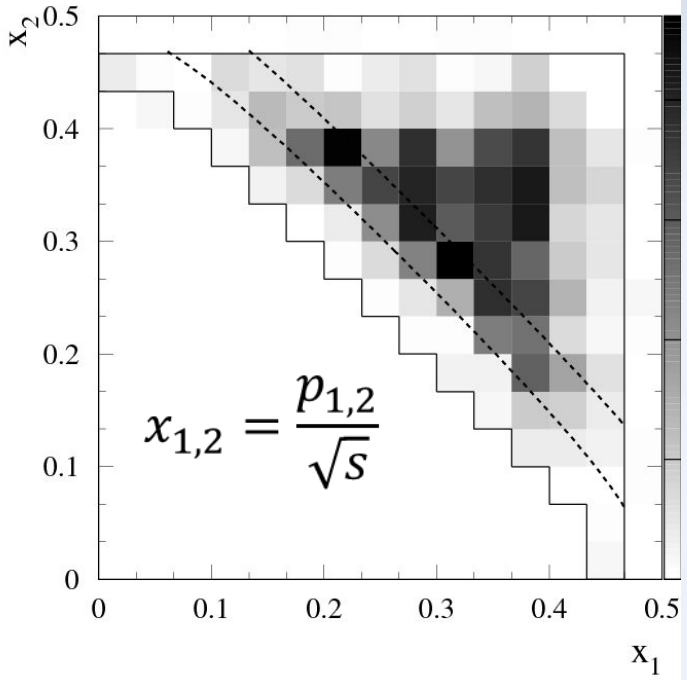
$e^+e^- \to \pi^+\pi^-\pi^0$ cross section

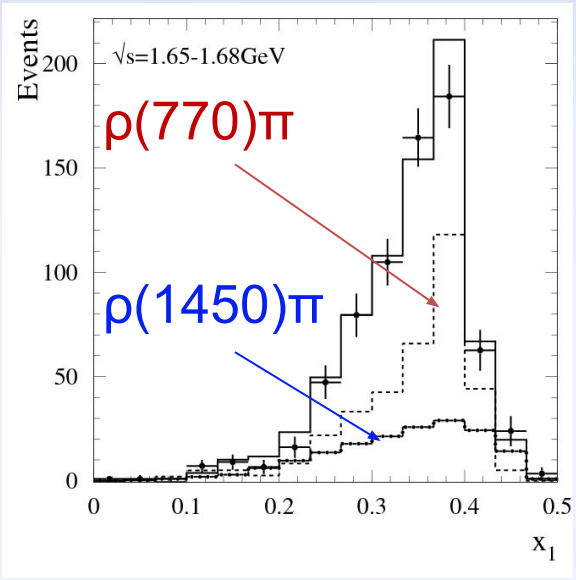


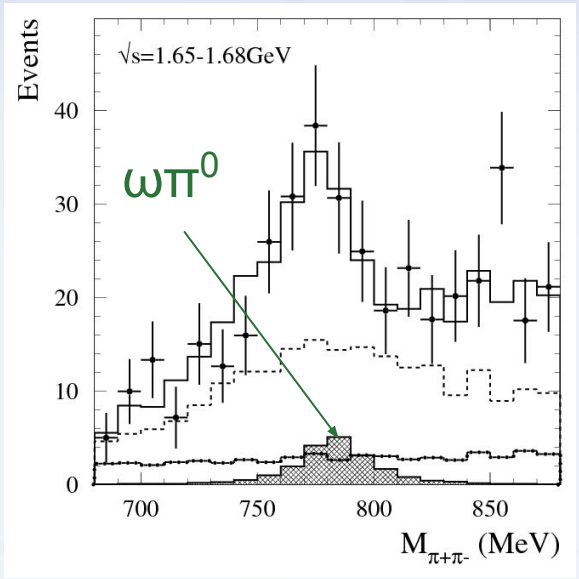
- Both SND measurements are consistent with each other and with the the BABAR measurement.
- Two peaks in the cross section corresponds to the ω (1420) and ω(1480) resonances.
- The systematic uncertainty on the cross section is 4.4%.

The previous SND measurement [J. Exp. Theor. Phys. 121, 27 (2015)] is based on 2011 data set. The 2012 data set has been added.

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

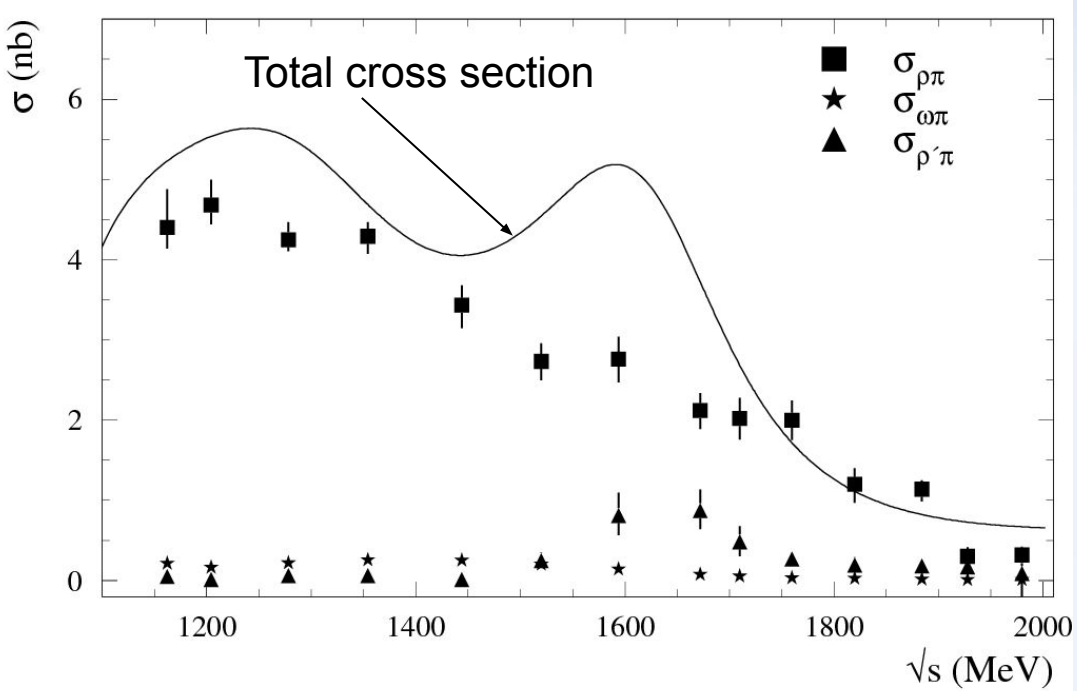






- We analyze the two-dimensional distribution of the charged-pion momenta and the $\pi^+\pi^-$ mass spectrum.
- These distributions are fitted with a model including the $\rho(770)\pi$, $\rho(1450)\pi$, and $\omega\pi^0$ intermediate states.
- A significant fraction of the $\rho(1450)\pi$ intermediate state is observed in the energy region 1.55-1.75 GeV.

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

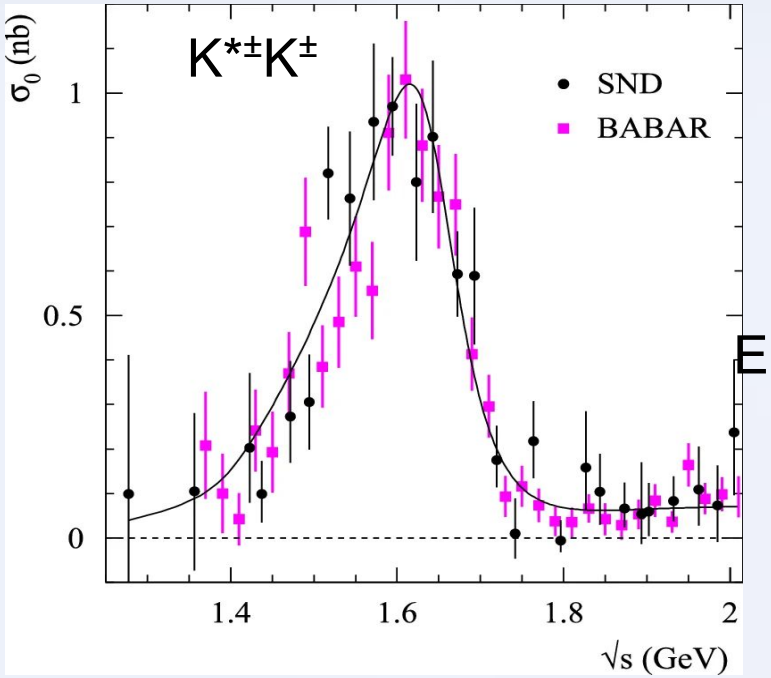


- The cross section for the intermediate state ρ(1450)π differs significantly from zero in the range 1.55 - 1.75 GeV, where the resonance ρ(1680) is located.
- In the ρ(770)π cross section the resonance structure near 1680 MeV is not seen.

We conclude that the ρ(1450)π intermediate state gives a significant contribution to the decay $\omega(1680) \to \pi^+\pi^-\pi^0$, and that the $\omega(1420) \to \pi^+\pi^-\pi^0$ decay is dominated by the ρ(770)π intermediate state.

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

The analysis is based on 26 pb^{-1} data recorded in the c.m.s. energy range 1.27- 2 GeV.
Cross sections of $e^+e^- \to K^{*\pm}K^\pm \to K^+K^-\pi^0$ and $e^+e^- \to \phi\pi^0 \to K^+K^-\pi^0$ processes are measured separately



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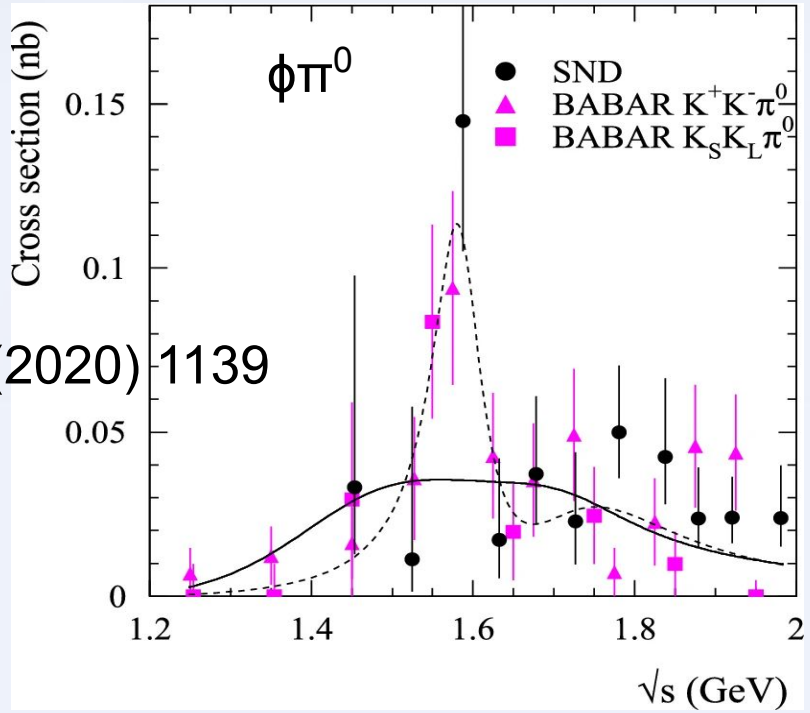
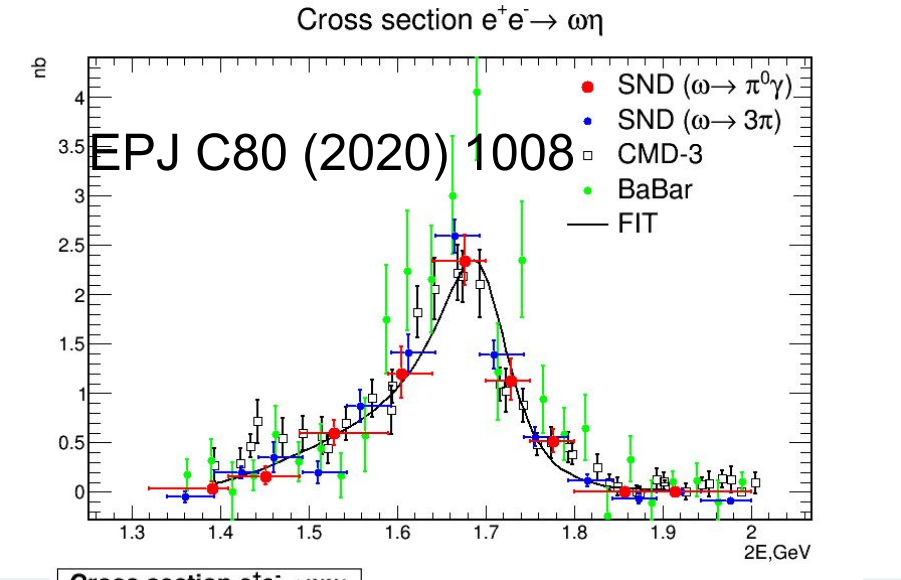
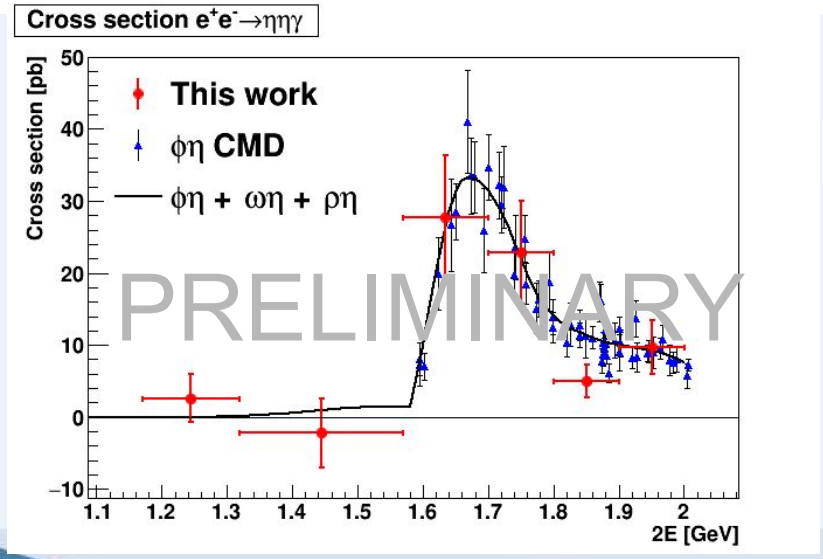


$\phi(1680)$ gives the main contribution to the $e^+e^- \to K^{*\pm}K^\pm \to K^+K^-\pi^0$ cross section

The $e^+e^- \to \phi\pi^0 \to K^+K^-\pi^0$ cross section can not be described by $\rho(1450)$ and $\rho(1700)$. It can be fitted by $\rho(1700)$ and an unknown resonance with m=1585±15 MeV and Γ=75±30 MeV

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



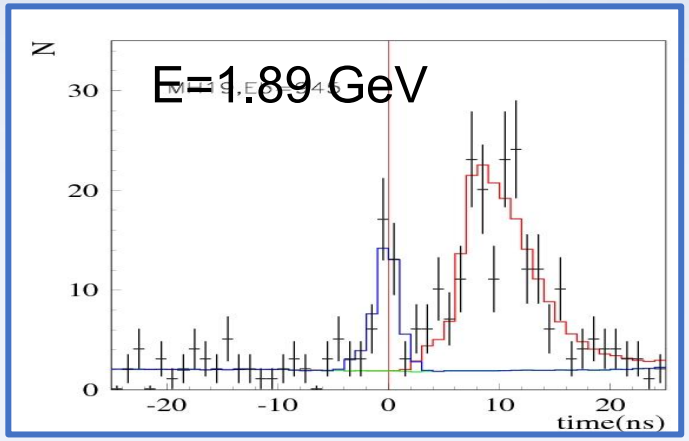


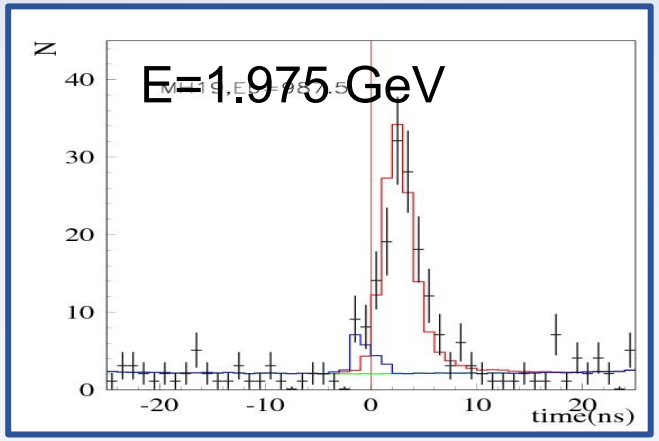
The process $e^+e^- \to \eta\pi^0\gamma$ above 1.05 GeV is studied for the first time. The analysis is based on 100 pb^{-1} data set recorded in 2010-2012 and 2017. Five-photon final state is used.
The measured $e^+e^- \to \omega\eta$ cross section is in good agreement with the SND and CMD-3 measurements in the $\omega \to 3\pi$ mode

The analysis of the process $e^+e^- \to \eta\eta\gamma$ is based on the data recorded in 2010-2012, 2017, 2019 and 2020. The similar five-photon final state is used.

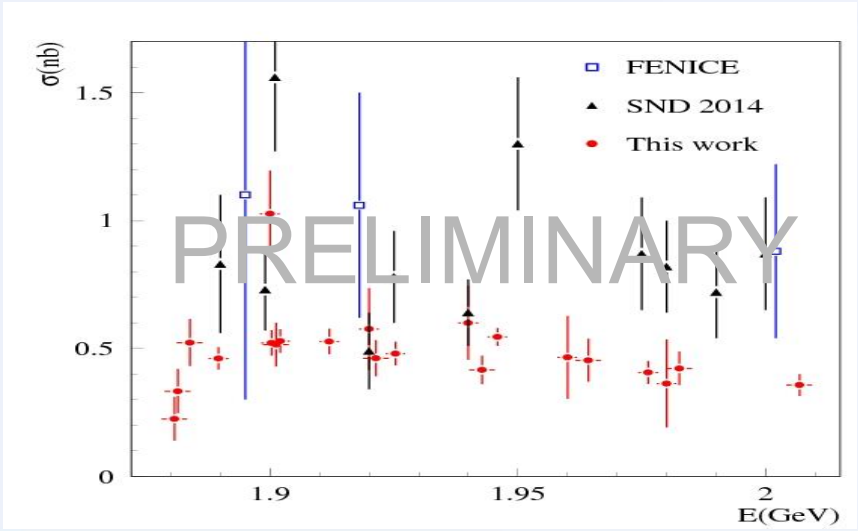
$e^+e^- \to n\bar{n}$

Time spectra in 2019 run



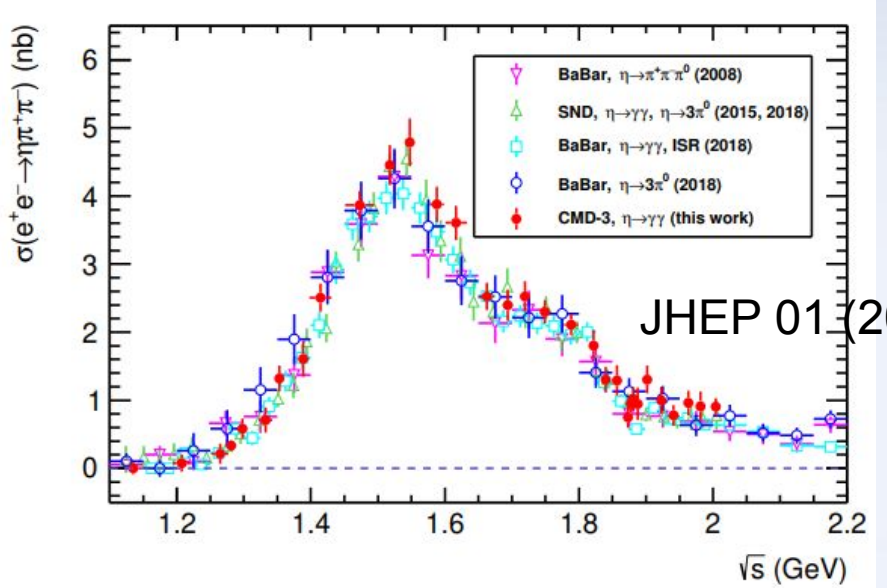


The analysis is based on 70 pb^{-1} data recorded in 2012, 2017, 2019 and 2020. Events are selected using event time measurement (calorimeter trigger time in 2012 and 2017, flashADC in 2019 and 2020).



The cross section is measured from nucleon-antinucleon threshold up to 2 GeV.
The cross section value is ≈0.5 nb.
The ratio of neutron form factors is $|G_E|/|G_M| = 1.16 \pm 0.25$

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



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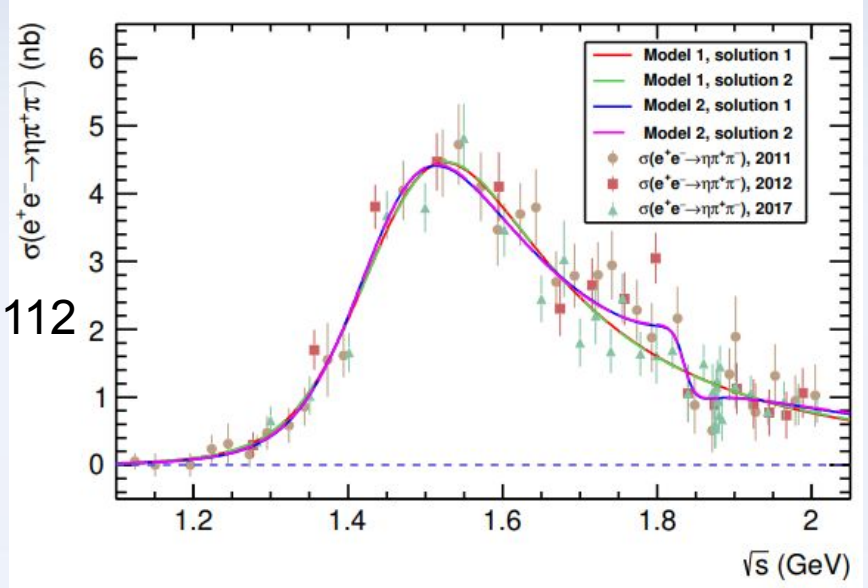
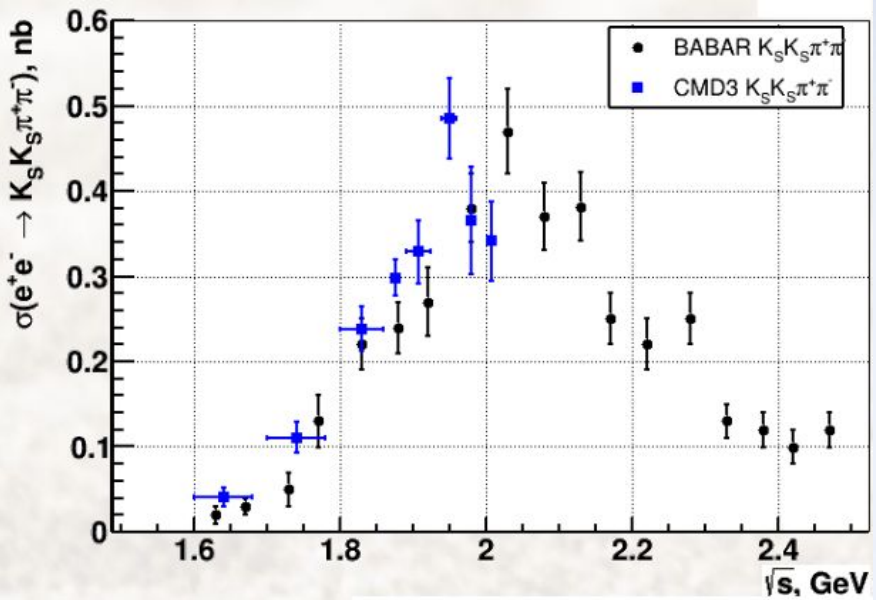


Model 1:
ρ(770),ρ(1450)→ρ(770)η

Model 2:
ρ(770),ρ(1450),ρ(1700)→ρ(770)η

- The analysis is based on 78.3 pb^{-1} of integrated luminosity collected in the 1.2-2.0 GeV c.m. energy range, the η decay mode is η→γγ
- The systematic uncertainty is about 6% (BaBar - 4.5-6.5%, SND - 6-8 %)
- ρ(770)η intermediate state is dominant
- ρ(1700) significance is 2.5σ
- $B(\tau^- \to \eta\pi^-\pi^0\nu_\tau)$ = 0.166 ± 0.006 ± 0.011%, differs by 1.8σ from BaBar value 0.163 ± 0.008 % and PDG value 0.139 ± 0.007 %

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



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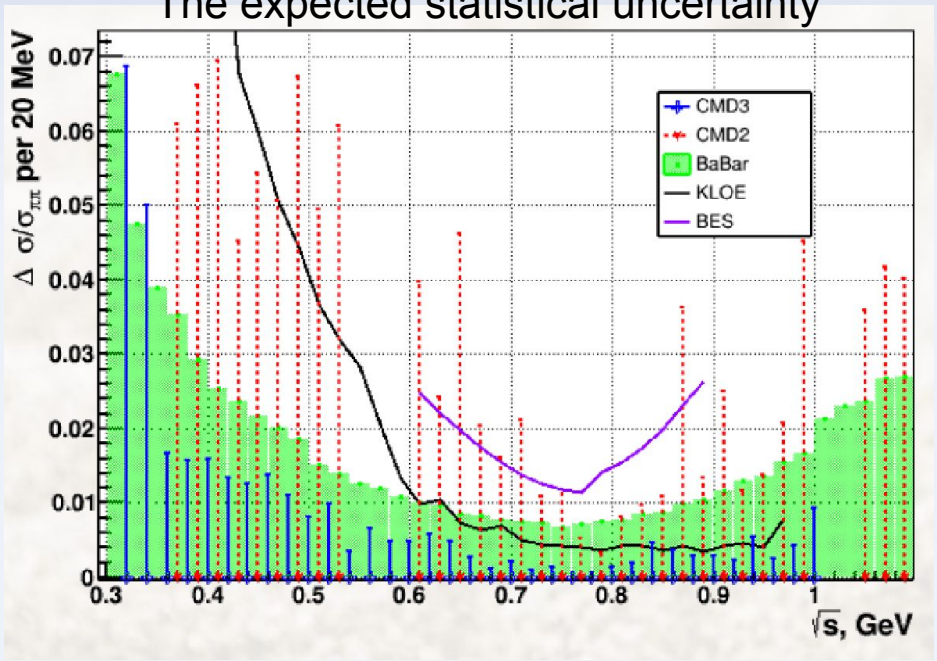
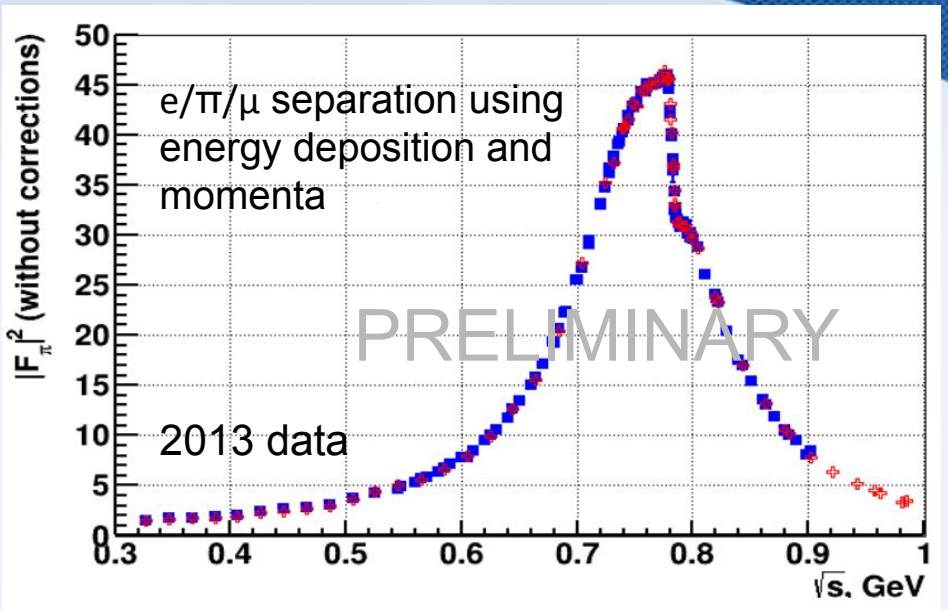
- The analysis is based on 56.7 pb^{-1} of integrated luminosity collected in the 1.6-2.0 GeV c.m. energy range
- The systematic uncertainty is about 10%

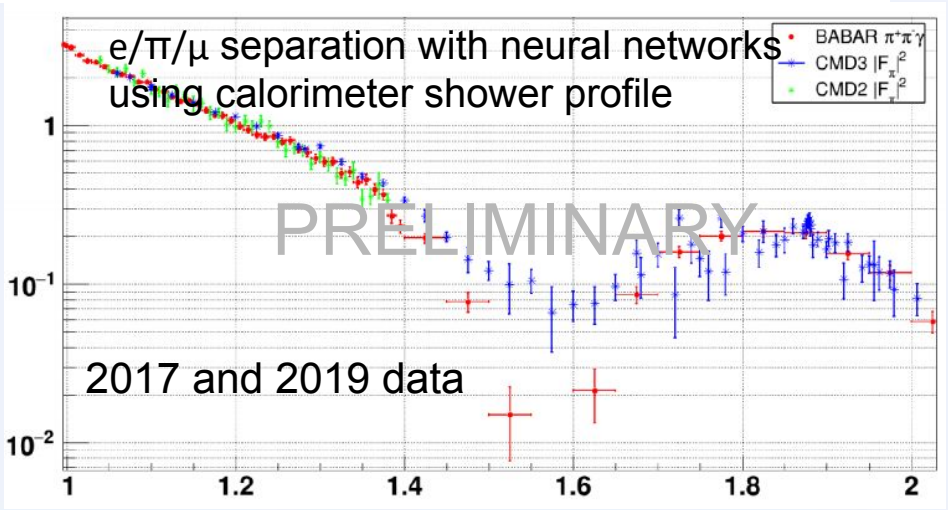
- CMD-3 and BaBar measurements are in reasonable agreement
- The cross section can be described by the $e^+e^- \to K^*(892)^+K^*(892)^-$ reaction, but ≈30-35% contribution of $K_1(1270)K_s$ is not excluded

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

The expected statistical uncertainty







The analysis is close to the final stage. The main sources of systematic errors are studied.
The aim is to obtain systematic uncertainty of ~ 0.5%

Summary

- The CMD-3 and SND detectors accumulated 320 pb^{-1} per detector of integrated luminosity in the energy range 0.3-2 GeV
- The $e^+e^-\to K^+K^-\pi^0$ process has been studied in the energy range 1.27-2.0 GeV, the cross sections of the $e^+e^-\to K^{*\pm}K^\pm\to K^+K^-\pi^0$ and $e^+e^-\to\phi\pi^0\to K^+K^-\pi^0$ processes are measured separately
- Rare radiative processes $e^+e^-\to\eta\pi^0\gamma$ and $e^+e^-\to\eta\eta\gamma$ have been studied
- The $e^+e^-\to\eta\pi^+\pi^-$ and $e^+e^-\to K_sK_s\pi^+\pi^-$ cross sections has been measured

- The accuracy of the $e^+e^-\to n\bar{n}$ cross section measurement has been significantly improved
- The dynamics of the $e^+e^-\to\pi^+\pi^-\pi^0$ process has been studied in the energy range 1.15-2.0 GeV
- The $e^+e^-\to\pi^+\pi^-$ cross section has been measured by SND with systematic uncertainty better than 1%. Even better uncertainty is expected in CMD-3 measurement