

14th edition of the International Workshop on e⁺e⁻ collisions from Phi to Psi

Pisa, Italy, June 8 - 11, 2026

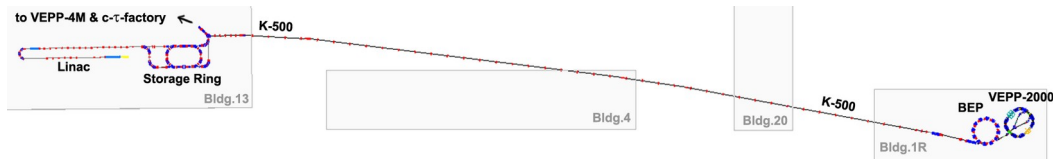
Recent results from the SND experiment at the VEPP-2000 collider

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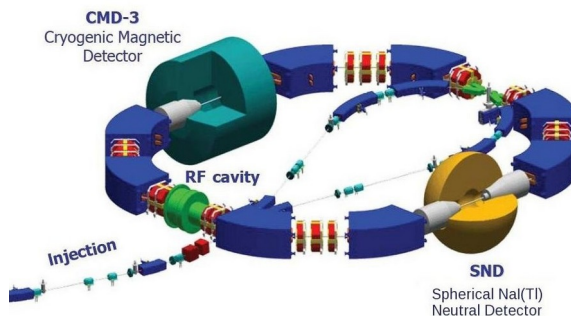
on behalf of the SND collaboration

VEPP-2000 e^+e^- collider

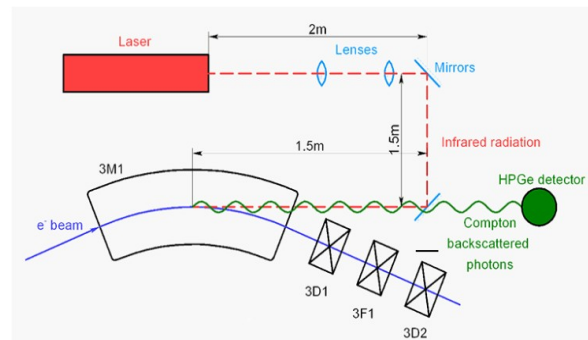


VEPP-2000 parameters:

- C.m. energy $E=0.3-2.0$ GeV
- Circumference – 24.4 m
- Number of bunches – 1×1
- Round beam optics
- Luminosity at $E=1.8$ GeV
 $1 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ (project)
 $9 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ (achieved)
- Two detectors: SND and CMD-3
- Energy measurements using Compton Backscattering



Beam energy measurements: CBS system

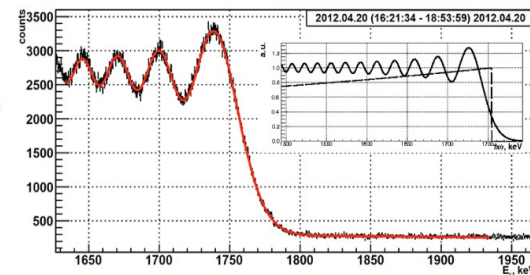


The systematic error of the beam energy determination is tested by comparison with a measurement using the resonance depolarization method:

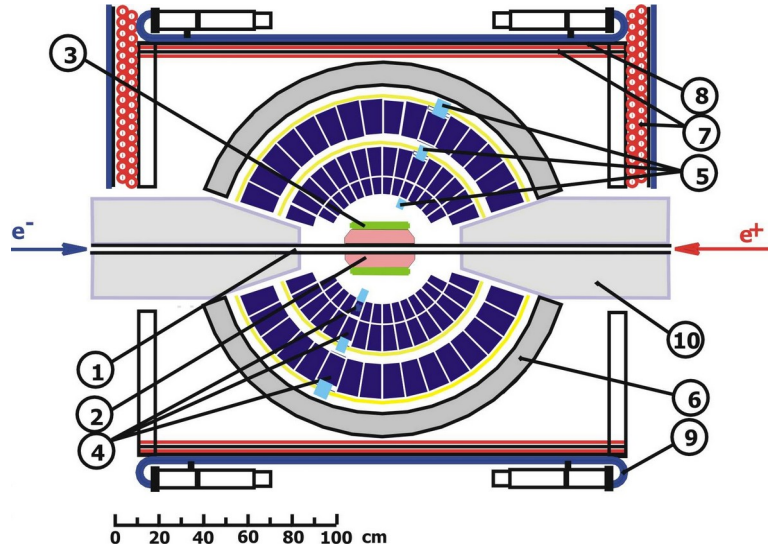
$$\frac{\Delta E}{E} \leq 6 \cdot 10^{-5}$$

$$E = 993.662 \pm 0.016 \text{ MeV}$$

The high accuracy of collider beam energy determination is crucial for a lot of physical studies. For example, in order to measure the cross section of the process $e^+e^- \rightarrow \pi^+\pi^-$ with accuracy better than 1%.



SND 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.

Calorimeter

Thickness	$13.5 X_0$
Acceptance	$0.95 \times 4\pi$
Energy resolution	$\frac{\sigma_E}{E} = \frac{0.042}{\sqrt[4]{E[\text{GeV}]}}$
Angular resolution	$\sigma_{\phi,\theta} = \frac{0.82^\circ}{\sqrt[4]{E[\text{GeV}]}} \oplus 0.63^\circ$

Tracking system

Acceptance (9 layers)	$0.94 \times 4\pi$
Angular resolution	$\sigma_\phi = 0.55^\circ, \sigma_\theta = 1.2^\circ$
Vertex resolution	$\sigma_R = 0.12\text{cm}, \sigma_Z = 0.45\text{cm}$

The main physics task of SND is study of all possible processes of e^+e^- annihilation into hadrons below 2 GeV.

- ✓ The total hadronic cross section, which is calculated as a sum of exclusive cross sections.
- ✓ Dynamics of multihadron exclusive processes.
- ✓ Properties of vector mesons of the ρ , ω , φ families.
- ✓ Nucleon-antinucleon production near threshold.

Data collection

2010-2013 – 64 pb⁻¹

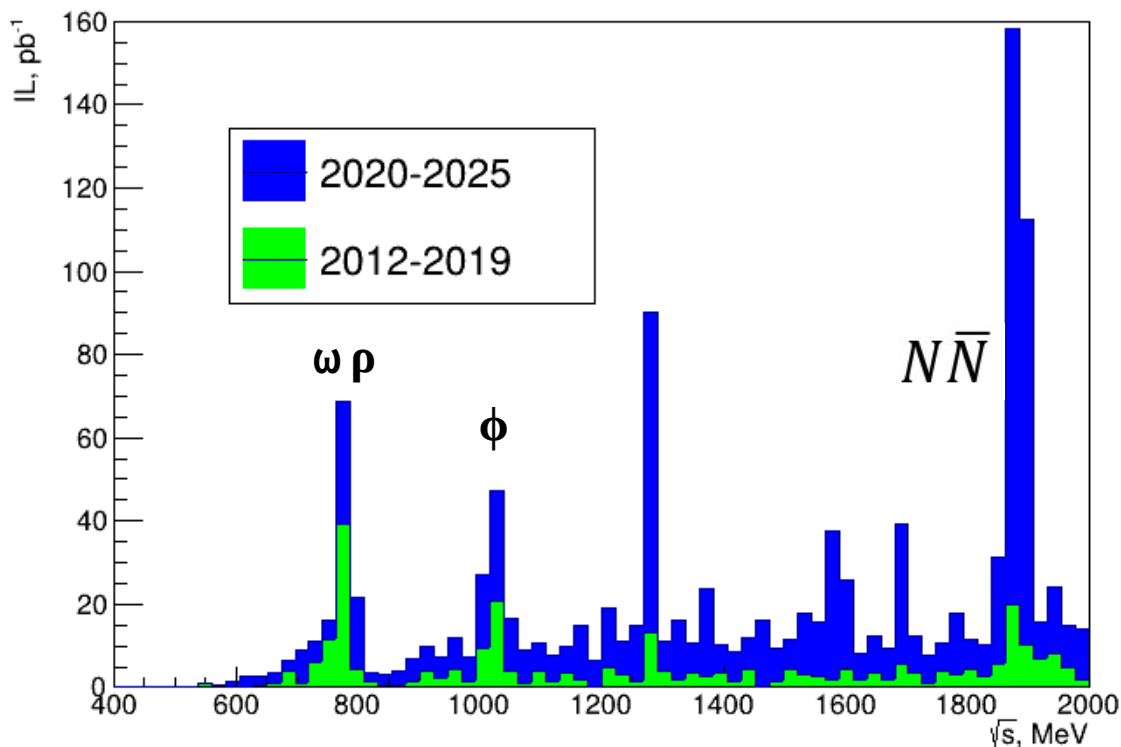
2013-2016 – stop

2017-2019 – 167 pb⁻¹

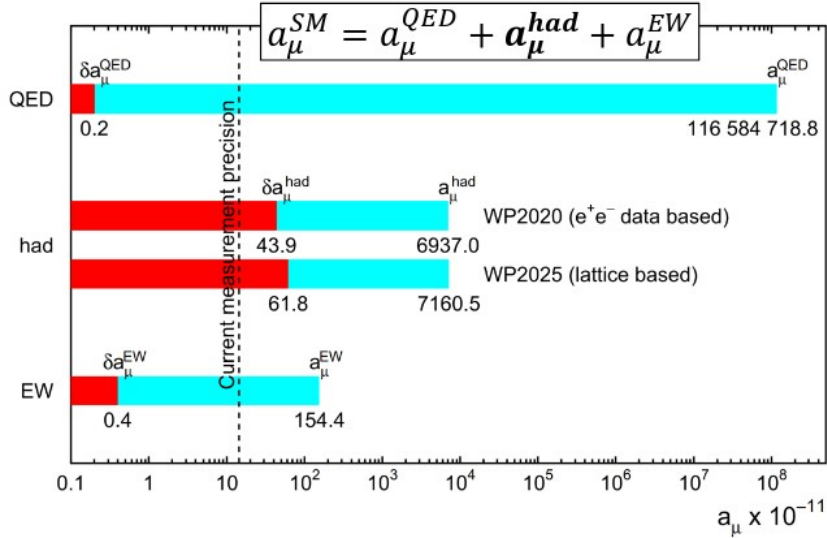
2020-2026 – 800 pb⁻¹

Total ~1 fb⁻¹

2024-2026 – Scan of the -
region (150-500 MeV) with
3-fold increase in statistics



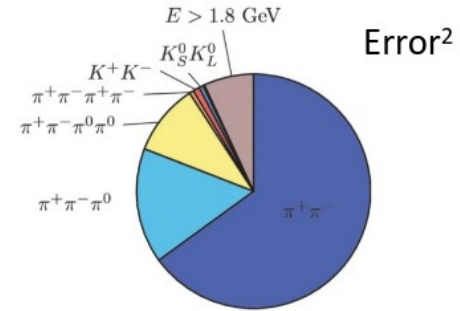
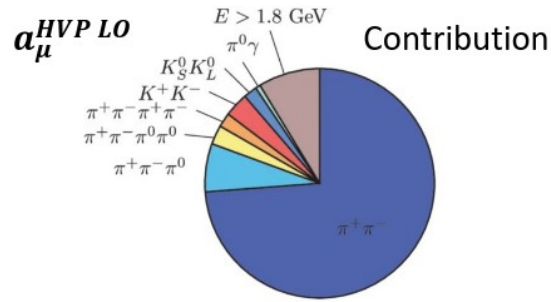
Motivation for the high precision measurements



- I. There is no tension: $a_\mu^{exp} - a_\mu^{SM} = 38(63) \cdot 10^{-11}$
- II. The theoretical error is ~ 5 times greater than the experimental error
- III. SM error is determined by the hadronic contribution a_μ^{had}
- IV. The main contribution to a_μ^{had} is $a_\mu^{HVP LO}$
- V. Finally, the main contribution to the magnitude and error of $a_\mu^{HVP LO}$ is given by $\pi^+\pi^-$ and $\pi^+\pi^-\pi^0$

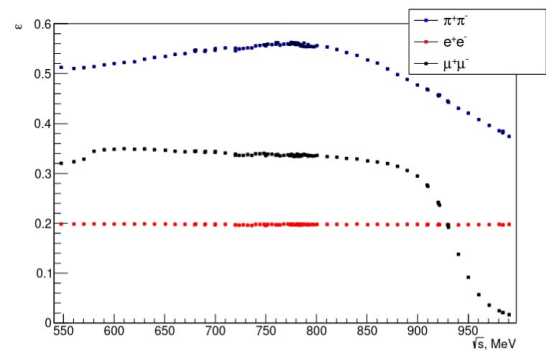
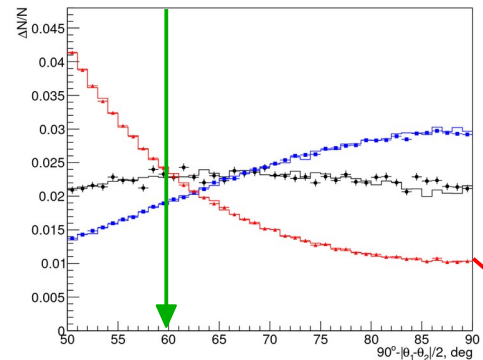
$$a_\mu^{had} = a_\mu^{HVP LO} + a_\mu^{HVP HO} + a_\mu^{HLbL}$$

had	HVP LO	HVP HO	HLbL
	$a_\mu [10^{-11}]$ (uncertainty)		
WP2020	6931 (40)	-85.9(0.7)	92 (18)
WP2025	7132 (61)	-87.2(1.3)	115.5 (9.9)



PR Vol. 1143, 2 (2025), PP 1-158

$$e^+e^- \rightarrow \pi^+\pi^-$$

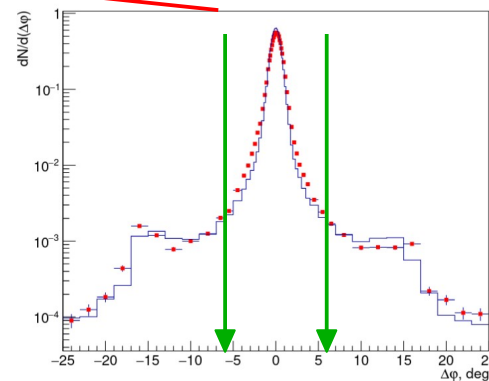
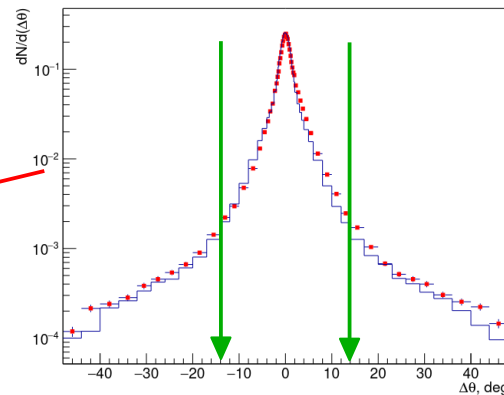


Selection criteria:

- Number of charge particles ≥ 2
- Origin from e^+e^- collision:
 - $|r_i| < 1$ cm
 - $|z_i| < 8$ cm
- Collinearity:
 - $|\Delta\theta| < 14^\circ$
 - $|\Delta\phi| < 6^\circ$
- Polar angle: $60^\circ < \theta_0 < 120^\circ$
- Particle energy deposition: $E_{1,2} > 40$ MeV
- Cosmic veto
- Identification in calorimeter

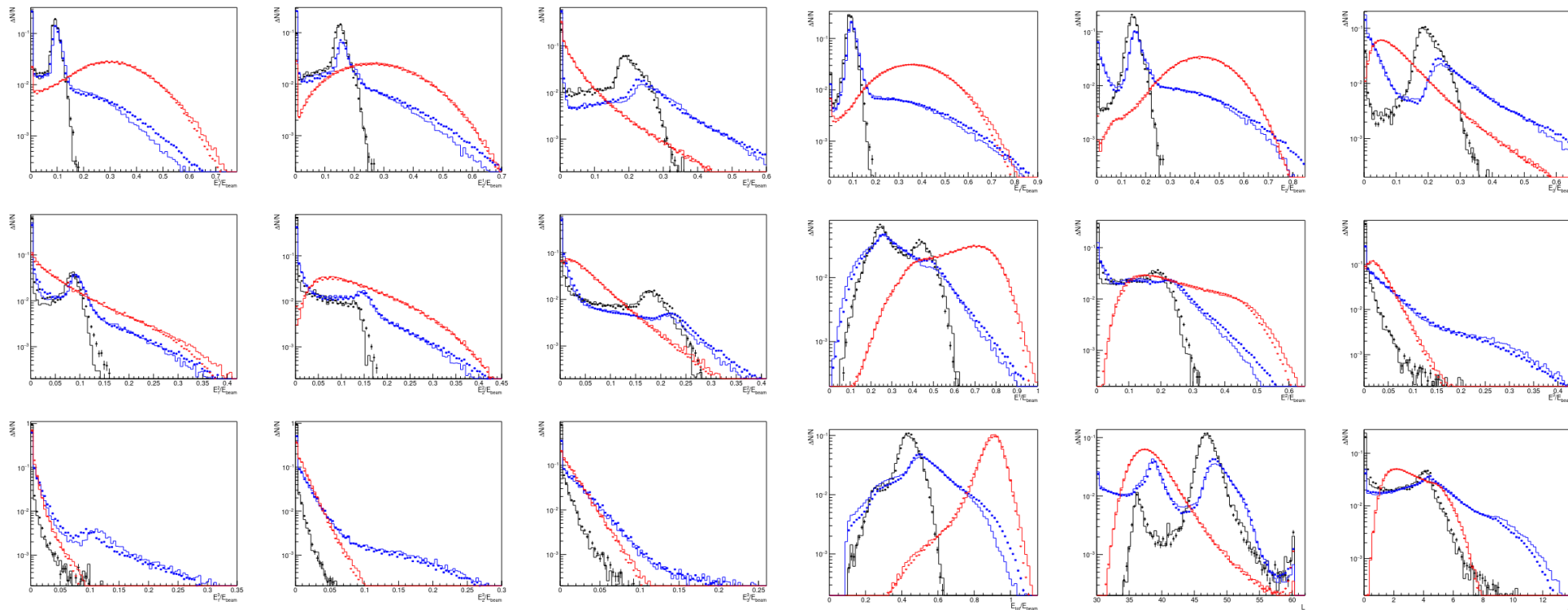
Background processes:

1. $e^+e^- \rightarrow \mu^+\mu^-$
2. $e^+e^- \rightarrow e^+e^-$
3. Cosmics
4. $e^+e^- \rightarrow e^+e^-e^+e^-$ (0.2-3.5%)
5. $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ (0.01-0.6%)



$$e^+e^- \rightarrow \pi^+\pi^-$$

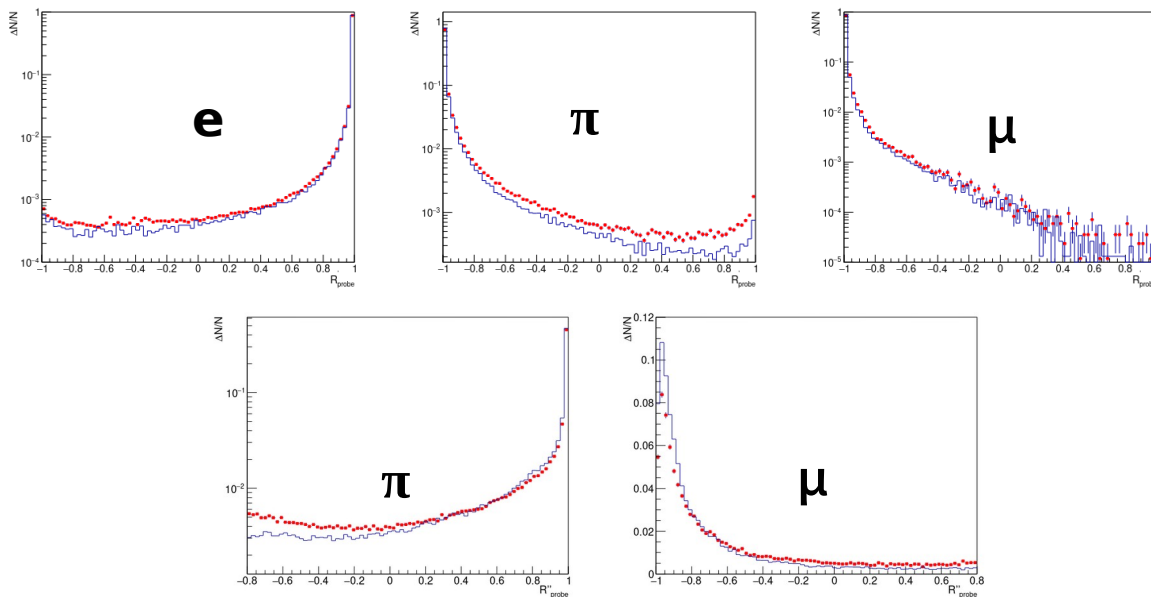
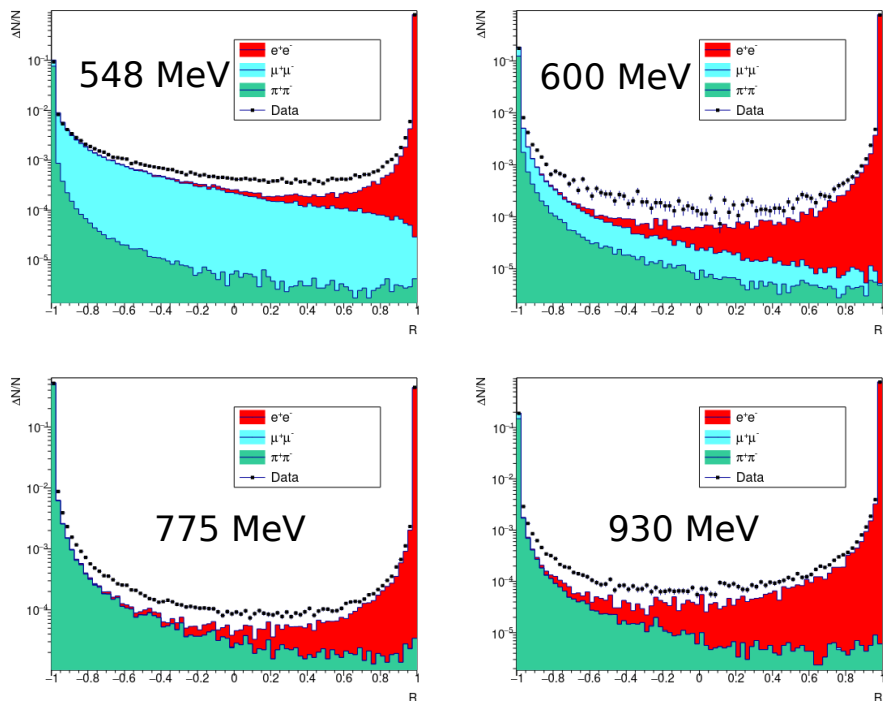
Different energy deposition profiles for **pions**, **electrons** and **muons**



$$e^+e^- \rightarrow \pi^+\pi^-$$

Machine learning method (**Gradient Boosted Decision Trees**) demonstrated the best separation performance, with total of **36** input parameters

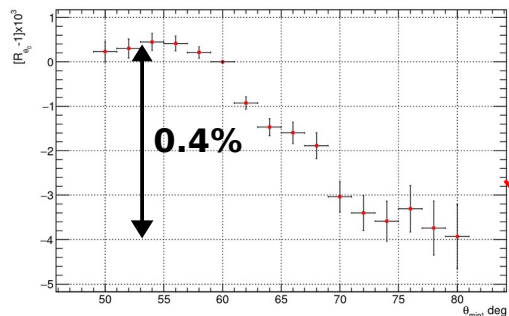
Similar **e/ π** and **μ / π** separation algorithms are also constructed, but for individual particles, with **18** input parameters



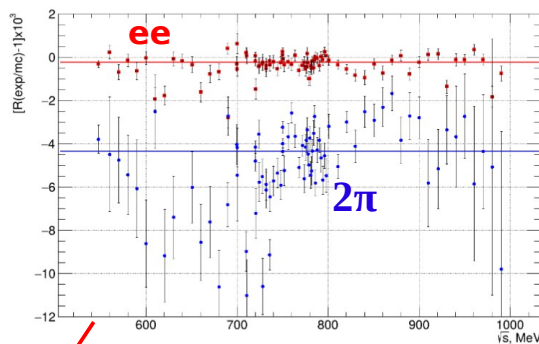
Used to create pure samples of events and pseudo-events

$e^+e^- \rightarrow \pi^+\pi^-$

Variation of polar angle cut



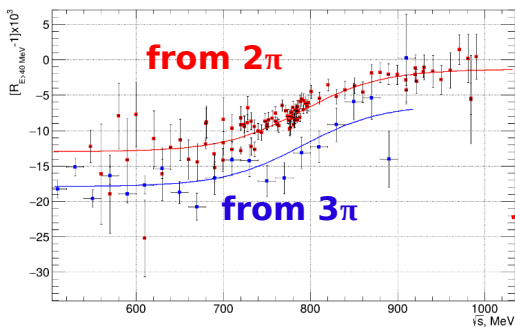
Uncertainty of the correction for e/ π selection efficiency



From muon background subtraction

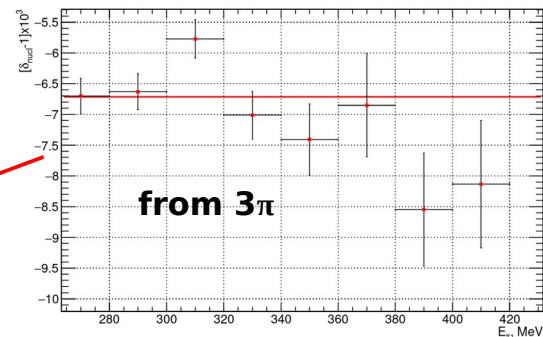
$$\sigma_\mu = (\sigma_{\theta_0} \oplus \sigma_\Delta \oplus \sigma_{rad}) \times \frac{\epsilon_{\mu\mu}^1 \sigma_{\mu\mu}}{\epsilon_{\pi\pi}^1 \sigma_{\pi\pi}}$$

Correction for probability of pion loss in the vacuum chamber



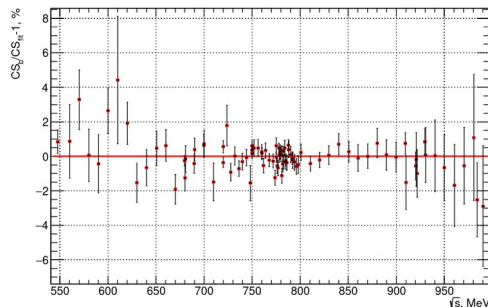
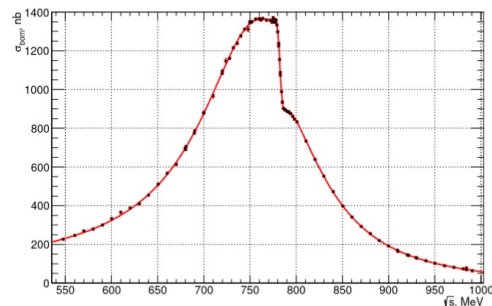
Variation of $E_{dep} > 40$ MeV correction

Error	$600 < \sqrt{s} < 900$ MeV, %	$\sqrt{s} \leq 600$ MeV and $\sqrt{s} \geq 900$ MeV, %
$\sigma_{e/\pi}$	0.05-0.1	0.1-0.3
σ_μ	0.03-0.1	0.1-0.3
σ_Δ		0.2
σ_{θ_0}		0.4
$\sigma_{E>40}$		0.5
$\sigma_{nc>1}$		0.1
σ_{rad}		0.1
σ_{uncor}		0.1
σ_{nucl}		0.1
total	0.7	0.7-0.8



Current estimates of systematic error: **0.7-0.8%**.

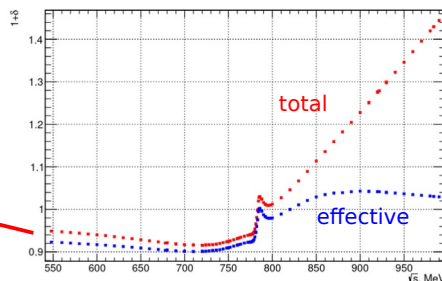
$e^+e^- \rightarrow \pi^+\pi^-$



Current analysis is based on 2018 data (47 pb⁻¹), collected below 1 GeV. **BabaYaga-NLO** generator is implemented in MC. Process $e^+e^- \rightarrow e^+e^-$ is used for IL measurement, it's separated from other events with the machine learning methods. Efficiency corrections are based on study of experimental events. With radiative and beam energy spread corrections born cross section is calculated.

$$\sigma_{\pi^+\pi^-} = \frac{\pi\alpha^2}{3s} \beta_\pi^3 |F_\pi(s)|^2$$

$$\sigma_{\pi\pi}^0(s_i) = \frac{\sigma_{\pi\pi}(s_i)}{1 + \delta_{rad}(s_i)}$$



$$F_\pi(s) = \frac{GS_\rho(s) \left(1 + \frac{A_\omega s}{s - m_\omega^2 + im_\omega \Gamma_\omega}\right) + \beta \cdot GS_{\rho'}(s) + \delta \cdot GS_{\rho''}(s)}{1 + \beta + \delta}$$

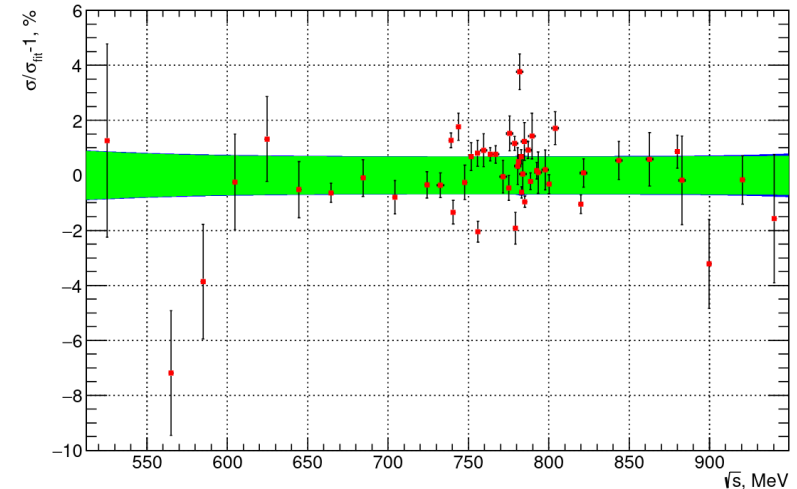
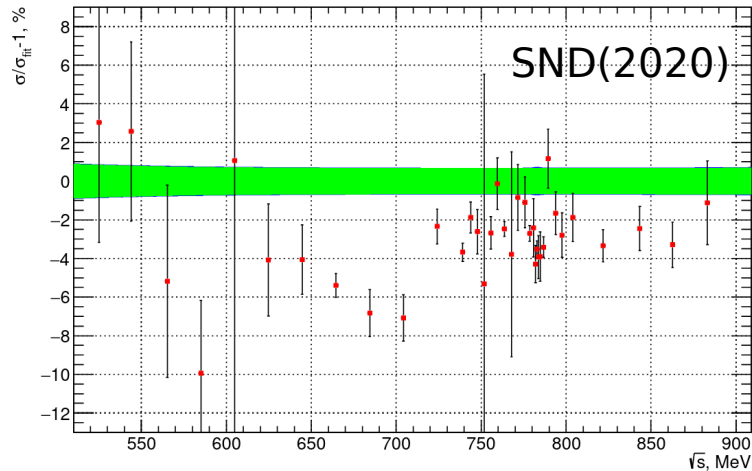
Born cross section is fitted with VMD: $\rho(770)$, $\rho(1450)$, $\rho(1700)$ and ω

Parameter	Baseline model	A1
m_ρ , MeV	$775.769 \pm 0.143 \pm 0.084$	$775.809 \pm 0.148 \pm 0.132$
Γ_ρ , MeV	$149.649 \pm 0.26 \pm 0.112$	$149.579 \pm 0.276 \pm 0.153$
m_ω , MeV	$782.443 \pm 0.064 \pm 0.06$	$782.45 \pm 0.064 \pm 0.061$
Γ_ω , MeV	$8.906 \pm 0.137 \pm 0.061$	$8.909 \pm 0.137 \pm 0.063$
$B(\omega \rightarrow \pi^+\pi^-) \cdot B(\omega \rightarrow e^+e^-), 10^{-6}$	$1.212 \pm 0.021 \pm 0.008$	$1.21 \pm 0.021 \pm 0.01$
$ \beta $	$0.746 \pm 0.002 \pm 0.061$	$0.404 \pm 0.013 \pm 0.107$
$ \delta $	$0.726 \pm 0.002 \pm 0.077$	$0.581 \pm 0.077 \pm 0.525$
$\phi_{\rho\omega}$, rad.	$0.179 \pm 0.013 \pm 0.003$	$0.174 \pm 0.013 \pm 0.008$
$\phi_{\rho\rho'}$, rad.	$-1.07 \pm 0.005 \pm 0.073$	$-0.515 \pm 0.121 \pm 1.127$
$\phi_{\rho\rho''}$, rad.	$2.8 \pm 0.007 \pm 0.058$	$3.835 \pm 0.007 \pm 1.691$
$ c $	—	$0.273 \pm 0.014 \pm 0.442$
$\arg(c)$, rad.	—	$2.558 \pm 0.124 \pm 2.56$
χ^2/ndf	108/83	107.8/81
Parameter	A2	A3
m_ρ , MeV	$775.759 \pm 0.142 \pm 0.074$	$775.91 \pm 0.154 \pm 0.143$
Γ_ρ , MeV	$149.666 \pm 0.259 \pm 0.1$	$149.644 \pm 0.304 \pm 0.062$
m_ω , MeV	$782.77 \pm 0.065 \pm 0.06$	$782.786 \pm 0.068 \pm 0.061$
Γ_ω , MeV	$8.975 \pm 0.139 \pm 0.061$	$8.991 \pm 0.143 \pm 0.065$
$B(\omega \rightarrow \pi^+\pi^-) \cdot B(\omega \rightarrow e^+e^-), 10^{-6}$	$1.209 \pm 0.021 \pm 0.009$	$1.202 \pm 0.021 \pm 0.018$
$ \beta $	$0.729 \pm 0.002 \pm 0.018$	$0.26 \pm 0.04 \pm 0.523$
$ \delta $	$0.727 \pm 0.002 \pm 0.043$	$0.071 \pm 0.005 \pm 0.656$
$\phi_{\rho\omega}$, rad.	$0.251 \pm 0.013 \pm 0.001$	$0.237 \pm 0.014 \pm 0.022$
$\phi_{\rho\rho'}$, rad.	$-1.039 \pm 0.006 \pm 0.068$	$-1.669 \pm 0.044 \pm 0.731$
$\phi_{\rho\rho''}$, rad.	$2.836 \pm 0.006 \pm 0.07$	$2.203 \pm 0.078 \pm 0.882$
$ c $	—	$0.148 \pm 0.014 \pm 0.059$
$\arg(c)$, rad.	—	$-2.81 \pm 0.165 \pm 1.169$
χ^2/ndf	108/83	107.8/81

200 KeV Off from PDG

$$e^+e^- \rightarrow \pi^+\pi^-$$

Comparing with fit curve

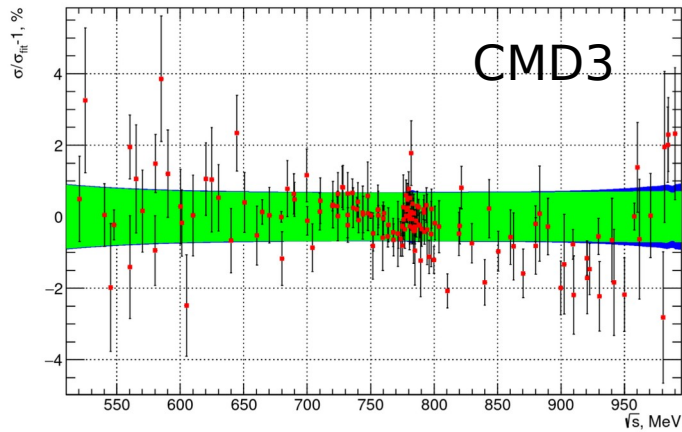


New measurement is 3% higher than previously published SND results

[J. High Energ. Phys. 2021, 113 \(2021\)](#)

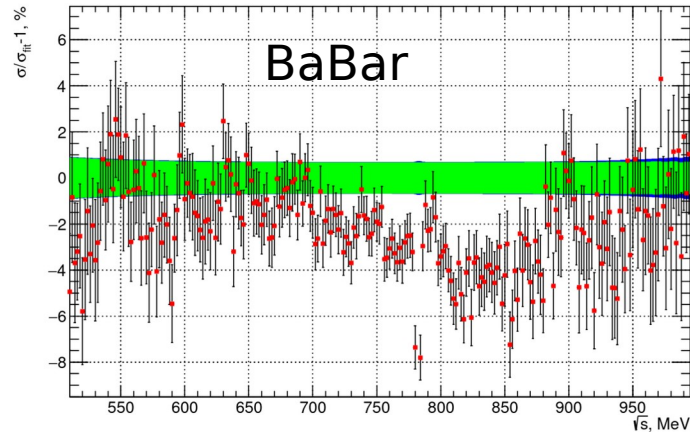
After re-analysis the **2012-2013 SND** data (used in the last SND publication) is more consistent with new results. **Current explanation:** shortcomings of the old version of reconstruction resulted in unaccounted loss of the pion tracks.

$$e^+e^- \rightarrow \pi^+\pi^-$$



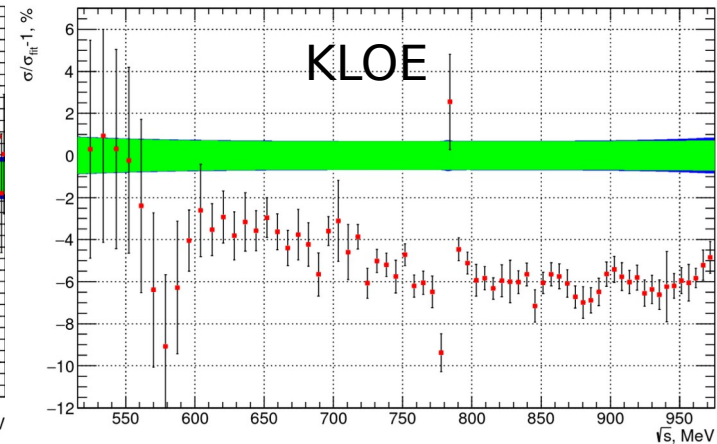
New SND result is consistent with **CMD3**

Stat. errors for dots



SND measurement is consistent with **BaBar** results below ρ , and 3% higher above 0.78 GeV

green band - syst. uncertainty
blue one — total error



Our measurement is 2-6% higher than combined **KLOE** result

$$e^+e^- \rightarrow \pi^+\pi^-$$

Contribution to g-2

The contribution of the $e^+e^- \rightarrow \pi^+\pi^-$ to the anomalous magnetic moment of the muon in the leading order of perturbation theory is expressed through the dispersion relation:

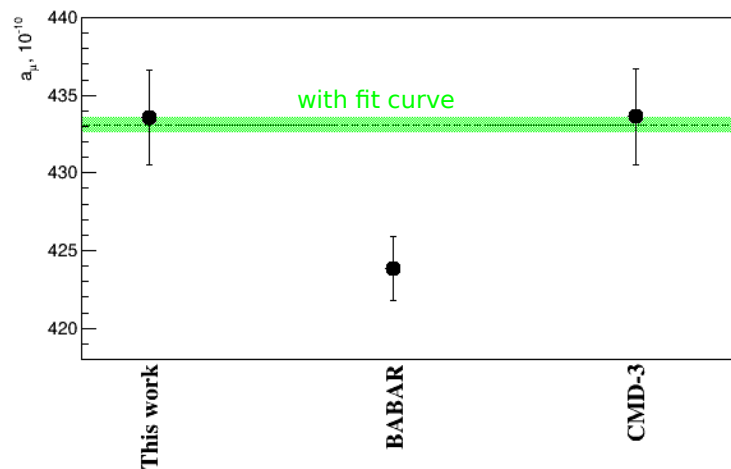
$$a_\mu(\pi\pi, \sqrt{s_{max}} \leq \sqrt{s} \leq \sqrt{s_{min}}) = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{s_{min}}^{s_{max}} \frac{R(s)K(s)}{s^2} ds,$$

$$R(s) = \sigma_{\pi\pi}^{pol} \times \frac{3s}{4\pi\alpha^2} \quad \sigma_{\pi\pi}^{pol}(s) = \sigma_{\pi\pi}^0(s) \times |1 - \Pi(s)|^2 \times \left(1 + \frac{\alpha}{\pi} a(s)\right)$$

<https://cmd.inp.nsk.su/ignatov/vpl/>

The value of the anomalous magnetic moment according to the results of this work, BABAR and CMD3 calculated in the interval of [548 – 990] MeV

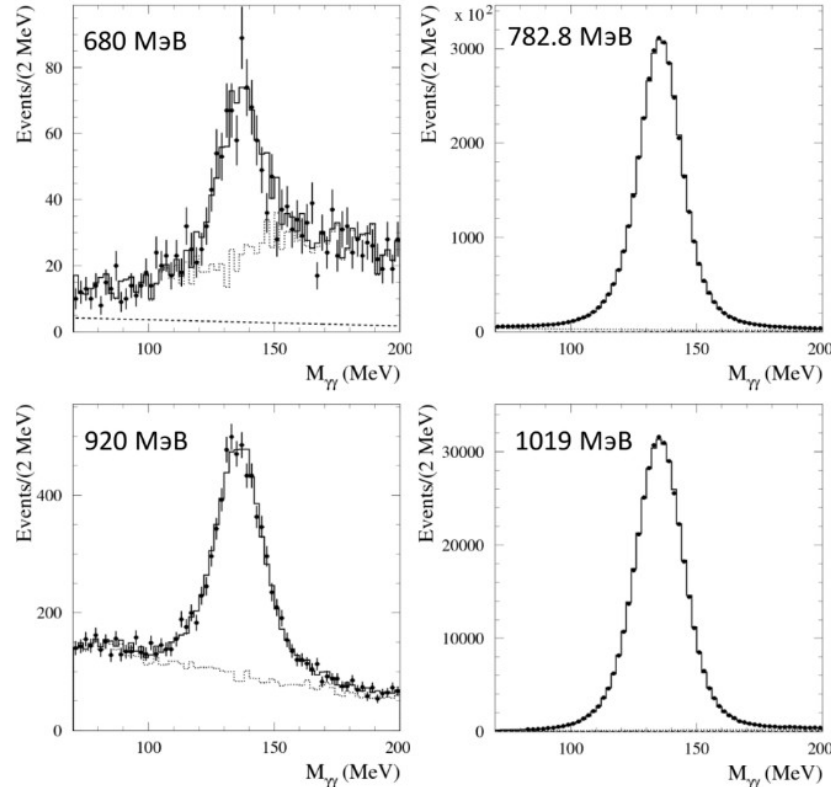
Cover \approx 80% of total $\pi^+\pi^-$ contribution



$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ in the 0.61-1.1 GeV region

Selection criteria:

- Number of charge particles ≥ 2
- Number of neutral particles ≥ 2
- Origin from e^+e^- collision:
 - $|r_i| < 1$ cm
 - $|z_i| < 15$ cm
 - $|z_1 - z_2| < 5$ cm
- Kinematic reconstruction:
 - Finding a common vertex given the beam collision point for two charged particles
 - Kinematic reconstruction in hypothesis $e^+e^- \rightarrow \pi^+\pi^-\gamma\gamma$
 - If there are several photons in the event, then the combination with the smallest χ^2 is selected
 - $\chi^2 < 100$
- Additional conditions for different energy region
- Identification by the invariant mass $M_{\gamma\gamma}$

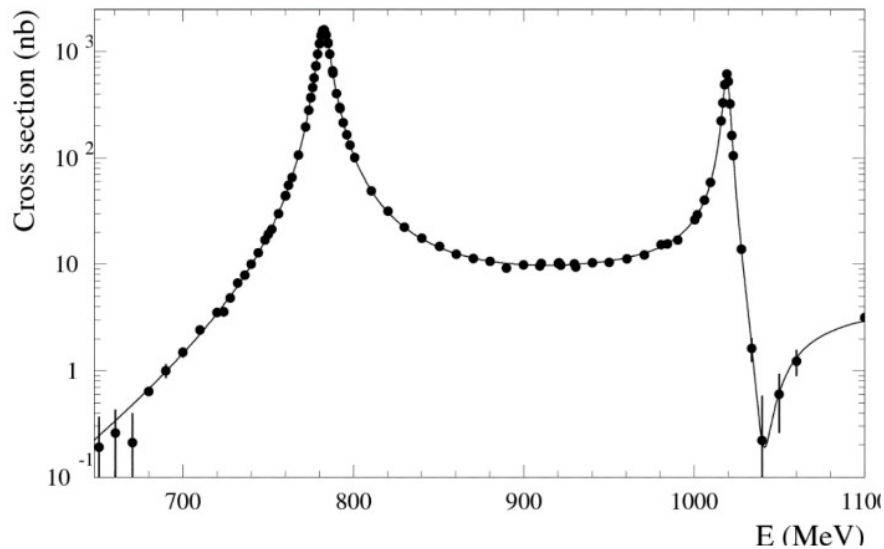


Background processes:

$$\begin{aligned} &\pi^+\pi^-(\gamma) \\ &e^+e^-(\gamma\gamma) \\ &\mu^+\mu^-(\gamma\gamma) \\ &\eta\gamma \\ &\pi^0\gamma \\ &\pi^0e^+e^- \\ &\pi^0\pi^0\pi^+\pi^- \\ &K^+K^-, K_S K_L \end{aligned}$$

$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ in the 0.61-1.1 GeV region

Data from 2018, 102 points, luminosity 66 pb^{-1}



Parameter	Fitted value	PDG value
$\mathcal{B}(\omega \rightarrow e^+e^-)\mathcal{B}(\omega \rightarrow 3\pi) \times 10^5$	$6.648 \pm 0.022 \pm 0.058$	6.61 ± 0.16
m_ω , MeV	$782.703 \pm 0.011 \pm 0.047$	782.66 ± 0.13
Γ_ω , MeV	$8.598 \pm 0.023 \pm 0.004$	8.68 ± 0.13
$\mathcal{B}(\phi \rightarrow e^+e^-)\mathcal{B}(\phi \rightarrow 3\pi) \times 10^5$	$4.154^{+0.102}_{-0.066} \pm 0.066$	4.42 ± 0.11
m_ϕ , MeV	$1019.488 \pm 0.017 \pm 0.061$	1019.460 ± 0.016
Γ_ϕ , MeV	$4.265 \pm 0.033 \pm 0.014$	4.249 ± 0.013
φ_ϕ , deg	$156.8^{+6.5}_{-4.6} \pm 1.9$	163 ± 7
$\mathcal{B}(\rho \rightarrow 3\pi) \times 10^5$	$4.7 \pm 1.2 \pm 1.3$	9 ± 4
φ_ρ , deg	$-95.3 \pm 8.3 \pm 4.0$	-99 ± 17

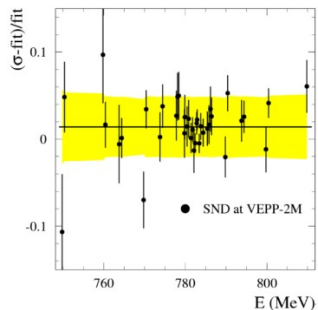
Source of systematics	near ω	near ϕ	Between ω and ϕ
Luminosity	0.7	0.7	0.7
Events	0.2	0.6	0.8
Efficiency	0.5	0.8	1.0
Total	0.9	1.2	1.5

Fit model:

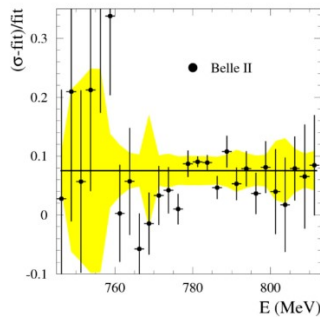
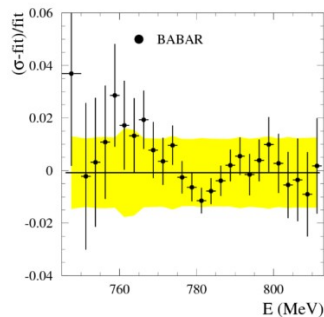
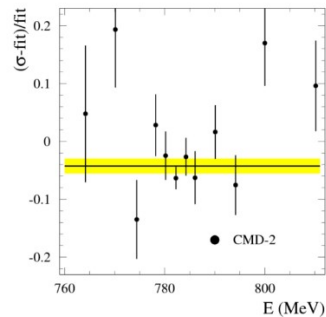
- VDM: $\omega(782) + \rho(770) + \phi(1020) + \omega(1420)$
- The phase $\omega(1420)$ relative to $\omega(782)$ is fixed at 180°
- To the statistical error in the number of $\pi^+\pi^-\pi^0$ events, an additional spread of about $\sim 0.6\%$ was added

$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ in the 0.61-1.1 GeV region

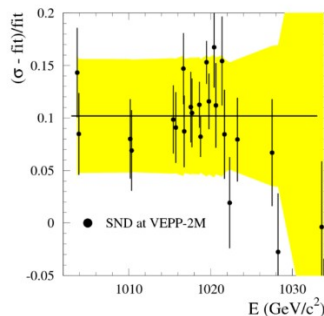
SND in comparison with other experiments near ω



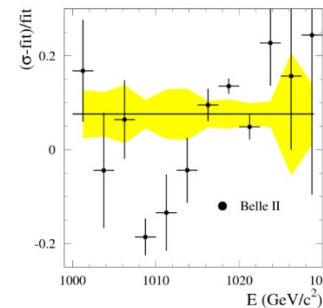
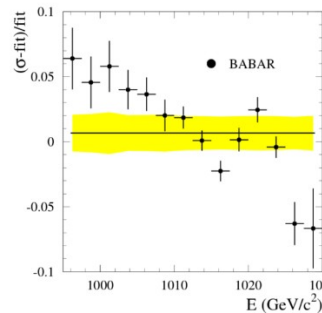
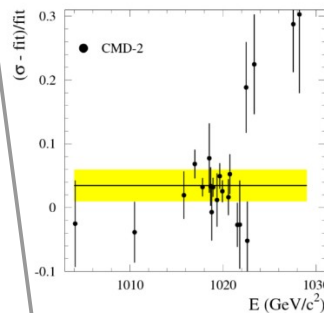
Our measurement is consistent with the BABAR and SND data on VEPP-2M, 4% (2σ) higher than the CMD-2 result and 8% (2σ) lower than the Belle-II result



SND in comparison with other experiments near ϕ



Our measurement is consistent with the BABAR and CMD-2 data, 10% (2σ) lower than the SND results on VEPP-2M and 7% (2σ) lower than the Belle-II result



$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ in the 0.61-1.1 GeV region

To calculate $a_\mu^{3\pi}$ below 1.1 GeV, an approximating function was used. The statistical error was determined using the toy MC. The systematic error in $a_\mu^{3\pi}$ was determined by shifting the measured cross section up or down by the systematic error.

The contribution of the SND to $a_\mu^{3\pi}$ above 1.1 GeV was calculated using data from the paper M.N. Achasov *et al.*, Phys. Atom. Nucl. **87**, 747(2024)

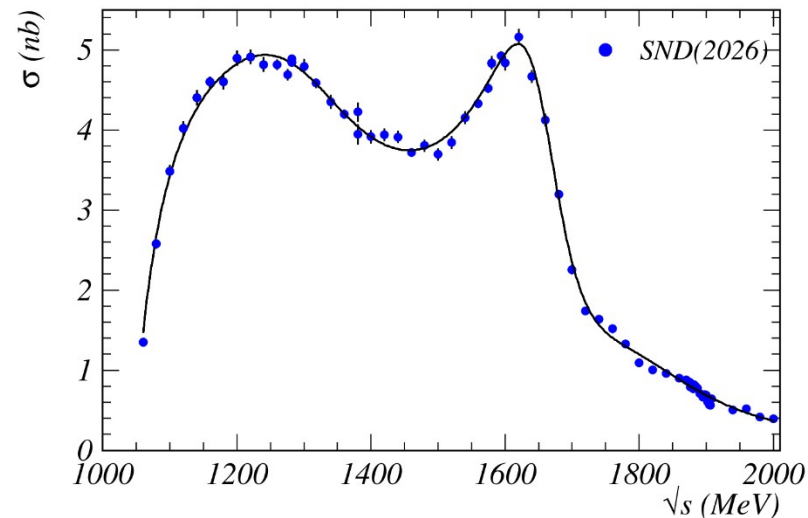
$$a_\mu^{3\pi} = \frac{\alpha^2}{3\pi^2} \int_{m_\pi^2}^{\infty} \frac{K(s) \sigma(s) |1 - \Pi(s)|^2}{s \cdot 4\pi\alpha^2/s} ds$$

E , GeV	$a_\mu^{3\pi} \times 10^{10}$
0.61–1.10 (SND)	$42.96 \pm 0.06 \pm 0.45$
1.10–1.975 (SND)	$2.99 \pm 0.02 \pm 0.08$
0.61–1.975 (SND)	$45.95 \pm 0.06 \pm 0.46$
0.62–1.10 (BABAR)	$42.91 \pm 0.14 \pm 0.55 \pm 0.09$
1.10–2.00 (BABAR)	$2.95 \pm 0.03 \pm 0.16$
< 2.00 (BABAR)	$45.86 \pm 0.14 \pm 0.58$
0.62–1.80 (Belle II)	$48.91 \pm 0.23 \pm 1.07$
< 1.8 before 2021 *	$46.2 \pm 0.6 \pm 0.6$

* M. Hoferichter, B. L. Hoid and B. Kubis, JHEP 2019, 137 (2019)

The SND result is in agreement with the BABAR and $a_\mu^{3\pi}$ result calculated using data up to 2021, but is 2.5σ lower than the Belle II result

$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ in the 1.06-2.0 GeV region

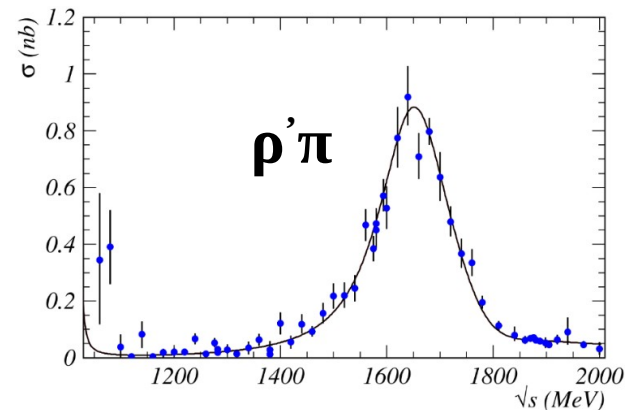
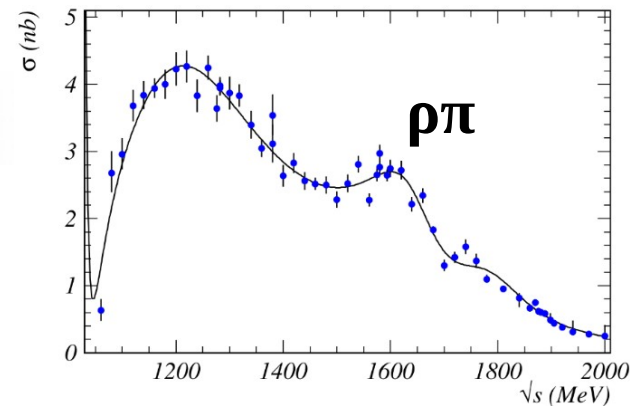


Background processes:

- $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$
- $e^+e^- \rightarrow \pi^+\pi^-\gamma$
- $e^+e^- \rightarrow K_S K_L$
- $e^+e^- \rightarrow K^+K^-\pi^0$
- $e^+e^- \rightarrow \mu^+\mu^- \gamma$

$$\frac{d\sigma}{d\Gamma} = |\alpha A_{\rho\pi} + \beta A_{\rho'\pi} + \gamma A_{\omega\pi}|^2$$

parameters	SND (previous)	this work
$M(\omega')$ (MeV)	1350 ± 43	1215 ± 26
$\Gamma(\omega')$ (MeV)	590 ± 90	480 ± 33
$\sigma(\omega' \rightarrow \rho\pi)$ (nb)	4.17 ± 0.73	1.35 ± 0.09
$\sigma(\omega' \rightarrow \rho'\pi)$ (nb)	$0.053^{+0.021}_{-0.015}$	0.72 ± 0.16
$M(\omega'')$ (MeV)	1643 ± 6	1648 ± 5
$\Gamma(\omega'')$ (MeV)	148 ± 13	173 ± 10
$\sigma(\omega'' \rightarrow \rho\pi)$ (nb)	$0.046^{+0.042}_{-0.028}$	0.023 ± 0.012
$\sigma(\omega'' \rightarrow \rho'\pi)$ (nb)	1.65 ± 0.16	1.54 ± 0.18
$M(\omega_x)$ (MeV)		1782 ± 20
$\Gamma(\omega_x)$ (MeV)		200 ± 10
$\sigma(\omega'' \rightarrow \rho\pi)$ (nb)		0.36 ± 0.10
$\sigma(\omega'' \rightarrow \rho'\pi)$ (nb)		0.11 ± 0.06



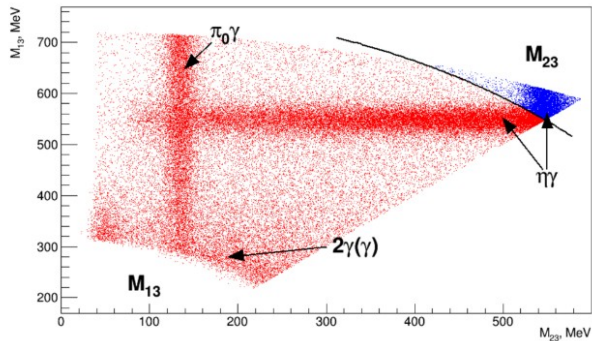
$e^+e^- \rightarrow \eta\gamma (\eta \rightarrow \gamma\gamma)$

Selection criteria:

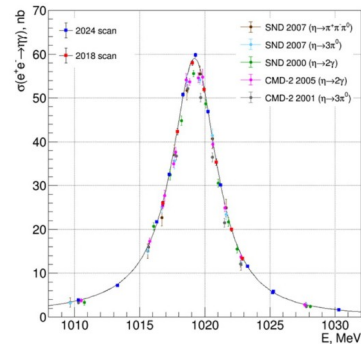
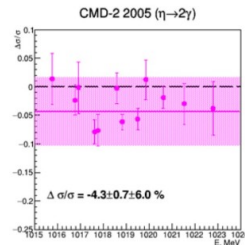
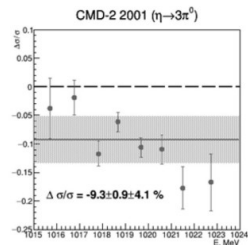
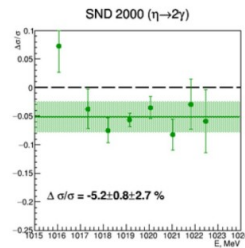
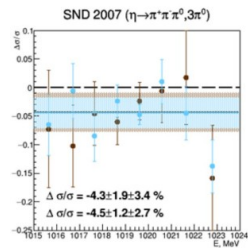
- Number of charge particles = 0
- Number of neutral particles ≥ 3
- Kinematic reconstruction: $\chi^2_{e^+e^- \rightarrow 3\gamma} < 30$
- Identification by the invariant mass $M_{\gamma\gamma}$

Background processes:

- $e^+e^- \rightarrow 2\gamma(\gamma)$
- $e^+e^- \rightarrow \pi^0\gamma$

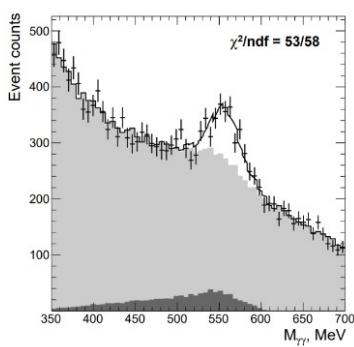
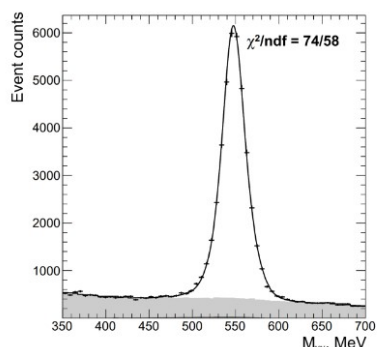
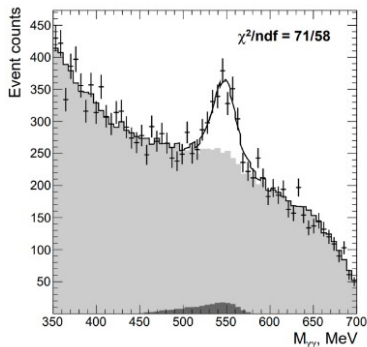


Data from 2018 & 2024, luminosity 73 pb⁻¹

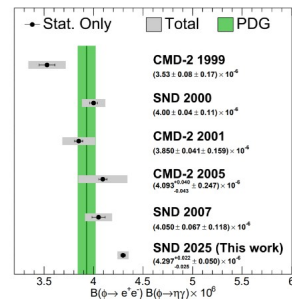


Fit model:

- VDM: $\rho(770)$, $\omega(782)$, $\phi(1020)$, $\rho(1450)$, $\phi(1680)$
- $\varphi_\omega = 0^\circ$, $\varphi_\phi(1680) = \varphi_\rho(1450) + 180^\circ$



- The $e^+e^- \rightarrow \eta\gamma$ cross section was measured in the energy range of 980-1060 MeV.
- The total systematic error of the measured cross section at the phi meson maximum was 1.5%.
- The measured cross section has the highest accuracy.



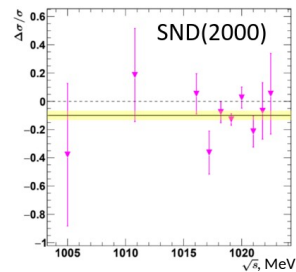
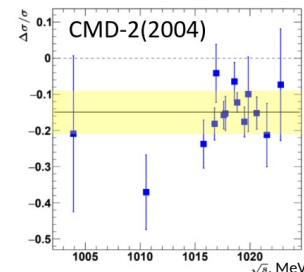
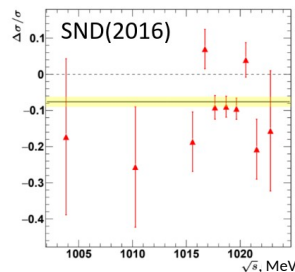
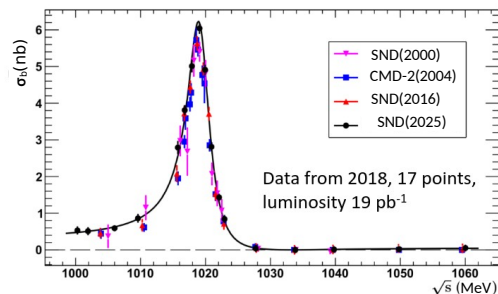
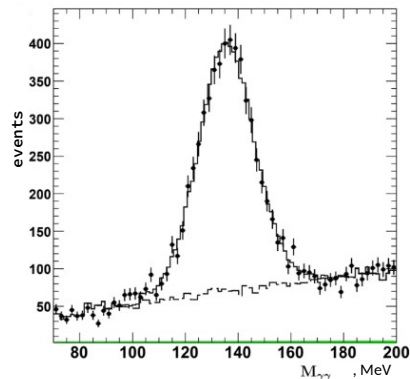
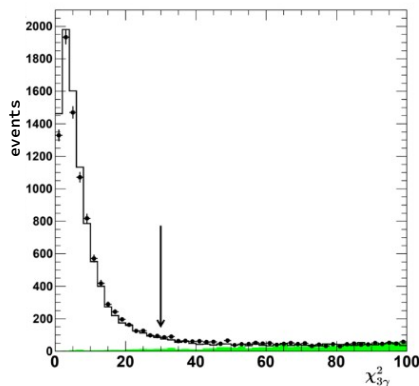
$e^+e^- \rightarrow \pi^0\gamma (\pi^0 \rightarrow \gamma\gamma)$ near ϕ

Selection criteria:

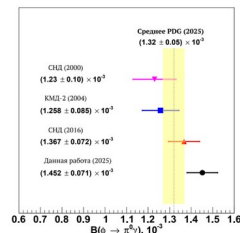
- Number of charge particles = 0
- Number of neutral particles =>3
- $E_{total} > 0.65\sqrt{s}, P_{total} < 0.3\sqrt{s}$
- $70 < M_{\gamma\gamma} < 200$ MeV
- Kinematic reconstruction: $\chi_{e^+e^- \rightarrow 3\gamma}^2 < 30$
- $36^\circ < \theta_{1,2,3} < 144^\circ$
- Identification by the invariant mass $M_{\gamma\gamma}$

Background processes:

- $e^+e^- \rightarrow n\gamma$ (QED)
- $e^+e^- \rightarrow \eta\gamma$
- $e^+e^- \rightarrow \pi^0\pi^0\gamma$
- $e^+e^- \rightarrow K_S K_L$
- Cosmics



The measured cross section for the $e^+e^- \rightarrow \pi^0\gamma$ process is 7–15% higher than the results of previous measurements performed in the SND and CMD-2 experiments at the VEPP-2M collider. This difference significantly exceeds the systematic measurement errors.



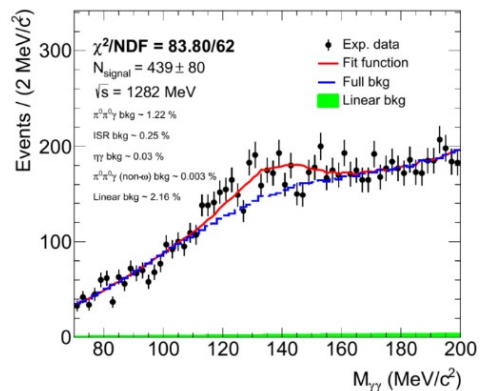
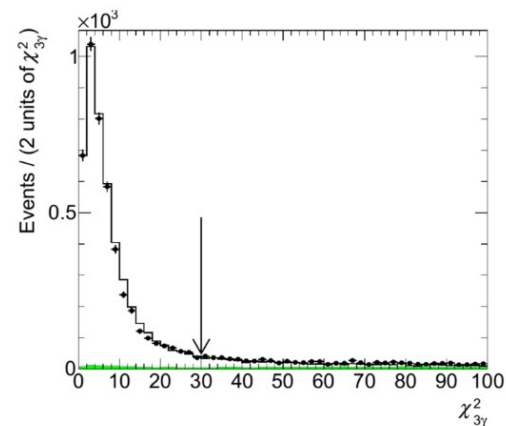
$$\sigma_{\pi^0\gamma}(s) = \frac{q^3(s)}{s^2} \left| \sum_V A_V(s) \right|^2,$$

$$A_V(s) = \frac{m_V \Gamma_V e^{i\varphi_V}}{m_V^2 - s - i\sqrt{s}\Gamma_V(s)} \sqrt{\frac{m_V^2}{q(m_V^2)^3} \sigma_V},$$

VDM: ρ, ω, ϕ and their excitations

- The systematic error of the cross section at the $\phi(1020)$ resonance maximum is 1.3%, while the statistical error is 2.1%.
- To date, this is the most accurate measurement of the cross section for the process $e^+e^- \rightarrow \pi^0\gamma$.

$e^+e^- \rightarrow \pi^0\gamma(\pi^0 \rightarrow \gamma\gamma) \sqrt{s} > 1\text{GeV}$



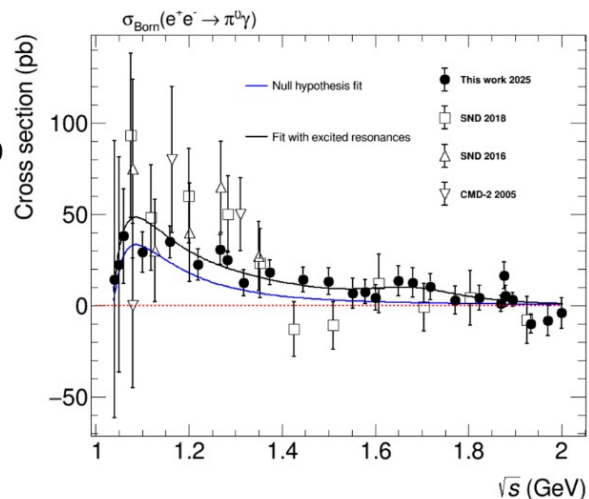
Selection criteria:

- Number of charge particles = 0
- Number of neutral particles = 3
- $E_{total} > 0.65\sqrt{s}, P_{total} < 0.3\sqrt{s}$
- $70 < M_{\gamma\gamma} < 200\text{ MeV}$
- Kinematic reconstruction: $\chi^2_{e^+e^- \rightarrow 3\gamma} < 30$
- $36^\circ < \theta_{1,2,3} < 144^\circ$
- $E_{\gamma,min} > 125\text{ MeV}$
- Identification by the invariant mass $M_{\gamma\gamma}$

Background processes:

- $e^+e^- \rightarrow \gamma\gamma(\gamma)$ (QED)
- $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma \rightarrow 5\gamma$
- $e^+e^- \rightarrow \eta\gamma(\gamma) \rightarrow 3\gamma(\gamma)$

Data from 2017-2024, 153 points, luminosity 909 pb^{-1}

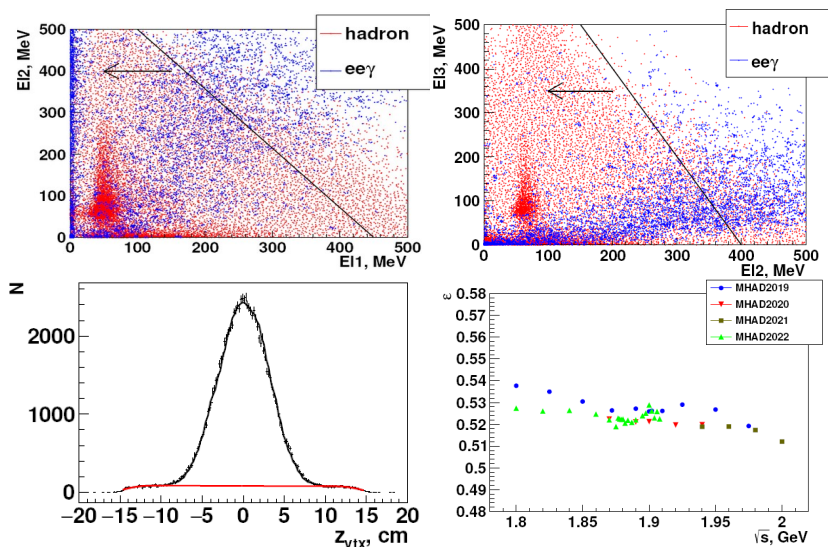


The null hypothesis: used only ρ, ω, ϕ
Hypothesis with excited resonances: used ρ, ω, ϕ and their excitations, but instead of $\omega(1420), \rho(1450), \omega(1650)$ and $\rho(1700)$, two effective resonances were used $m_{V_1} = 1450\text{ MeV}$ and $m_{V_2} = 1700\text{ MeV}$

- The most accurate measurement of the process cross section was performed in the energy range of 1.08-2.00 GeV.
- The systematic error varies from 2.5% to 10.4% in the energy range from 1.1 to 1.5 GeV, respectively.
- The cross section is well described by a VDM with two effective resonances.
- The null hypothesis (without excited resonances) is excluded at the 4.65 σ level.

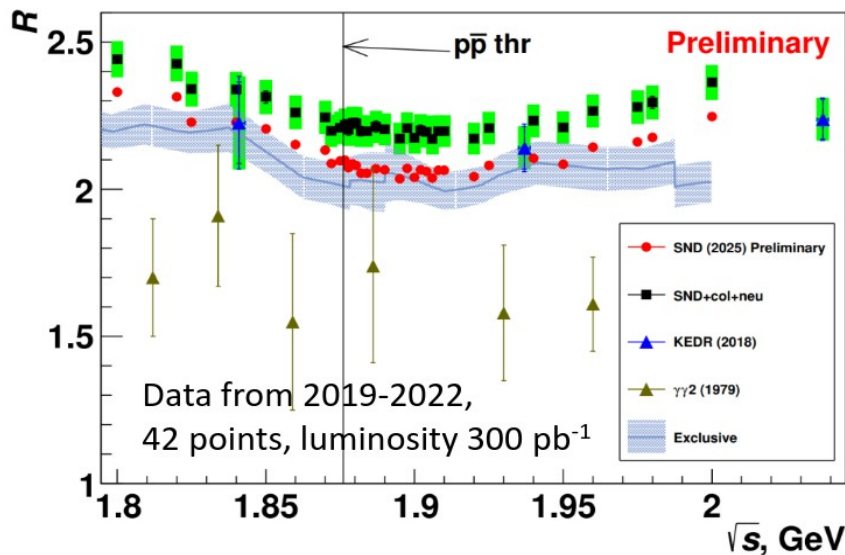
Inclusive measurement of charged* noncollinear hadronic cross section in the 1.8-2.0 GeV region

* decays of K_s and η with charged particles in the final state are included



- Efficiency is calculated using MC of exclusive hadronic processes, mixed according to previously measured cross sections
- Main QED background is suppressed by the cuts on energy deposition in the different layers of EMC
- Beam background is subtracted via z_{vtx} fit

R measured in this work is systematically greater than sum of exclusive cross sections and compatible with KEDR results, but have much greater statistical accuracy

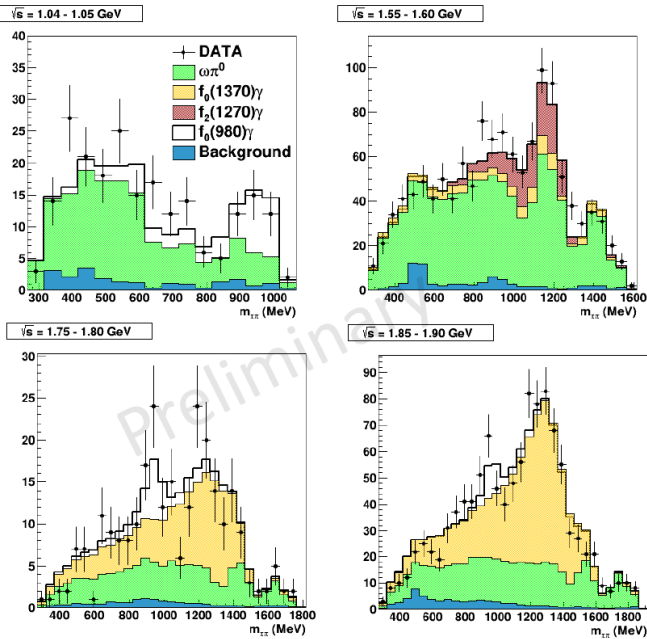


In order to calculate total cross section, previously measured cross sections of the neutral ($\eta\pi^0\gamma$, $\pi^0\pi^0\gamma$, $\pi^0\gamma$, $\eta\eta\gamma$, $K_s K_L$ etc.) and collinear (K^+K^- , $\pi^+\pi^-$, $p\bar{p}$) hadronic processes are added

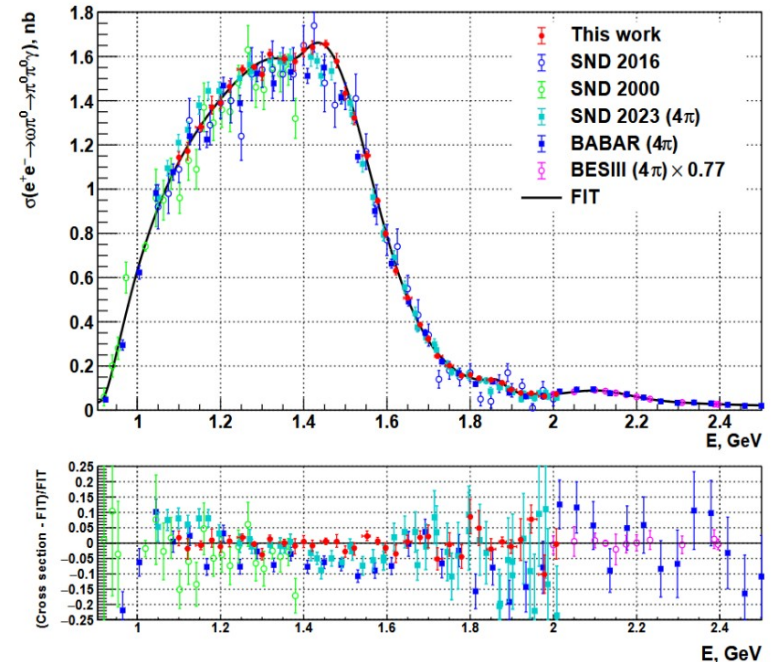
Current estimates for systematic uncertainty: **1.3%**

Phys. Lett. B Vol. 788, (2019), pp 42-51
 Phys. Lett. B, Vol. 86, (1979), pp 234-238
<https://cmd.inp.nsk.su/ignatov/vpl/>

$e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ (in the 1.05-2.0 GeV region)



- Fit quality is good $\chi^2/\text{ndf} = 39.4/40$
- Good agreement with previous measurements in decay channel $\omega \rightarrow \pi^0\gamma$
- Notable disagreement (10%) with measurements in decay channel $\omega \rightarrow \pi^+\pi^-\pi^0$ below 1.6 GeV
- Good agreement with SND 2023 above 1.6 GeV
- A scale factor 0.77 ± 0.04 obtained from the fit was applied to BESIII data



Summary for $e^+e^- \rightarrow \eta\gamma, \pi^0\gamma, \omega\pi^0$, hadrons (inc.)

- The most accurate measurement of the $e^+e^- \rightarrow \pi^0\gamma$ process in the 1000-1060 MeV energy range was obtained
- The systematic measurement error at the $\phi(1020)$ resonance maximum is 1.3%, and the statistical error is 2.1%
- The decay probability was measured $B(\phi \rightarrow \pi^0\gamma) = (1.452 \pm 0.024 \pm 0.067) \cdot 10^{-3}$
- The most accurate measurement of the $e^+e^- \rightarrow \pi^0\gamma$ cross section was performed in the energy range of 1.08-2.00 GeV
- The systematic error varies from 2.5% to 10.4% in the energy range from 1.1 to 1.5 GeV, respectively
- The most accurate measurement of the $e^+e^- \rightarrow \eta\gamma$ process was obtained in the 980-1060 MeV energy range, with systematic uncertainty at the $\phi(1020)$ resonance maximum being 1.5%
- The most precise measurement of $B(\phi \rightarrow e^+e^-)B(\phi \rightarrow \eta\gamma)$ was performed [[Phys.Rev.D 113 \(2026\) 052003](#)]
- The cross section of the process $e^+e^- \rightarrow \omega\pi^0$ has been measured with the best accuracy to date
- In this work the inclusive cross section of e^+e^- -annihilation into charged hadronic states with more than two particles in the region of $\sqrt{s} = 1.8 - 2.0$ GeV is measured
- R measured in this work is systematically greater than sum of exclusive cross sections and compatible with KEDR results, but have much greater statistical accuracy

Summary for $e^+e^- \rightarrow \pi^+\pi^-, \pi^+\pi^-\pi^0$

- The most precise measurement of the $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ process cross section at energies below 1.1 GeV has been achieved [[arXiv:2603.01635](https://arxiv.org/abs/2603.01635)]
- The systematic error in measuring the cross section near the ω and ϕ resonance maxima is 0.9% and 1.2%, respectively
- The SND data are consistent with the BABAR measurements and are approximately 7-8% (2σ) lower than the Belle II data
- The most precise measurements of the $B(\phi \rightarrow e^+e^-)B(\phi \rightarrow \pi^+\pi^-\pi^0)$, m_ω and Γ_ω parameters have been made within VDM framework
- Study of the $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ process at energies above 1.1 GeV showed that $\omega(1420)$ and $\omega(1650)$ decay predominantly via $\rho\pi$ and $\rho'\pi$ mechanisms, respectively.
- The total cross section of the $e^+e^- \rightarrow \pi^+\pi^-$ process was measured in the $\sqrt{s} = 548 - 990$ MeV energy range with a systematic error of 0.7-0.8% at $\sqrt{s} < 600$ and $\sqrt{s} > 900$ MeV and 0.7% at $600 < \sqrt{s} < 900$ MeV
- The results are consistent with the CMD-3 measurement, and there is a difference with BABAR (KLOE) data at the 2σ ($>5\sigma$) level
- Contribution of the $e^+e^- \rightarrow \pi^+\pi^-$ process to the anomalous magnetic moment of the muon is $a_\mu = (433.59 \pm 0.52 \pm 3.04) \cdot 10^{-10}$ in the $548 < \sqrt{s} < 990$ MeV energy range

Thank you for attention!