

Recent Results on $e^+e^- \rightarrow$ hadrons Cross
Sections from SND and CMD-3 Detectors at
VEPP-2000 collider

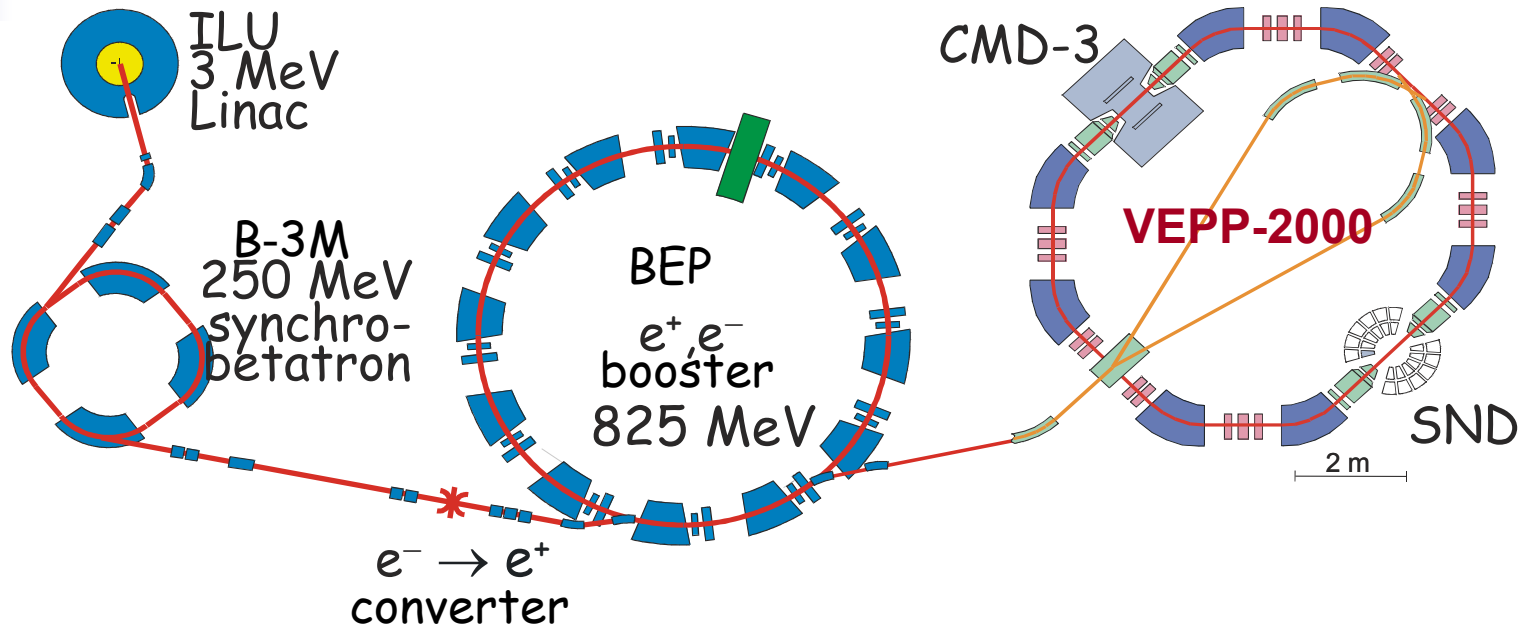


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VEPP-2000 Collider



Main parameters:

- collision period 82ns
- beam current 0.2 A
- bunch length 3.3cm
- perimeter 24.4 m
- Energy spread 0.7 MeV
- $\beta_x \approx \beta_z = 6.3\text{cm}$

Designed luminosity:

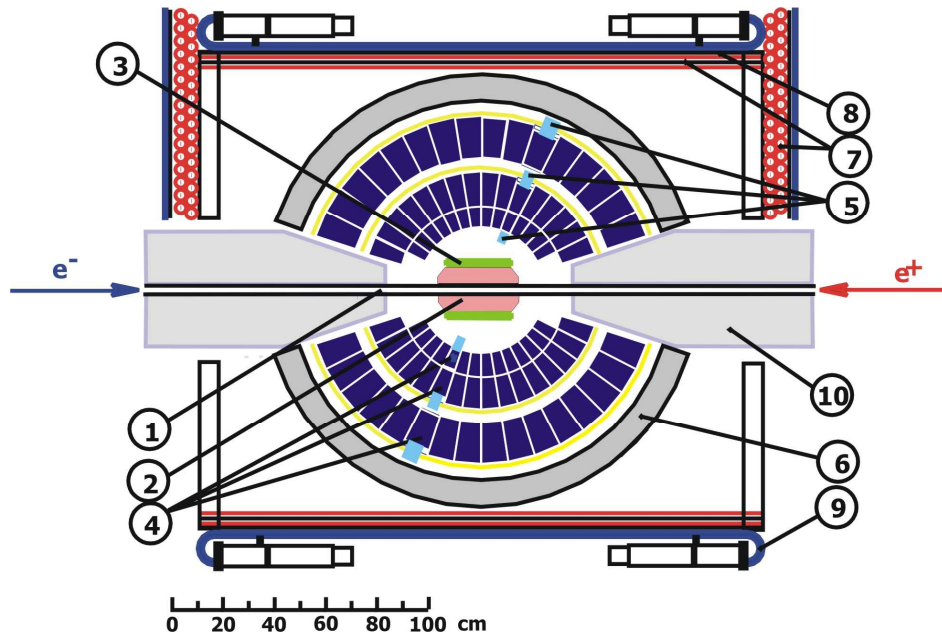
- $L \sim 2 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$ ($2E=1.0 \text{ GeV}$)
- $L \sim 10^{32} \text{cm}^{-2} \text{s}^{-1}$ ($2E=2.0 \text{ GeV}$)

Achieved luminosity:

- $L \sim 5 \times 10^{30} \text{cm}^{-2} \text{s}^{-1}$ ($2E=1.0 \text{ GeV}$)
- $L \sim 2 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$ ($2E=2.0 \text{ GeV}$)

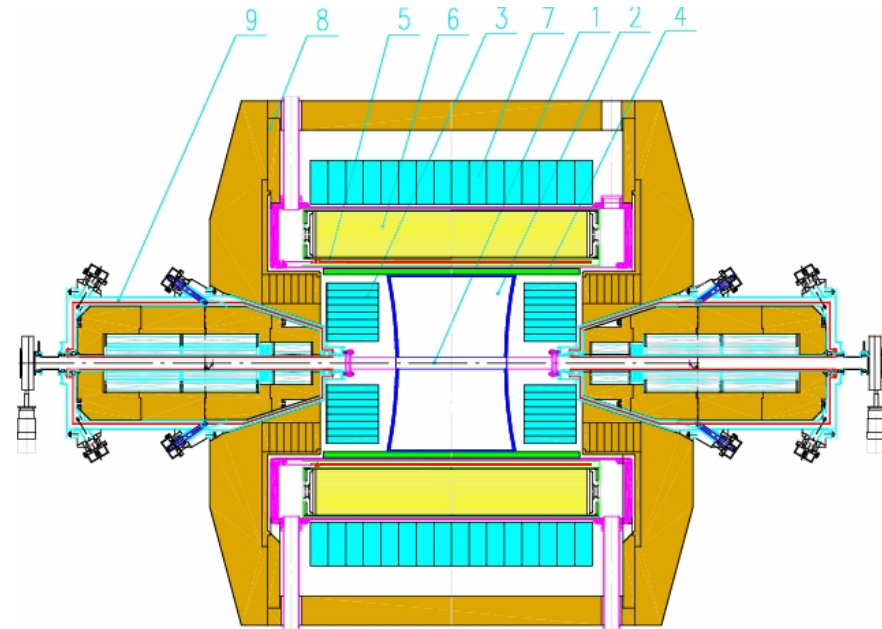
Detectors for VEPP-2000

SND



1 – beam pipe, 2 – tracking system, 3 – aerogel threshold Cherenkov counters , 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron electromagnetic shower absorber, 7–9 – muon detector, 10 – VEPP-2000 focusing SC solenoids.

CMD-3

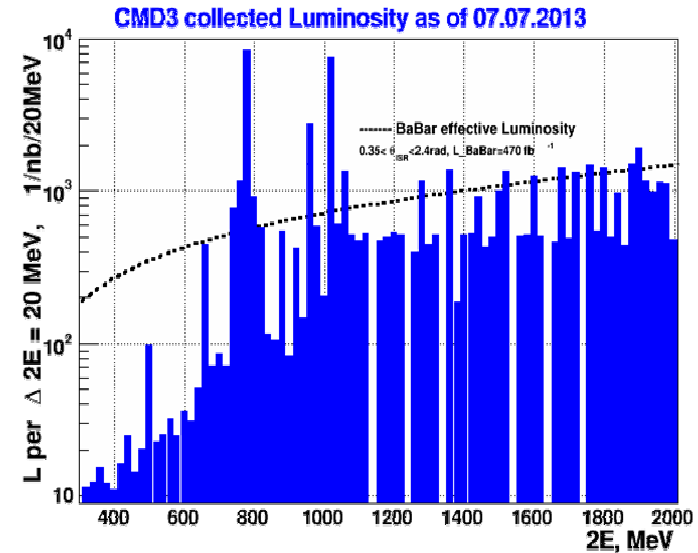


1 – vacuum chamber	6 – electromagnetic calorimeter LXe
2 – drift chamber	7 – electromagnetic calorimeter CsI
3 – electromagnetic calorimeter BGO	8 – yoke
4 – Z – chamber	9 – VEPP-2000 solenoid
5 – CMD SC solenoid	

Collected Integrated Luminosities

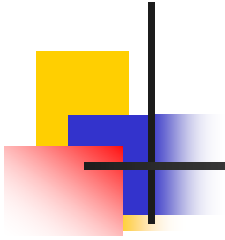
Experiments 2010 – 2012

Experiment/ year (1.05 – 2.0 GeV)	Integrated luminosity	$\sqrt{s} > 1.88$ GeV
2010	5 pb ⁻¹	0.07 pb ⁻¹
2011	25 pb ⁻¹	3.8 pb ⁻¹
2012	17 pb ⁻¹	4.9 pb ⁻¹
Total	47 pb ⁻¹	8.8 pb ⁻¹



Experiment 2013

Energy region (\sqrt{s} , GeV)	Integrated luminosity, pb ⁻¹	$\rho - \omega$ region, pb ⁻¹	$\eta' - \text{meson}$ region, pb ⁻¹	$\phi - \text{meson}$ region, pb ⁻¹	non- resonant, pb ⁻¹
0.32–1.06	25	8.8	2.7	6.9	6.6



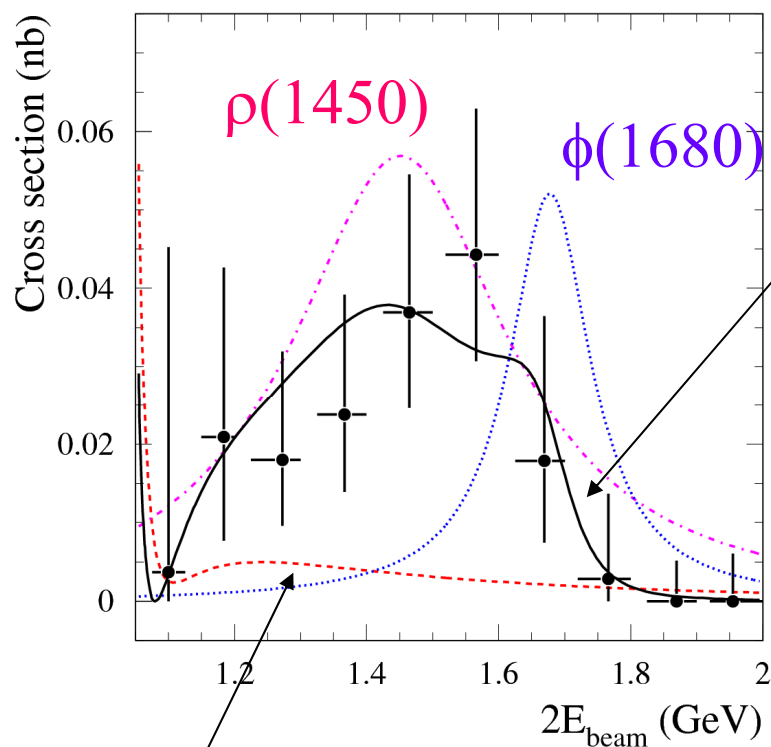
List of Processes

1. $e^+e^- \rightarrow \eta\gamma \rightarrow 7\gamma$
2. $e^+e^- \rightarrow \pi^+\pi^-$
3. $e^+e^- \rightarrow K^+K^-$
4. $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$
5. $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$
6. $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$
7. $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$
8. $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
9. $e^+e^- \rightarrow \pi^+\pi^-\eta$
10. $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$
11. $e^+e^- \rightarrow \eta'(958)$
12. $e^+e^- \rightarrow p \text{ anti-}p$
13. $e^+e^- \rightarrow n \text{ anti-}n$

$$e^+e^- \rightarrow \eta\gamma \rightarrow 7\gamma \quad (32\text{pb}^{-1})$$



It is first observation of radiative decays of $\rho(1450)$ and $\phi(1680)$ mesons



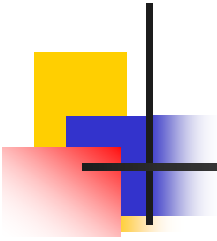
$\rho(770), \omega(782), \phi(1020)$

Sum of $\rho(770), \omega(782), \phi(1020)$ and $\rho(1450)$ и $\phi(1680)$ with interference

About 30 events $\eta\gamma$ above 1.15 GeV, are explained by $\rho(1450)$ and $\phi(1680)$ decays.

Peak cross sections are much larger of theoretical predictions from quark model: about 15 pb for $\rho(1450)$ and about 10 pb for $\phi(1680)$.

arXiv:1312.7078 [hep-ex]
Phys. Rev. D 90, 032002



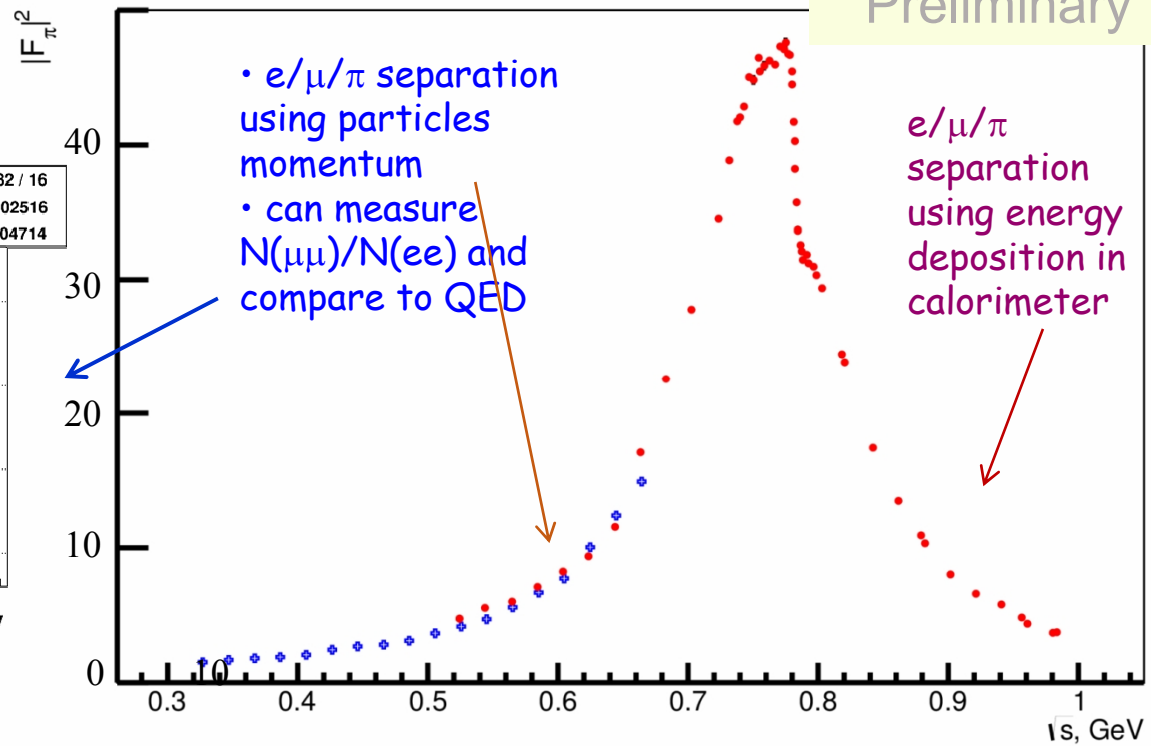
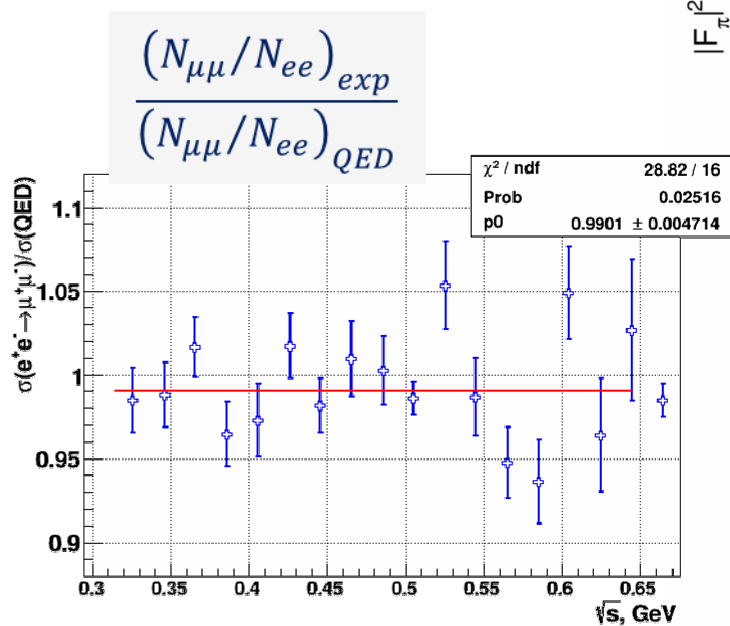
$$e^+e^- \rightarrow \pi^+\pi^-$$



- Gives largest contribution to $(g-2)_\mu$ calculation (65% of δa_μ)
- Goal is to reach systematic uncertainty at the level of 0.35%

$$|F_\pi|^2$$

Preliminary



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

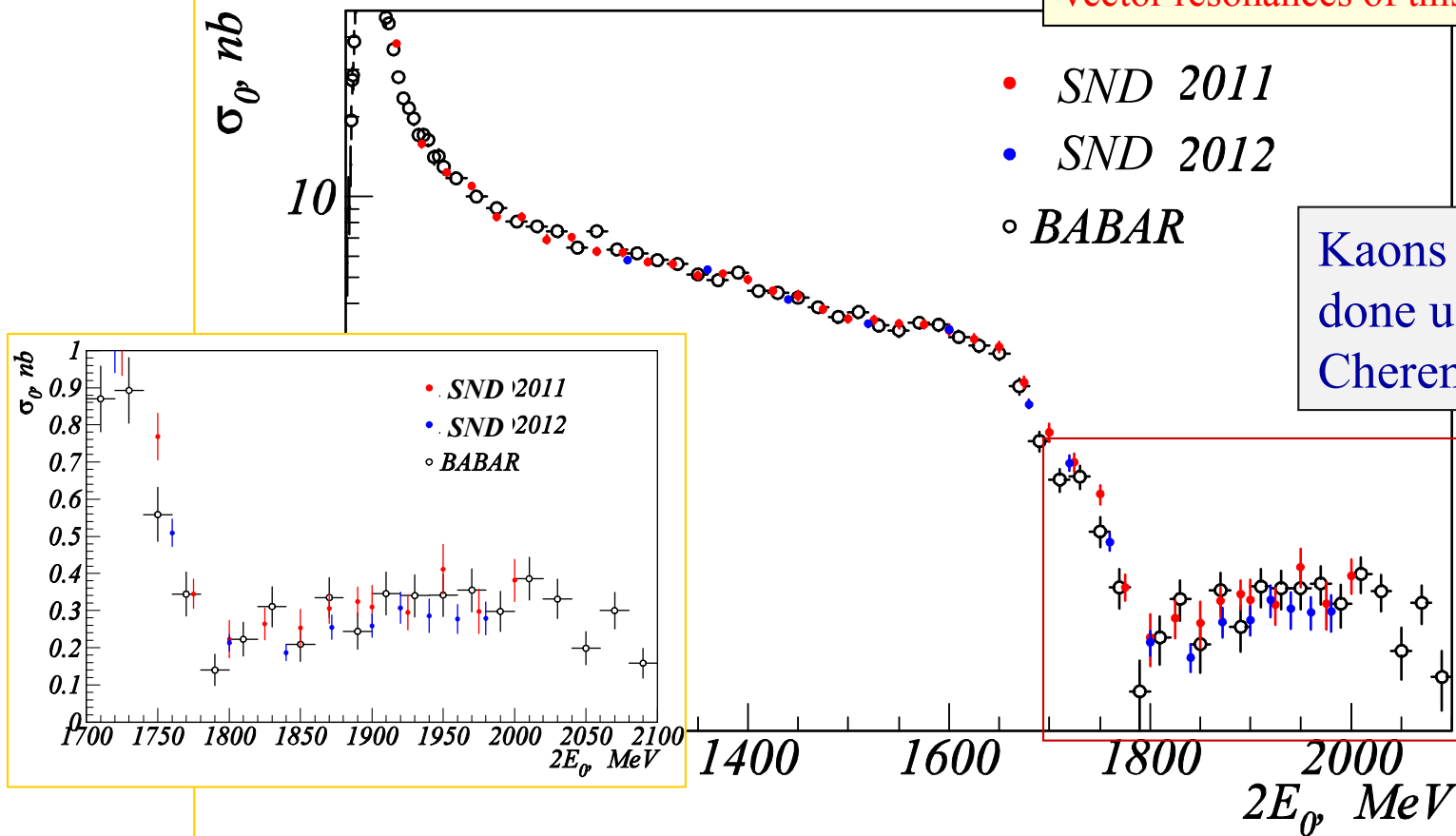


Preliminary

Complicated form of cross section is connected with interference of all excited vector resonances of this energy region

- *SND 2011*
- *SND 2012*
- *BABAR*

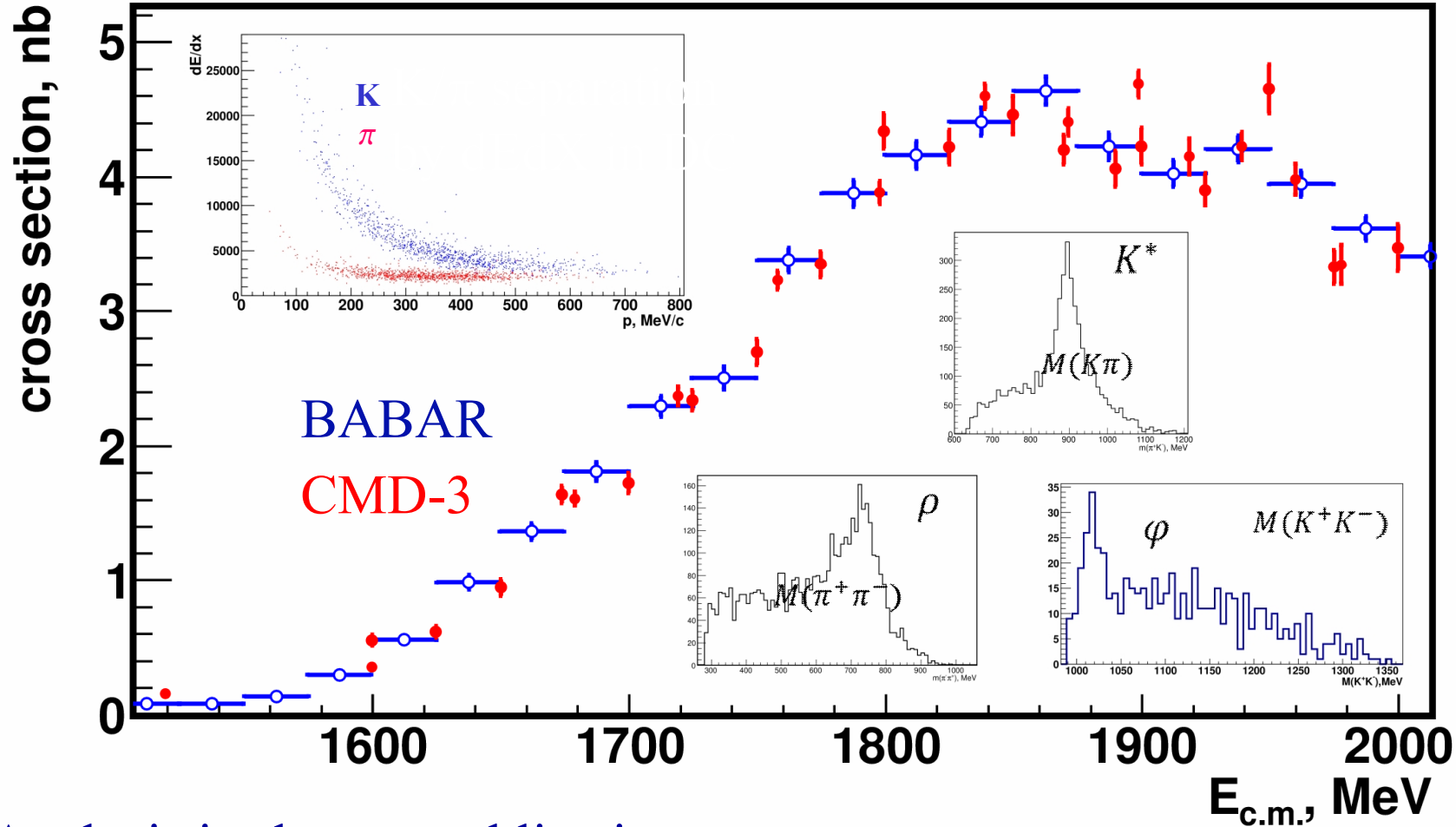
Kaons selection was done using aerogel Cherenkov counters



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



Preliminary



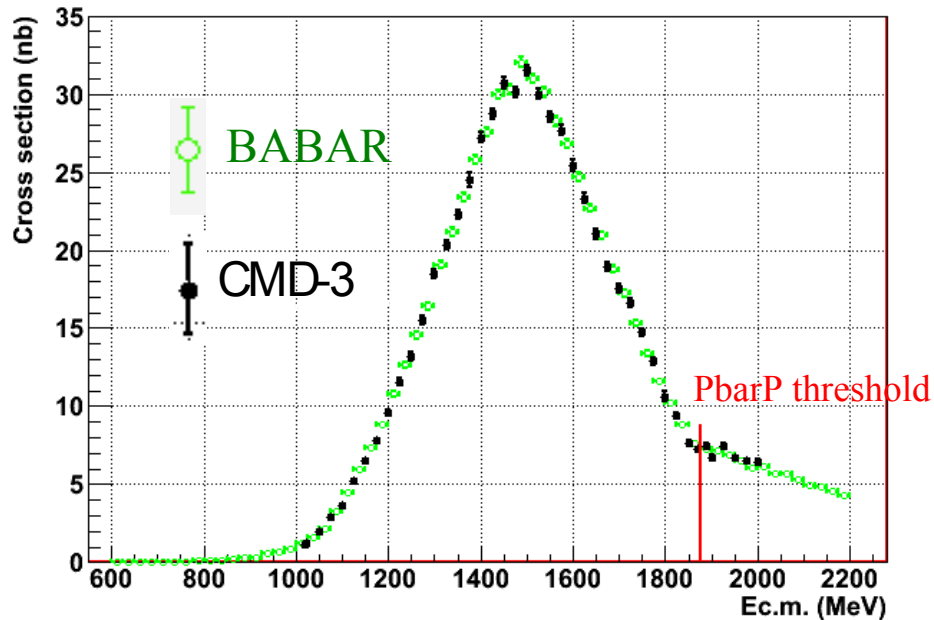
Analysis is close to publication

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

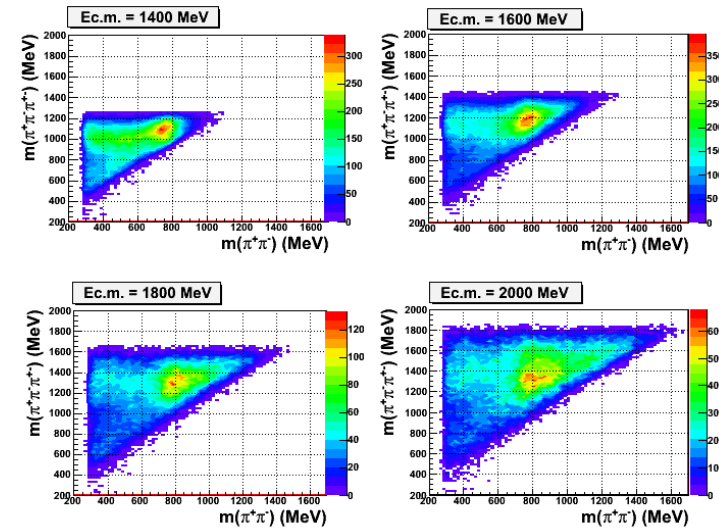


- clean selection of 4 and 3 charged pions
- statistical errors are at the level of 1-2% per point
- systematical errors are under investigation

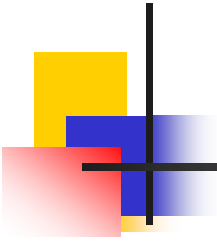
Preliminary



Preliminary mass distributions:



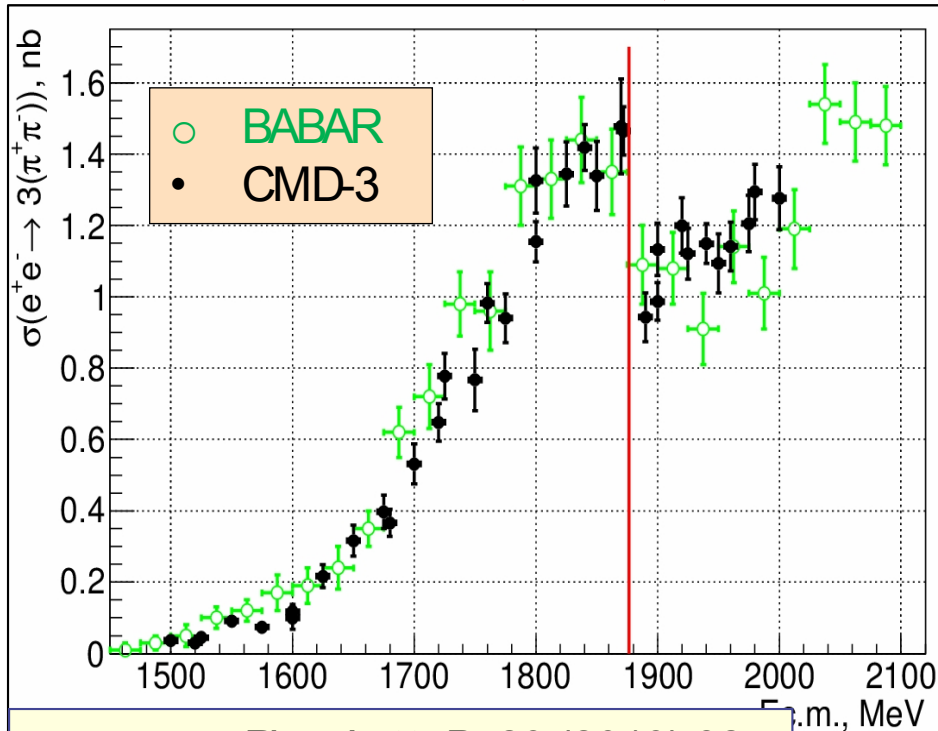
- $a_1(1260)\pi$ dominance
- other states ($\rho(770)f_0(600)$, $\rho(770)f_0(980)$, etc.) are seen, but small.



$$e^+e^- \rightarrow 6\pi$$

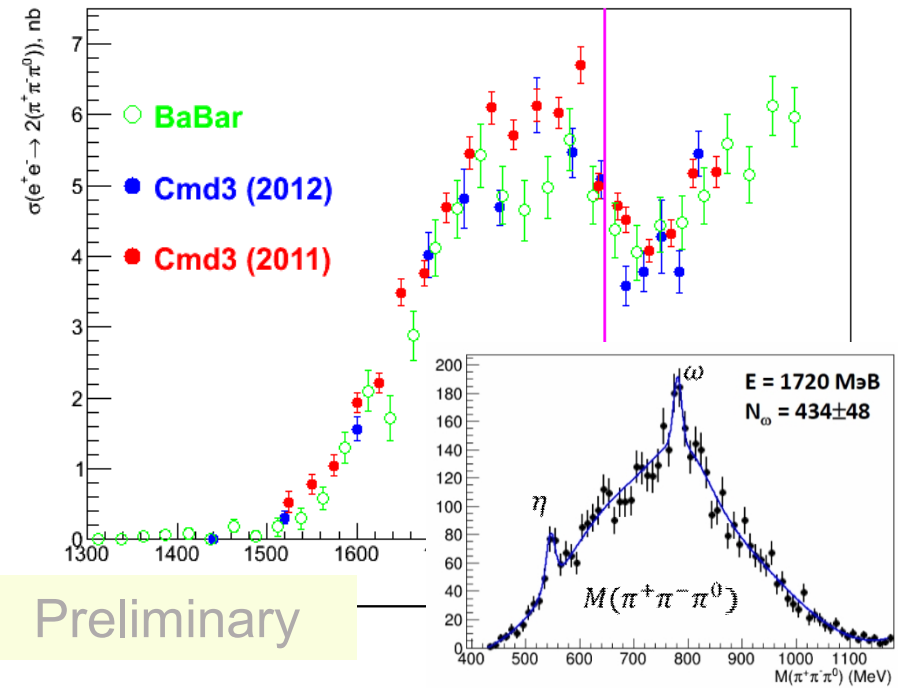


$$e^+e^- \rightarrow 3(\pi^+\pi^-)$$

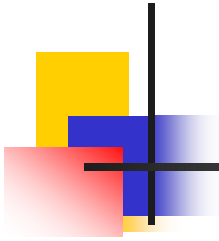


Published: Phys.Lett. B723 (2013) 82

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



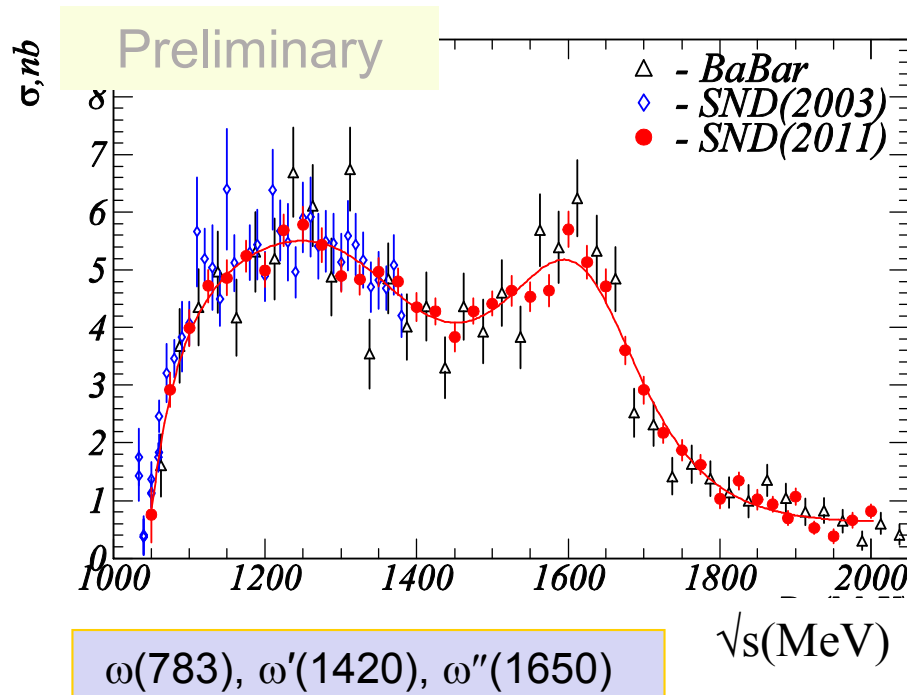
Preliminary



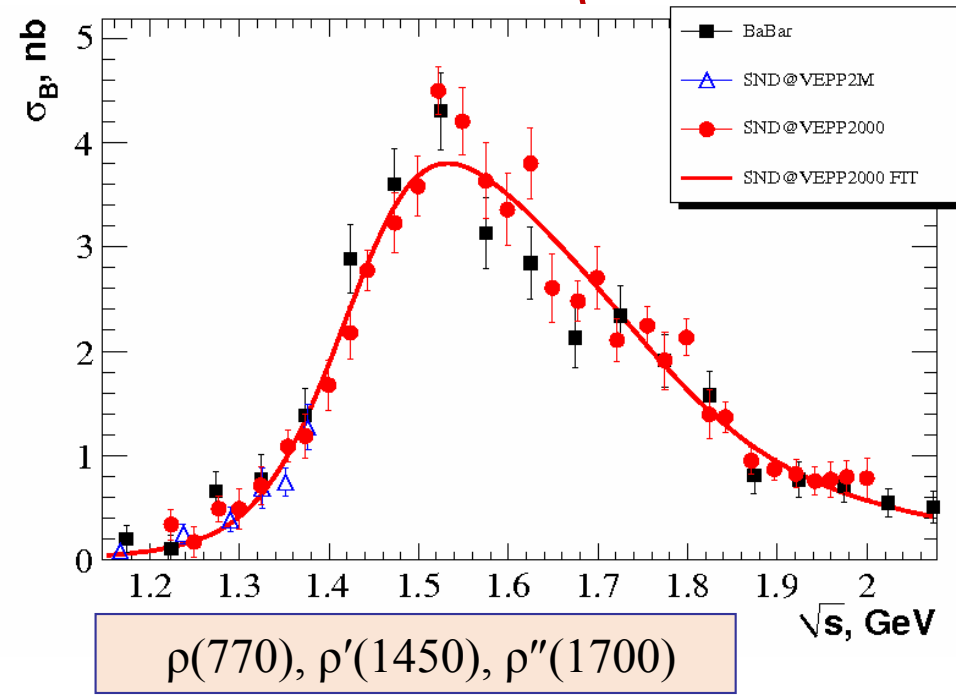
$$e^+e^- \rightarrow \pi^+\pi^-\gamma\gamma$$



$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$



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



Only half of statistics

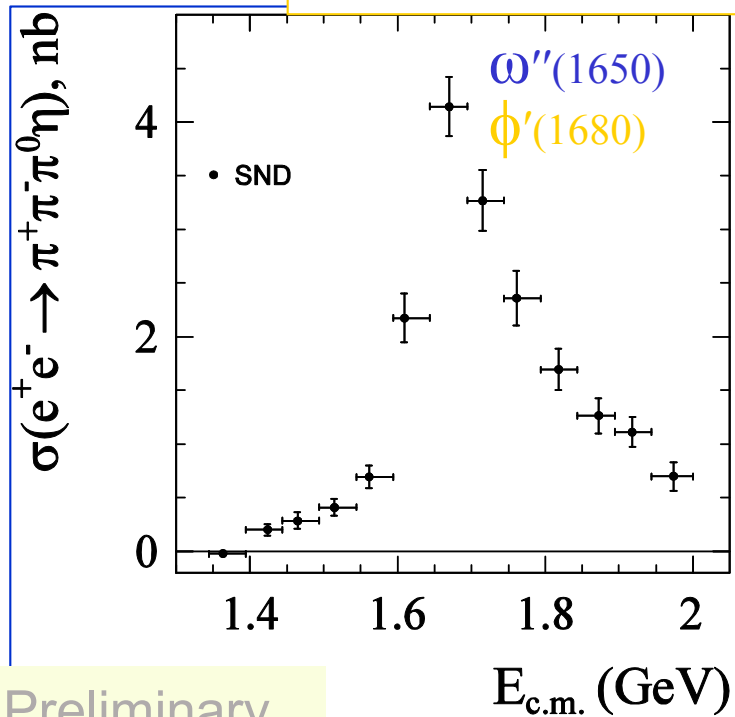
Systematic error: ~5%

Calculated using measured $e^+e^- \rightarrow \eta\pi^+\pi^-$ cross section energy dependence the $\tau^- \rightarrow \eta\pi^-\pi^0\nu_\tau$ branching fraction based on CVC hypothesis is equal to $(0.180 \pm 0.048)\%$, which is compatible with PDG value $(0.139 \pm 0.01)\%$

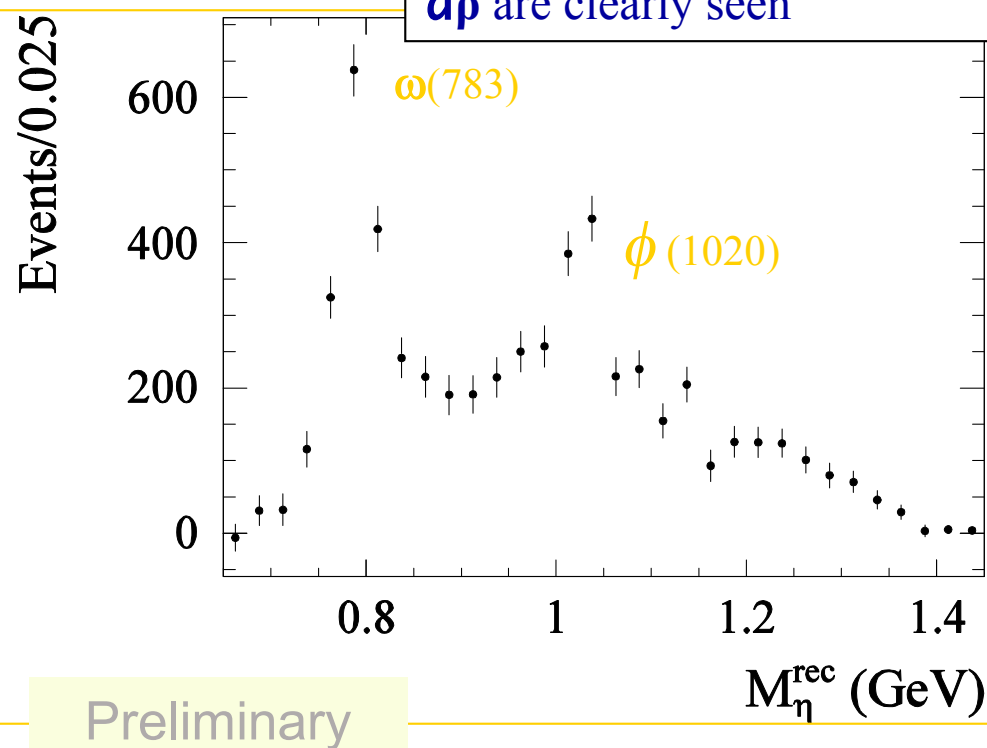
$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta \quad (\eta \rightarrow 2\gamma)$$



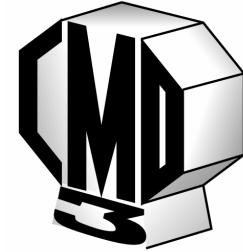
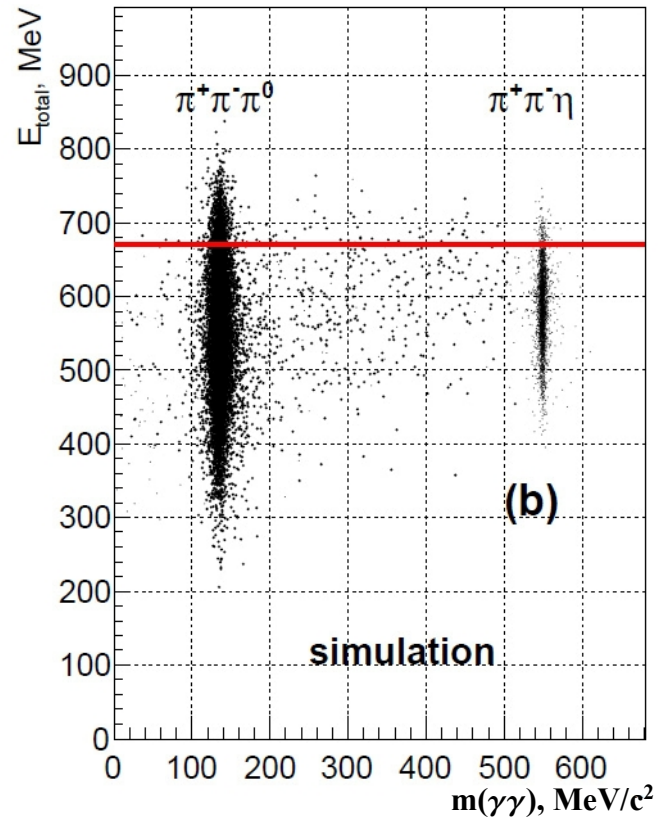
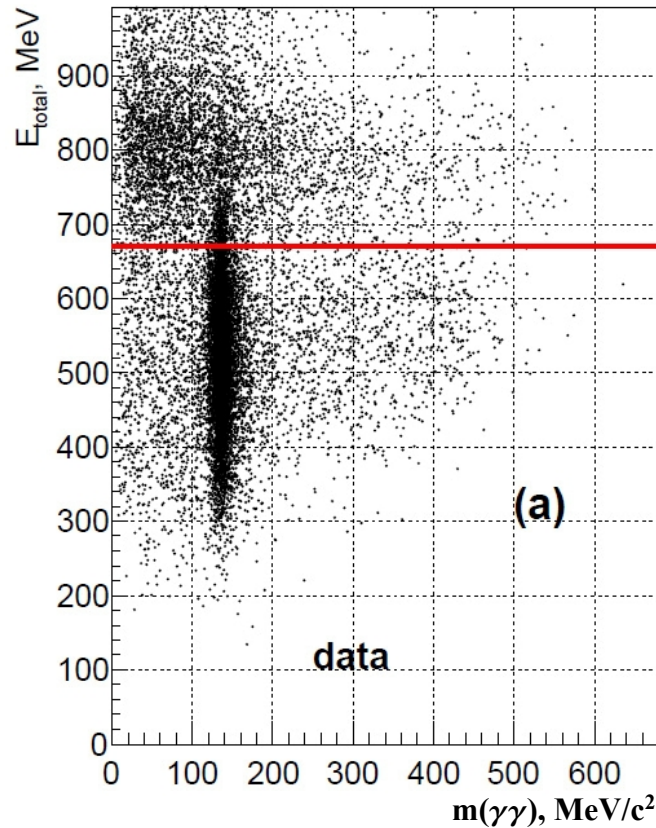
first measurement



intermediate states $\omega\eta$, $\phi\eta$,
 $\rho\pi$ are clearly seen

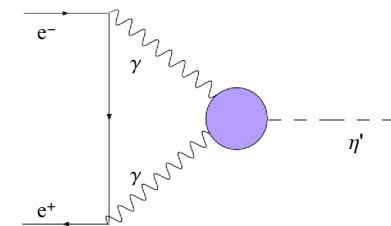


Search for the process $e^+e^- \rightarrow \eta'(958) \rightarrow \pi^+\pi^-\eta \rightarrow \pi^+\pi^-\gamma\gamma$



arXiv: 1409.1664 [hep-ex]

Result: $\Gamma(\eta' \rightarrow e^+e^-) < 2.4 \times 10^{-3} \text{ eV}$; $B(\eta' \rightarrow e^+e^-) < 2.1 \times 10^{-7}$ at 90% C.L..
 These limits are 10 times lower compared to the previous measurement
 The $\Gamma(\eta' \rightarrow e^+e^-)$ unitarity limit is $\approx 7.4 \times 10^{-6} \text{ eV}$





Baryon cross sections

Total cross section:
$$\sigma(s) = \frac{4\pi\alpha^2\beta C}{3s} \left(|G_M(s)|^2 + \frac{2M_N^2}{s} |G_E(s)|^2 \right),$$

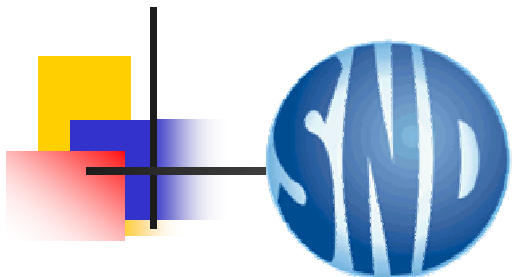
where C is the Coulomb factor, G_E and G_M are the electric and magnetic form factors.

For protons: $C \approx \frac{\pi\alpha}{\beta} / (1 - e^{-\frac{\pi\alpha}{\beta}})$ \longrightarrow Cross section is not zero at threshold
for neutrons: $C=1$

From the measured cross section, a combination of the squared form factors (G_E, G_M) can be extracted.

Differential cross section:
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta C}{4s} \left(|G_M(s)|^2 (1 + \cos^2 \vartheta) + \frac{4M_N^2}{s} |G_E(s)|^2 \sin^2 \vartheta \right)$$

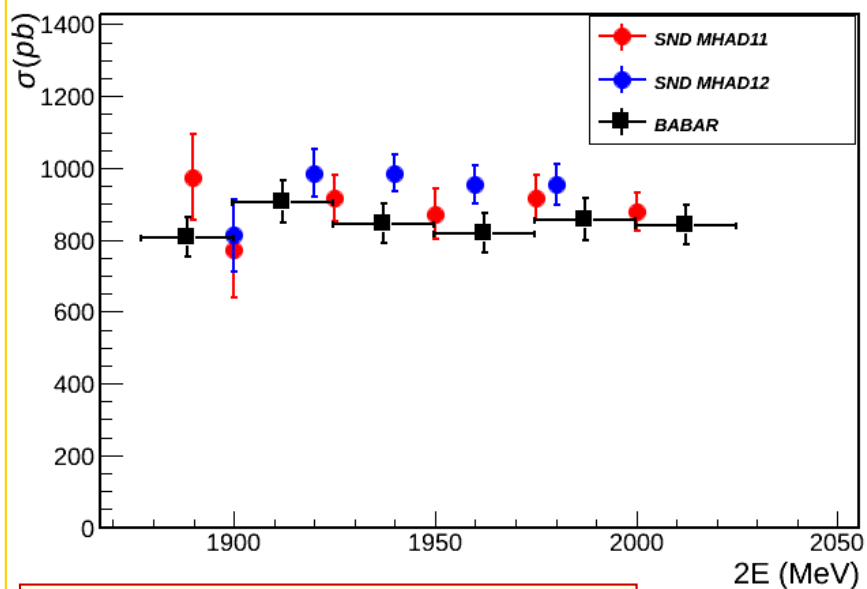
The ratio of the form factors $|G_E/G_M|$ can be determined from the analysis of the polar-angle distribution.



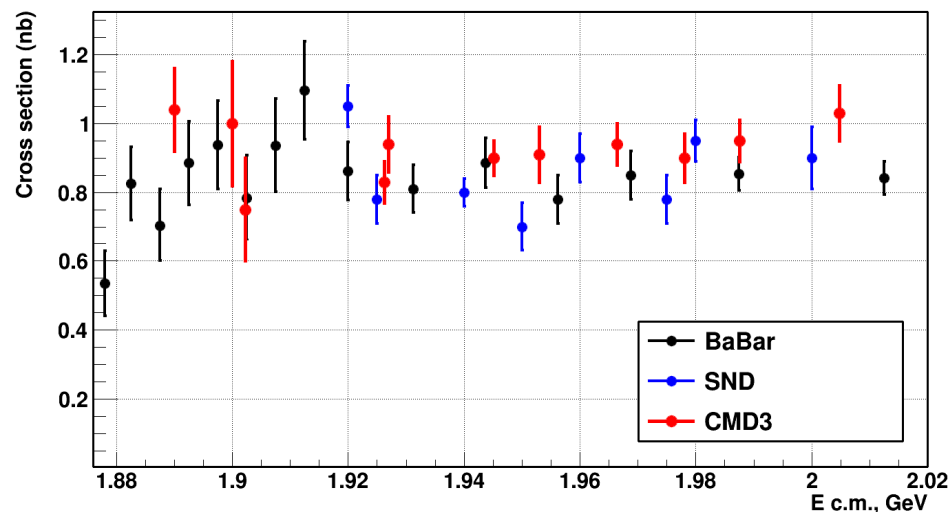
$$e^+e^- \rightarrow p\bar{p}$$



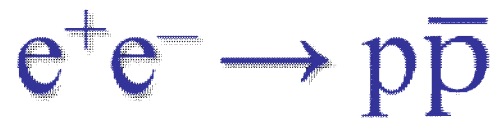
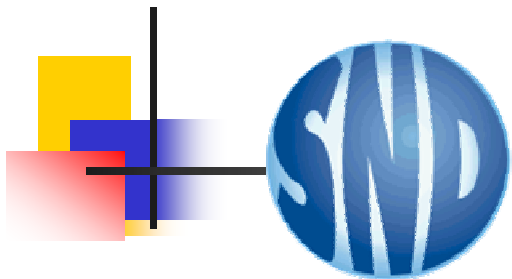
Preliminary



Preliminary



Systematic error $\sim 6\%$



(Angular distribution)



cosθ

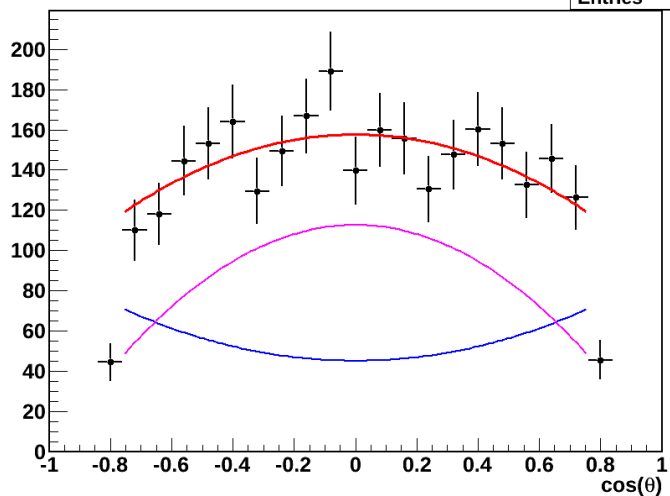
$$|G_E|^2 \leftrightarrow \sin^2\theta$$

$$|G_M|^2 \leftrightarrow (1 + \cos^2\theta)$$

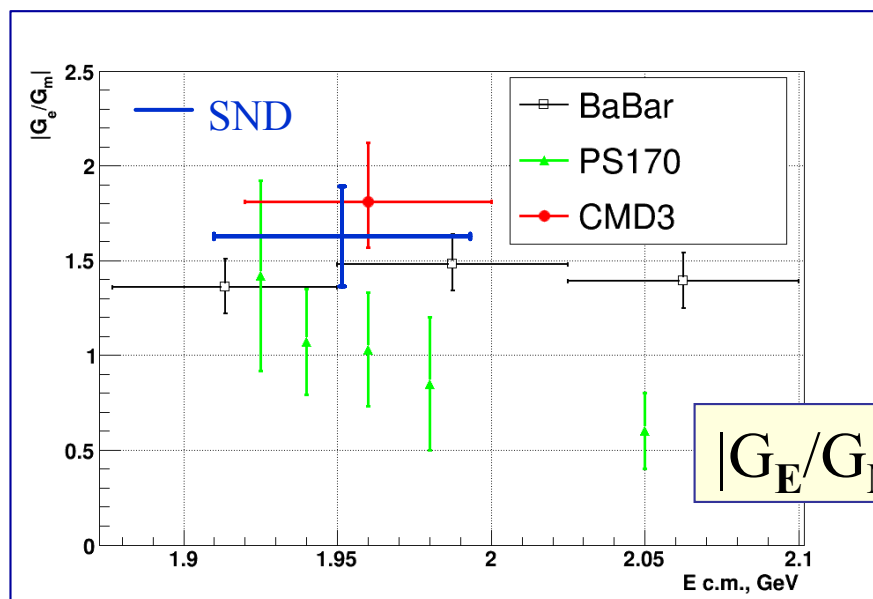
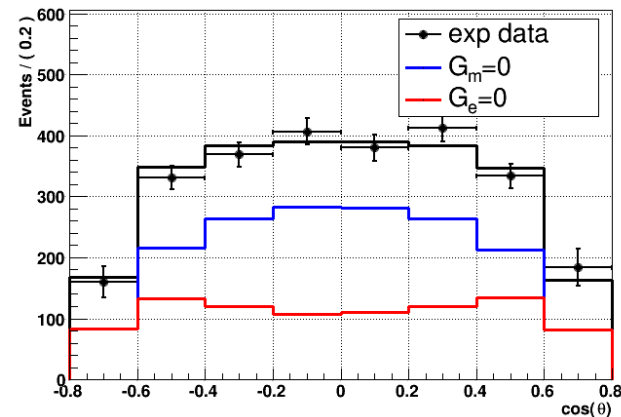
$E_{\text{beam}} = 960\text{-}1000\text{MeV}$,
 $|G_E/G_M| = 1.64 \pm 0.26$

cosθ

hx39b
 Entries 2866



Preliminary



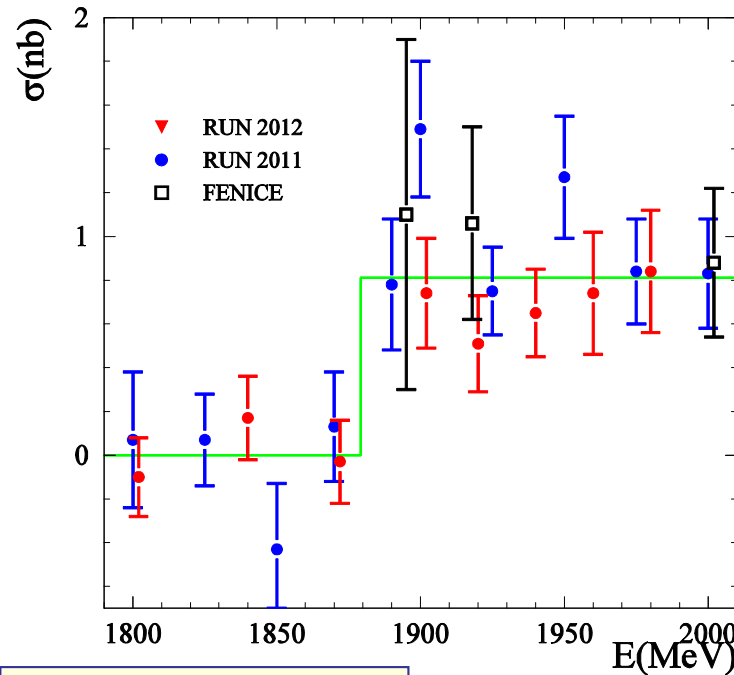
$|G_E/G_M|$

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



Cross section

Preliminary



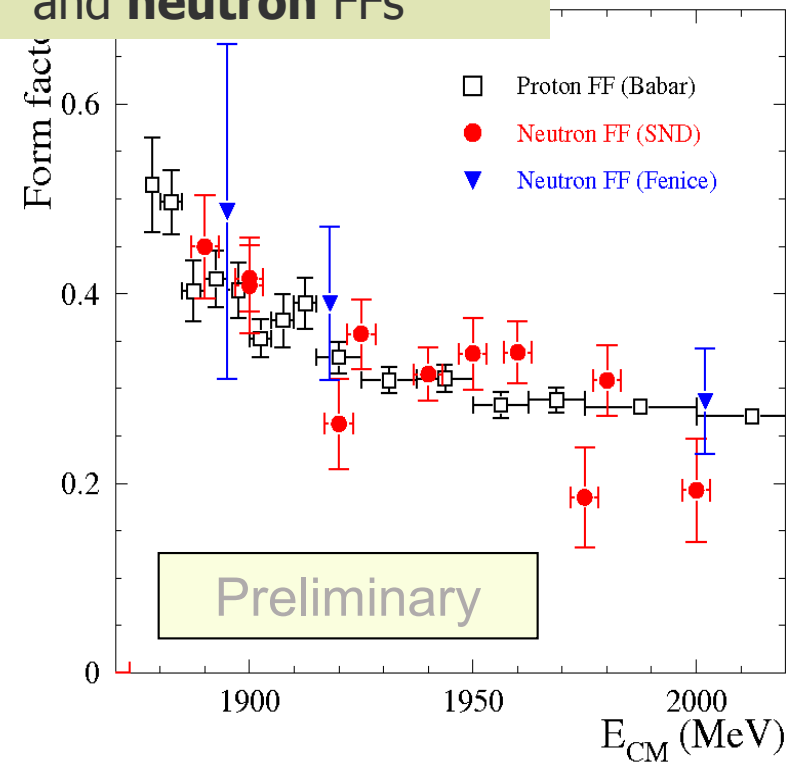
$$\sigma_{\text{aver}} = 0.8 \pm 0.2 \text{ nb}$$

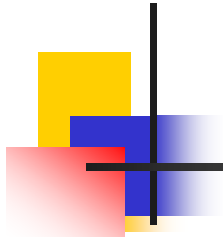
Systematics: $\sim 0.25 \text{ nb}$ ($\sim 30\%$)

Effective form factor:

$$|F|^2 = \frac{|G_M|^2 + |G_E|^2 / 2\tau}{1 + 1/2\tau}, \quad \tau = \frac{s}{4m_N^2}$$

A comparison of **proton** and **neutron** FFs





Conclusions

1. Since 2010 VEPP-2000 e+e- collider had accumulated $\sim 70 \text{ pb}^{-1}$ data with each SND and CMD-3 detectors in the energy range $E=0.3 - 2 \text{ GeV}$.
2. Data analysis on meson and nucleon production is in progress. The already collected data promise higher statistical precision on cross sections than previous experiments.
3. First publications on data analysis appeared (6π , $\omega\pi^0$, $\eta\gamma$), many preliminary results are in preparation for publications.
4. After VEPP-2000 upgrade in 2015 the data taking runs will be resumed with the goal of $\sim 1 \text{ fb}^{-1}$ integrated luminosity.