Hadronic cross-section measurement at SND

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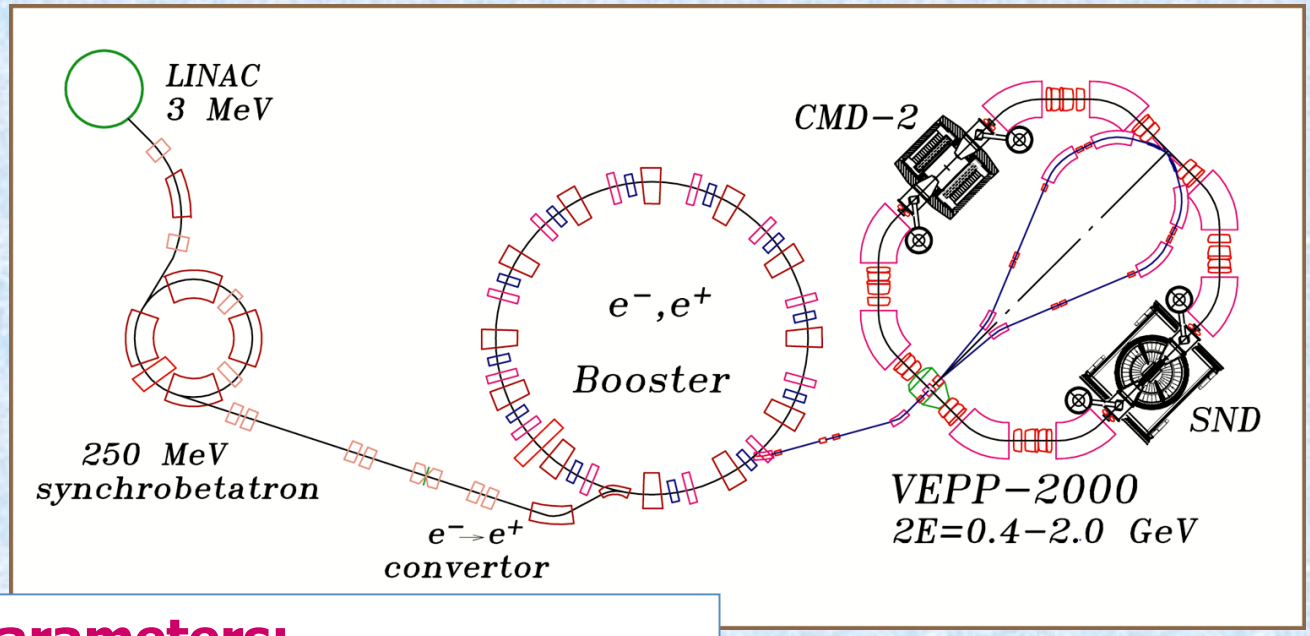
See details in Koop's talk

VEPP-2000 Collider



Main parameters:

- collision period – 82 ns
- beam current – 0.2 A
- bunch length – 3.3 cm
- perimeter – 24.4 m
- Energy spread – 0.7 MeV
- $\beta_x \simeq \beta_z = 6.3$ cm
- $L \simeq 10^{32}$ (2E=2.0 GeV)
- $L = 10^{31} cm^{-2} c^{-1}$ (2E=1.0 GeV)

designed

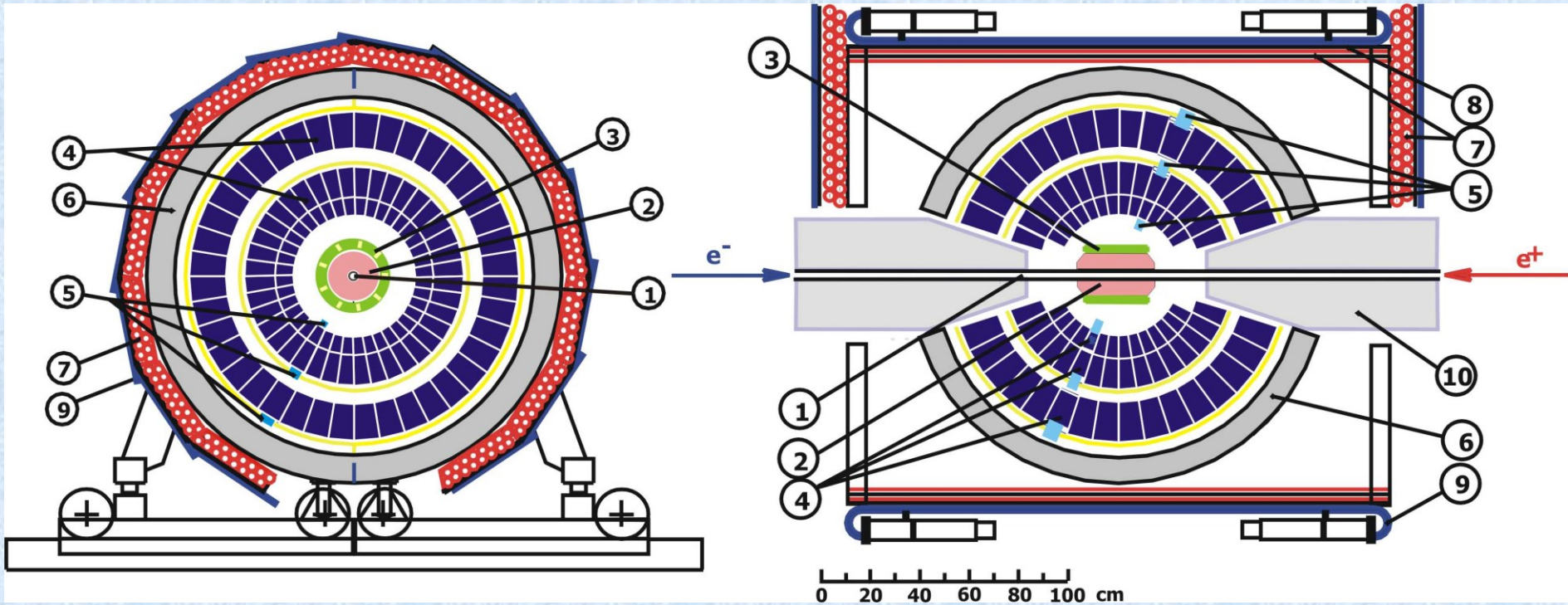
Achieved (2011-2013):

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

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

SND for VEPP-2000

NIM A449 (2000) 125-139



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.

SND parameters

Calorimeter:
1632 NaI(Tl) crystals
VPT reading
13.5 X_0
solid angle - 90% from 4π
$\Delta\varphi$ x $\Delta\theta$ =9° x 9°

Cherenkov counter:
9 counters with n=1.13
PMT reading
0.09 X_0
solid angle - 60% from 4π

Tracking system:
9-layer cylindrical drift chamber with 24 jet-type cells
solid angle - 94% from 4π
90% Ar + 10% CO_2 gas mixture
particle identification at p<300 MeV/c using dE/dx

Energy resolution:

$$\frac{\sigma_E}{E} = \frac{4.2\%}{\sqrt[4]{E(GeV)}}$$

Angular resolution:

$$\sigma_\phi = \frac{0.82^\circ}{\sqrt{E(\mathrm{GeV})}} \oplus 0.63^\circ$$

π- threshold: 300MeV/c

K- threshold: 950MeV/c

Efficiency(P=350MeV/c):

K – 7%, π – 90%

Angular resolution:

$$\sigma_\varphi = 0.55^\circ,\ \sigma_\theta = 1.2^\circ$$

Spatial resolution:

$$\sigma_R = 0.12cm,\ \sigma_Z = 0.45cm$$

Current work on detector upgrade

1. Upgrade of calorimeter electronics
2. Development of time measurements in calorimeter
3. Increasing events readout rate
4. Improving particle reconstruction and ID

Experiments 2010 - 2012

Experiment/year (1.05 – 2.0 GeV)	Integrated luminosity	$\sqrt{s} > 1.88$ GeV
MHAD 2010	5 pb^{-1}	71 nb^{-1}
MHAD 2011	25 pb^{-1}	3.8 pb^{-1}
MHAD 2012	17 pb^{-1}	4.9 pb^{-1}
Total	47pb^{-1}	8.8 pb^{-1}

Experiment 2013

Energy region ($\sqrt{s}$, GeV)	Integrated luminosity, pb^{-1}	ρ - ω region, pb^{-1}	η' - meson region, pb^{-1}	φ - meson region, pb^{-1}	non-resonant, pb^{-1}
0.32–1.06	32	15.5	3.5	7.5	5.5

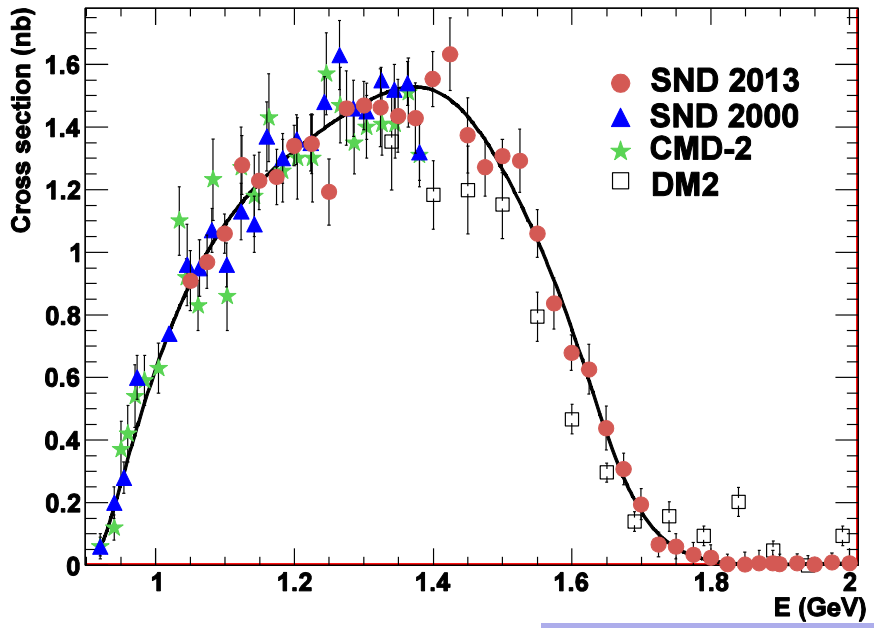
VEPP-2000 Physical program

- 1. Precise measurement of the quantity
  $R=\sigma(e^+e^- \to hadrons) / \sigma(e^+e^- \to \mu^+\mu)$
- 2. Cross section measurements of the processes of e^+e^- -annihilation into hadrons: $e^+e^- \to 2h, 3h, 4h \ldots, h= \pi, K, \eta, \ldots$
- 3. Study of "excited" vector mesons: $\rho', \rho'', \omega', \omega'' \varphi', ..$
- 4. CVC tests: comparison of $e^+e^- \to hadrons$ cross sections and $\tau \to \nu_\tau + hadrons$ decay spectra
- 5. Study of nucleon - antinucleon pair production $e^+e^- \to n\bar{n}, p\bar{p}$ and nucleon electromagnetic form factors, search for N anti-N resonances
- 6. Hadron production in "radiative return" processes:
  $e^+e^- \to \gamma^*\gamma, \gamma^* \to hadrons$
- 7. Two photon physics: $e^+e^- \to e^+e^- + hadrons$
- 8. Test of high order QED $2 \to 4, 5$

Process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ (30 pb^{-1})

(arXiv:1303.5198[hep-ex])

The most accurate measurement for 2E>1.4GeV



Systematic error: 3.4%
(2E<1.55 GeV)

Selection criteria:

≥ 5 γ; no charged particles;
total energy depos. > E_{beam};
kinematic fits:
$\chi^2_{5\gamma}<30$; $\chi^2_{\pi0\pi0\gamma} - \chi^2_{5\gamma}<10$;
$|M_{\pi0\gamma} - M_{\omega}|<100$ MeV

SND using CVC hypothesis:
$Br(\tau^- \to \omega\pi^-\nu_\tau) = (1.96\pm0.02\pm0.10)\%$
PDG:
$Br(\tau^- \to \omega\pi^-\nu_\tau) = (1.95\pm0.08)\%$
No difference within experimental accuracy.

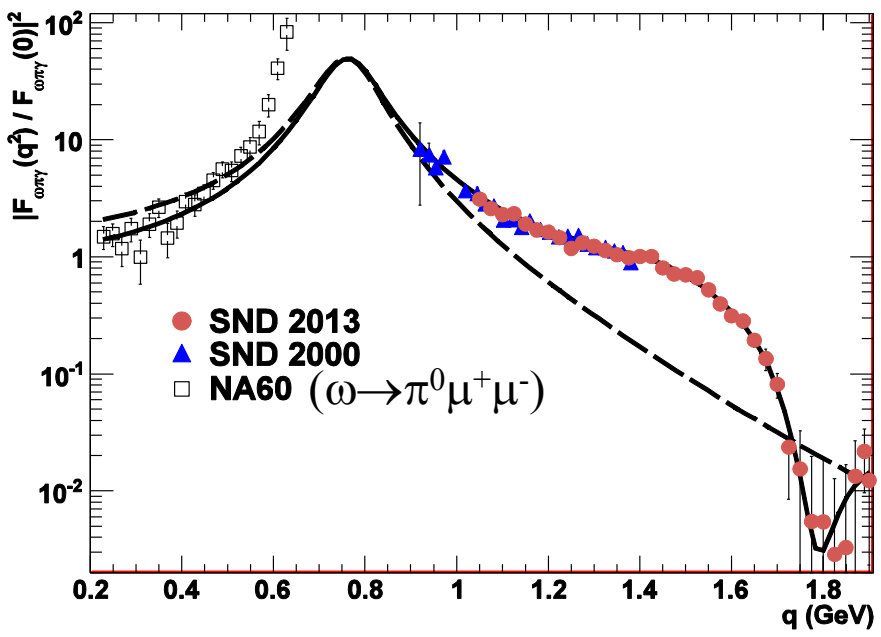
Fit:
sum of ρ(770), ρ′(1450), ρ″(1700)

Process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ (30 pb^{-1})

(Transition form factor $\gamma^* \to \omega\pi^0$, $F_{\omega\pi\gamma}$)

$$\sigma_{\omega\pi^\circ} = \frac{4\pi\alpha^2}{E^3}\left|F_{\omega\pi\gamma}(E^2)\right|^2 P_f(E),\ P_f(E) - \text{phase space factor}$$

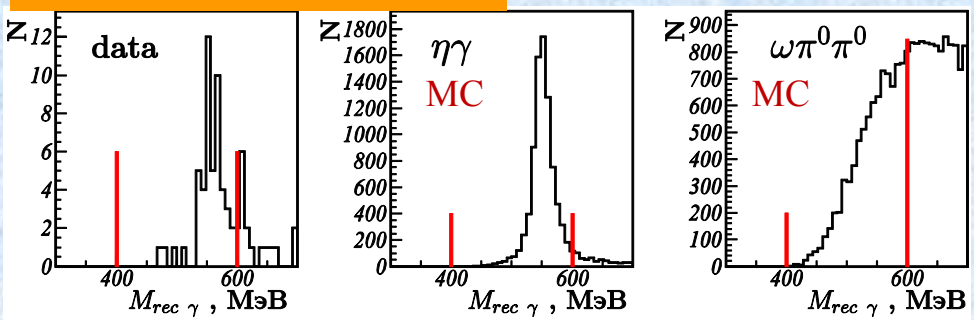
$|F_{\omega\pi\gamma}(q^2)/ F_{\omega\pi\gamma}(0)|^2$



Solid line – model prediction with ρ(770), ρ′(1450), ρ″(1700) parameters from the cross section fit.
Dashed line – ρ(770) contribution.

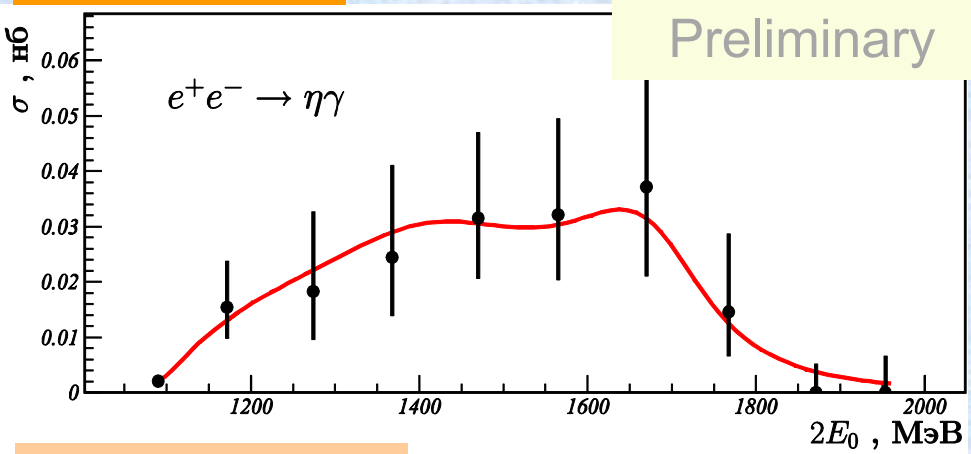
$e^+e^- \to \eta\gamma \to 7\gamma$ (32 pb^{-1})
(first measurement for $\sqrt{s}$ >1.4GeV)

Photon recoil energy



Cross section

Preliminary



Total ~60 events

Selection criteria:

≥7γ, no charged tracks ;

energy dep. > (0.7÷1.2)2E_{beam};

Kinematic fits:

$\chi^2_{n\gamma}$ <30; $\chi^2_{\pi0\pi0\gamma}$ >50;

$\chi^2_{7\gamma}$ <50;

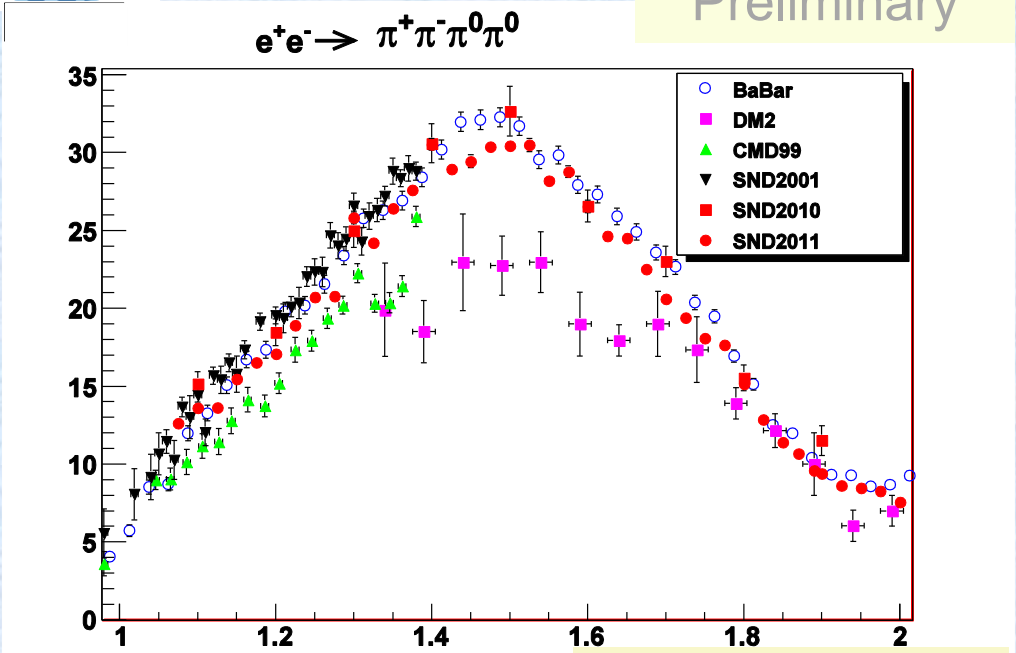
400 MeV< $M_{\gamma\ rec}$ <600 MeV

Fit:

Sum of ρ(770), ρ′(1450), ρ″(1700)

Process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ ($30pb^{-1}$)

Preliminary



Only statistical errors

Systematics ≤ 10%

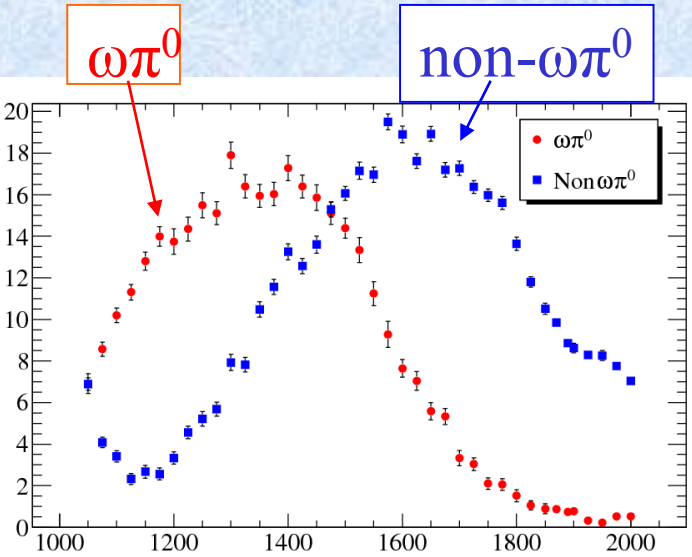
Selection criteria :

- at least 2 charged particles and 4 γ's;
- 2 tracks are from IP;

Kinematic fit:

$\chi^2 < 40$

$M_{\pi 0}$ in 70-200 MeV.

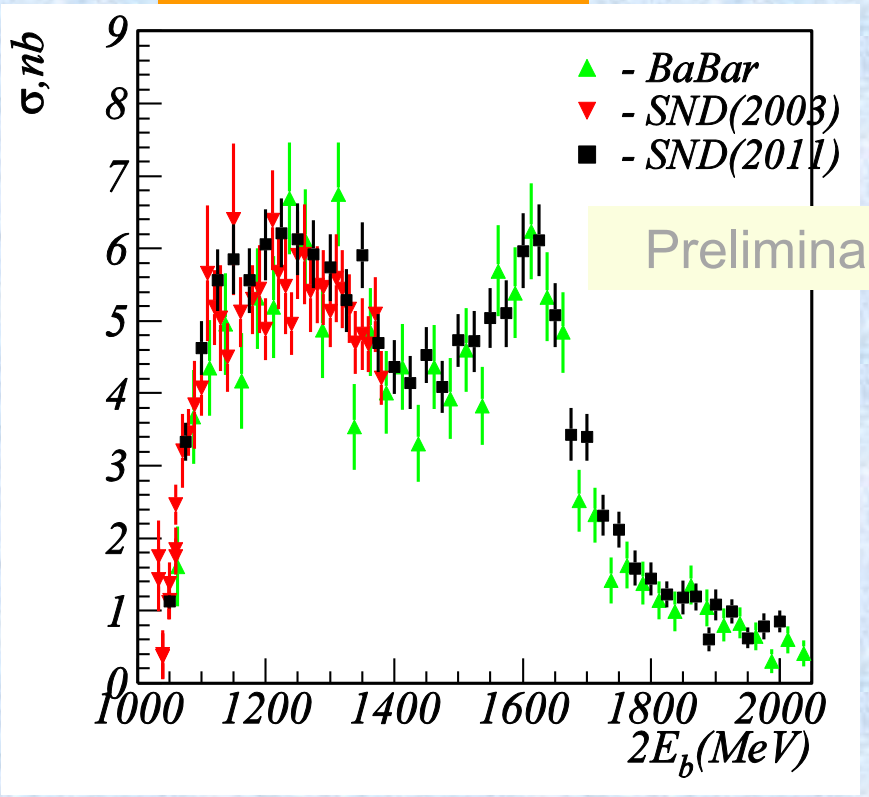


The bump is a sum of contributions of ρ(770), ρ′(1450), ρ″(1700).

Main feature – many intermediate states: $\omega\pi^0$, $a_1\pi$, $\rho\pi\pi$, $\rho^+\rho^-$, ρf_0.

Process $e^+e^- \to \pi^+\pi^-\pi^0$ ($22pb^{-1}$)

Cross section



Only statistical errors

Systematic: ~5%

Selection criteria :

– 2 central charged particles

– 2 γ's

– $\Delta\varphi_{ch..} > 10°$

– total energy dep. $(0.3\text{-}0.8)E_{beam}$

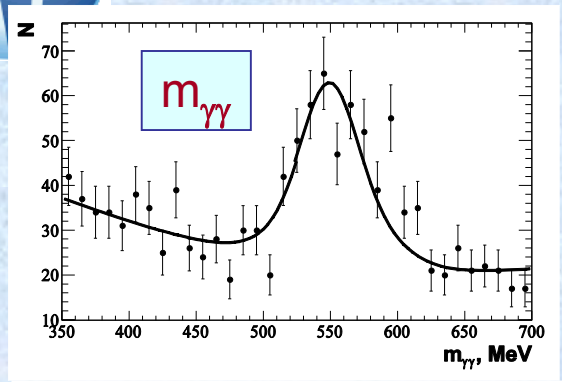
Kinematic fit:

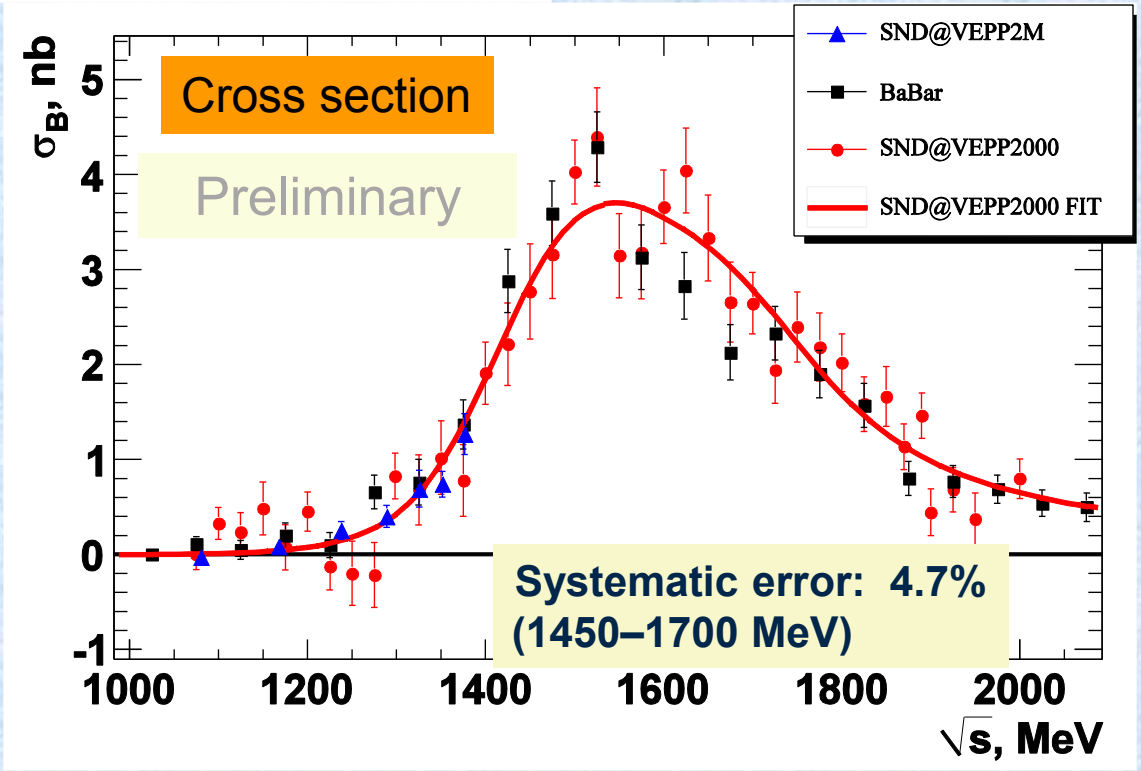
– $\chi^2_R < 40$, $\chi^2_{\pi+\pi-\gamma\gamma} < 40$;

Fit to $M_{\pi 0}$ spectrum (effect + background)

Spectrum is a sum of contributions from ω(782), ω′(1420), ω″(1650).

Process $e^+e^- \to \eta\pi^+\pi^-$ ($30pb^{-1}$)





Selection criteria :

2 central charged particles,
2 photons,
$\theta_{charged}$ (22.5°-157.5°),
θ_{photon} (36°-144°),
kinematic fit
($\pi^+\pi^-\gamma\,\gamma$): $\chi^2 < 20$

Fit: sum of
$\rho(770)$, $\rho'(1450)$, $\rho''(1500)$

CVC hypothesis:
$Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau)$=
(0.188+0.058-0.057)%
PDG:
$Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau)$ =
(0.139±0.01)%

Baryon cross sections

Details in Serednyakov's talk (Wednesday, 11.09)

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: $C\approx\frac{\pi\alpha}{\beta}/(1-e^{-\frac{\pi\alpha}{\beta}})$

for neutrons: C=1

→ Cross section is not zero at threshold

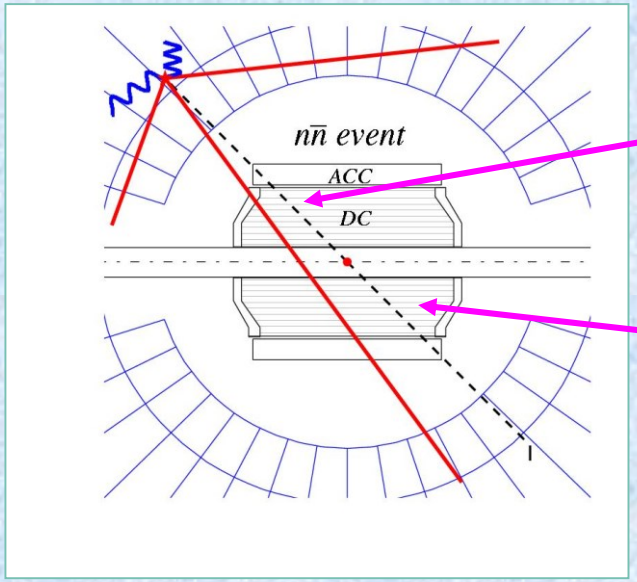
From the measured cross section, a combination of the squared form factors (G_E,G_M) can be extracted.

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.

Process $e^+e^- \to n\bar{n}$ (10 pb^{-1})

Event signature:



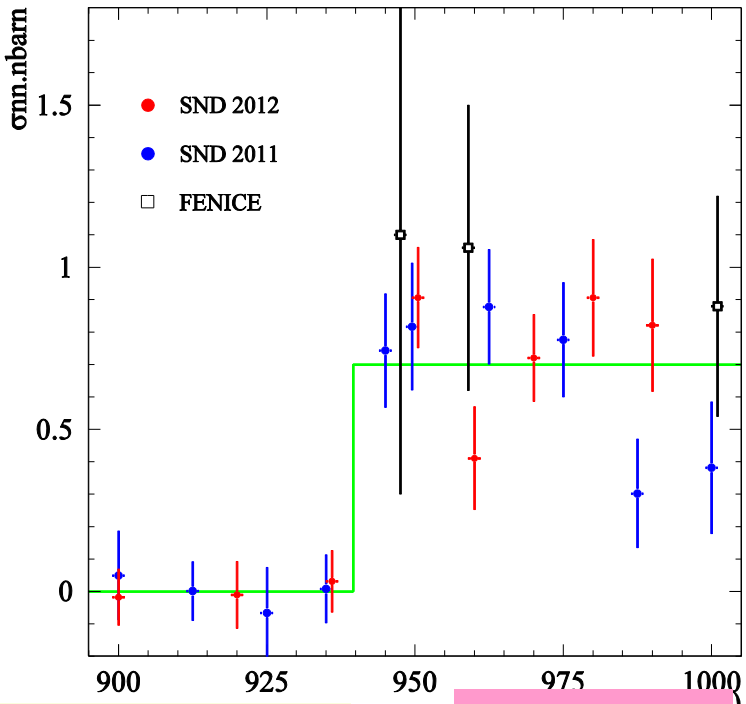
$\bar{n}$

n

- Small energy deposition in calorimeter from ***n***
- "star" from $\bar{n}$ annihilation point in Cherenkov counters or calorimeter

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

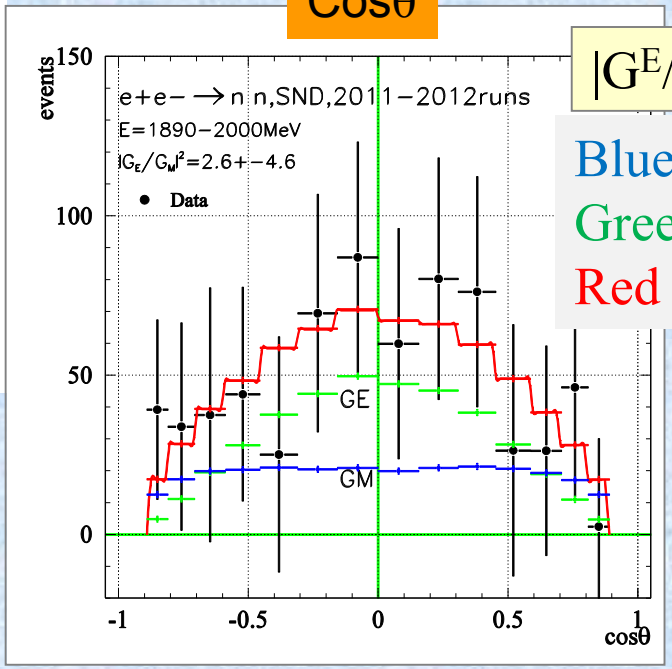
Cross section



Main features of the cross section:
1 – cross section has a threshold behavior,
2 – selected events are delayed on 5-10 nsec,
3 – cross section is stable under condition variations,
4 – uniform ϕ distribution.

Systematics: ~0.25 nb (~30%)

Cosθ



$|G^E/G^M|^2 = 2.6 \pm 4.6$

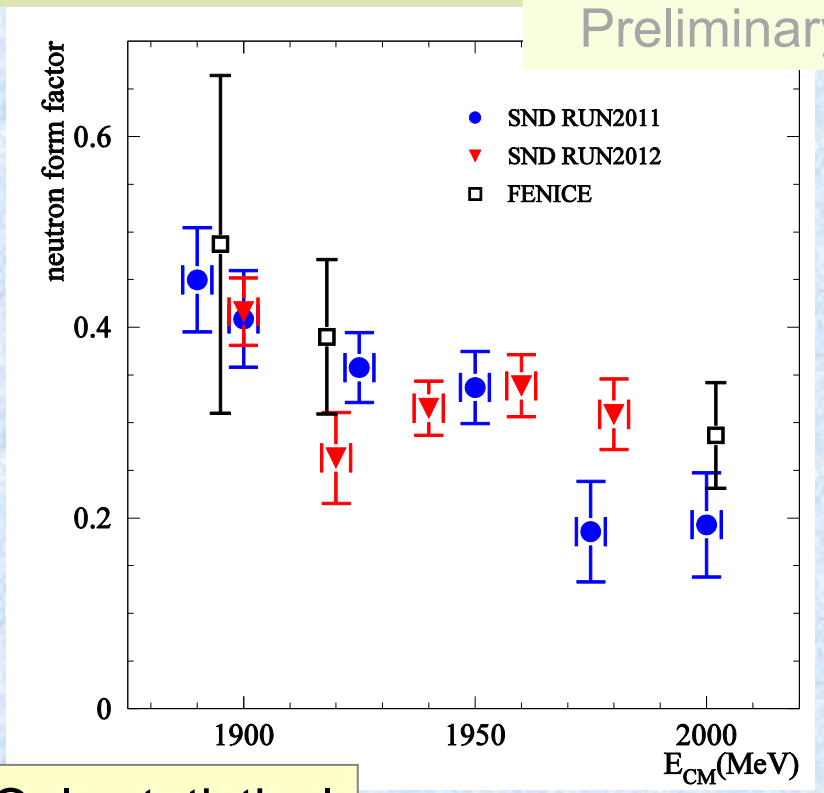
Blue – G_M contribution
Green – G_E contribution
Red – best fit

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

Effective form factor: $|F|^2 = \dfrac{|G_M|^2 + |G_E|^2 / 2\tau}{1 + 1/2\tau}, \quad \tau = \dfrac{s}{4m_N^2}$

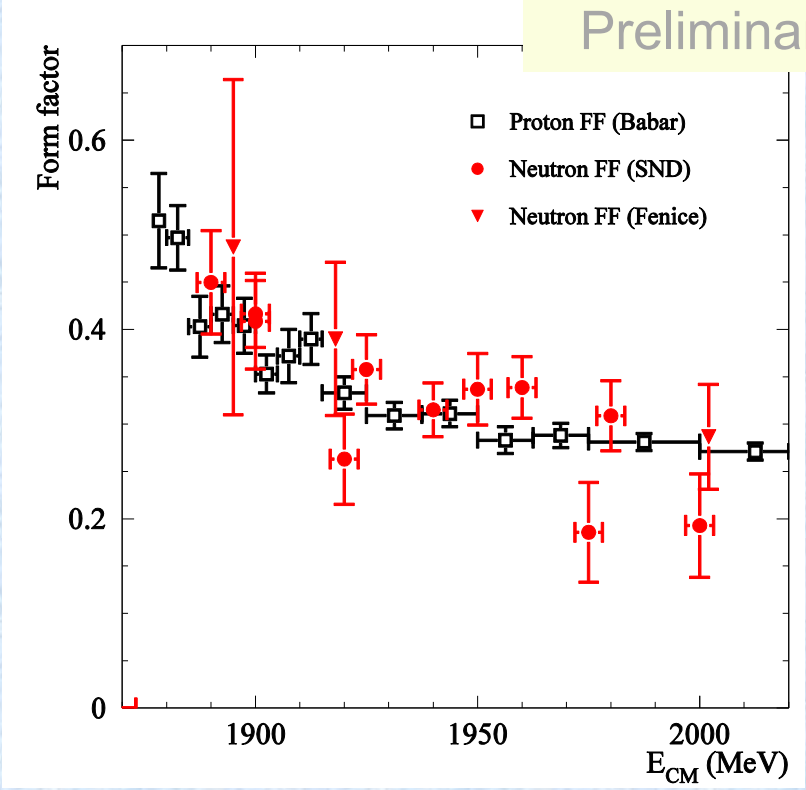
Neutron effective time-like form factor

Preliminary



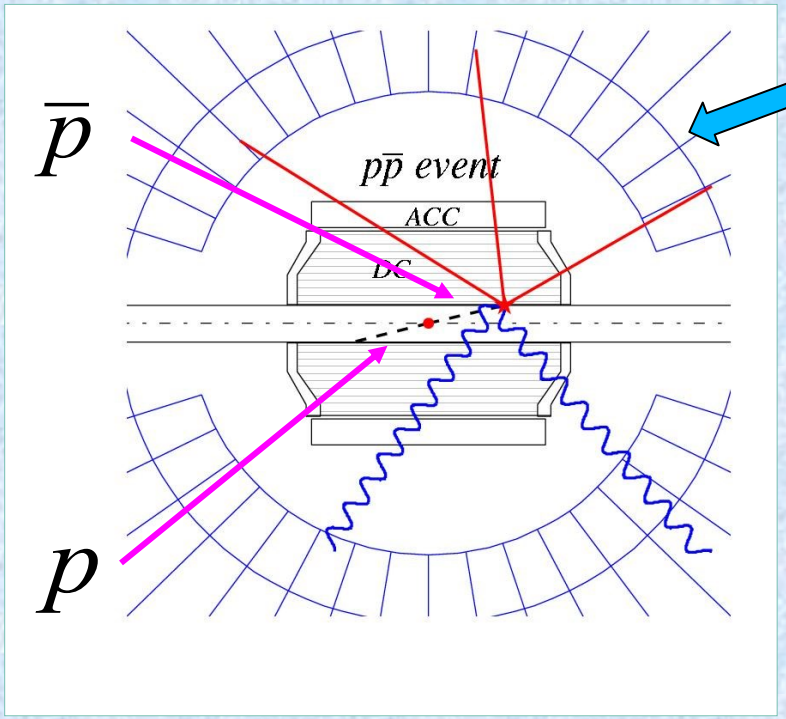
A comparison of proton and neutron FFs

Preliminary



Only statistical errors

Process $e^+e^- \to p\bar{p}$ (10 pb^{-1})



Events features (from threshold up to E_{beam}=960MeV):

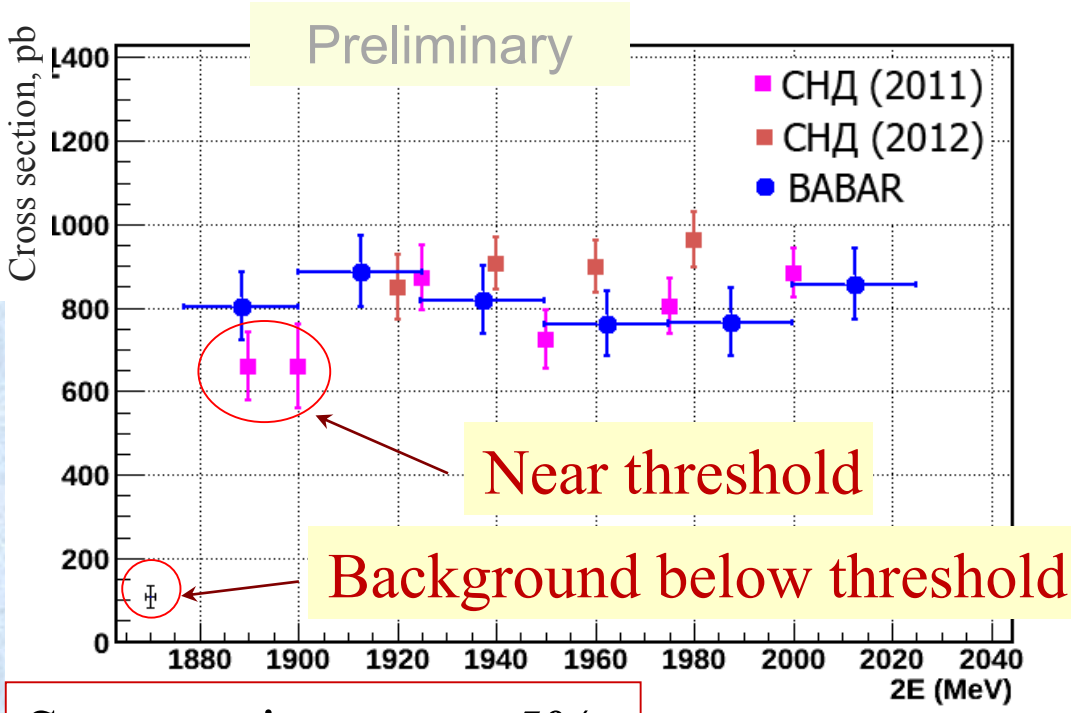
- No signal from p
- "star" from $\bar{p}$ annihilation in vacuum tube

Events features (E_{beam}>960MeV):

- charged track and no energy deposition for p
- charged track and "star" from $\bar{p}$ annihilation in Cherenkov counters

Process $e^+e^- \to p\bar{p}$ ($10\ pb^{-1}$)

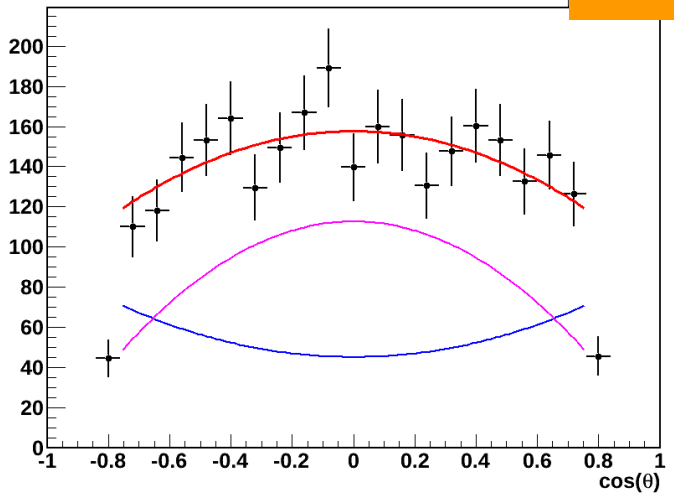
Cross section



Systematic error ~ 5%

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

Cosθ

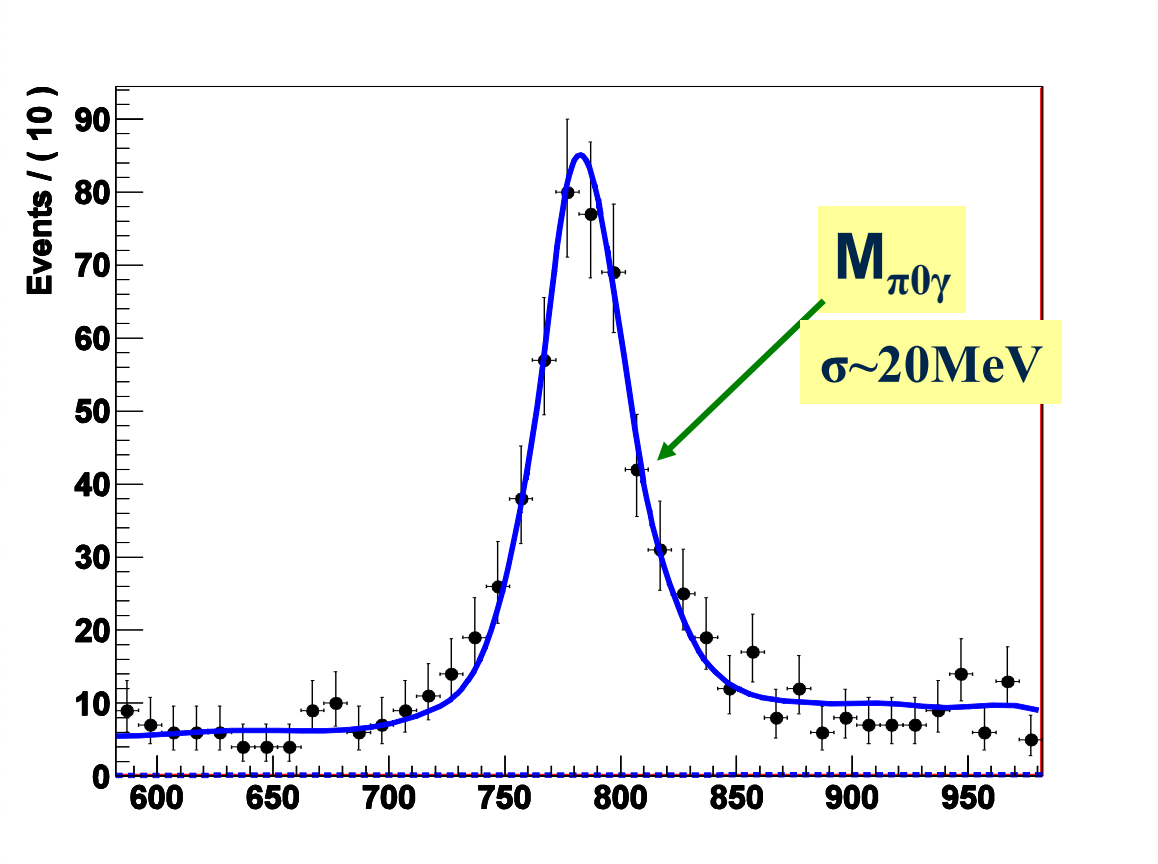


Conclusions & Plans

1. **Successful experiments with the SND detector at the VEPP-2000 were performed during last four years. About 80 pb^{-1} of data were collected in the energy range 0.32-2.0 GeV.**
2. **Preliminary results on different hadronic cross sections at the energy range 1.05 – 2.0 GeV have been obtained: $e^+e^- \to \omega\pi^0$, $\eta\gamma$, $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^0\pi^0$, $\eta\pi^+\pi^-$, $n\bar{n}$, $p\bar{p}$. The results are in agreement with previous measurements.**
3. **To obtain results on the full SND data sample.**
4. **To study more hadronic processes: $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, K_SK_L, K^+K^-, $K_s(K^+\pi^-)_{cc}$, etc .**
5. **To upgrade SND detector for high luminosity runs.**

Thank you

Process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$



Cuts:

- at least 5γ
- no charged particles
- total energy depos. > E_{beam}
- kinemat. reconstruction:

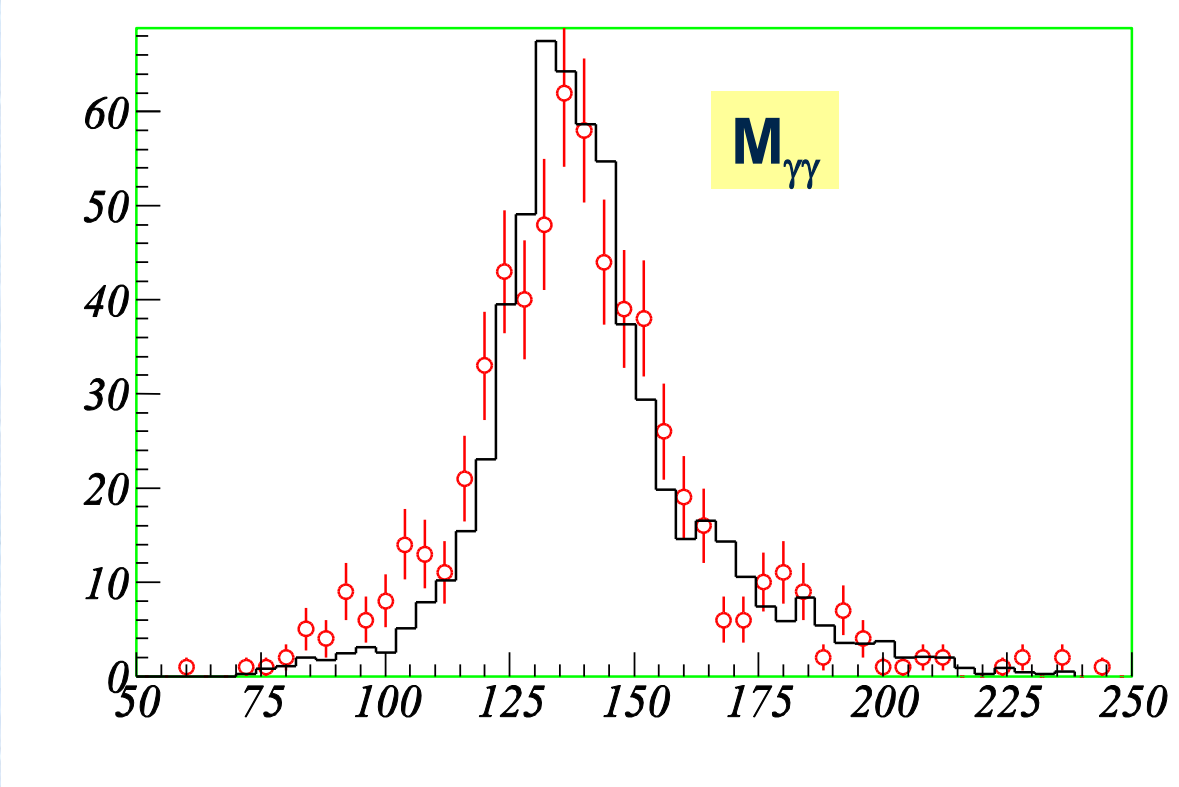
$\chi^2_{5\gamma} < 30$; $\chi^2_{\pi 0\pi 0\gamma} - \chi^2_{5\gamma} < 10$;

$|M_{\pi 0\gamma} - M_\omega| < 100$ MeV

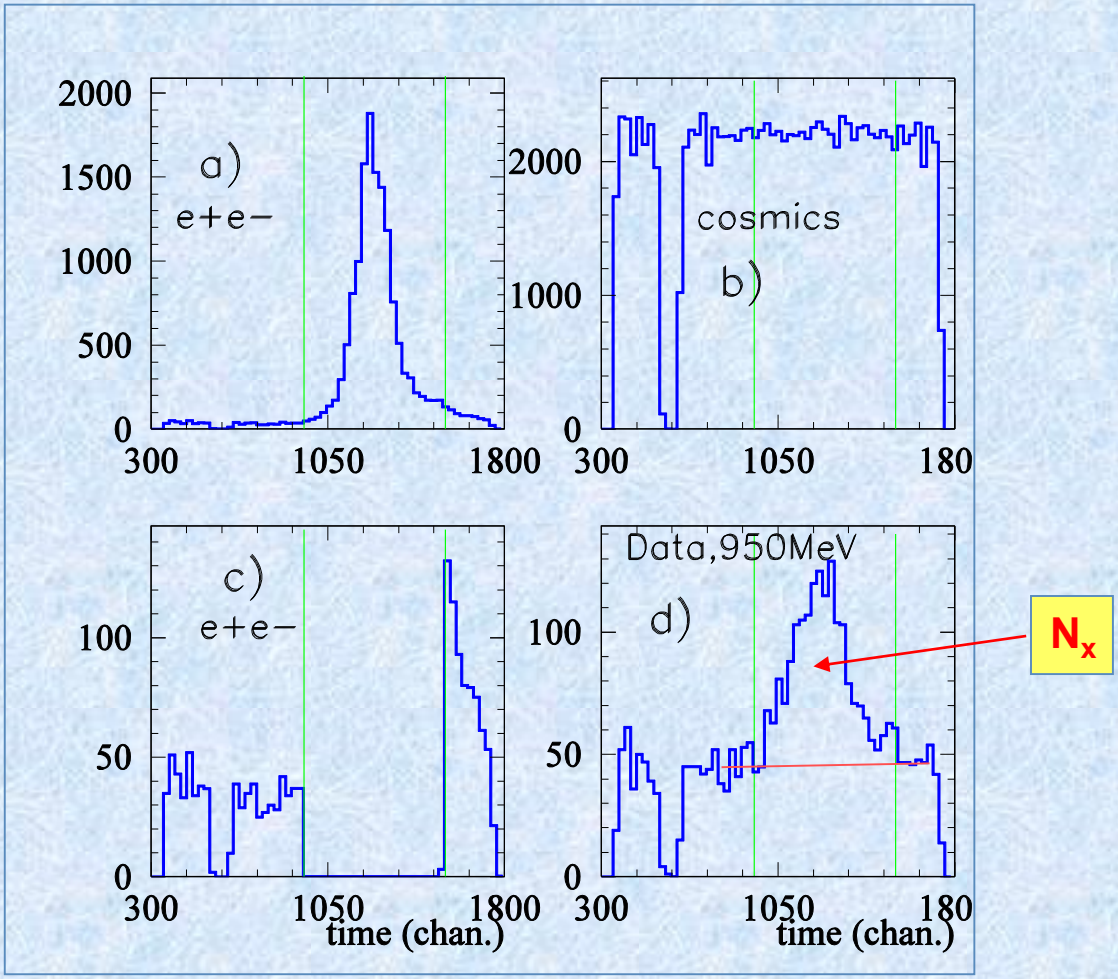
Fitting:

sum of ρ(770) and ρ(1450)

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



Cosmic suppression using event time



CVC: $Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.188+0.058-0.057)\%$

PDG: $Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.139 \pm 0.01)\%$

Typical view of
$e^+e^- \to \pi^+\pi^-\pi^0$ event