Measurement of the timelike neutron and proton form factors at VEPP-2000

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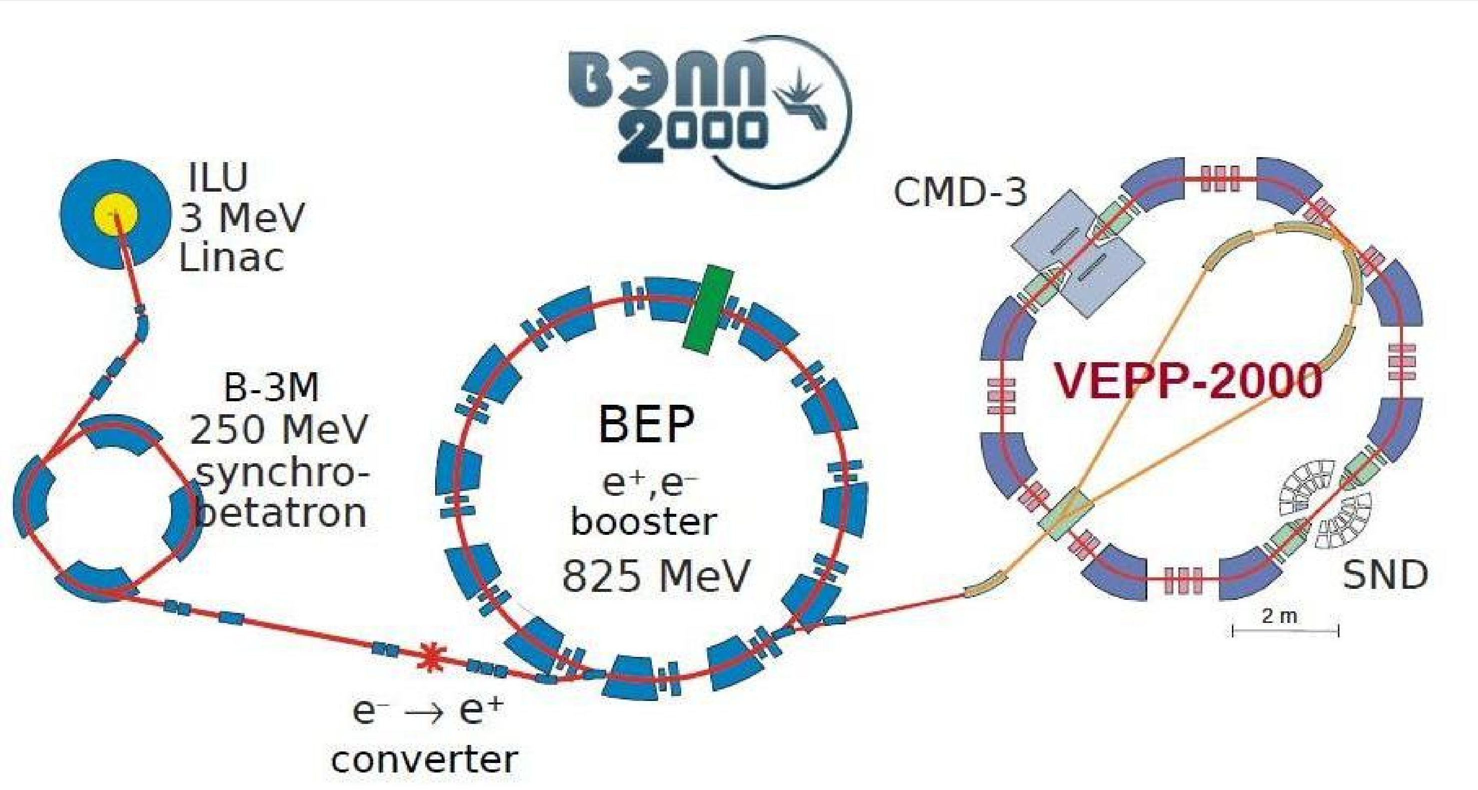
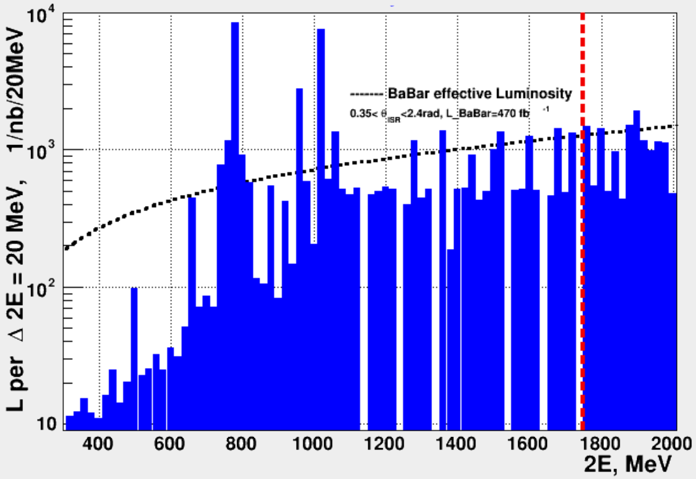
VEPP-2000 complex



Center-of-mass energy (E)	0.3-2.0 GeV
Beam energy spread	0.6 МэВ (at E=1.8 GeV)
Luminosity (L)	$0.7 \cdot 10^{31}$ cm^{-2} sec^{-1} (at E=1.8 ГэВ)

Data 2010-2012

Experiment (1.05 – 2.0 GeV)	**Integrated luminosity**	**$\sqrt{s} > 1.88$ GeV**
02.2010 – 06.2010	5 pb^{-1}	71 nb^{-1}
12.2010 – 06.2011	25 pb^{-1}	3.8 pb^{-1}
01.2012 – 04.2012	17 pb^{-1}	4.9 pb^{-1}
Total	47pb^{-1}	8.8 pb^{-1}



$e^+e^- \to$ nucleon anti-nucleon

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

$C\approx\frac{\pi\alpha}{\beta}/\left(1-e^{-\frac{\pi\alpha}{\beta}}\right)$ for proton

$C=1$ for neutron

G_E and G_M are the electric and magnetic form factors.

Differential cross section:

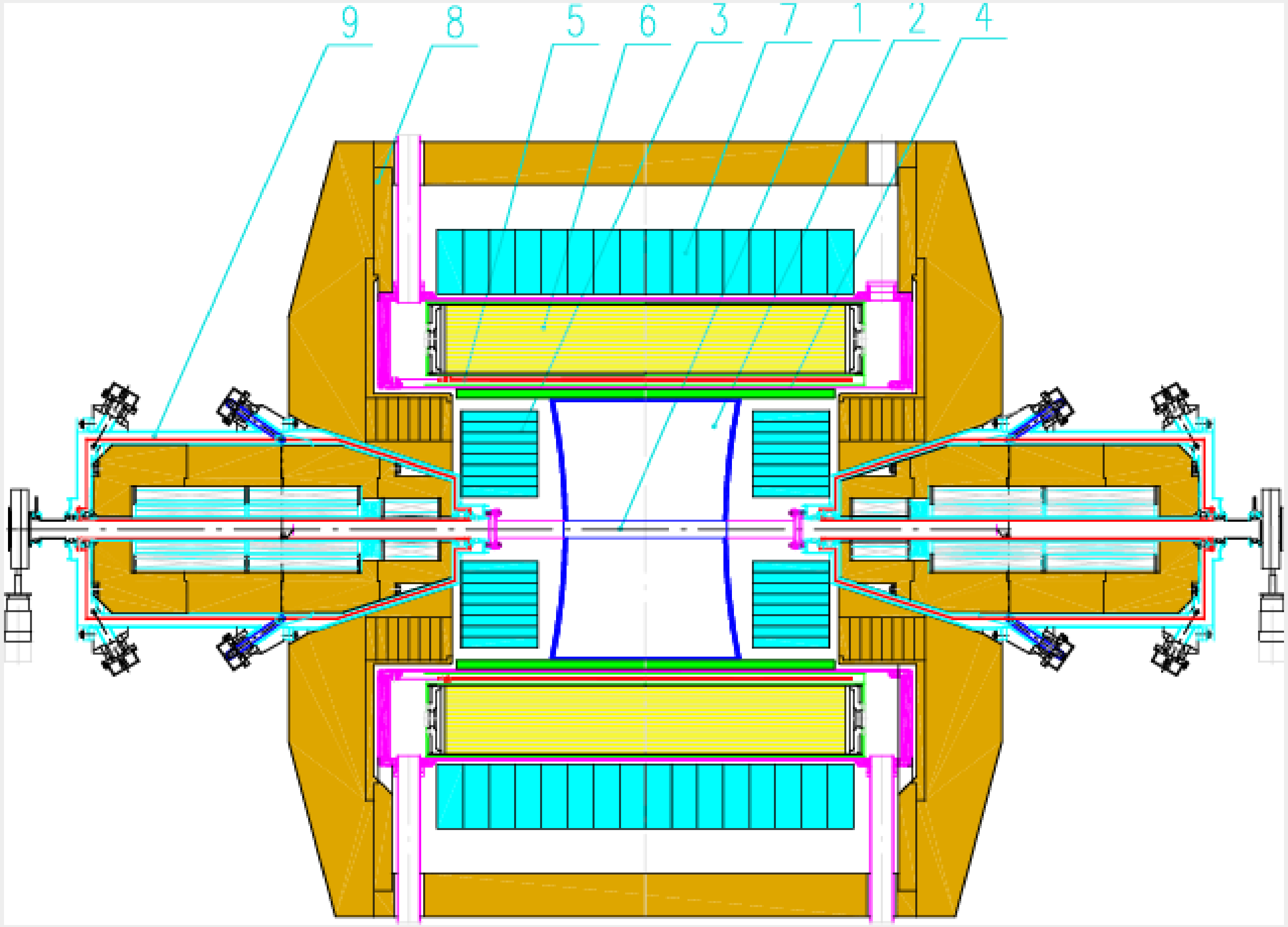
$$\frac{d\sigma}{d\Omega}=\frac{\alpha^2\beta C}{4s}\left(|G_M(s)|^2(1+\cos^2\theta)+\frac{4M_N^2}{s}|G_E(s)|^2\sin^2\theta\right)$$

Angular distributions is used to extract $|G_E/G_M|$

"Effective form factor":

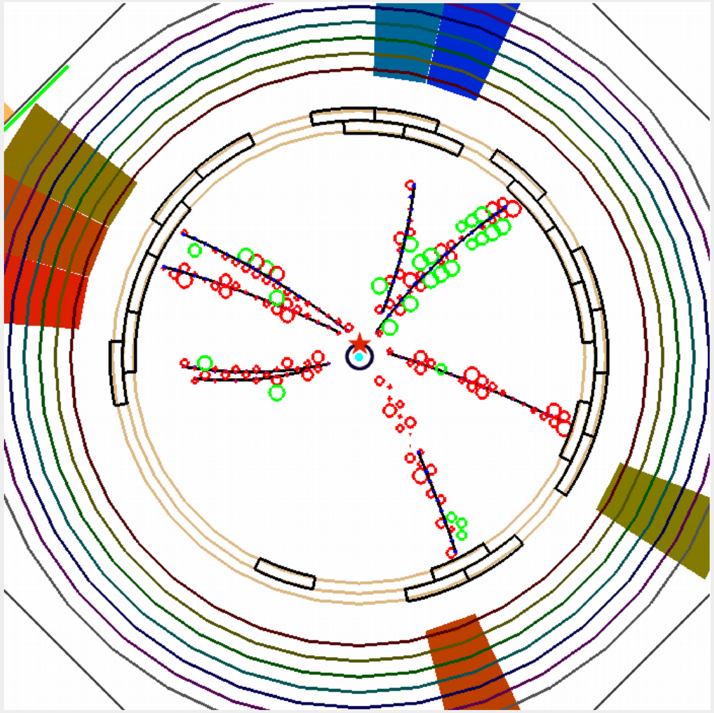
$$F(s)=\frac{|G_M(s)|^2+\frac{2M_N^2}{s}|G_E(s)|^2}{1+\frac{2M_N^2}{s}}$$

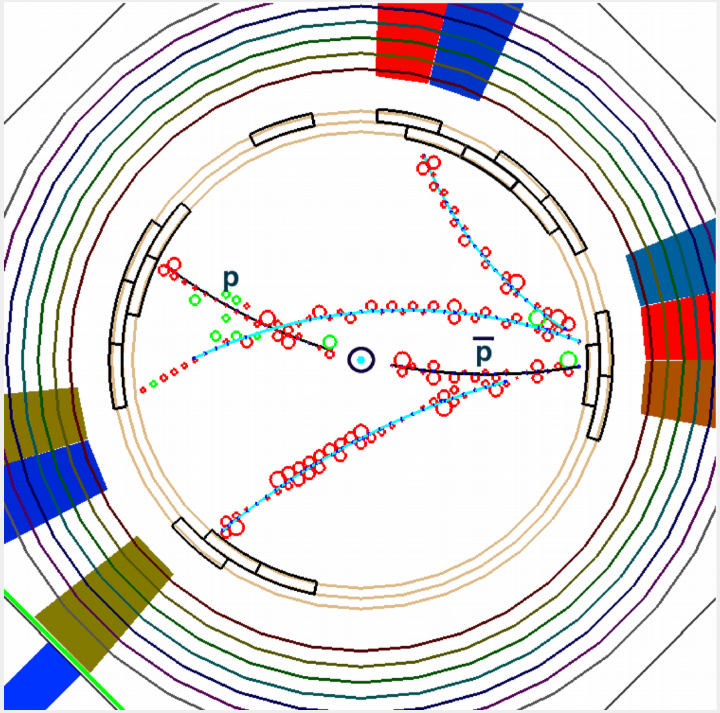
CMD-3



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

$e^+e^- \to p\bar{p}$ events





- E_{beam}= 945 MeV
- $\bar{p}$ stops and annihilates in the beam pipe
- produces secondary particles

- E_{beam}= 970 MeV
- p is absorbed in the Z-chamber
- $\bar{p}$ annihilates
- some secondary particles came back

$p\bar{p}$: Signal selection

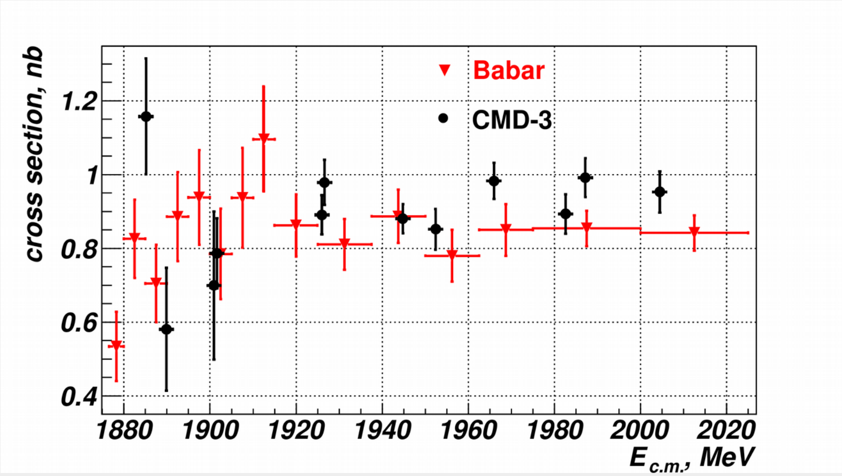
E_{beam} ≤ 950 MeV:

- 4 or more tracks common vertex found in the beam pipe material;
- no tracks with energy deposition in calorimeter higher than 400 MeV.

E_{beam} > 950 MeV:

- two opposite-charge collinear central tracks in DC;
- $|p1 - p2|/(p1 + p2) < 0.15$ (< 0.2 for E_{beam} <955 MeV);
- total energy deposition in the calorimeter >200 MeV.

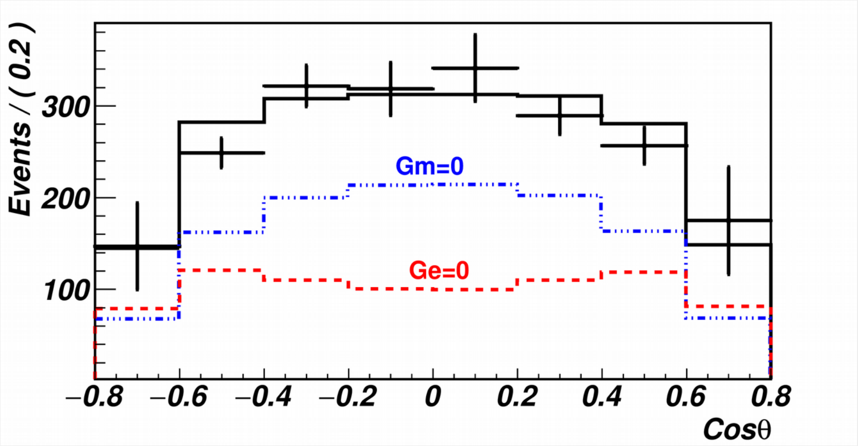
$p\bar{p}$: CMD-3 Results



arXiv:1507.08013

Cross section

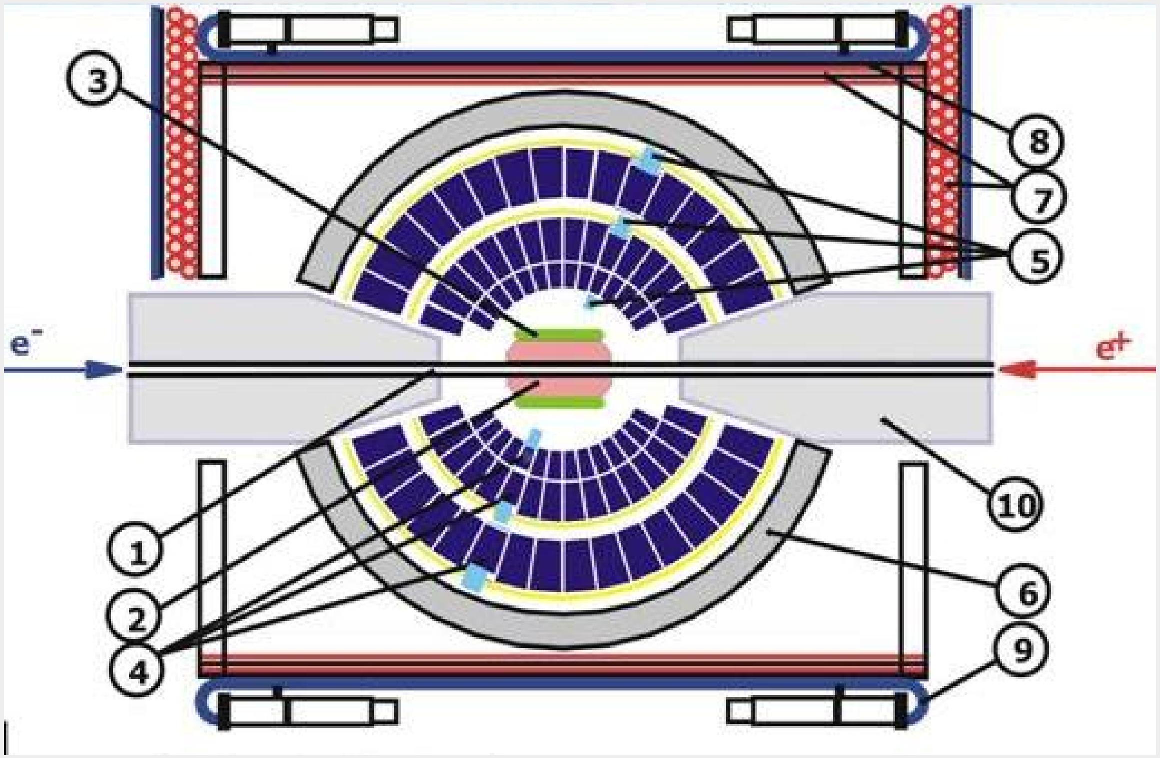
systematic uncertainty ~ 6%



Fit

$|G_E/G_M| = 1.49 \pm 0.23 \pm 0.3$

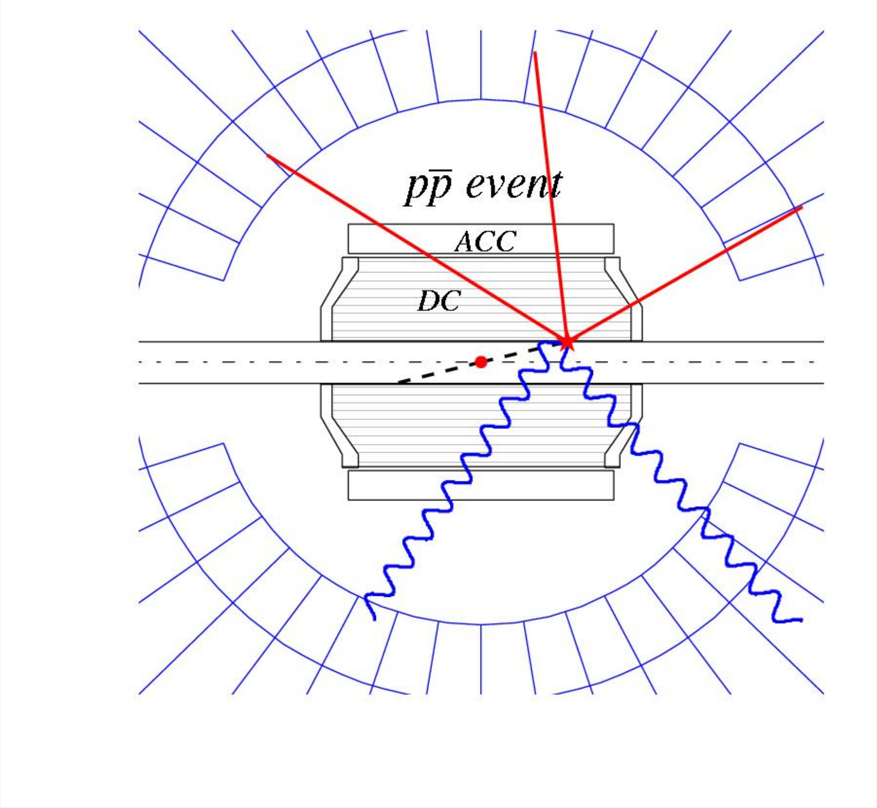
SND

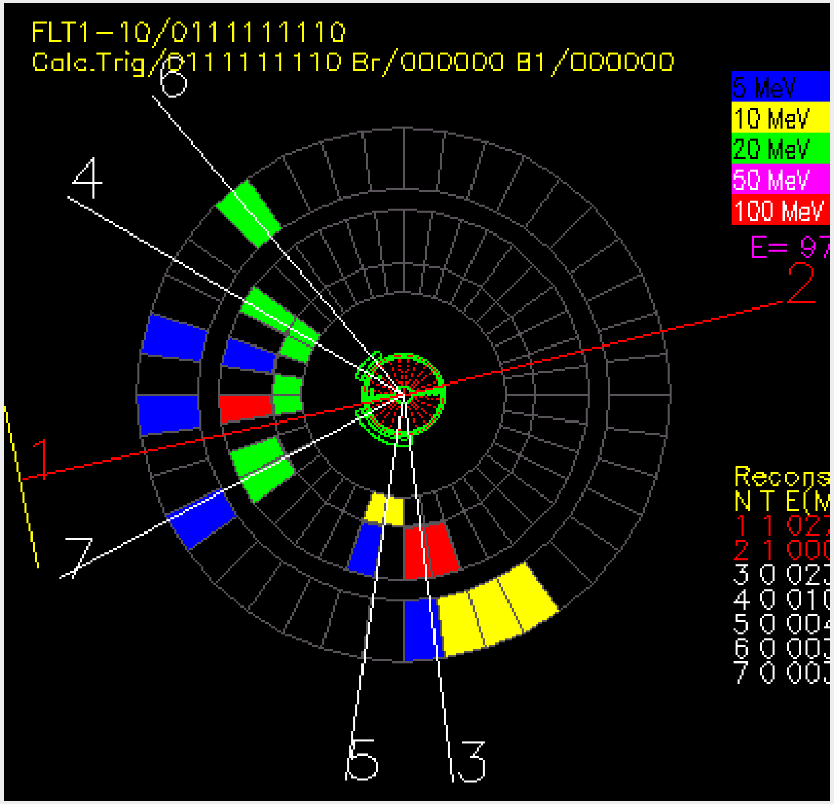


NIM A449 (2000) 125-139

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

$e^+e^- \to p\bar{p}$ events





960 MeV

> 960 MeV

$p\bar{p}$: Signal events selection

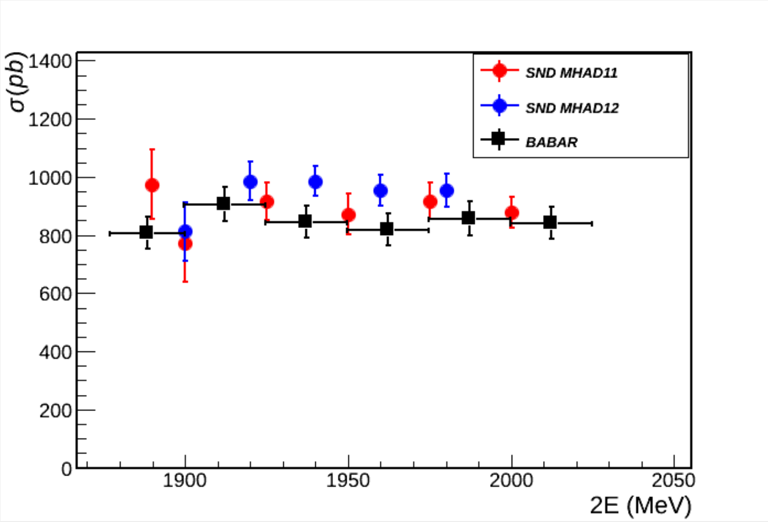
E_{beam} < 960 MeV:

- exactly 3 tracks with a common vertex located in the beam pipe material;
- no other tracks (proton is not registered).

$E_{beam} \geq$ 960 MeV:

- two collinear central tracks in DC with large dE/dx;
- total energy deposition in the calorimeter > 650 MeV;
- one of tracks is not associated with calorimeter cluster.

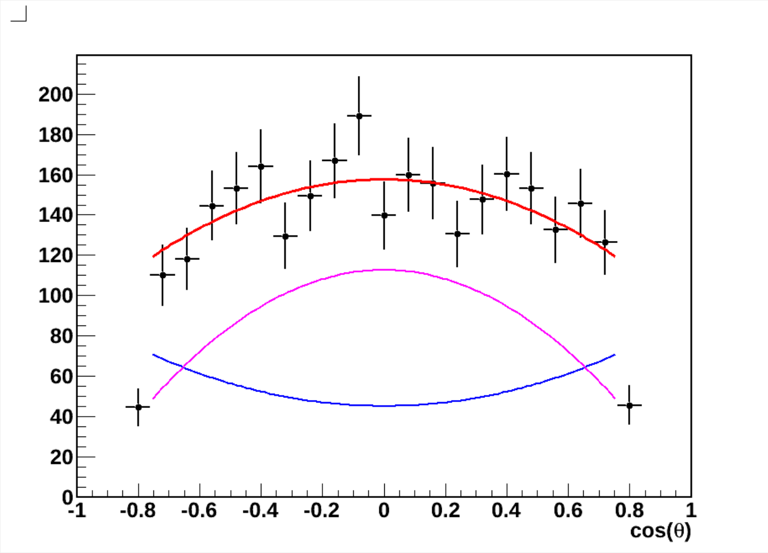
$p\bar{p}$: SND Results



Preliminary!

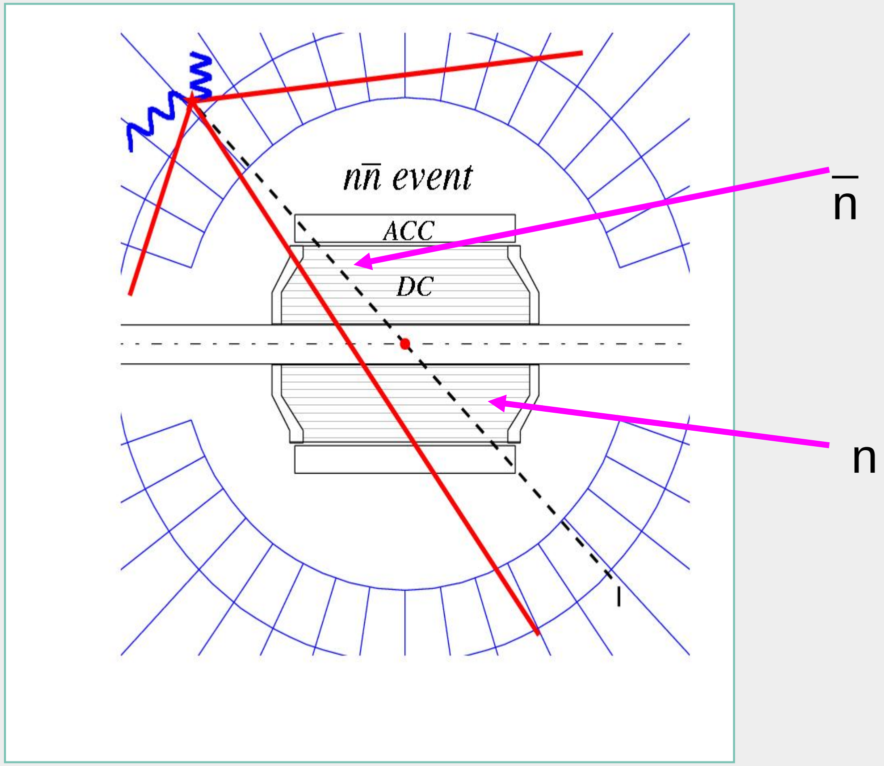
Cross section

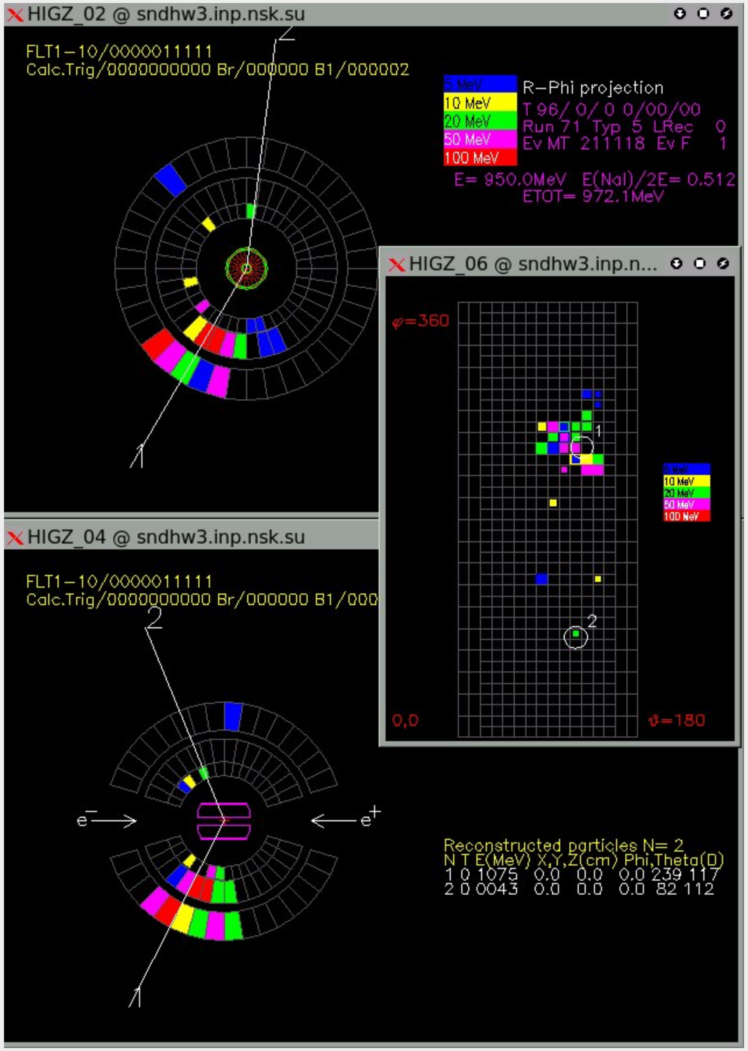
systematic uncertainty ~ 7%



Fit:
$|G_E/G_M| = 1.64 \pm 0.26$

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





- no signal from neutron
- “star” from anti-neutron

$n\bar{n}$: Signal events selection and background substraction

Selection:

- Muon system veto;
- At least 2 clusters in EMC

- $950\text{MeV} < E_{emc} < 1500\text{MeV}$
- $P_{emc} > 0.5 \cdot E_{beam}$
- $25 < \theta_{PEMC} < 155$
- no e+e-, γγ events

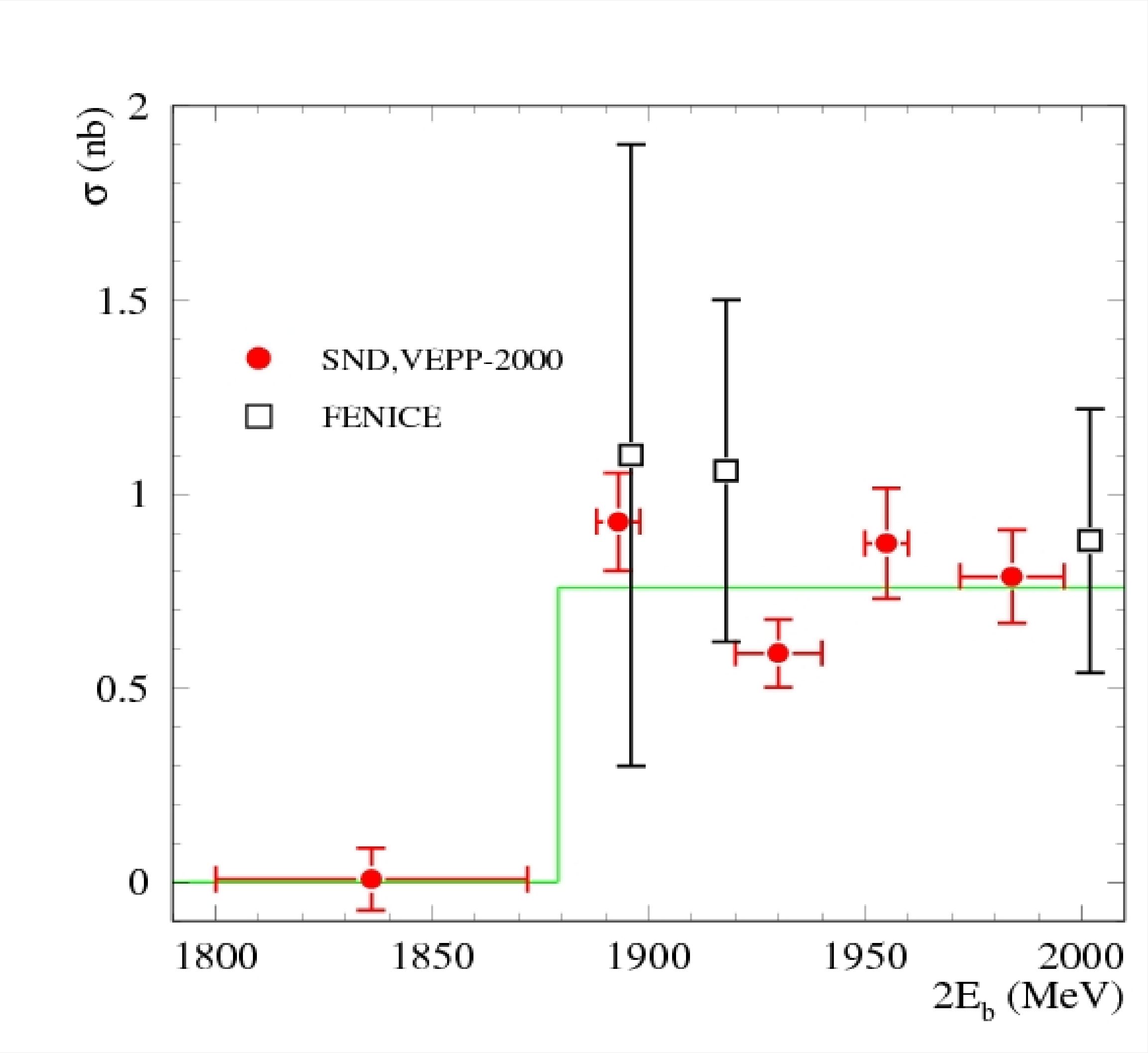
Cosmic background substracted using

- $N_i = x \cdot T_i + \sigma_{vis}(E_{beam}) \cdot L$

Other processes controlled with

- $\sigma_{n\bar{n}} = 0$

$n\bar{n}$: Cross section

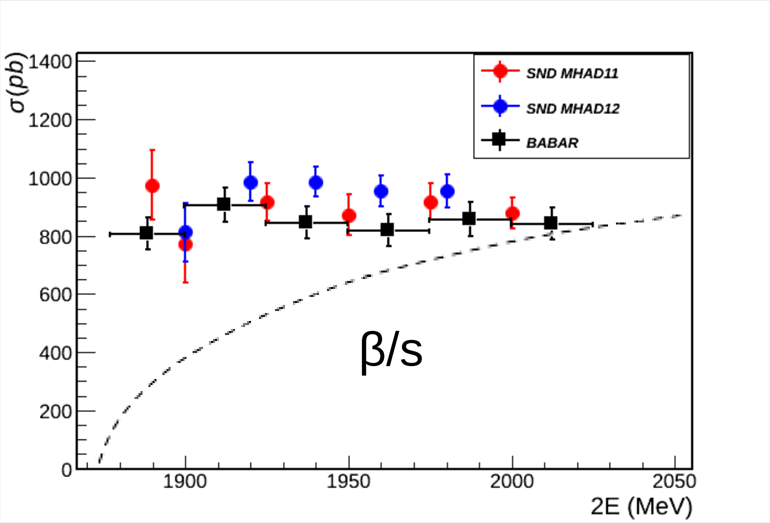


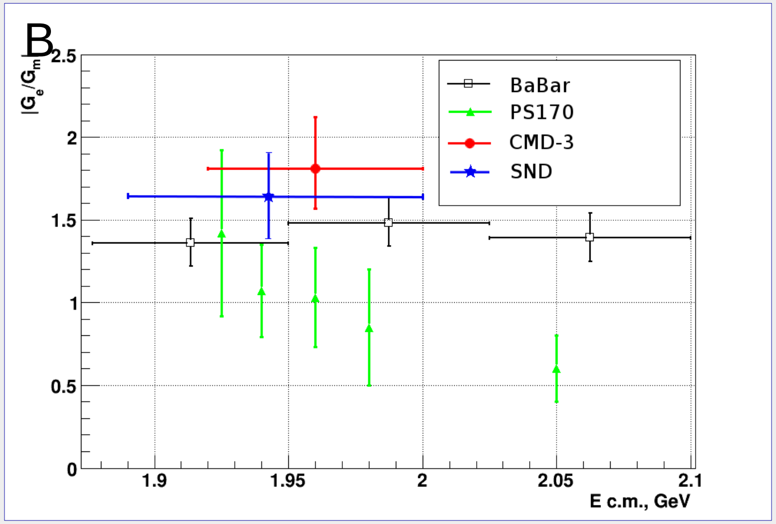
Cross section

systematic uncertainty ~ 17%

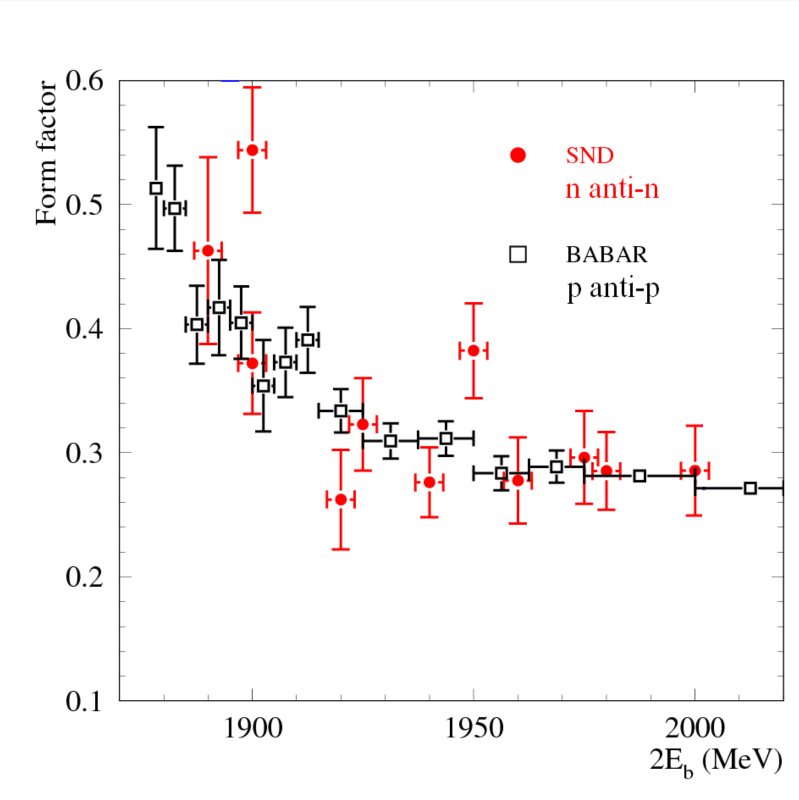
Discussion on proton results

- The cross section is constant, through it is natural to expect its decrease as $\beta = (1-4m_p^2/s)^{1/2}$ when approaching the threshold.
- Both SND and CMD-3 results confirm the BABAR result, that $|G_E/G_M|$ near threshold strongly differs from unity. This was somewhat unexpected, because $G_E = G_M$ at threshold





Nucleon form factors



- The $e^+e^- \to n\bar{n}$ cross section is constant and coincides within the errors with that for proton anti-proton (asymptotics pQCD $\sigma_p/\sigma_n = 4$).
- $\sigma_p = \sigma_n \Rightarrow$ either isoscalar or isovector amplitude dominates in $e^+e^- \to n\bar{n}$

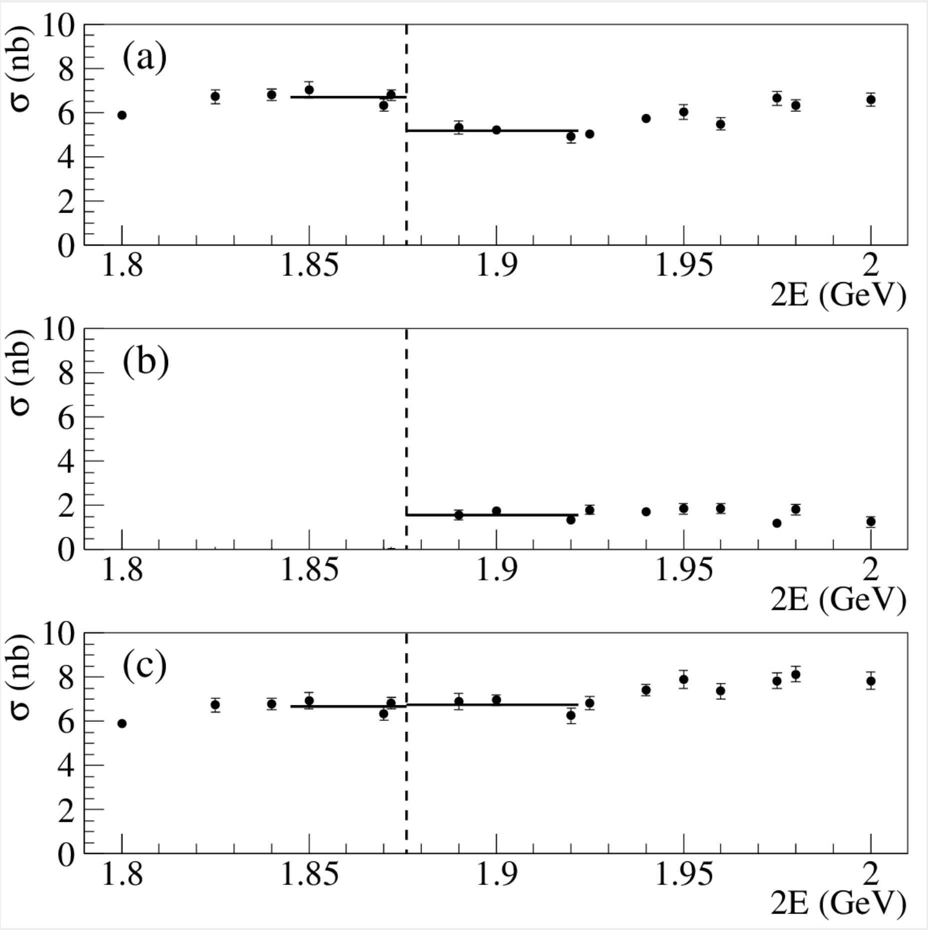
I. Subthreshold resonance
II. Final state interaction

V. F.Dmitriev, A.I.Milstein, S.G.Salnikov Phys.Atom.Nucl. 77 (2014) 1173:

Paris N anti-N optical potential:

I=0 – attraction, I=1 – repulsion $\Rightarrow$ the isoscalar form factor dominates.

Relation with $e^+e^- \to 6\pi$



A.E. Obrazovsky, S.I. Serednyakov
JETP Lett. 99 (2014) 363

In the total $e^+e^- \to$ *hadrons* cross section, the appearance of the $e^+e^- \to n\bar{n}$ processes is fully compensated by the dip in the cross section for the isovector processes $e^+e^- \to 3(\pi^+\pi^-)+2(\pi^+\pi^-\pi^0)$.

In other cross sections near $n\bar{n}$ threshold, any features, comparable in magnitude with that for $e^+e^- \to 6\pi$, are not observed.

Plans

- VEPP-2000: upgrade to increase a luminosity by the order of magnitude;
- Use of the laser Compton backscattering method for beam energy measurement;
- SND: the time measurement in the calorimeter electronics, will allow to separate $\bar{n}$ signal from the cosmic background;
- CMD-3: using the new TOF system for the $n\bar{n}$ events selection;

Conclusion

- Cross section of the $e^+e^- \to p\bar{p}$ process and the timelike form factor of the proton are measured;
- Cross section of the $e^+e^- \to n\bar{n}$ process and the timelike form factor of the neutron are measured;
- Results for both the neutron and the proton form factor near the pair birth threshold raise some interpretation questions;