Measurement of the neutron electromagnetic timelike form factor at the VEPP-2000 e+e- collider

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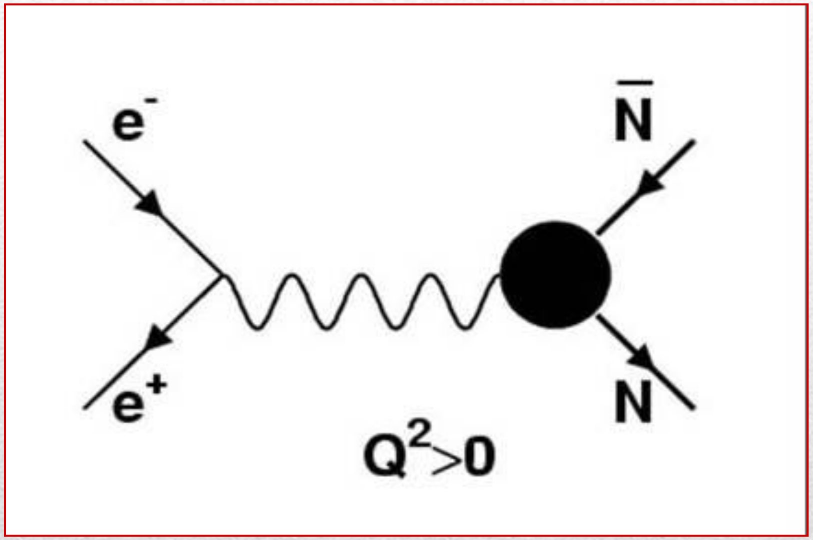
Quantum numbers



$J^{PC} = 1^{--}$,   J = L+S,
$P=(-1)^{L+1}=-1$, L=0,2 ,
$C=(-1)^{L+S}=-1$, S=1,

S, D – waves,

two form factors
e.g. G_E , G_M

$e^+e^- \longrightarrow N\bar{N}$ cross section

Differential cross section (N=p,n) :

$$\sigma(e^+e^- \to N\bar{N}) = \frac{\alpha^2\beta C^2}{4m^2}\left(|G_M|^2(1+\cos^2\theta) + \frac{4m_B^2}{m^2}|G_E|^2(1-\cos^2\theta)\right)$$

C for neutrons = 1

Total cross section:

$$\sigma(e^+e^- \to N\bar{N}) = \frac{4\pi\alpha^2\beta C}{3m^2}\left(|G_M|^2 + \frac{2m_B^2}{m^2}|G_E|^2\right)$$

Effective form factor

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

Two measurable values:

1 - effective FF,

2 - $|G_E/G_M|$

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Expectations for the nucleon form factors

-- $|G_E|=|G_M|$ at threshold, S-wave only

-- σ -> const at threshold, C ~ 1/v (only for proton)

-- final transverse polarization ~ $\phi(G_E-G_M)$

perturbative QCD constrains the FF asymptotic behavior

$$q^2 \to -\infty \Rightarrow G_{E,M} \to \frac{\text{constant}}{q^4 \ln\left(q^2/\Lambda^2_{QCD}\right)^2}$$

pQCD + analyticity

$$q^2 \to \pm\infty \Rightarrow G_{E,M}(q^2) = G_{E,M}(-q^2)$$

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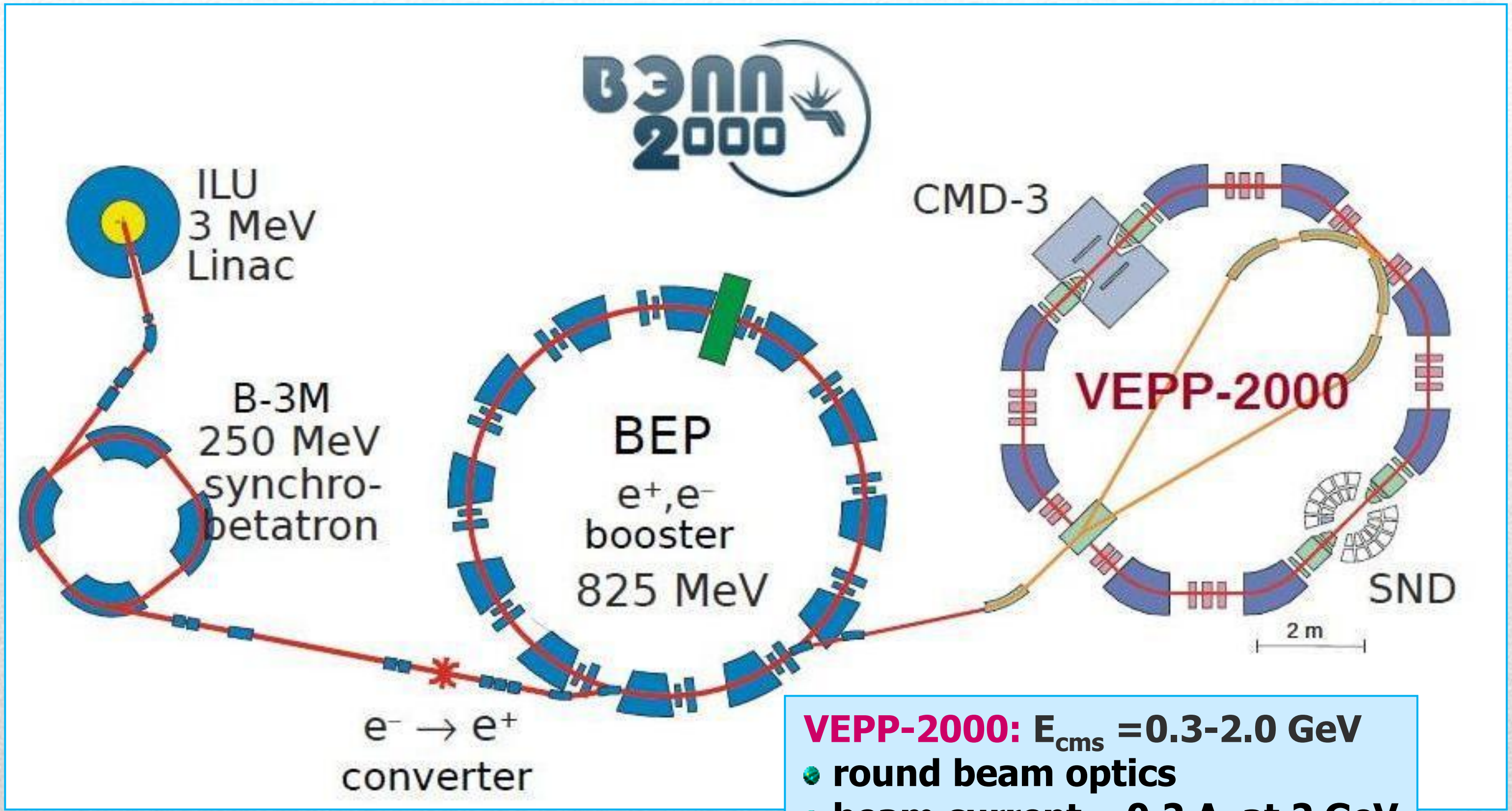
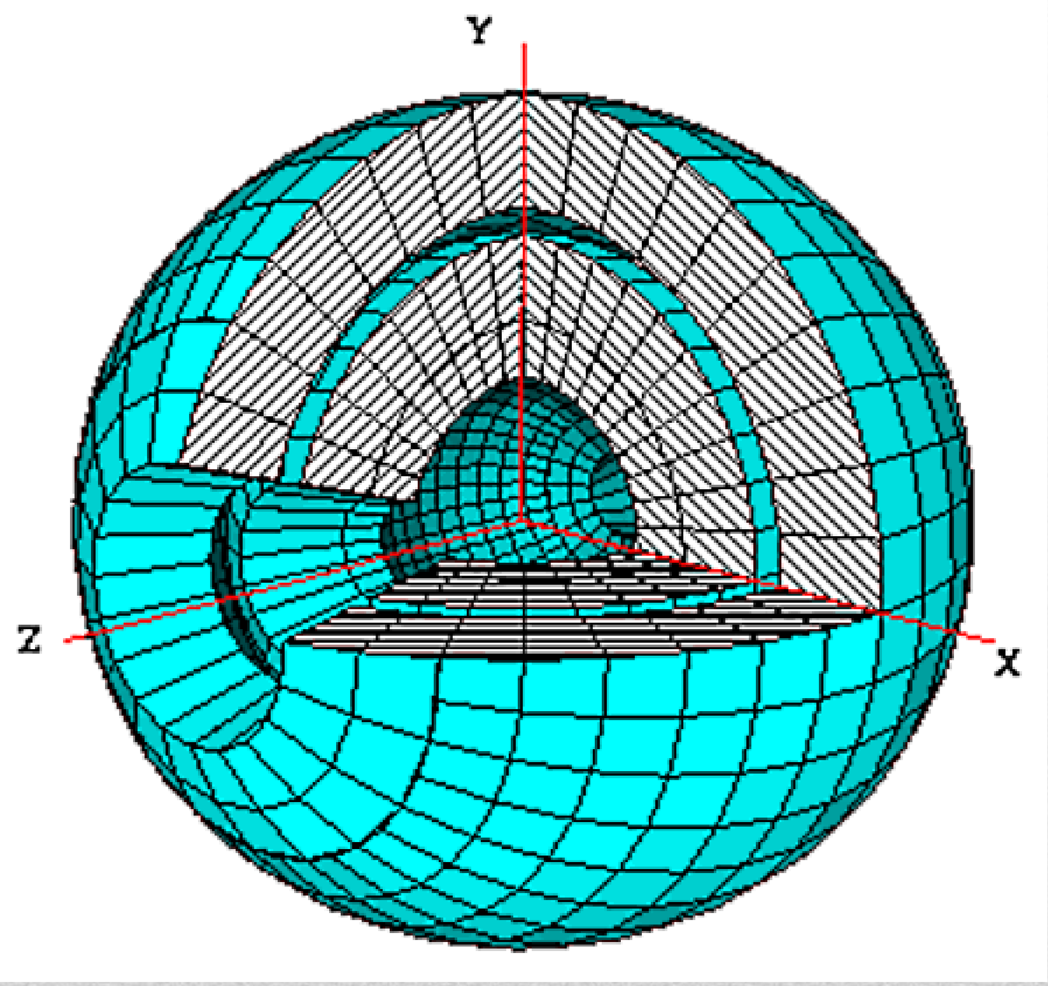
VEPP-2000 e^+e^- collider complex



In: Proc.7-th.Eur.Part.Accel.Conf., Vienna, p.439 (2000)

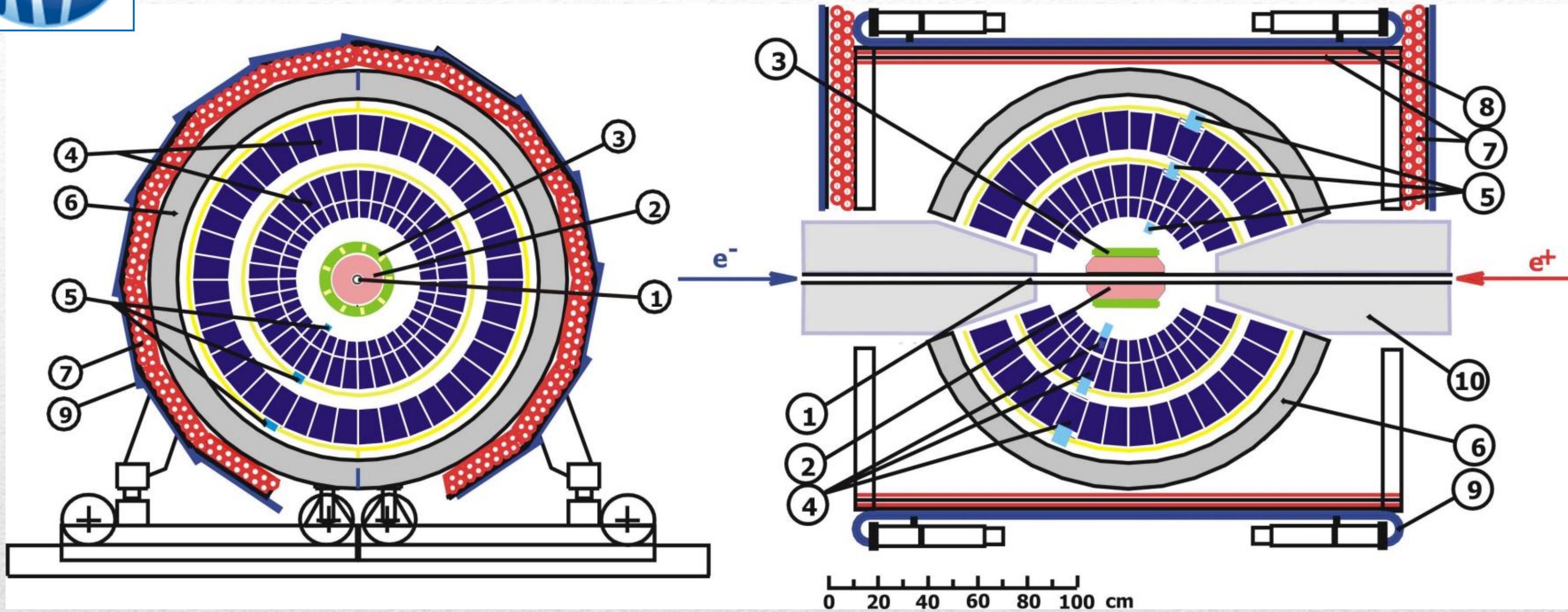
VEPP-2000: E_{cms} =0.3-2.0 GeV
- round beam optics
- beam current – 0.2 A at 2 GeV
- beam length – 3.3 см at 2 GeV
- beam energy spread – 0.7 МэВ at 1 GeV
- $L \simeq 1.10^{32}$ at 2 ГэВ
- $L=2.10^{31} cm^{-2}s^{-1}$ at 1 ГэВ

SND – Spherical Neutral (Nonmagnetic) Detector



NaI(Tl)
1680 crystals
3.6 t
90% 4π

SND

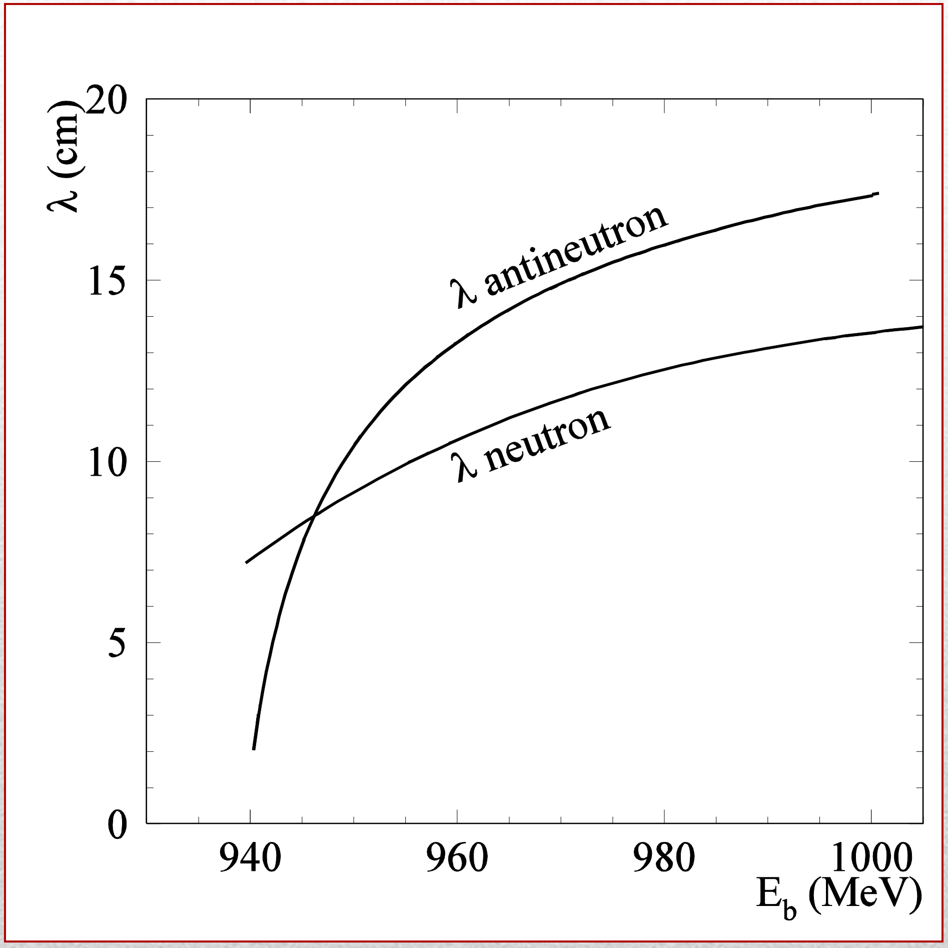


1 – **beam pipe, 2 – tracking system,**
3 – aerogel, 4 – NaI(Tl) crystals,
5 – phototriodes, 6 – muon absorber,
7–9 – muon detector, 10 – focusing solenoid.

NIM A449 (2000) 125-139

Advantages for VEPP-2000:
1- cherenkov counter, n=1.05, 1.13 – e/πseparation E<450 MeV, π/K separation E<1 GeV,
2 –drift chamber – better tracking,
3- time of flight in ECAL (будущий)

Attenuation length in NaI(Tl)

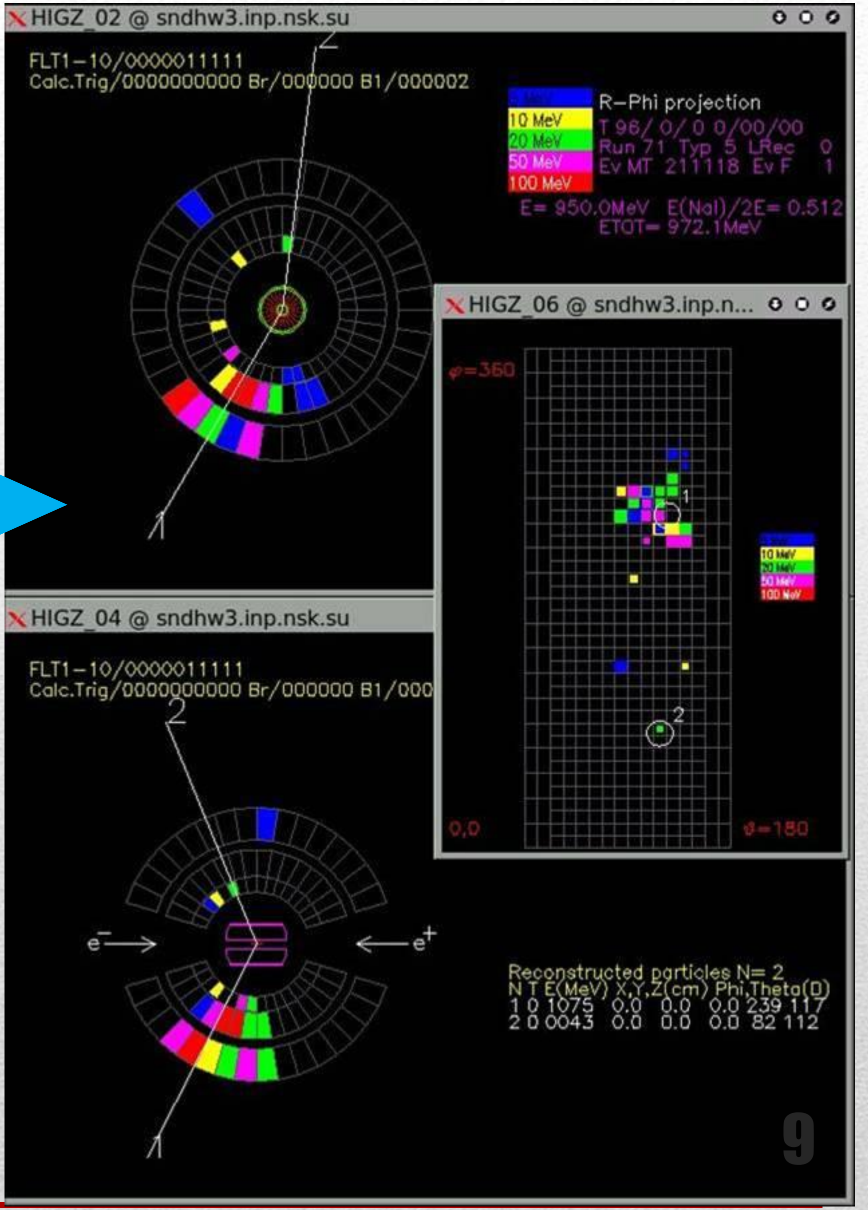


λ < L (=35 cm)
L = ~ 3 λ

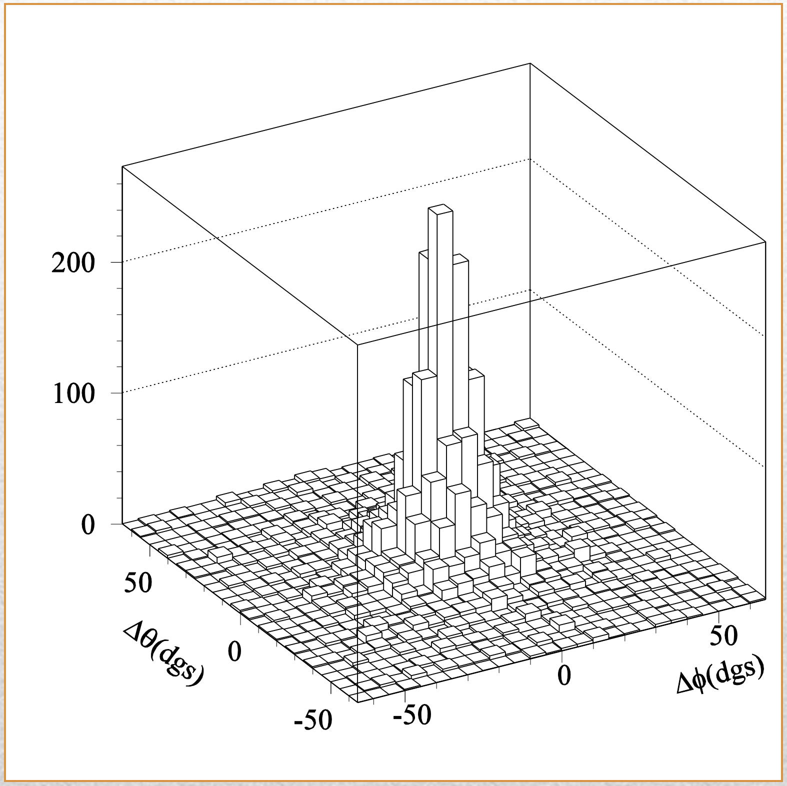
X_0 = 2.5 cm
L = 14 X_0

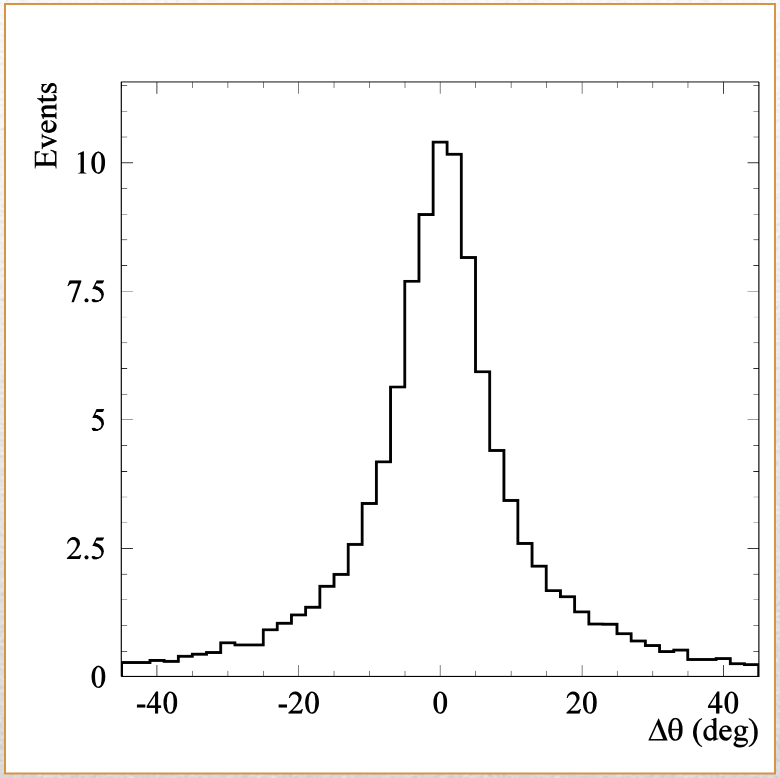
$e^+e^- \to n\bar{n}$

$n\bar{n}$ event,
E_{beam}=950MeV



Angular resolution ~ 7°



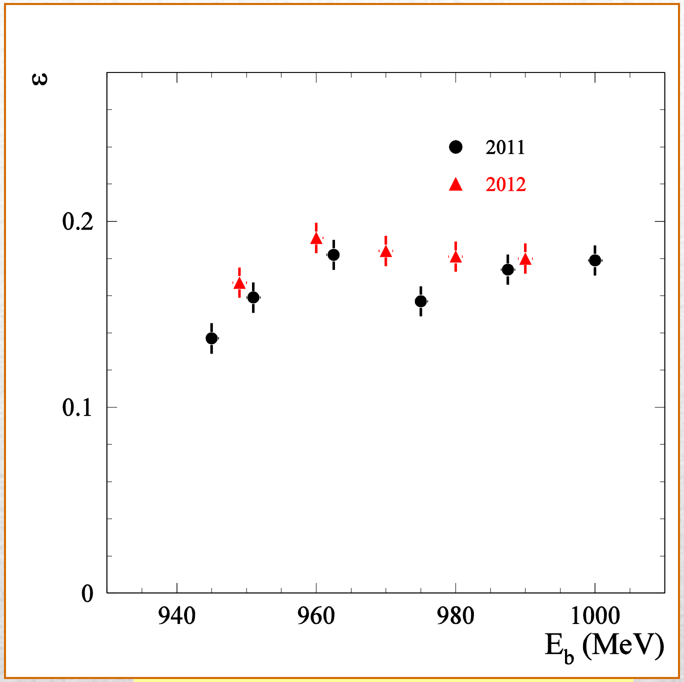


Distinctive features of $e^+e^- \to n\bar{n}$ process

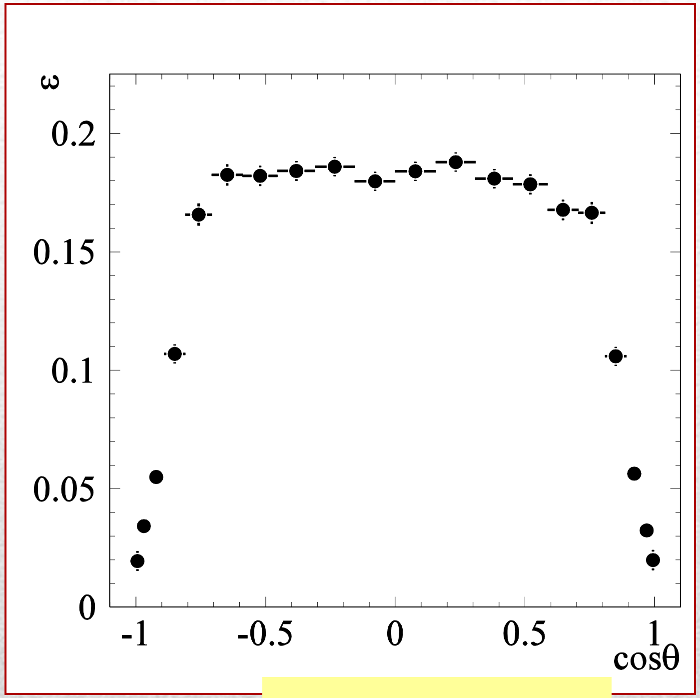
1. No central tracks
2. No central photons
3. Energy assymetry ~ 1 ГэВ or large event momentum
4. Only antineutrons signal

Selection criteria for $n\bar{n}$ events

Detection efficiency



… from beam energy



… from cosθ

Cross section calculation

1500 runs in total

N_1, N_2 – events in 2 runs

$$N_1 = xT_1 + \sigma \dot{L}_1 \bullet T_1$$

$$N_2 = xT_2 + \sigma \dot{L}_2 \bullet T_2$$

Solution for σ:

$$\sigma = \frac{\dot{N}_1 - \dot{N}_2}{\dot{L}_1 - \dot{L}_2}$$

No solution if $L_1 = L_2$

x – cosmic rate
T – run time
σ – visible cross section
L – luminosity

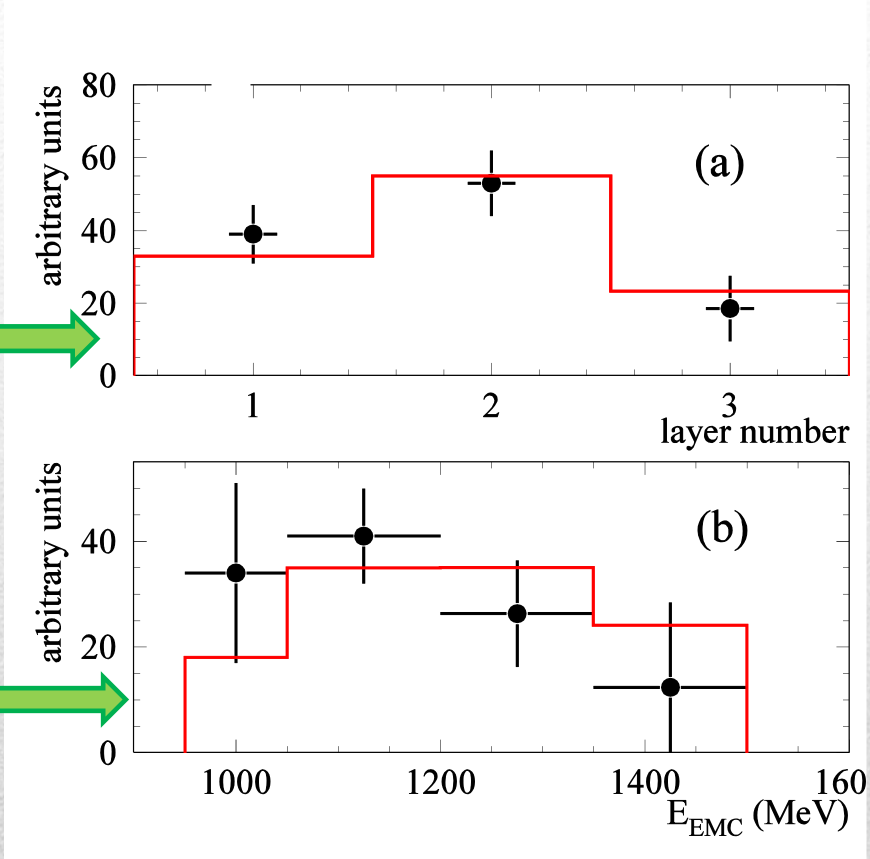
$\sigma_{nn} = (\sigma_{vis} - \sigma_0 - \sigma_{vpp}) / \varepsilon(1+\delta)$
= ~ 0.8 nb,

ε - detection efficiency
δ - radiative correction ,
σ_{vpp}=> e+e->p anti-p
σ_0 – phys. background

Compare data and MC

EMC layers energy

Energy in EMC



Data – points, MC – histogram

Physical background

1. e+e- -> $\gamma \gamma (\gamma)$ σ ~ 50 pb
2. e+e- -> p anti-p σ ~15 pb
3. e+e- -> $K_S K_L$ ~ 1 pb
4. e+e- -> $K_S K_L \pi^0$ ~ 5 pb
5. e+e- -> $K_S K_L 2\pi^0$ ~ 20 pb
6. e+e- -> $K_S K_L 3\pi^0$ ~0.5 pb

Total e+e- -> hadrons σ ~80 pb

Compare with nn cross section ~ 800 pb

Systematics

- Cosmic subtraction– 0.12 nb,
- efficiency error – 15%,
- GE/GM – 3%,

-- physical bkgd – 0.05 нб

-- luminosity -3%,

-- rad. correction – 2%,

Total - 17% ,

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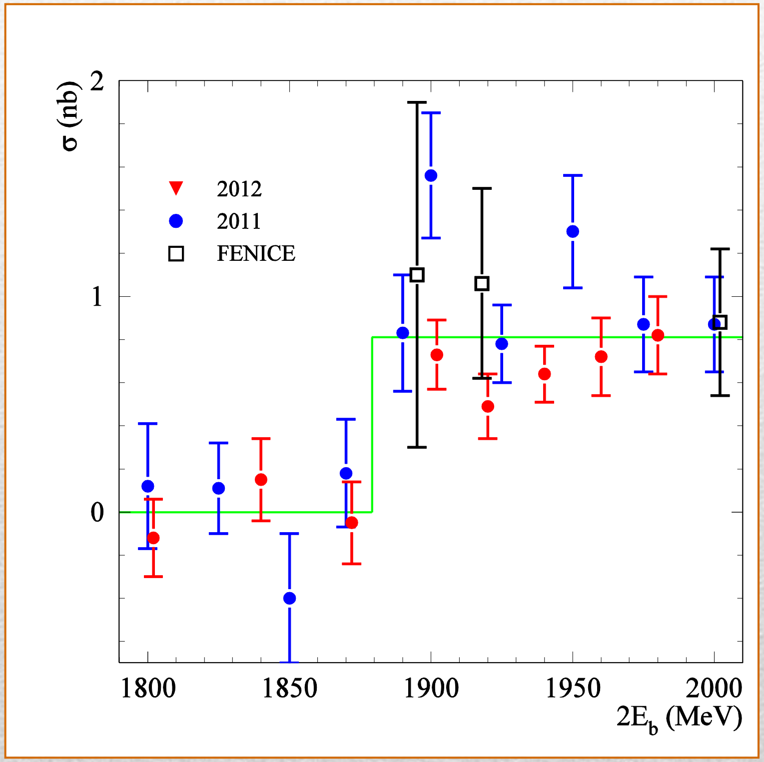
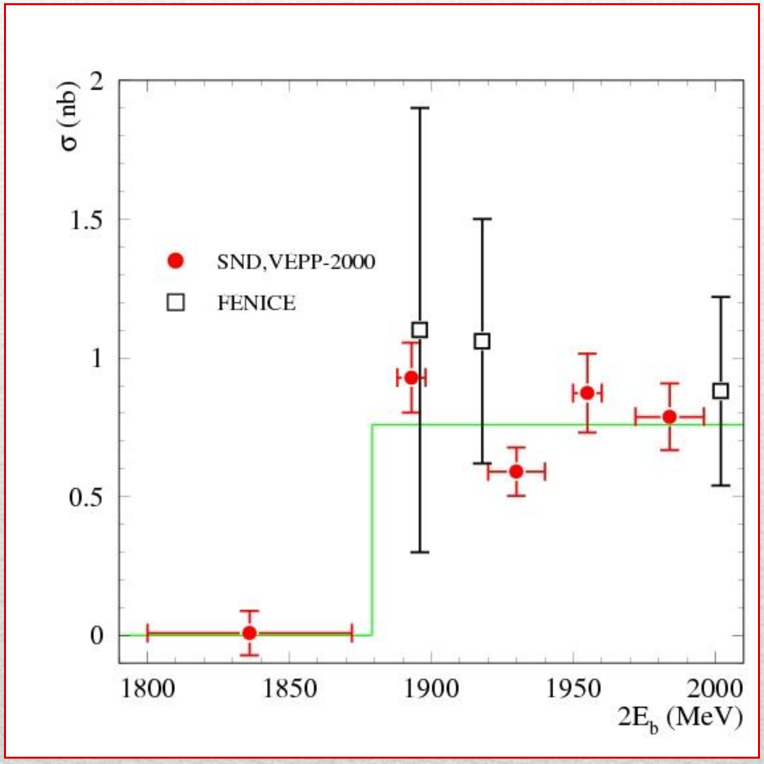
statistical error in energy point
is limited by coosmic bkgd
subtraction ~ 20%

σ = 0.85 nb (+- 0.20(stat)+- 0.15(syst) nb)

Cross section

arXiv:1410.3188 [hep-ex]
Phys.Rev.D. 90 112007(2014)





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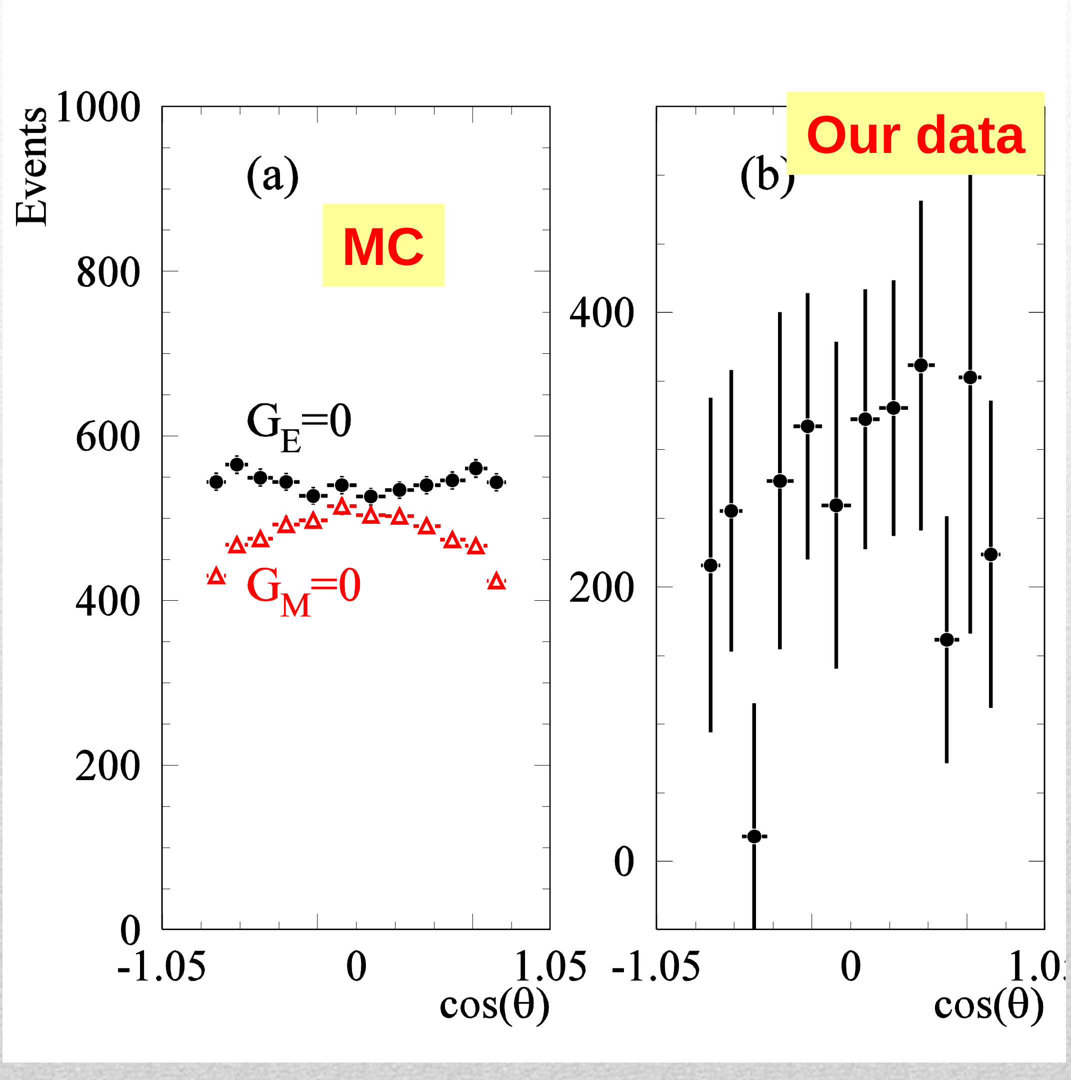
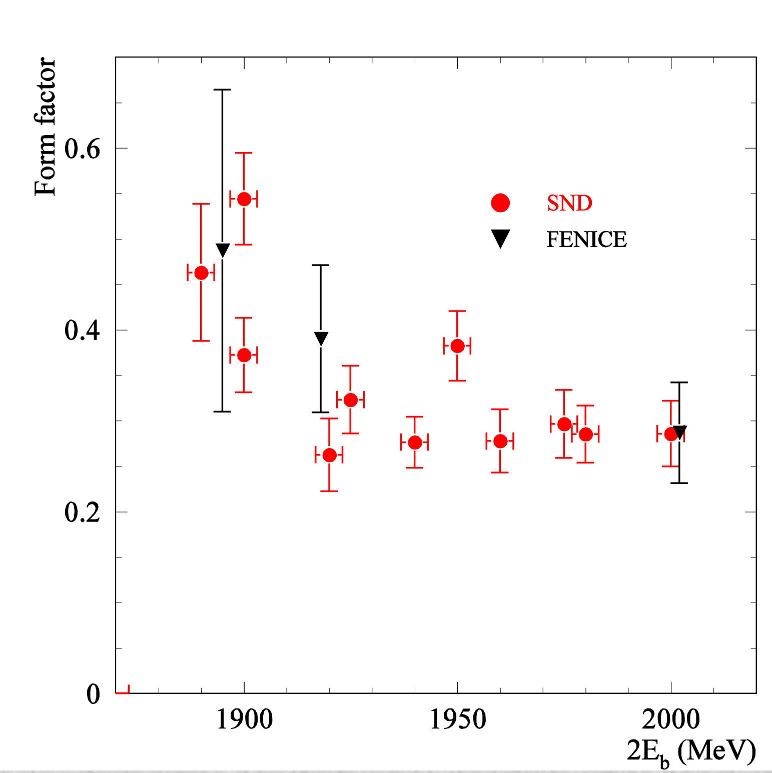
G_E/G_M , $\Delta\theta=9^o$

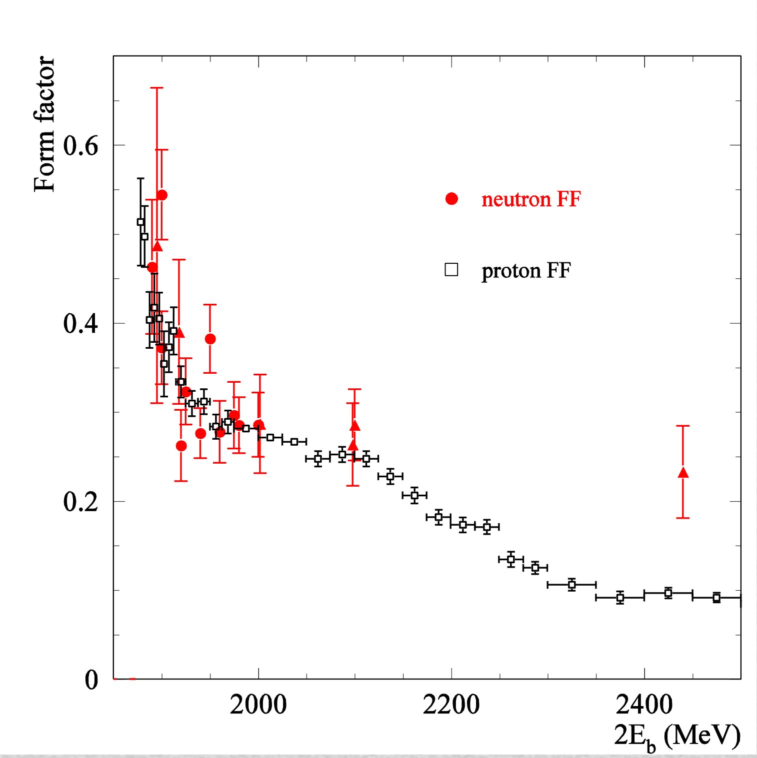


Fit results
G_E/G_M =25+-45,
χ^2/ND=0.8

A comparison of FENICE and SND neutron FF's

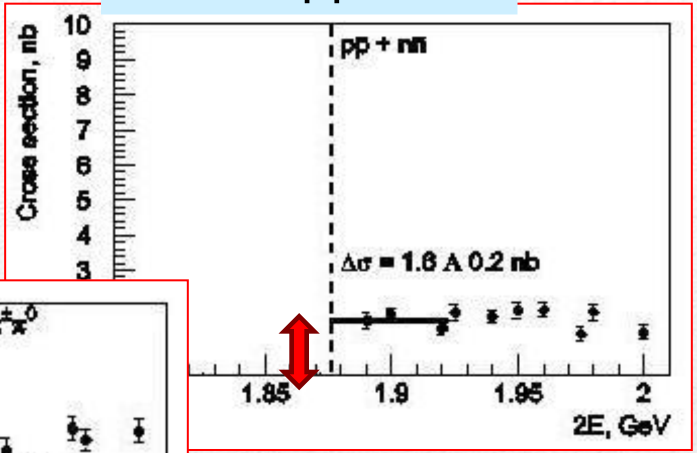


A comparison of neutron and proton FF's

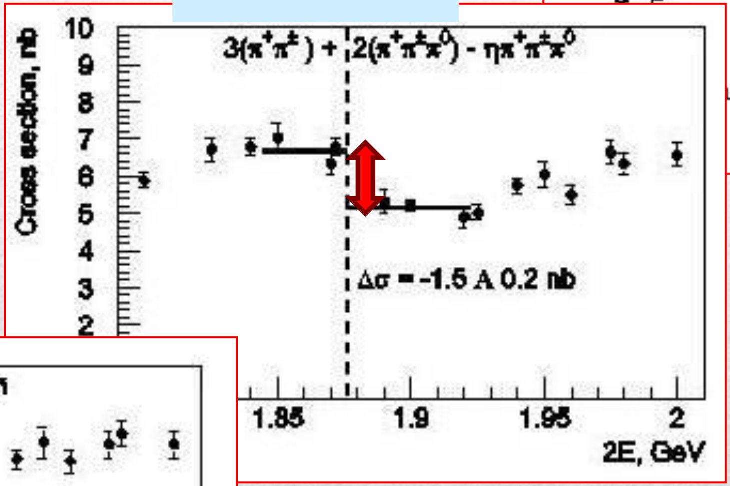


$e^+e^- \rightarrow$ hadrons cross section near nucleon-antinucleon threshold

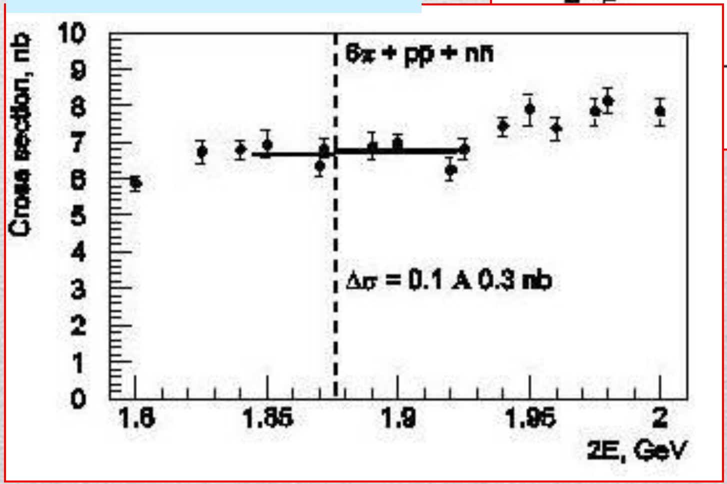
$e^+ e^- \rightarrow p\bar{p} + n\bar{n}$



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



$e^+e^- \rightarrow$ hadrons



arXiv:1402.5225v1 [hep-ph] 21 Feb 2014

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Conclusions

1. The $e^+e^- \to n\bar{n}$ cross section is measured at VEPP-2000 e+e- collider by SND detector in the near threshold region
2. The measured $e^+e^- \to n\bar{n}$ cross sections ~ 0.8 nb is found to be close to the $e^+e^- \to p\bar{p}$ cross section
3. The developped technique of antineutron detection can be applied in PANDA experiments

Thank you for listening !