LXX International conference “Nucleus-2020”

Measurement of the neutron timelike electromagnetic form factor at the VEPP-2000 e^+e^- collider with the SND detector

On the behalf of SND Collaboration
Sergey Serednyakov
Novosibirsk State University
Budker Institute of Nuclear Physics

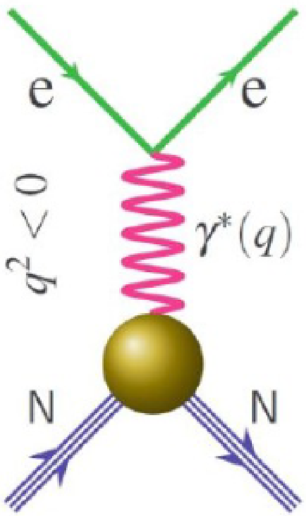
Novosibirsk State University
*THE REAL SCIENCE

OUTLINE

1. Introduction
2. Detector, collider, experiment
3. Selection of $n\bar{n}$ events
4. $e^+e^- \rightarrow n\bar{n}$ cross section
5. Neutron timelike form factor
6. Conlusions

$e^- N \to e^- N$

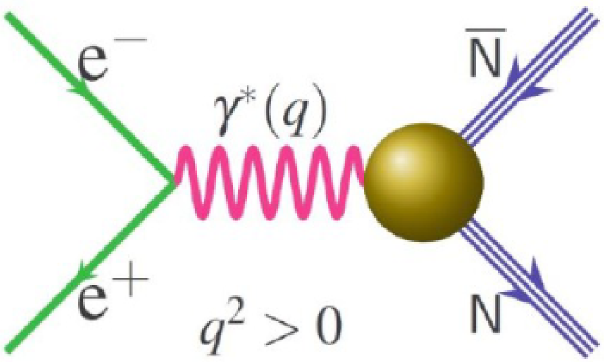
scattering



Spacelike form factor

$e+e- \to N \bar{N}$

annihilation



Timelike form factor

From Yu. Nefedov

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

Differential cross section:

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

Total cross section:

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

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

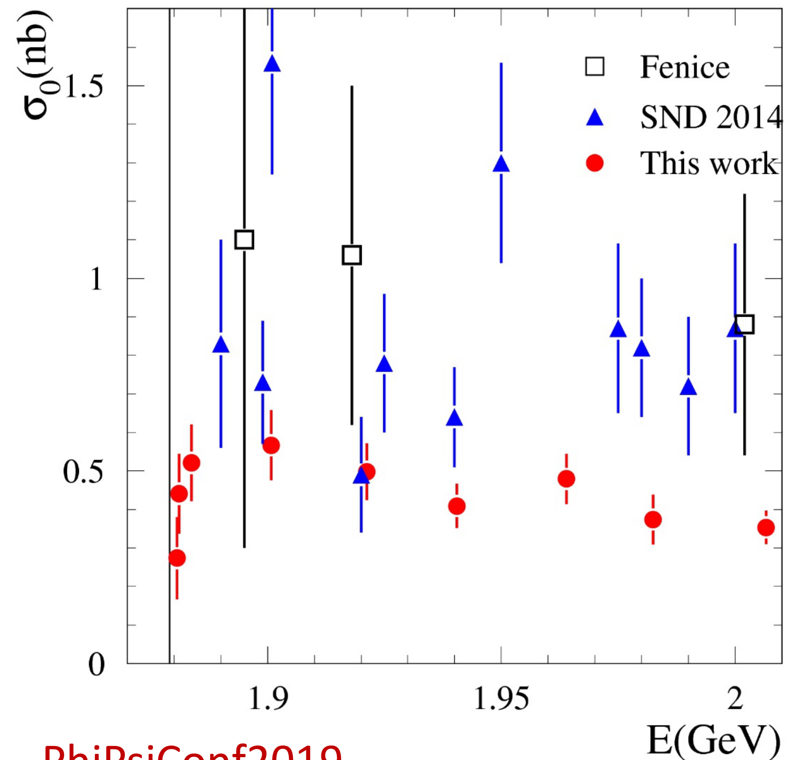
C=1 for neutrons

At threshold : $s=4m_B^2 \to |G_E| = |G_M| = |F|$

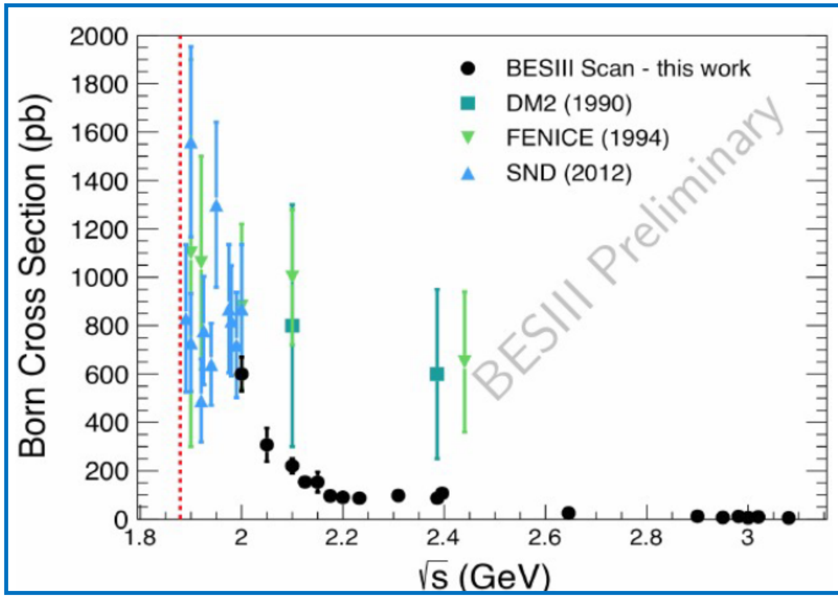
$F_n = - F_p / 2$

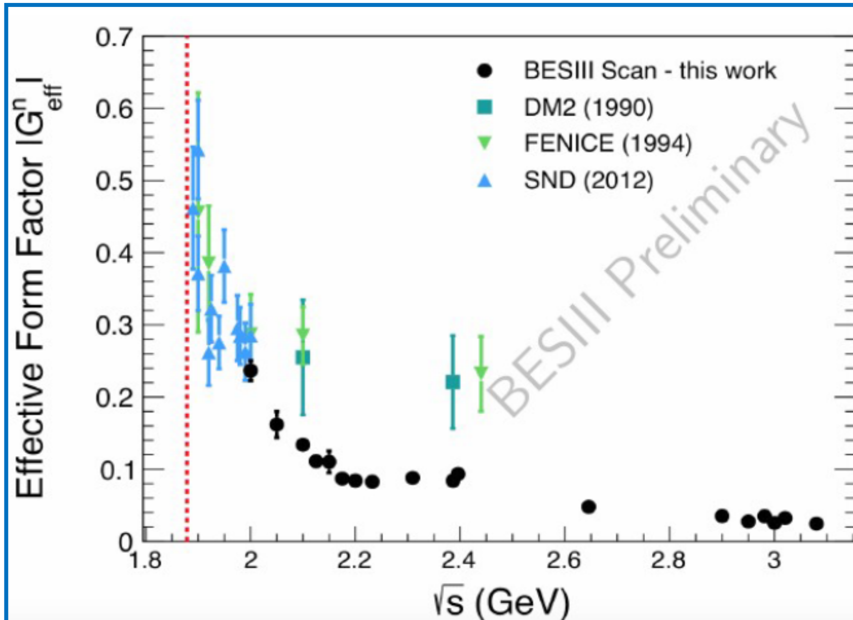
Asymptotic prediction: $F(+\infty) = -F(-\infty) \sim 1/s^2$

Existing data on the $e^+e^- \to n$+anti-n cross section



PhiPsiConf2019

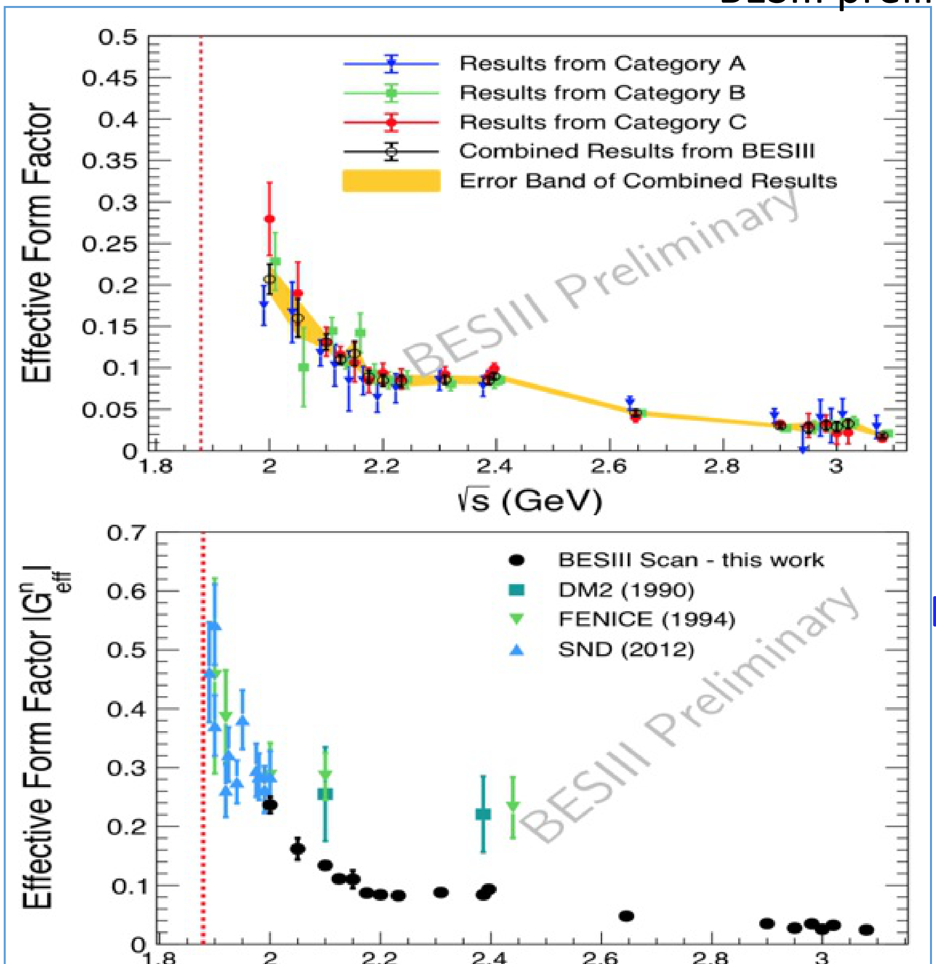


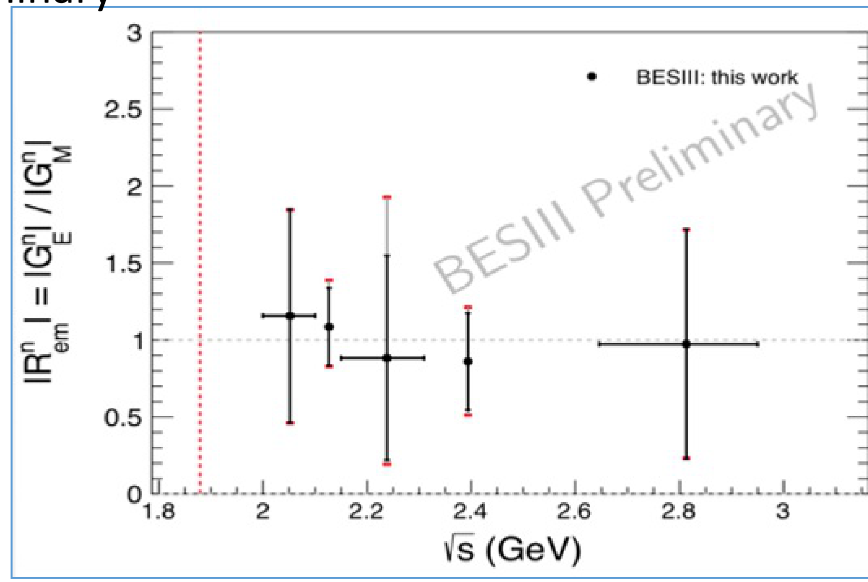


Nefedov, Sess.March,2020

Existing data on the neutron timelike form factor

BESIII preliminary

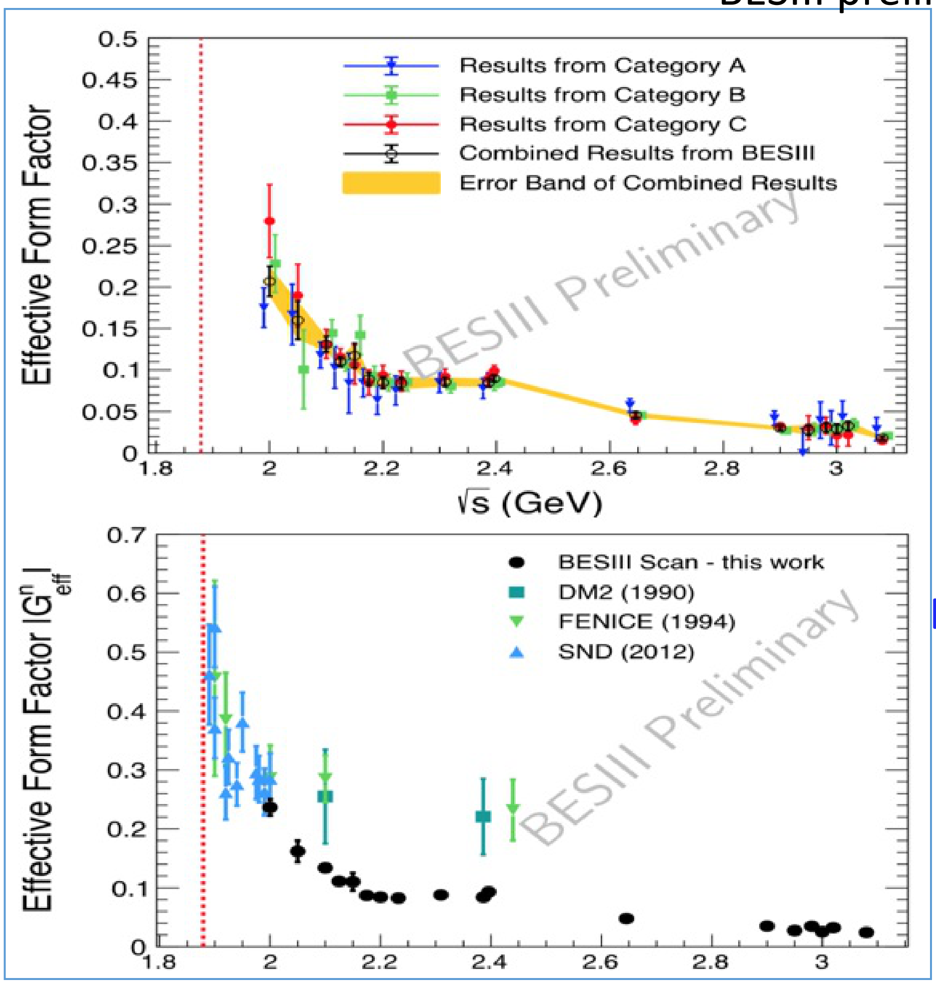


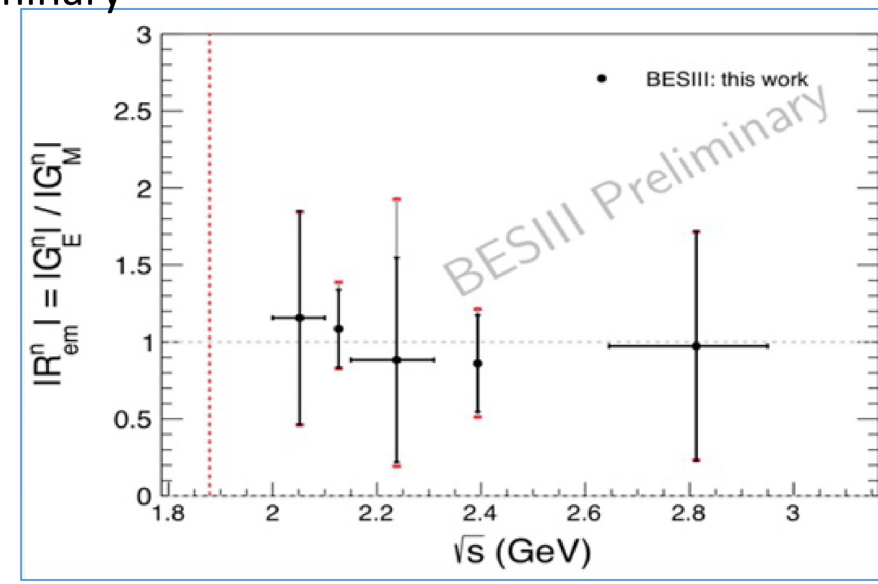


B. Zhang

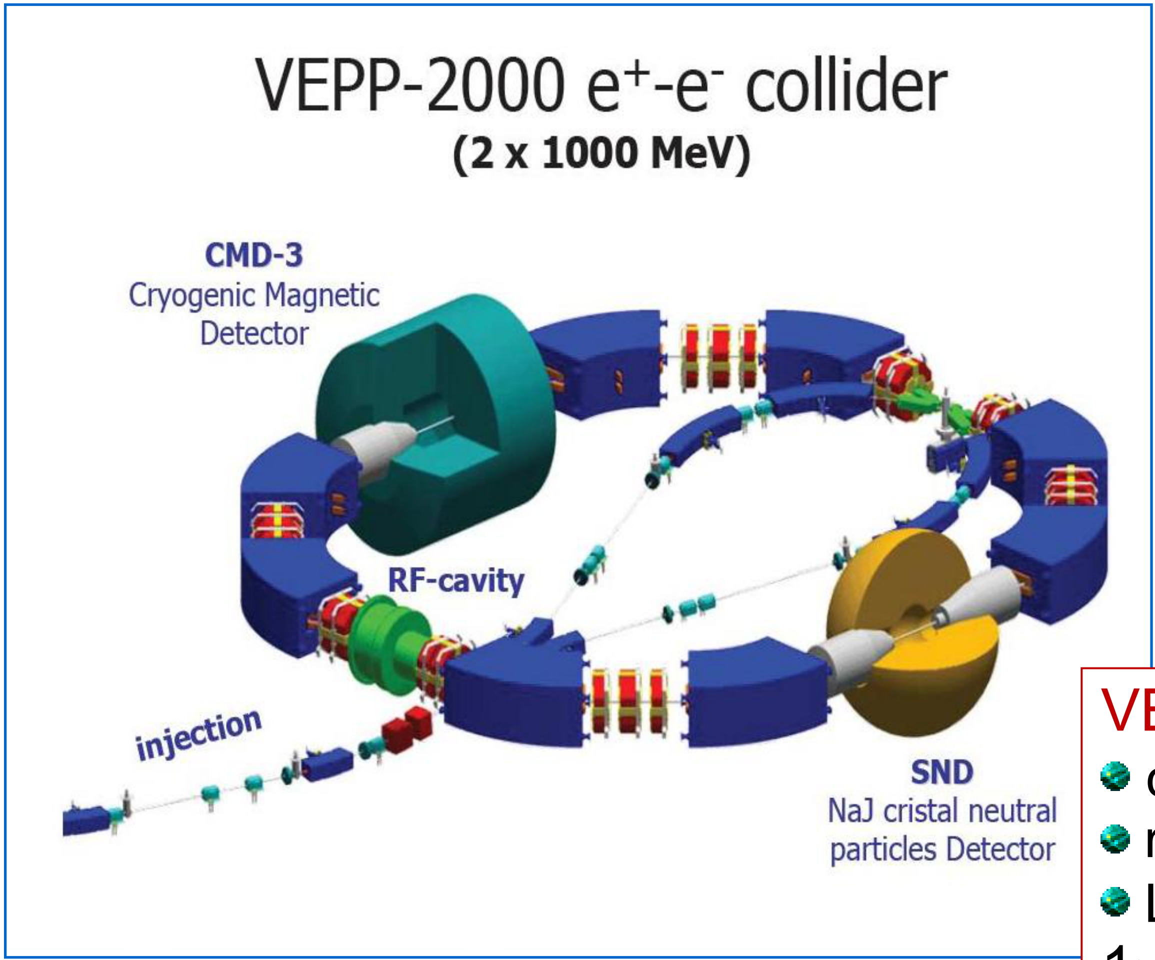
Existing data on the neutron timelike form factor

BESIII preliminary





B. Zhang



In operation since 2010

Total integrated luminosity
at CMD-3 and SND ~300 inv.pb.

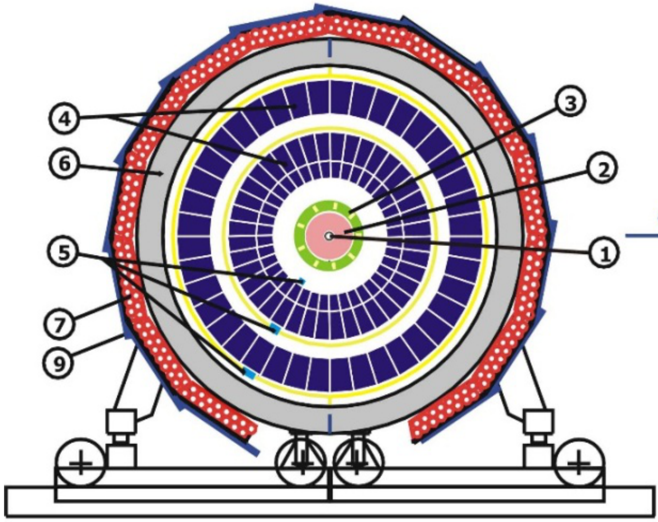
Planned luminosity ~ 2 inv.fb

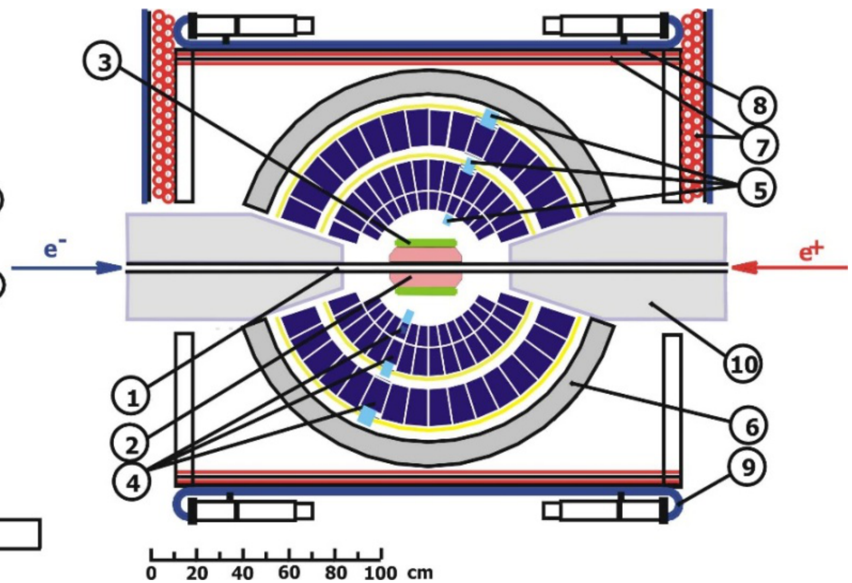
VEPP-2000 parameters:

- c.m. energy E=0.3-2.0 GeV
- round beam optics
- Luminosity at E=1.8 GeV

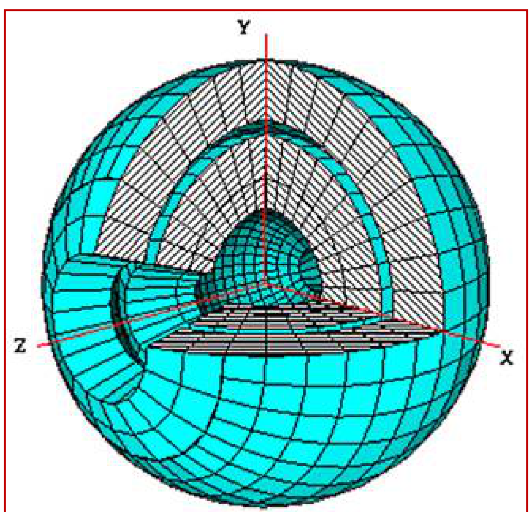
1×10^{32} cm^{-2} sec^{-1} (project),
5×10^{31} cm^{-2} sec^{-1} (achieved)

SND detector (since 1995)

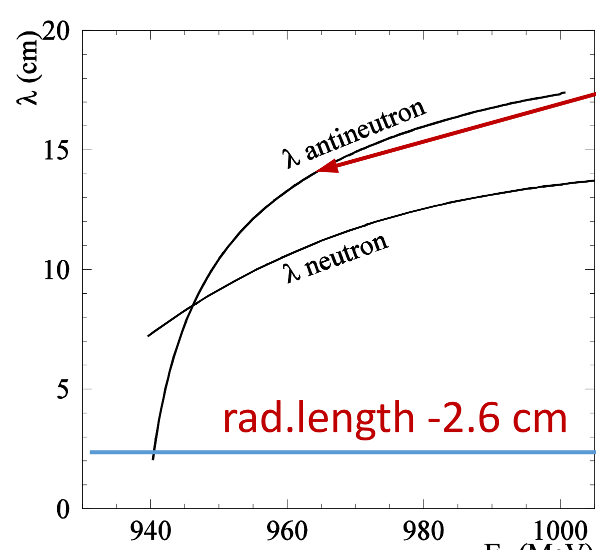




1 – **vacuum chamber,**
2 – **tracking DC,**
3 – **aerogel n=1.13, 1.05**
4 – **NaI(Tl) crystals,**
5 – **phototriodes,**
6 – **absorber,**
7–9 – **muon detector,**
10 – **SC solenoids**



Solid angle - 90% 4π



Attenuation length

SND – good antineutron detector

Data taking run 2017

E_{beam}= 900 – 1004 MeV,
9 energy points (above threshold)

Integr. luminosity =16.5 pb^{-1}

Reconstructed nn candidate events ~ 1000

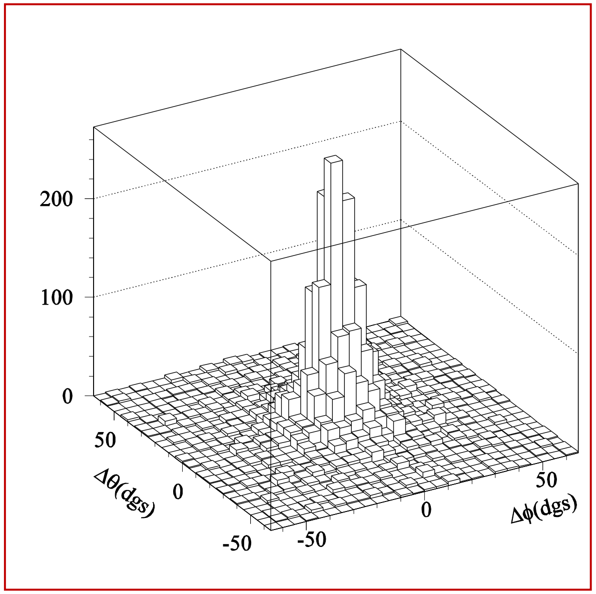
Data taking run 2019

E_{beam}= 900 – 987.5 MeV,
7 energy points (above threshold)

Integr. luminosity =18 pb^{-1}

Reconstructed nn candidate events ~ 1000

Selection of n+anti-n events



Key features

(No tracks*, no photons*, no kinematic χ^2)

1 - veto μ system
2 - no cosmic muon track in EMC
3 - event momentum : $P>0.3E_{beam}$
4 - EMC energy : $E_{tot} > 1.05E_{beam}$
5 - 3-d EMC layer energy: $E_3 < 0.7E_{beam}$

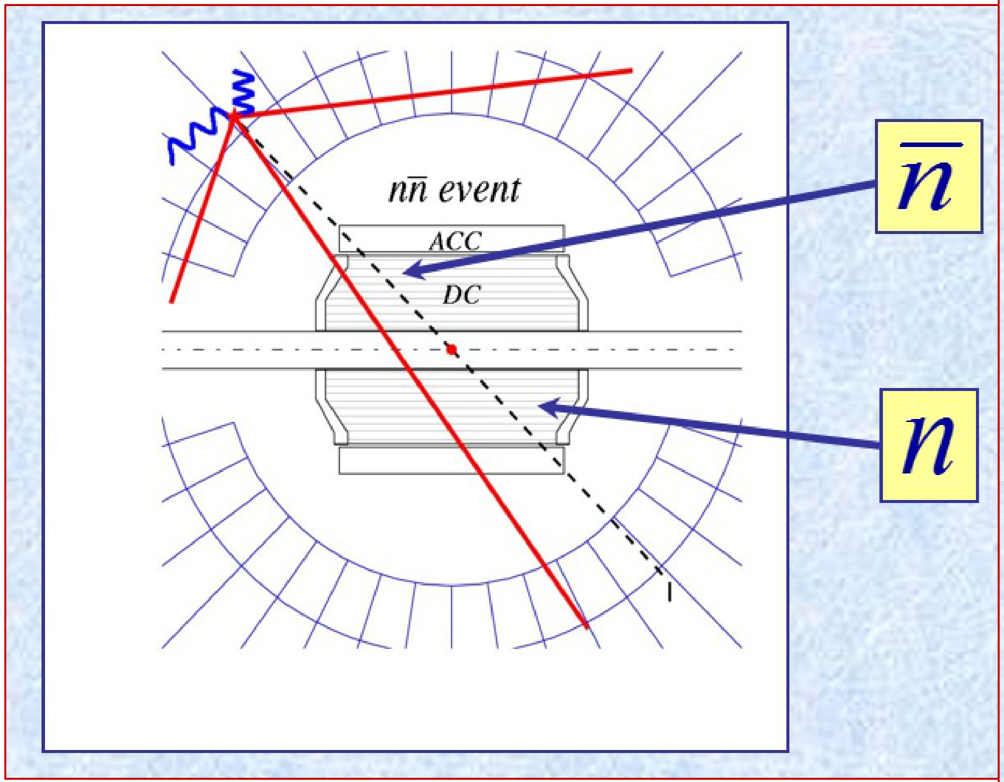
Selection results:

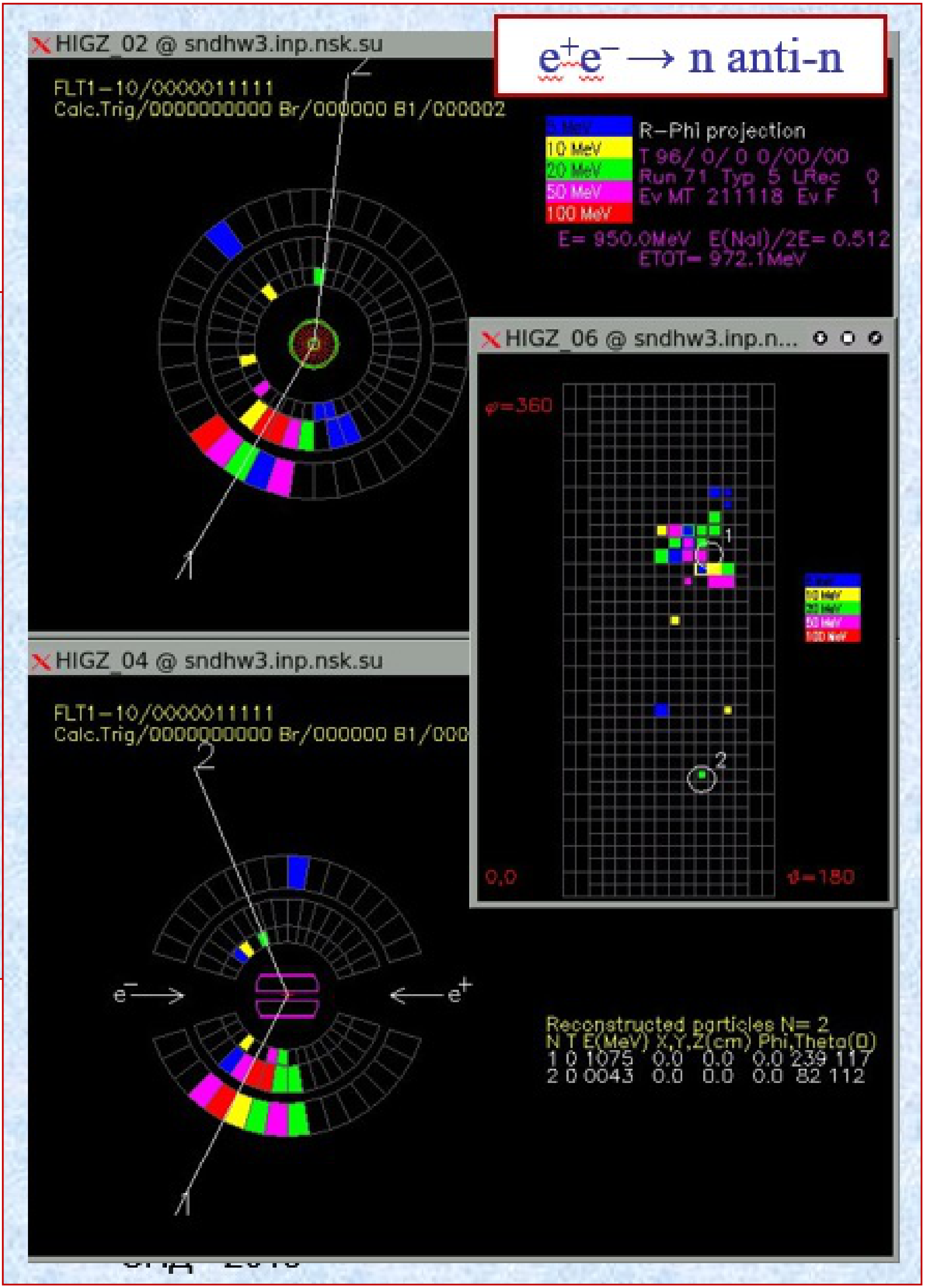
1 – total events recorded ~2 10^7 events/pb -1
2 – after applying cuts ~ 100 events/pb -1, including
physical, beam and cosmic background and n anti-n events

Selection efficiency :

$\varepsilon_{MC} \approx 18$ % (951,955 MeV)

Events pictures



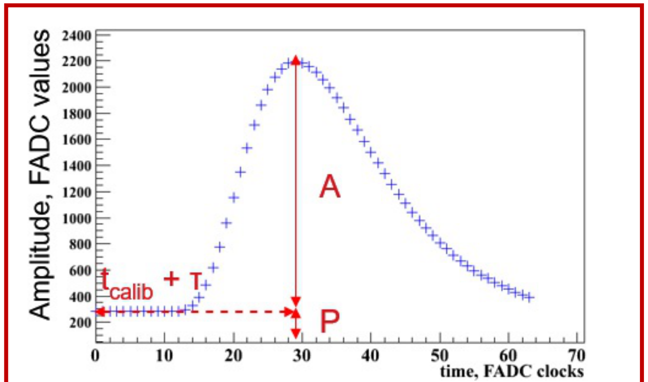


Physical, beam and cosmic backgrounds

Three types of background for $e^{\pm}e^{-} \to$ n+anti-n :

1. Physical background - from processes $e^{+}e^{-} \to \gamma\gamma(\gamma)$, $K_S K_L + n\pi^0(\gamma)$, ppbar etc, suppressed to ~1 pb of detection cross section.
2. Cosmic background - trigger rate ~ 150 Hz, suppressed to ~ 10^{-3} Hz.
3. Beam background - suppressed to ~ 1pb by the condition on the total EMC energy $E_{cal} > E_{beam}$.

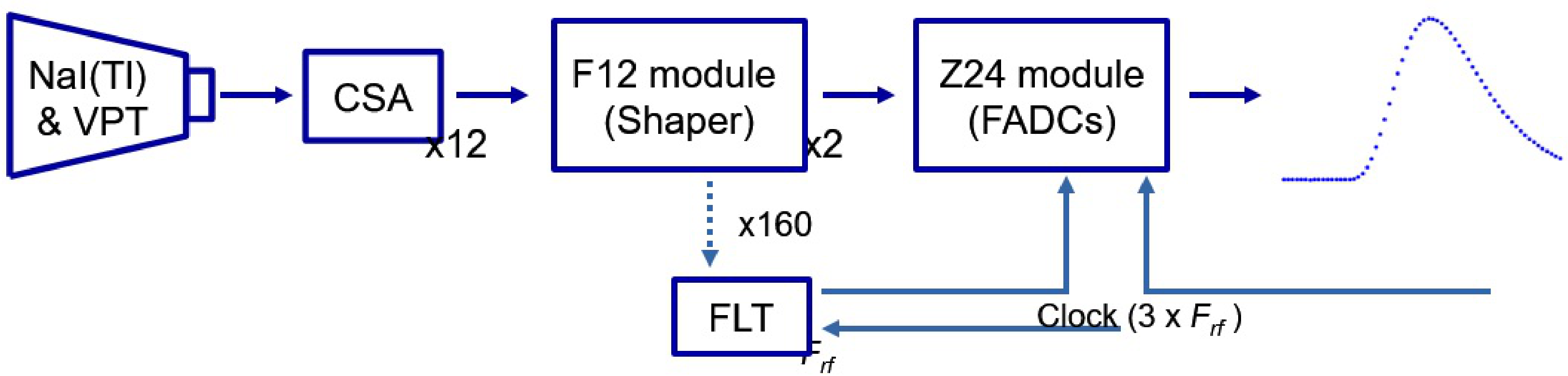
Spectrometric channel in 2019 run. The measured parameters are pulse time and pulse hight.



Typical signal waveform from an EMC channel.

* NIMA v.936 (2019) pp.117-118

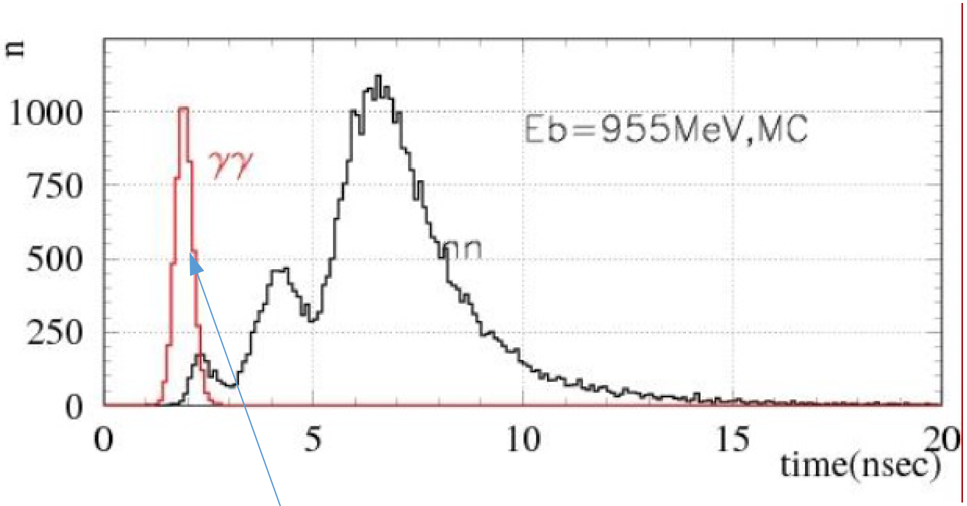
The EMC spectrometric channel



N.A. Melnikova

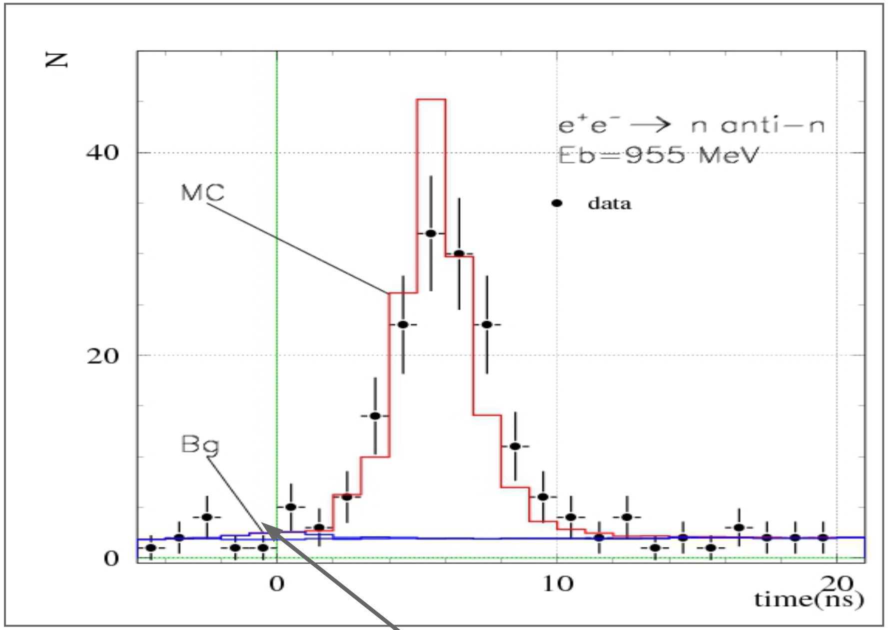
Event time spectra in 2019 run

Ideal MC time picture



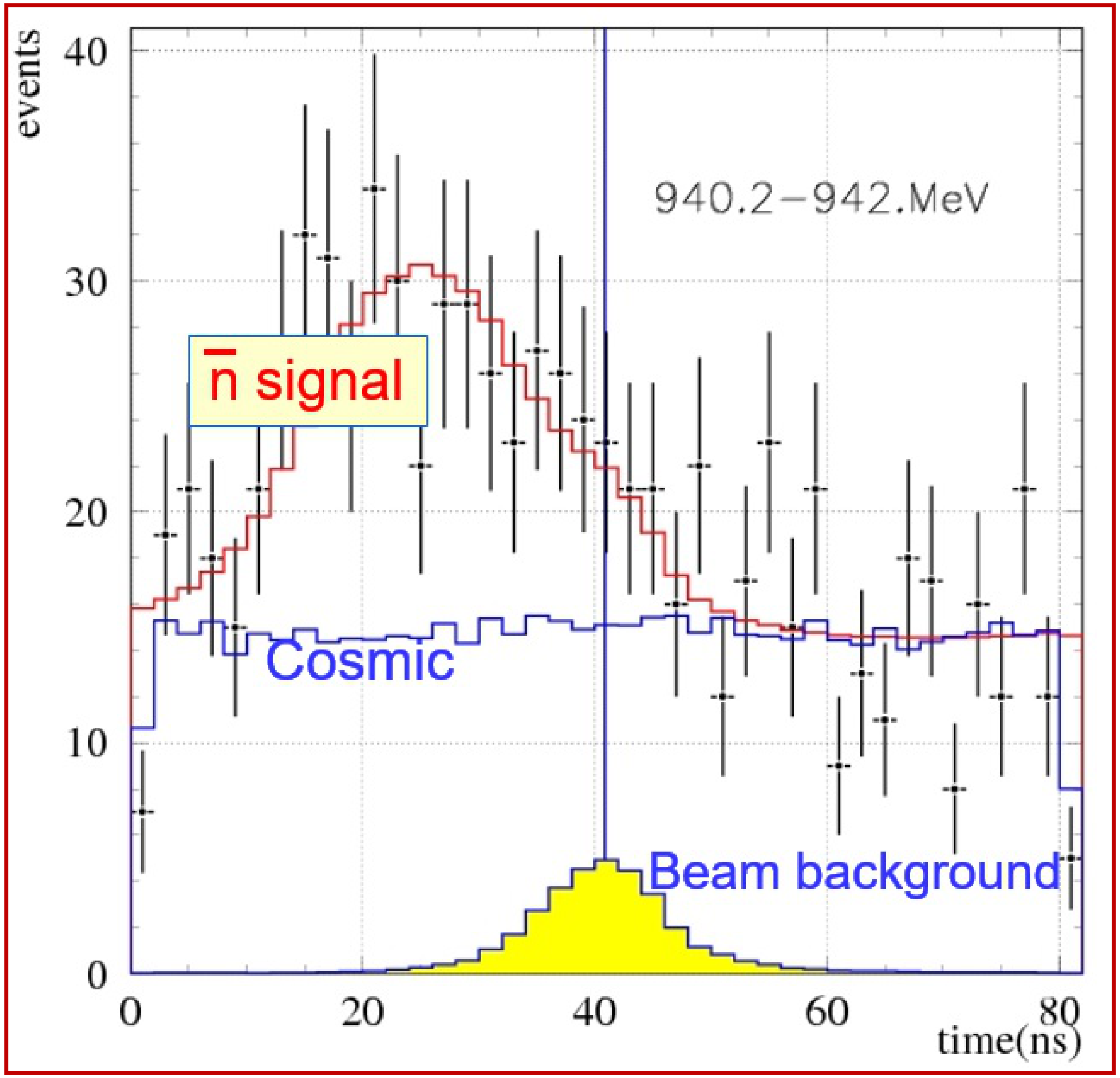
σ=0.8 ns time resolution

Exp. data time picture



Suppressed beam background

Time spectra in 2017 run



Calculation of $e^{\pm}e^{-} \rightarrow$ n+anti-n cross section

$$\sigma_B = N / \varepsilon \, \delta \, L$$

N – detected events number, ~100

L - integrated luminosity, ~ 1 pb^{-1},

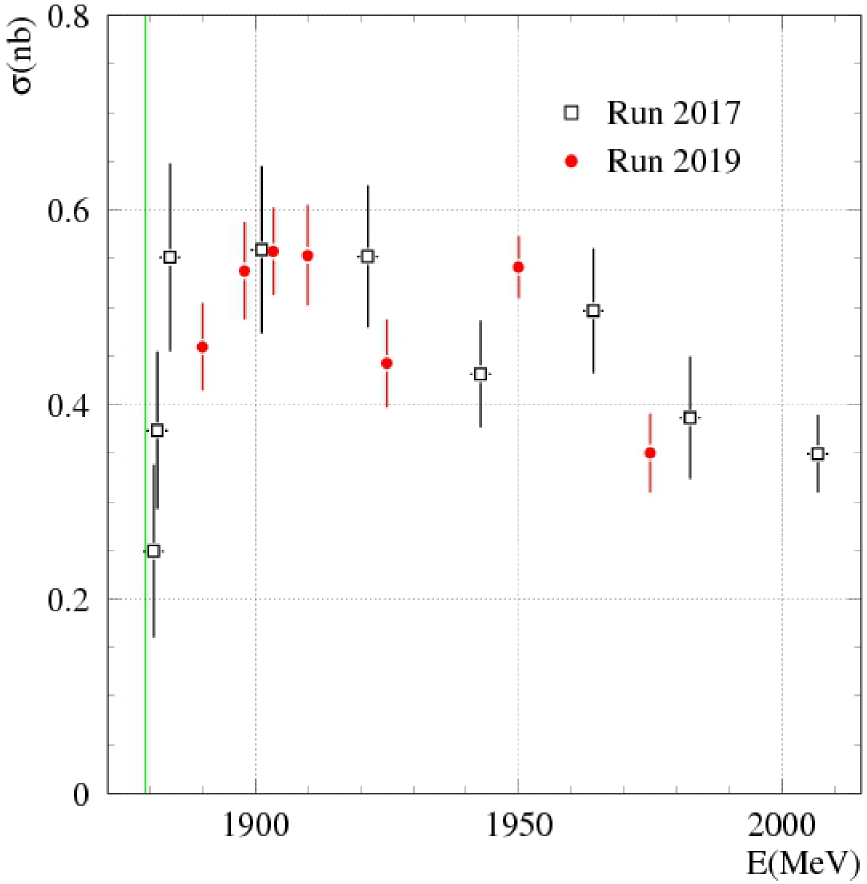
ε - MC detection efficiency, ~ 0.15

δ - radiative correction, ~ 0.8

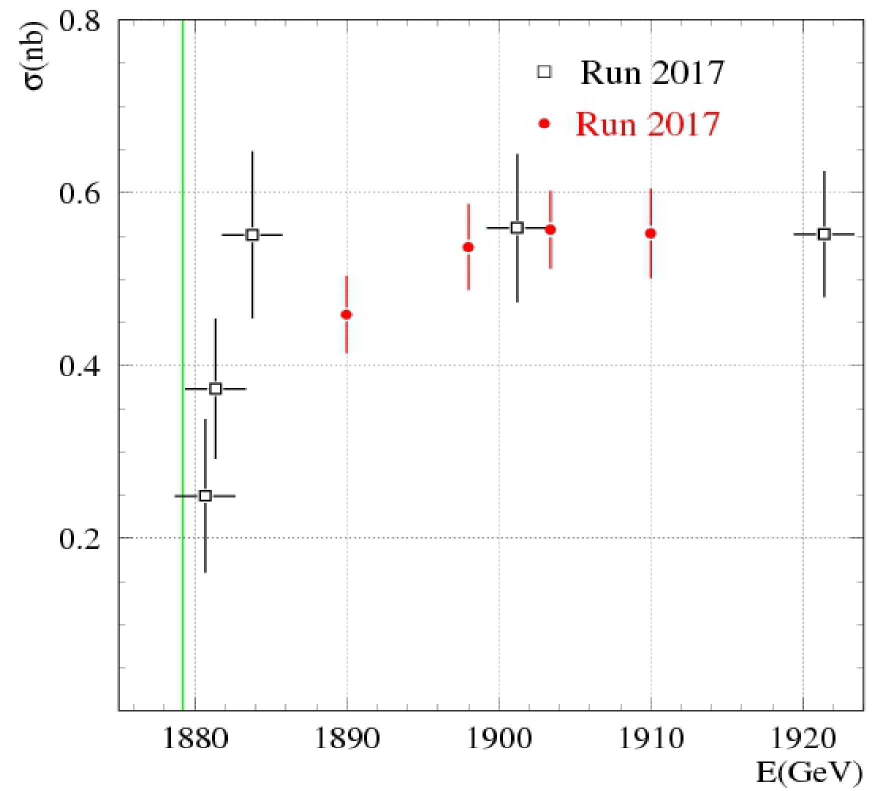
σ_B - total cross section ~ 0.4-0.8 nb

$e^+e^- \to$ n+anti-n cross section

SND data of 2017 and 2019 runs comparison

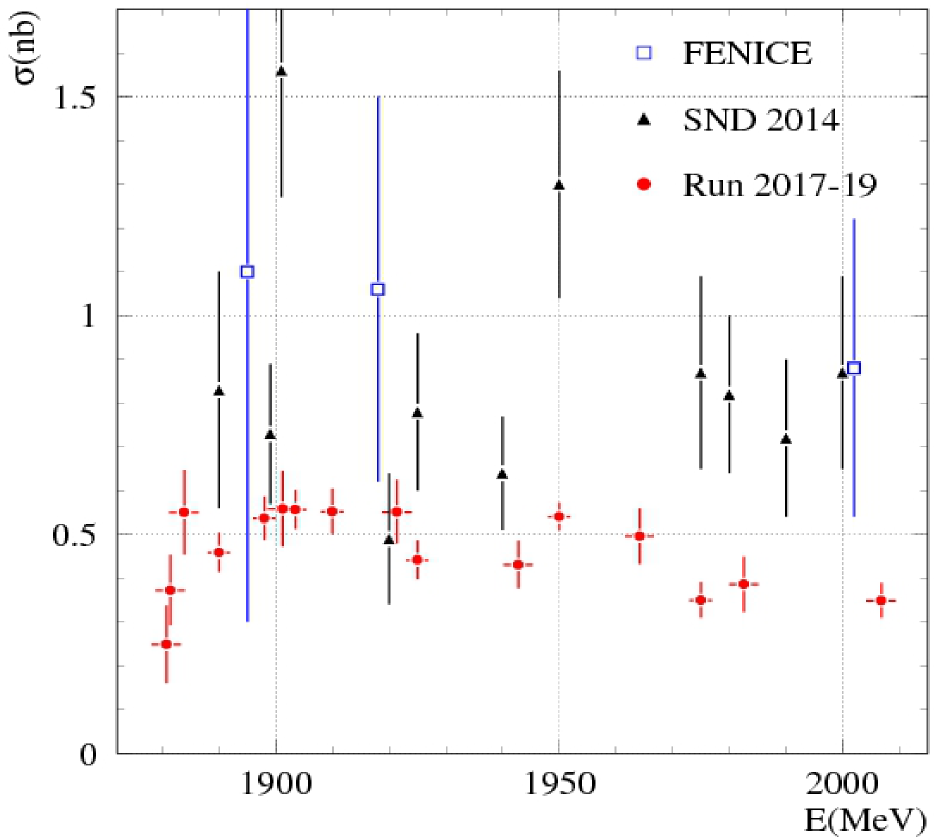


Near threshold

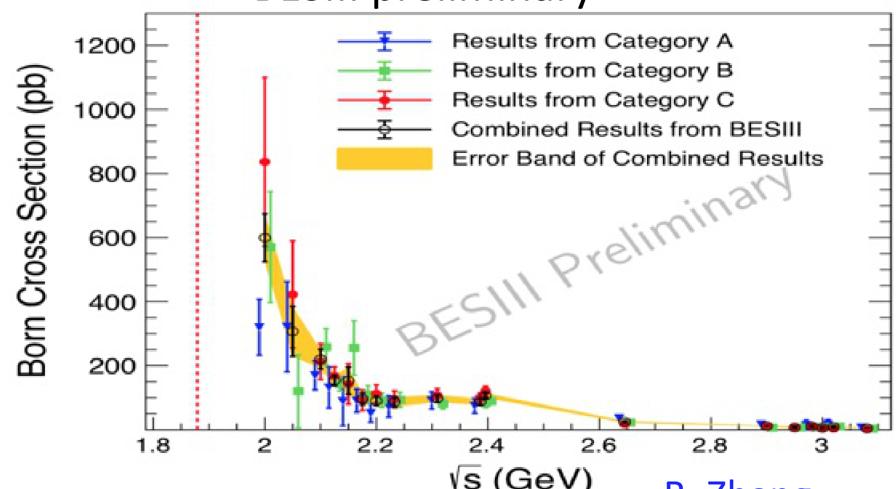


$e^+e^- \rightarrow$ n+anti-n cross section

Comparison of the new SND results with the previous data



BESIII preliminary



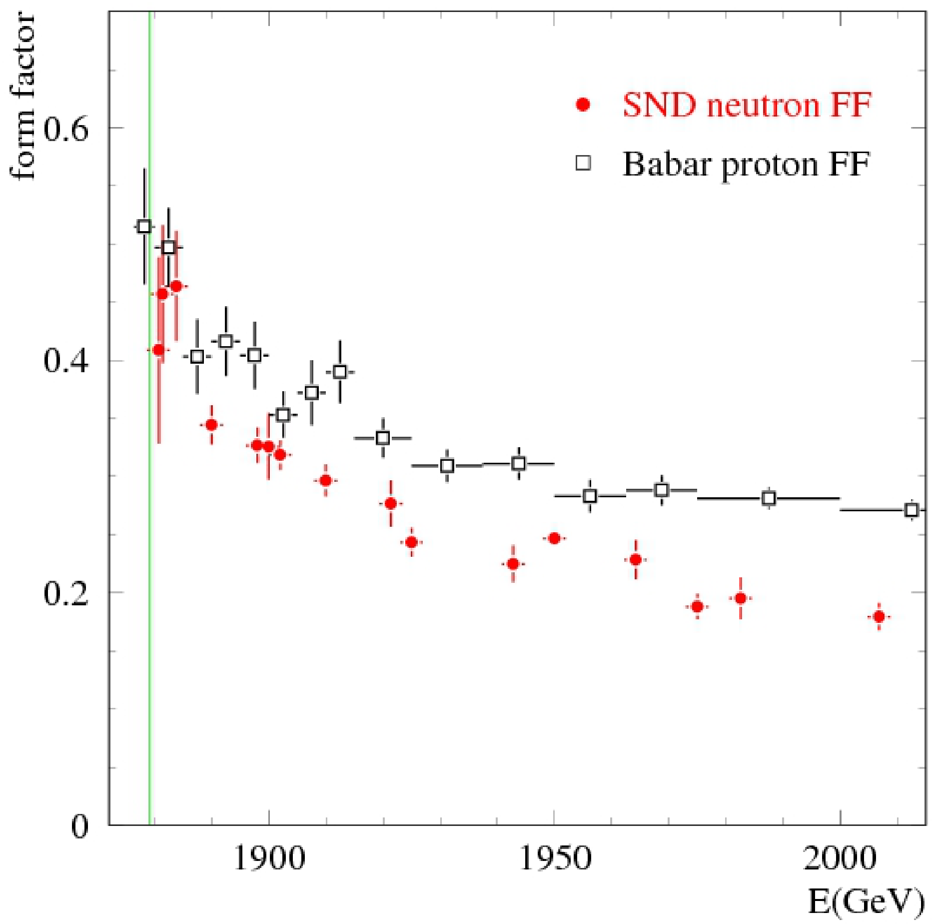
B. Zhang

Systematic uncertainties in $e^+e^- \to n+\text{anti-}n$ cross section

1. Detection efficiency uncertainty ~ 10-15%
   ~ 20-30% close to threshold
2. Physical and beam background uncertainty ~ 5-10%
3. Energy calibration and bg MC mixing uncertainty ~ 5%
4. Luminosity and radiative corrections ~ 3%
5. Total systematics ~ 15-20 %, (~ 20-30% at threshold)

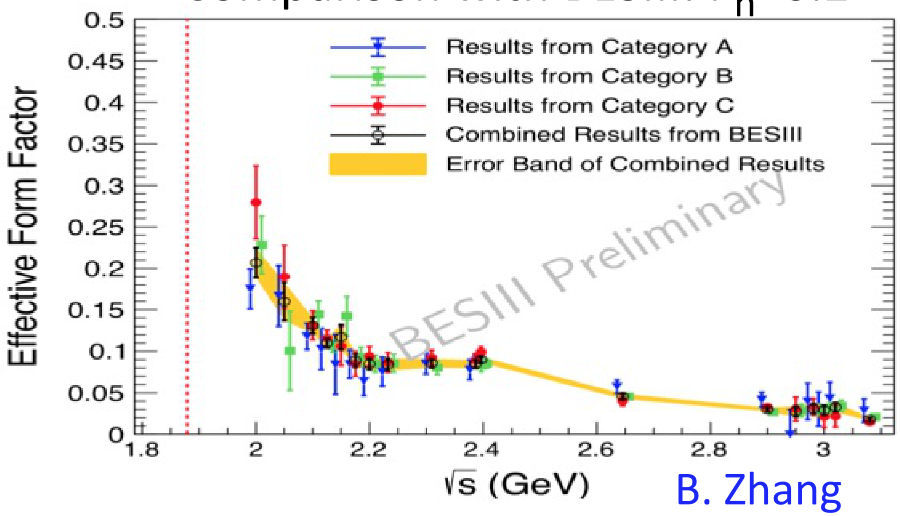
Statistical error $\Delta\sigma/\sigma$ at one energy point if
from 10% to 30%.

The neutron timelike form factor compared with the proton form factor



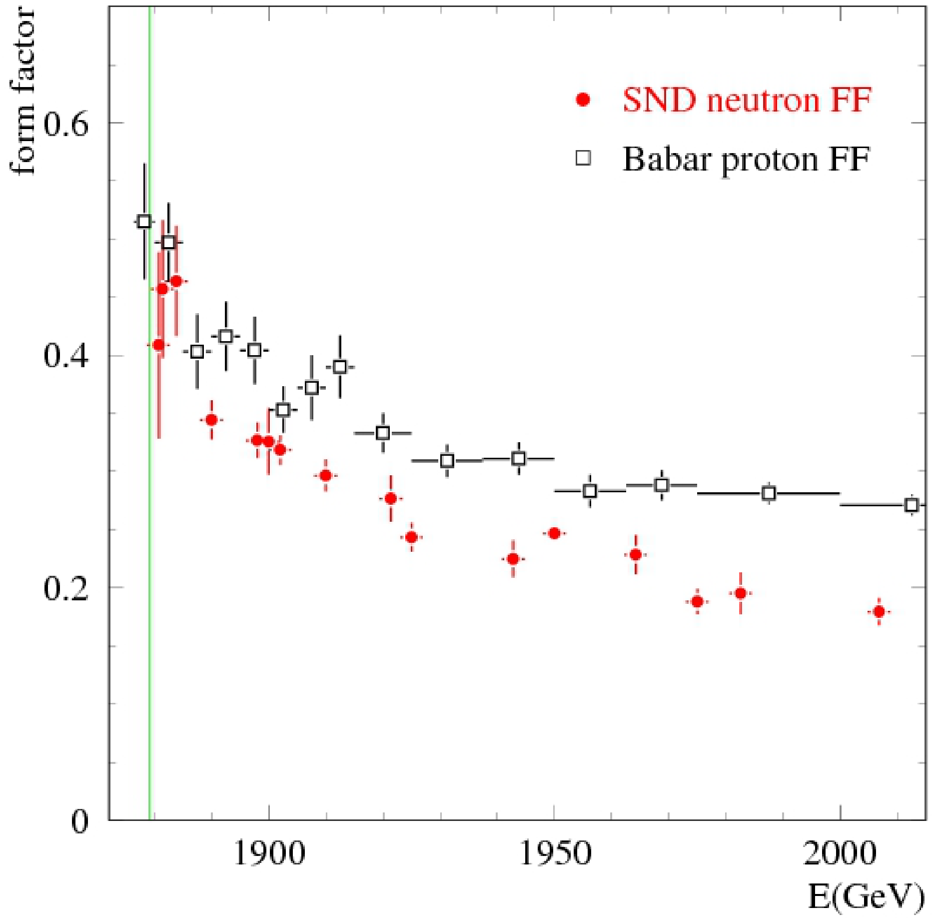
The neutron FF is found to be close to the proton FF near the threshold, but becomes lower with the rise of energy.
The asymptotic prediction is $F_n = - F_p/2$

Comparison with BESIII: F_n~0.2



B. Zhang

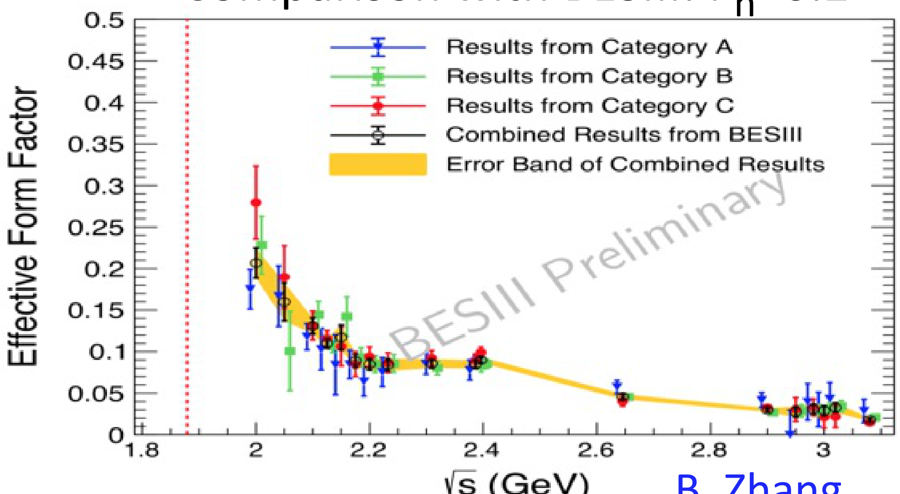
The neutron timelike form factor compared with the proton form factor



The neutron FF is found to be close to the proton FF near the threshold, but becomes lower with the rise of energy.

The asymptotic prediction is $F_n = - F_p/2$

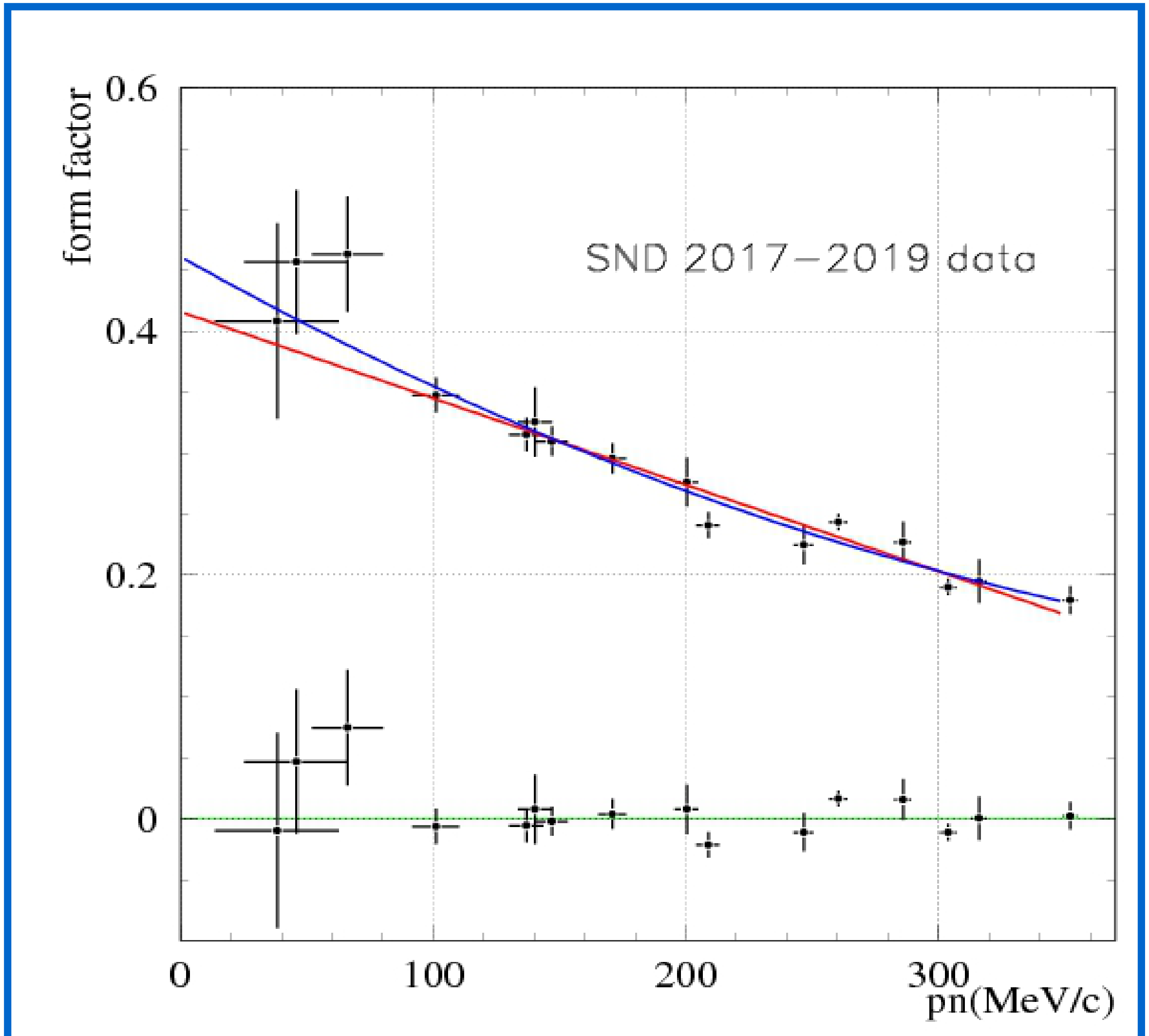
Comparison with BESIII: F_n~0.2



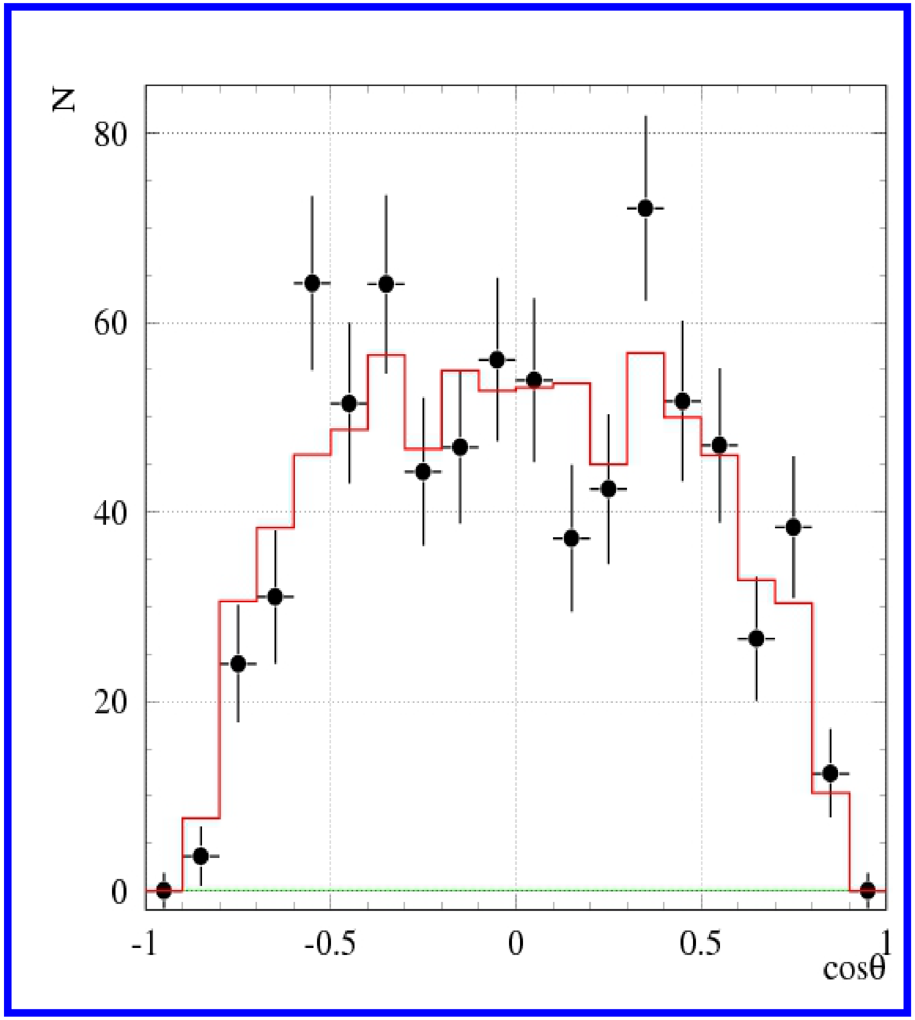
B. Zhang

Measurement of the neutron TL form factor …

Linear fit to the neutron timelike form factor vs neutron momentum



Extraction of the |GE|/|GM| ratio from the cosθ distribution



$|G_M|^2 \sim 1+\cos^2\theta$,

$|G_E|^2 \sim 1-\cos^2\theta$,

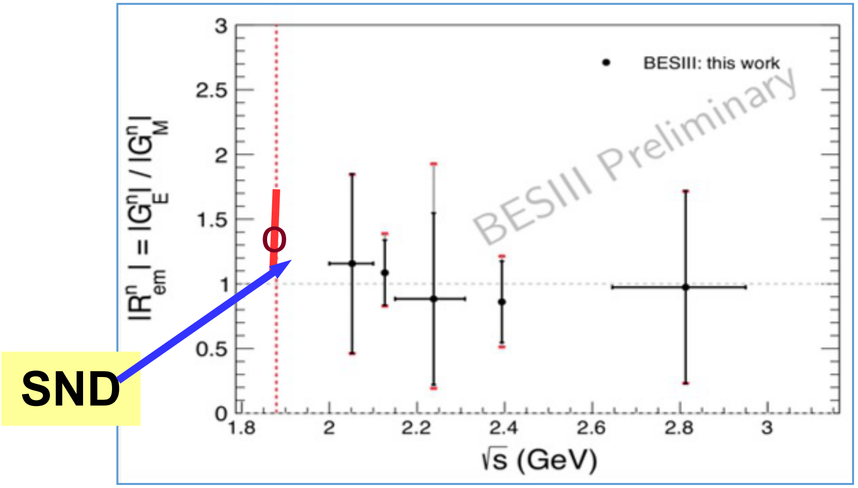
Fit results:

$|G_E| / |G_M| = 1.35 +- 0.35$,

$\chi 2/\nu = 1.1$

Conclusion : the measured $|G_E| / |G_M|$ is with 1σ significance above the $|G_M| = |G_E|$ model

Comparison with BESIII : $G_E/G_M \sim 1$



B. Zhang

Conclusions and perspectives

1. Experiment have been carried out with the SND detector at the VEPP-2000 e+e- collider to measure the $e^+e^- \to$ n+anti-n process cross section and the neutron timelike e.m. form factor
2. The SND electromagnetic calorimeter based on 1680 NaI(Tl) crystals is used as an effective antineutron detector.
3. Due to the selection conditions and delay time measurements the events of $e^+e^- \to$ n+anti-n process are selected.
4. The $e^+e^- \to$ n+anti-n cross section is measured from the threshold up to 2 GeV of c.m. energy, its value is ~0.6-0.3 nb.
5. The measured neutron timelike e.m. form factor varies from 0.5 to 0.2. the data are mostly consistent with the $|G_E| \approx |G_M|$ model.

----

6. Now we continue data taking above the threshold of the $e^+e^- \to$ n+anti-n process with the goal to collect the 300 inv.pb data. The analysis of recorded data is going on.

Thank you
for listening