Выделение процесса $e^+e^- \to \bar{n}\, n$ по времени в калориметре

С.И. Середняков

Институт ядерной физики им. Г.И. Будкера СО РАН

Сессия-конференция СЯФ ОФН РАН

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Detection of $e^+e^- \to n\bar{n}$ events using time measurements in the calorimeter

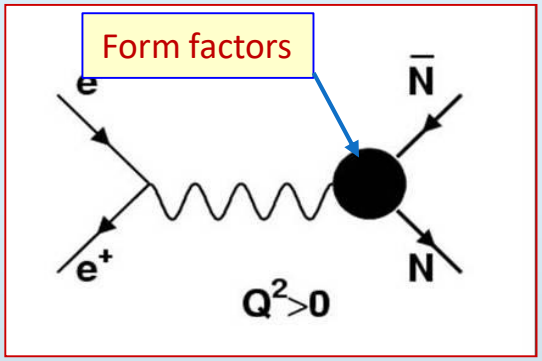
OUTLINE

1. Physical motivation
2. Detector, collider, experiment
3. Selection of $n\bar{n}$ events
4. Electronics channel
5. Signal waveform fitting
6. Time resolution ($e^+e^- \to \gamma\gamma$)
7. Time spectra of nn events
8. $e^+e^- \to n\bar{n}$ cross section
9. Conlusions

Physical motivation of the experimental study of $e^+e^- \to n\bar{n}$ process

The internal structure of neutron can be derived from the measured $e^+e^- \to nn$ cross section.

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



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

S, D – waves,

two form factors
e.g. G_E, G_M

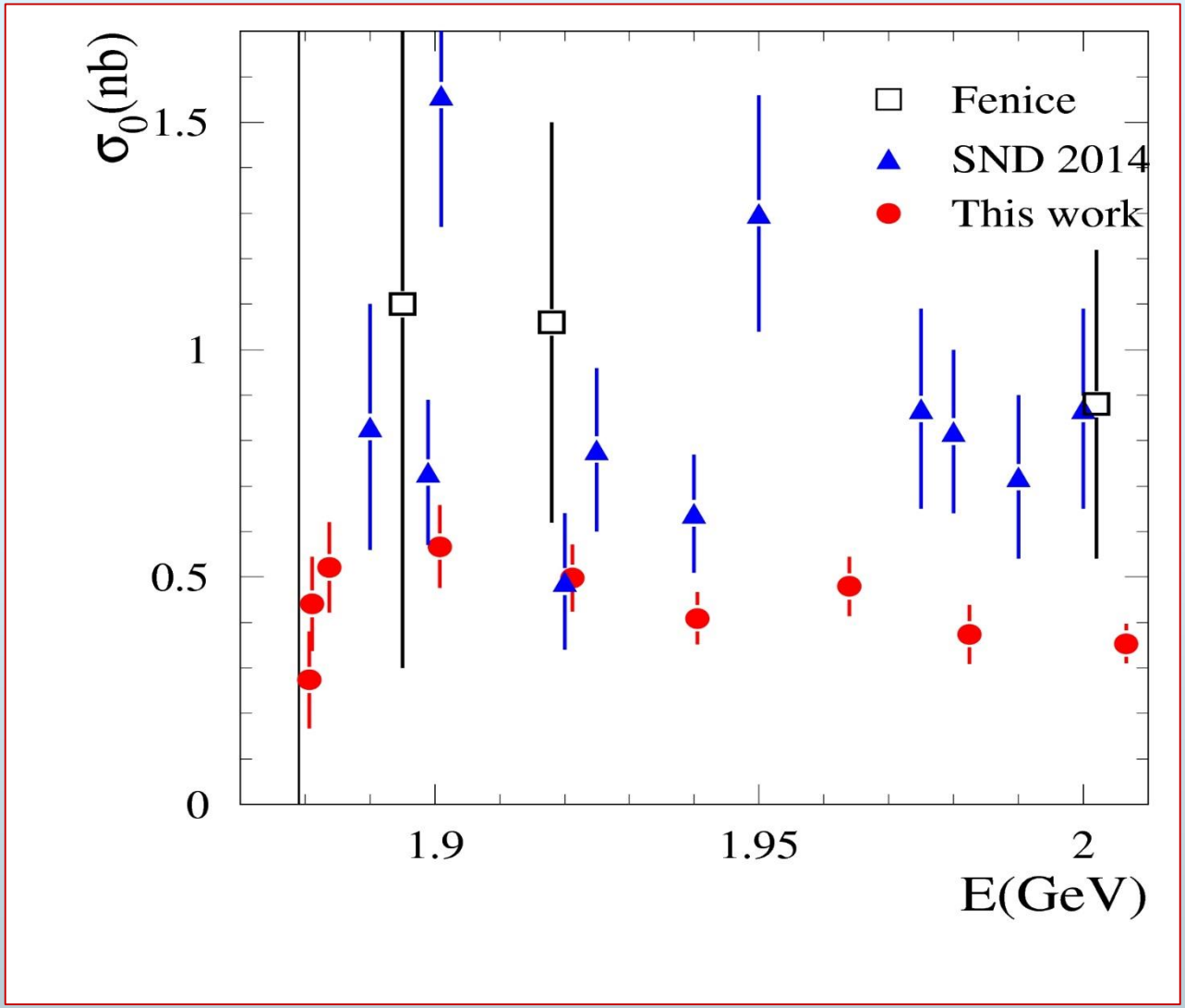
Expression for nucleon pair e+e- production, *C*=1 for neutrons

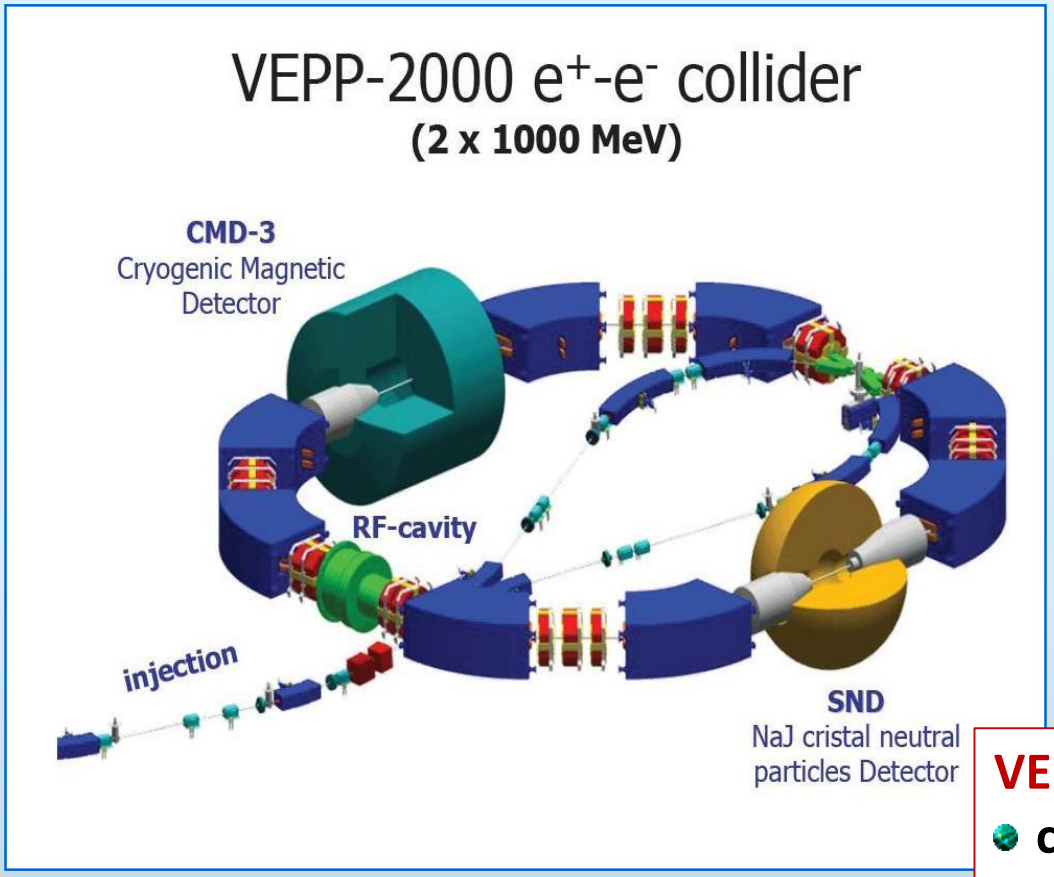
$$\sigma(e^+e^- \to B\bar{B}) = \frac{\alpha^2\beta C^2}{4m^2}\left(|G_M|^2(1+\cos^2\theta) + \frac{4m_B^2}{m^2}|G_E|^2(1-\cos^2\theta)\right)$$

m – cms energy
β – nucleon velocity
θ – polar angle
m_b – nucleon mass

Form factors G_E and G_M describe the distribution of electric charge and current inside nucleons

Existing data on e+e- → n n̄ cross section





In operation since 2010

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

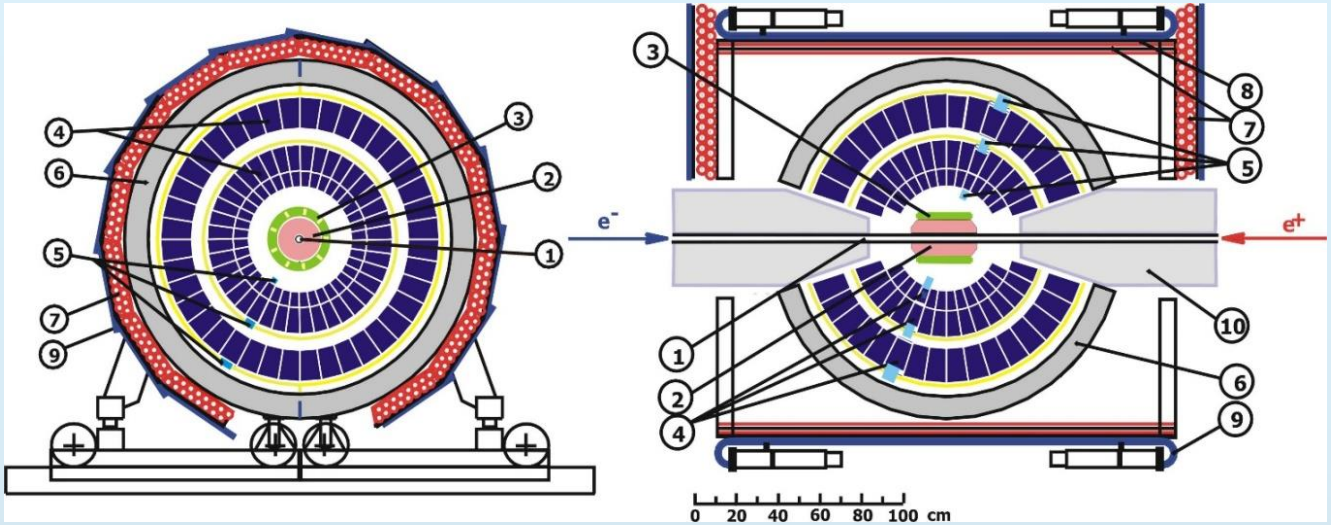
Planned luminosity ~ 2 inv.fb

VEPP-2000 parameters:

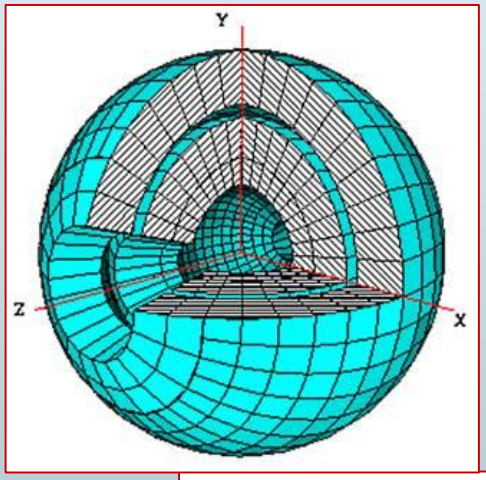
- **c.m. energy E=0.3-2.0 GeV**
- **round beam optics**
- **Luminosity at E=1.8 GeV**

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

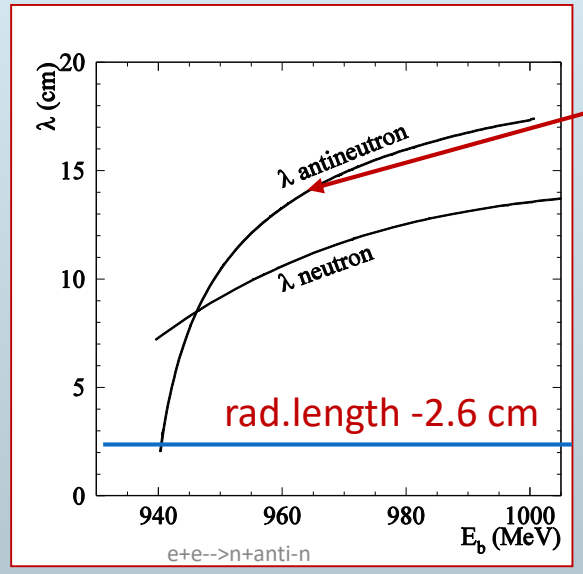
SND detector (since 1995)



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

2019 run data used in analysis

DATA RUN 2019 :

Eb=900 MeV, L=1.29 pb^{-1}

Eb=912.5 MeV, L=1.17 pb^{-1}

Eb=925 MeV, L=1.17 pb^{-1}

* Eb=936 MeV, L=2.32 pb^{-1} — Threshold

Eb=950 MeV, L=2.36 pb^{-1}

Eb=962.5 MeV, L=2.03 pb^{-1}

Eb=975 MeV, L=4.66 pb^{-1}

Eb=987.5 MeV, L=2.06 pb^{-1}

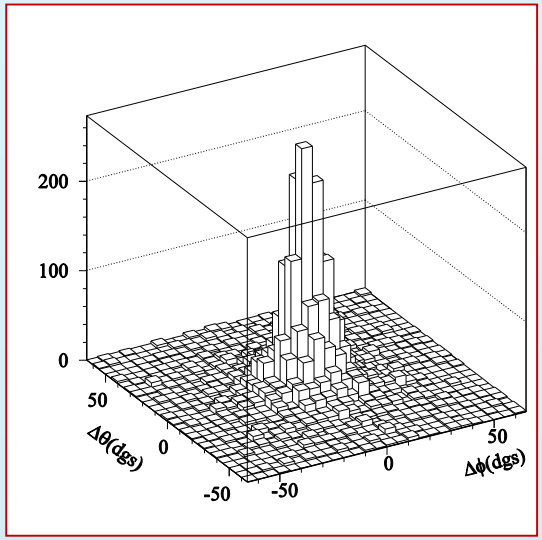
* Eb=955 MeV, L=1.90 pb^{-1}

* Eb=951 MeV, L=1.83* pb^{-1}

Eb=945 MeV, L=2.60 pb^{-1}

$\Sigma L=23\ pb^{-1}$

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: $E_3 < 0.7E_{beam}$
6 - photon χ^2 : >-2.5

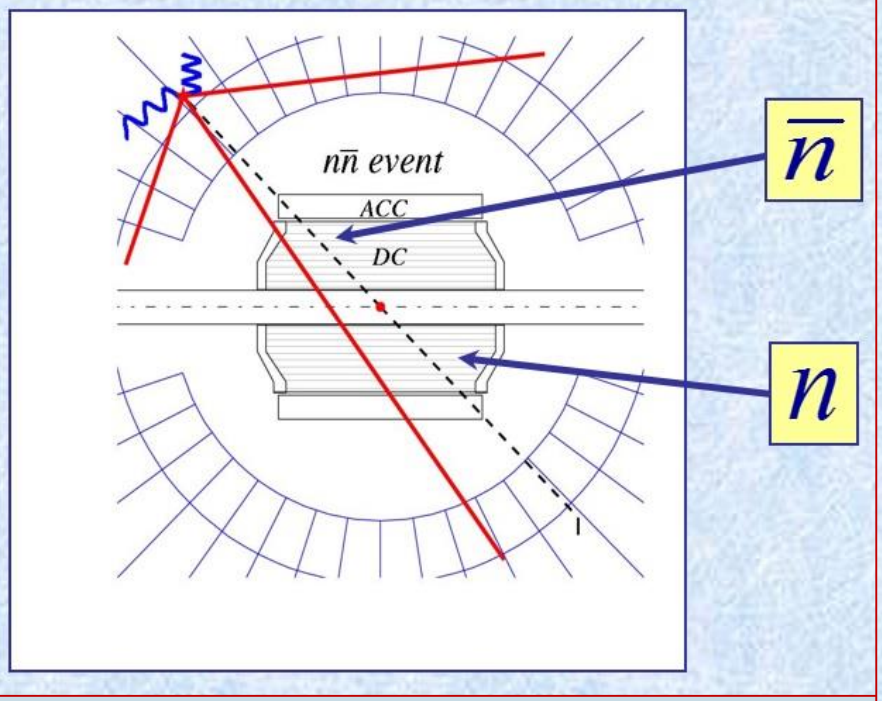
Selection results:

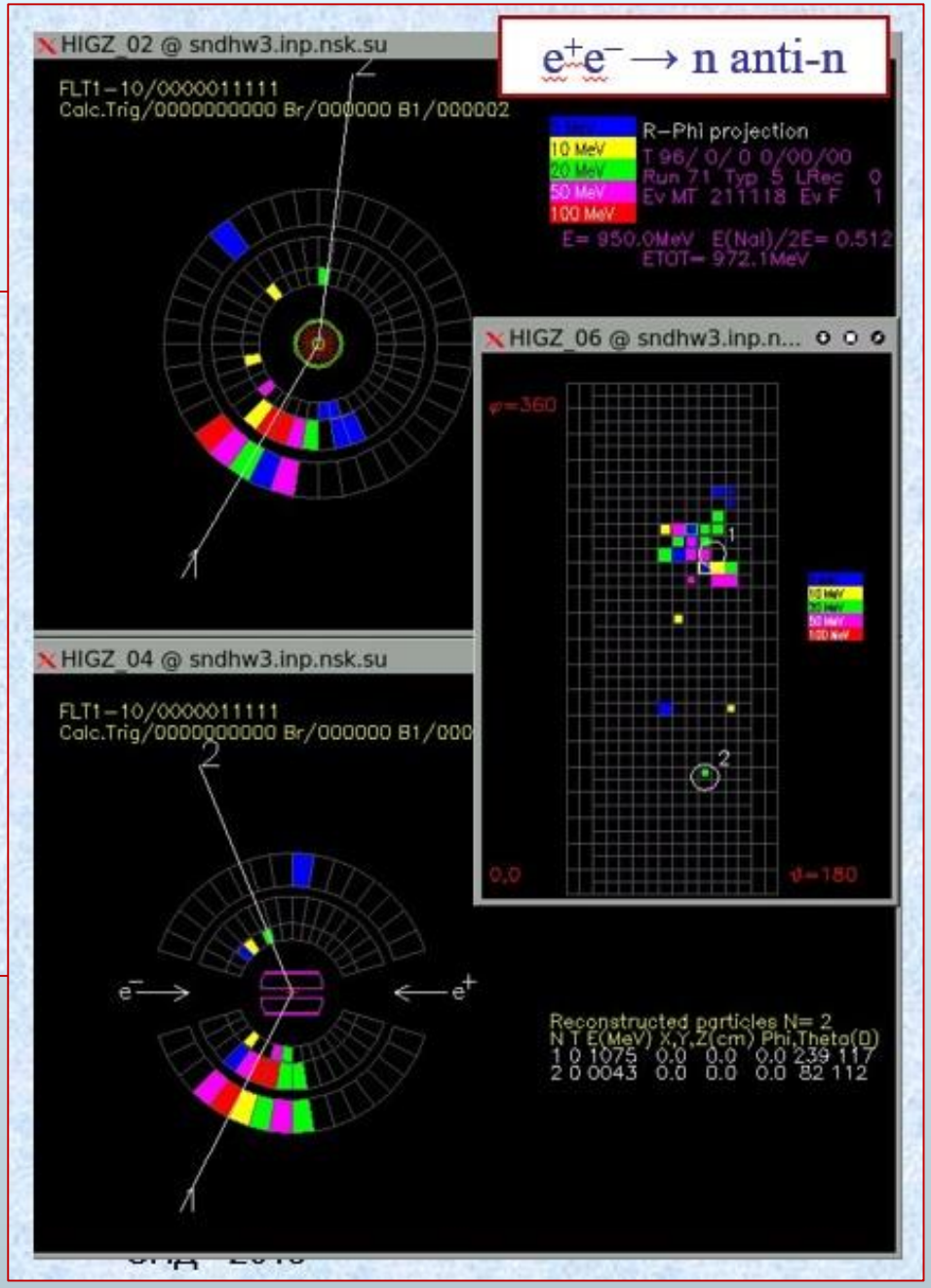
1 – total events recorded ~2 10^7 events/pb -1
2 – after applying cuts ~ 100 events/pb -1, including
physical, beam and cosmic background and n anti-n events

Selection efficiency :

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

Events picture



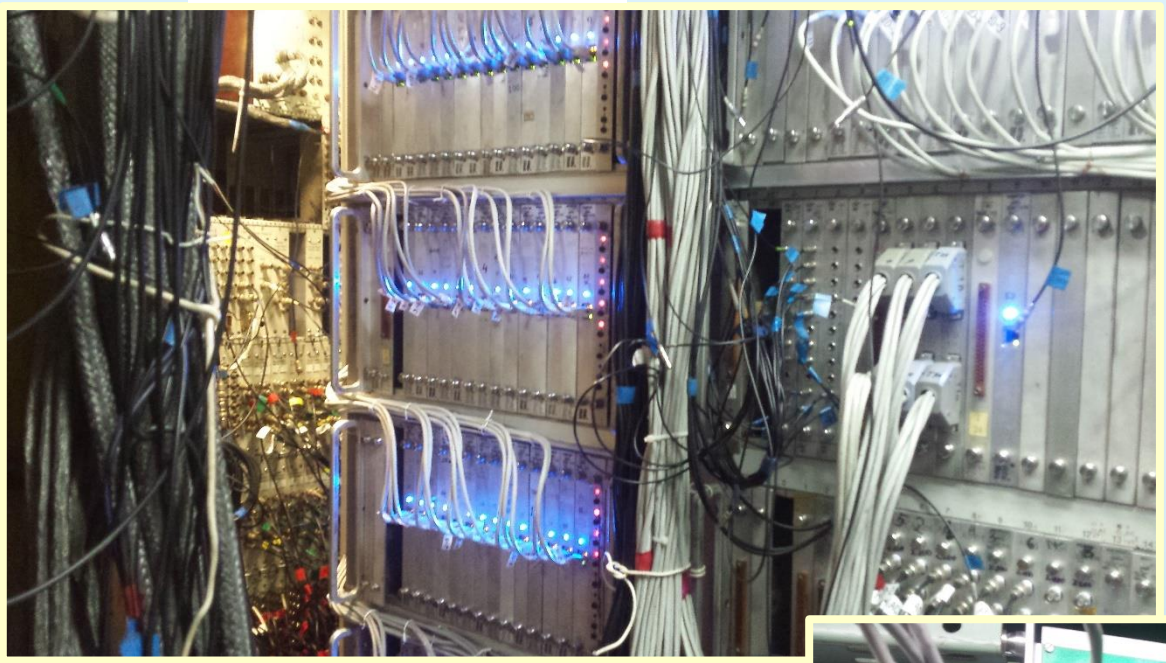


Physical, beam and cosmic backgrounds

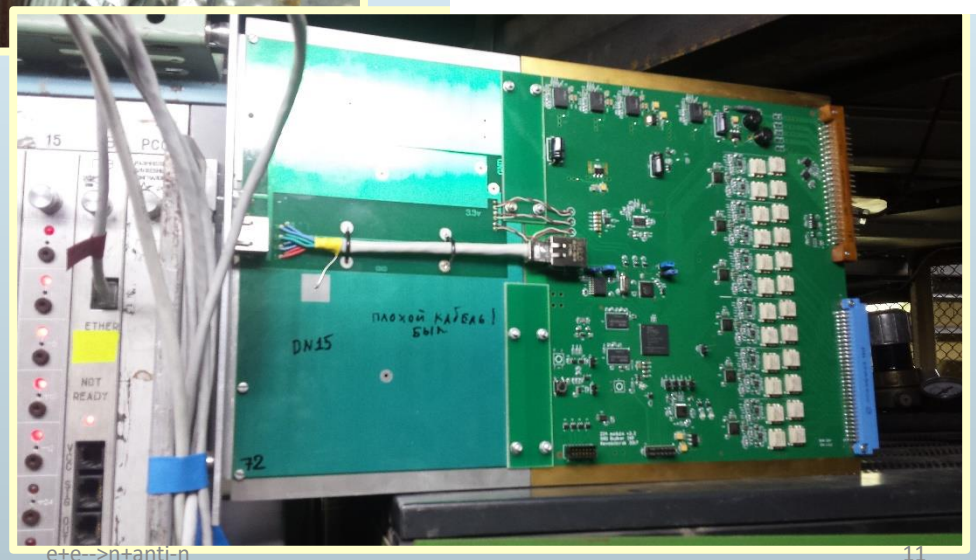
Three types of background for e+e- $\rightarrow$ n+anti-n :

1. Physical background - from processes e+e→ $\gamma\gamma(\gamma)$, $K_S K_L + n\pi 0(\gamma)$, 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 $E_{cal} > E_{beam}$.

Flash ADC crates

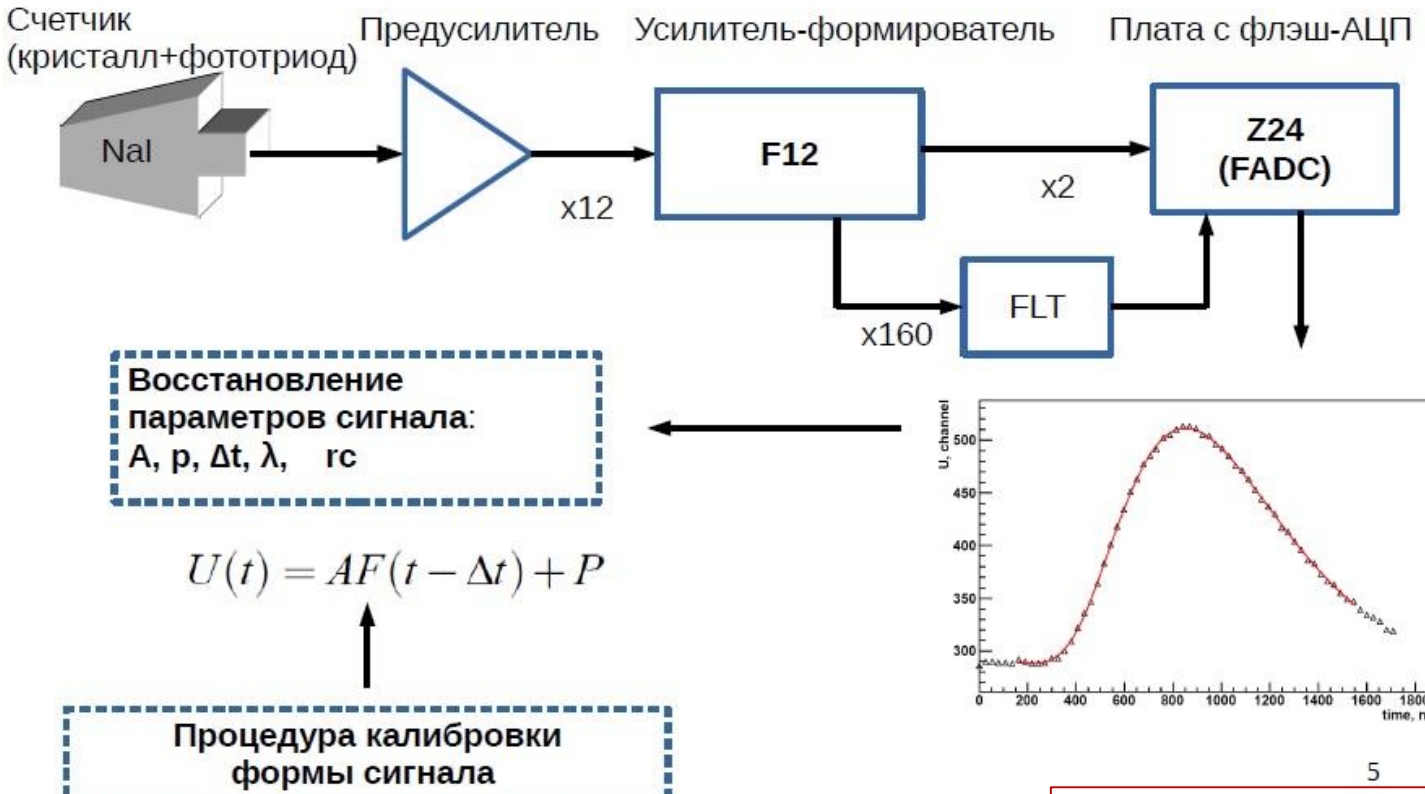


Flash ADC module (Z-24)



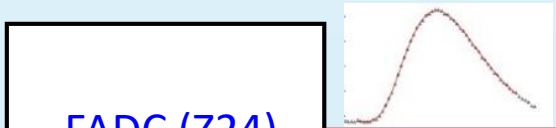
Calorimeter channel electronics

Новая электроника измерительного канала калориметра:



Slide from N.A. Melnikova

Time and energy calculation



Fit calculations

FADC (Z24)

ON-LINE FARM

A, p, Δt, λ, rc

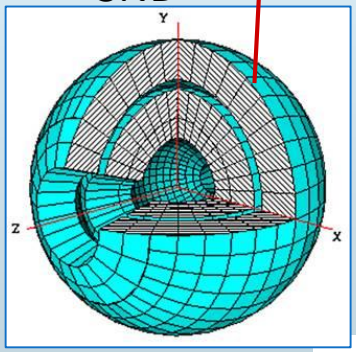
EVENT BUILDER

DATA STORAGE

Fit function

$$U(t) = AF(t - \Delta t) + P$$

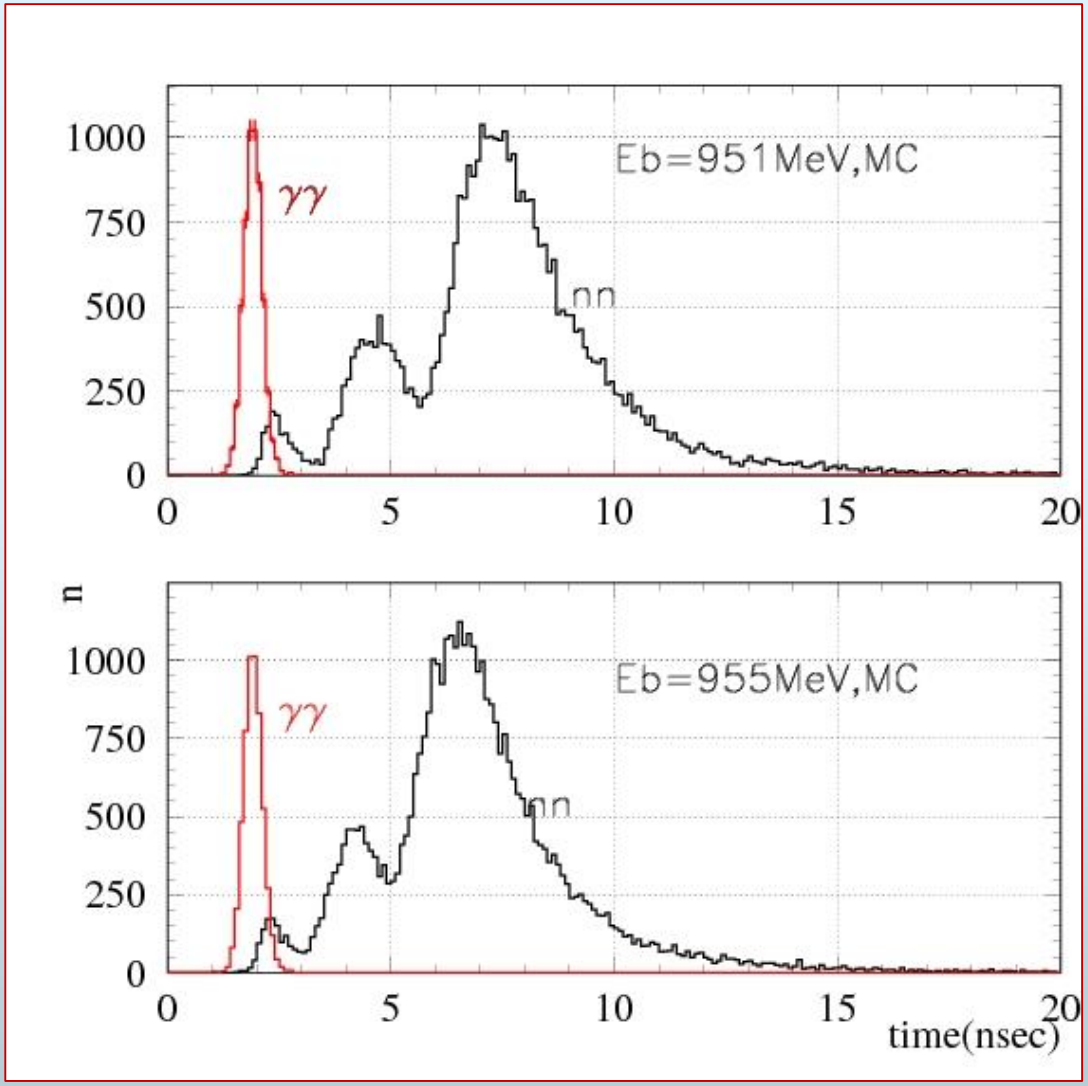
SND



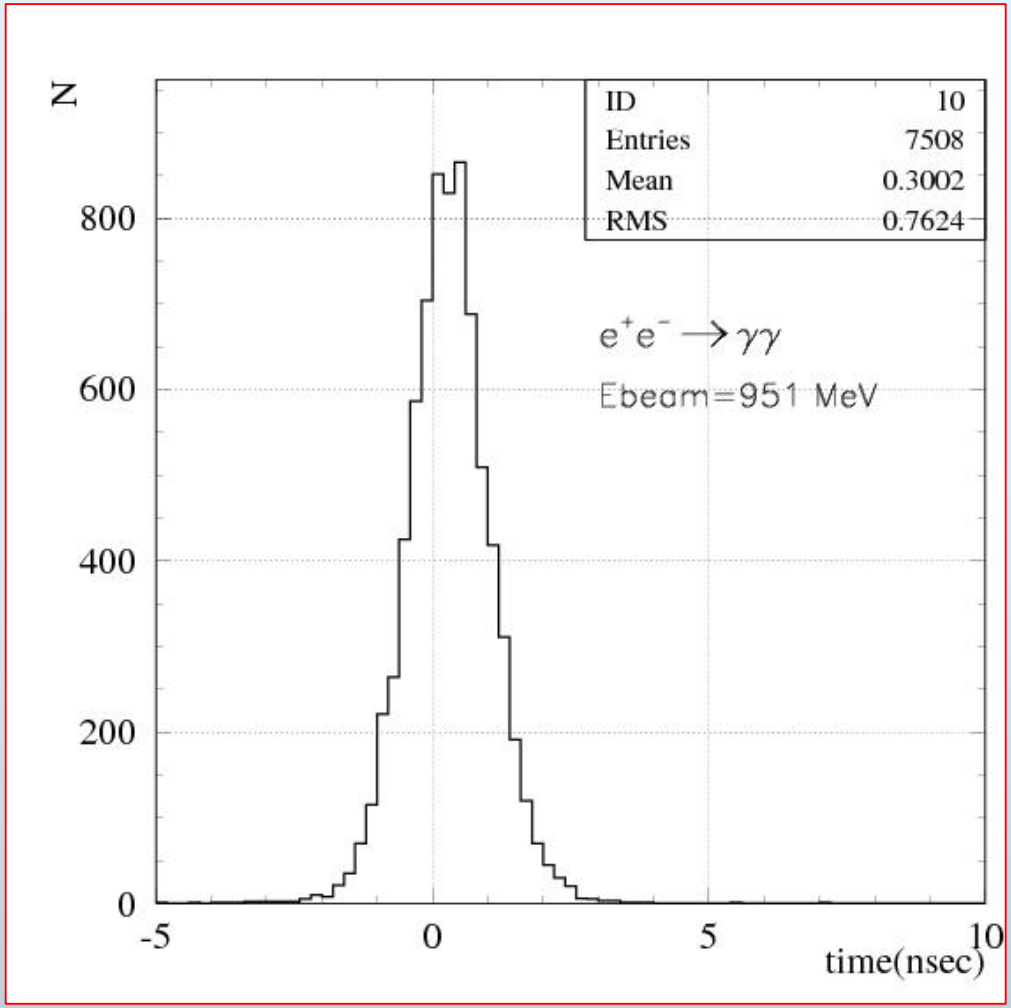
Fit function minimization

$$\chi^2 = (y_i - A \cdot F(t_i - \tau) - P) S_{ij}^{-1} (y_j - A \cdot F(t_j - \tau) - P)$$

Monte Carlo time spectra for e+e- -> γγ, n anti-n



Time resolution of the SND calorimeter from e+e→ γγ process



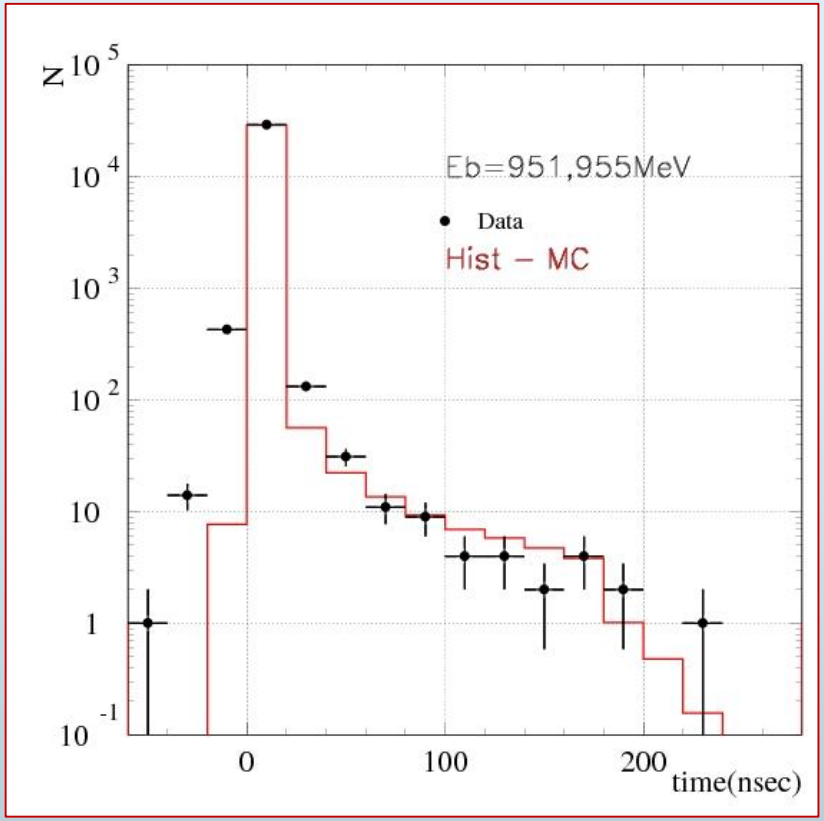
Data
Eb=951 MeV

σ_τ=0.76 nsec

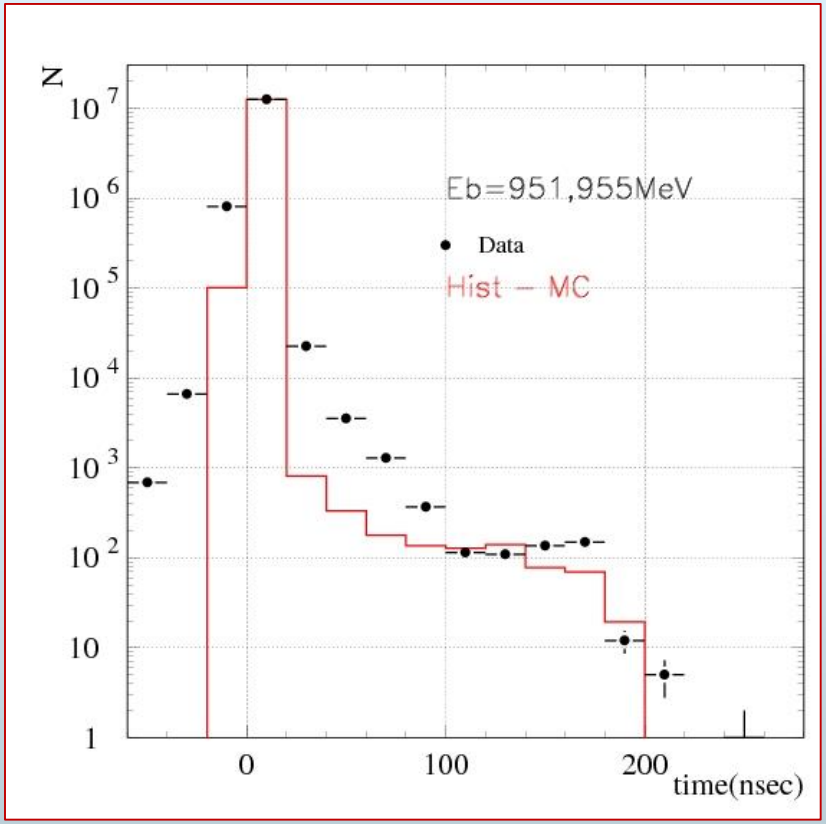
$<T>=\Sigma t_i E_i / \Sigma E_i$

Распределение по времени срабатывания “хитов” EMC (e+e- → γγ, n+anti-n, run 2019)

e+e- → n+anti-n

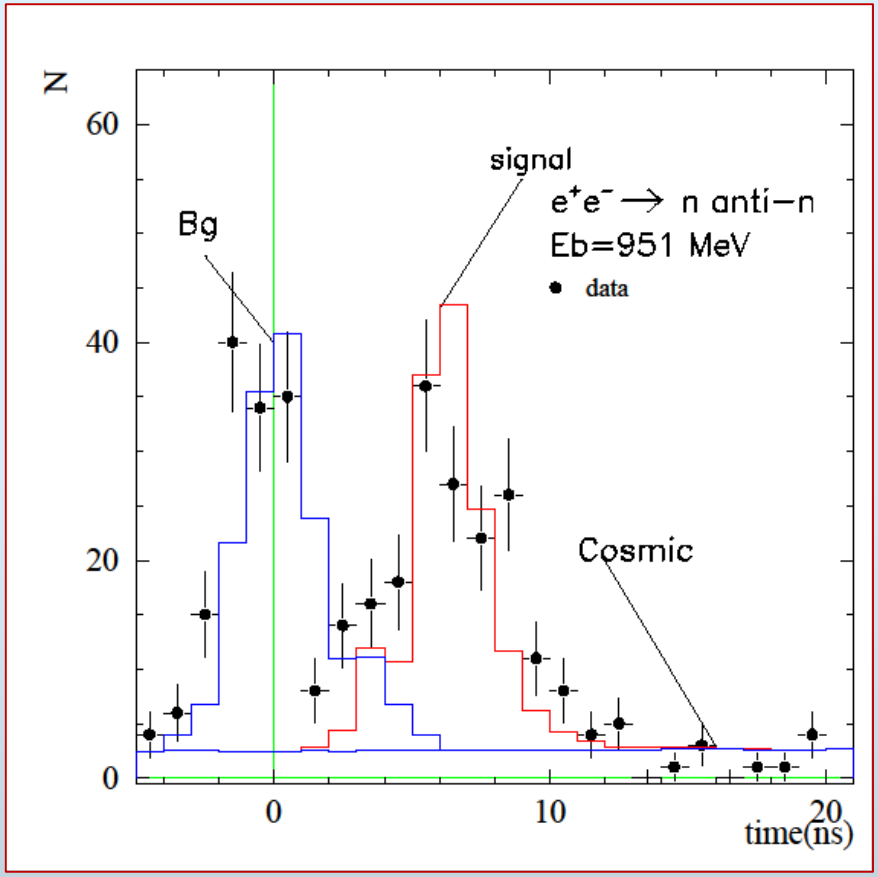


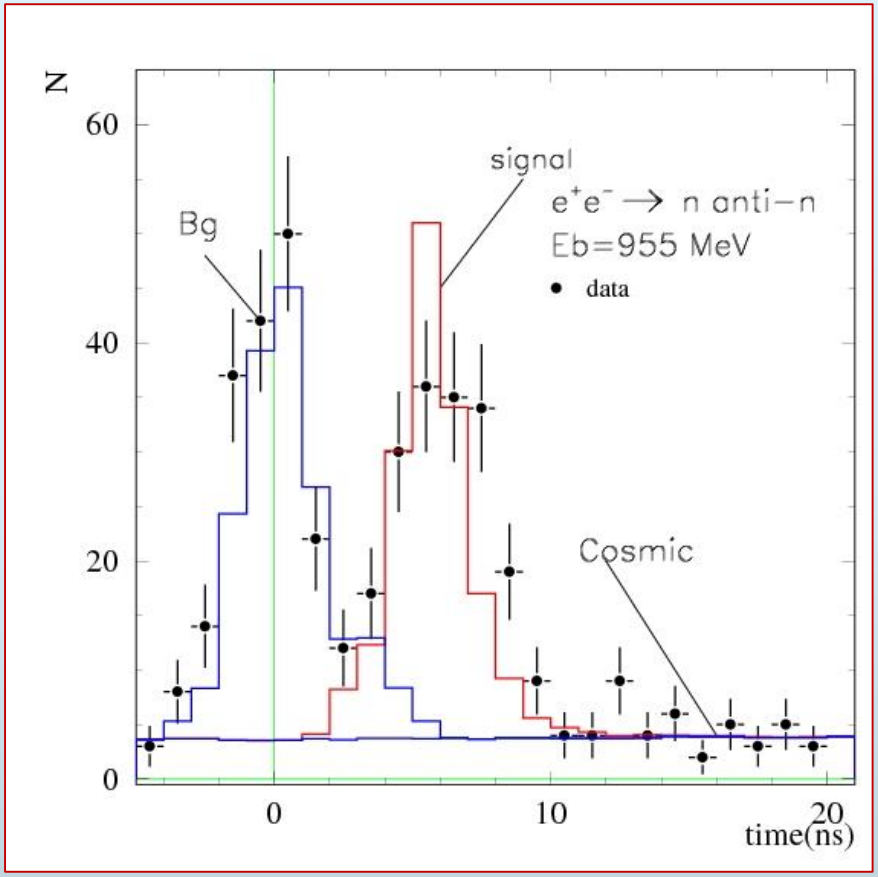
e+e- → γγ



Time spectra of e+e- → n anti-n candidates events

EMC energy threshold – $E_{thr}>0.8*E_{beam}$





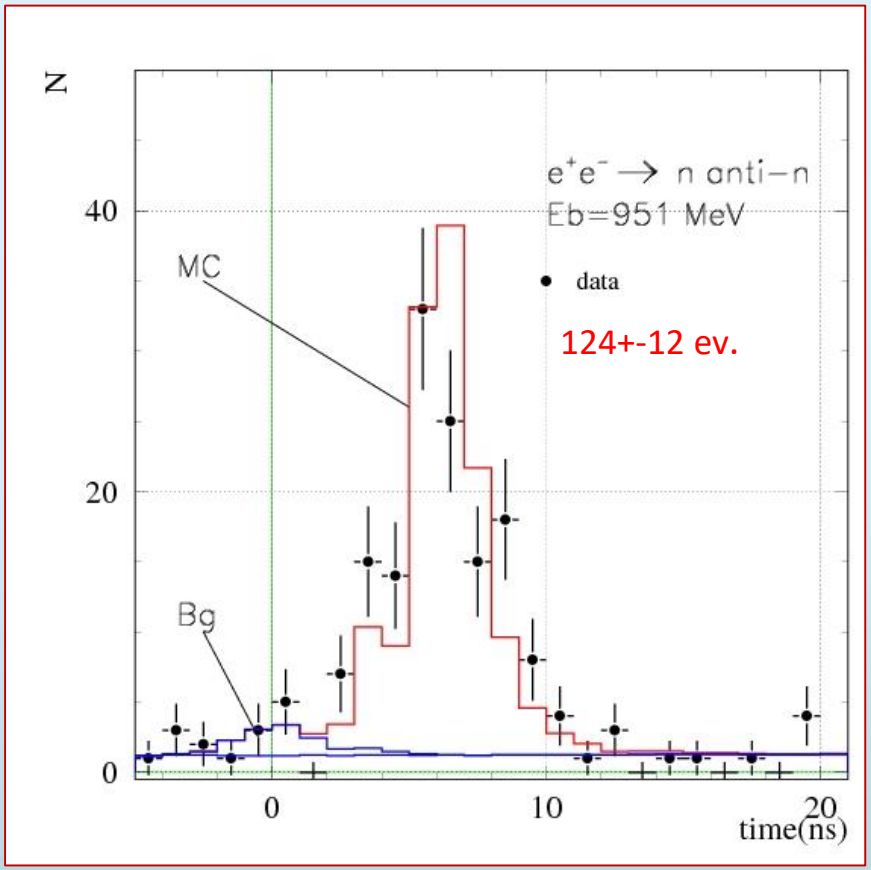
Conclusions: signal and background time spectra overlap strongly but a separation between them is observed

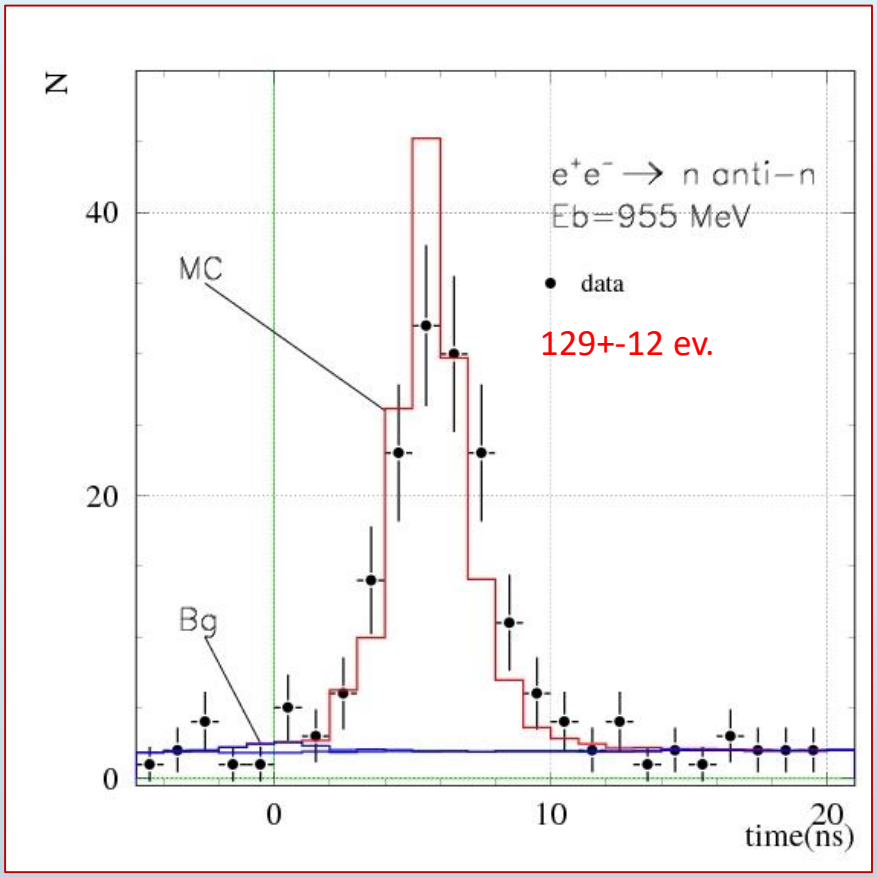
Time spectra of e+e- → n anti-n candidates events

σ_{nn}= 504+-49 pb

The threshold in EMC is raised - E_{thr}>1.05E_{beam}

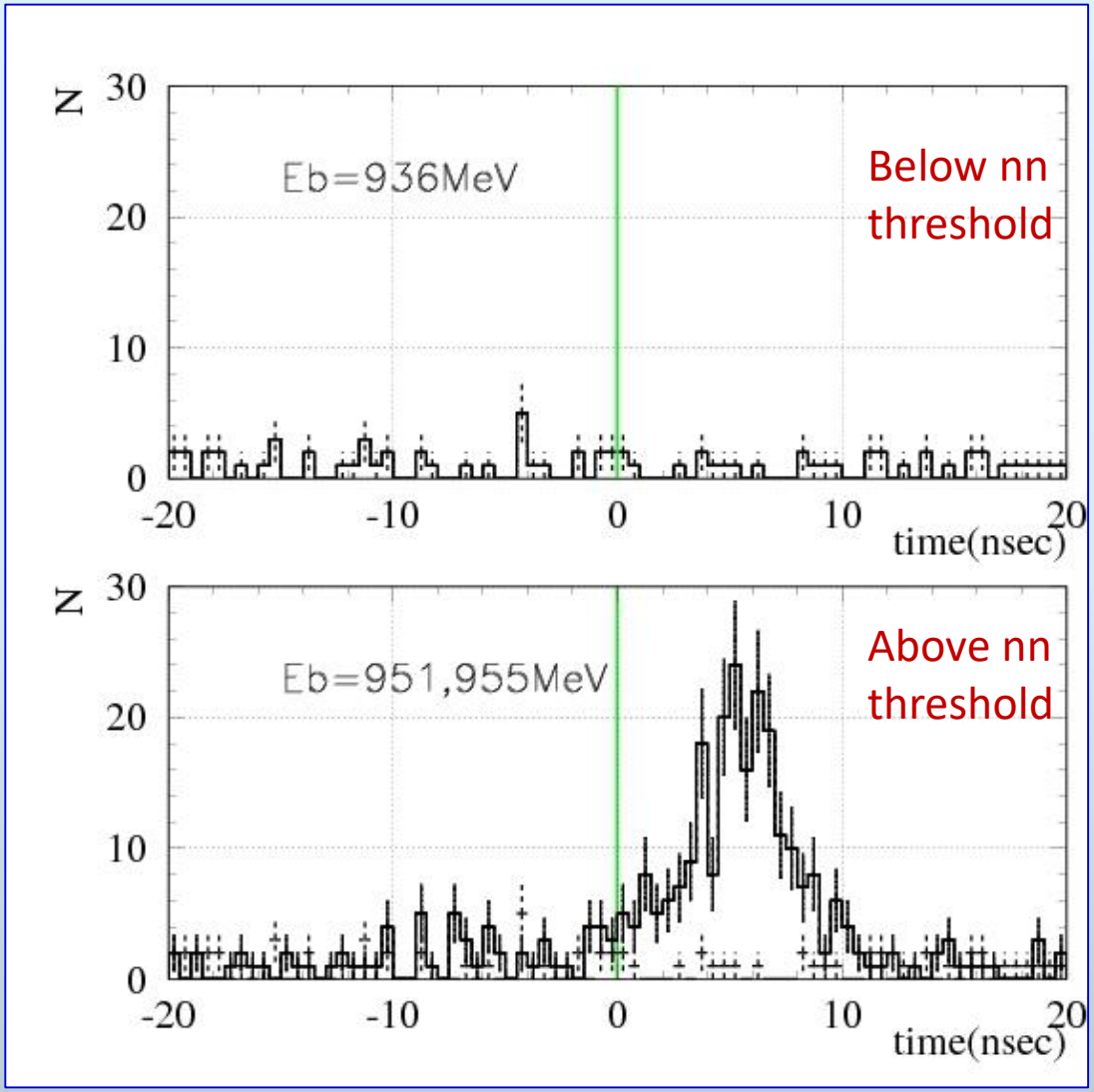
σ_{nn}= 475+-44 pb



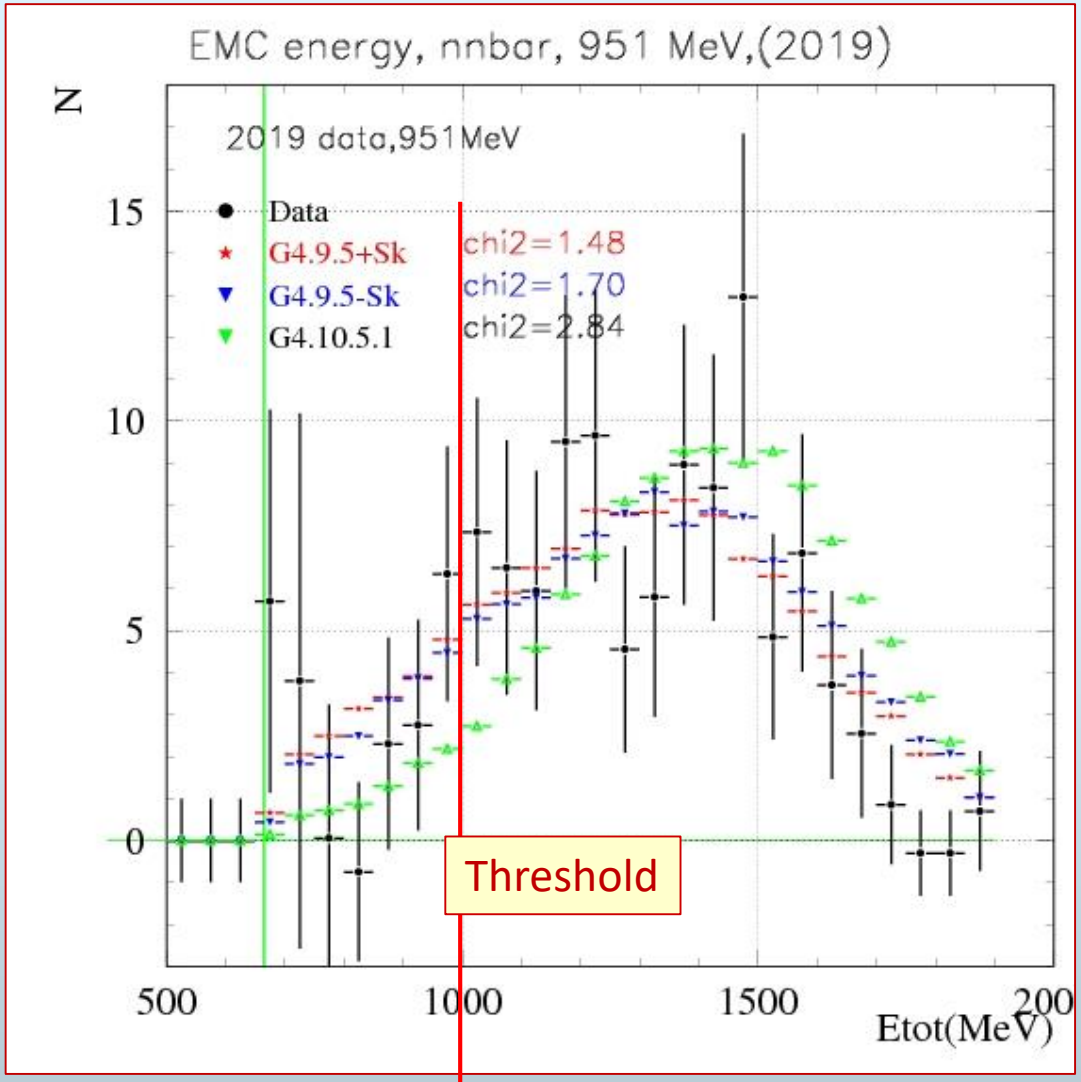


Conclusions: the beam background is strongly suppressed. The residual cosmic background doesn't effect on statistical and systematic uncertainty.

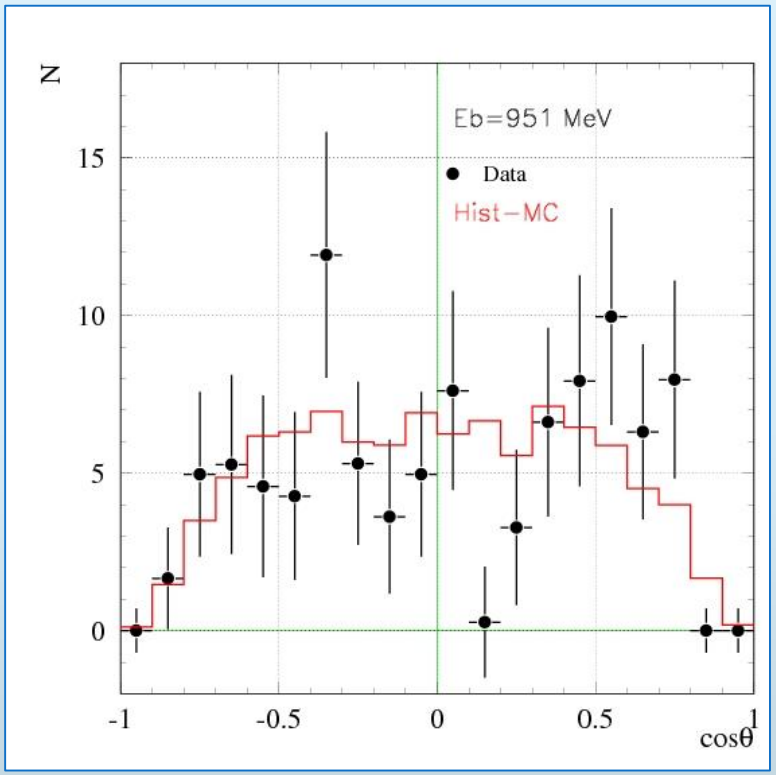
Measured time spectra for n+anti-n selection

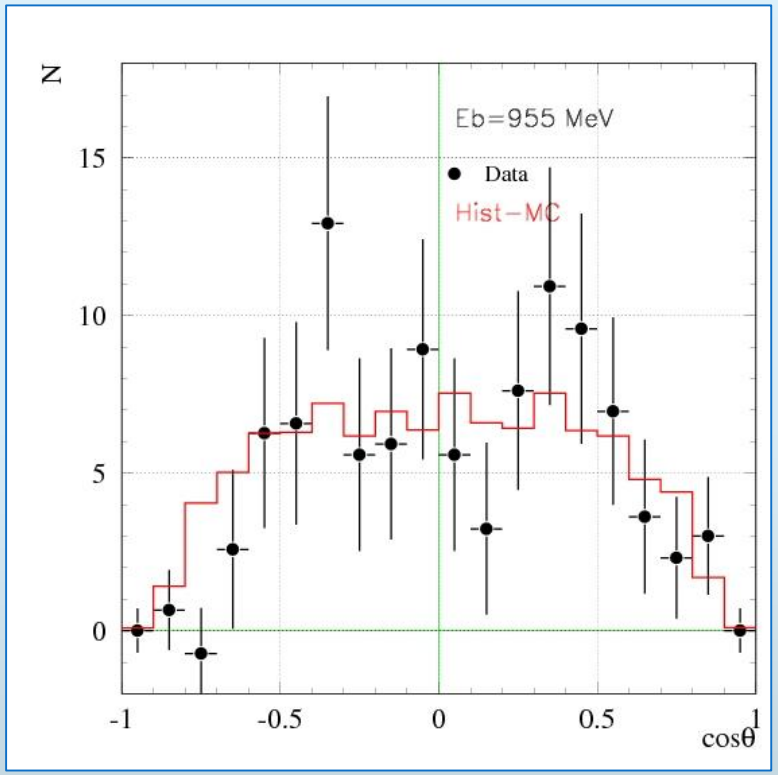


Total energy in EMC for data and MC e+e→n+anti-n events



Cos θ distribution for e+e→n+anti-n (data vs MC)





Red histogram corresponds to MC uniform over cosθ spectra

e+e- → n anti-n cross section

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

N – detected events number, ~130

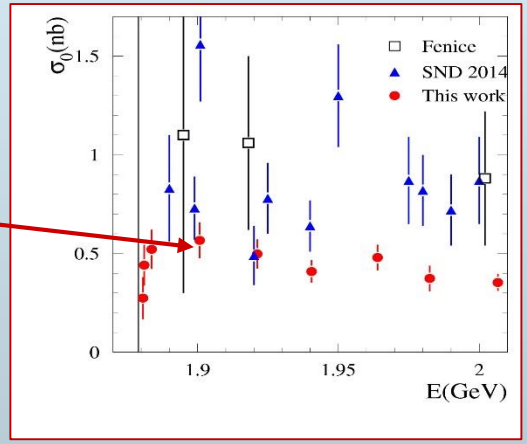
L - integrated luminosity, ~ 2 pb -1 ,

ε - MC detection efficiency, ~ 0.18

δ - radiative correction, ~ 0.8

σ_B - total cross section,
~ 0.5 nb (preliminary)

Slide 4



Systematic uncertainties in the cross section

1. Detection efficiency uncertainty ~ 10-15%
2. Pulse shape fitting in data and MC ~ 5%
3. Physical and beam background uncertainty ~ 5%
4. Luminosity and radiative corrections ~ 3%
5. Total ~ 15-20 %

Statistical error $\Delta\sigma/\sigma$ at one energy point with L=2 inv.pb is ~ 10%. With higher luminosity $\Delta\sigma/\sigma \rightarrow 3\%$

Results and perspectives

1. In experiment with the SND detector at the VEPP-2000 e+e- collider the process e+e-→ n anti-n has been studied.
2. The SND electromagnetic calorimeter based on 1680 NaI(Tl) crystals is used as an effective antineutron detector.
3. To measure the delay time of produced n anti-n pairs in each calorimeter channel new Flash ADC modules are installed.
4. The time resolution of the calorimeter measured using e+e→γγ process photons is ~ 0.8 ns.
5. Due to selection conditions and delay time measurements the events of e+e- → n anti-n process are selected.
6. The developed method allows accurate measurements of e+e-→ n anti-n cross section

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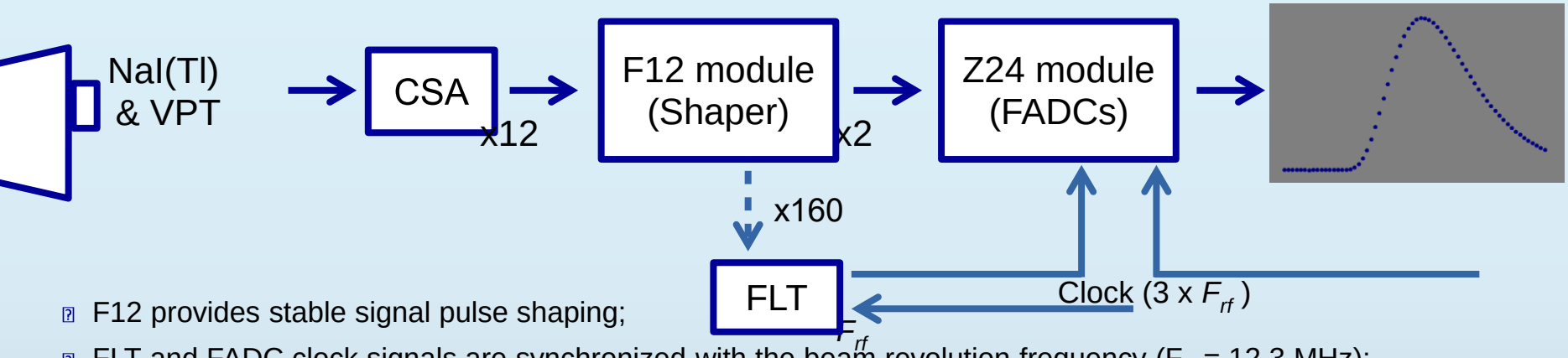
7. Now we continue data taking runs above the threshold of e+e-→ n anti-n process with the goal to collect 100 inv.pb. The analysis of recorded data is going on.

Спасибо за внимание !

Thank you for listening !

BACKUPS

The EMC spectrometric channel

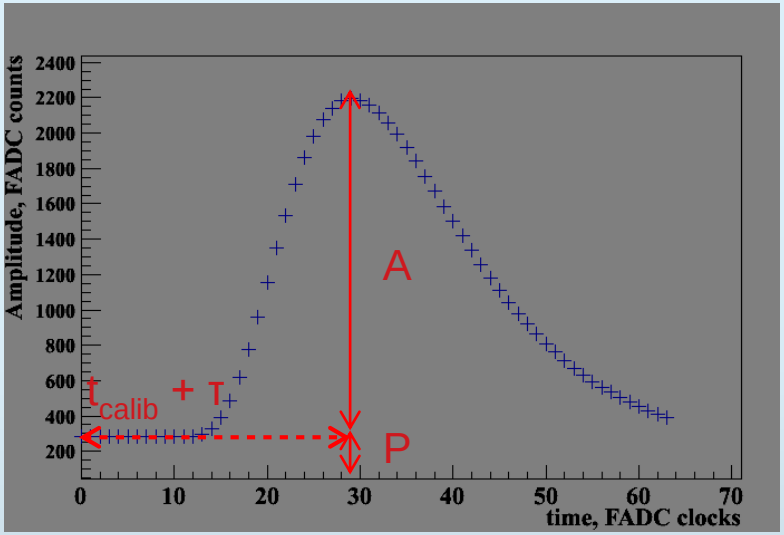


- F12 provides stable signal pulse shaping;
- FLT and FADC clock signals are synchronized with the beam revolution frequency (F_{rf} = 12.3 MHz);
- **New digitizing module (Z24)***:
  - System-on-Chip Xilinx Zynq-7000 & 6 FLASH ADCs (4 channels, 12 bit, 40 MBPS);
  - In use for data taking since ~ 09.2018;
  - Produces the digitized signal oscillogram that can be processed to **reconstruct signal arrival time and energy deposition.**
- We process oscillograms on an online-farm and store them for offline re-processing.

* NIMA v.824 (2016), pp. 362-364

Slide from N.A. Melnikova

Digitized signal pulse properties



Typical signal waveform from an EMC channel.

- We expect the signal waveform to be stable for each EMC channel and use **a special calibration procedure*** to retrieve it;
- 64 samples;
- Sampling period = 27.12 ns;
- 1 FADC value = ~ 0.25 MeV;
- Maximum sample value = 4095 (FADC);
- Typical pedestal values:

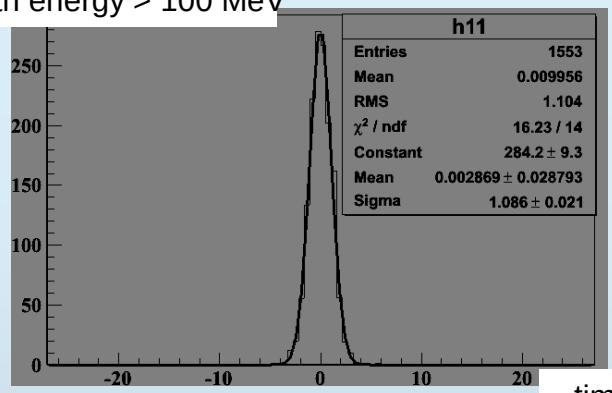
Amplitude, FADC values

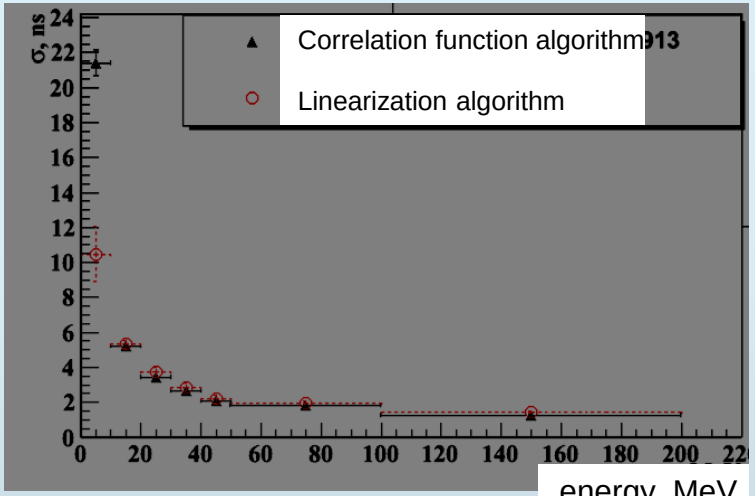
* NIMA v.936 (2019) pp.117-118

Slide from N.A. Melnikova

The correlation function algorithm results on $e^+e^- \rightarrow e^+e^-$ events

Time for one EMC channel
over hits with energy > 100 MeV





? Can process almost all signals with the good waveform;

\+ Can handle special cases: shifted and saturated signals;

\- Relatively slow (~1.2 ms per signal);

! Bad time resolution for small amplitudes.

Slide from N.A. Melnikova