Waveform calibration of the SND electromagnetic calorimeter

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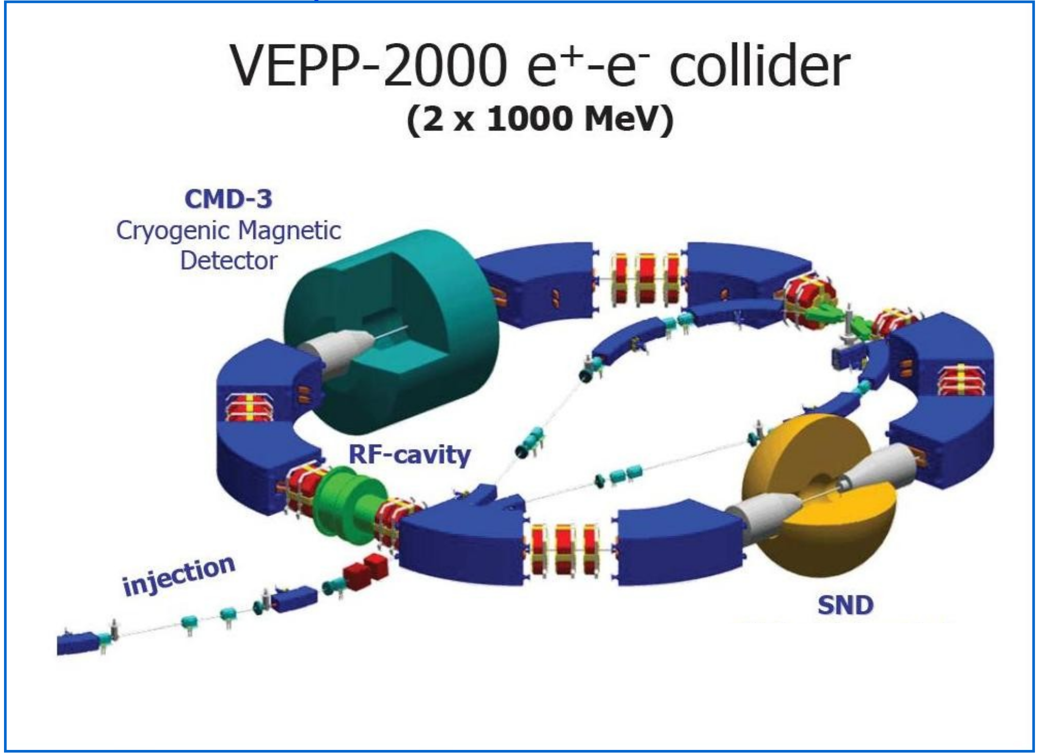
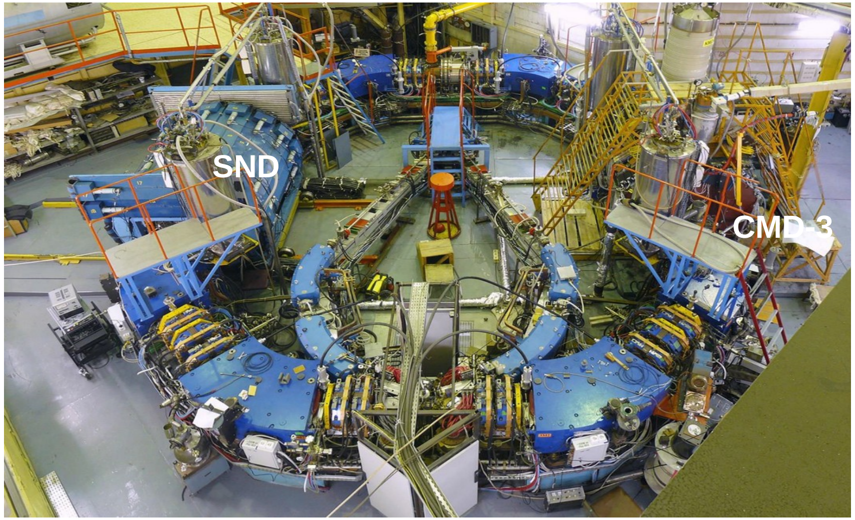
VEPP-2000 e^+e^- collider

- e^+e^- collider at BINP (Novosibirsk, Russia);
- 2 interaction points: the CMD-3 and SND detectors;





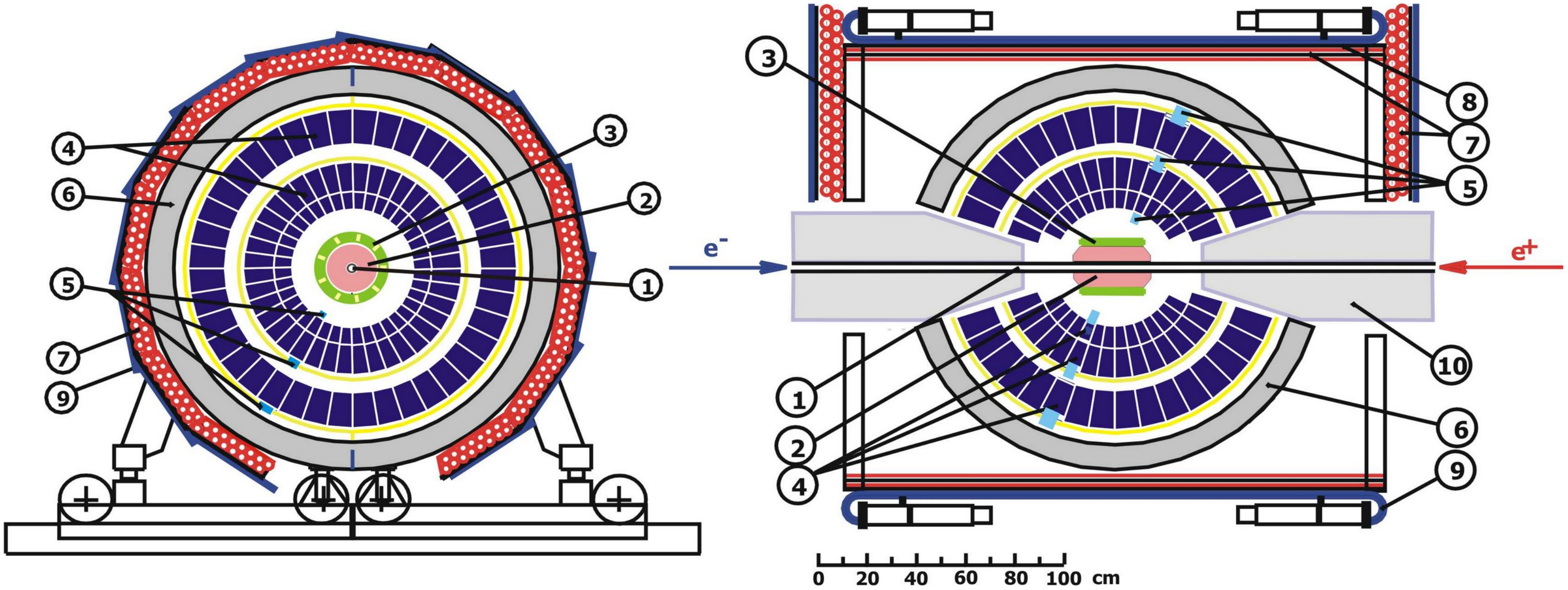
- c.m. energy 0.3-2.0 GeV;
- Round beams concept;
- Circumference = 24.4 m;
- Luminosity = 1 x 10^{32} cm^{-2} sec^{-1} (at 1GeV);

Physical goals

SND experiment at VEPP-2000 collider studies e+e– annihilation to hadrons at low energy region ($\sqrt{s}<2$ GeV). These studies include:

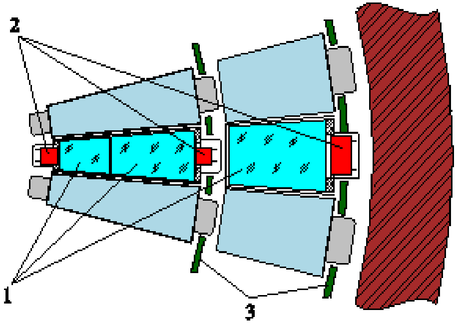
- **Measurement of the cross sections $e^+e^- \to$ *hadrons*.**
- **Study of multi-hadron processes dynamics.**
- **Study of the vector mesons ρ, ω, ϕ and their excited states ρ', ρ'', ω', ω'', ϕ', …**

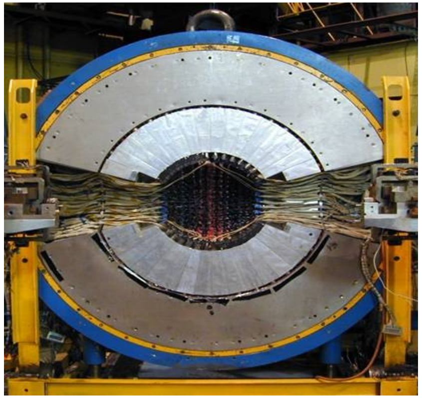
Spherical Neutral Detector

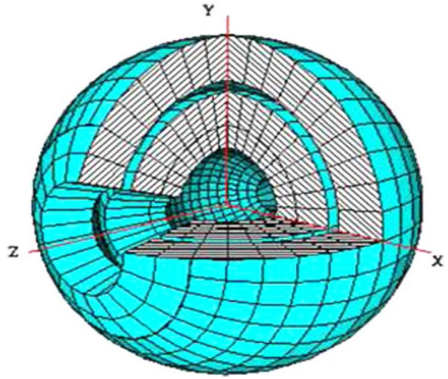


1 – beam pipe, 2 – tracking system, 3 – aerogel Cherenkov counter , 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids.

SND Electromagnetic Calorimeter







The segment of the EMC:

1 - NaI(Tl) crystals

2 - vacuum phototriodes (VPT)

3 - aluminum supporting spheres

The quantum efficiency of the VPT is about 15 %

SND EMC general parameters:

total weight of NaI(Tl) - 3.5 tons,

1632 crystals, VPT readout,

13.4 X_0NaI=(2.9+4.8+5.7)X_0 (34.7 cm),

$0.9 \cdot 4\pi$ solid angle,

angular size of the counter $\Delta\varphi=\Delta\theta=9°$

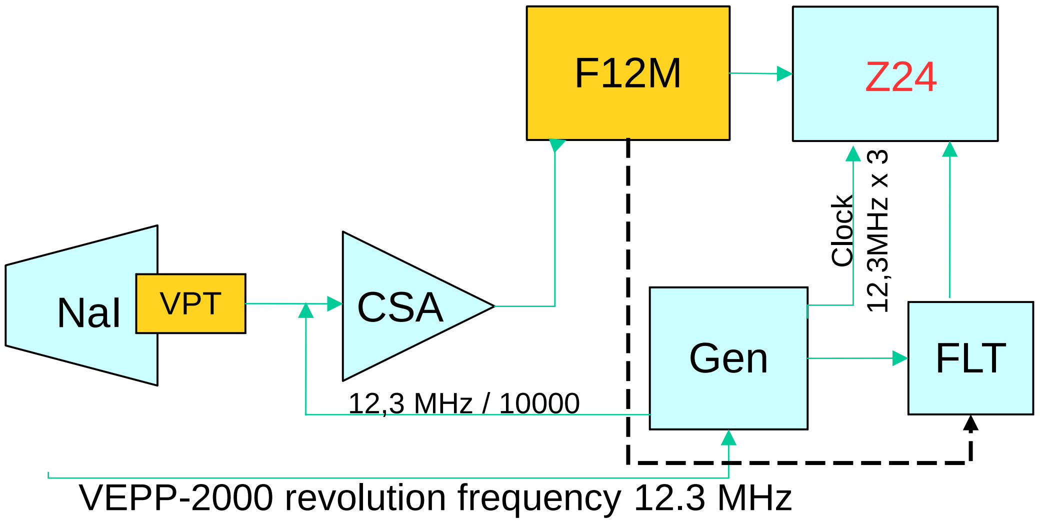
Energy resolution $4.2\% / \sqrt[4]{E(GeV)}$

Angular resolution $0.82° / \sqrt{E(GeV)} \oplus 0.63°$

Motivation

- To achieve time resolution (~1.5 ns) for measuring $e^+e^- \rightarrow$ n anti-n cross section near threshold
- To improve data acquisition monitoring

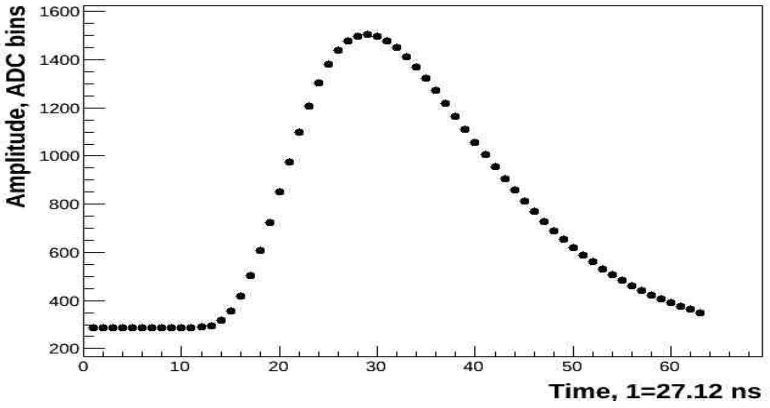
EMC spectrometric channel



Z24 digitizing module with:

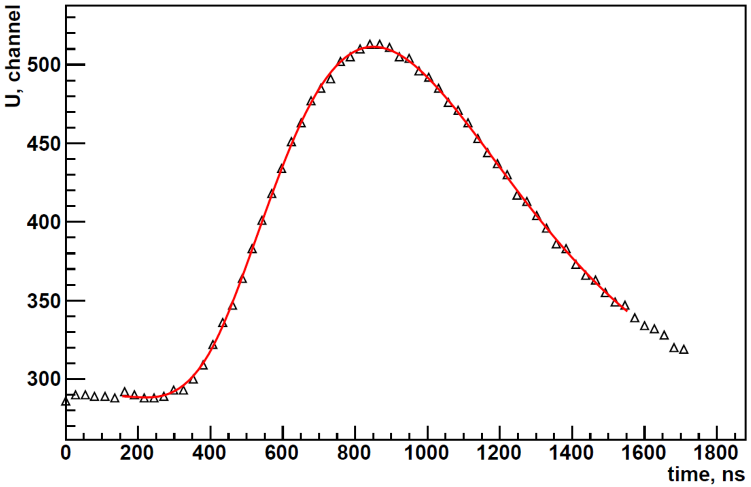
- System-on-Chip Xilinx Zynq-7000;
- 6 FLASH ADCs AD9228BCPZ-40 (4 channel, 12 bits, 40 MBPS)

Allows us to obtain the full pulse waveform, which we use to measure pulse parameters (amplitude, arrival time, pedestal)



Z24 – Digitizer module
NaI – NaI(Tl) scintillator
VPT – vacuum phototriode
CSA – charge-sensitive preamplifier
Gen – calibration generator
F12M – shaper,
FLT – first-level trigger

Digitized pulse properties



A typical pulse from the EMC channel obtained with the generator

- We expect the waveform of the pulse to be stable for each EMC channel;
- 64 samples;
- Sampling period = 27.12 ns;
- 1 ADC channel = ~ 0.2 MeV;
- Maximum sample value = 4095 channels;
- Typical values:
  - P = 280 ÷ 350 channels;
  - σ_P = 2 ÷ 4 channels;

Waveform calibration procedure

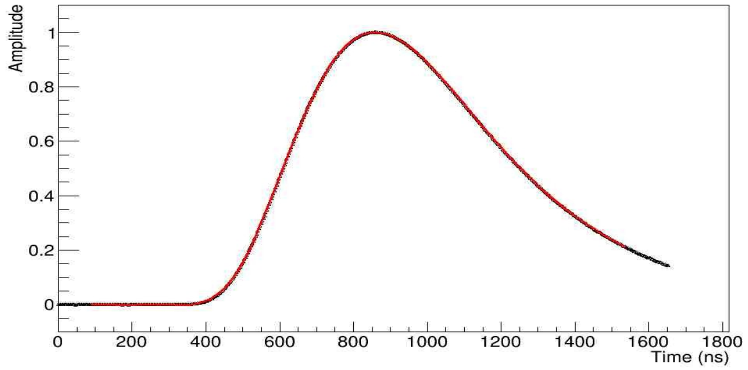
Select Bhabha Events

Select pulse with optimal parameters (time, amplitude)
The pulse is fitted by a cubic B-spline for obtaining initial waveform.

This waveform is used to determine A(amplitude), Δt (arrival time) for all selected pulses.

Selection pulses to construct averaged pulse for each EMC channel by:
Amplitude: A > 20 MeV
Arrival time: |Δt| < 5 ns

Averaged pulses are checked and fitted by a cubic B-spline to obtain waveforms. B-spline coefficients are stored into the database.



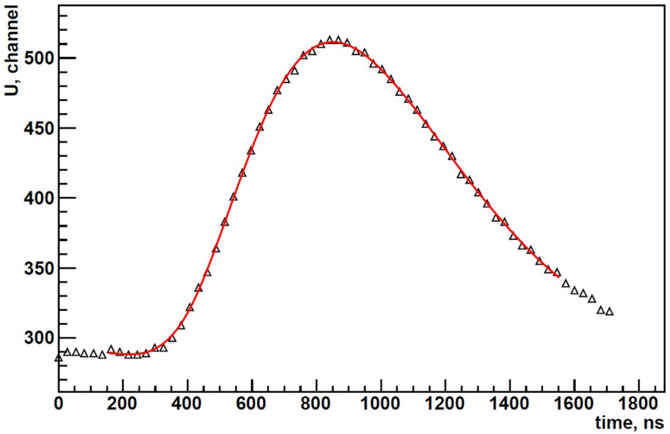
Typical waveform

Pulse processing

Fit the EMC digitized pulse with U(t) to extract:

- A – the amplitude
- P – the pedestal
- τ – the pulse arrival time
- *F(t)* – the calibrated waveform in the channel.

$$U(t)=A\cdot F(t-\tau)+P$$



Fitting algorithm:

Minimizes the function:

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

where y_i – the pulse sample, *F(t)* – the calibrated EMC waveform (cubic B-spline), S_{ij} – the noise covariance matrix;

F(t) is linearized on a time grid so all needed coefficients are calculated in advance.

The correlation function algorithm

- **Step 1** – to determine the signal maximum position (τ) with respect to the calibration waveform (*F(t)*) by searching for the maximum of the correlation function between them:

$$\omega(\tau)=\sum_{i=0}^{i=63}(y_i-P)\cdot F(t_i-\tau)$$

  - Minimization with the Brent's algorithm (GSL) using FFT for faster calculations;

- **Step 2** – to determine A of the signal with fixed P using the extracted time by minimizing:

$$\chi^2=\sum_{i=0}^{i=63}\frac{(y_i-P-A\cdot F(t_i-\tau))^2}{\sigma_P^2}$$

https://arxiv.org/abs/2305.03359

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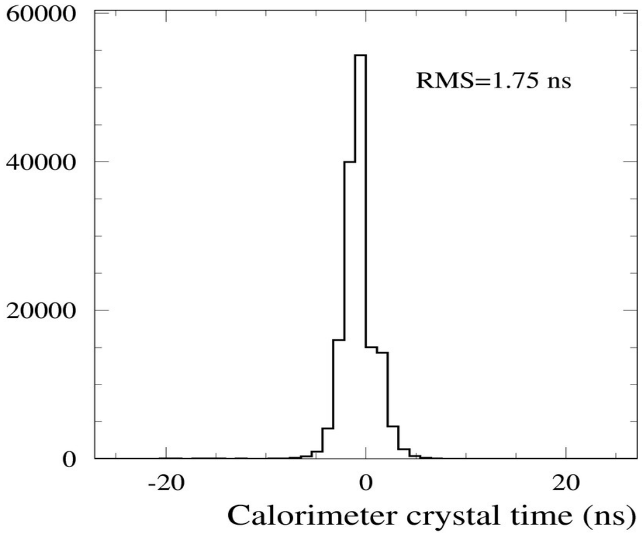
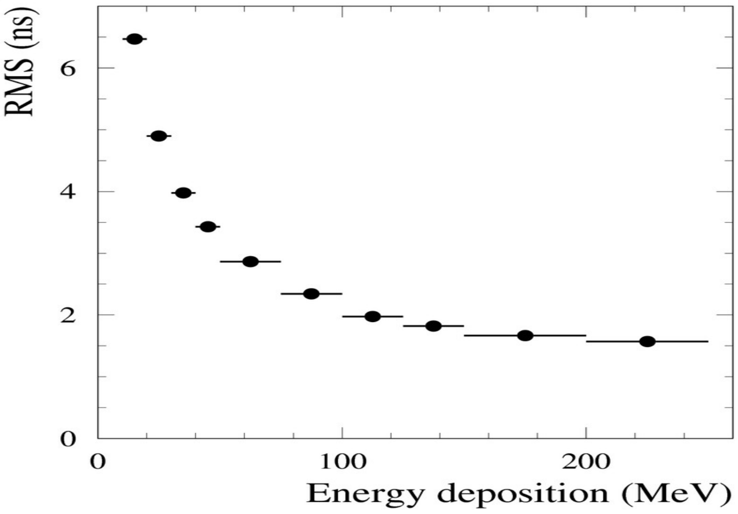
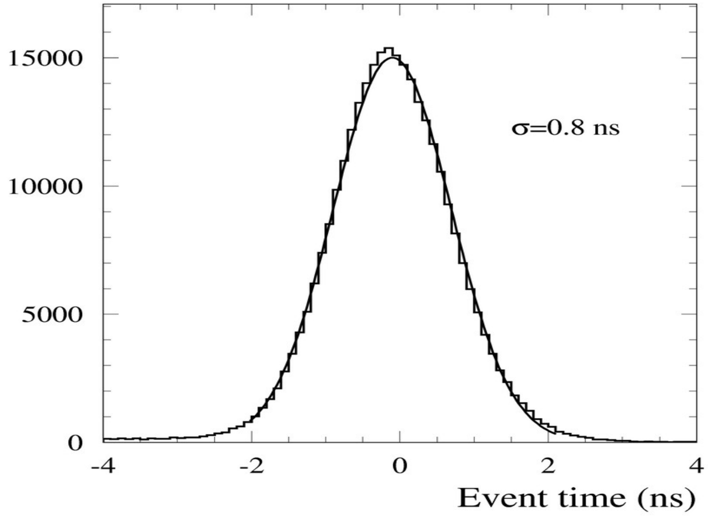
The time resolution for $e^+e^- \rightarrow e^+e^-$ events







Distribution of the arrival time for channels with energy deposition more than 100 MeV for $e^+e^- \rightarrow e^+e^-$ events.

Dependence of the arrival time RMS on the energy deposition for $e^+e^- \rightarrow e^+e^-$ events

Averaged arrival time in $e^+e^- \rightarrow e^+e^-$ events:

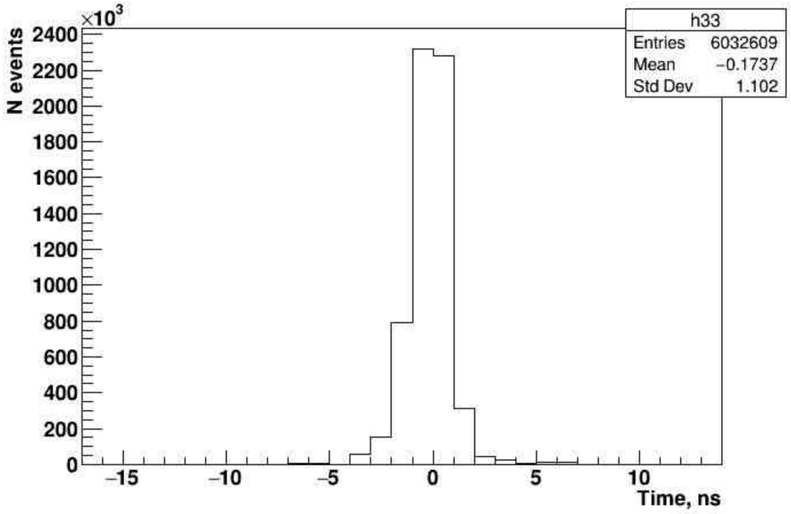
$$T = \frac{\sum t_i w_i}{\sum w_i} \qquad w_i = \frac{1}{RMS_i^2}$$

Pulse processing application

- Control pulse parameters using calibration generator.
- Data quality monitoring (DQM) during experimental run.

Pulse parameters:

1) Amplitude distribution
2) Noise level (pedestal distribution)
3) Arrival time distribution
4) Waveform quality monitoring



Typical DQM arrival time distribution

Summary

- All necessary calibration procedures were developed and implemented;
- Algorithms for pulse processing was designed. We have been using them since 2019 year;
- We have successfully used EMC arrival time in physical analysis, specially for n anti-n;

Thank you for your attention