Study of the PSD CBM response on hadron beams

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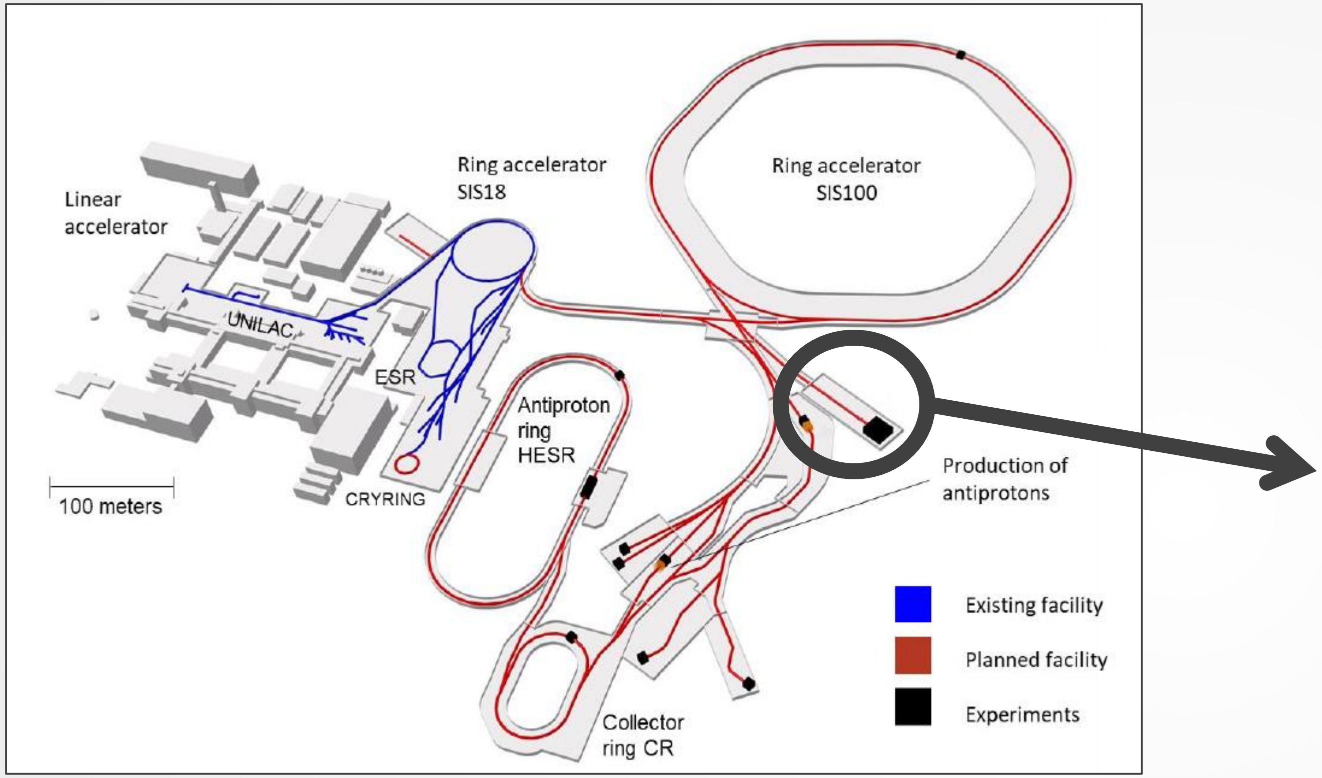
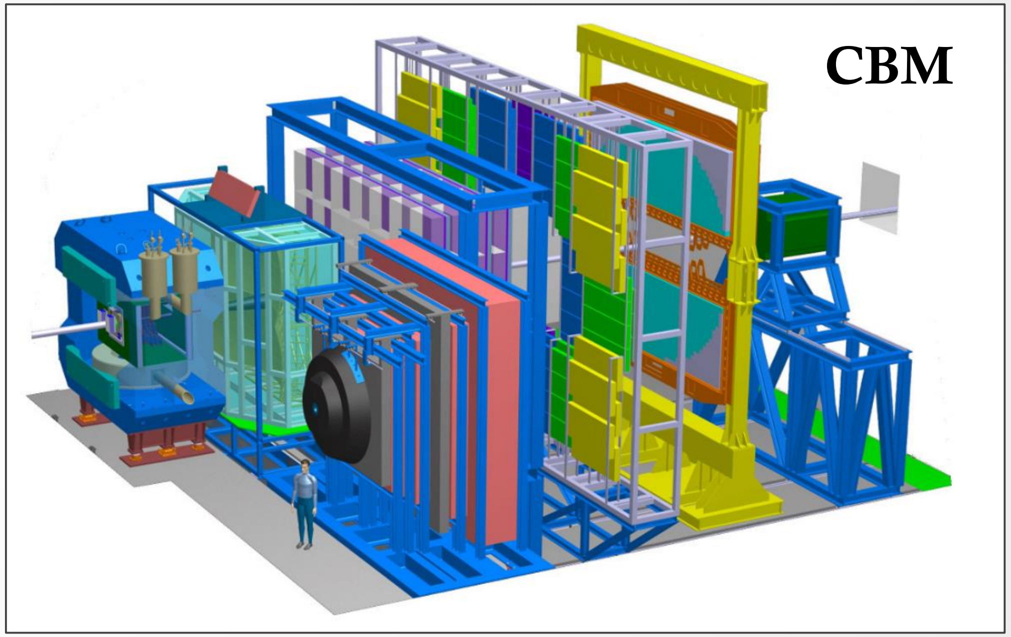
Outline

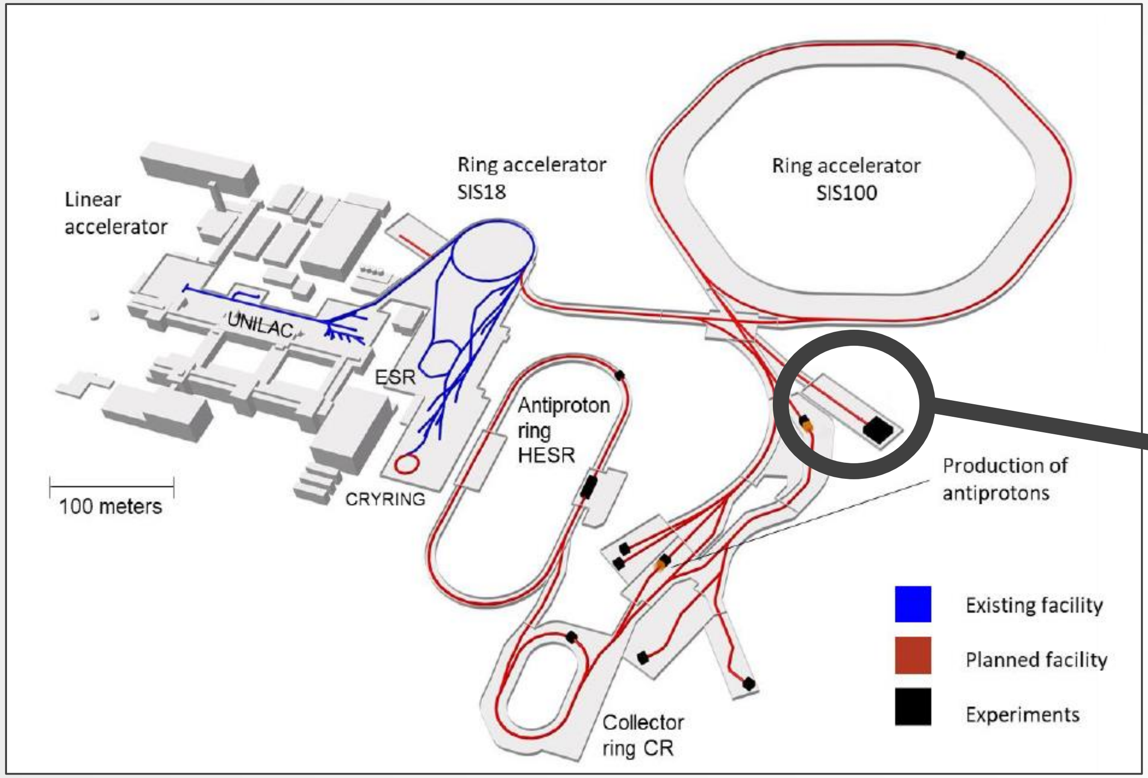
- CBM experiment and PSD
- PSD structure and supermodule tests on hadron beams
- BM@N FHCAL and tests on Ar beam
- Why do we need waveform fitting procedure
- Prony LS method and fit quality assessment
- New muon calibration approach

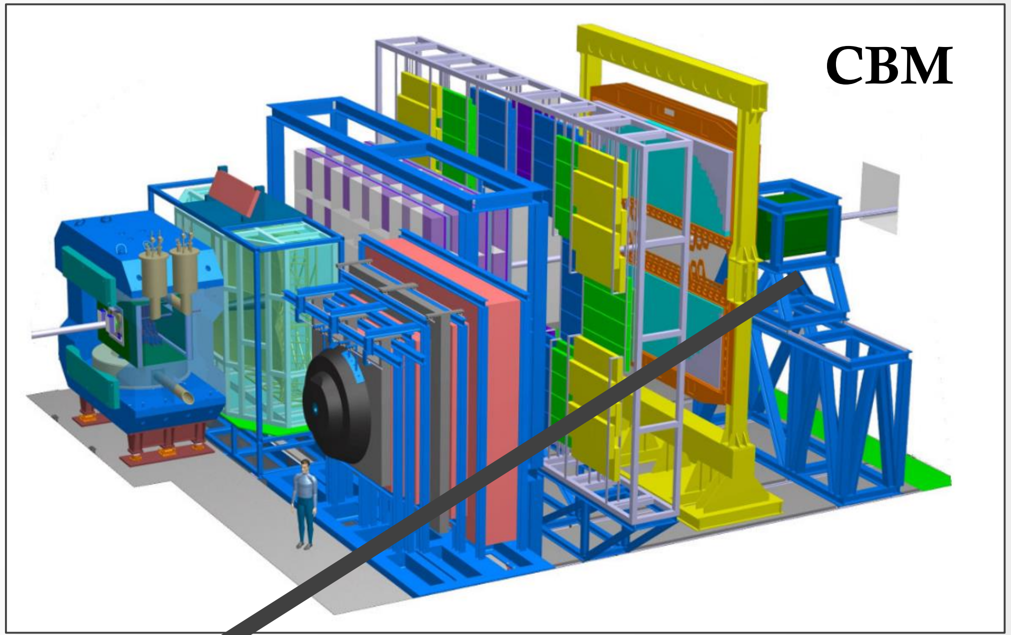
CBM experiment at FAIR

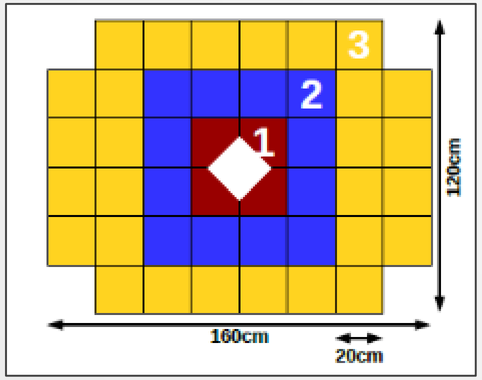




CBM experiment at FAIR



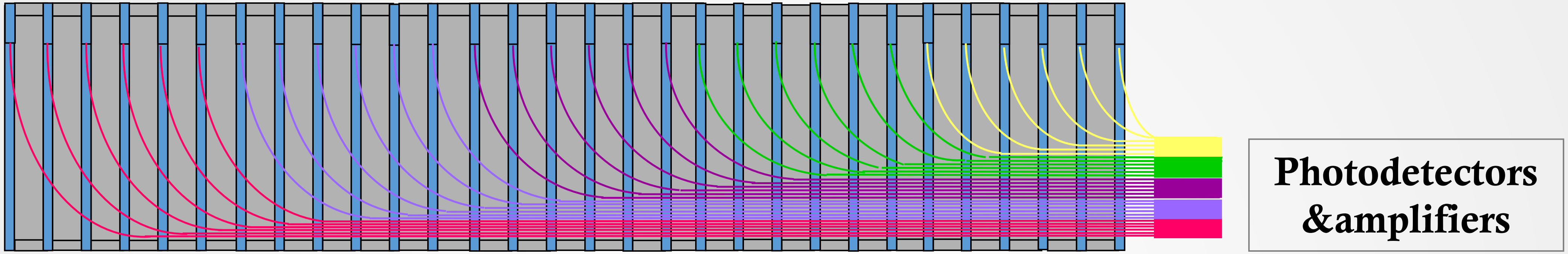




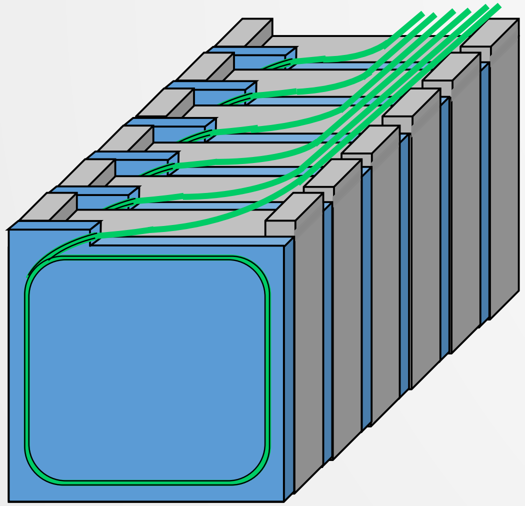
- ❖ Centrality
- ❖ Reaction plane orientation

44 modules, Beam hole, Weight ~22 tons.

Structure of calorimeter module



Photodetectors &amplifiers

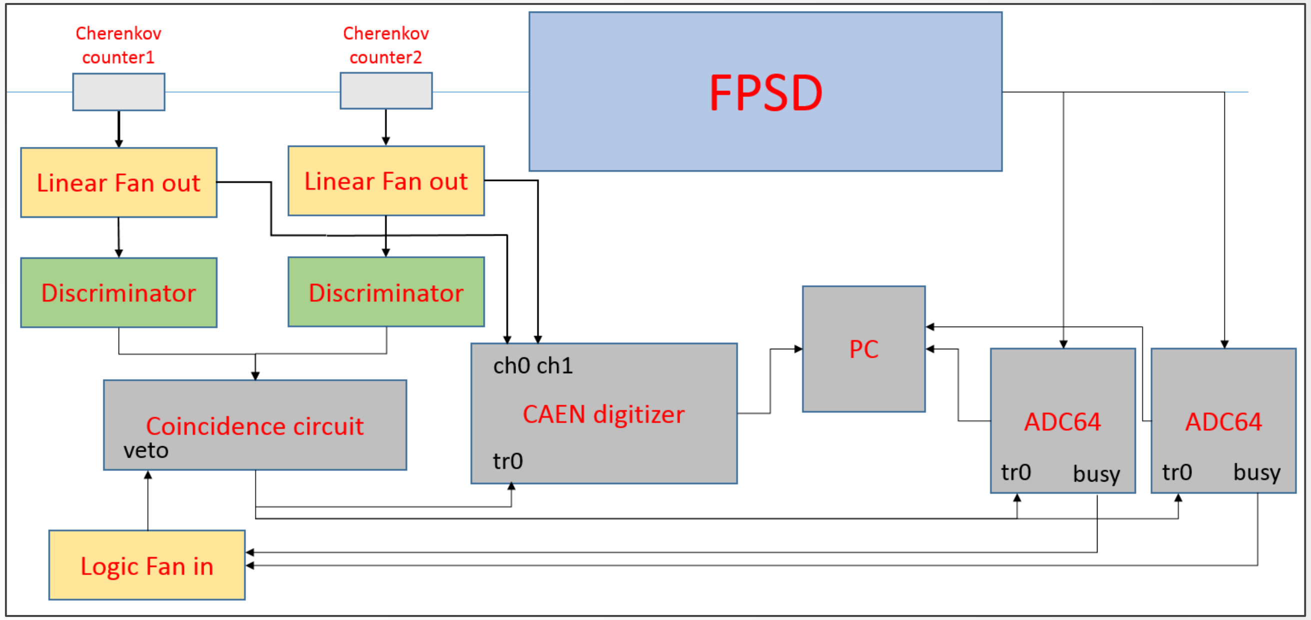


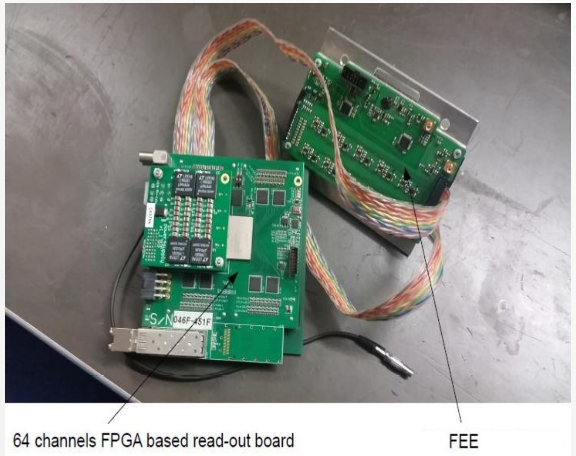
- Transverse size - 20x20cm^2 ;
- Total length - 165cm;
- Interaction length – 5.6 λ_{int};
- Longitudinal segmentation – 10 sections;
- 10 photodetectors/module;
- Photodetectors – silicon photomultipliers.

PSD supermodule tests

Supermodule – array of 3x3 modules
Total size 600x600x1650 mm^3
Total weight - 5 tons

T10 beamline





Tasks:

- **PSD modules calibration with beam muons;**
- **Study of PSD supermodule response at hadron beams with Dubna FEE and readout electronics;**

CBM PSD supermodule at T9 CERN beamline

PSD at T10 beamline

CERN PS T9 beamline

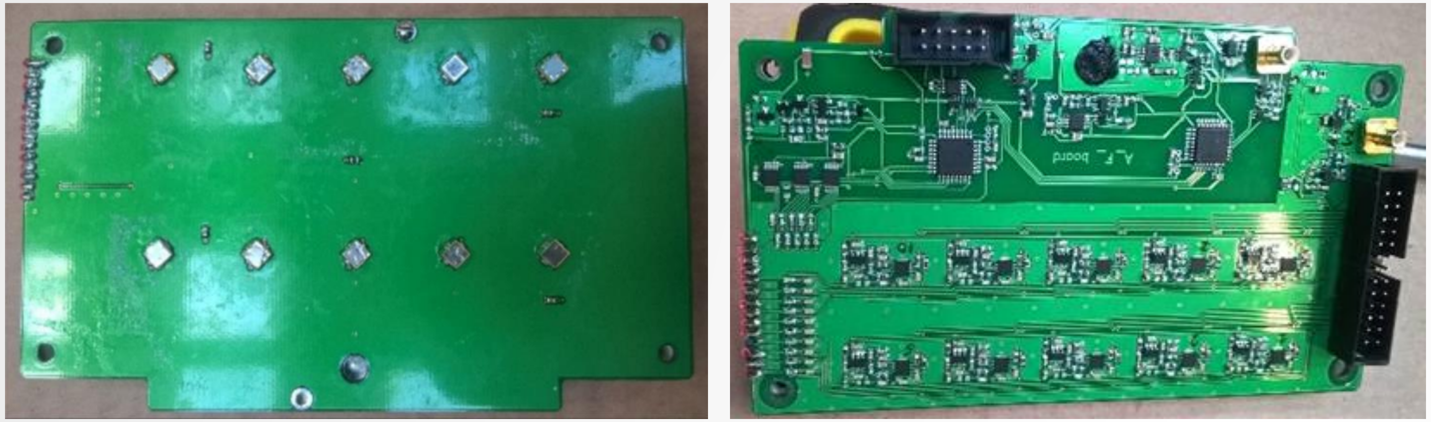
Beam momenta: 1-10 GeV/c
Particle ID: Cherenkov gas counter
Position of PSD: fixed

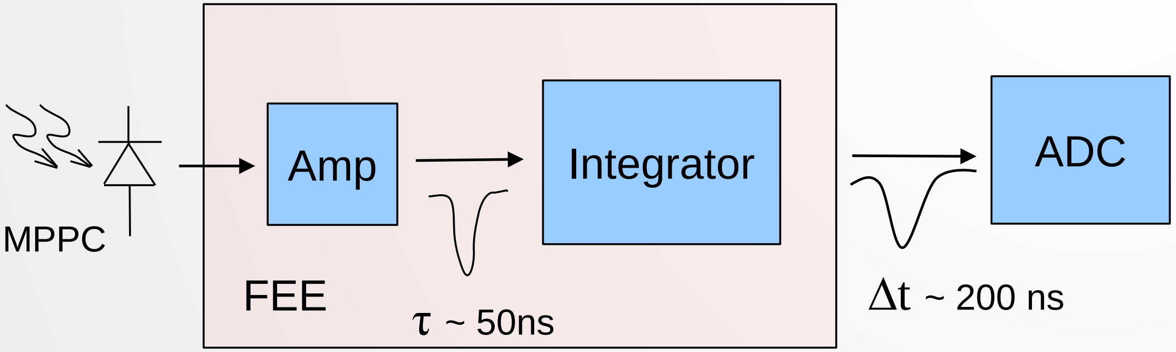
CERN PS T10 beamline

Beam momenta: 1-6 GeV/c
Particle ID: TOF system
Position of PSD: movable platform

Photodiodes, FEE and readout electronics

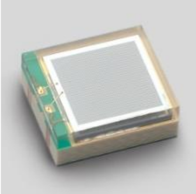
Front-End-Electronics:





10 channels: two-stage amplifiers; HV channels; LED calibration source.

Photodetectors:

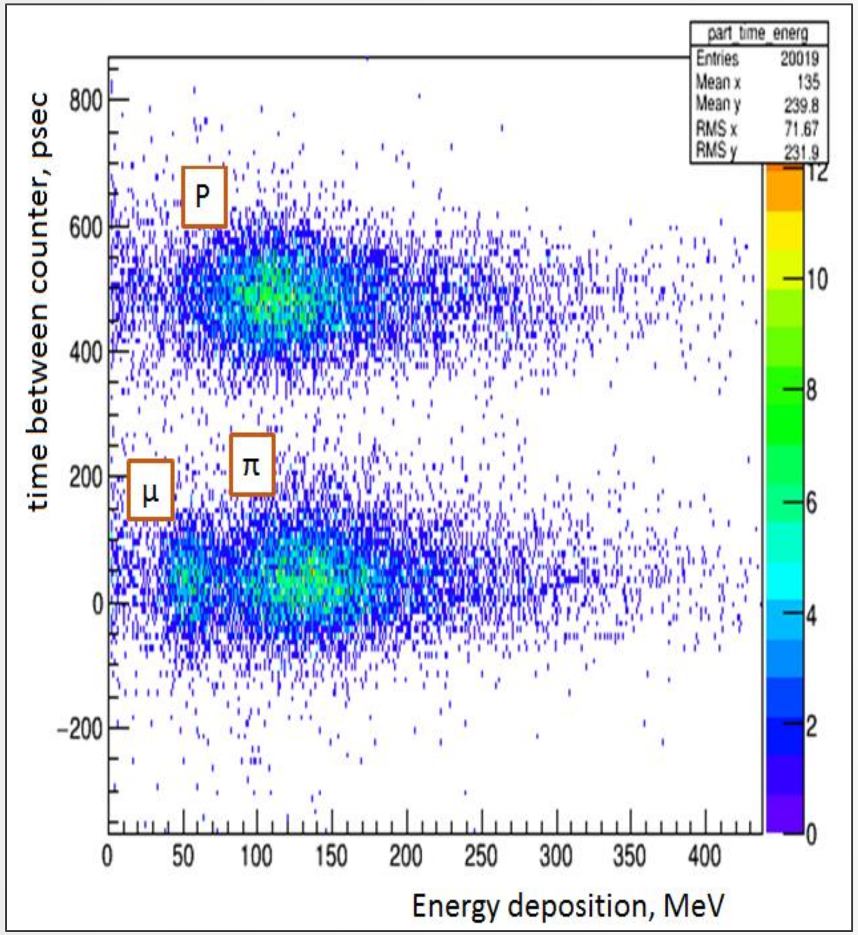


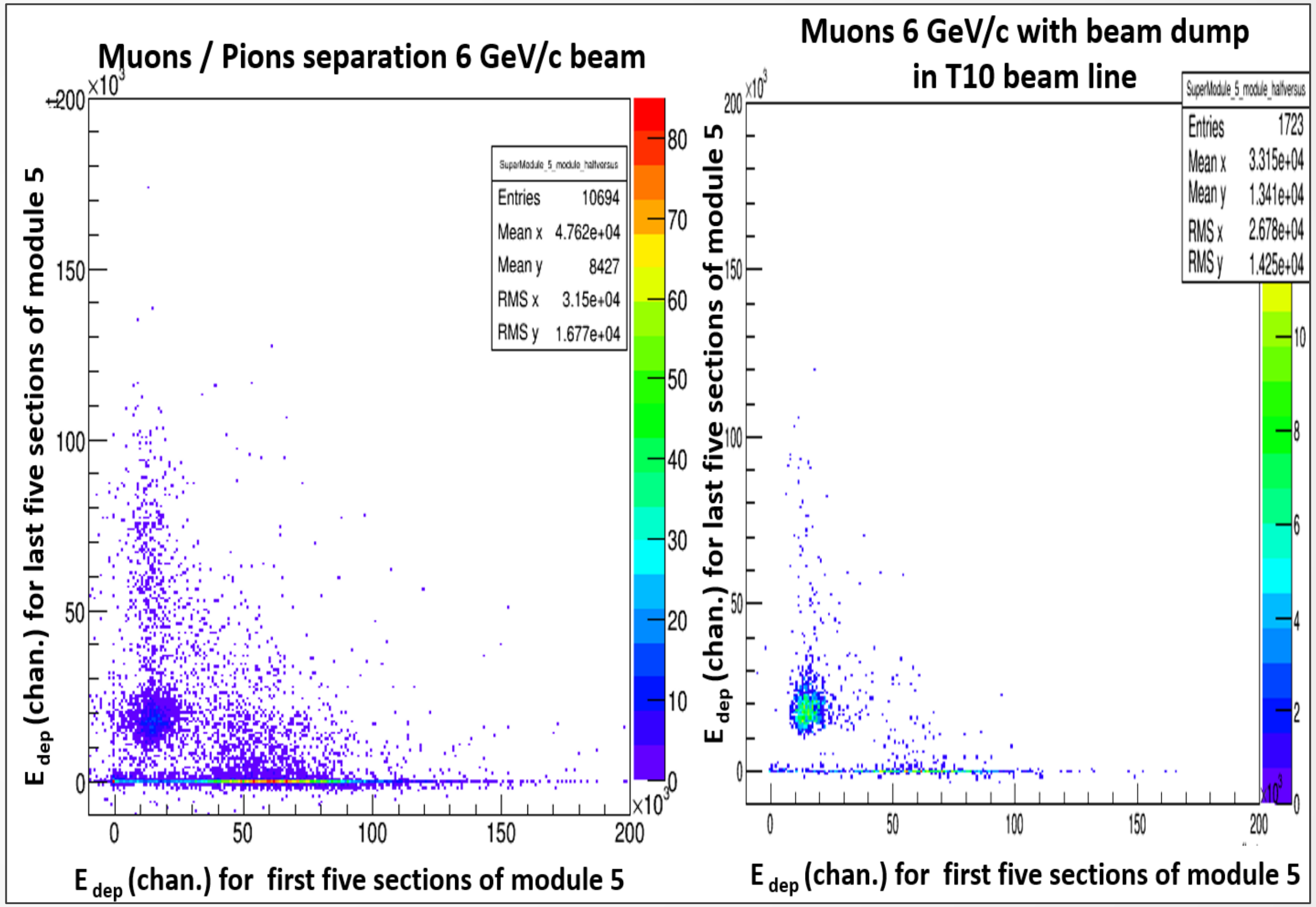
Hamamatsu MPPC:
size – 3x3 mm^2;
pixel -10x10 μm^2;
PDE~12%.

Readout electronics:

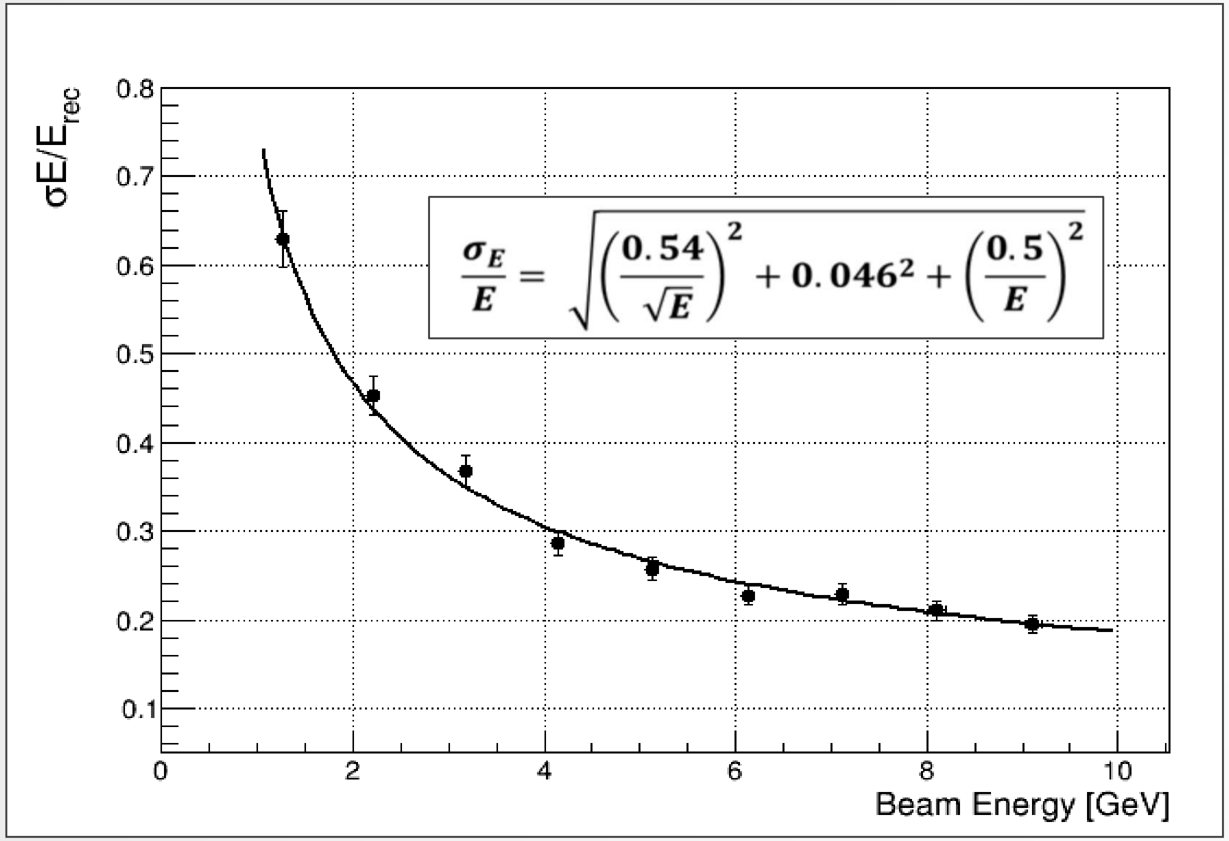
FPGA based 64 channel ADC64 board, 62.5MS/s (AFI Electronics, JINR, Dubna).

Particle identification by TOF

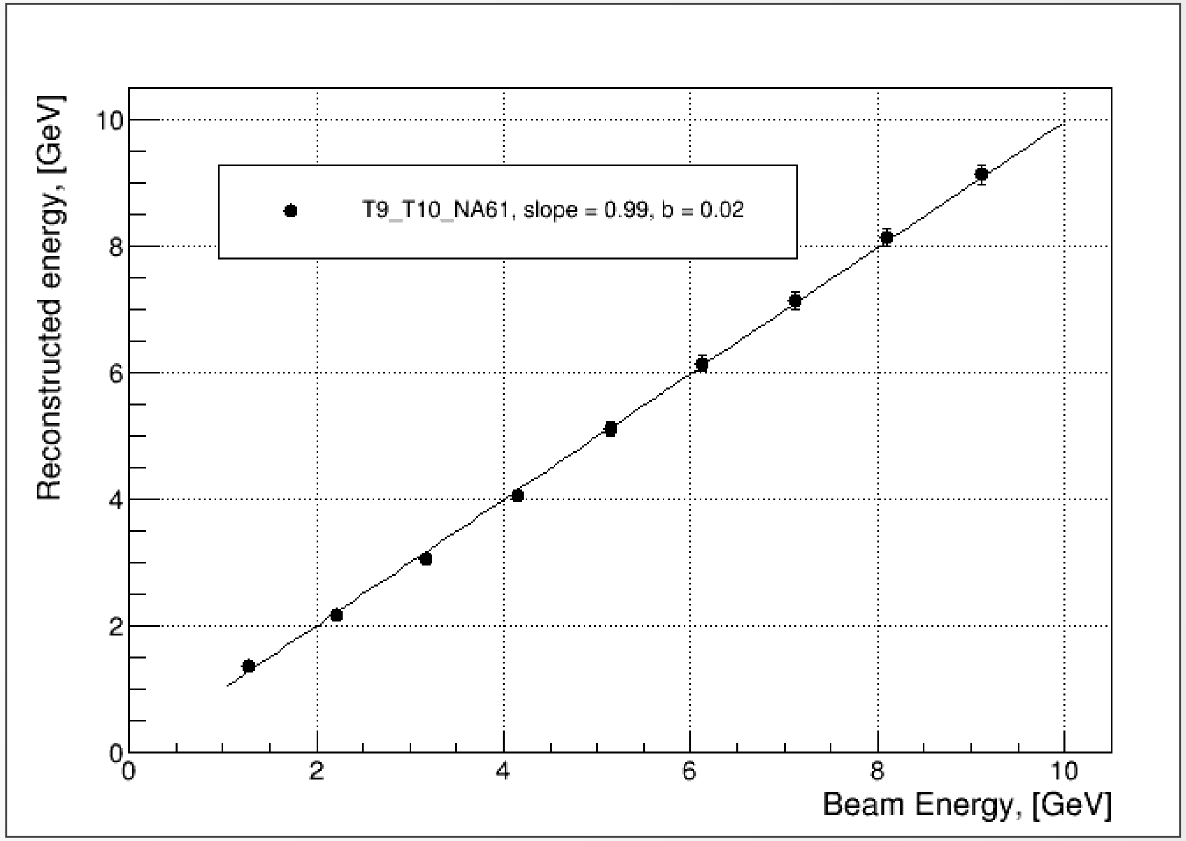




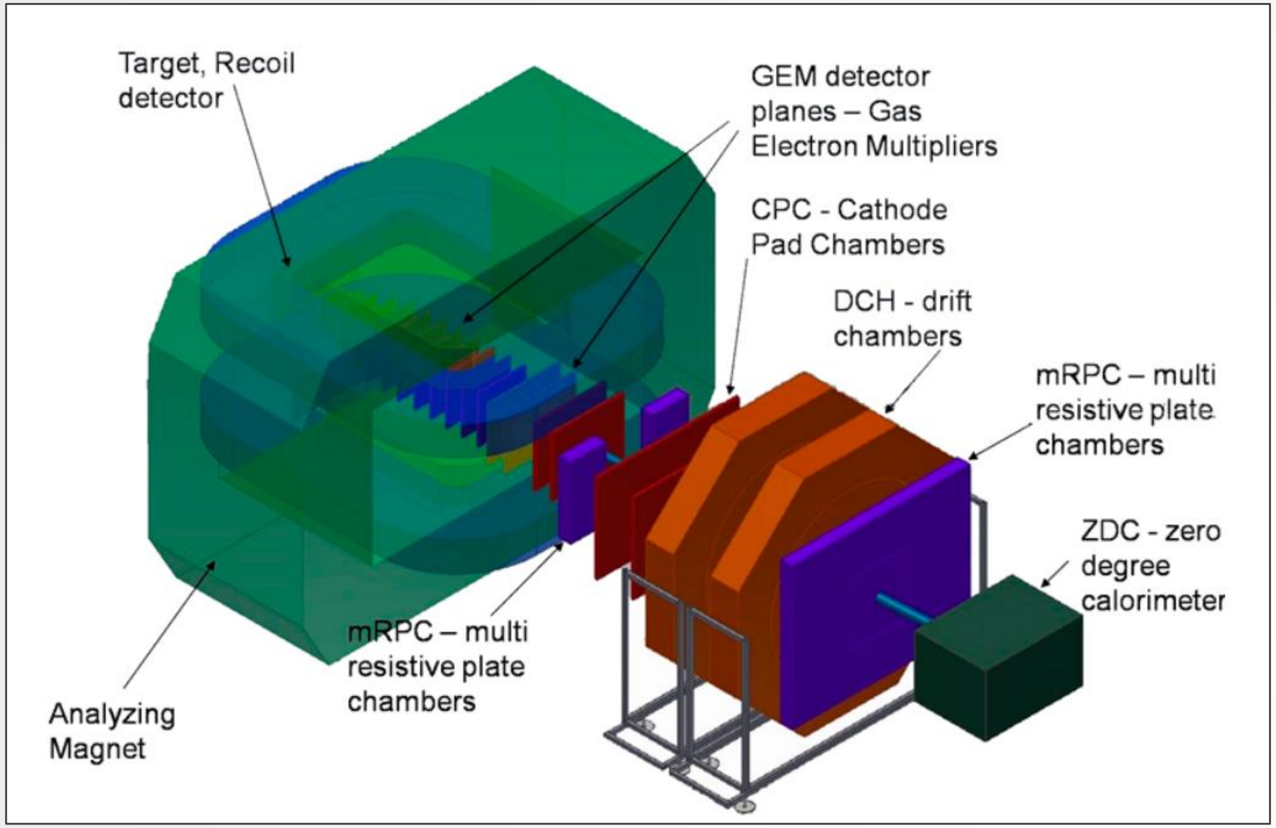
Combined T10 and T9 results

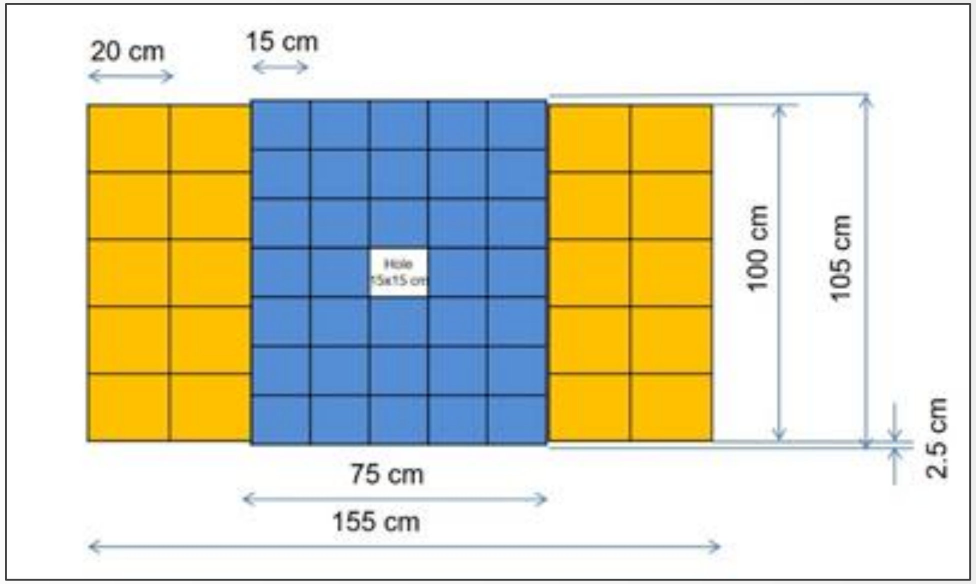


$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{0.54}{\sqrt{E}}\right)^2 + 0.046^2 + \left(\frac{0.5}{E}\right)^2}$$



BM@N and new FHCAL



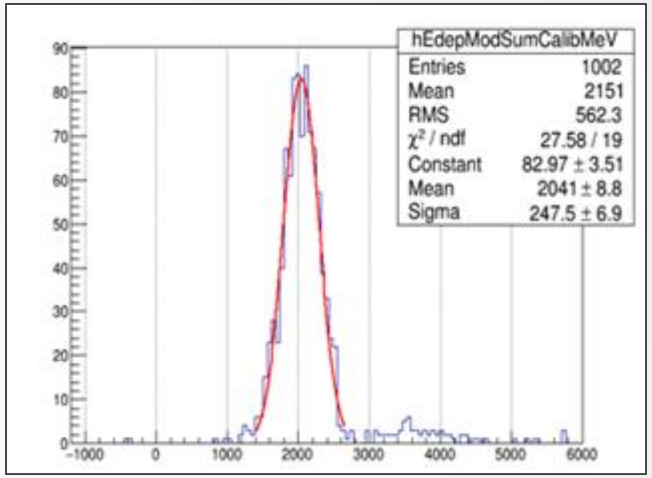


20 PSD CBM modules, 200x200x1650mm +
35 FHCAL MPD modules, 150x150x1000mm

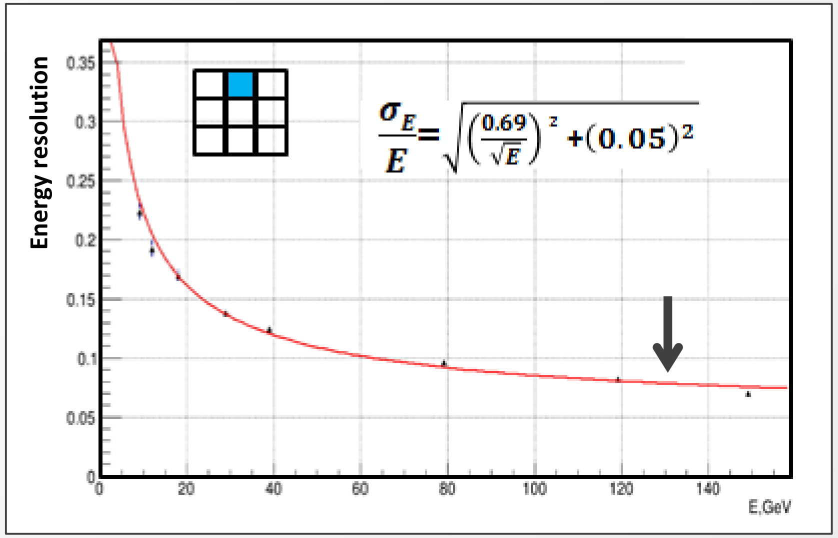
The use of the CBM and MPD modules in FHCAL BM@N will give the possibility to study its response in real experiment before CBM and MPD experiments start their operation.

PSD single module resolution

BM@N
Ar beam 3.3 AGeV
March 2018
Energy resolution – 12%
(Preliminary)

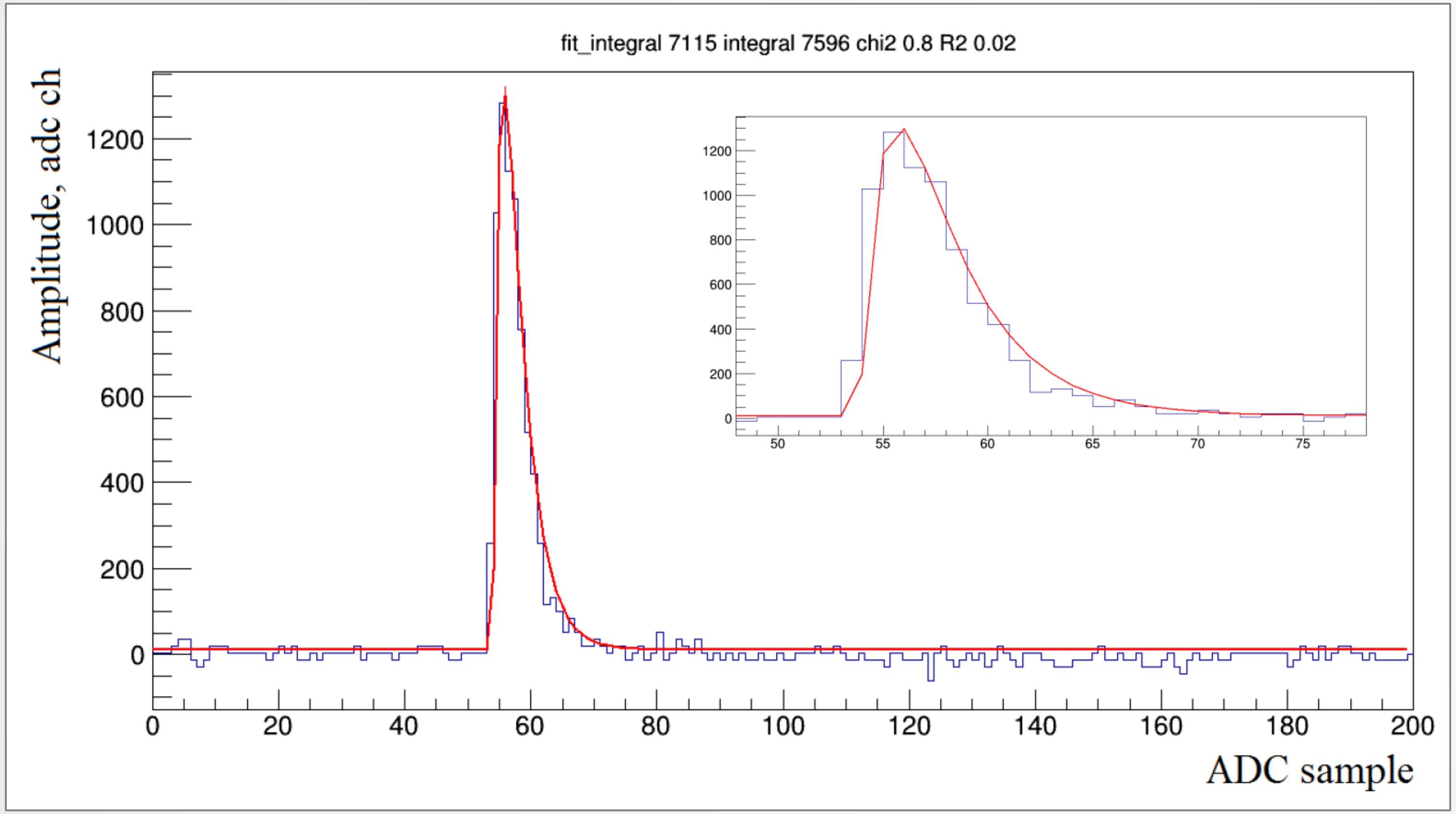


CERN NA61/SHINE
proton beam
May 2018
Energy resolution – 7%



Why do we need waveform fitting

Fast signals → Few samples per signal → Large fluctuations of charge



Advantages of the fitting procedure:

- ❖ More correct determination of amplitude and charge
- ❖ Working with small signals near the noise level
- ❖ Interference and pile-up identification
- ❖ True signal recovery

Prony Least Squares method

Allows to estimate a set of complex data samples x[n] using the p-term model of exponential components:

$$\hat{x}[n] = \sum_{k=1}^{p} A_k \exp[(\alpha_k + j2\pi f_k)(n-1)T + j\theta_k] = \sum_{k=1}^{p} h_k z_k^{n-1}$$

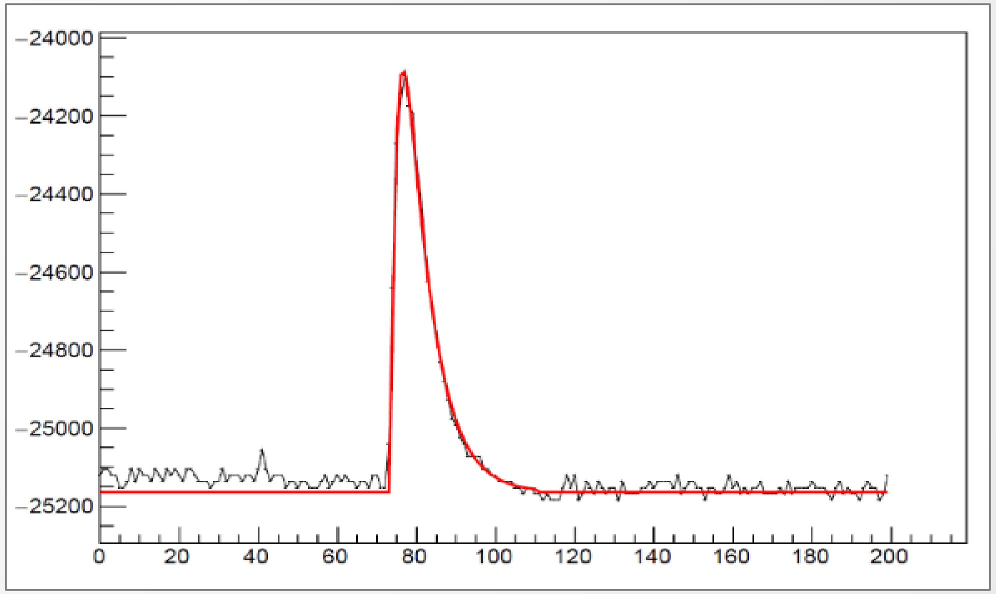
$n = 1, 2, \ldots, N$, $j^2 = -1$, T – sampling interval. $\boldsymbol{h_k} = A_k \exp(j\theta_k)$, $\boldsymbol{z_k} = \exp[(\alpha_k + j2\pi f_k)\mathrm{T}]$.

Objects of estimation are: amplitudes of complex exponentials $\boldsymbol{A_k}$, attenuation parameters $\boldsymbol{\alpha_k}$, harmonic frequencies $\boldsymbol{f_k}$ and phases $\boldsymbol{\theta_k}$.

3 algorithm steps:

1. Composing and solving SLE p×p
2. Polynomial factorization $\Big\}\ \boldsymbol{z_k}$
3. Composing and solving SLE (p+1)×(p+1) $\longrightarrow$ $\boldsymbol{h_k}$

3 orders of magnitude faster than MINUIT



Fit quality assessment

Determination coefficient*

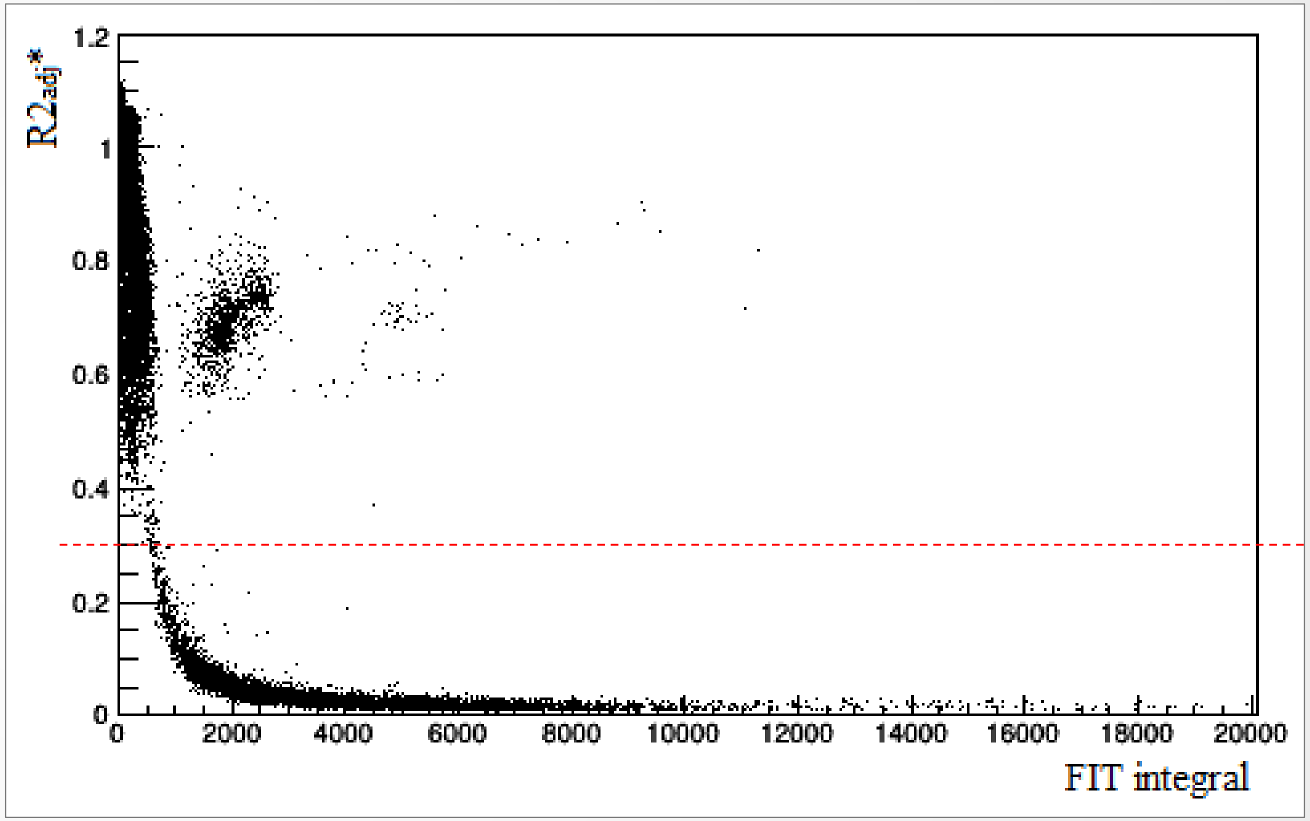
$$R^2 = \frac{\sum_{n=1}^{N}(x[n] - \hat{x}[n])^2}{\sum_{n=1}^{N}(x[n] - \overline{x})^2}$$

$x[n]$ and $\hat{x}[n]$ are the experimental and model values of the variable, respectively. $\overline{x}$ is the experimental values average.

Adjusted determination coefficient*

$$R_{adj}^2 = R^2 \frac{N-1}{N-\lambda}$$

N is the number of measurements, λ is the number of model parameters.



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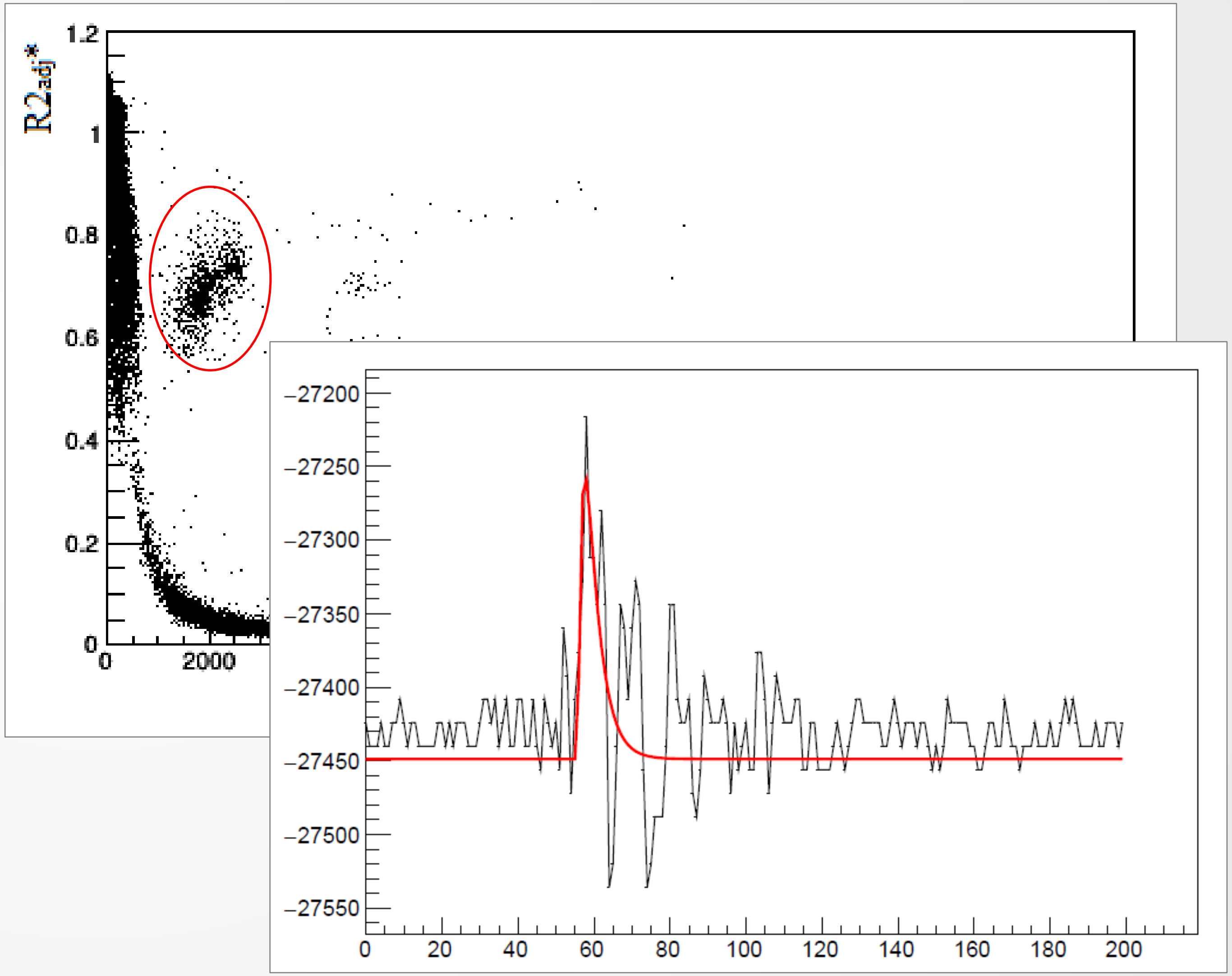
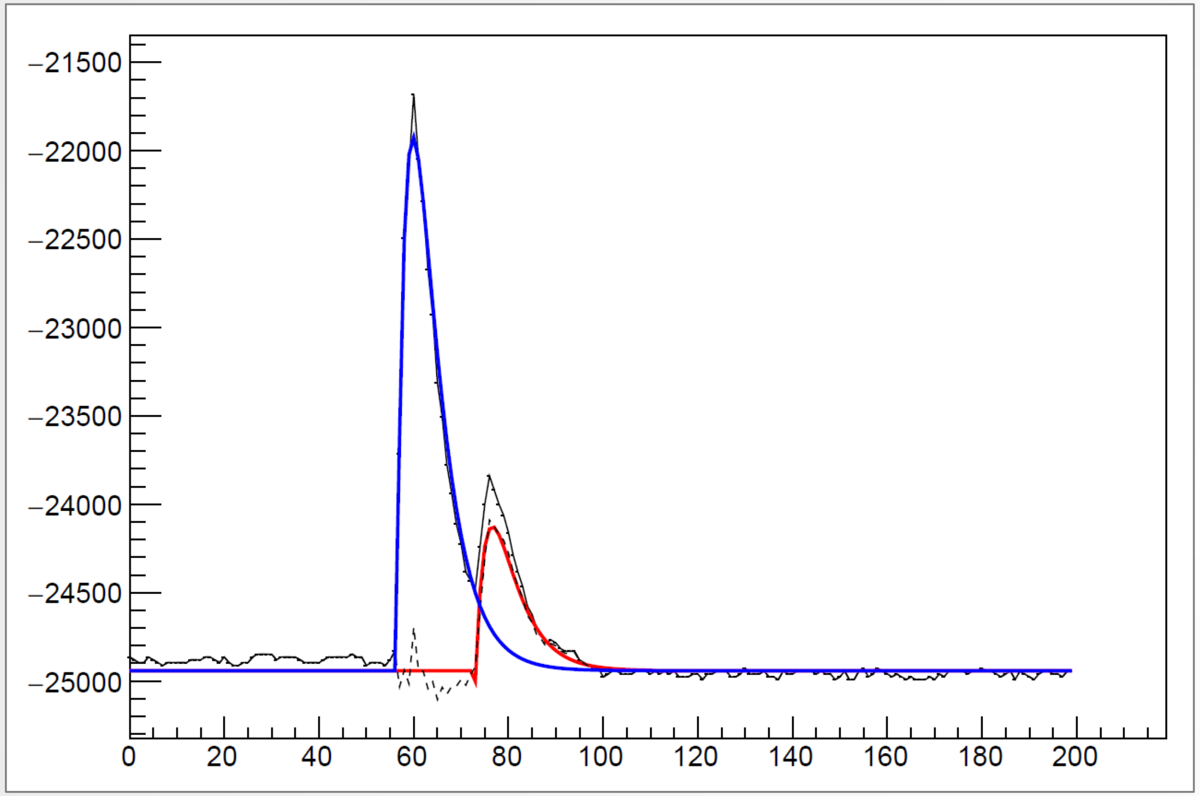
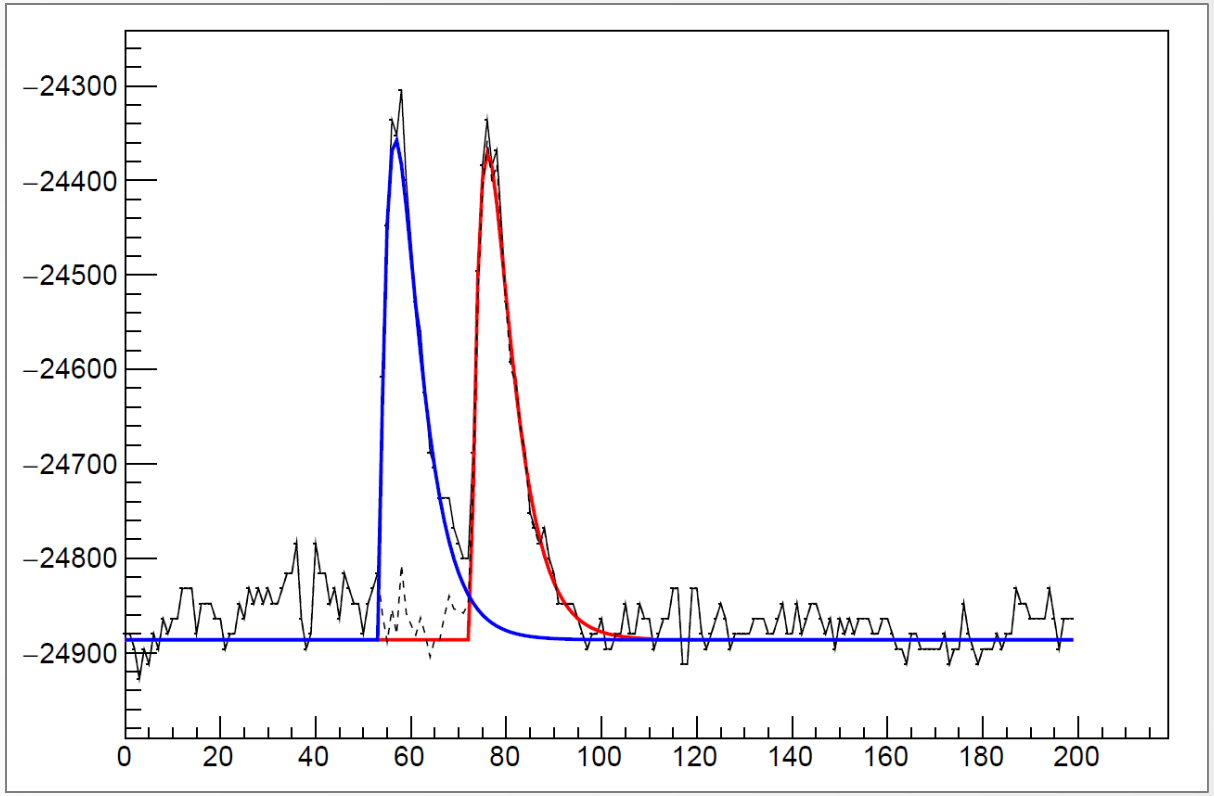


Pileup rejection

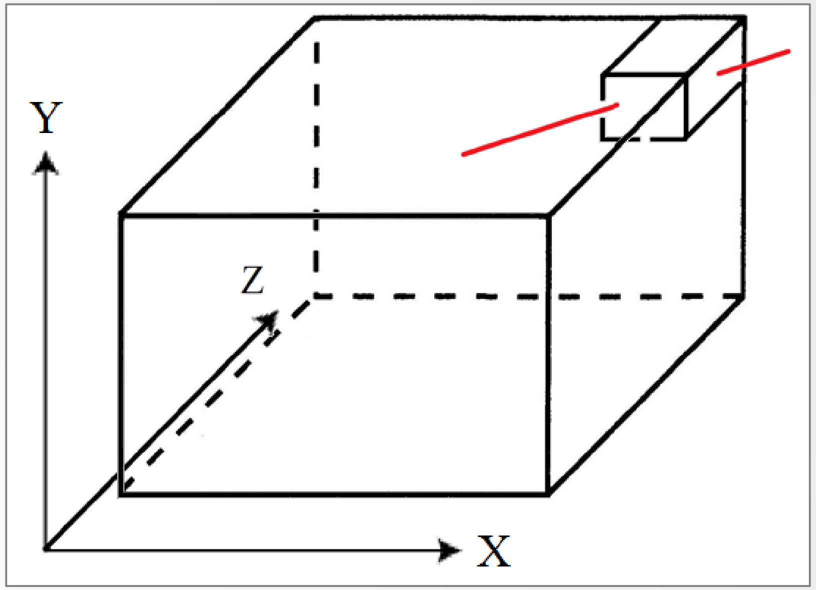




- ❖ Minimum distance between the pileup and the true signal ≥ length of the leading edge
- ❖ Edge sensitive digital filter
- ❖ Pileup rejection and the true signal recovery

New muon calibration approach

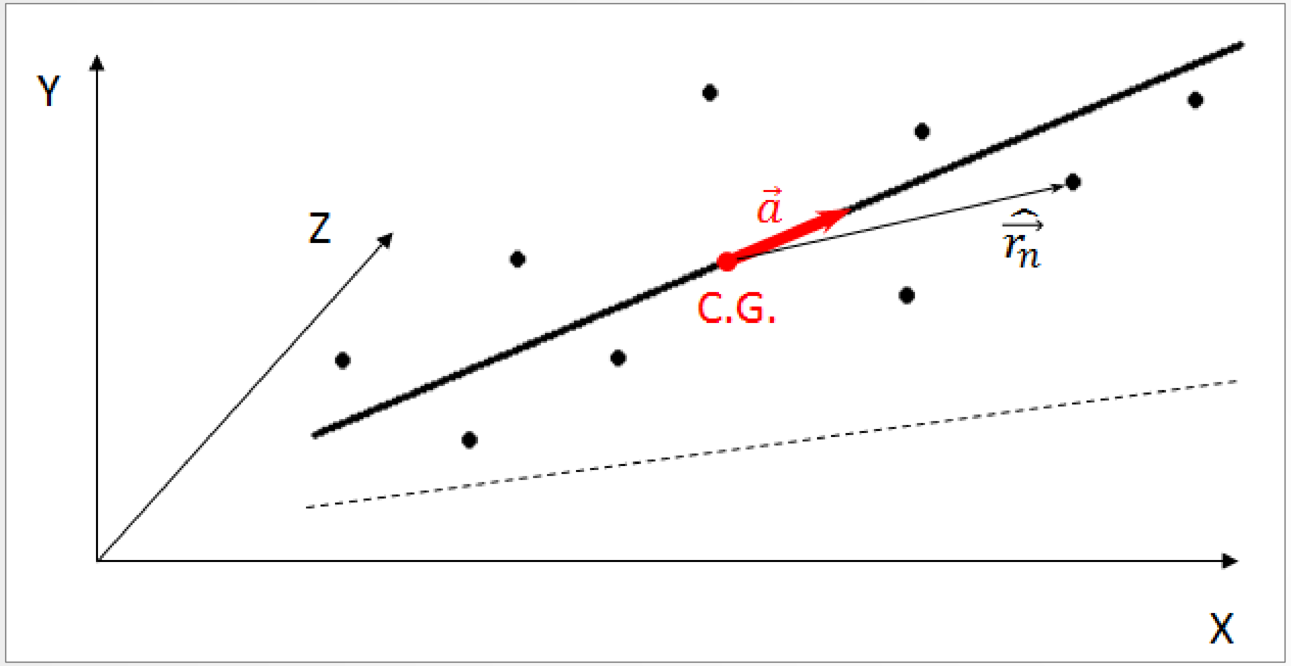
Cosmic muons deposit different amounts of energy in the calorimeter sections depending on the position and direction of the particle track. This should be taken into account when conducting a muon calibration.



Calibration approach:

- Reconstruct muon tracks using signals selected with fit QA
- Determine the thickness of the scintillator passed by track in each cell
- Make corrections when calculating energy deposition

Muon track reconstruction



$$\sum_{n=1}^{N}\left(\frac{(\hat{\vec{r}}[n],\vec{a})}{|\vec{a}|}\right)^2 \to \max \qquad \varphi = \sum_{n=1}^{N}\hat{r}_i a_i \hat{r}_j a_j \to max$$

Maximizing the quadratic form φ on the unit vector $\vec{a}$. The quadratic form is maximal on the eigenvector corresponding to the maximal eigenvalue.

- Selection of triggered sections by fit QA
- Shift reference system to the center of gravity

$$\vec{R}_{C.G.} = \frac{1}{N}\sum_{n=1}^{N} E[n]\,\vec{r}[n].$$

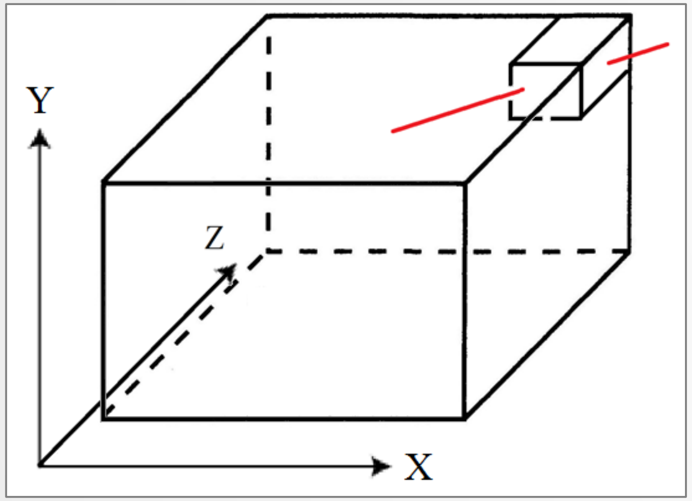
- Extremum search

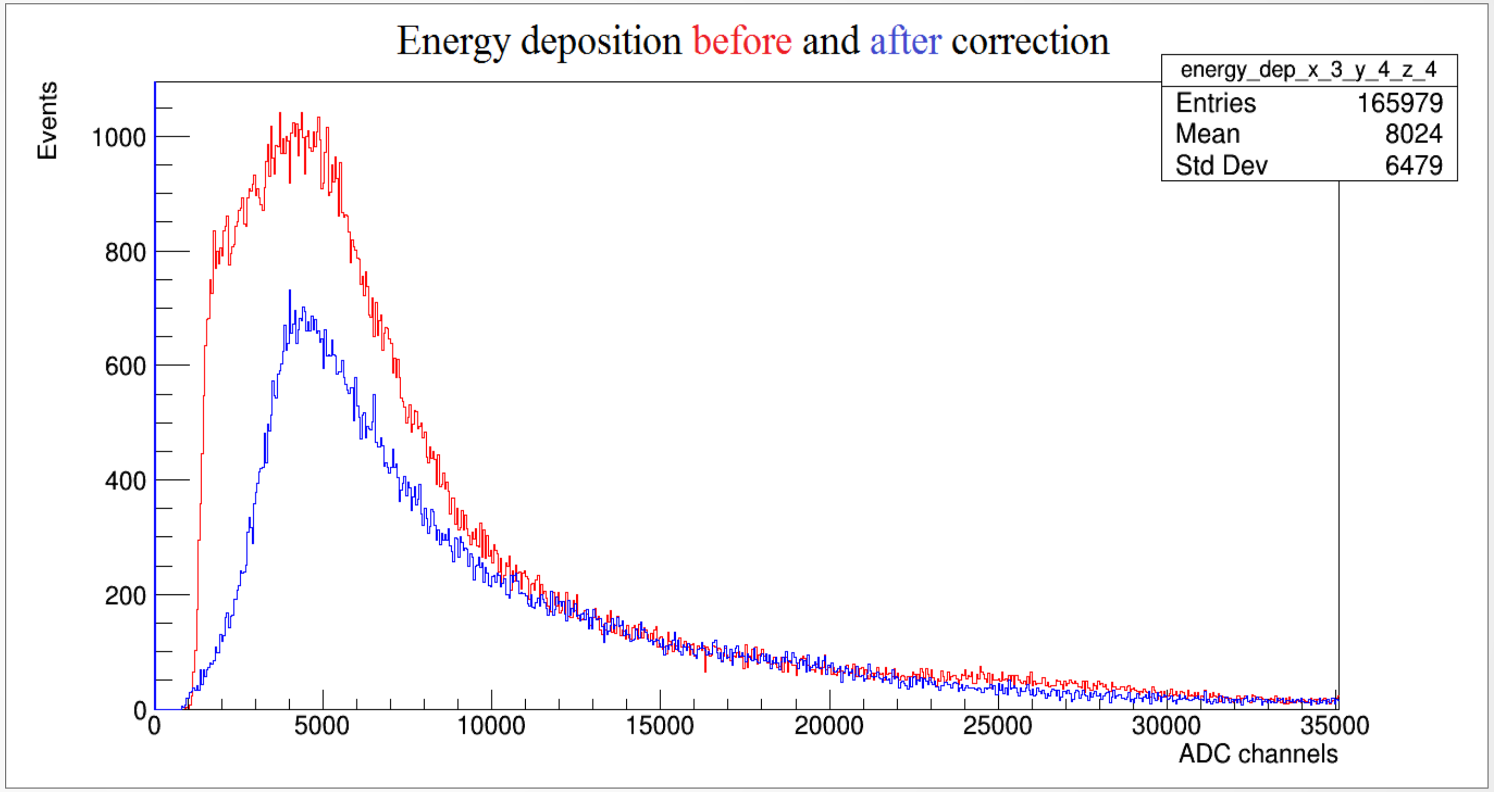
$$\sum_{n=1}^{N}\left(\hat{\vec{r}}^{\,2}[n] - \left(\frac{(\hat{\vec{r}}[n],\vec{a})}{|\vec{a}|}\right)^2\right) \to min$$

$$M = \begin{pmatrix} \sum_{n=1}^{N} r_n^x\, r_n^x & \sum_{n=1}^{N} r_n^x\, r_n^y & \sum_{n=1}^{N} r_n^x\, r_n^z \\ \sum_{n=1}^{N} r_n^y\, r_n^x & \sum_{n=1}^{N} r_n^y\, r_n^y & \sum_{n=1}^{N} r_n^y\, r_n^z \\ \sum_{n=1}^{N} r_n^x\, r_n^z & \sum_{n=1}^{N} r_n^y\, r_n^z & \sum_{n=1}^{N} r_n^z\, r_n^z \end{pmatrix}$$

Adjusted charge calculation

Calculation of the thickness of scintillator material traversed by the particle track by enumerating 6 faces of each triggered section.





The adjusted charge is considered as if the particle has passed straight through the section, traversing 6×4 mm of the scintillator. In the case when the track did not pass through the section, it is impossible to correct the charge, the adjusted energy deposition is considered to be zero.

Summary

- ❖ Results of supermodule response tests at hadron beams are presented
- ❖ A new method for fitting signals is developed
- ❖ The application of the fit QA is shown
- ❖ Pileup rejection method is used to restore the true signal
- ❖ New approach to the muon calibration is implemented

Thank you for your attention!