CALOR 2024 Tsukuba

The 20th International Conference on Calorimetry in Particle Physics

Beam Test Results of the Calorimeter Prototype Based on Lead Tungstate Crystal with SiPM Readout

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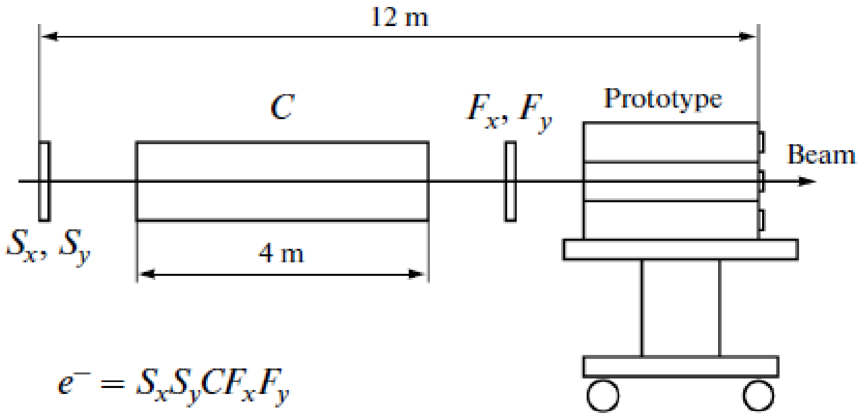
Introduction

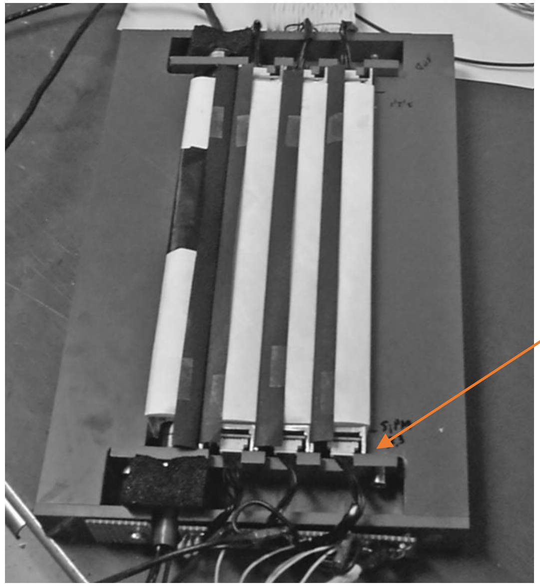
- Good time resolution in calorimetry can provide strong capability to neutral particles identification
  - Hadron PID (neutron/antineutrons, protons/antiprotions etc.)
  - Photon/electron PID
- Lead tungstate crystal ($PbWO_4$) has demonstrated excellent performance in the experiments in high-energy physics
- Silicon photomultipliers (SiPM) with short rising time of an output signal are capable to provide good time resolution

BEAM TEST CAMPAIGN 2014
PS T10

Experimental layout

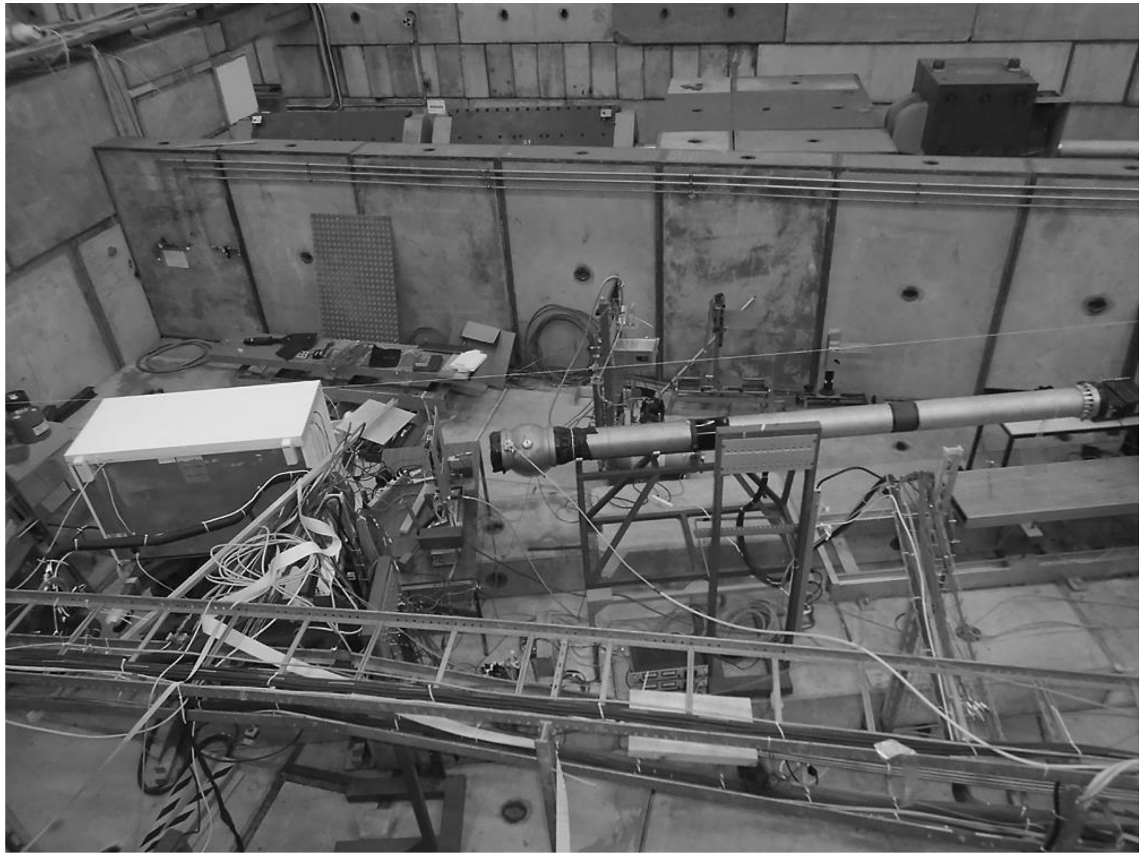


Prototype is build of 2×2 crystals matrix:



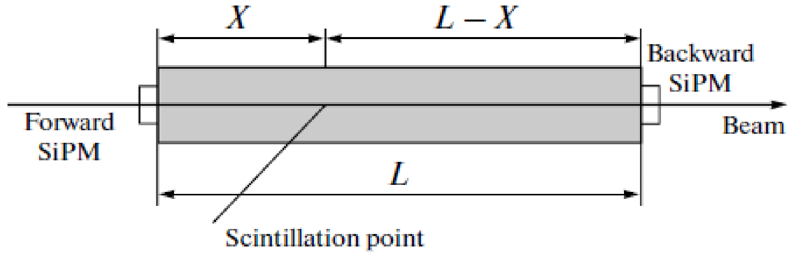
Readout:

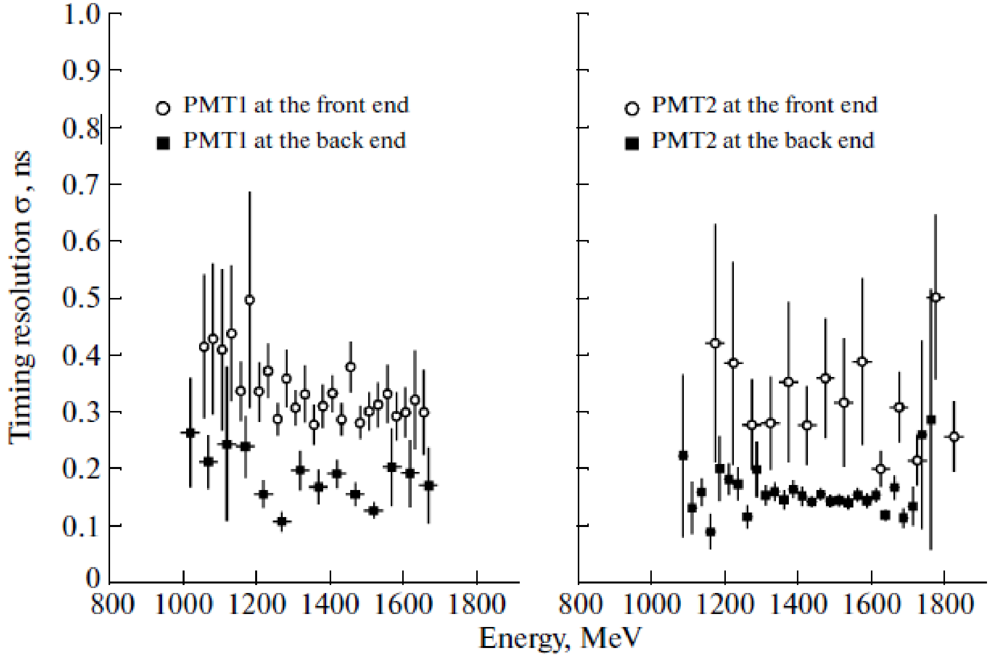
- MPPC S10362-33-025C
- MPPC S10362-33-050C
- MPPC S10362-33-100C
- R7400 PMT

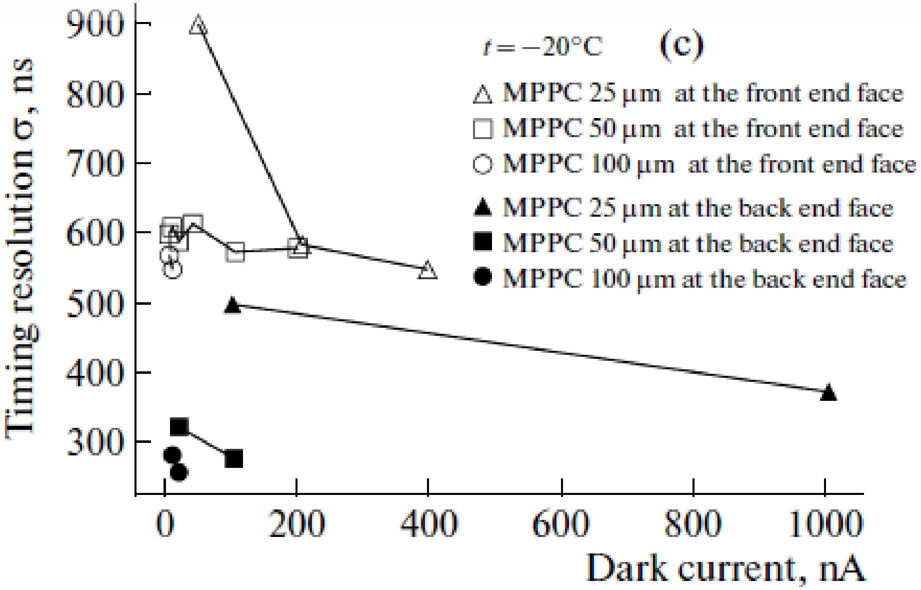


Time Resolution

SiPM/PMT readout at front and rear sides:







Possible explanation (see ref):

- high reflecting index (n = 2.2) ⟶ low speed of the light propagation
- Simple model shows that the front side is more sensitive to longitudinal shower fluctuations

Similar results with Calvision: Bob Hirosky

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BEAM TEST CAMPAIGNS 2023, 2024
PS T09, SPS H2

Prototype Design

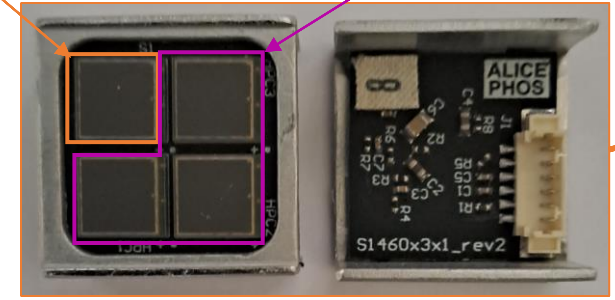
- The calorimeter prototype is build of $PbWO_4$ crystals size of 22×22×180 mm^3:
  - homogeneous $PbWO_4$ crystal is served both as scintillator and absorber

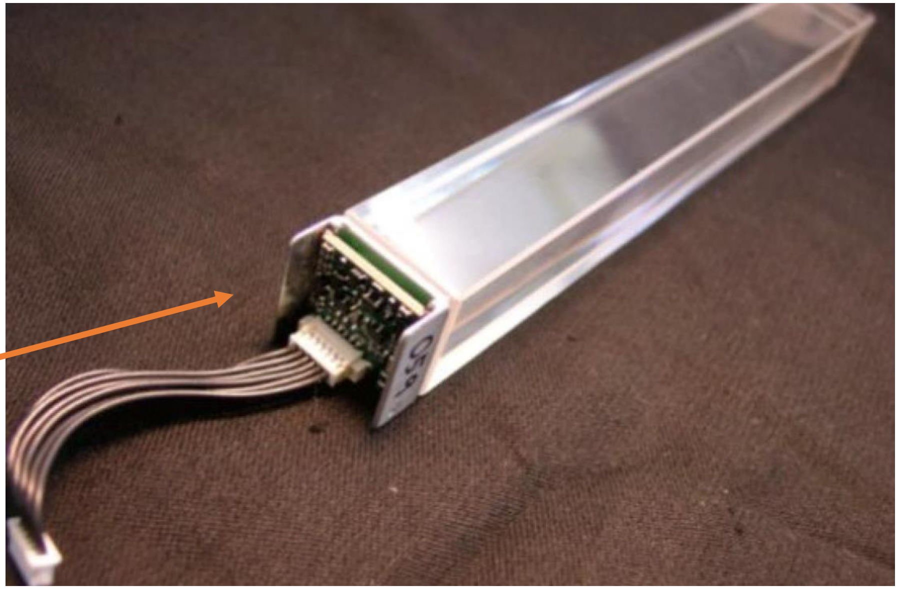
Density, g/cm^3	Radiation length, cm	Light yield, % of NaI:Tl	Molière radius, cm	Decay time, ns
8.28	0.89	0.5%	2.2	5-15

- The readout channels consists of Hamamatsu MPPC S14160-6015PS and S14160-6010PS photodetectors:
  - Hybrid SiPM connection: signal in serial, voltage in parallel

1×**S14160-6010PS:**
- 10 μm pixel pitch
- gain $1.8 \cdot 10^{15}$ (low gain, **LG**)
- for high energy measurements (E > 10 GeV)

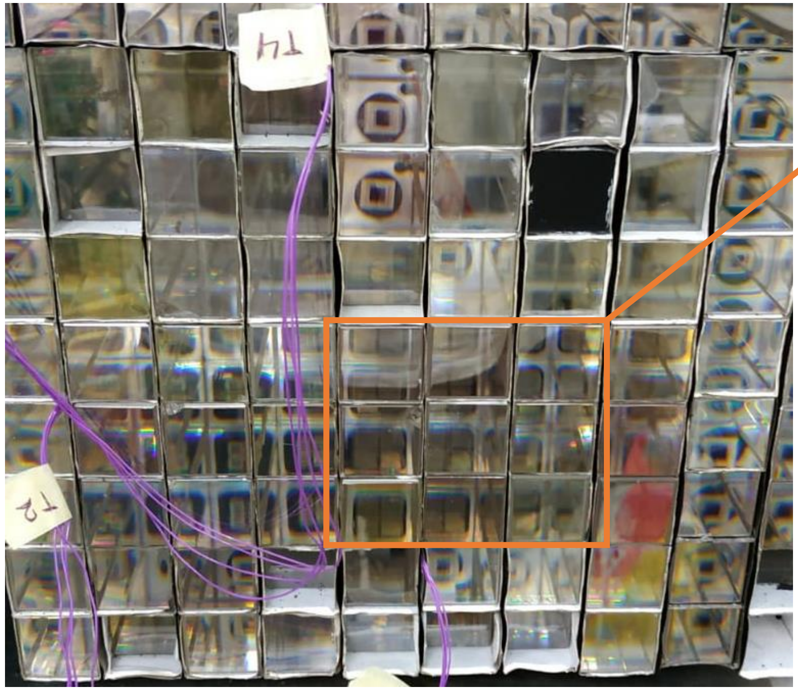
3×**S14160-6015PS:**
- 15 μm pixel pitch
- gain $3.6 \cdot 10^{15}$ (high gain, **HG**)
- for low energy measurements (0.5 GeV < E < 10 GeV)

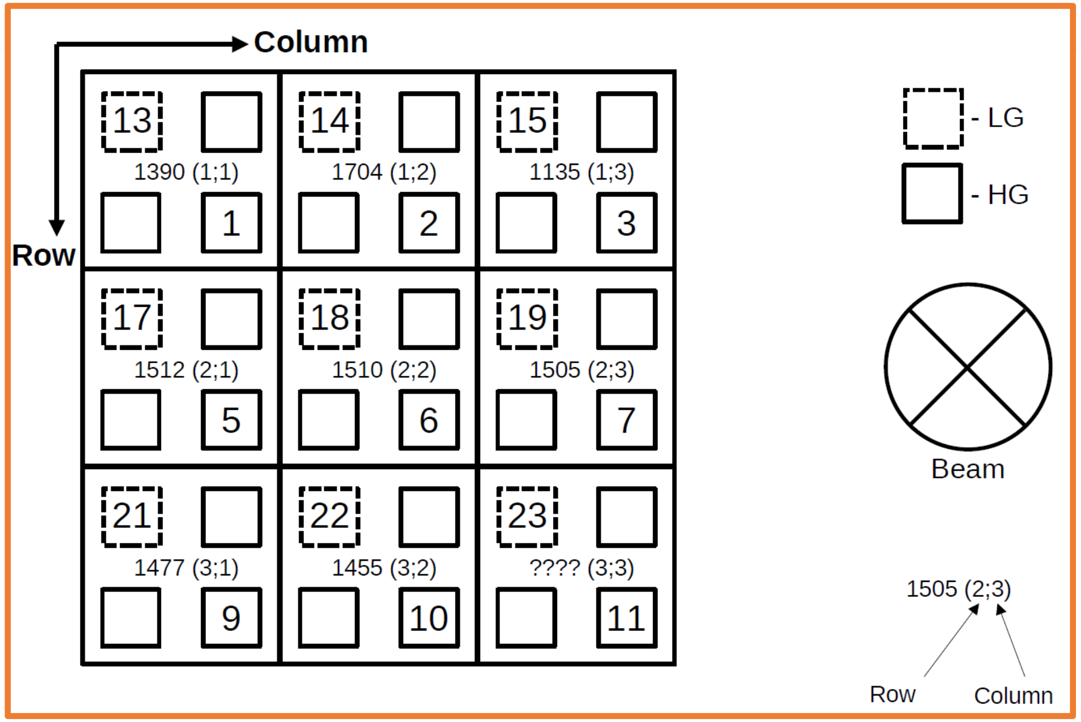




Prototype Design

Cluster of 3×3 crystals was equipped with SiPMs





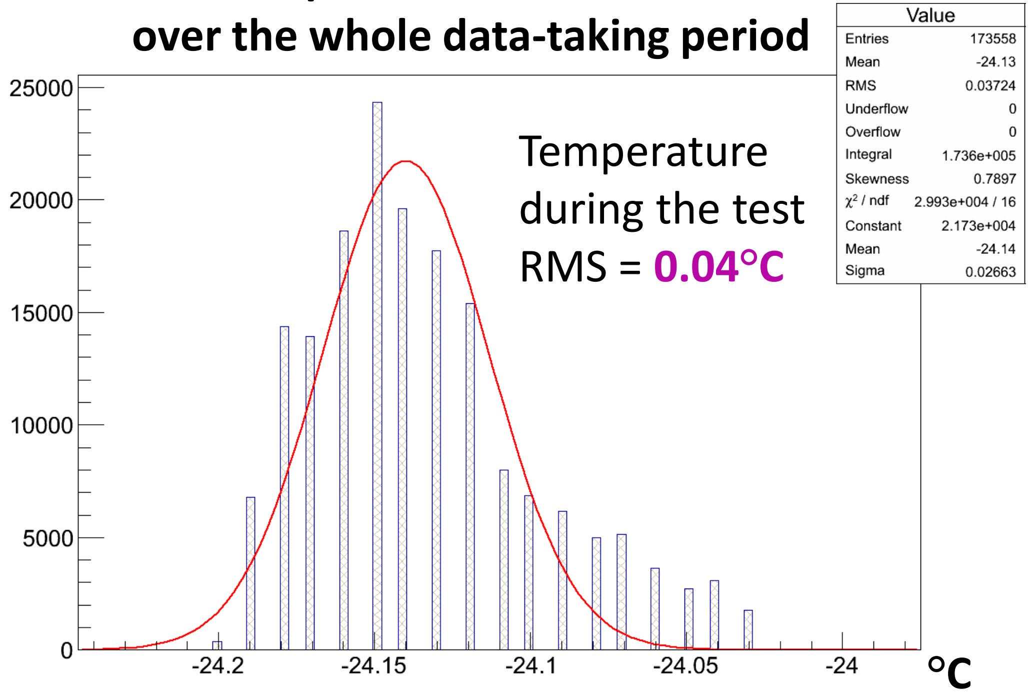
- LG – Low Gain channel for high energy measurements (13-24)
- HG – High Gain channel for low energy measurements (1-12)

Temperature Regime

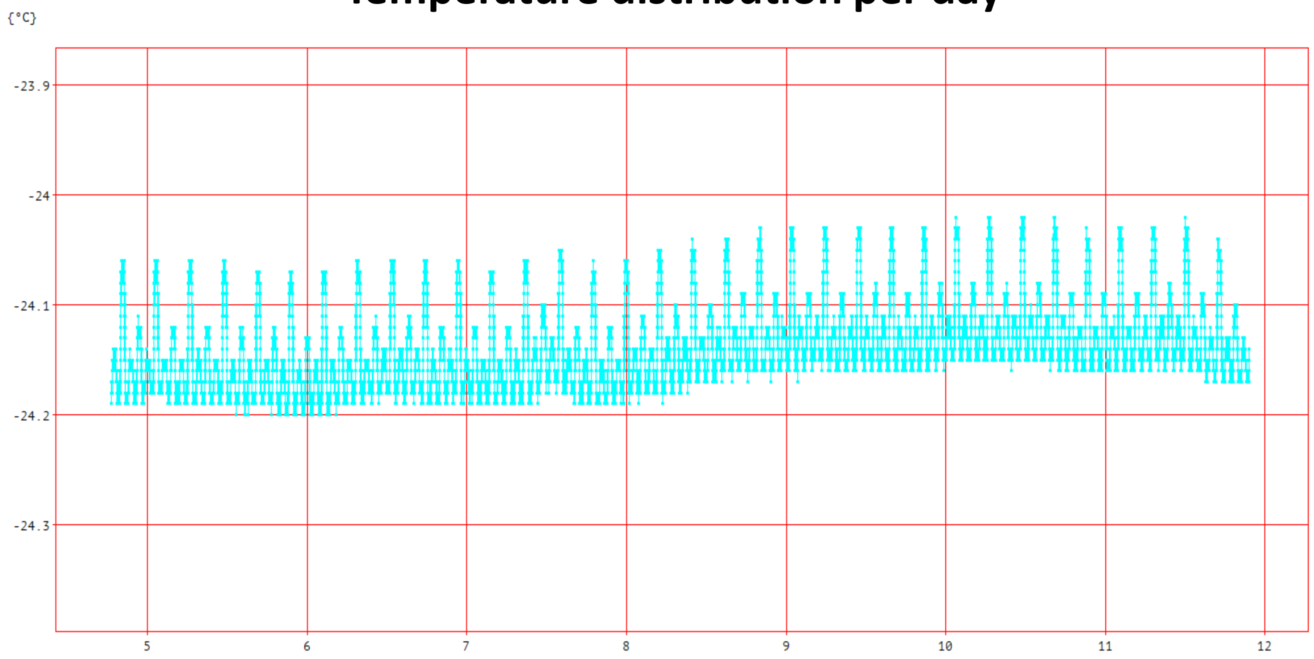
The light yield (LY) of $PbWO_4$ crystals significantly depend on the operating temperature **(-2%LY/°C)**:

- During the tests, the prototype was thermalized by high-precision cooling plant
- Operating temperature has been set to **-24.13°C**
- The thermal stability of the prototype is essential during the data-taking period

Temperature distribution over the whole data-taking period



Temperature distribution per day



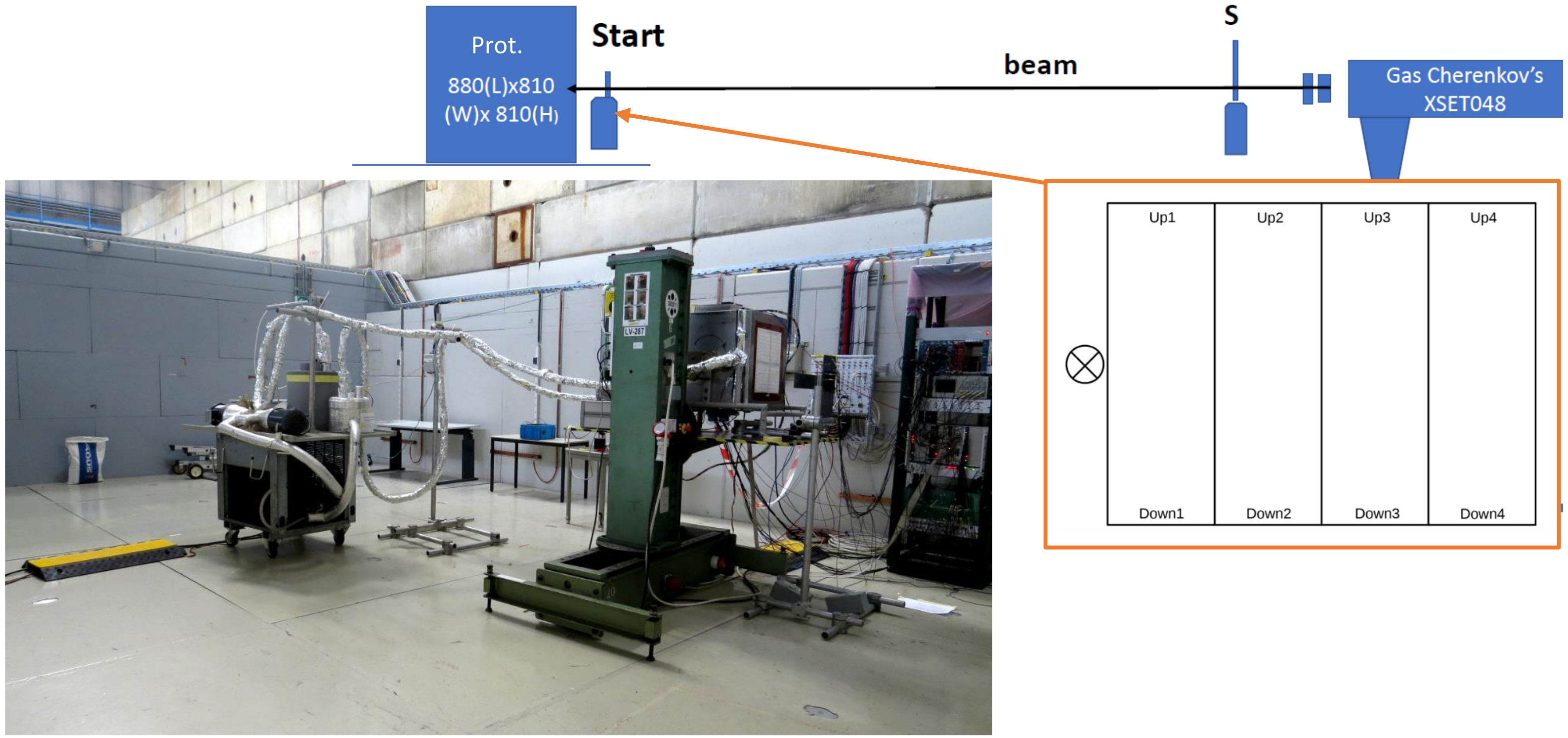
Days since 2023/09/20

Experimental Setup

Configuration of the T9 secondary beam at Proton Synchrotron in CERN:

- Primary proton beam of momentum 24 GeV/*c* + production angle 30 mrad
- Hadron target Be+W (200mm+3mm) for the secondary beam production
- Additional Pb foil converter of 4 mm for e^-/e^+ pair production of momentum $p < 5$ GeV/*c*

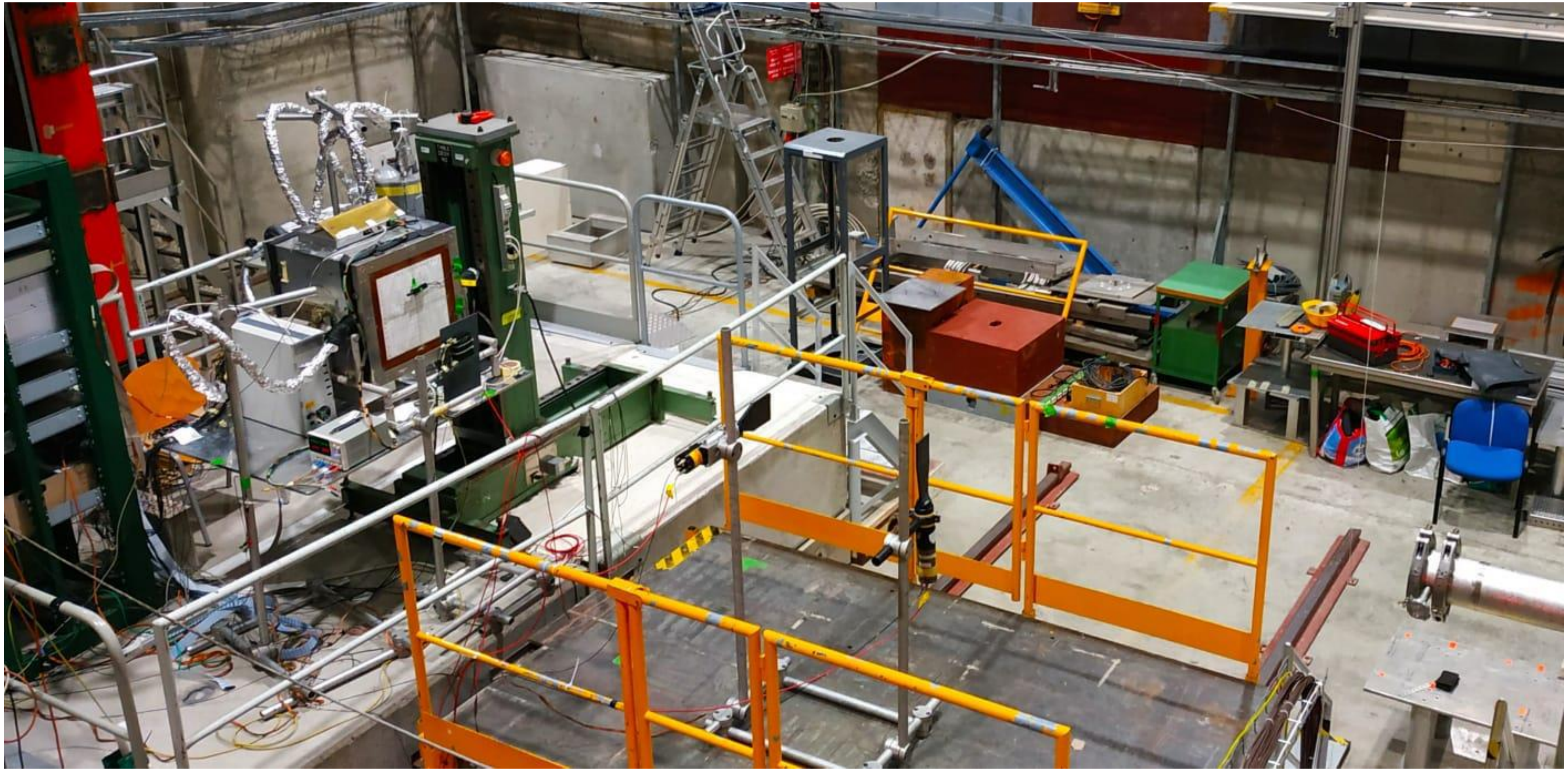
The experimental layout:



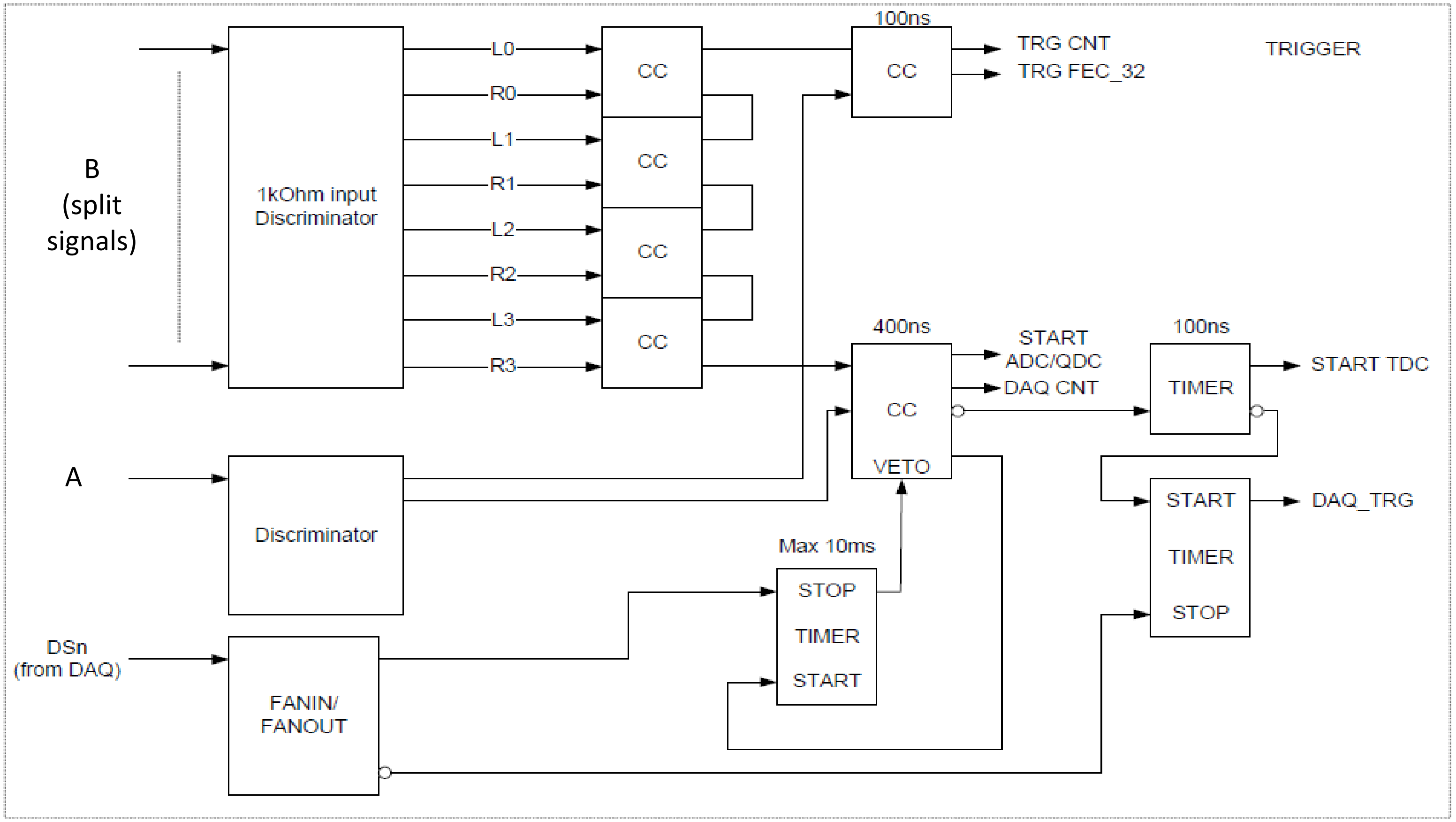
- Cherenkov detector XSET048:
  CO_2 gas pressure variation → variation of electron signal purity
- Scintillator A (100×5×5 mm^3) and scintillator B are used for the trigger system in coincidence connection
- The prototype itself is placed on the DESY table that provide the prototype fine positioning
- Cooling system for the prototype cooling

Experimental Setup

The same layout at H2 at SPS:



Trigger System

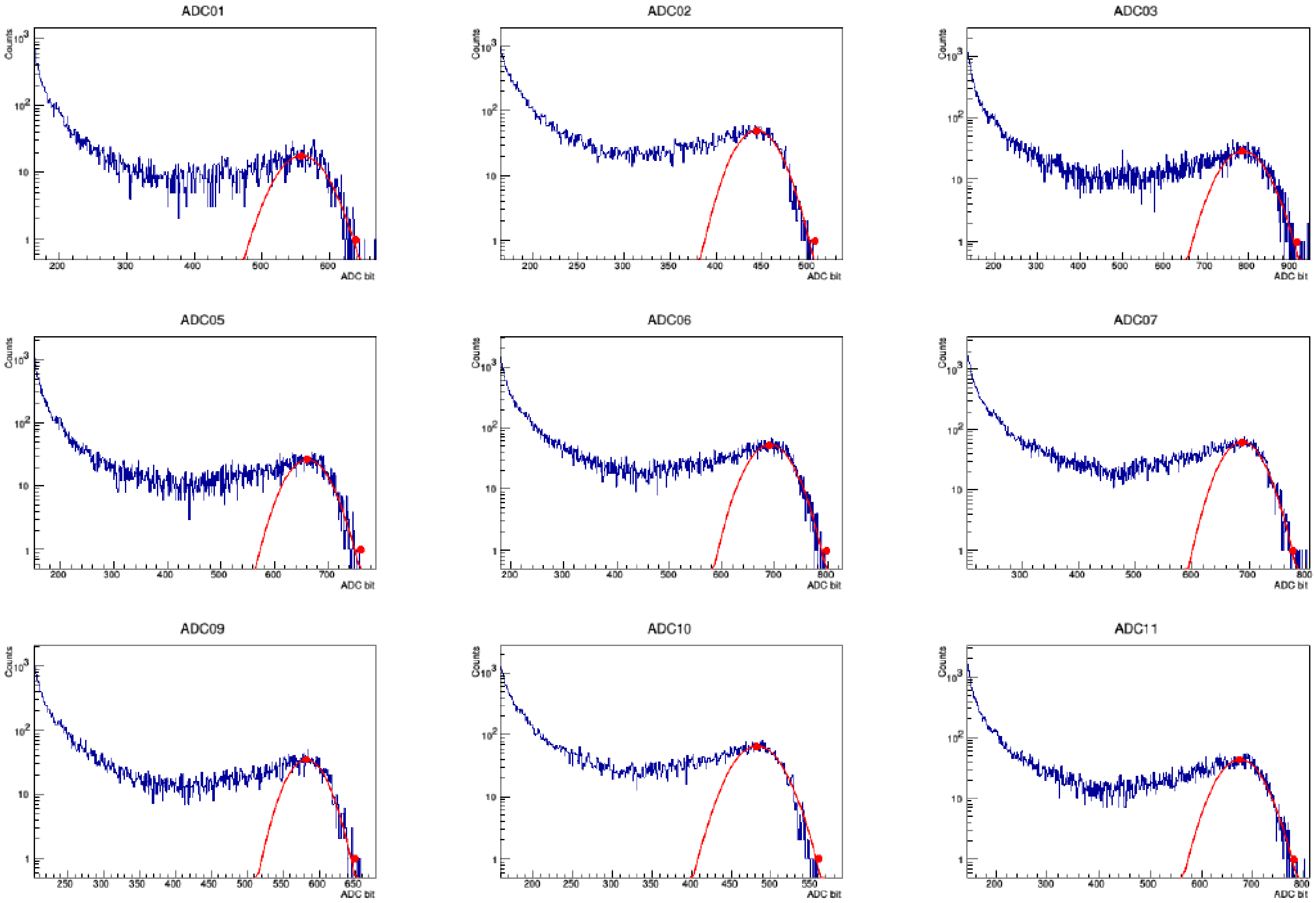


- All the signals from scintillator A and scintillator B are connected in the coincidence circuit (CC)
- for measuring of electrons $p > 5$ GeV/c, signal from Cherenkov detector is added to the CC
- DSn is a clear busy signal from the frontend electronics
- for the time measurements, the reference signal for TDC is also produced by the trigger system

VME frontend electronics:

- CAEN V785 ADC for SiPM amplitude measuring
- CAEN V792 QDC for signal measuring from scintillators
- CAEN V1290 TDC for SiPM time measuring
- CAEN V2718 – V2818 controllers for VME-PCI bridge. DSn is formed by V2718

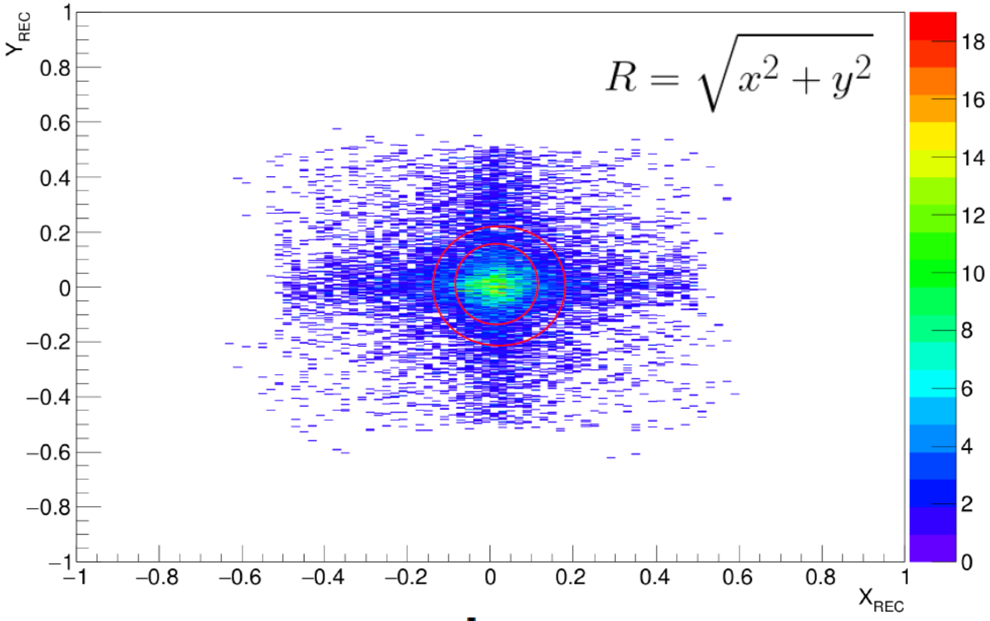
Energy Calibration



- Beam momentum p = 2 GeV/c
- Pedestals are subtracted
- Gauss fit of the maximum signal at the right tail of the distribution
- Mean value of Gauss = correspond beam energy at a given channel

→ energy scale for each ADC channel

Energy Resolution

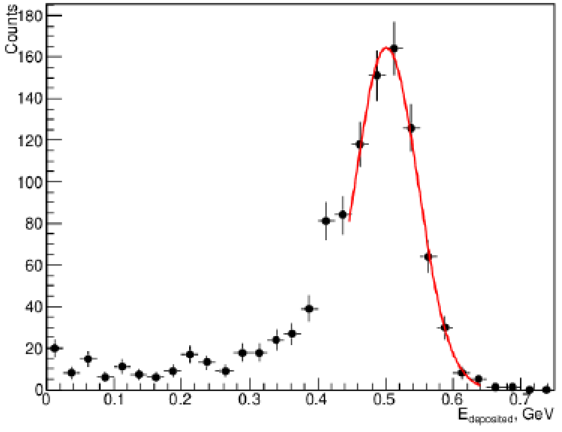


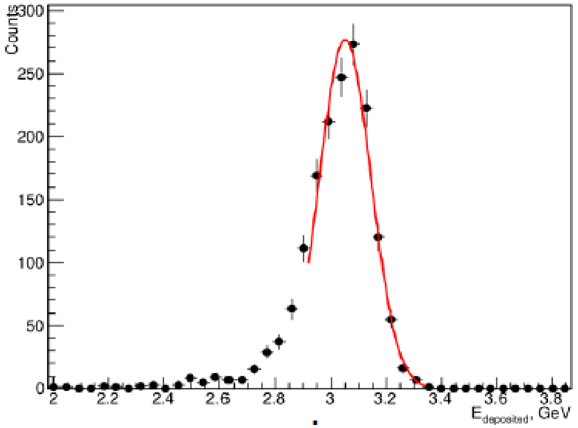
The gravity center of an event is $x = \sum_{i=1}^{9} x_i \cdot \frac{E_i}{E_{tot}}$

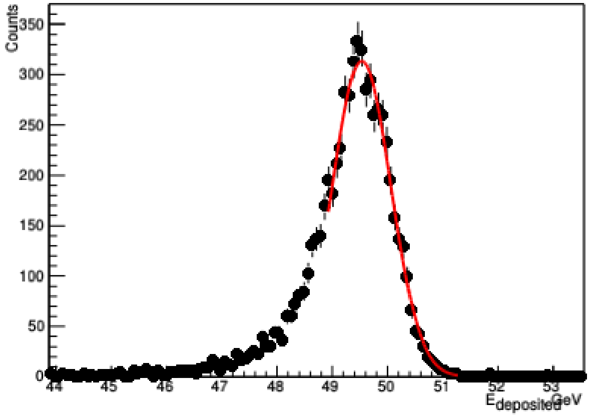
The range of x_i (y_i) is 1,2,3 (according to chosen matrix 3×3)

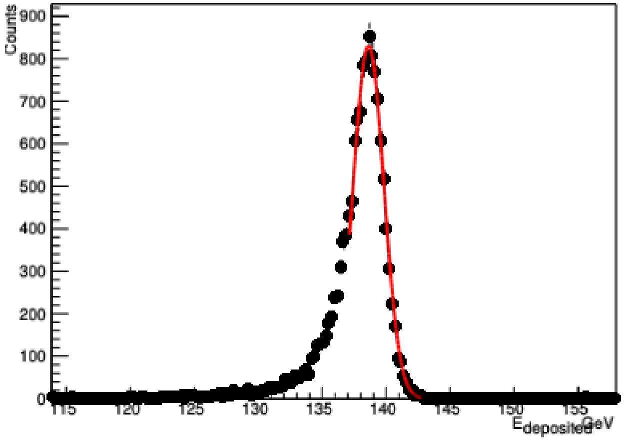
To exclude asymmetric clusters the cut on the gravity center has been applied: $R = \sqrt{x^2 + y^2}$

Resulting resolutions are presented below:



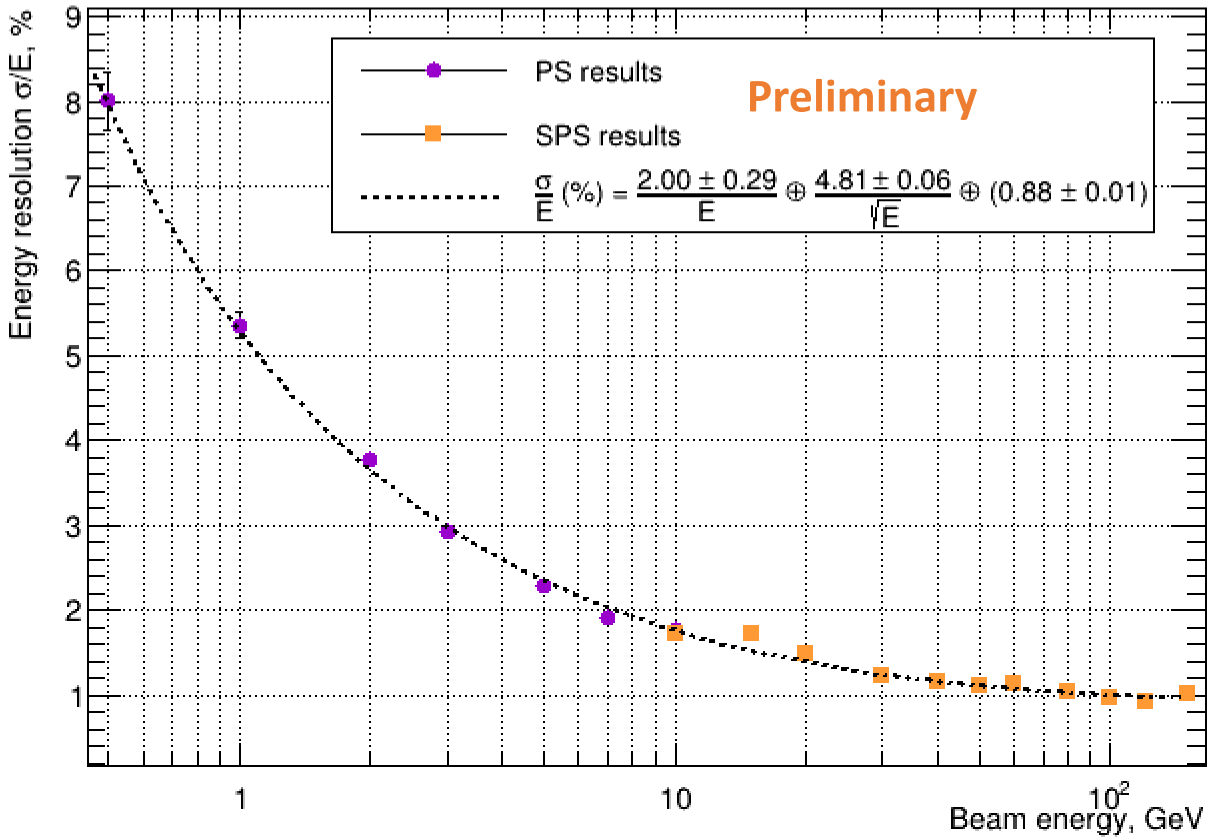




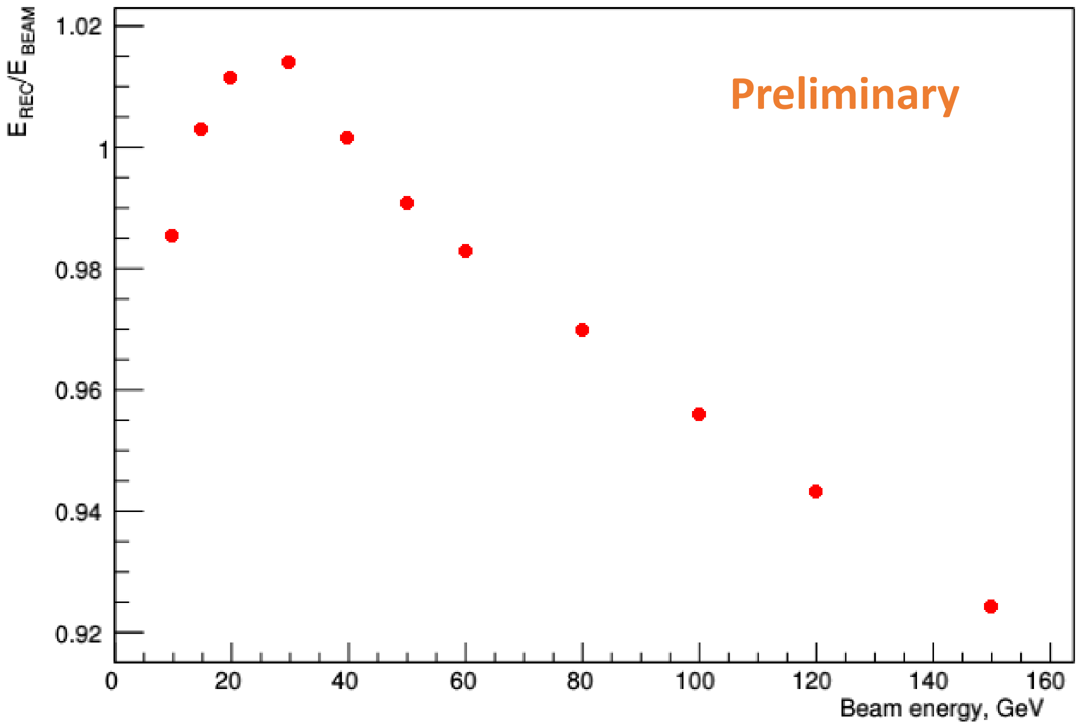


Energy Resolution

Combined energy resolution for PS and SPS energies:

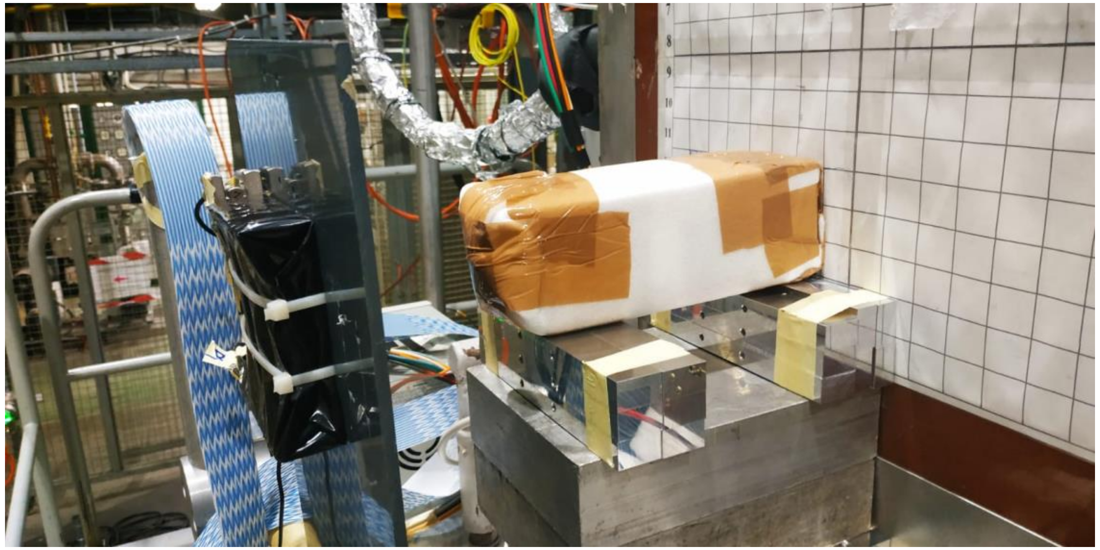


Nonlinearity at SPS energies:

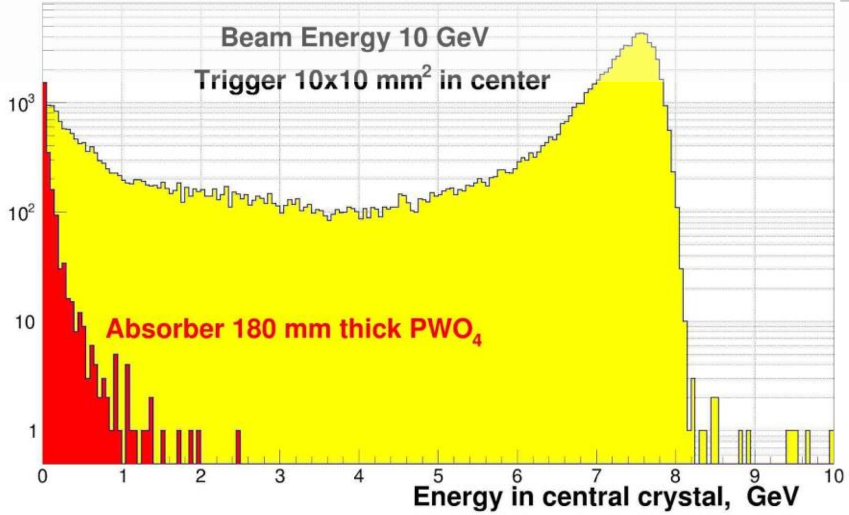


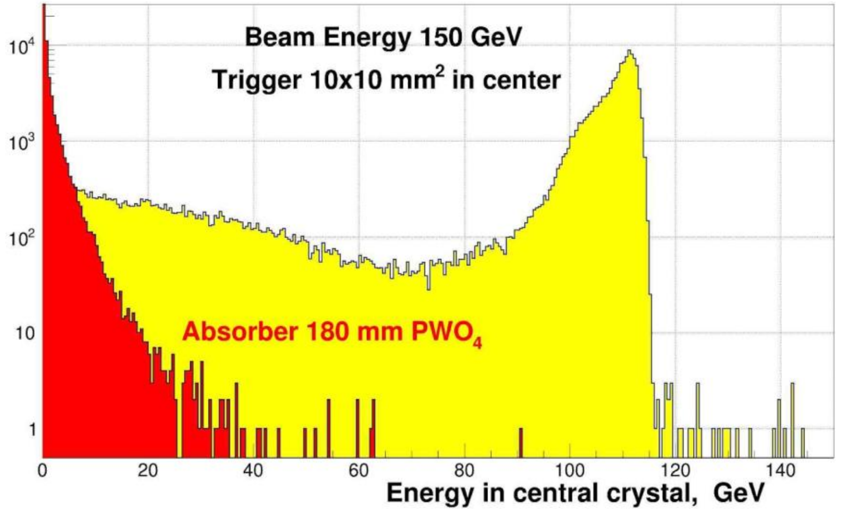
EM Leakage Estimation

For the EM shower leakage estimation, an assembly of 3×3 PWO crystals has been installed in front of prototype



→ the prototype measures EM shower leakage from 3×3 absorber in front of it





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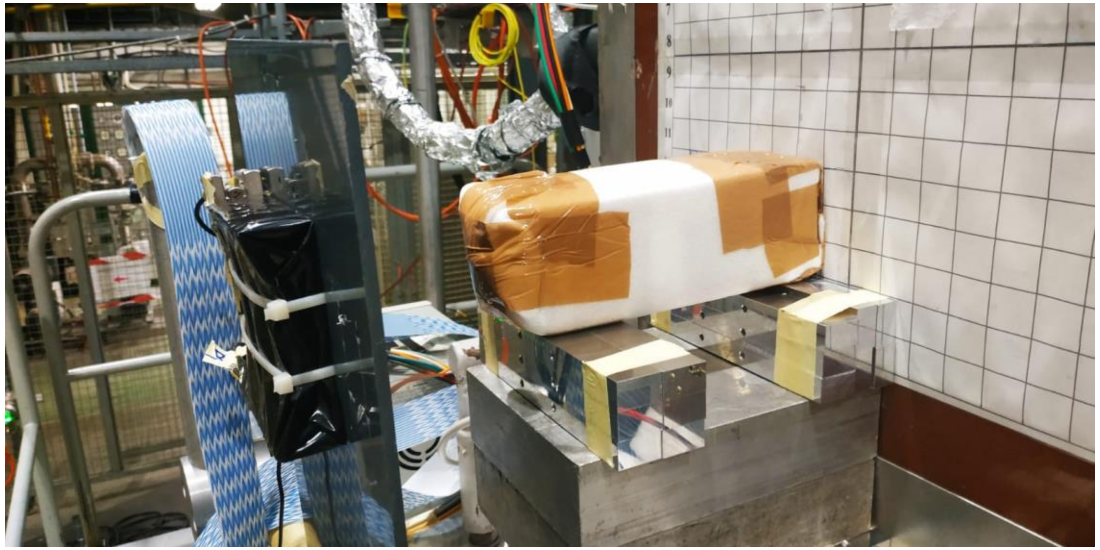

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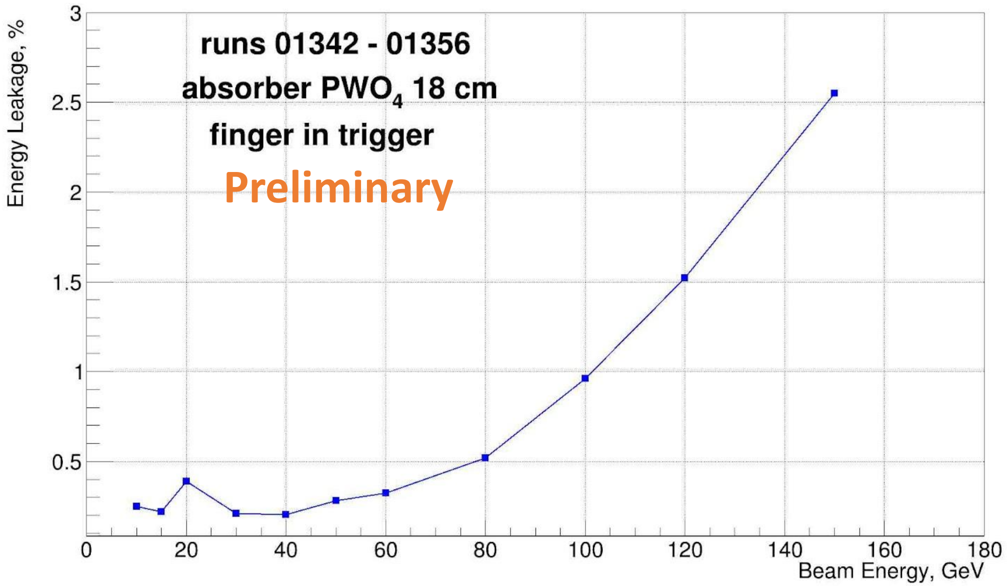
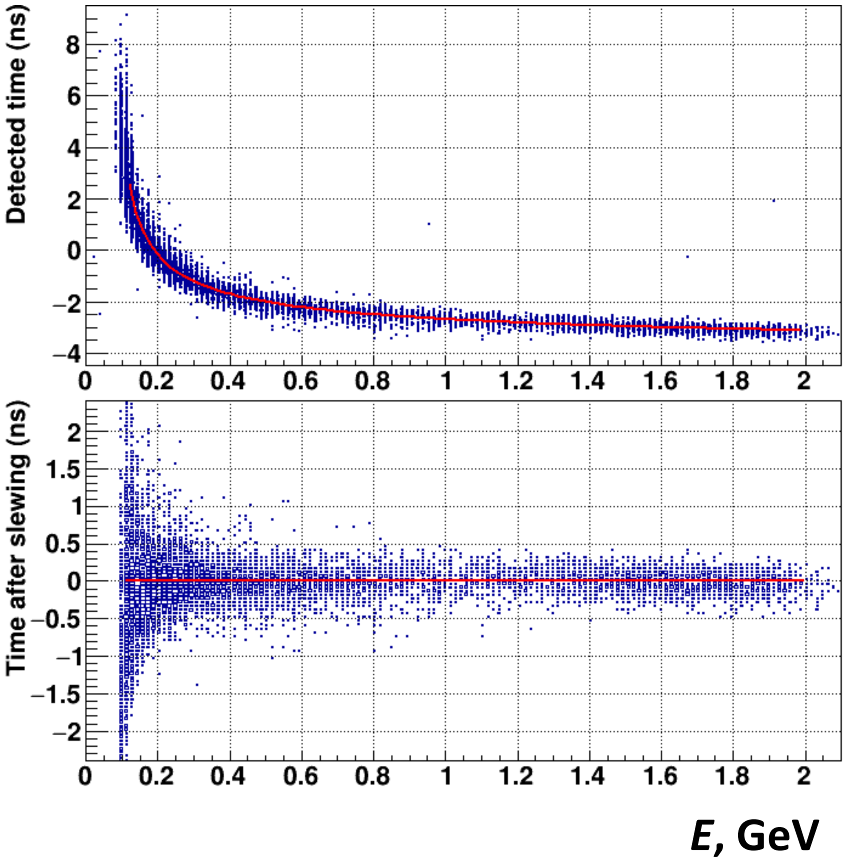
Energy leakage at SPS energies:



Time Resolution

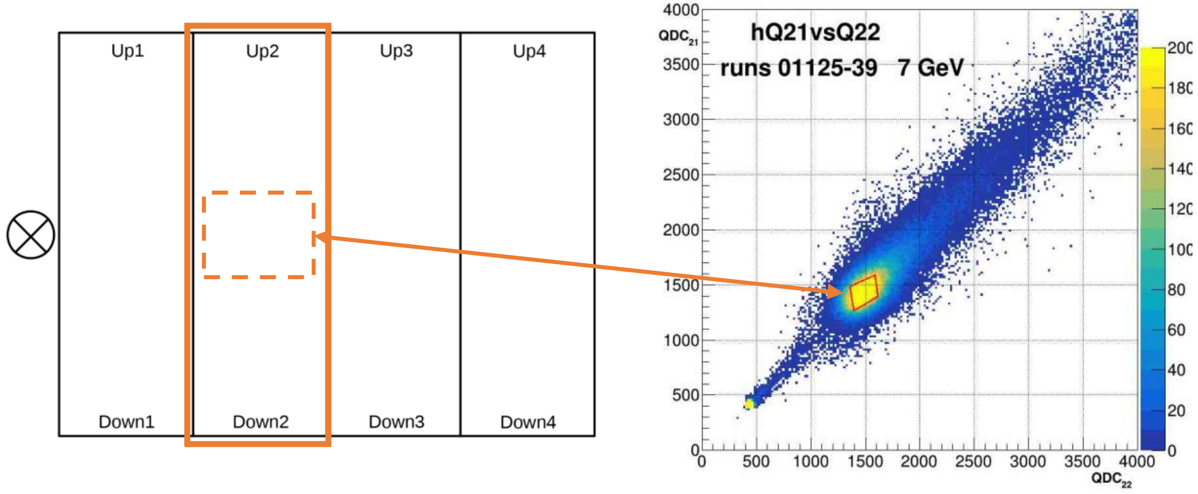


A leading edge discriminator has been exploited for the time and energy measurements

→ The time-energy distribution has a characteristic nonlinear dependence caused by the discriminator threshold

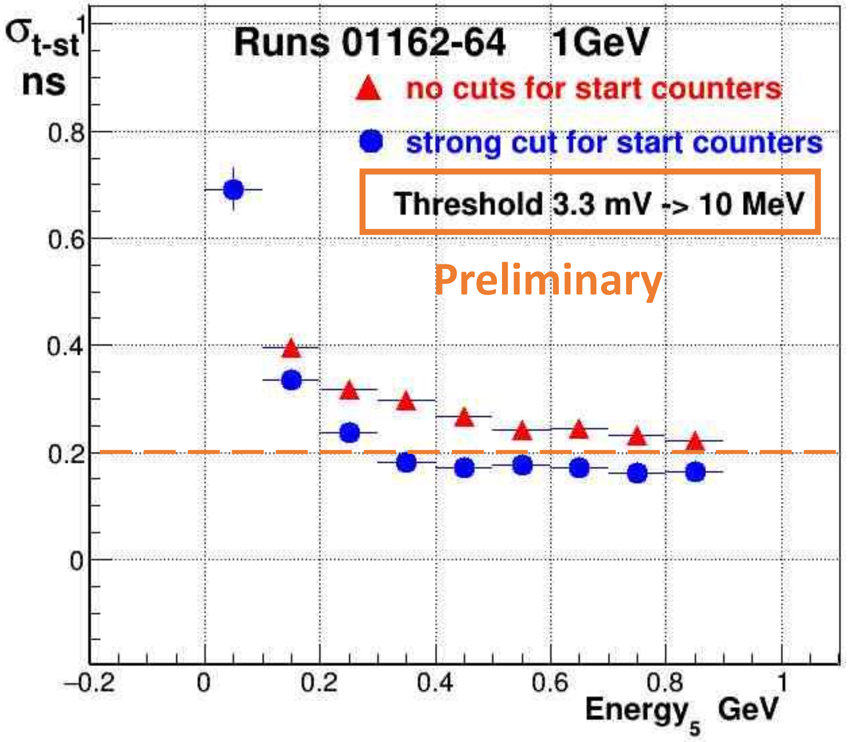
Thus, to increase the accuracy of time resolution calculations, the slewing correction has been applied

A criterion on matching of output signals from edges of central scintillator in front of 3×3 matrix to select for central crystal selection:



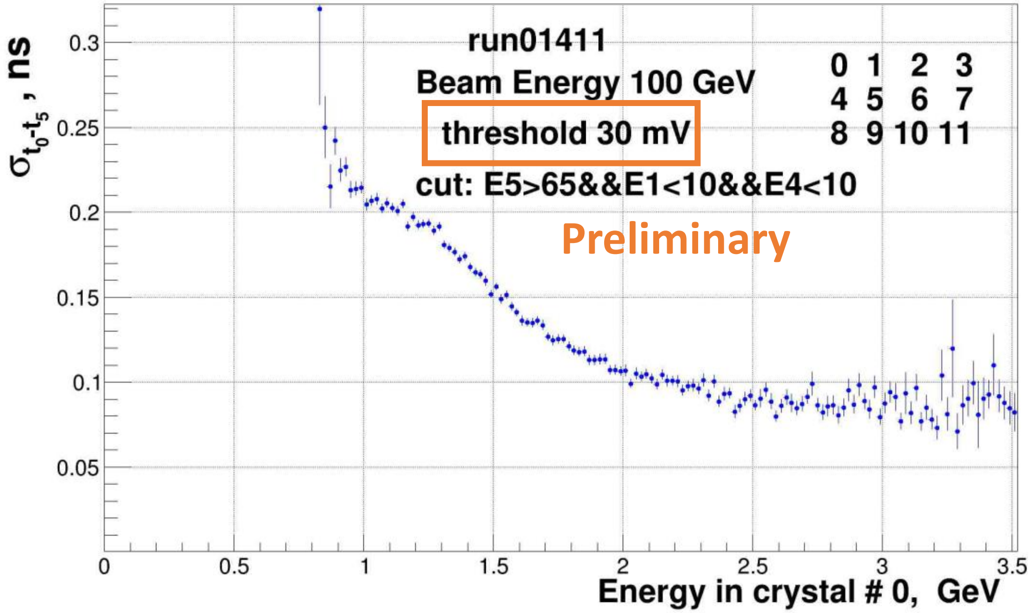
Time Resolution

Beam momentum **p = 1 GeV/*c***, SPS results



After applying criterion on central crystal selection, the time resolution reaches value of σ_t **< 200 ps** for deposited energies *E* > 0.3 GeV

Beam momentum **p = 100 GeV/*c***, SPS results



During test beam at SPS, the threshold on discriminator was much higher then one for test beam at PS

Summary

- The prototype has shown good results in terms of time and energy characteristics:
  - time resolution of **σ_t < 200 ps** for deposited energies ***E* > 0.3 GeV** has been achieved
  - nonlinearity of the prototype reach the value of **8%** at electron momentum *p* = 150 GeV/*c*, while EM shower leakage reaches level of **2.5%**
  - good energy resolution
- Achieved time and energy resolution could be relevant for the photon physics at low energies and hadron PID (i.e. neutrons/antineutrons) for the future experiments in particle physics

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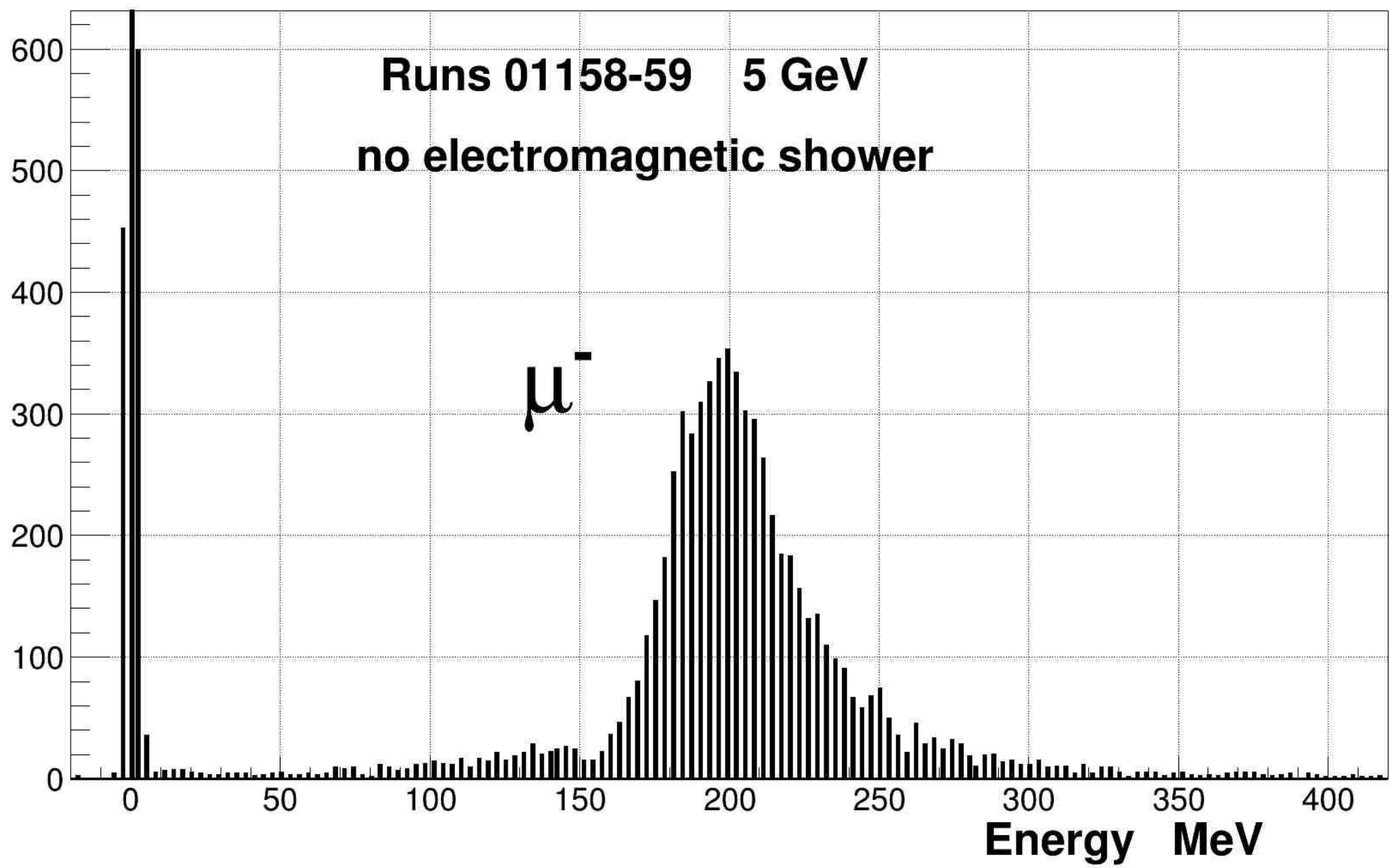
THANK YOU!

Backup slides
Energy Calibration

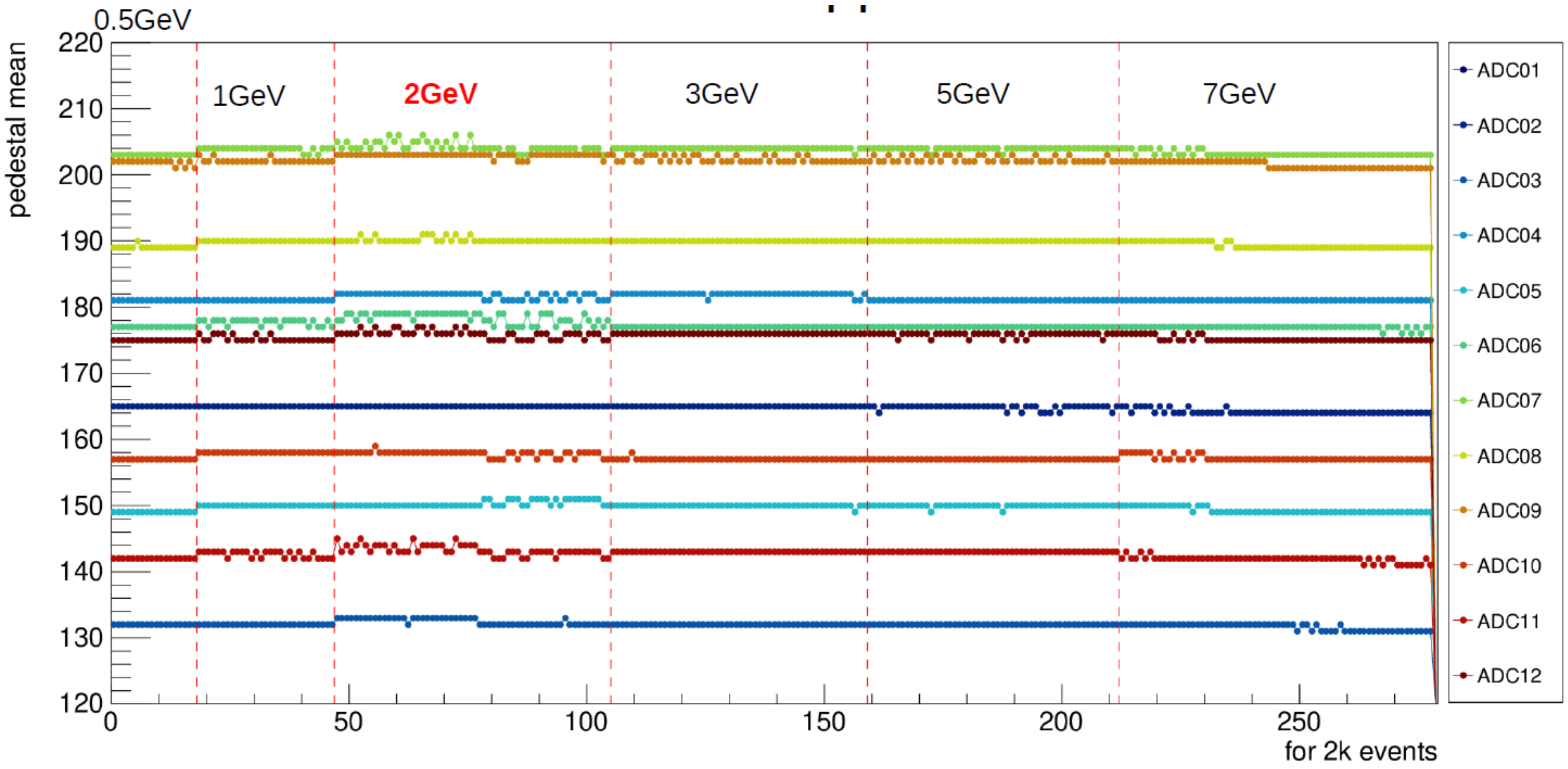
- The peak in the plot below is taken during the beam stop
- The peak mean position at ≈ 200 MeV corresponds for the muon signals (which penetrate the beam stopper)



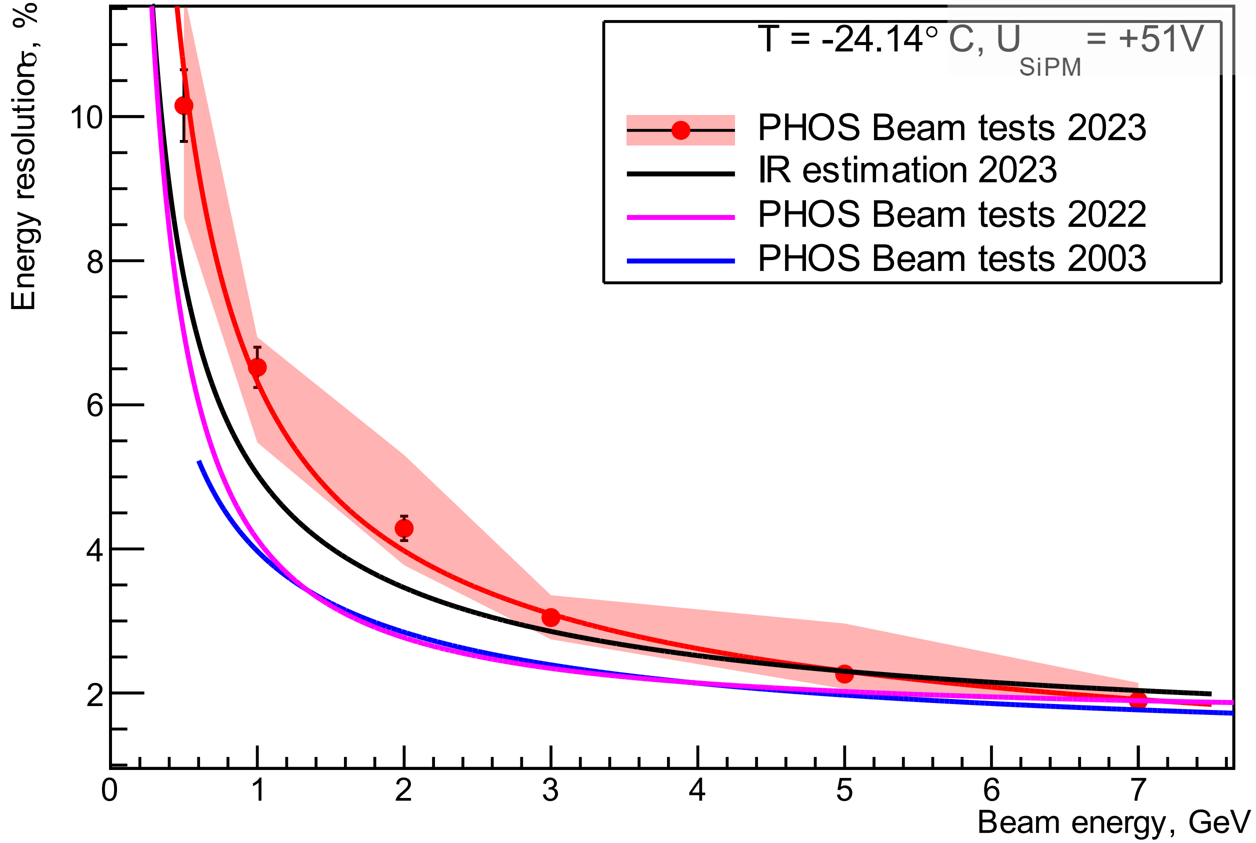
The peak position is close to the MIP signal which indicates fine energy calibration of the assembly

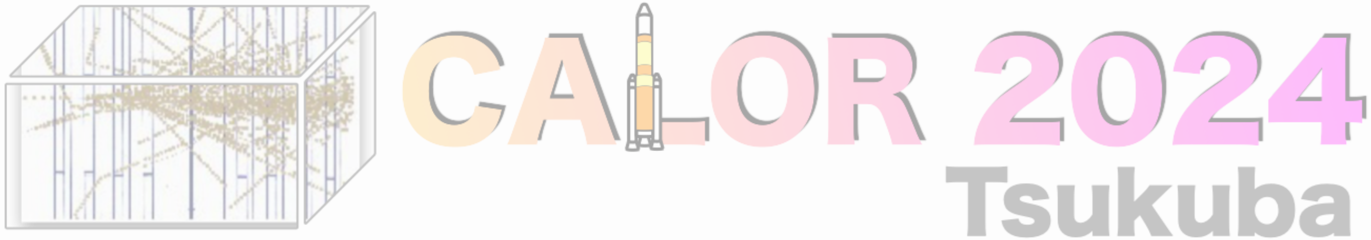
Backup slides
Electrical interferences

- During the beam tests, the ADC pedestal positions for each channel have been stable
- Only neglectable pedestal shifts in ±1 ADC bit have been observed over the whole period of data taking



Energy Resolution Systematic Study





For the energy resolution calculations systematic study has been done:

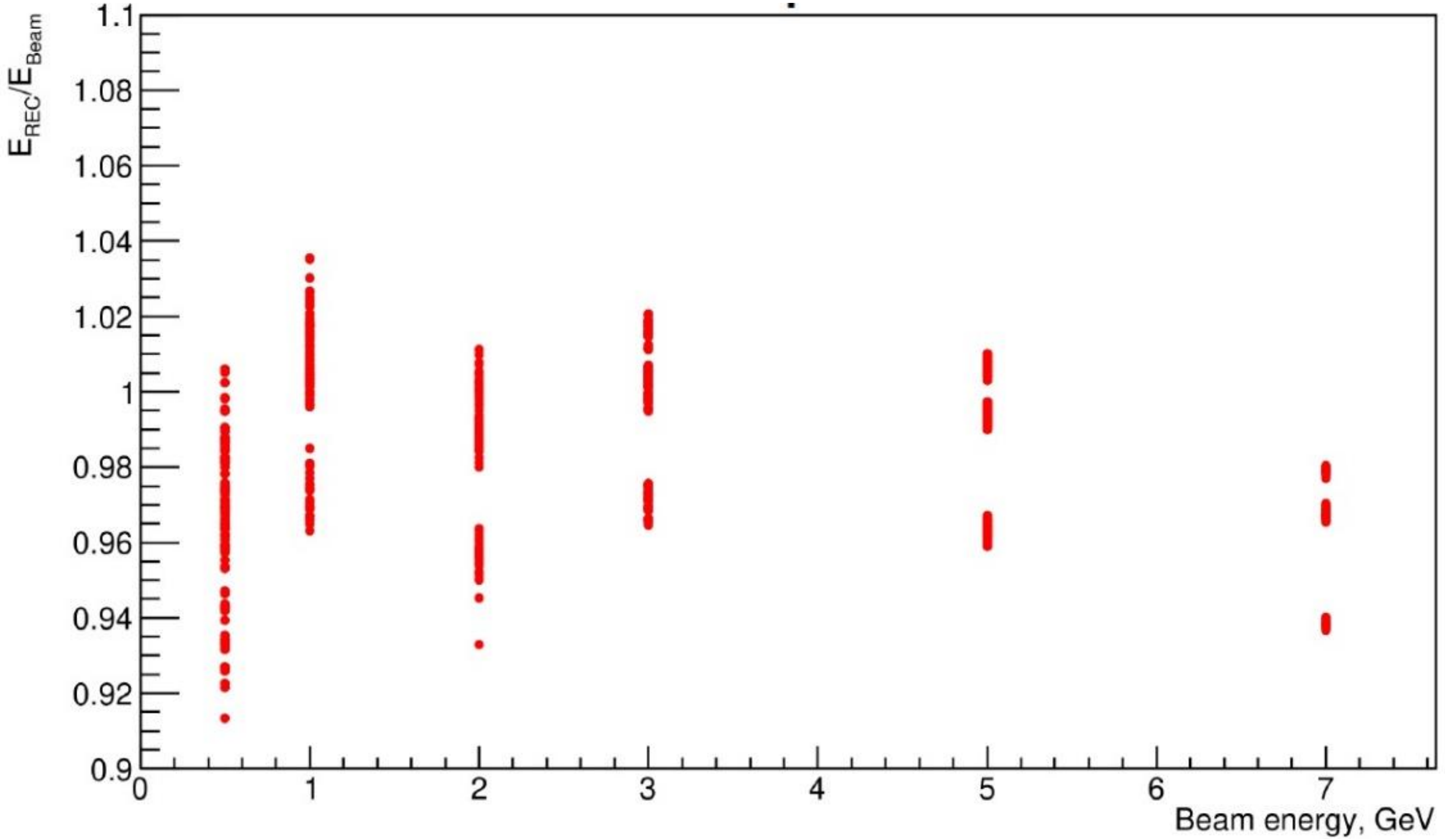
- Red dots and line stand for mean value of the energy resolution
- Red band stands for systematic uncertainties which comes from gravity center variation, calibration energy variation and Gaus fiting configuration
- Black line stands for the best estimation of measurements
- Blue and magenta lines are reference from previous studies with APDs

Estimated energy resolution:

$$\frac{\sigma_E}{E} = \sqrt{\frac{2.344}{E} + \frac{2.344}{\sqrt{E}} + 1.18}$$

Backup slides
Nonlinearity at PS En

- Each dot in the plot below stand for one measurement at the given beam energy (x axis)
- The ration of deposited energy over beam energy (y axis) shows energy leakage form assembly (dots systematically lays under 1)



Energy Resolution at PS energies

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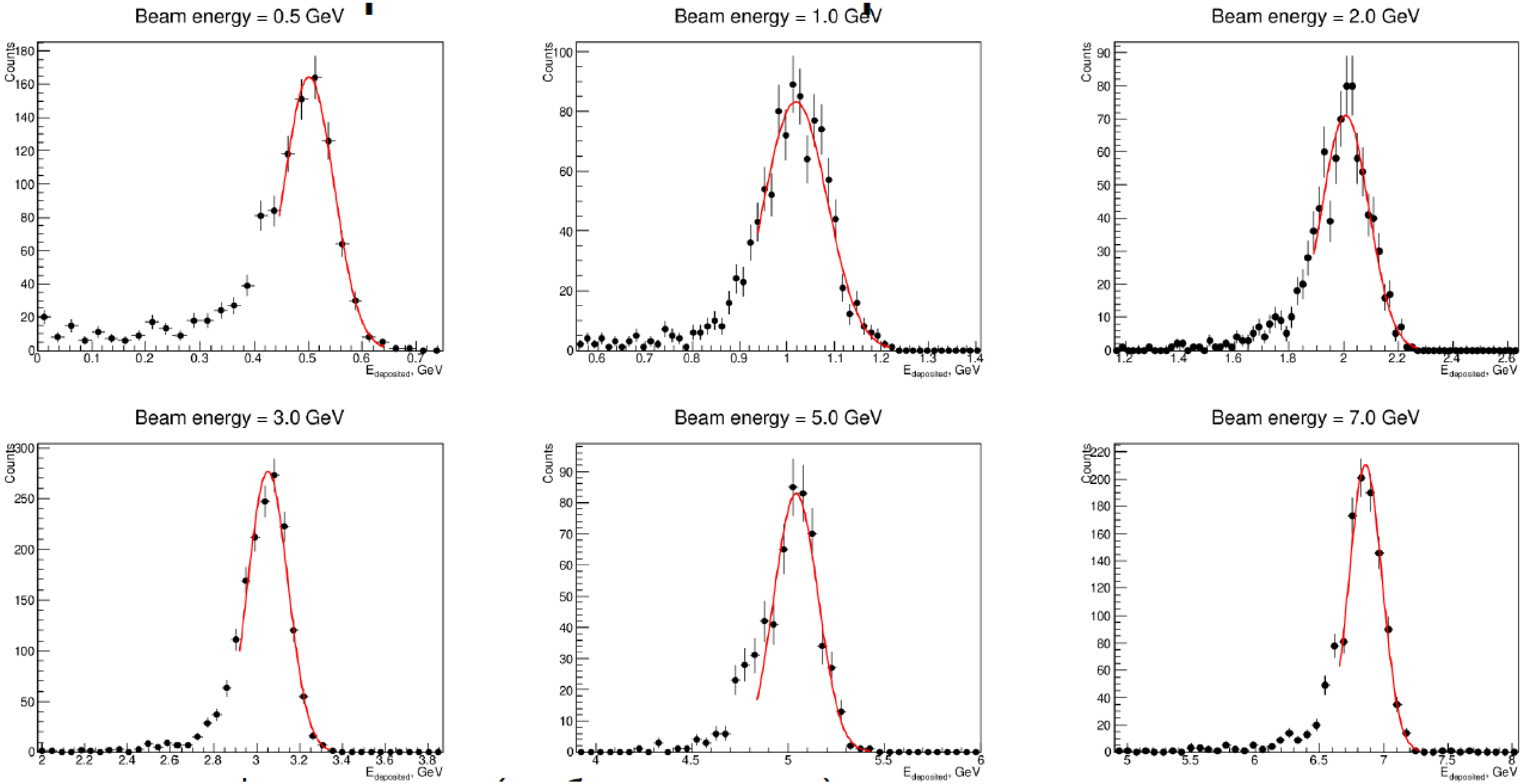

Energy Resolution at SPS energies

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