Status of Forward Hadron Calorimeter (FHCal) construction

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on behalf of the FHCal group (INR, MEPhI, JINR,INP)

- **FHCal in MPD/NICA setup;**
- **Tasks of FHCal ;**
- **Status of FHCal modules production;**
- **Front-End-Electronics;**
- **Tests of FHCal modules with cosmic muons;**
- **Approaches in FHCal signal analysis;**
- **Open issues.**

3rd MPD collaboration meeting, April 16, 2019.

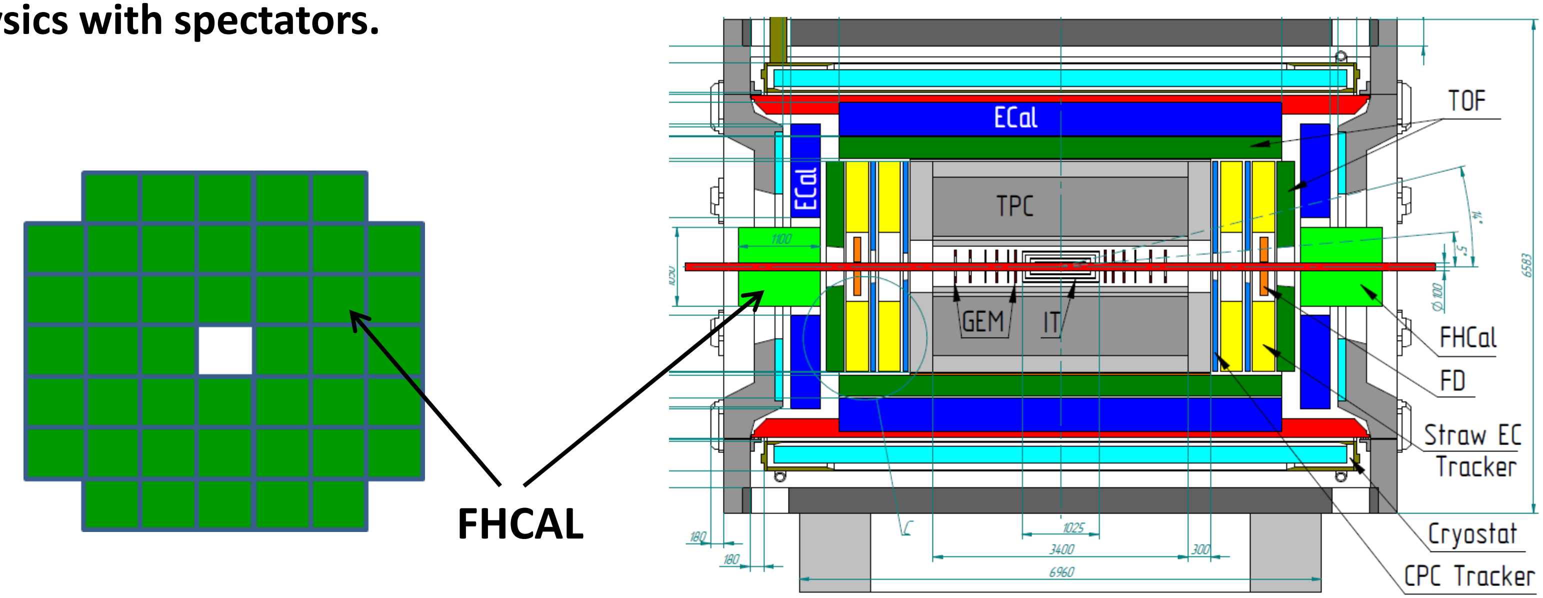
The forward hadron calorimeter in MPD setup

Tasks: detection of spectators to measure:

a) The centrality of the collision;

b) The reaction plane orientation.

c) Physics with spectators.

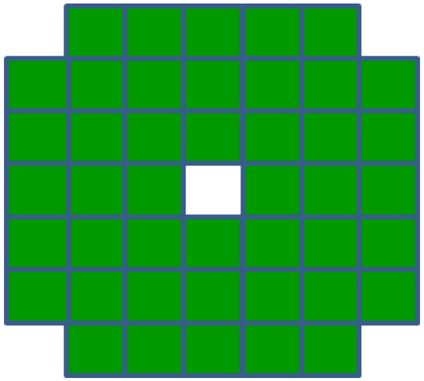


- Two arms of hadron calorimeters at opposite sides in forward regions.
- At the distance 3.2 meters from the interaction point.
- Available acceptance corresponds to pseudorapidity $2.0<\eta<5.0$

FHCAL consists of 2x44 modules of ~1.1x1.1 m^2 each part.

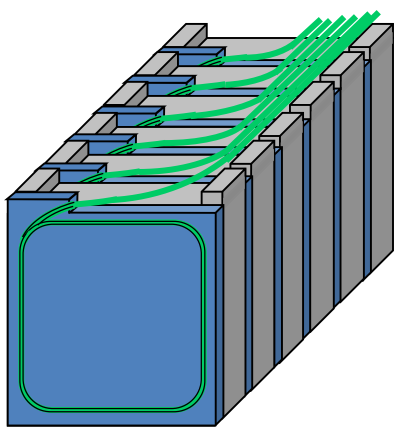
Structure of FHCal – two left/right arms.

Modular Lead/Scintillator sandwich compensating calorimeter.
Sampling ratio Pb:Scint=4:1.



Each arm:

- **44 modules;**
- **Beam hole;**
- **Weight – 9 tons.**



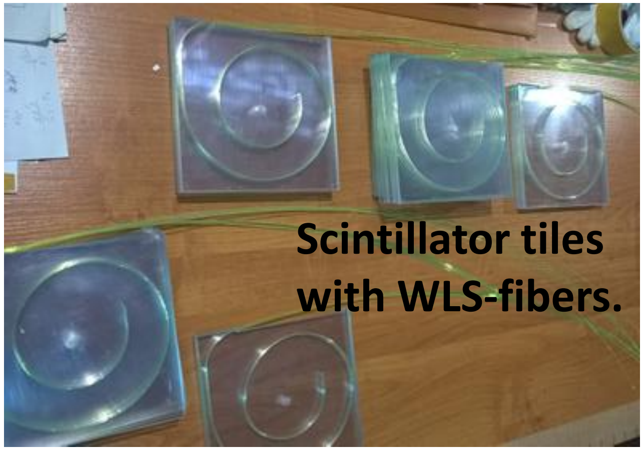
Light from scintillator tiles is captured by WLS-fibers and transported to SiPM.

Each module:

- **Transverse size - 15x15cm^2 ;**
- **Total length - 106 cm.**
- **Interaction length ~4 λ_{int};**
- **Longitudinal segmentation – 7 sections;**
- **1 section ~ 0.56λ_{int};**
- **7 photodetectors/module;**
- **Photodetectors – silicon photomultipliers (SiPM).**

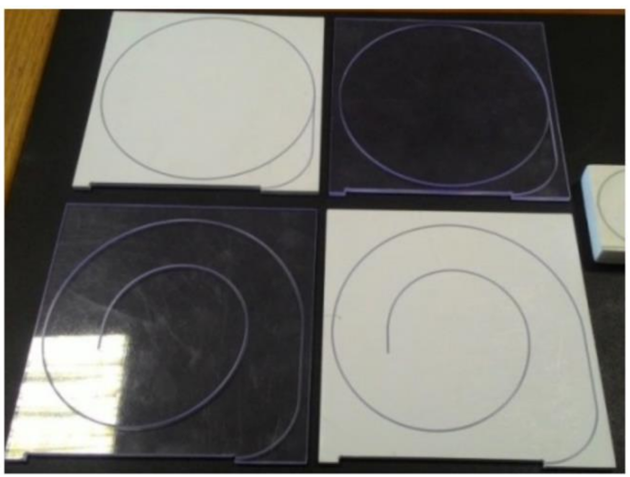
Stages of FHCal production: scintillators.

FHCal scintillator tiles and modules are assembled in workshop of INR, Moscow.

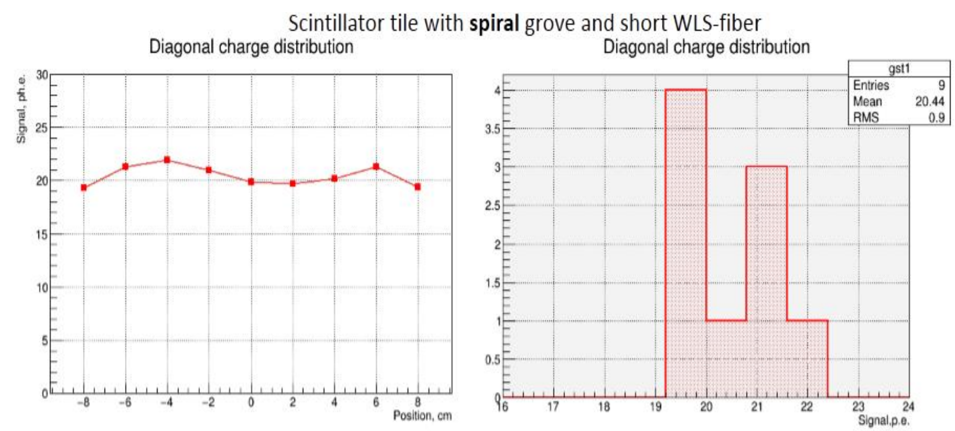


Scintillator tiles with WLS-fibers.

Scintillator tiles in TYVEC reflector.

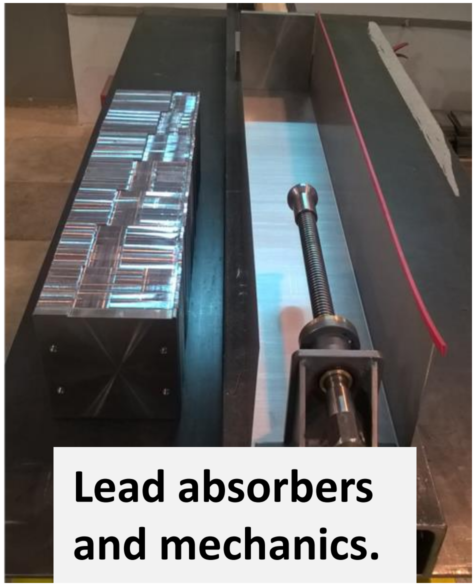


Tests of different grooves and reflectors

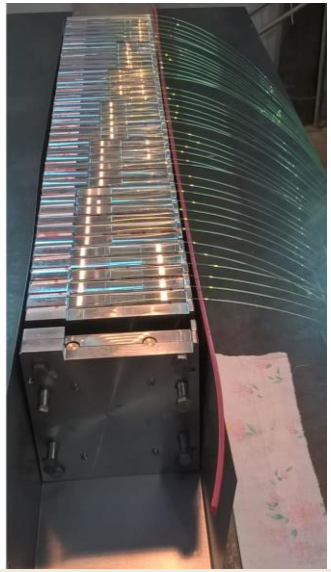


Permanent quality control of scintillator tiles, WLS-fibers and gluing is performing with ^{90}Sr β-source.

Stages of FHCal production: modules.



Lead absorbers and mechanics.

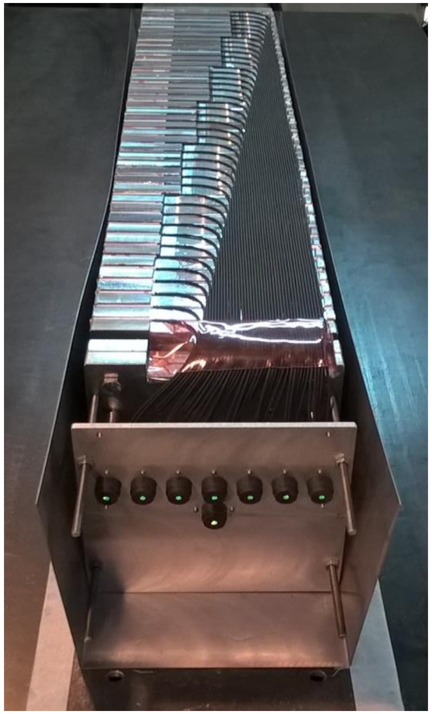


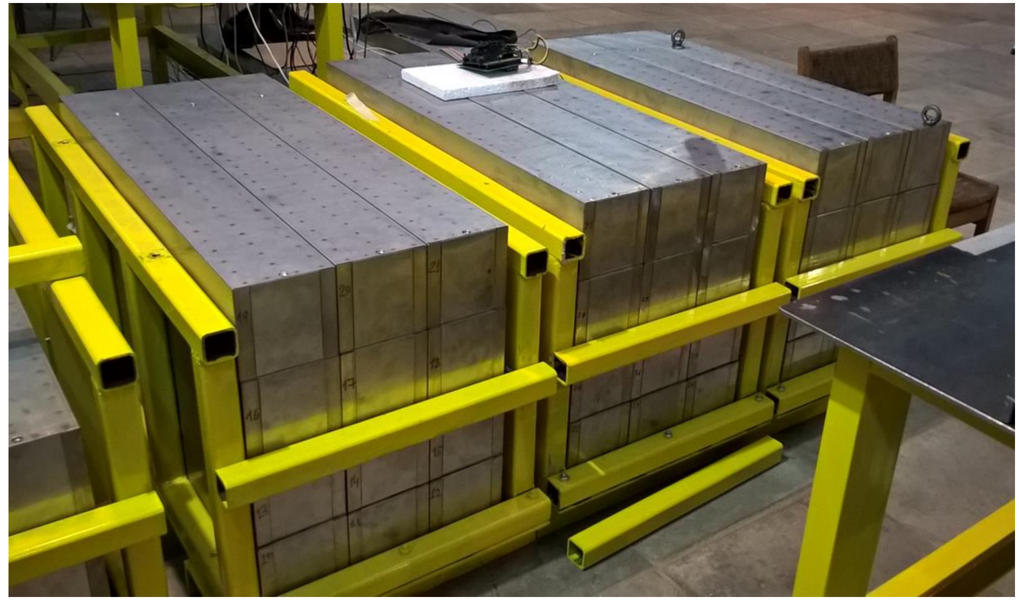
Lead and scintillators sandwiches in box.

WLS-fibers are aligned.

Optical connectors are polished.

Status of FHCal modules production.





At present, almost 80% of FHCal modules are ready for the tests.
All FHCal modules will be ready this year.

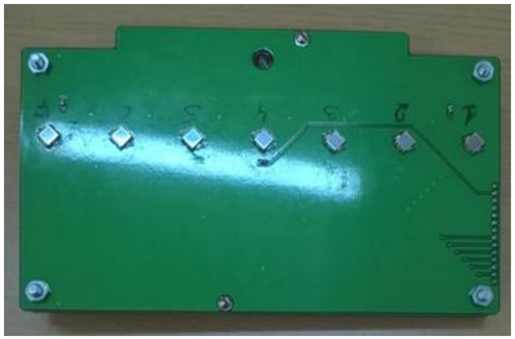
Tests of modules with cosmic muons are done in parallel with the development of Front-End-Electronics and readout.

Photodiodes, FEE and readout electronics.

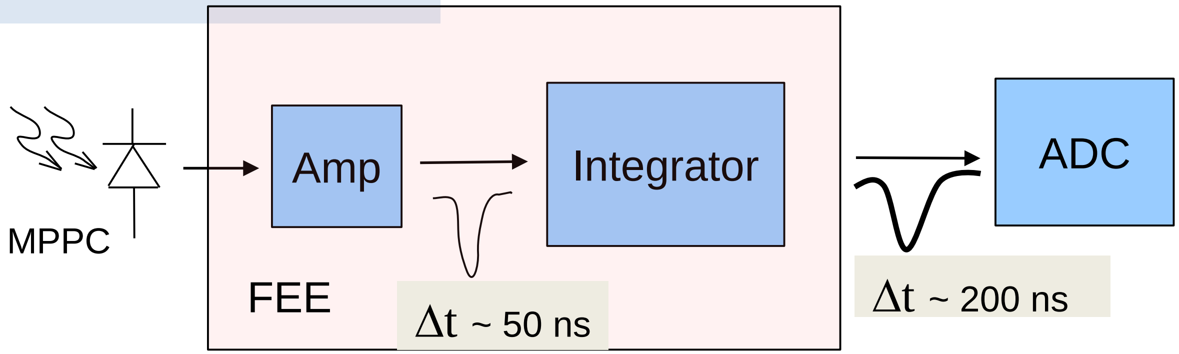
A first samples of FEE with MPPC photodetectors were developed and produced.

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

Front-End-Electronics:



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

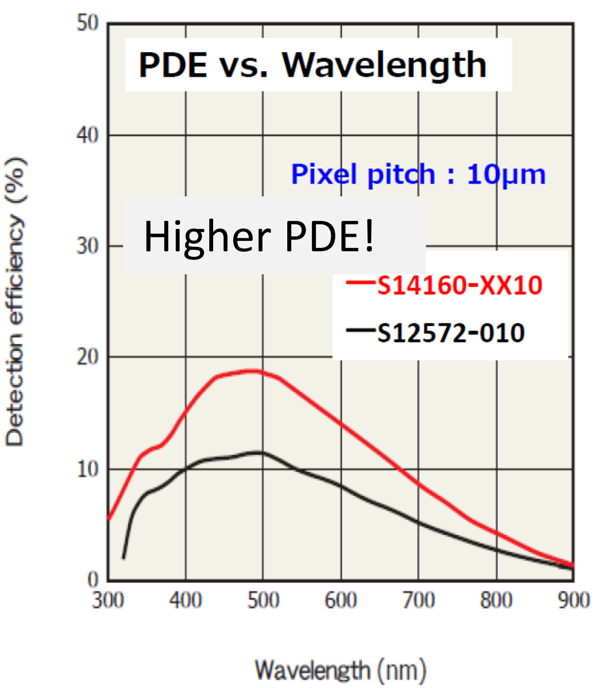


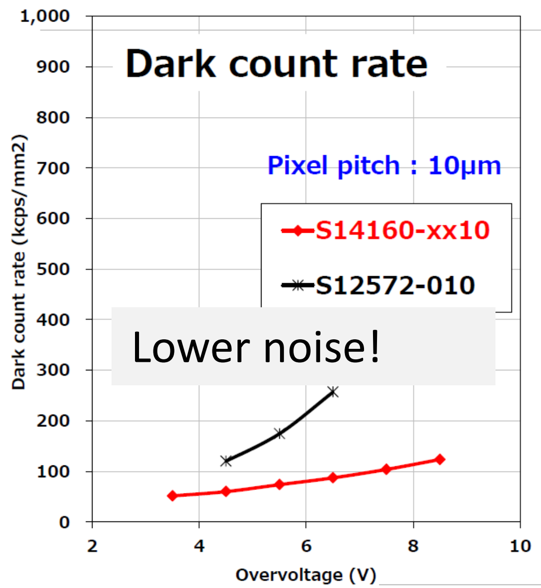
The readout electronics:
FPGA based 64 channel ADC64 board, 62.5MS/s (AFI Electronics, JINR, Dubna).

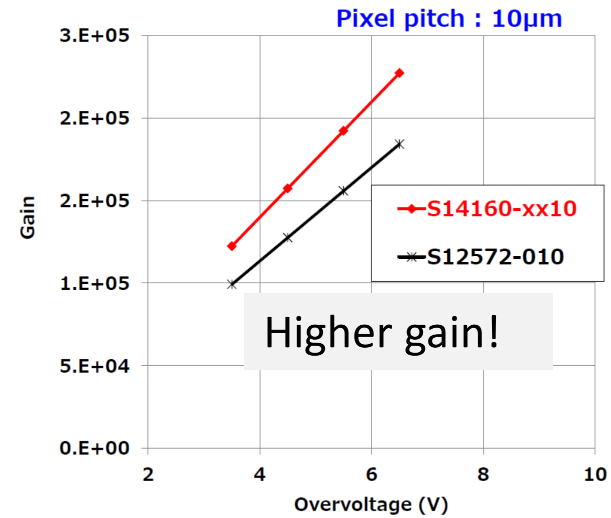
Full readout chain was tested with cosmic muons and at beam!

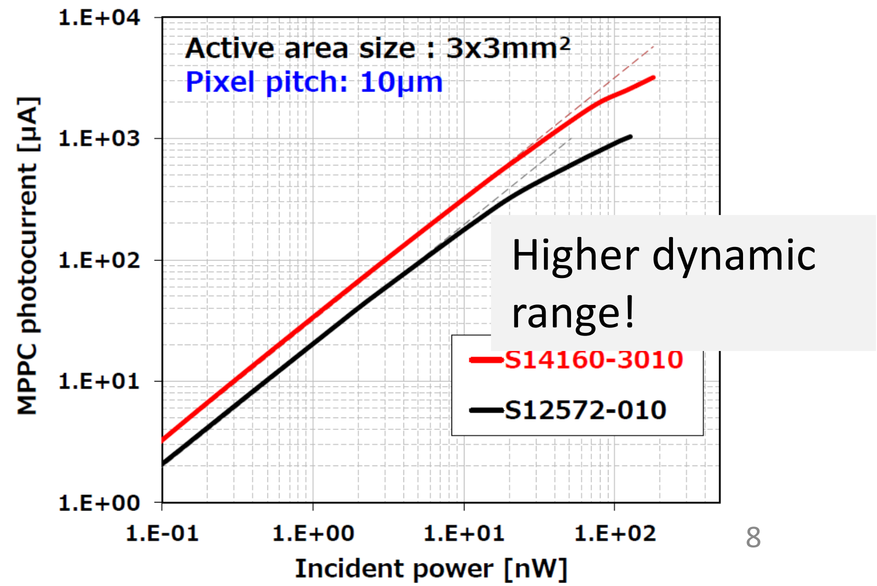
New photodetectors are at market.

A few months ago Hamamatsu Co. announced a new type of high dynamic range MPPC.







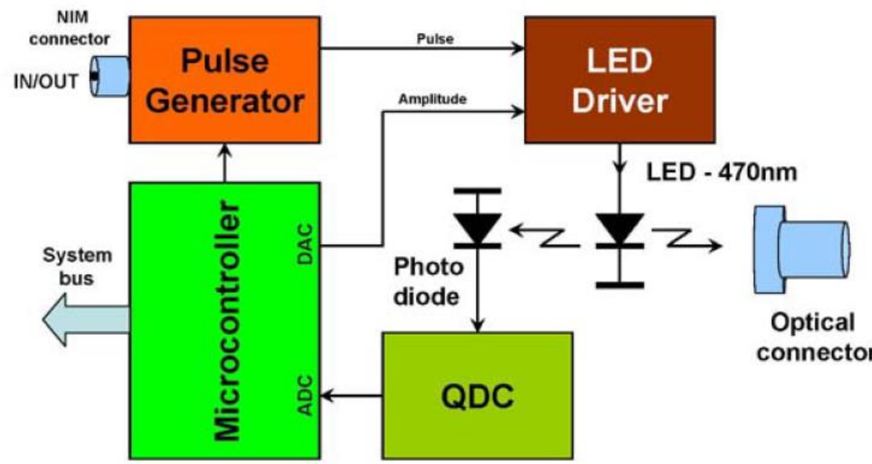


Time to get new photodetectors!

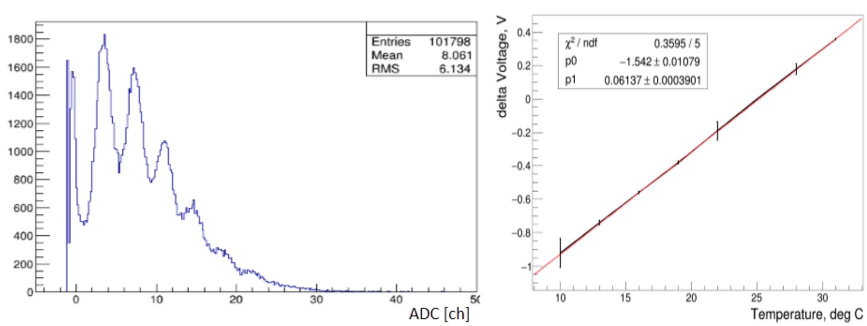
Slow control and monitoring system.

HV system and LED-monitoring is based on the developments of HVSYS Co., Dubna

HV and SC-box



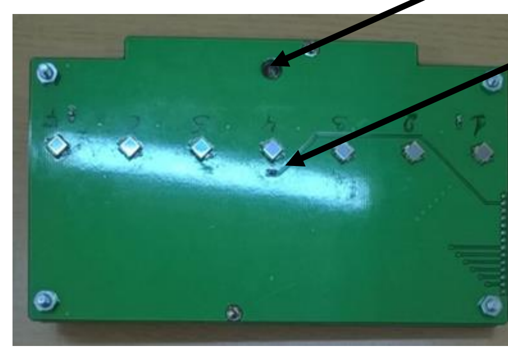
MPPC gain stabilization – by HV correction with temperature.



Dependence of MPPC gain on temperature.

LED

T-sensor

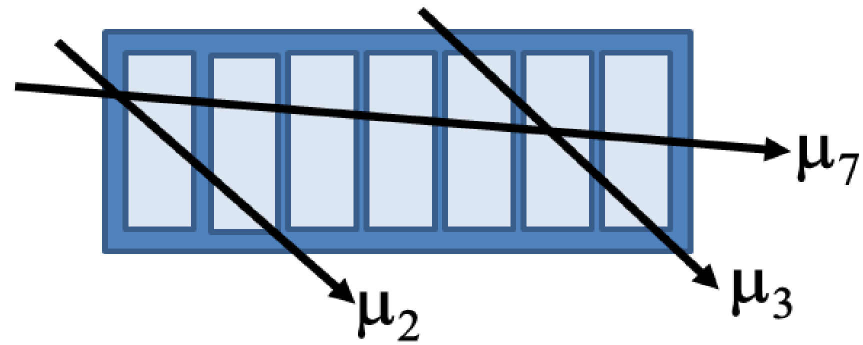


All MPPC are placed on Al-plate.

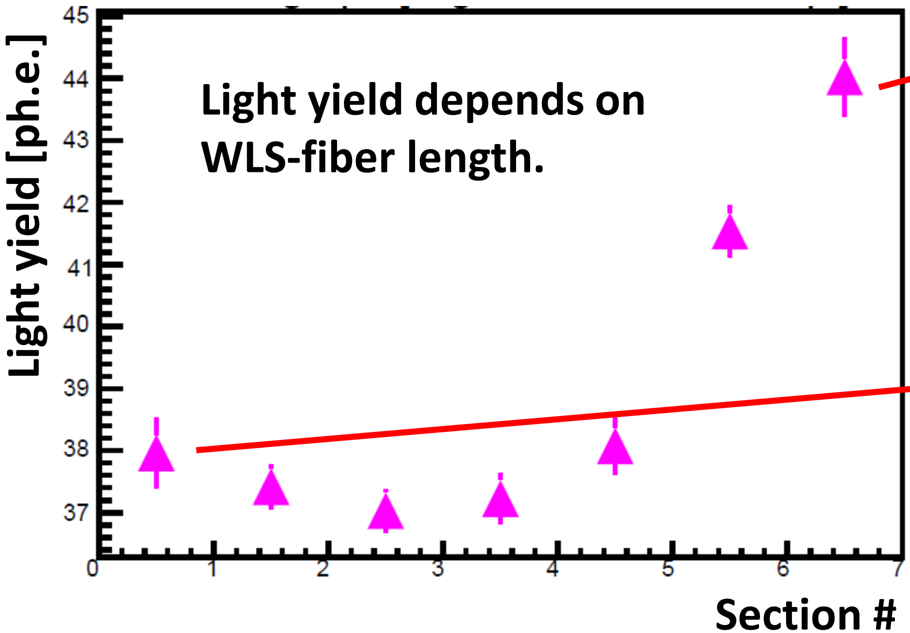
Test of calorimeter modules with cosmic muons.

Geometries of muon tracks in FHCal module.

Tracks passed through 2, 3 or all of 7 sections were studied.



After assembling each module was tested.



Average light yield for 50 modules.

Cosmic muon calibration – signal analysis.

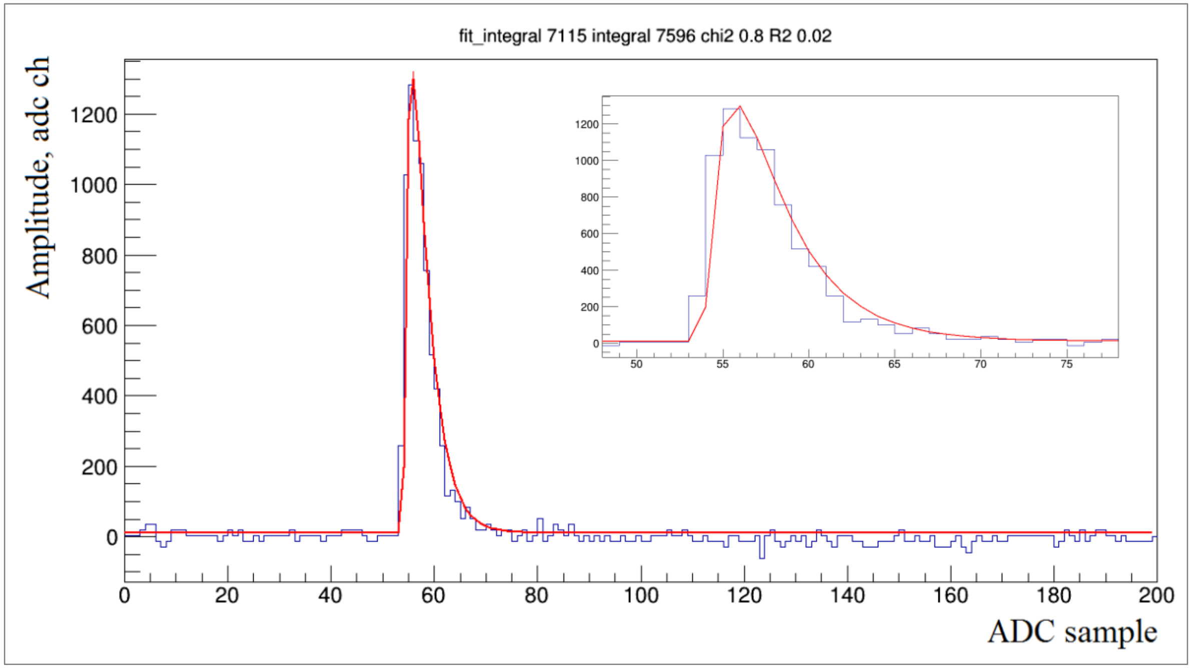
Why do we need to fit the waveform?

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

Small signals ➔ contribution of electronic noise ➔ rejection of noise

Prony Least Squares method:

- **fit by composition of exponential functions;**
- **no iteration procedure;**
- **solution of system of linear equations;**
- **speed is comparable with the simple charge calculation.**



Advantages of signal fitting :

- ❖ More accurate determination of amplitude/charge
- ❖ Identification of small signals near the noise level
- ❖ Identification of pick-up noise
- ❖ Pile-up rejection

Cosmic muon calibration – identification of signals.

Criterion of fit quality

Coefficient of determination:

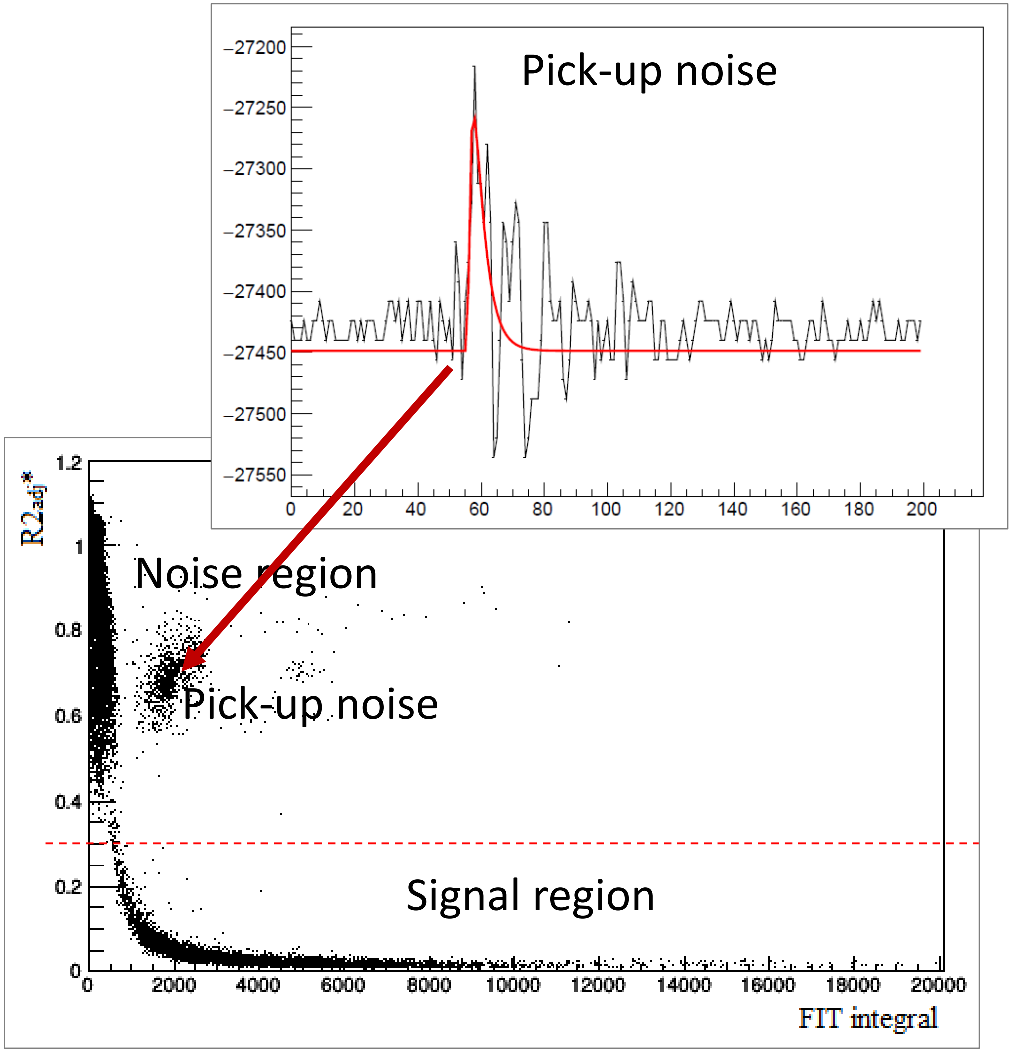
$$R^2 = \frac{\sum_{n=1}^{N}(x[n] - \hat{x}[n])^2}{\sum_{n=1}^{N}(x[n] - \overline{x})^2}$$

$x[n]$ *and* $\hat{x}[n]$ are the actual and calculated values of the explained variable, $\overline{x}$ is the sample average.

Adjusted coefficient of determination

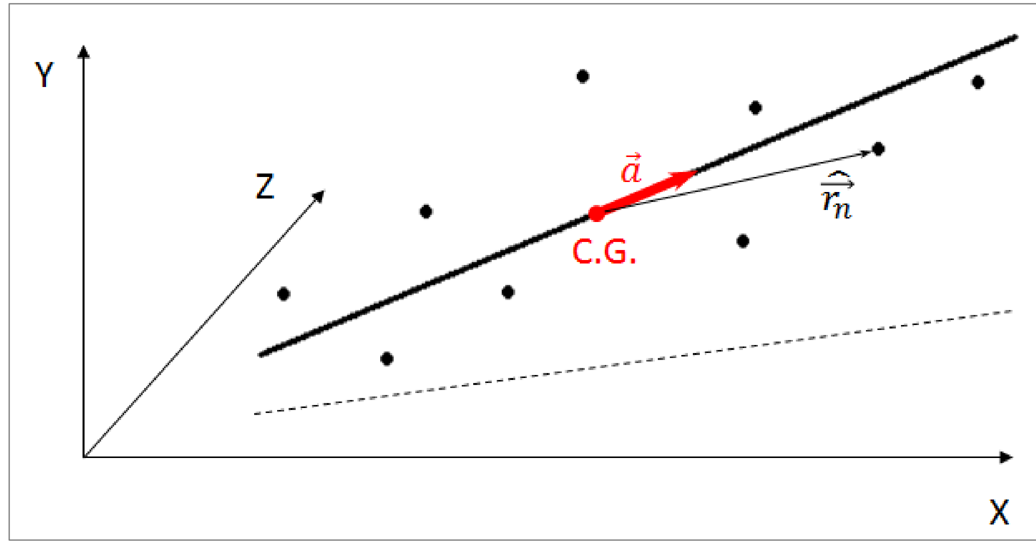
$$R_{adj}^2 = R^2 \frac{N-1}{N-\lambda}$$

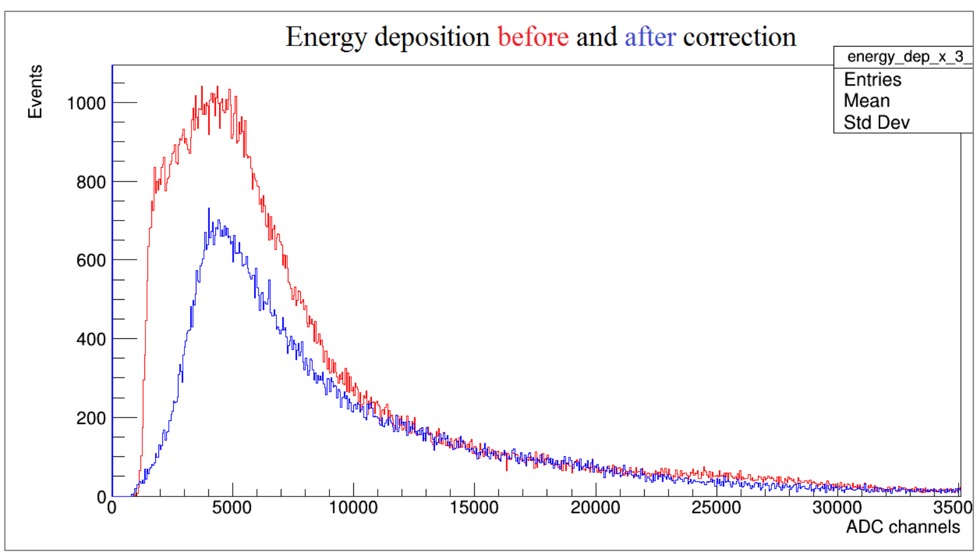
N is the number of measurements, λ is the number of model parameters.



Cosmic muon calibration - track reconstruction

Dots are longitudinal sections in different modules.





Correction for the path length in scintillators.

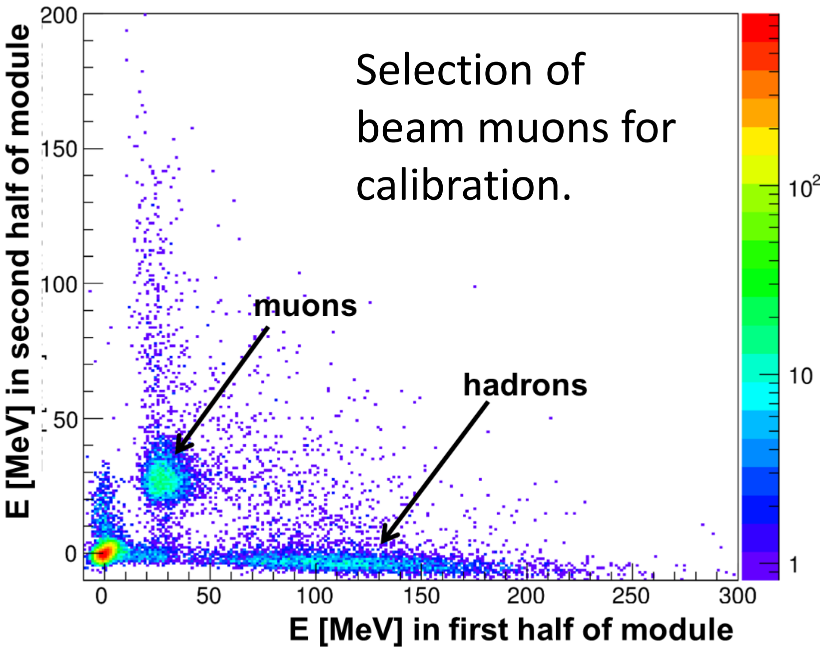
- Shift reference system to the center of gravity

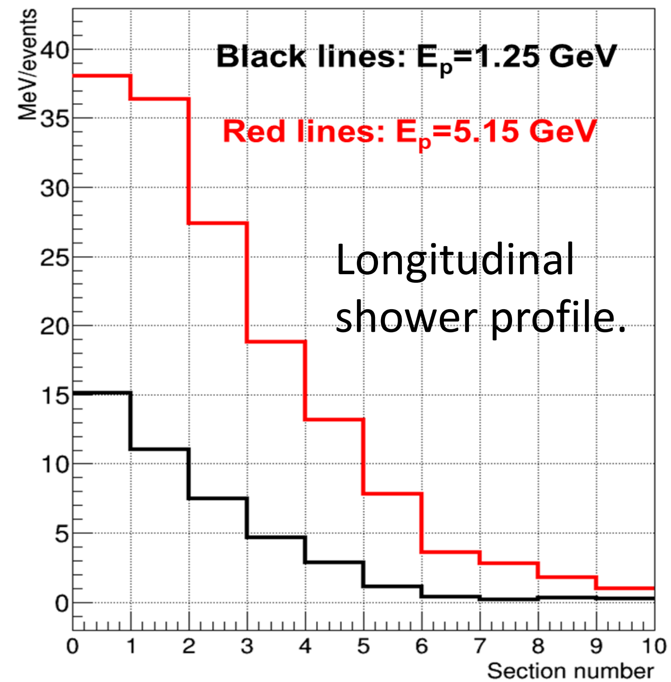
$$\vec{R}_{C.G.} = \frac{1}{N}\sum_{n=1}^{N} E[n]\,\vec{r}[n].$$

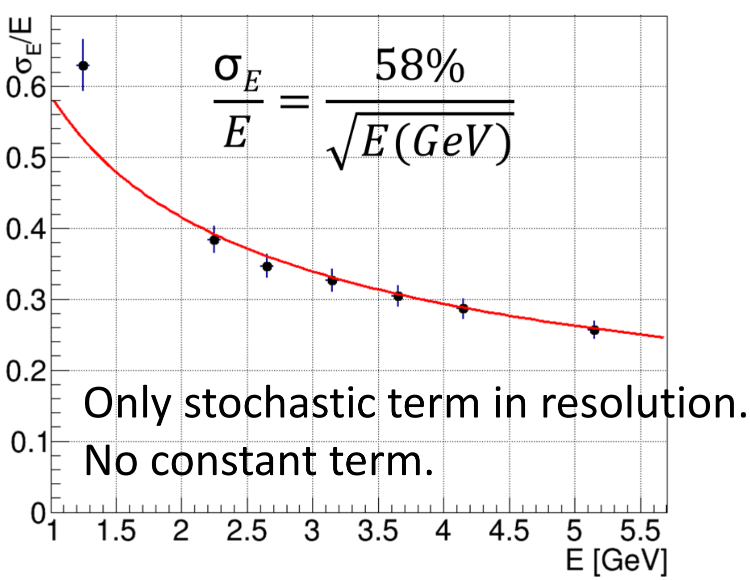
- Extremum search

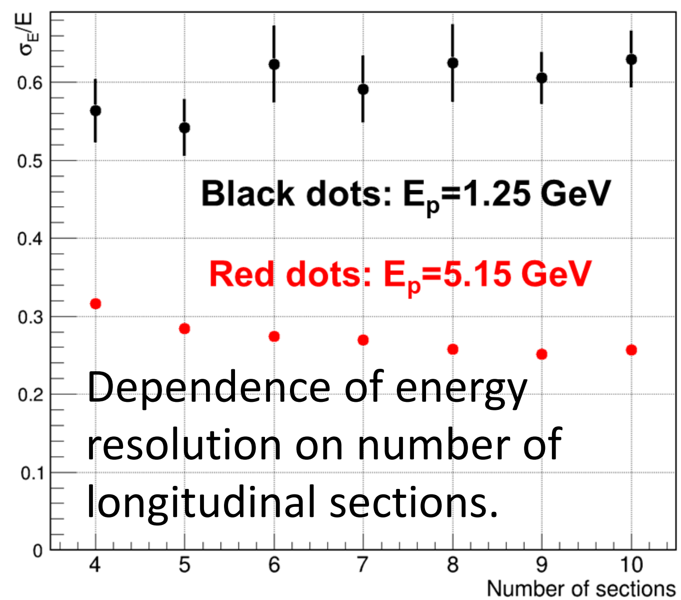
$$\sum_{n=1}^{N}\left(\hat{\vec{r}}^{2}[n] - \left(\frac{(\hat{\vec{r}}[n],\vec{a})}{|\vec{a}|}\right)^{2}\right) \rightarrow min$$

Beam tests of modules at T9/T10 lines (CERN, 2017-2018).



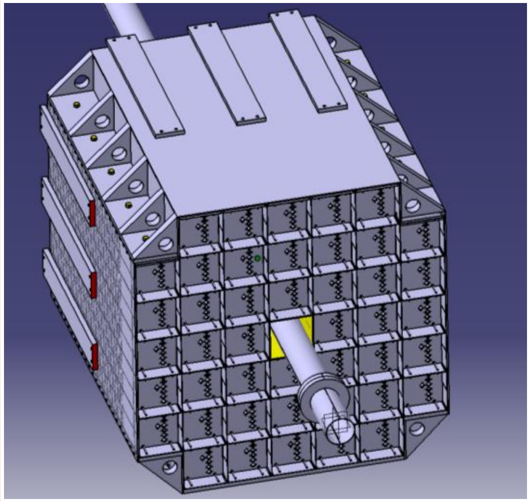


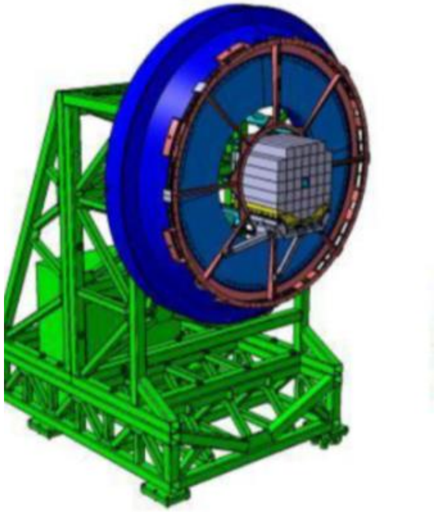




Open issues.

- Mechanical support. The concept only.
- Integration with beam pipe.
- Photodiodes. New type is on market.
- Mounting of readout elements. Full integration to MPD.
- Trigger from FHCal. Fast adder of signal from all modules.
- Mass-production of FEE and readout. (In progress!)
- Software for FHCal data analysis.
- Simulations: detector performance and physics performance.

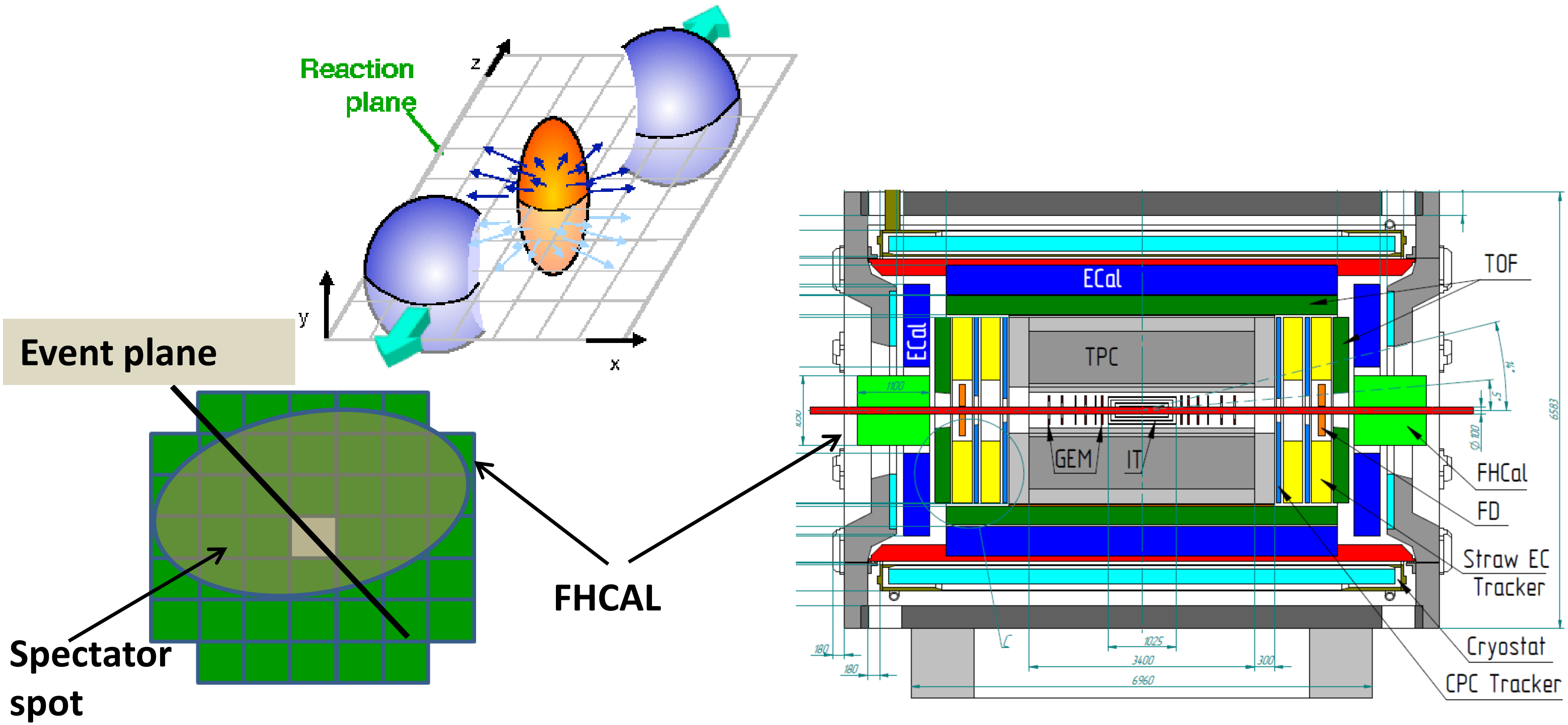




Magnet pole with FHCal.

Thank you!

FHCal will detect the spectators to measure the geometry of ion collisions.



- **FHCal will detect the energy of spectators;**
- **FHCal will detect the space distribution of the spectators.**

By using the spectators energy and space distribution one can determine the centrality and the event plane of collisions.

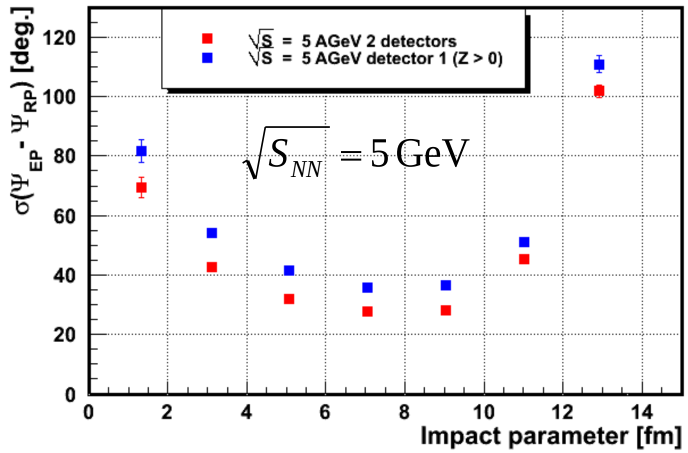
Event plane resolution with FHCal.

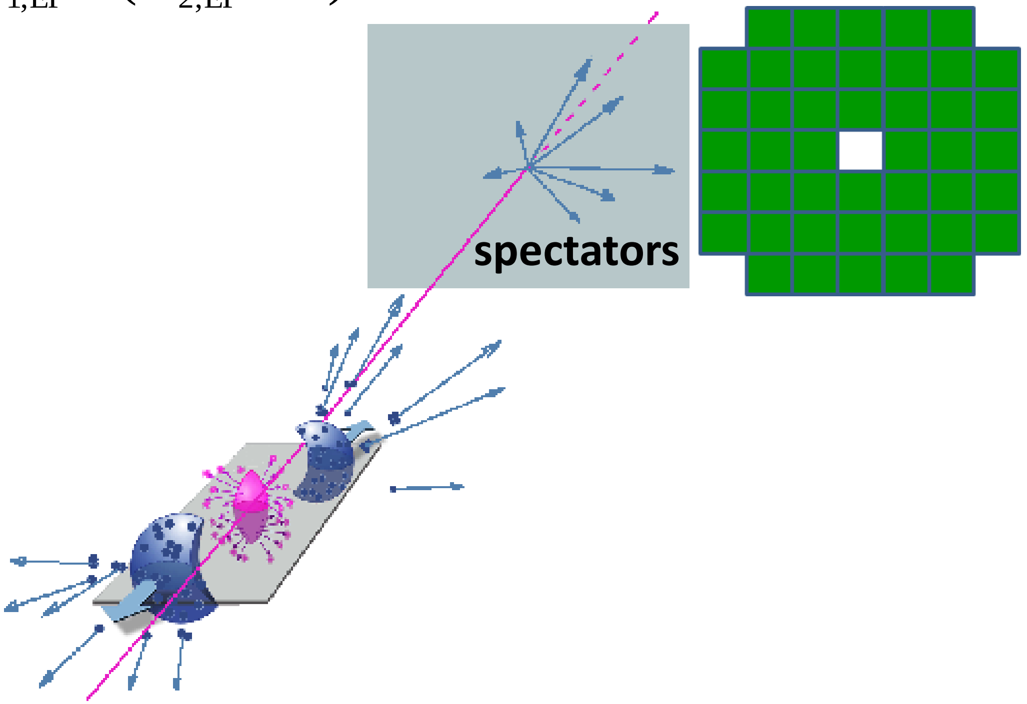
Event plane in first FHCal arm.

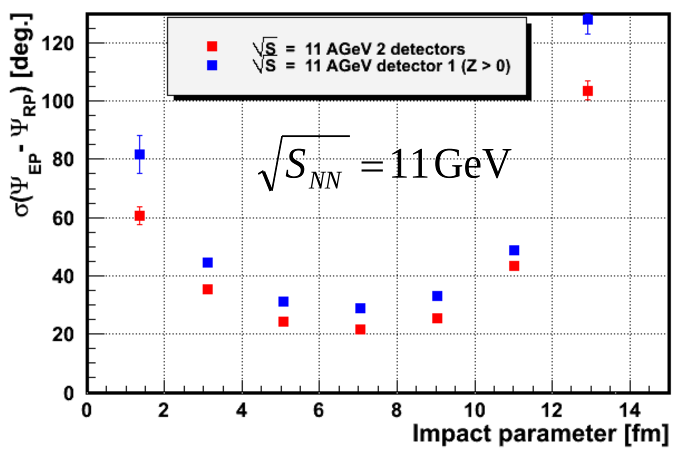
$$\Psi_{1,EP} = acrtg\frac{\sum E_i \sin(\varphi_i)}{\sum E_i \cos(\varphi_i)}$$

Event plane in full FHCal.

$$\Psi_{EP} = \Psi_{1,EP} + (\Psi_{2,EP} + \pi)$$

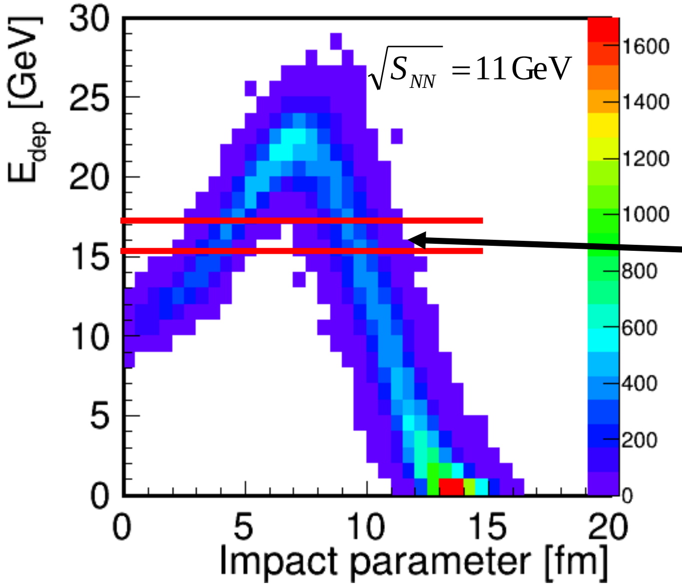






The detection of all types of the spectators (protons, neutrons) for both colliding nuclei would ensure nice angular resolution of the event plane!

Centrality. Problem with energy depositions in FHCAL.

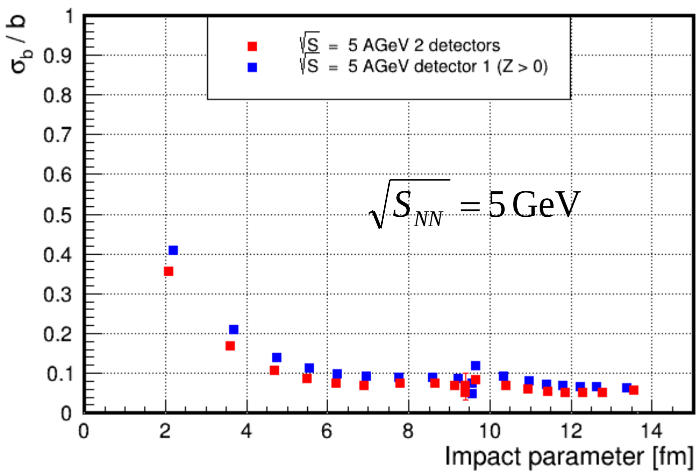


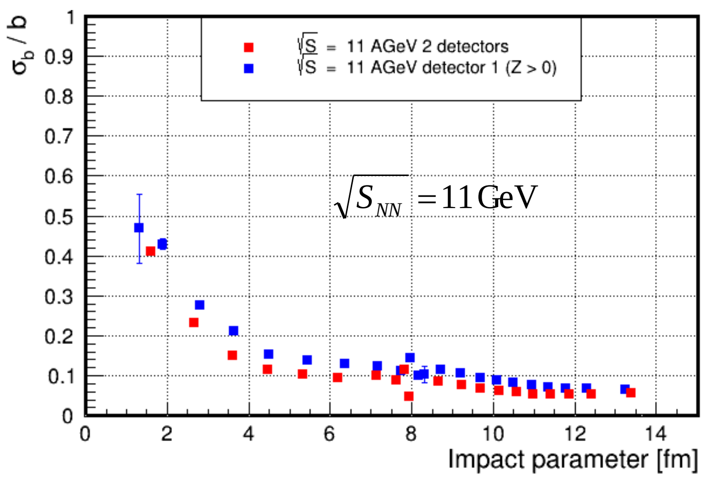
Effect of beam hole and escape of heavy fragments.

Energy deposition in FHCal isn't monotonic and can't resolve the central and peripheral events.

Ambiguity in the centrality measurements might be resolved by using the TPC multiplicity. But other approaches are preffered.

Resolution of impact parameter for different FHCal energy (centrality) bins.

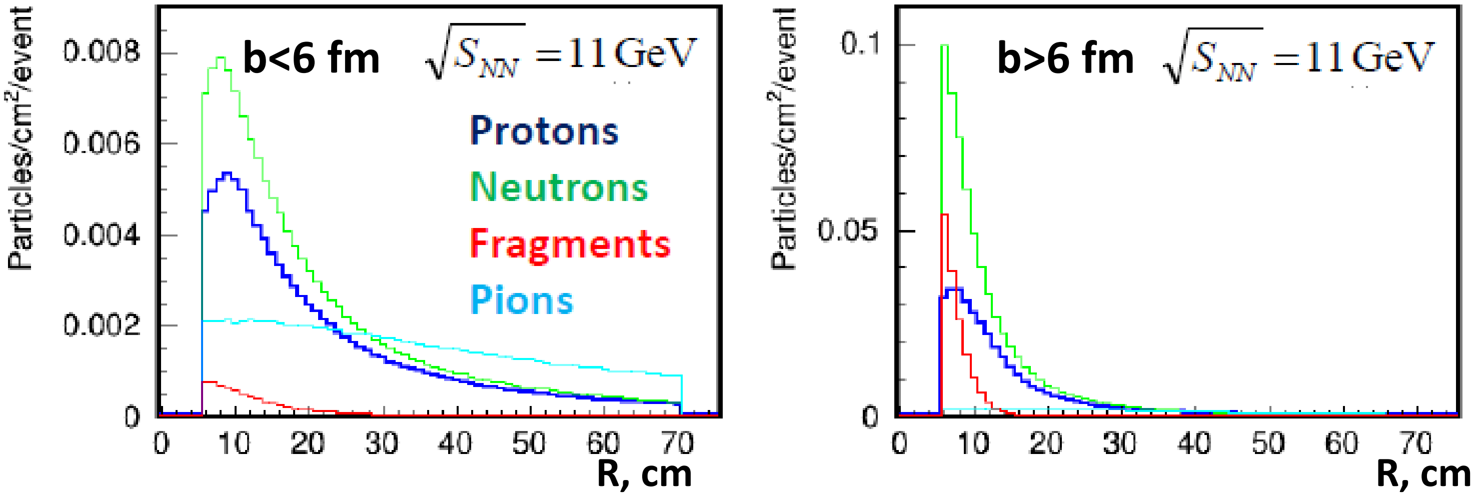


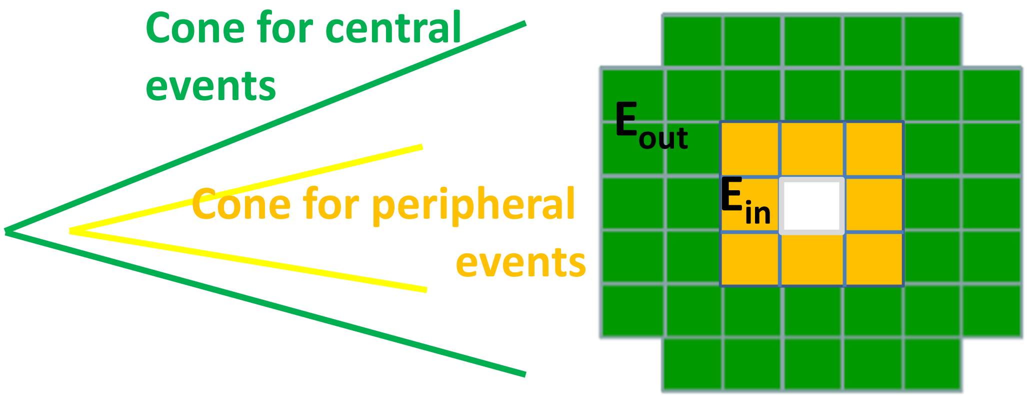


Other approaches are requested!

Spectators spots at FHCal surface have different sizes for different centralities.

Occupancy of particles at front of FHCal

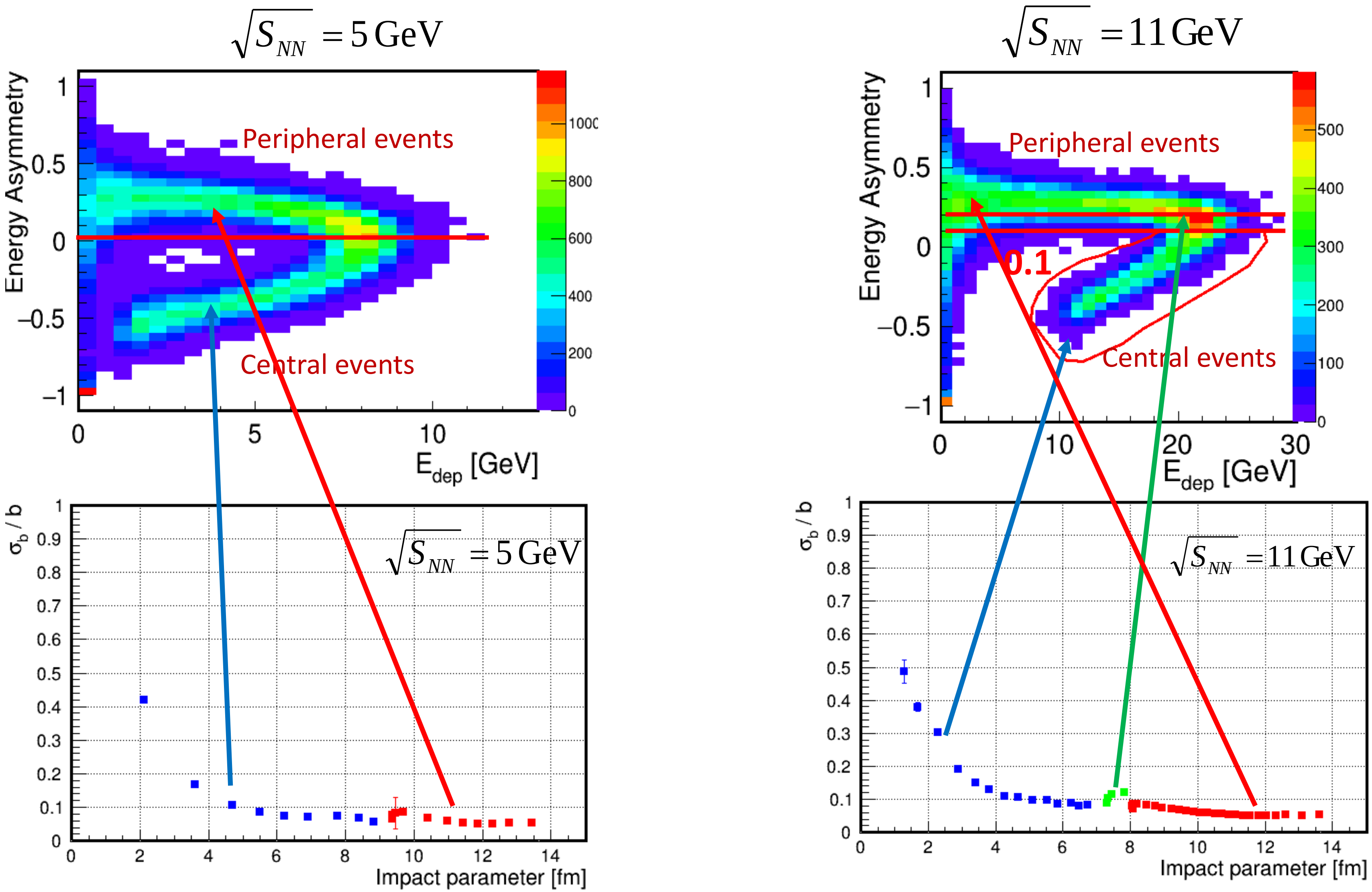




The energy deposition in inner and outer parts of calorimeter must be different for different centralities.

Let's introduce *energy asymmetry:* $A_E = \frac{E_{in} - E_{out}}{E_{in} + E_{out}}$

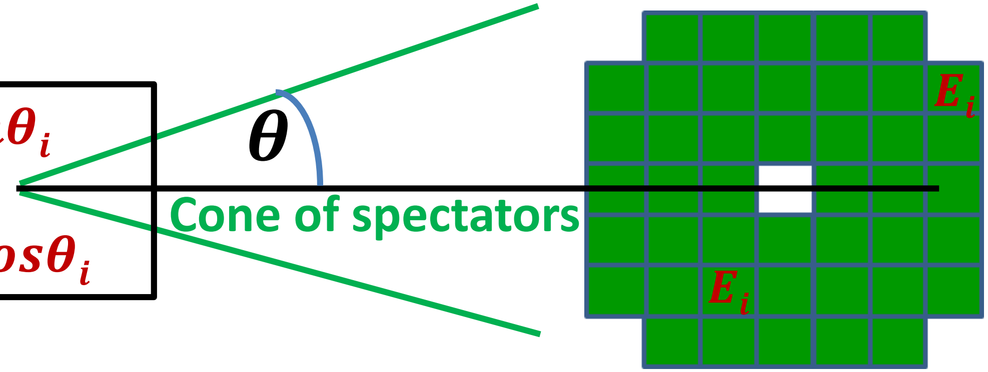
Centrality measurements with two FHCal observables (E_{dep} and A_E).

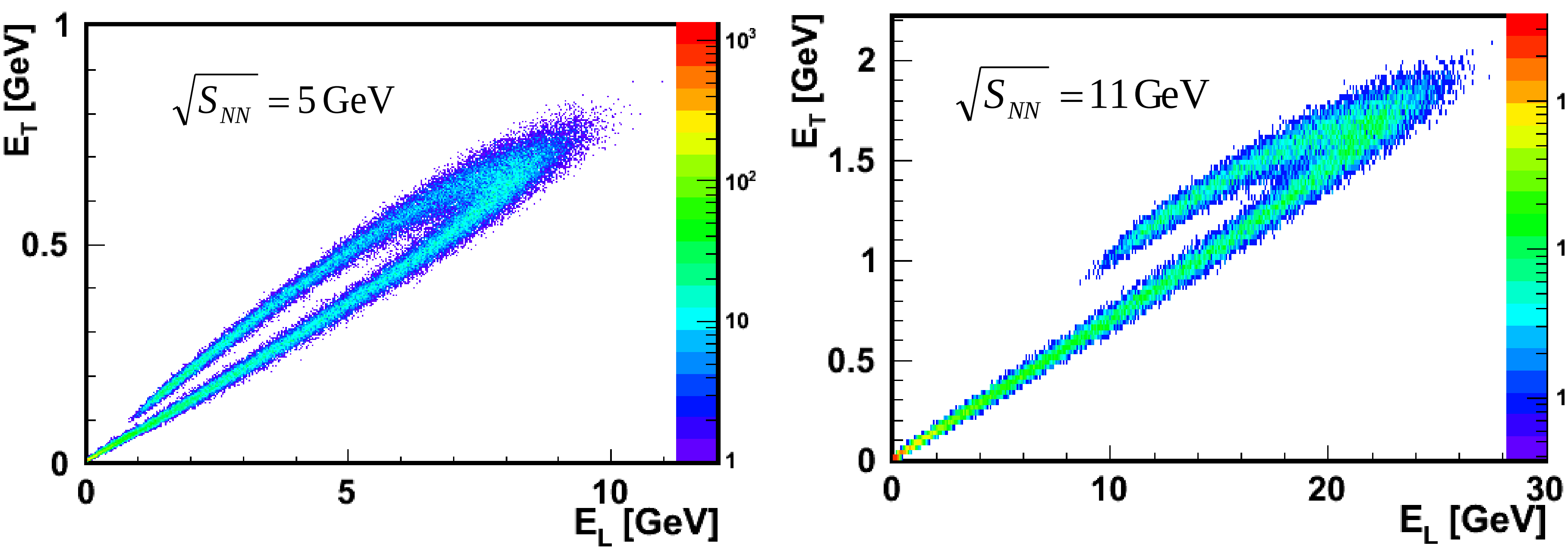


With only FHCal the centrality resolution is below 10% excepting the most central, where the fluctuations of spectator energies dominate.

Construction of other observables in FHCal for the centrality measurement.

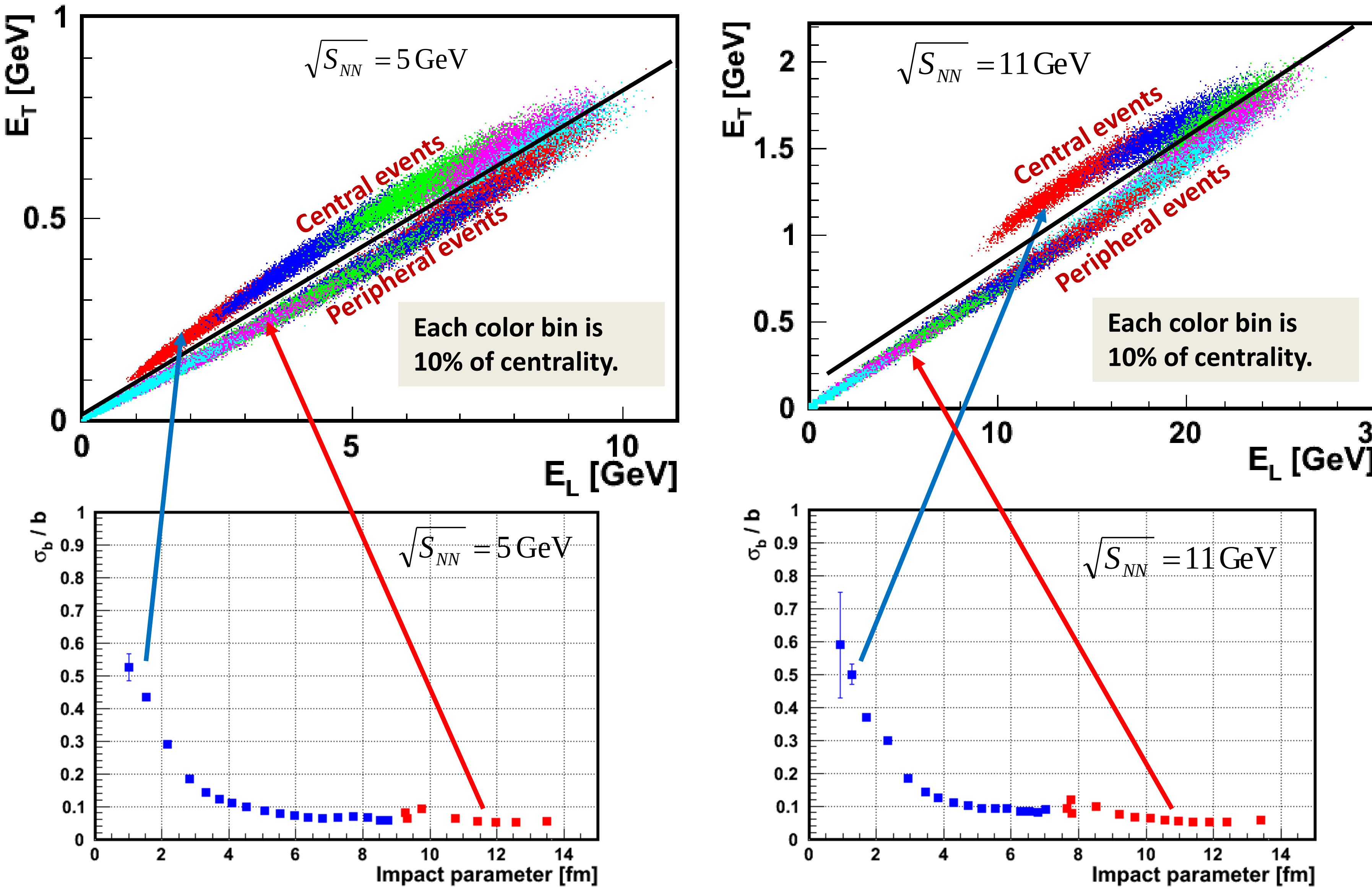
Transverse energy: $\mathbf{E_T} = \sum E_i \sin\theta_i$
and
Longitudinal energy: $\mathbf{E_L} = \sum E_i \cos\theta_i$





A bagel structure in E_T, E_L correlations.

Centrality measurements with E_T and E_L.

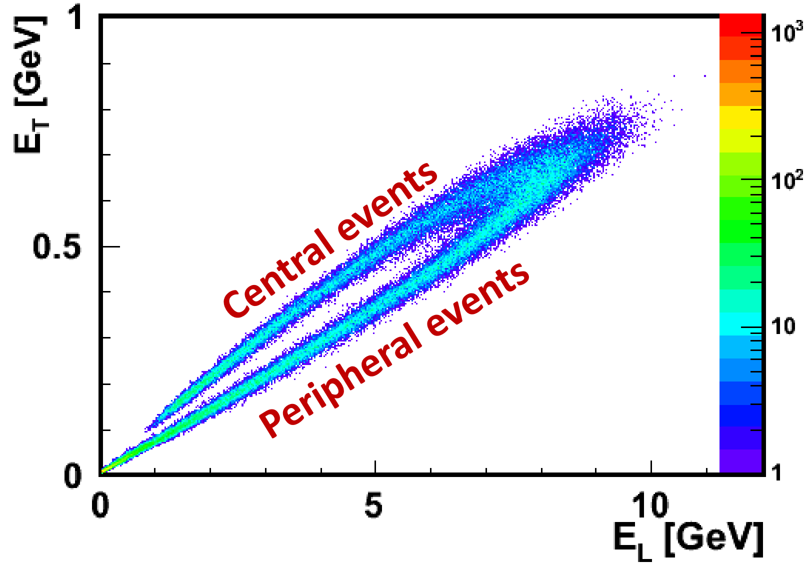


With only FHCal the centrality resolution is below 10% excepting the most central, where the fluctuations of spectator energies dominate.

FHCal: Physics case.

Fine transverse/longitudinal segmentation of FHCal allows the construction of many experimental observables for spectators:

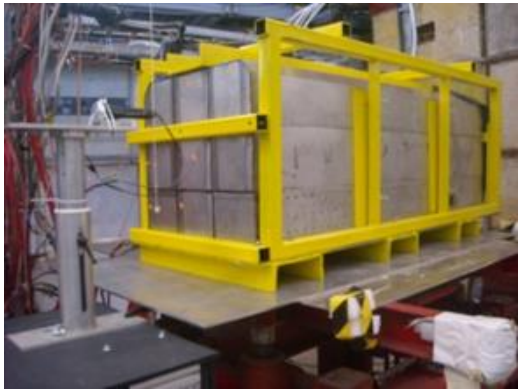
- Asymmetry of energy deposition A_E ;
- Transverse energy: $E_T = \sum E_i \sin\theta_i$;
- Longitudinal energy: $E_L = \sum E_i \cos\theta_i$;
- Spread (compactness) of spectator spots;
- And others….



- These observables would depend on centrality;
- These observables would reflect the recoil momenta of the spectators;
- These observables would be different in different physics models;
- Can spectators probe the fireball ?

Test of calorimeter supermodule at CERN T9/T10 line.

- **Proton momentum range: 2-10 GeV/c**

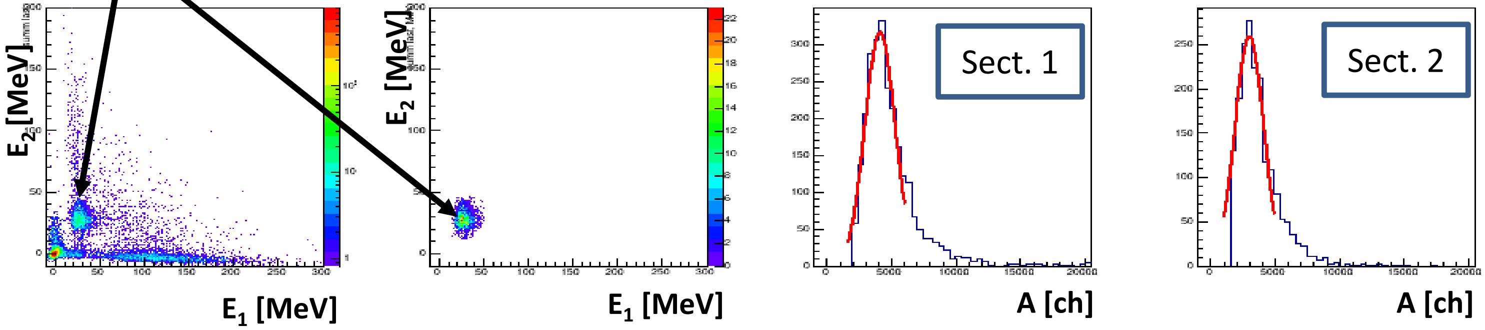


- **Each module has 10 longitudinal sections with 10 SiPMs at the end (CBM option).**
- **Full size 60x60x160 cm^3.**
- **Readout electronics – for FHCal.**

Calibration of longitudinal sections with beam muons, 6 GeV/c

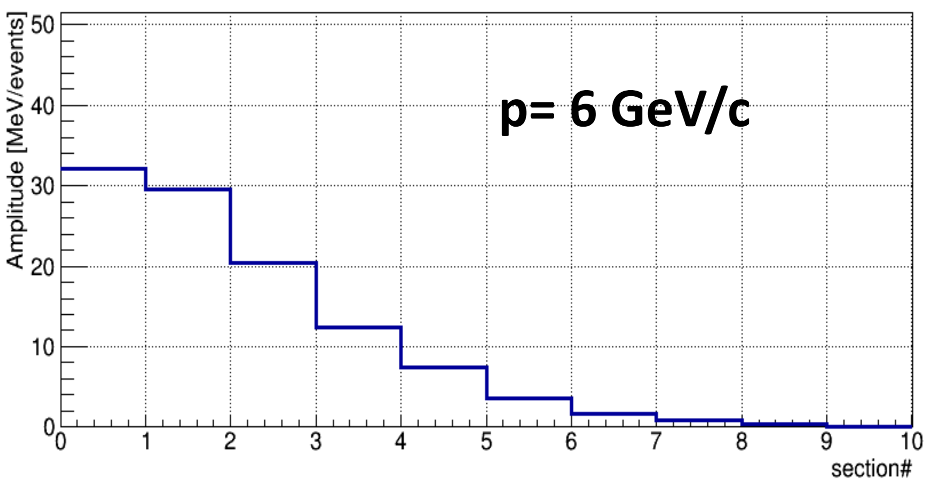
Identification of muons – equal energy deposition in first and last half of modules.

Muons deposit ~5 MeV in each section

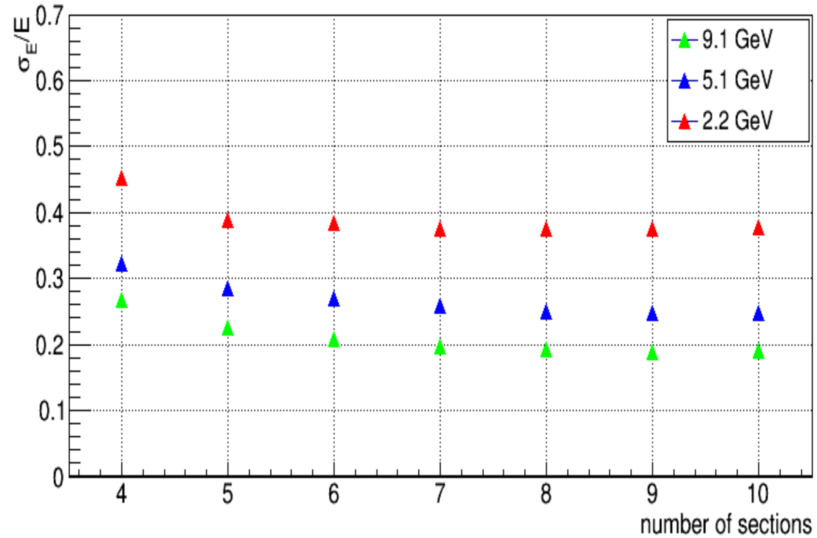


Dependence of energy resolution on supermodule length.

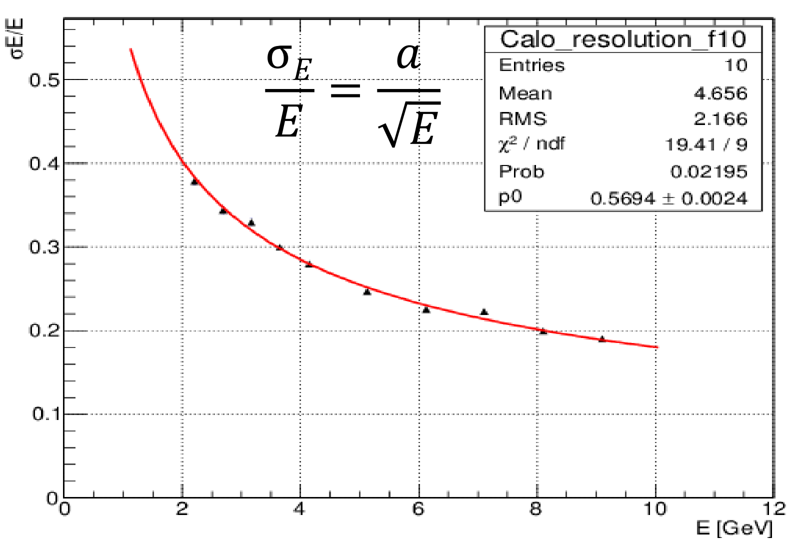
Longitudinal profile of hadron shower.



Dependence of resolution on module length.



Length of $4\lambda_I$ or 7 longitudinal sections is optimum for momentum range 2-6 GeV/c



The stochastic term of ~56% is in good agreement with MC results.