Combined test beam with IDEA

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On behalf of a group of enthusiastic people (half of them PhD and post-doc)

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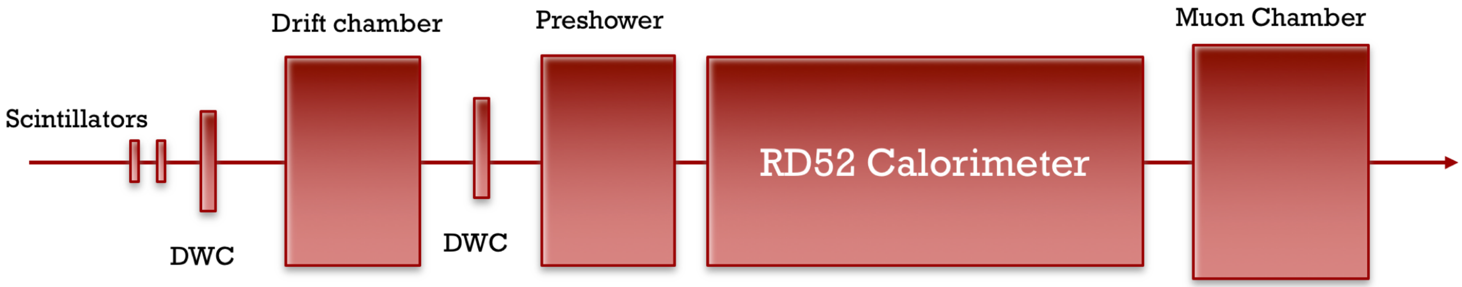
Outline

- Test Beam setup
- Test beam preliminary results: Combined program
- Test beam preliminary results: Standalone program

The test beam layout



- Trigger with 2 scintillators in coincidence + 1 veto
- 2 DWC (Delay Wire Chamber)
- 2 CEDAR (Differential Cherenkov detector)

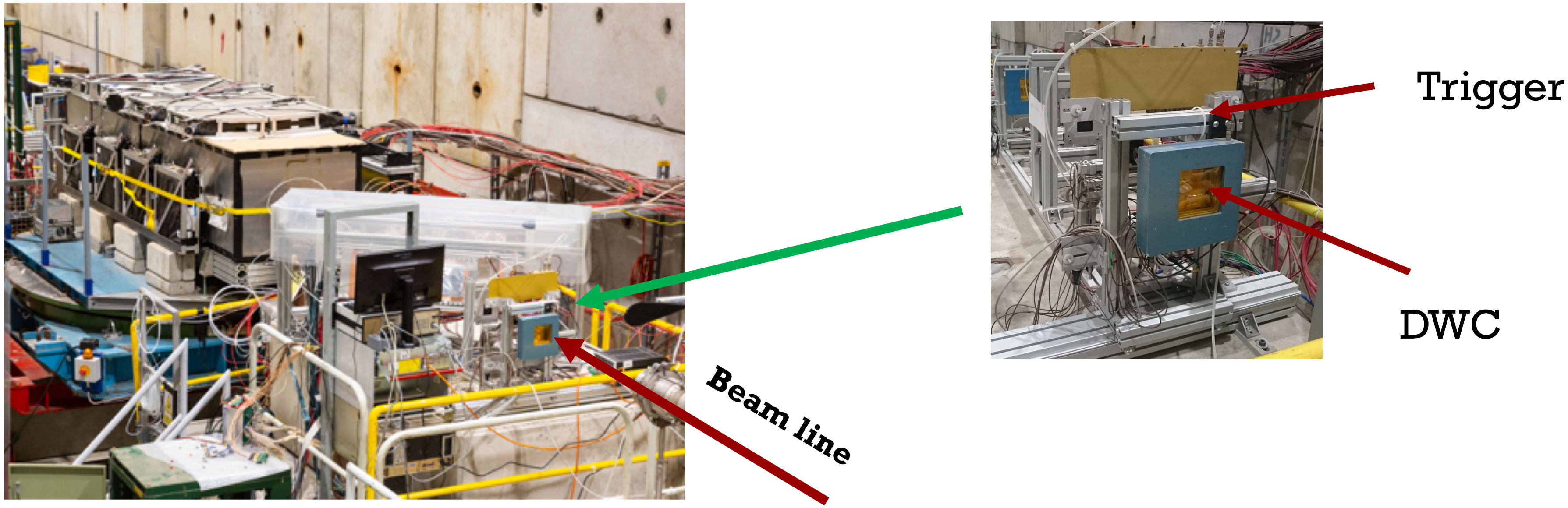
} Beam instrumentation

- Drift Chamber Prototype
- Preshower:
  - 2 layers of GEM + the converter
- Different Dual Readout prototypes
  - RD52 calorimeter with PMT readout
  - RD52 calorimeter with staggered fibers
  - Small calorimeter module with SiPM readout
- Muon chamber: 1 layer GEM + 2 layers μRWell

Test beam program

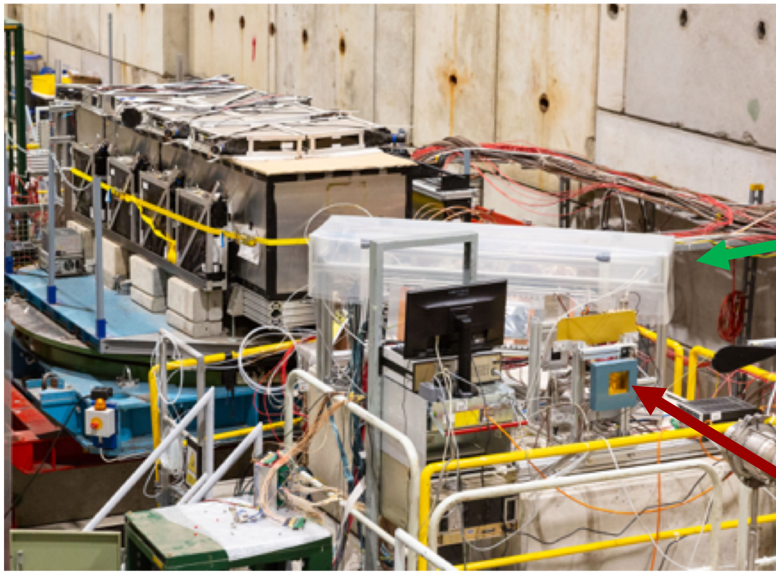
- Combined measurements: data taking with all detectors
  - Particle Identification with:
    - Drift Chamber Prototype (p, π, k) using dE/dx VS cluster counting
    - Preshower + RD52 Dual Readout Calorimeters (e, π, μ)
    - μRWell (e, μ)
  - Preshower optimization studies
  - Tracking qualification
- Calorimeter R&D: standalone program
  - Qualification of a RD52 calorimeter with staggered fibers
  - Qualification of a small calorimeter module readout with SiPM

The real setup



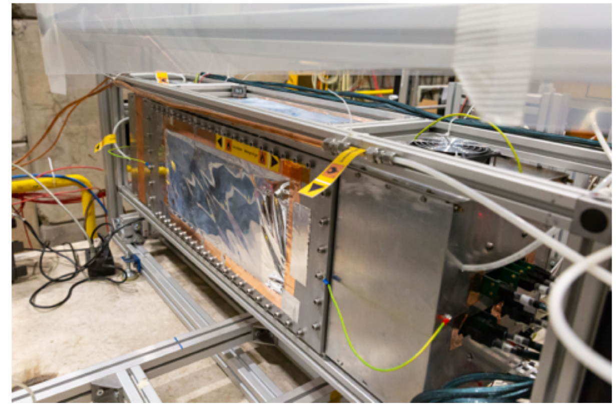
The real setup

See also Tassielli's Talk

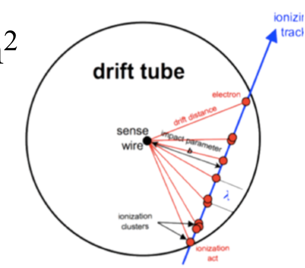


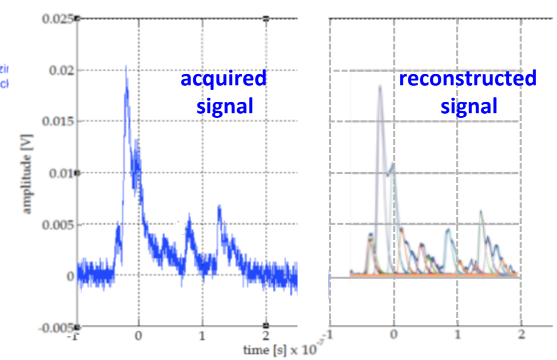
Beam line

Drift Chamber prototype



Tracking





- 144 channels: 12 layers X 12 cells, 1x1 cm^2 drift cells
- 5 field sense instrumented with MEG2 front-end
- readout with
  - DRS4 (32 channels)
  - Discriminator + TDC 96 channels

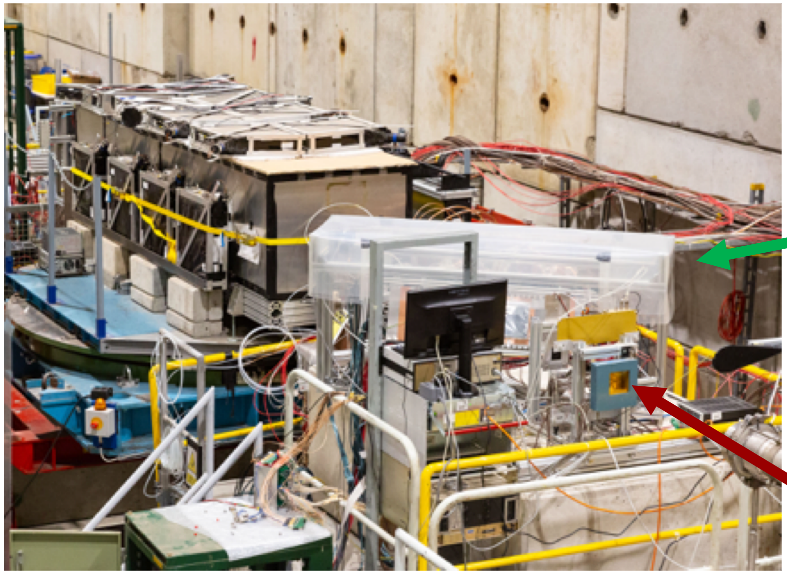
Measured resolution for the MEGII prototype:

$\sigma_{xy} \approx 100\ \mu m$

$\sigma_z \approx 1000\ \mu m$

The real setup

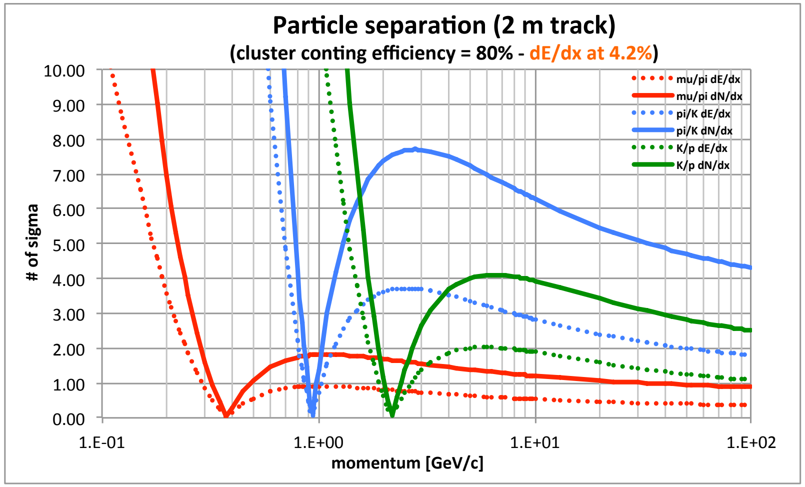
See also Tassielli's Talk



Beam line

Drift Chamber prototype

Particle Identification



Cluster counting for improved particle identification:

based on the truncated mean method dE/dX replacing the ANALOG information with a DIGITAL one: namely the number of ionisation clusters per unit length

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43} \cdot \left(L_{track}[m] \cdot P[atm]\right)^{-0.32}$$

Walenta parameterization (1980)

dE/dx

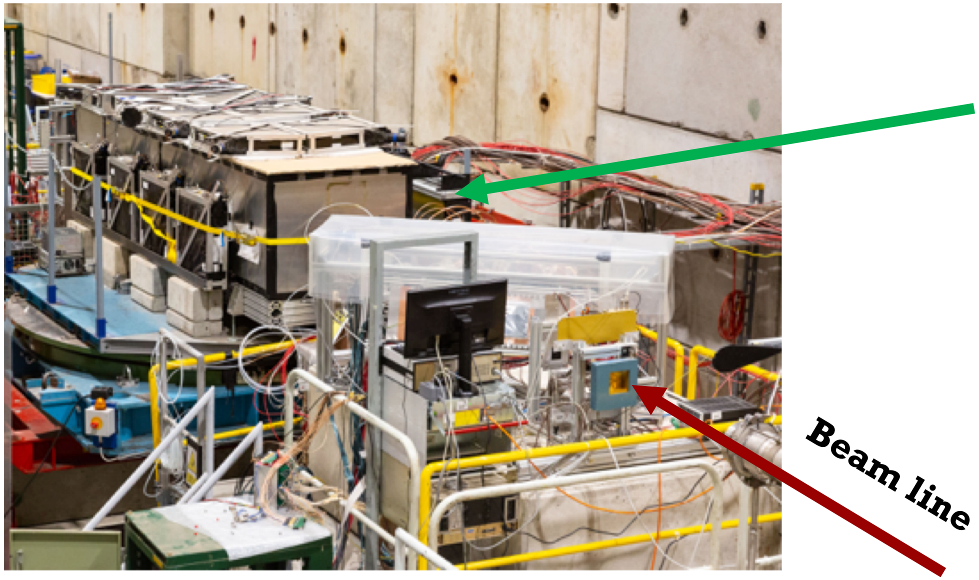
vs

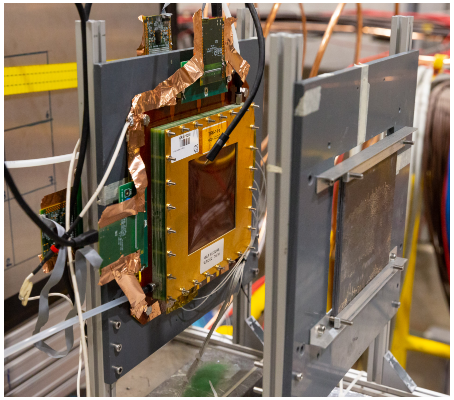
$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = \left(\delta_{cl} \cdot L_{track}\right)^{-1/2}$$

Poisson distribution

dN_{cl}/dx

The real setup



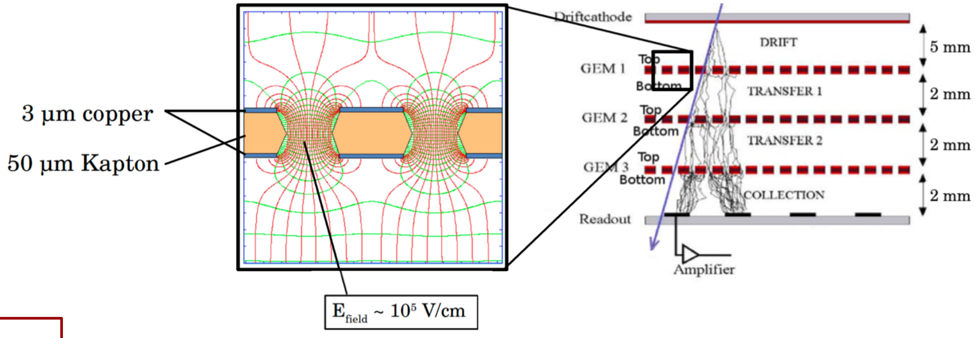


Preshower: 2 triple GEM chambers 10 x 10 cm² with different material upstream: from 1 to 2.5 X_0

128 strips, 650 μm pitch
GAS mixture: Ar/CO_2/CF_4 (45/15/40)

Planar prototypes of triple GEM have already been tested on a muon/pion beam @ H4CERN.

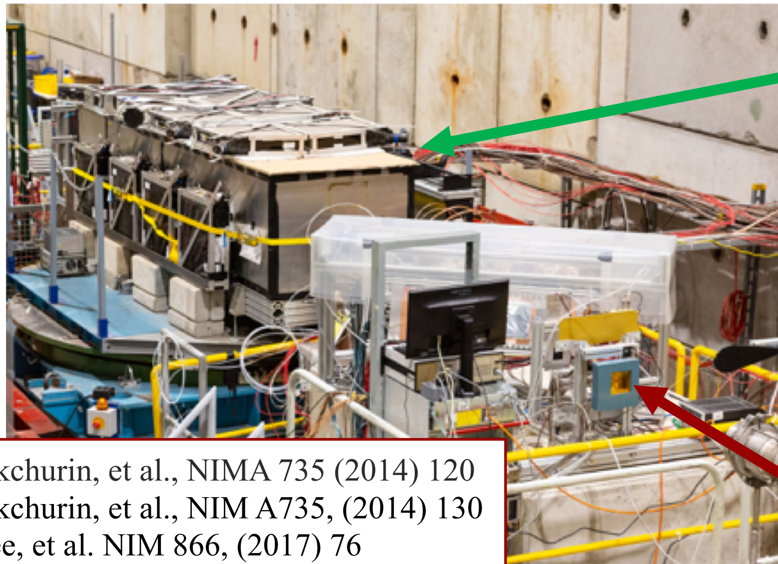
- The plateau efficiency has been measured to be ~97% at a gain of ~ 6000
- Resolution better than 100 μm with average cluster size larger than 2
- Performances have been measured with different geometries, gas mixtures and electric fields.



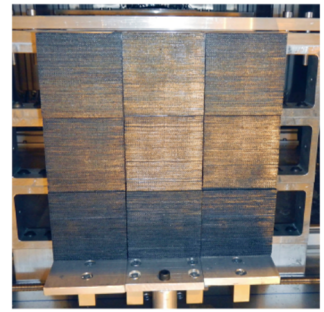
S. Marcello et al., Int.J.Mod.Phys.Conf.Ser. 48 (2018) 1860119

The real setup

See also Gaudio's Talk



N. Akchurin, et al., NIMA 735 (2014) 120
N. Akchurin, et al., NIM A735, (2014) 130
S. Lee, et al. NIM 866, (2017) 76



Dual Readout Calorimeter RD52 Module

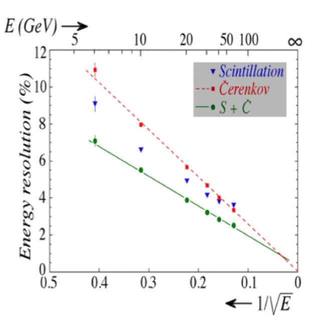
9 lead modules 9.3 x 9.3 x 250 cm3

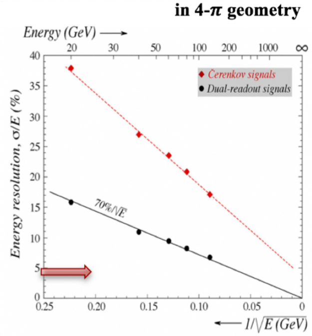
Sampling fraction 5.0 %

Energy Resolution

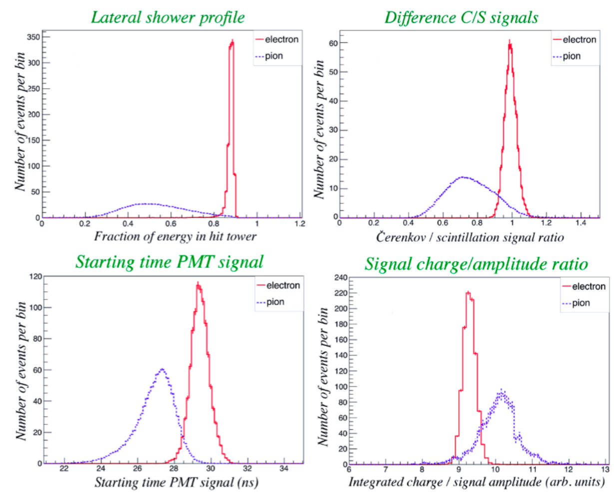
Em resolution: $\frac{11\%}{\sqrt{E}} + 1\%$

Had resolution: $\frac{70\%}{\sqrt{E}}$ Leakage dominated → $\frac{34\%}{\sqrt{E}}$ From simulation in 4-π geometry



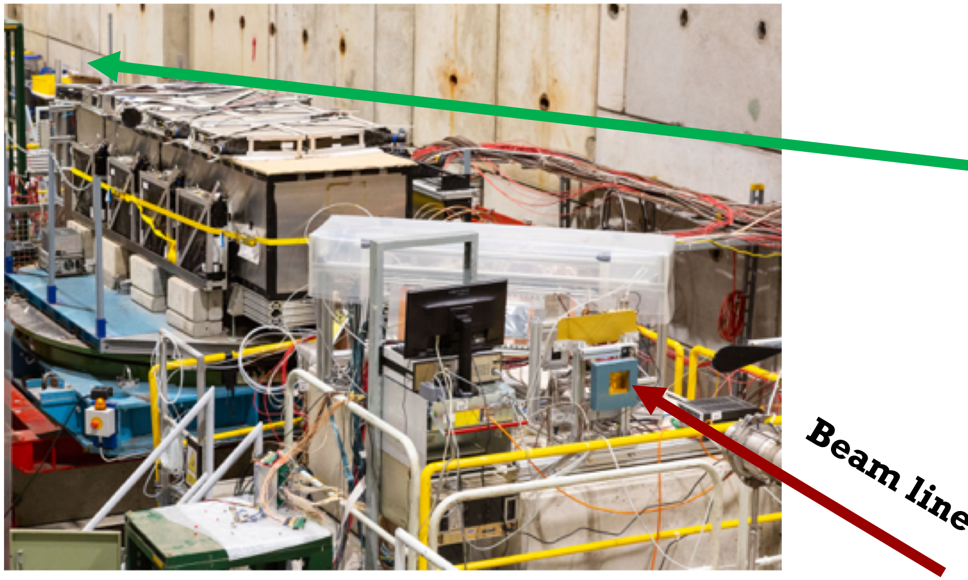


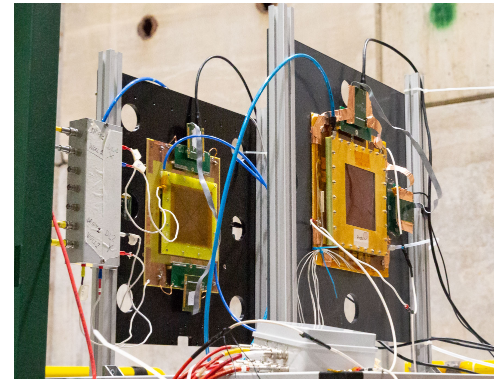
Particle Identification:



Electron hadron identification efficiency ≈ 99.8%

The real setup





Muon detector with μR-Well

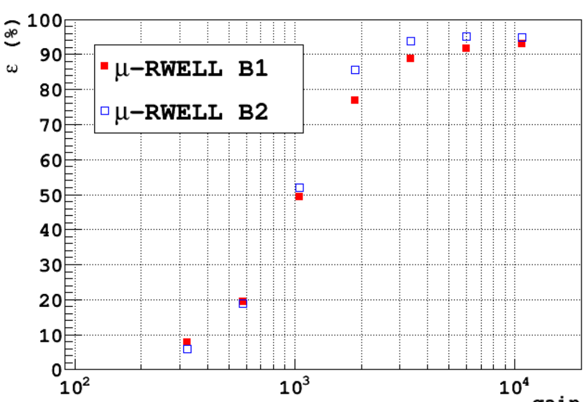
chambers 10x10 cm^2

256 strips, 400 µm pitch

GAS mixture: $Ar/CO_2/CF_4$ (45/15/40)

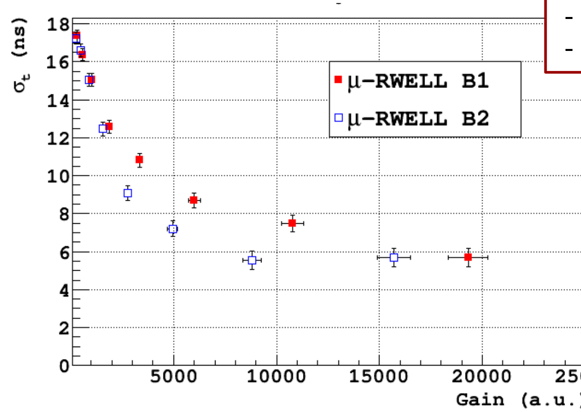
Tracking efficiency

above **97%** at gain of about 3000

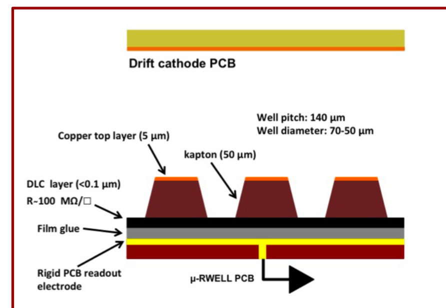


Time Resolution

5.7 ns at the optimal gain



- G. Bencivenni et al., JINST 12 (2017) no.06, C06027
- G. Morello et al., PoS BORMIO 2017 (2017)
- G. Bencivenni et al., NIM A 886 (2018) 36



Test beam condition

- 1 week beam time at SPS CERN (H8-line)
- Different beam condition
  - Muon beams
  - Electrons at different energies (10 – 60 GeV)
  - Hadrons at different energies (50 – 60 GeV)
- Trigger based on the coincidence from scintillators
- Particle identification also performed with external detectors (CEDARs preshower and muon counter) for cross reference
- 3 different DAQ systems and QAs running in parallel
  - Central (trigger, calorimeters, CEDAR and leakage detectors, installed around the calorimeter to measure the energy leakage)
  - Preshower and muon chamber
  - Drift chamber
- Time sharing:
  - ≈ 2 days for commissioning and calibration
  - ≈ 2.5 days for the combined program
  - ≈ 2 days to test the 2 calorimeters prototypes

Outline

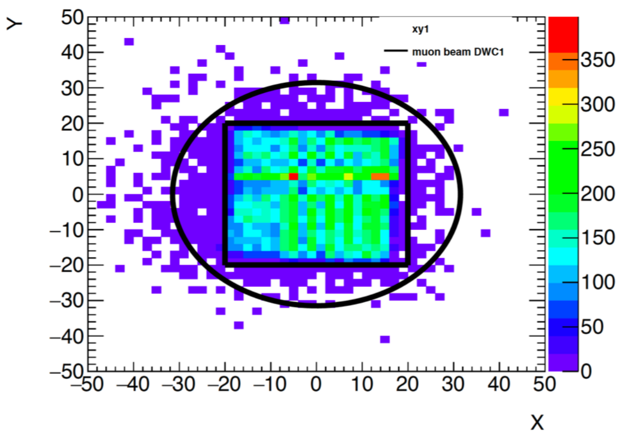
- Test Beam setup
- Test beam preliminary results: Combined program
- Test beam preliminary results: Standalone program

DAQs synchronization

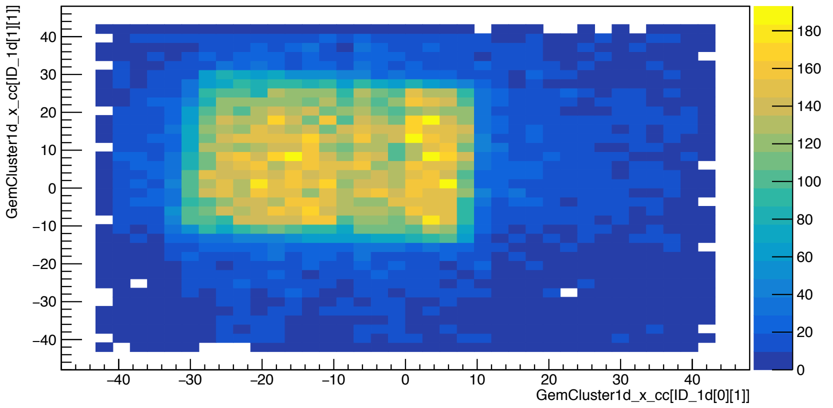
Beam profile with muons :

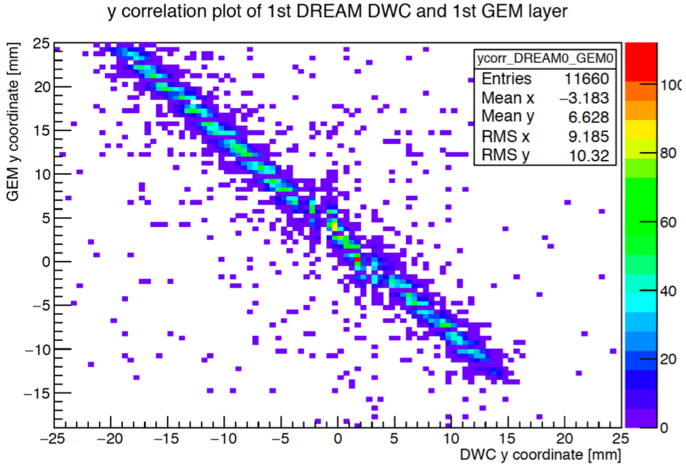
Trigger with 2 scintillators in coincidence with no veto (only for this run)

Delay Wire Chamber



Preshower: GEM



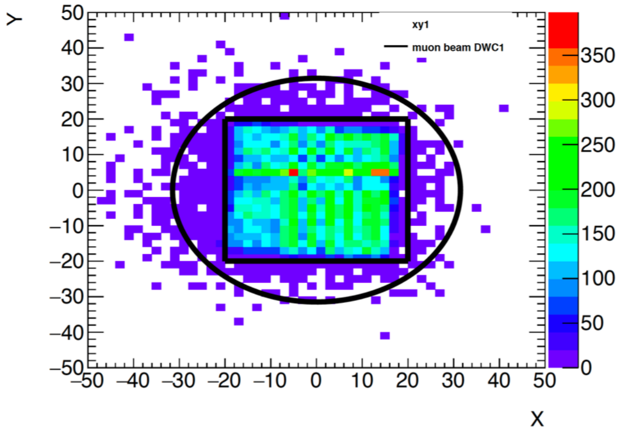


Correlation plots between the 1st DWC layer and the 1st GEM layer (2 different DAQ systems)

DAQs synchronization

Beam profile with muons :
Trigger with 2 scintillators in coincidence with no veto (only for this run)

Delay Wire Chamber



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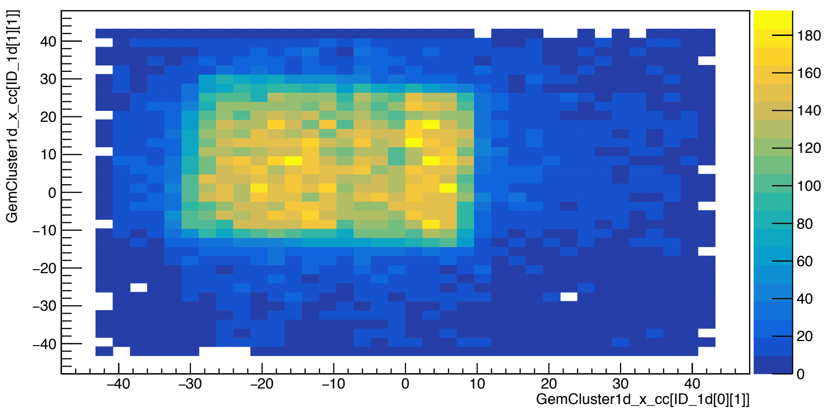
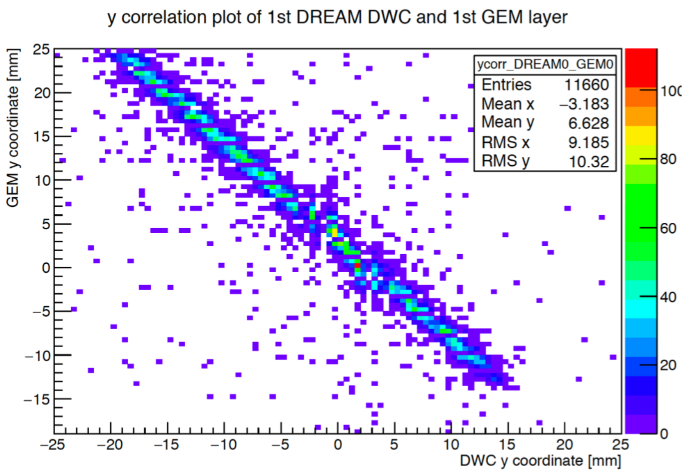
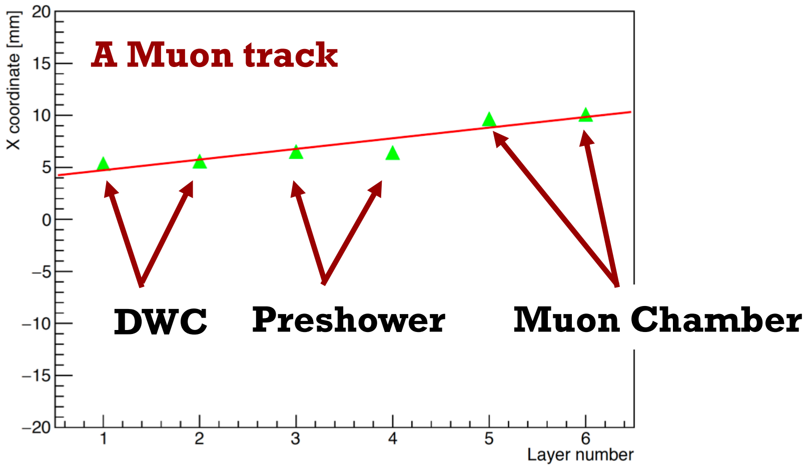




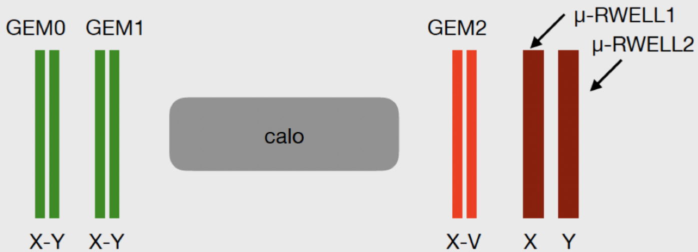


Cluster study for e⁻ selection

- Beam condition:
  - 40 GeV muon beam
  - 20 GeV electron beam with a small muon contamination
  - Data with electron beam are collected with different thickness of lead upstream the GEM

- Muon / electron selection

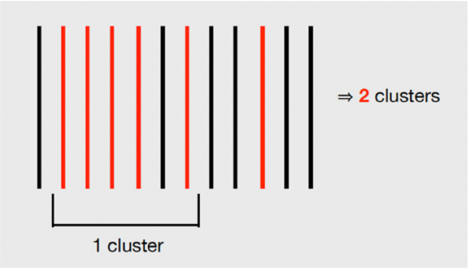
- Local muon/electron selection (not used DWC info yet)
  - to evaluate contamination of electrons in muon beam and vice versa
- **Muon selection**:
  - pre-shower: ≥ 2 layers*
  - muon-system: ≥ 3 layers* ⇒ to be sure to hit more than one chamber
- **Electron selection:**
  - pre-shower: ≥ 2 layers*
  - muon-system: NO layers* ⇒ no particles in the muon-system

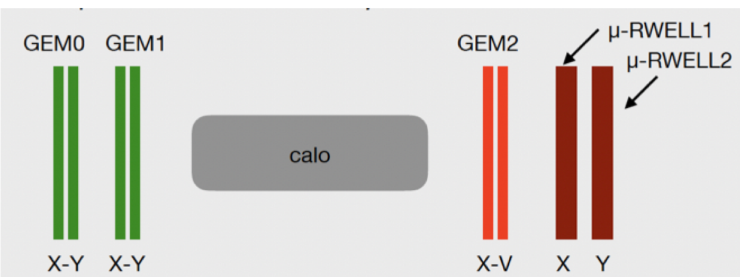


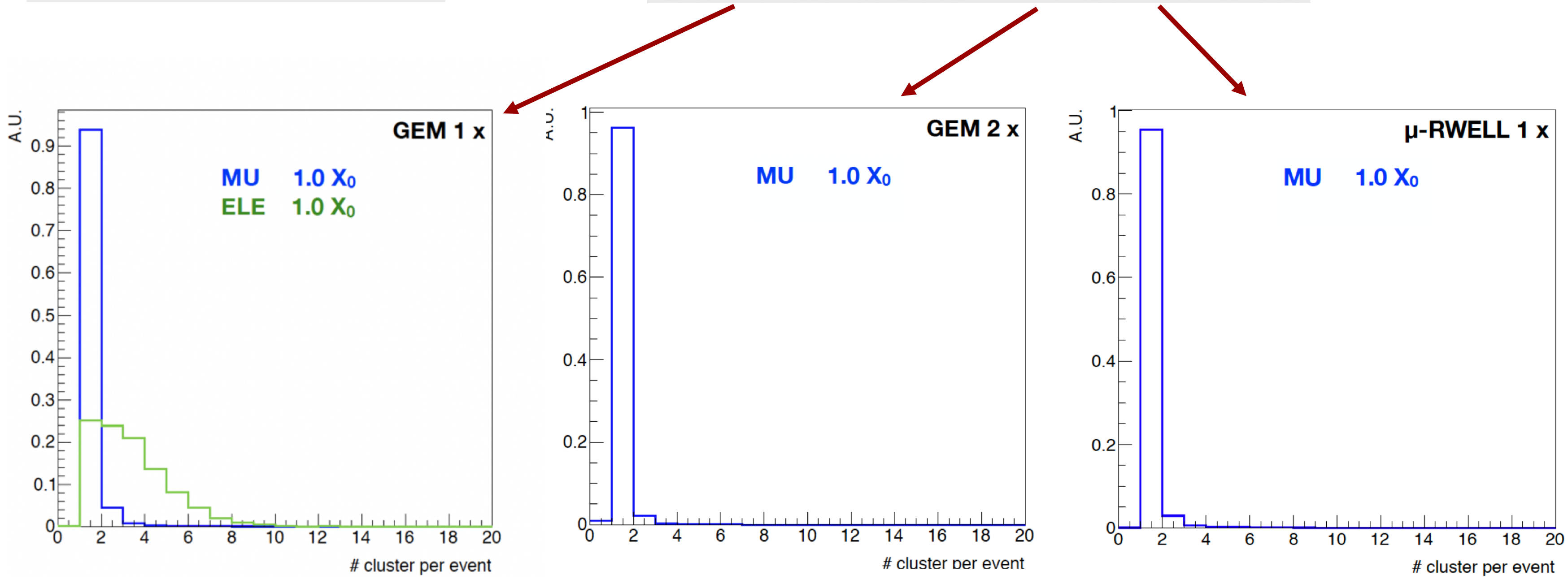
***Layer:** one dimension only
(x separated from y etc)

Number of clusters per event

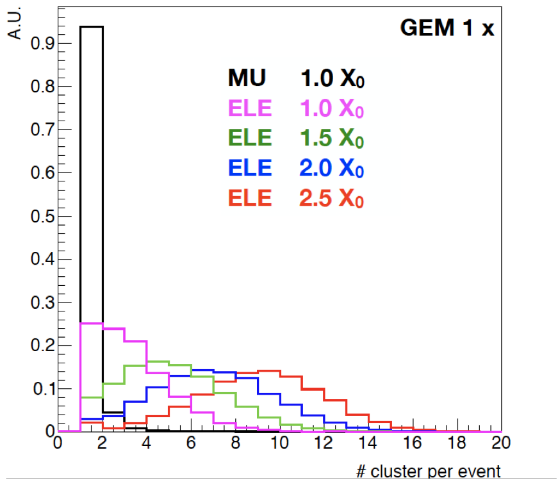
Cluster definition: contiguous strips with no more than 1 not fired strip

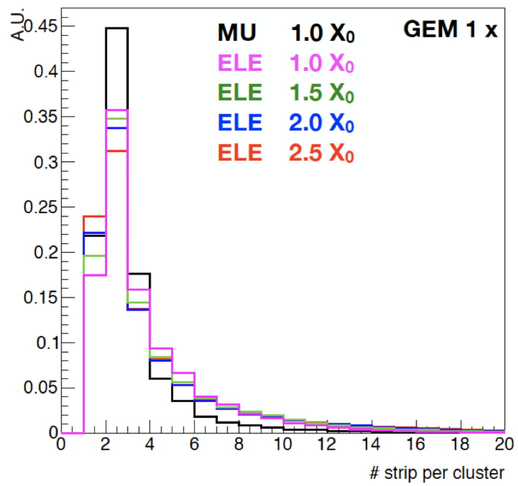




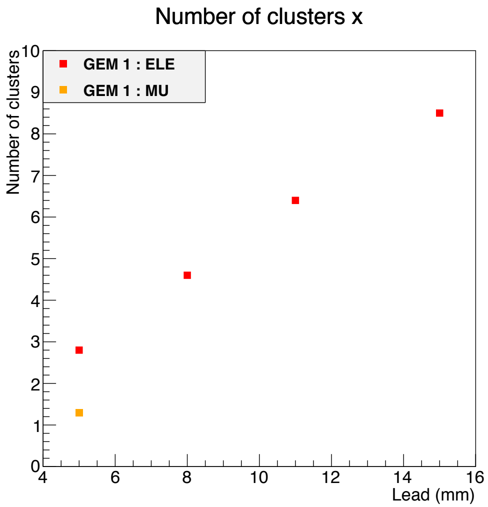


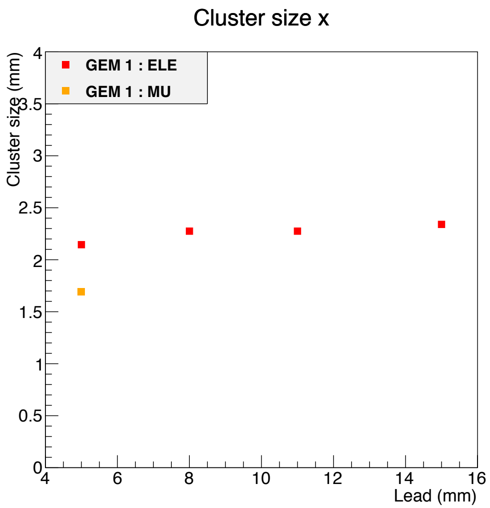
Number of clusters VS cluster size (I)





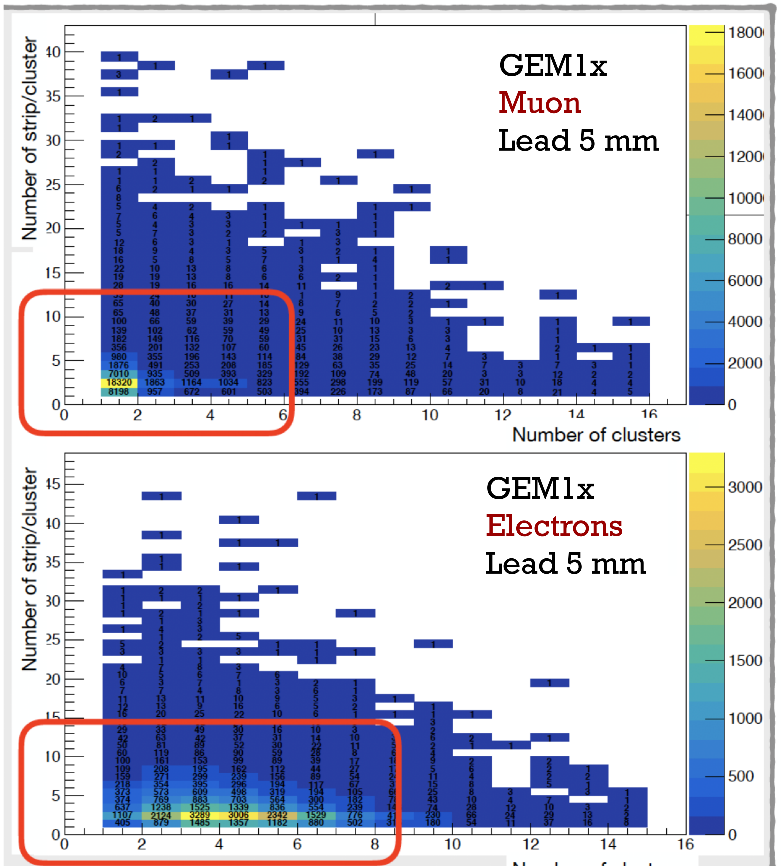
Here is shown the impact on the number of clusters and cluster size when muons or electrons pass thorough a converter with increasing thickness placed upstream the GEM layers



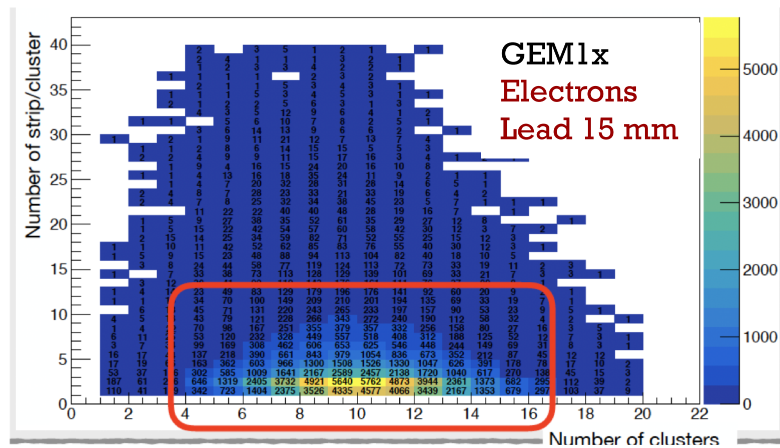


The number of clusters seems to be the quantity that better tags the presence of electrons

Number of clusters VS cluster size (II)



A different way to see the same effect



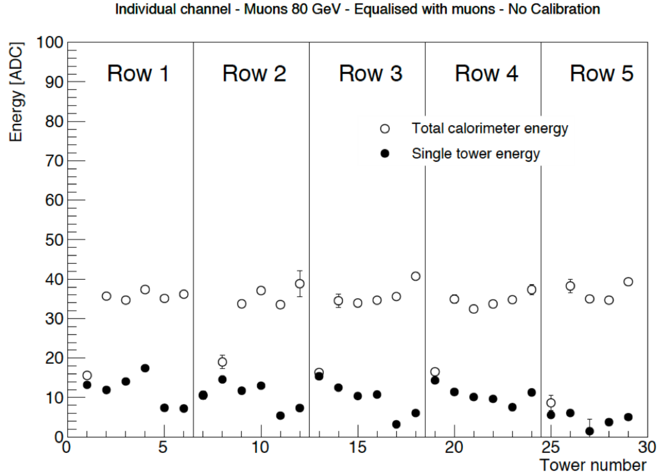
RD52 calorimeter

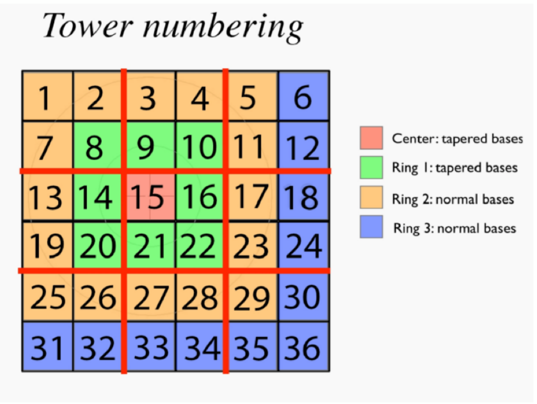
- Equalization and Calibration:
  - Normally performed with a pure sample of electrons centred in each tower
  - For this test beam we were forced to equalize the towers response using a 80 GeV pions beam (not optimal condition) with a muon contamination
  - We tried the equalization using pions or muons and we concluded that the best (not optimal) equalization is obtained with muons
  - The calibration is finally performed using a 20 GeV electron beam placed in the centre of the calorimeter

- Particle selection performed with ancillary detectors normally used in all the RD52 test beams

Scintillating channels equalized with the total energy released by muons.

The calorimeter is tilted by 1.5 deg, this is the reason why the energy is not fully released in one tower.





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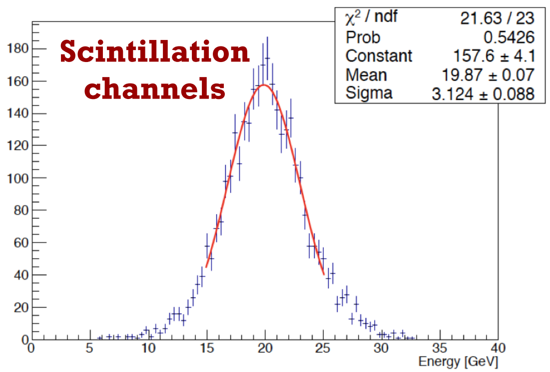
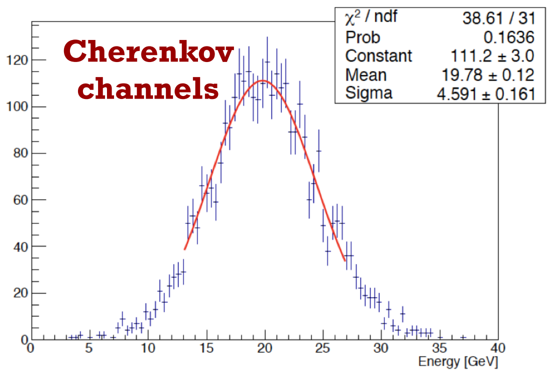
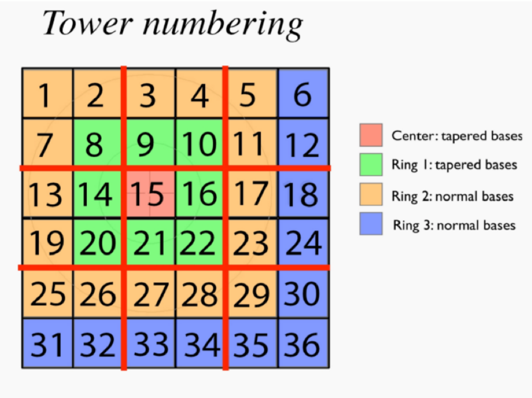


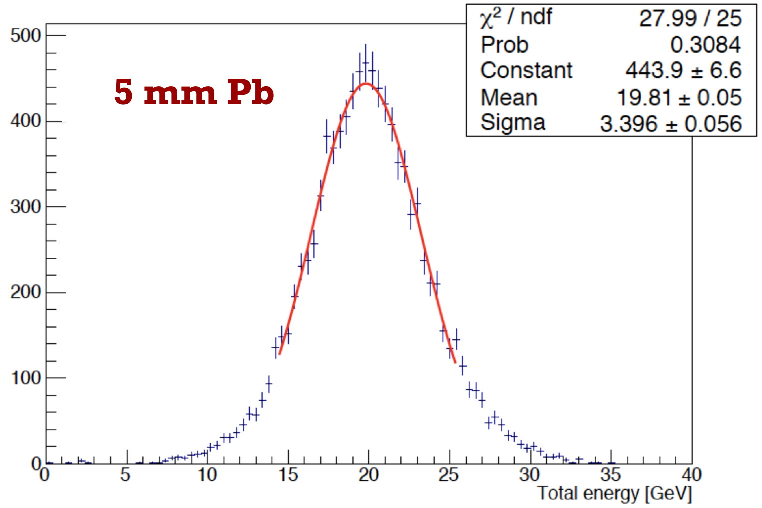


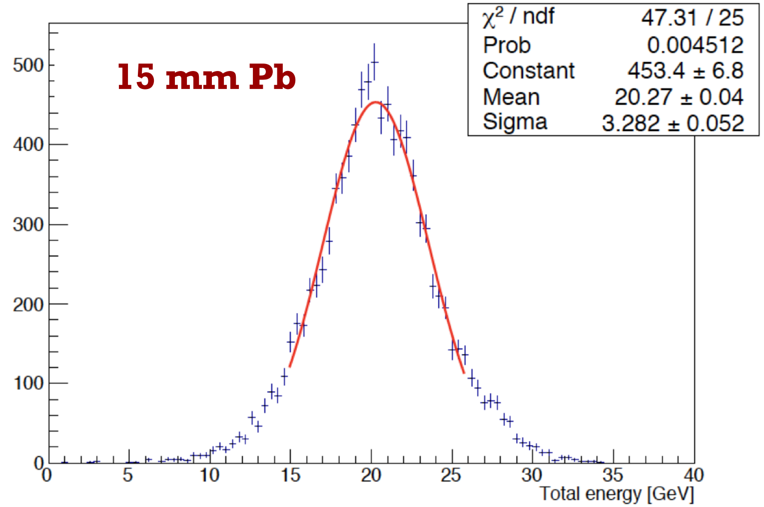


RD52 calorimeter: Energy response

- Only the scintillation channels
- Gaussian fit in the range: $\mu \pm 1.5\ \sigma$
- There is not a clear impact, if any, on the mean energy and the resolution due to the material placed upstream

20 GeV Electron Beam

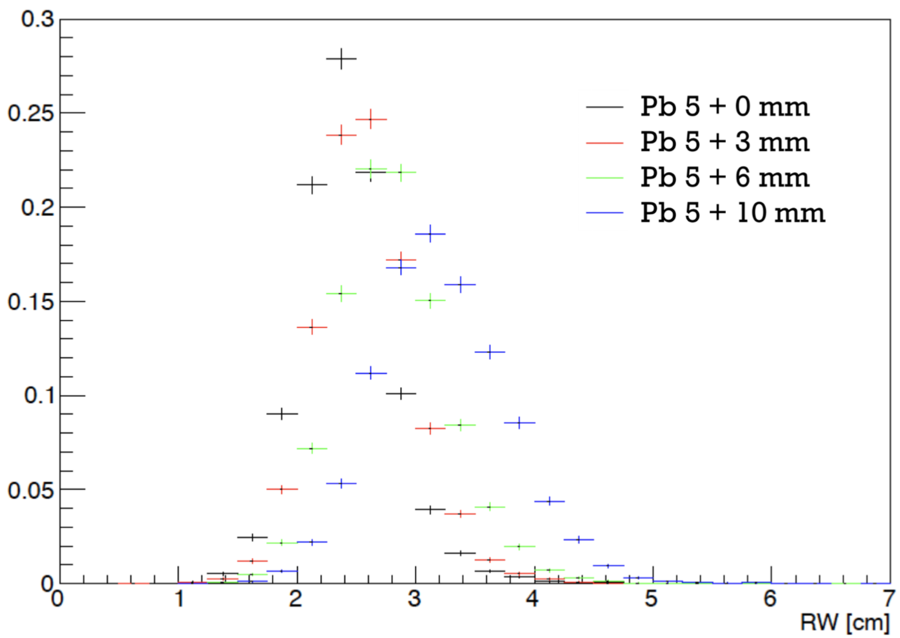




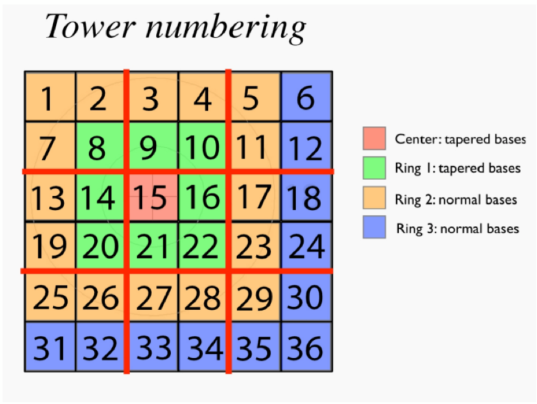
RD52 calorimeter: Shower shape

- While a small impact on the shower shape is visible

- R_W: energy-weighted shower width
  - Tower15 has coordinate (x,y) = (0,0)
  - The coordinates of al other tower centres are based on tower position and tower width (4.6cm x 4.6 cm)

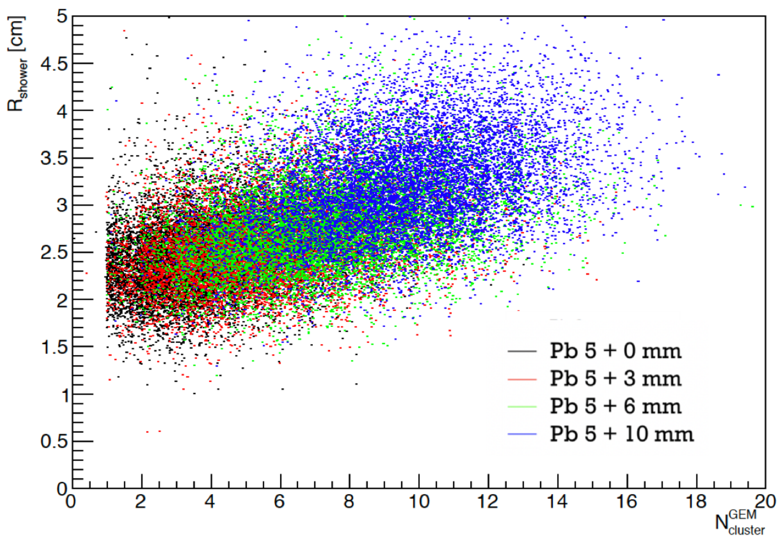


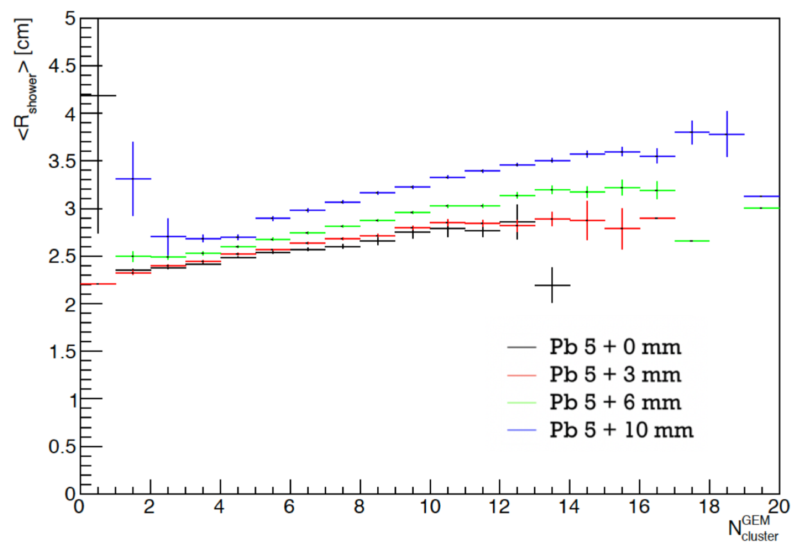
$$R_W = \frac{E_{\mathrm{ch}} \cdot \sqrt{x_{\mathrm{ch}}^2 + y_{\mathrm{ch}}^2}}{\sum_{\mathrm{ch}} E_{\mathrm{ch}}}$$



Shower shape: combined plot

The same effect is confirmed by the correlation plot performed using the number of clusters seen in the preshower and the shape measured in the calorimeter





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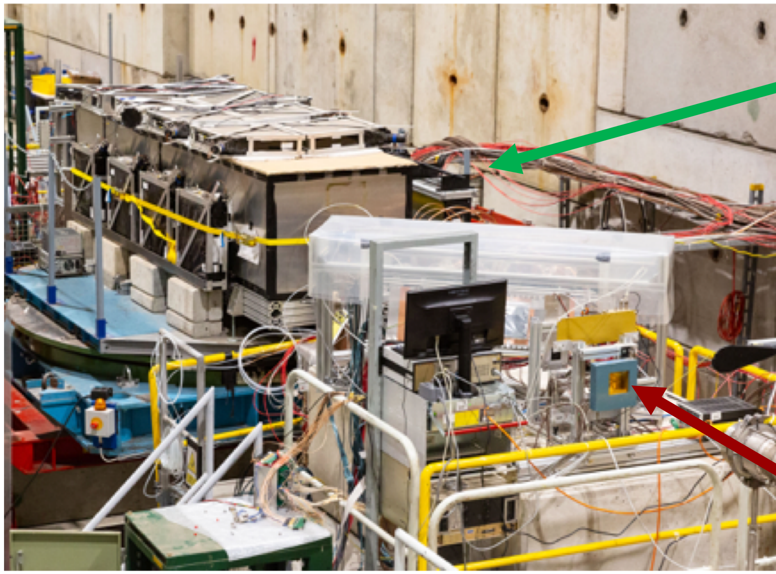
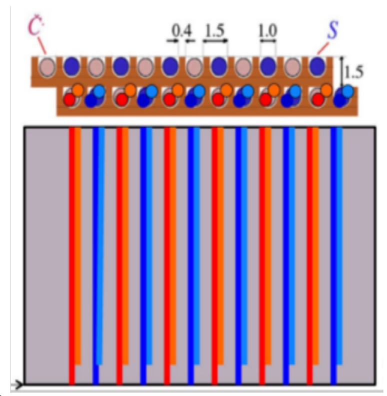
Calorimeter with staggered fibers

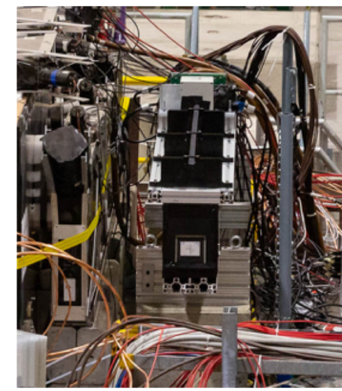


Beam line

Calorimeter R&D program

Standalone runs



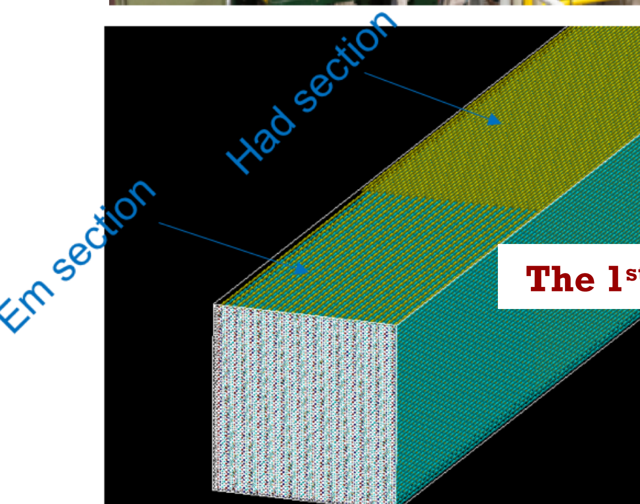


Dual Readout Calorimeter Module with staggered fibers: longitudinal segmentation

1 lead modules 9.3 x 9.3 x 250 cm3

Sampling fraction 5.0 %

All fibers (long and short) are readout with PMTs



The 1st time on beam

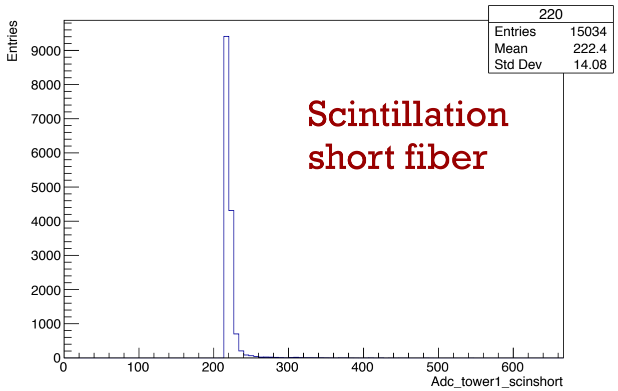
Main goal

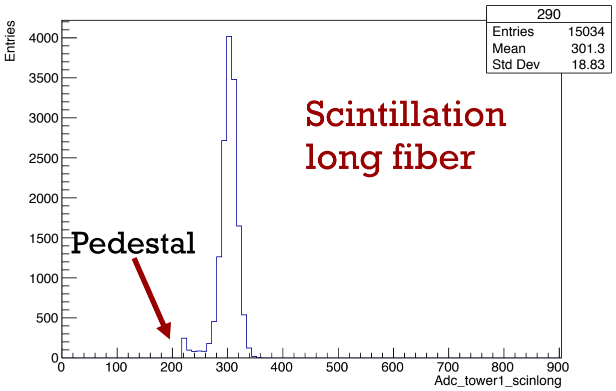
study the behavior of short/long fibers with electromagnetic and hadronic environments.

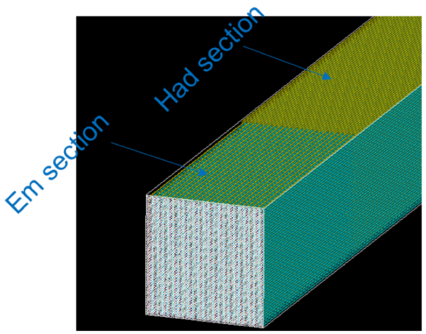
Understand possible particle identification capability in multi particle environment.

Calorimeter with staggered fibers: preliminary

20 GeV electron beam centred in tower 1







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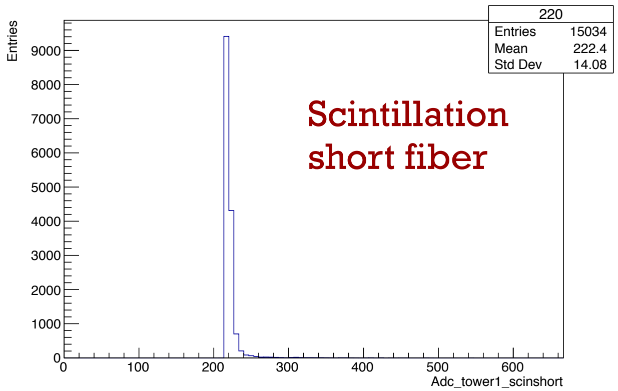
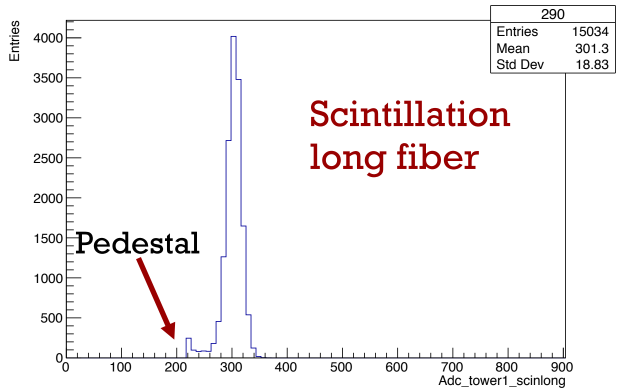
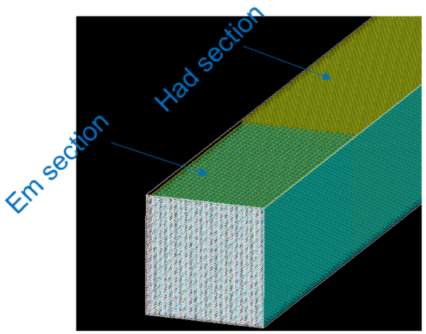
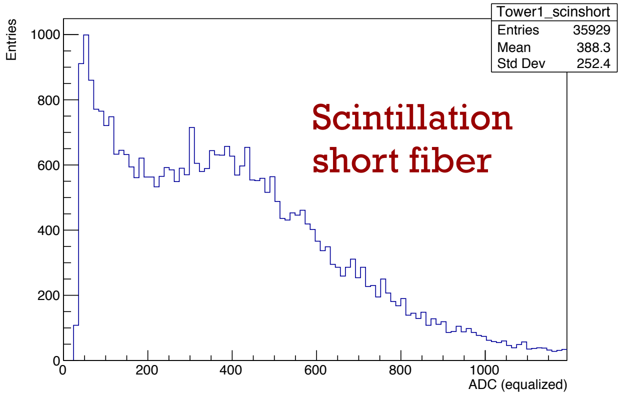




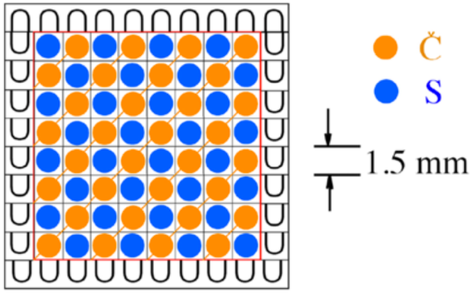


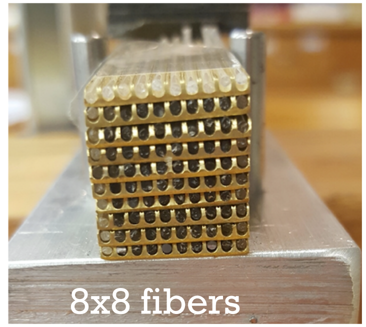
60 GeV pions centred in tower 1



The response of short fibers can only be studied with pions

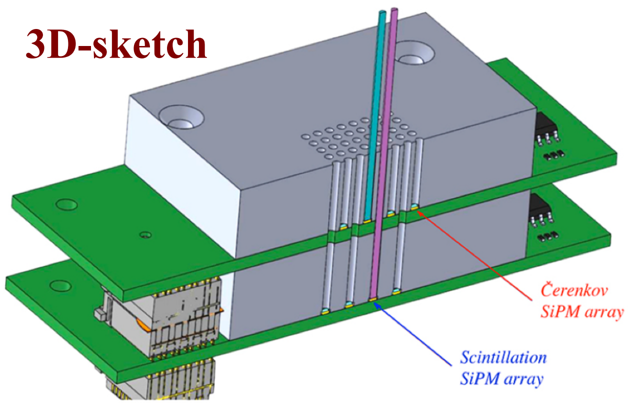
Calorimeter readout with SiPM (I)





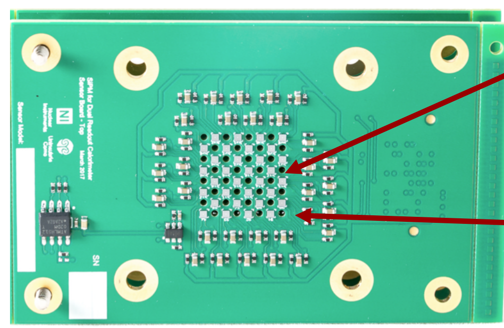
The module (112 cm long, X_0 = 29 mm) is built from stacked brass layers, housing 1mm diameter clear & scintillating fibers with a pitch of 1.5 mm (R_M = 31 mm)

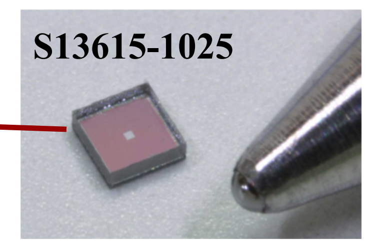
3D-sketch



Top layer (Front view)

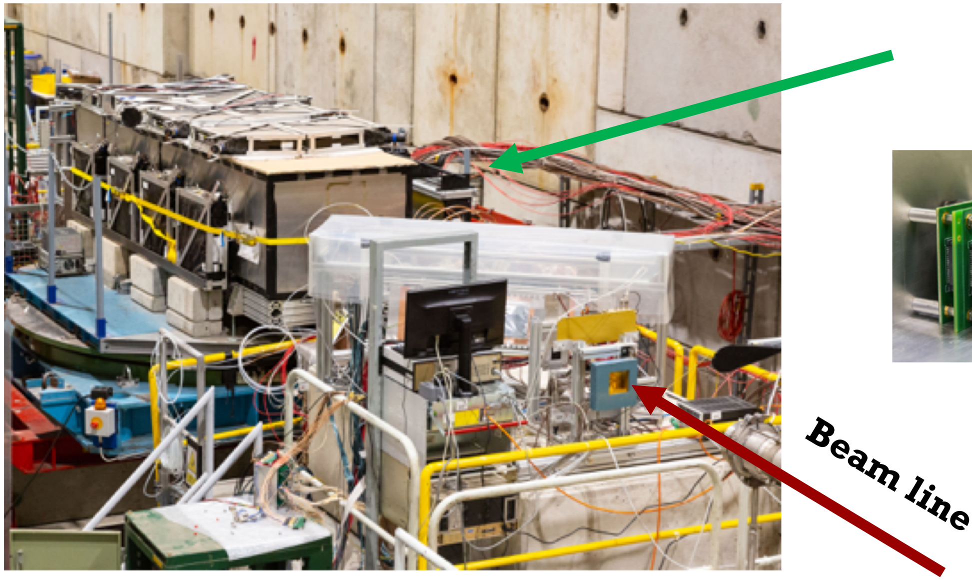
Through – holes





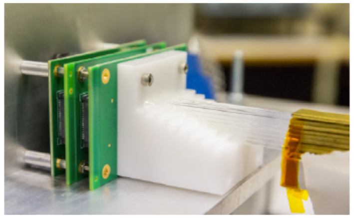
- The light propagated in each fiber is sensed by individual SiPMs
- The SiPMs collecting Cerenkov / scintillating light are placed on separate boards to avoid that Cherenkov light is contaminated by scintillating light. The latter is expected to be ≈ 50 time more intense

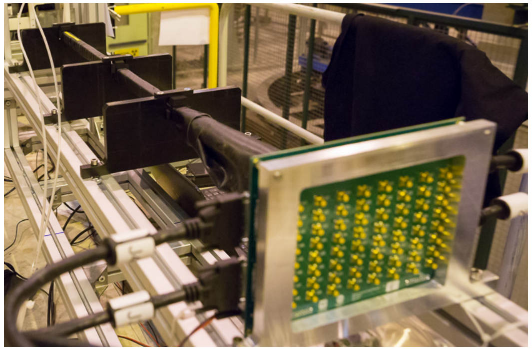
Calorimeter readout with SiPM (II)



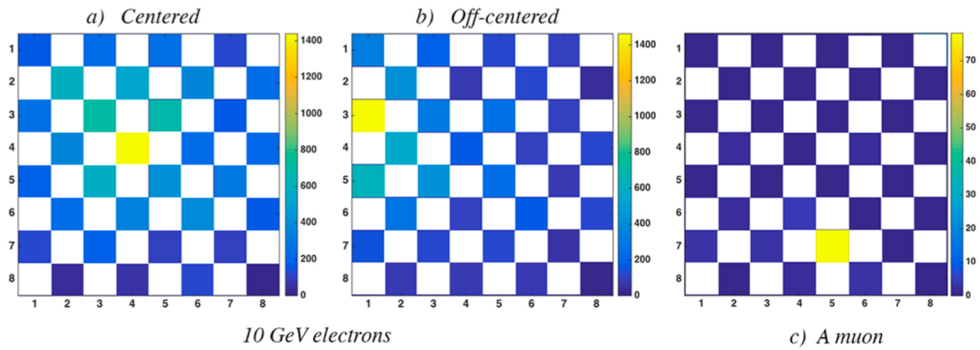
Calorimeter R&D program

Standalone runs



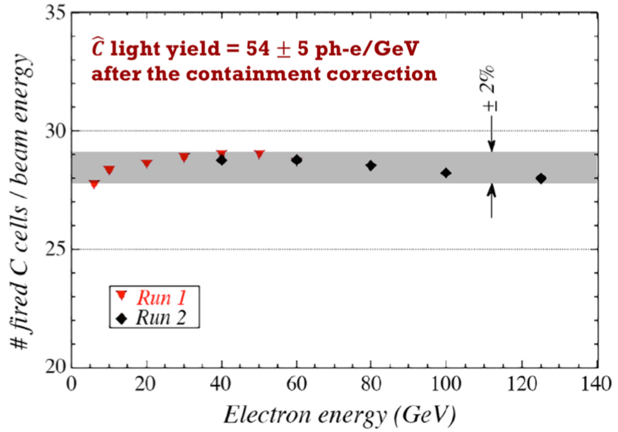


Event Display



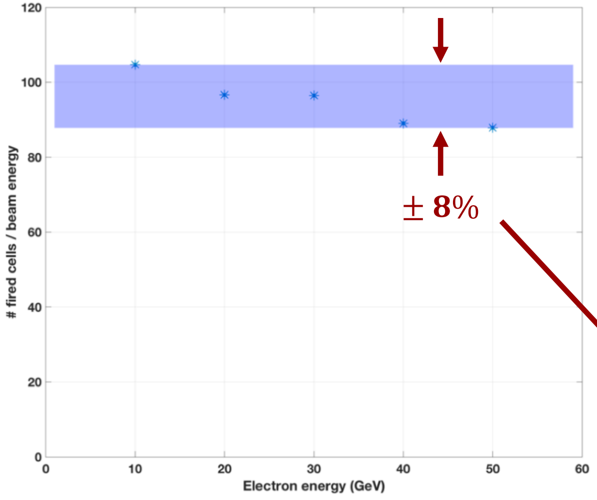
M. Antonello, et al, NIM-A 899 (2018) 52

Results from 2017 test beam



Scintillating light yield

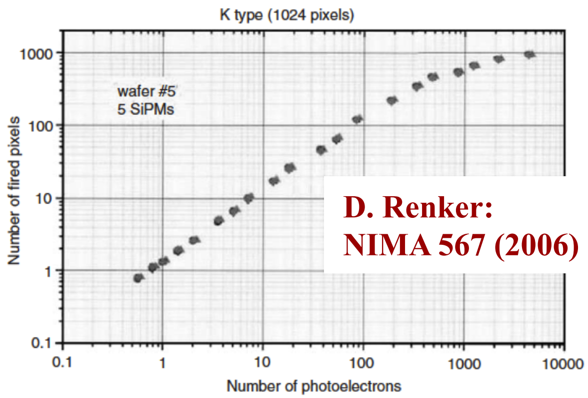
Results from 2017 test beam



- Detector operated at 0.5V over breakdown (PDE ≈ 2%)
- Temperature stability correction:
  - < 0.5°C during a single run (negligible)
  - < 2°C during the full scan (considered)
- PDE correction for temperature variation

$$N_{fired} = N_{total} \times \left[1 - e^{-\frac{N_{photons} \times PDE}{N_{total}}}\right]$$

Even if the SiPMs are not saturated with this setting, they are working in a strongly non linear regime: a correction is required



D. Renker: NIMA 567 (2006) 48–56

Valid as a first approximation: the light uniformly illuminate the SiPMs, all photons come at the same time and spurious effects are negligible

Scintillating light yield

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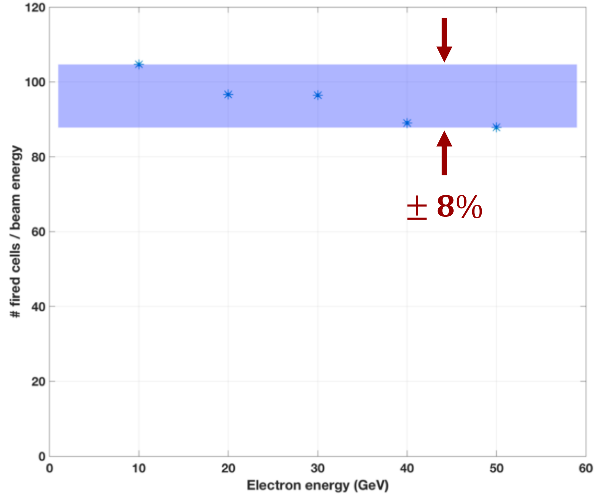

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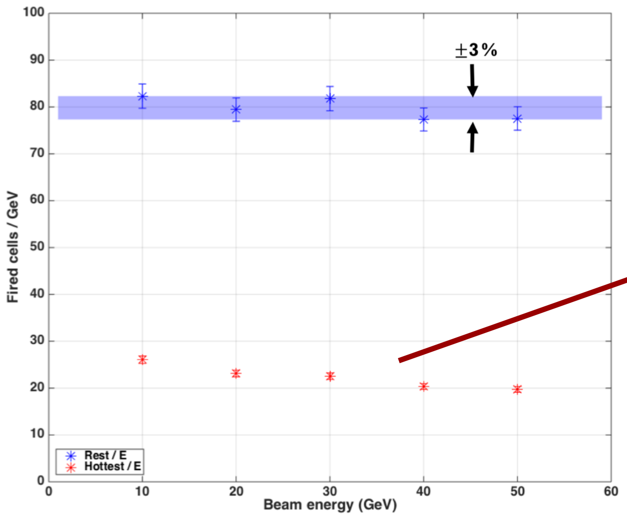
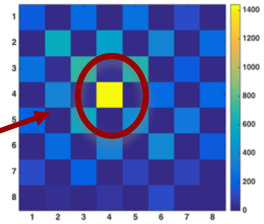




Once the correction is applied, the linearity is improved even if it is not fully recovered

(i.e. signal from the seed)

To reduce this effect we decided to attenuate the scintillating light using a yellow filter

Signal linearity results from 2018 TB

***Measurement conditions*:**

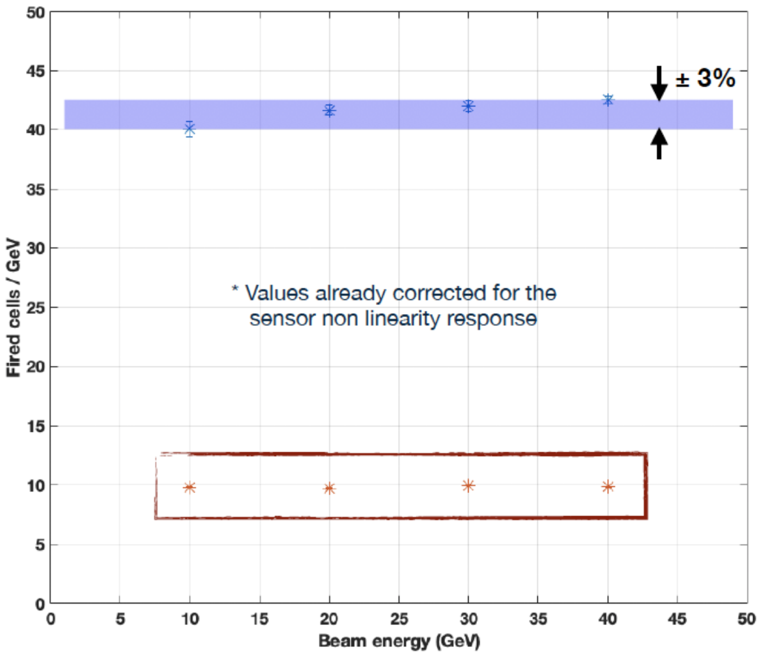
V_{op} = 5.5 V_{ov} (57.5 V) and **PDE ~ 22% (S)**

Signal is linear from 10 to 40 GeV within 3%

Correcting for 45% e.m. energy containment: ~ ***93 Spe/GeV***

Stochastic term ~ ***10.9%***

Scintillation channel



To be checked with a simulation: sending electrons in the center of the module (4x4) with an angle: -1 < ϑ < 1 mRad

Total: ***41.9 ± 0.1 Spe/GeV***

Hottest fibre: ***9.8 ± 0.1 Spe/GeV***

No saturation effects: linear within ***1%***

Summary

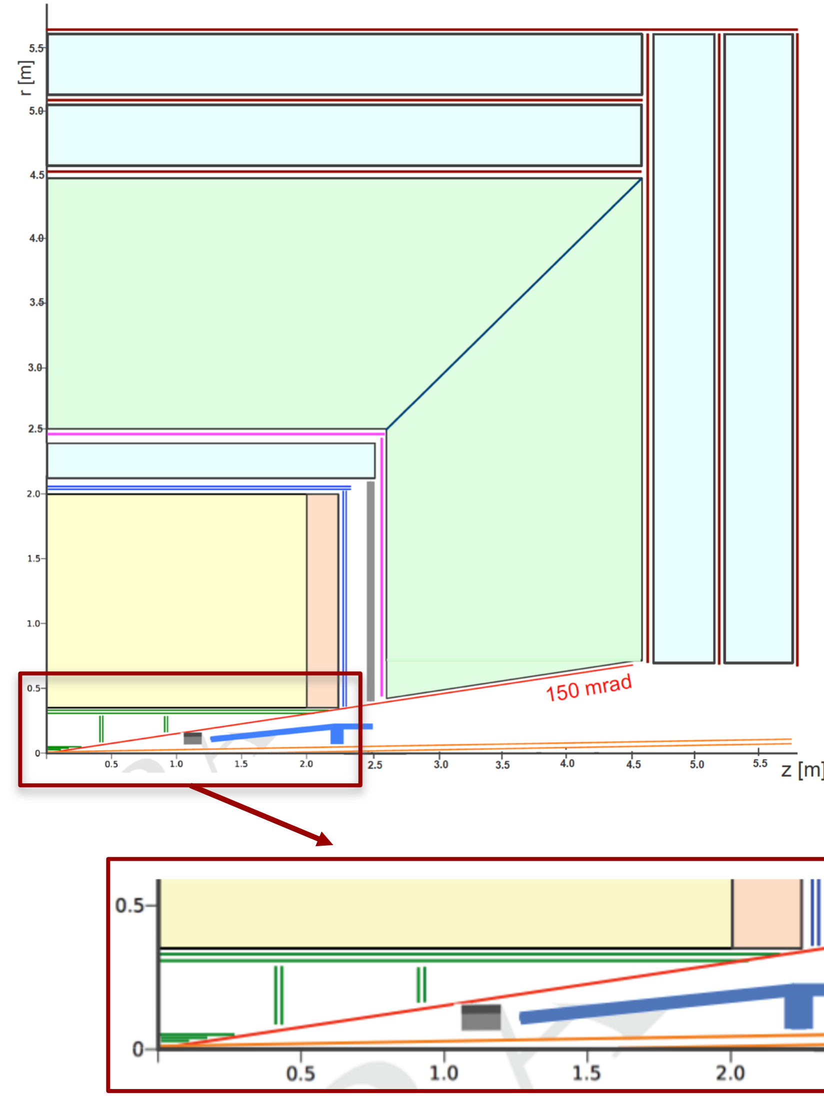
- The preliminary analysis confirms we collected usable data to test the combined detector performances
- A first attempt to use the GEM as preshower is on-going but additional work is still needed to be quantitative
- The additional material budget placed upstream the detectors has negligible impact on the calorimeter performance even if it changes the shower shape
- The standalone program is also progressing:
  - An RD52 calorimeter with staggered fibers has been tested on beam for the first time and the data analysis is just started
  - The non linearity response observed in the scintillating fibers of a small calorimeter module readout with SiPM (TB 2017) has been recovered using a yellow filter

A lot of work is still needed to complete the analysis and precious inputs for the simulation will come soon

Backup

IDEA - Layout

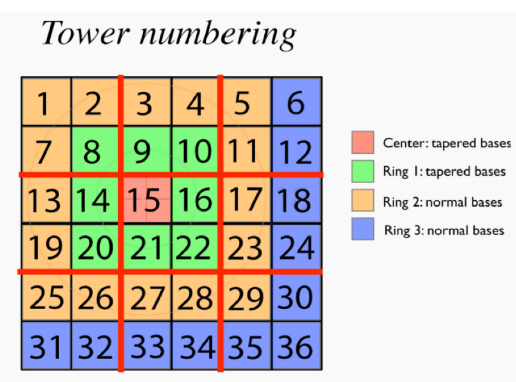
- Beam Pipe (≈1.5 cm radius)
- Vertex Detector (R ∈ [1.7; 34] cm)
- Drift Chamber (L = 400 cm, R ∈ [35; 200] cm)
- Outer Silicon Layer (strips)
- SC Coil (2T, ≈2.1m); 30 cm THIN! ($0.74X_o$; 0.16 λ @90°)
- Pre-shower (1-2 X_o)
- Dual Readout Calorimeter (2m, 7 λ)
- Yoke & Muon Chambers

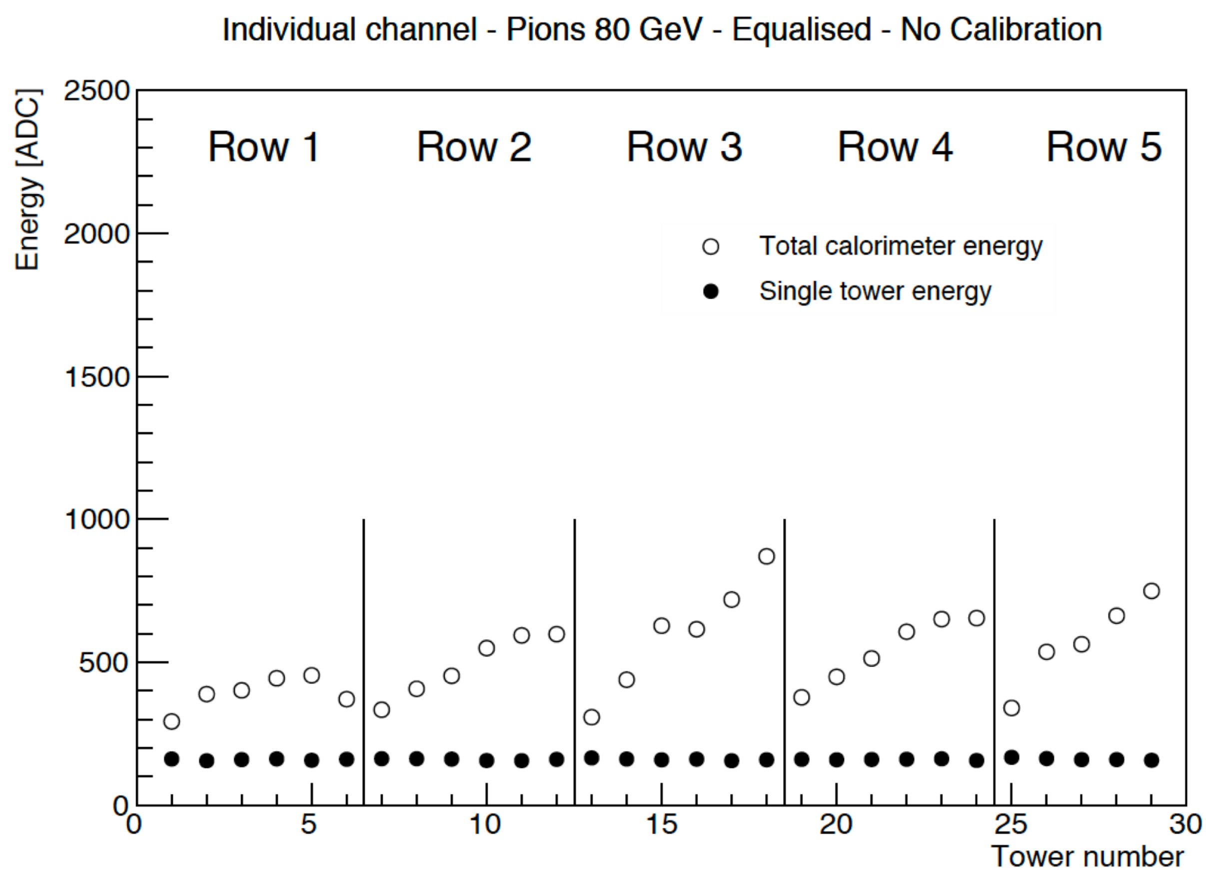


Equalised results

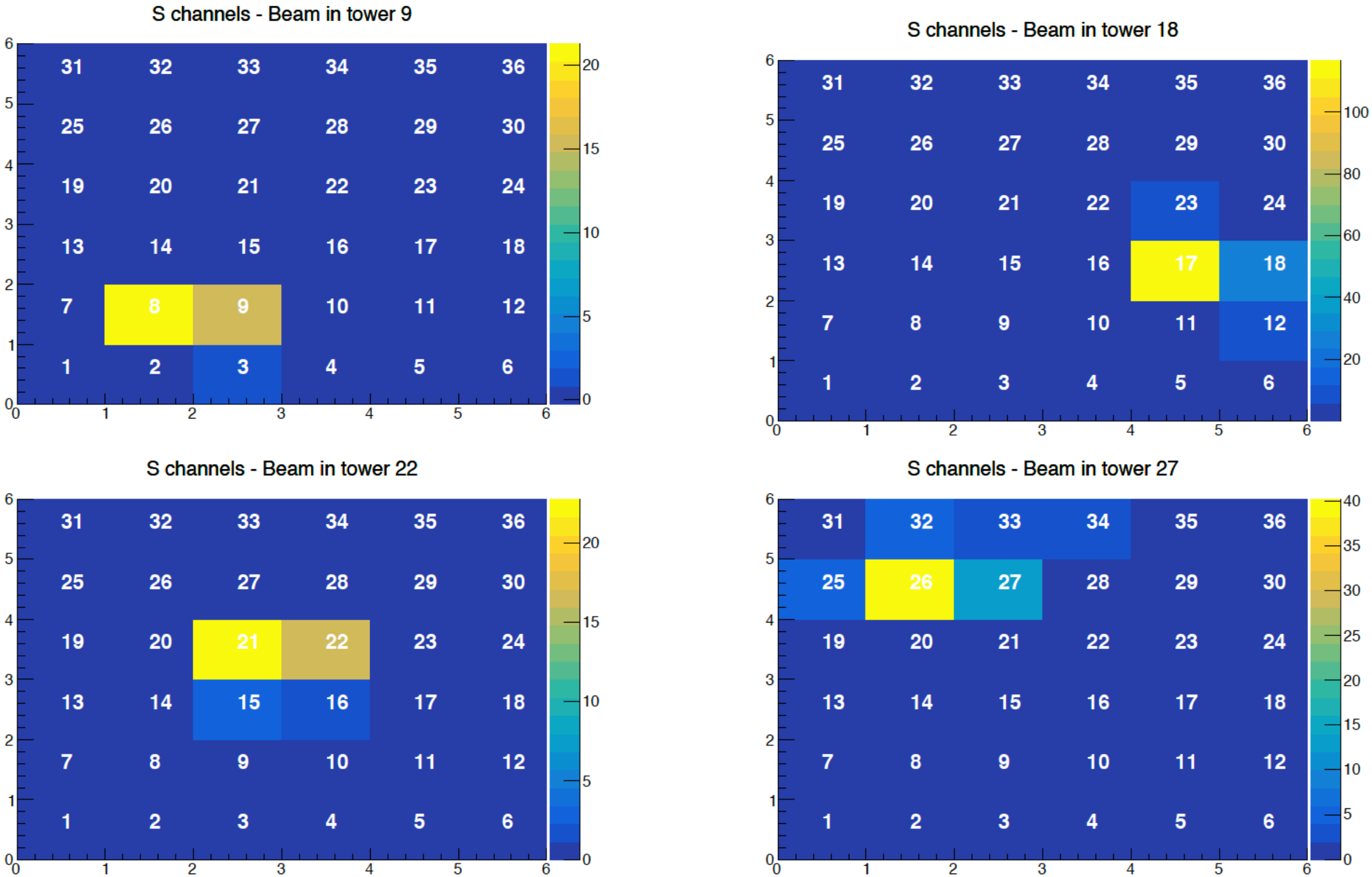
- Let's blindly apply the equalisation coefficients from single channel pion response.

- Clear improvement
- However, the residual total energy trend is not obvious.





Muon energy deposit, few examples



Attenuation effect

Error from sampling fluctuations:

$$\epsilon_{Sampling} \sim 10.5\,\%$$

Relative error of signal:

$$\epsilon_{N_{FC/GeV}} = \frac{1}{\sqrt{N_{FC/GeV}}}$$

Combined error for each channel:

$$\epsilon_{Combined} = \sqrt{\epsilon^2_{Sampling} + \epsilon^2_{N_{FC/GeV}}}$$

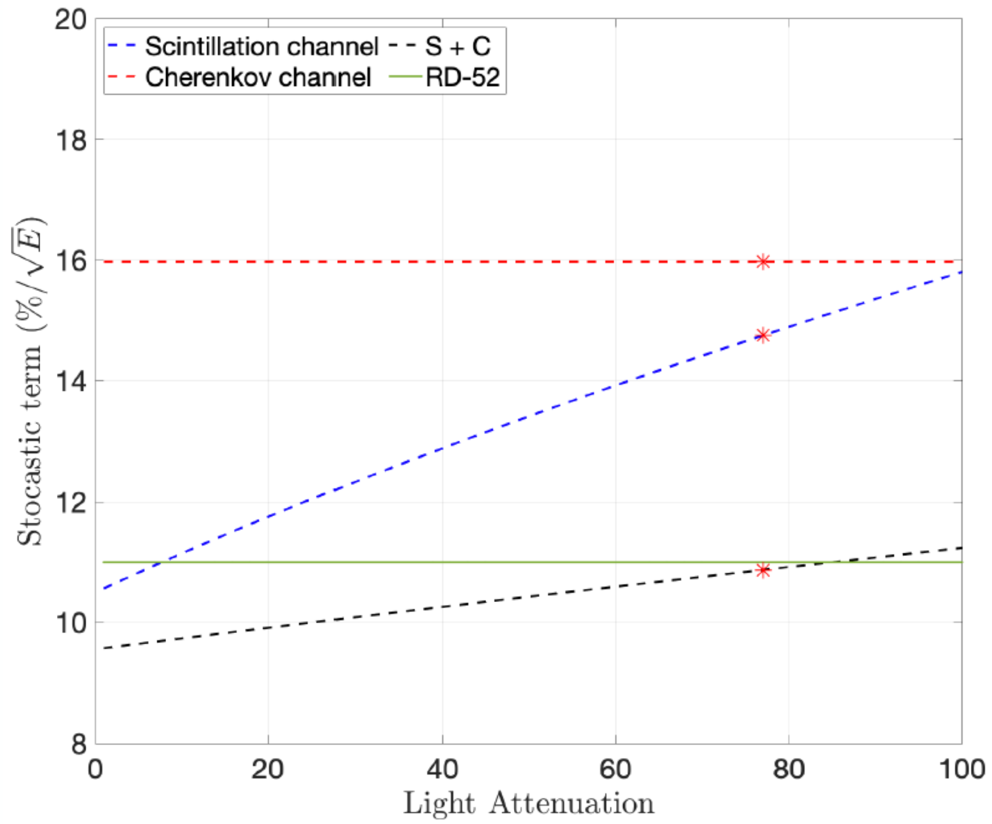
Stochastic term in e.m. resolution:

$$\epsilon_{C+S} \sim \frac{\sqrt{\epsilon^2_{Combined}(S) + \epsilon^2_{Combined}(C)}}{2}$$

C: 69 Cpe/GeV $\rightarrow \epsilon_{Combined} \sim 16.0\,\%$

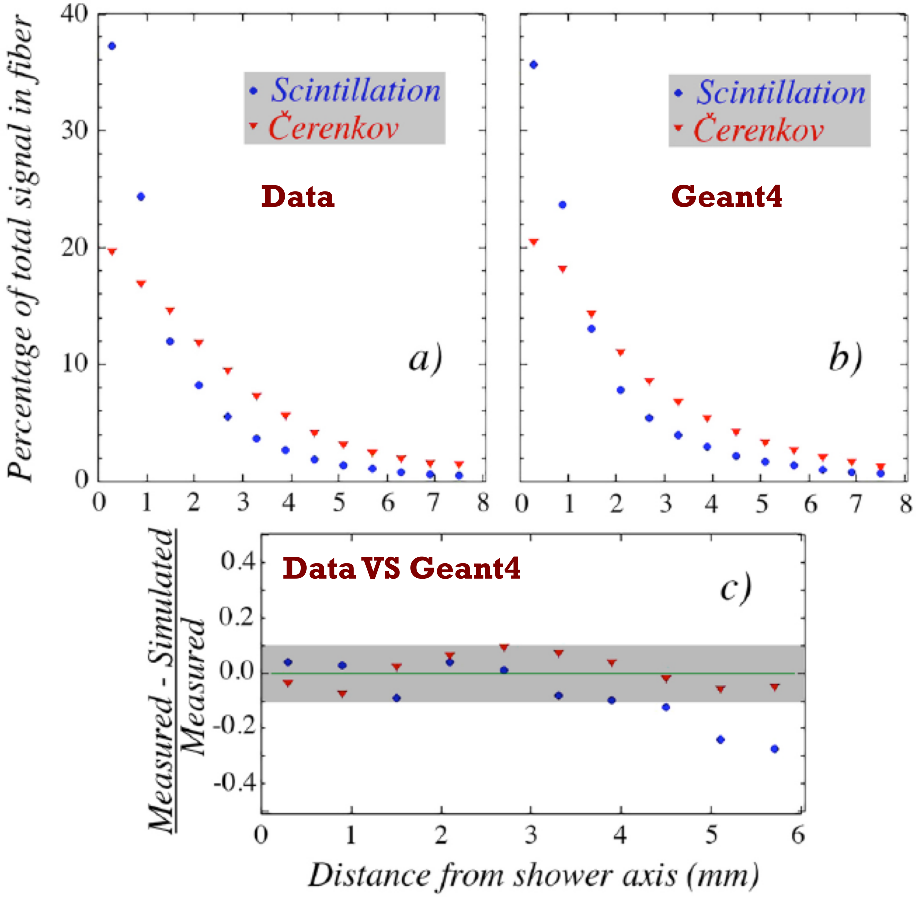
S: 93 Spe/GeV $\rightarrow \epsilon_{Combined} \sim 14.8\,\%$

$$\epsilon_{C+S} = 10.9\,\%$$



Lateral shower profile

In addition, this segmentation allowed to measure the electromagnetic lateral shower profile with an unprecedented granularity



$$\bar{x} = \frac{\sum_i x_i E_i}{\sum_i E_i}, \quad \bar{y} = \frac{\sum_i y_i E_i}{\sum_i E_i}$$

$$r_i = \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}$$

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