Performance results of a high-granularity electromagnetic calorimeter

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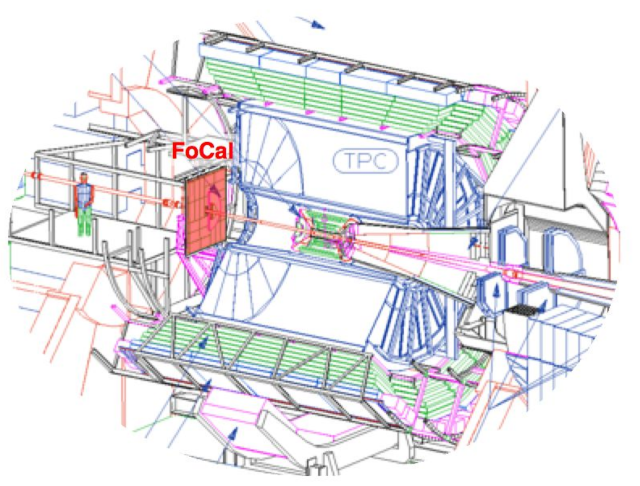
Motivation



Physics motivations: At small x the high gluon density should lead to a nonlinear evolution and saturation → new state of QCD matter, crucial to understand initial state of high energy collisions.

Expect suppression of forward direct photons in p-Pb collisions at LHC relative to pp compared to pQCD expectations.

Proposal for a forward calorimeter (FoCal) in ALICE under discussion [1].

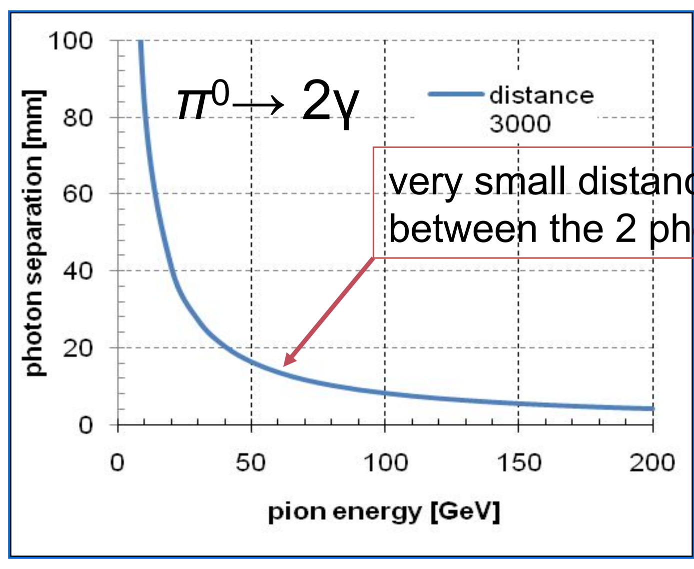
Main measurement: needs discrimination between direct photons and photons from π^0 decay.

Measurement at forward rapidity implies large particle energies, small π^0 opening angle.

Detector with MAPS should allow :

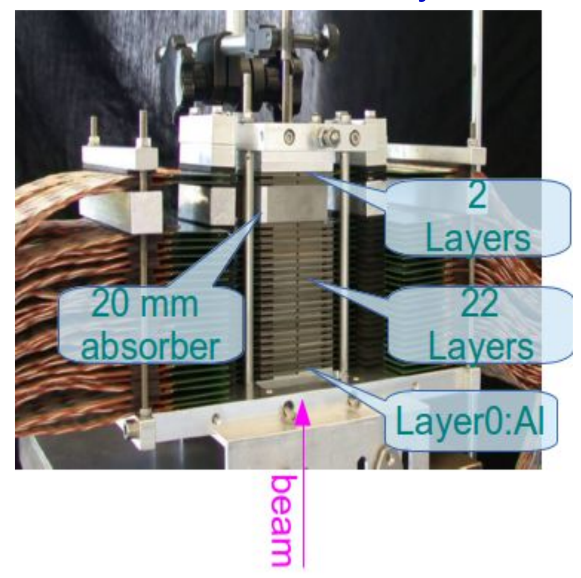
Gamma/π^0 discrimination

- 3D shower shape analysis
- Particle flow
- Energy measurement by particle counting: requires high granularity due to high density of shower particles (10^3 mm^{-2})

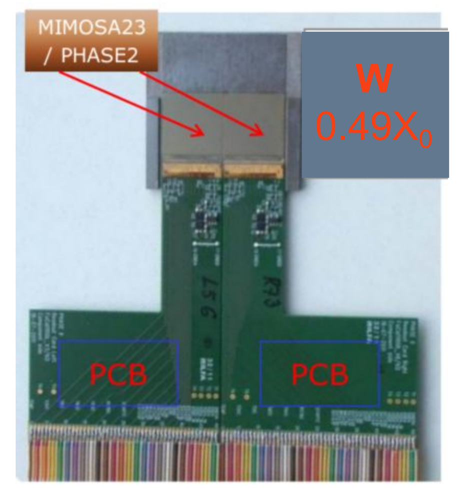


FoCal Prototype

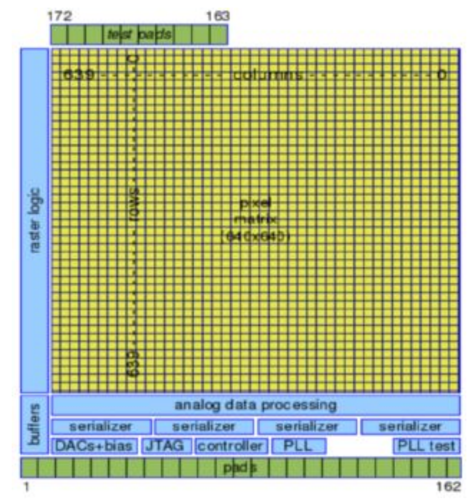
Stack of W and Si layers



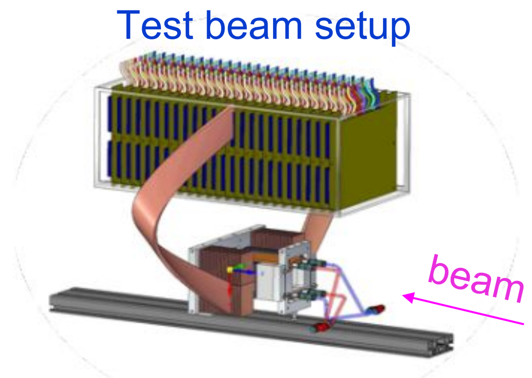
Single half layer($0.49X_0$)



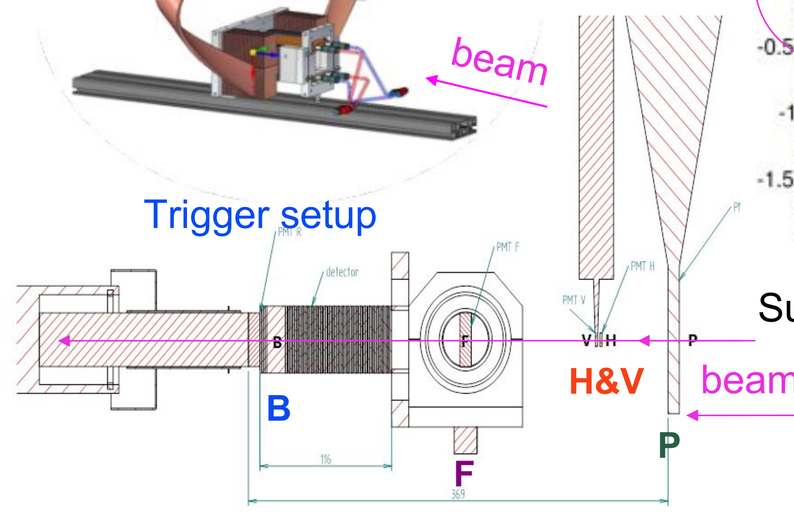
Sensor schematics



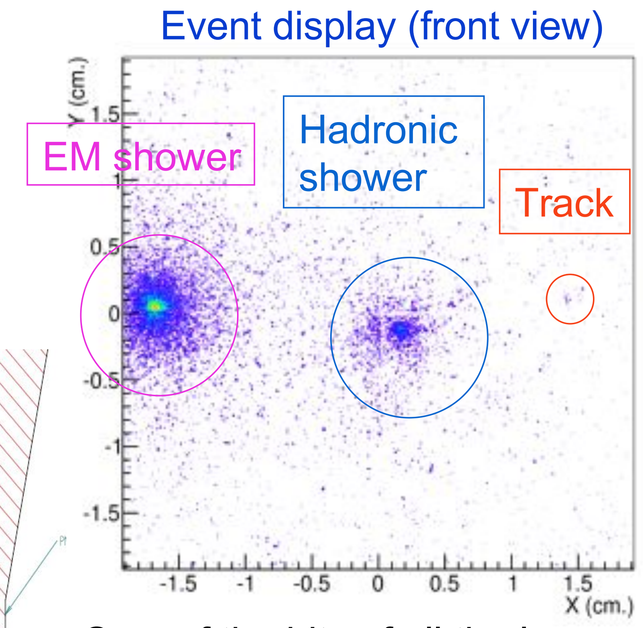
Test beam setup



Trigger setup



Event display (front view)



Sum of the hits of all the layers

Unique features:

High granularity: total ~39M pixels small Molière radius (R_M ~ 11mm)

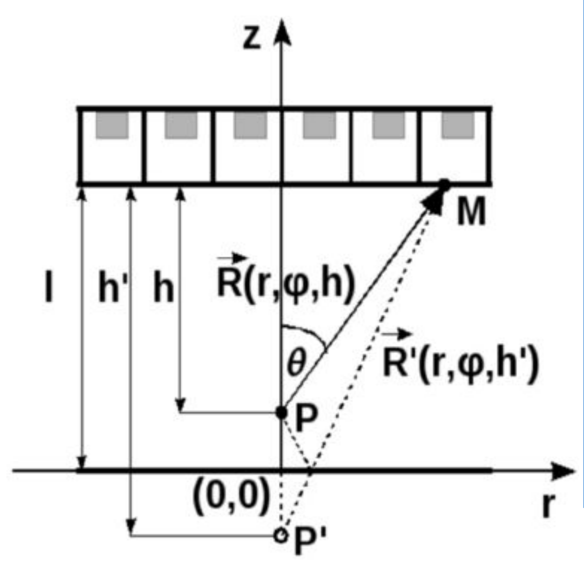
CMOS silicon sensor PHASE2 MIMOSA 23 [2]

- 640×640 pixels
- Pitch: 30μm
- Rolling shutter
- 640μs/frame

Scintillators were mounted to the Prototype: (P)resence (F)ront (B)ack (H)orizontal x (V)ertical

The FoCal prototype was built and tested with group of Bergen University.

Simulation



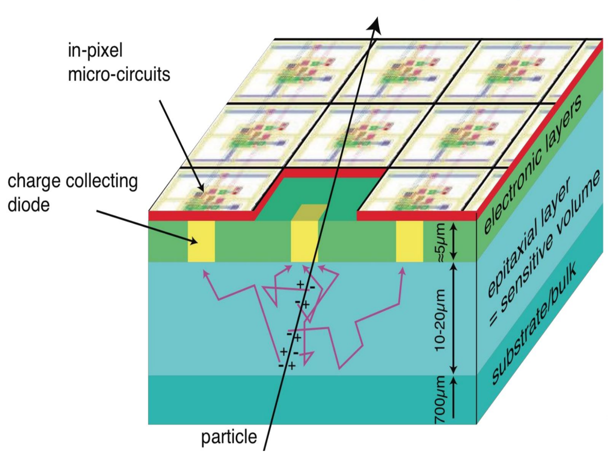
A charge diffusion model [3] was added to Geant 4 simulation.

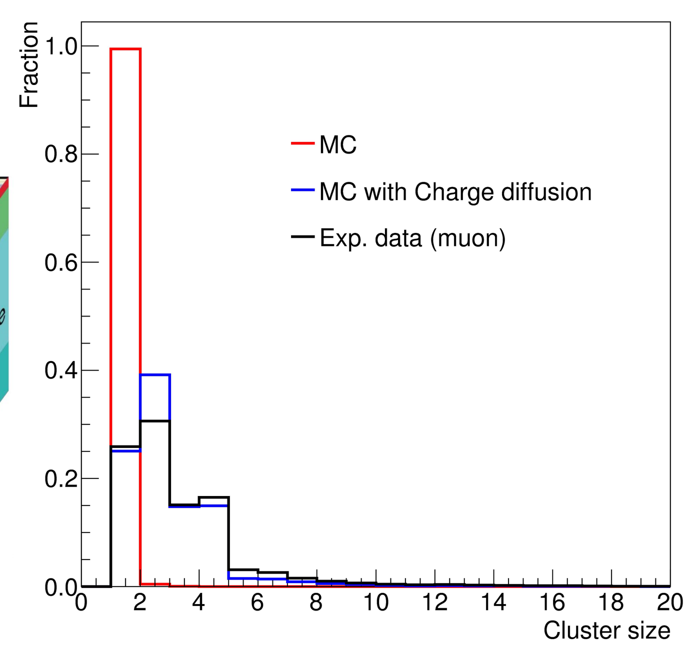
Charge distribution function:

$$d\rho(r,\varphi,h) = \frac{d\Omega}{4\pi} \cdot \exp\left(-\frac{R}{\lambda}\right) = \frac{1}{(4\pi L)} \frac{hr}{(h^2+r^2)^{3/2}} \exp\left(-\frac{\sqrt{h^2+r^2}}{\lambda}\right) dr\, d\varphi\, dh$$

Assumes: **isotropic diffusion**, **attenuation** due to recombination with attenuation length λ

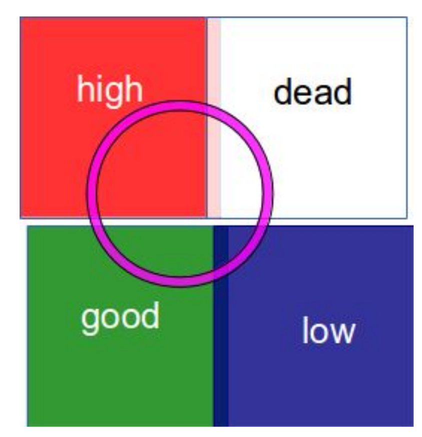
CMOS sensor principle





Cluster size distribution for MIPs. The parameters (λ and threshold) are found by comparison to the experimental data

Correction



- Sensor sensitivity correction
- Dead area correction

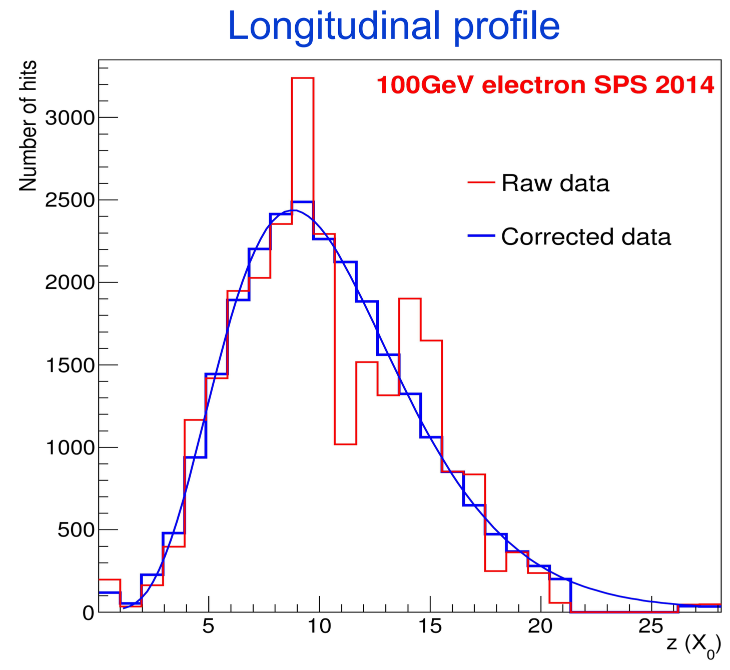
Hit density ρ(r) → Normalization ρ(r)·S → The number of hits in this ring → Accumulation → The number of hits in this layer

The above procedure can be described as

$$N = \sum_{i=0}^{3} c_i \int 2\pi r \rho_i(r)\, dr$$

c_i is the sensor sensitivity factor
$\rho_i(r)$ is the hit density at distance to the shower axis r

Longitudinal profile



Sensor sensitivity correction performed in two steps:

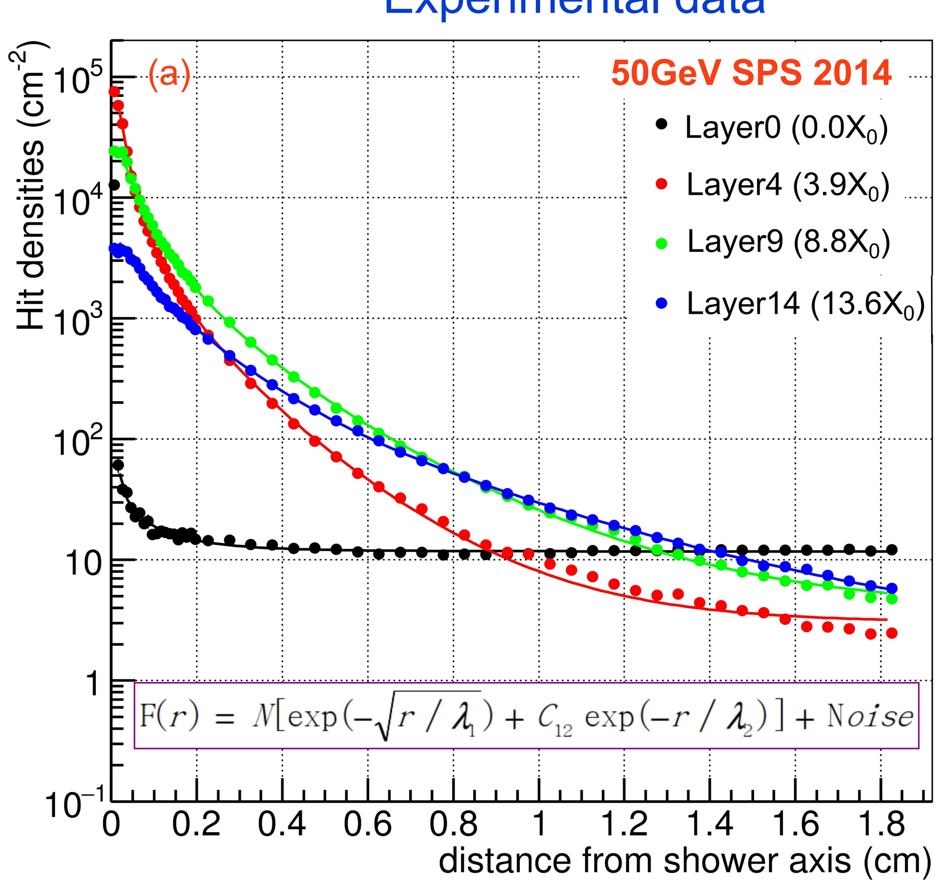
1) Normalize the relative sensitivities in the same layer.

2) Correct layers to obtain a continuous longitudinal shower profile by Gamma function fitting.

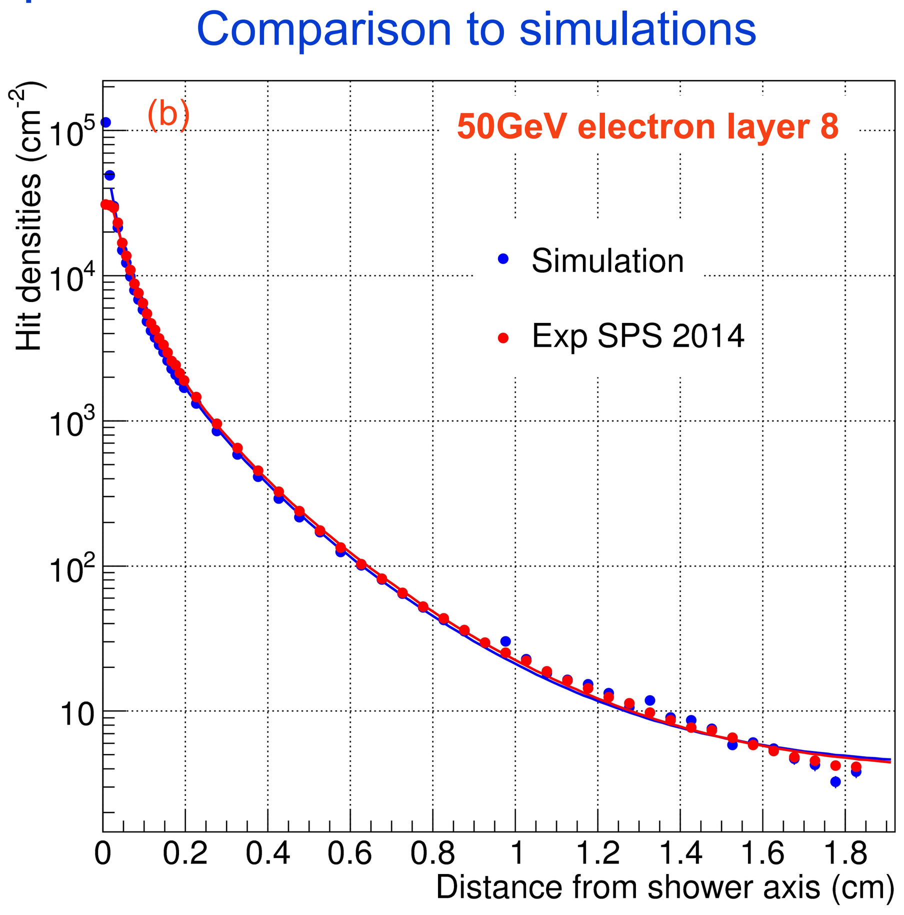
Results

Lateral profile

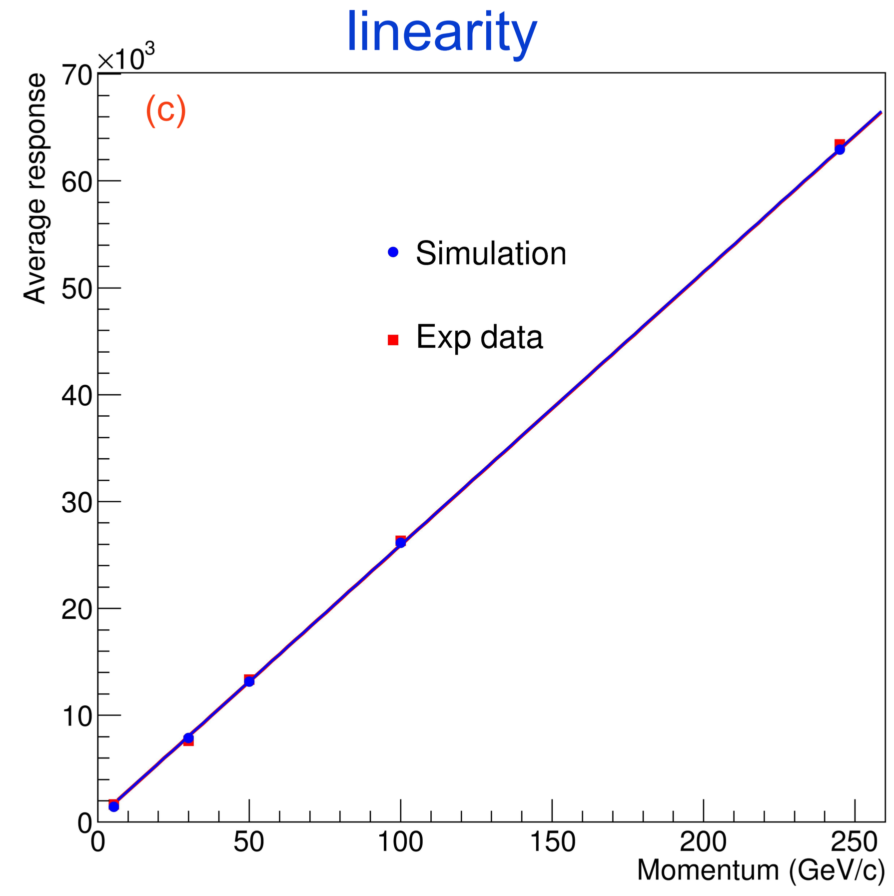
Experimental data



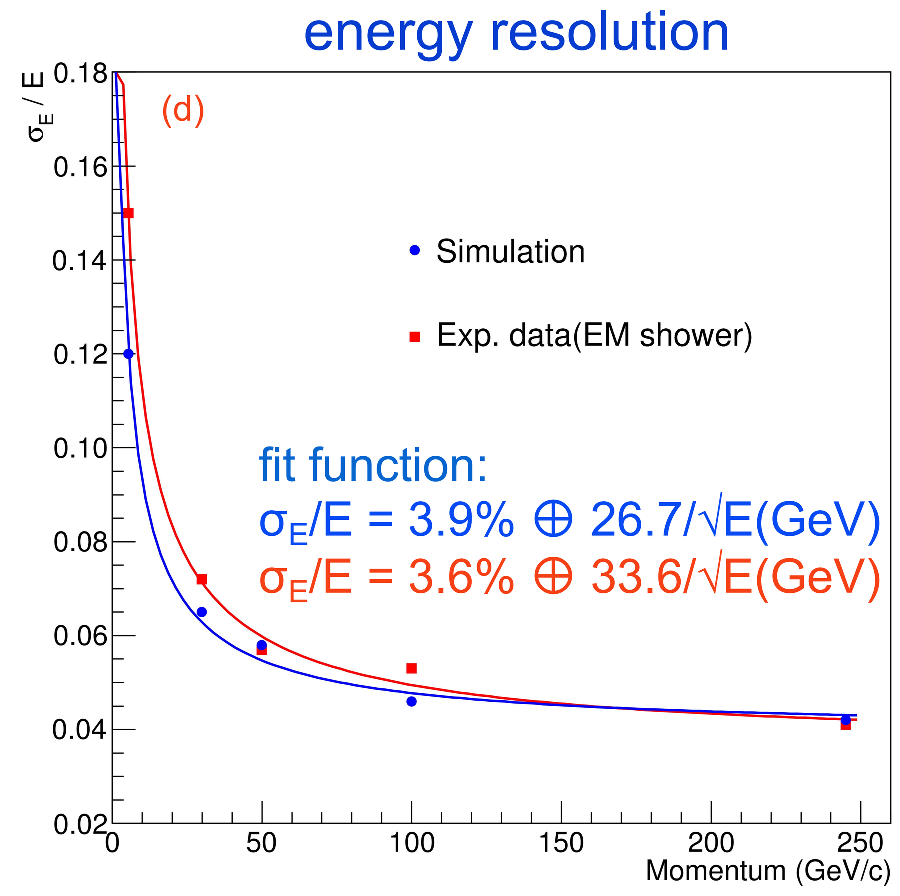
Comparison to simulations



linearity



energy resolution



Examples of transverse hit density distribution in different layers (i.e. depth)

Good agreement between experiment and simulation for (b) lateral profile, (c) linearity, (d) energy resolution. Charge diffusion is crucial in the description.

Conclusion

- A high granularity digital Si-W calorimeter prototype for FoCal has been built and tested.
- Very small Molière radius (11±0.5mm) has been measured.
- Unique high resolution lateral shower profiles have been obtained, narrow shower shape will allow very efficient two-shower separation.
- An additional charge diffusion model works well to improve the description in Geant 4 simulations.
- Sensor sensitivities and dead area have been corrected for.
- Performance of our prototype agrees reasonably well with the simulation.

Reference

[1] T. Peitzmann, Proceedings of CHEF 2013, preprint arXiv:1308.2585.
[2] PHASE-1 User Manual, Strasbourg, http://www.iphc.cnrs.fr/List-of-MIMOSA-chips.html
[3] Digitalisation for the Geant4 simulation of the MAPS pixel detectors, Łukasz Mączewski, Warsaw University