CLIC Workshop 2017

Studies with the CMS Silicon Tungsten HGC Using 2016 Test Beam Data

On behalf of the CMS HGCal Test Beam Working Group

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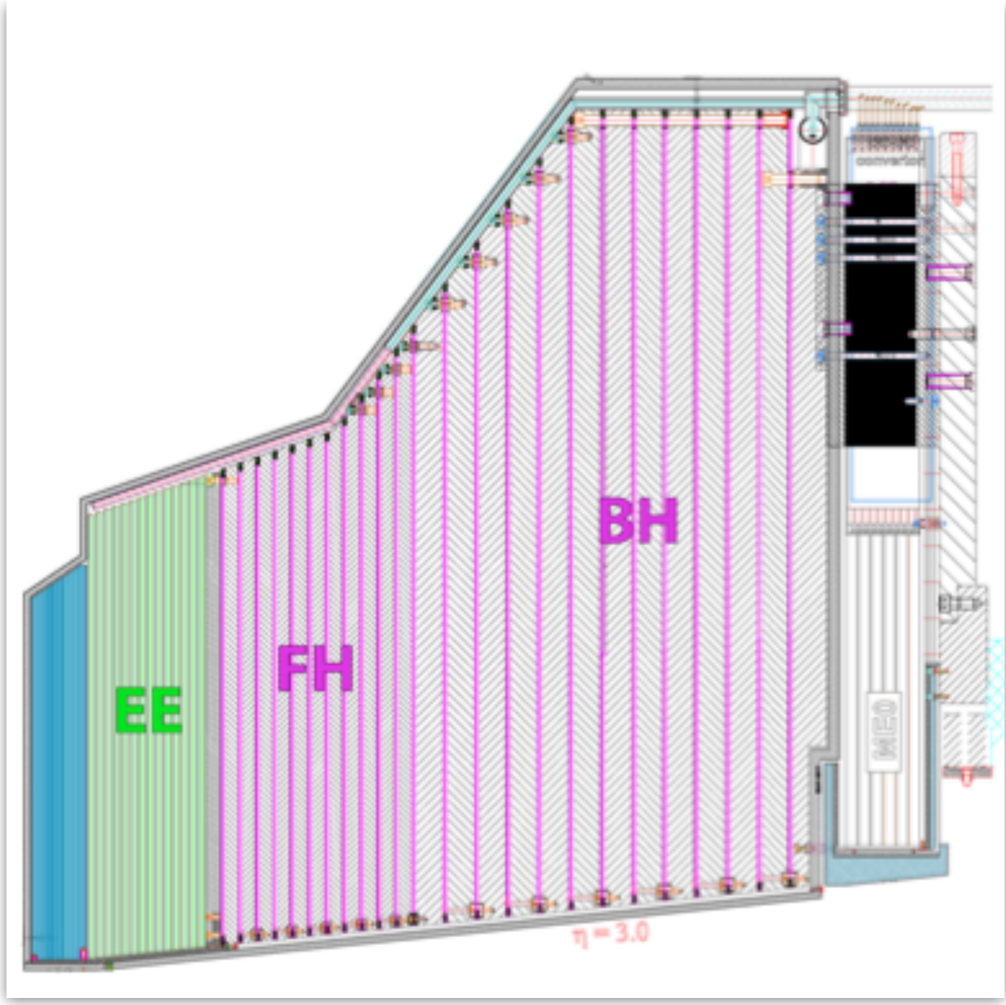
3/7/17

EE Elements Tested in 2016



	Sensor	Absorbers	Sampling layers & depth
EE	silicon	Cu, CuW, Pb	28: 25 X_0, ~1.3 λ
FH	si. & scint.	stainless steel	12: ~3.5 λ
BH	si. & scint.	stainless steel	12: ~5 λ

Active Elements:

- **Silicon sensor based hexagonal modules in high-radiation regions.**
- Scintillators with SiPM readout in low-radiation region.
- **Multiple modules mounted on cooling plates with electronics and absorbers.**

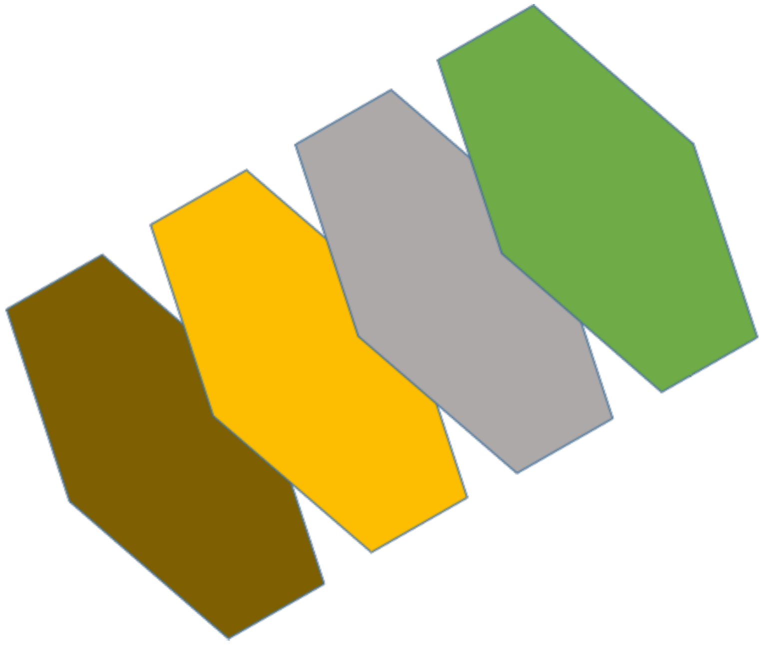
➡Fine-grained calorimetry both for the CMS endcap calorimeter and CALICE prototypes.

Differences between the concepts:

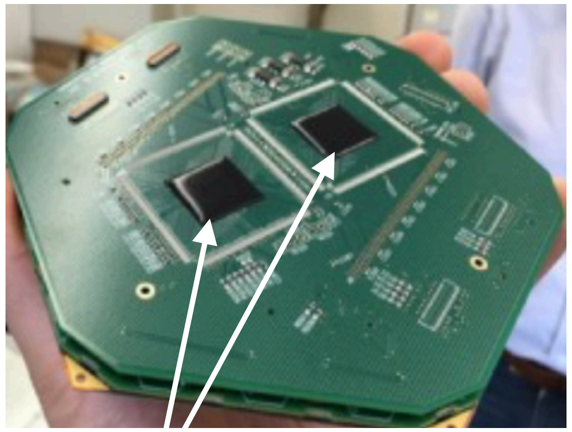
- Radiation environment: HGCal requires cooling at -30° C.
- Collision frequency: Bunch crossing at 25ns does not allow for power pulsing.
- Pileup: Timing in HGCal critical to mitigate pileup effects.

Prototype Assembly in 2016

Module assembled as glued stack of **baseplate**, **Kapton**, **Si sensor** and **PCB**.

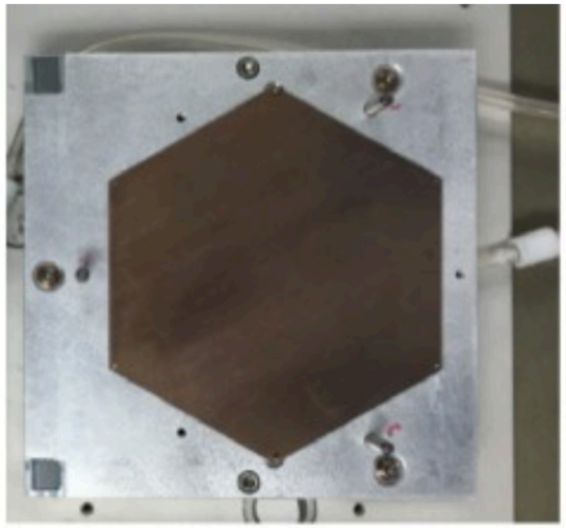


PCB

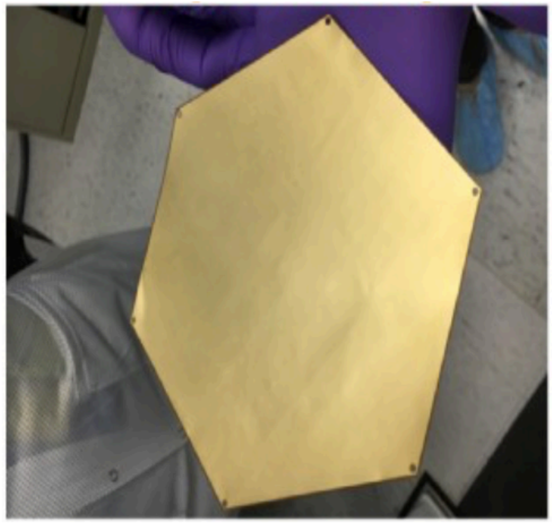


SKIROC2 ASIC
(64 ch., 2 chips/module)
Developed for CALICE.

CuW baseplate



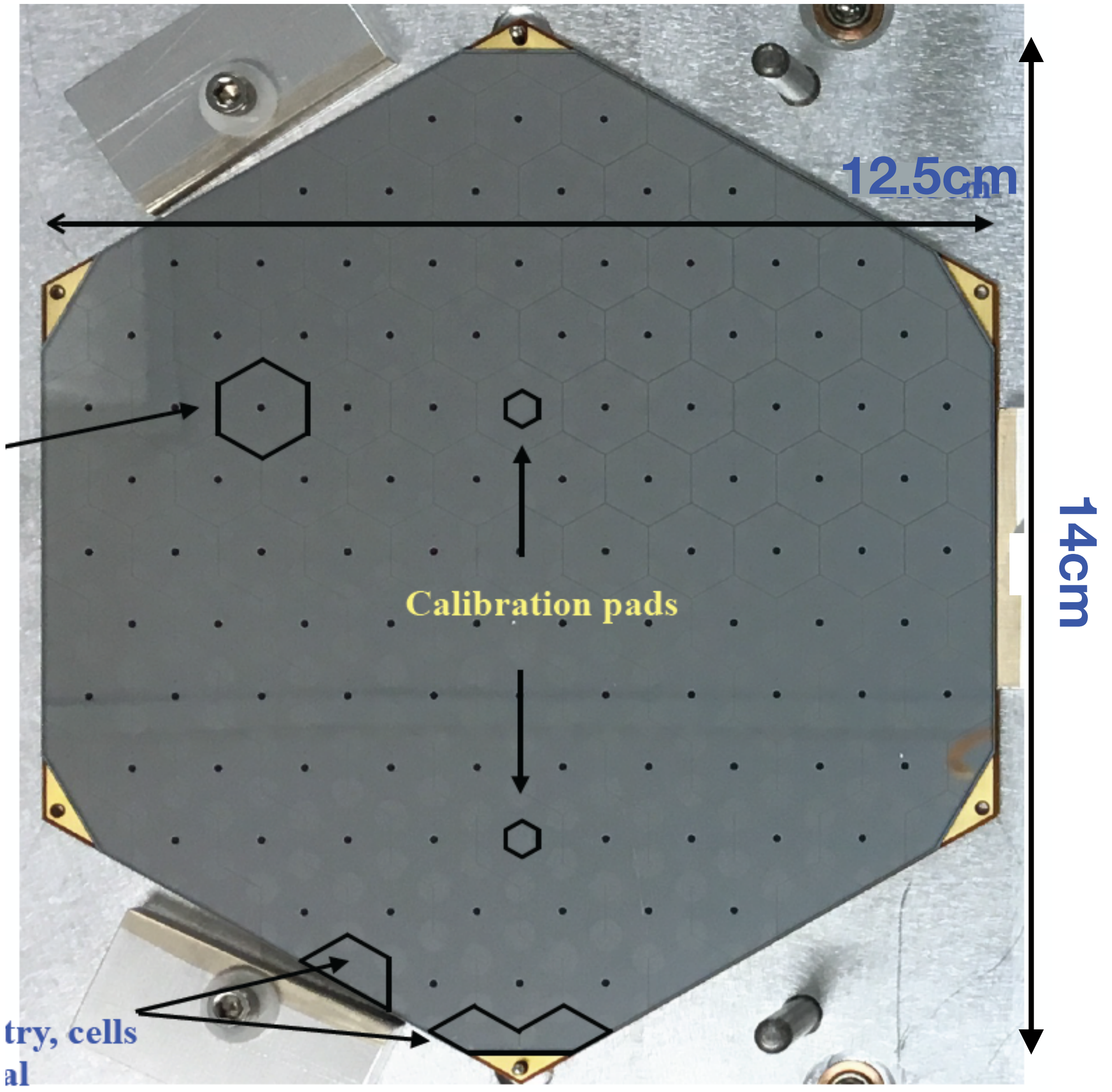
Gold plated kapton



Si sensor

128 channels sensors from 6” wafers:

- n-type
- 1 cm^2 cell-size
- 200 µm depleted region

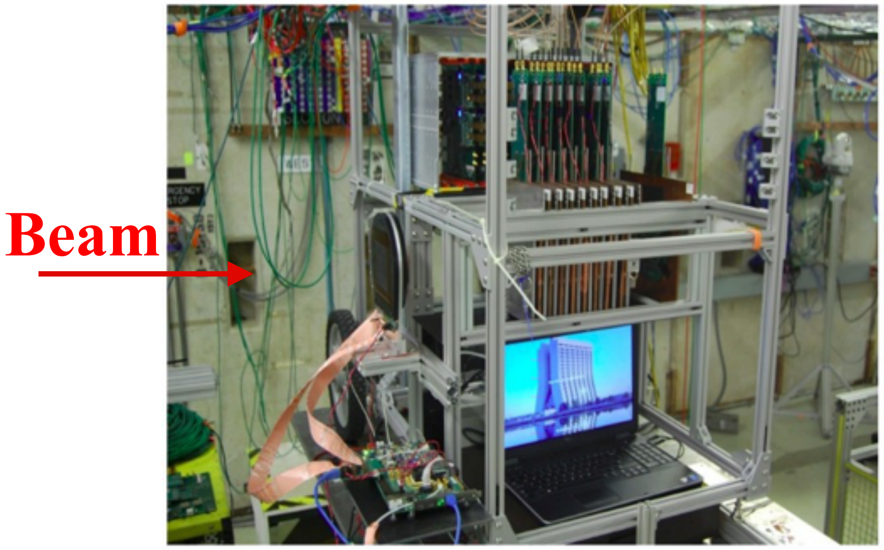


Test Beam Setups at FNAL and CERN

- Common effort between CERN and FNAL in test beams 2016.

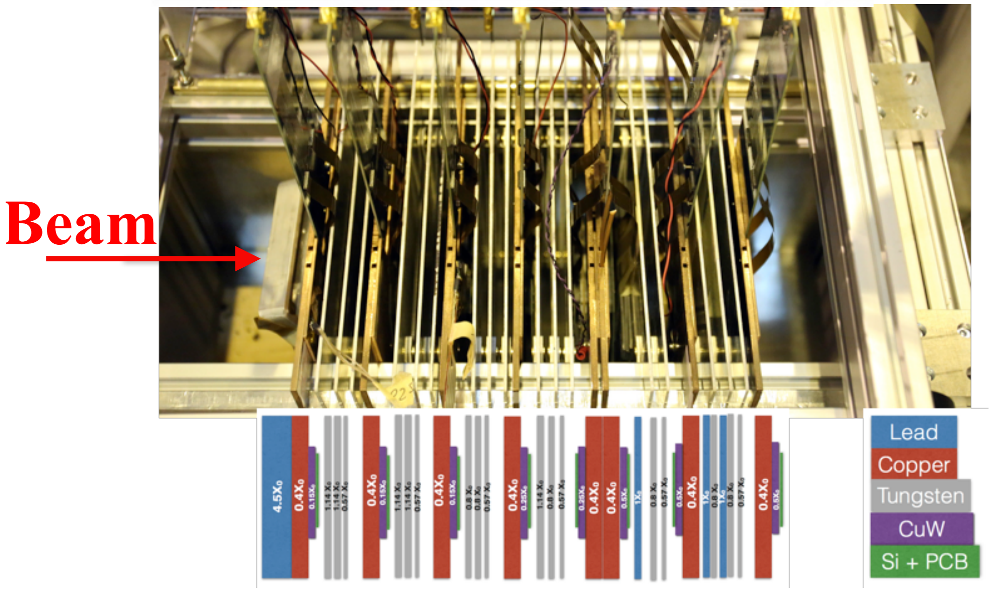
Fermilab

- Up to **16 HGC** modules tested.
- **Electron** beam with **4-32 GeV**.
- **0.6-15 X_0** absorber configuration.
- 120 GeV protons.



CERN

- Up to **8 HGC** modules tested.
- **Electron** beam with **20-250 GeV**.
- **6-15 X_0 & 5-25 X_0** absorber configurations.
- 125 GeV muons and pions.

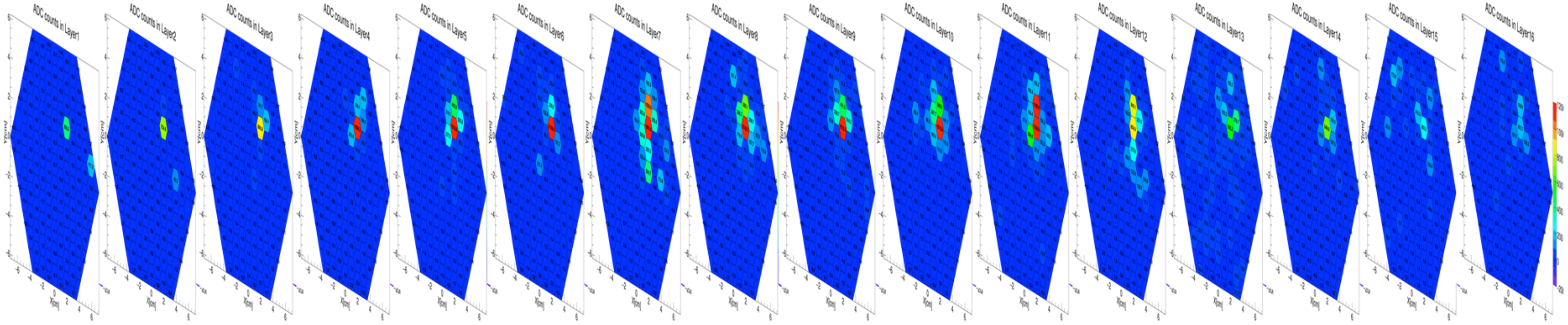


- Goals for test beams 2016:
  1. Proof of concept of the proposed design.
  2. Study calorimetric performance, spatial precision and timing resolution.
  3. Comparison of results to simulation.

Event Displays for Electron Induced Showers

Fermilab: **32 GeV electrons** passing through **15 X_0**.

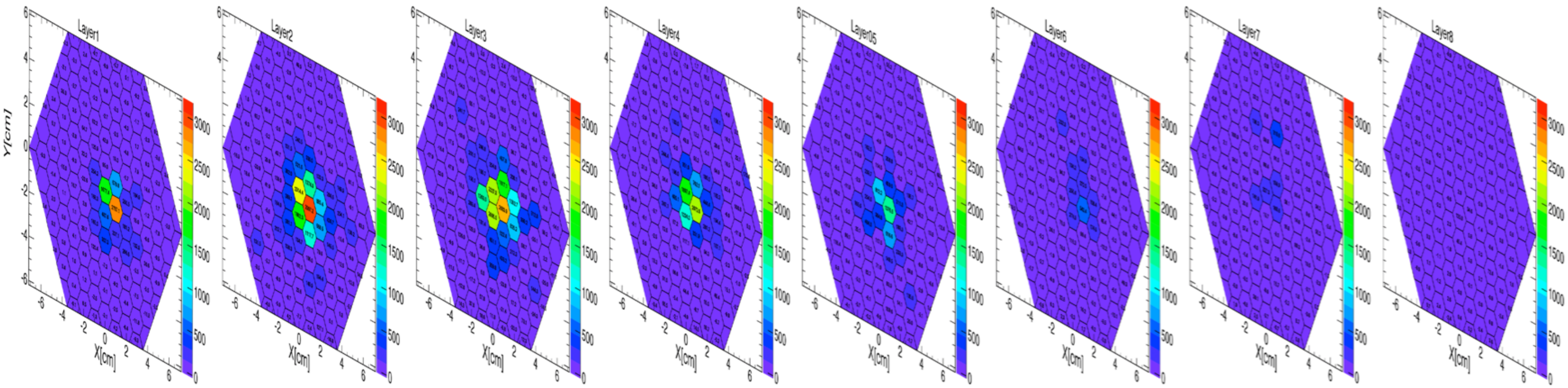
e^-
32 GeV
→



0.6 X_0 **15 X_0**

CERN: **250 GeV electrons** passing through **27 X_0**.

e^-
250 GeV
→



5 X_0 **8.5 X_0** **12 X_0** **15 X_0** **17 X_0** **19 X_0** **21 X_0** **27 X_0**

Many Studies Performed

- **Pedestal and noise stability:**
  - For each channel and as a function of time.

- **Electronic gain:**
  - Determine saturation in High Gain to find optimum switchover point to Low Gain.

- **MIP calibration:**
  - With and without signal event selection using tracking techniques.

- **Energy reconstruction:**
  - Different energy reconstruction schemes studied, e.g. with and without “dE/dX-weighting”.
  - Energy linearity and resolution.

- **Shower profiles:**
  - Transverse shower width, e.g. through energy fractions of different energy sum radii.
  - Longitudinal shower depth, e.g. through energy-weighted sum of depths.

- **Explore imaging capabilities:**
  - Spatial precision.
  - Timing resolution.

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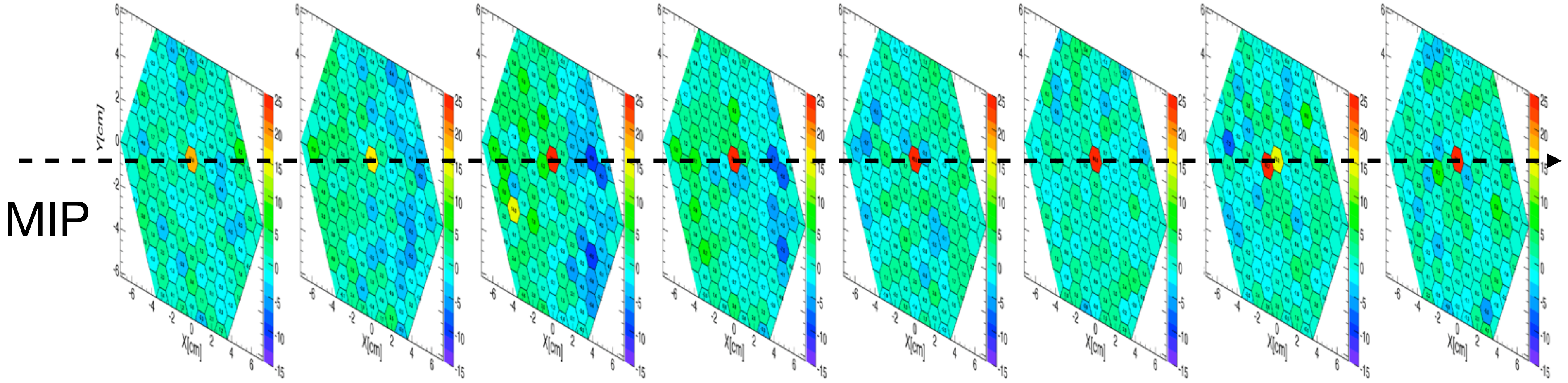
Energy Calibration with Pions

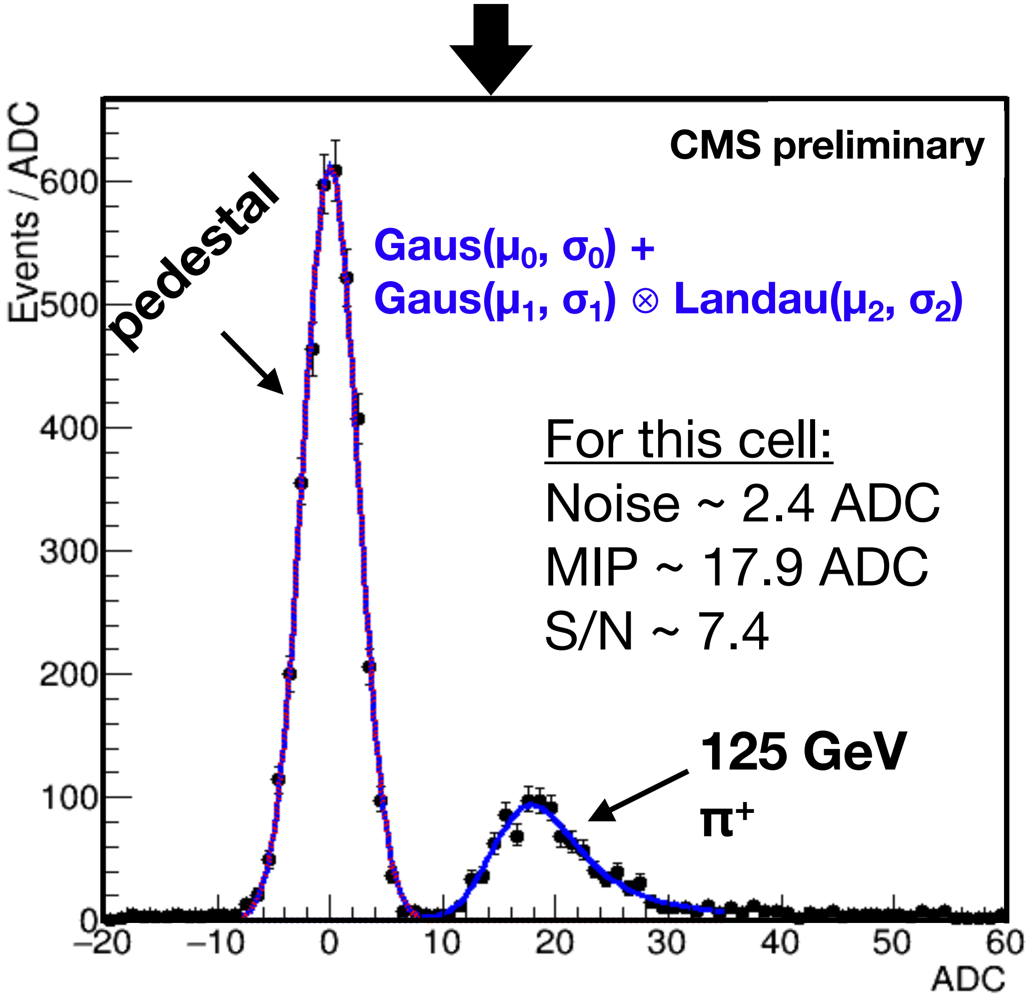
MIP calibration = response to single muons / pions / protons.

- Energy response intercalibration of cells.

CERN:
125 GeV π^+ beam



ADC count distribution for each cell:

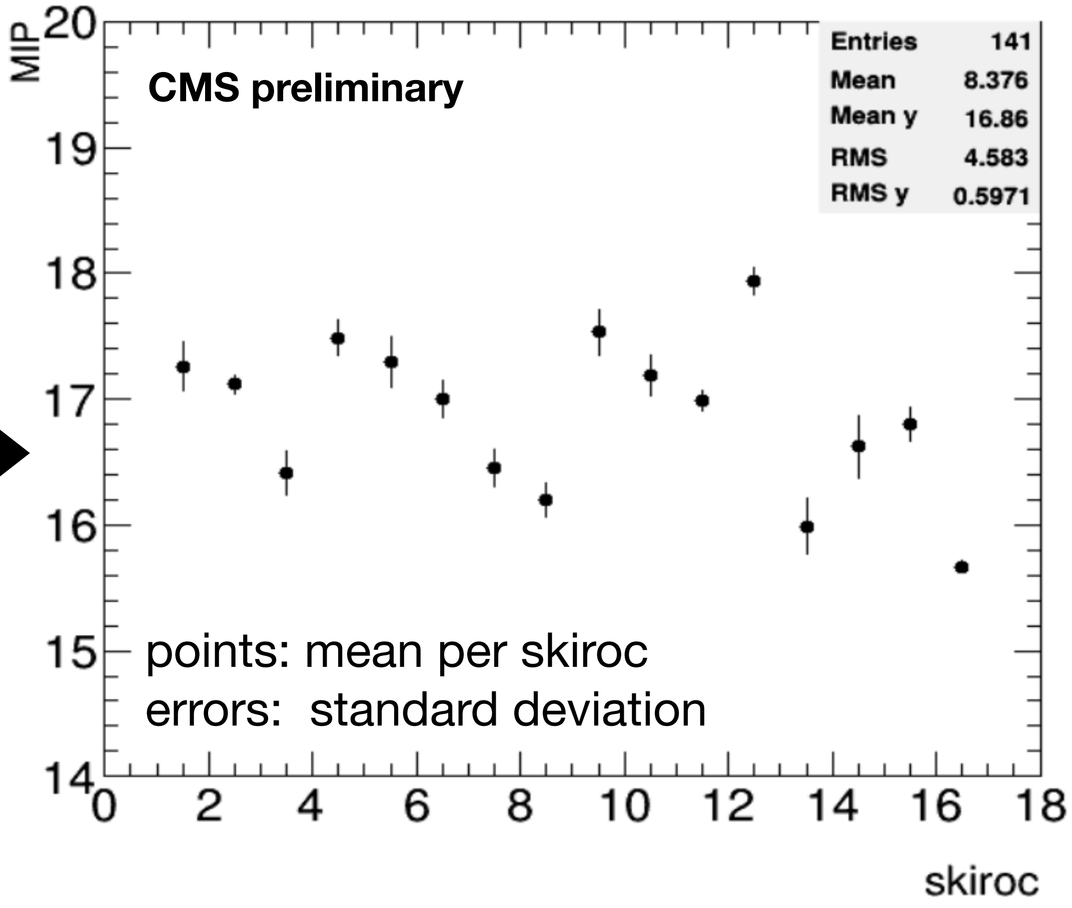


Gaus(μ_0, σ_0) +
Gaus(μ_1, σ_1) ⊗ Landau(μ_2, σ_2)

For this cell:
Noise ~ 2.4 ADC
MIP ~ 17.9 ADC
S/N ~ 7.4

Averaging

only cells with sufficiently high signal



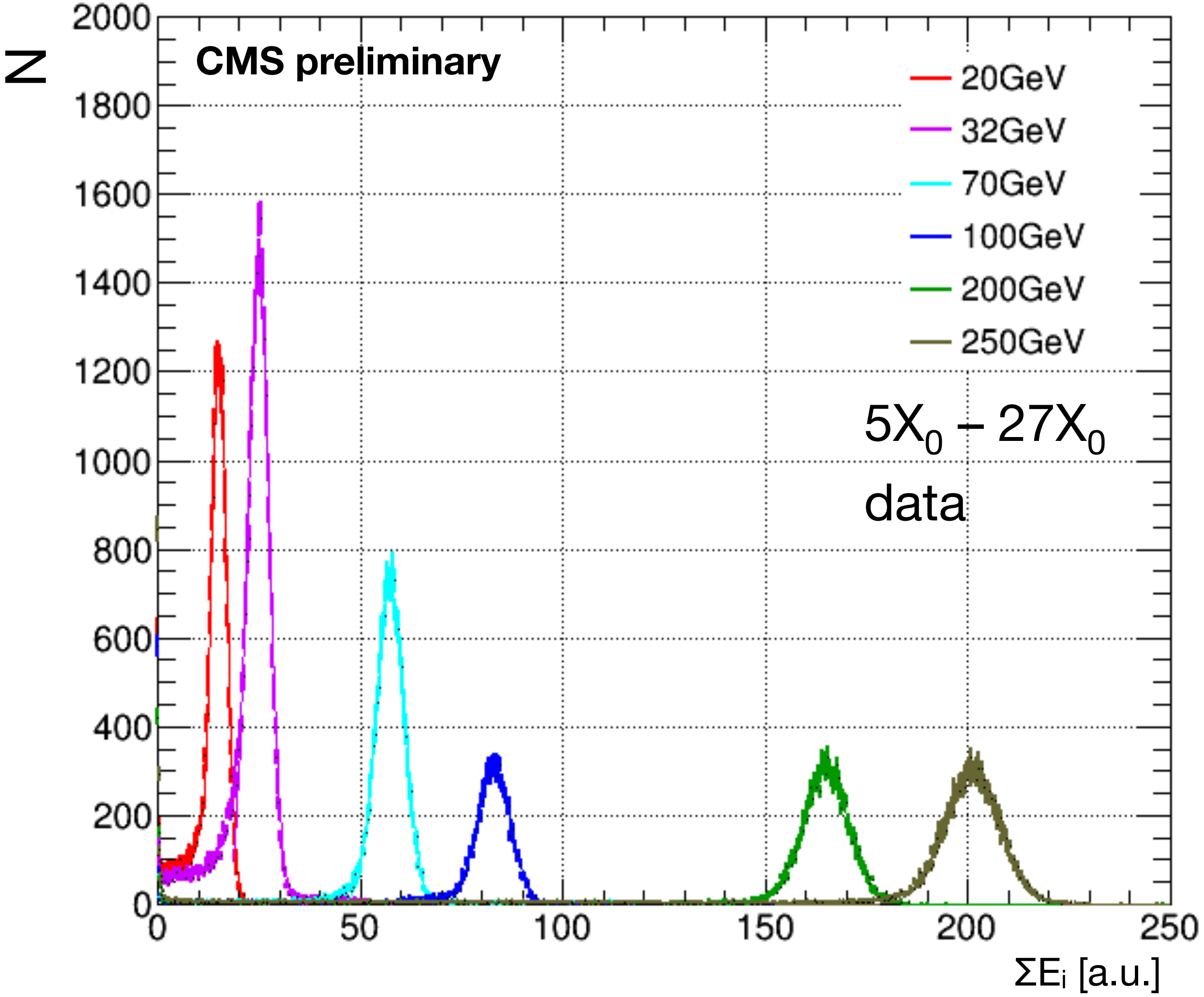
points: mean per skiroc
errors: standard deviation

Energy Reconstruction

Procedure:

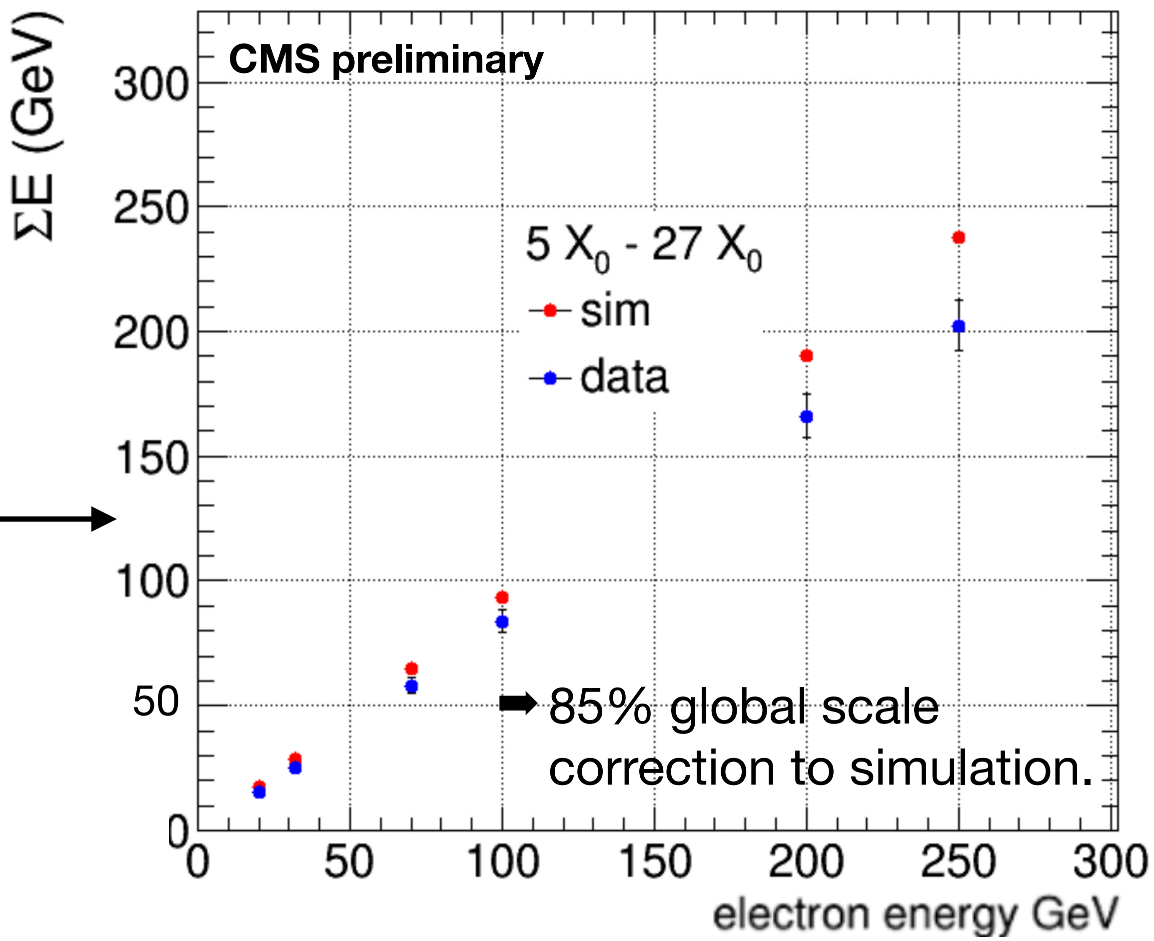
1. Subtract pedestals for each cell.
2. Cut on cells with less than 2 MIPs in an event, exclude types with unstable noise.
3. Sum of energy deposits over all cells. ⟵ *Other summing schemes were studied.*
4. Correct for losses in the absorbers. ⟵ *dE/dx based weighting of layer contributions. Assumes: Ionisation dominates.*

Reconstructed Energies



⟶

Energy Scale



➡ 85% global scale correction to simulation.

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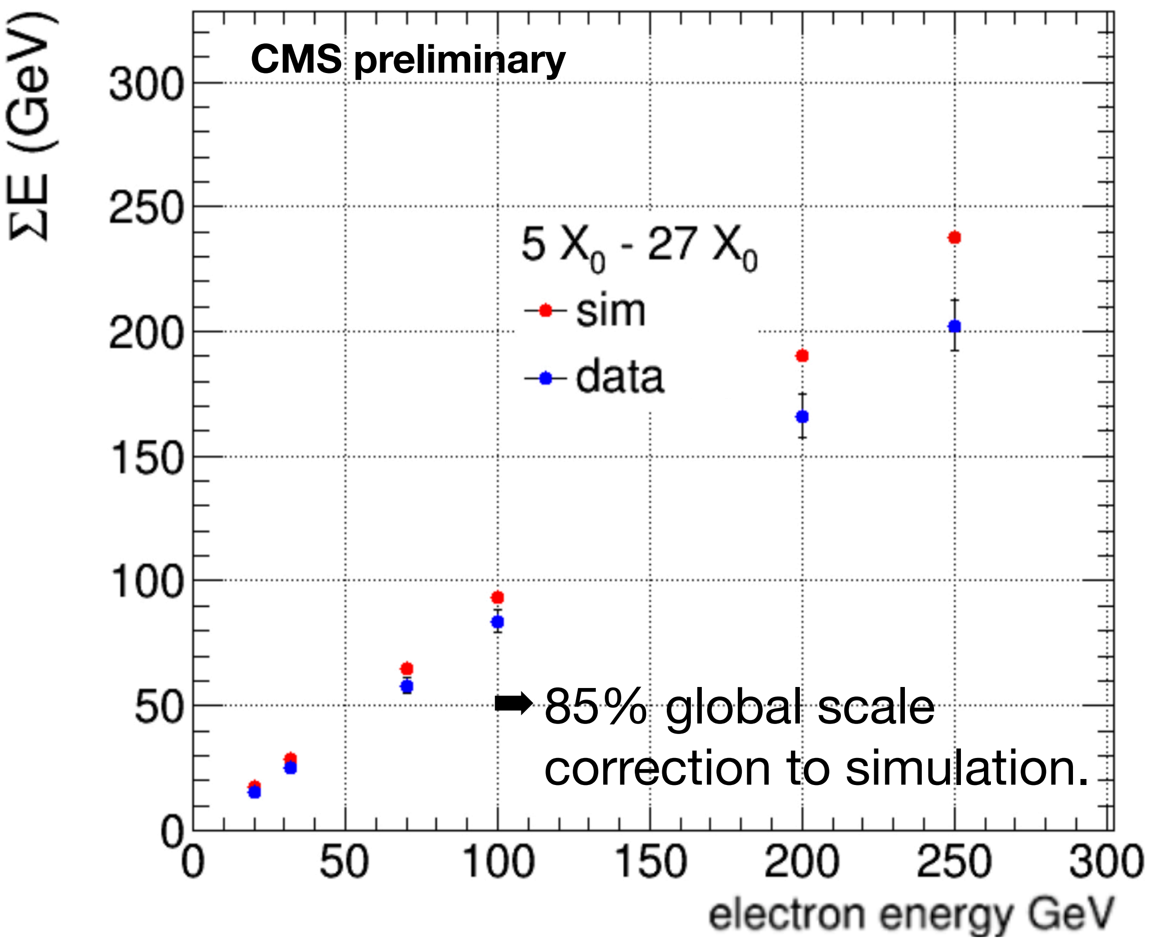
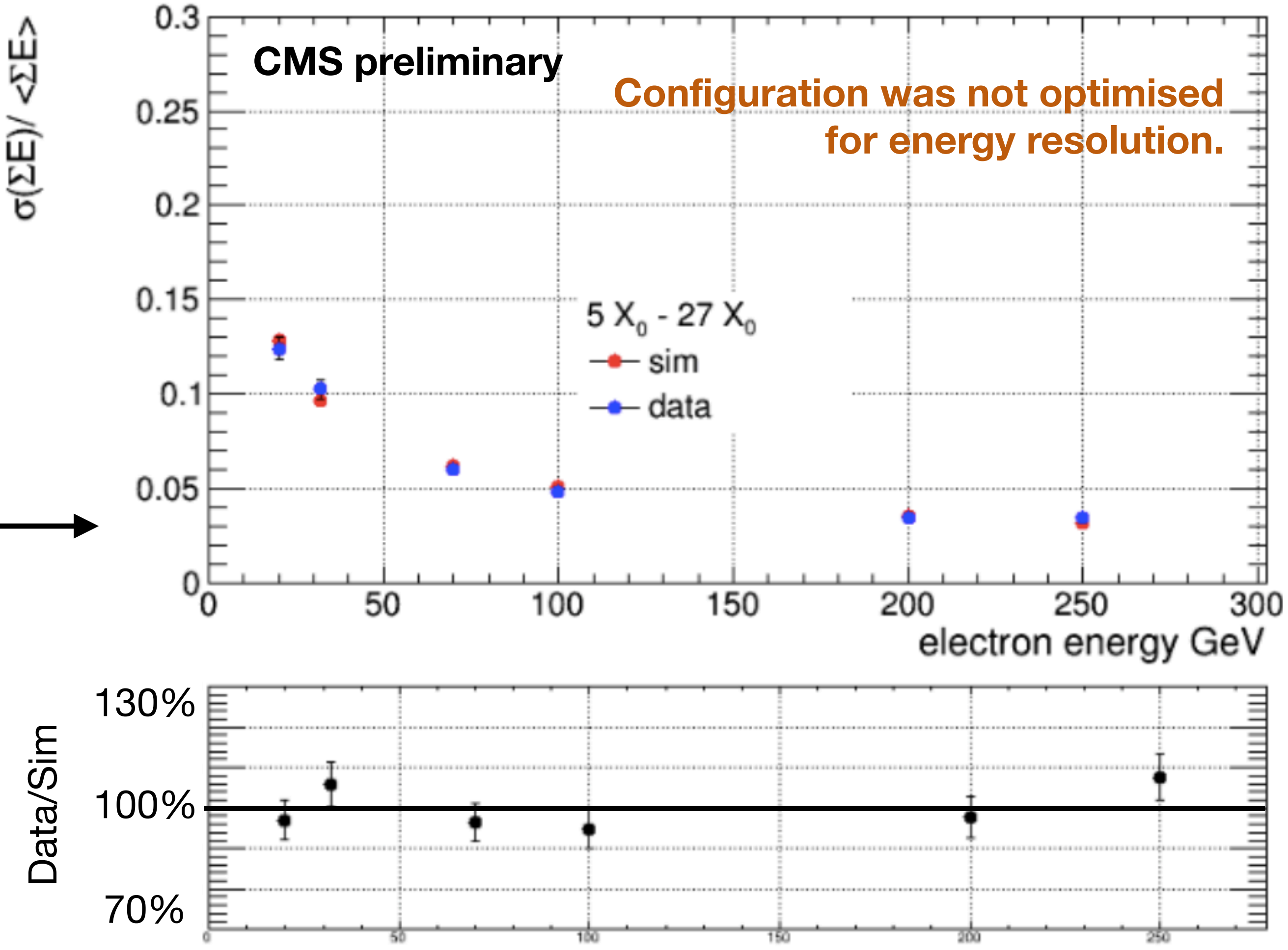


➡ 85% global scale correction to simulation.

⟶

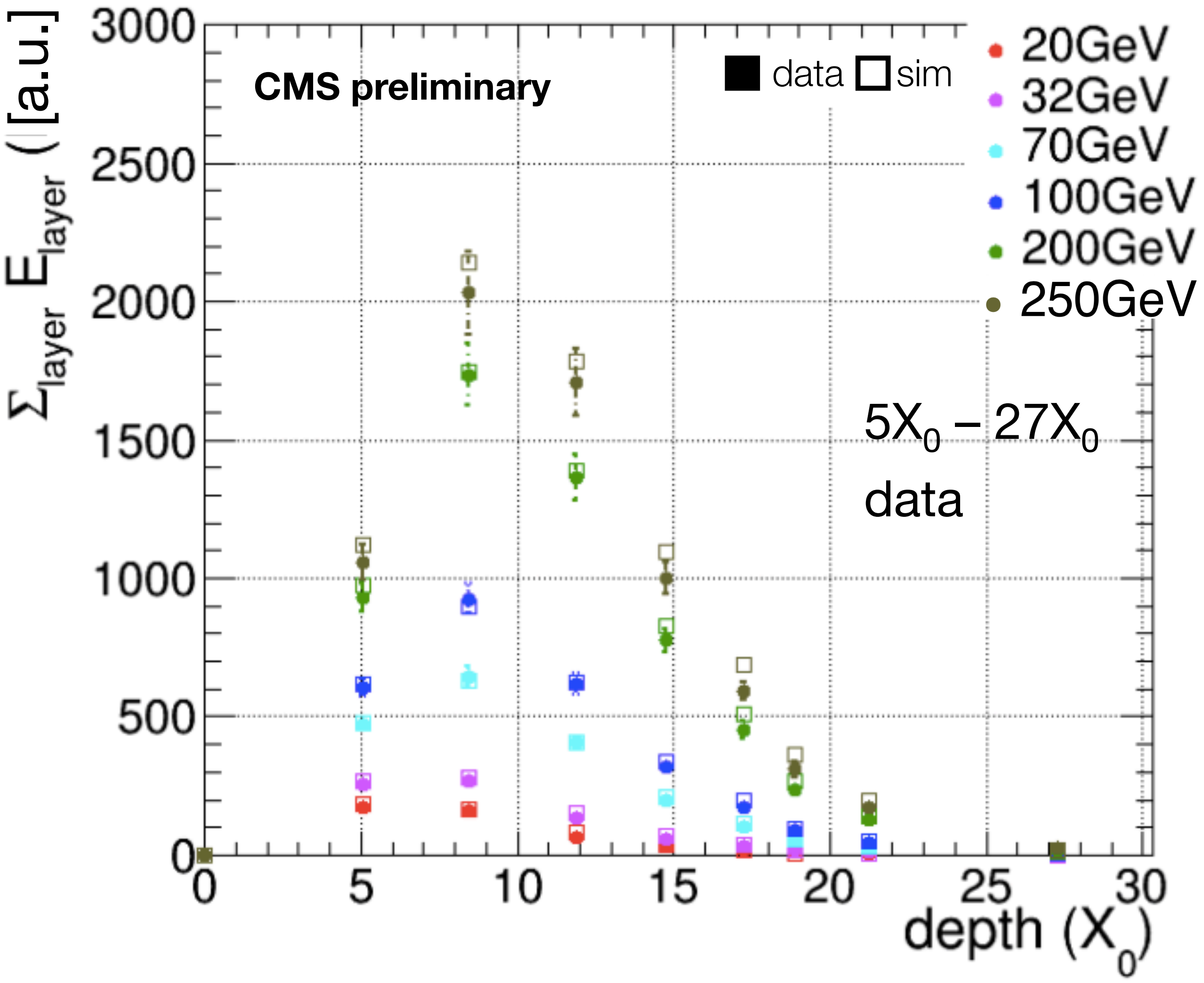
Energy Resolution



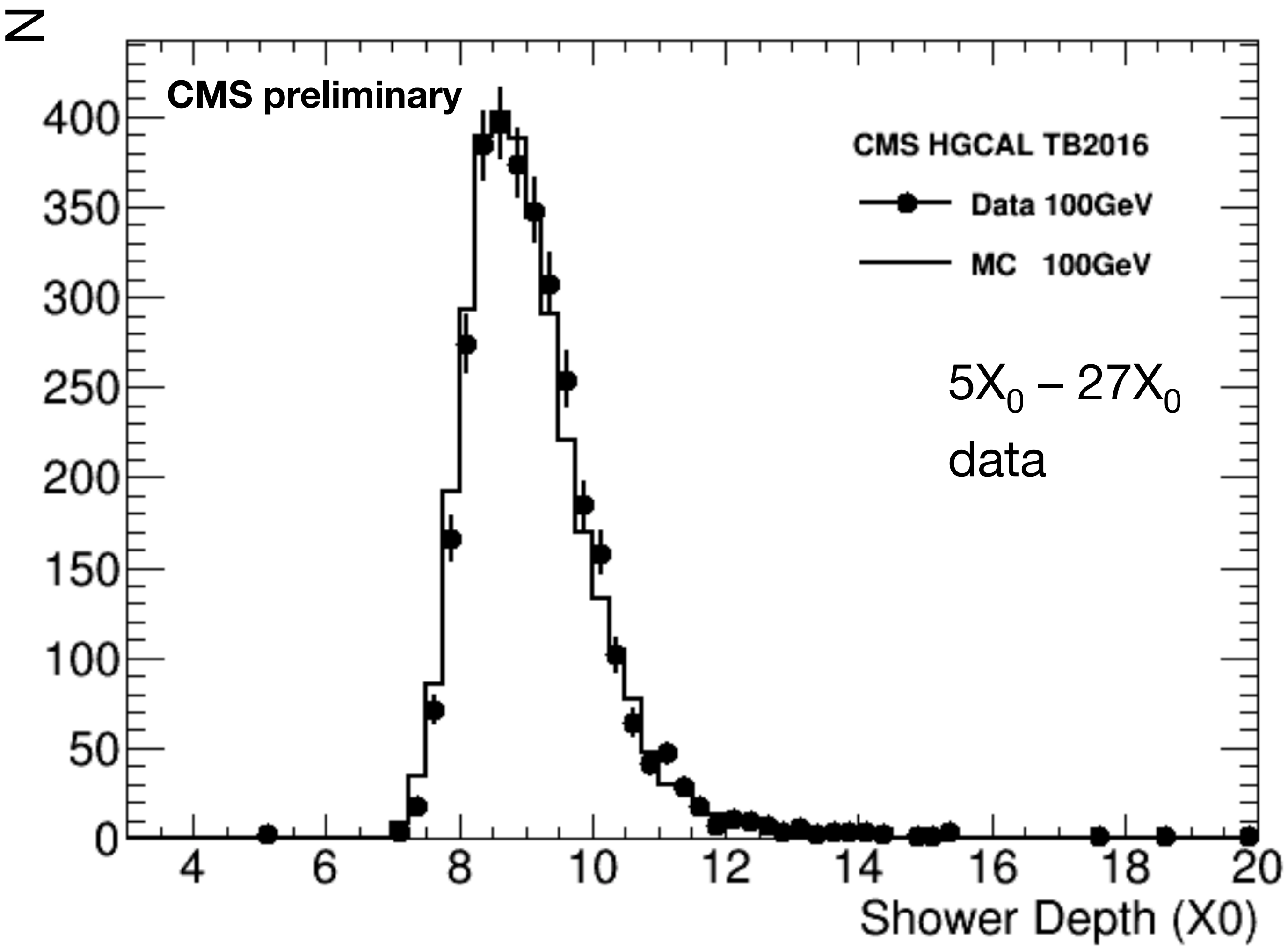
Configuration was not optimised for energy resolution.

Longitudinal Shower Depth

Deposited energy per layer



Shower Depth



➡ Shower maximum dependence on electron energy.

- Shower depth
  $= \Sigma X_{0,layer} \times E_{layer} / \Sigma E_{layer}$.

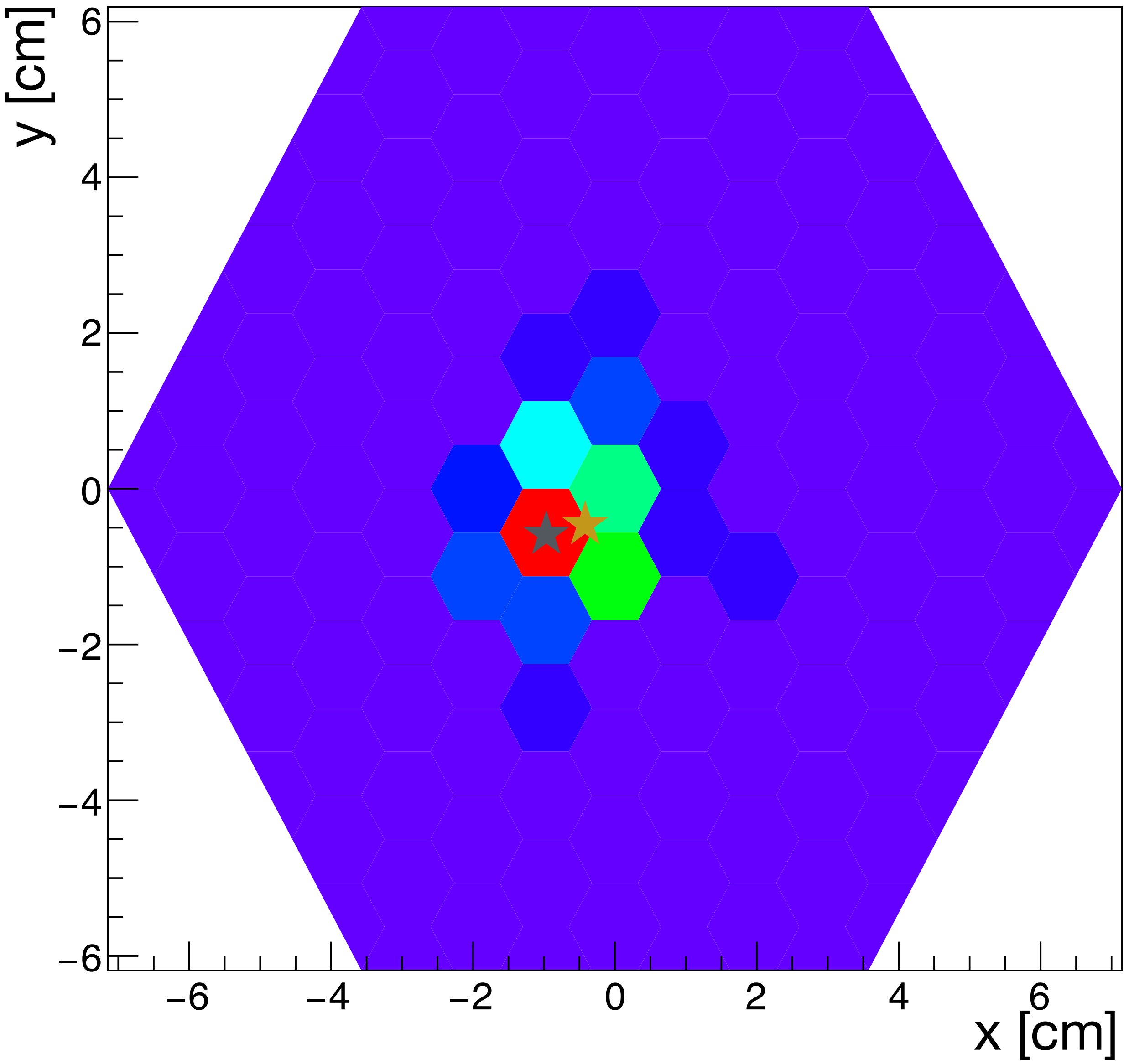
Definition of Spatial Precision

Study performed on the 6 - 15 X_0 setup at CERN.

Spatial precision:

Which information can be extracted from the electron data w.r.t. the shower position resolution?

A 200 GeV electron induced shower in the third layer



What is the shower's main impact position ?

Impact position reconstruction:

Option A:

most intense cell

Option B:

$x_{weight} \sim \Sigma_i^{layer} w(E_i) \times x_i$

Comparison to extrapolation from straight line fit to delay wire chamber reference.

Residuals:

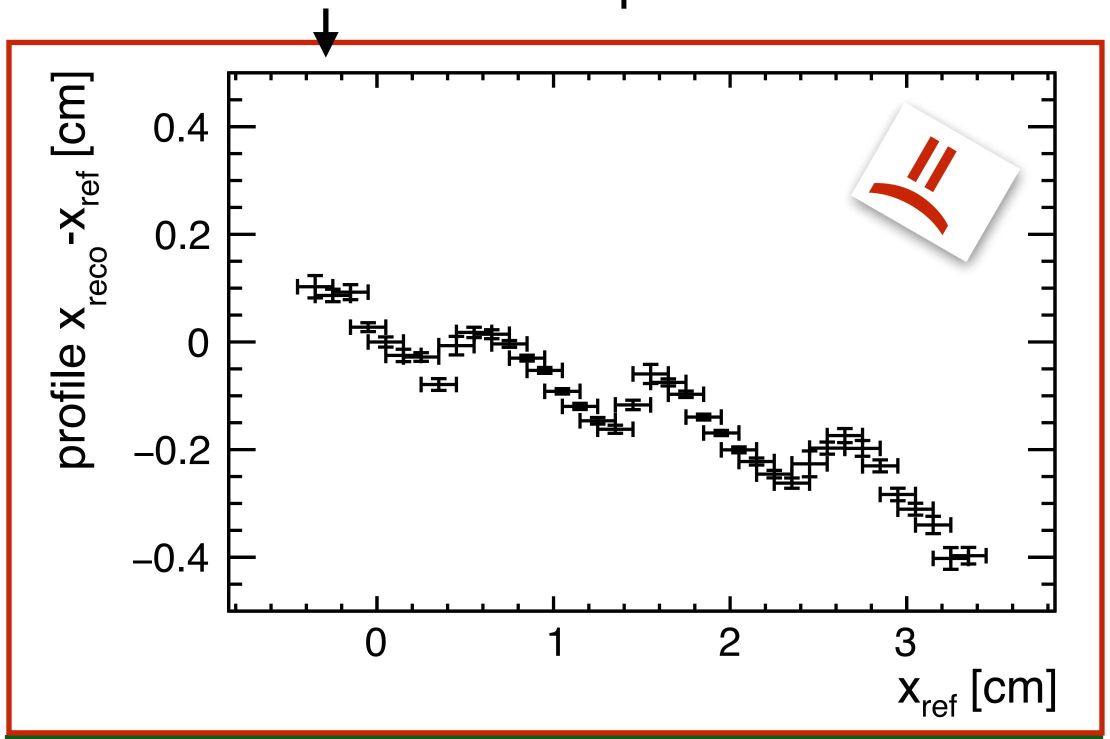
- Widths as spatial resolution.

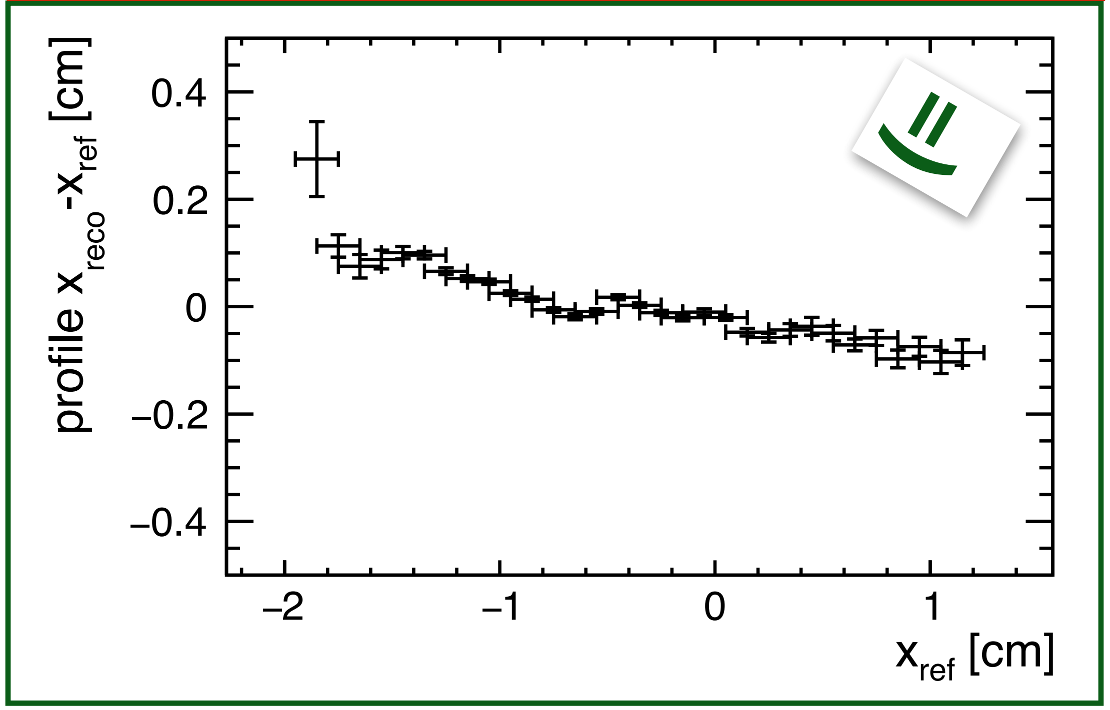
Expect better resolution than cell diameter/√12.

Spatial Precision: Reconstruction and Results

Tune reconstruction scheme:

- Minimize residual width.
- Reduce bias towards preferred coordinates.

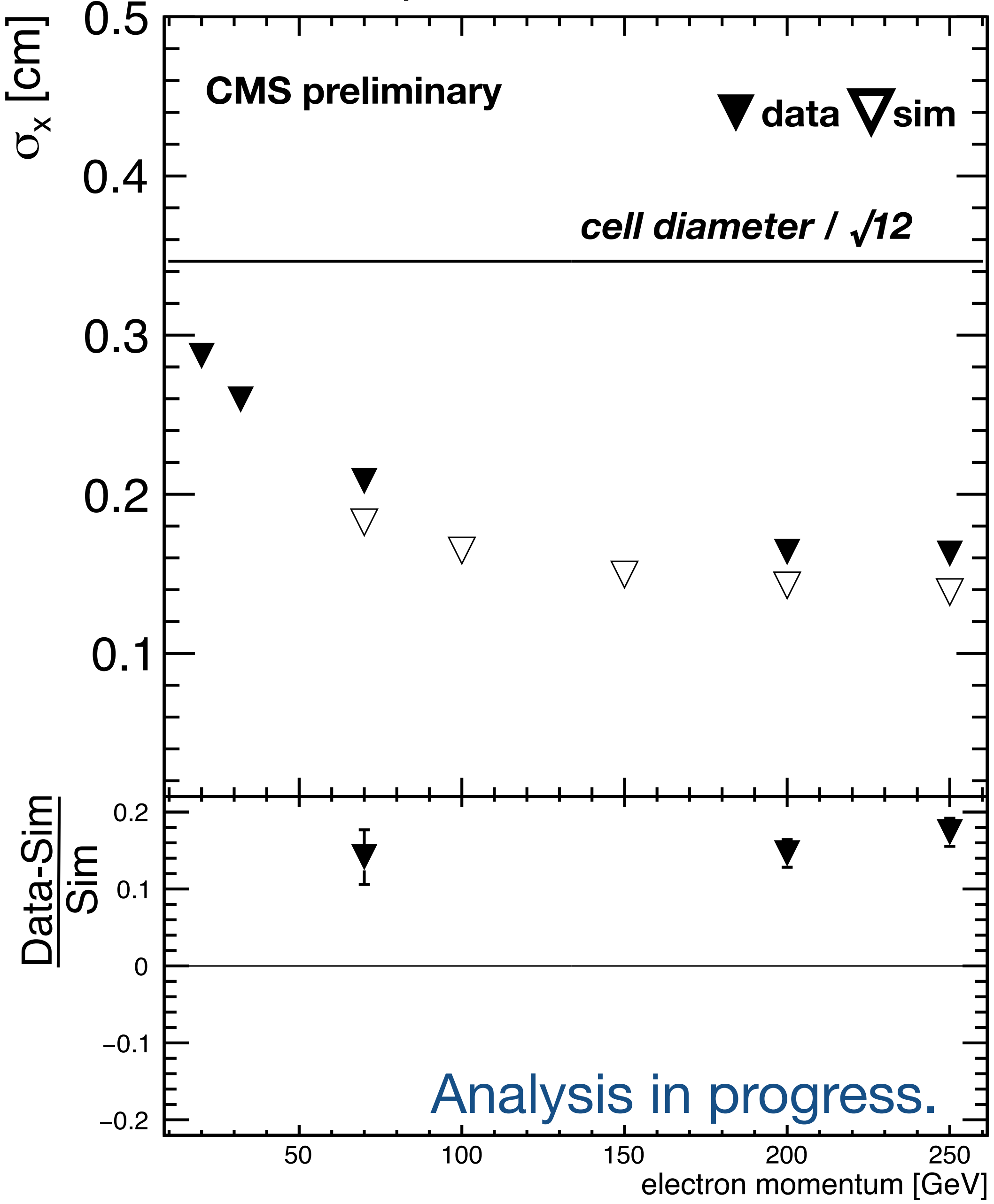




Evaluate widths of residual histograms:

- Both coordinates (x/y).
- All eight layers.
- All energies.

Spatial resolution after 6 X_0



Analysis in progress.

Timing Resolution

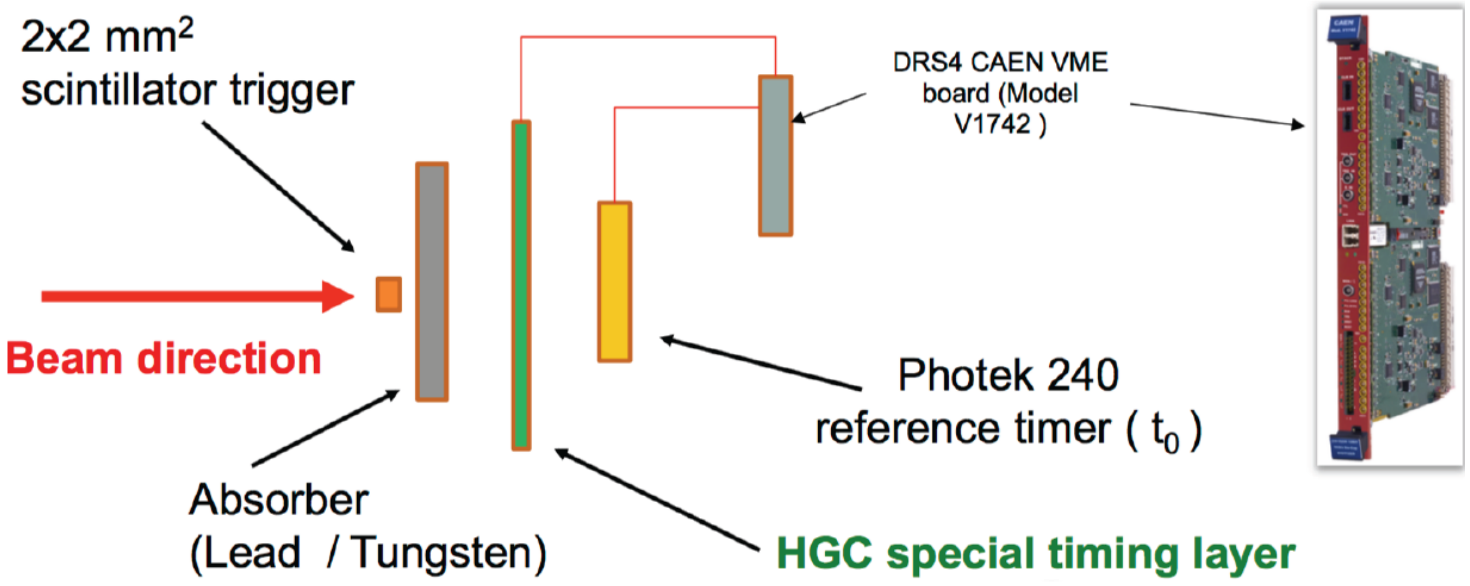
Initial study at FNAL.

Purpose of a good timing resolution:

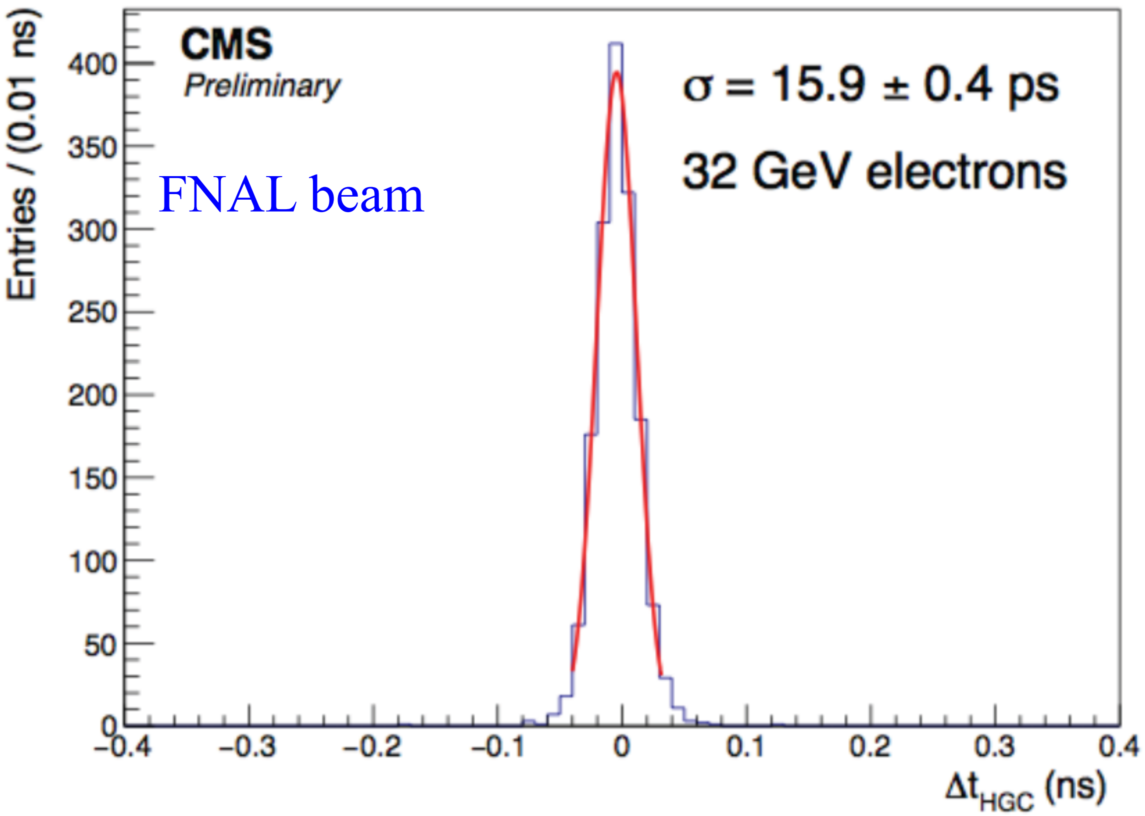
Use precision timing of EM shower for pileup energy removal.

➡ Reduction of impact of pileup.

Timing test with 300 μm HGC layer with fast readout:



Comparison of time stamps in HGC timing layer vs. Photek MCP-PMT



Results with 32 GeV e$^-$ test beam:

➡ Precision around 16ps.

➡ Scaling with S/N.

Energies up to 250 GeV at CERN last November:

- Analysis ongoing.
- Expect better resolution with higher S/N, usage of multiple cells.

Three Weeks of Test Beam in 2017

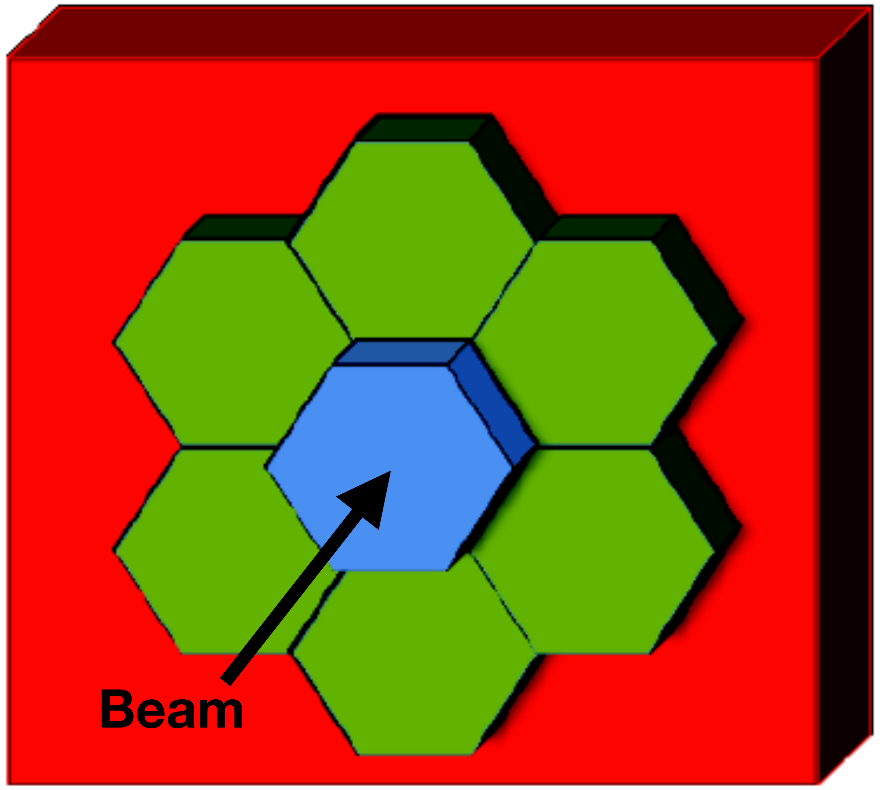
Three weeks of test beam scheduled.

- One week in May, June and July at CERN.
- Gradual upscaling of the system towards a full **EE** + **FH** + **BH** prototype.

➡ Extend and consolidate measurements.

➡ Measurements on hadron-induced showers with HGC modules.

TDR at the end of the 2017.



EE+**FH**: ~1000kg, ~14k channels

EE:
- 26 X_0, ~1 λ
- 28 layers of 6” Si hex modules

FH:
- 4 λ
- 12 layers of 7x6” Si hex modules

BH:
- 5 λ
- CALICE AHCAL prototype

Summary

- HGCAL EE prototype successfully constructed and operated in different absorber configurations.

- Many studies are performed.
    - ✓ Assessment of noise and its stability.
    - ✓ Energy reconstruction and resolution.
    - ✓ Shower profile measurements.
    - ✓ Studies relevant to particle flow and to pileup rejection.
- Results are still being collected.
- Comparison between data and simulation ongoing.

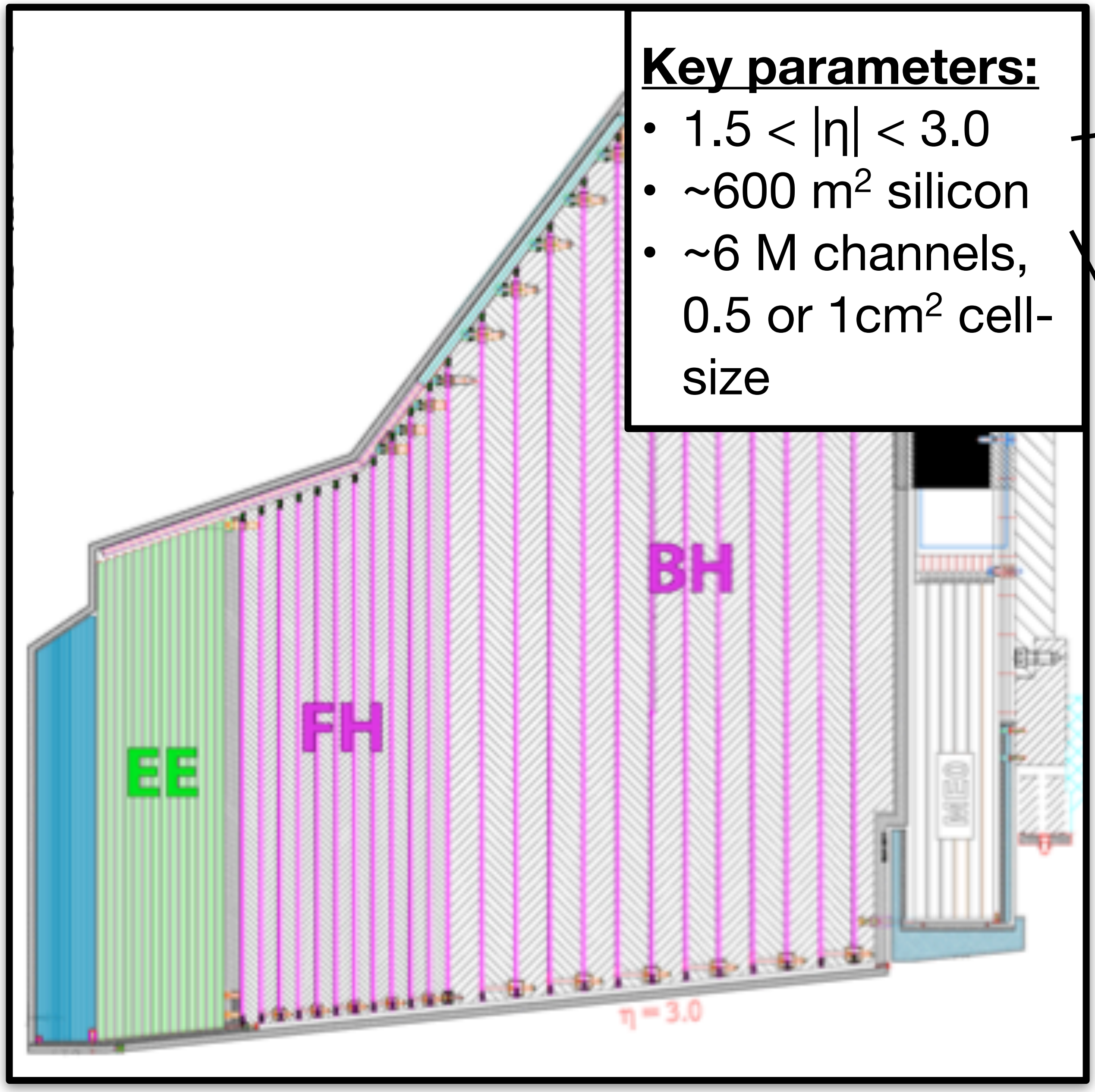
- Upcoming test beams with extended EE+HAD sections in 2017.

Backup

CMS High-Granularity Calorimeter Upgrade

Detector designed for radiation dose equivalent to 300fb^{-1}.

➡ Replacement of CMS' complete endcap calorimetry during HL-LHC upgrade.



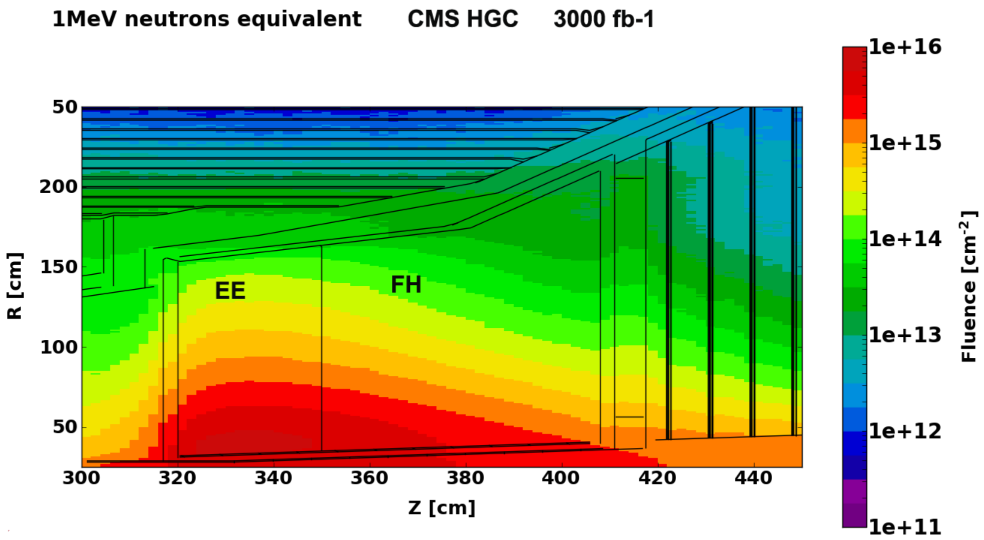
Key parameters:

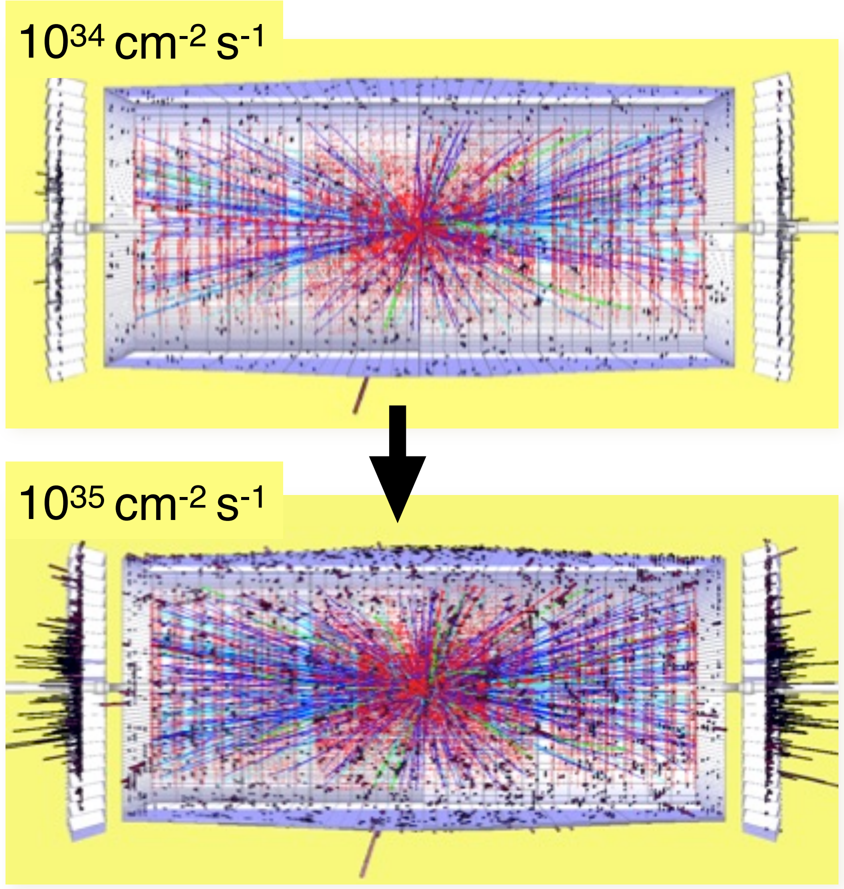
- $1.5 < |\eta| < 3.0$
- ~600 m^2 silicon
- ~6 M channels, 0.5 or 1cm^2 cell-size

Radiation hardness

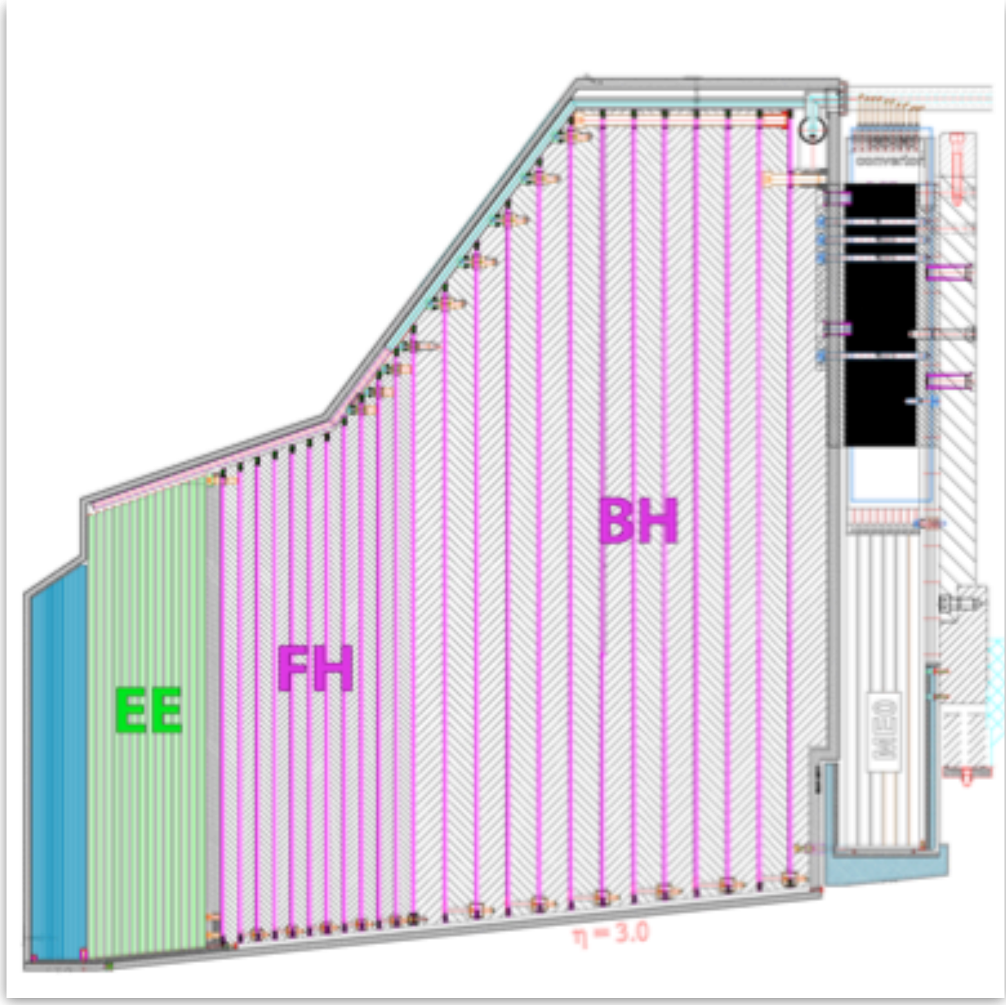
Increased pileup

HL-LHC Conditions





CMS HGCal Design



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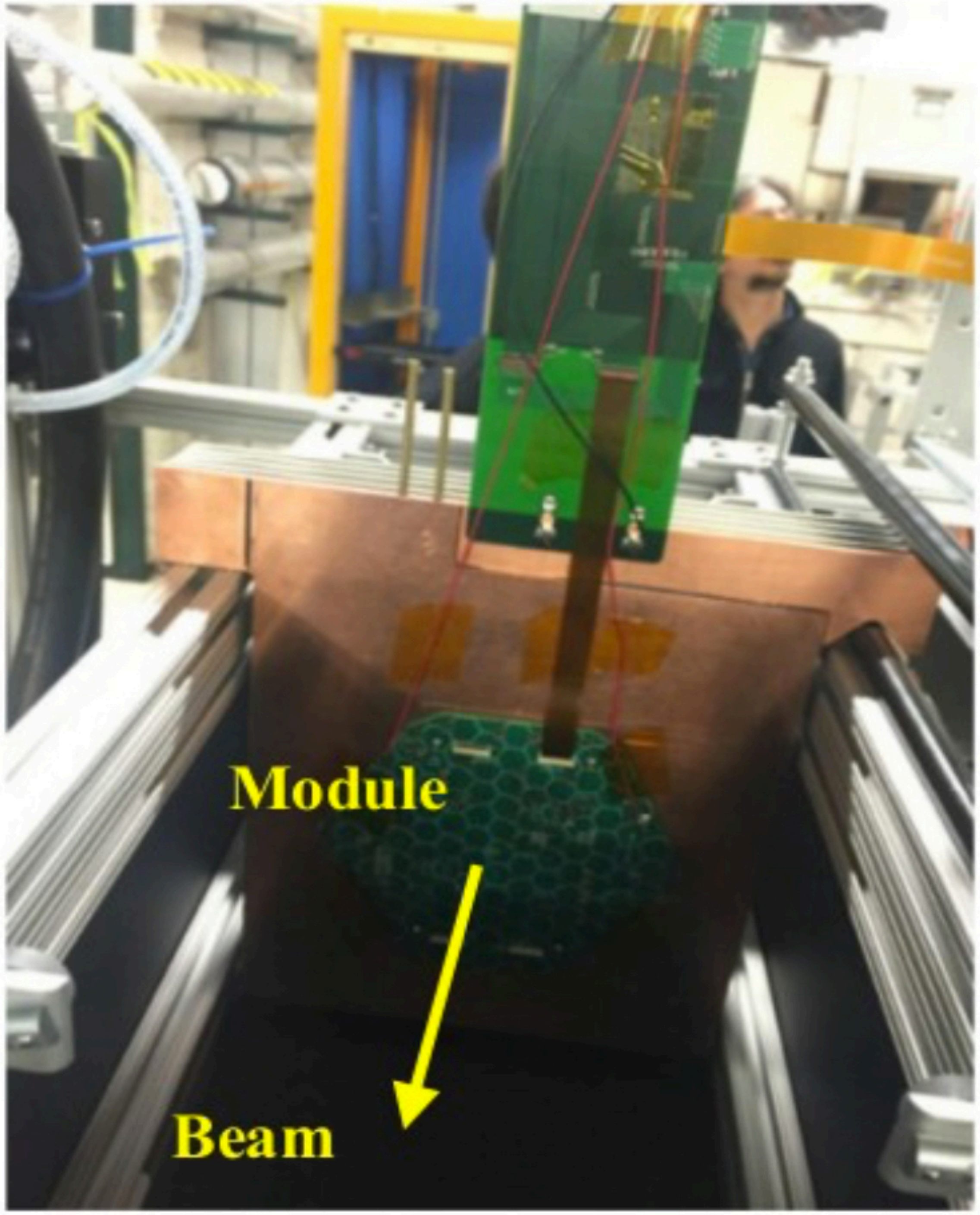
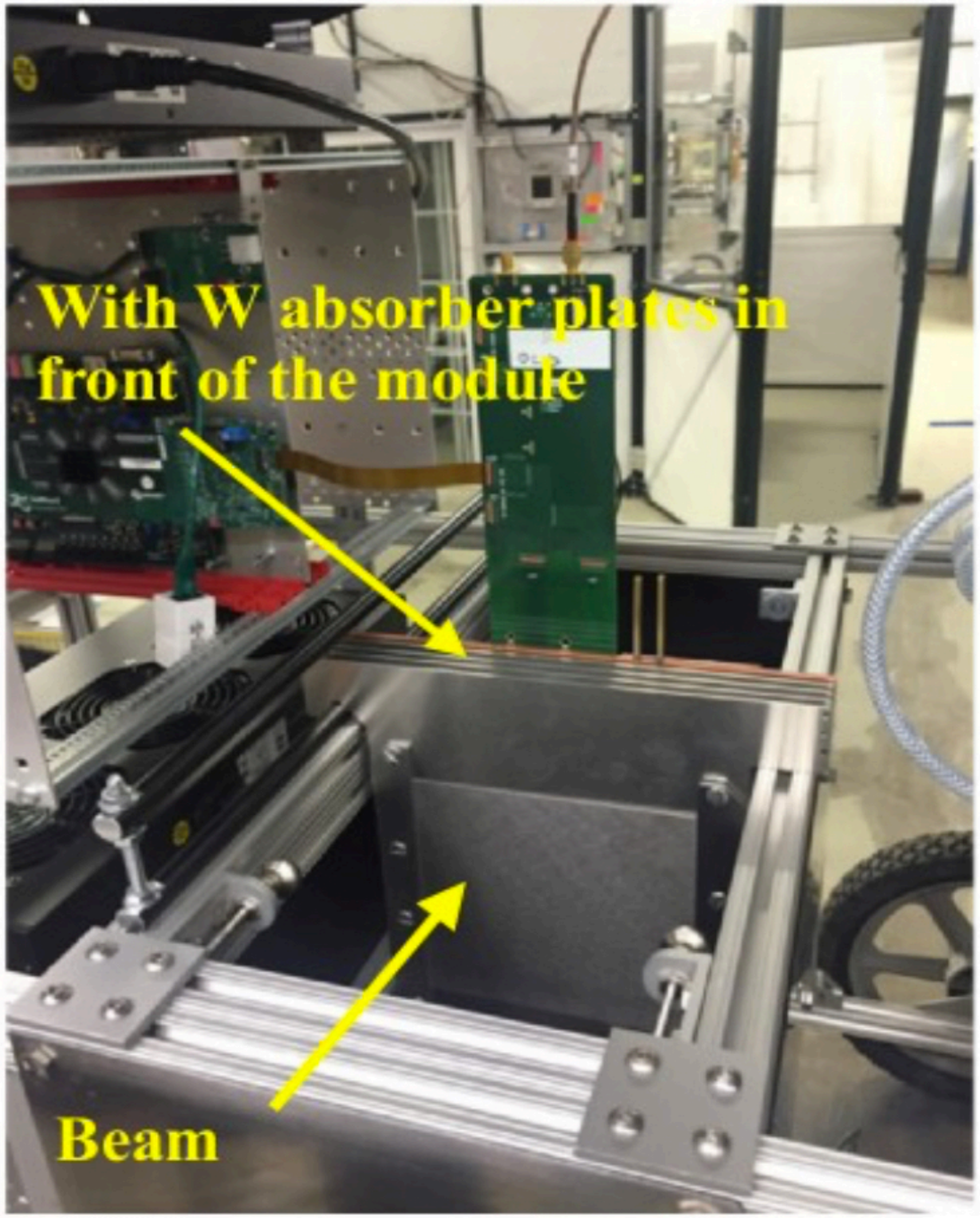
Test Beam Mechanics





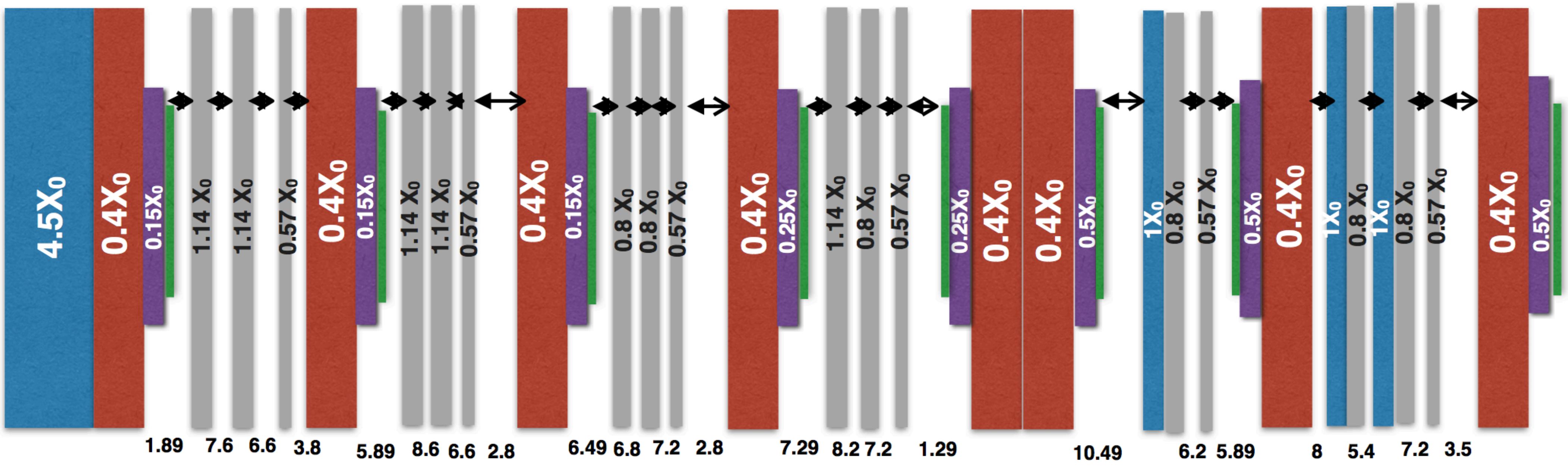
Hanging file design for flexibile insertion of absorbers and modules on cooling plates.

Simulation

Standalone version in CMSSW 8.1.0.

Physics list FTFP_BERT_EMM

Geometry description for both configurations

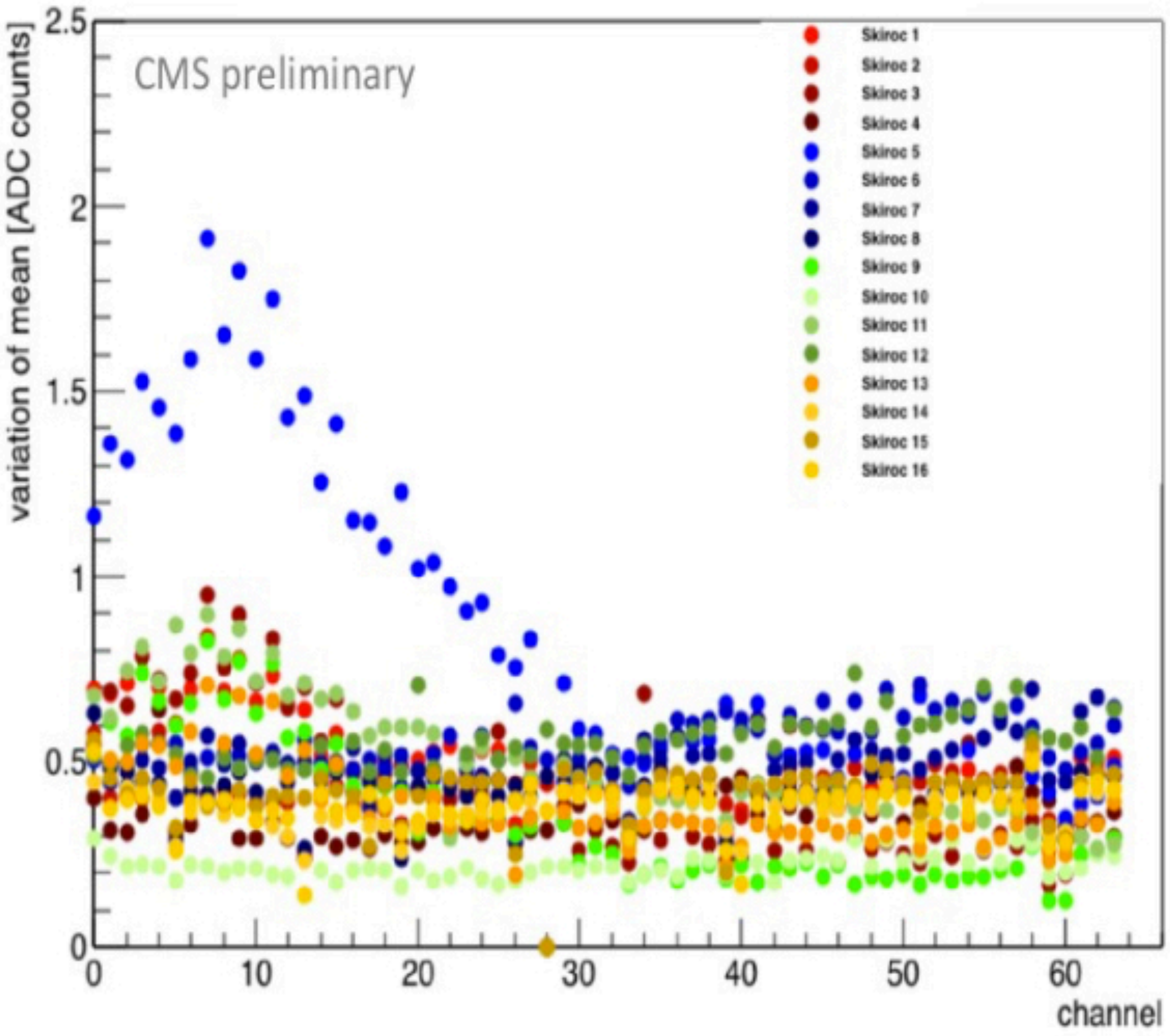


Numbers at the bottom
are the distances between
the consecutive layers (in mm)

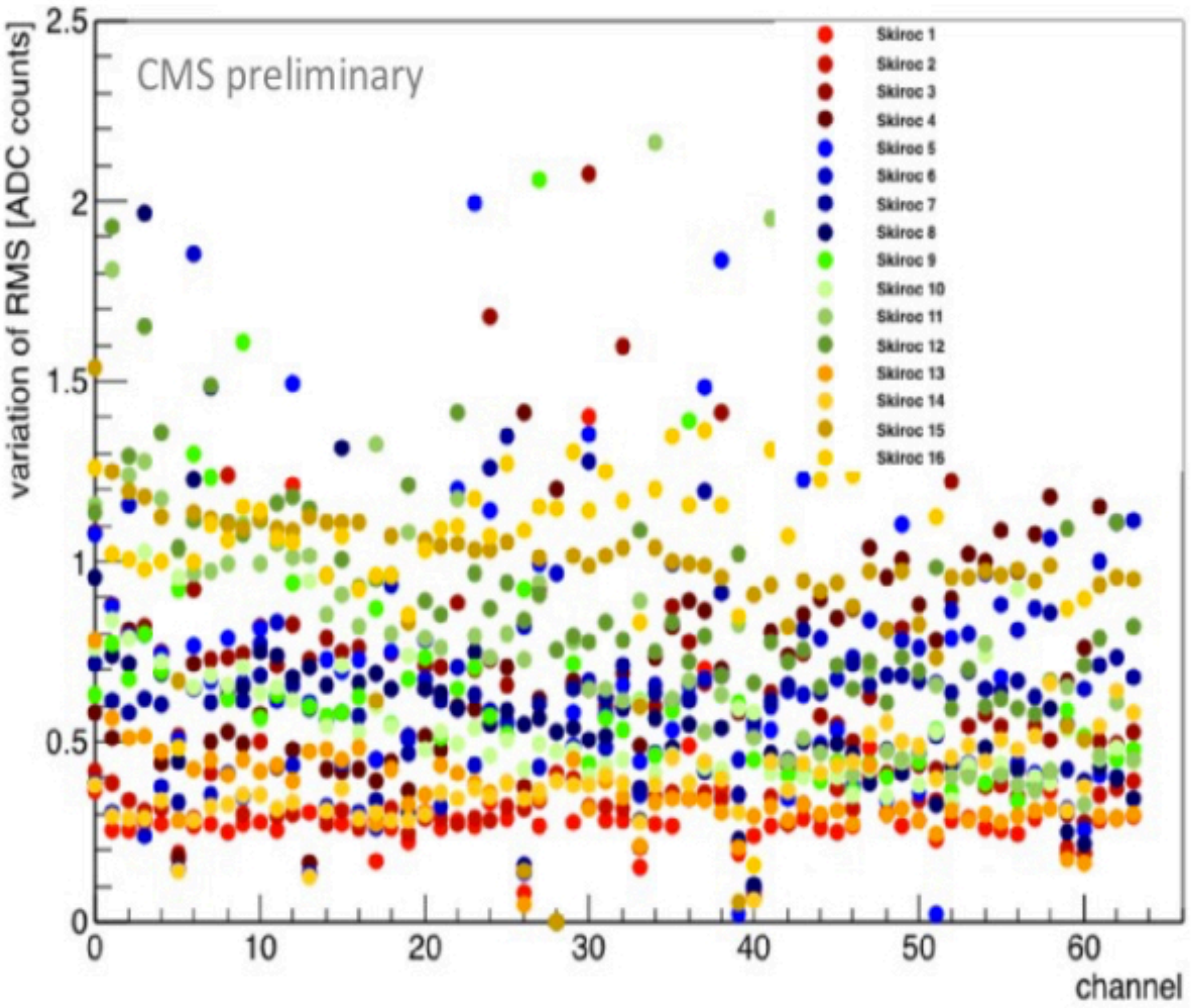
Lead
Copper
Tungsten
CuW
Si + PCB

Pedestal and Noise Stability

PEDESTAL Stability

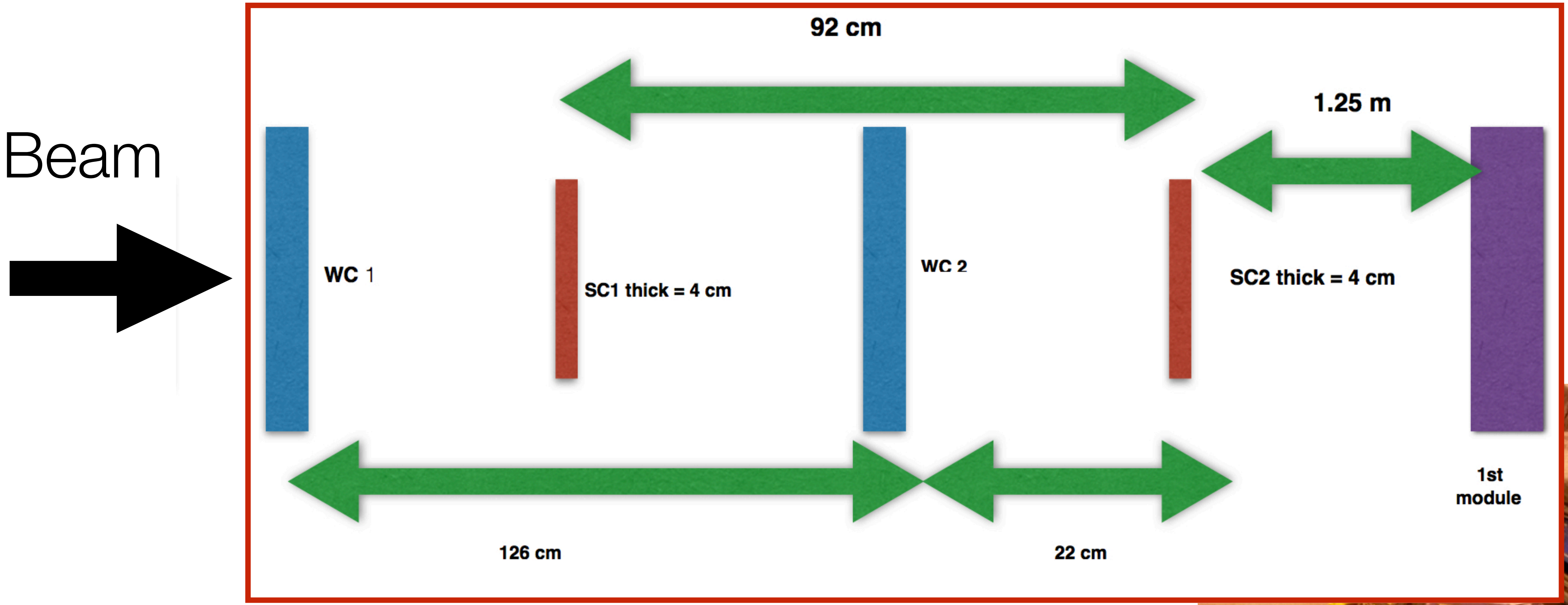


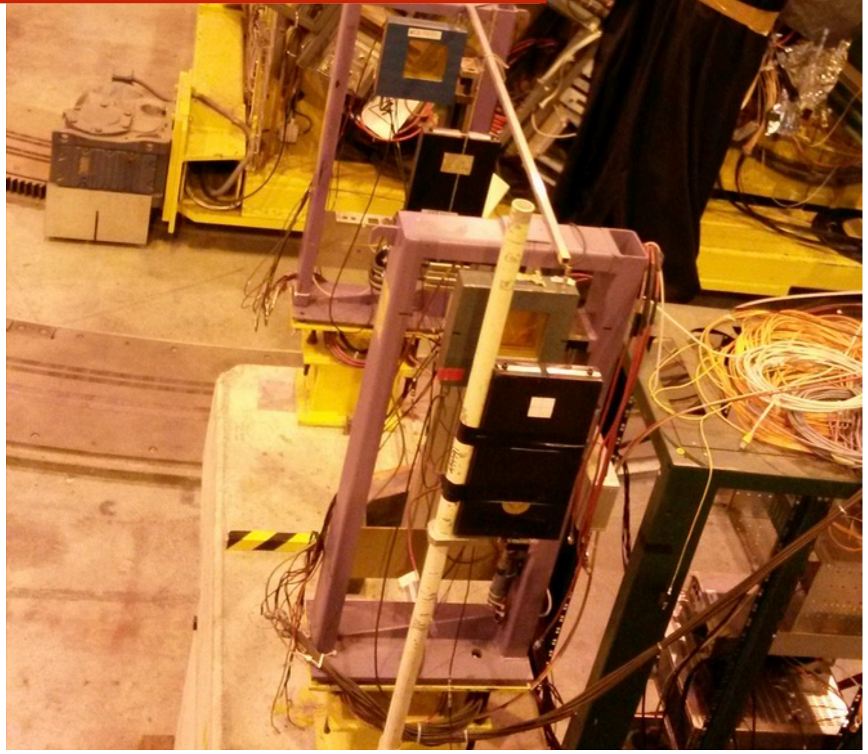
NOISE Stability



- **Pedestal across all channels were stable. Less than 2 ADC counts[1 MIP ~ 16.5 ADC].**
- **Noise stability over time across all channels were less than 2 ADC counts.**

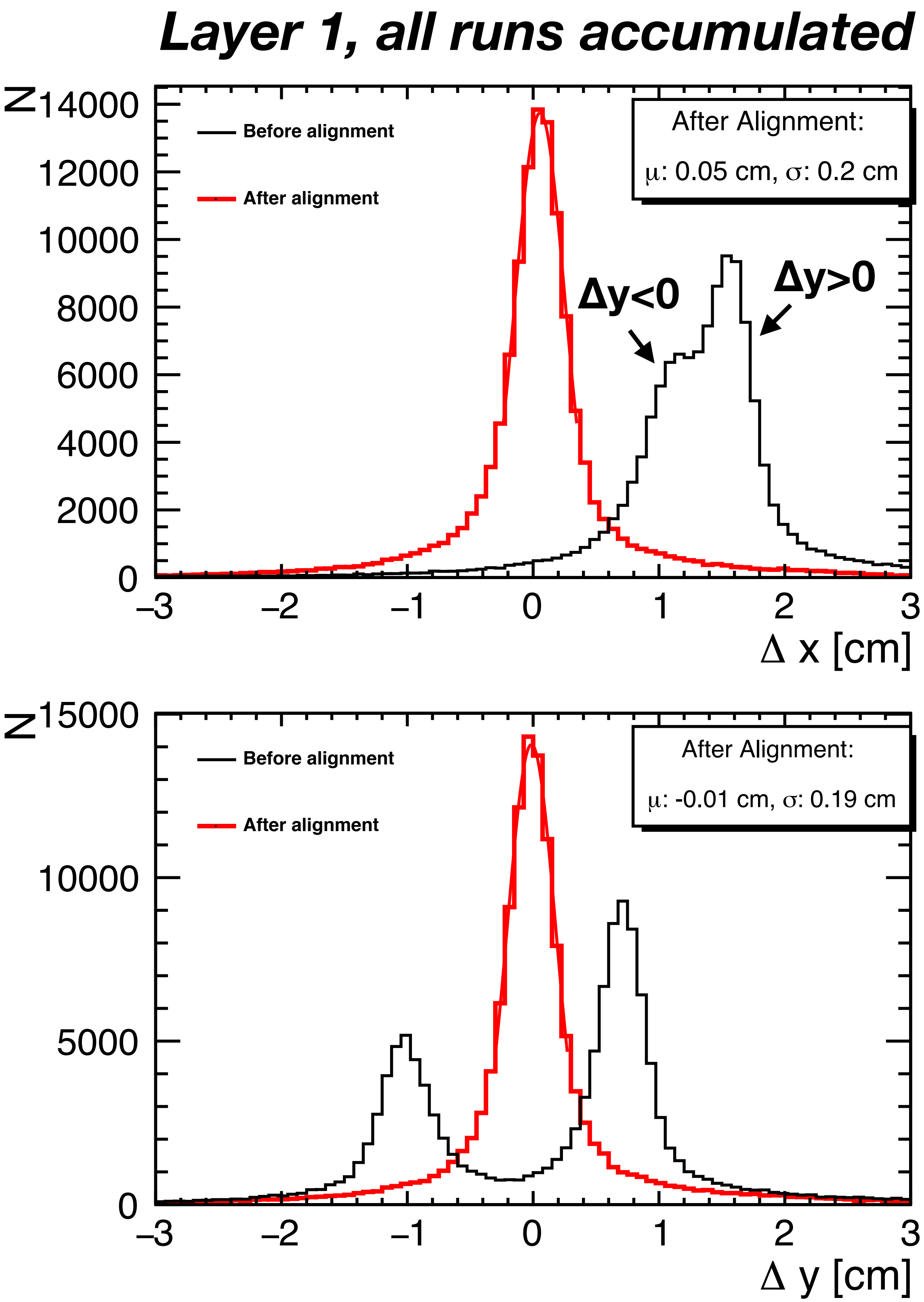
Multi-Wire Chambers in the Setup





- Independent DAQs for MWCs & HGC.

Alignment using Millepede



Double peaks

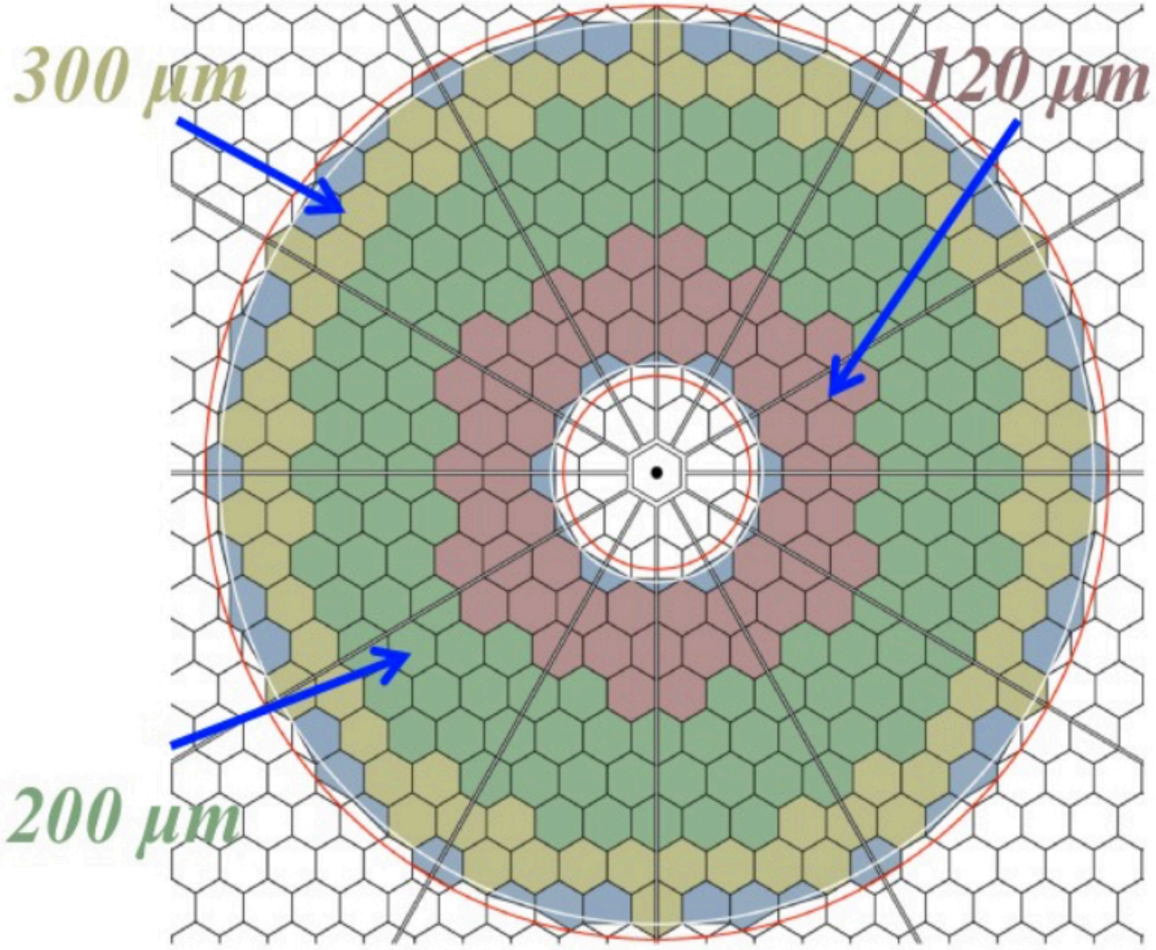
➡ Table has moved.

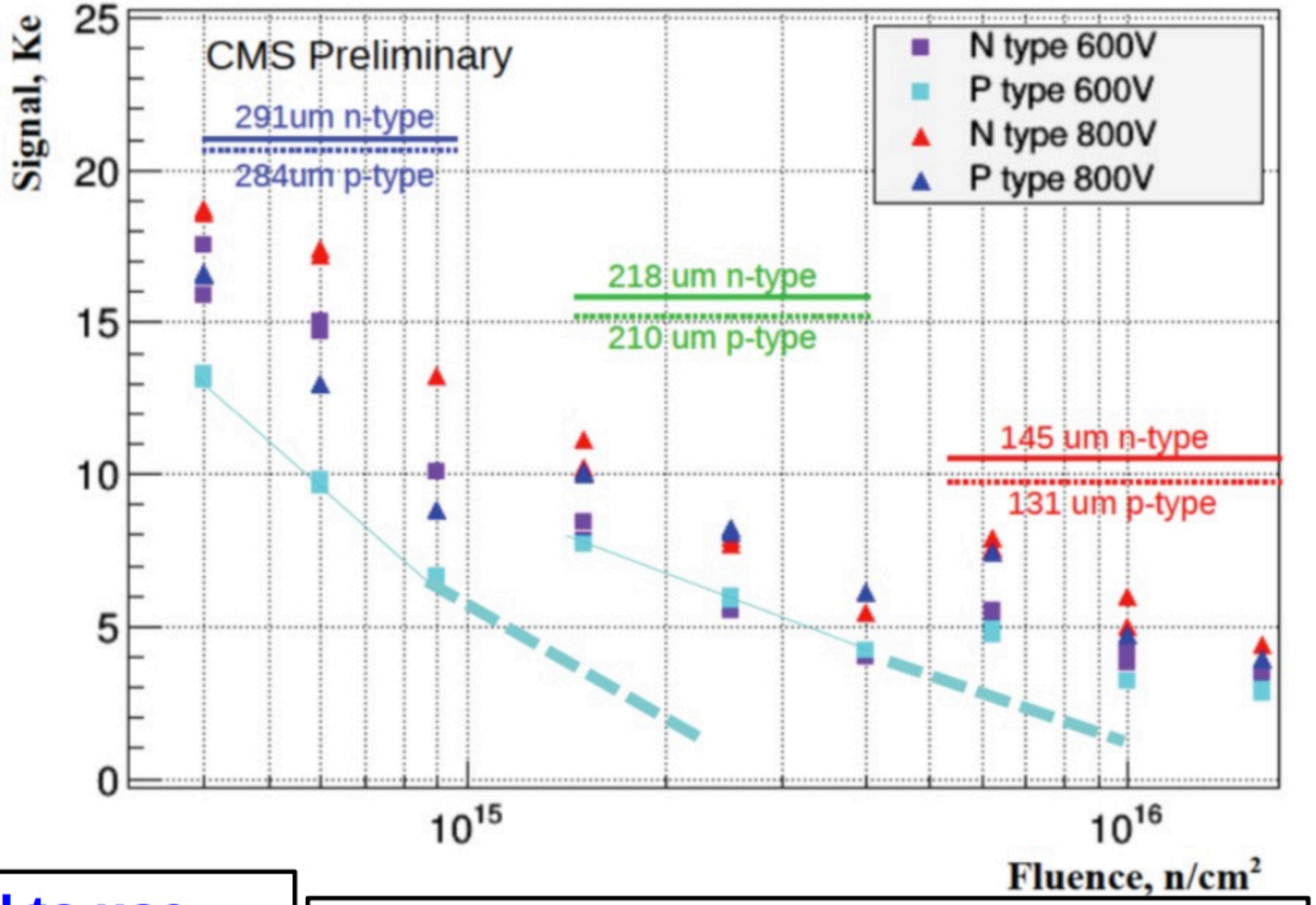
➡ Perform alignment for each run (comparable corrections between runs of same energy)

- Multi-wire chambers are fixed.

Note: Alignment should not influence resolution if coordinate systems are fixed within a run.

Sensor Thickness





- **At higher radiation levels its beneficial to use thinner sensors. E-field higher for the same bias.**
- **Higher η region:** **Sensors with 120 µm depletion depth.**
- **Lower η region:** **200 µm & 300 µm**

- **Cell size ~ 1 cm² for 200 µm & 300 µm depletion sensors.**
- **~ 0.5 cm² for 120 µm depletion sensors.**
- **Cell size reduction to maintain moderate capacitance(< 50 pF).**

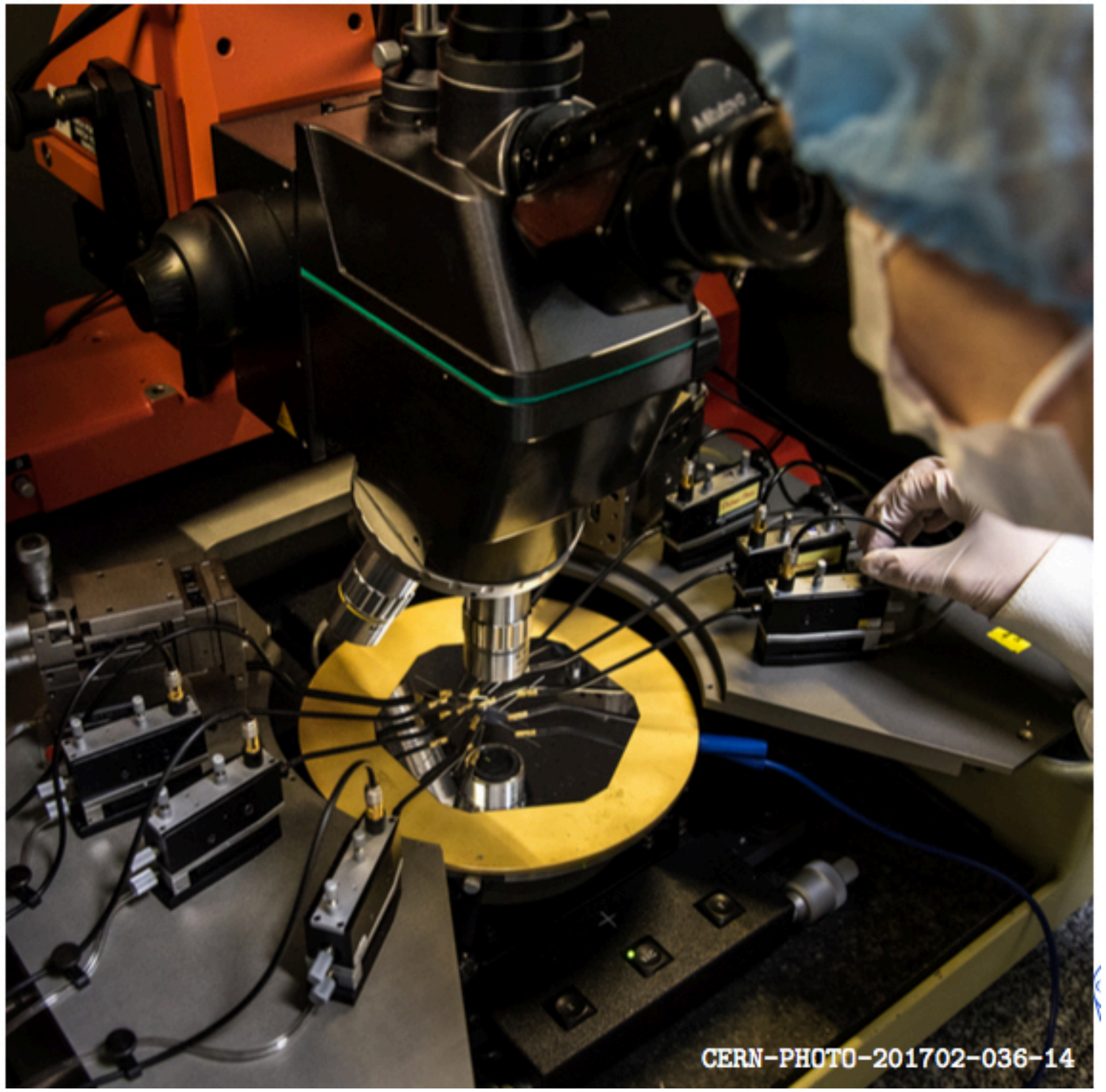
Sensor Testing

- Perform IV and CV measurements on “probestation”
- Contact cells temporarily via needles and sensor backside contact

- Probe-needle measurements
  - + Very flexible
  - – Needle placement is time consuming
  - – Need to bias also 6 neighbours cells for reliable measurement

→ Probe-card approach
  - + Contact all cells with spring-loaded pins
  - + Alignment and contact done once for full sensor
  - + All neighbour cells biased
  - + Automatic switching between cells (switching unit)
  - – One probe card each per sensor layout

Probe-needle measurement in probestation



CERN-PHOTO-201702-036-14

- See Eva’s talk during FCal Workshop