The Initial Run of the High Granularity Calorimeter Test Beam System

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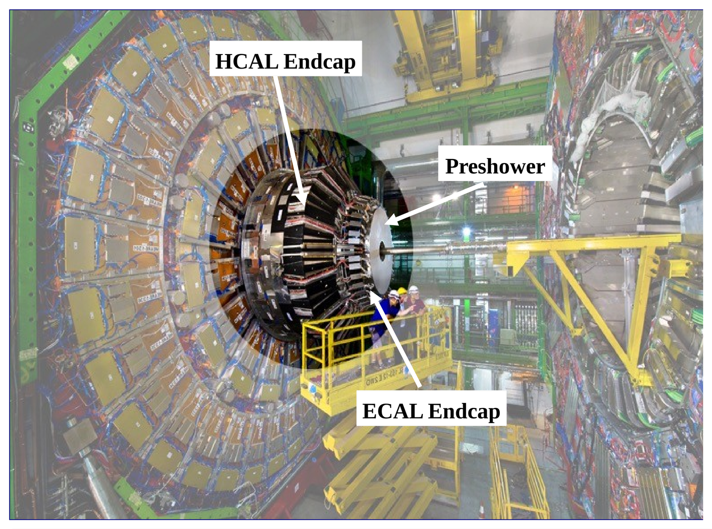
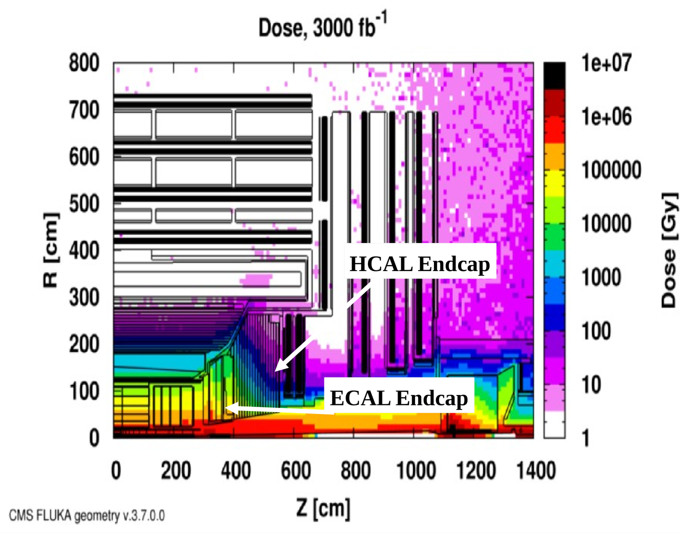
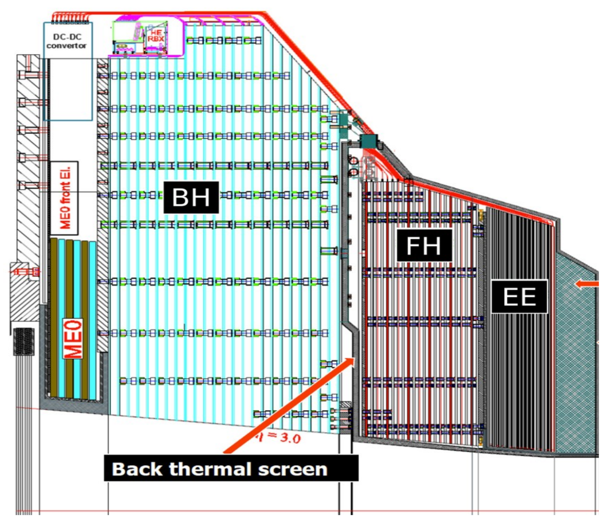
HL-LHC environment: need for HGCAL





- To operate in the high radiation levels of the HL-LHC the CMS endcap calorimeter will need replacement.
- With 25 ns bunch crossing the <pileup> is expected to be ~140 at a luminosity of $5*10^{34}$ Hz/cm².
  - ➔ The current CMS calorimeters do not have a "pointing capability".
  - ➔ In the HGC, high granularity along with particle flow reconstruction enables association of charged
  - ➔ tracks in a shower to a particular vertex, thus allowing operations in the presence of very high pileup.

High Granularity Calorimeter: Design



Construction:
- Hexagonal Si-sensors built into modules.
- Modules with a W/Cu backing plate and PCB readout board.
- Modules mounted on copper cooling plates to make wedge-shaped cassettes.
- Cassettes inserted into absorber structures at integration site (CERN)

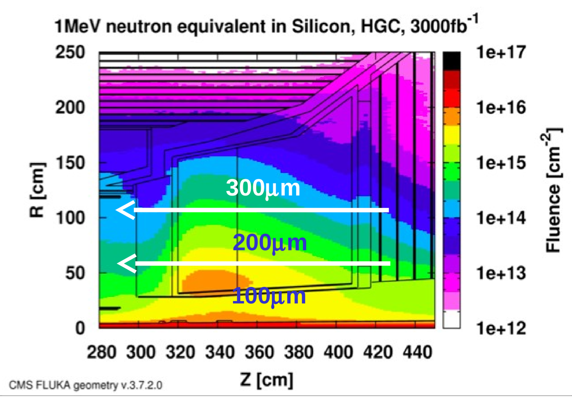
Key parameters:
- 593 m² of silicon
- 6M ch, 0.5 or 1 cm² cell-size
- 21,660 modules (8" or 2x6" sensors)
- 92,000 front-end ASICS.
- Power at end of life 115 kW.

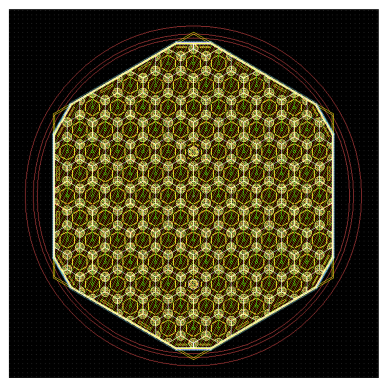
System Divided into three separate parts:

Endcap Electromagnetic calorimeter (EE) – Silicon with tungsten absorber – 28 sampling layers – 25 X_0 (~1.3 λ)
Front Hadronic calorimeter – Silicon with stainless steel absorber – 12 sampling layers – 3.5 λ
Backing Hadronic calorimeter(BH) – Scintillator with stainless steel absorber – 11 layers – 5.5 λ

EE and FH are maintained at – 30°C. BH is at room temperature.

The HGCAL Silicon sensor

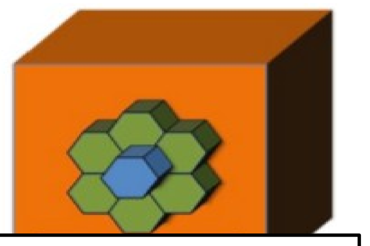




- Wafer diameter will be 6" or 8".
- The hexagonal shape is chosen for optimal use of the wafer surface and hence minimizes cost.
- Sensors of 3 different active thicknesses 100 µm, 200 µm and 300 µm, based on the neutron fluence at that location.
- The sensor is mainly divided into hexagonal cells.
- Cell size of ~ 1.1 cm², adjusted to limit cell capacitance to 60 pF.

Overview of the HGCAL test beam campaign

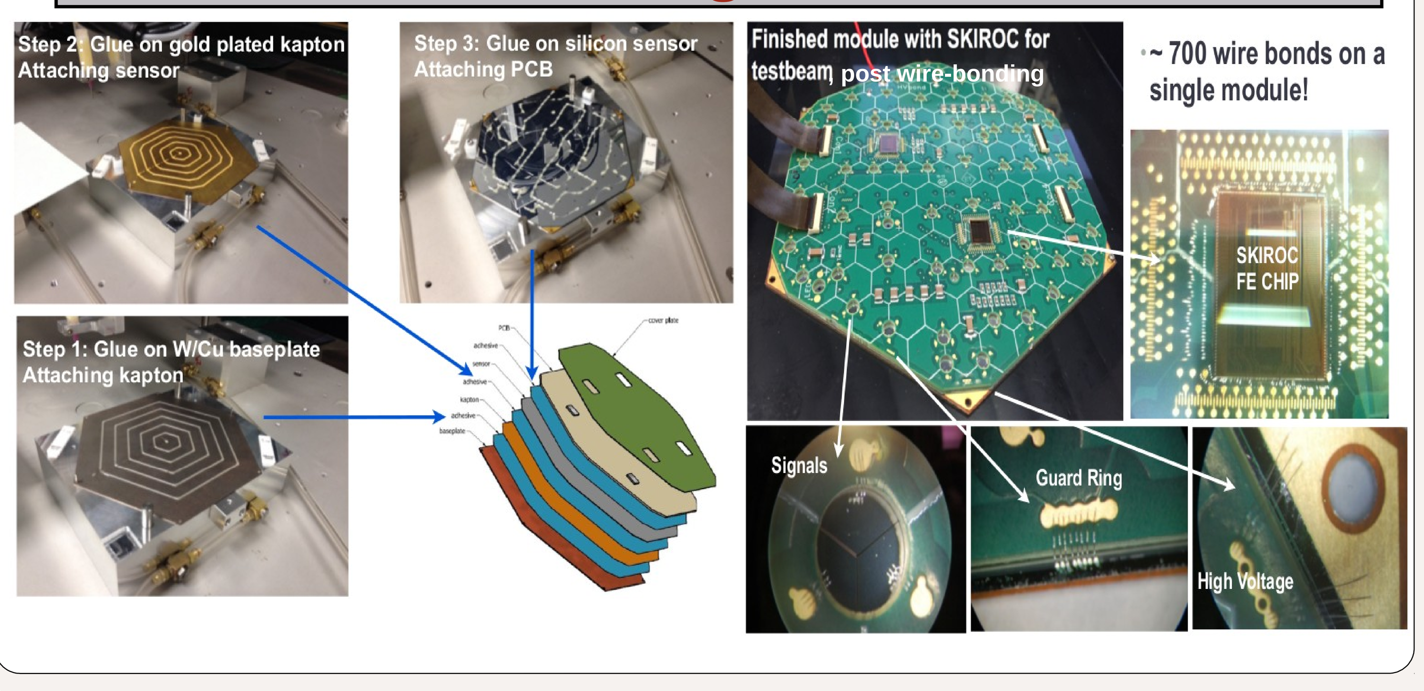
- The primary goal of the test beam program at FNAL and CERN are:
  - ➔ Proof of concept of the baseline design with a closely spaced stack-up of modules.
  - ➔ Test the proposed design of a compact detector module with deep access wire-bonding.
- The test beam prototype will comprise of:
  - ➔ A 28 layer EE section with a single 6" sensor module per layer.
  - ➔ A 12 layer FH section with 7x6" sensor modules per layer.
  - ➔ A realistic readout system to acquire data from the EE+FH system
  - ➔ with ~14000 channels.
- Study the calorimetric performance :-
  - ➔ Calibration with MIPs, measurement of Signal-to-noise
  - ➔ Response to electrons/hadrons.
  - ➔ Position, timing and angular resolutions.
  - ➔ Comparison of test beam results with simulation.



EE + FH + BH schematic

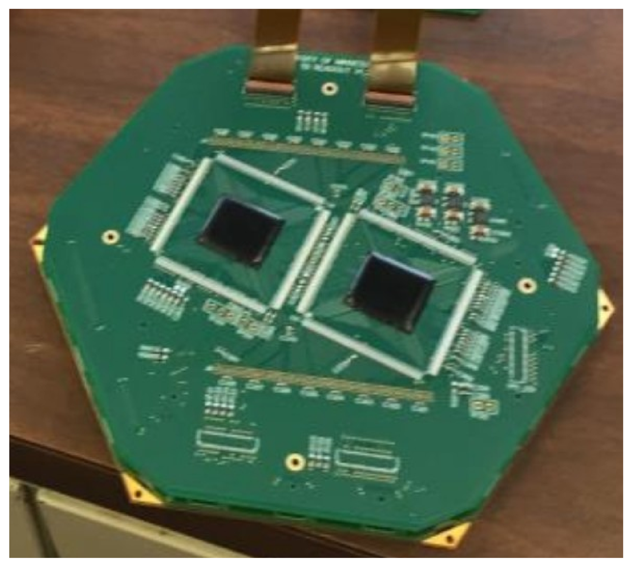
- In 3 rounds of test beams at FNAL we have made measurements with electrons at energies ranging from 4-32 GeV, as well as protons at 120 GeV.
- There will be further tests at CERN where we will have access to beams at higher energies.

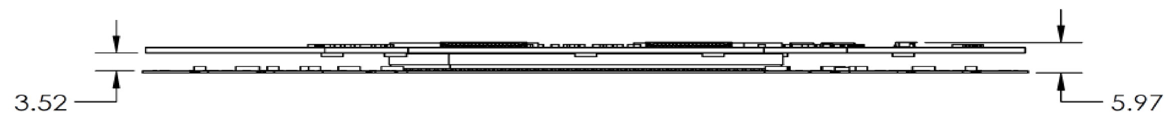
Assembling a Module



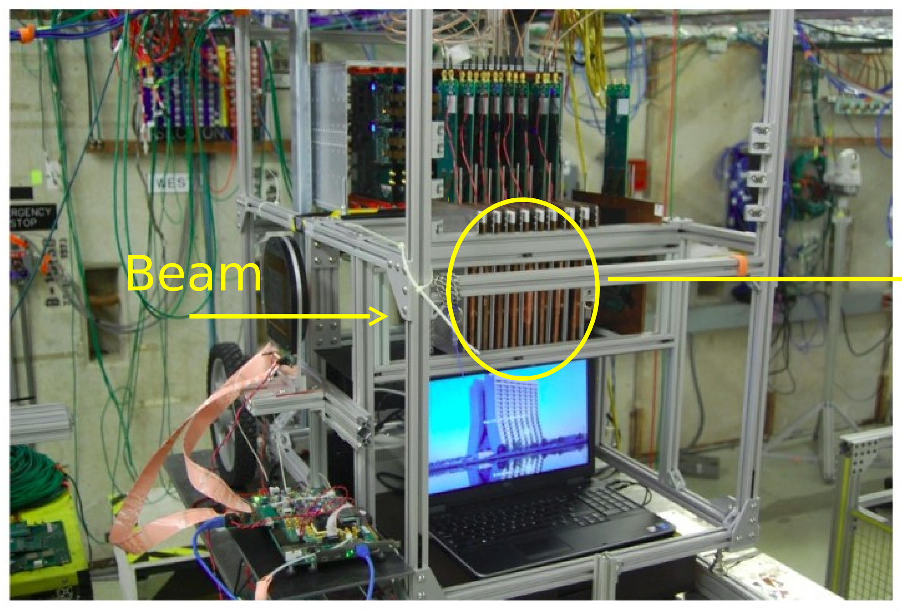
The HGCAL detector module

- For the most recent tests we have used, 200 µm active thickness silicon sensors and a dual board readout shown in the schematic :-
  - ➔ One passive board glued to the sensor.
  - ➔ Connected to a second board with the SKIROC2 chip mounted on top, with connectors between the two board.
- We have used the 64-channel SKIROC2 ASIC developed by the OMEGA group for the CALICE collaboration as a starting point. This is not the final front-end chip.
  - ➔ Shaping time 200 ns.
  - ➔ Two 12-bit ADCs, with selectable low and high gain.
  - ➔ Programmable gain, max sensitivity 0.02 fC (125 e) /ADC count.





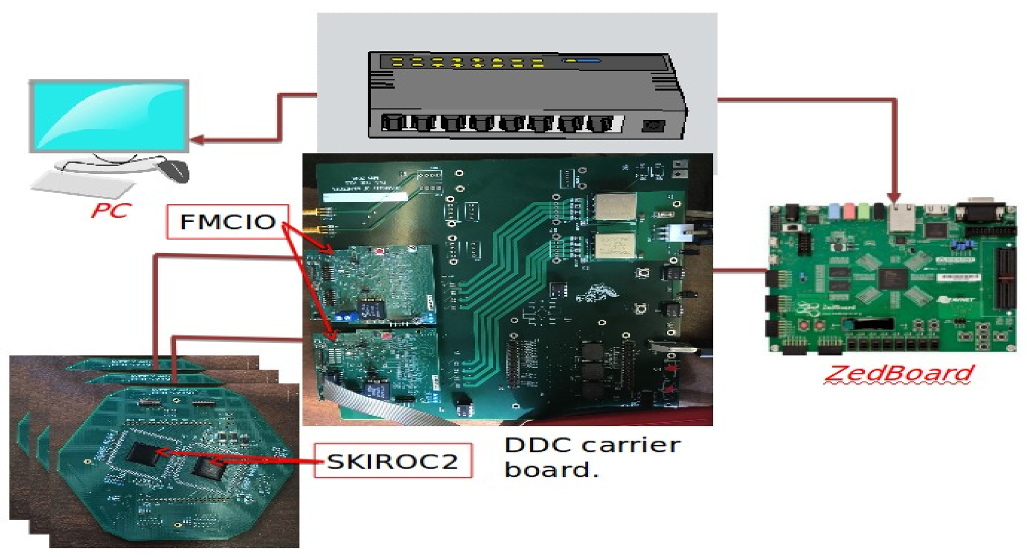
HGCAL EE prototype in FNAL Test Beam



Basic structure of the calorimeter repeated eight times.

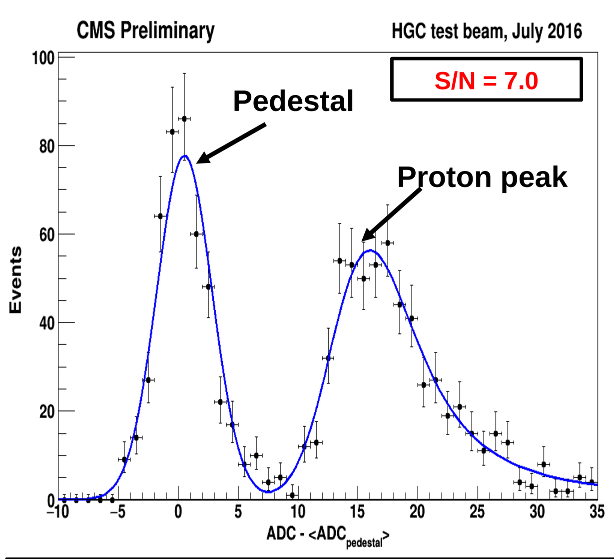
- The 16 detector modules are at depths of: 0.6, 1.4, 2.0, 2.8, 3.4, 4.3, 5.1, 6.1, 6.9, 7.9, 8.7, 10.1, 11.3, 12.7, 13.9 and 15.3 X_0 respectively.
- The mechanics consists of a hanging file structure for flexibility:
- Enables easy insertion of detector modules as well as absorbers of different thicknesses.
- It is easy to have different distances between the layers.

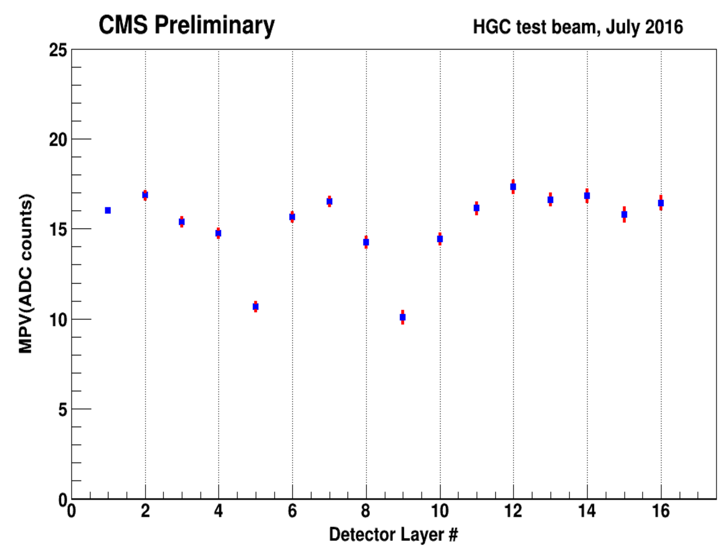
Data Acquisition System



The DAQ system is designed to be scaleable, largely using commercial components mounted on custom PCBs :-
- ➔ Each sensor module is connected to the data collection FPGA(Artix on the FMCIO) that stores data during a spill.
- ➔ A second FPGA based system(The ZedBoard) collects data from all FMCIOs between spills.
- ➔ Pairs of FMCIOs are mounted on a Dual Daughterboard carrier that communicate with the ZedBoard via HDMI link.

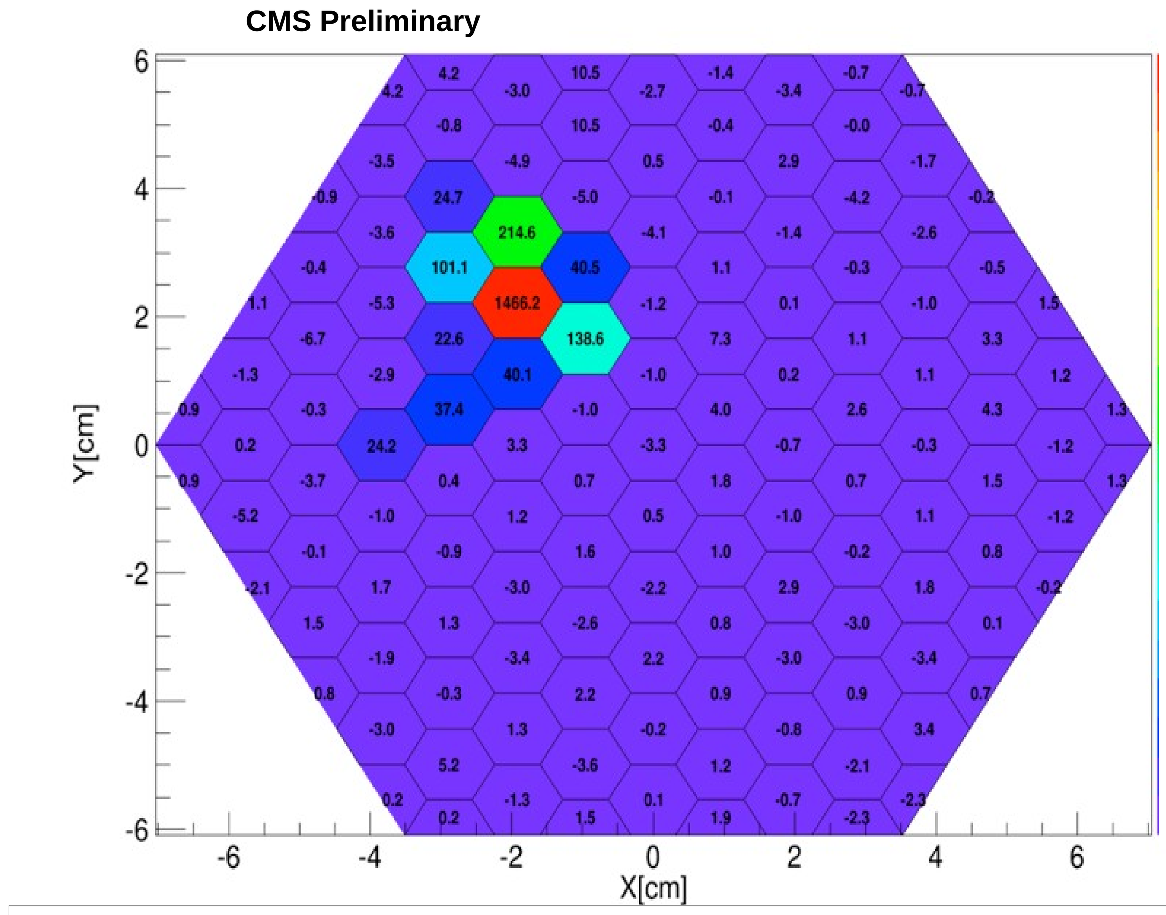
Calibration with 120 GeV protons





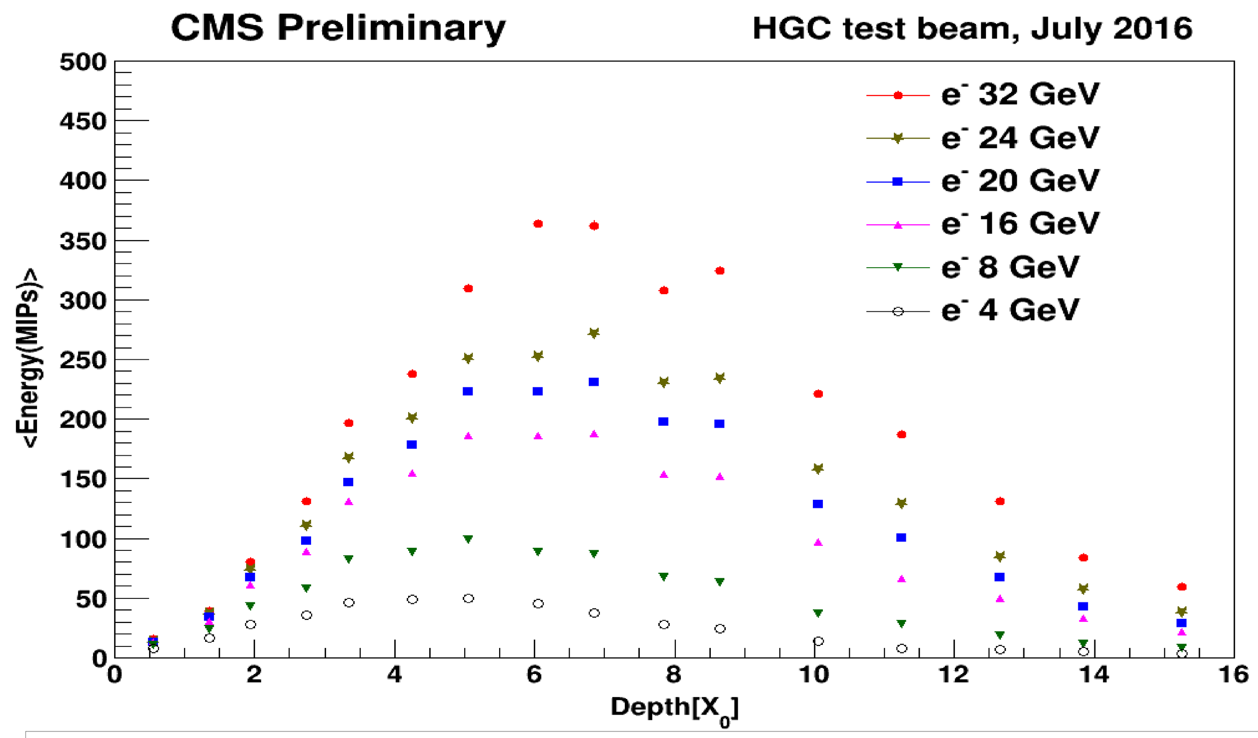
The plot on the left shows the response of a cell to 120 GeV protons.
- ➔ The distribution is modelled with a Gaussian + Landau convoluted Gaussian function.
- ➔ The MPV of the Landau is the response to a 120 GeV proton.
- ➔ The plot on the right shows the MPV of the proton peak for each of the 16 layers.
- ➔ We use the response to 120 GeV protons(1.3 MIPs) to obtain the ADC → MIP translation factor for each of the 16 detector layers.

A typical 32 GeV e⁻ event



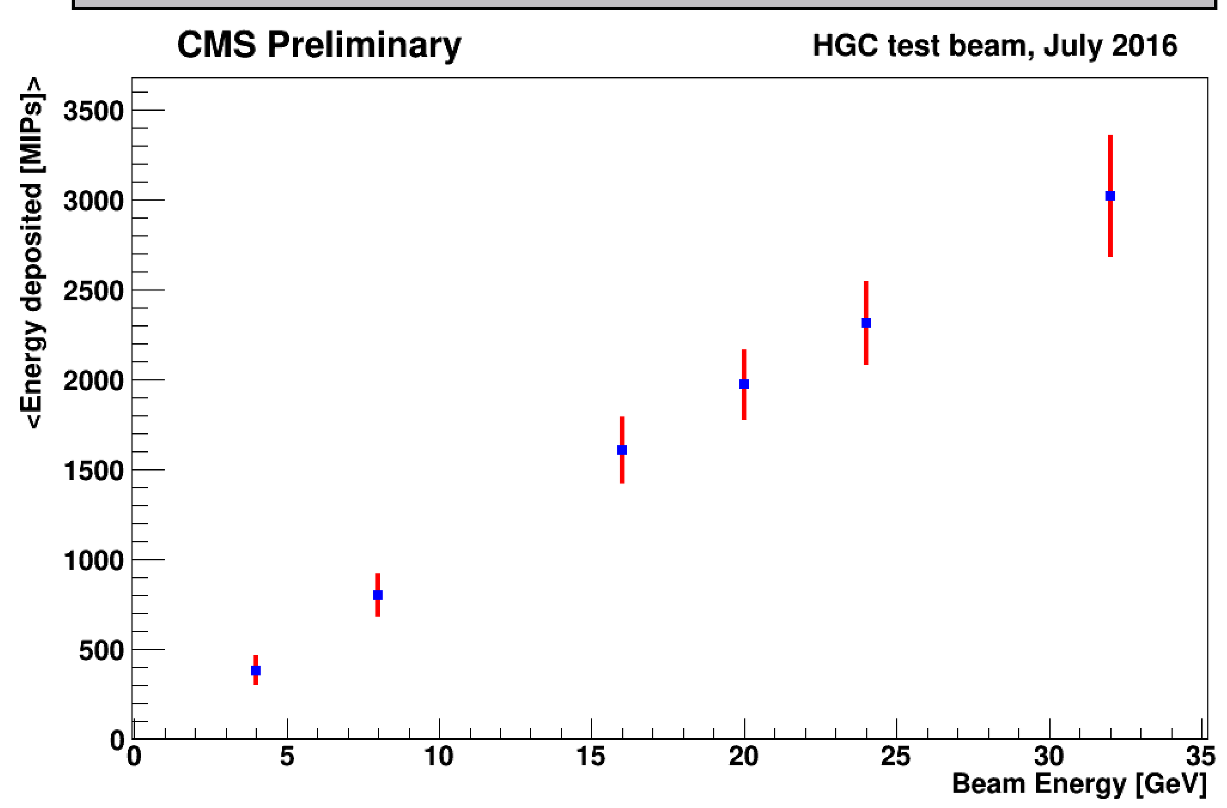
- The above event display is for a detector layer at 6 X_0 with a 32 GeV e⁻ beam.
- We see that ~70% of the energy contained in 0.5 cm and ~96% in 1 cm.
- Based on this we use a 19 cell cluster around the maximum hit to reconstruct electron energy in a given layer.

Longitudinal shower profile



- The energy deposited in each of the 16 layers, expressed in terms of MIPs , for 6 different e⁻ beam energies is plotted above.
- The evolution of the shower maximum towards higher depths for higher beam energies can be seen.

Detector response versus beam energy



Plans

2016:
- Setup in the H2 beamline at CERN
- Investigate high energy response and the constant term of the energy resolution.
- Replace the current readout ASIC with a custom ASIC for tests with precision timing

2017:
- Test with EE & FH prototype.