Progress of Semi-Digital HCAL

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On behalf of the CALICE SDHCAL group

CEPC Workshop 2018
Nov 13, IHEP

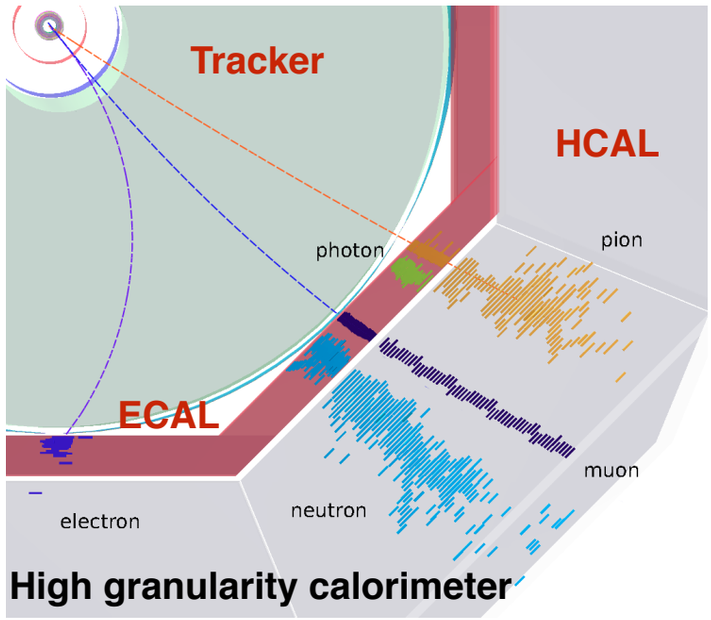
Outline

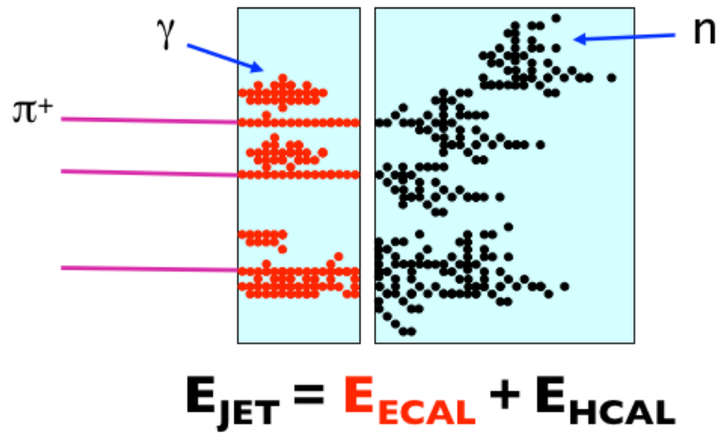
- SDHCAL prototype
- New developments
- Summary

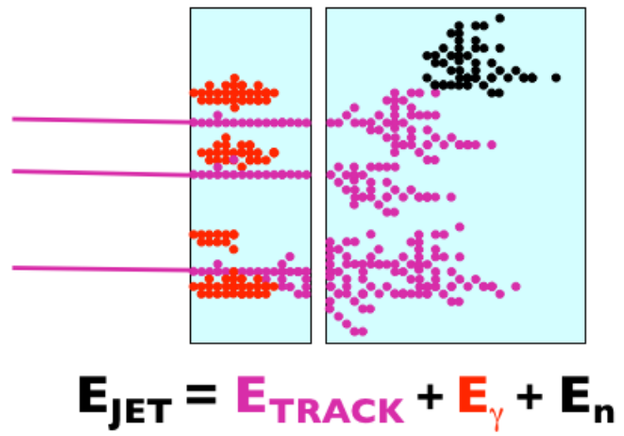
SDHCAL prototype

Particle flow calorimetry

- Particle flow calorimetry: attempt to reconstruct visible final state particles from the information recorded by detector

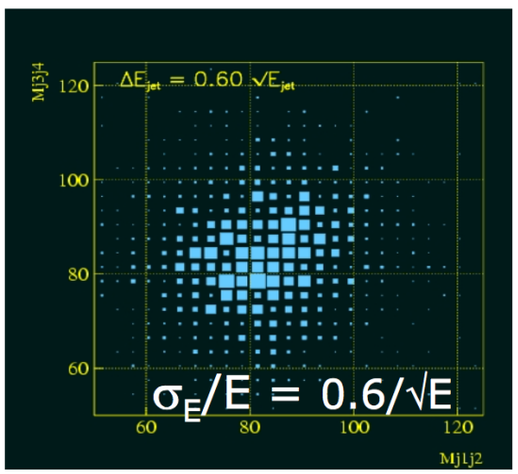


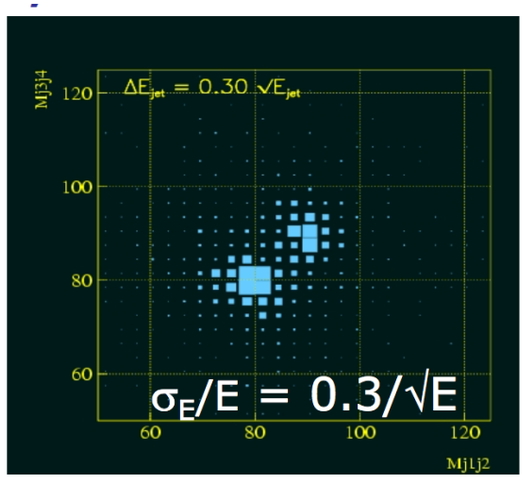




arXiv: 1308.4537

- Two high granularity HCAL options at ILD
  - Analog HCAL
  - **Semi-Digital HCAL**

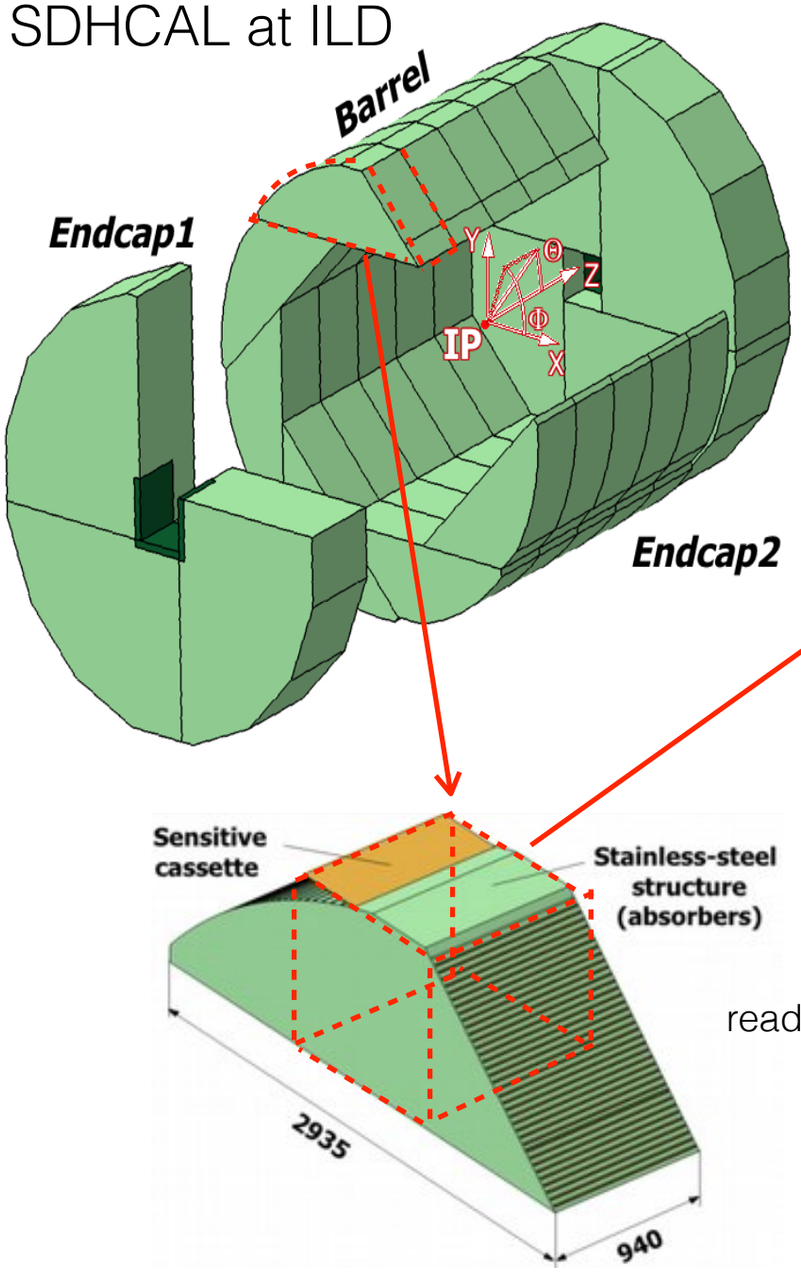


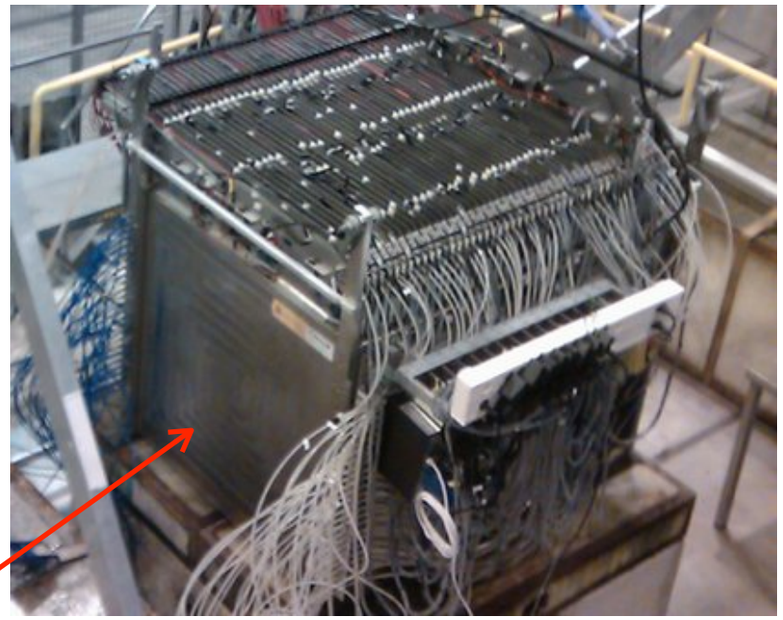


- Jet energy resolution at ILC: $\sigma_E/E \approx 3-4\%$ in the range of 50 to 500 GeV

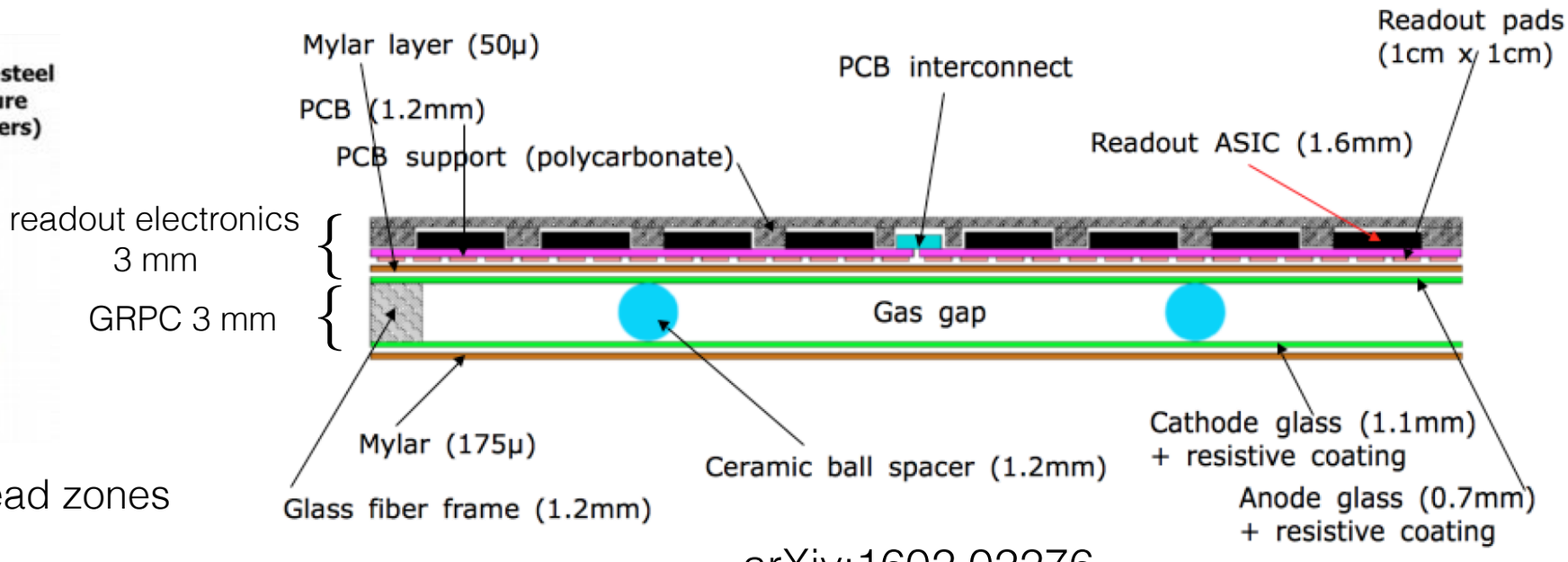
Semi-Digital HCAL

SDHCAL at ILD





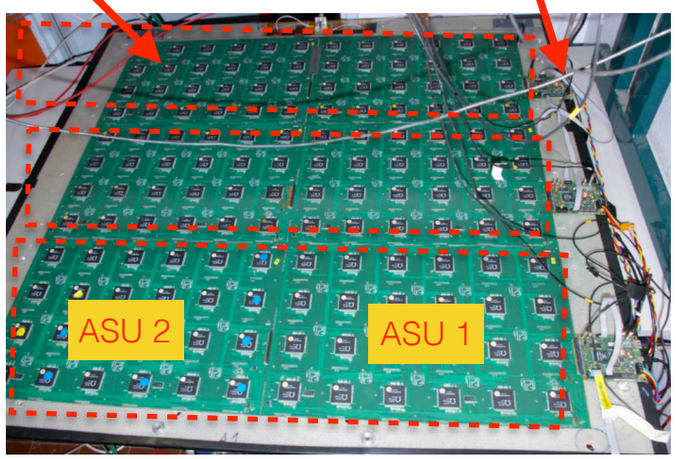
- 48 layers, 6 λ_I
- GRPC (1×1 m^2)
- Cell pads:1×1 cm^2
- On each layer, ASIC: 12 x 12; 64 ch. on each ASIC; 9612 ch. in total
- Three thresholds readout (2 bits): (0.11, 5, 15) pC
- Power-pulsing electronics
- Self-supporting mechanical structure as absorber as well

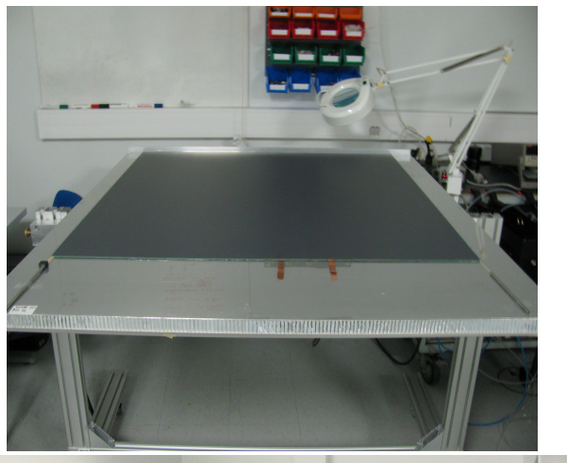


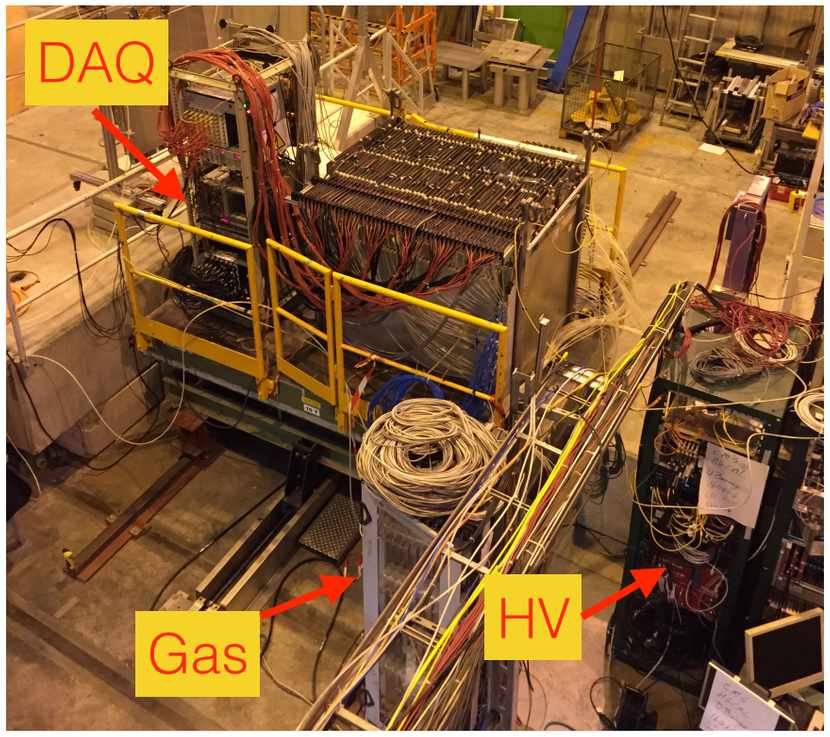
arXiv:1602.02276

- Very compact with negligible dead zones
- Eliminates projective cracks
- Minimizes separation of barrel and endcap

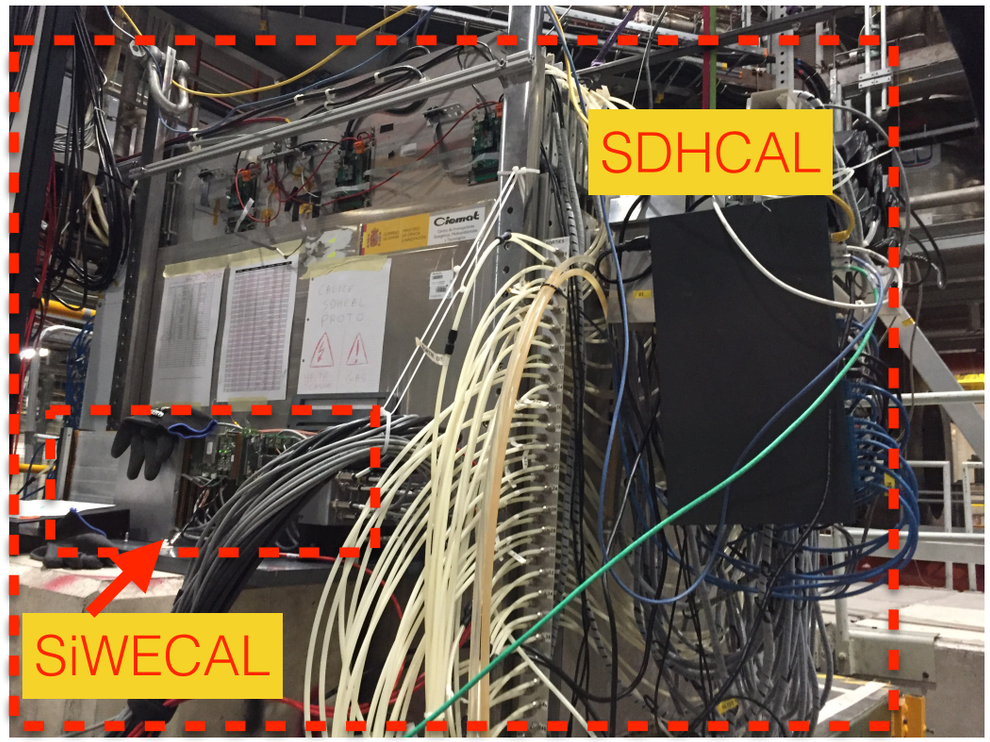
Prototype





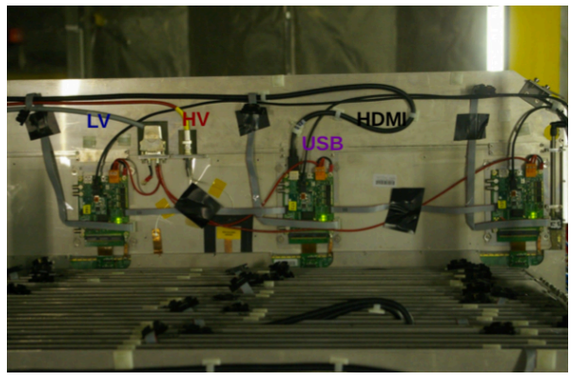


Beam test@CERN, 2017

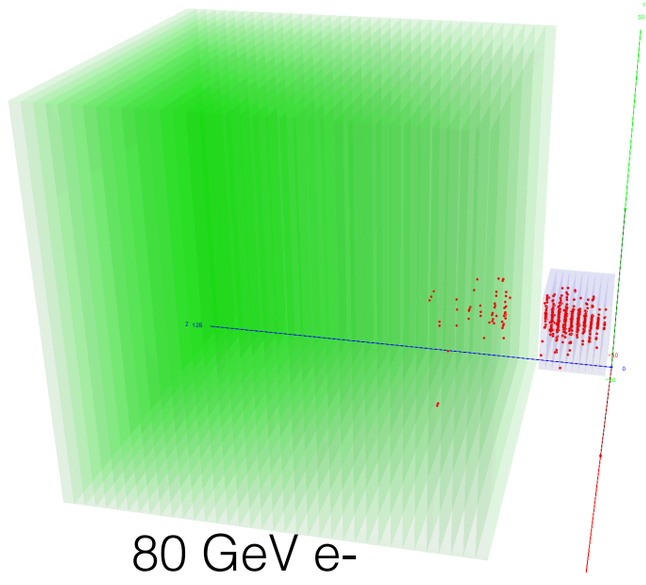


Combined beam test@CERN, 2018

The SDHCAL prototype was exposed to hadron, muon and electron beams in beam test since 2012

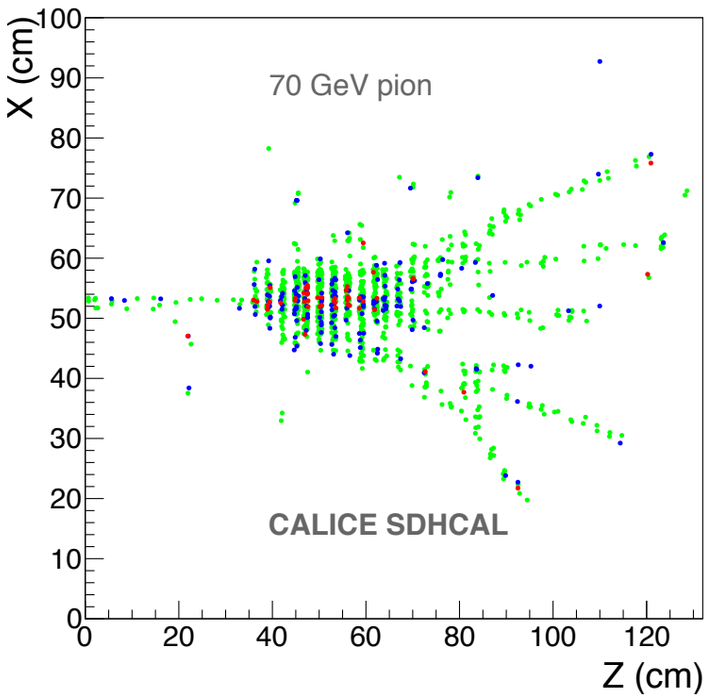


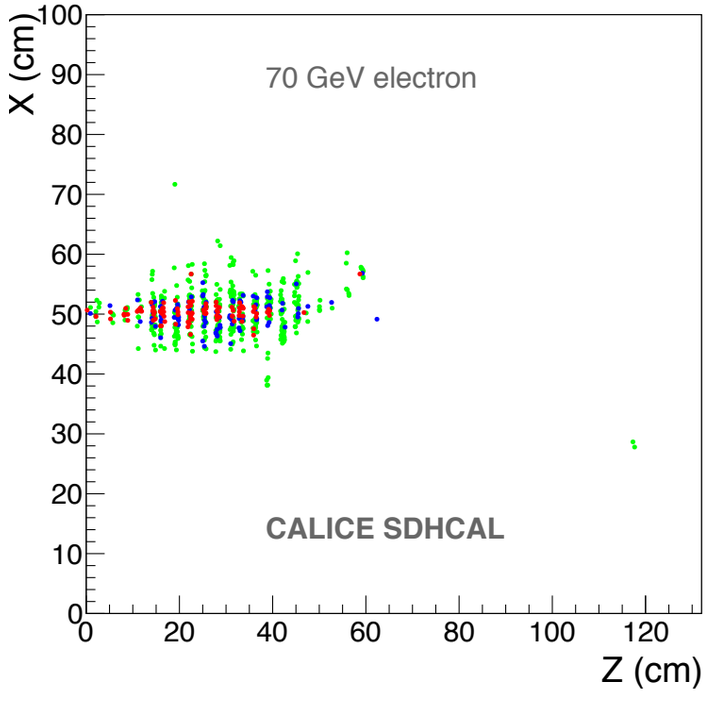
JINST 10 (2015) P10039



80 GeV e-

Shower in SDHCAL



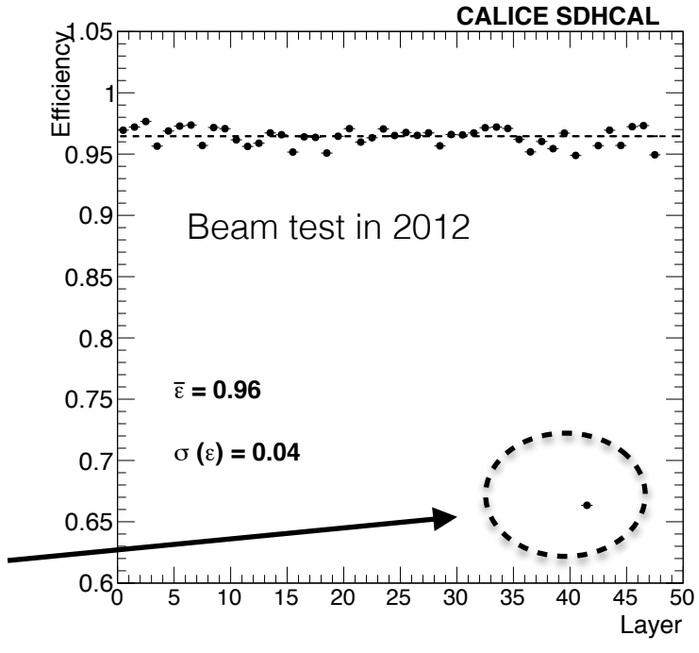


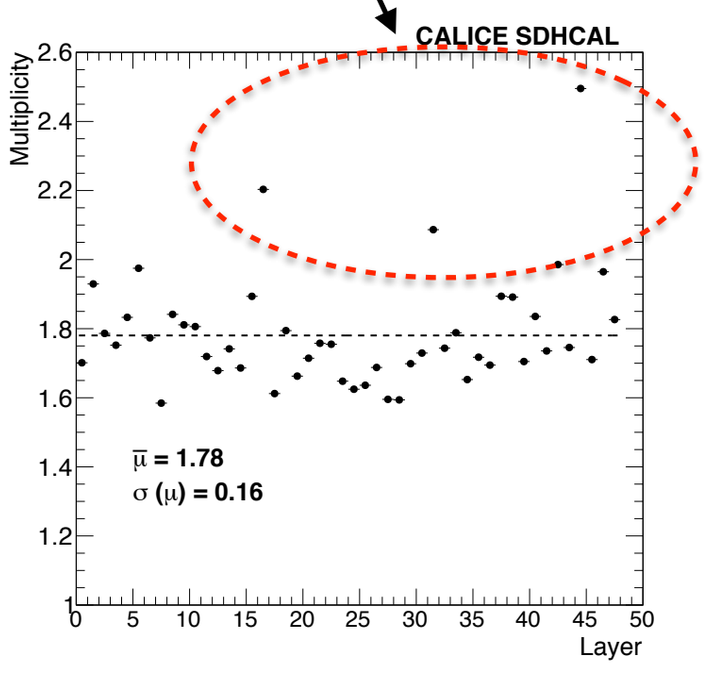
- Excellently depict the shower structure
- Choice of threshold is influential to energy estimation
- Hit density can be taken into account in energy estimation (software compensation)
- Almost perfect performance

- Lower surface resistivity of electrode
- Slightly smaller gas gap in these layer

Efficiency and multiplicity are evaluated by muon events

1/3 of electronics on this layer have problem on power line





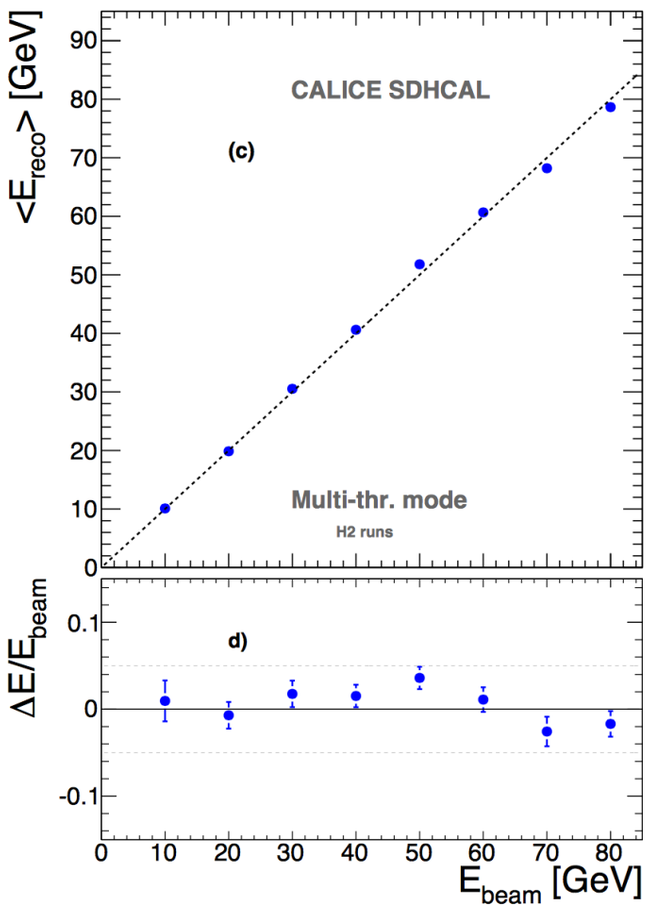
Energy estimation

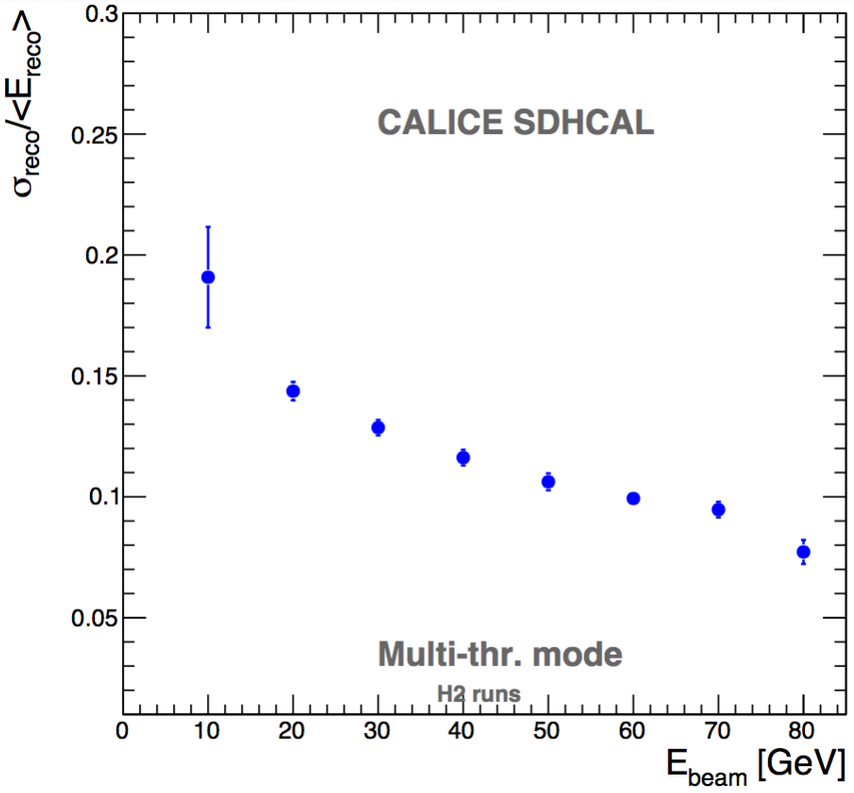
Linear formula

$$E_{rec} = \alpha N_1 + \beta N_2 + \gamma N_3$$

Quadratical formula

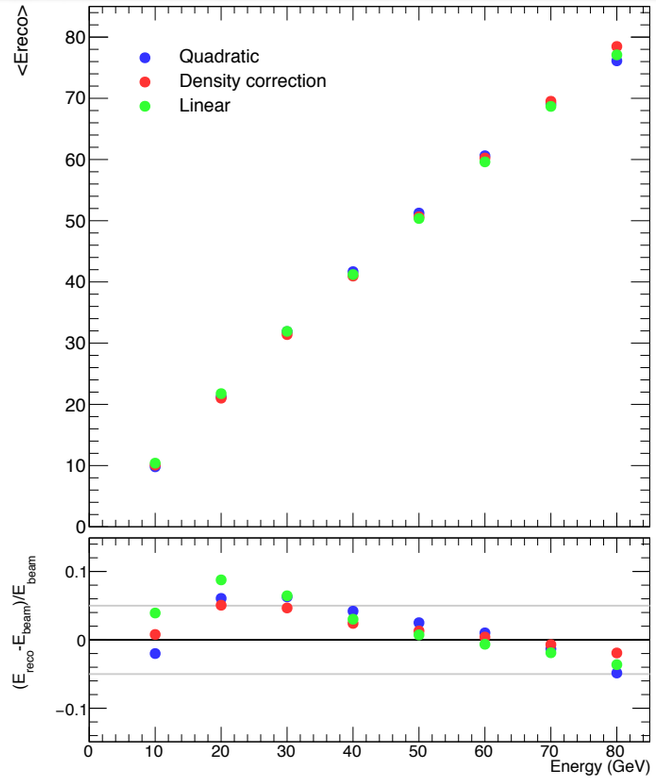
$$E_{rec} = (\alpha_1 + \alpha_2 N_{tot} + \alpha_3 N_{tot}^2) N_1 + (\beta_1 + \beta_2 N_{tot} + \beta_3 N_{tot}^2) N_2 + (\gamma_1 + \gamma_2 N_{tot} + \gamma_3 N_{tot}^2) N_3$$

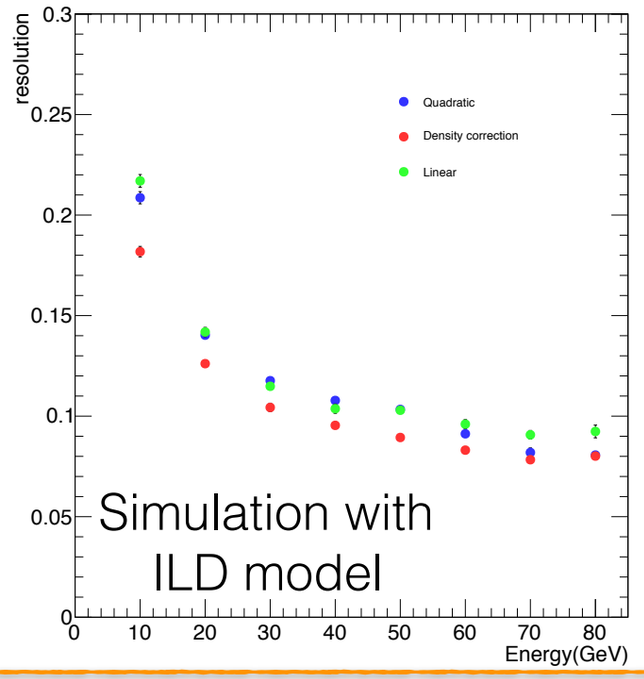




Beam test data

arXiv:1602.02276

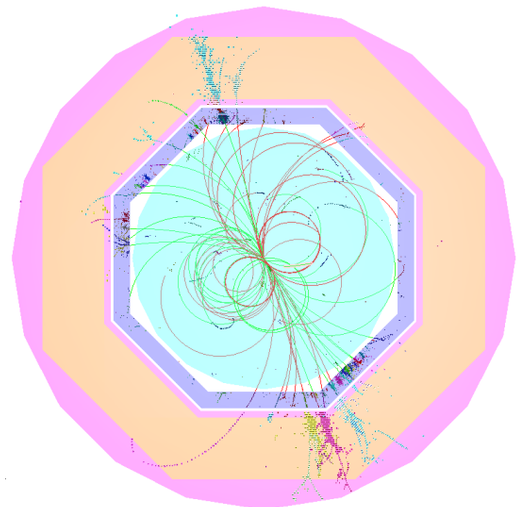


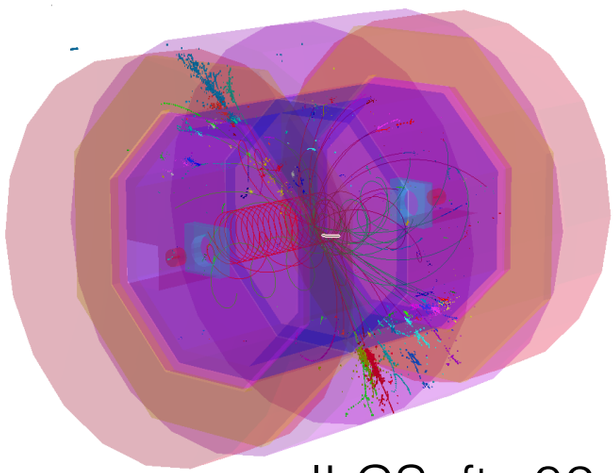


Simulation with ILD model

Jet energy resolution

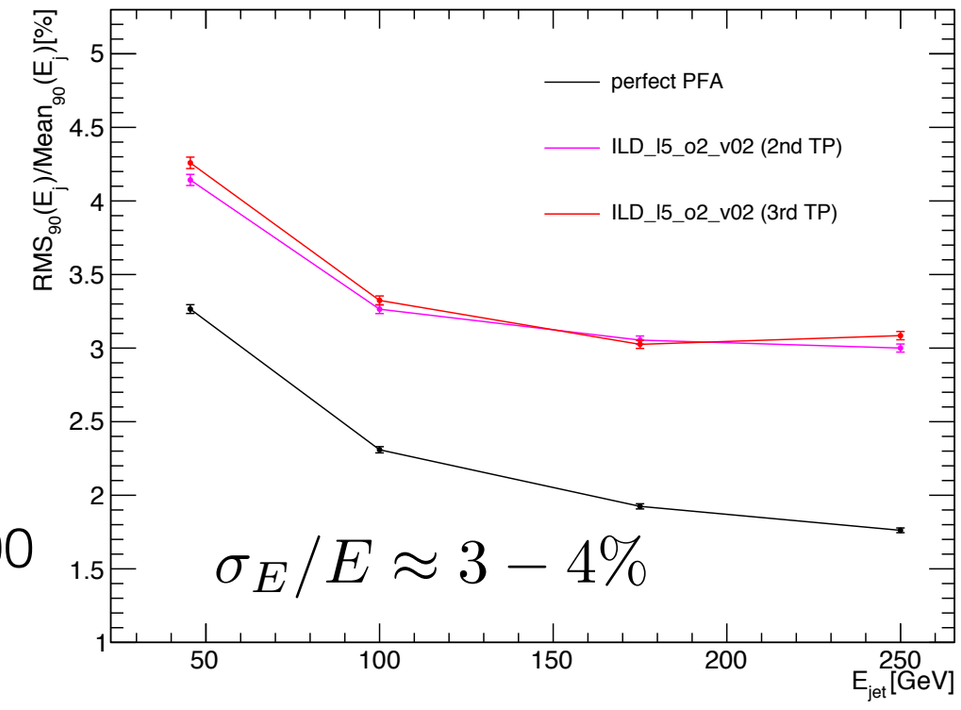
ILD_l5_o2_v02: SiWECAL + SDHCAL

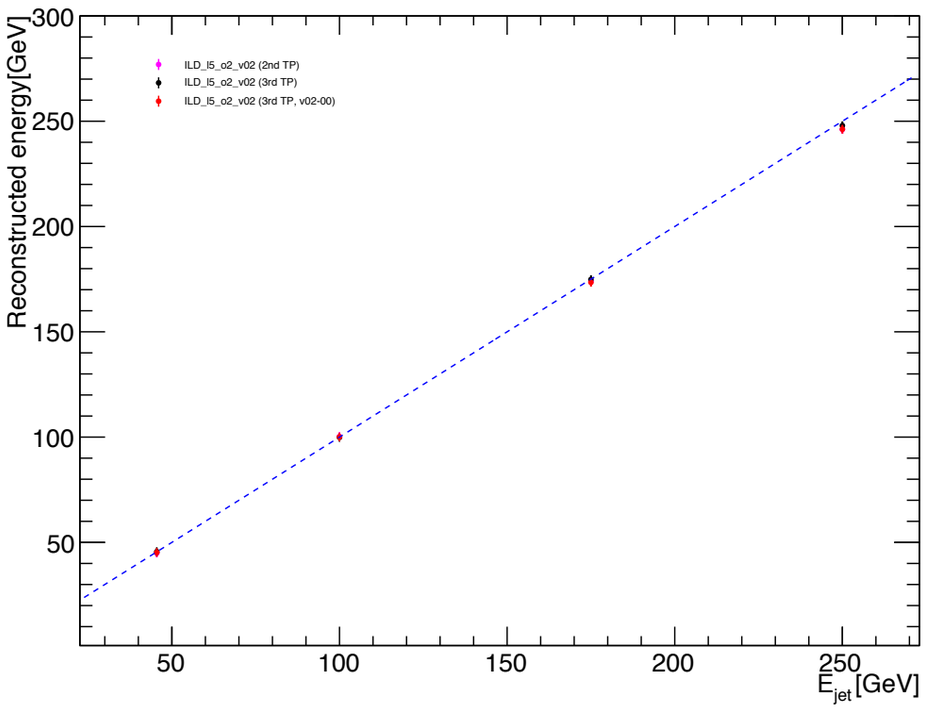


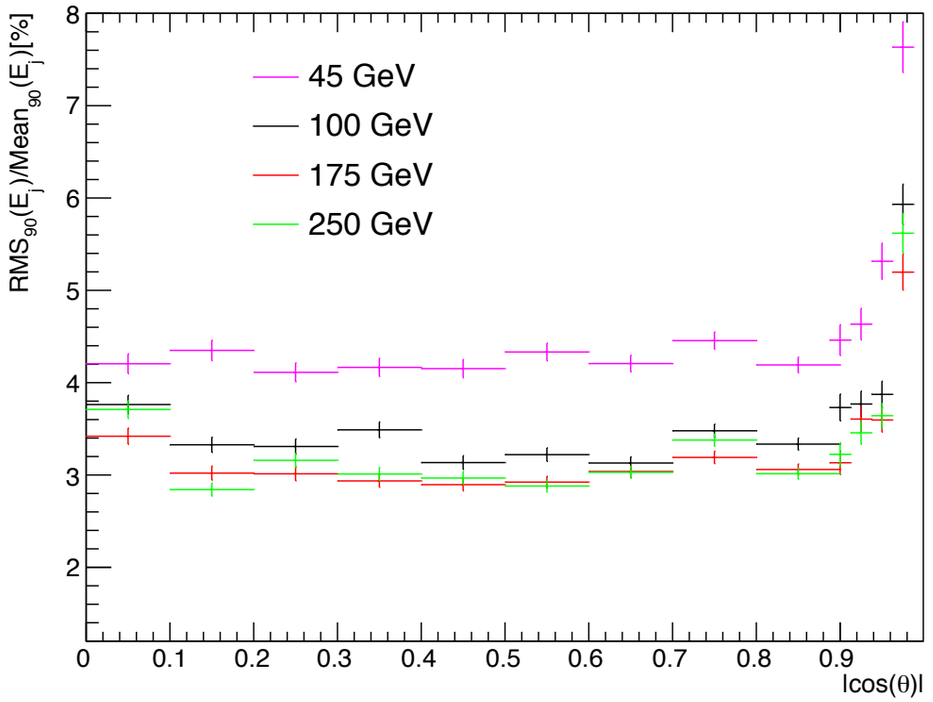


ILCSoft v02-00

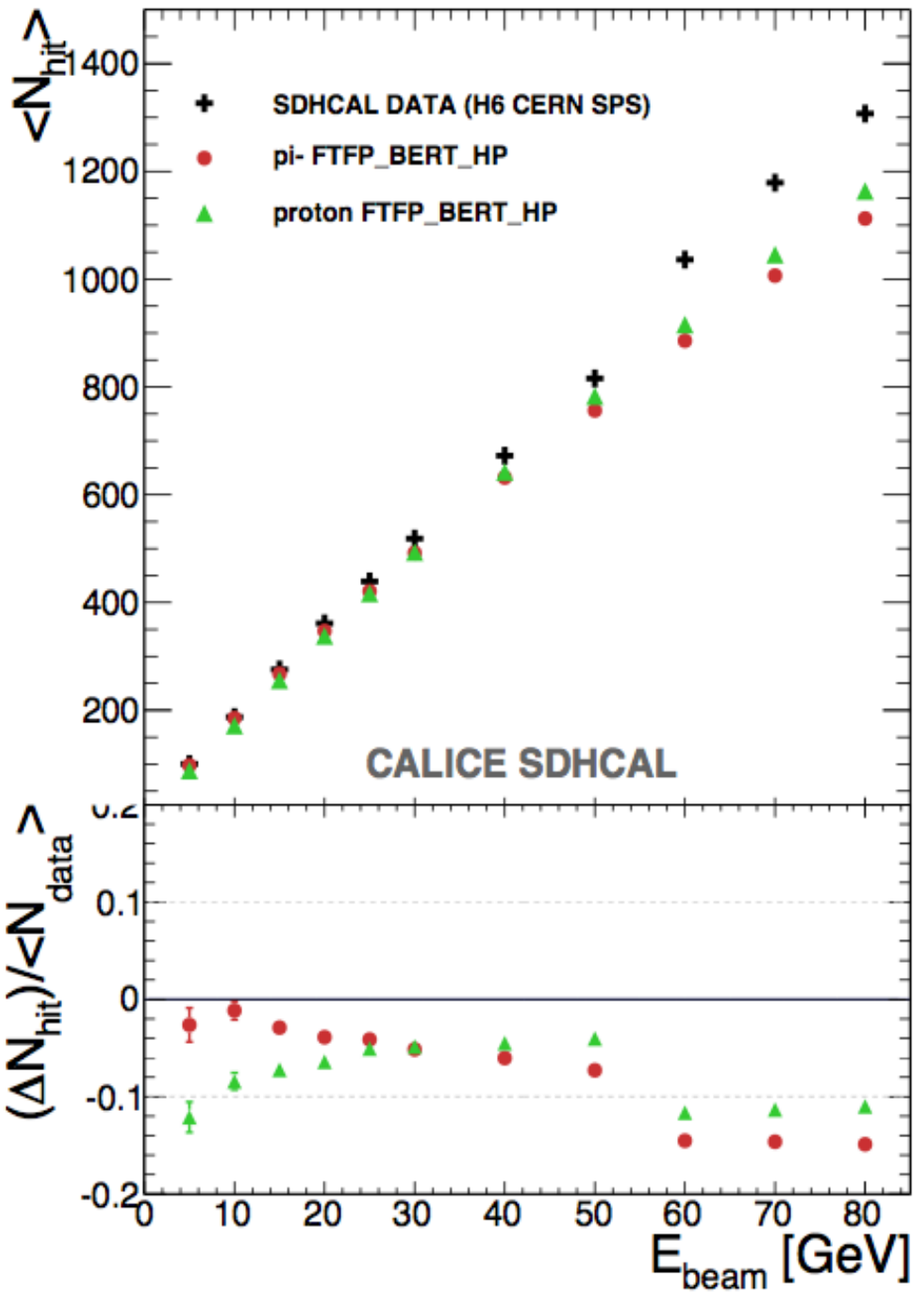
$e^+e^- \to q\bar{q}, E_{\mathrm{cm}} = 500\ \mathrm{GeV}$

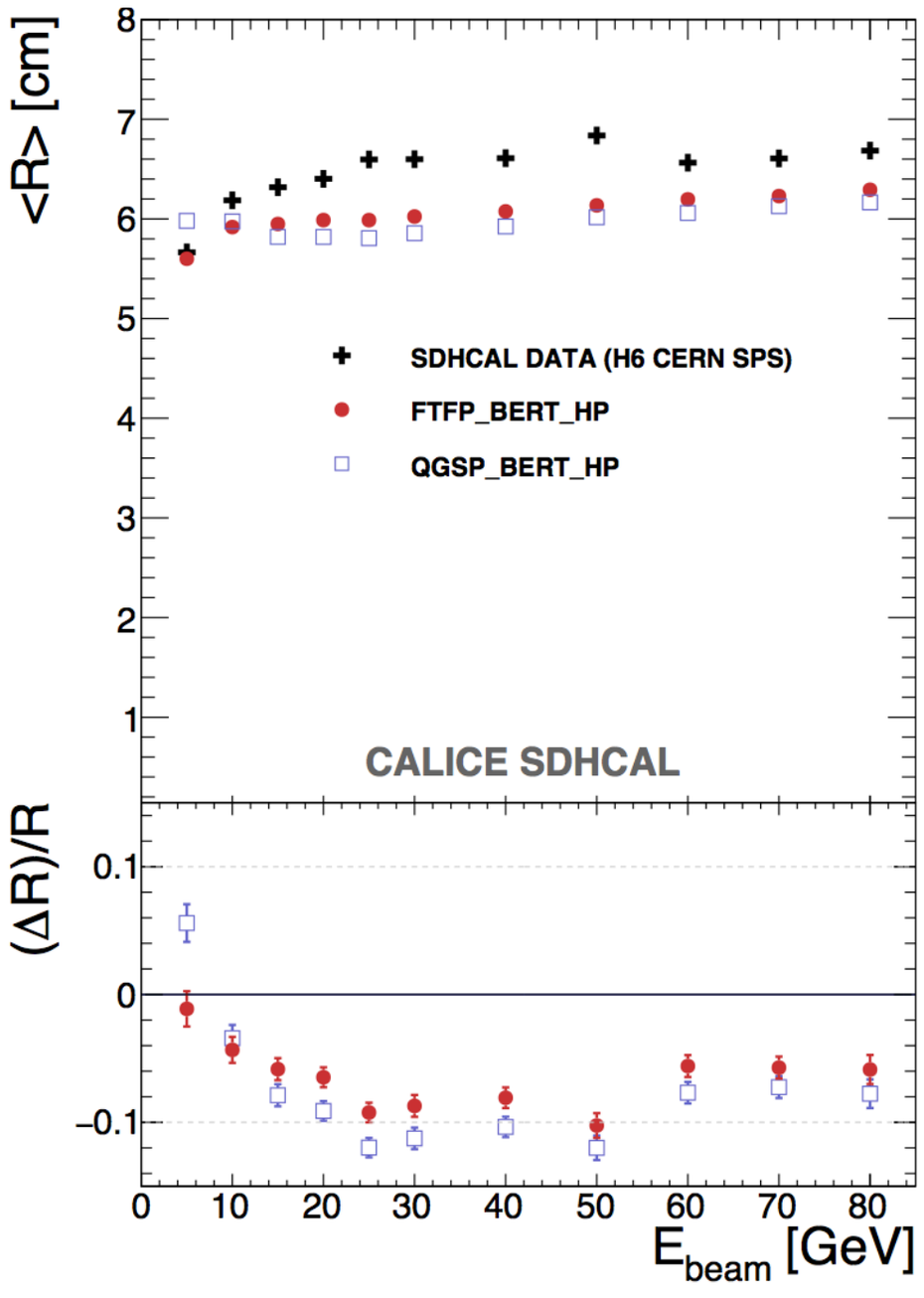






Comparison of data and simulation

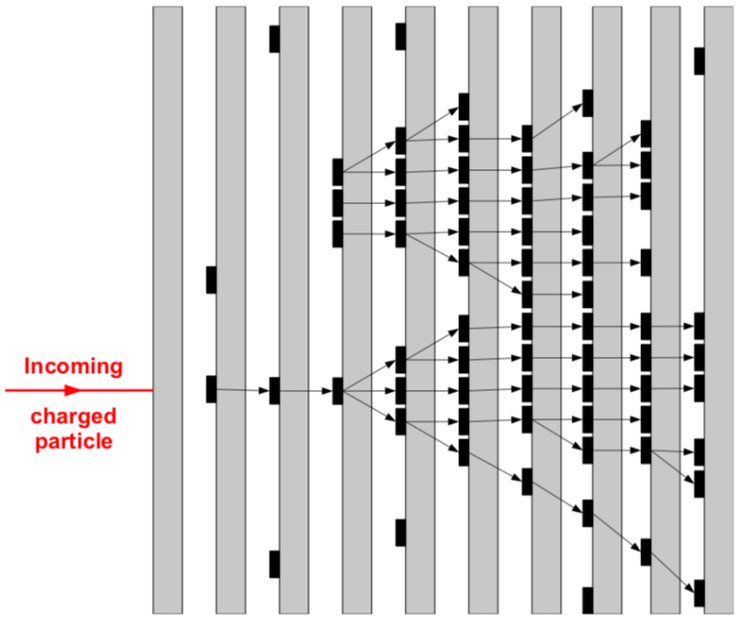




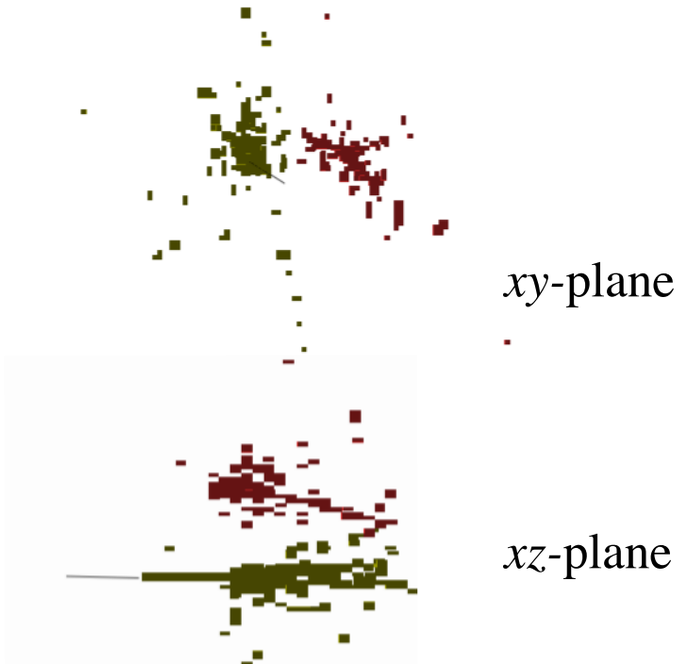
JINST 11 (2016) P06014

Hadronic shower is more compact in simulation than in data

Cluster separation



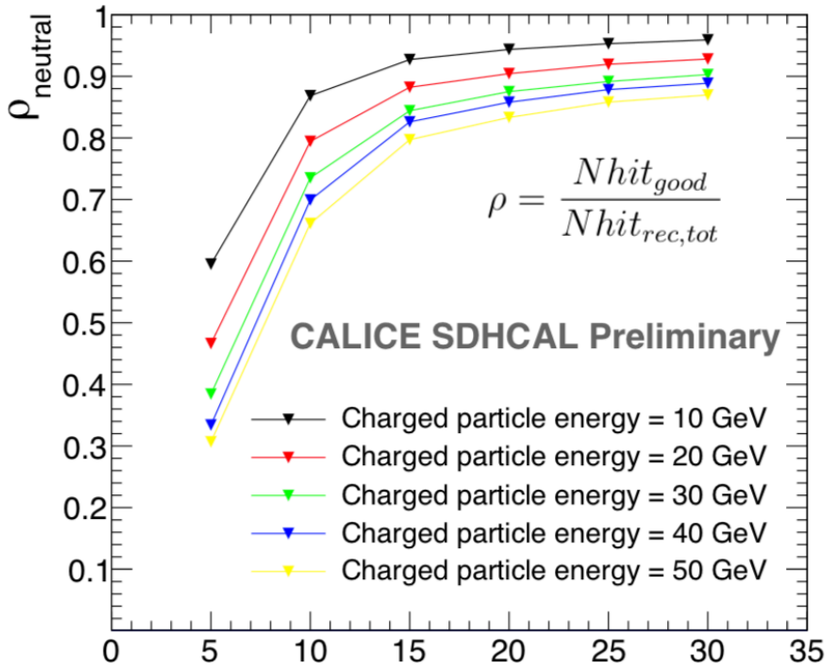
CALICE note CAN054



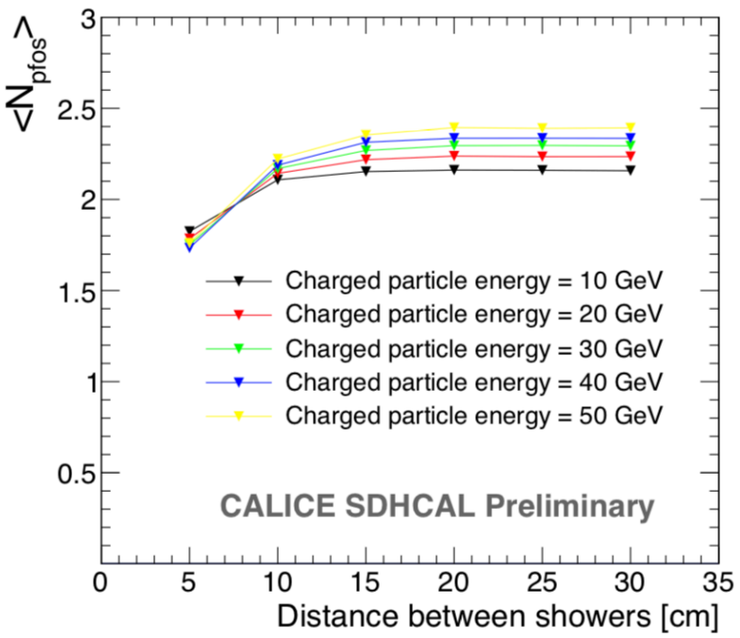
xy-plane

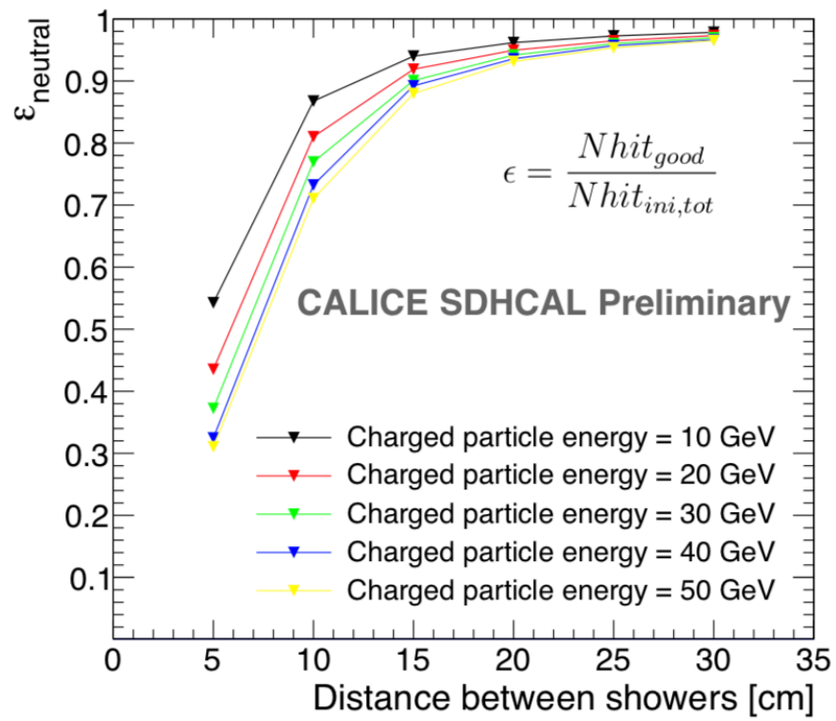
xz-plane

10 GeV neutral kaon + 30 GeV charged pion

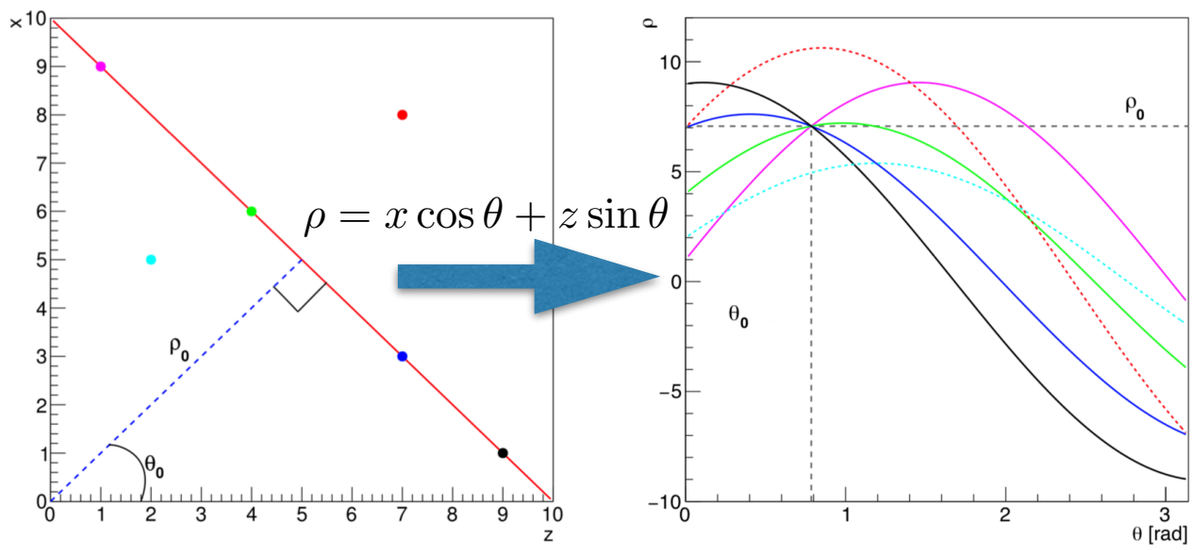


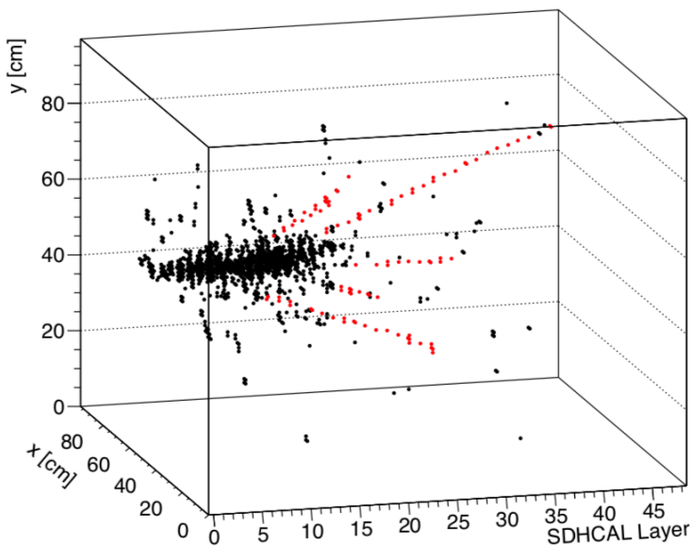
- ArborPFA clustering algorithm: tree topology of reconstructed shower is expected
- Cluster separation is possible at some level and high granularity support this idea from the detector side.

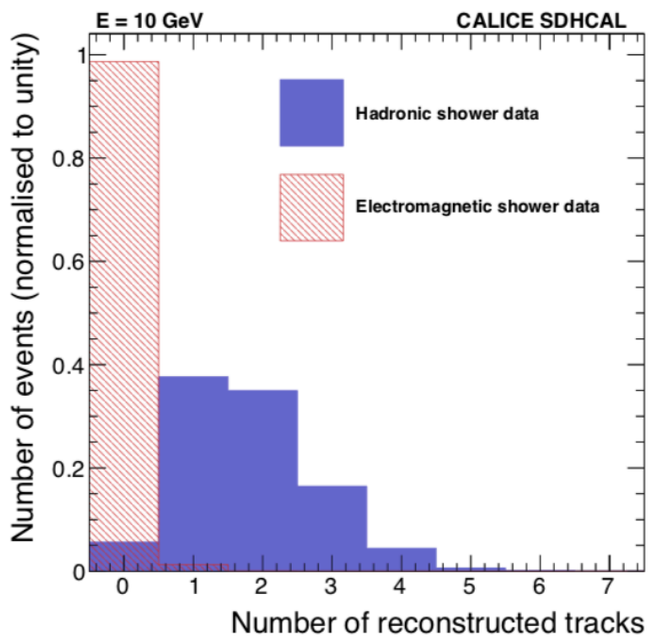


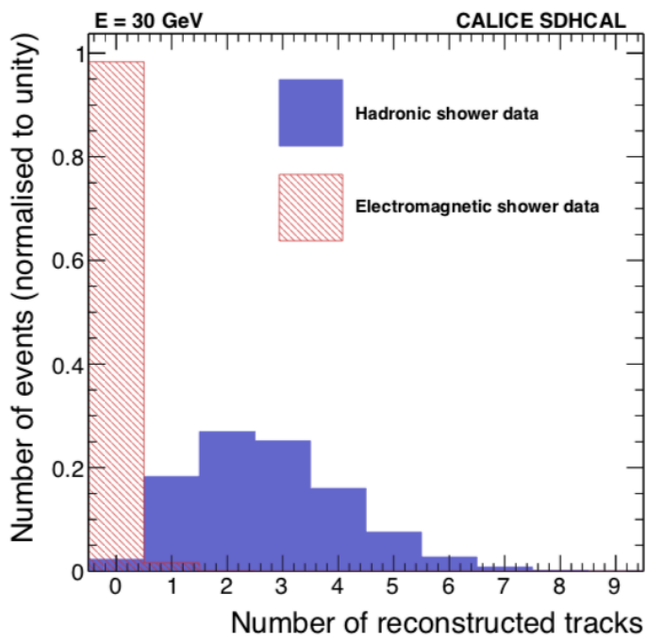


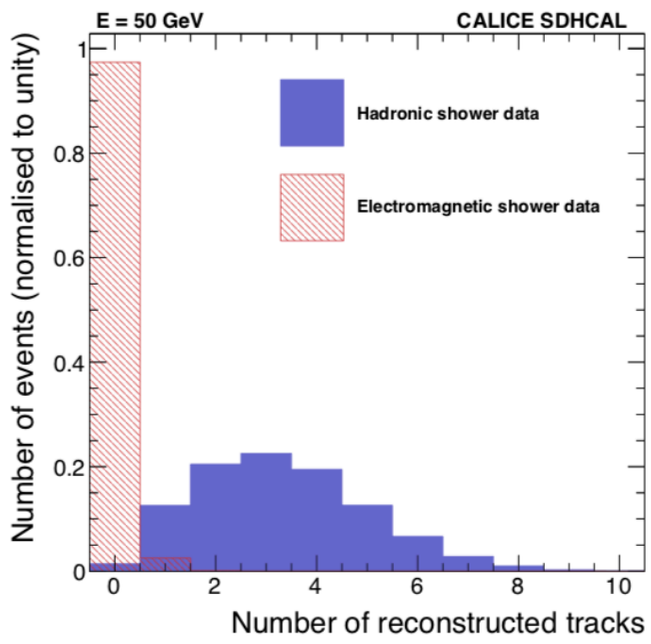
Hough transform







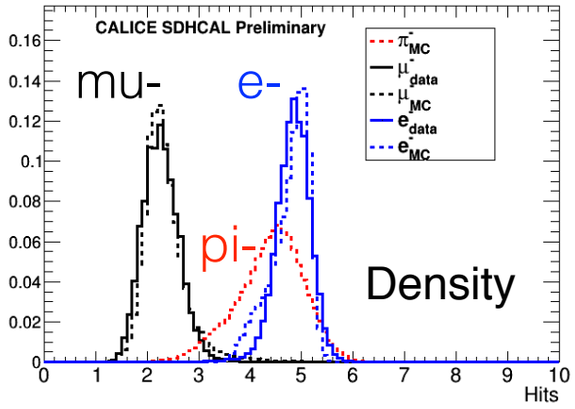


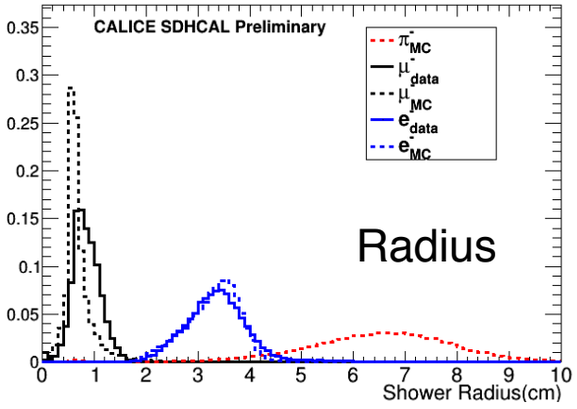


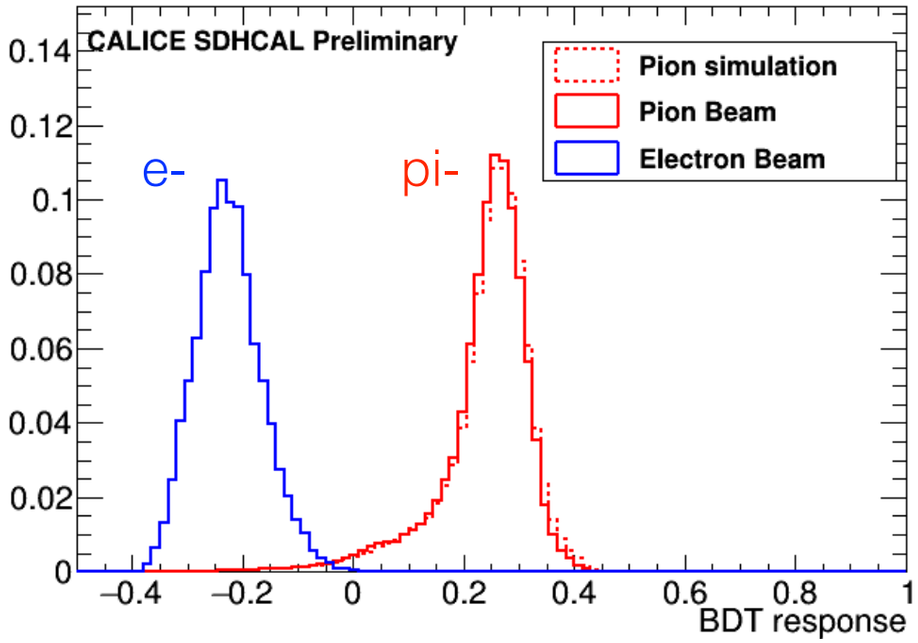
- Good tool to discriminate electron and hadron
- It also can improve he energy reconstruction by dealing with track segment energy

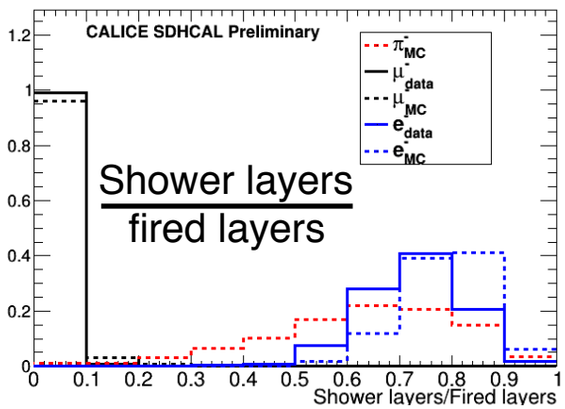
JINST 12 (2017) P05009

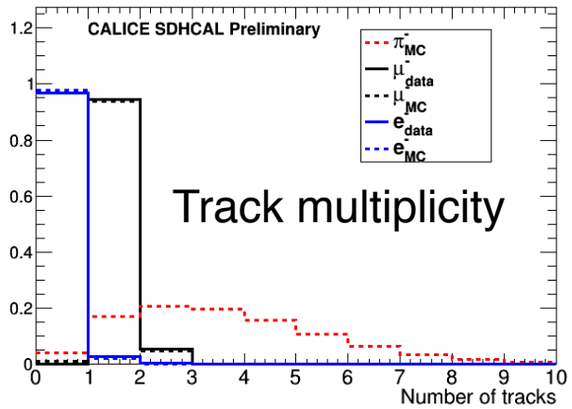
Particle identification by BDT

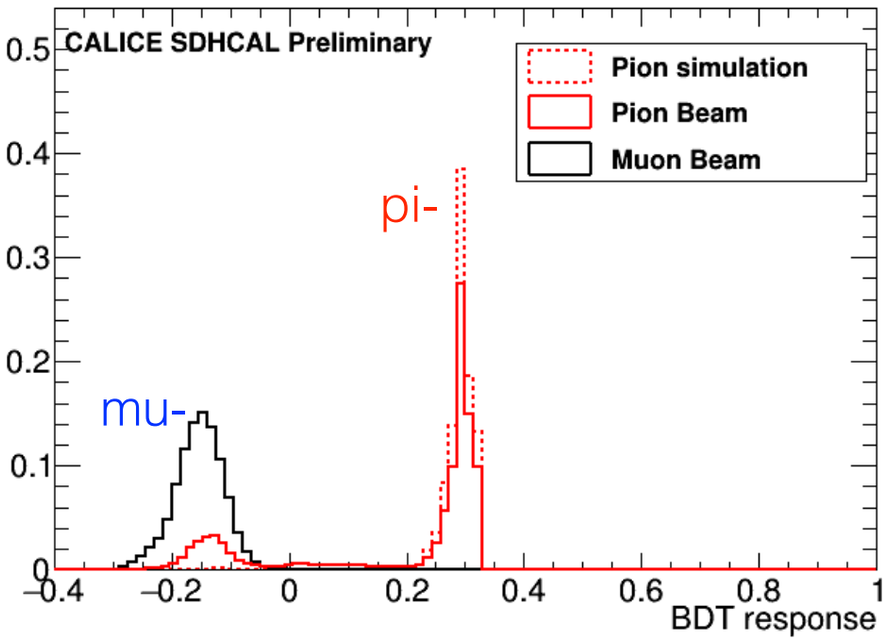


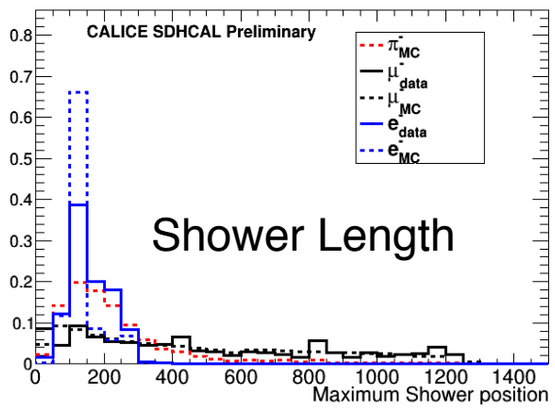


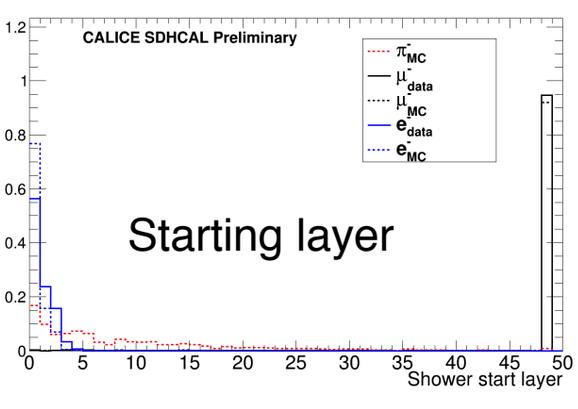








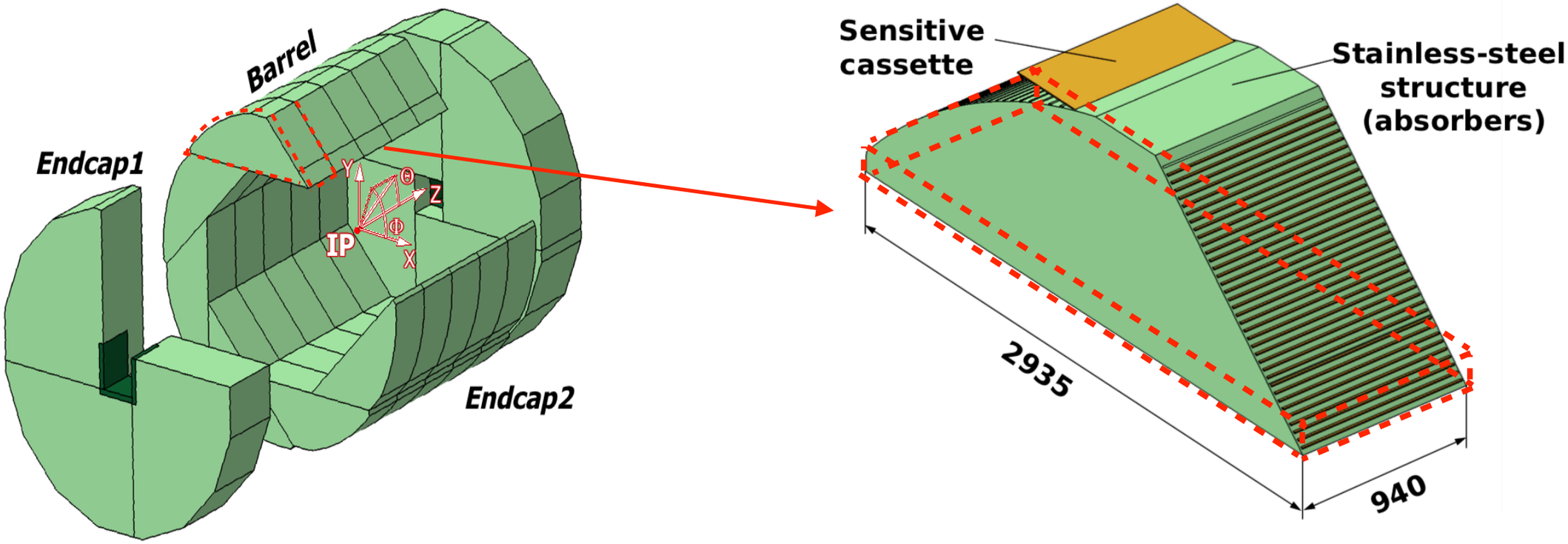




The performance of pi-e and pi-mu separation is quite excellent for both simulation and data

New developments

To the new prototype

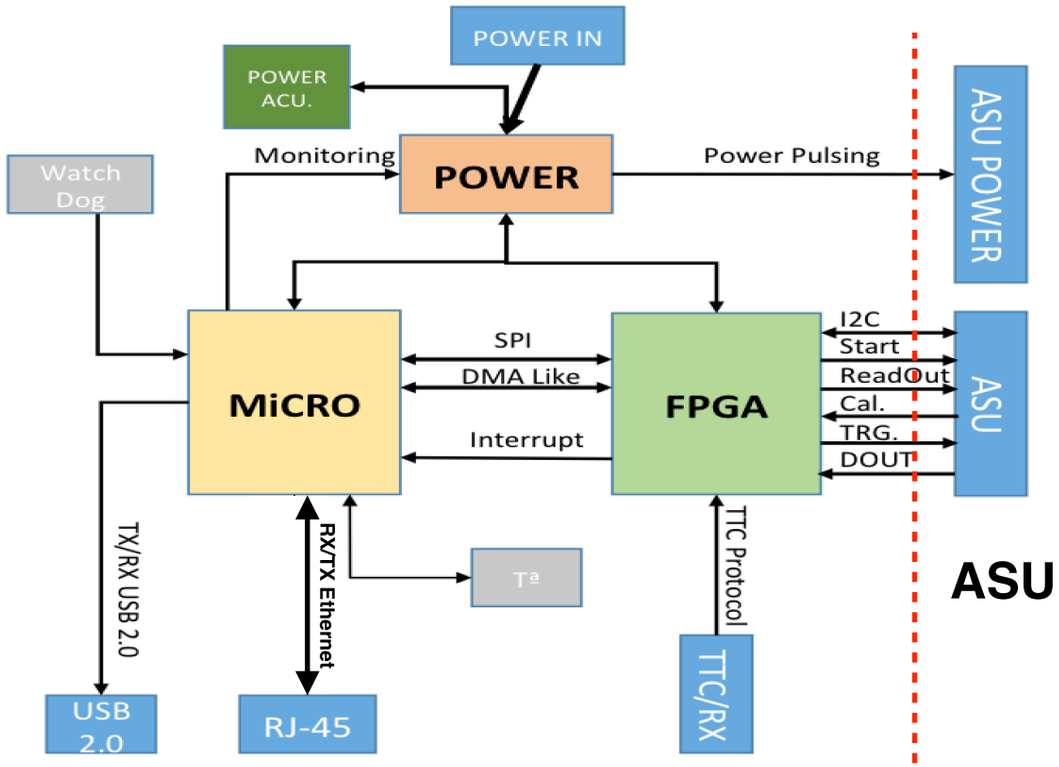


- Next goal: to build a new prototype with a mechanical structure of 4 plates of ~ 1 x 3 m^2
- Large RPCs equipped with improved electronics

Challenges

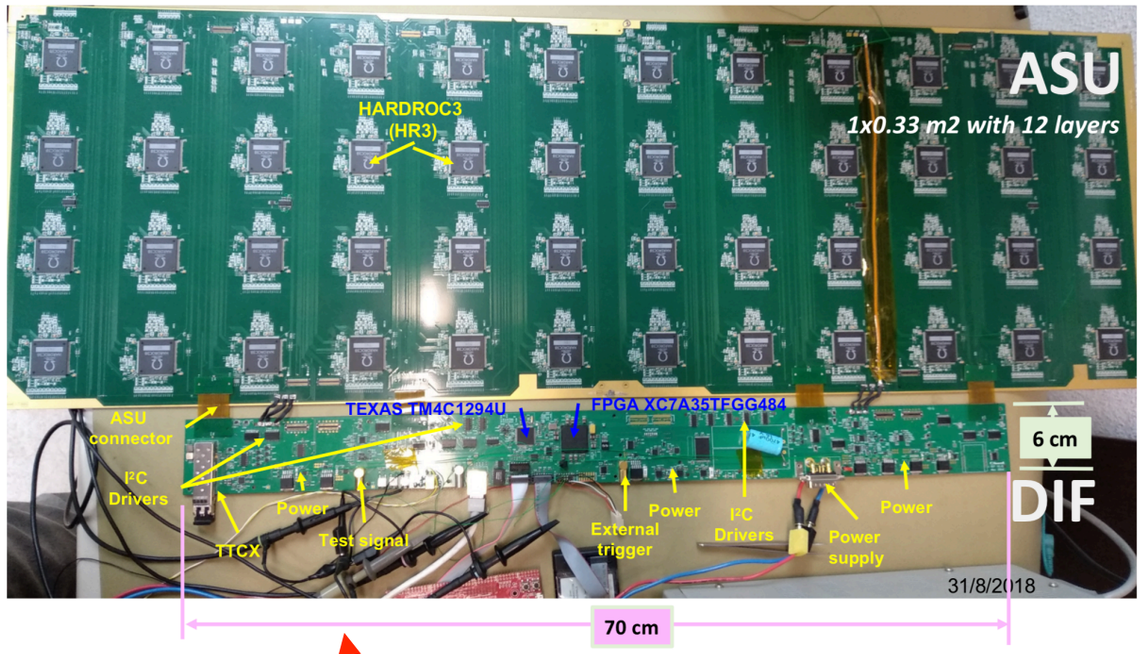
-Homogeneity for large surfaces
-Thickness of only few mms
-Lateral segmentation of 1 cm X 1 cm
-Services from one side
-Self-supporting mechanical structure

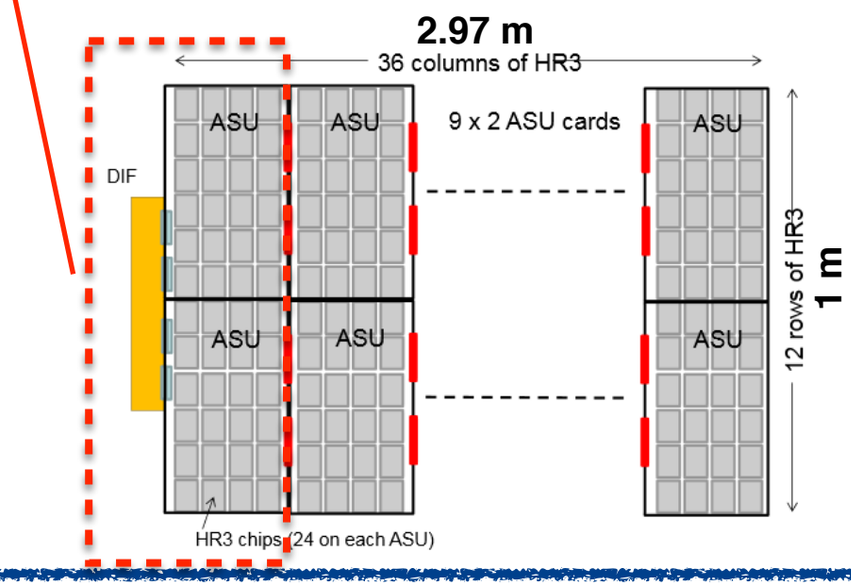
Electronics



DIF(Detetor interface)

- Building a PCB up to 1m length with good planarity to have a homogeneous contact of pads with RPCs
- 1 x 0.33 m^2 with 12 layer ASUs have been built



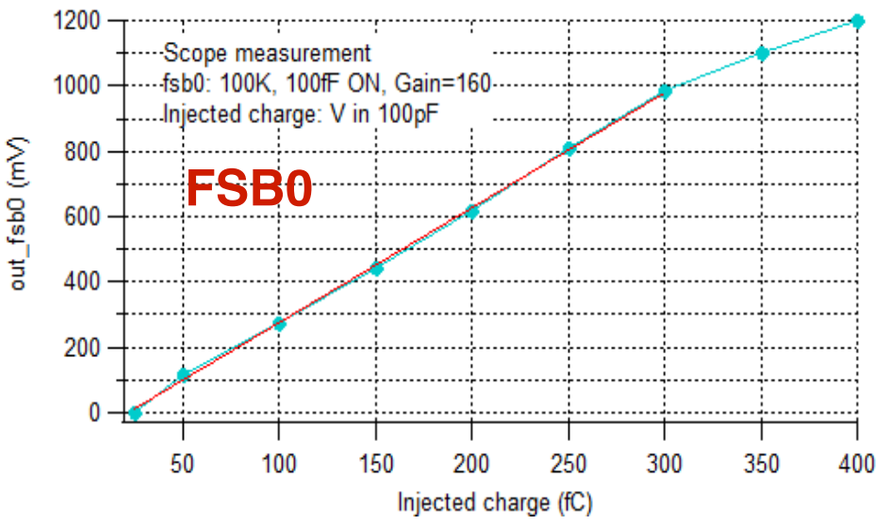


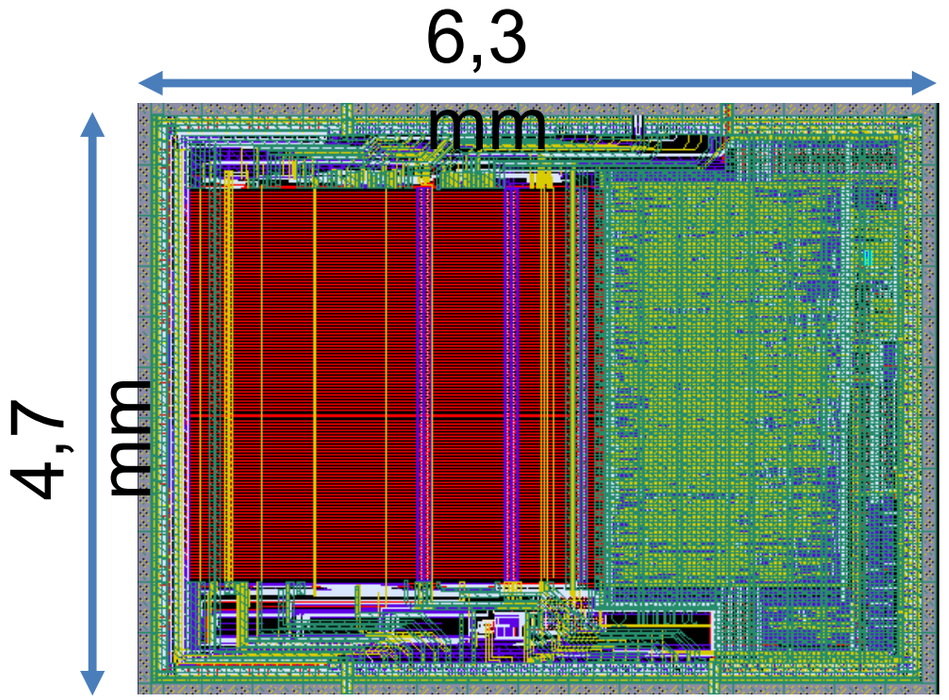
- Only one DIF per plane (instead of three)
- DIF handle up to 432 HR3 chips (48 HR2 in previous DIF)
- HR3 slow control through I2C bus
- Data transmission to/from DAQ by Ethernet
- Clock and synchronization by TTC (already used in LHC)
- 93W Peak power supply with super-capacitors (8.6 W in previous DIF)
- Spare I/O connectors to the FPGA (i.e. for GBT links)
- Upgrade USB 1.1 to USB 2.0

ASIC - HARDROC3

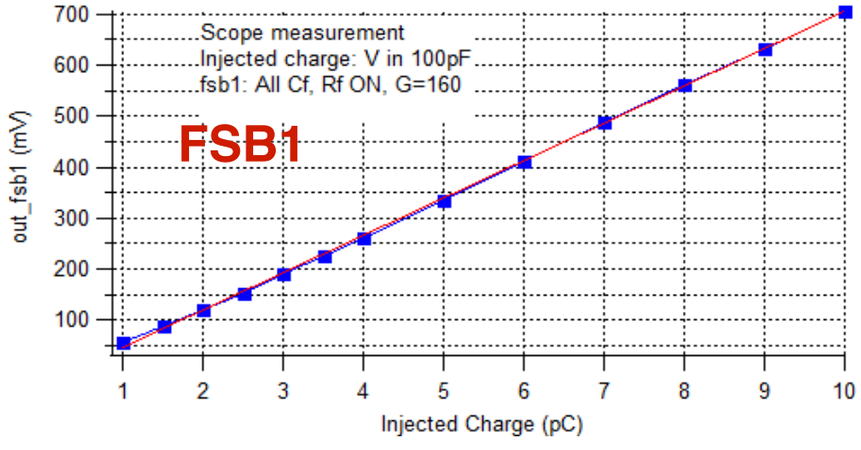
HARDROC3 features:

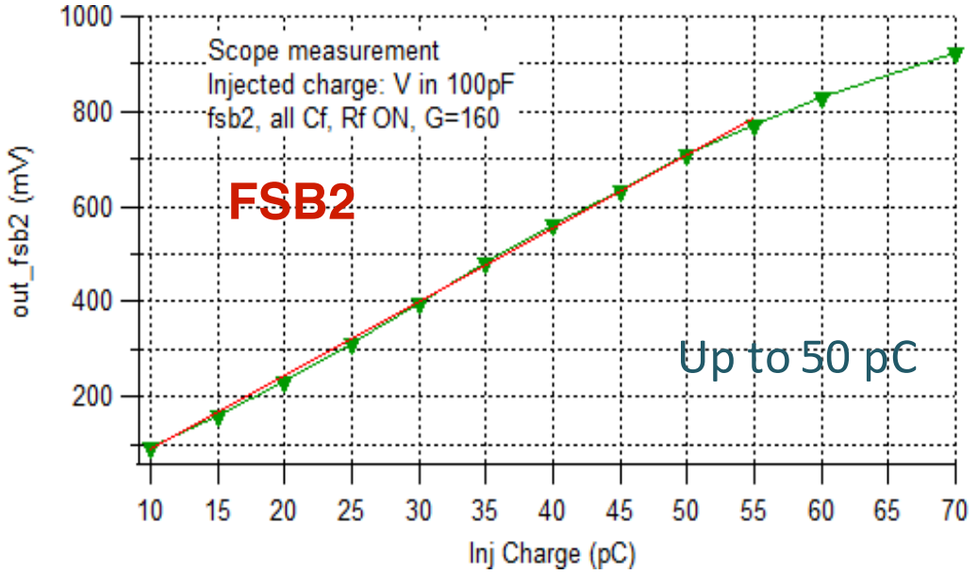
- Independent channels
- Zero suppress
- **Extended dynamic range (up to 50 pC)**
- I2C link with triple voting for slow control parameters
- packaging in QFP208
- Consumption increase (internal PLL, I2C)



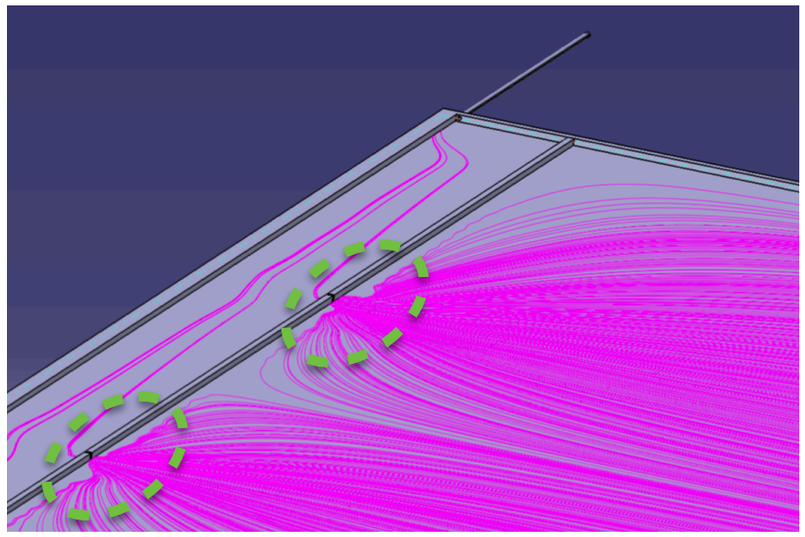


Tested : 786, Yield : 83.3 %

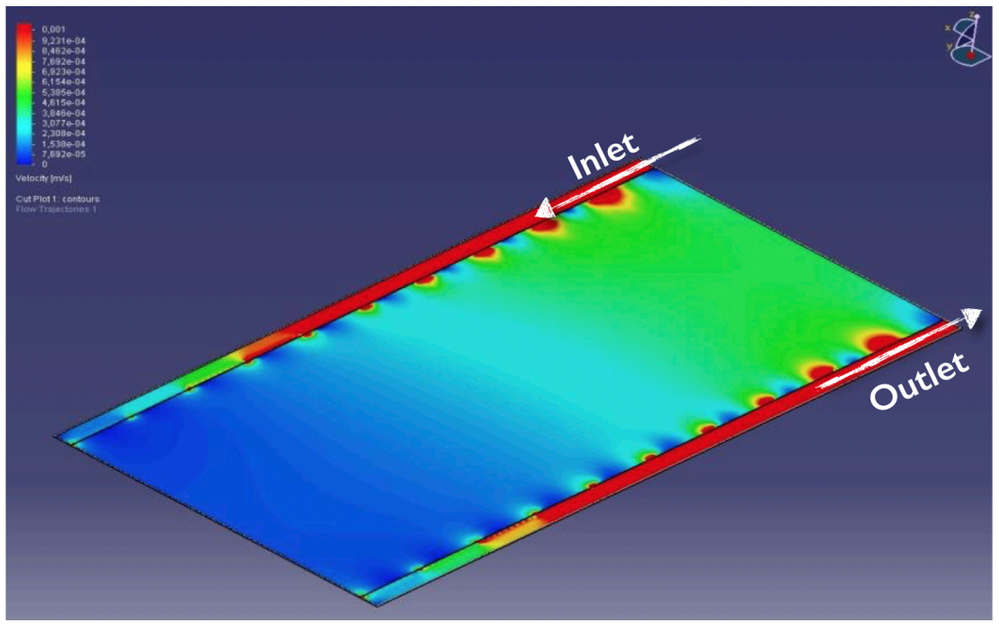




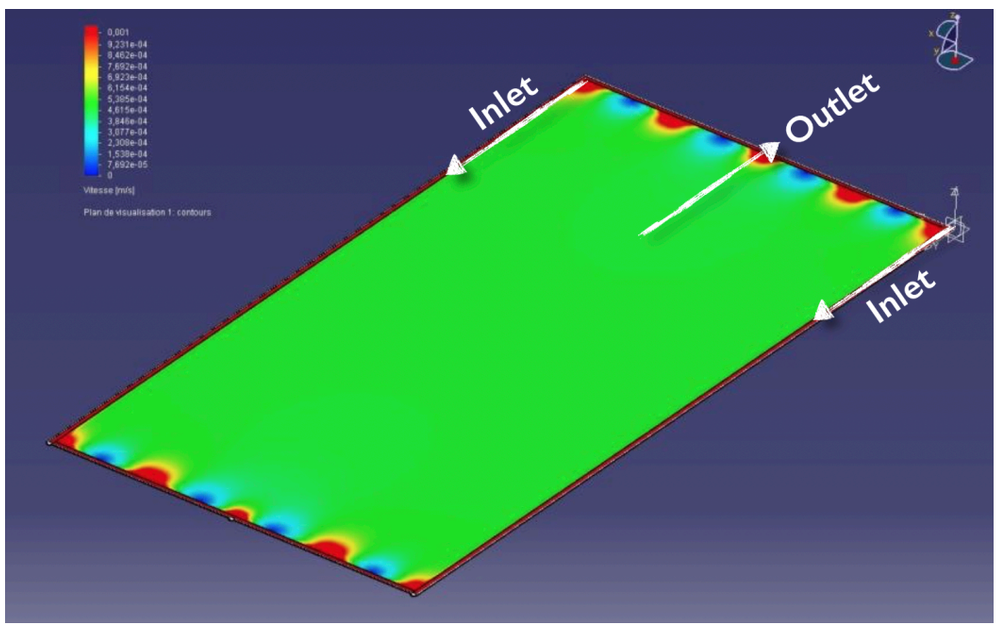
Gas distribution



- A proper homogeneity of the gas circulation inside the GRPC volume is an important factor to ensure high efficiency of detection and low noise
- Construction and operation of large GRPC necessitate some improvements with respect to the present scenario
- New scheme of gas distribution is proposed
- Construction of a few large RPC has started



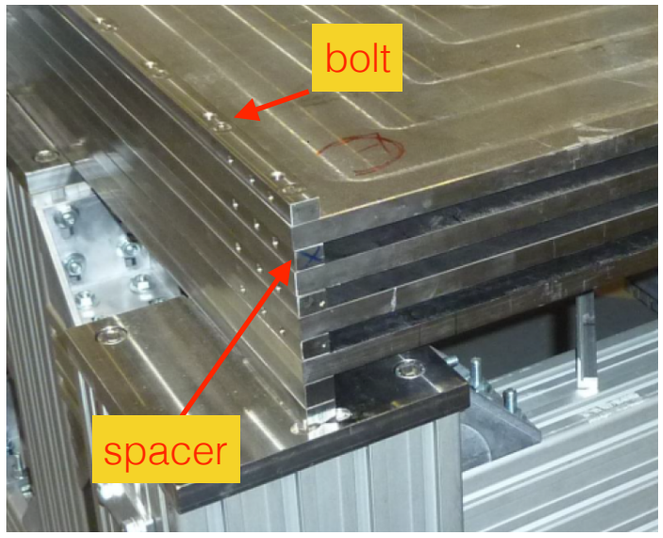
Old scheme

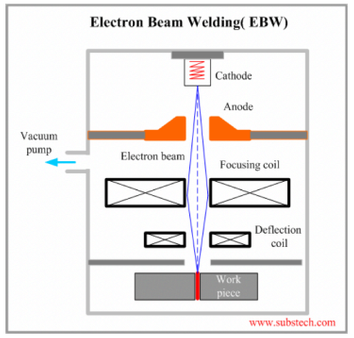


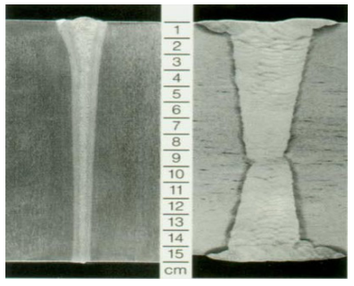
New scheme

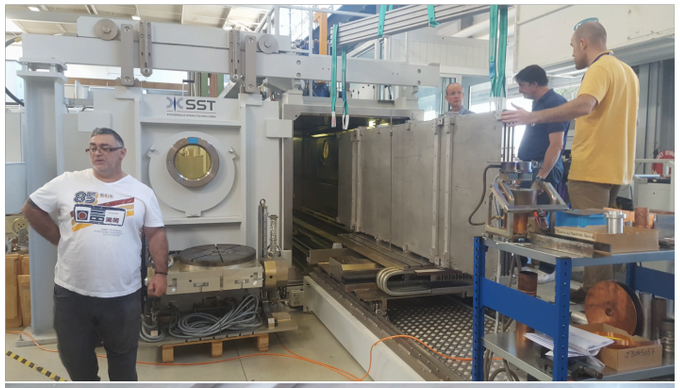
Mechanical structure

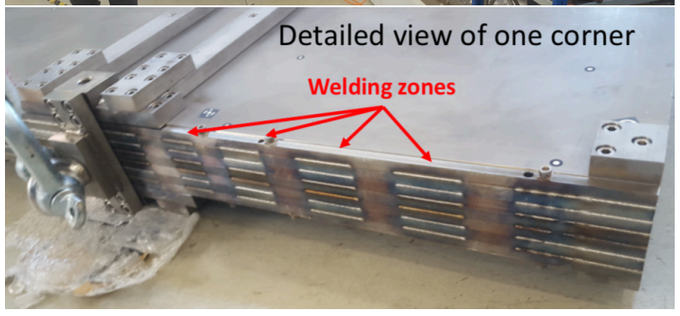
- Use Electron Beam Welding to reduce the dead spaces (and deformation if using standard welding)







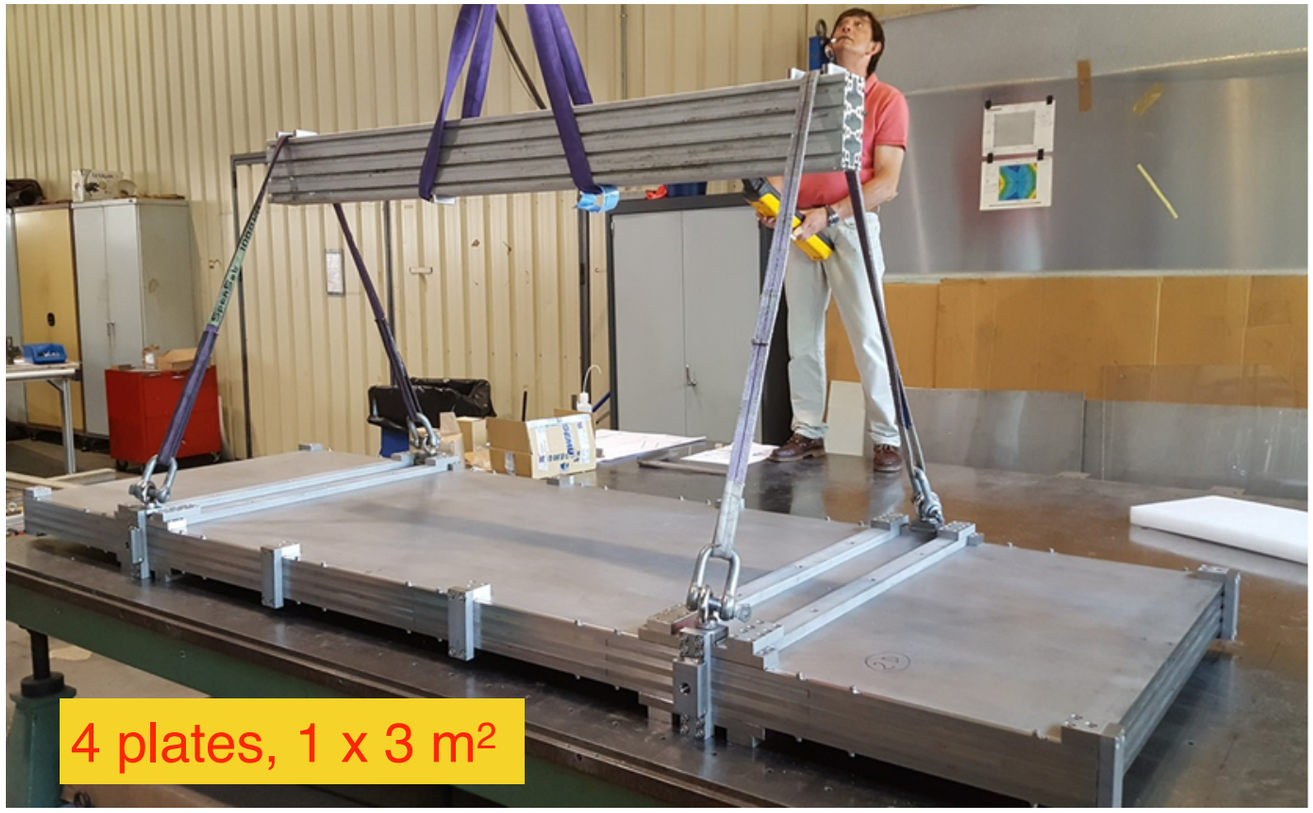




- Plate need to be very flat for reducing the extra tolerance space for the GRPC insertion
- Industrial production of flat large absorber plates (1 x 3 m^2) by roller levelling process

Measurement of flatness using laser interferometer

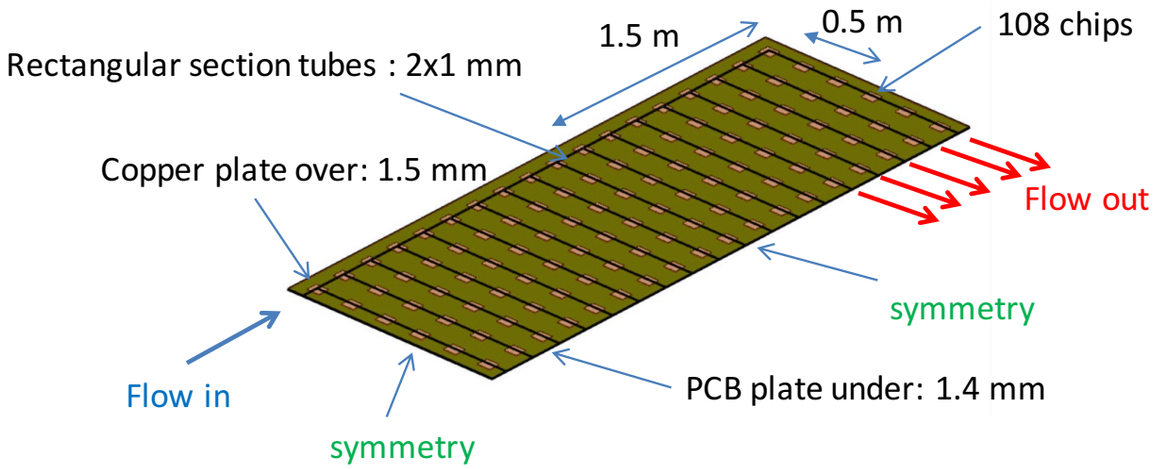
Mechanical structure (cont.)



An empty cassette (small, length: 1m) was inserted into the mechanical structure check the future insertion of the new larger GRPC.

Cooling

- Cooling becomes necessary if the power pulsing scheme is not possible at CEPC project: an estimation of power consumption of SDHCAL is **110 kW**



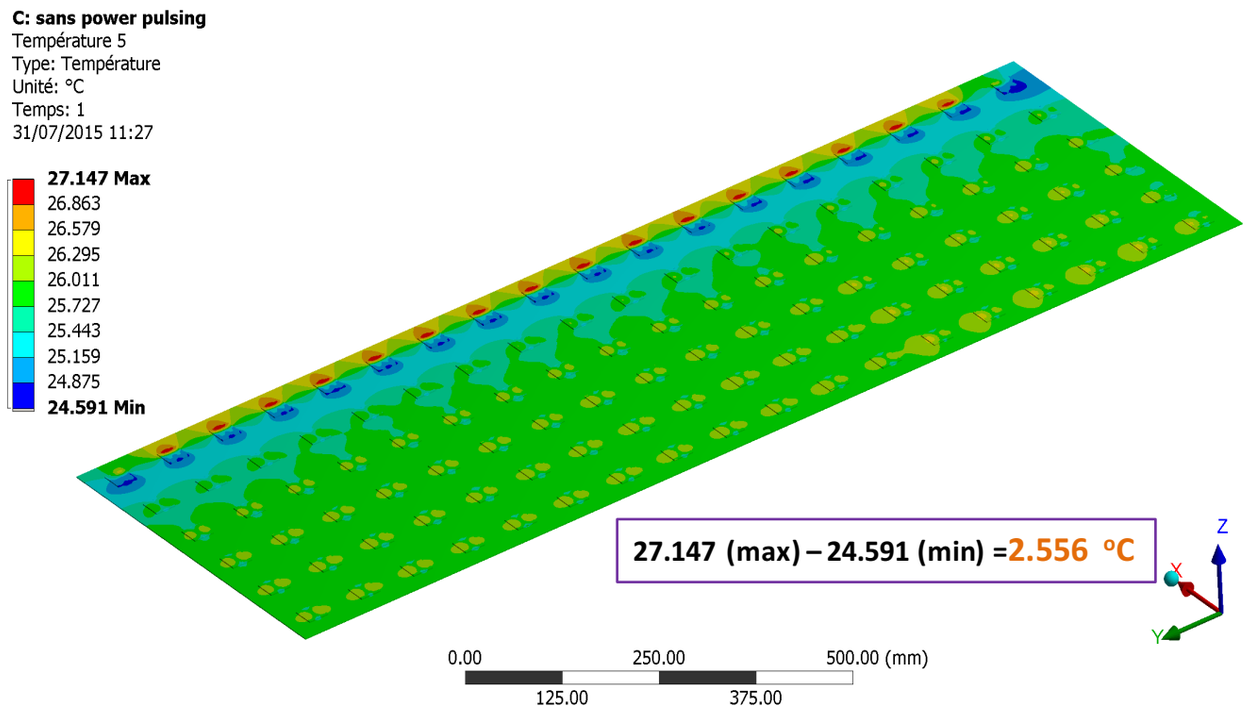
Water cooling :

h = 10000 W/m²/k

Thermal load :

80 mW/chip without power pulsing

Simulation ¼ structure pcb + chips



- Collaboration with SJTU; Optimisation is ongoing

Summary

- SDHCAL prototype
  - It has been validated that SDHCAL can fulfil the requirements at ILD
  - Benefits coming from high granularity add many functionalities for SDHCAL
- New development
  - Toward to the new prototype, we need more efforts to overcome the all challenges.
  - Novel technologies were proposed and implemented in the development of electronics and mechanical structure, and cooling for the new prototype