Performance of the SDHCAL technological prototype

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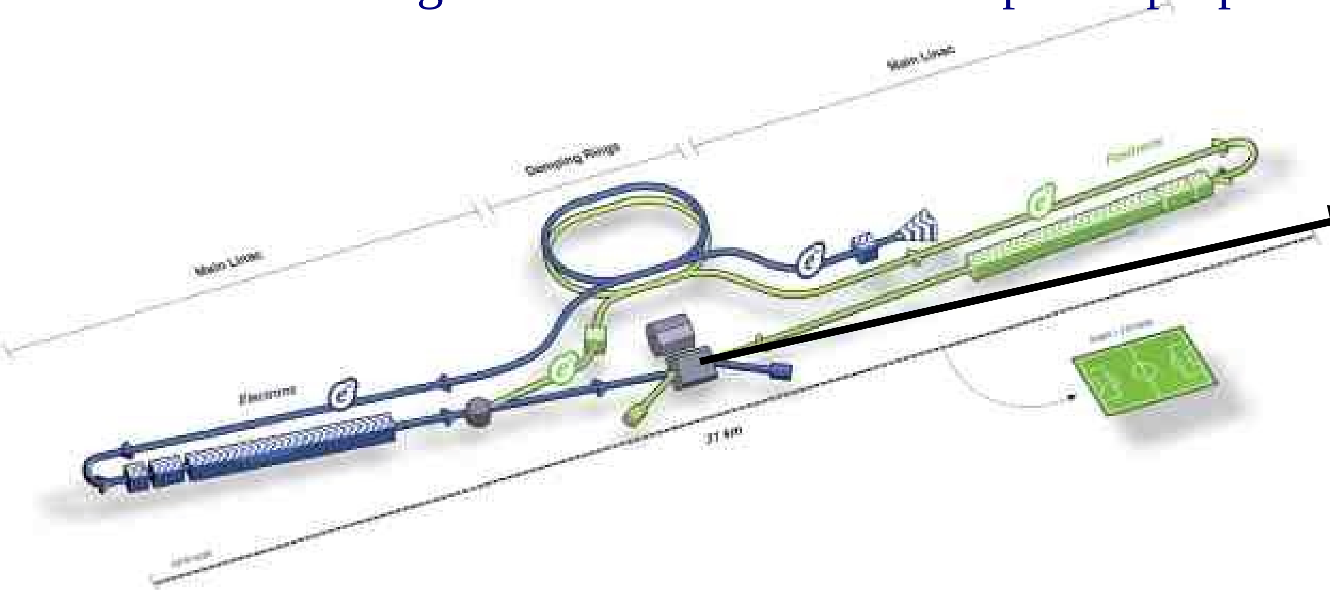
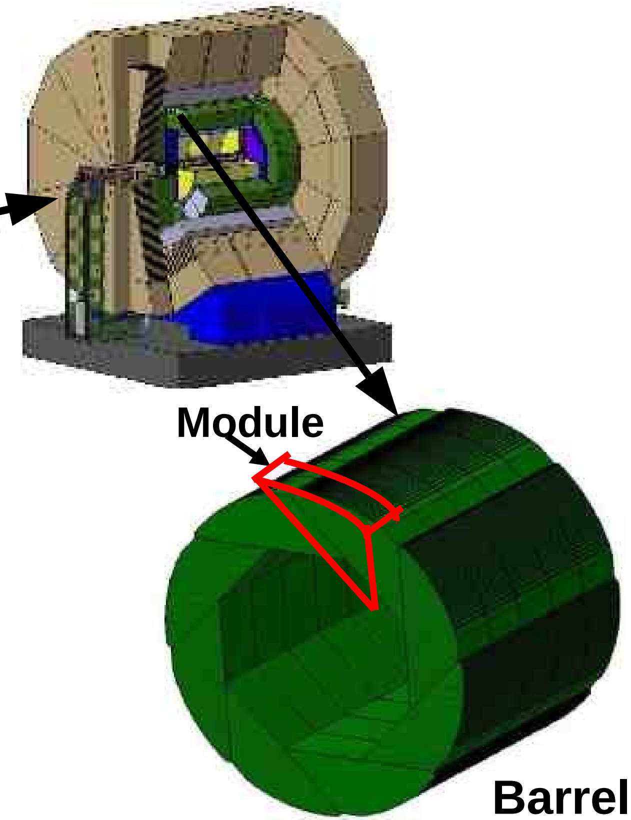
ILC, ILD and SDHCAL projects

- The Semi-Digital HCAL is one of two options proposed in the ILD LOI.



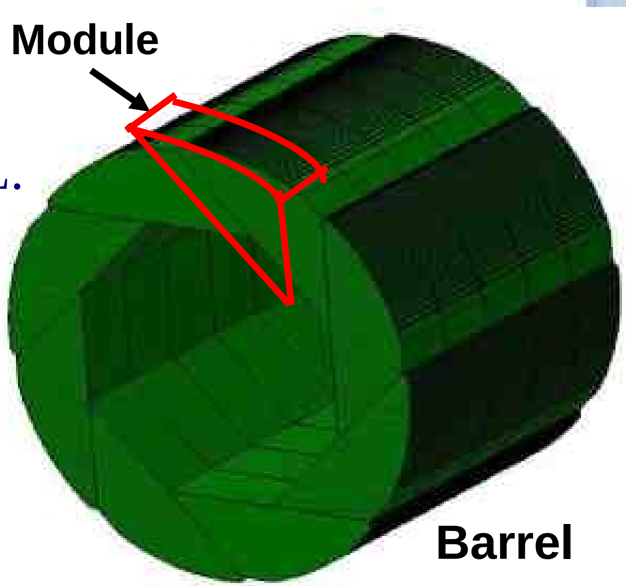


Several groups of the CALICE collaboration contribute to the SDHCAL project :

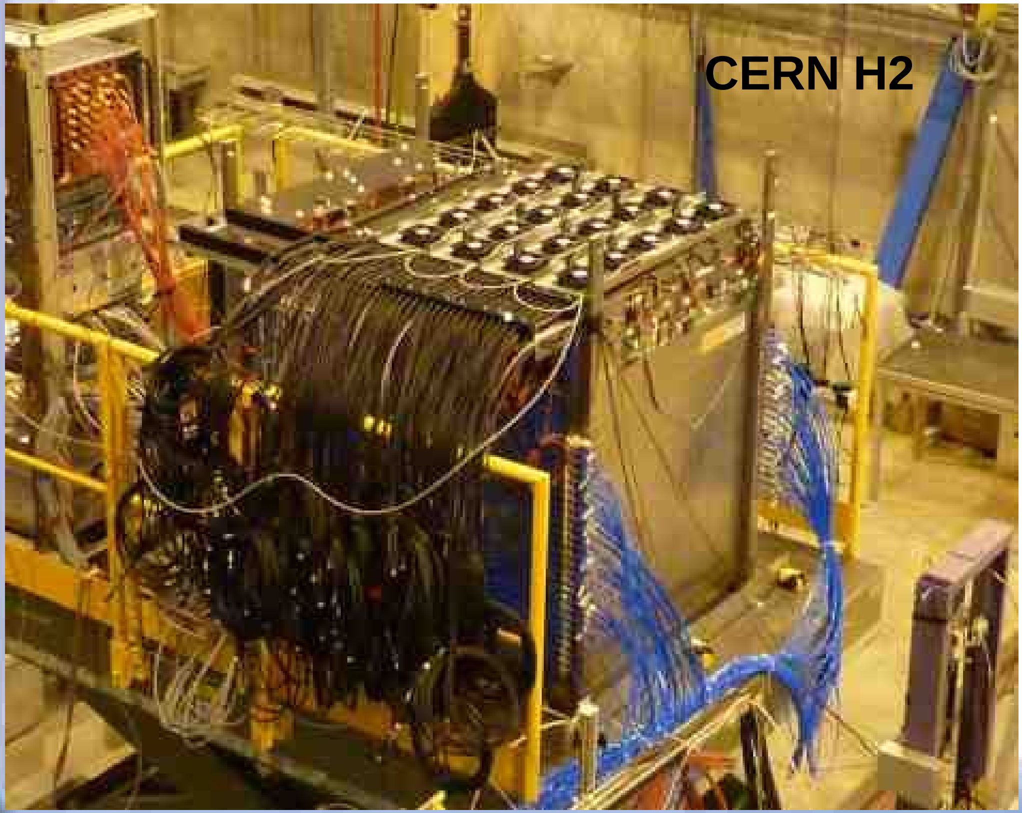
France : IPNL, LAPP, LLR, LPC, OMEGA;
Spain : CIEMAT;
Belgium : UCL, Gent;
China : Tsinghua university, NCEPU;
Tunisia : Tunis university.

Motivation

- The Semi-Digital HCAL is one of two options proposed in the ILD LOI.
- It proposes Glass-RPC detectors as sensitive medium with embedded readout electronics providing $1cm^2$ lateral segmentation.
- Design for PFA
- A genuine mechanical structure is proposed for the SDHCAL.



- A technological prototype with up to 50 $1\ m^2$ GRPC was conceived as a demonstrator



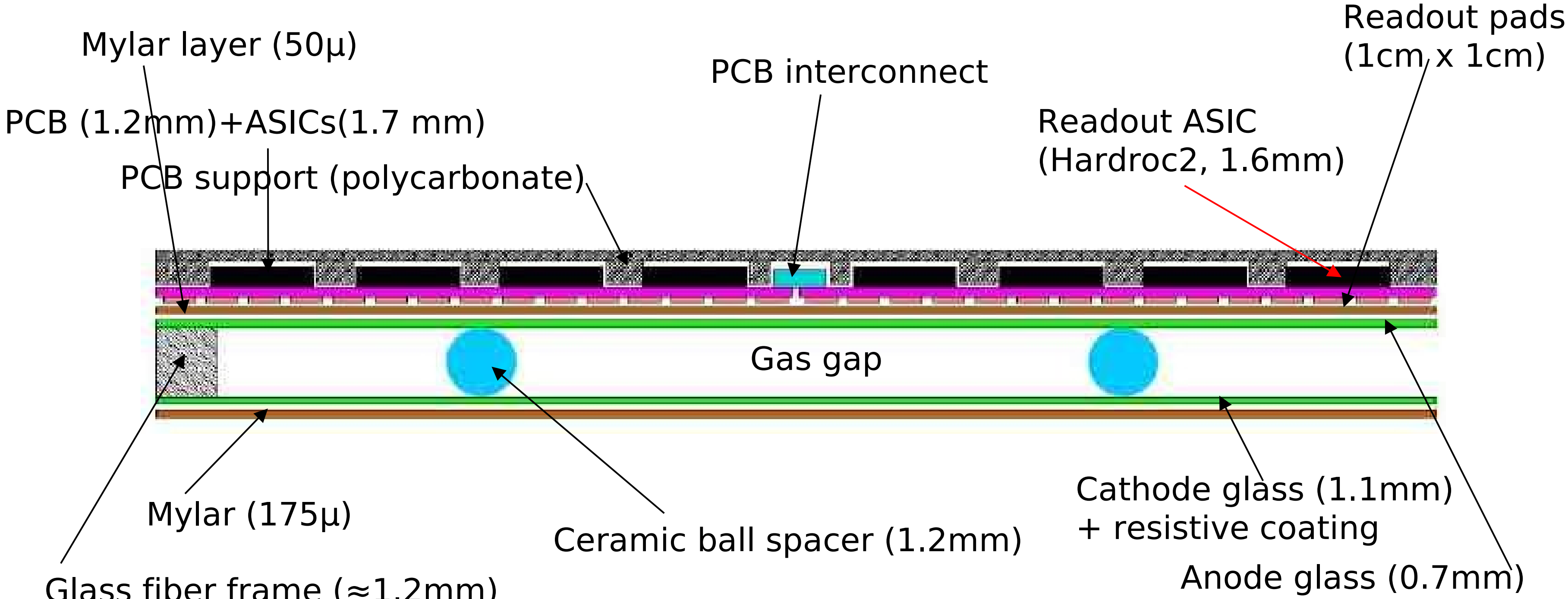
Challenges
-homogeneity for large surfaces
-Thickness of only few mms
-Services from one side
-Embedded electronics

SDHCAL prototype

- Self-supporting stainless-steel structure.
- Up to 50 slots to insert GRPC K7
- K7 = GRPC+embedded electronics+ steel cover (11 mm thick)
- 1 m^2 GRPC read by ~1cm^2 readout pads
- 96x96x50 channels for the full Prototype = 460800 channels
- Less than 1‰ dead channels
- All services on one side.

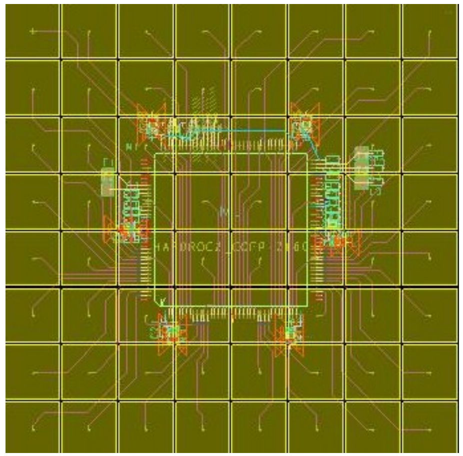
Chamber cross-section view

- 1 m^2 GRPC
  - Saturated avalanche mode : spatial charge distribution on glass anode ~ 1 mm^2
  - Read by pad 1 cm^2 copper pads : max particle density in shower ~ 100/cm^2 : 3 readout thresholds.
  - Embedded readout electronics



Total thickness: 6.0mm

Readout electronic



- ASICs=HARDROC2 (http://omega.in2p3.fr)
- Each ASIC reads 64 copper pads,
  - Amplification, shaping, 3-level discriminator (dynamic range 10 fC to 30 pC), triggerless : store up to 127 first threshold crossing (pad ID and time (200 ns clock))
  - See A. Kumar's talk yesterday
- ASICs are daisy-chained (data readout, configuration)

PCB used in CMS- muon upgrade project (see F. Lagarde's talk on Thursday)

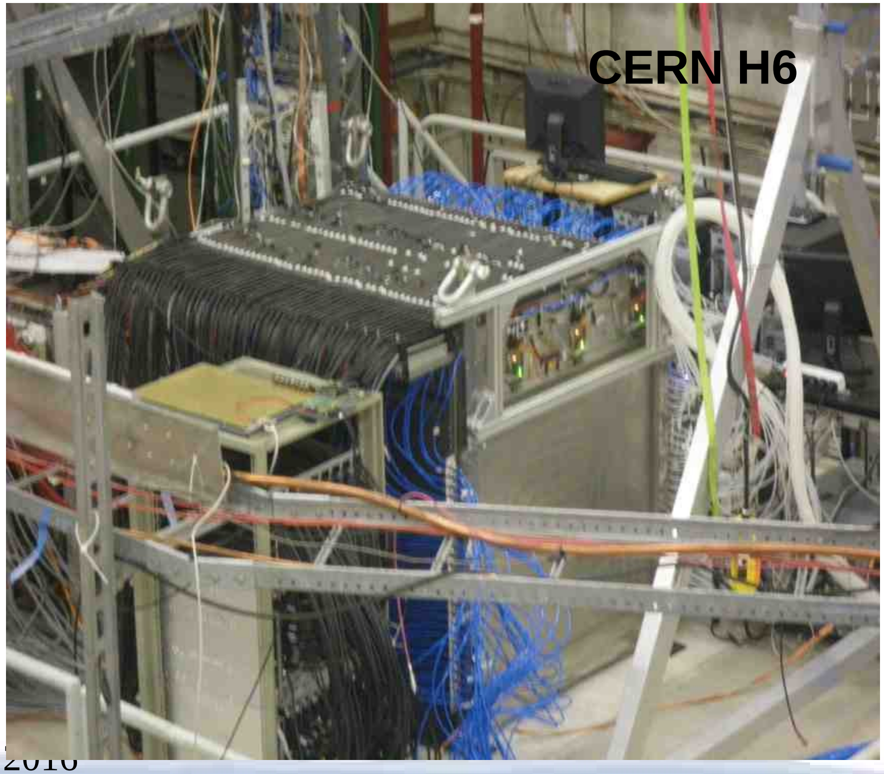
3 thresholds readout : at high energy the shower core is very dense and pure digital readout suffers saturation effect

Semi-digital readout (2-bit) can improve the energy resolution.

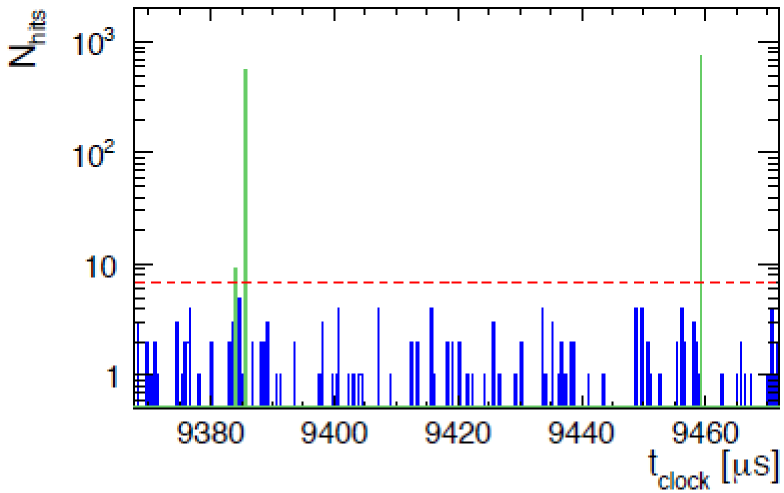
Beam tests

Tests have been performed on CERN SPS H2 and H6 beam lines

- Beam optics set to enlarge the beam
- Particle rate set to max 1000 particle/spill (spill length ~ 9 s)
- Positively-charged (H6) and negatively-charged (H2) hadrons and electrons beams were used with energy ranging between 5 and 80 GeV
- 48 layers in prototype

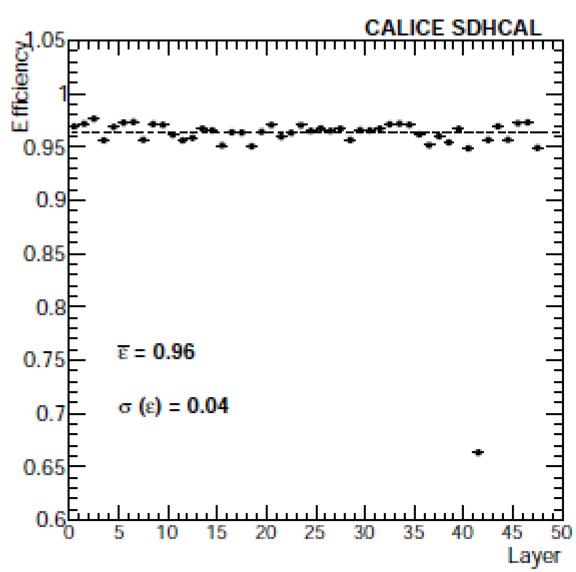


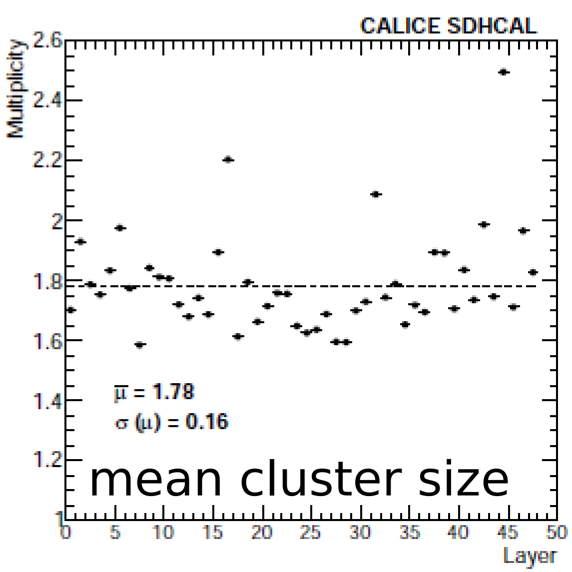
measurements with muon beams



Event reconstruction

- Select clock tick with more than 7 cells fired.
- Aggregate 2 neighbor clock ticks
- Noise rate : ~1 Hz/cm^2





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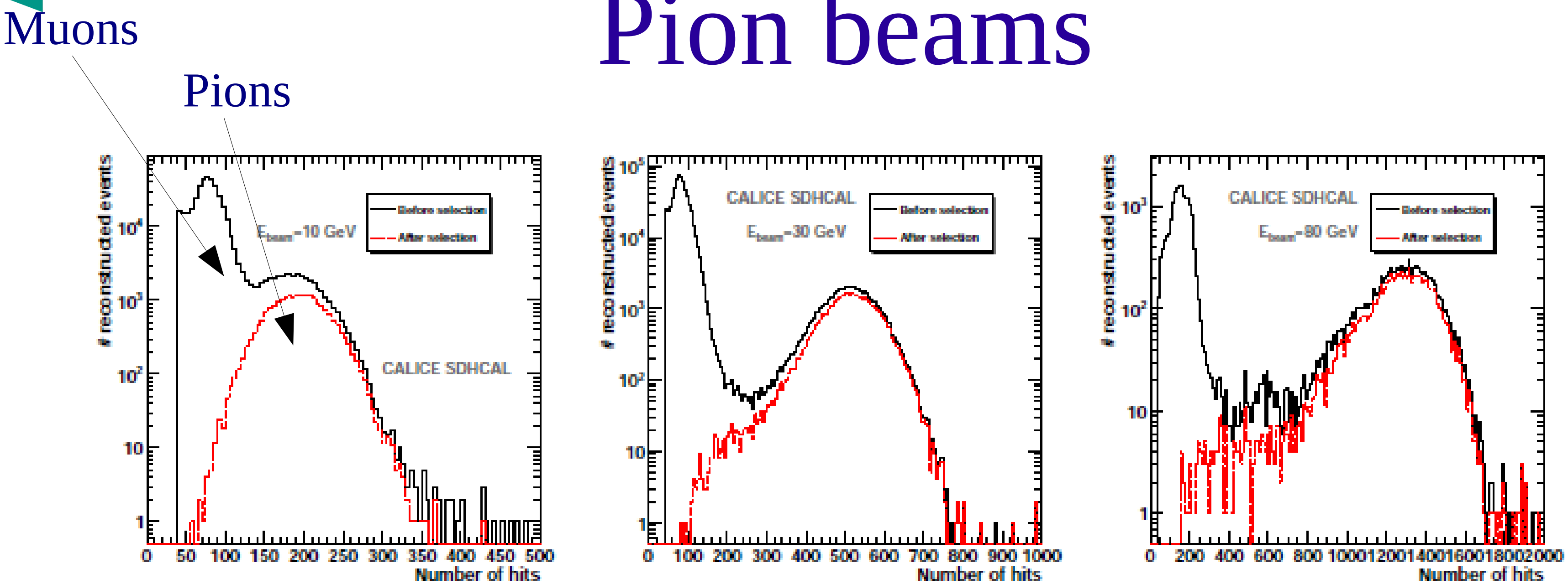
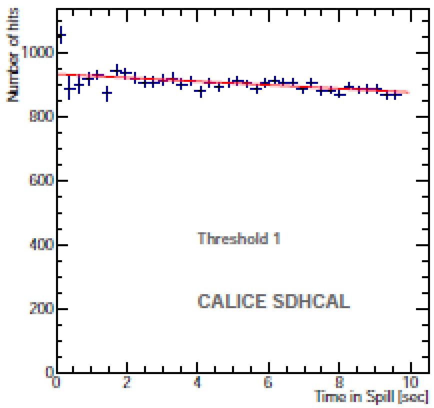
Pion beams

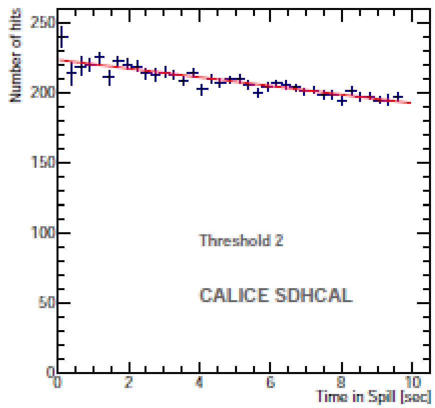


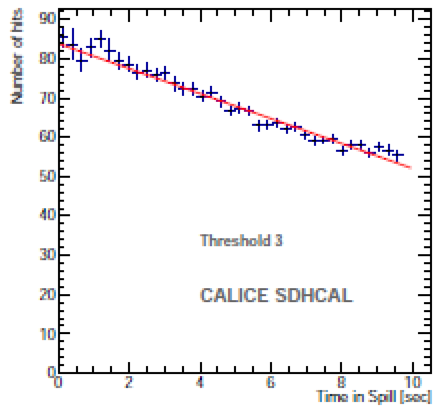
- Muon rejection : based on the fact that muons produce few hits per layer and tend to cross many layers.
- Electron-pion separation
  - An EM shower should start within the first 5 layers.
  - And end before the 30th layer (EM showers don't reach the end of the calorimeter)

Effect of spill intenstity

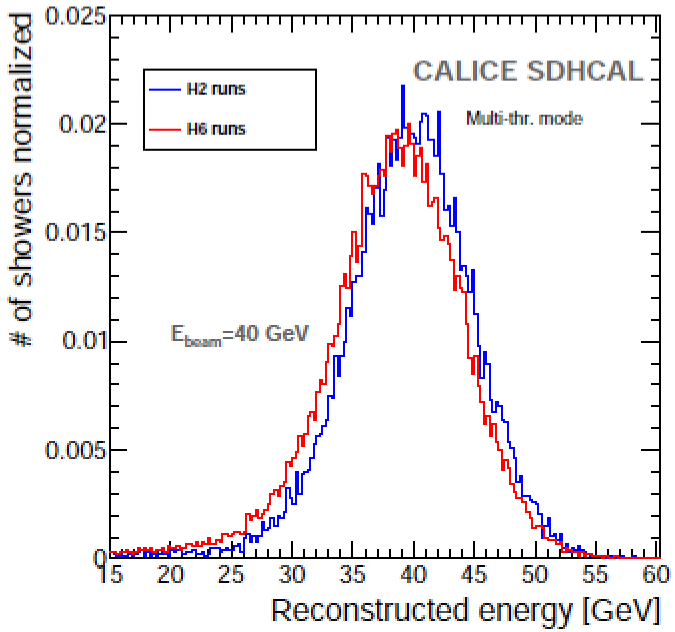
- Mean number of hits for 80 GeV pions
- Beam intensity too high for GRPC full recovery time

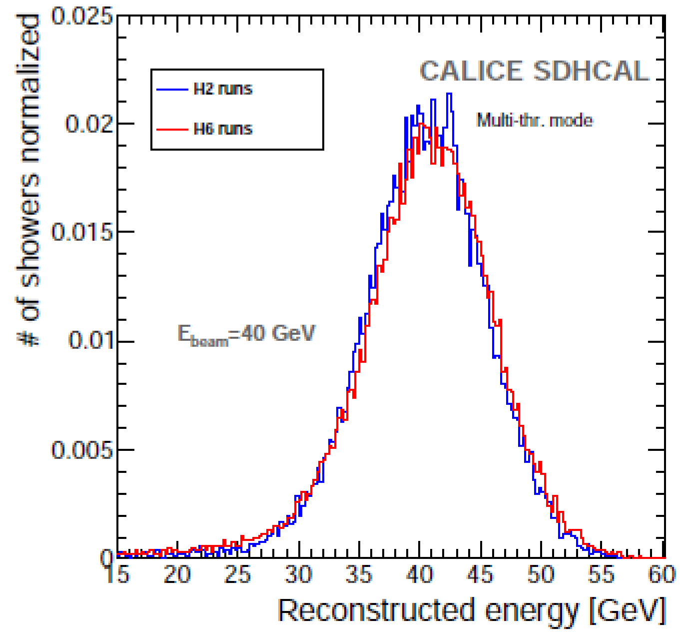






- Linear correction of the number of hits as a function of the time since spill starts
- Electron runs need quadratic correction.





Energy estimation

$$E_{reco}=\alpha(N_{tot})N_1+\beta(N_{tot})N_2+\gamma(N_{tot})N_3$$

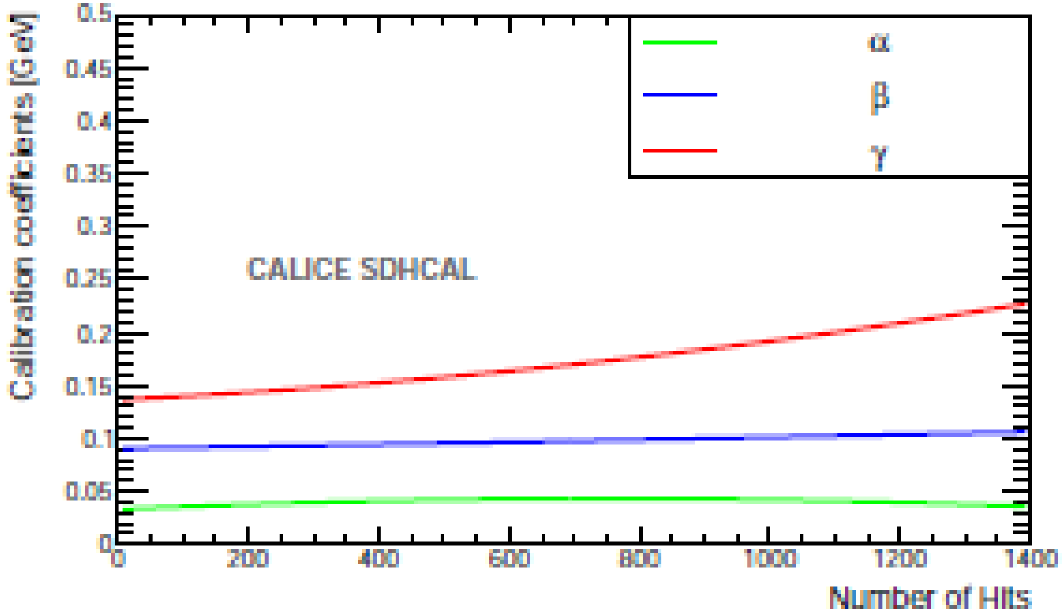
N_1,N_2 and N_3 : exclusive number of hits associated to first, second and third threshold.

α, β, γ are quadratic functions of the total number of hits $(N_{tot}=N_1+N_2+N_3)$

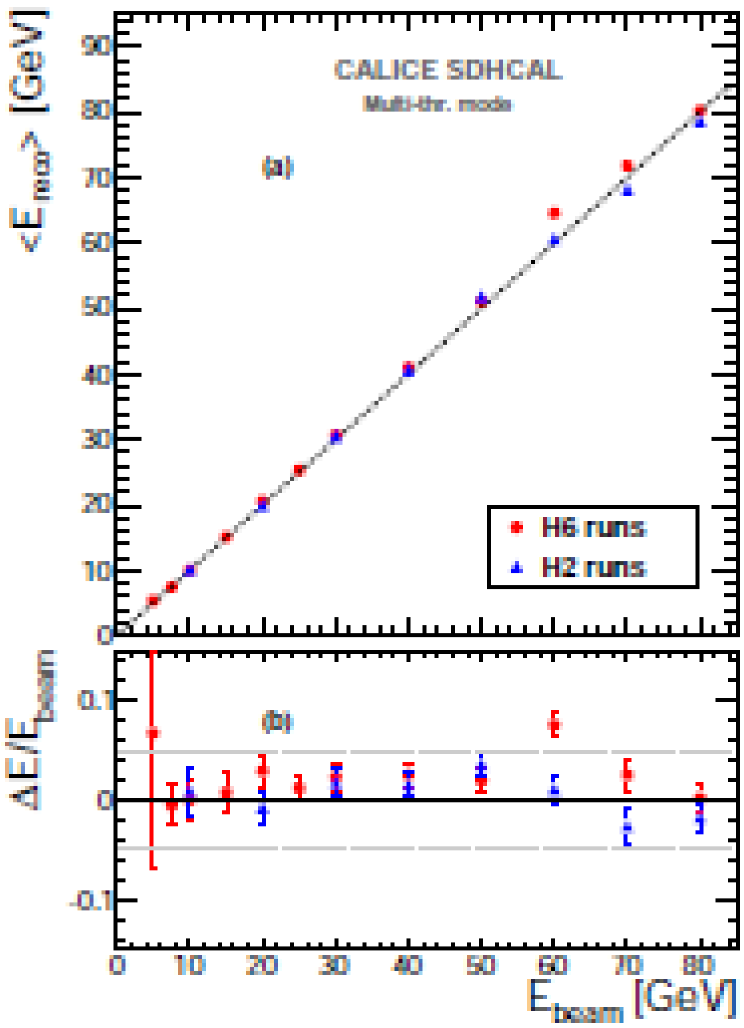
For instance $\alpha=\alpha_0+\alpha_1 N_{tot}+\alpha_2 N_{tot}^2$

Coefficient determined by minimising $$\chi^2=\sum_{i=1}^{N}\frac{(E_{beam}^i-E_{reco}^i)^2}{E_{beam}^i}$$

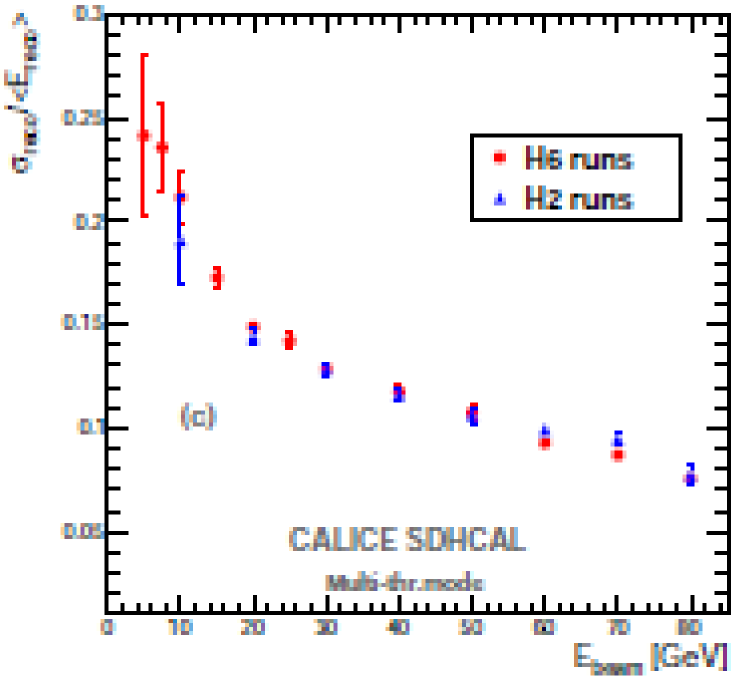
Sum on ~ 1/3 of H2 selected pion events



Pion energy estimation



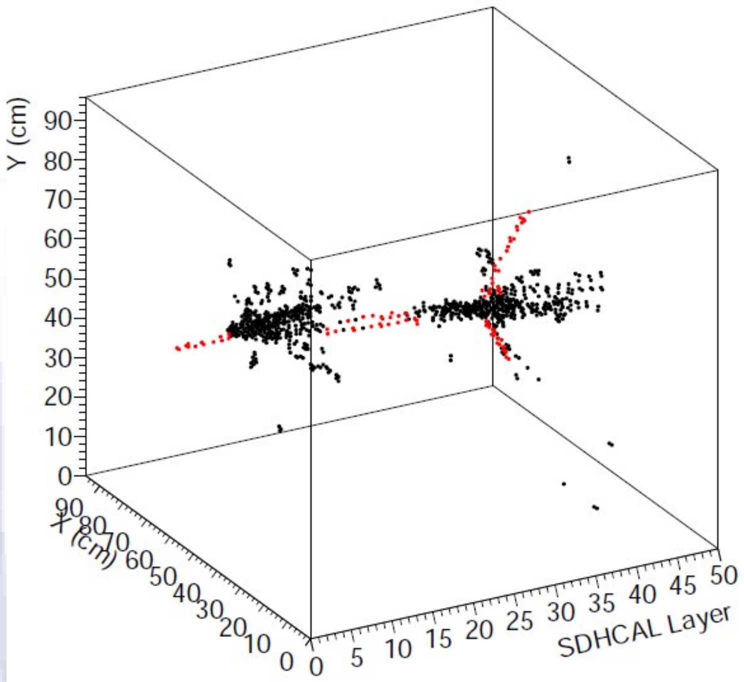
- 4-5% deviation from linearity
- 7.7% resolution at 80 GeV.



Tracking inside showers

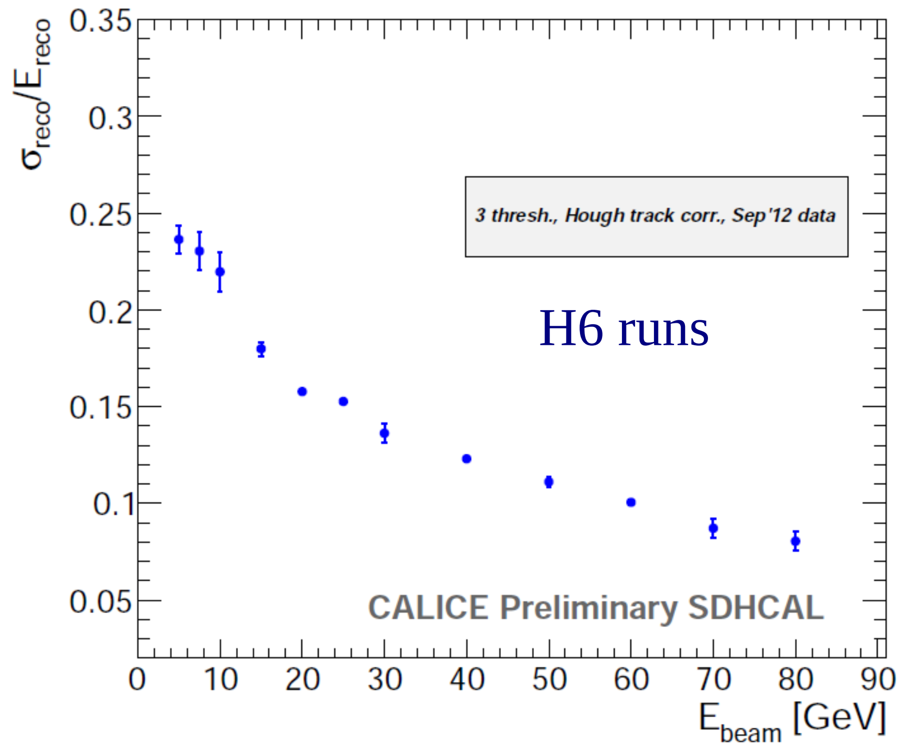
Using tracking algorithm, tracks inside pion shower can be identified.

Using Hough Transform track finding algorithm, change energy etimation



$$E_{reco} = \alpha(N_{tot})N_1 + \beta(N_{tot})N_2 + \gamma(N_{tot})N_3 + c\,N_{HT}$$

N_{HT} = number of hits found in tracks



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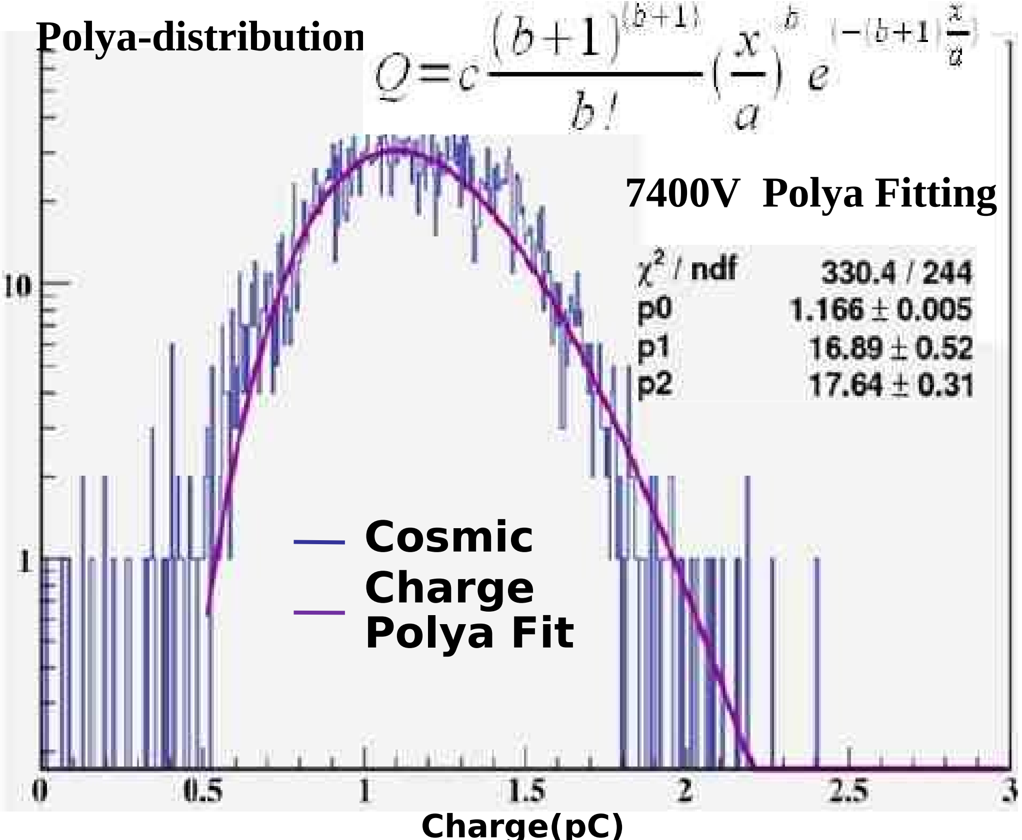
SDHCAL simulation

- A GEANT4-based simulation for the prototype has been implemented.
- Final step of simulation is digitisation : simulates the electronic response to crossing particles

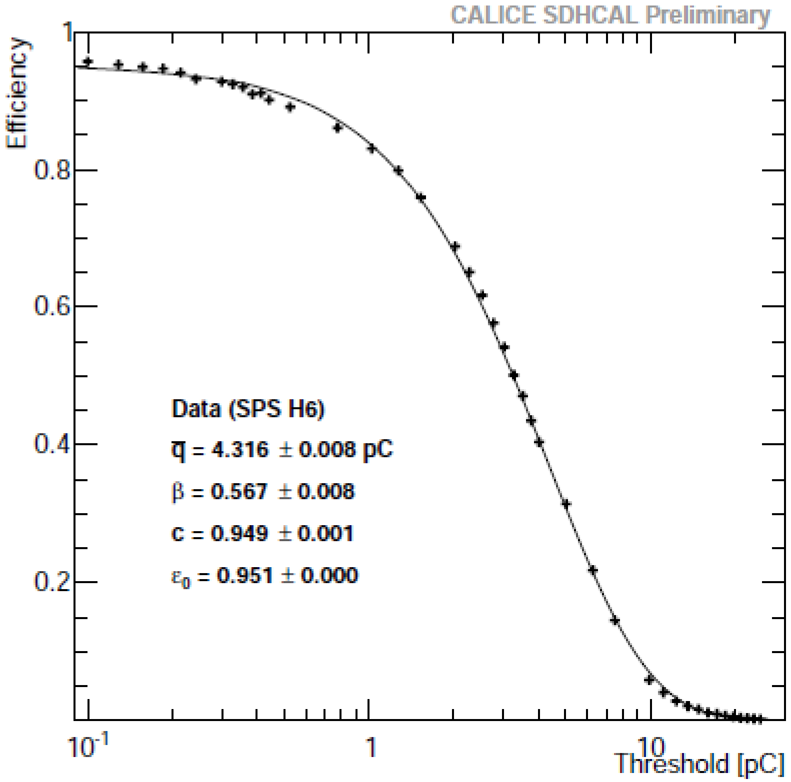


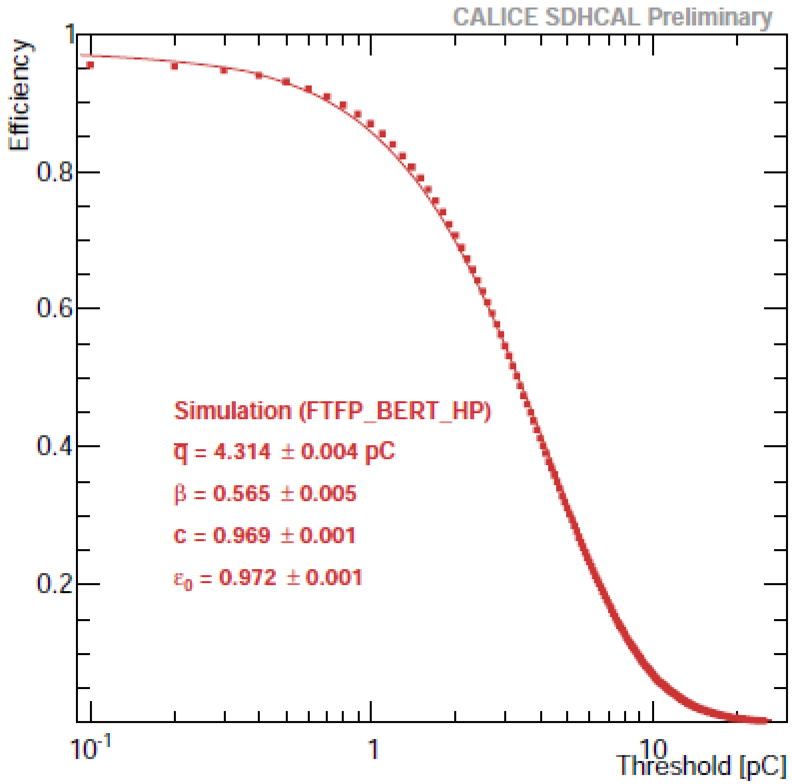
- For each crossing particle
  - Simulate induced charge.
  - Dispatch the charge on the pad and neighbour pads.
    - If a hit for this pad already exist, add the new charge.
    - Else create the hit and give it the charge.
- Remove candidate hits below first threshold.
- Apply thresholds and store hits in output collection

- Different approach to RPC simulation, see V.Français' talk tomorrow.

Data tuning of digitizer parameters

- Polya parameters tunes to reproduce efficiency in muon runs thresholds scans



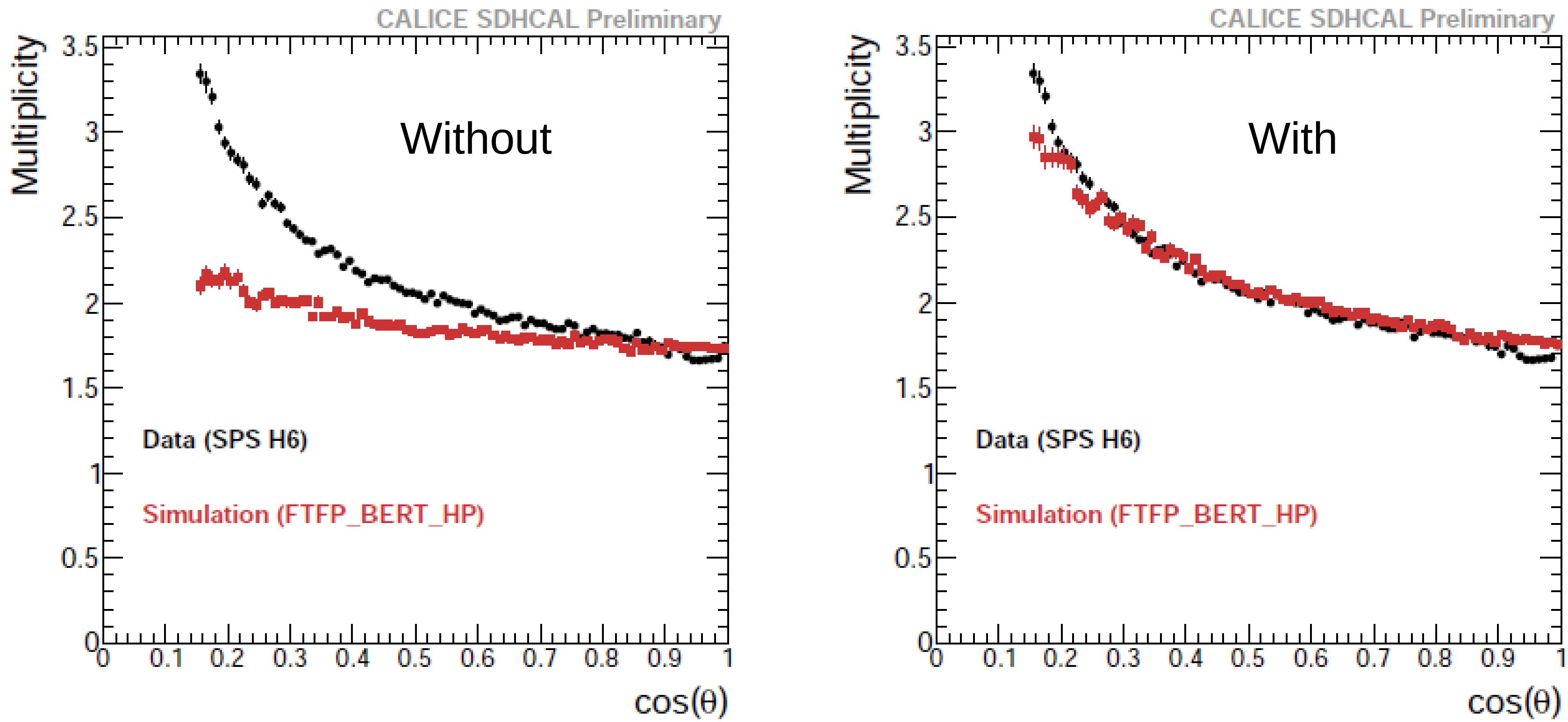


$$\epsilon(q)=\epsilon_0-c\int_0^q \frac{1}{\Gamma(\beta+1)}\left(\frac{1+\beta}{\bar{q}}\right)^{\beta+1} q'^{\beta} e^{\frac{-q'}{\bar{q}}(1+\beta)}\, dq'$$

Data tuning of digitizer parameters

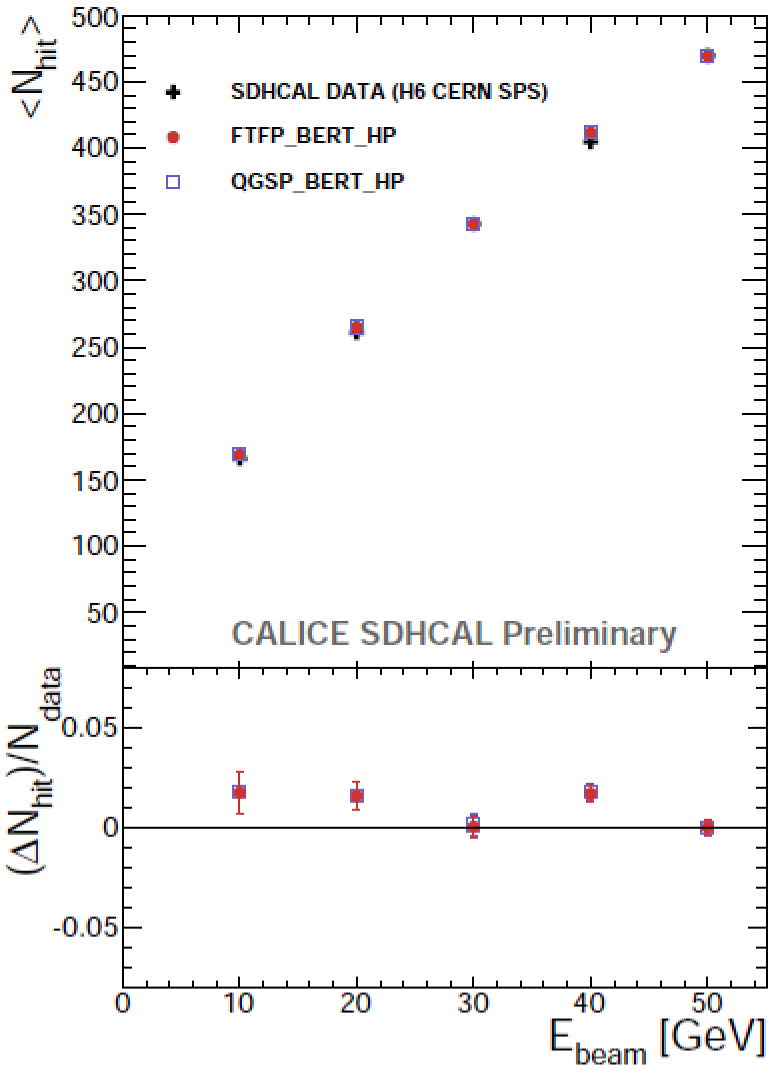
- Polya parameters tunes to reproduce efficiency in muon runs threshols scans
- Charge dispatching parameters tuned to reproduce muon pad multiplicity

Exemple of particle crossing angle correction

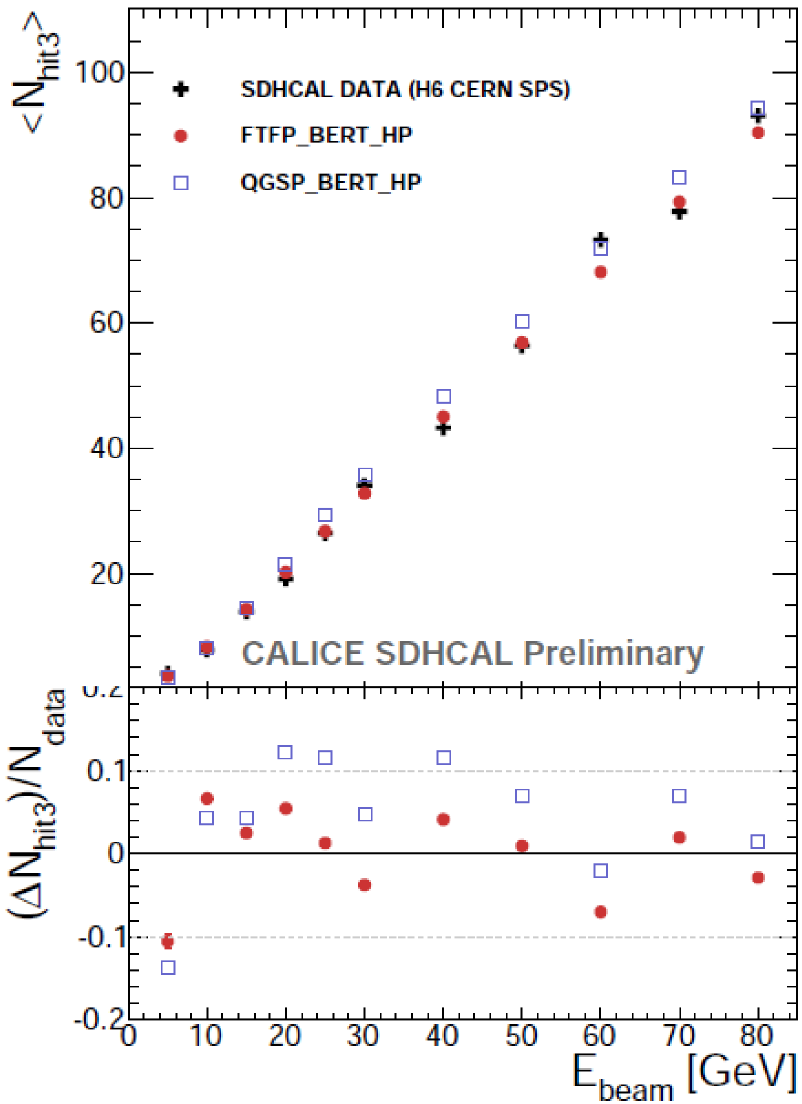


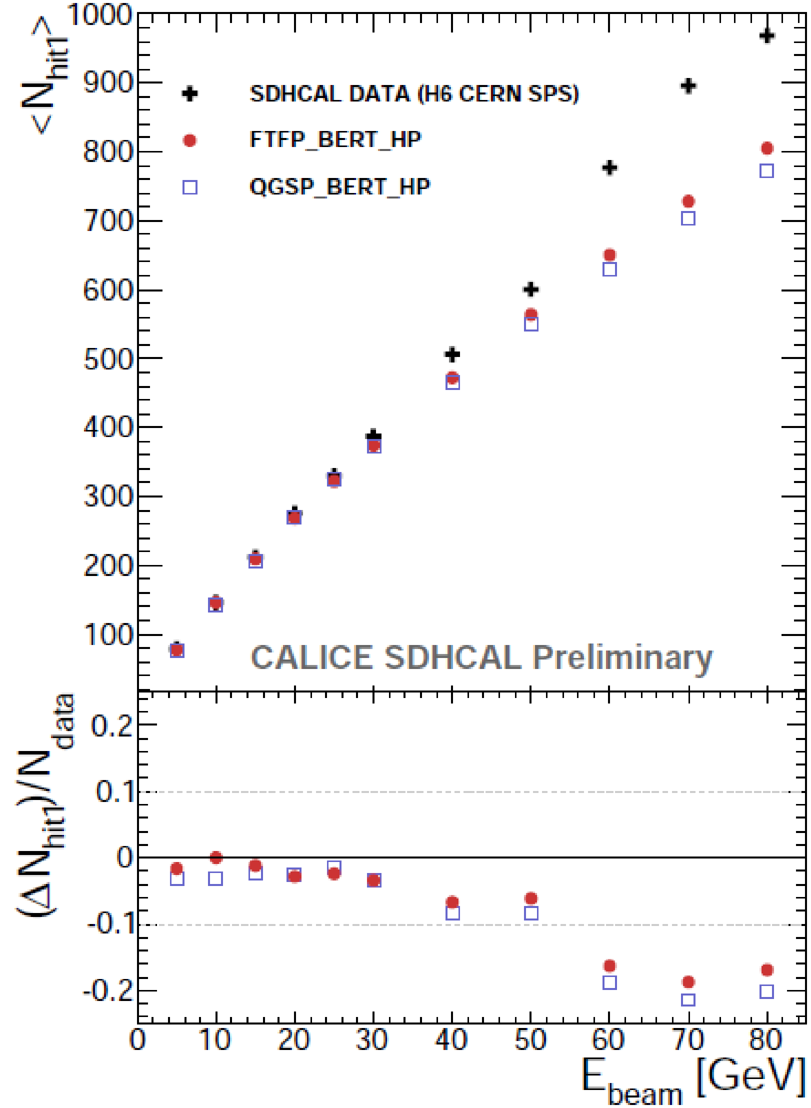
Data tuning of digitizer parameters

- Polya parameters tunes to reproduce efficiency in muon runs thresholds scans
- Charge dispatching parameters tuned to reproduce muon pad multiplicity
- Screening effect in avalanche tuned on electron data : only one avalanche if 2 crossing particles are entering GRPC within a distance less than d_{cut}.
  - d_{cut} set to 0.5 mm



Pion simulation

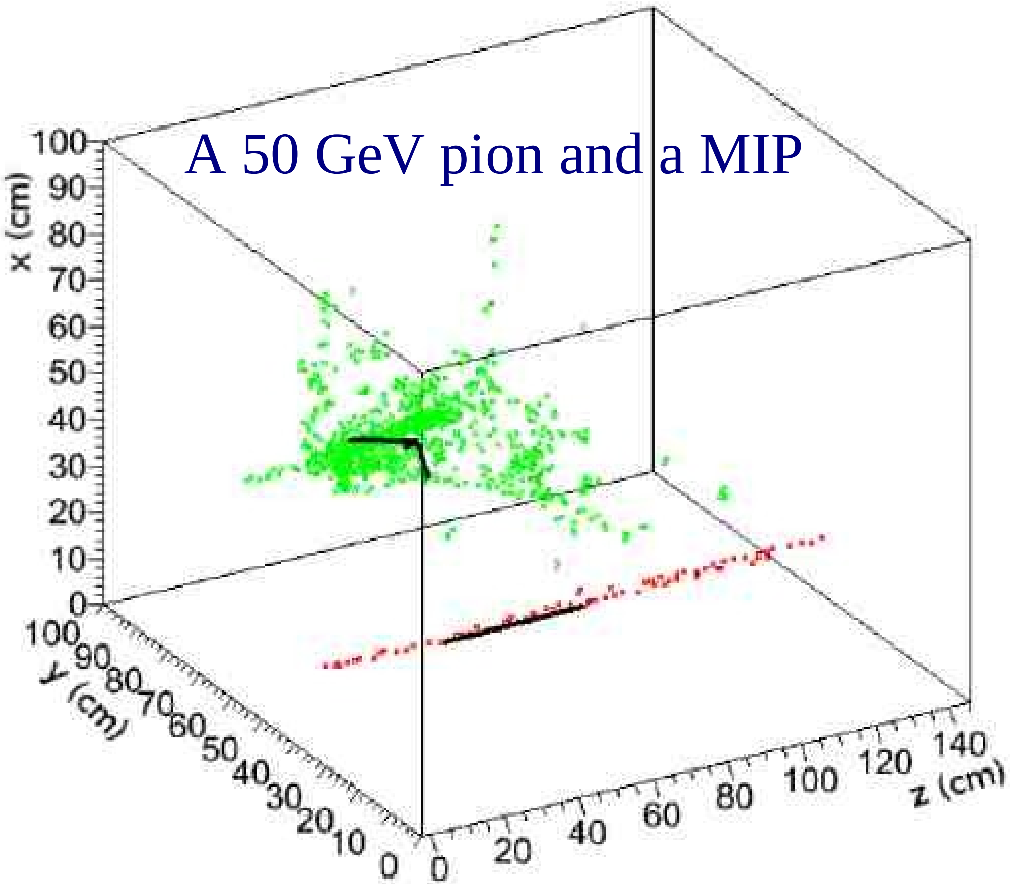


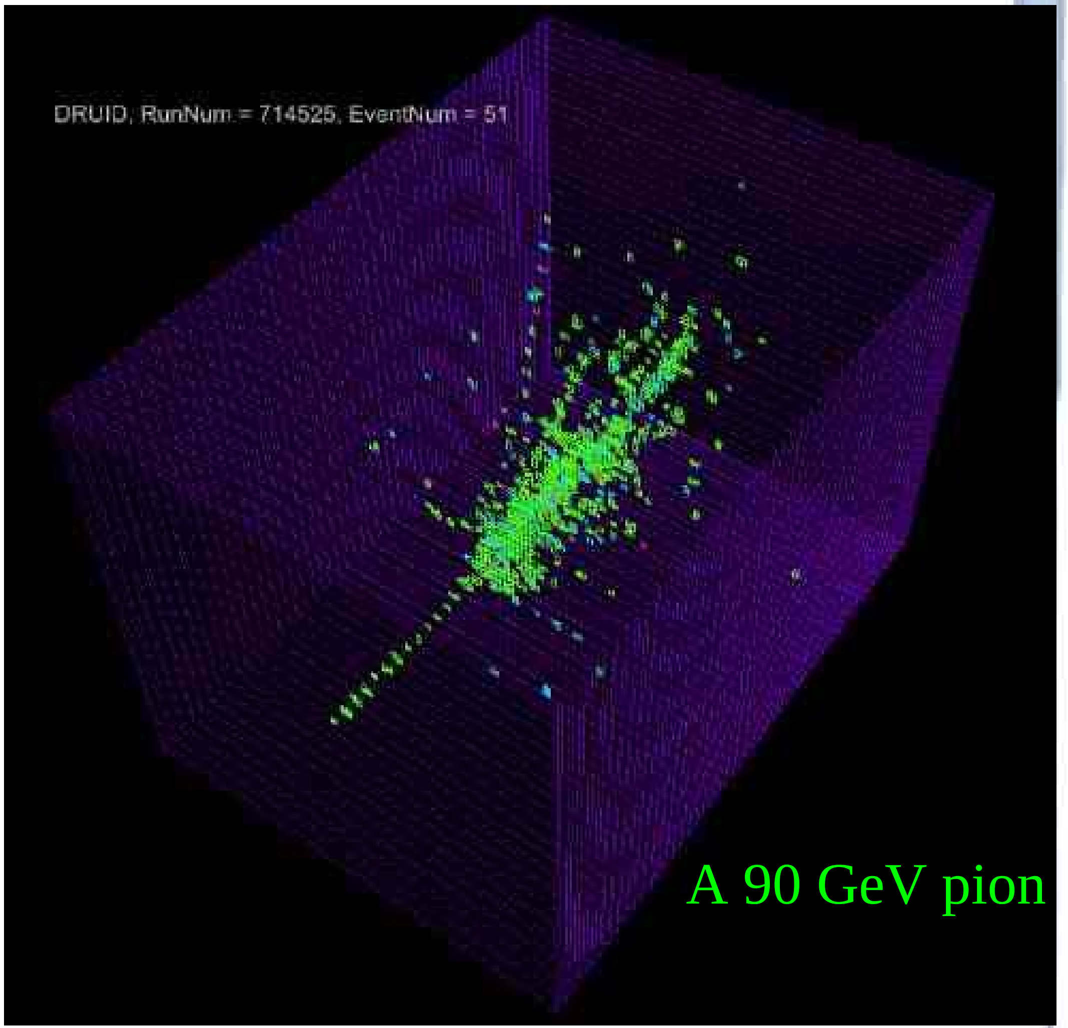


Testing GEANT4 hadronic models is now possible

High granularity Calorimetry

- 1 cm^2 pads in layer separated by 2.6 cm.
- You can see hadronic showers





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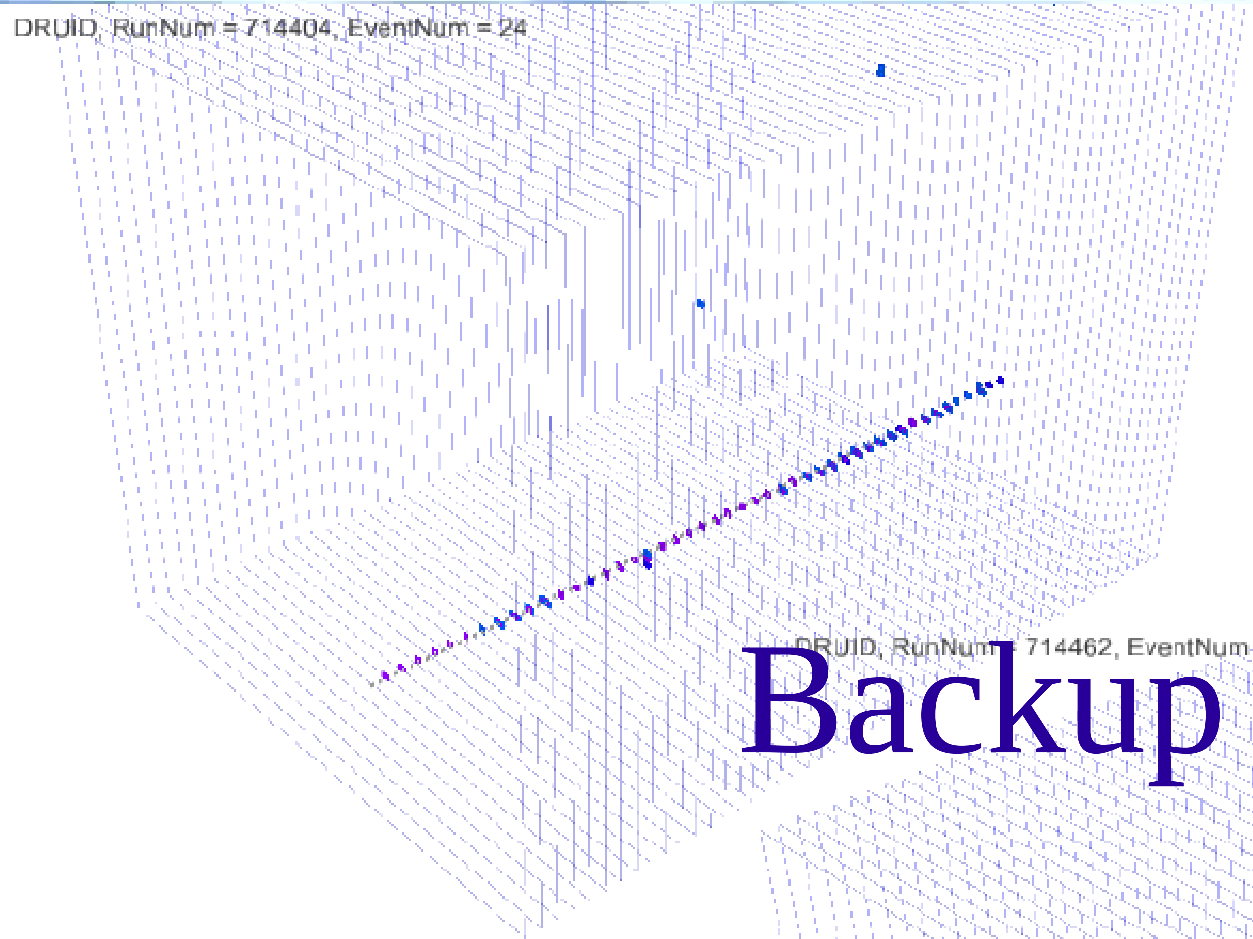
Conclusion

- A technological prototype for a Semi-Digital Hadronic CALorimeter has been build for the ILD detector.
  - New development will be shown in next talk by A. Pingault
- It allows hadronic energy reconstruction with 4-5% deviation from linearity for pion energies in the 5-80 GeV range
- Energy resolution is at 7.7% for 80 GeV pions.
- Modeling of the electronics response of the GRPC has been done and tuned to reproduce muon and electron data.
- Comparison of hadronic GEANT4 models and high granularity hadronic calorimetry (1 cm^2 pads in layer separated by 2.6cm) has started.

Backup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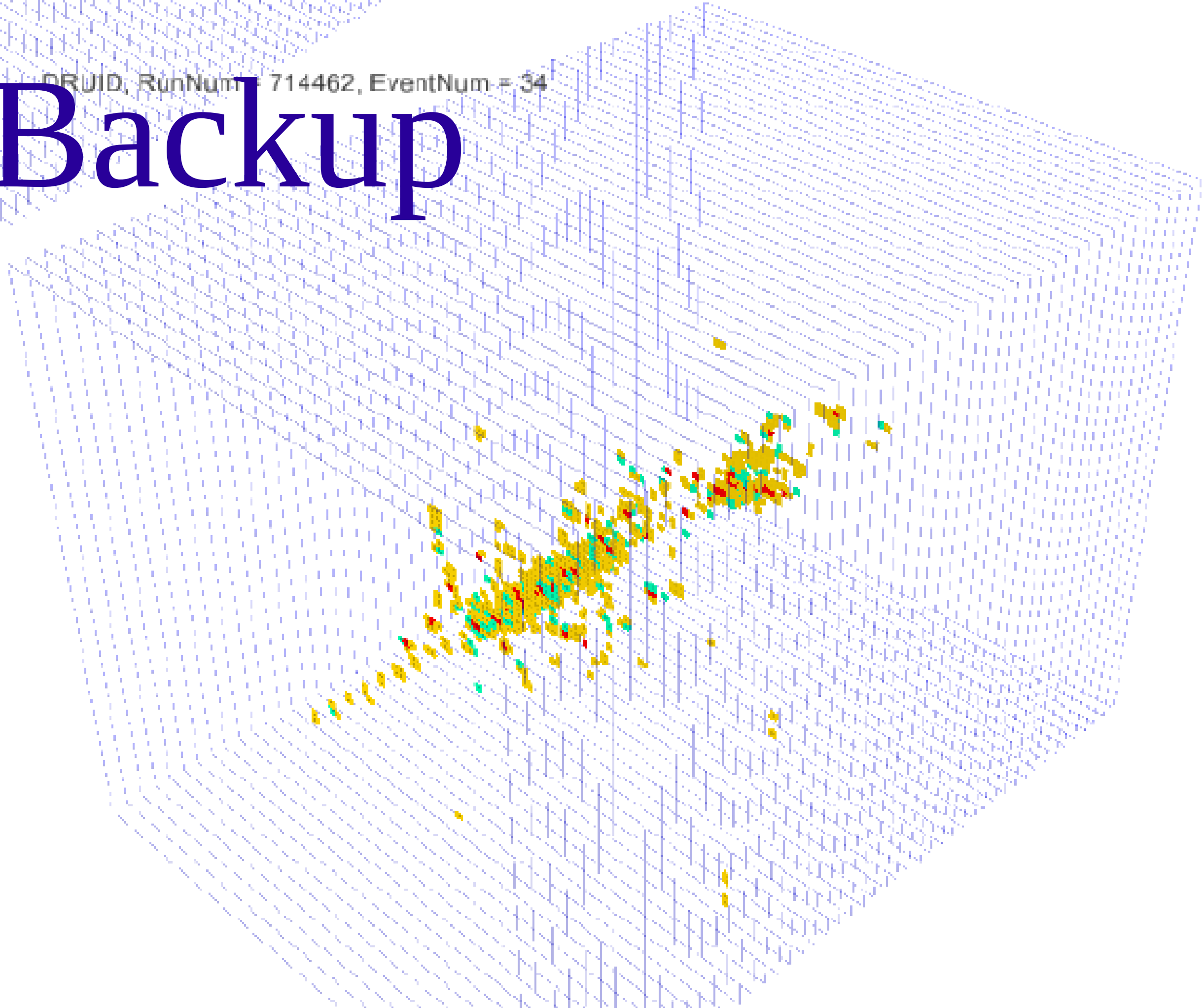
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Articles

Published :

-Performance of Glass Resistive Plate Chambers for a high granularity semi-digital calorimeter, Bedjidian et al, 2011_JINST_6_P02001.

-First test of a power-pulsed electronics system on a GRPC detector in a 3-Tesla magnetic field, Caponetto et al, 2012_JINST_7_P04009.

-Construction and commissioning of a technological prototype of a high-granularity semi-digital hadronic calorimeter, JINST 10 (2015) 10, P10039

-First results of the CALICE SDHCAL technological prototype, arXiv:1602.02276 [physics.ins-det]

In preparation :

-Resistive Plate Chamber Digitization in a Hadronic Shower Environment

Calice notes :

-First results of the SDHCAL technological prototype and its addendum (CAN-037).

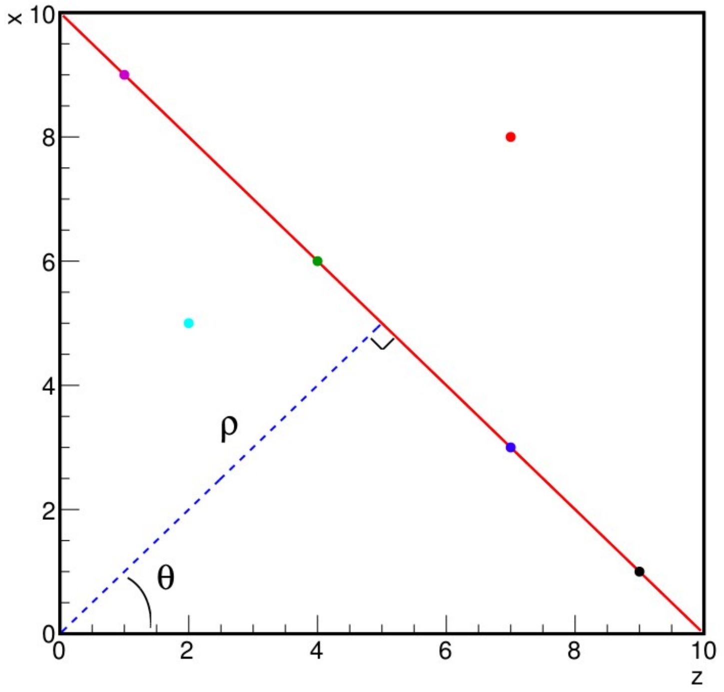
-Tracking within Hadronic Showers in the SDHCAL prototype using Hough Transform Technique (CAN-047).

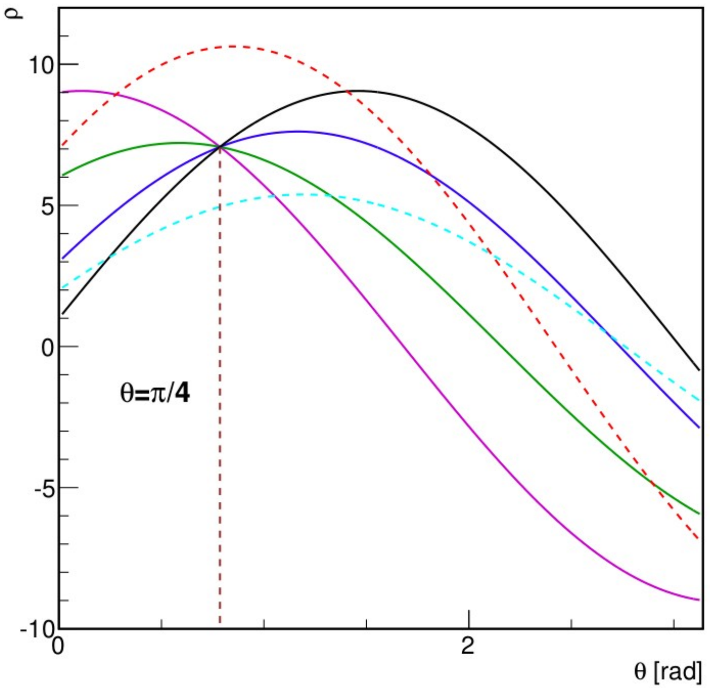
Hough transform

- Find lines from collection of points in planes
- In a plane, let's say (z,x), associate to each point a curve in polar coordinates:

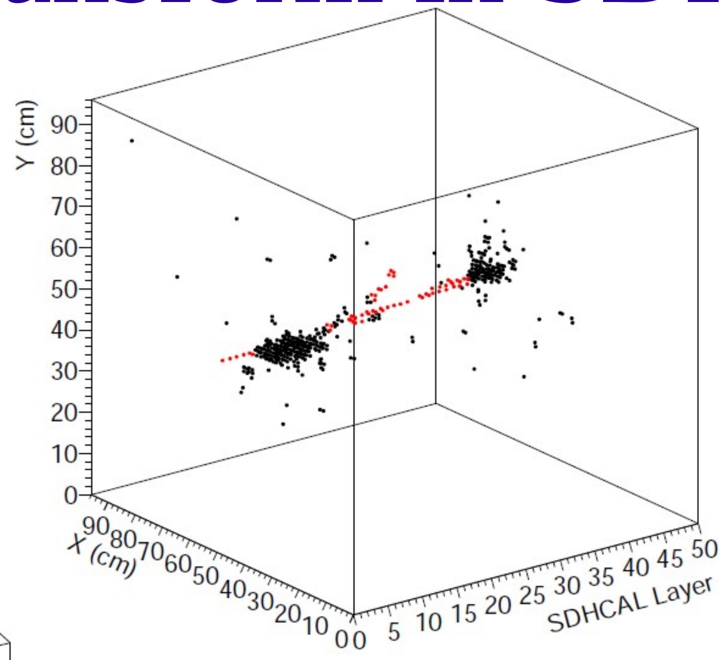
$$\rho = z\cos\theta + x\sin\theta$$

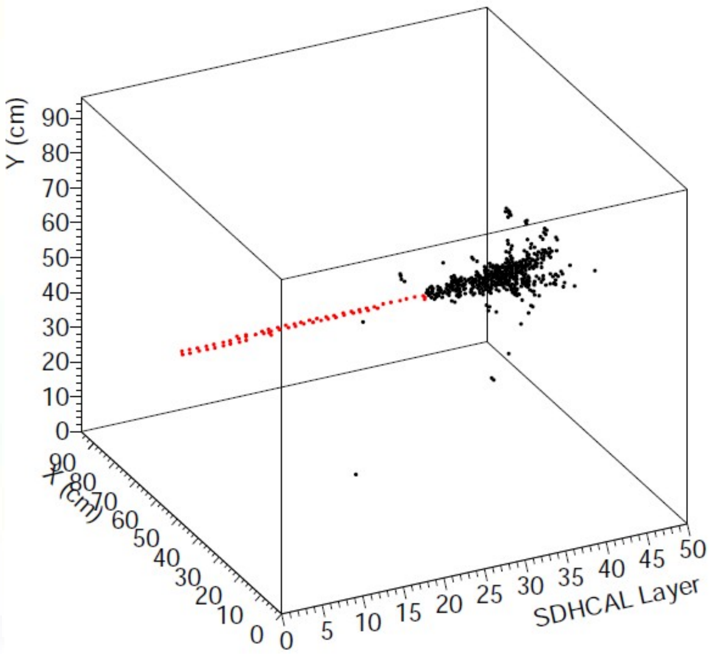
- Curves associated with aligned points will intersect at the same point.

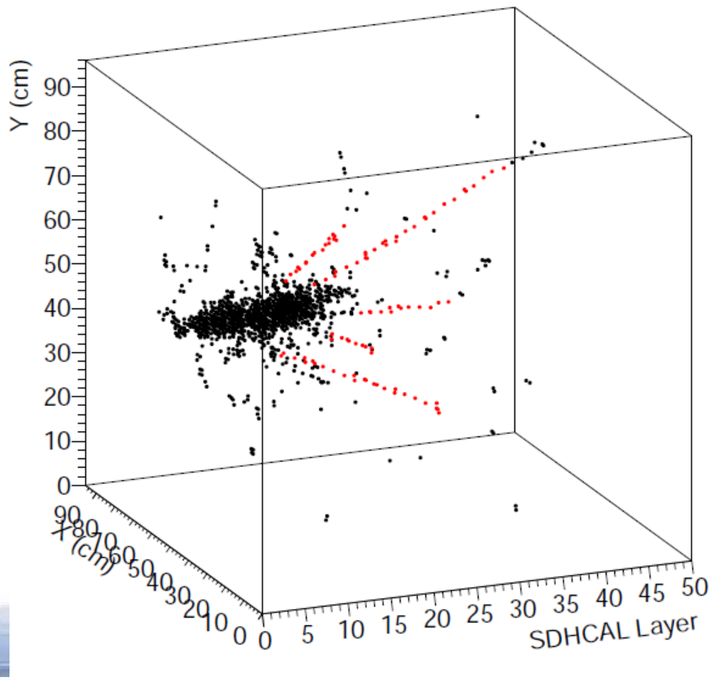




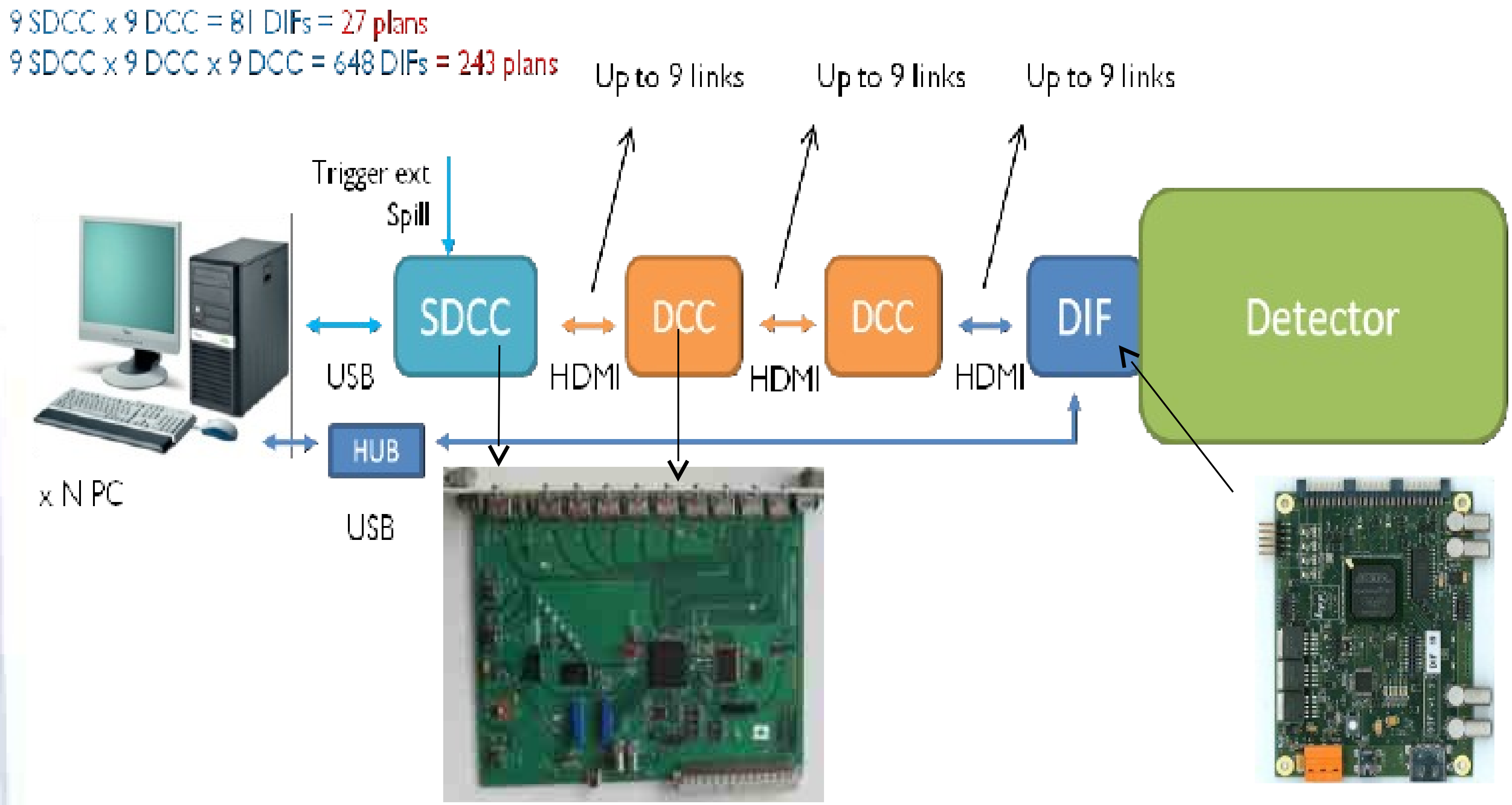
Hough Transform in SDHCAL







SDHCAL acquisition system



→ Acquisition software was developed to deal with the output of large number of electronics channels (> 460 000).

→ Oracle database used for ASIC configurations and slow control.

□ CMS Xdaq used to provide the DAQ framework.

SDHCAL prototype construction

- ✓ 10500 ASIC were tested and calibrated using a dedicated robot that was used by CMS (IPNL, OMEGA) (ASICs layout : 93%).
- ✓ 310 PCBs were produced, cabled and tested (IPNL). They were assembled by sets of six to make 1m2 ASUs
- ✓ 170 DIF(LAPP), 20 DCC(LLR) were built and tested.
- ✓ 50 detectors were built and assembled with their electronics into cassettes. Cassettes were tested by sets of 6 using a cosmic test bench (IPNL).
- ✓ The mechanical structure was built in CIEMAT.
- ✓ HV, cooling services were built by UCL, Gent.
- ✓ Full assembly took place at CERN.

The m[3] prototype

- Self supporting steel (absorber) structure

50 chambers build

6 mm thick GRPC cased in steel : total thickness 11 mm

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Readout Electronics : ASIC : HR2

64-Channel

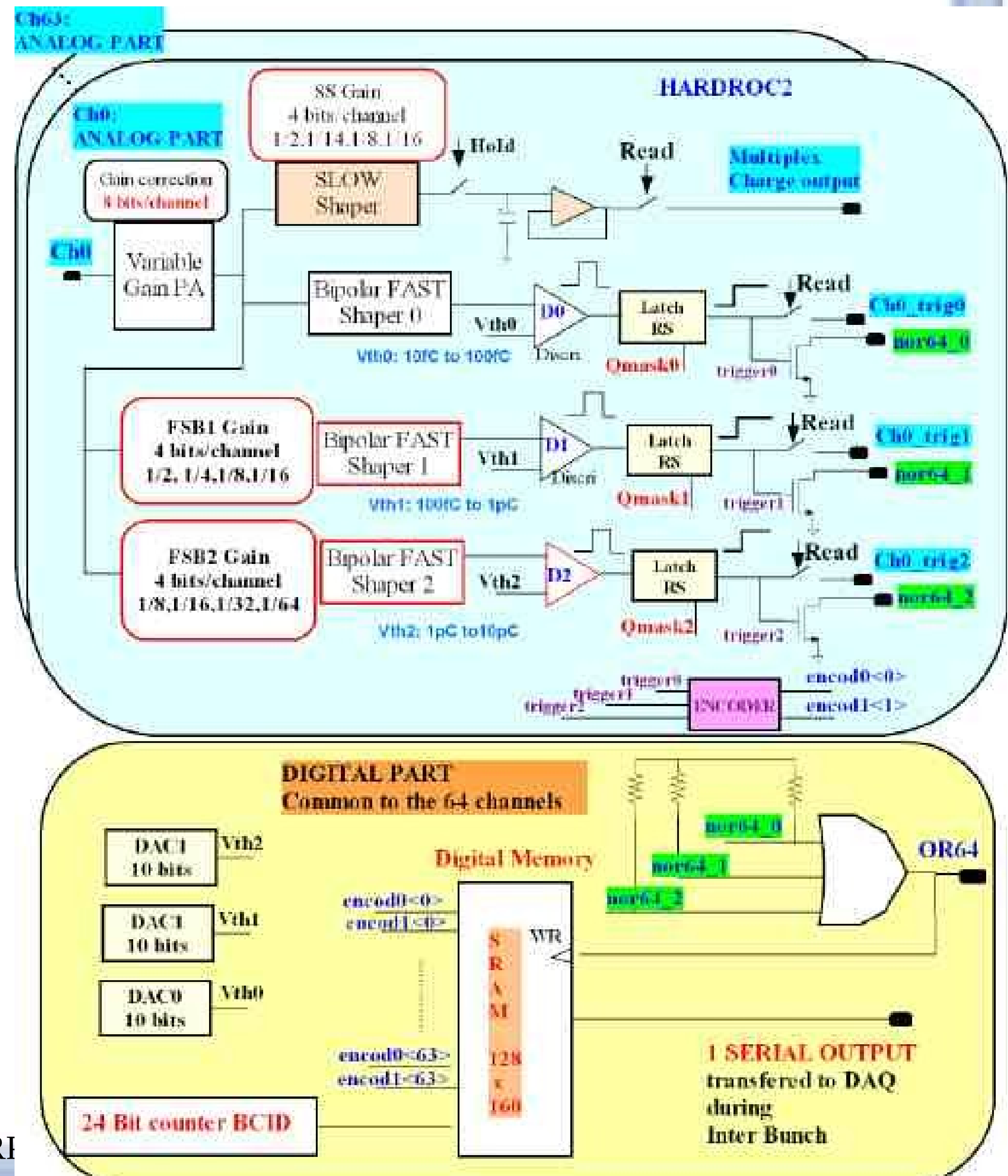
- **Dynamic range**

  - Gain correct.: **8 bits**
    G=0 to 255 (analog G=0 to 2)
    - **3 shapers, different Rf,Cf and gains**:
      - Fsb1, G= ½,**1/4**,1/8,1/16
      - Fsb2, G= 1/8,**1/16**,1/32,1/64
    - **3 thresholds** (=> 3 DACs):
      - 100fC, 1pC, 10pC (GRPC)
  - 128 memory depth

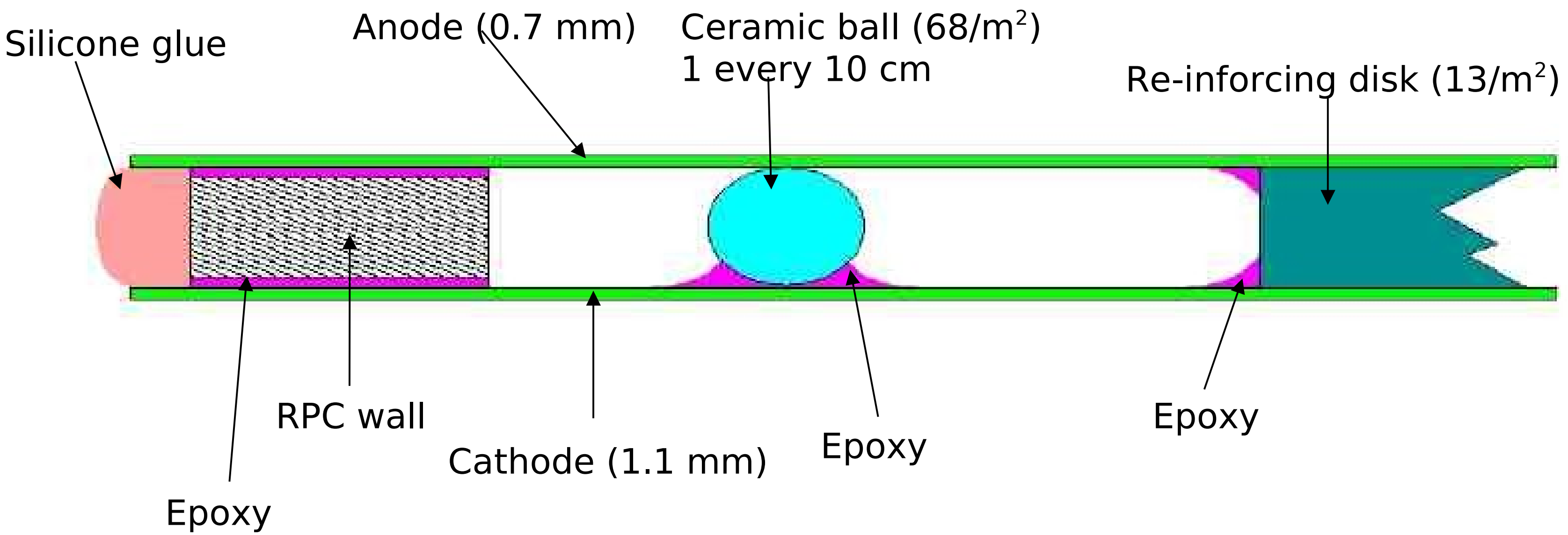
- Mask

- **872 SC registers**, default config

- **Power pulsing:**
  - Bandgap +ref Voltages + master I: power pulsed
  - POD module (power budget)



Homogeneous gas thickness



Max deformation 44 µm

includes :

- Glass weight
- Electrostatic force

Ignores :

- Gas pressure (1 mbar overpressure)