Calorimeter for ILC

Construction and Status of a Semi-Digital Hadronic Calorimeter

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LLR

in behalf of ***CALICE****-SDHCAL group*

CIEMAT, Ghent U., IPNL,LAL, LAPP, LLR, Tsinghua U., Tunis, UCL

Title:IN2P3Filaire-Q
Creator:Adobe Illust
CreationDate:1/28/2
LanguageLevel:2

ECFA R&D Panel

DESY, 05/11/2012

AGENCE NATIONALE DE LA RECHERCHE ANR

AIDA

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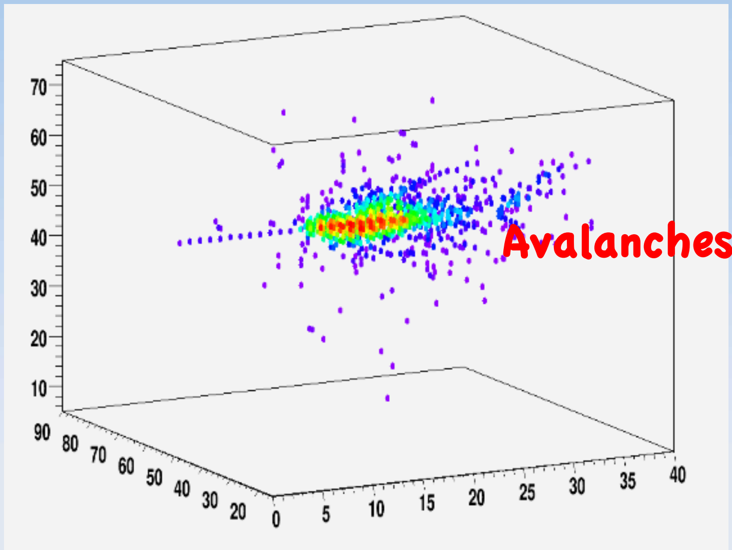
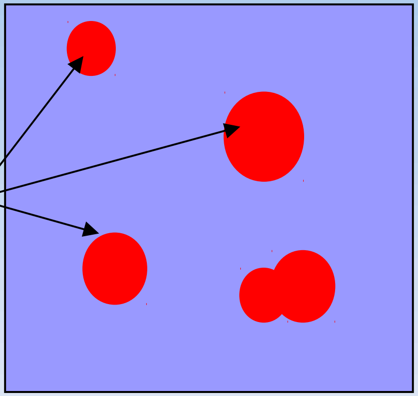
- The SDHCAL concept
- Technological prototype construction
- Readout & reconstruction
- Test Beam Preliminary Results for GRPC
- Simulation studies
- A word about μ-Megas
- Perspectives and Conclusion

Semi-Digital HCAL Concept

Ultra-granular HCAL can provide a powerful tool for the **PFA** leading to an excellent Jet energy resolution.





1 cm² pad

It is based on two points:

1- Gaseous Detector

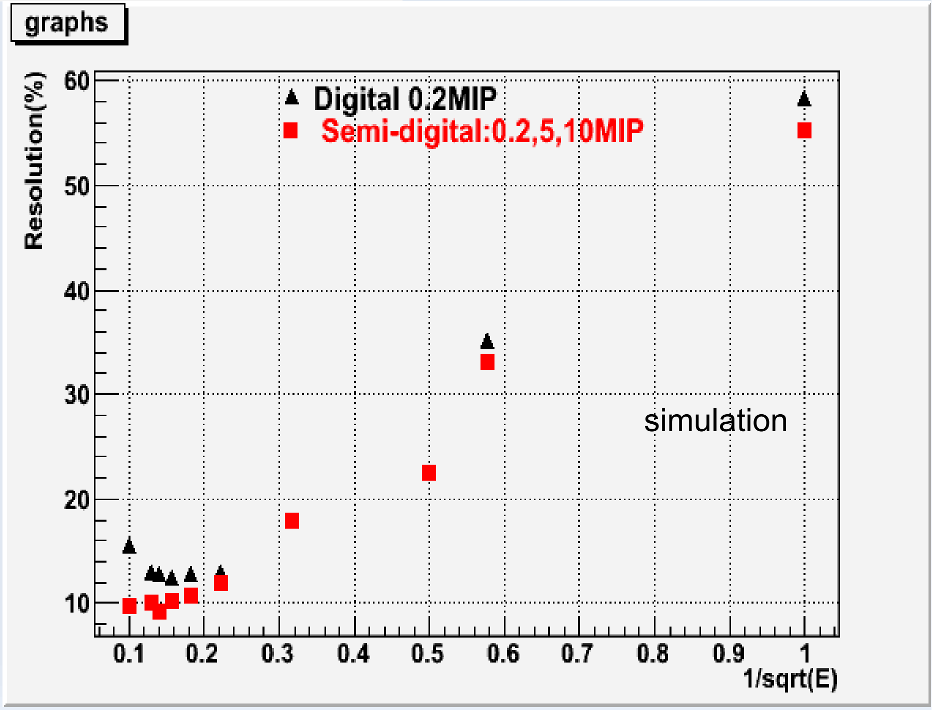
Gaseous detectors like **GRPC** are homogenous, cost-effective, and allow high longitudinal and transverse segmentation. (MicroMegas was considered as an option)

2- Embedded electronics Readout

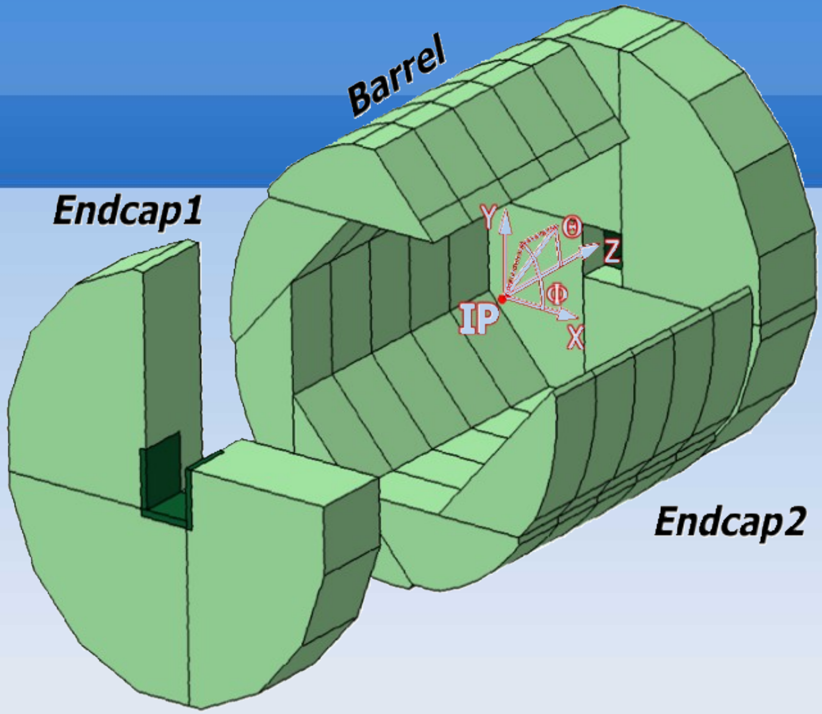
A simple binary readout leads to a very good energy resolution

However, at high energy the shower core is very dense and saturation shows up

→ 2-bit readout improves on energy resolution at energies> 30 GeV



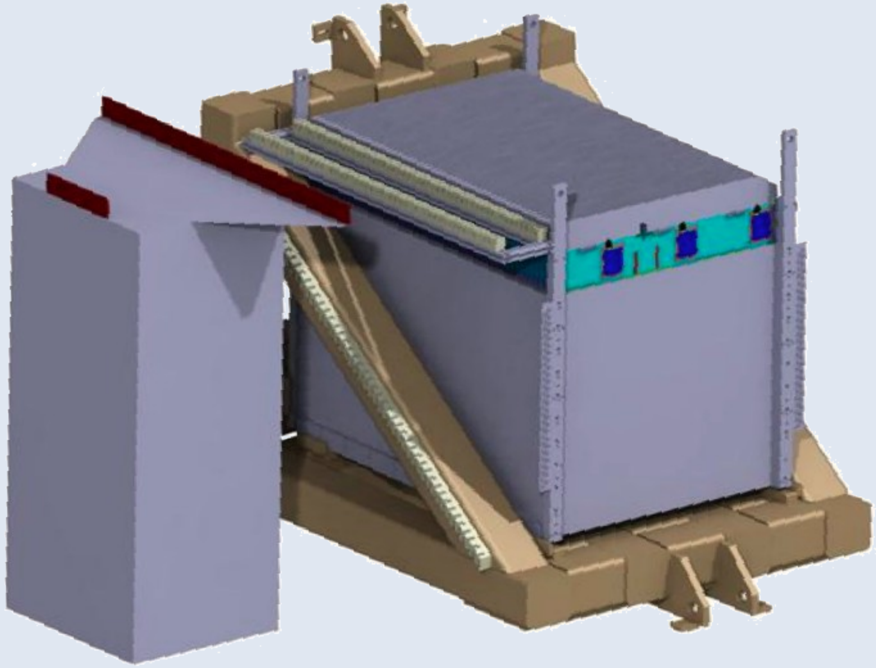
SDHCAL technological prototype



SDHCAL is one of the two HCAL options of the **ILD** project.
It was proposed with a genuine mechanical structure with no projective cracks and no dead zone between the Barrel and the Endcaps since services are on the periphery

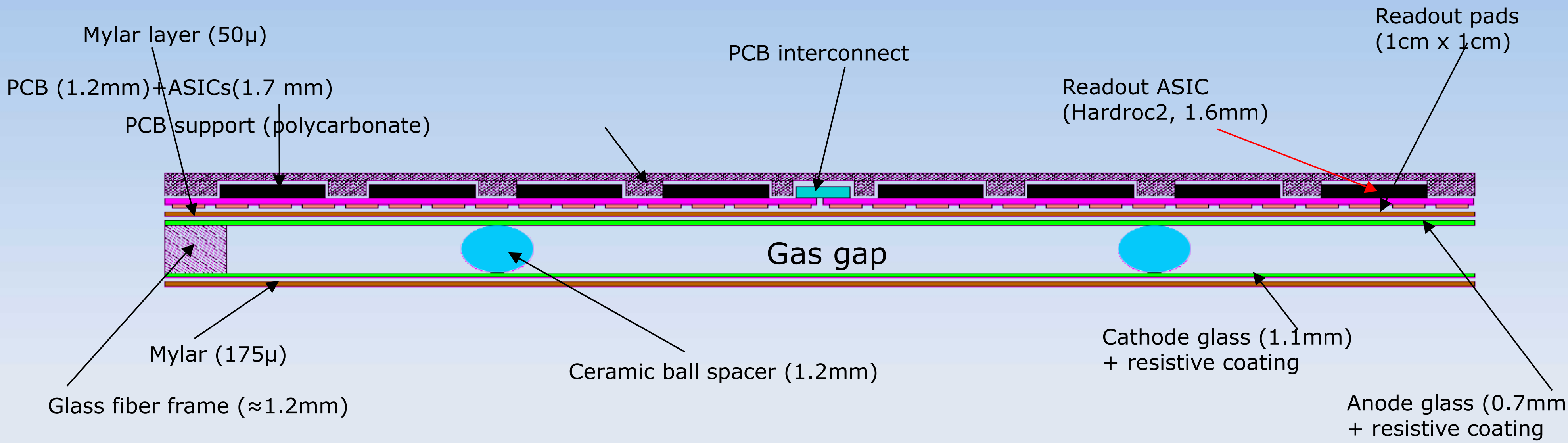
Challenges

- homogeneity for large surfaces
- Thickness of only few mms
- Services from one side
- Embedded power-cycled electronics
- Self-supporting mechanical structure



Technological prototype
A prototype with 48 GRPC of 1m²
and stainless steel absorber
corresponding to 6 λ_I was conceived
as a demonstrator

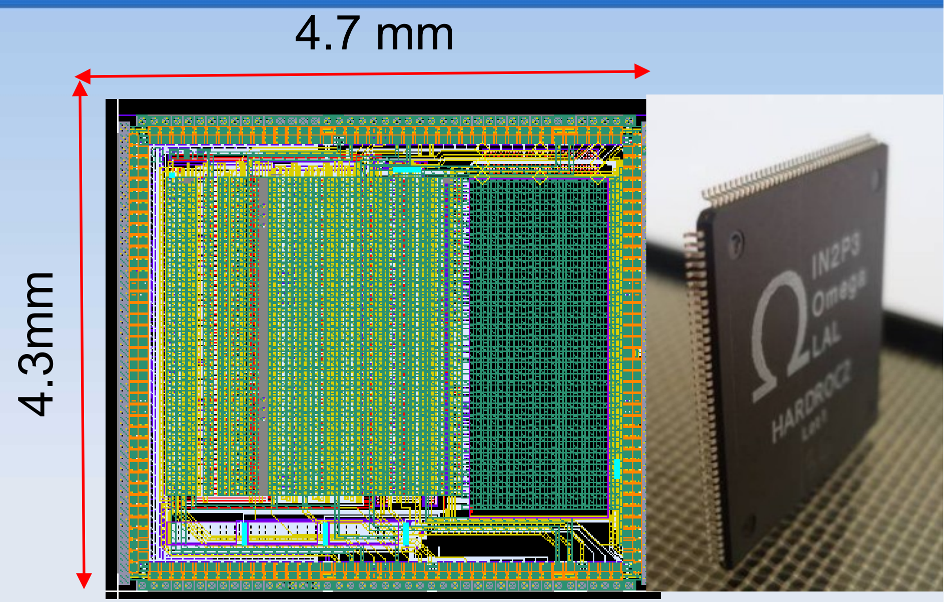
Structure of an active layer of the SDHCAL



Large GRPC R&D

- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Efficient gas distribution system (channeling gas inlet and outlet)
- ✓ Homogenous resistive coating (special paint mixture, silk screen print)

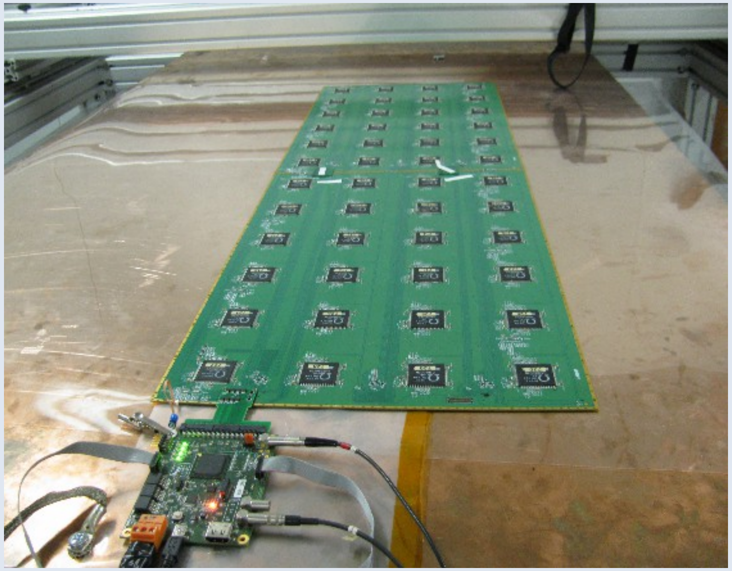
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity
Power-Pulsed (7.5 μW in case of ILC duty cycle)



Printed Circuit Boards (PCB) were designed to reduce the x-talk with 8-layer structure and buried vias.

Tiny connectors were used to connect the PCB two by two so the 24X2 ASIC are daisy-chained.

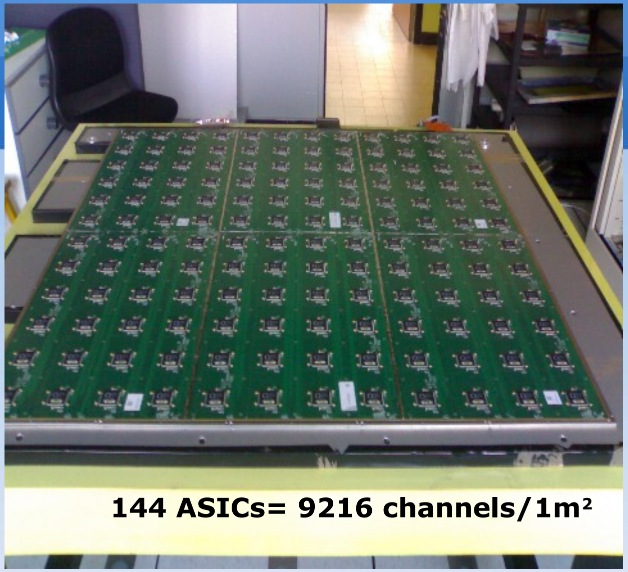
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.

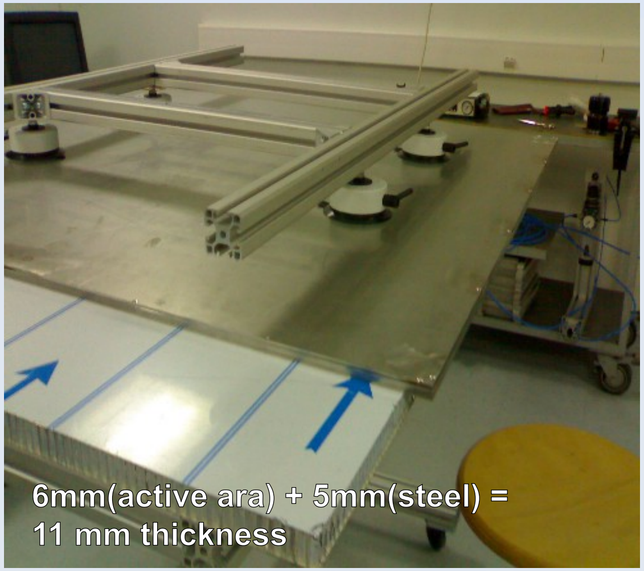


Cassette R&D

Cassettes were conceived

- ✓ To provide a robust structure.
- ✓ To maintain good contact between the readout electronics and the GRPC.
- ✓ To be part of the absorber.
- ✓It allows to replace detectors and electronics boards easily.

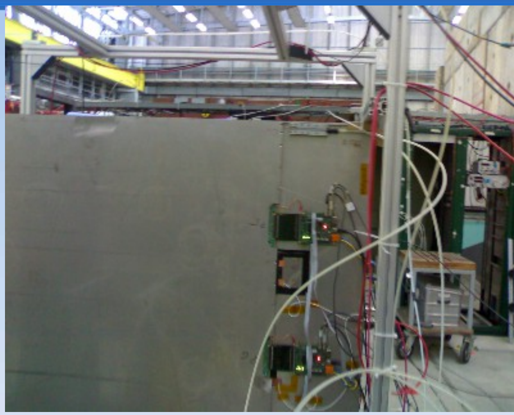


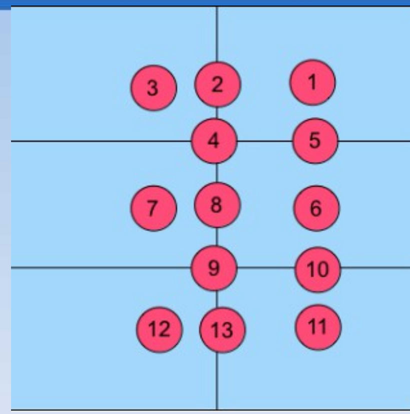


The cassettes are built of no-magnetic stainless steel walls 2.5 mm thick each → Total cassette thickness = 6mm (active layer)+5 mm (steel) = 11 mm

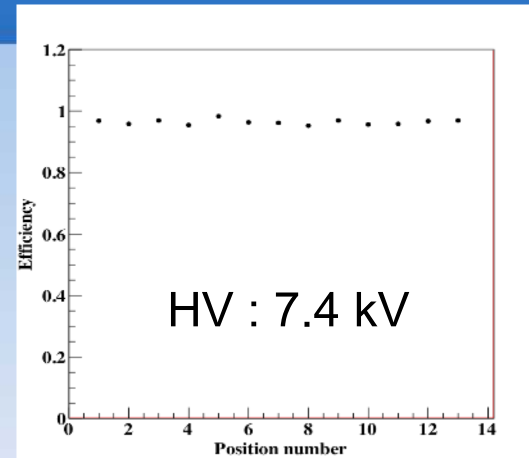
7

The homogeneity of the detector and its readout electronics were studied

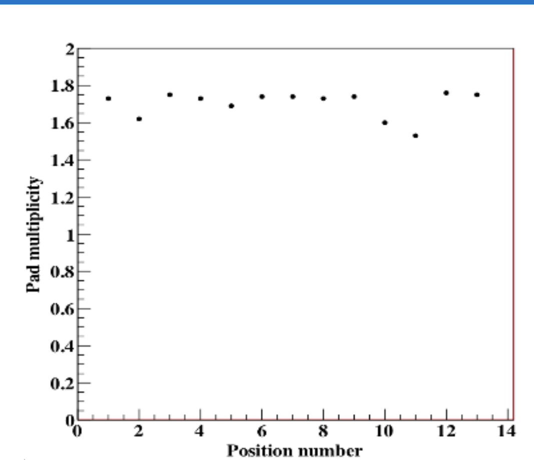




Beam spot position

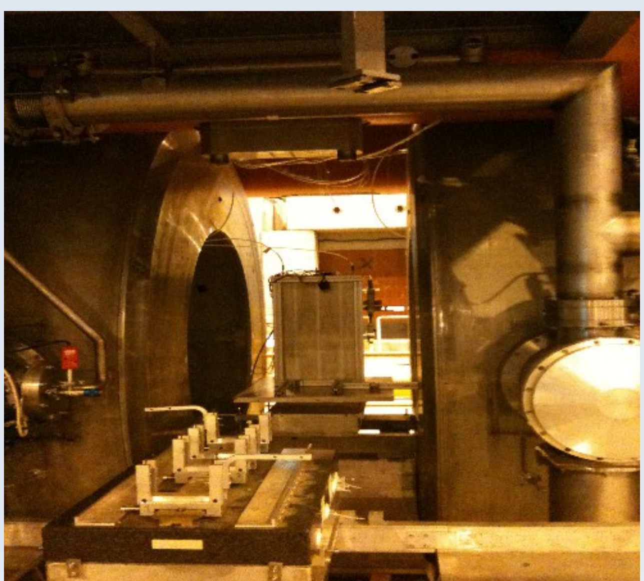


Efficiency



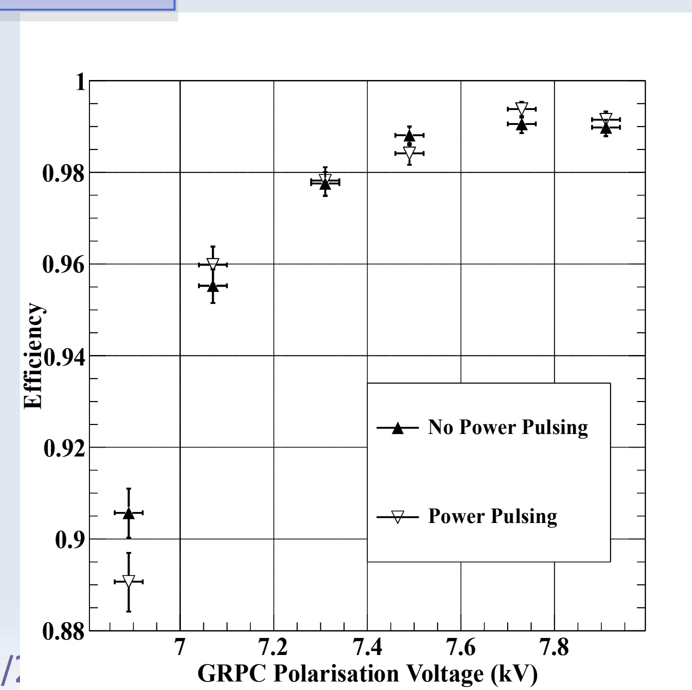
Multiplicity

Power-Pulsing mode was tested in a magnetic field of 3 Tesla



The Power-Pulsing mode was applied on a GRPC in a 3 Tesla field at H2-CERN
(2ms every 10 ms)
No effect on the detector performance

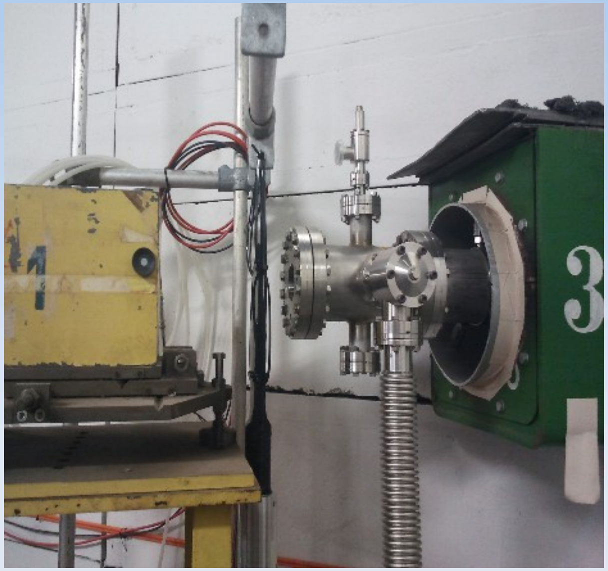
ILC duty cycle :
1ms (BC) every 200 ms



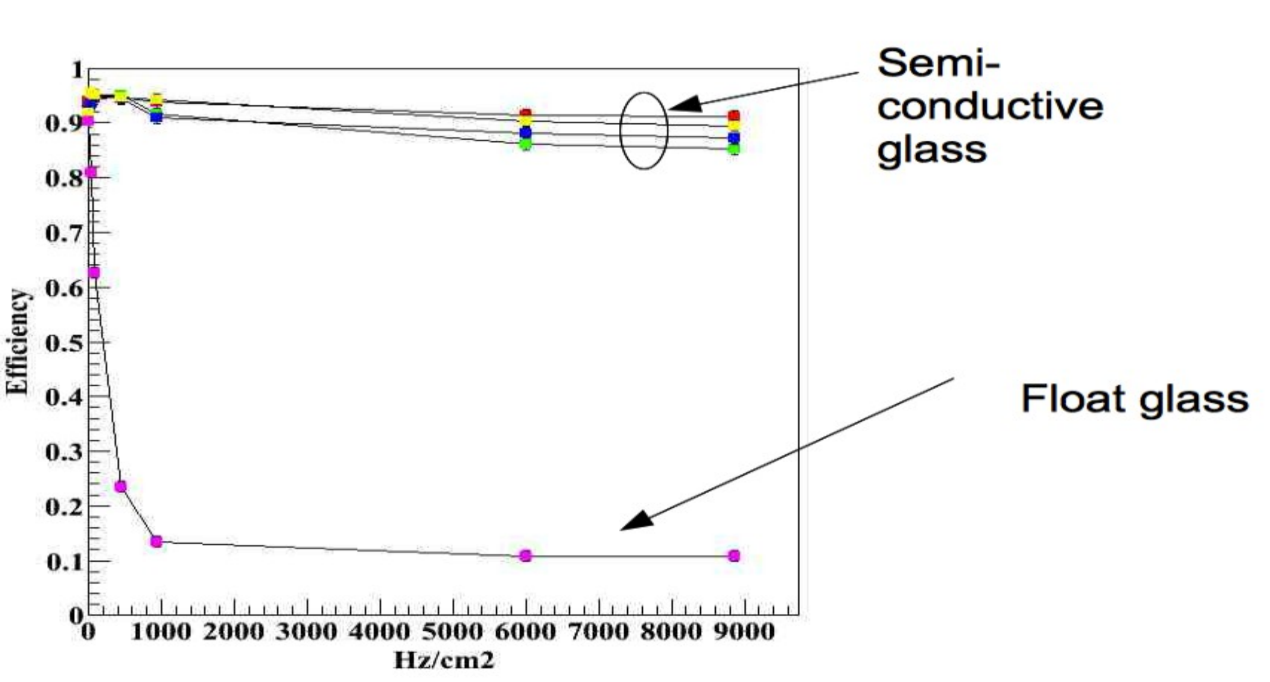
High-Rate GRPC (option)

High-Rate GRPC may be needed in the very forward region

- ✓Semi-conductive glass (10^{10} Ω.cm) produced by our collaborators from Tsinghua University was used to build few chambers.
- ✓4 chambers were tested at DESY as well as standard GRPC (float glass)



Performance is found to be excellent at high rate for GRPCs with the semi-conductive glass and can be used in the very forward region if the rate > 100 Hz/cm^2



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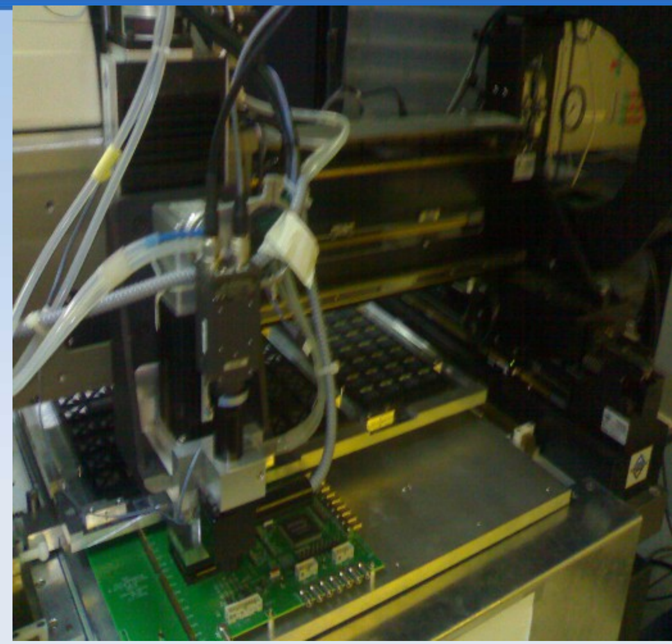
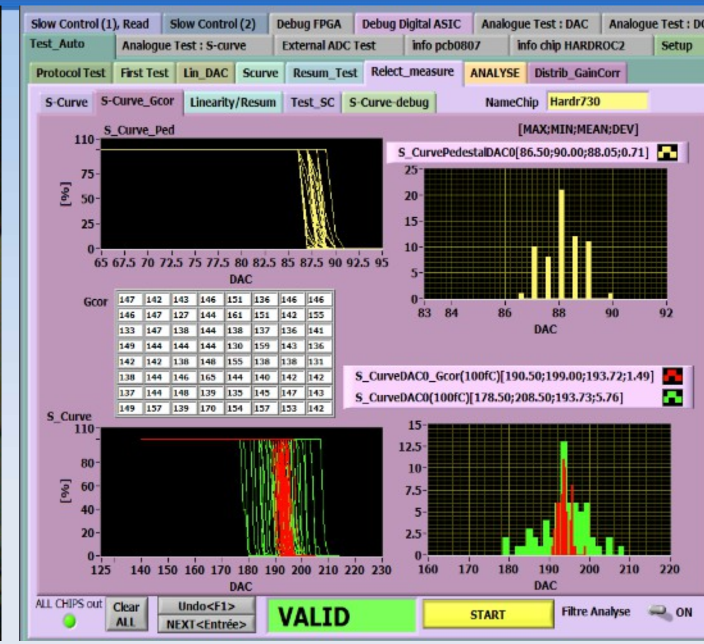
SDHCAL prototype construction

✓ 10500 ASIC were tested and calibrated using a dedicated robot(93% layout)
✓ 310 PCBs were produced, cabled and tested according to strict quality control rules

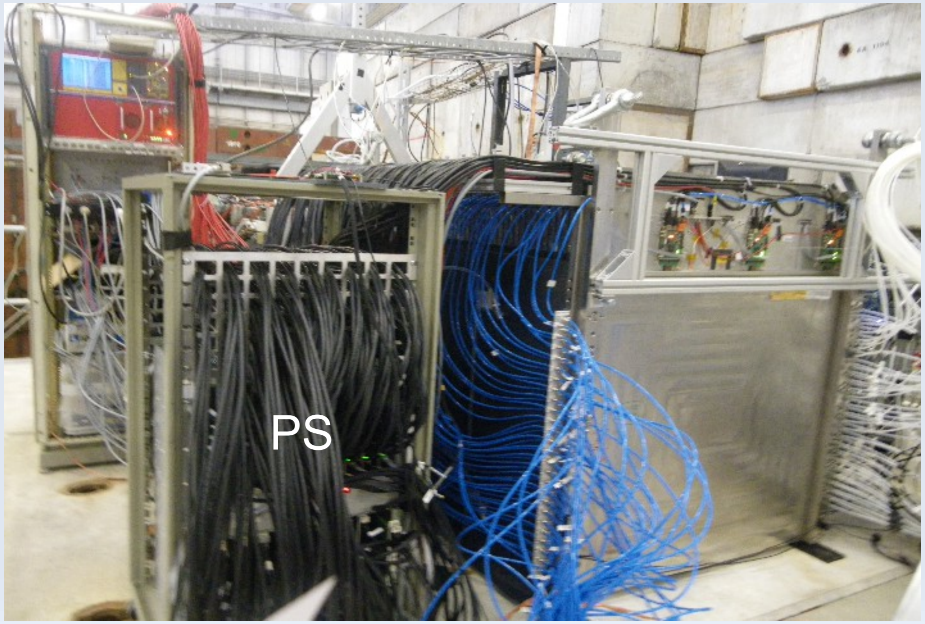


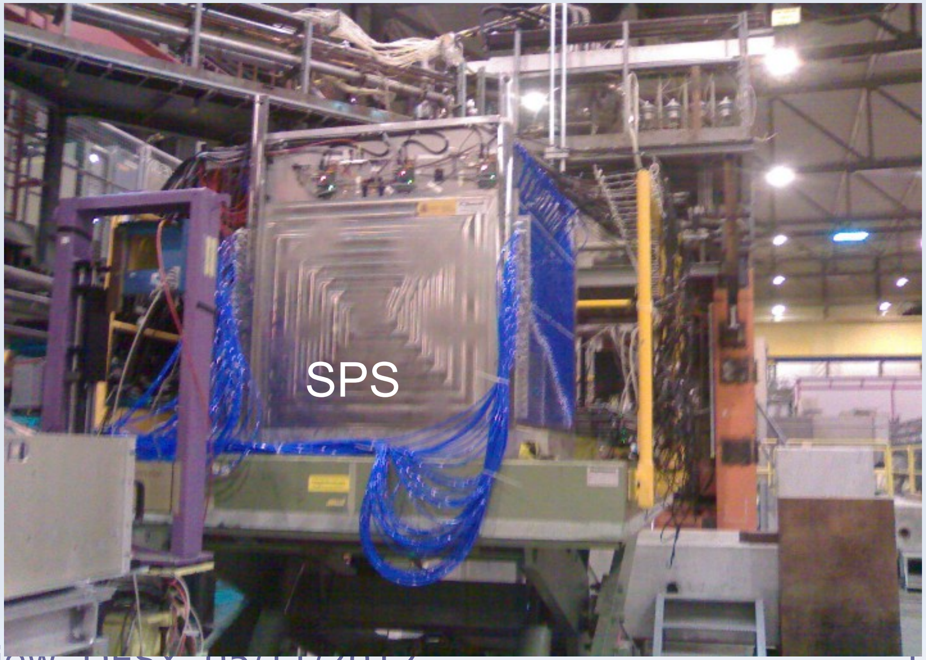


✓ self-supporting mechanical structure was conceived and built.

✓ 51 stainless steel 15mm thick plates with planarity <250 μm were machined and tested

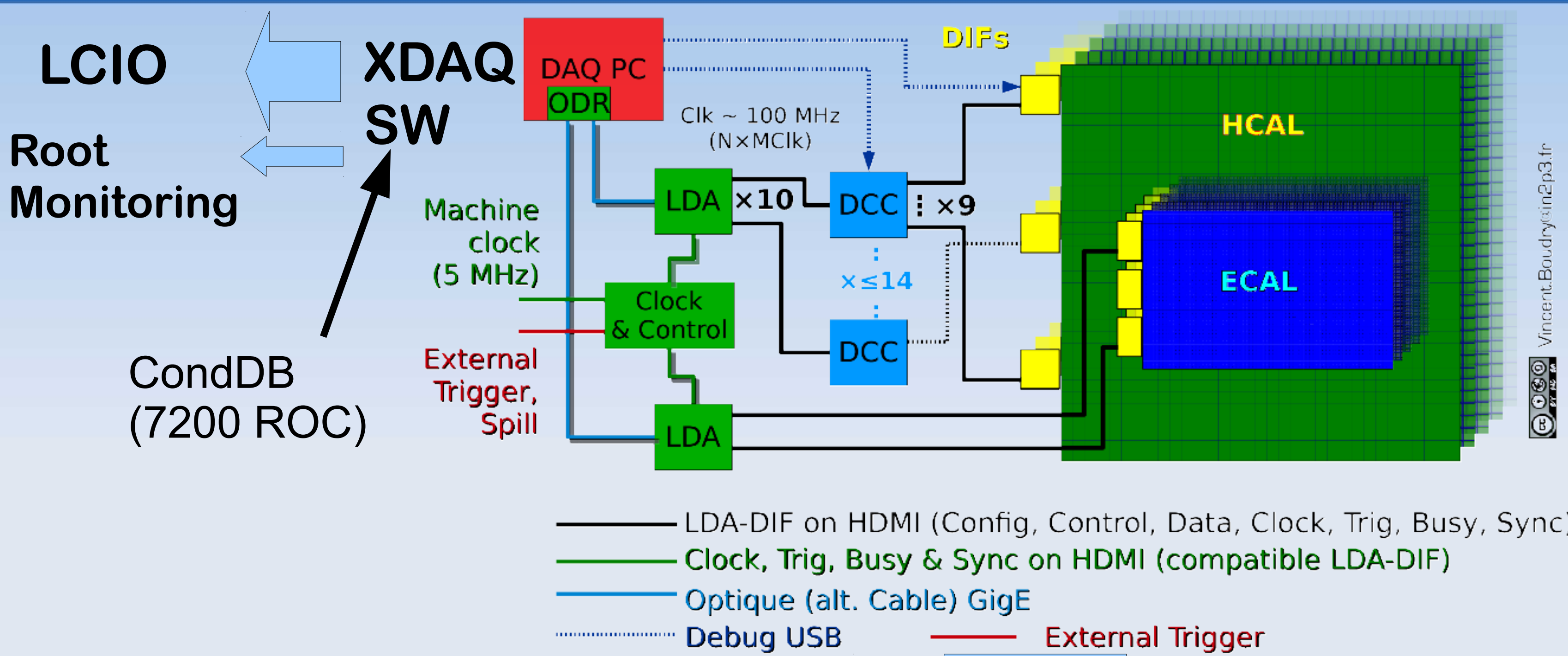
Prototype integration



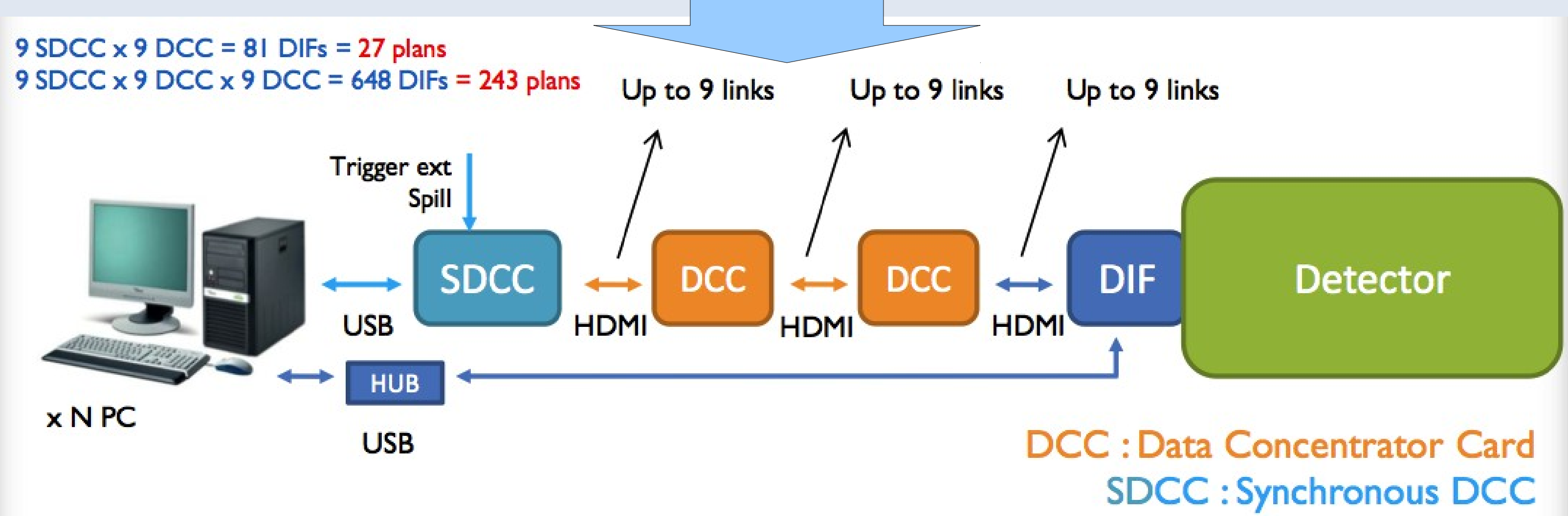


DAQ

Data readout for SDHCAL

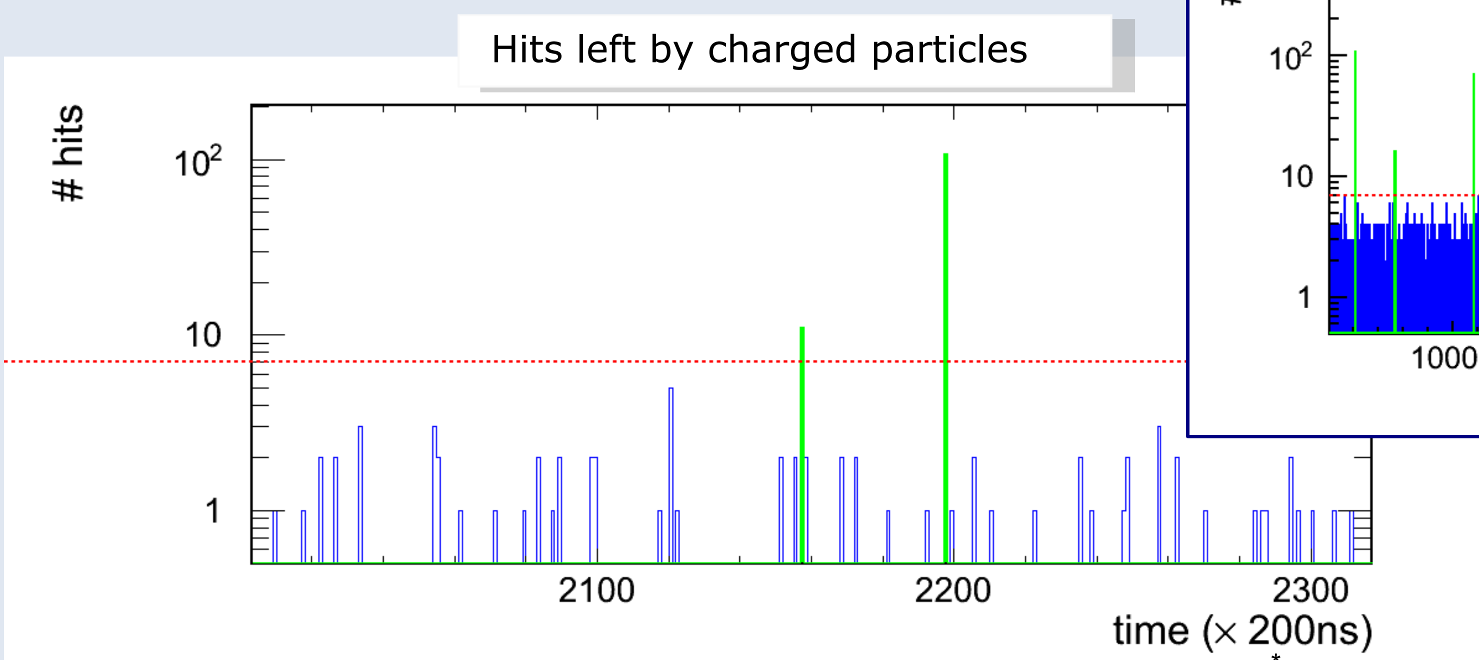


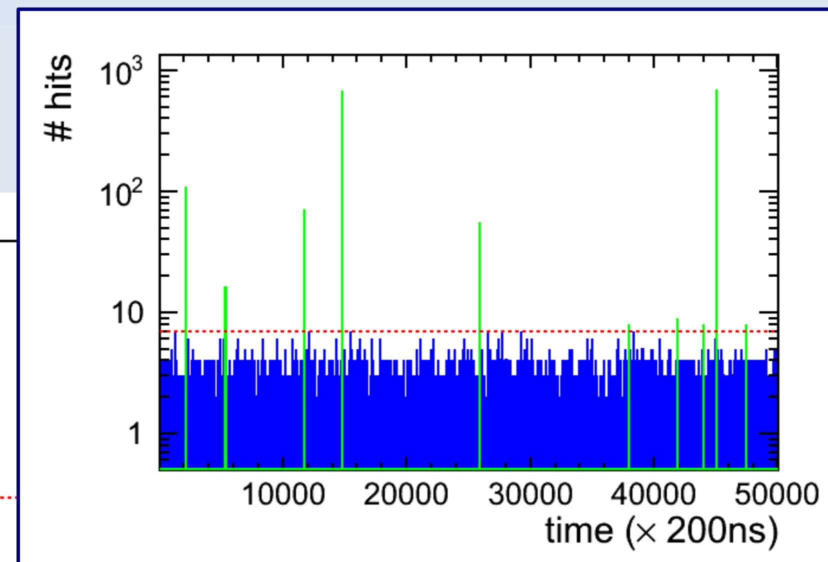
Modified DAQ



Data taking

- Trigger-less mode : record events until memory is full, then data transfer and restart.
- Power-Pulsed mode : According to the time spill structure
  - (N×400 ms (PS)*, 10s (SPS) every 45 s)
- Physics events are built as follows: 3 consecutive BC (200ns) around a peak with Nhit/BC>7
  - Based on cosmic studies



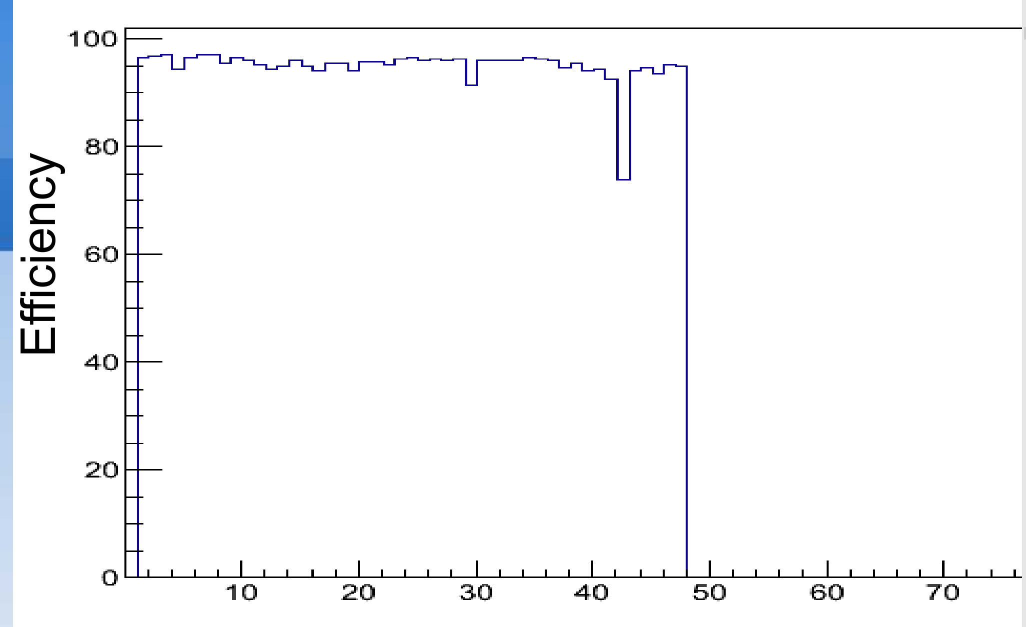


* N is often 1 and sometimes 2-3 spills/cycle

Prototype data acquisition

Online control

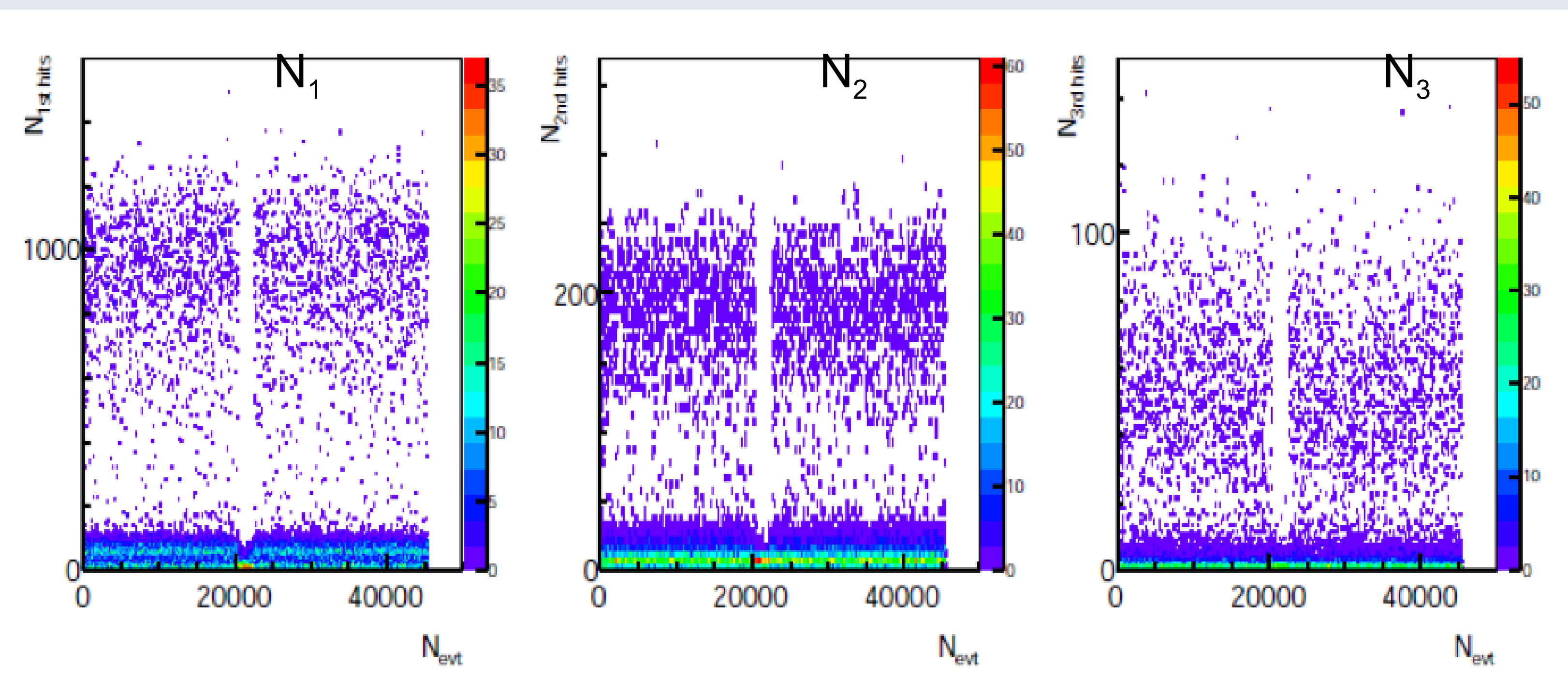
During data taking, efficiency and multiplicity are estimated ever now and then using the muon beam, cosmics. This allows to control the detector quality and its stability during the run.



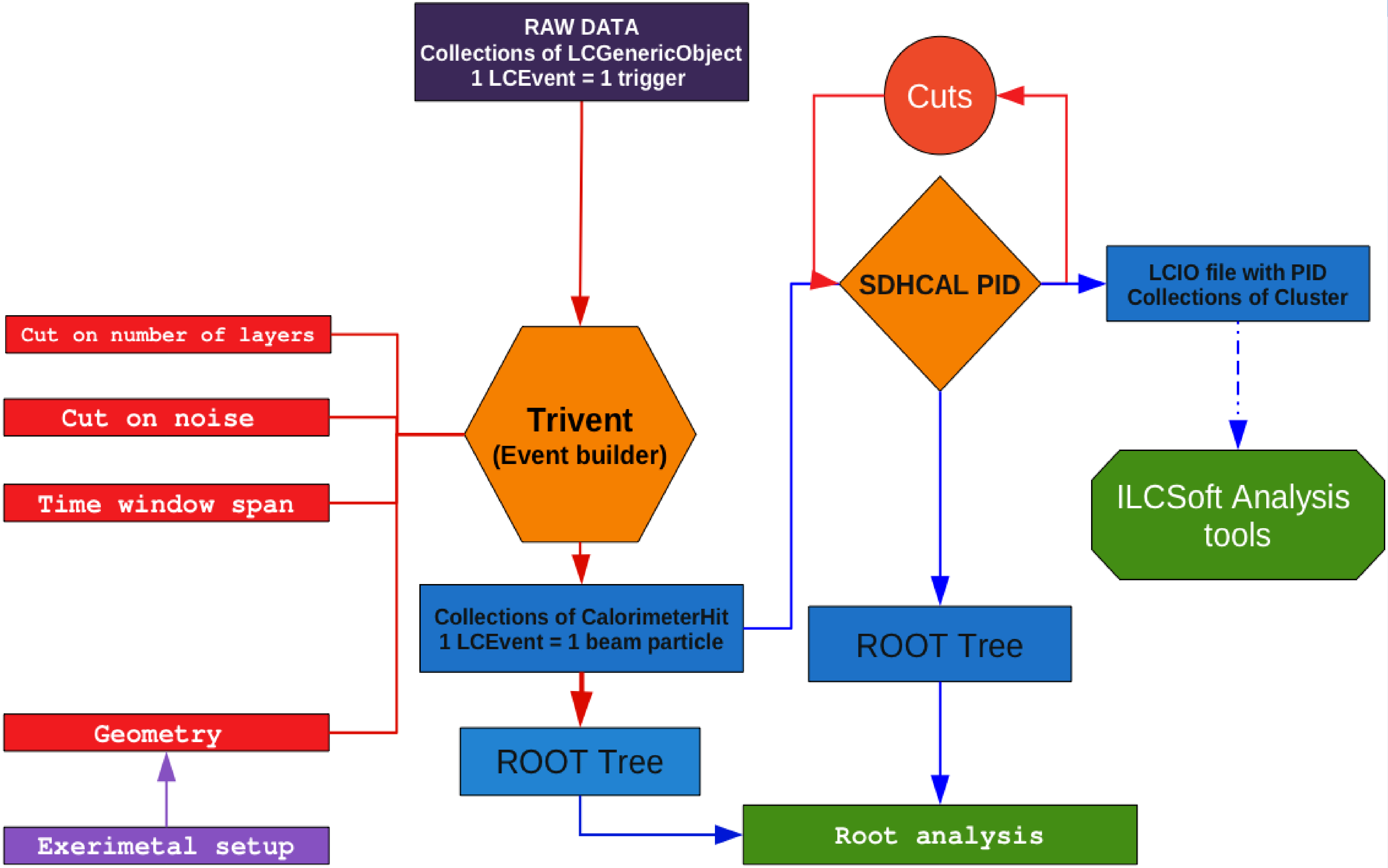
Efficiencies for 43138

1	298770	288178	96
2	299923	289999	96
3	300587	291836	97.
4	302290	285384	94.
5	303182	292831	96.
6	304359	295212	96.
7	303836	295208	97.
8	303234	289097	95.
9	301413	290684	96.
10	299341	287161	95
11	296713	282710	95
12	295025	278118	94
13	292102	277133	94
14	289232	277629	95
15	287725	273191	94
16	285409	268881	94
17	283921	271082	95
18	281189	268578	95
19	279243	262735	94
20	276900	265080	95
21	274932	263257	95
22	273358	260185	95
23	271427	261003	96
24	269284	260190	96
25	267388	256939	96
26	265796	255818	96
27	264488	253723	95
28	262853	253066	96
29	260714	238445	91
30	258935	248365	95
31	257347	247229	96
32	256354	246290	96
33	255078	244701	95
34	253576	244776	96
35	252403	243090	96
36	251564	241647	96
37	250462	237246	94
38	249468	237927	95
39	248213	233770	94
40	252447	238044	94
41	251368	232604	92
42	249871	184524	73
43	247550	232840	94
44	245550	232342	94
45	243090	227223	93
46	240189	228552	95
47	237527	225465	94

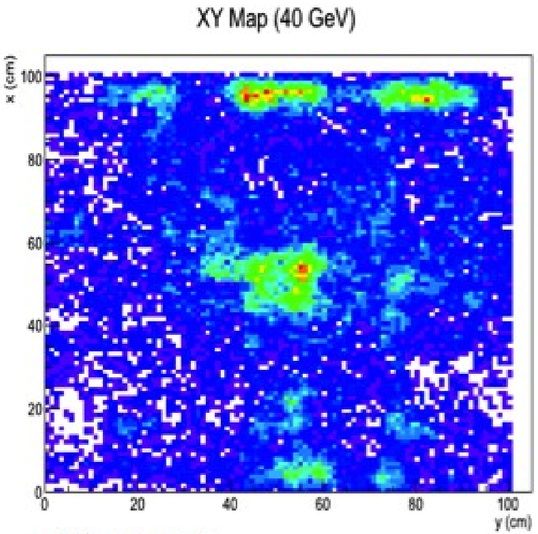
Stability of the three thresholds is also controlled by the hits distribution hadronic showers



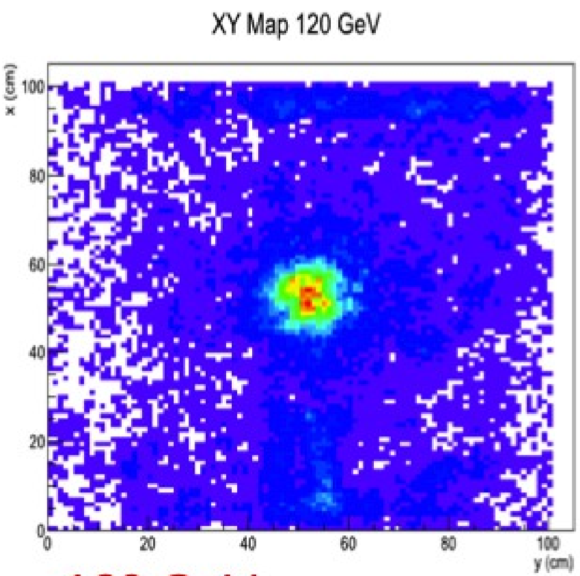
Summary Diagram of SDHCAL Data Reconstruction



Number of fired layer cut



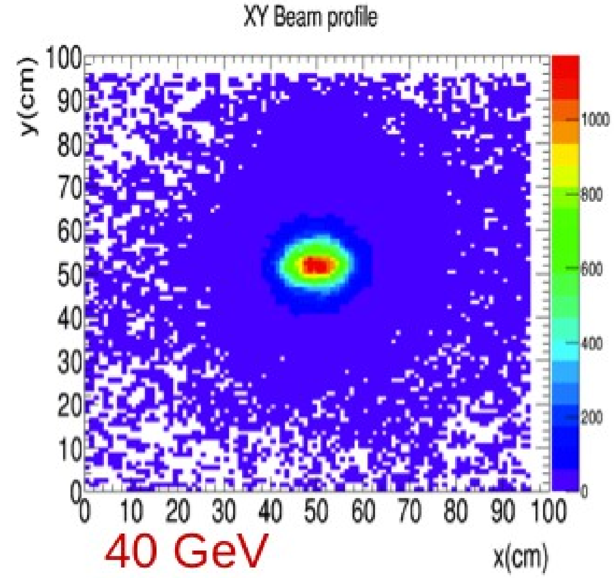
40 GeV



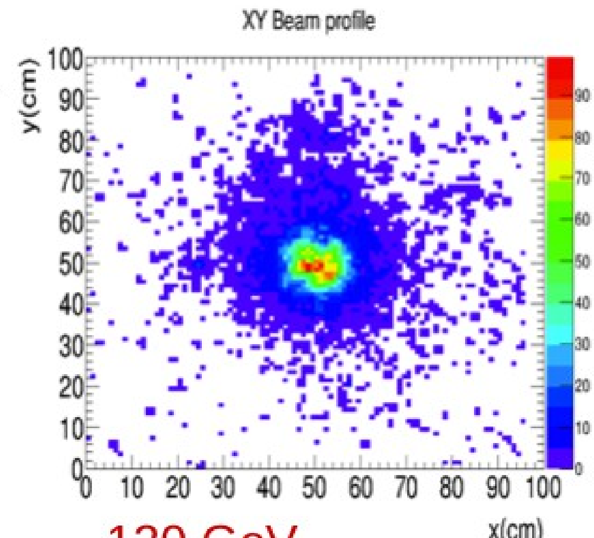
120 GeV

More than few layers
must be hit at the same time

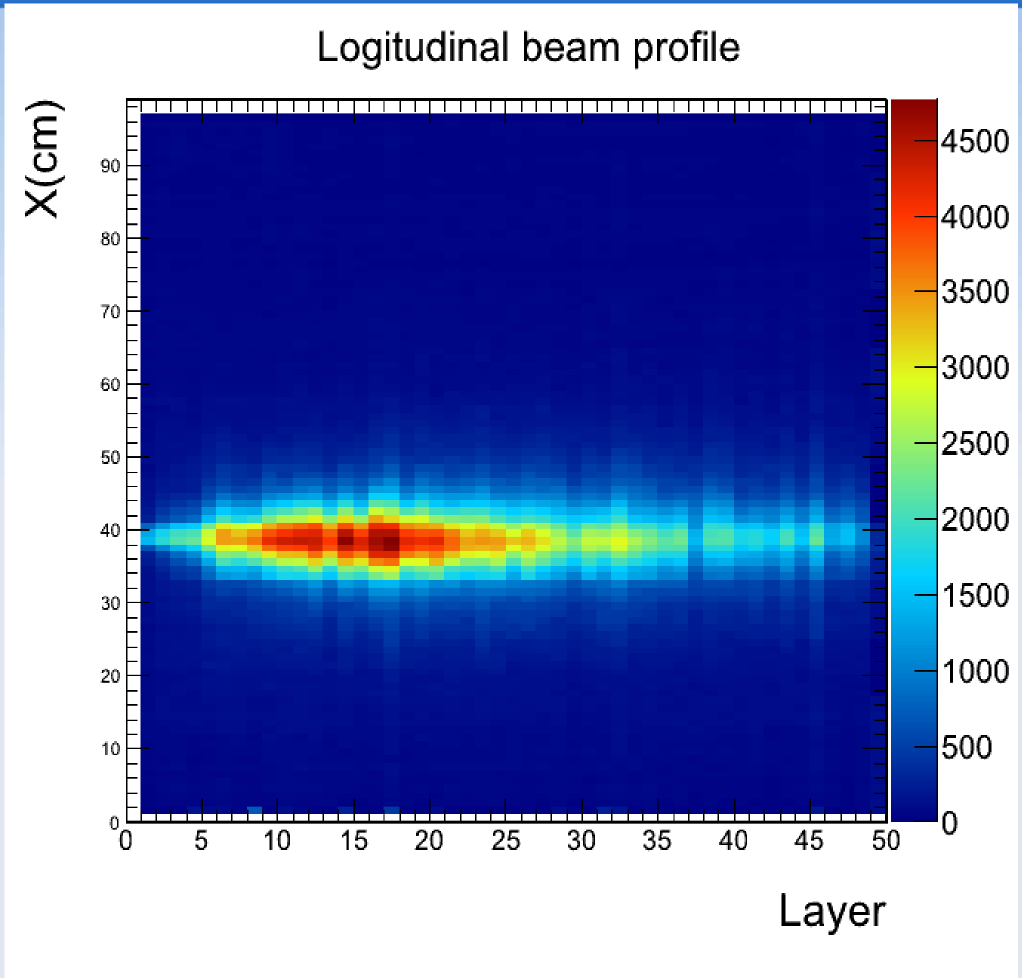
- This cut reduces significantly the noise.

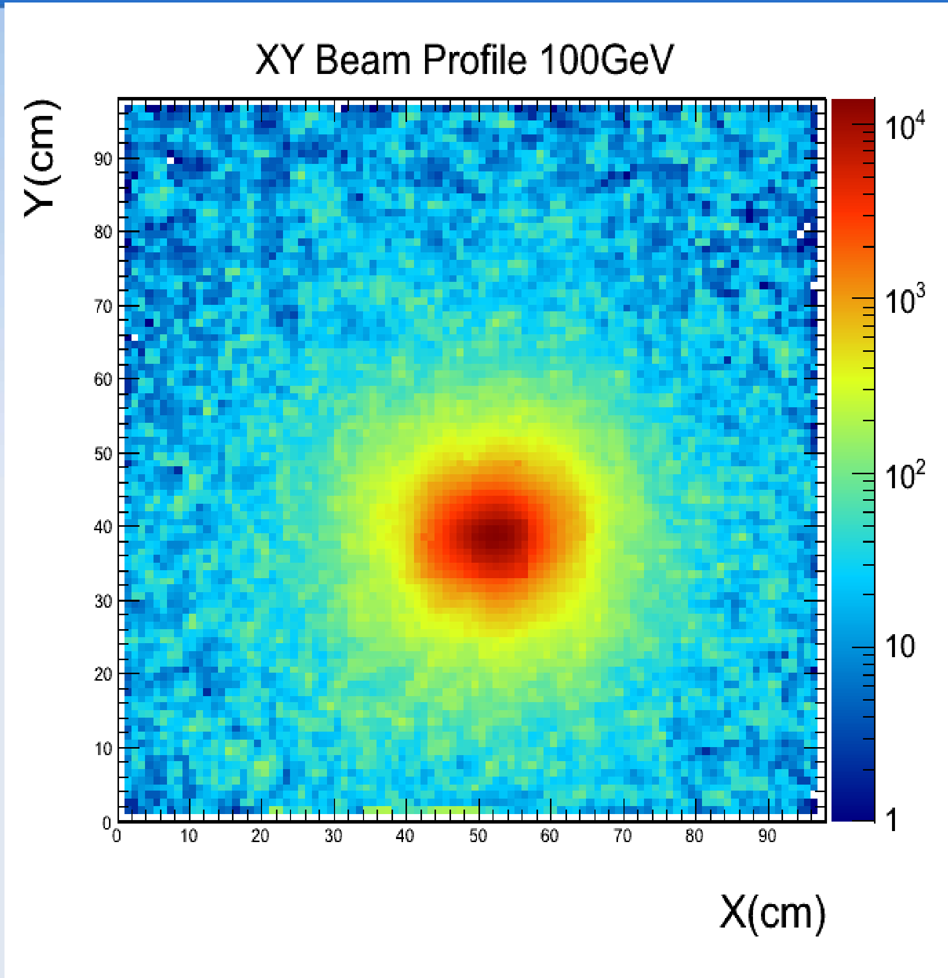


40 GeV



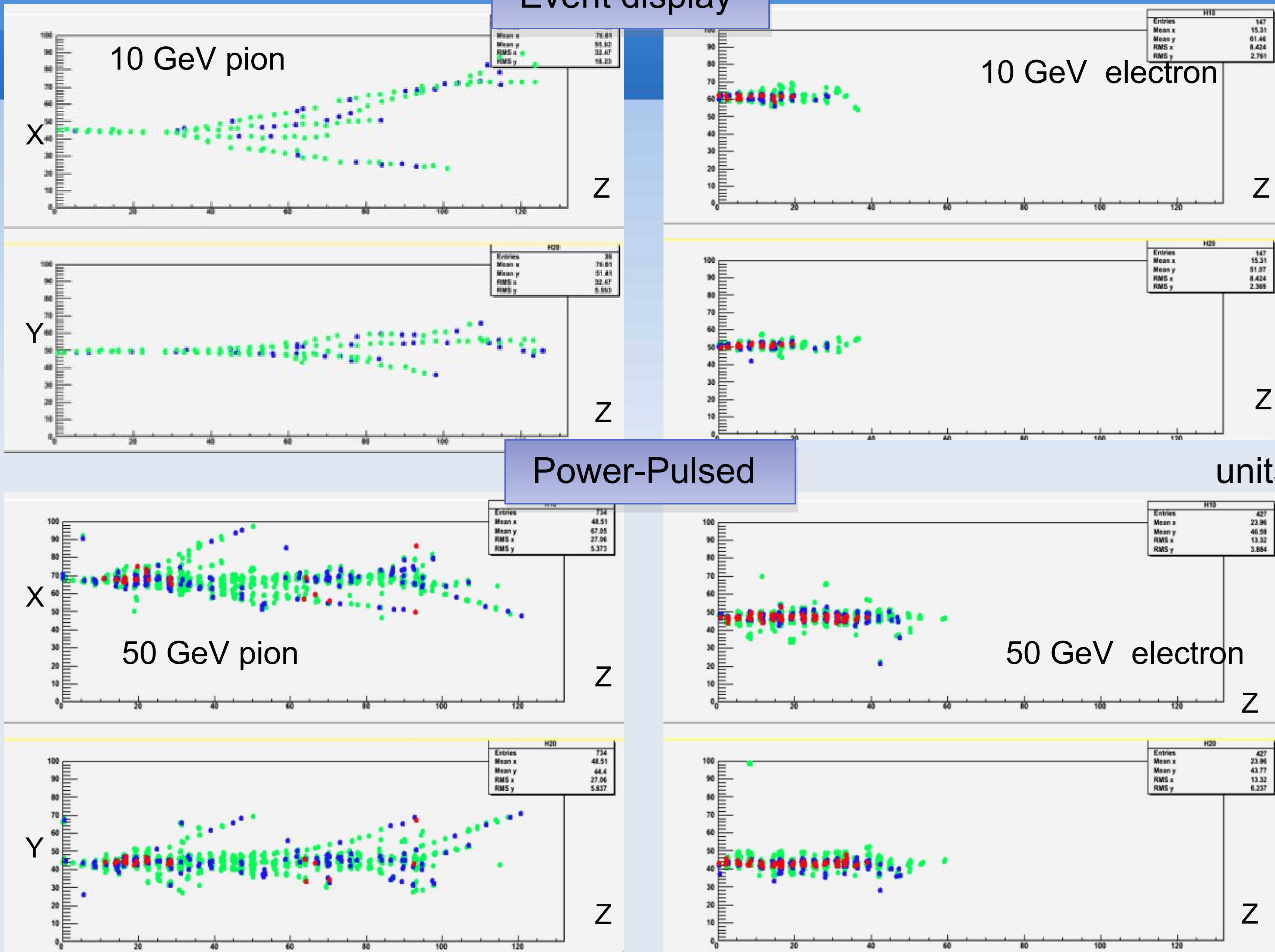
120 GeV





100 GeV pions

Event display

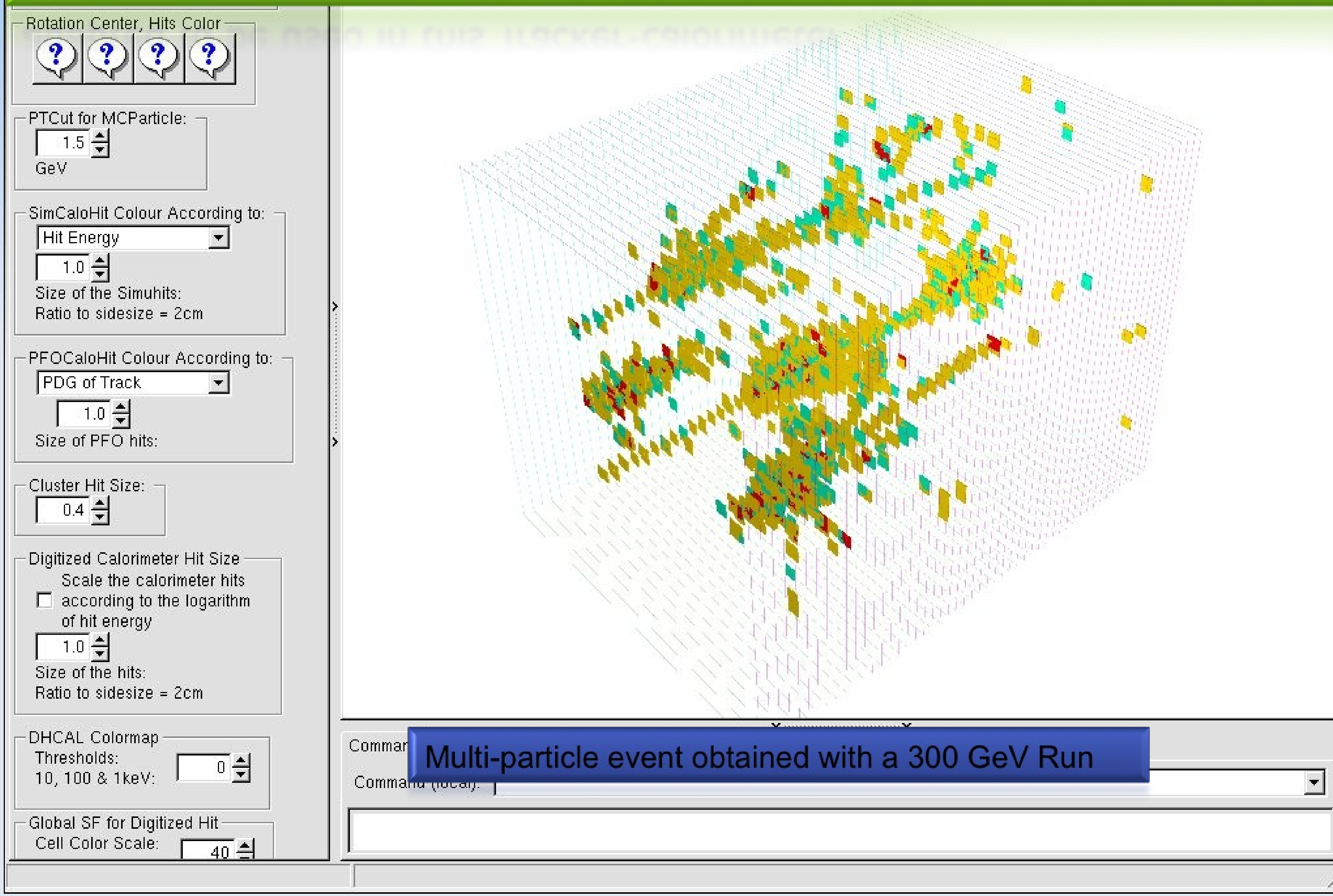


units in cm

Colours correspond to the three thresholds: Green (100 fC), Blue (5 pC), Red (15 pC)

Raw data, no treatment except time hit clustering

✓The SDHCAL granularity will allow to separate easily close-by hadronic showers.
✓Hough Transform and Minimum Spanning Tree algorithms are being adapted to be used in this Tracker-calorimeter



Multi-particle event obtained with a 300 GeV Run

Test beam results

FOREWORDS

- Results from August and May runs
- **Raw performances** of the Semi-Digital HCAL,
  1 m^3 based on 1×1 cm^2 GRPC
  - response to single beam particles
  - Uncalibrated (cell-wise or sensor-wise) calorimeter sensors
  - Not a Particle Flow performances estimation
- **Data driven analysis**
  - no use the Ebeam knowledge
  - MC needs tuning to data (on going)
  - esp. particle ID.
- Mainly results from 1 integrated analysis
  - rush effort of the SDHCAL group and CALICE referee's to validate results
    → CALICE preliminary tag
  - Not final numbers (but good enough !)

Beam conditions

- Beams of pions, electrons and muons at CERN
  - 2 weeks in May 2012 @ SPS H2
    - π+: 20, 30, 40, 50, 60, 70, 80 GeV
    - e- :10, 20, 30, 40, 50, 60 GeV
    - μ dedicated runs...
  - 2 weeks in August (& September) 2012 @ SPS H6
    - π+: 5, 7.5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 GeV
    - \+ few μ dedicated runs
- Beam composition:
  - all runs contain μ's (esp. e-) and cosmics
  - π's runs filtered by 4mm Pb to remove e- (esp. for E≥20 GeV)
  - proton component in HE π's runs (@ E≥20 GeV)
  - $\delta E_{beam}/E \sim 1$ %
- Large beam profile
  - **low rates** (ε ↘ at $f \geq 100$ Hz)
  - Rate monitored online by μ tracks and π tracks segments
    - Only run with $f \leq 1000$ part/spill ⇔ $\varphi \leq 100$ Hz/cm^2

Configuration:

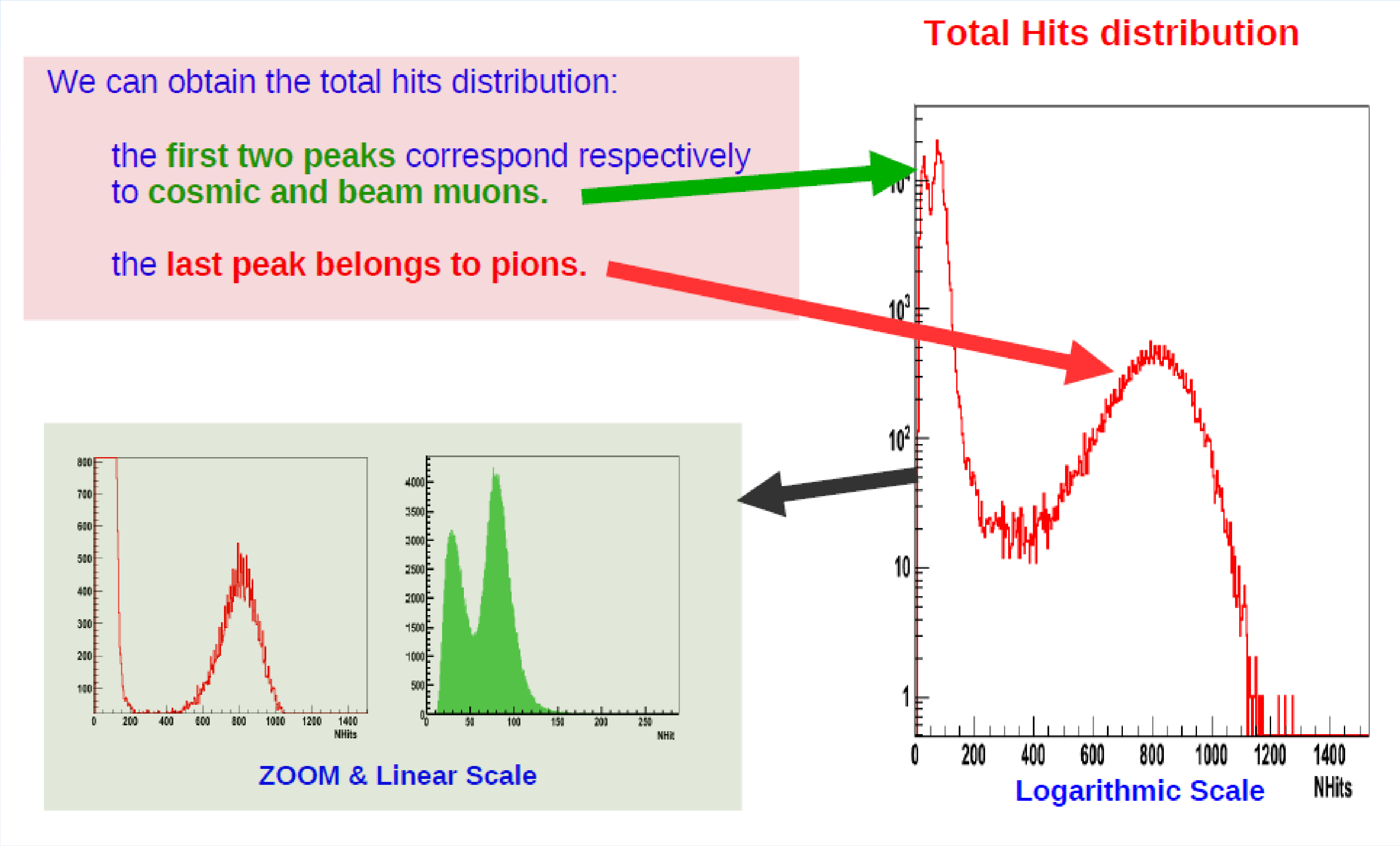
- GRPC set-up & response
  - gas: TFE 93%, CO_2 5%, SF_6 2%
  - HV = 6.9 kV
  - the average MIP induced charge being around 1.2 pC
  - Thresholds set at 0.11 pC, 5 pC and 15 pC (0.1; 4; 12.5 mip)
- Dead zones:
  - 1/3 slab of plane # 46 dead in May ; repaired for August runs
  - 1st 47 planes available during 1st week fo August.
  - 7 ASIC switched off (and not replaced) ↔ 1 ‰ dead zone.
- Gains
  - All set to 1 (no gain corr.) during this data taking
    - (will be done for next period)

Selections & particle ID

Events classification (I)

- Noises
- Muons (from beam and cosmics)
- Pions
- electrons

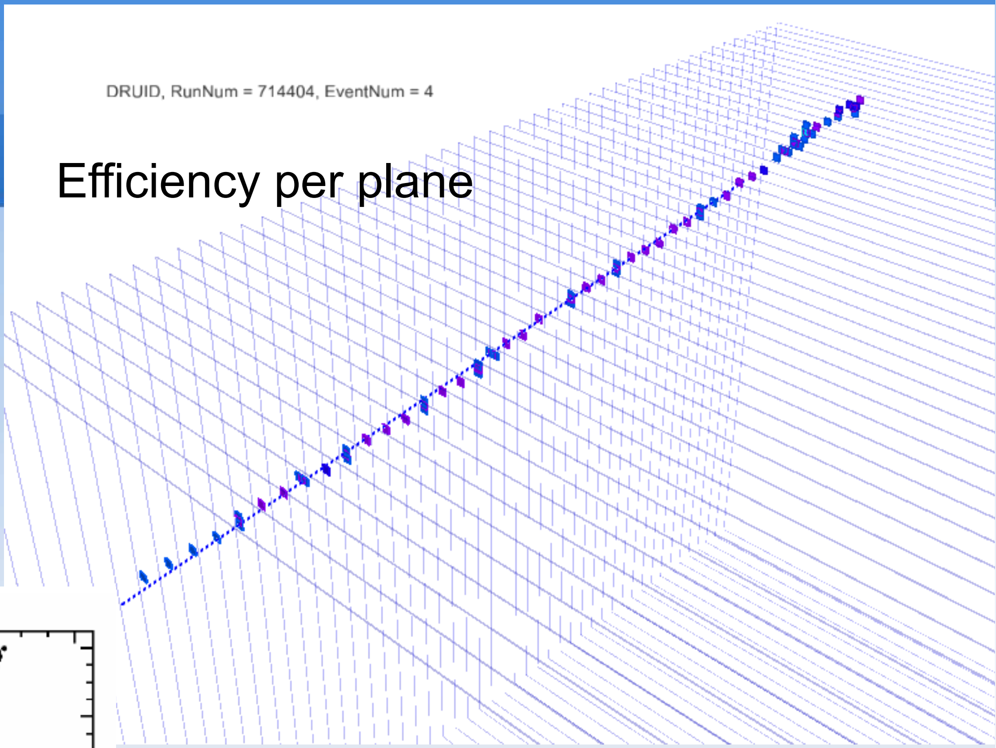
- Just the total number of hits is already a good hint.

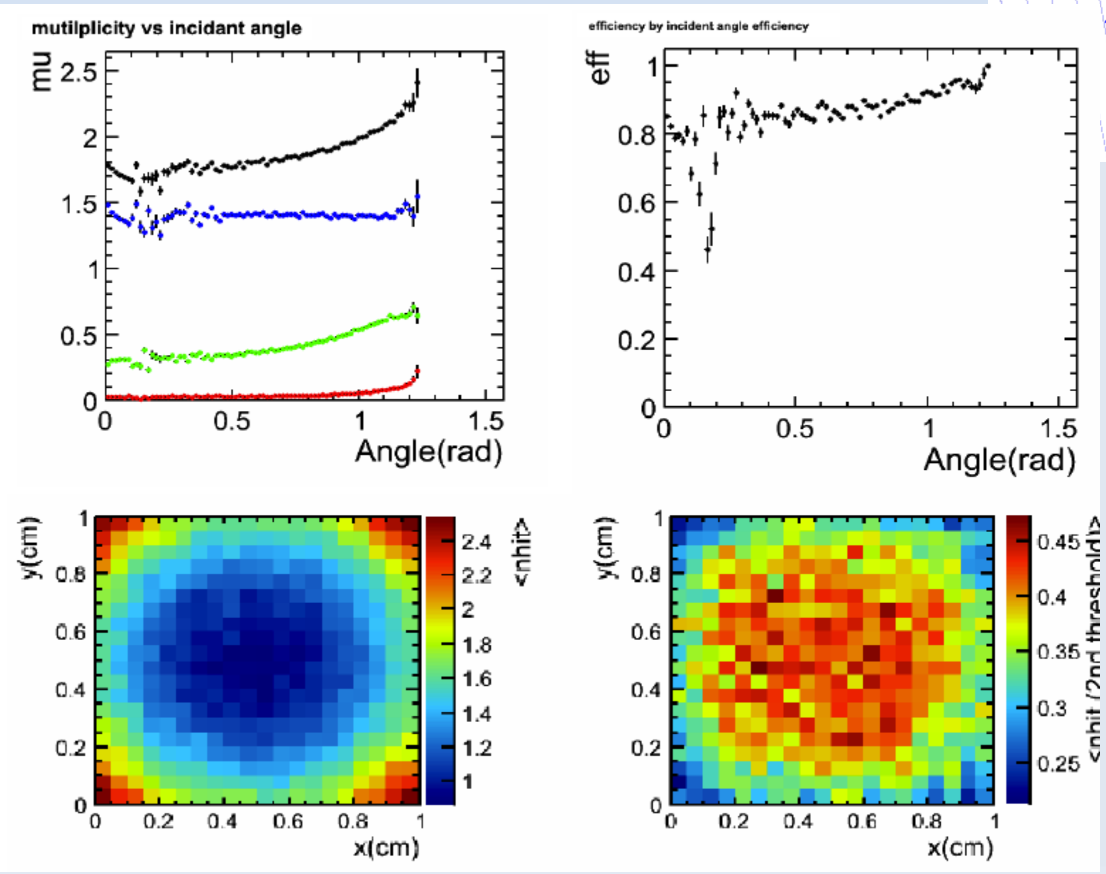


Efficiency and multiplicity from all muons (cosmics & beam)

- With muons, one can derive efficiencies and multiplicities per plane, per ASIC, per channel or per area smaller than a cell.

Muons recorded during august test beam.



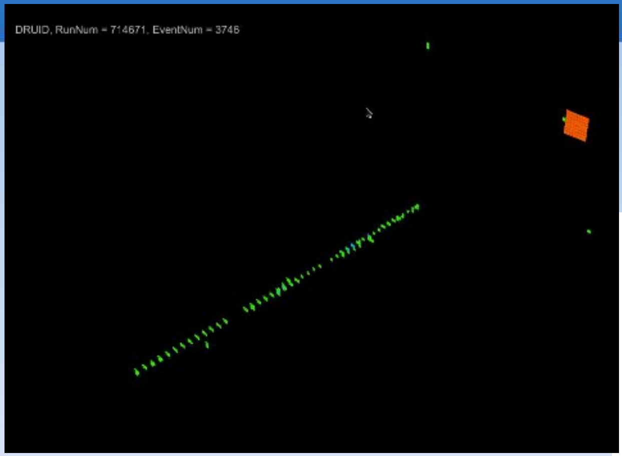


Multiplicity & Efficiency vs Angle

"folded" in a single cell

⇒ Input to simulation

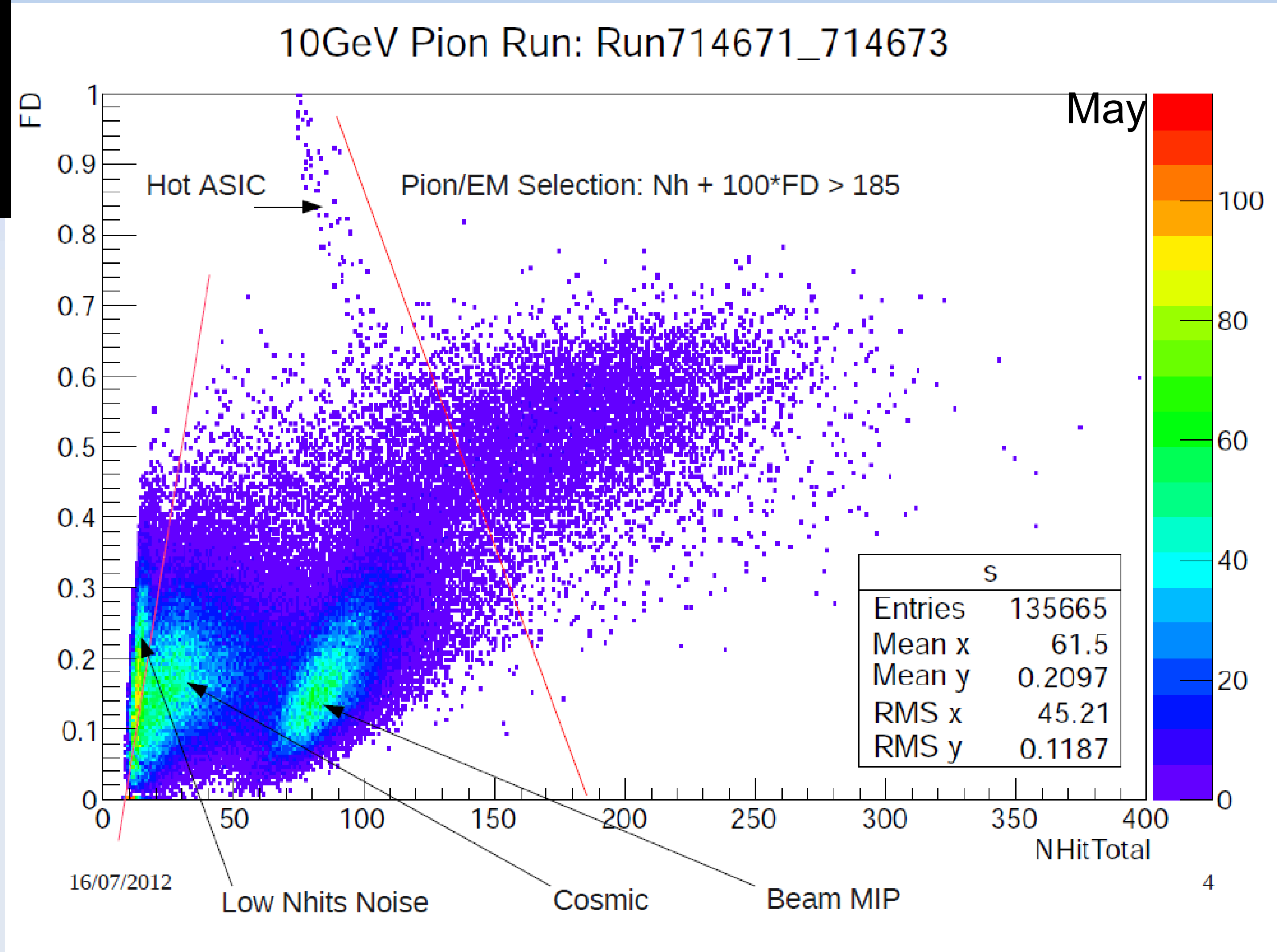
Fractal dimension (FD) versus total number of hits.



$$f(a) = \frac{\ln\left(\frac{N_b}{N_a}\right)}{\ln\left(\frac{a}{b}\right)};$$

$$FD = \langle f(a) \rangle; a > b; \frac{a}{b} \in \mathbb{N}$$

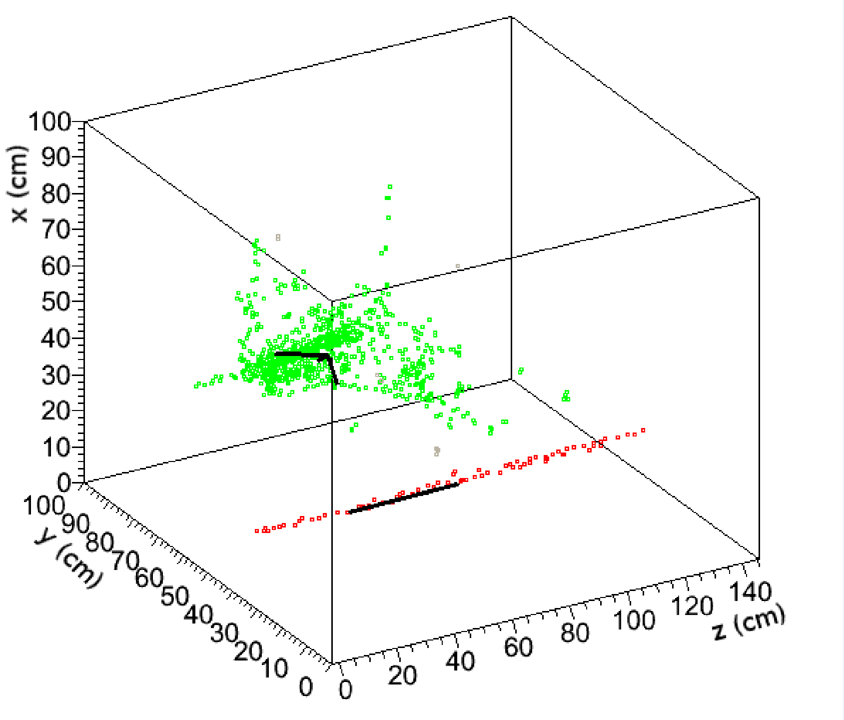
- Can be computed for any thresholds
- We also use : $\frac{FD}{\ln(Nhit)}$



Particle ID variables

- Topological:
  - Principal Component Analysis (PCA) on all hits or clusters
  - 3 main ⊥ axis eigenvalues
    $\lambda_i \equiv \sigma$ (hits) on axis

    $\lambda_1, \lambda_2, \lambda_3$ with $\lambda_1 < \lambda_2 < \lambda_3$
    - λ_3 = longitudinal comp.
  - Transverse Ratio $(\lambda_1 \oplus \lambda_2) / \lambda_3$ → muons vs e, π
- Shower start
  - λ_{1p}, λ_{2p} idem to λ_1, λ_2 restricted to 1 plane
  - *1st interaction plane (FIP) ≡*
    - $\lambda_{1p} \oplus \lambda_{2p} > 1.5cm$
    - $N_{hit}^{plane} > 5$



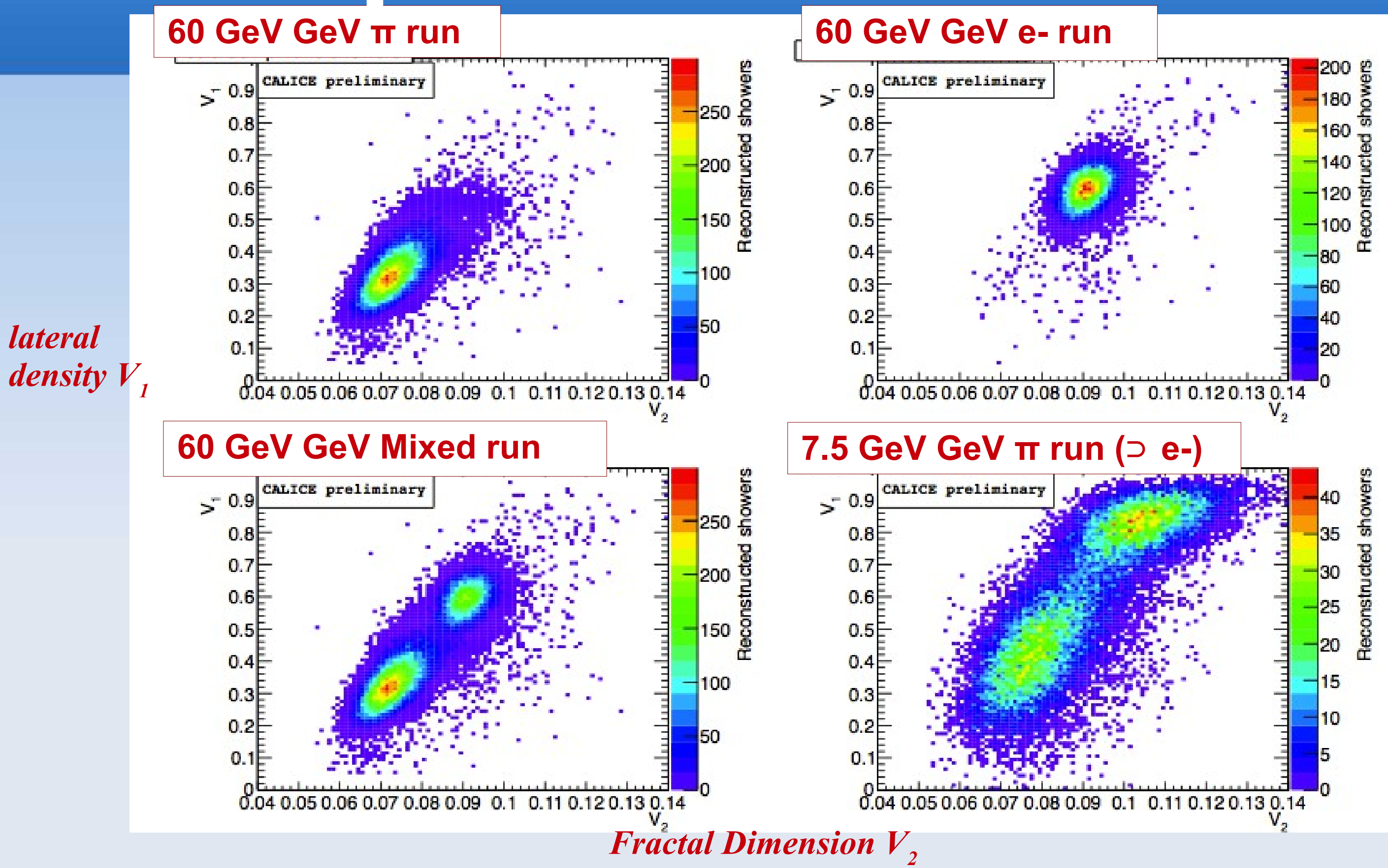
Particle ID (cont'd)

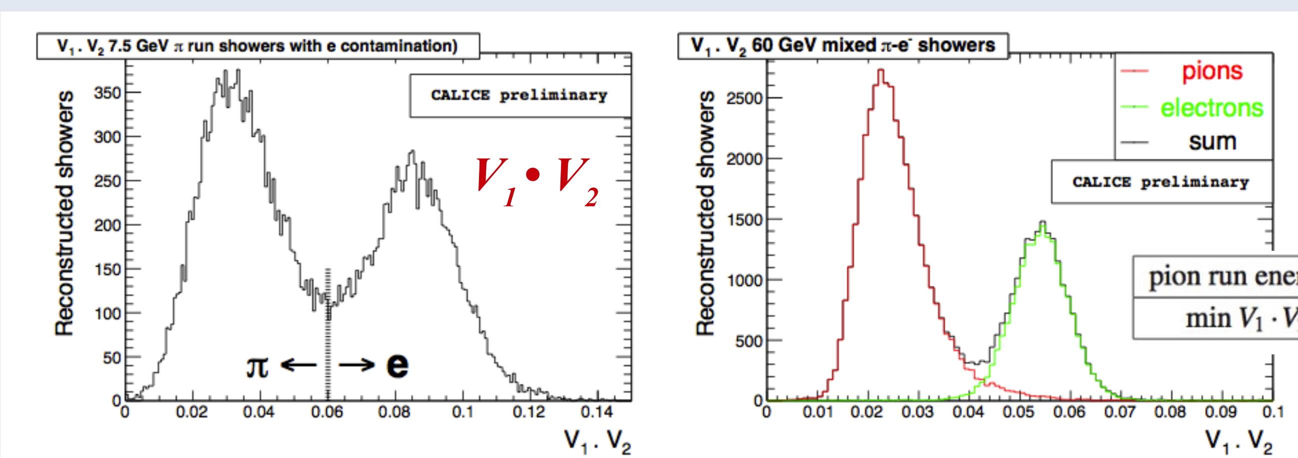
- Density
  - $V_1 = (\sum_{layers} N_{25}^{layer}) / N_{hits}$
    - $N_{25}^{layer} = N_{hits}$ in 5×5 around barycenter in 1 layer
  - $V_2 = FD_{3D} / \ln(N_{hits})$
    - Fractal dimension: $$\mathrm{FD}_{3\mathrm{D}} = \frac{1}{|I|}\sum_{n\in I}\frac{\ln(N_{\mathrm{hit}}/N_{\mathrm{cube}}(n))}{\ln(n)}$$

      $N_{cube}(n)$ ≡ number of cube in $I=\{2,3,4,6,8,12,16\}$

- Clustering :
  - removal of isolated hits and tagging of overlapping events
  - MST à la charm-II using $$D_{\alpha,\beta} = \left|\mathrm{plane}_\alpha - \mathrm{plane}_\beta\right| + 2\times\left(\left|I_\alpha - I_\beta\right| + \left|J_\alpha - J_\beta\right|\right)$$
    - $N_{hits} > 25$; $\lambda_3 > 4.5$ cm; $\lambda_2 / \lambda_3 > 0.01$.

e/π separation





- Operation on clusters
- Negligeable loss of π's @ HE
- few % e- residual contamination @ LE

10% variation of cut
⇒ Systematics

Variation of cut with E_{beam}

pion run energy (GeV)	5	7.5-15	20	30-40	50-60	70-80
min $V_1 \cdot V_2$ value	0.065	0.06	0.055	0.05	0.045	0.04

Leakage reduction; Statistics of π's

- FP # ≤ 4.
  - removes cosmics (lateral entrance)
- First Interaction Plane (FIP) # < 15
  - removal of late interacting hadrons.

OR
- The last shower plane (LP) # < 42
- or Nhit(last 7 planes) / Nhit(first 30 planes) < 0.15

- The first (last) plane (FP, LP) of the reconstructed shower
  - containing a hit:
  - could be ≠ from interaction plane

After all Selection

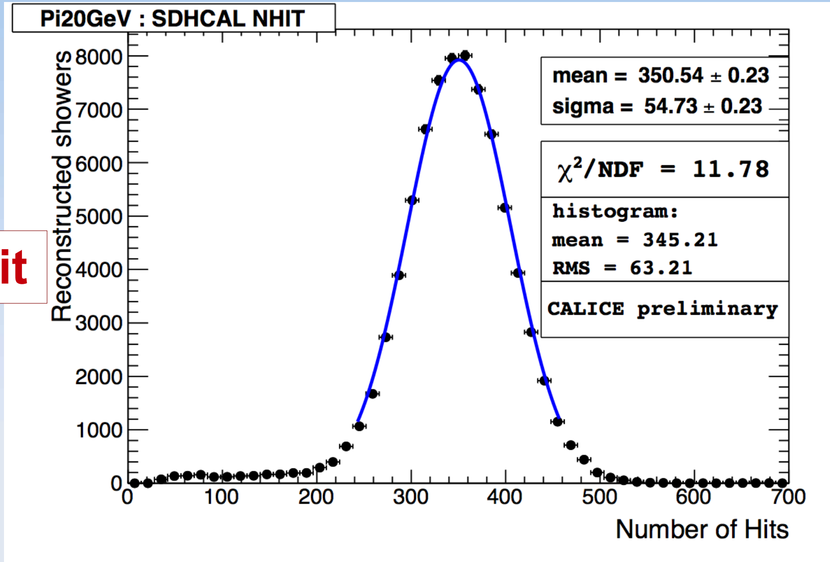
Energy [GeV]	Number of π's events
5	9504
7.5	15074
10	20406
15	33405
20	78391
25	59495
30	53179
40	48720
50	76566
60	38917
70	30893
80	32964

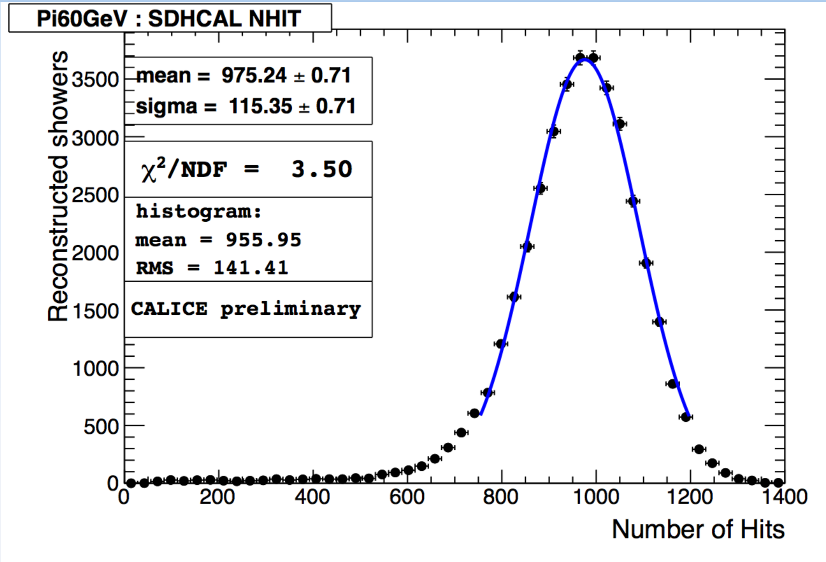
Results

Raw number of hits (binary HCAL)

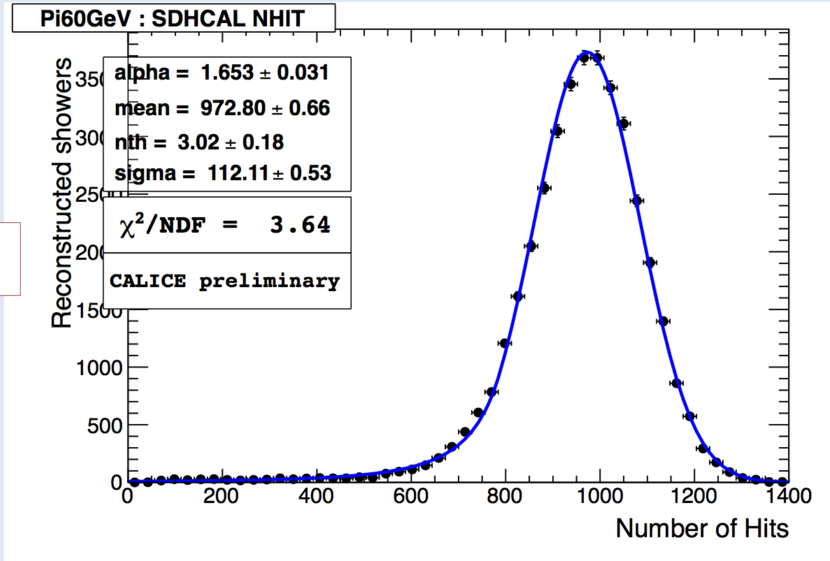
20 GeV π's | **60 GeV π's**

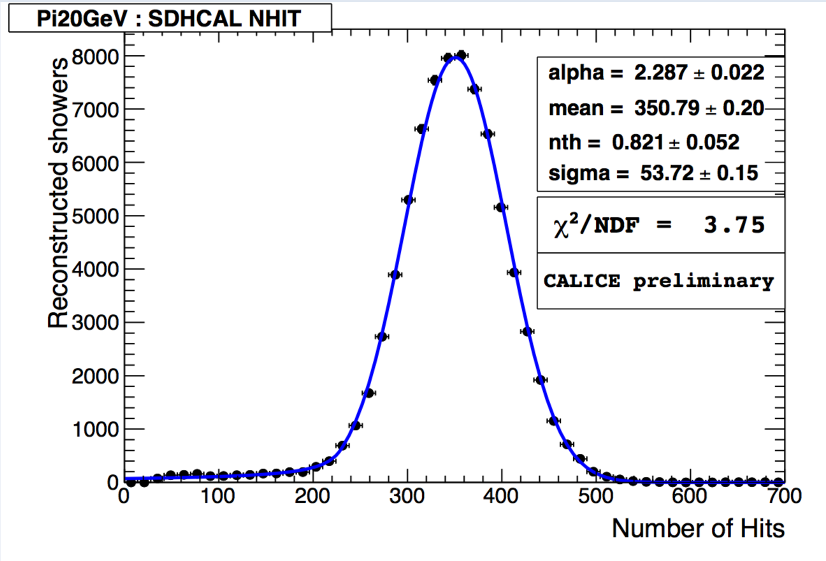
±2σ Gaussian fit



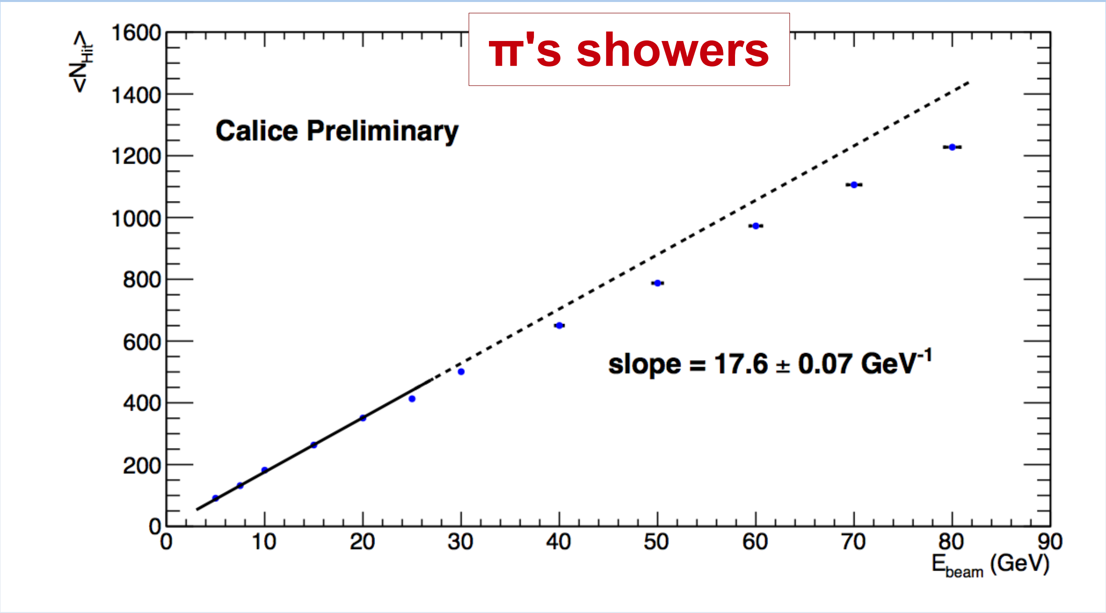


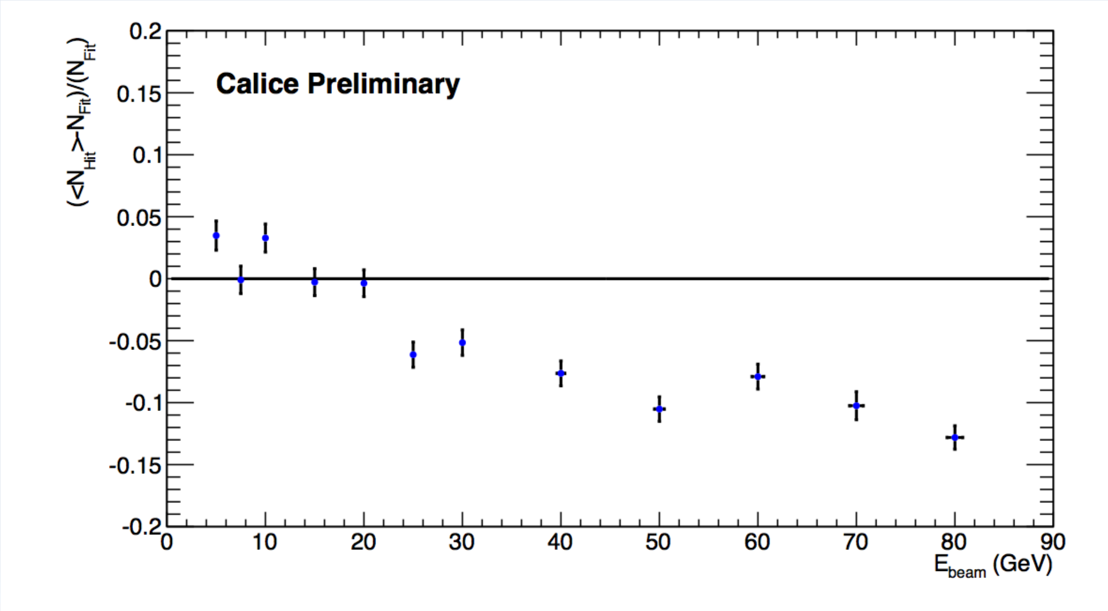
Crystal Ball fit





Nhit response (binary HCAL)





- Saturation observed for $E_{beam} \geq 30$ GeV
- Offset (~4 hits) compatible with noise over 3 clock cycles
- Fit by quadratic function:

  E = (C+ D • Nhit) Nhit

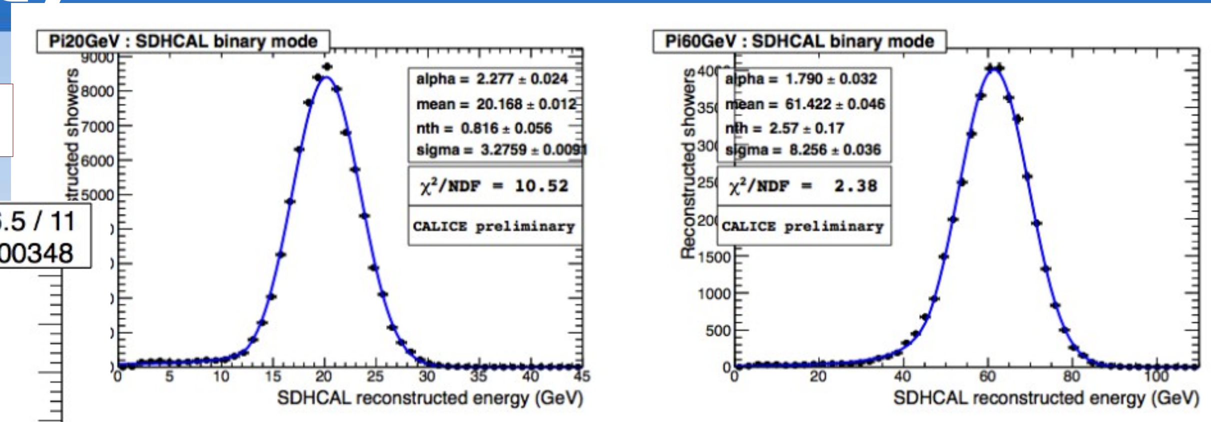
  yields:

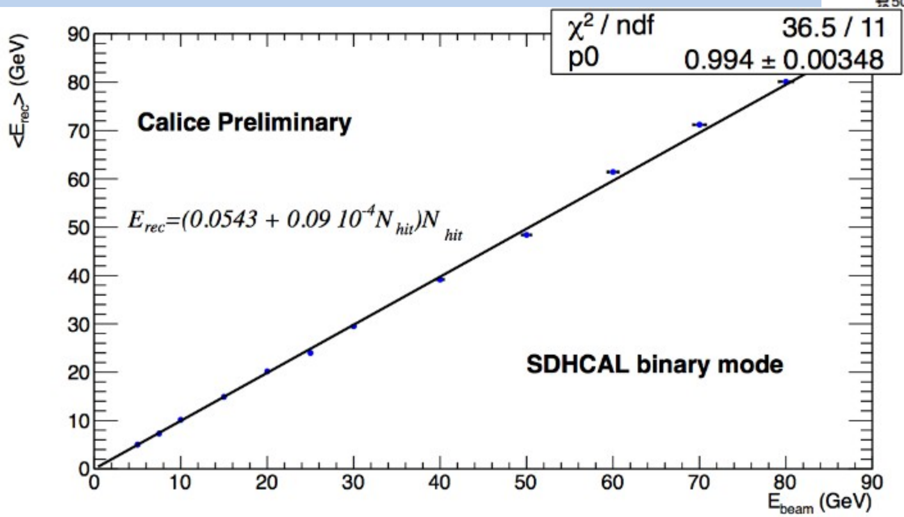
  C = 54.3 MeV

  D = 0.009 MeV

Linearised response (event by event)

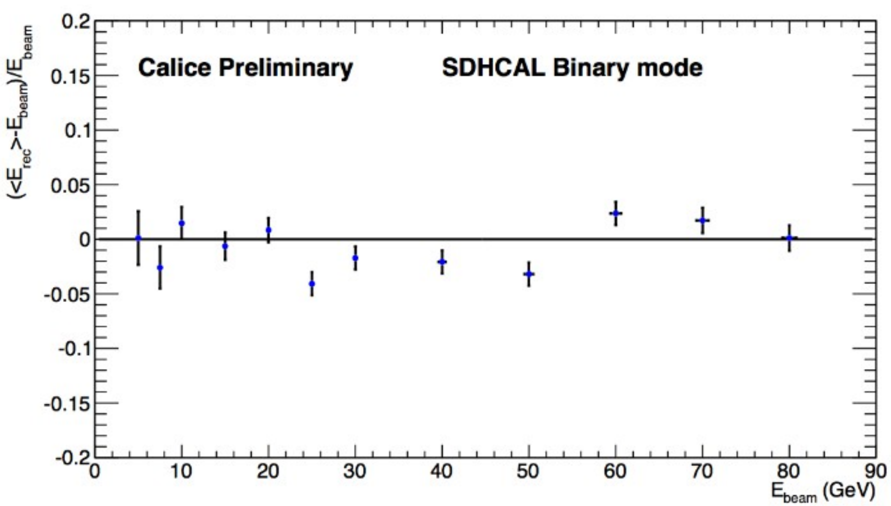
Crystal Ball fit

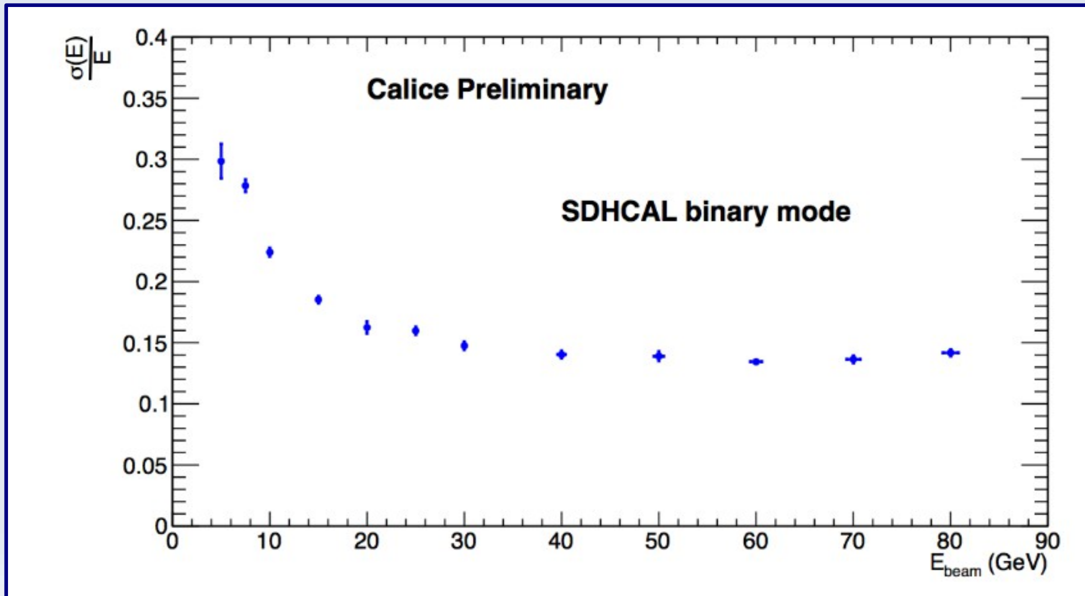




Width (Gauss, CB) → **σ**(E)/E

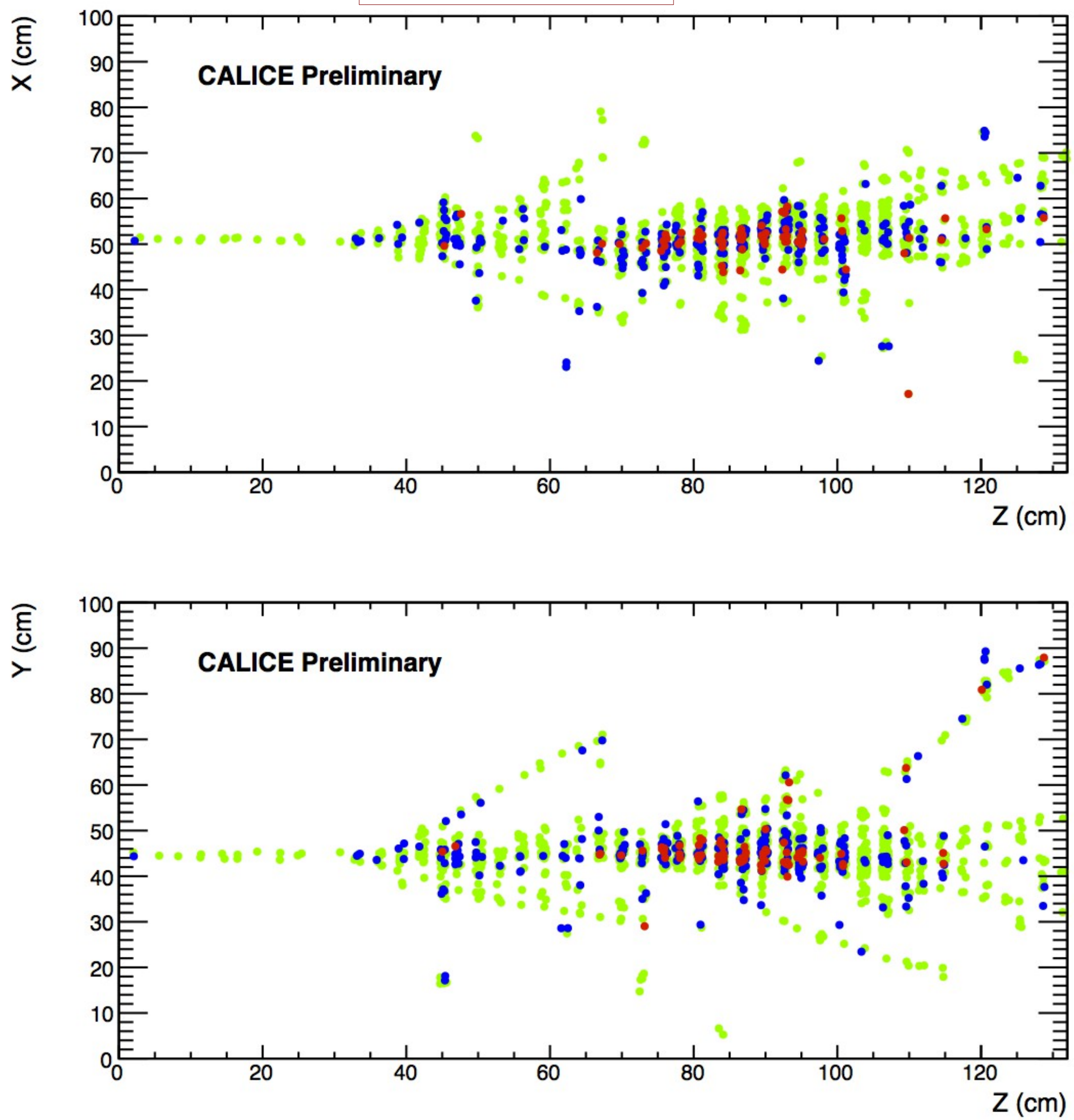
- Err = Stat ⊕ **δ**(Gauss, CB fit) ⊕ cut var ±10%





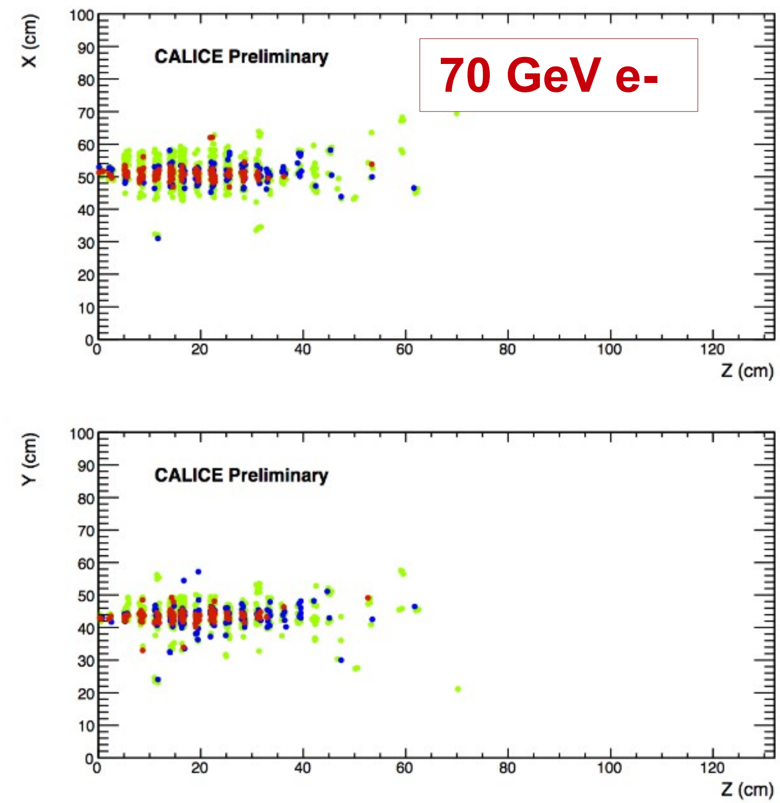
SDHCAL response (multi-thr.)

80 GeV Pion

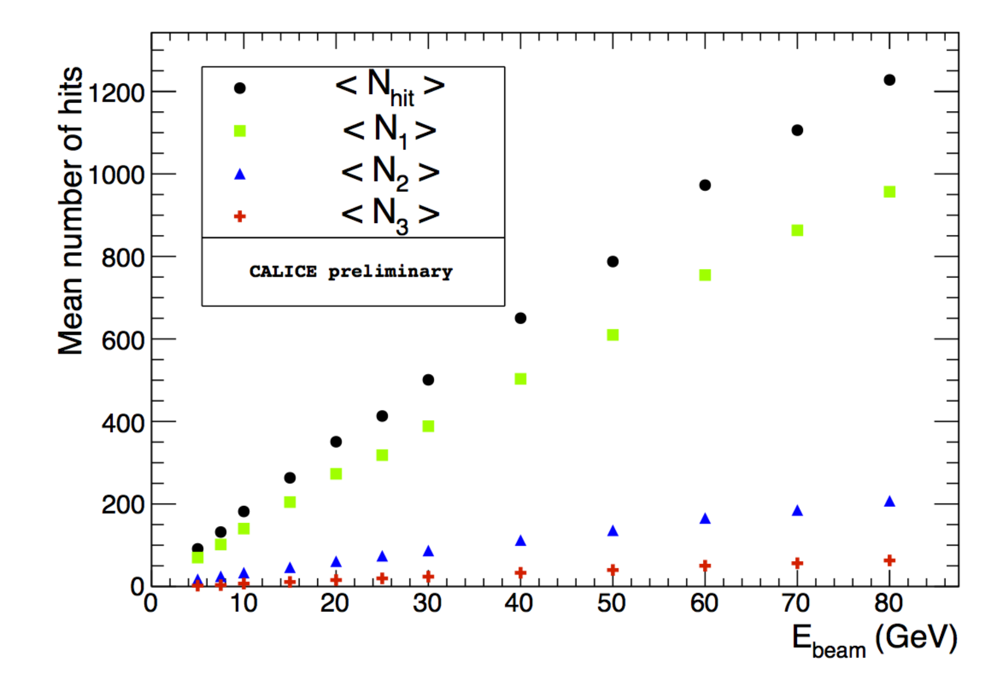


Thresholds set at
114 fC, 5 pC and 15 pC
(~ 0.1; 4; 12.5 mip)

- Additional information on shower structure



SDHCAL response (multi-thr.); Nhits



- N1 = # of Hits ≥ thr1, <thr2
- N2 = # hits ≥ thr 2, <thr3
- N3 = # hits ≥ thr3

Nhit = N1+N2+N3

$E_{rec} = \alpha$ N1 + β N2 + γ N3.

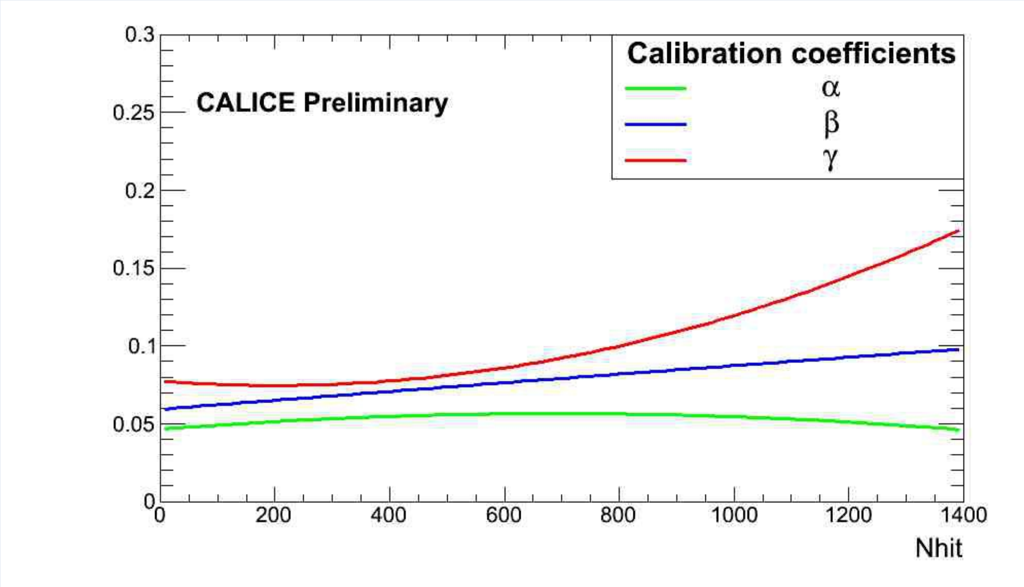
$\alpha,\beta,\gamma = f(\text{Nhit})$

- Min of χ^2 with

$$\chi^2 = \sum_i^N \frac{\left(E^i_{true} - E^i_{rec}\right)^2}{E^i_{true}}$$

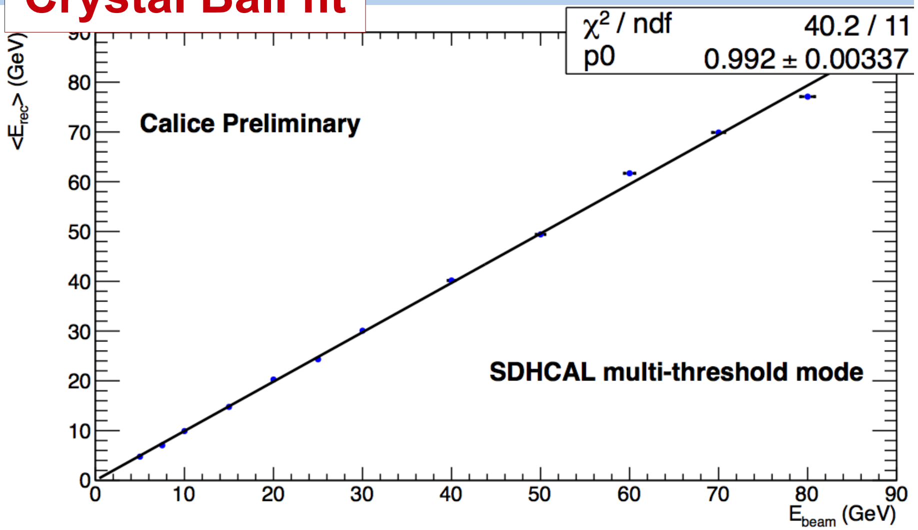
over 10, 20, 30, 40, 50 and 60 GeV samples (1/3 of stat.)

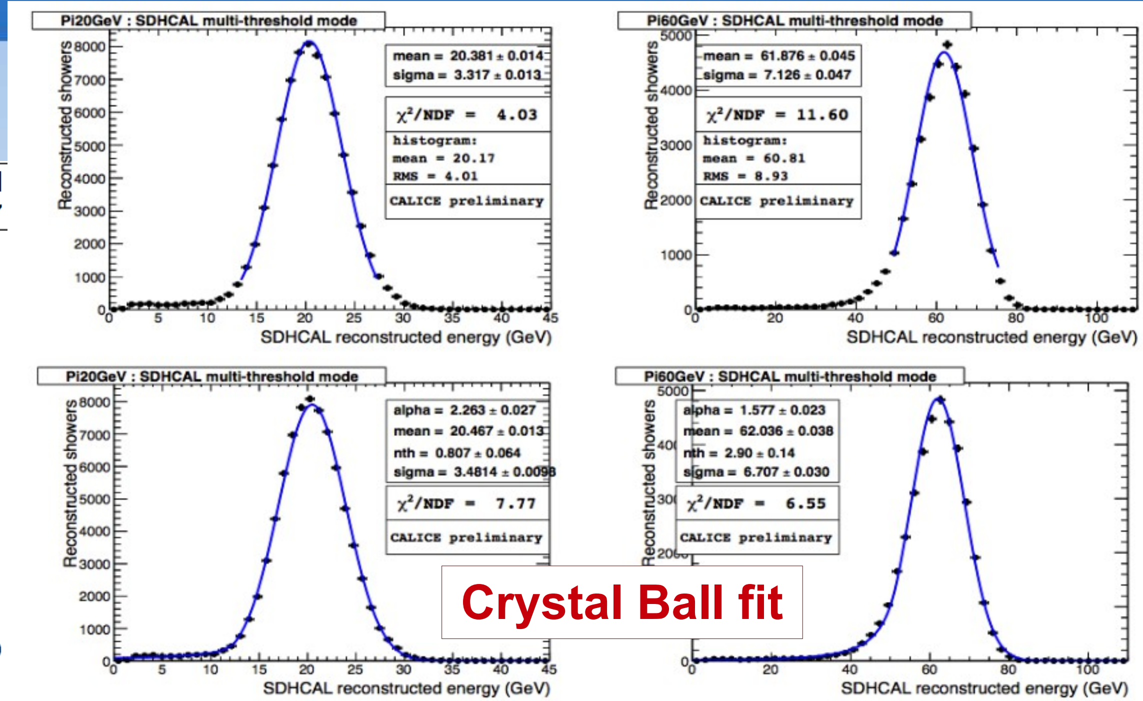
- Parametrised as quartic function of Nhit
- Valid for *single – known – particle...*



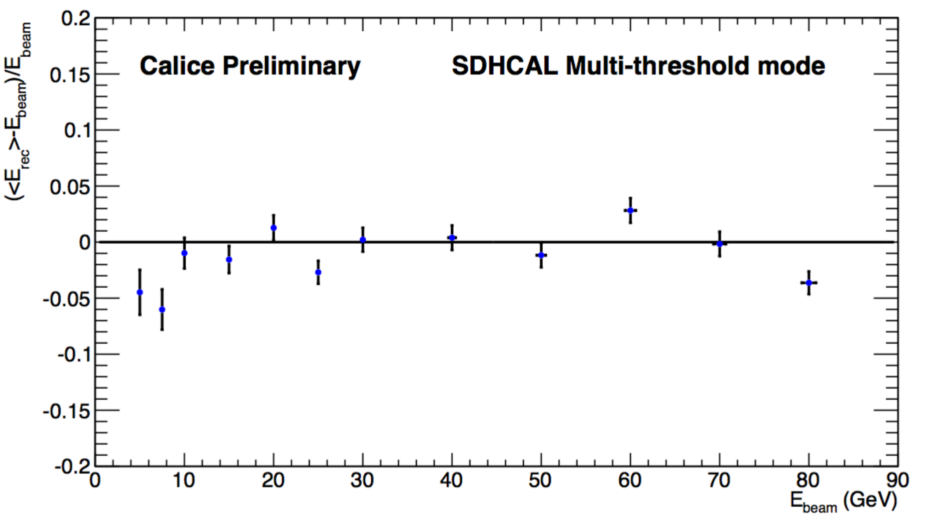
SDHCAL response

Crystal Ball fit



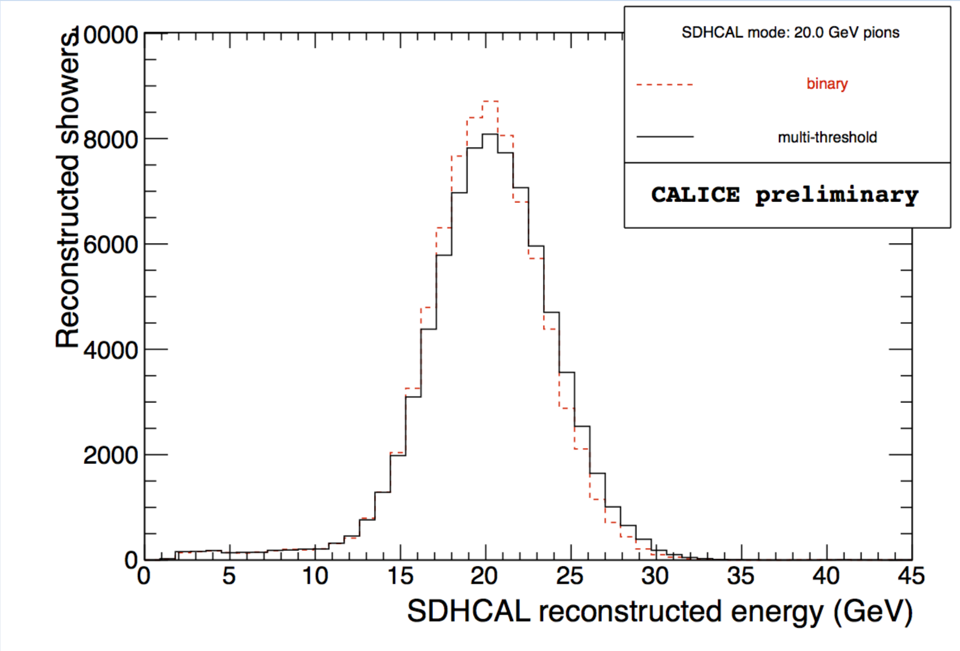


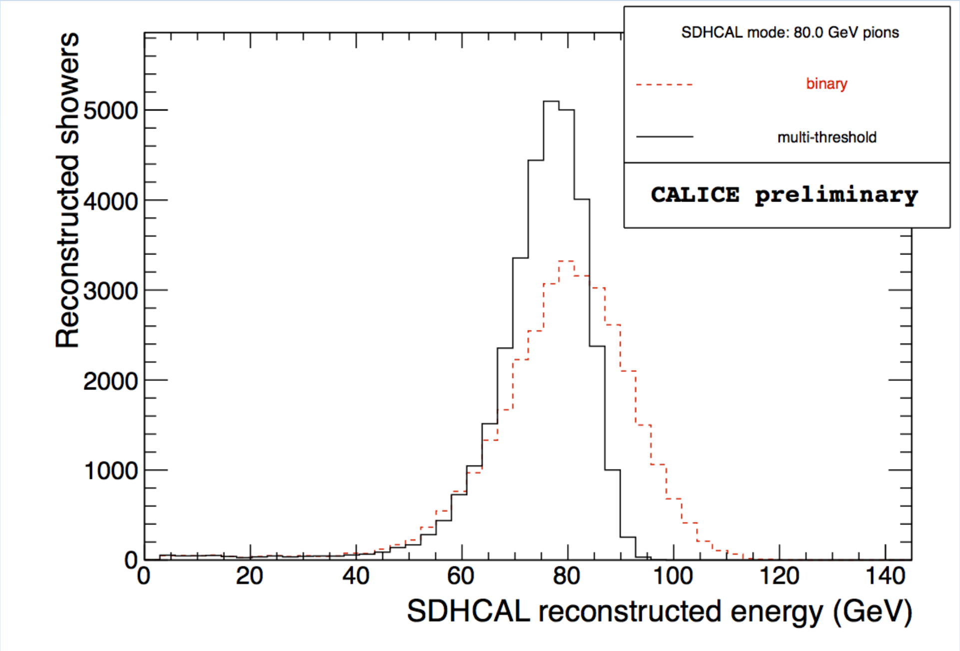
Crystal Ball fit



- Linearity ≤ 5% over full range
  - Tuning done for E_{beam}≥10 GeV
  - e- contamination @ low E.

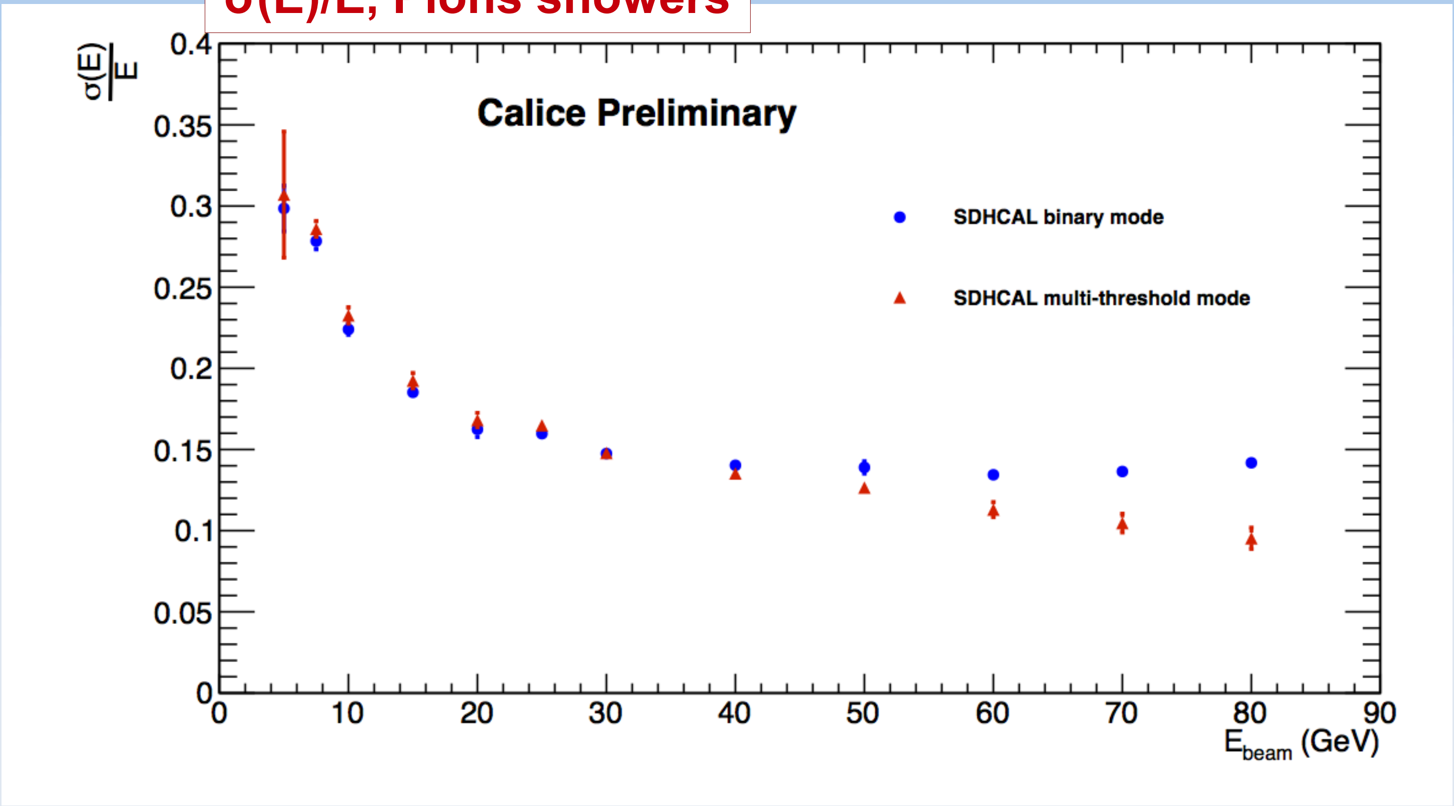
SDHCAL: binary vs multi-thr.





SDHCAL binary & multi-thr modes

σ(E)/E, Pions showers



- Raw resolution of **untuned** calorimeter
  - SDHCAL
  - DHCAL
- Single pions, filtered for leakage
- Err = Stat ⊕ δ(Gauss, CB fit) ⊕ cut var ±10%SHCAL

- Visible improvement of resolution for Eπ ≥50 GeV
  - ≤10% at 80 GeV.
- **Raw performances** (no pattern recognition, PFA, ...)

Simulation

Comparison with simulation: Digitisation

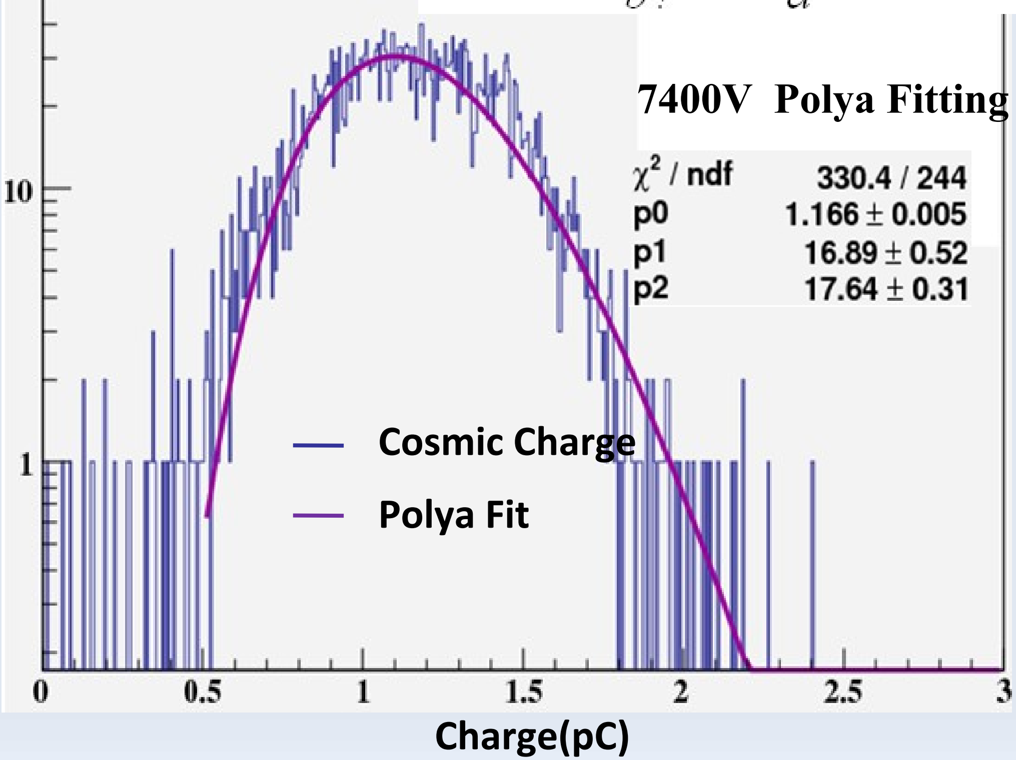
- Use standalone GEANT4 application to simulate the prototype.
- Digitisation included in the prototype
  - reproduce ε, μ

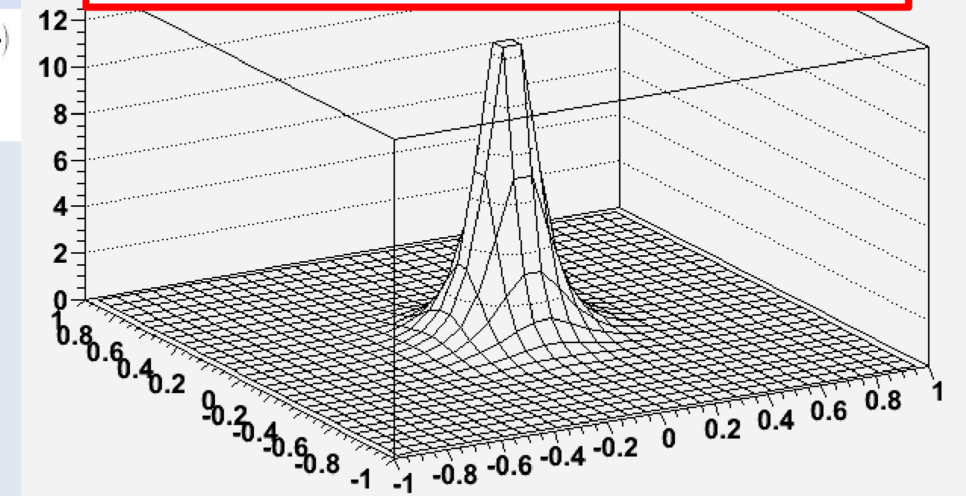
Induced charge location

$$\sigma(x,y) = c\frac{-q}{2a}\frac{1}{\cosh\left(\pi\frac{\sqrt{(x-x_0)^2+(y-y_0)^2}}{a}\right)}$$

Polya-distribution:

$$Q = c\frac{(b+1)^{(b+1)}}{b!}\left(\frac{x}{a}\right)^{b} e^{\left(-(b+1)\frac{x}{a}\right)}$$



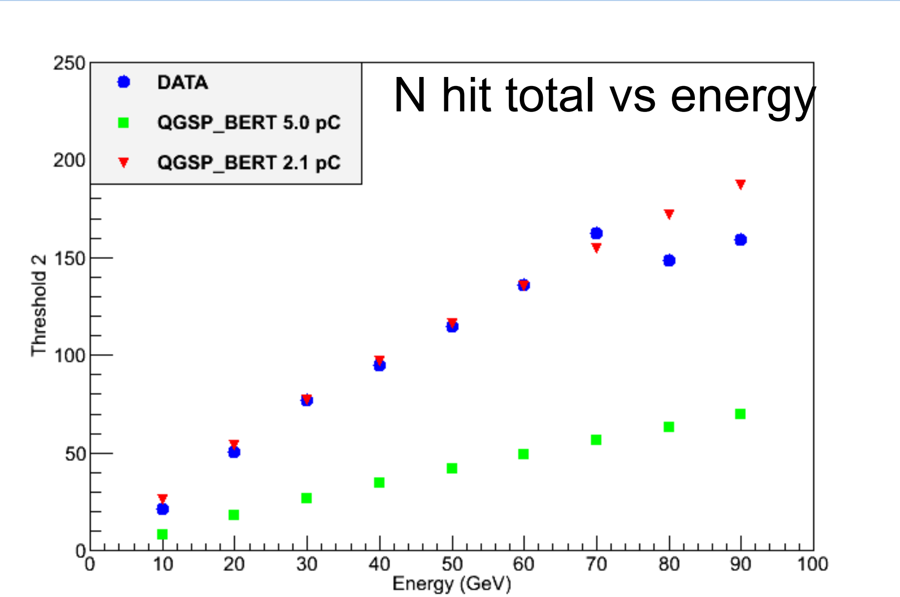


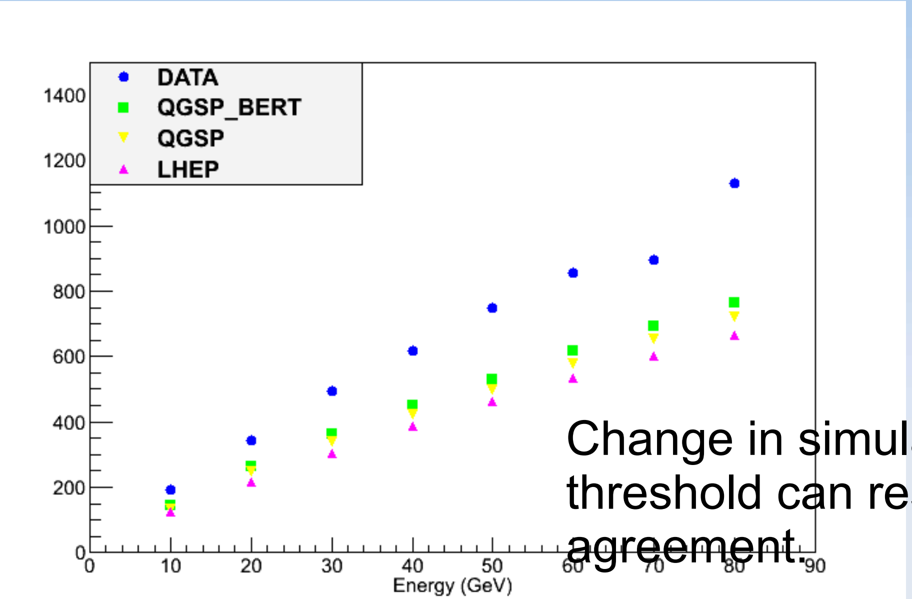
- Two approaches & Marlin modules:
  - Single GEANT hit smearing
  - mm^2 pseudo cells re-grouped

Comparison with simulation : Hit smearing

- Compare GEANT4 physics lists with data

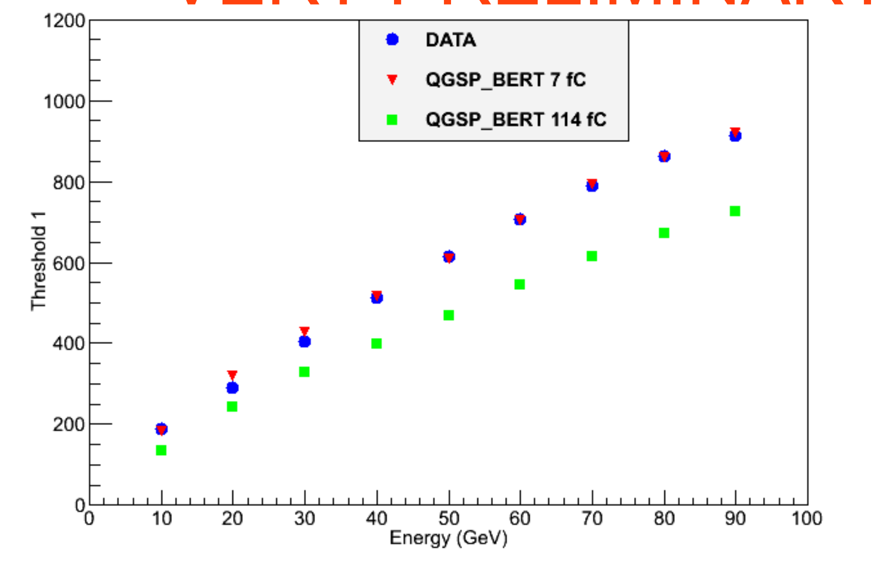
N hit total vs energy

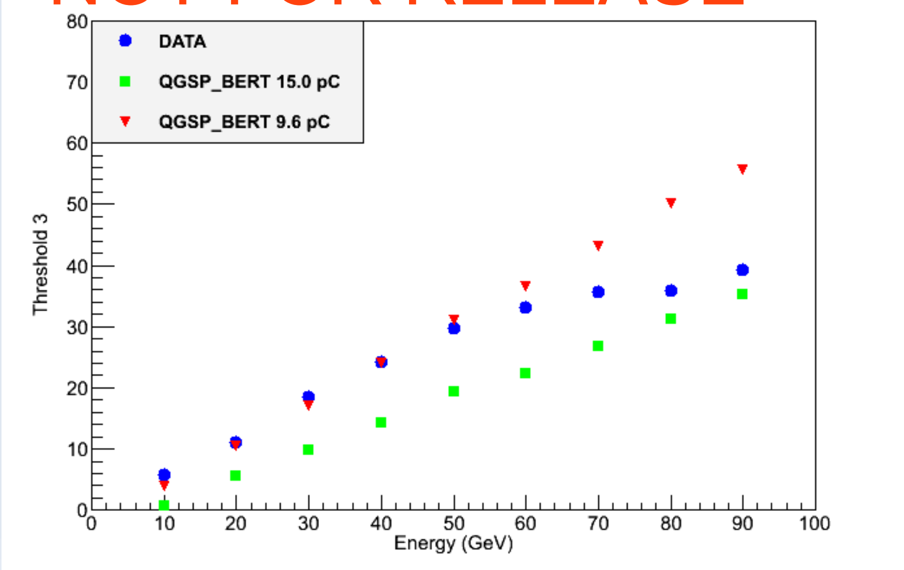




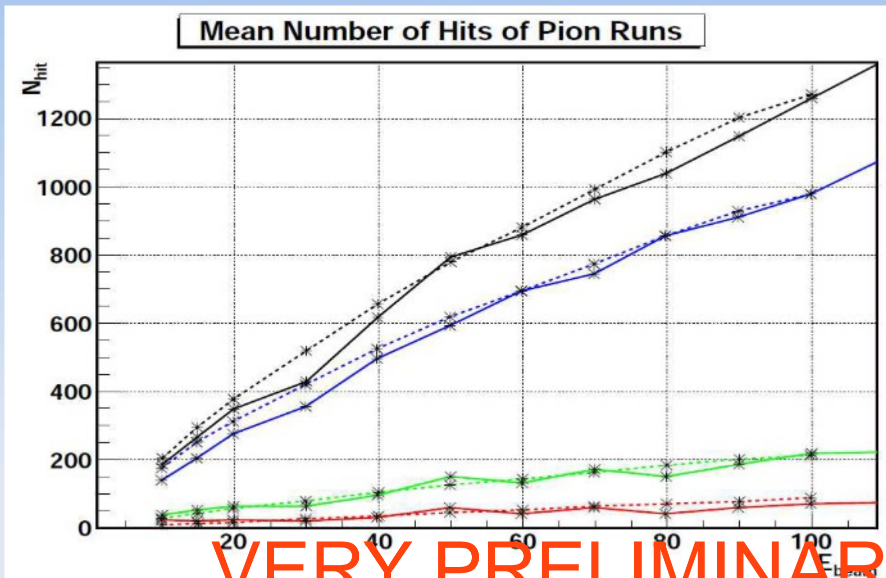
Change in simulated threshold can restore agreement.

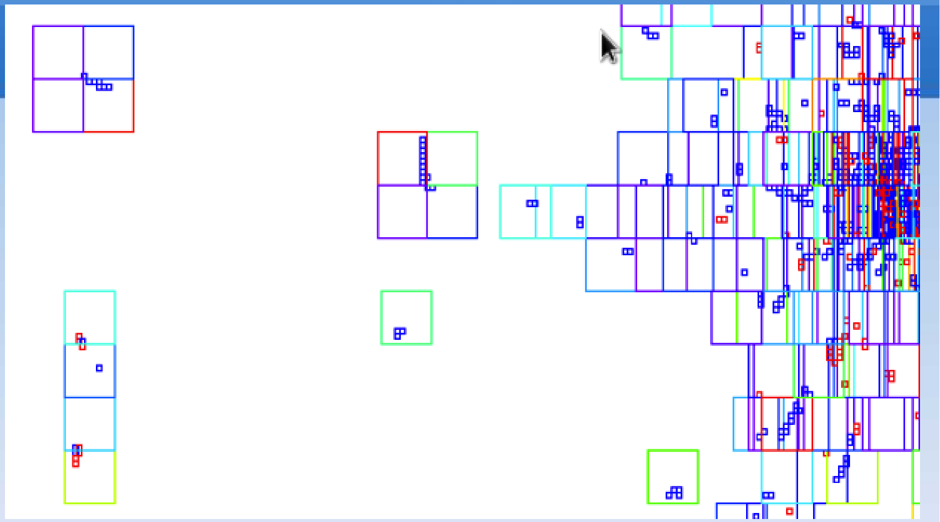
VERY PRELIMINARY!! NOT FOR RELEASE



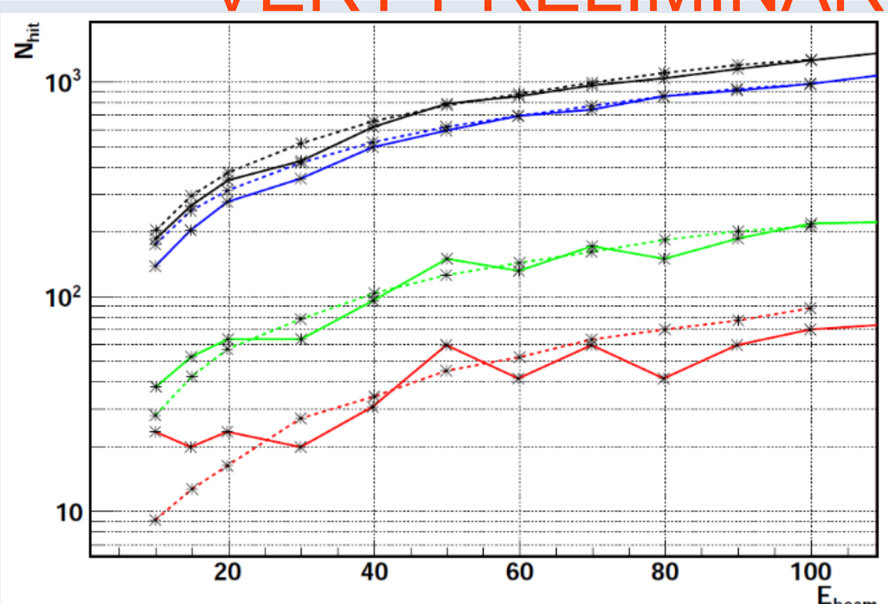


Comparison with simulation : mm² hit re-grouping

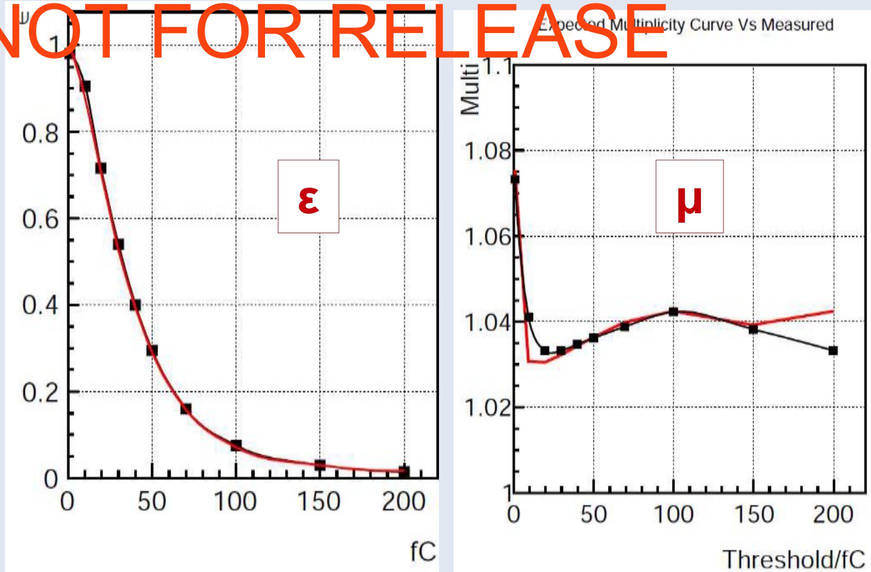




VERY PRELIMINARY!! NOT FOR RELEASE



GRPC-SDHCAL response



Single plane MicroMegas response

MicroMegas

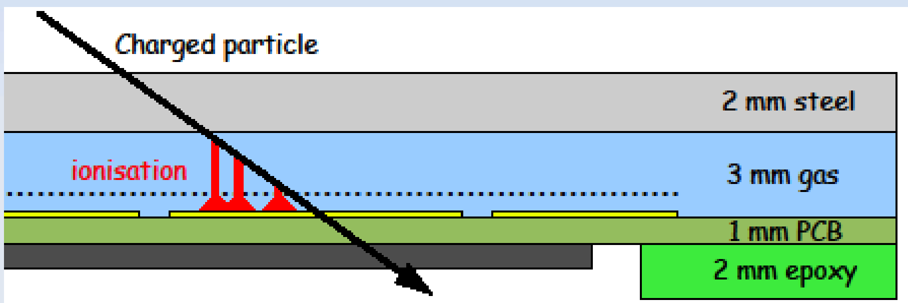
Micromegas for a 2-bit semi-digital HCAL

Alternative to RPCs operating in the proportional amplification mode

→ No saturation of the avalanche process makes the energy measurement with 3 thresholds more precise

+ High rate capability, basically no ageing and minimal hit multiplicity

+ Operating voltage below 500 V and simple gas mixtures (e.g. Ar/CO_2)



Active Sensor Unit (ASU) of 32x48 cm^2

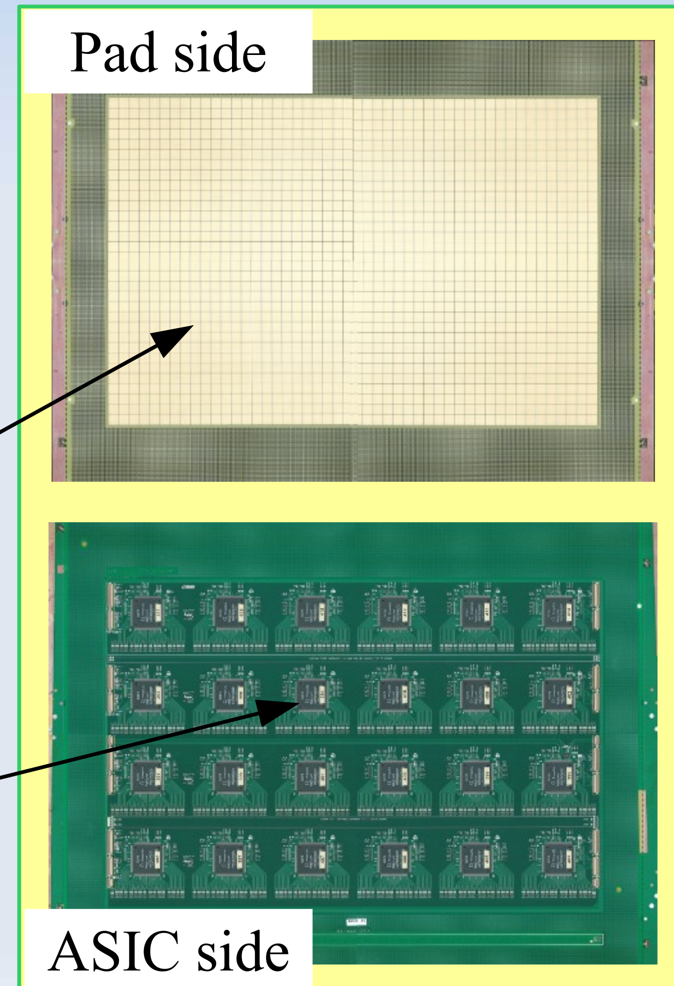
1cm^2 pads + mesh on 1 side

24 MICROROC ASIC + spark protections on other side

MICROROC ASIC (LAPP/LAL Omega)

ILC-like → power pulsing, self-triggering with internal memory

3 thresholds → down to 0.25 MIP, up to 100 MIPs



Design of the 1×1 m² chamber

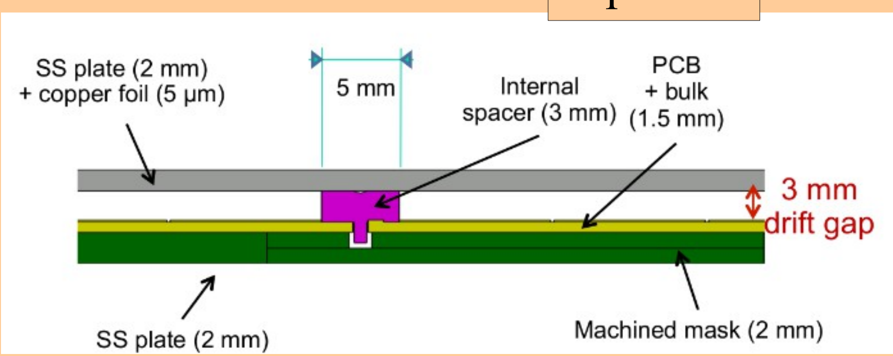
The 1x1 m^2 chamber consists of 3 slabs of 2 ASUs and some readout boards (DIF + interDIF)

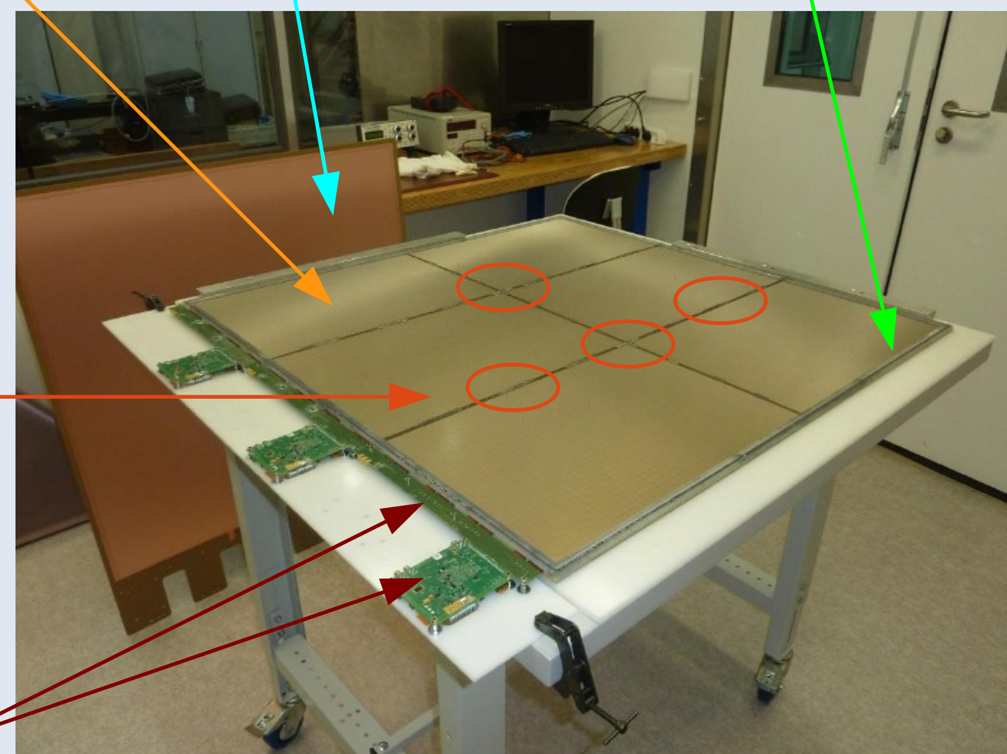
This design introduces very little dead zone (below 2%) and is fully scalable to larger sizes

The drift gap is defined by small spacers and a frame

The final chamber thickness is 9 mm

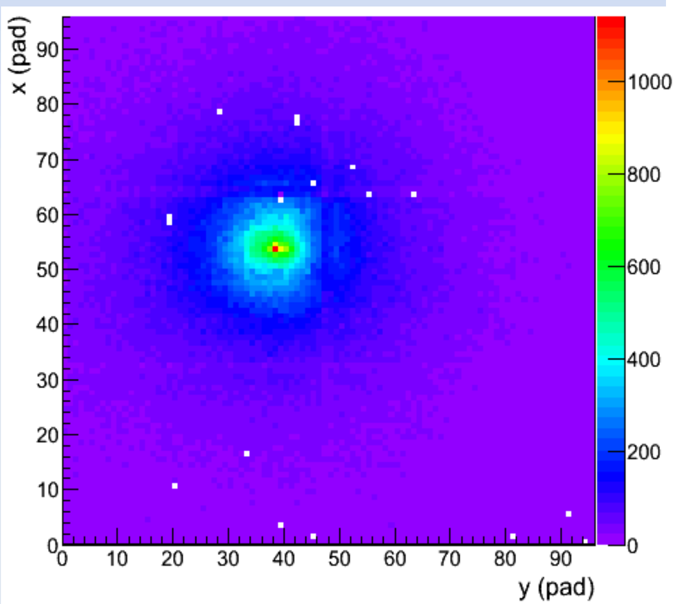
Spacers



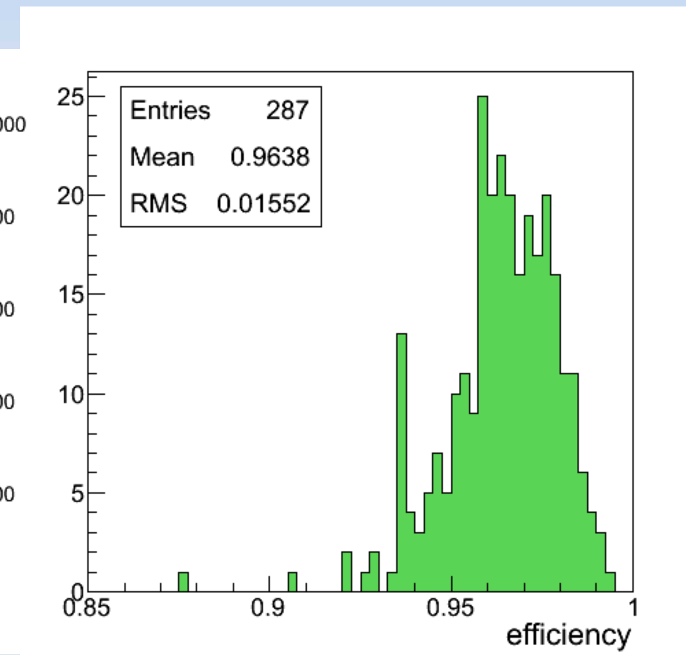


Main performance results

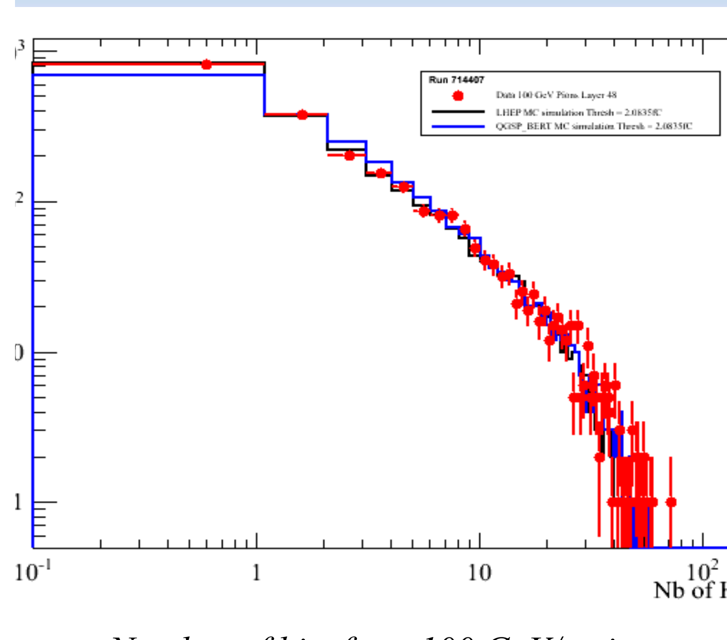
1. The XY plot shows a uniform response, no noise and 99.98% working channels
2. The average efficiency measured on 2 chambers inside the SDHCAL is (96 ± 2 RMS) %
3. The number of hit distribution at layer 49/50 of the SDHCAL is well re-produced by simulation



150 GeV/c pions after 1 λ_{int} of Fe
XY occupancy for 50 k events



Efficiency to 100 GeV/c muons over 287 regions of 8x8 cm²



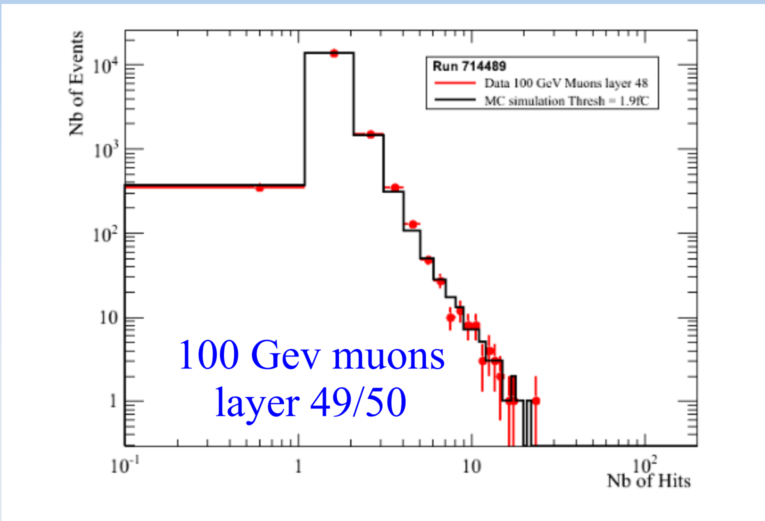
Number of hits from 100 GeV/c pions at layer 49/50 of the CALICE SDHCAL

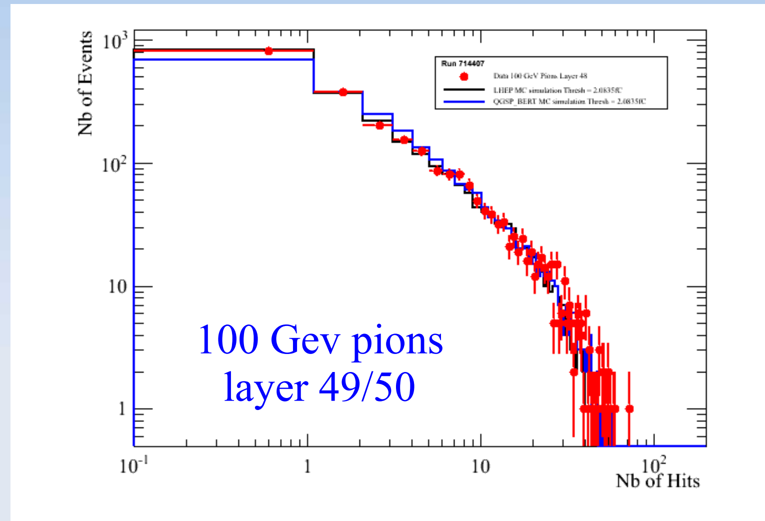
4 chambers are now ready for test beam, in November, inside the CALICE SDHCAL.

In 2013, we will concentrate on the development of spark protections using resistive layers.

Performance inside CALICE/SDHCAL

The distributions measured in the Micromegas chambers are well reproduced by MC simulation

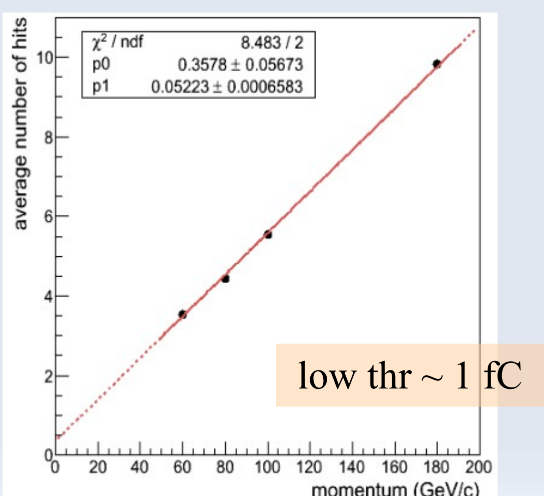


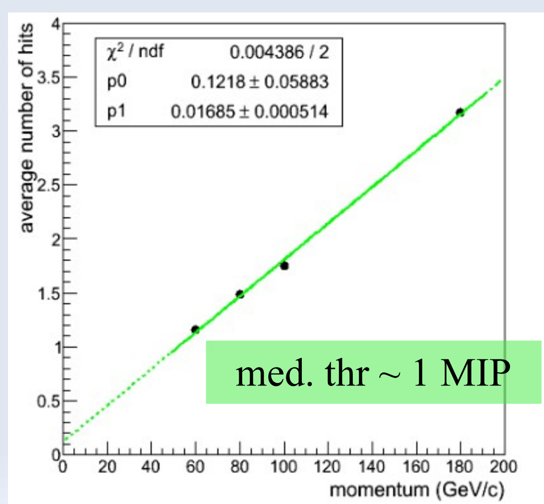


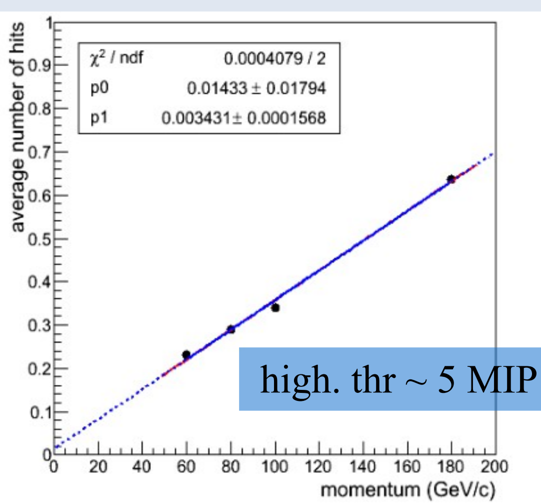
Average Nhit versus pion energy

No saturation at the back of SDHCAL → <u>linear response of 3 thresholds</u>

pions
layer 47/50







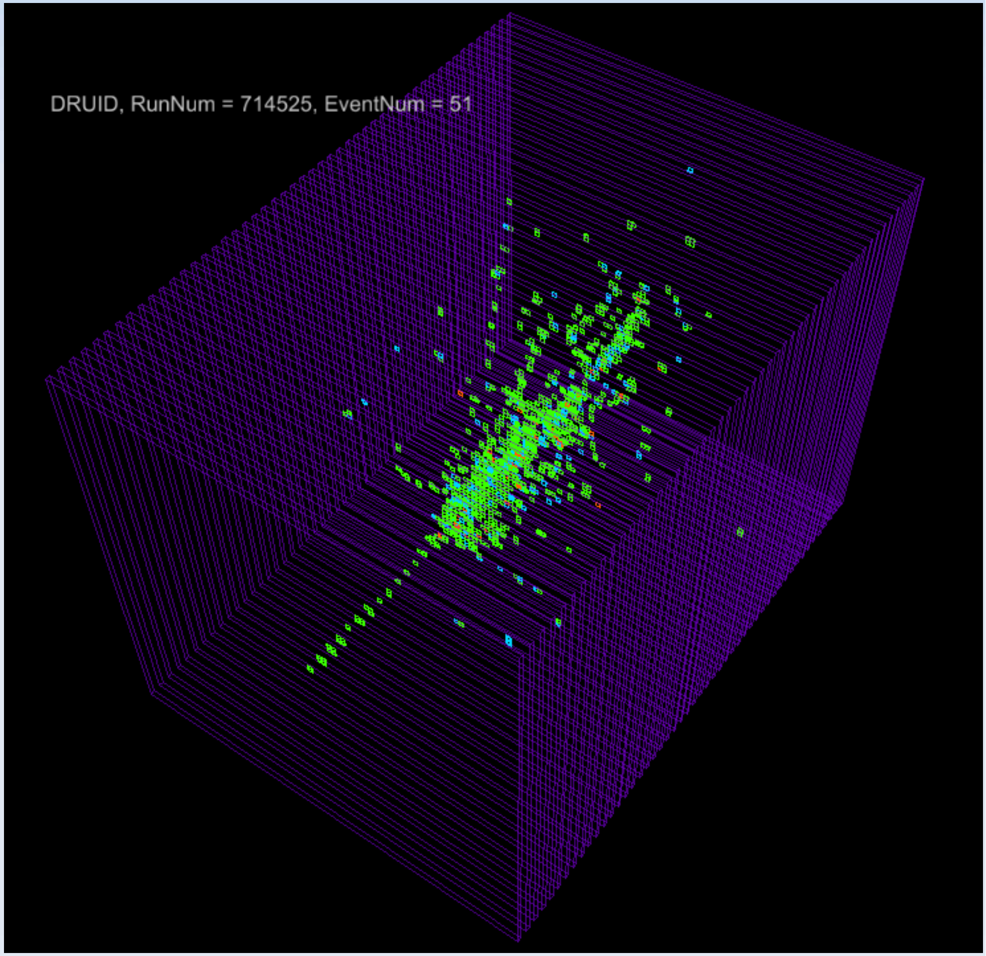
Conclusions & Perspective

- A semi-digital, high granular hadronic calorimeter seems an excellent tool to achieve PFA in the future linear collider experiments.
- The CALICE technological SDHCAL-GRPC prototype was successfully tested with its 48 layers and its 6 λ_I in different places (SPS, PS)
  - Power-Pulsing allows optimal conditions (temperature, noise) and it was the running mode during this year different TB.
  - Excellent data quality was obtained in TB (especially in August with gas installation under our own control) with smooth running conditions (no intervention for the 2-week TB period).
- Preliminary results without data treatment (no gain correction, no local calibration, ...) indicate an excellent single particle energy resolution on pions
  - Multi-threshold mode brings significant improvement at $E\pi \geq 50$ GeV.
  - Many many studies still to be done
    - Electron response; thr. scan; PFA disambiguation; pattern recognition; ...
- Comparison with simulation is ongoing and will bring rich information to better understand the hadronic showers.

Prospects

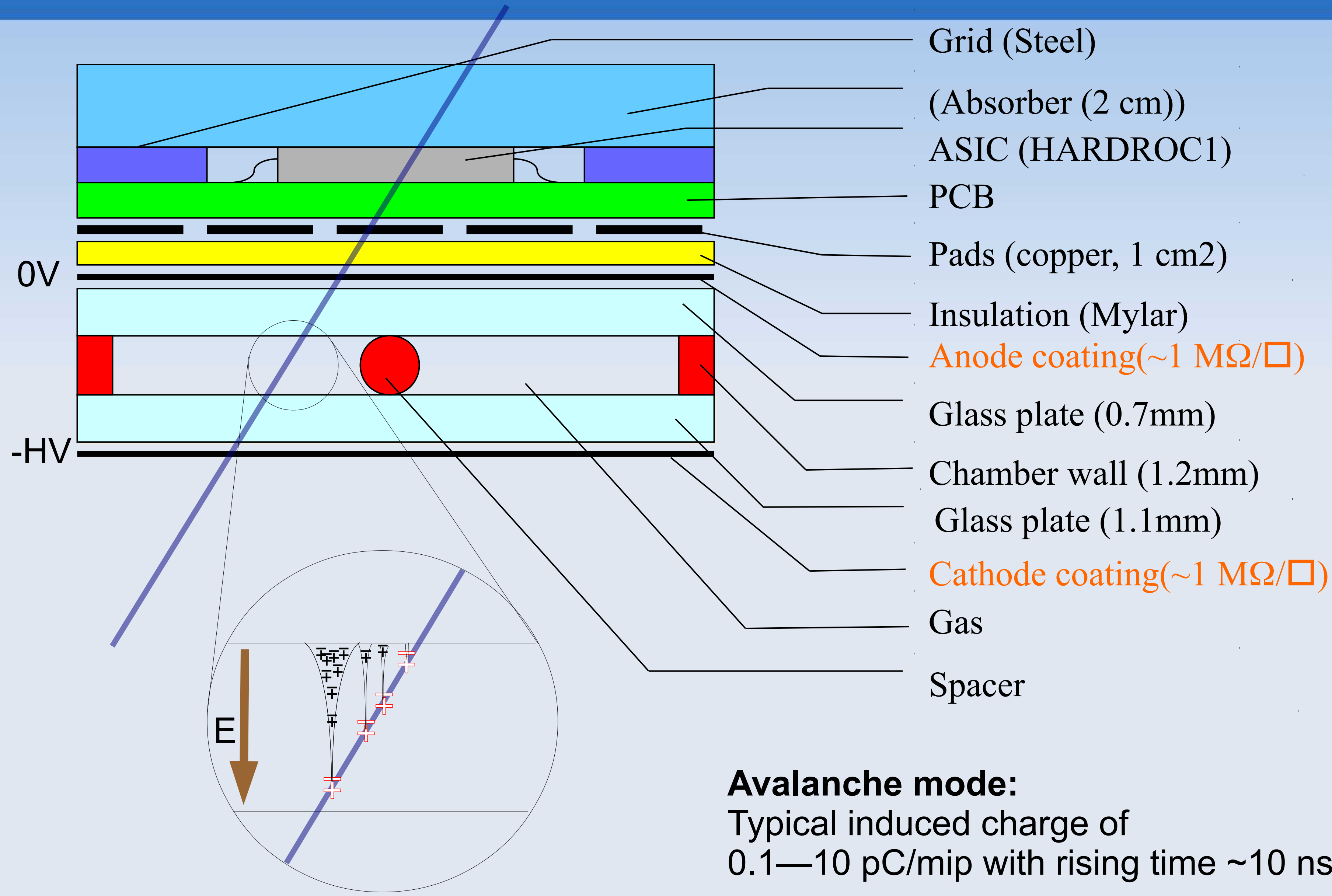
- Prospects50 GRPC will used for the November TB at CERN. Gain correction will be applied. A tail catcher using 4 chambers of MicroMegas will be used
  - A week with 4 MicroMegas & 46 GRPC will follow

- Work on very large GRPC 2-3 m^2 has started and will be completed next year.
  - new ASIC generation (HR3),
  - new PCB
  - improved readout system.



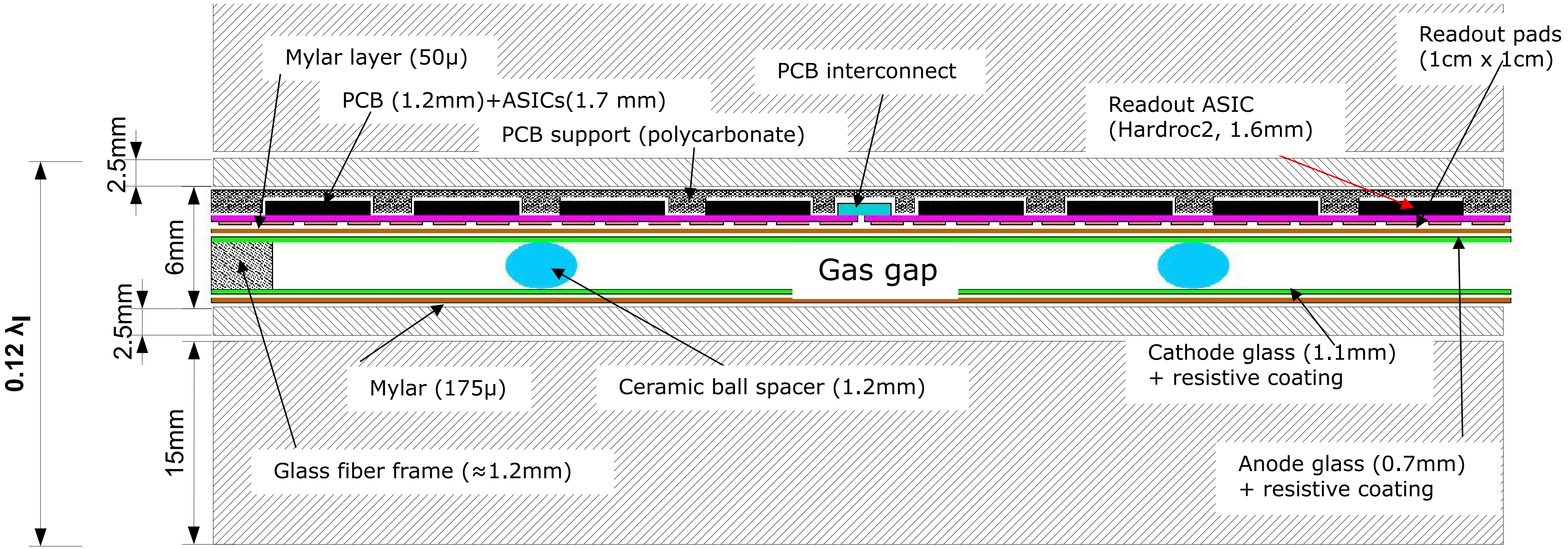
Back up

Glass Resistive Plate Chamber



Avalanche mode:
Typical induced charge of
0.1—10 pC/mip with rising time ~10 ns

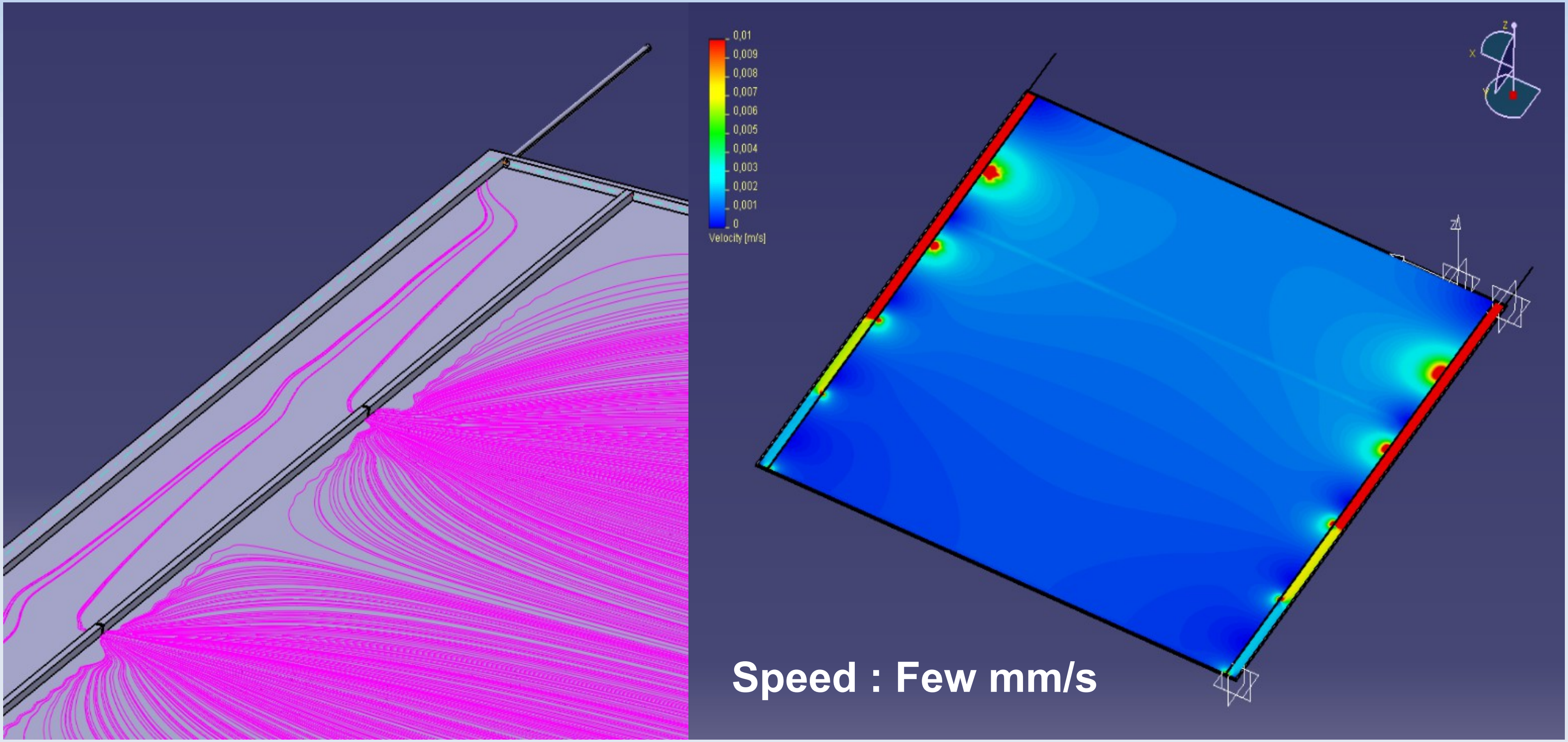
Structure of an active layer of the SDHCAL



50 layers of $0.12\ \lambda_I = 6\ \lambda_I$

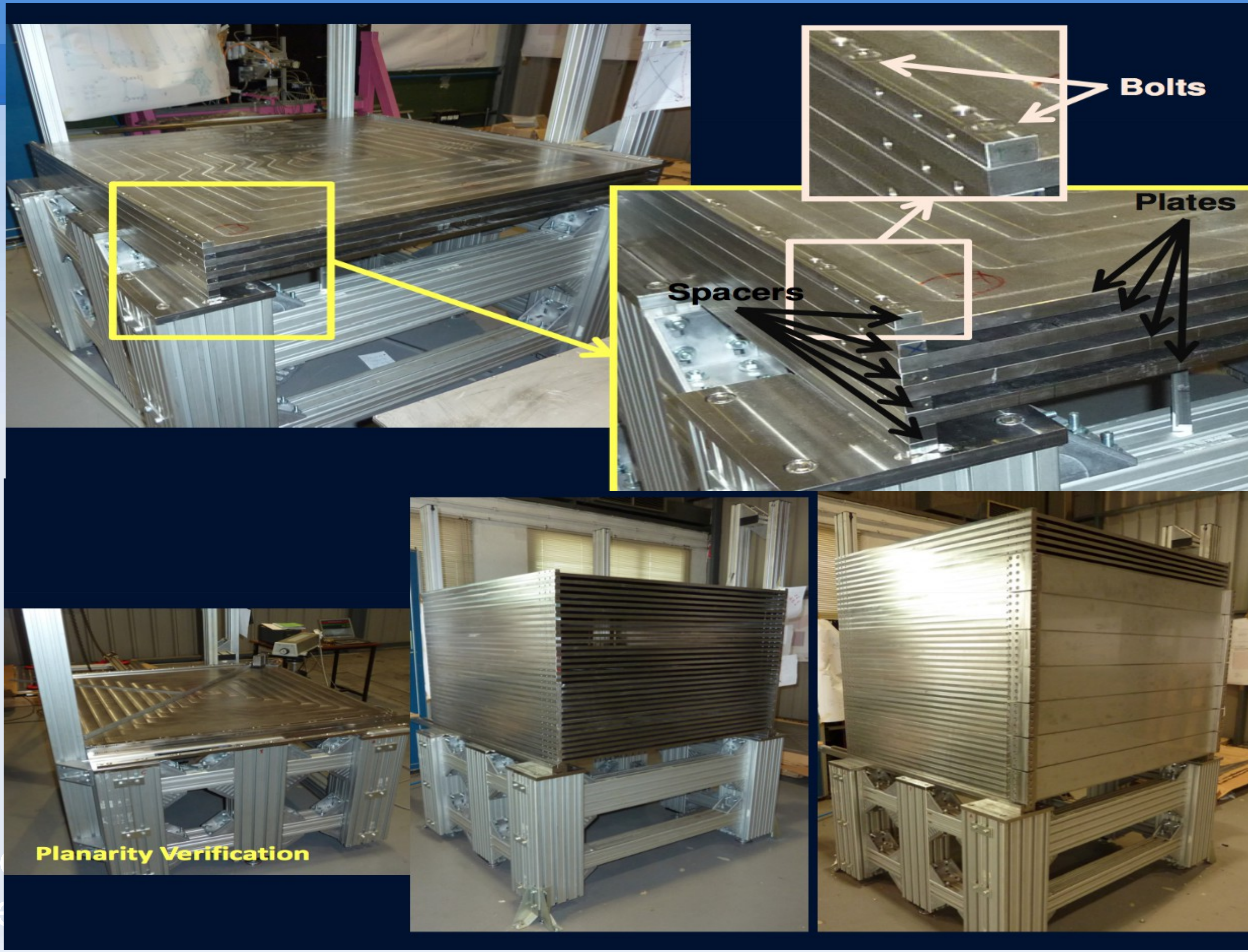
Gas distribution system

The services being on one side of the detector, a new gas distribution design is used. It allows to distribute the gas uniformly in the large chamber.

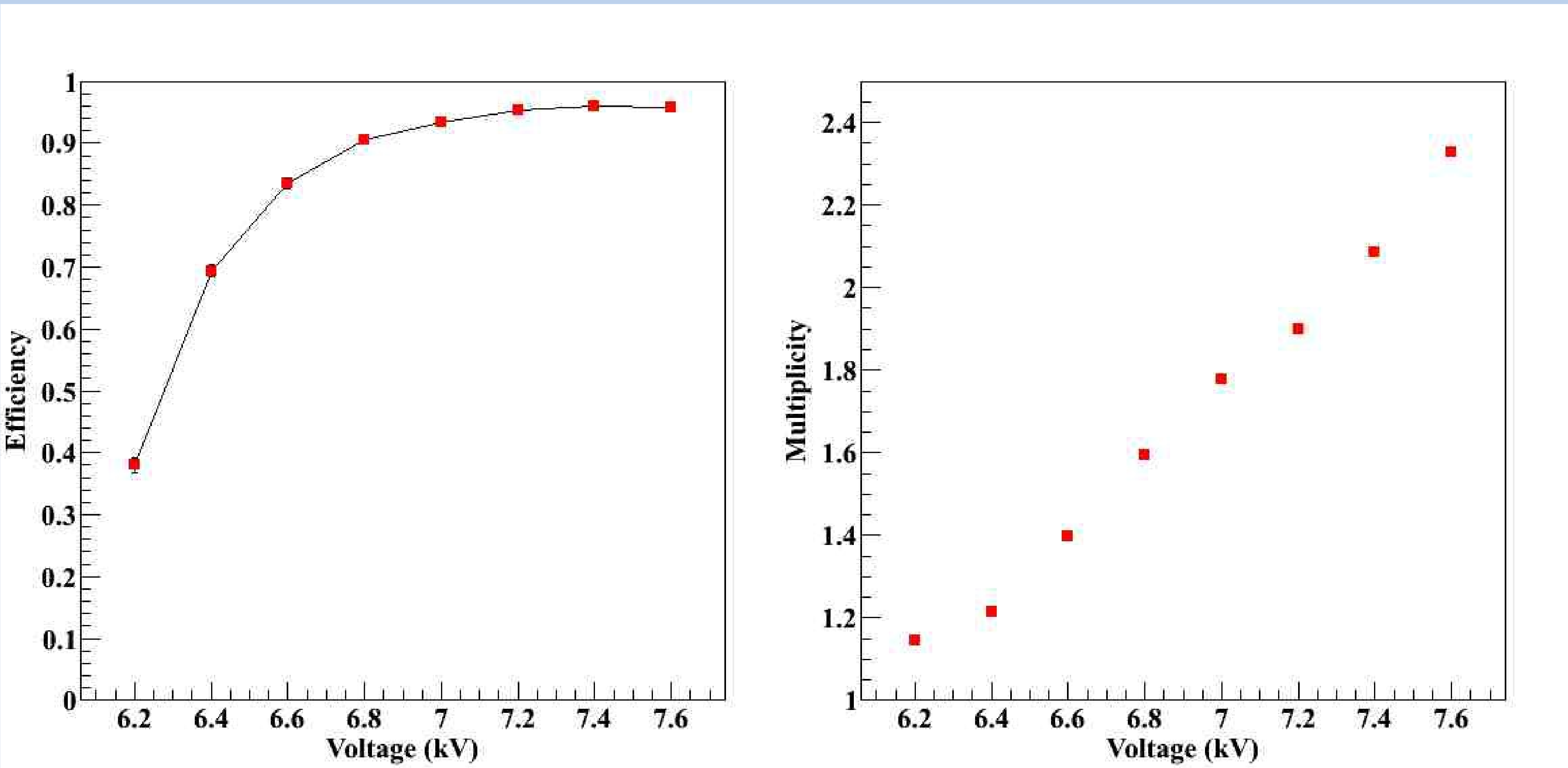


When diffusion is included→ Homogeneity is expected to be even better

A test using Kr83m radioactive gas is scheduled to monitor online the gas distribution

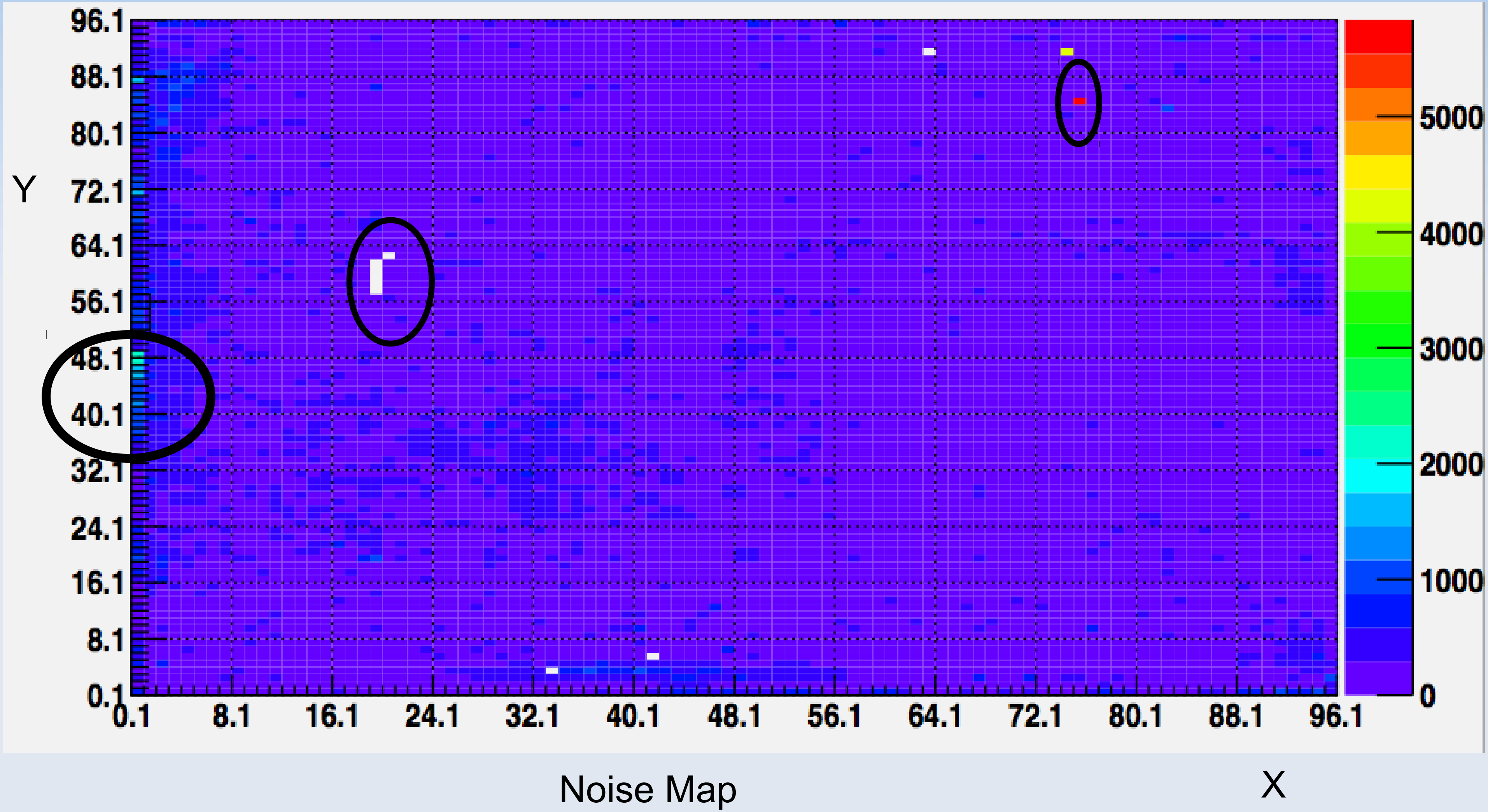

Bolts
Plates
Spacers
Planarity Verification

To check that the detectors and electronics are not at the origin of this...
A short beam test was organized at PS in November 2011 with 6 detectors taken from the prototype



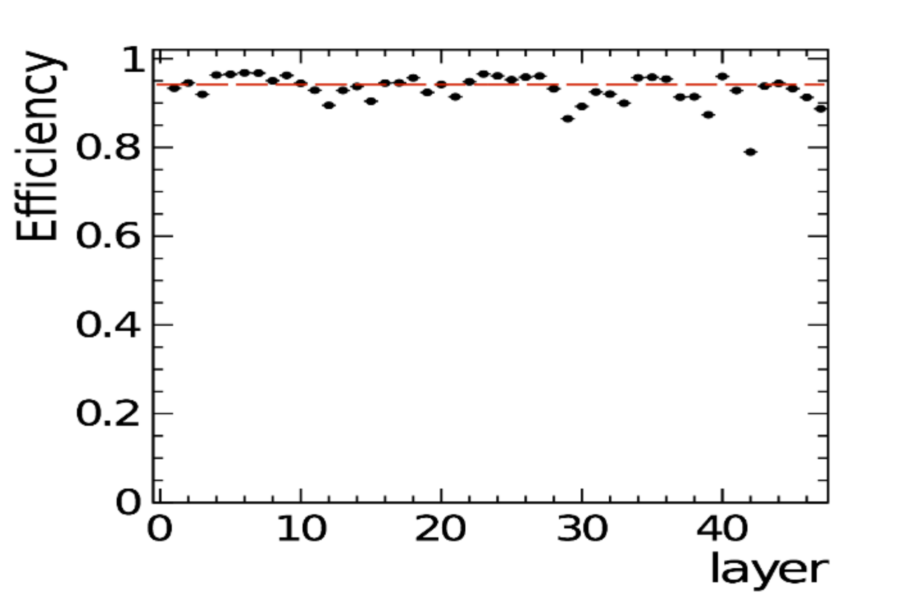
Validation

Noise was measured and found to be < 1 Hz/cm² outside the channeling tubes and HV connection zones



Noise Map

μ track selection (monitoring)

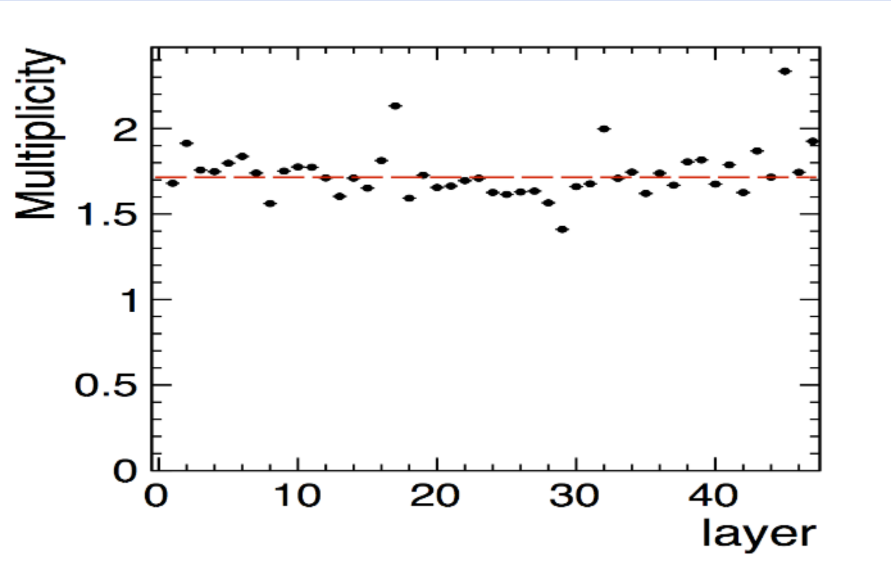


- ε, μ estimated from tracks reconstructed from other layers
  - hits are grouped in clusters if sharing an edge
  - isolated clusters ($\Delta r_{in\ layer}$ > 12 cm) dropped
  - Tracks reconstructed if remaining N_{layers} > 7,
    - with at least 1 layer on each side of investigated one (except 1st and last layer)
  - χ^2 with $\Delta x,y$ = Span(cm) in (x,y) / √12
- Efficiency

$$\frac{Nb\ tracks\ with \geq 1\ hit\ \delta r \leq 3\,cm\ from\ track\ impact\ in\ plane}{Nb\ of\ tracks}$$

- Multiplicity =

$$\langle Nb\ hit\ in\ cluster\ closest\ to\ tracks,\ if\ any \rangle$$



Crystal Ball function

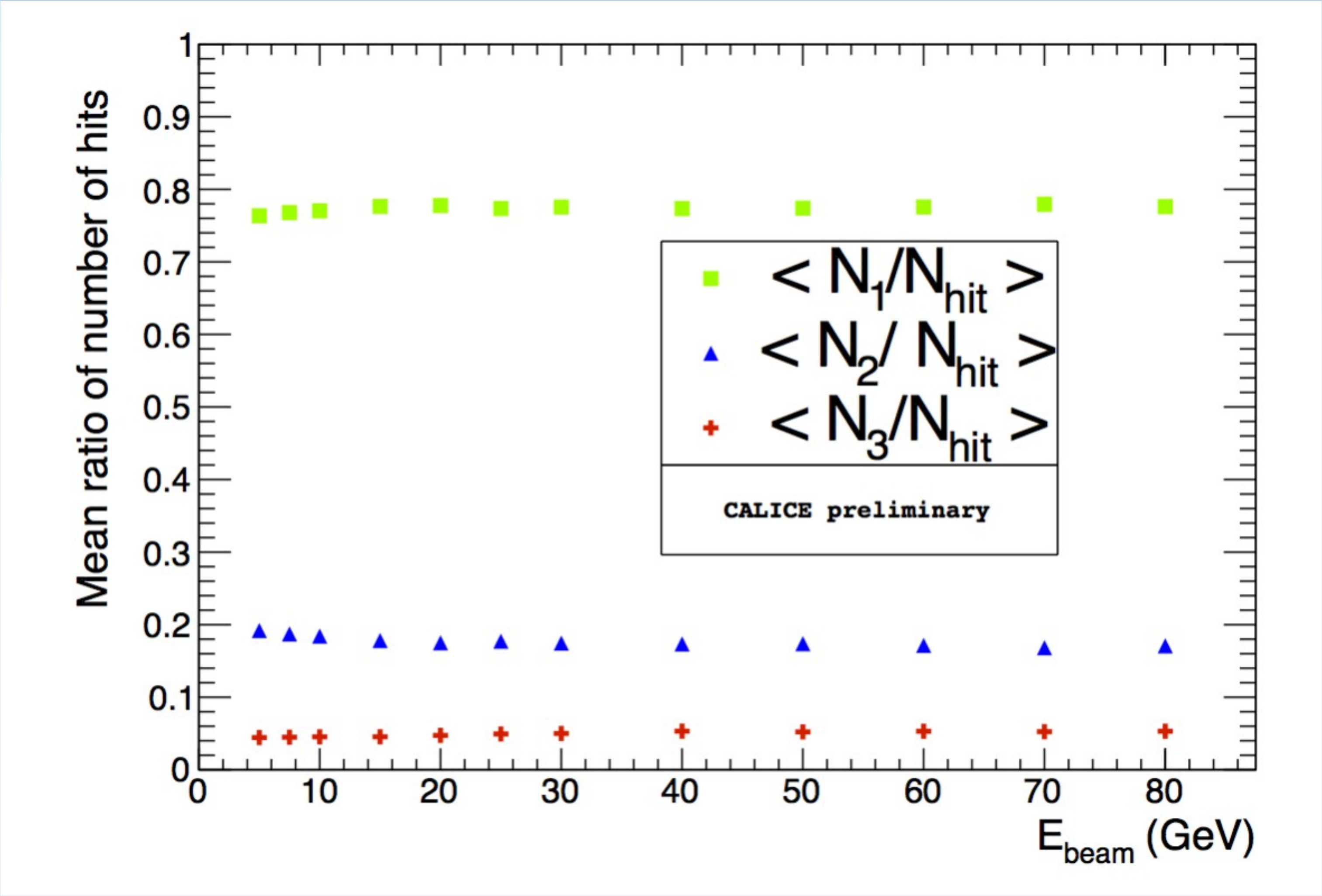
$$f(x;\alpha,nth,\bar{x},\sigma) = N\cdot\begin{cases}\exp(-\frac{(x-\bar{x})^2}{2\sigma^2}) & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A\cdot(B-\frac{x-\bar{x}}{\sigma})^{-nth} & \text{for } \frac{x-\bar{x}}{\sigma} \le -\alpha\end{cases}$$

where:

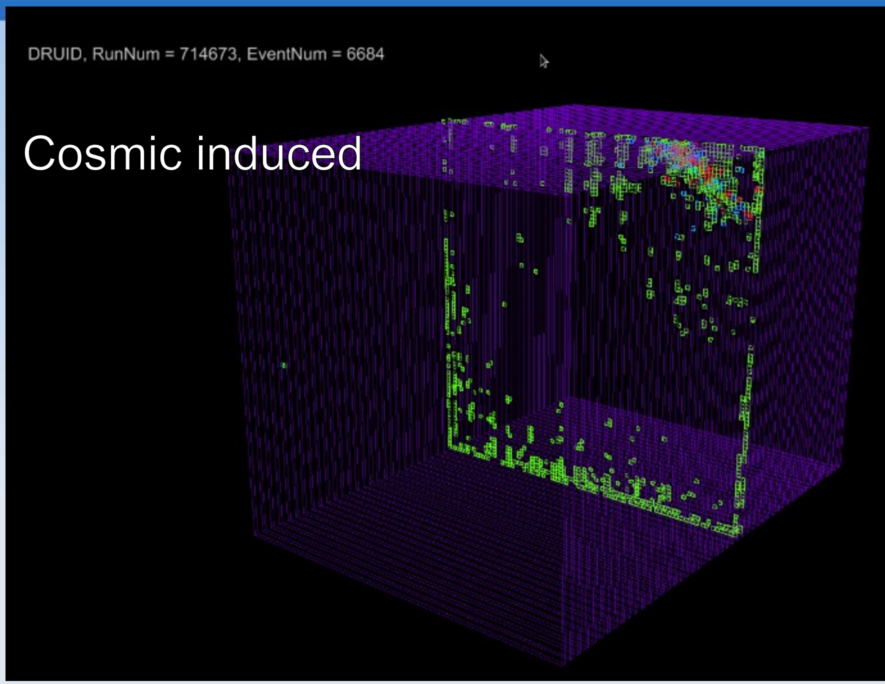
$$A = \left(\frac{nth}{|\alpha|}\right)^{nth}\cdot\exp\left(-\frac{|\alpha|^2}{2}\right)$$

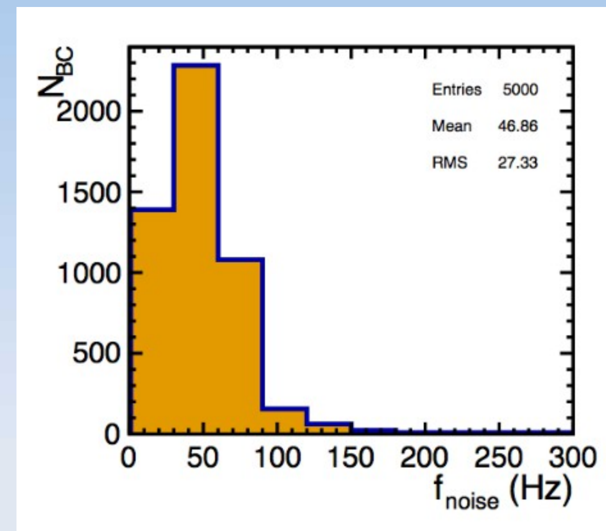
$$B = \frac{nth}{|\alpha|} - |\alpha|$$

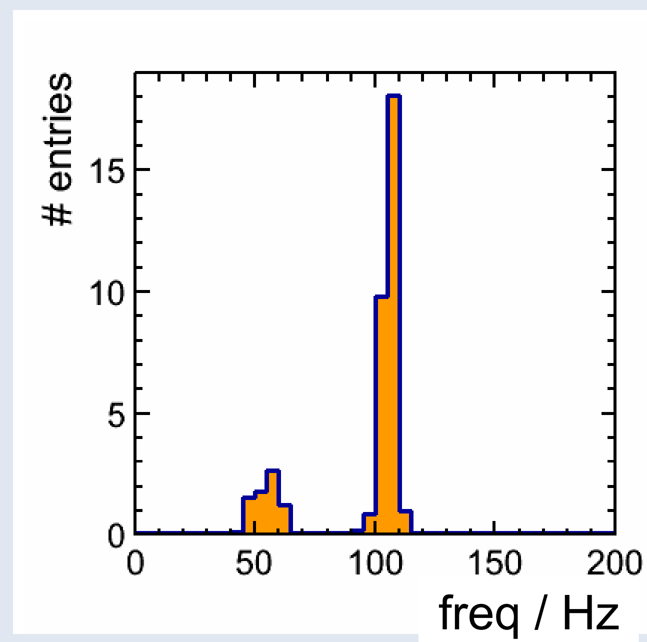
N is a normalization factor.


Mean ratio of number of hits
$< N_1/N_{hit} >$
$< N_2/ N_{hit} >$
$< N_3/N_{hit} >$
CALICE preliminary
E_{beam} (GeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10
20
30
40
50
60
70
80

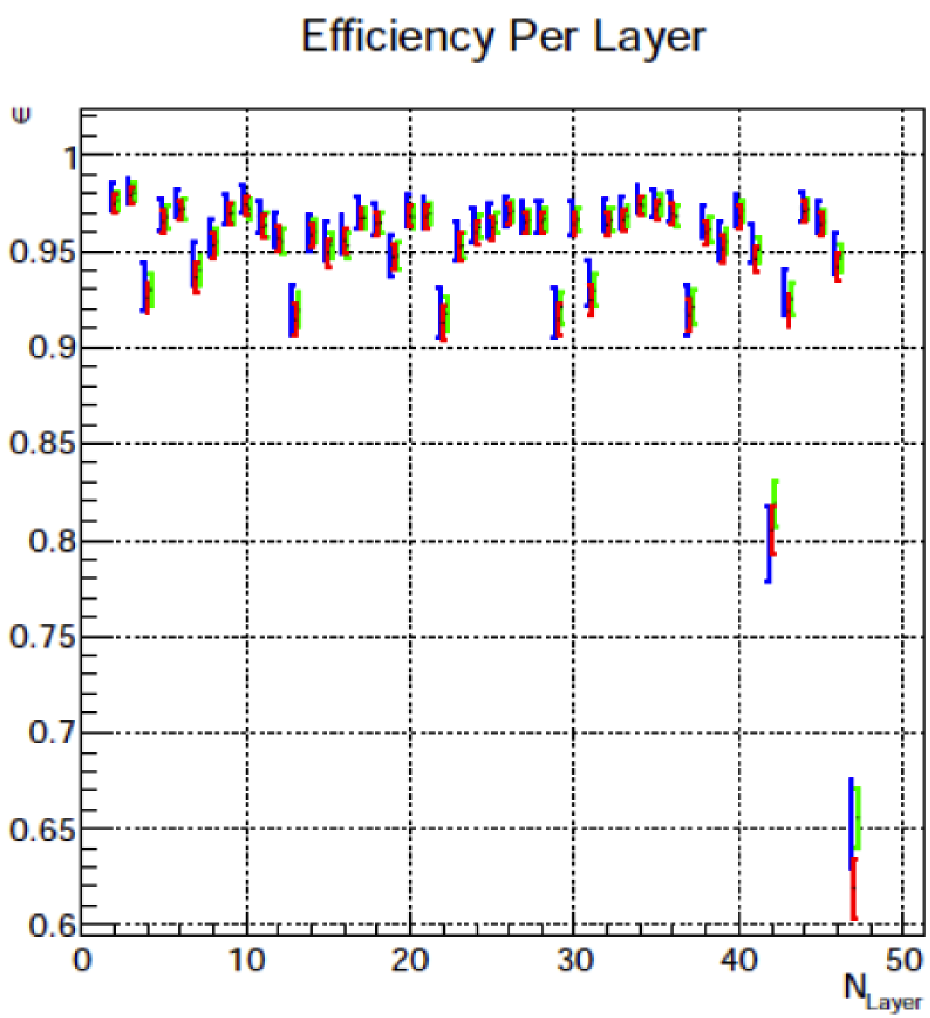
Coherent noise

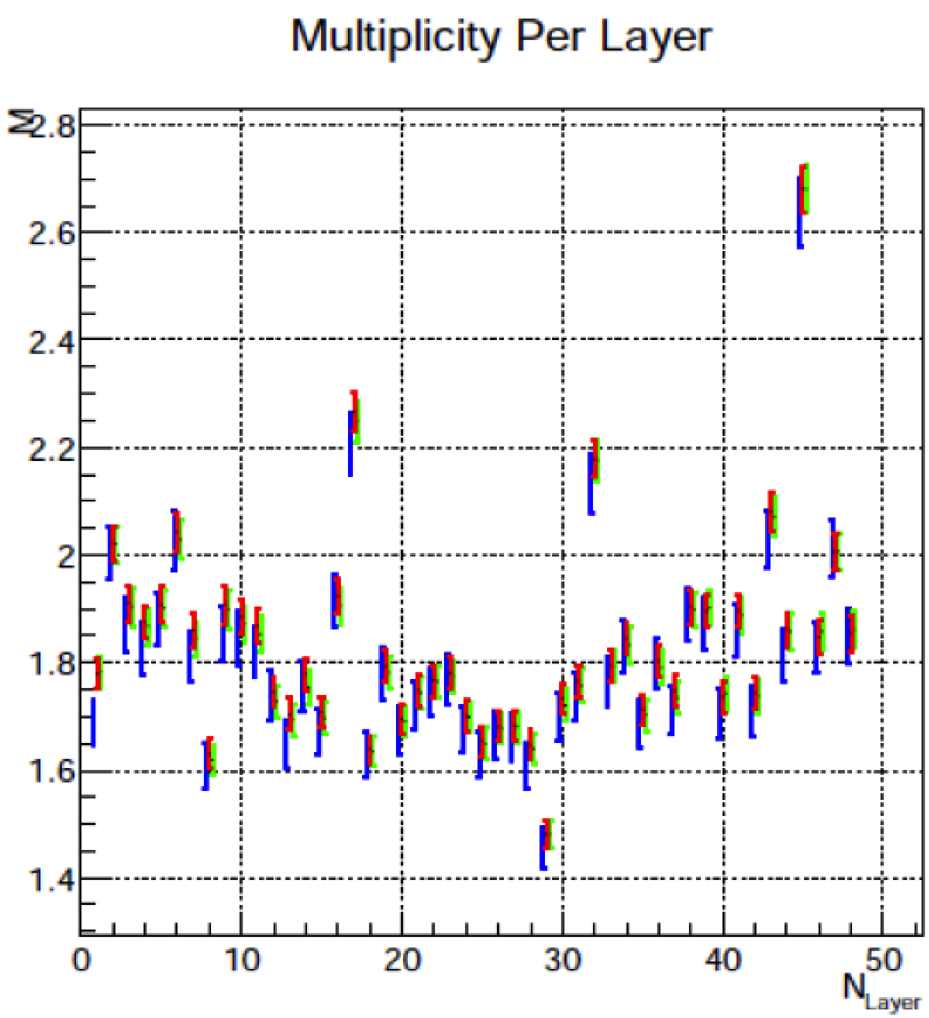






Efficiency & Multiplicity: Stability





Stable with sensible fluctuation (error bar scaled by 10 times)

15 GeV Pion (714439, 4441): 43797 long beam mip evts

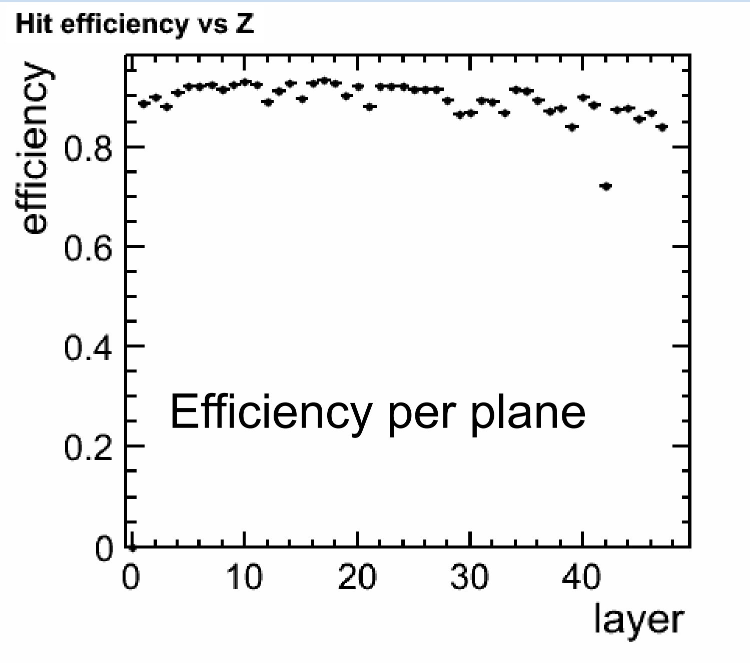
20 GeV Pion (714565, 4573): 103109 evts

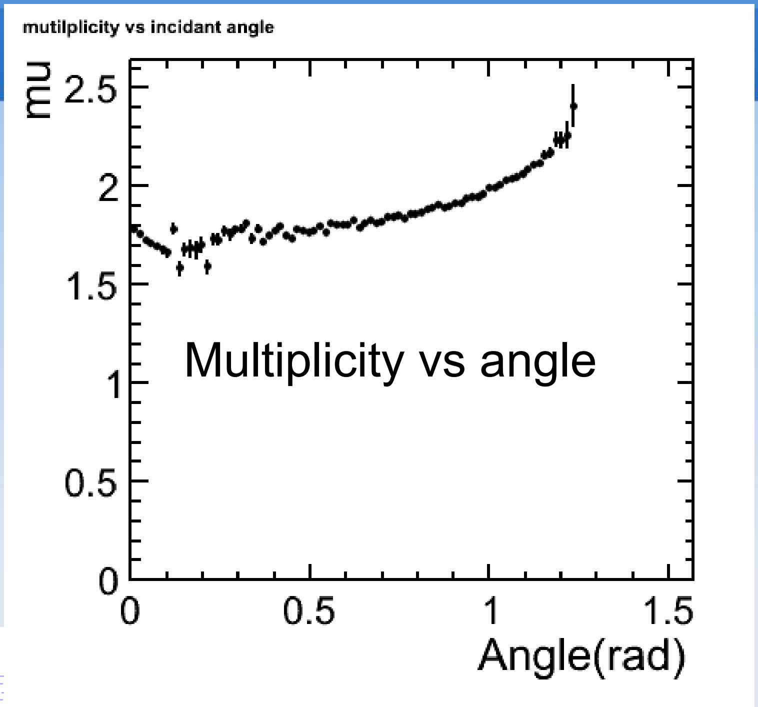
60 GeV Pion (714551, 4552, 4553): 98960 evts

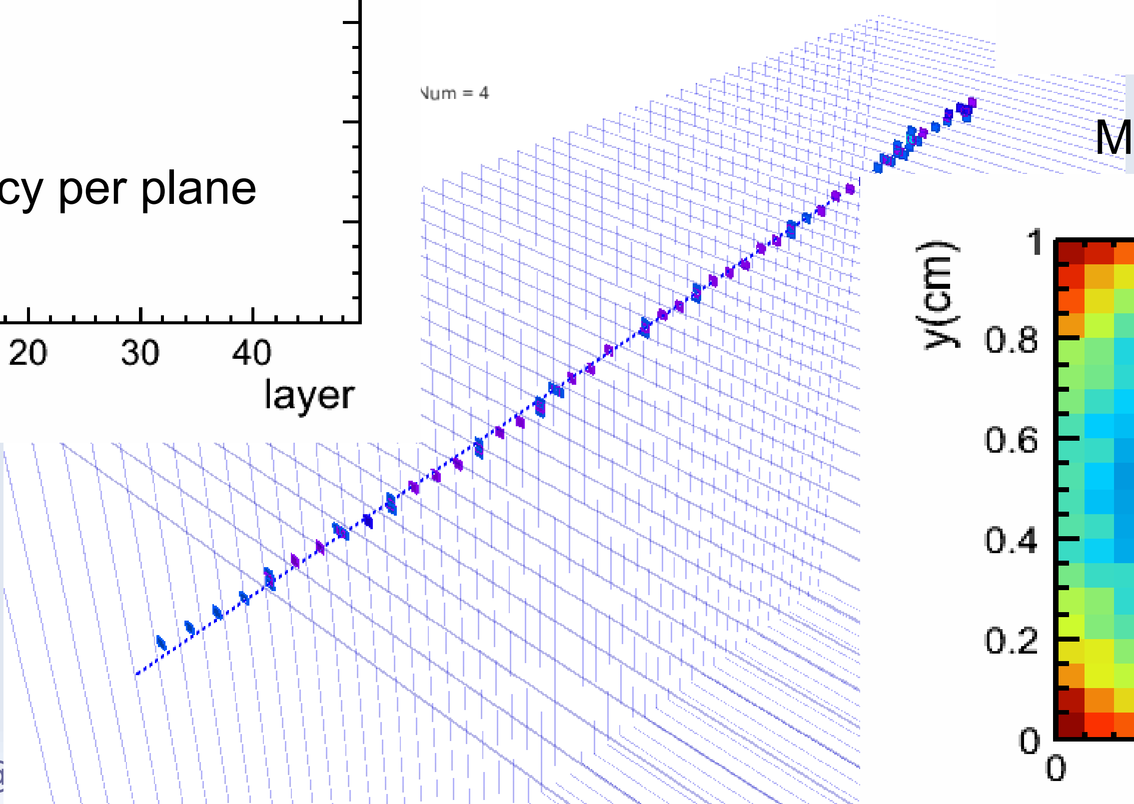
Micro structure of segmented GRPC response…

With muons (beam + cosmics), one can derive efficiencies and multiplicities per plane, per ASIC, per channel or per area smaller than a cell.

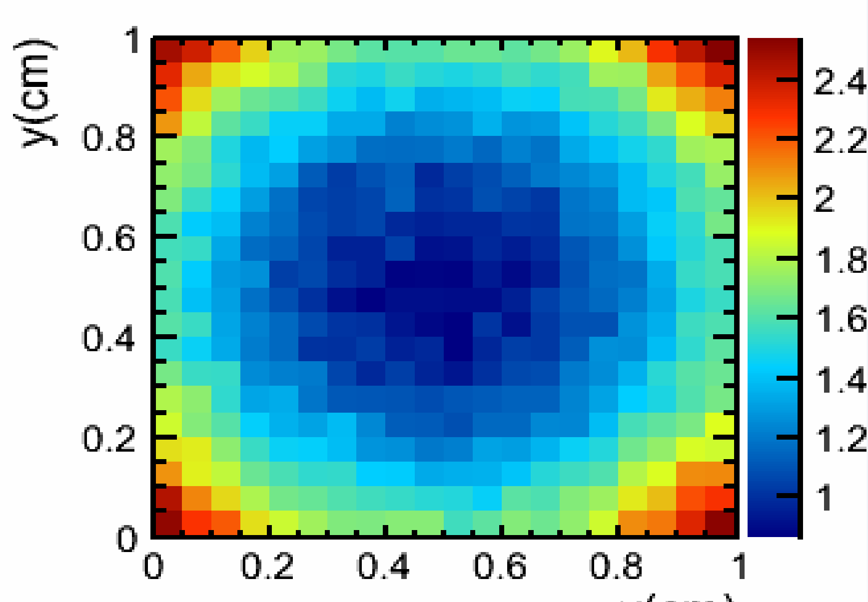
Muons recorded during august test beam.







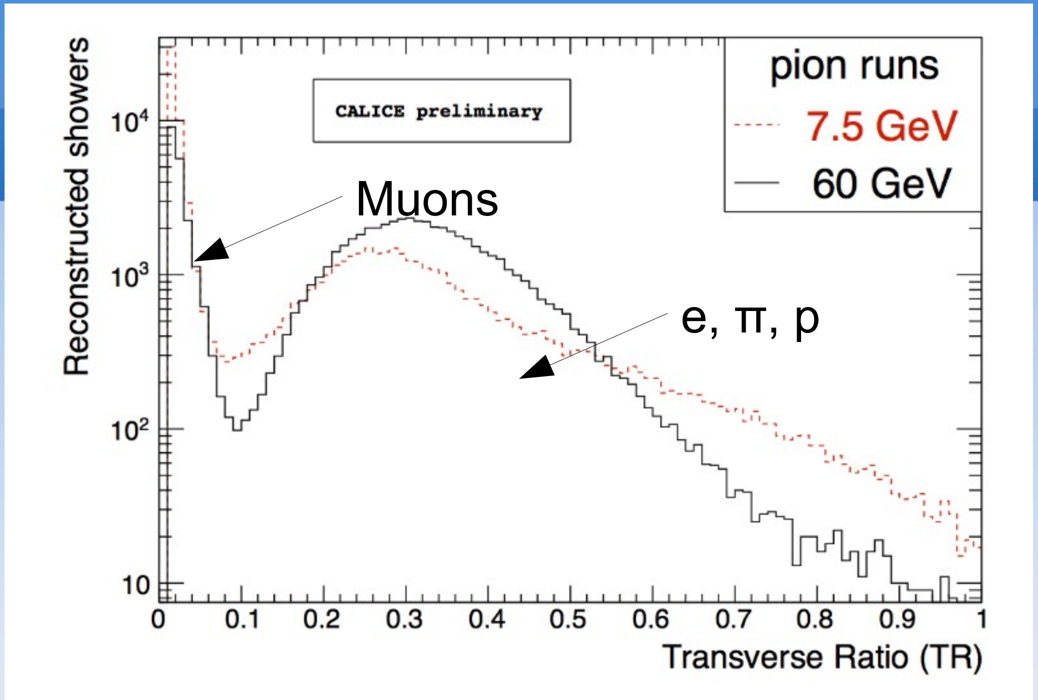
Multiplicity in a cell

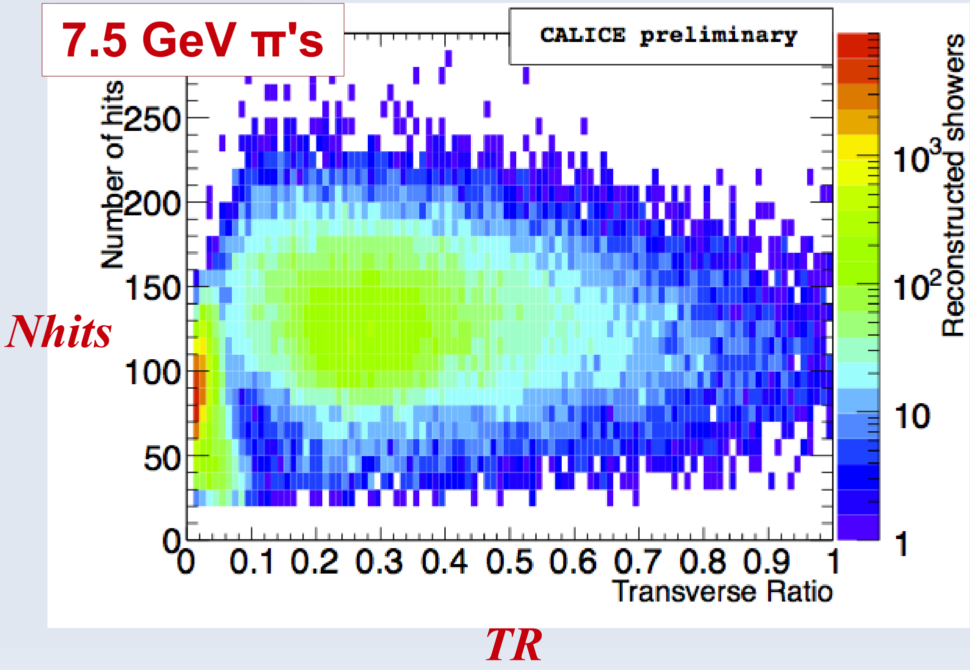


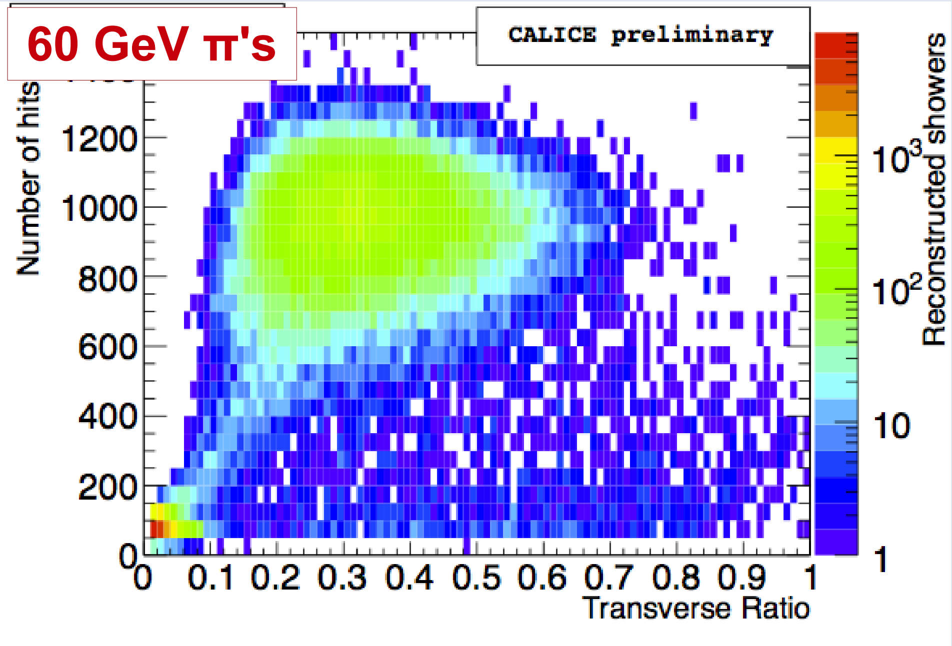
Vincent.Boudry@

Event selection

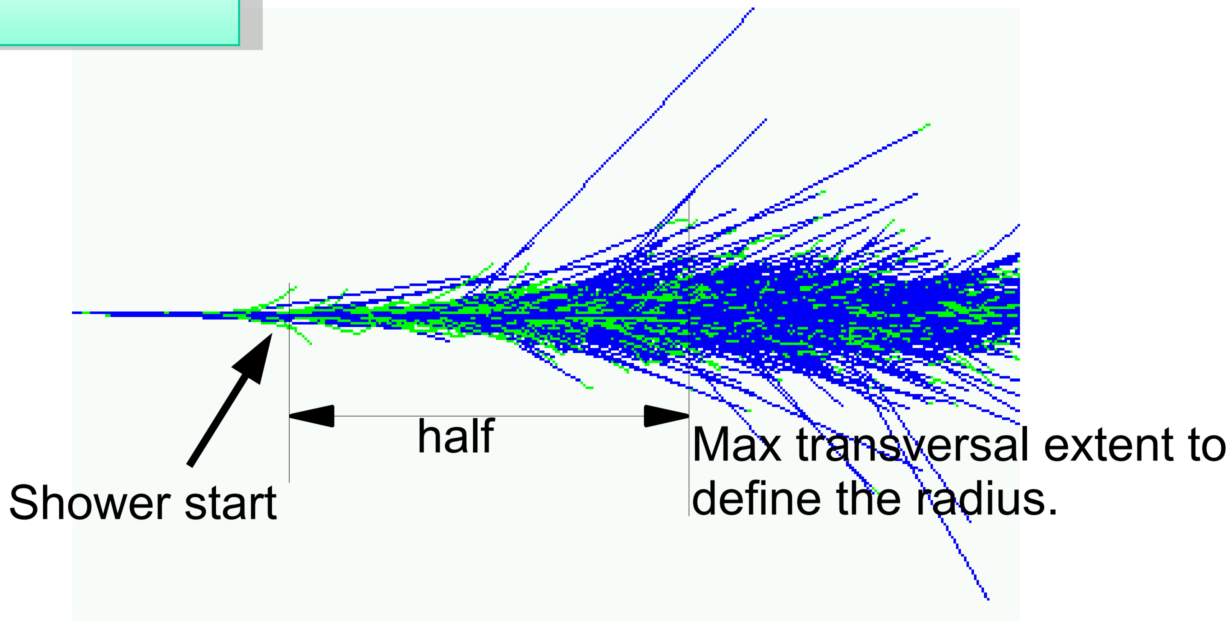
- μ rejection:
  - Transverse ratio
    TR ≥ 0.1 → 98% of μ's







Shower shape variables

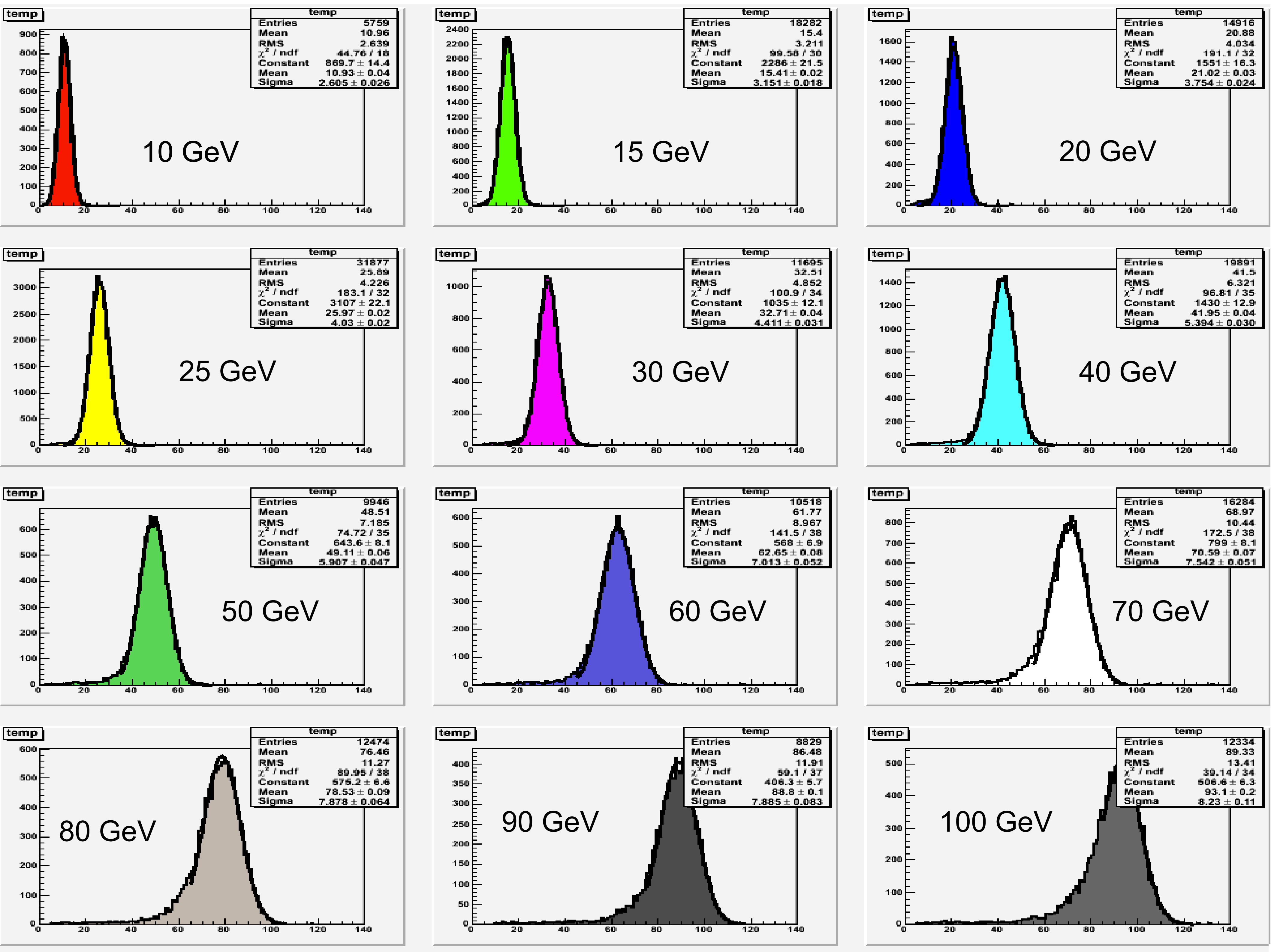


Shower start = layer for which a hit has at least 8 3D-Nearest Neighbours if layer+3 has at least 12 Nearest Neighbours.

Then for each layer, clusterise the hits, removing hits which are at more than 3 rms (spatial distribution) from the center of gravity.

Find the layer which has the biggest spatial rms of the hit distribution. That rms is the radius.

Half is the distance between the shower start layer and the layer that has the biggest spatial rms.



temp
Entries 5759 Mean 10.96 RMS 2.639 χ² / ndf 44.76 / 18 Constant 869.7 ± 14.4 Mean 10.93 ± 0.04 Sigma 2.605 ± 0.026
10 GeV
temp
Entries 18282 Mean 15.4 RMS 3.211 χ² / ndf 99.58 / 30 Constant 2286 ± 21.5 Mean 15.41 ± 0.02 Sigma 3.151 ± 0.018
15 GeV
temp
Entries 14916 Mean 20.88 RMS 4.034 χ² / ndf 191.1 / 32 Constant 1551 ± 16.3 Mean 21.02 ± 0.03 Sigma 3.754 ± 0.024
20 GeV
temp
Entries 31877 Mean 25.89 RMS 4.226 χ² / ndf 183.1 / 32 Constant 3107 ± 22.1 Mean 25.97 ± 0.02 Sigma 4.03 ± 0.02
25 GeV
temp
Entries 11695 Mean 32.51 RMS 4.852 χ² / ndf 100.9 / 34 Constant 1035 ± 12.1 Mean 32.71 ± 0.04 Sigma 4.411 ± 0.031
30 GeV
temp
Entries 19891 Mean 41.5 RMS 6.321 χ² / ndf 96.81 / 35 Constant 1430 ± 12.9 Mean 41.95 ± 0.04 Sigma 5.394 ± 0.030
40 GeV
temp
Entries 9946 Mean 48.51 RMS 7.185 χ² / ndf 74.72 / 35 Constant 643.6 ± 8.1 Mean 49.11 ± 0.06 Sigma 5.907 ± 0.047
50 GeV
temp
Entries 10518 Mean 61.77 RMS 8.967 χ² / ndf 141.5 / 38 Constant 568 ± 6.9 Mean 62.65 ± 0.08 Sigma 7.013 ± 0.052
60 GeV
temp
Entries 16284 Mean 68.97 RMS 10.44 χ² / ndf 172.5 / 38 Constant 799 ± 8.1 Mean 70.59 ± 0.07 Sigma 7.542 ± 0.051
70 GeV
temp
Entries 12474 Mean 76.46 RMS 11.27 χ² / ndf 89.95 / 38 Constant 575.2 ± 6.6 Mean 78.53 ± 0.09 Sigma 7.878 ± 0.064
80 GeV
temp
Entries 8829 Mean 86.48 RMS 11.91 χ² / ndf 59.1 / 37 Constant 406.3 ± 5.7 Mean 88.8 ± 0.1 Sigma 7.885 ± 0.083
90 GeV
temp
Entries 12334 Mean 89.33 RMS 13.41 χ² / ndf 39.14 / 34 Constant 506.6 ± 6.3 Mean 93.1 ± 0.2 Sigma 8.23 ± 0.11
100 GeV