GRPC/SDHCAL results

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On behalf of SDHCAL group

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outline

- SDHCAL concept, validation and construction
- Test Beam and technological prototype performance
- Perspectives and Conclusion

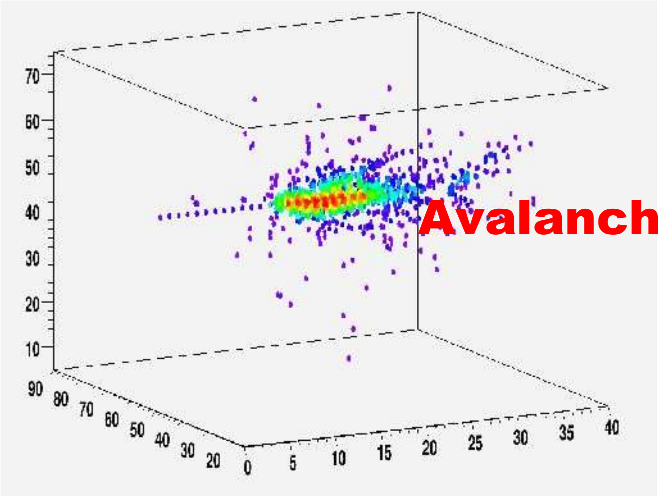
Semi-Digital HCAL Concept

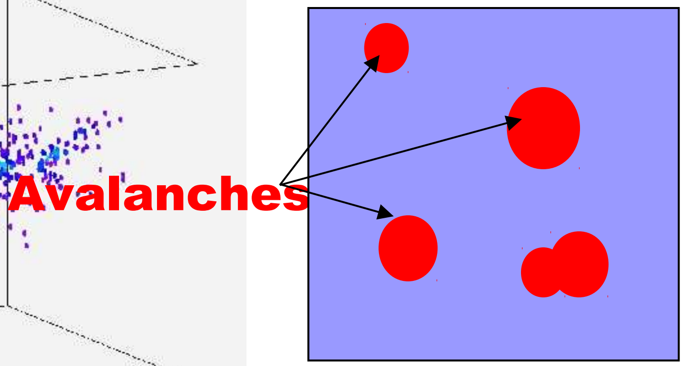
Ultra-granular HCAL can provide a powerful tool for the **PFA** leading to an excellent Jet energy resolution.

It is based on two points:

1- Gaseous Detector

Gaseous detectors like **GRPC** are homogenous, cost-effective, and allow high longitudinal and transverse segmentation.





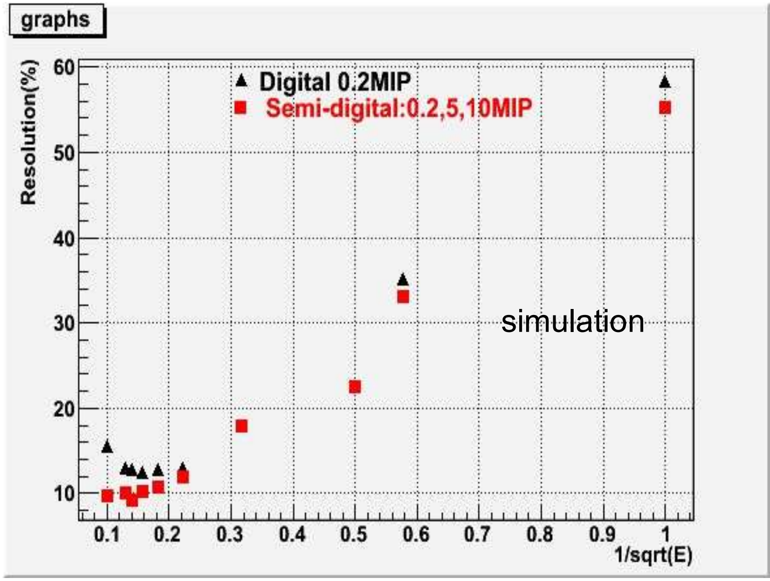
1 cm² pad

2- Embedded electronics Readout

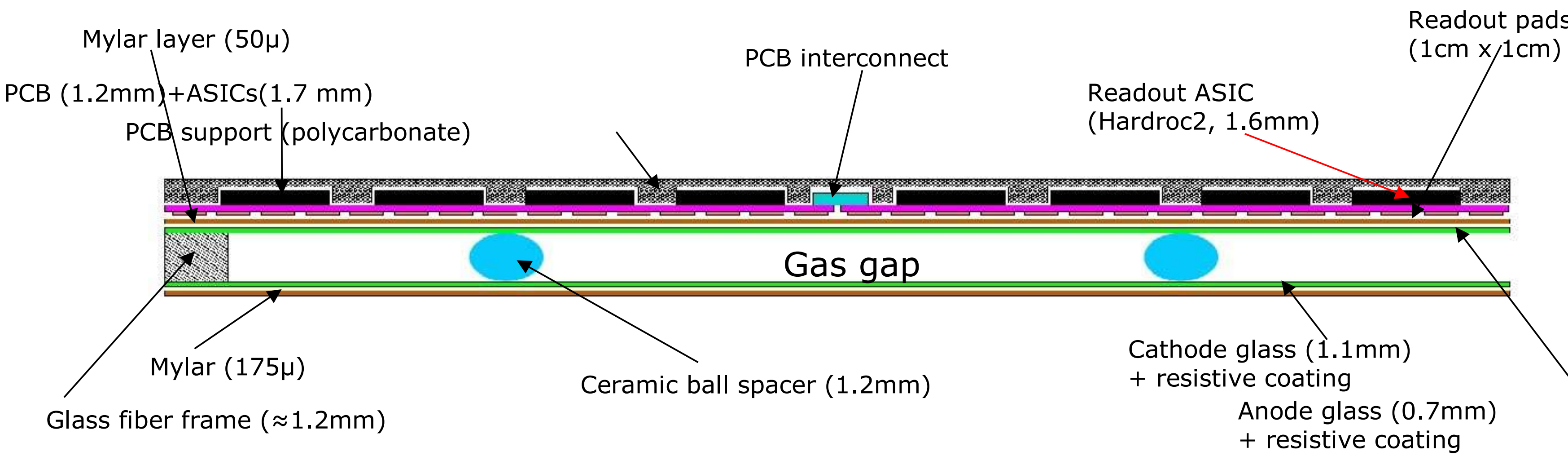
A simple binary readout leads to a very good energy resolution

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

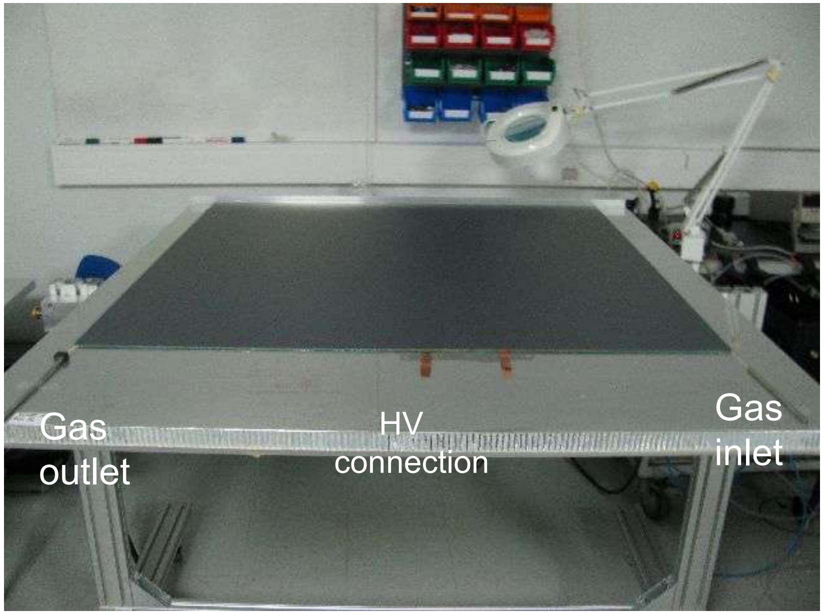


Structure of an active layer of the SDHCAL



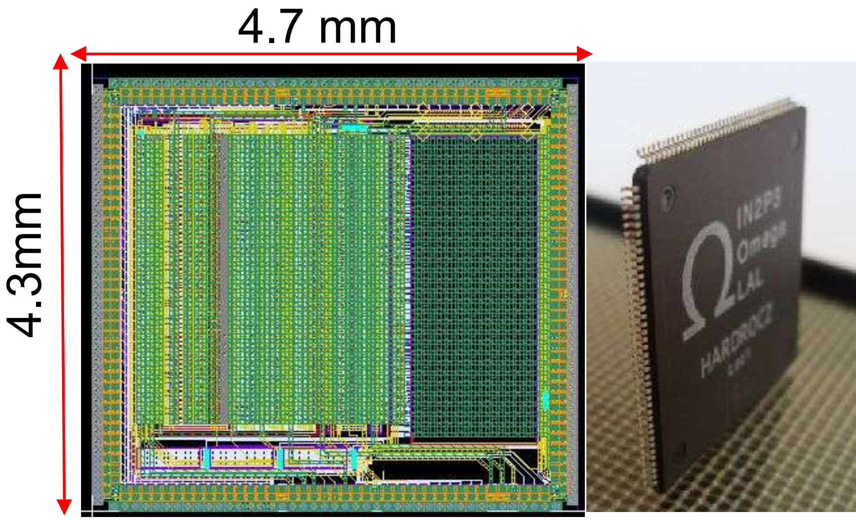
Large GRPC R&D

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



Electronics readout system R&D

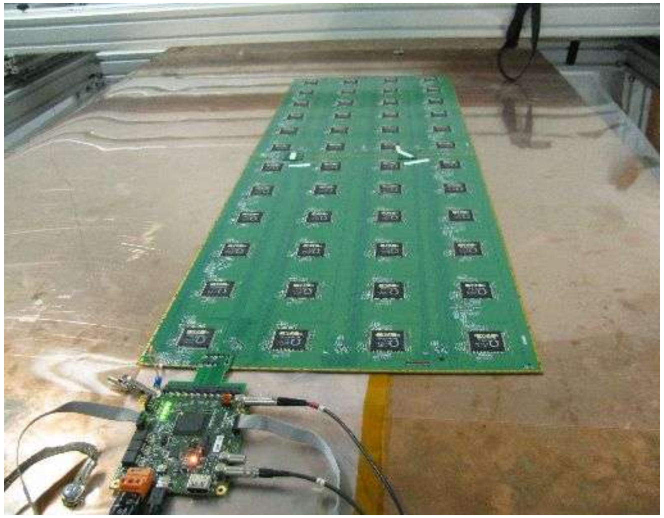
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-20pC
Gain correction → uniformity
Power-Pulsed (7.5 μW in case of ILC duty cycle)



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 PCBs two by two so the 24X2 ASICs are daisy-chained.

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



Cassette R&D

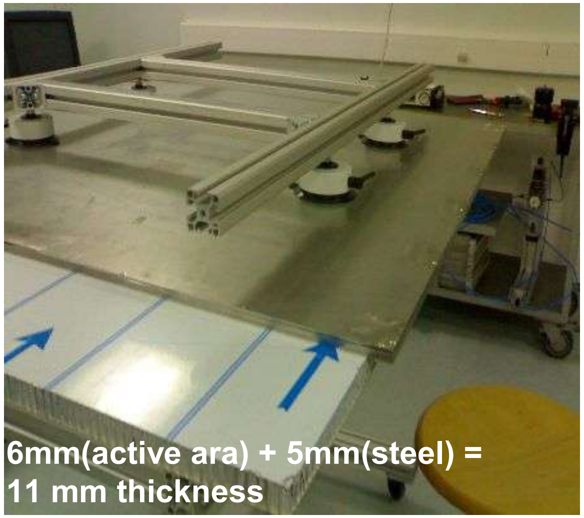
Cassettes were conceived

✓ To provide a robust structure.

✓ To maintain good contact between the readout electronics and the GRPC.

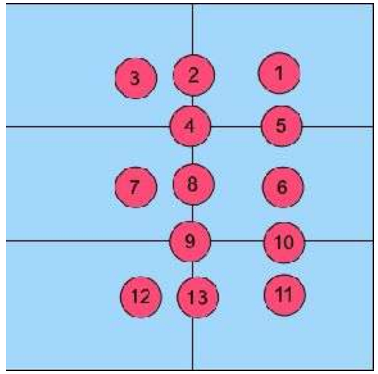
✓ To be part of the absorber.

✓It allows to replace detectors and electronics boards easily.

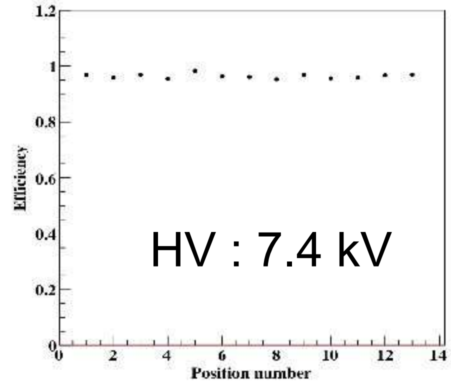


The cassettes are built of non-magnetic stainless steel walls 2.5 mm thick each
→ Total cassette thickness = 6mm (active layer)+5 mm (steel) = 11 mm

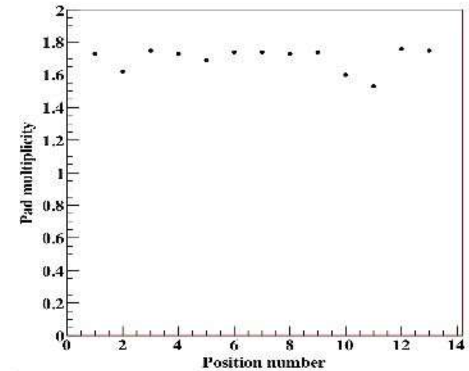
The homogeneity of the detector and its readout electronics were studied (CERN TB)



Beam spot position



Efficiency

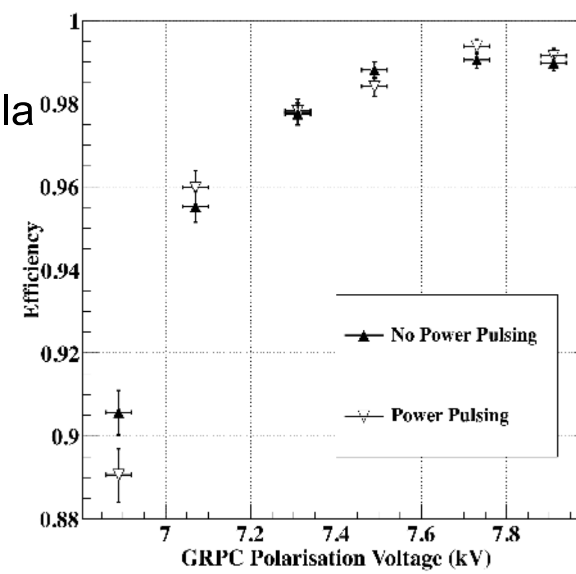


Multiplicity

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

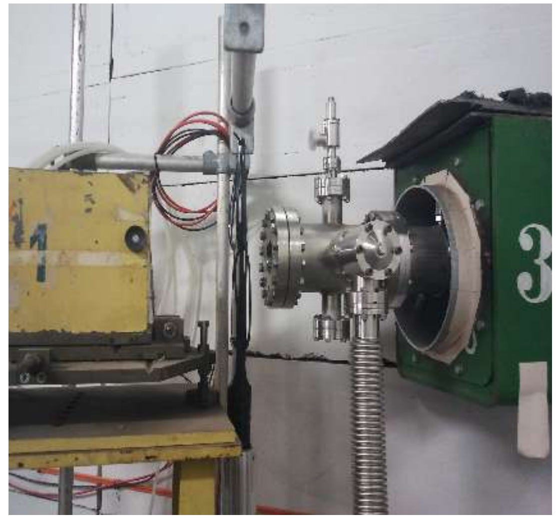
The Power-Pulsing mode was applied on a GRPC in a 3 Tesla field at H2-CERN (2ms every 10 ms)
No effect on the detector performance

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



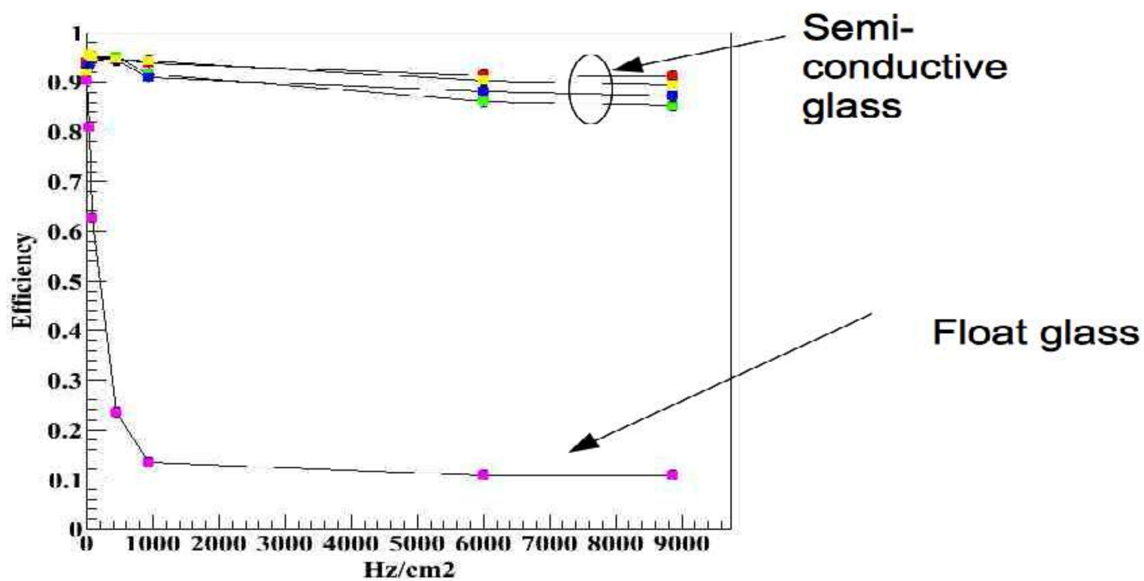
High-Rate GRPC

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



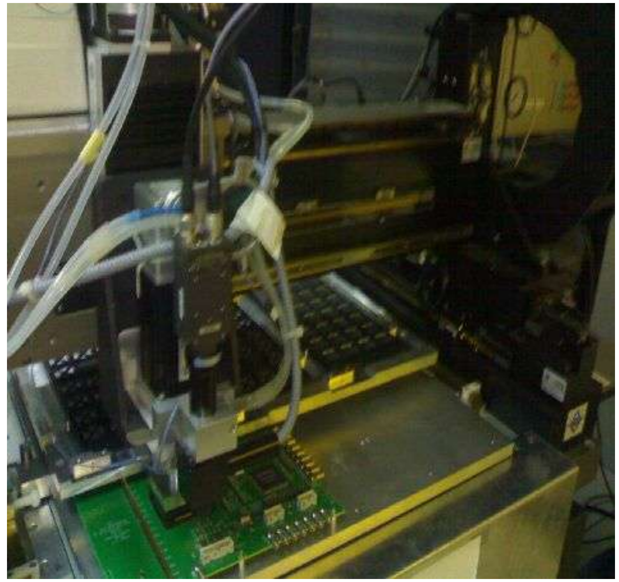
- ✓Semi-conductive glass (10^{10} Ω.cm) produced by our collaborators from Tsinghua University was used to build few chambers.
- ✓4 chambers were tested at DESY as well as standard GRPC (float glass)

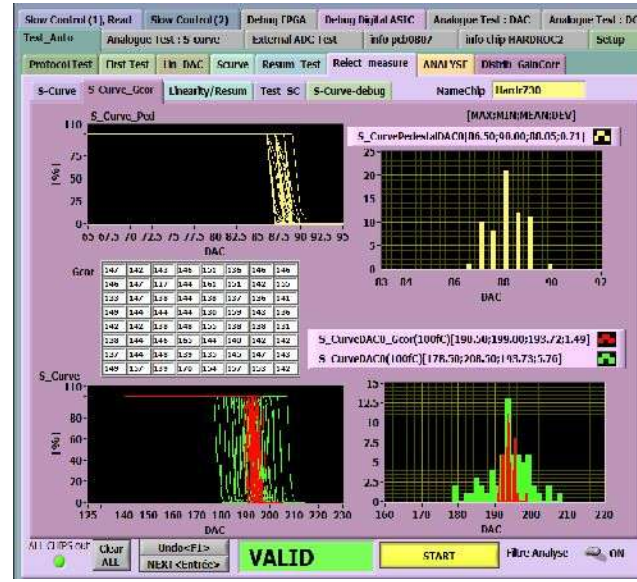
Performance is found to be excellent at high rate for GRPCs with the semi-conductive glass and can be used in the very forward region if the rate > 100 Hz/cm^2



SDHCAL prototype construction

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

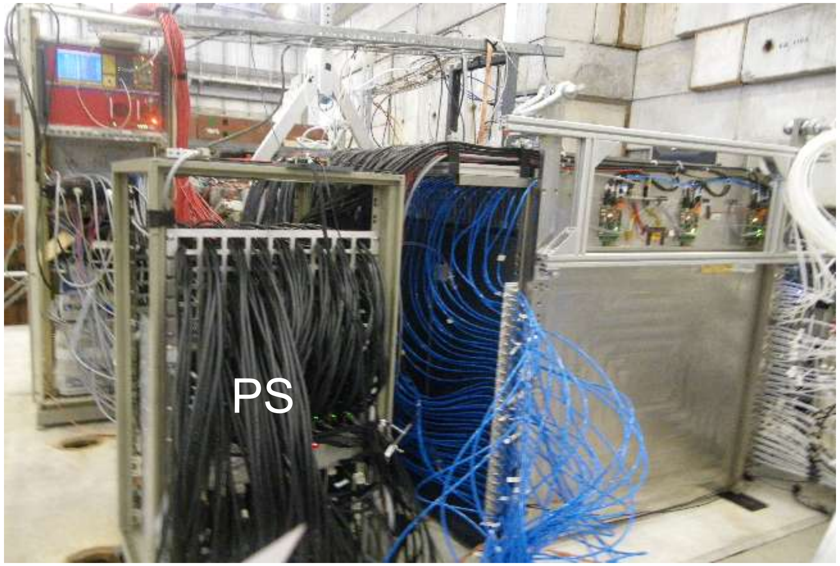


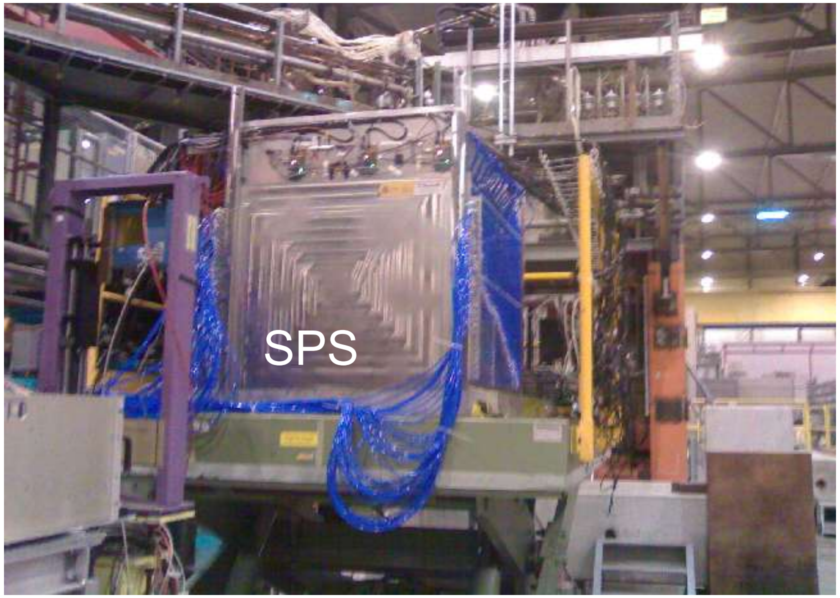


✓ self-supporting mechanical structure was conceived and built.

✓ 51 stainless steel 15mm thick plates with planarity <500 μm were machined and tested

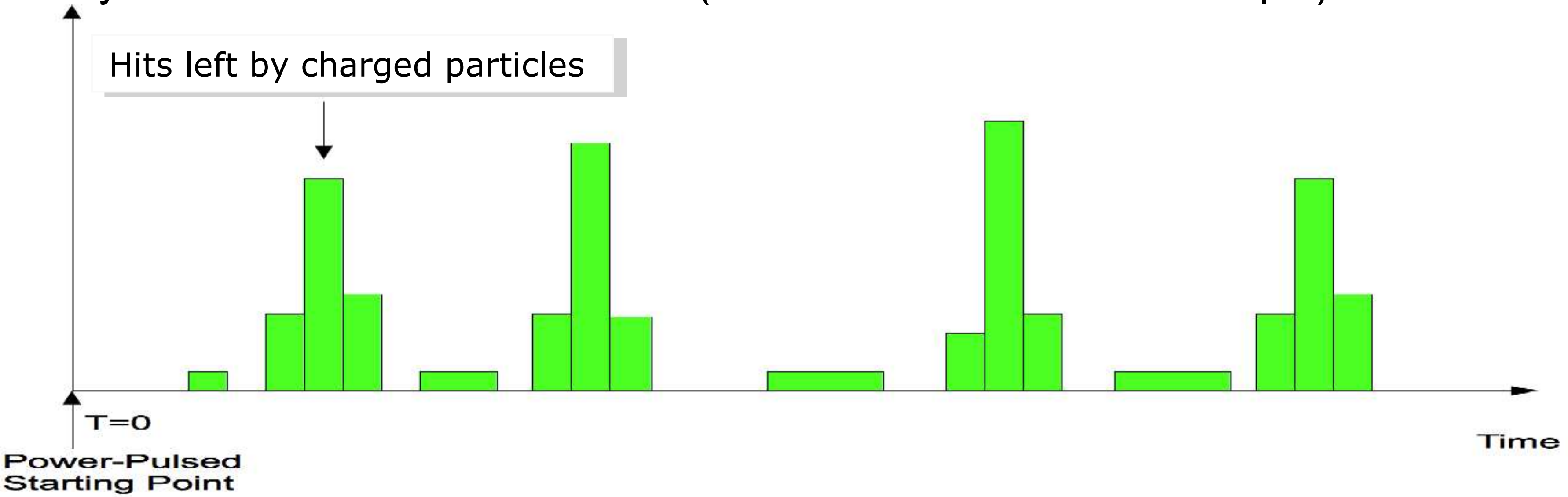
Prototype integration





Prototype data acquisition

- Triggerless mode : record events until memory is full, then data transfer and restart.
- Power-Pulsed mode : According to the time spill structure
  (NX400 ms (PS)*, 10 s(SPS) every 45 s)
- No gain correction applied for TB
  - April 2012 : PS
  - May 2012 : SPS H2
  - August-September 2012 : SPS H6
- Physics events are built as follows (see Yacine's talk for an example) :



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

Events classification (I)

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

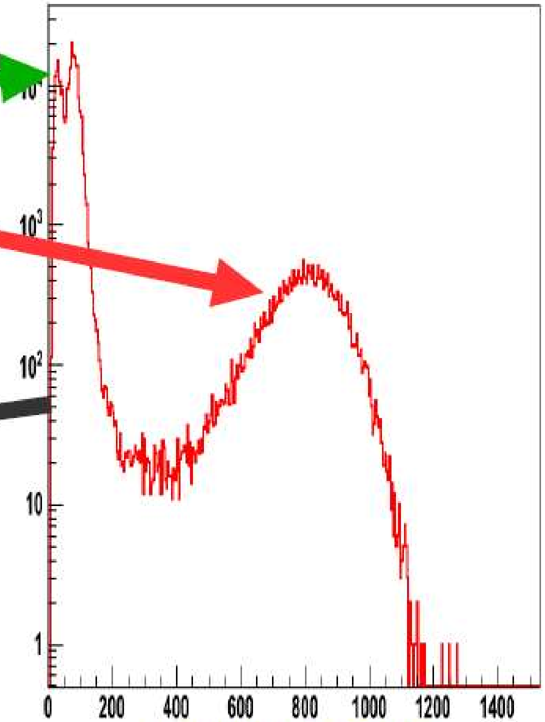
- Just the total number of hits is already a good hint.

Total Hits distribution

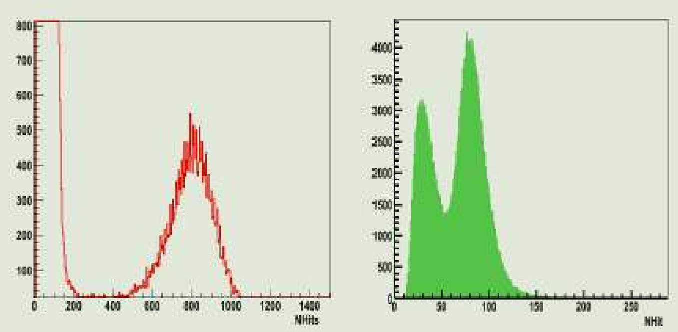
We can obtain the total hits distribution:

the **first two peaks** correspond respectively to **cosmic and beam muons.**

the **last peak belongs to pions.**



Logarithmic Scale



ZOOM & Linear Scale

Events classification (II) : Fractal dimension (FD) versus total number of hits.

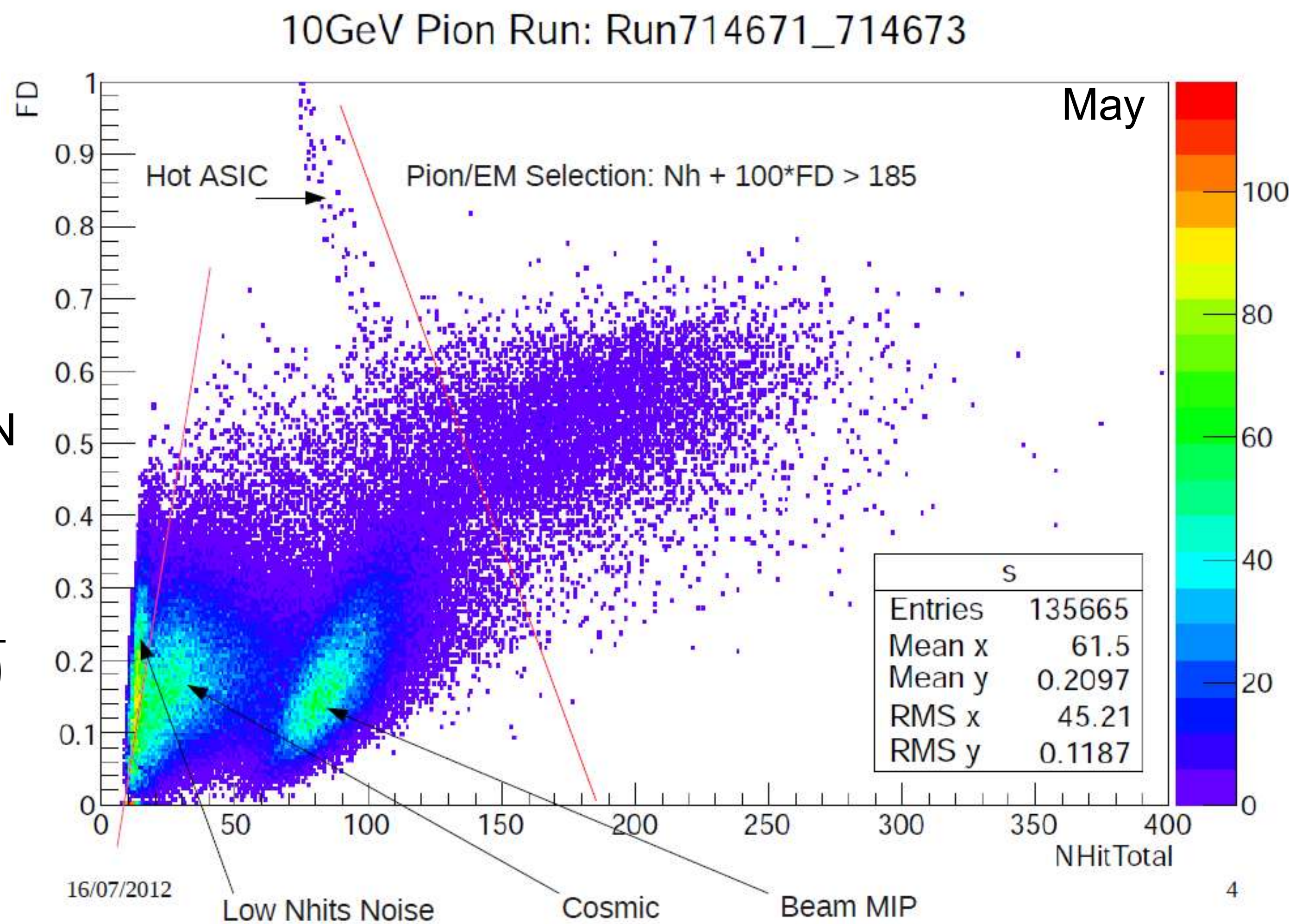
- Noises
- Muons (from beam and cosmics)
- Pions
- electrons

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

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

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

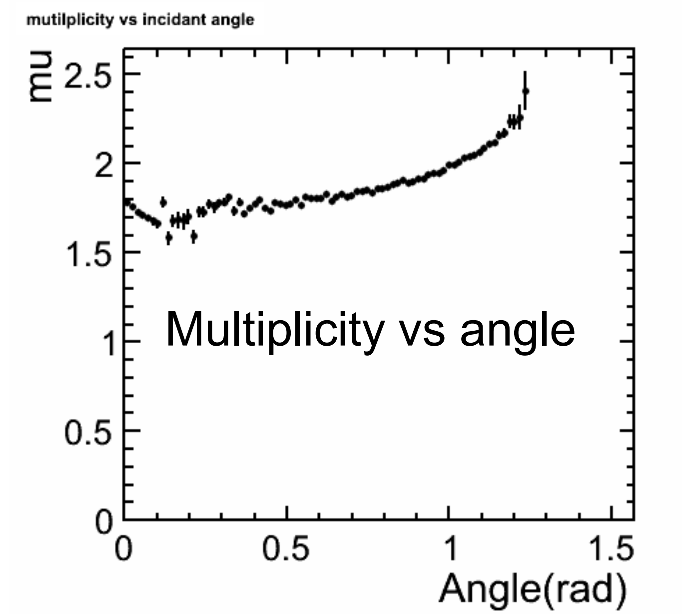
- See Manqi's talk for further examples.

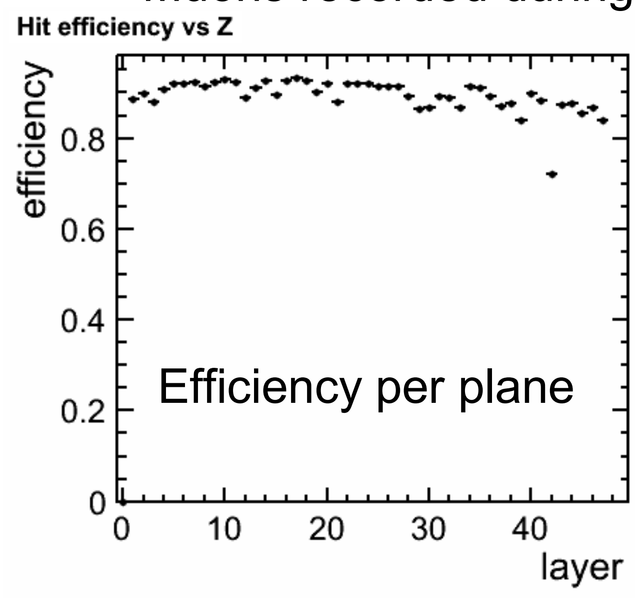


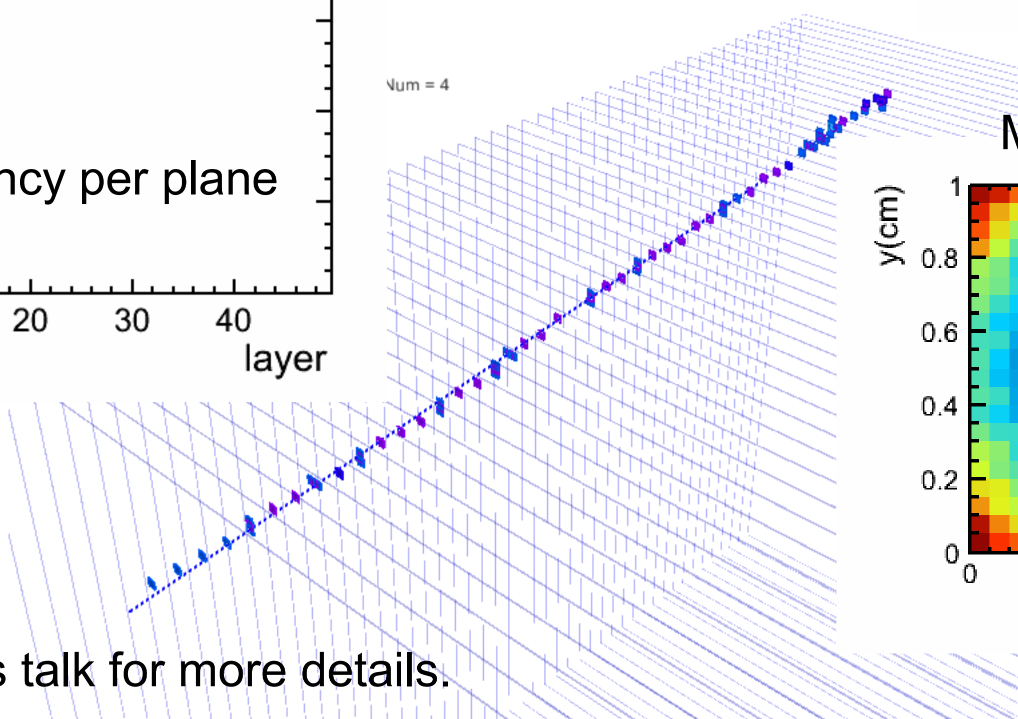
Efficiency and multiplicity

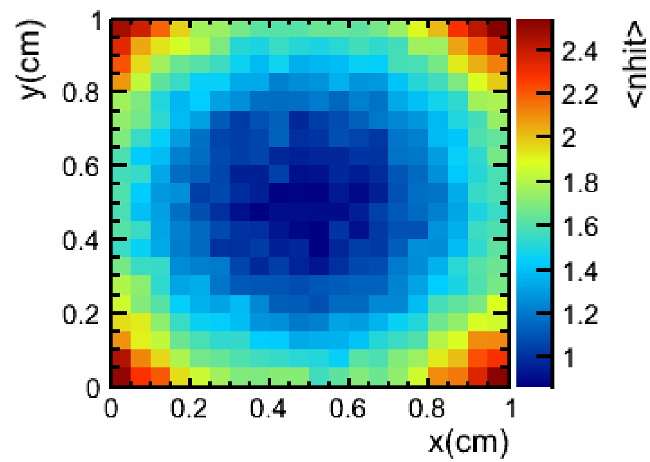
- With muons, one can derive efficiencies and multiplicities per plane, per ASIC, per channel or per area smaller than a cell.

Muons recorded during august test beam.









- See Manqi's talk for more details.

e/pi separation based on the shower differences (I)

➔ Electrons should be contained mostly in the first part of the calorimeter, hadronic shower will extend much more. We can compute: LongitudinalCut (LC)

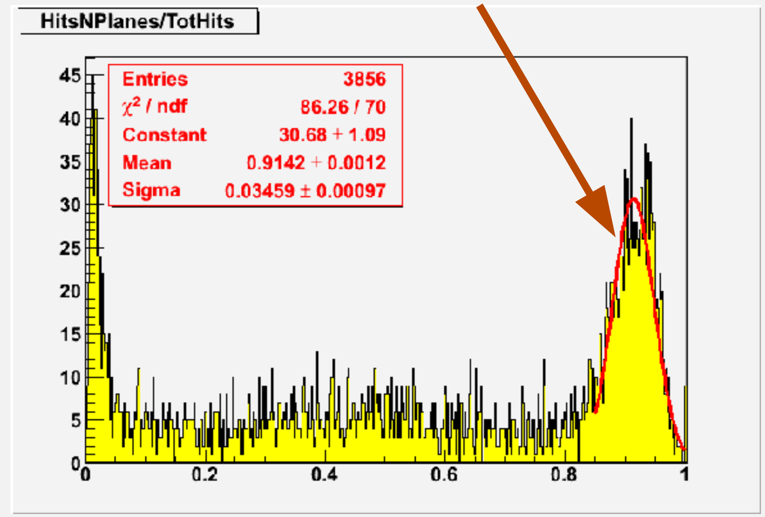
LC = Hits in the first **N** Plates / Tot. Nb. of hits

➔ Electromagnetic showers are narrower compared to the hadronic ones. We can compute: TransversalCut (TC)

TC = Hits in the **X** central Cells / Tot. Nb. of hits

But, which are the optimal N & X values?

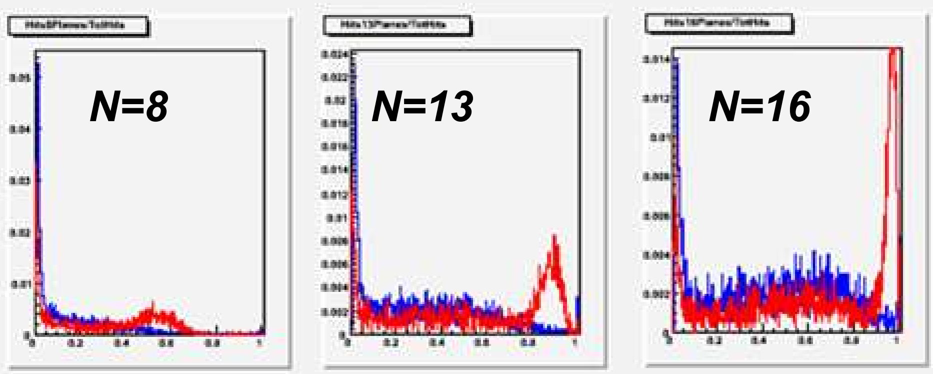
LC distribution using N=14
electron – pion run of 80 GeV



We can compute the distributions for different N & X values for:

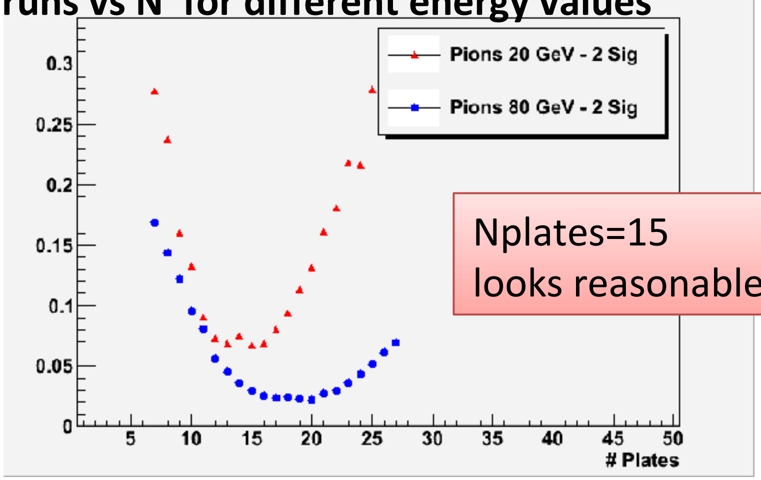
a) Runs with a mixture of pions and electrons ➔ We fit the peak and **estimate the cut as Mean - nSigma**

b) Runs with ONLY pions, we **count how many pions are misidentified as electrons**



Example of longitudinalCut distributions with different N for **Pion Runs (80 GeV)** and **Pion+Electron runs (80 GeV)**

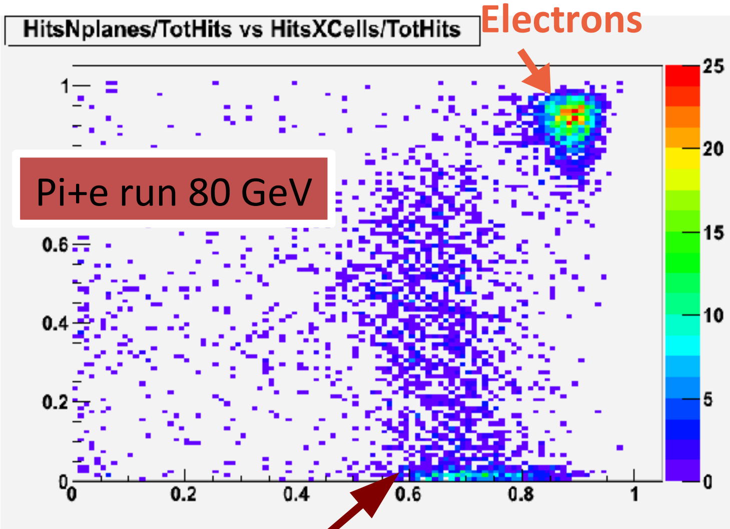
Percentage of entries assigned as electrons in pion runs vs N for different energy values



Nplates=15 looks reasonable

e/pi separation based on the shower differences (II)

After fixing X=13x13 cells and N=15 plates for the previous two variables we can see the correlation



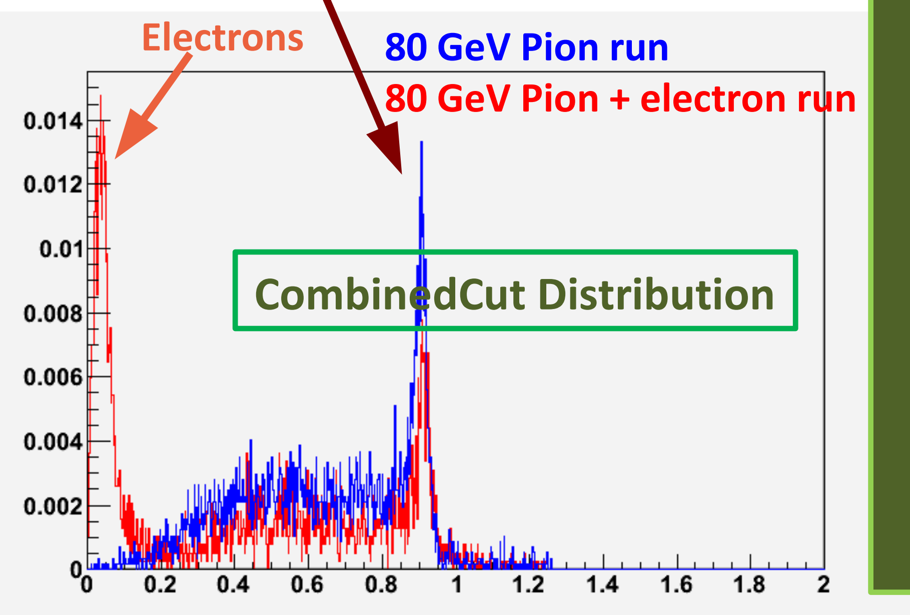
A new variables can be obtain as:

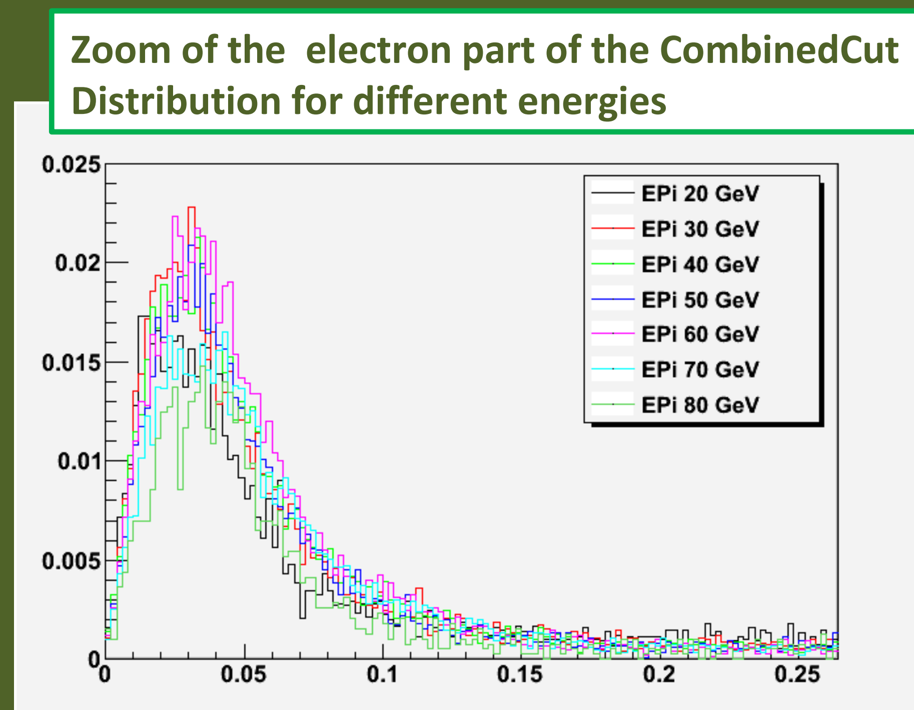
$$\text{CombinedCut(E)} = \sqrt{(\text{LC}-\text{MeanLC(E)})^2 + (\text{TC} - \text{MeanTC (E)})^2}$$

E= Energy

MeanLC(E) and MeanTC (E) ➔ Expected (as computed from data) mean value for the LongitudinalCut and TransversalCut Variables for Electrons of Energy E

Pions not interacting in the first planes

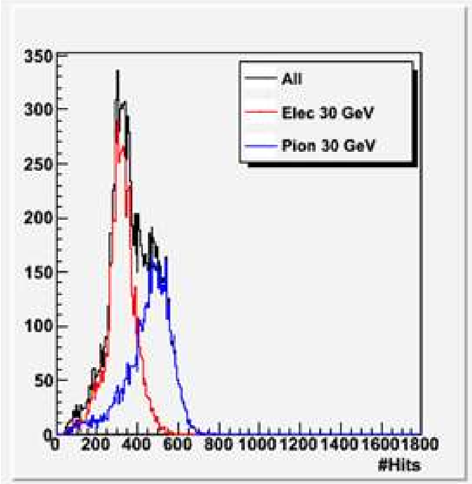


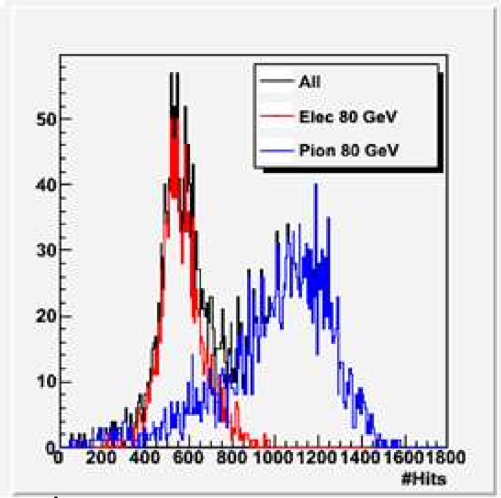


The distributions are very similar for all energies. The same cut can be apply to all

e/pi separation based on the shower differences (III)

The CombinedCut(E) can be used as a discriminant between electrons and pions.

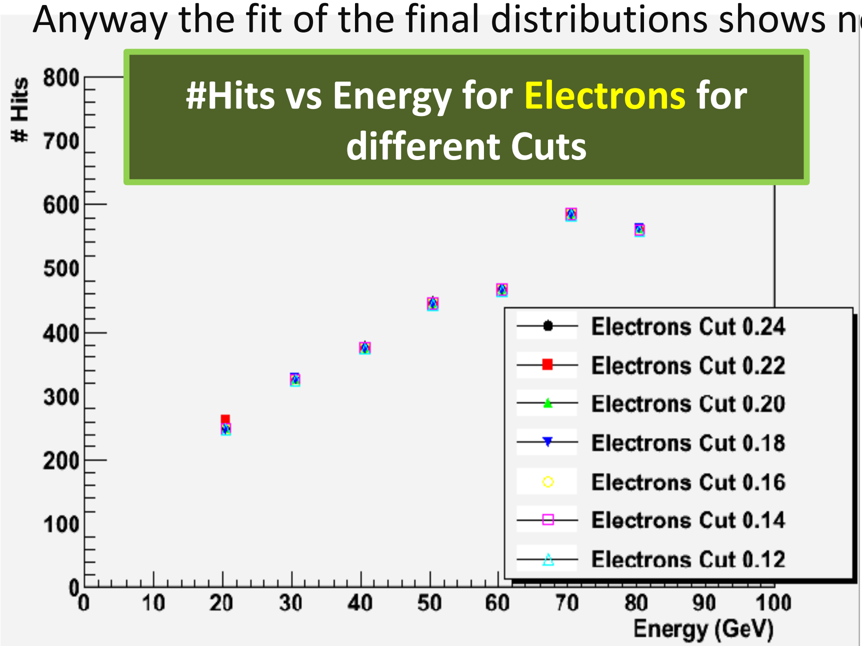


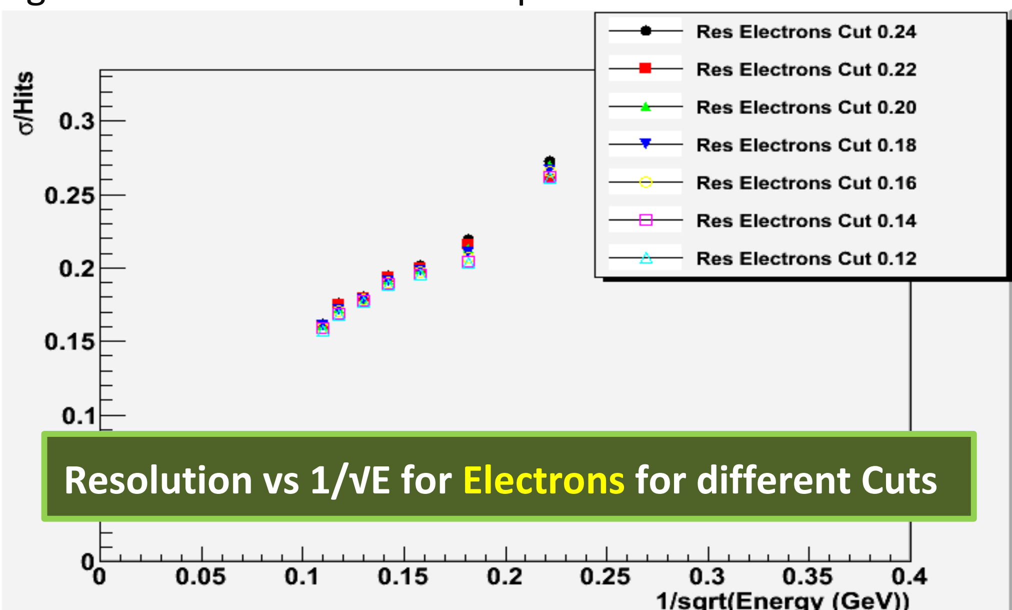


Distributions of the total number of hits for the runs with electrons and pions for a particular CombinedCut(E) value

Depending on the cut and on the energy a pion misassignment from few per mill to 7% was obtained, Lower cut values give less pion missasignment but contaminate the pions with electrons.

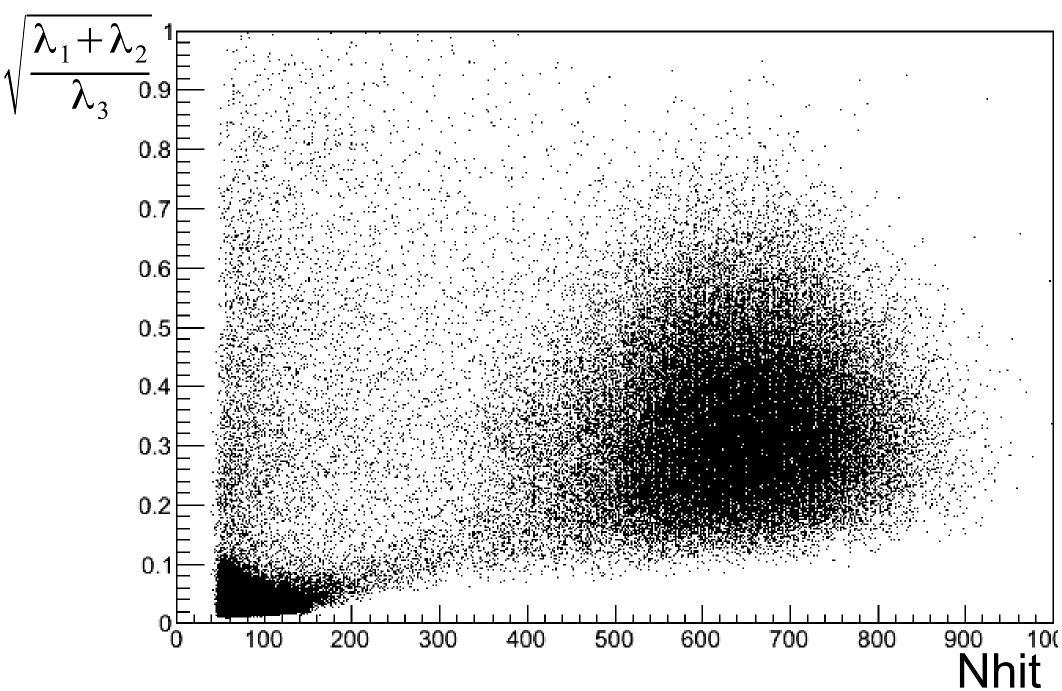
Anyway the fit of the final distributions shows no significant differences for the performance studies

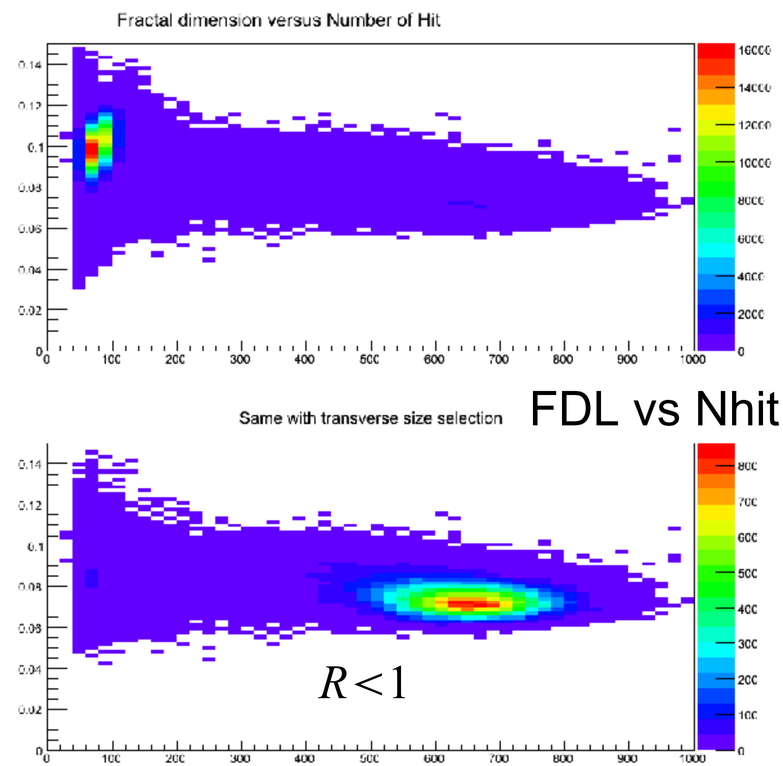




Hadronic shower selection

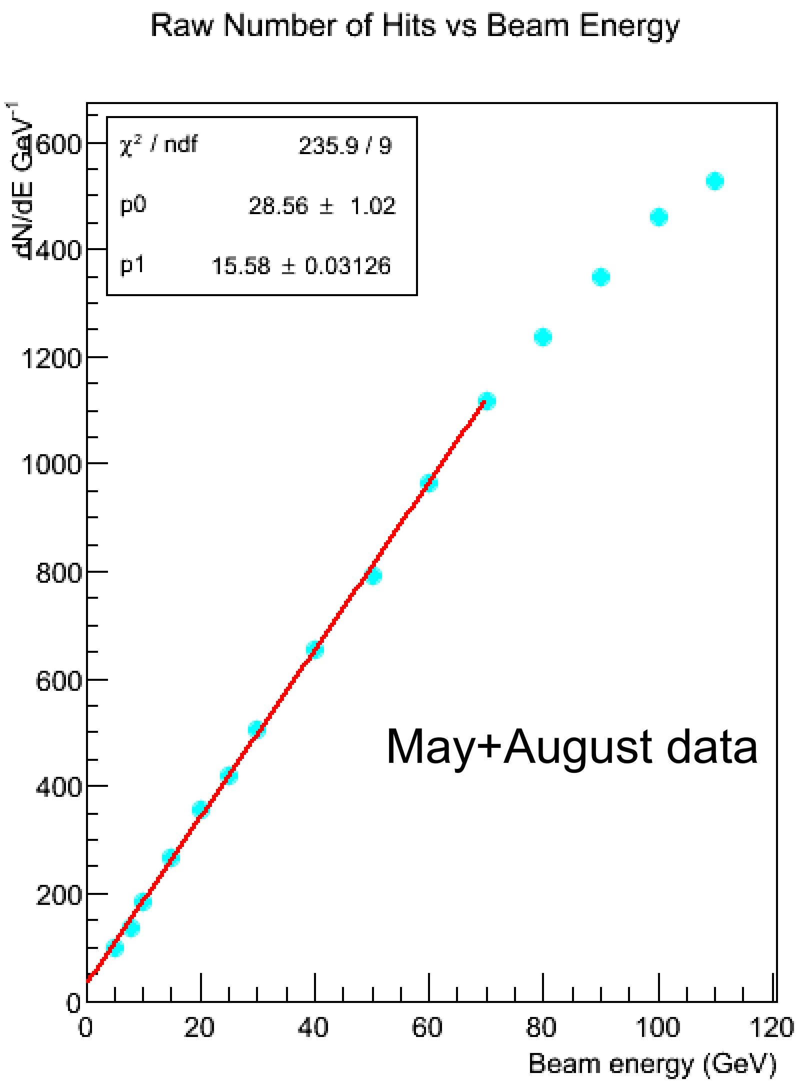
- Clusterisation : from layer 1 to 50, add hits if Δlayer + 2*(ΔI +ΔJ) < 15
- Event selection
  - Muon rejection based on cluster principal axis ($\lambda_1 < \lambda_2 < \lambda_3$) : $L=\sqrt{\frac{\lambda_1+\lambda_2}{\lambda_3}}>0.1$
  - Electron rejection : $FDL=\frac{FD_{allhits}}{\ln(N_{allhits})}<0.085 \text{ AND } R=\frac{\sum_0^5 N_i}{\sum_{15}^{46} N_i}<1$
  - Shower containment : $\frac{\sum_{41}^{46} N_i}{\sum_0^{30} N_i}<0.1 \text{ OR } \textit{last plane} \leq 40$

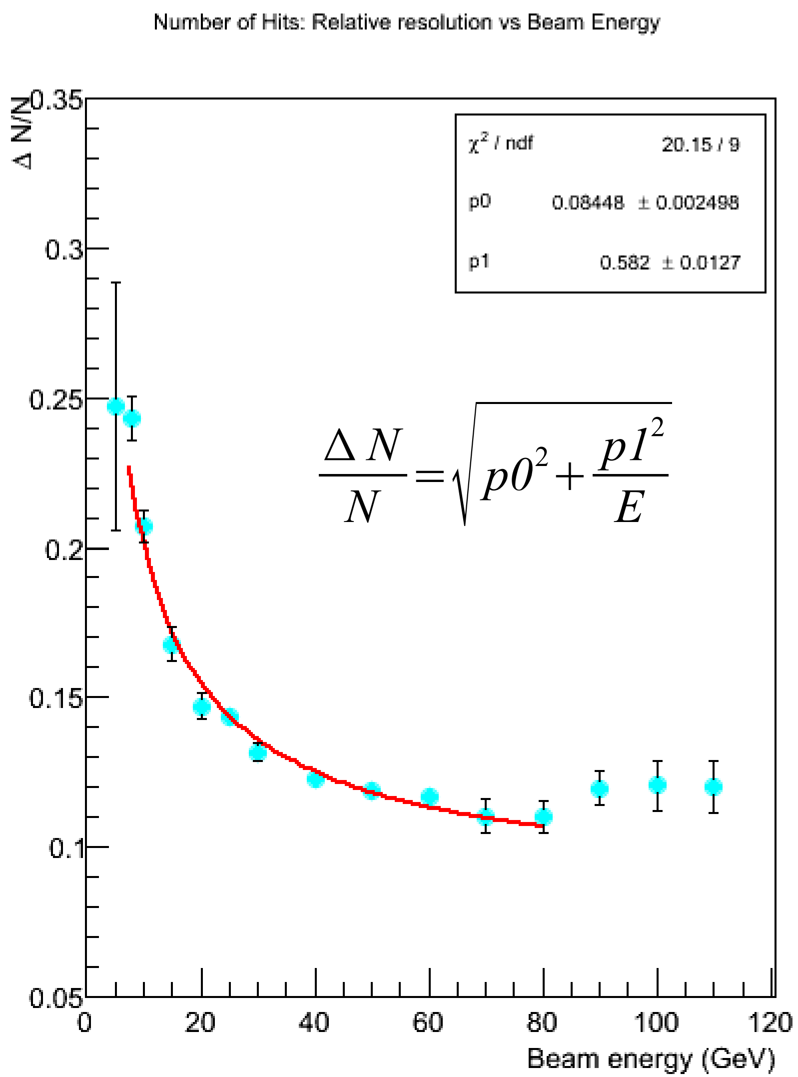




Hadronic energy resolution (I)

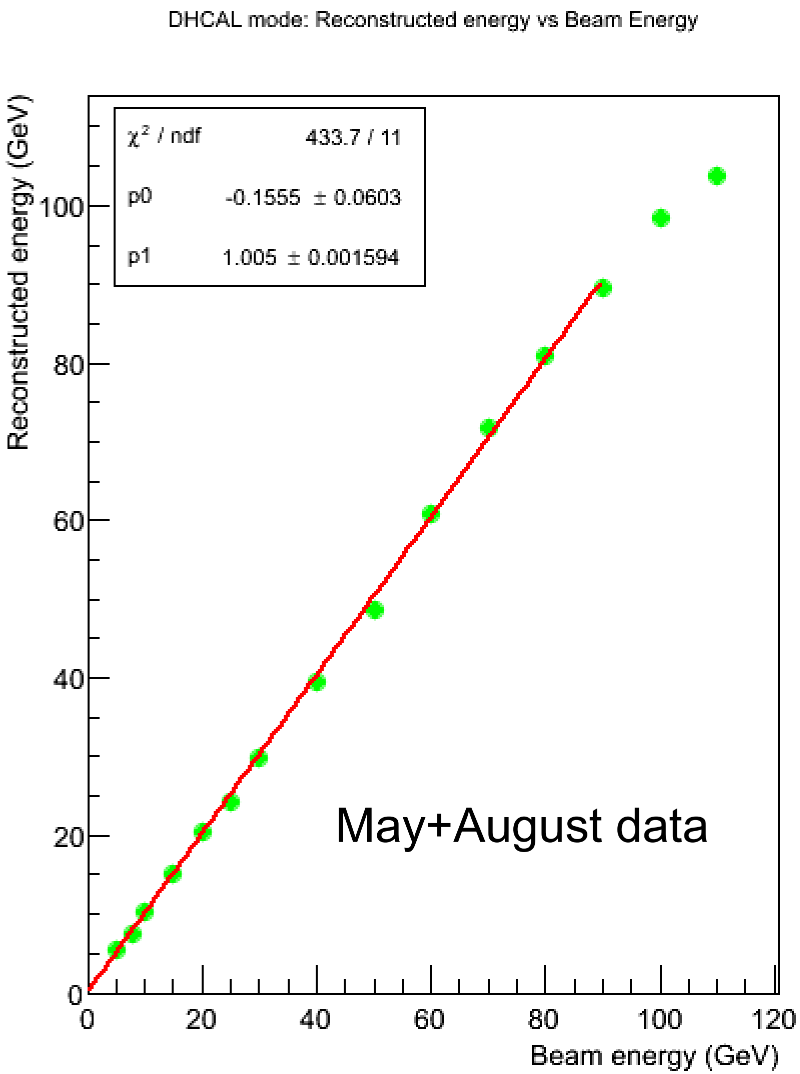
Just using the number of hits
(no leakage correction)

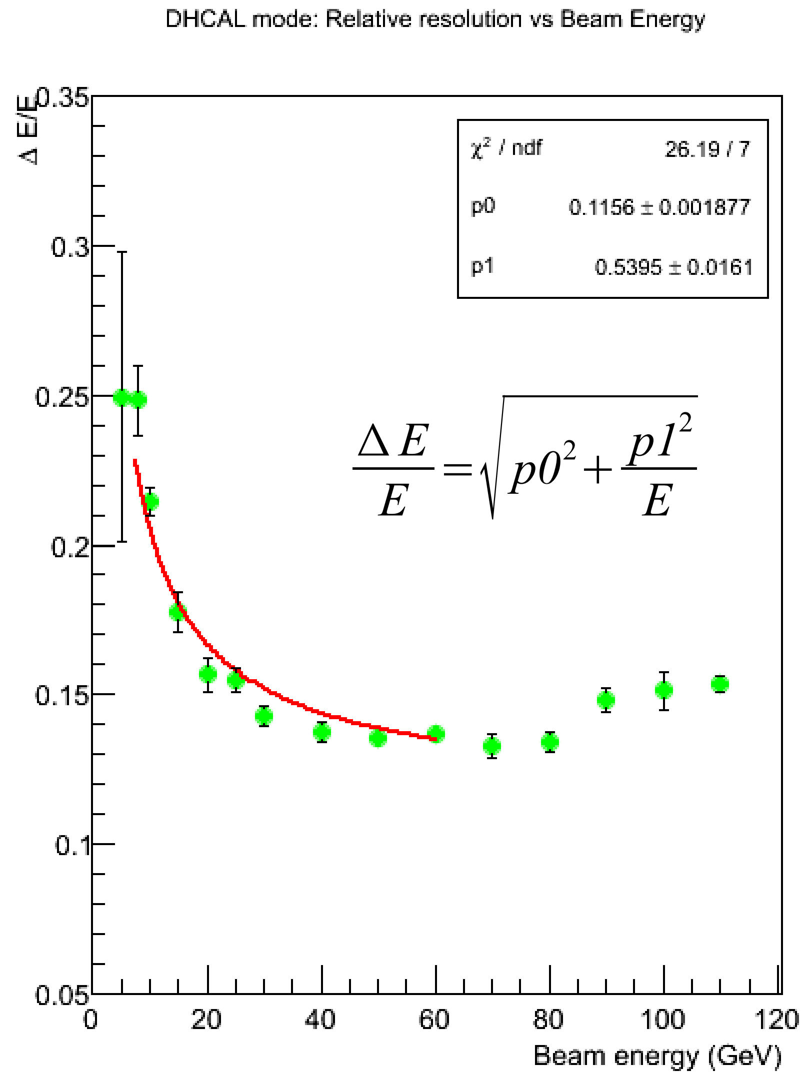




Hadronic energy resolution (II)

DHCAL : E= a Nhit with a= a0+a1*Nhit

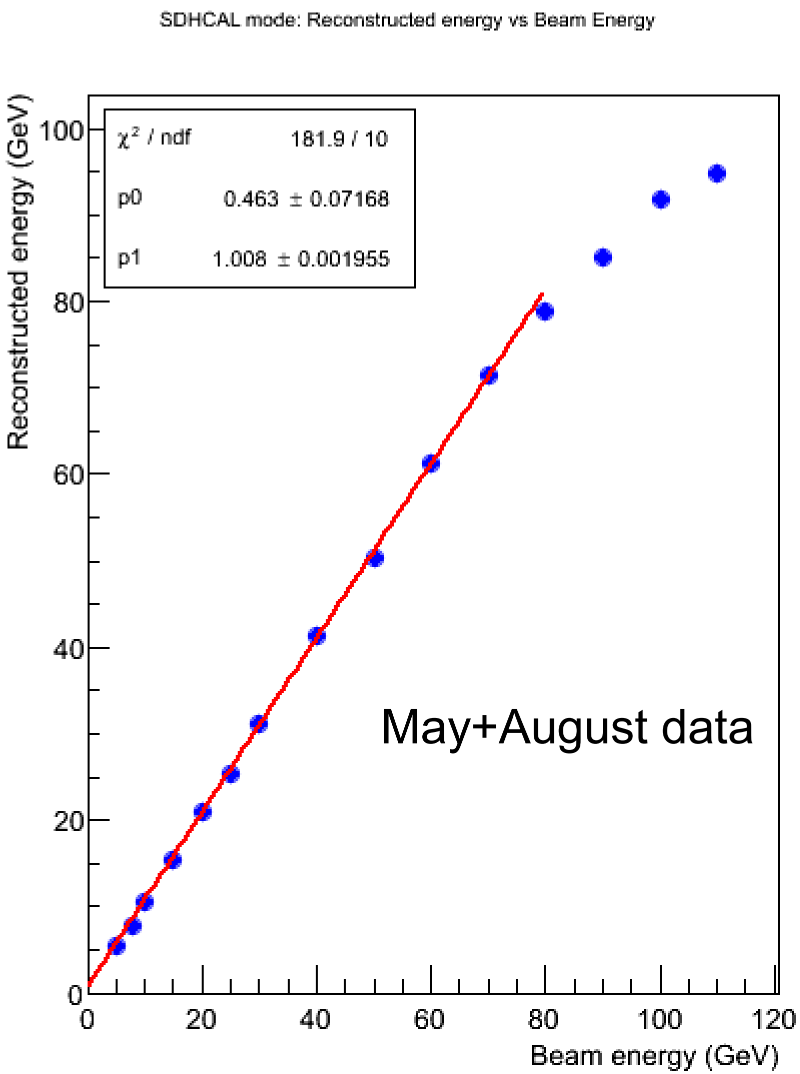


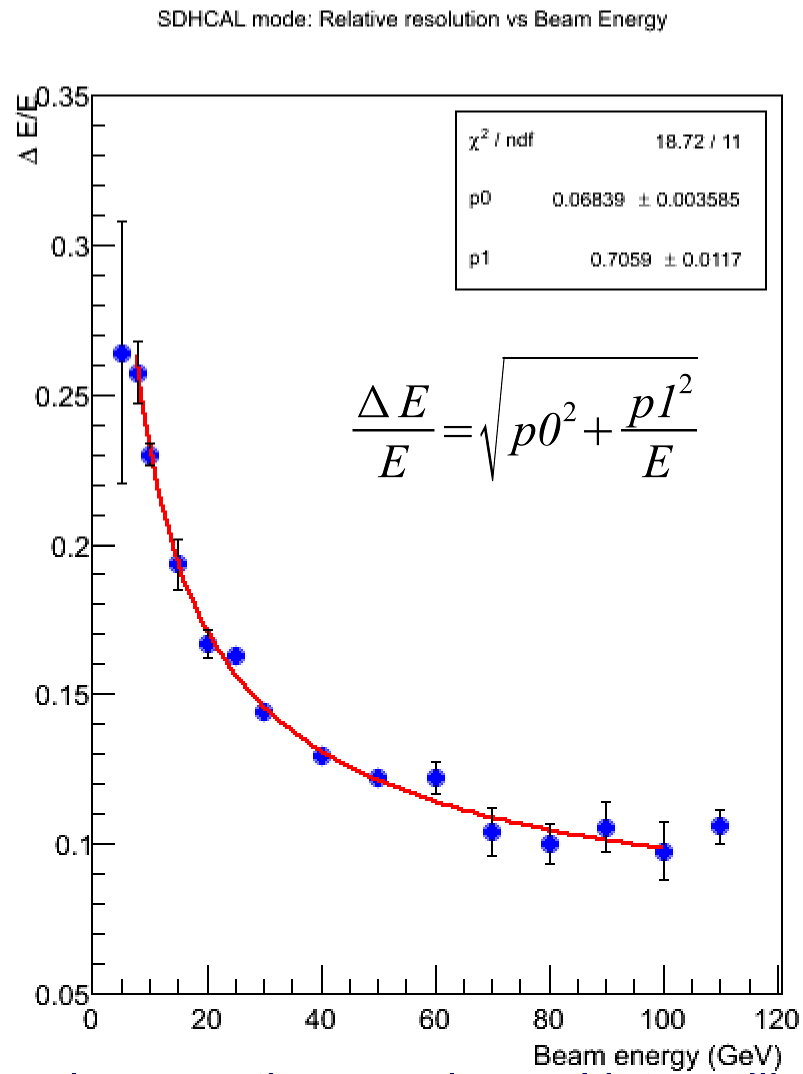


No gain correction, no channel intercalibration.

Hadronic energy resolution (III)

SDHCAL :E= a*N1+b*N2+c*N3 with a,b,c quadratic in Nhit :
a=a0+a1*Nhit+a2*Nhit*Nhit (see next slides for coefficient determination)

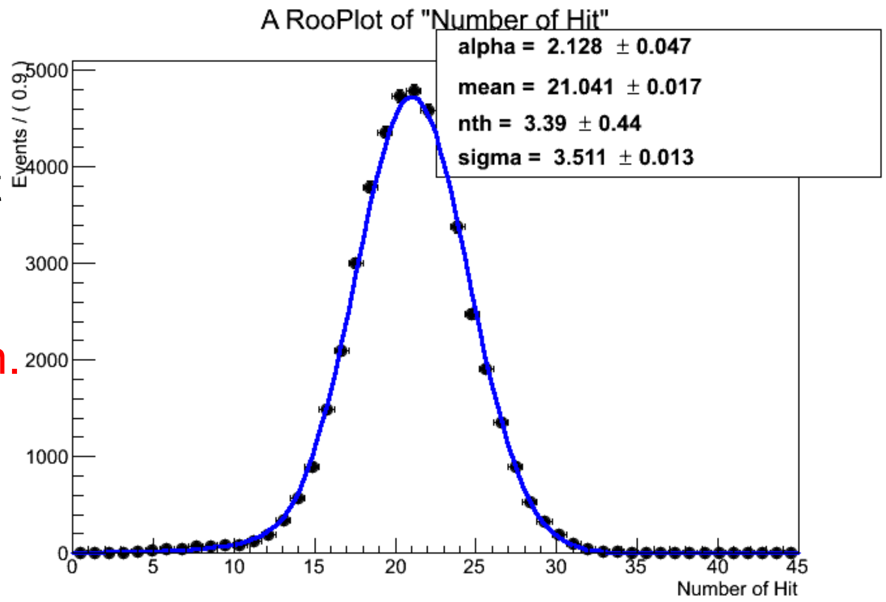


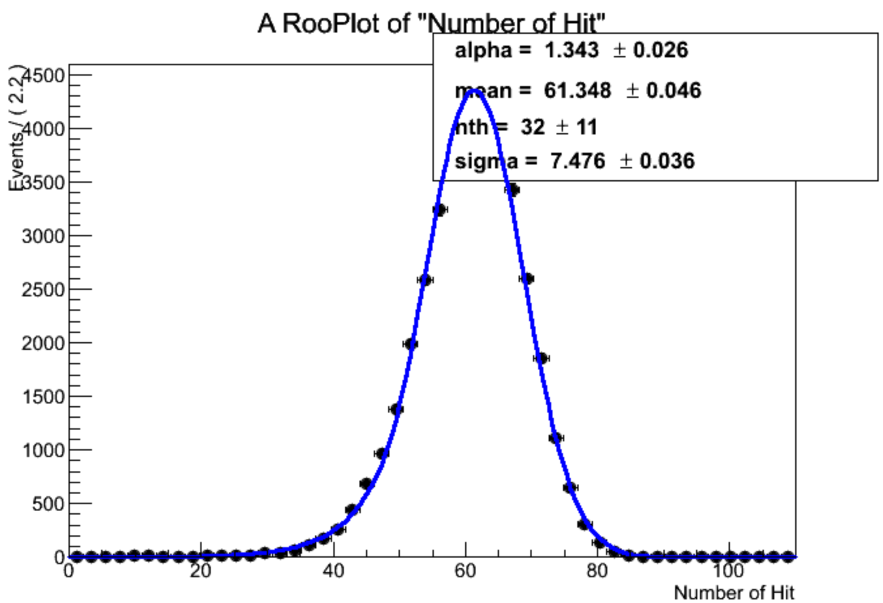


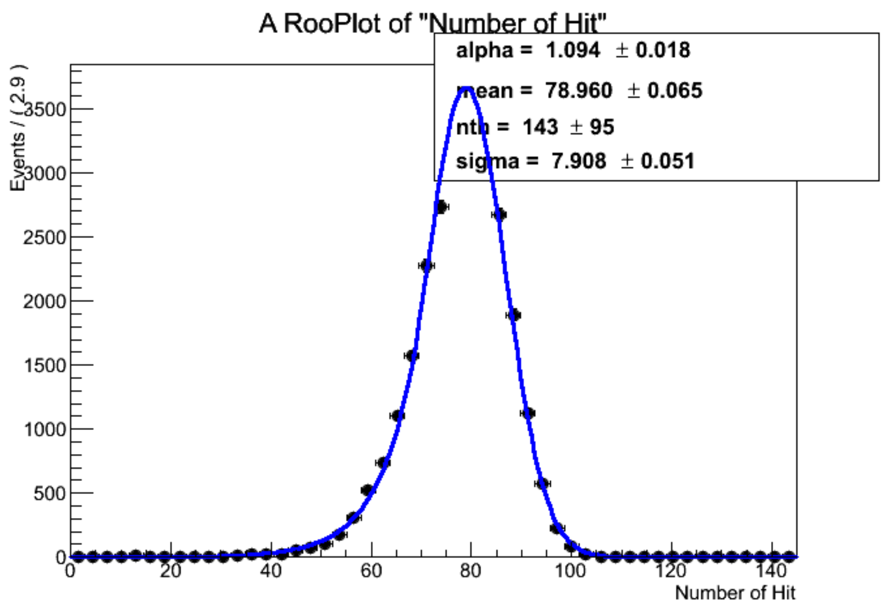
No gain correction, no channel intercalibration.

Hadronic energy resolution (IV)

- Reconstructed energy with the current analysis using SDHCAL calibration coefficient computed with the analysis shown in next slides.
- Stability of calibration against event selection.





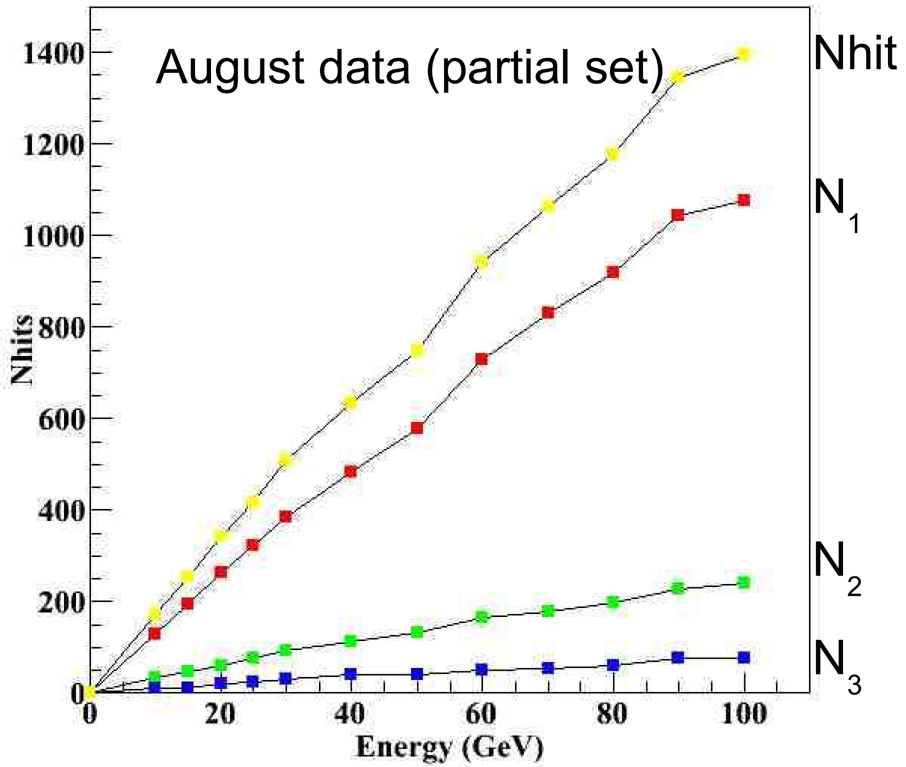


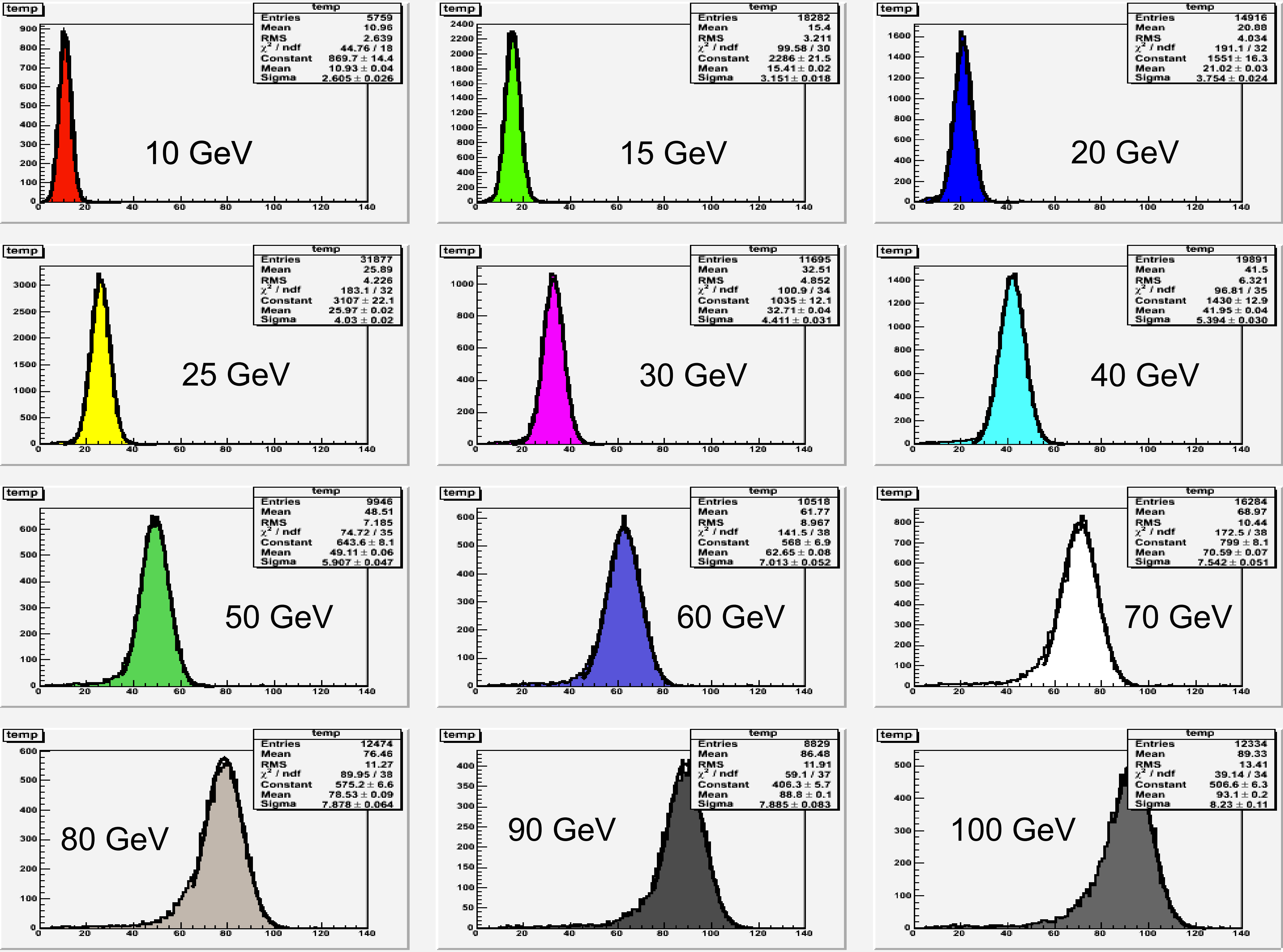
Hadronic energy resolution : determination of the SDHCAL 9 calibration coefficients

- Same clusterisation
- Event selection : shower start in first 5 layer, L>0.2, FDL<0.085, at least 5 layer hits, a mean of at least 5 hits per layer and the shower should be around the detector center.
- Energy calibration parameters obtained by minimizing

$$chi^2 = \sum_{event} (E - E_{rec})^2$$

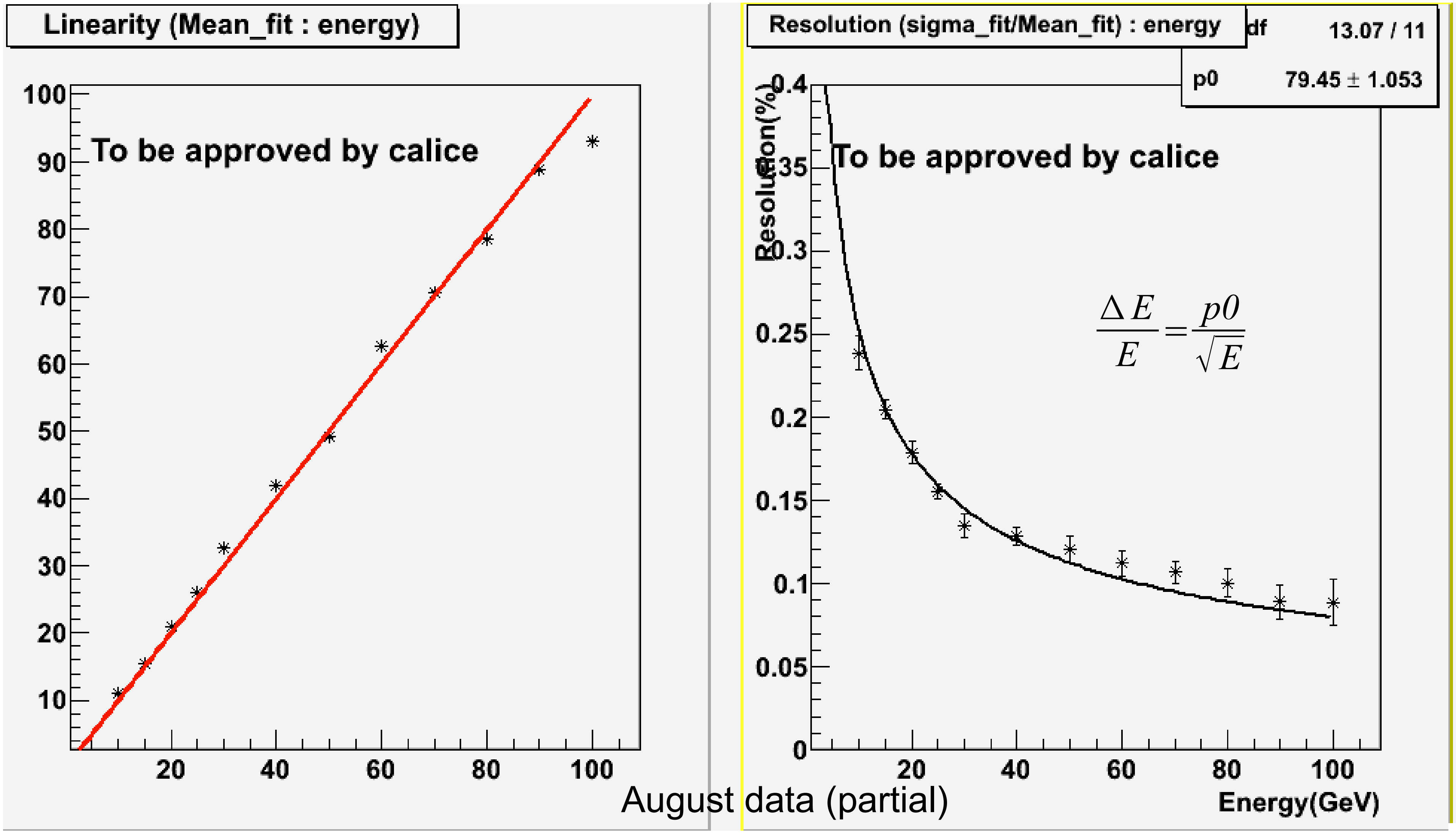
$$E_{rec} = a*N_1 + b*N_2 + c*N_3 \text{ where } a = a_0 + a_1*Nhit + a_2*Nhit^2 \text{ ; same for } b \text{ and } c$$





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

Hadronic energy resolution (V)

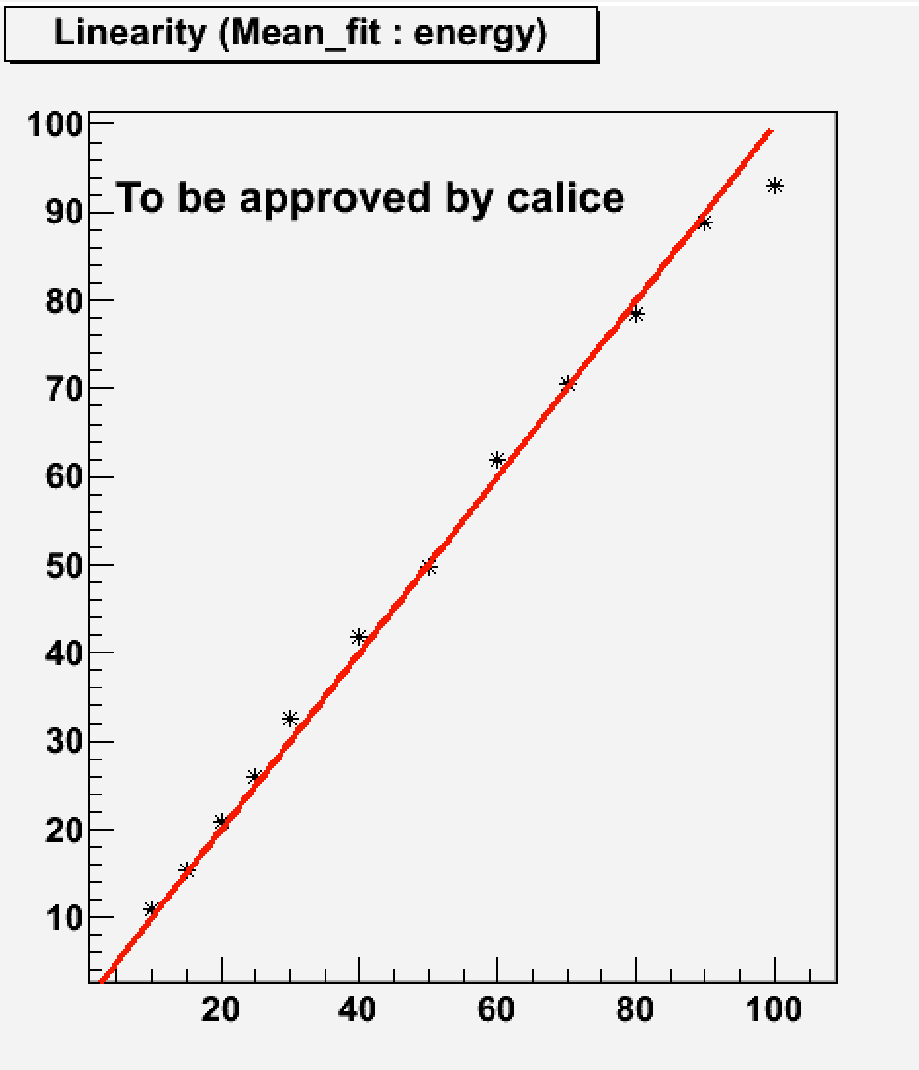


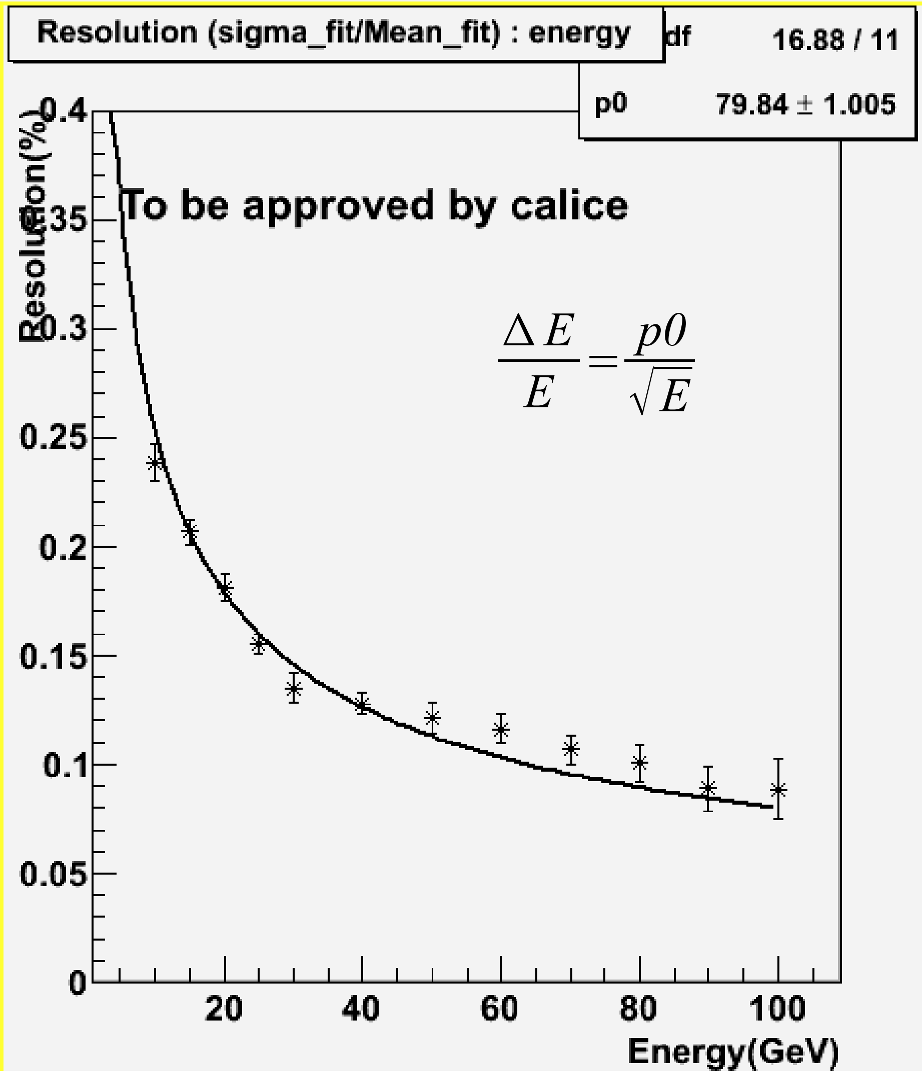
August data (partial)

No gain correction, no channel intercalibration.

Hadronic energy resolution (VI)

August (partial set)+May data using the calibration based on august data.



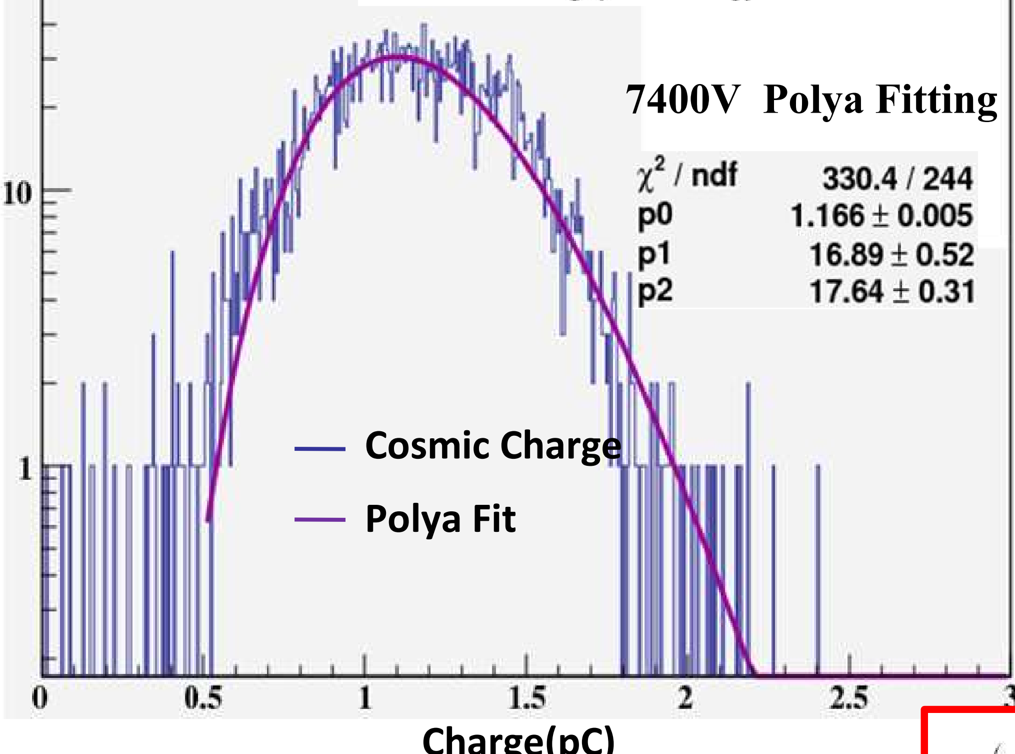


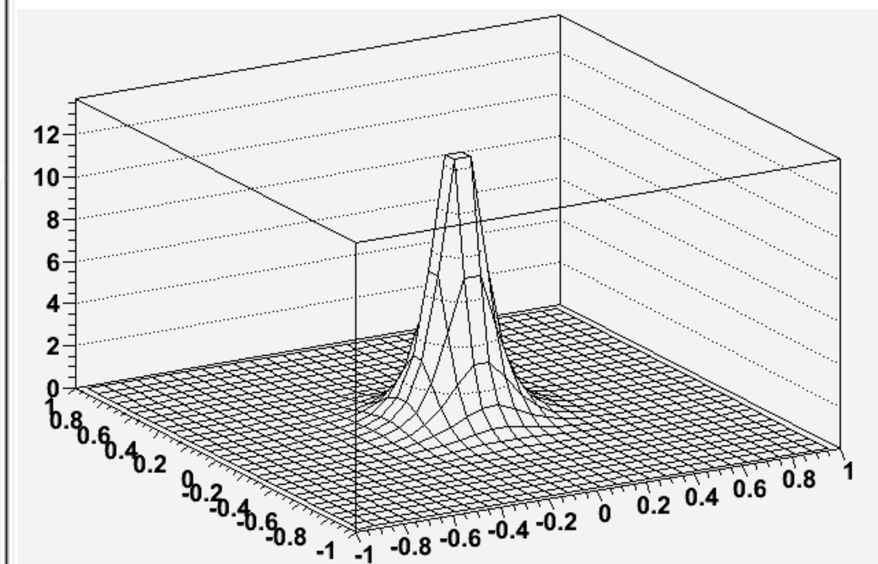
No gain correction, no channel intercalibration.

Comparison with simulation (I)

- Use standalone GEANT4 application to simulate the prototype.
- Digitisation included in the prototype

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

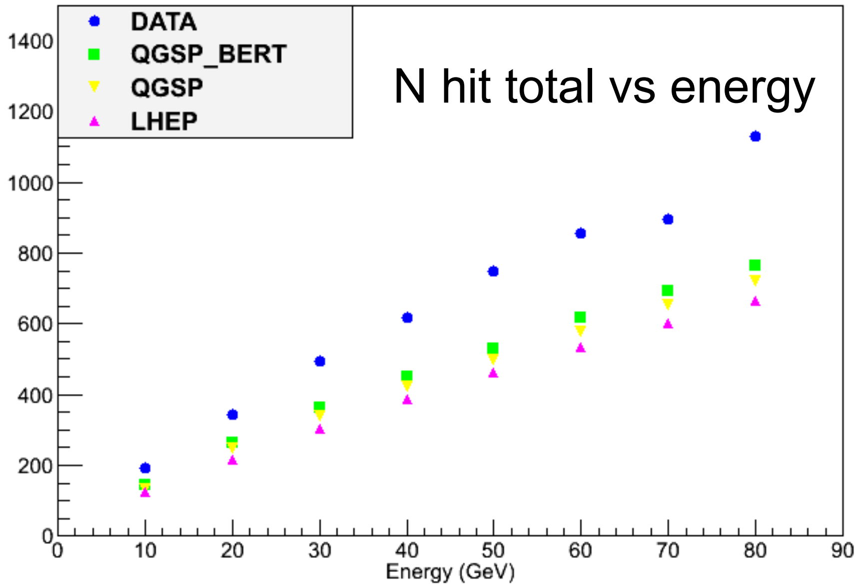


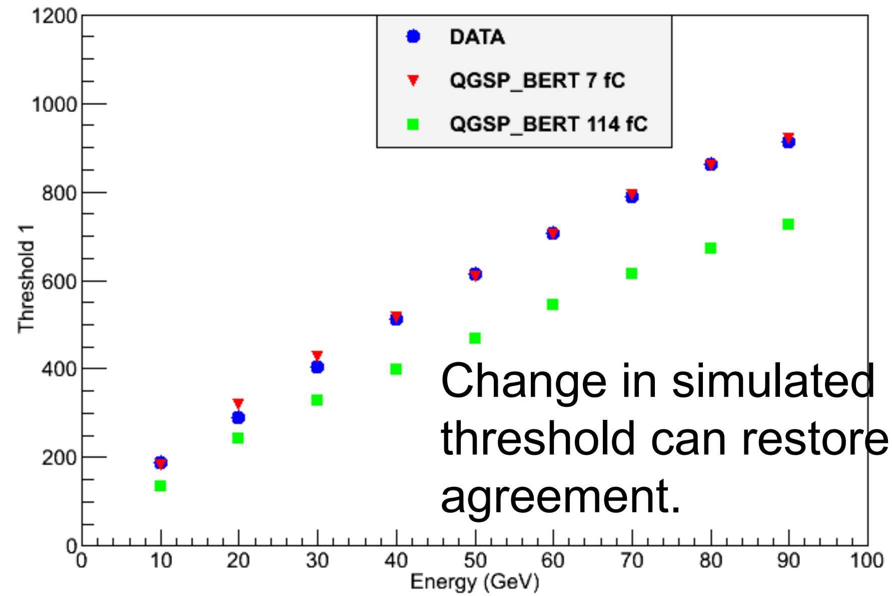


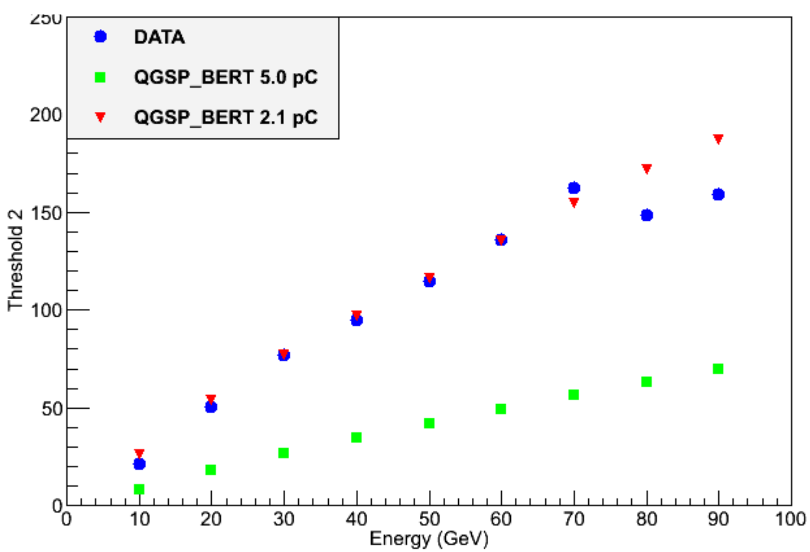
$$\sigma(x,y) = c\frac{-q}{2a}\frac{1}{\cosh\left(\pi\frac{\sqrt{(x-x_0)^2+(y-y_0)^2}}{a}\right)}$$

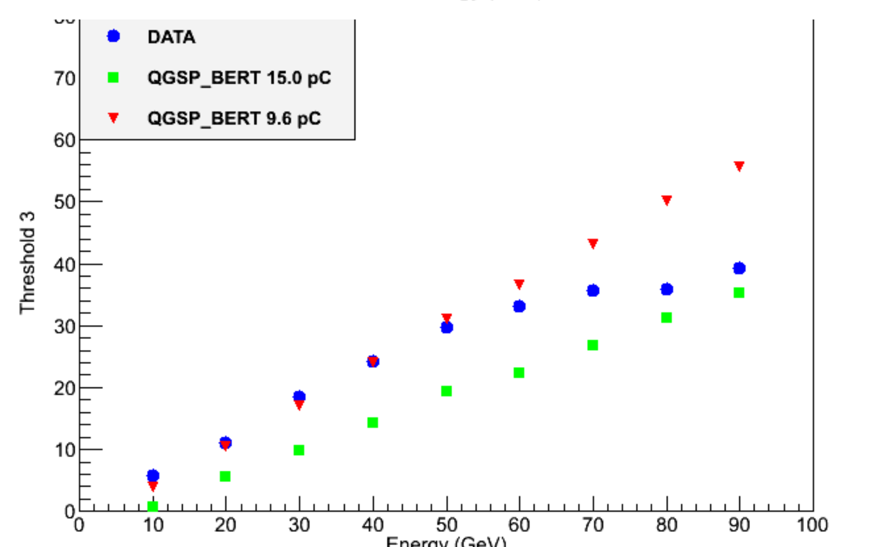
Comparison with simulation(II)

- Compare GEANT4 physics lists with data



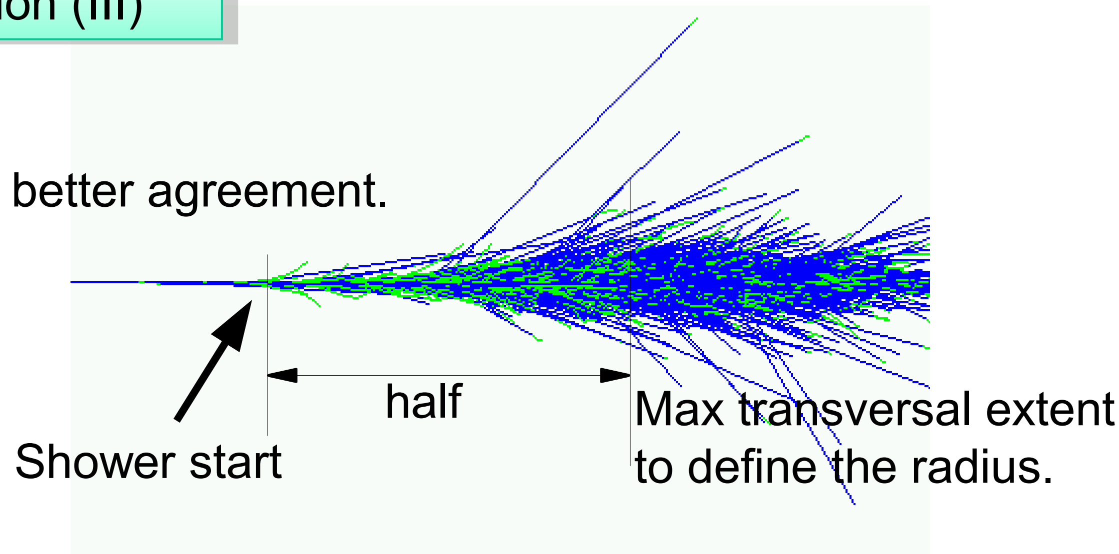


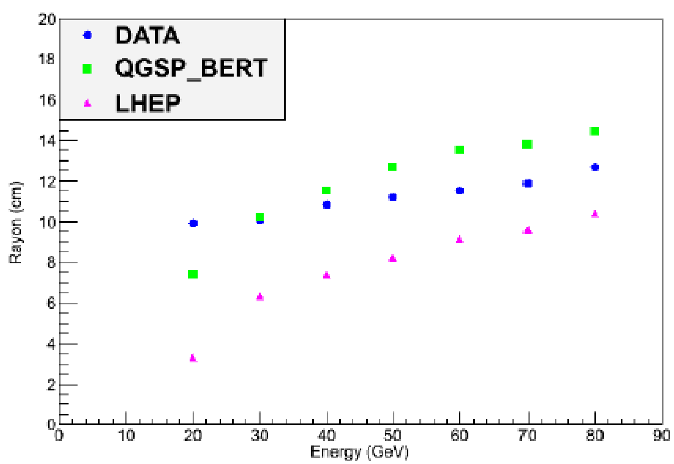




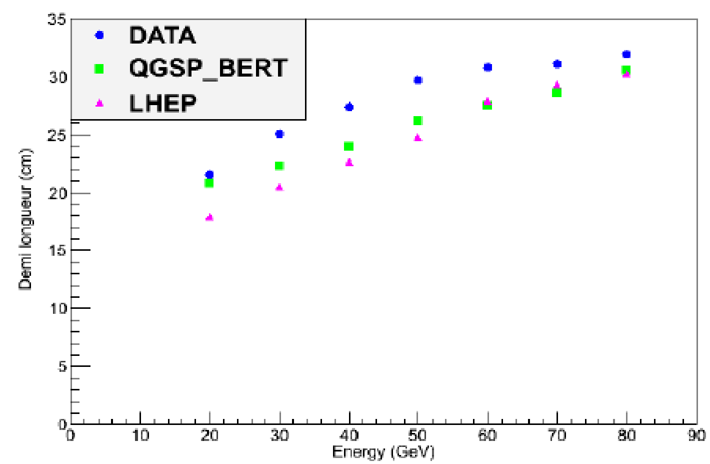
Comparison with simulation (III)

- Shower shape variable in better agreement.





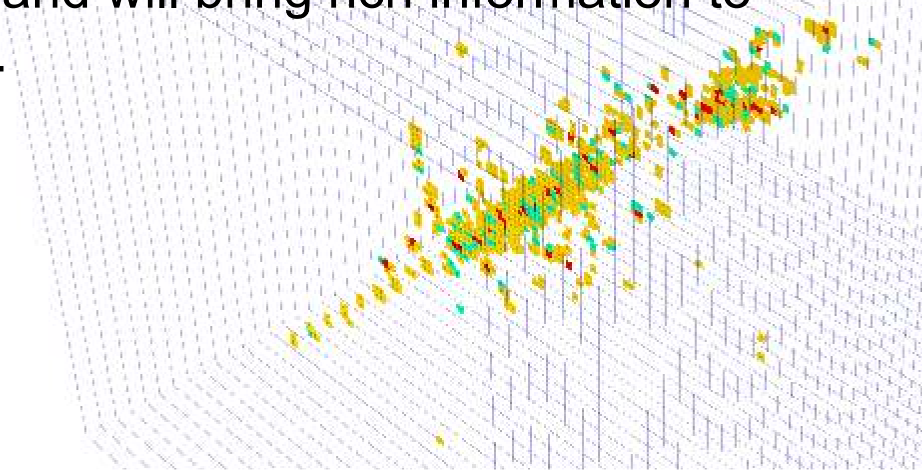
Result of the variable Radius



Result of the variable Half

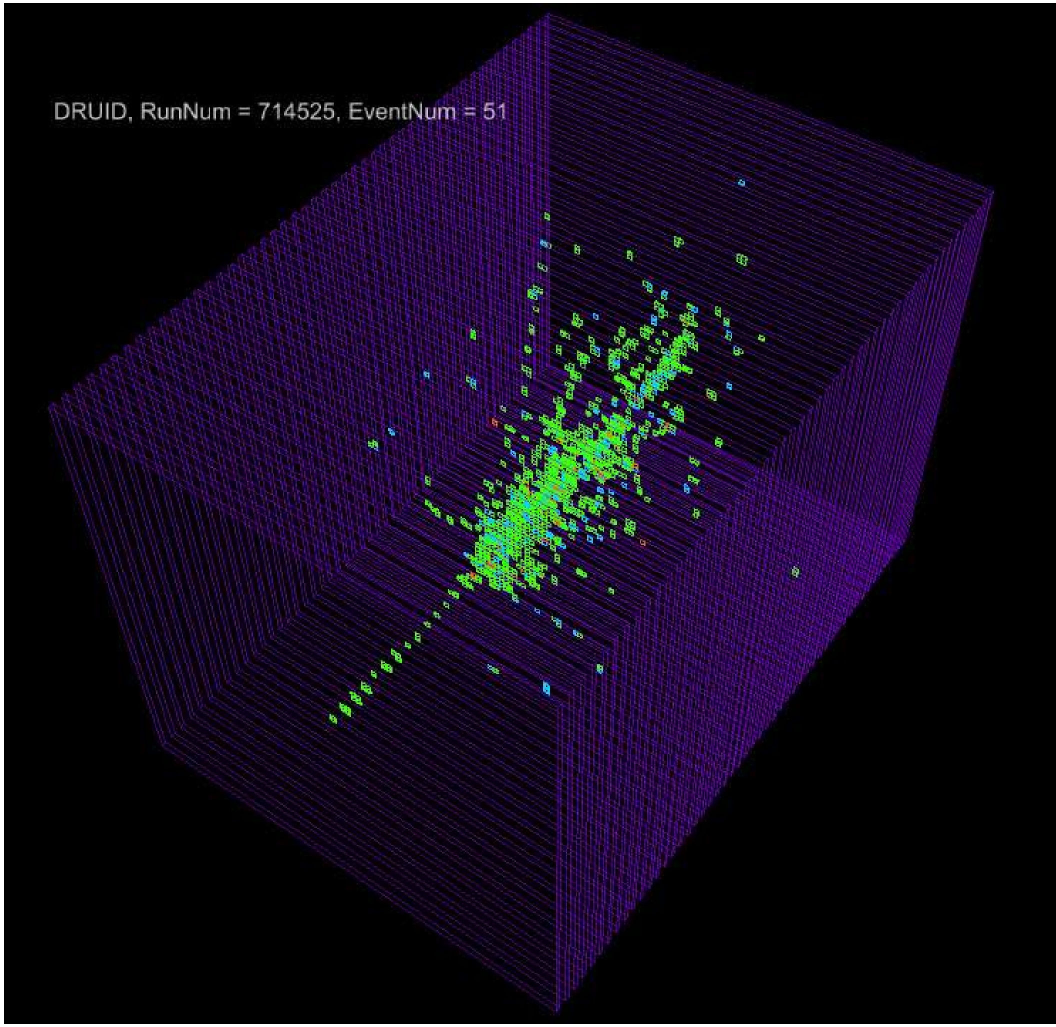
Conclusion and prospects

- The **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 energy resolution**.
- Comparison with simulation is ongoing and will bring rich information to better understand the hadronic showers.



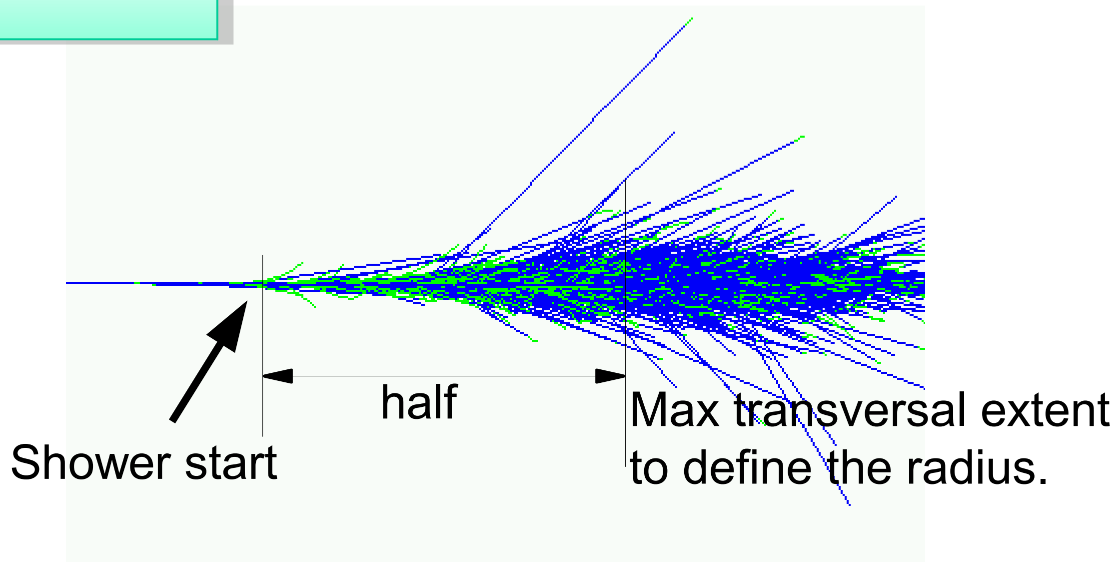
Conclusion and prospects

- Gain correction will be applied in next TB in November to assess its benefit (noise, dead DAQ time, more statistics)
- We would like to use the MicroMegas of our LAPP colleagues to build a tail catcher for out next TB.
- We would like also to have the physics ECAL (either SiW or ScW) prototype in front.
- We will start building large GRPC (2-3 m^2) to be read out with the HardRoc3.



Backups

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.

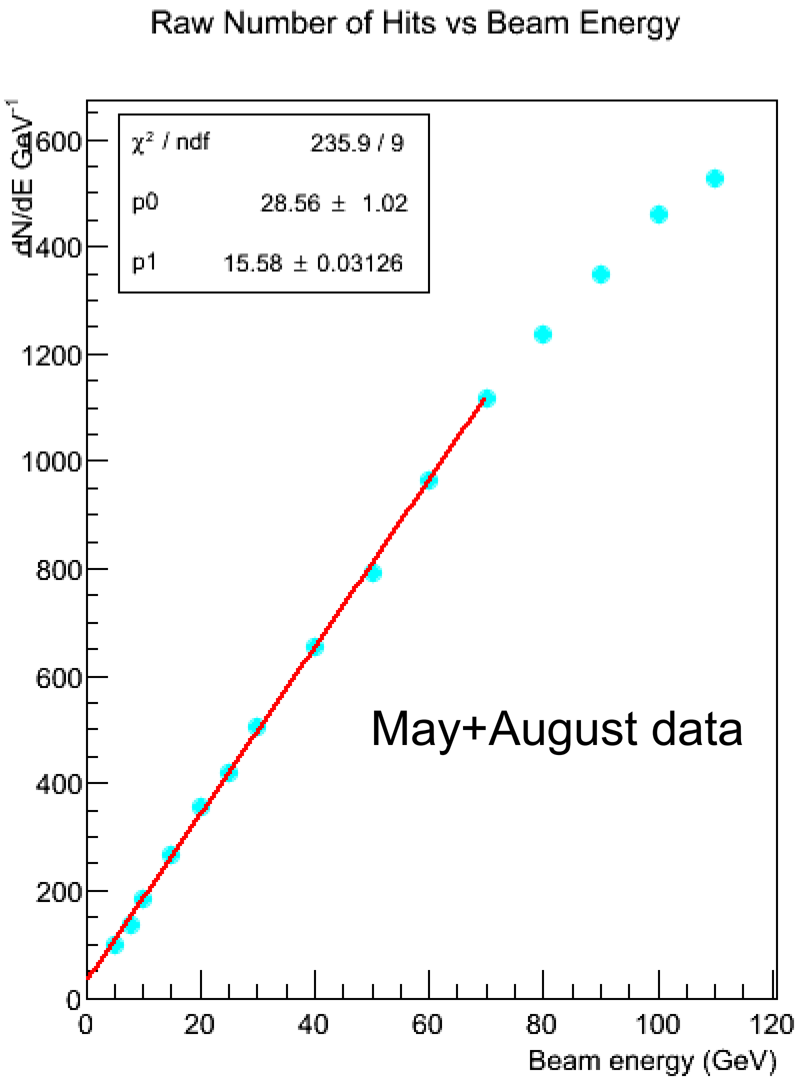
Then for each layer, clusterise the hits, removing hits which are at more than 3 rms (spatial distribution) from the center of gravity.

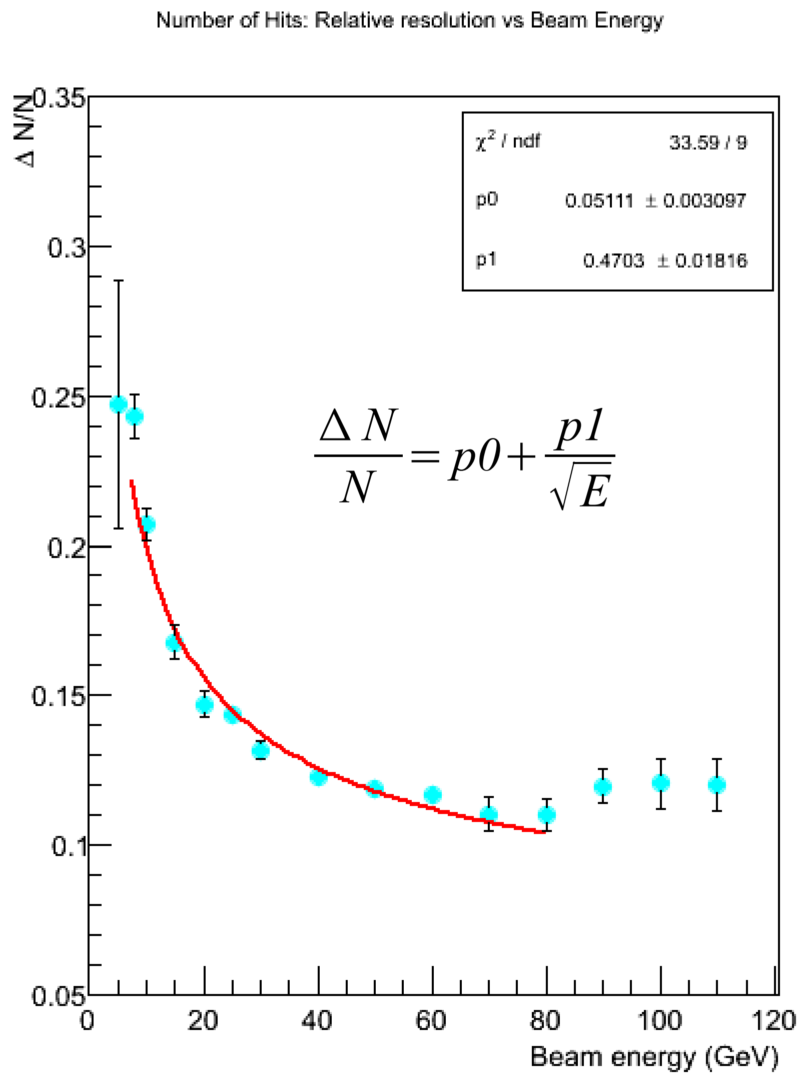
Find the layer which has the biggest spatial rms of the hit distribution. That rms is the radius.

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

Hadronic energy resolution : Wigmans'style(I)

Just using the number of hits



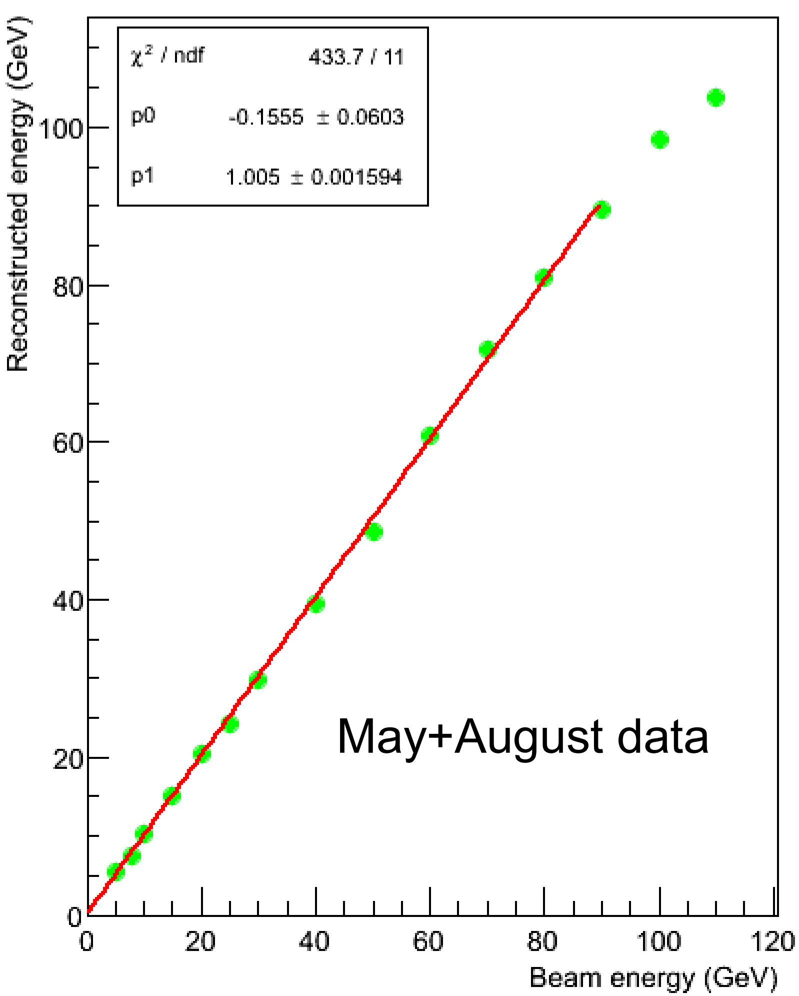


$$\frac{\Delta N}{N} = p0 + \frac{p1}{\sqrt{E}}$$

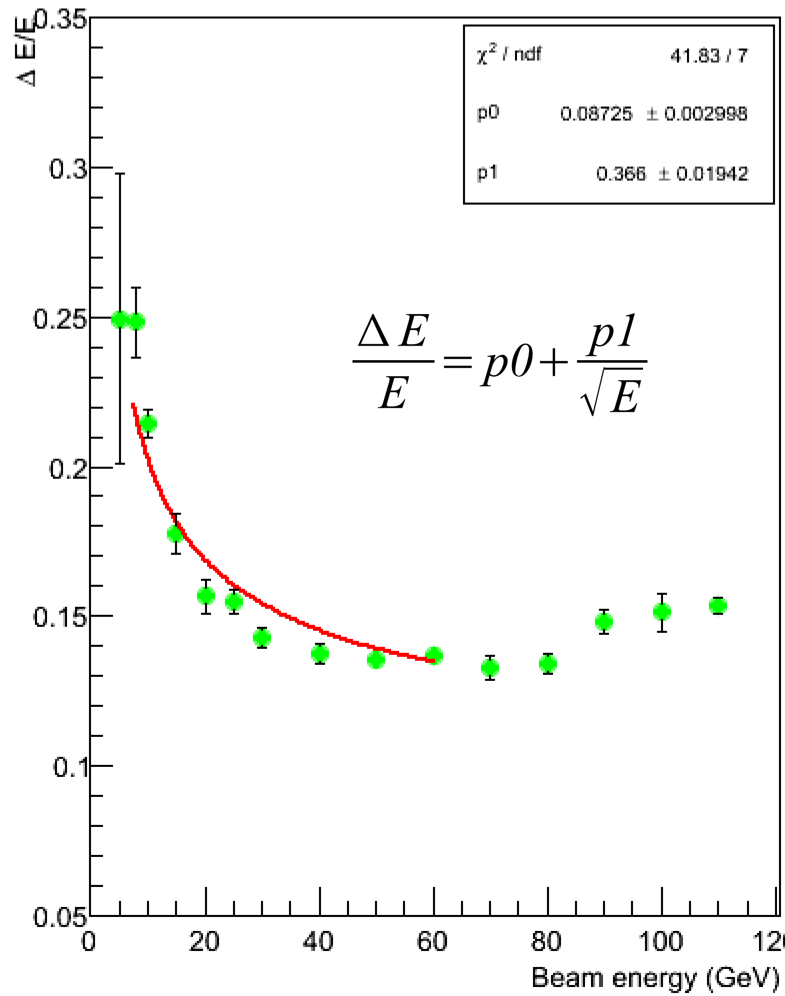
Hadronic energy resolution Wigmans' style(II)

DHCAL : E= a Nhit with a= a0+a1*Nhit

DHCAL mode: Reconstructed energy vs Beam Energy



DHCAL mode: Relative resolution vs Beam Energy



Hadronic energy resolution Wigmans' style(III)

SDHCAL :E= a*N1+b*N2+c*N3 with a,b,c quadratic in Nhit :
a=a0+a1*Nhit+a2*Nhit*Nhit