Interactions of hadrons in the SiW ECAL (CAN-025)

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Introduction

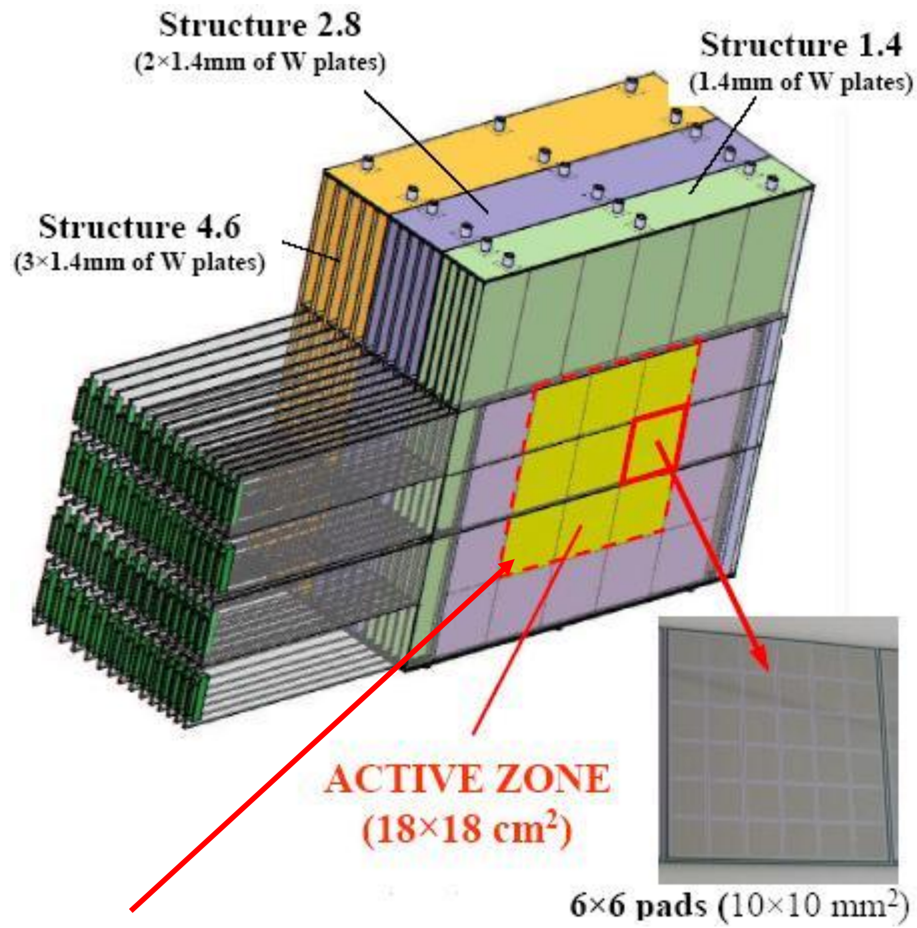
- Studying interactions of hadrons naturally supports the development of Particle Flow Algorithms (PFA) with a better knowledge of hadronic showers
- Our goal : analysis and comparison of interactions of pions in the SiW ECAL using test beam data samples and Monte Carlo simulations
- Today : draft of CAN paper submitted, answers to the Editorial Board are given, in particular concerning the optimisation of the algorithm to find the interaction layer and its stability

Outline

- The SiW ECAL (in 2008)
- The test beam at FNAL (May & July 2008)
- MC simulations
- How to find interactions ?
- Classification
- Optimisation
- Rates of interaction
- Conclusions

The SiW ECAL in 2008

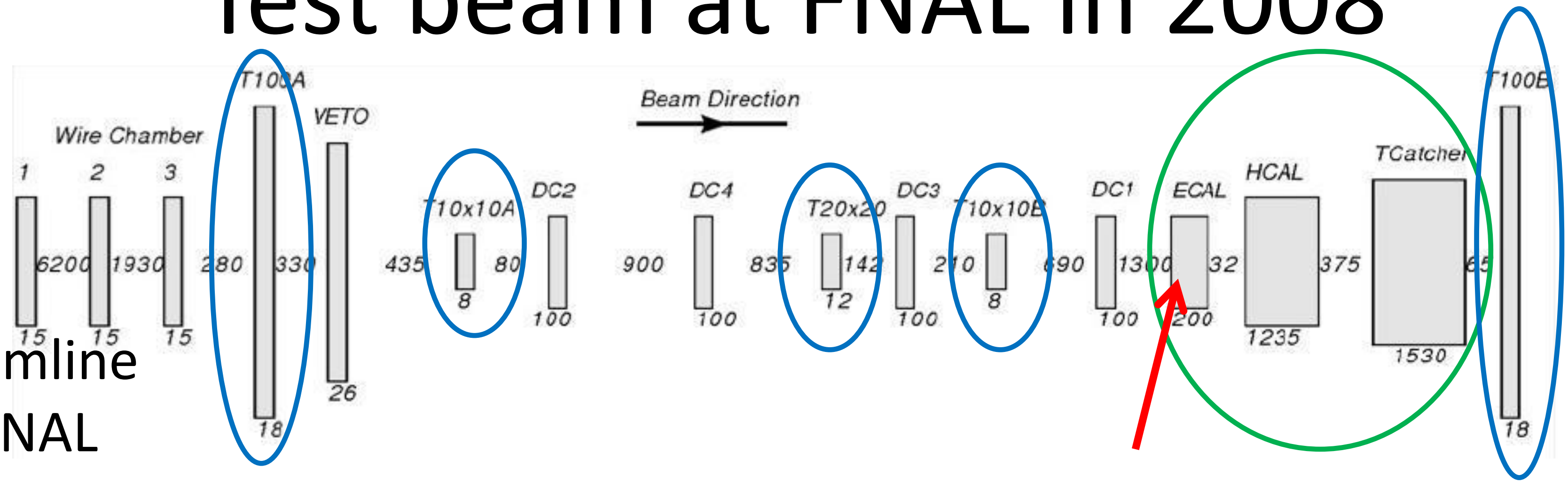
- Fully equipped ECAL
- 3 x 3 wafers of 6 x 6 pads
- Sensors = Si pixels of 1 cm x 1 cm → tracking possibilities
- Absorber = W
- 30 layers in 3 different stacks :
    - 1.4 mm of W
    - 2.8 mm
    - 3.6 mm
- ≈ 24 X_0 ≈ 1 λ_I ≈ half of the hadrons interact inside the ECAL volume



9 Si wafers

Picture of the fully equiped SiW ECAL

Test beam at FNAL in 2008



Beamline at FNAL

- 3 CALICE calorimeters installed : SiW ECAL, Analogue HCAL, TailCatcher (TCMT)
- Triggers : scintillators, Cherenkov counters
- Muon cuts added on the basis of simulated muons : < 0.6% remaining
- Ask for only one primary track found with the MipFinder
- Events left :

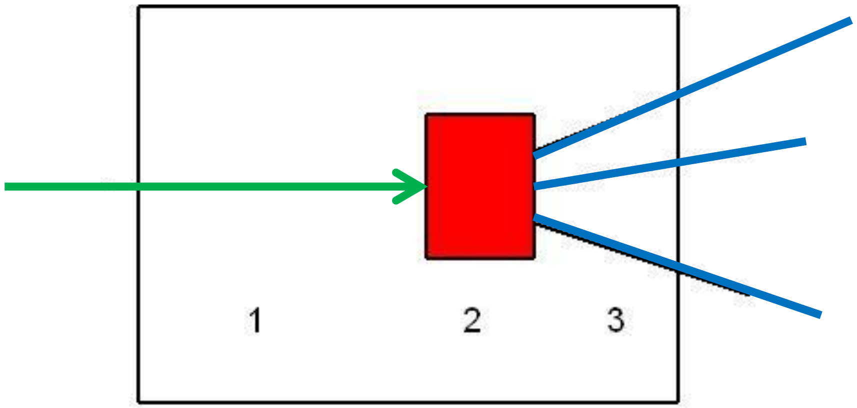
E (GeV)	2	4	6	8	10
N evts	13723	84849	55486	161522	369021

Monte Carlo simulations

- For comparisons, different physics lists were simulated
- QGSP BERT is used as reference for optimisation : no difference between physics lists is seen at this level

E (GeV)	2	4	6	8	10
QGSP BERT	Bertini				
QGS BIC	LEP				
QGSP BIC	LEP				
LHEP	LEP				
FTFP BERT	Bertini		Fritiof		

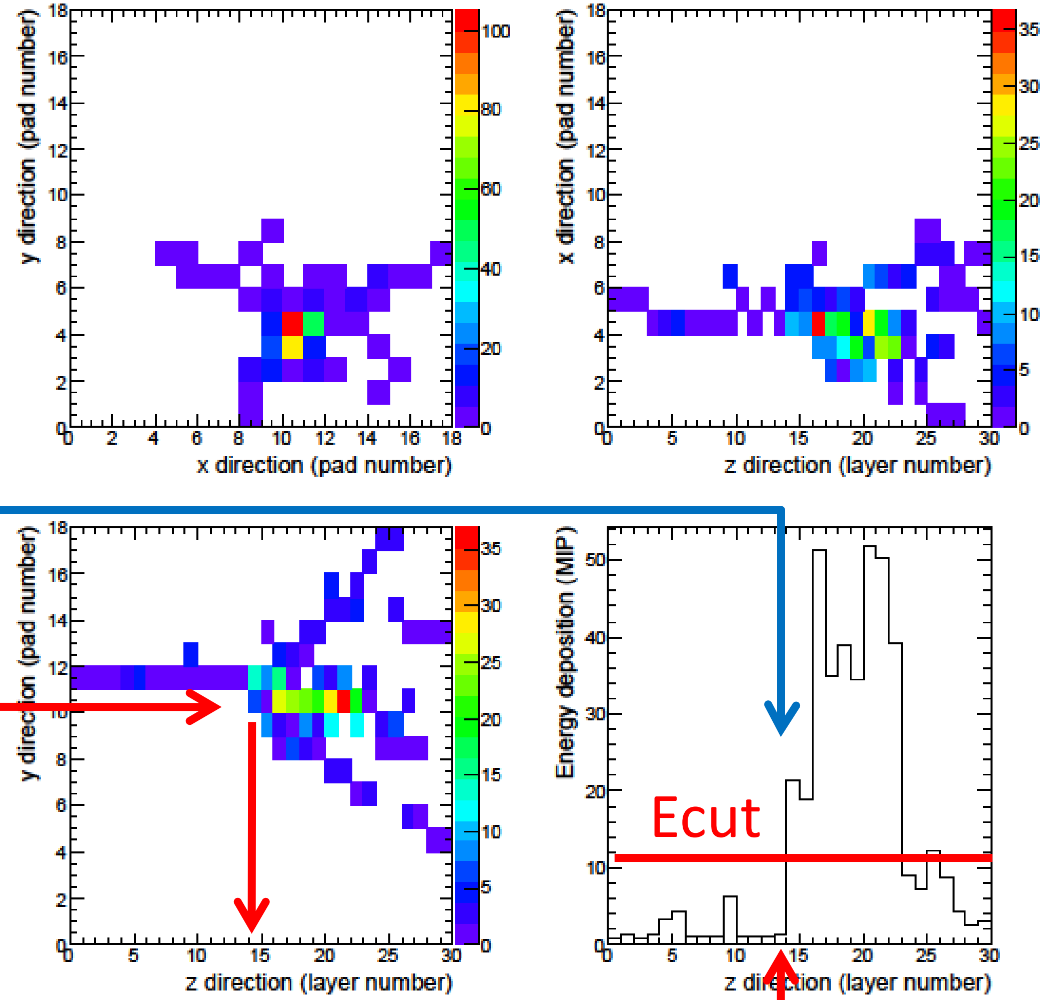
A look at interactions of hadrons



- Picture of a generic interaction in the calorimeters :
  1) A primary track enters the detector (« MipFinder »)
  2) The interaction occurs
  3) Secondaries emerge from the interaction zone

Visual examples (1/2)

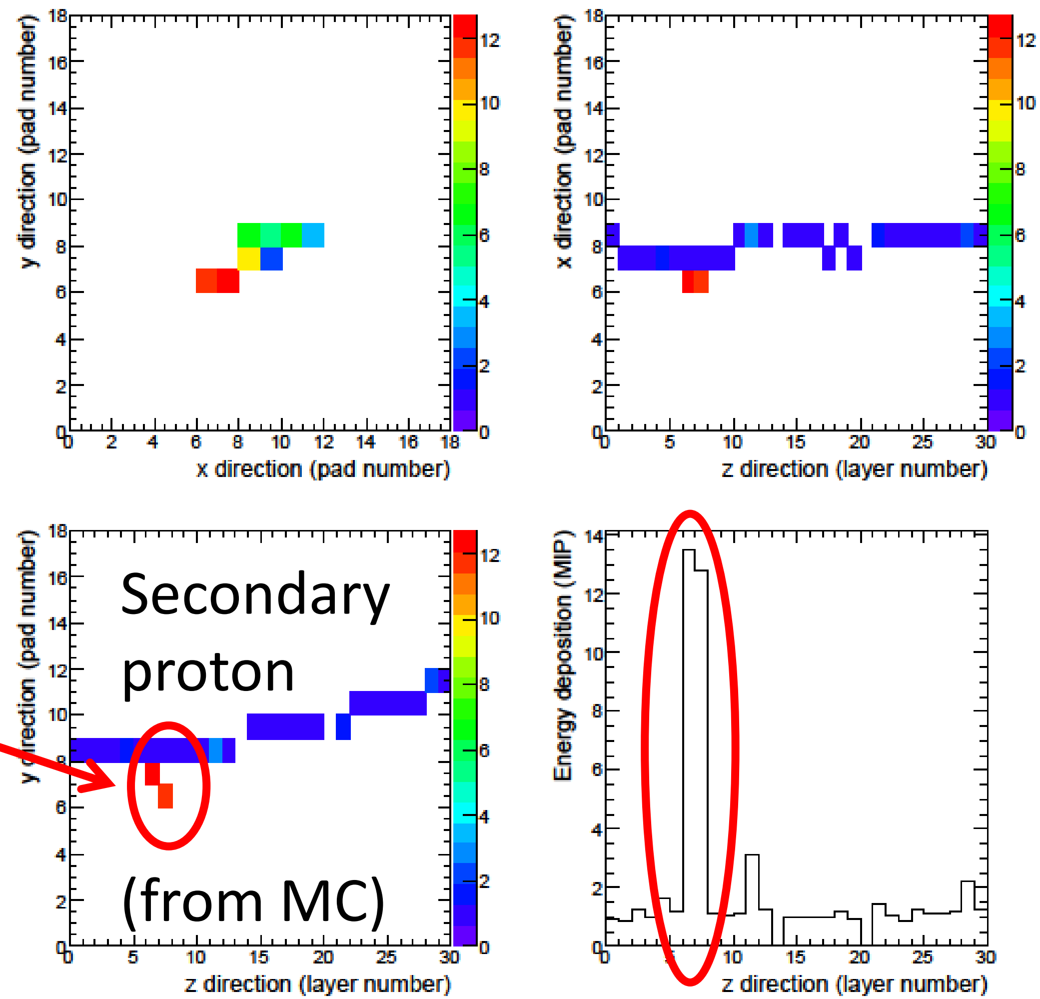
- 2D profiles of an event at 10 GeV in the SiW ECAL
- High energy deposition when the interaction starts
- Interaction layer confirmed by visual inspection
- Large number of secondaries created
- Equation to be satisfied:



$$E_i > \mathrm{Ecut}\ ,\ E_{i+1} > \mathrm{Ecut}\ ,\ E_{i+2} > \mathrm{Ecut}$$

Visual examples (2/2)

- Previous example not always valid, especially at low energies
- Sometimes, slow increase in energy
- Here, local energy deposition
- Quantified by the relative increase in energy:



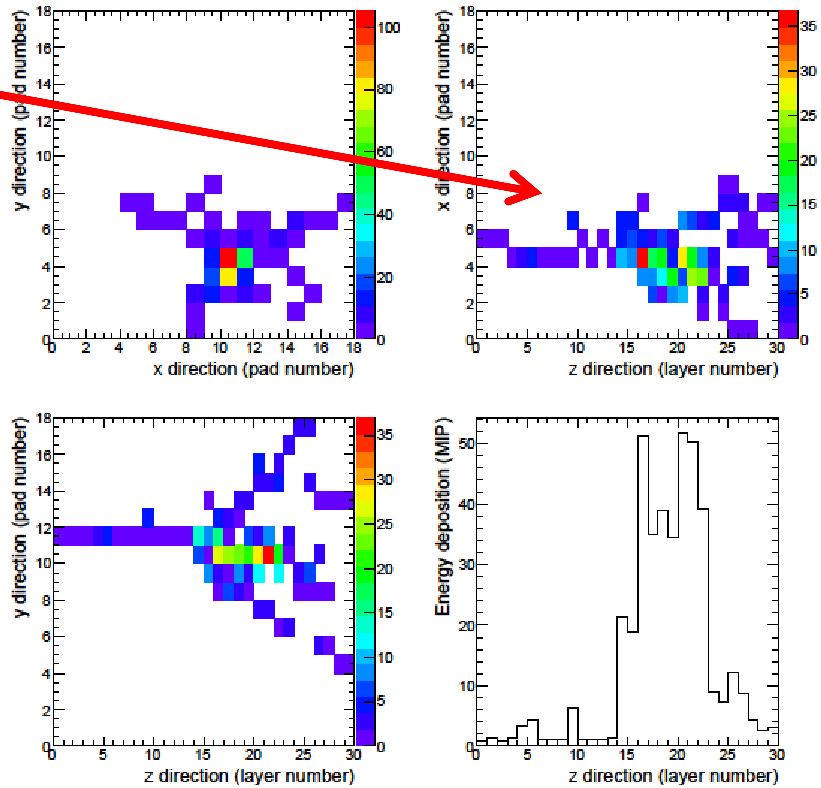
$$\frac{E_i + E_{i+1}}{E_{i-1} + E_{i-2}} > \mathrm{Fcut} \text{ and } \frac{E_{i+1} + E_{i+2}}{E_{i-1} + E_{i-2}} > \mathrm{Fcut}$$

Classification

- High energy deposition
  → « FireBall »
- Increase continues + veto for backscattering
  → « FireBall »

$$\frac{E_{i+2}+E_{i+3}}{E_{i-1}+E_{i-2}} > \mathrm{Fcut} \quad + \quad \frac{E_{\mathrm{around},i}}{E_i} > 0.5$$

Works here and meant for small energies



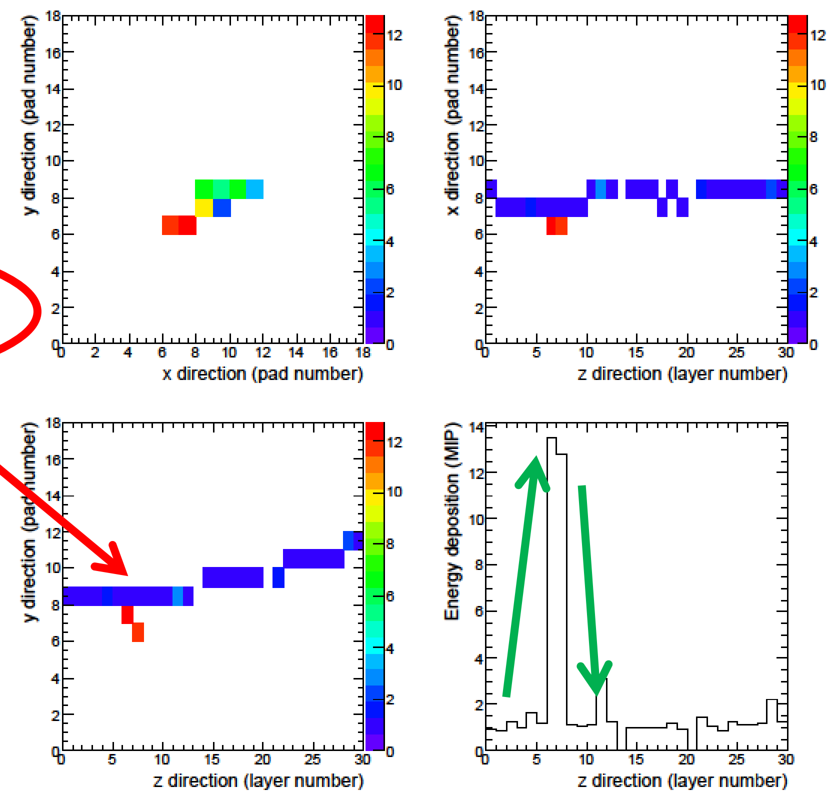
Event view of the « FireBall » type at 10 GeV

Classification

- High energy deposition
  → « FireBall »
- Increase continues + veto for backscattering → « FireBall »
- Local increase → « Pointlike »

$$\frac{E_{i+2}+E_{i+3}}{E_{i-1}+E_{i-2}} < \mathrm{Fcut}$$

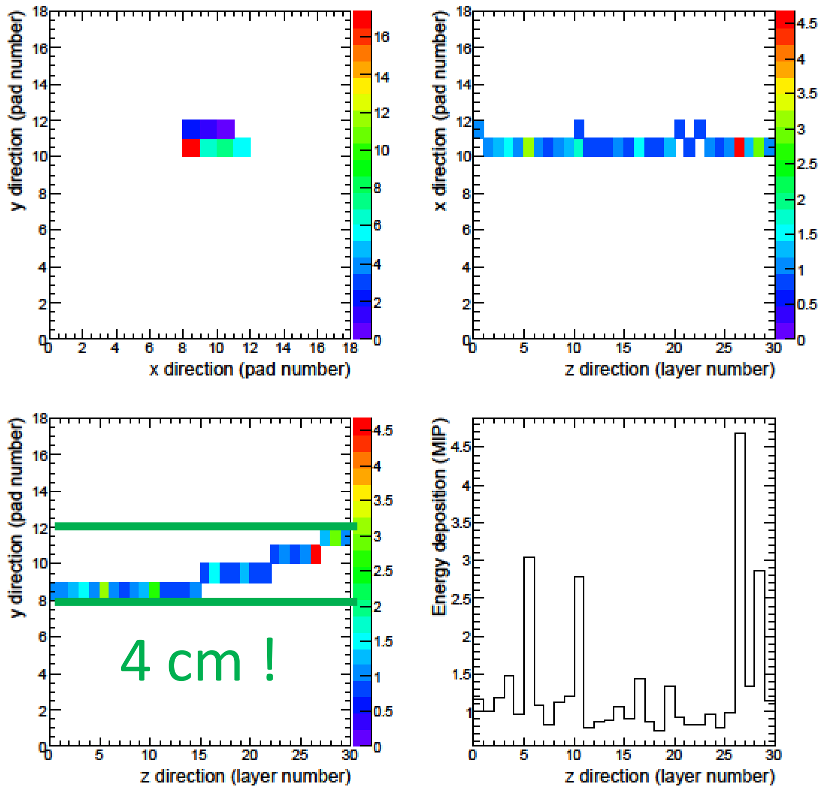
- Remark : delta rays are naturally included in « Pointlike » but contribute less than 4%



Event view of the « Pointlike » type at 2 GeV

Classification

- High energy deposition
  → « FireBall »
- Increase continues + veto for backscattering → « FireBall »
- Local increase → « Pointlike »
- Others = non interacting
  - « MIP »
  - « Scattered »
- Remark : delta rays are naturally included in « Pointlike » but contribute less than 4%



Event view of the « Scattered » type at 2 GeV

Optimisation of the cuts (with MC)

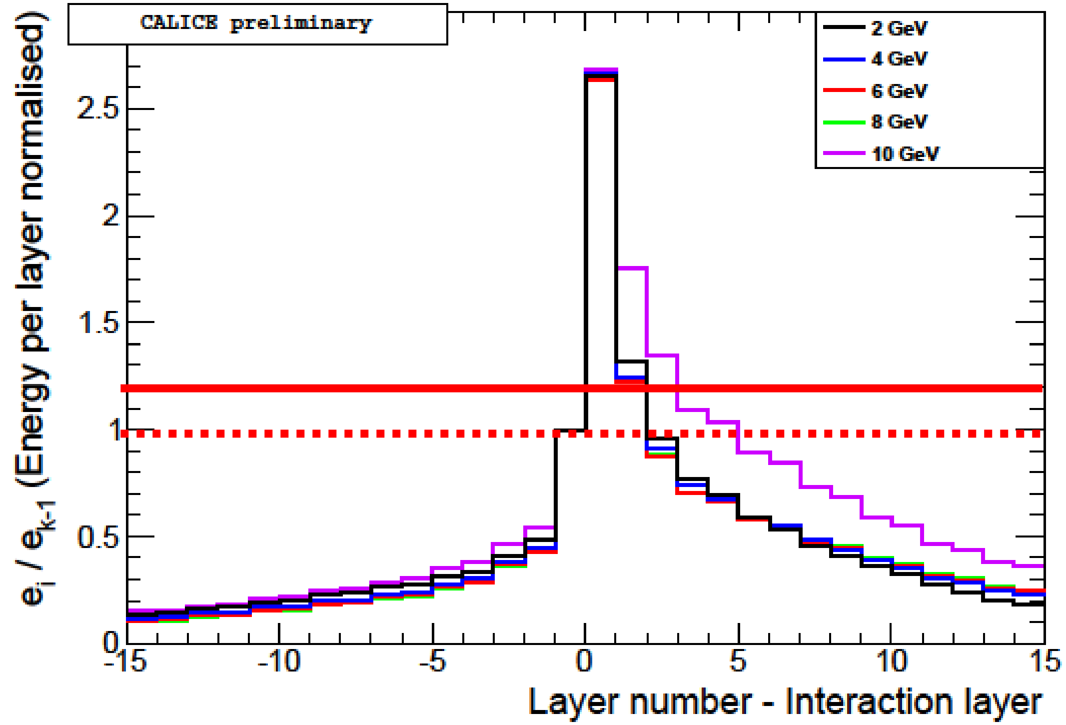
- Method: use MC to optimise 3 parameters
  - Standard deviation of « reconstructed – true » layer
  - Interaction fraction = fraction of events with interactions found
  - Purity with non interacting events = fraction of events with no interaction found
- Graphs:
  - Ecut varied from 1 to 20 by steps of 1 unit
  - Fcut varied from 1 to 10 by steps of 0.5 unit

Interaction fraction : defining interacting and non interacting events

- Simulated events
- Interaction layer known from the endpoint of the primary

•Energy per cell / energy in the last layer before interaction for each layer

- Interacting events are selected with $e_k > 1.2 \times e_{k-1}$ (thus « Scattered » events will not be taken)
- Other events are non interacting events and used to calculate purity



Interaction fraction = fraction of interacting events found

→ should contain « FireBall » + « Pointlike »

Purity = fraction of non interacting events found

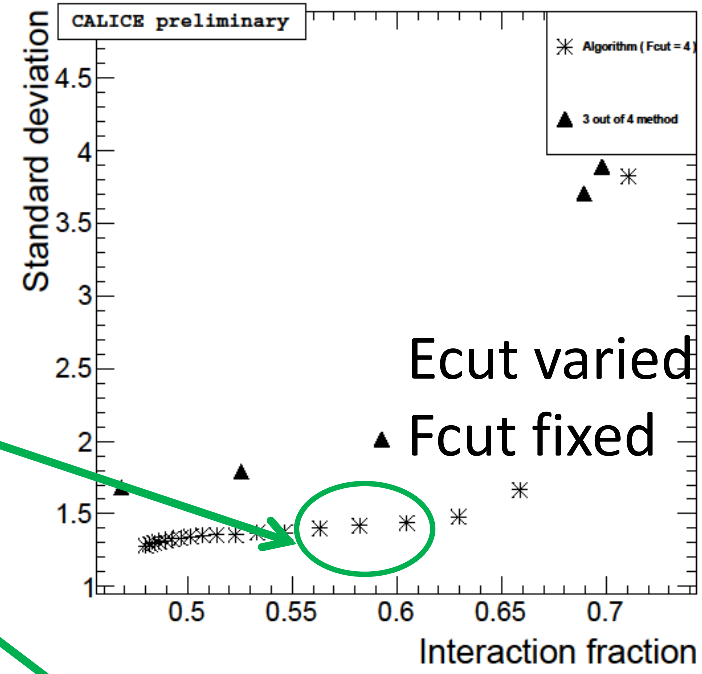
→ should contain « MIP » + « Scattered »

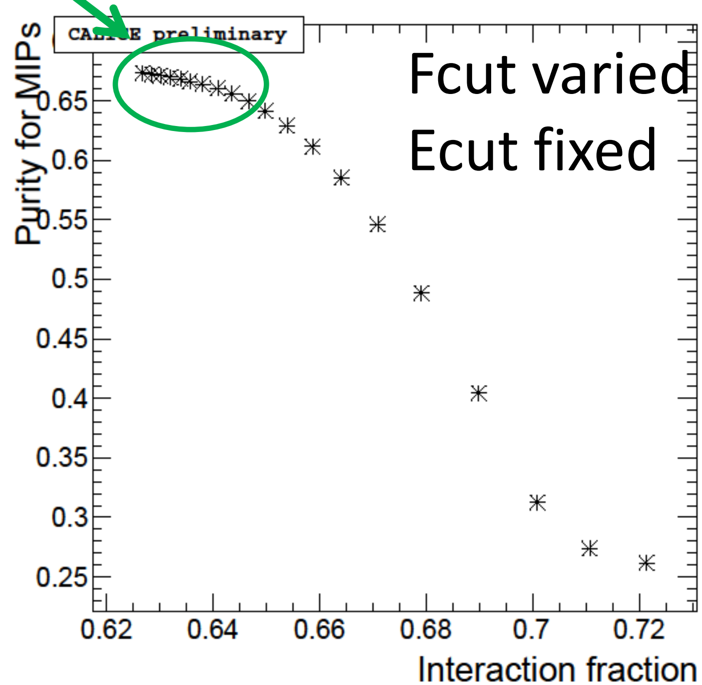
Example at 2 GeV

- Areas of interest
- Results :

E (GeV)	Ecut	Fcut
2	3	4 → 6
4	8	5.5 → 6
6	10	6.5 → 6
8	13	7 → 6
10	10	6 → 6

choice to merge all Fcuts for simplicity since changes have little systematics



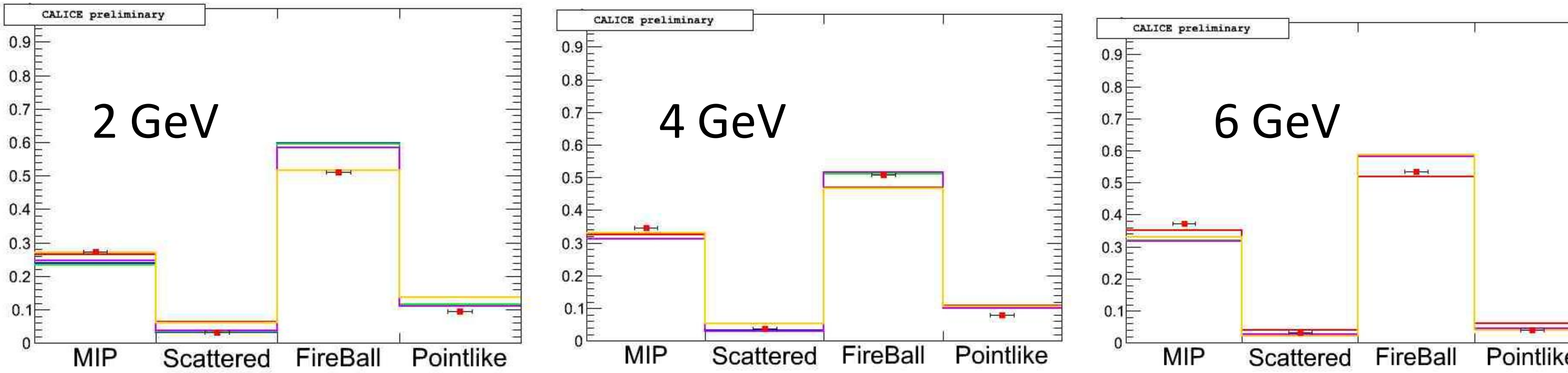


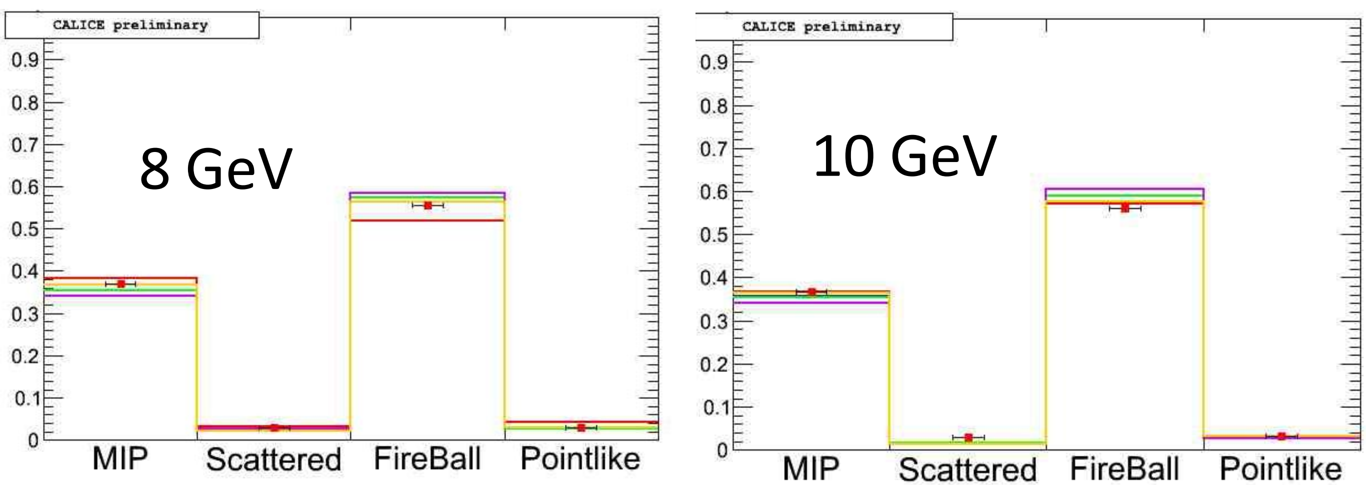
Efficiencies after optimisation

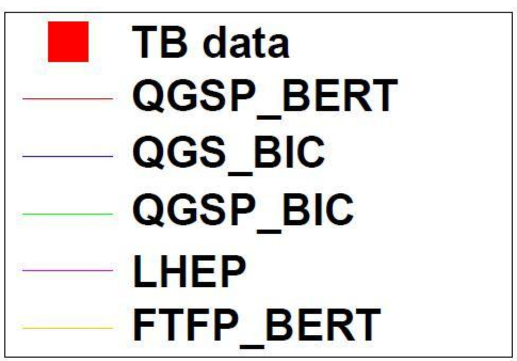
- The efficiency to find the true interaction layer within ±1 and 2 layers is the result of the optimisation.
- It is compared with another method.

E (GeV)	η (±1)	η (±2)	η (3-4, ±2)
2	56 %	67 %	28 %
4	60 %	73 %	61 %
6	62 %	76 %	69 %
8	64 %	78 %	71 %
10	72 %	84 %	76 %

Rates of interactions







Small systematics with Ecut and Fcut in ±1

Interaction rates similar between physics lists

Conclusions

- Interactions of hadrons in the SiW ECAL at energies from 2 GeV to 10 GeV are found and classified into 4 kinds, using energy deposition and high granularity
- Efficiencies to reconstruct the interaction layer within ± 2 layers are > 67 %
- Systematic effects have been checked and are small, O(1%) (muons, physics list, cuts)
- The CAN note is being reviewed and discussions are ongoing

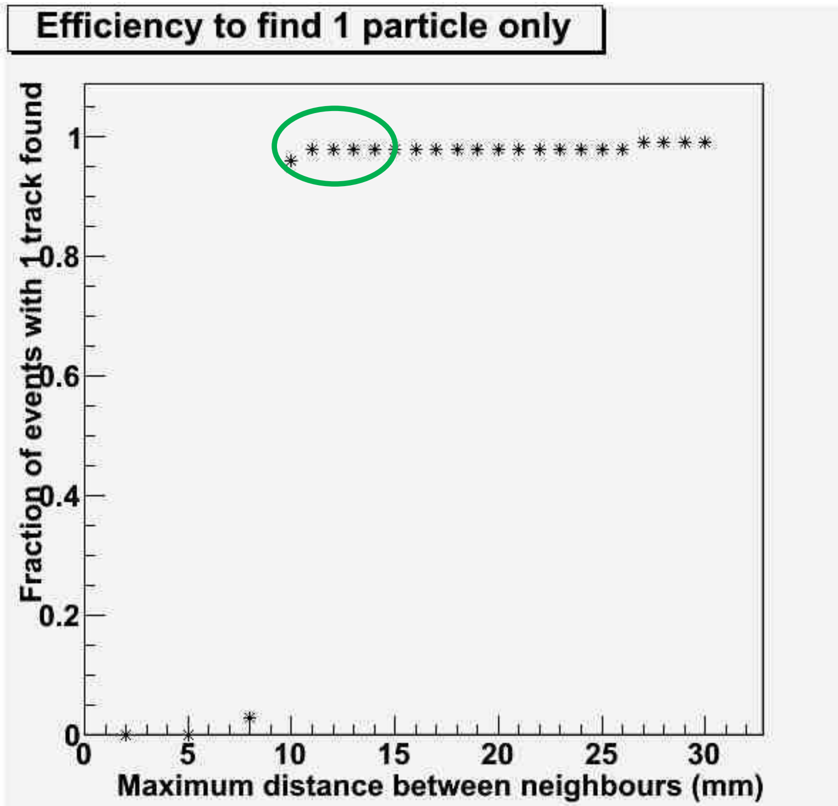
Backup slides

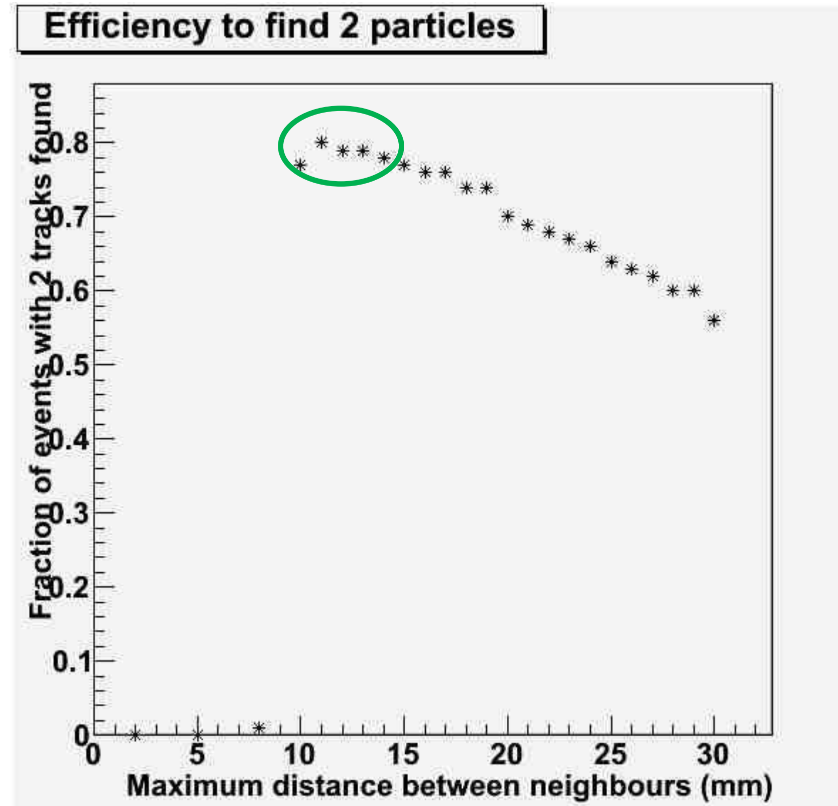
Efficiency to select events with one particle

Cuts against noise

Systematics due to the physics list

Efficiency of the MipFinder

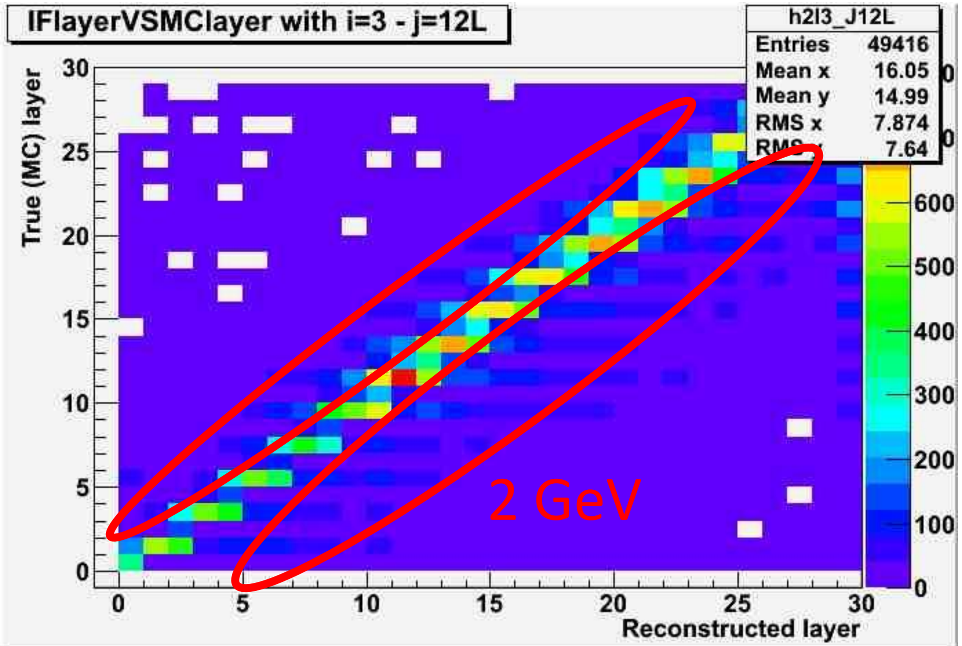


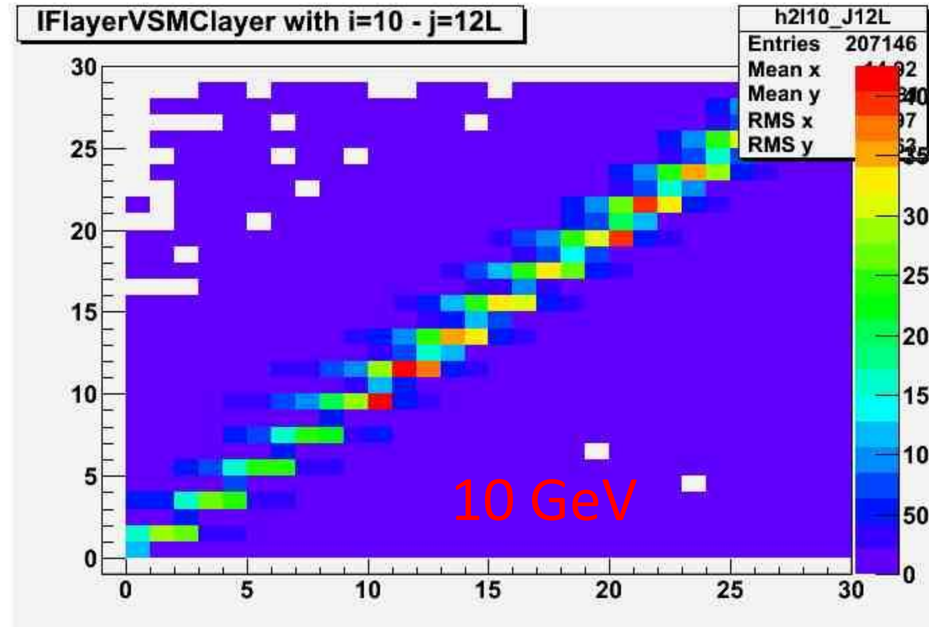


Efficiencies to find the correct number of particles entering the ECAL

- Efficiencies : 99% with one track, 80% with two tracks (muons)
- 12% of irreducible background for overlaid muons (enter the same cell)

2D correlations between reconstructed and true layer



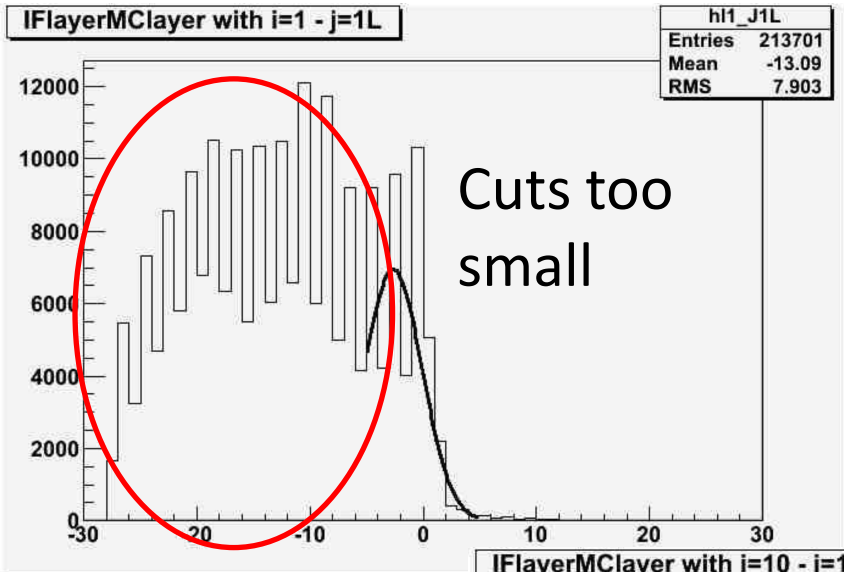


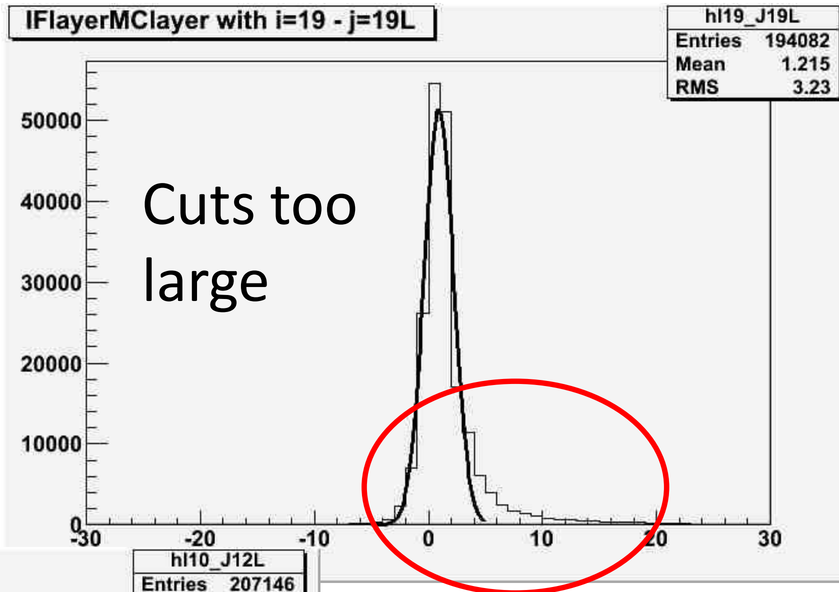
Horizontal axis = Reconstructed layer

Vertical axis = True (MC) layer (given by the endpoint of the primary particle)

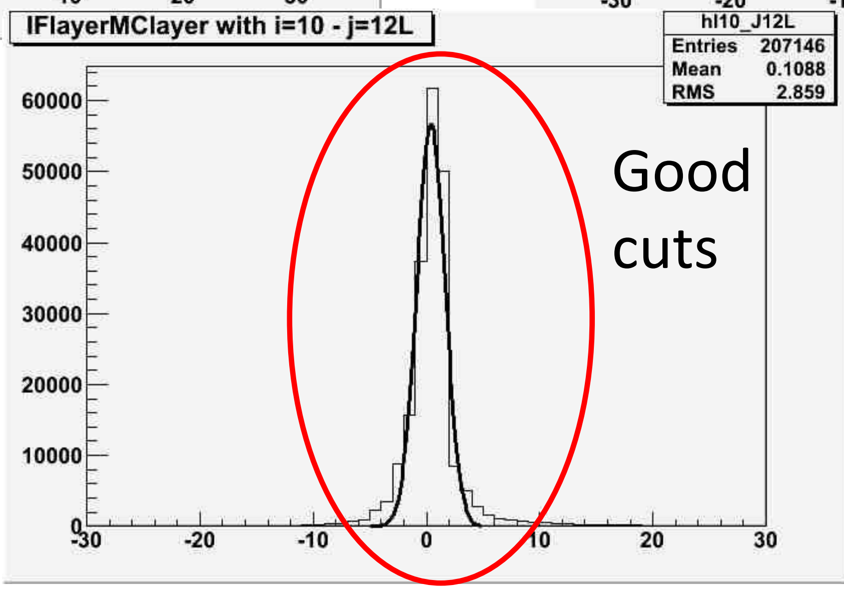
Good at 10 GeV, more difficult at 2 GeV : smaller depositions, but fluctuations

Standard deviation : Reconstructed layer – True (MC) layer



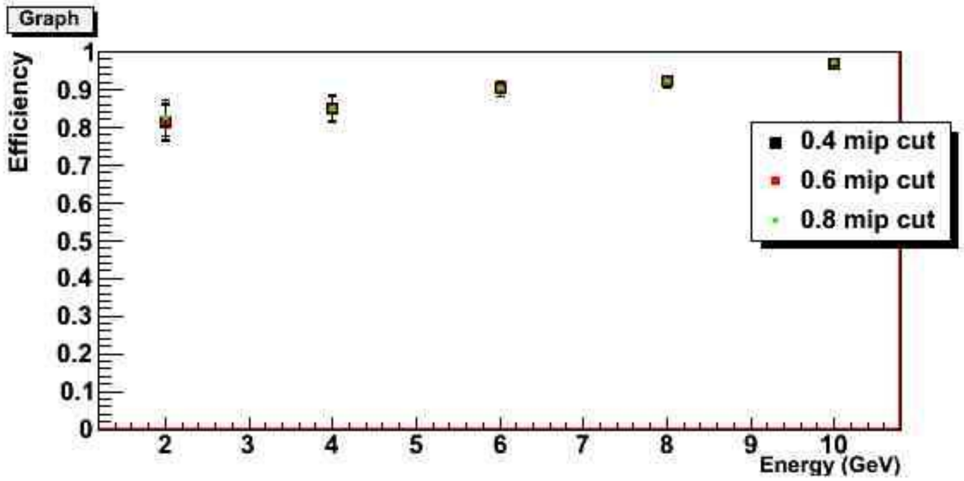


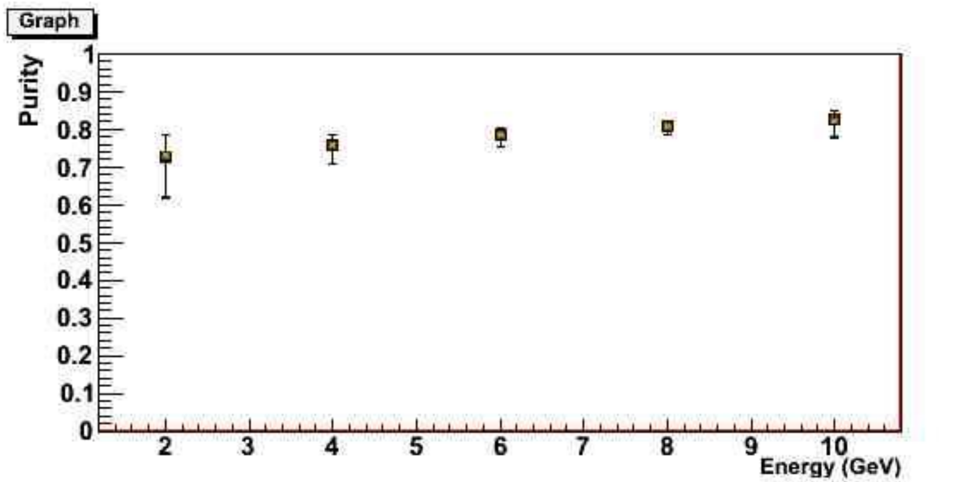
Measure of the standard deviation with different Ecut/Fcut



Cuts against noise

- Efficiency (interaction fraction) and purity for each energies
- Calculated with different cuts on the minimum cell energy (mip cut)
- Not sensitive
- Error bars are systematics from (Ecut±1,Fcut±1)





Systematics due to physics lists

- Efficiency (interaction fraction) and purity are calculated for all physics lists
- Error bars are systematics due to (Ecut±1,Fcut±1)
- Differencies are < systematics due to (Ecut,Fcut)