



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

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Outline

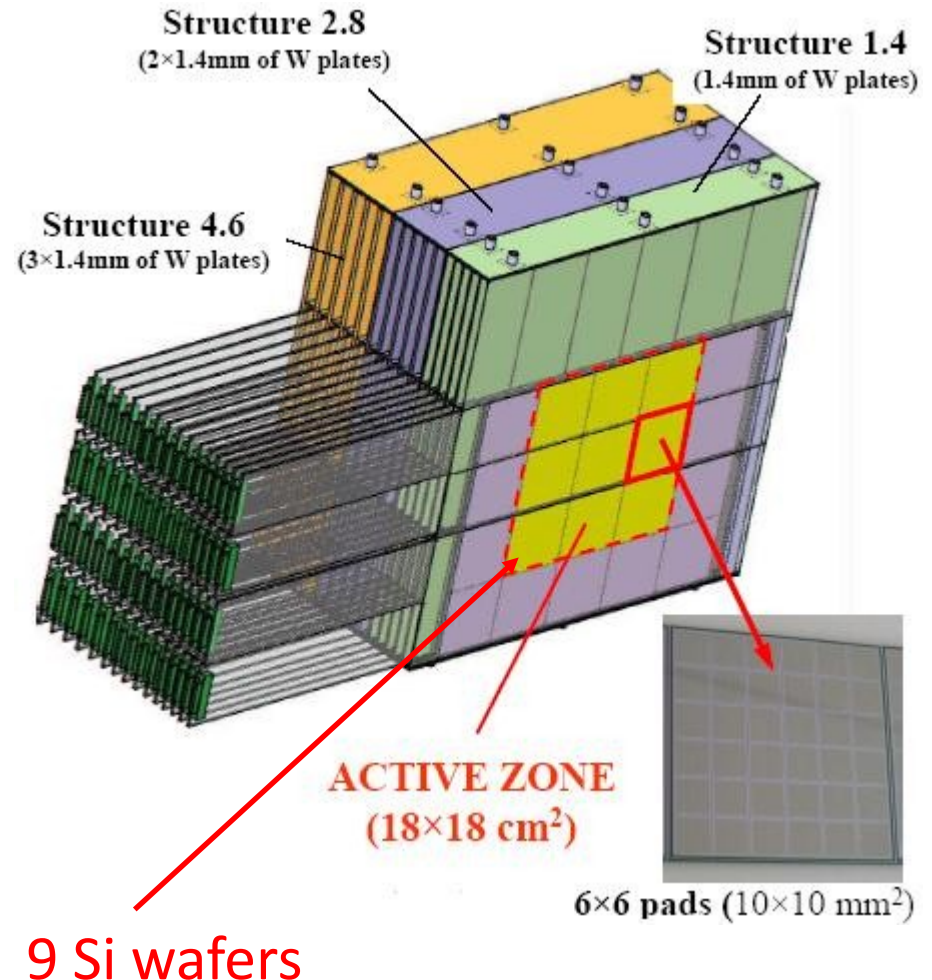
- Introduction
- The SiW ECAL (in 2008)
- Beam test setup at FNAL
- MC simulations
- Algorithm to find interactions
- Classification
- Optimisation
- Results
- Conclusions

Introduction

- Studying interactions of hadrons naturally supports the development of **Particle Flow Algorithms (PFA)** with a better knowledge of hadronic showers
 - We want to investigate the hadronic shower structure with the fine 3D sampling of the ECAL
- **Our goal** : analysis and comparison of interactions of pions in the SiW ECAL using test beam data samples and Monte Carlo simulations
 - We compare observables with various models of interactions in Geant4

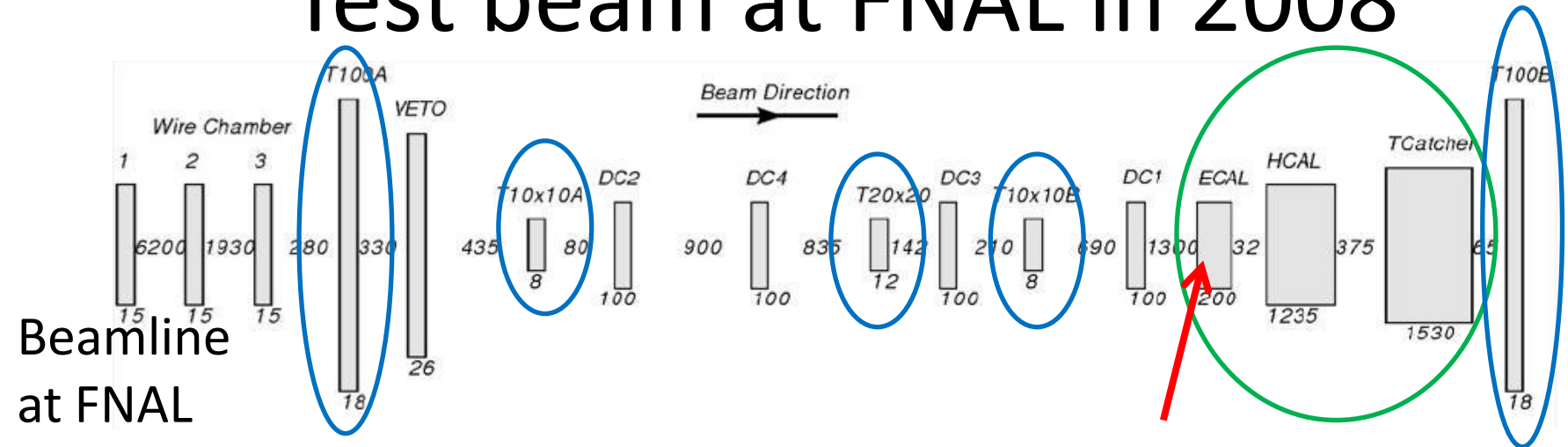
The SiW ECAL in 2008

- 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
- $\approx 24 X_0 \approx 1 \lambda_1 \approx$ half of the hadrons interact inside the ECAL volume



Picture of the fully equipped SiW ECAL

Test beam at FNAL in 2008



- 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 :

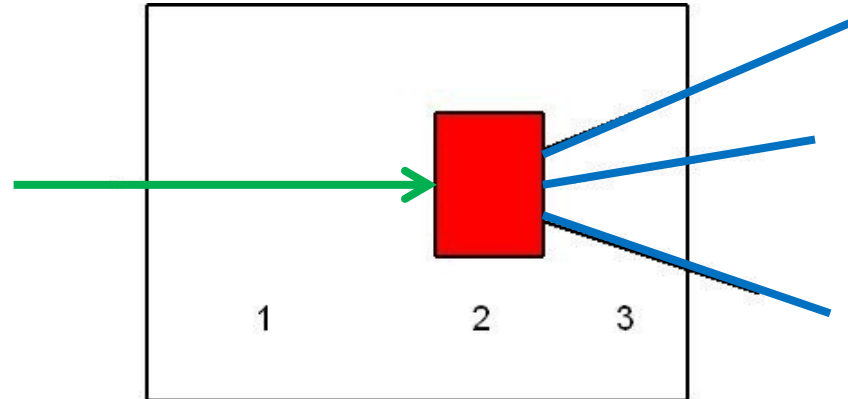
E (GeV)	2	4	6	8	10
N evts	13723	84849	55486	161522	369021

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				+ LEP
QGS BIC	LEP + BIC (secondaries)				
QGSP BIC	LEP				
LHEP	LEP				
FTFP BERT	Bertini		Fritiof		

A look at interactions of hadrons

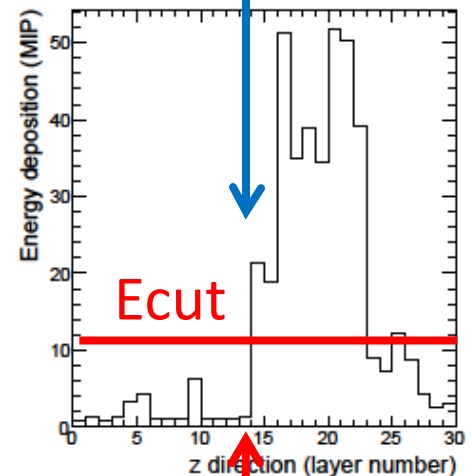
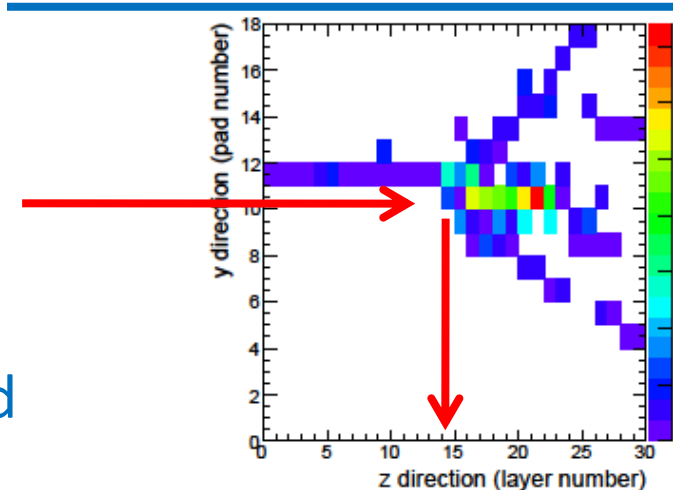
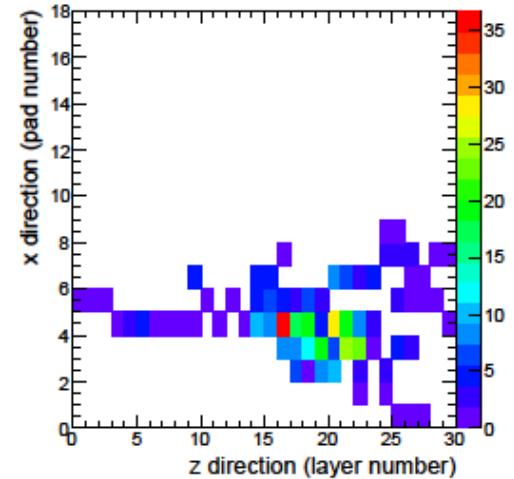
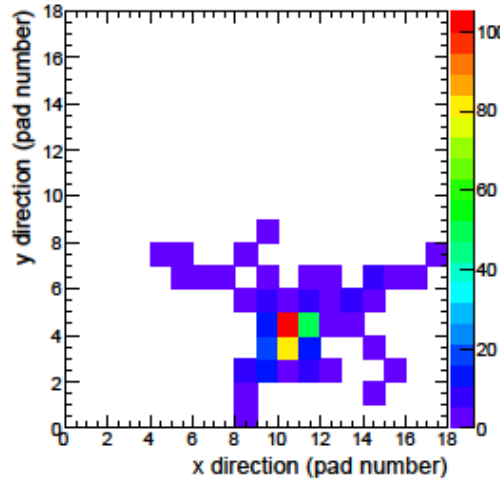


- Picture of a generic interaction in the calorimeters :
 - 1) A primary track enters the detector (« MipFinder »)
 - 2) The interaction occurs
 - 3) Secondaries emerge from the interaction zone

Visual example

- 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:

$$E_i > E_{cut} , E_{i+1} > E_{cut} , E_{i+2} > E_{cut}$$



(sort of naïve cut)

New cut needed at these small energies

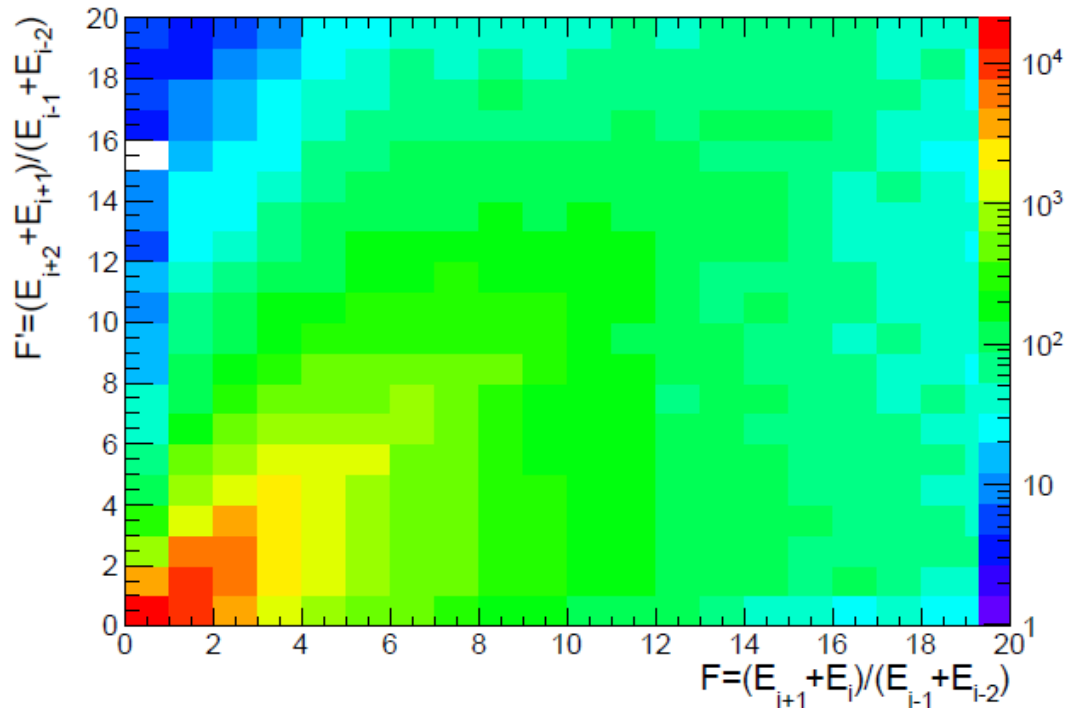
The previous cut (E_{cut}) will fail at smaller energies : fluctuations no more negligible.

Need a new criterion : relative increase in consecutive layers

→ 25% of the events with an endpoint in the ECAL are seen where 10% could not be found using the other criteria

→ Use both in combination

$$F = \frac{E_i + E_{i+1}}{E_{i-1} + E_{i-2}} \gg F_{cut} \quad \text{and} \quad F' = \frac{E_{i+1} + E_{i+2}}{E_{i-1} + E_{i-2}} \gg F_{cut}$$



F and F' values after the known endpoint of the MC particle in the ECAL

Visual example : a new kind is found

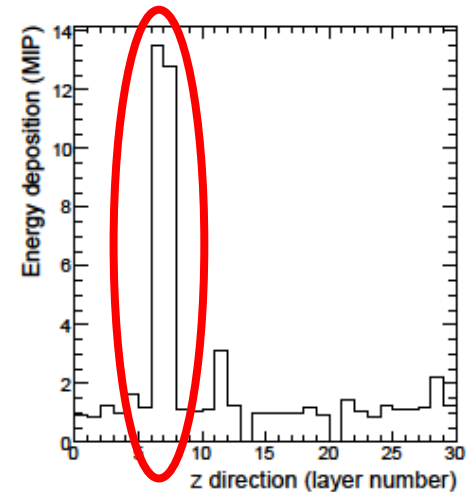
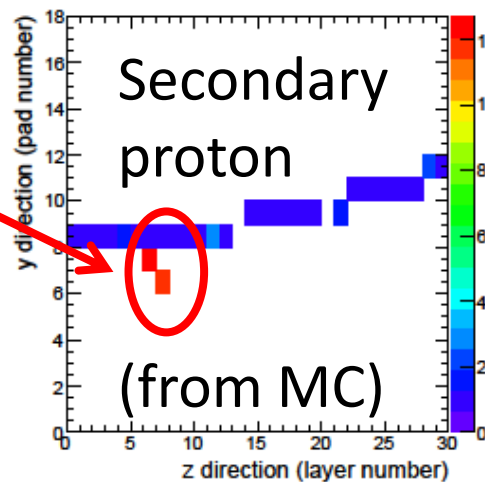
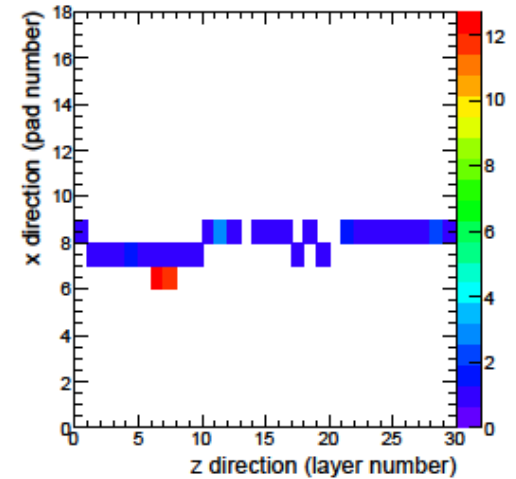
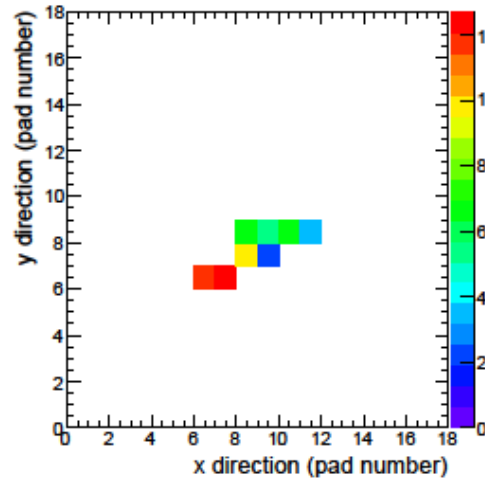
- Using the new criterion, one finds a new kind of event

- Here, local energy deposition

- Quantified by the relative increase in energy and a decrease :

$$\frac{E_i + E_{i+1}}{E_{i-1} + E_{i-2}} > F_{cut} \text{ and } \frac{E_{i+1} + E_{i+2}}{E_{i-1} + E_{i-2}} > F_{cut}$$

$$+ \frac{E_{i+2} + E_{i+3}}{E_{i-1} + E_{i-2}} < F_{cut}$$

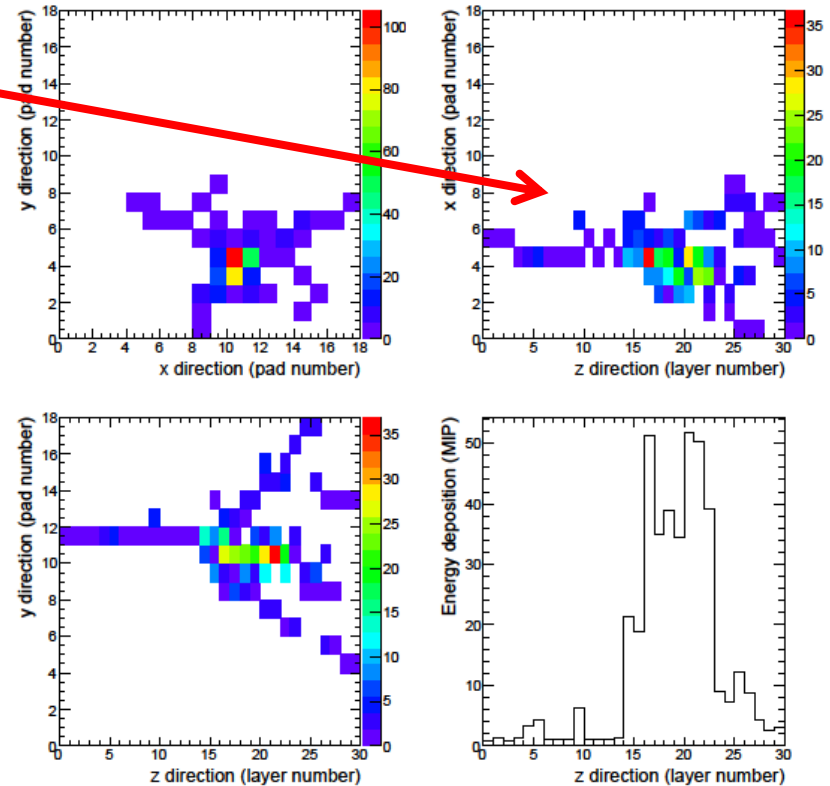


Classification

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

$$\frac{E_{i+2} + E_{i+3}}{E_{i-1} + E_{i-2}} > F_{\text{cut}} + \frac{E_{\text{around},i}}{E_i} > 0.5$$

Works here and meant for small energies



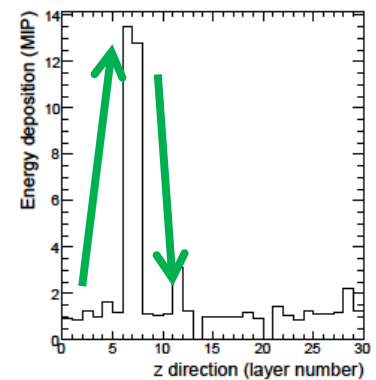
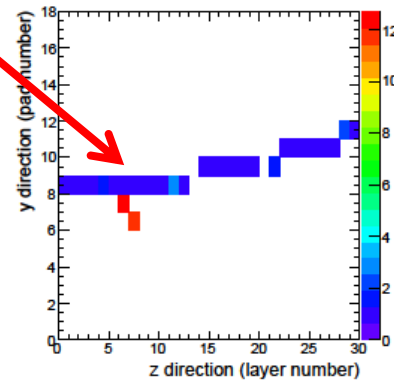
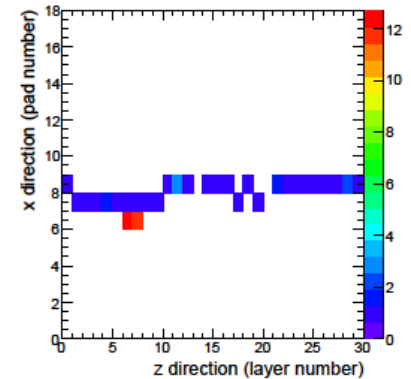
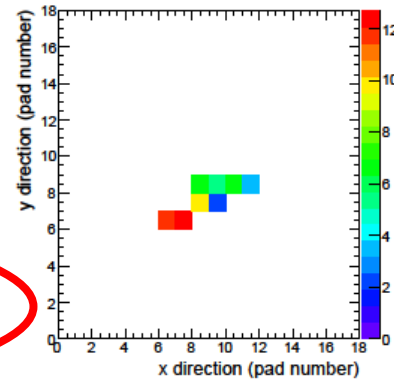
Event view of the
« FireBall » type at 10 GeV

Classification

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

$$\frac{E_{i+2} + E_{i+3}}{E_{i-1} + E_{i-2}} < F_{\text{cut}}$$

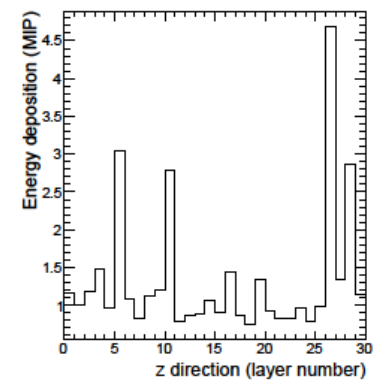
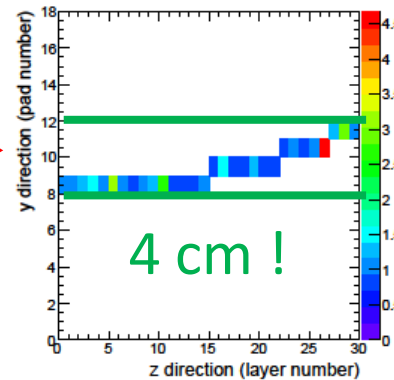
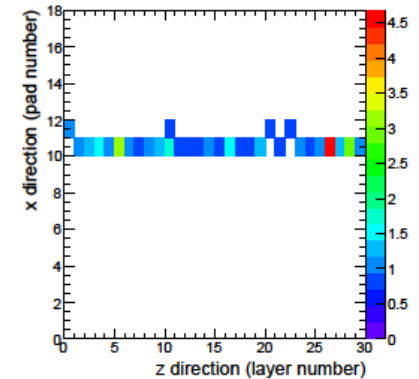
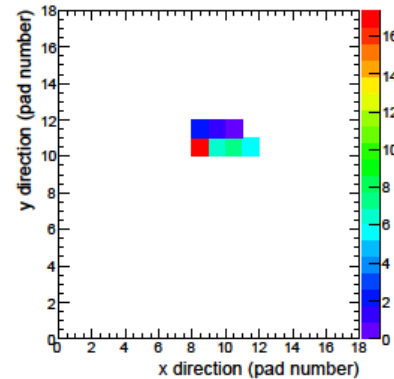
- Remark : delta rays are naturally included in « Pointlike » but contribute less than 4%



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%



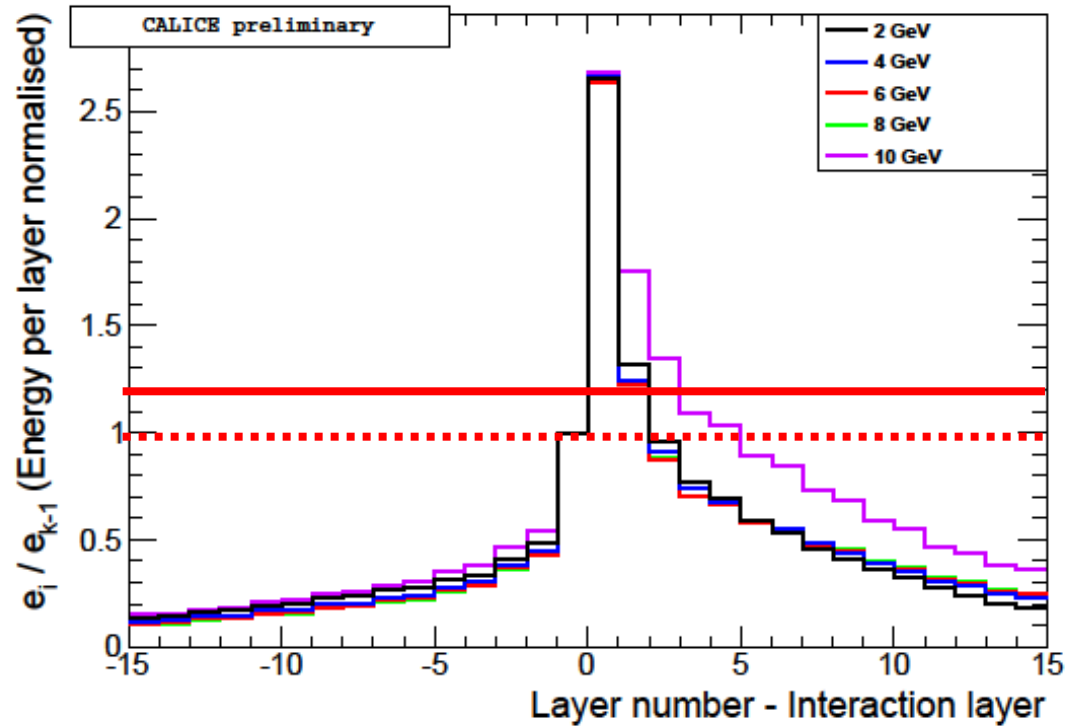
Event view of the
« Scattered » type at 2 GeV

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**

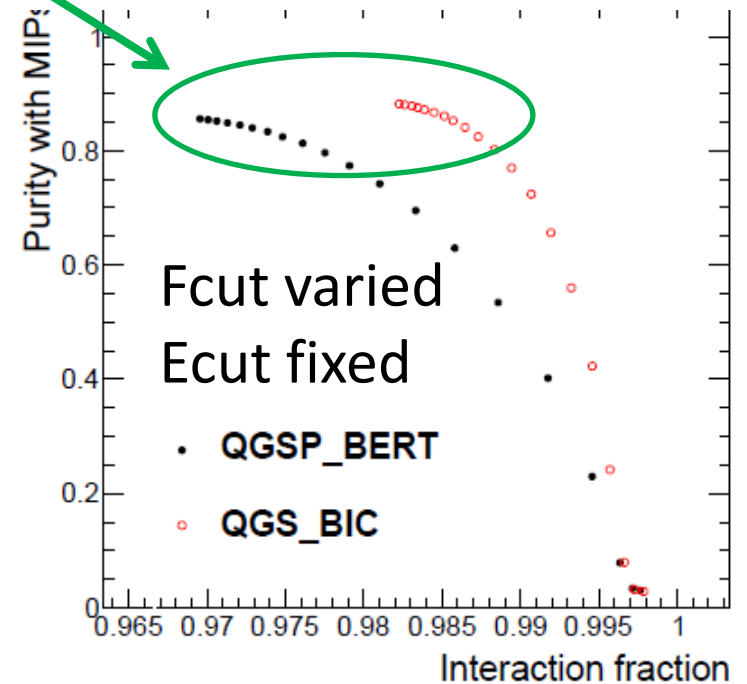
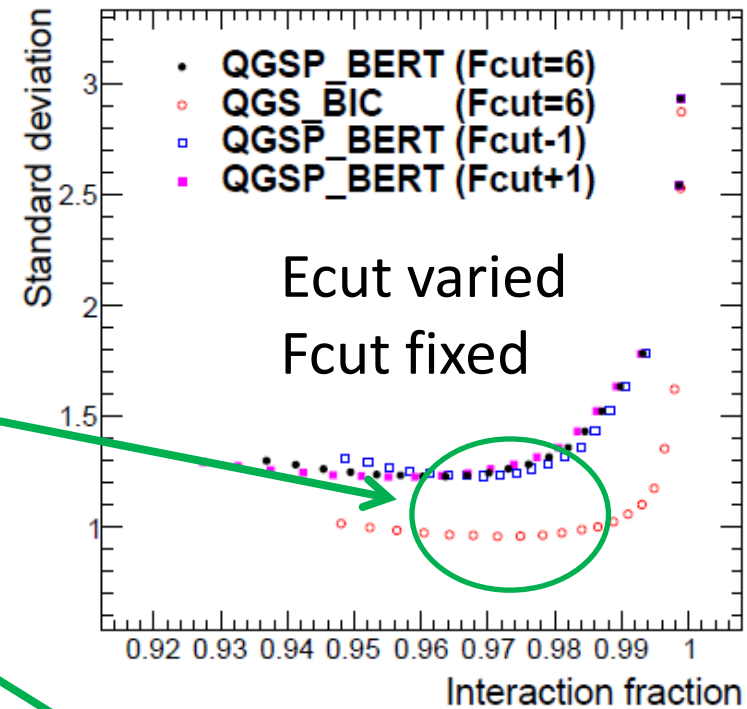
→ should contain « MIP » + « Scattered »

Example at 10 GeV

- Areas of interest
- Results :

E (GeV)	Ecut	Fcut
2	3	5 → 6
4	4	6 → 6
6	7	6 → 6
8	9	6 → 6
10	8	6.5 → 6

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

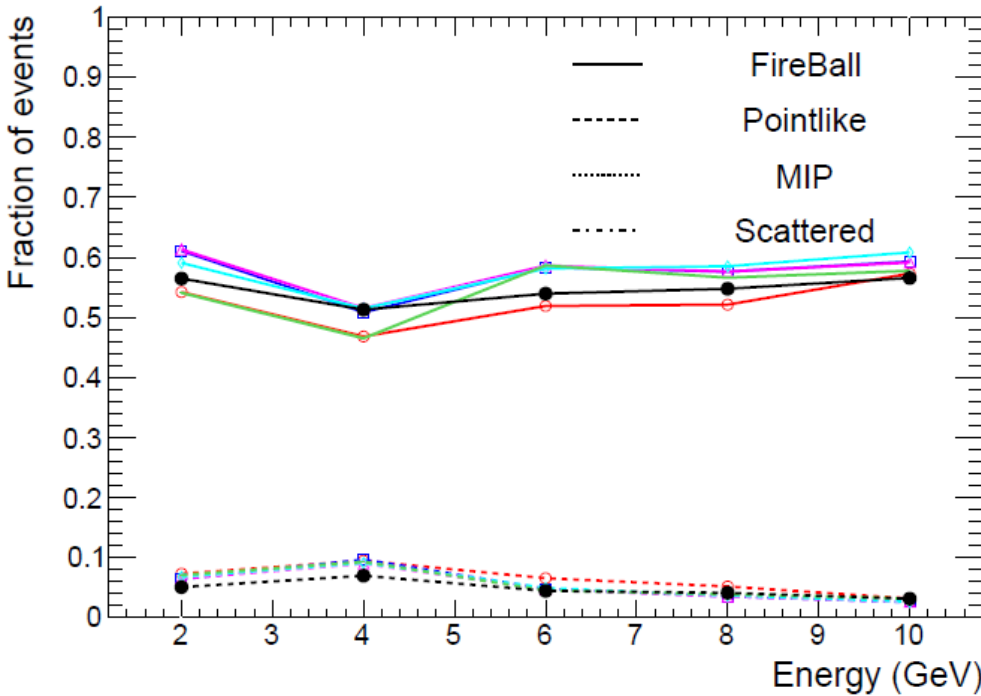


Efficiencies after optimisation

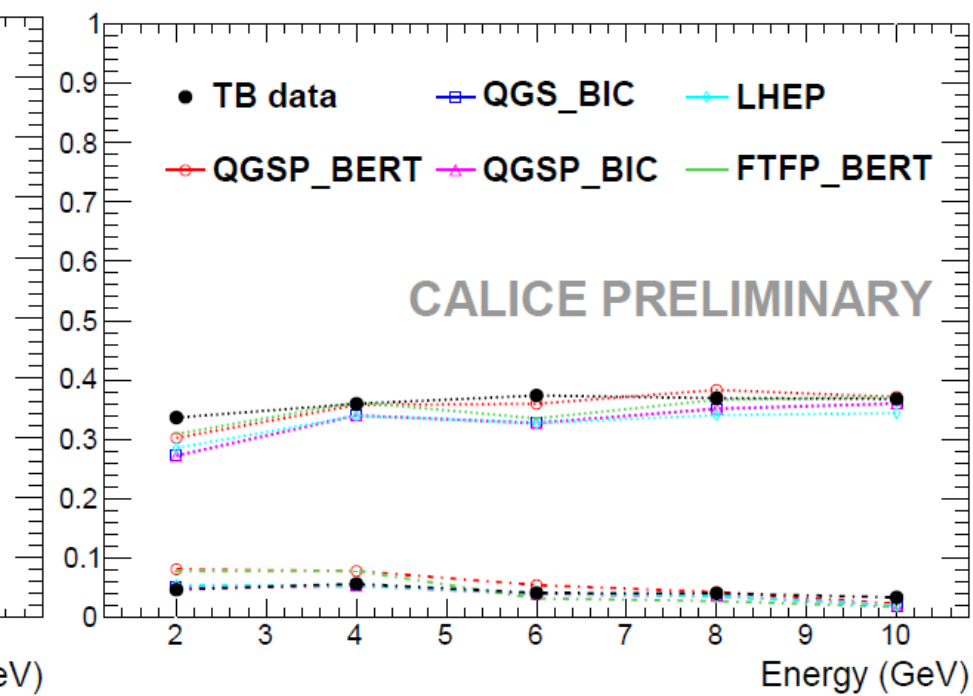
- The efficiency to find the true interaction layer within ± 1 and 2 layers is the result of the optimisation.
- It is compared with another method.

E (GeV)	$\eta (\pm 1)$	$\eta (\pm 2)$	$\eta (3-4, \pm 2)$
2	54 %	62 %	22 %
4	58 %	67 %	51 %
6	62 %	72 %	64 %
8	64 %	75 %	69 %
10	74 %	83 %	78 %

Rates of interactions



(a) Interaction classes



(b) Non interaction classes

Interaction rates similar between physics lists

Small systematics
with Ecut and Fcut
in ± 1

Mean shower radius

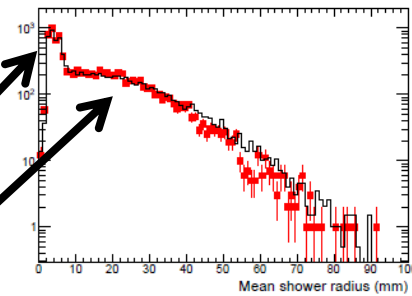
$$\langle r \rangle_E = \sqrt{\sigma_{E,x}^2 + \sigma_{E,y}^2}$$

Gives an idea of the lateral extension of the shower

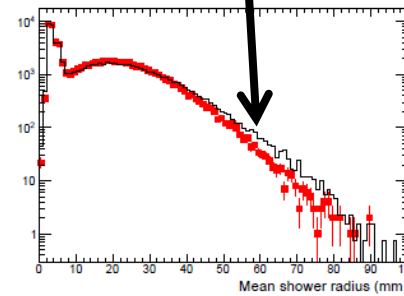
$$\sigma_{E,x}^2 = \frac{\sum_{\text{hits}} x_{\text{hit}}^2 E_{\text{hit}}}{\sum_{\text{hits}} E_{\text{hit}}} - \left(\frac{\sum_{\text{hits}} x_{\text{hit}} E_{\text{hit}}}{\sum_{\text{hits}} E_{\text{hit}}} \right)^2$$

Discrepancy for $r > 50$ mm

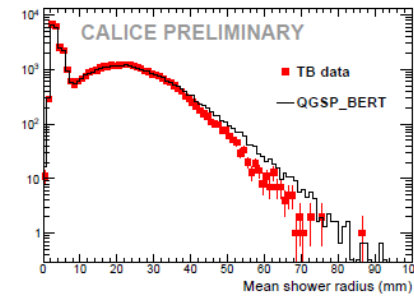
MC normalised
to number of
data events



(a) 2 GeV

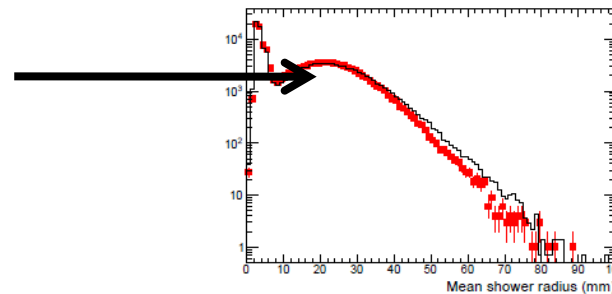


(b) 4 GeV

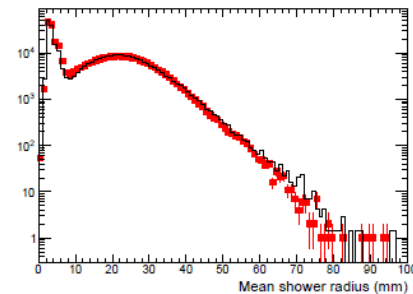


(c) 6 GeV

MIP peak
Broad peak for interaction
classes

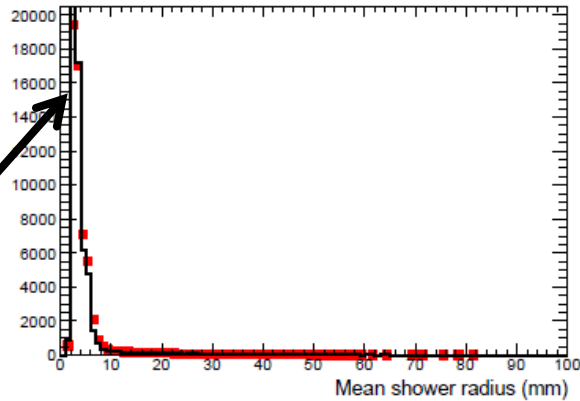


(d) 8 GeV

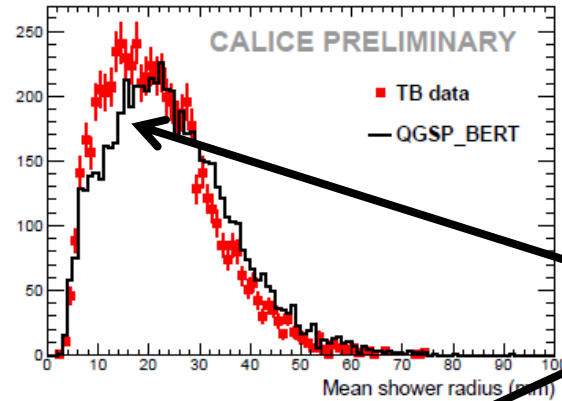


(e) 10 GeV

Separation per class of event : 8 GeV

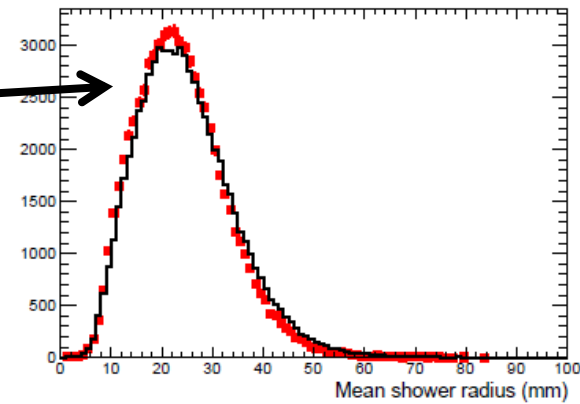


(a) "MIP"

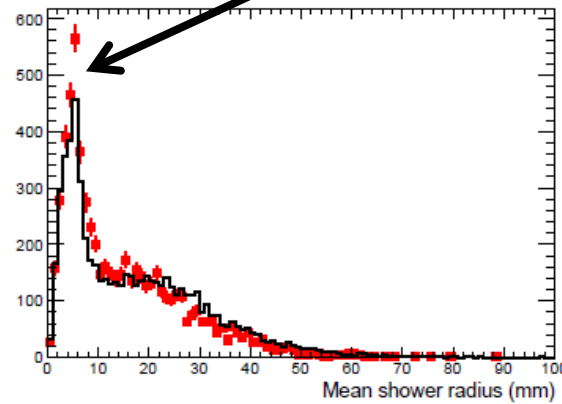


(b) "Scattered"

Discrepancy



(c) "FireBall"

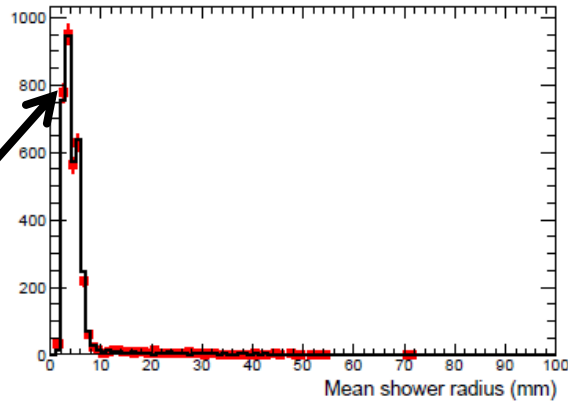


(d) "Pointlike"

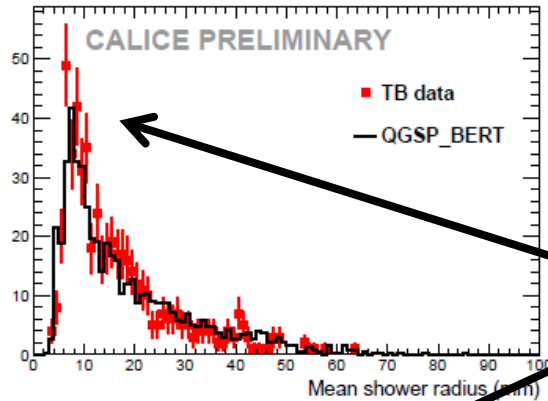
MIP and FireBall have a correct behaviour

Data vs QGSP_BERT at 8 GeV

Separation per class of event, even at 2 GeV

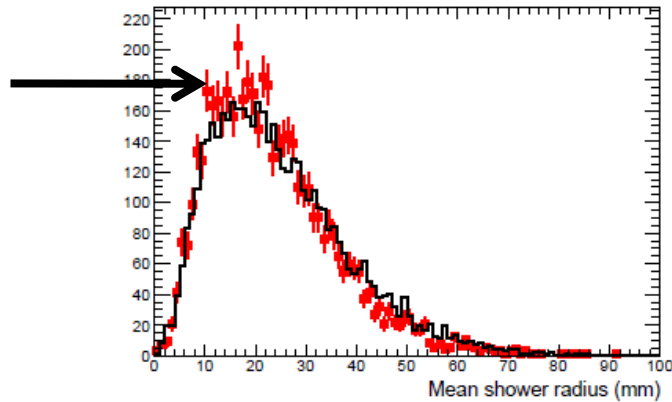


(a) "MIP"

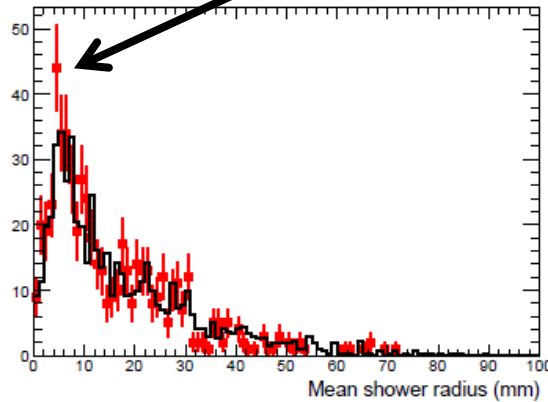


(b) "Scattered"

Tendency to have the same behaviour



(c) "FireBall"

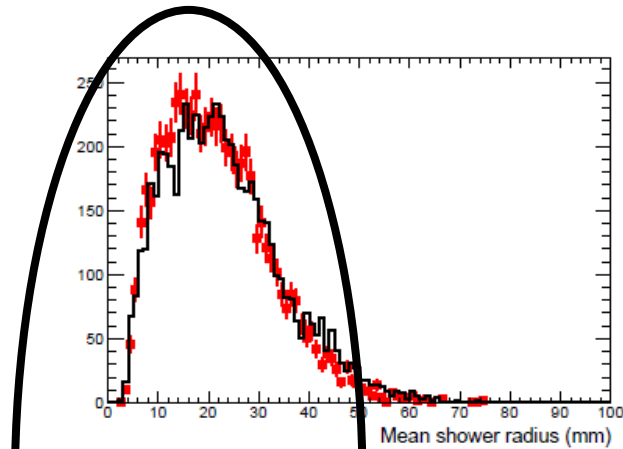


(d) "Pointlike"

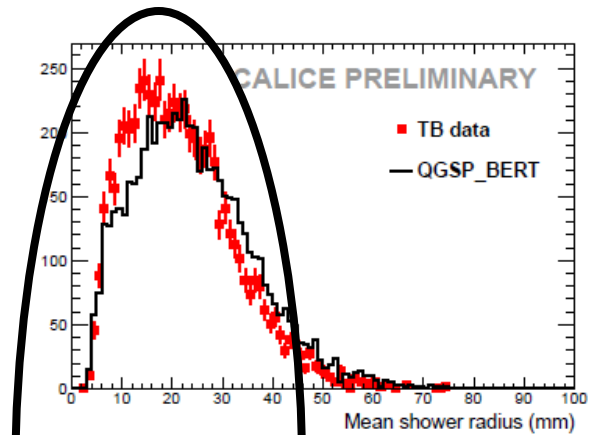
MIP and FireBall still have a correct behaviour despite smaller statistics

Data vs QGSP_BERT at 2 GeV

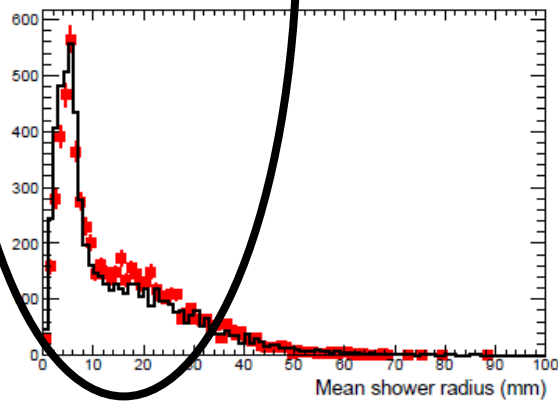
Spotted discrepancy at 8 GeV : QGSP and FTFP



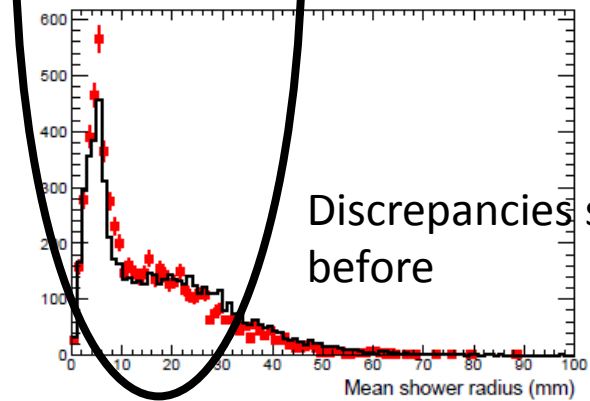
(a) "Scattered" - FTFP_BERT



(b) "Scattered" - QGSP_BERT



(c) "Pointlike" - FTFP_BERT



(d) "Pointlike" - QGSP_BERT

No discrepancy with FTFP_BERT (uses Fritiof model at 8 GeV)

Longitudinal profiles

Build longitudinal profiles with pseudolayers :

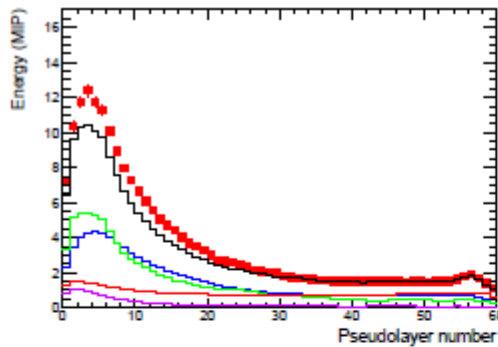
= 1 pseudolayer in first stack

= 2 pseudolayers in second stack

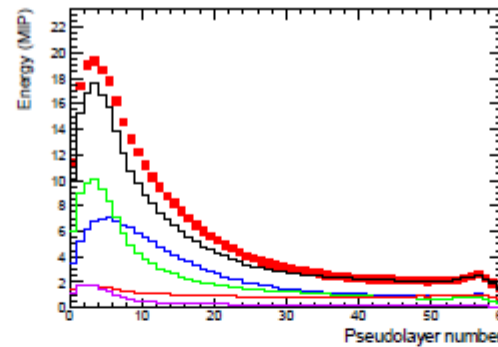
= 3 pseudolayers in third stack

With energies extrapolated linearly

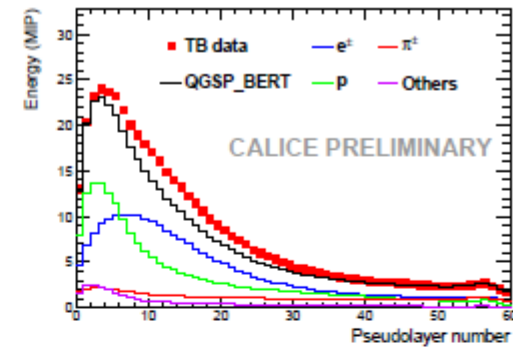
Colors are for various secondary contributions (from MC table)



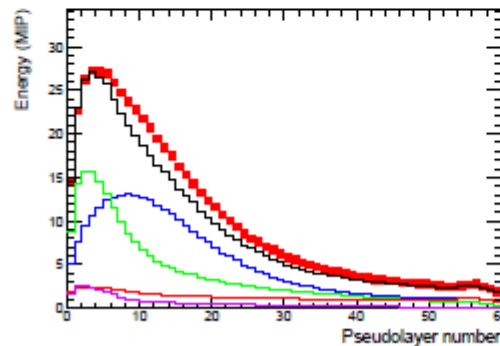
(a) 2 GeV



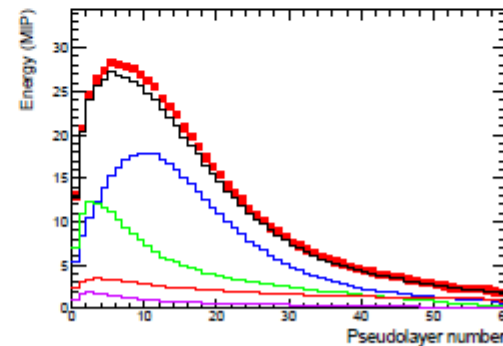
(b) 4 GeV



(c) 6 GeV



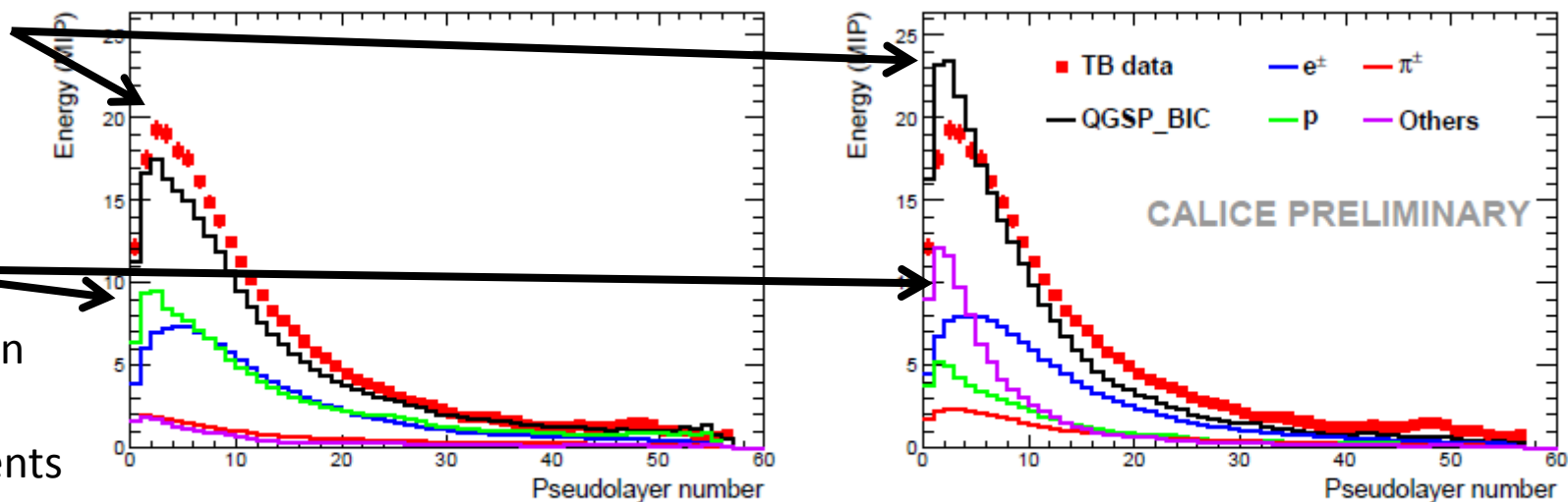
(d) 8 GeV



(e) 10 GeV

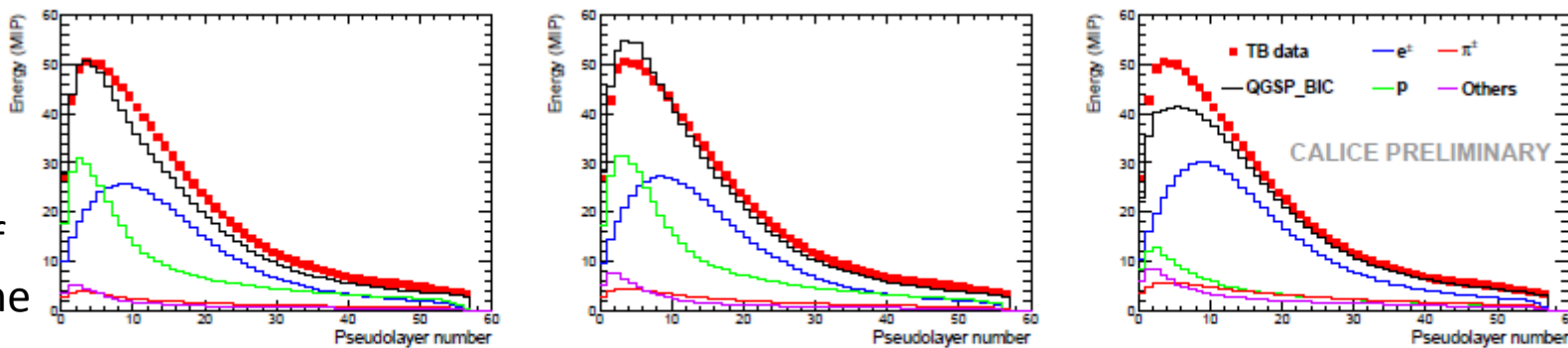
Longitudinal profiles : FireBall

2 GeV :
Large
differences
in total
Also
differences in
shower
subcomponents



(a) BERT : valid for QGSP_BERT (shown here) and FTFP_BERT
(b) LEP : valid for QGSP_BIC (shown here), QGS_BIC and LHEP

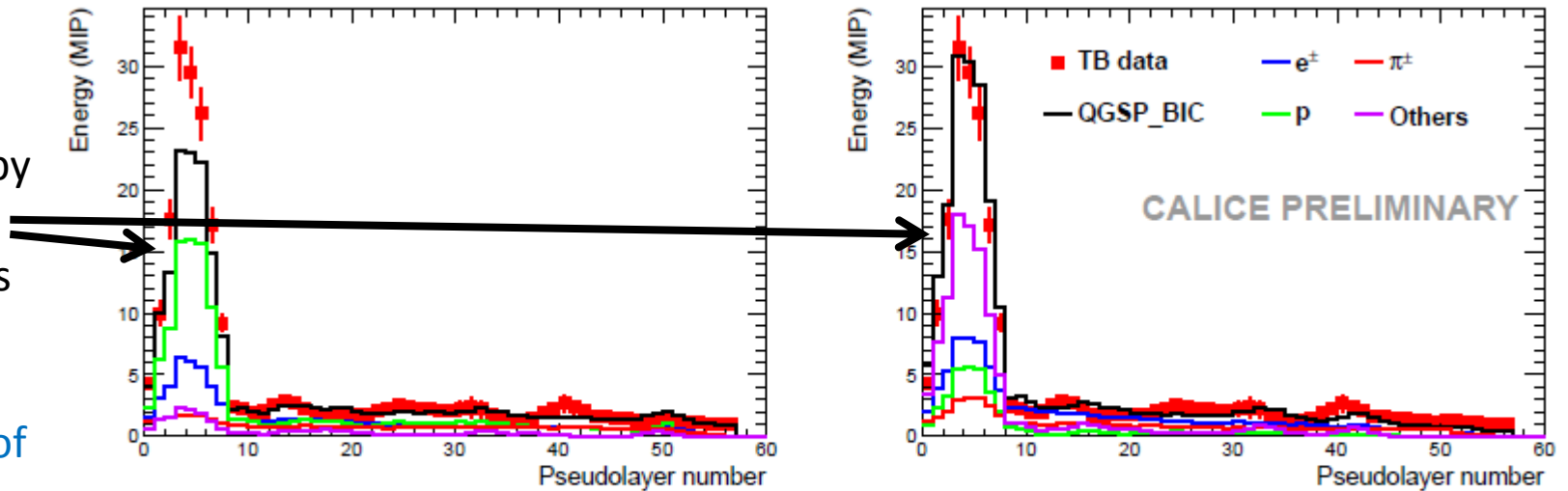
8 GeV :
Recovers
previous
analysis of
pions in the
ECAL



(a) QGSP_BERT featuring the BERT model
(b) FTFP_BERT featuring the FTFP model
(c) QGSP_BIC featuring the LEP model

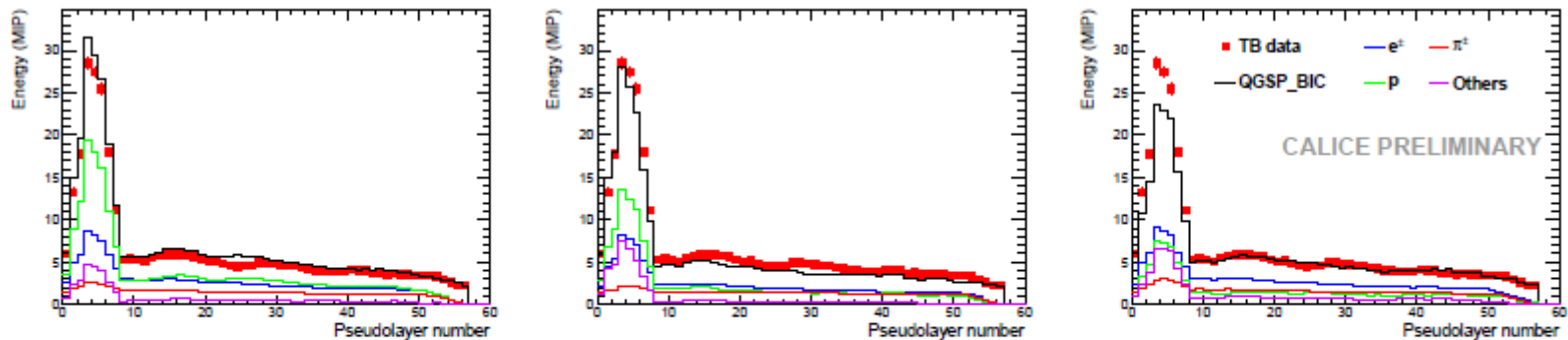
Longitudinal profiles : PointLikes

2 GeV :
Energy deposited by different secondaries
Remark : good behaviour of LEP



(a) BERT : valid for QGSP_BERT (shown here) and FTFP_BERT
(b) LEP : valid for QGSP_BIC (shown here), QGS_BIC and LEP

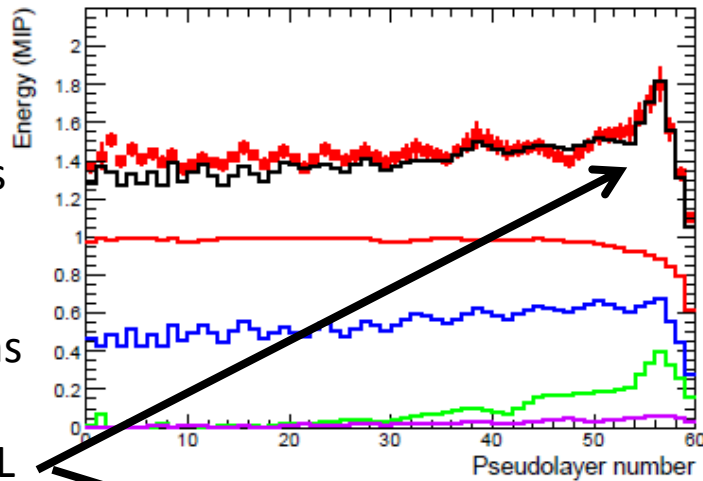
8 GeV :
BERT physics lists perform best here



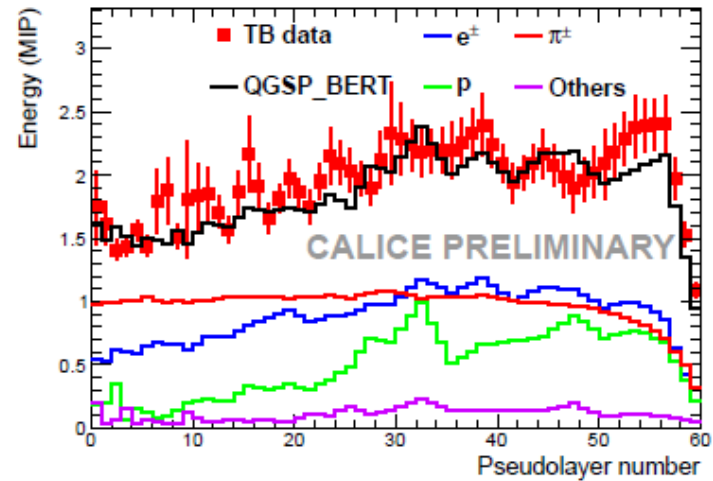
(a) BERT : used by QGSP_BERT
(b) FTFP : used by FTFP_BERT
(c) LEP : used by QGSP_BIC (shown here), QGS_BIC and LEP

MIPs and Scattered events

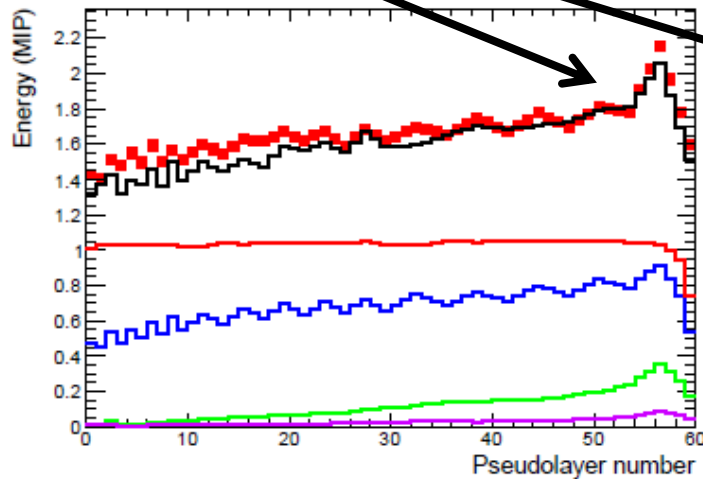
Good behaviours but unfound interactions in the end of the ECAL are seen



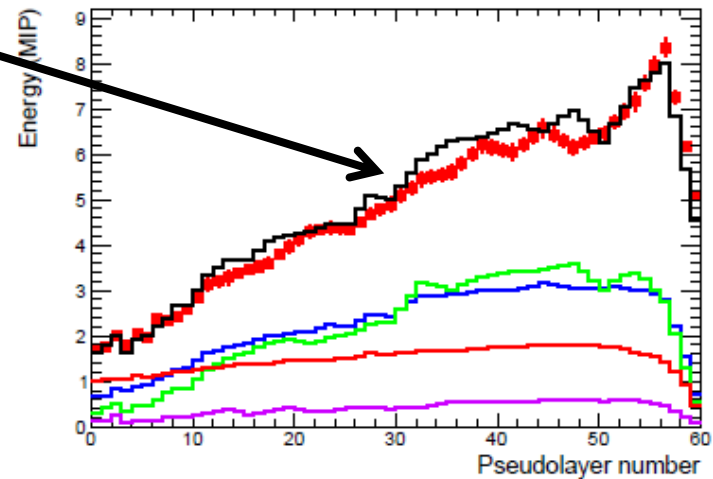
(a) "MIP" - 2 GeV



(b) "Scattered" - 2 GeV



(c) "MIP" - 8 GeV



(d) "Scattered" - 8 GeV

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 $> 62\%$
- Systematic effects have been checked and are small, $O(1\%)$ (muons, physics list, cuts)
- The CAN note is almost complete and ready for circulation within the collaboration

Backup slides

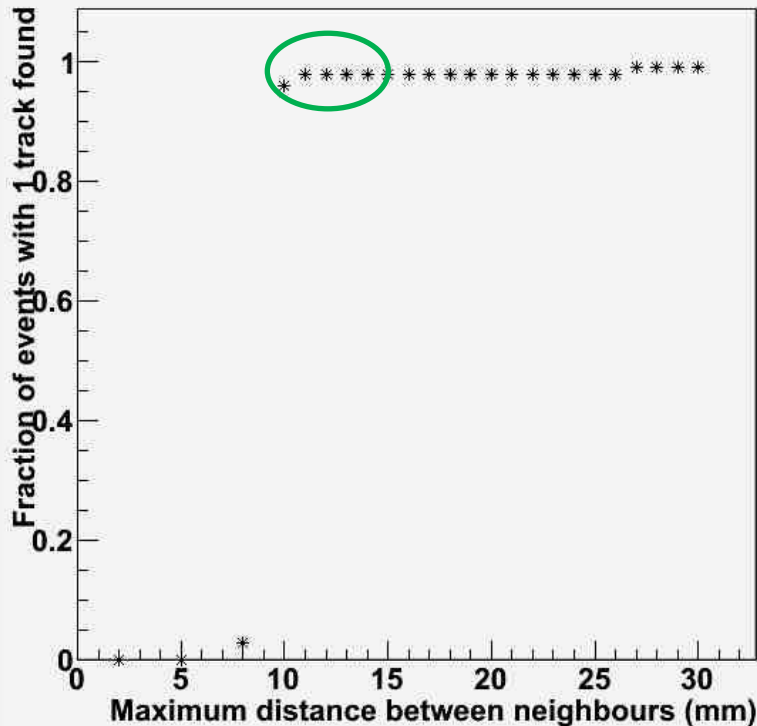
Efficiency to select events with one particle

Cuts against noise

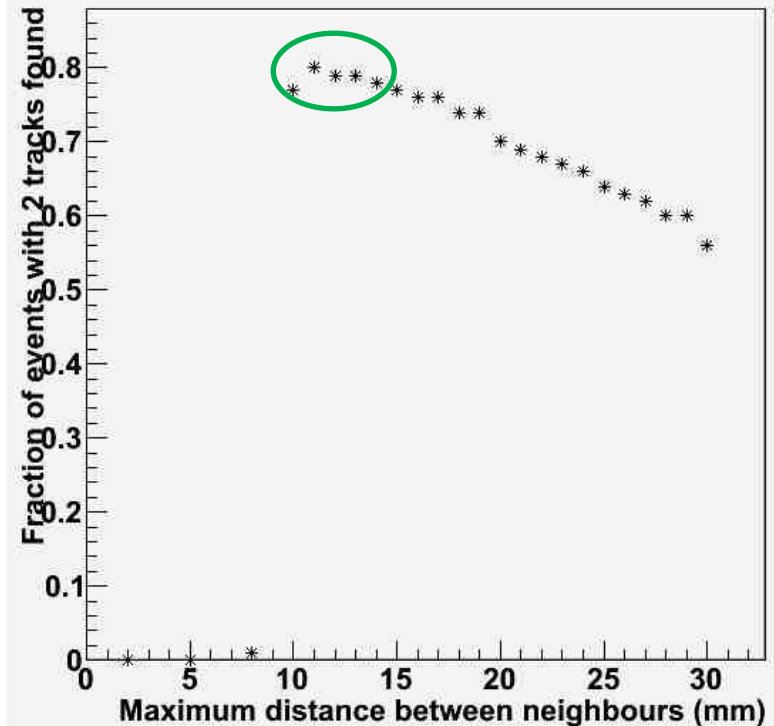
Systematics due to the physics list

Efficiency of the MipFinder

Efficiency to find 1 particle only



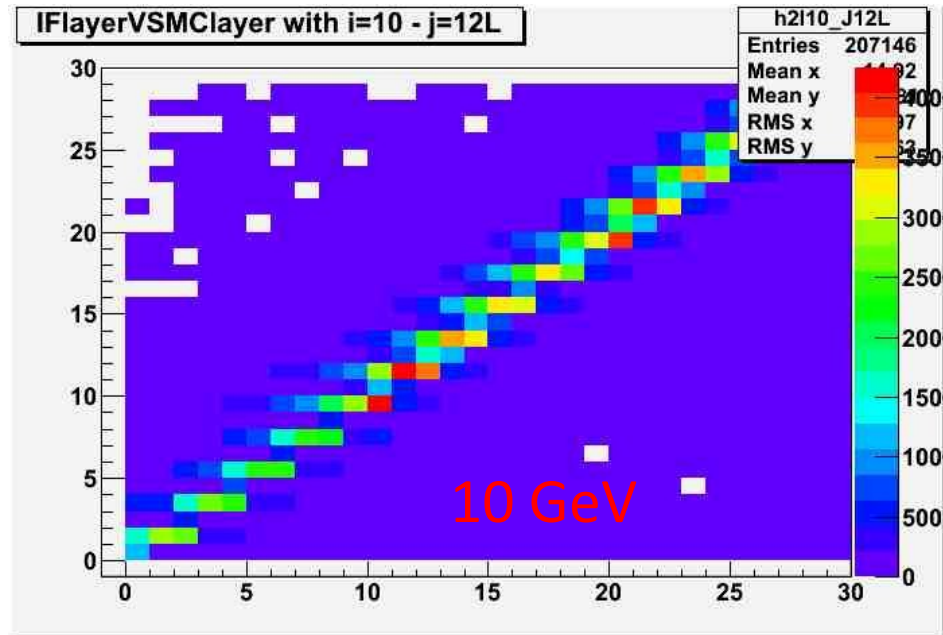
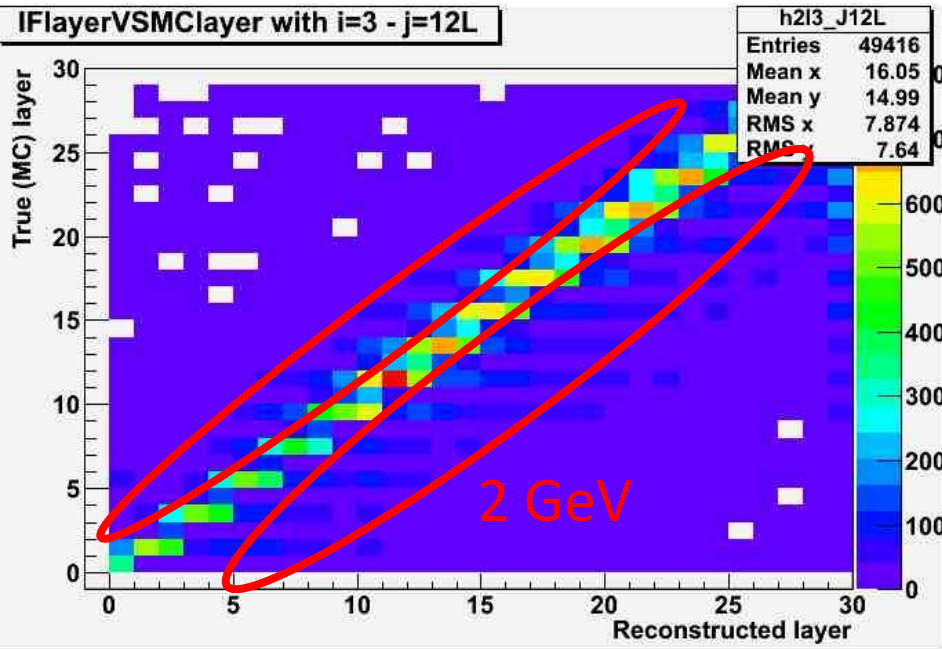
Efficiency to find 2 particles



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

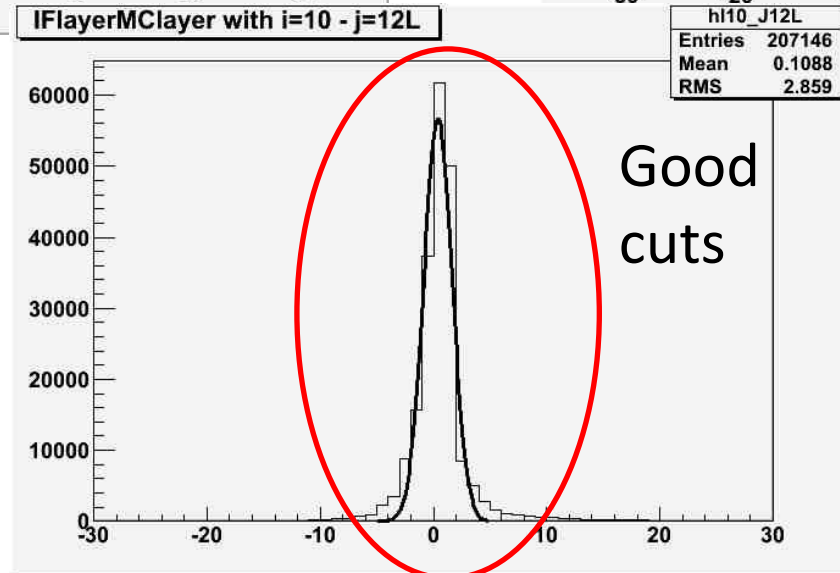
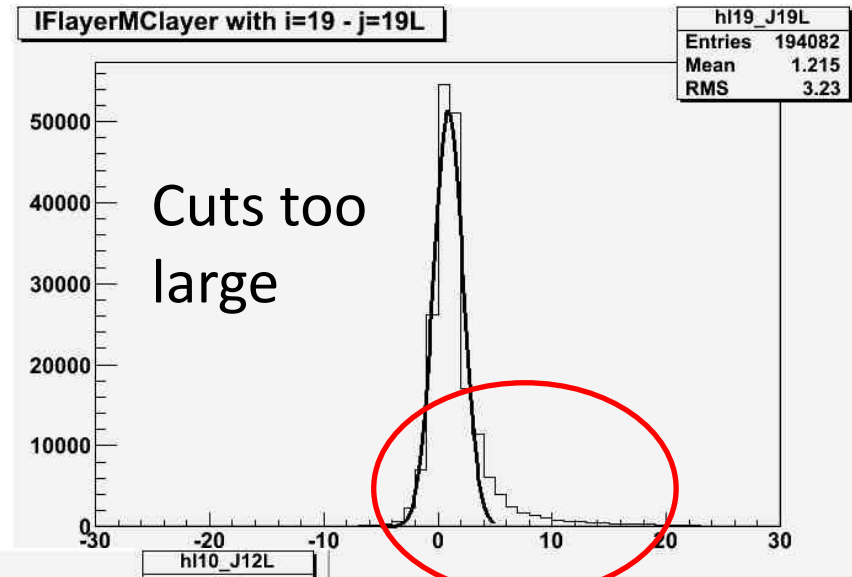
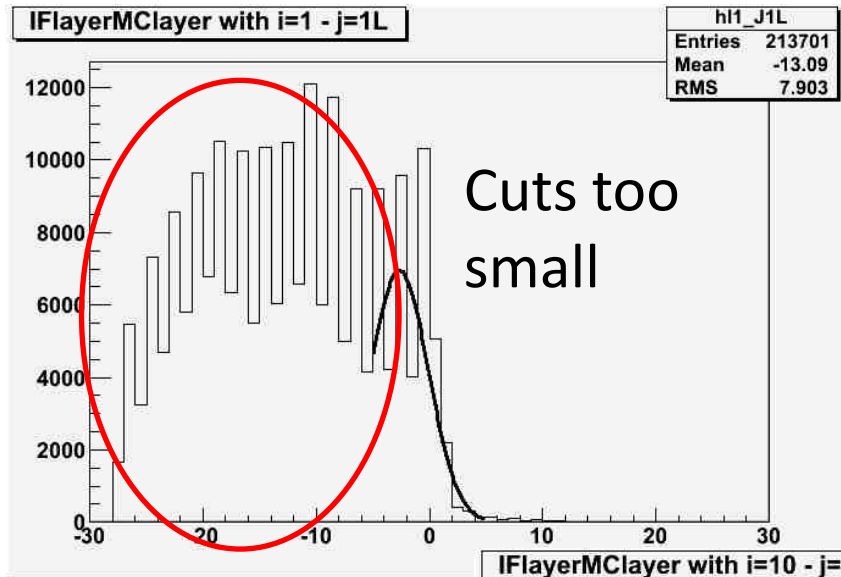


Horizontal axis = Reconstructed layer

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

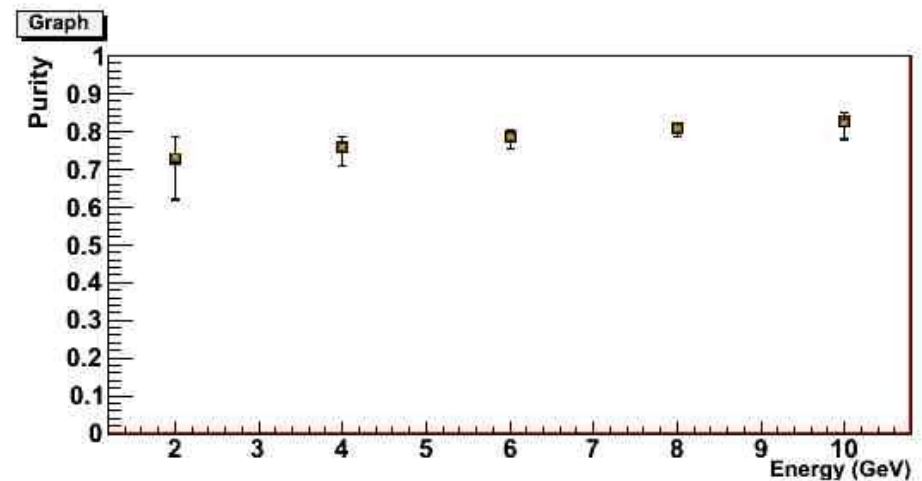
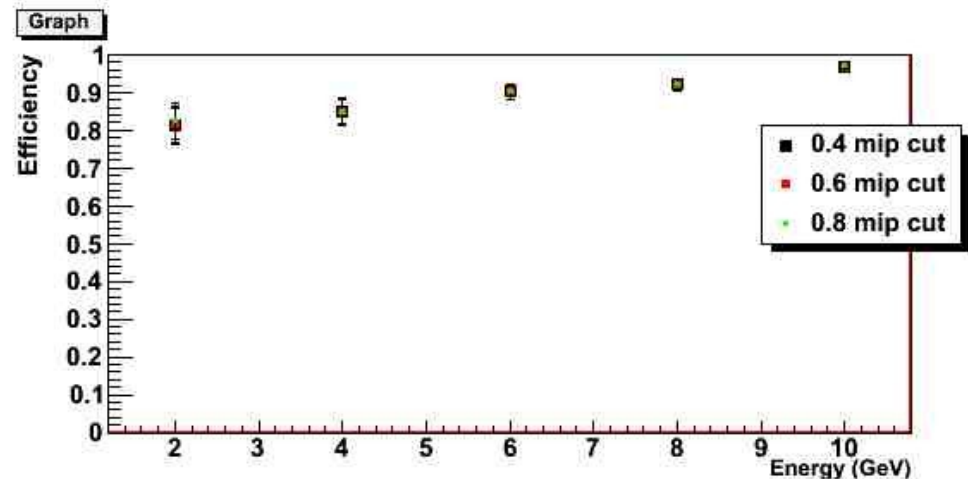
Standard deviation : Reconstructed layer – True (MC) layer



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 (**$E_{cut} \pm 1, F_{cut} \pm 1$**)



Systematics due to physics lists

- **Efficiency** (interaction fraction) and **purity** are calculated for all physics lists
- Error bars are systematics due to $(E_{cut} \pm 1, F_{cut} \pm 1)$
- **Differences are $<$ systematics due to (E_{cut}, F_{cut})**

