Muon identification with the hadron calorimeter

Nicola D'Ascenzo

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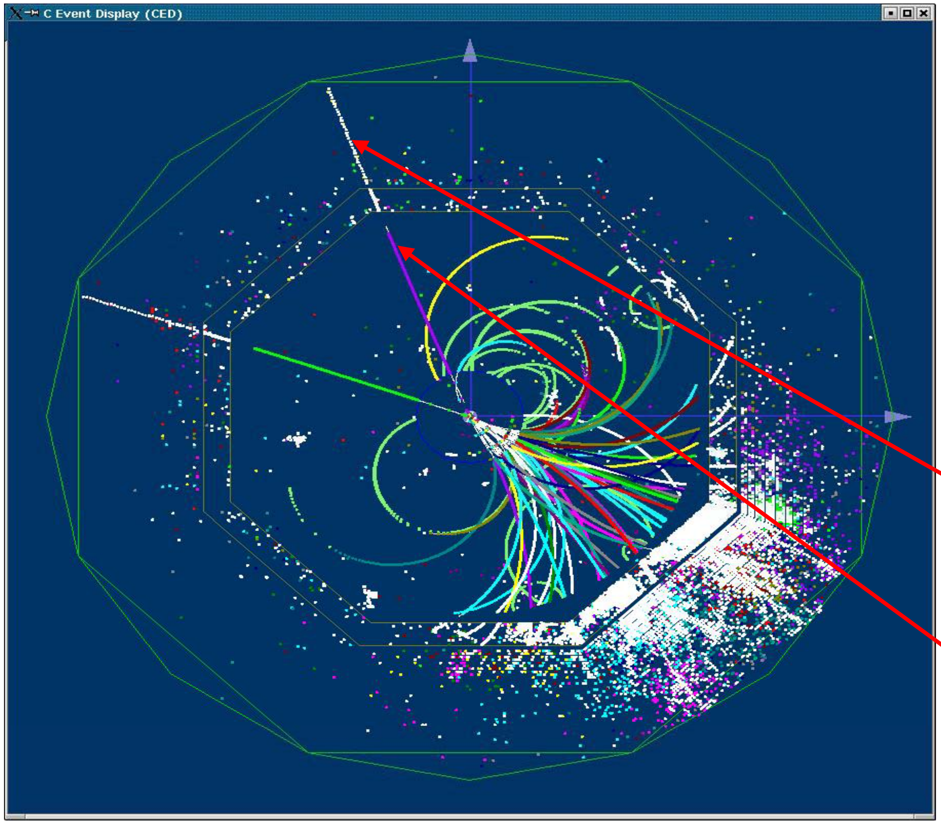
Outline

- Motivations of the study
- Reconstruction of the energy loss by a muon in iron
- The muon signal in the HCAL
  - Transversal profile
  - Totopological properties of the muon response
  - Likelihood
- Muon/Pion separation at low energies (6-10 GeV)

Detecting muons with the ILD detector



Only the muon chamber is outside the magnetic coil

A muon is identified with the Muon chambers. This is no problem for high energetic muons.

The soft muons either loose lots of energy in the ECAL, HCAL and in the magnetic coil, or are totally absorbed there.

Muon identification algorithm:

1. Identify a track, connecting the TPC with the calorimeters and the Muon chamber hits.
2. Verify that the energy deposits in the calorimeters is "muon like".

The momentum is measured in the TPC, the identification is determined with the other detectors.

Questions:

1. **Is the calorimeter system able to resolve the signal of the muon?**
2. **Will this method help to distinguish muons and pions inside the jets?**

The data collected by the calice collaboration are a unique opportunity to test these methods!

Analysed runs

- Runs 300774-300788 (2006)
  - Total luminosity: 3 Milions events.
- HCAL:
  - First 17 layers fully equipped
    - Last 6 layers excluded because of the high noise level
- Simulation:
  - MOKKA TBCERN1006, version
  - Plugin for the extraction of the full G4 step by step physics information.

Event selection

The number of hits in the ECAL, the energy of the Tail catcher and the number of tracks in the HCAL are chosen as event selection variables

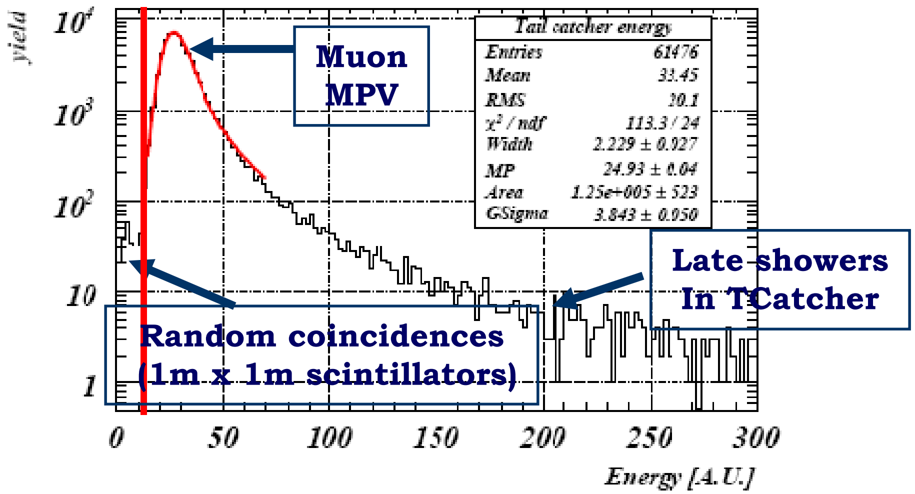


Fig. 1 - Energy deposited in the Tail Catcher

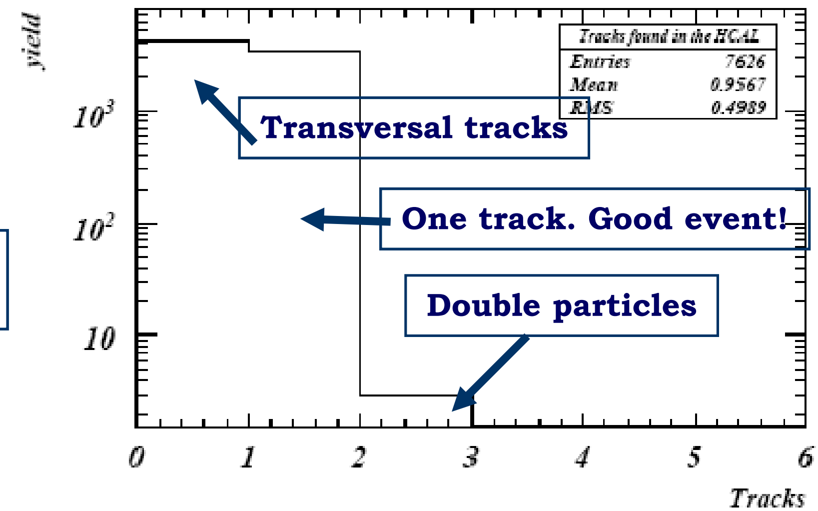


Fig. 3 - Number of perpendicular tracks found in the HCAL.
A track is defined with at least two hits in the first two and in the last two layers.

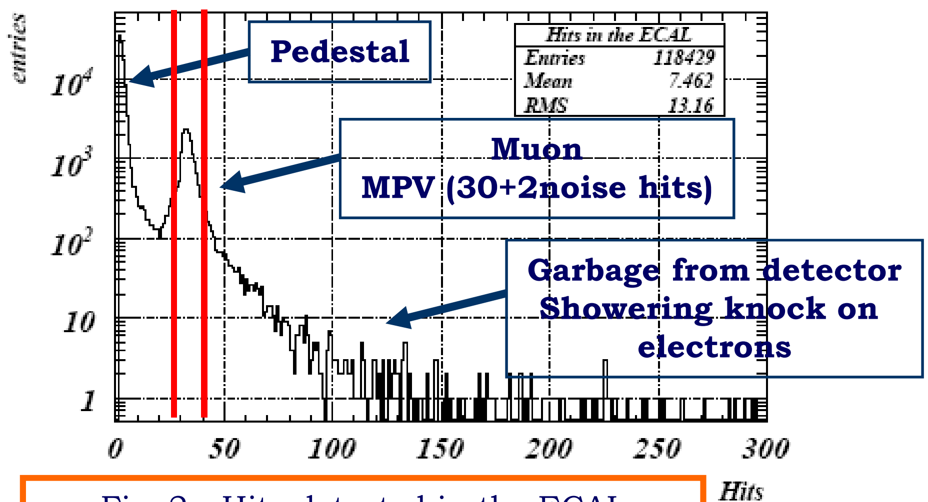
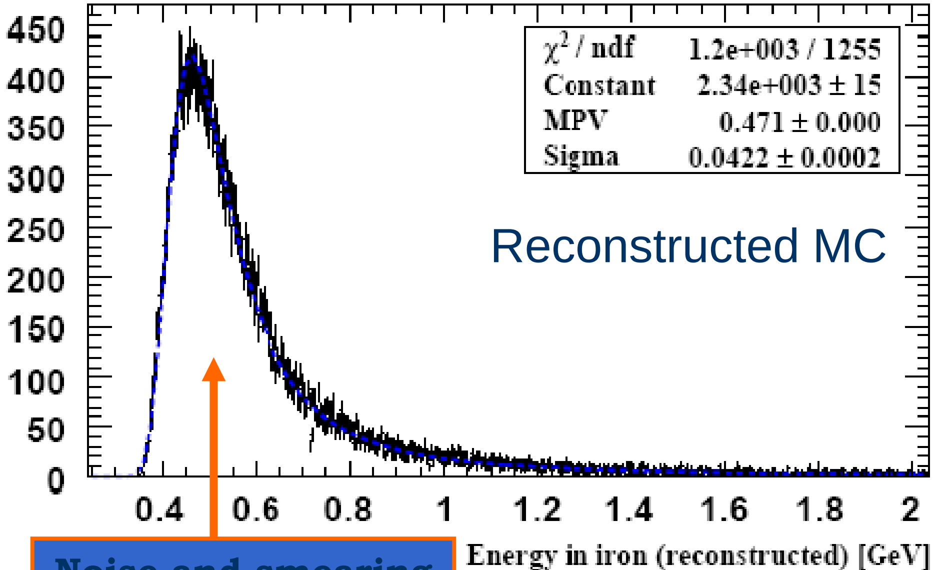


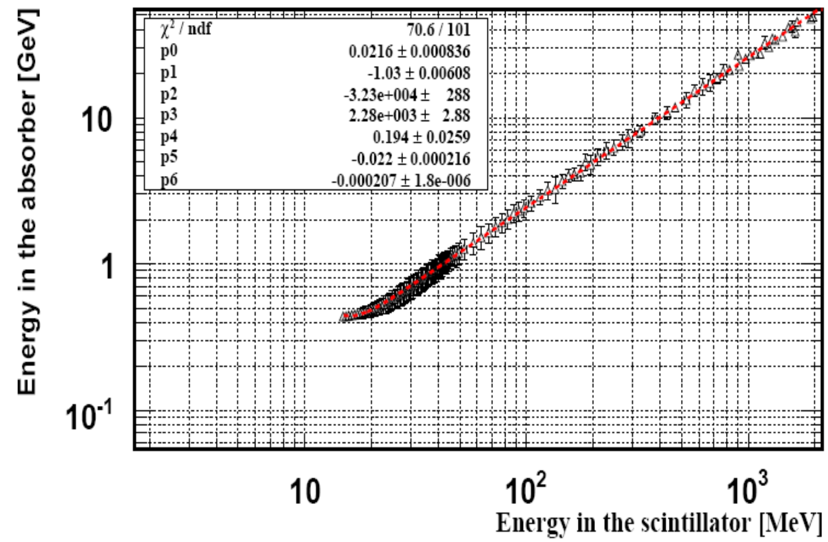
Fig. 2 - Hits detected in the ECAL

Cut	Efficiency
$30 < Hits_{ecal} < 34$	7.3%
$Energy_{tcatcher} > 10 A.U.$	99.9%
$tracks_{hcal} = 1$	45%

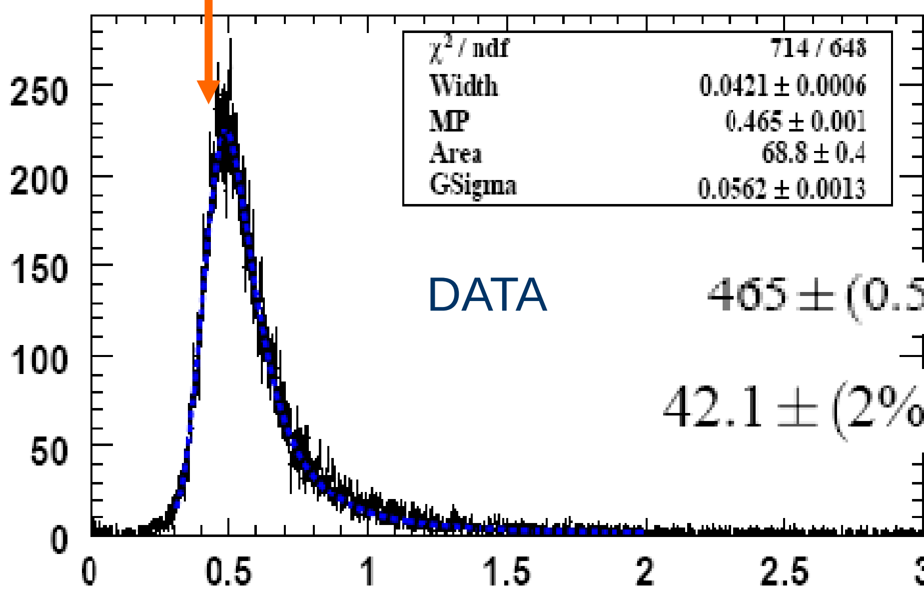
The reconstruction of the energy lost by a muon in iron

The total energy lost (total sum) by the muon in the calorimeter is reconstructed using parametrization computed in the MC





Noise and smearing



$$465 \pm (0.5\%_{stat} \oplus 3\%_{syst})\ \text{MeV}$$

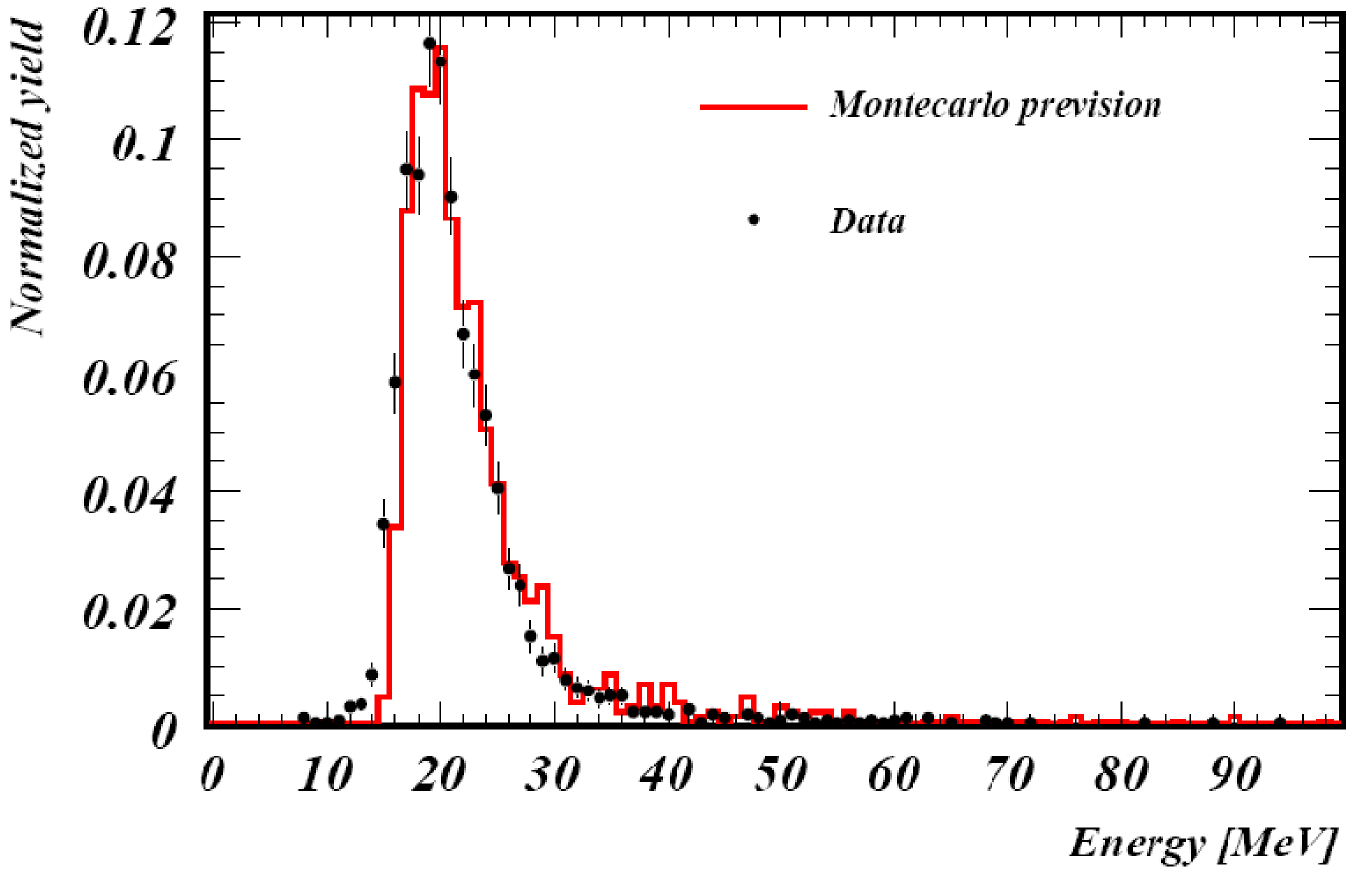
$$42.1 \pm (2\%_{stat} \oplus 3\%_{syst})\ \text{MeV.}$$

The reconstruction of the total energy deposited in the iron shows a **good agreement** between **data and Montecarlo.**

Ref. To the talk at the internal phone meetings

Reconstruction of the visible energy

The total visible energy in a tube of 3cm x 3 cm (1 cell) around the found track in the HCAL is measured

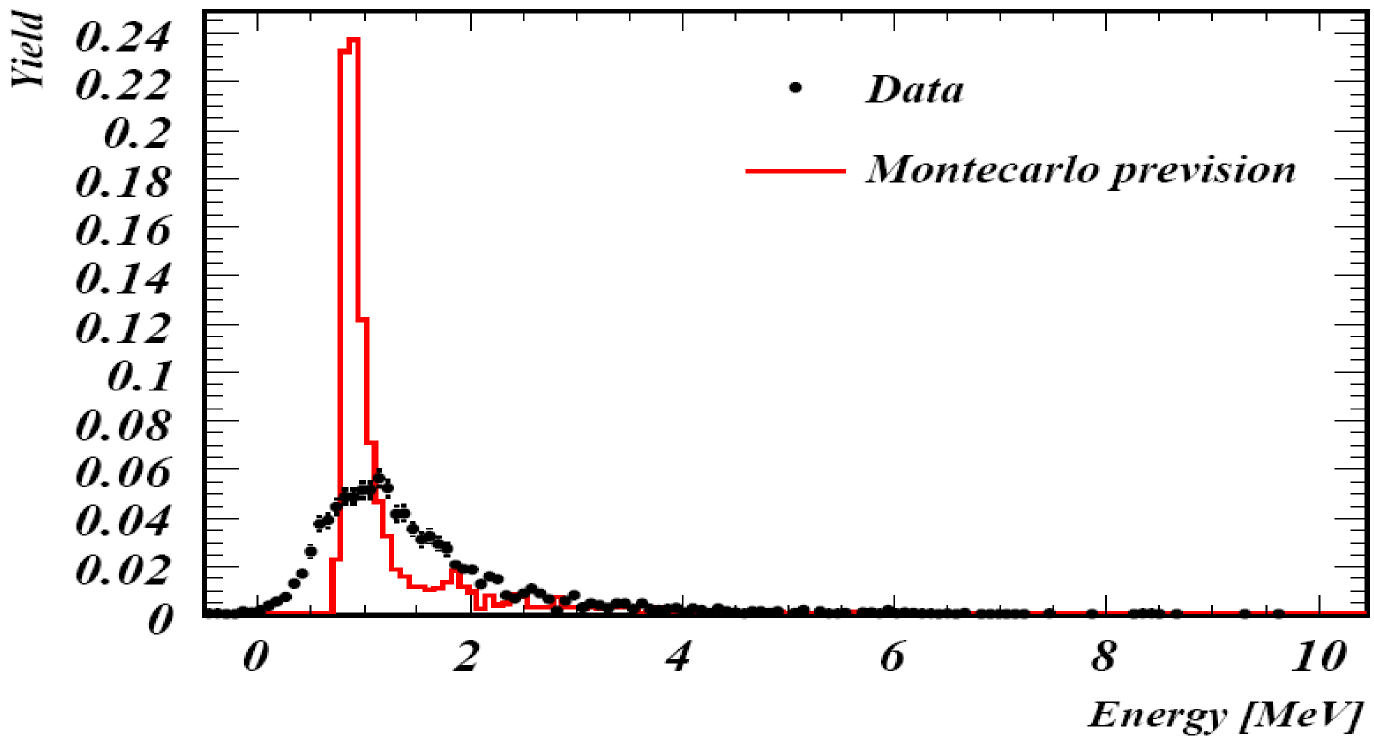


A very good agreement between data and montecarlo! – NO DIGITIZATION!

The smearing effect of the detector dies out just statistically when summing up the cells…

Reconstruction of the visible energy : single layer

The total energy deposited in a single hcal layer (1 cell) is shown. The contrbution of the detector smearing (both Poisson and noise) is relevant.



The disagreemet between DATA and MC is huge.

The noise can not be extracted with the simple landau convoluted with gaussian.

How can we extract the physics information cell by cell?

Likelihood and muon identification

The likelihood method allows to extract phisics information from the signal, on a statistical basis

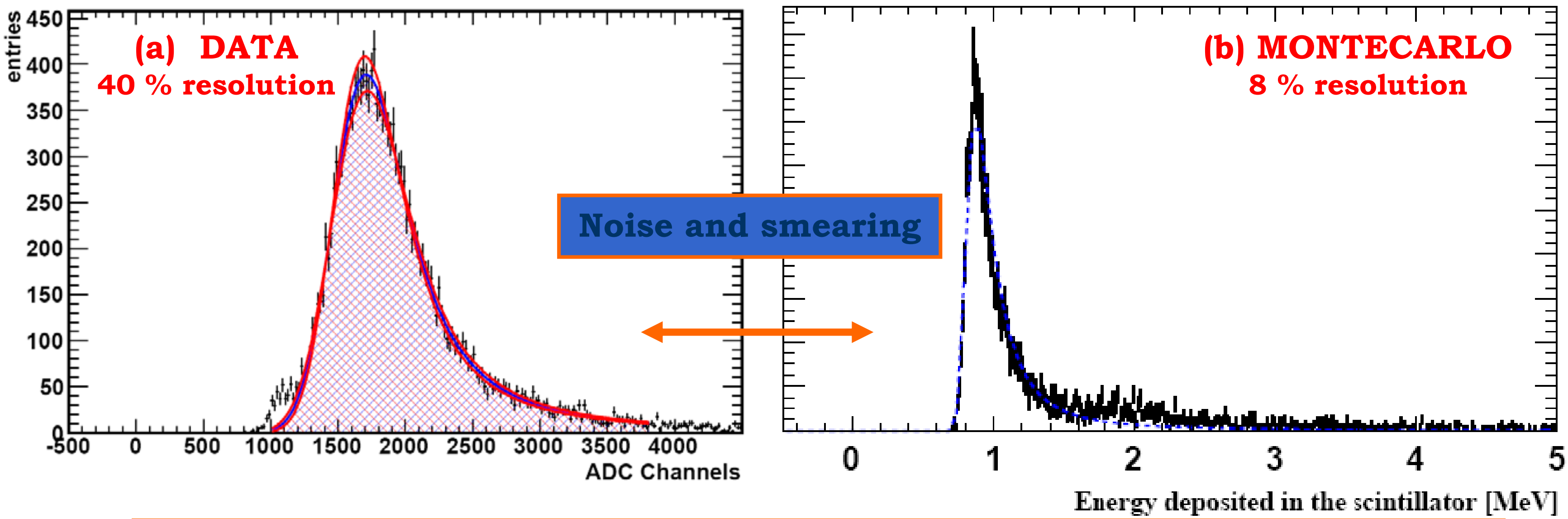


Fig. 1 Muon signal in one hadron calorimeter cell (a) DATA – (b) Montecarlo

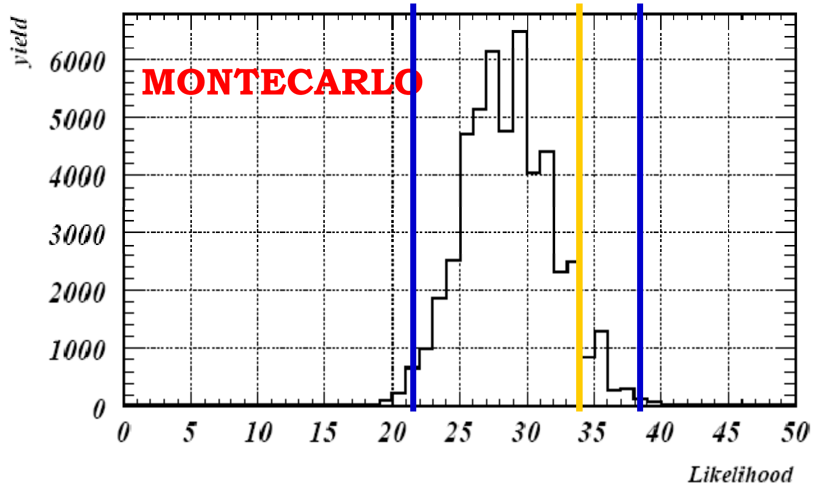
Bin	Probability
(0, MPV-σ)	11.6 %
(MPV-σ,MPV)	28.97%
(MPV,MPV+3.78 σ)	27.91 %
(MPV+3.78 σ,MPV+2 x 3.78 σ)	16.65 %
(MPV+2 x 3.78 σ, infinite)	21.65%

1. The signal is divided in 5 bins
   1. The MPV sets the scale
   2. The σ sets the binning width
2. The probability function is the response calculated with the montecarlo (b)

$$L = -log\left(\prod_{n_{hits}}^{i=1} P(E_i)\right)$$

Likelyhood method: distributions

The likelihood sets the acceptance criteria of the statistical hypothesis.



Significance	Lower bound	Upper bound
5% two tails	22.2	38.2
10% two tails	23.2	36.2
10% one tail	-	34.5

Fig. 1 Likelihood distribution for muon identification (Montecarlo). The significance thresholds are shown in the table

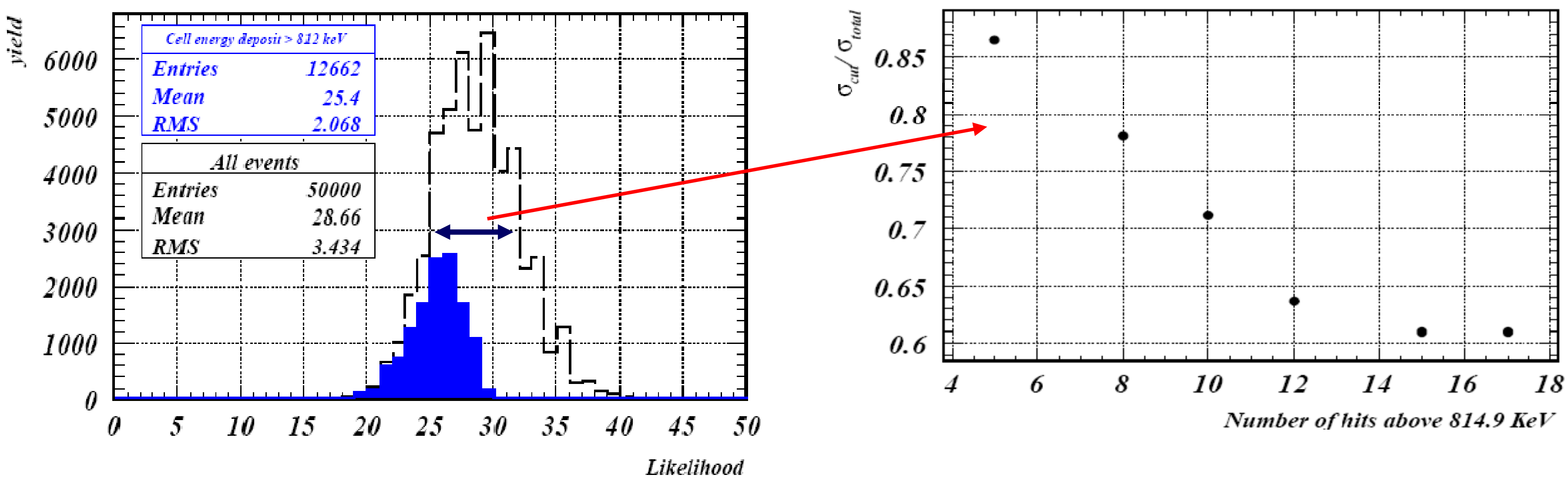
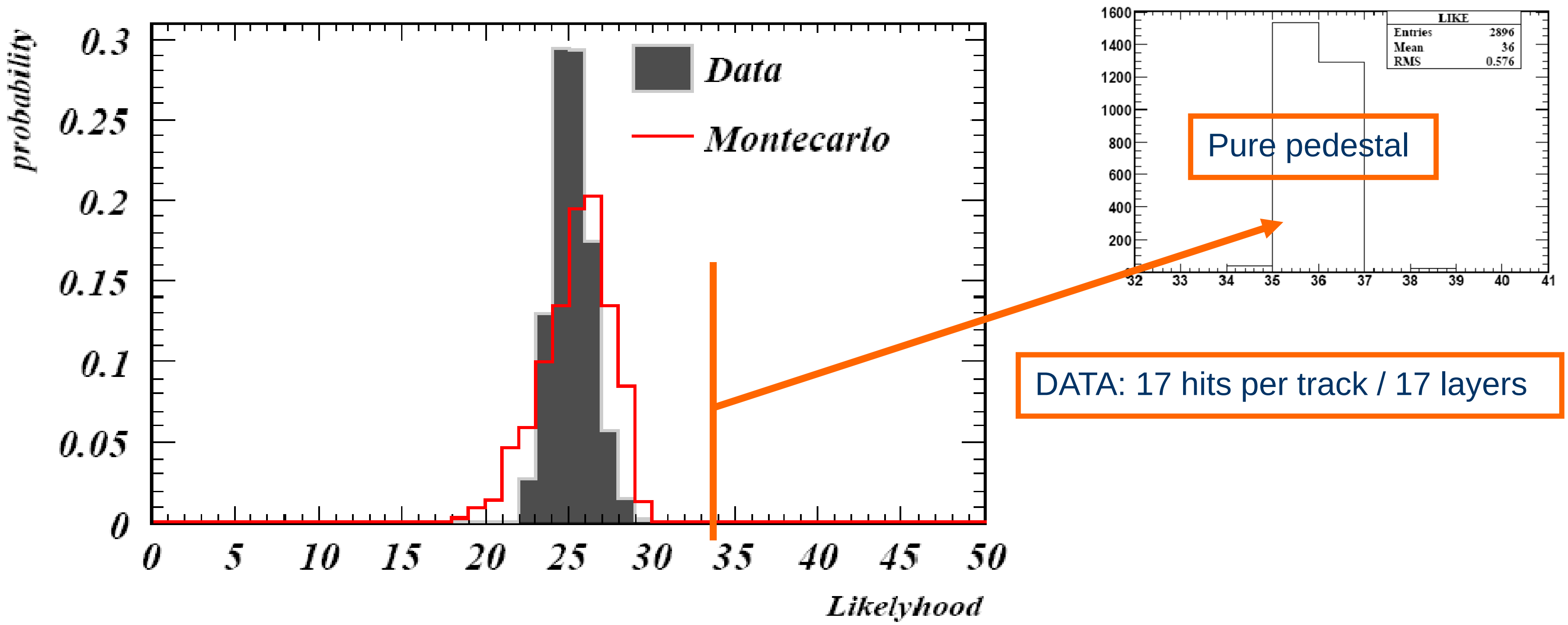


Fig. 2 (a) Subsample of the muons which deposits always energy above the first bin (17 hits/17 layers)
(b) Relative change of the width of the likelyhood distribution for different number of hits requested.

Application of the likelihood to the DATA



1. There is a good agreement between the significance bounds in MC and DATA.
2. The diatributions are different in shape, due to efficiencies in the DATA collection
3. **The same significance bounds can be used for DATA and MC: the m.i.p. hypothesis can be tested directly**

Significance	Lower bound	Upper bound
5% two tails	22.2	38.2
10% two tails	23.2	36.2
10% one tail	-	34.5

Muon interaction in the iron : transversal profile

The study of the transversal profile points to identify some variables which are typical of the muon

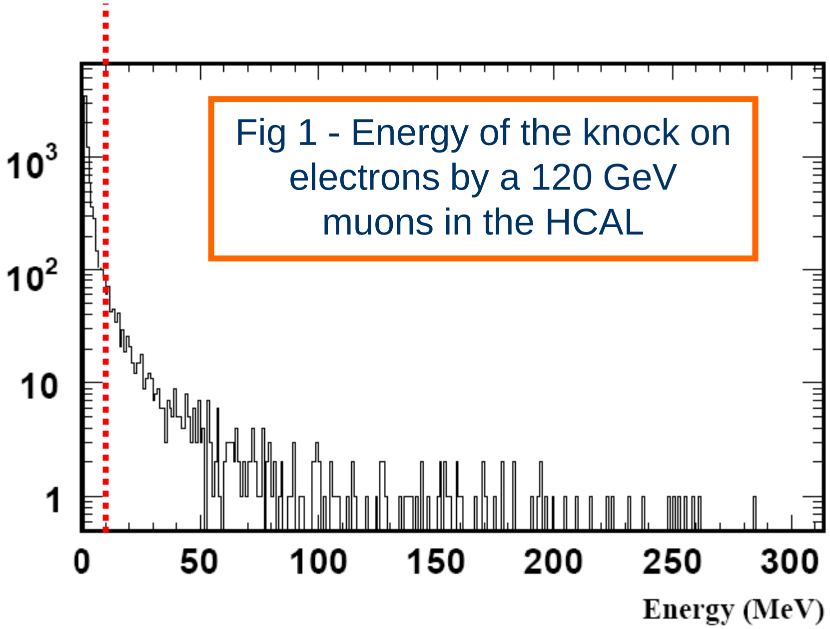


Fig 1 - Energy of the knock on electrons by a 120 GeV muons in the HCAL

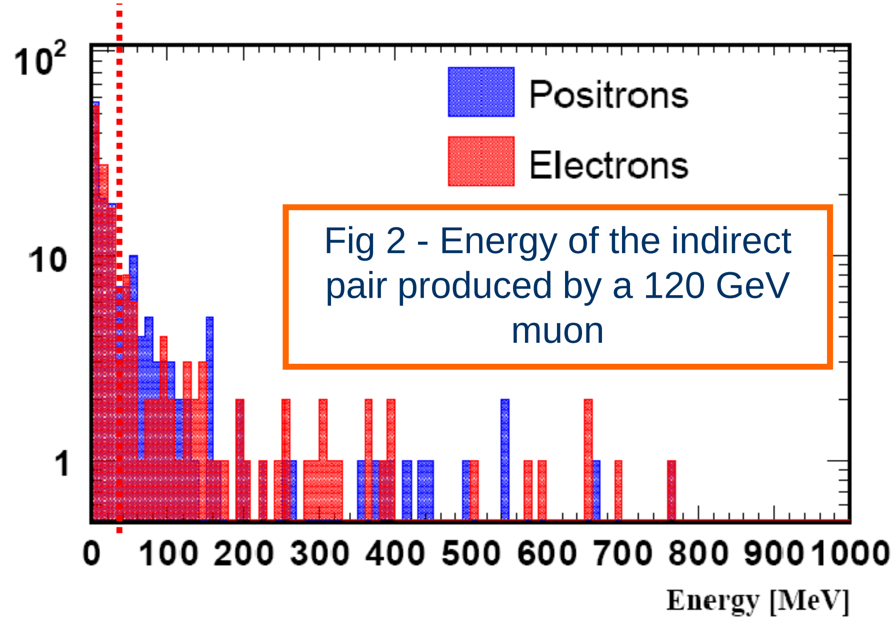


Fig 2 - Energy of the indirect pair produced by a 120 GeV muon

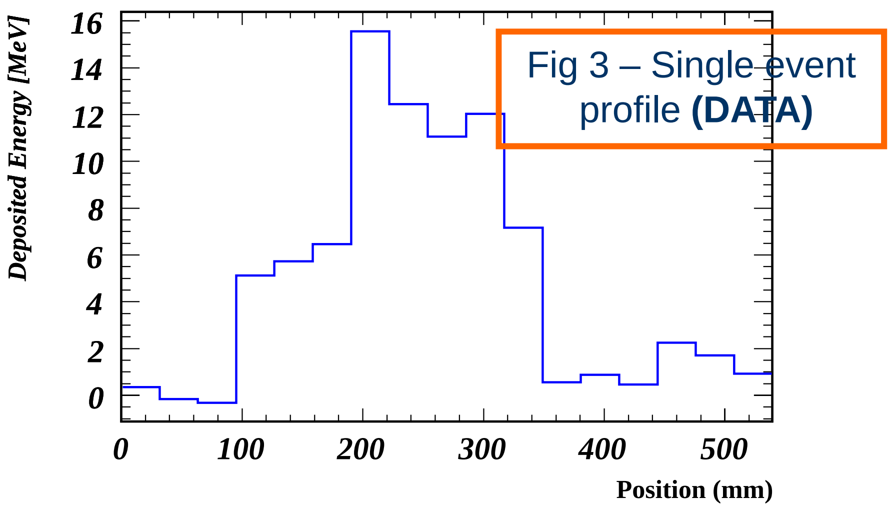


Fig 3 – Single event profile **(DATA)**

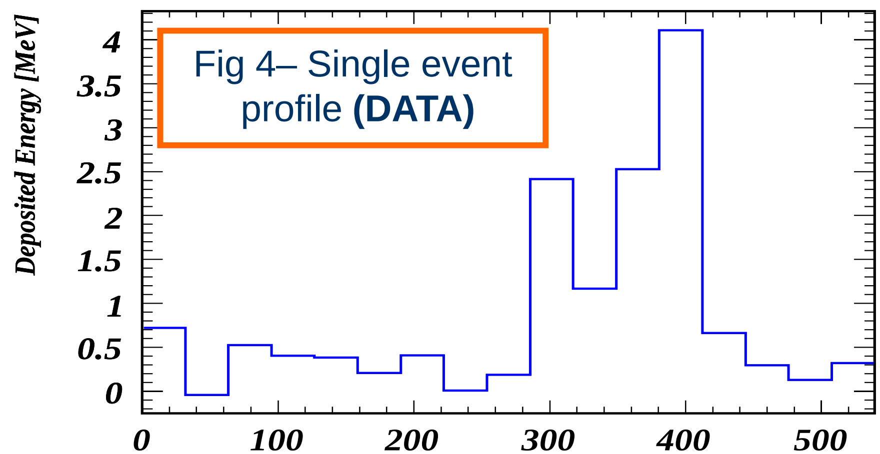


Fig 4– Single event profile **(DATA)**

Delta ray production around the muon track

The total number of showering knock on electrons is seen as first variable which identifies a m.i.p. track

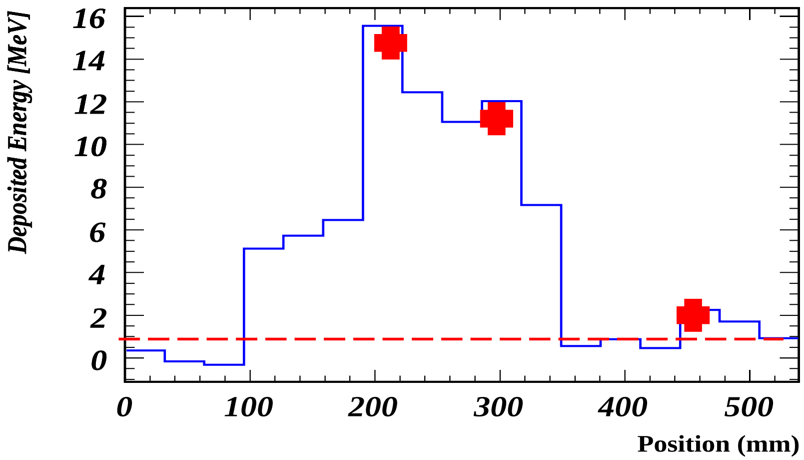


Fig 1 – Delta rays finder. **The threshold is the 5th bin of the likelihood binning.**

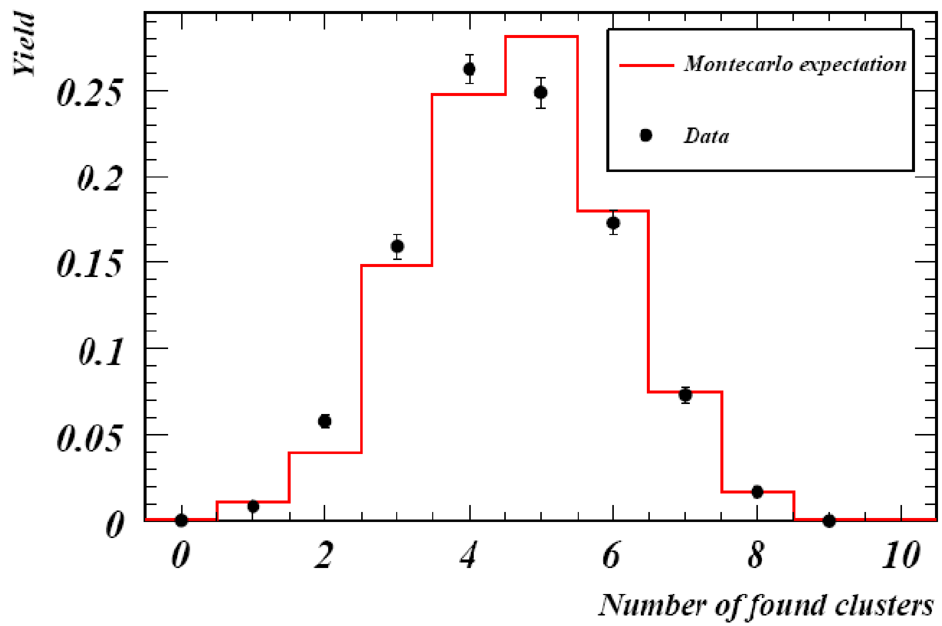


Fig 2 – Number of showering delta rays found in data and MC

The agreement between data and montecarlo is achieved only using statistical techniques.

NO DIGITIZATION NEEDED!

Local observables for the muon identification

More local observables can be found, in order to characterize the muon response and to separate it from other "m.i.p." like particles (e.g. Pions)

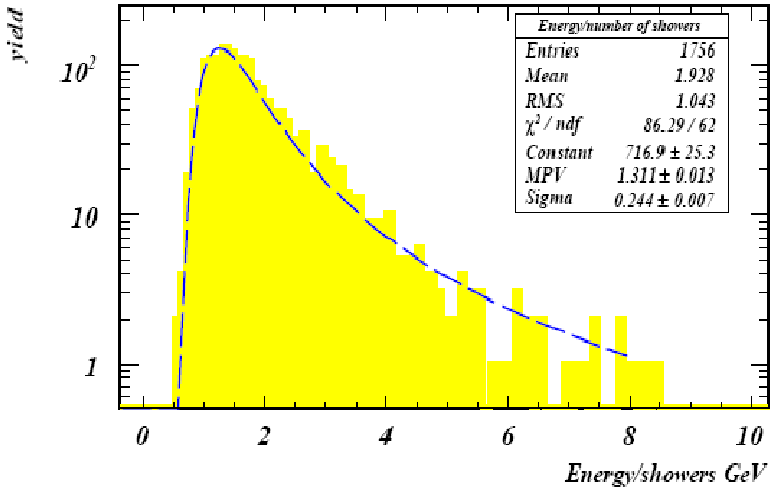


Fig 1 – Total visible energy deposited [MeV] / number of showers

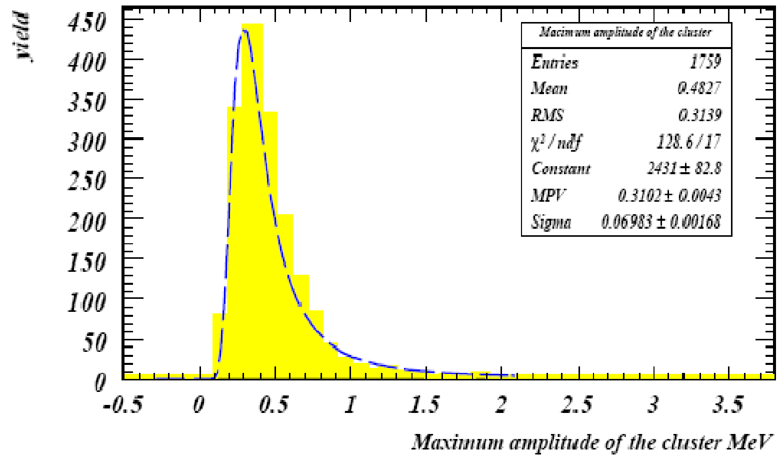


Fig 2 – Amplitude of the shower peak [MeV] / number of modules (17)

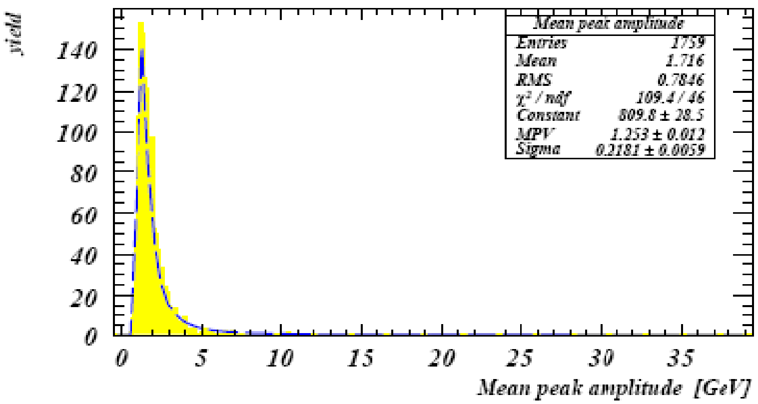
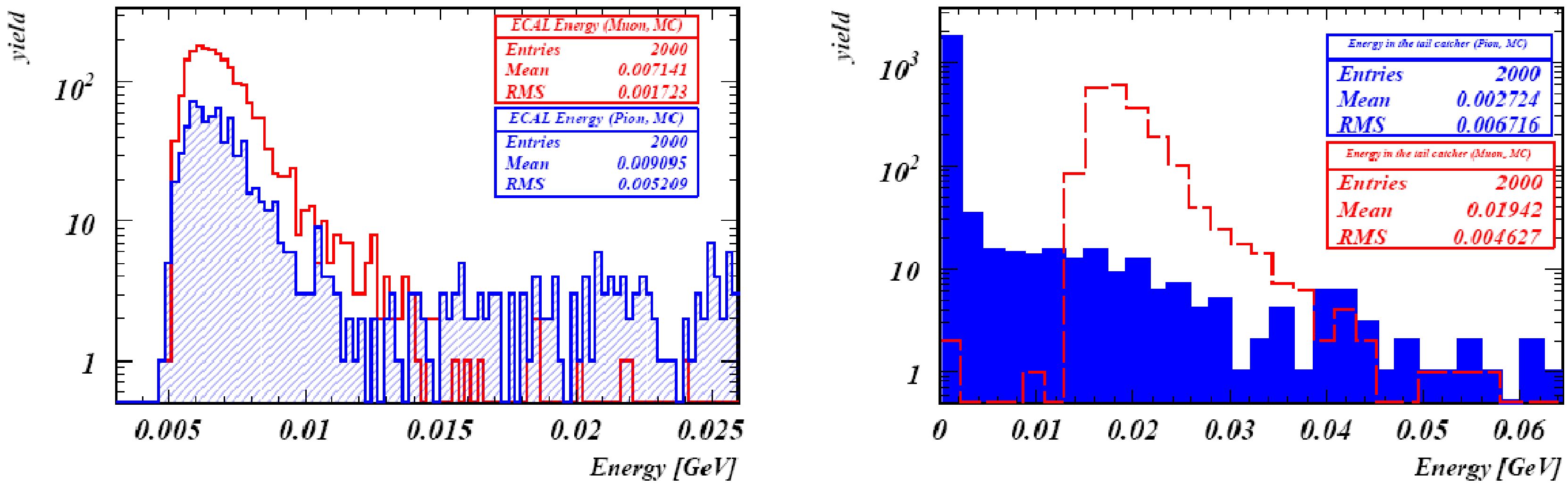


Fig 3 – Amplitude of the shower peak [MeV] / number of showers

The muon can be described hence with:

1. E_vis/n_showers < 8 MeV
2. A_shower/n_showers < 5
3. A_showers/n_sampling(17) <1
4. N_showers<9

"*Mip like*" pions in the hcal



MC : 6 GeV Pions in the hcal (blu) and muon response (red). Response of the ECAL and of the Tail Catcher.

• Pions mainly strngly interact in the hcal. However, the probability of penetration of the HCAL, with further interaction in the Tail catcher is possible.

•The tracks corresponding to the penetrating pions are "m.i.p." like, not easy to disentangle from a muon with simple cuts

Local observables for pions (6 GeV)

The local observables used to describe a muon are here applied to a 6 GeV pion

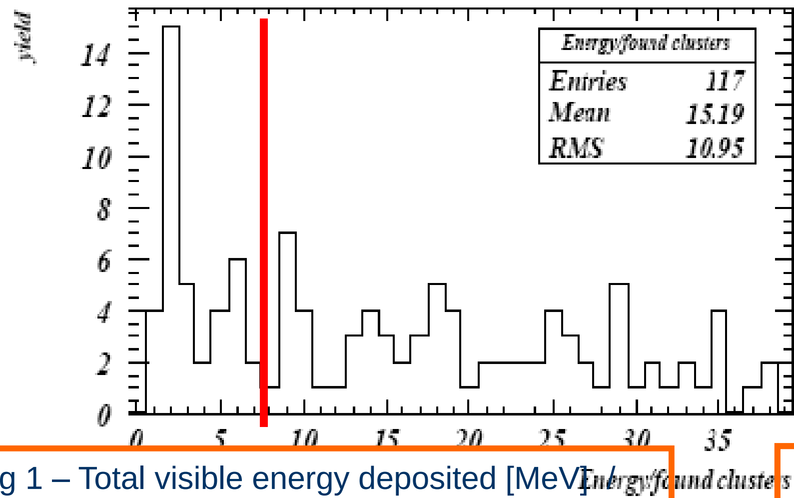


Fig 1 – Total visible energy deposited [MeV] / number of showers

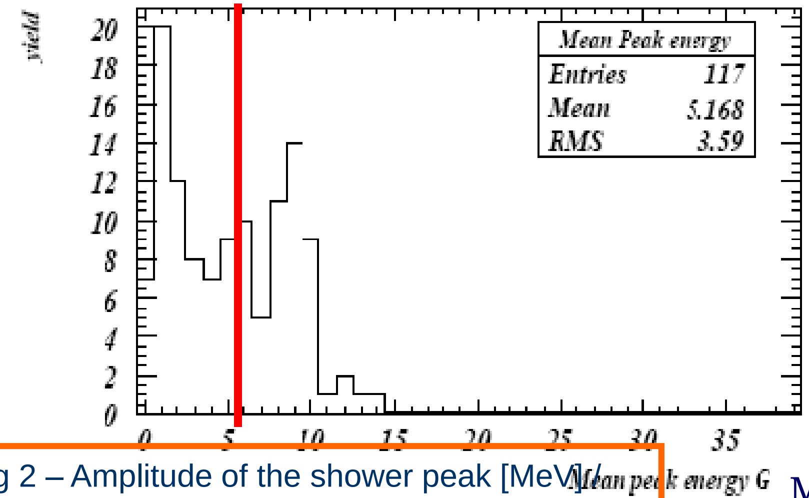


Fig 2 – Amplitude of the shower peak [MeV] / number of showers

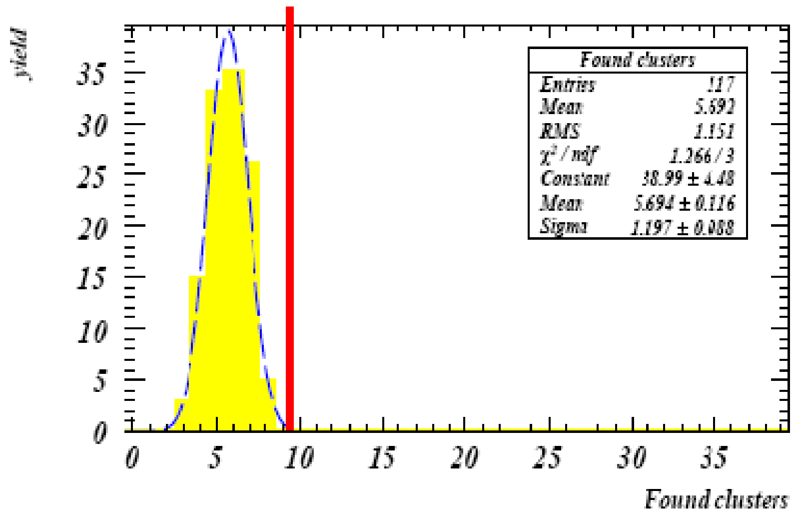


Fig 3– Number of showers

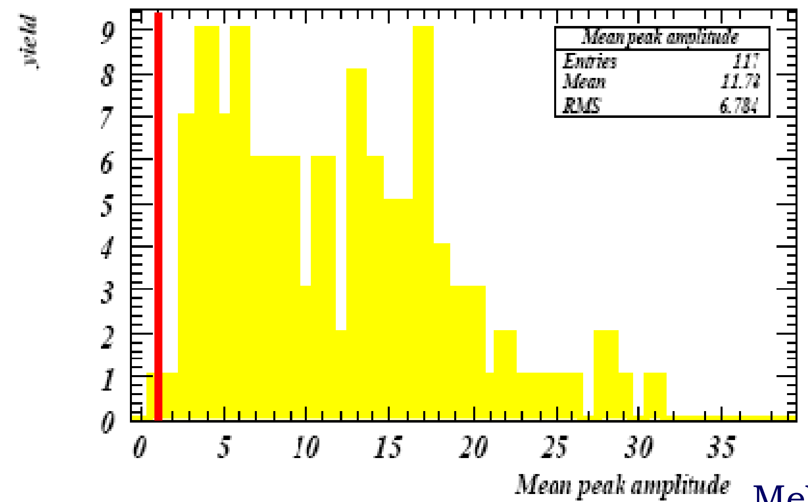


Fig 4 – Amplitude of the shower peak [MeV] / number of modules (17)

Purity of the pion selection

Energy	Mip like Pions/muons (cut in ECAL and TC)	Pions/muons passing all the cuts
6 GeV	5.8%/87%	1 % / 80%
8 GeV	7.5% / 89 %	0.6 % / 85 %
10 GeV	5 % / 90 %	0.25 % / 88%

The application of the delta rays production properties to the muon/pion separation allows to gain a factor 5-10 in the purity of the samples.

The cuts need now to be optimized for the muons: relax cut in the tail catcher!

Conclusions

- Data and Montecarlo are in good agreement at % level
  - We start to understand the calorimeter and its systematics at the mip level, which is the basis of the hcal test beam analyses
- This study addresses the potential of a 3cm x 3 cm granular calorimeter for particle ID
  - The mu/pi separation can be obtained with a detailed analysis of the delta rays produced around the track
  - The m.i.p. like particle identification can be done with a likelihood statistical tool
- The techniques can be exported to the full ILD detector studies, in order to optimise the muon identification using the information of the calorimeter
  - Muon finding in jets
  - Physics channels with isolated muons