The muon response of the CALICE higly granular analog hadronic calorimeter

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Outline

- Data samples
- Results
  - Systematic effects of the detector operation
  - Energy dependence of the muon response
  - Angular dependece of the muon response
  - Measurement of e/mip
  - Measurement of the production of highly energetic knock on electrons
  - Measurement of muons produced in pion showers
- Conclusions

Experimental data

(i) Monocromatic 120 GeV parasitic muon beam (about 1000000 events for the 2006 set-up and for the 2007 set-up) — sections 4.1, 4.7, 4.9, 4.10

(ii) Muons contaminating pion runs in the 2006 set-up (about 20000 events for each of the following energies: 10 GeV, 15 GeV, 18 GeV, 20 GeV, 40 GeV, 80 GeV) — sections 4.4

(iii) Pions interacting after the 7^{th} layer of the AHCAL, selected from the pion runs in the 2006 set-up (about 500000 events for each of the following energies: 10 GeV, 15 GeV, 18 GeV, 20 GeV, 40 GeV, 80 GeV) — sections

(iv) Muons generated from a hadronic shower in the pion runs in the 2007 set-up (about 500000 events for each of the following energies 10 GeV, 15 GeV, 20 GeV, 25 GeV) — section

(v) 50 GeV muons impinging the detector at different angles contaminating the pion runs in the 2007 set-up (30000 events for each of the following configurations : $0°$,$(10.0° \pm 0.1°)$,$(19.71° \pm 0.14°)$,$(28.3° \pm 0.1°)$) — section 4.6.

Event selection

Parasitic muons:

(i) A cut on the total number of hits in the ECAL $30 < N_{hits}^{ECAL} < 34$

(ii) Mip like signature in the *fine section* of the TCMT $1 < e_{TCMT1}/hits_{TCMT1} < 1.5$

(iii) Mip like signature in the *coarse section* of the TCMT $1 < e_{TCMT2}/hits_{TCMT2} < 1.5$

Muons Contaminating Pions Runs:

(i) One isolated perpendicular track in the ECAL and in the HCAL

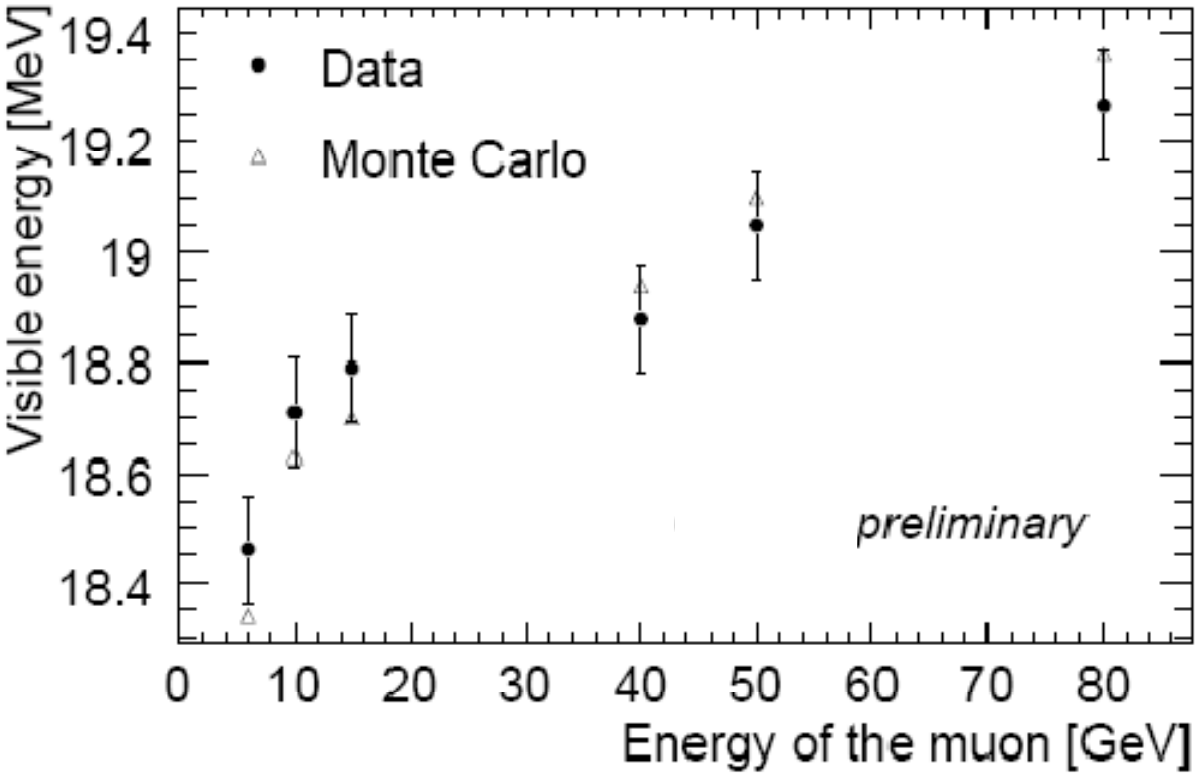
(ii) The number of hits in the ECAL is about the total number of layers ($30 < N_{hits}^{ECAL} < 34$)

Pion tracks

(i) The track in the first 7 layers has to be isolated: not more than 10 hits in the volume of 3×3 cells around the track.

(ii) The number of hits in the second part of the hadronic calorimeter is more than 100.

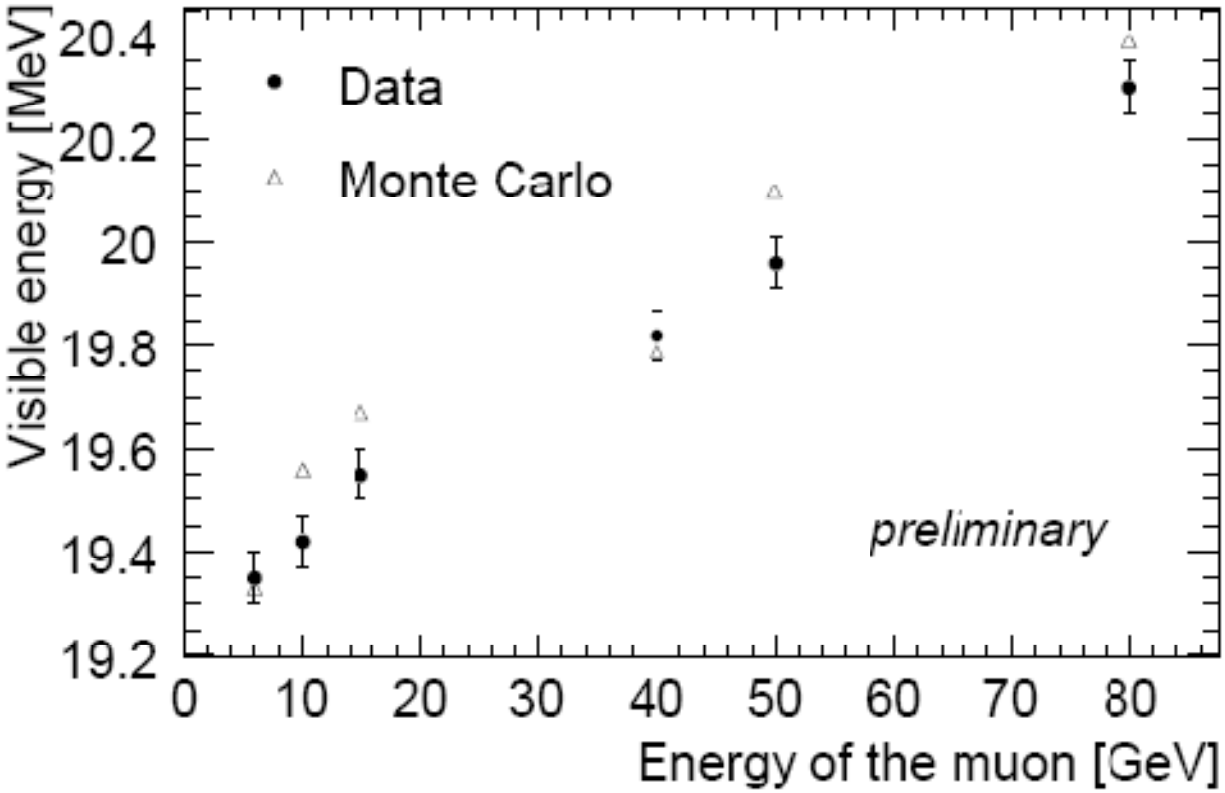
Results – 1
Energy Dependence -1



Most Probable value of the total energy deposited by a muon in the HCAL

2006 data

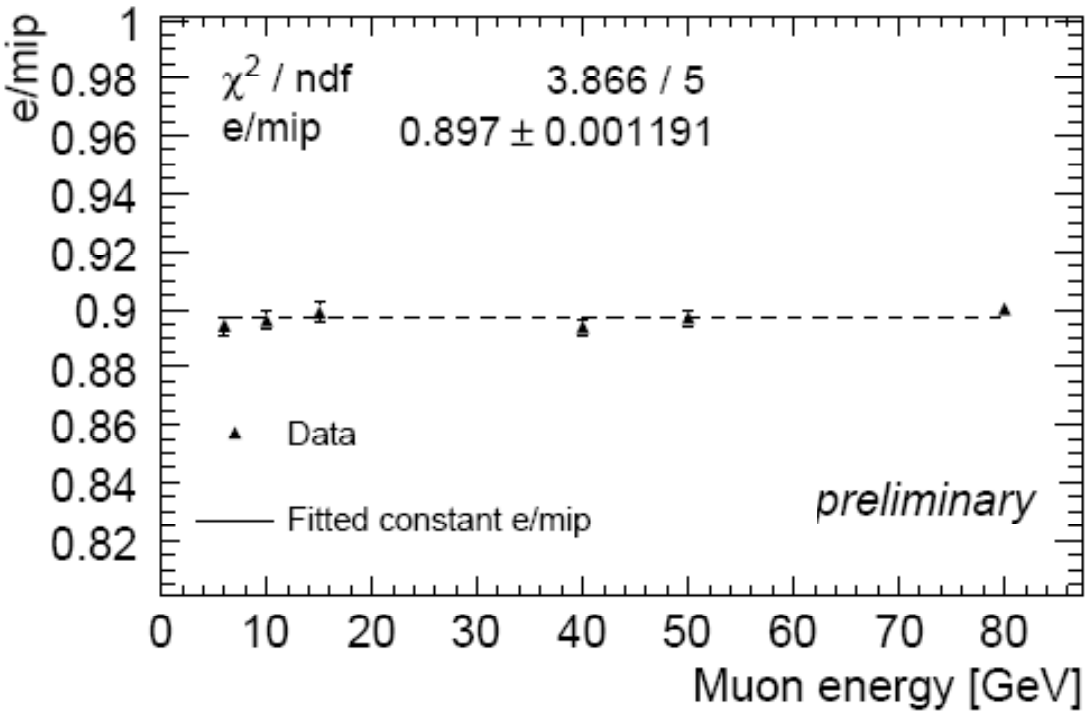
Results – 1
Energy Dependence -2



Average value of the total energy deposited by a muon in the HCAL

2006 data

Results – 2
e/mip -1



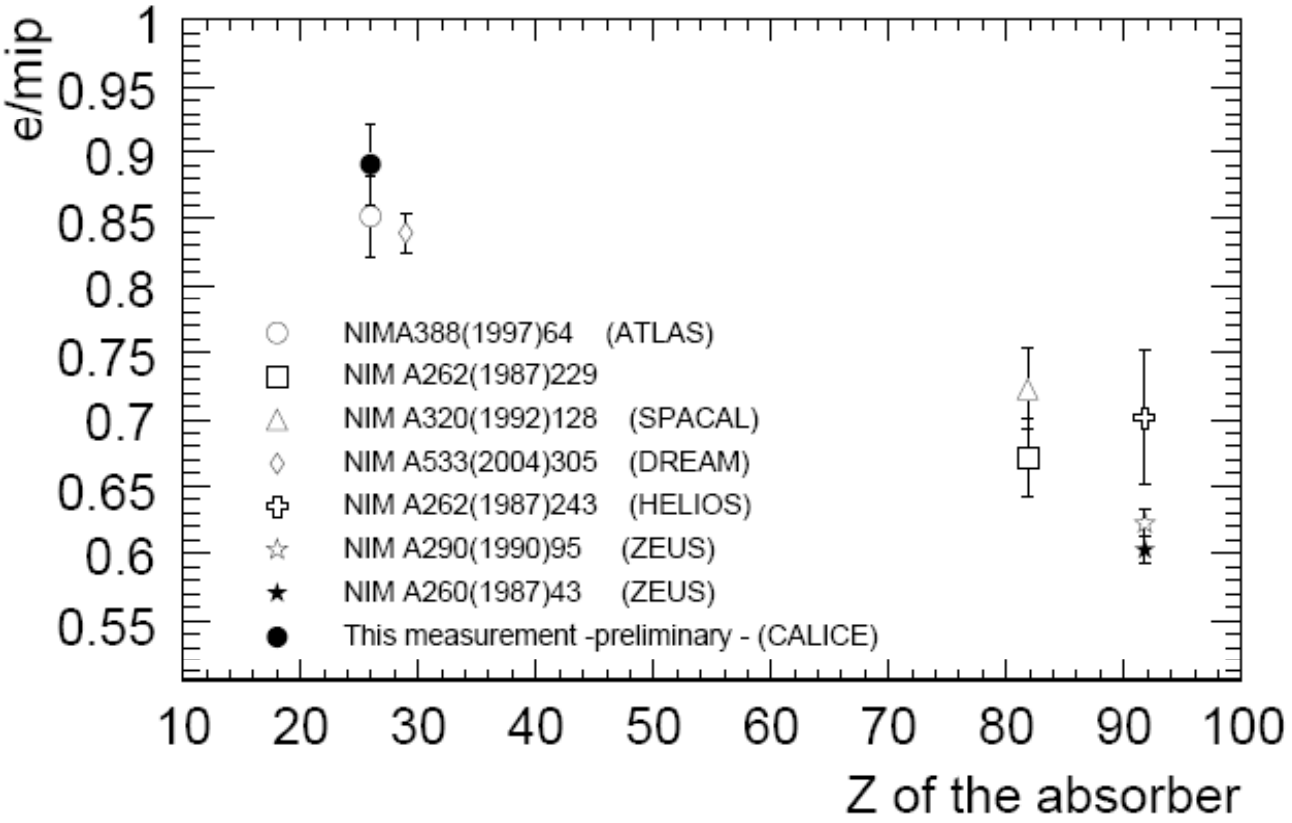
The e/mip ratio is measured as the deviation of the reconstructed muon energy at the electromagnetic scale from the energy of a mip:

$$\frac{e}{mip} = \frac{S_f^e}{S_f^{m.i.p.}} = \frac{E_{mip}^{tot}}{E_\mu^{tot}} \qquad (4)$$

$$\frac{E_{mip}^{tot}}{E_\mu^{tot}} \quad \frac{E_{MC}^{vis}}{E_{mip}^{vis}}$$

NON MIP Correction

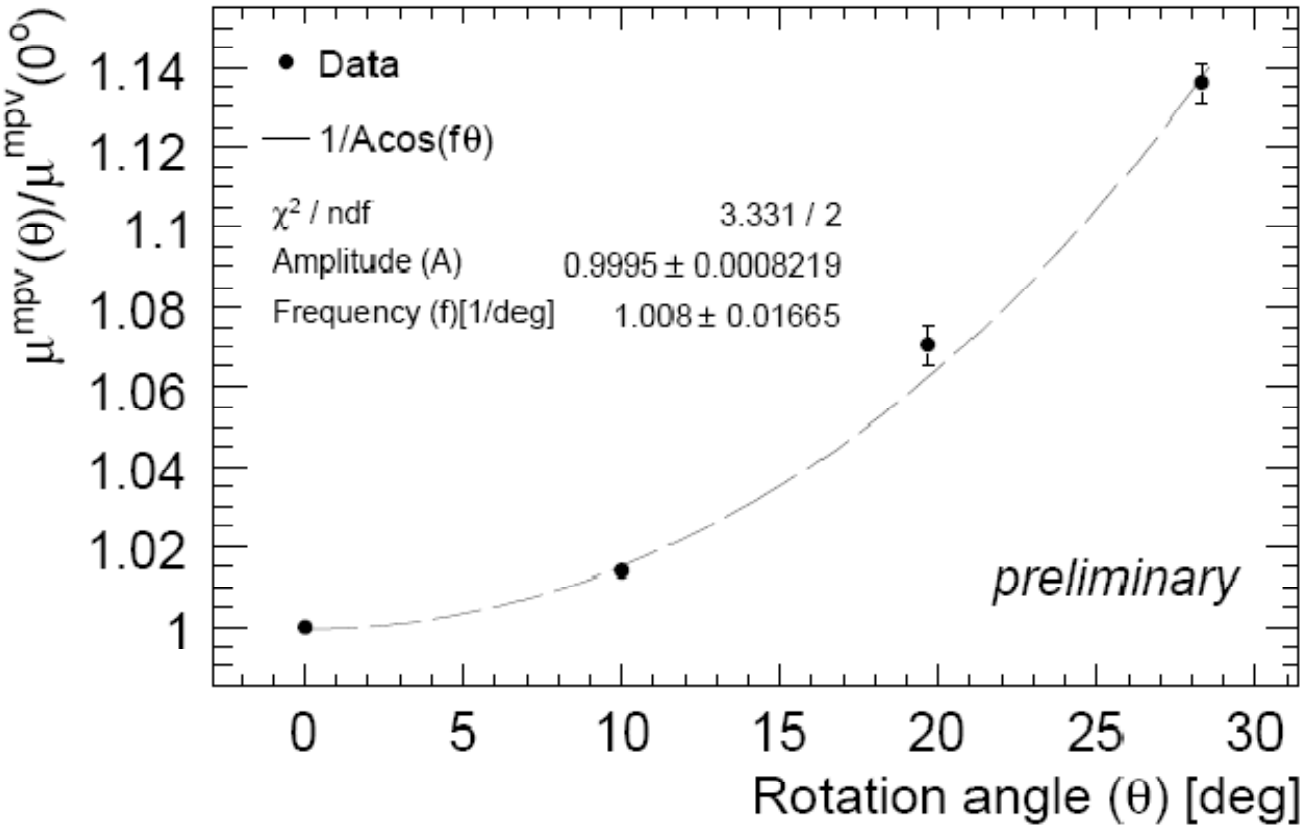
Results – 2
e/mip - 2



The measurement of e/mip compared with the other calorimeters

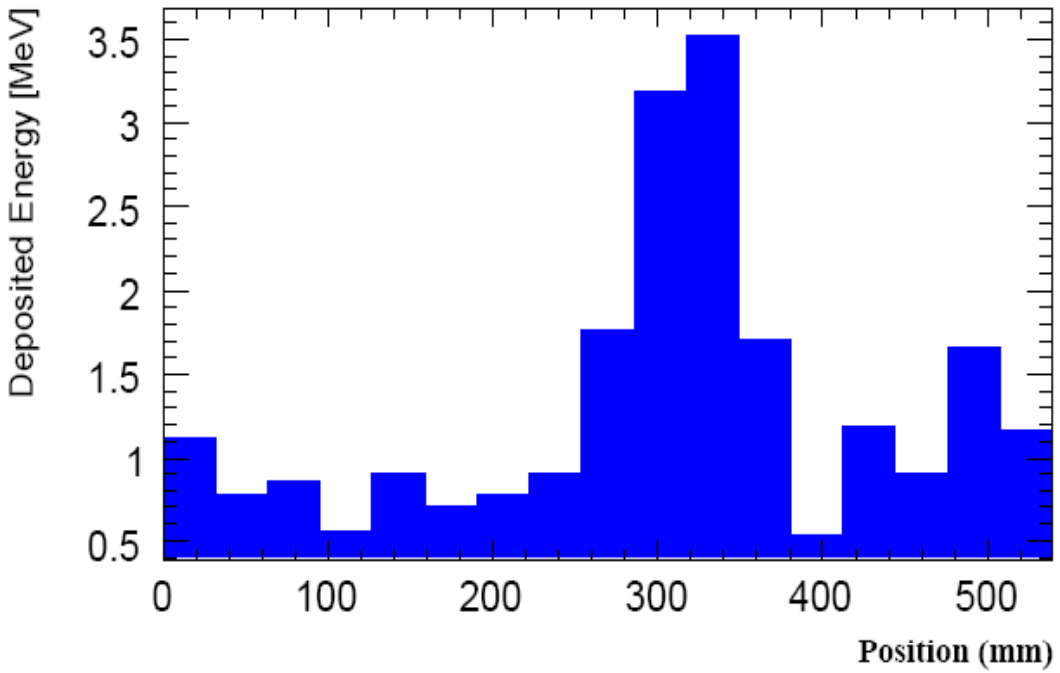
The dependence of e/mip on Z is evident

Results – 3
Angular dependence



Results – 4

The spin dependence of the delta ray emission - 1



$$\frac{d^2N}{dTdx} = \frac{1}{2}Kz^2\frac{Z}{A}\frac{1}{\beta^2}\frac{F(T)}{T^2}$$

Figure 21. Transversal profile of a s
calorimeter. A electromagnetic shower
deposition.

$$F(T) - \begin{cases} 1-\beta^2\frac{T}{T_{max}} & spin \quad 0 \\ 1-\beta^2\frac{T}{T_{max}}+\frac{1}{2m^2c^4}\left(\frac{T}{1+\gamma}\right)^2 & spin \quad \frac{1}{2} \\ \left(1-\beta^2\frac{T}{T_{max}}\right)\left(1+\frac{1}{3}\frac{T}{T_c}\right)+\frac{1}{3m^2c^4}\left(\frac{T}{1+\gamma}\right)^2\left(1+\frac{1}{3}\frac{T}{T_c}\right) & spin \quad 1 \end{cases}$$

Results – 4

The spin dependence of the delta ray emission - 2

(i) The shower maximum candidate has a visible energy deposition consistently above noise ($E^{vis}_{max} > 2$ MeV).

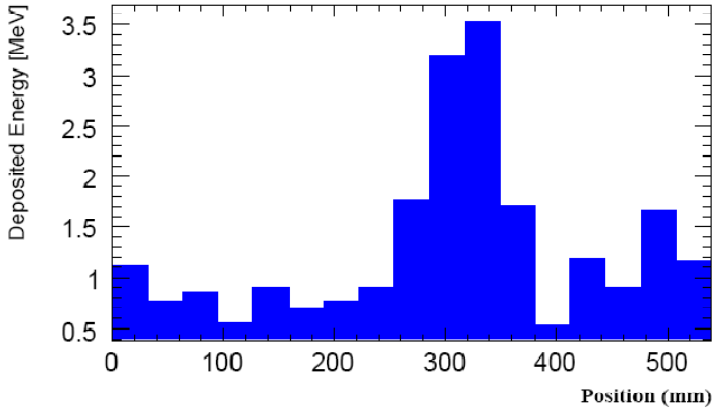
(ii) The energy deposit of the layer before and after the shower maximum candidate is above noise ($E^{vis}_{max-1} > 1.5$ MeV,$E^{vis}_{max+1} > 1.5$ MeV)

(iii) The shower maximum candidate region satisfies the condition ($E^{vis}_{max-1} < E^{vis}_{max}$ and $E^{vis}_{max+1} > E^{vis}_{max}$)

(i) The lower energy fluctuations are excluded imposing that $E^{vis}_{\delta} > 9$ MeV.

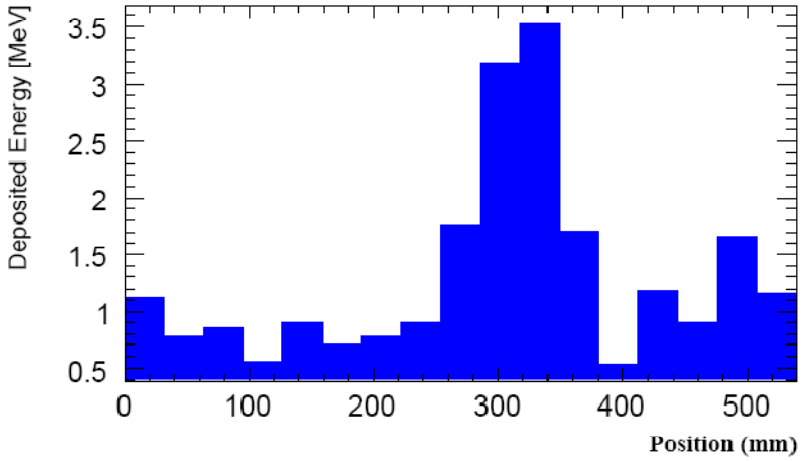
(ii) Failed fits and not regular profiles are excluded asking that σ_{δ} <100 mm.

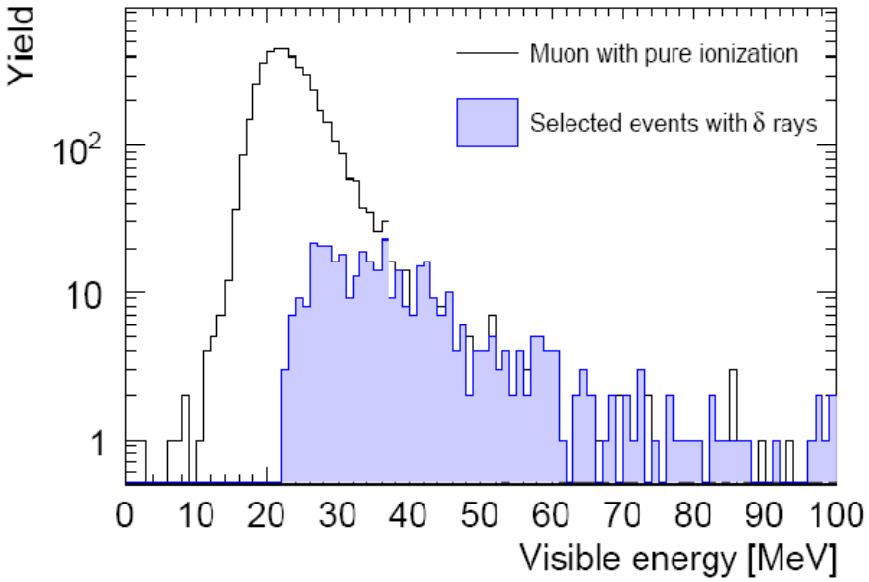
(iii) Overlapping δ rays and e^+e^- pairs produced along the track are excluded asking that the distance of the maximum of two showers on the same track is less than 100 mm.



Results – 4

The spin dependence of the delta ray emission - 3





Delta ray candidate (left) and energy distribution of the selected events (right)

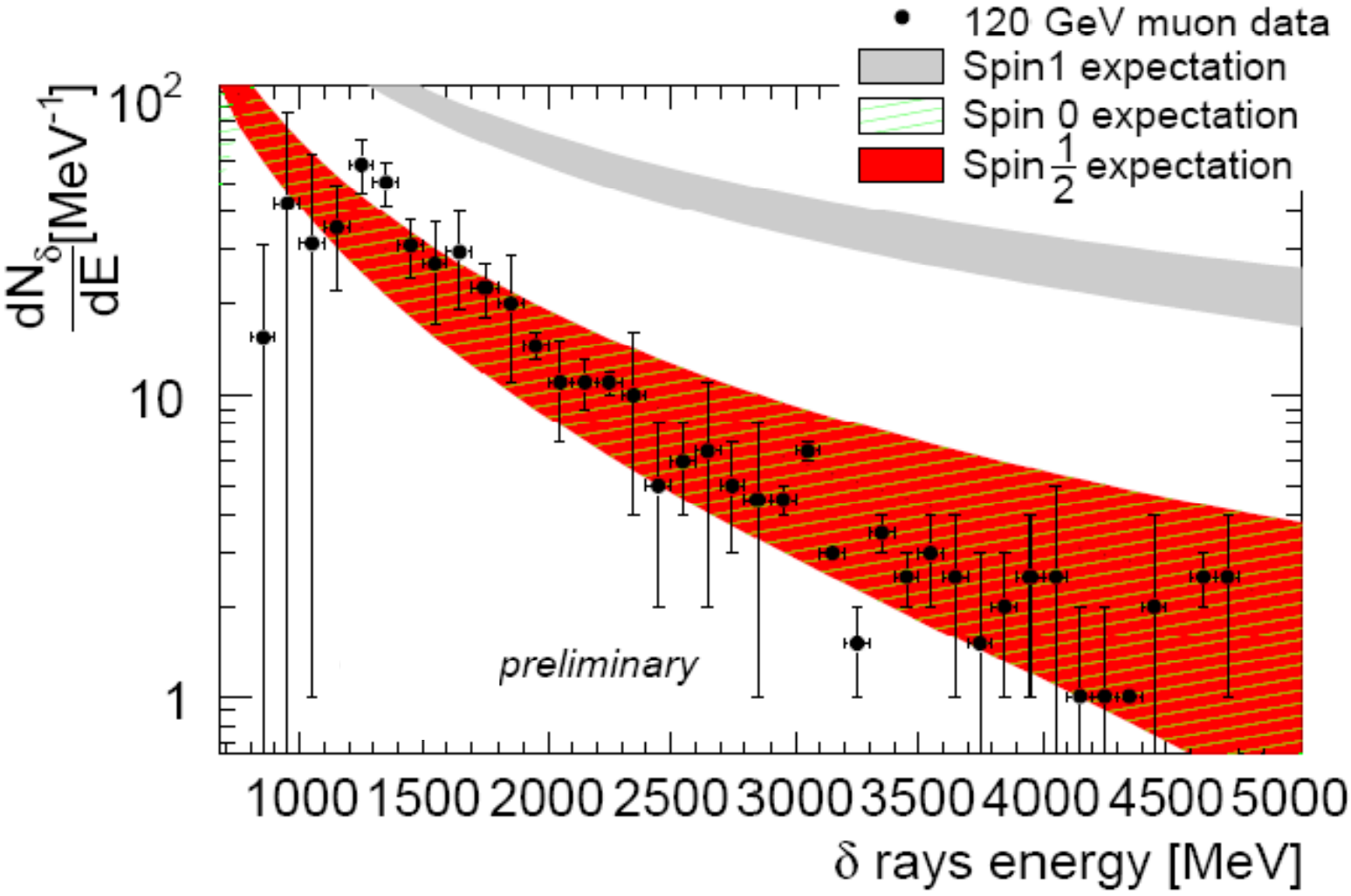
Results – 4

The spin dependence of the delta ray emission - 4

- The following systematic errors are considered:
- Uncertainty on the hitting position of the muons -DATA
  - Sampling of the energy of delta rays. Calibration constants for electrons are found at different impact points
- Total thickness of material – THEORY
  - Because of the selection 13+-2 layers considered
  - Chemical composition (5% relative error on the density)

Results – 4

The spin dependence of the delta ray emission - 5



Muons From Pion Showers

Muon from Pion Showers

(i) Hadronic shower in the AHCAL ($N_{hits}^{HCAL1} > 100$)

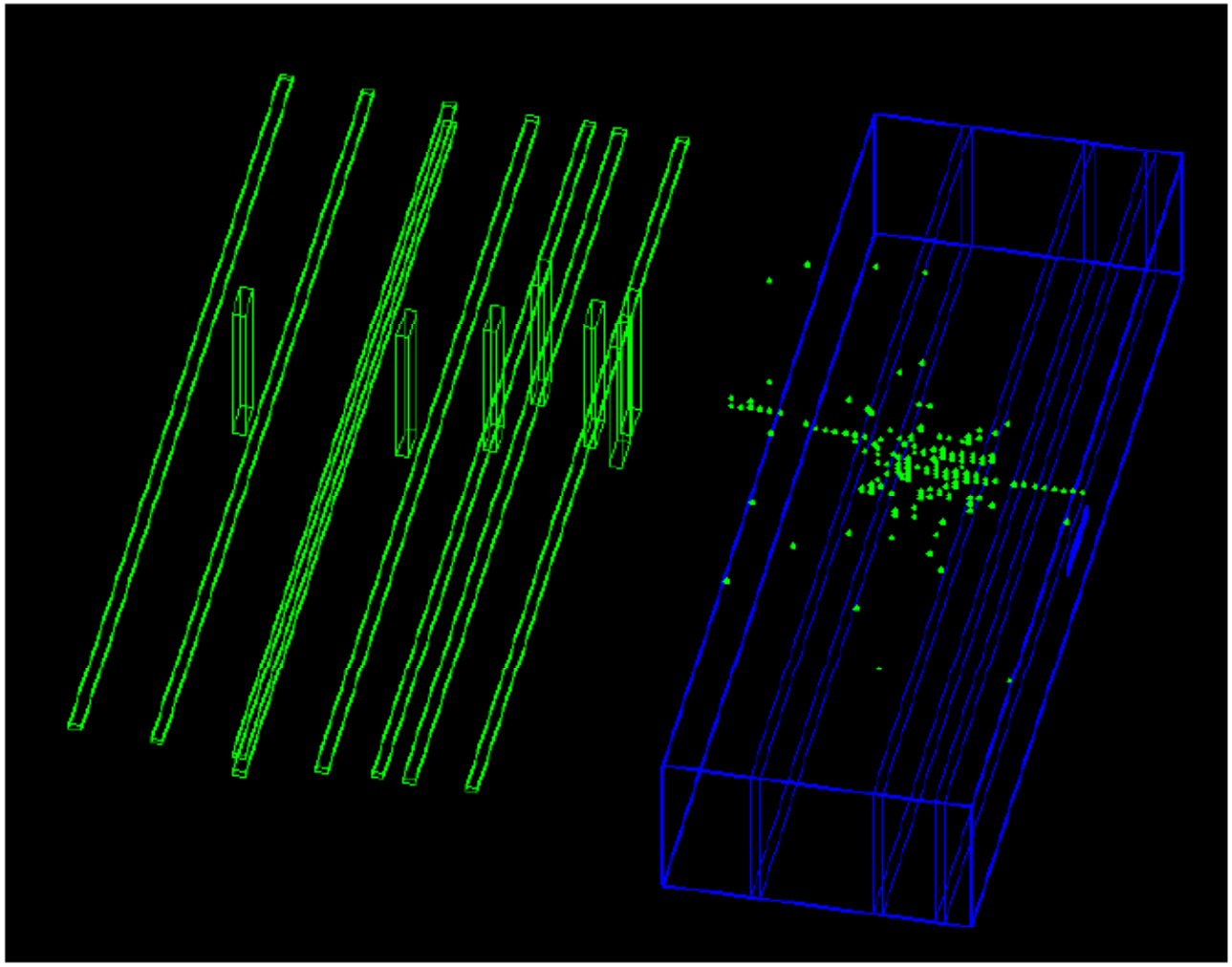
(ii) One isolated track found in the last 4 layers of the HCAL; the hits found in a volume of 1×1 tiles around the track candidate are less than 5 and more than 2.

(iii) Mip like signature in the *fine section* of the TCMT $1 < e_{TCMT1}/hits_{TCMT1} < 1.5$

(iv) Mip like signature in the *coarse section* of the TCMT $1 < e_{TCMT2}/hits_{TCMT2} < 1.5$

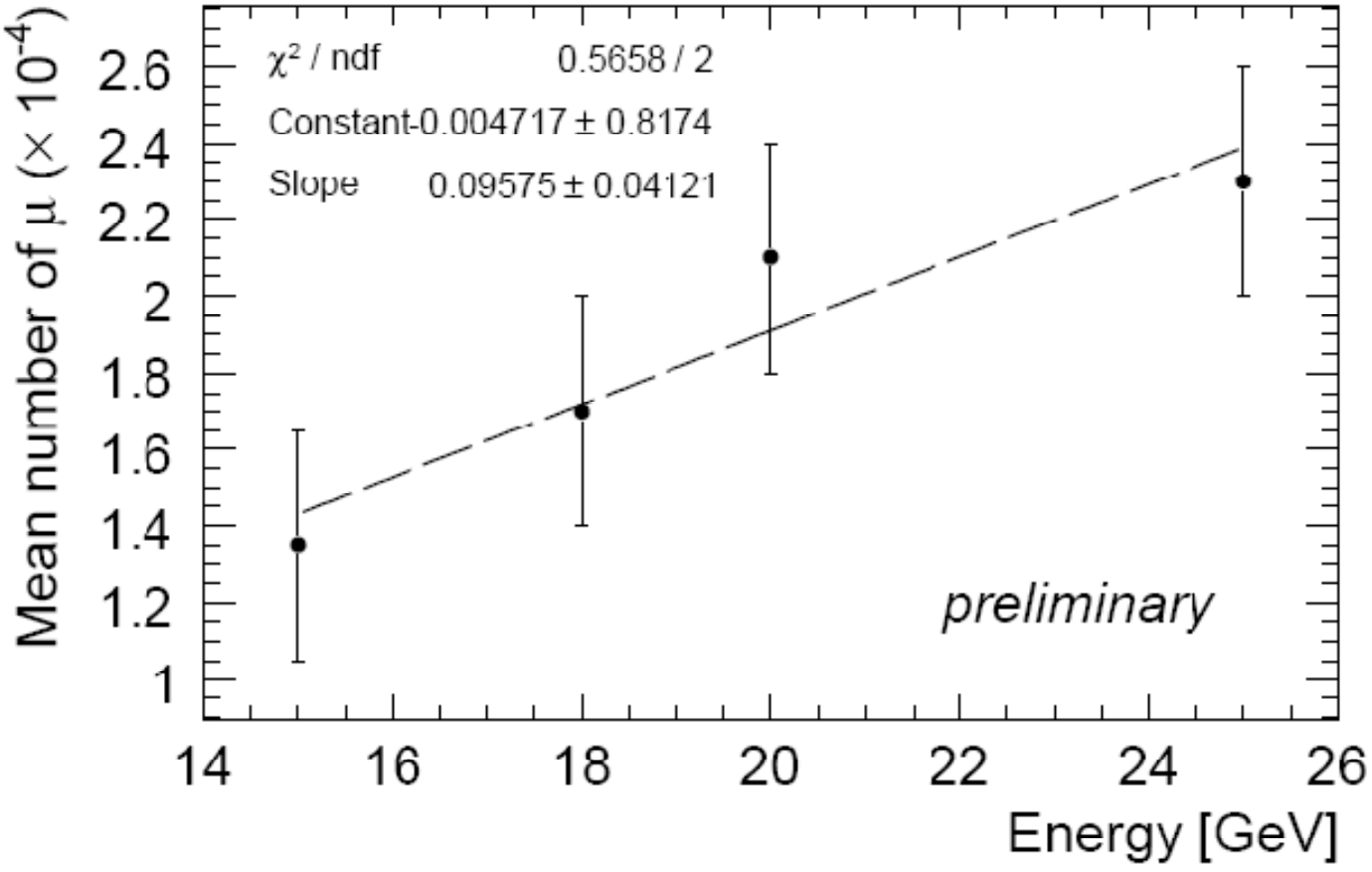
(v) The event has to be *symmetric* in the TCMT $(0.8 < hits_{TCMT2}/hits_{TCMT1} < 1.2)$

Muons From Pion Showers



Results – 5

Muons generated in a Pion Shower



Conclusions

- Good sensitivity to muons
  - Energy
  - Angles
- The e/mip measured in this study agrees with the expectations.
- Good muon detection in shower envinronment
  - TCMT good muon tracker
  - Imaging performance of the hadronic calorimeter optimal!
  - A good tracking alorithm for the tail catcher would improve the measurement!
  - In fact, the identification of muons from the pion shower is a first hint that mons can be easily identified also in the more complicated jets…
- The Measurement of Delta Rays
  - This measurement opens the possibility of the search of “spin 1 long lived charged particles”… At the moment I hadn’t find any theory descibing this processes…