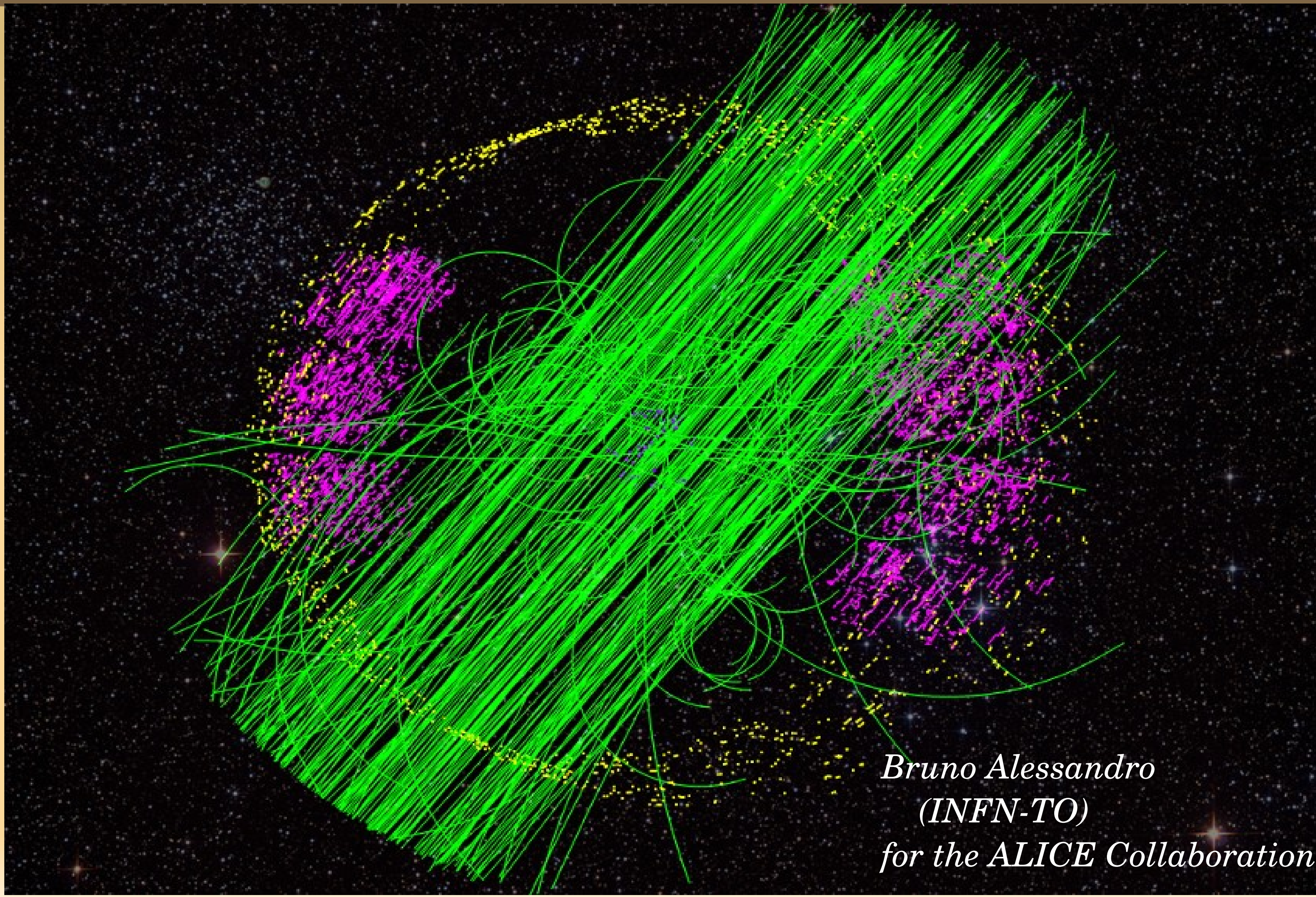
High muon multiplicity cosmic events in ALICE

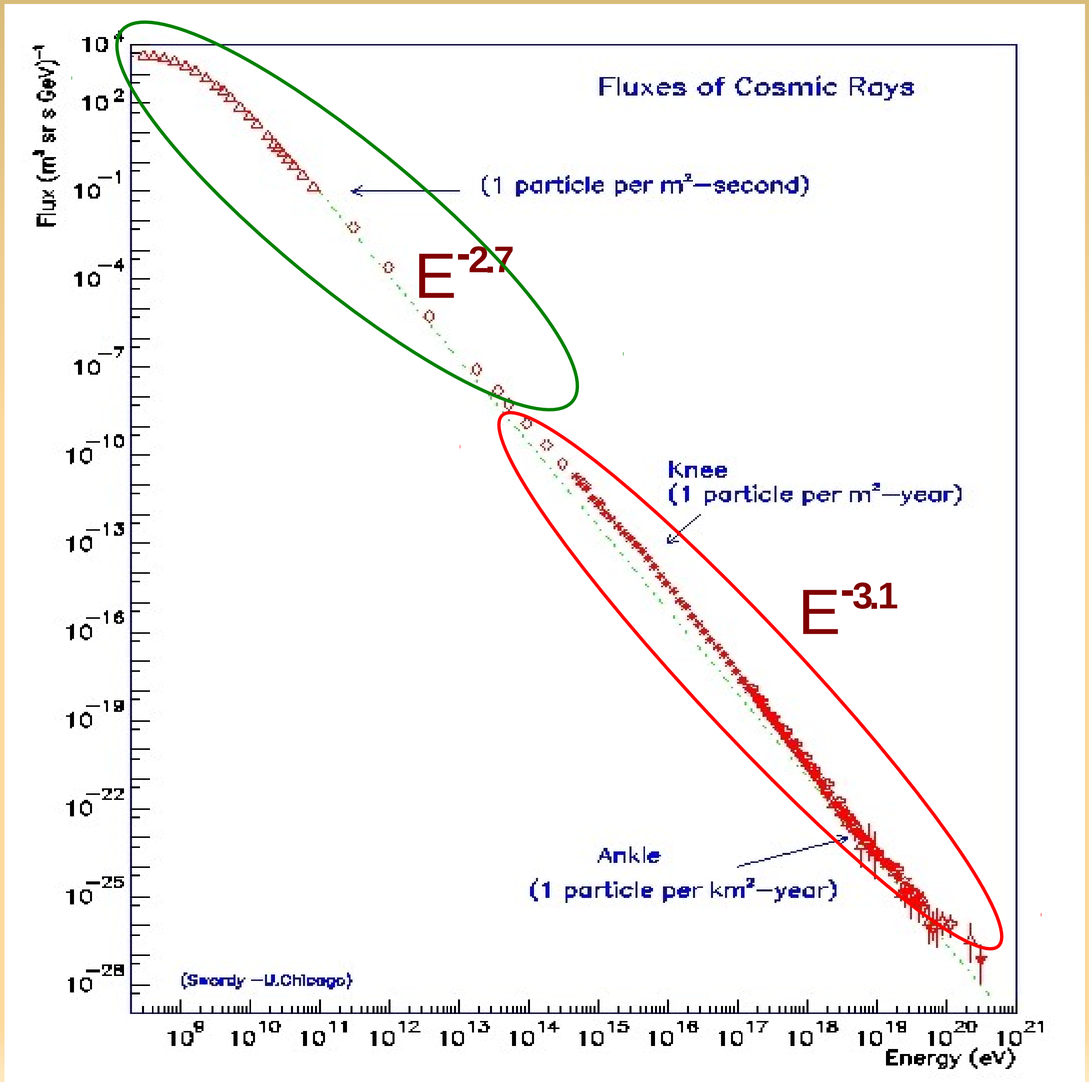


Bruno Alessandro
(INFN-TO)
for the ALICE Collaboration

Contents

- Introduction on Cosmic Ray Detection
- ALICE experiment :
  Trigger and Tracking Detectors for Cosmics
- Muon Multiplicity Distribution
- High Muon Multiplicity Events (hme)
- Simple Monte Carlo to study the hme
- Final Remarks

Measurements : Direct and Indirect

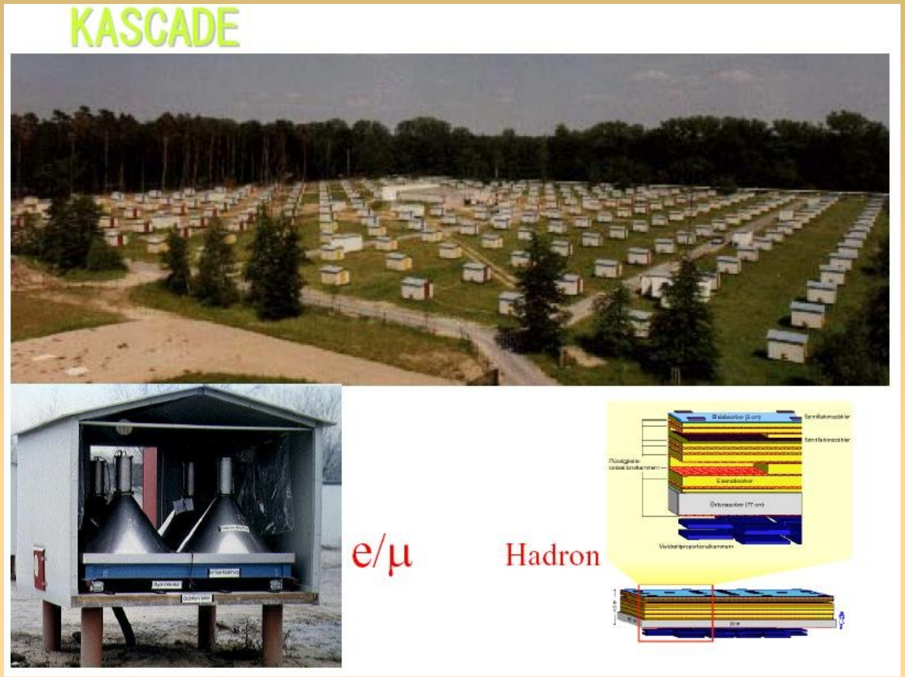


- Direct measurements up to E ~ 10^{14} eV → Primary particles (ballons, satellites)

- Indirect measurements E > 10^{14} eV → Secondary particles
  - Measurements around the knee (Eas-Top, Kascade, Casa, …) E~10^{15}eV

    and beyond (Kascade-Grande)E~10^{16}eV
  - Ultra high energy cosmic rays (Auger, HiRes) E~10^{19}eV
  - Underground experiment (Macro, Emma) E ~ 10^{15} eV
  - Cosmic ray physics at CERN (LEP : L3+C, ALEPH, DELPHI. LHC : CMS, ALICE) E~10^{15} eV

Indirect measurements : Ground and Underground Experiments

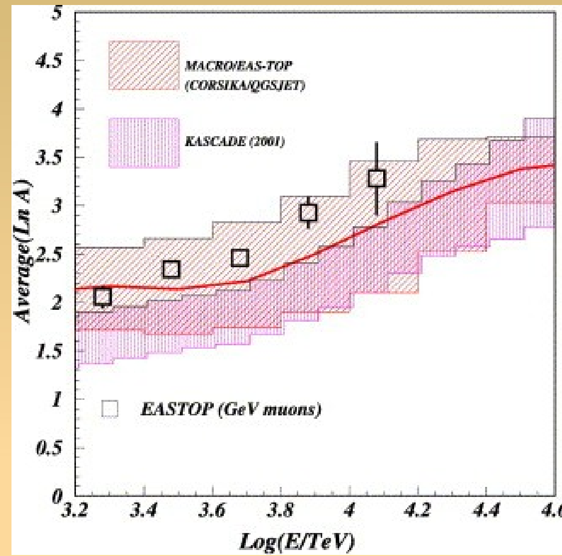


GROUND → Very large detector arrays :
KASCADE 200 x 200 m^2 EAS-TOP 300 x 500 m^2
Detection of all the components of an Extensive Air Shower (EAS)
electromagnetic
muons
hadrons

UNDERGROUND → Large detectors :
MACRO 12 x 70 m^2
Detection of the muons crossing the rock above

Physics

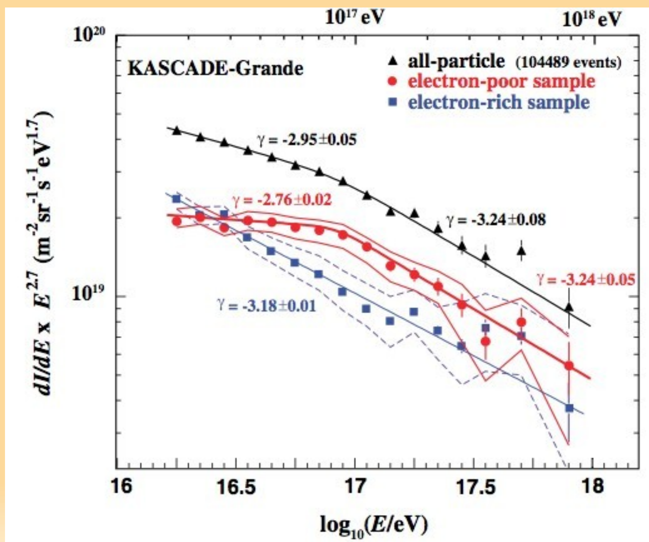
Primary Energy Spectrum
Primary Composition
Anisotropy
Gamma ray sources
Gamma ray bursts
p-Air cross section
Test hadronic int. models
 ………….



MACRO-EASTOP
KASCADE :
Primary Composition
Ln(A) vs Energy

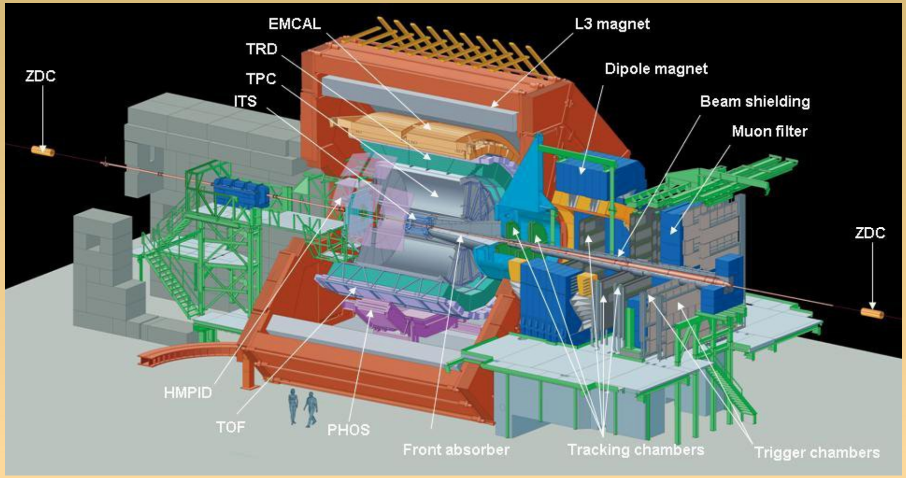
A=mass of the primary nucleus

There is an increase of the <A> above the knee
<A> ~ 8 at 3 10^{15} eV
<A> ~ 30 at 3 10^{16} eV



KASCADE-GRANDE :
- electron-poor sample selects heavy elements (Fe) and shows a knee at E ~ 8 10^{16} eV
- electron-rich sample selects light elements and the knee is at lower energy E ~ 3 10^{15} eV

Cosmic rays with the accelerator detectors



- Small detectors
- Low underground
- Detection of muons crossing the rock

These experiments are not designed for cosmic ray physics.

Small detectors compared with standard cosmic ray apparata, only muons are detected, short live time of data taking

Advantage : Detectors with very high performances, presence of magnetic field

Main Topics with accelerator detectors

Magnetic field + Precise P measurement

Muon momentum spectrum and charge ratio (L3)

Charge ratio (CMS)

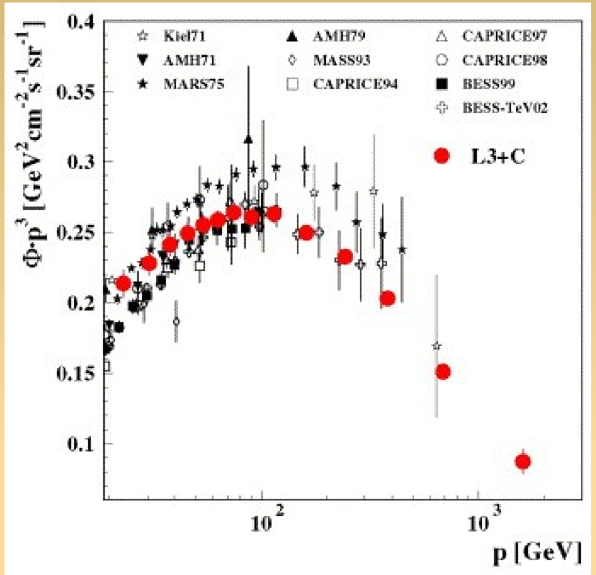
High tracking capabilities

Muon-bundles (high muon density):

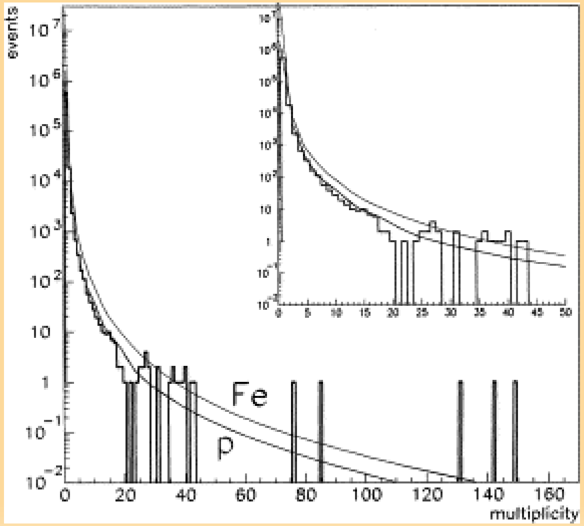
Aleph

Delphi

Alice

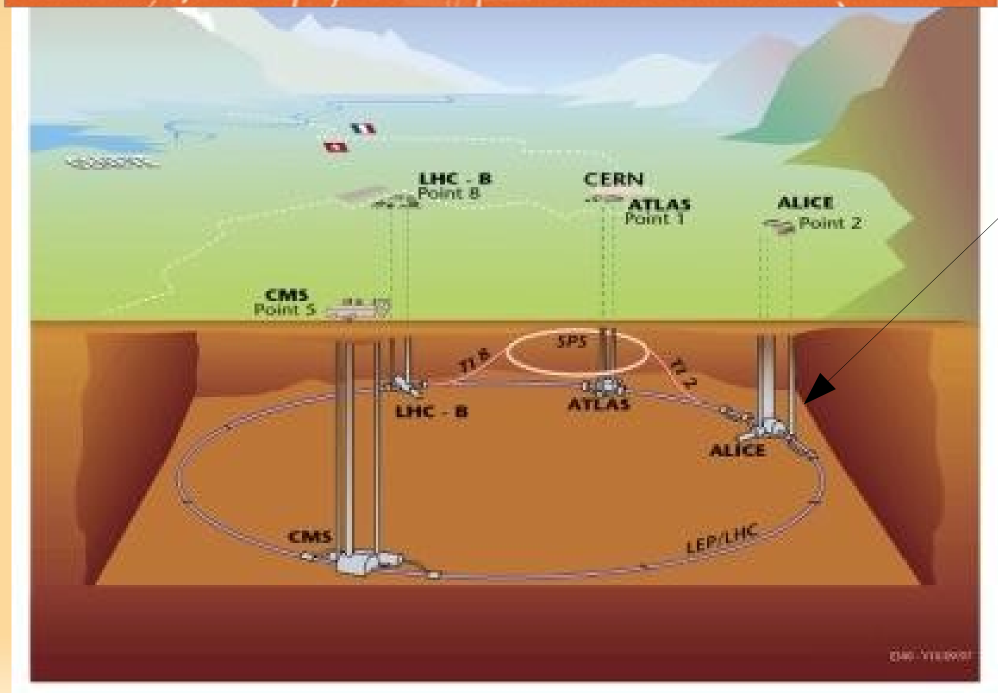


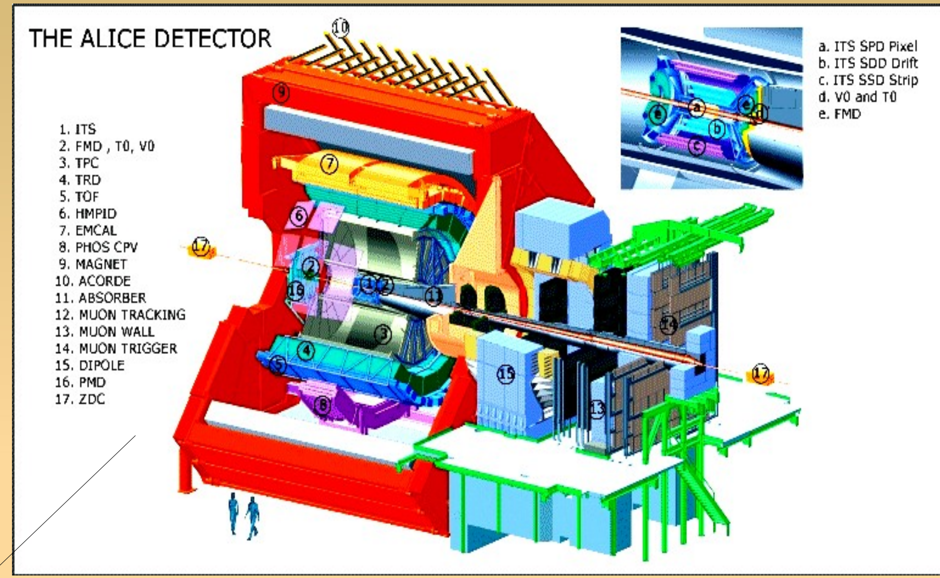
L3+C



ALEPH :
5 high muon multiplicity events

ALICE experiment at LHC

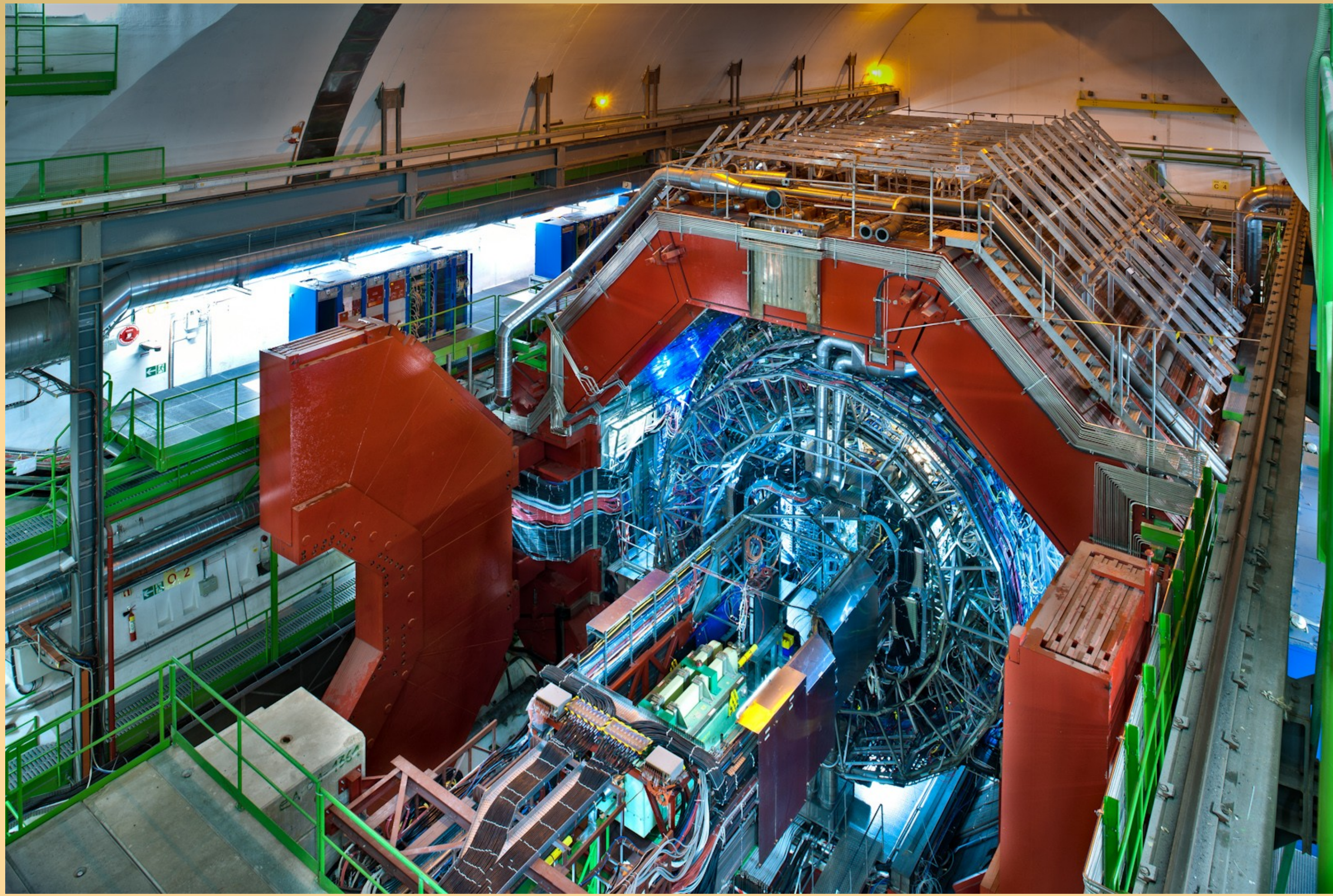




ALICE located 40 m. underground
30 m of rock (molasse)
10 m of air

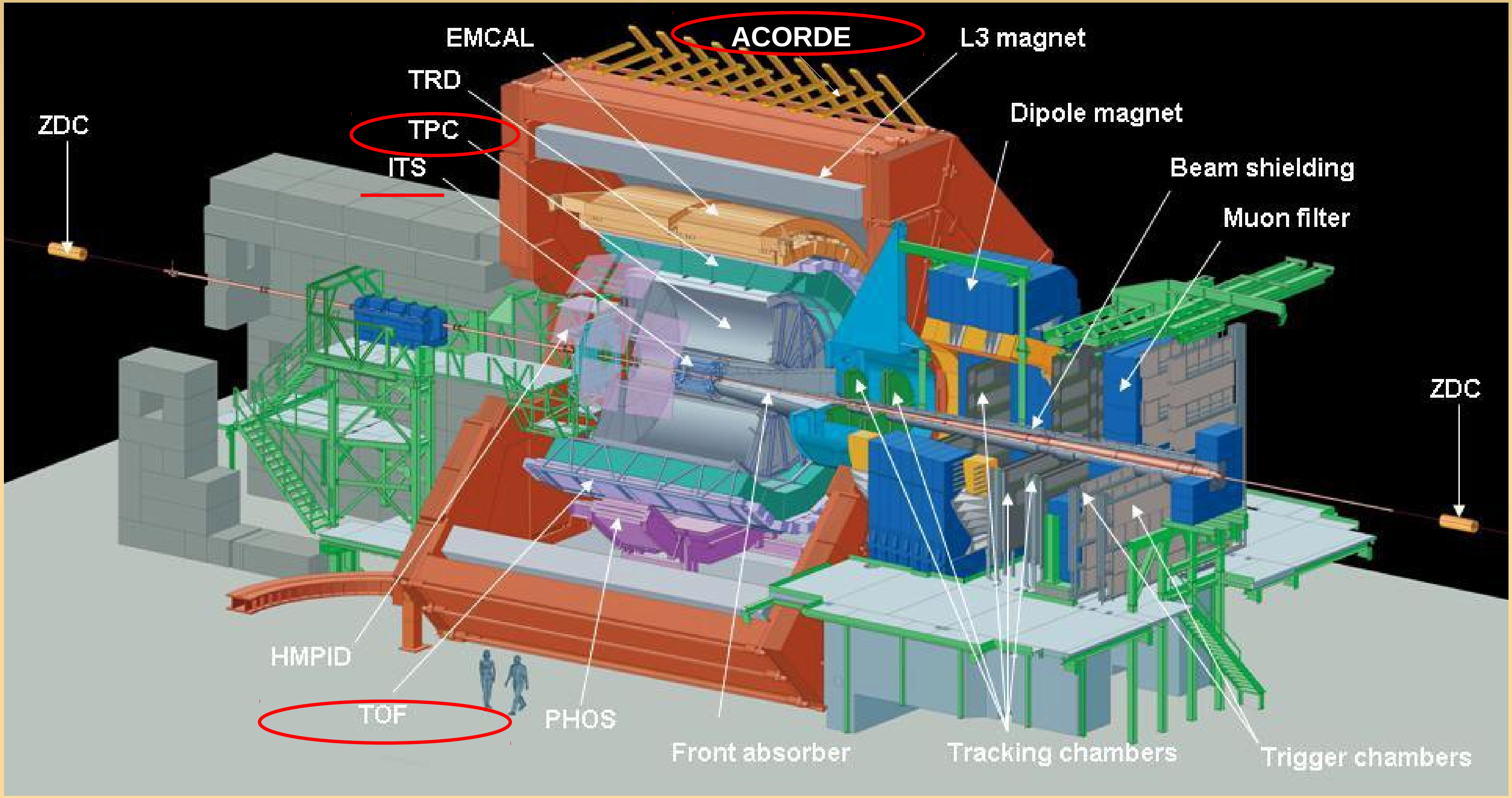
Threshold Muon Energy ~ 15-16 GeV

ALICE Experiment

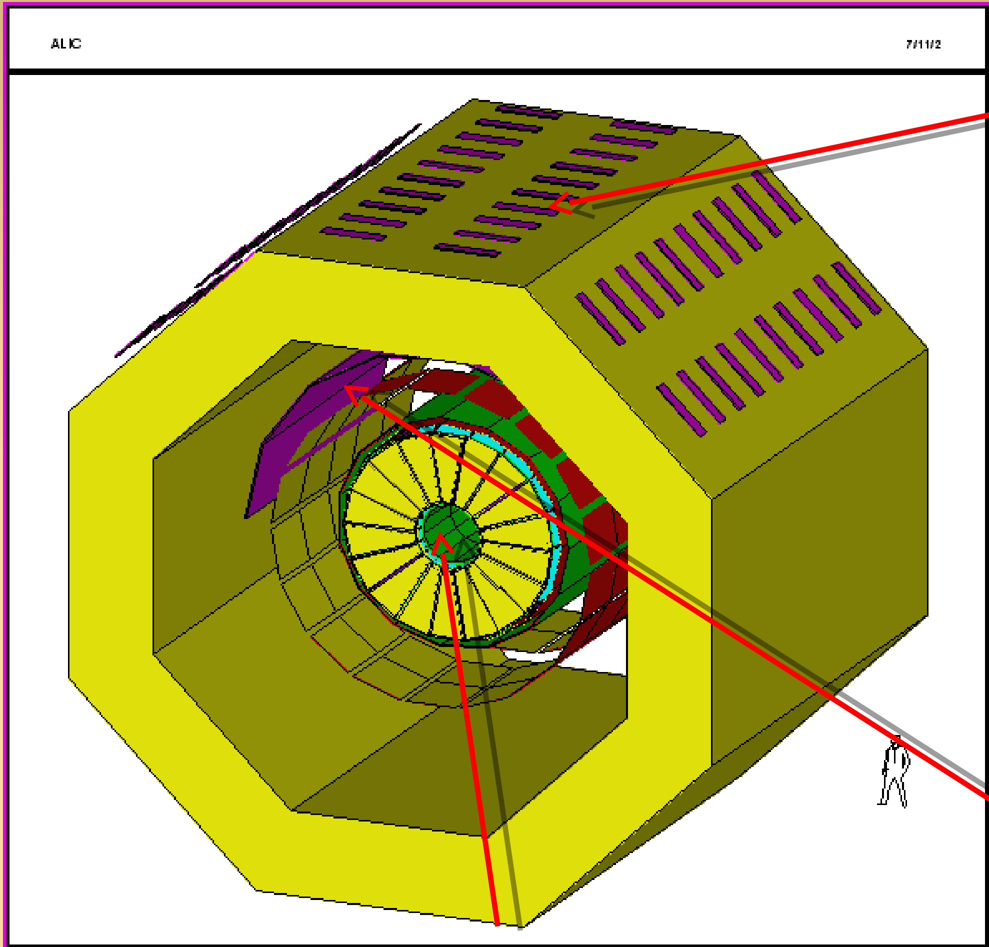


Detectors used for cosmic events in the central barrel

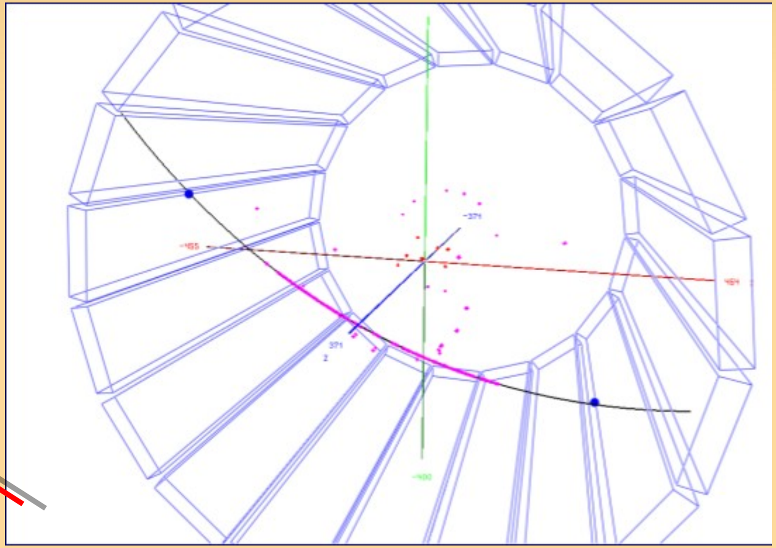
Detectors used for cosmics (0^o-50^o) in the central barrel :
Trigger : ACORDE, TOF, (SPD)   Tracking : TPC



Trigger Detectors



ACORDE : 60 scintillator modules
Trigger coincidence of at least two modules

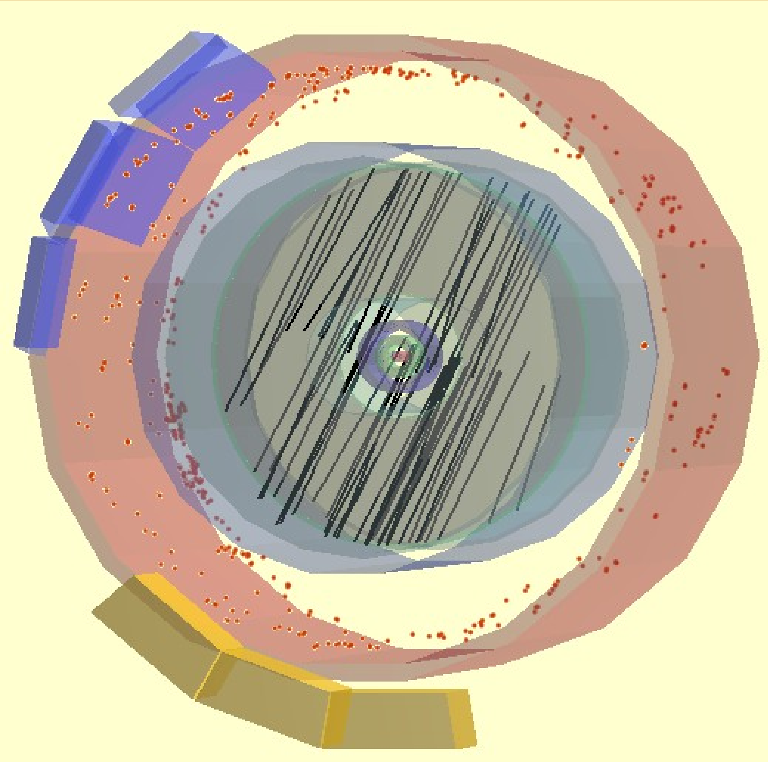


SPD small detector in the ITS
Trigger when muon crosses two layers

TOF cylinder of MRPC surrounding the TPC
Trigger : 1 pad up → 1 pad down +- n pads

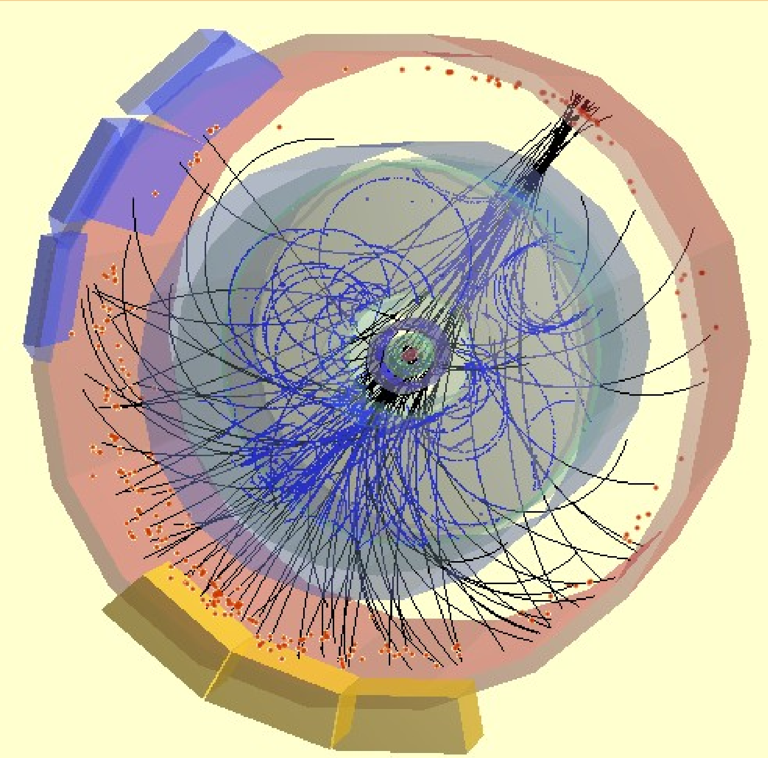
Tracking Detector : TPC

TIME PROJECTION CHAMBER (TPC) : N.of muons, P, charge, direction, x-y-z

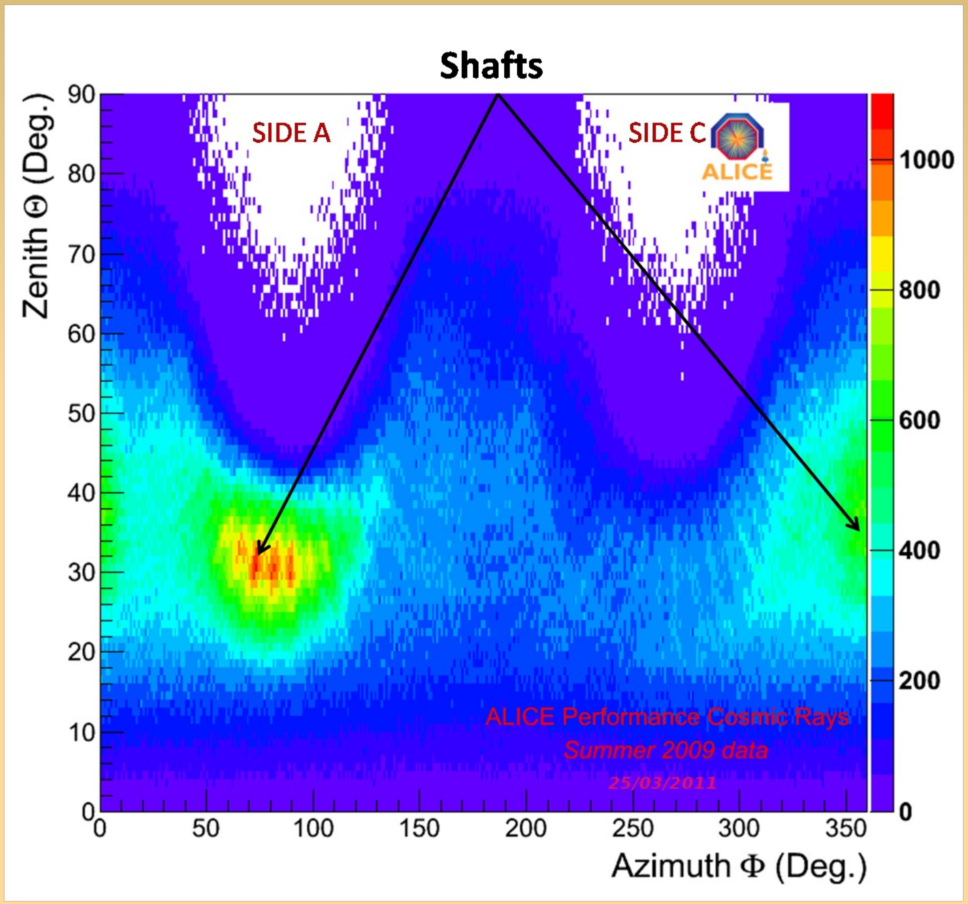


Standard Muon Event (multimuon)

Muon Interaction Event

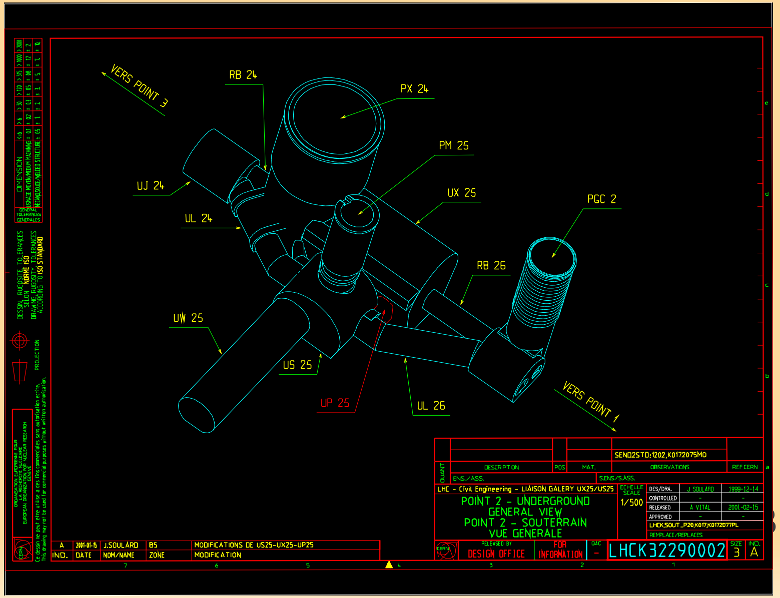


Effects of the ALICE environment

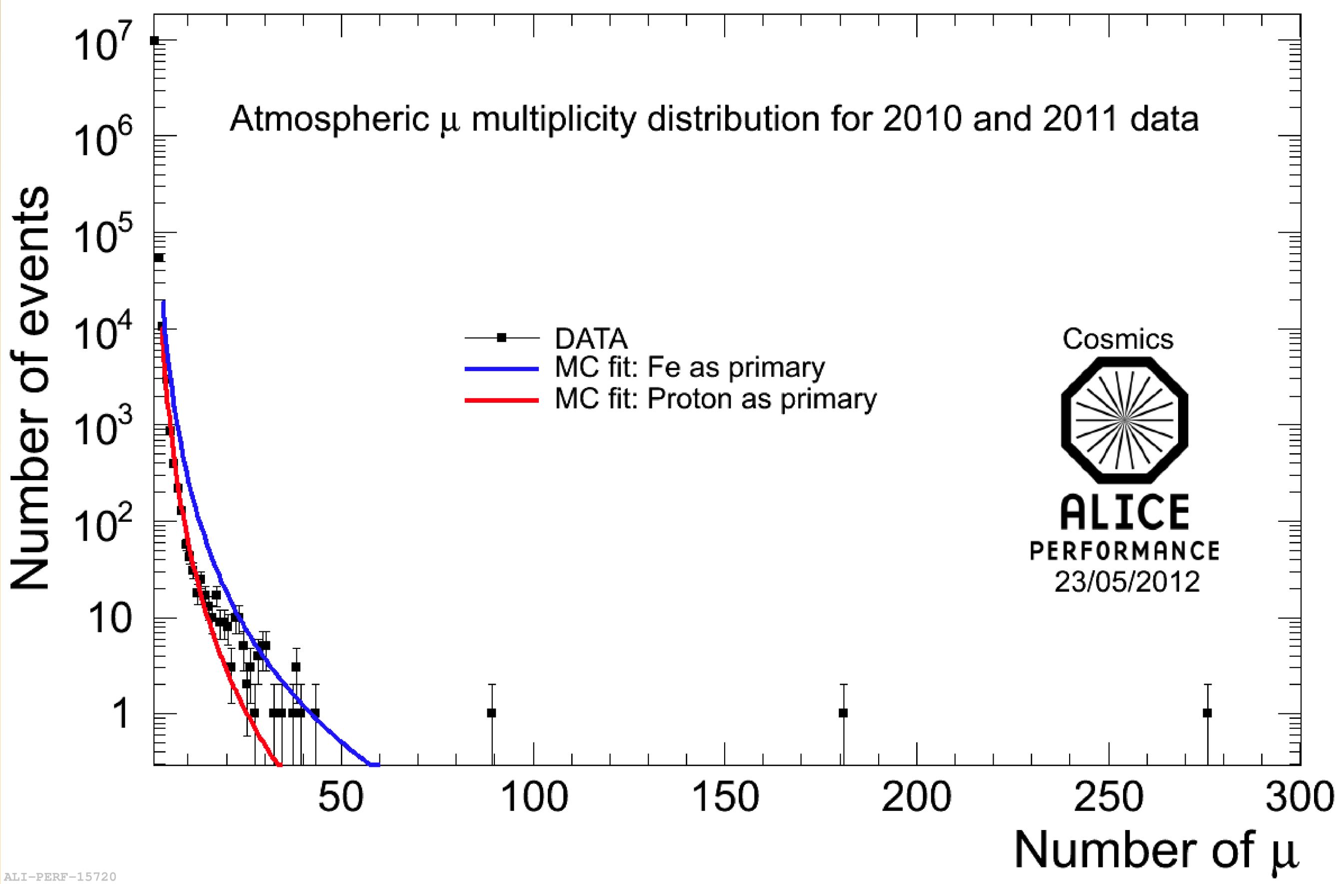


The muons crossing the shafts have a lower energy cut-off.
A larger number of muons arrive at the experiment in the directions of the shafts

ALICE experimental site



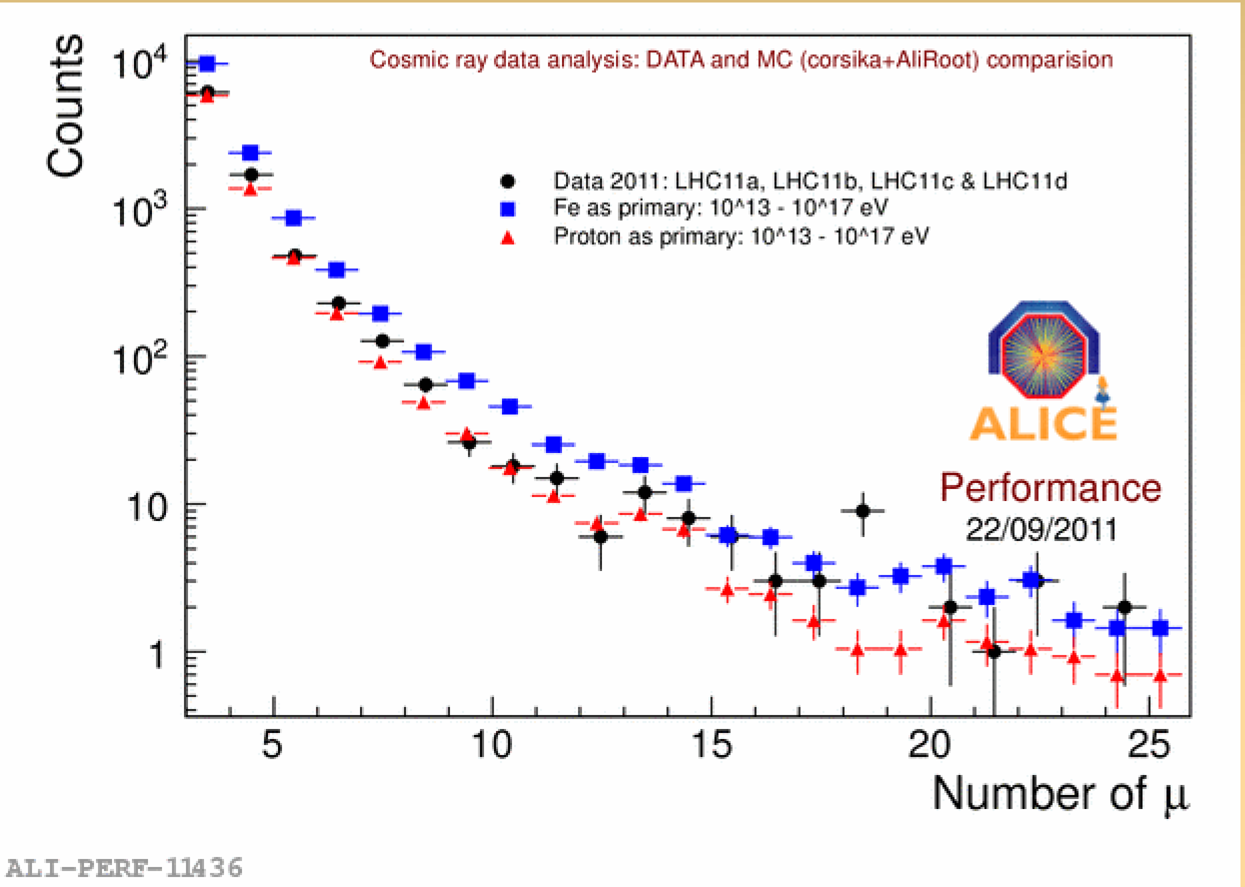
Muon multiplicity Distribution 2010-2011 data (~ 11 days of data)



In ~ 11 days of data we found three high muon multiplicity events (hme) not explained with the simulations.
Two of them have more than 100 muons.

We have to understand these events.

Muon Multiplicity Distribution (low multiplicities)



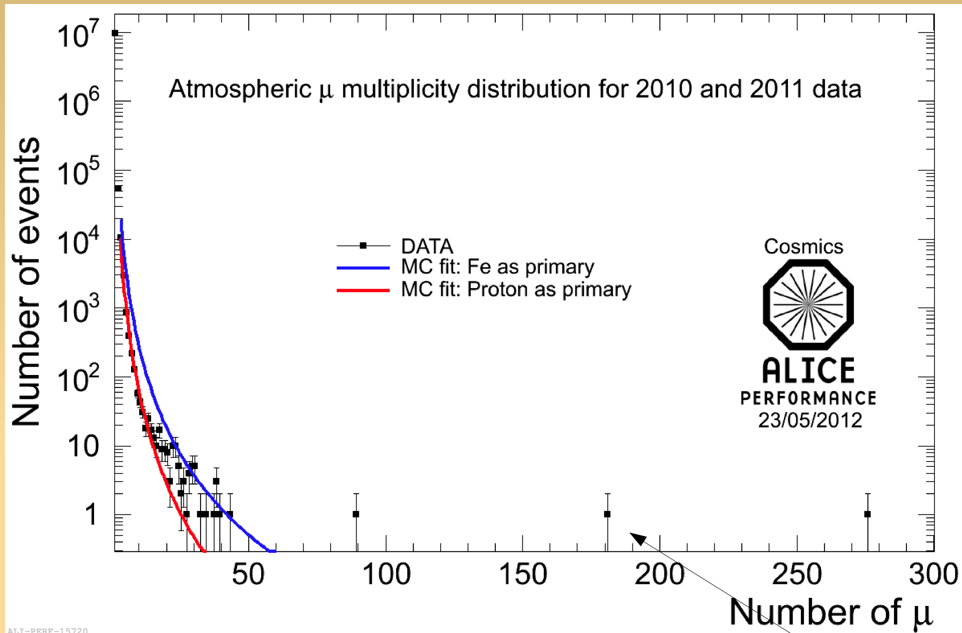
Data taken Feb.-Aug. 2011
~ 9.5 days live time
Trigger : ACORDE + TOF

Comparison with simulation
CORSIKA code with
QGSJET II-03
Proton primary
Fe primary

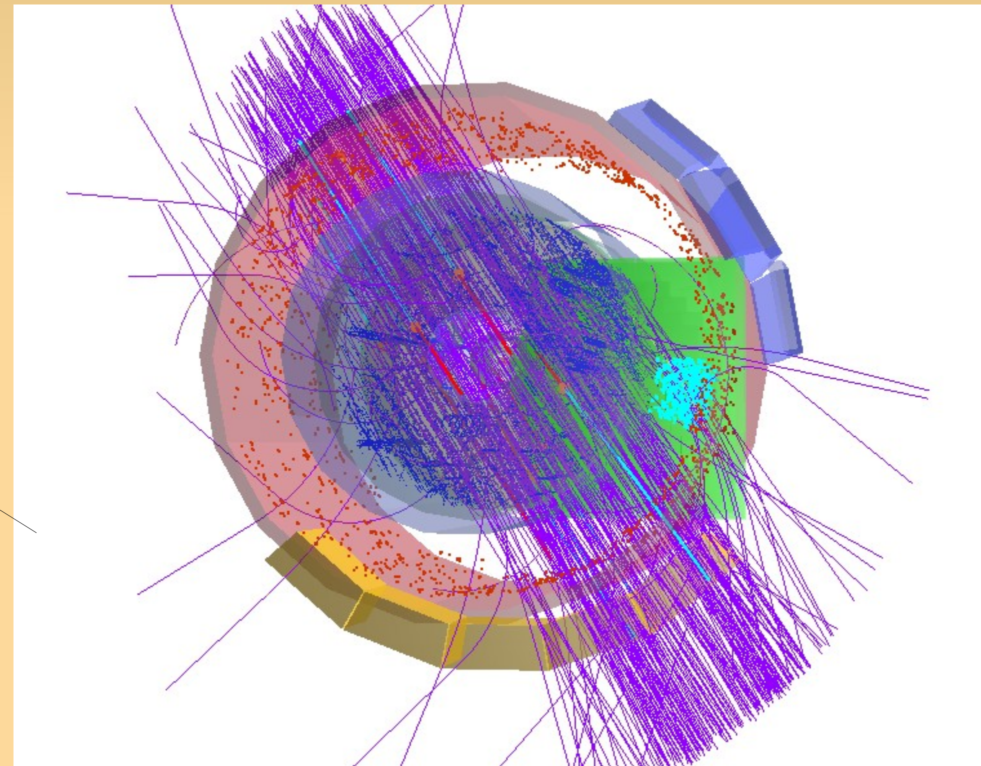
The data as expected are inside the pure proton and pure Fe composition. At low multiplicities (low primary energy) the data are closer to the proton curve approching the Fe curve at higher multiplicities in agreement with previous results.

CORSIKA code :
http://www.ik.fzk.de/corsika/

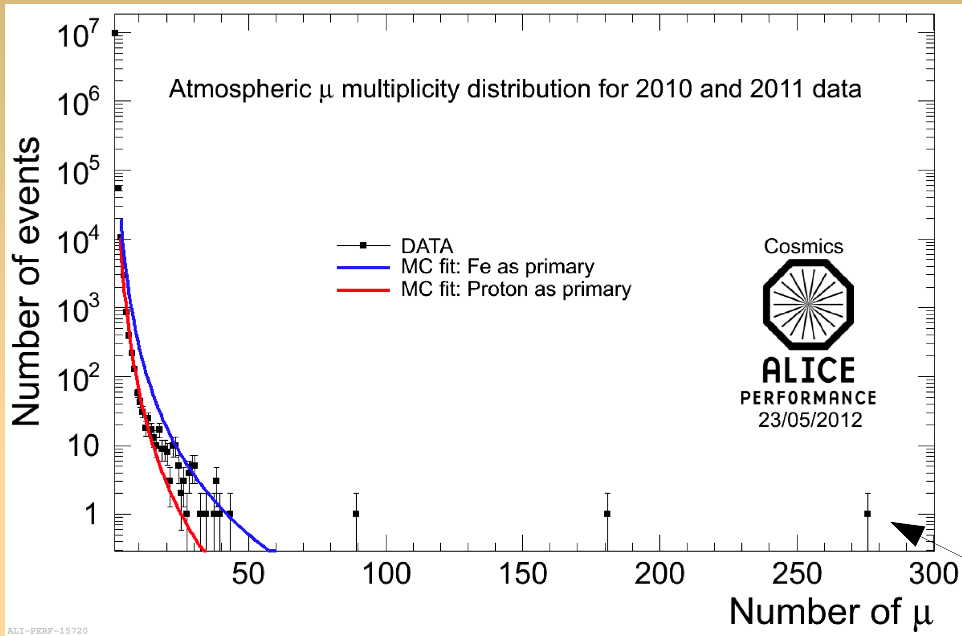
High muon multiplicity events : February 2010



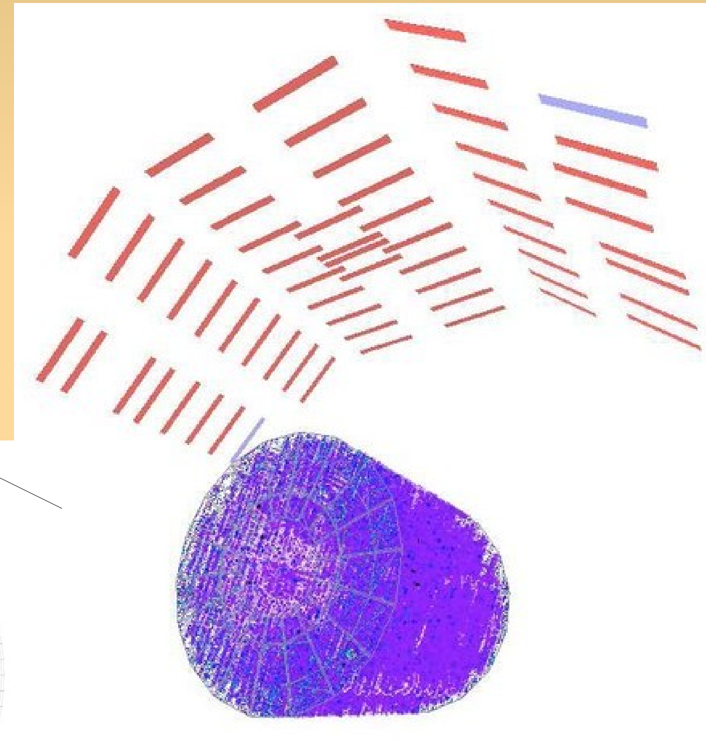
Mean Zenith Angle : 40°
Density of muons : ~ 12 μ/m²

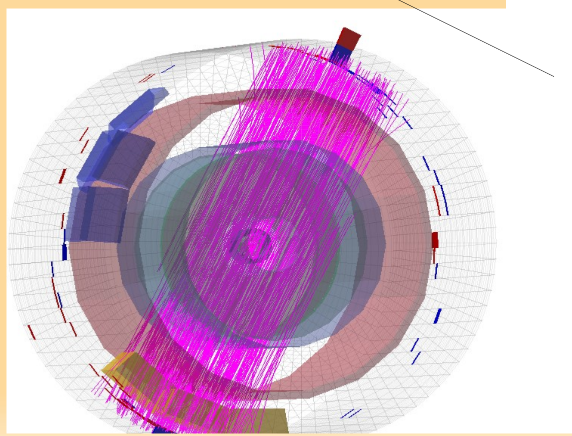


High muon multiplicity event : June 2011

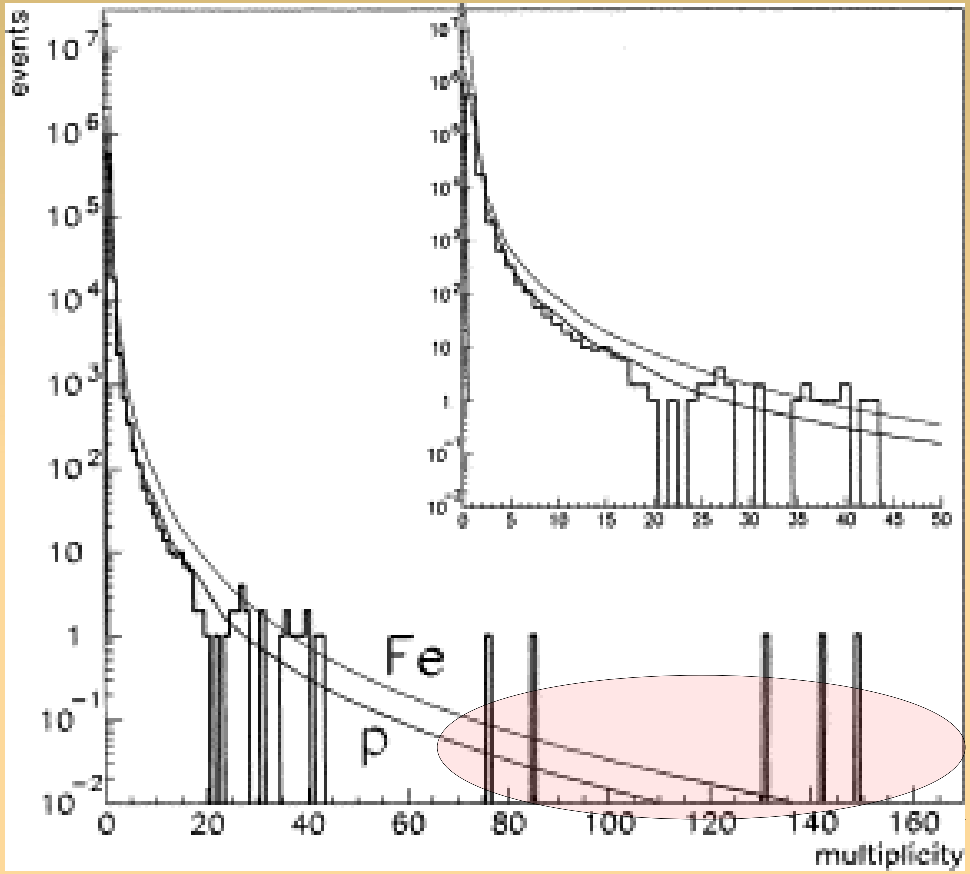


Mean Zenith Angle : 26°
Density of muons : ~ 18 μ/m^2





Aleph at Lep : Five high muon multiplicity events (~ 20 days of data)



1) 4.75 μ/m^2 Zenith(^{o})=40.8
Primary energy = 3 10^{16} eV

2) 5.3 μ/m^2 Zenith(^{o})=37.7
Primary energy = 3 10^{16} eV

3) 8.9 μ/m^2 Zenith(^{o})=40
Primary energy = 6 10^{16} eV

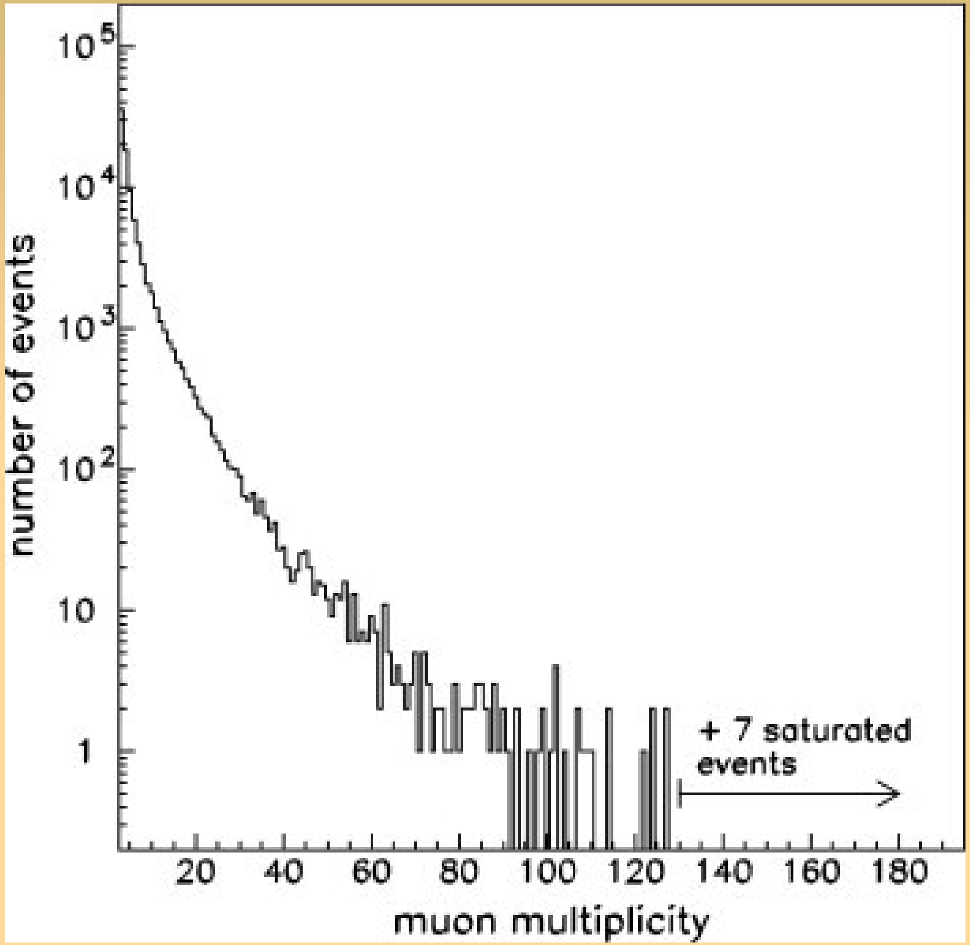
4) 8.2 μ/m^2 Zenith(^{o})=48.6
Primary energy = 7 10^{16} eV

5) 18.6 μ/m^2 Zenith(^{o})=27
Primary energy = 10^{17} eV

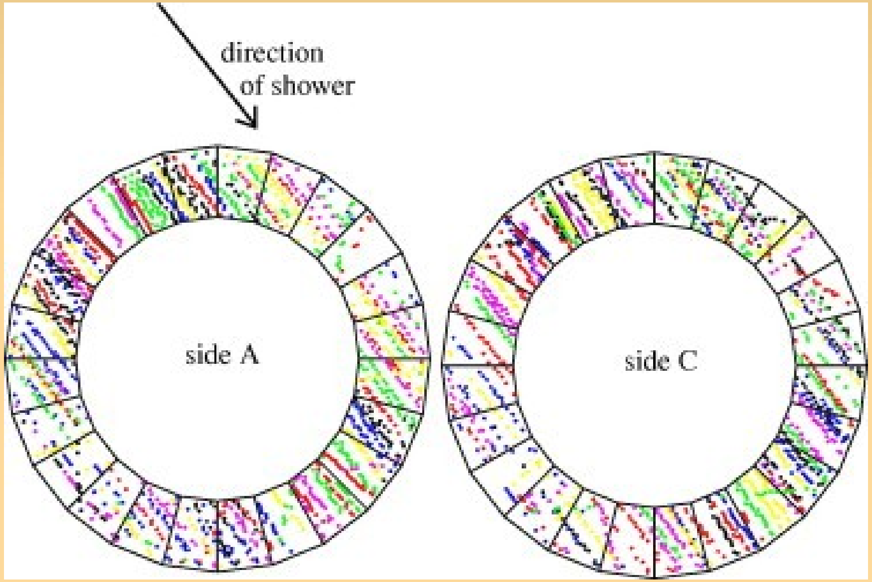
The five highest multiplicity events, with up to 150 muons within an area of 8 m^2,occur with a frequency which is almost an order of magnitude above the simulation.

Astroparticle Physics 19 (2003) 513–523

Muon Multiplicity Distribution in Delphi at Lep (~ 18.5 days of live time)

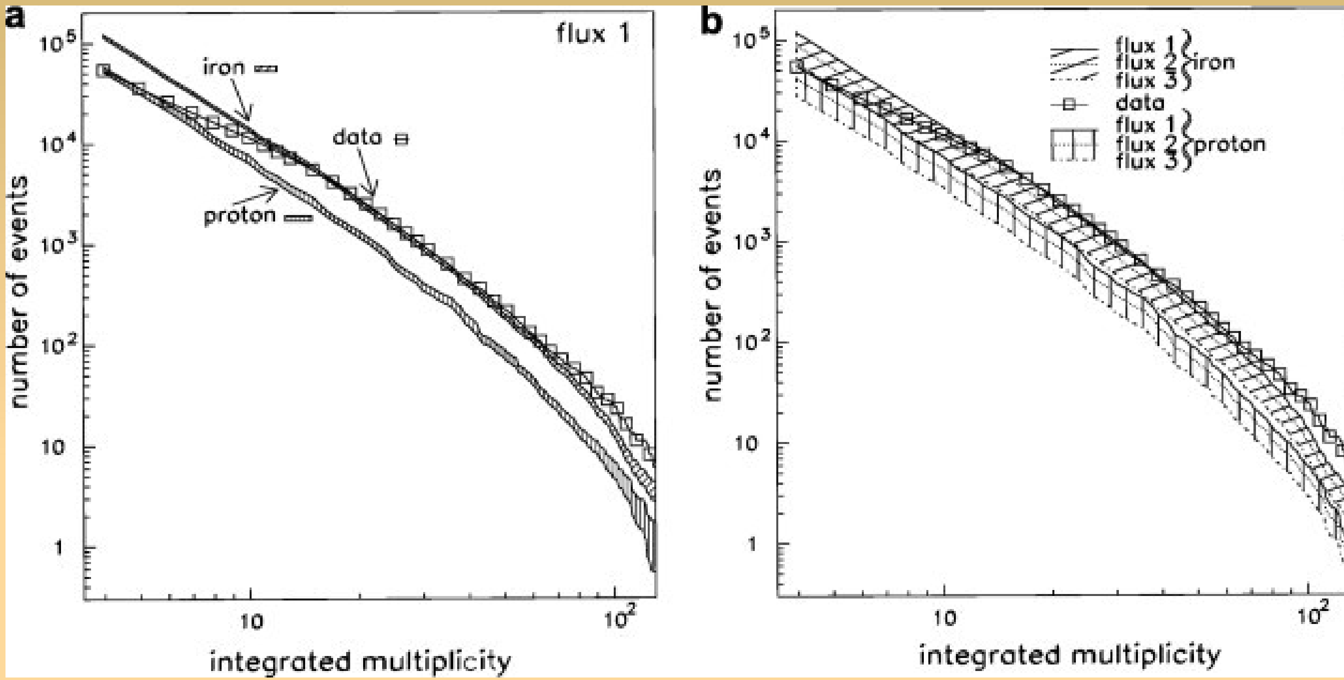


Astroparticle Physics 28 (2007) 273–286



7 high multiplicity events that saturate the detector (HAB)

Delphi : Integrated muon multiplicity



Interaction model : QGSJET01

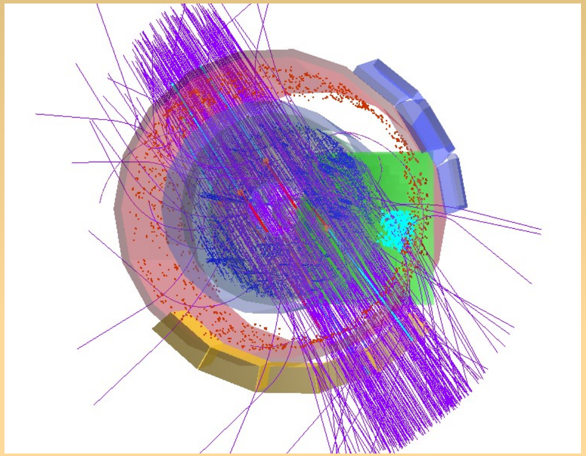
Different Flux assumption

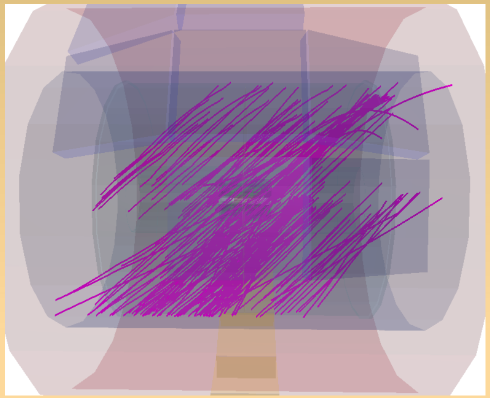
Astroparticle Physics 28 (2007) 273–286

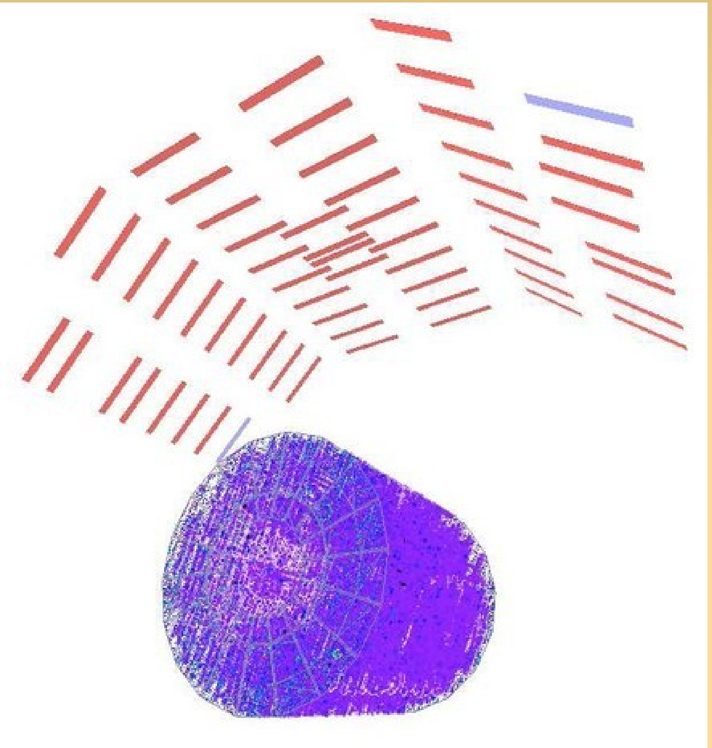
The conclusion is similar to Aleph :
However, even the combination of extreme assumptions of highest measured flux value and pure iron spectrum fails to describe the abundance of high multiplicity events.

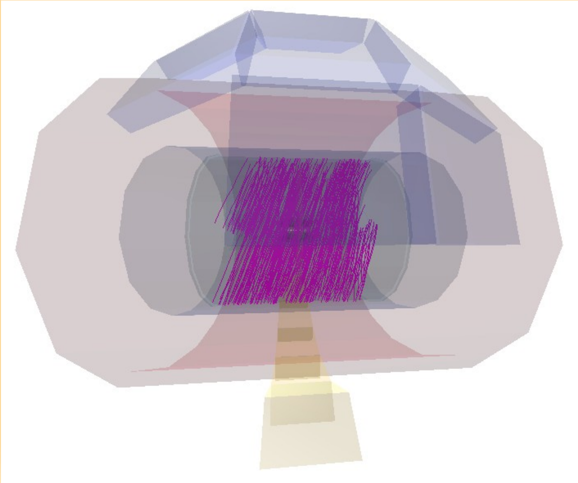
High muon multiplicity events in Alice

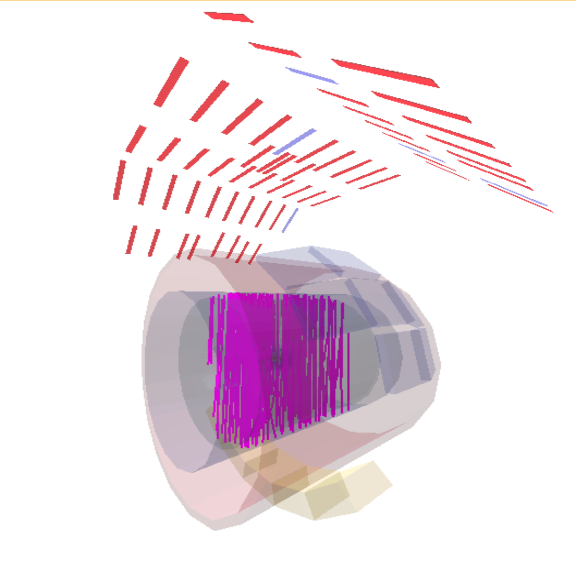
2010-2013 : 5 events with Nμ > 100 in ~ 22 days → ~ 1 event every 5 days





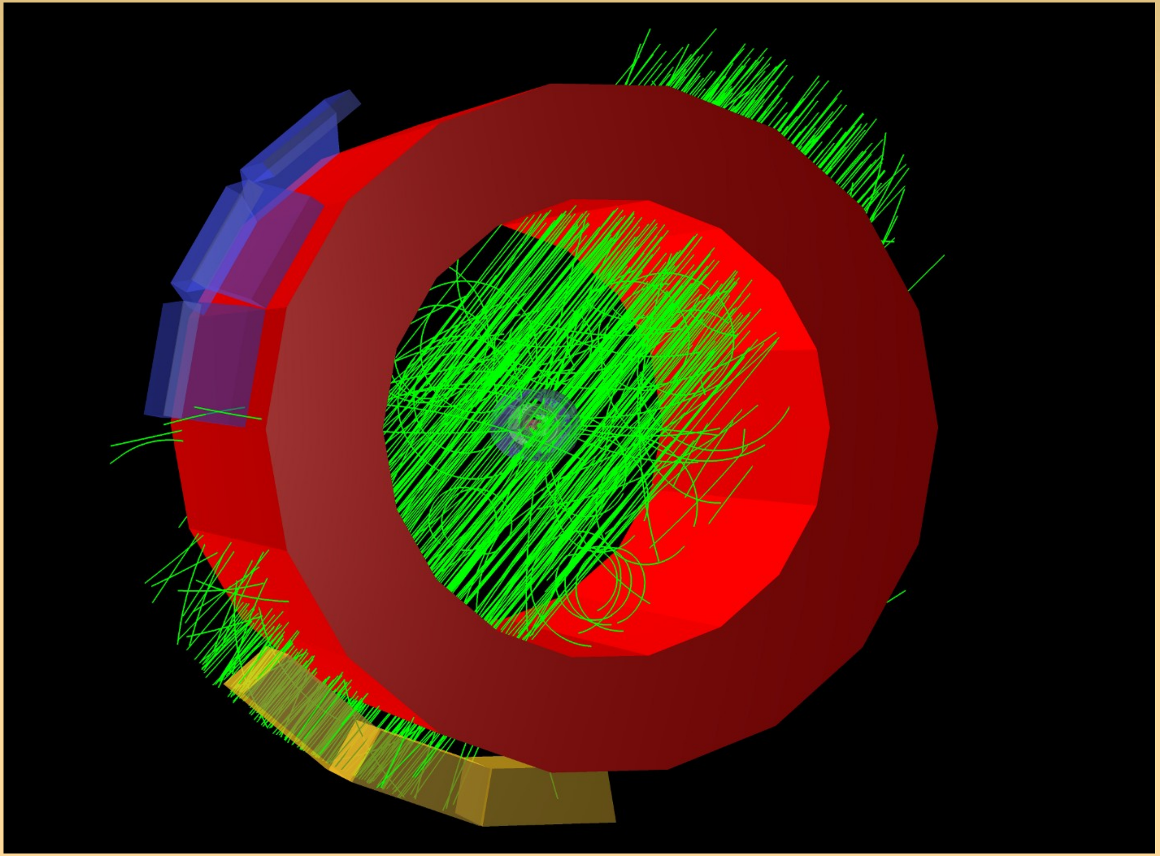






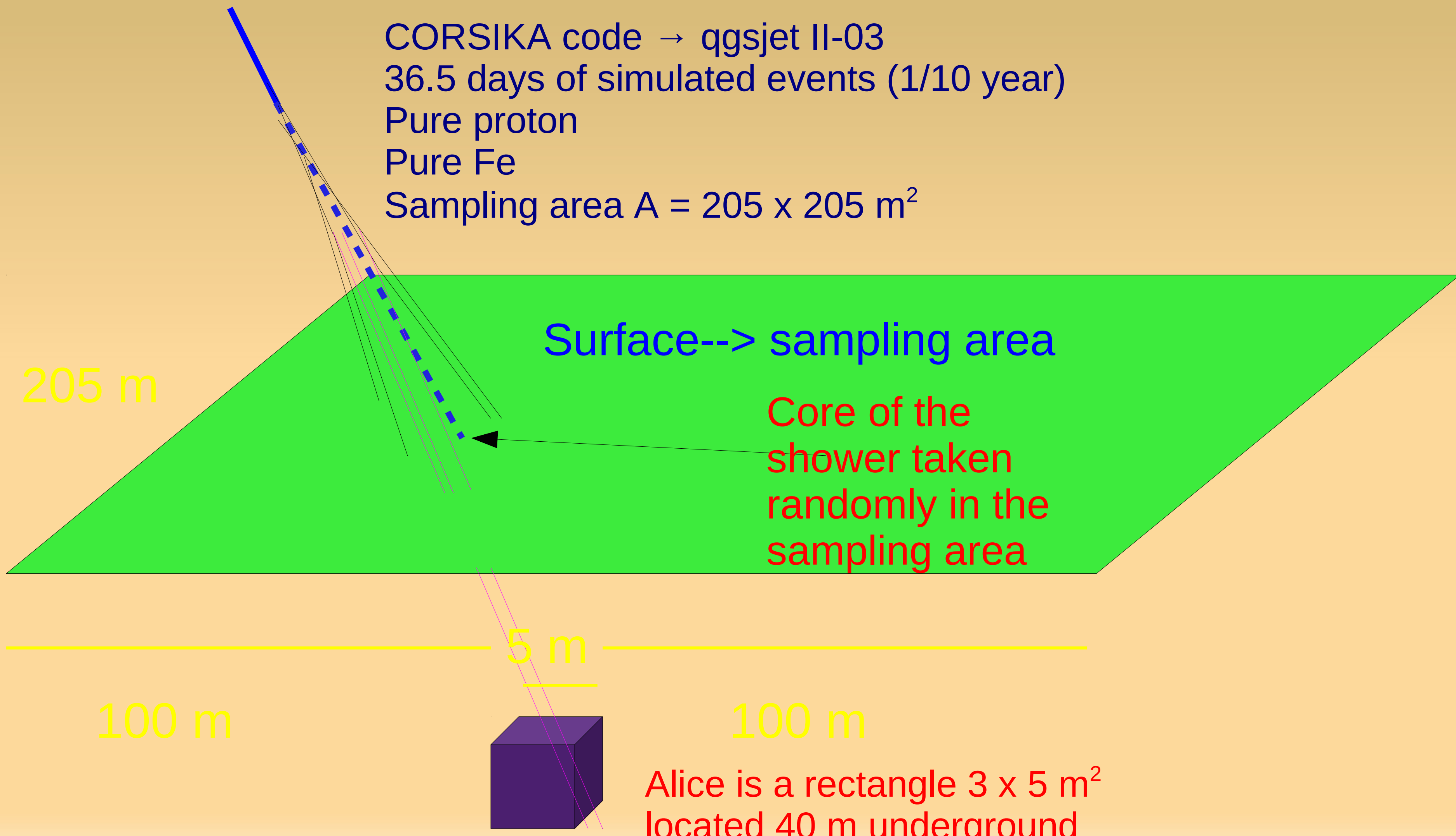
Question

Is it possible to explain these high muon multiplicity events (hme) with a standard composition of primary cosmic rays and actual hadronic interaction model ?

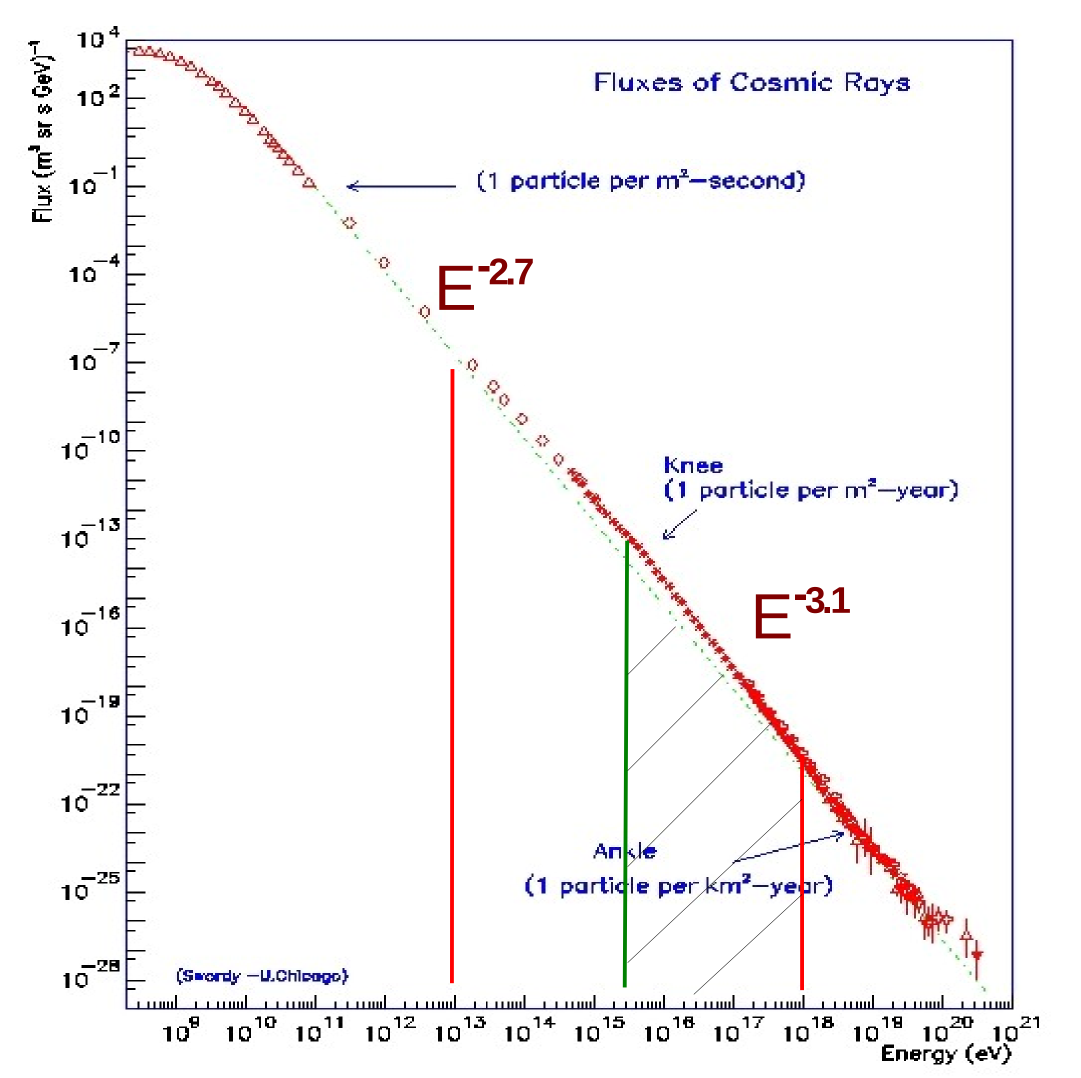


Simplified Monte Carlo for first studies on high mult. events (hme)

CORSIKA code → qgsjet II-03
36.5 days of simulated events (1/10 year)
Pure proton
Pure Fe
Sampling area A = 205 x 205 m^2



Energy of the primaries in Alice



Primary Energy in Alice :
$10^{13} < E < 10^{18}$ eV

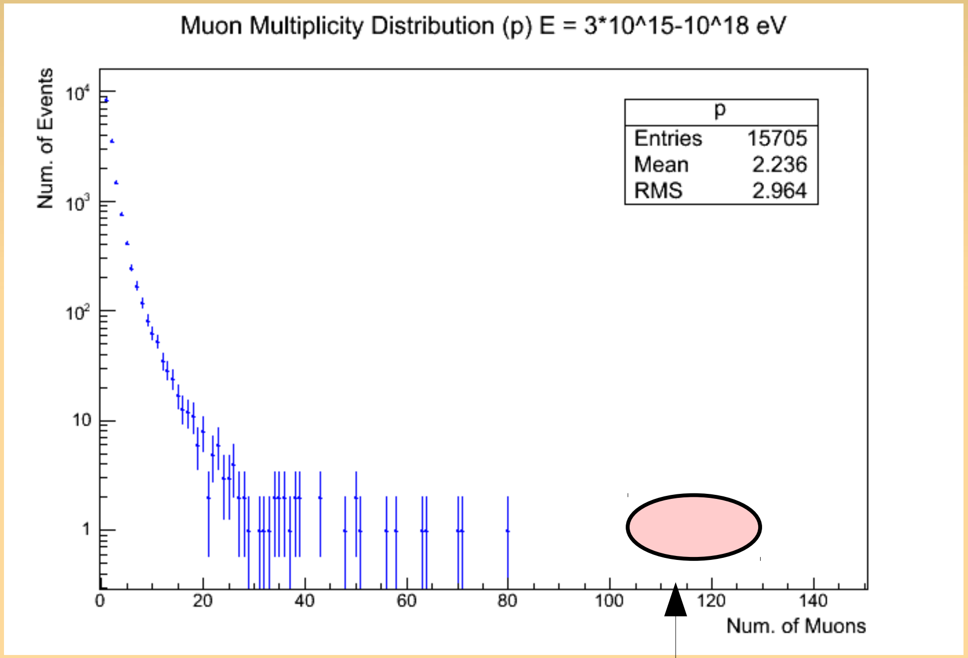
To study high multiplicity events
Restrict the energy range above the knee :
$3\ 10^{15} < E < 10^{18}$

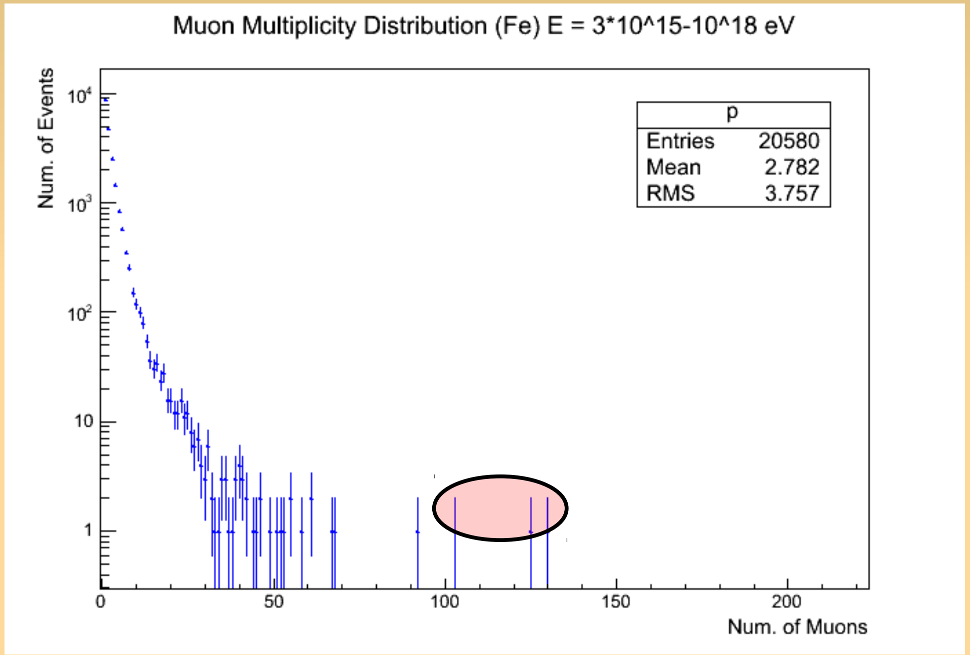
Flux of the all-particles extrapolated from
J. Horandel, Astrop.Phys. 19 (2003) 193-220
Try with 2 slopes of the energy spectrum
above the knee = -3.0 , -3.1

Real data ~ 22 days (5 hme)
Start to simulate 36.5 days
The purpose is to simulate 365 days to reduce the fluctuations

Muon mult. dist. for pure Proton and pure Fe composition with slope = -3.1

36.5 days of simulated data





Proton

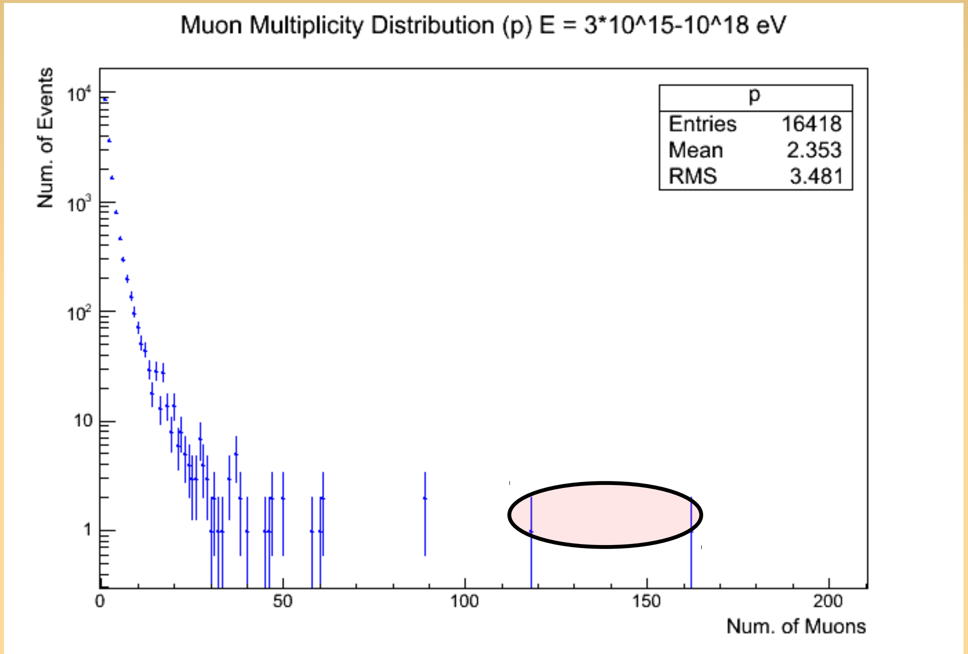
No events here

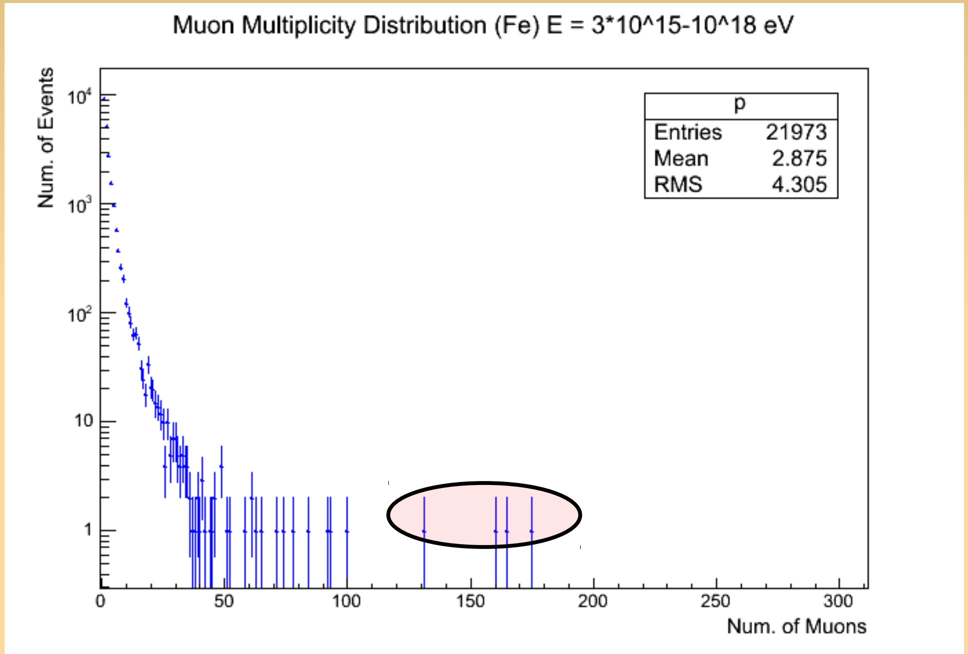
Fe

Nμ > 100 = 3 events

Muon mult. dist. for pure Proton and pure Fe composition with slope = -3.0

36.5 days of simulated data





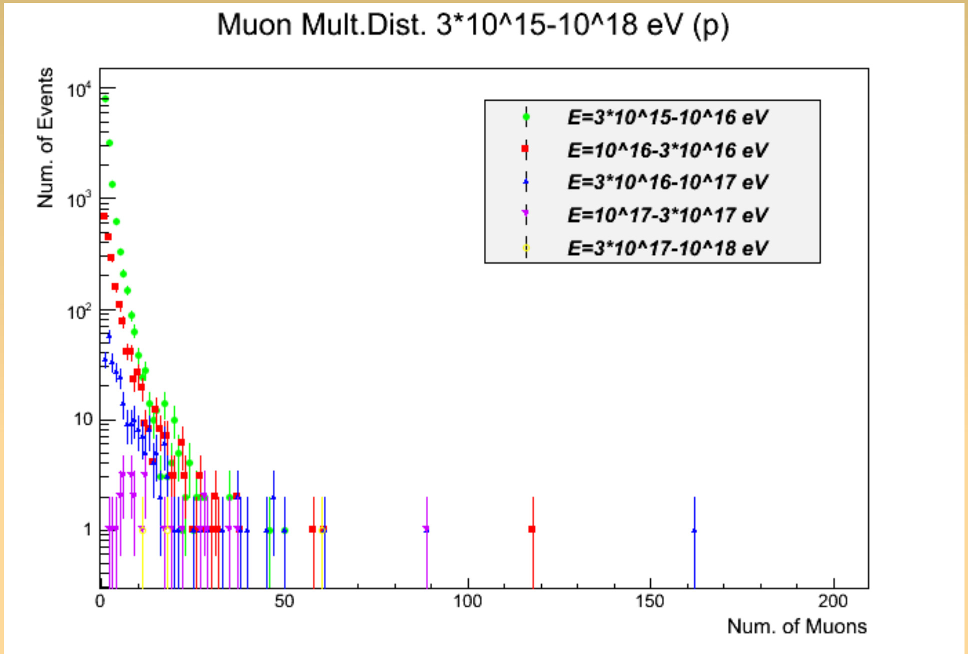
Proton

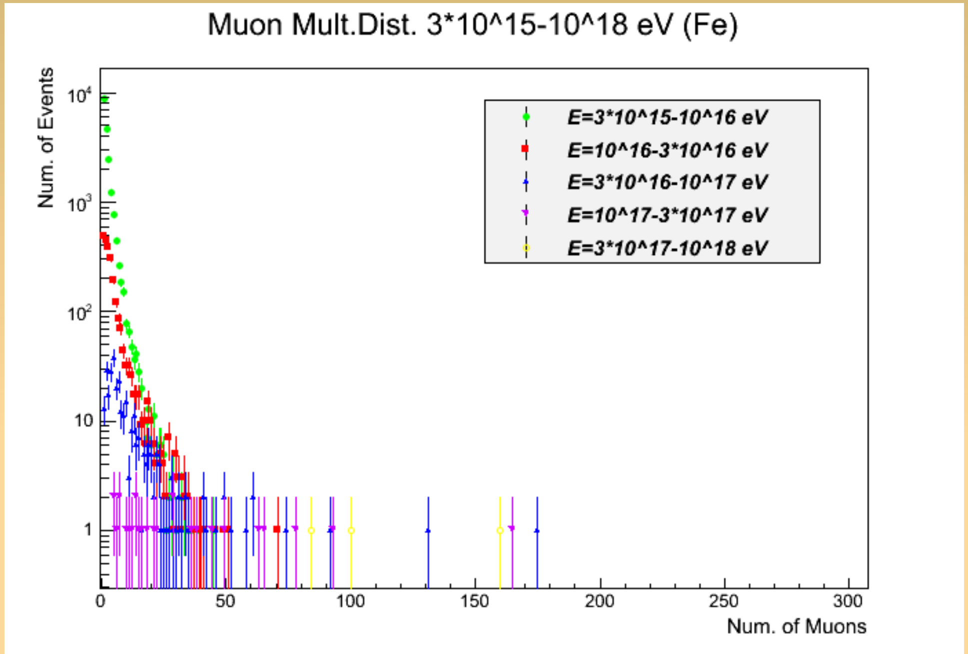
Nμ > 100 = 2 events

Fe

Nμ > 100 = 4 events

Muon mult. dist. for pure Proton and pure Fe composition with slope = -3.0



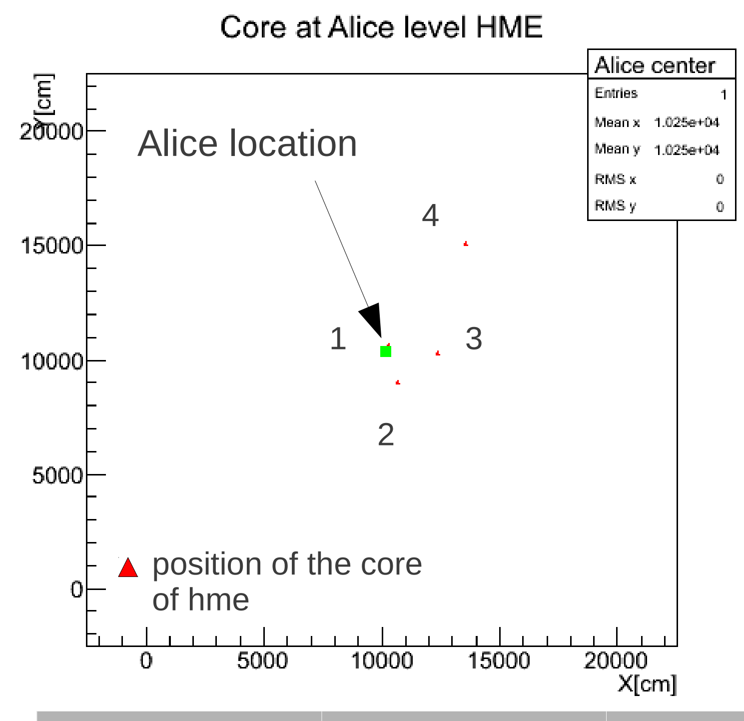


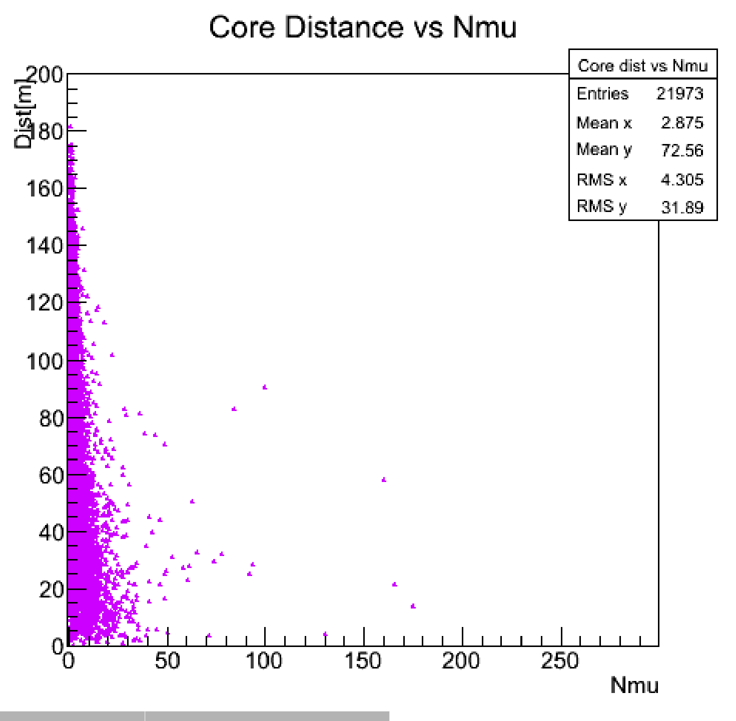
Proton

Fe

All the events with N_μ>100 have E>10^{16} eV

Distance of the core from Alice for pure Fe composition with slope = -3.0





Event Num.	Dist. of the core [m]	Primary Ener. [PeV]	N. of muons
1	3.8	34	131
2	13.7	60	175
3	21.5	148	165
4	58.3	755	160

It seems possible to explain hme :
-primary energy E > 10^{16} eV
-core location close to Alice
-probably heavy primary.
Try now with the last version of qgsjet.

Comparison between qgsjet II-03 and II-04

CORSIKA 6990 → qgsjet II – 03

CORSIKA 73500 → qgsjet II – 04
tuned with the results obtained in LHC

To compare the two intercation models and obtain avarage values we perform 5 runs of 36.5 days of simulated events using the two samples of generation :
qgsjet II – 03
qgsjet II – 04
and changing the location of the core in the sampling area

Comparison between qgsjet II – 03 and qgsjet II - 04 (LHC tuned)

Num. ev. with Nμ > 100 for 5 runs.
Each run = 36.5 days of simulated events

Pure proton composition

2	2	0	1	0	CORSIKA-6990 qgsjet II – 03
3	3	0	2	4	CORSIKA-73500 qgsjet II - 04

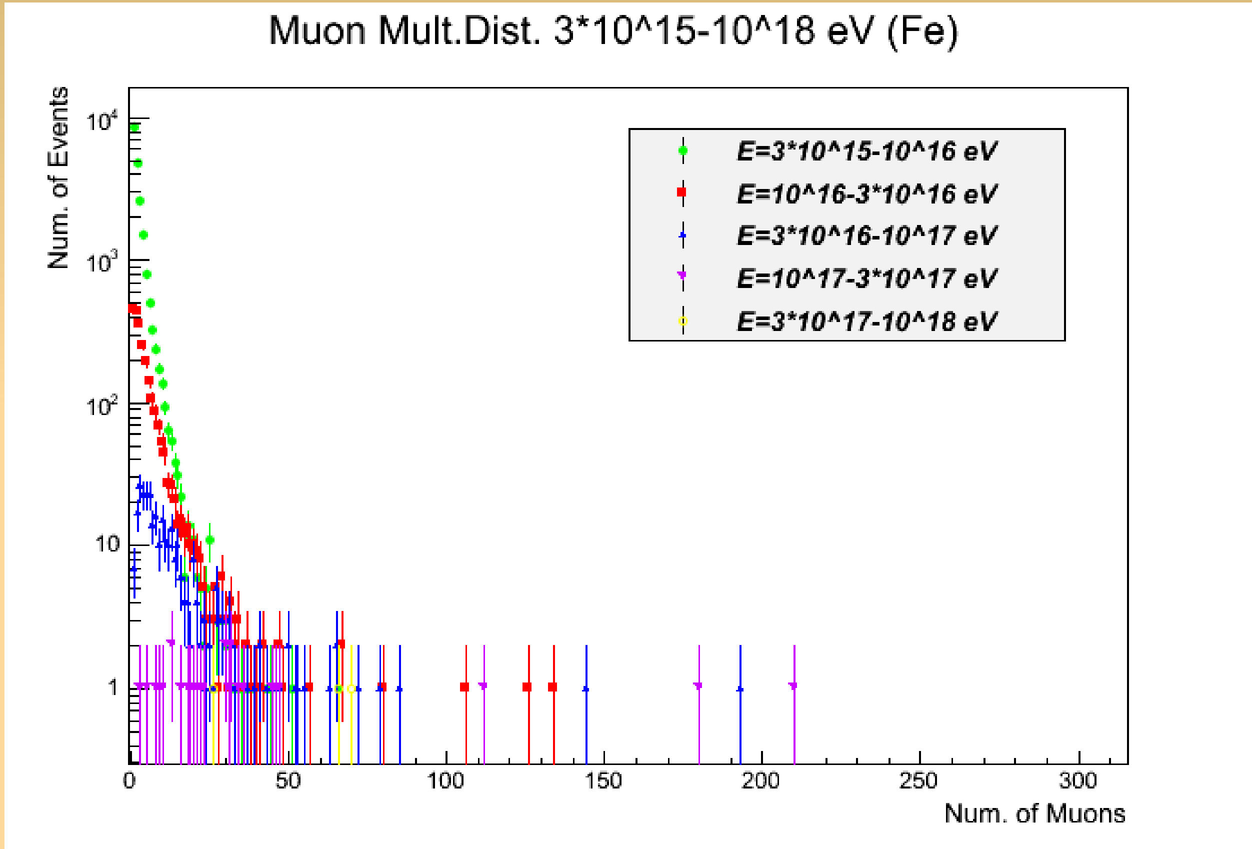
Pure Fe composition

CORSIKA-6990 qgsjet II – 03	4	6	3	3	5
CORSIKA-73500 qgsjet II - 04	2	5	8	3	5

Average Proton = 1.0 qgsjet II-03
Average Proton = 2.4 qgsjet II-04

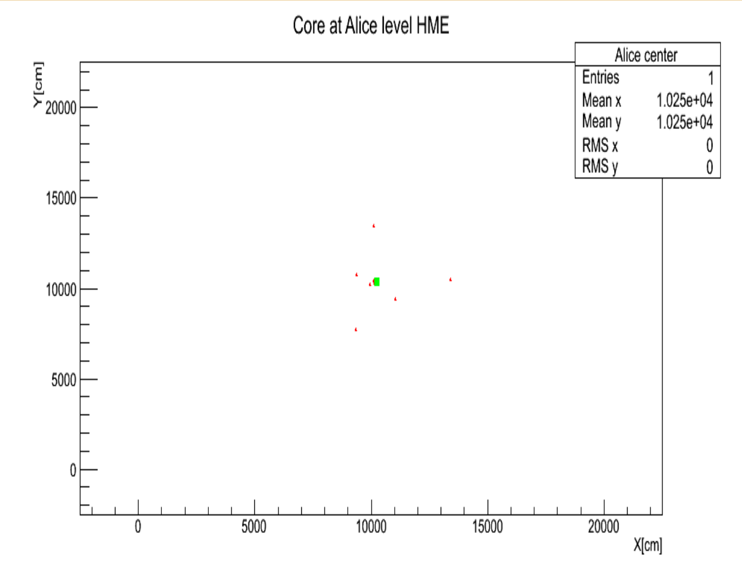
Average Fe = 4.2 qgsjet II-03
Average Fe = 4.6 qgsjet II-04

Muon mult. pure Fe comp. slope = -3.0 CORSIKA-73500 → qgsjet II-04



Largest run found : 8 events with Nμ > 100

Core location pure Fe comp. slope = -3.0 CORSIKA-73500 → qgsjet II-04



Location of the core

Event Num.	Dist. of the core [m]	Primary Ener. [PeV]	N. of muons
1	1.2	49	193
2	2.1	29	134
3	2.6	19	106
4	10.4	15	126
5	11.2	61	144
6	26.8	151	112
7	31.6	170	180
8	32.2	195	210

Final Remarks

- Alice can detect atmospheric muons up to very high muon multiplicity with the possibility to measure for each muon the momentum, the charge, the direction, the spatial coordinates and the arrival time.

- It seems possible to explain the high multiplicity events as due to very high energetic primaries, probably of heavy component, with a core located near Alice

- To reach a final conclusion on these events we plan to :
  - Increase the statistics of simulated events to reduce the fluctuations
  - Passing the generated events in the AliRoot to have more realistic distributions to compare with data instead the actual upper limits
  - Try to use different interaction models to see the changes
  - Use all the other measured variables like the momentum, the spatial distribution, the charge to reach a full comprehension of these events