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ANALYSIS OF COSMIC EVENTS WITH ALICE AT LHC

Mario Rodríguez Cahuantzi for the ALICE Collaboration

Physics Department – CINVESTAV, México

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Cinvestav

ALICE

Plan of this talk

- ✧ Introduction
- ✧ ALICE detector at LHC
- ✧ Atmospheric Muon Multiplicity Distribution (MMD)
- ✧ Monte Carlo to study MMD and High Multiplicity Events (HME)
- ✧ Summary

Introduction

LEP experiments were pioneers in the study of atmospheric muon bundles

- ❑ **Astroparticle Physics 19 (2003) 513–523**
- ❑ **Astroparticle Physics 28 (2007) 273–286**

- ✧ Small apparatus
- ✧ Detection of muons crossing the rock

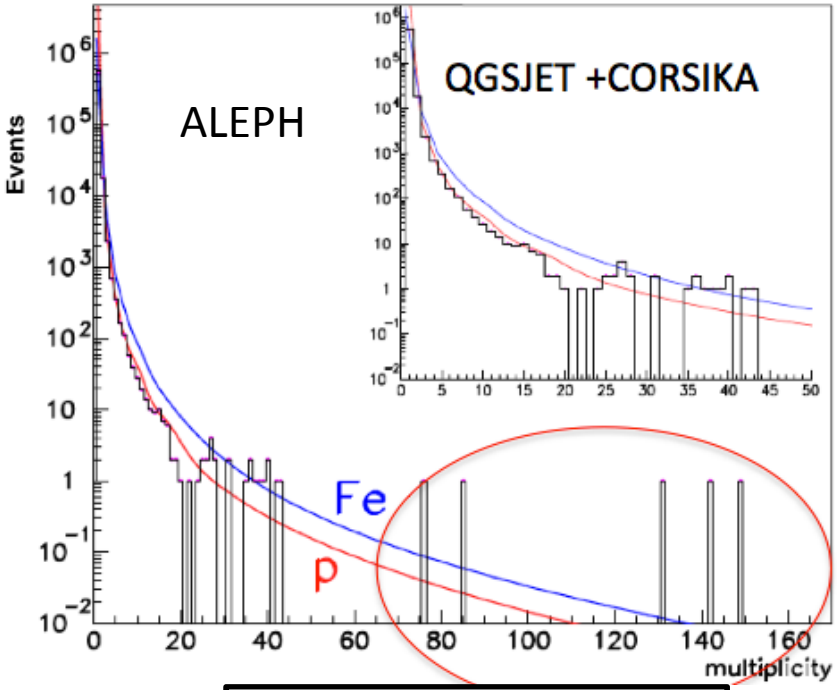
- ✓ Advantage: detectors with very high performances (tracking and presence of magnetic field)

- ✓ Why to study cosmic ray events with dedicated accelerator experiments? → **remember that the ONLY result out of LEP that did not agree "perfectly" with the standard hadronic interaction models was the observation of too many multiplicity muon bundles.**

Introduction

- ALEPH: 140 m of rock, momentum muon threshold $p > 70$ [GeV/c]/cos θ
  - ✓ underground scintillators, horizontal area of HCAL ~ 50 m^2, TPC projected area ~ 16 m^2
- DELPHI: 100 m of rock, momentum muon threshold $p > 52$ [GeV/c]/cos θ
  - ✓ Hadron calorimeter with an horizontal area ~ 75 m^2, muon barrel, TPC, TOF and outer detectors
- L3+C: 30 m of rock, momentum muon threshold $p > 20$ [GeV/c]/cos θ + surface array
  - ✓ Scintillator surface array of 200 m^2, trigger, muon barrel with horizontal area ~100 m^2, etc

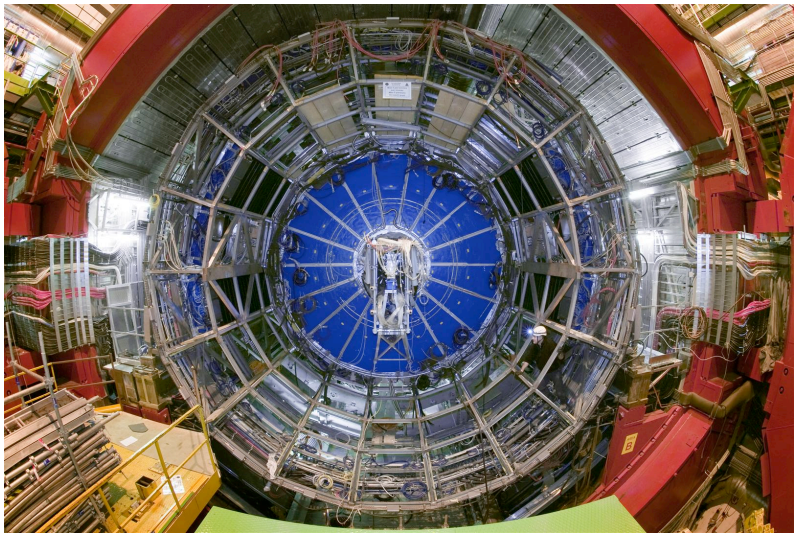
COSMIC RAY ENERGY COVERAGE FROM 10^{14} – 10^{18} eV



Astroparticle Physics 19 (2003) 513–523

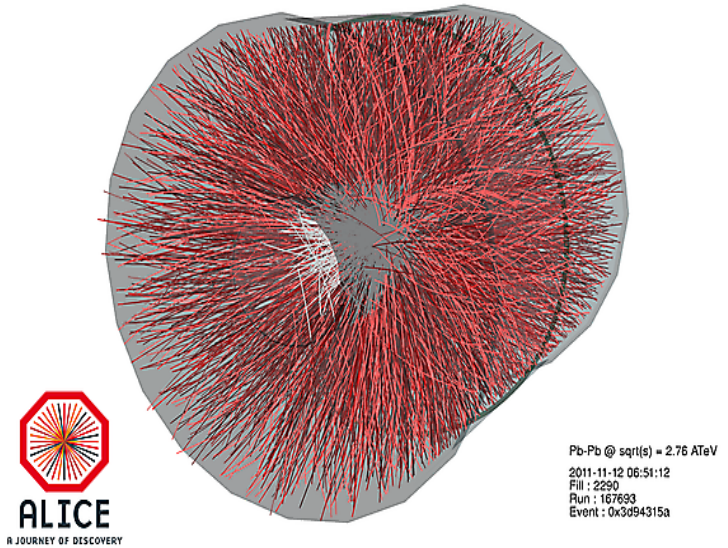
- ✓ these muon bundles are not well described (almost an order of magnitude above the simulation)
- ✓ even the combination of extreme assumptions of highest measured flux value and pure iron spectrum fails to describe the abundance of high multiplicity events.
- ✓ the conclusions of DELPHI and L3+C are similar to ALEPH

ALICE detector at LHC

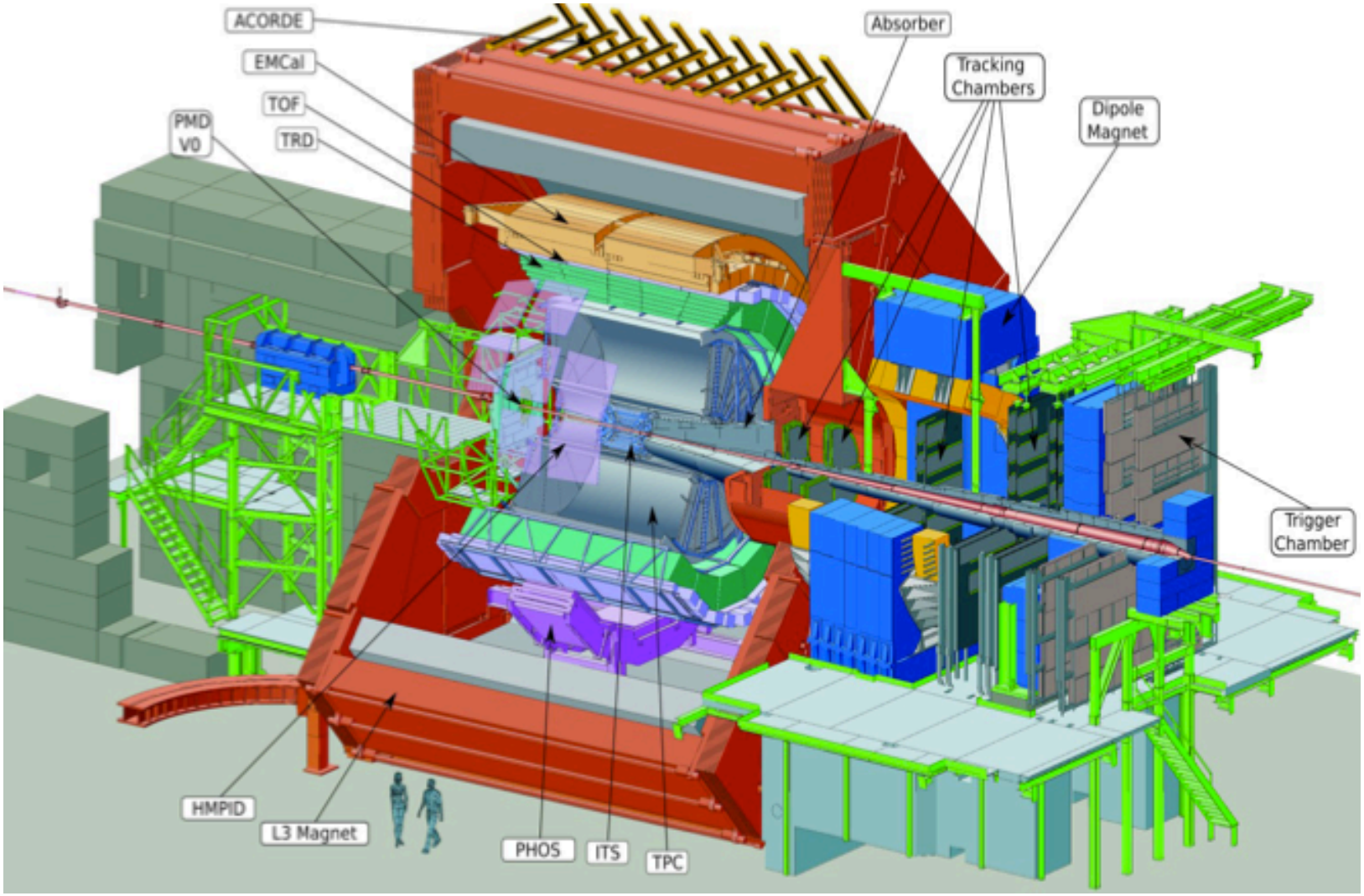


- ALICE at LHC is an experiment devoted to the study of strongly interacting matter in proton-proton, proton-nucleus and nucleus-nucleus collisions at ultra-relativistic energies.

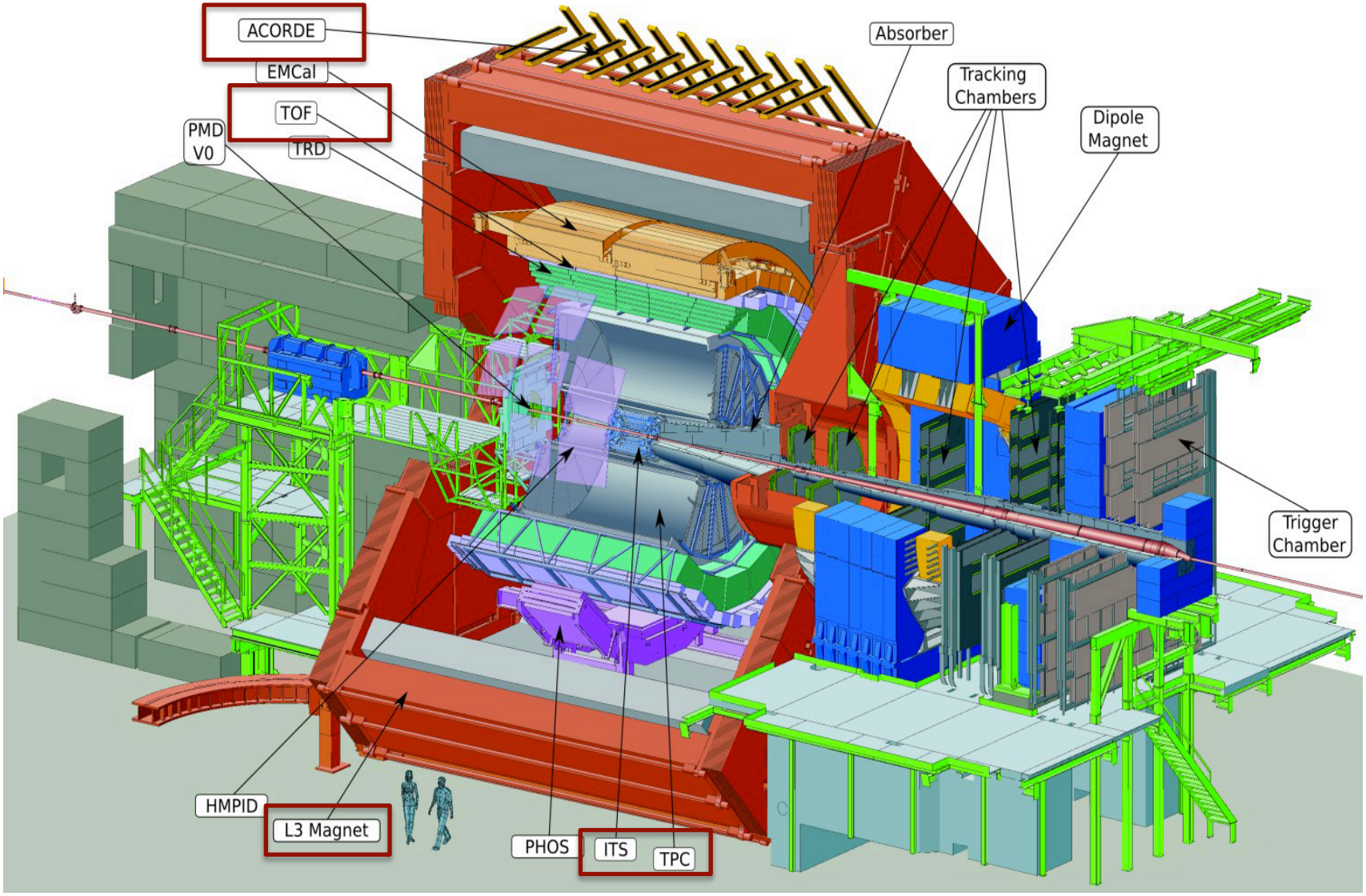
- Besides the Heavy Ion physics program, ALICE has a dedicated physics group that is interested in ultra peripheral collisions (γγ, γX), diffractive physics, charged particle multiplicity and cosmic ray physics



ALICE detector at LHC



ALICE: configuration for cosmics



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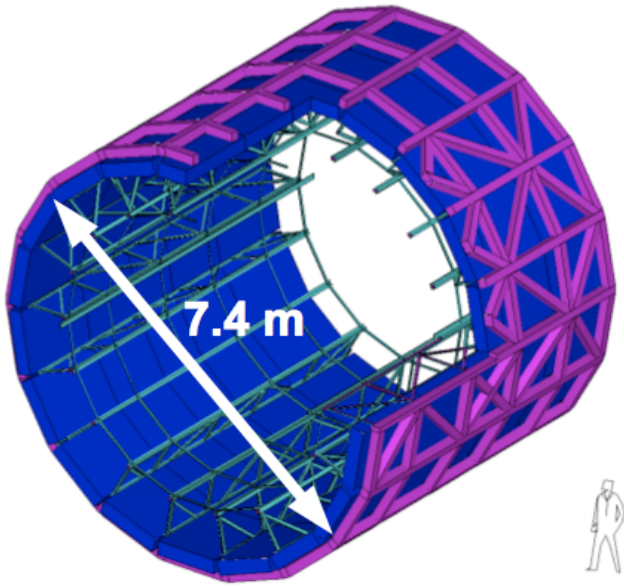
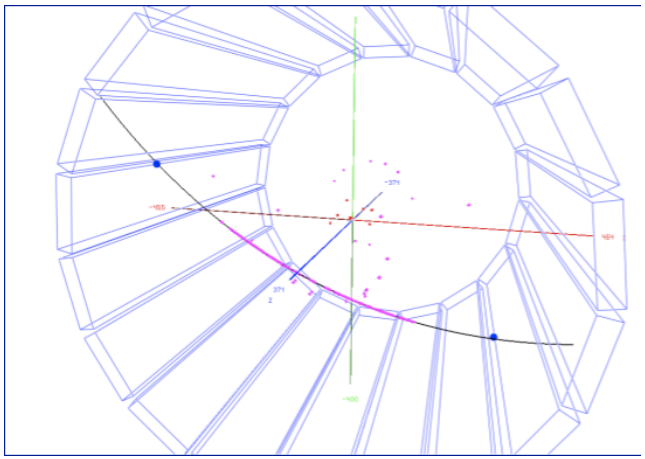
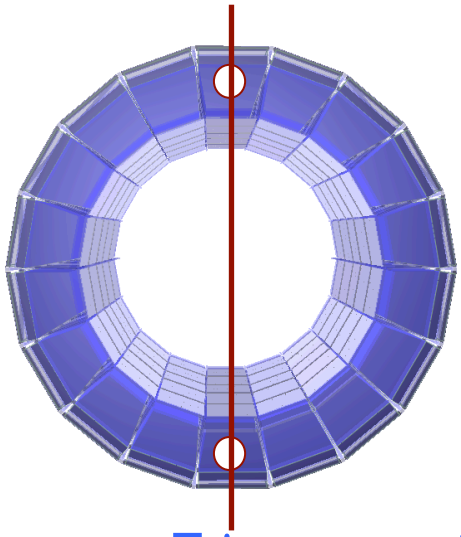
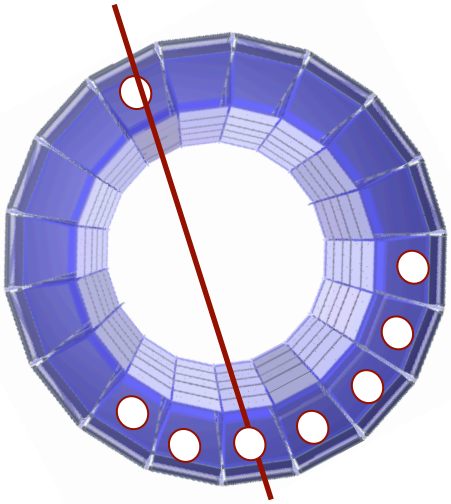




- ✓ TOF has an effective area of detection of 160 m^2
- ✓ full ϕ and $45 \leq \theta \leq 135$ coverage.
- ✓ time resolution less than 100 ps
- ✓ Efficiency around 95%.





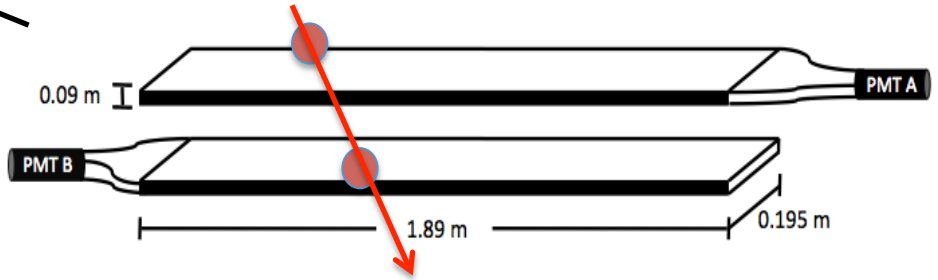
Trigger configuration:

✓Back to back

✓Back to back + 1,2 or 3 pads

ALICE: configuration for cosmics

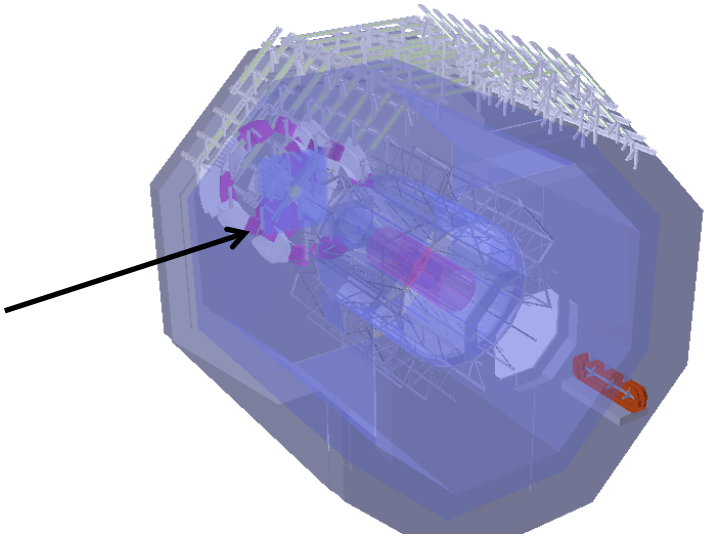
ACORDE is used to trigger on atmospheric muons in ALICE. It consists of an array of 60 scintillators modules located on the three top octants of the L3 magnet.



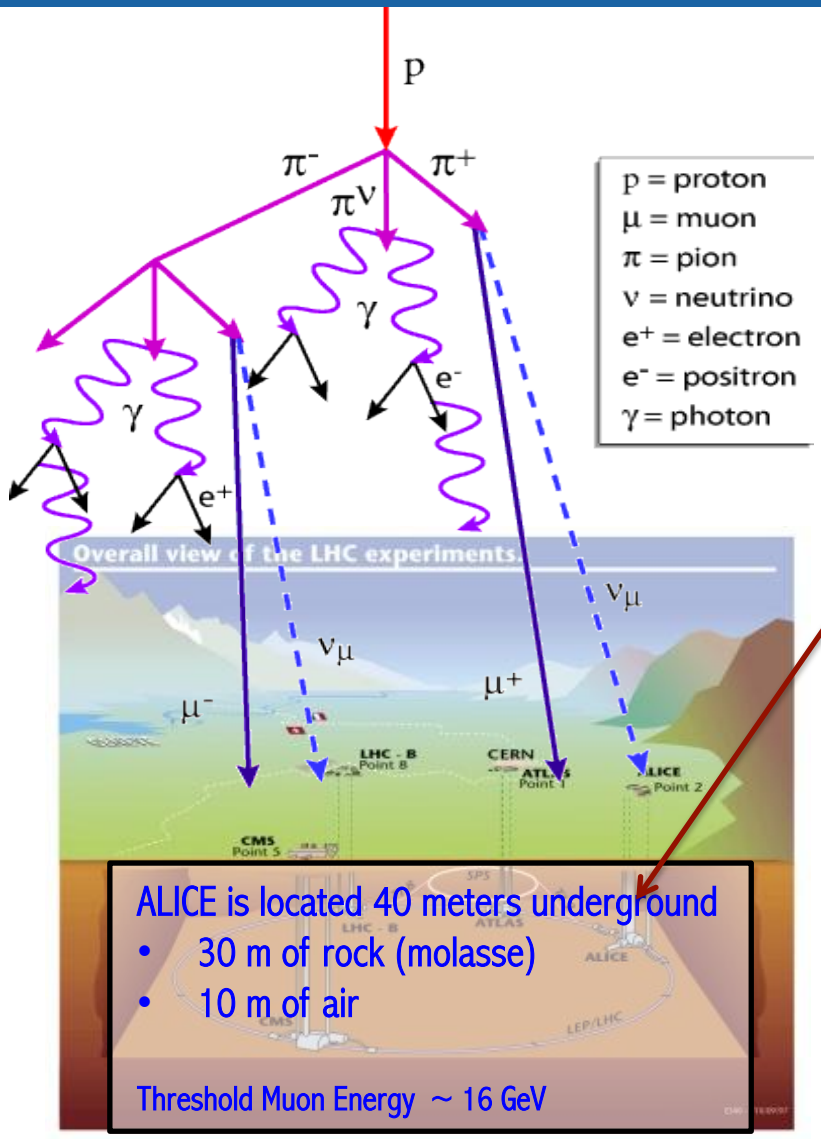
- ✓ Each module consists of two superimposed plastic scintillators paddles with an effective area of 0.38 m^2.

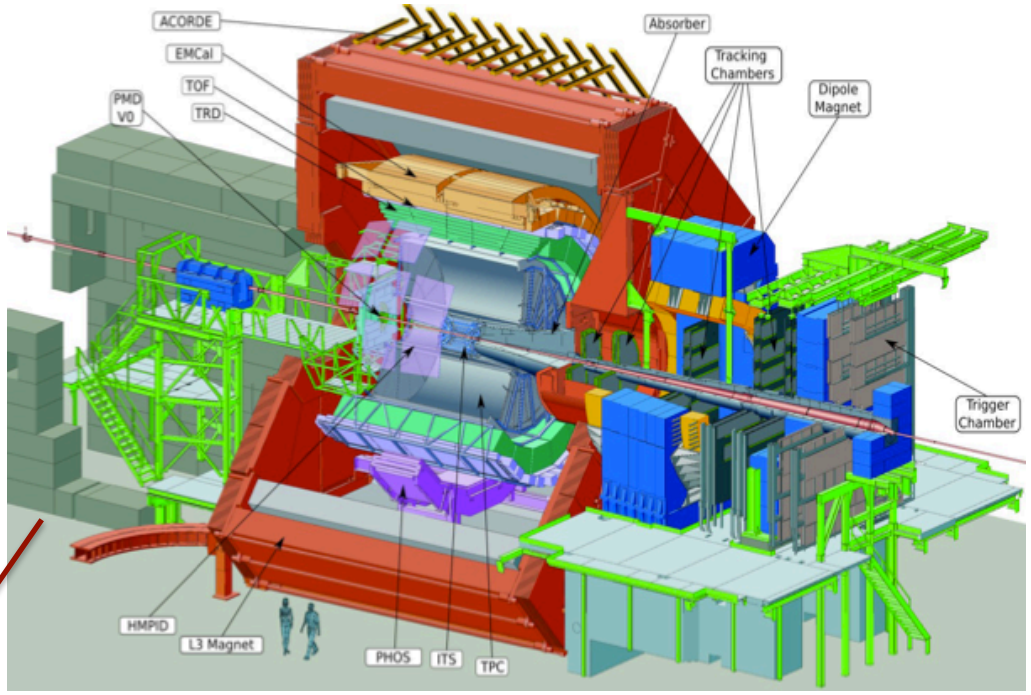
The muons have been used to

- ✓ Calibrate and align the central detectors of ALICE
- ✓ Cosmic ray physics



ALICE: configuration for cosmics





Topics of interest in Cosmic ray analysis in ALICE:

- ❑ Muon multiplicity distribution
  - ✓ Study of cosmic muon bundles

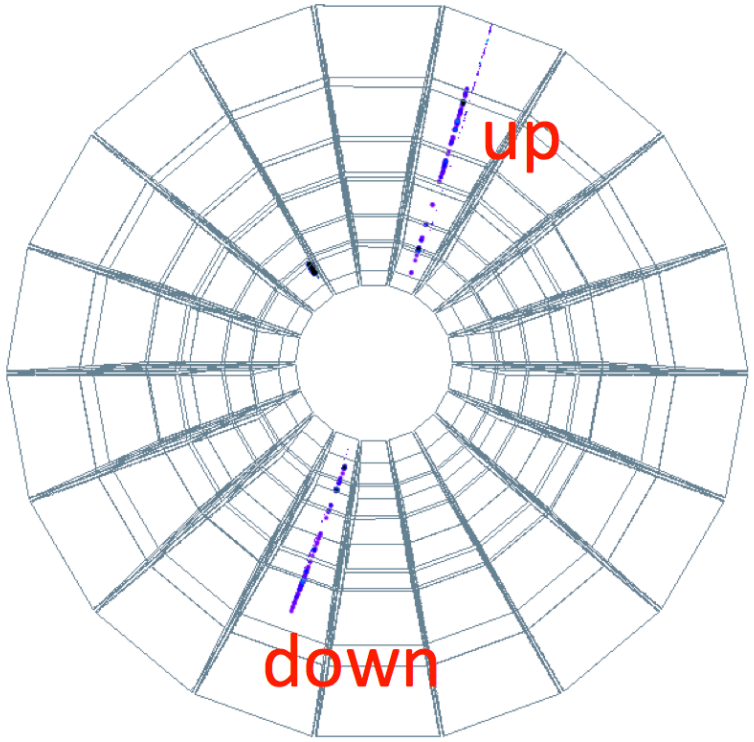
Atmospheric muon multiplicity dist. (MMD)

Between the years 2010 and 2013, ALICE collected several million events during the cosmic data taking sessions. The run selection took into account the relevant system for cosmic ray studies: ACORDE, SPD and TOF as trigger detectors and the TPC as readout.

Year	Days of data taking	Mag. Field OFF	Mag. Field ON
2010	4.4	1.4	3
2011	13.4	0	13.4
2012	11	2.7	8.3
2013	2.5	0	2.5
Total	**31.3**	**4.1**	**27.2**

The total sample corresponds to 31.3 days of data taking.

Atmospheric muon multiplicity dist. (MMD)

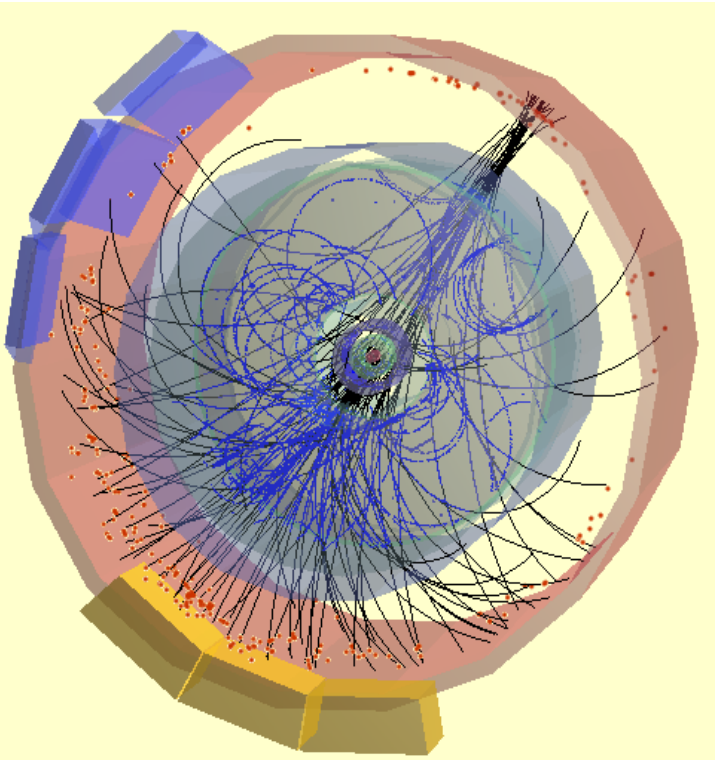


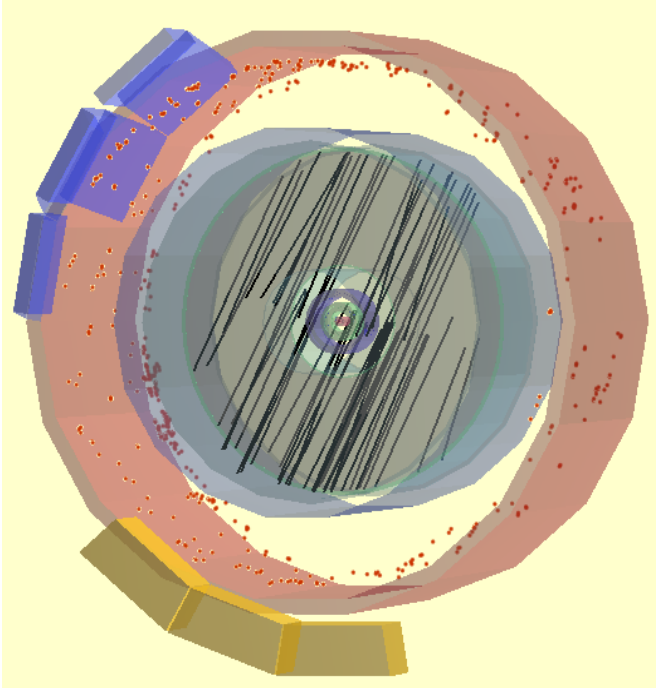
- ✓The TPC reconstructs a single muon with two tracks (up and down).
- ✓A specific algorithm has been worked out to obtain the whole track of the muon.
- ✓Monte Carlo events and data of high multiplicity have been used to optimize the parameters of the matching algorithm.

Atmospheric muon multiplicity dist. (MMD)

The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events - Alme, J. *et al.*
Nucl.Instrum.Meth. A622 (2010) 316-367 arXiv:1001.1950

Muon Interaction Event

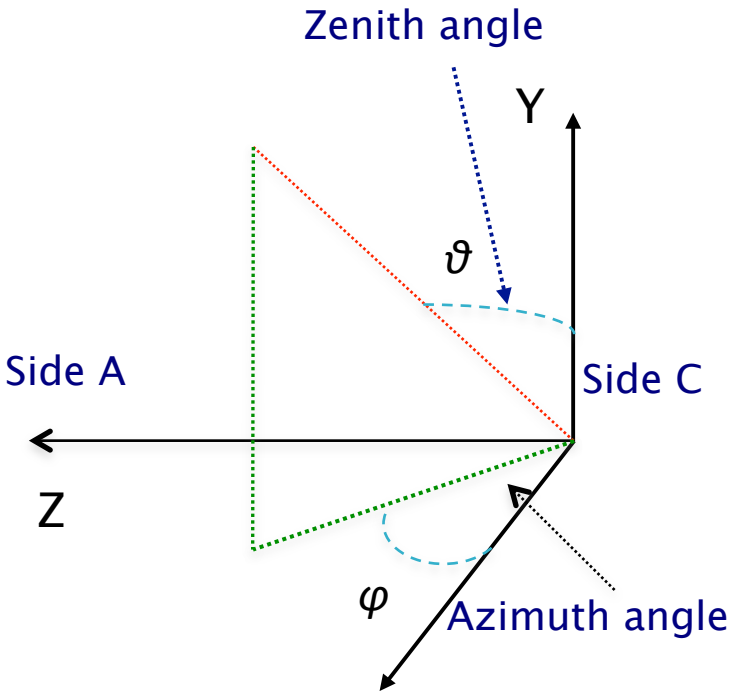


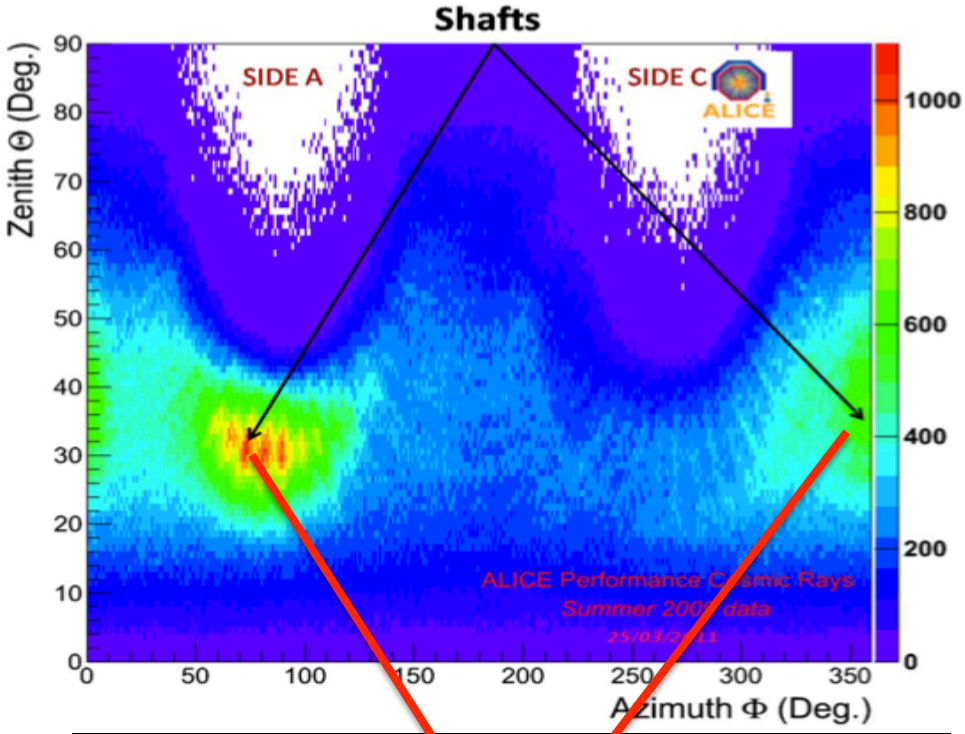


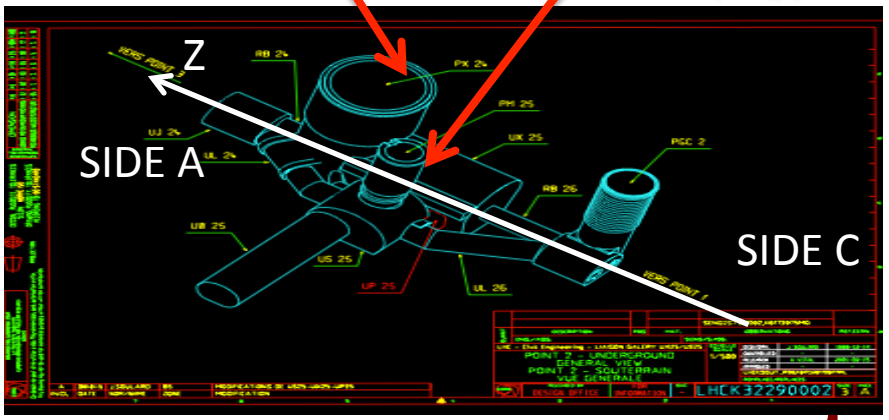
Standard Muon Event (multimuon)

Atmospheric muon multiplicity dist. (MMD)

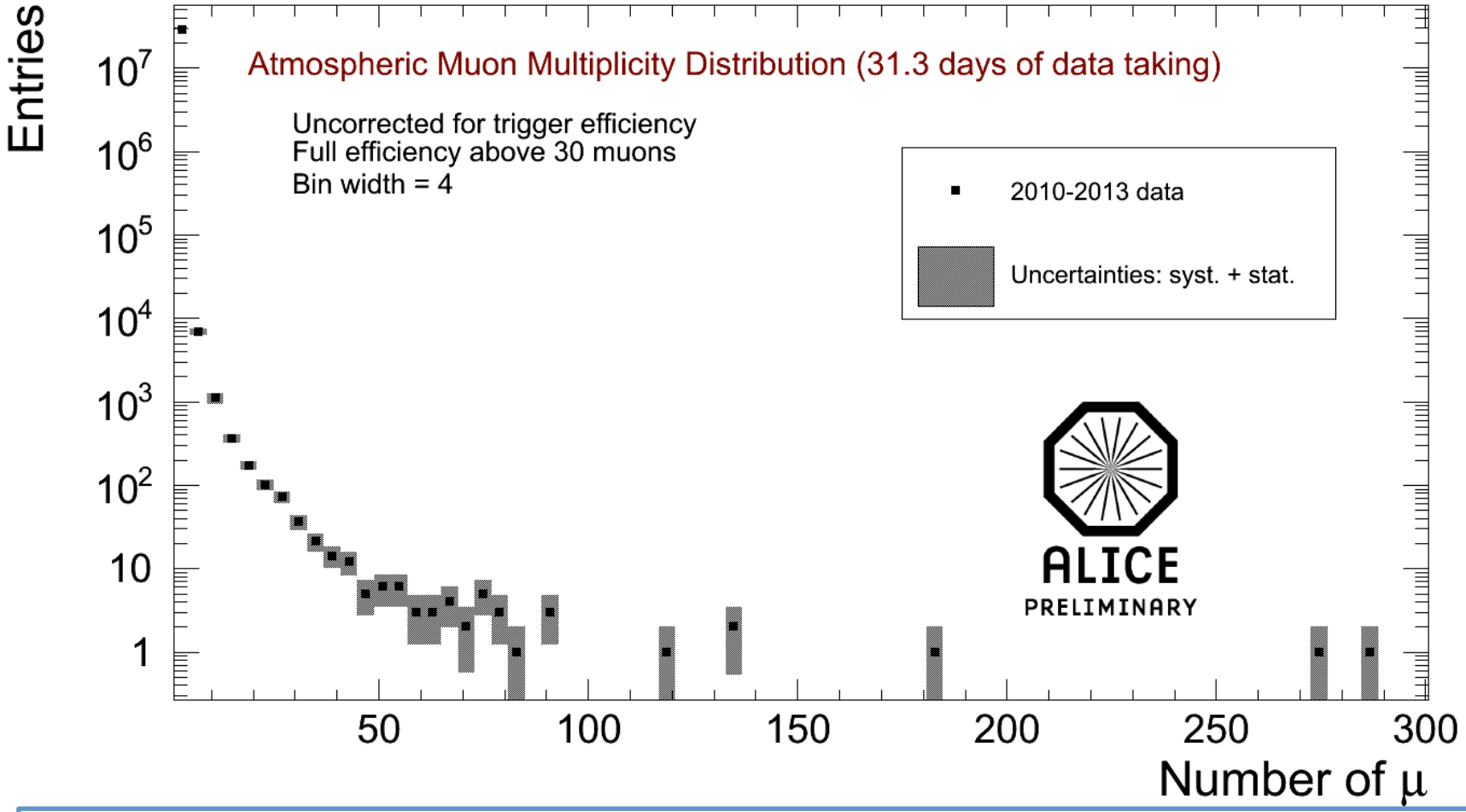
- ✓ The muons crossing the shafts have a lower energy cut-off.
- ✓ A larger number of muons arrive at the experiment in the directions of the shafts







Atmospheric muon multiplicity dist. (MMD)



ALICE collected 6 events with more than 100 atmospheric muons during 31.3 days of data taking with TOF and ACORDE triggers

Monte Carlo to study MMD and HME

The purpose of the following analysis is the study of the HME:

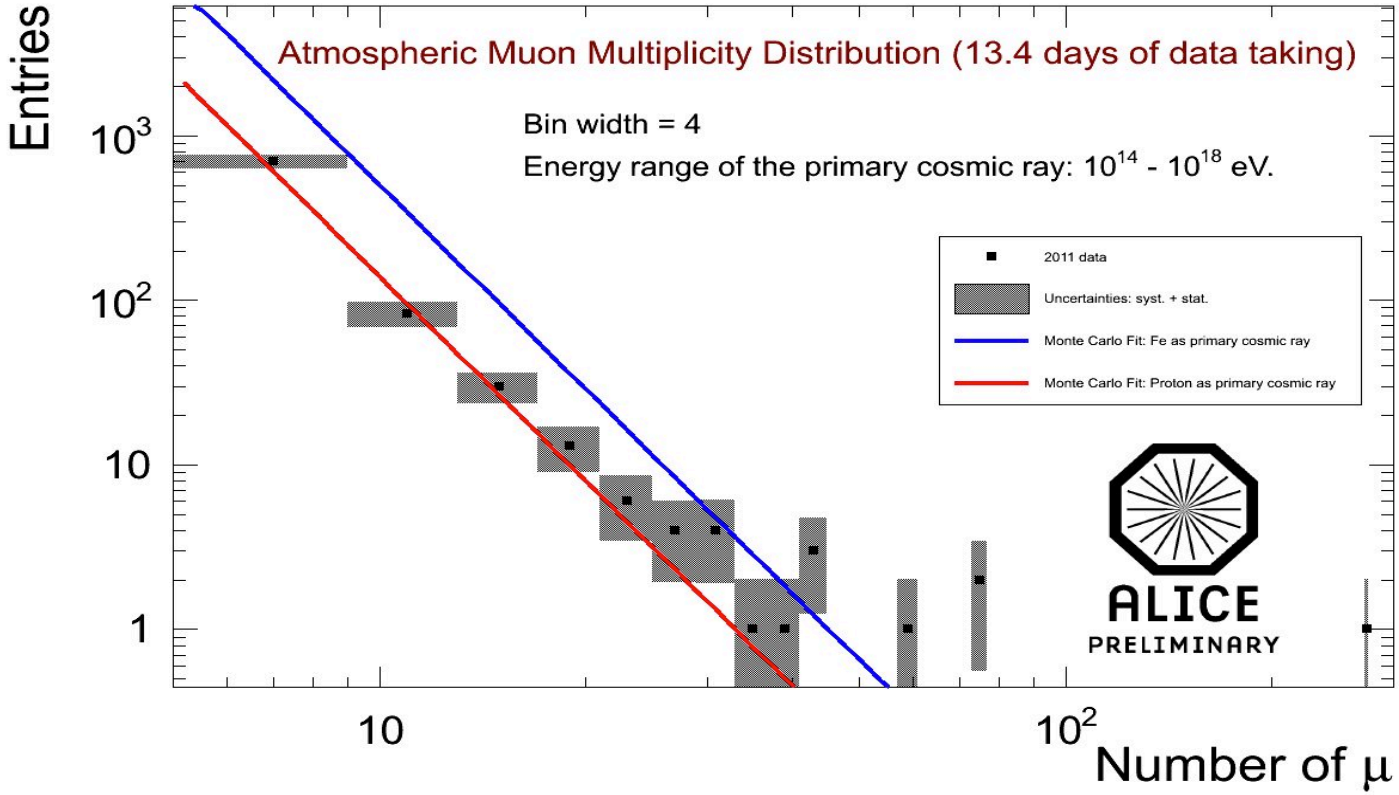
- To have a quantitative estimation of the rate of them, we define an HME when #muons > 100
- CORSIKA version 6990 with QGSJET II-03 was used to reproduce the MMD at intermediate multiplicity.
- CORSIKA version 6990 and 7350 with QGSJET II-03 (04) were used to study HME.

Monte Carlo to study MMD and HME

- Two assumptions: pure **p** (lighter composition) and **Fe** (extreme heavy composition)
- Usual power law spectrum $E^{-\gamma}$ adopted ($\gamma = 2.7$ for energies below the knee and $\gamma = 3.0$ for energies above the knee)
- The total (all-particle) **absolute flux** of the cosmic rays taken as in **J. R. Hörandel, Astrop. Phys. 19 (2003) 193-220.**
- The core of each shower was scattered randomly at surface level, in an area 205 x 205 m^2 centered around the Alice apparatus.

Monte Carlo to study MMD at intermediate range

As a first step, we compare the MMD (from 2011 data, 13.4 days) with the MC. The comparison of MC with the full sample would appear in the forthcoming publication that is in preparation.



- Primary energy range of the simulation : $10^{14} < E < 10^{18}$ eV
- The data are, as expected, in between the pure Proton composition (light elements) and pure Fe (heavy elements).
- The lower multiplicities (lower primary energies) are closer to pure Proton as expected.

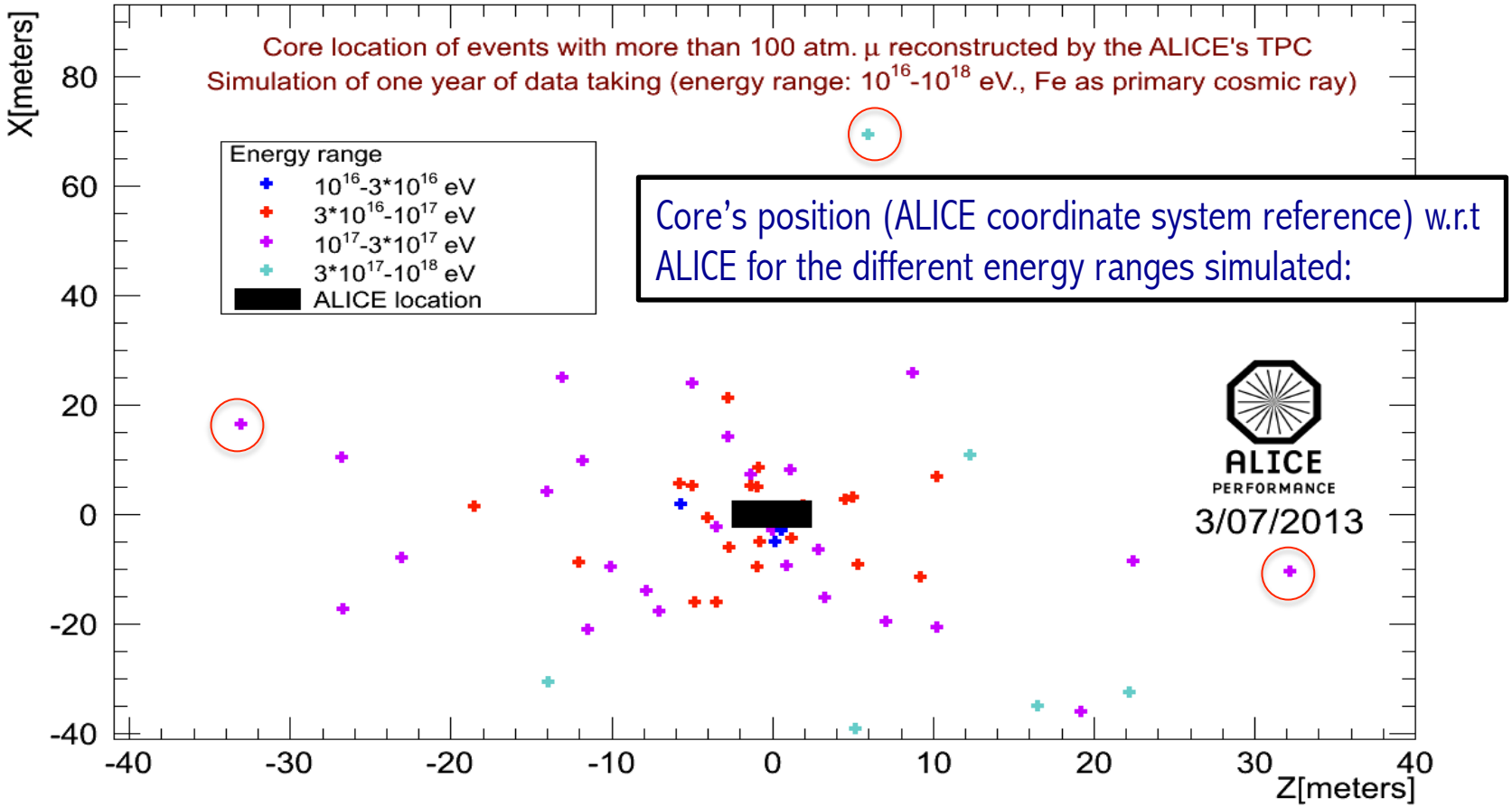
Monte Carlo to study HME

We want to measure the rate of the HME events.

To reduce the fluctuations, we simulate 1 year of data with Corsika 6990 (QGSJET II-03) and Corsika 7350 (QGSJET II-04)

- Energy range: $10^{16} - 10^{18}$ eV (30,308 events)
- Primary cosmic ray composition: proton, Fe nuclei
- Theta <= 50^{0}

Monte Carlo to study HME



- ✓ The black rectangle shows the ALICE's surface in the XZ plane (the core of 8 events are located within ALICE's location).
- ✓ Most of the HME events have a core located very close to ALICE (< 30 m), only some events are out of this distance (red circles, 3/72 events)

DATA vs Monte Carlo comparison

Model	Primary cosmic ray	HME rate [/day]	HME rate [Hz x 10^{-6}]	Uncertainty (%), sys.+stat. in quadrature
QGSJET II-03	p	1 event in 11.8 days	0.9	17
	Fe	1 event in 5.7 days	2	20
QGSJET II-04	p	1 event in 10.7 days	1.1	17
	Fe	1 event in 4.9 days	2.3	20
Real data		1 event in 6.3 days	1.8	40

- ✓ These events, already detected in the past from some LEP experiments like ALEPH and DELPHI, and actually without any explanation, have been recorded also in ALICE.
- ✓ Using CORSIKA 6990 with the QGSJET II-03 as hadronic interaction model and the more recent CORSIKA 7350 with QGSJET II-04, the first hadronic interaction model tuned with the LHC data, we are able to reproduce the rate of HME.

Summary

- ✓ The comparison of the MMD between real data and Monte Carlo simulation suggests a mixed composition with an increasing average mass of the primary at higher energies.

- ✓ This confirms the reliability of cosmic data taking and its explanation with simulation programs, allowing us to face the study of HME events

- ✓ These events indicate that they are mostly due to primary cosmic rays of heavy nuclei with an energy above 10^{16} eV, and a shower core located near ALICE

Outlook

- ✓In the period 2010-2013 ALICE experiment took more than 31 effective days of dedicated cosmic runs. A publication is in preparation.

- ✓ALICE is preparing a special trigger to continue data taking of HME during p-p runs (we acquired some experience with this trigger during 2012 p-p run). The data taking for no beam runs will continue → with more statistics a detailed study of HME characteristics can be done.