Study of cosmic-ray events with high muon multiplicity using the ALICE detector at the CERN Large Hadron Collider

Arturo Fernández Téllez * for the ALICE Collaboration

*Facultad de Ciencias Físico Matemáticas, Benemérita Universidad Autónoma de Puebla, México

INTRODUCTION

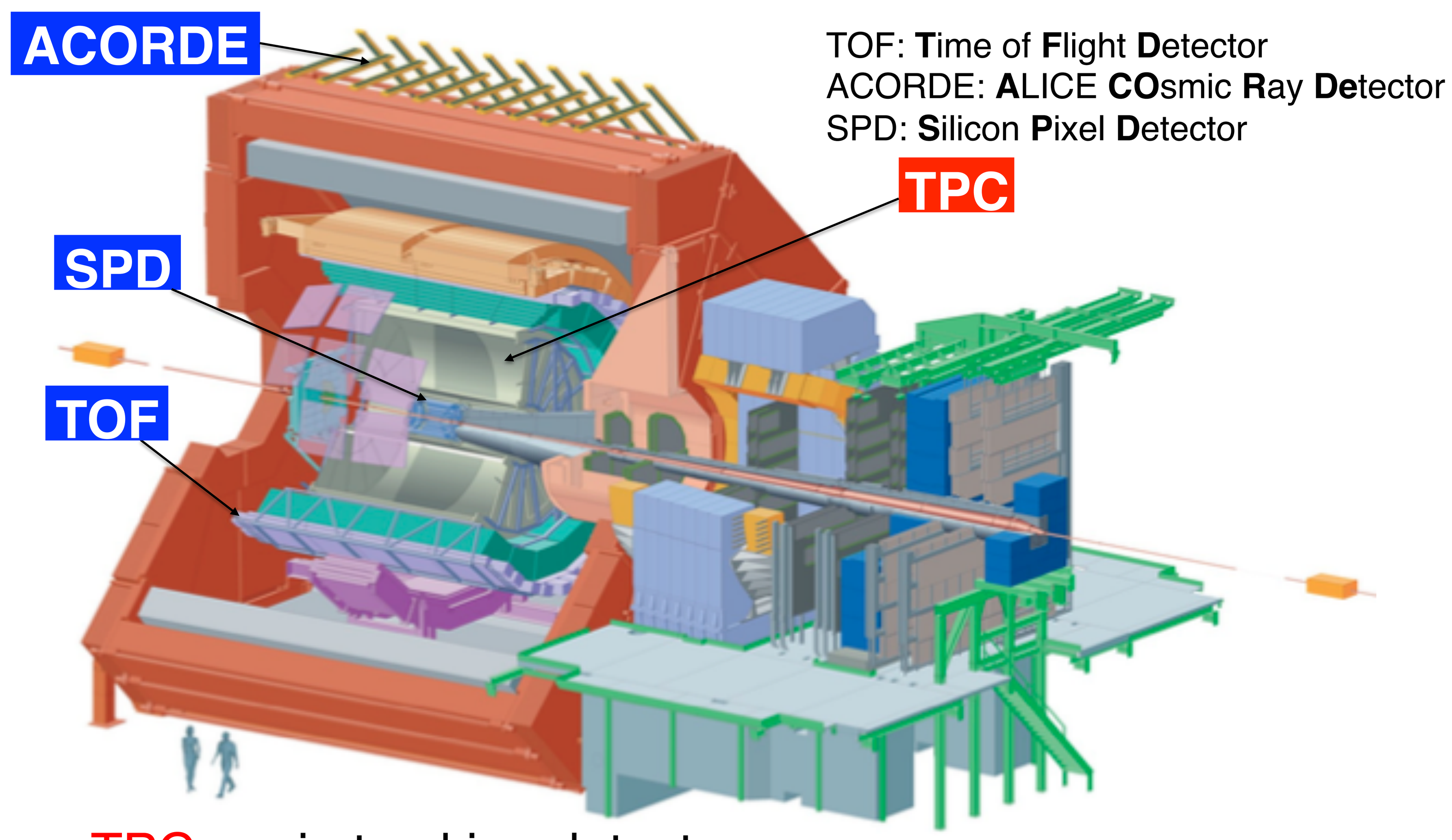
Cosmic-ray (CR) muons are created in Extensive Air Showers (EAS) produced by the interaction of primaries (protons and heavier nuclei) with nuclei in the upper atmosphere. The detection of EAS has been performed by large detector arrays at ground level while underground detectors have studied the high-energy muonic component of EAS. The multiplicity distribution of muons generated by primaries with energies around the knee in the energy spectrum ($E_k \sim 3 \times 10^{15}$ eV) is sensitive to the mass composition of primary CR.

Cosmic Ray physics with high-energy detectors: The muon multiplicity distribution (MMD) was measured at LEP by ALEPH and [1], DELPHI [2] detectors. The bulk of the data were successfully described by standard hadronic models, but the highest multiplicity events ($N_\mu > 75$) occurred with a frequency which is almost an order of magnitude above expectation of the then available models .

[1] *NIM A* ***503*** (2003) 190
[2] *Nucl. Phys. B. Proc. Suppl.* **138** (2005) 298

THE ALICE EXPERIMENT

Located 52 m underground with 28 m of overburden rock, ALICE can detect multi-muon events from EAS created by primaries with $E > 10^{14}$ eV. The large size and excellent tracking capability of the ALICE Time Projection Chamber (TPC) is the main strength of ALICE to perform CR physics.



TPC: main tracking detector
TOF, ACORDE and SPD: Trigger detectors for cosmics.

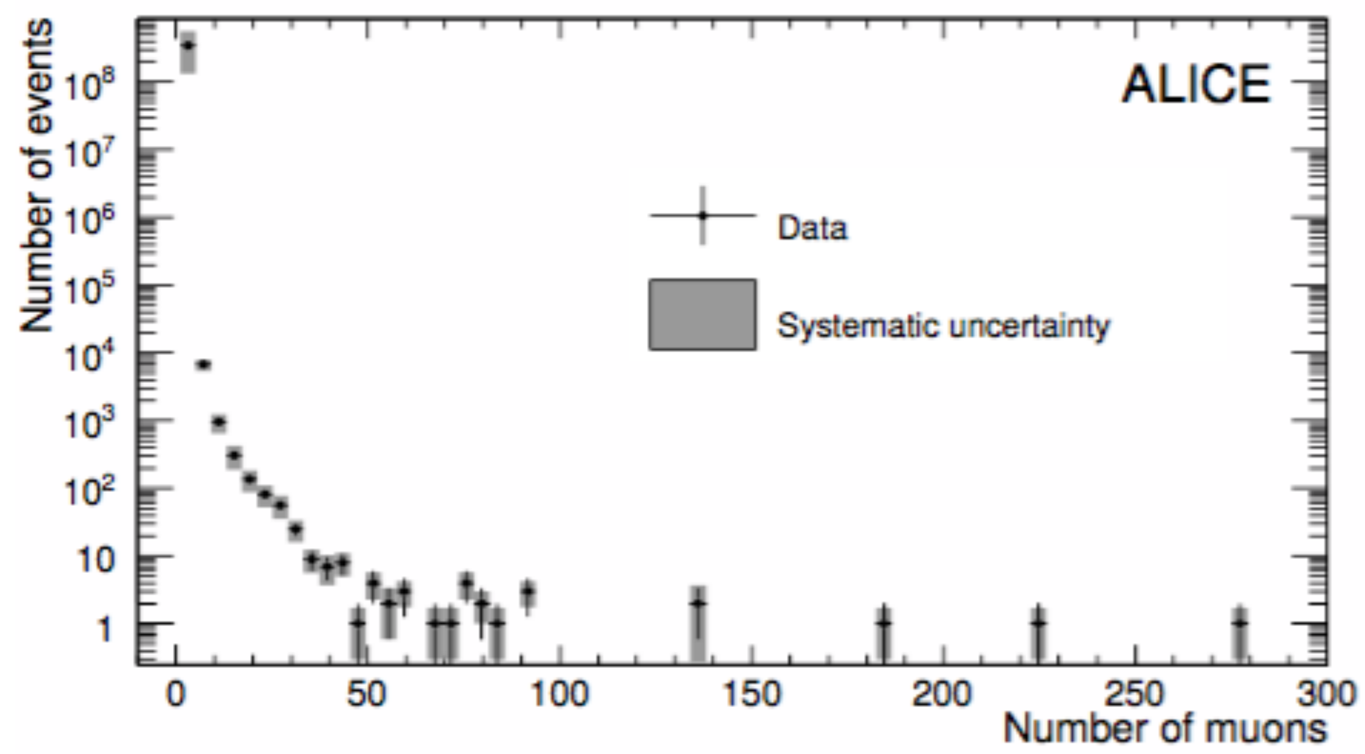
MAIN OBJECTIVES

- Measure the muon multiplicity distribution at low and intermediate multiplicities and compare to Monte Carlo models.
- Explore the origin of the high muon multiplicity events.

MEASURED MULTIPLICITY DISTRIBUTION

ALICE undertook a programme of CR data taking in the period 2010-2013 when there was no beam circulating in the LHC.

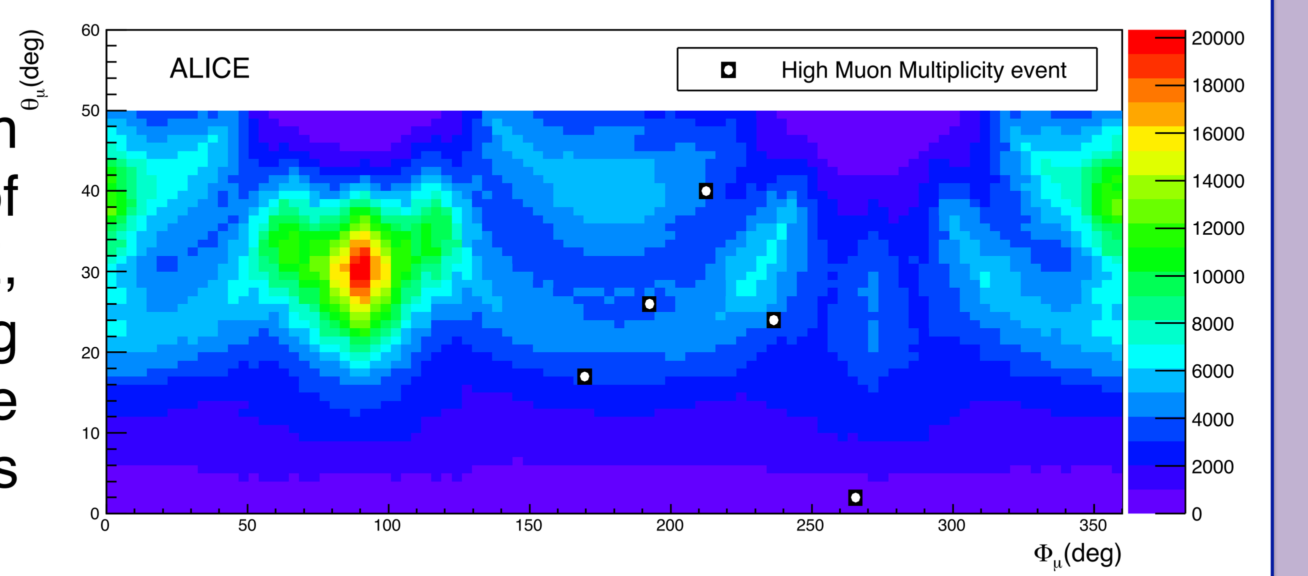
The MMD, corrected for trigger efficiency and corresponding to 30.8 days is shown below.



ALICE collected 5 high muon multiplicity (HMM) events: $N_\mu > 100$

Arrival directions of HMM events

Zenith vs. Azimuth angle distribution of the muons in ALICE, by superimposing the location of the five HMM events (empty circles)



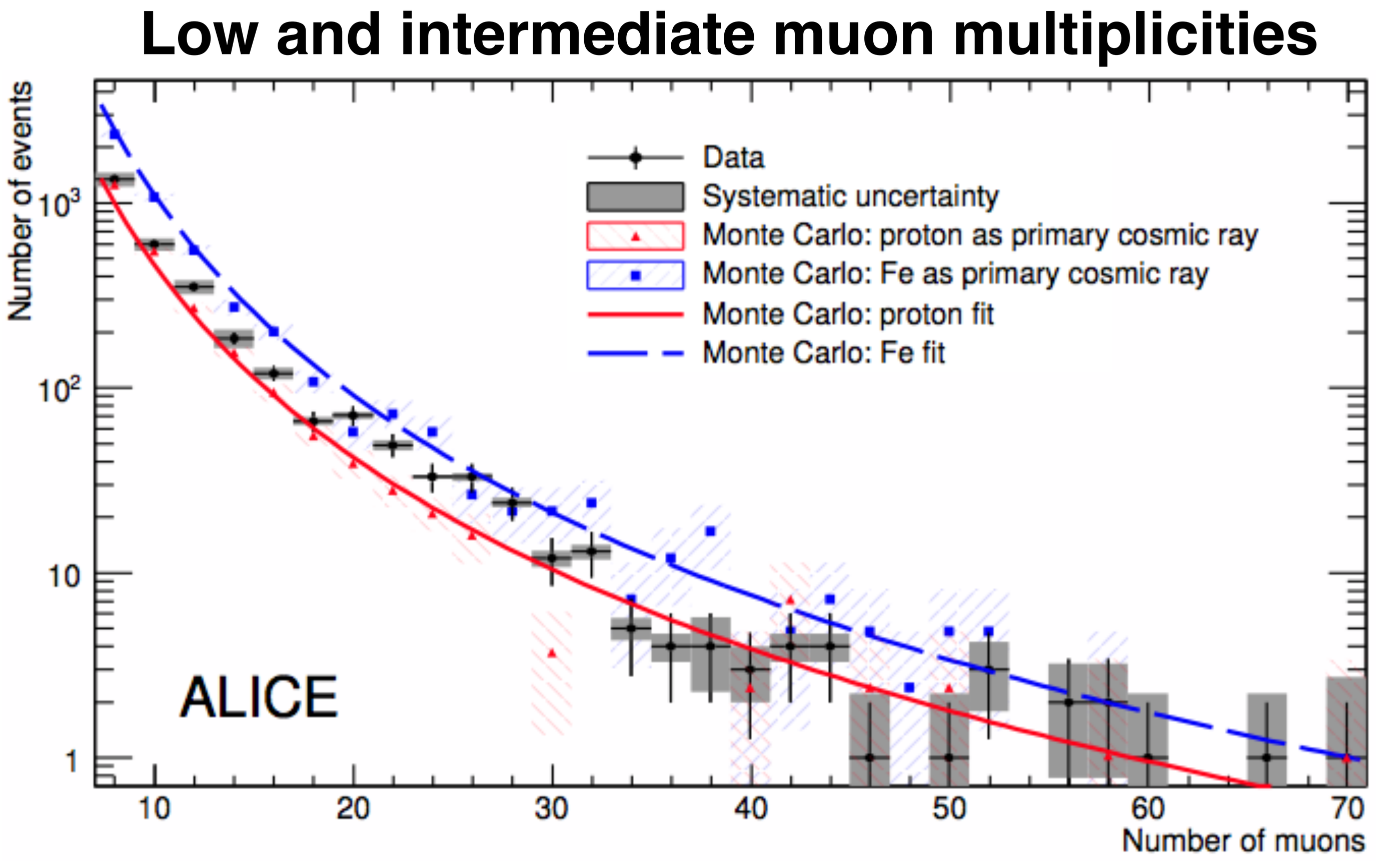
MC STRATEGY

We adopted **CORSIKA** event generator incorporating the latest versions of **QGSJET** [3,4] for the hadronic interaction model to generate primaries and simulate the development of the EAS.

[3] *Phys. Rev.* **D83** (2011) 014018
[4] *EPJ Web Conf.* **52** (2013) 02001

RESULTS: comparison DATA *vs* MC

Low and intermediate muon multiplicities



Data uncert.: stat. and syst. (separated)

MC uncert.: $[(stat^2)+(syst)^2]^{1/2}$

Rate of high muon multiplicity events

HMM events	CORSIKA 6990 QGSJET II-03		CORSIKA 7350 QGSJET II-04		Data
	proton	iron	Proton	iron	
Period [days per event]	15.5	8.6	11.6	6.0	6.2
Rate [x 10^{-6} Hz]	0.8	1.3	1.0	1.9	1.9
Uncertainty (%) (syst + stat)	25	25	22	28	49

CONCLUSIONS

- The muon multiplicity distribution for $7 \le N_\mu \le 70$ is satisfactorily reproduced using standard hadronic models.
- The measurements suggest a mixed-ion primary cosmic-ray composition with an average mass that increases with energy.
- The rate of HMM is consistent with the one predicted by MC using latest hadronic model and assuming Fe composition with $E > 10^{16}$ eV.
- For the first time the HMM events, observed the relatively shallow position of ALICE, have been reproduced using a standard hadronic model to describe EAS.

ALICE CR Publication: ***J**ournal of **C**osmology and **A**stroparticle **P**hysics* **01** (2016) 032