Azimuthal asymmetry in the risetime of the Surface Detector signals of the Pierre Auger Observatory

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I.A. Minaya[1] for the Pierre Auger Collaboration[2]

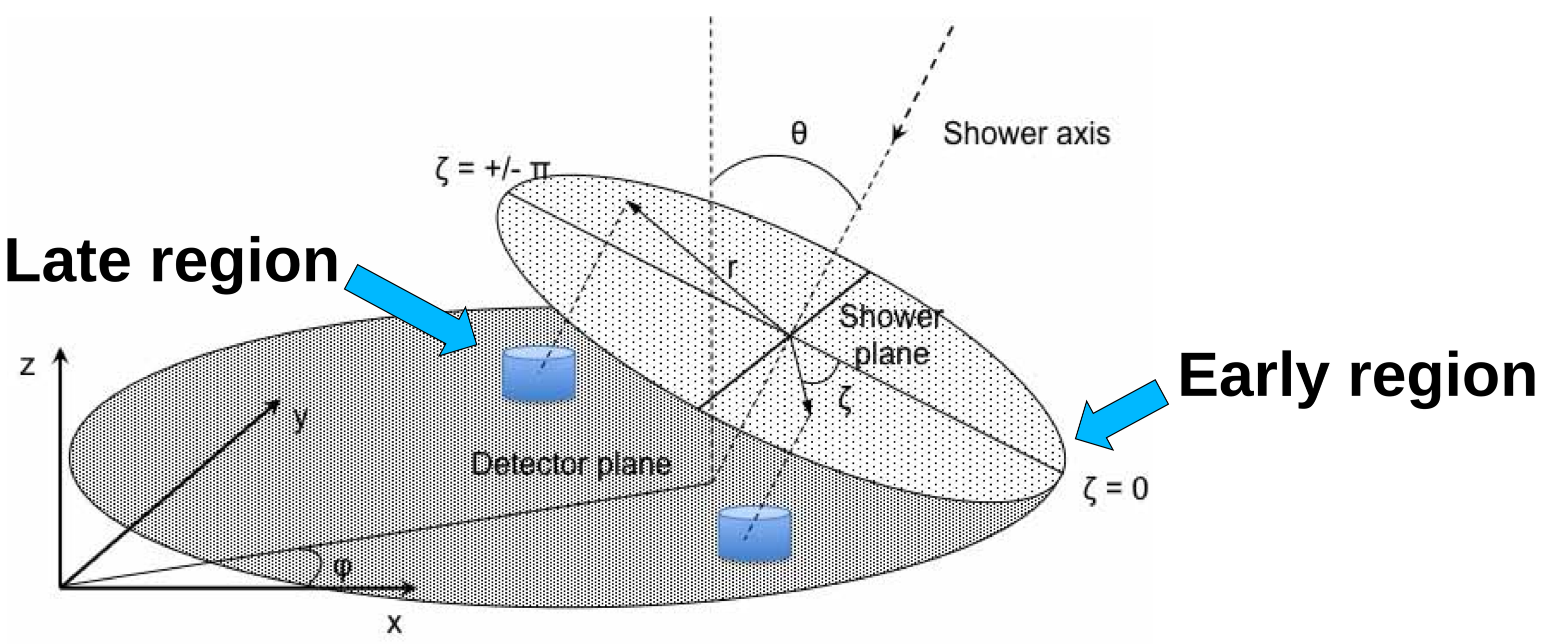
[1] Universidad Complutense de Madrid, Madrid, Spain
[2] Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina
Contact: auger_spokespersons@fnal.gov   Full author list: http://www.auger.org/archive/authors_2015_06.html

1. Introduction

The azimuthal asymmetry in the risetime $t_{1/2}$ of the signals registered by the Surface Detector of the Pierre Auger Observatory is related to the stage of the shower development at ground, and thus has the potential to give insights into the matching of data to mass and hadronic models for $E > 3 \times 10^{18}$ eV [1].

2. Azimuthal asymmetry of $t_{1/2}$

In inclined showers, particles reaching the detectors later have traversed longer atmospheric paths. Thus, both the intensity and $t_{1/2}$ of the signals depend on ζ.



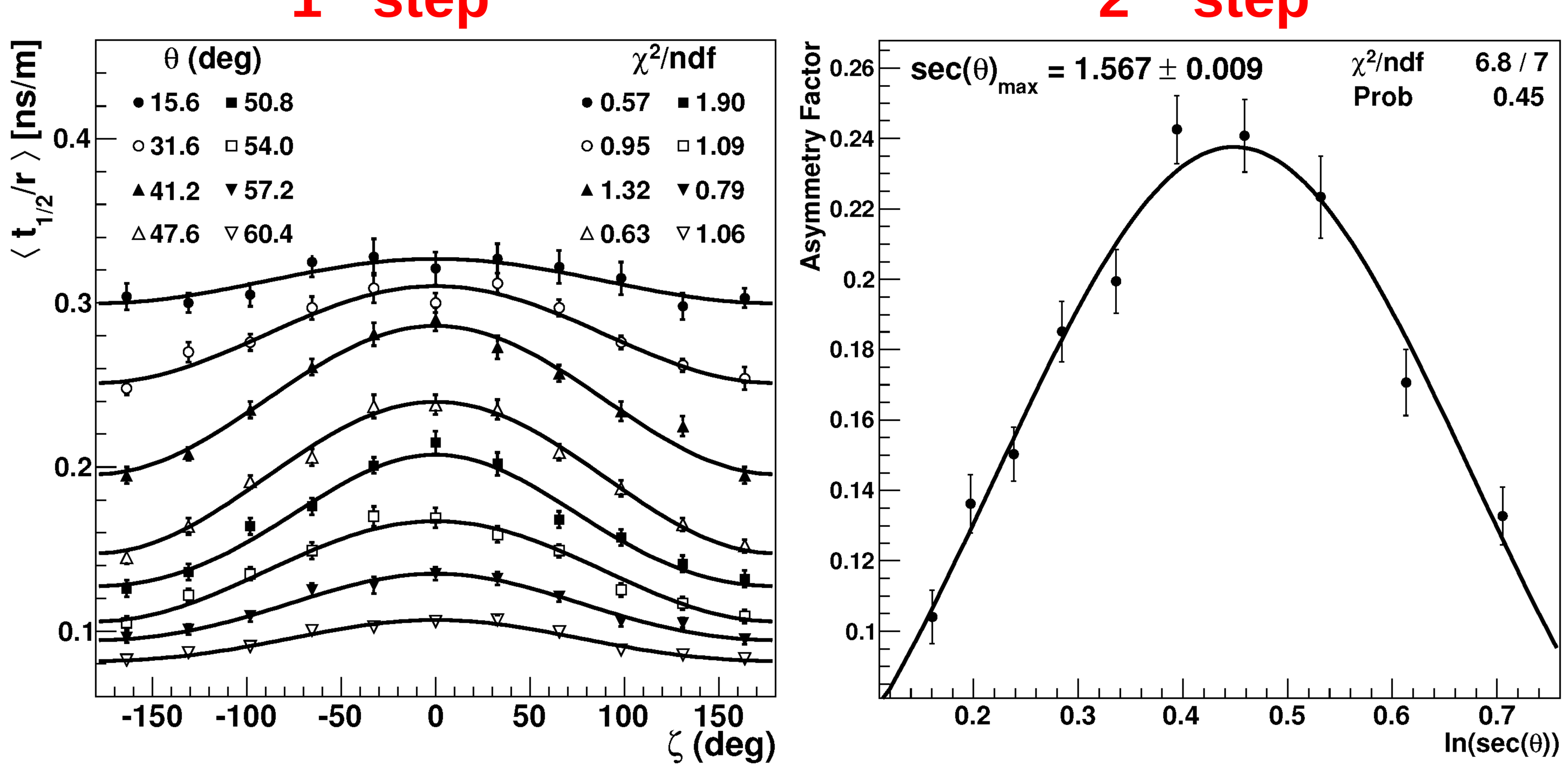
This azimuthal asymmetry grows with zenith angle θ until the electromagnetic component is quenched and the shower is mainly composed of muons.

3. Analysis using Auger data

Data sample: 01/01/04 – 29/10/14
1.9×10^5 FADC signals from 5.5×10^4 events.
$E > 3 \times 10^{18}$ eV; $30^o < \theta < 62^o$; $500 < r < 2000$ m.
$S > 10$ Vertical Equivalent Muon (VEM);

The asymmetry depends on the core distance: the larger is r, the larger is the difference in atmospheric paths between early and late stations. The analysis has been carried out independently for two r-intervals, i.e., 500 - 1000 m and 1000 - 2000 m.

19.2<log(E/eV)<19.5



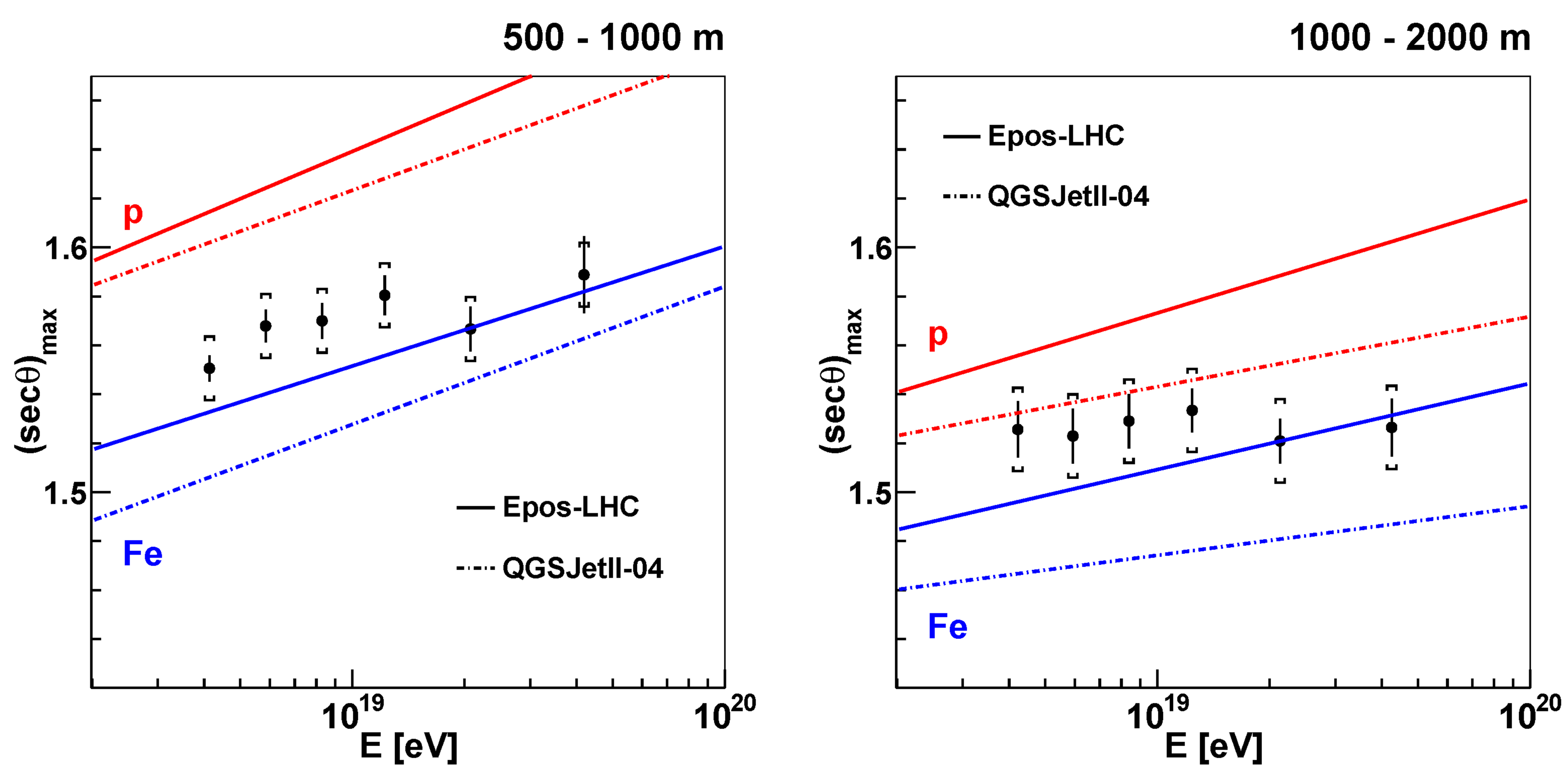
1st step: measure the azimuthal asymmetry of $t_{1/2}/r$ for intervals of E and θ. Data are fitted to:

$$\langle t_{1/2} / r \rangle = a + b \cos\zeta + c \cos^2\zeta$$

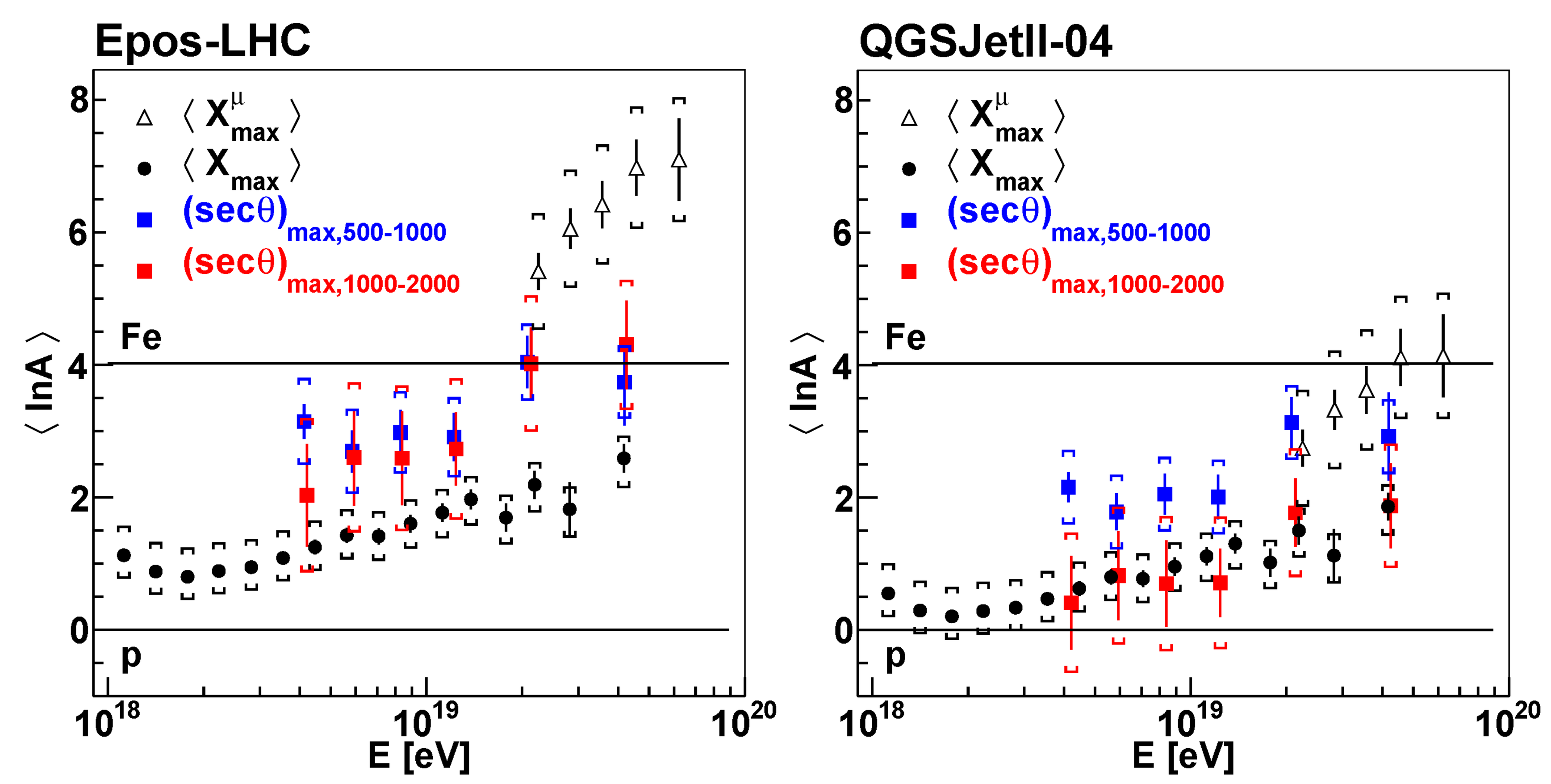
The $\boldsymbol{b/(a+c)}$ factor is used to quantify the asymmetry.

2nd step: represent the asymmetry factor as a function of atmospheric depth, measured by $\sec\theta$. For each E bin, $b/(a+c)$ vs ln ($\sec\theta$) is fitted to a Gaussian function. The value of θ that maximizes the asymmetry, $\boldsymbol{(\sec\theta)_{max}}$, is the mass sensitive parameter.

Data and MC predictions of $(\sec\theta)_{max}$ vs. E are compared using Epos-LHC and QJSJetII-04 models of hadronic interactions.



$(\sec\theta)_{max}$ can be transformed into $\ln A$ values and compared with results from X_{max} [2] and the Muon Production Depth (MPD) method [3].



Epos-LHC results are compatible in both r-intervals, in between X_{max} and MPD. However, the consistency between intervals is less evident for QGSJetII-04.

4. Conclusions

The azimuthal asymmetry of $t_{1/2}$ is a useful tool for mass analysis through the $(\sec\theta)_{max}$ parameter.

Model-dependent discrepancies between data and MC have been found.

Deficiencies in our understanding of shower modeling have to be resolved before the mass composition can be inferred from $(\sec\theta)_{max}$.

References
[1] M. Dova *et al.*, Astropart. Phys. **31** (2009) 312-319.
[2] The Pierre Auger Coll., Phys. Rev. **D90** (2014) 122005.
[3] The Pierre Auger Coll., Phys. Rev. **D90** (2014) 012012, Erratum: Phys. Rev. **D92** (2015) 019903 [arXiv:1407.5919].