The Auger story: results and challenges

Balázs Kégl

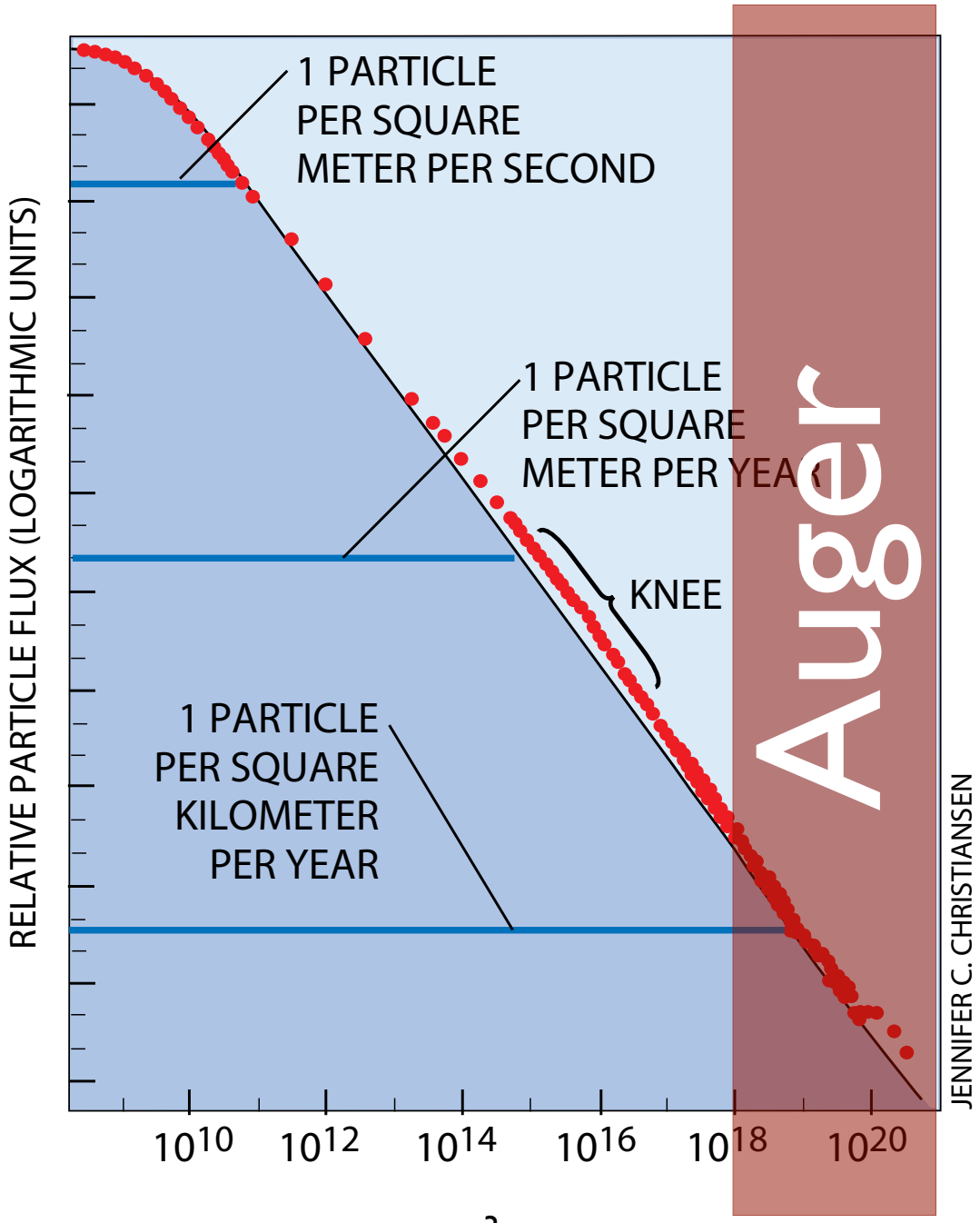
LAL seminar

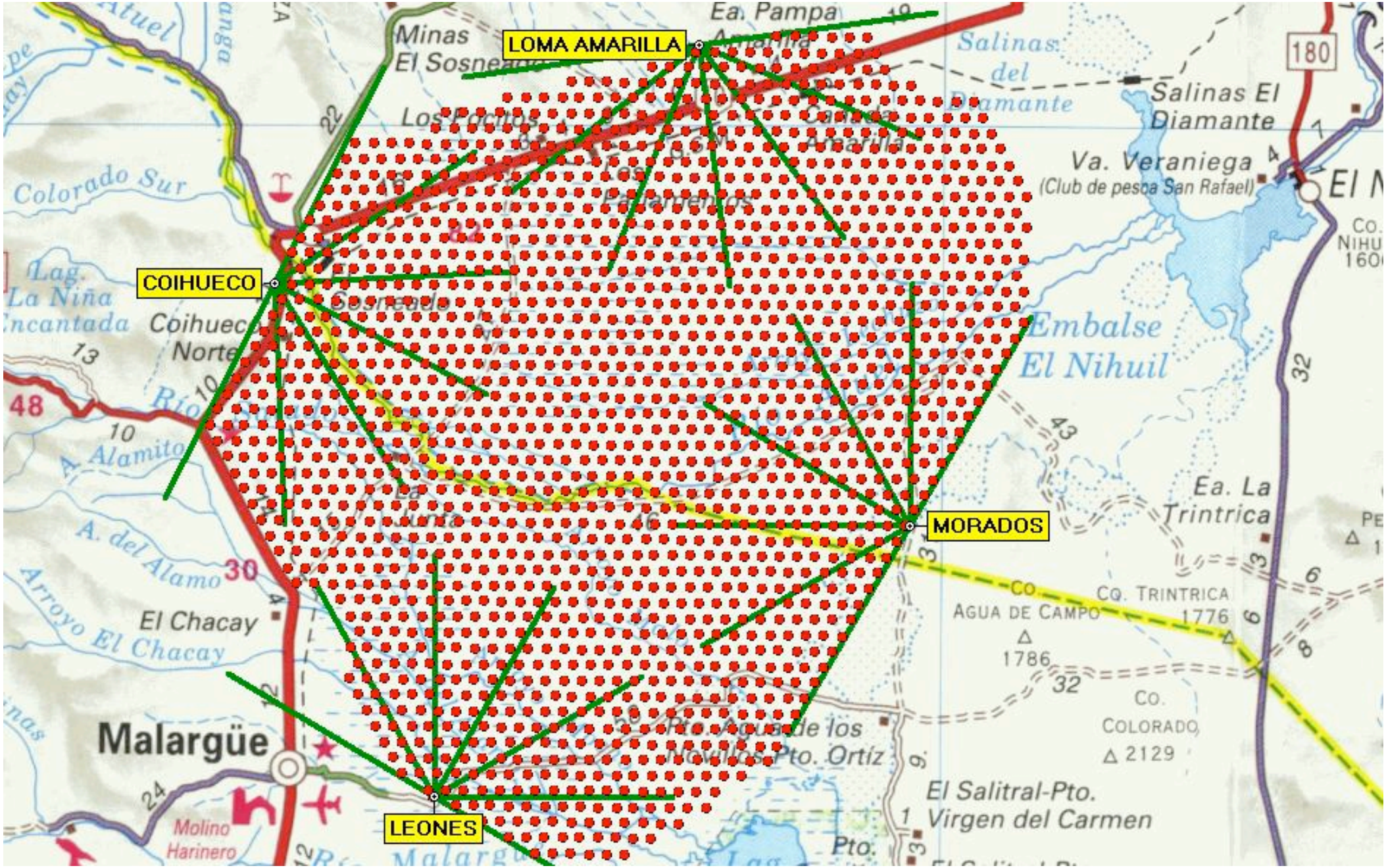
January 2013

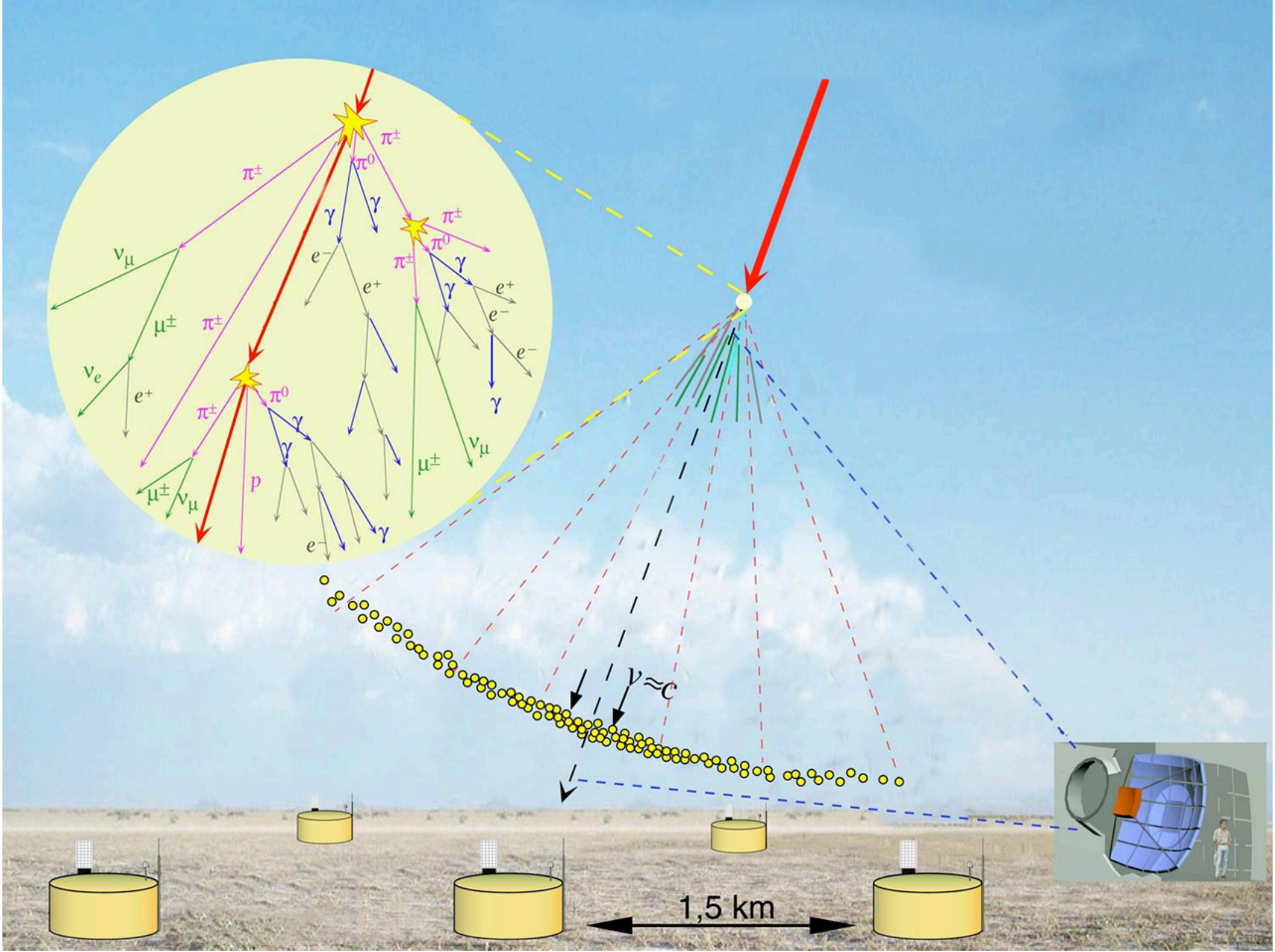
Outline

- Overview of the detector and the experiment
- Where we are
  - some recent results
  - the composition challenge
- Where we're going
  - large-scale computational statistics
  - hardware upgrade

The energy spectrum of cosmic rays




LOMA AMARILLA
COIHUECO
MORADOS
LEONES
Minas El Sosneado
Los Pocitos
Colorado Sur
Lag. La Niña Encantada
Coihueco Norte
Río Colorado
Alamito
A. del Alamo
Arroyo El Chacay
El Chacay
Malargüe
Molino Harinero
Ea. Pampa Amarilla
Salinas del Diamante
Salinas El Diamante
Va. Veraniega
(Club de pesca San Rafael)
Embalse El Nihuil
Ea. La Trintrica
CO. AGUA DE CAMPO
1786
CO. TRINTRICA
1776
CO. COLORADO
2129
Pto. Aguada de los Novillos
Pto. Ortíz
El Salitral-Pto. Virgen del Carmen
Pto.
180
48
30
24
32


π±
π0
γ
e−
e+
νμ
μ±
νe
p
v≈c
1,5 km

Scientific questions

- Where are they coming from?
  - AGN correlation
- At what energies?
  - precise spectrum above 10^{18} eV
- What is the nature of the primary particle?
  - proton? iron? in between?
- Particle physics?
  - high energy and shower physics

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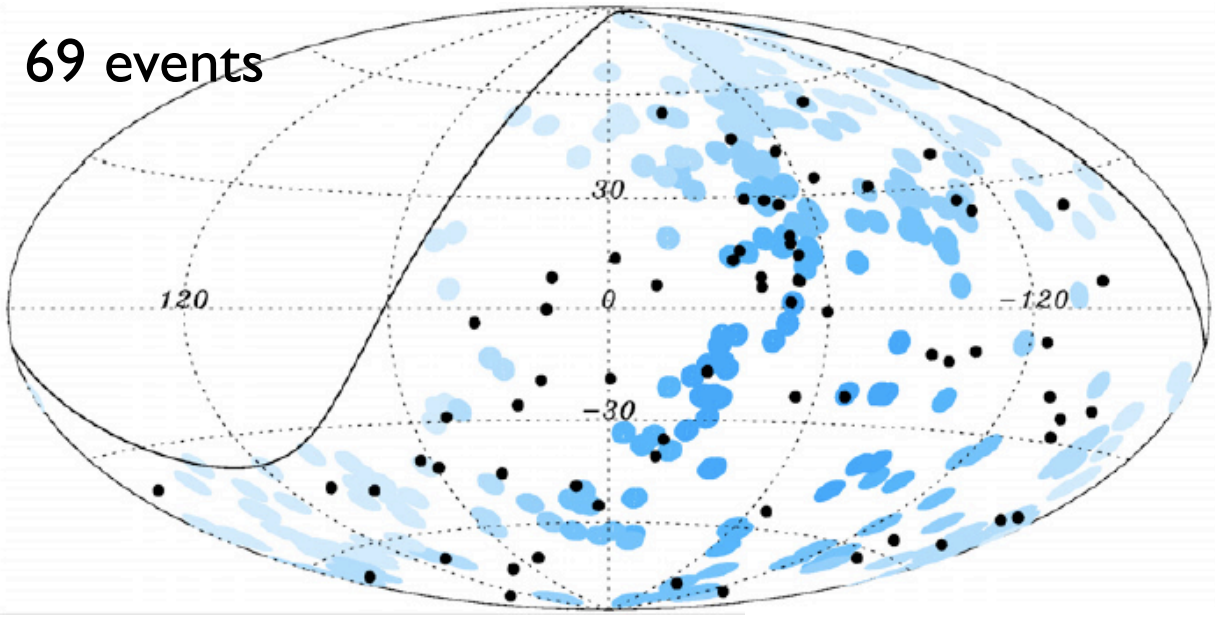
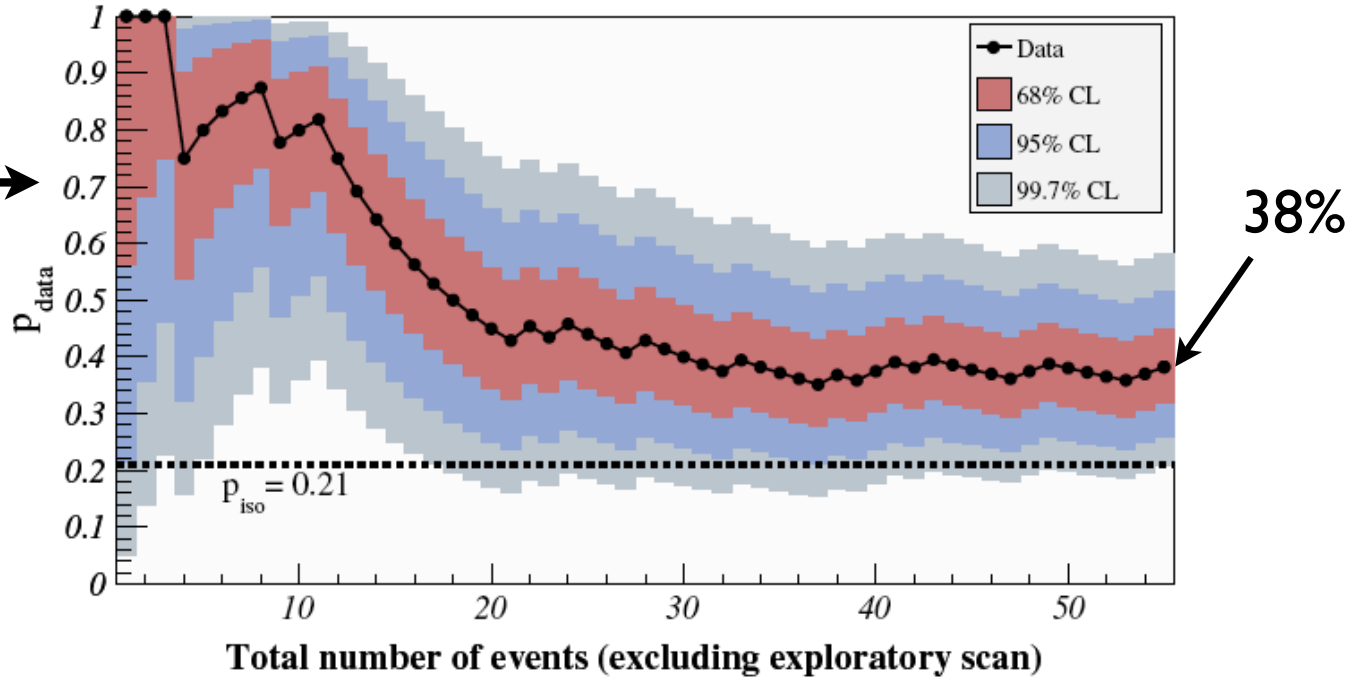
Correlation with nearby AGN



Parameters defined *a priori*:

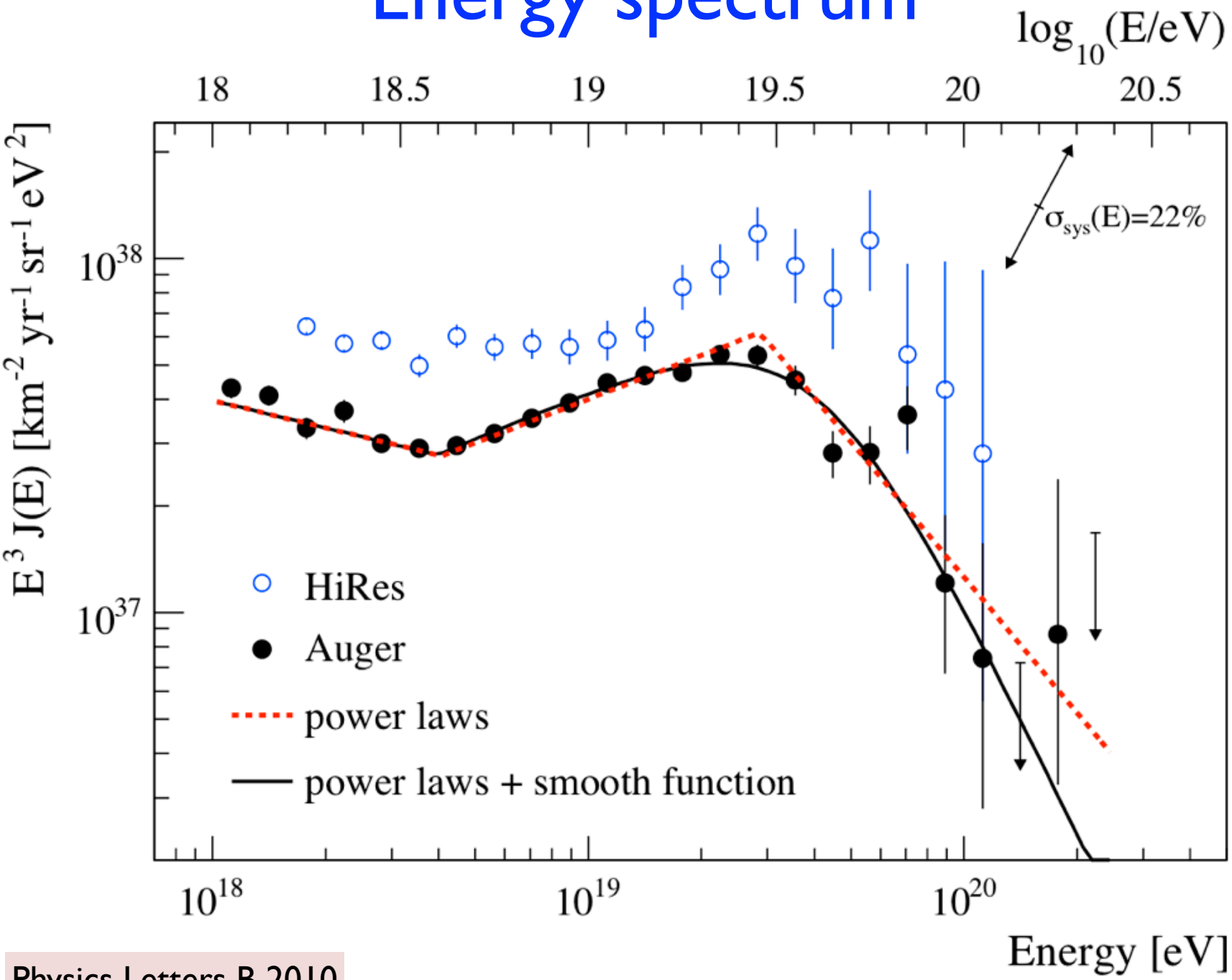
$$E_{min} = 55 \text{ EeV}$$
$$\psi = 3.1 \text{ deg}$$
$$d_{max} = 75 \text{ Mpc}$$

Fraction of events correlating with nearby VCV AGN



Astropart. Phys. 2010, 34: 314

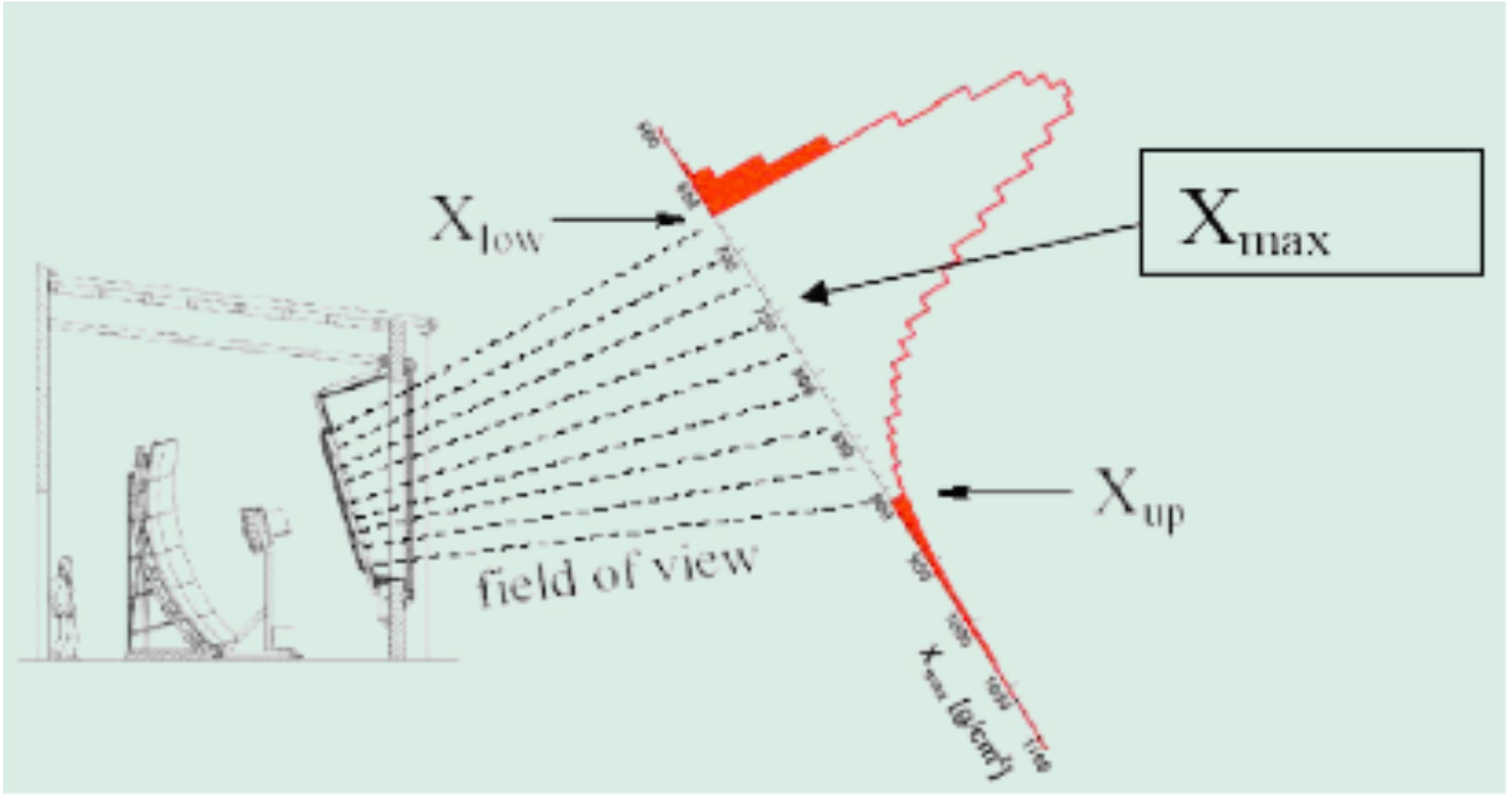
Energy spectrum



Physics Letters B 2010

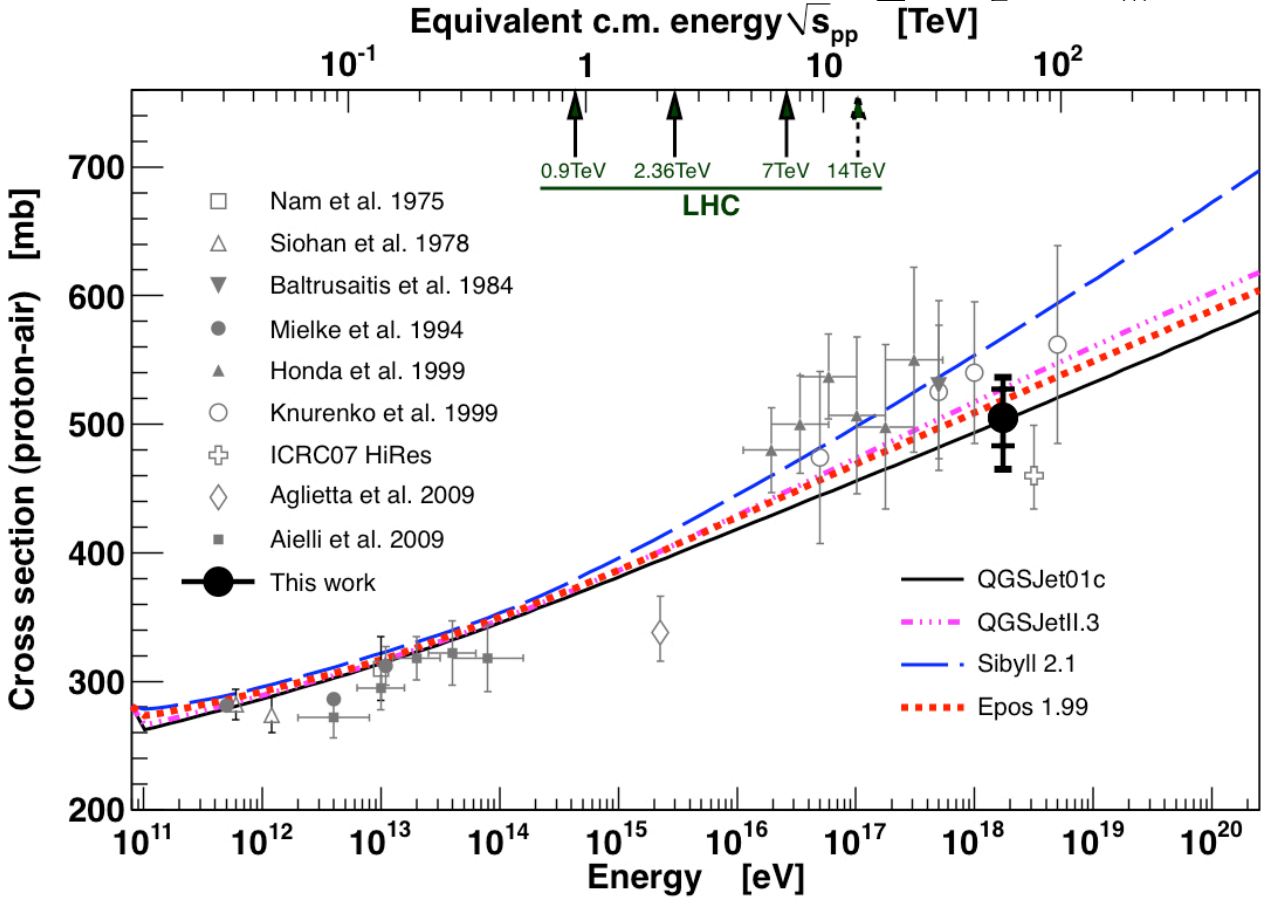
Nature of primary: proton? iron?

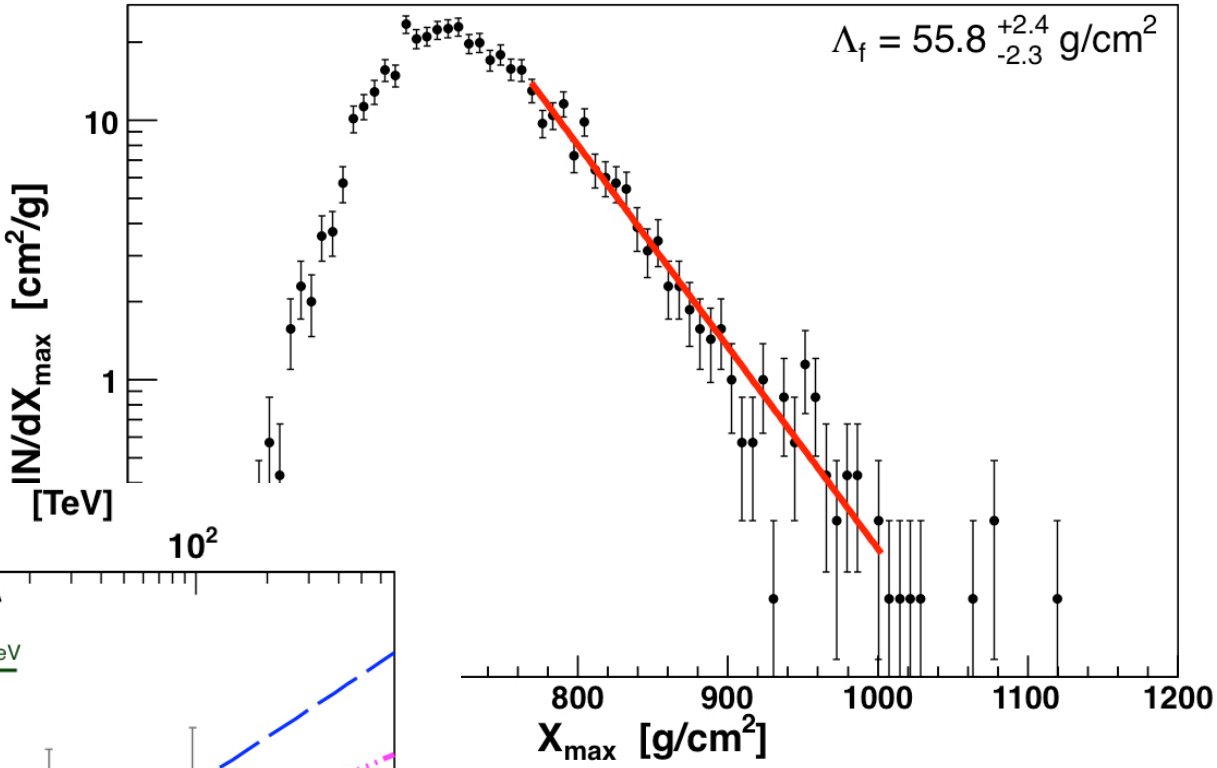
- Main FD observable: EM shower depth



Also particle physics

Proton-air cross section at center-of-mass energy of 57 TeV





Physical Review Letters 2012

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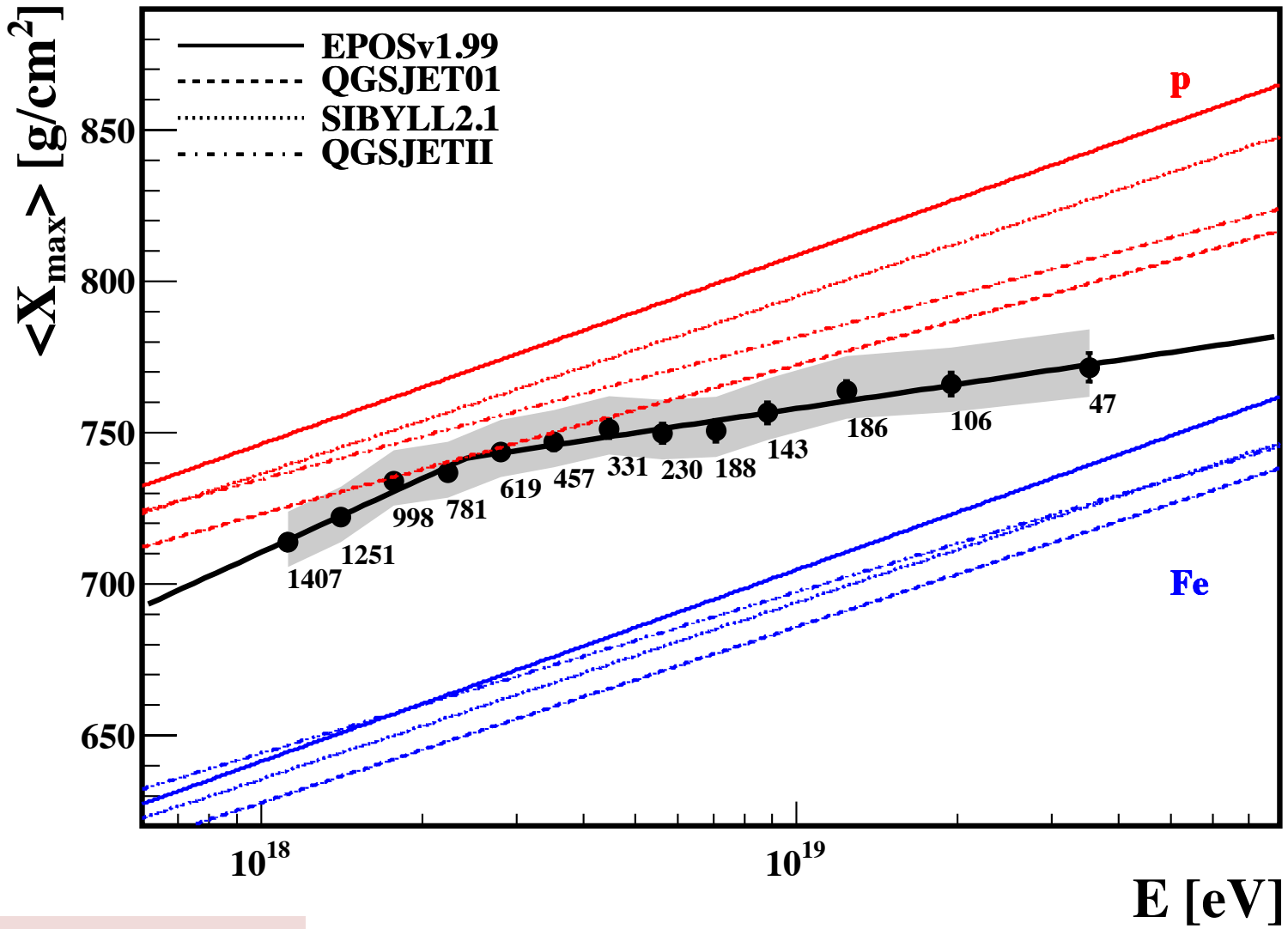

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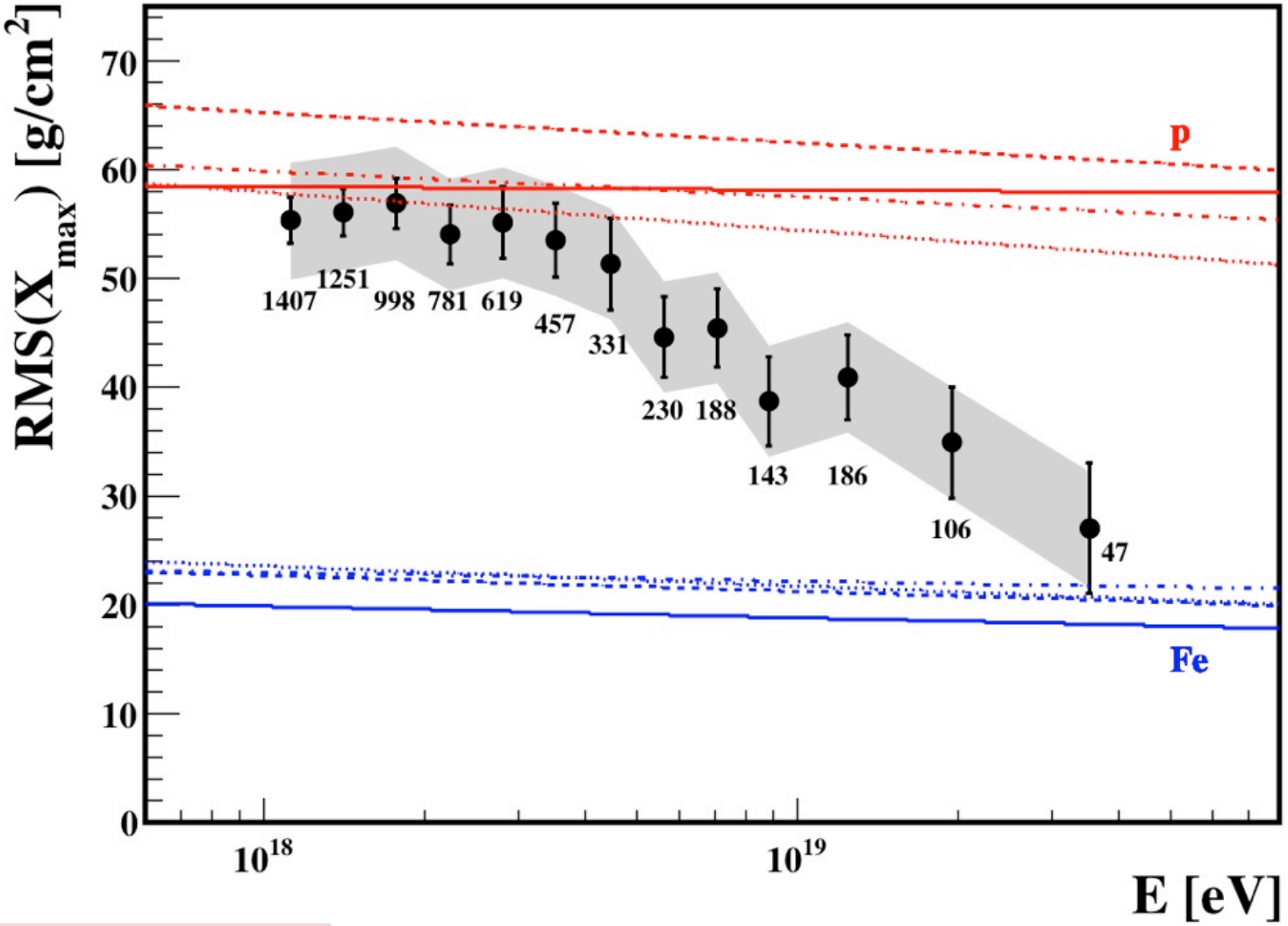

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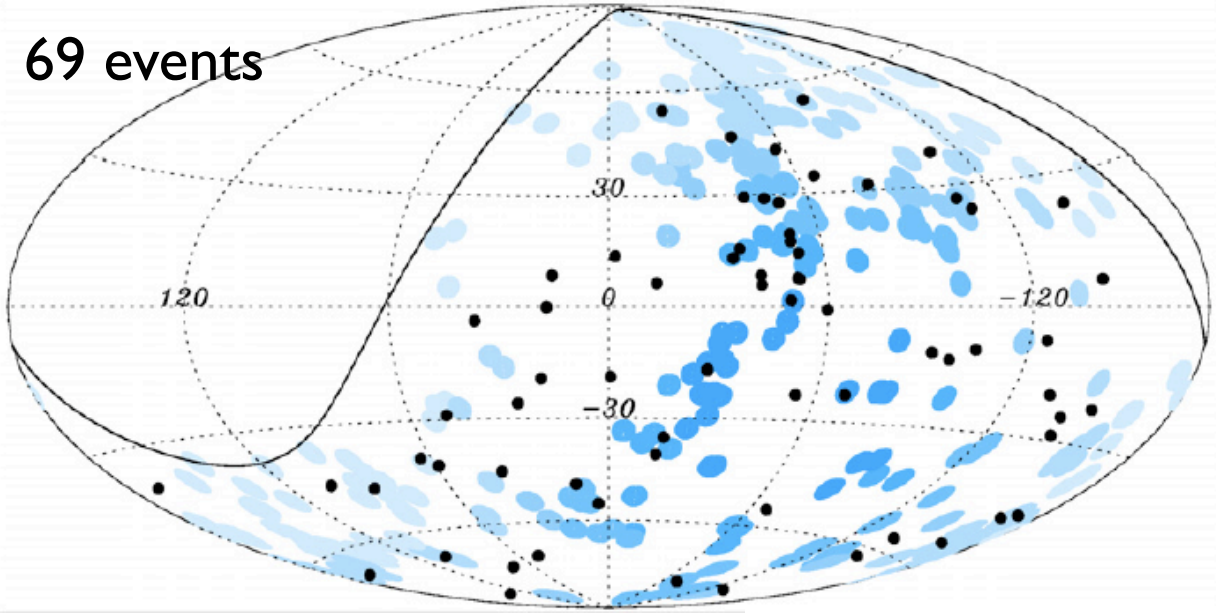

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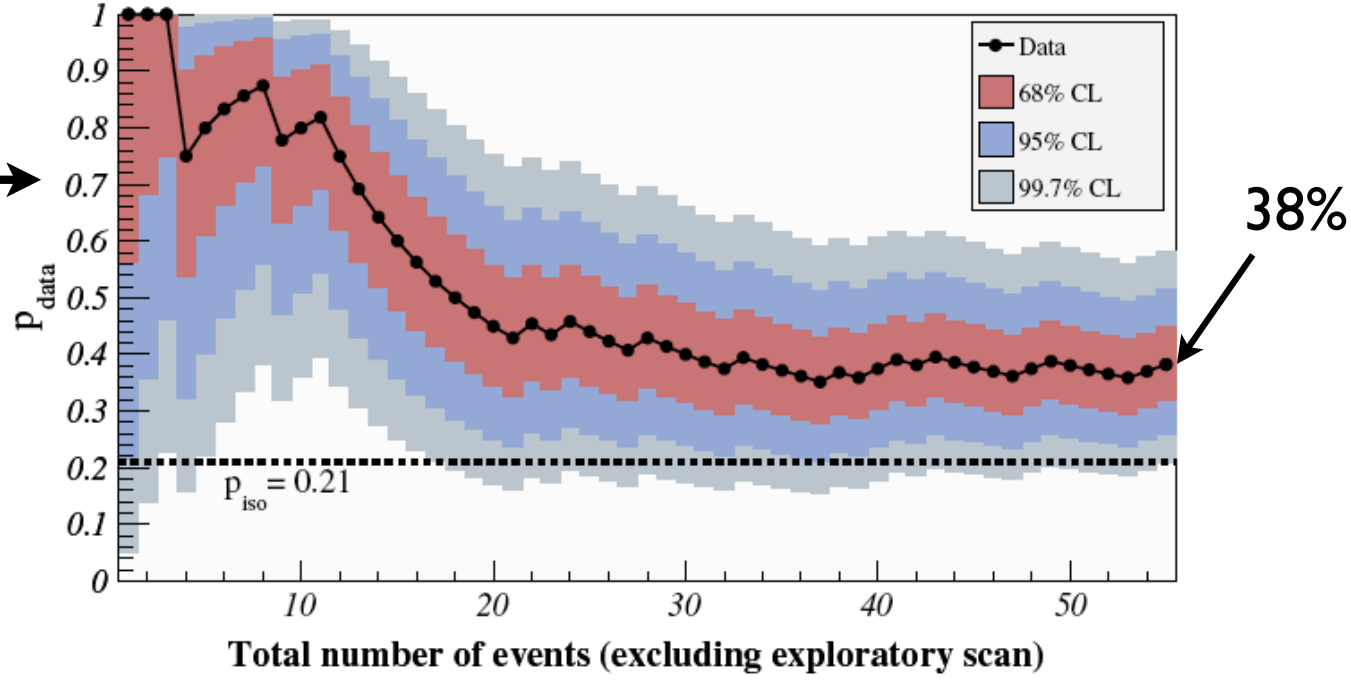

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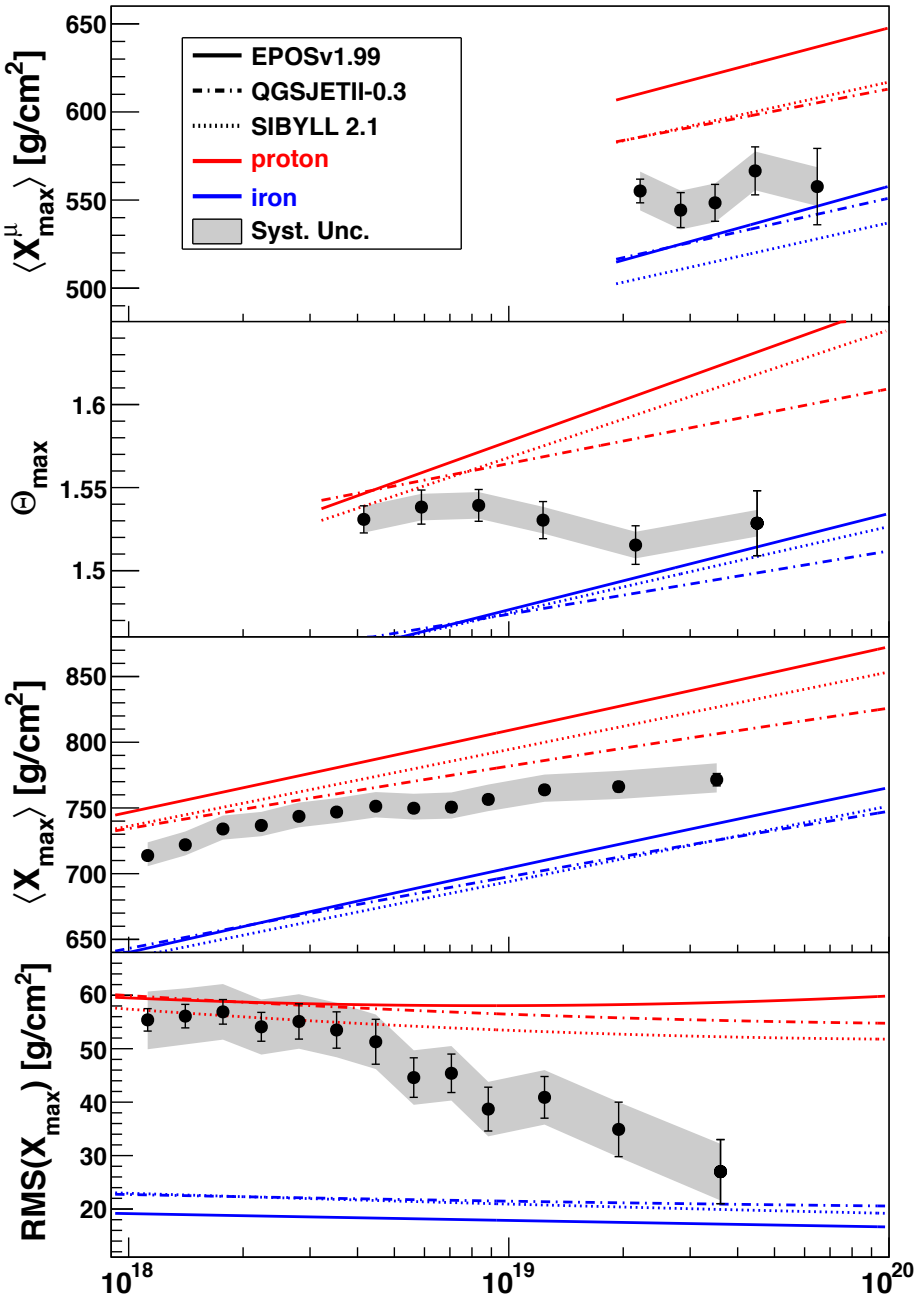
Nature of primary: proton? iron?

muon shower depth

asymmetry at ground

EM shower depth

EM shower depth fluctuation



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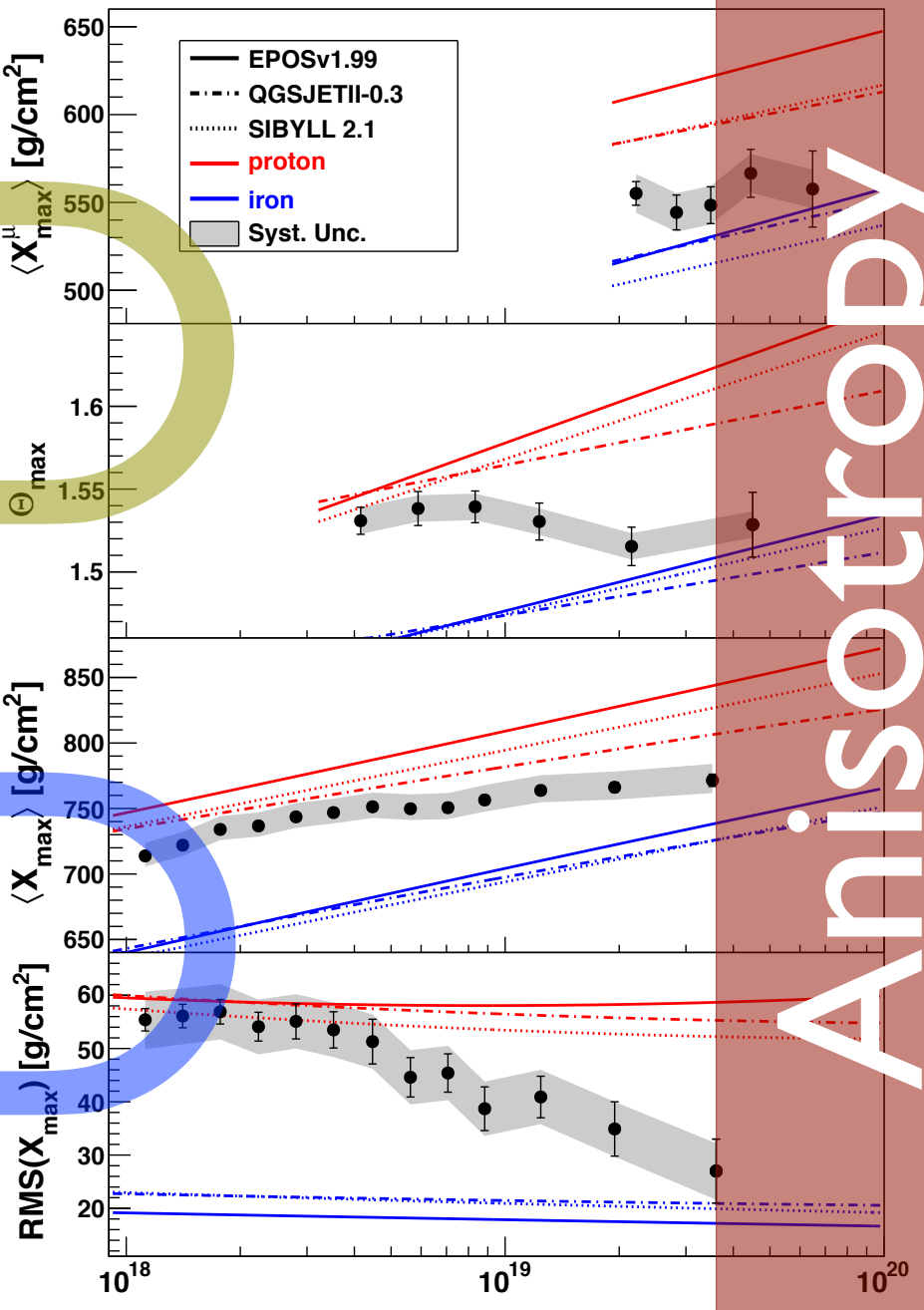


SD

FD

Anisotropy

Nature of primary: proton? iron?

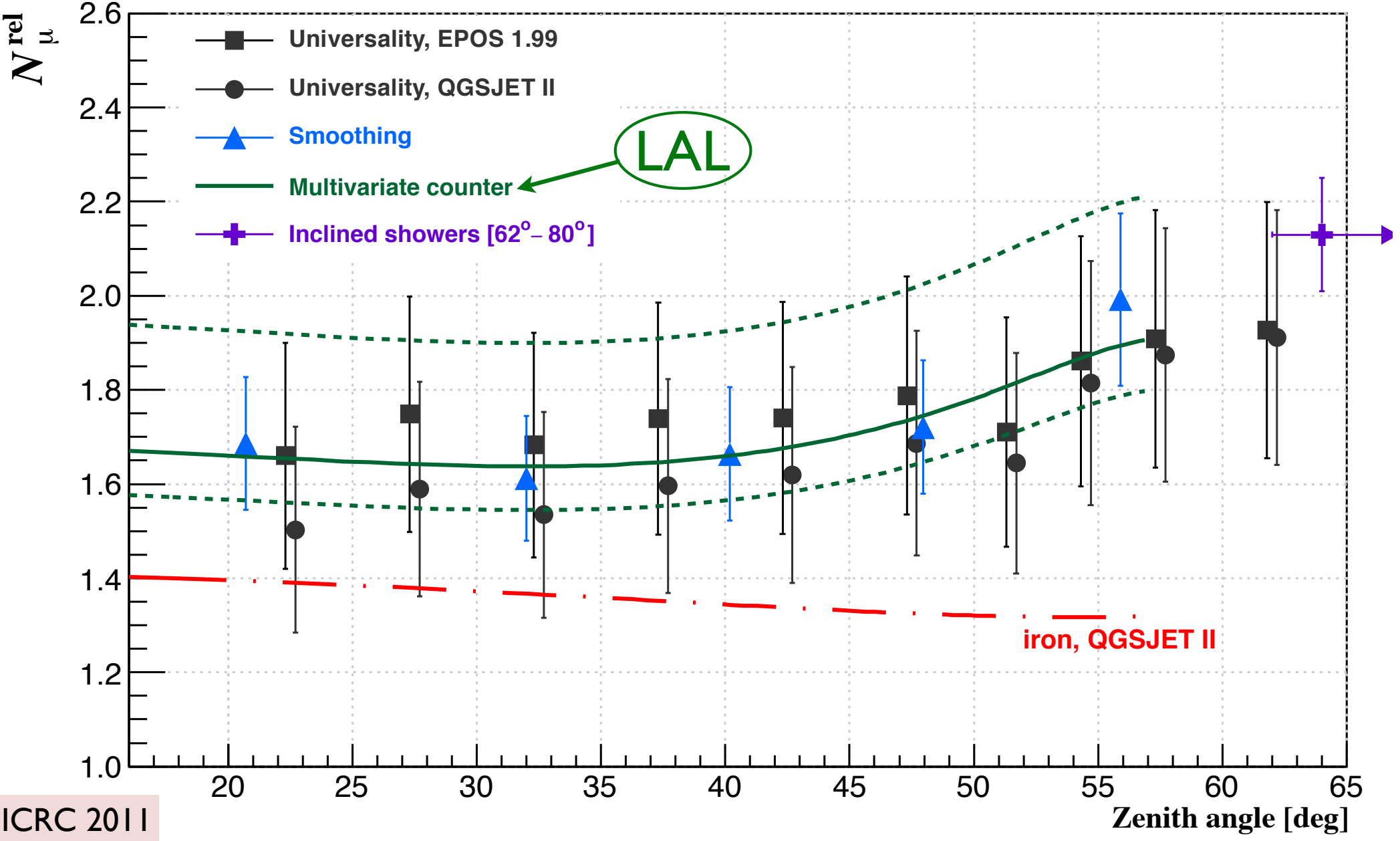
- We need to identify the nature of the primary on an event-by-event basis at the highest energies
- We have a fantastic surface detector observable:

  1) irons produce 40% more muons than protons

  2) the total signal above zenith angle of 45 degrees are muon dominated

Do we?

Nature of primary: proton? iron?



ICRC 2011

Muon deficit in simulations

- Hypotheses
  - first interaction - high energy physics
  - shower development - low energy physics
  - calorimetric energy
  - SD detector calibration
  - probably a combination of all of above

Muon deficit in simulations

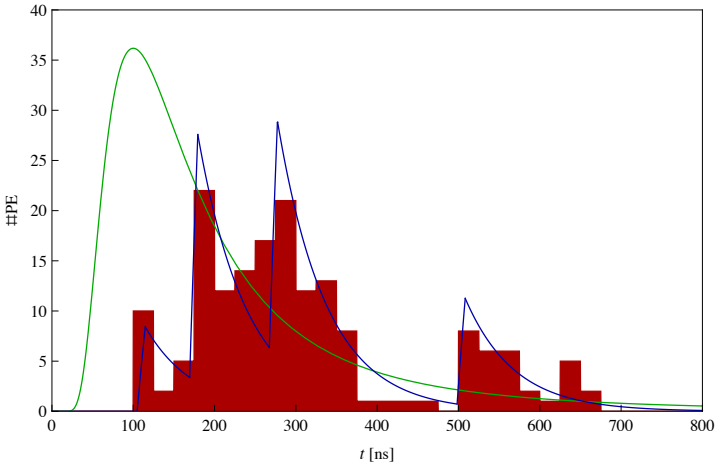
- First interaction - high energy physics
  - no way of direct measurement
  - the only way of "measuring" anything is by controlling all other sources of systematics: composition, energy, SD, shower development

Composition, shower development

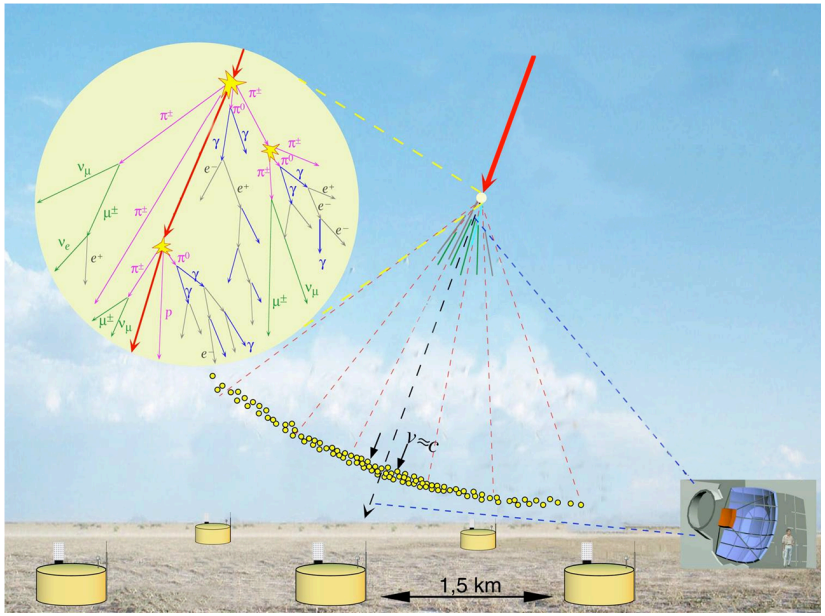
- Analysis effort
  - Goal: detailed reconstruction of muon signal, lateral distribution function, arrival time distribution
  - Developing a comprehensive but computationally "managable" generative model
  - Full fit using numerical Bayesian methods
  - Methodology exists but the scale is unprecedented (50K showers, 300K surface detector signals)

Adaptive Metropolis for mixture signals

The Auger tank signal



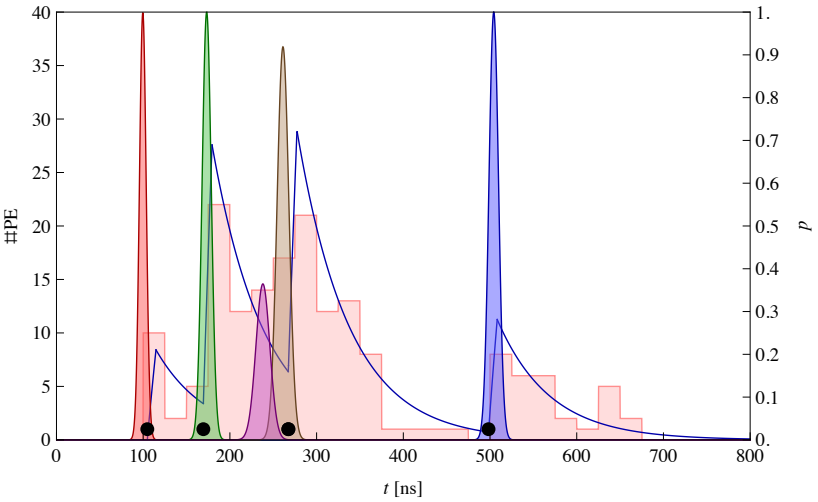
Cosmic rays and the Pierre Auger observatory



Classical adaptive Metropolis was suboptimal due to symmetries (label switching)

We designed adaptive Metropolis with online relabeling (AMOR) that works well on our problem

AMOR is extendible to any problem involving inference on parametrized mixture signals



R. Bardenet, O. Cappé, G. Fort, and B. Kégl, “Adaptive Metropolis with online relabeling,” in International Conference on Artificial Intelligence and Statistics (AISTATS), 2012.

Composition, shower development

- Hardware effort: detector upgrade
  - Station trigger update (accepting pure muon traces)
  - Electronics update (higher sampling rate)
  - Muon counters (over or underground)
  - Radio detection
  - "Black top" or "double bag" tanks