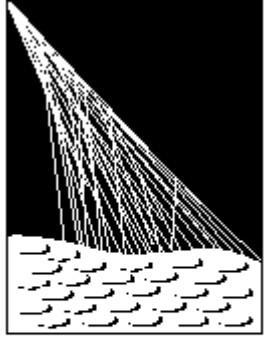


PIERRE AUGER OBSERVATORY

UNIVERSITY OF LEEDS

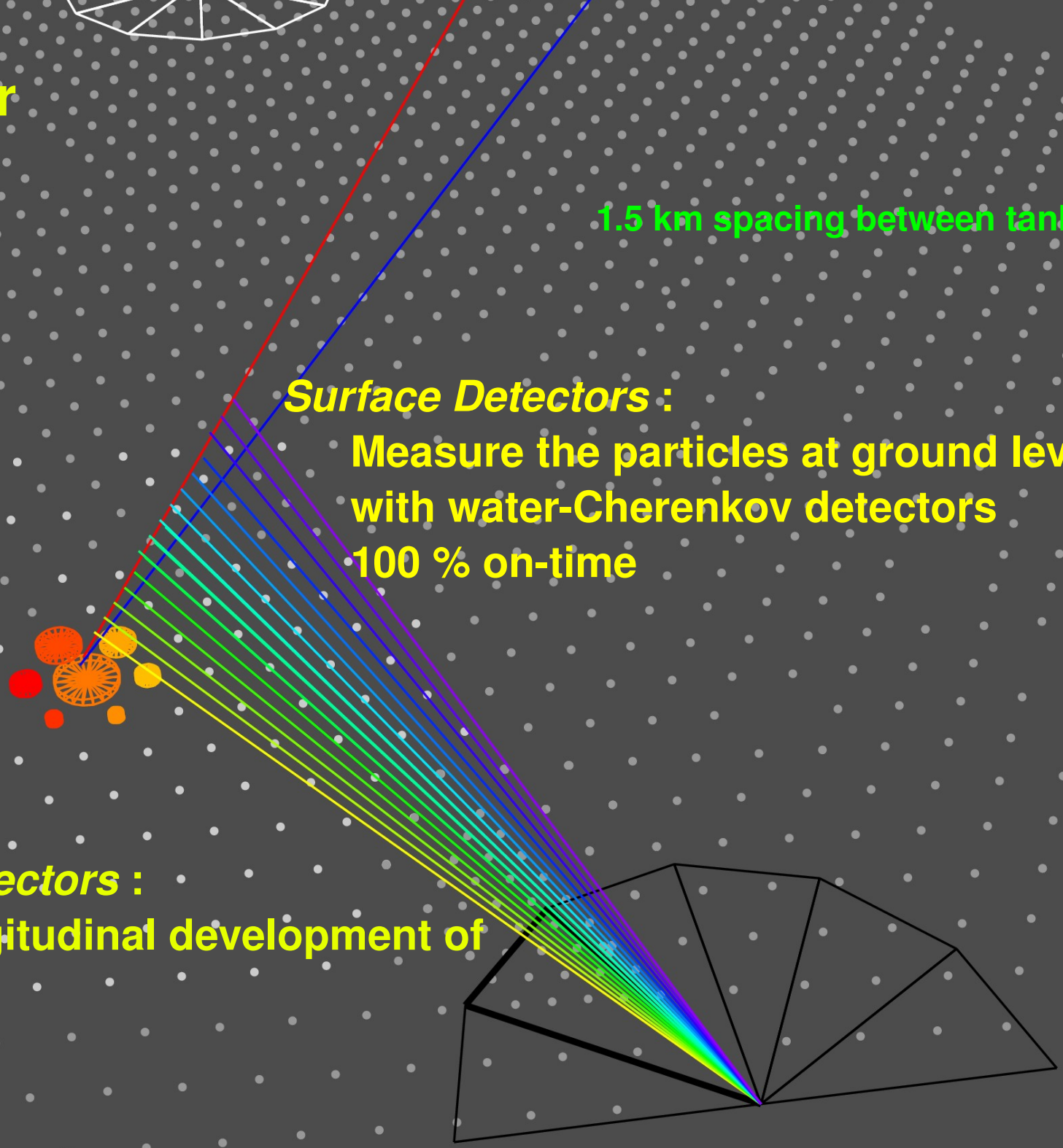
Measurements of Cosmic Ray Composition with the Pierre Auger Observatory

1. Composition measurements with the fluorescence detectors
2. Composition measurements with the surface detectors

Ronald Bruijn
for The Pierre Auger Collaboration
University of Leeds

APP Meeting, UCL, 30 April 2010

Hybrid Detector



1.5 km spacing between tanks

Surface Detectors **:**

Measure the particles at ground level with water-Cherenkov detectors

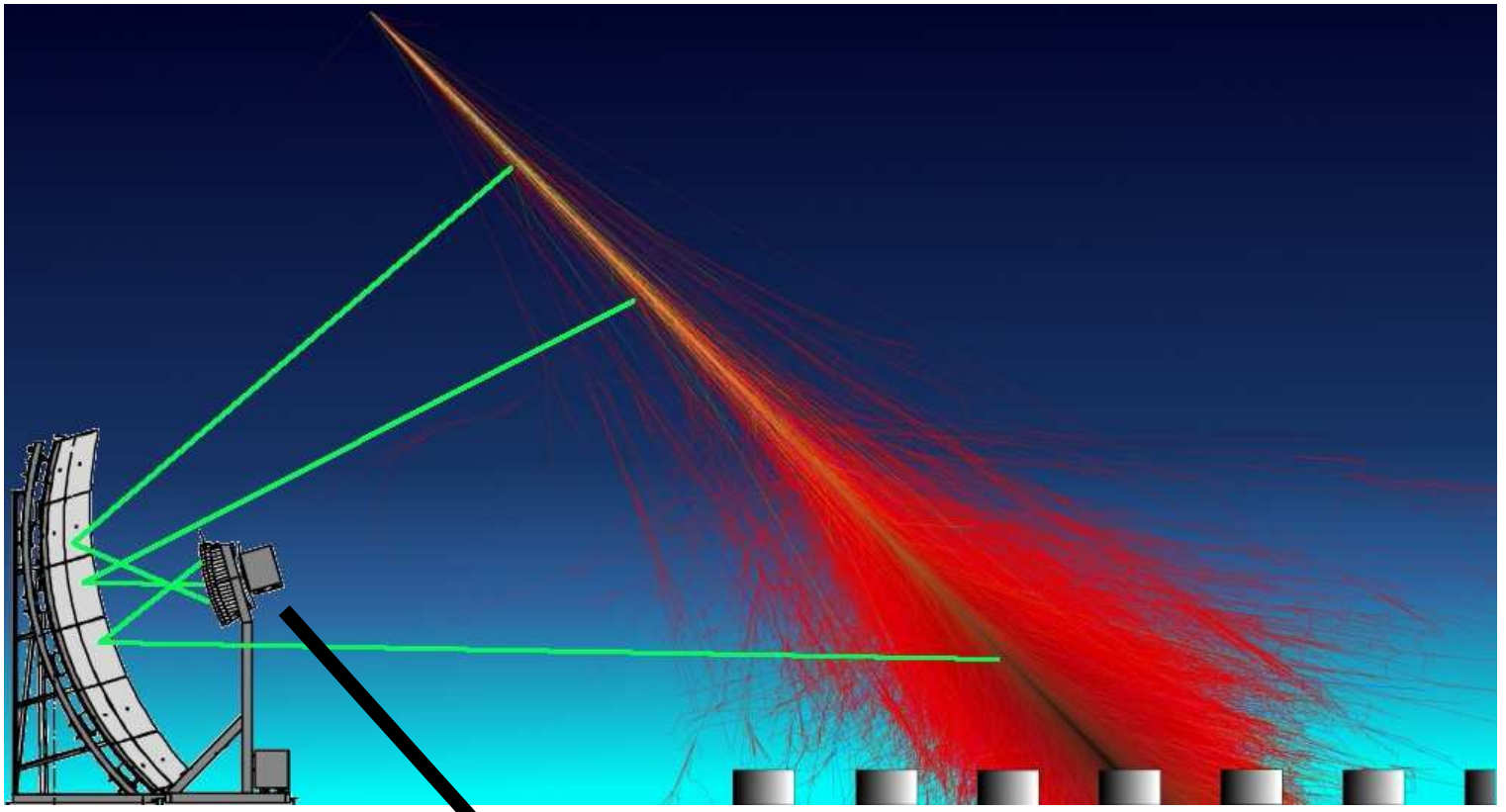
100 % on-time

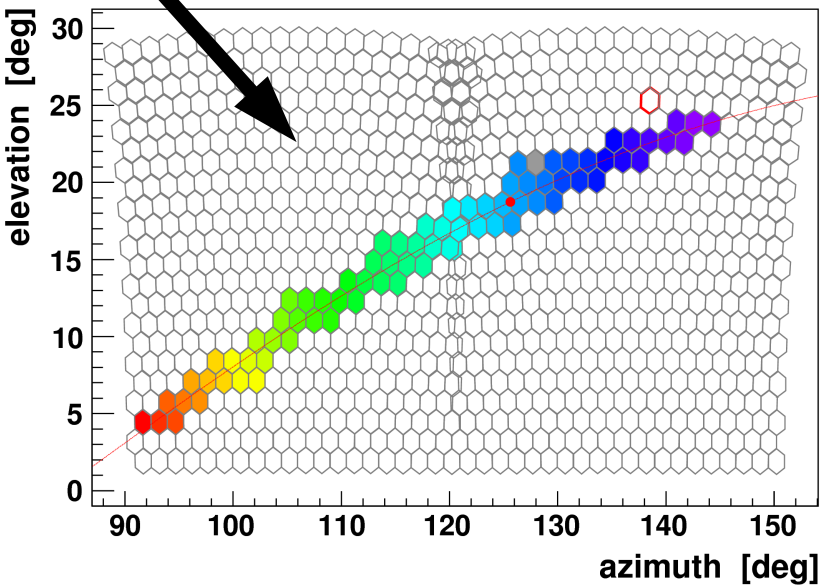
Fluorescence Detectors **:**

Image the longitudinal development of the shower

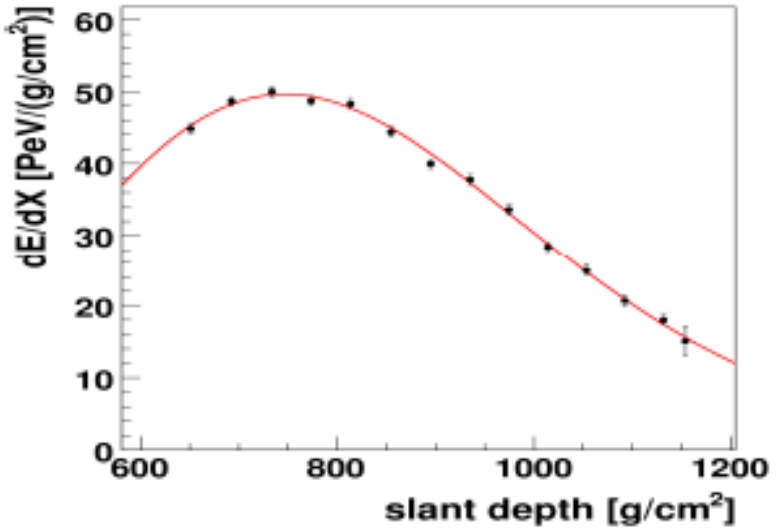
~10 % on-time

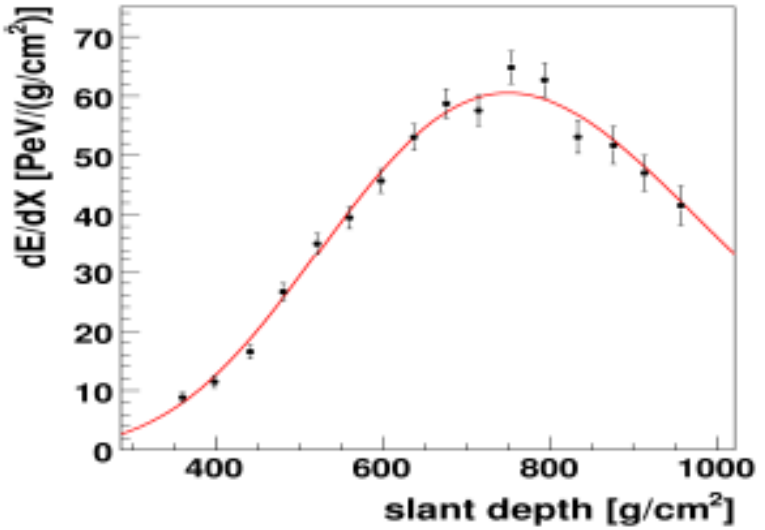
Longitudinal shower profile

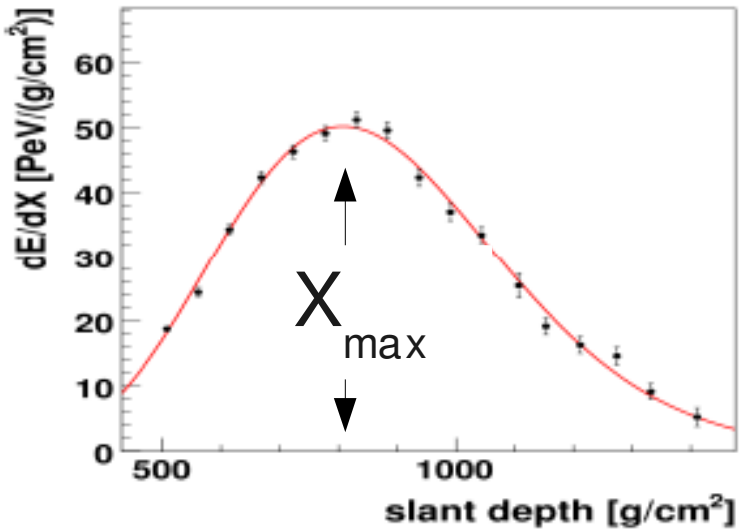


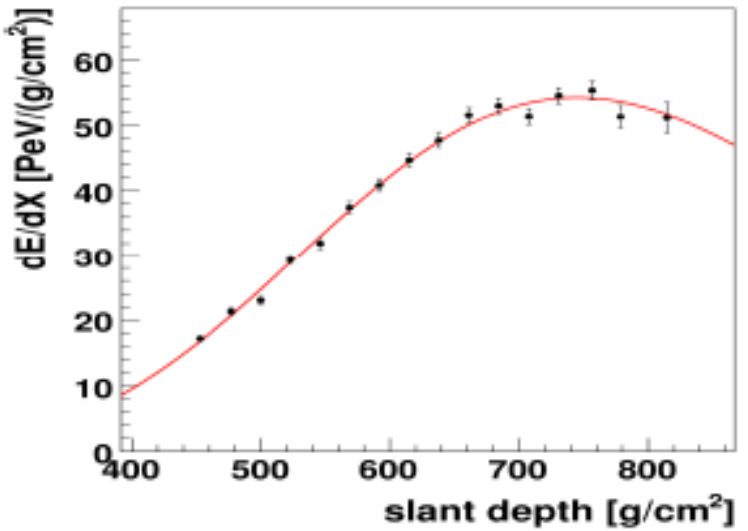


Some Longitudinal Profiles measured with Auger









X_{max} – Depth of shower maximum

The atmospheric depth at which a shower reaches its maximum depends on the energy and nuclear mass :

$$\langle X_{max} \rangle = \alpha (\ln(E) - \langle \ln(A) \rangle) + \beta$$

The elongation rate is the rate of change per decade of energy :

$$D_{10} = \frac{d\langle X_{max} \rangle}{\log(E)} \approx \alpha (1 - \frac{d\langle \ln(A) \rangle}{d\ln(E)}) \ln(10)$$

The spread on X_{max} is expected to decrease with increasing A and increase with interaction length.

Data Selection

Period :
December 2004 to March 2009

Atmosphere&Calibration

- Good camera calibration constants
- Measured aerosol profile
- Reject dusty periods
- Cloud fraction < 25 %

Fiducial volume

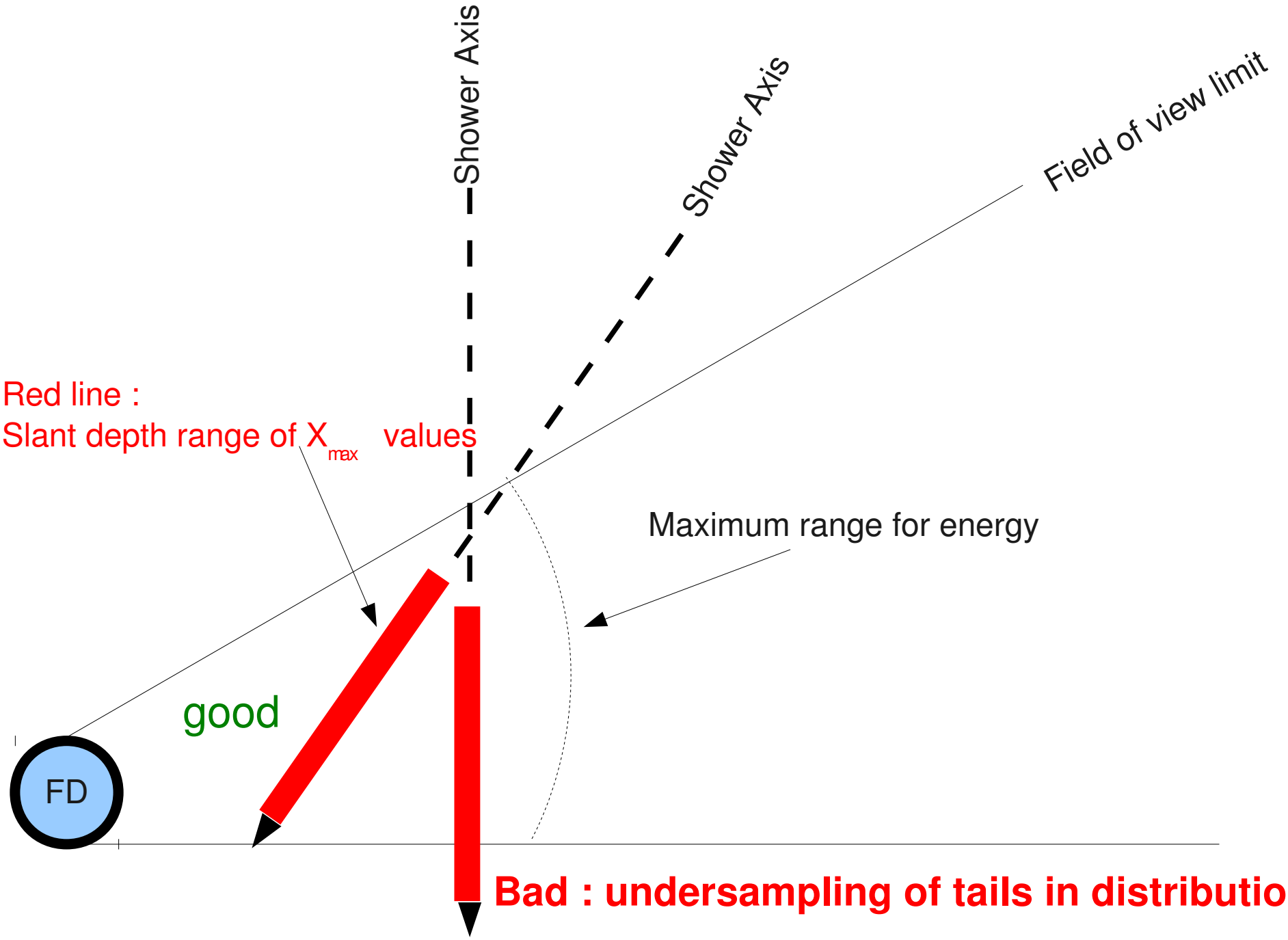
- Tank distance and zenith angle
- Field of view
- Minimum viewing angle > 20°

Quality

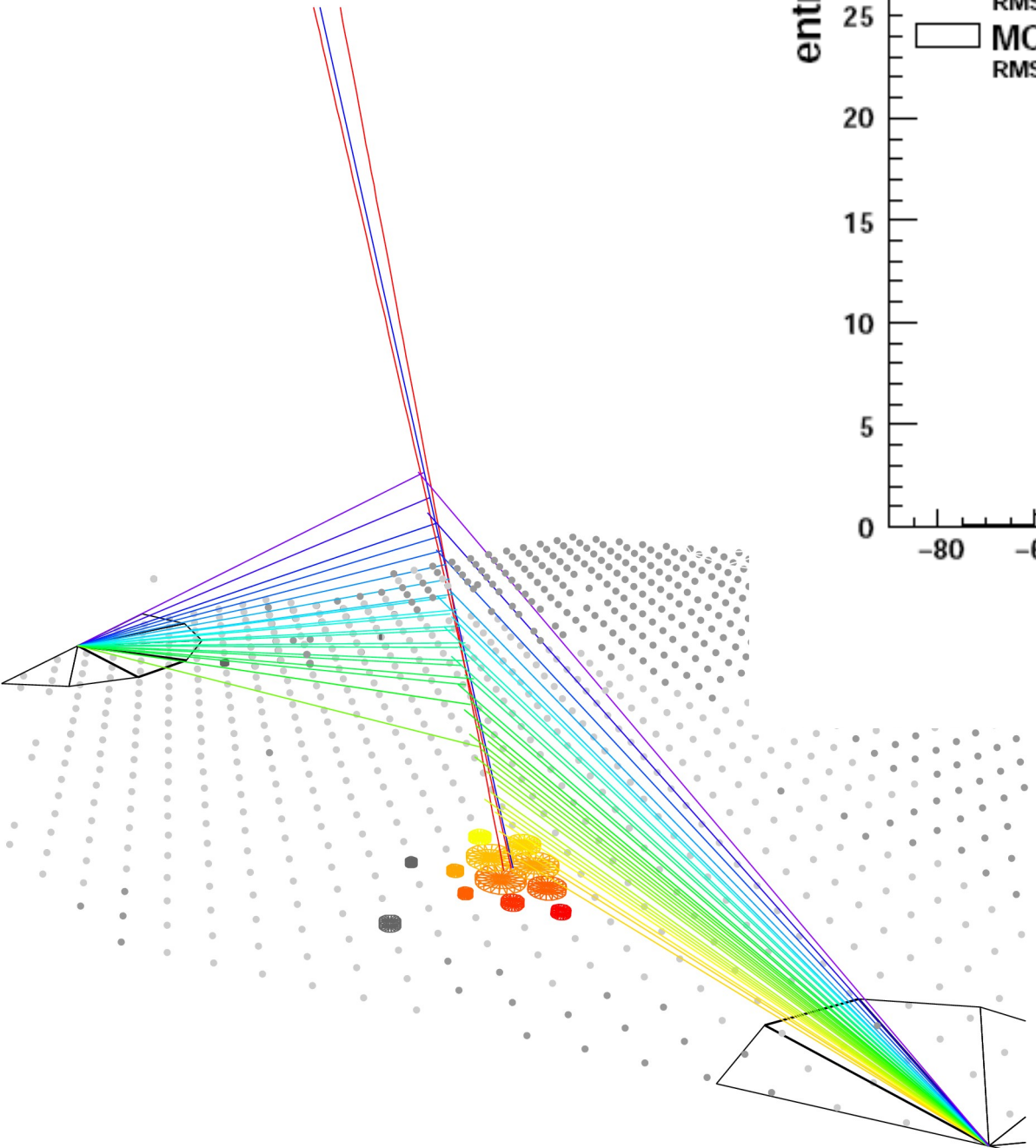
- Hybrid geometry reconstruction
- X_{max} observed
- Expected error on Xmax < 40 g/cm^2
- Reduced χ^2 on longitudinal profile fit < 2.5

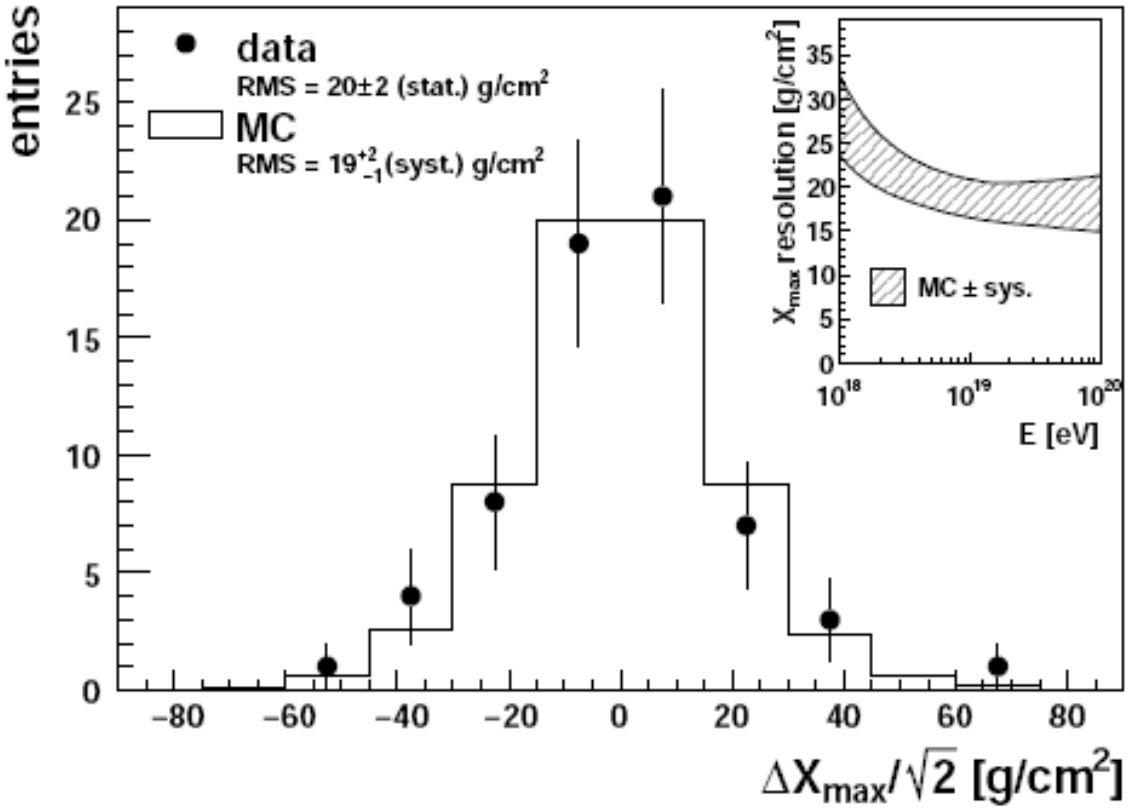
Angular resolution : 0.6°

X_{max} – field of view cuts



X_{max} resolution

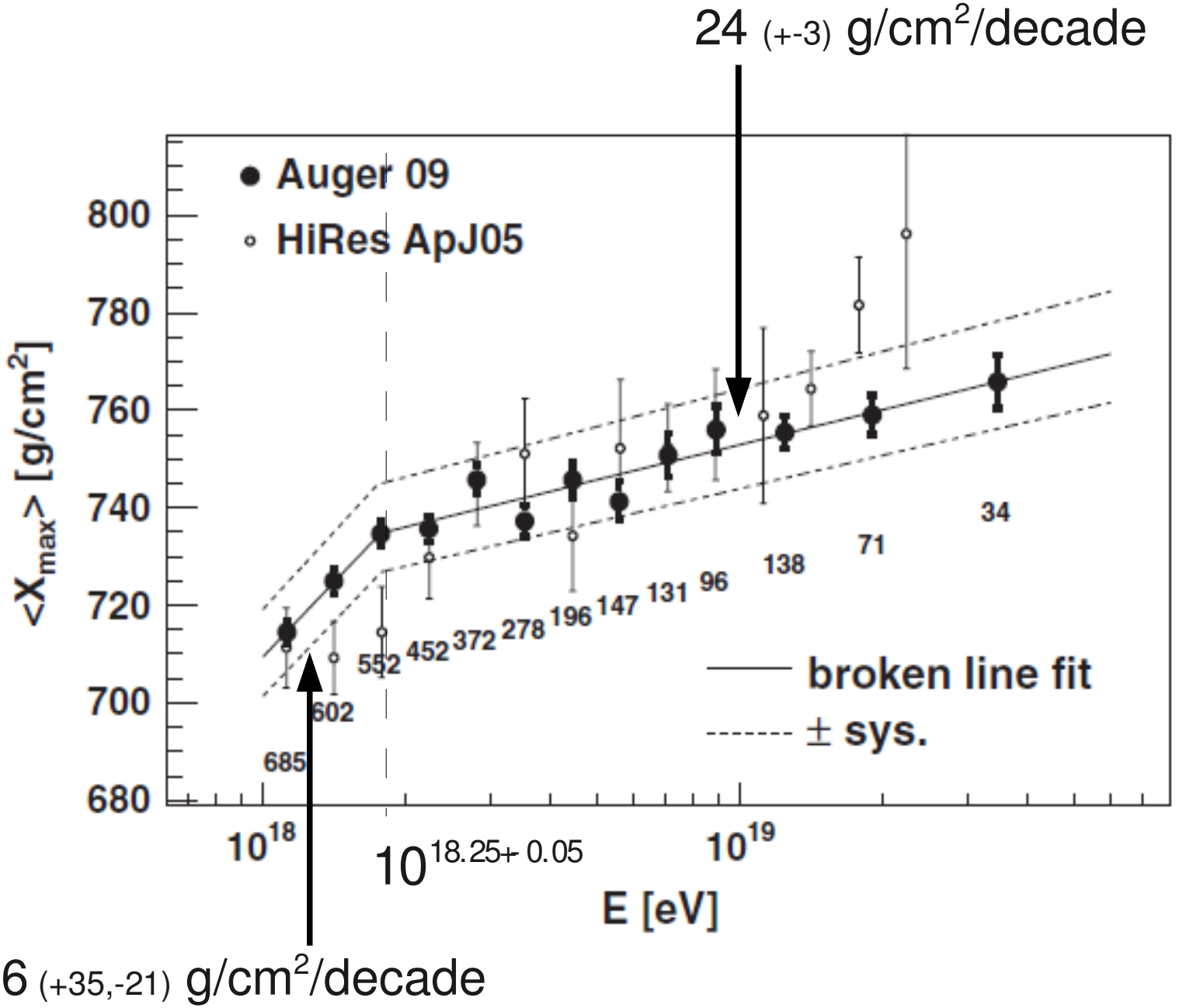




Resolution : 20 g/cm²

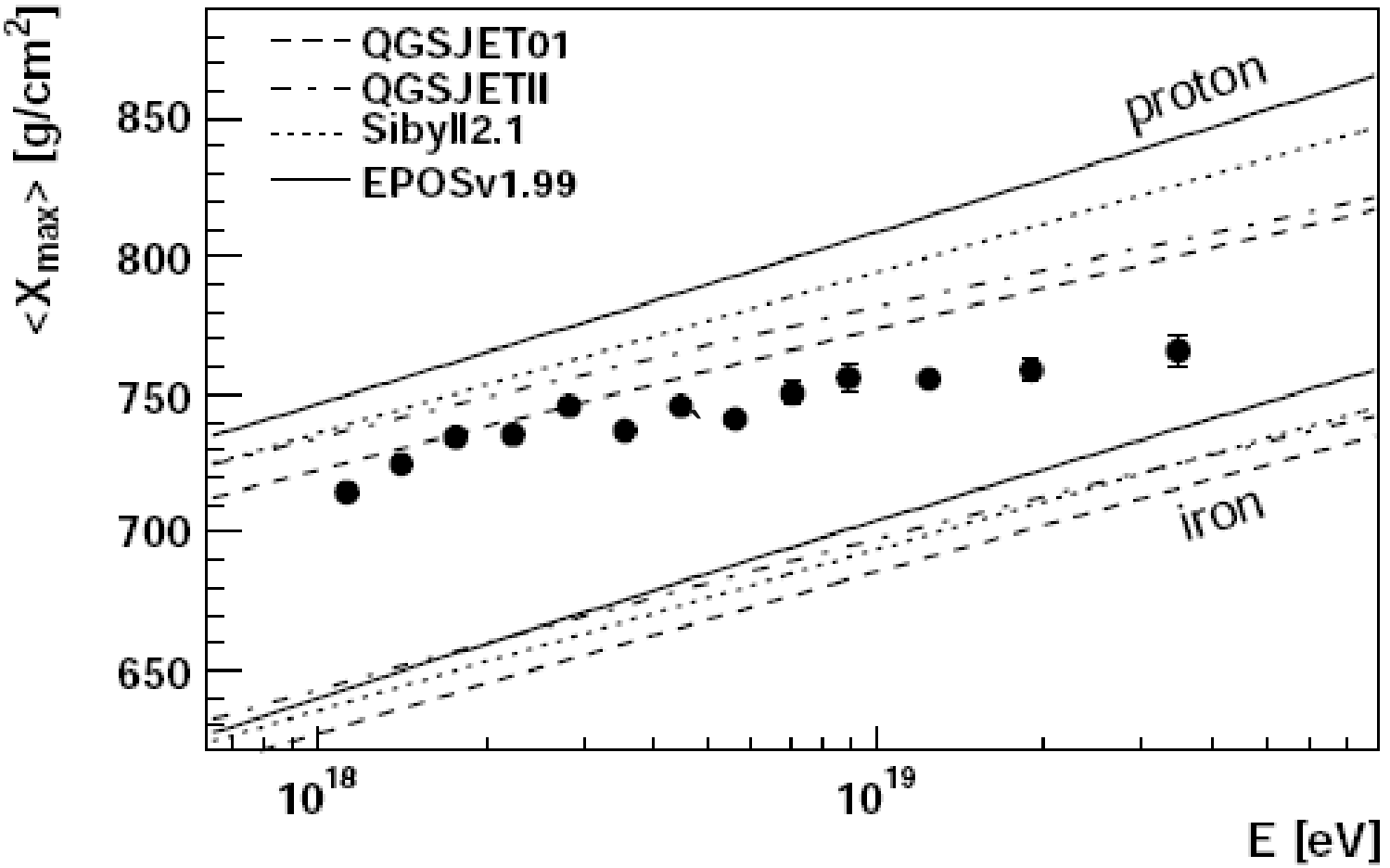
The resolution prediction on X_{max} can be validated with stereo events

$\langle X_{max} \rangle$ as function of energy



Physical Review Letters 104 (2010) 091101

$\langle X_{max} \rangle$ as function of energy

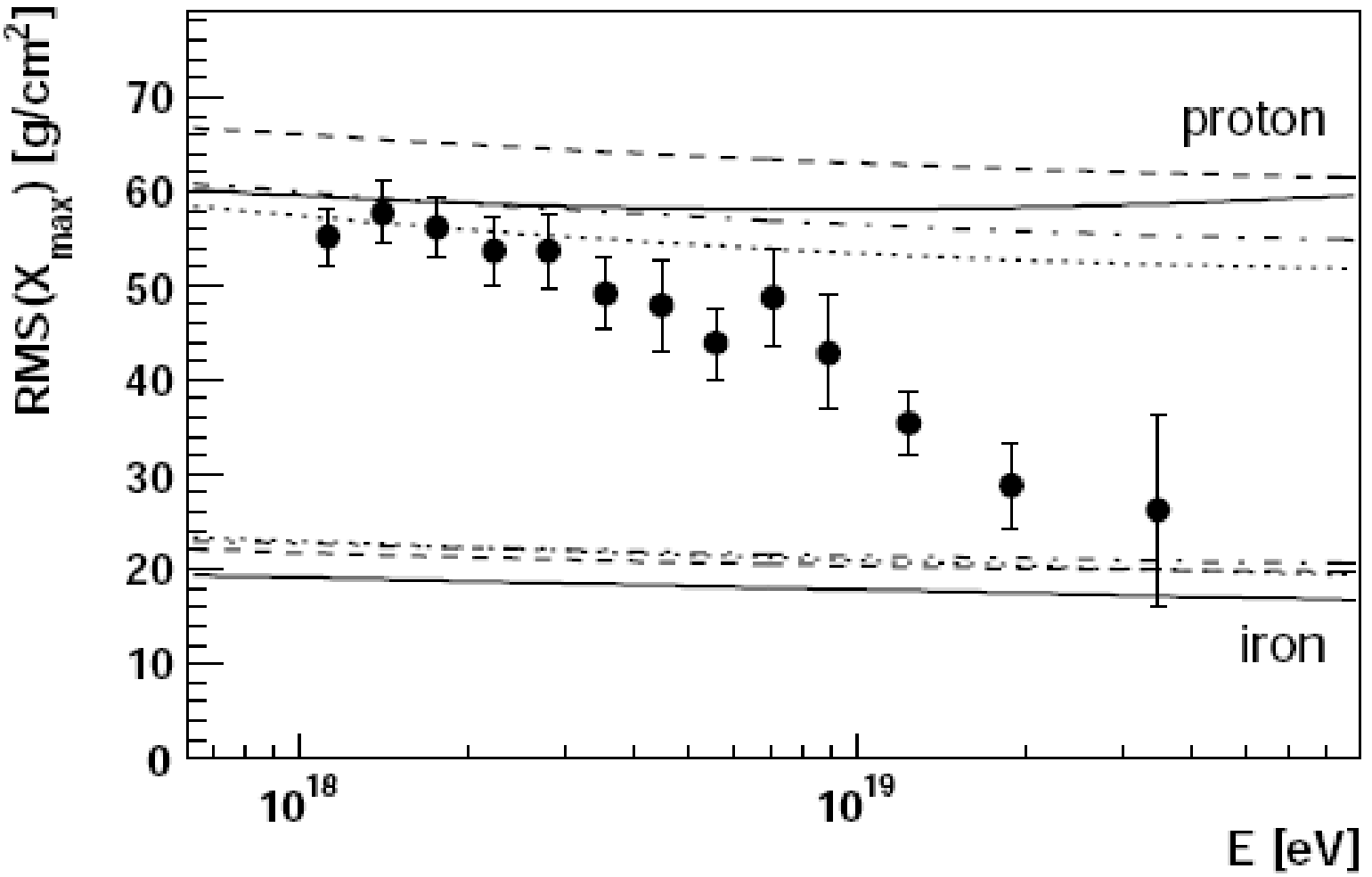


With increasing energy, the showers develop earlier in the atmosphere

Suggestive of heavier nuclear composition

Physical Review Letters 104 (2010) 091101

RMS(X_{max})



The RMS of the X_{max} distributions confirms the trend to heavier composition

Physical Review Letters 104 (2010) 091101

Composition measurements using surface detectors

Pro : Large statistics

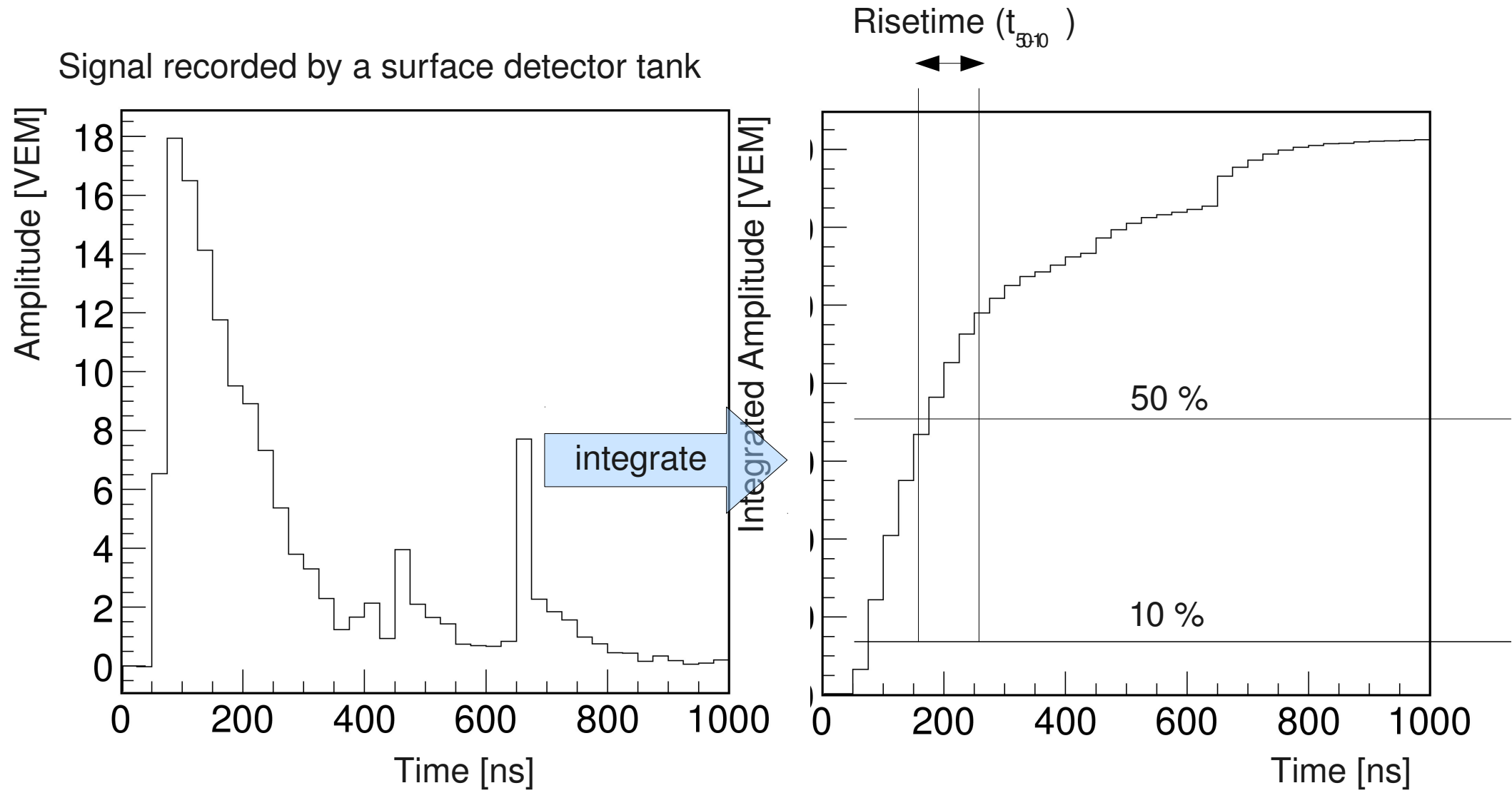
- 100 % uptime vs. ~10% of fluorescence detectors

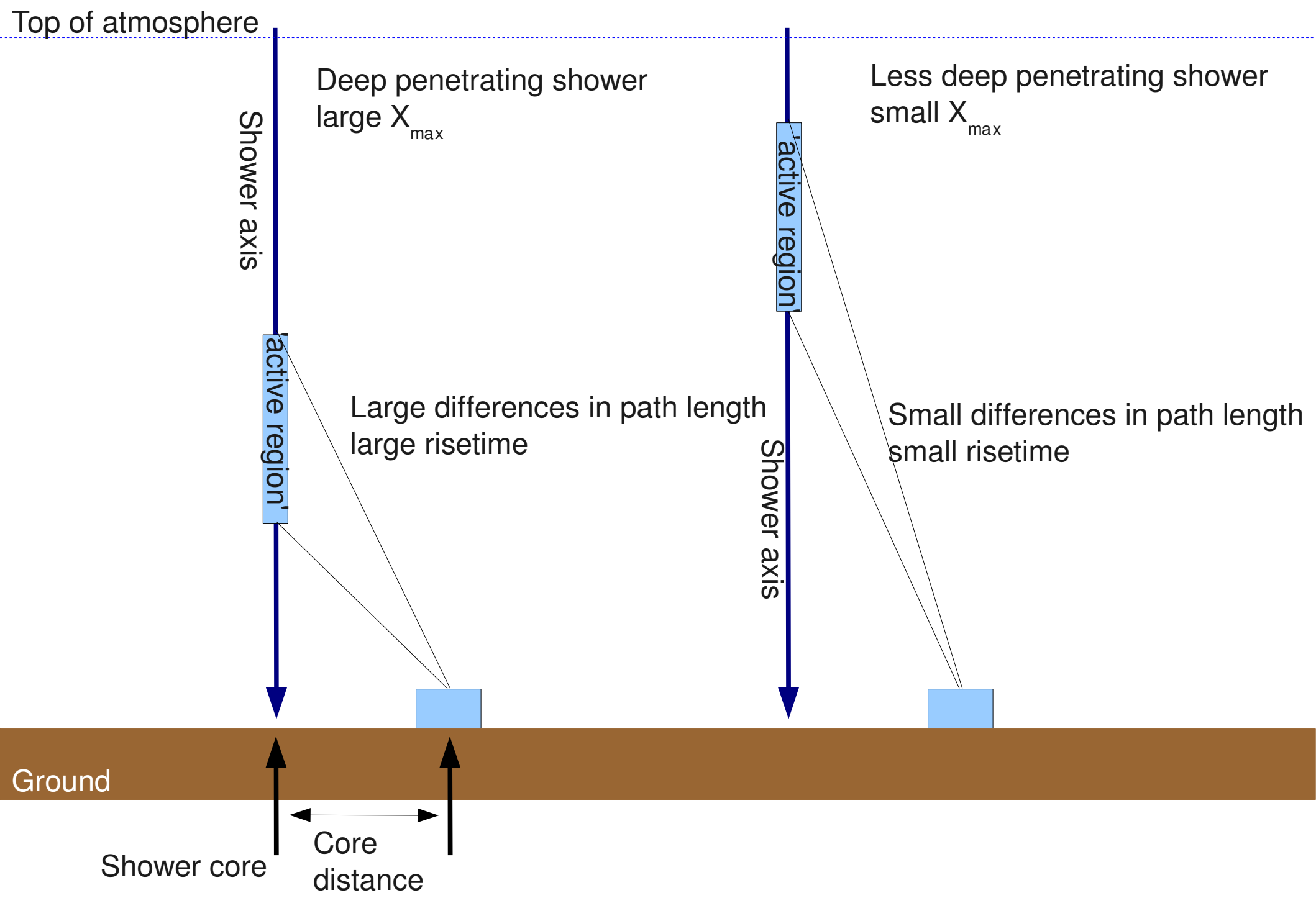
Con : No direct handle on shower development

Need SD variables which give handle on a shower development

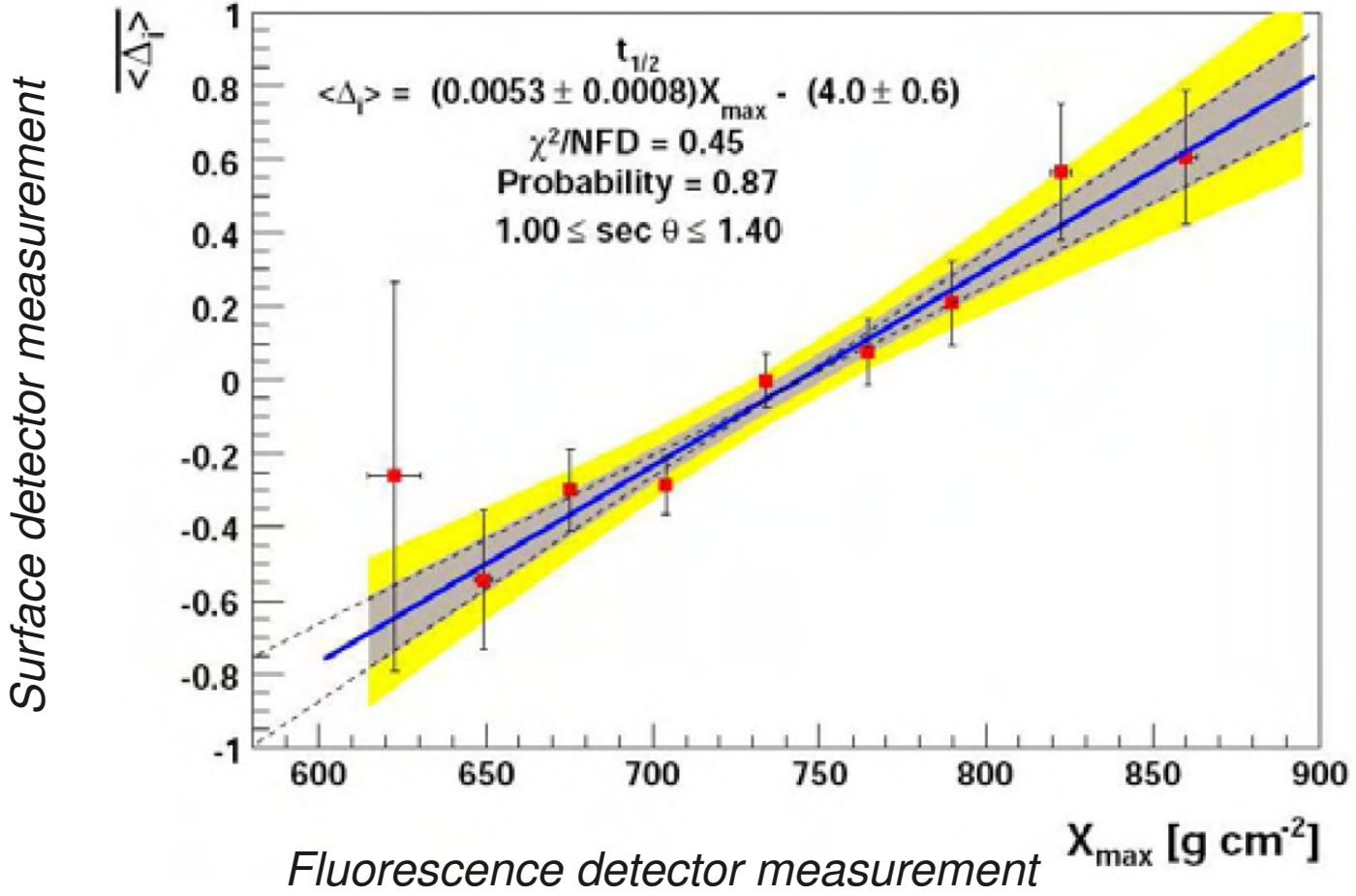
- Time structure of shower front
- Azimuthal asymmetry on ground

Risetime


Risetime (t_{50-10})
Signal recorded by a surface detector tank
Amplitude [VEM]
Time [ns]
integrate
Integrated Amplitude [VEM]
50 %
10 %
Time [ns]

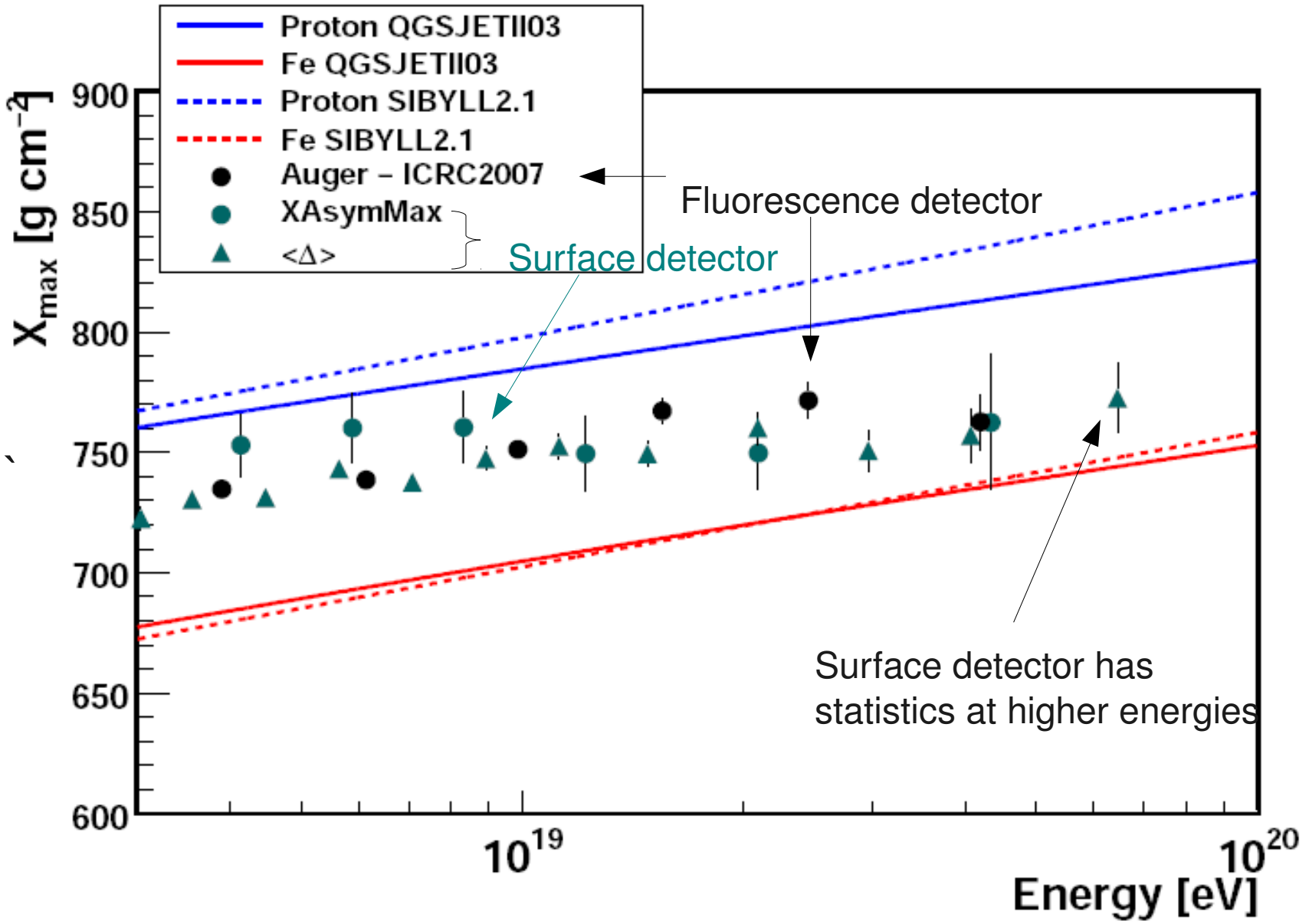

Top of atmosphere
Deep penetrating shower
large X_{max}
Shower axis
'active region'
Large differences in path length
large risetime
Less deep penetrating shower
small X_{max}
'active region'
Shower axis
Small differences in path length
small risetime
Ground
Shower core
Core
distance

<Δ> : a surrogate parameter for X_{max}



Events measured in both the surface detector and fluorescence detector can be used to calibrate <Δ> with X_{max} .

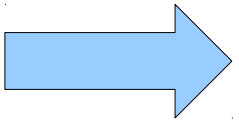
Composition measurements using surface detectors



SD measurements of X_{max} are compatible with direct measurement by FD

Summary

- Fluorescence detector measurements of X_{max}:
  - Showers develop earlier with increasing energy
  - Fluctuations decrease with energy



Composition getting heavier

- Surface detector measurements :
  - Confirm trend to earlier developing showers with energy