AUGER results and implications for UHE neutrinos

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PIERRE AUGER OBSERVATORY

- Motivation for the Pierre Auger Observatory
- Status of the Observatory
- First Science results
- Outlook and plans

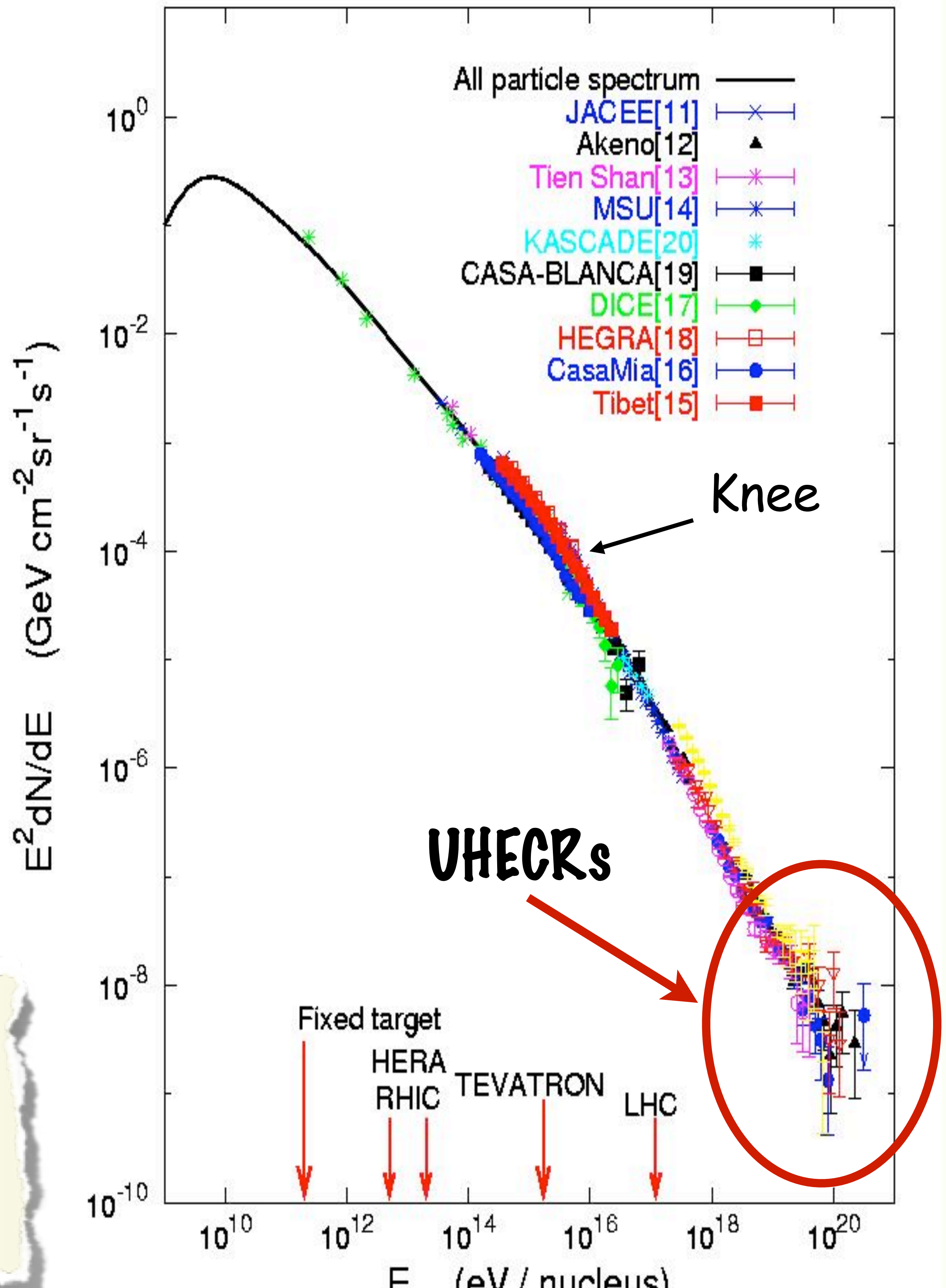
NOW 2008, Conca Specchiulla, Otranto, Italy, September 11, 2008

Ultra-High Energy Cosmic Rays

- Energies above 10^{18} eV or 10^{19} eV
- Center of mass energies larger than that of the LHC
- Low flux: 1 per 100 km² per year (or even less)
- Acceleration mechanism not known
- Sources not known

Have hints...

Theoretical ideas exist...



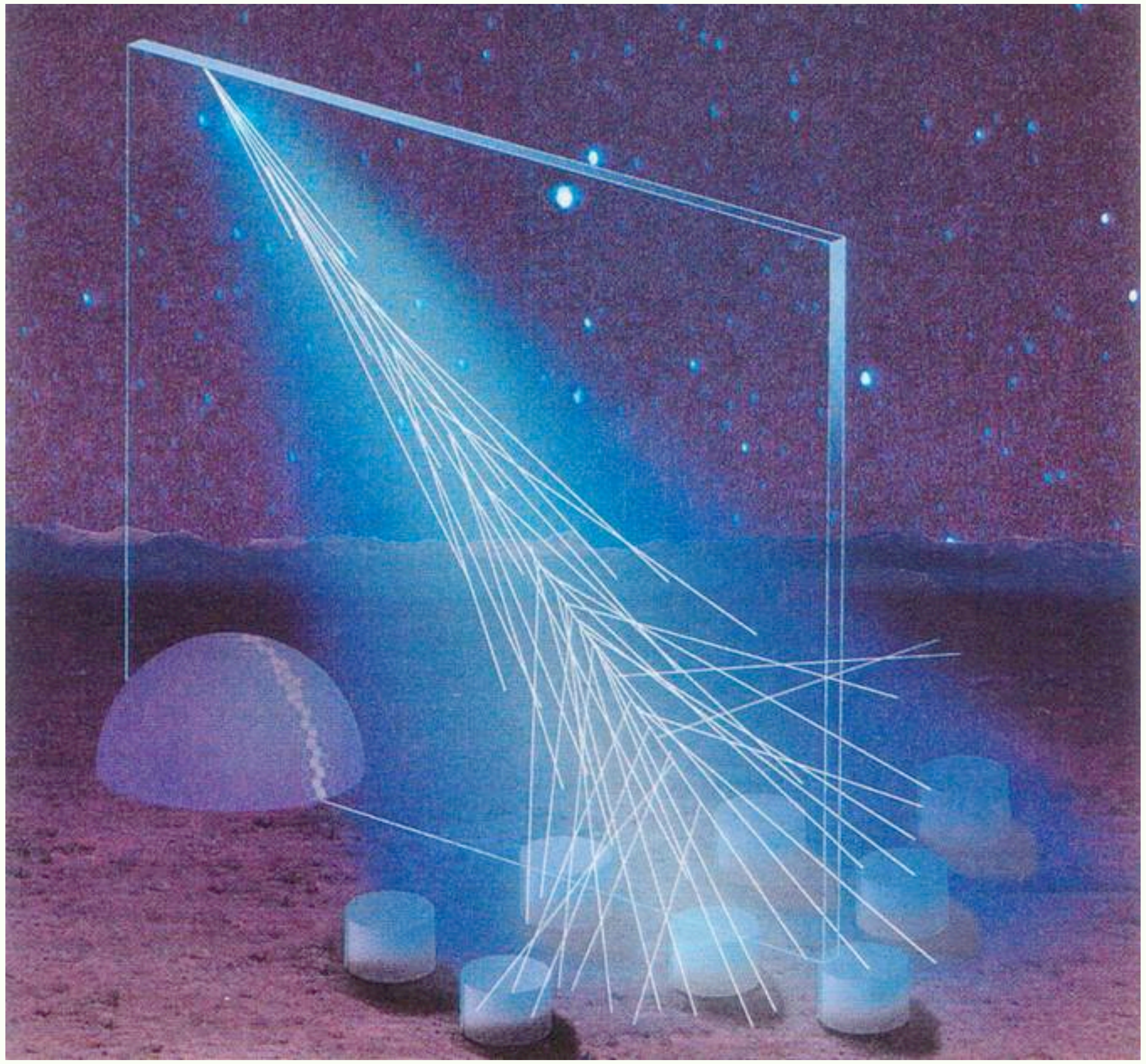
Goals of the Observatory

PIERRE AUGER OBSERVATORY

- Detection of cosmic rays with energies $>10^{19}$eV.
  - Spectrum
    - ➡ Requiers a good energy determination ≈ 20 - 30 %
  - Arrival directions
    - ➡ Energy resolution ≈1°
  - Composition
    - ➡ Fast electronics to measure details of the shower front (SD)
    - ➡ Field of view to observe shower development (FD)
- Good statistics
  - Size matters: area of 3000 km^2

Hybrid design

- Fluorescence detector
  - Direct, calorimetric energy measurement
  - Observes longitudinal development
- Surface detector
  - 100% duty cycle
  - Measures lateral distribution
- Geometrical aperture
- Hybrid reconstruction as good as stereo fluorescence



Auger Location

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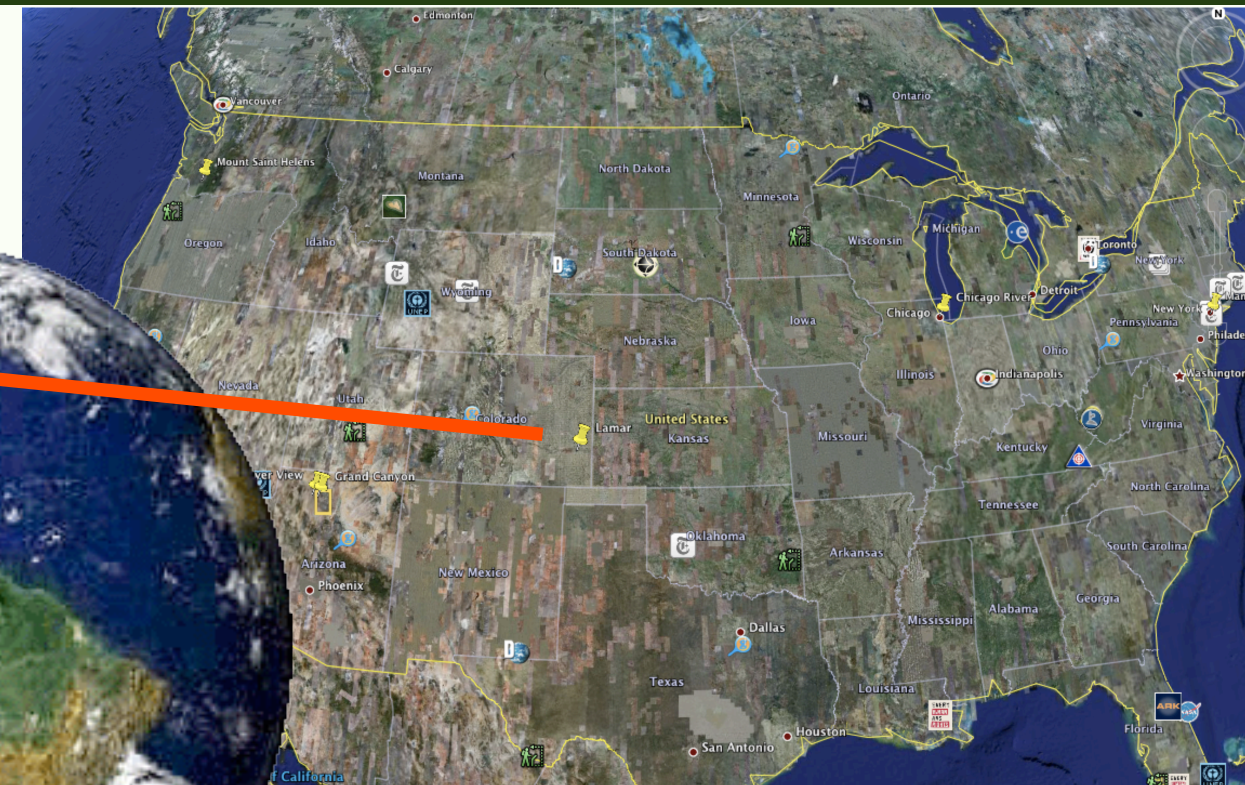
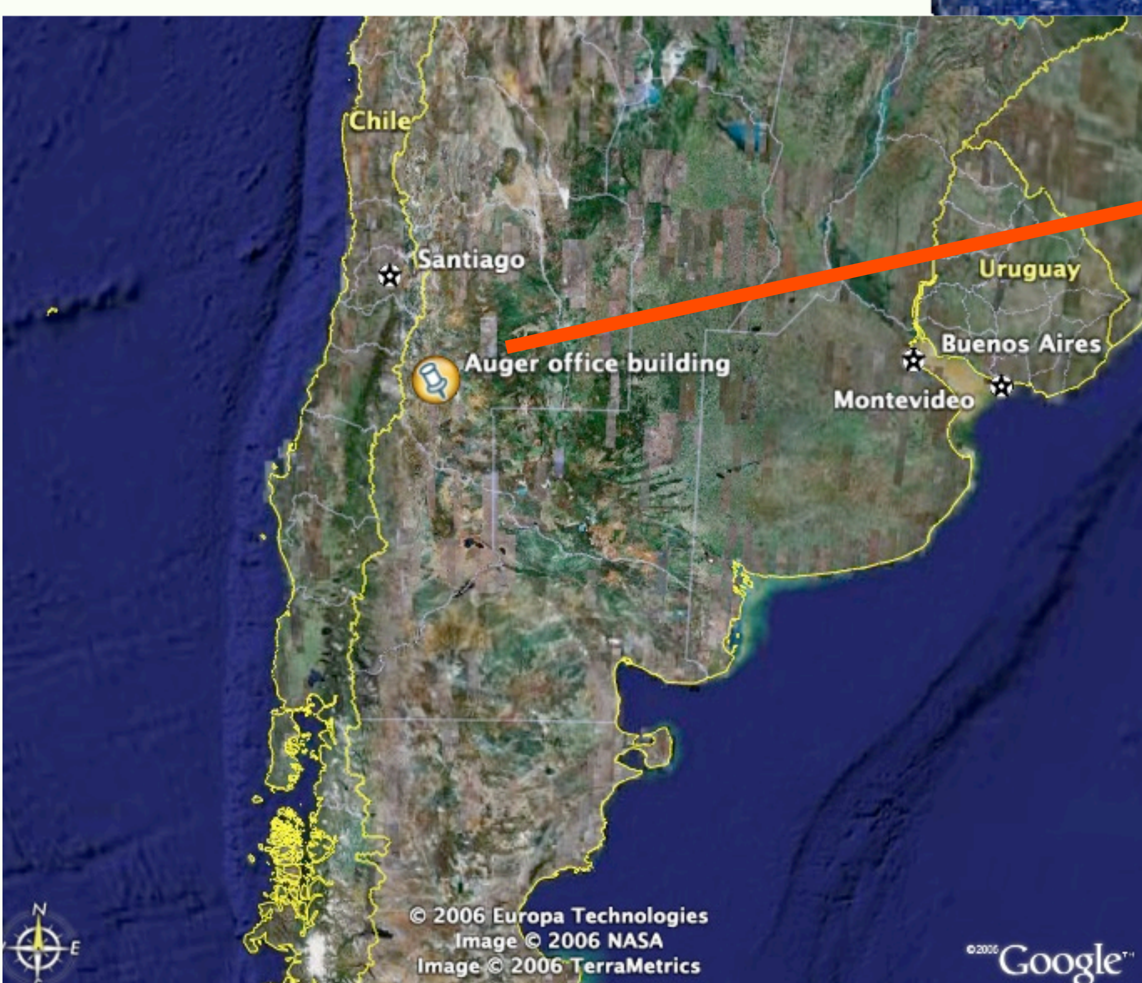


Malargüe, Mendoza, Argentina

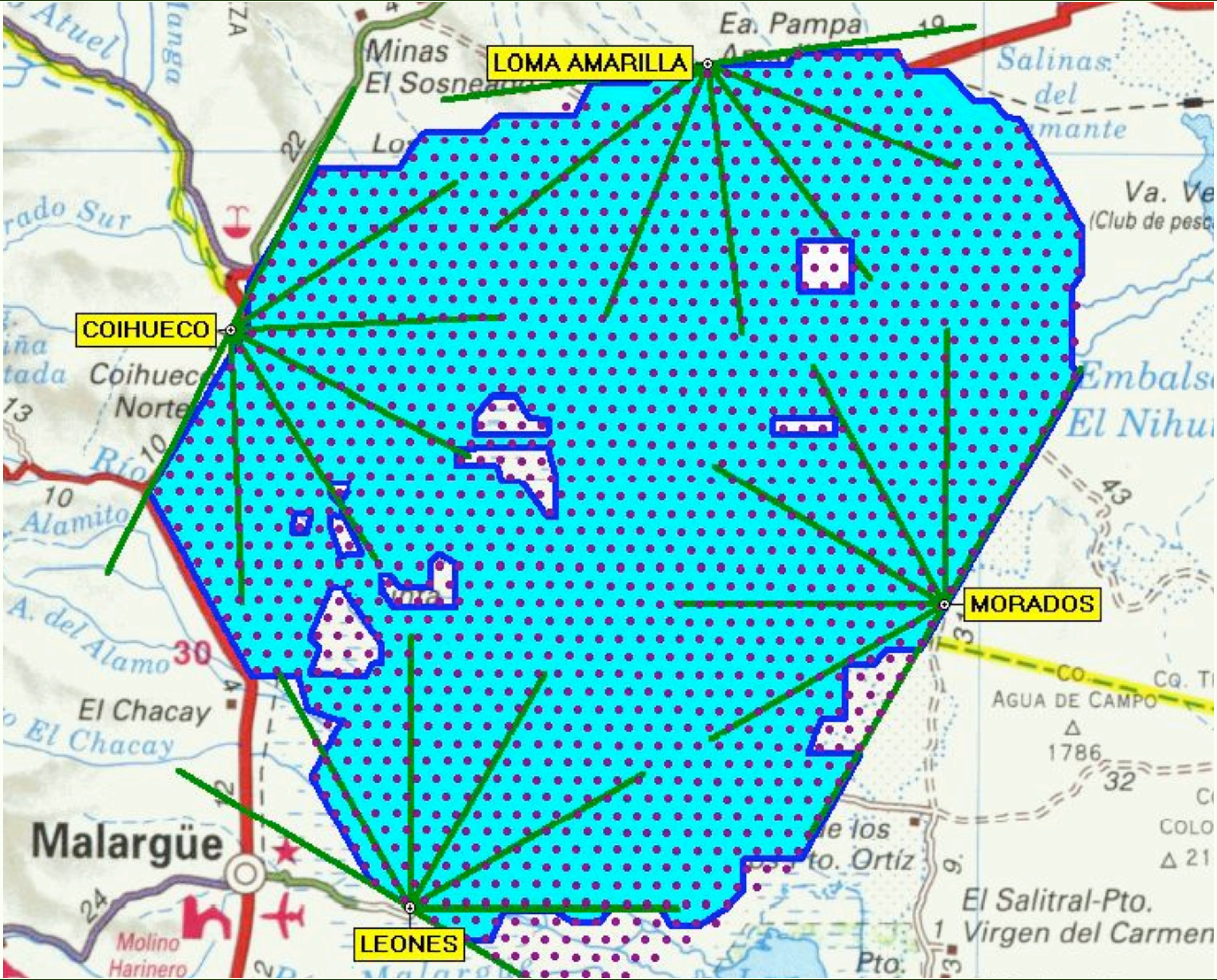


Lamar, South-East Colorado, USA (Planned)

15+2 countries,
>85 institutions
>300 authors

The Auger Site

The Auger Site



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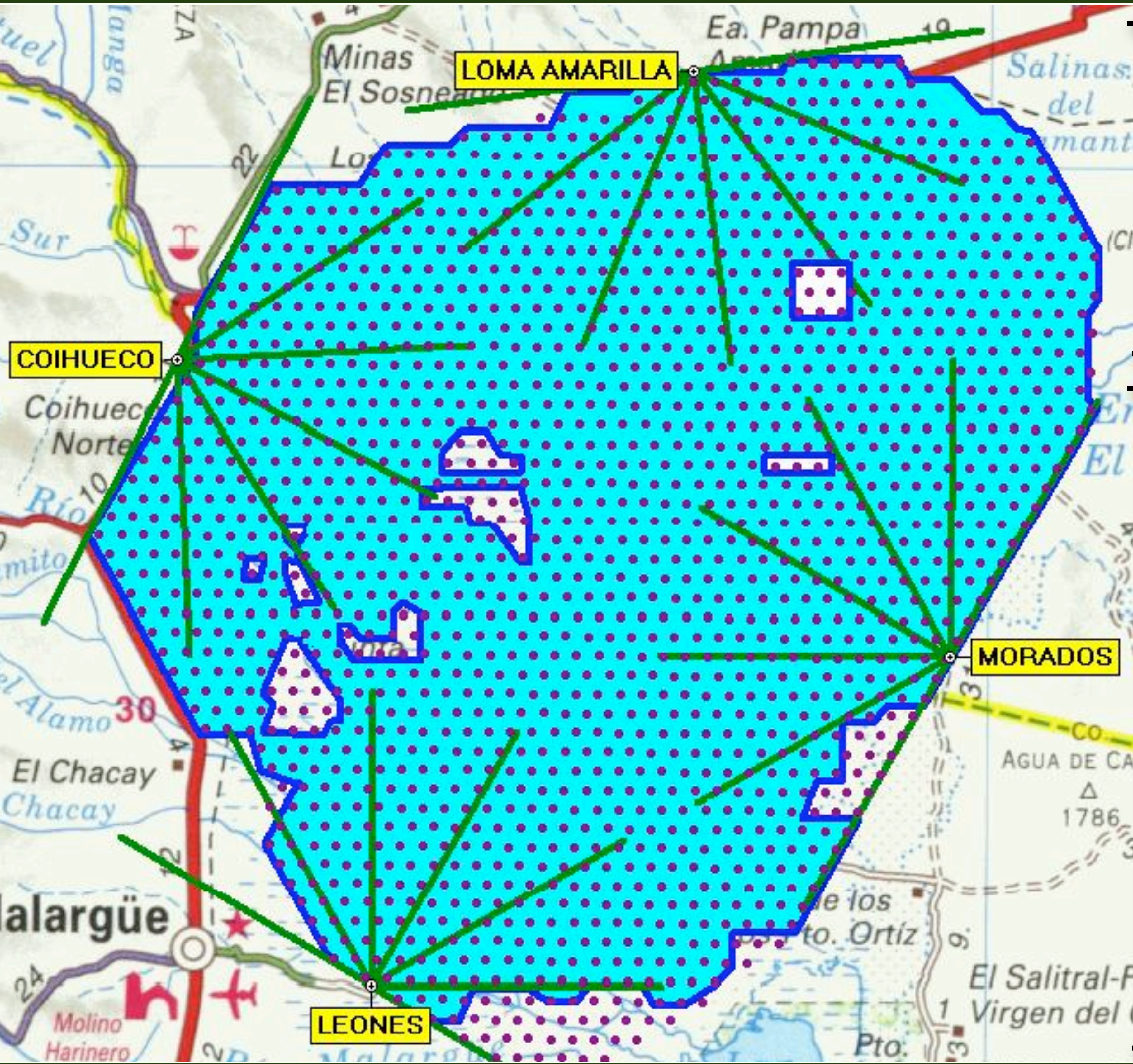


1660 surface detector stations, 1.5 km spacing

- **1638** with water
- **1605** with electronics

4 Fluorescence detector sites

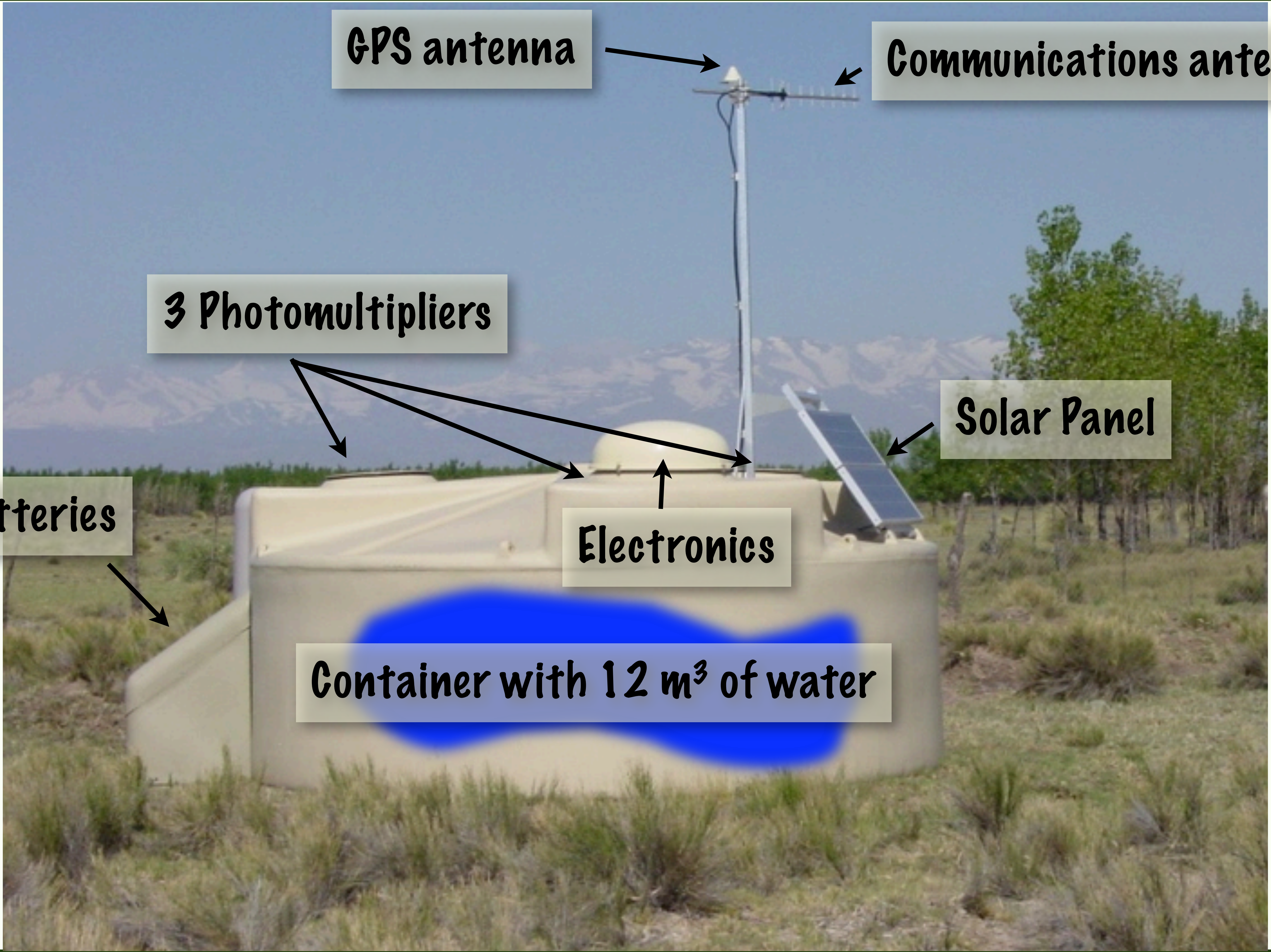
- **6** telescopes each
- **24** telescopes in total

- Full coverage of the surface array
- Capability to detect stereo events

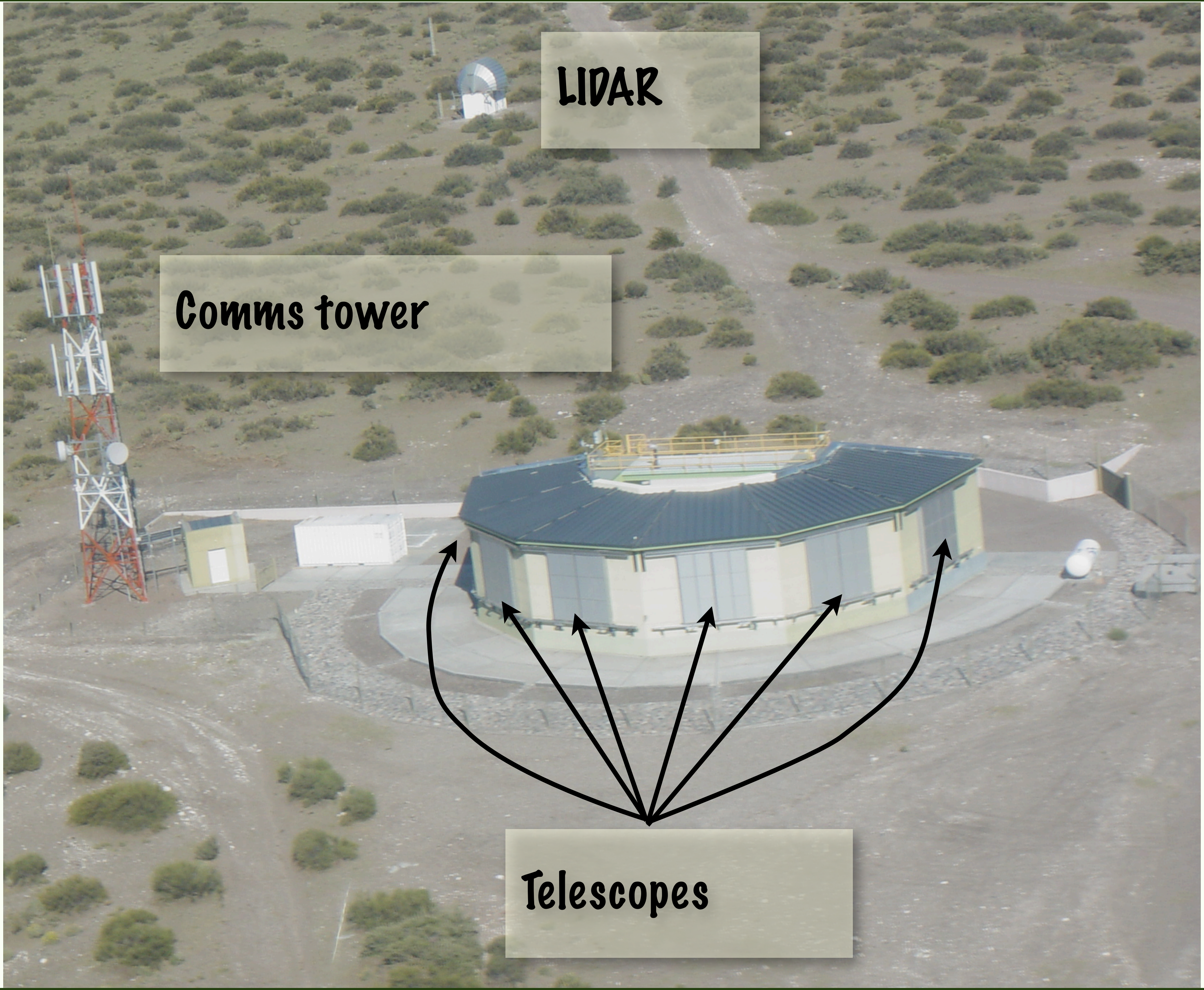
- Quadruple events seen

A surface detector station

A surface detector station



A Fluorescence Detector Site



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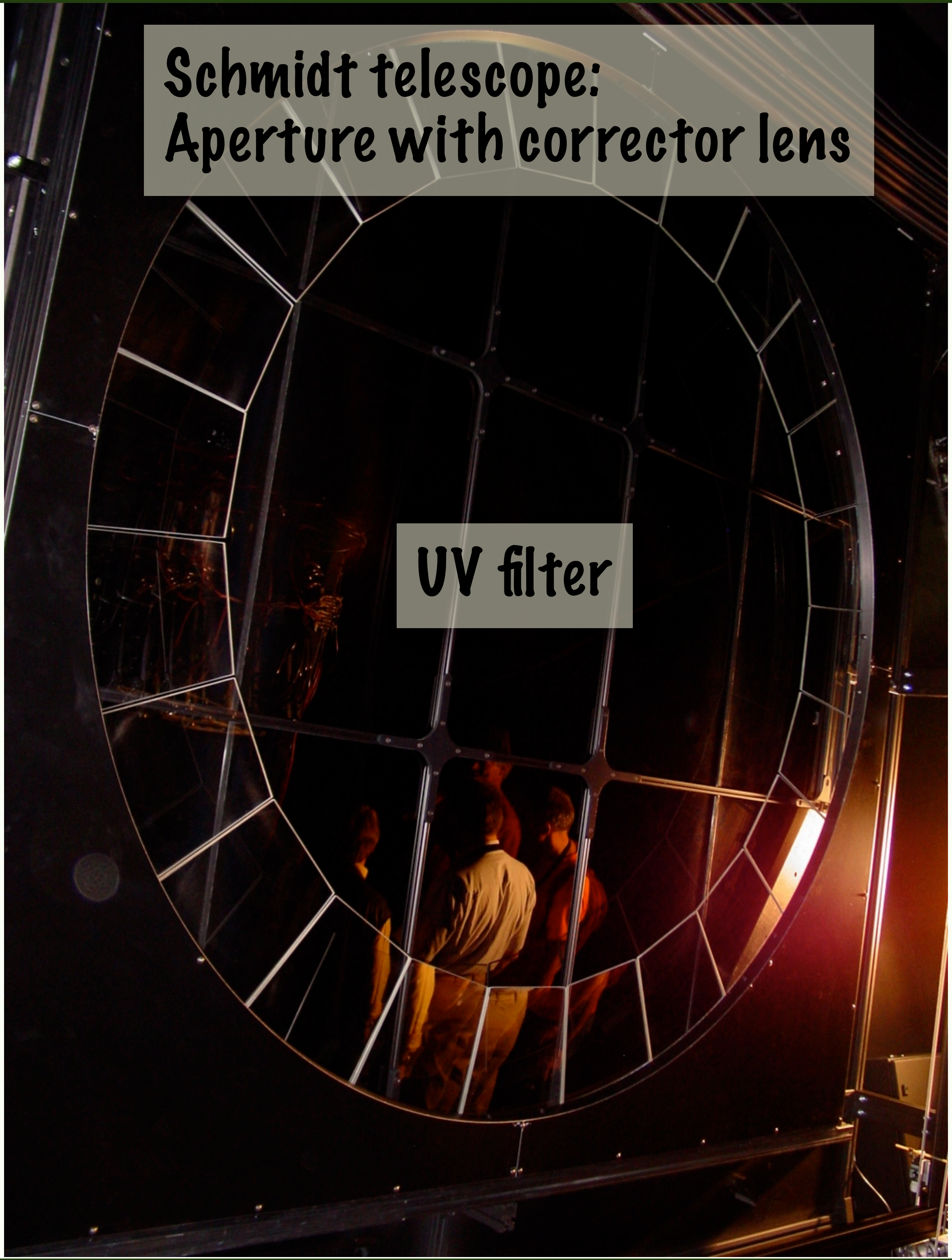

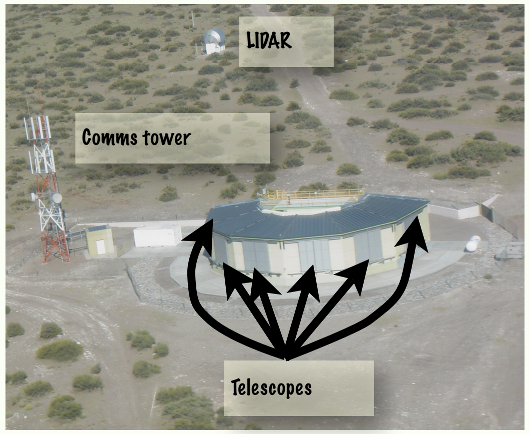

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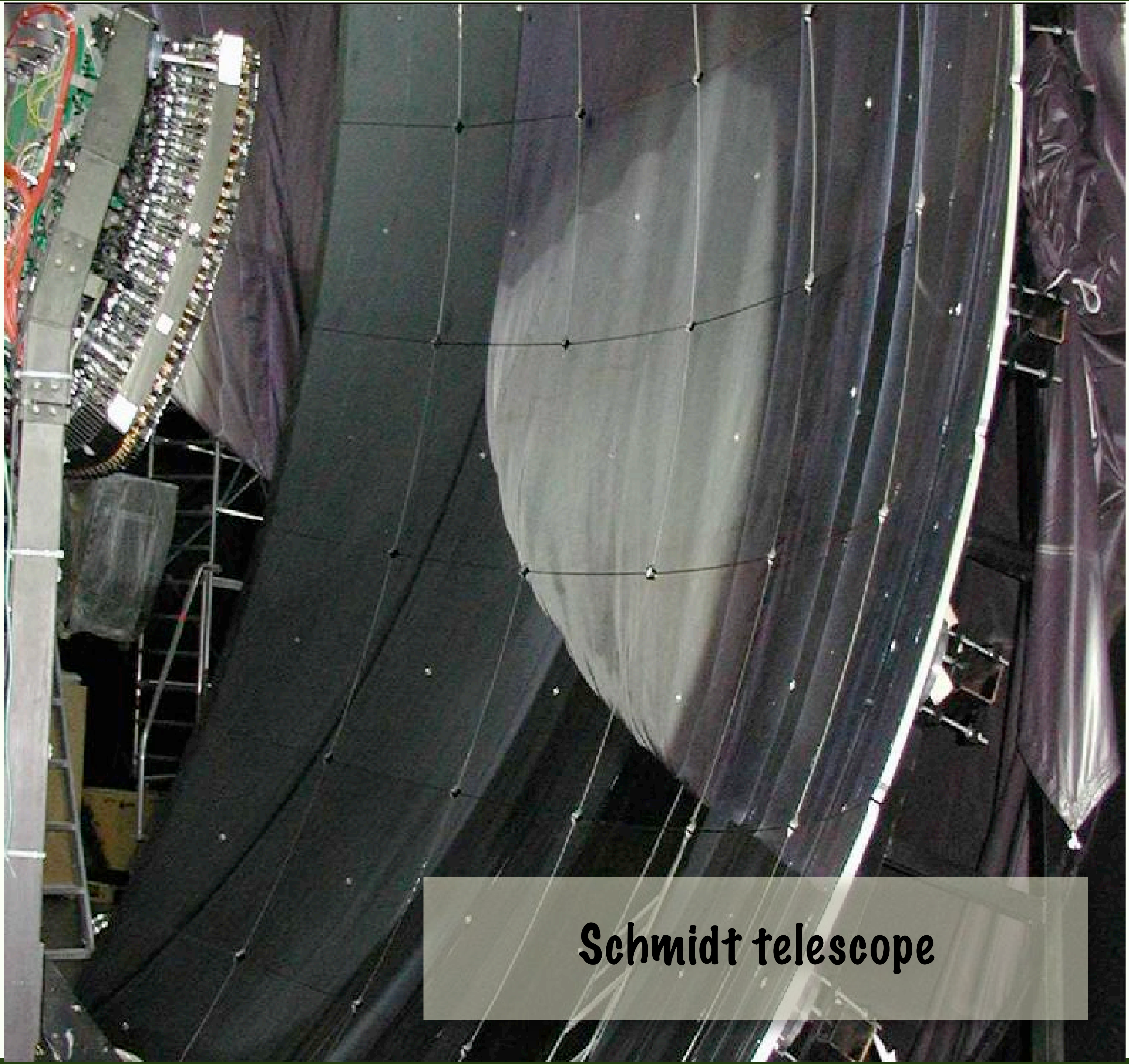

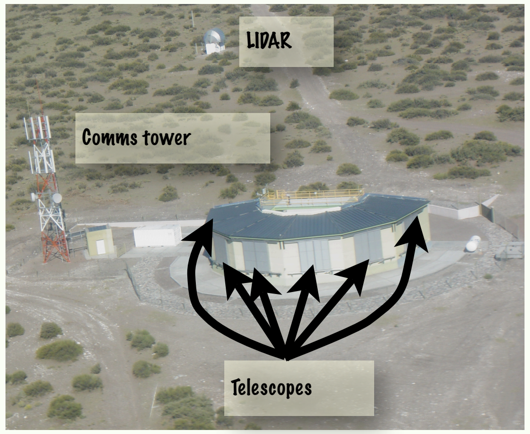

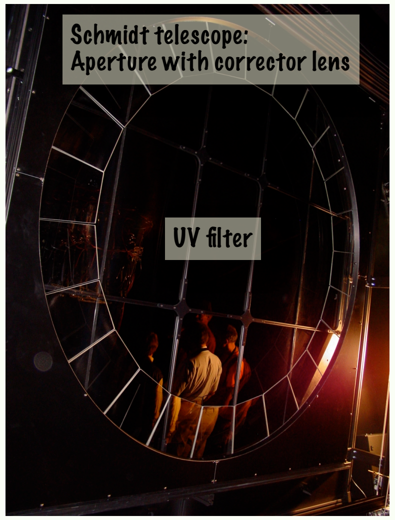

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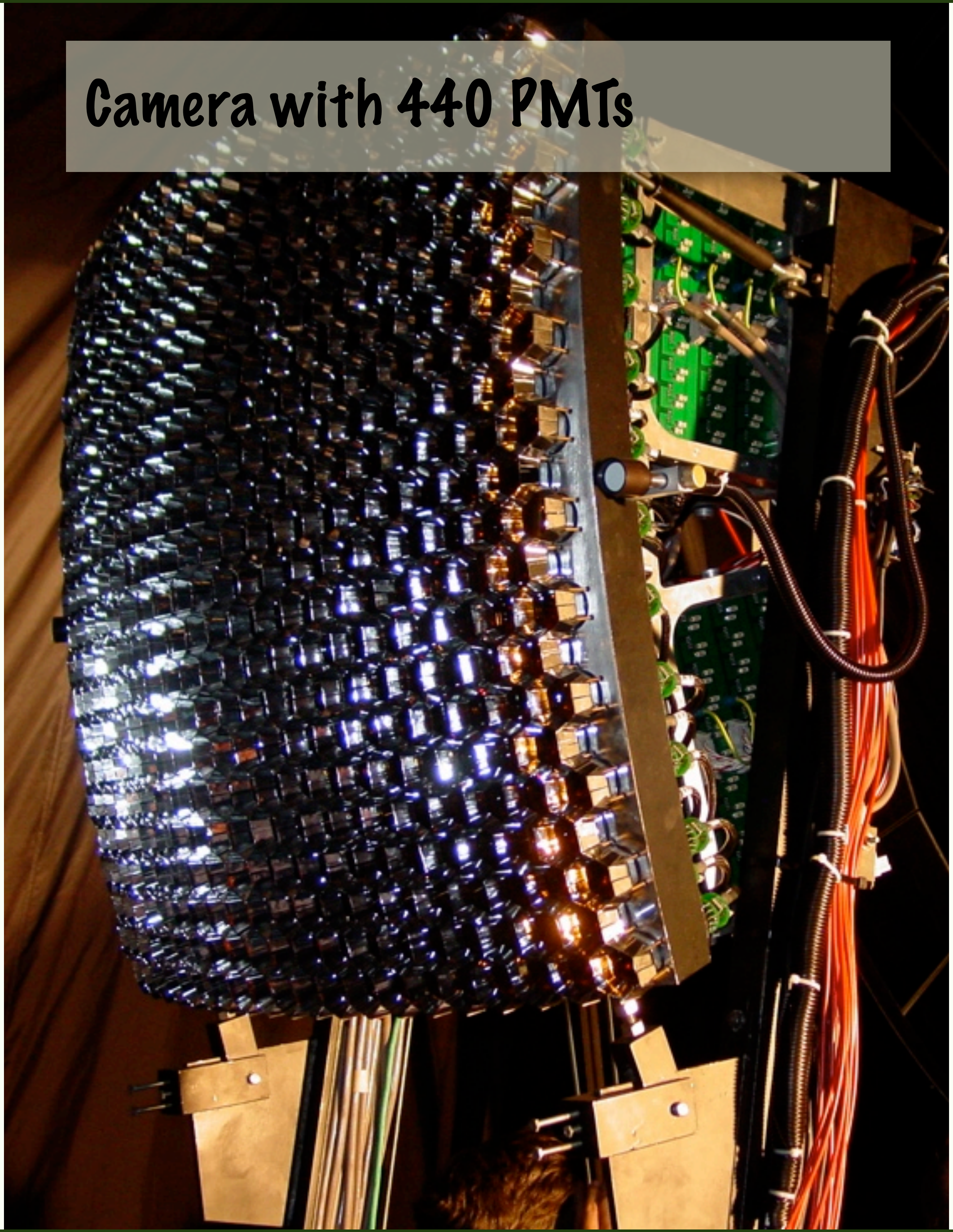
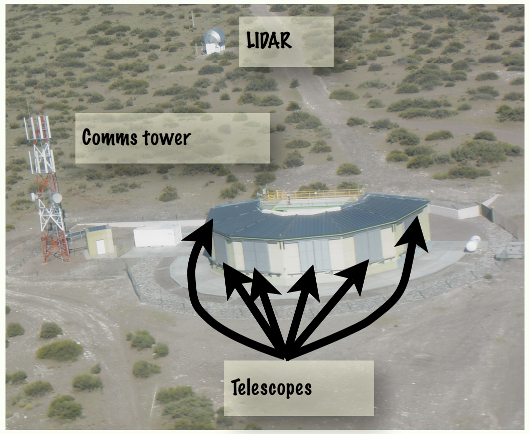
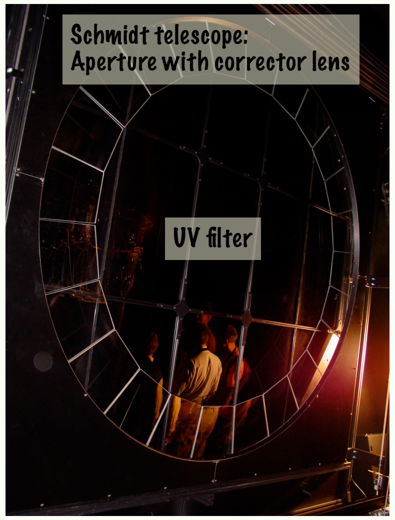
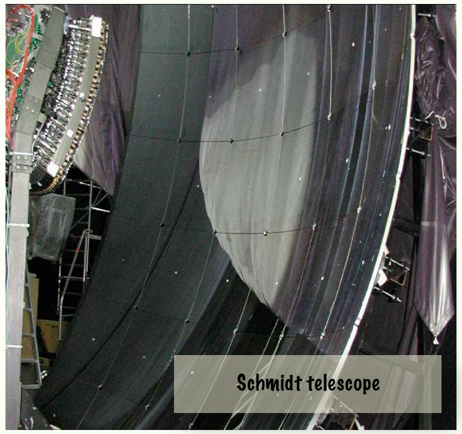








Calibration and Atmospheric monitoring

Central Laser Facility
- Energy calibration
- Reconstruction accuracy

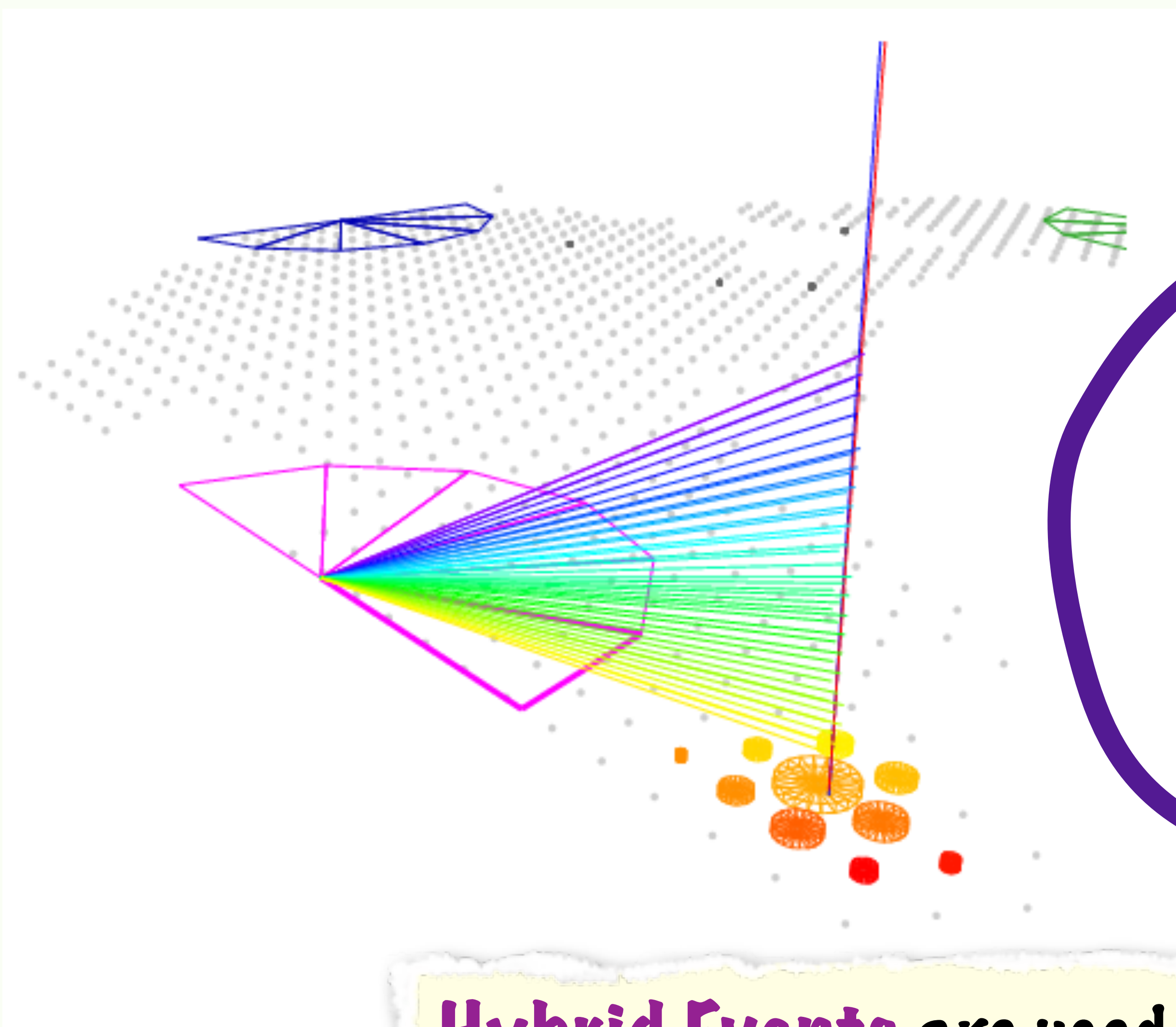
Drum calibration:
- FD end-to-end calibration

Lidar
- Atmospheric conditions

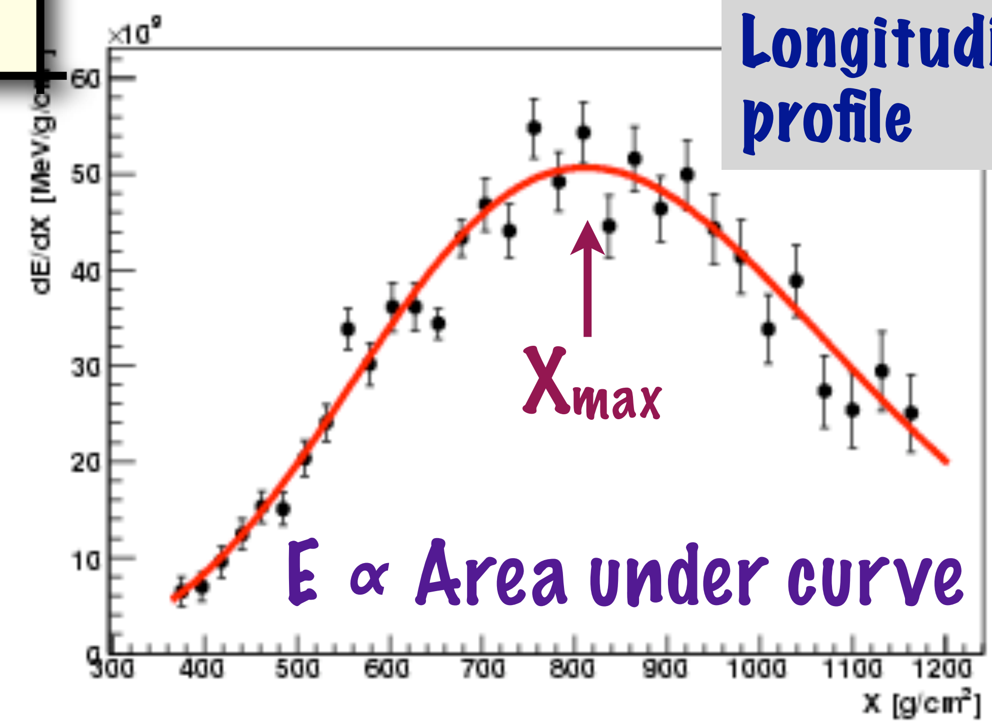
Also: Weather stations,
Cloud cameras
Balloon launches


Energy,
Spectrum

Energy Determination

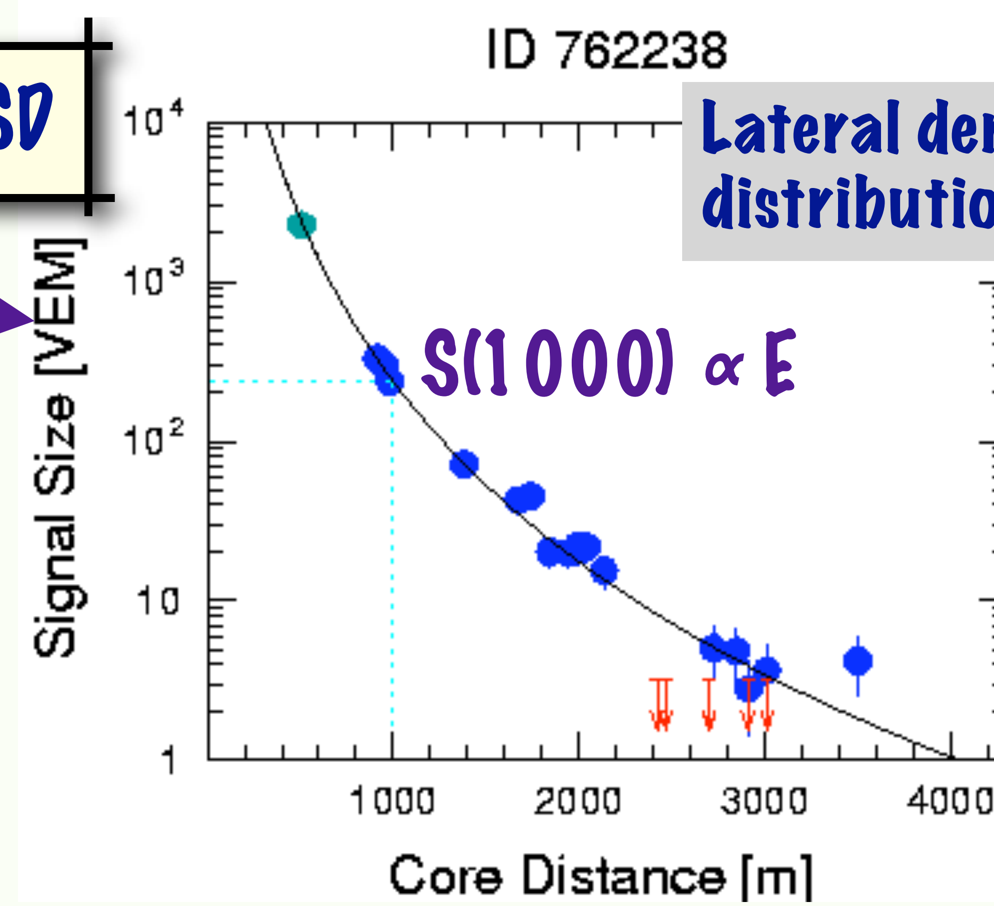


FD



Longitudinal profile

SD

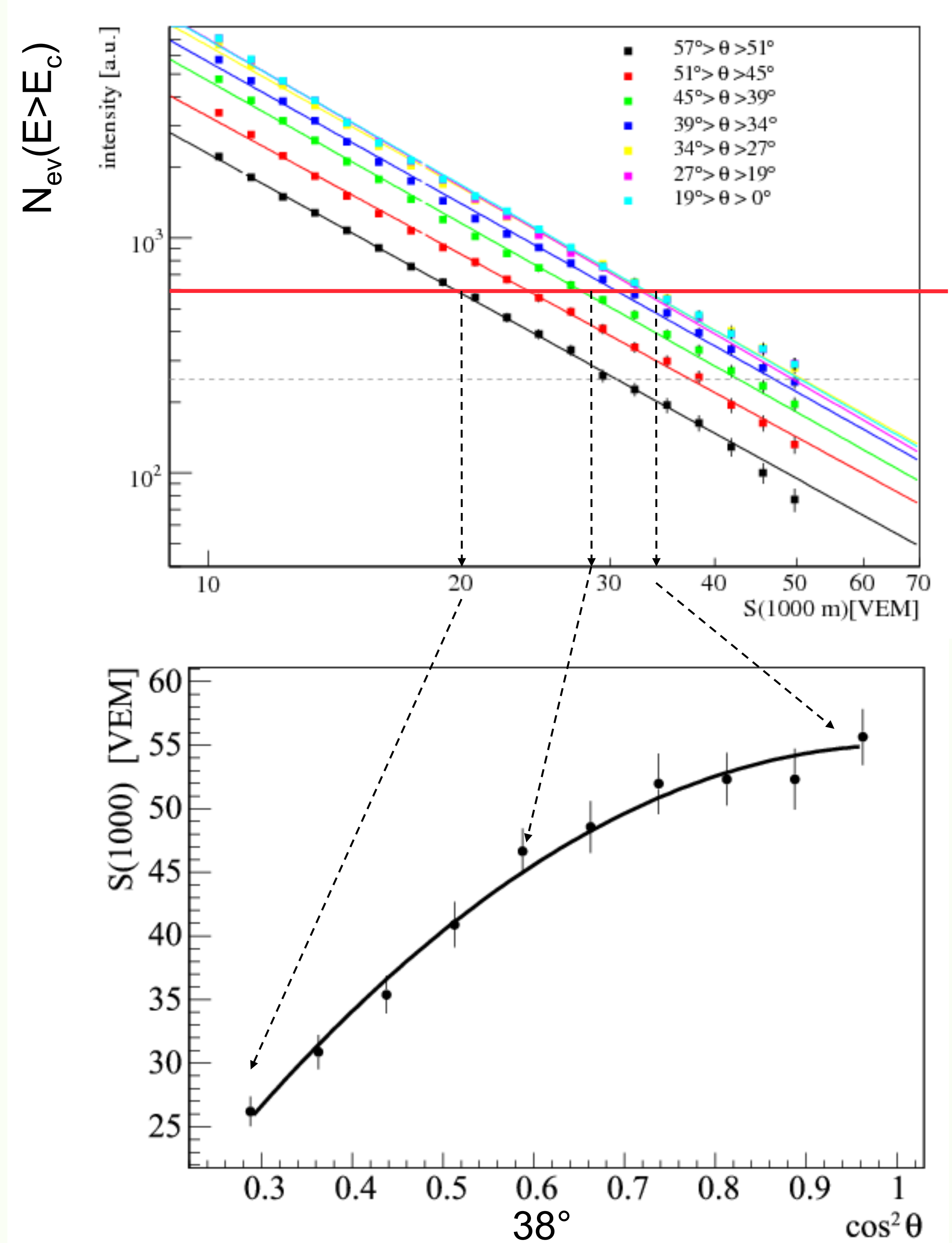


Lateral density distribution

Hybrid Events are used to **calibrate** the
SD energy estimator
from the
FD calorimetric energy

Constant Intensity Cut

- Isotropy of Cosmic Rays
  ⇨ Integrated constant Intensity
- Constant Intensity
  ⇨ Constant Energy
- Relate S(1000) to S_{38} (signal at 38°)
  - 38° is the average zenith angle of events



Calibration curve

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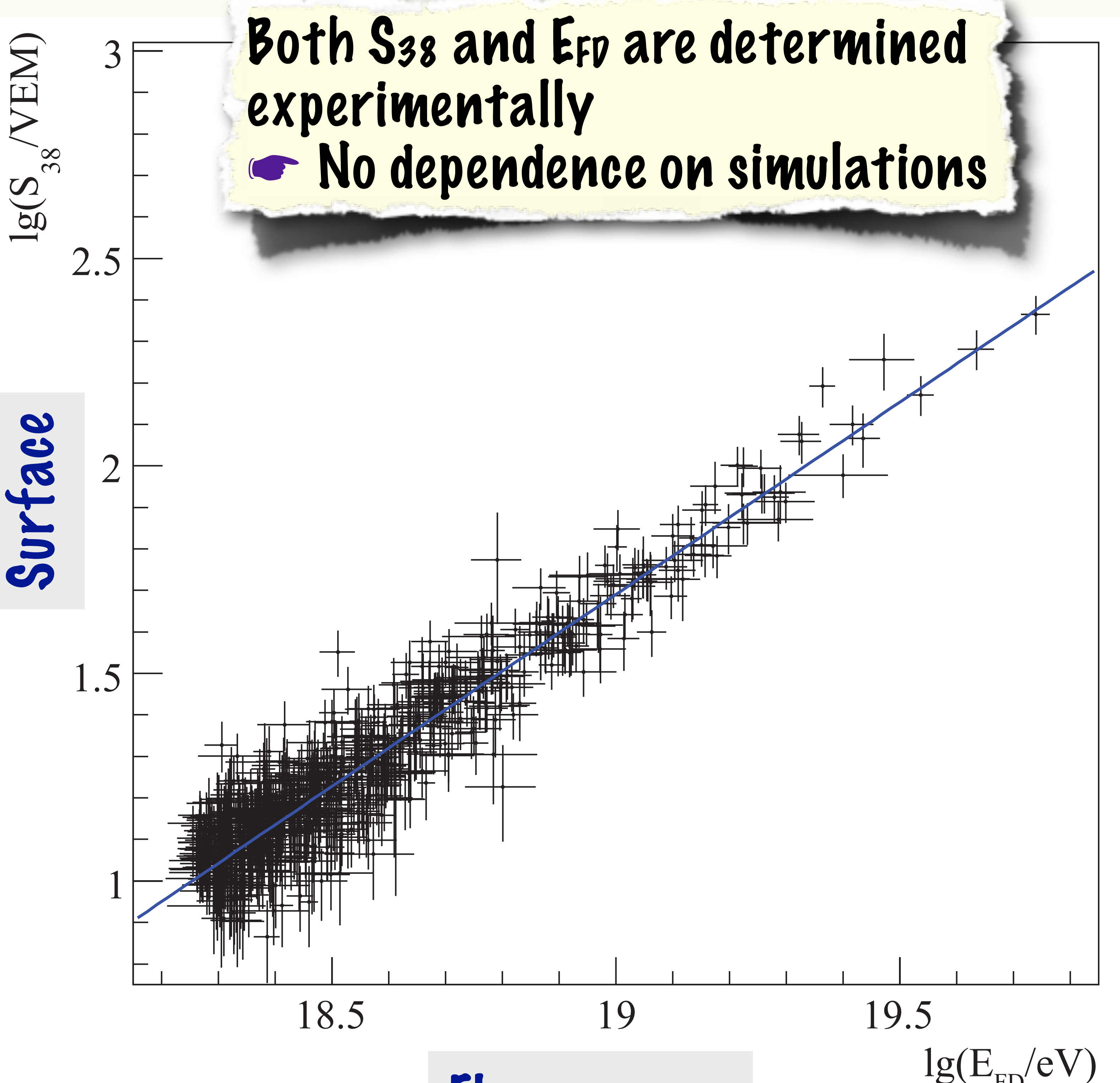
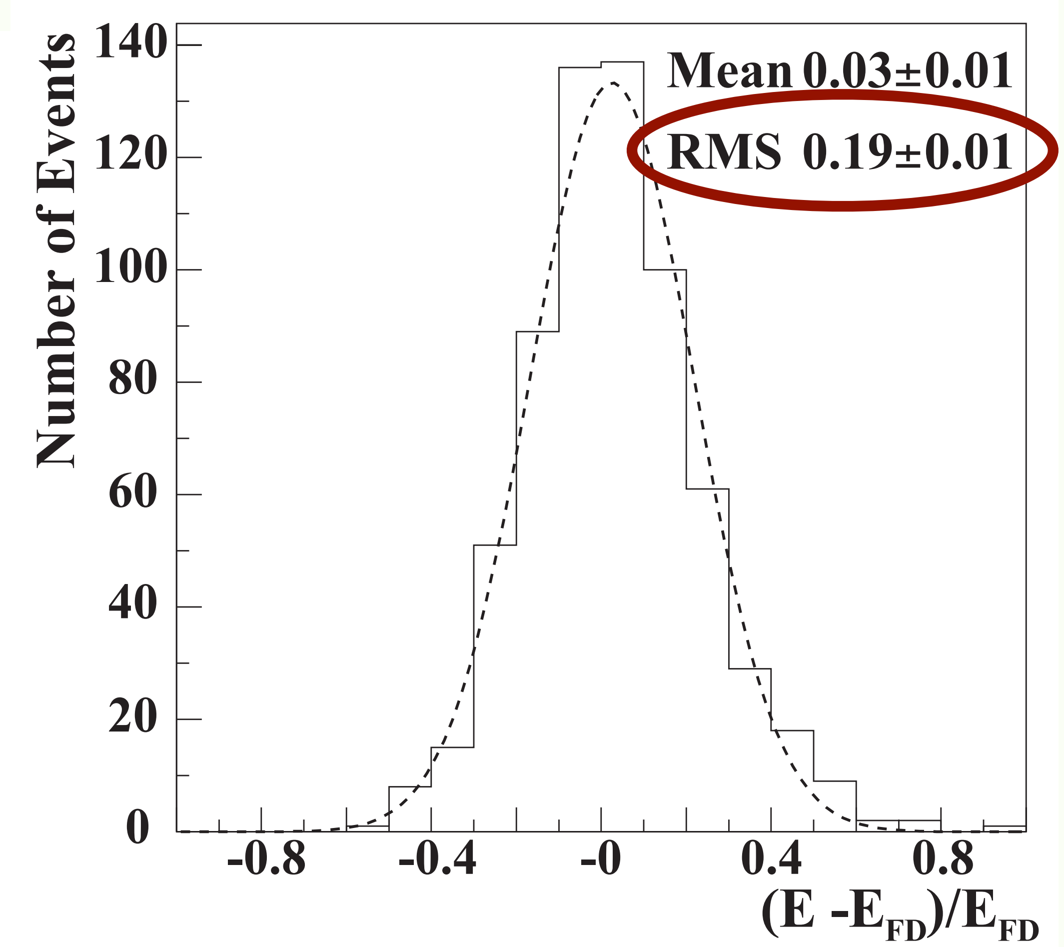
Both S_{38} and E_{FD} are determined experimentally

☛ No dependence on simulations



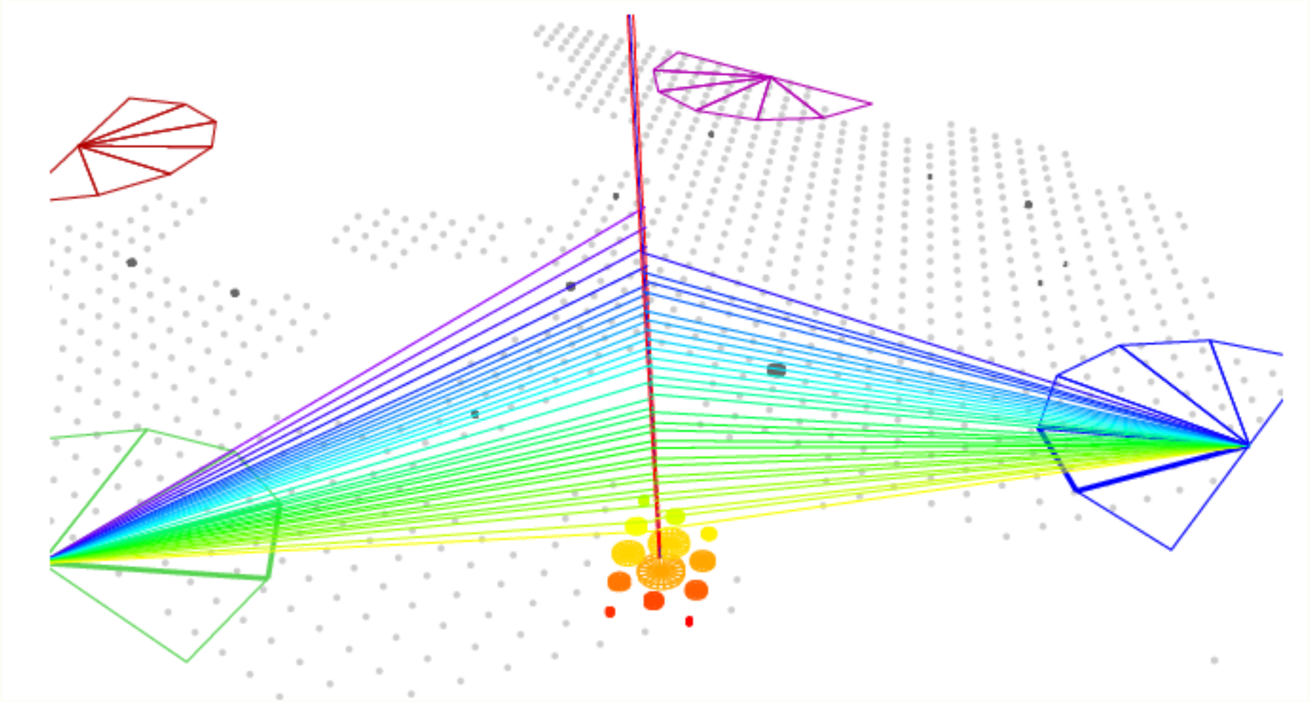
Surface

Fluorescence

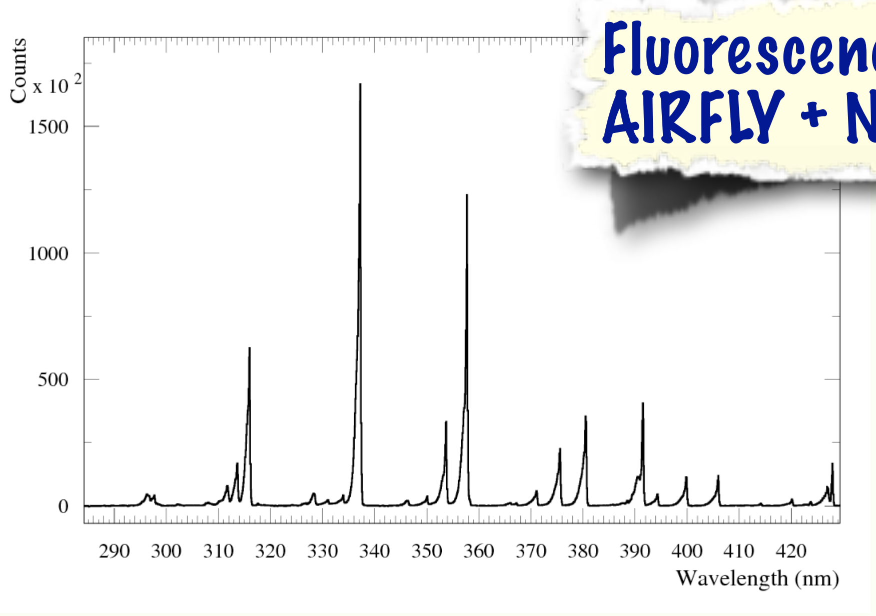


Energy calibration improves with statistics

FD Energy Uncertainty



- Stereo events
  ⇒ reconstruction uncertainty
  - 10%, consistent with MC



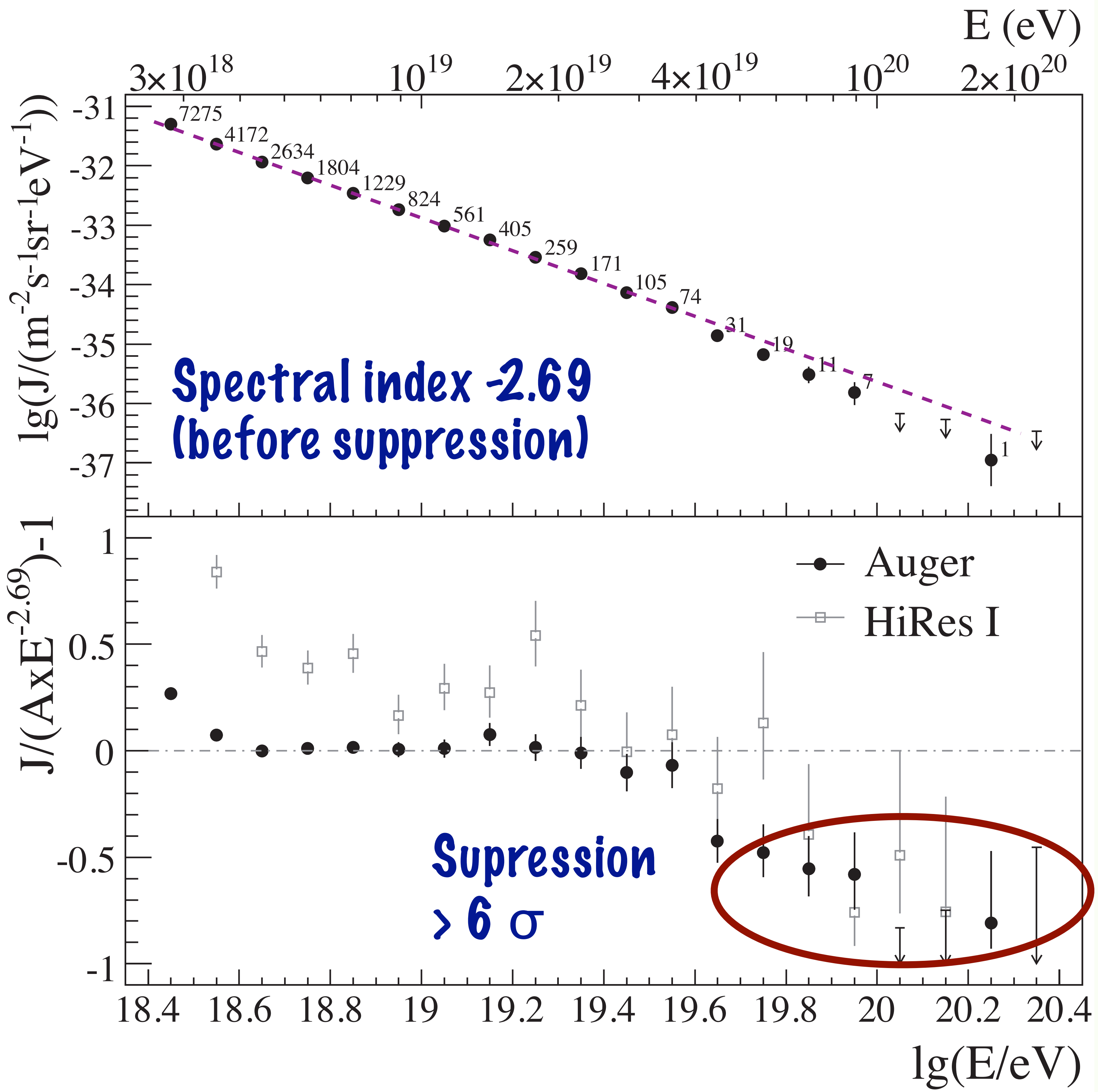
Fluorescence yield
AIRFLY + Nagano

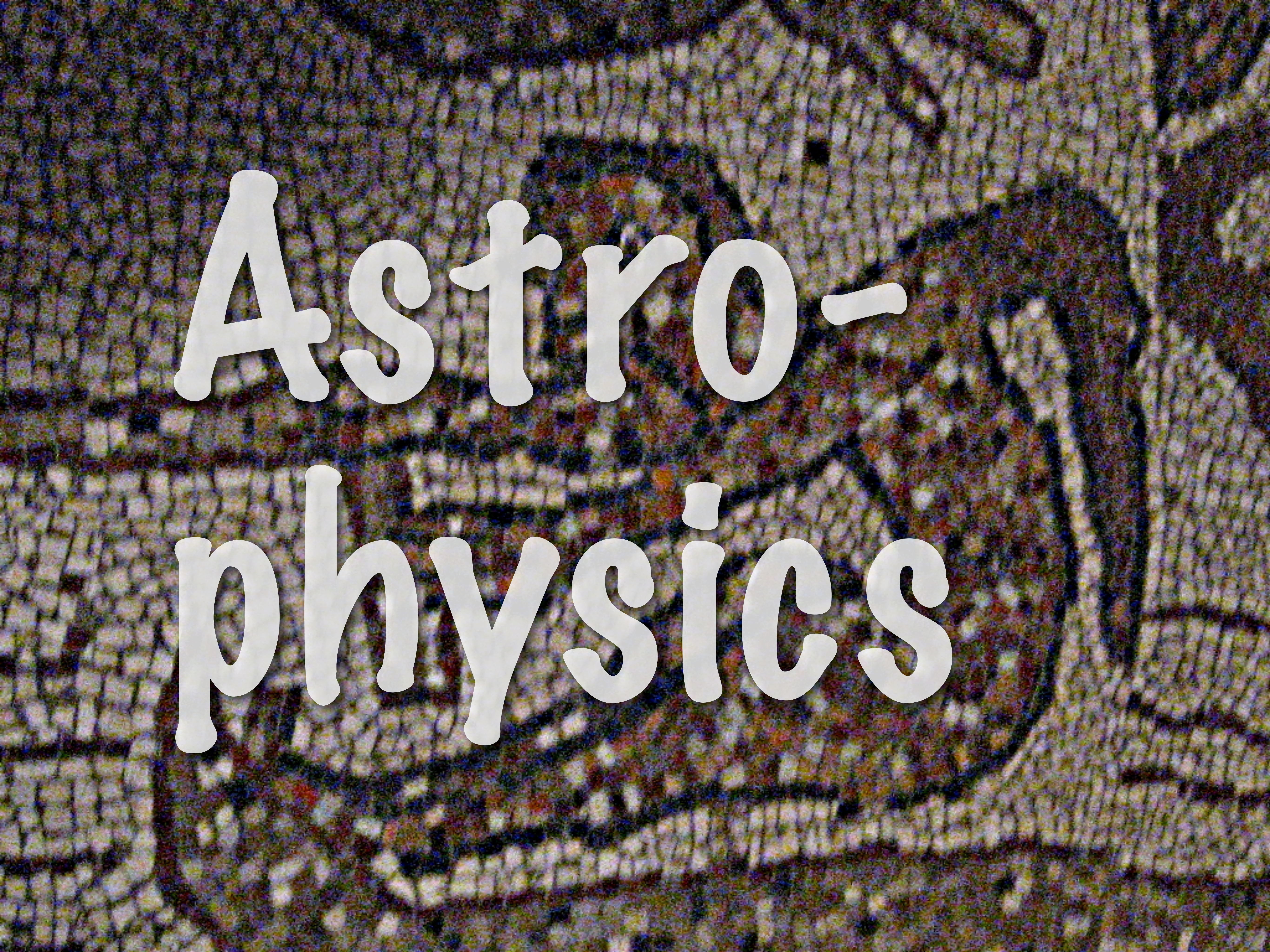
Source	Systematic uncertainty
Fluorescence yield	14%
P,T and humidity effects on yield	7%
Calibration	9.5%
Atmosphere	4%
Reconstruction	10%
Invisible energy	4%
TOTAL	22%

Total FD E uncertainty: 22%

Spectrum: Flux supression

- Flux suppression at the highest energy
  - Significance does not depend on energy scale
- Auger and HiRes compatible within 15%
  - Consistent with the uncertainties of the experiments



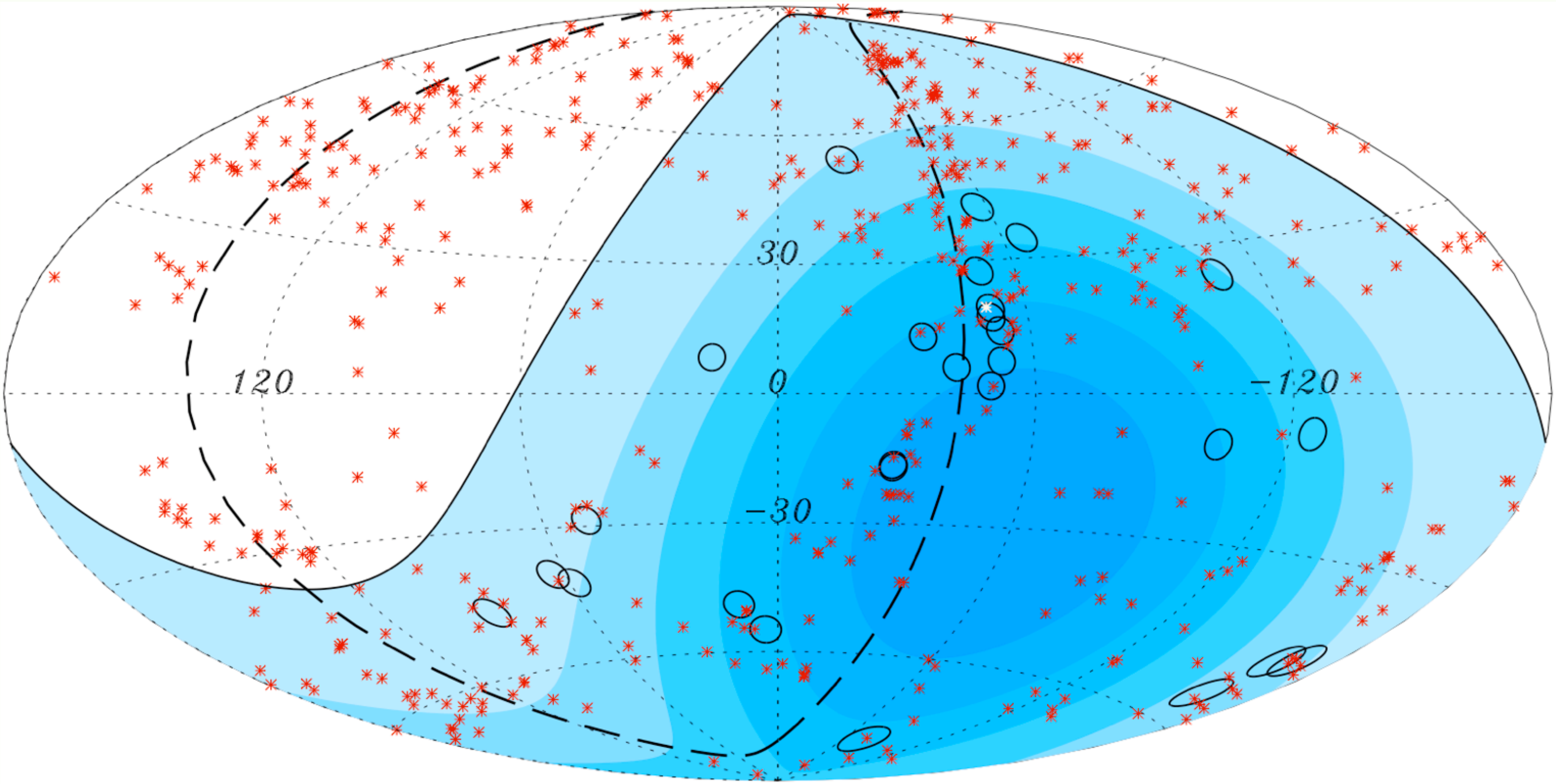

Astro-
physics

Prescription to reject Isotropy

- Cover sky with search windows, following sources from the Veron-Cetty, Veron Catalogue
- Select parameters, using data Jan 1, 2004 to May 27, 2006
  - z_{max} = 0.018
  - ψ = 3.1°
  - E_{th} = 56 EeV
  - Covered fraction of sky p = 0.21
- Start on May 27, 2006, get 6 of 8 events in search windows on May 25, 2007
- By August 31, 2007, we had 8 of 18 events in search windows

Reject isotropy with >99% confidence

Correlation with AGN



20 of 27 events correlate with AGN from the VC catalogue

Primary Particle

Tagging primaries:

Currently:
Cross-section

Future will also use:
details of shower signal

Mass composition and X_{max}

Primary protons

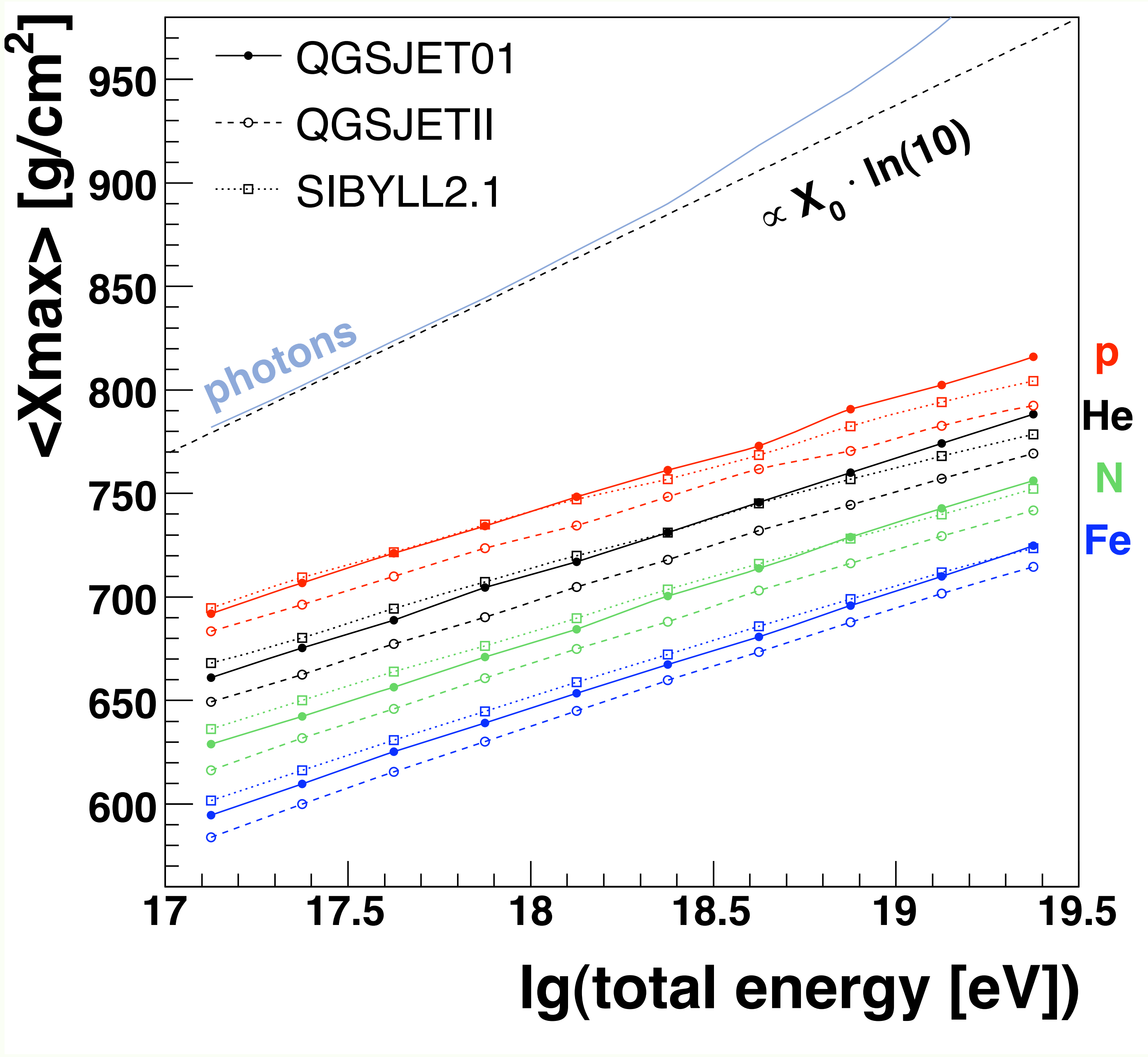
$$\langle X_{\rm max}\rangle = D_{10}\log(E) + {\rm const}$$

Superposition model

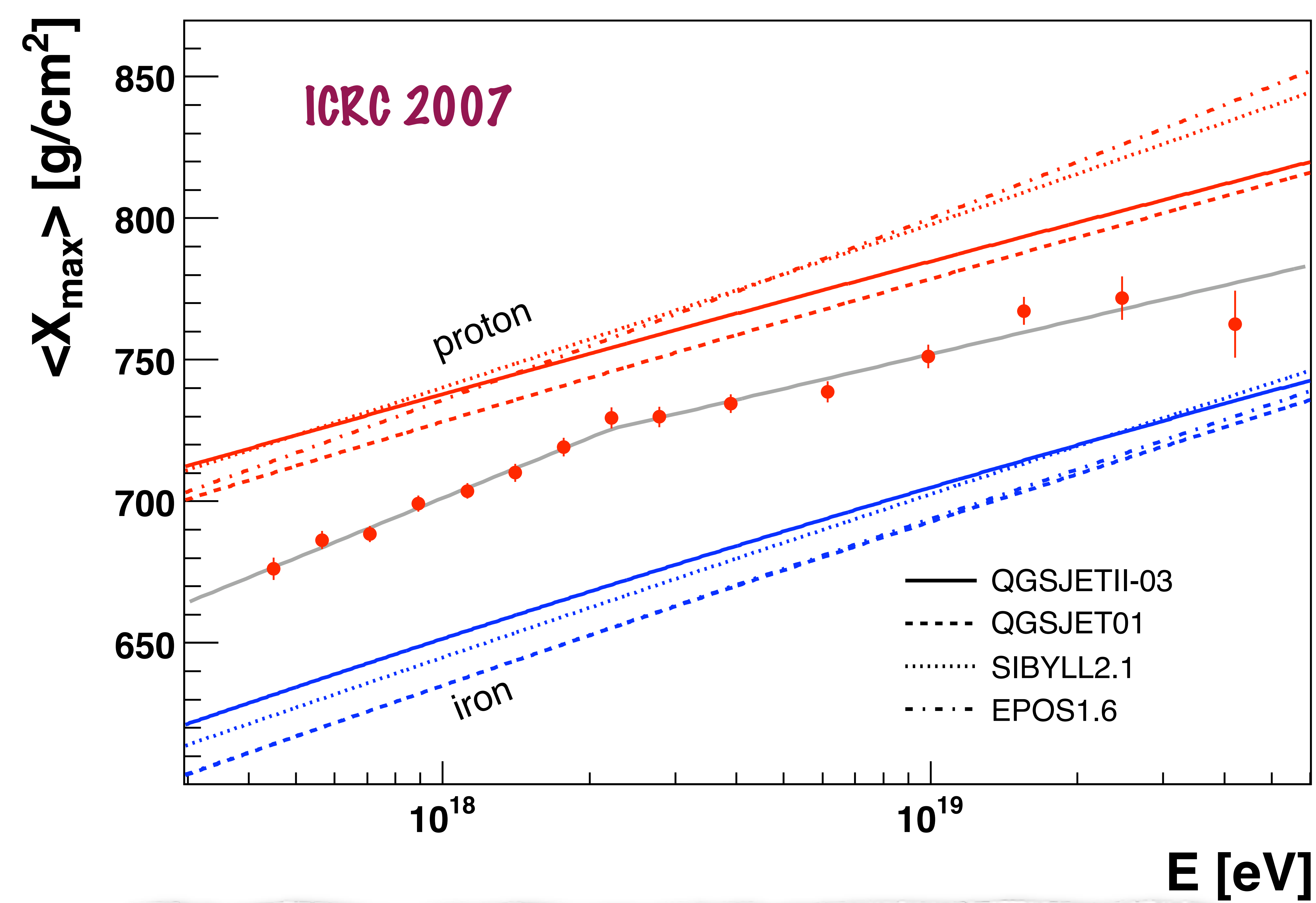
$$\langle X_{\rm max}\rangle = D_{10}\log(E/A) + {\rm const}$$

Elongation rate theorem

$$D_{10} \le X_0 \ln(10)$$

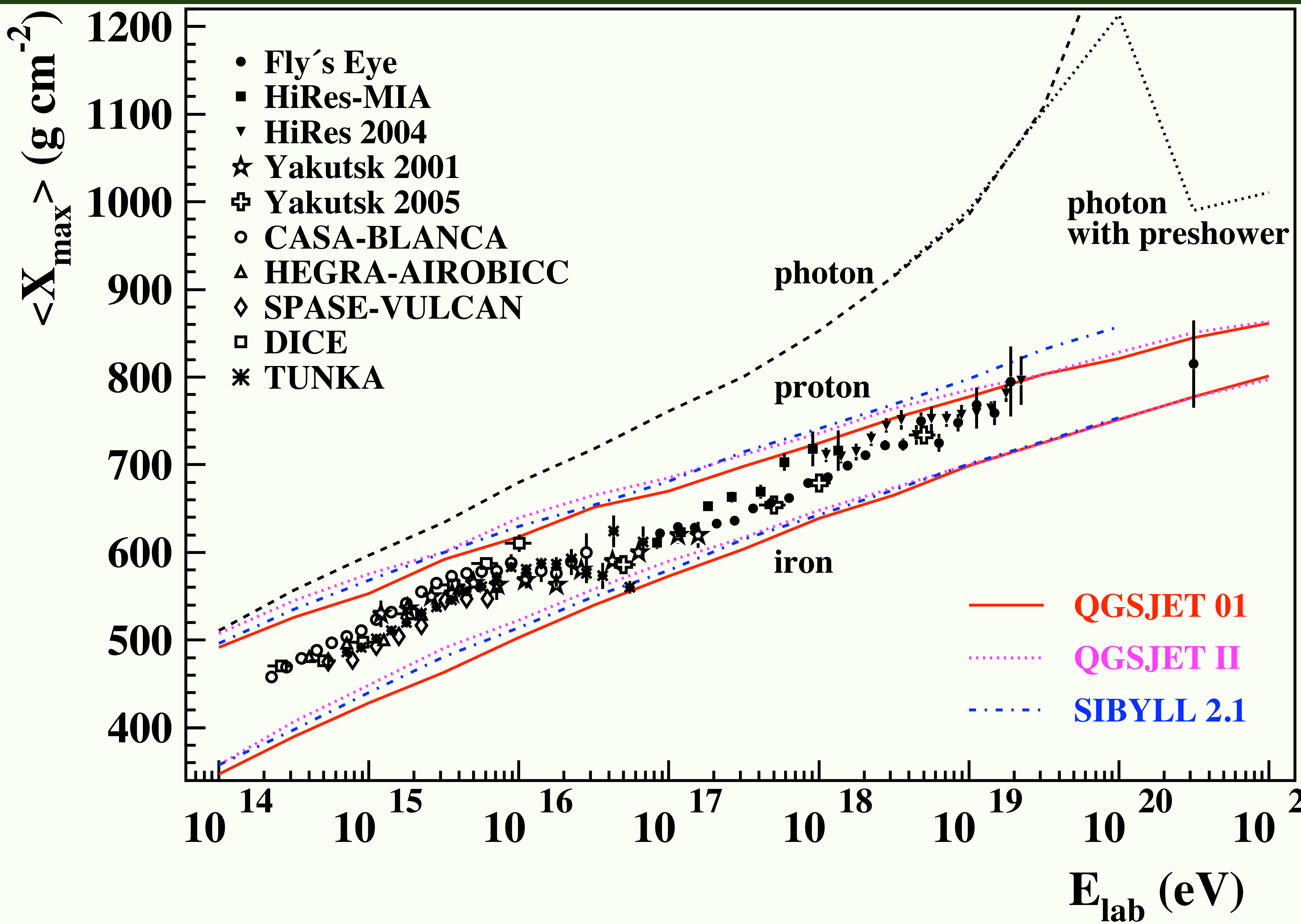


Elongation rate

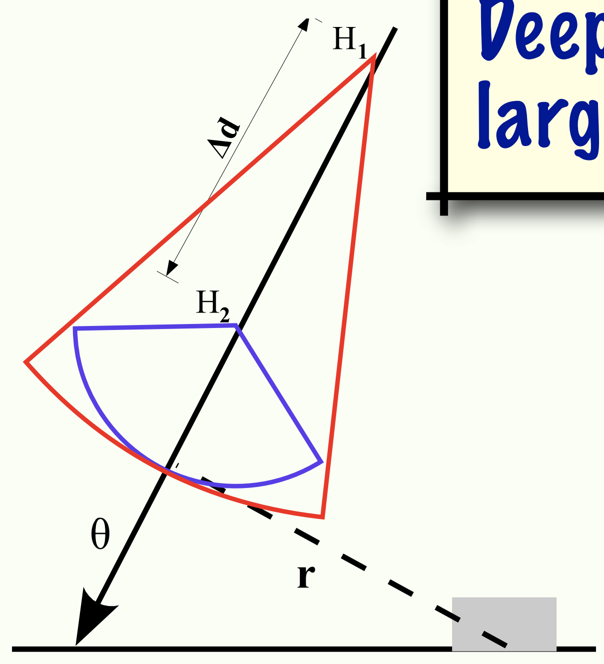


NB: the interpretation requires the use of simulations

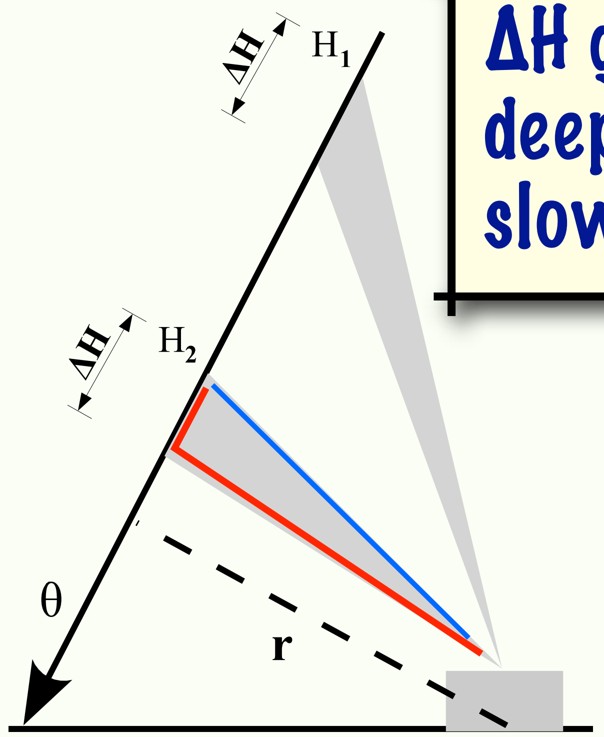
FD photon discrimination



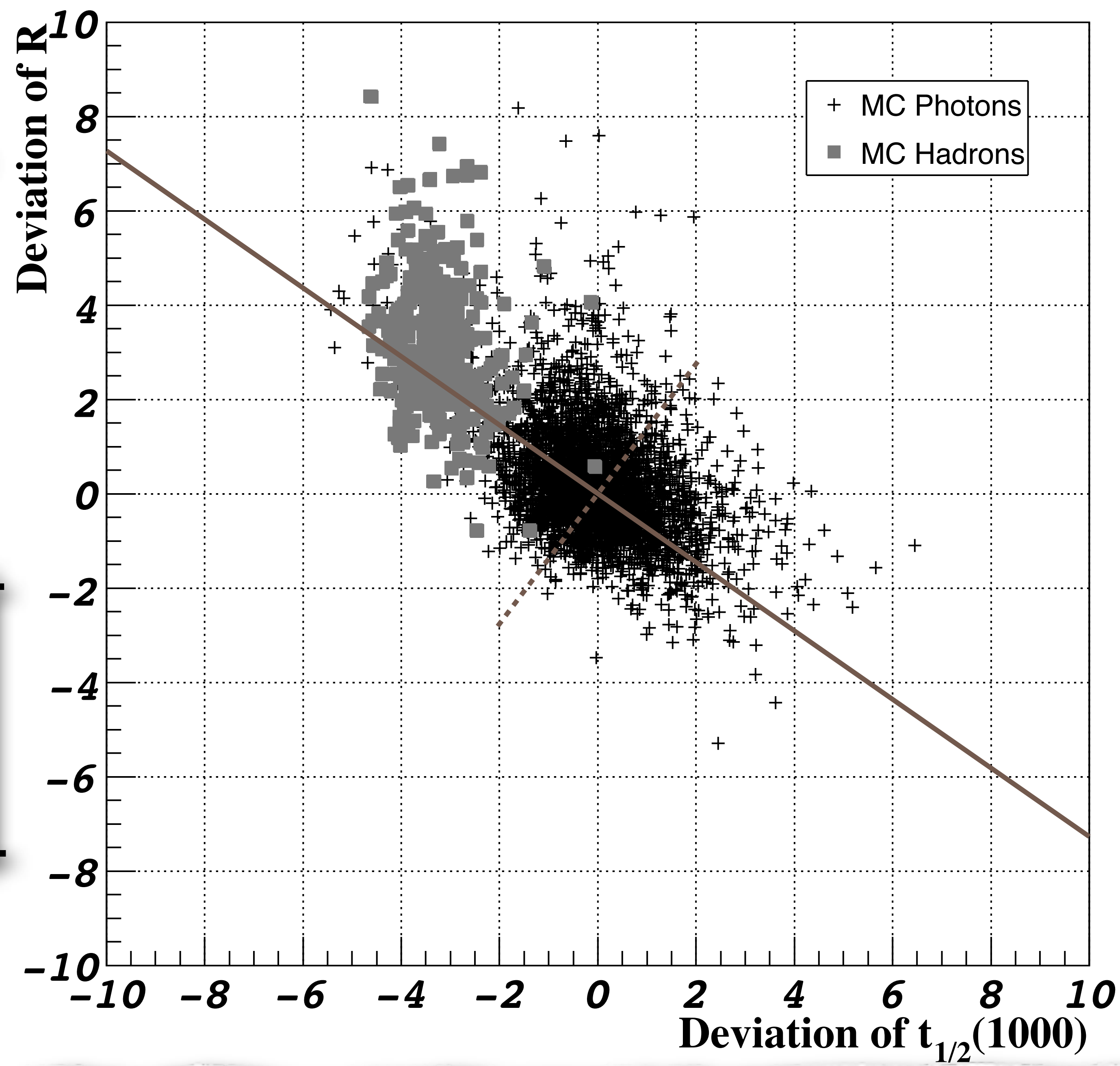
SD photon discrimination



Deeper shower: larger curvature



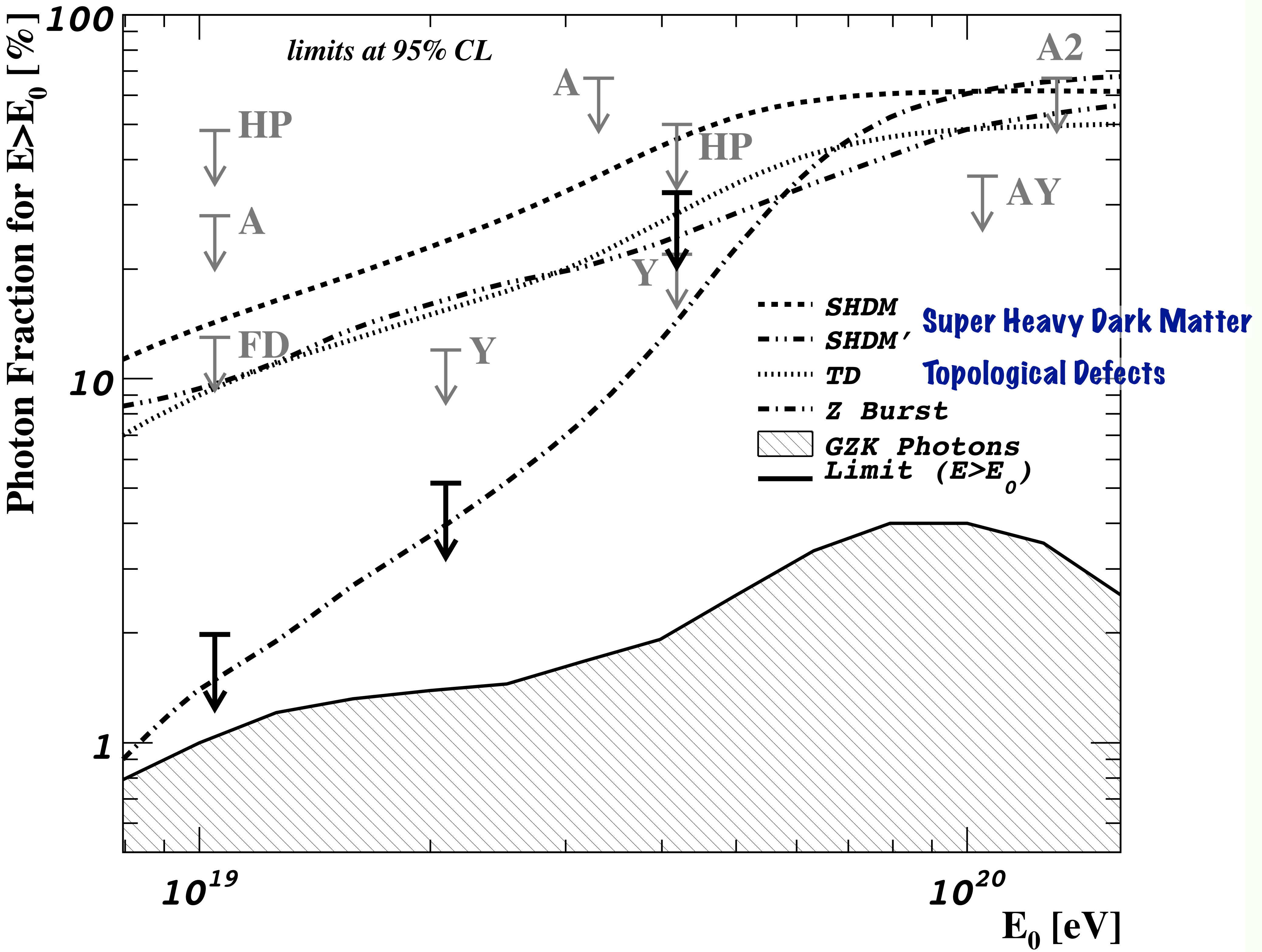
ΔH gives Δt: deeper shower has slower signals



Parametrize with simulations
Principal component analysis on deviation

Limit on the photon fraction

FD: auger FD
A: AGASA
HP: Haverah Park
Y: Yakutsk
AY: AGASA-Yakutsk

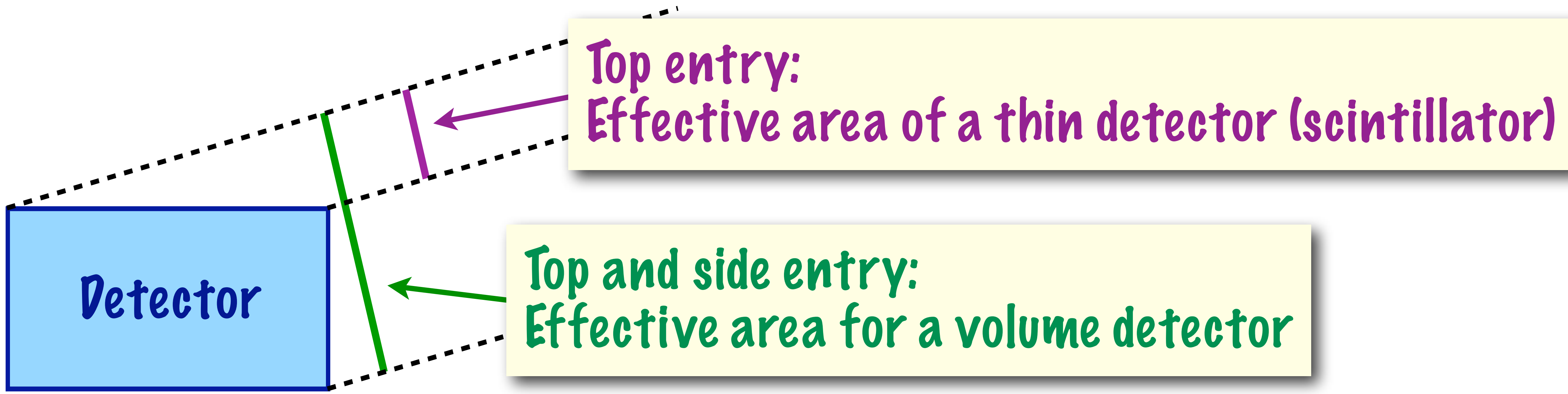


Neutrino detection in Auger

- We can tag neutrino events in very inclined showers
- Vertical atmosphere: ≈1000 g/cm^2
- Horizontal atmosphere: ≈36000 g/cm^2

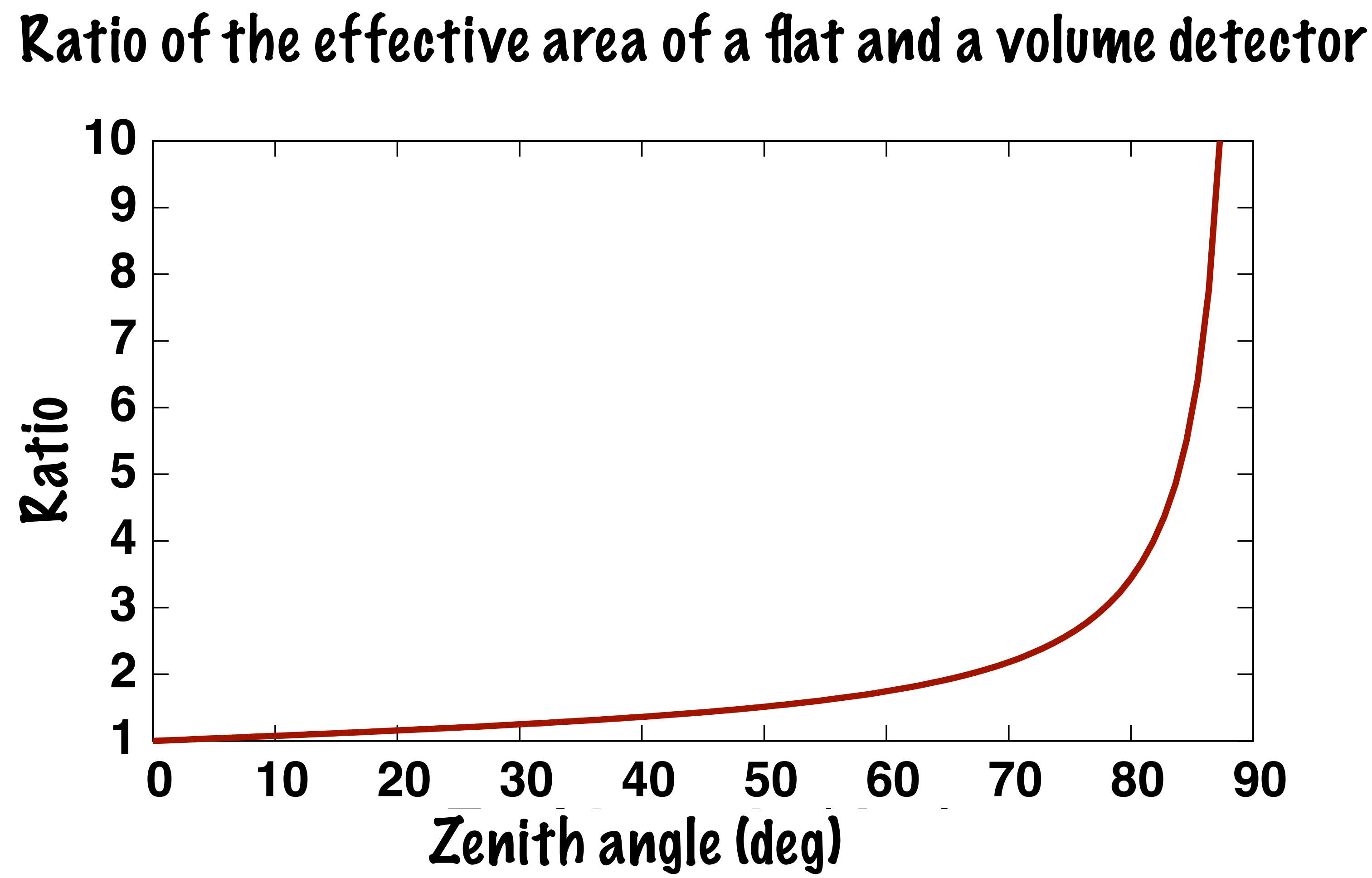
- Only neutrino induced showers can start deep in the atmosphere
- Caveat: or showers from exotics with low cross-section

Inclined shower detection

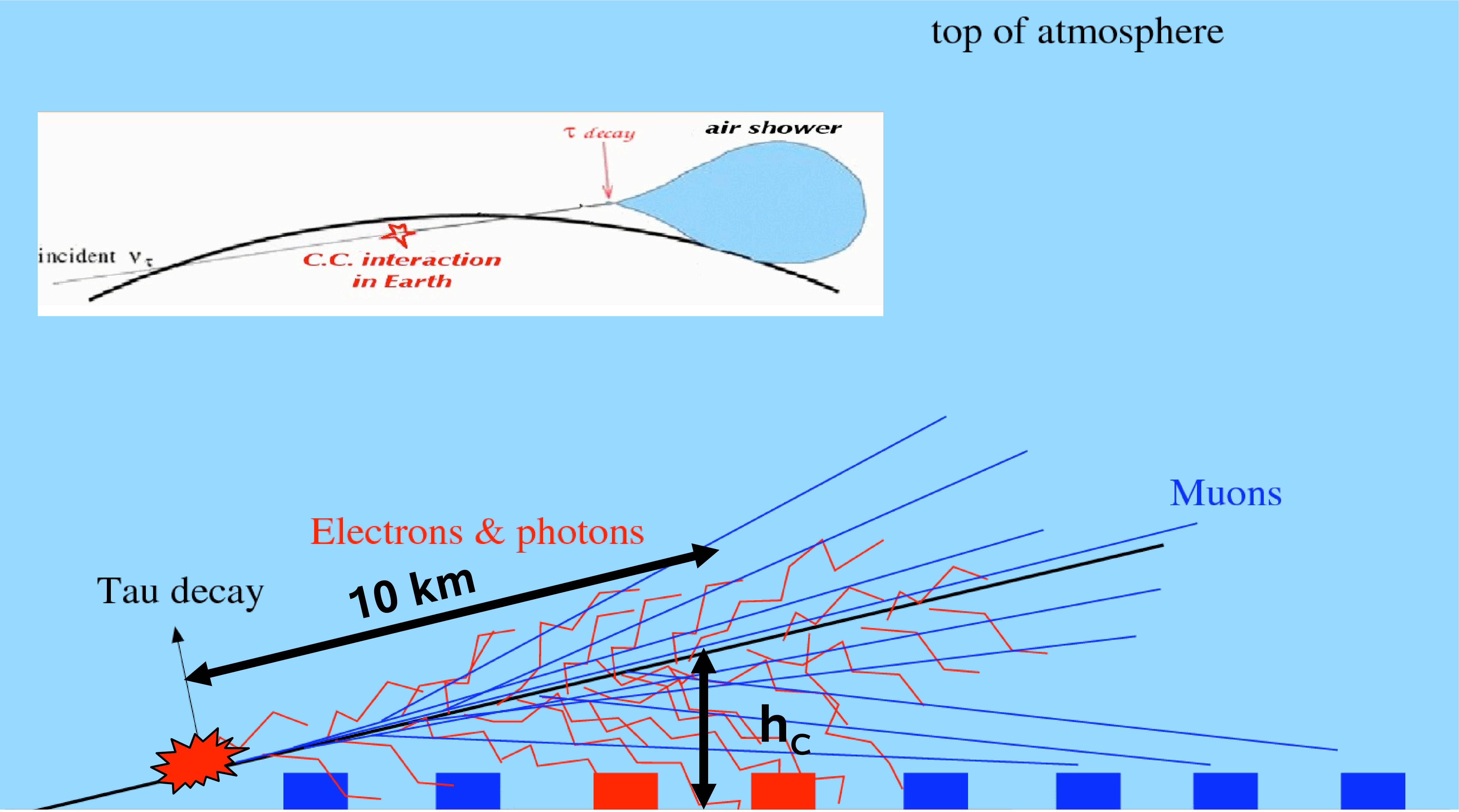


A volume detector captures more particles than a flat detector.

For Auger, the minimum area is 4.3 m² for horizontal entry.



up-going τ-neutrinos



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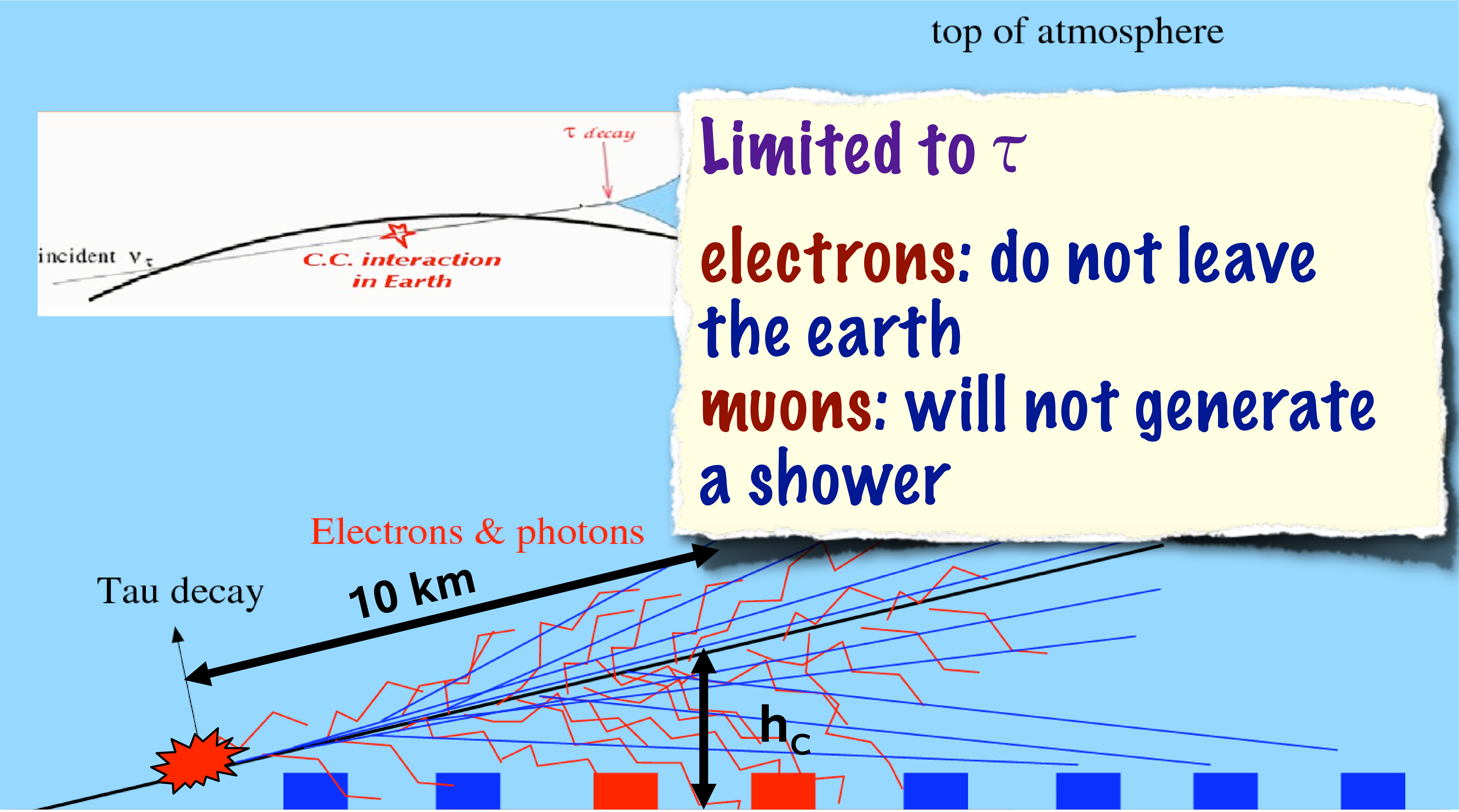


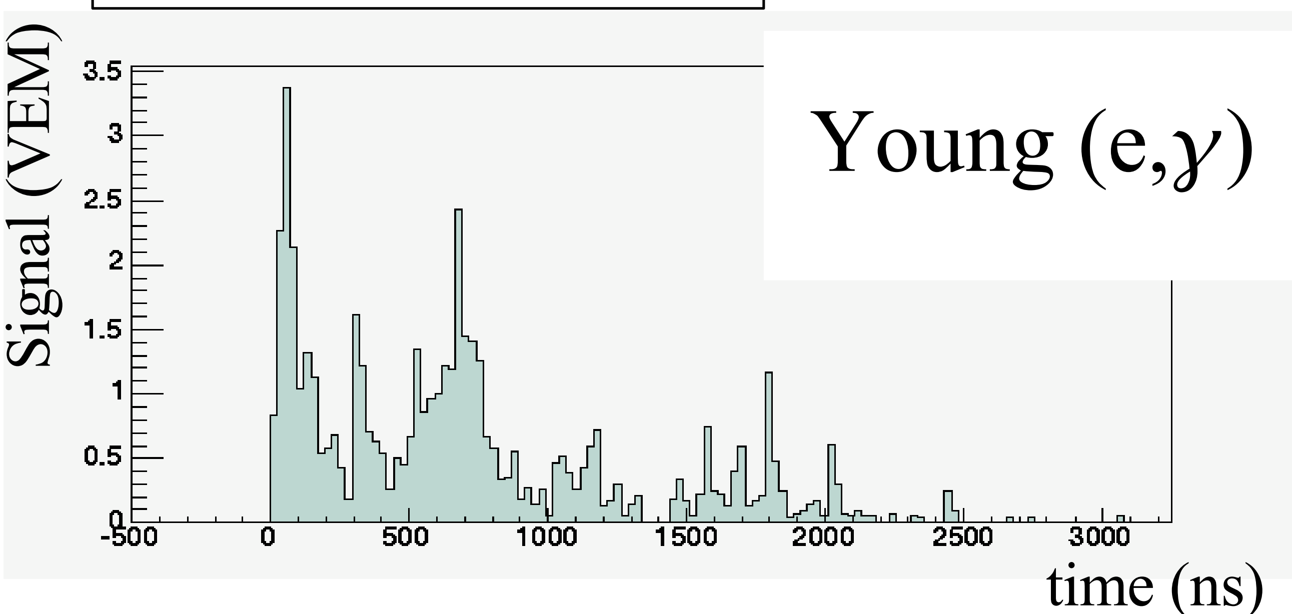
Limited to τ

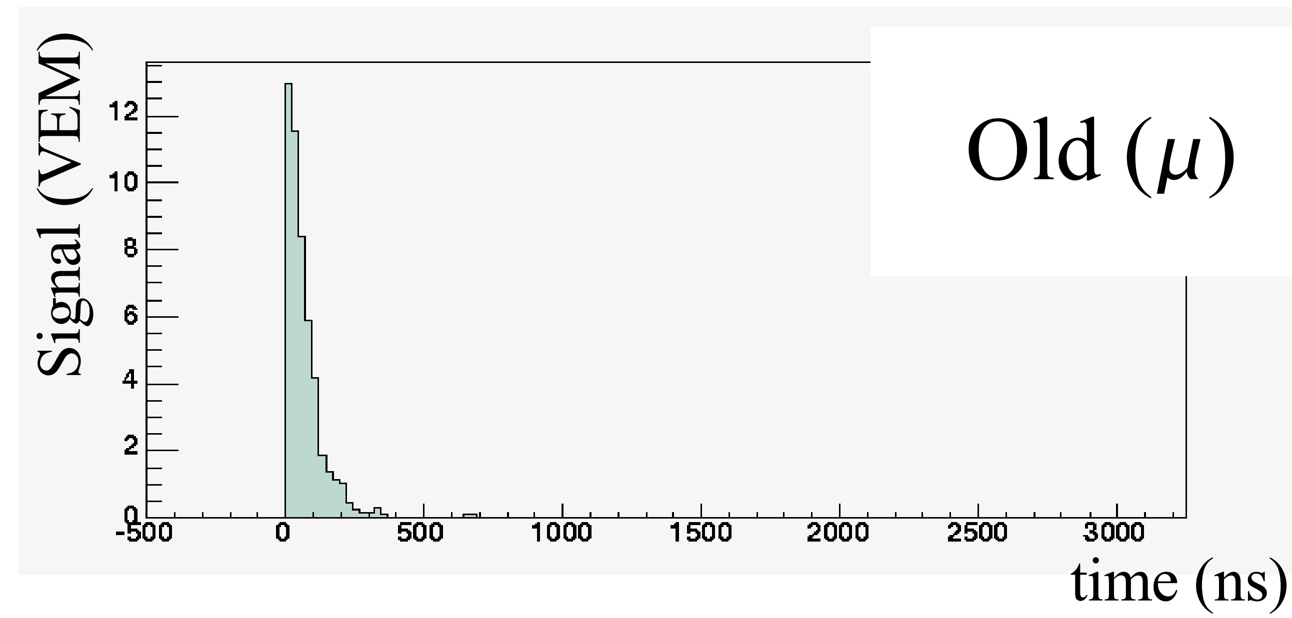
electrons: do not leave the earth

muons: will not generate a shower

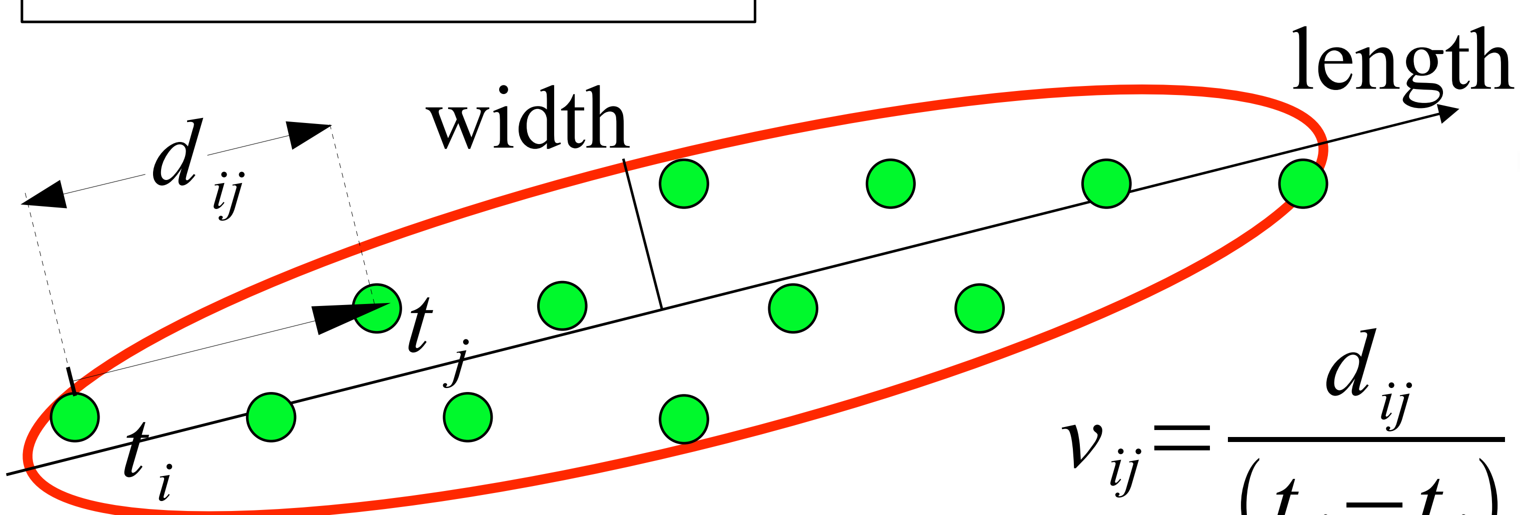
τ-identification

Young Showers





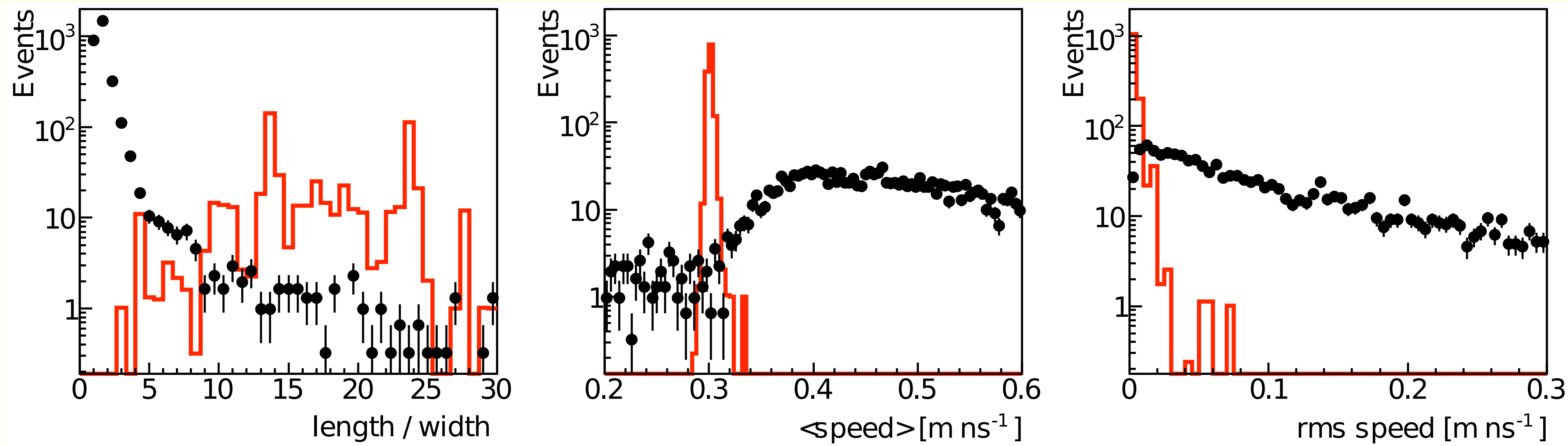
Inclined Showers

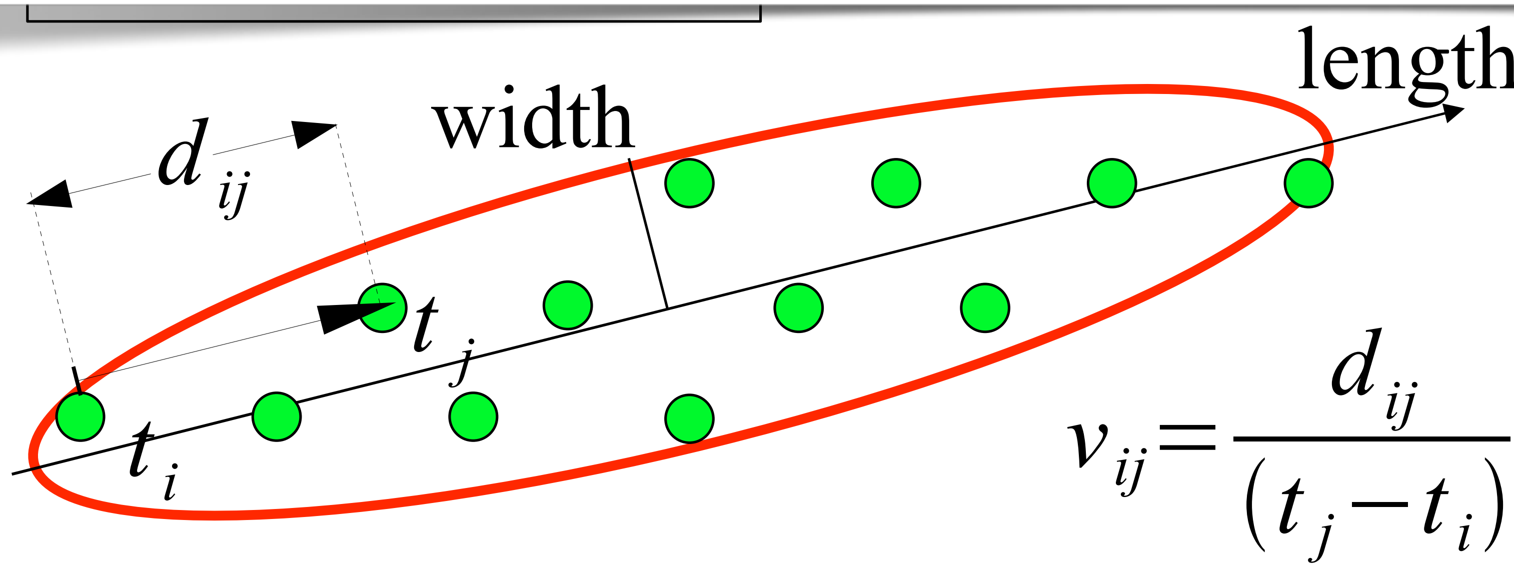


$$v_{ij} = \frac{d_{ij}}{(t_j - t_i)}$$

Length/width > 5
speed 0.29 < ⟨v⟩ < 0.32 m/ns
RMS(v) < 0.08 m/ns

τ-identification





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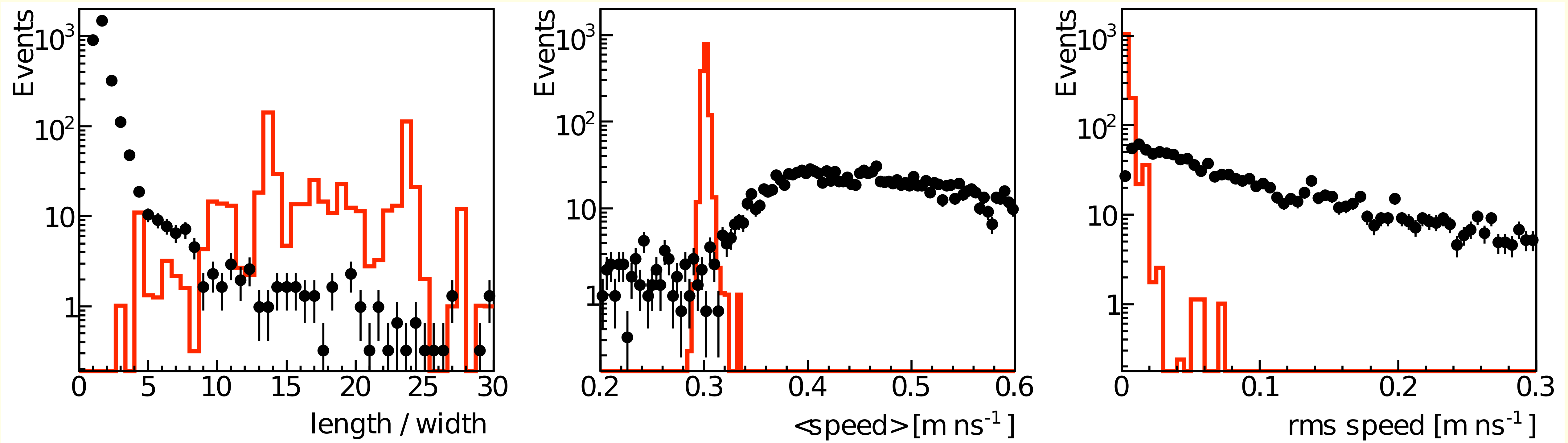

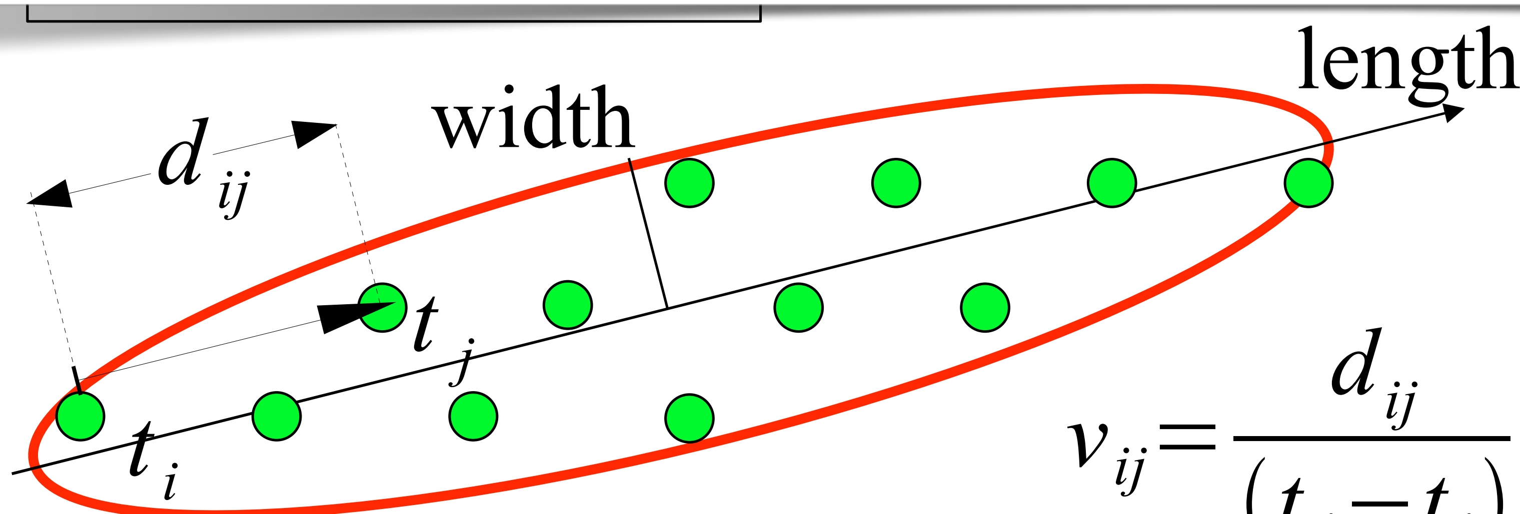

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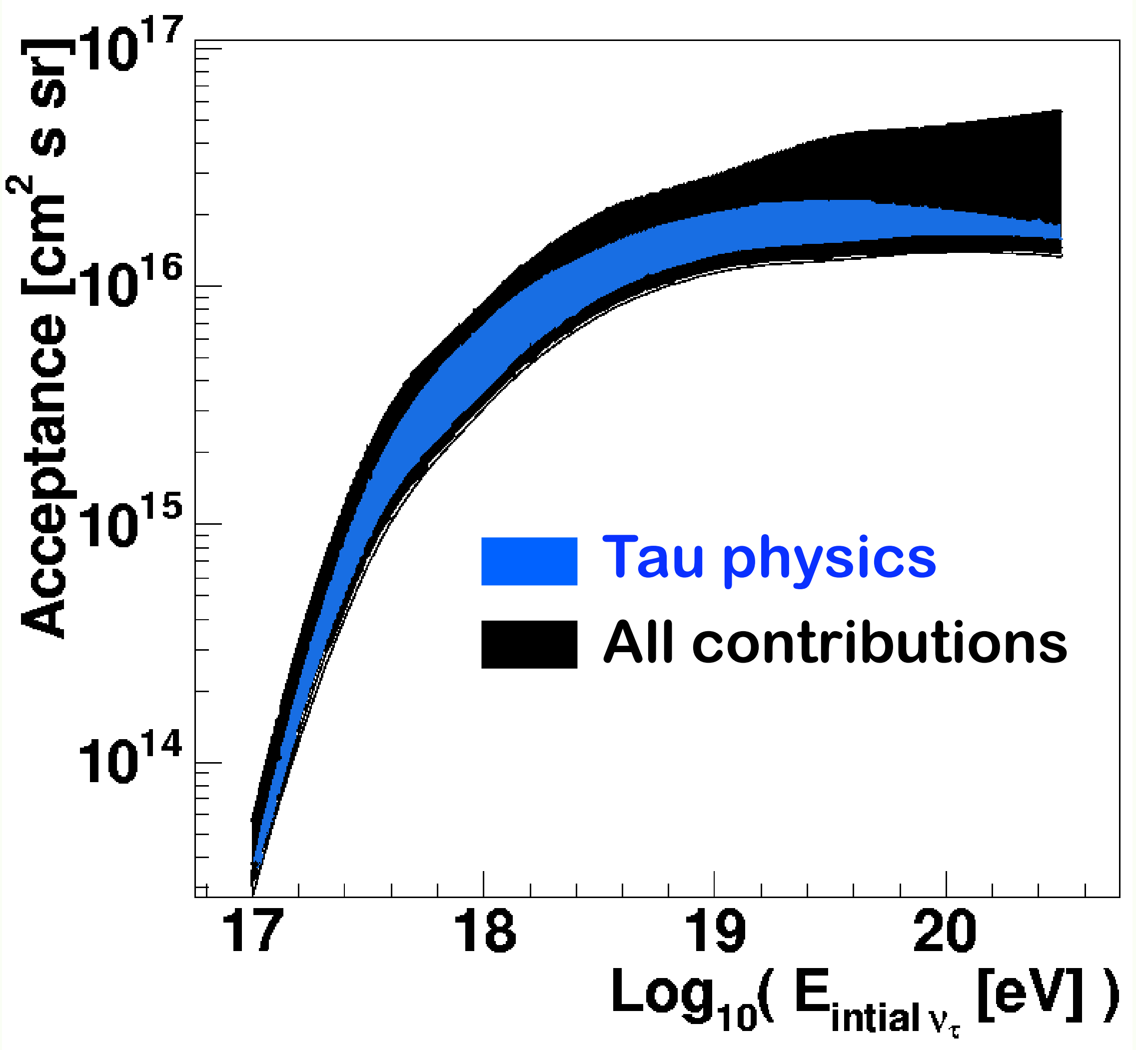
No candidates survive at 80% identification efficiency

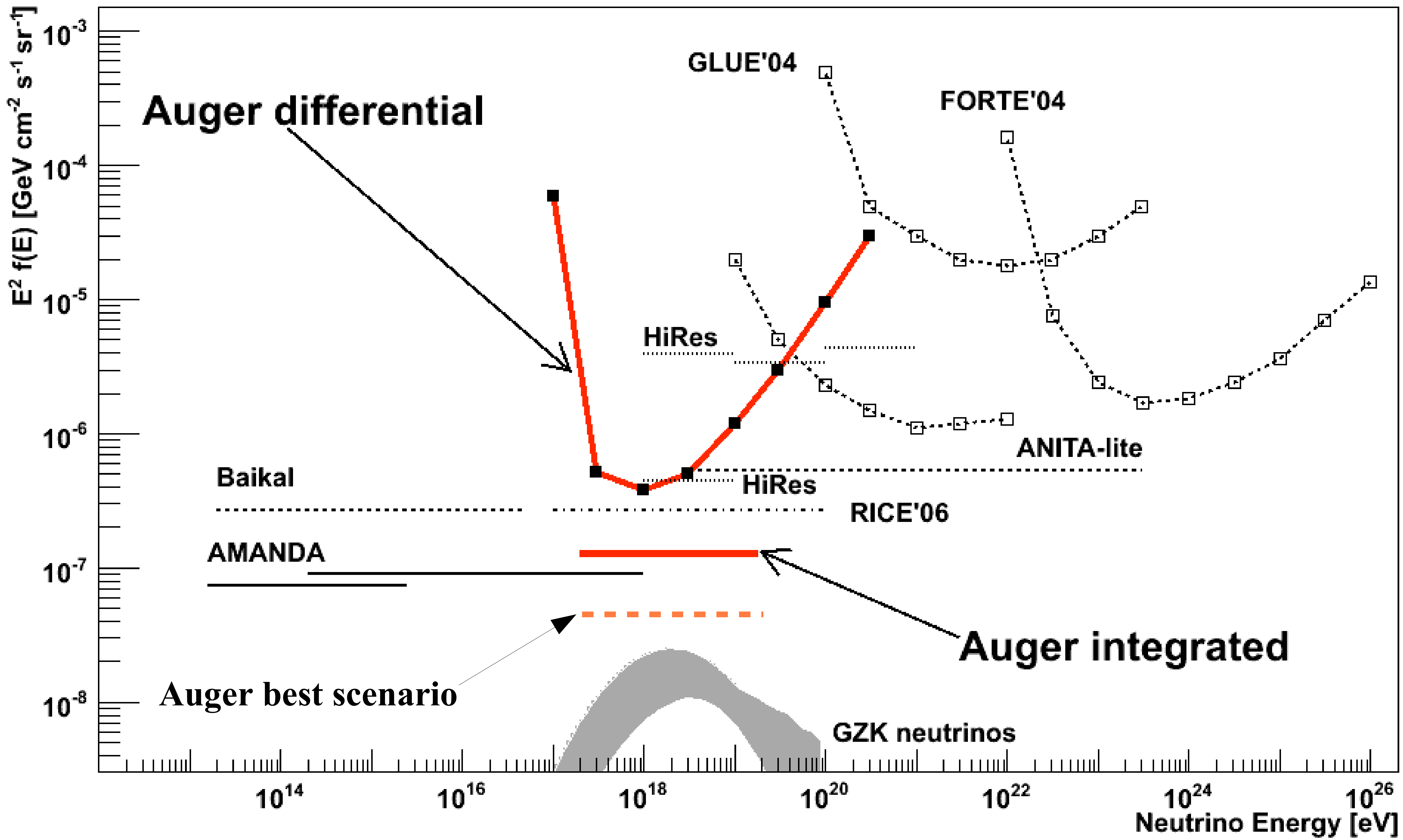
Systematics

- **Simulations**
  - Tau transport ±5%
  - EAS interations +20%, -5%
- **Pierre Auger Observatory**
  - Acceptance ±2%
  - Topography +18%
- **Tau Physics**
  - Polarisation +17%, -10%
  - Cross section +5%, -9%
  - Energy losses +25%, -10%
- **Combined +132%, -45%**



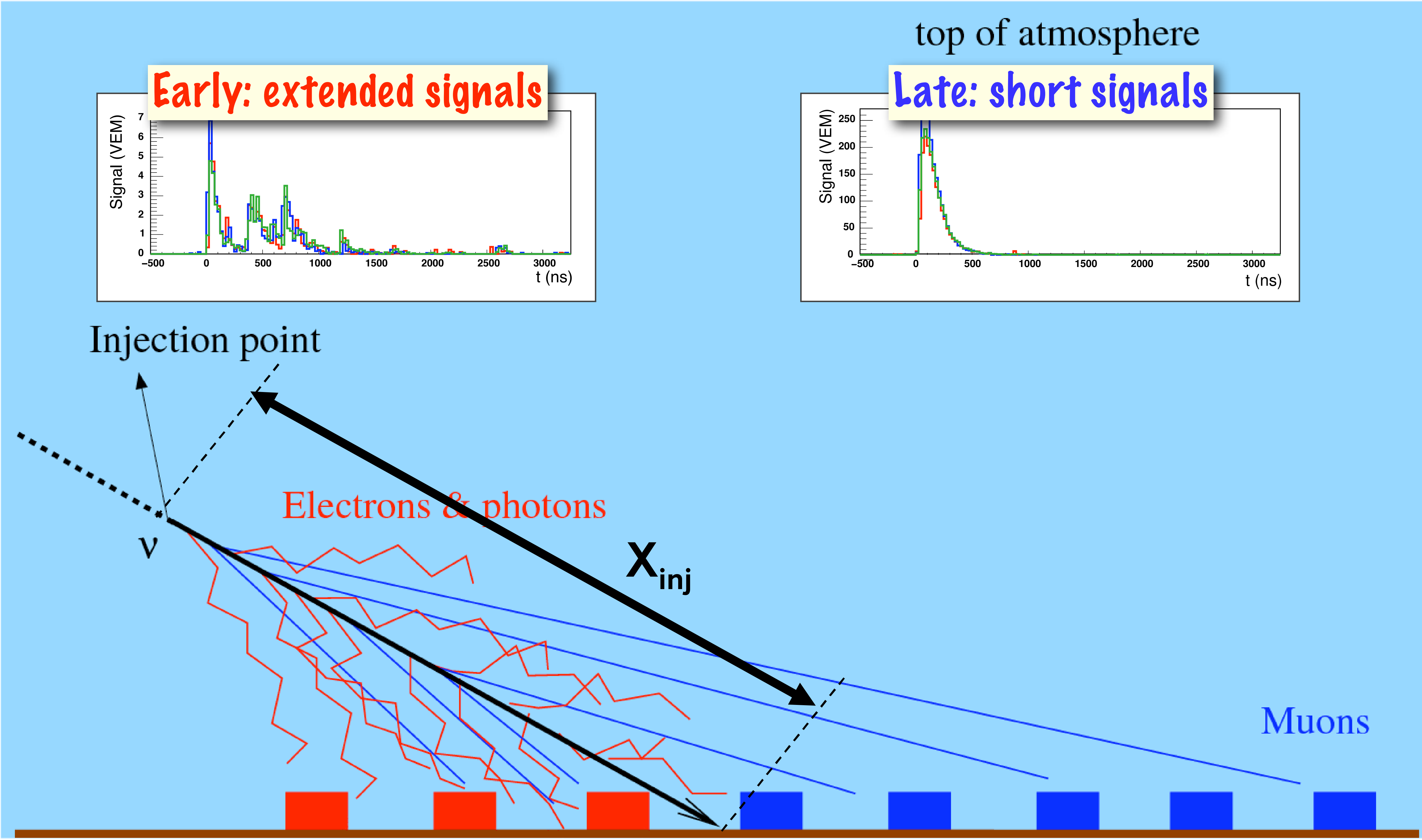
Factor 3 between best and worst case flux limits

Flux limit



E² f(E) [GeV cm⁻² s⁻¹ sr⁻¹]
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
GLUE'04
FORTE'04
Auger differential
HiRes
ANITA-lite
Baikal
HiRes
RICE'06
AMANDA
Auger integrated
Auger best scenario
GZK neutrinos
10¹⁴
10¹⁶
10¹⁸
10²⁰
10²²
10²⁴
10²⁶
Neutrino Energy [eV]

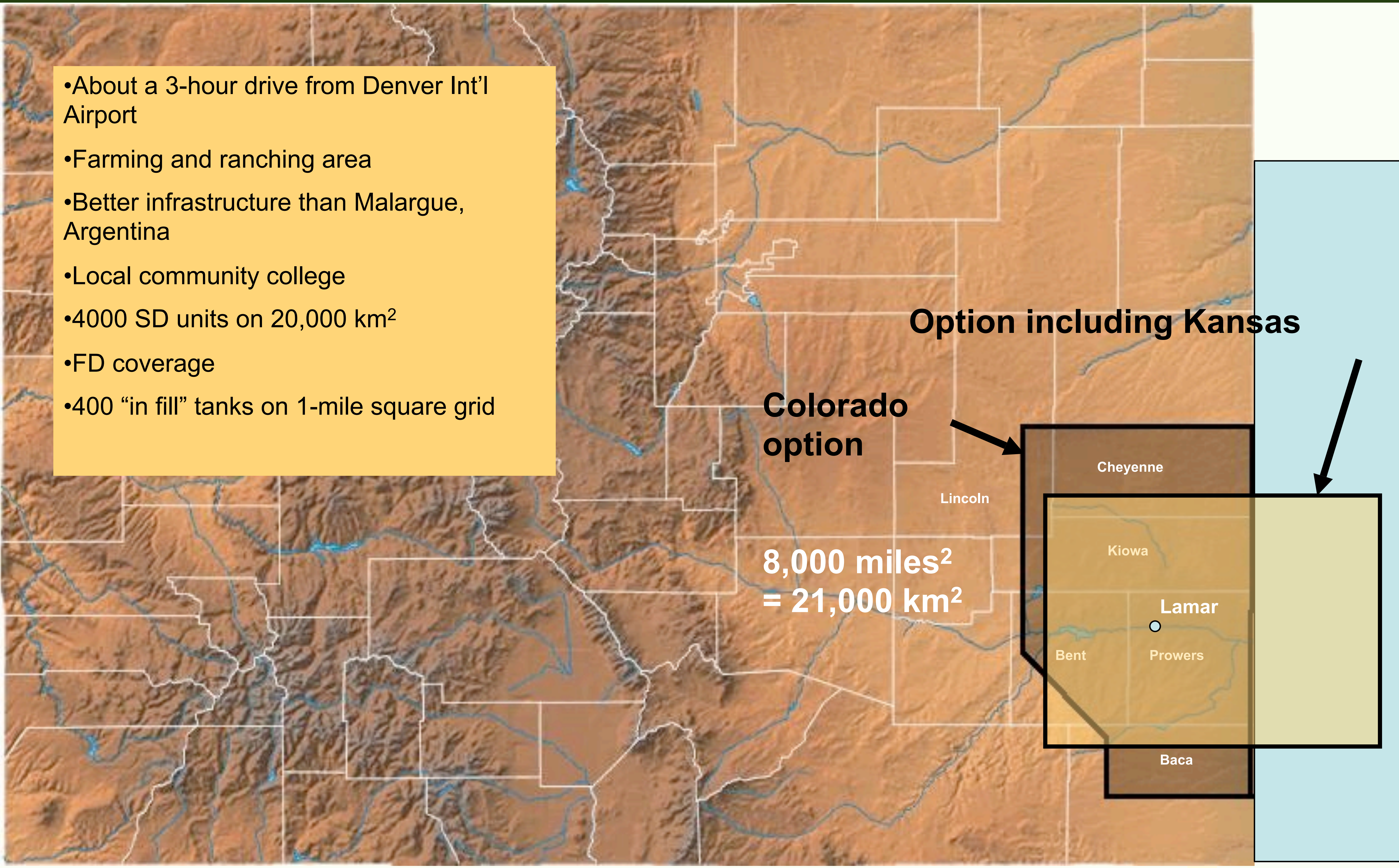
Down-going neutrinos



The Future

Auger North

- About a 3-hour drive from Denver Int'l Airport
- Farming and ranching area
- Better infrastructure than Malargue, Argentina
- Local community college
- 4000 SD units on 20,000 km^2
- FD coverage
- 400 "in fill" tanks on 1-mile square grid

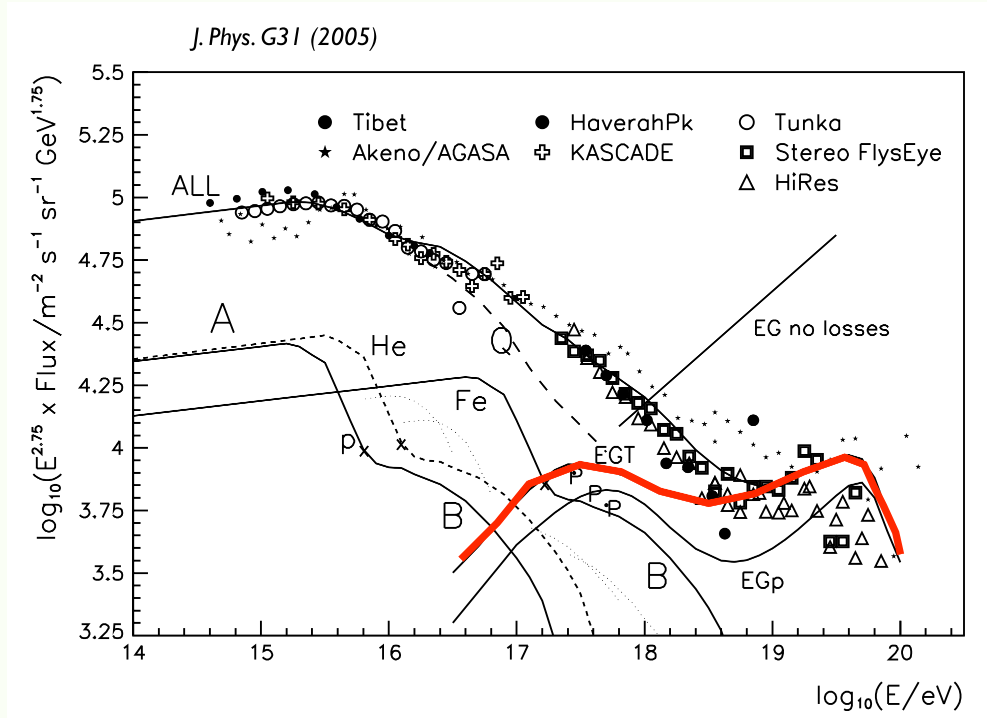


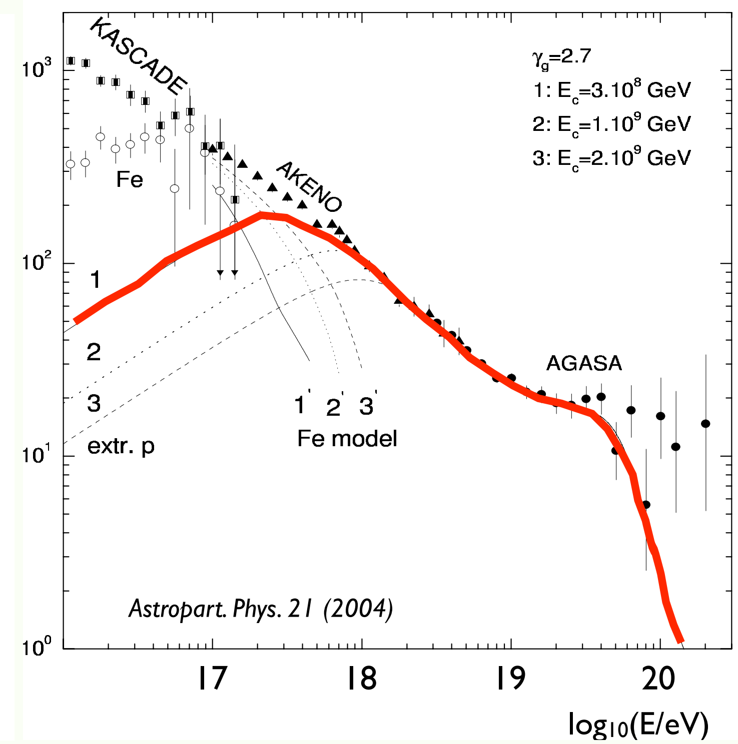
Why Auger North

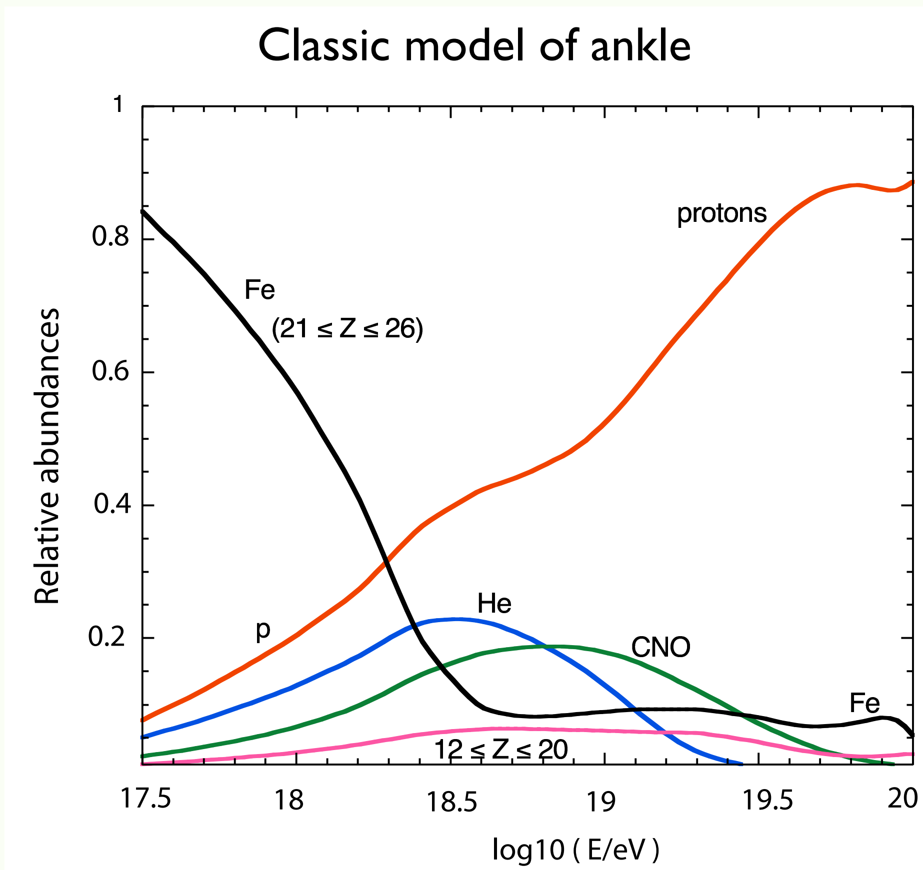
- Auger was always designed for full sky coverage
  - Is the northern sky different from the southern sky?
- Northern hemisphere air-shower detector complements ice-cube on the south-pole
- Flux suppression: we need bigger area
- Would like to get spectra from individual sources: we need bigger area
- Additional benefit: more statistics for neutrino detection

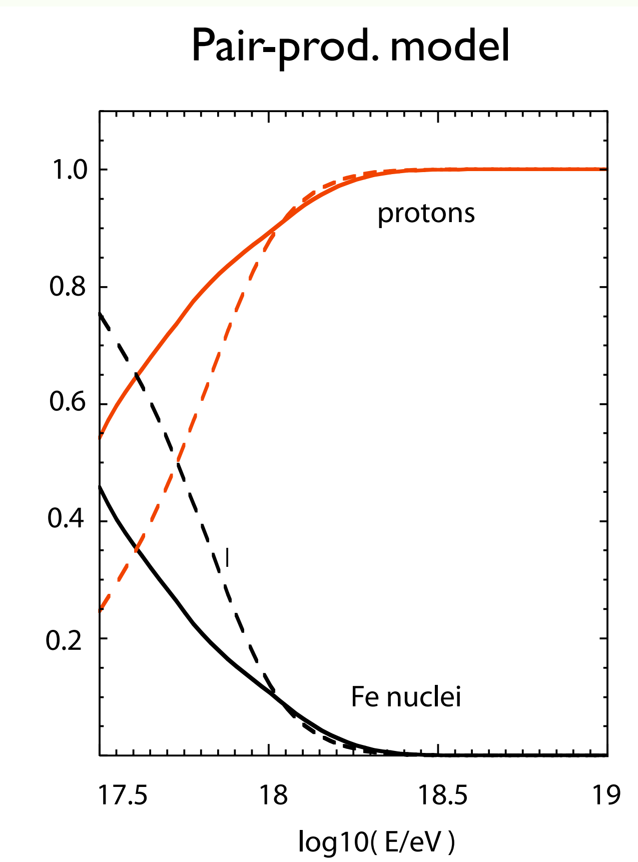
Low Energy extensions

- Study region of the knee
  - Transition from galactic to extra-galactic cosmic rays
  - Different models predict different composition





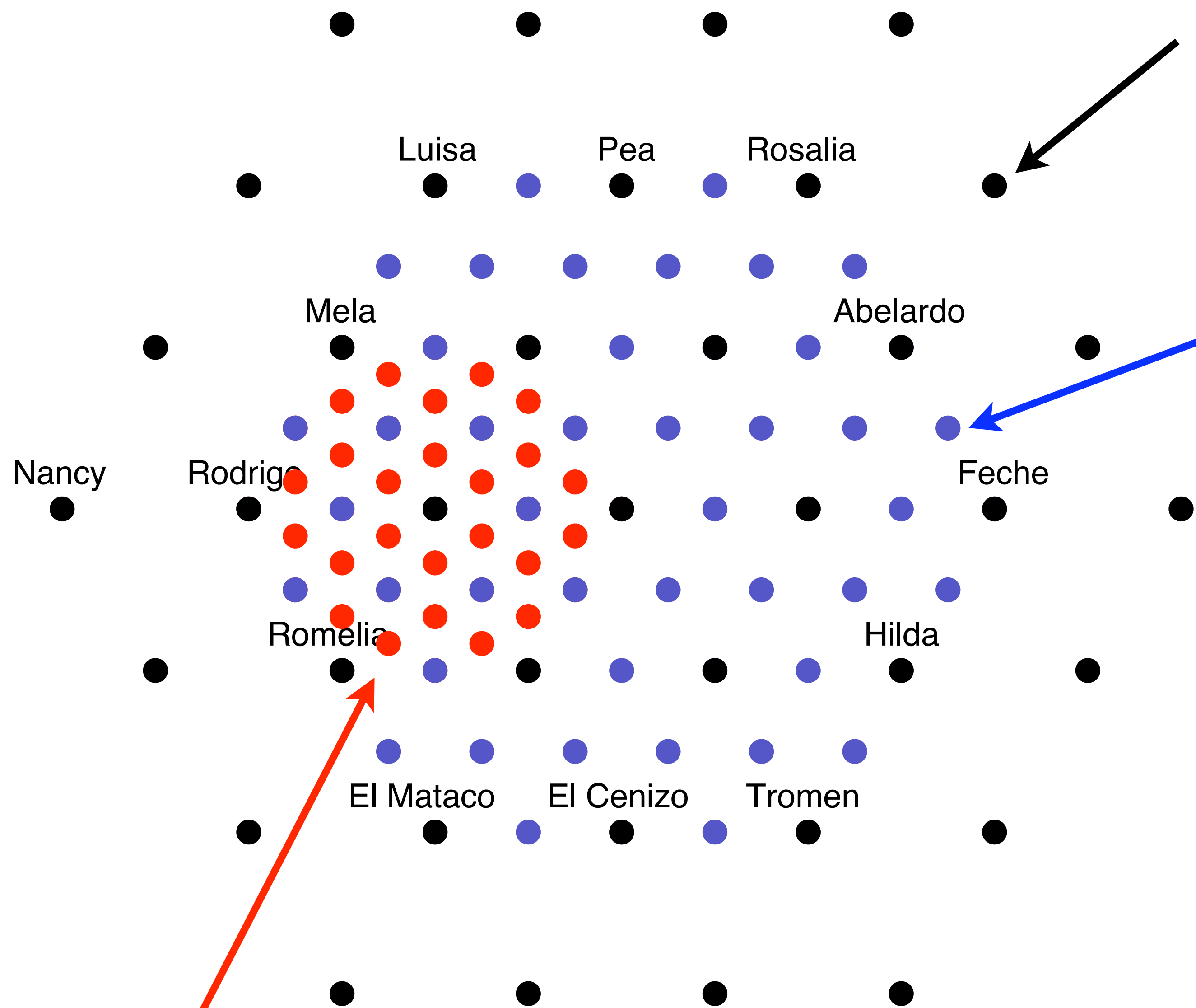




In-fill and muon detectors

PIERRE AUGER OBSERVATORY

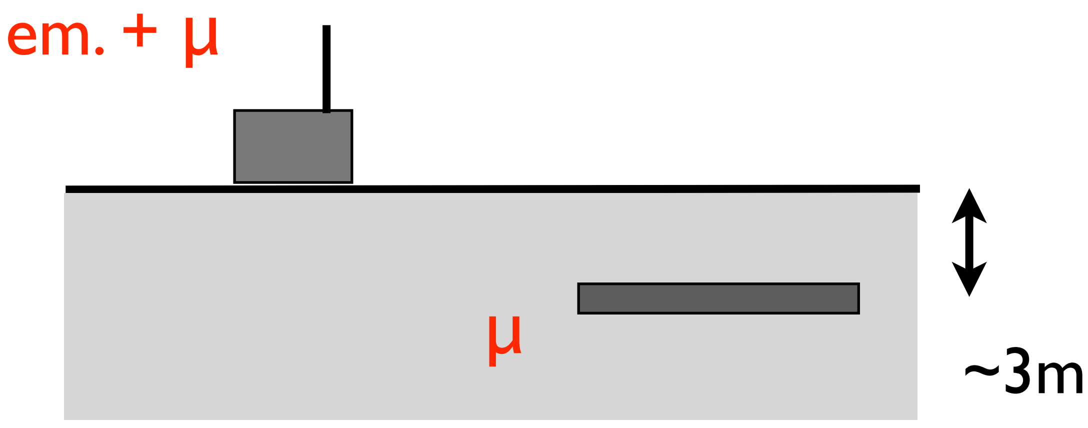
Existing tank array 1500m



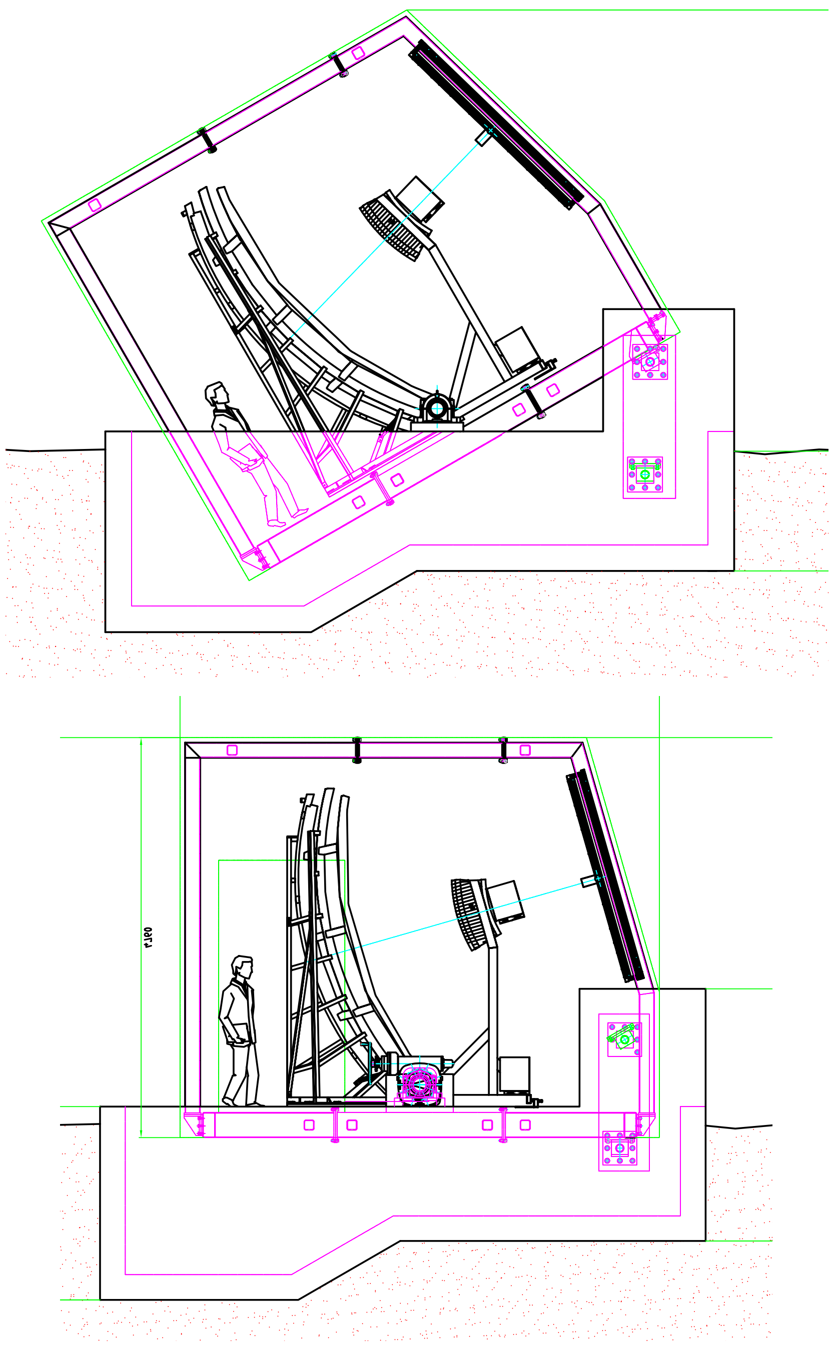
Infill array 750m
42 additional detectors
Area ~ 23.5 km^2

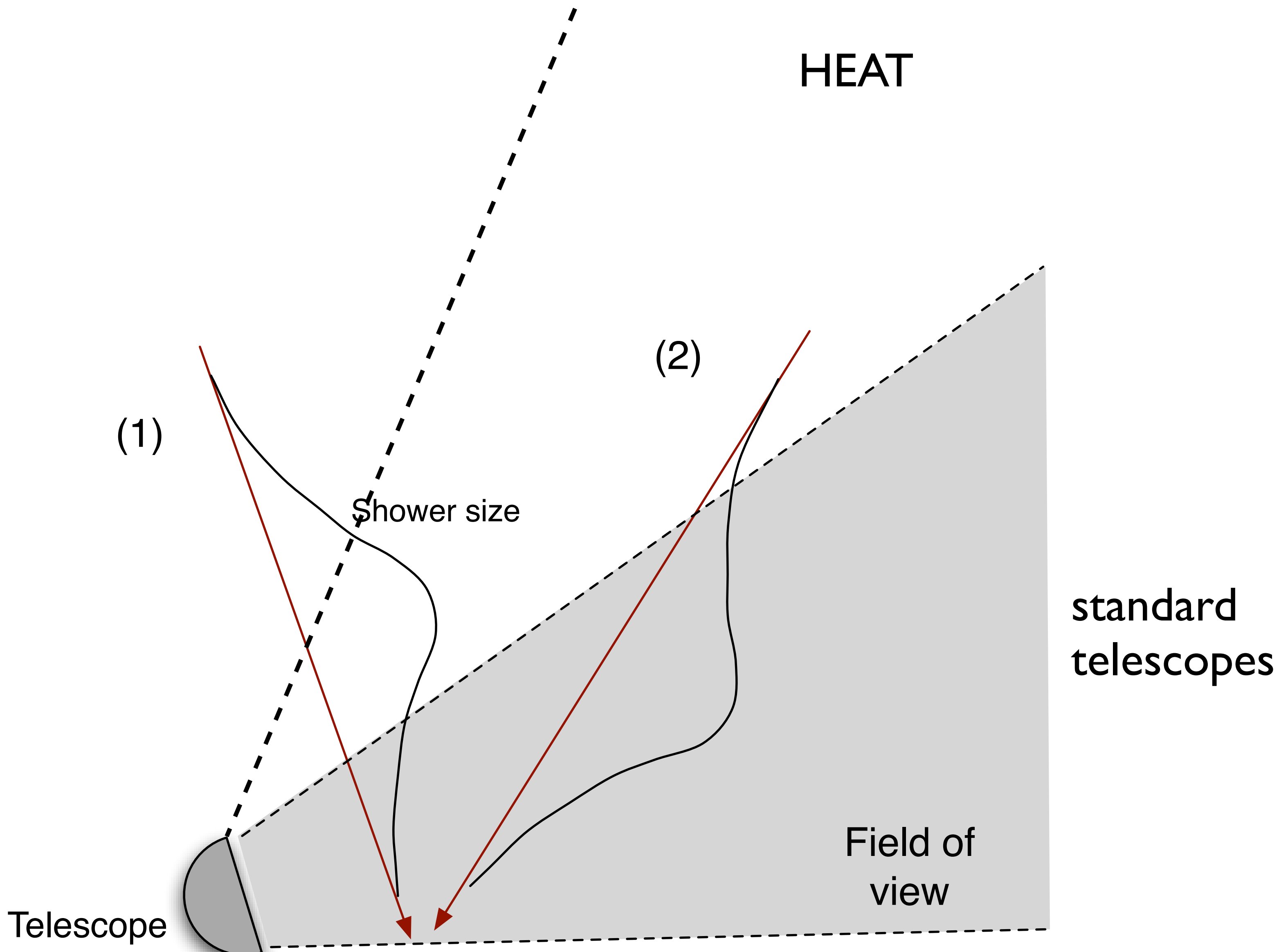
Infill array 433m
24 additional detectors
Area ~ 5.9 km^2

Each of the 85 detectors:
pair of Cherenkov tank
and muon counter



High-Elevation telecopes





- 3 ``standard´´ Auger telescopes tilted to cover 30 - 60° elevation
- Custom-made metal enclosures
- Also prototype study for northern Auger Observatory


Thank you