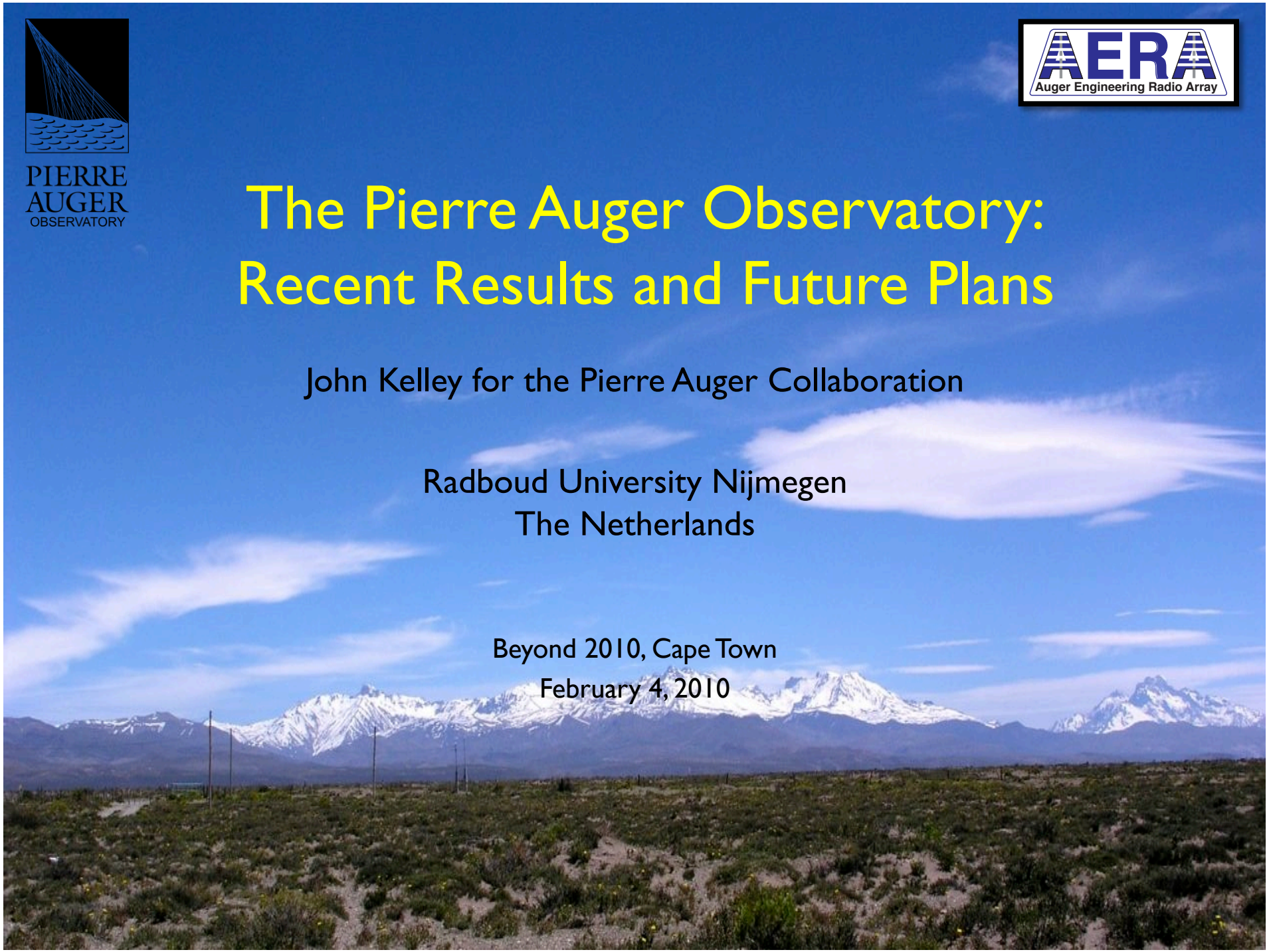


The Pierre Auger Observatory: Recent Results and Future Plans

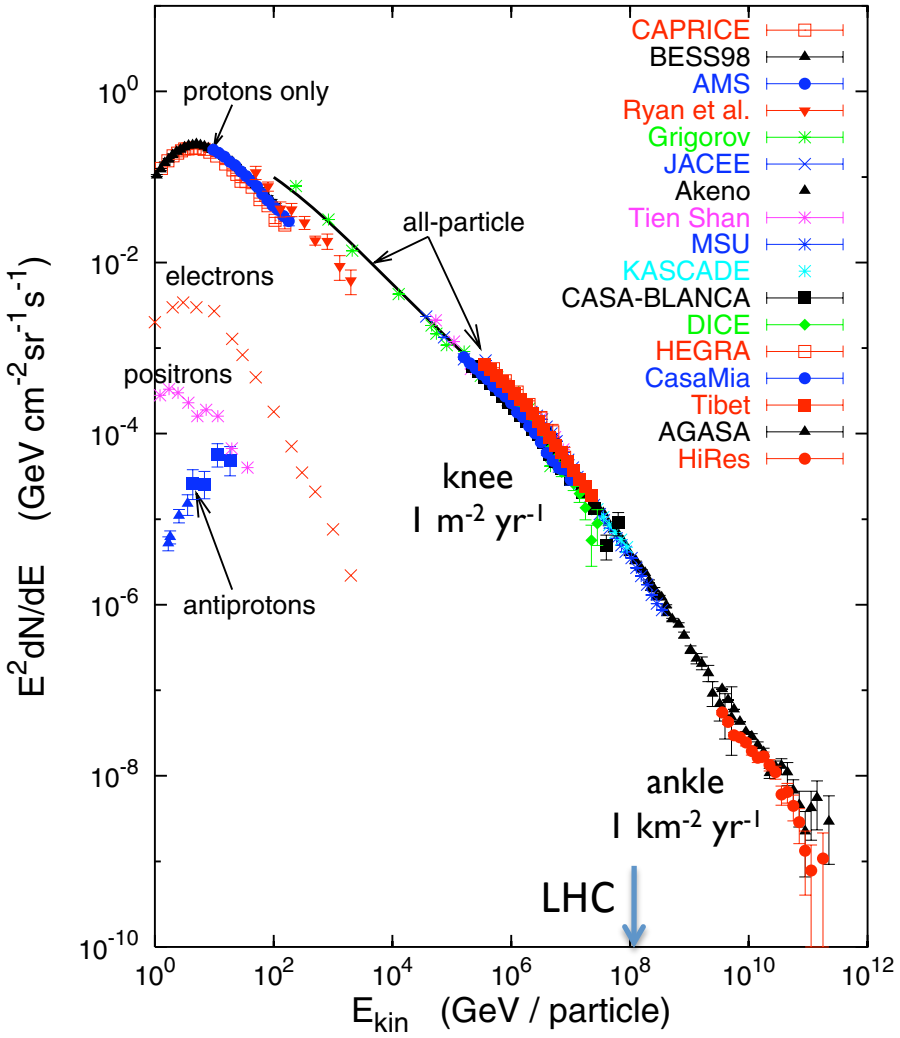
John Kelley for the Pierre Auger Collaboration

Radboud University Nijmegen
The Netherlands

Beyond 2010, Cape Town
February 4, 2010

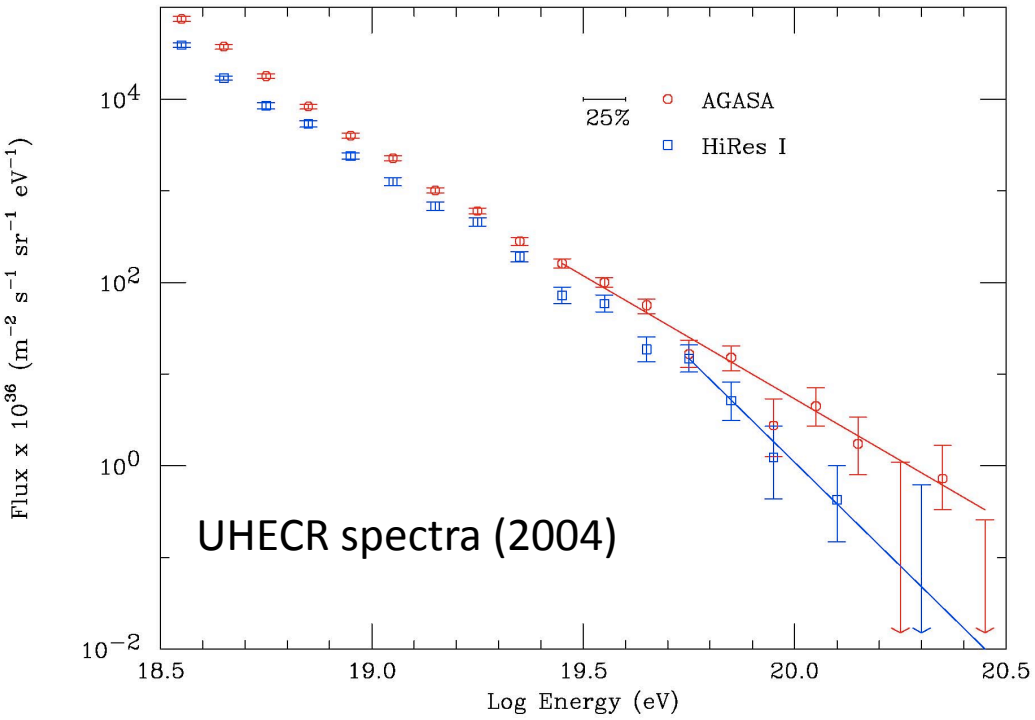
Cosmic Ray Spectrum

- Charged particles with steep power law spectrum
- Low flux at high energy: detect via extensive air showers
- Opportunities for new physics:
  - cosmic ray sources
  - cosmic ray composition
  - UHE particle interactions / propagation



Gaisser 2004

Ultra-High Energy Cosmic Rays (UHECR)

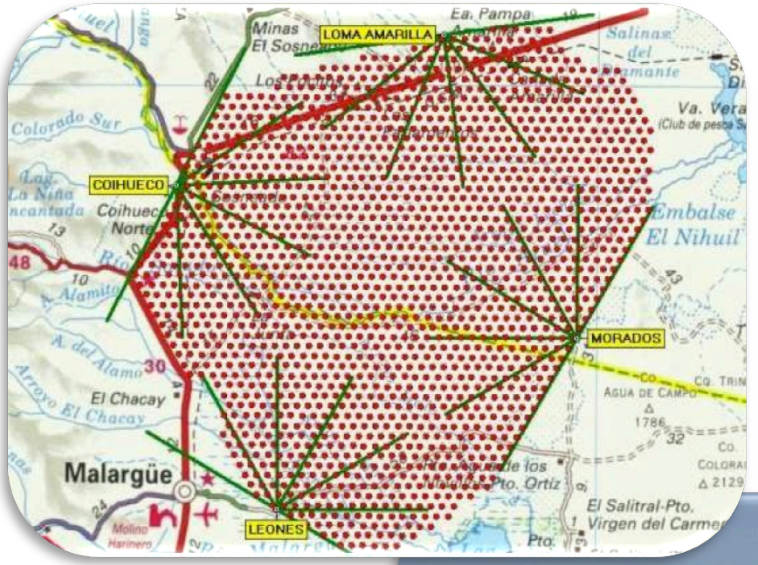


UHECR spectra (2004)

- Highest energy particles known in the Universe
- Composition unknown
- Sources + acceleration mechanism unknown
  - Astrophysical acceleration or decay of exotic particles? More later…
- Cutoff in spectrum or not?
  - Expected from interactions with CMB (GZK effect)

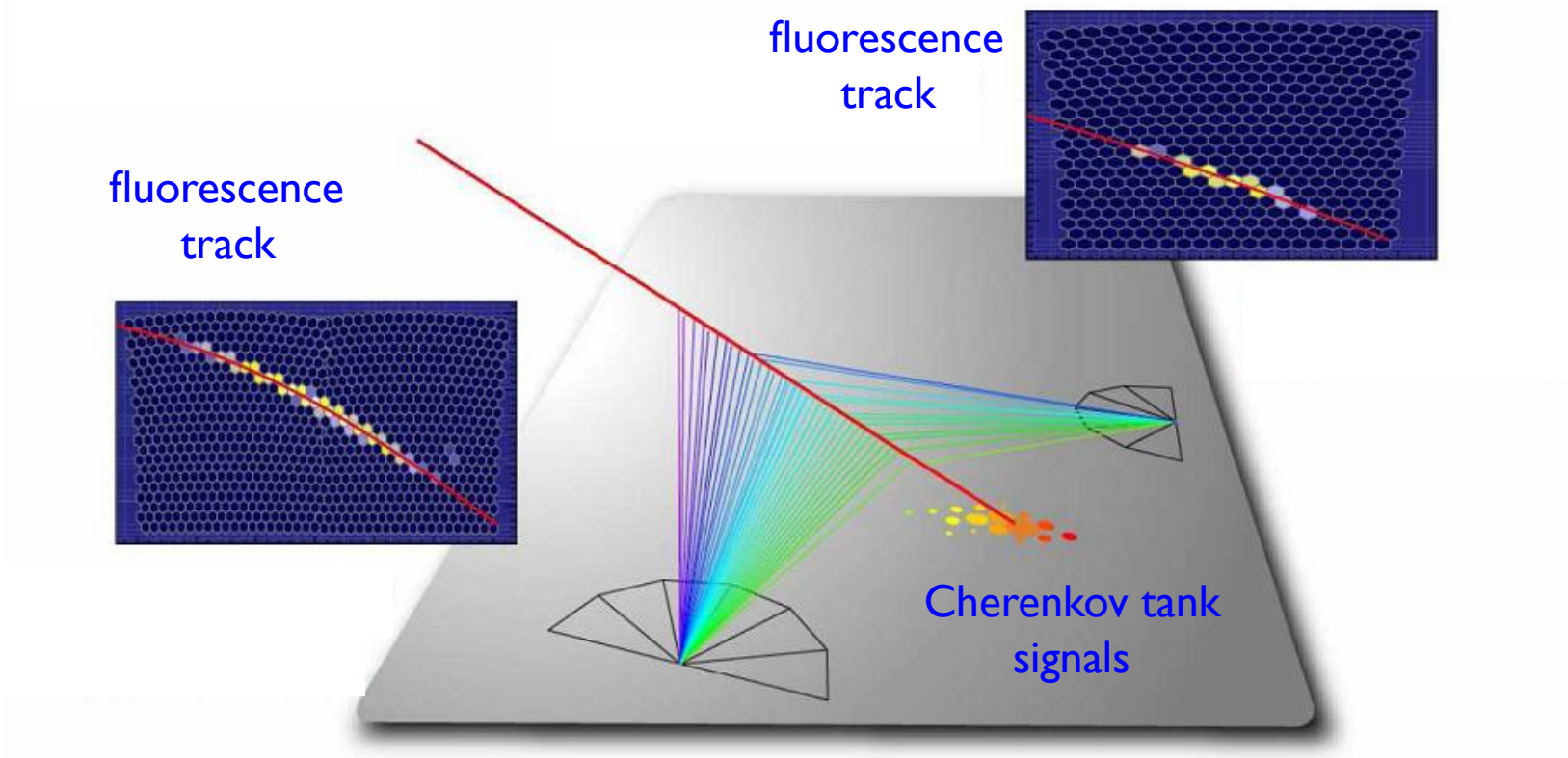
Pierre Auger Observatory

- Hybrid air shower detector
- Southern site (3000 km^2) in Argentina completed 2008
- Northern site (21000 km^2) planned for Colorado, U.S.A.



Auger South

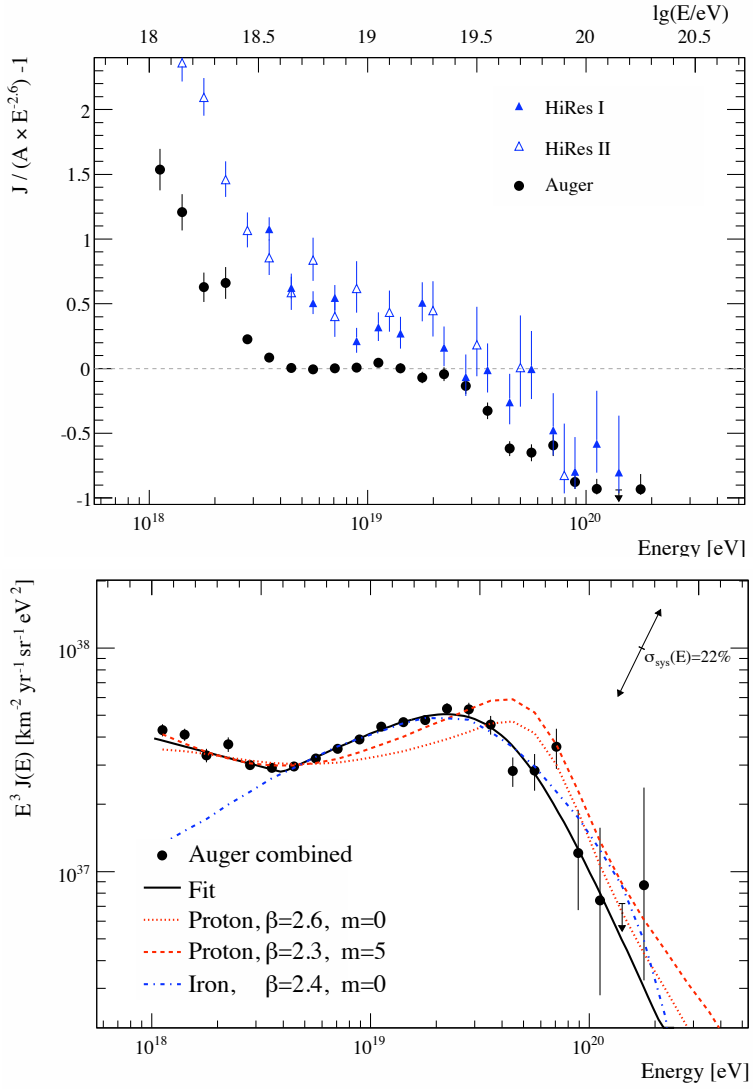
Hybrid Detection



Hybrid observation: energy cross-calibration (~20%), better angular resolution (~0.5°)

… but FD duty cycle is ~10%

Latest Results: UHECR Energy Spectrum



Schüssler *et al.* 2009

- 2008: Continuation of power law rejected at 6σ (confirms HiRes)
- Suppression energy consistent with GZK onset
- 2009: combined FD + SD spectrum
  - protons with strong source evolution?
  - iron with another component below ankle?
- Difficult to rule out non-GZK causes
  - source cutoff?
  - Lorentz violation? see *e.g.* Scully & Stecker 2008

Latest Results: Anisotropy

Hague *et al.* 2009 (ICRC)

Release pending

2007: 27 events above 55 EeV (ovals); correlation with nearby AGN (red crosses)

2009: 58 events above 55 EeV: correlation with original AGN catalog weakens

Isotropy rejected at 99% CL

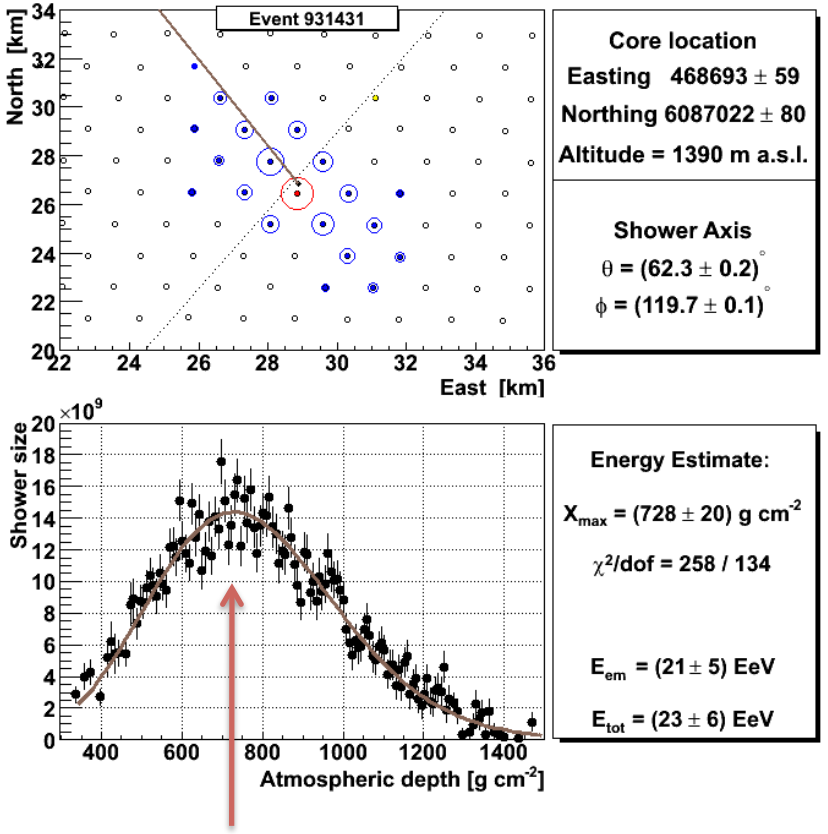
A posteriori investigations of:

- Centaurus A region
- correlations with other catalog(s)
  e.g. SWIFT-BAT

Composition

- Slant depth X_{max} (integrated density) of shower maximum in atmosphere
  - energy and composition-dependent
  - higher in atmosphere for heavier nuclei (interact, lose energy sooner)

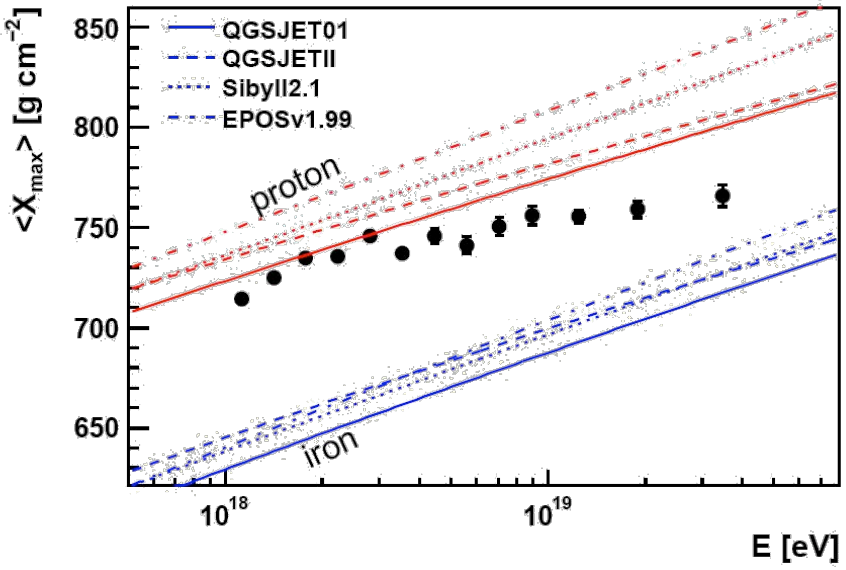
- Shower-to-shower fluctuations of X_{max}
  - iron showers (~superposition of many single-nucleon showers) have fewer fluctuations

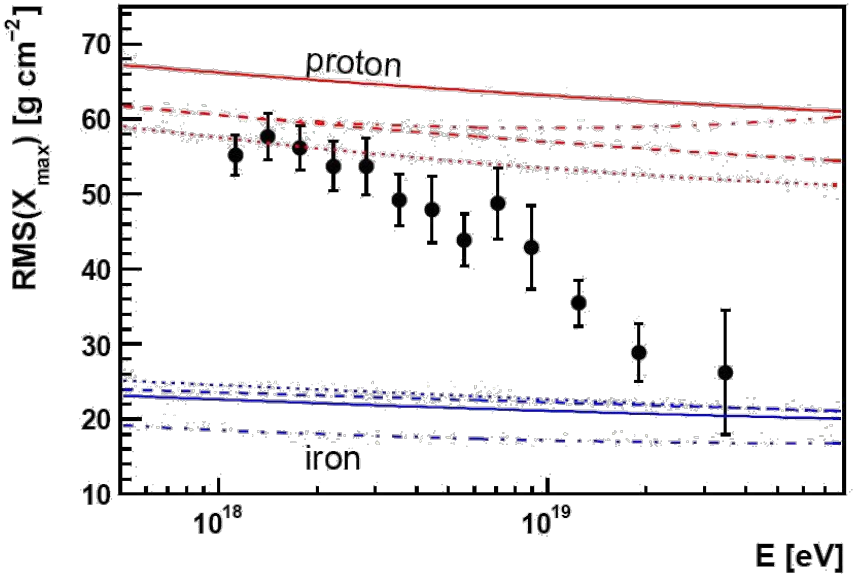


X_{max}

Latest Results: Composition

Bellido *et al.* 2009 (ICRC)
Abraham *et al.*, accepted PRL (2010)

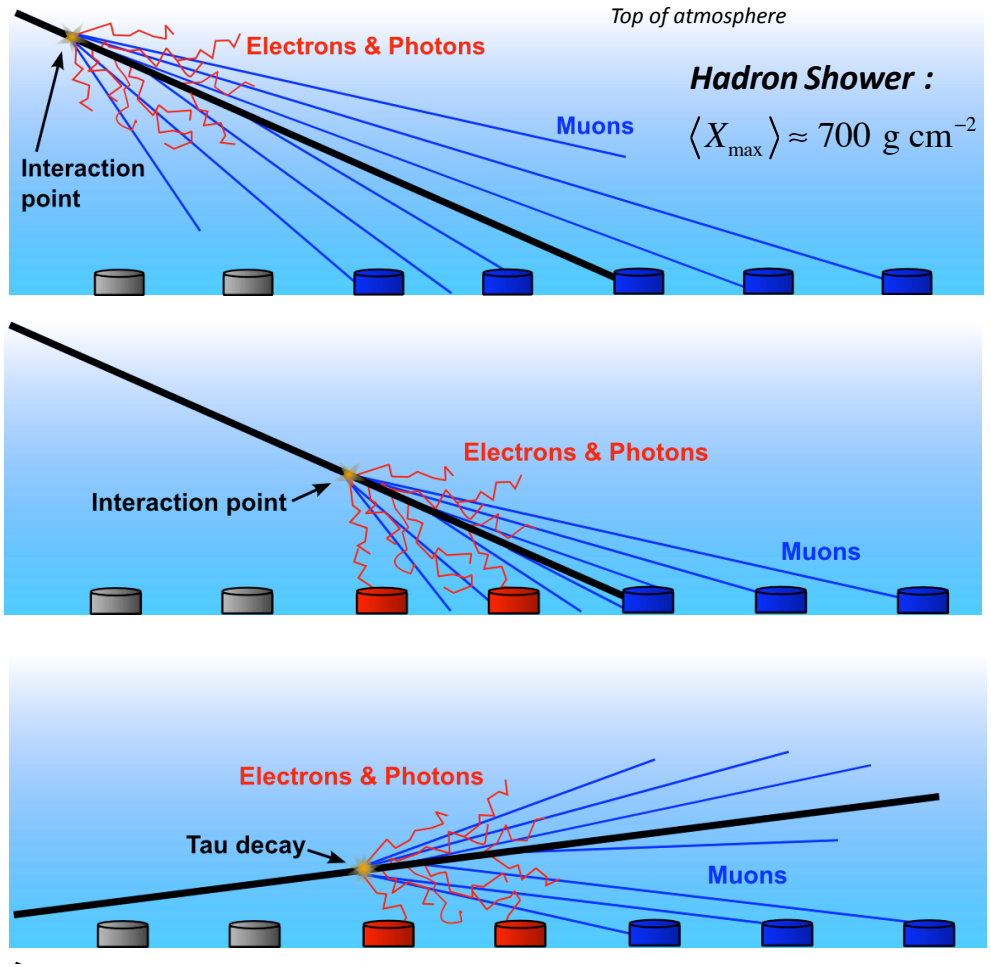




Both indicate composition getting heavier…

or protons behaving differently than expected?
(see e.g. Ulrich *et al.*, arXiv:0906.3075)

Neutrino Detection via Air Showers

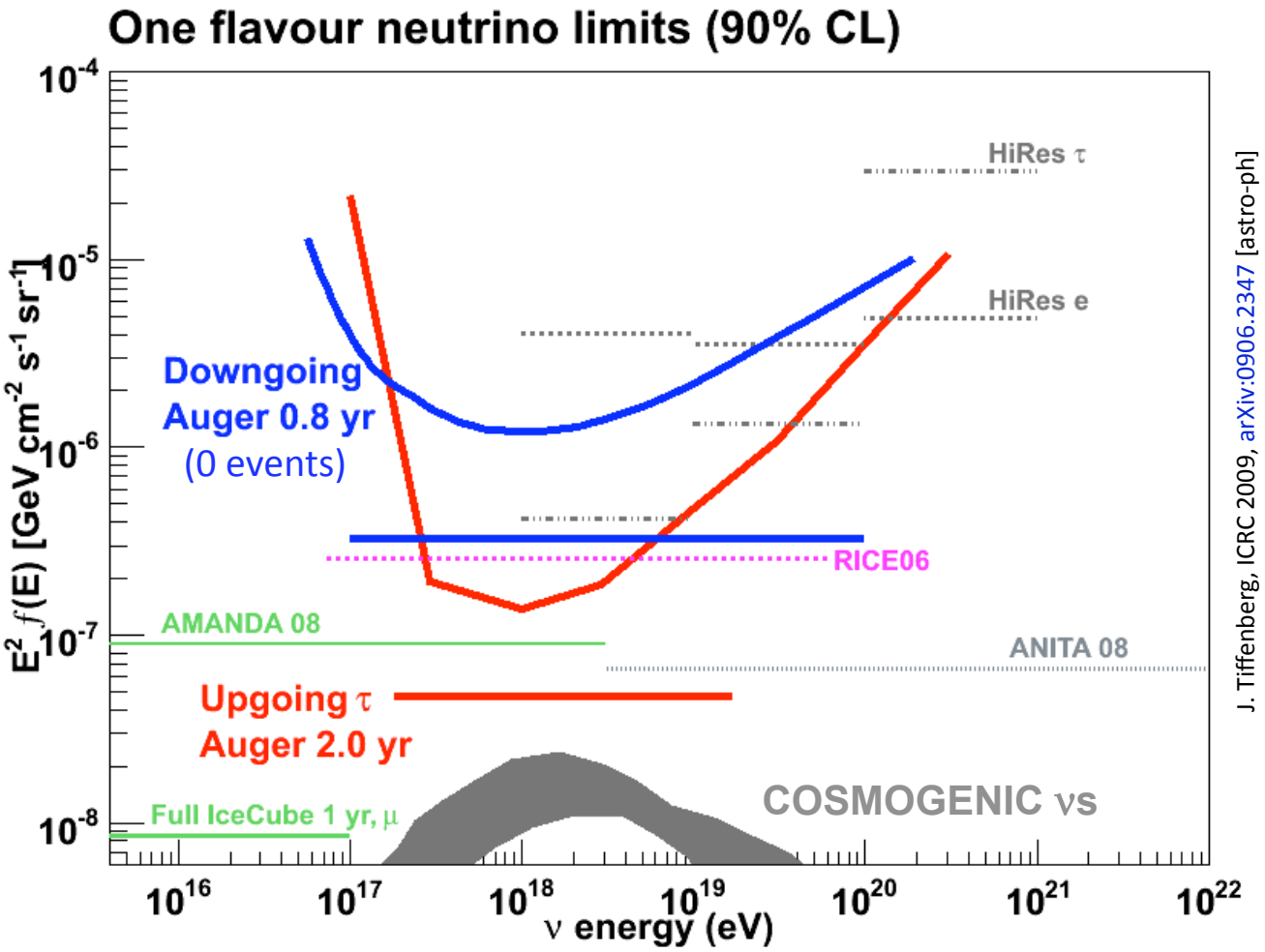


"normal" inclined shower:
only muons left

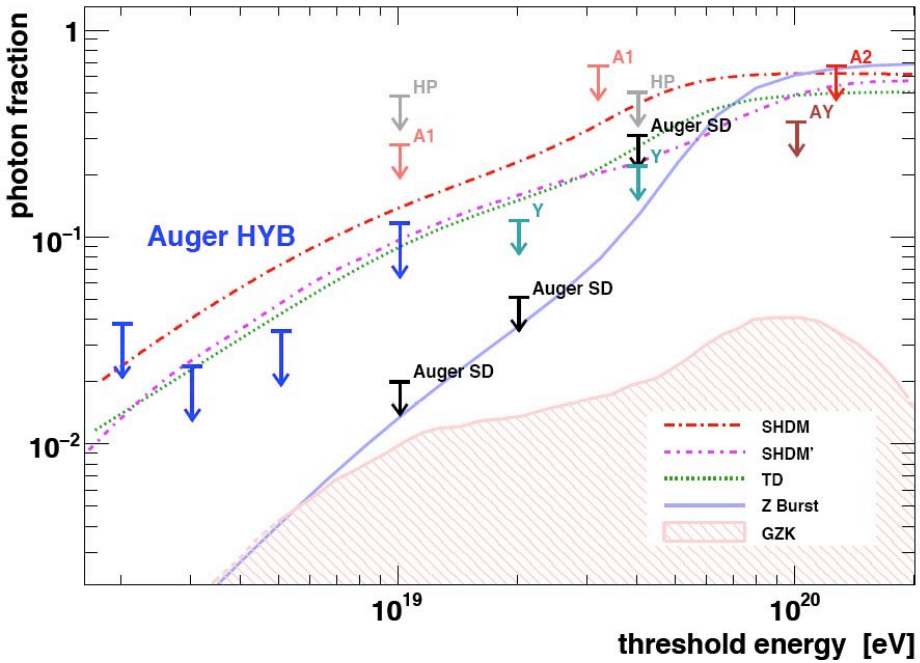
neutrino-induced shower:
young EM component
(broad signals in tanks)

tau decay from Earth-skimming ν_τ:
dense target, but only one flavor

Limits on Diffuse Neutrino Flux



Photon Fraction Limits

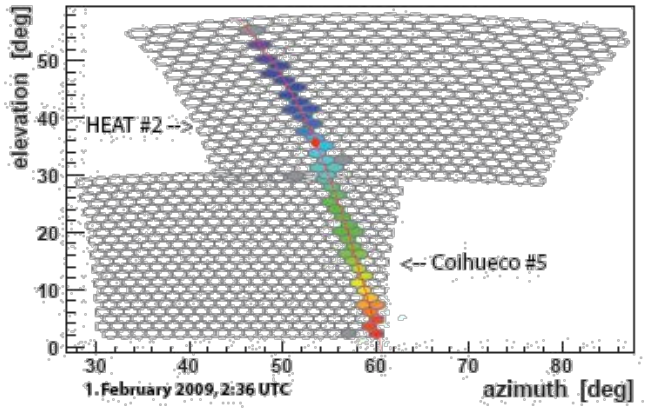


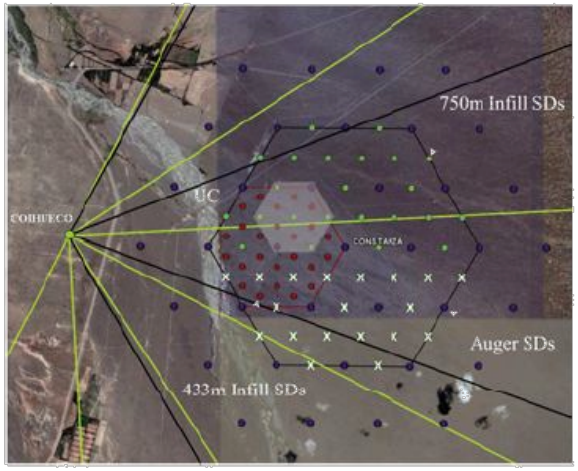
Abraham *et al.* 2009

- UHE photons predicted in many "top-down" models
  - super-heavy dark matter
  - topological defects
  - Z-bursts
- Photon-induced showers:
  - develop deeper in atmosphere
  - SD: measure shower front curvature, thickness
  - FD: measure longitudinal profile directly
- Data consistent with only hadrons
  - top-down models disfavored
  - GZK photon flux may be eventually accessible

Enhancements at Auger South

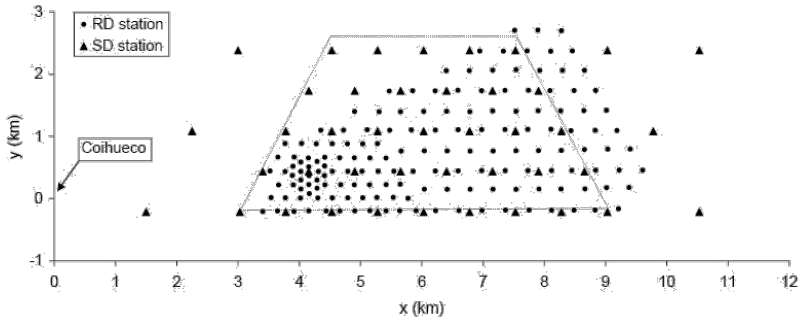
HEAT: High Elevation Auger Telescopes





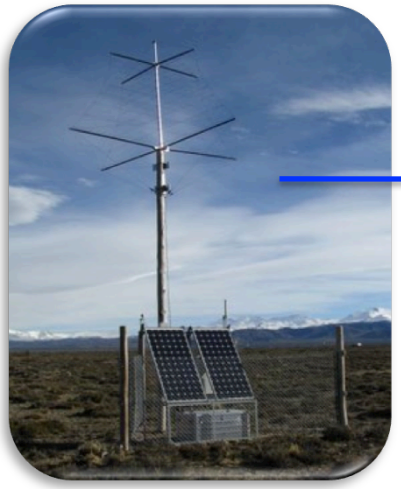
AMIGA: Auger Muon and Infill Ground Array

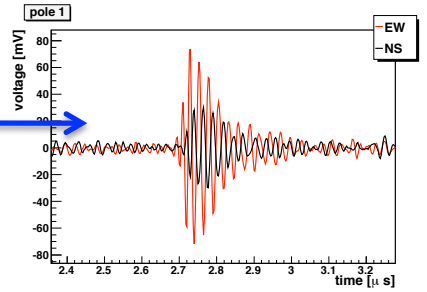
AERA: Auger Engineering Radio Array



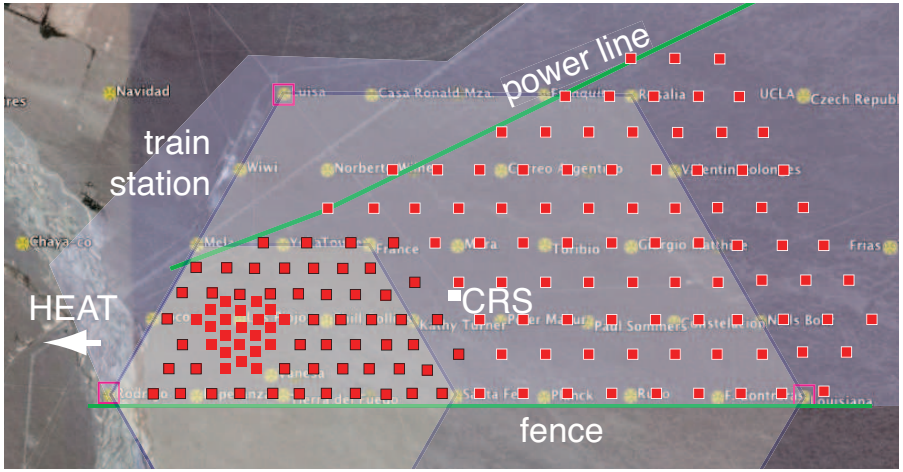
Auger Engineering Radio Array

- AERA: Auger Engineering Radio Array
- Detect air showers via radio pulses (e^+e^- in geomagnetic field)
- 20 km^2 extension to southern site: 150 stations
- Duty cycle: ~100%; ~5000 events/year
- Start deployment this year!





sample 2×10^{18} eV event



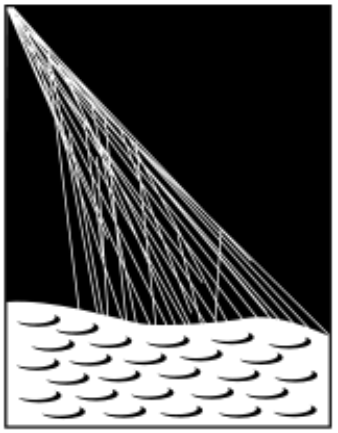
Summary

- Pierre Auger UHECR results:
  - suppression in spectrum observed
  - suggestive anisotropy results… need more statistics
  - neutrino and photon limits: no hints beyond SM yet
  - composition getting heavier?

- Strategy for further research:
  - more data from Auger South
  - searches for exotics: Q-balls, magnetic monopoles, etc.
  - 7x larger array: Auger North
  - expand complementary detection techniques like radio

Thank you!

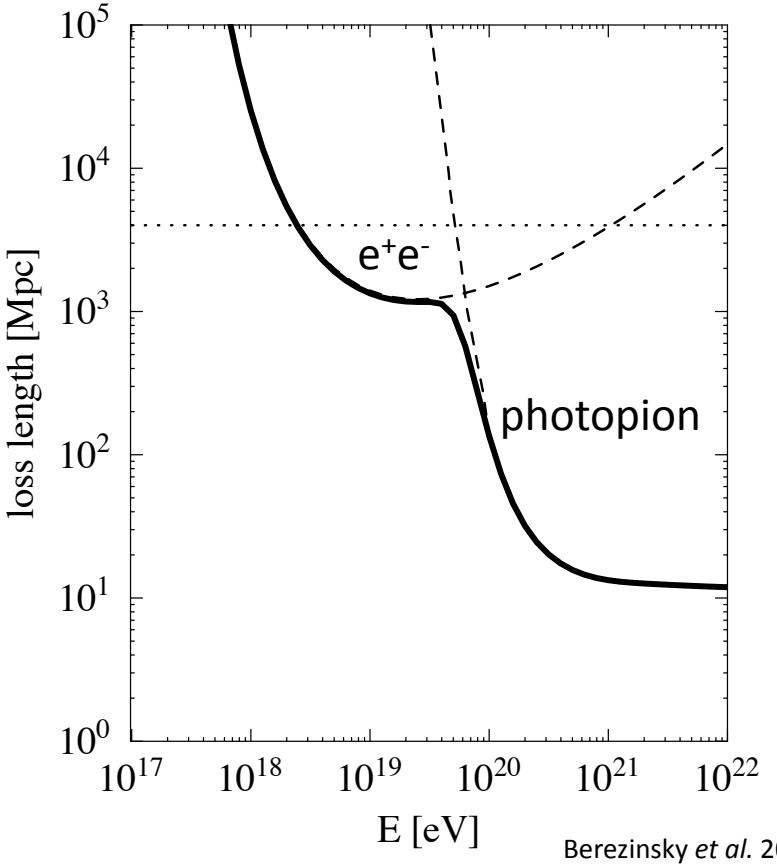
Czech Republic	Argentina
France§	Australia
Germany§	Brazil
Italy	Bolivia*
Netherlands§	Mexico
Poland	USA
Portugal	Vietnam*
Slovenia	
Spain	**Associate Countries*
United Kingdom	§ Radio Working Group



PIERRE AUGER OBSERVATORY

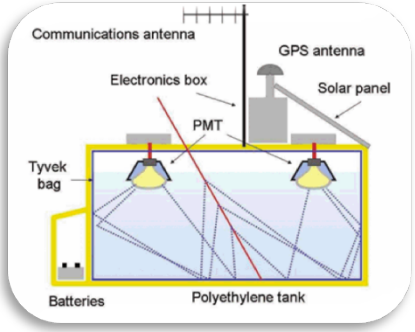
GZK Suppression

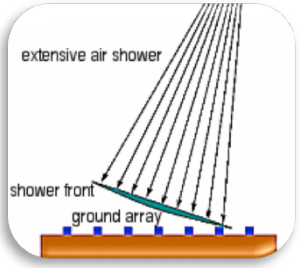
- Suppression expected above 50 EeV due to interaction with CMB photons (Greisen-Zatsepin-Kuzmin)
- If spectrum keeps going…
  - Sources unexpectedly close?
  - New physics (e.g. violation of Lorentz invariance)?
  - Situation 4-5 years ago totally unclear

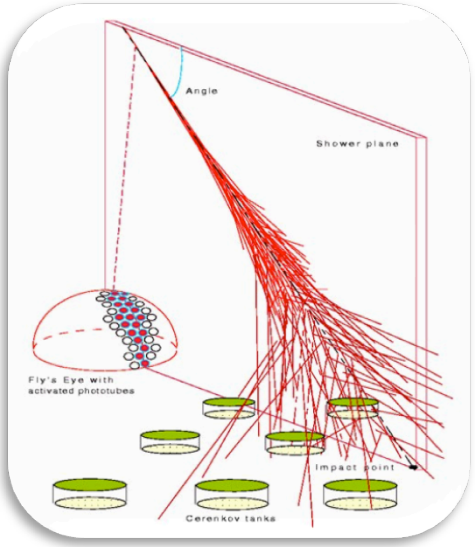


Berezinsky *et al.* 2007

Air Shower Detection







- Water (or ice) Cherenkov tanks
  - detect EM shower front on ground
  - near-100% duty cycle
- Fluorescence telescopes
  - follow Nitrogen fluorescence as shower develops
  - good for calorimetry, measurement of shower maximum (particle ID)
  - duty cycle is ~10%

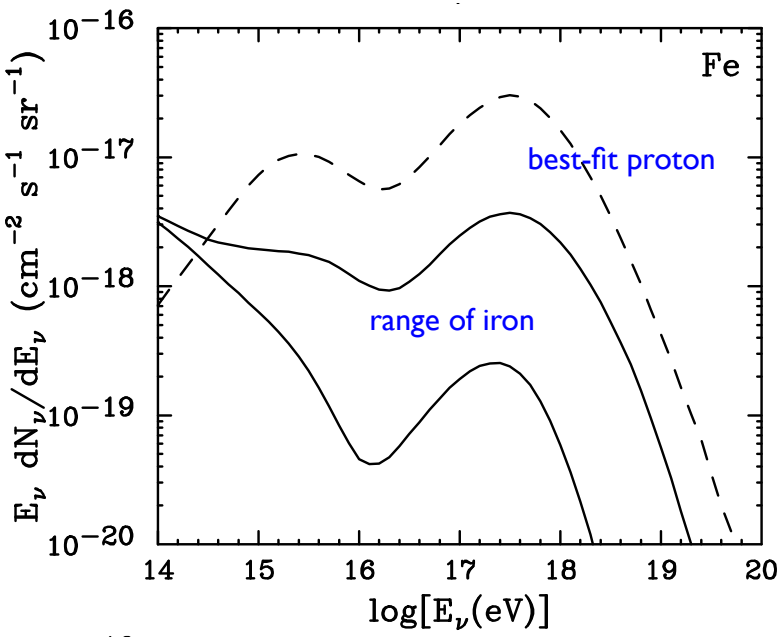
The Neutrino Connection

- Trans-GZK protons lose energy via CMB photopion production
- Also produces UHE neutrinos!

$$p\gamma \rightarrow n\pi^{+} \rightarrow n\mu + \nu_{\mu}$$

- Nuclei will tend to photodisintegrate first (reduced flux)
- Measurement of GZK neutrino flux:
  - source spectrum
  - source evolution
  - composition

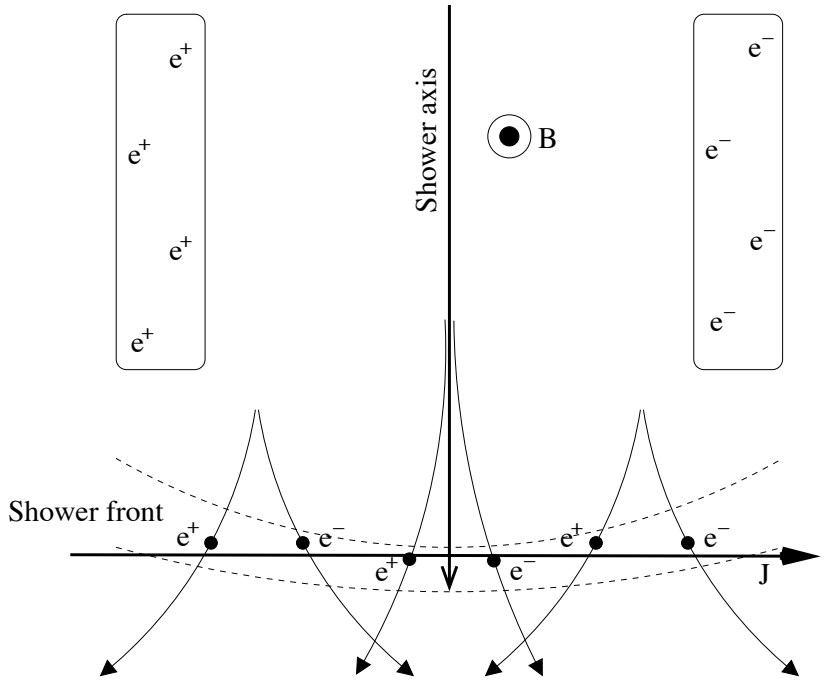
GZK neutrino flux



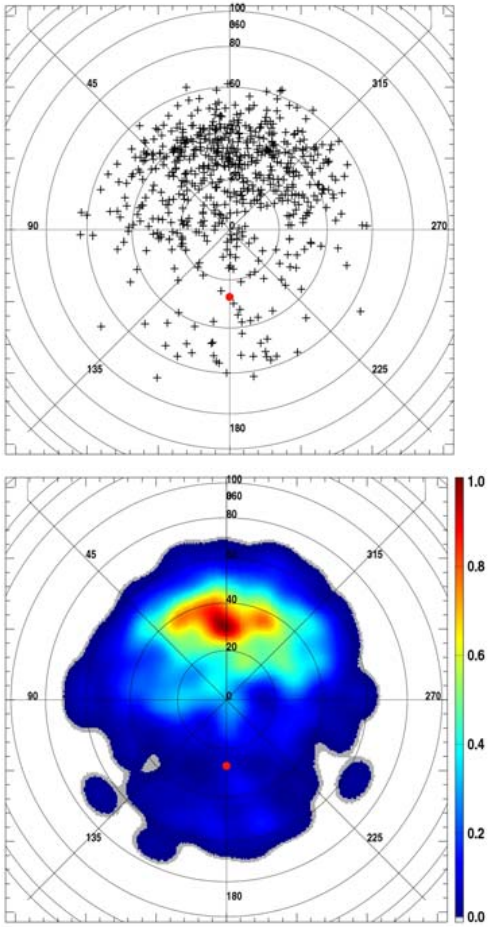
Anchordoqui *et al.* 2007

Radio Emission from Air Showers

- Separation, acceleration of e^+, e^- in geomagnetic field
  - secondary: charge excess, moving dipole
- Broadband radio pulse (width ~50 ns)
- Emission is coherent up to 100 MHz
  - RF power scales as $(E_{primary})^2$
- Observed by LOPES, CODALEMA, MAXIMA detectors
  - geomagnetic asymmetry verified
  - larger experiment needed to verify details of emission



Geomagnetic Origin



Ardouin *et al.* 2009

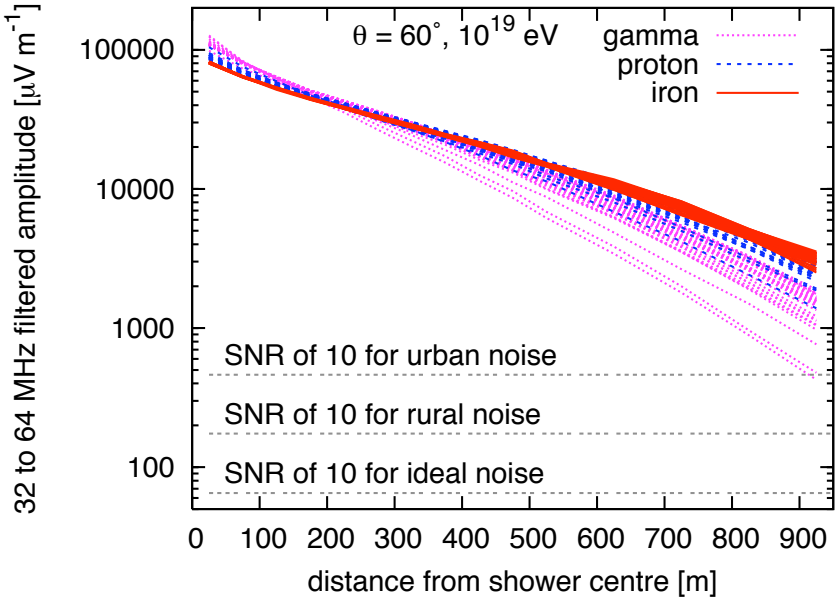
- Simplification: geomagnetic origin implies

$$\vec{E} \propto \vec{v} \times \vec{B}$$

- Asymmetry confirmed with LOPES, CODALEMA experiments

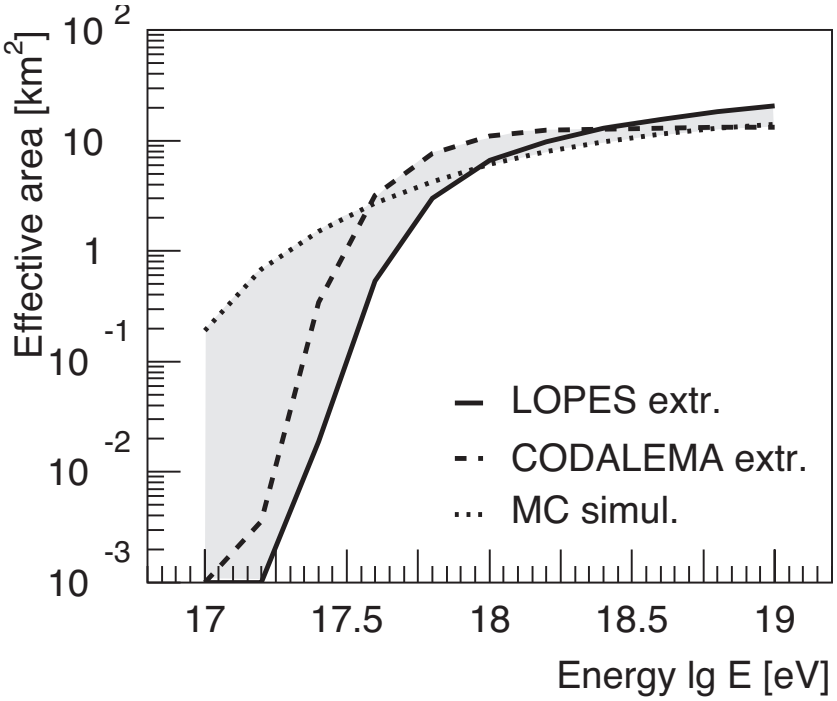
Composition

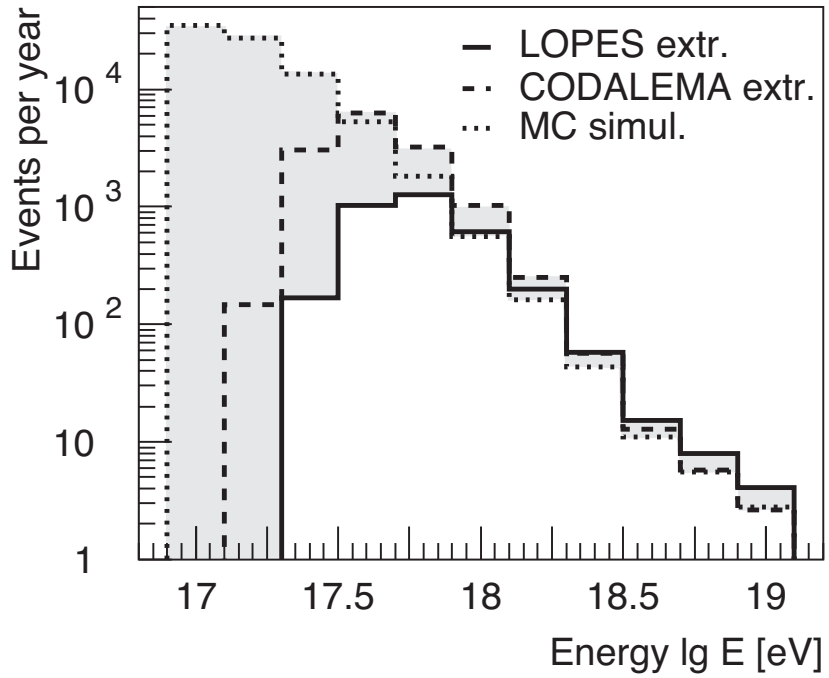
- Primary composition by:
  - lateral distribution
  - reconstruction of shower front curvature
- Simulations only at this point: need larger array, more events!



Huege *et al.* 2008

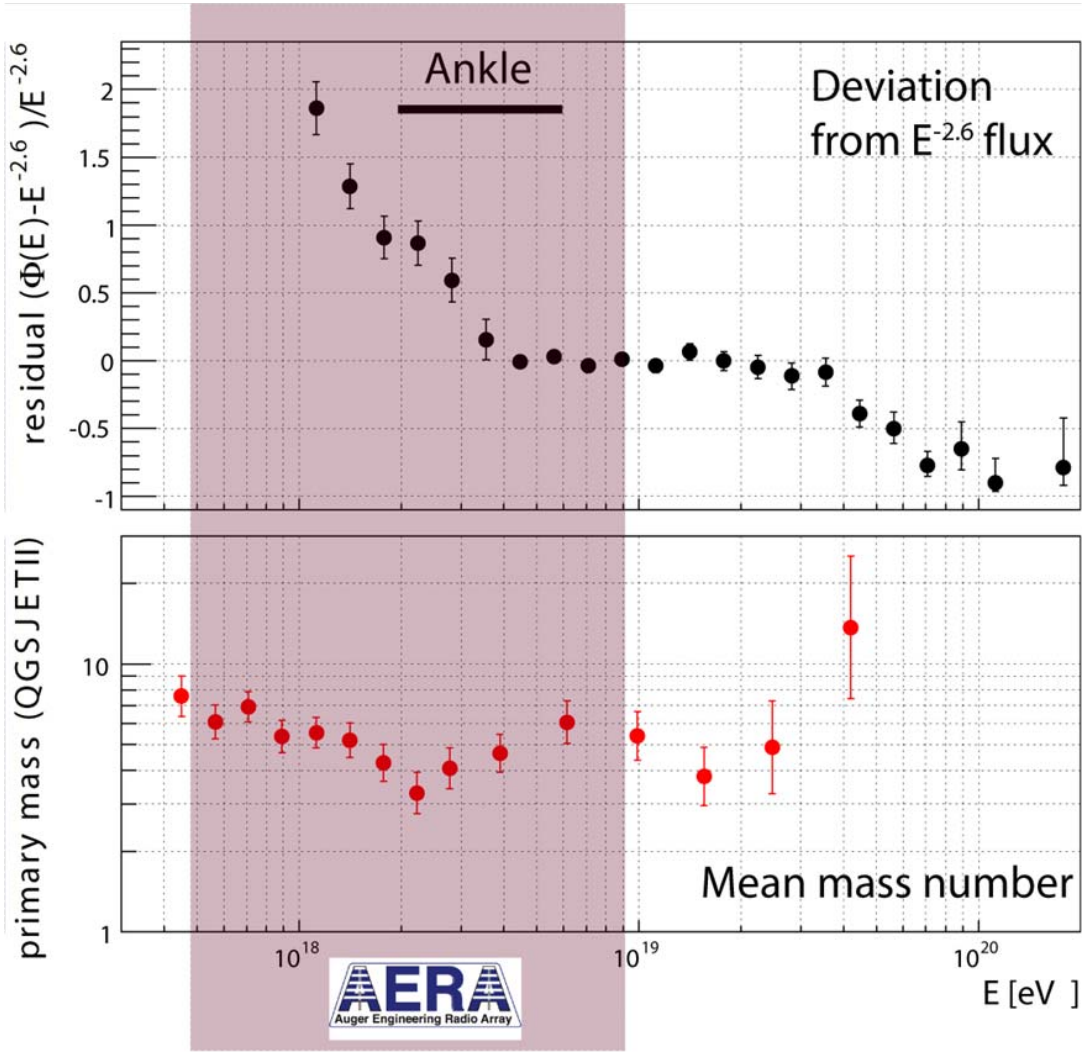
Expected Event Rates





~5000 events / year with E > 3 x 10^{17} eV
~800 events / year with E > 1 x 10^{18} eV

AERA Physics



Radio will open a new window onto cosmic ray physics!