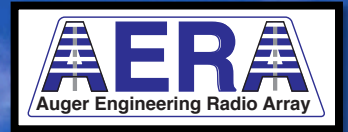


PIERRE
AUGER
OBSERVATORY



The Pierre Auger Observatory: Recent Results and Future Plans

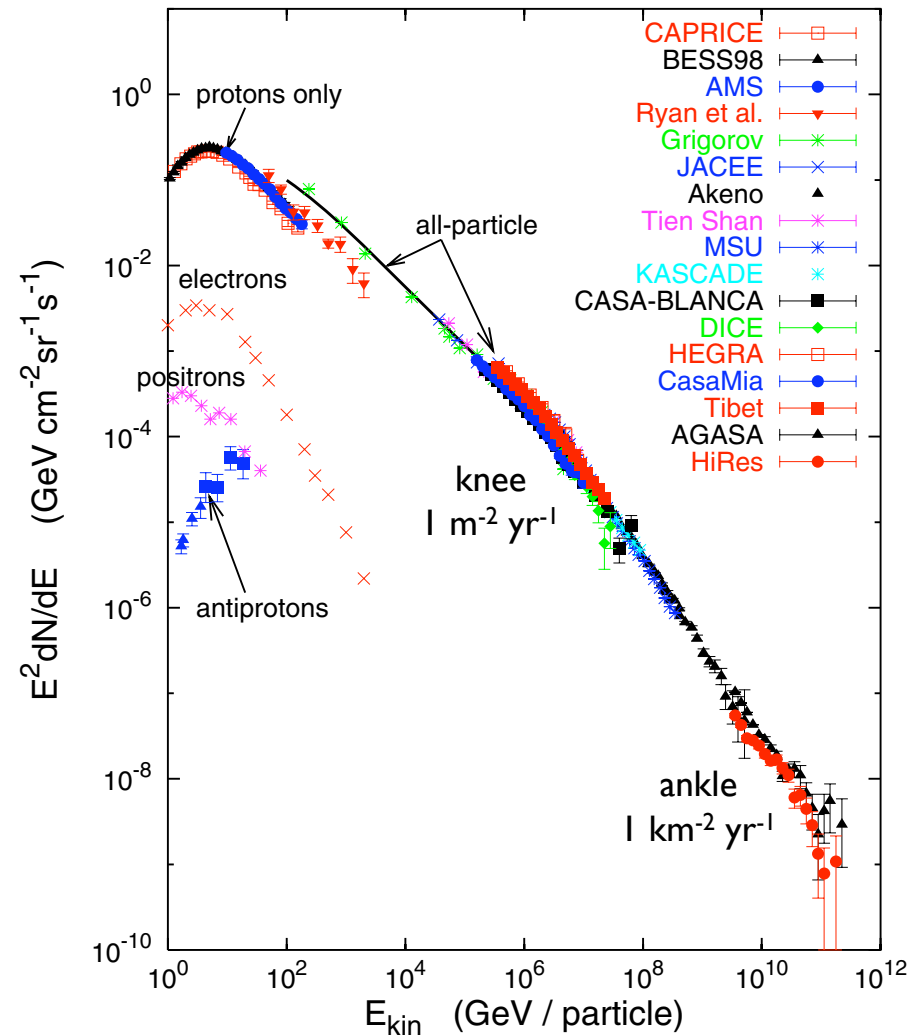
John Kelley
Radboud Universiteit, Nijmegen

12th Astroparticle Physics Symposium
December 4, 2009



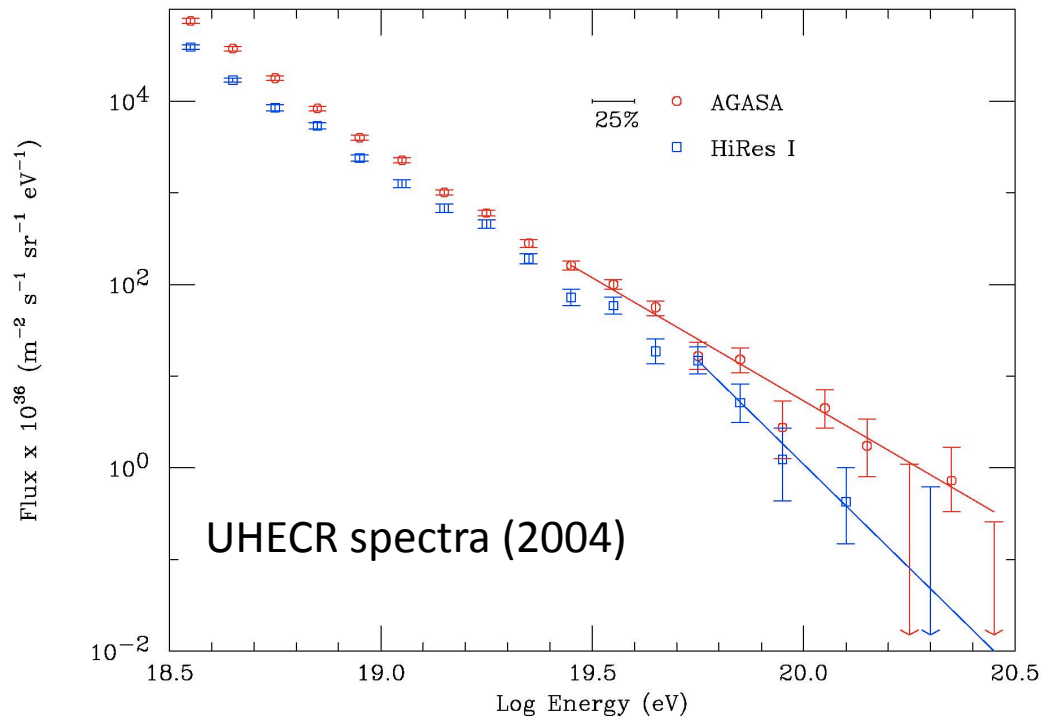
Cosmic Ray Spectrum

- Charged particles with steep power law spectrum
- Low flux at high energy: detect via extensive air showers
- “Ankle”: transition from galactic to extragalactic sources?
- Composition: protons vs. heavy nuclei?



Gaisser 2004

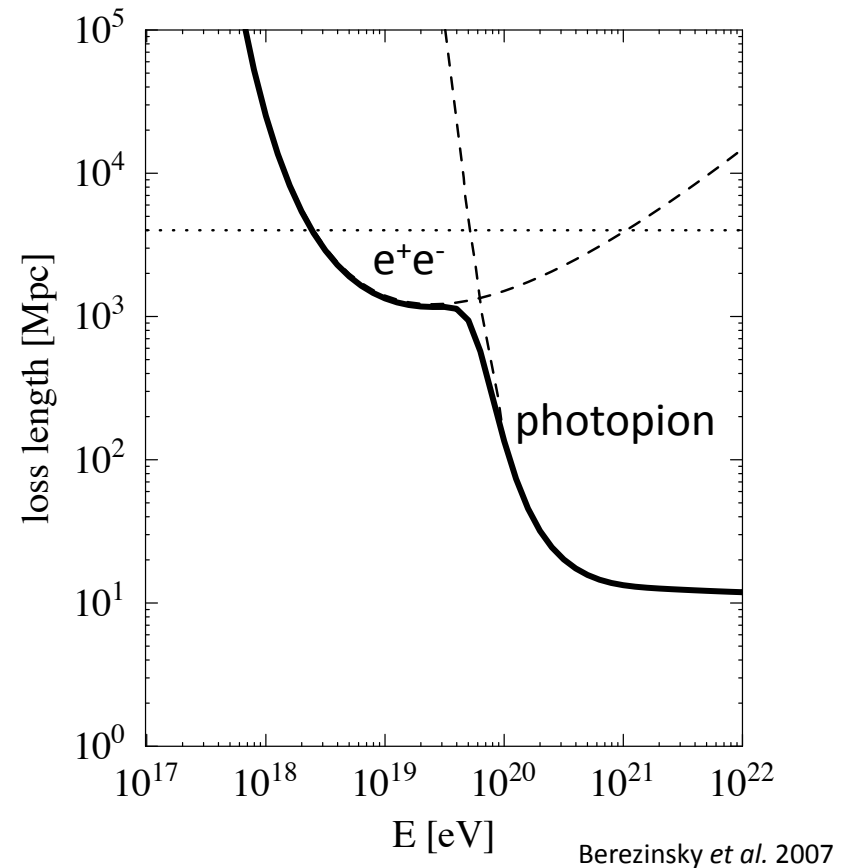
Ultra-High Energy Cosmic Rays (UHECR)



- Highest energy particles known in the Universe
- Composition unknown
- Sources + acceleration mechanism unknown
 - presumably extragalactic
 - AGN? GRBs?
 - top-down models now disfavored
- Cutoff in spectrum or not?

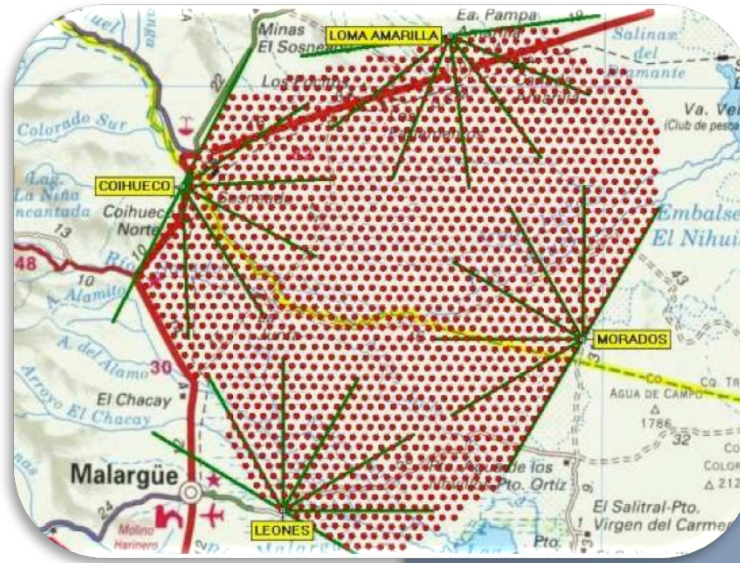
GZK Suppression

- 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



Pierre Auger Observatory

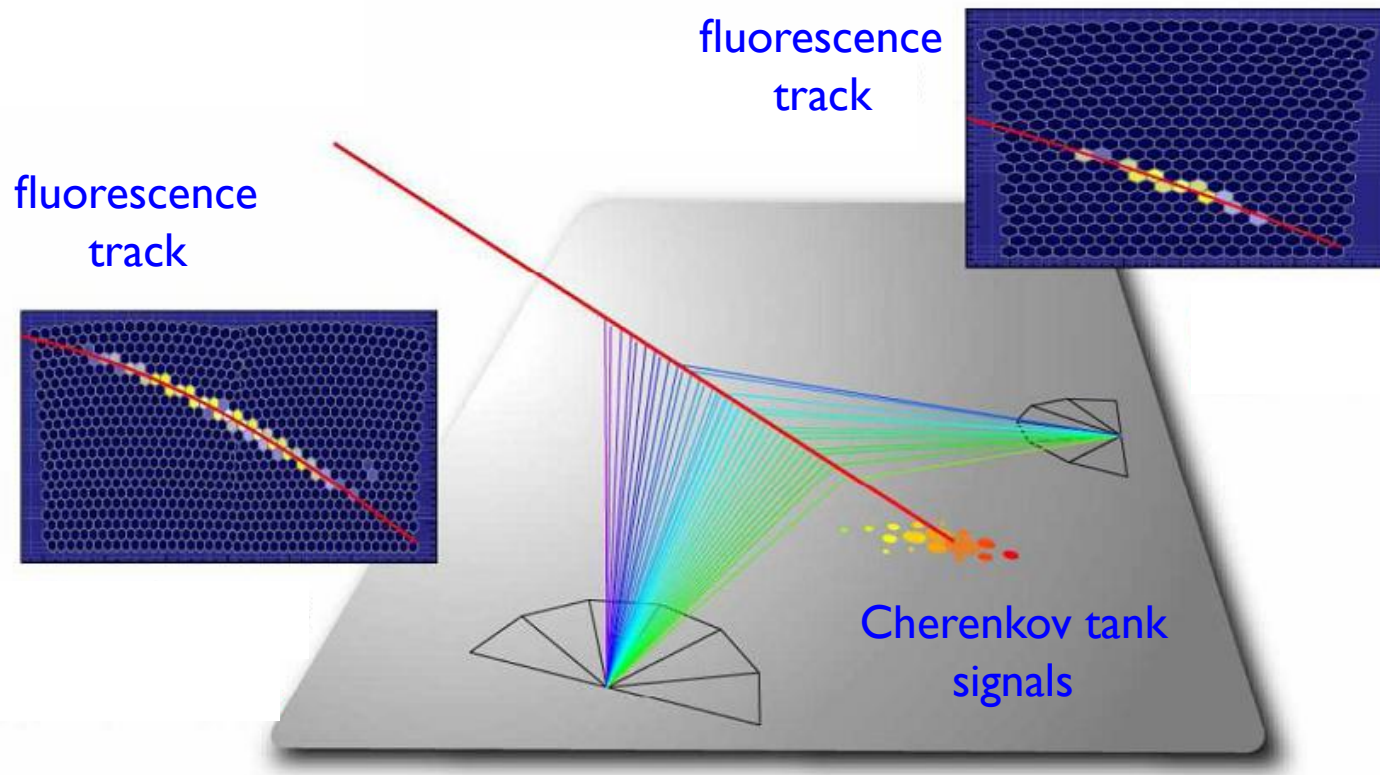
- Hybrid air shower detector
- Southern site (3000 km²) in Argentina completed 2008
- Northern site (21000 km²) planned for Colorado, U.S.A.



Auger South



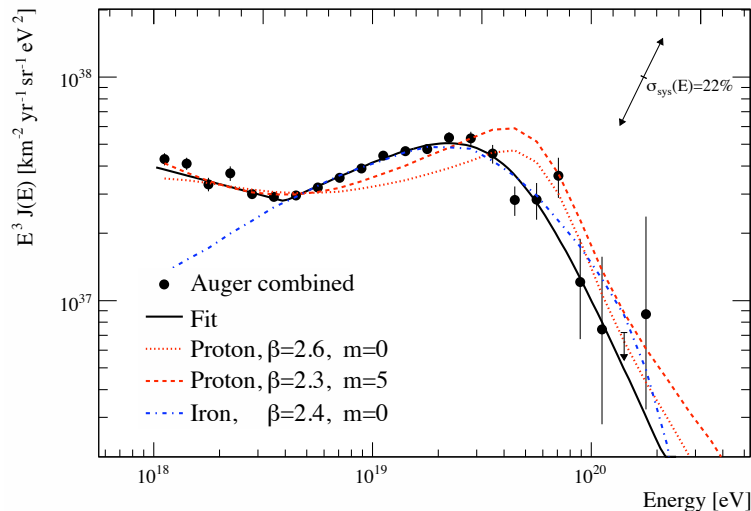
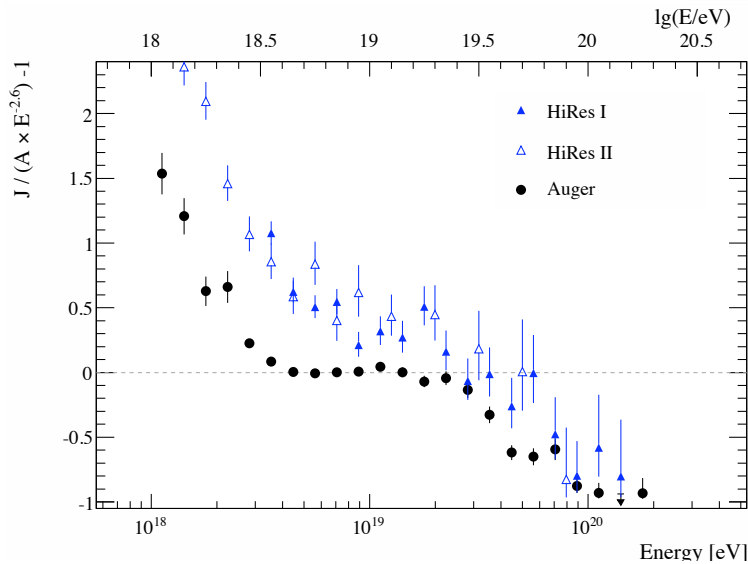
Hybrid Detection



Hybrid observation: energy cross-calibration, better angular resolution

... but FD duty cycle is $\sim 10\%$

Latest Results: UHECR Energy Spectrum



- 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?

UHECR Anisotropy

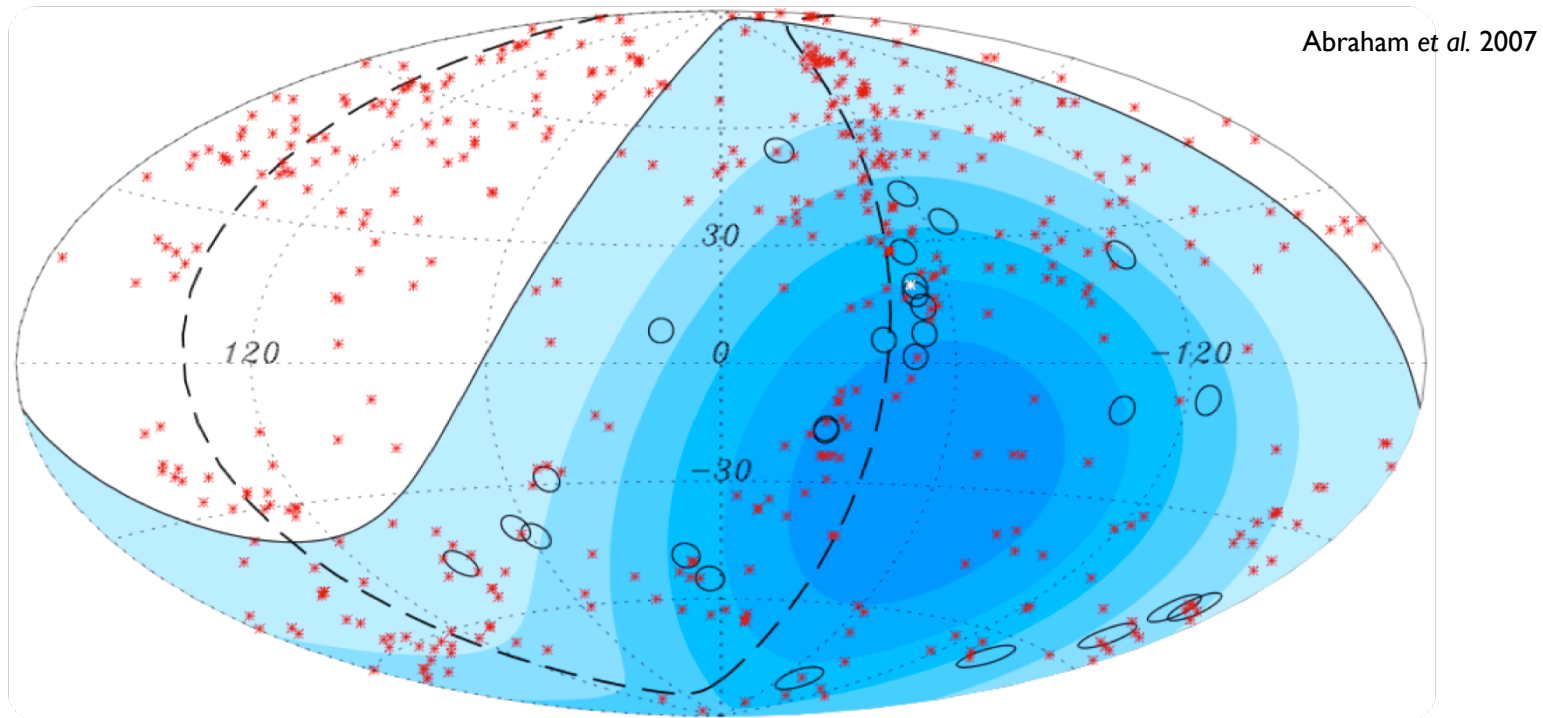
- Extragalactic protons above 50 EeV or so should point back to sources (within a few degrees)

$$\theta(E, Z) \approx \left(\frac{L}{L_{\text{coh}}}\right)^{0.5} \alpha \approx 0.8^\circ \left(\frac{10^{20} \text{ eV}}{E}\right) \left(\frac{L}{10 \text{ Mpc}}\right)^{0.5} \left(\frac{L_{\text{coh}}}{1 \text{ Mpc}}\right)^{0.5} \left(\frac{B}{1 \text{ nG}}\right) Z,$$

Hooper *et al.* 2008

- Pre-Auger: claims of excess from galactic center, BL-Lacs, etc.
- Anisotropy with low statistics is a tricky business

Anisotropy, cont.



2007: 27 events above 55 EeV (ovals); correlation with nearby AGN (red crosses) with chance $P \sim 2 \times 10^{-3}$

Isotropy rejected at $\sim 99\%$ confidence level

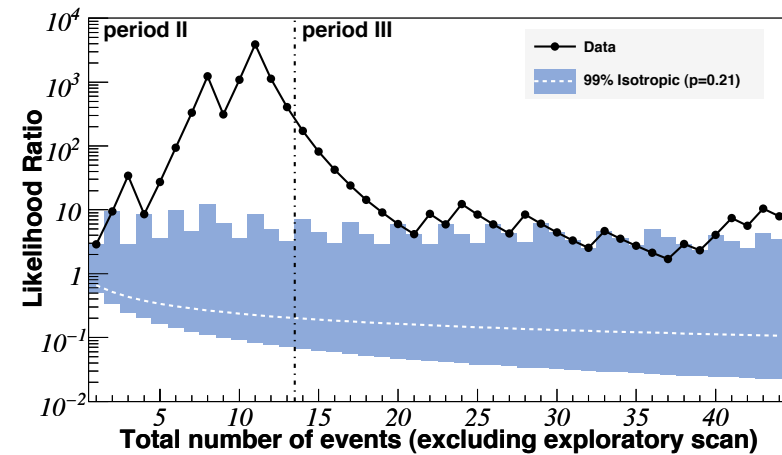
Separate analyses: No correlation found with galactic center or BL-Lacs

Latest Results: Anisotropy

2009: 58 events above 55 EeV

Hague et al. 2009 (ICRC)

Release pending



Correlation with original AGN catalog weakens
(P value $\sim 6 \times 10^{-3}$)

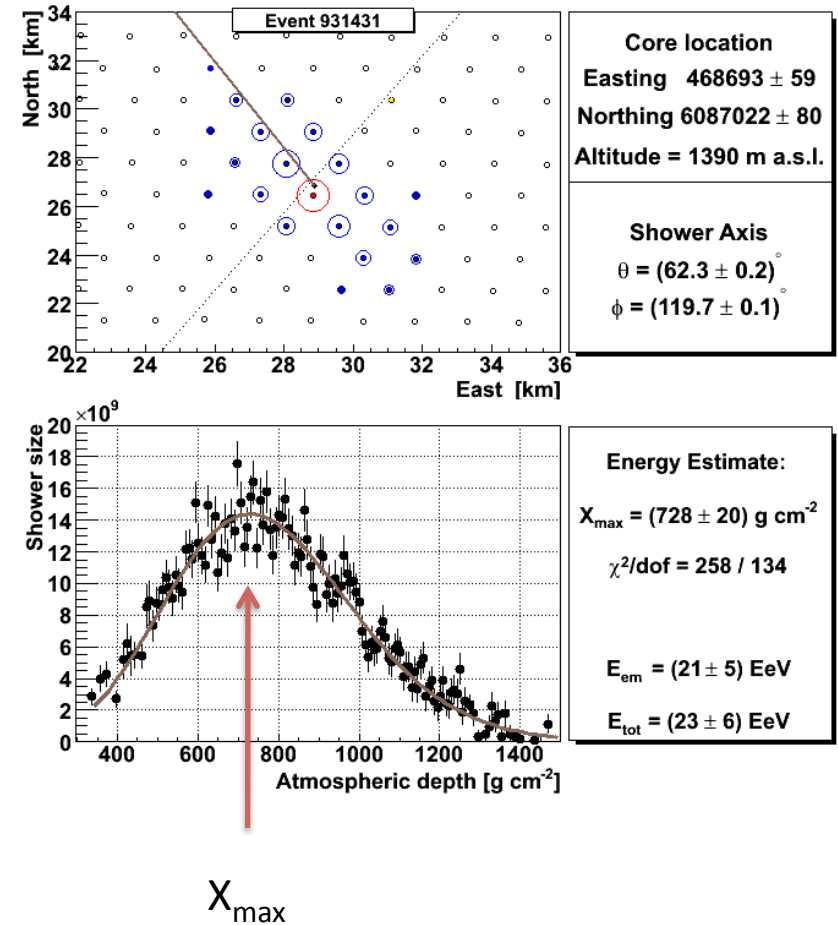
Isotropy rejected at about same CL (99.4%)

A posteriori investigations of:
– Centaurus A region
– correlations with other catalog(s)
e.g. SWIFT-BAT

New prescriptions will allow tests of significance

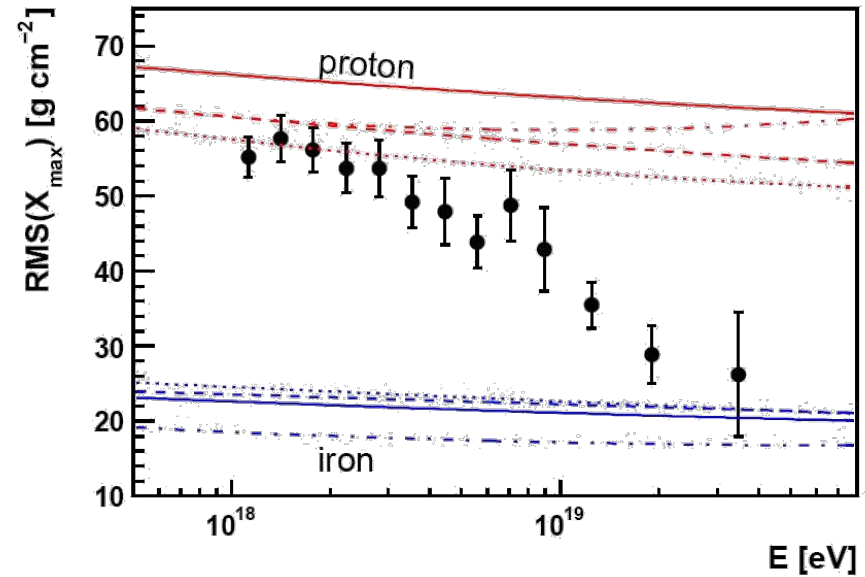
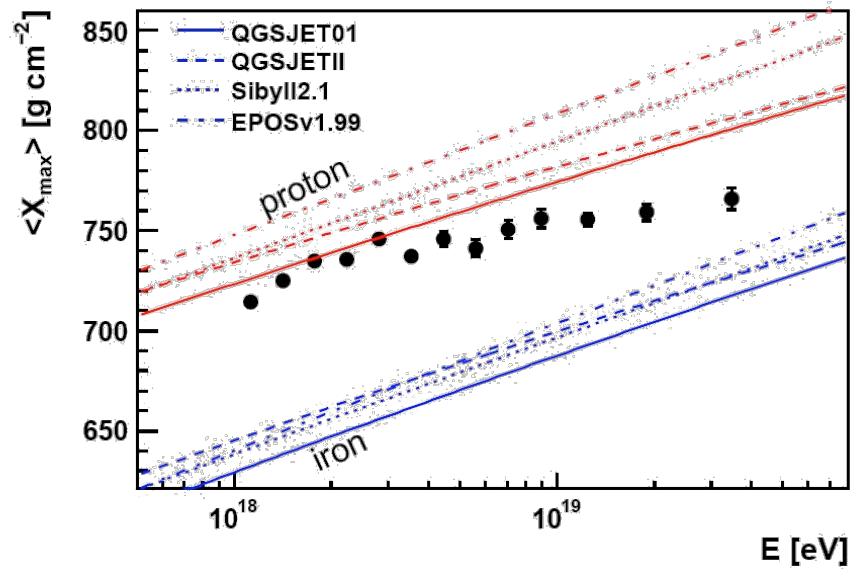
Composition

- 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 56 proton showers of 1/56 energy) have fewer fluctuations



Latest Results: Composition

Bellido et al. 2009 (ICRC)

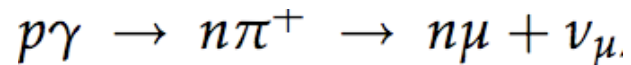


Both indicate composition getting heavier...
or protons behaving very differently than expected

The Neutrino Connection

- Trans-GZK protons lose energy via CMB photopion production

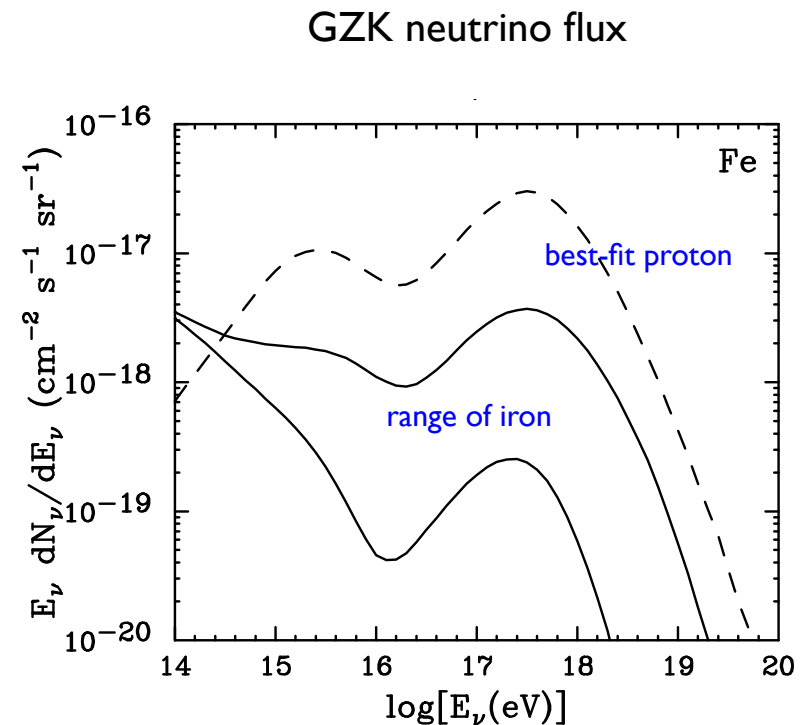
- Also produces UHE neutrinos!



- Nuclei will tend to photodisintegrate first (reduced flux)

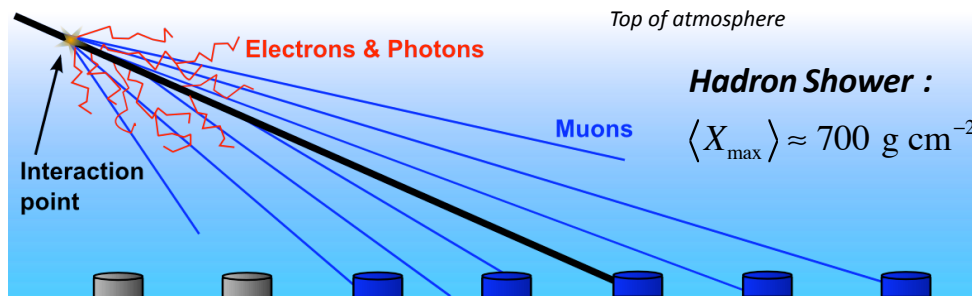
- Measurement of GZK neutrino flux:

- source spectrum
- source evolution
- composition

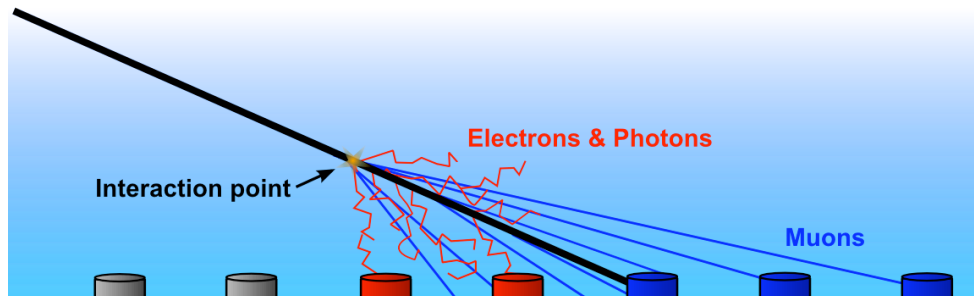


Anchordoqui et al. 2007

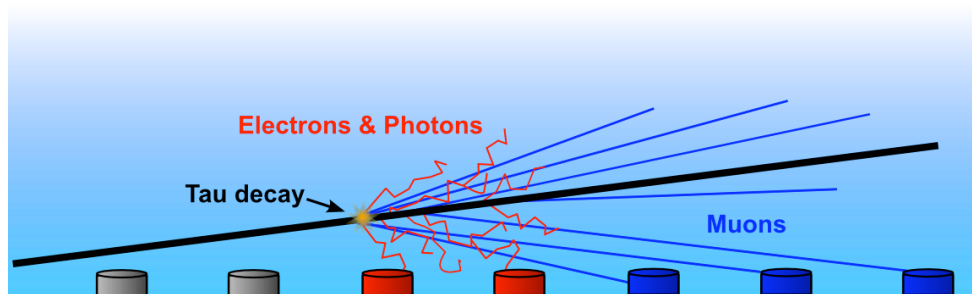
Neutrino Detection via Air Showers



“normal” inclined shower:
only muons left

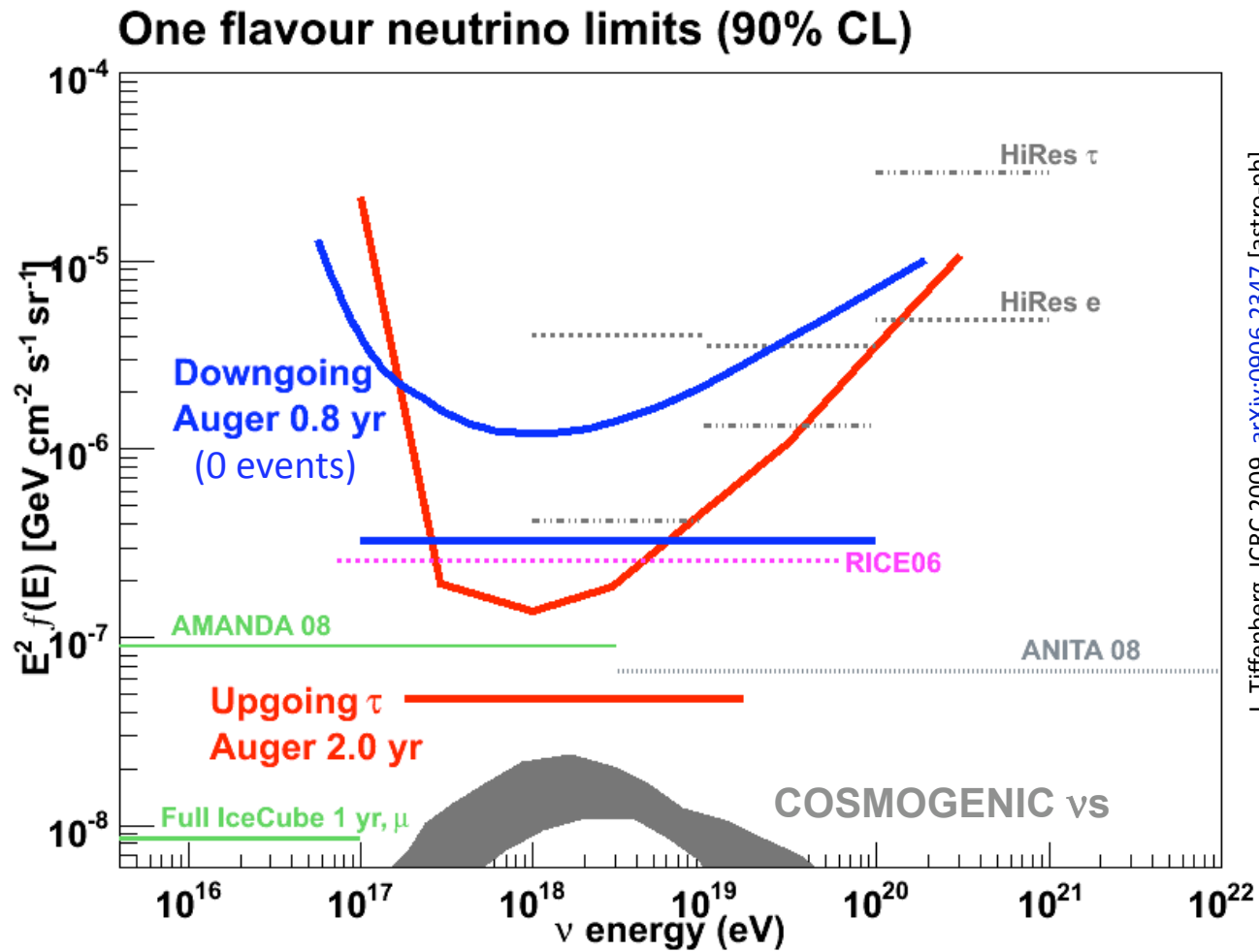


neutrino-induced shower:
young EM component
(broad signals in tanks)



tau decay from Earth-skimming ν_{τ} :
dense target, but only one flavor

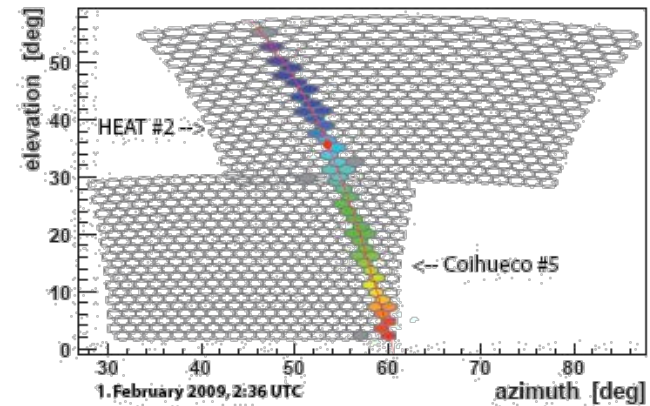
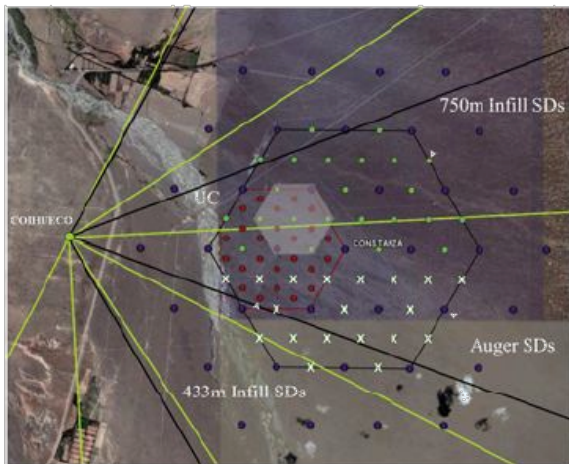
Limits on Diffuse Neutrino Flux



J. Tiffenberg, ICRC 2009, arXiv:0906.2347 [astro-ph]

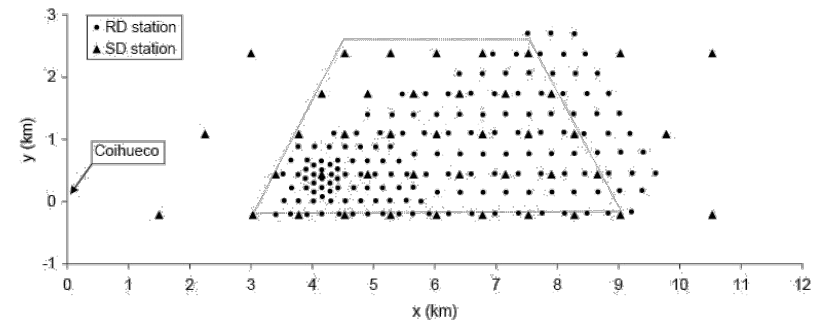
Enhancements at Auger South

HEAT: High Elevation Auger Telescopes



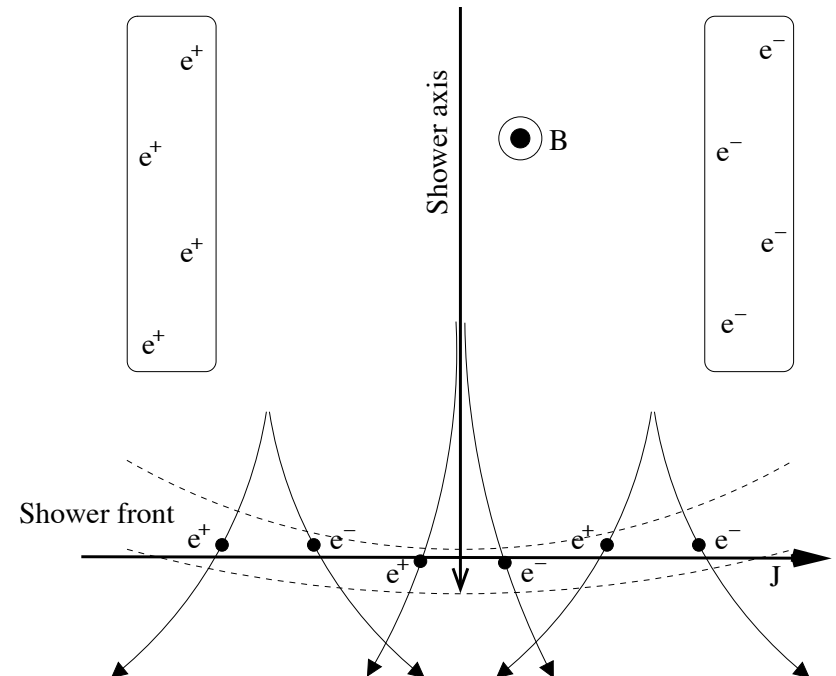
AMIGA: Auger Muon and Infill Ground Array

AERA: Auger Engineering Radio Array



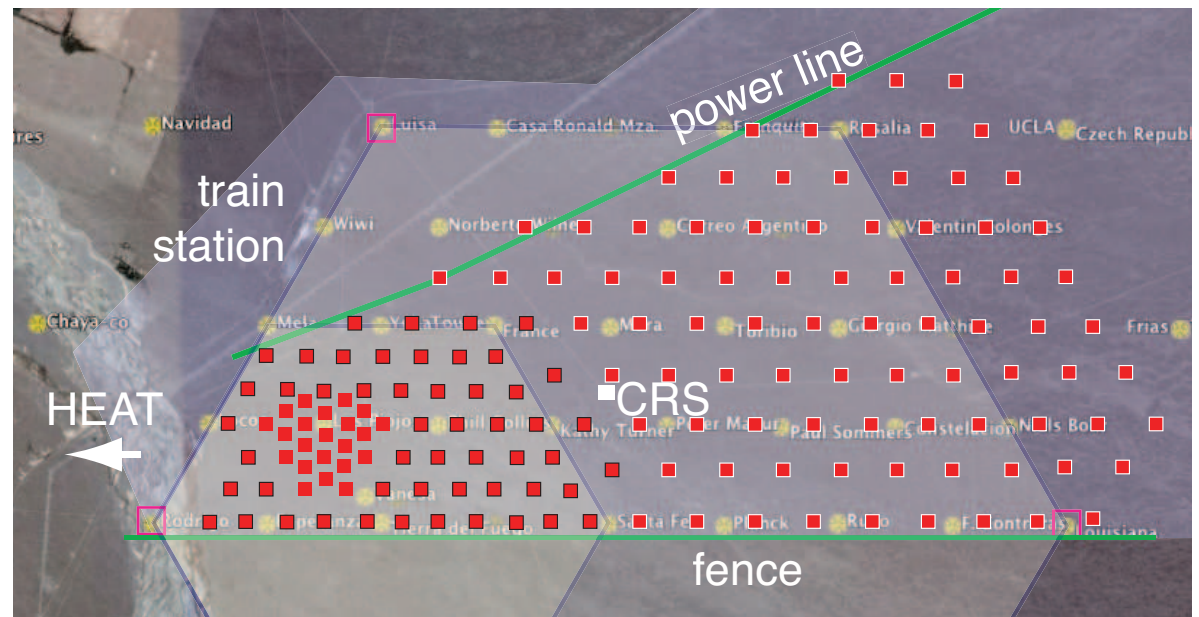
Radio Emission from Air Showers

- 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 $(E_{\text{primary}})^2$
- Observed by LOPES, CODALEMA, MAXIMA detectors
 - geomagnetic asymmetry verified
 - larger experiment needed to verify details of emission



Auger Engineering Radio Array

- AERA: Auger Engineering Radio Array
- 20 km² extension to southern site (at infill array)
- Phase I: 25 stations, early 2010 (total: 150)
- Duty cycle: ~100%



Radio Detection Station

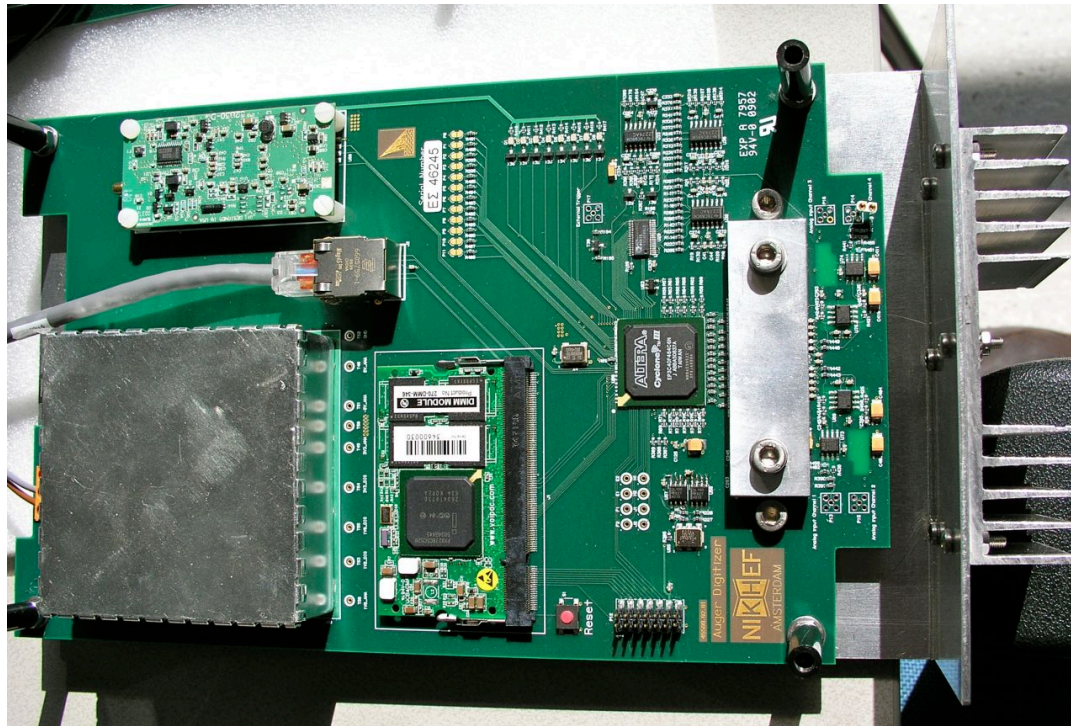


- Autonomous, solar power
- LPDA antenna, 30-80 MHz bandpass
- Local digitizer and trigger
- Multi-station coincidence via central DAQ

Digital Electronics (NIKHEF and RU)

GPS receiver
(timestamping)

Cyclone III FPGA (triggering & readout)



Ethernet
(to comms)

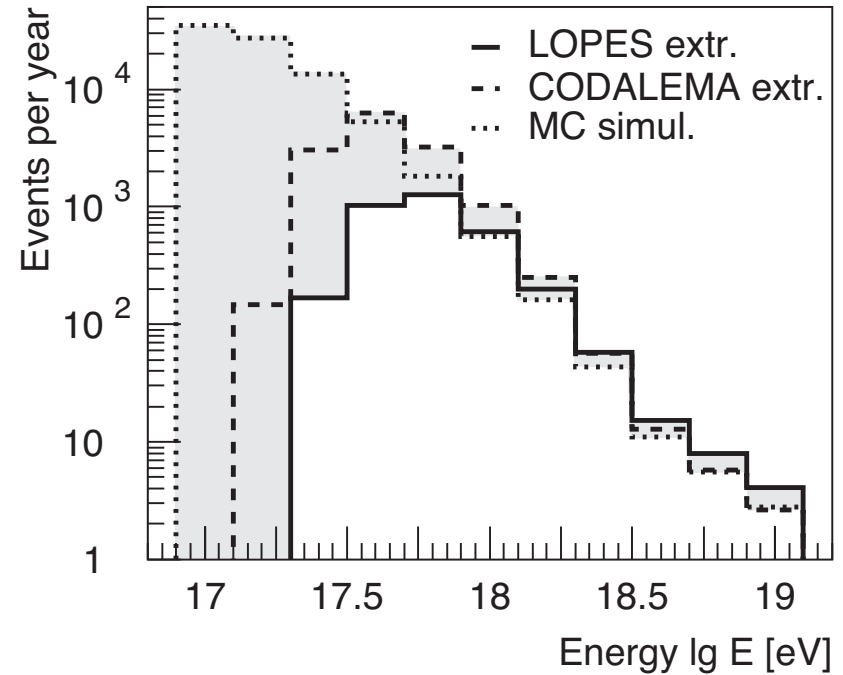
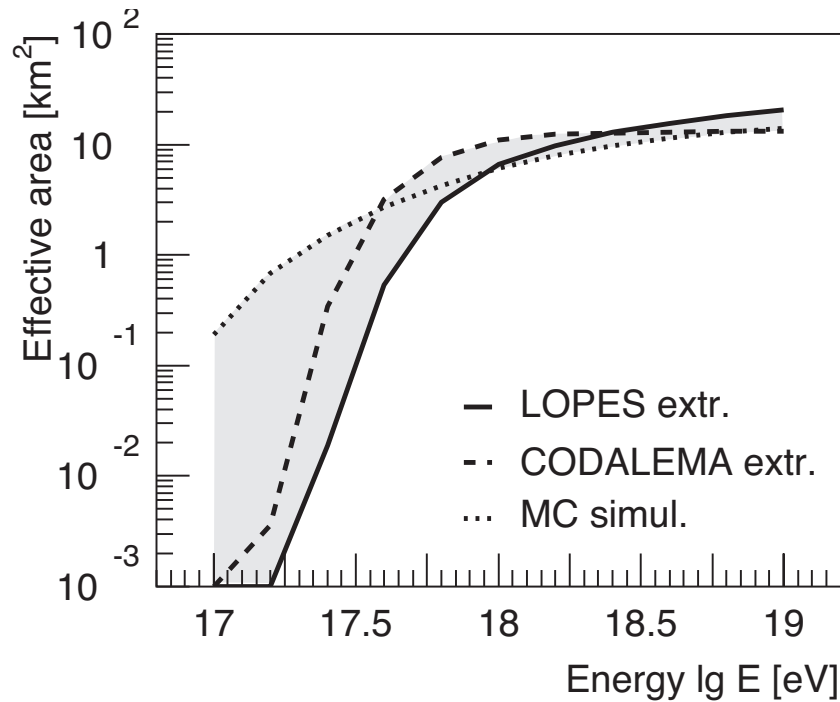
DC/DC conv.
(shielded)

4 channel, 200 MHz
ADCs

XScale-based PC
board (running Linux)


serial interface

Expected Event Rates



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

AERA Science Program

- 
- Detailed calibration of radio signal
 - self-triggering
 - coincidences with other Auger components
 - full understanding of all RF emission mechanisms
 - Resolution of radio technique
 - energy and direction
 - composition via shower maximum, lateral distribution
 - Independent cosmic ray and neutrino physics
 - composition of critical ankle region
 - radio signals from inclined showers: neutrino sensitivity

Summary

- Pierre Auger UHECR results (and remaining questions)
 - suppression in spectrum (GZK or intrinsic to source?)
 - suggestive anisotropy results (really AGN? role of Cen A?)
 - composition getting heavier (or new physics?)
 - competitive neutrino limits (level of cosmogenic flux?)
- Multi-pronged strategy for further research:
 - more data from Auger South
 - 7x larger array: Auger North
 - expand complementary detection techniques like radio
 - measure cosmogenic neutrino flux

Thank you!

Czech Republic

France§

Germany§

Italy

Netherlands§

Poland

Portugal

Slovenia

Spain

United Kingdom

Argentina

Australia

Brazil

Bolivia*

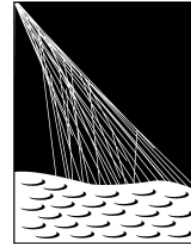
Mexico

USA

Vietnam*

*Associate Countries

§ Radio Working Group



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A. Horneffer

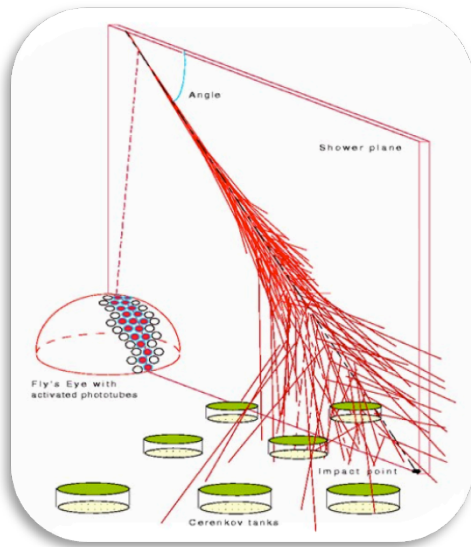
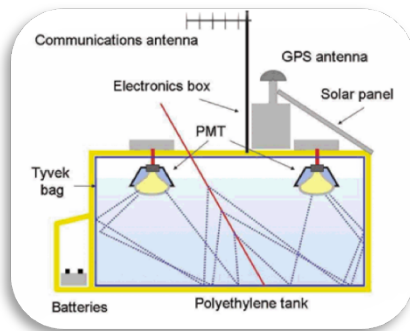
S. Jiraskova

S. J. de Jong

J. L. Kelley

H. Schoorlemmer

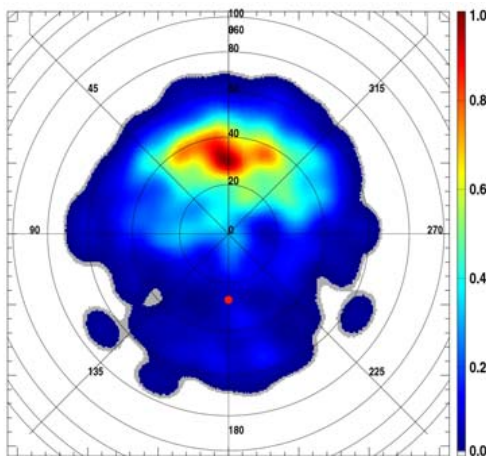
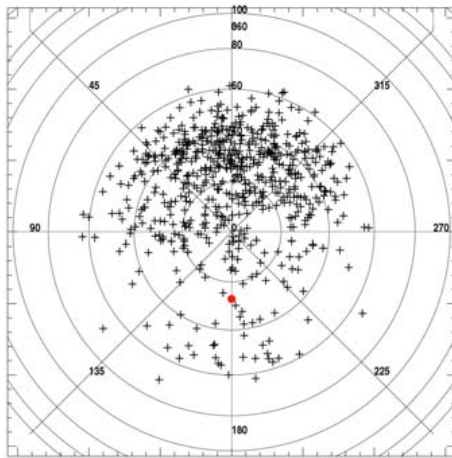
Air Shower Detection



- 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 $\sim 10\%$

Geomagnetic Origin



Arduin *et al.* 2009

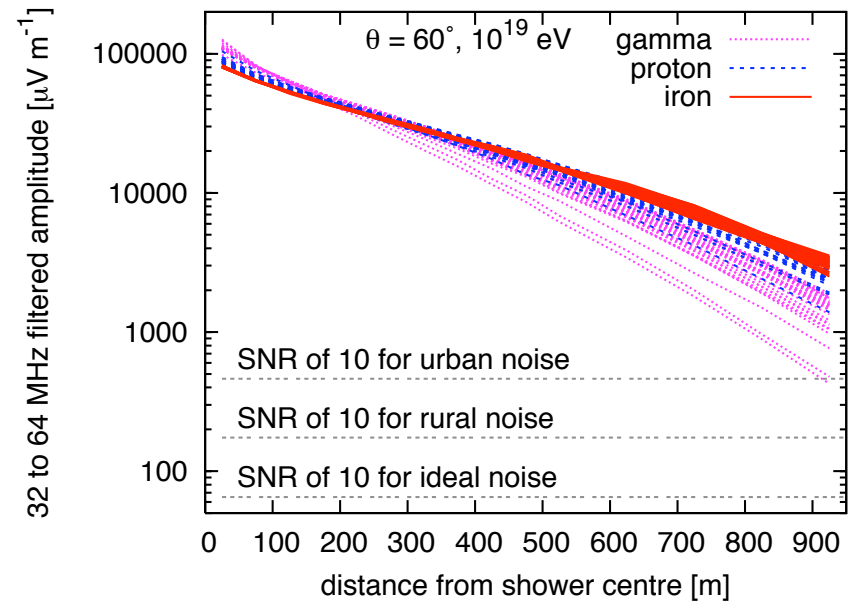
- Simplification: geomagnetic origin implies

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

- Asymmetry confirmed with LOPES, CODALEMA experiments

Composition

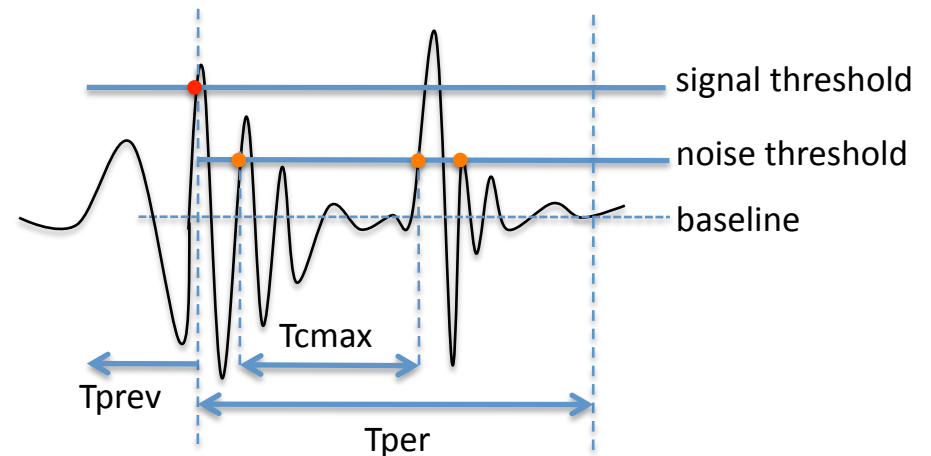
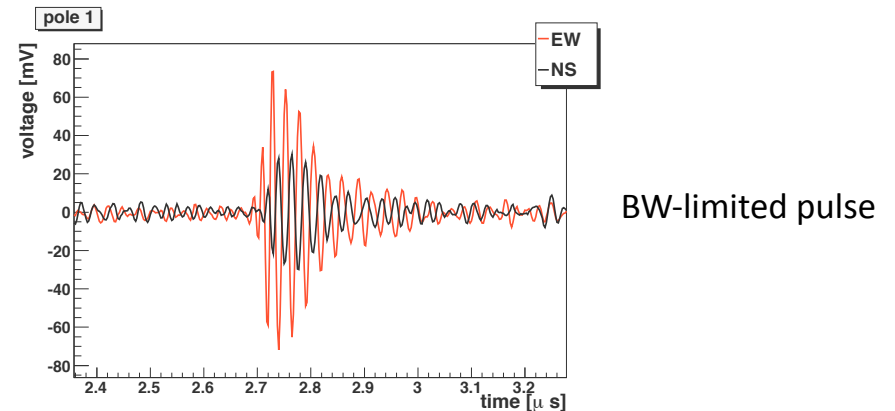
- Primary composition by:
 - lateral distribution
 - reconstruction of shower front curvature
- Simulations only at this point: need larger array, more events!



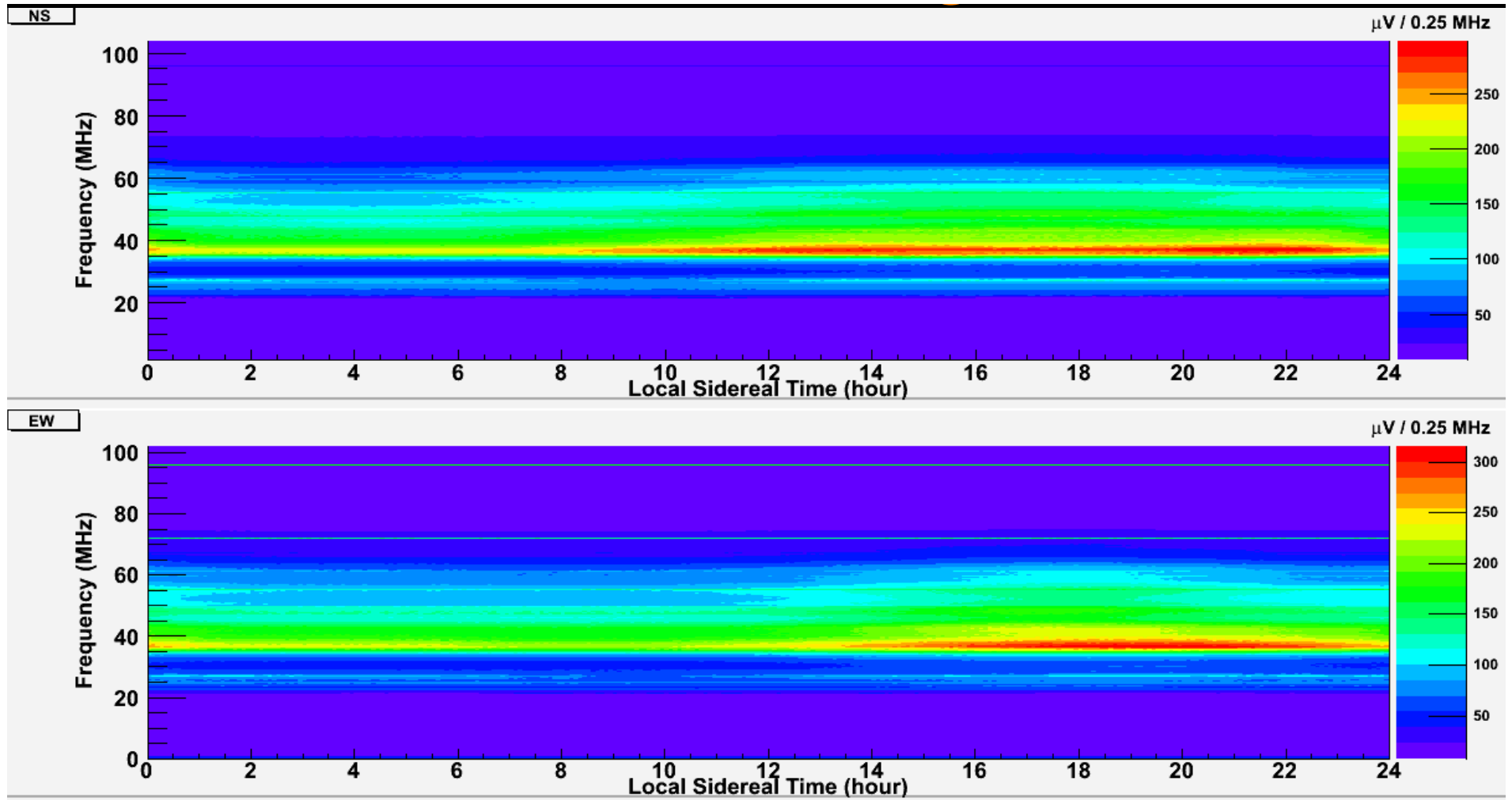
Huege *et al.* 2008

Self-Triggering

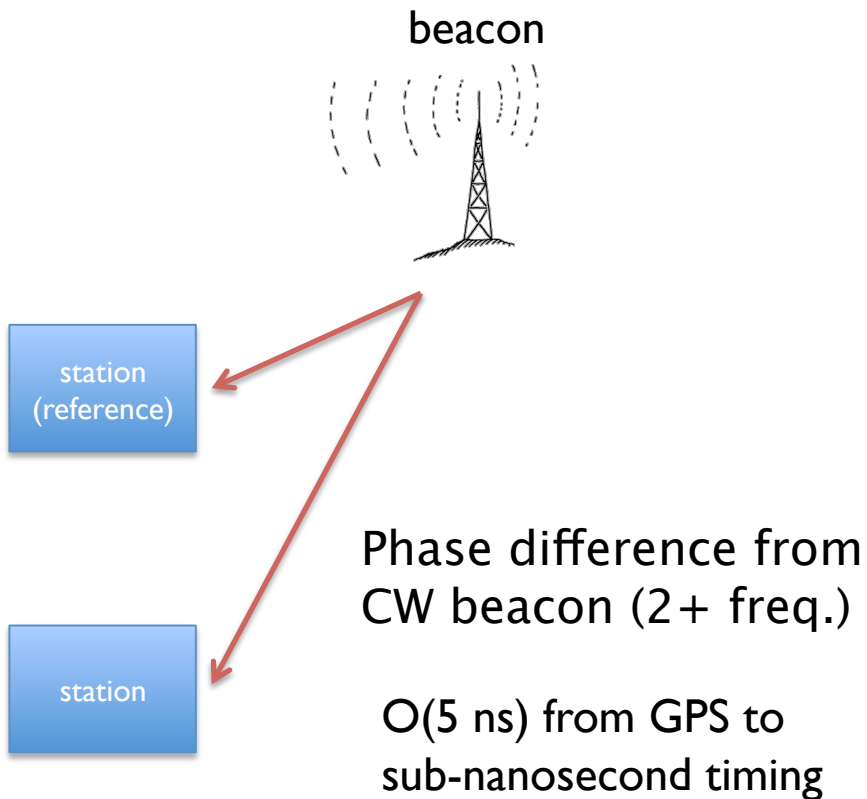
- Technological challenge: impulsive RFI
- Current algorithms focus on time-domain analysis
- New techniques under development:
 - power detection circuit
 - periodic veto (e.g. 50 Hz)
 - wavelet filtering



Calibration Techniques (I)



Calibration Techniques (II)



Also: solar flares, lightning

