



PIERRE  
AUGER  
OBSERVATORY

# Recent Results from The Pierre Auger Observatory

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LPNHE, France



# Outline



- ▶ Energy spectrum
- ▶ Measurement of the mean shower maximum,  $\langle X_{\max} \rangle$
- ▶ Limit on photon flux at 3 and 10 EeV
- ▶ Limit on neutrinos using Earth-skimming air showers
- ▶ Anisotropy of arrival directions above 55 EeV

# Pierre Auger Observatory

*Colorado, USA  
(in planning)*

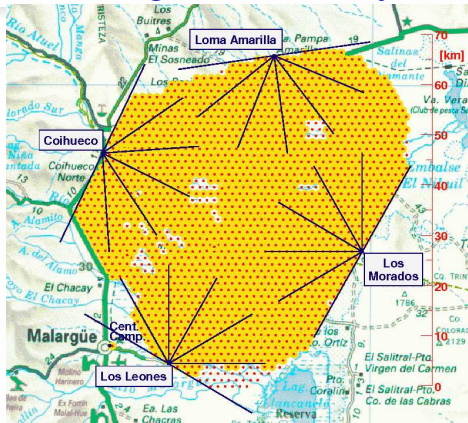


*Mendoza, Argentina  
(Auger South)*



- ▶ 18 countries, 476 scientists

# Pierre Auger Observatory



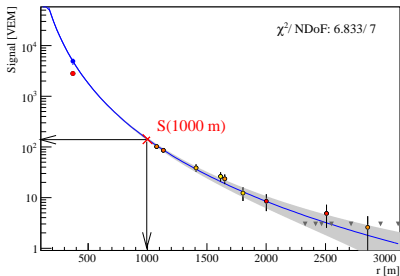
Hybrid detection (area: 3000 km<sup>2</sup>)

- ▶ 4 fluorescence detectors (30° × 180°)
- ▶ 1663 water Cherenkov detectors
- ▶ taking data since 2004, completed: 2008



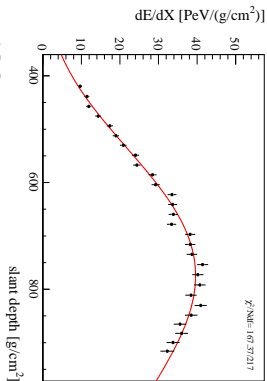


# Air shower measurements

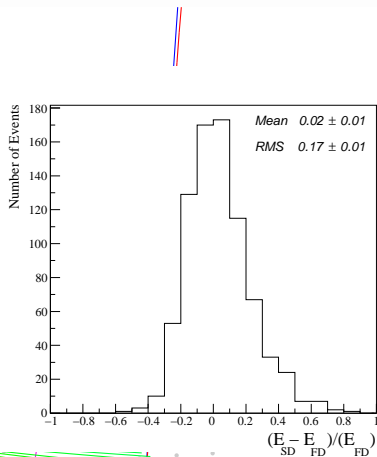
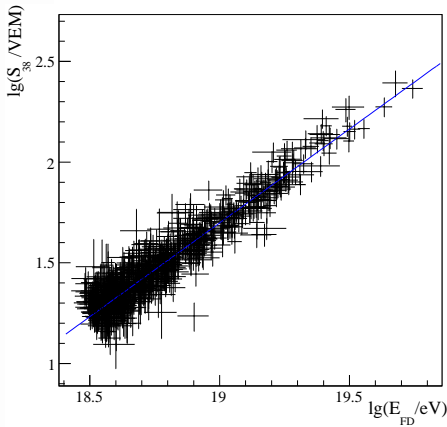


Lateral distribution: S(1000 m)  
Longitudinal profile: energy

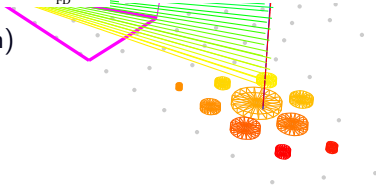
$X_{\text{max}} \Rightarrow$  composition



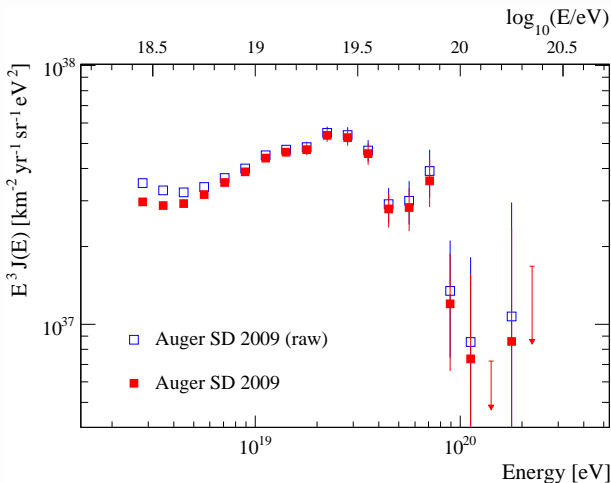
# Air shower measurements



Lateral distribution:  $S(1000 \text{ m})$   
Longitudinal profile: energy



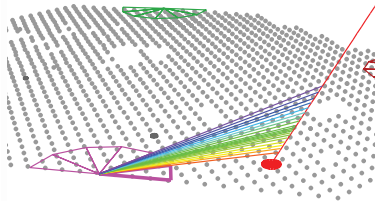
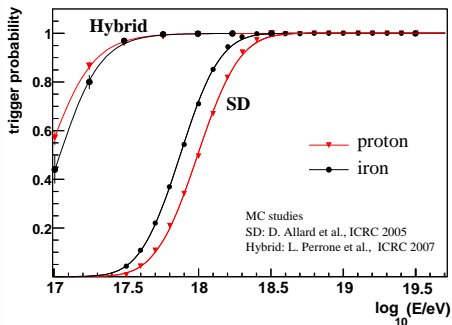
# The surface detector energy spectrum



- ▶  $\mathcal{E} = 12790 \text{ km}^2 \text{ sr yr}$
- ▶ resolution of  $E_{\text{SD}}$  10 – 17%
- ▶ forward folding used to derive flux correction  $< 20 \pm 5\%$



# Extending the energy range with hybrid events



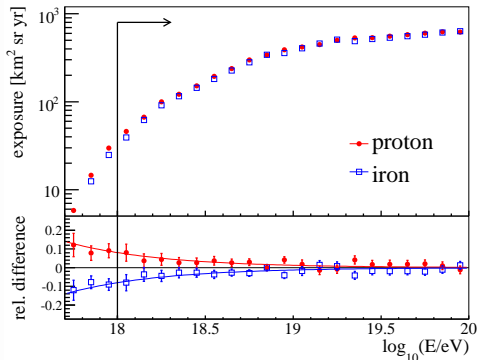
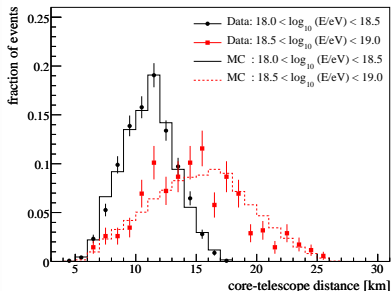
- ▶ energy threshold  $10^{18}$  eV covering the ankle region
- ▶ good energy resolution  $\sigma(E)/E < 10\%$
- ▶ calorimetric energy measurement

# Hybrid Exposure

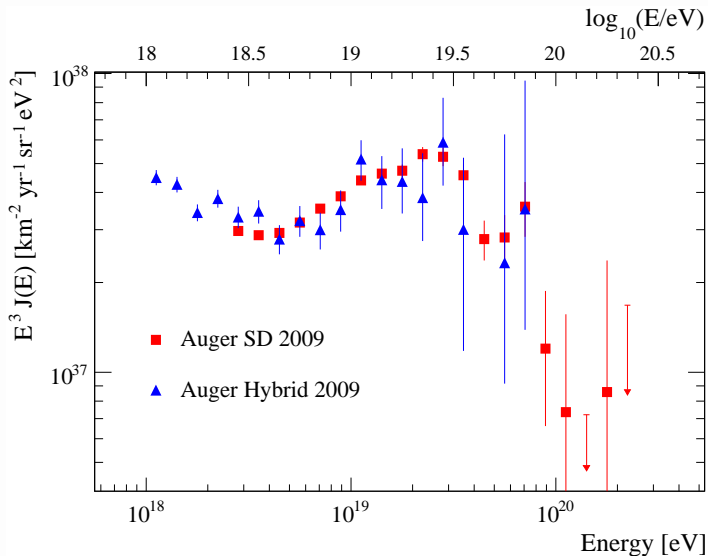
- ▶ atmospheric conditions (aerosols, background light, ...)
- ▶ detector configuration (hardware, software, ontime, ...)
- ▶ primary energy (higher E  $\rightarrow$  more light  $\rightarrow$  larger exposure)

## Time dependent detector MC

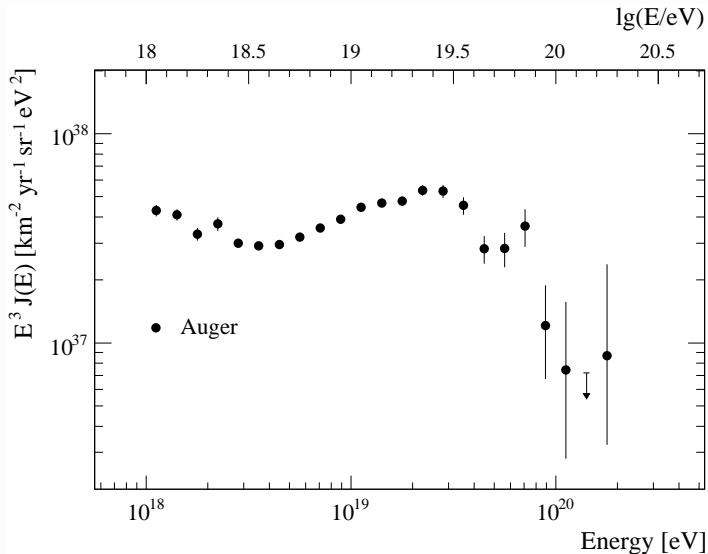
- ▶ reproduce actual data taking conditions
- ▶ good agreement between data and MC



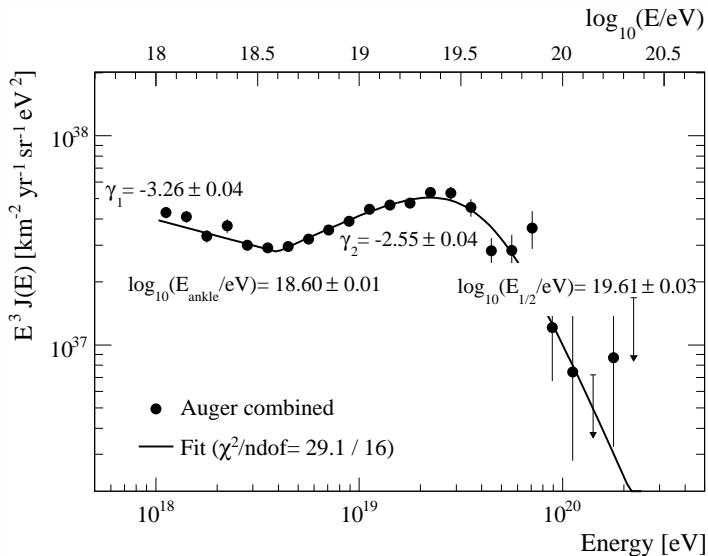
# Energy spectrum from hybrid data



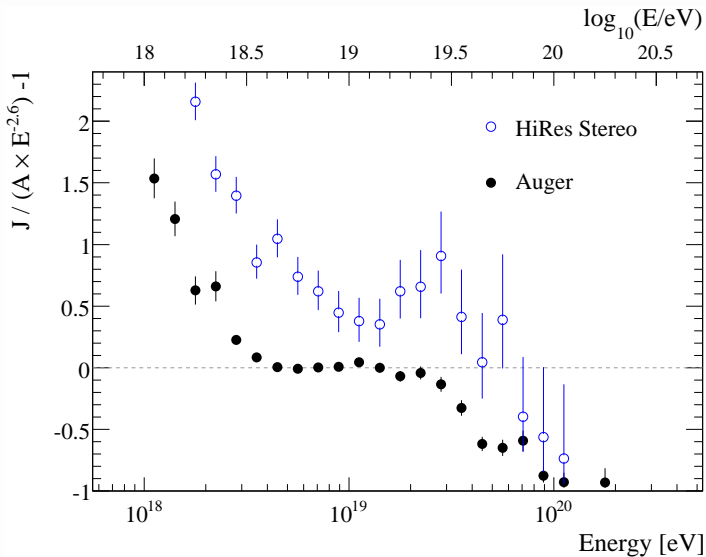
# Energy spectrum



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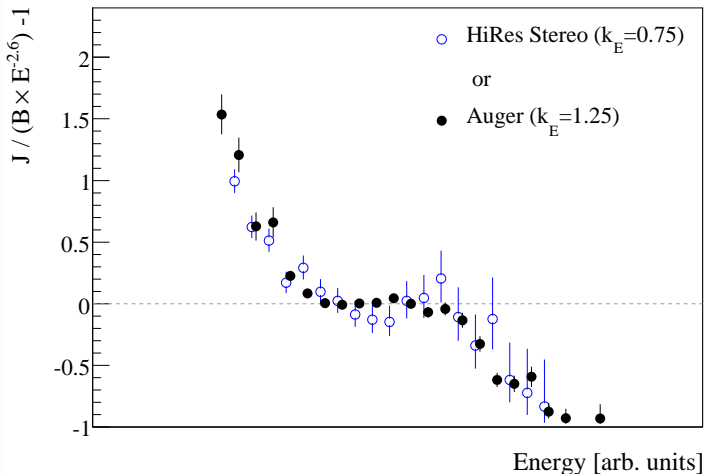


# Comparison with the HiRes stereo spectrum

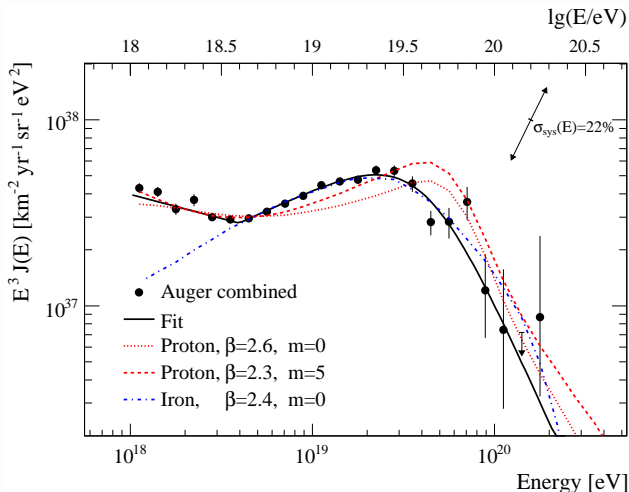


(Auger, PRL 101 61101, PLB (2010))

# Comparison with the HiRes stereo spectrum



# Energy spectrum - comparison with models

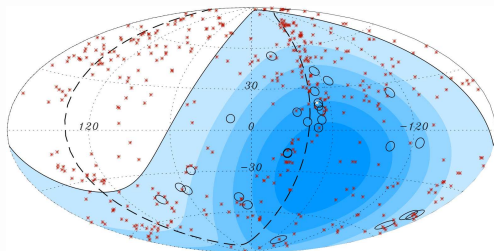


- ▶ simple models,  $J_{\text{source}} \propto E^{-\beta}, (1+z)^m$
- ▶ mass composition important



# Anisotropies: status of prescribed test

data up to March 2009 ( $E > 55 \text{ EeV}$ , correlation with VCV catalogue,  $\delta < 3.1^\circ$ ,  $D < 75 \text{ Mpc}$ )

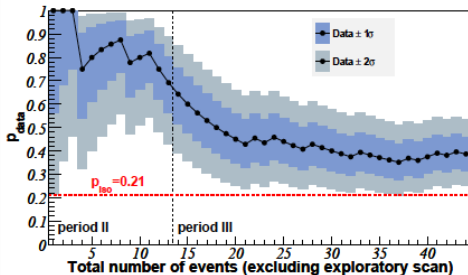


- ▶ 39% correlate (21% expected for isotropy)
- ▶ present confidence level 99.4%

(Auger, Science **318** (2007) 938)

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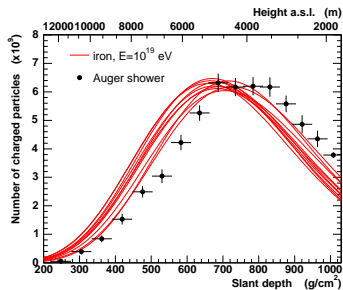
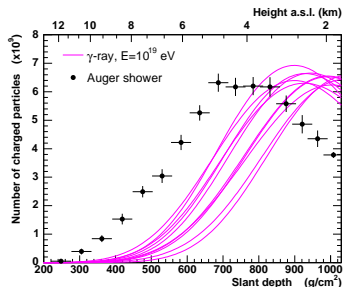
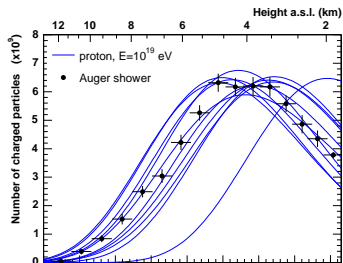
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(paper in preparation)

# Mass composition

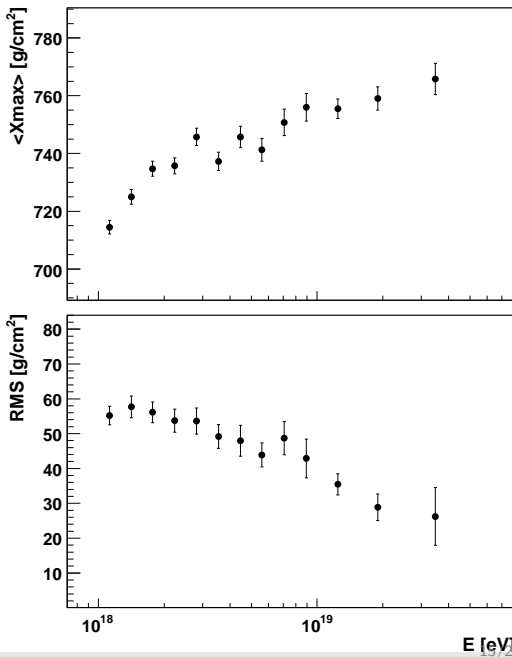


- ▶  $\langle X_{\max} \rangle$  and  $\text{RMS}(X_{\max})$   
⇒ FD composition
- ▶ shower front properties  
⇒ SD composition

# FD Results

- ▶  $\langle X_{\max} \rangle$  and RMS vs  $E$
- ▶ comparison to air shower simulations
- ▶ comparison to HiRes data

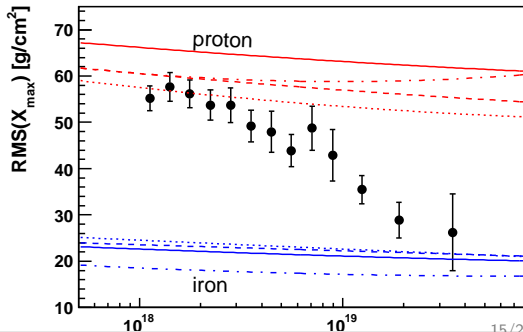
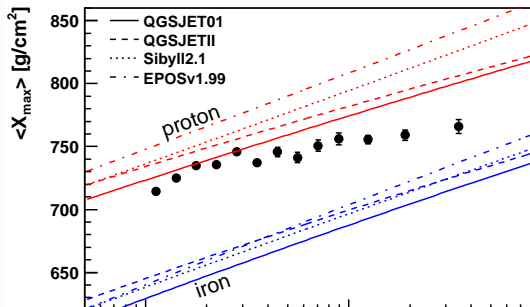
(Auger, PRL(2010))



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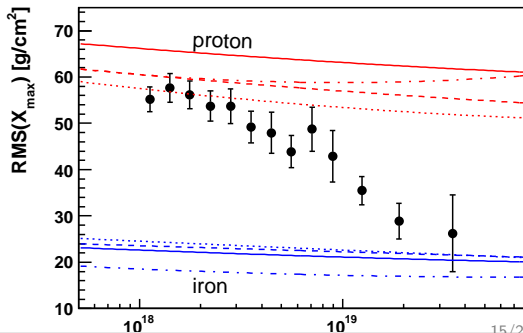
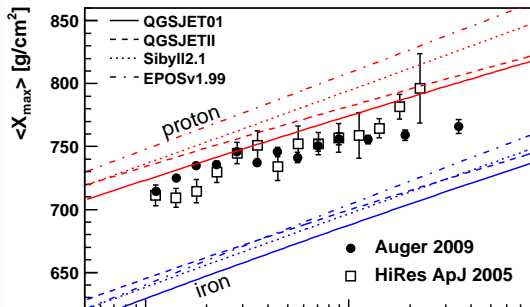
(Auger, PRL(2010))



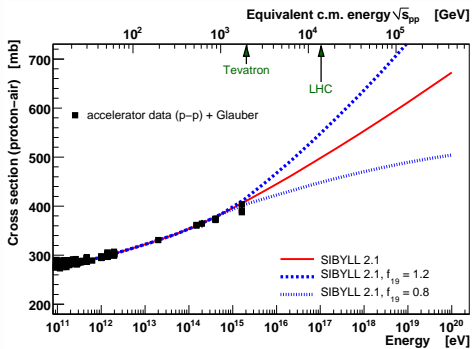
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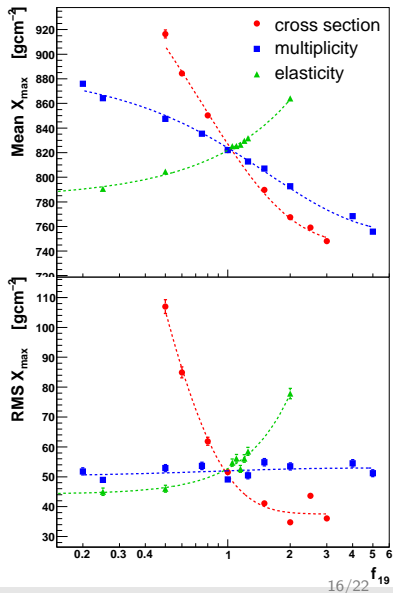
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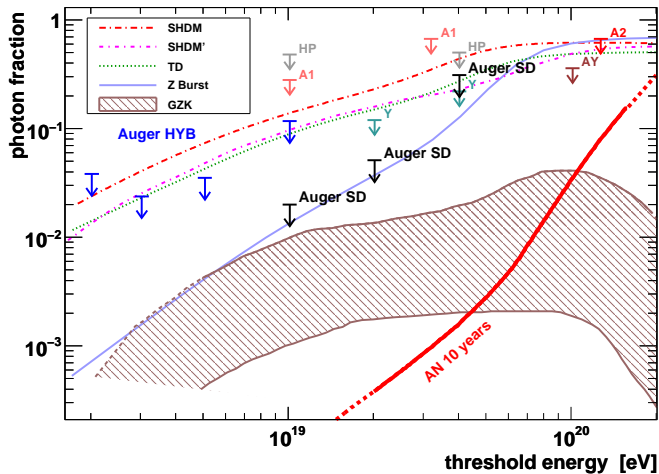
# Hadronic interactions



(R. Ulrich et al., arXiv:0906.0418)

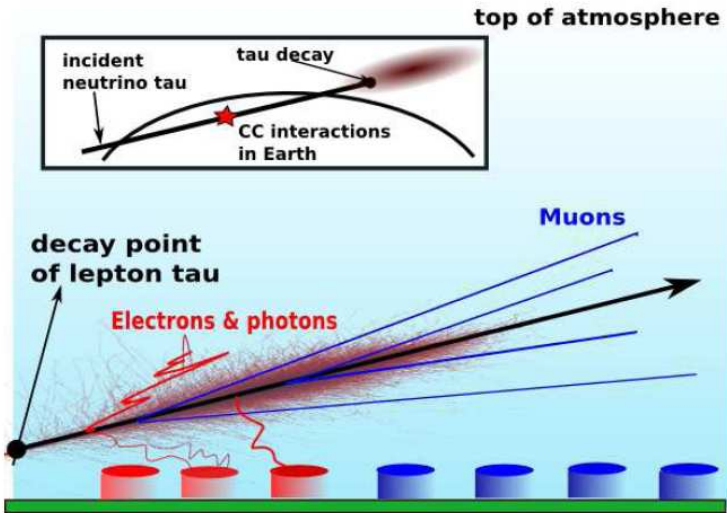


# Photon limits



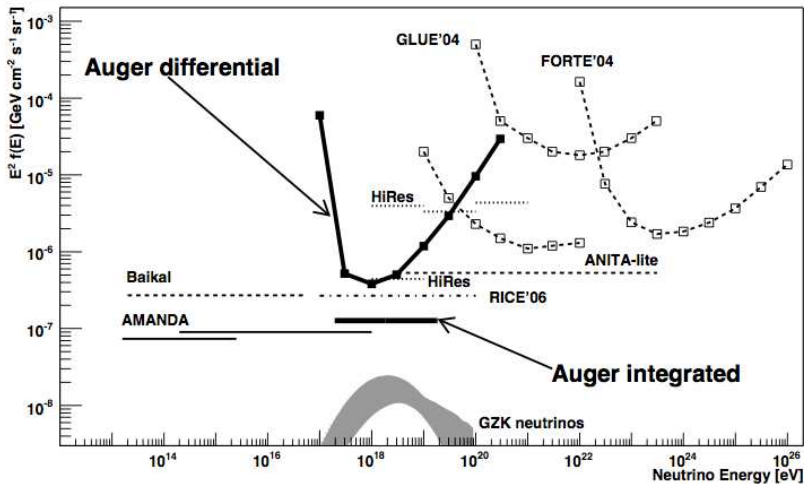


# Search for neutrinos



(Gora et al., ICRC09)

# Search for neutrinos



# Auger South enhancements

## High Elevation Auger Telescope (HEAT)



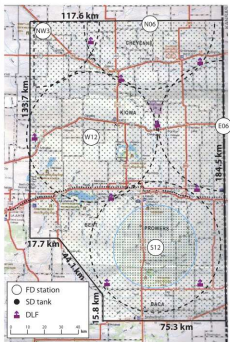
## Auger Muons and Infill for the Ground (AMIGA)

+

## Auger Engineering Radio Array (AERA)

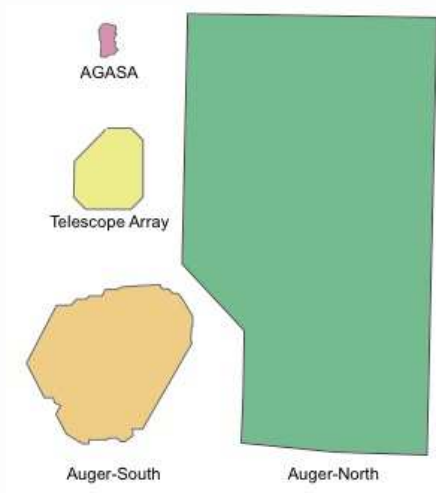
- ▶ fluorescence
- ▶ water cherenkov
- ▶ 30 m<sup>2</sup> muon counters
- ▶ radio antennas

# Auger North



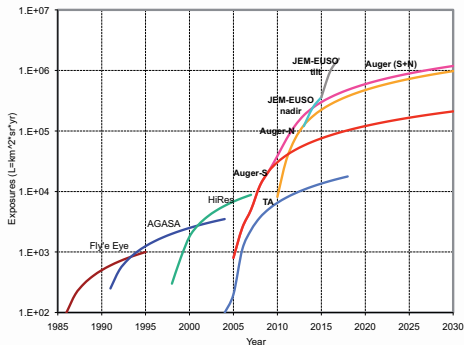
- ▶ 20,000 km<sup>2</sup>, 4400 tanks
- ▶ 39 telescopes
- ▶ expands Auger aperture 8-fold above 55 EeV
- ▶ enables full-sky exposure
- ▶ 200 events/year (now: 25 events/year)
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# Conclusions

- ▶ deployment of Auger South is complete
- ▶ unambiguous observation of flux suppression
- ▶ photon limits → top-down models disfavoured
- ▶ evidence for anisotropy within the GZK sphere
- ▶ evidence for mixed particle composition