UHECR & ν: Progress from giant air shower arrays

PIERRE AUGER OBSERVATORY

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Overview

Giant UHECR Observatories
- Spectrum
- Composition
- Arrival directions

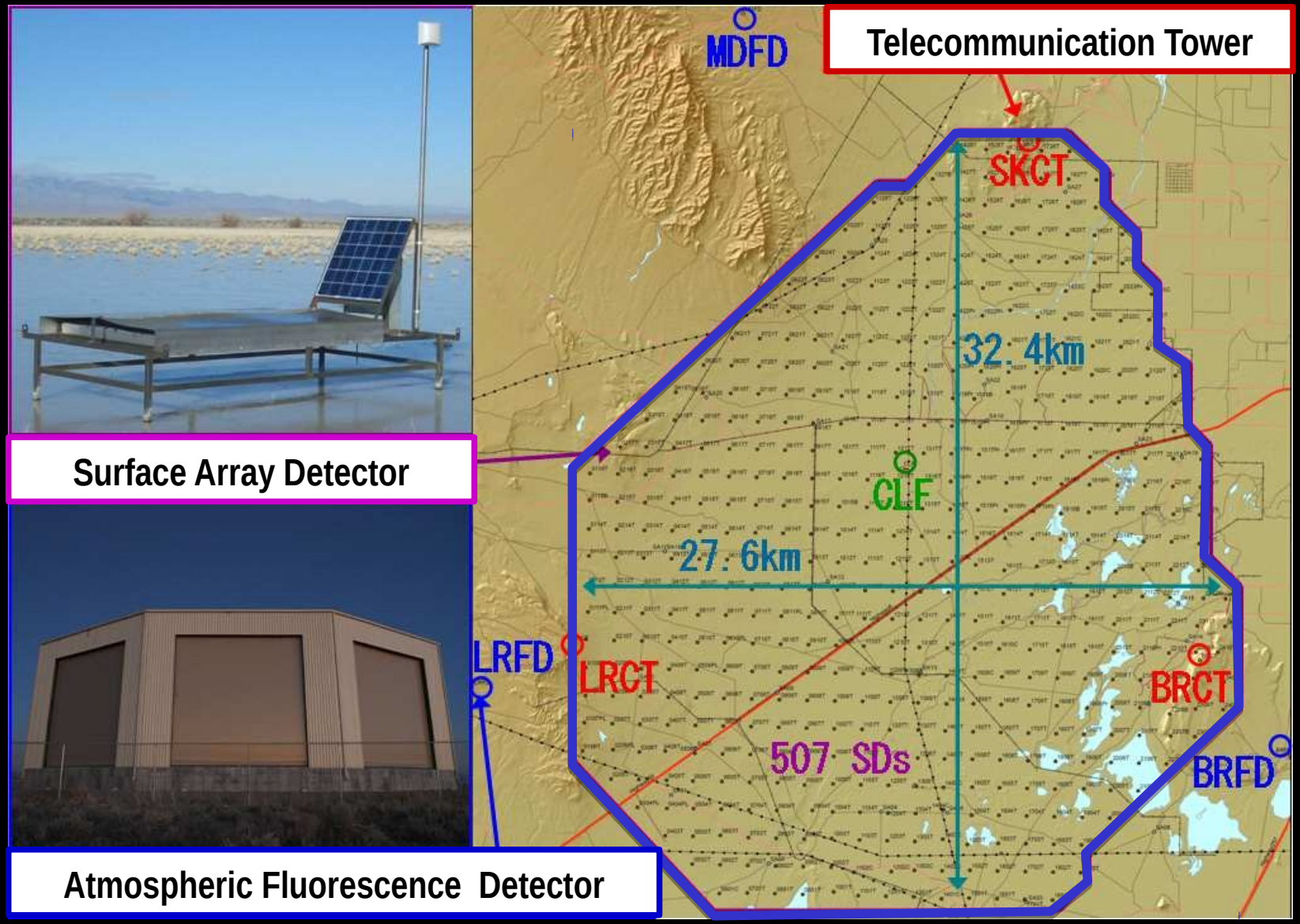
Multimessenger capabilities
- Neutrino searches
- (Photon searches)

Future directions

Hybrid success story

Precision, redundancy and large aperture

TA

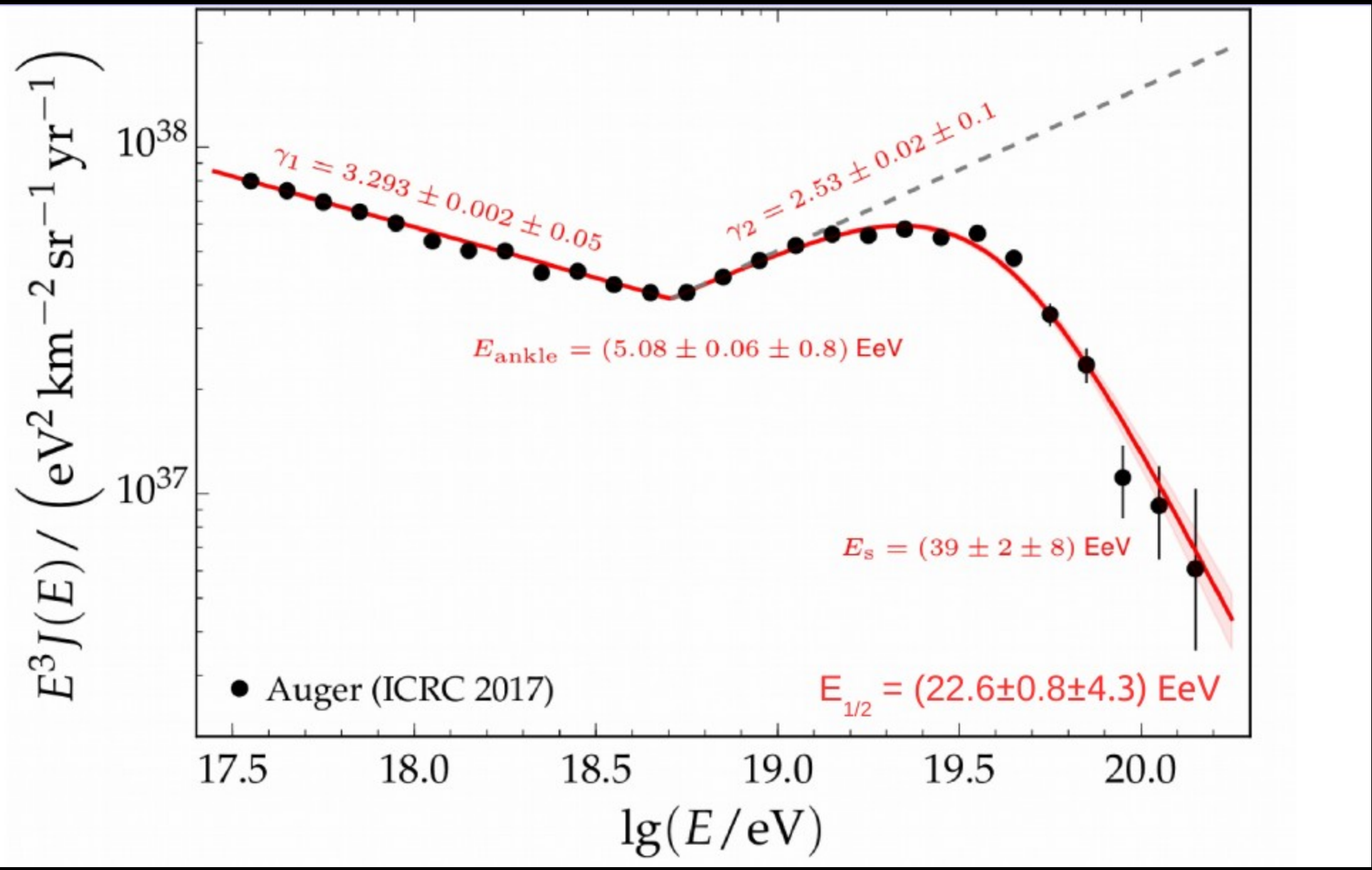


The Pierre Auger Observatory


Capo
d'Orlando
Patti
Barcellona
Pozzo di Gotto
Messina
Auger
Parco dei
Nebrodi
Taormina
Acireale
Enna
TA
Catania

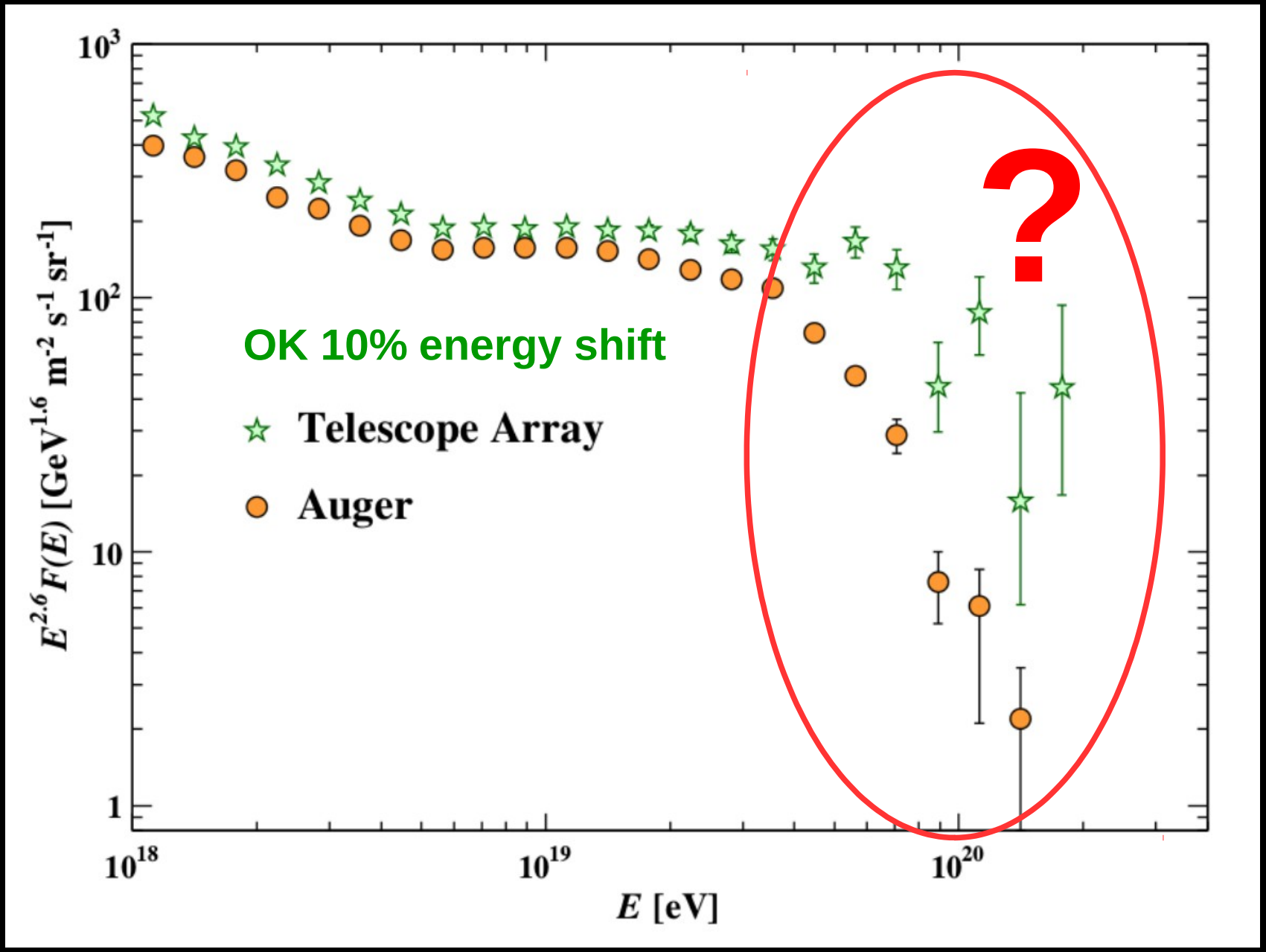
Spectrum

Spectrum results (Auger)



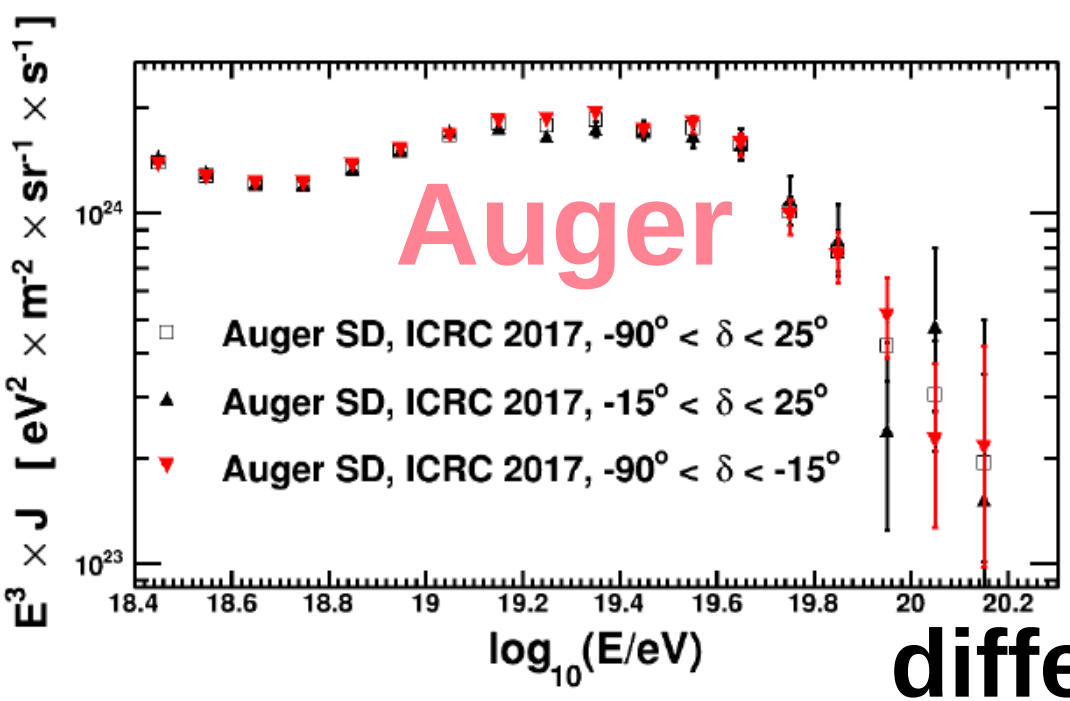
F. Fenu; Proc. of ICRC 2017, PoS (2017) 486.

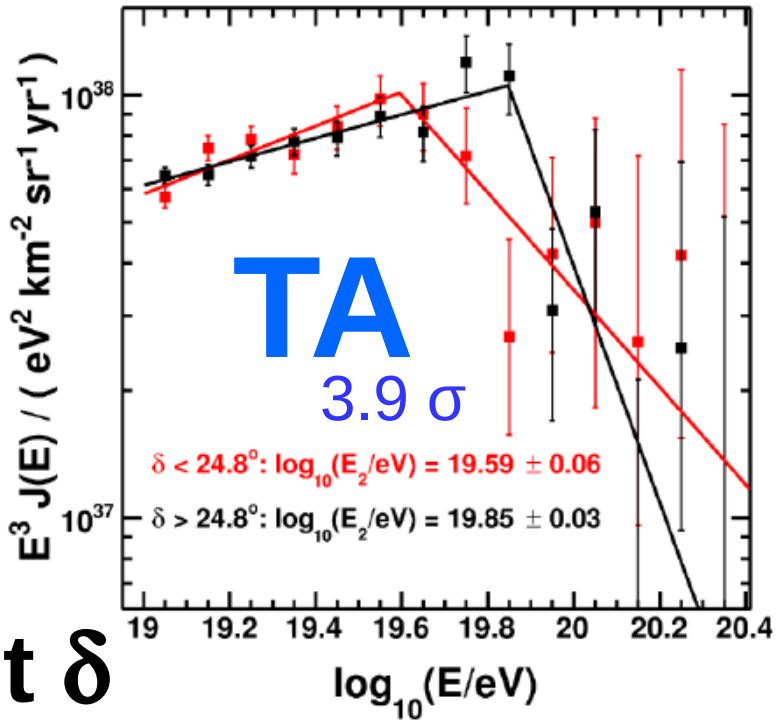
Spectrum results compared



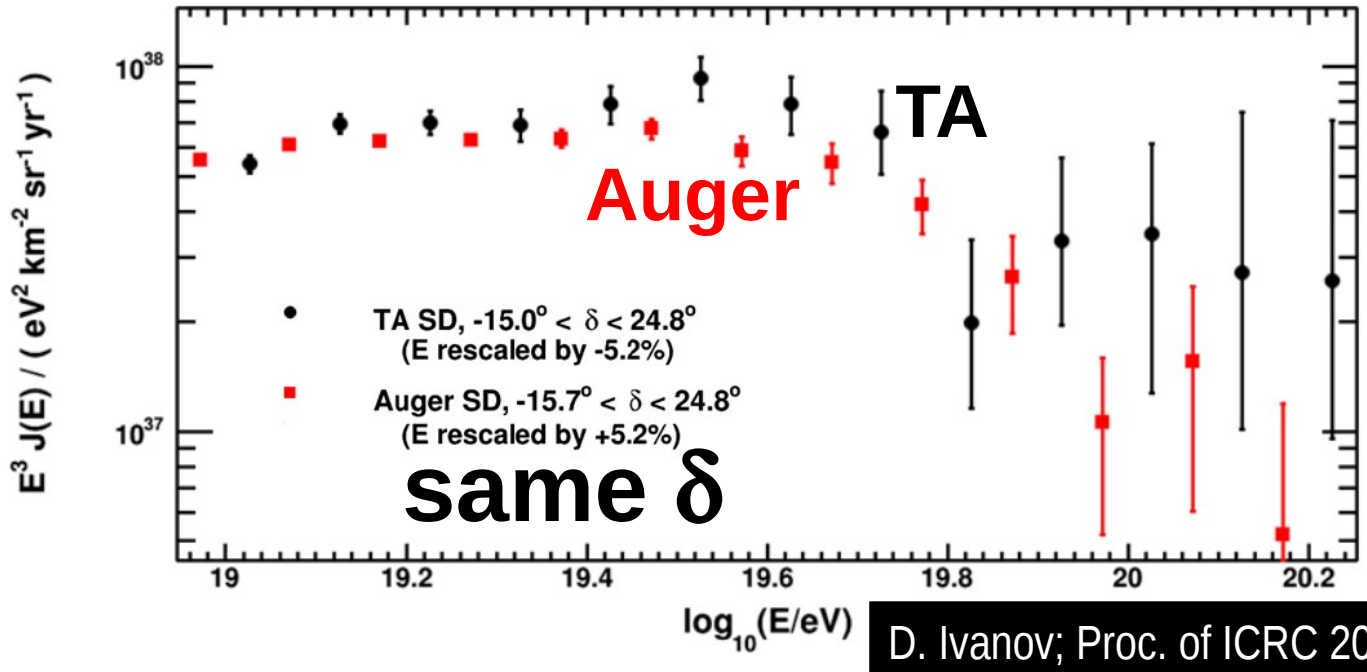
D. Ivanov; Proc. of ICRC 2017, PoS (2017) 498.

Can it be due to anisotropy?





different δ



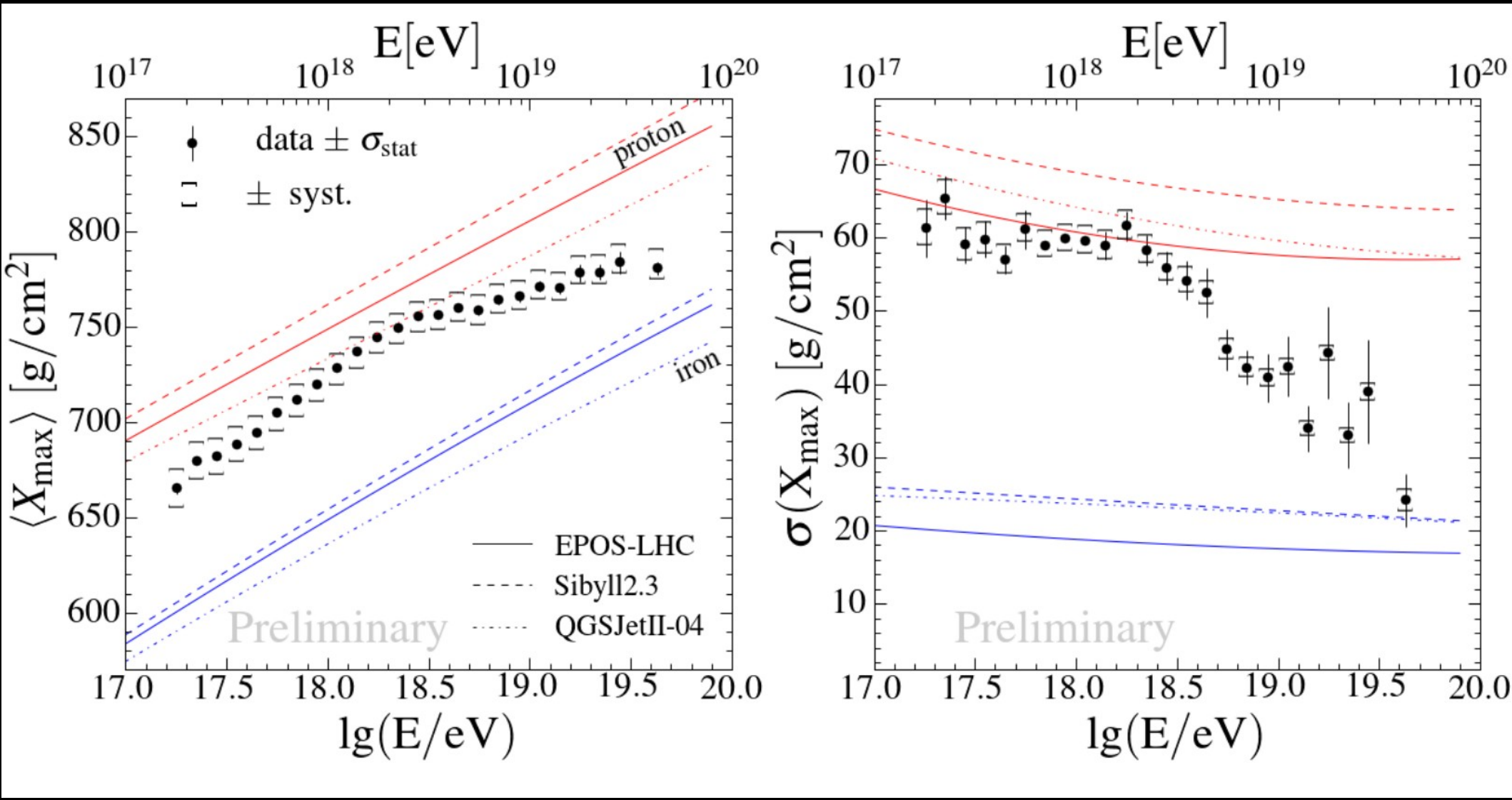
3.9 σ discrepancy
(broken power law fit)
Not due to biases in
energy or exposure

Common declination band
agreement
same break points

D. Ivanov; Proc. of ICRC 2017, PoS (2017) 498.

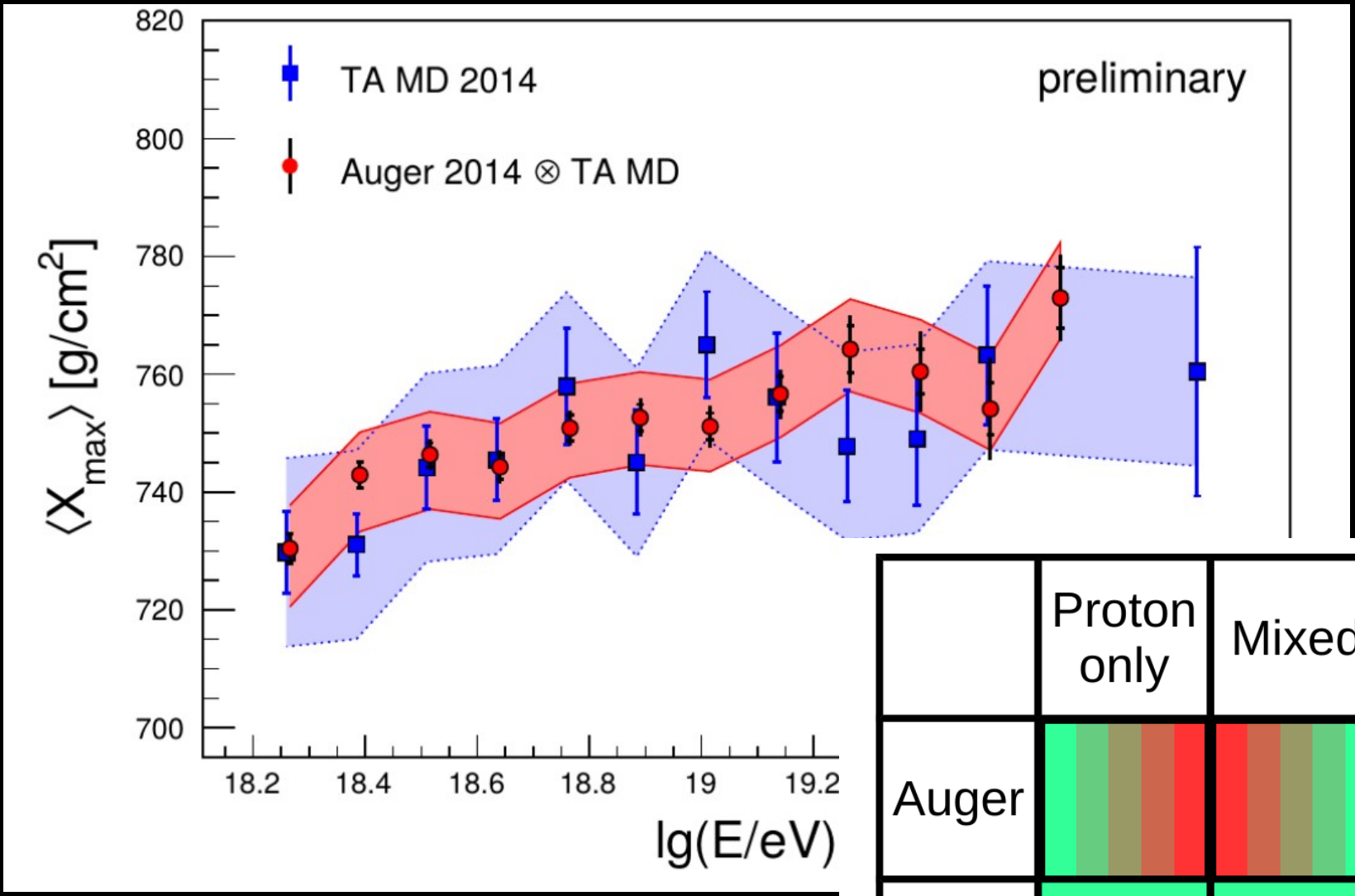
Composition

Composition results (Auger)



J. Bellido; Proc. of ICRC 2017, PoS (2017) 506.

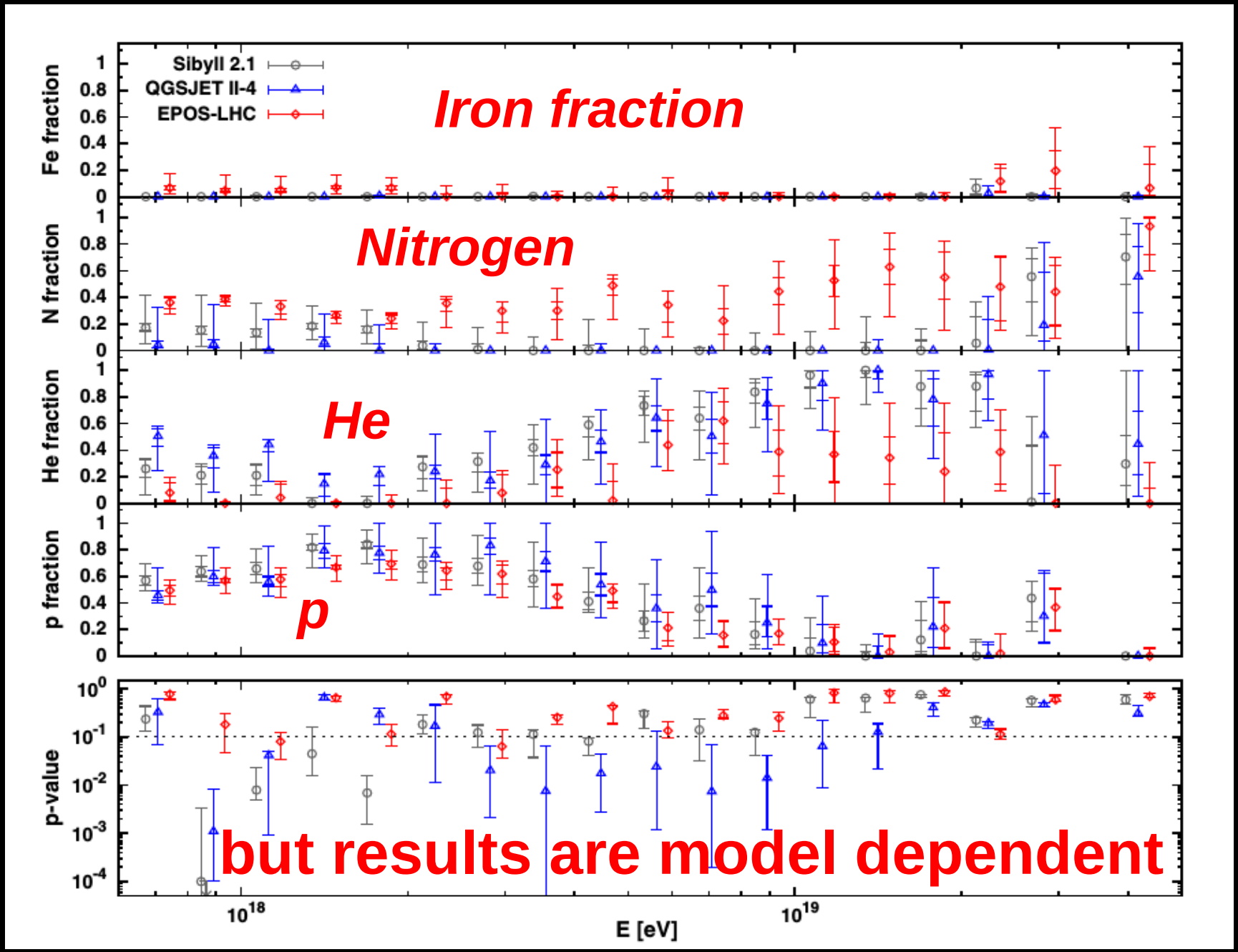
About the TA proton claim



	Proton only	Mixed	Iron only	Auger
Auger				
TA				!!!

V. de Souza; Proc. of ICRC 2017, PoS (2017) 522.

Clear composition trends



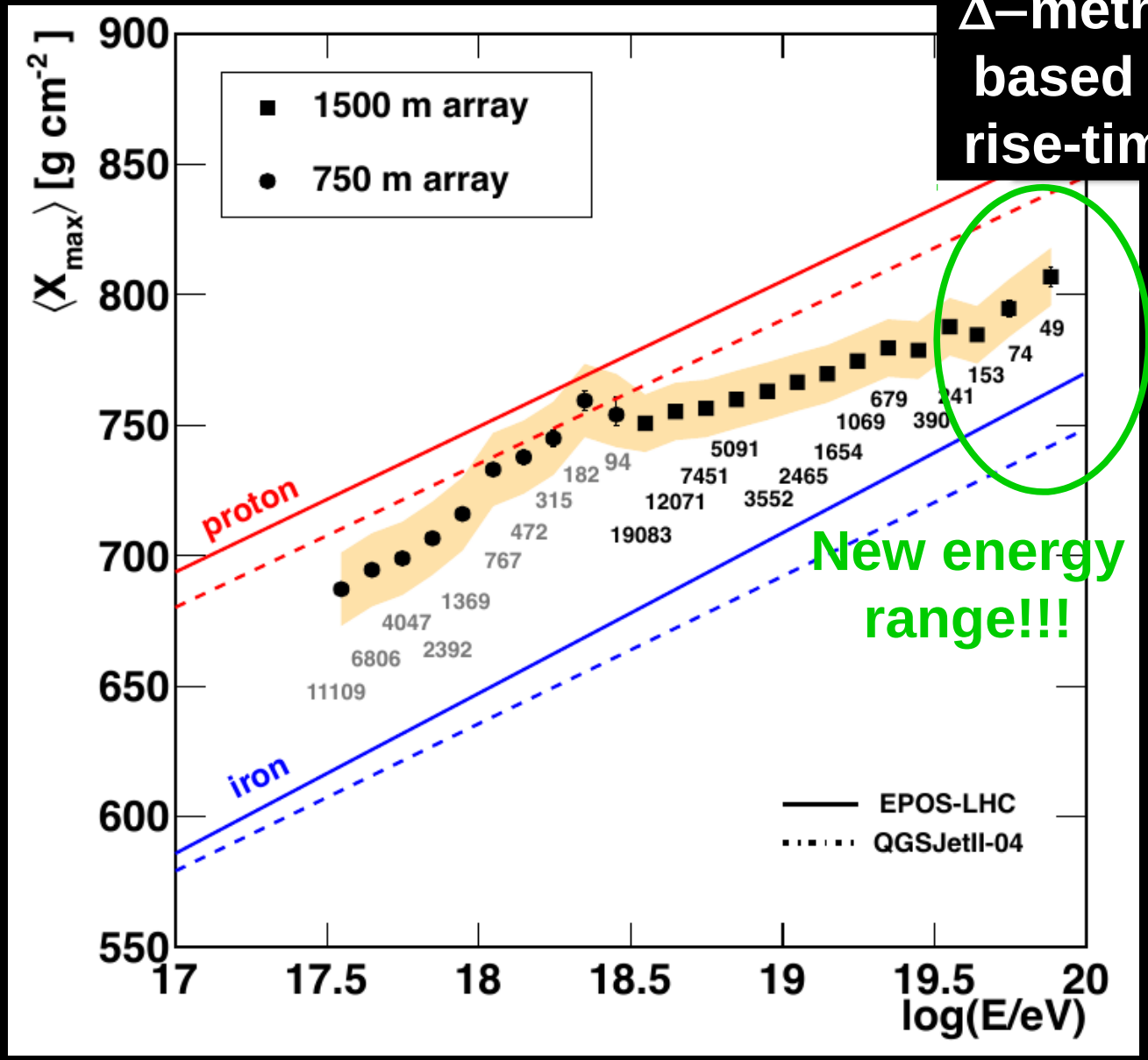
Composition also addressed from SD

Using muons:
1 Inclined showers
2 X_{μ}^{max}

Using time structure
3 risetime asymmetry
4 Δ-Method

"Calibrated" with FD

Δ–method based on rise-times



P. Sánchez Lucas; Proc. of ICRC 2017, PoS (2017) 495.

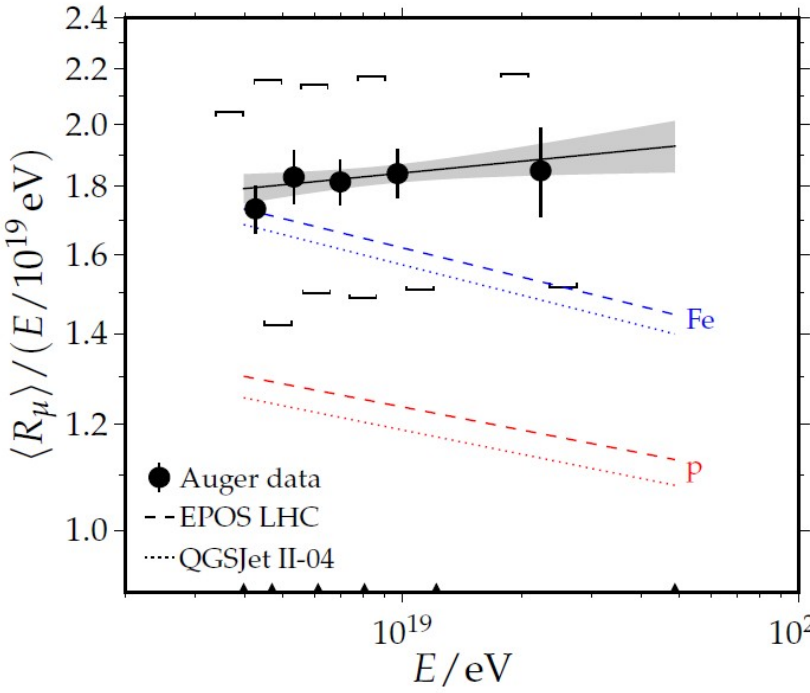
No hadronic model is fully consistent!!

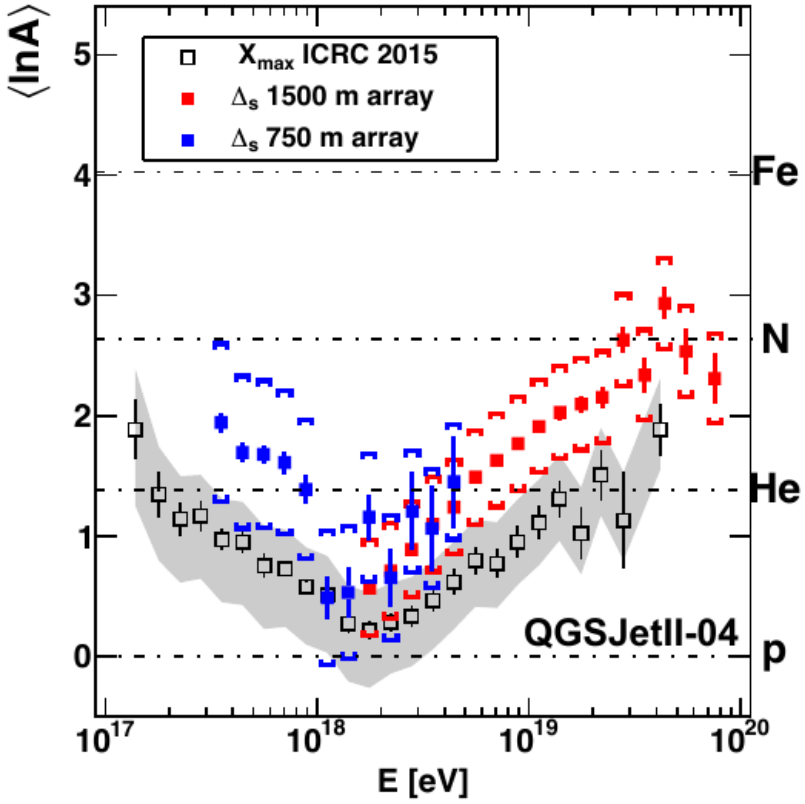
1 Inclined showers: μ deficit of **models**
PRD 91, 032003 (2015)

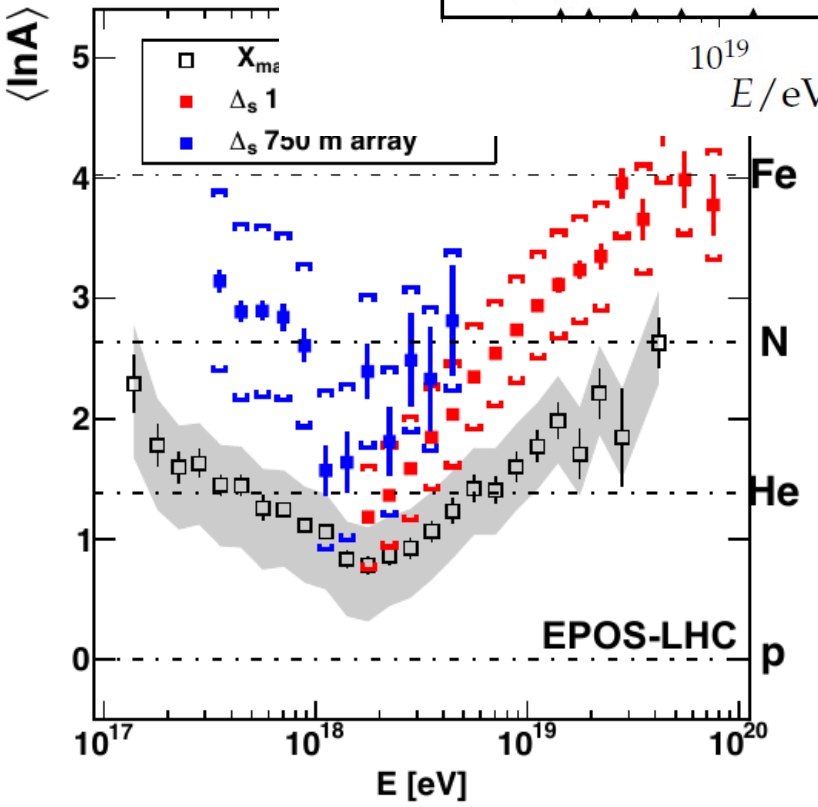
2 X_{μ}^{max} showers: μs produced later

3 risetime asym: lower angle
PRD v91 012012 (2015); 92 019903 (2015)

4 Δ-Method: more rise-time
PRD 93, 072006 (2016)



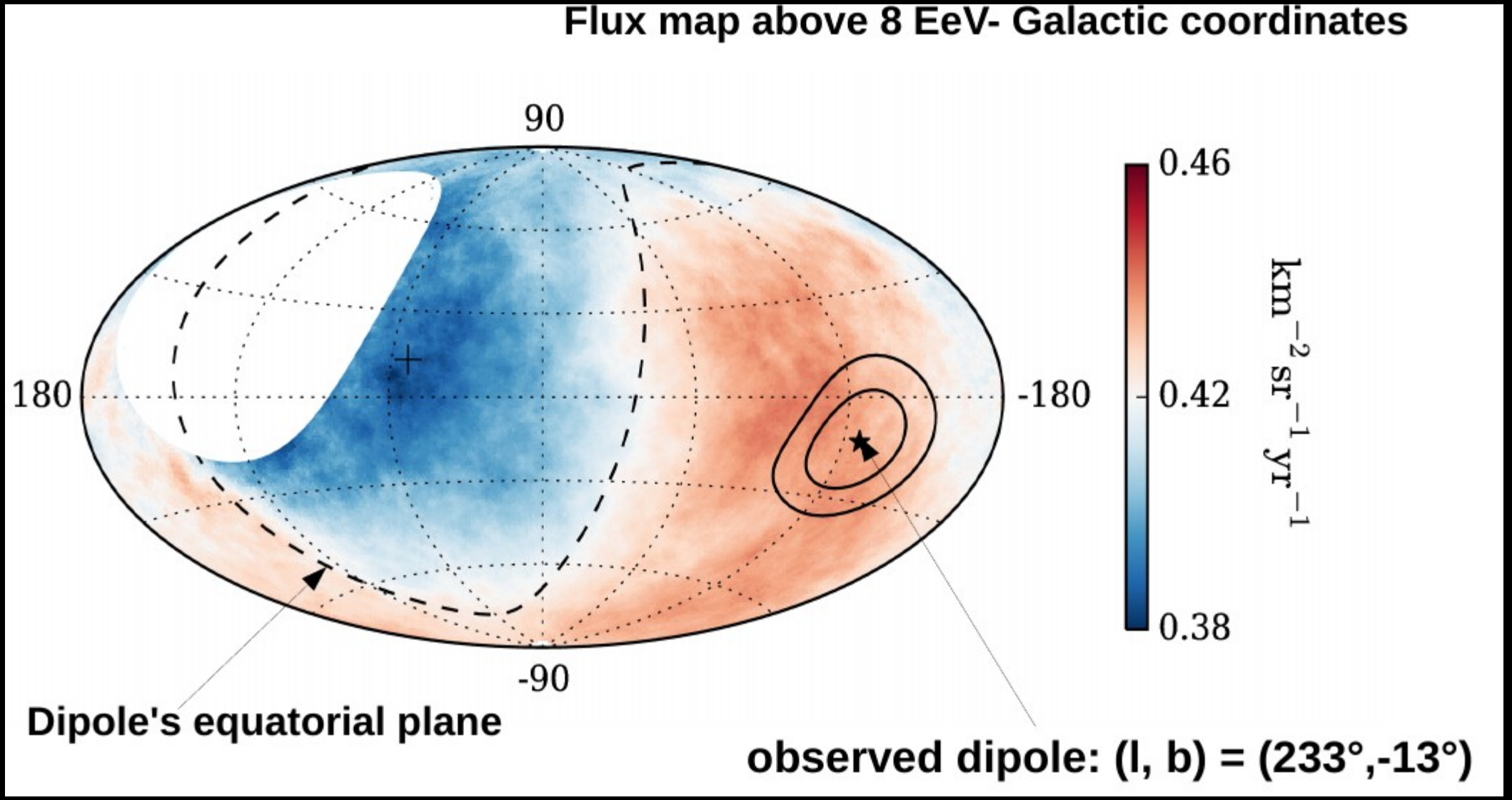




Anisotropy searches:

Anisotropy searches: dipole E>8 EeV!

Auger Collab. Science 2017) 357 (2017) 1266-1270

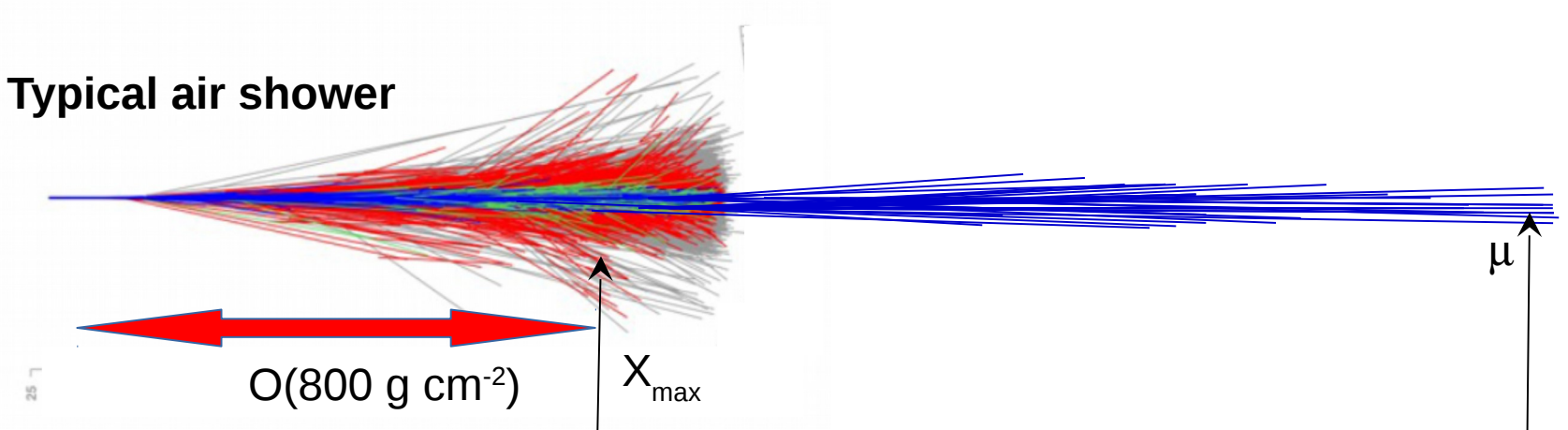


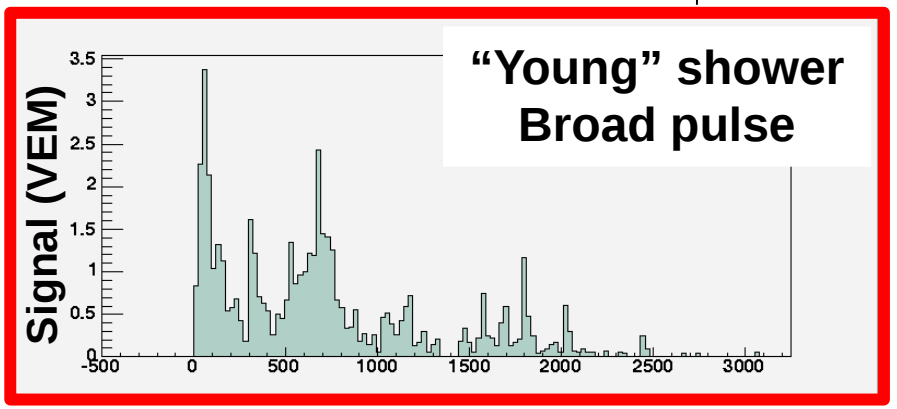
Signs of small angular scale anisotropy at highest energies,
TA: Hot spot E> 57 EeV & Auger: SBG correlation E> 40 EeV, 3.9 σ ...
Expect more results in near future

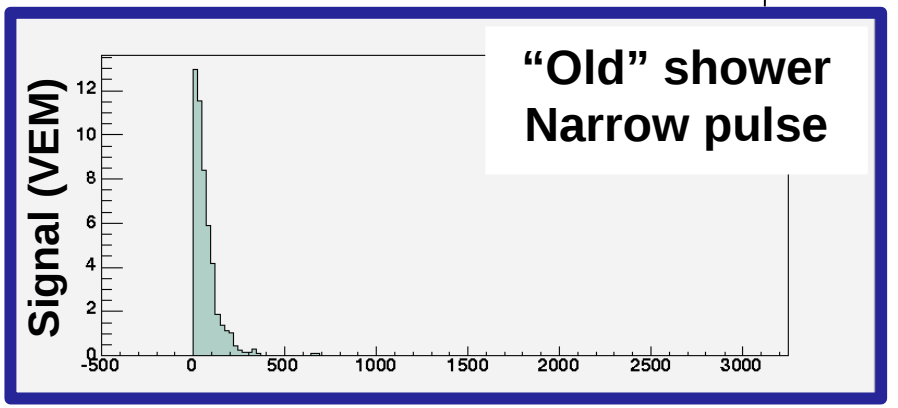
Neutrino searches:

Old versus young CR showers

CRI 267 F. Fenu 18/7 14:15 room 101
JCAP 08 (2014) 019, JCAP 08 (2015) 049

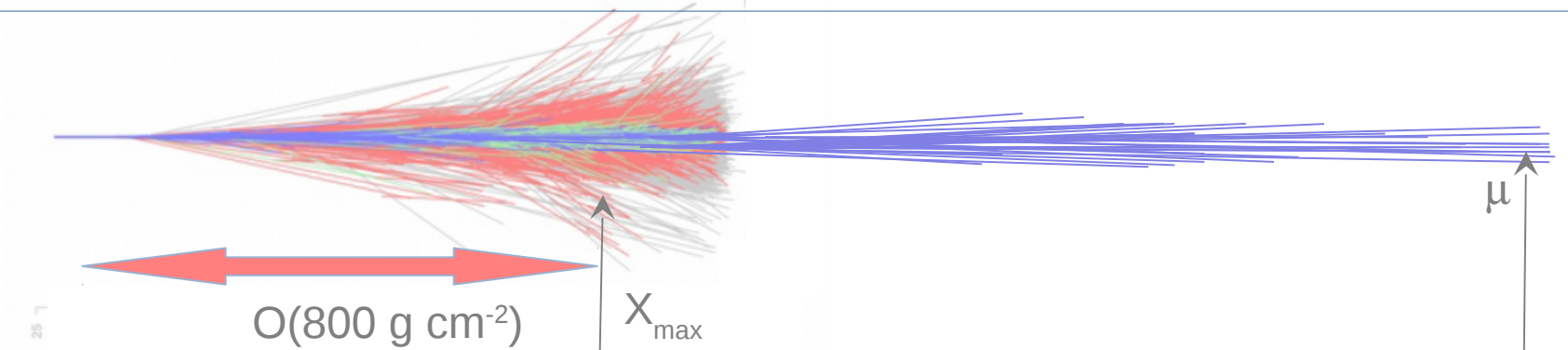


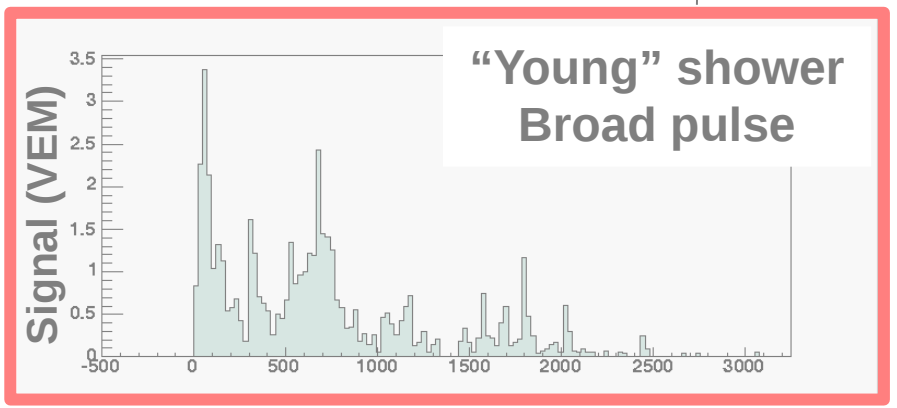


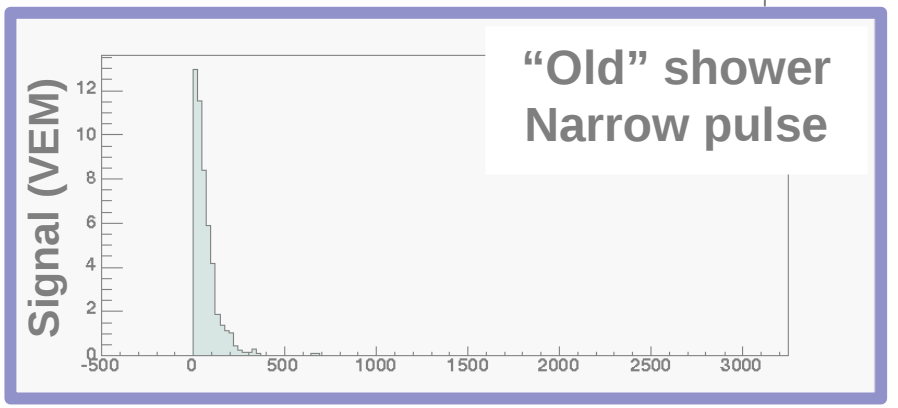


Inclined and young = ν

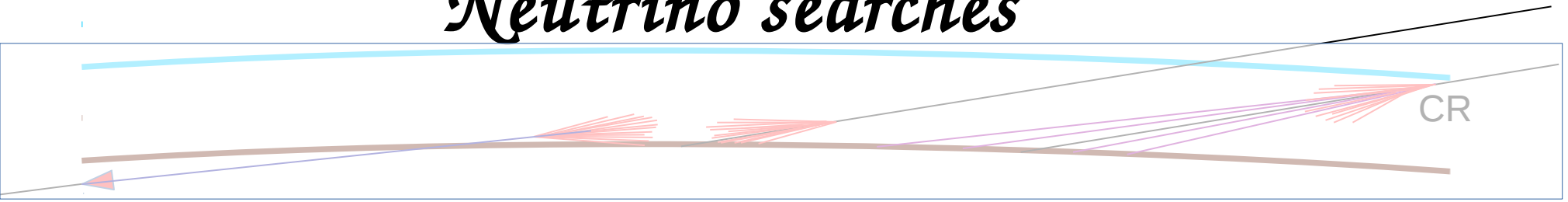
Neutrino: Inclined air shower with broad component







Neutrino searches



Three search categories (**different flavor sensitivities for** ES and DG):

- **(1) ES** Earth skimming tau neutrinos
  Between 90^0 and 95^0 (upcoming)
  Decay early

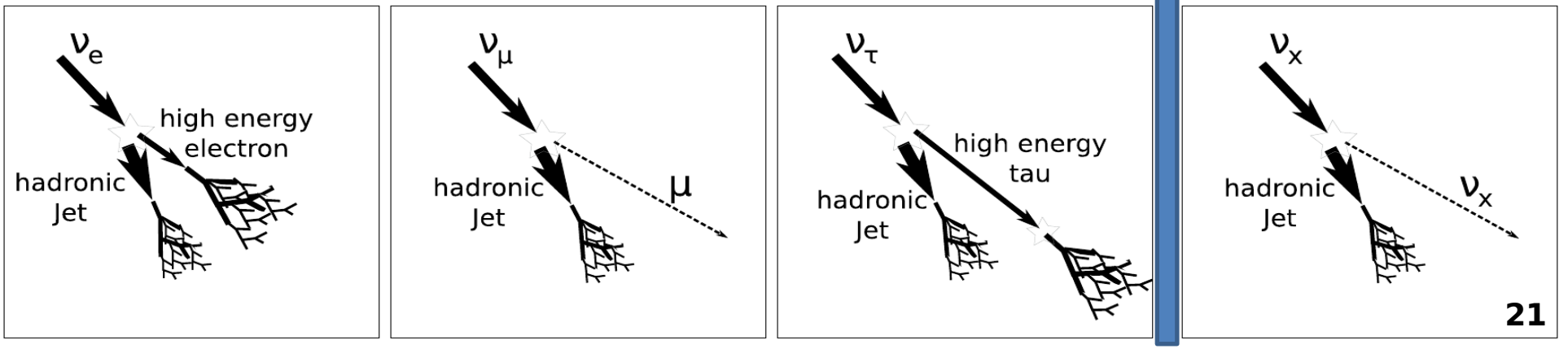
  } *To trigger SD array*

- DG Atmospheric interactions ($\theta > 60^0$ ⇒ $X_{atm} > 1700$ g cm^{-2})

  + **(2) DGL $60^0<\theta<75^0$**
  + **(3) DGH $75^0<\theta<90^0$**

  } *All ν NC & ν_μ CC 20% energy to shower*
  ν_eCC 100% energy to shower
  ν_τCC 20% to shower #1 50% to shower #2

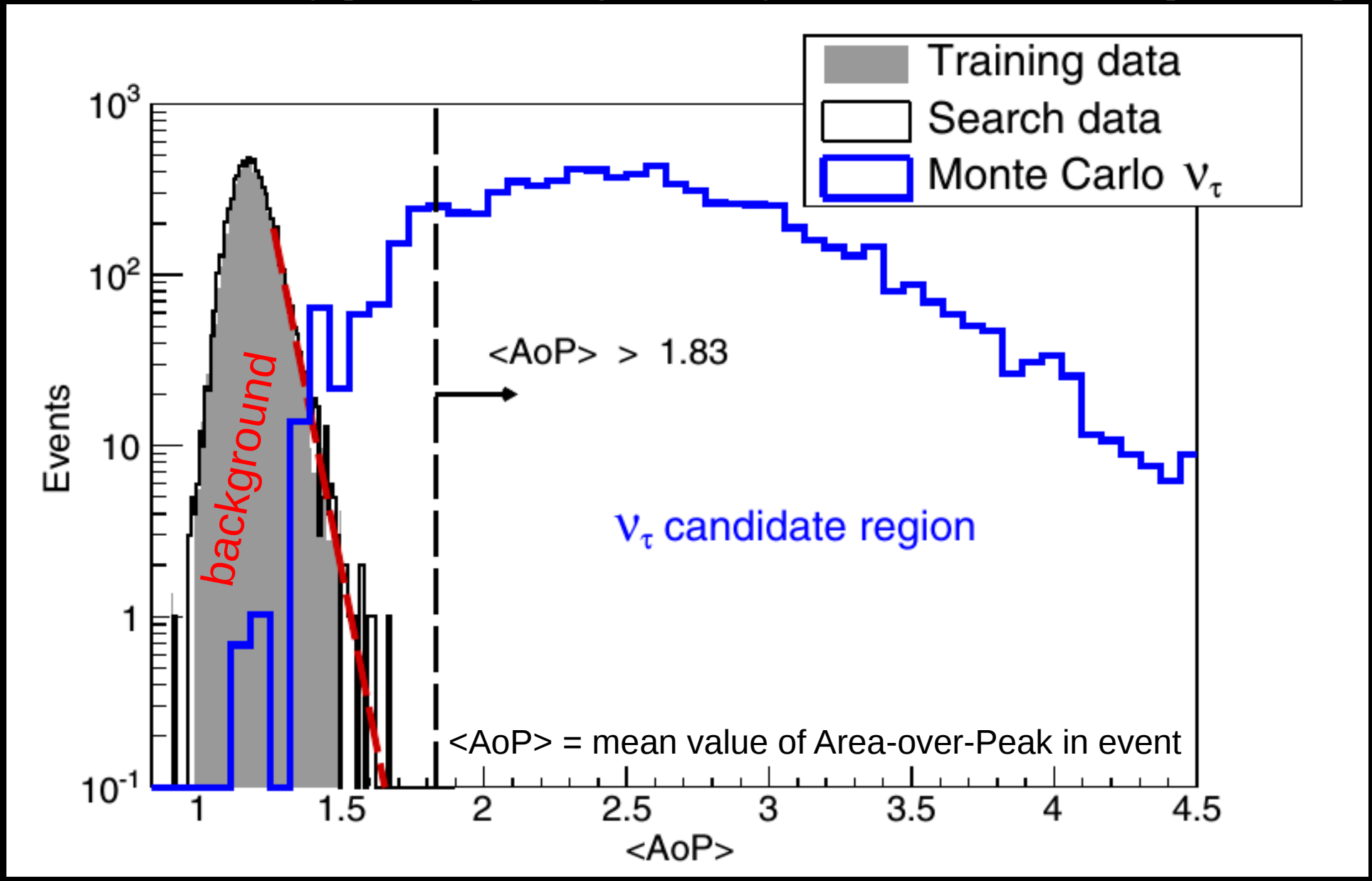
Charged Current



Neutral Current

Earth Skimming search

Most sensitivity [0.2 - 2] EeV practically excluded to zeniths [90^0 - 95^0]



Phys. Rev. D **91**, 092008 (2015); Ap JL 755:L4 (2012)

Exposure $\mathcal{E}_{tot}(E_\nu)$

$$N_{\text{events}} = \int_{E_\nu} \Phi_{\text{single flavor}}(E_\nu)\ \mathcal{E}_{\text{tot}}(E_\nu)\ \mathrm{d}E_\nu$$

Very sensitive to ES ν_τ

1 Jan 04 – 31 Mar 17

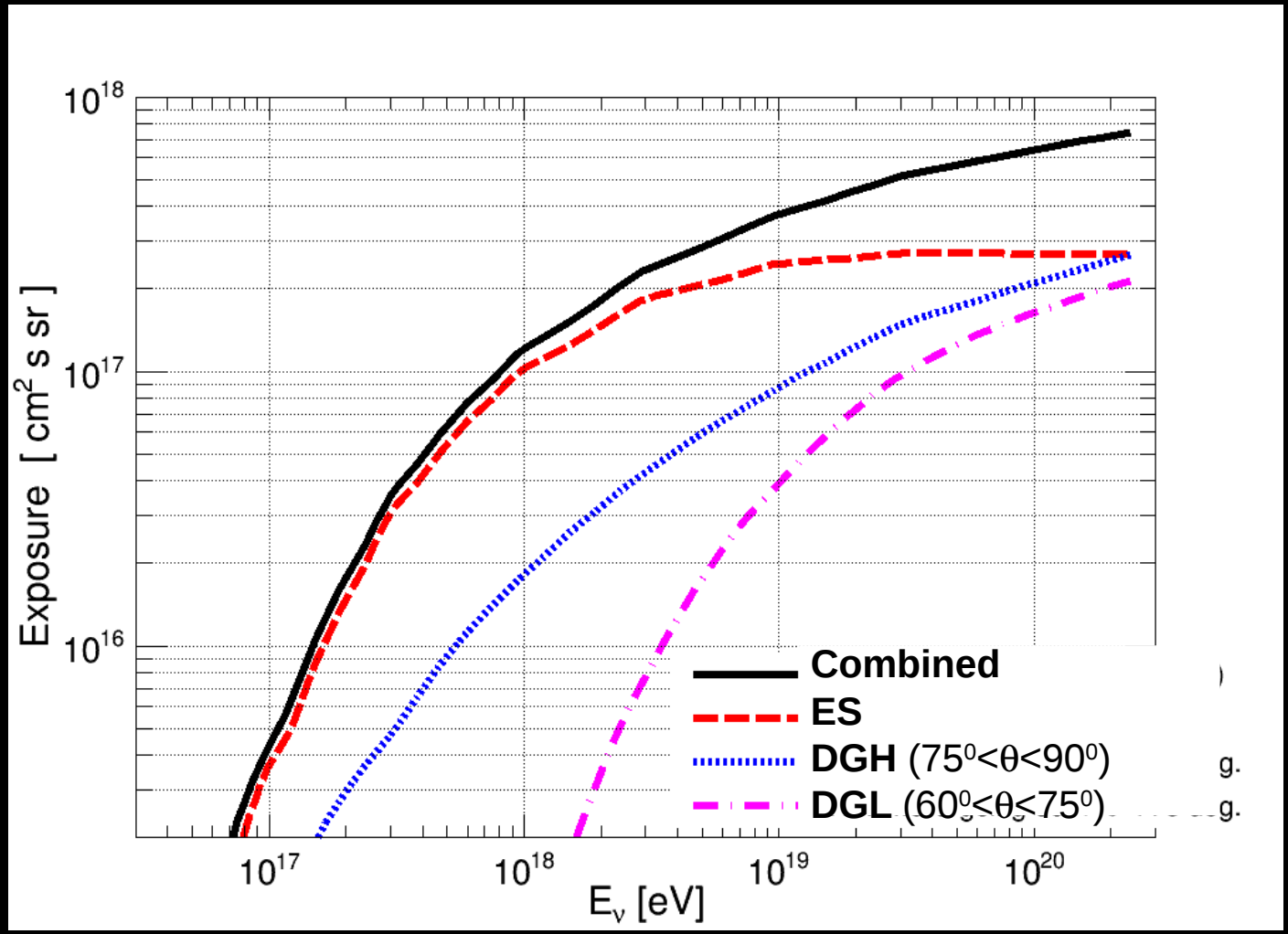
Relative contributions (E^{-2} flux)

CHANNELS

ES	79.4%
DGH	17.6%
DGL	3.0%

FLAVOURS

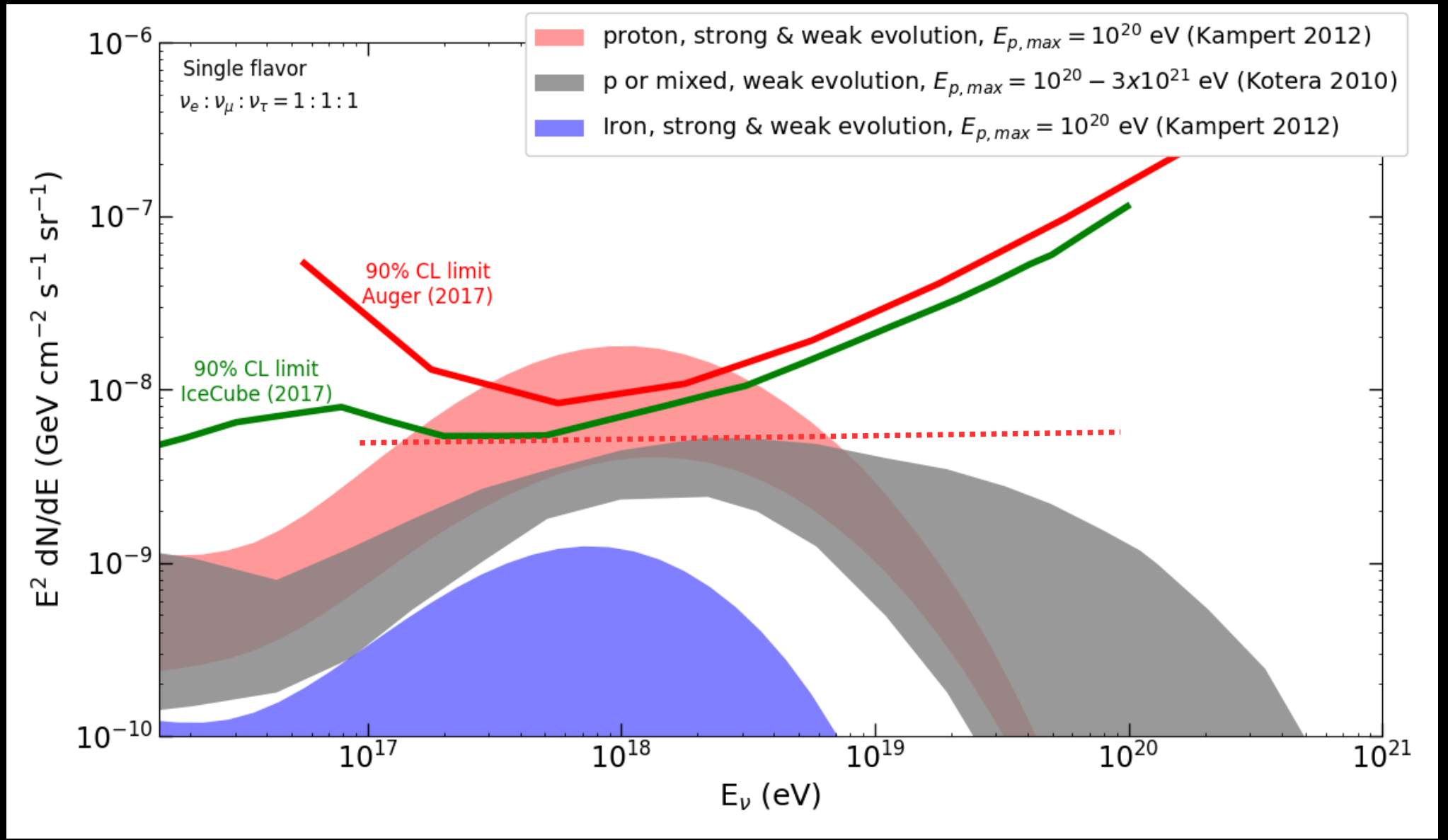
ν_e	10.1%
ν_μ	3.8%
ν_τ	86.1%



E. Zas; Proc. of ICRC 2017, PoS (2017) 972.

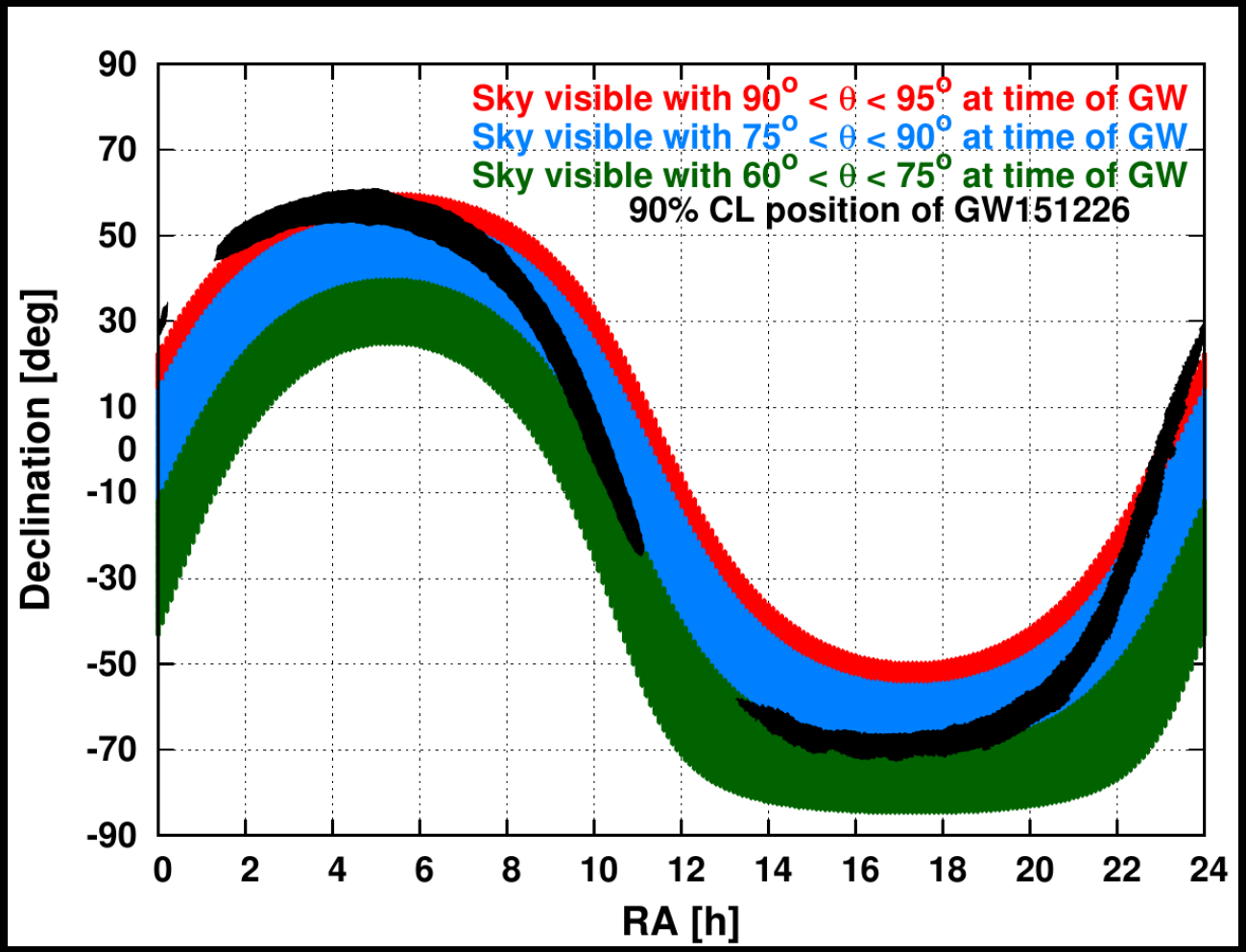
Limits to diffuse flux

J. Alvarez-Muñiz Highlight talk ICRC2017



Search for point sources

i.e. GW150914, GW151226, GW170104 (& LVT151012)



Sensitivity limited to large zenith angles =>

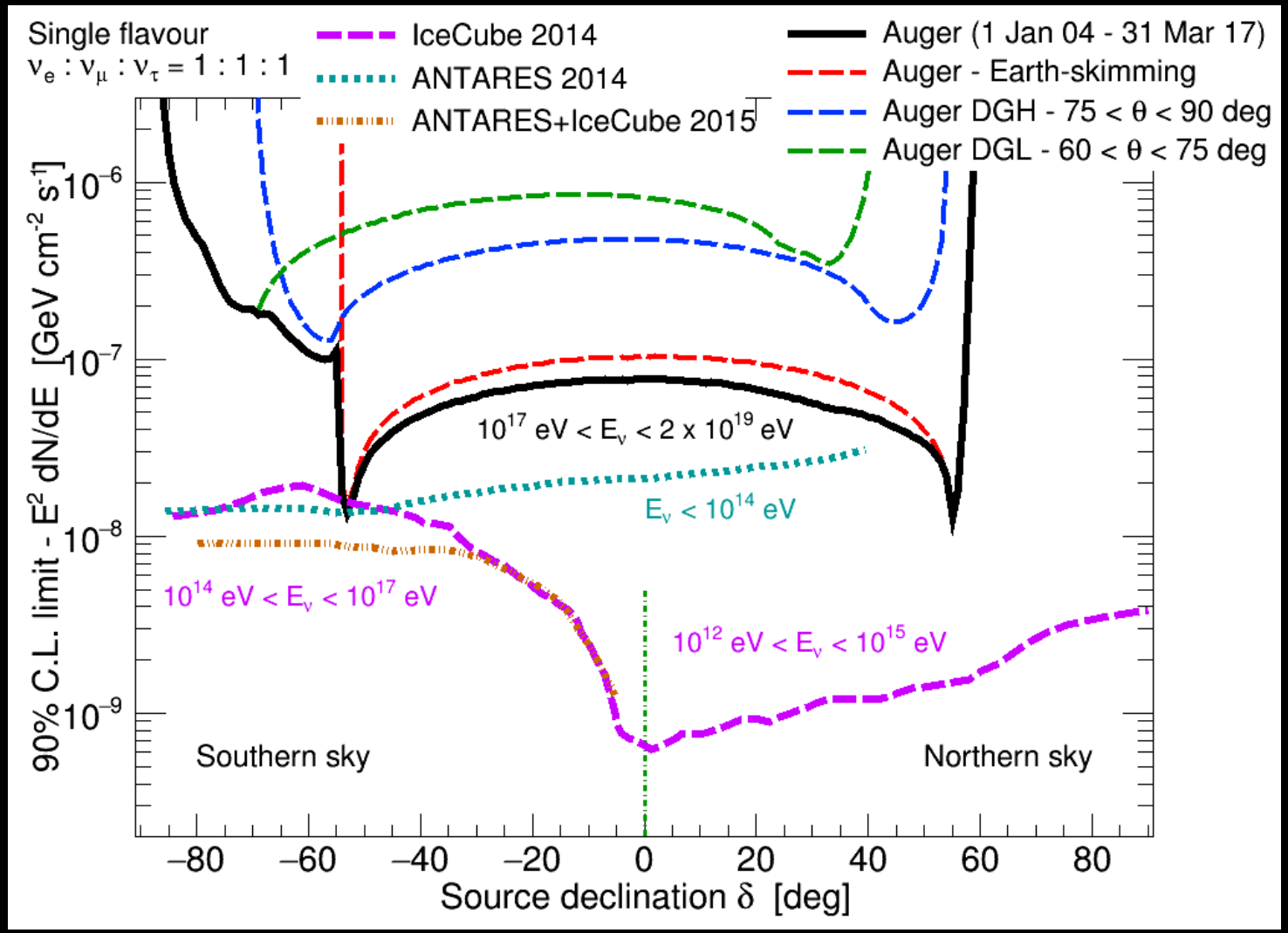
Instantaneous sky Coverage is limited

BUT: Covered region has excellent sensitivity to ES ν_τ

(Surface area >> Ice3)

Limits to point sources

When averaging over a sidereal day limits become declination dependent



1 Jan 04 – 31 Mar 17

Note different energy ranges of different experiments

GW151226 (1 day steady): $E^2 d\Phi/dE <$ (0.5, 3 solar masses) for $-55^0 < \delta < 57^0$

MoU Signed with Ligo-Virgo Expect more news!!

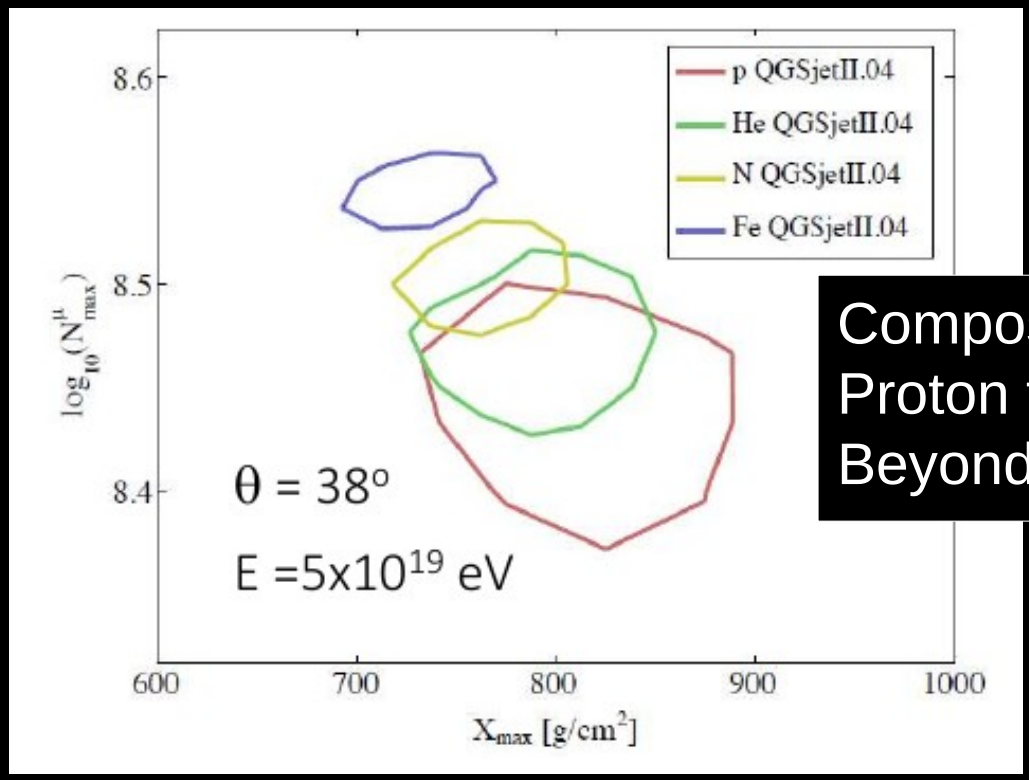
Pierre Auger Collab., Phys. Rev. D **94**, 122007 (2016)

- Air Shower Arrays provide crucial information for UHECR and ν
- They have multimessenger capablities
- Auger complementary ν telescope: EeV, directional & ν_τ
- Simple proton source models are inconsistent with data
- Complex picture emerges: further experimental constraints needed
- Expect more results to come from these Observatories

Future trends

AugerPrime Upgrade:

Scintillator (SSD) + Cherenkov (WCD)
==> μs i.e. masscomposition
Underground Muon Detector (AMIGA)
cross-check the SSD WCD
Upgrade the SD Electronics (SDE)
(faster sampling rate)
Small PMT for dynamic range of WCD
Extend FD duty cycle



KEY OBJECTIVES

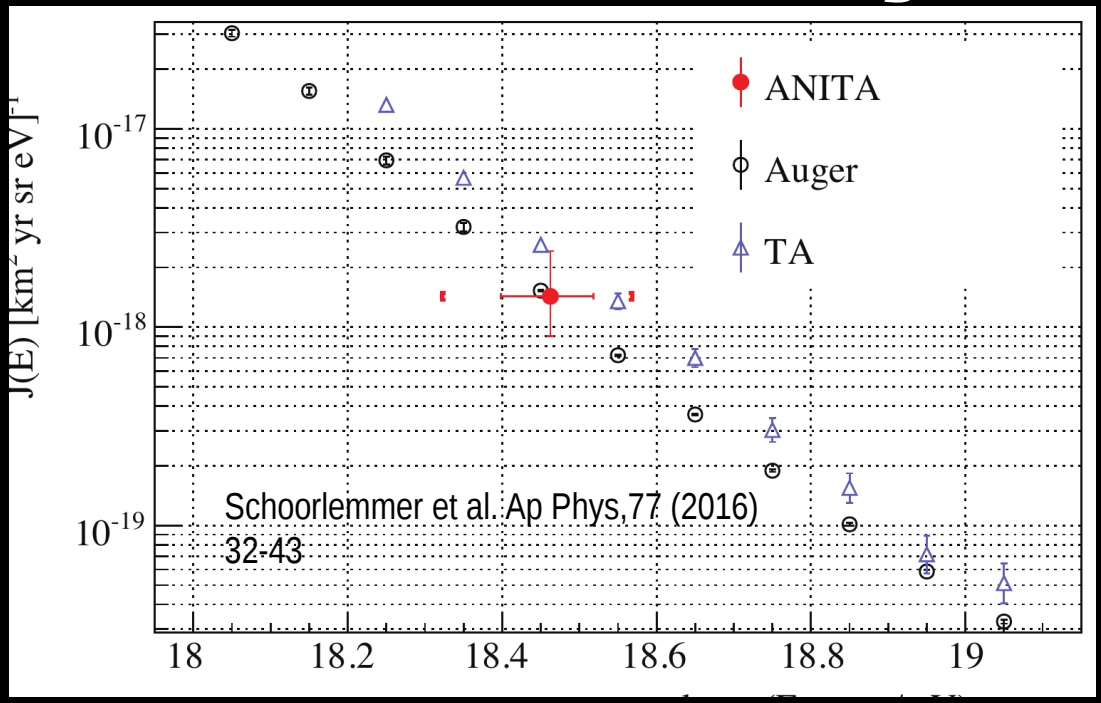
Composition & origin of flux suppression
Proton fraction at suppression: E>40 EeV
Beyond accelerators: EAS and models

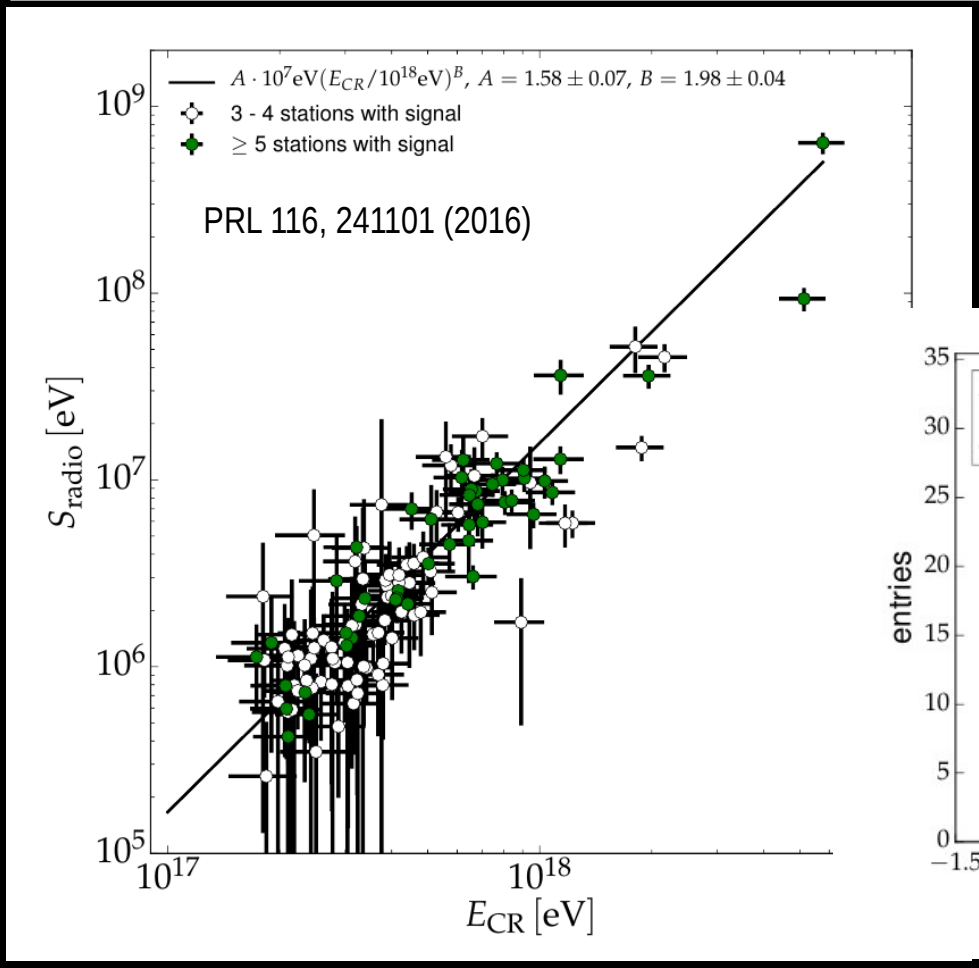
Fundamental questions for the field
Can we reconstruct trajectories from sources?
Prospects for UHE neutrino γ-ray telescopes
More results for particle interactions?

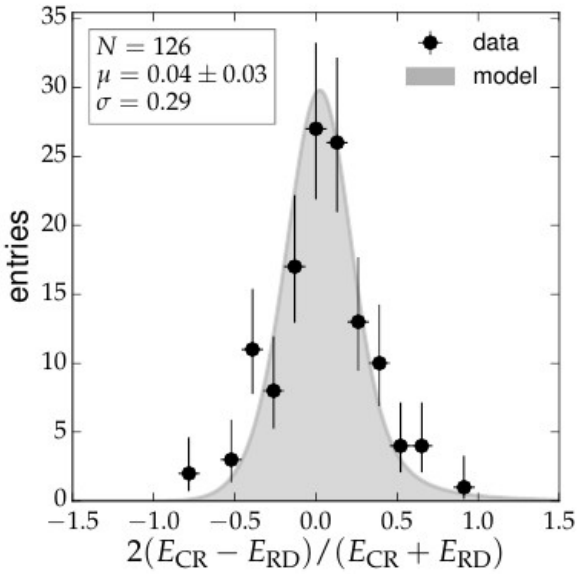
Enormous progress with Radio: New ways?

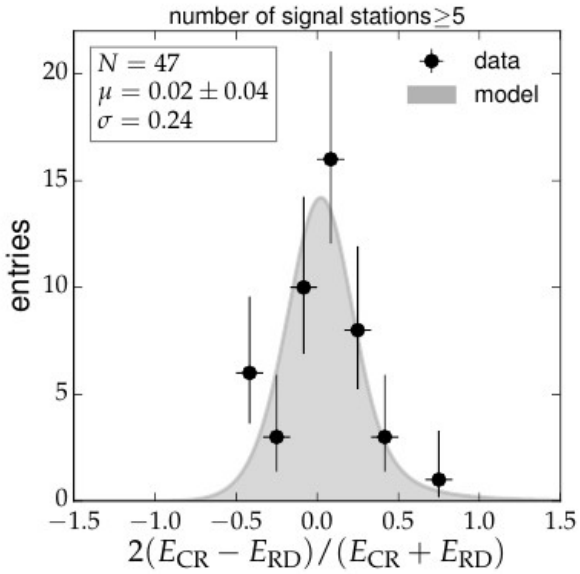
ANITA: reflected pulses from UHECR seen & reconstructed

Auger: New energy estimator
Radio energy in 30-80 MHz









Thank you