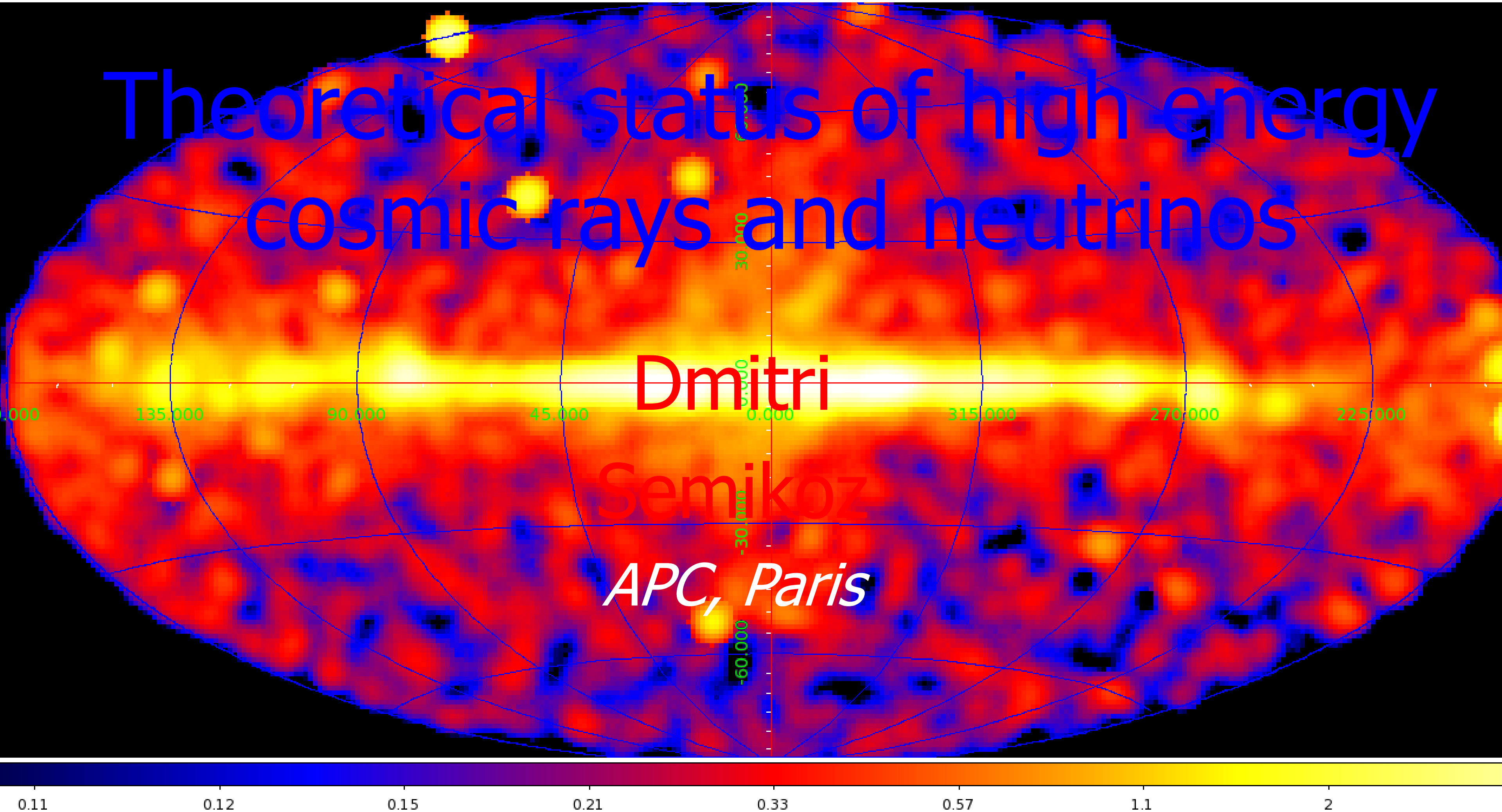
Theoretical status of high energy cosmic rays and neutrinos

Dmitri Semikoz

APC, Paris

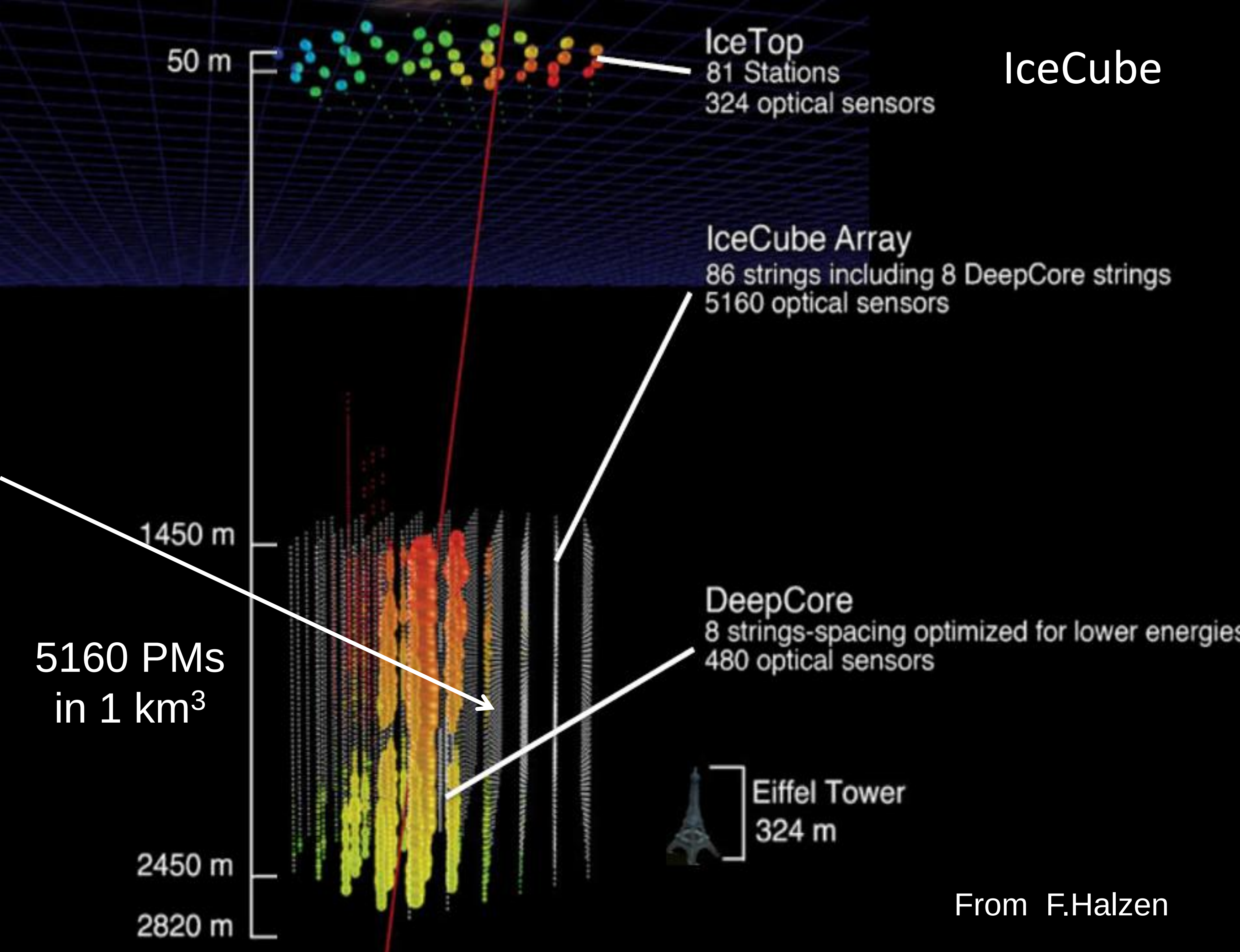


Overview:

- *Astrophysical neutrinos*
- *Galactic to extragalactic transition of cosmic rays*
- *Extragalactic UHECR sources*
- *Minimal model combining astrophysical neutrinos and UHECR*
- *Conclusions*

Astrophysical neutrinos

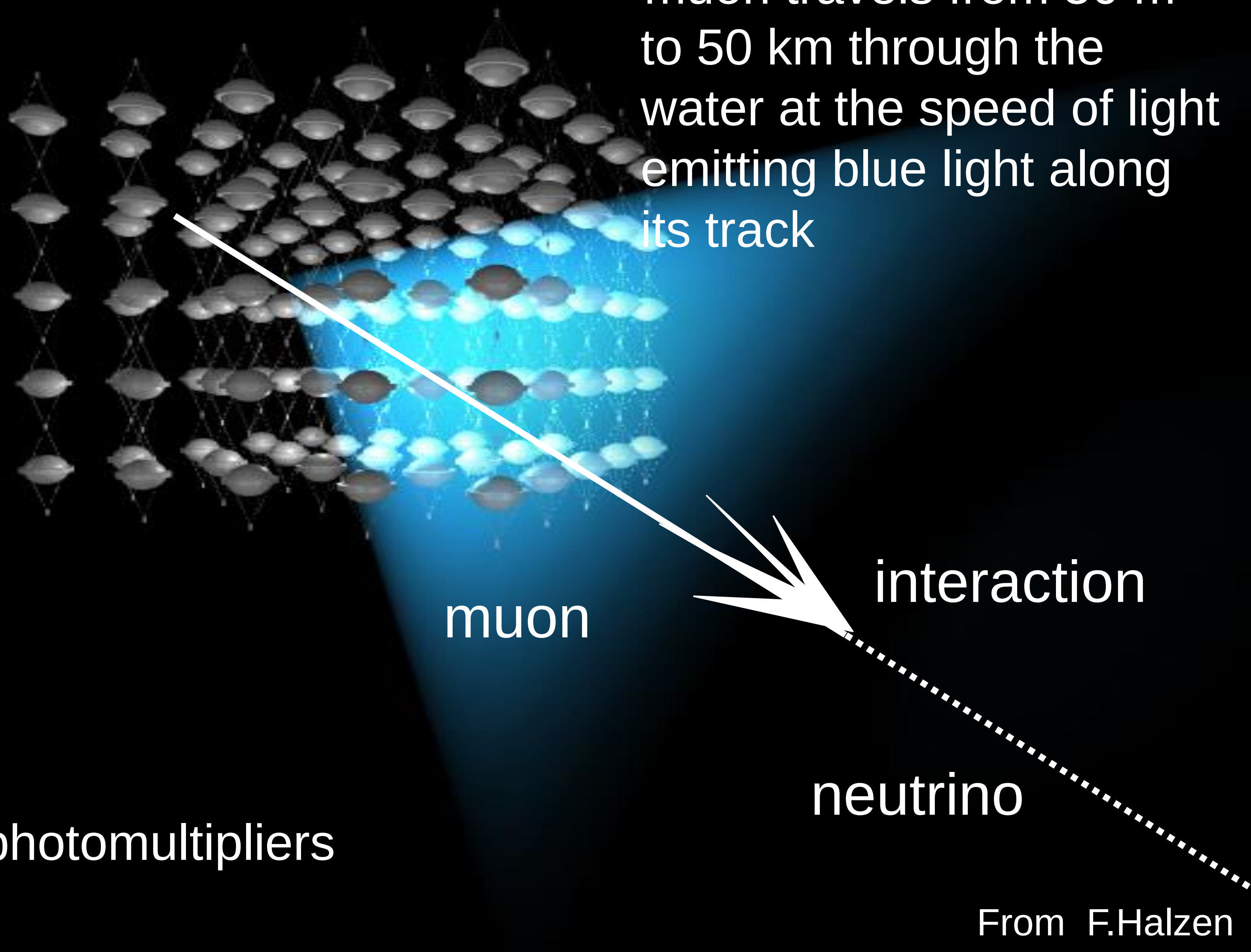
IceCube



5160 PMs
in 1 km^3

From F.Halzen

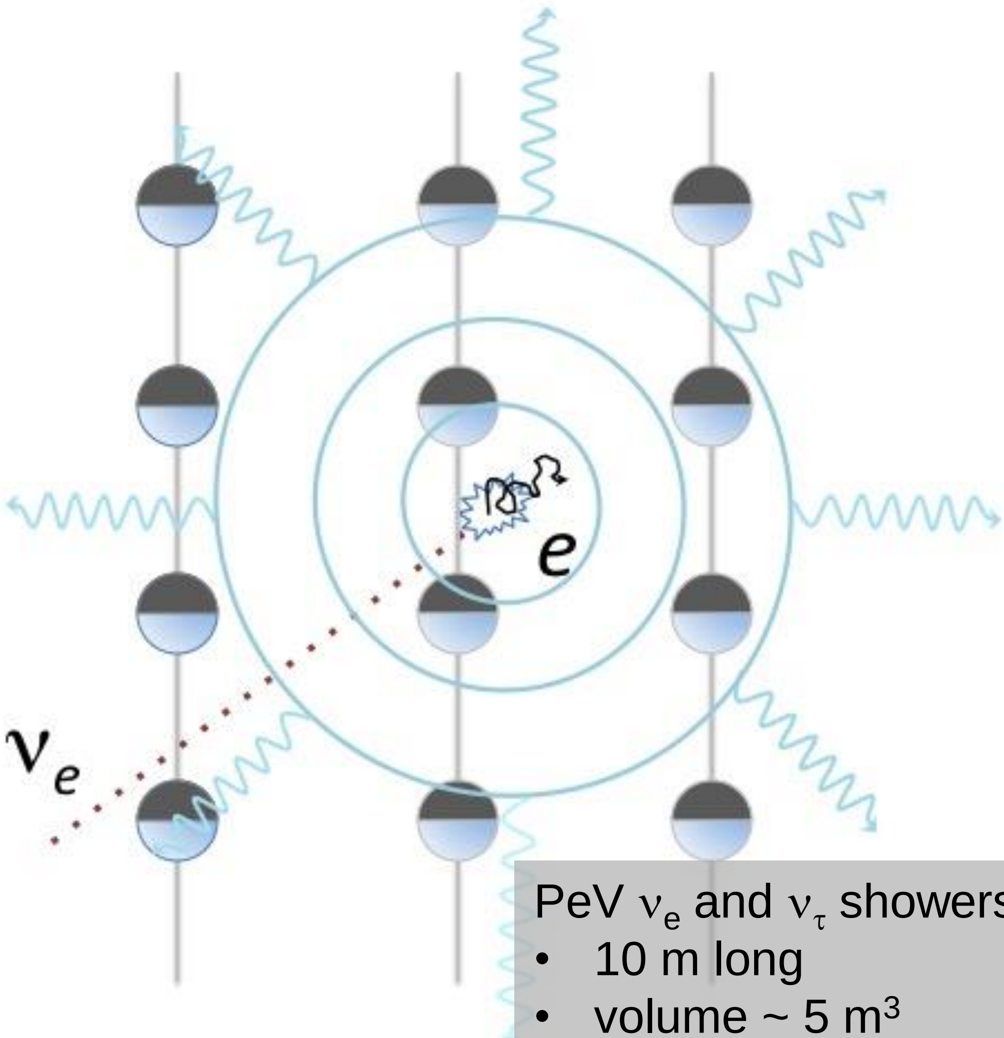
- shielded and optically transparent medium
- muon travels from 50 m to 50 km through the water at the speed of light emitting blue light along its track



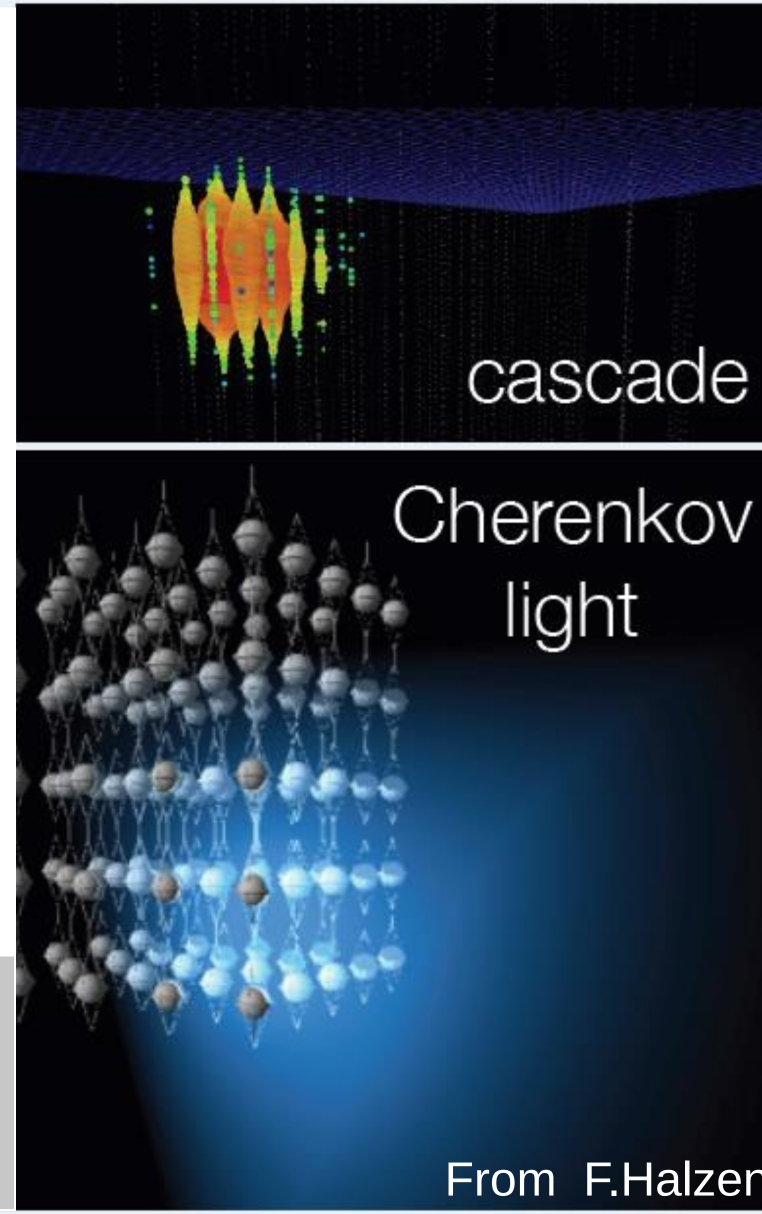
- lattice of photomultipliers

From F.Halzen

tracks and showers

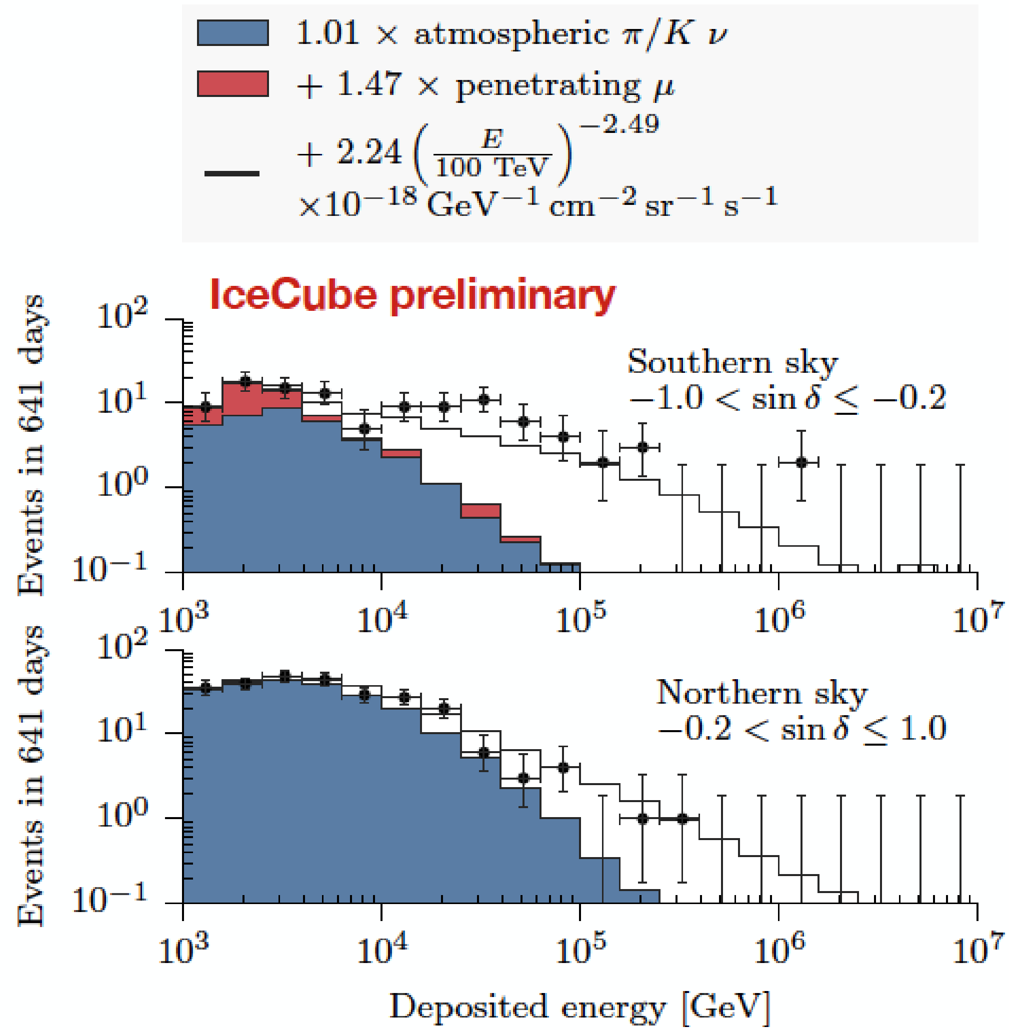


PeV ν_e and ν_τ showers:
- 10 m long
- volume ~ 5 m^3
- isotropic after 25~ 50m

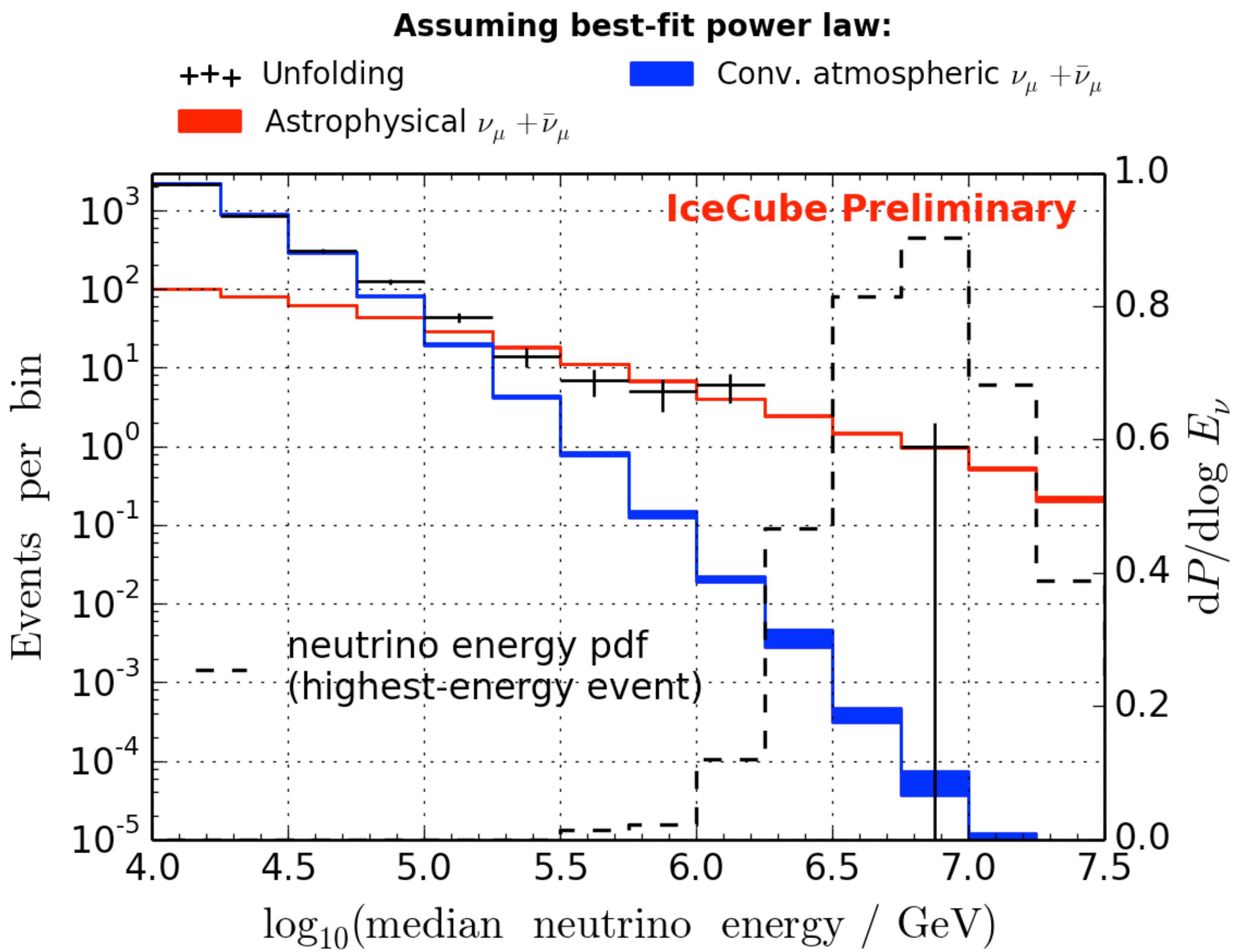


Results: energy spectrum

- 283 cascade and 105 track events in 2 years of data
- 106 > 10 TeV, 9 > 100 TeV (7 of those already in high-energy starting event sample)
- Conventional atmospheric neutrino flux observed at expected level with starting events



muon neutrinos through the Earth → 6 sigma

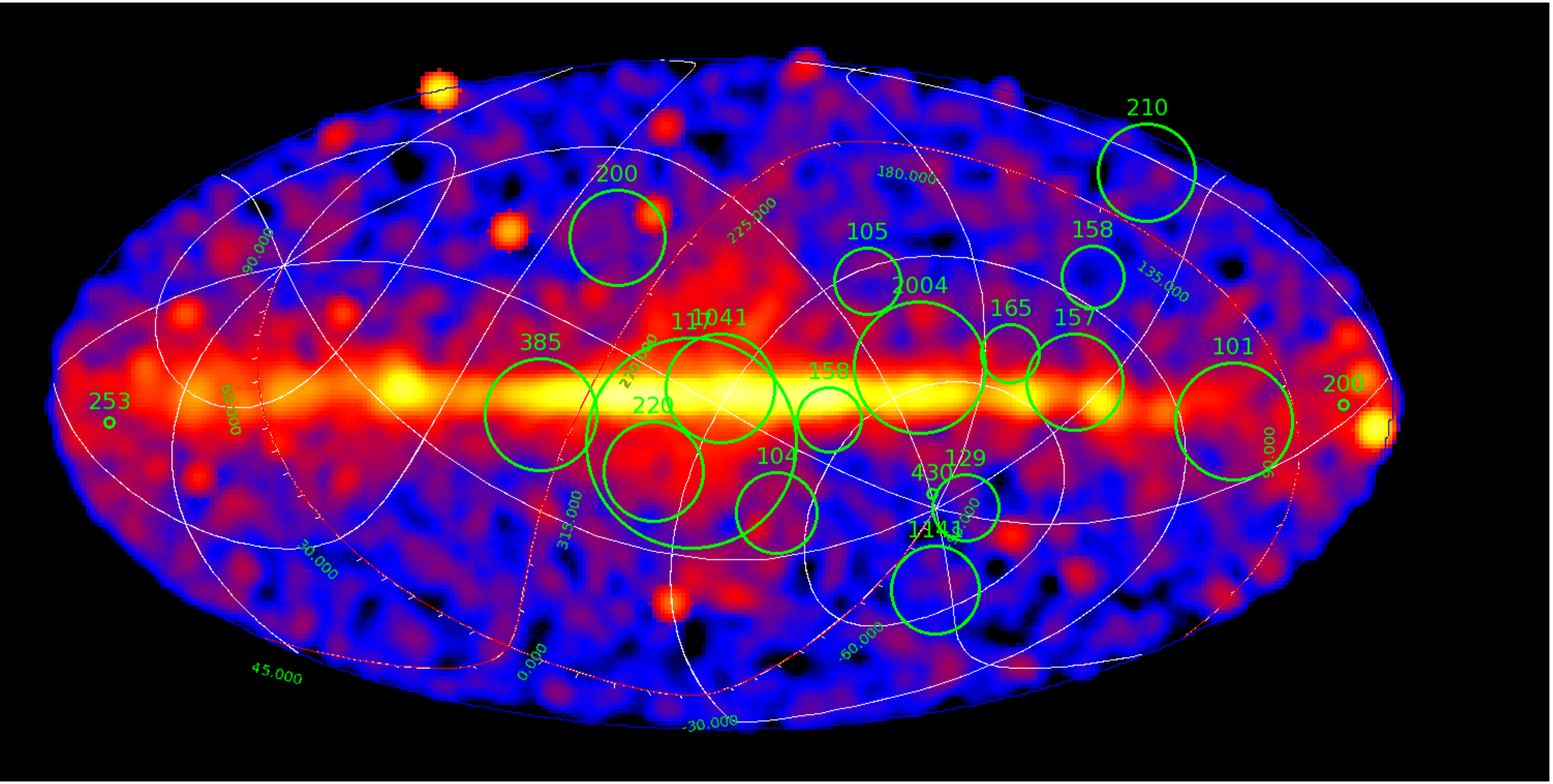


From F.Halzen, Paris 2016

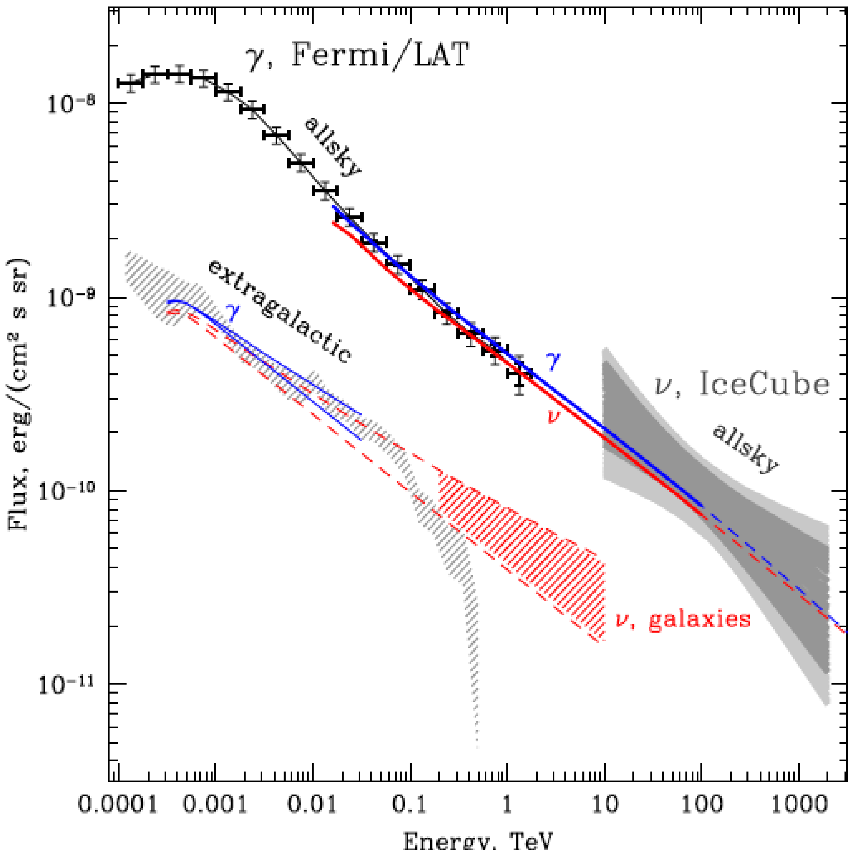
Neutrino astrophysics

- IceCube detected first astrophysical neutrinos. New field started: neutrino astrophysics.
- Best flux for cascades 1/E^(2.46+-0.14)
- Flux 1/E^2 disfavored with more then 3 sigma significance
- Muon neutrino data favors 1/E^2.06+-0.13 flux !
- Flavor ratio consistent with 1:1:1 as expected
- Cosmogenic neutrinos best constrained by IceCube, but in case of nuclei primaries bigger detector needed to find flux
- Bigger detectors needed for next step

IceCube neutrino sky map 4 years E> 100 TeV and Fermi E>100 GeV 5 degree smoothed

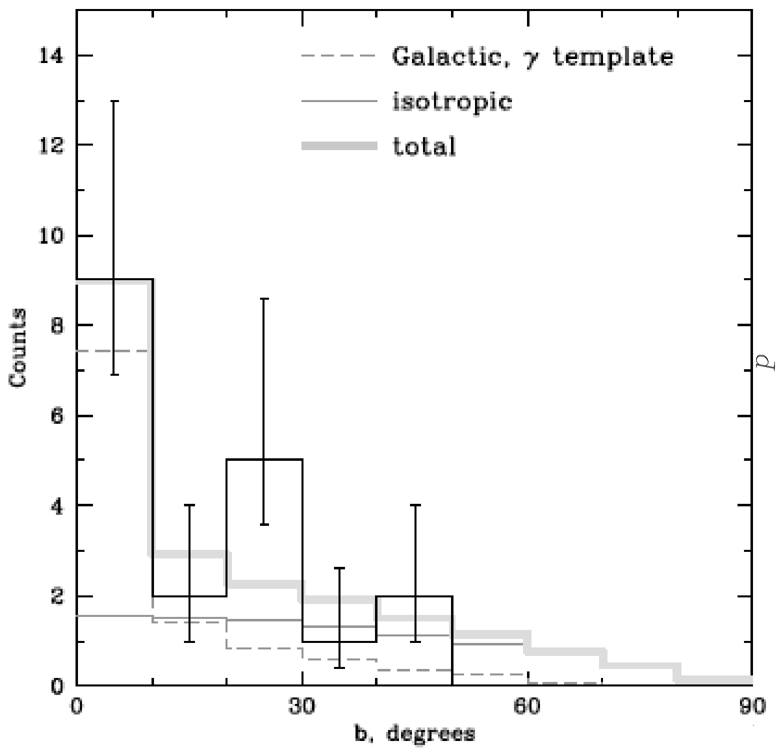


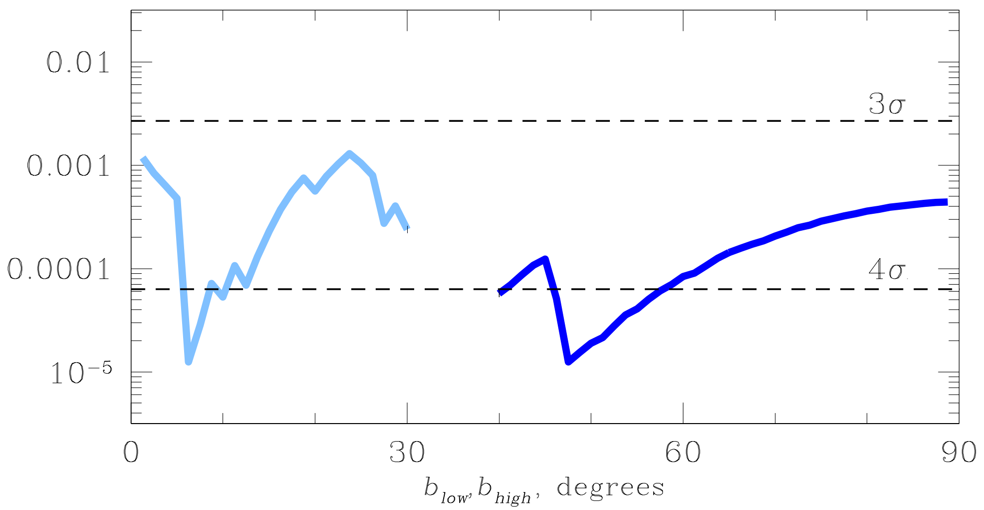
IceCube + Fermi LAT all sky: protons 1/E^2.5



A.Neronov, D.S. arXiv:1412.1690

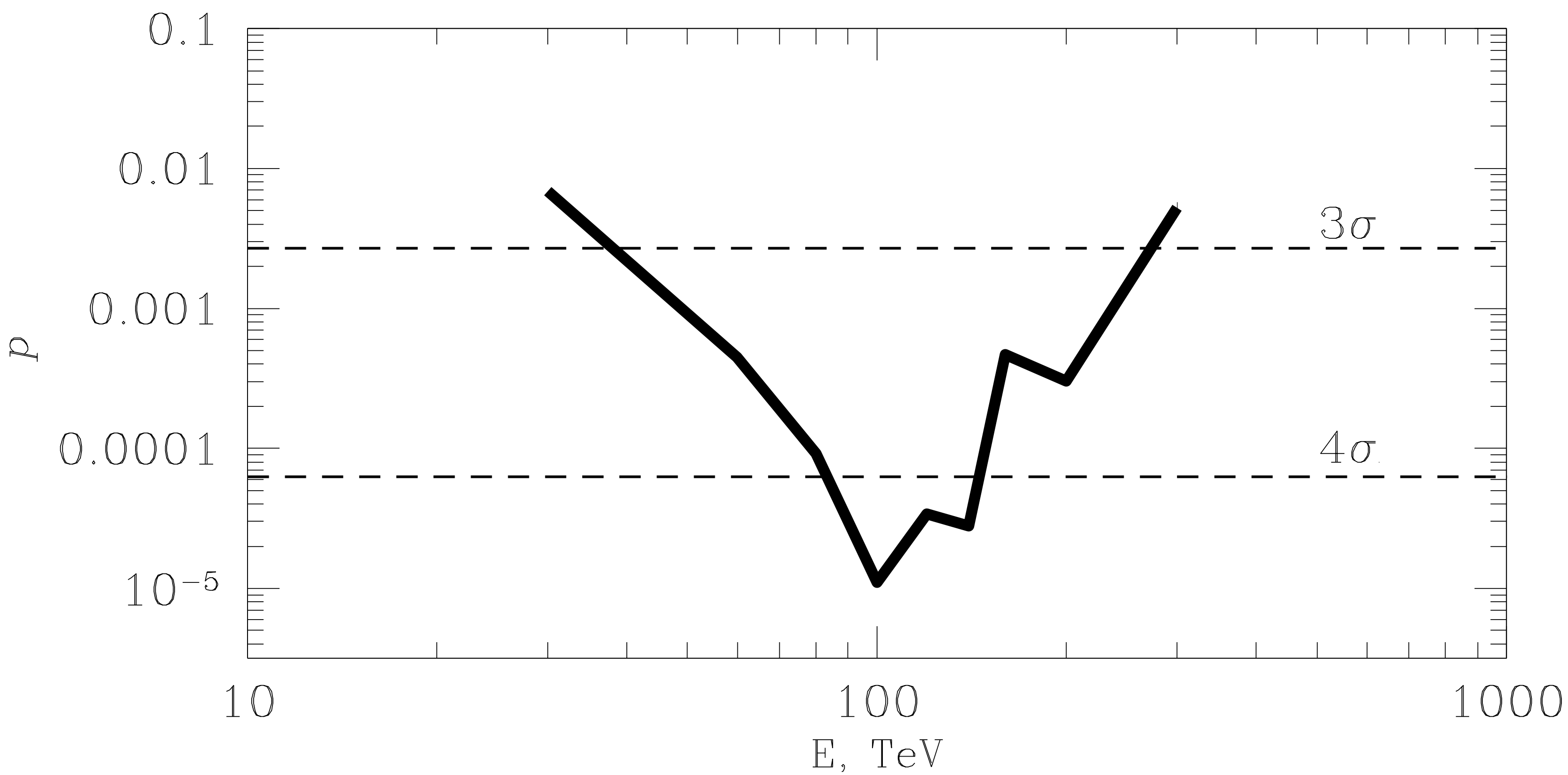
Evidence of Galactic component in 4 year IceCube data E>100 TeV



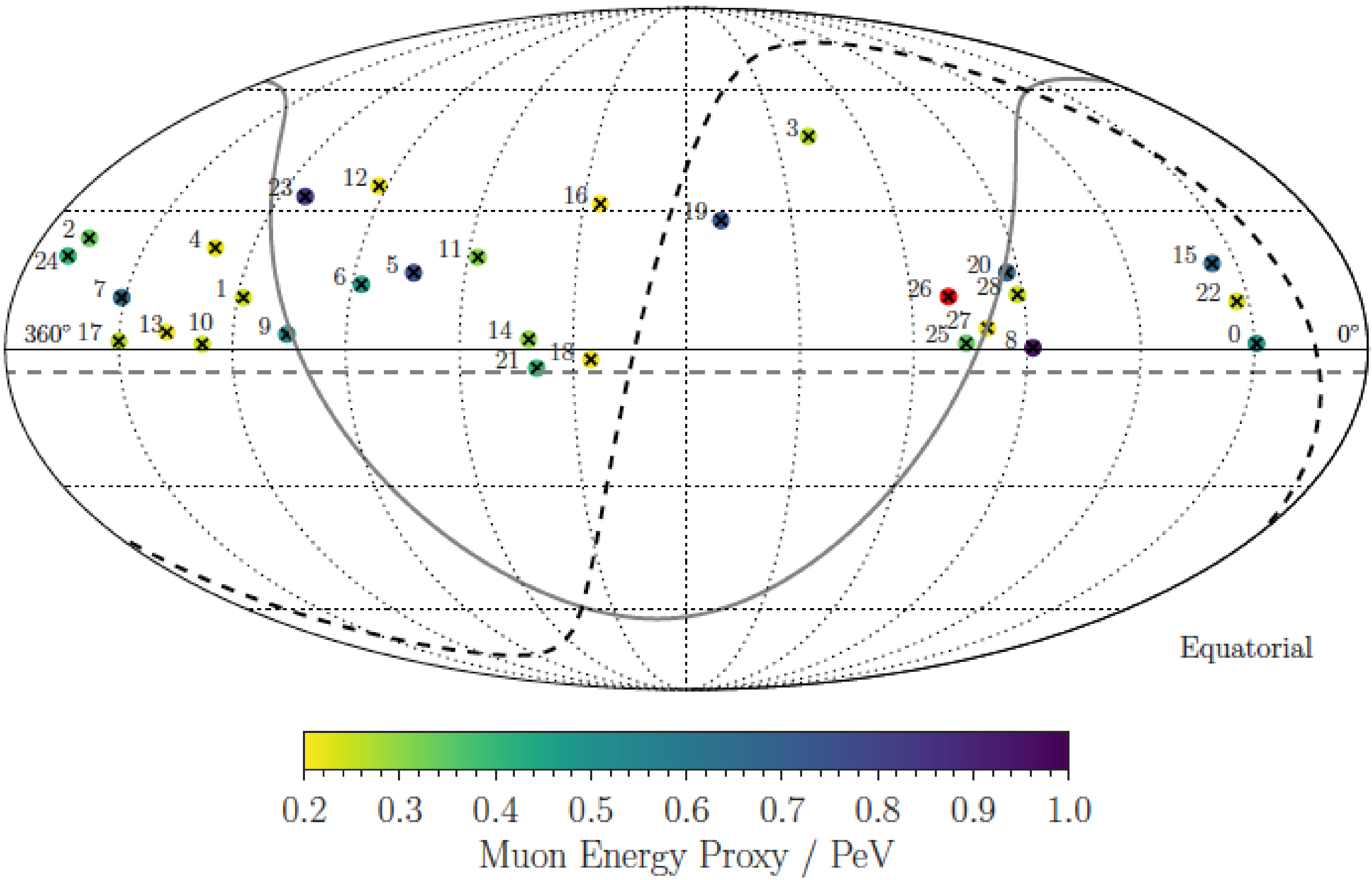


A. Neronov & D.S. arXiv: 1509.03522

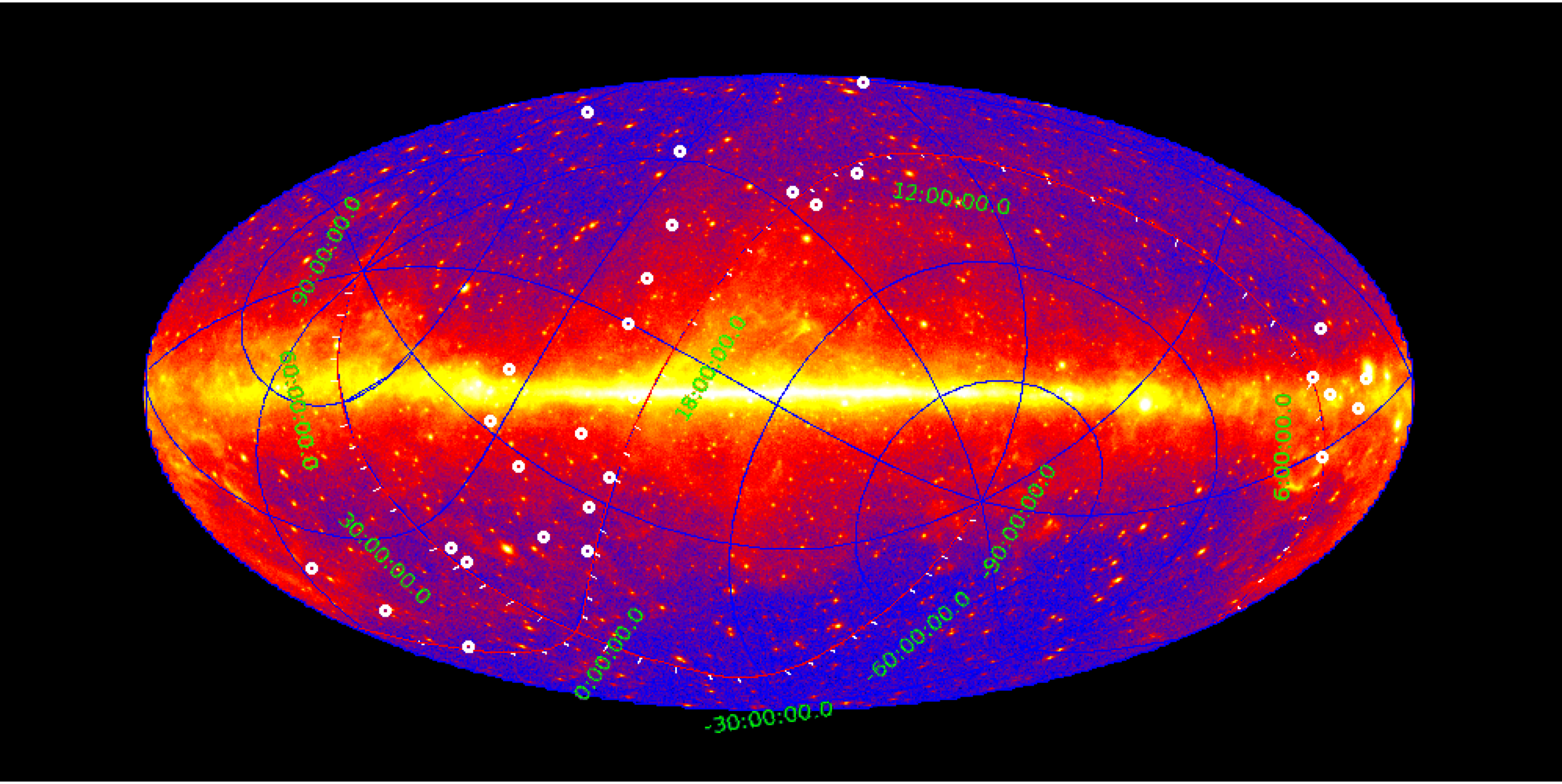
Post-trial probability is $1.7*10^{-3}$

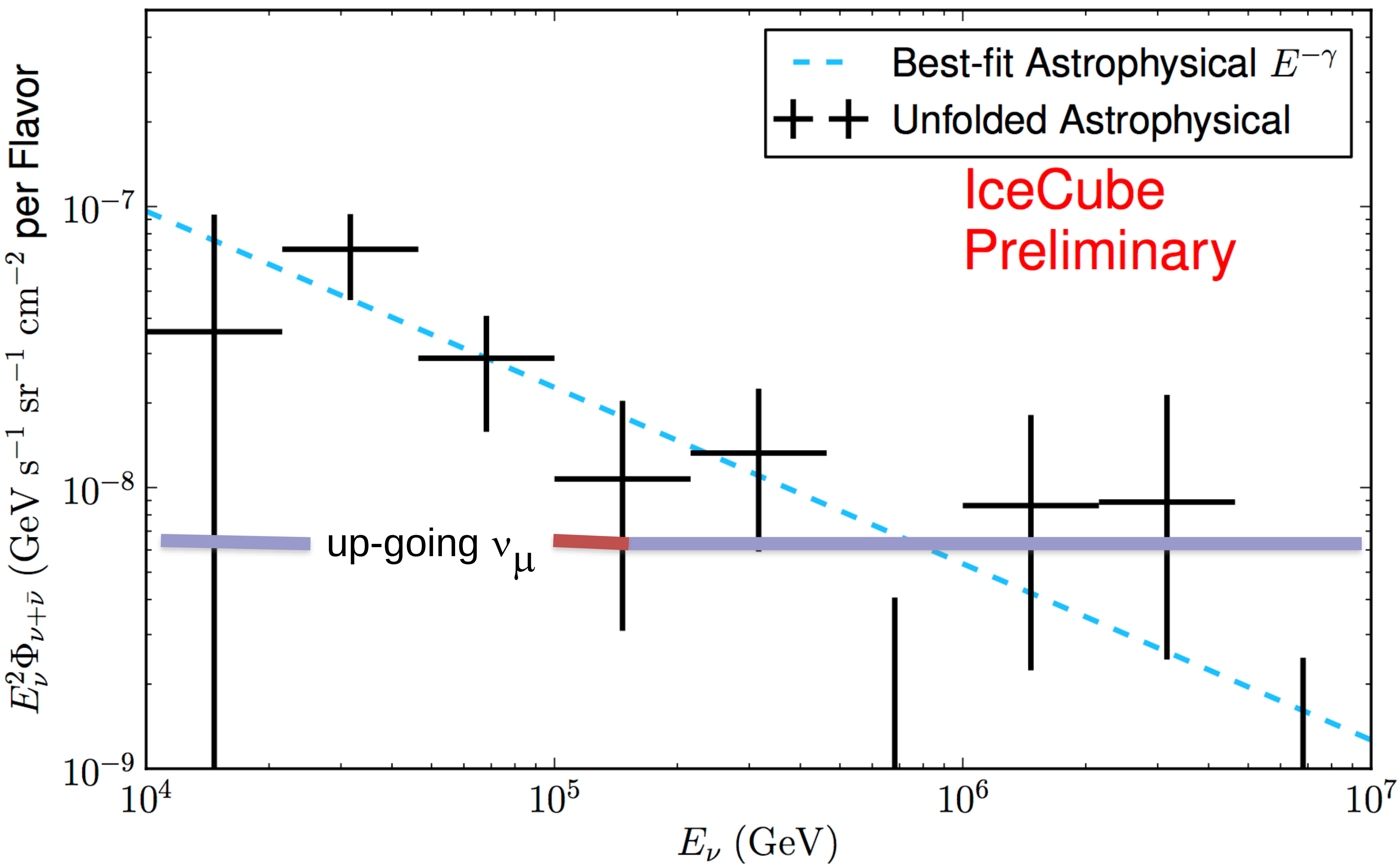


A. Neronov & D.S. arXiv: 1509.03522



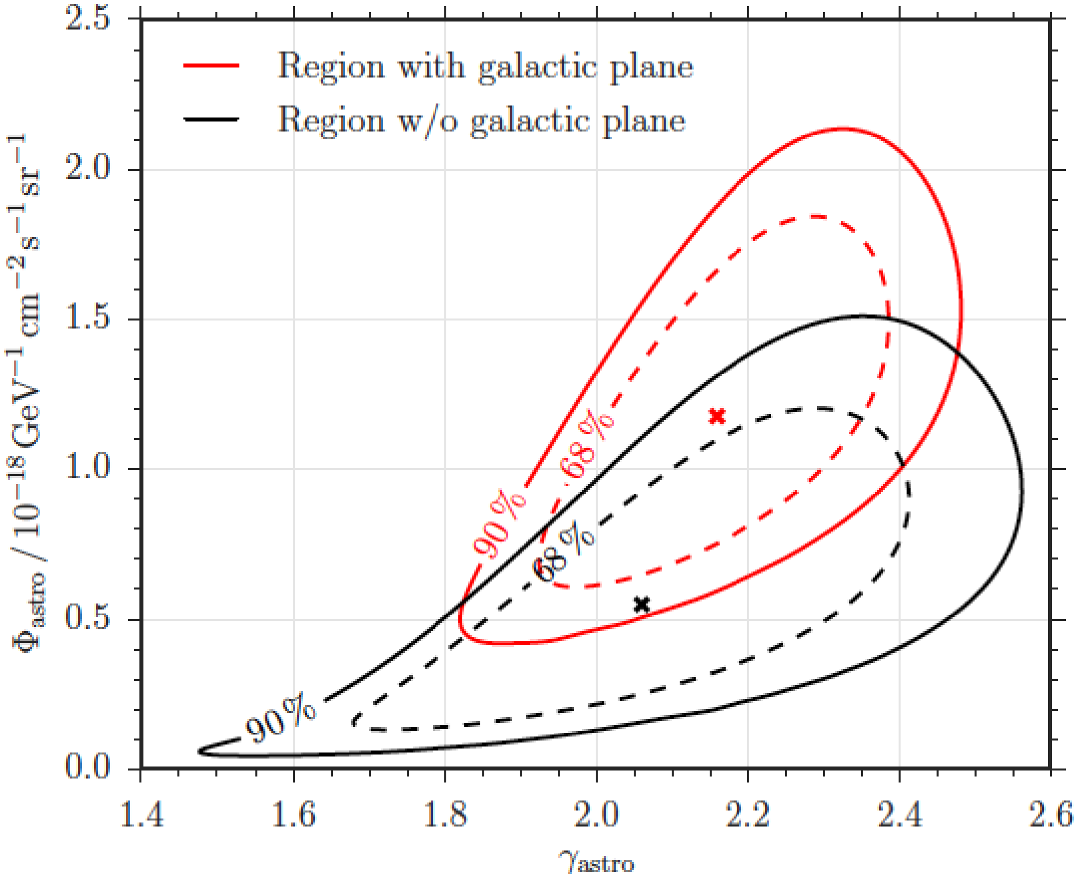
From F.Halzen, Paris 2016


12:00:00.0
90:00:00.0
18:00:00.0
30:00:00.0
0:00:00.0
-30:00:00.0
-60:00:00.0
-90:00:00.0
6:00:00.0



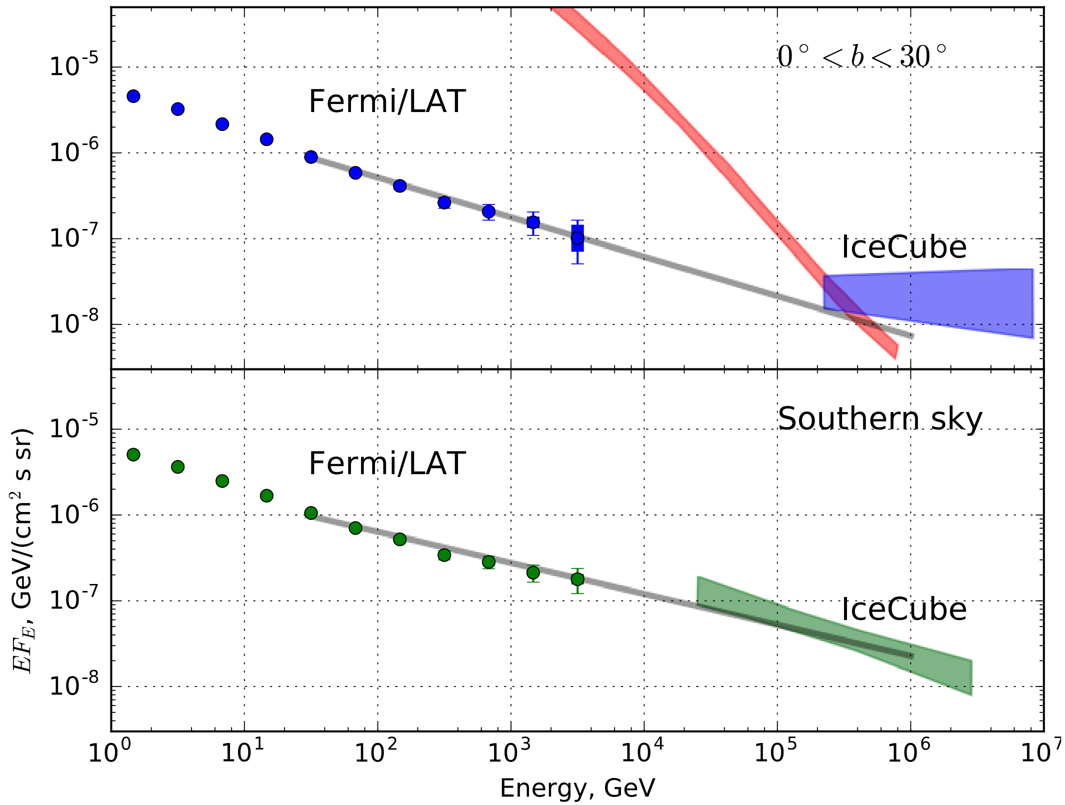
From F.Halzen, Paris 2016

6 years of IceCube data: sensitivity to Galactic plane



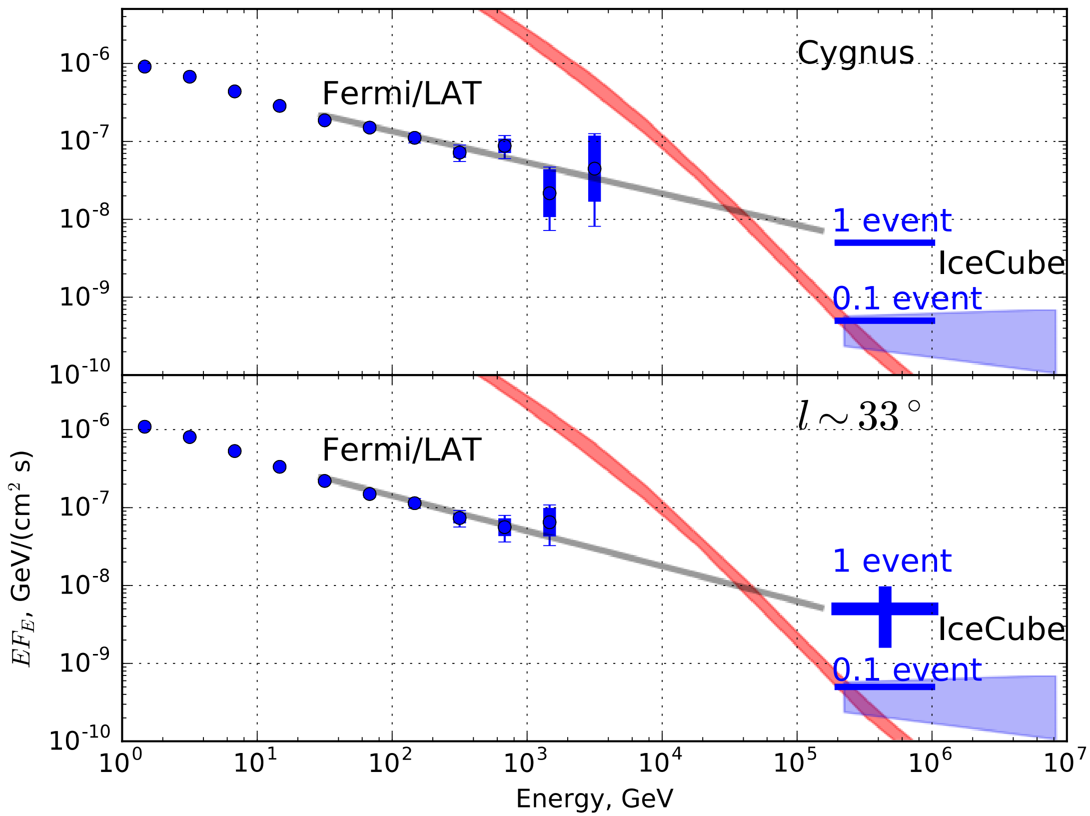
IceCube collabortion, arXiv: 1607.08006

North and South sky: IceCube



A. Neronov & D.S. arXiv: 1603.06733

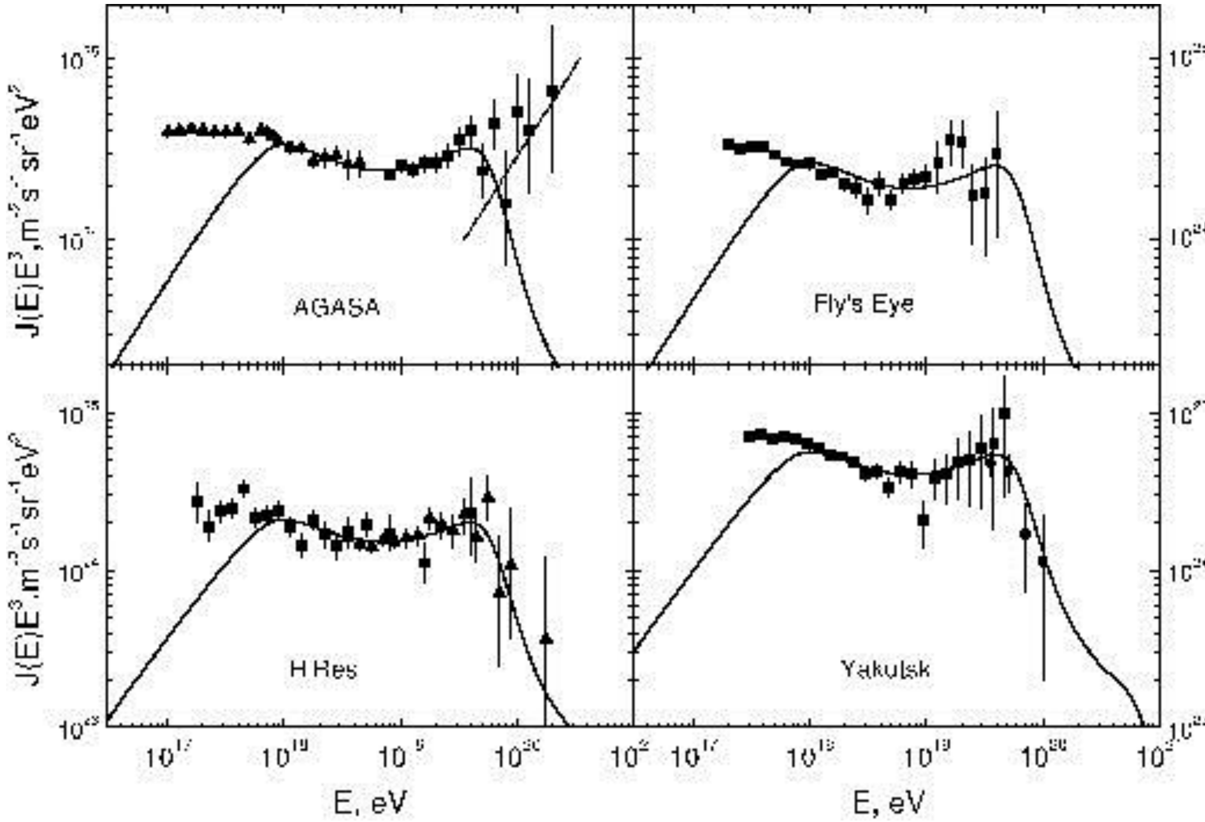
First galactic diffuse sources



A. Neronov & D.S. arXiv: 1603.06733

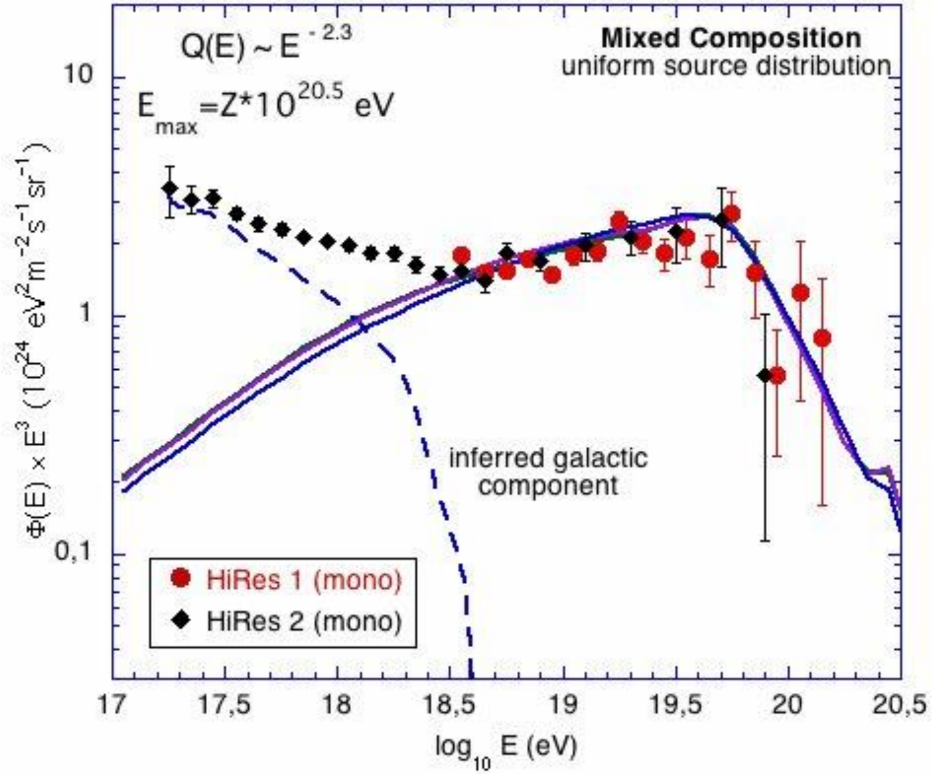
Transition from galactic to extragalactic cosmic rays

Dip model: Protons can fit UHECR data



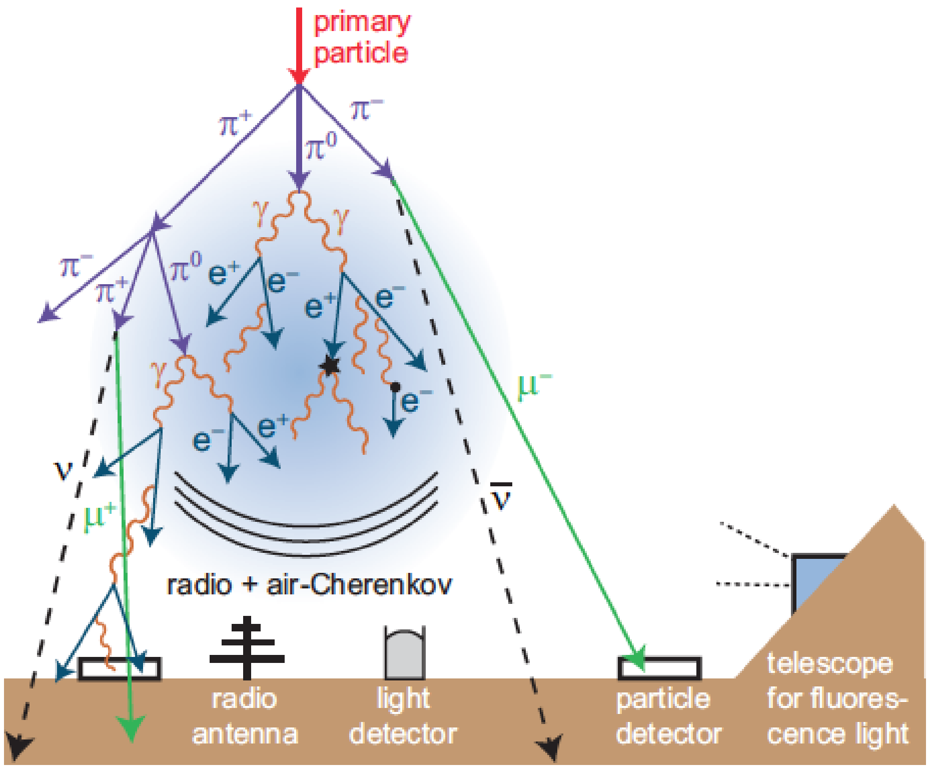
V.Berezinsky , astro-ph/0509069

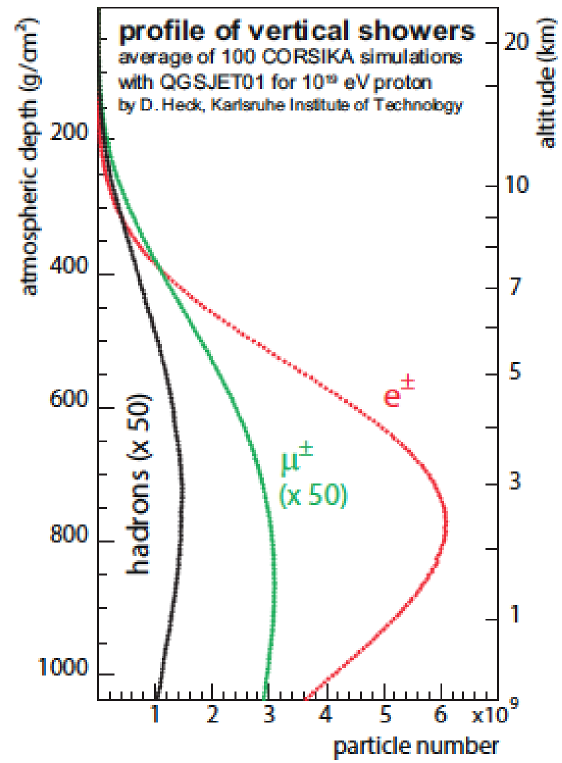
Mixed composition model



D.Allard, E.Parizot and A.Olinto, astro-ph/0512345

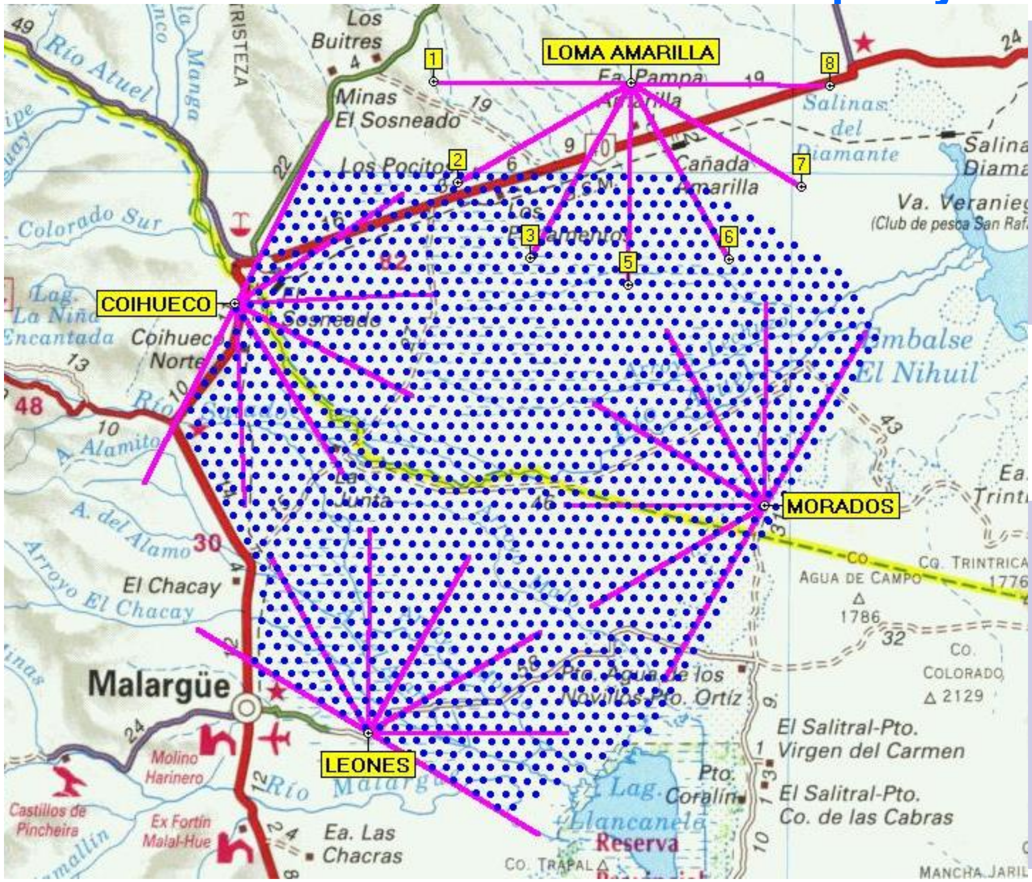
Detection techniques





Pierre Auger Observatory

South site in Argentina almost finished
North site – project



Surface Array

1600 detector stations

1.5 Km spacing

3000 Km^2 (30xAGASA)

Fluorescence Detectors

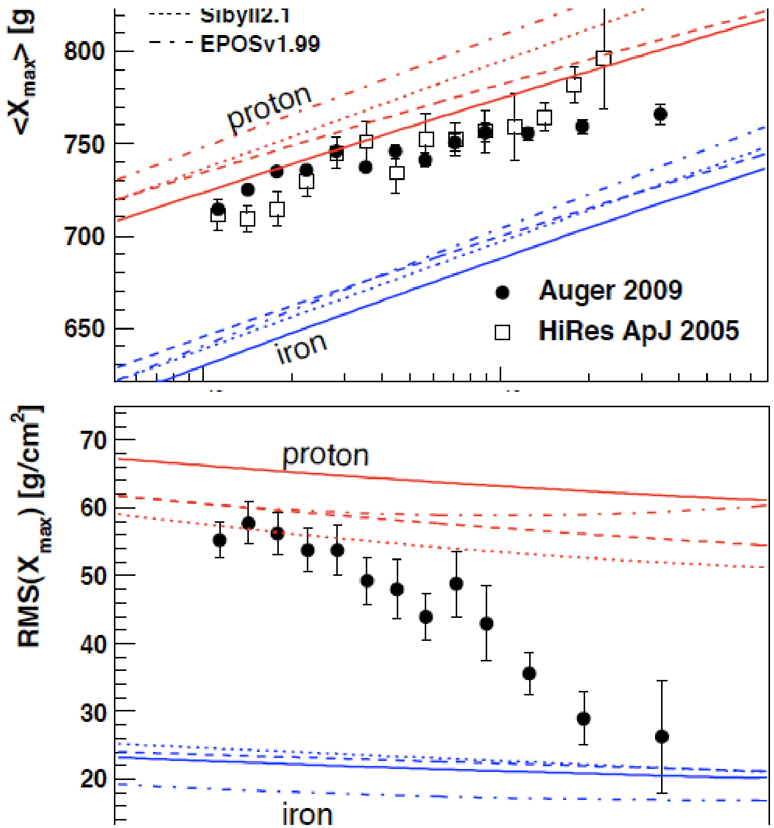
4 Telescope enclosures

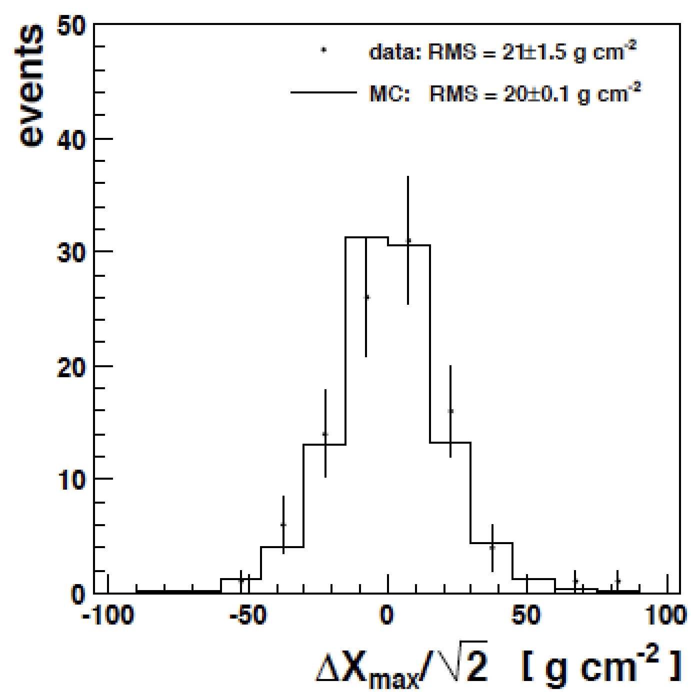
6 Telescopes per enclosure

24 Telescopes total

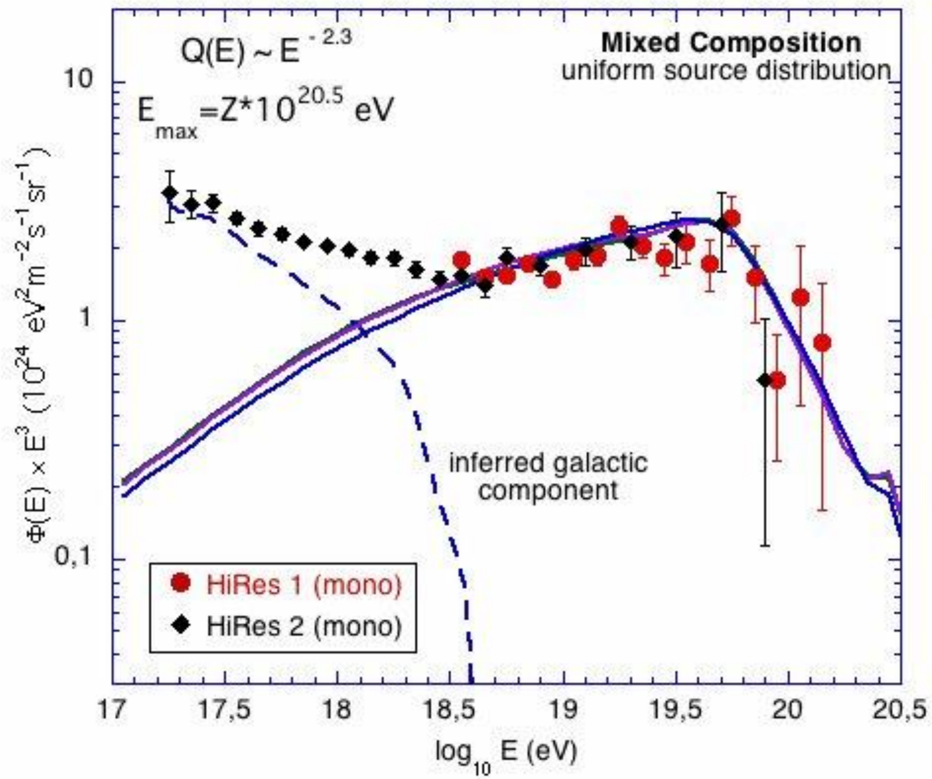
Tanks aligned seen from Los Leones

Auger composition 2009: nuclei!





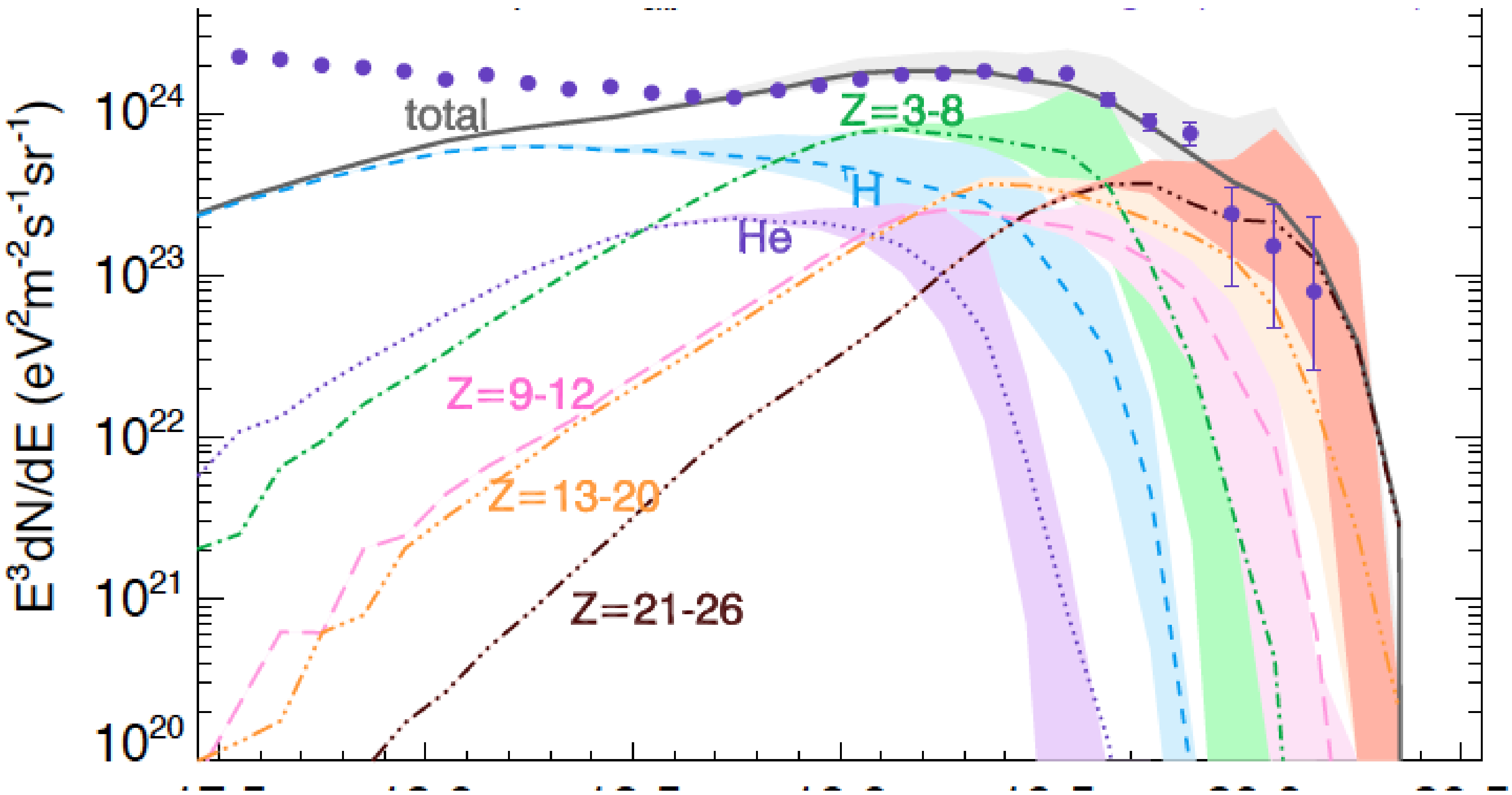
Mixed composition model



D.Allard, E.Parizot and A.Olinto, astro-ph/0512345

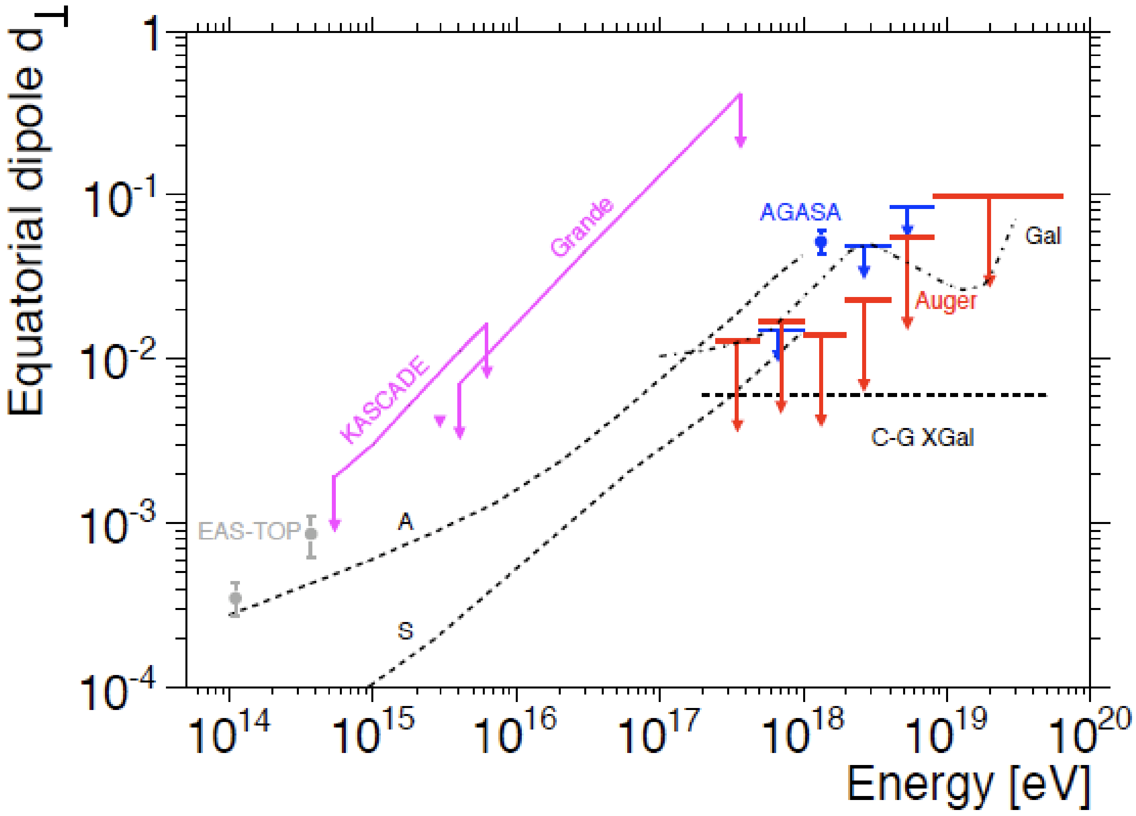
UHECR sources

UHECR sources with mixed composition



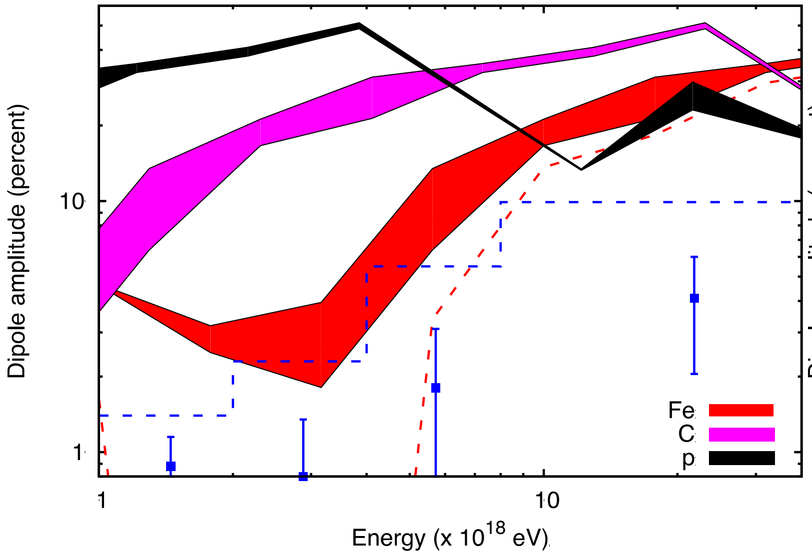
From D.Allard et al

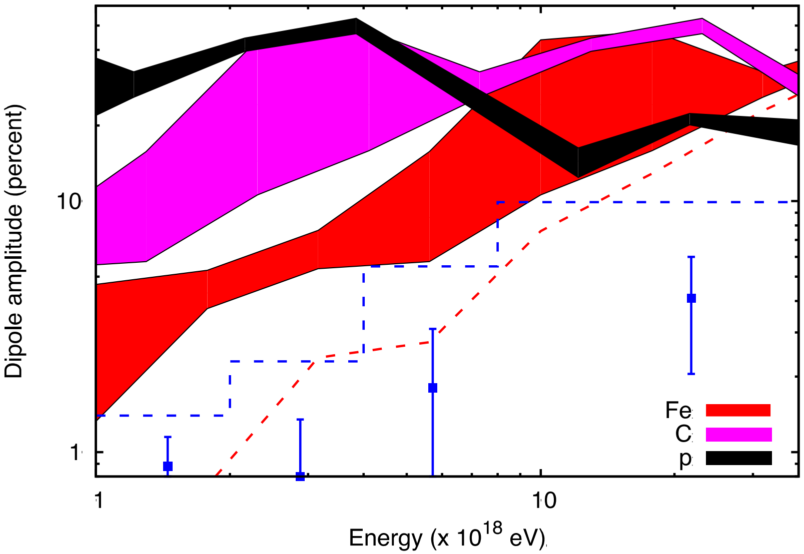
Anisotropy dipole



Pierre Auger Collaboration, arXiv:1103.2721

Galactic sources: dipole calculation



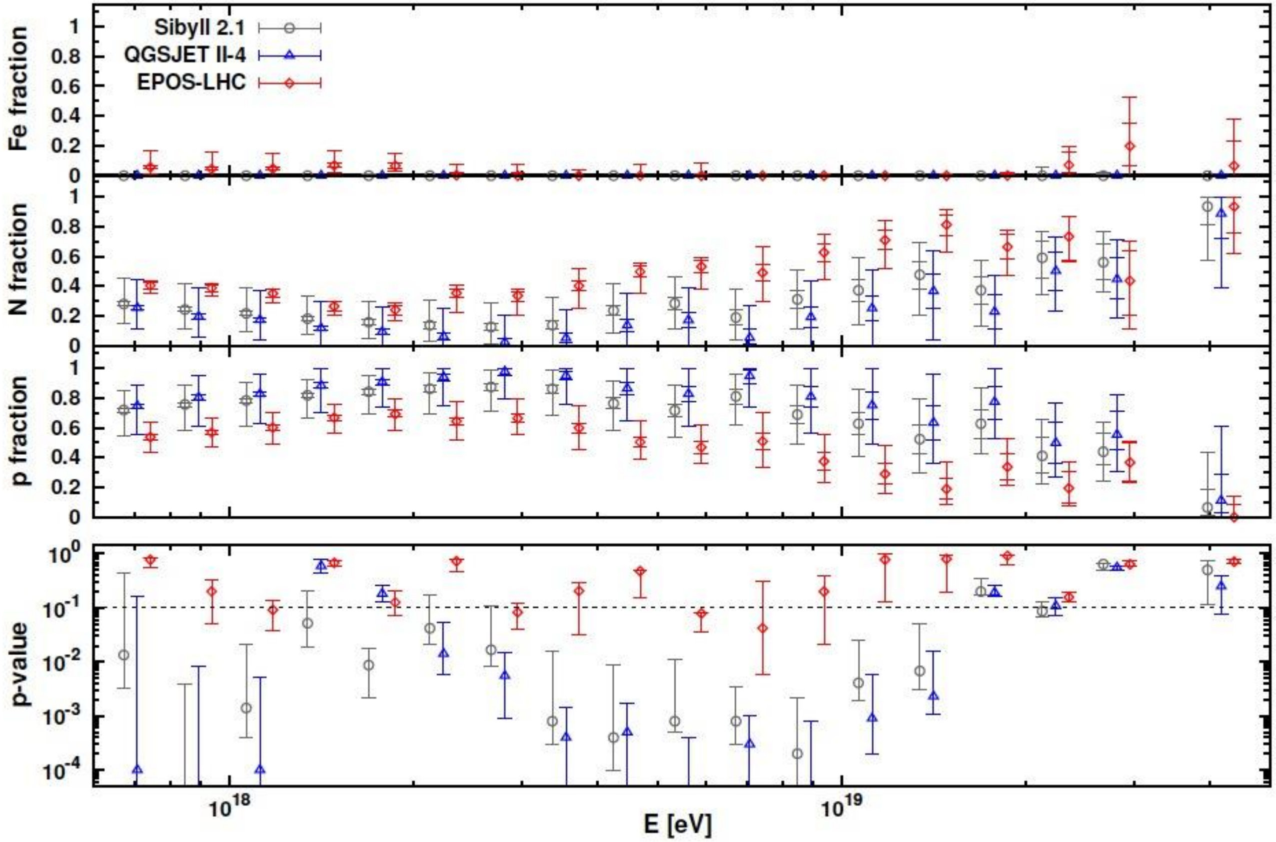


Turb. Magn. Field spectrum Kolmogorov/Kraichnan

Lmax = 100-300 pc

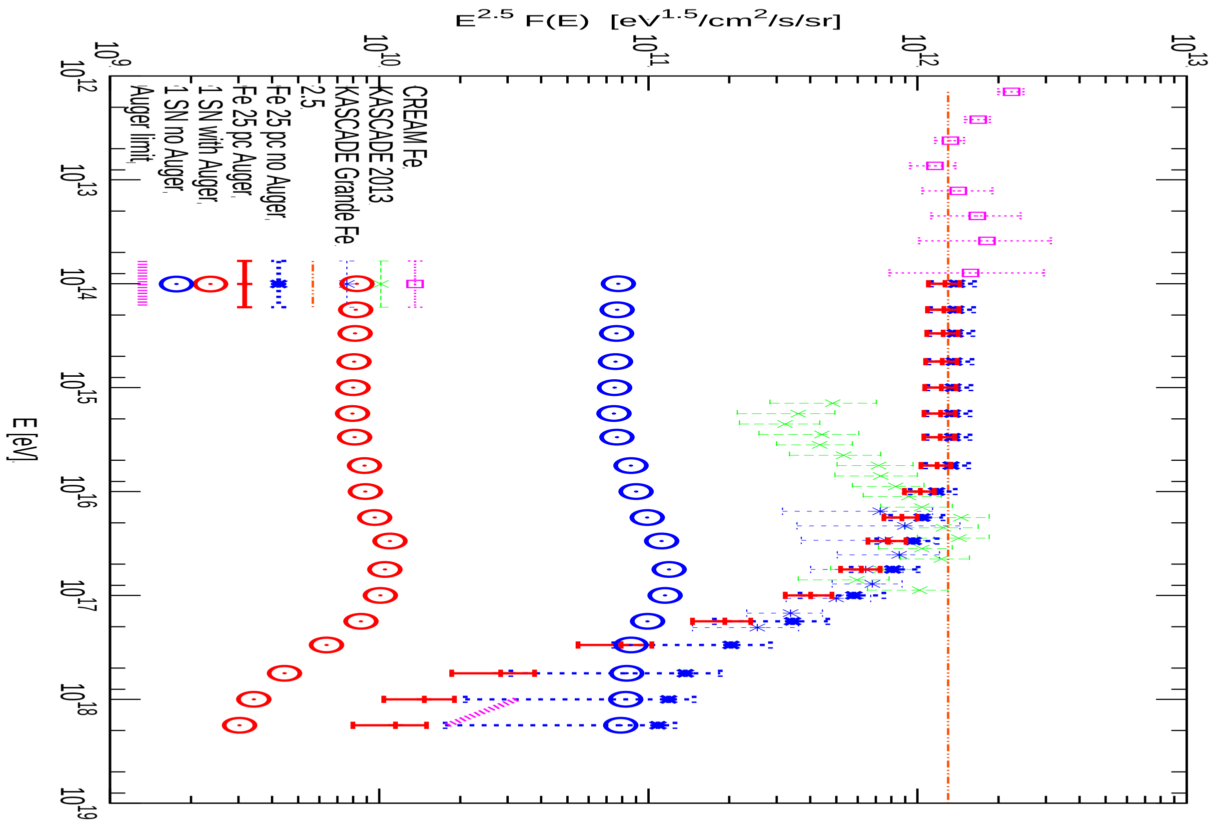
G.Giacinti, M.Kachelriess, D.S. and G.Gigl, **arXiv:1112.5599**

Auger cosmposition measurements

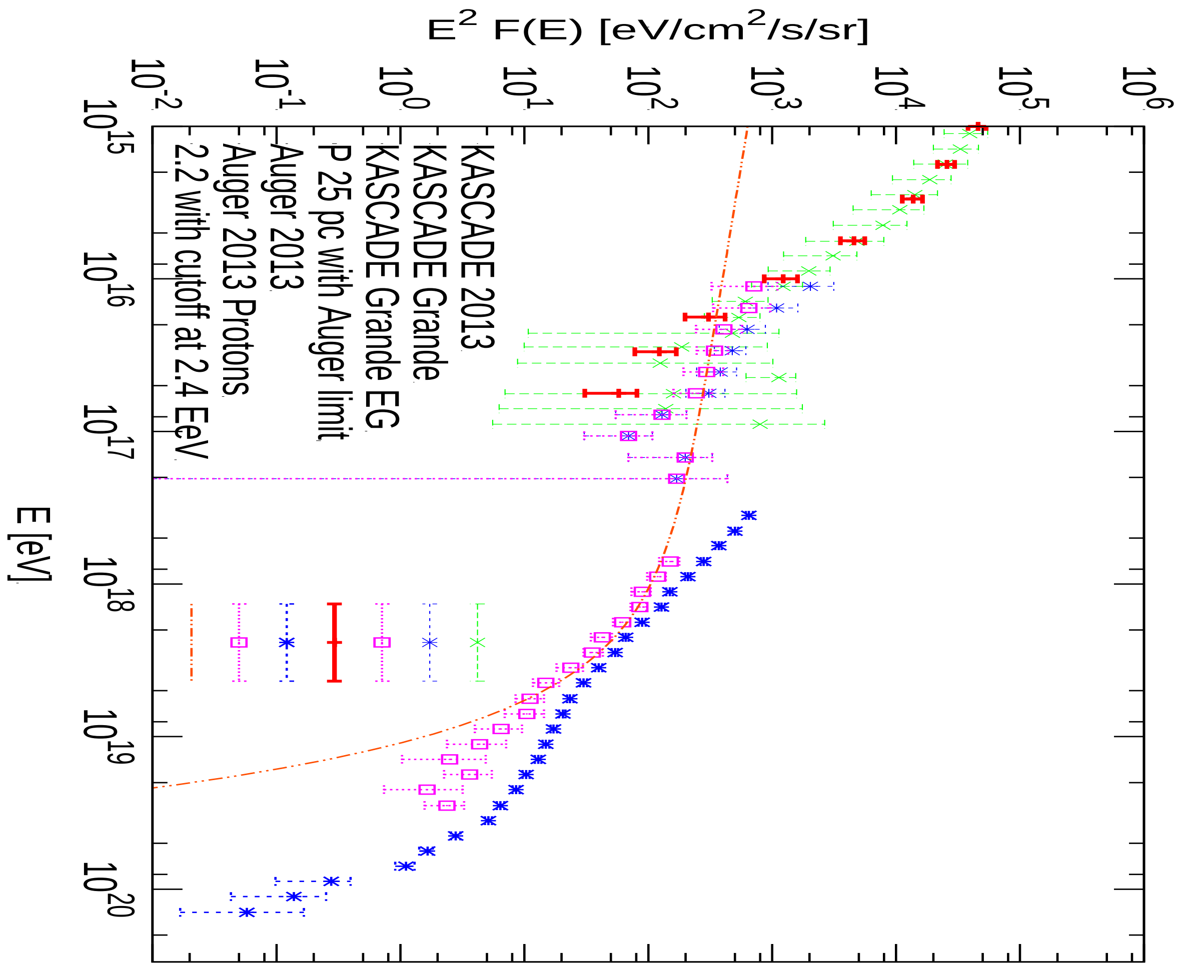


Auger Collaboration, **arXiv:1409.5083**

Auger limit on Fe fraction

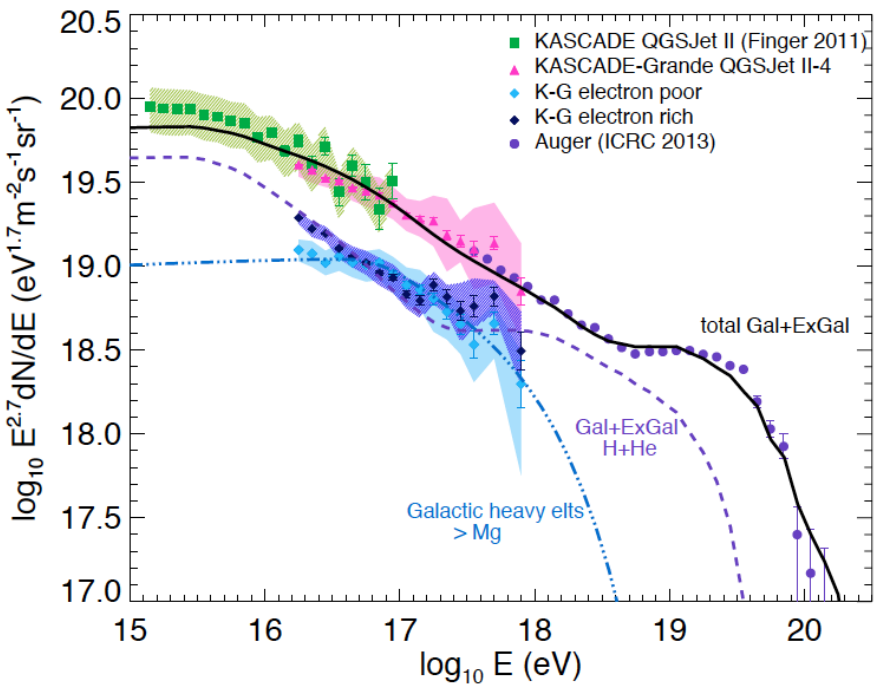


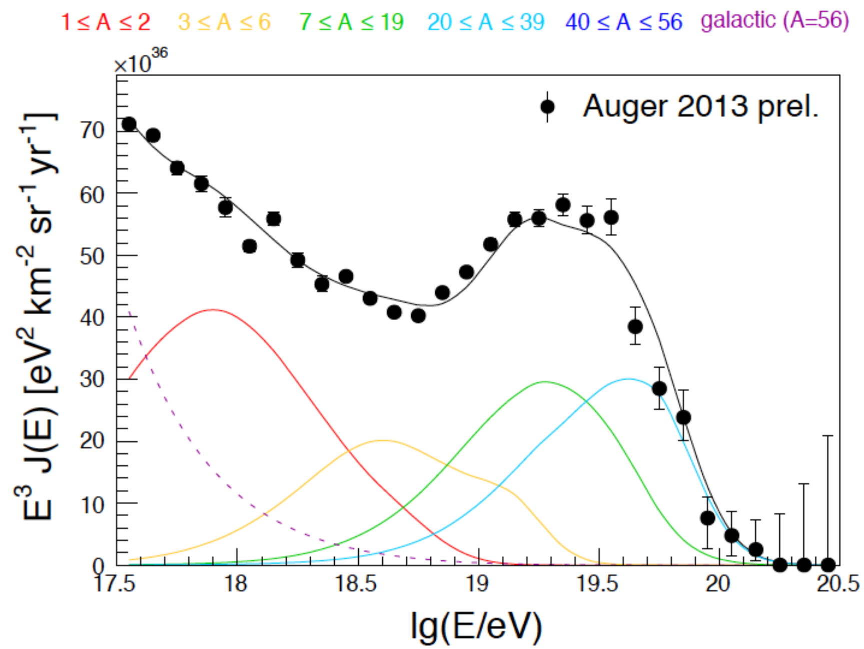
Extragalactic proton sources



G.Giacinti et al,1502.01608

UHECR sources p-gamma interaction with tau>1 for nuclei

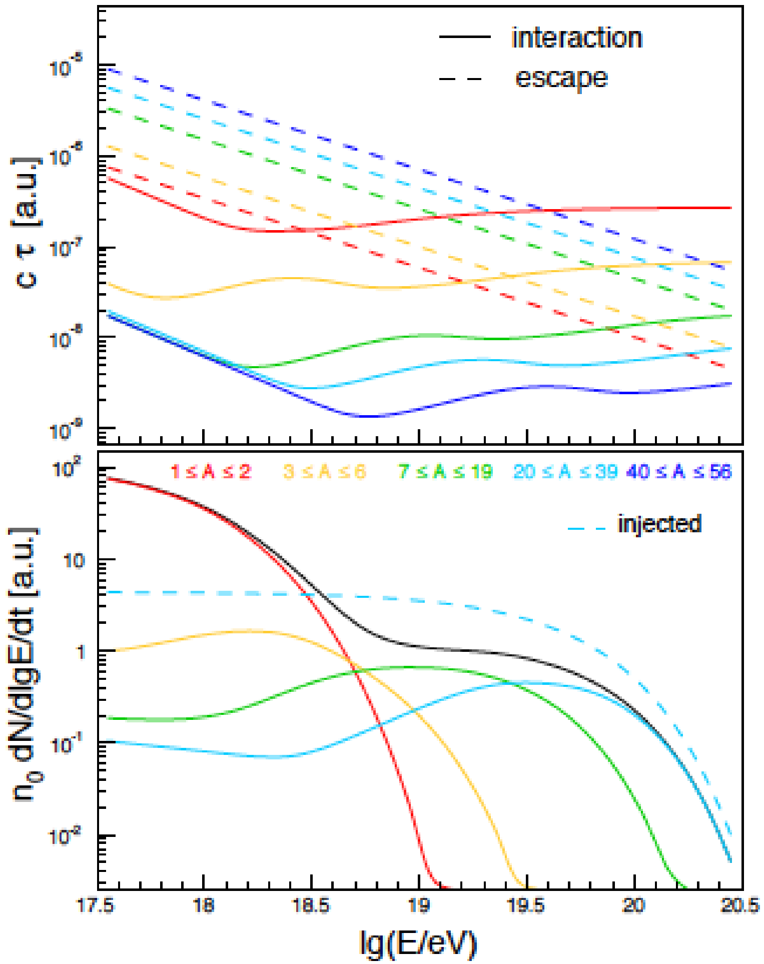




D.Allard et al, 1505.1377

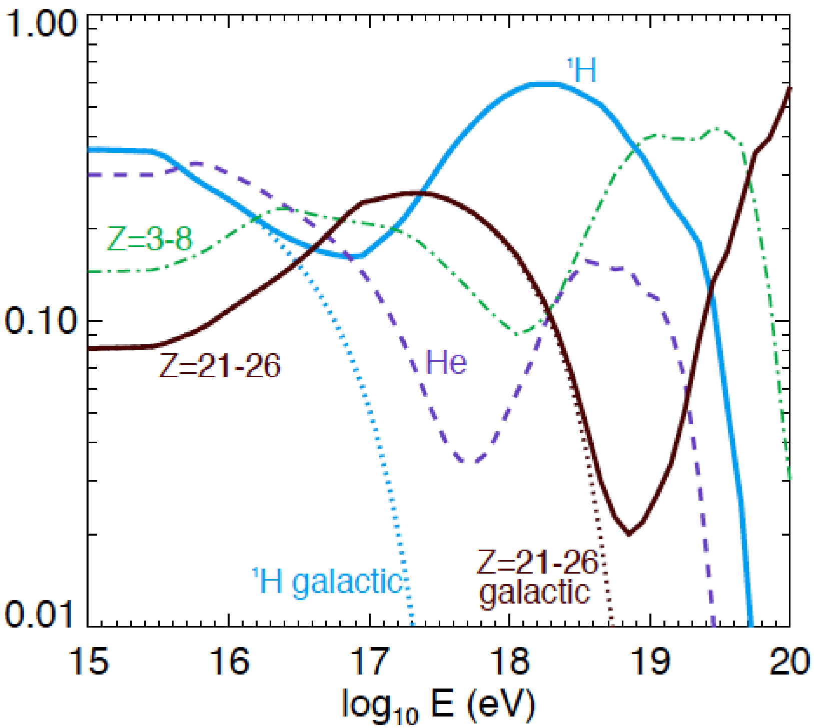
M.Unger et al, 1505.02153

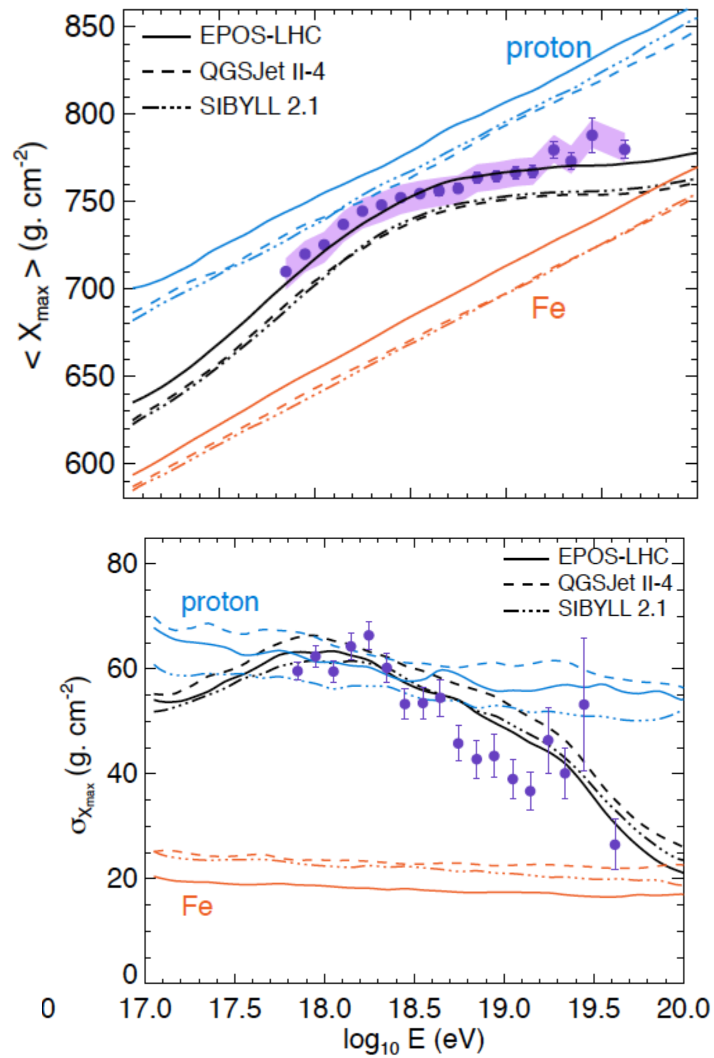
Idea: nuclei interact with photon background and neutrinos escape



M.Unger et al, 1505.02153

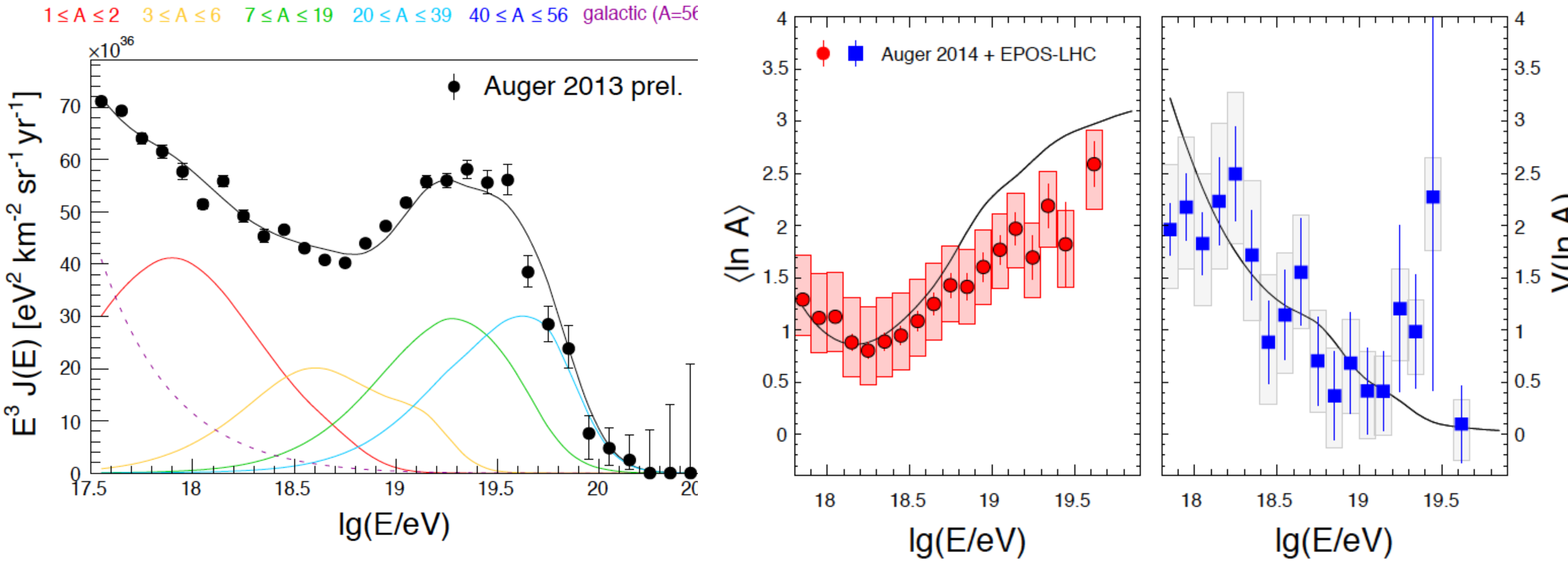
UHECR sources with tau>1 for nuclei





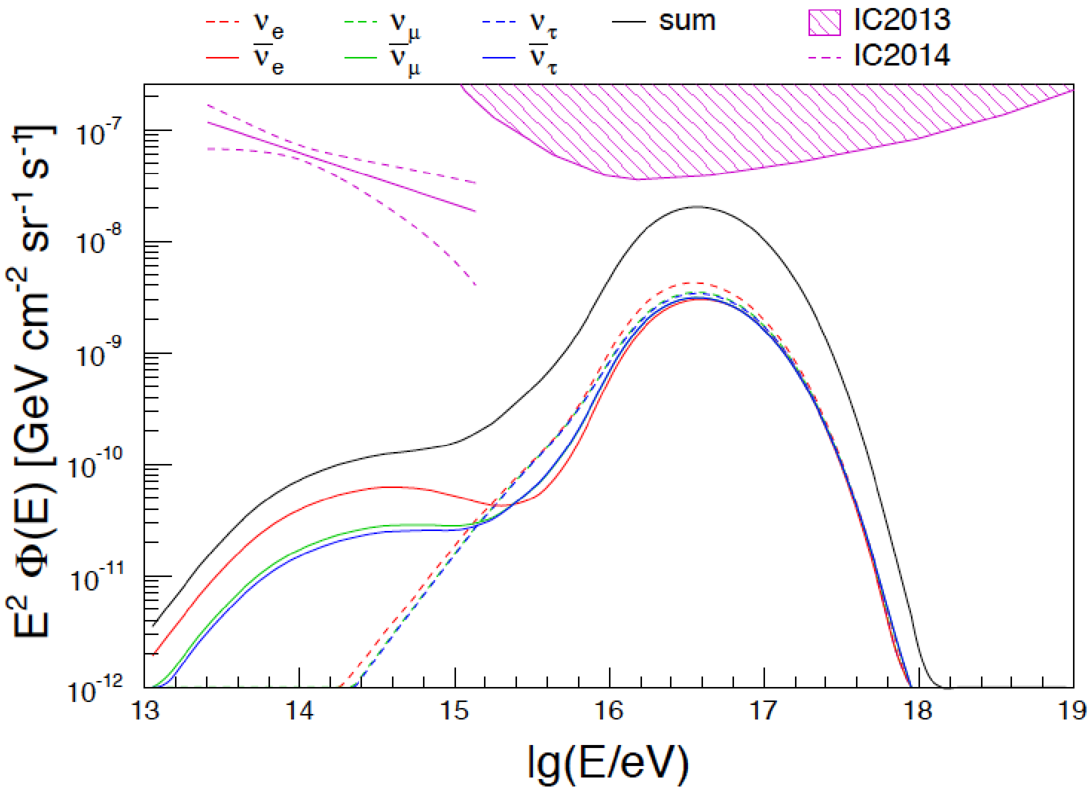
D.Allard et al, 1505.1377

UHECR sources with tau>1 for nuclei



M.Unger et al, 1505.02153

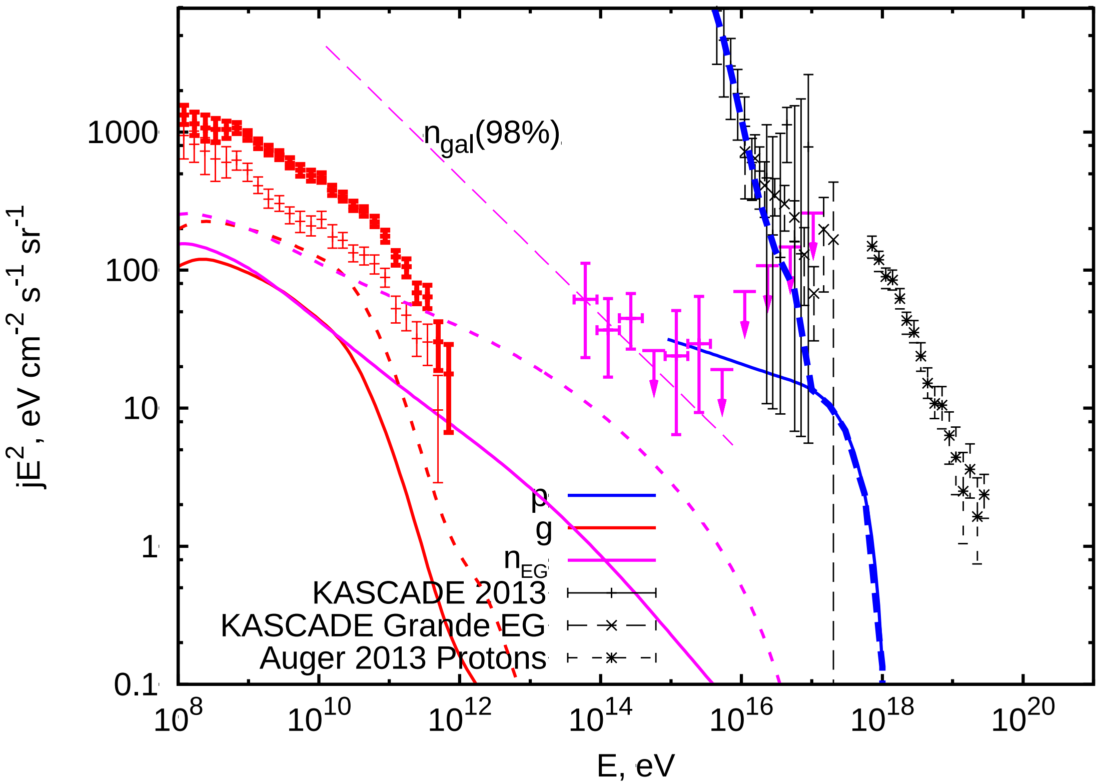
Problem: does not explain IceCube



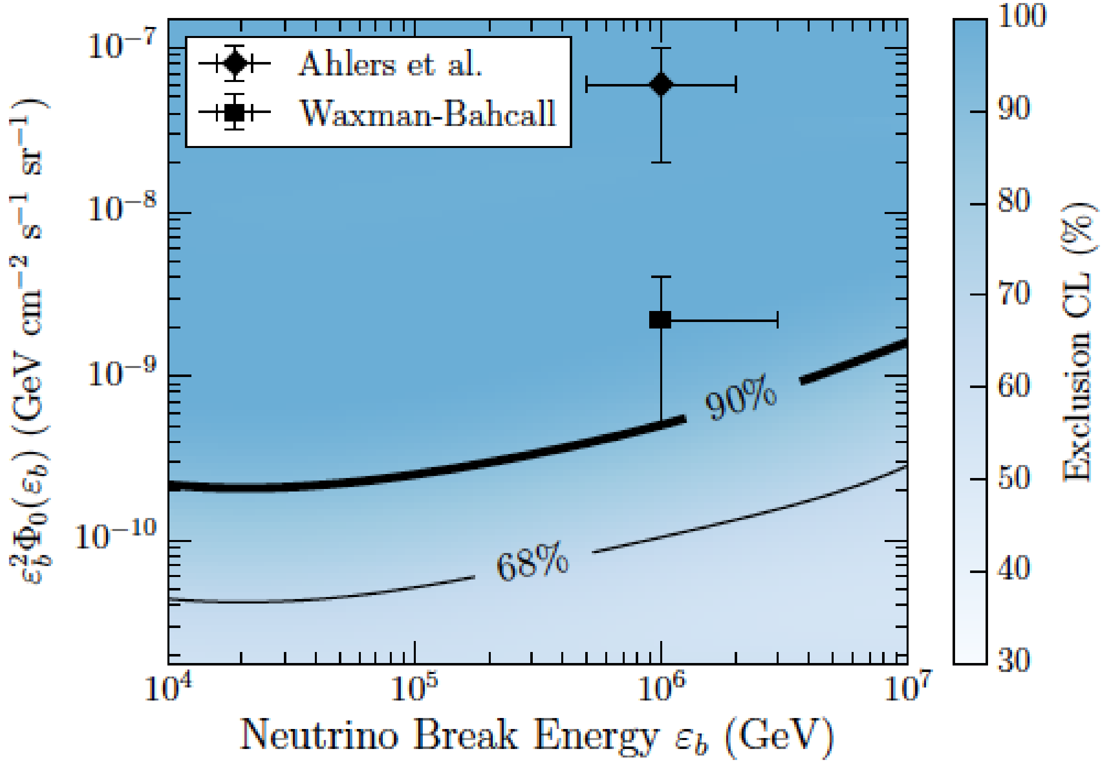
M.Unger et al, 1505.02153

UHECR, neutrino and gamma-ray sources

UHECR proton flux from Star Burst galaxies



Neutrinos not from GRB

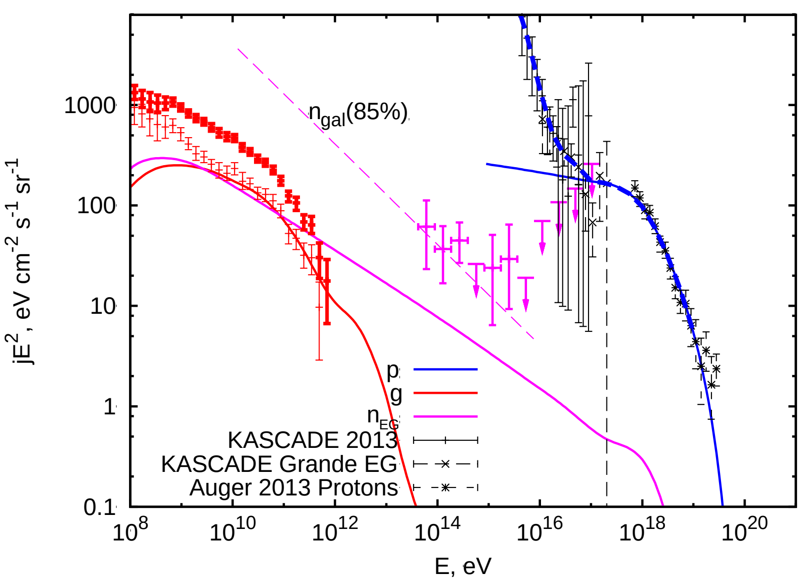


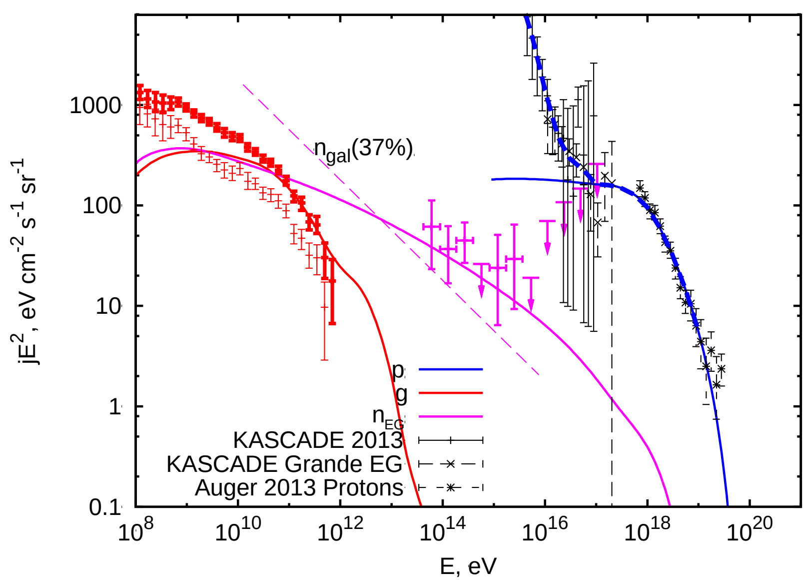
IceCube collaboration:1601.06484

Miltimessenger signal from BL Lacs: dependence on escape energy

0.3 TeV

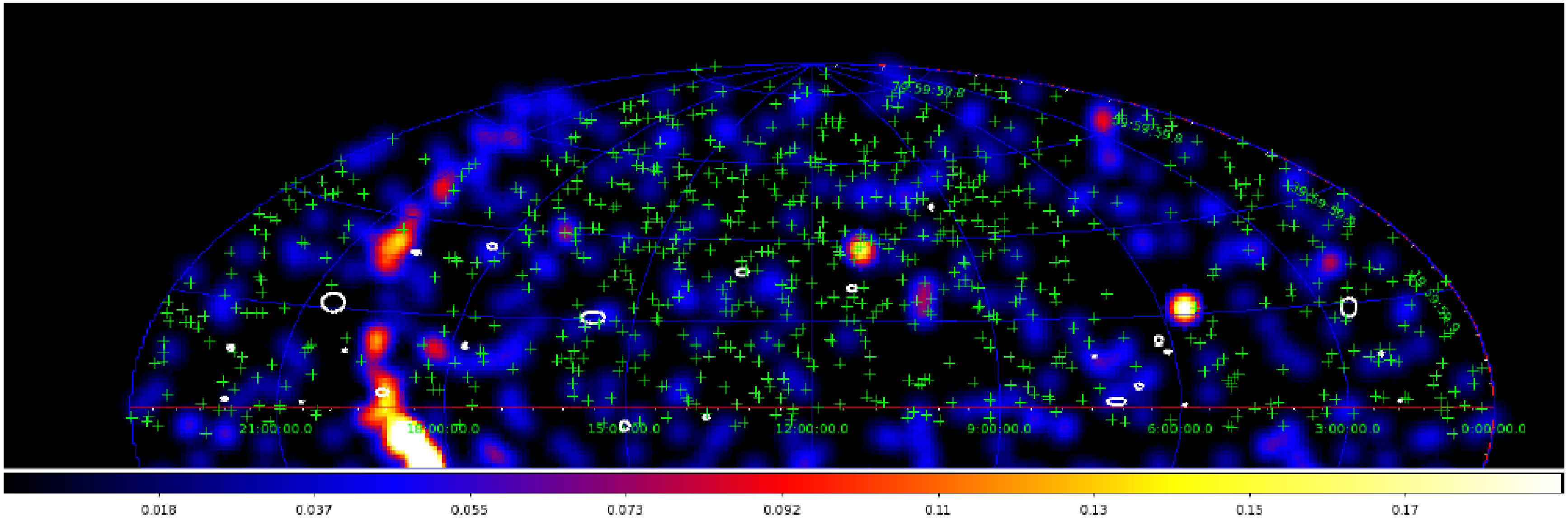
100 TeV





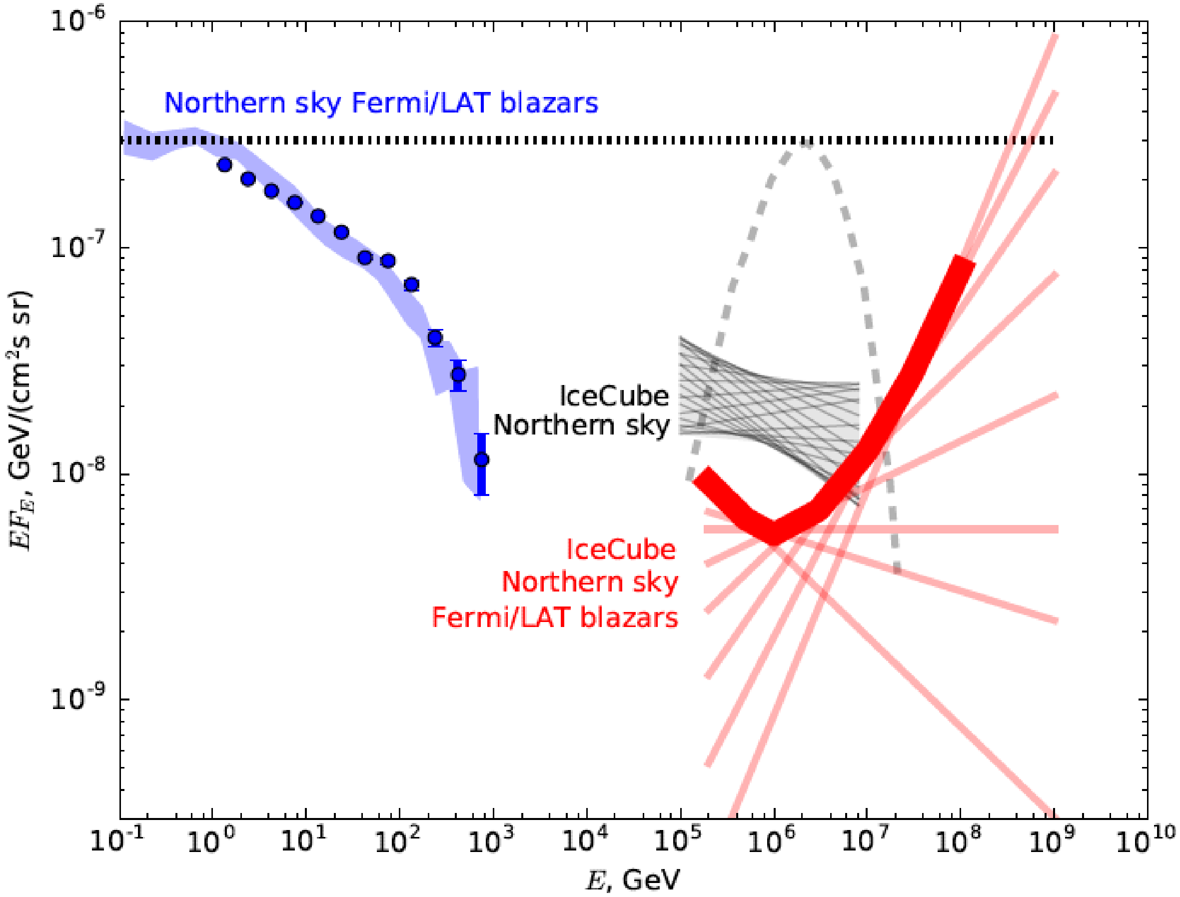
G.Giacinti, M.Kachelriess, O.Kalashev, A.Neronov and D.S., **arXiv: 1507.07534**

Fermi blazars and IceCube neutrinos



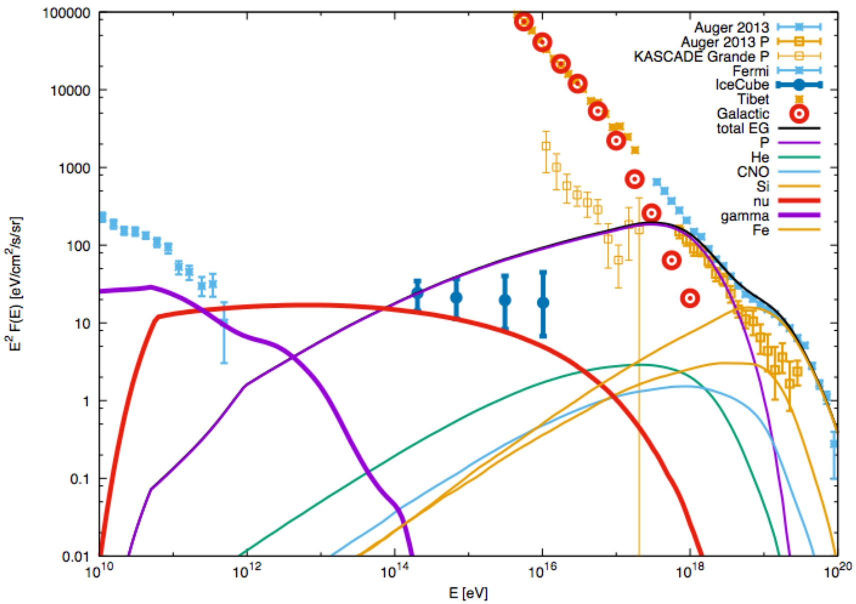
A.Neronov et al, arXiv:1611.06338

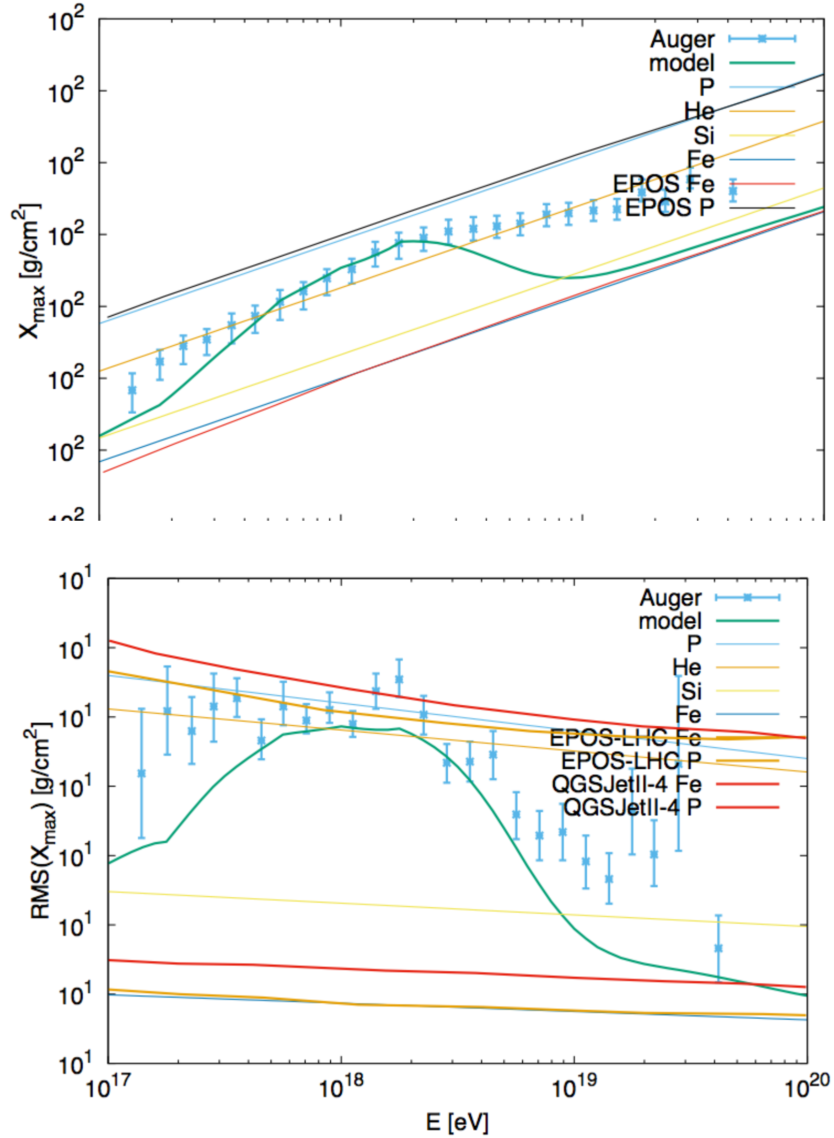
Neutrinos not from blazars



A.Neronov et al, arXiv:1611.06338

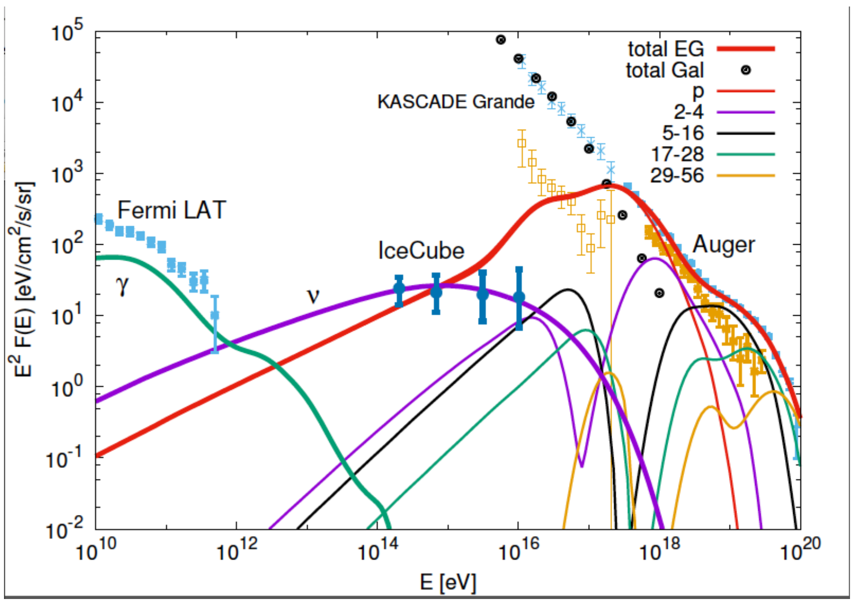
AGNs: Proton-proton interactions in the source region

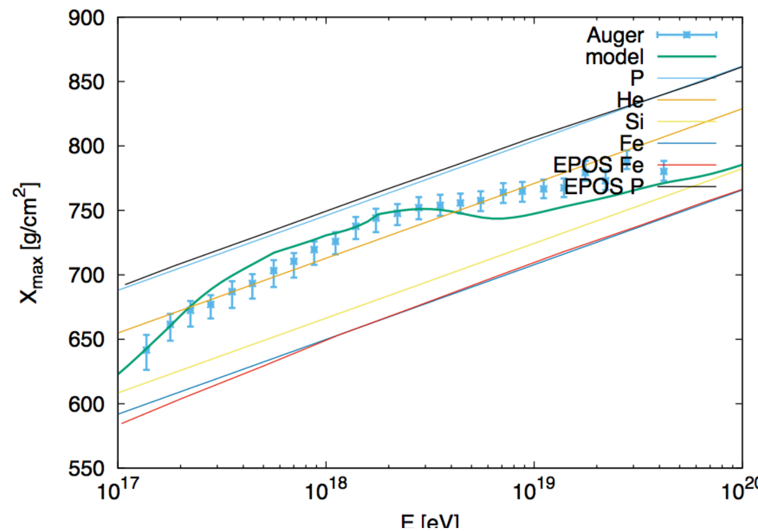


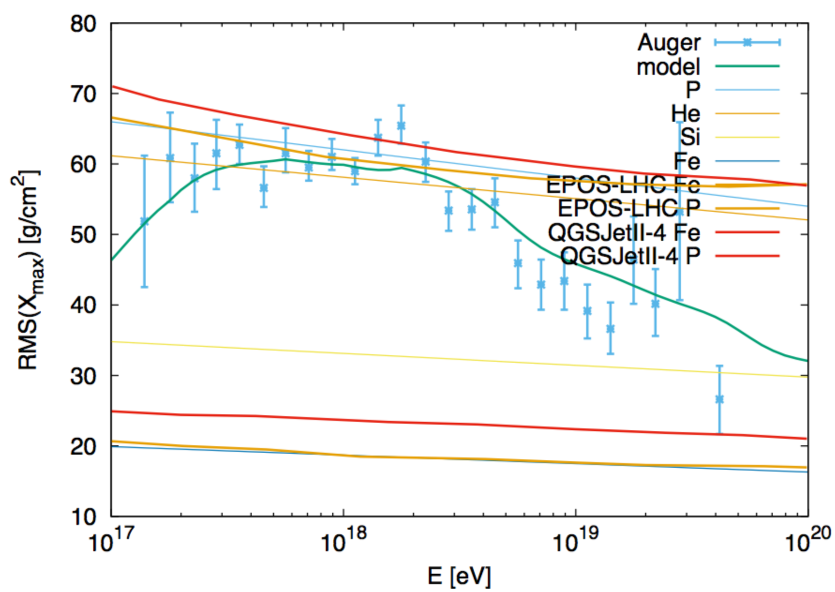


Kachelriess et al, 1704.06893

AGN's: P-gamma + Proton-proton interactions in the source region







Kachelriess et al, 1704.06893

Summary

- *First diffuse neutrino flux measurements contain both galactic and extragalactic components. Evidence of Galactic component come in 4 years of IceCube cascade data*
- *Galactic component give at least 50% of total flux, but can be as low as 10% in the north sky*
- *Galactic to extragalactic transition is around 10 PeV in protons, i.e. one expects both contributions for 1 PeV neutrinos*

Summary

- *Extragalactic component was measured with 6 years of muon neutrino data. It has flux 1/E^2.1 above 200 TeV and unknown origin*
- *One can explain UHECR data with p-gamma interaction in UHECR sources*
- *Sources of UHECR can give main contribution to extragalactic astrophysical neutrinos if after p-gamma protons come through p-p interactions*