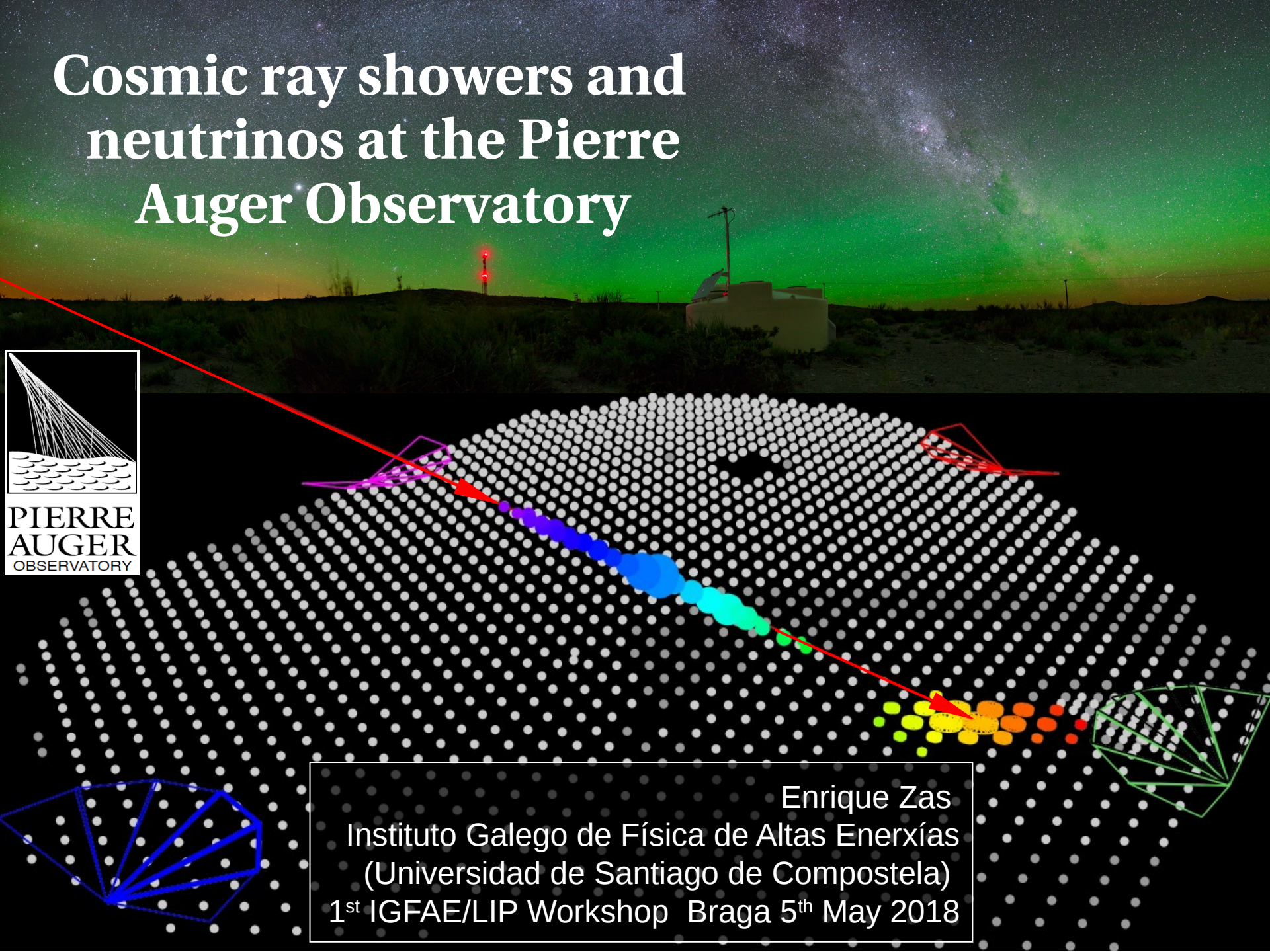
Cosmic ray showers and neutrinos at the Pierre Auger Observatory



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(Universidad de Santiago de Compostela)
1st IGFAE/LIP Workshop Braga 5th May 2018

Pierre Auger Observatory

Loma Amarilla

[km]

60

50

40

30

HEAT

17 km²

Coihueco

AERA

24 km²

XLF

CLF

BLF

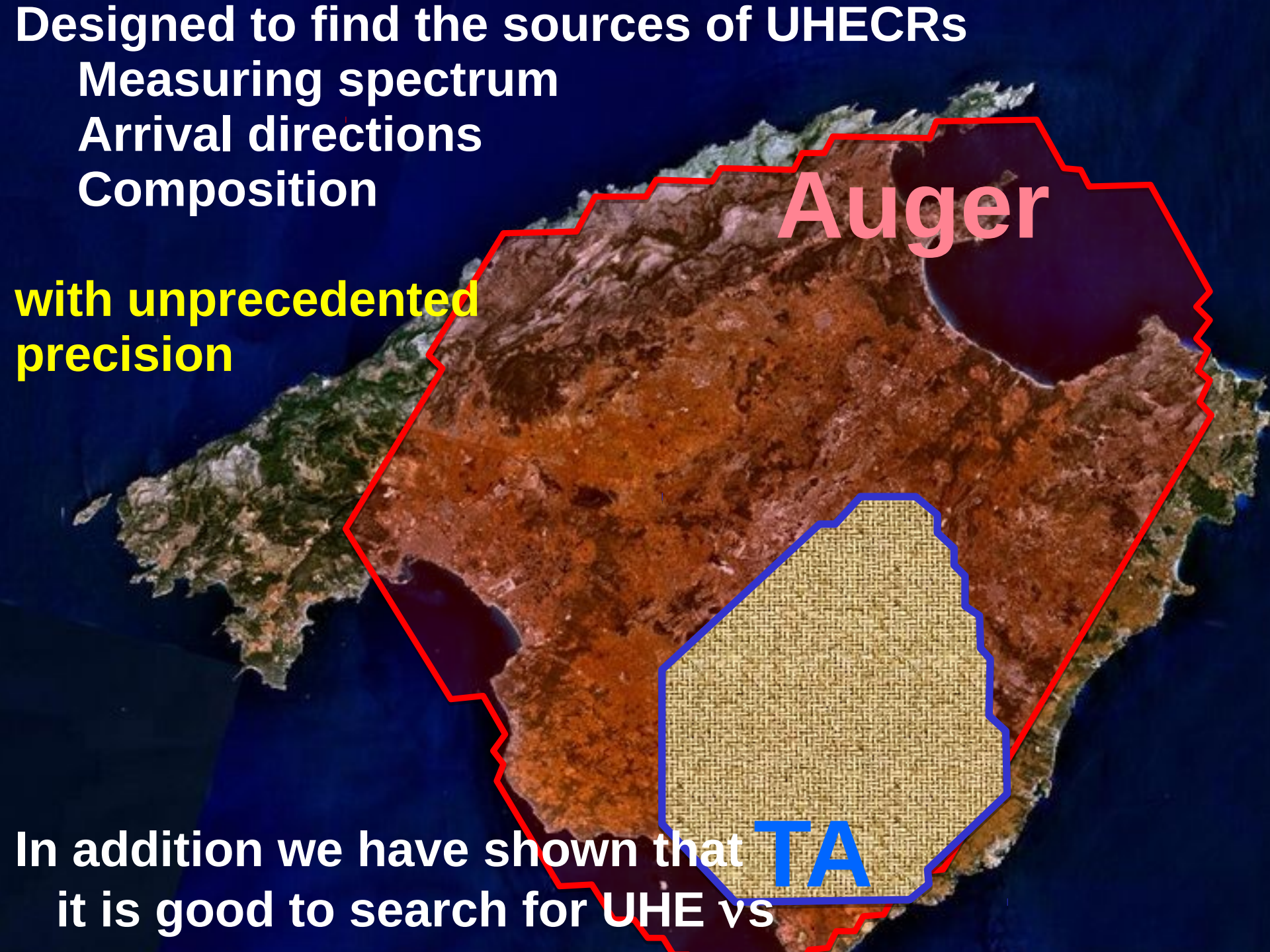
Los Morados

MALARGÜE

Los Leones

3000 km²


Auger
TA


Designed to find the sources of UHECRs
Measuring spectrum
Arrival directions
Composition
with unprecedented precision
Auger
TA
In addition we have shown that
it is good to search for UHE νs

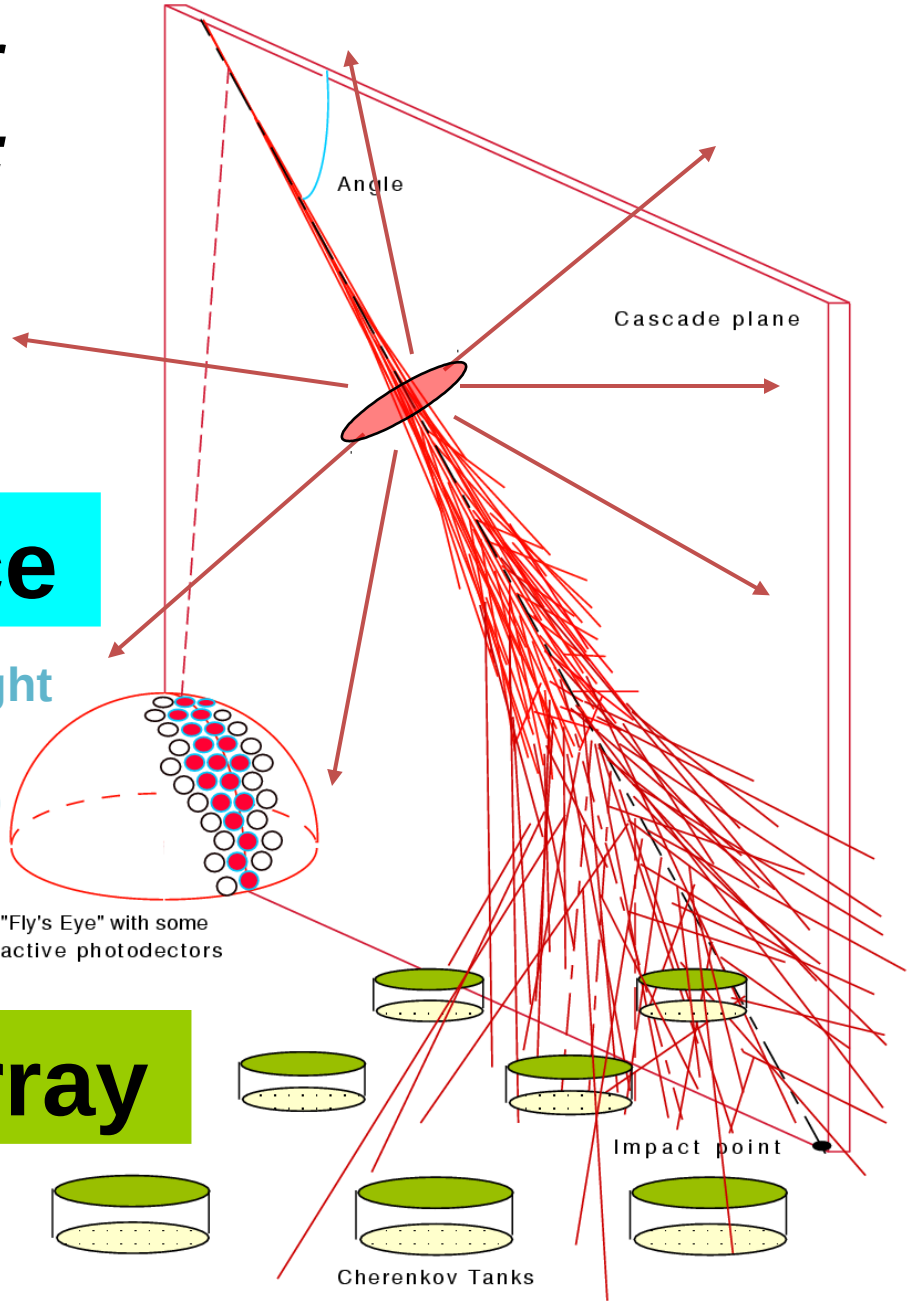
Spectrum

TA and the Pierre Auger Observatory are Hybrid: Combine the two succesful techniques

Fluorescence

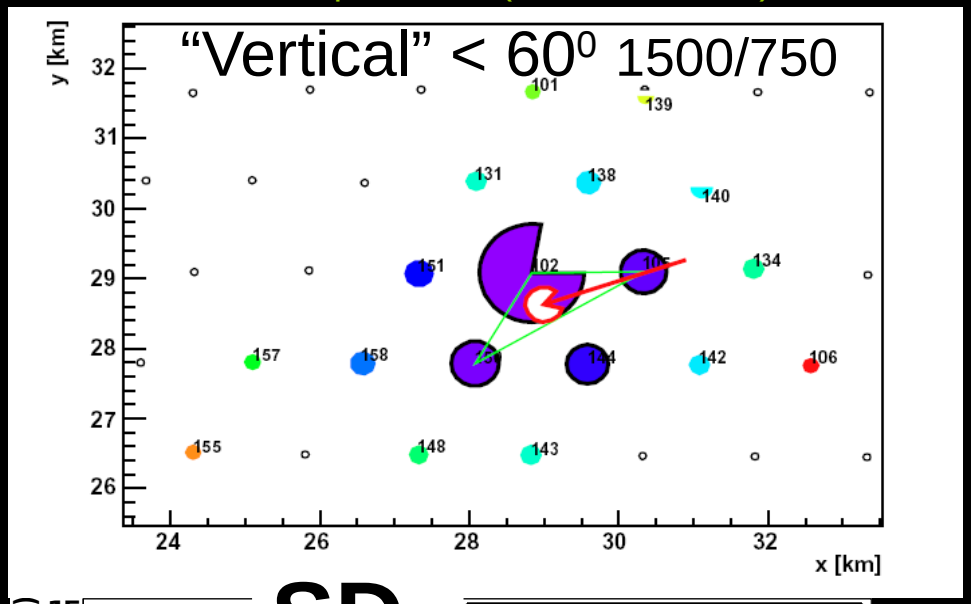
Isotropic Fluorescence light from nitrogen (~4 γ per meter of track)

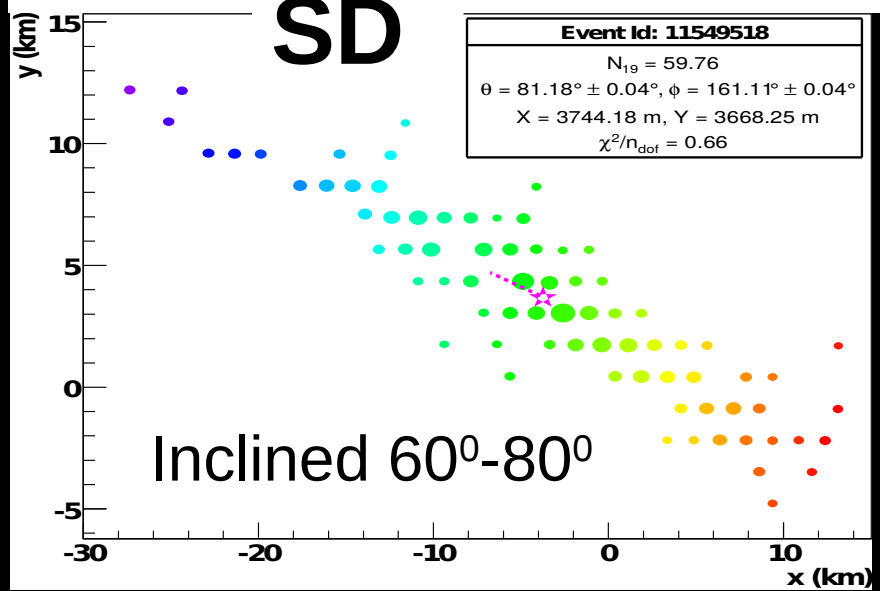
Particle array

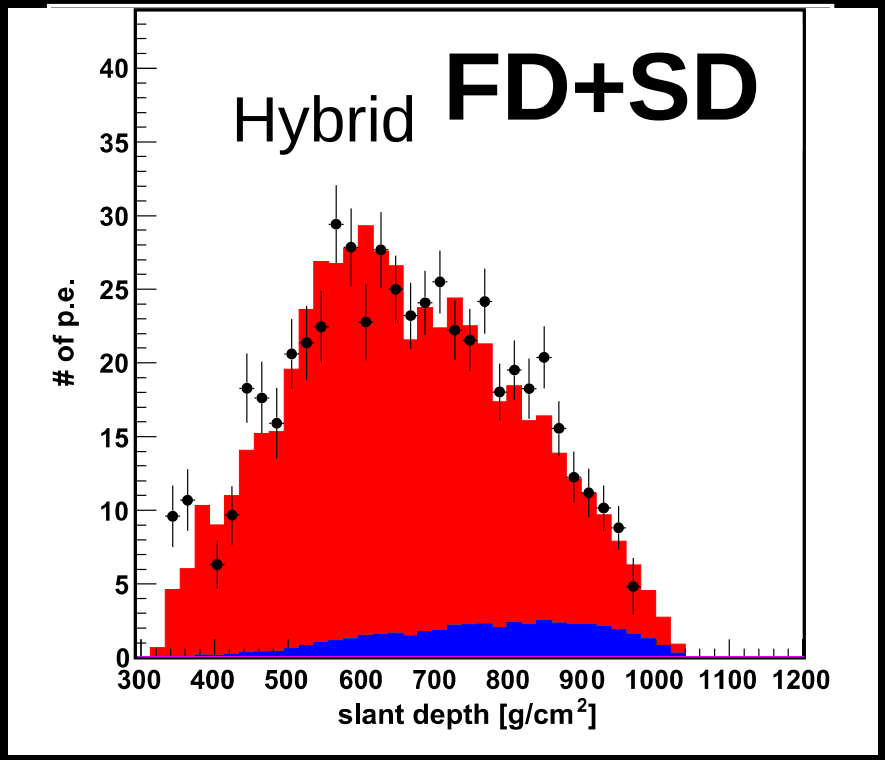


Four independent spectra

Example Event (48°, E~70 EeV)

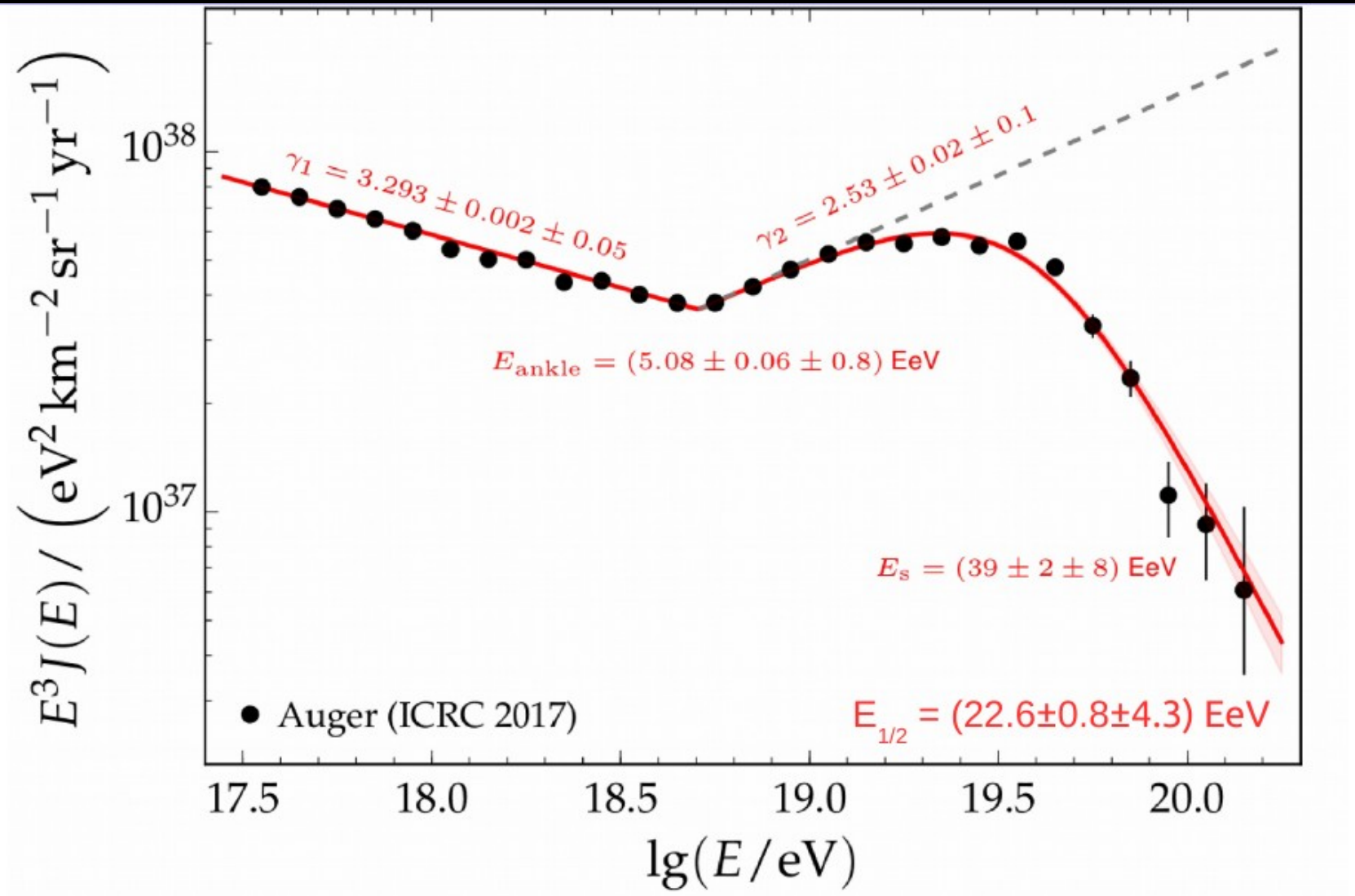






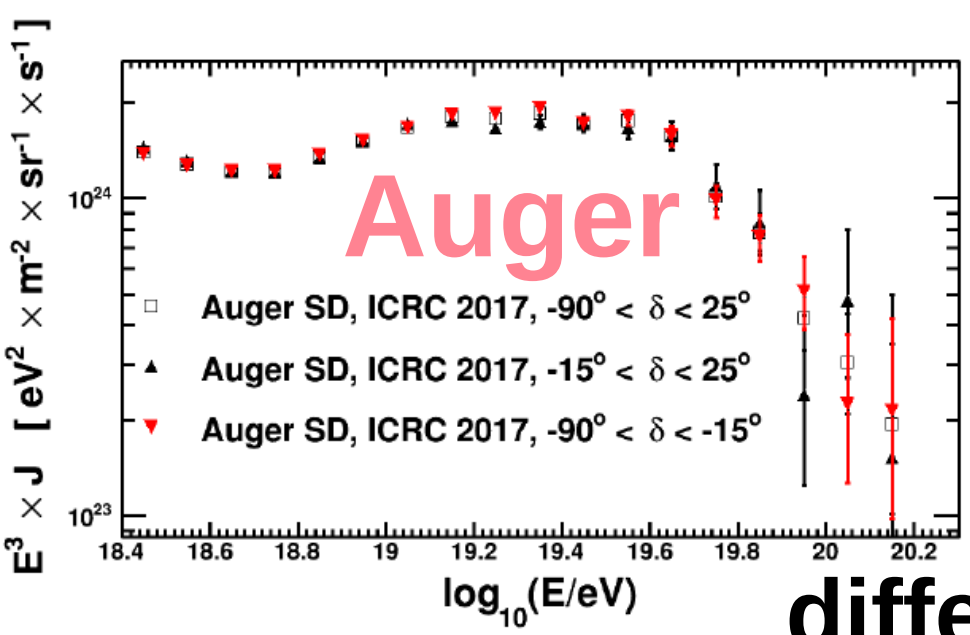
TA SD 2013
4,580 km² sr y
Auger SD
40,000 km² sr y

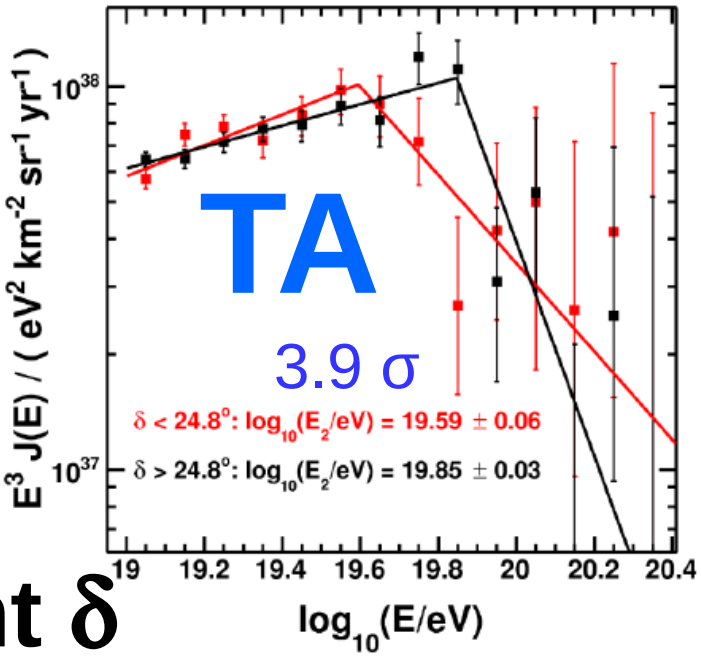
Combined Results



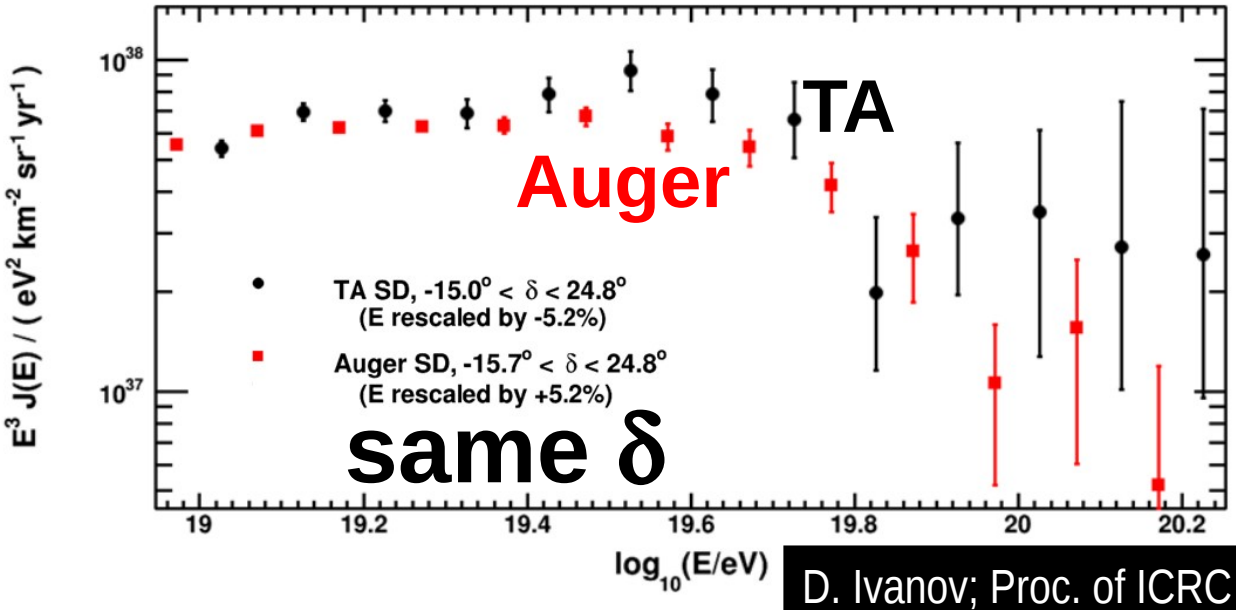
F. Fenu; Proc. of ICRC 2017, PoS (2017) 486.

TA Auger: anisotropy issues?





different δ

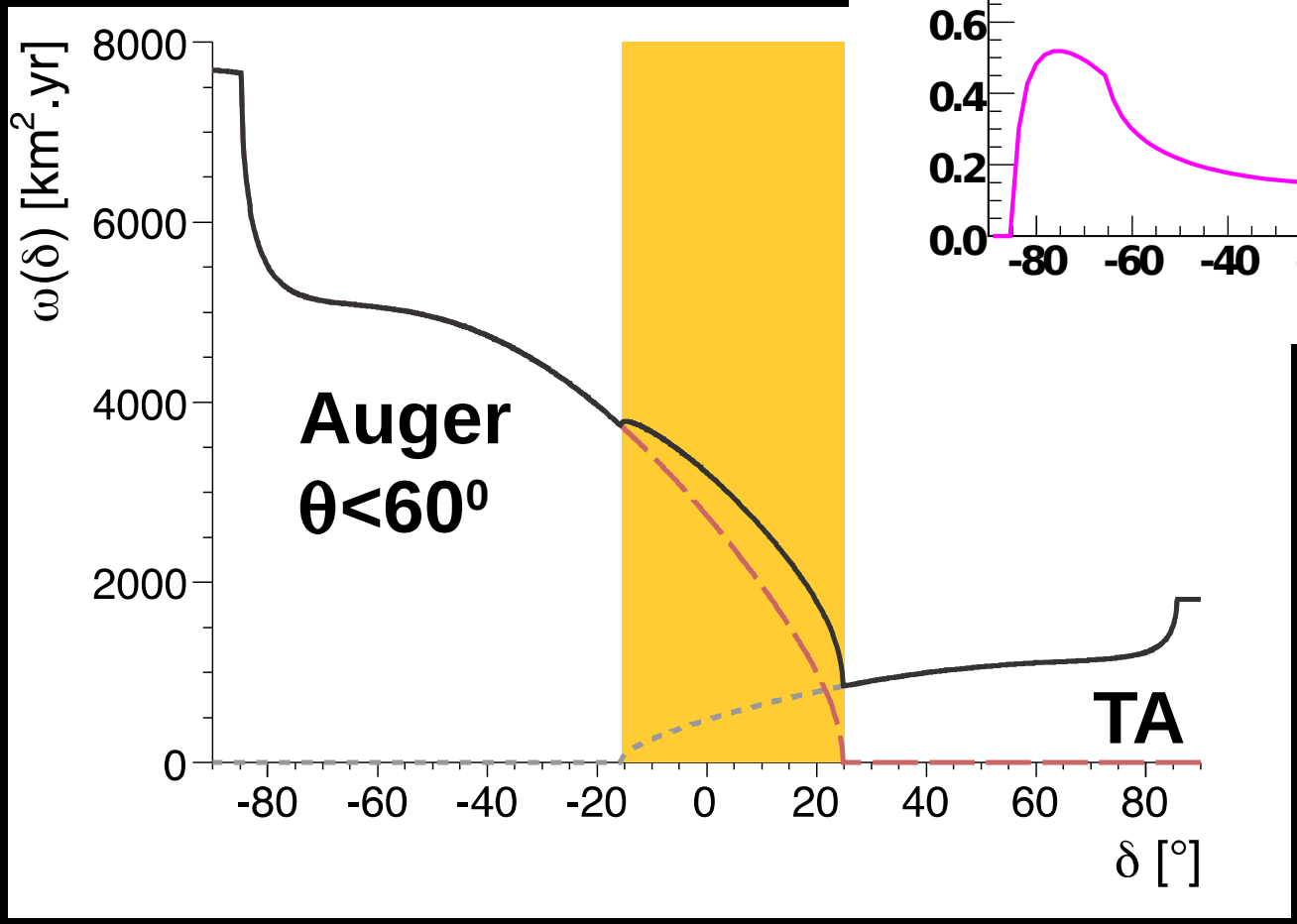


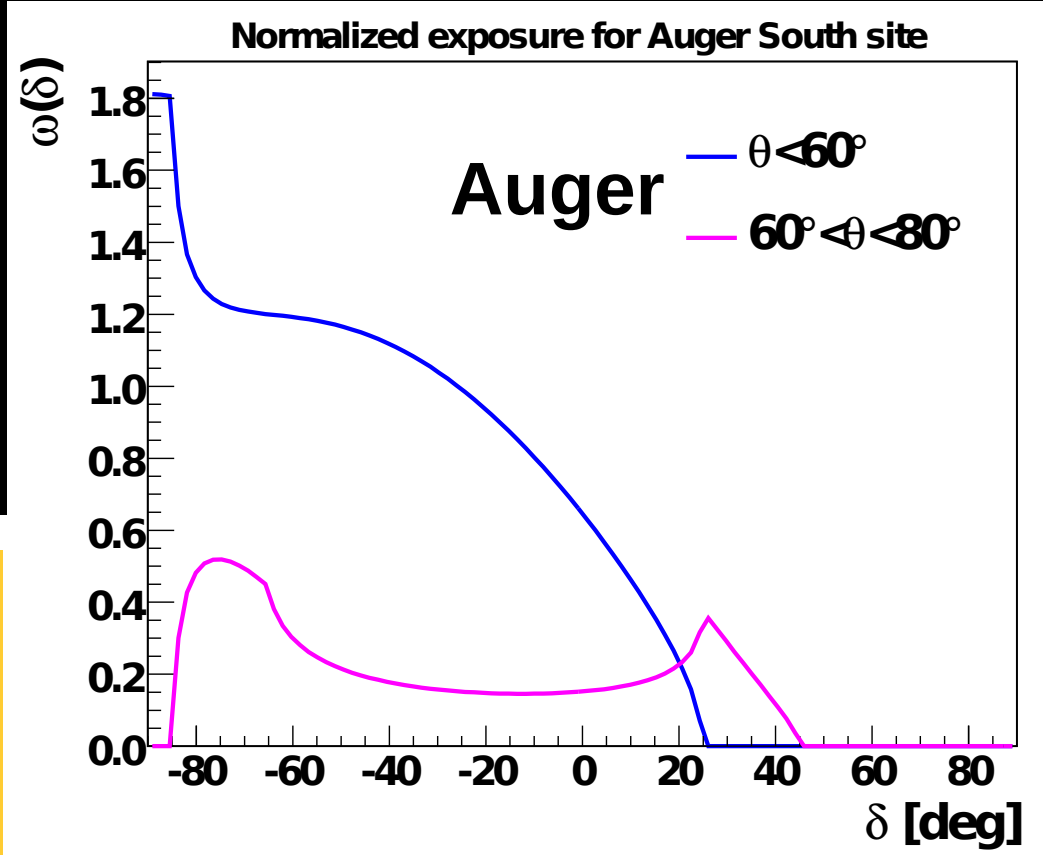
3.9 σ discrepancy (broken power law fit)
Not due to biases in energy or exposure

Common declination band agreement
same break points

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

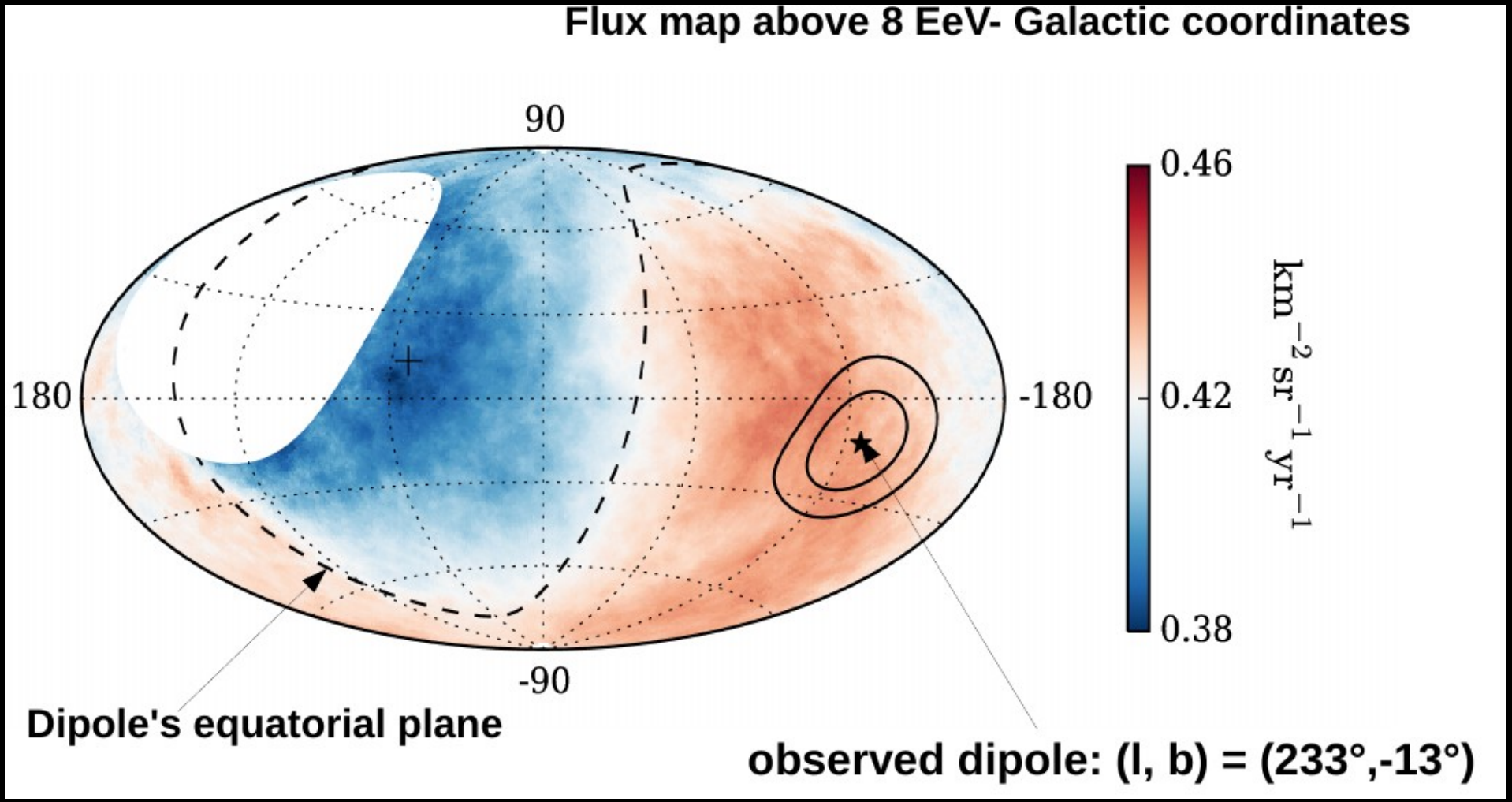
Sky coverage





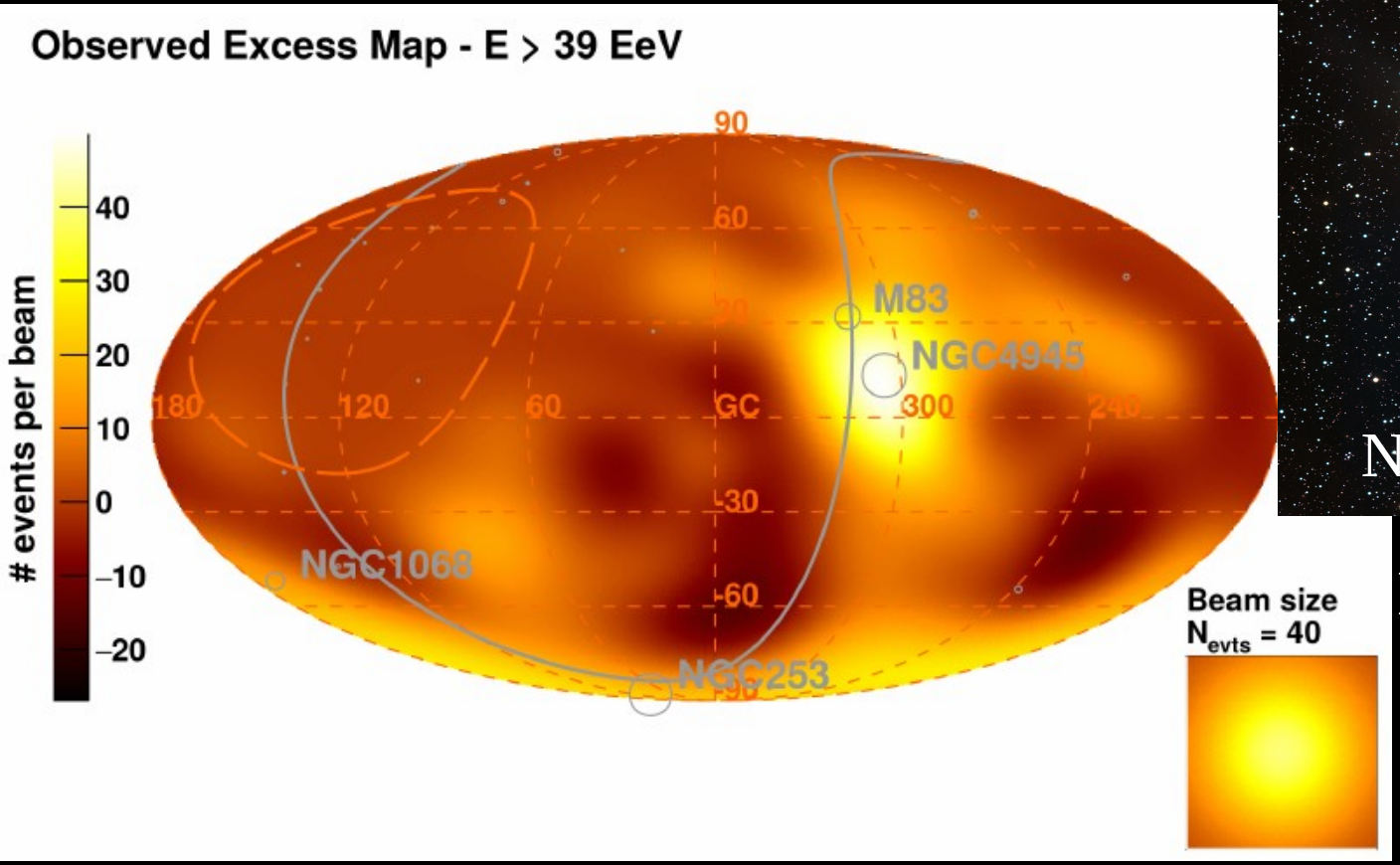
Anisotropy searches: dipole E>8 EeV!

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



More details to appear soon

Other signs of smaller angle correlations



Highest Energy CR and γ ray sources, particularly Star Burst Galaxies

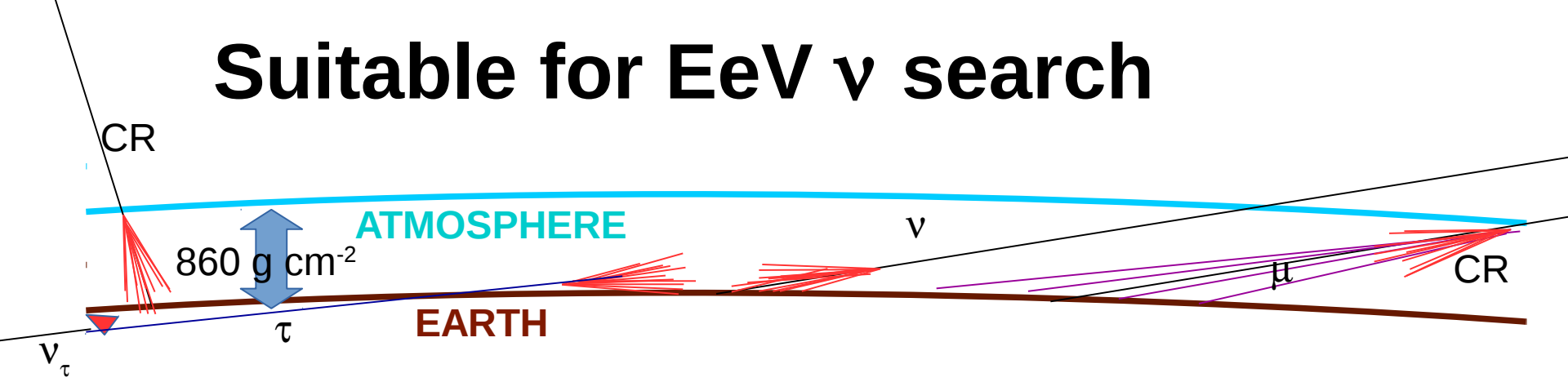
Starburst Galaxies → 39^0
f = 10%, ψ = 13^0
pre-trial⋆ p-value: 4 × 10−6
post-trial⋆⋆ p-value: 4 × 10−5
post-trial⋆⋆ significance: 3.9 σ

AGN Swift-BAT Catalogue → 60^0
f = 7%, ψ = 7^0
pre-trial⋆ p-value: 5 × 10−4
post-trial⋆⋆ p-value: 3 × 10−3
post-trial⋆⋆ significance: 2.7 σ

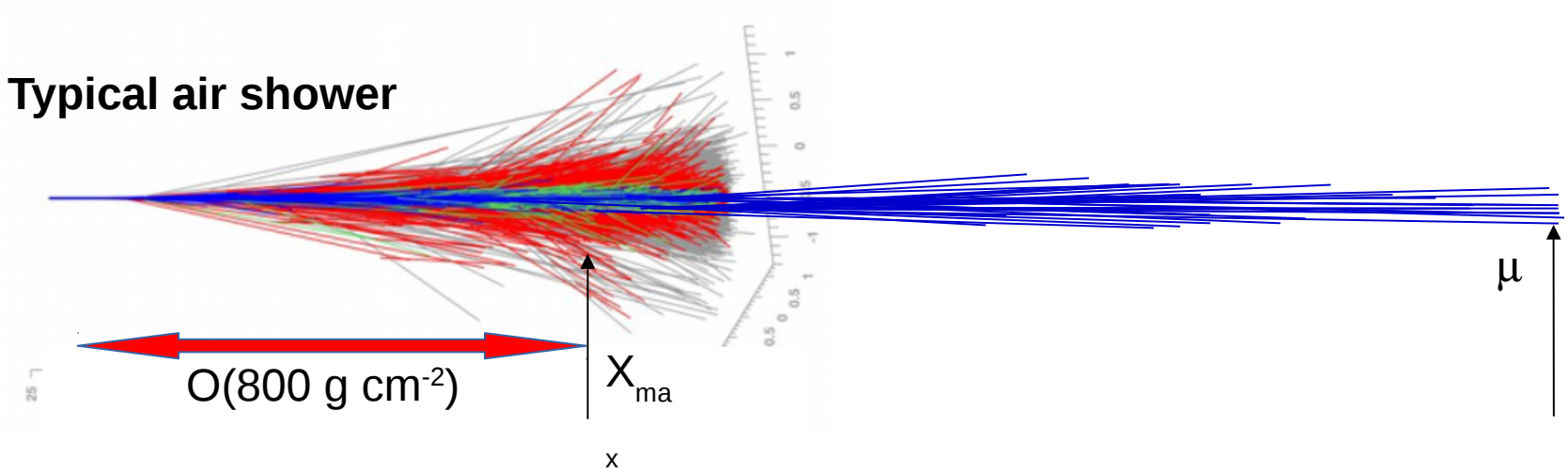
Multi-messenger:

Neutrino search potential

Suitable for EeV ν search

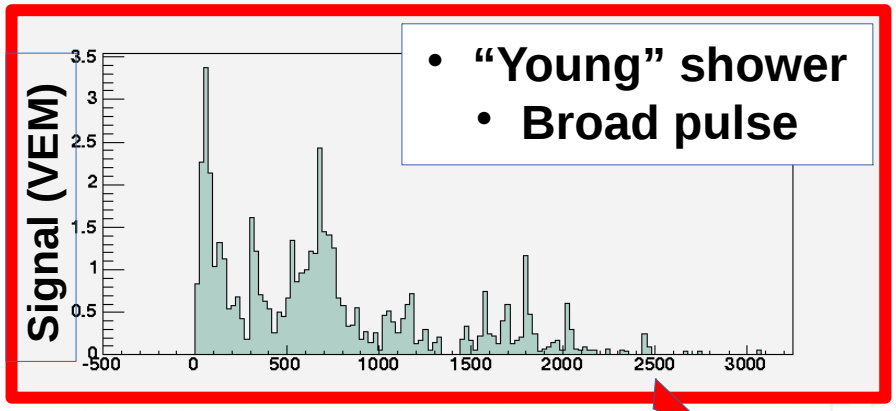


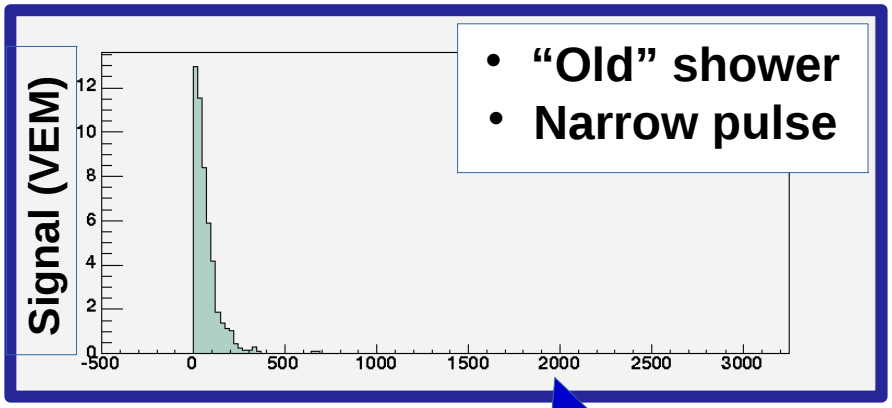
Typical air shower

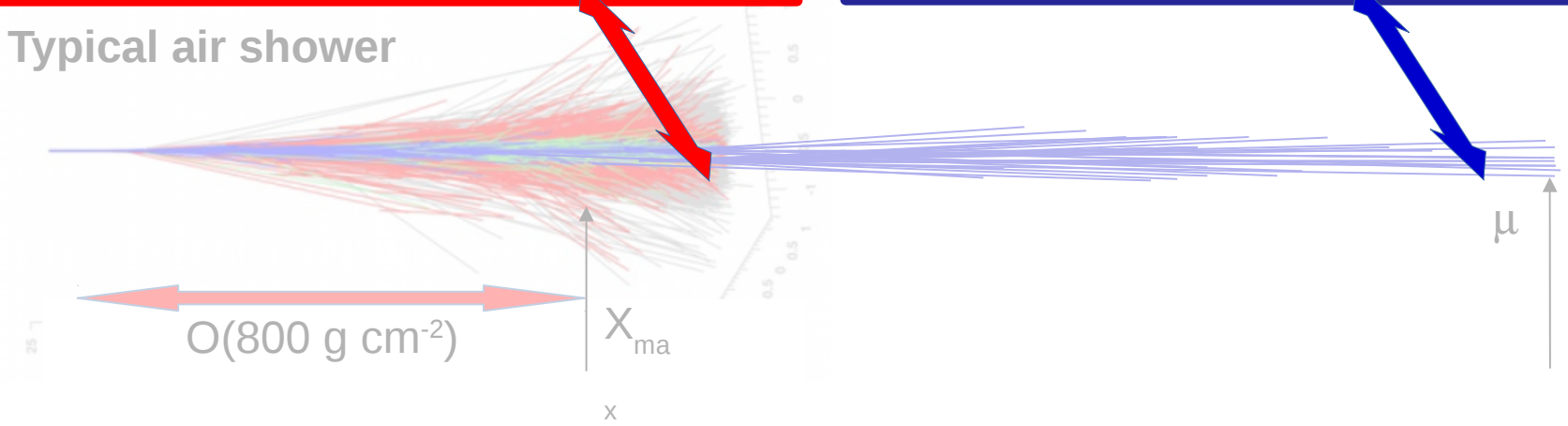


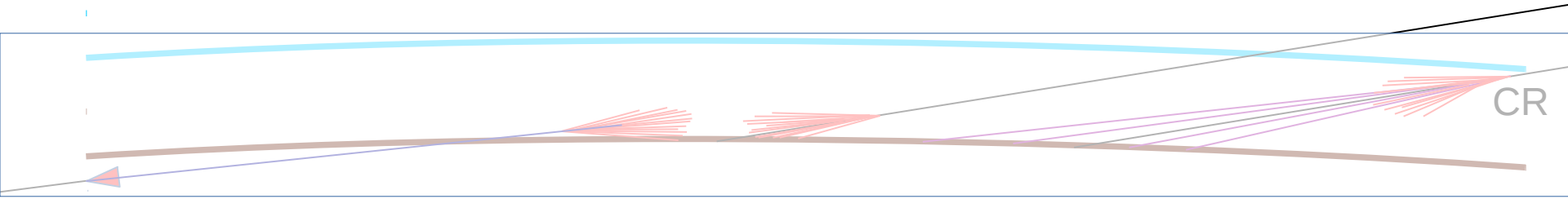
Suitable for EeV ν search

Neutrino: Inclined air shower with broad component









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

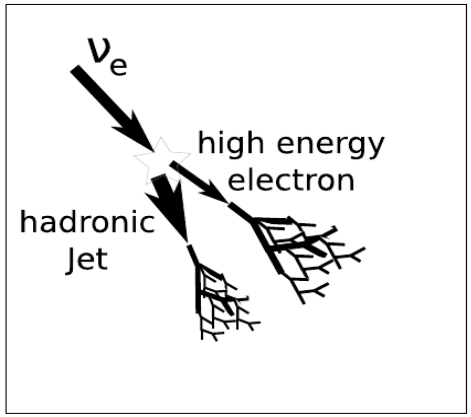
} *To trigger SD array*

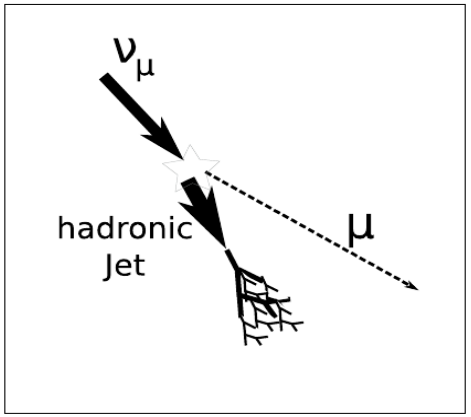
- DG Atmospheric interactions ($\theta > 60^0$ ⇒ $X_{atm} > 1700$ g cm^{-2})

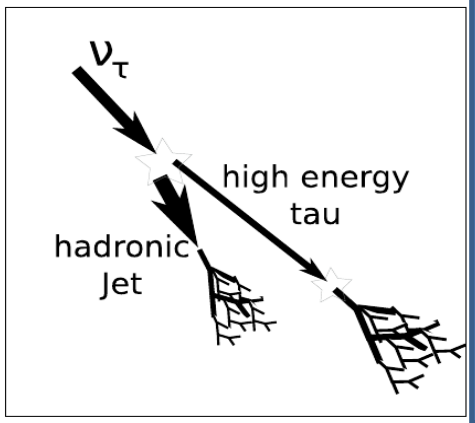
  + **(2) DGL $60^0<\theta<75^0$**
  + **(3) DGH $75^0<\theta<90^0$**

} *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

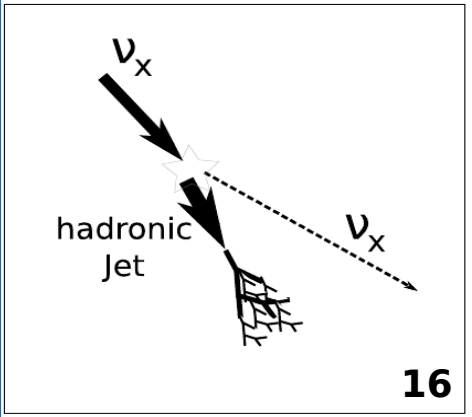
Charged Current





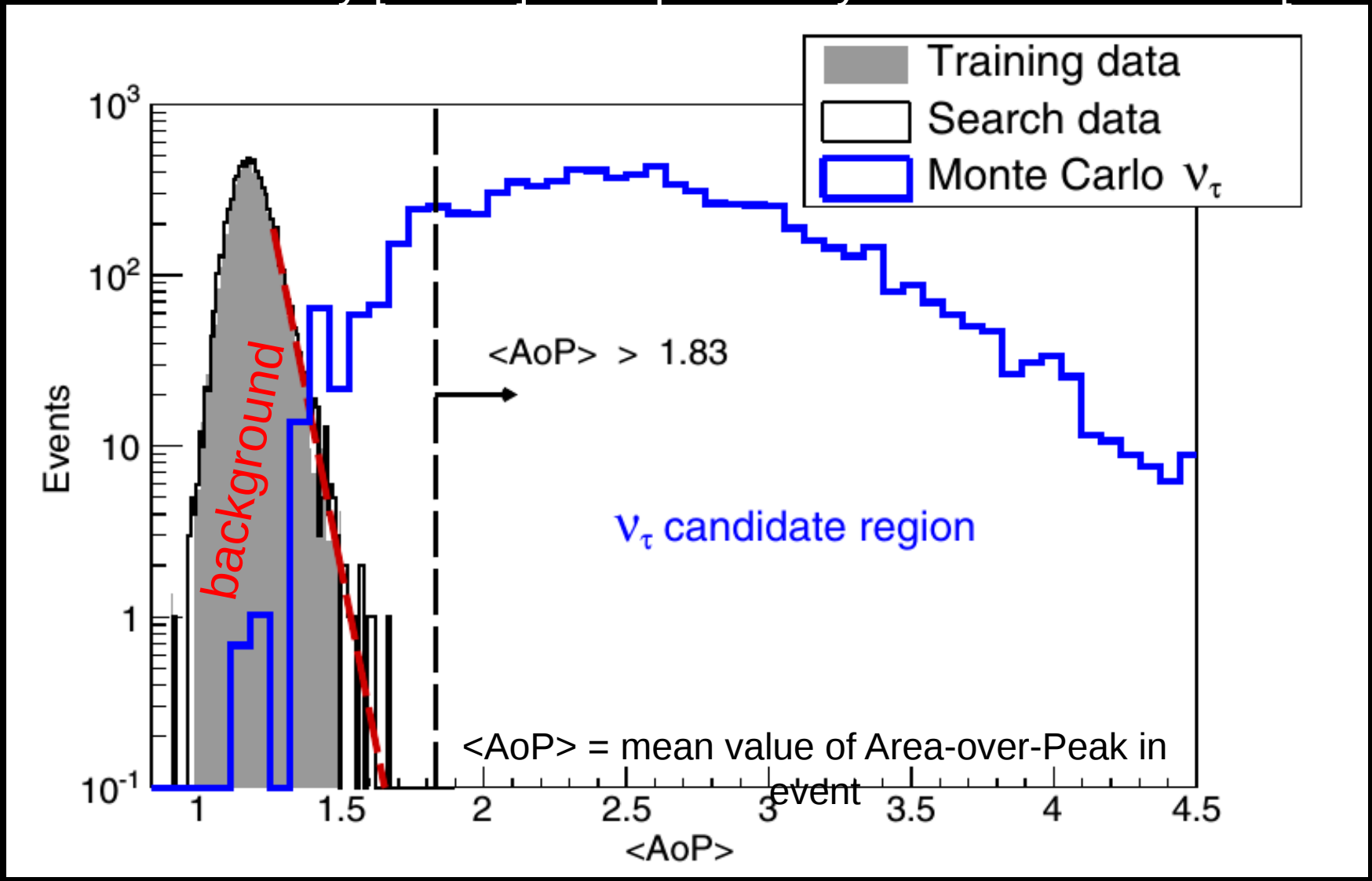


Neutral Current



Earth Skimming search

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



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

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

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

Very sensitive to ES ν_τ

1 Jan 04 – 31 Mar 17

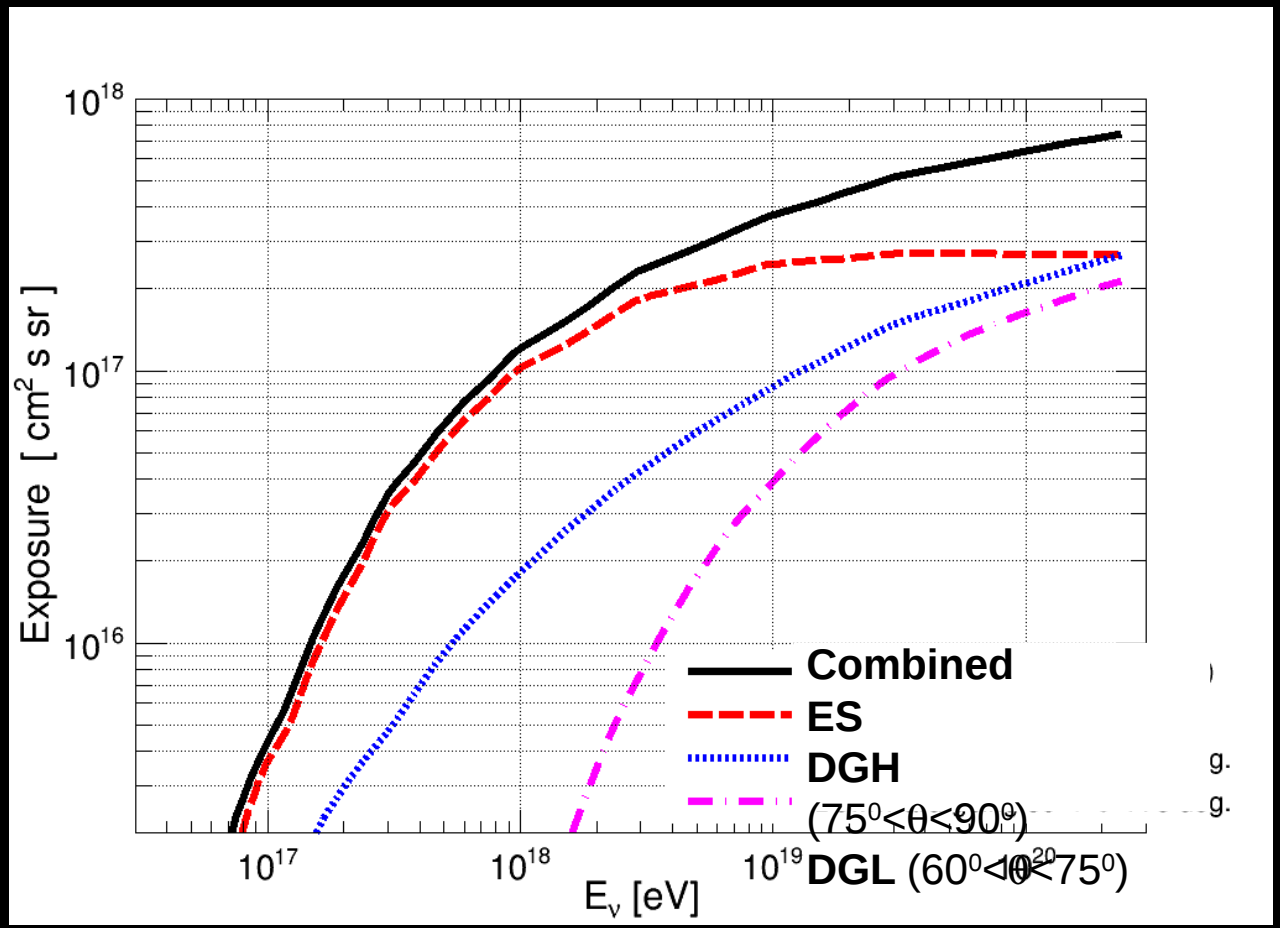
Relative contributions (E^{-2} flux)

CHANNELS

ES	79.4%
DGH	17.6%
DGL	3.0%

FLAVOURS

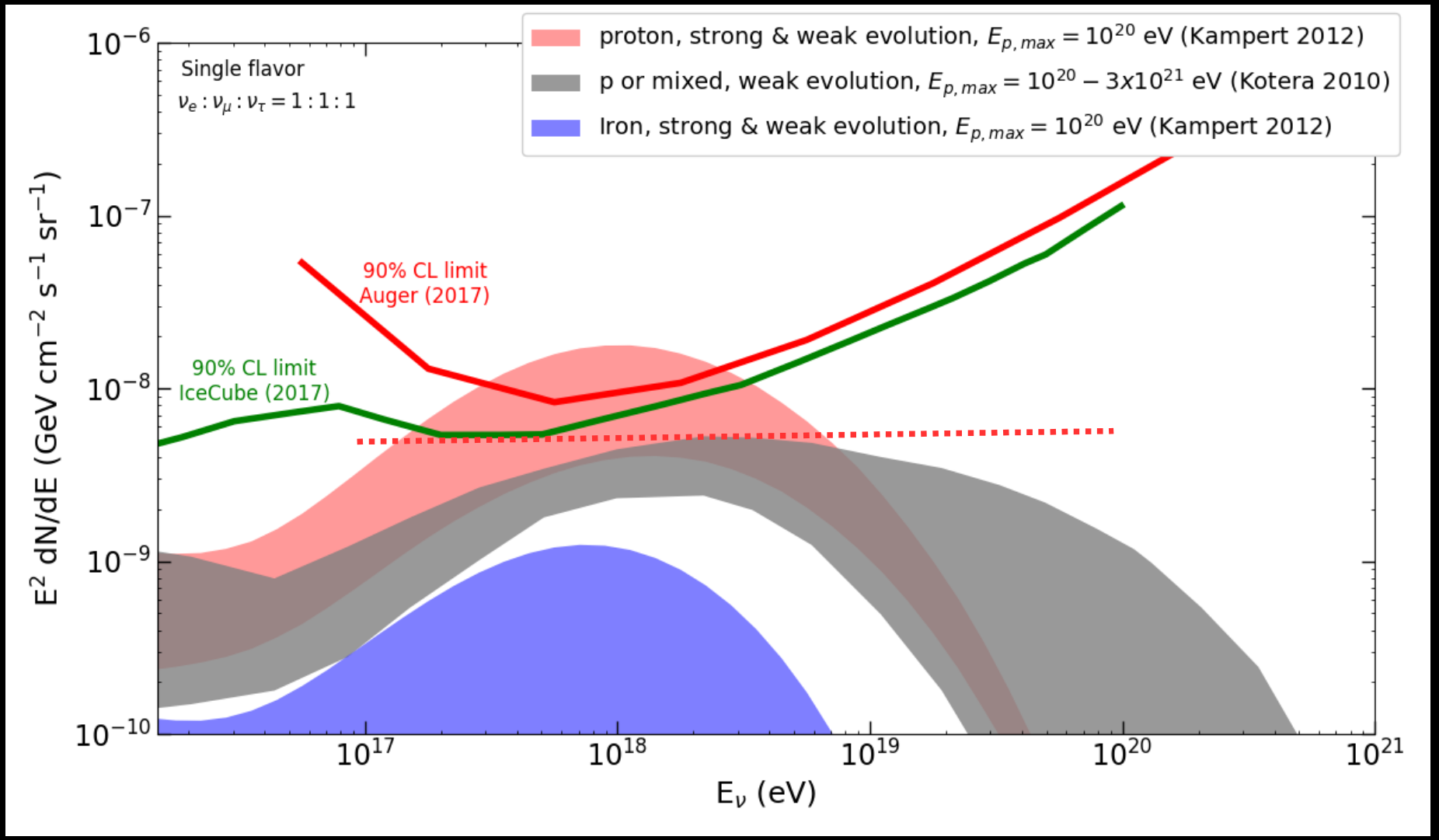
ν_e	10.1%
ν_μ	3.8%
ν_τ	86.1%



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

Limits to diffuse flux

J. Alvarez-Muñiz Highlight talk
ICRC2017



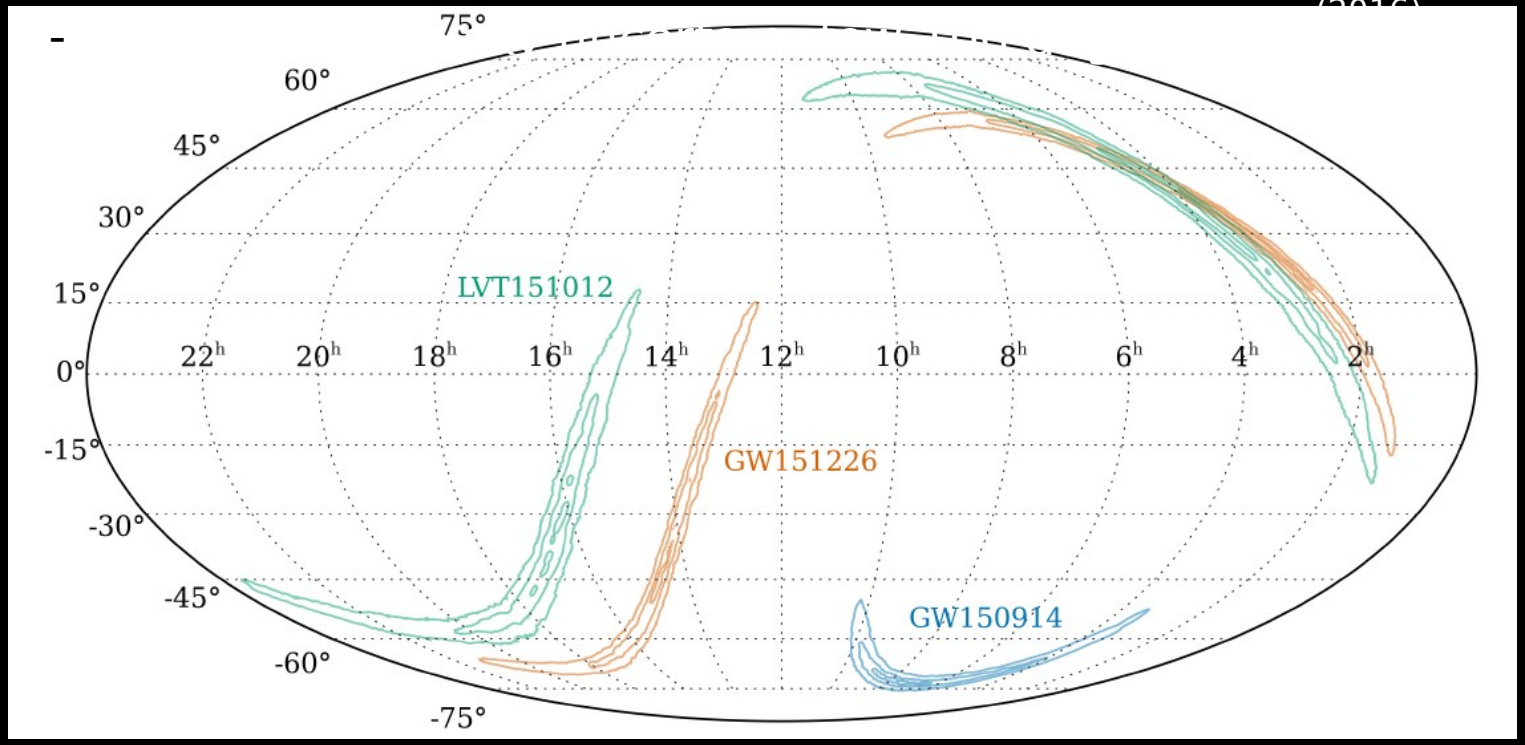
Search for UHEν in coincidence with Gravitational Wave events with Auger

Gravitational Wave events (GW150914 & GW151226) detected by Advanced-LIGO detectors (also LVT151012 candidate):

Inferred source: **merger of binary black-hole** at D = 410 & 440 Mpc

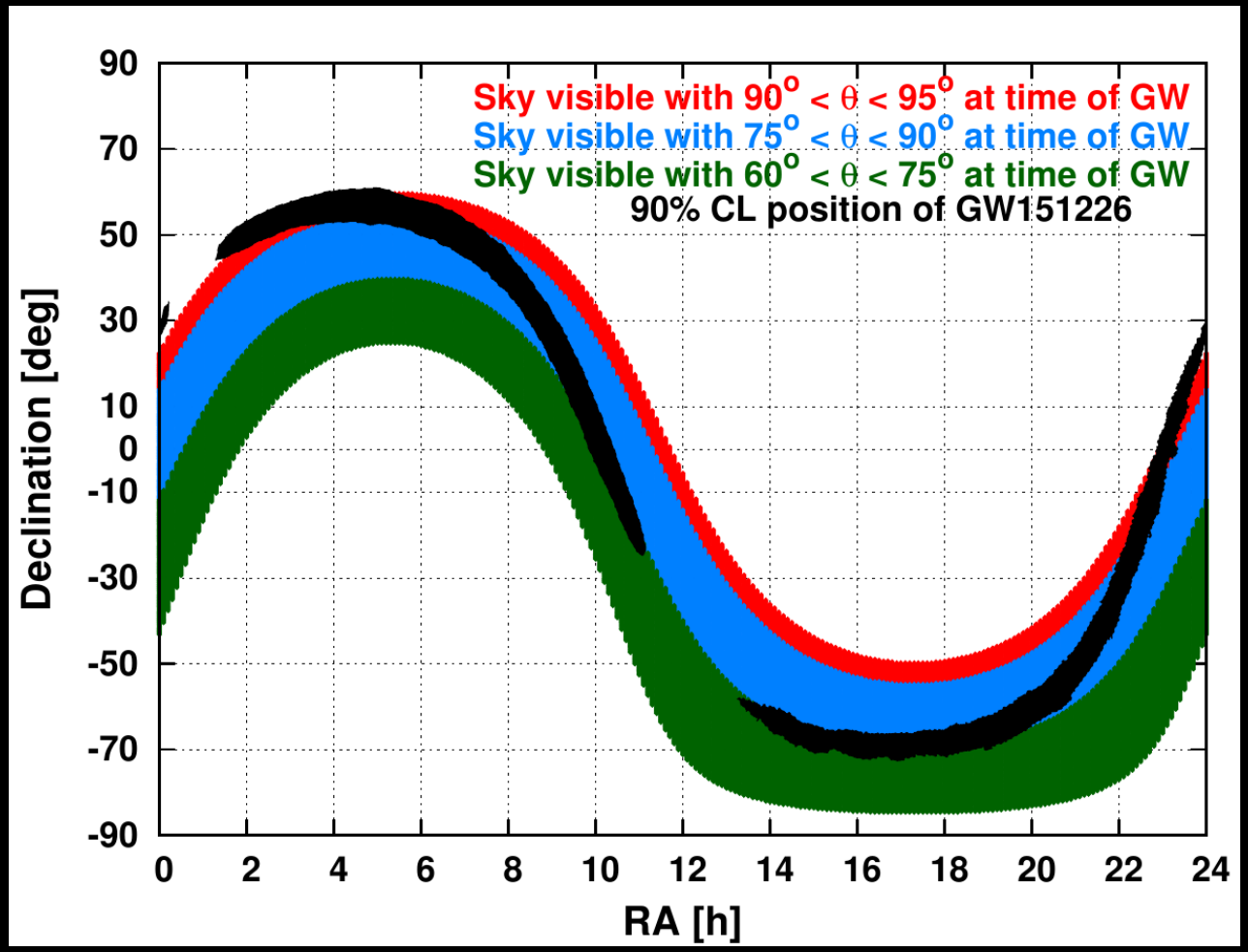
~ 3 & 1 solar masses released in the form of GW

LIGO & Virgo Collab. Phys. Rev. Lett. **116**, 061102 & 241103 (2016)



Instantaneous coverage

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



Sensitivity limited to large zenith angles =>

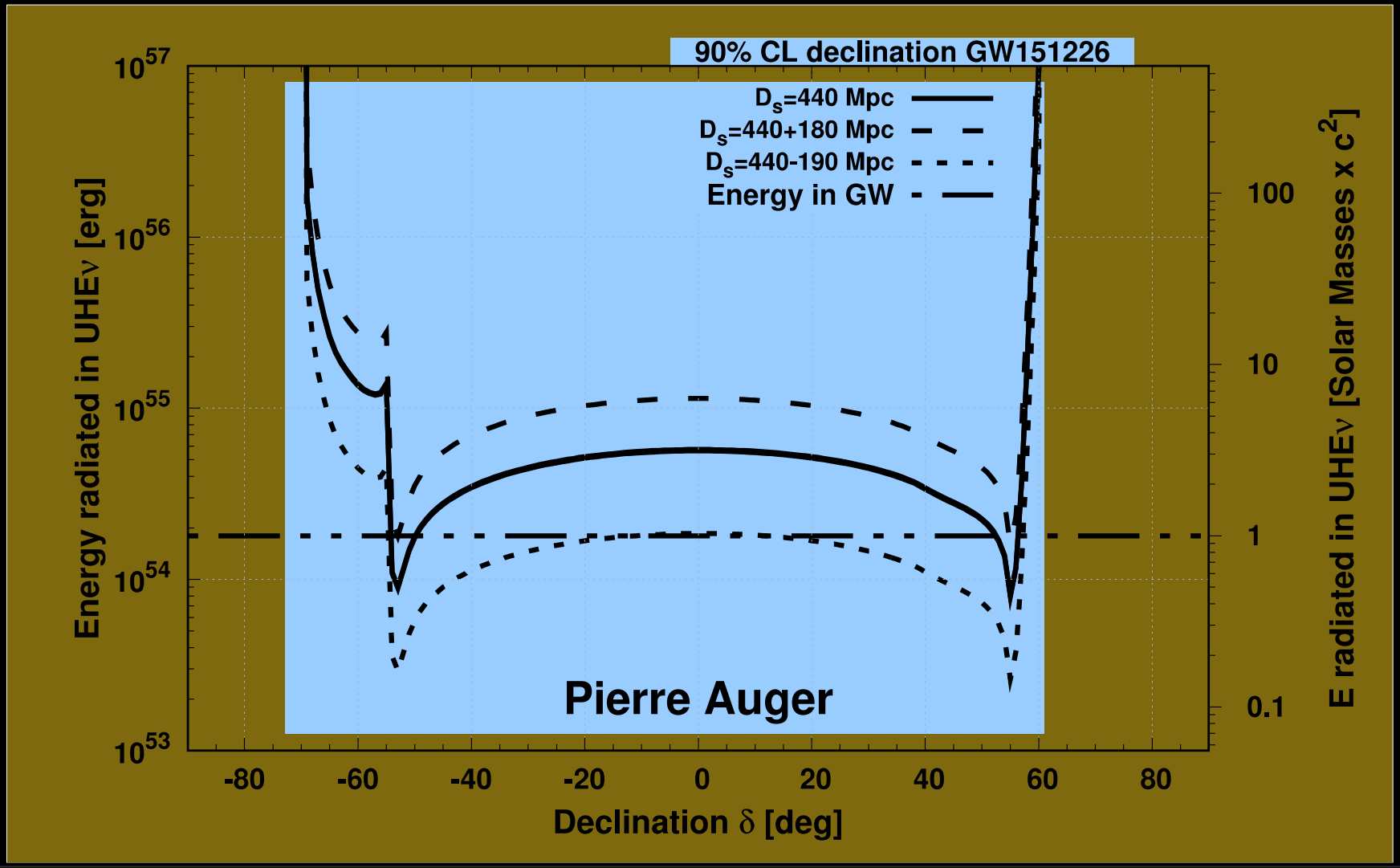
Instantaneous sky Coverage is limited

BUT: Covered region has excellent sensitivity to ES ν_τ

(Surface area >> Ice3)

Limits to radiated ν energy

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

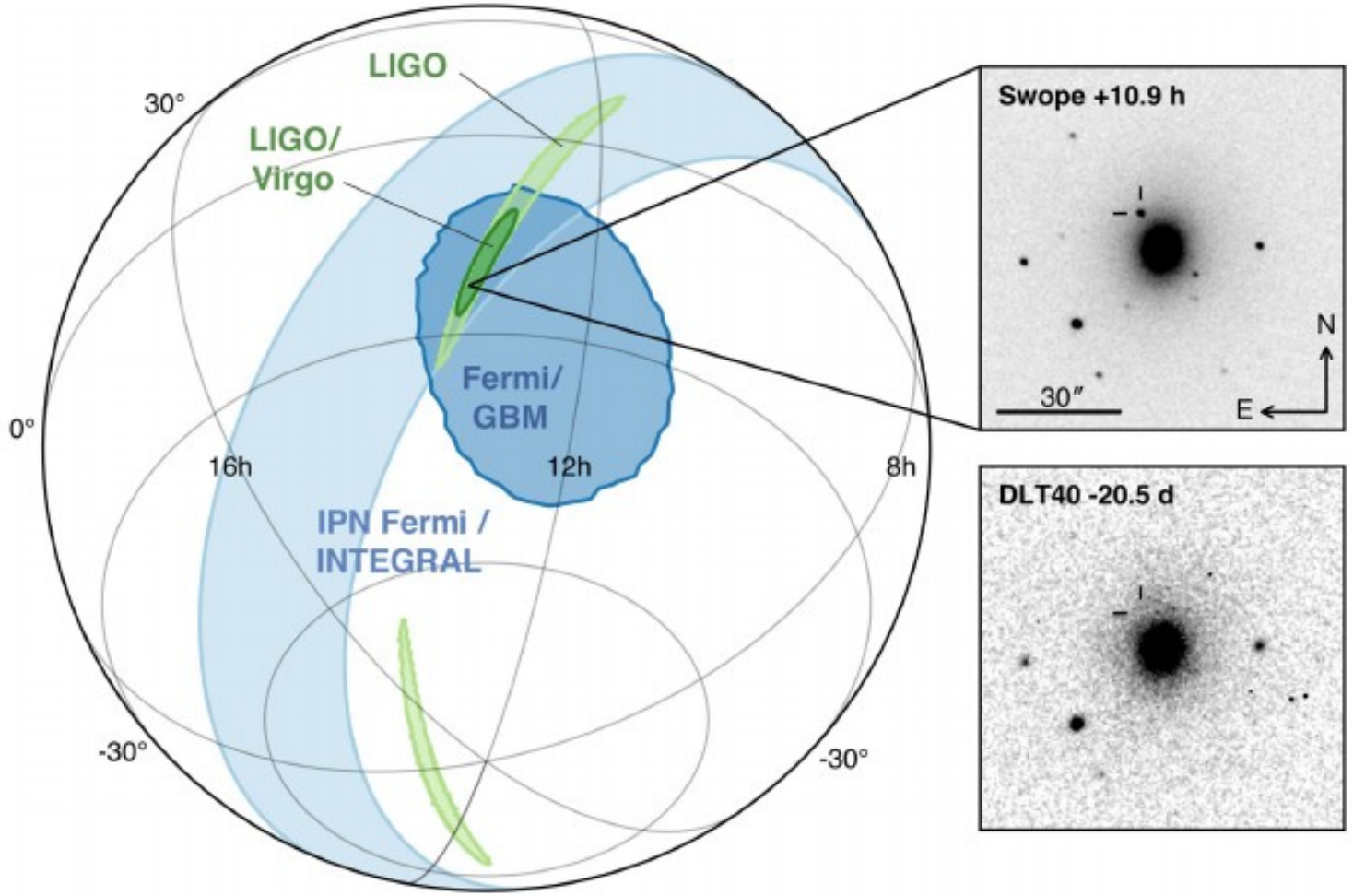


GW151226 (1 day steady): E< (0.5, 3 solar masses) for $-55^0 < \delta < 57^0$

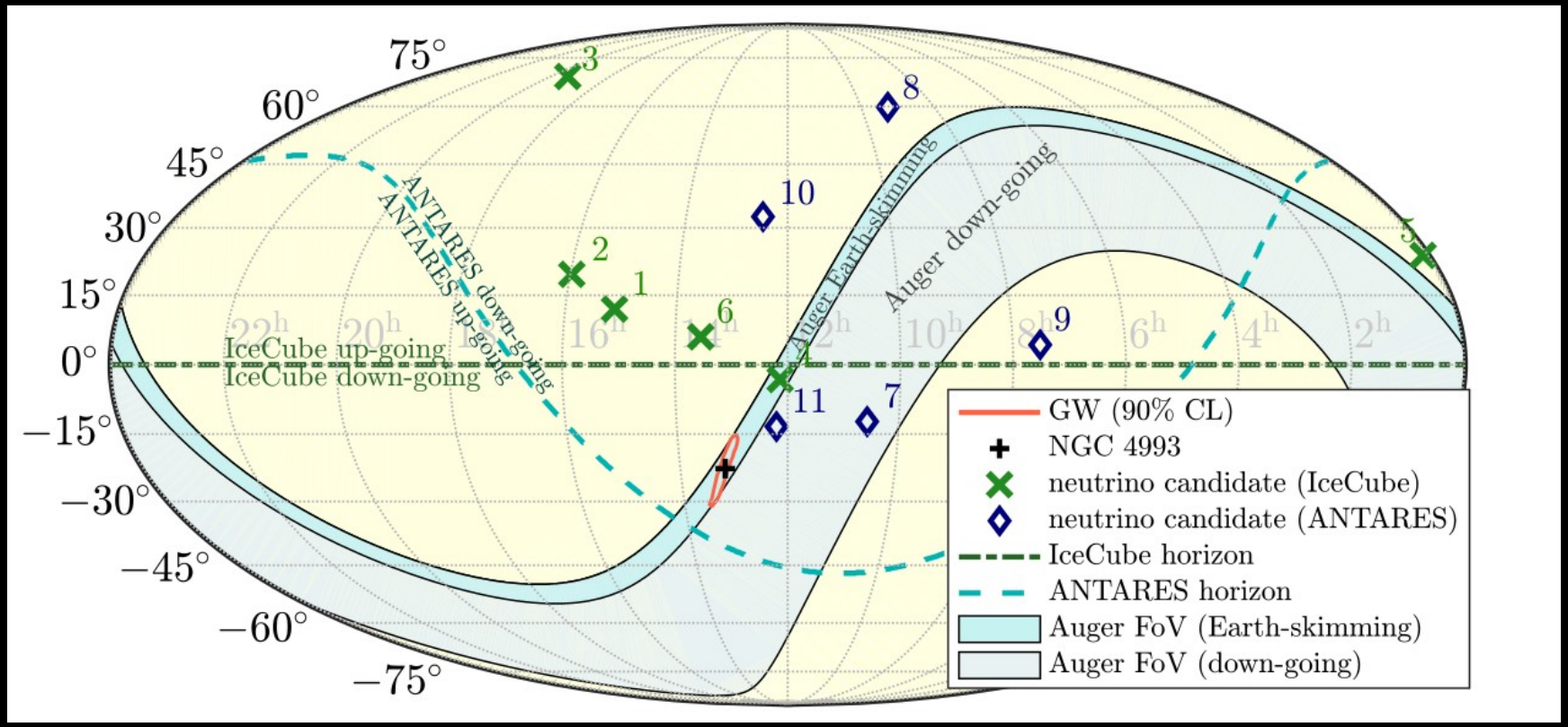
GW150914 and LVT151012 similar constraints, **GW170114**

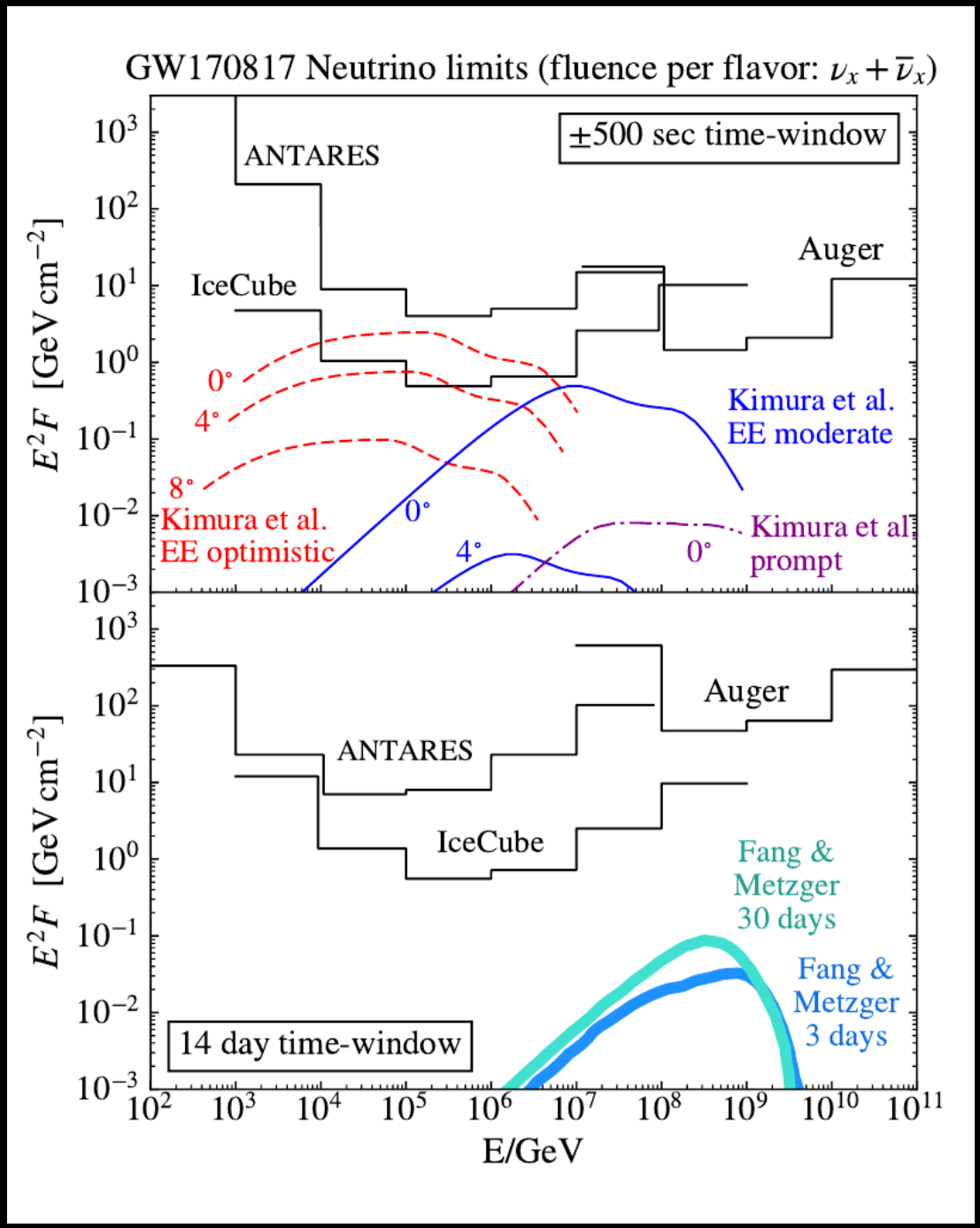
NS coalescence: A leap in Science

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20



SKY MAP 170817




GW170817 Neutrino limits (fluence per flavor: $\nu_x + \bar{\nu}_x$)
±500 sec time-window
ANTARES
IceCube
Auger
0°
4°
8°
Kimura et al.
EE optimistic
Kimura et al.
EE moderate
0°
4°
Kimura et al
prompt
0°
E^2F [GeV cm^{-2}]
Auger
ANTARES
IceCube
Fang &
Metzger
30 days
Fang &
Metzger
3 days
14 day time-window
E/GeV

Summary

The Pierre Auger Observatory has a rich program in which the IGFAE group is actively involved

I have selected recent results that are particularly relevant

Reconstruction and spectrum measurement leading to:

- The discovery of Large Scale Anisotropy
- Signs of smaller scale anisottropies: SBG
- The potential as a neutrino detector
  - Role in GW detection of BH mergers
  - Constraints of neutrino fluxes in GW170817

Thank you