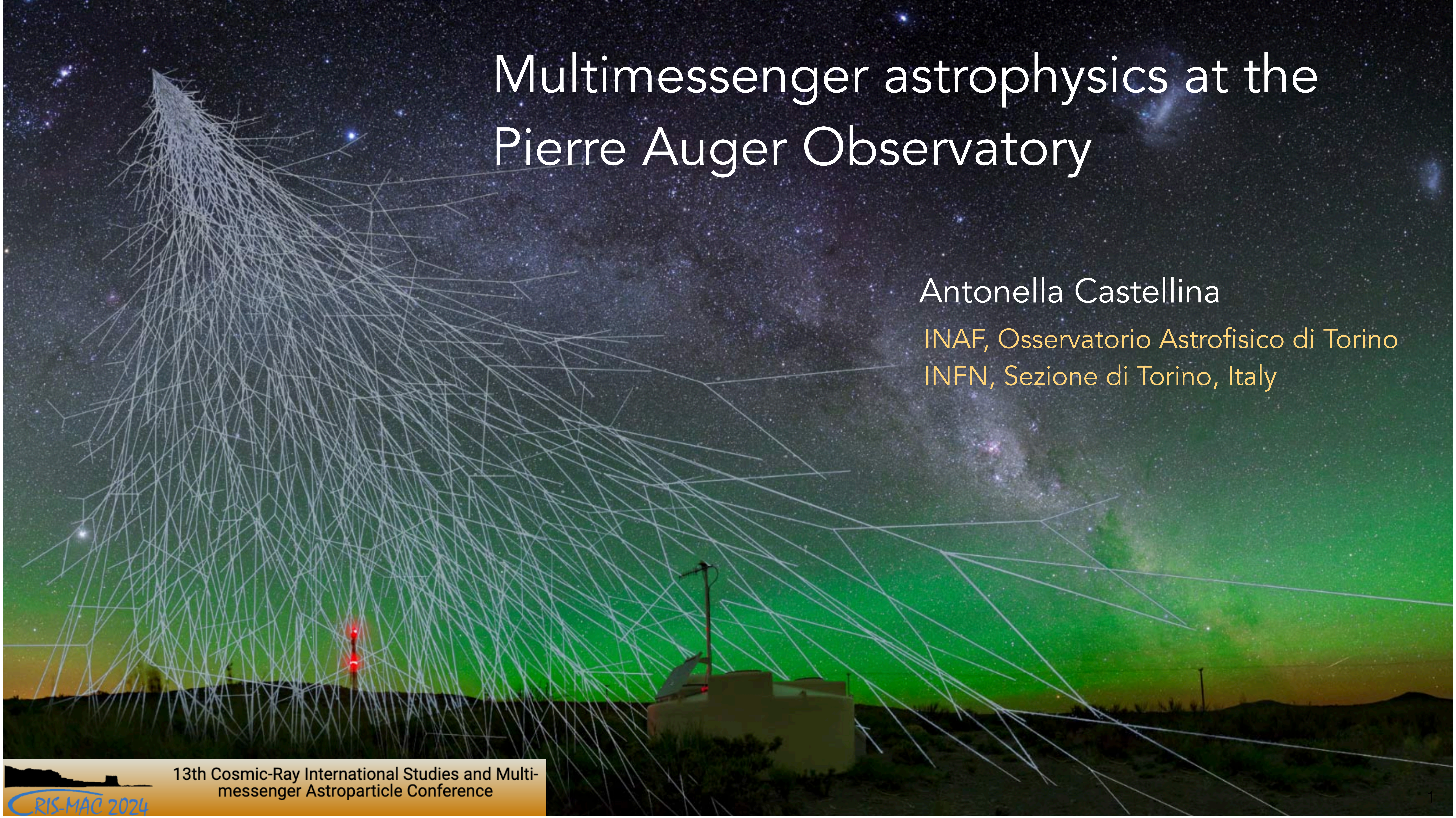
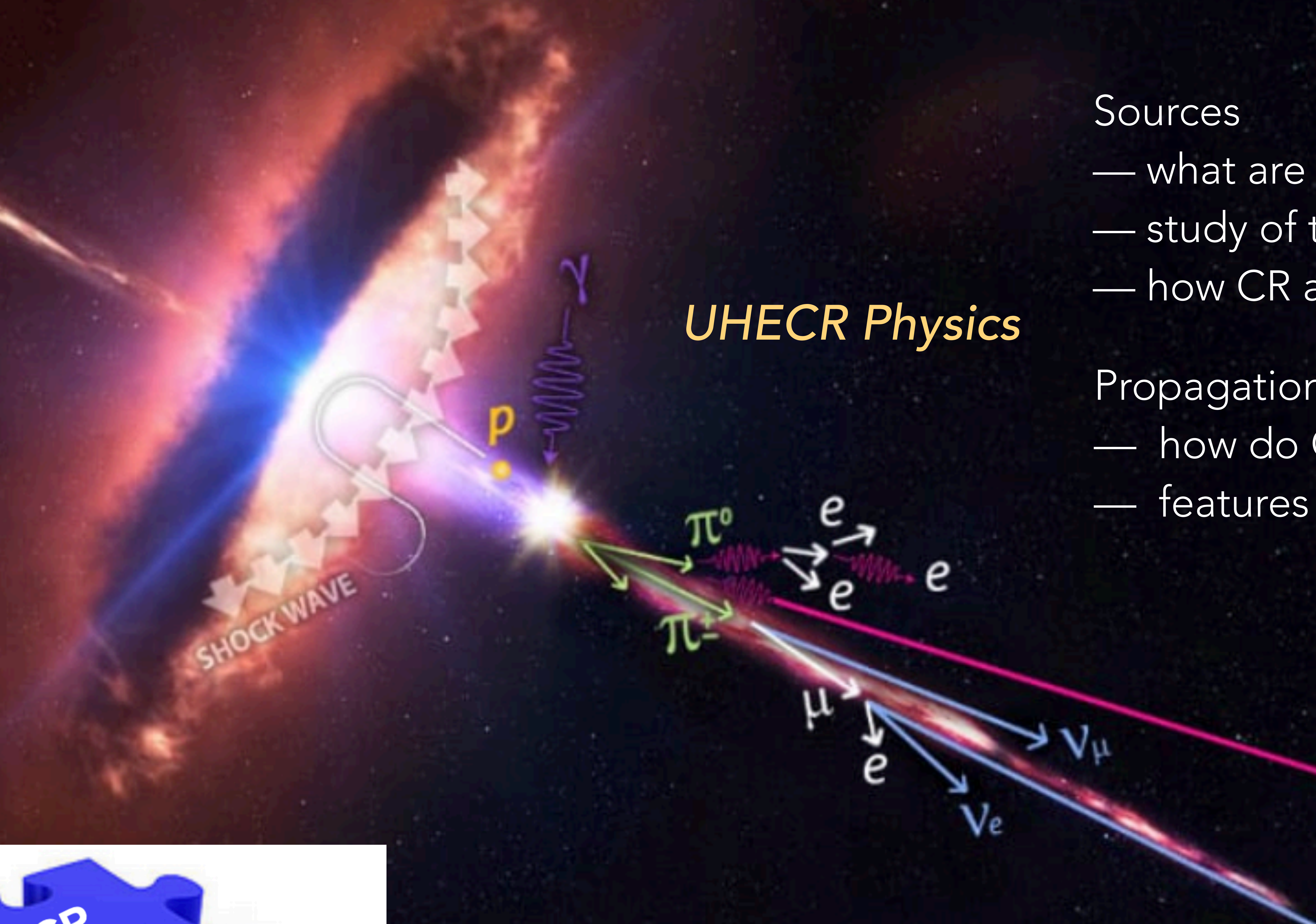


Multimessenger astrophysics at the Pierre Auger Observatory

Antonella Castellina
INAF, Osservatorio Astrofisico di Torino
INFN, Sezione di Torino, Italy

13th Cosmic-Ray International Studies and Multi-messenger Astroparticle Conference
CRIS-MAC 2024



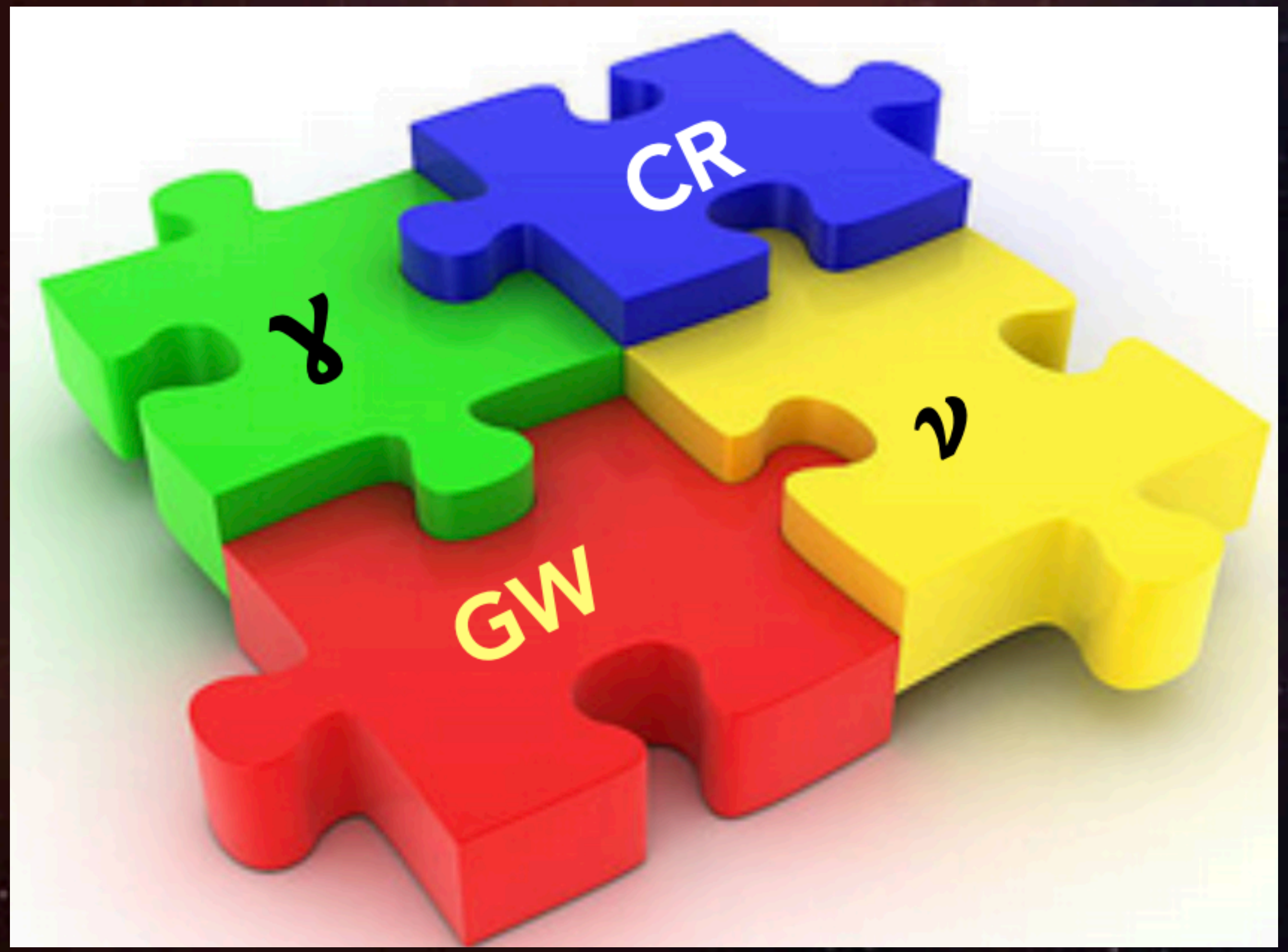
UHECR Physics

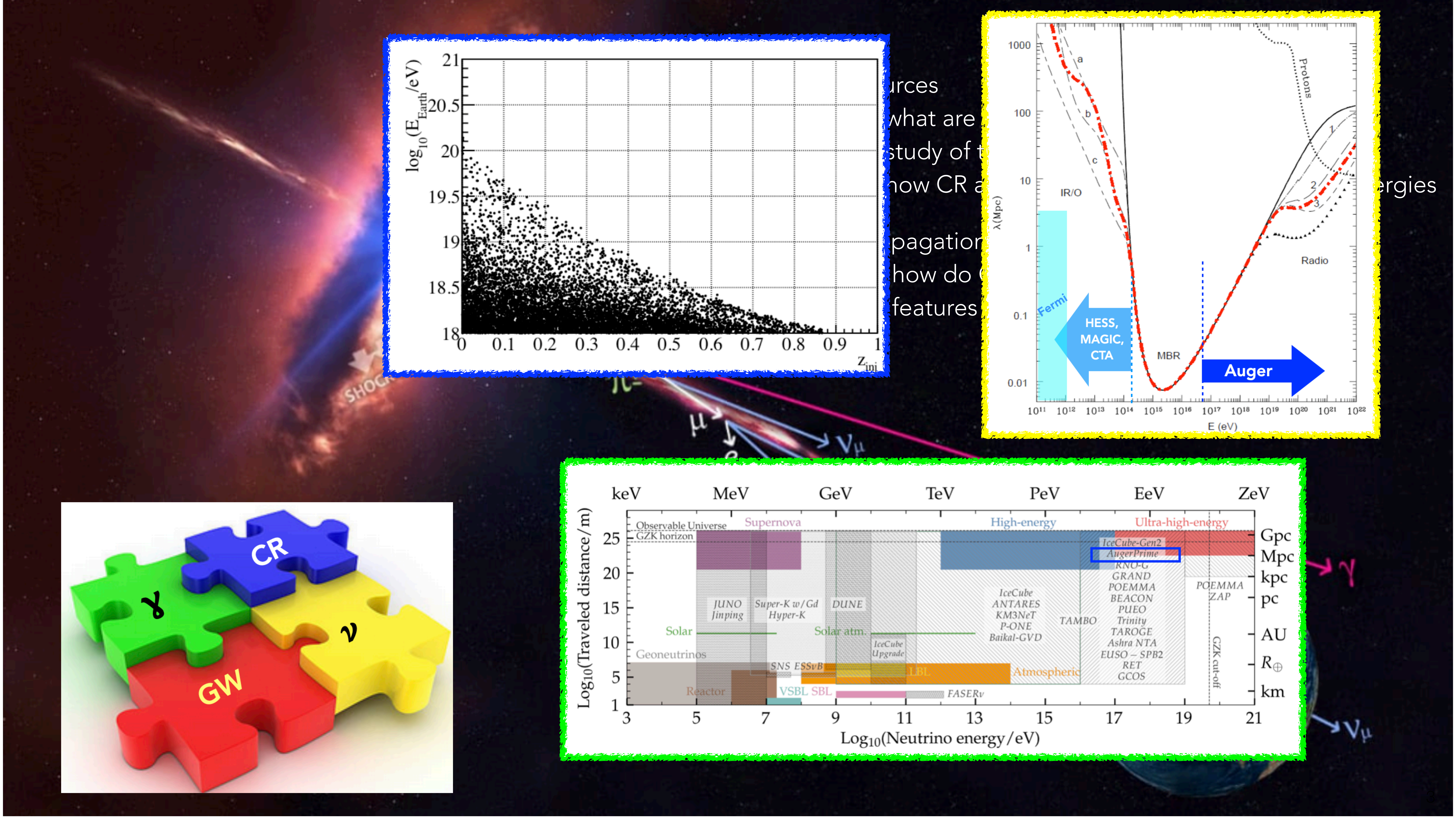
Sources
— what are they
— study of their evolution
— how CR are accelerated to such ultra-high energies

Propagation
— how do CR propagate in space?
— features of the magnetic fields

Particle Physics at UHE

Hadronic interactions beyond human-made accelerators
Particle physics beyond the Standard Model
Dark matter





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E (eV)
IR/O
MBR
Radio
Protons
Fermi
HESS, MAGIC, CTA
Auger
keV MeV GeV TeV PeV EeV ZeV
Log10(Traveled distance/m)
Log10(Neutrino energy/eV)
Observable Universe
GZK horizon
Supernova
High-energy
Ultra-high-energy
IceCube-Gen2
AugerPrime
RNO-G
GRAND
POEMMA
BEACON
PUEO
Trinity
TAROGE
Ashra NTA
EUSO – SPB2
RET
GCOS
POEMMA
ZAP
JUNO
Jinping
Super-K w/Gd
Hyper-K
DUNE
IceCube
ANTARES
KM3NeT
P-ONE
Baikal-GVD
TAMBO
Solar
Solar atm.
IceCube Upgrade
Geoneutrinos
SNS
ESSνB
LBL
Atmospheric
Reactor
VSBL
SBL
FASERν
GZK cut-off
Gpc
Mpc
kpc
pc
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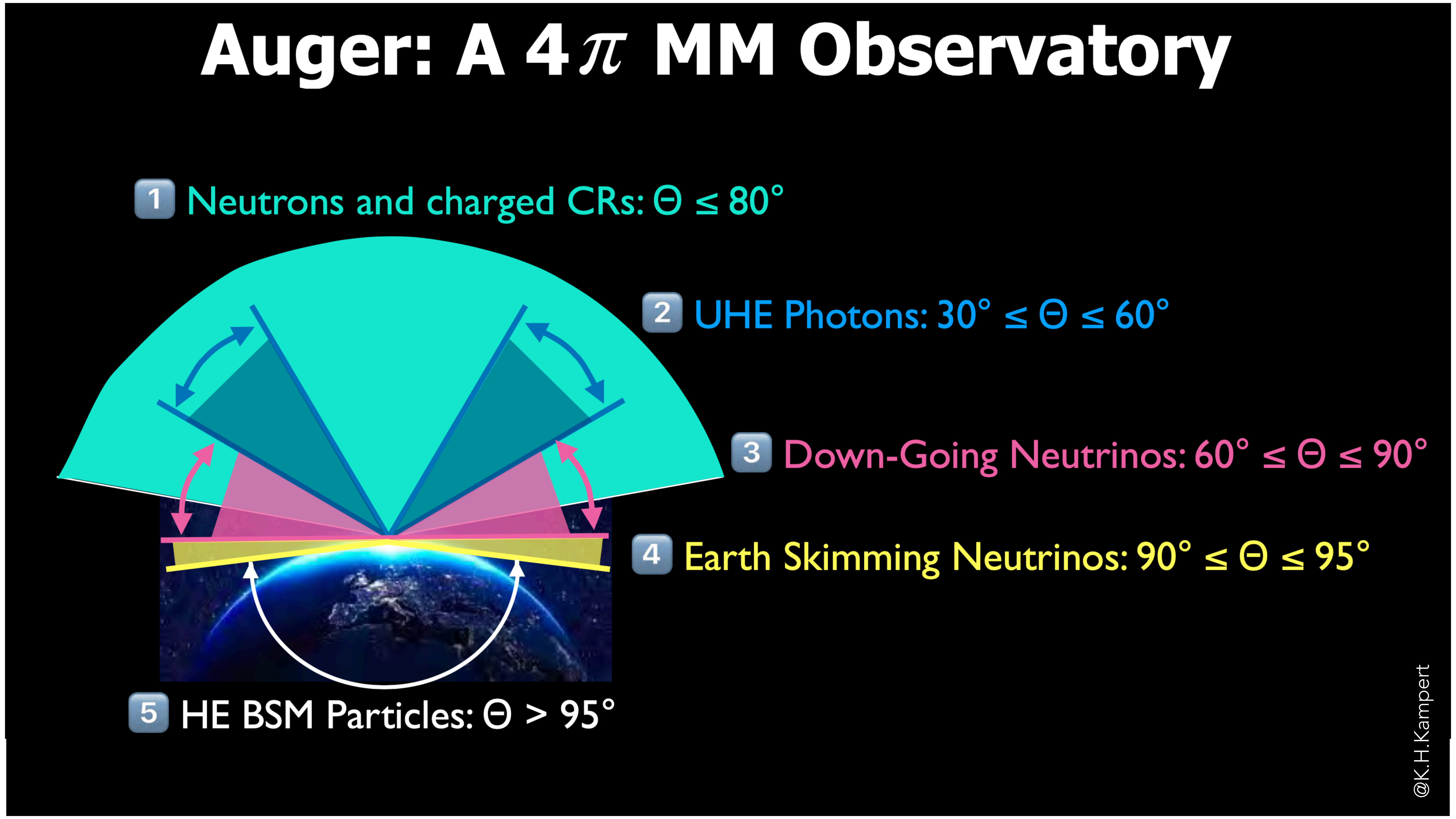
GW

Auger Observatory: measures charged UHECRs

Energy spectrum
Nuclear composition
Anisotropies
Iinformation on UHE hadronic interactions



Provides the largest exposure to UHE photons

Diffuse flux of UHE photons
Steady photon point sources
Follow-up searches in coincidence with transients

Allows studies on UHE neutrinos

Diffuse flux of UHE neutrinos
Steady neutrino point sources
Follow-up searches in coincidence with transients

…on Galactic neutron sources

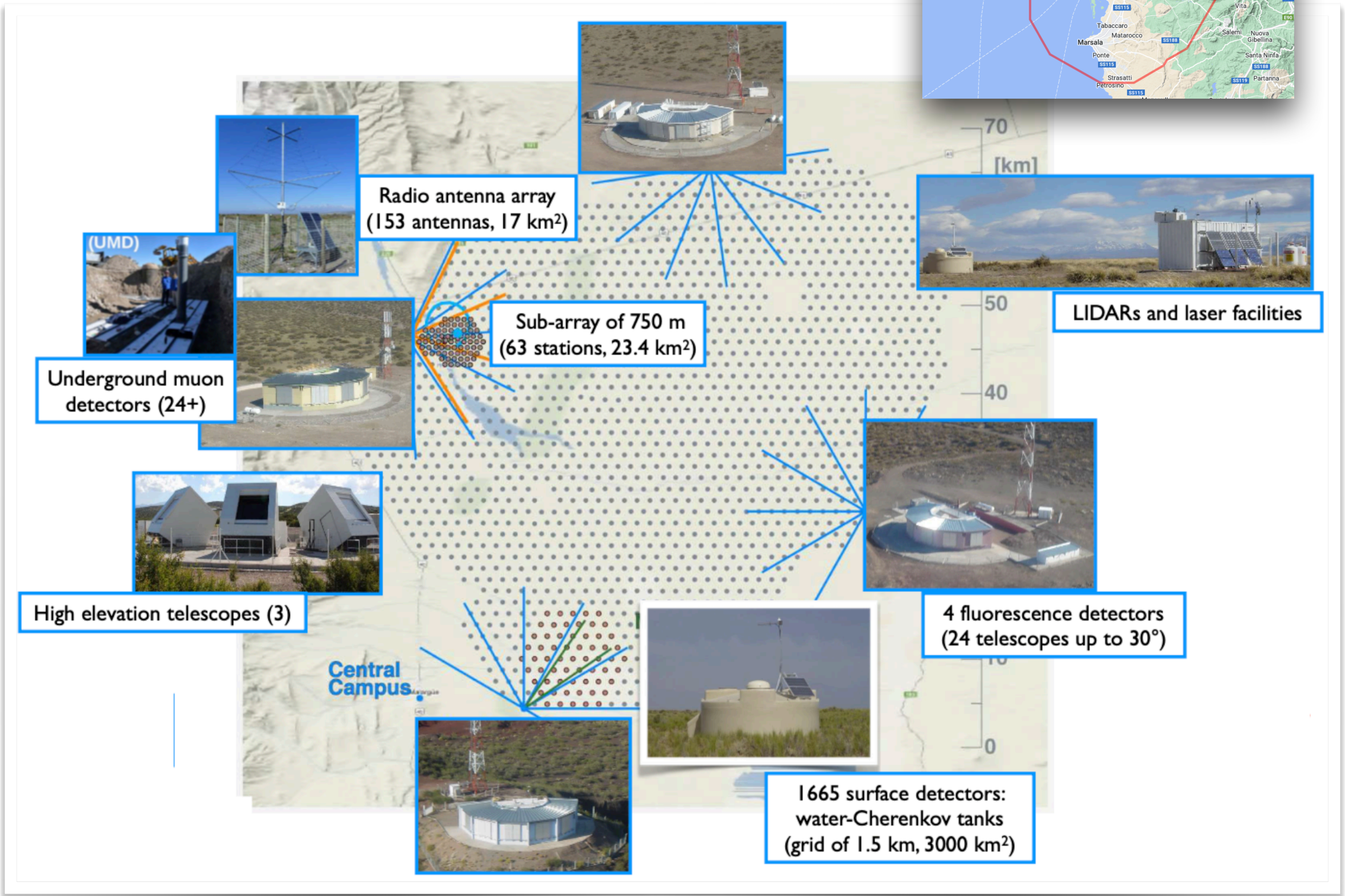
and searches on BSM effects

(not covered here, see O.Deligny talk at this conference)

The Pierre Auger Observatory

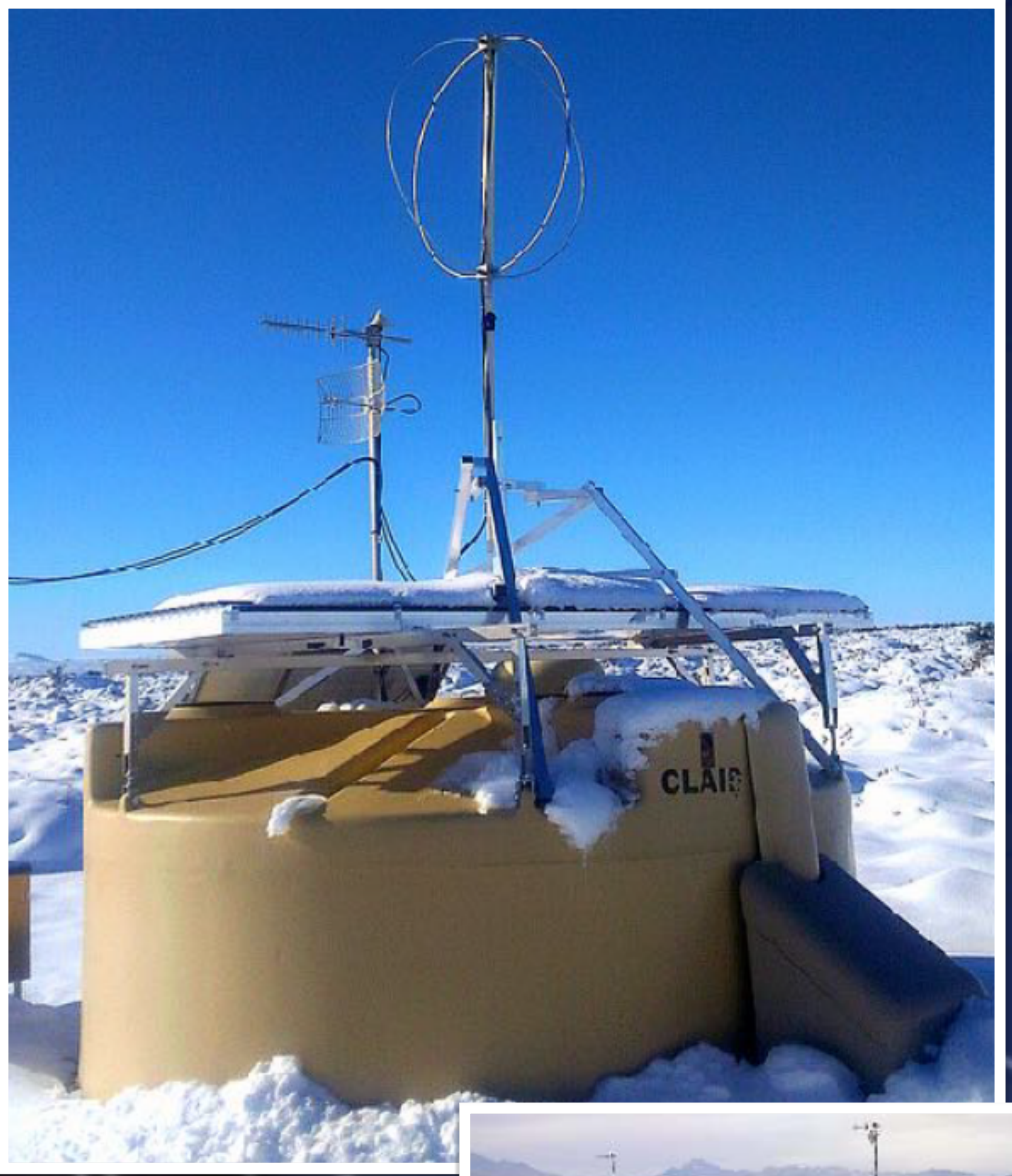
Pampa Amarilla
(Malargüe, Argentina
17 Countries
>400 members

- **1661 Water-Cherenkov stations:**
  - SD1500 : 1600, 1.5 km grid;
  - SD750: 61, 750 m grid
  - SD433: 19, 433 m grid
- **4 Fluorescence sites:**
  - 24 telescopes, 1-30^0 FoV
  - 3 High Elevation Telescopes, 30-60^0 FoV
- **Engineering arrays:**
  - AERA: 153 radio antennas
  - UMD: 24 underground mun detectors



Geolocalization: (−69.0° longitude, −35.4° latitude)

***AugerPrime**: exploiting the richness of extensive air showers*



More insight in the mass composition + increased statistics

Measure of the longitudinal development of the extensive air showers (EAS) while crossing the atmosphere
➡ ***Fluorescence telescopes***

Discrimination between the electromagnetic and muonic components of the EAS
➡ **Water Cherenkov Stations** and ***Scintillators***
➡ ***Larger dynamic range to measure high particle densities closer to the core***

Measure of the radio emission of EAS
➡ ***Radio antennas***

Direct measure of the muonic component
➡ ***Underground detectors***

Phase 1 :
data taking from 2004 to end of 2021
- ✓ Over 120, 000 km^2 sr yr for anisotropy studies
- ✓ Over 90, 000 km^2 sr yr for spectrum studies

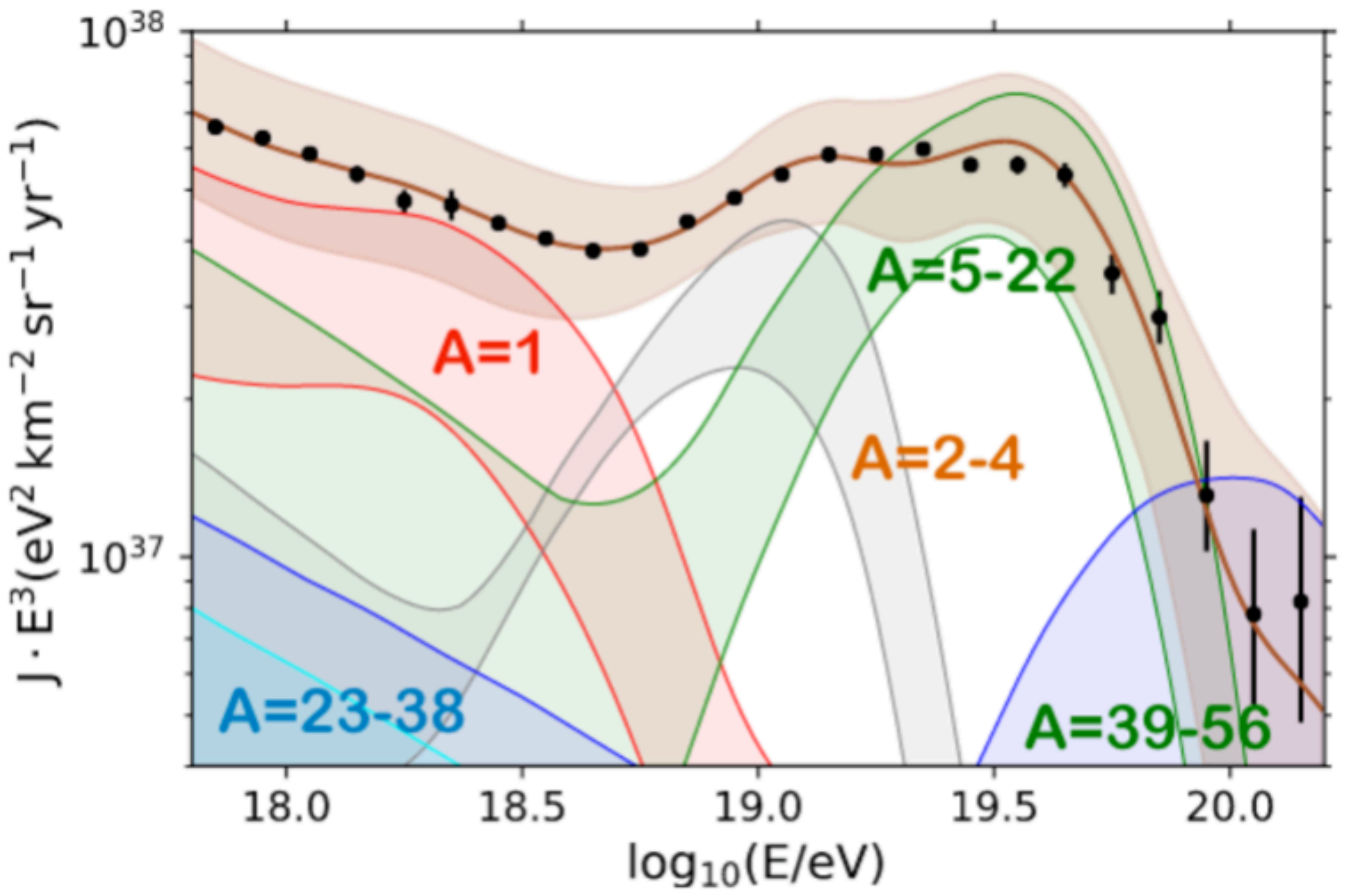
…2022-2024
transition period (commissioning) to AugerPrime

Phase 2 - the AugerPrime upgrade
Data taking from 2025 to >2035…
- ✓ + 40, 000 km^2 sr yr
- ✓ Multi-hybrid events : FD, SD, SSD, RD, UMD

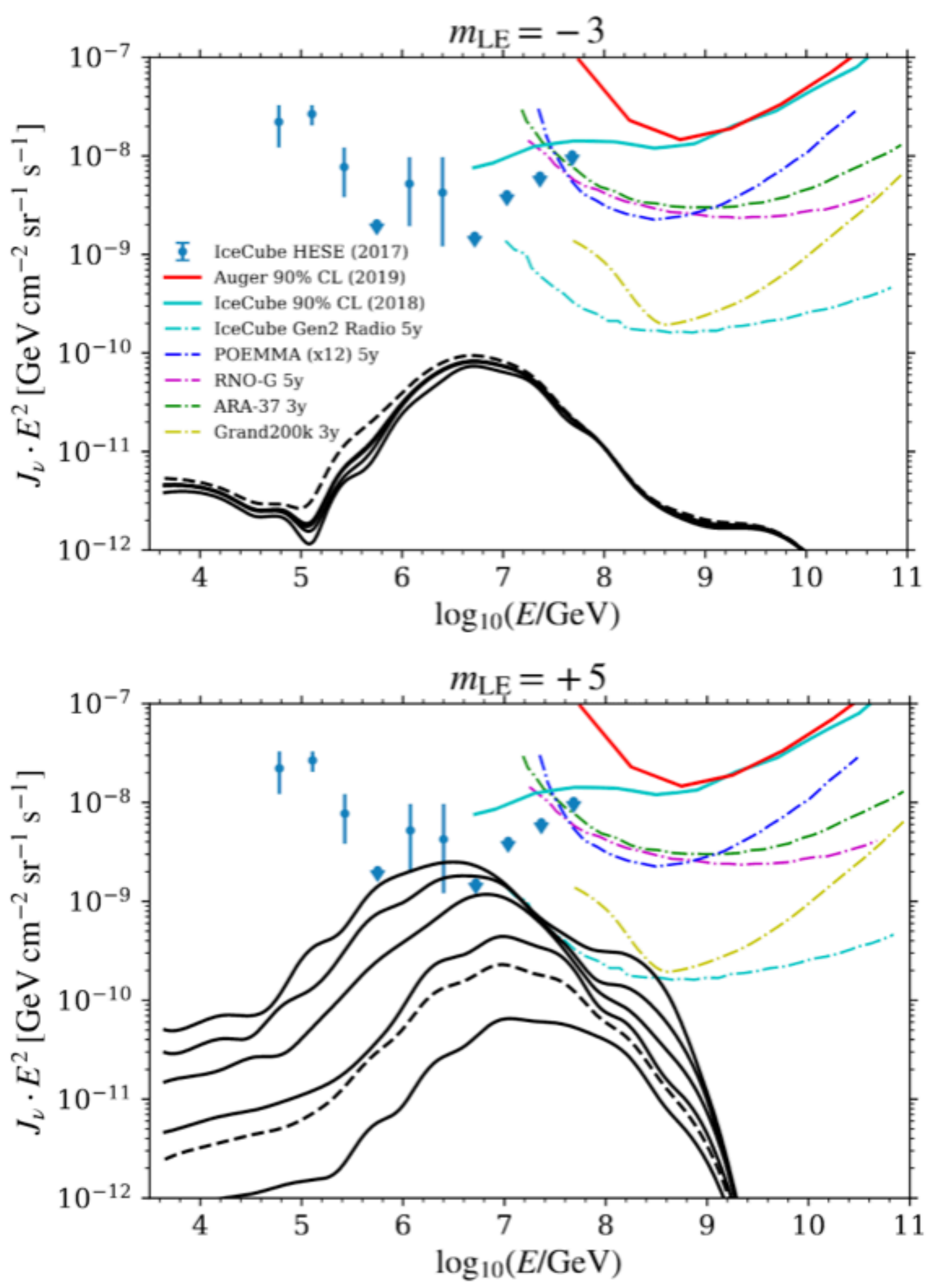
performing hybrid measurements and applying new analysis techniques

Astrophysical interpretation (energy spectrum+mass composition)

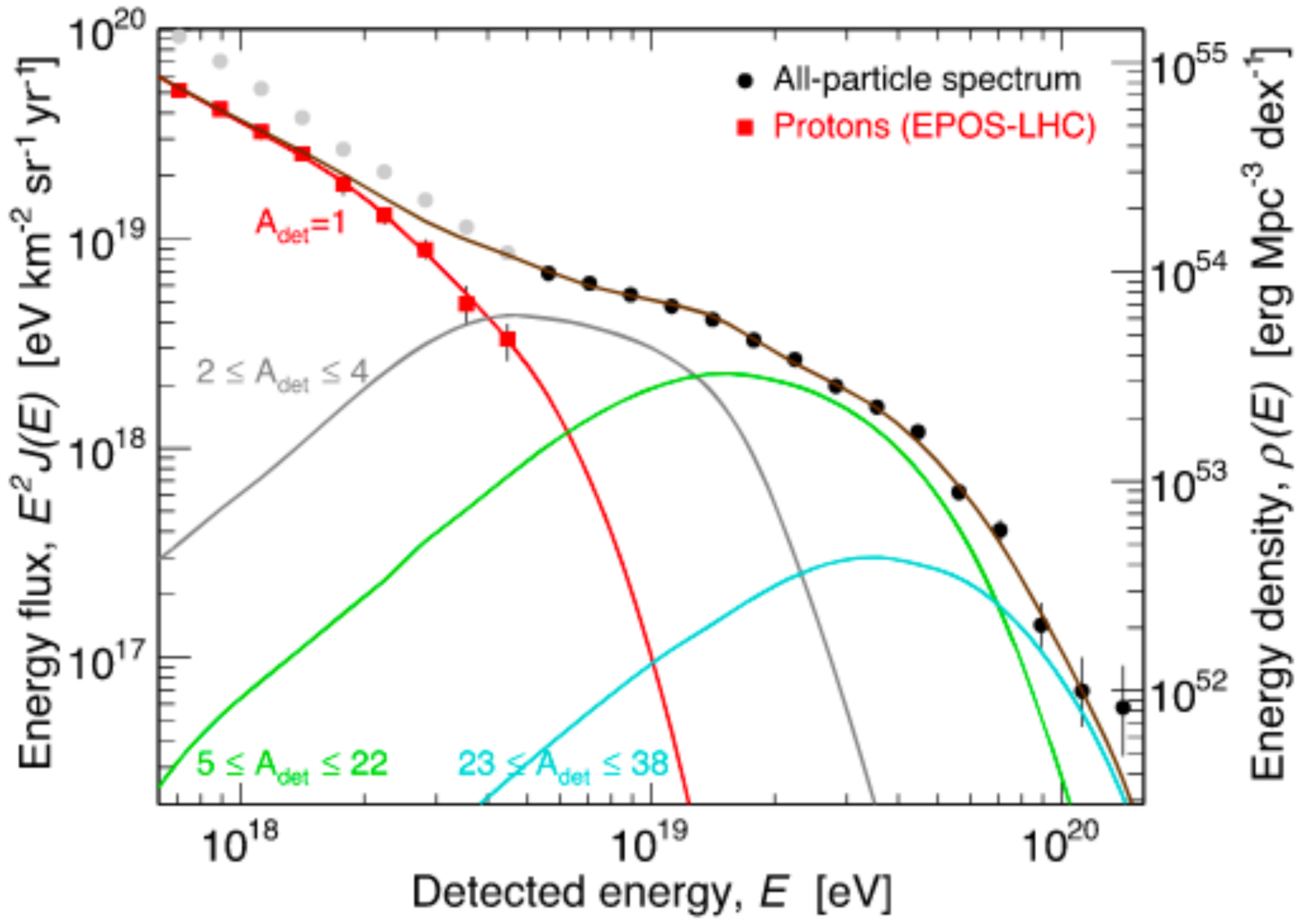
Basic scenario:
— 2 populations of EG identical sources, uniformly distributed
— power law injected energy spectrum + rigidity cutoff
— ***propagation only*** (no in-source interactions considered)



Auger Coll., JCAP05 (2023) 024



More refined scenario:
— one population only
— **in-source interactions +propagation**



Luce Q. et al., ApJ 936 (2022) 62
Unger M. et al., PRD92 (2015) 123001

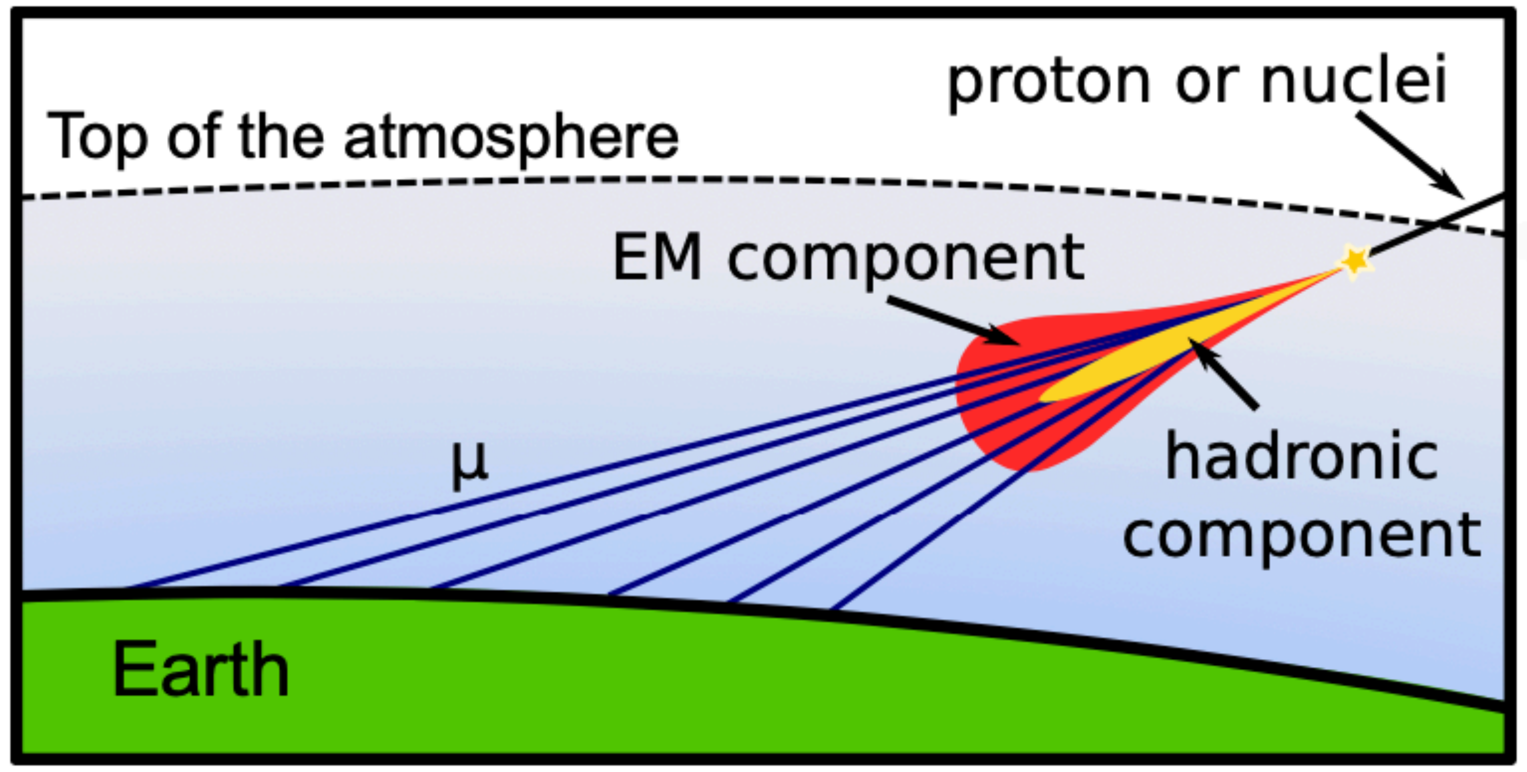
In all cases the observed energy spectrum and composition at Earth is best described by

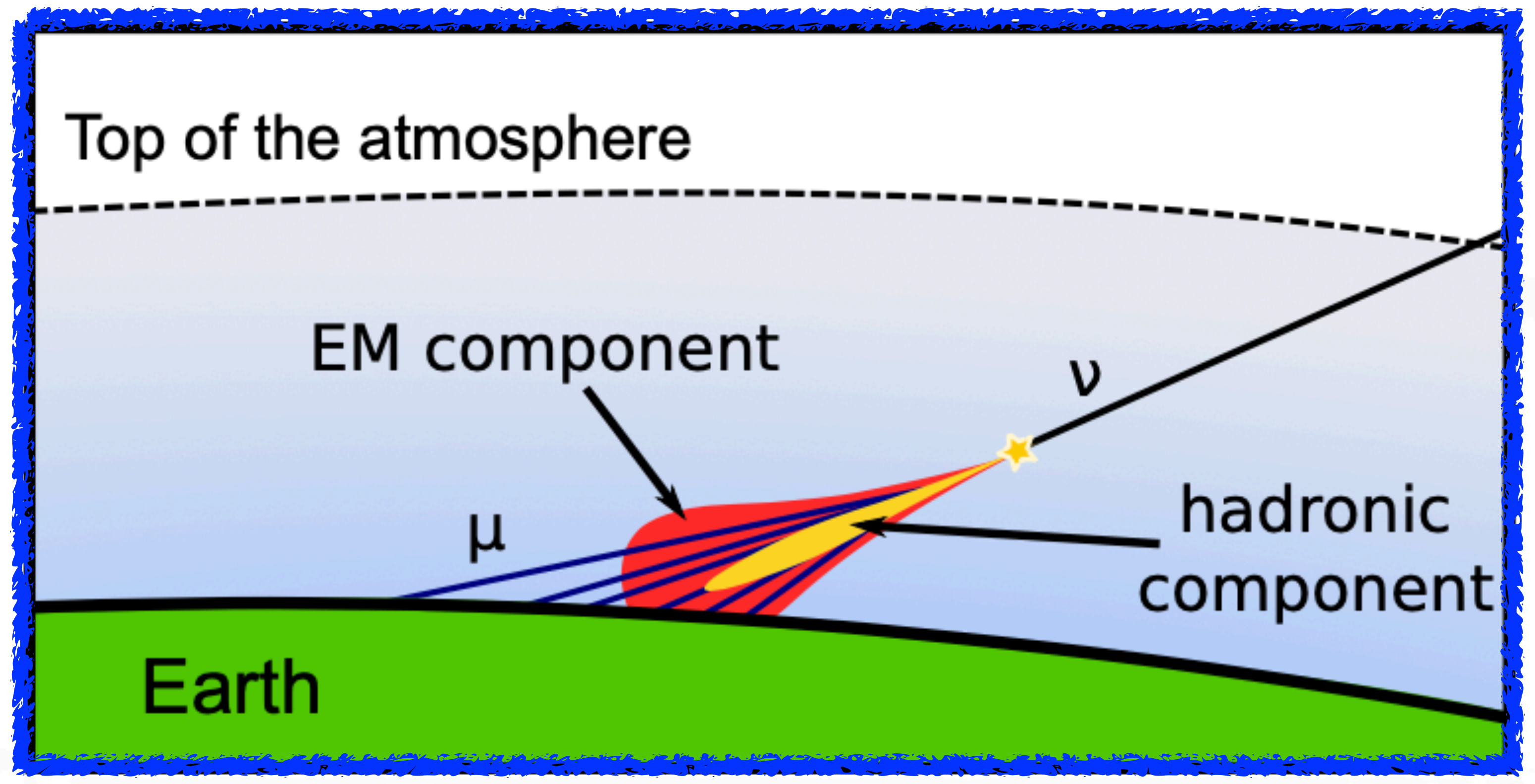
1/ a hard HE component with low rigidity cutoff
2/ a soft LE component with unconstrained rigidity cutoff
3/ a (possible) additional component

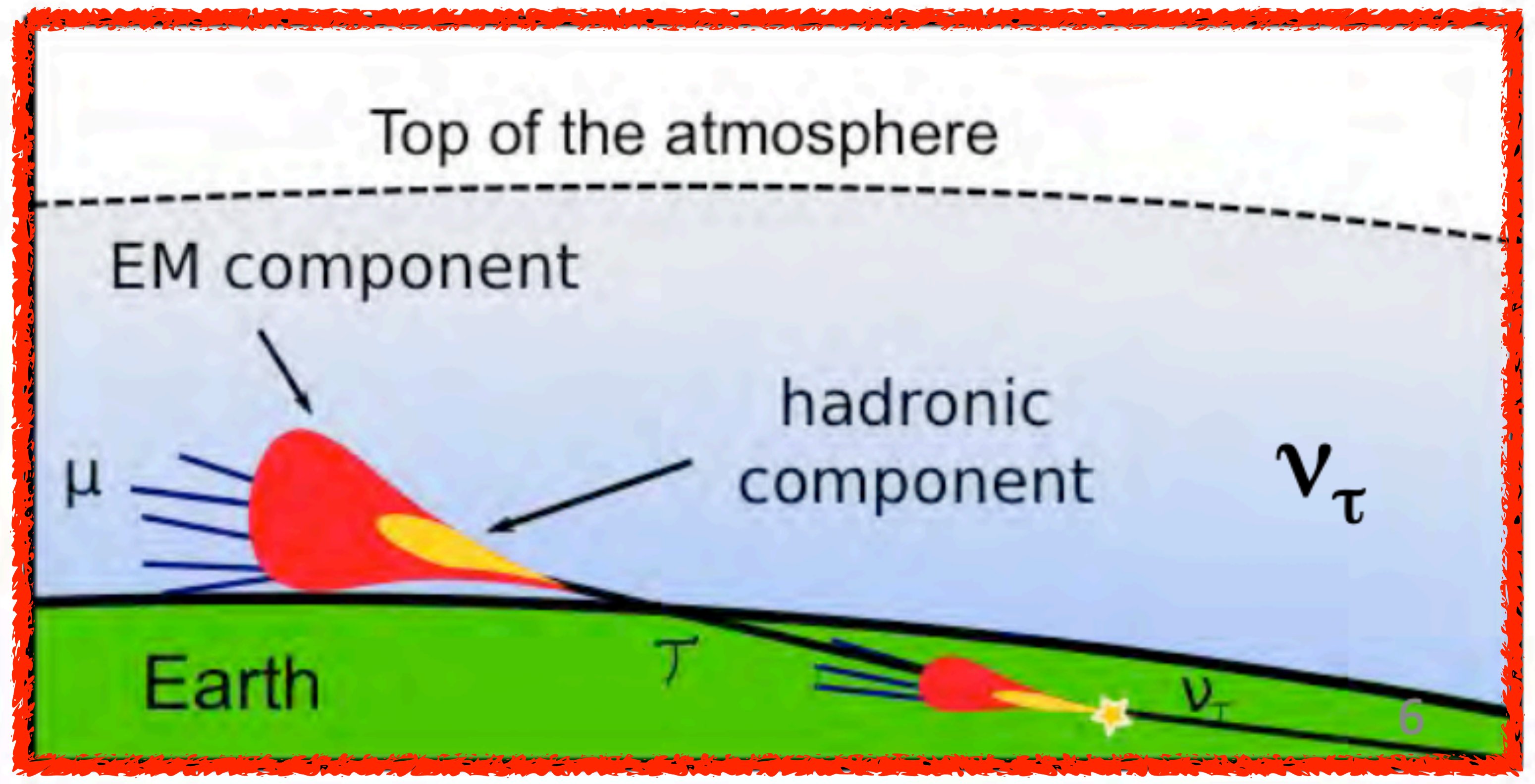
Composition getting heavier
Cutoff mostly due to source effects rather than GZK

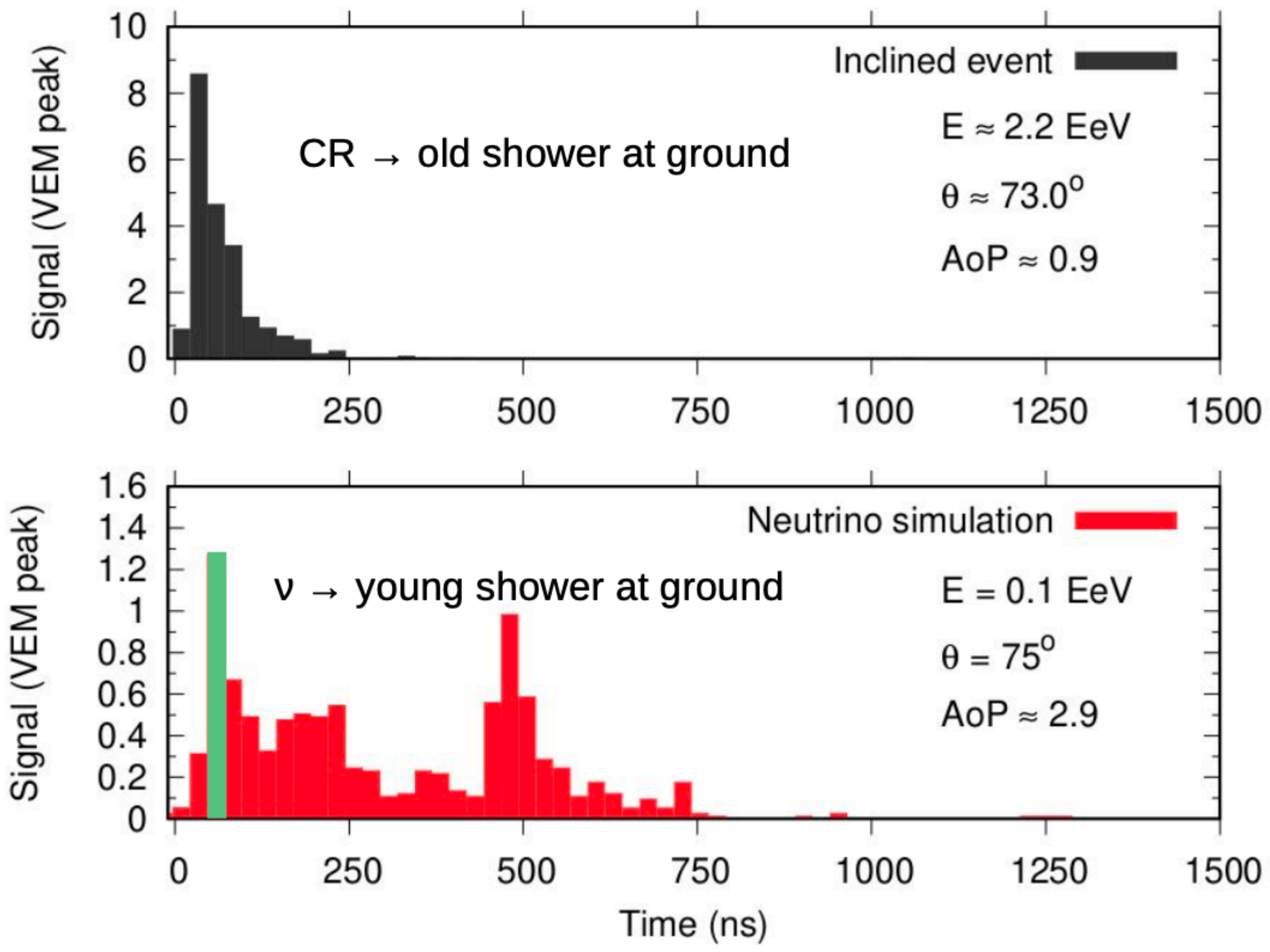
Much reduced flux of cosmogenic neutrinos and photons

Detecting neutrinos in Auger







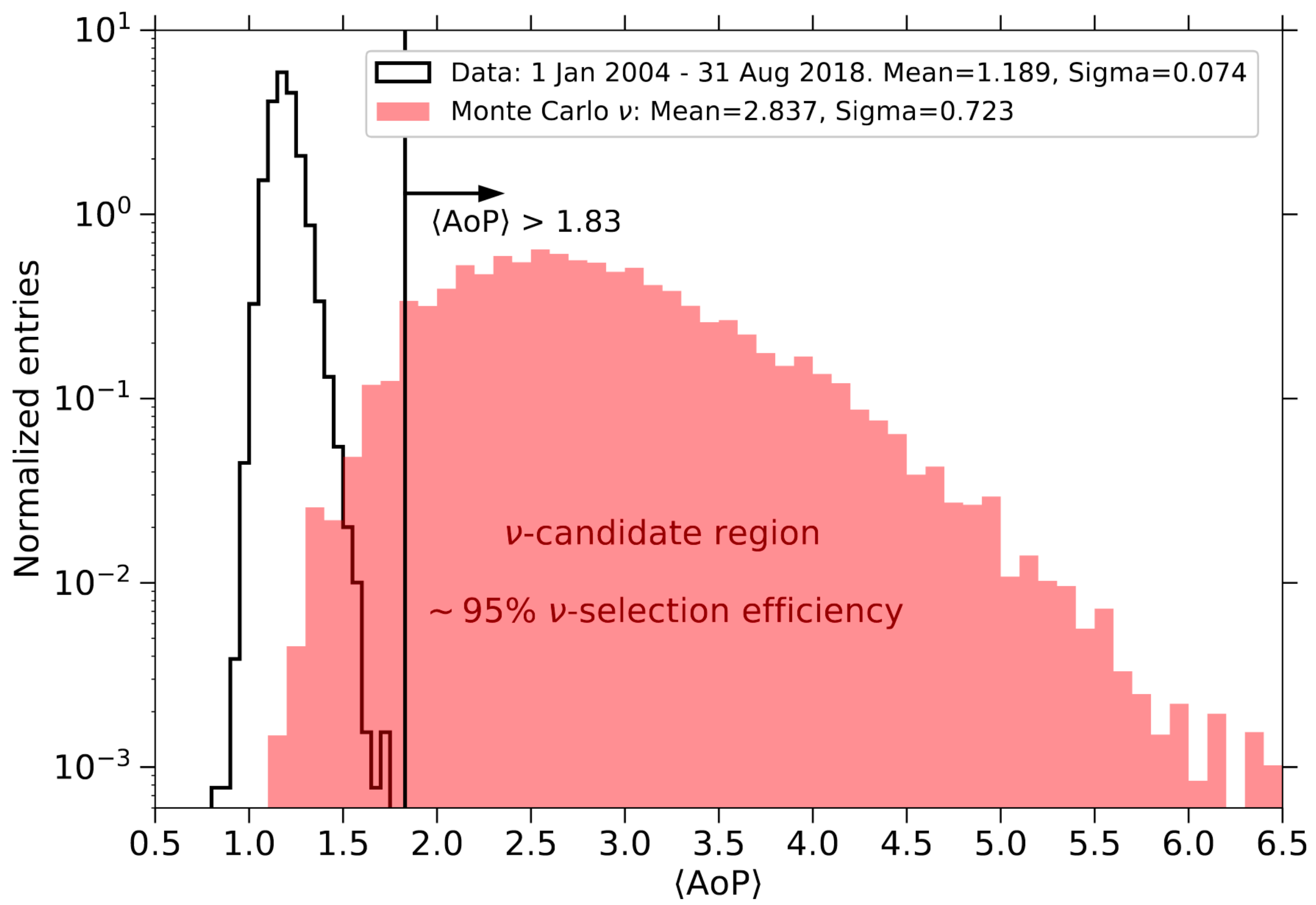


Neutrino-induced air showers:

- deep showers
- em+μ component at ground

They can be identified by

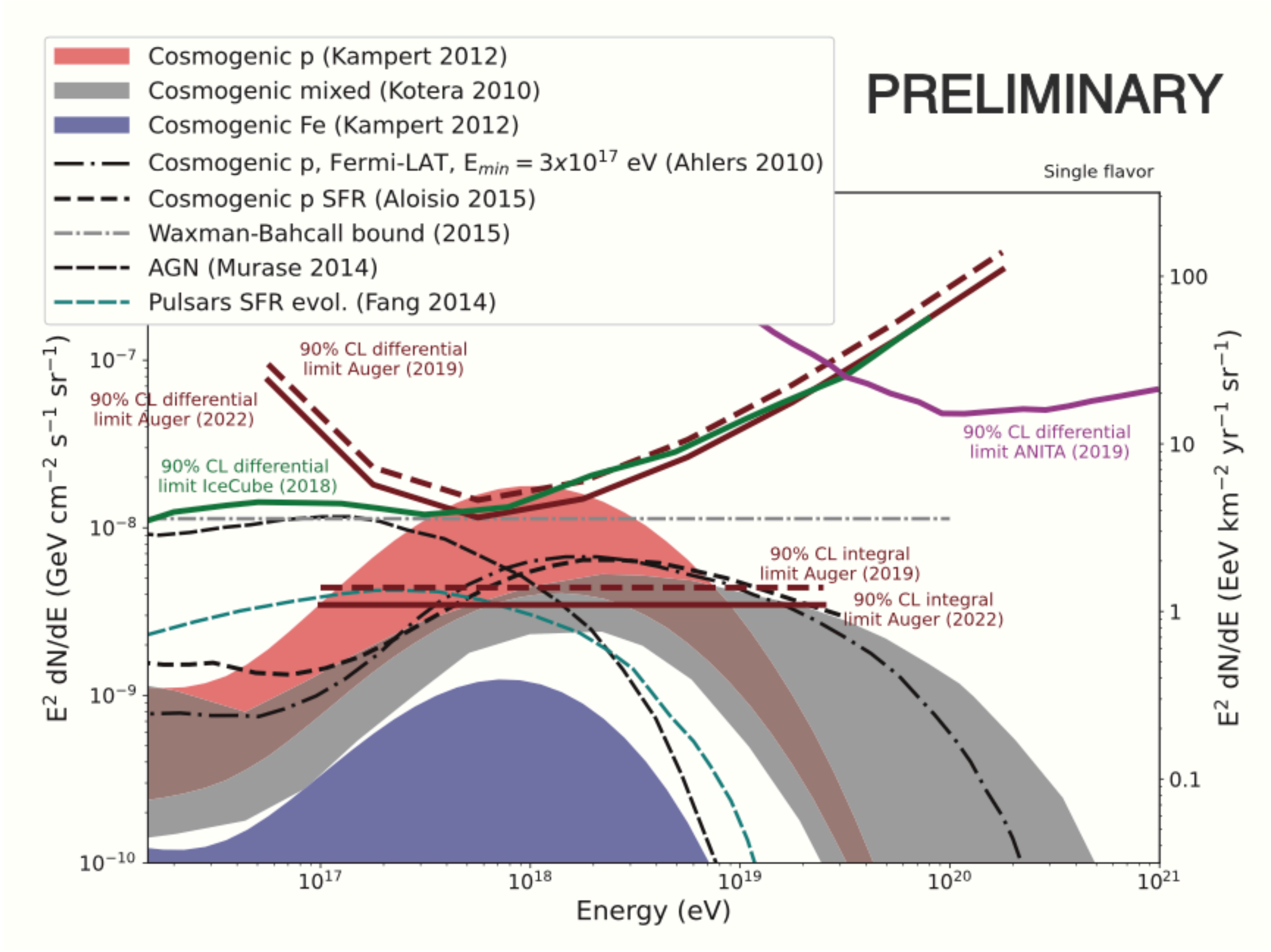
- selecting inclined showers
- with large electromagnetic component
- Large Area over Peak (~1 for muonic showers)



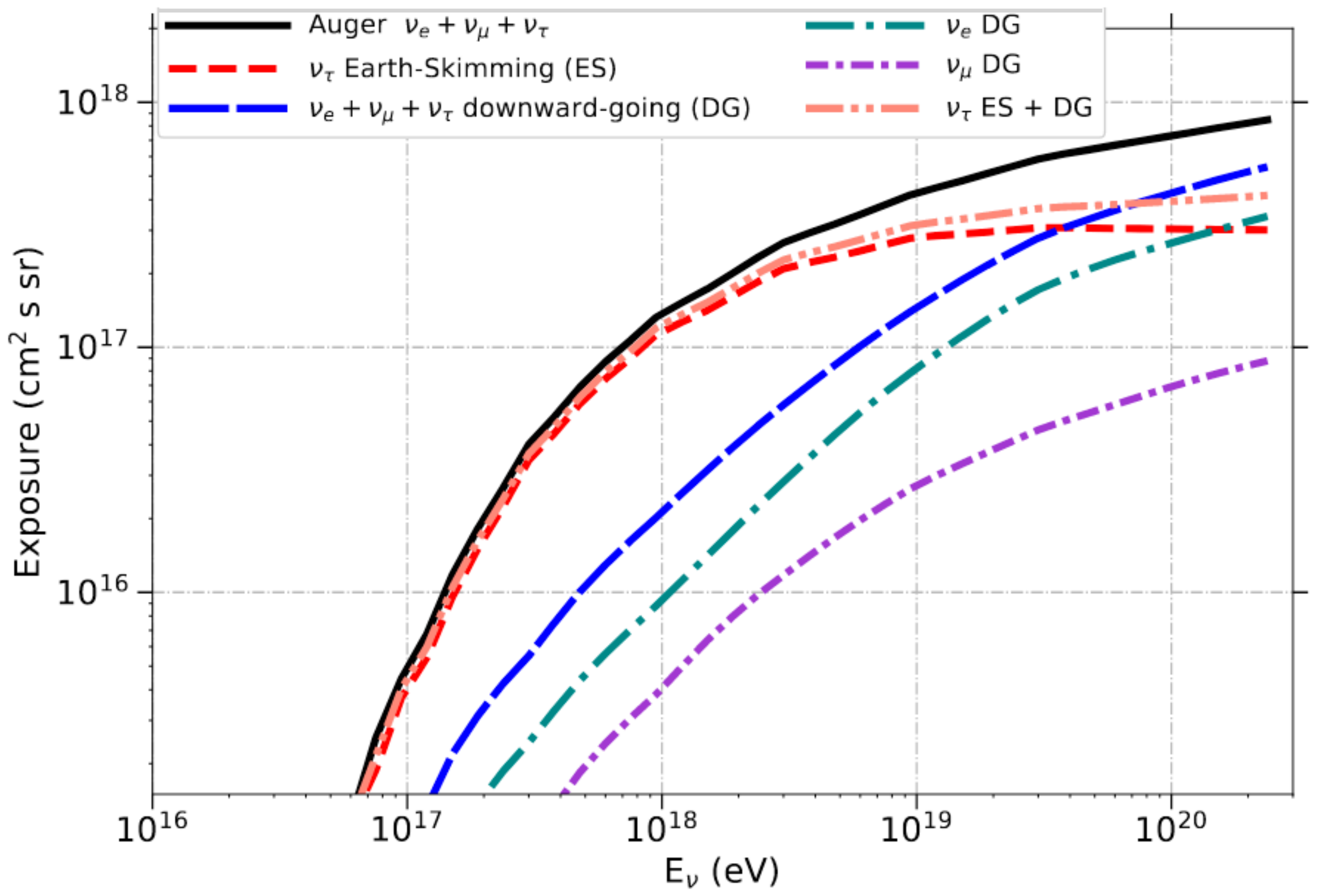
Among inclined showers we select

- Earth-skimming (ES) : 90^0-95^0
- Downgoing at high angle (DGH): 75^0-90^0
- Downgoing at low angle (DGL): 60^0-75^0

Search for a diffuse flux of neutrinos



Energy (eV)



Relative contribution of channels and flavours

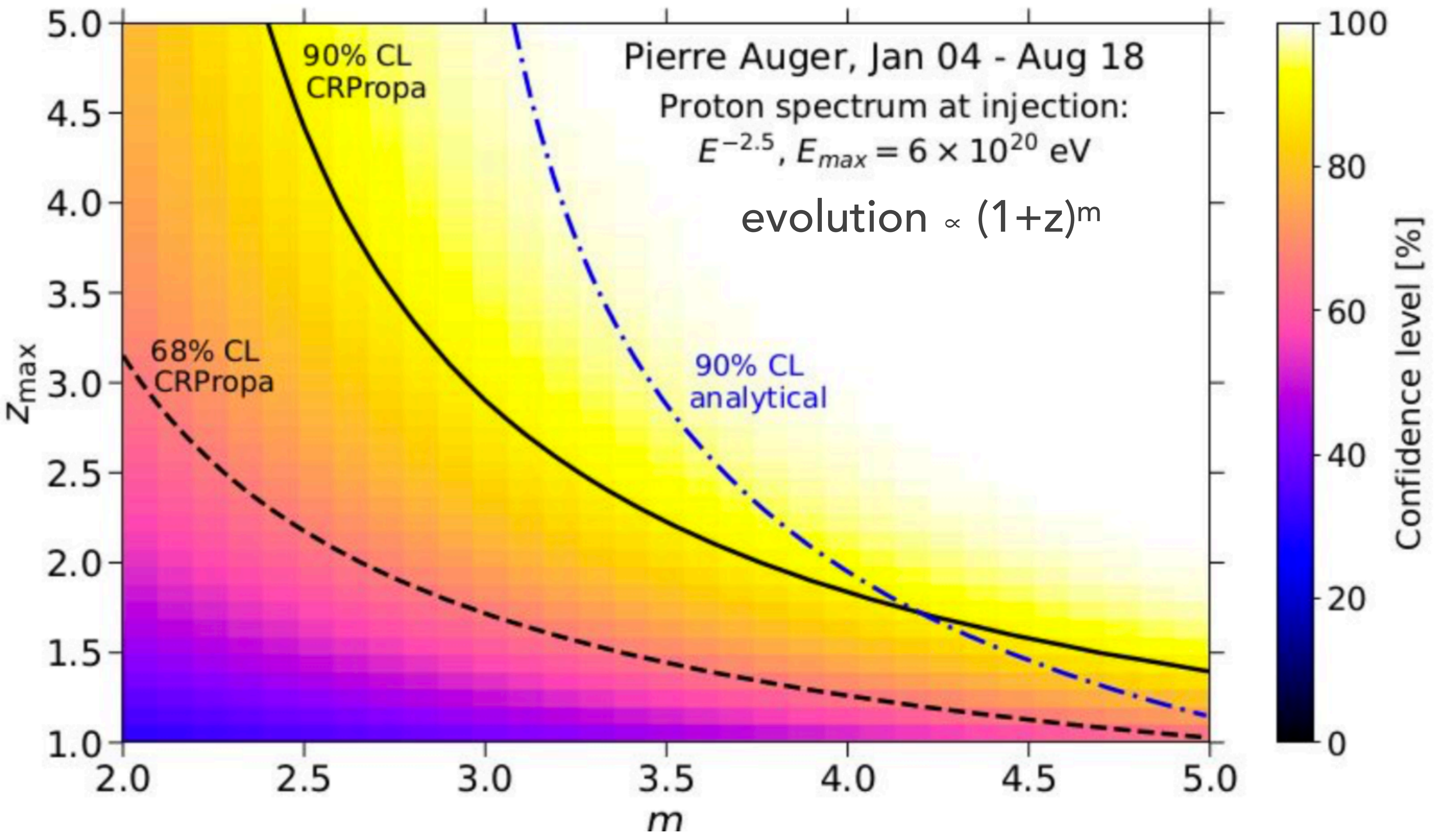
ES	79%
DGH	18%
DGL	3%

ν_τ	86%
ν_e	10%
ν_μ	4%

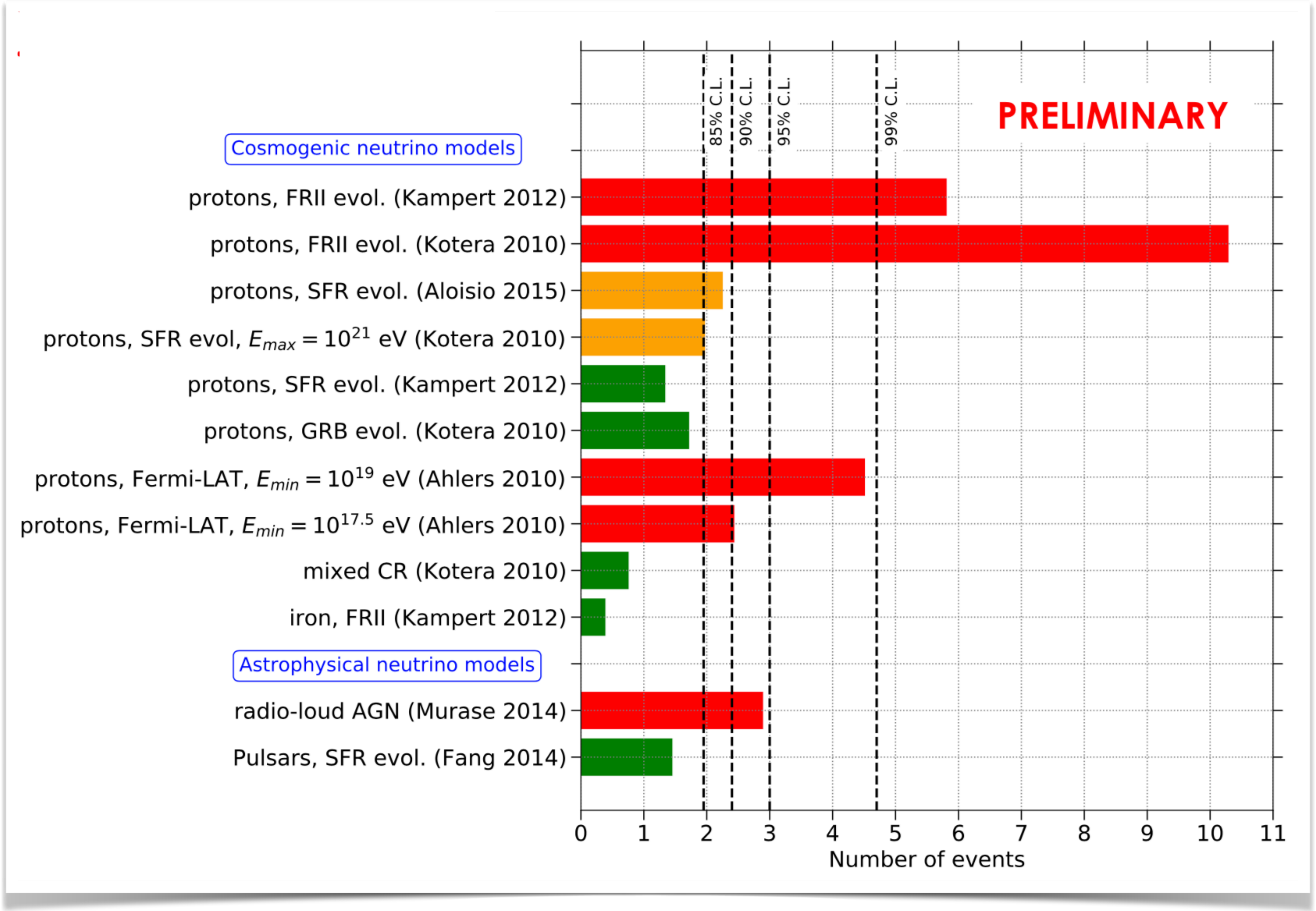
➡️No candidates found; best sensitivity slightly below 10^{18} eV
➡️Background very low, sensitivity limited by exposure

Auger Coll., JCAP 10 (2019) 022
UHECR2022

Constraints to neutrino models

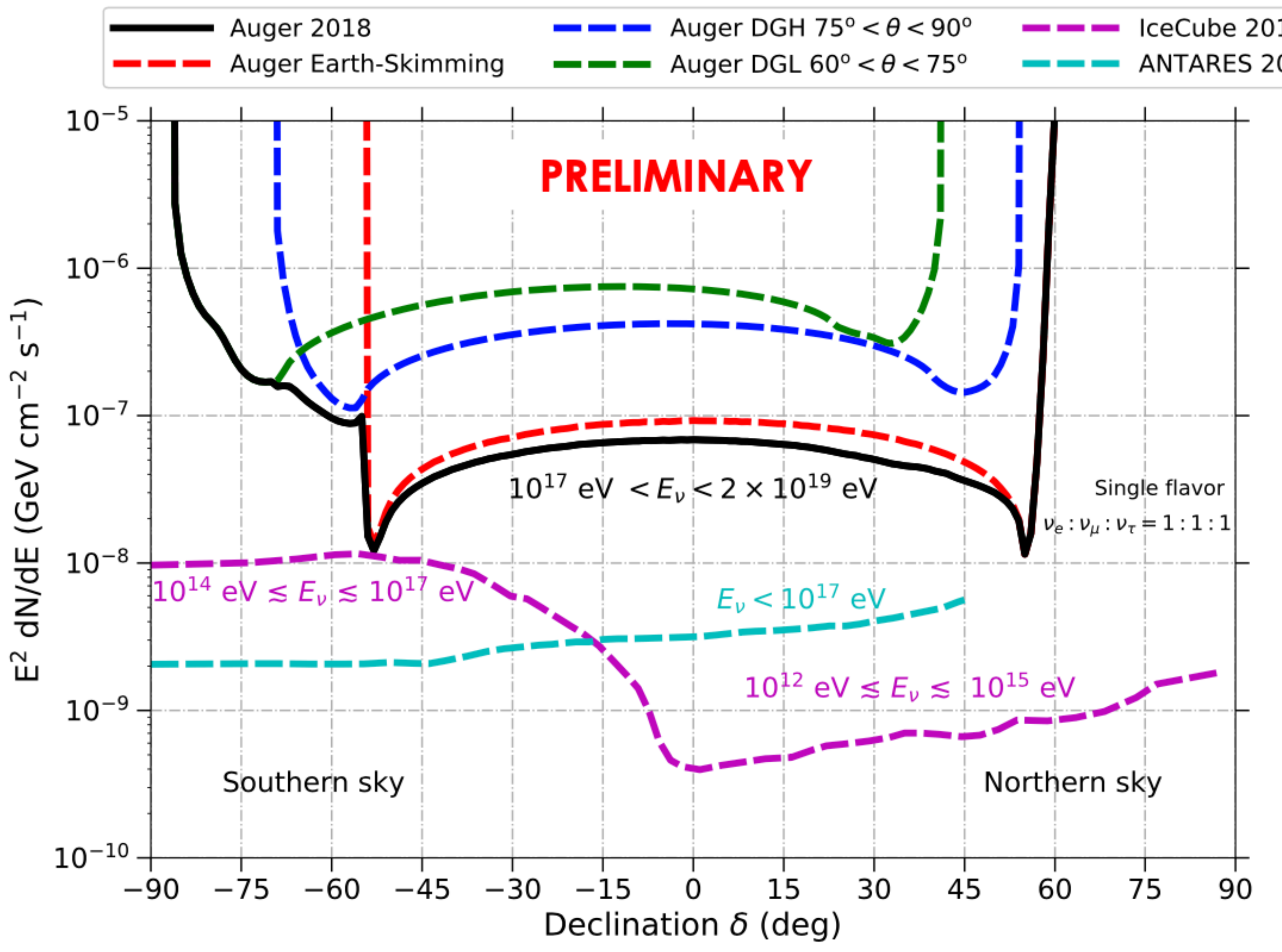


Black lines & colored background: ν fluxes obtained with Monte Carlo CRPropa 3 (A. Van Vliet et al.) - proton flux at Earth normalized to Auger spectrum at E = 7 x 10^{18} eV.
Blue line: fluxes obtained with approx. analytical approach (Yoshida et al.)



➡️Constraints on models assuming proton composition: independent confirmation of result from composition analysis
➡️Exclusion of a significant part of the (z,m) parameter space from non observation of neutrinos

Point like sources of neutrinos

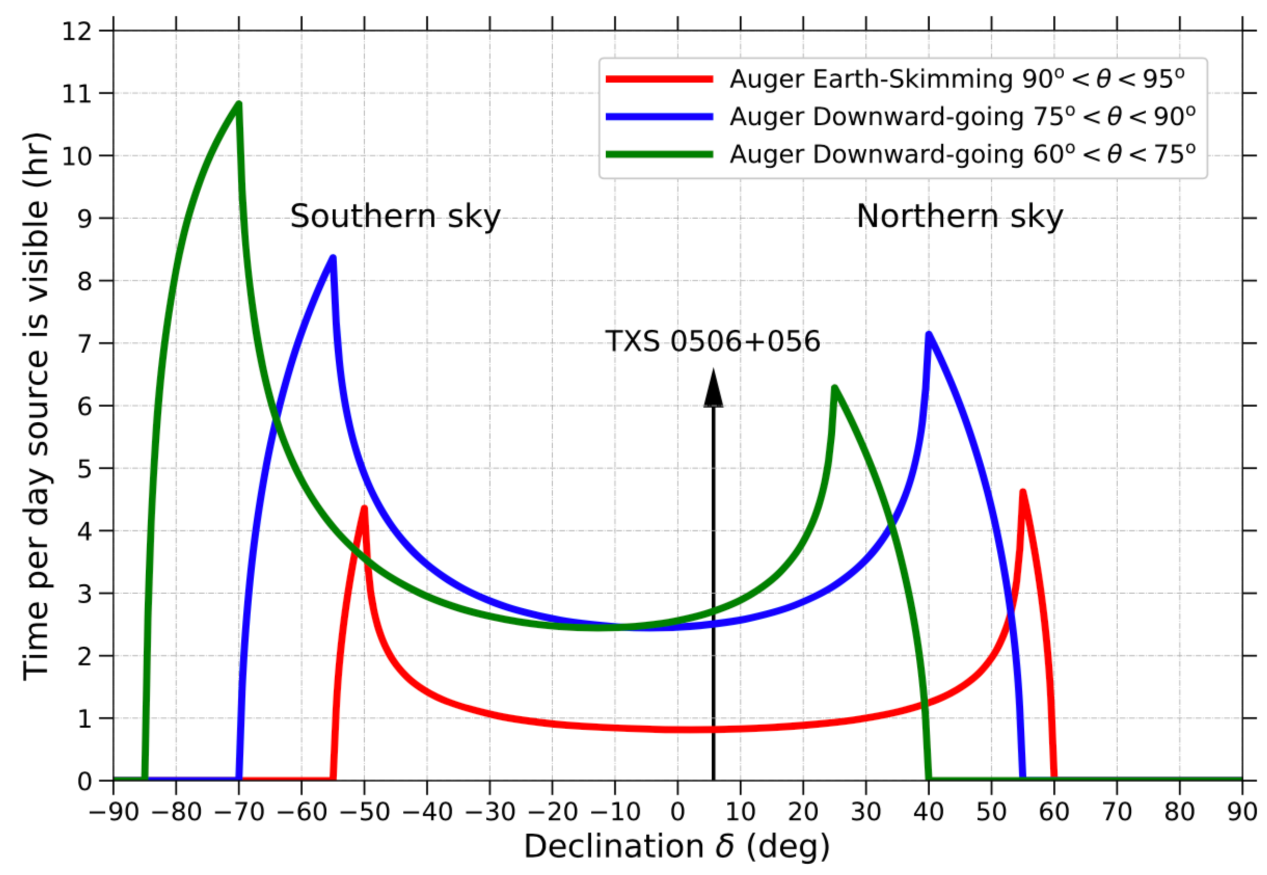


Steady sources

Energy range complementary to that of IceCube and Antares

Unmatched sensitivity to EHE neutrinos in the Northern hemisphere

Auger Collaboration, JCAP 11 (2019) 004



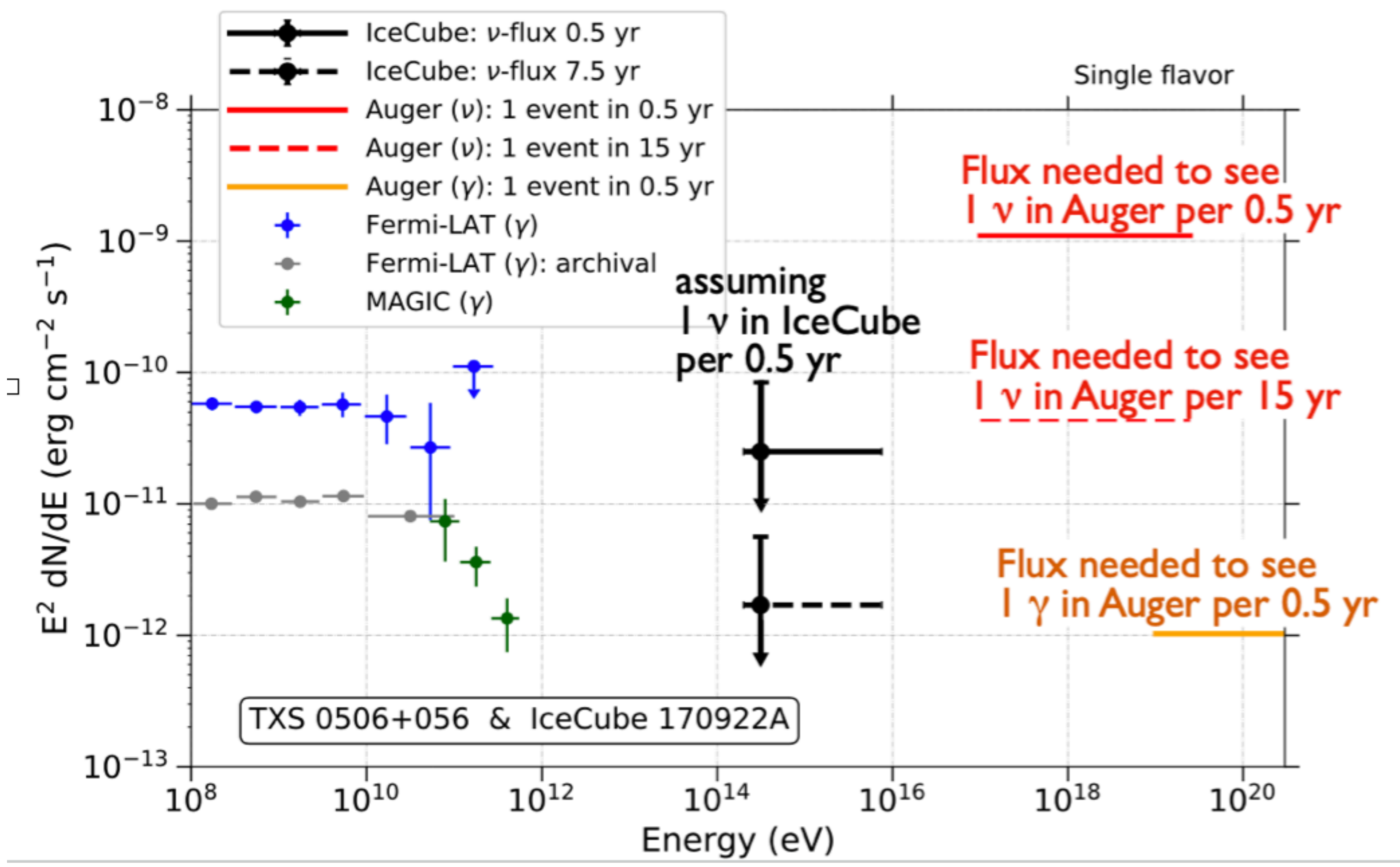
Neutrinos from TXS 0506+56

In Sept. 2017, IceCube observed a 290 TeV ν from the direction of TXS 0506+56 during a flaring state [Science 361, 146 (2018)]

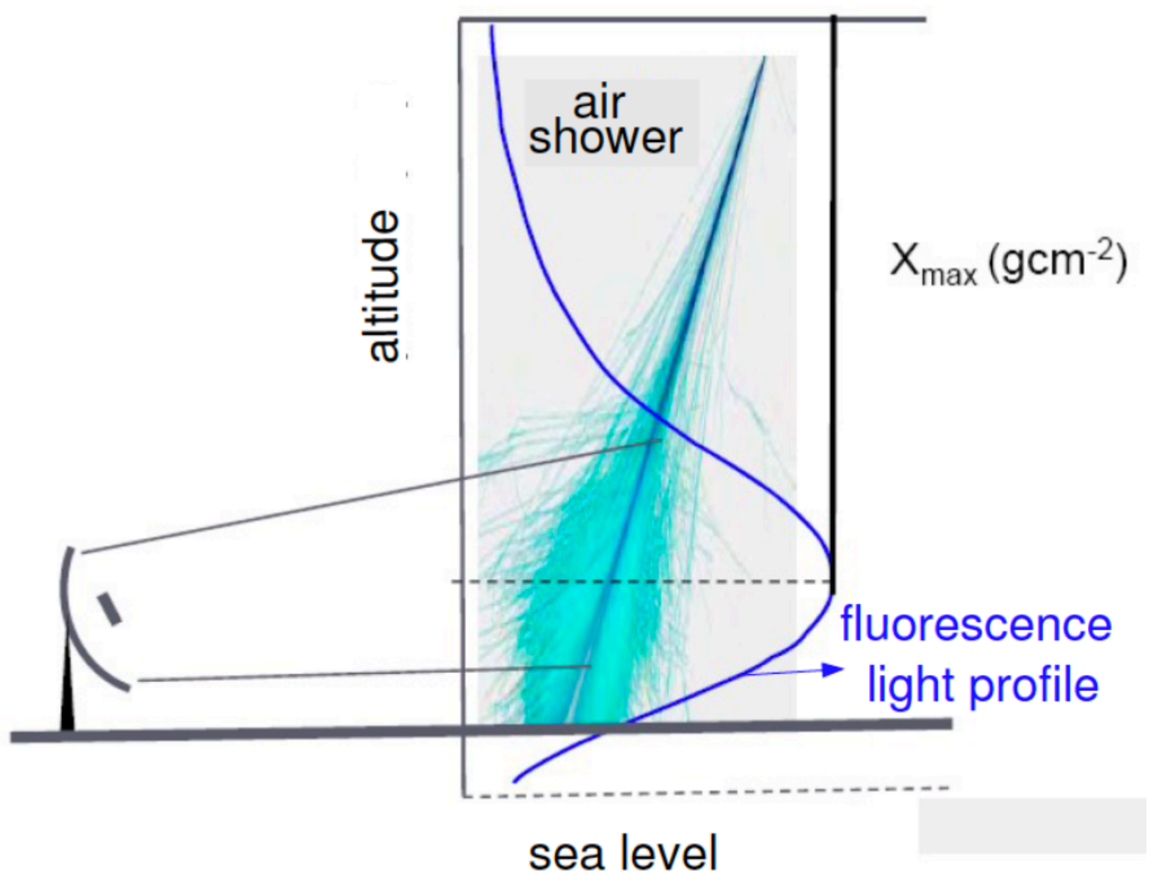
Source is ~21% T_{sid} in our FoV, but it was not at the time of neutrino detection

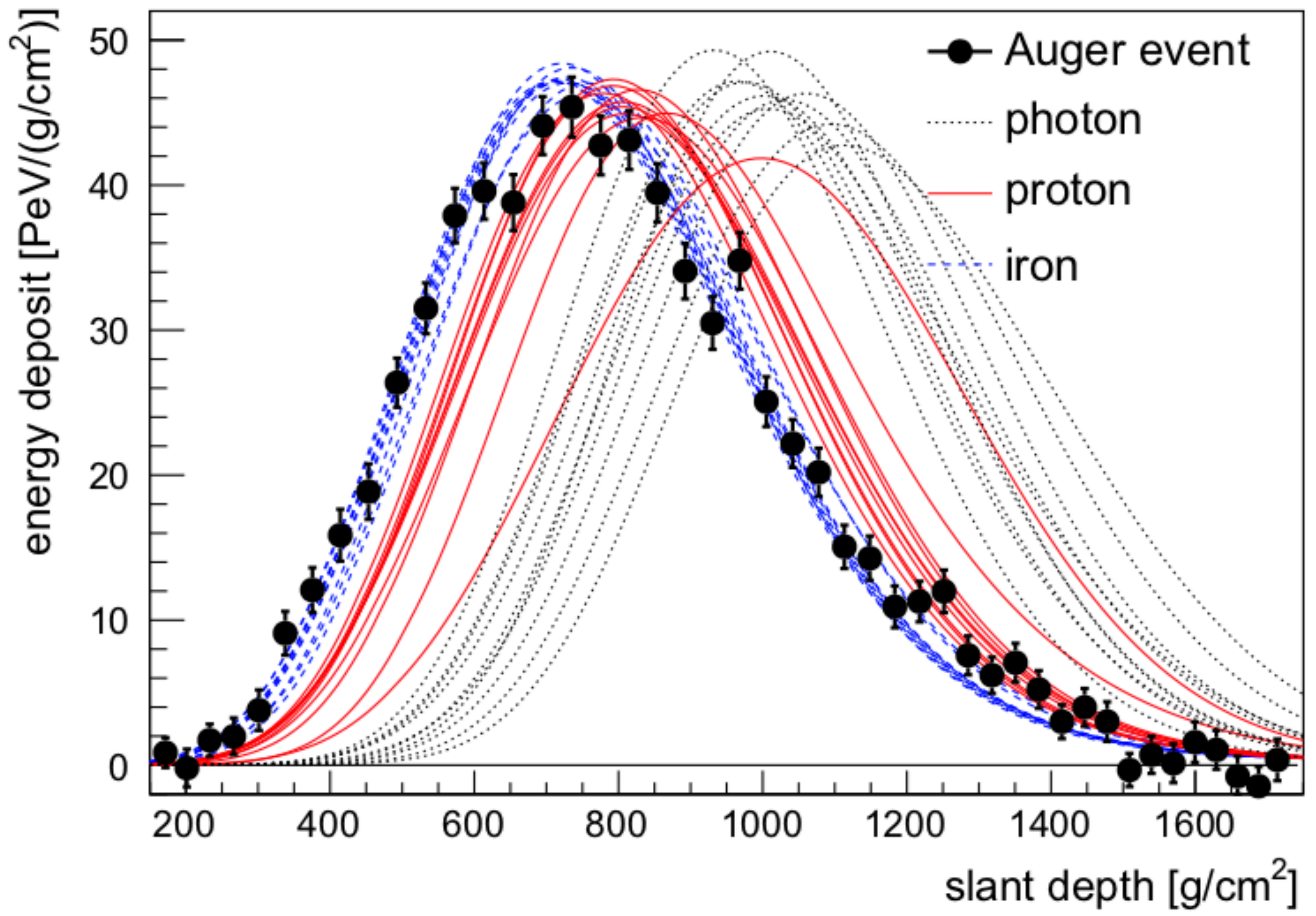
Auger Collaboration,ApJ 902 (2020) 105

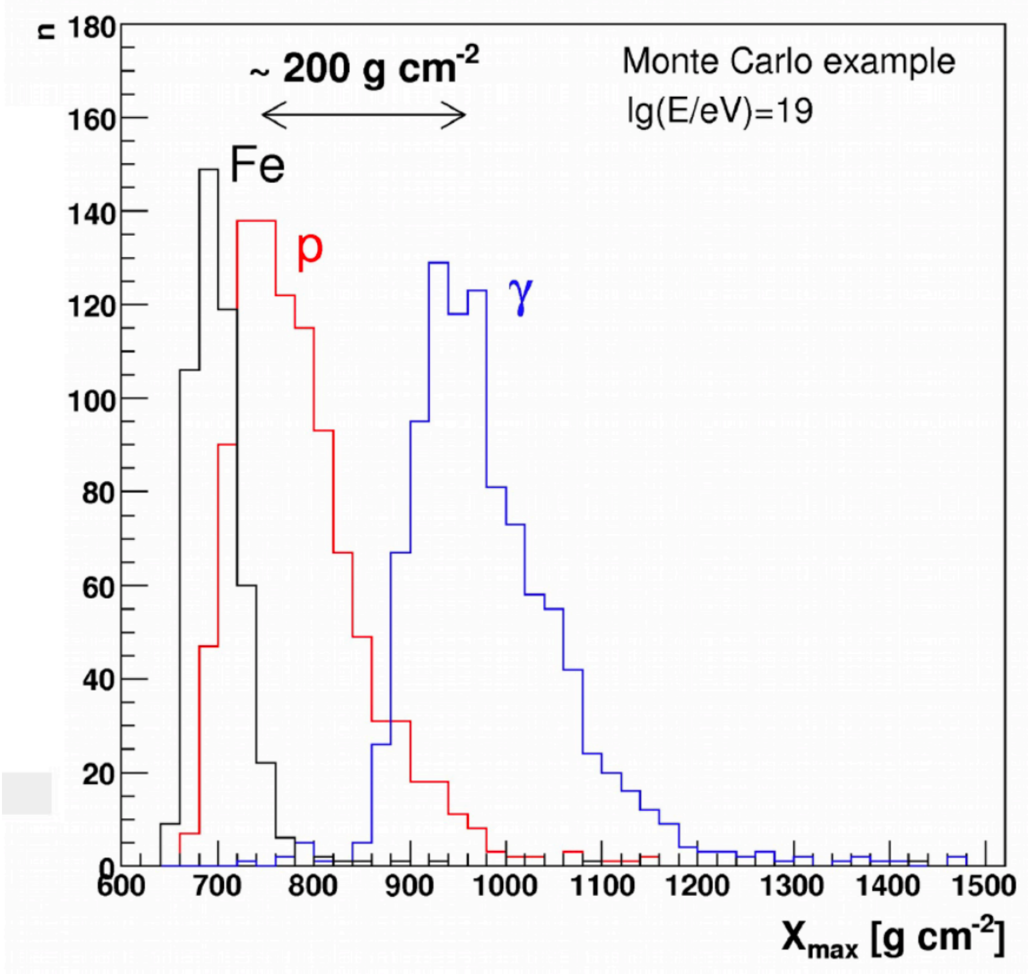
Flux comparison from single event assuming E^{-2} spectrum



Detecting photons in Auger

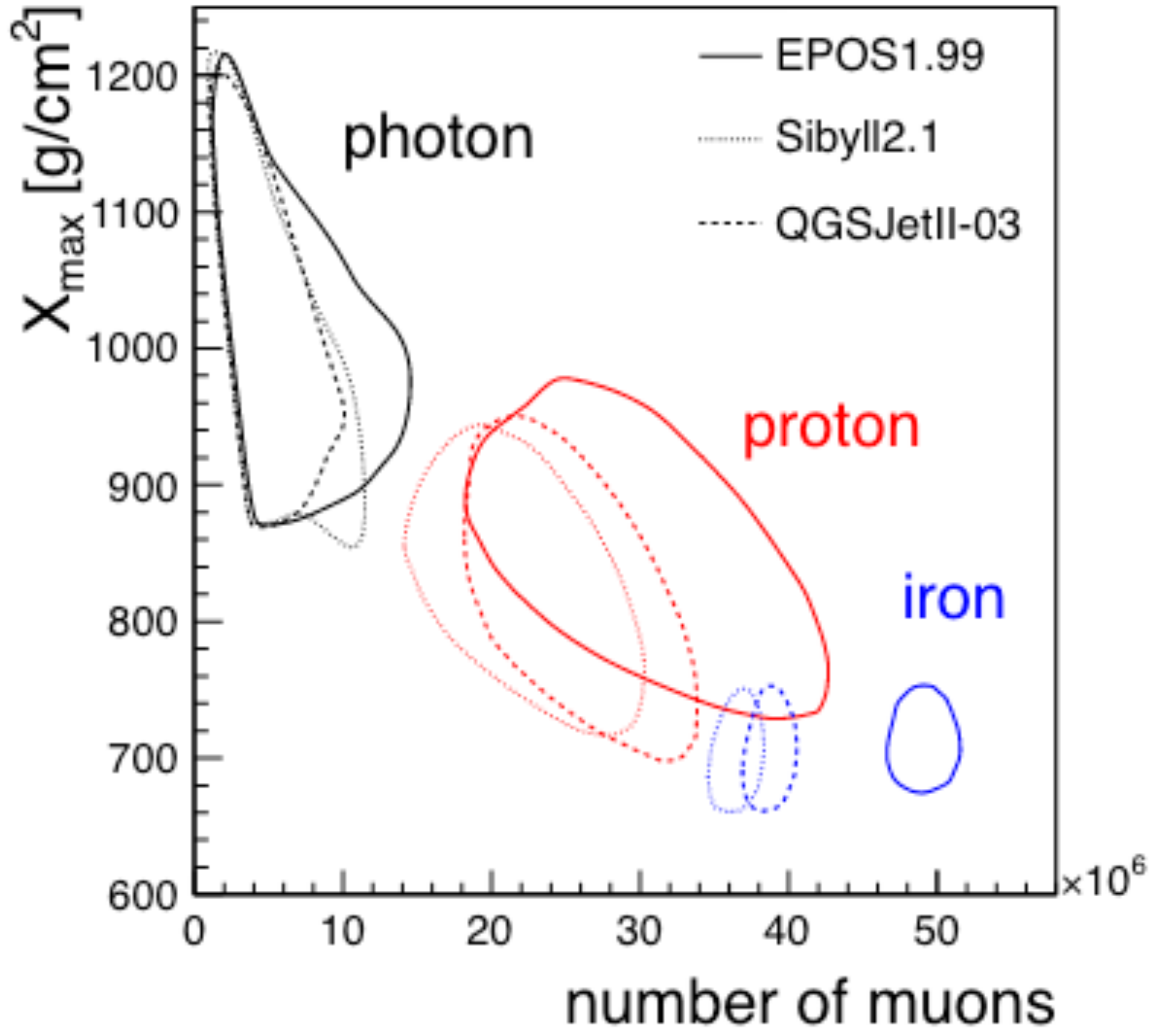


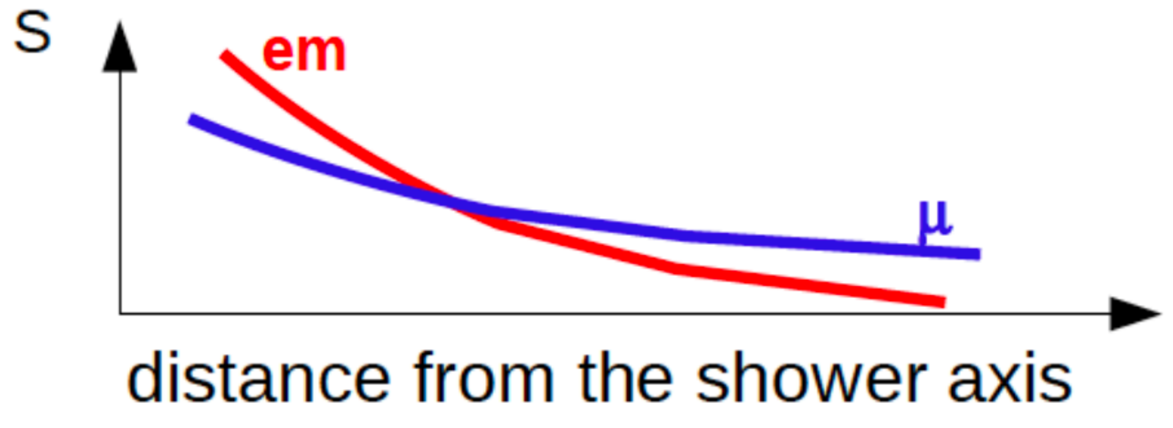


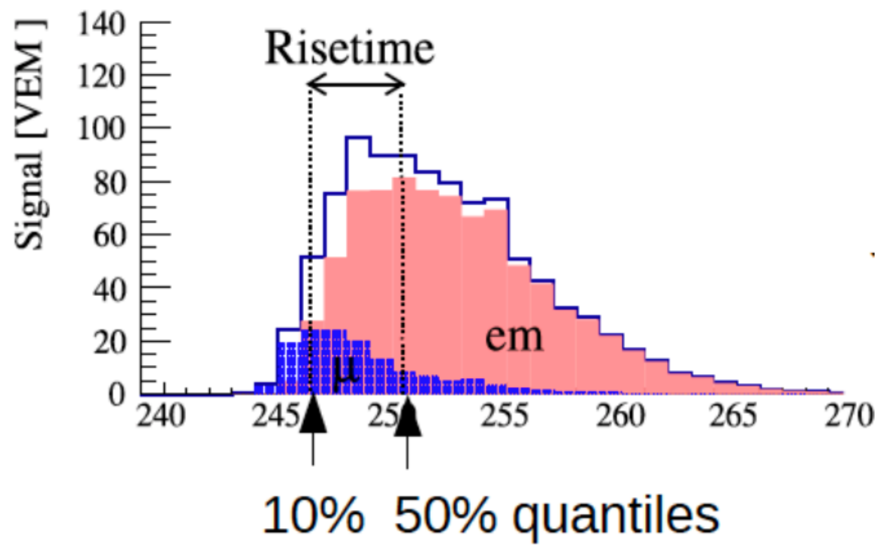


Photon-induced air showers are almost purely electromagnetic:

- deeper X_{max}
- μ-poor
- steeper lateral ditribution
- spreaded in arrival time





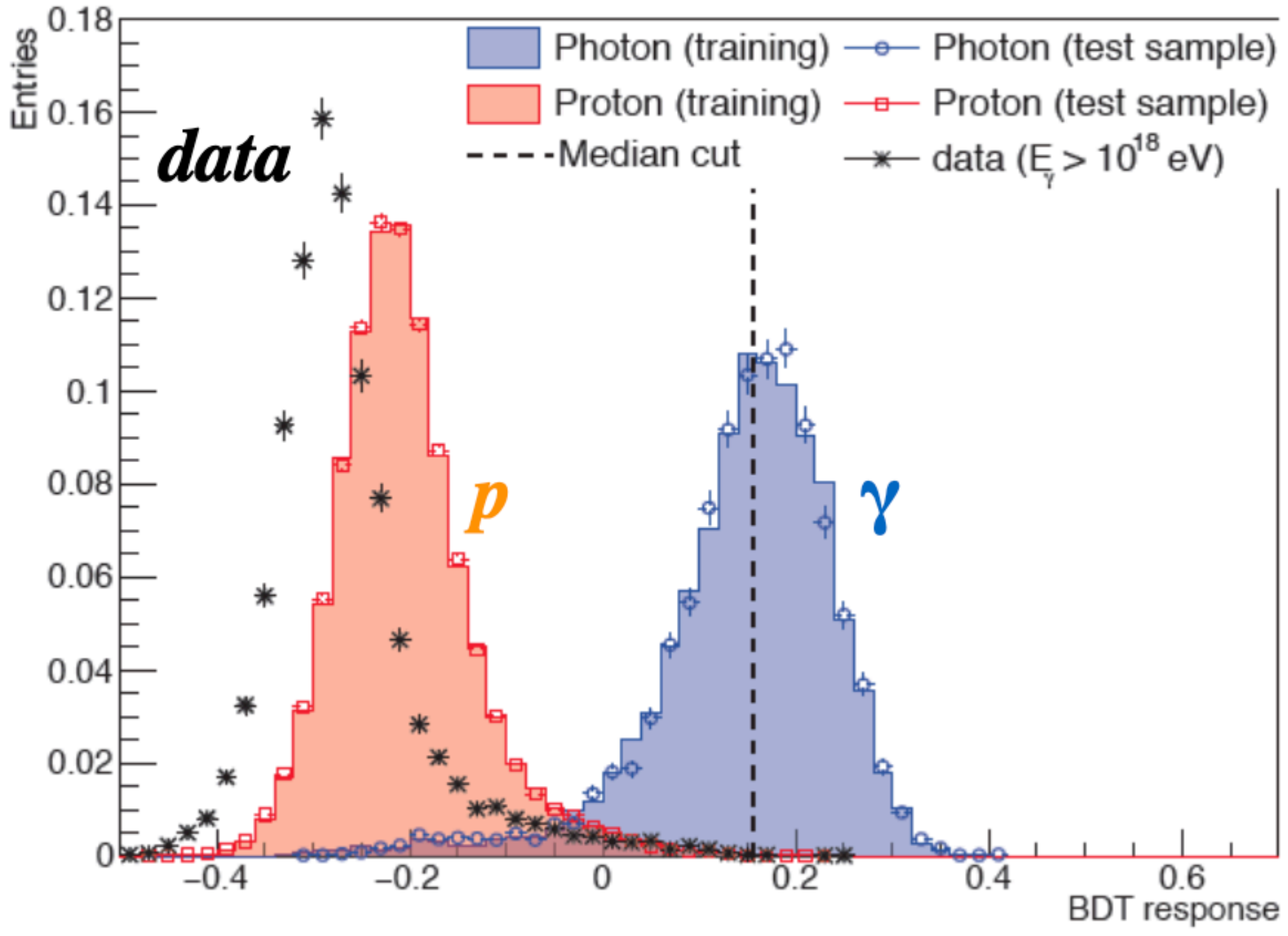


Detecting a diffuse flux of photons in Auger

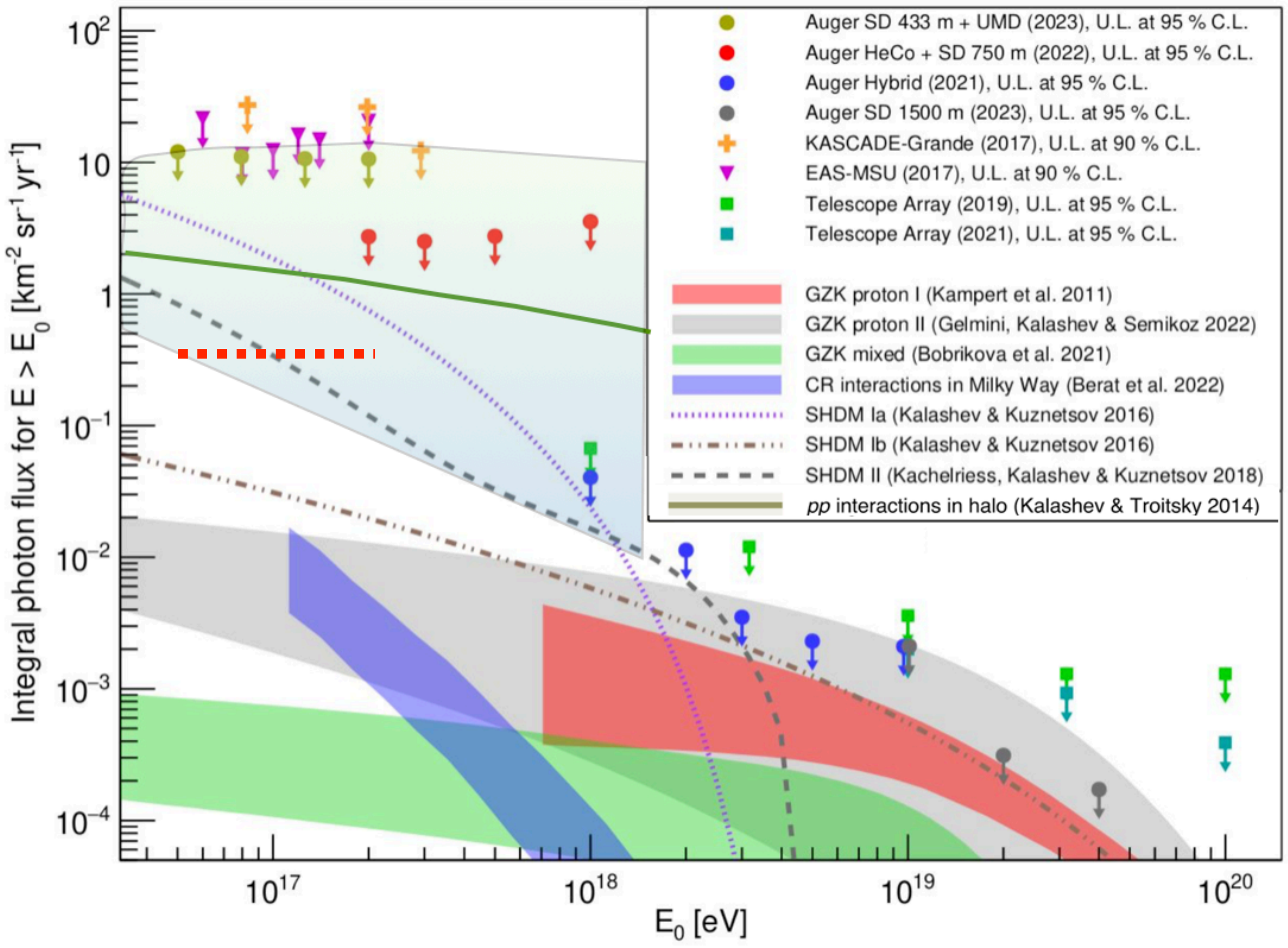
Method	Energy range [eV]	Detectors	Exposure [km² sr yr]	Observables	Cit.
1	>5 10^{16}	UMD - SD433	0.6	Muon densities in SD433	Proc. of Science 444, 238 (2023)
2	>0.2 10^{18}	SD750 and FD	2.5	X_{max}, N_{st}, SD750 signals	Astrophys. J. 933 (2022) 125
3	>10^{18}	SD1500 and FD	1000	X_{max}, F_{μ} (SD1500)	arXiv:2406.07439 subm.PRD
4	>10^{19}	SD1500	17000	LDF, risetime in SD1500	JCAP 05 (2023) 021

Discrimination Methods

Different observables combined into a single discriminator
Candidate cut: median of the discriminant distribution (50% efficiency)
Measured and simulated events passing the cut are compared



Search for a diffuse flux of photons



➡️Limits provided across 4 decades in energy

➡️Start closing the gap to the smaller air-shower experiments

➡️Below 10^{18} eV: most stringent limits available

➡️At the highest energies, most optimistic models of cosmogenic photon flux can be probed and excluded

Using AugerPrime exposure up to 2035

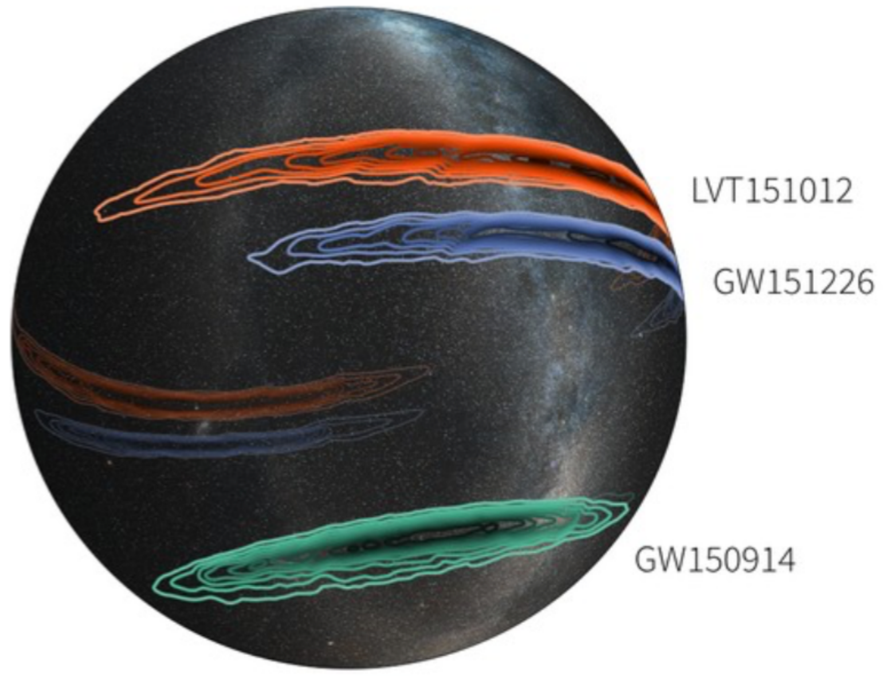
Neutrinos and photons from gravitational mergers

First direct GW signal : GW150914

- D_{GW} ~ 410 and 440 Mpc
- position few 100 deg^2

- inferred source : BBH merger
- EM signal detected (Fermi-GRB, ZTF) but not significant enough 3 and 1 $M_\odot$ released in GW

Image: LIGO/Leo Singer (Milky Way image: Axel Mellinger)



[@LIGO and Virgo Coll, PRL116 (2016) 061102 & 241103]

BBH

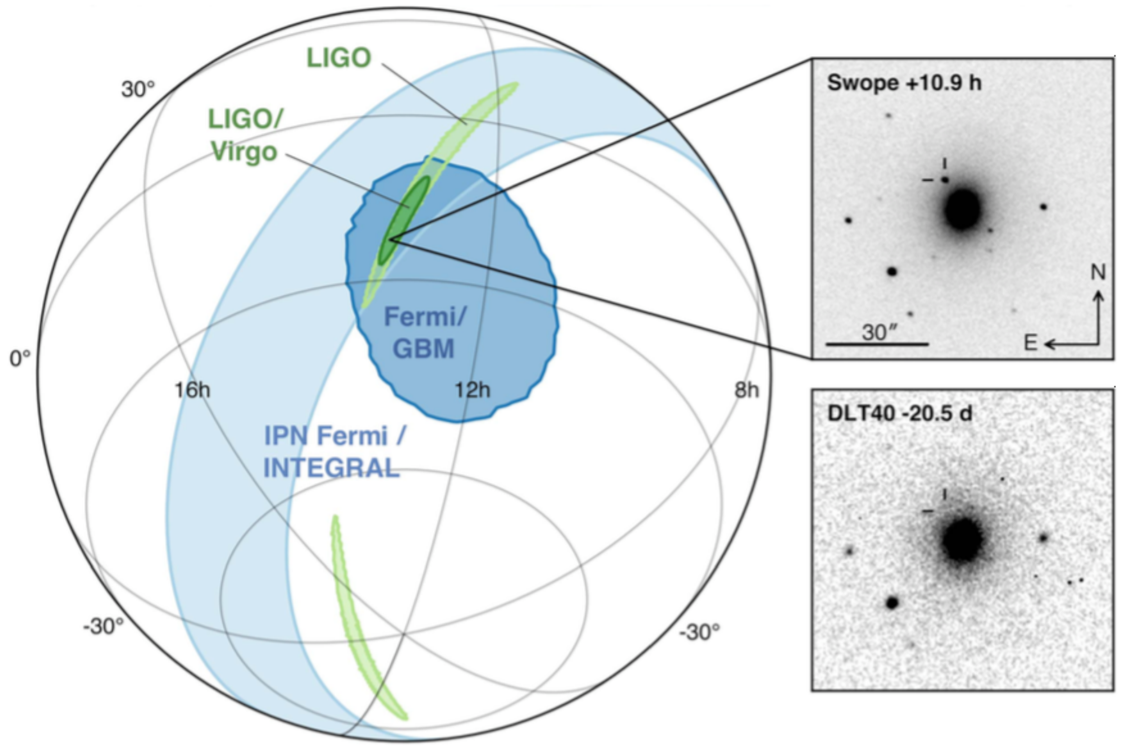
Production and acceleration of UHECRs could lead to production of UHE neutrinos and photons

- Rare transients (~ 1 Gpc^{-3} yr^{-1}) could produce a dense population [e.g. K.Kotera & J.Silk, ApJL823 (2016) L29]
- BH mergers should be surrounded by metal-rich debris and able to accelerate heavy nuclei
  (Fulfil constraints from Pierre Auger:
  - lower bound to source number density : >10^{-5} Mpc^{-3}
  - heavier composition at UHE)

First GW signal from NS merger: GW170817

- 1.36-2.26 and 0.86-1.36 $M_\odot$ released in GW
- D_{GW} ~ 40^{+8}_{-14} Mpc
- position few 31 deg^2

- inferred source : BNS merger
- multimessenger observation !!!



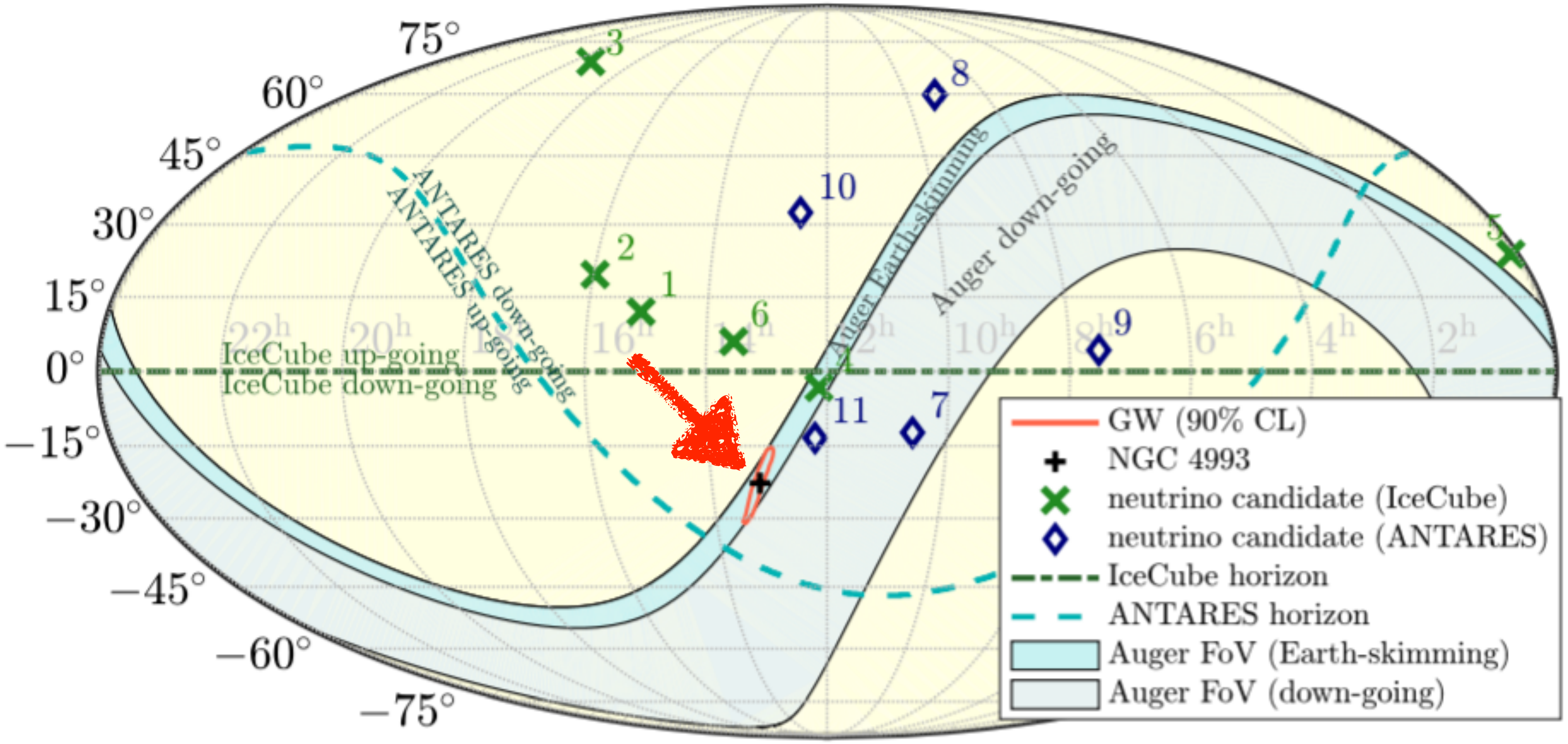
[@LIGO and many others…. ApJL 848 (2017) L123]

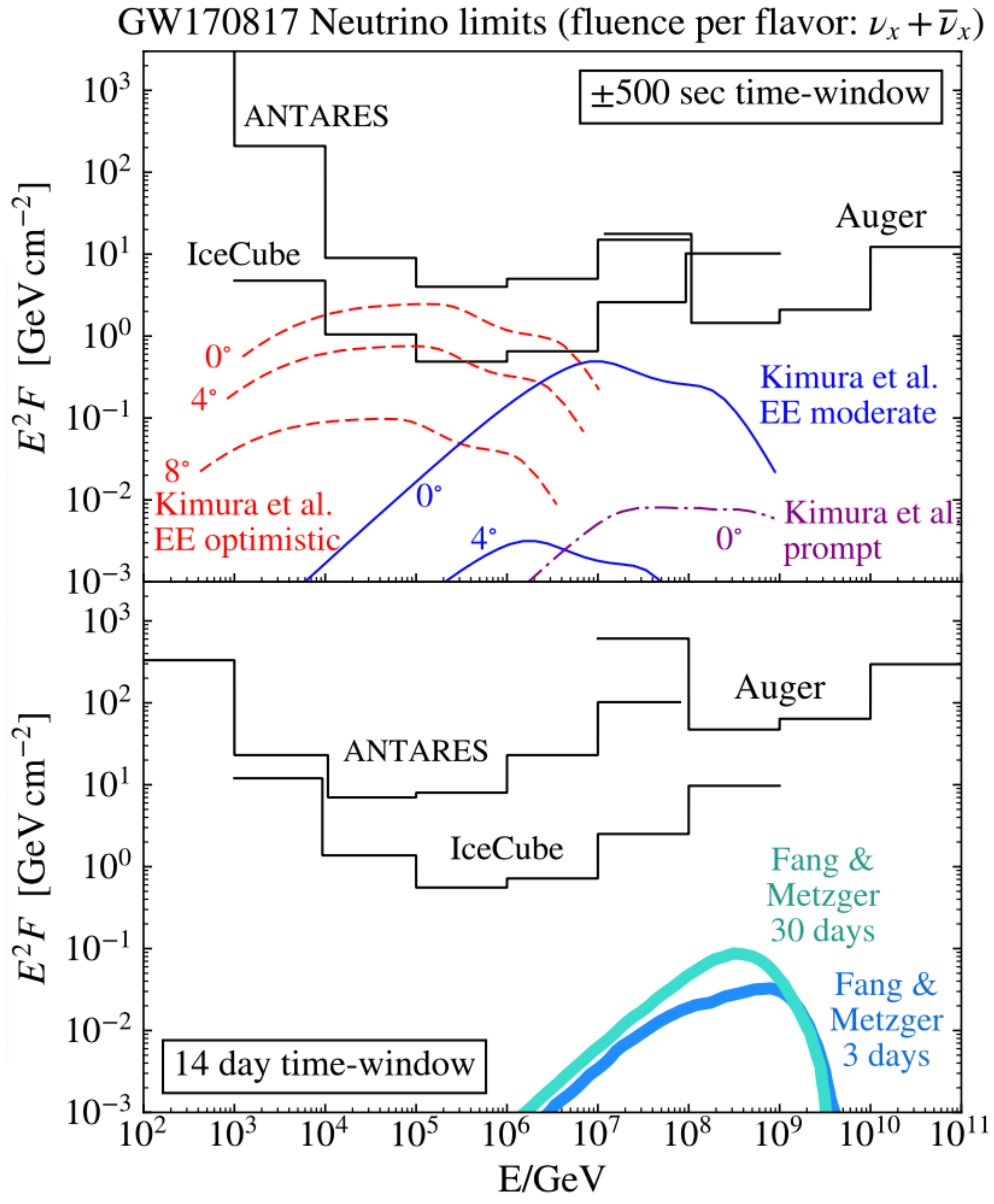
NS-NS

- relativistic particles accelerated in the outflows from the inner part of the BH [e.g. V.Decoene et al., JCAP 04 (2020) 045]
- sGRB: prompt (internal energy dissipation in the jet) or extended emission (forward shocks around the burst), viewed on-axis or off-axis [e.g. S.Kimura et al., Astrop.J. 848 (2017) L4]
- msec Magnetar remnant late production from UHECRs interactions with ambient photons and baryons [e.g. K.Fang et al., Astrop.J. 849 (2017) 153]

- >90 GW observations from LVC since the first run, from BBHs, BNSs, NSBHs

Follow-up of GW170817 in neutrinos





LVC, ANTARES, IceCube, Auger, ApJL 850 (2017) L35

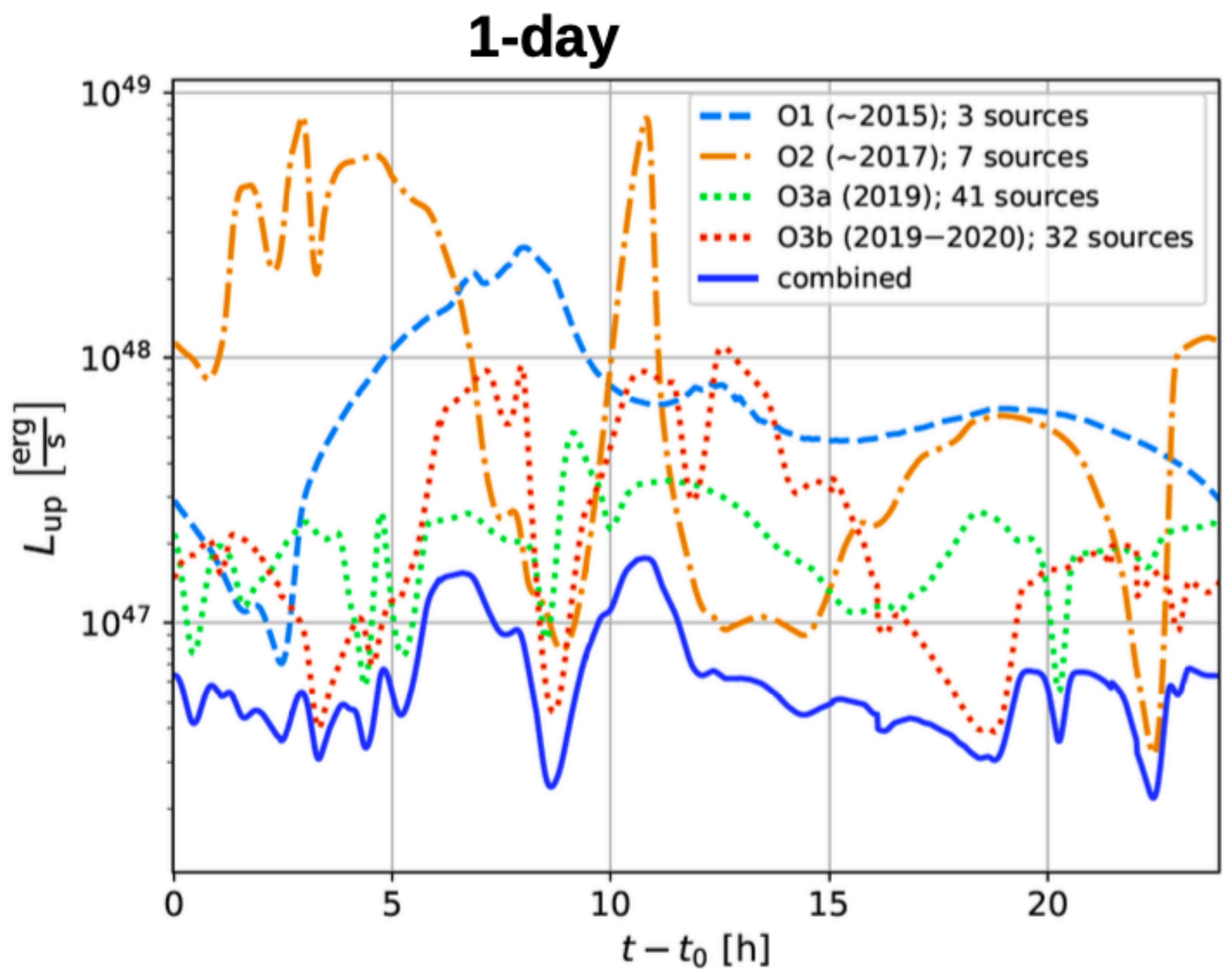
- Source in the field of view of ES neutrino search
- No UHE neutrino candidates found in either coincidence windows (±500 sec around the GW or in the 14 days period after it)
- Limits on the total emitted energy in the range 10^{17}-2.5 10^{19} eV

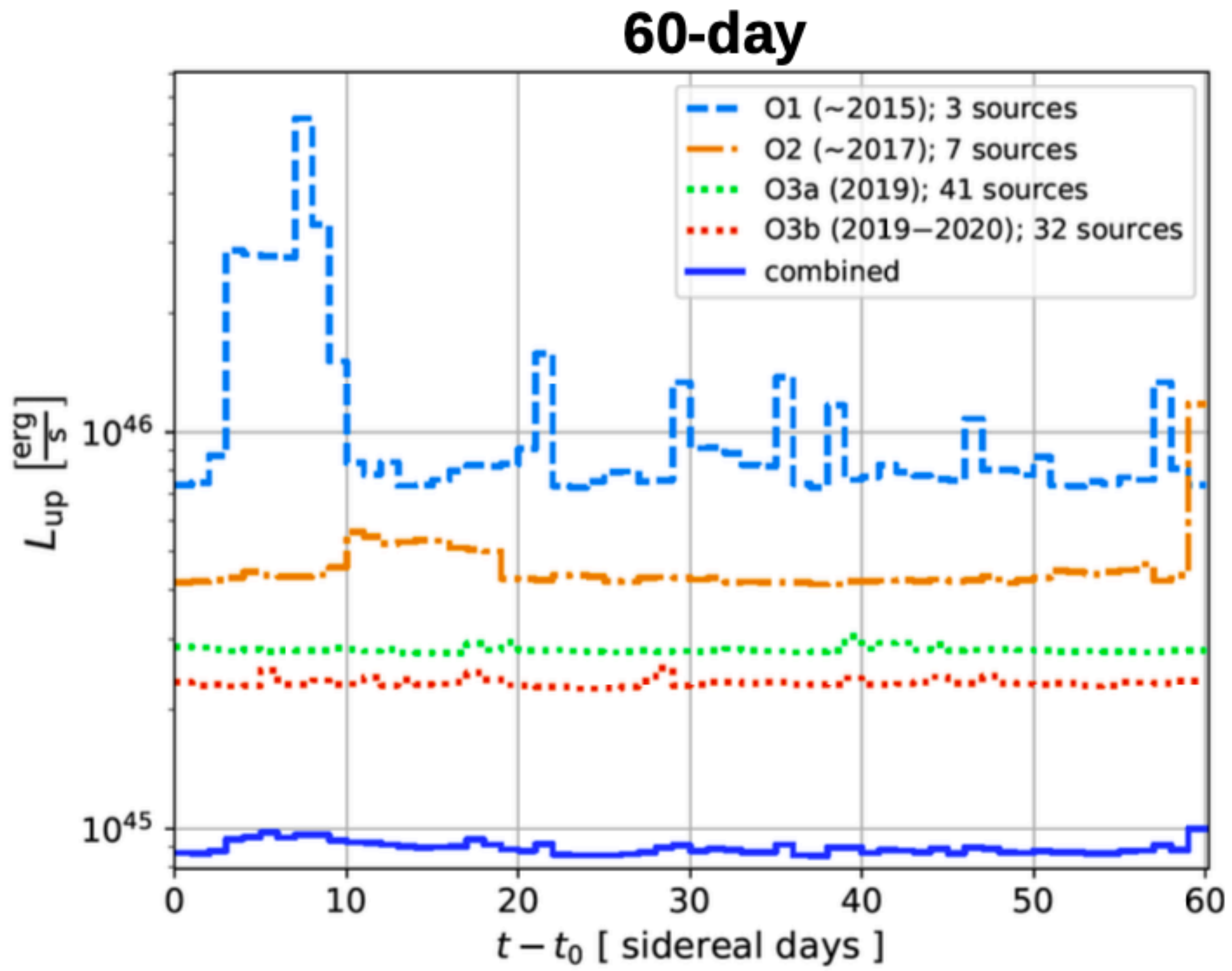
  ±500 s : < 6.9 10^{-4} $M_\odot$ +14 days : < 2.3 10^{-2} $M_\odot$

- Lack of detection consistent with expectation from a short GRB viewed at off-axis angle >20^0

BBH Follow-up: stacked neutrino searches

Look for time and directional coincidence with 83 BBH events from LIGO/Virgo runs O1-O3 —> automatic follow-up search !





➡️ No candidates, limits provided across 4 decades in energy

➡️ Limits (90% C.L.) on the total energy emitted in neutrinos in the range E_ν=[10^{17}-2.5 10^{19}] eV

~5.2 10^{51} erg (~ $M_\odot c^2$/ 300) independent of the time window

➡️ Limits are >2 orders of magnitude below the radiated GW energy (~ $M_\odot c^2$)

L.Perrone, EPJ Web of Conf.283, 04004 (2023)
(Paper ready for submission)

ɣ searches from GW sources

Search for ɣ from transients challenged by

- attenuation of UHE photons (λmax~few Mpc)
- Separation of ɣ from overwhelming hadronic background

Look for time and directional coincidence with 91 GW events from LIGO/Virgo runs O1-O3

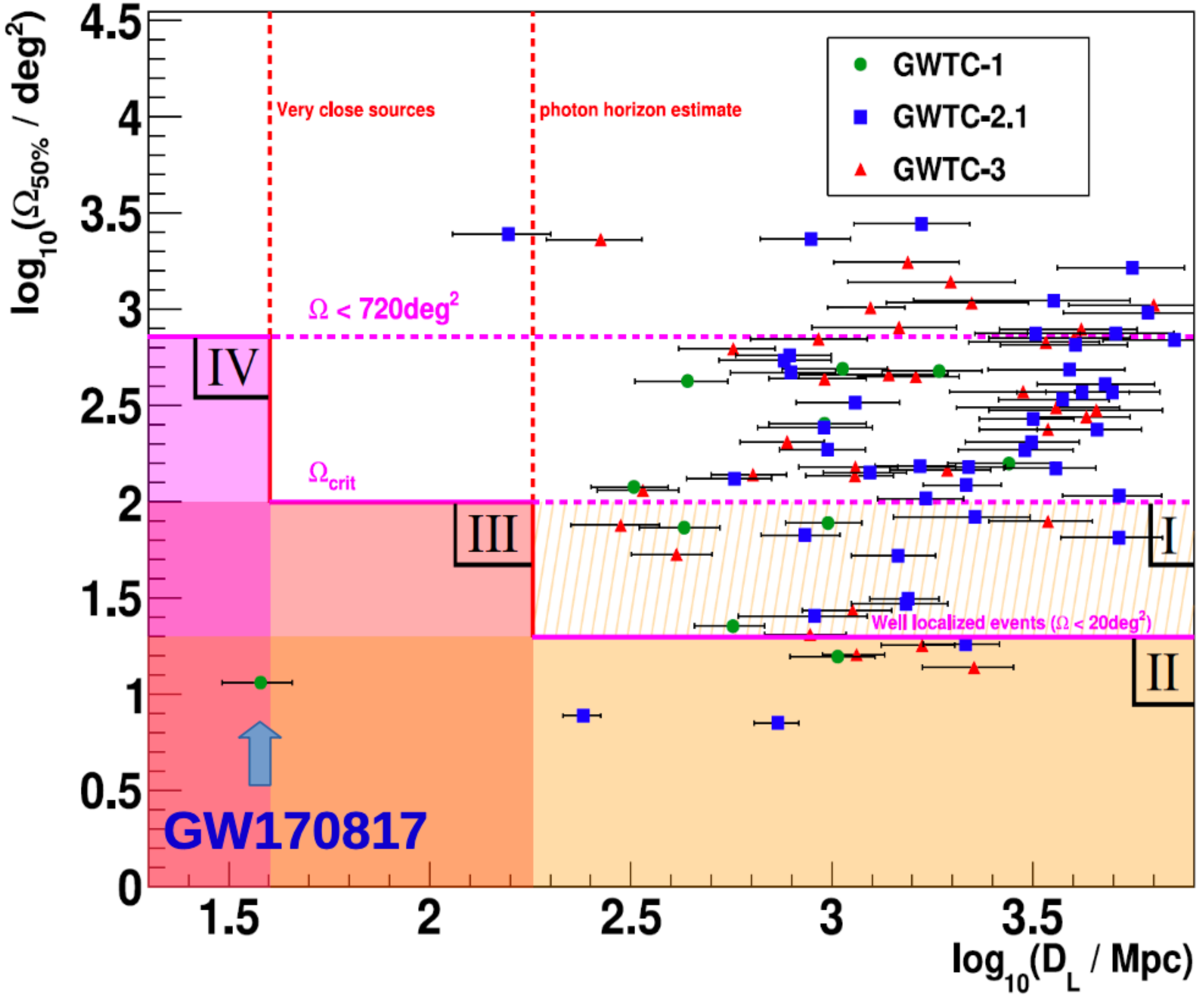
Search region

- $\Omega_{50\%}$ solid angle contour in localization of the GW source
- Two mutually exclusive time windows: 1000 s centered at t_{GW} and 1 day after it

4 regions in distance and localization (not mutually exclusive)

- best region for observation if sources are closeby (IV)
- a candidate at large distance (I,II) could point to new physics

$$(D_L < \infty \text{ and } \Omega_{50\%} < 100 \text{ deg}^2)_s \text{ “class I”}$$
$$(D_L < \infty \text{ and } \Omega_{50\%} < 20 \text{ deg}^2)_l \text{ “class II”}$$
$$(D_L < 180 \text{ Mpc and } \Omega_{50\%} < 100 \text{ deg}^2)_l \text{ “class III”}$$
$$(D_L < 50 \text{ Mpc and } \Omega_{50\%} < 720 \text{ deg}^2)_{l,s} \text{ “class IV”}$$



Auger Coll., Astrop.J.952 (2023) 91

ɣ searches from GW sources

No air showers >10^{19} eV in coincidence with GW time window
(in agreement with expected background 0.03 of random showers)

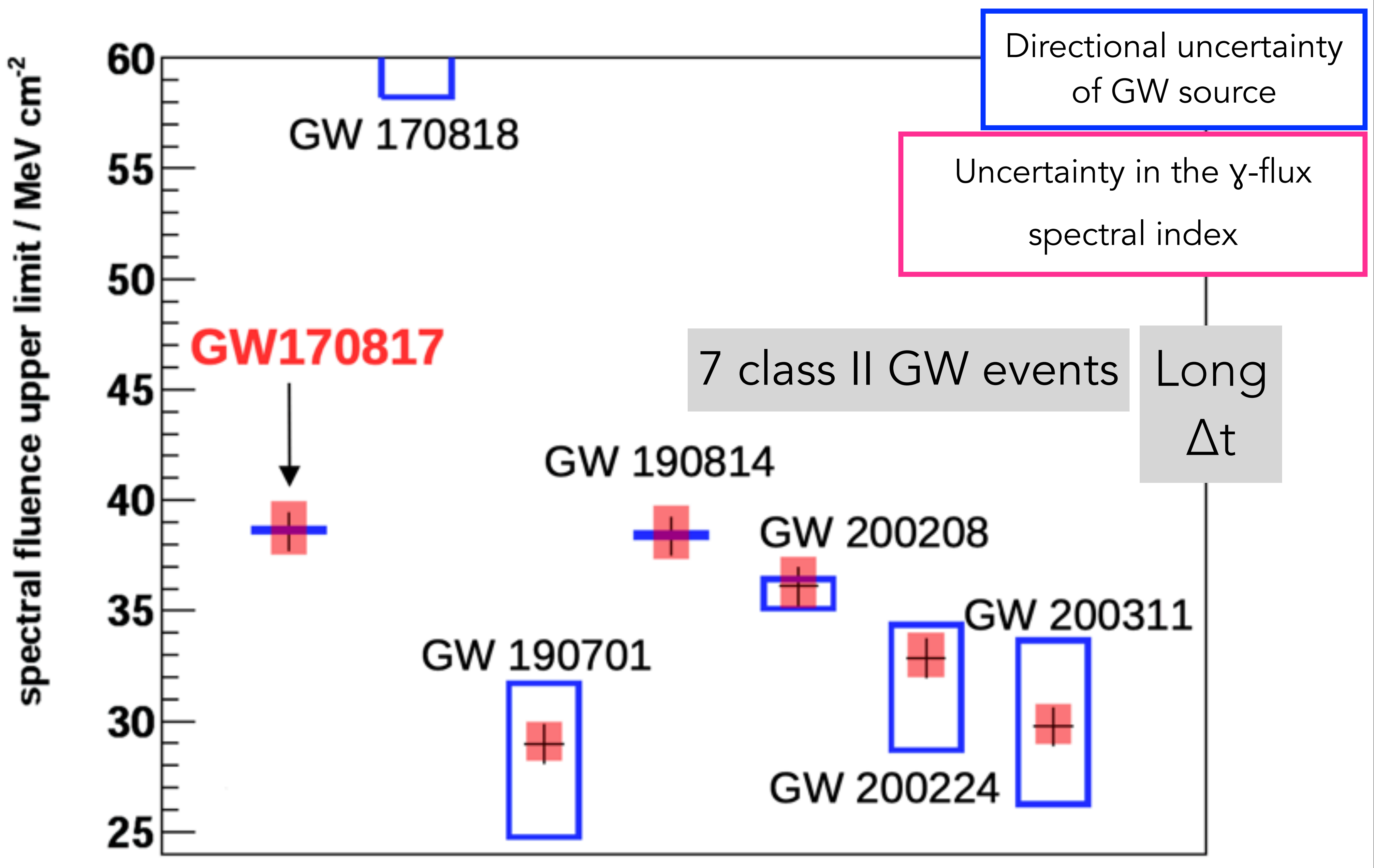
- ➡️8 BBH (I,II)
- ➡️1 NSBH : GW190814 (I and II)
- ➡️1 BNS : GW170817 (all classes)

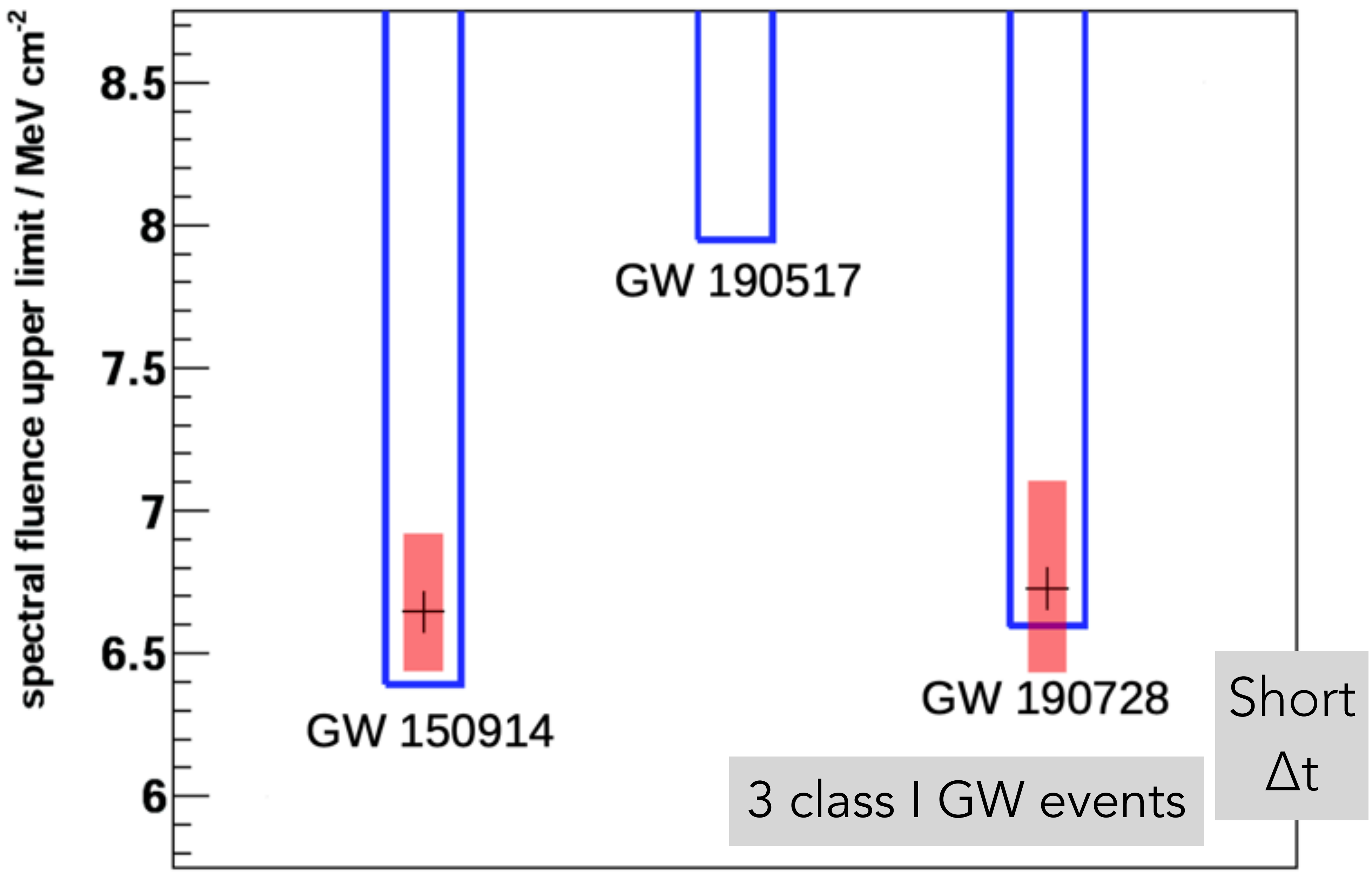
$$\frac{d\Phi_\gamma^{GW}}{dE_\gamma}(E_\gamma) = k_\gamma E_\gamma^\alpha$$

$$k_\gamma^{UL} = \frac{N_\gamma^{UL}}{\int_{E_0}^{E_1} dE_\gamma E_\gamma^\alpha \mathcal{E}(E_\gamma, \theta_{GW}, \Delta t)}$$

$$\mathcal{F}_\gamma^{UL} = \int_{t_0}^{t_1}\int_{E_0}^{E_1} dt\, dE_\gamma\; E_\gamma \frac{d\Phi_\gamma^{GW}}{dE_\gamma}$$

Spectral ɣ fluence →





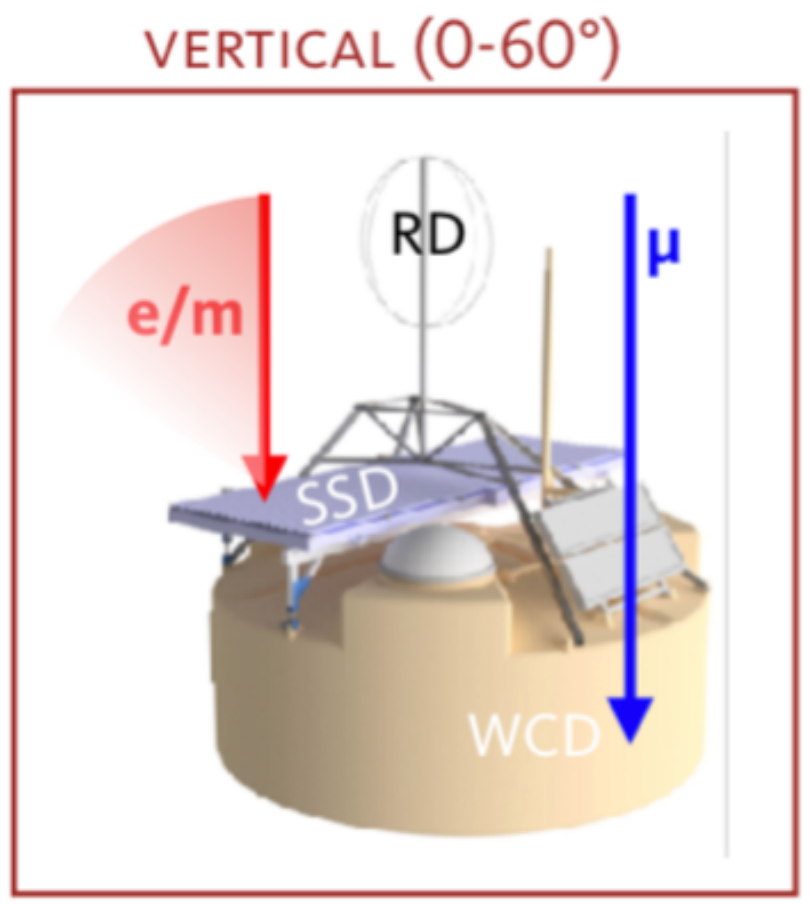
- ➡️ First ever limits on ɣ from GW sources at UHE
- ➡️ GW170817: best upper limit on the photons energy above 40 EeV, <20% of the GW energy goes to photons
- ➡️ Expect great improvement from closer GW events

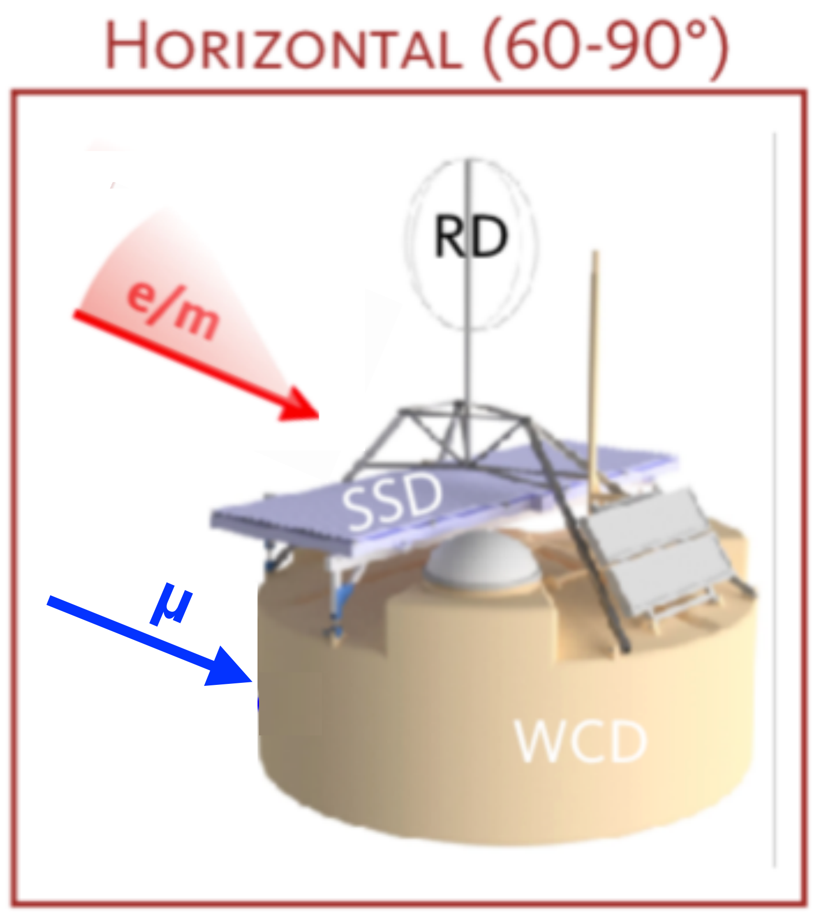
Waiting for AugerPrime high-quality data

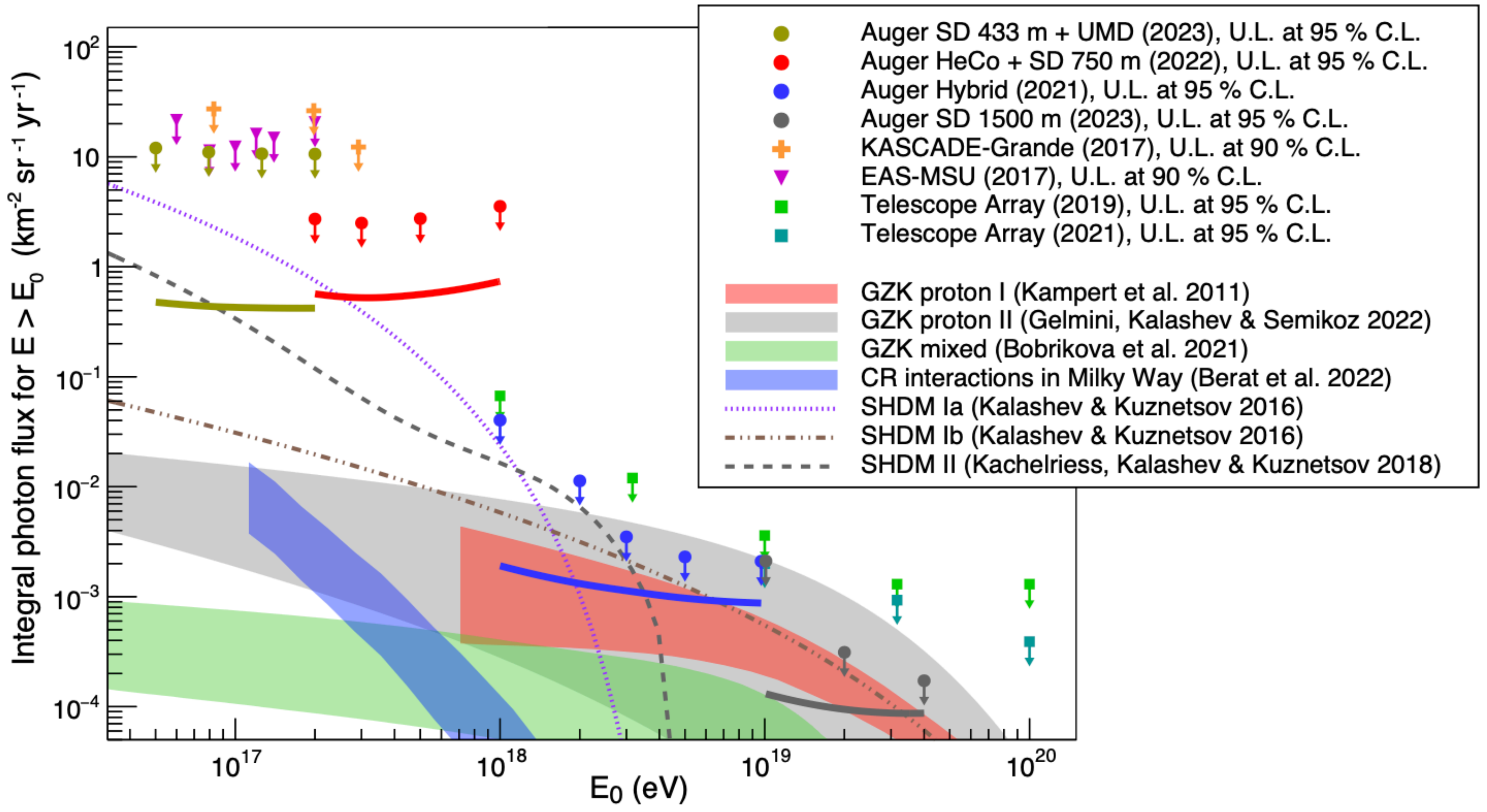
WCD/SSD/RD can collect multi-hybrid events with a 100% duty cycle
Separation of shower components can be obtained

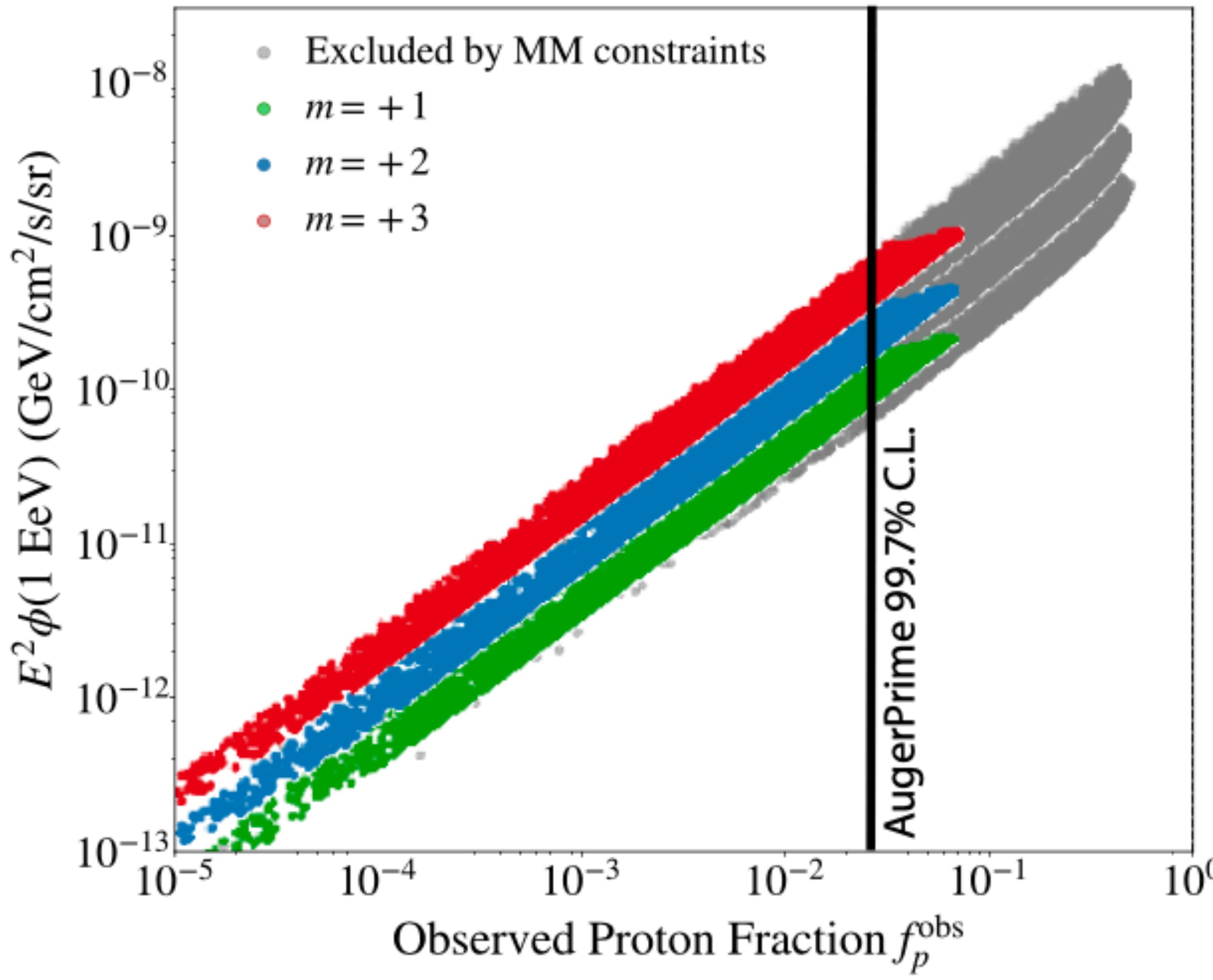
- by WCD/SSD for events up to ~60^0
- by WCD/RD for inclined events >60^0
- by WCD/SSD/UMD extending the mass sensitivity to the lower energies and improving the photons/hadrons discrimination

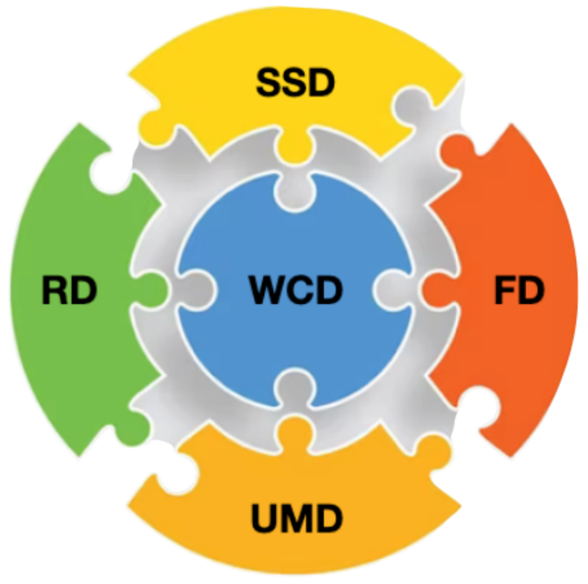
With the new electronics we will enhance the sensitivity of triggers to electromagnetic signals, specifically for photons and neutrinos using the RD, and the combination of WCD and SSD. WCD and UMD)











The Pierre Auger Observatory is part of the international multi-messenger astrophysics network

Automatic Global Coordinate Network (GCN) alerts listener

- SD events update every 15′, 3 ν reconstruction analyses running
- Read GCN alerts and look for ν candidates in 90% CL region
- Automatic alert if any findings and possible GCN notice if confirmed

AMON and DWF triggering and follow-up partner

- Alerts from private or GammaCN notices
- High quality SD events shared every few minutes
- SD events in DWF field of view shared
- Plans to include lower energy SD events from infill arrays

Only a strong collaboration among the various communities (GW, γ, ν, hadrons) can bring new insights…
The different groups interconnections must be continued and improved

BACKUP

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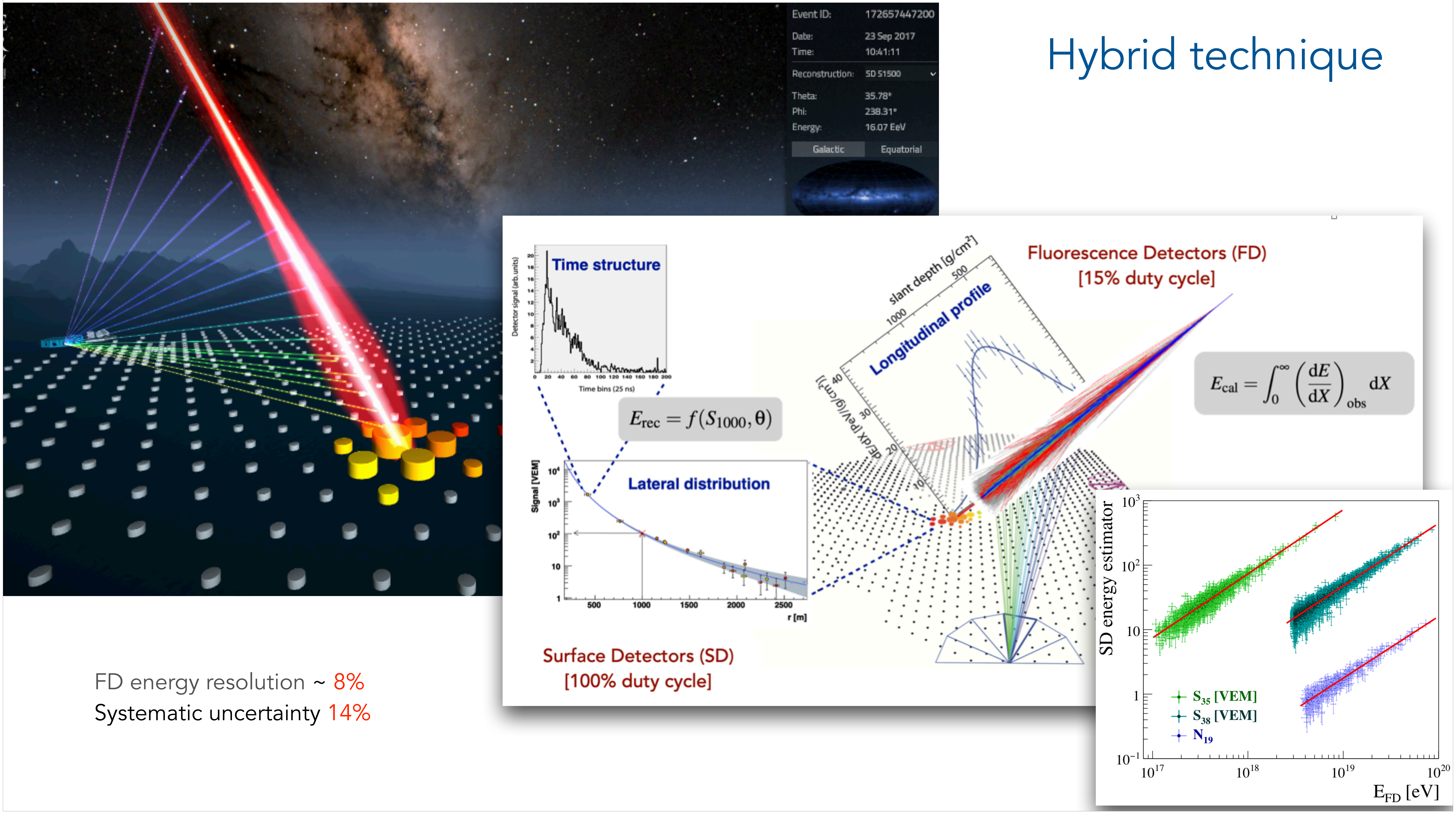
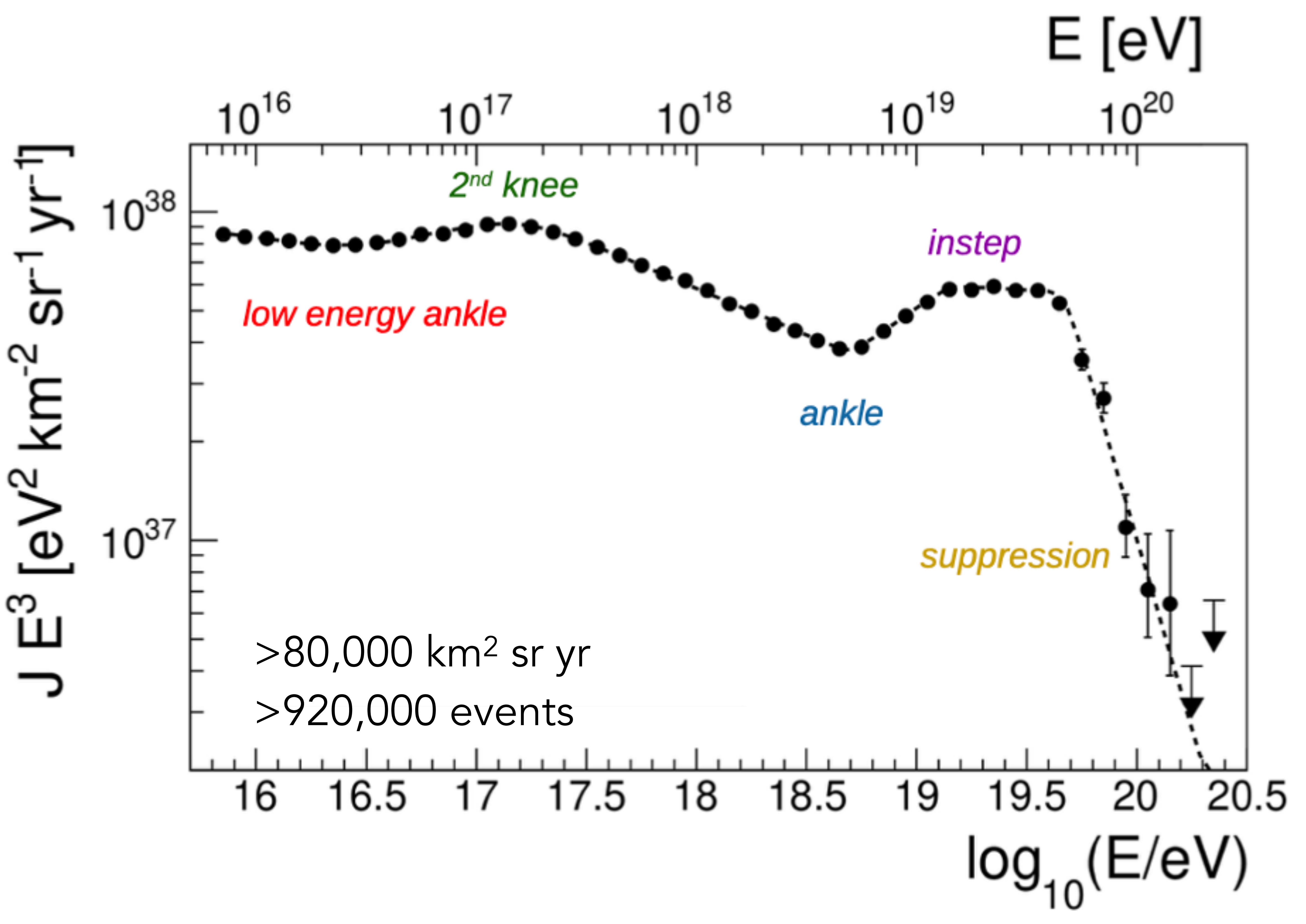
Hybrid technique



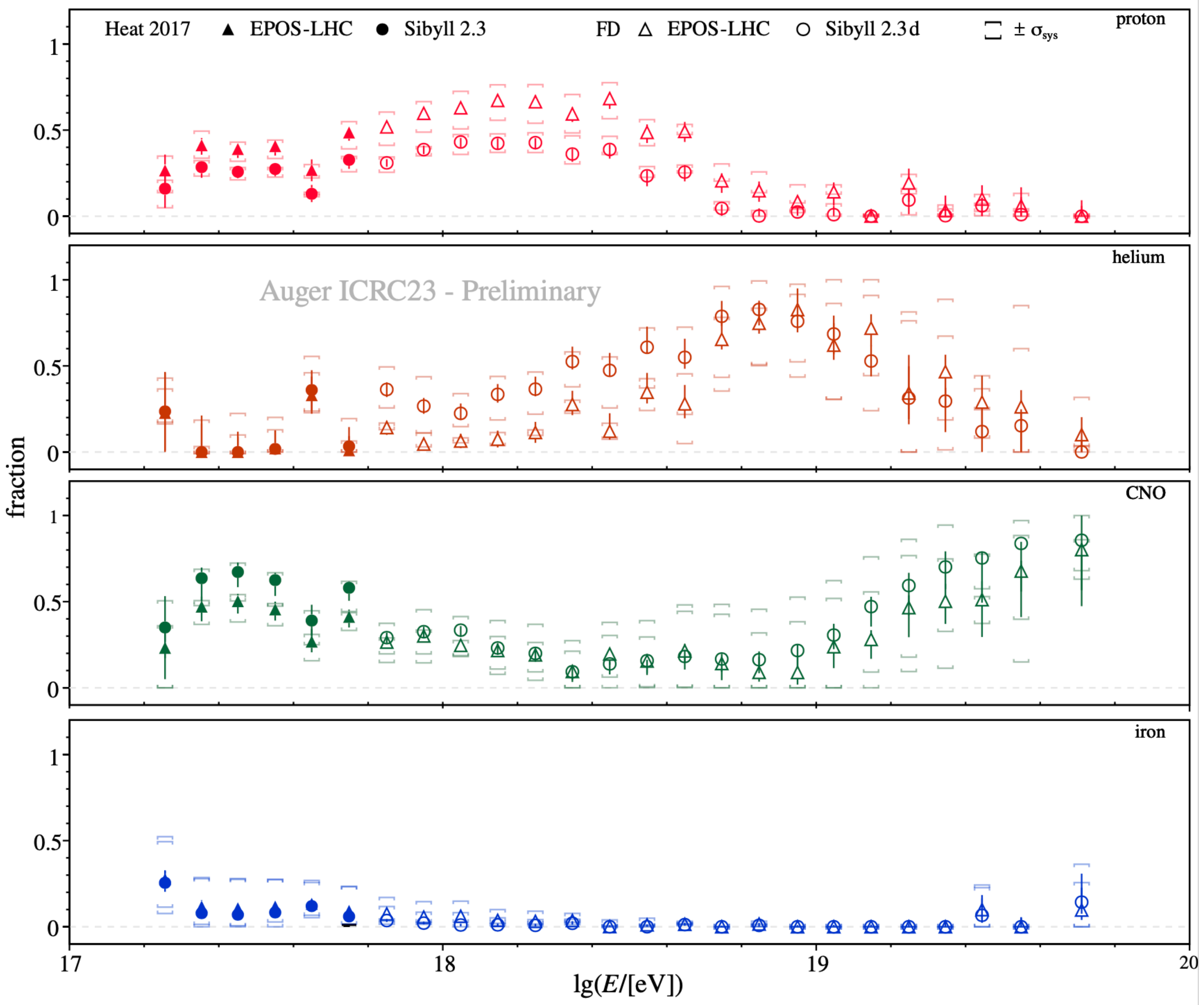
FD energy resolution ~ 8%

Systematic uncertainty 14%



Energy spectrum

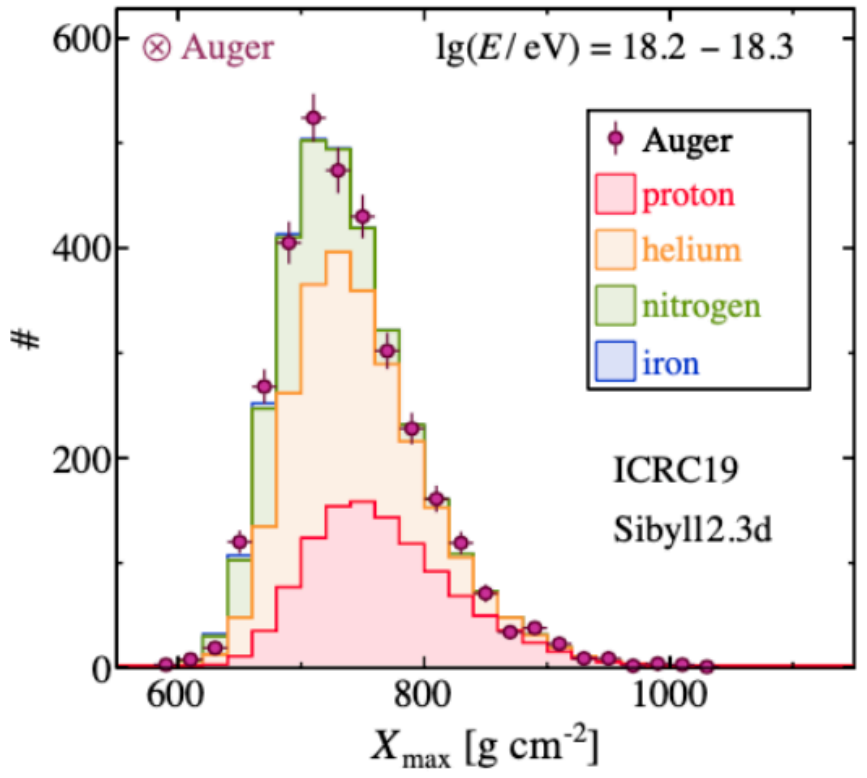
- ➡️A measure completely independent of any assumptions on the primary mass
- ➡️It provides constraints on source properties, injected masses, interactions/escape



Fractions of elements

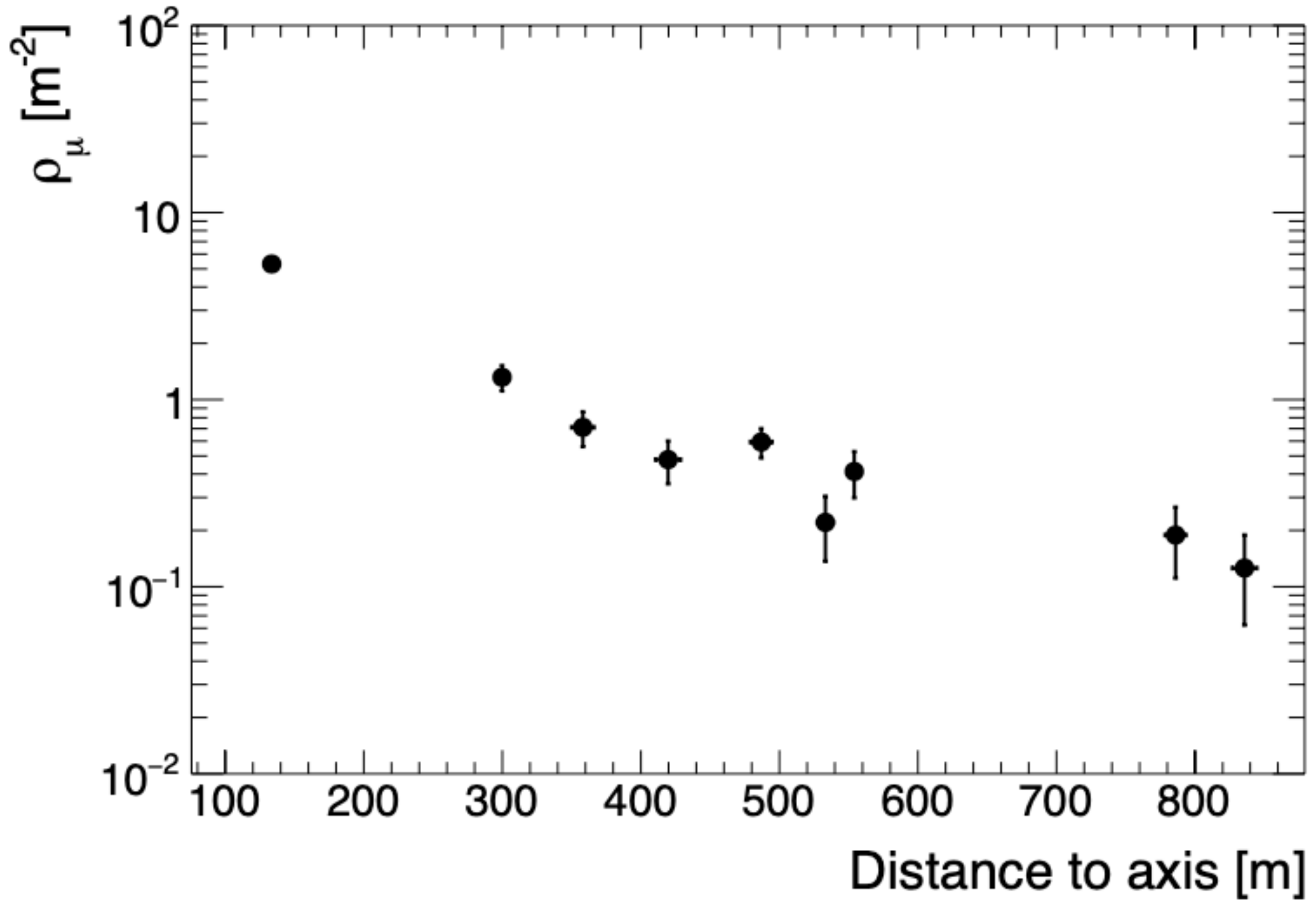
derived from model dependent fits of the X_{max} distributions (+ many other measurements)

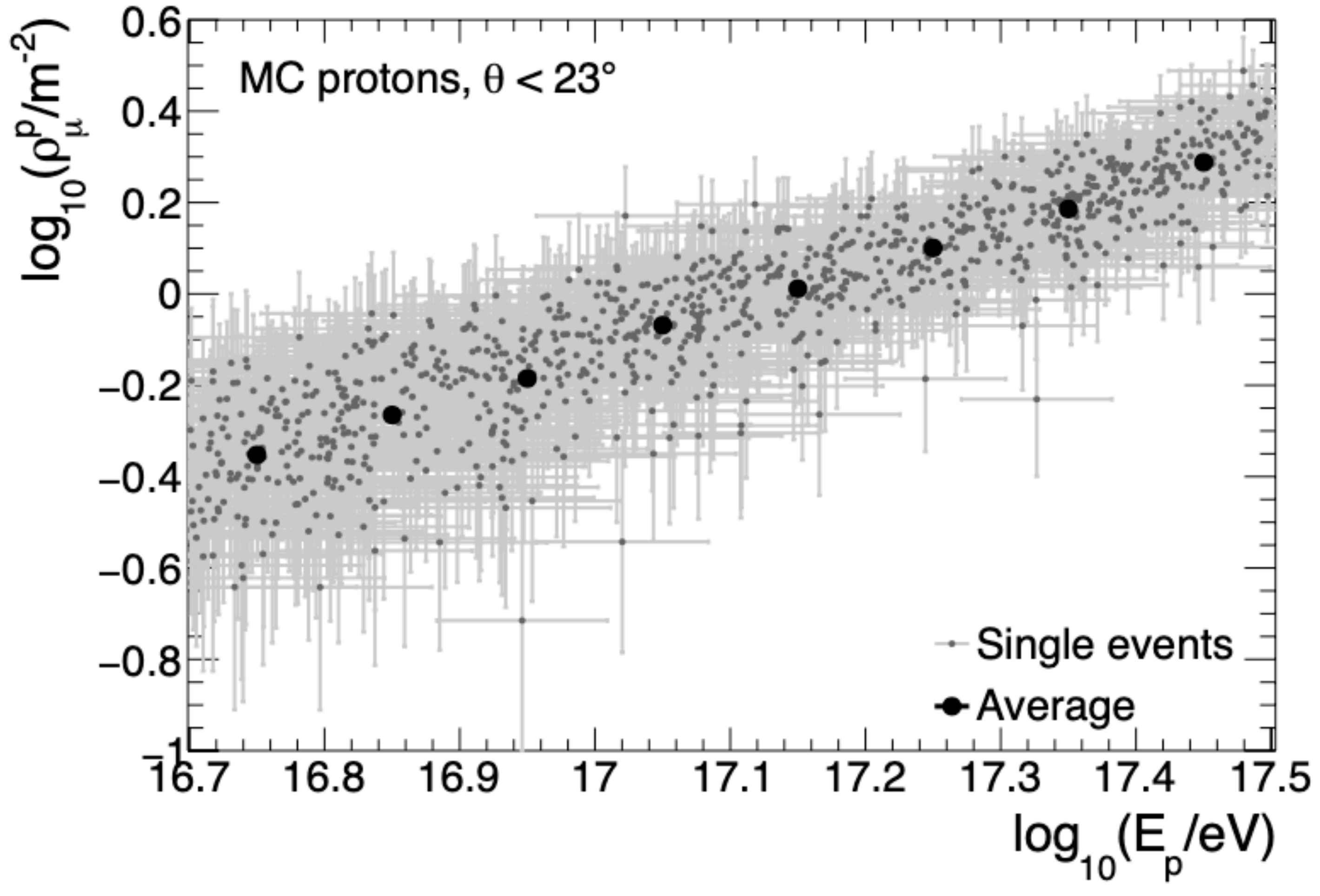
- they provide model dependent information on the mass evolution



Auger Coll., Phys.Rev.D102 (2020) 062005
Auger Coll., Eur. Phys. J. C 81 (2021) 966
E.Mayotte, PoS(ICRC2023) 365 and refs.therein

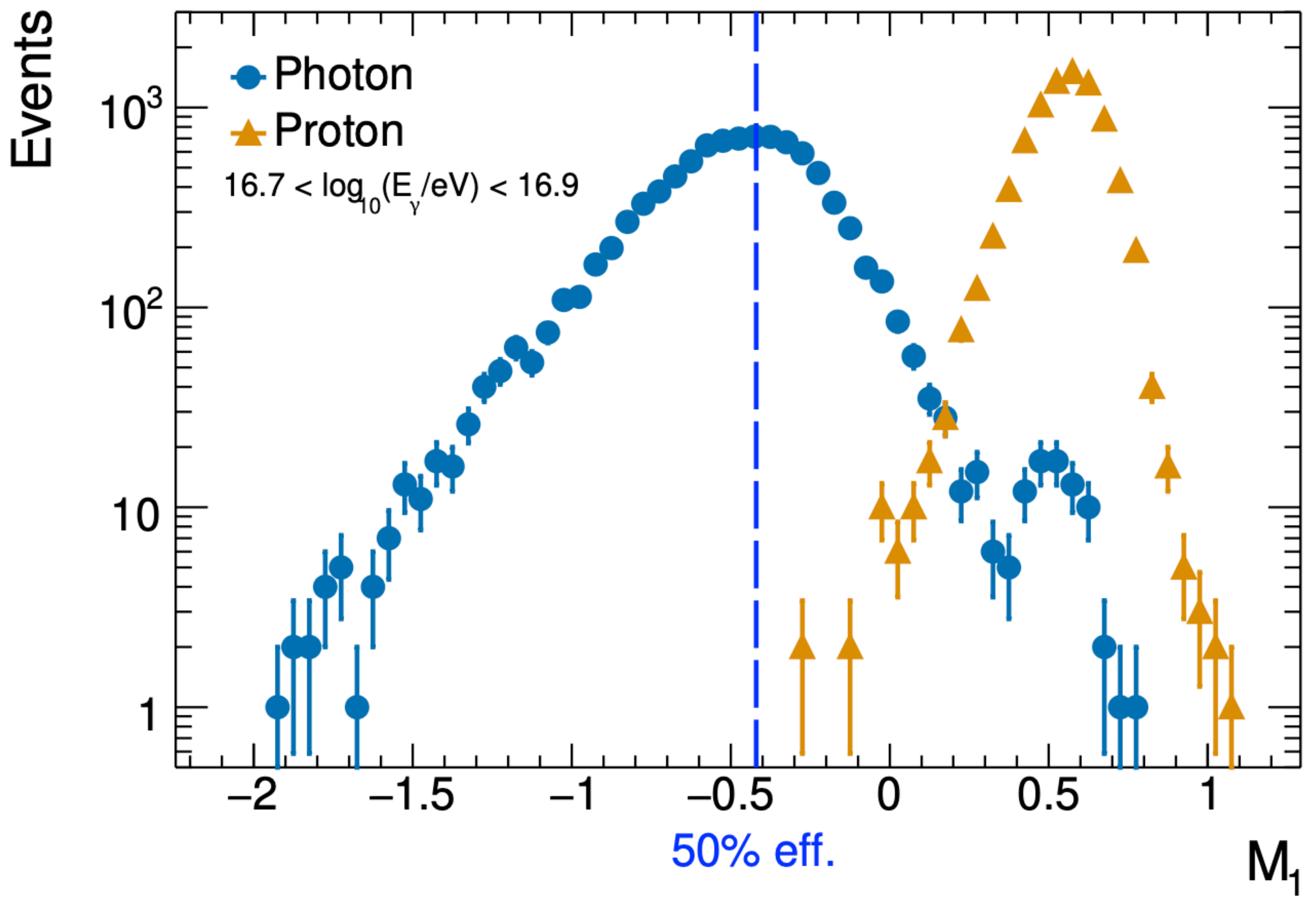
Detecting a diffuse flux of photons above 5 10^{16} eV





$$M_1 = \log_{10}\left(\sum_i \frac{\rho^i_\mu}{\rho^p_\mu} \times \frac{r_i}{200\,\mathrm{m}}\right)$$

M_1 <0 for photons



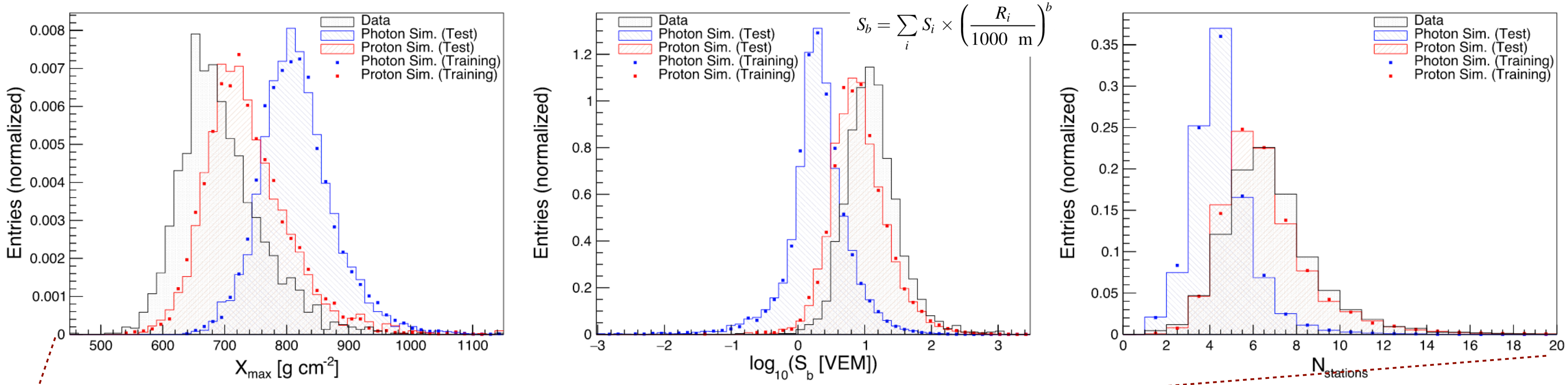
Data based on SD433 + Underground muon detectors = 2204 events after selection cuts (mostly due to geometry)

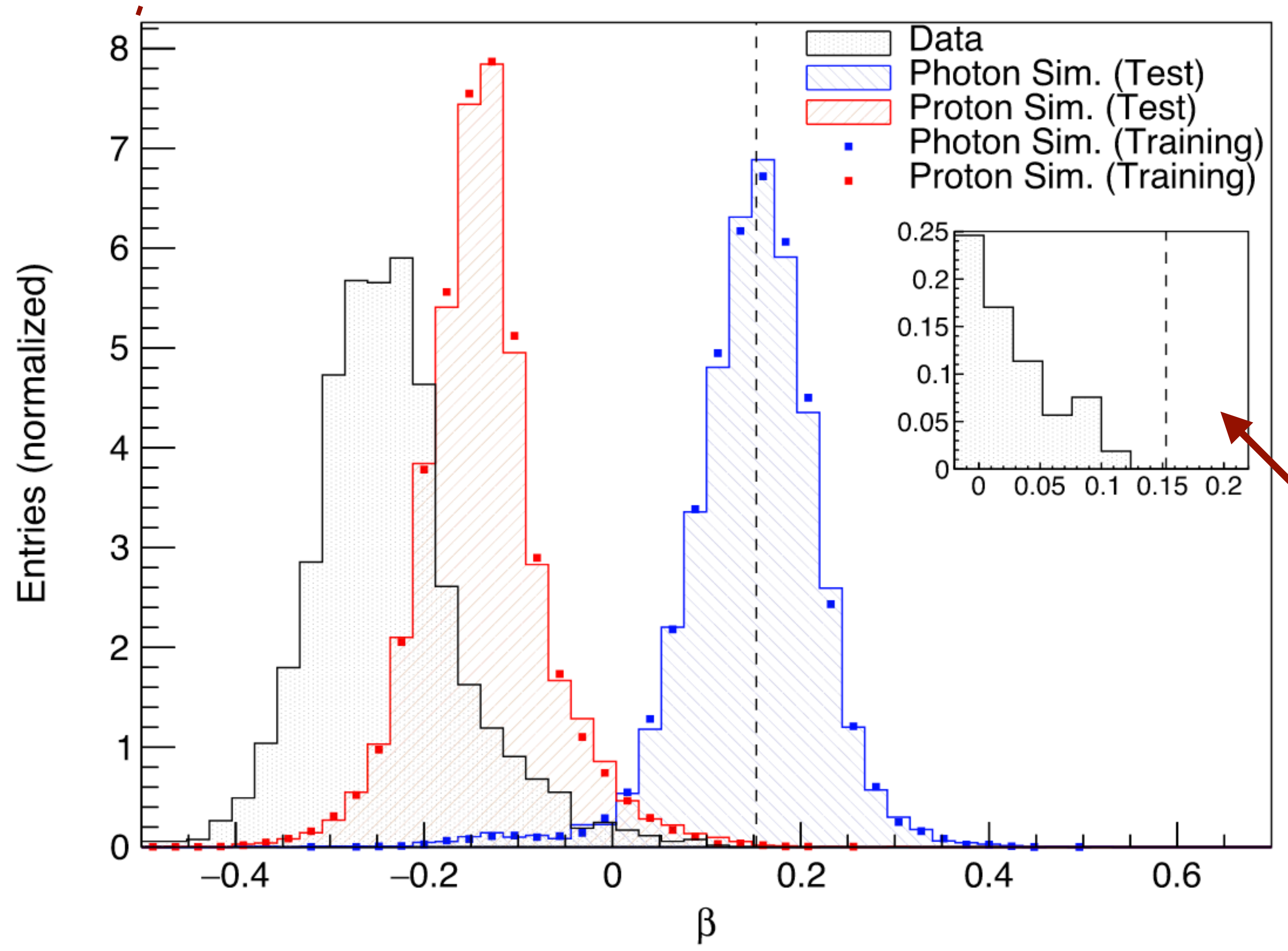
From simulations: background rejection < 10^{-5}
~15000 events after cuts, background free

0 candidates

First measurement of the diffuse photon flux from the Southern hemisphere

Detecting a diffuse flux of photons above 2 10^{17} eV





Data based on SD750 + Coihueco&HEAT telescopes = 2204 events after selection cuts (mostly due to geometry)

From simulations: background rejection ~9 10^{-4}
2204 events after cuts, 2 bckg events

0 candidates

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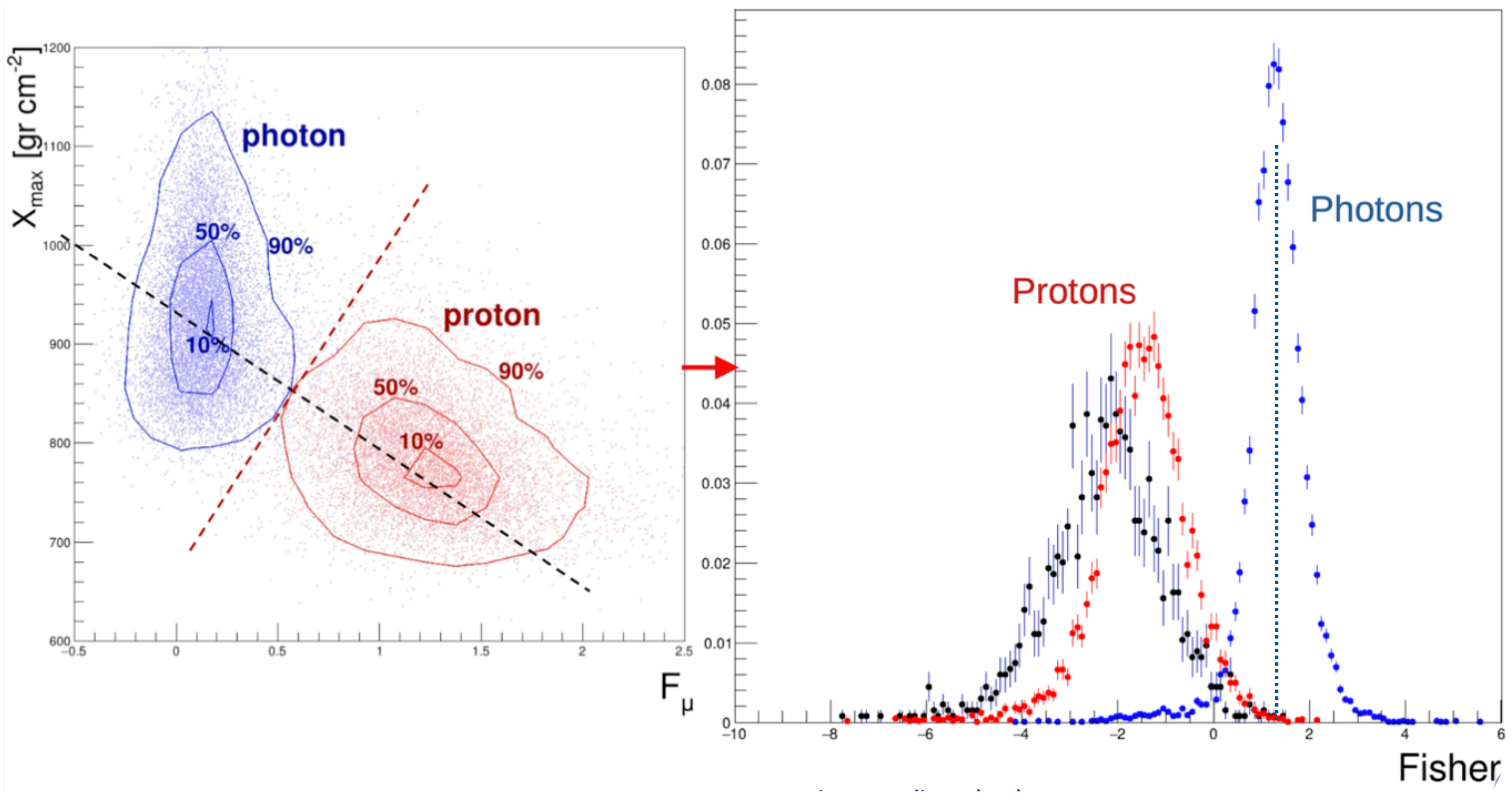
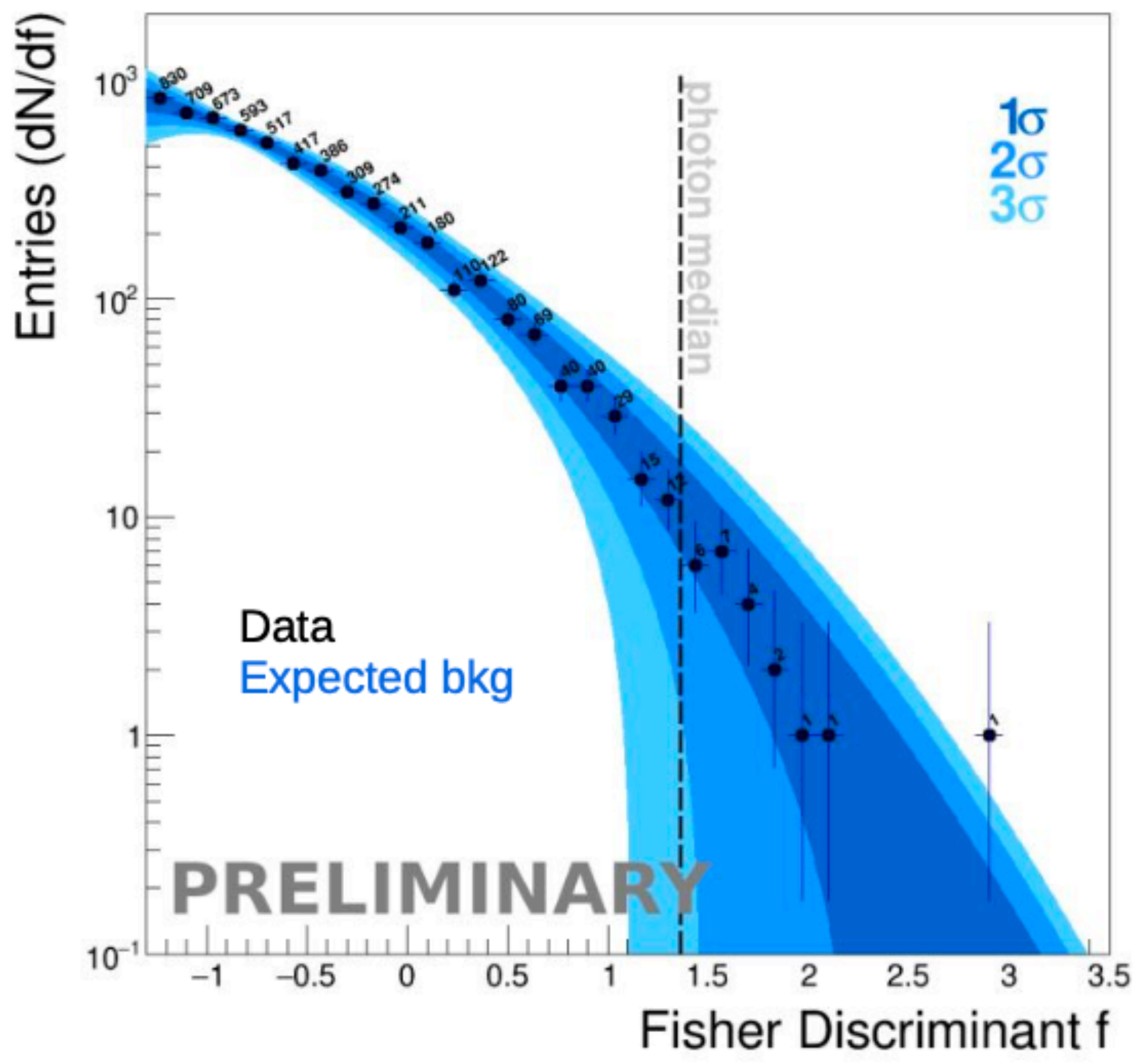
Detecting a diffuse flux of photons above 10^{18} eV



$$S_{pred} = \sum_{i=1}^{4} S_i = \sum_{i=1}^{4} f_i(F_\mu)\, S_{i,comp}$$

$$F_\mu = \frac{S_{rec} - \sum_i (1-\alpha_i) S_{i,comp}}{\sum_i \alpha_i S_i}$$

- ➡️ $S_{i,comp}$ depends only on E, X_{max} and geometry, provided from hybrid reconstruction
- ➡️ F_μ = proxy for muon content, derived from universality properties of EAS



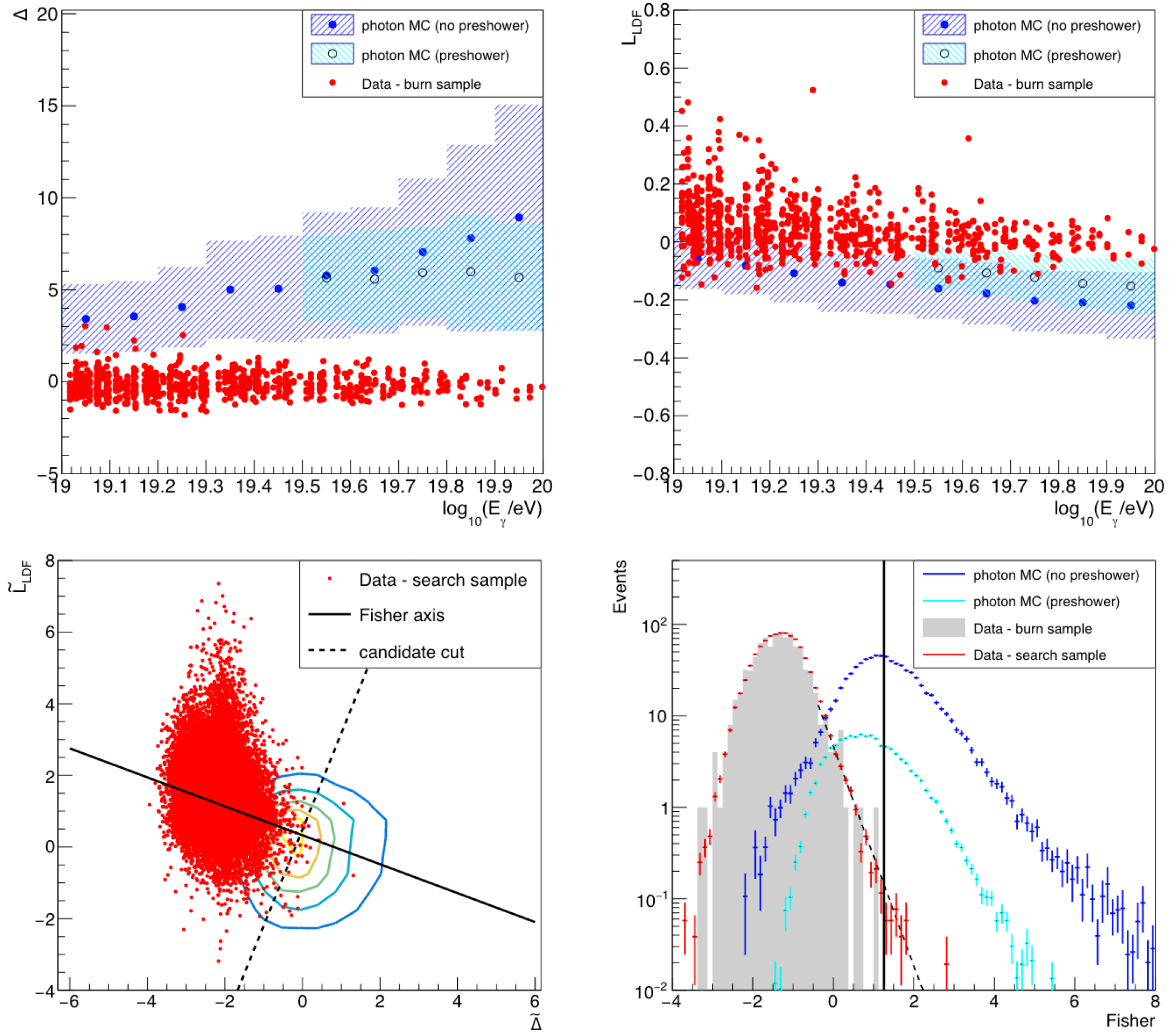
Hybrid events : >65000 after selection cuts

Fisher analysis based on Xmax, F_μ, E_γ

Background estimated from data : background rejection ~ 10^{-4}

22 candidates, consistent with expected (30±15) bckg events

Detecting a diffuse flux of photons above 10^{19} eV



Steeper LDF and large risetime of photon-induced showers are used as discriminants

$$\Delta = \frac{1}{N}\sum_i \frac{(t^i_{1/2} - t^{\text{bench}}_{1/2})}{\sigma_{t_{1/2}}} \qquad L_{\text{LDF}} = \log_{10}\left(\frac{1}{N}\sum_{i=1}^{N}\frac{S_i}{f_{\text{LDF}}(r_i)}\right)$$

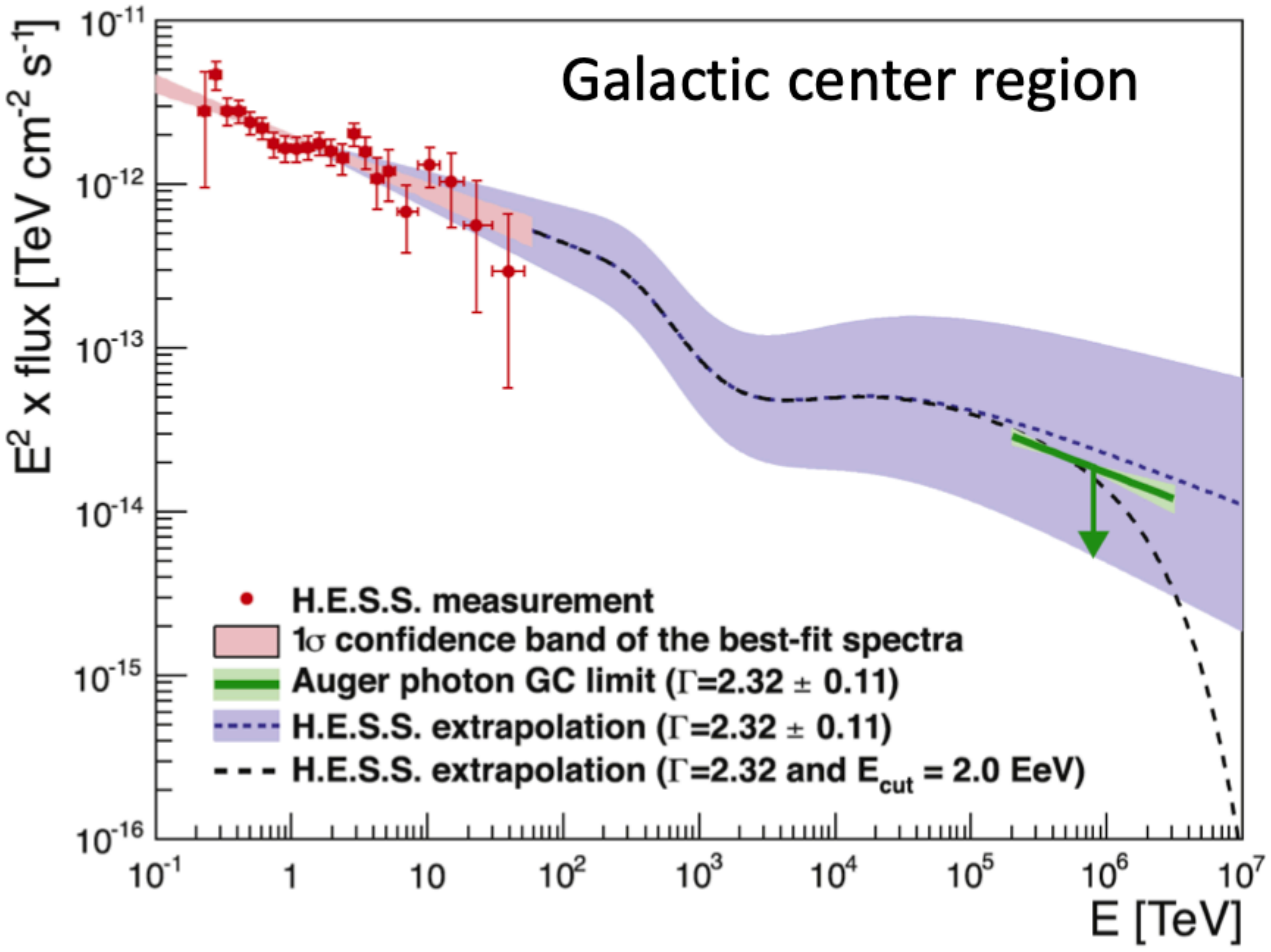
Huge exposure

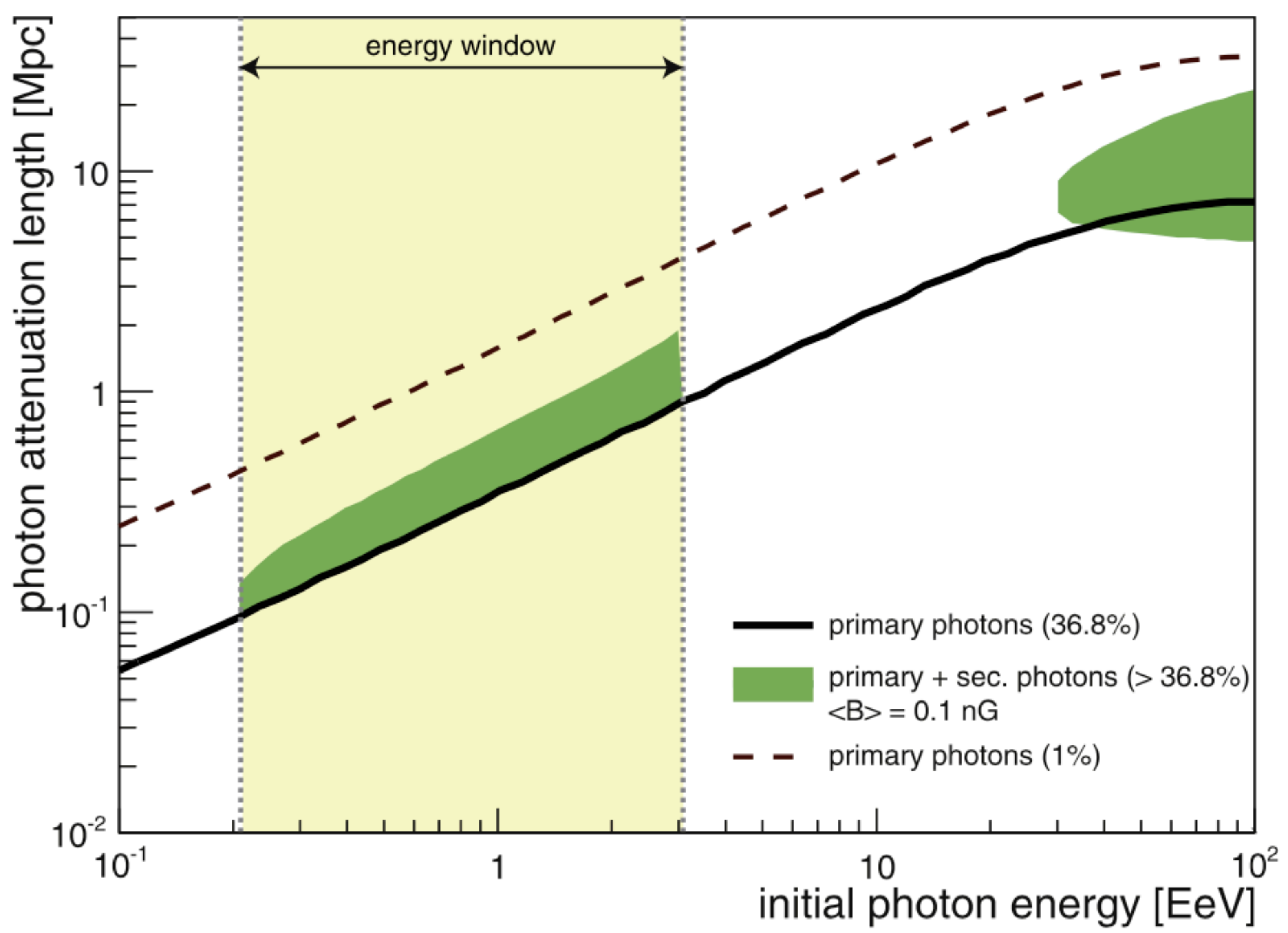
SD1500 events : ~50000 after selection cuts
Fisher analysis based on Δ and L_{LDF}

Background estimated from data

16 candidates, consistent with expected bckg

Search for point-like sources of photons





Targeted search

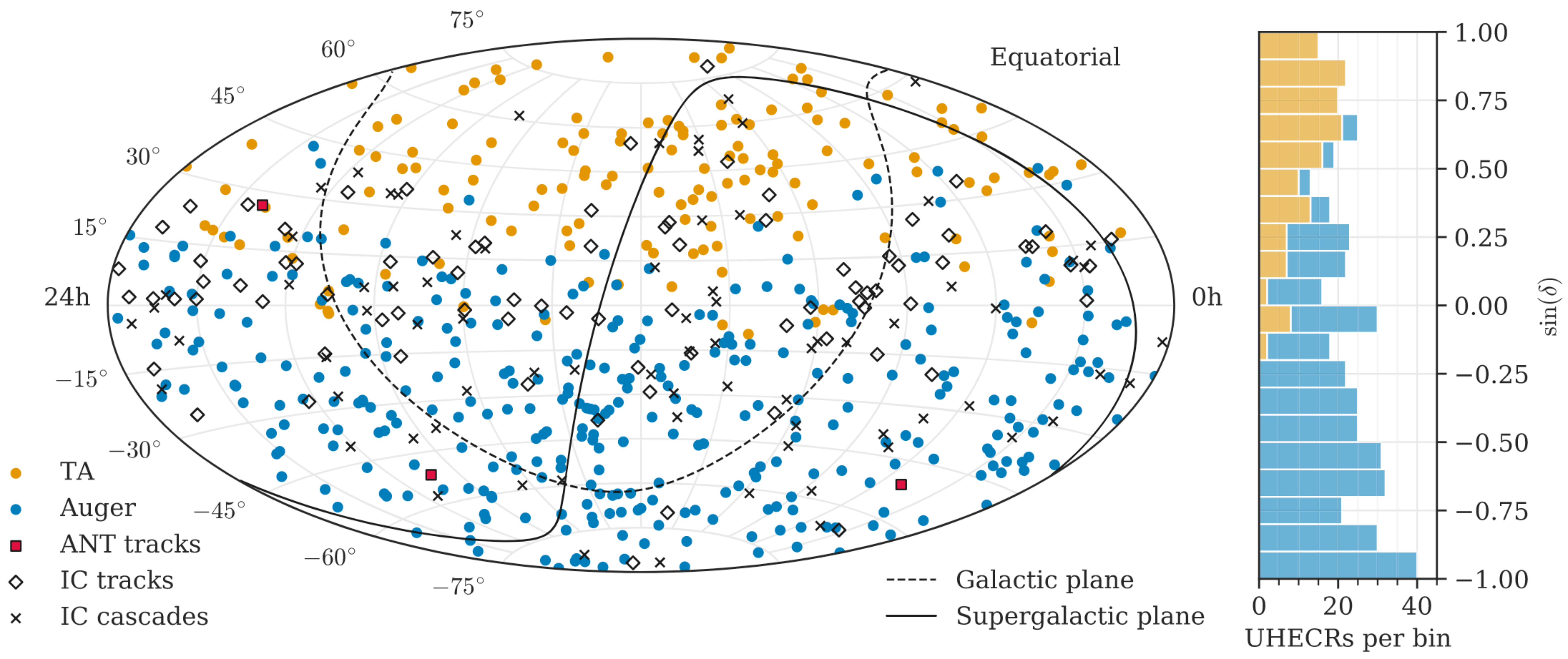
- Stacked analysis focussing on 12 target sets (364 candidate sources in total)
- no significant excess, excluding nearby and steady sources of photons in the EeV range

- Extrapolating the HESS flux : constrains on the continuation of the measured TeV fluxes to EeV energies
- upper limit on cut-off energy at ~ 2 EeV

Auger Coll., ApJ 837 (2017) L25

Neutrinos (IceCube, ANTARES) and UHECRs (Auger, TA)

3 complementary analyses looking for possible correlations between UHECR (Auger and TA) and HE neutrinos (IceCube and ANTARES)
For both the UHECR and ν data sets, the combination of data from the two respective observatories provides a FoV over the entire sky



all results compatible with background hypothesis (Isotropic flux for either UHECR or ν)

But

- UHECR composition getting heavier with increasing energy
- Neutrino sources beyond the horizon of UHECR sources (e.g.TXS0506+056: ~1.3 Gpc)
- if transient sources, UHECRs arrive much later, due to deflections (uncertainties in EGMF)
- sources producing HE neutrinos could be unable to produce UHECRs and viceversa

Direct correlations may be found with UHE neutrinos, not yet observed

IceCube, ANTARES, Auger, TA, Astrop.J.934 (2022) 164

Search for Galactic neutron sources

12 classe of objects (888 sources)

Produced in interactions of UHE protons, but impossible to distinguish from proton-induced showers

Mean travel distance $\sim 9.2 \times (E_{EeV}) \quad kpc$

Identification: excess of CRs from a given direction.

$$\rho_j^{\text{obs}} = \sum_i^N w_{ij}$$

CR density from j-th target

$$w_{ij} = \frac{1}{2\pi\sigma_i^2} \exp\left(-\frac{\xi_{ij}^2}{2\sigma_i^2}\right)$$

Most significant target from each target set – ≥ 1 EeV				
Class	R.A. [deg]	Dec. [deg]	Flux U.L. [km^{-2} yr^{-1}]	E-Flux U.L. [eV cm^{-2} s^{-1}]
msec PSRs	286.2	2.1	0.026	0.19
γ-ray PSRs	296.6	−54.1	0.023	0.17
LMXB	237.0	−62.6	0.017	0.12
HMXB	308.1	41.0	0.13	0.97
H.E.S.S. PWN	128.8	−45.6	0.016	0.12
H.E.S.S. other	128.8	−45.2	0.014	0.11
H.E.S.S. UNID	305.0	40.8	0.15	1.1
Microquasars	308.1	41.0	0.13	0.95
Magnetars	249.0	−47.6	0.011	0.079
LHAASO	292.3	17.8	0.038	0.28
Crab	83.6	22.0	0.020	0.15
Gal. Center	266.4	−29.0	0.0053	0.039

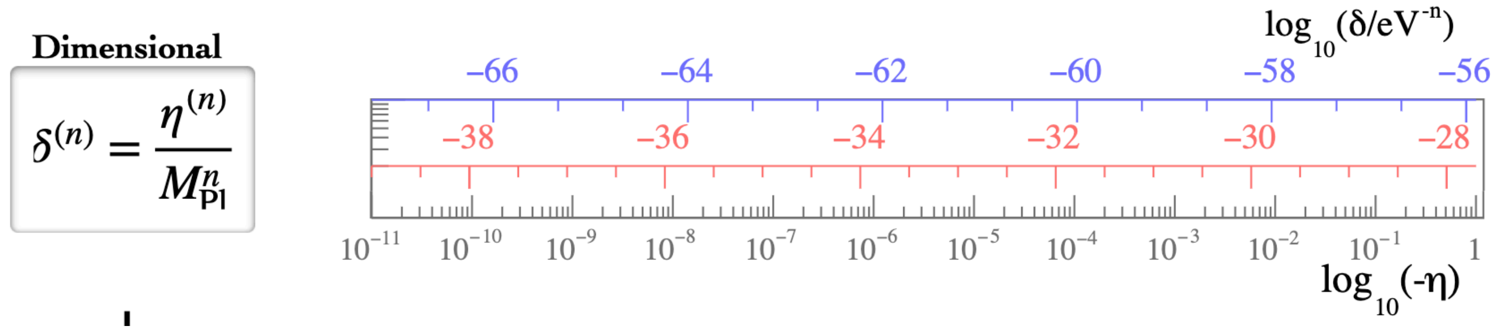
Auger Coll., PoS(ICRC2023) 246

- no significant evidence for point sources of neutrons
- excess, excluding nearby and steady sources of photons in the EeV range
- Better limits can be obtained by combining objects in the same class (combined p-value)

- no transient sources are considered, work ongoing

Search for Lorenz invariance violation

$$E_i^2 - p_i^2 = m_i^2 + \sum_{n=0}^{N} \delta_i^{(n)} E_i^{2+n} = m_i^2 + \eta_i^{(n)} \frac{E_i^{2+n}}{M_{Pl}^n}$$

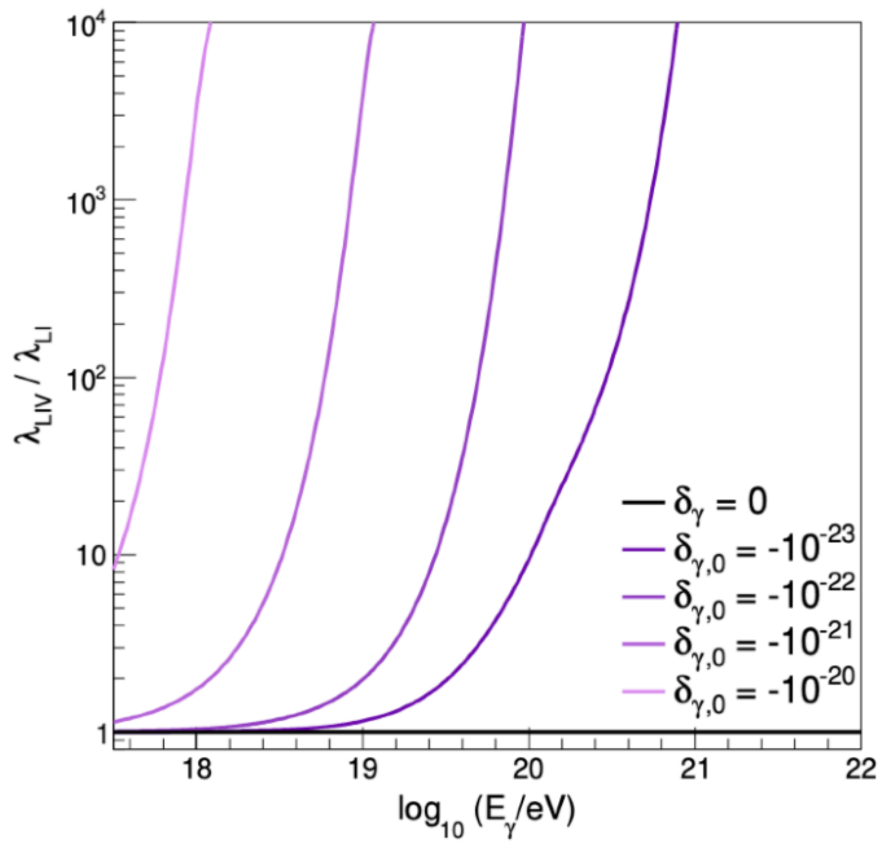


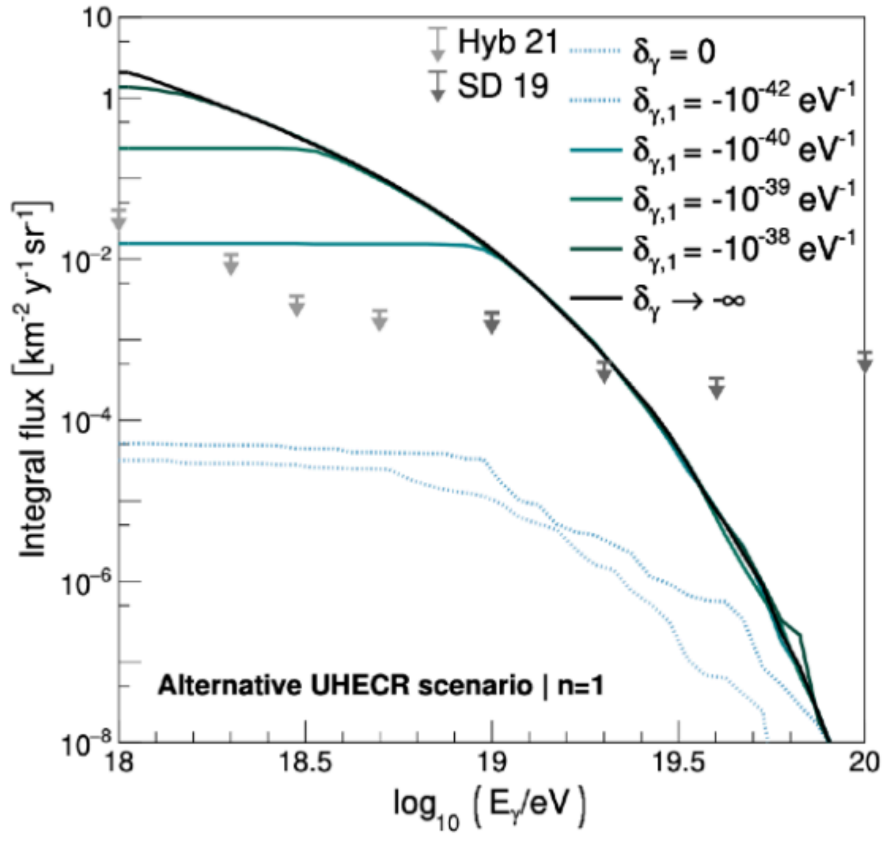
Effects suppressed for low energy and short travel distances : UHECRs !!!

Modification of CR interactions during propagation:

➡️EM : pp cross section modified —> increased mean free path —> less interactions —> more photons expected

➡️hadronic sector: number of interactions reduced —> if LIV lighter nuclear species needed at source to reproduce the composition



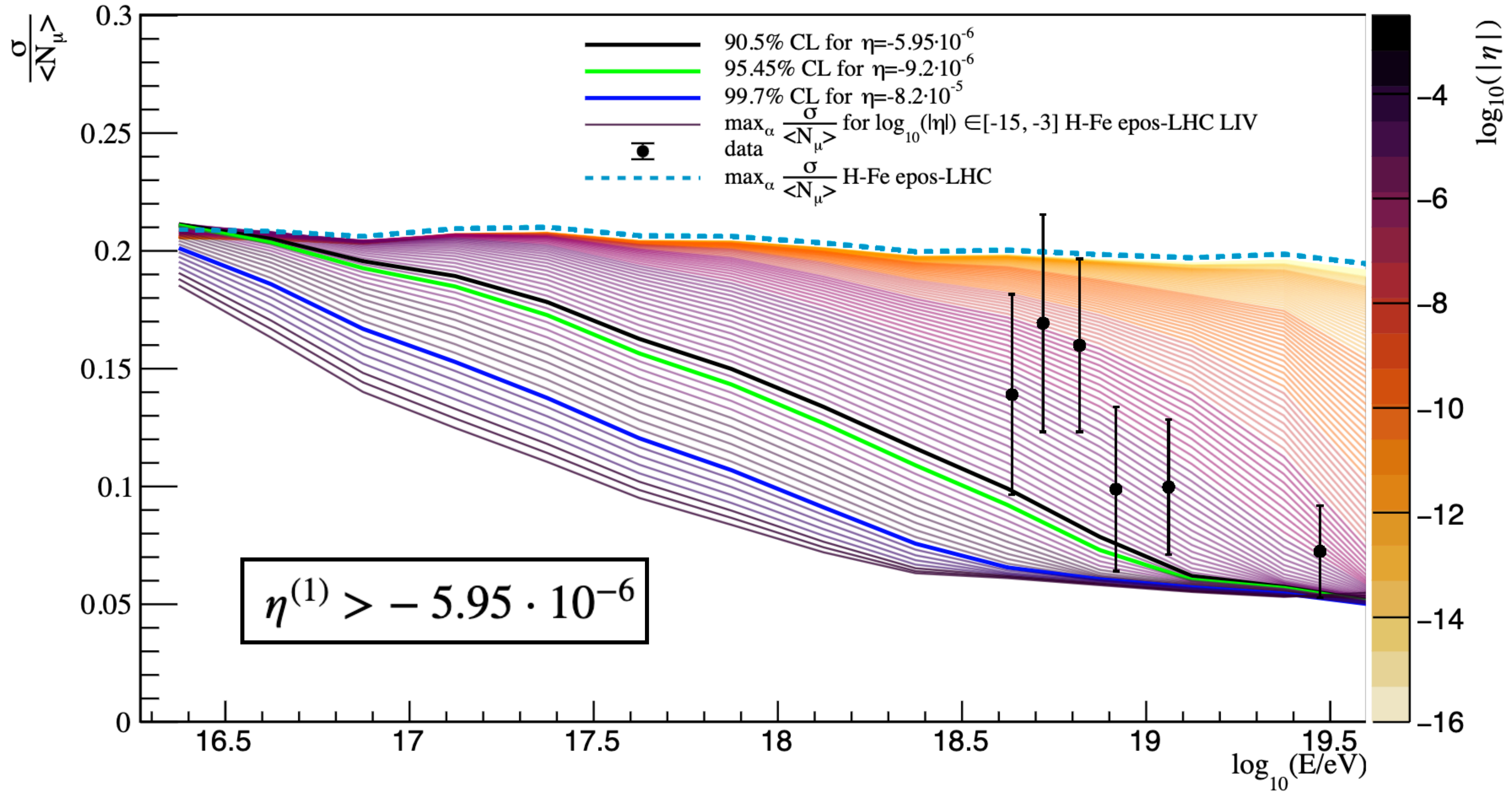


Air shower physics

- for $\eta^{(n)}<0$, decay of π^0 can become forbidden if

$$m_\pi^2 + \eta_\pi^{(n)} \frac{p_\pi^{n+2}}{M_{Pl}^n} < 0$$

- EM component decreasing, hadronic one increasing



Auger Coll., JCAP01 (2022) 023
C.Trimarelli (Auger Coll.), UHECR2022

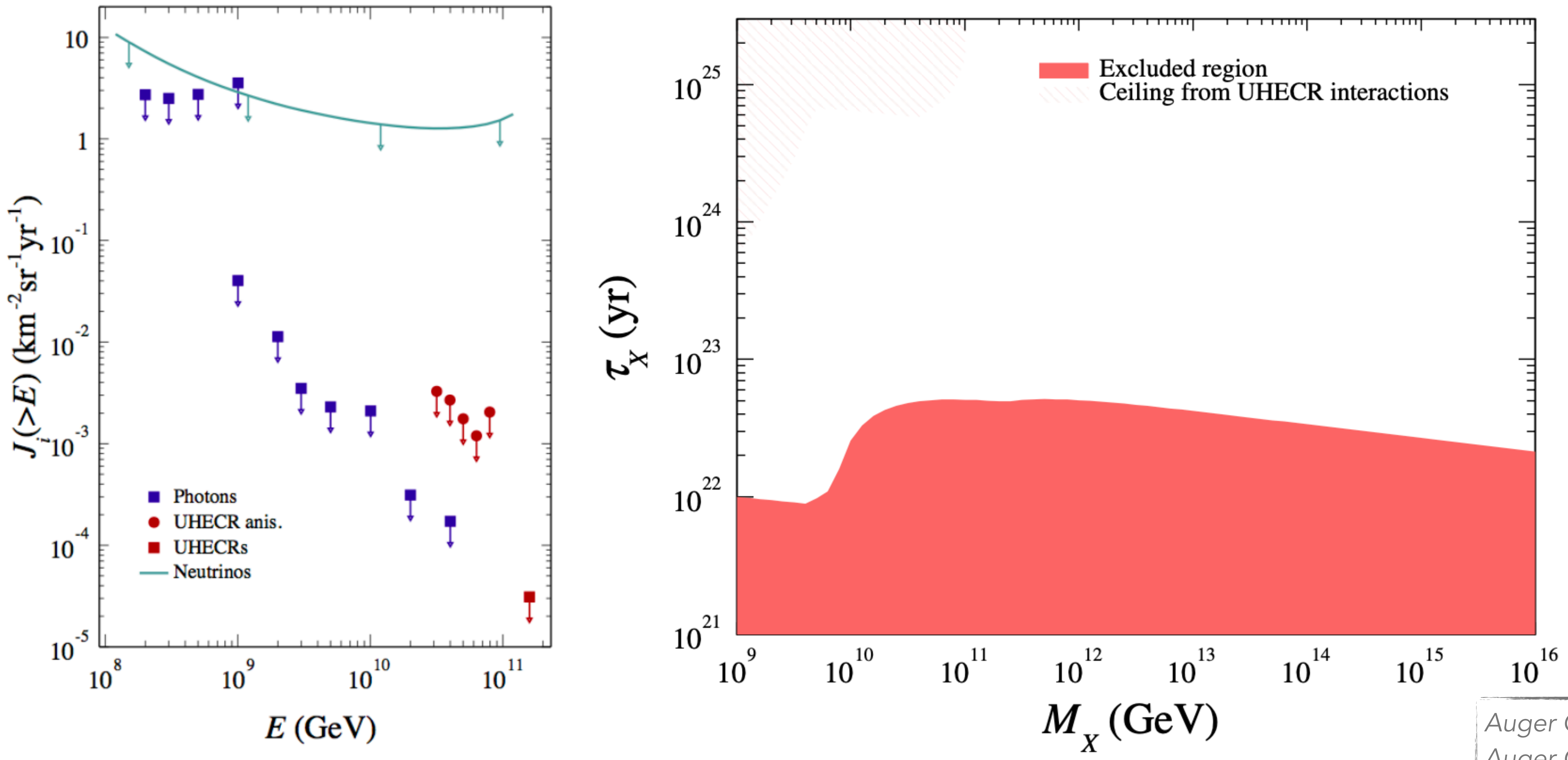
Search for SHDM

Flux of secondaries from SHDM decay ($i = \gamma, \nu, \overline{\nu}, N, \overline{N}$):

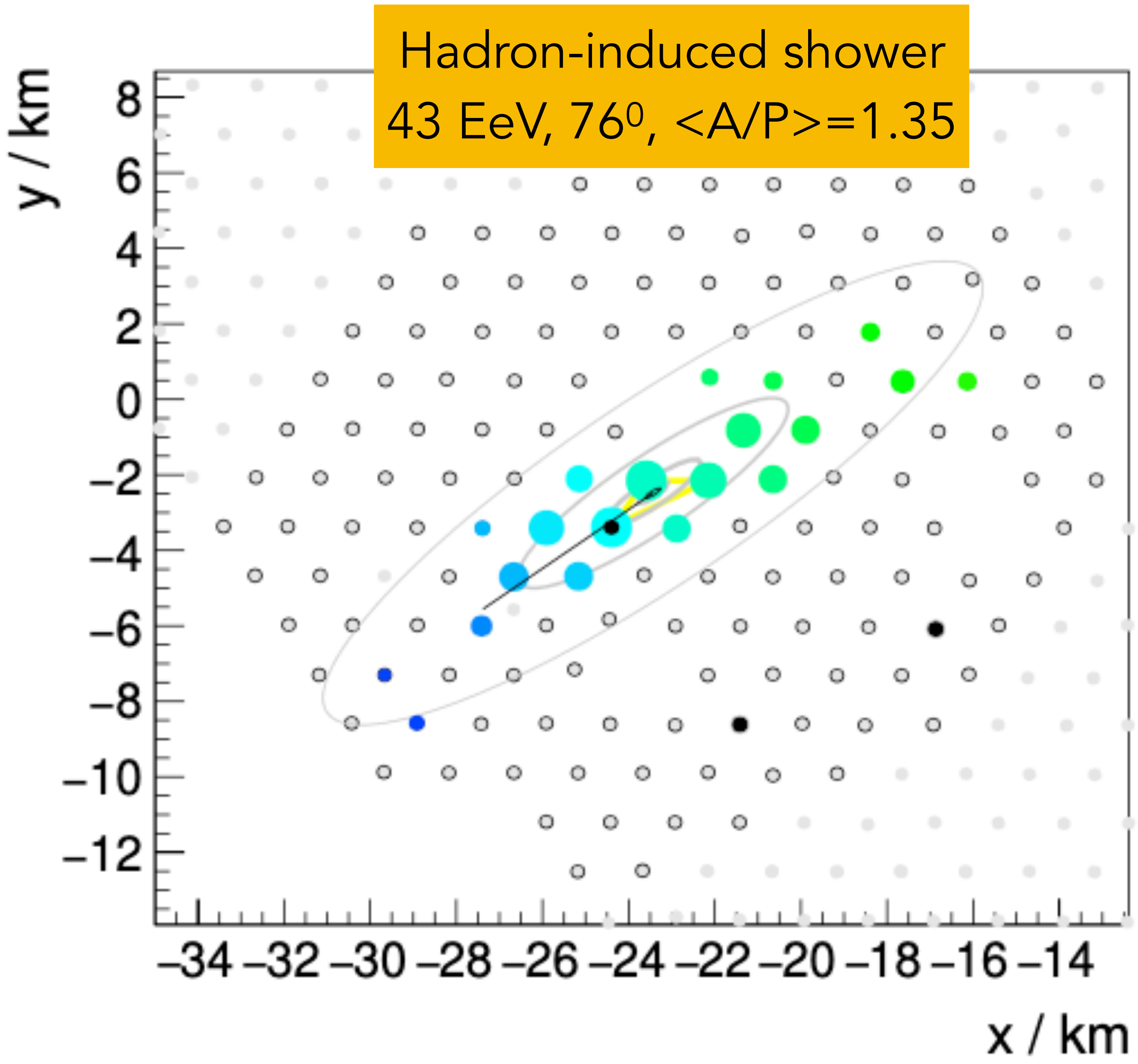
$$J_i^{\mathrm{gal}}(E) = \frac{1}{4\pi M_X c^2 \tau_X} \frac{\mathrm{d}N_i}{\mathrm{d}E} \int_0^\infty \mathrm{d}s\ \rho_{\mathrm{DM}}(\mathbf{x}_\odot + \mathbf{x}_i(s;\mathbf{n})).$$

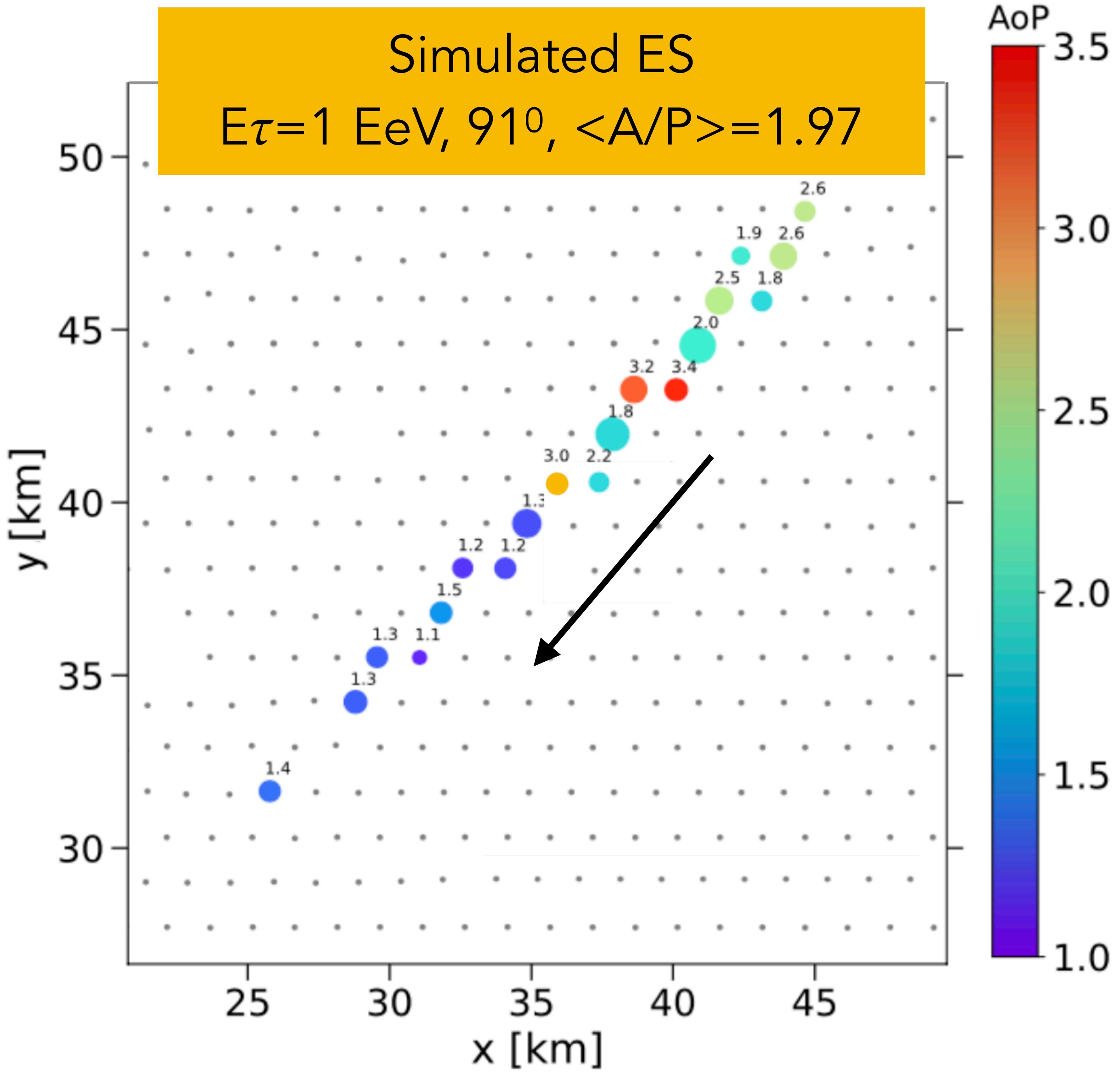
Free parameters

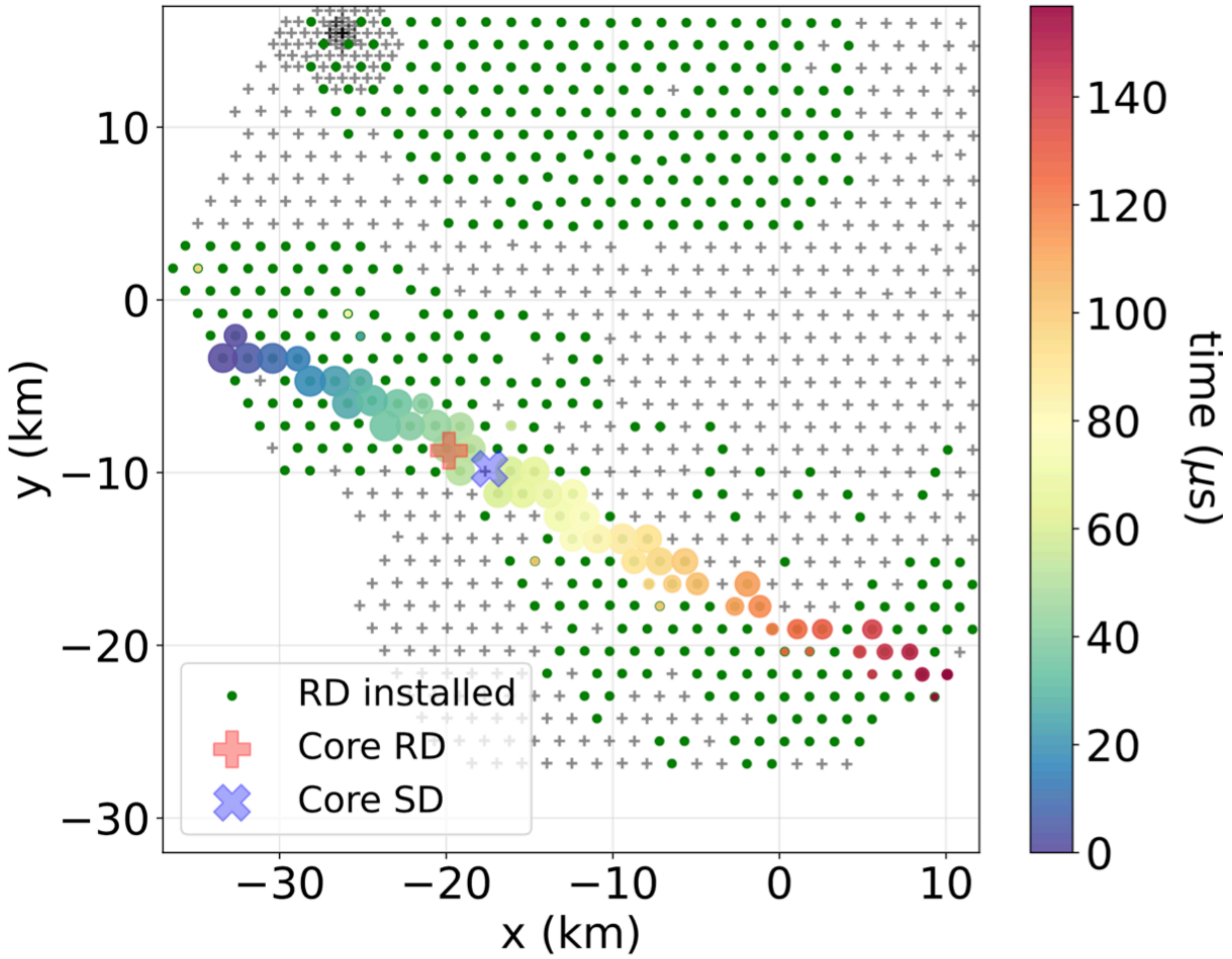
$$\tau_X = \hbar M_X^{-1} \exp(4\pi/\alpha_X)$$

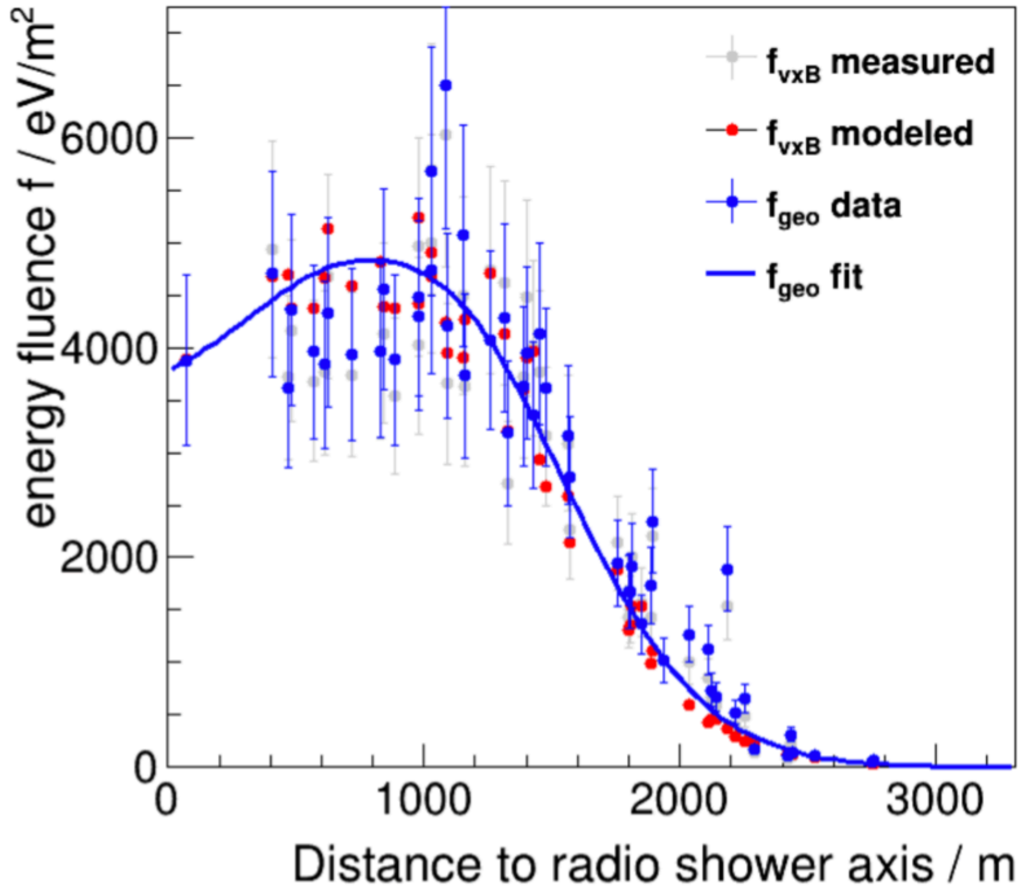


Auger Coll., PRD107 (2023) 042002
Auger Coll., PRL 130 (2023) 061001









Inclined event in radio

	RD	SD
Azimuth (deg)	156.99±0.01	157±0.1
Zenith (deg)	84.7±0.01	84.7±0.1
Energy (EeV)	36.23 ± 3.34	38.55 ± 2.92
Core X (km)	-19.8	-17.40±0.88
Core Y (km)	-8.73	-9.78±0.45

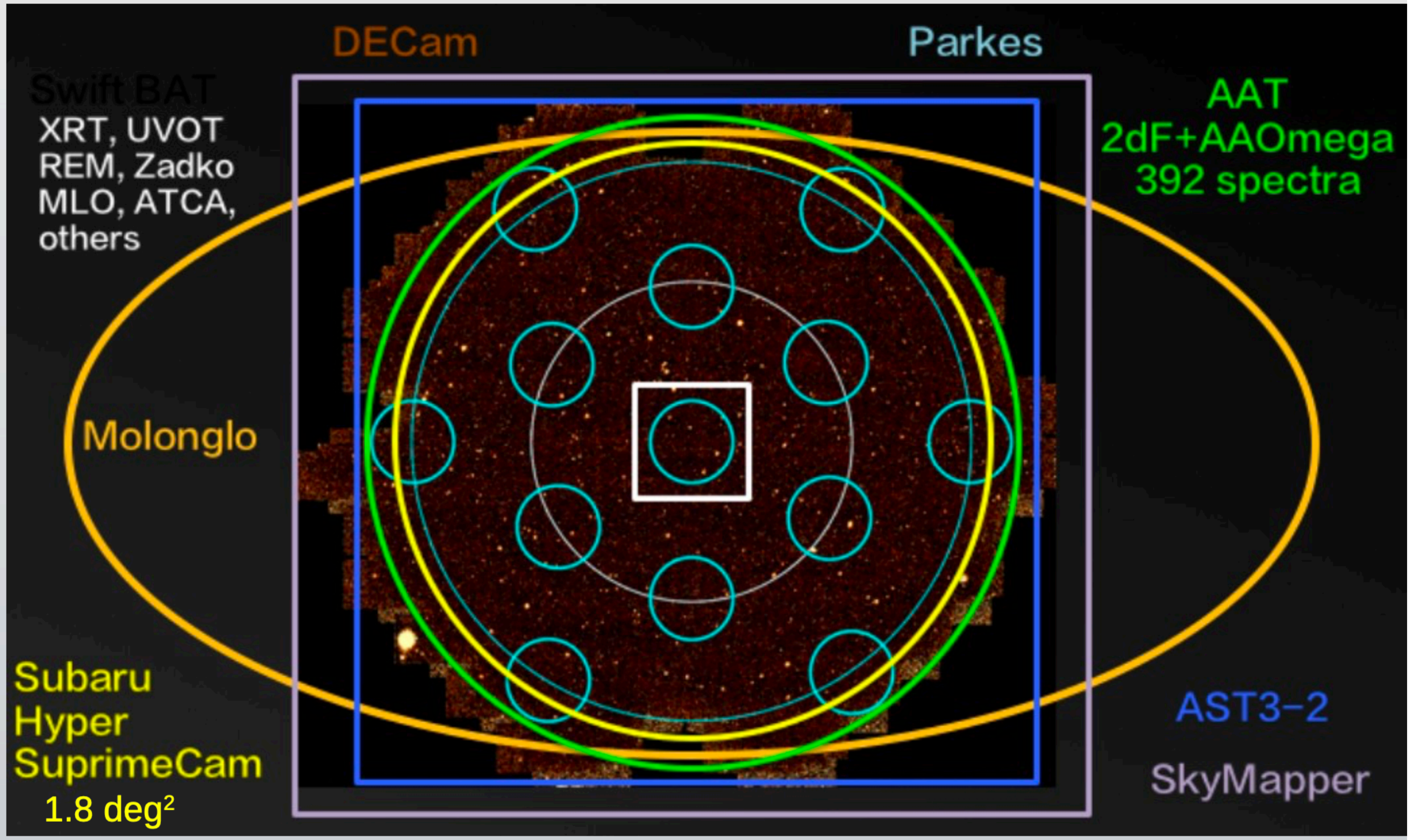
Deeper Wider Faster (DWF)

Multi-instrument (> 30) project

- Radio through **ultra-high energies incl. non-photons (Auger)**

~ 10 groups observe **simultaneously**

- Deep+wide-field fast (sampling and analysis) multi-wavelength + multi-messenger probing of **same field**



Auger:

- Full-SD events in DWF field of view shared, no significant coincidences found so far
- Future plan: include smaller sub-arrays of Auger for lower energy events

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