Karlsruhe Institute of Technology

Cosmic particles from distant galaxies: a new astronomy?

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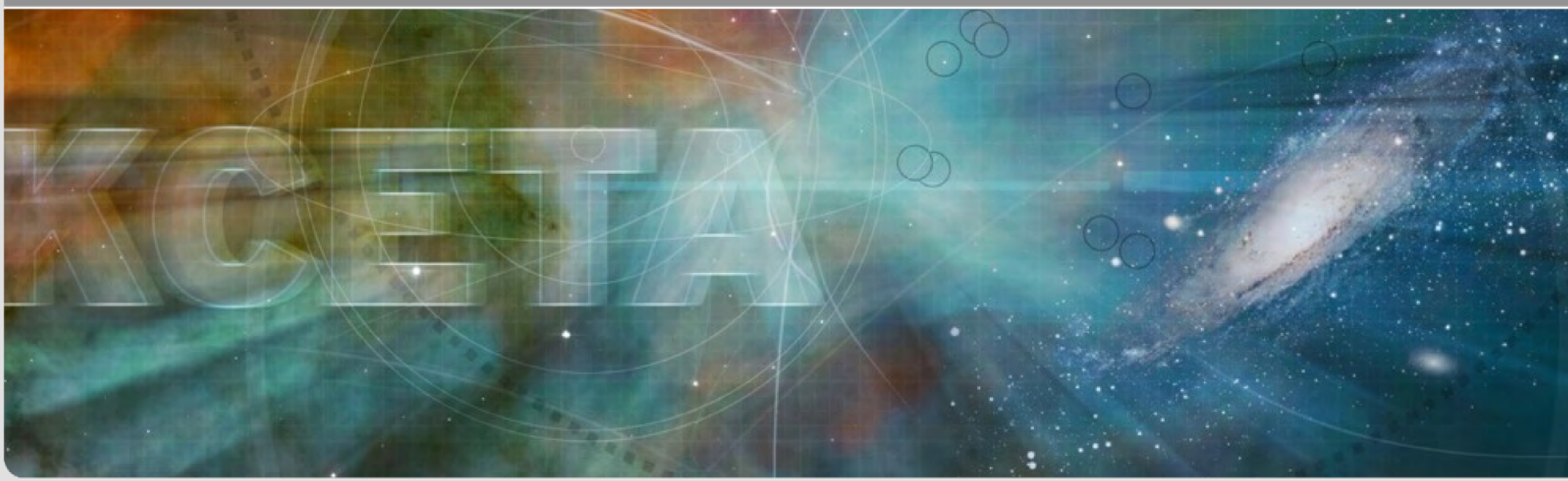
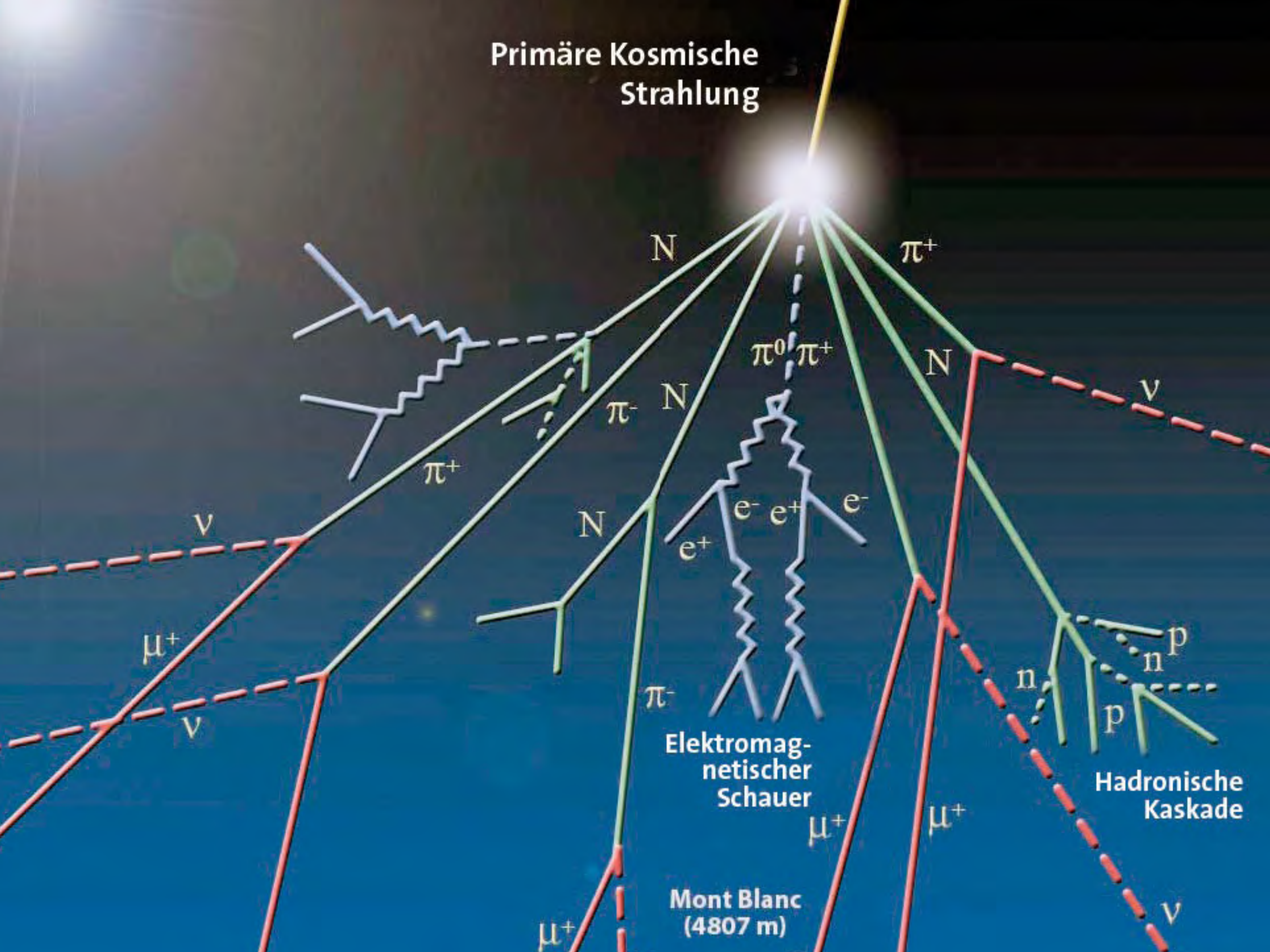
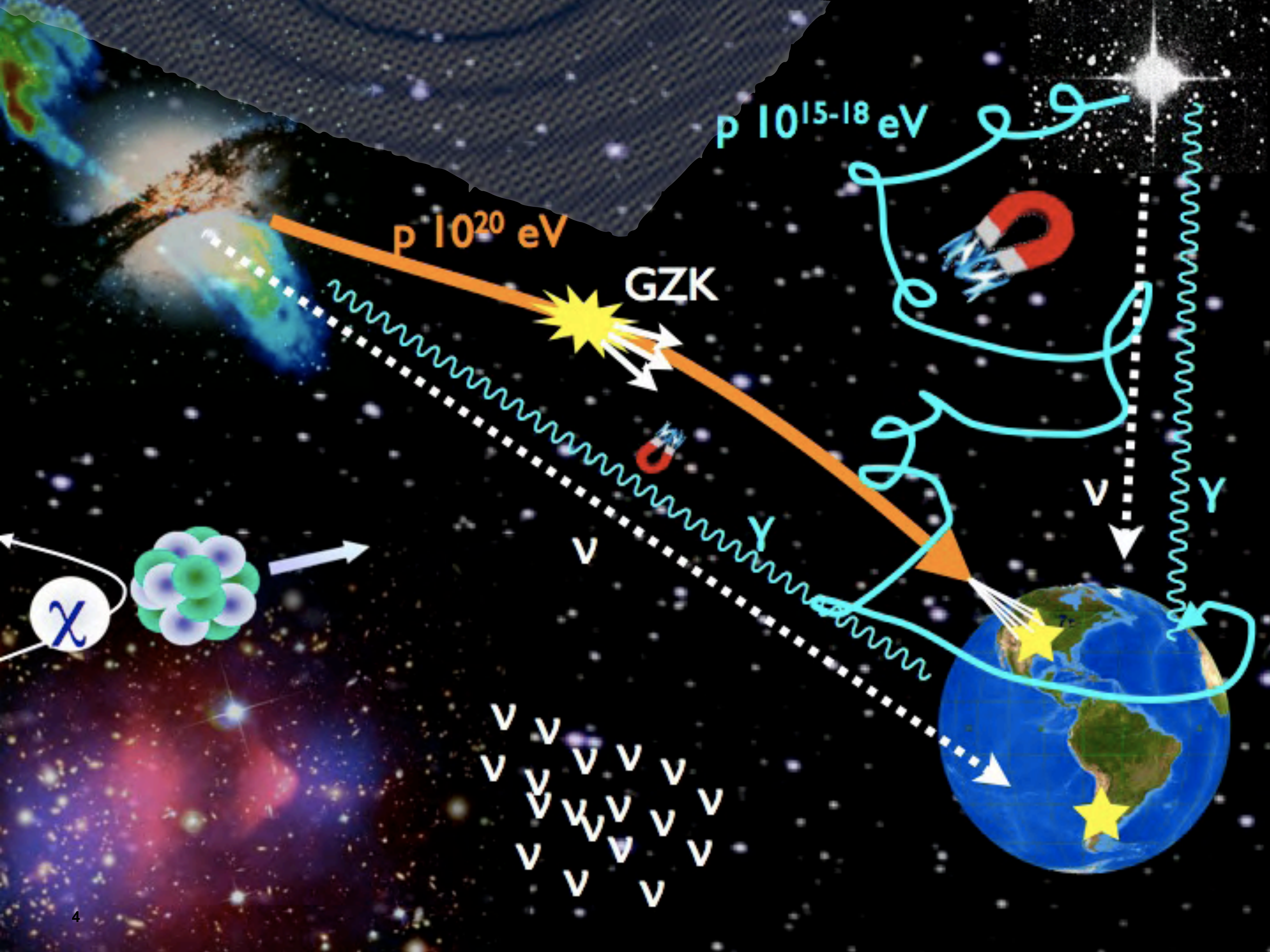
KIT-Center Elementary Particle and Astroparticle Physics KCETA

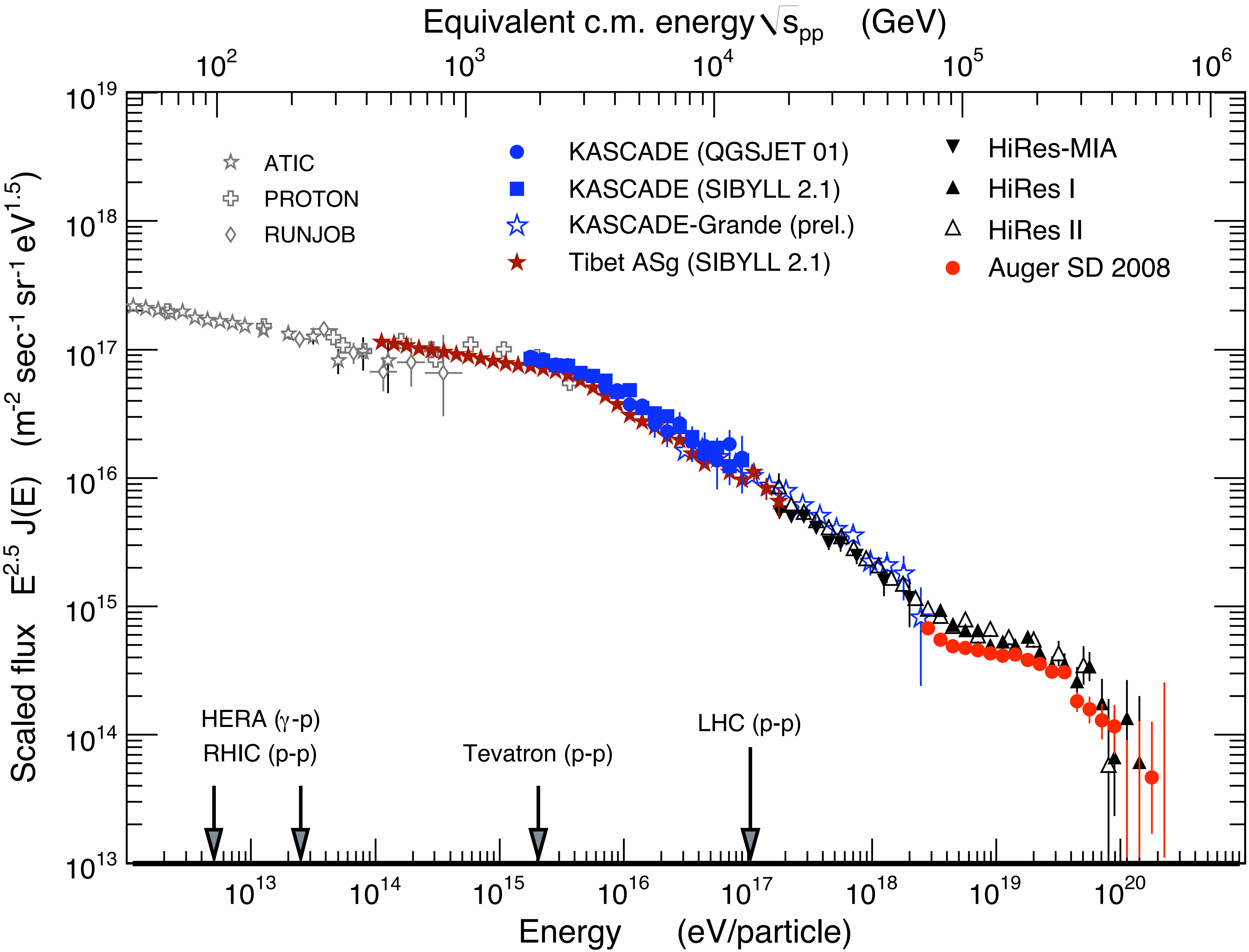


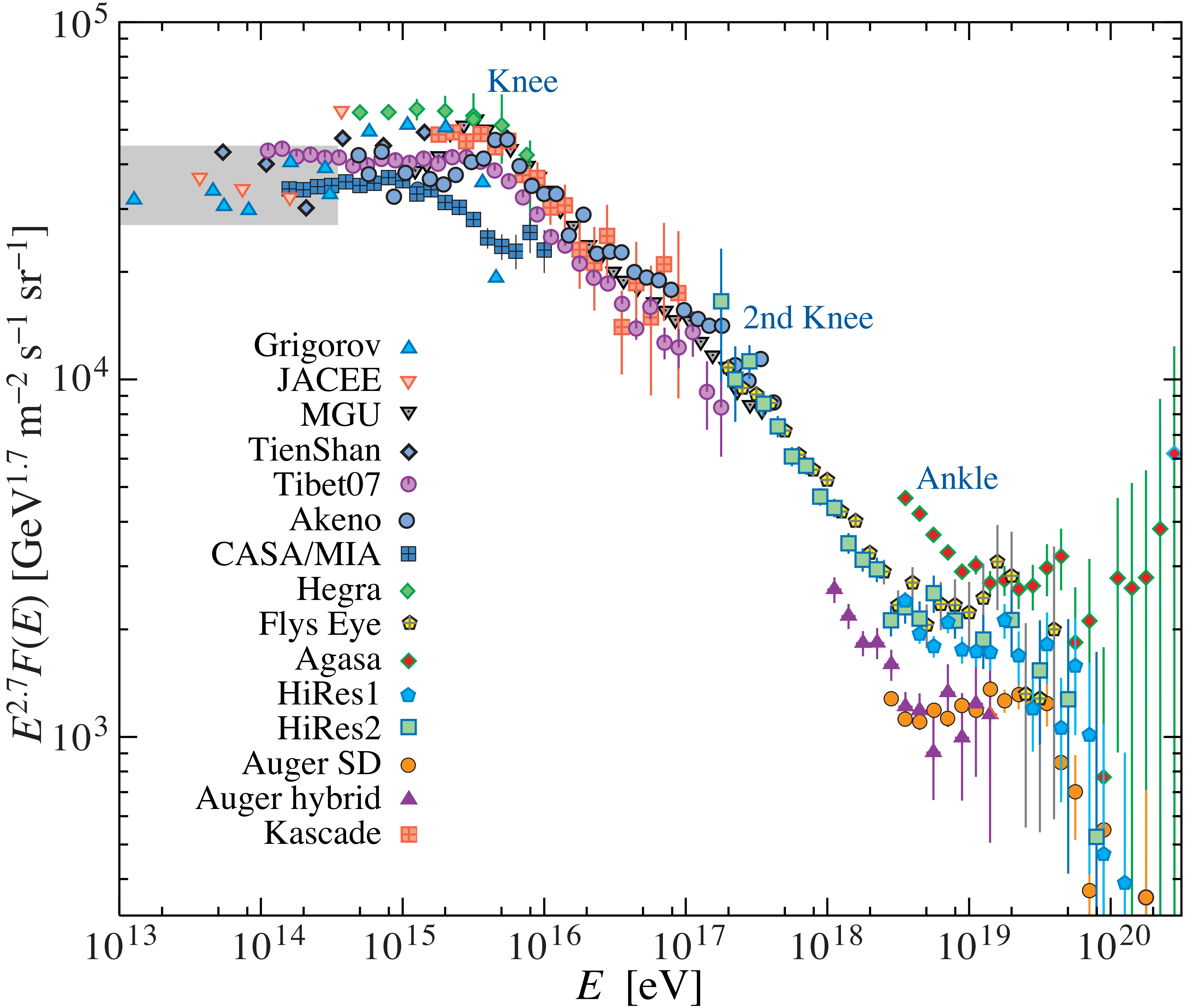


Primäre Kosmische Strahlung
N
π+
π0 π+
N
N
π-
ν
π+
ν
N
e- e+
e-
e+
μ+
ν
π-
p
n
n
p
Elektromagnetischer Schauer
Hadronische Kaskade
μ+
μ+
Mont Blanc (4807 m)
μ+
ν


μ-
e+
ν
ν
This cosmic ray image is a modified version of an original picture produced by CERN


p 10^20 eV
GZK
p 10^15-18 eV
γ
ν
γ
ν
ν
χ


Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2 10^3 10^4 10^5 10^6
10^{19} 10^{18} 10^{17} 10^{16} 10^{15} 10^{14} 10^{13}
Scaled flux $E^{2.5}$ J(E) (m^{-2} sec^{-1} sr^{-1} $eV^{1.5}$)
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande (prel.)
Tibet ASg (SIBYLL 2.1)
HiRes-MIA
HiRes I
HiRes II
Auger SD 2008
HERA (γ-p)
RHIC (p-p)
Tevatron (p-p)
LHC (p-p)
10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
Energy (eV/particle)



Knee
2nd Knee
Ankle
Grigorov
JACEE
MGU
TienShan
Tibet07
Akeno
CASA/MIA
Hegra
Flys Eye
Agasa
HiRes1
HiRes2
Auger SD
Auger hybrid
Kascade
$E^{2.7}F(E)$ [GeV$^{1.7}$ m^{-2} s^{-1} sr^{-1}]
E [eV]

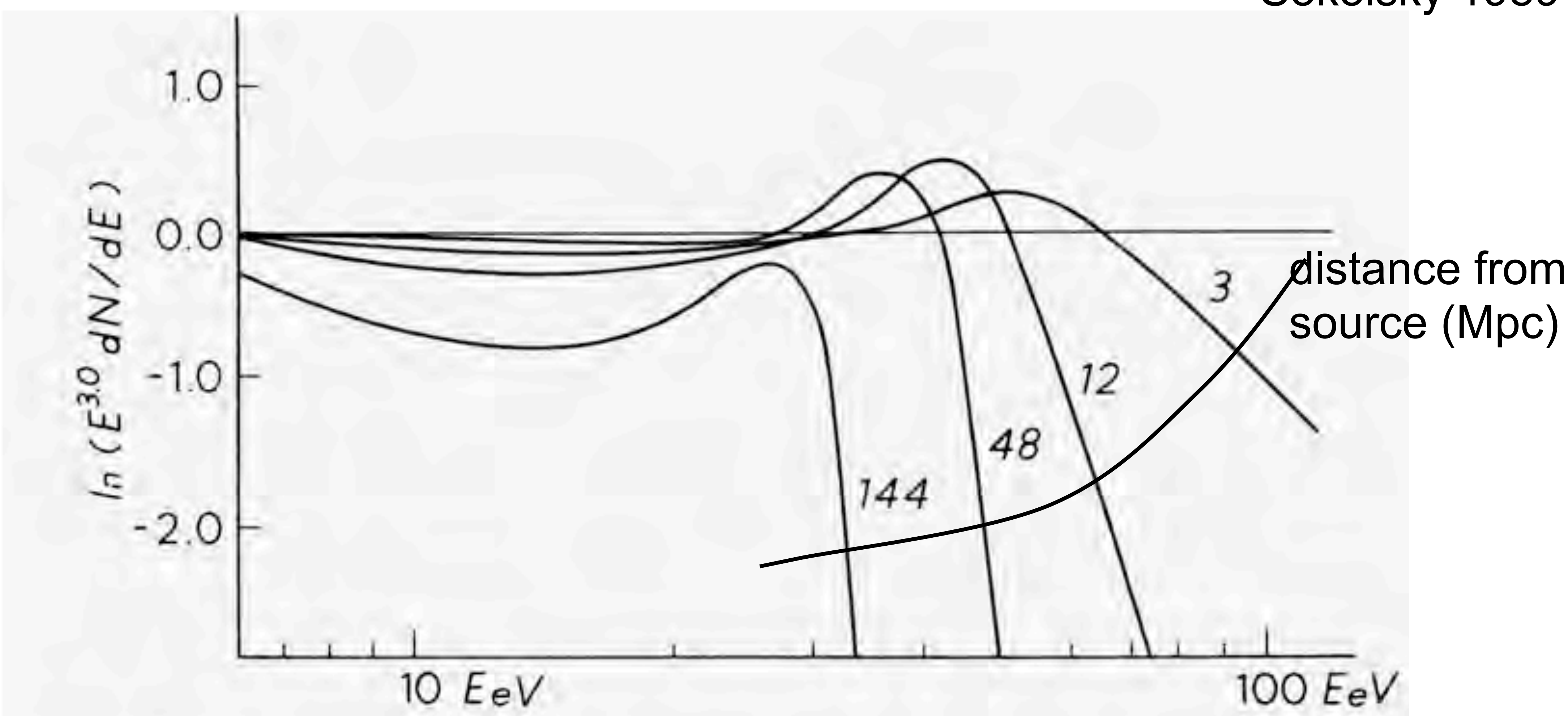
Greisen-Zatsepin-Kuzmin (1964)

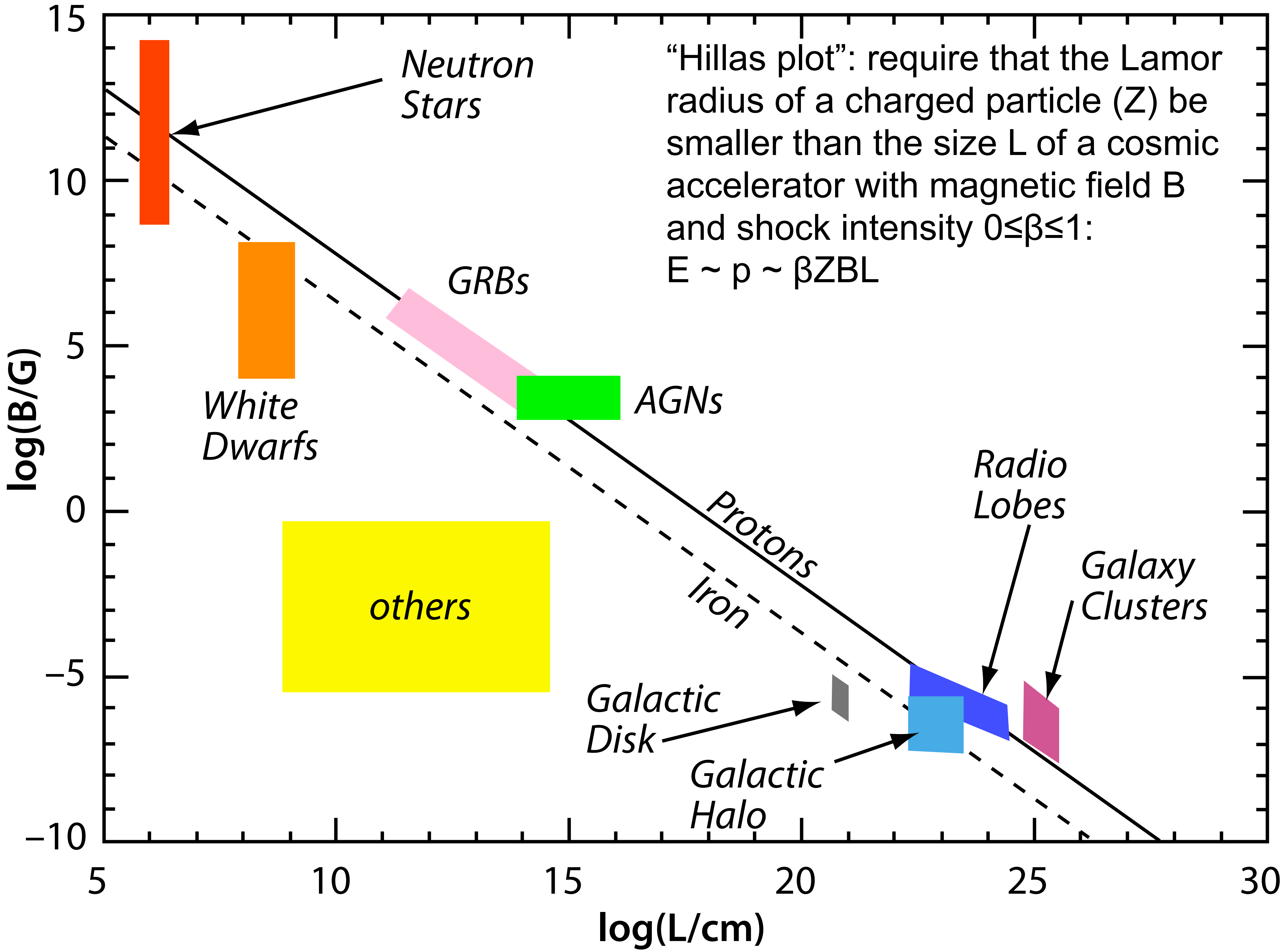
protons scatter with the CMB: threshold effect above 5×10^{19} eV:
$p+\gamma_{3K} \rightarrow \Delta(1232) \rightarrow p\pi^0 \rightarrow p\,\gamma\gamma$ or $n\pi^+ \rightarrow pe^+\nu$

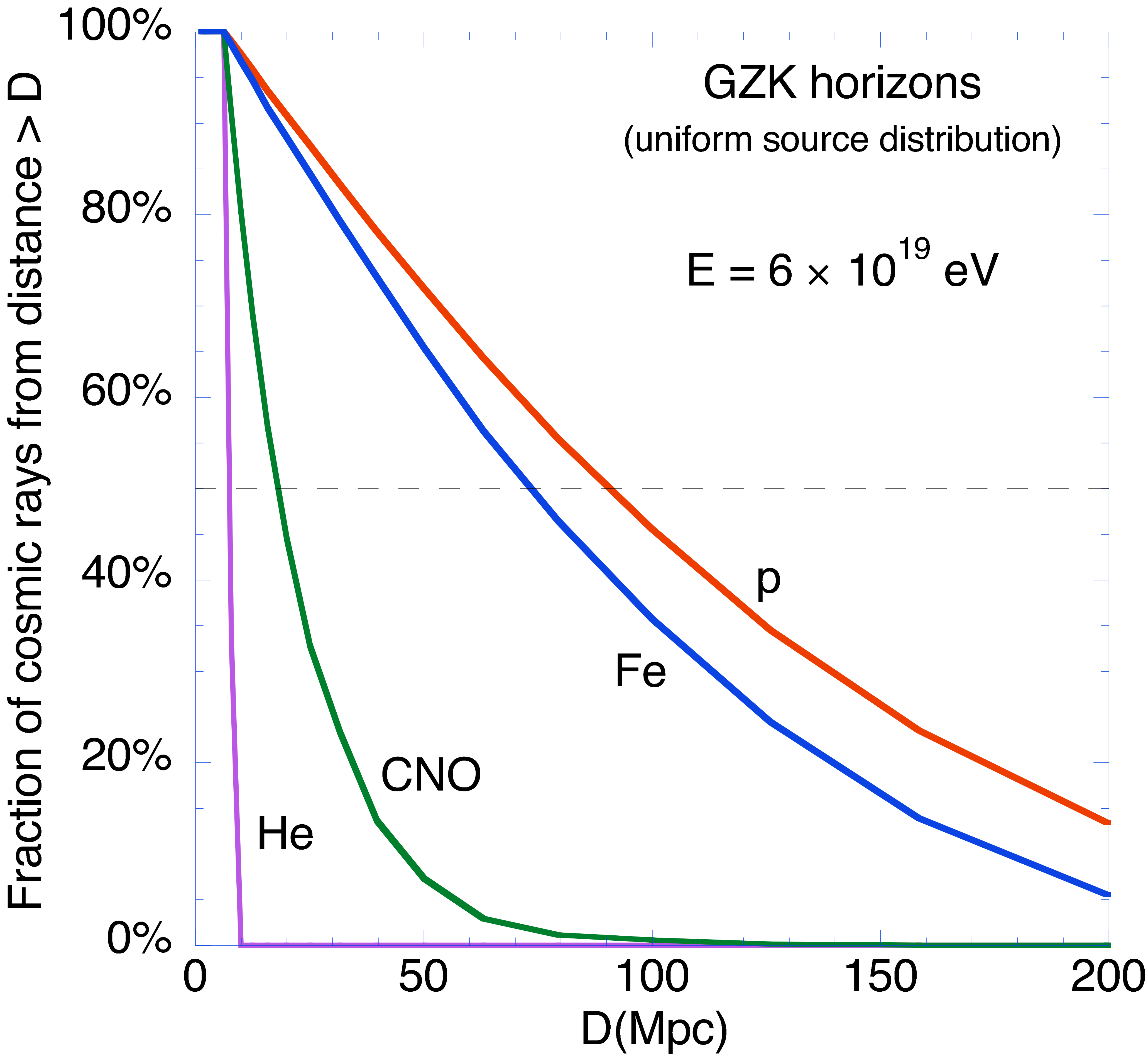
$$2E_p\epsilon > (m_\Delta^2 - m_p^2)$$

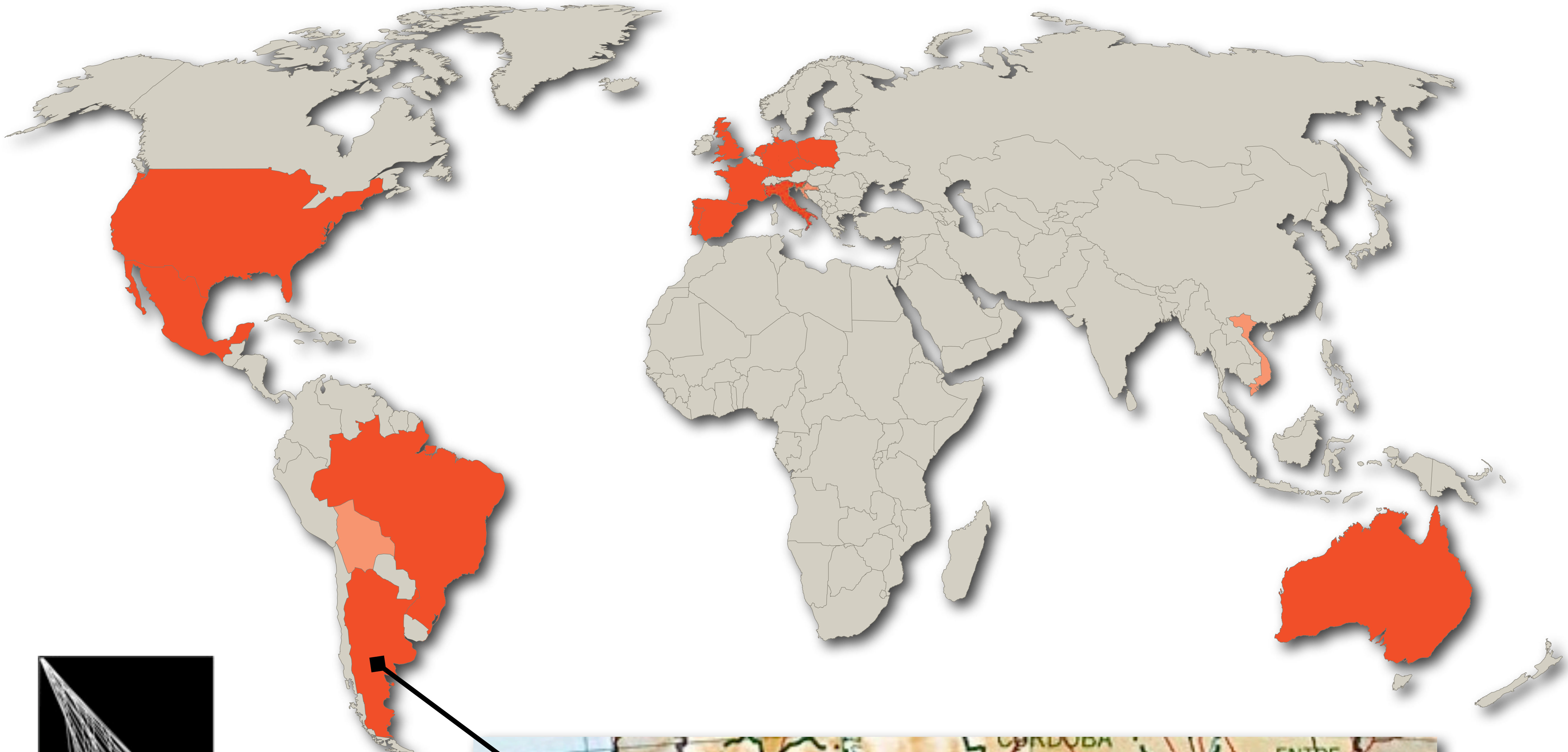
ε=meV, 400 cm^{-3}

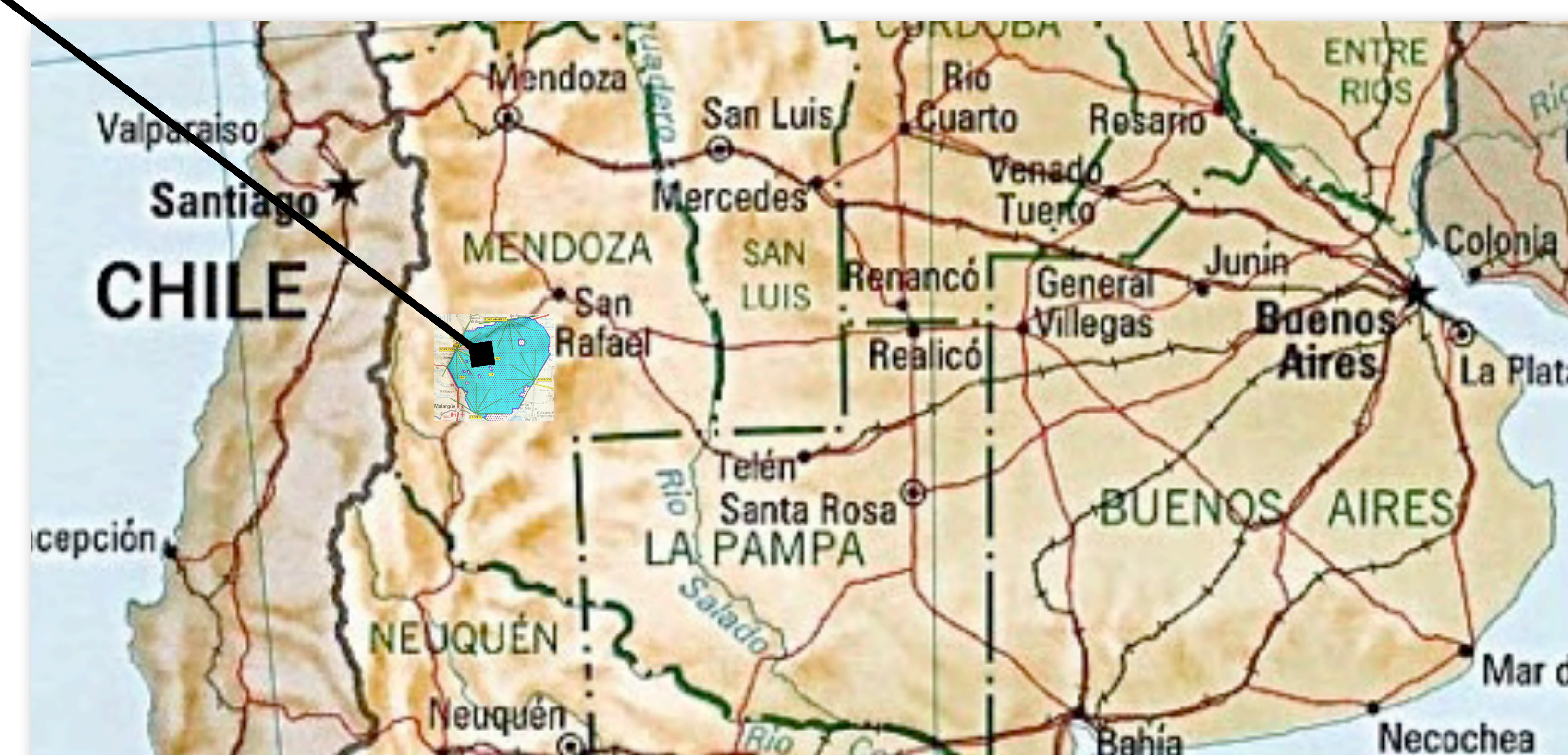
Sokolsky 1989



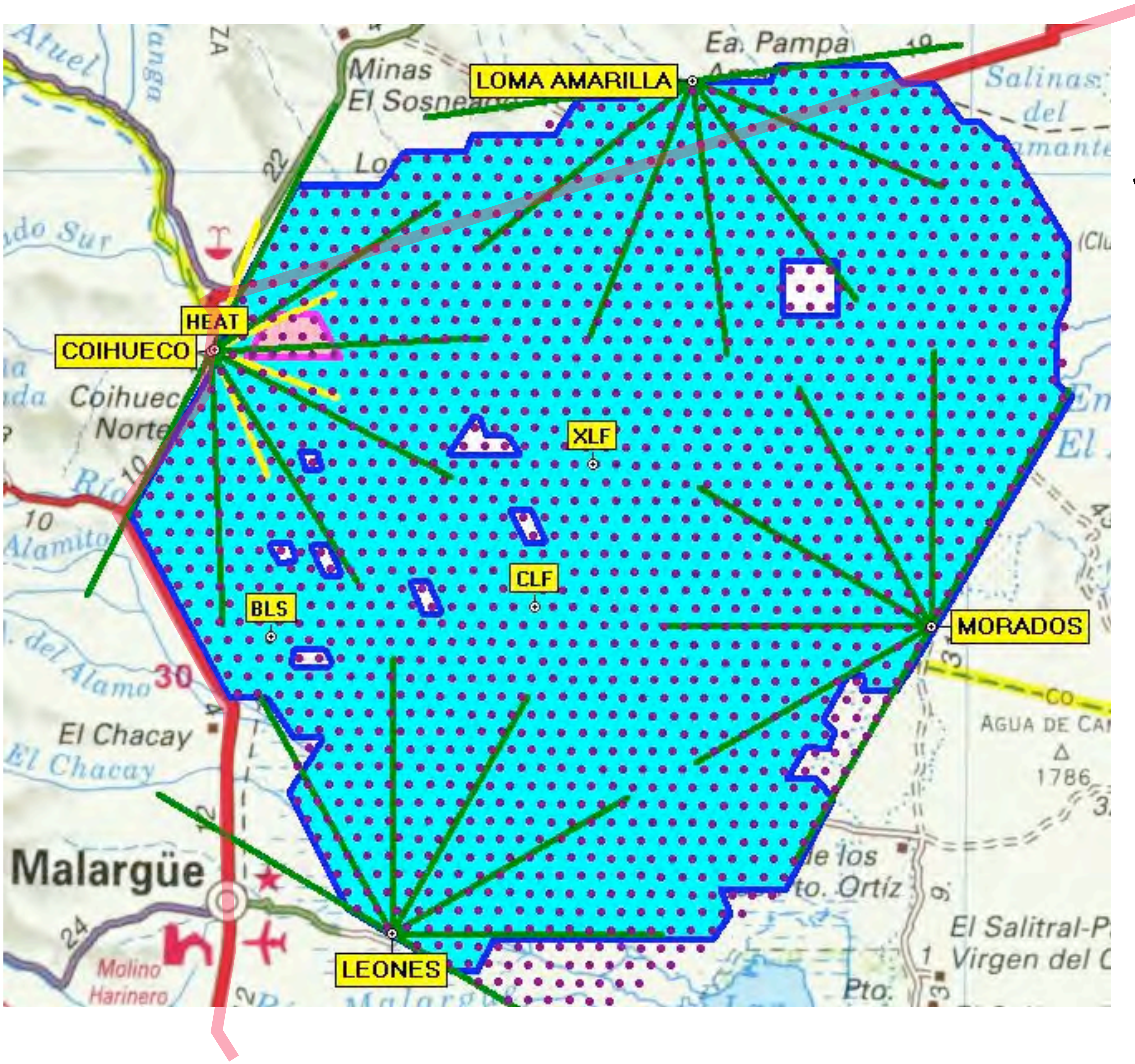

“Hillas plot”: require that the Lamor radius of a charged particle (Z) be smaller than the size L of a cosmic accelerator with magnetic field B and shock intensity 0≤β≤1:
E ~ p ~ βZBL
Neutron Stars
White Dwarfs
GRBs
AGNs
others
Protons
Iron
Radio Lobes
Galaxy Clusters
Galactic Disk
Galactic Halo
log(B/G)
log(L/cm)
15
10
5
0
−5
−10
5
10
15
20
25
30


GZK horizons
(uniform source distribution)
E = 6 × 10^19 eV
Fraction of cosmic rays from distance > D
100%
80%
60%
40%
20%
0%
0
50
100
150
200
D(Mpc)
p
Fe
CNO
He





PIERRE
AUGER
OBSERVATORY



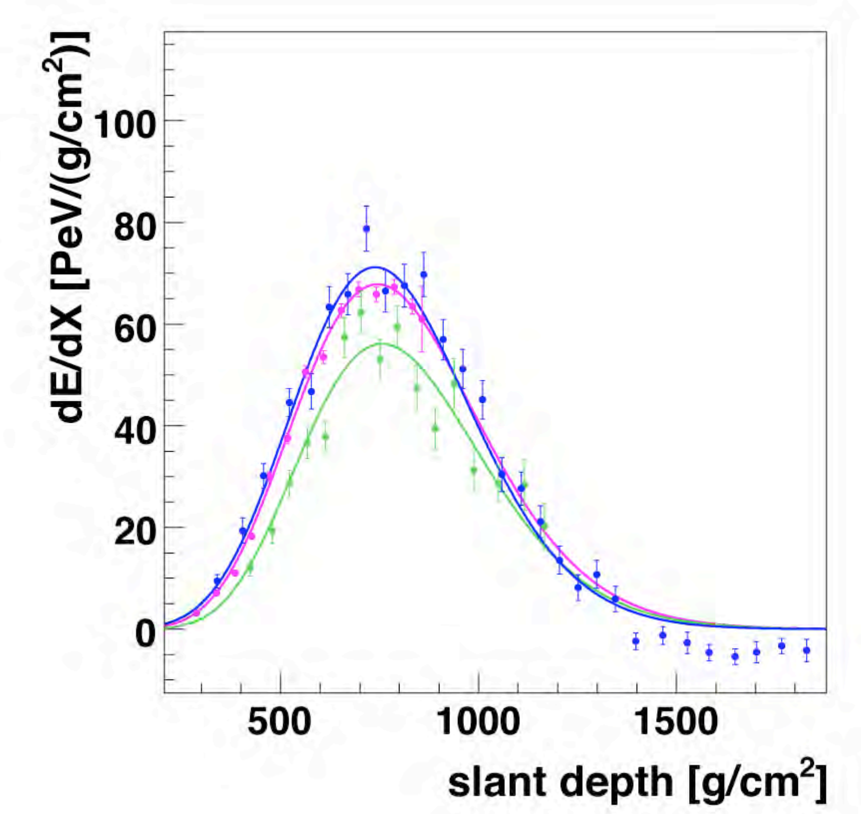
June 16, 2008:
1660 tanks deployed
1637 with water
1603 with electronics

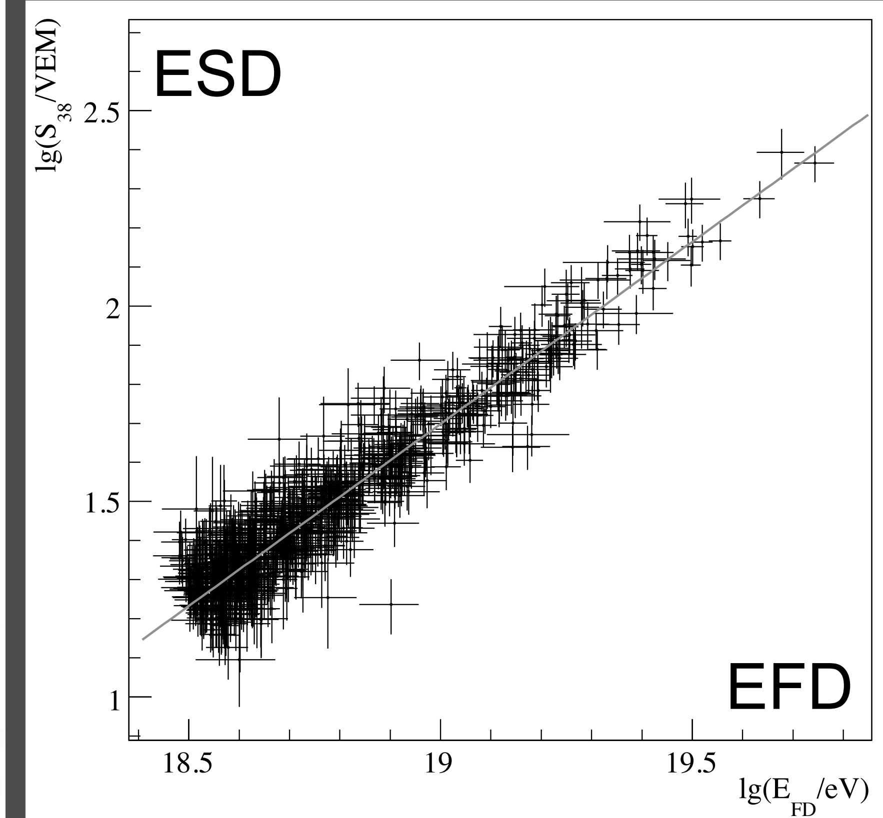
1.5 km between tanks

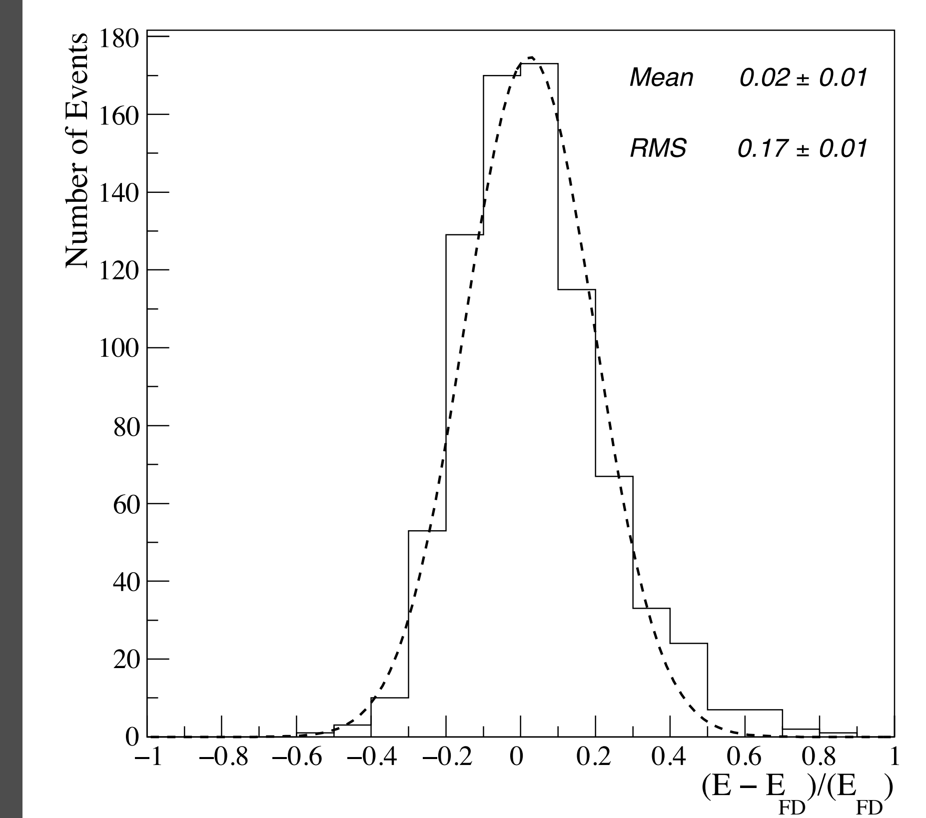
4 x 6 fluorescence telescopes

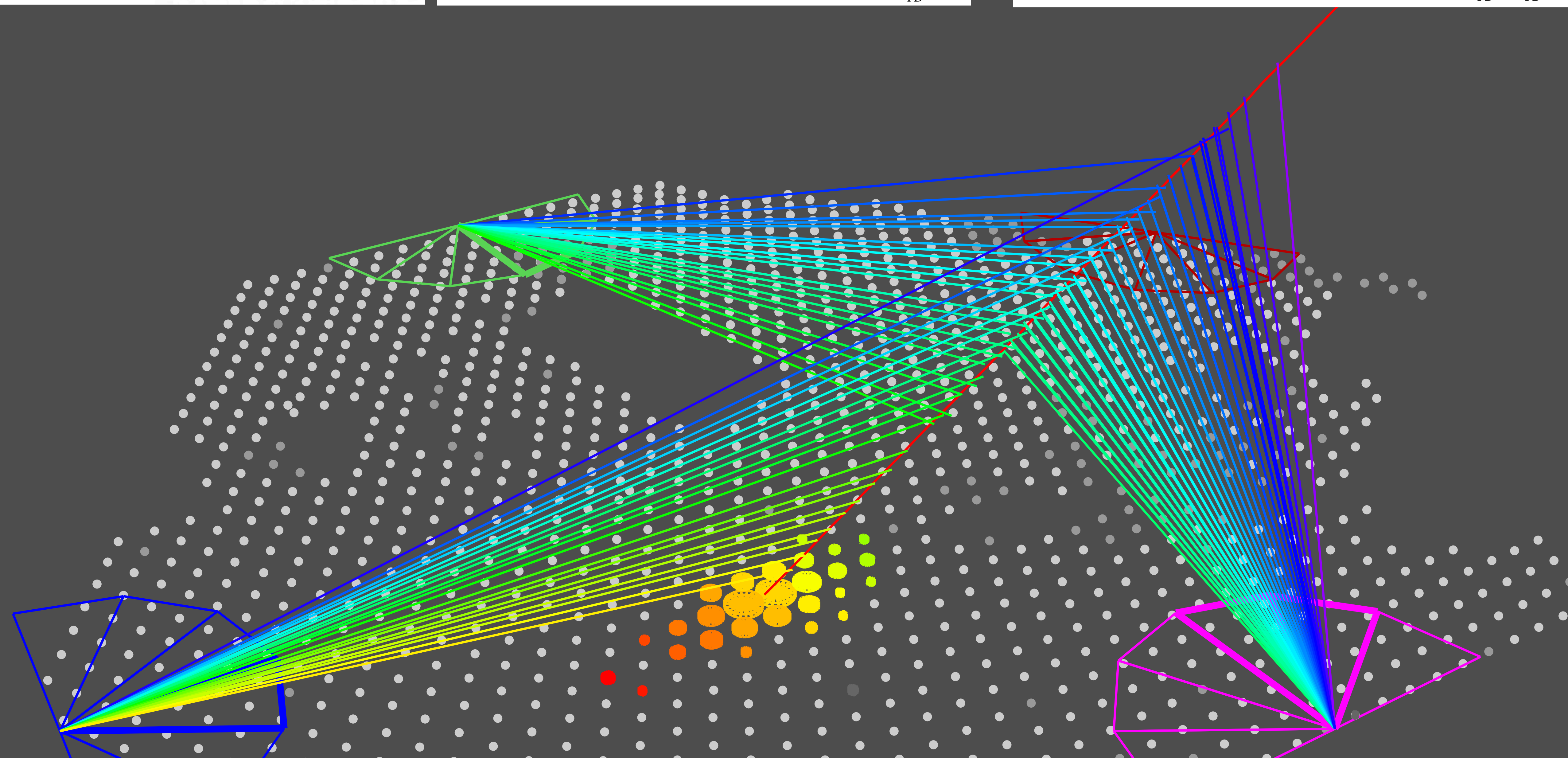
physics data since January 2004

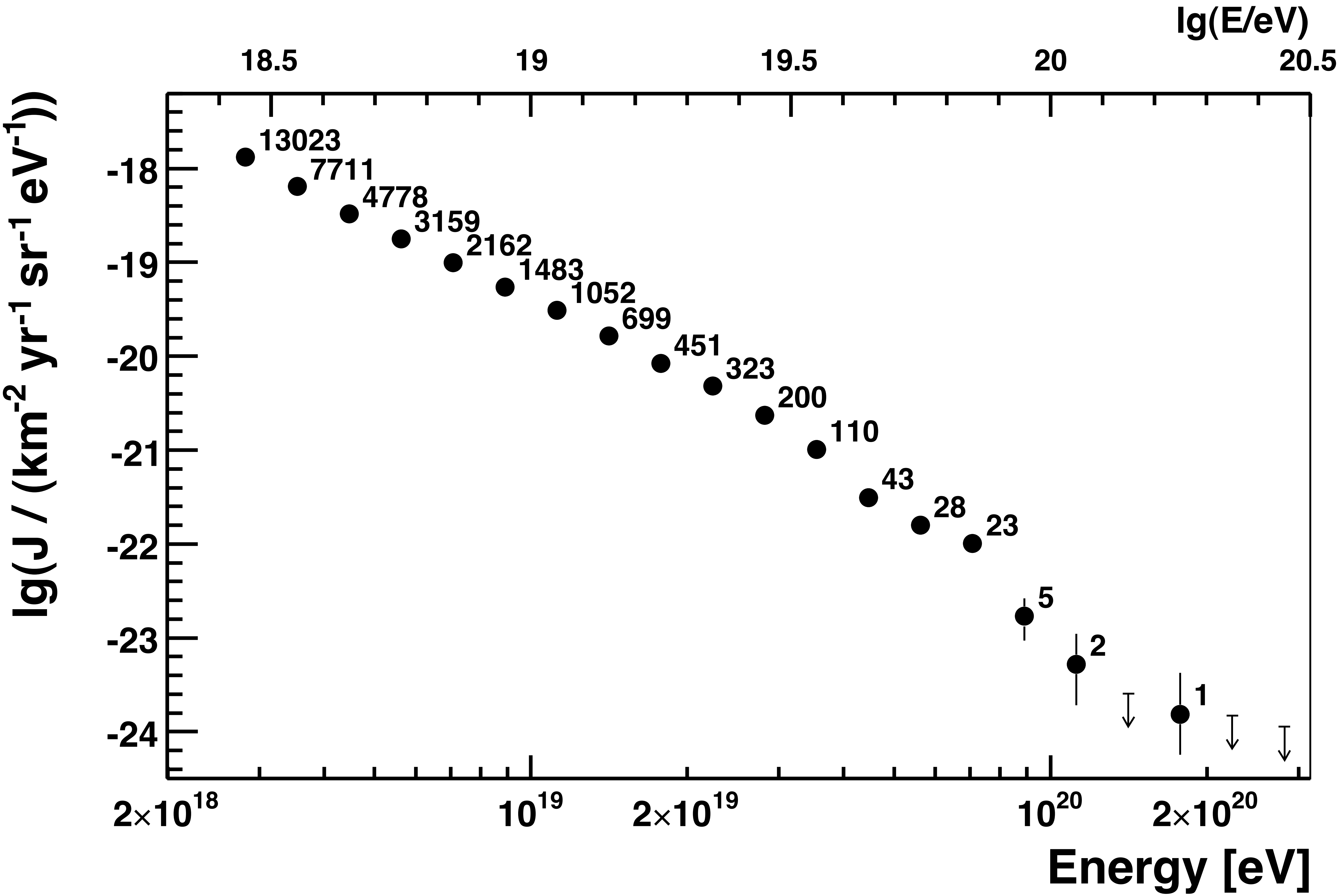

E

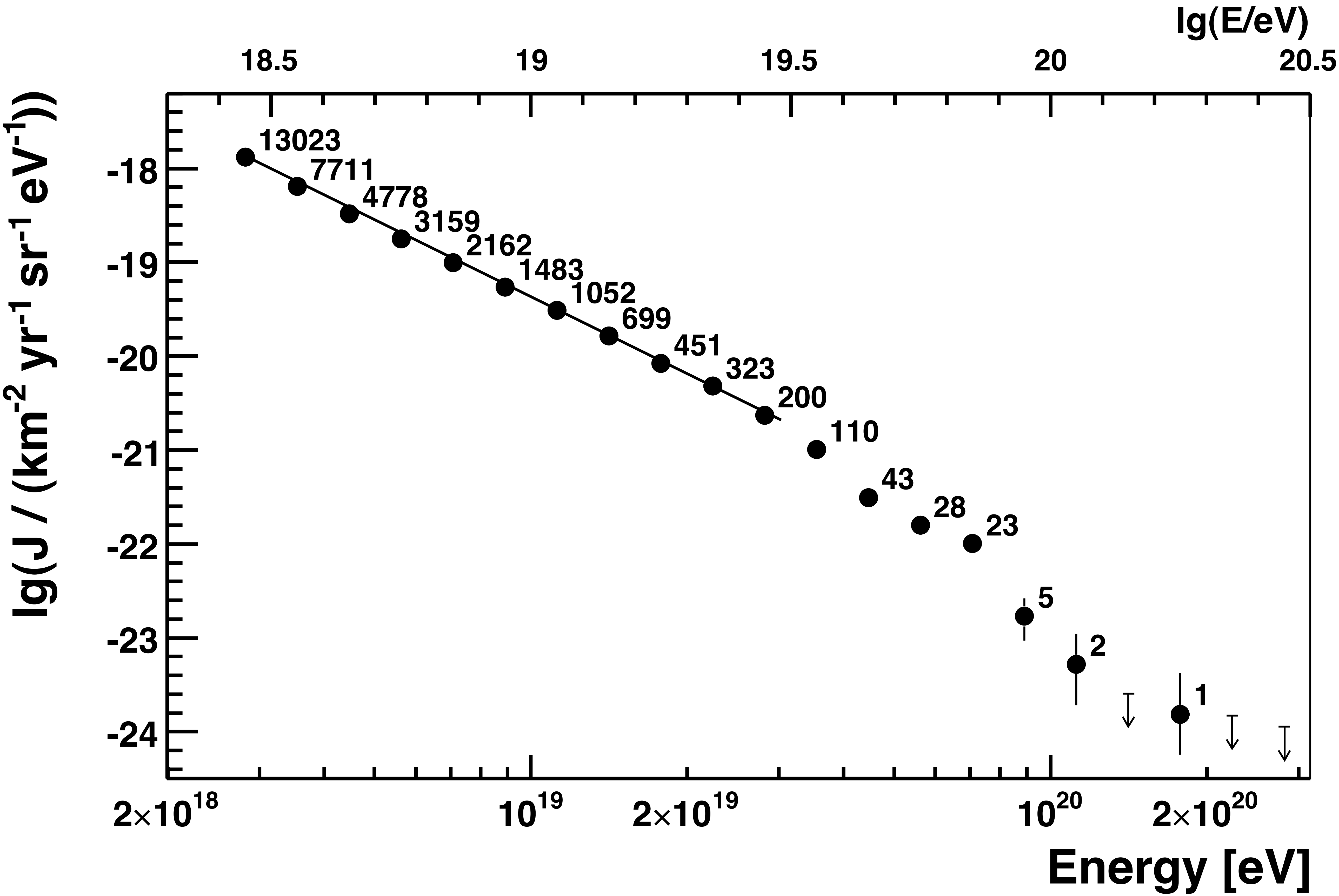

dE/dX [PeV/(g/cm²)]
slant depth [g/cm²]
0
20
40
60
80
100
500
1000
1500

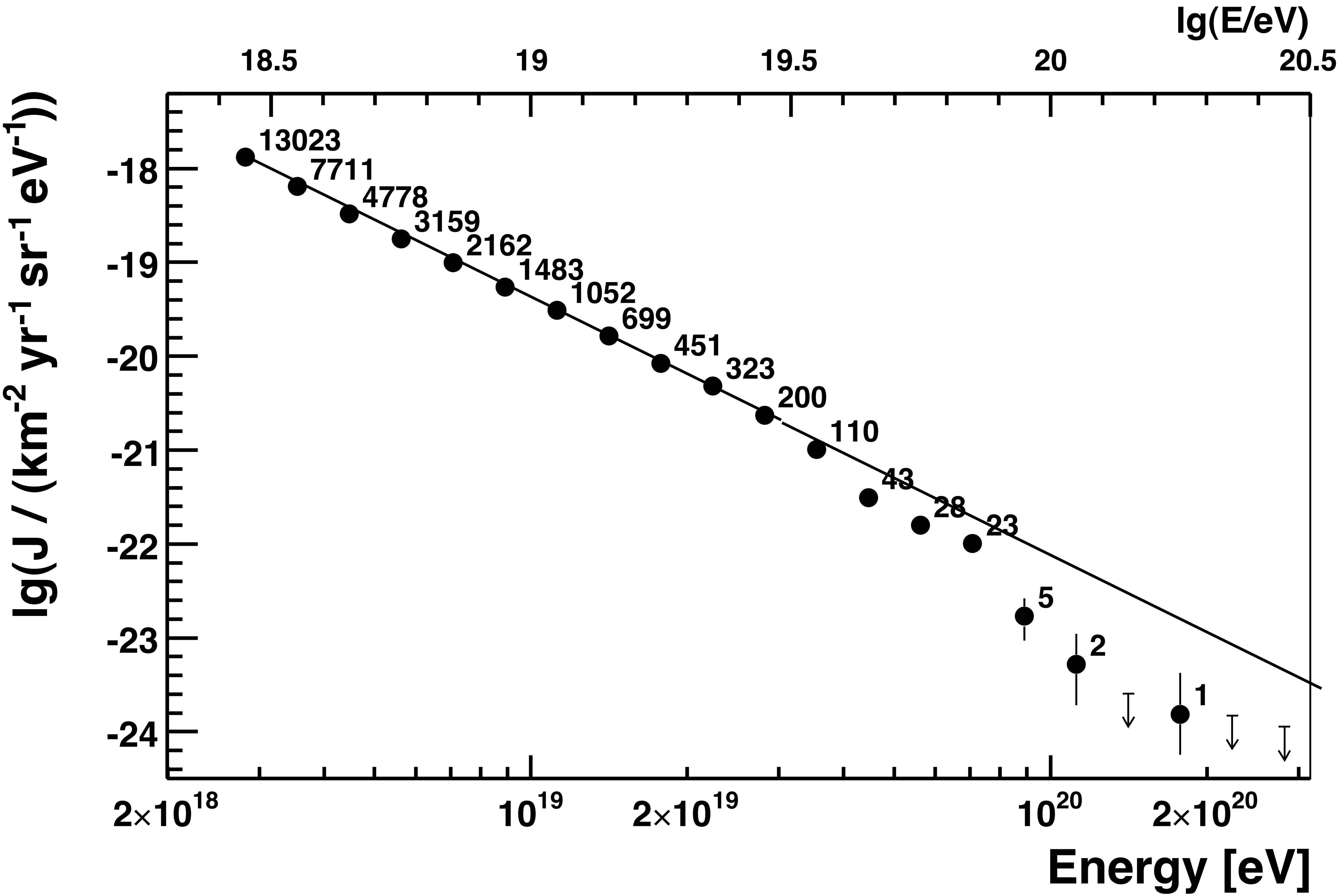

ESD
EFD
lg(S38/VEM)
lg(EFD/eV)
1
1.5
2
2.5
18.5
19
19.5

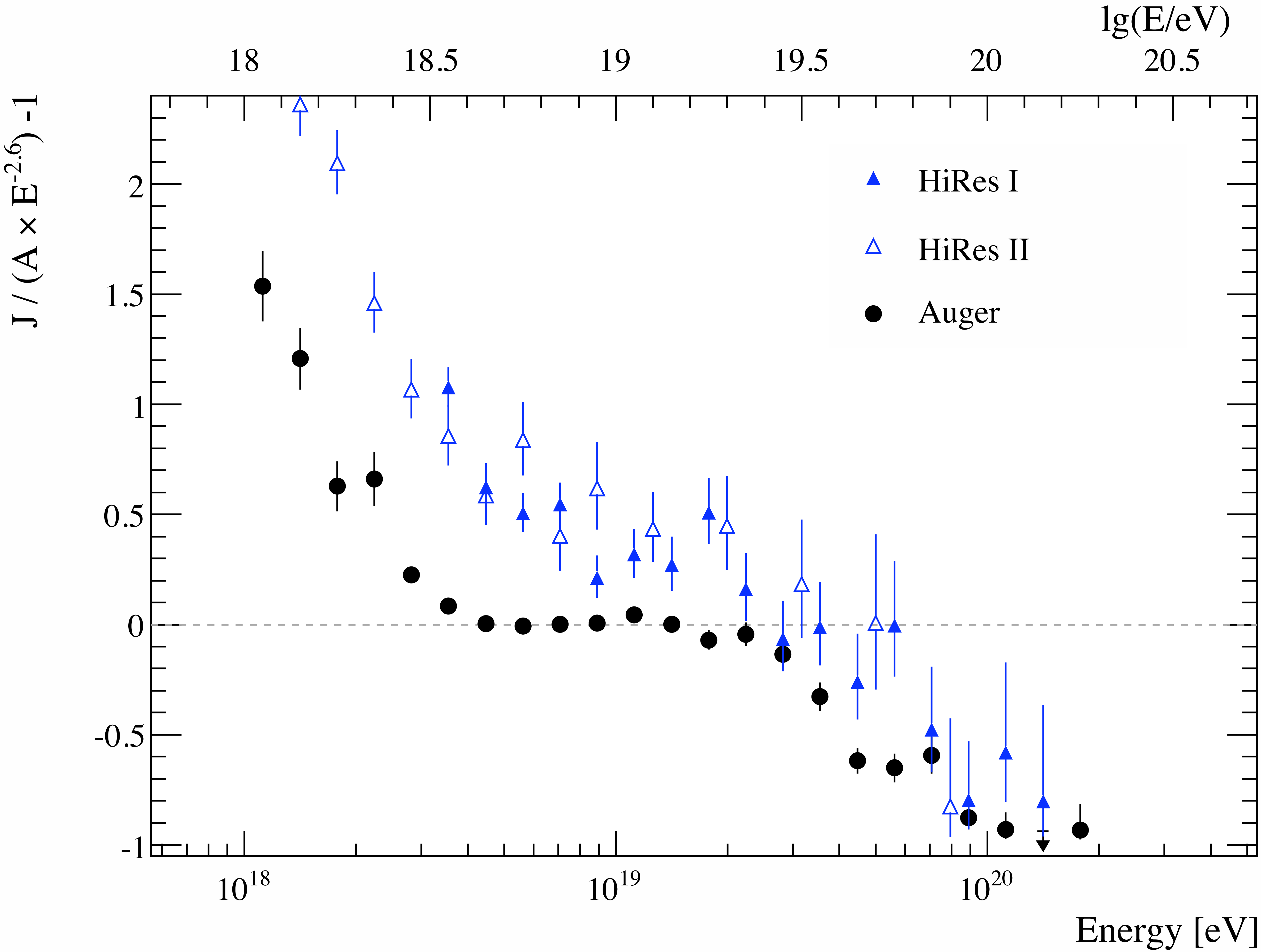

Number of Events
Mean 0.02 ± 0.01
RMS 0.17 ± 0.01
(E − EFD)/(EFD)
0
20
40
60
80
100
120
140
160
180
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1

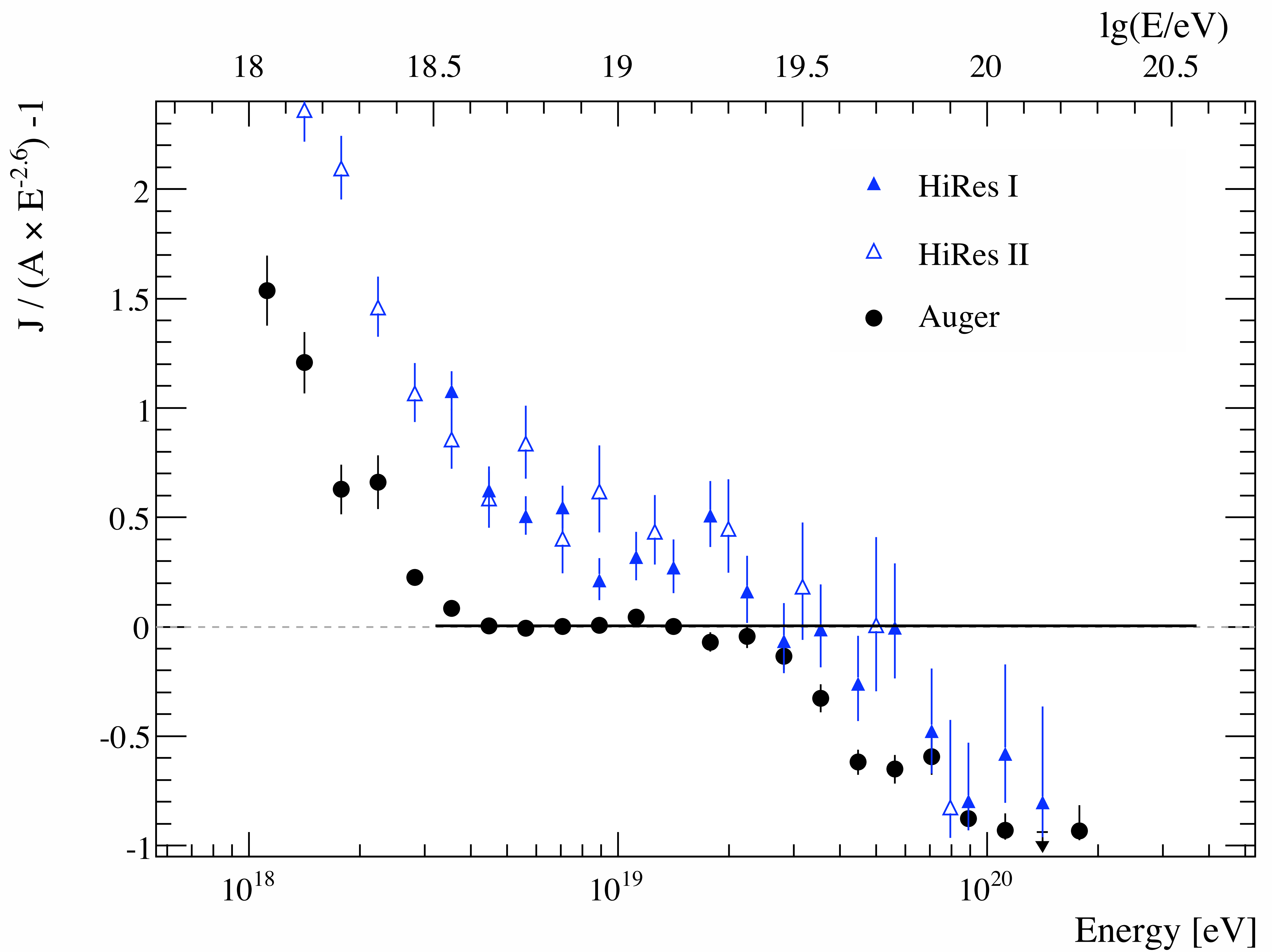



lg(E/eV)
18.5
19
19.5
20
20.5
-18
-19
-20
-21
-22
-23
-24
lg(J / (km-2 yr-1 sr-1 eV-1))
13023
7711
4778
3159
2162
1483
1052
699
451
323
200
110
43
28
23
5
2
1
2×10^18
10^19
2×10^19
10^20
2×10^20
Energy [eV]

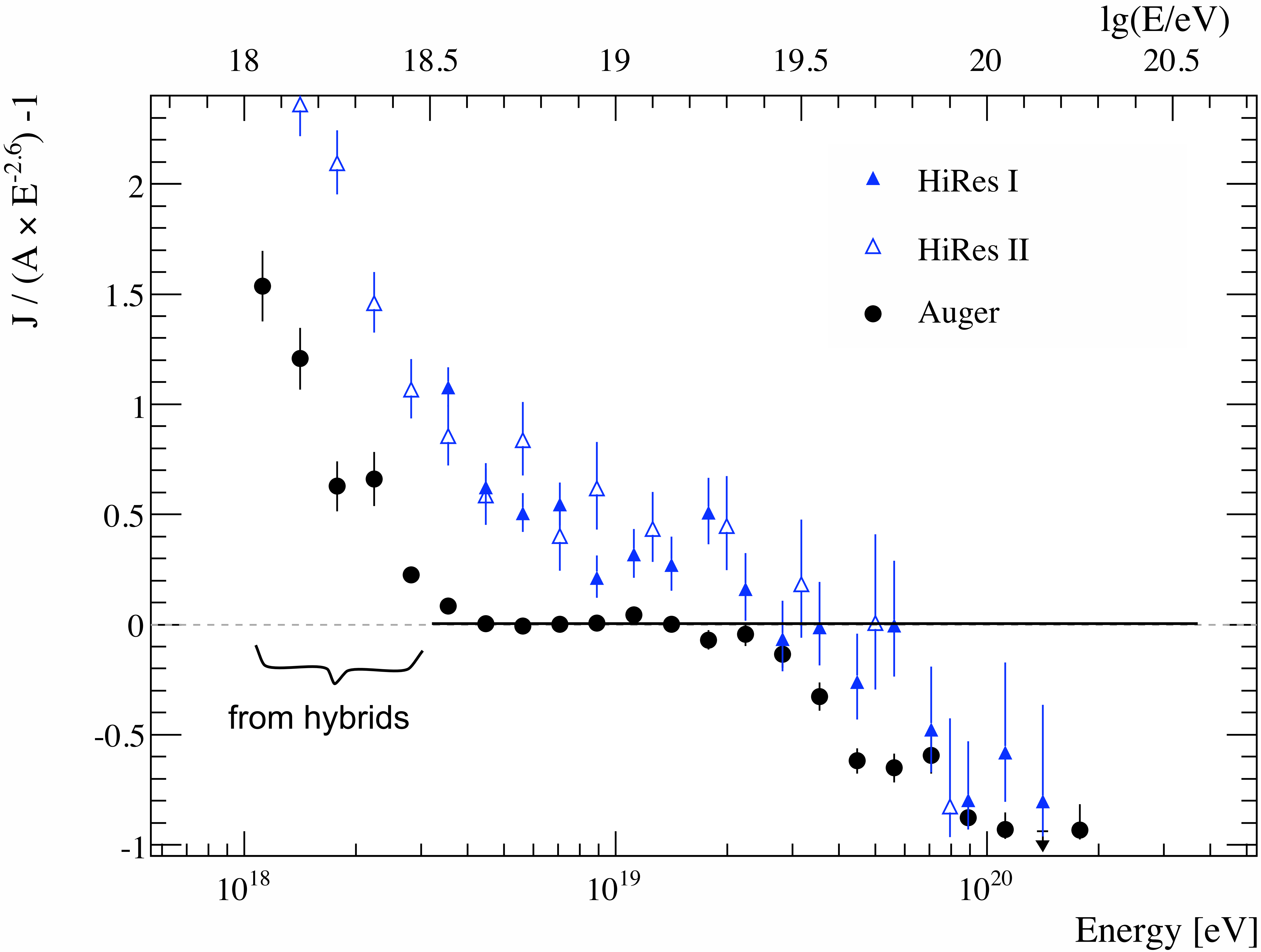

lg(E/eV)
18.5
19
19.5
20
20.5
lg(J / (km-2 yr-1 sr-1 eV-1))
-18
-19
-20
-21
-22
-23
-24
13023
7711
4778
3159
2162
1483
1052
699
451
323
200
110
43
28
23
5
2
1
2×10^18
10^19
2×10^19
10^20
2×10^20
Energy [eV]

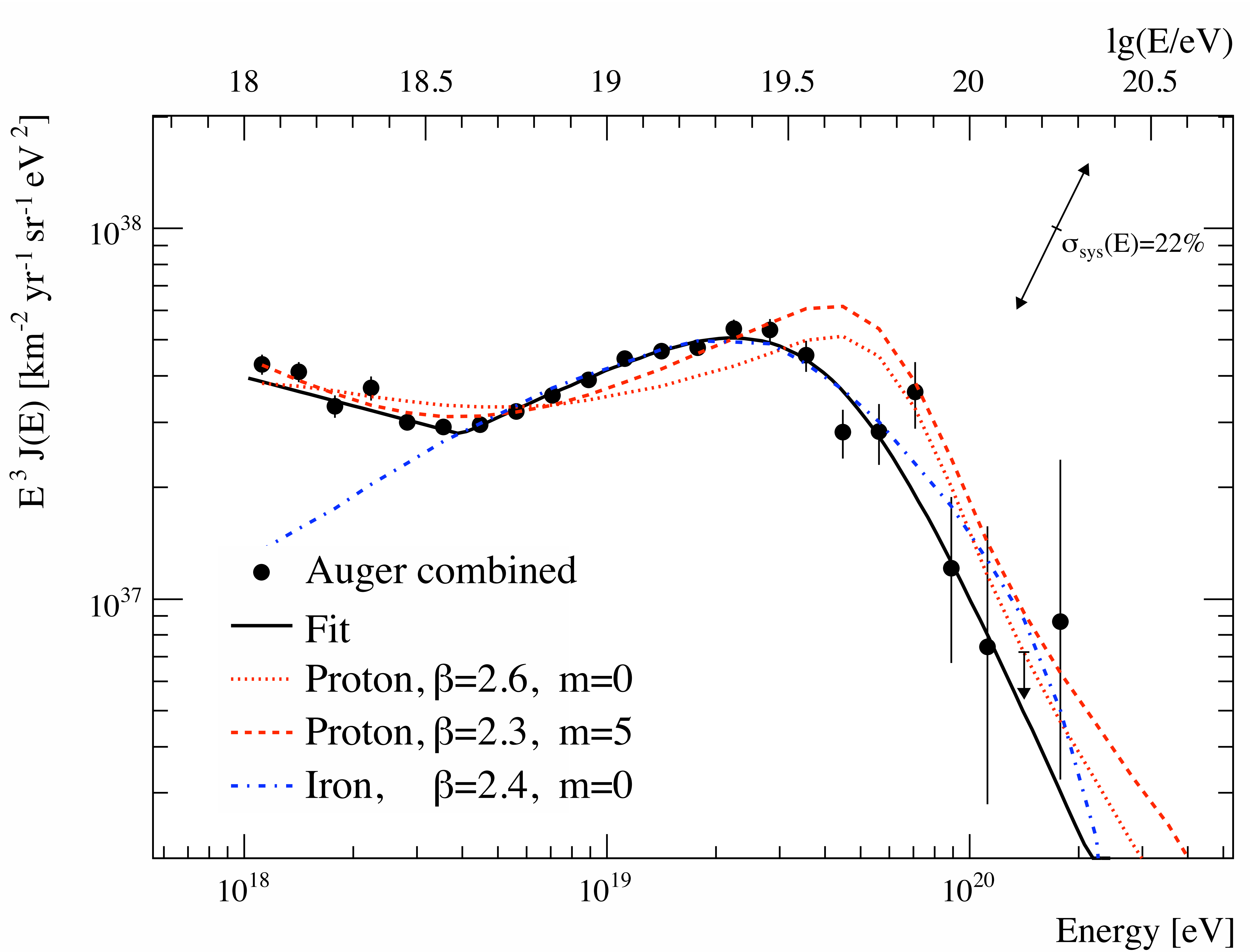

lg(E/eV)
18.5
19
19.5
20
20.5
lg(J / (km^-2 yr^-1 sr^-1 eV^-1))
-18
-19
-20
-21
-22
-23
-24
13023
7711
4778
3159
2162
1483
1052
699
451
323
200
110
43
28
23
5
2
1
2×10^18
10^19
2×10^19
10^20
2×10^20
Energy [eV]


lg(E/eV)
18
18.5
19
19.5
20
20.5
J / (A × E^-2.6) -1
2
1.5
1
0.5
0
-0.5
-1
HiRes I
HiRes II
Auger
10^18
10^19
10^20
Energy [eV]



lg(E/eV)
18
18.5
19
19.5
20
20.5
J / (A × E^-2.6) -1
2
1.5
1
0.5
0
-0.5
-1
HiRes I
HiRes II
Auger
10^18
10^19
10^20
Energy [eV]

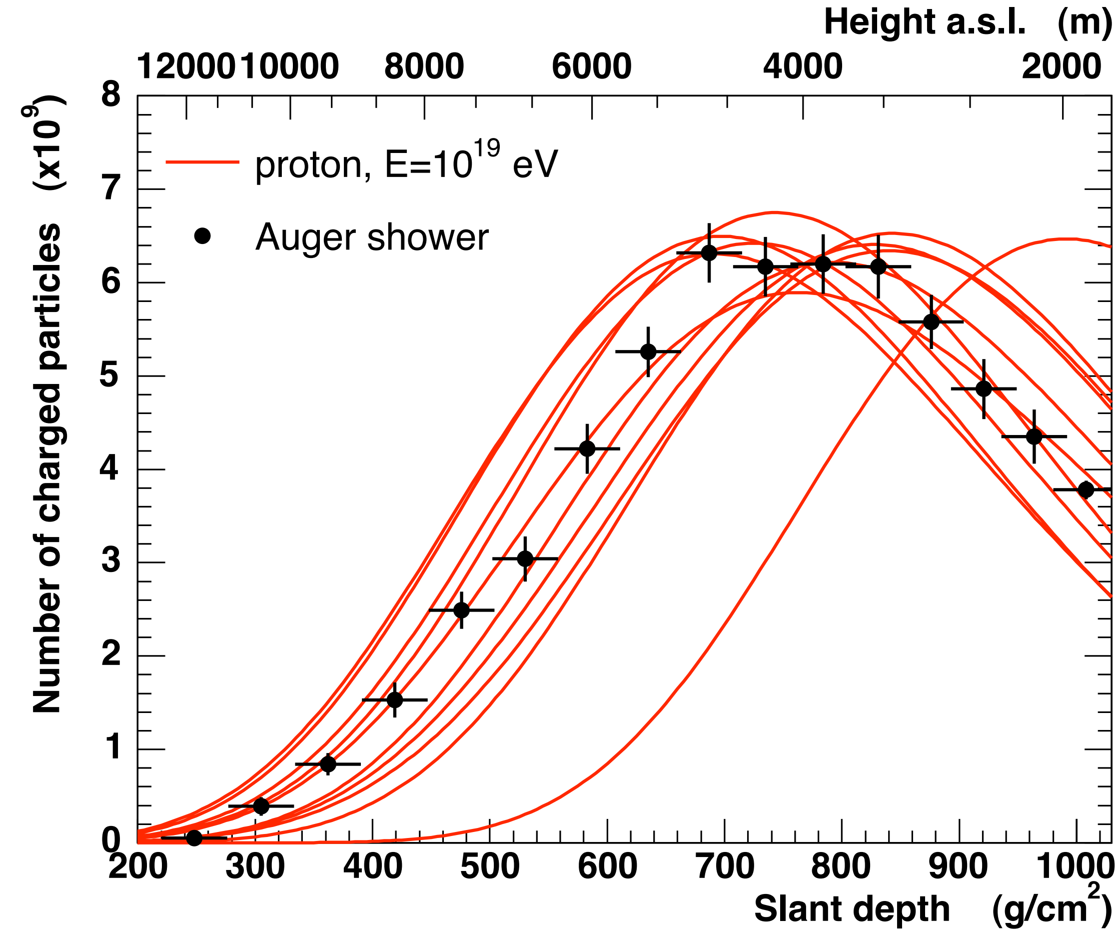

lg(E/eV)
18
18.5
19
19.5
20
20.5
J / (A × E^-2.6) -1
2
1.5
1
0.5
0
-0.5
-1
HiRes I
HiRes II
Auger
from hybrids
10^18
10^19
10^20
Energy [eV]



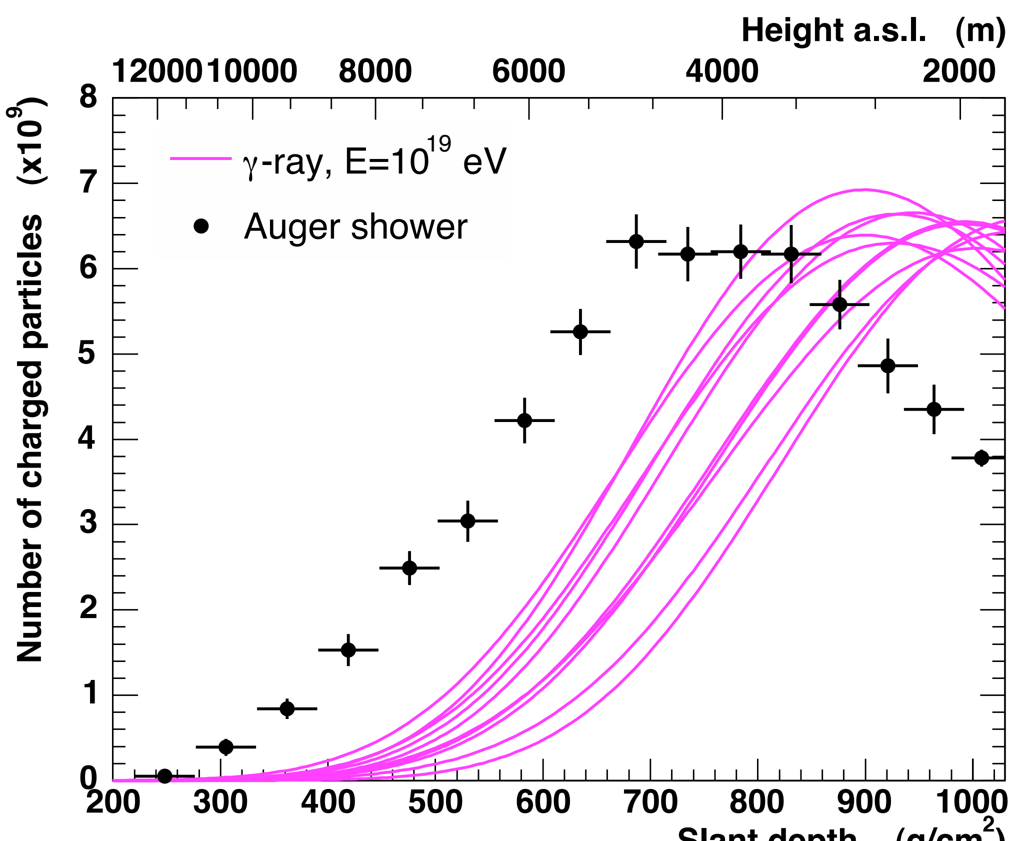
lg(E/eV)
18
18.5
19
19.5
20
20.5
E^3 J(E) [km^{-2} yr^{-1} sr^{-1} eV^2]
10^{38}
10^{37}
σ_{sys}(E)=22%
Auger combined
Fit
Proton, β=2.6, m=0
Proton, β=2.3, m=5
Iron, β=2.4, m=0
10^{18}
10^{19}
10^{20}
Energy [eV]

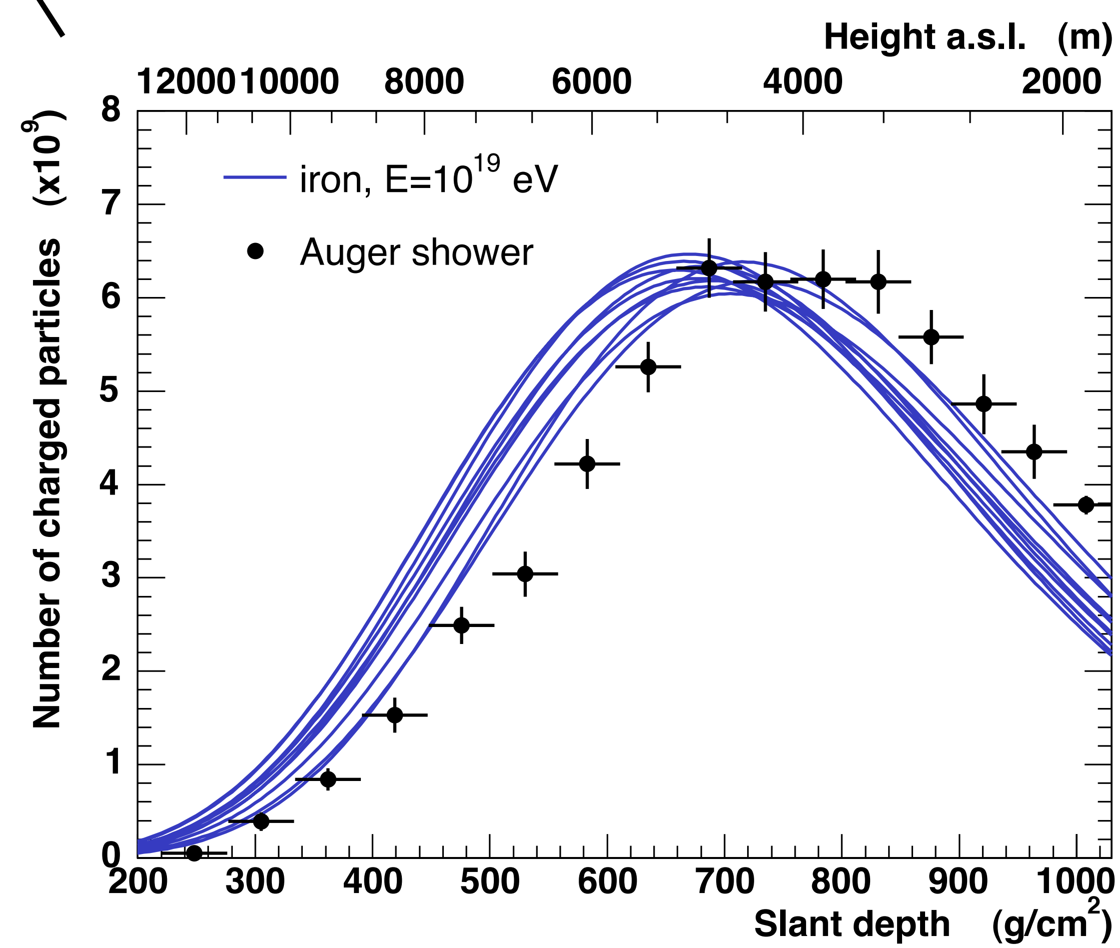
the best discriminator for the mass of the primary particle is the depth of shower maximum, “X_{max}”

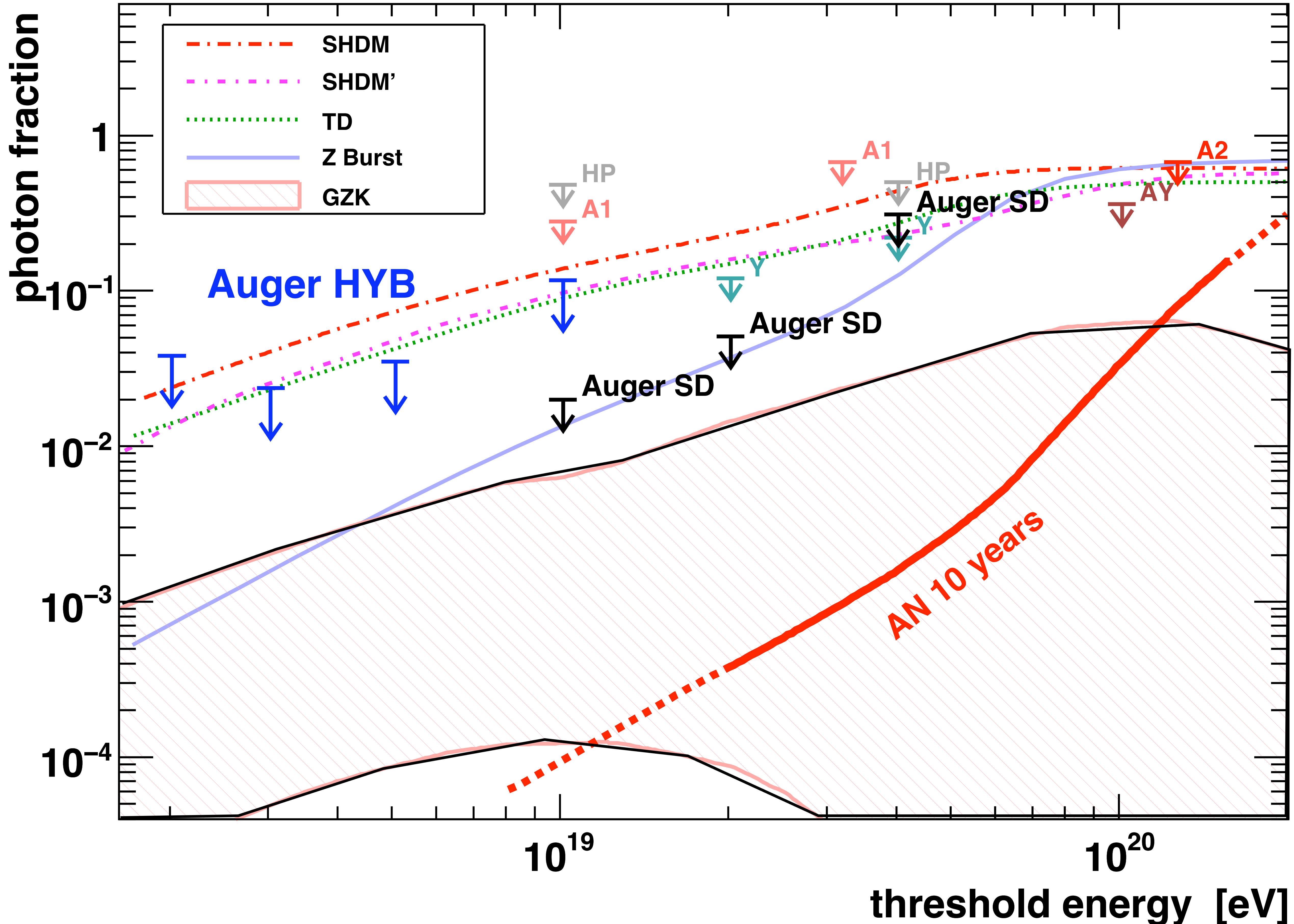
Protons ./. Iron: difficult, in progress



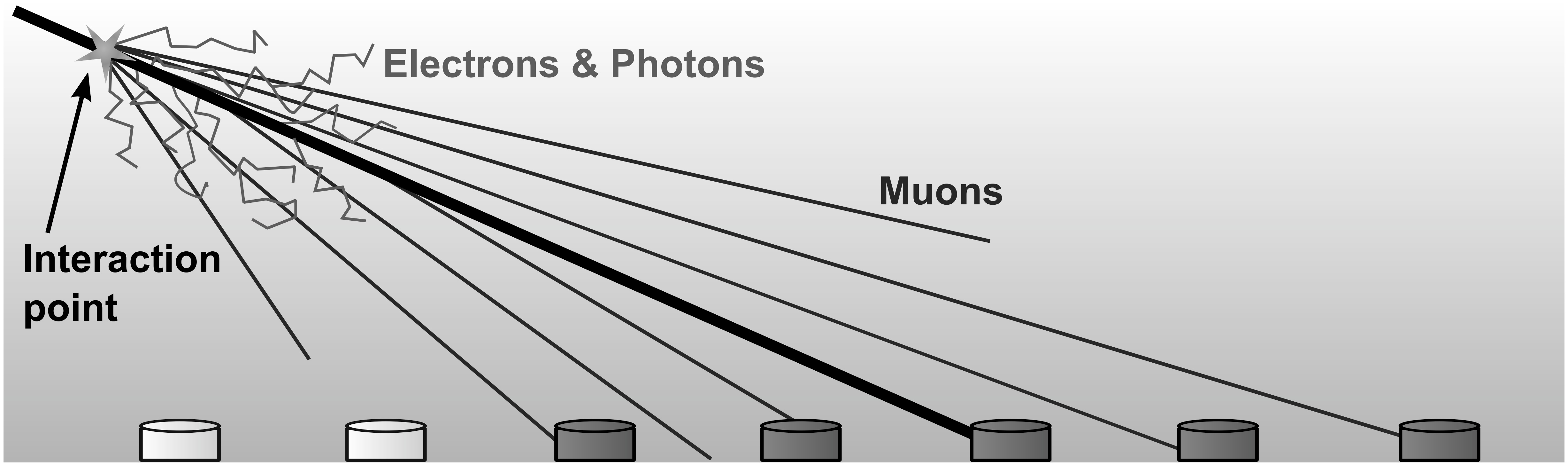
Photons: almost easy



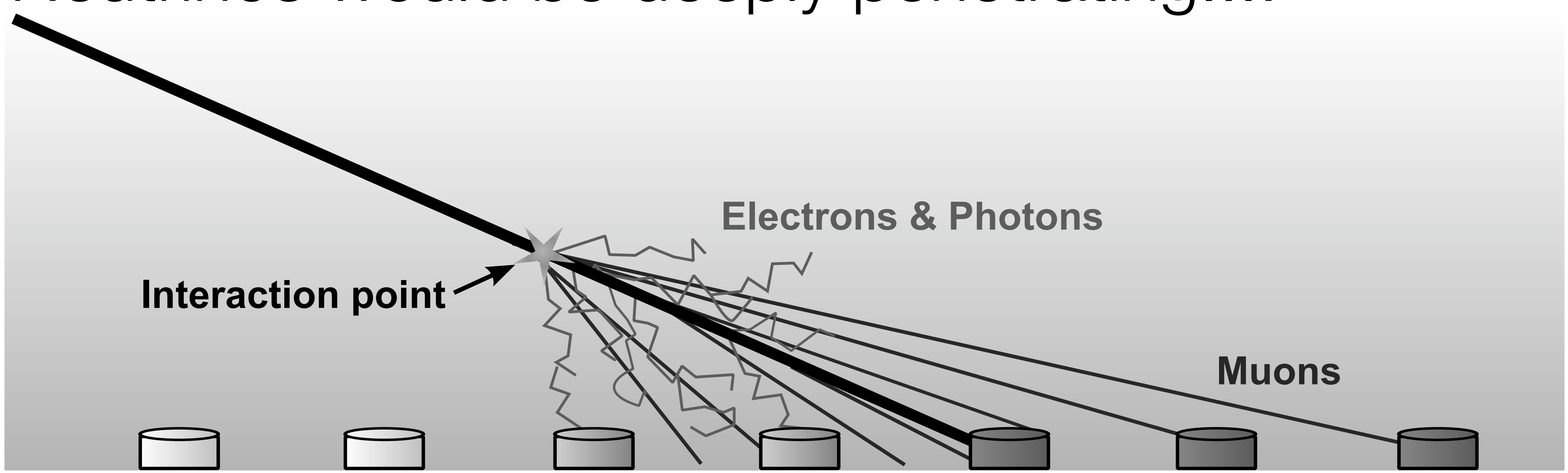




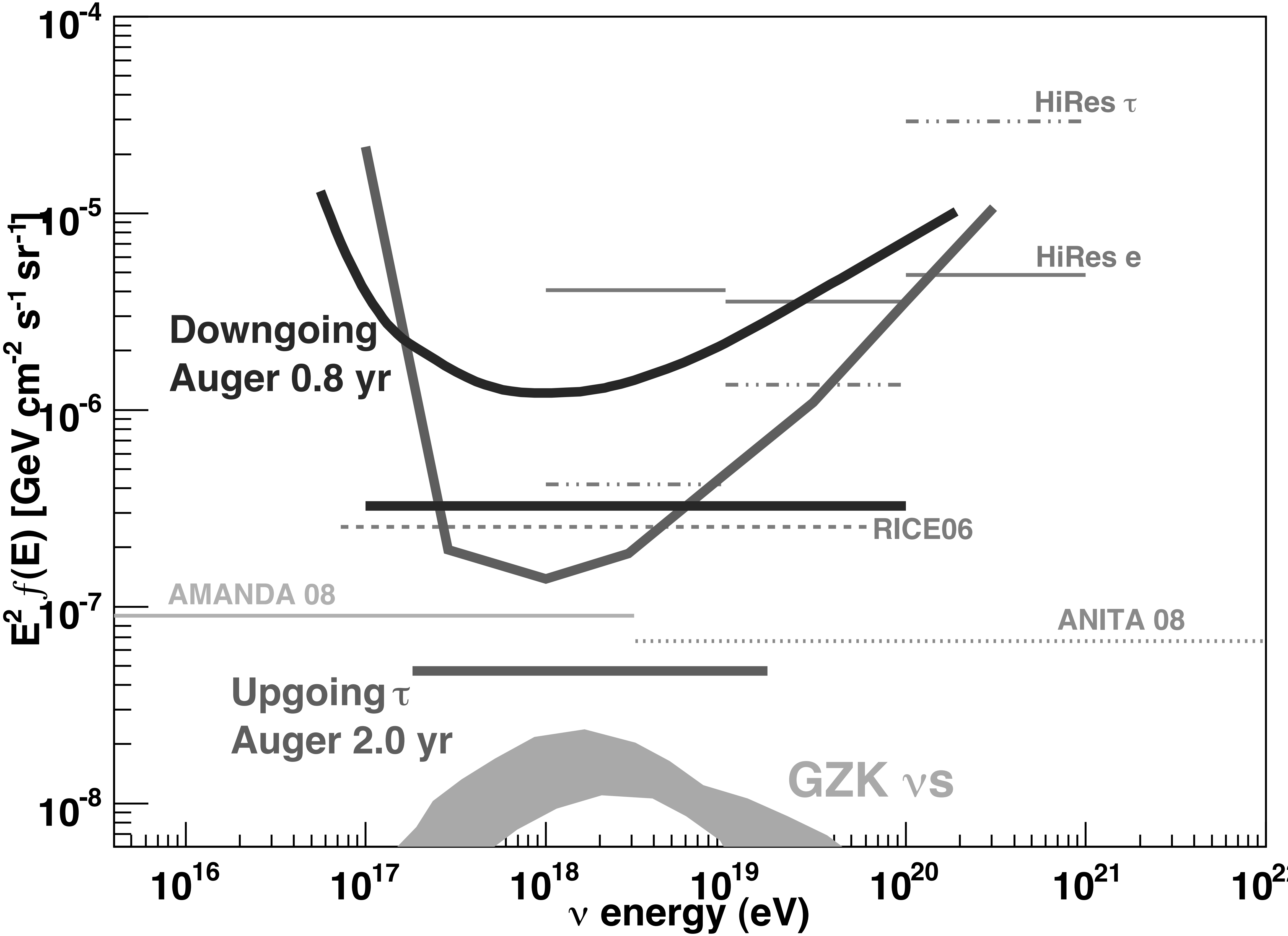
SHDM
SHDM'
TD
Z Burst
GZK
Auger HYB
HP
A1
Y
Auger SD
A2
AY
AN 10 years
photon fraction
1
10^-1
10^-2
10^-3
10^-4
10^19
10^20
threshold energy [eV]



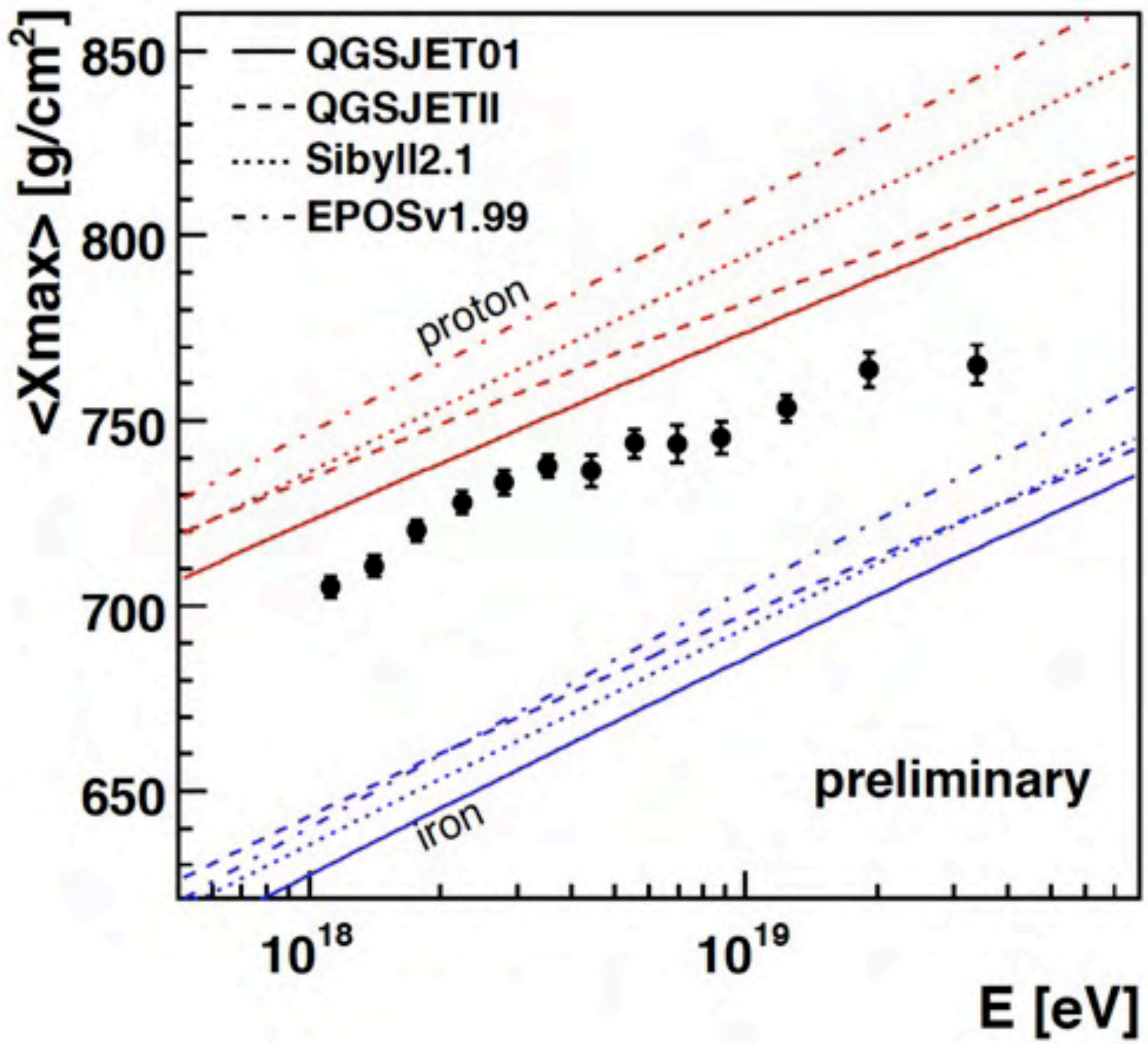
Neutrinos would be deeply penetrating...:

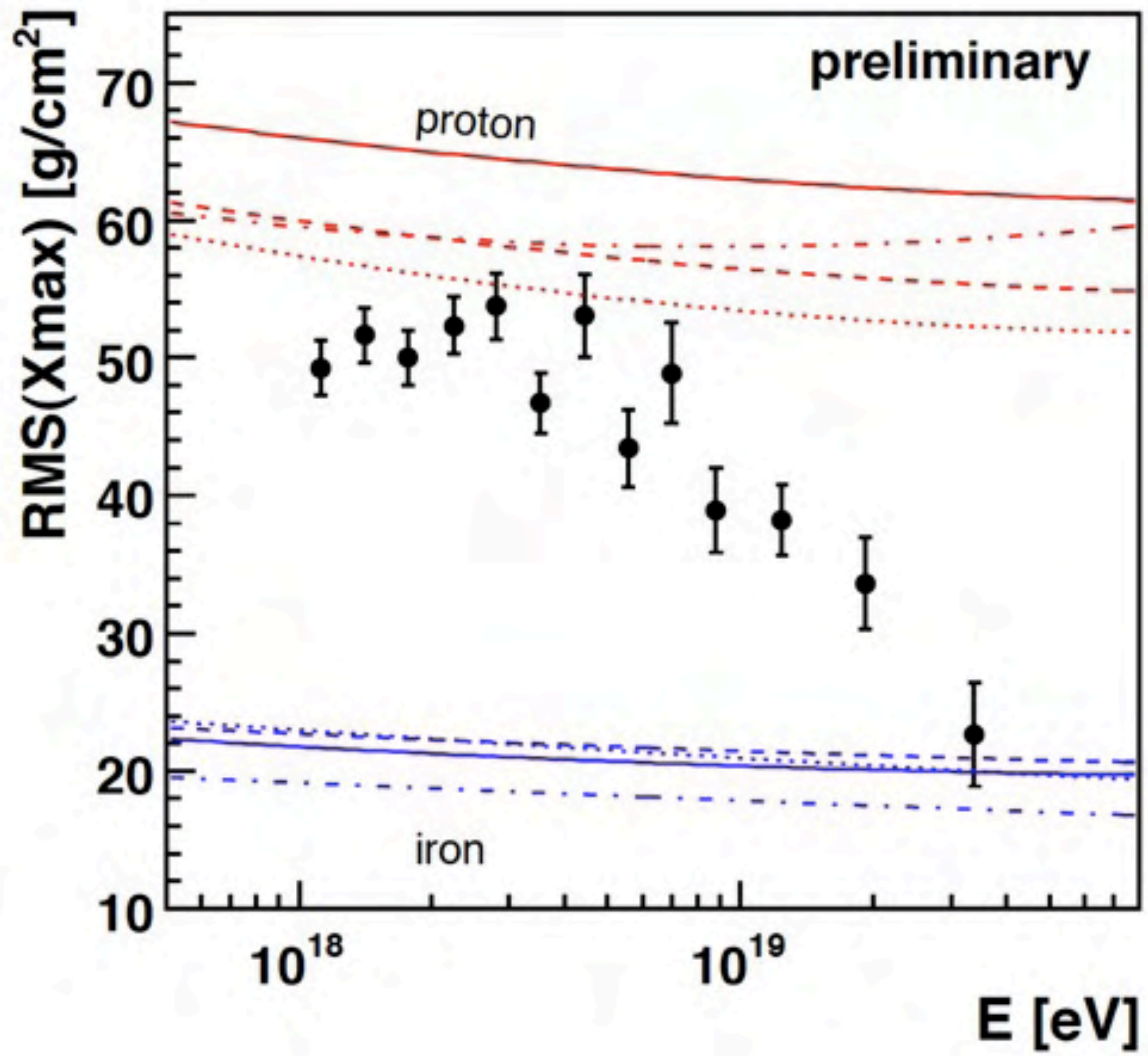


Single flavour neutrino limits (90% CL)



the Xmax puzzle...: a trend to heavy primaries?



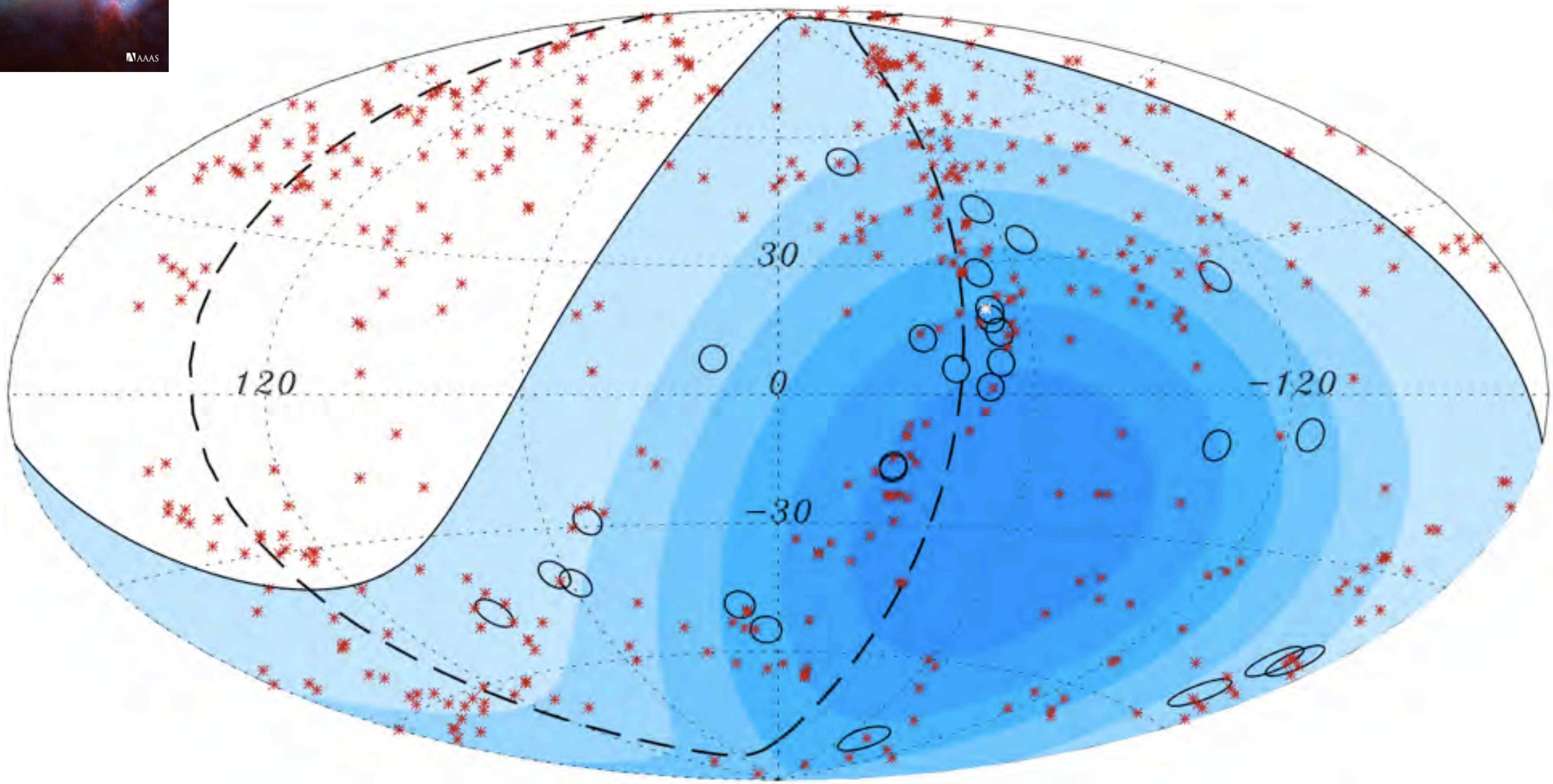


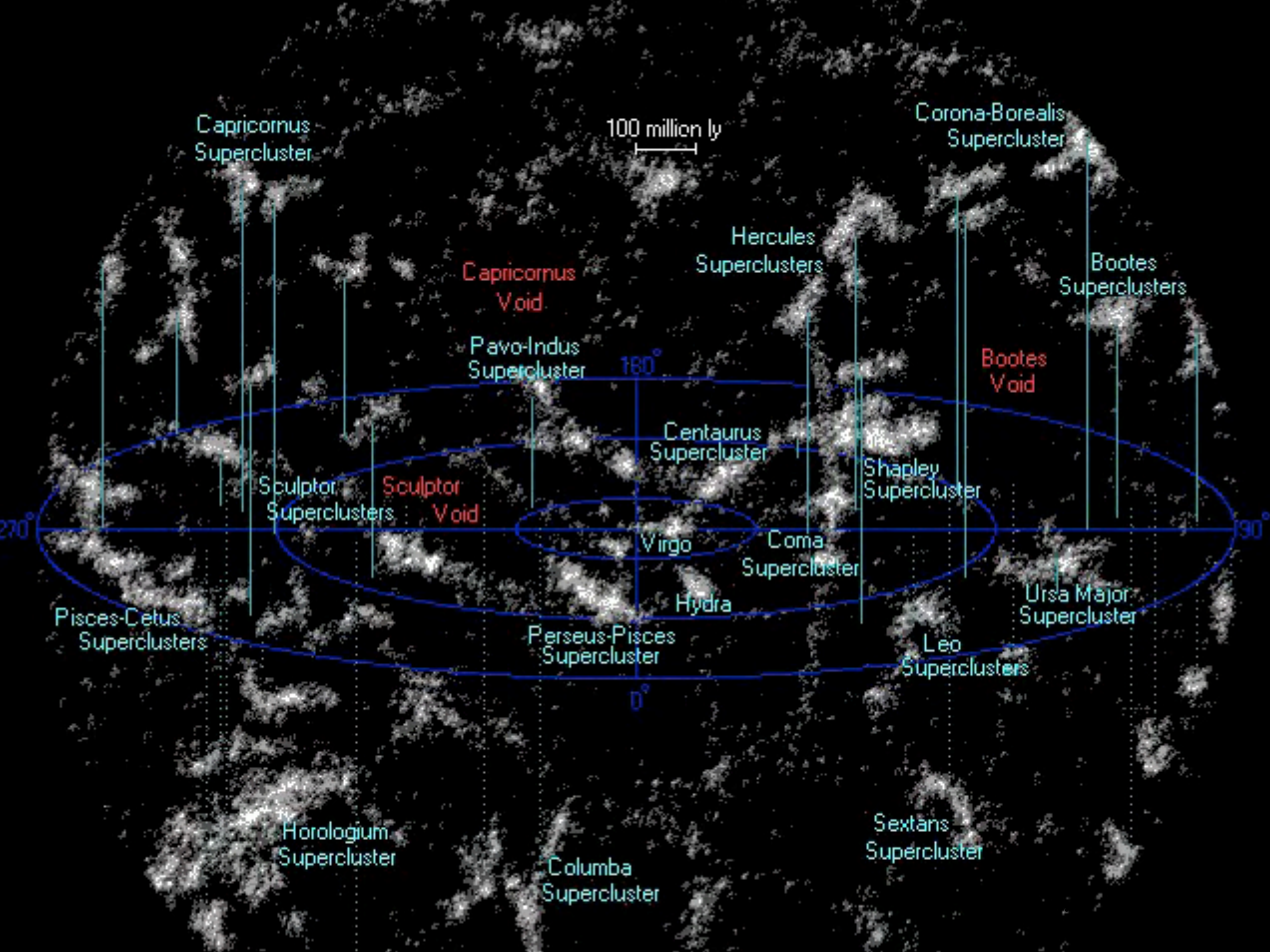
detector resolution unfolded!

3 remarks:

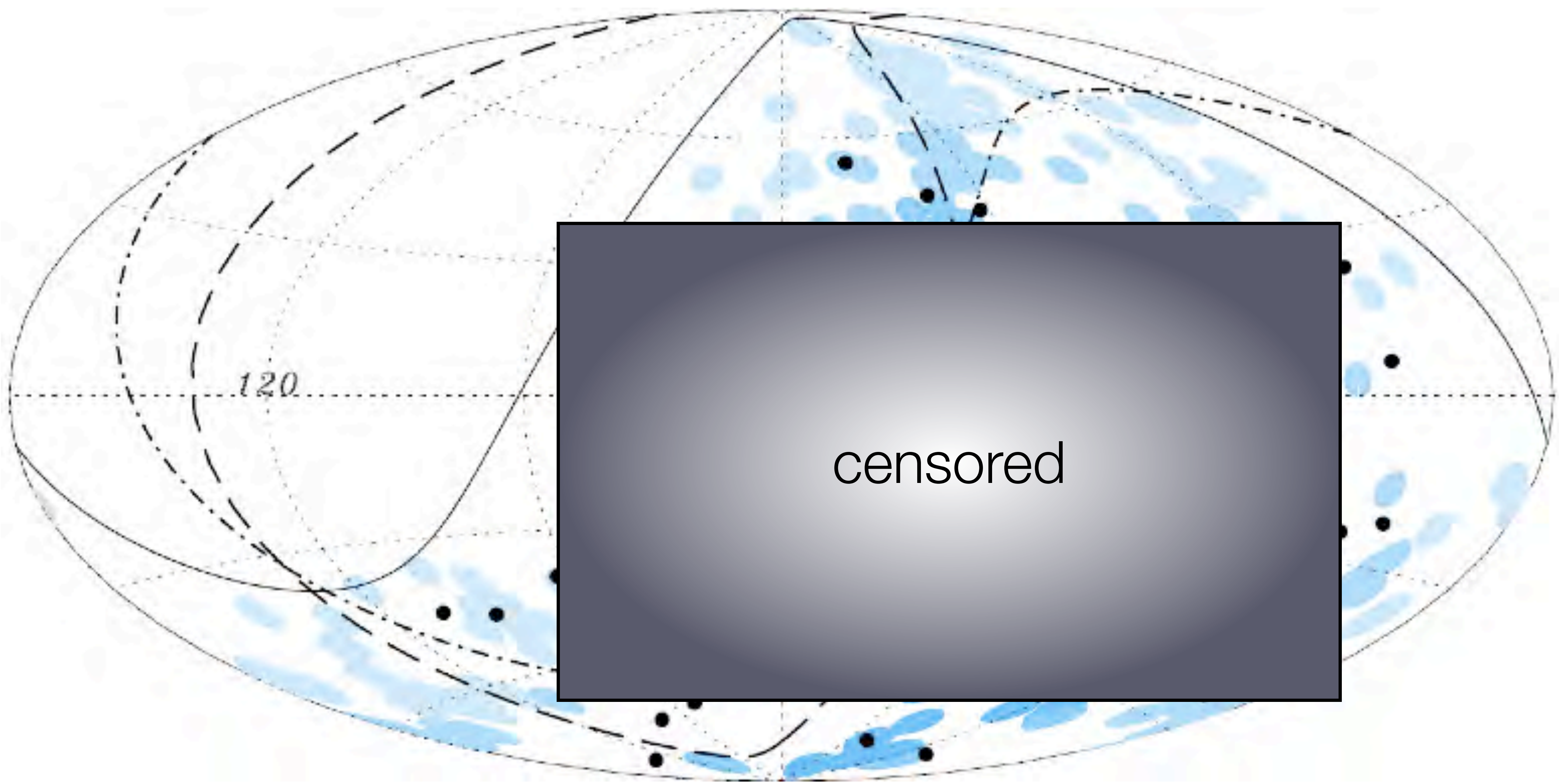
- the plot may be too suggestive
- hadronic interactions at play?
- beware the energy range...

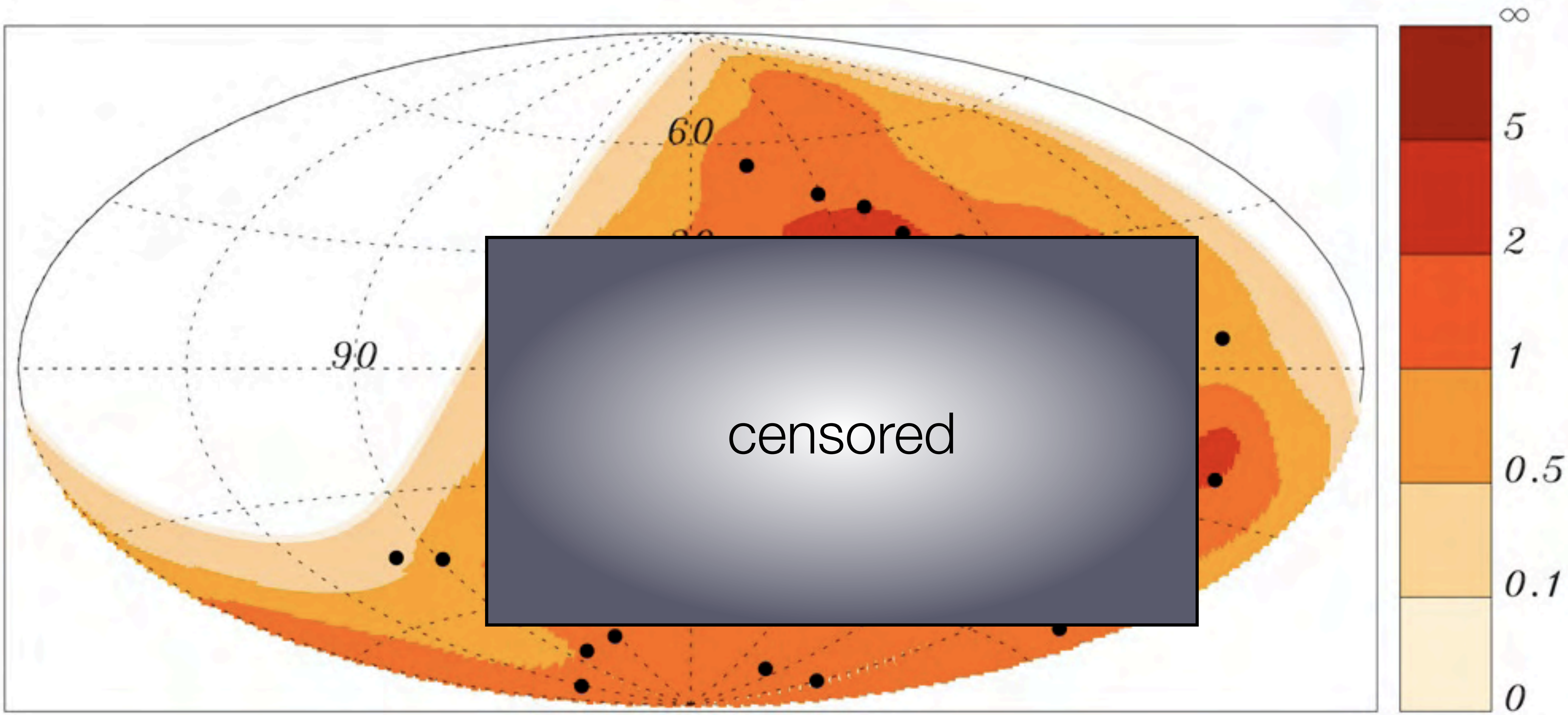
Correlation of the Highest-Energy Cosmic Rays with Nearby Extragalactic Objects



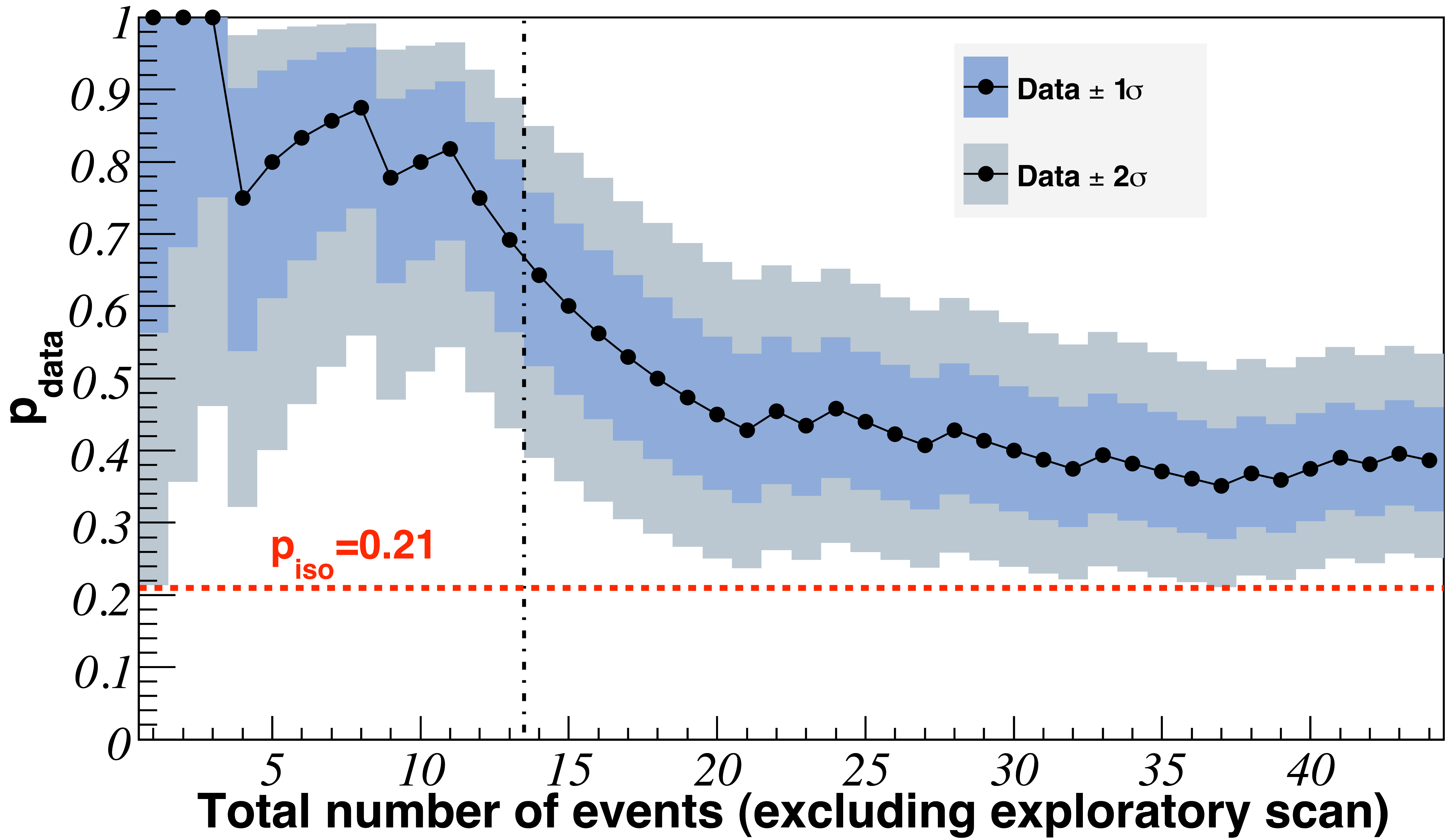


Capricornus Supercluster
100 million ly
Corona-Borealis Supercluster
Hercules Superclusters
Capricornus Void
Bootes Superclusters
Pavo-Indus Supercluster
180°
Bootes Void
Centaurus Supercluster
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
270°
90°
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Columba Supercluster
Sextans Supercluster


120
censored

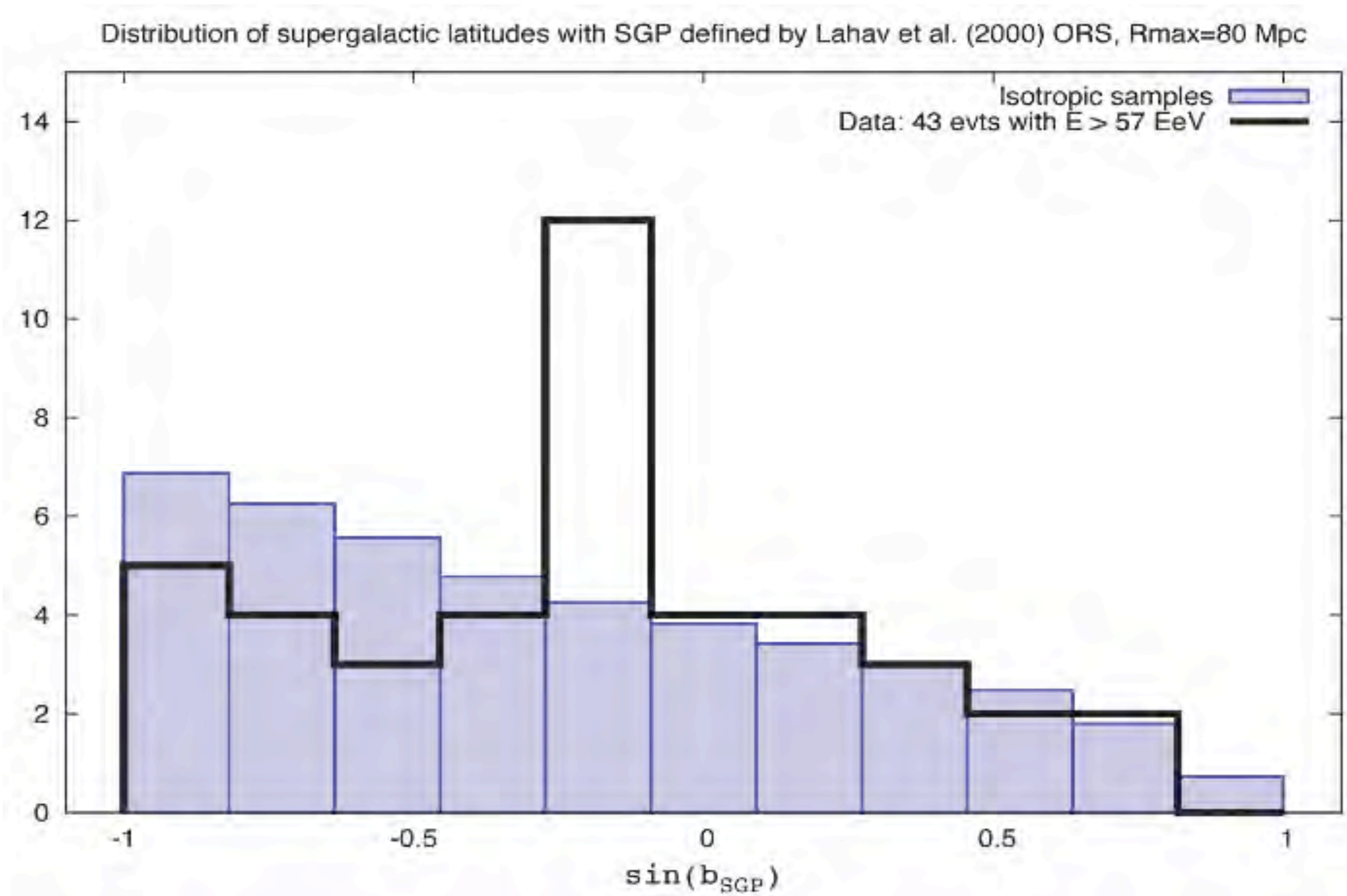


Cosmic ray density map predicted from the flux-weighted distribution of
X-ray AGNs detected by SWIFT, smoothed with an angular scale of 7◦. (An isotropic fraction of 35% was built into the maps to account for catalog incompleteness.) The dots represent the arrival directions of the 58 trans-GZK cosmic rays detected with Auger South up to March 31, 2009.

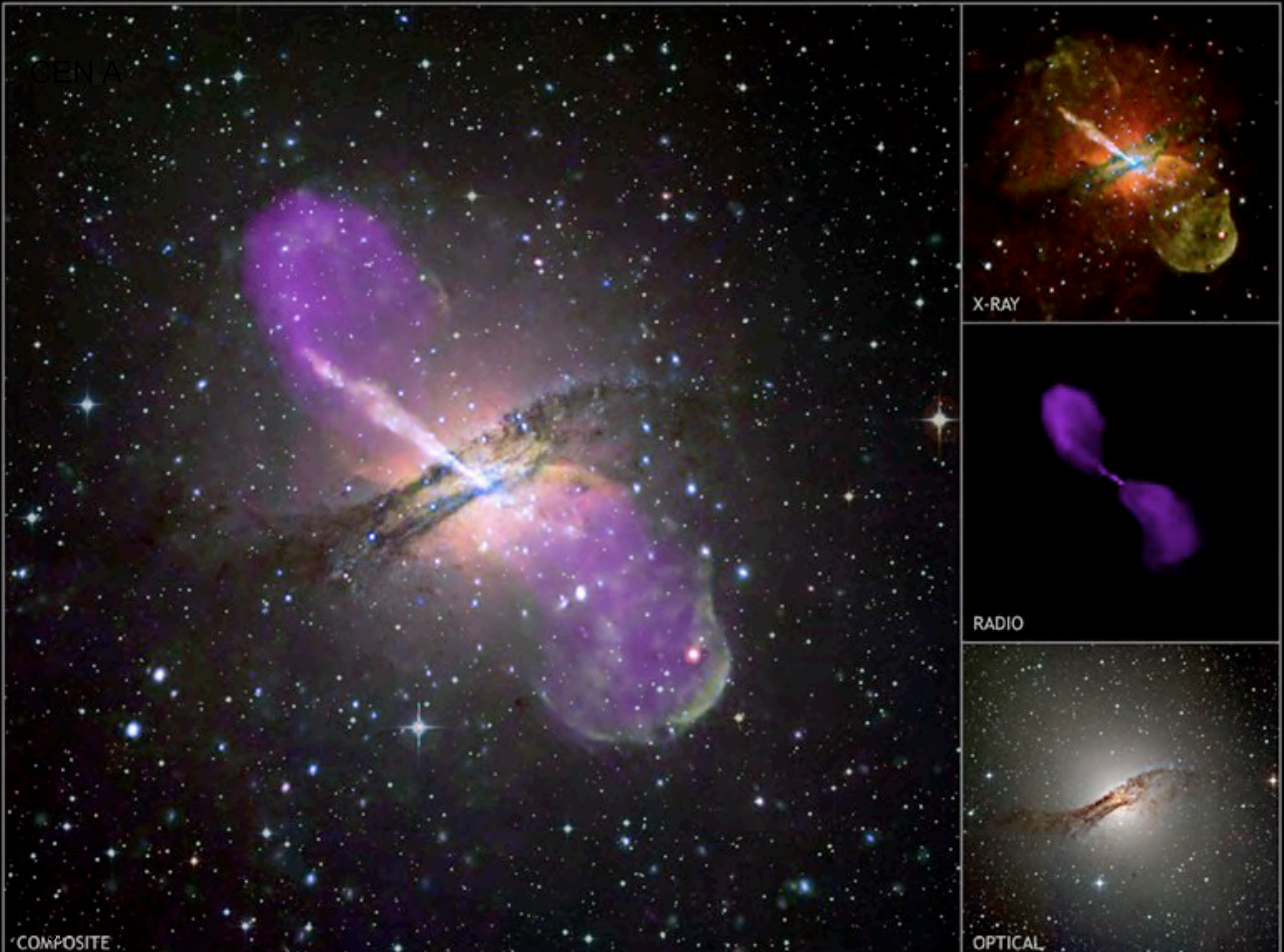


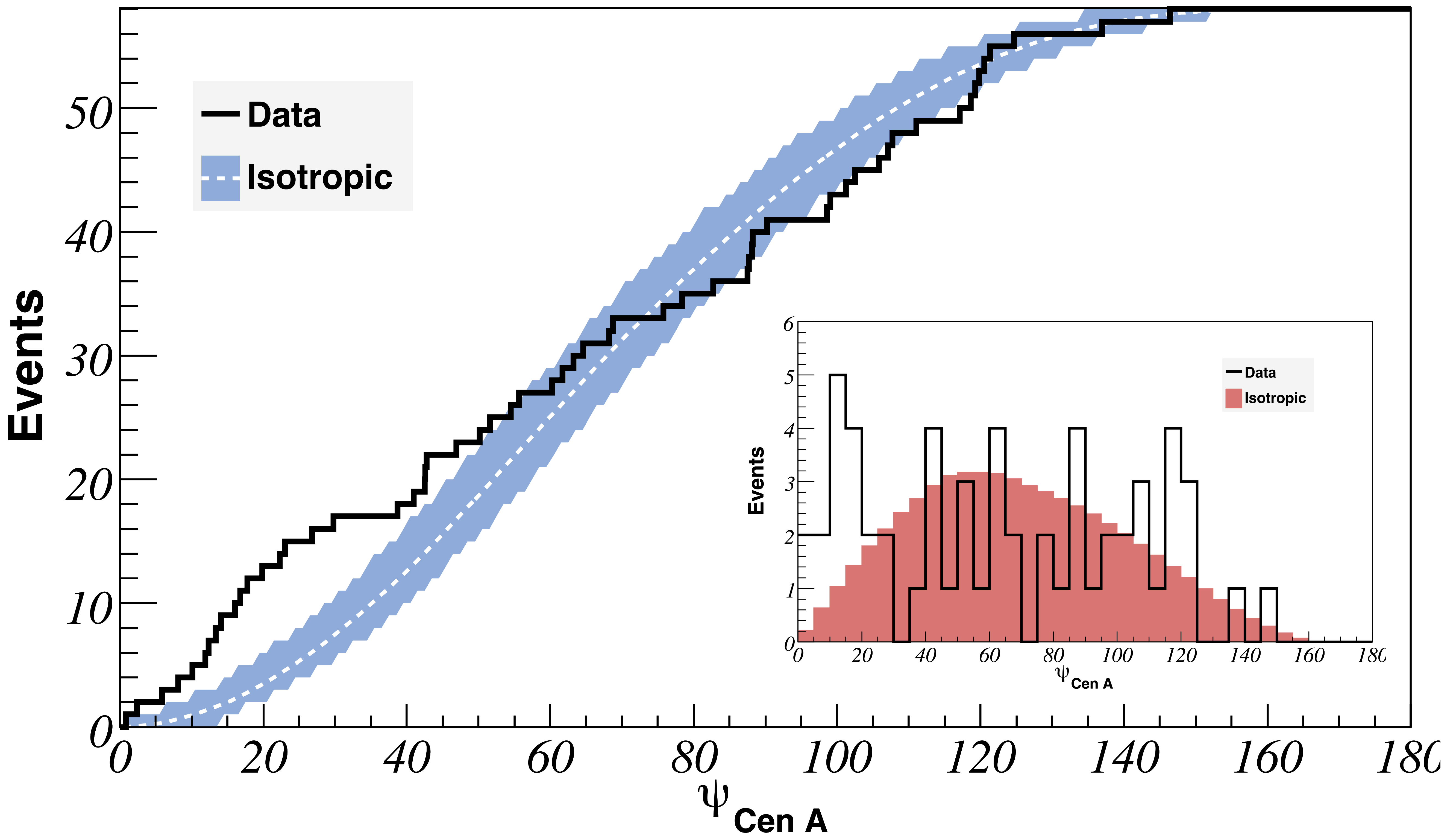
Data ± 1σ
Data ± 2σ
p_{iso}=0.21
p_{data}
Total number of events (excluding exploratory scan)

excess from the supergalactic plane



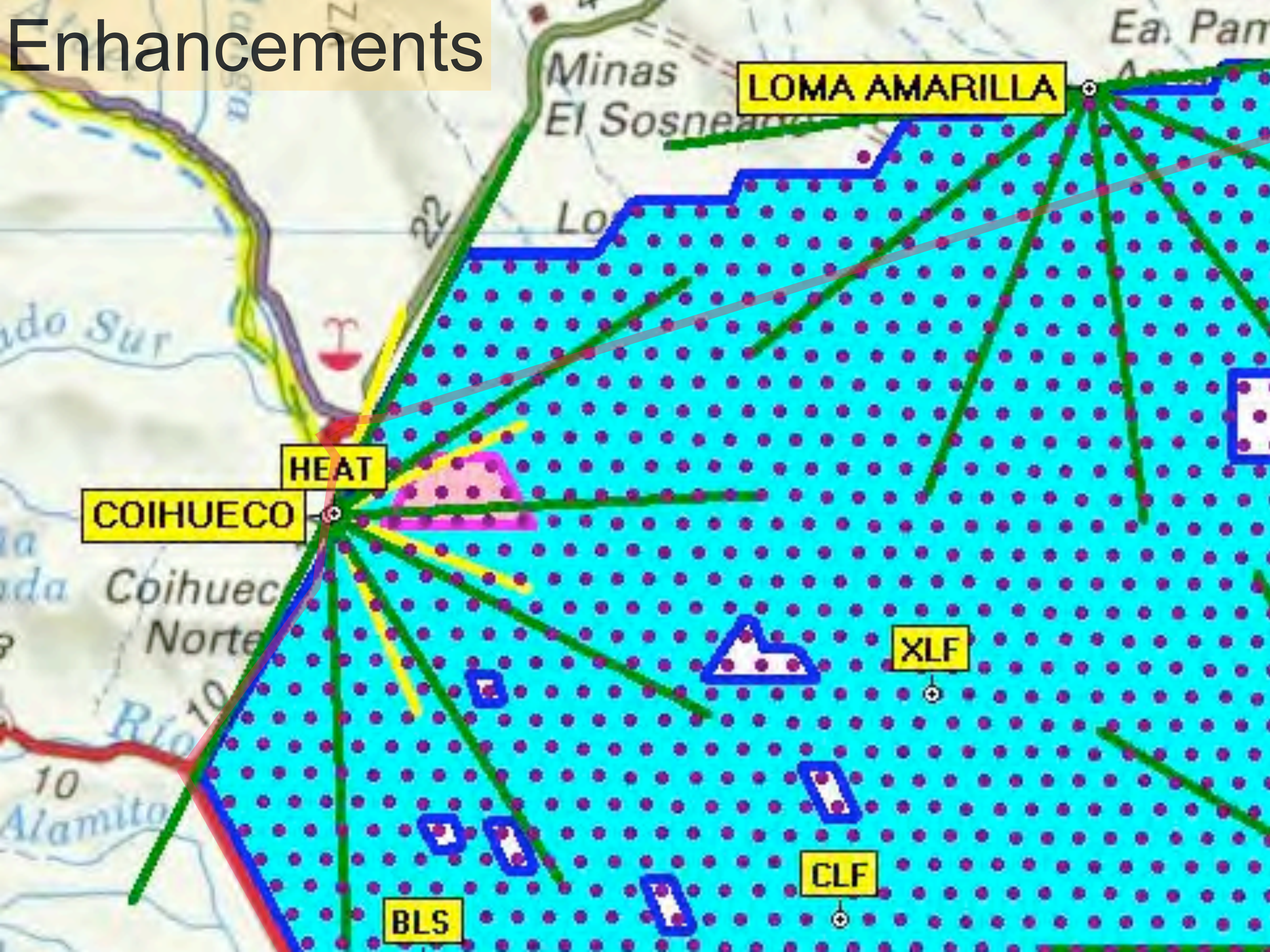
CEN A





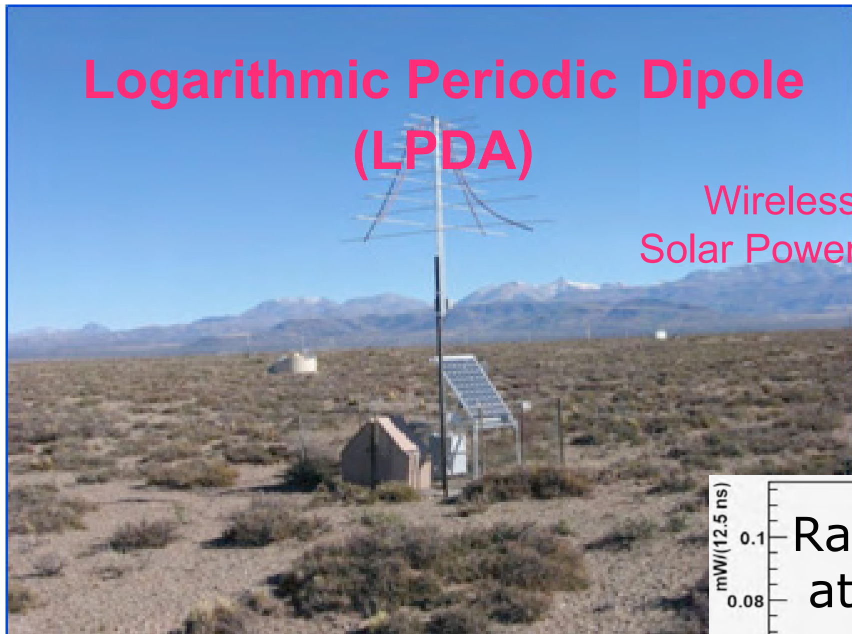
Events
Data
Isotropic
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160
180
ψ Cen A
Events
Data
Isotropic
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160
180
ψ Cen A

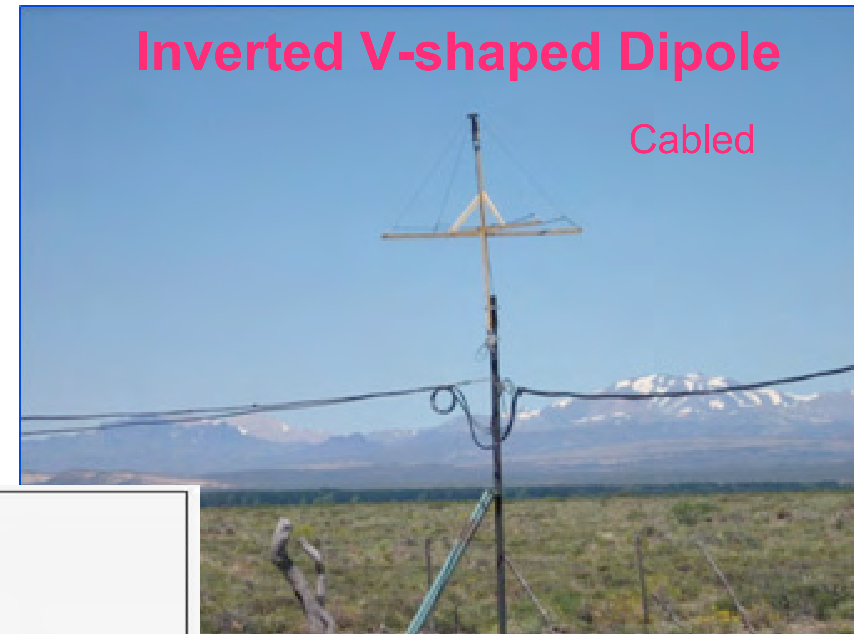
Enhancements

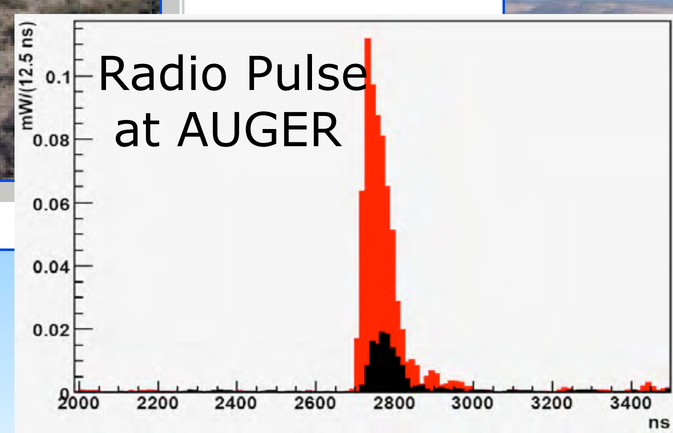


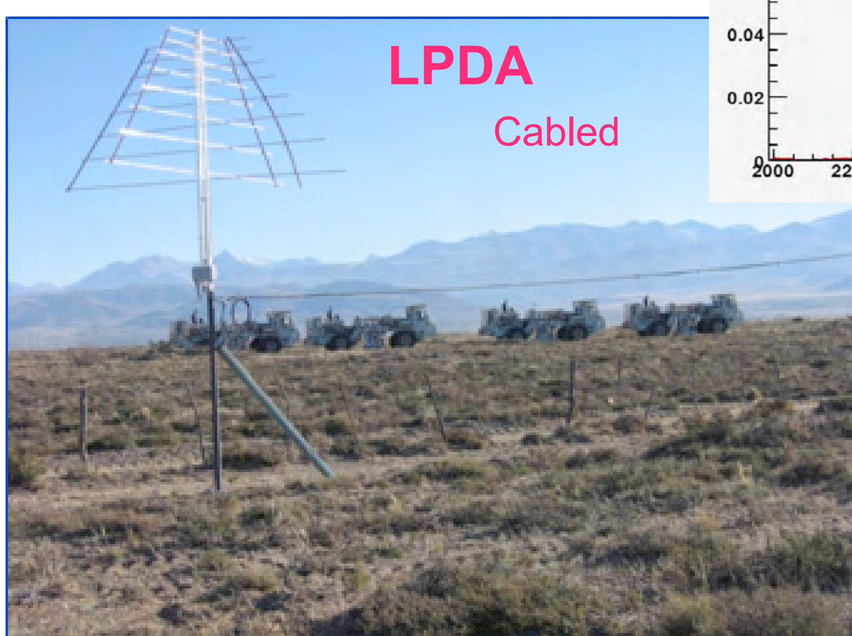
Radio R&D at Auger

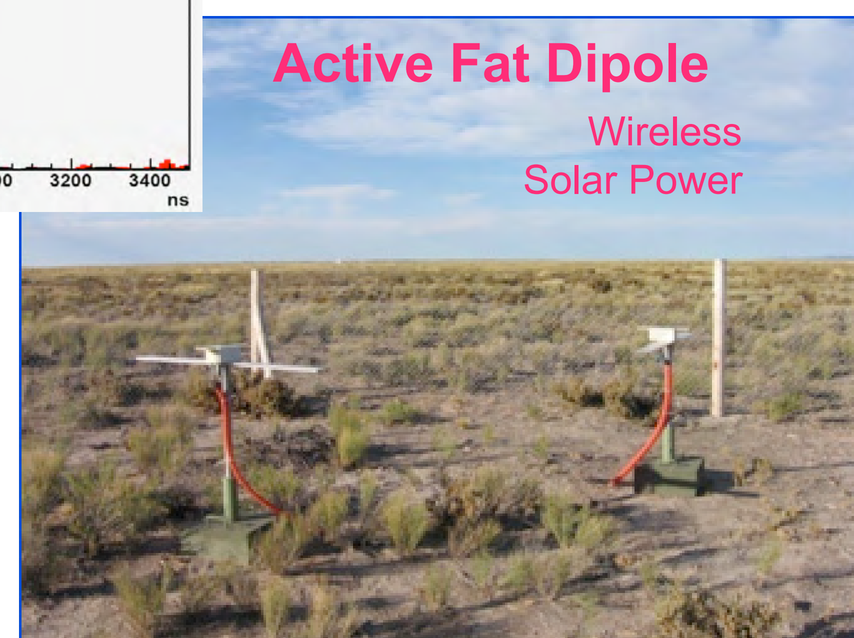
van den Berg & AUGER Collaboration (2007, ICRC)











Radio at Auger …

- Proposal: build a 20 km^2 self-triggering radio array
- Radio will allow triple-detection (radio, fluorescence, particles) to nail down energy scale and systematics at >10^{18} eV
- Questions to be answered:
  - Maximal lateral extent and shape on km scale?
  - composition with ~100% duty cycle possible?
  - < 0.1° localization with interferometric technique?
  - Self-triggering?
  - Large scale deployment?

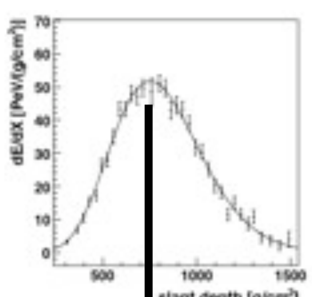
see van den Berg et al. (2007)


Lamar
Malargue

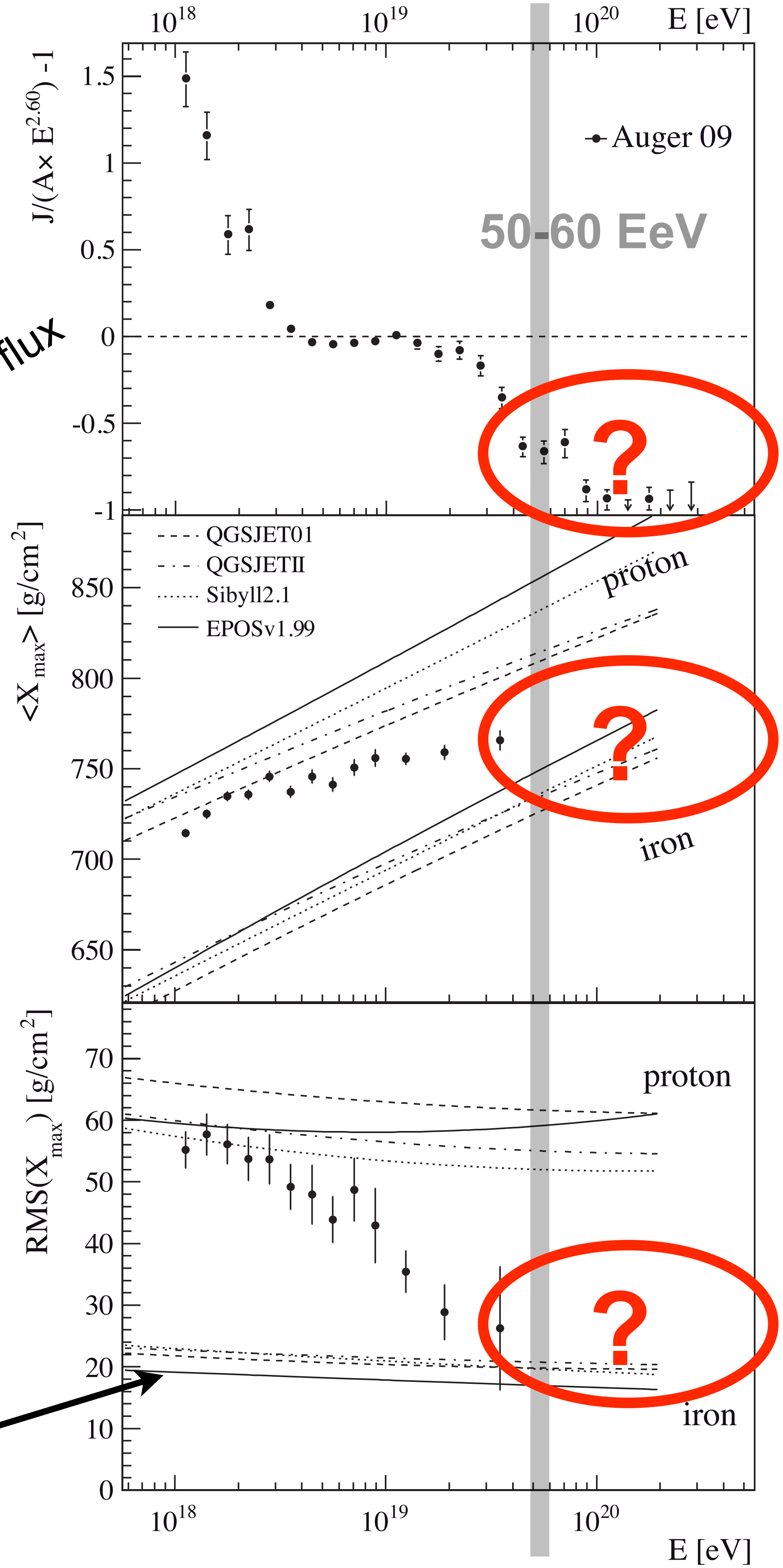
spectrum: convoluted information about sources, particles and propagation

shower profile: independent, best estimator of primary particle mass

de/dX



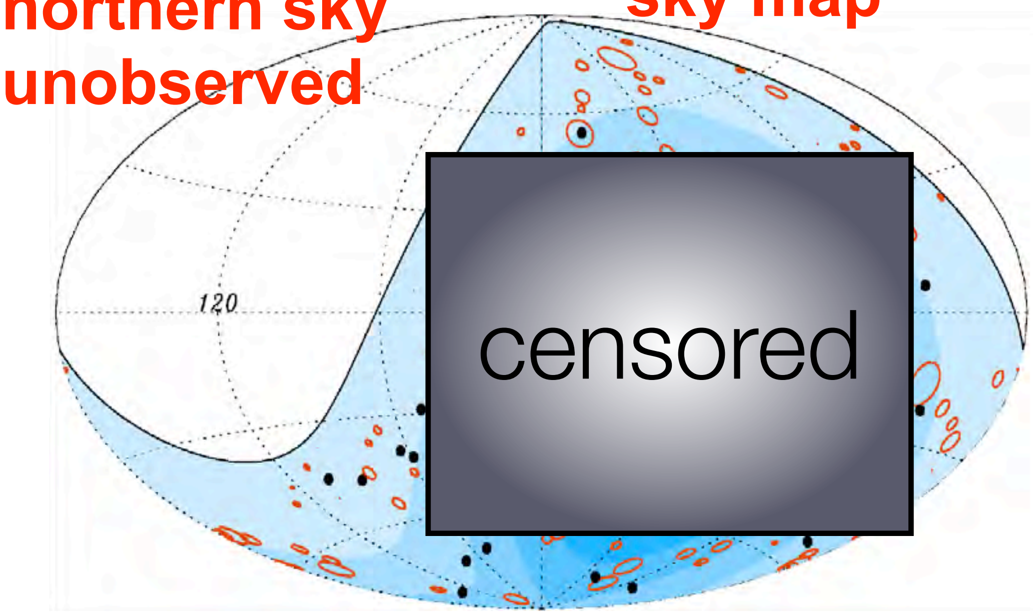
X_{max} X



models assume no change in basic physics

northern sky unobserved

few events in sky map

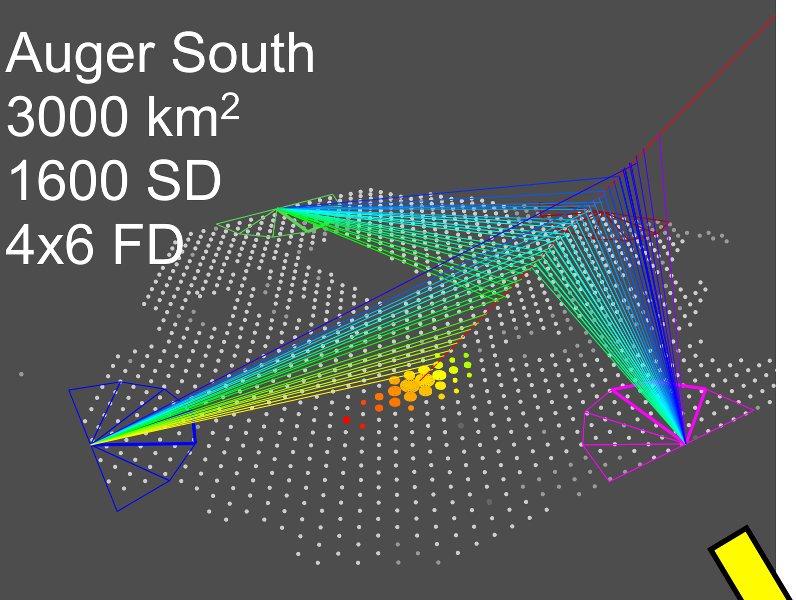


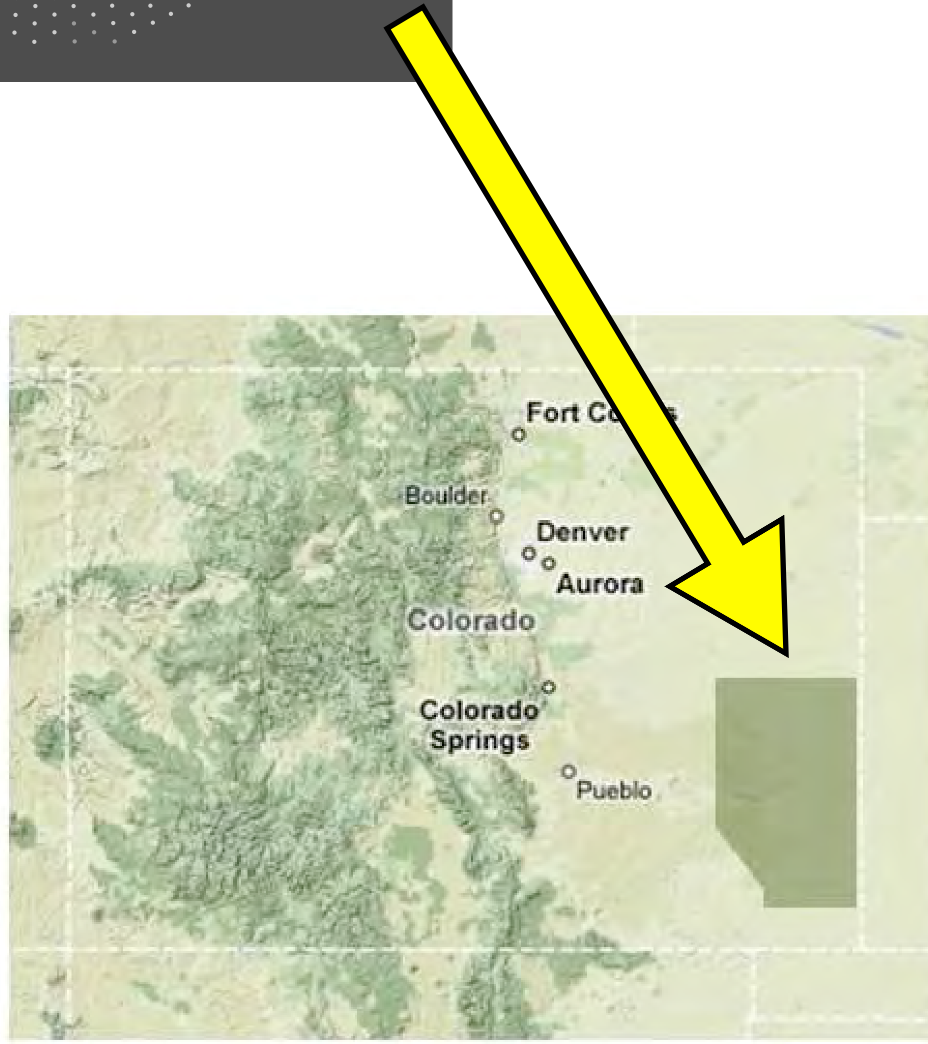
composition at and above the GZK threshold?

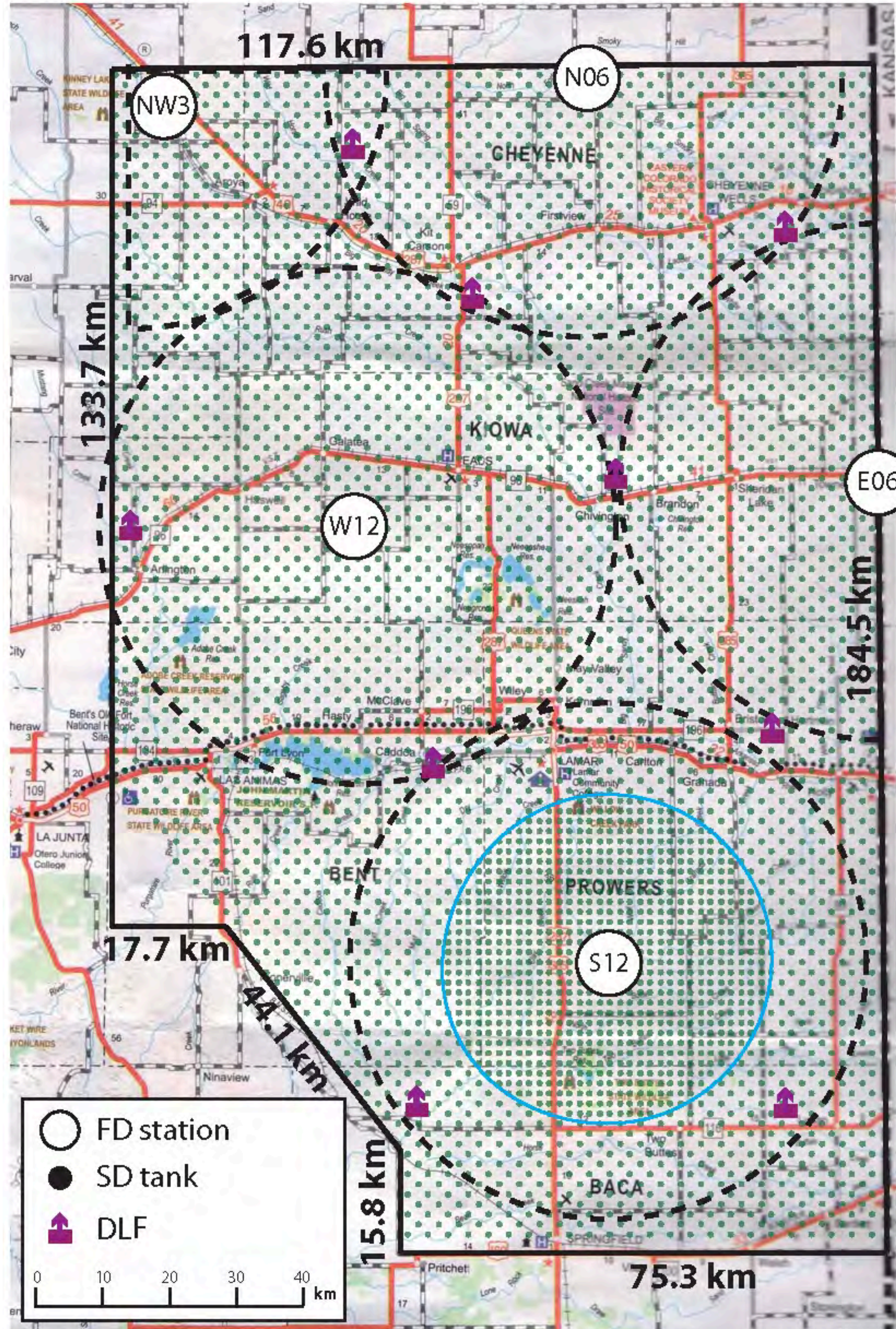
alternative explanations like increasing cross section?

particle physics at $\sqrt{s}$ > 350 TeV

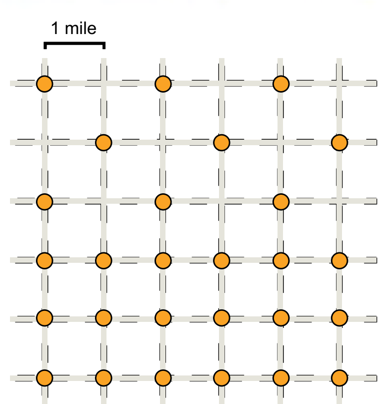
Addressing these questions needs much more statistics at the highest energies, i.e. a much larger area



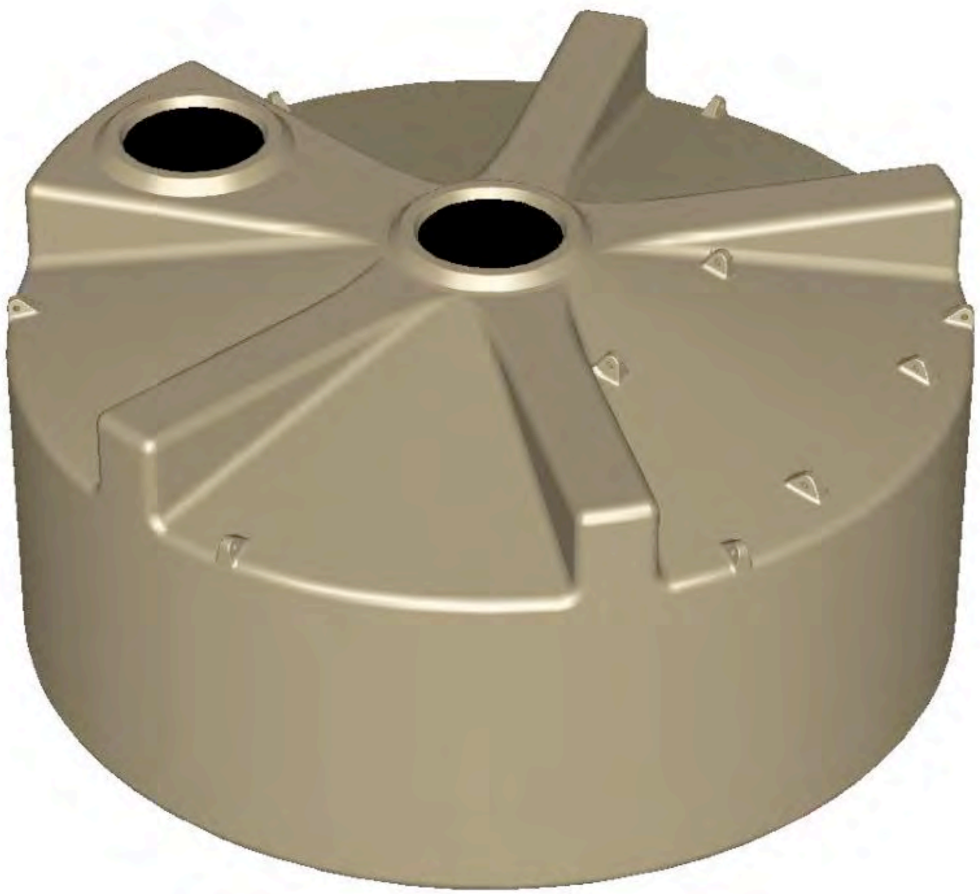


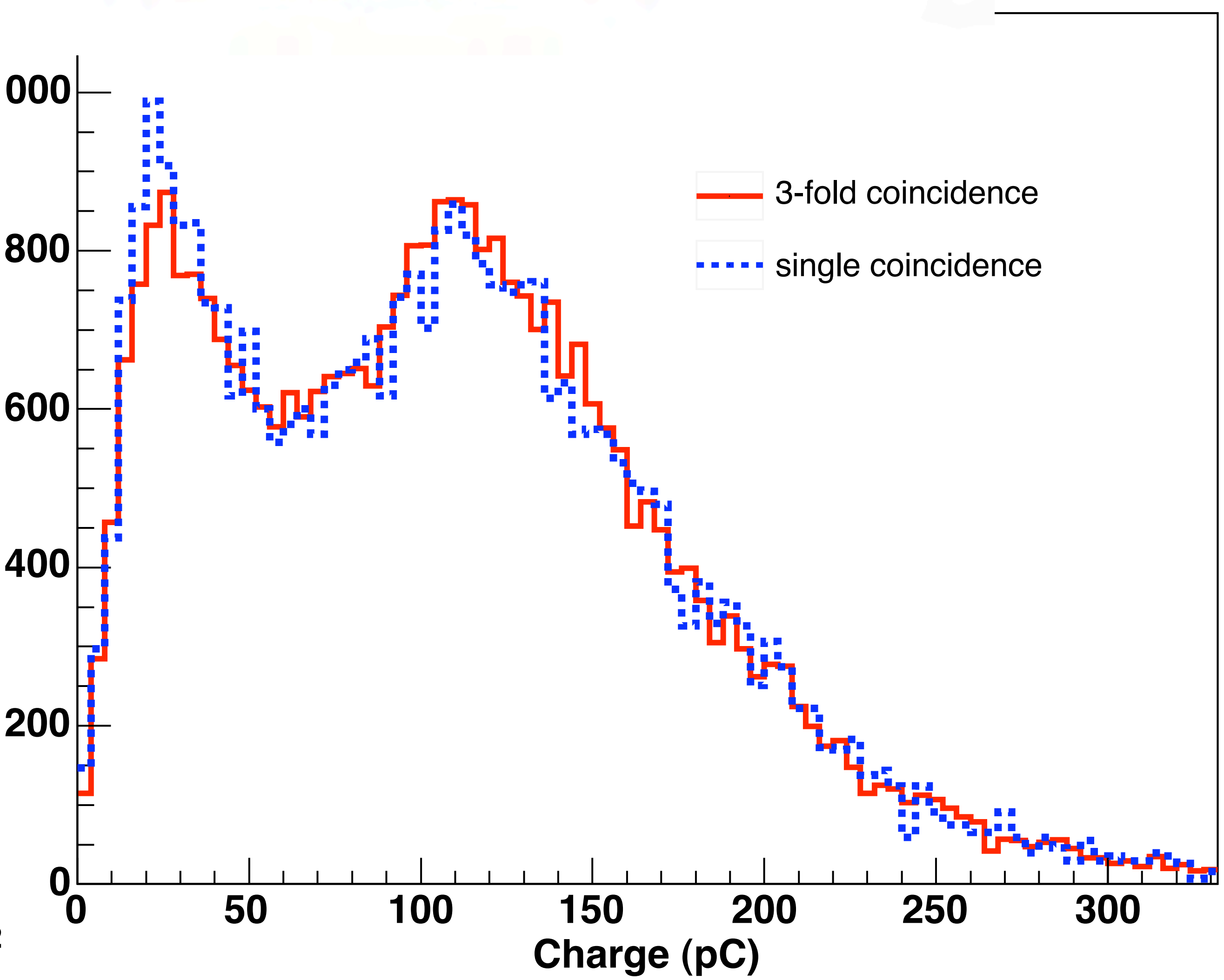


Auger North
20,000 km^2
4400 SD
39 FD

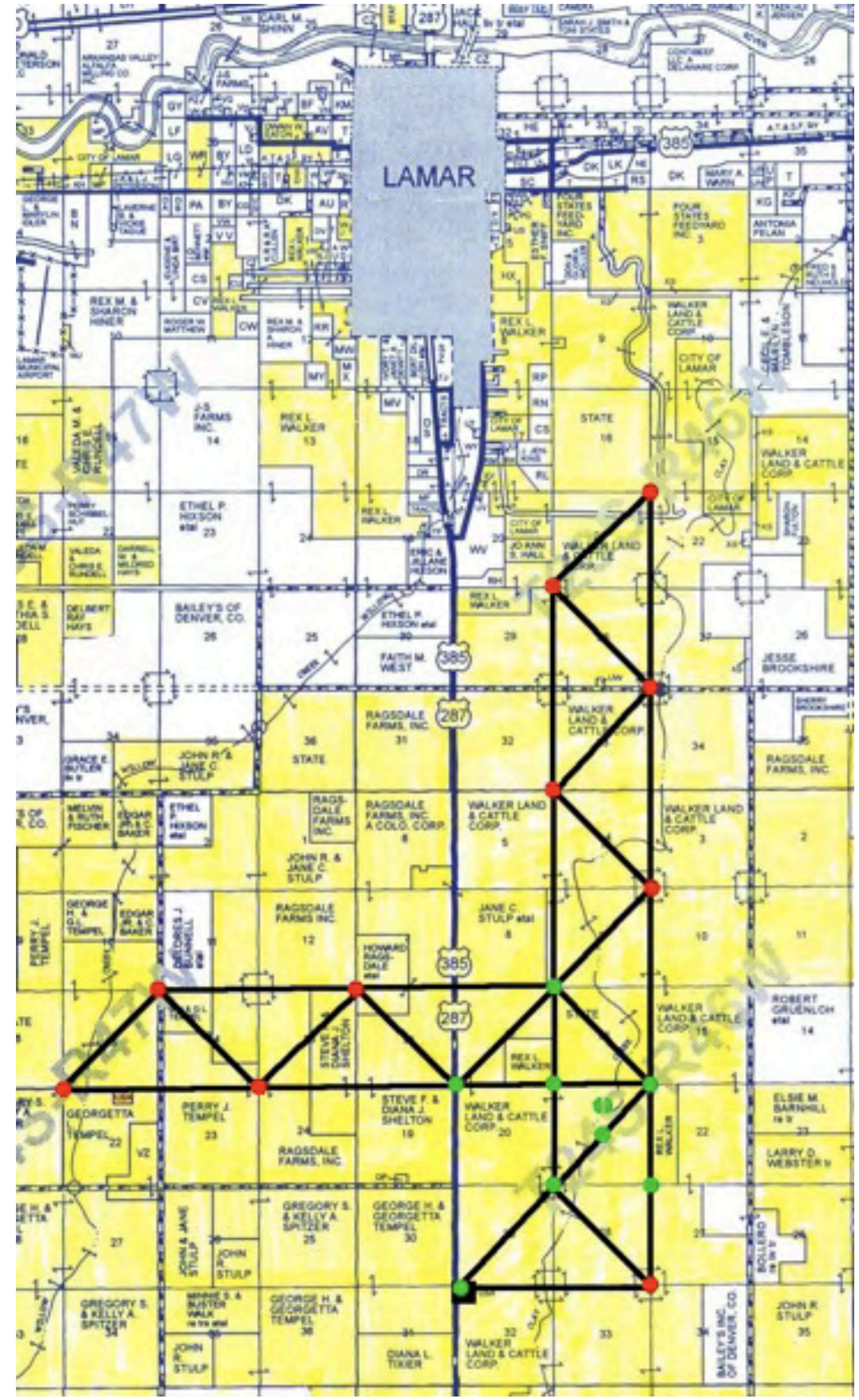



50
Lamar Community College
Auger North central facilities
287
Yucca Drive Wes
Prowers County Building
1
just examples
1.4
miles

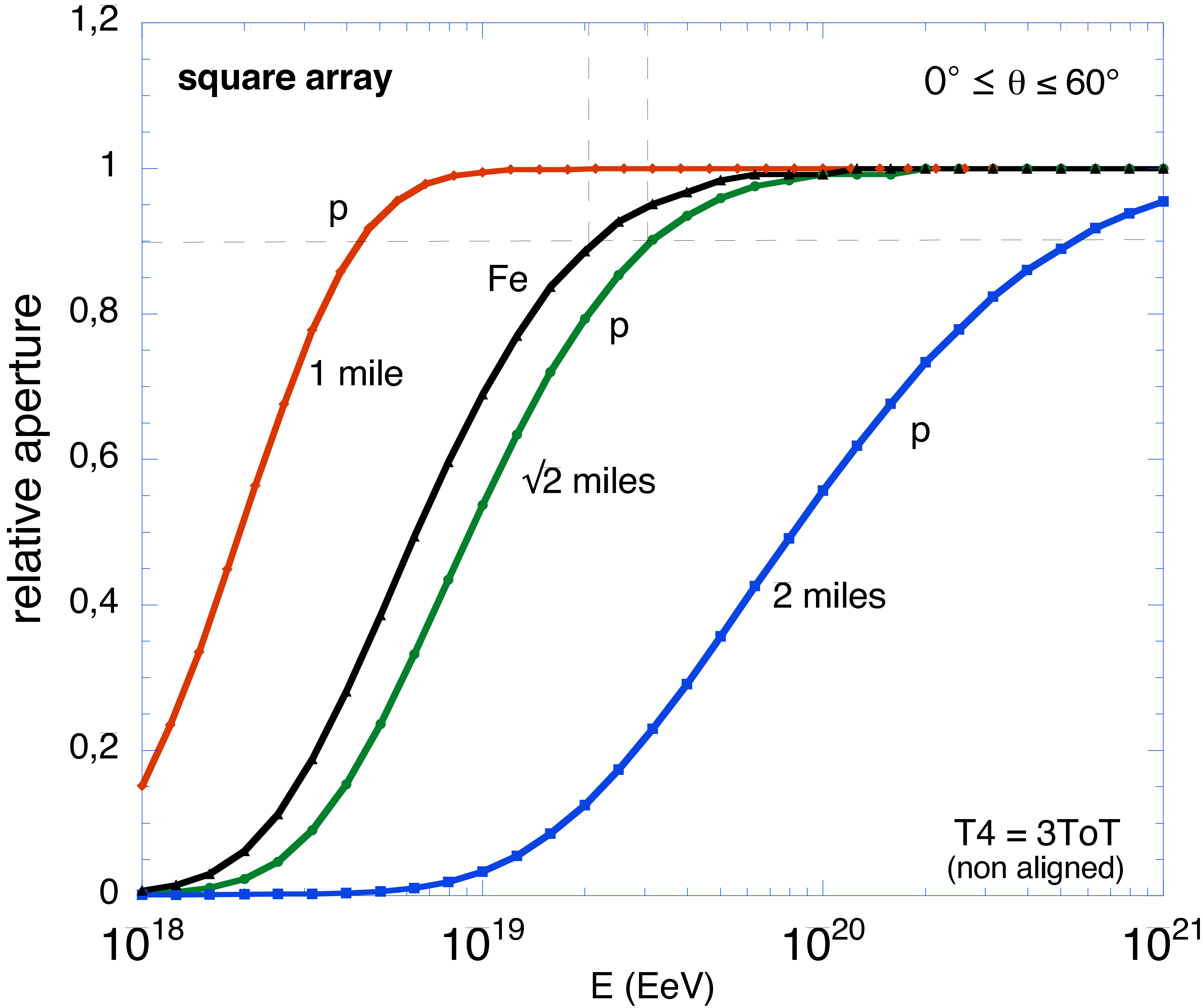


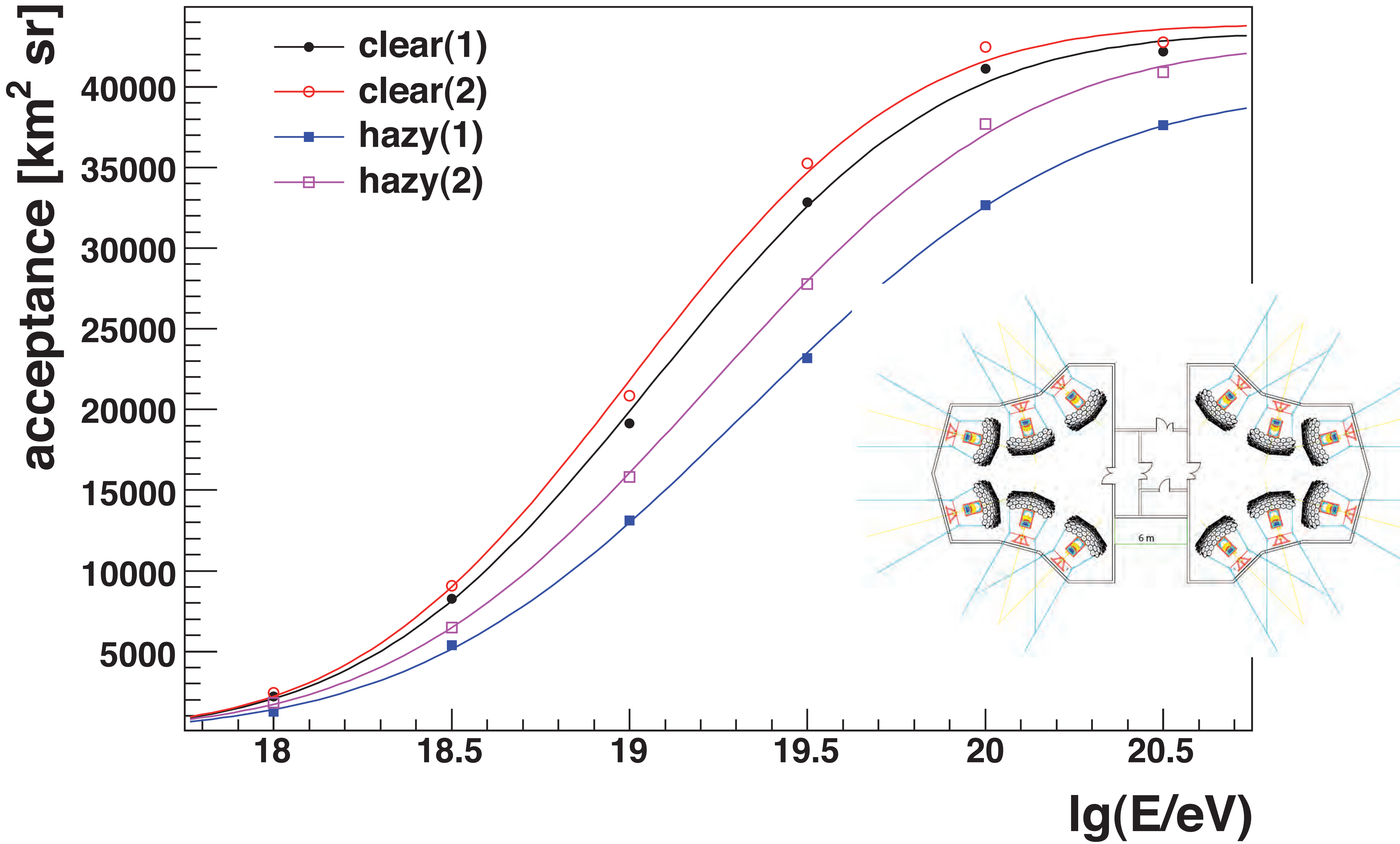


1000
800
600
400
200
0
0
50
100
150
200
250
300
Charge (pC)
3-fold coincidence
single coincidence



LAMAR


square array
$0° \leq \theta \leq 60°$
p
1 mile
Fe
p
√2 miles
p
2 miles
T4 = 3ToT
(non aligned)
relative aperture
0
0,2
0,4
0,6
0,8
1
1,2
10^{18}
10^{19}
10^{20}
10^{21}
E (EeV)

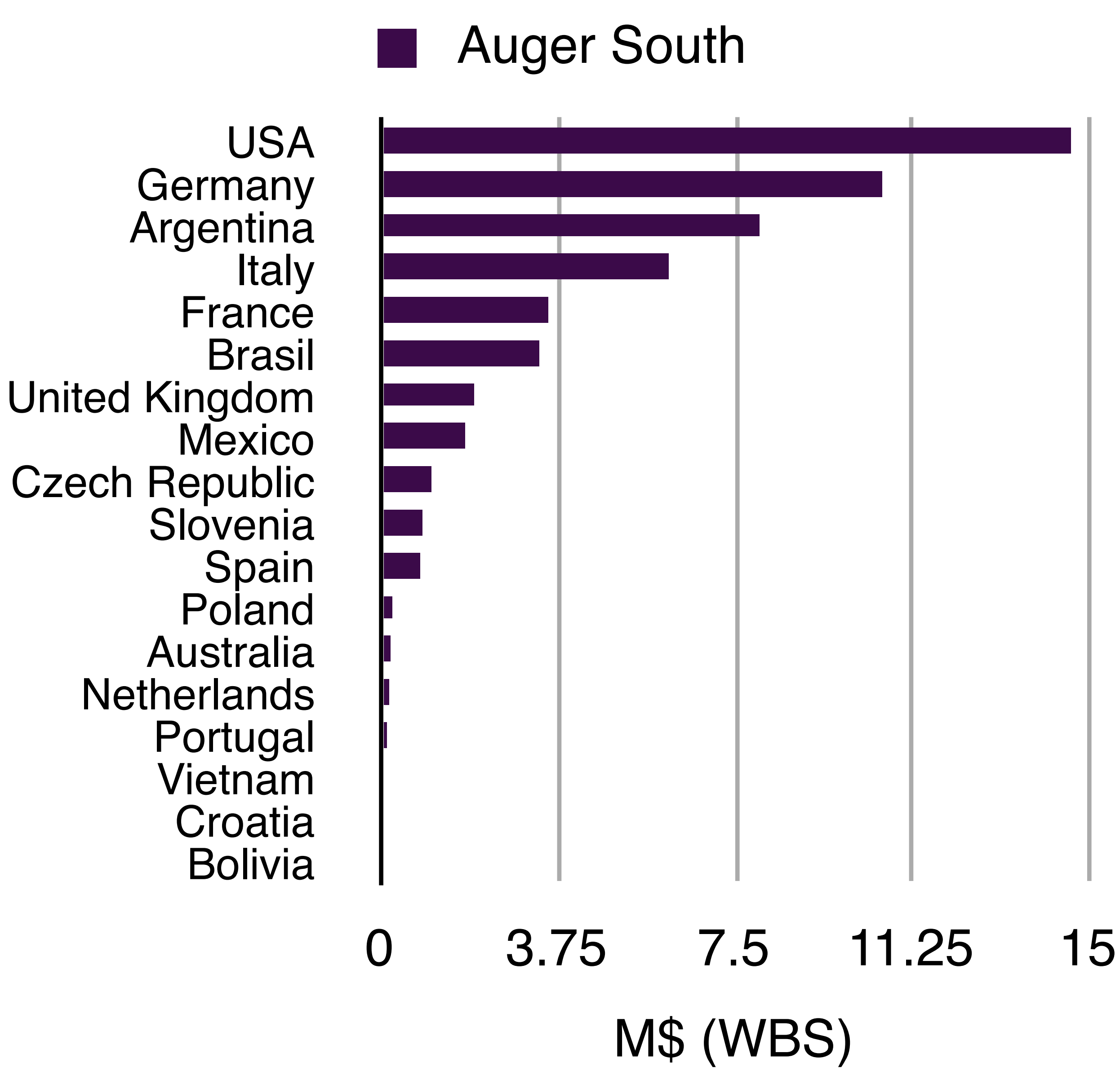

clear(1)
clear(2)
hazy(1)
hazy(2)
acceptance [km² sr]
40000
35000
30000
25000
20000
15000
10000
5000
18
18.5
19
19.5
20
20.5
lg(E/eV)
6 m

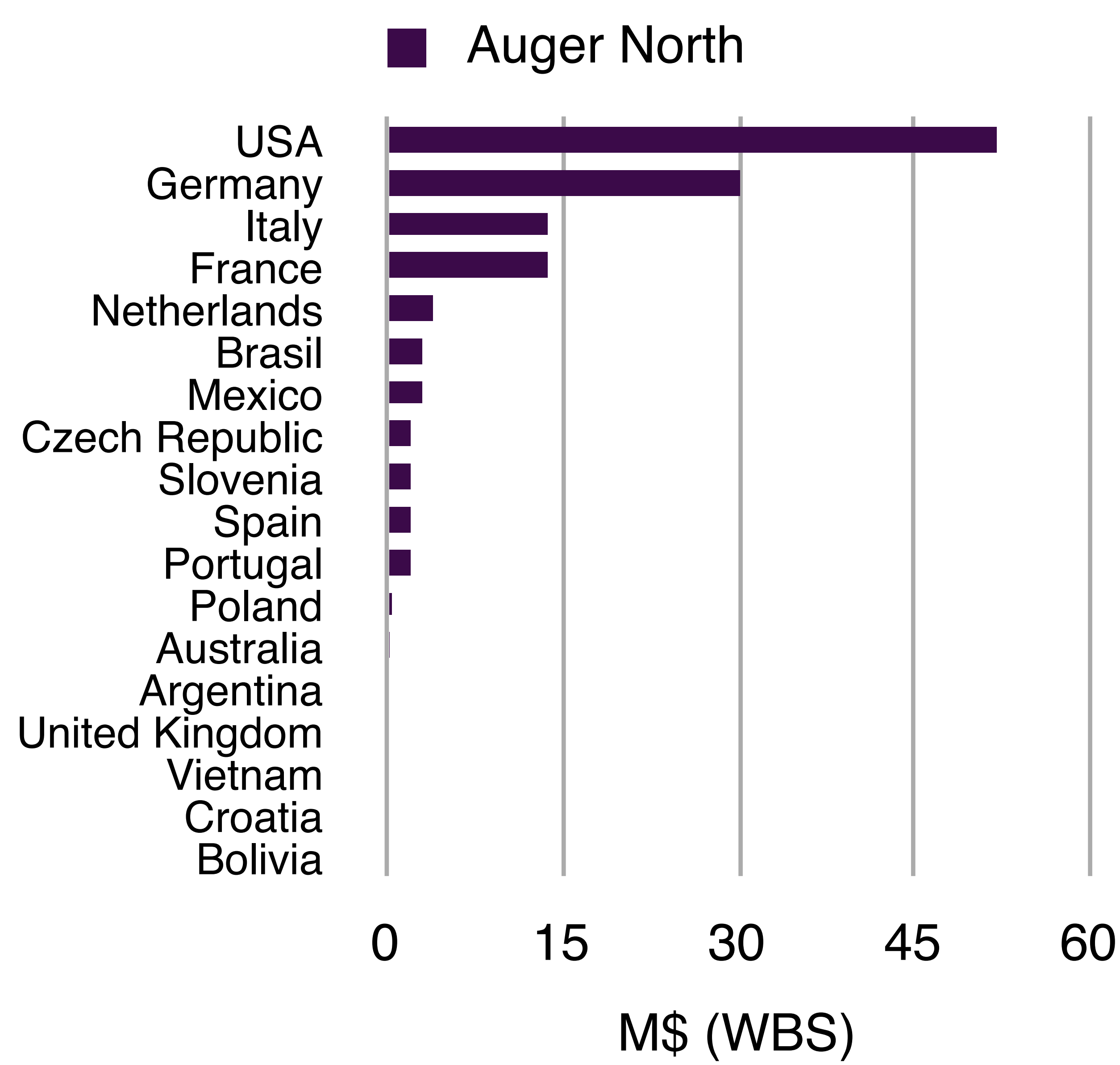
	Auger South	Auger North
Location	35° S, 69° W	38° N, 102° W
Altitude	1,300 - 1,500 [m a.s.l.	1,300 [m a.s.l.
Area	3,000 km^2	20,000 km^2
Number of SD stations	1,600	4,000
(infill)		(400)
SD spacing	1,500 m	2,300 m
(infill)		(1,600 m)
PMT sensors / SD station	3	1
Communications network	SD-tower radio	peer-to-peer
SD array 50% efficient at	0.7-1 EeV	8-10 EeV
SD array 100% efficient at	3 EeV	80 EeV
FD stations	4	5
FD telescopes	24 (4×6)	39 ($2 \times 12 + 2 \times 6 + 1 \times 3$)
Begin construction	1999	2011
End construction	2008	2015

Year	*Milestones*
1	Campus: Complete Office & Assembly Buildings FD: Construct 1st 12-Telescope enclosure; Install Telescopes 1–6 SD: Procure Detectors 1–100; Install Detectors 1–50
2	FD: Construct 2nd 12-Telescope enclosure; Install Telescopes 7–18 SD: Procure Detectors 101–1000; Install Detectors 51–400
3	FD: Construct 1st 6-Telescope enclosure; Install Telescopes 19–30 SD: Procure Detectors 1001–2400; Install Detectors 401–1000
4	FD: Construct remaining enclosures; Install Telescopes 31–39 SD: Procure 2401–3600; Install Detectors 1001–2500
5	FD complete SD: Procure remaining detectors; Install Detectors 2501–4400

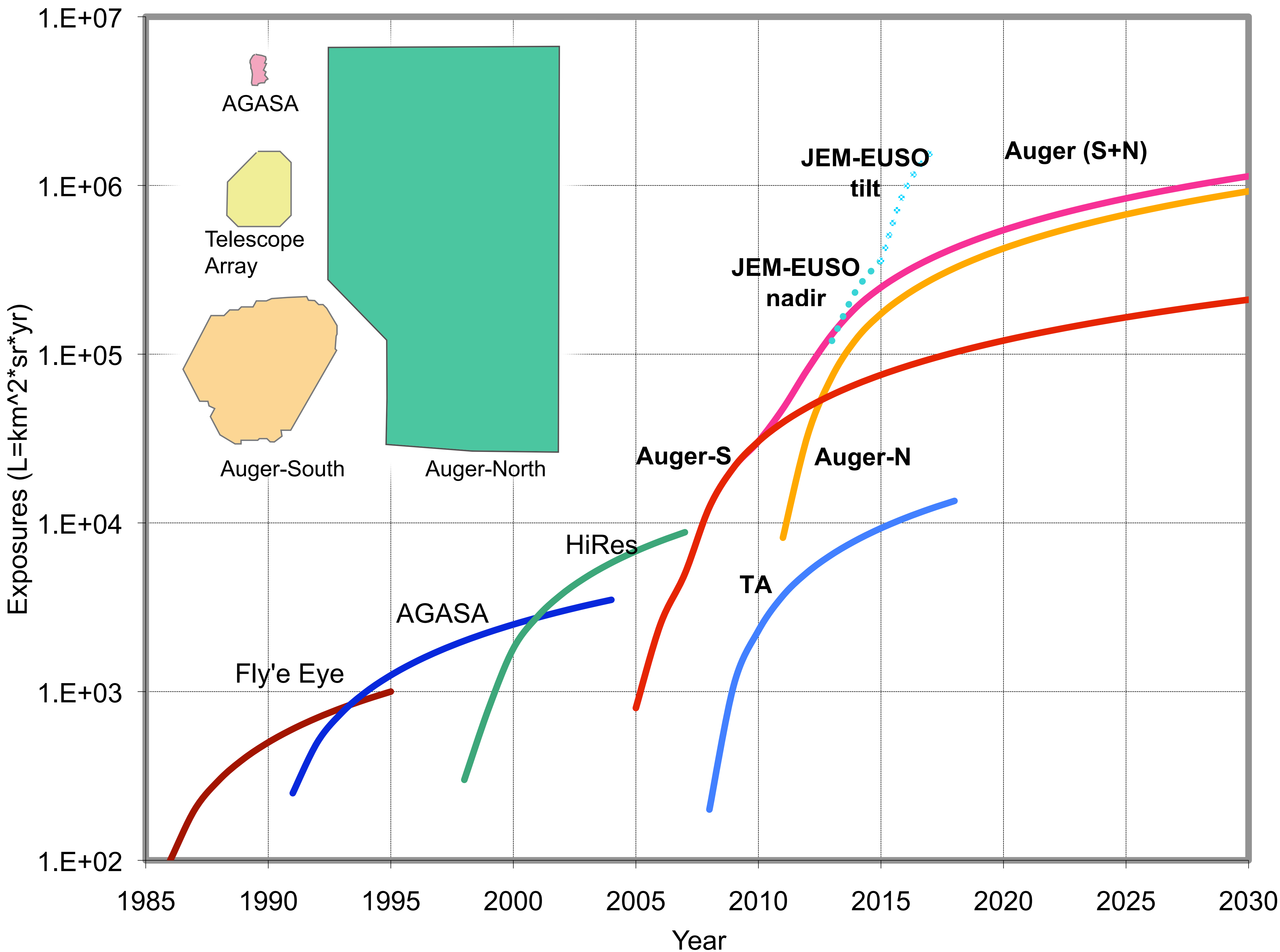
WBS	*Activity*	*Total Project Cost (M$)*
	AUGER NORTH Project	**126.7**
1.0	FLUORESCENCE DETECTOR	32.9
2.0	SURFACE DETECTORS	68.5
3.0	COMMUNICATIONS	6.8
4.0	CENTRAL DATA ACQUISITION	0.4
5.0	DATA PROCESS & ANALYSIS	1.1
6.0	SITE DEVELOPMENT	11.9
7.0	PROJECT MANAGEMENT	5.1

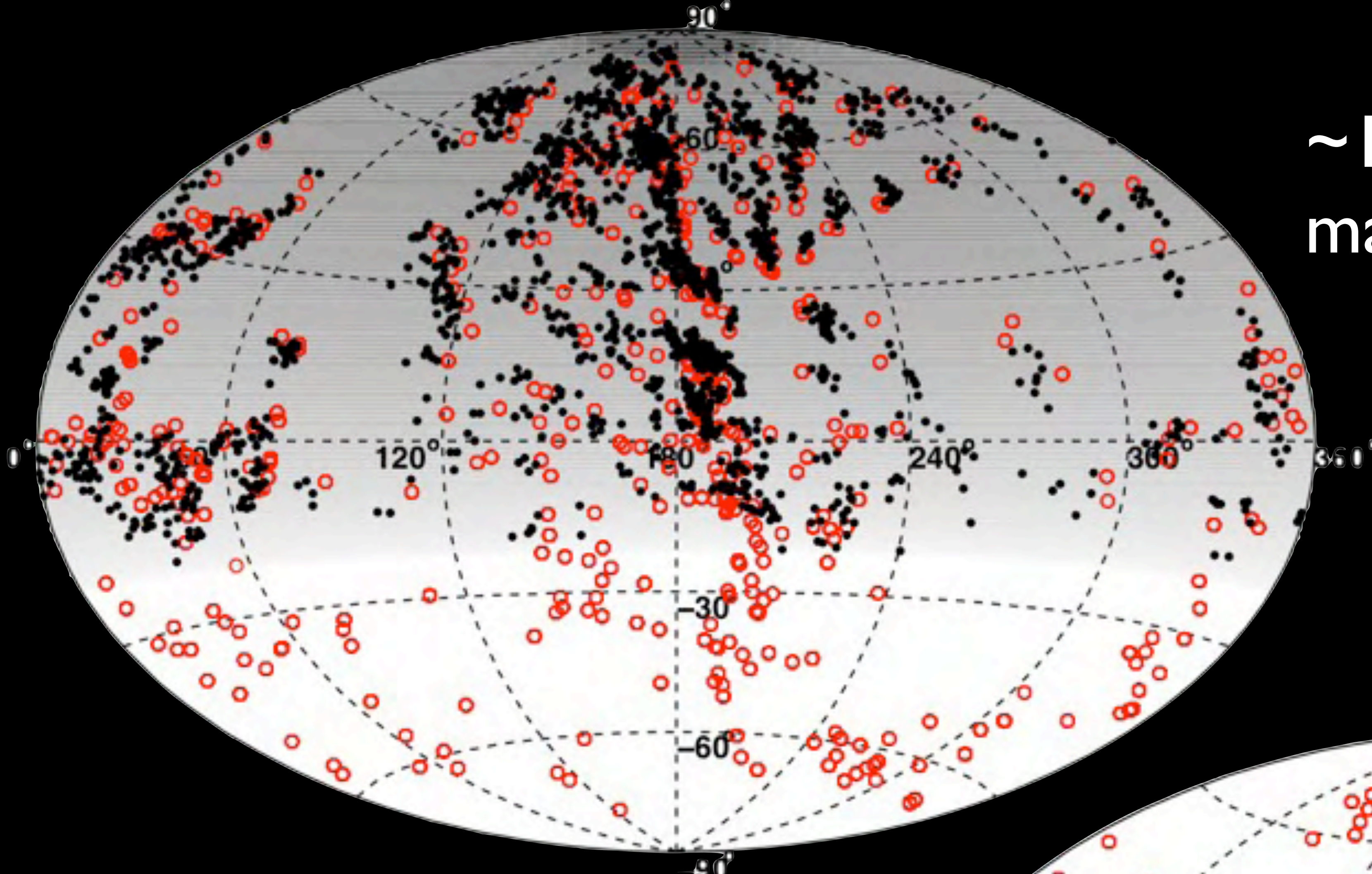
Country contributions to construction



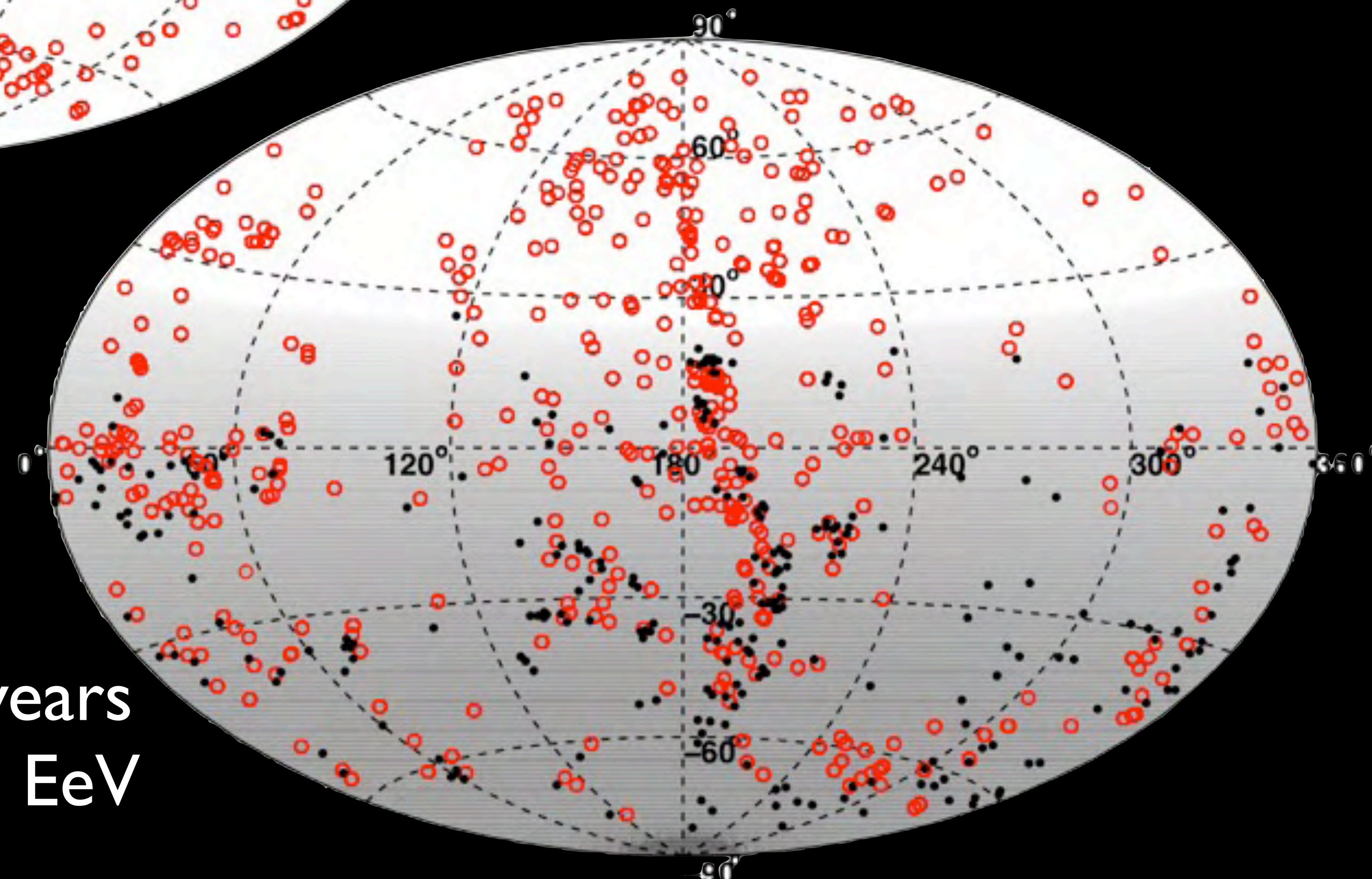


Sum(hopes) ≥ amount required


1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
Exposures (L=km^2*sr*yr)
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
AGASA
Telescope Array
Auger-South
Auger-North
JEM-EUSO tilt
Auger (S+N)
JEM-EUSO nadir
Auger-S
Auger-N
HiRes
TA
AGASA
Fly'e Eye



Auger North
~1,400 events E > 60 EeV
many particles per source



Auger South – 10 years
~200 events E > 60 EeV

in the context of modern cosmology this argument is actually correct!


PIERRE AUGER
Pierre Auger Observatory
Surface Detector Station
LAMAR
COMMUNITY COLLEGE
For more information, please
stop at the Visitor Center in the
LCC Library.


DORMITORY

Merci beaucoup!