Exposure calculation for GP300

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Exposure (In the Case of Isotropic Flux)

$$\text{\# of events} = \text{Flux } (\text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}) \times \text{Exposure } (\text{cm}^2\ \text{s sr})$$

\# of events dN detected from a fixed sky region in dΩ during a period of dt:

$$dN = \text{Flux} \times d\Omega \times A_{geo} \cos\theta \times R(\theta, \phi) \times dt$$

A_{geo}: Geometrical area of the array
$R(\theta, \phi)$: Response function of the array
(Including the effect of the atmosphere, non-uniformity of the array sensitivity over the sky)

Integration over Ω and t gives the total # of events from the whole sky during the DAQ period T

$$\int dN = N = \text{Flux}\ A_{geo} \int_{\Omega} R(\theta, \phi) \cos\theta\, d\Omega \int_{T} dt$$

$$\text{Exposure} = A_{geo} \int_{\Omega} R(\theta, \phi) \cos\theta\, d\Omega \int_{T} dt$$

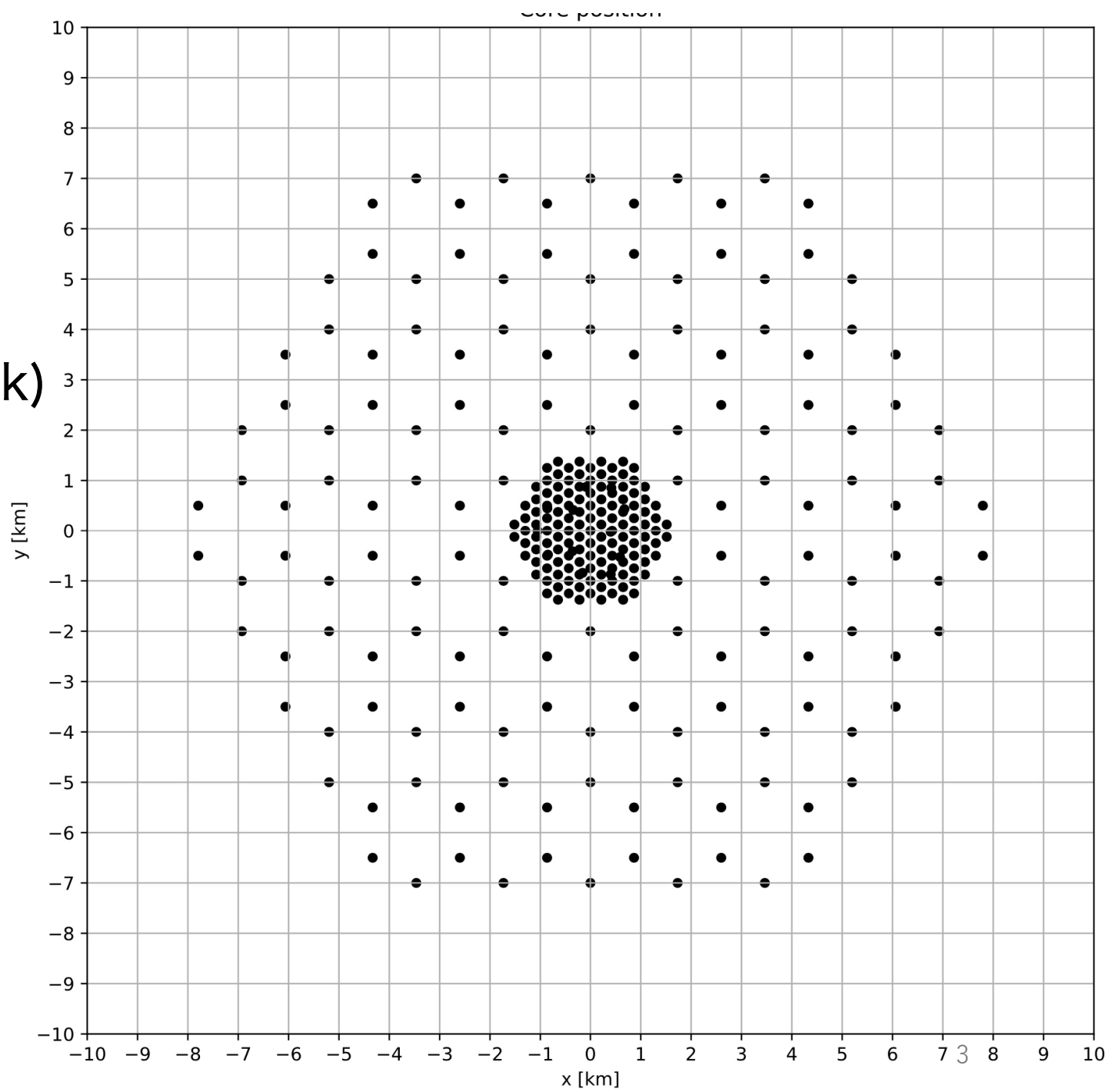
DC2 Simulation

GP300 array configuration

- ✓ Geometrical area: 168 km²
- ✓ 289 radio detector units (DUs)
  (12DUs of GP13 for crosscheck)
- ✓ Infill array (250m interval)
- ✓ Outer array (1km interval)

Site details

- ✓ Xiaodushan, Dunhuang
  (40.99°N, 93.94°E)
- ✓ 1264 m a.s.l.
- ✓ $B_{geo} = 56.5\,\mu T$
- ✓ Inclination angle: 61.6°
- ✓ Declination angle 0.13°



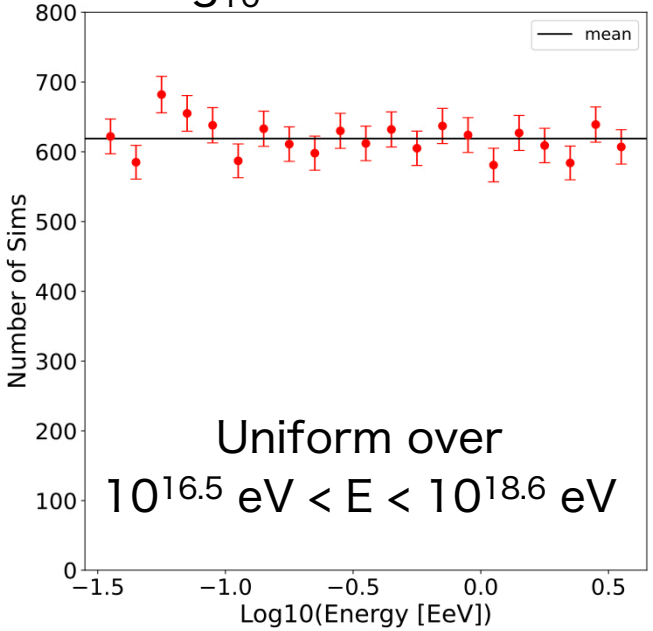
DC2 Simulation

- ✓ Dataset directory: /sps/grand/DC2Training/ZHAireS/.
- ✓ EAS simulation code: ZHAireS 1.0.30a
- ✓ Hadronic interaction model: Sibyll 2.3d
- ✓ Total # of events: 1.3×10^4

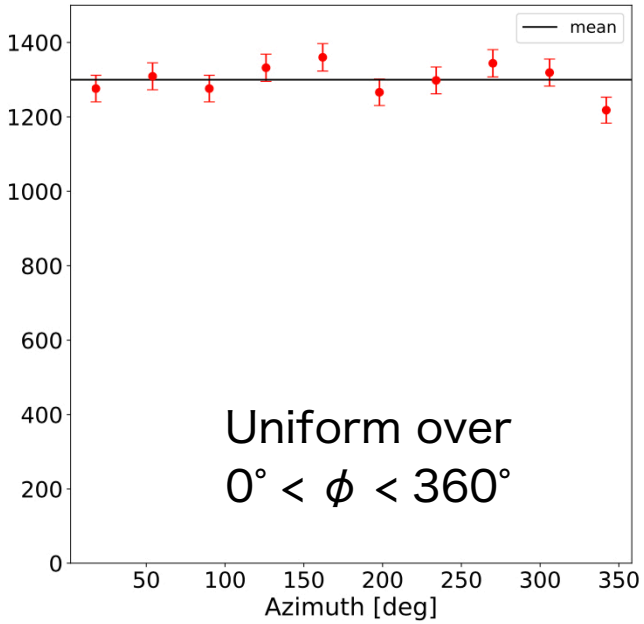
For each event,

- ✓ Shower is simulated until its maximal development: X_{max}
- ✓ Random generation of core locations are repeated until # of DUs inside the Cherenkov cone is >= 3
  => We get tested core positions & the final core position
- ✓ Finally, a full simulation is performed (time trace of DUs)

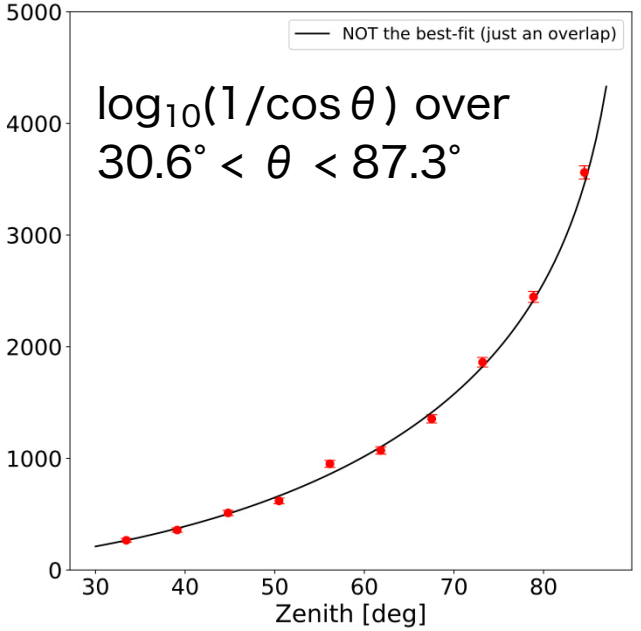
$\log_{10}$E distribution



Azimuth distribution



Zenith distribution



Proton: 6484 events
Iron: 6514 events
(~50:50)

Formula to Calculate Exposure

$$\text{Exposure} = S_{\text{geo}}\,\Delta\Omega\,T_{\text{obs}}\,\frac{\sum_i w_{E_i} w_{\theta_i} \cos\theta_i}{\sum_j w_{E_j} w_{\theta_j} N_{\text{draw},j}}$$

Summation runs over
- Numerator: Triggered events
- Denominator: All simulation events

S_{geo}: Area assumed in the simulation (= GP300 geometrical area, 168km^2)

$\Delta\Omega$: Solid angle of the sky

T_{obs}: Observation time

$N_{\text{draw},j}$: # of tested core positions + $\underline{1}$ for the j-th event

↑

Coming from the j-th event itself

Trigger Conditions

- DC2 ZHAireS L1 simulation (simulated Galactic noise + gps & amplitude jitters)
- Time trace filtered in the 50-200 MHz frequency range
- Peak Electric-field amplitude computed from Hilbert envelope (Epx, Epy & Epz)

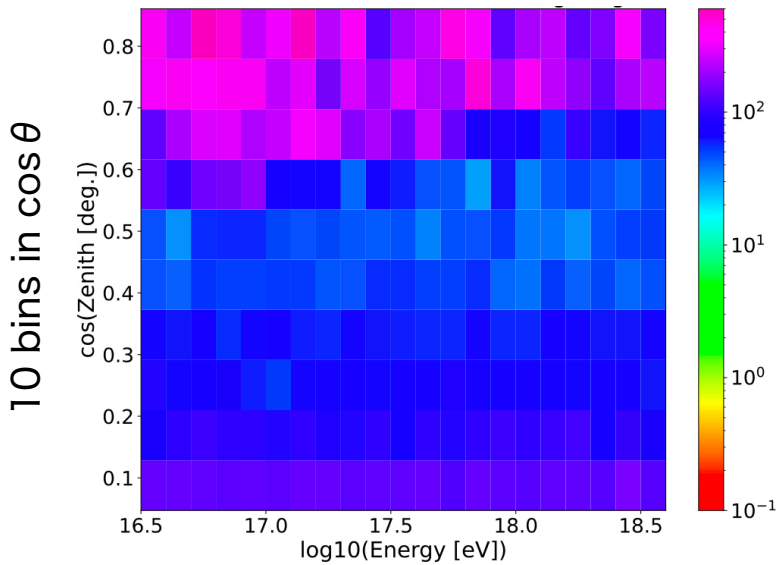
- Trigger condition:

  Amplitude threshold: $\mathrm{sqrt}(Epx^2 + Epy^2 + Epz^2) > 110\,\mu V/m\ (= 5\sigma)$

  Events left after the cut: 4680 events

Event Weighting

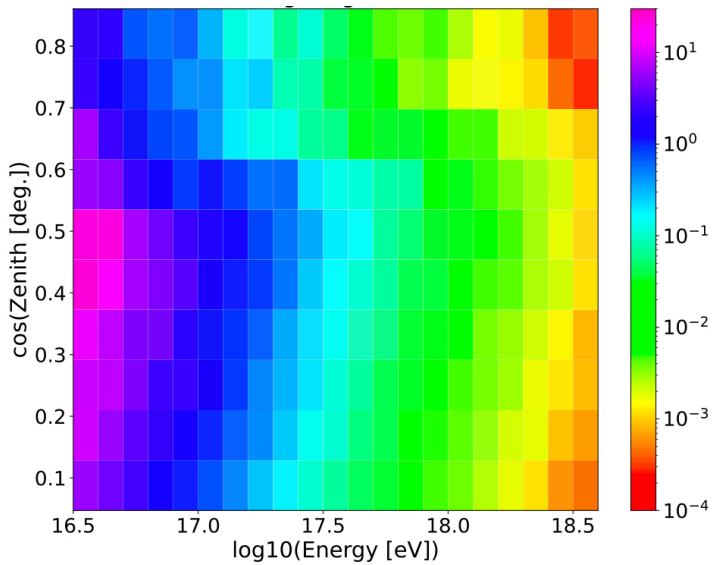
N_{draw} before weighting



21 bins in $\log_{10}$(E)

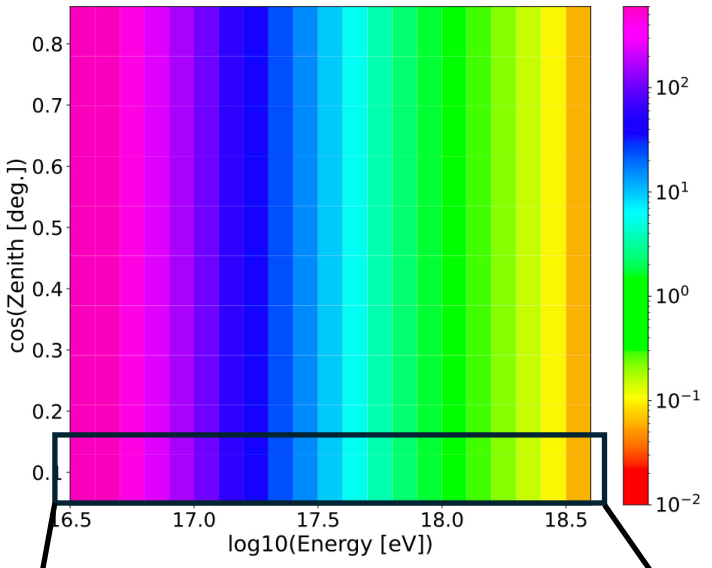
×

Weighting factor



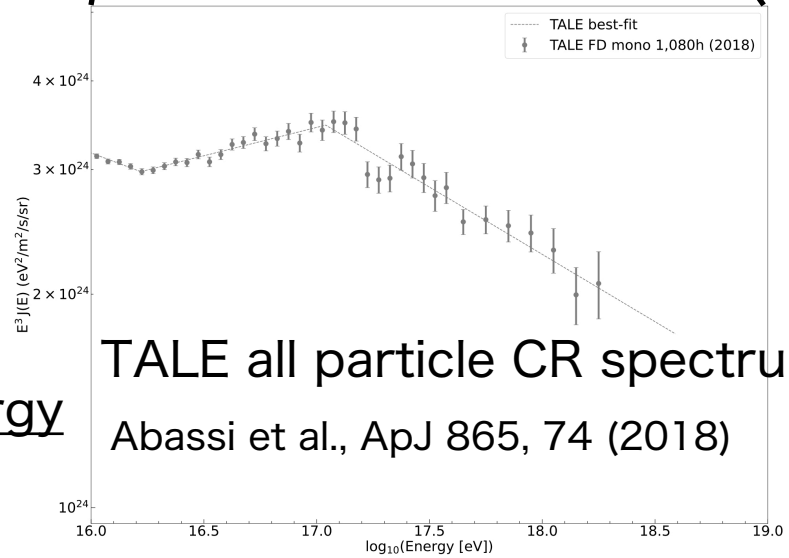
=

N_{draw} after weighting



- ✓ Total # of events ($\sum_{E,\theta} N_{\mathrm{draw}}$) is conserved before/after weighting
  (N_{draw}: # of tested core positions + 1)

- ✓ Weighting realizes <u>a uniform distribution along zenith angle</u>
  & <u>best-fit broken PL function to the TALE CR spectrum along energy</u>



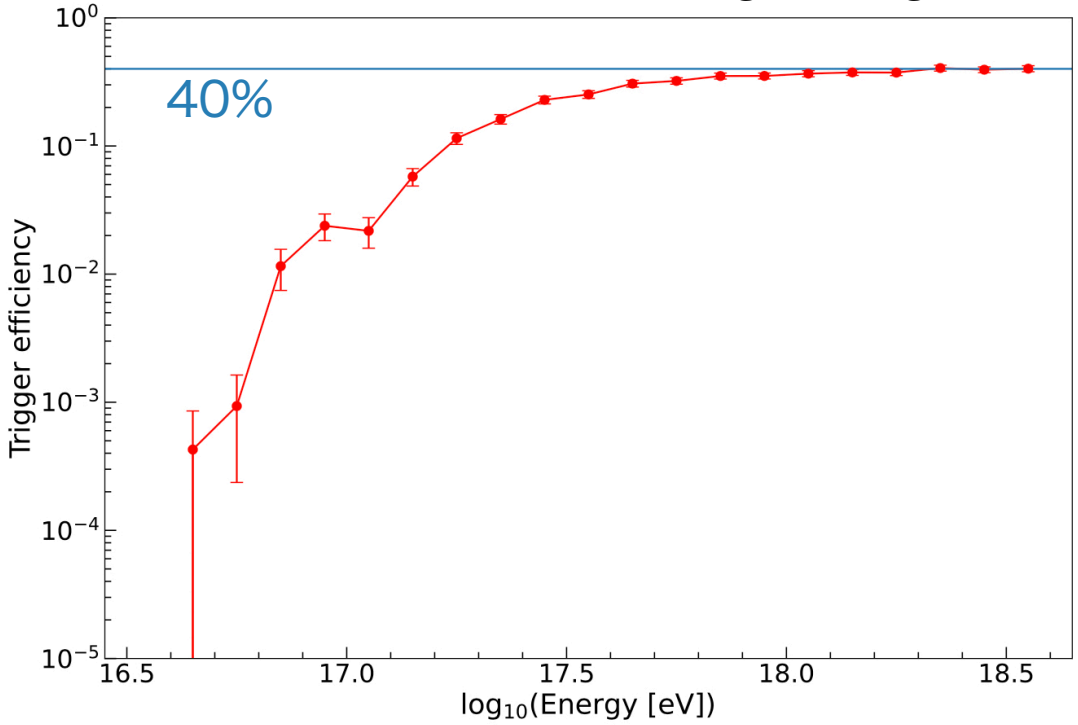
TALE all particle CR spectrum

Abassi et al., ApJ 865, 74 (2018)

Trigger Efficiency

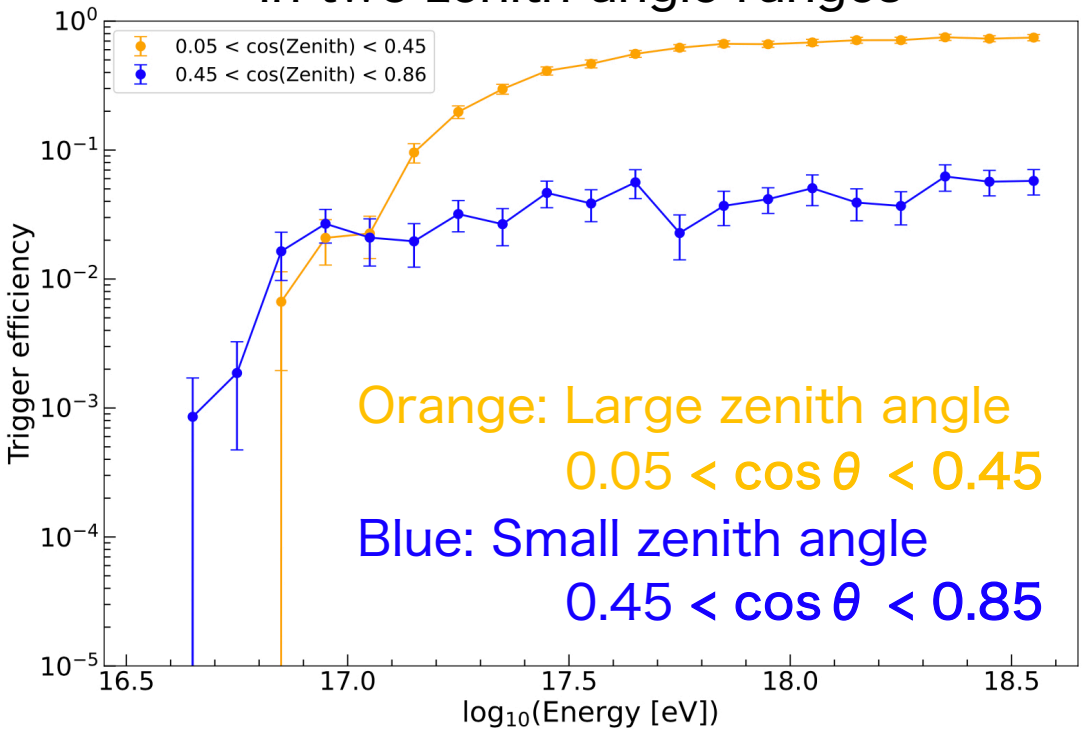
Fraction of triggered events inside the geometrical area of GP300

In the whole zenith-angle range



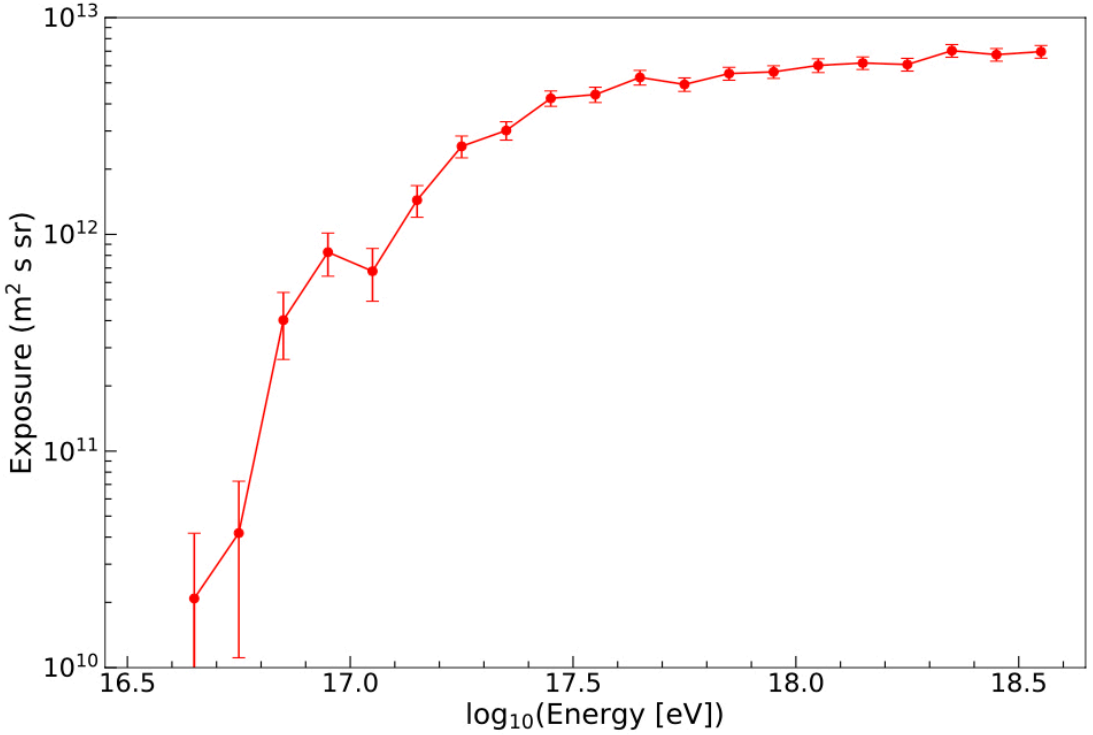
True energy from simulation
(NOT reconstructed)

In two zenith-angle ranges

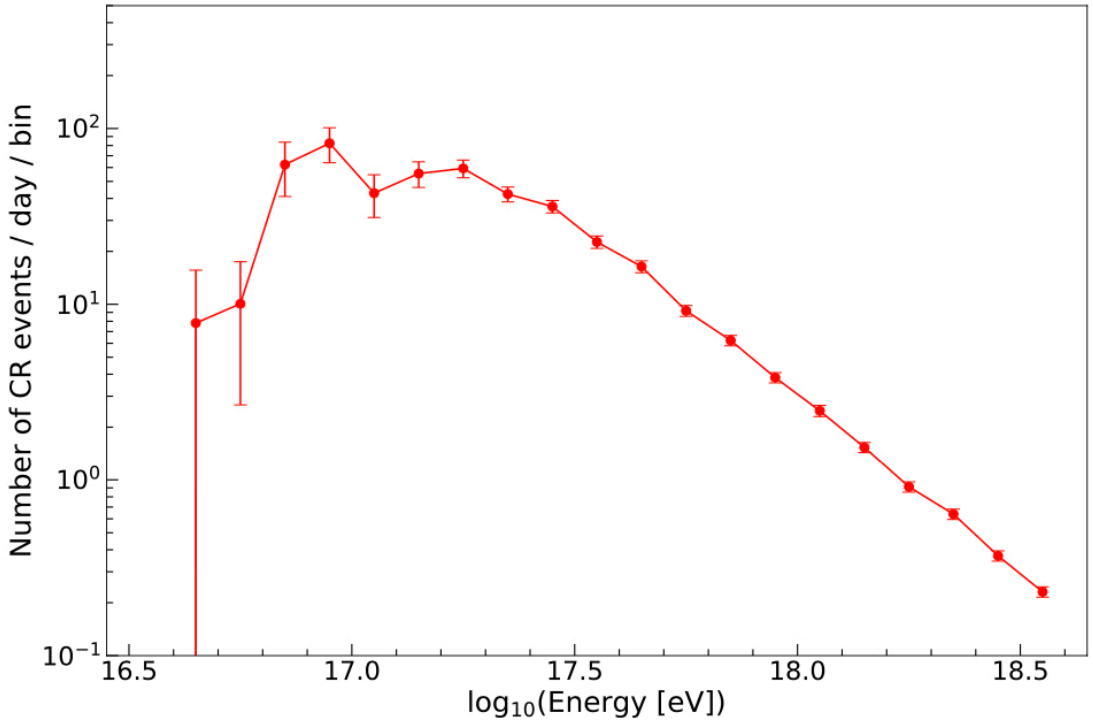


One-Day Exposure & # of Events / Day a.f.o. Energy

One-day exposure (m^2 s sr)



# of CR events/day/bin



Error bar: Mainly coming from the stat. uncertainty of # of triggered events

# of CR events/day: 463 ± 35 (MC stat.) ± 32 (syst.)* events/day

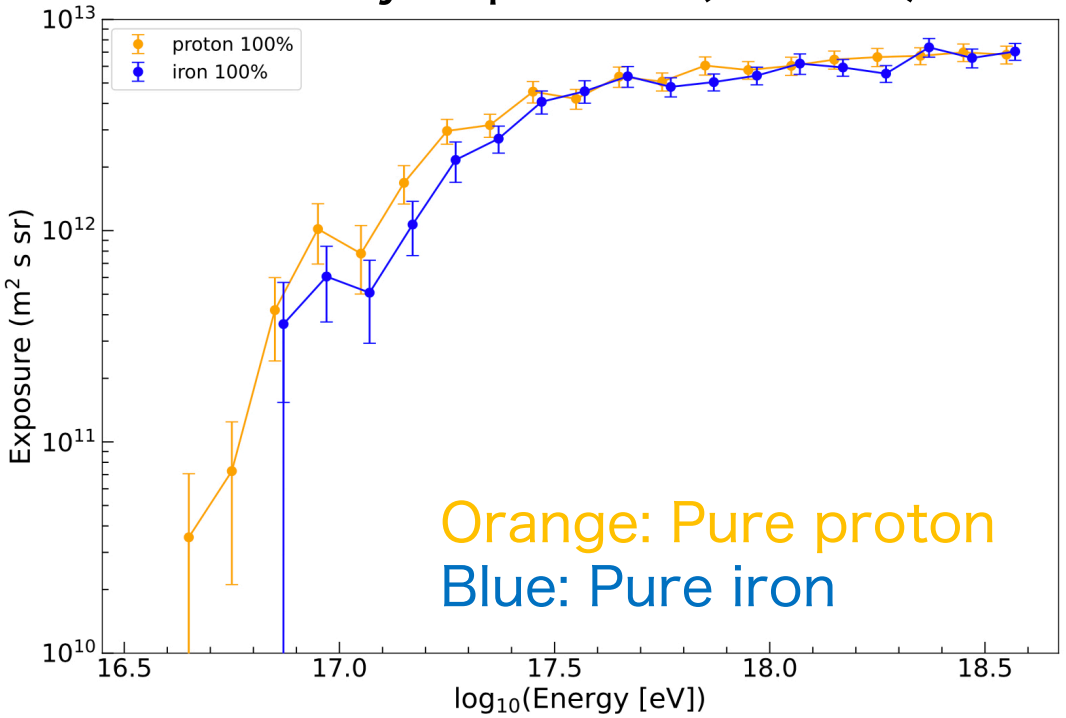
*Binning effect, different integration method, etc.

The result is crosschecked w/ Clément Prévotat

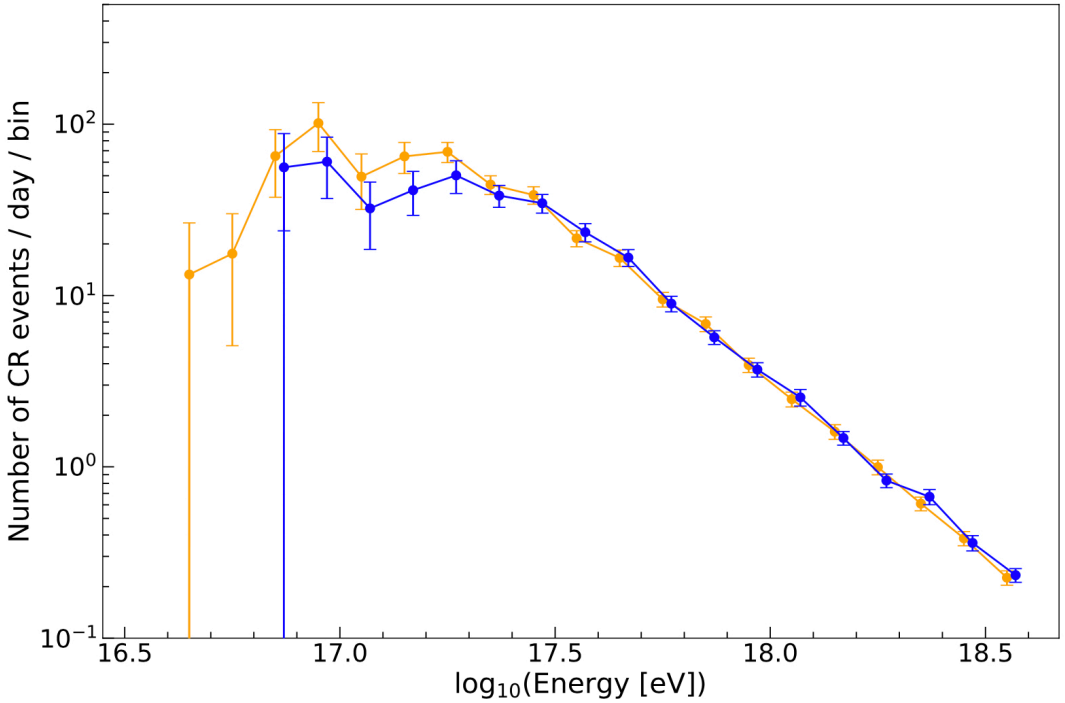
One-Day Exposure & # of Events / Day a.f.o. Energy

For Pure Proton & Pure Iron Cases

One-day exposure (m^2 s sr)



# of CR events/day/bin



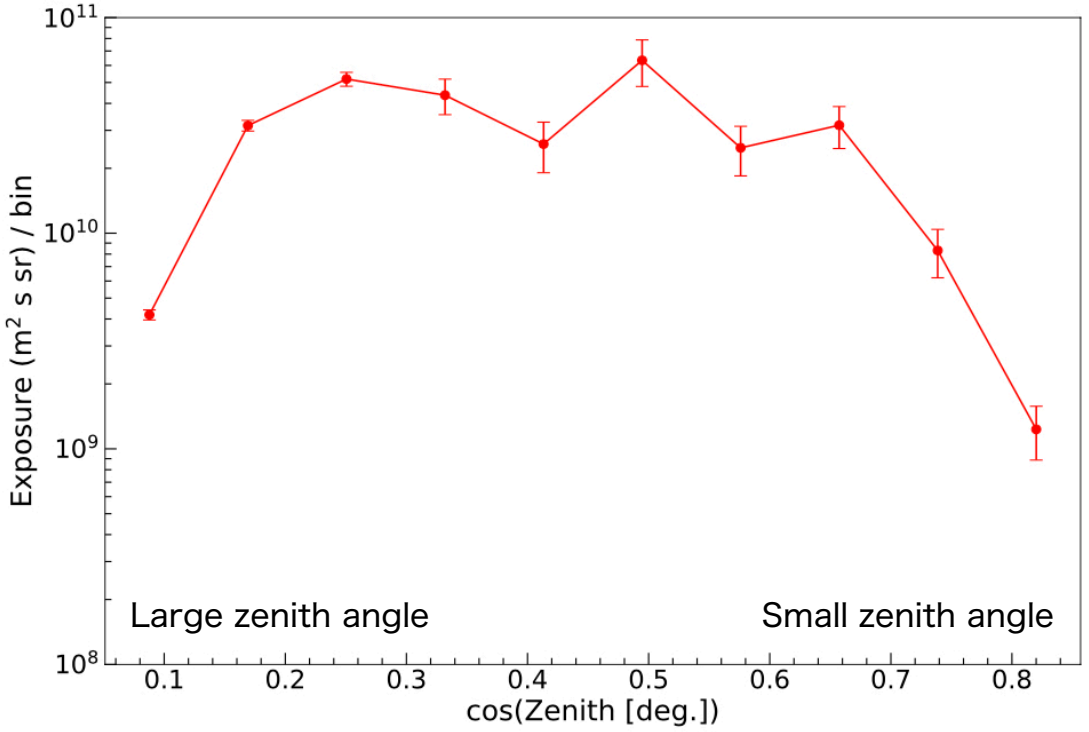
* Horizontal axis of the blue curve (iron) is systematically shifted for easy visibility

Pure proton: 528 ± 53 (MC stat.) events/day

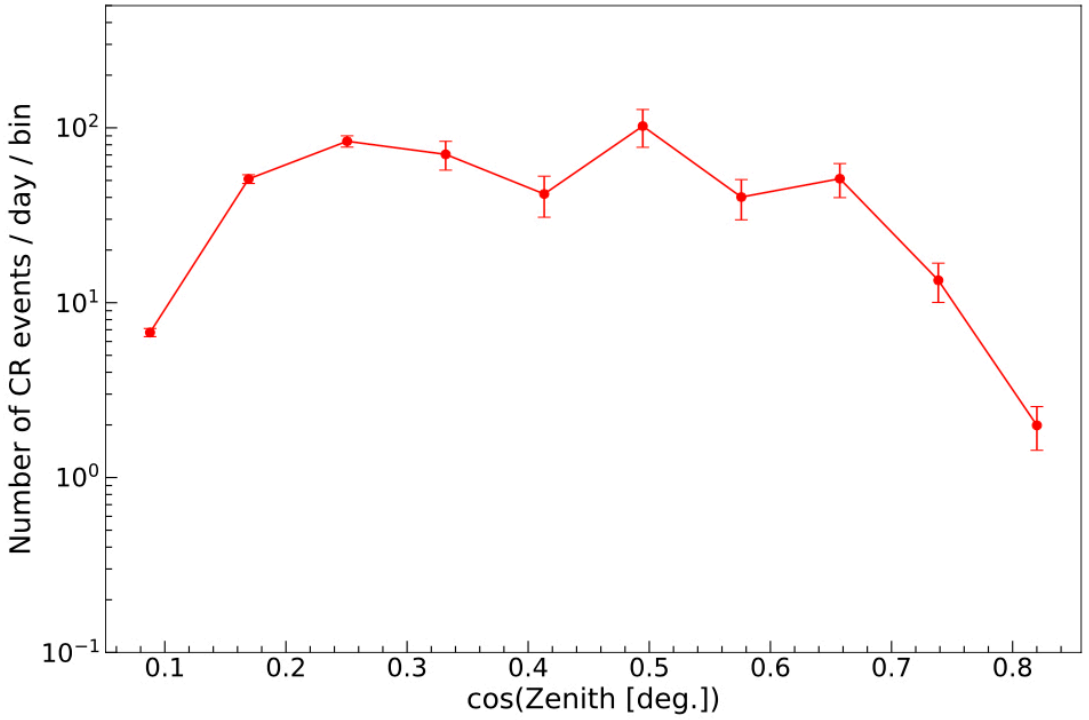
Pure iron: 377 ± 46 (MC stat.) events/day

One-Day Exposure & # of Events / Day a.f.o. Cos θ

Exposure (m^2 s sr)



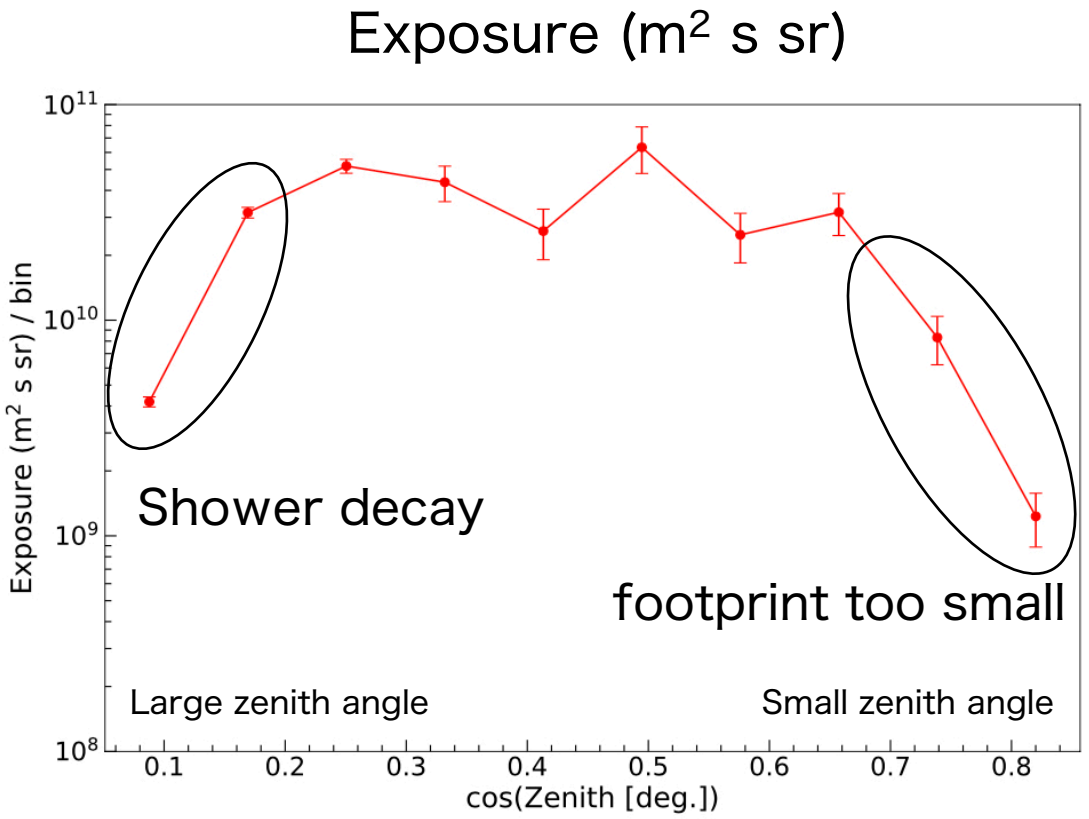
# of CR events/day



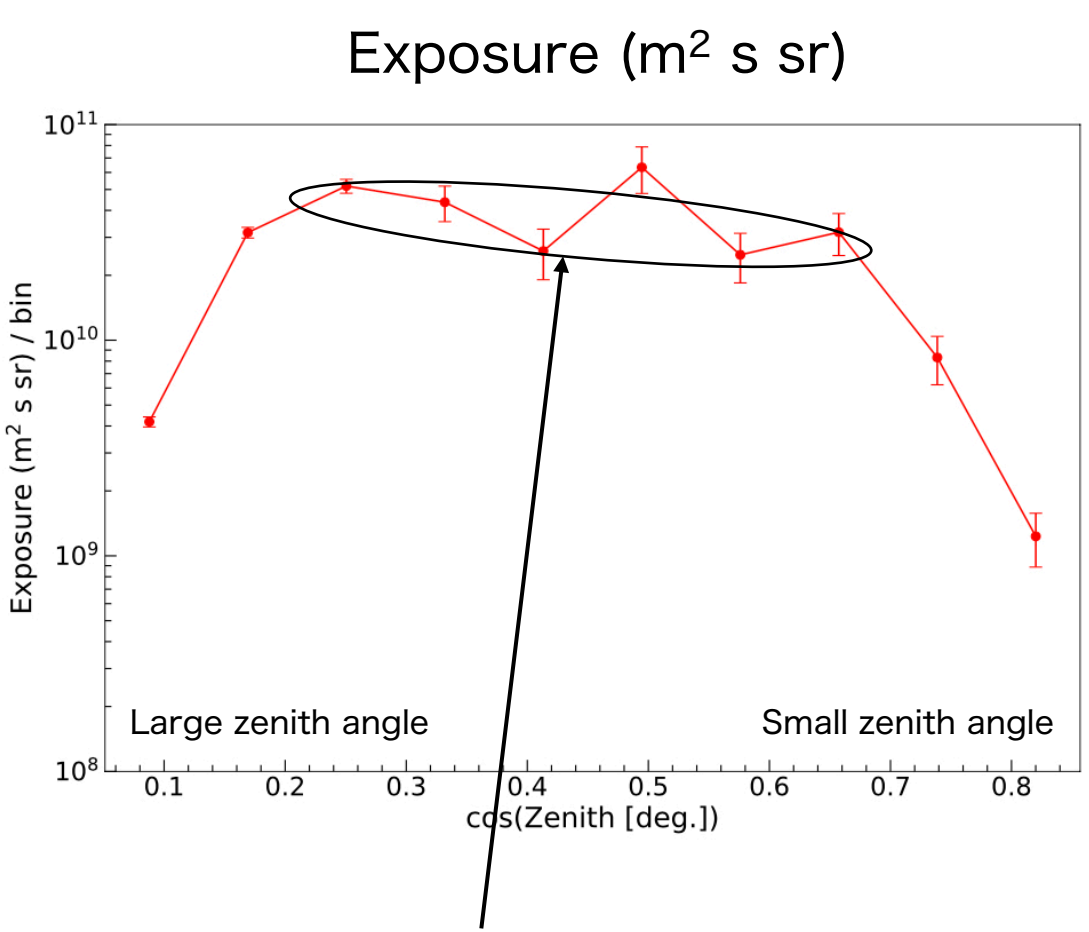
Error bar: Mainly coming from the stat. uncertainty of # of triggered events

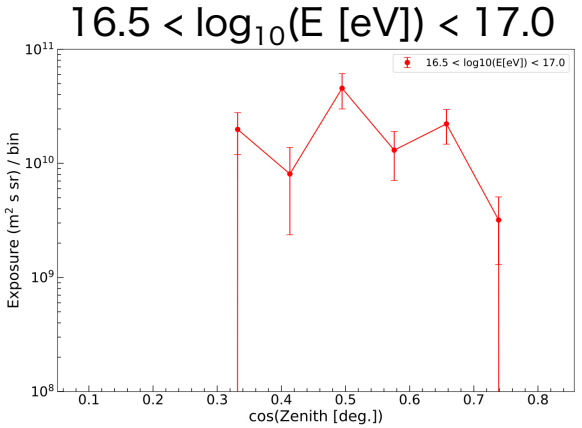
The result is crosschecked w/ Clément Prévotat

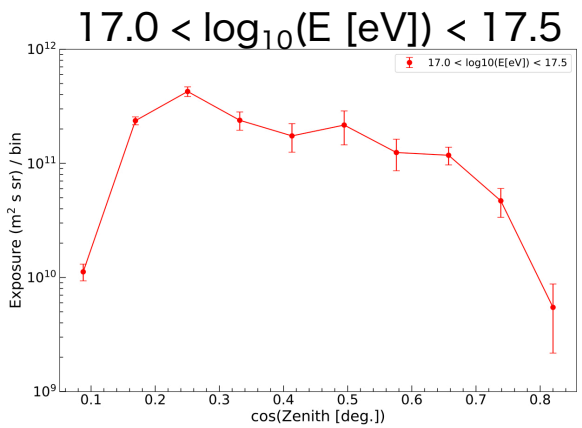
Structures of the Exposure a.f.o. Cos θ

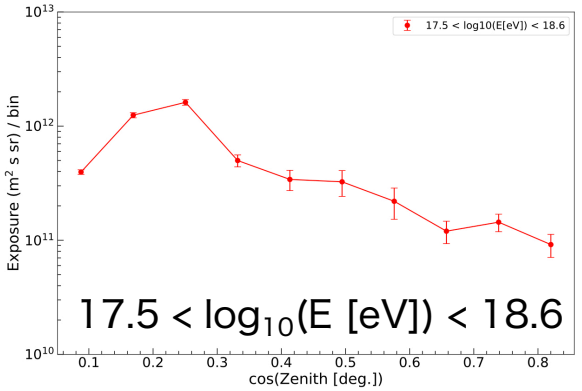


Structures of the Exposure a.f.o. Cos θ



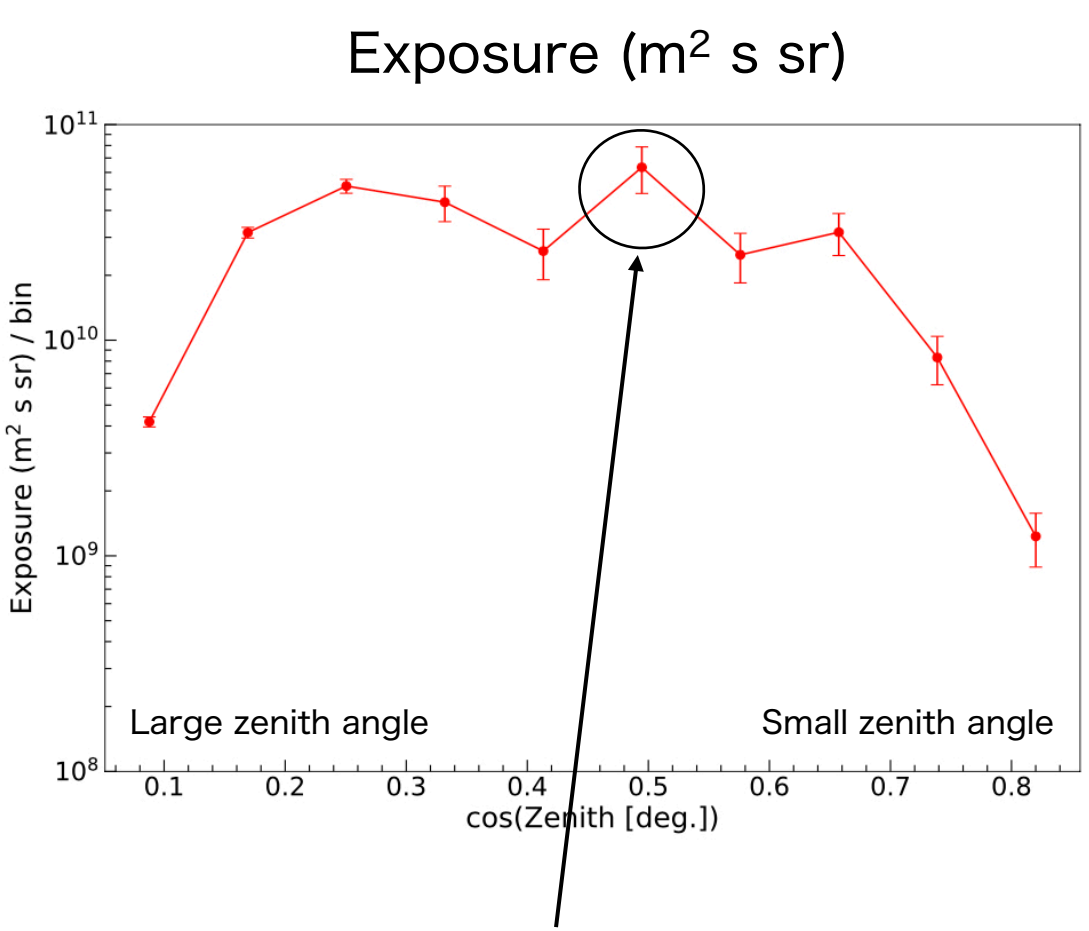


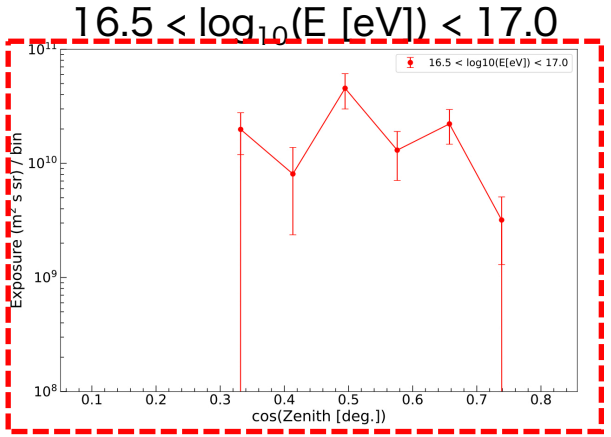


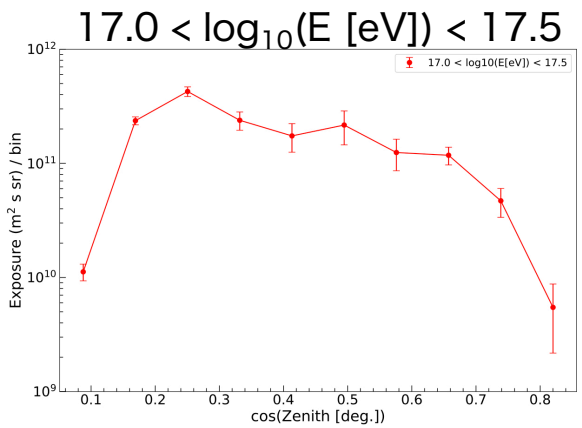


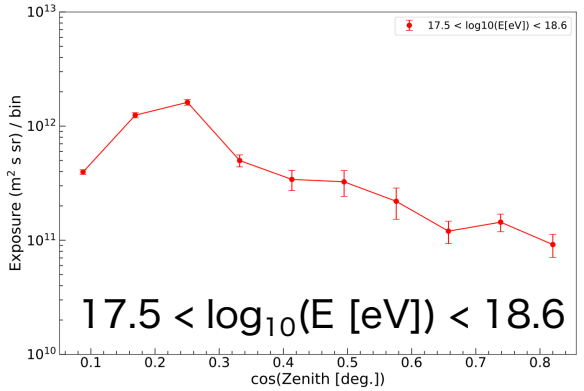
Increase toward the large zenith-angle range due to the increase of the physical size of the Cherenkov cone on the ground

Structures of the Exposure a.f.o. Cos θ



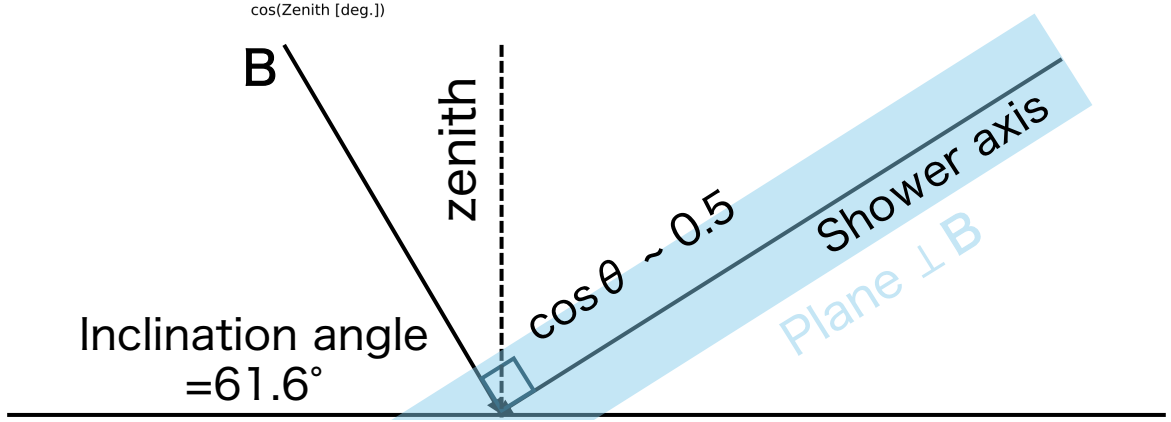






Peaky structure (statistically NOT significant)

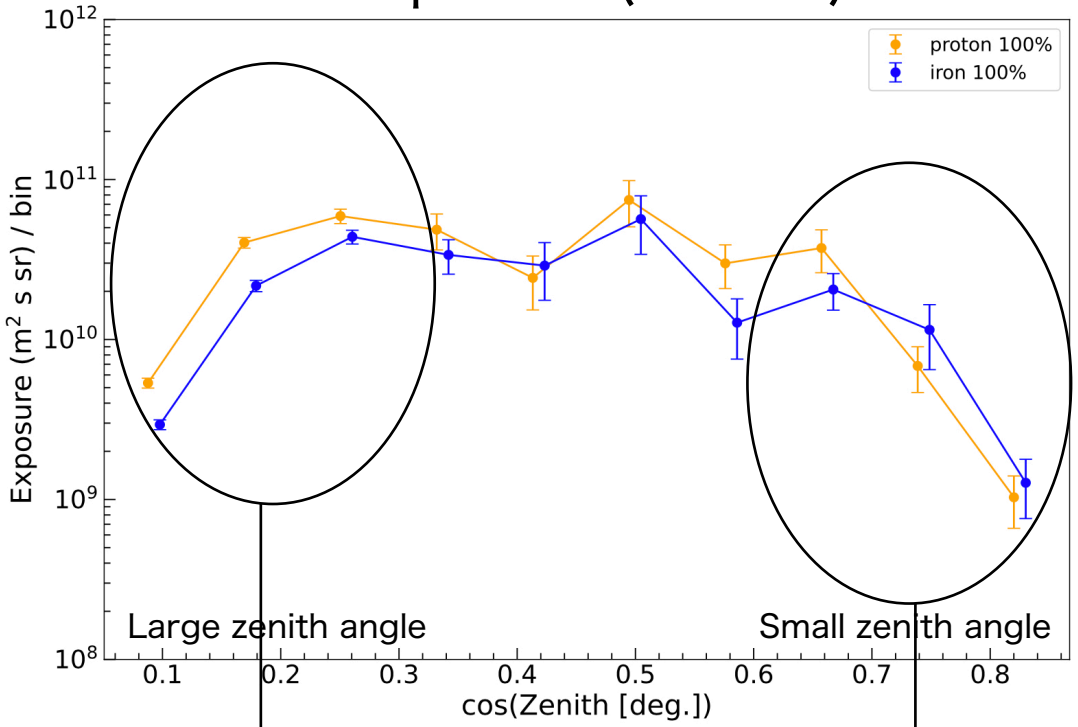
For low-energy events, it is crucial to have their shower axes perpendicular to the geomag. field so that they can trigger the array



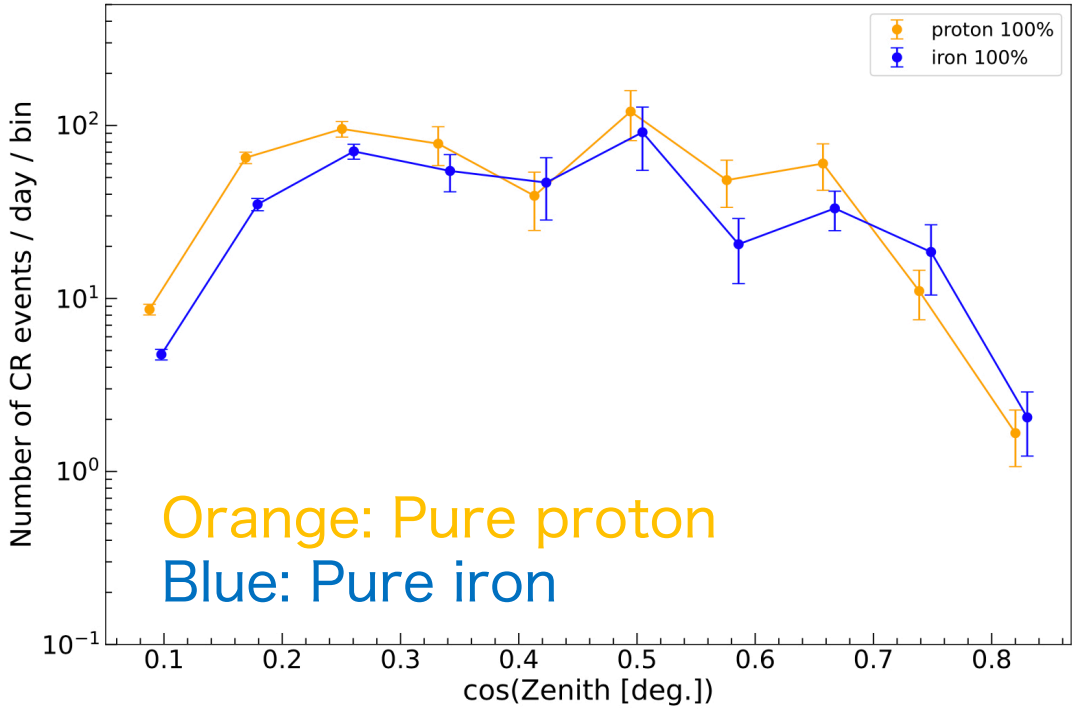
One-Day Exposure & # of Events / Day a.f.o. Cos θ

For Pure Proton & Pure Iron Cases

Exposure (m^2 s sr)



# of CR events/day



* Horizontal axis of the blue curve (iron) is systematically shifted for easy visibility

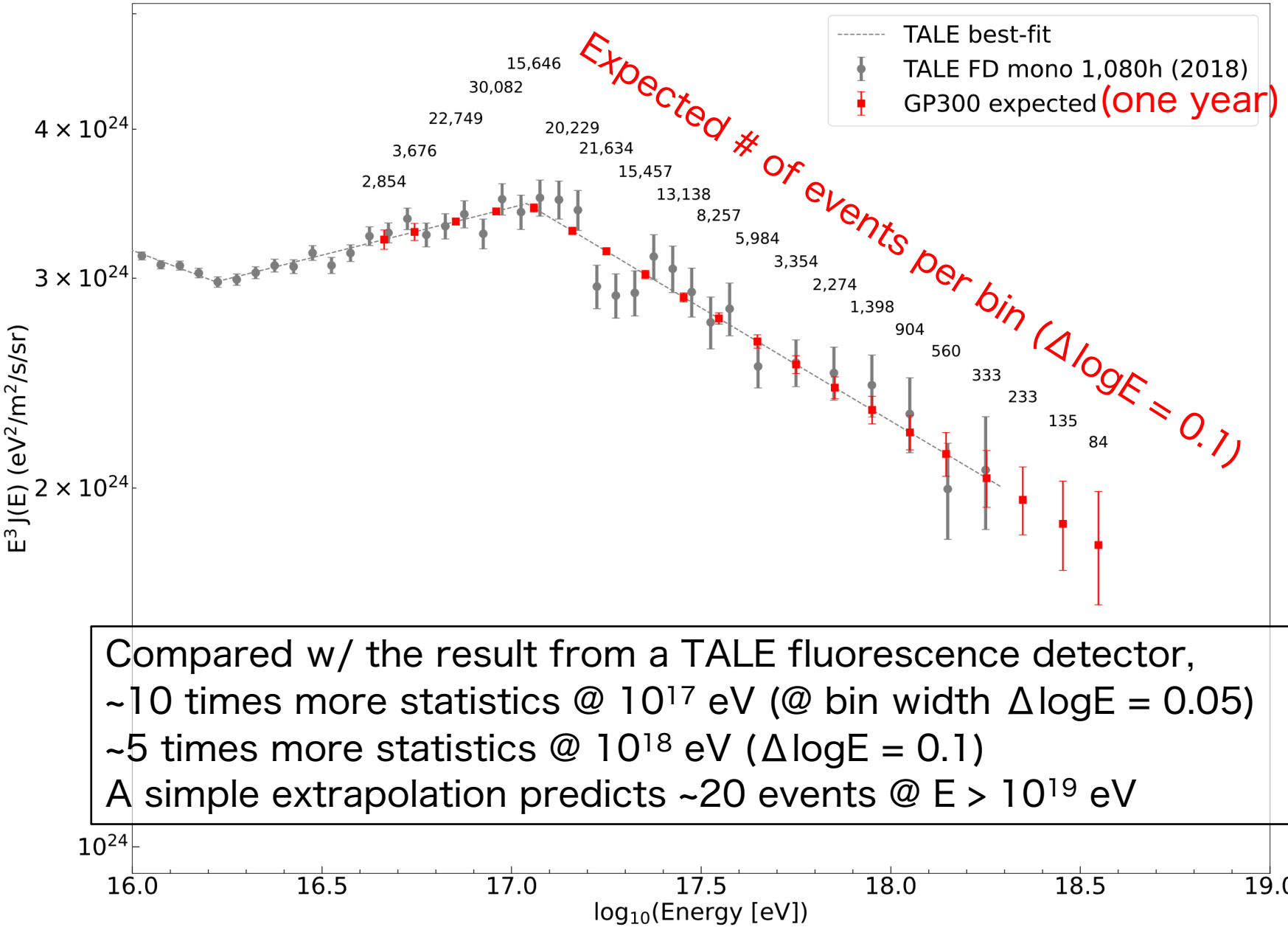
Iron showers heavily decay

Proton showers' footprint is too small

Pure proton: 528 ± 53 (MC stat.) events/day

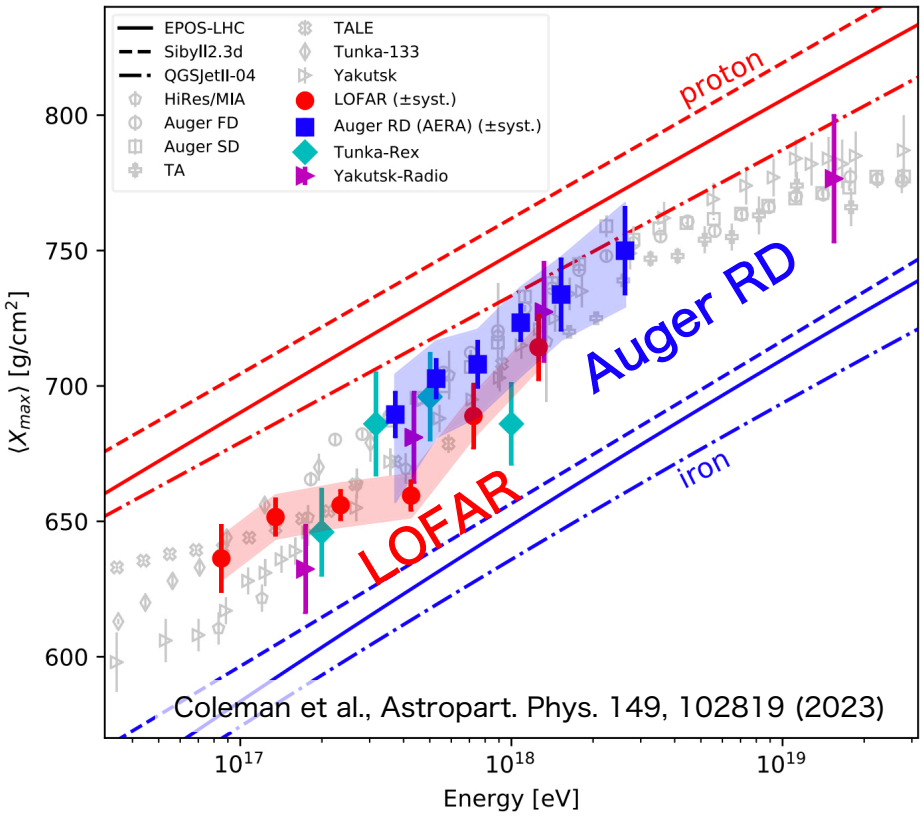
Pure iron: 377 ± 46 (MC stat.) events/day

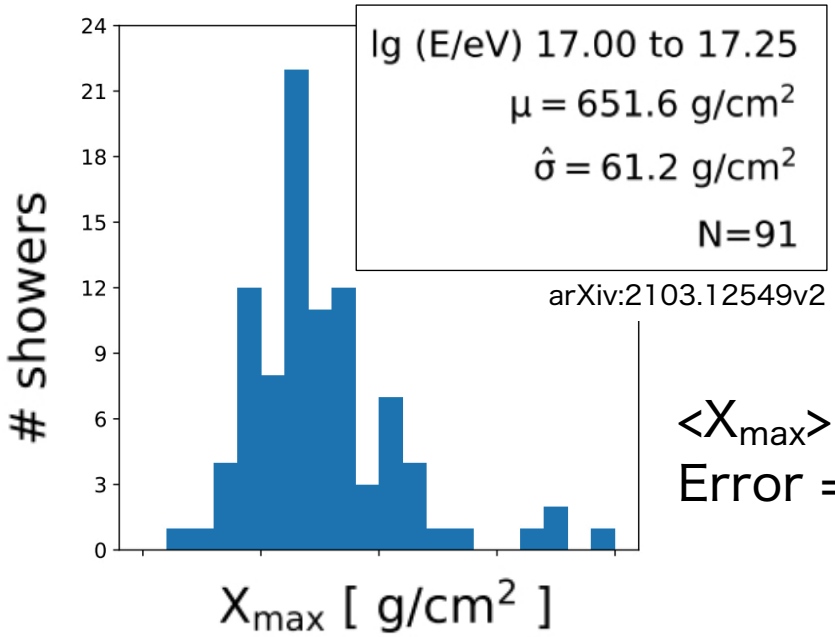
Prediction for the Future: All-Particle CR Energy Spectrum



Compared w/ the result from a TALE fluorescence detector,
~10 times more statistics @ 10^{17} eV (@ bin width ΔlogE = 0.05)
~5 times more statistics @ 10^{18} eV (ΔlogE = 0.1)
A simple extrapolation predicts ~20 events @ E > 10^{19} eV

Prediction for the Future: X_{max}





$\langle X_{max} \rangle$ = mean(μ)
Error = std(σ)/$\sqrt{N}$

Statistical uncertainty in the X_{max} measurement in GP300 observation (assuming σ = 60 g/cm²)

$\log_{10}$(Energy [eV])	Stat. unc. of $\langle X_{max} \rangle$
17.00	0.5 g/cm²
17.50	0.7
18.00	2.0
18.50	6.5

~10 times smaller stat. unc. than LOFAR →

~ 7 times smaller →

~ 5 times smaller →

~ 2 times smaller stat. unc. than Auger RD →

Systematic uncertainty will be dominant in the GP300 obs.

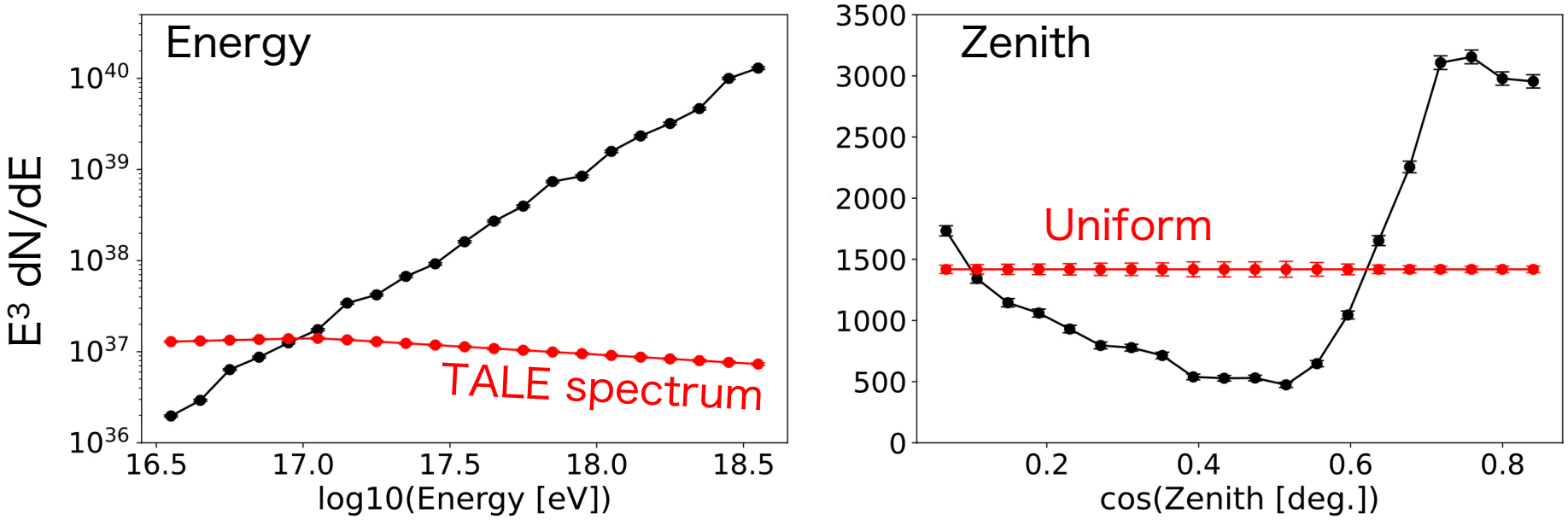
Summary

- ✓ Exposure of GP300 is calculated using the DC2 Simulation data
- ✓ GP300 exposure as a function of energy (one-day obs.):
  ~10^{12} m^2 sr s @ 10^{17} eV
  ~5 ×10^{12} m^2 sr s @ 10^{18} eV
- ✓ **# of triggered CR events / day ~ 460 events**
- ✓ Morphology of the exposure as a function of $\cos\theta$ is analyzed
- ✓ **The above results are crosschecked with Clément**
- ✓ All particle CR spectrum will be measured @ $10^{16.6}$ eV < E < 10^{19} eV in one-year obs.
- ✓ Stat. unc. in the X_{max} measurement will be much smaller than the previous radio-array experiments (syst. unc. dominant)

Backup Slides

Weighting Scheme

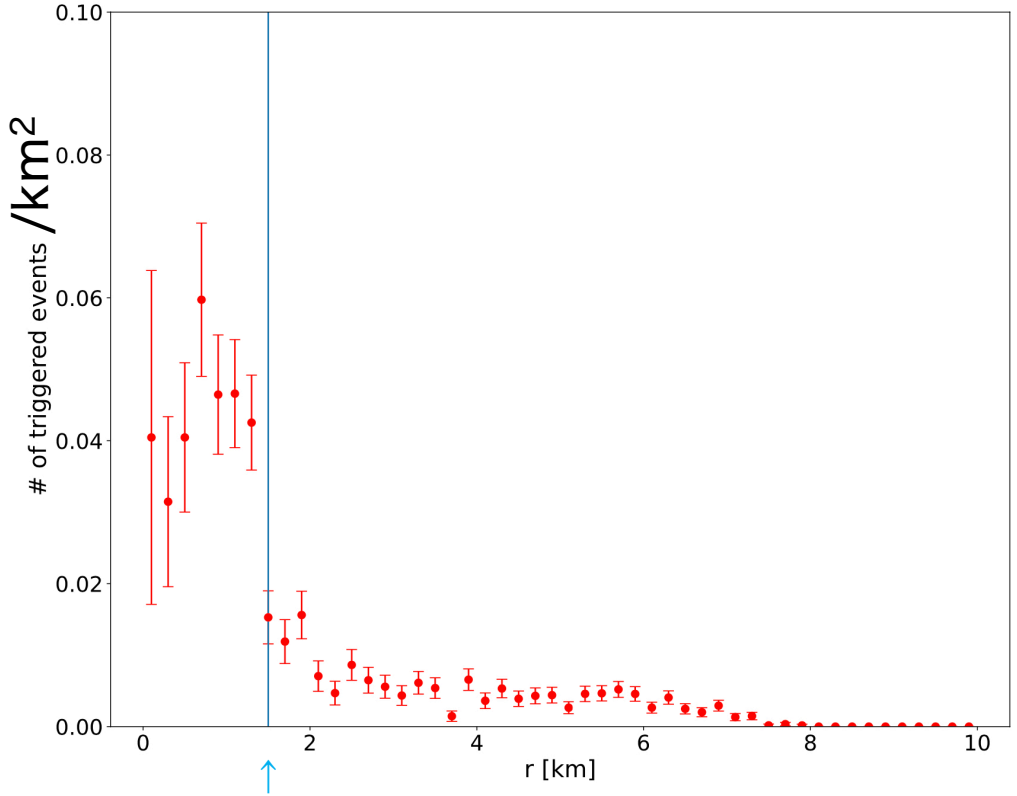
Black: Distribution of Ndraw before weighting
Red: After weighting



# of events are conserved before & after weighting

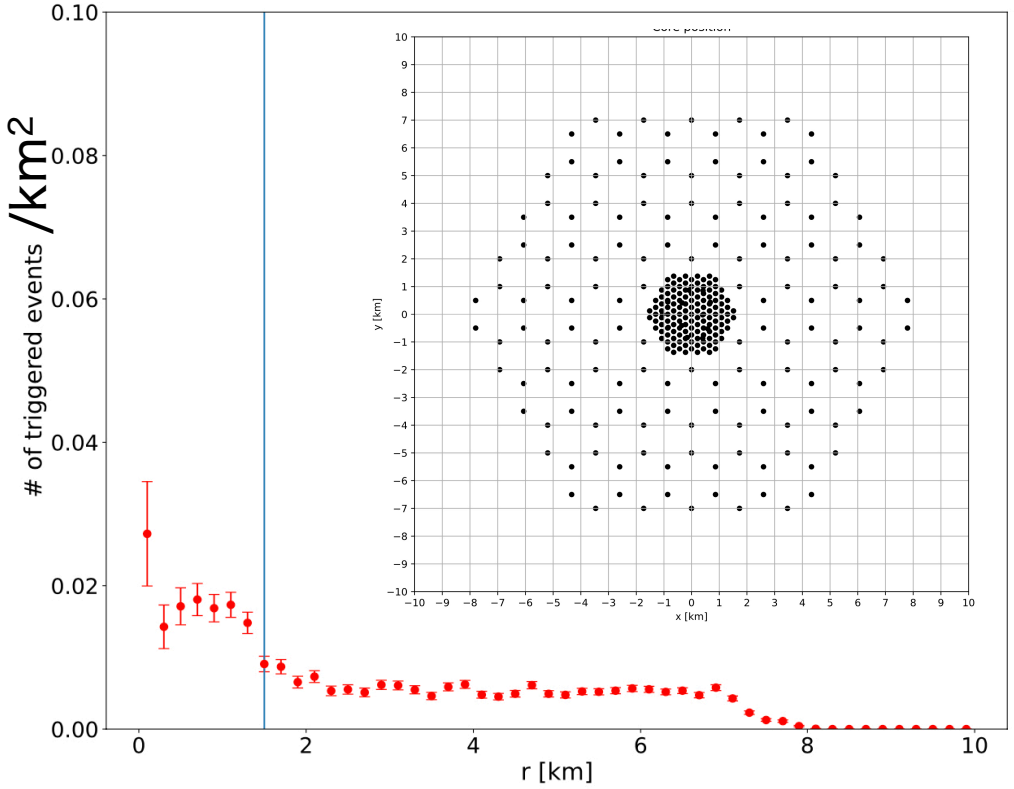
Radial Distribution of Triggered Events

$16.5 < \log_{10}(E\ [eV]) < 17.5$



Size of the infill array (r ~ 1.5km)

$17.5 < \log_{10}(E\ [eV]) < 18.6$



Events are NOT weighted.
The sum of the bin values is normalized to 1 in both plots