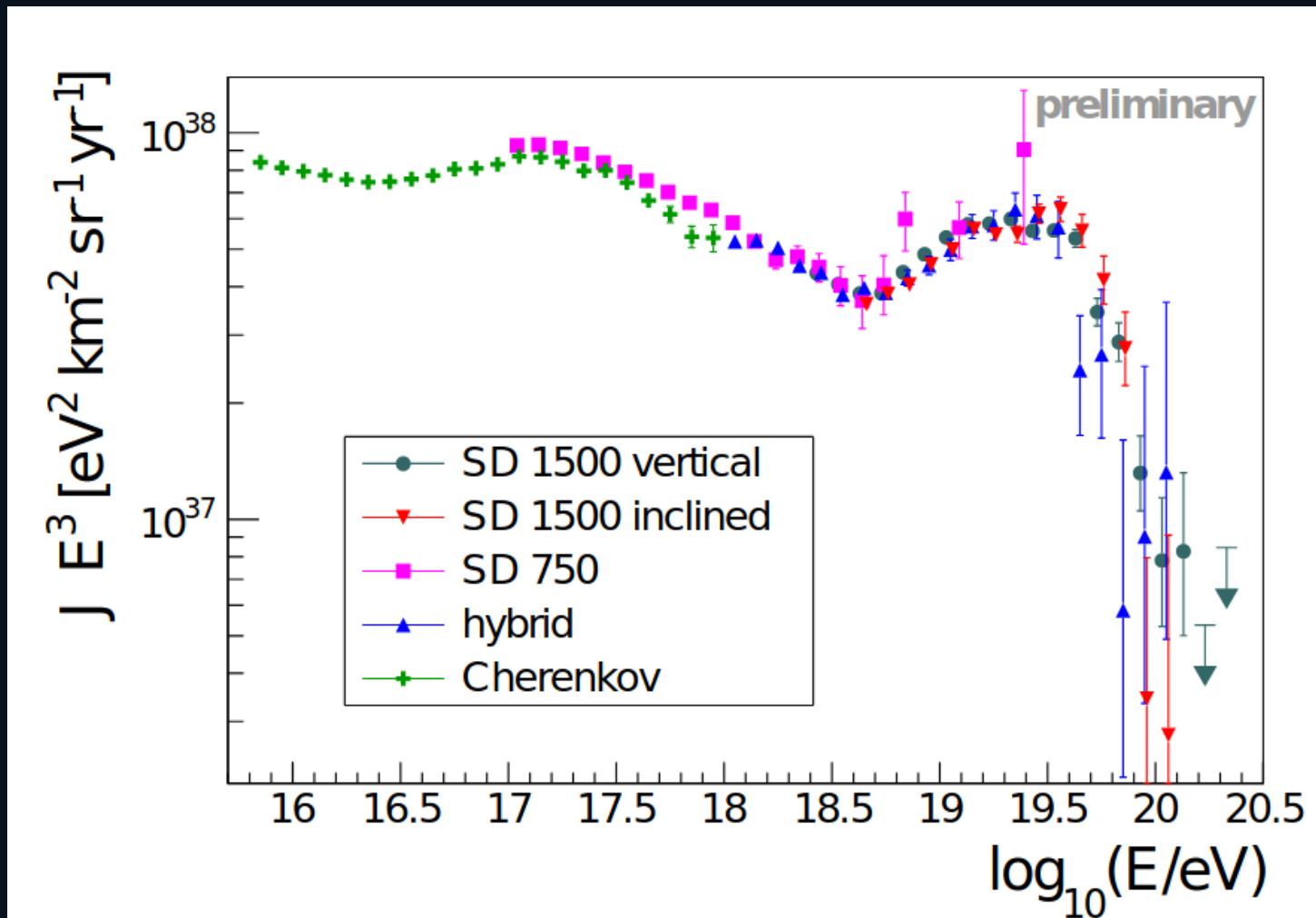

Determination of the Hybrid Energy Spectrum of UHECRs

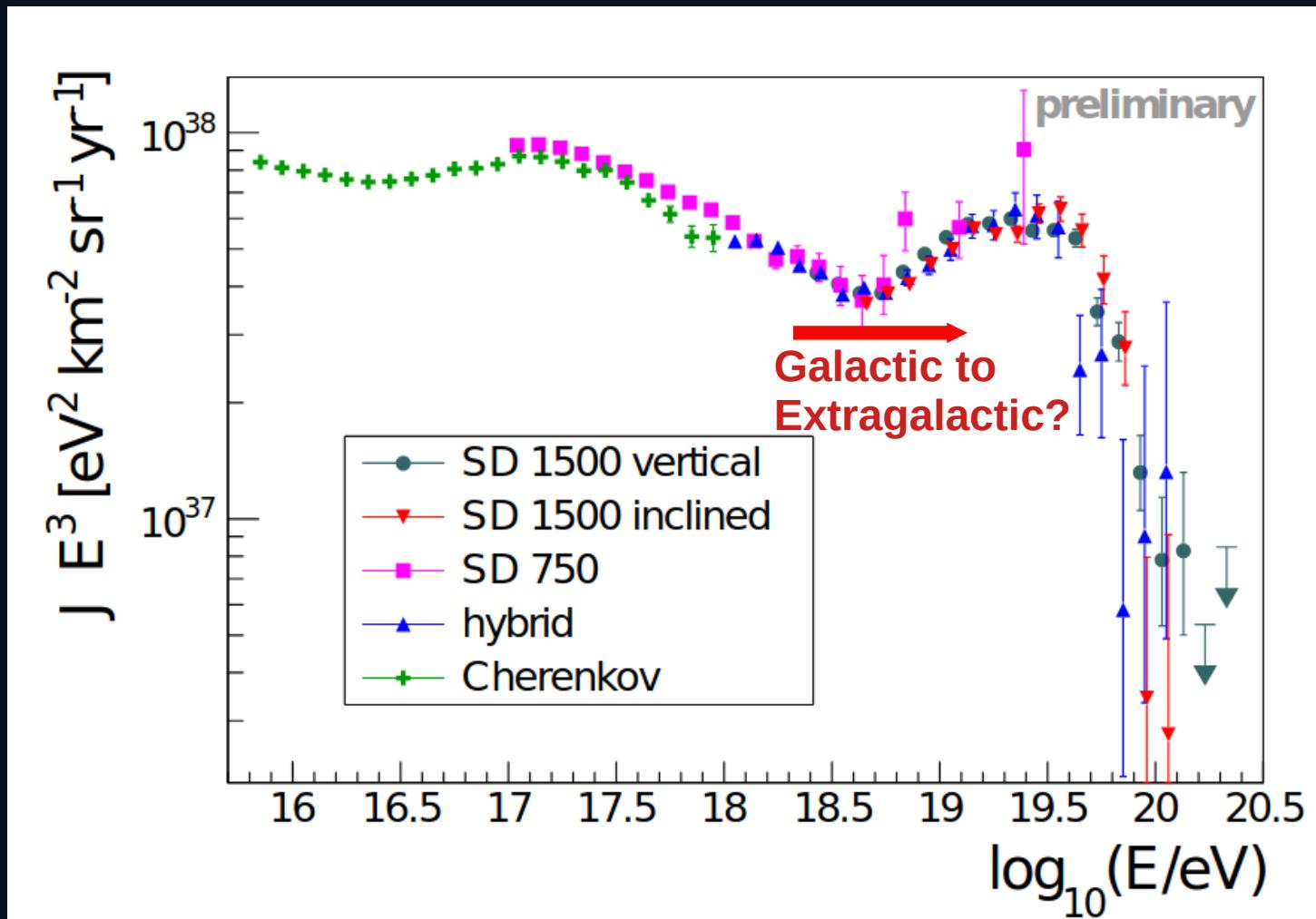
Kathrin Bismark (KIT/ IAP)

November, 2022

Energy Spectrum of UHECRs



Energy Spectrum of UHECRs



Overview

- **Goal:** Hybrid spectrum (≥ 1 FD triggered + ≥ 1 SD measured)

$$J(E) = \frac{d^4 N}{dE dA d\Omega dt} \approx \frac{\Delta N_{\text{sel}}(E)}{\Delta E} \frac{1}{\mathcal{E}(E)}$$

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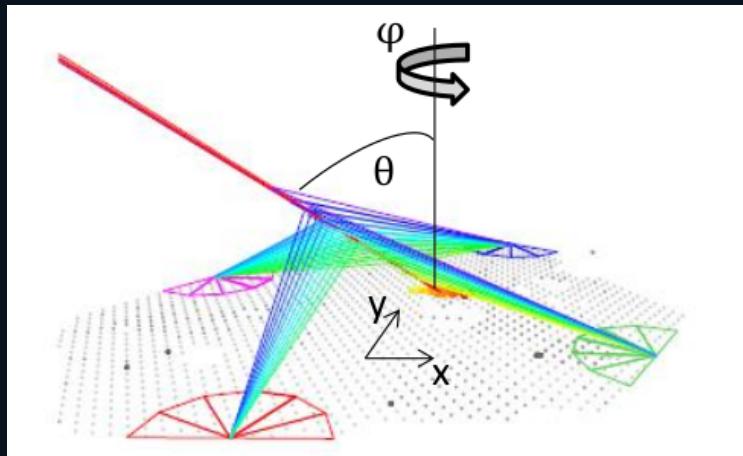
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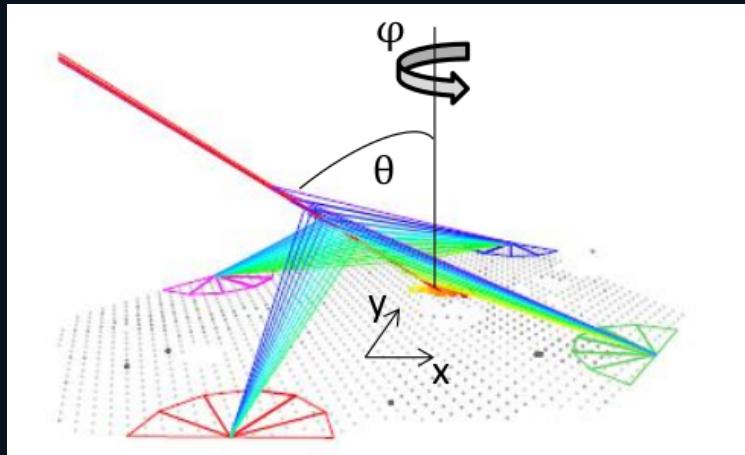
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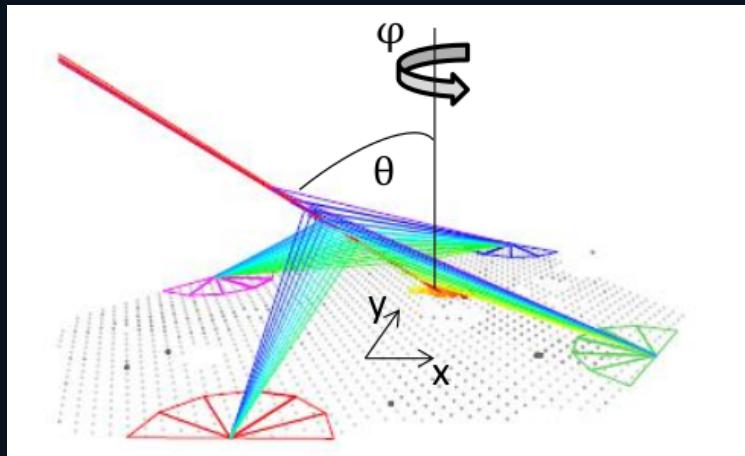
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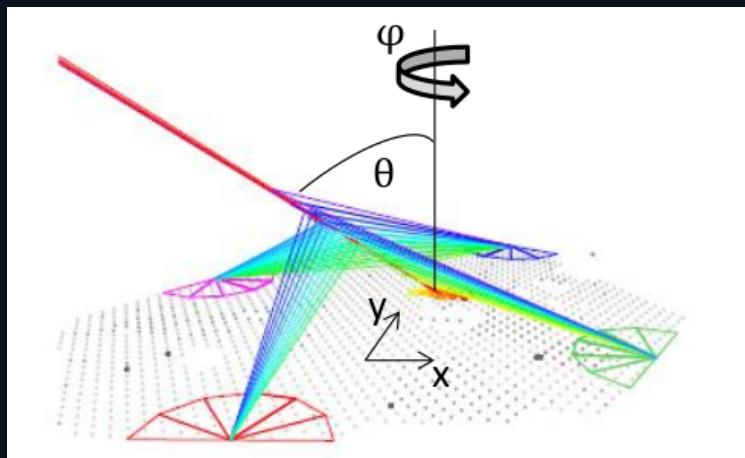
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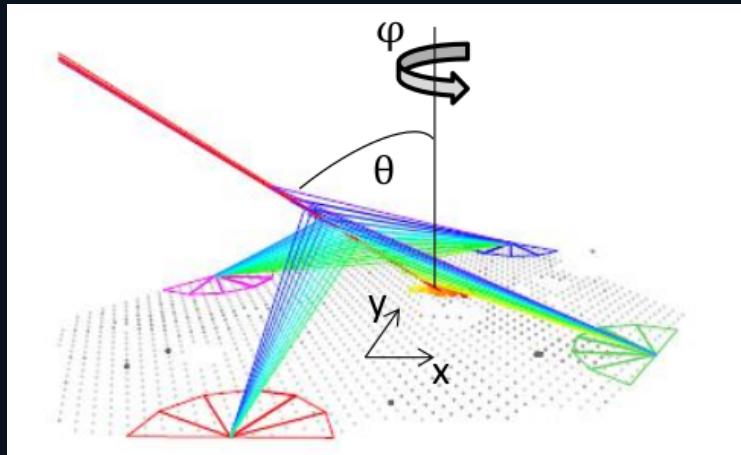
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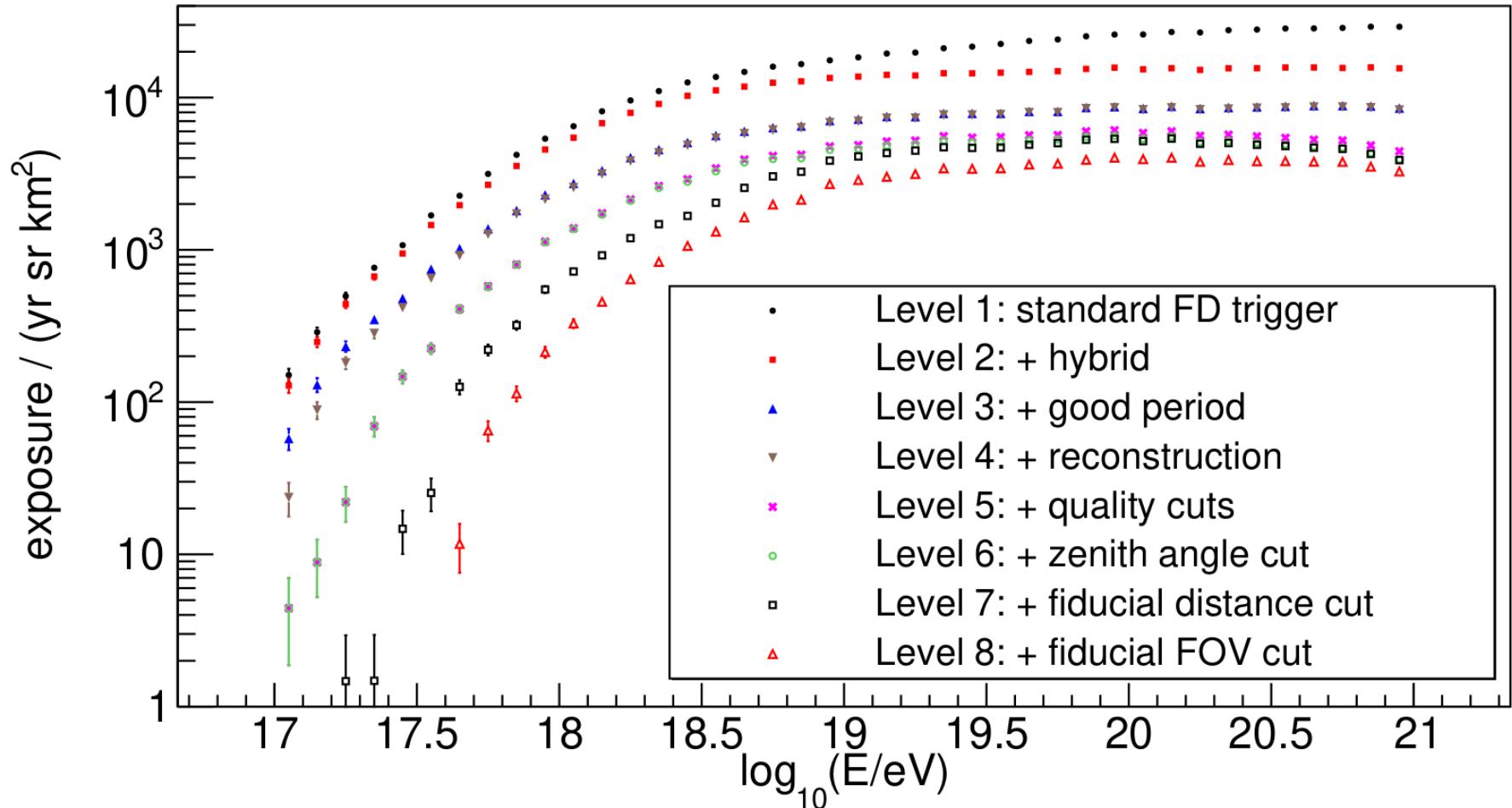
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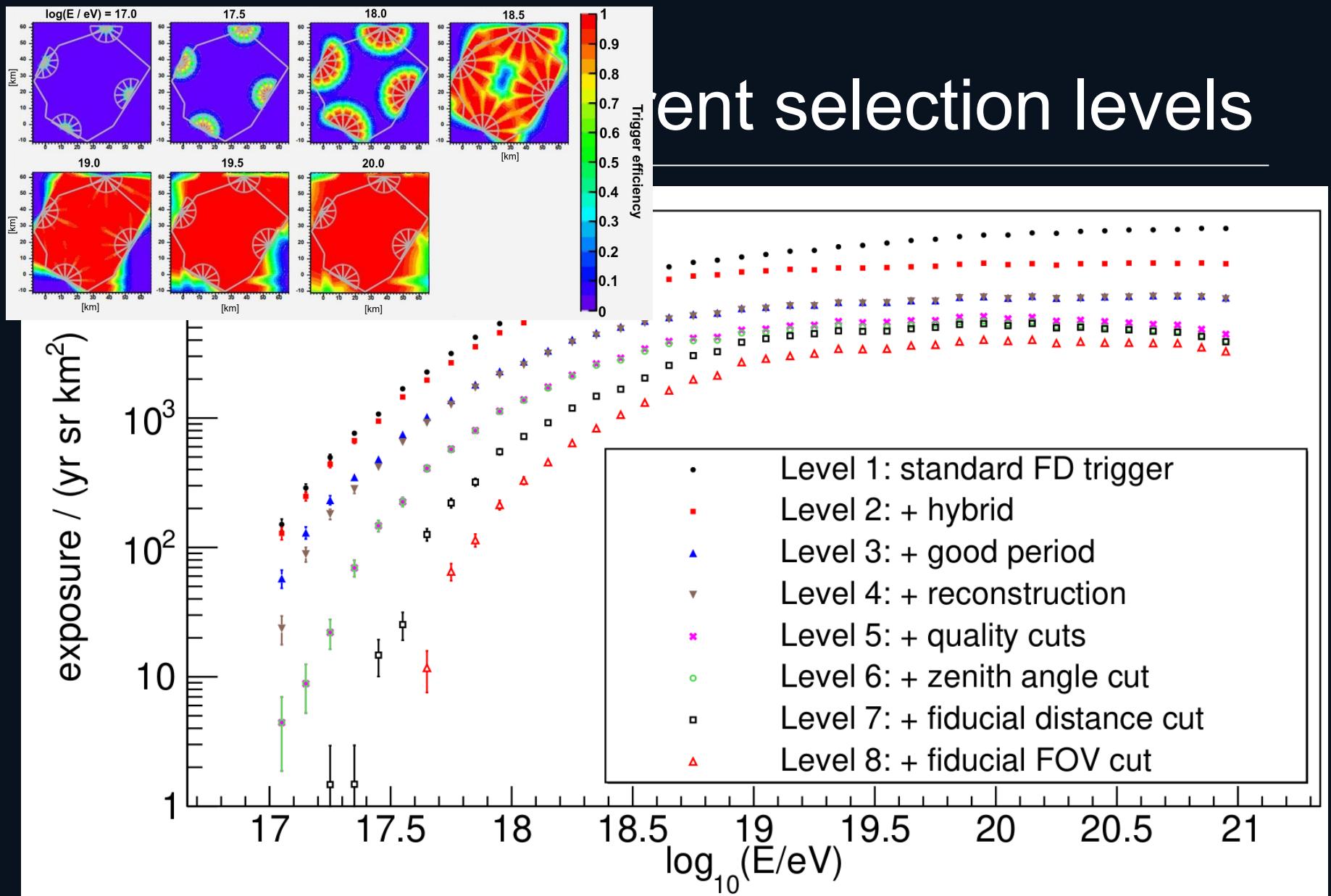
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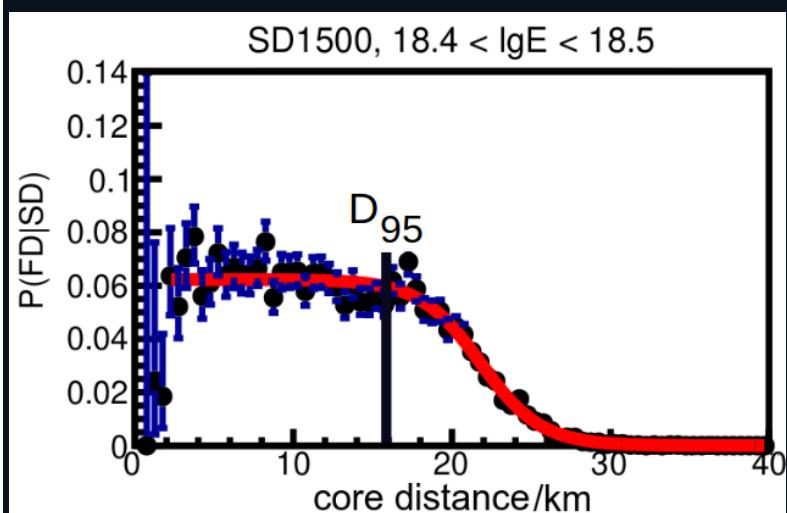
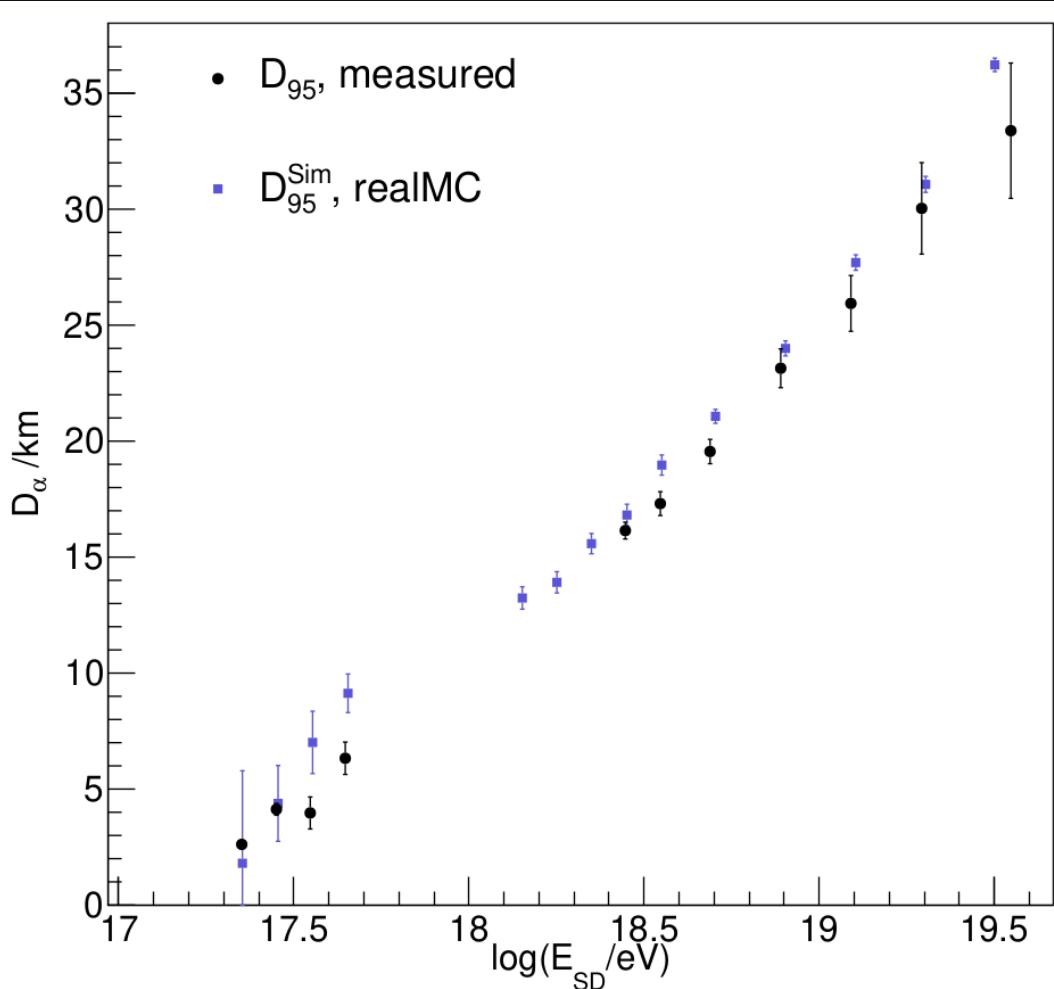


Exposure for different selection levels

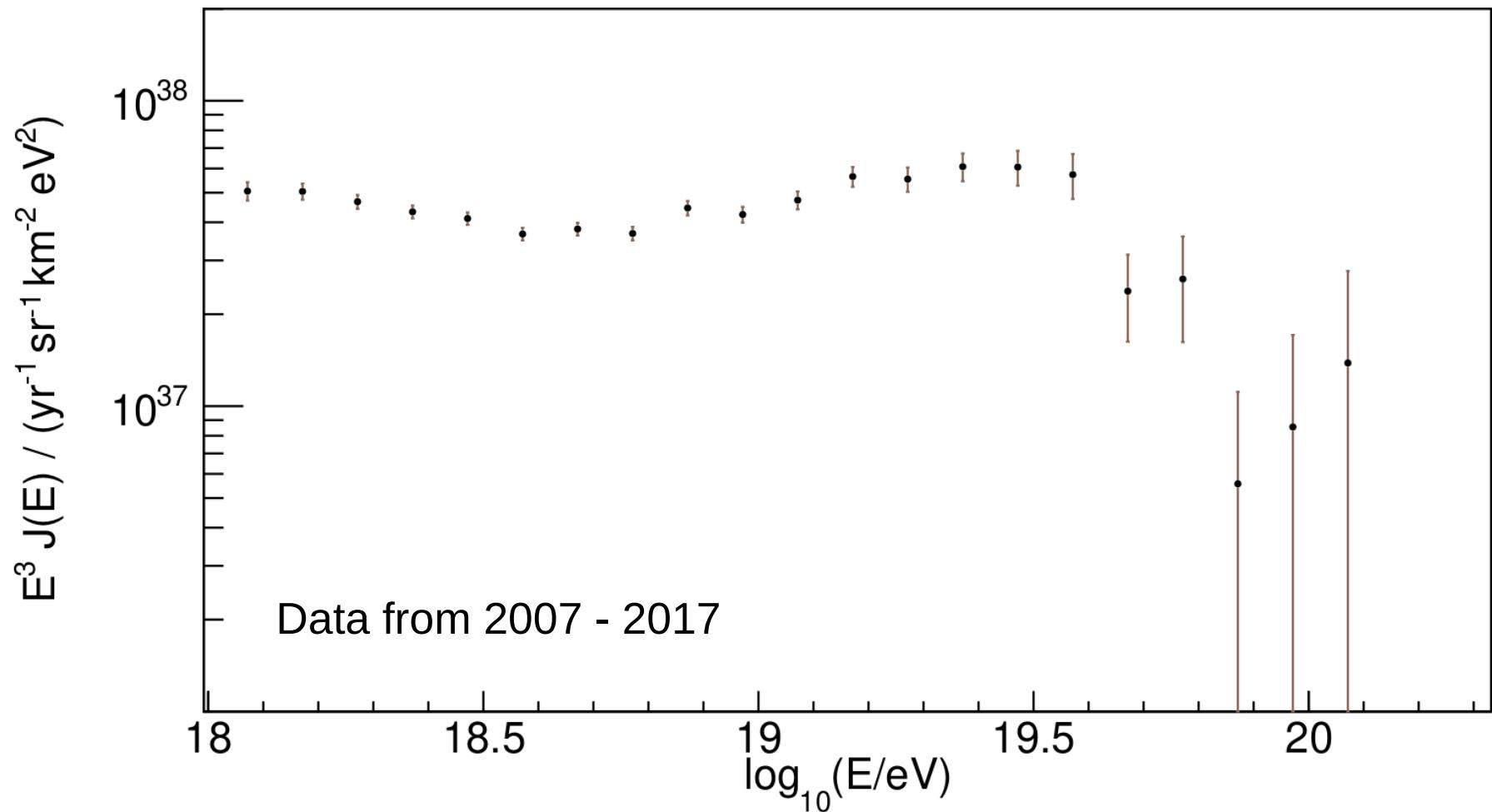




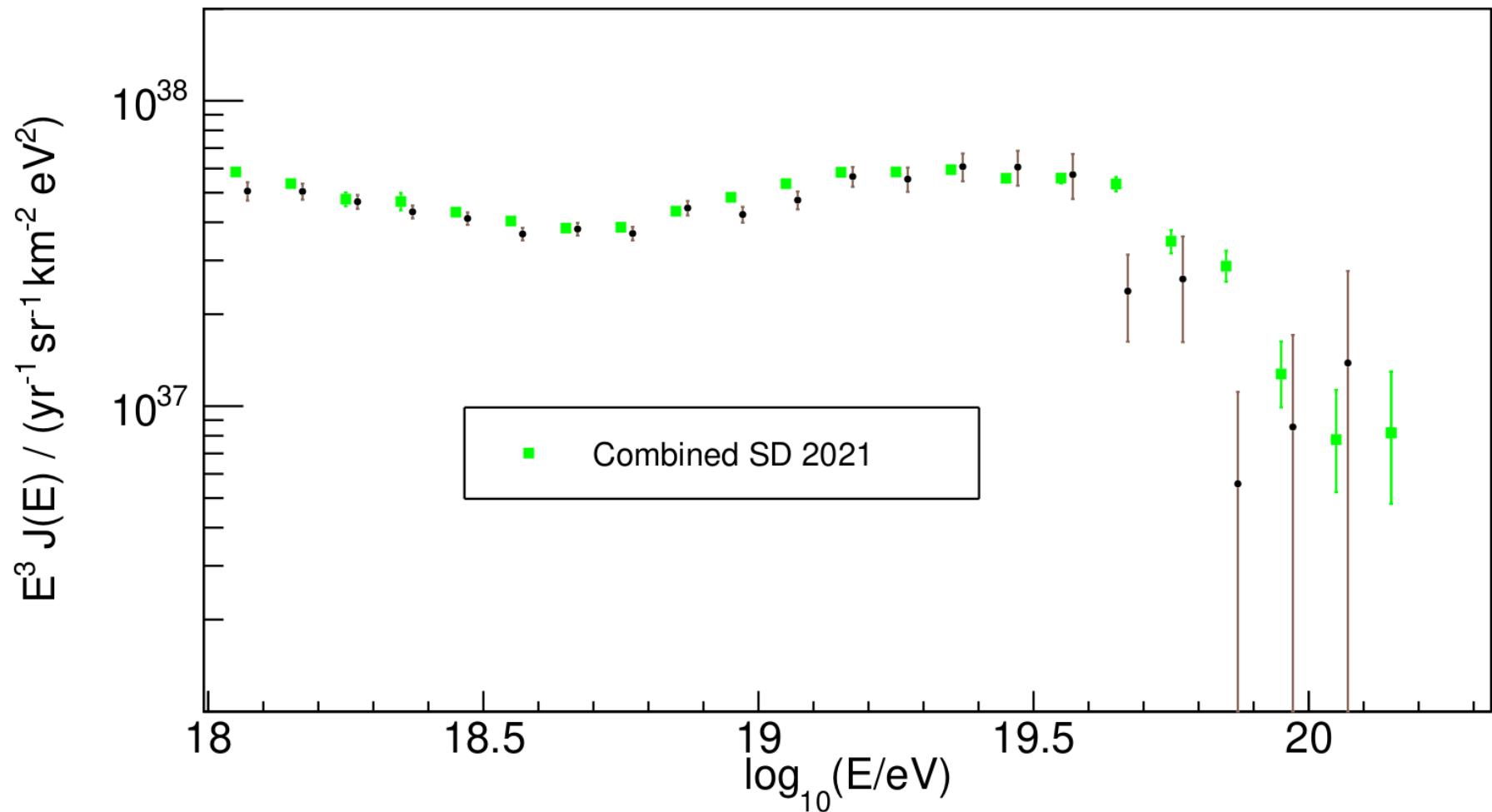
Fiducial distance cut



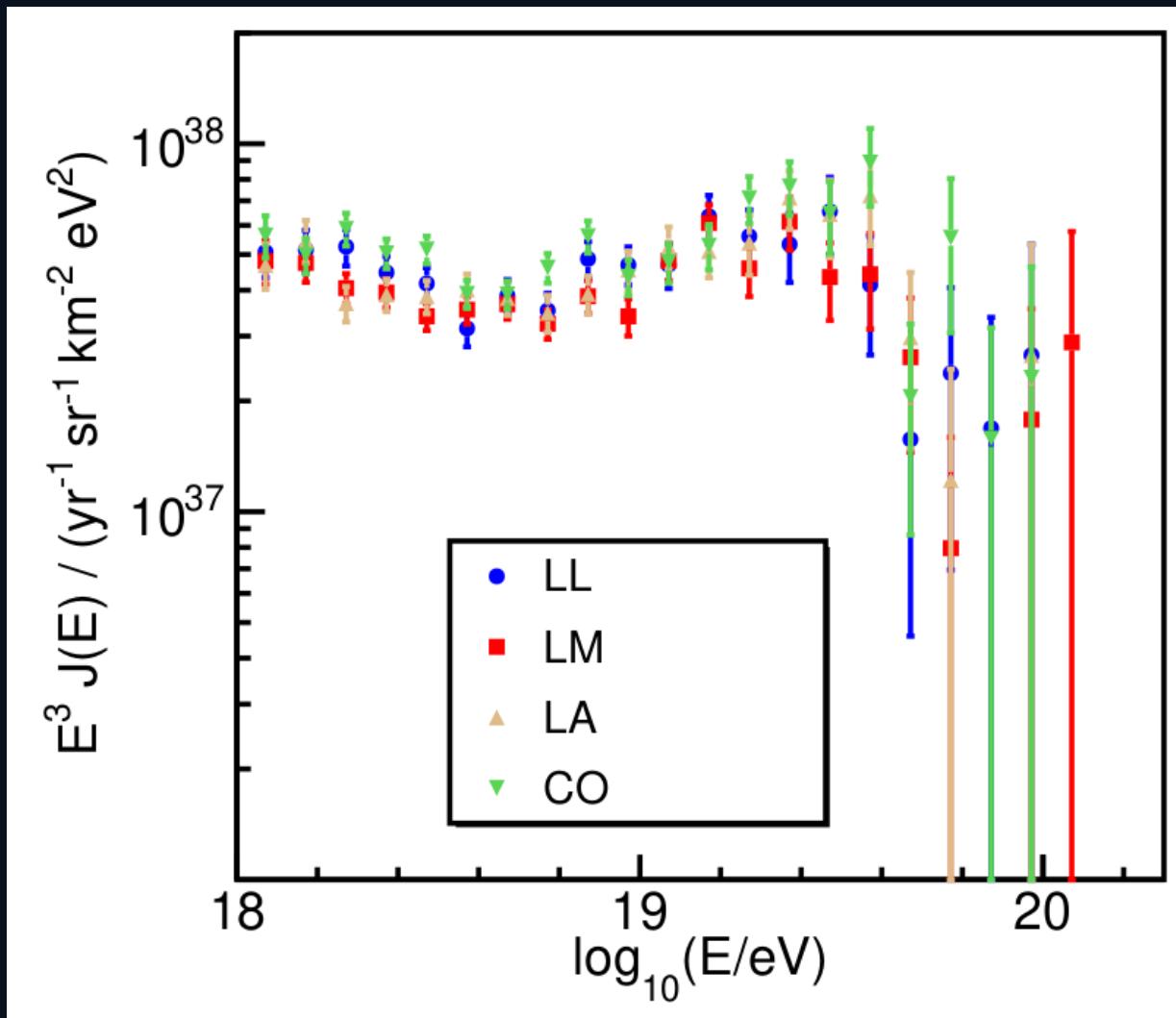
Hybrid energy spectrum



Hybrid energy spectrum



Hybrid energy spectrum - Eyes



Summary

- **Main goal:** Hybrid energy spectrum
- Exposure from detector simulation:
Depends on selection level & energy
- Cross check of maximum trigger distance with data ($P(\text{FD}|\text{SD})$)
- First results:
 - Hybrid spectrum agrees well with SD spectrum
 - Small differences between spectrum of eyes
- Outlook:
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Thank you for your attention!

Backup slides

Selection levels (Part I)

#standard FD trigger-----

eyeCut 001111

T3TimeAtGround

T3Class 1.

#hybrid-----

hybridTankTrigger 2

MaxCoreTankDist 1500.

#good period-----

badFDPeriodRejection

hasMieDatabase

maxVAOD 0.1

cloudCutXmaxPRD14 { params: 1 nMinusOne: 21 -10.5 10.5 }

good10MHzCorrection

!IsBadCO6

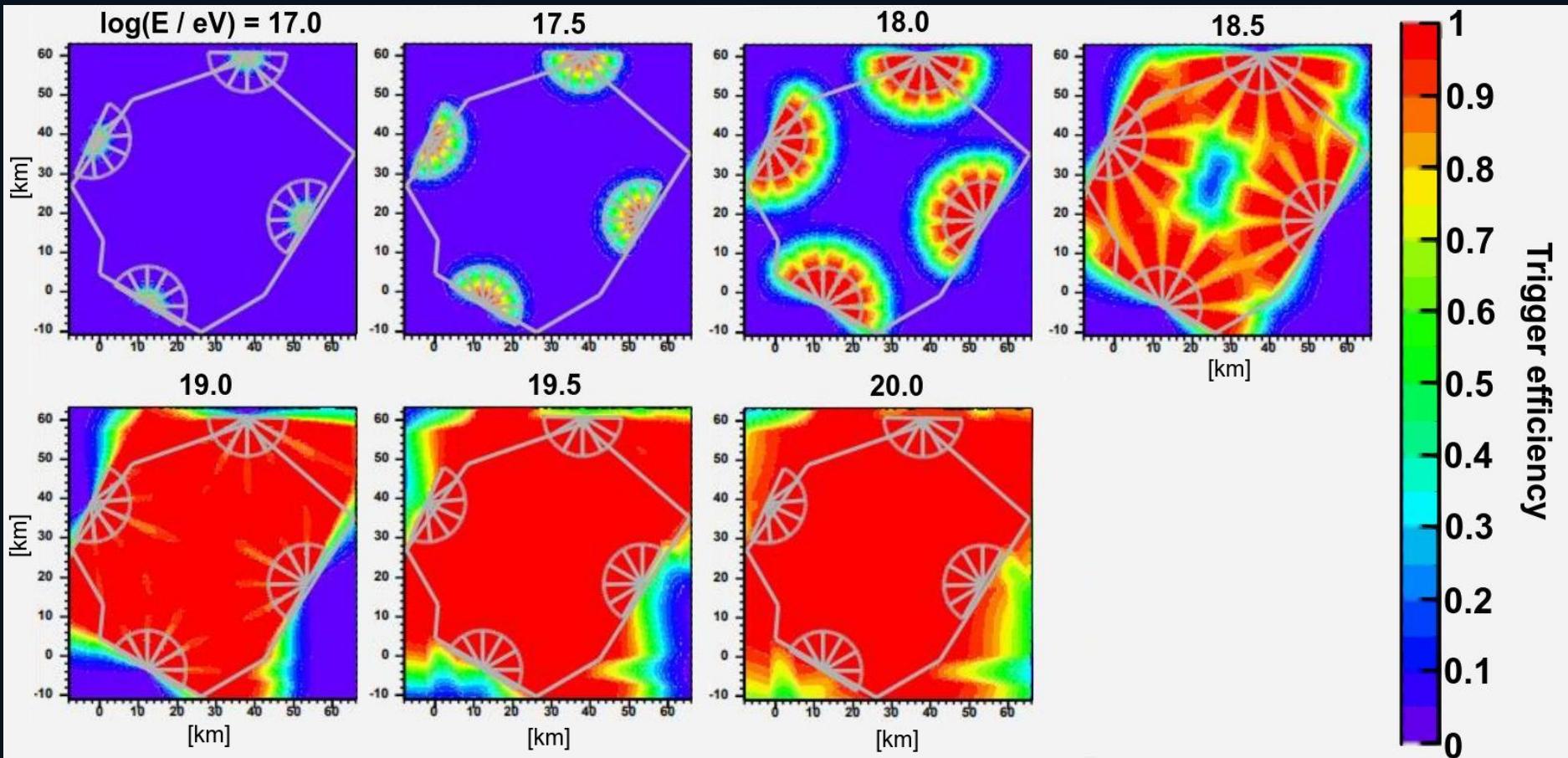
Selection levels (Part 2)

```
#reconstruction-----
minLgEnergyFD{ params: 17.      # minimum lg(E/eV)
                nMinusOne: 500 16. 22. }

#quality-----
skipSaturated
xMaxObsInExpectedFOV { params: 40 20 }
maxDepthHole        20.
energyError         .2
profileChi2Sigma   { params: 3 -1.1 nMinusOne: 400 -20 20 }

#fiducial cuts -----
maxZenithFD        60.
FidFOVICRC13      40 20
HD Spectrum Distance 1
```

Visibility range of FD

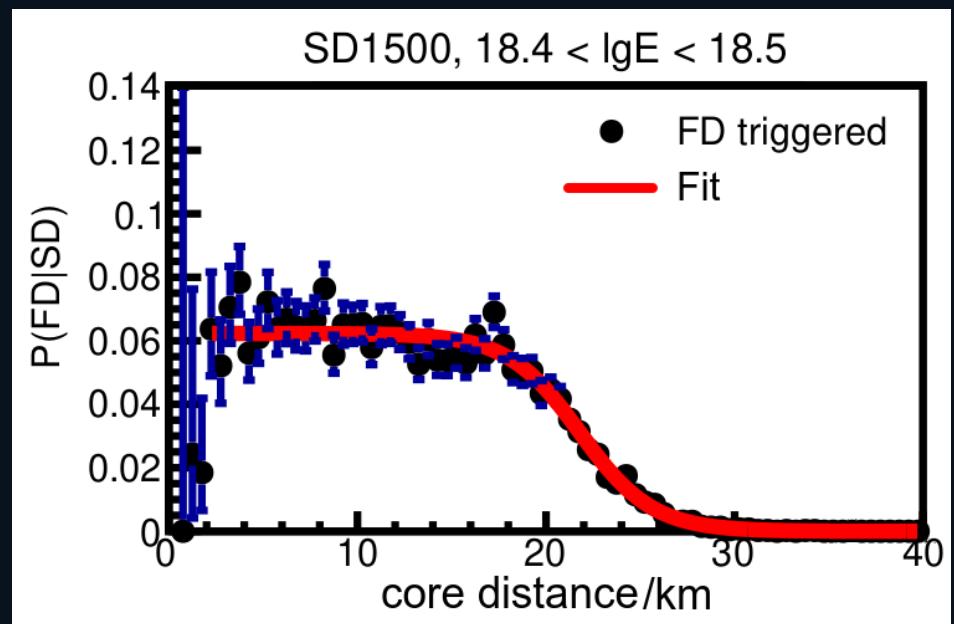


Internal Auger technical note by Sergio Petrera 2004

Fiducial distance

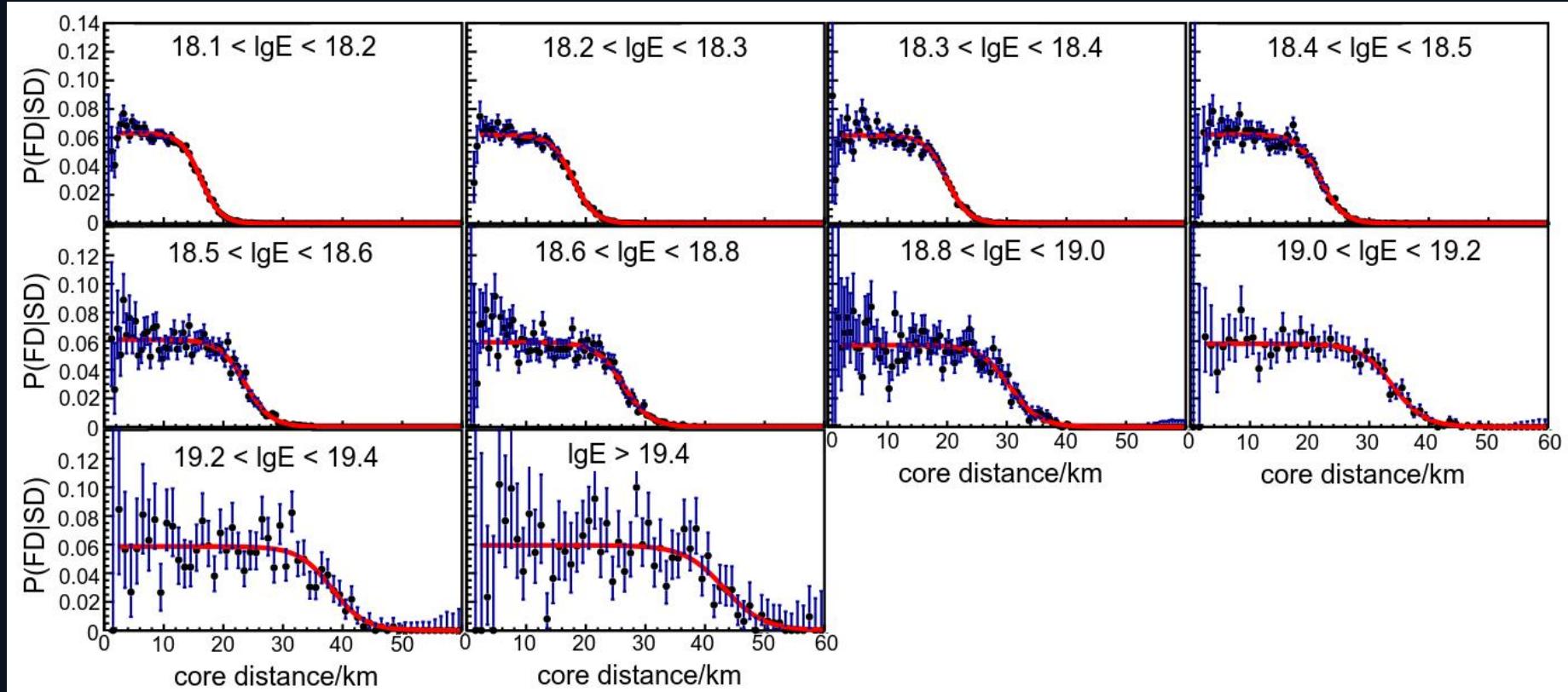
- Previous analysis:
detector simulation
- Here:
 - select good SD events
 - calculate probability
to detect FD event
given SD event:

$$P(FD|SD)(r, E) = \frac{N_{FD}(r, E_{SD})}{N_{SD}(r, E_{SD})}$$

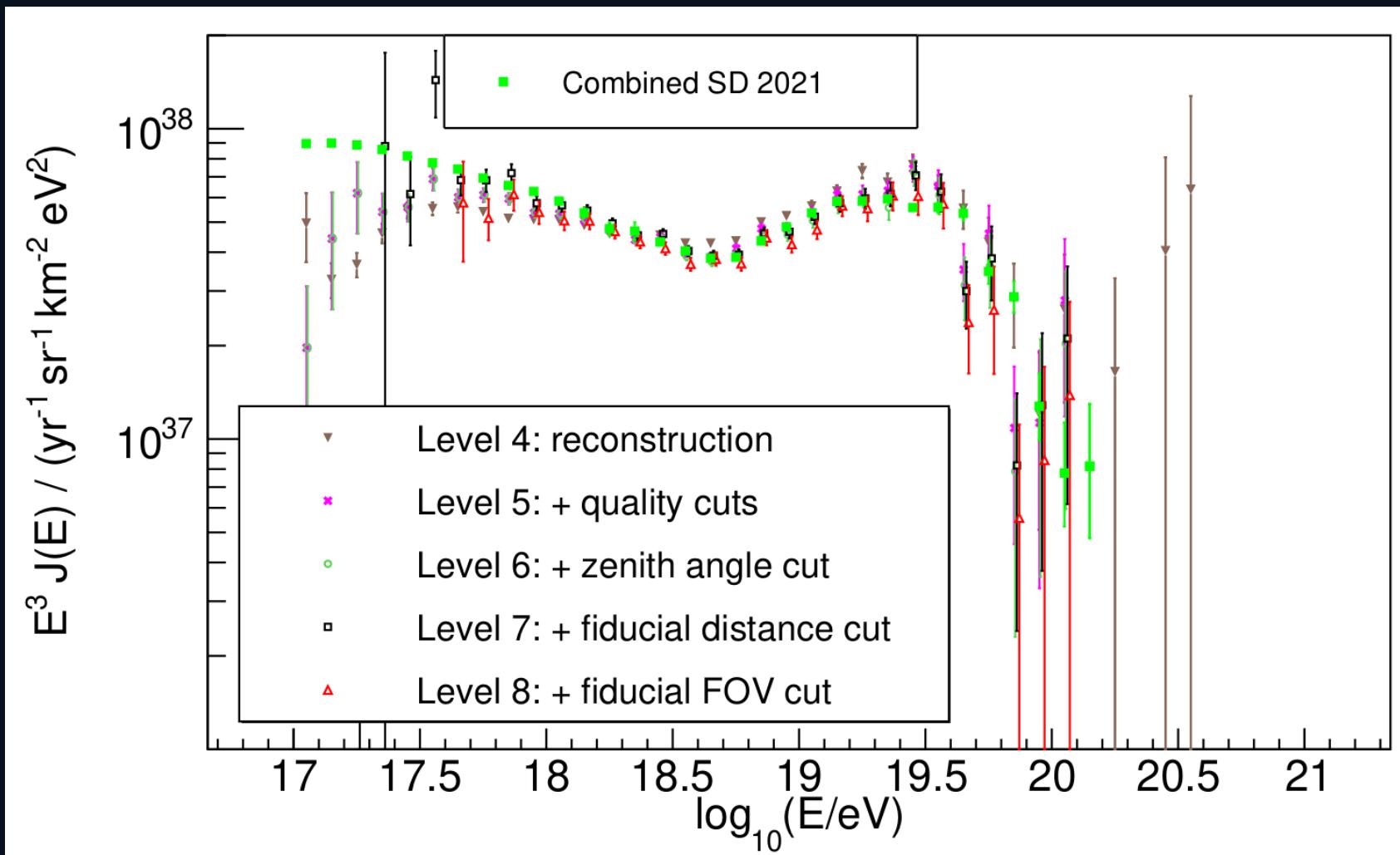


Fiducial distance

Visibility range grows with energy:



Hybrid energy spectrum

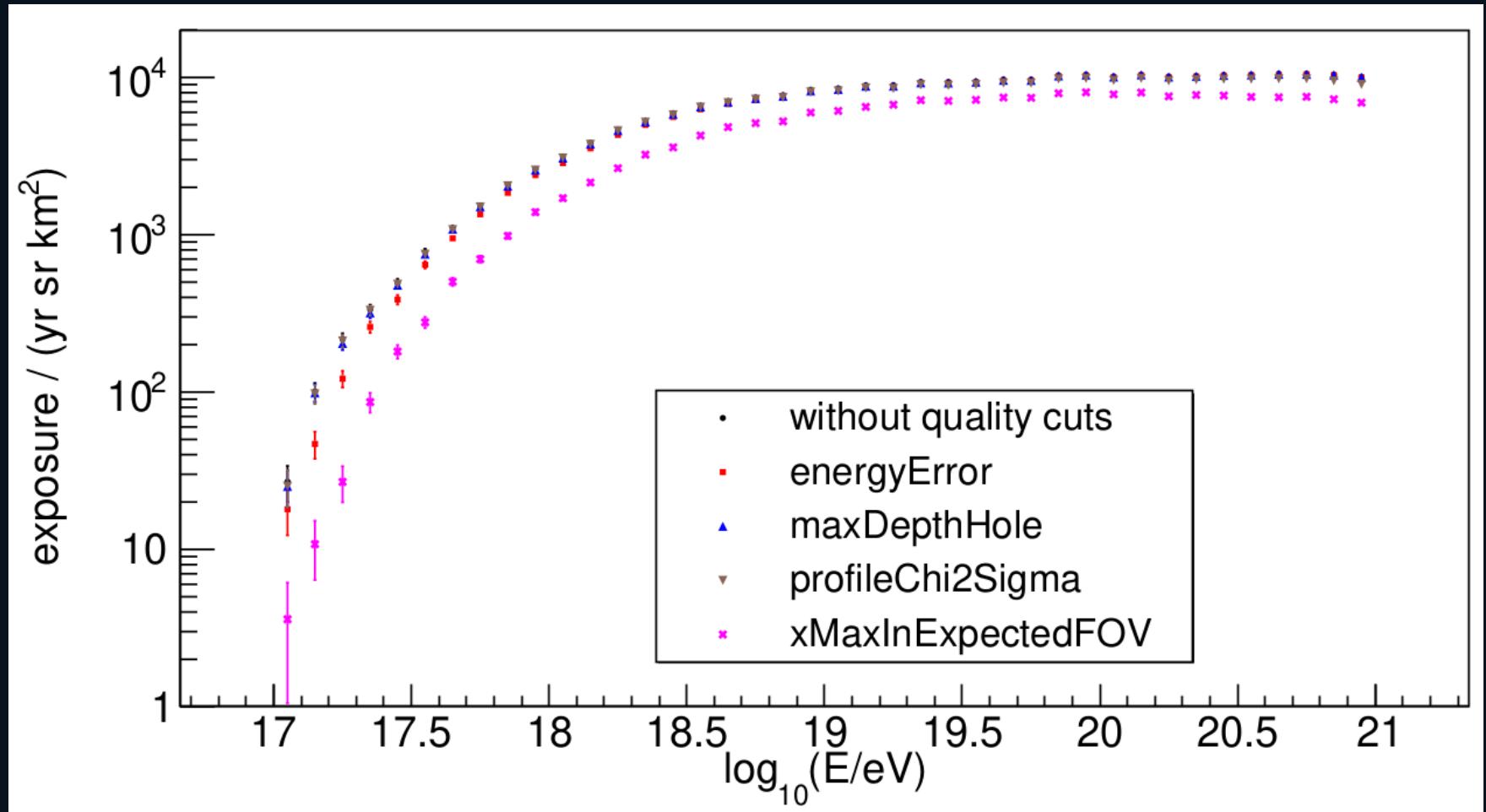


realMC for exposure

RealMC from Francesco Salamida, Offline v3r99p1-icrc-2019:

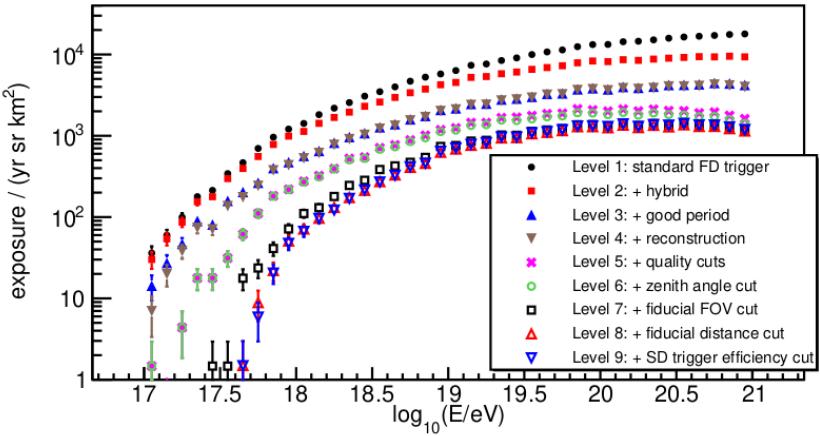
- From 1.1.2007 to 31.12.2017
- Area: 80km x 80km
- Max. zenith angle: 65°
- Energy from 10^{17} eV to 10^{21} eV
- Spectrum: E^{-1}
- Width of energy bins: $\Delta \log(E/\text{eV})=0.1$

Exposure: Quality cuts

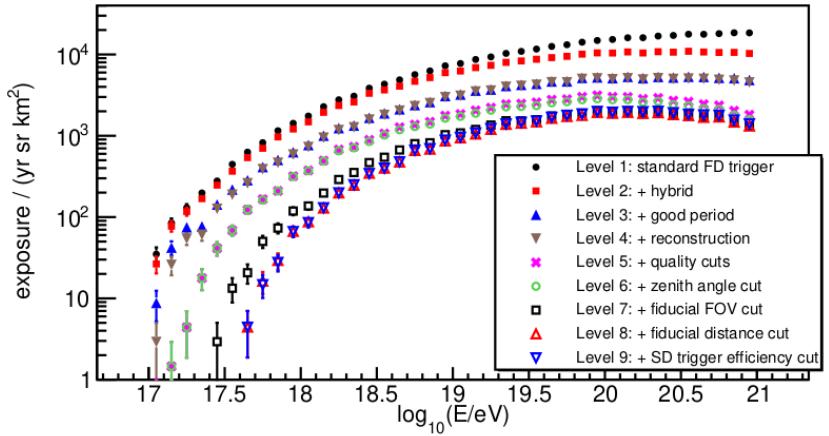


Exposure – Eyes in comparison

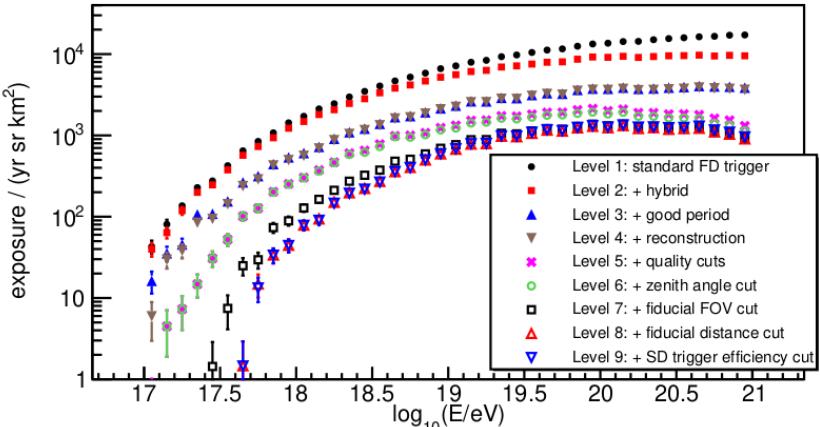
LL - Hybrid exposure for different selection levels



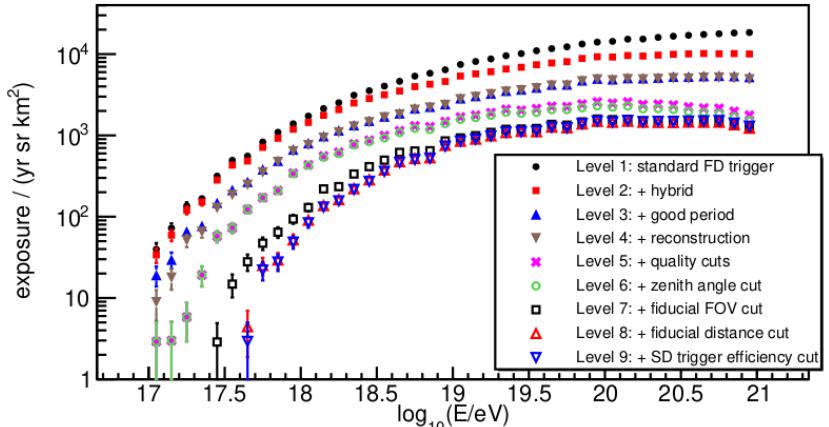
LM - Hybrid exposure for different selection levels



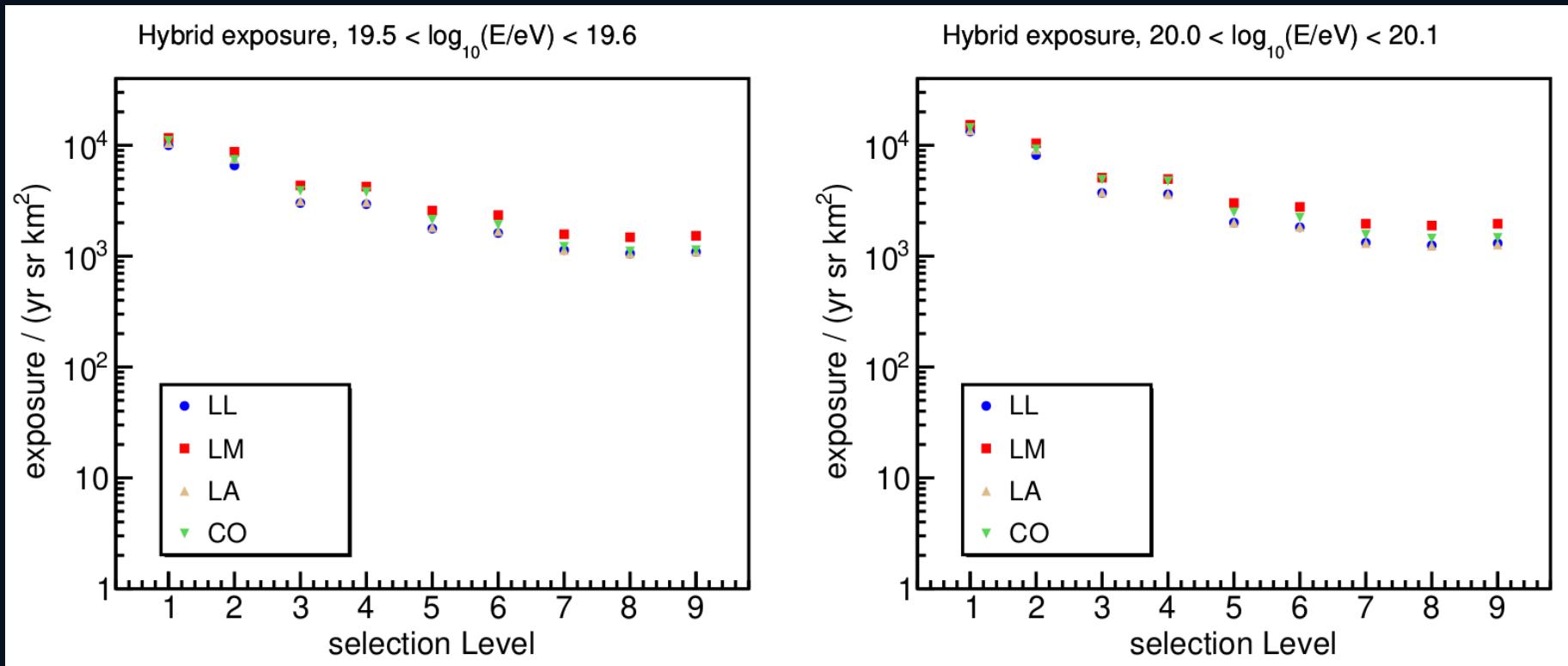
LA - Hybrid exposure for different selection levels



CO - Hybrid exposure for different selection levels



Exposure – Eyes in comparison



Exposure calculation - old

$$\mathcal{E}(E) = \int_T \int_{\Omega} \int_{A_{\text{gen}}} \varepsilon(E, t, \theta, \phi, x, y) \cos \theta \, dA \, d\Omega \, dt$$

Monte-Carlo integration for A, t:

$$\int_0^T \varepsilon(t) \, dt = k \int_0^T \frac{1}{k} \varepsilon(t) \, dt \equiv k \int_0^T \varepsilon(t) f(t) \, dt$$

$$\int_0^T \frac{1}{k} \stackrel{!}{=} 1 \rightarrow k = T$$

$$k \int_0^T \varepsilon(t) f(t) \, dt \approx \frac{k}{N} \sum_i \varepsilon(t_i) \hat{=} \frac{k}{N_{\text{sim}}} \sum_i N_{\text{sel}}(t_i) = k \frac{N_{\text{sel}}}{N_{\text{sim}}}$$

Solid angle:

$$\int d\Omega = \int_0^{2\pi} d\phi \int_0^{\pi/2} d\sin \theta \, d\theta = 2\pi \int_{\cos(\pi/2)}^{\cos 0} d\cos \theta$$

$$\mathcal{E}(E) = 2\pi T A_{\text{gen}} \sum_{\cos \theta_i} \varepsilon(E, \theta_i) \langle \cos \theta_i \rangle \Delta \cos \theta$$

discrete

Exposure calculation - new

$$\mathcal{E}(E) = 2\pi T_{\text{sim}} A_{\text{sim}} \int_{\cos \theta_{\text{max, sim}}}^{\cos \theta_{\text{min, sim}}} \varepsilon(E, \theta) \cos \theta d\cos \theta$$

Monte-Carlo integration for zenith angle:

$$k \int_{u_1}^{u_2} \frac{1}{k} \varepsilon(\theta) \cos \theta d\cos \theta \equiv k \int_{u_1}^{u_2} \varepsilon(\theta) f(\theta) d\cos \theta$$

Normalization: $k = \int_{u_1}^{u_2} \cos \theta d\cos \theta = \frac{1}{2} (u_2^2 - u_1^2)$

$$\rightarrow \frac{(u_2^2 - u_1^2)}{2} \int_{u_1}^{u_2} \varepsilon(\theta) f(\theta) d\theta \approx \frac{(u_2^2 - u_1^2)}{2N} \sum_i \varepsilon(\theta_i) \hat{=} \frac{(u_2^2 - u_1^2)}{2N_{\text{sim}}} N_{\text{sel}}$$

$$\mathcal{E}(E) = \pi T_{\text{sim}} A_{\text{sim}} (u_2^2 - u_1^2) \varepsilon(E)$$

$$(u_1 \equiv \cos \theta_{\text{max, sim}}, u_2 \equiv \cos \theta_{\text{min, sim}})$$