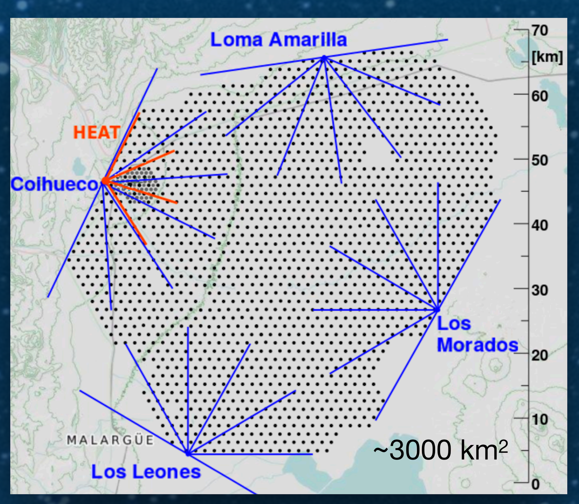
Constraints on UHE tau neutrino, tau, and tau-like particles generated from BSM scenarios with the Pierre Auger Observatory

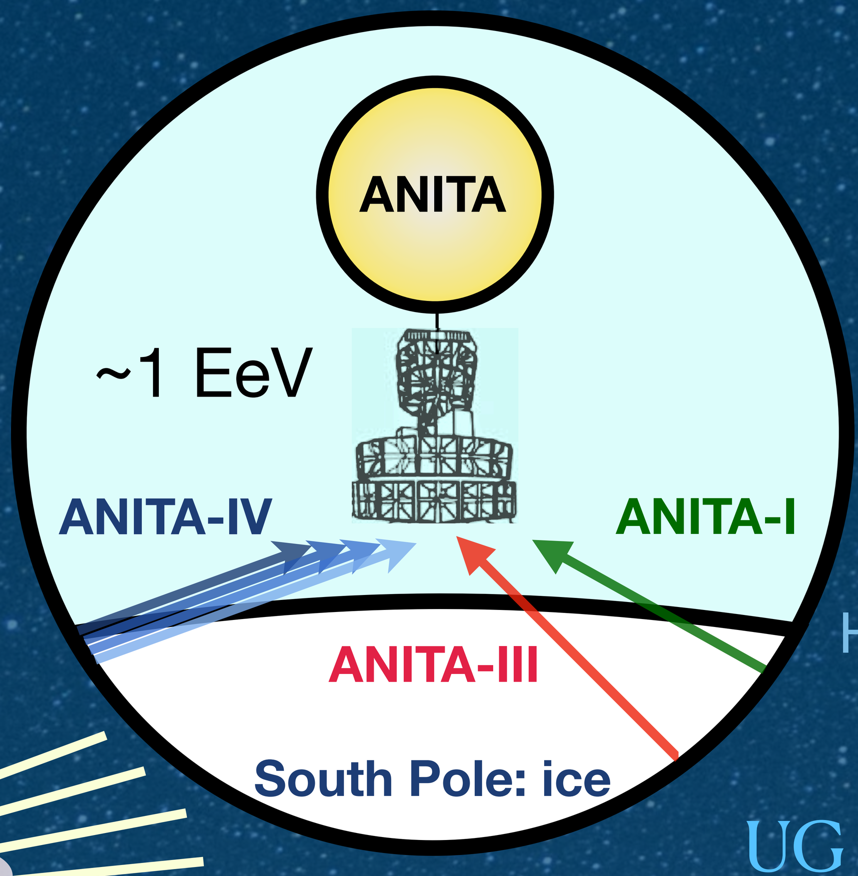
Baobiao Yue *on behalf of the Pierre Auger Collaboration*
bayue@uni-wuppertal.de, Bergische Universität Wuppertal, Wuppertal, Germany

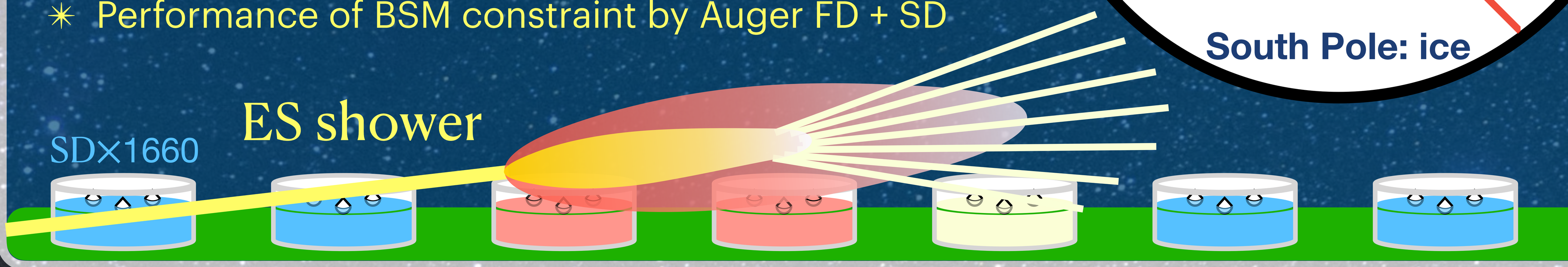
The Pierre Auger Observatory

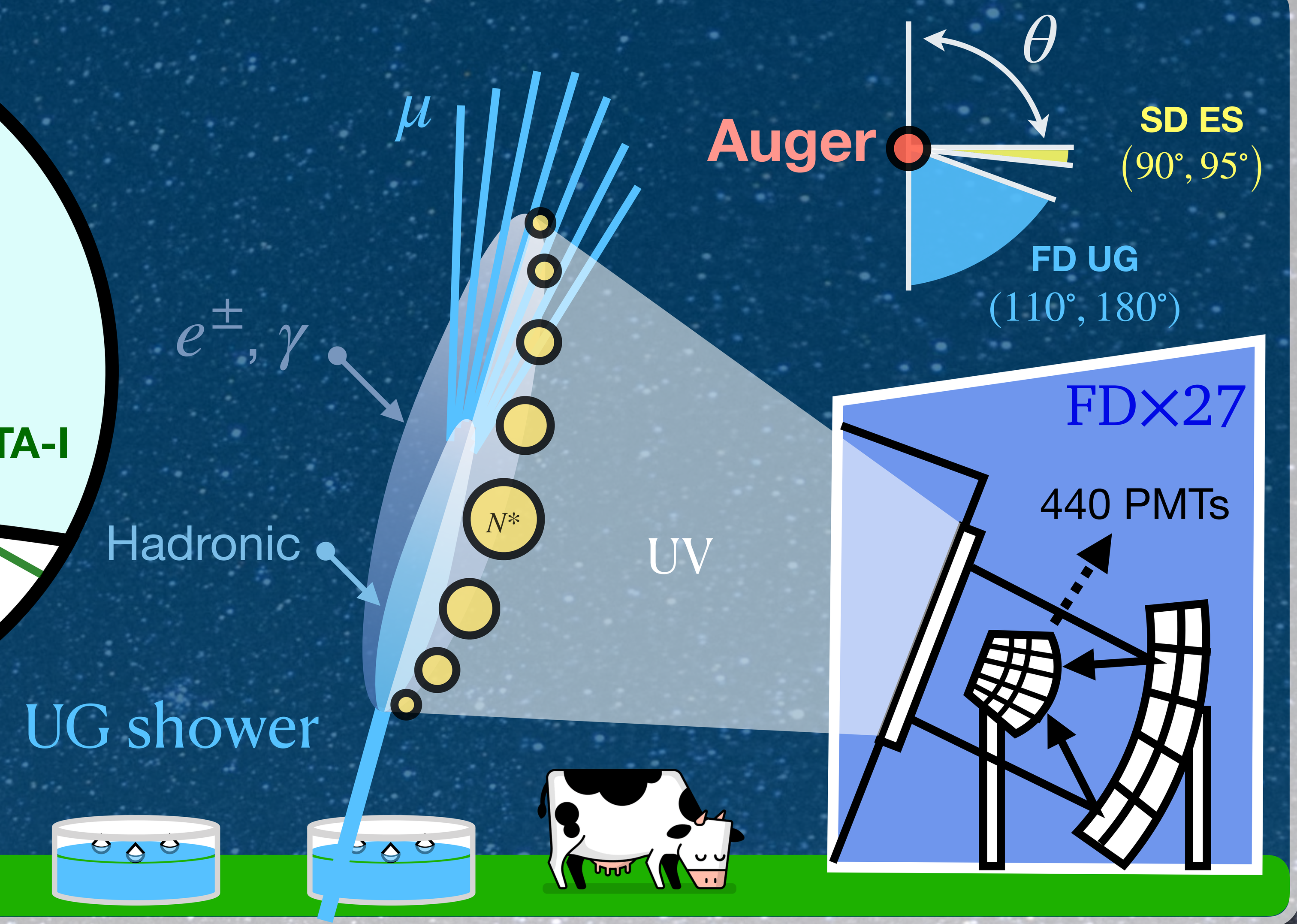


- Ultra-high-energy (**UHE**) Cosmic Ray (CR) detection in Argentina
- Earth-Skimming (**ES**) shower: Surface Detector (**SD**)
- Steep up-going (**UG**) shower: Fluorescence Detector (**FD**)

✳ Anomaly: 2 UG showers and 4 ES showers by ANITA
✳ Performance of BSM constraint by Auger FD + SD







Auger
FD-UG: Null-observation
SD-ES: Null-observation

BSM particle propagation with τ exiting to the ground | τ decay probability | τ decay detection efficiency

Auger	Shower energy	Theta	Time	Max H_{sh}
FD-UG [1]	> 10^{17} eV	110° - 180°	14 yrs × 14%	~9 km
SD-ES [2]	> $10^{16.5}$ eV	90° - 95°	9.6 equivalent yrs	~2.5 km

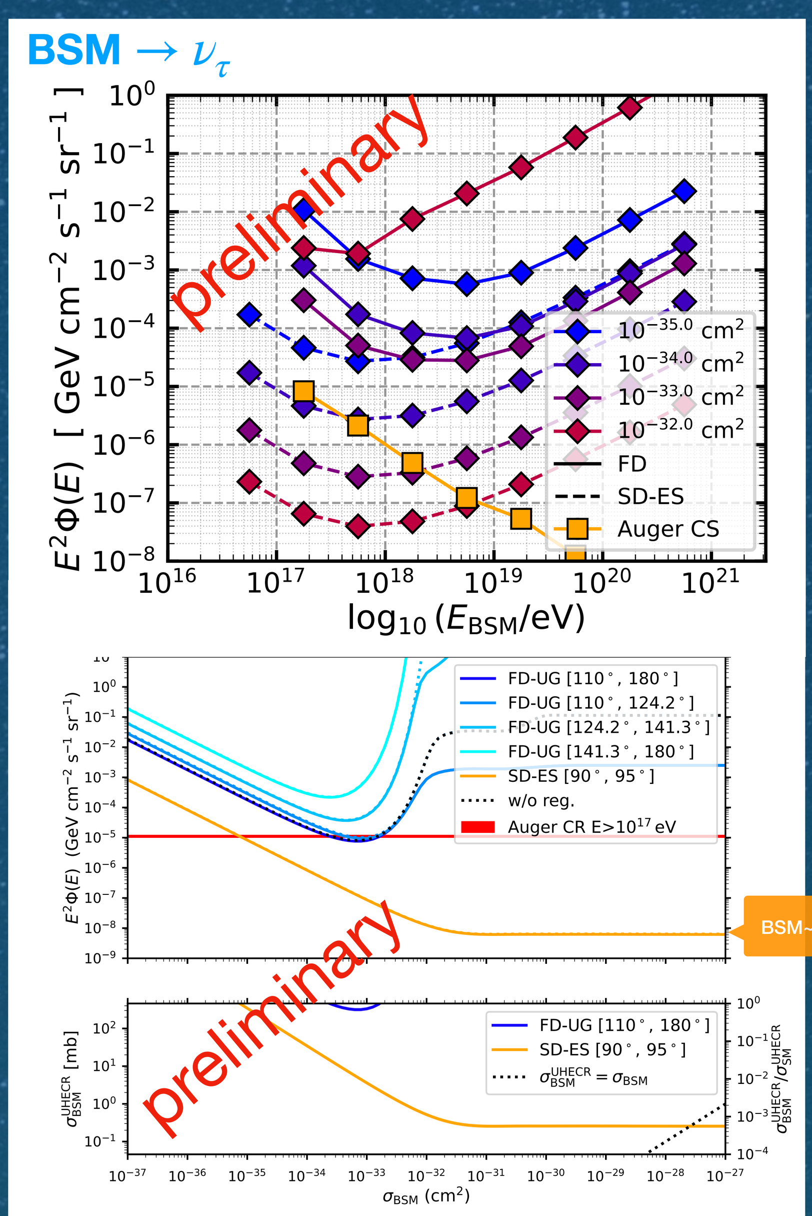
Srijan's poster #315

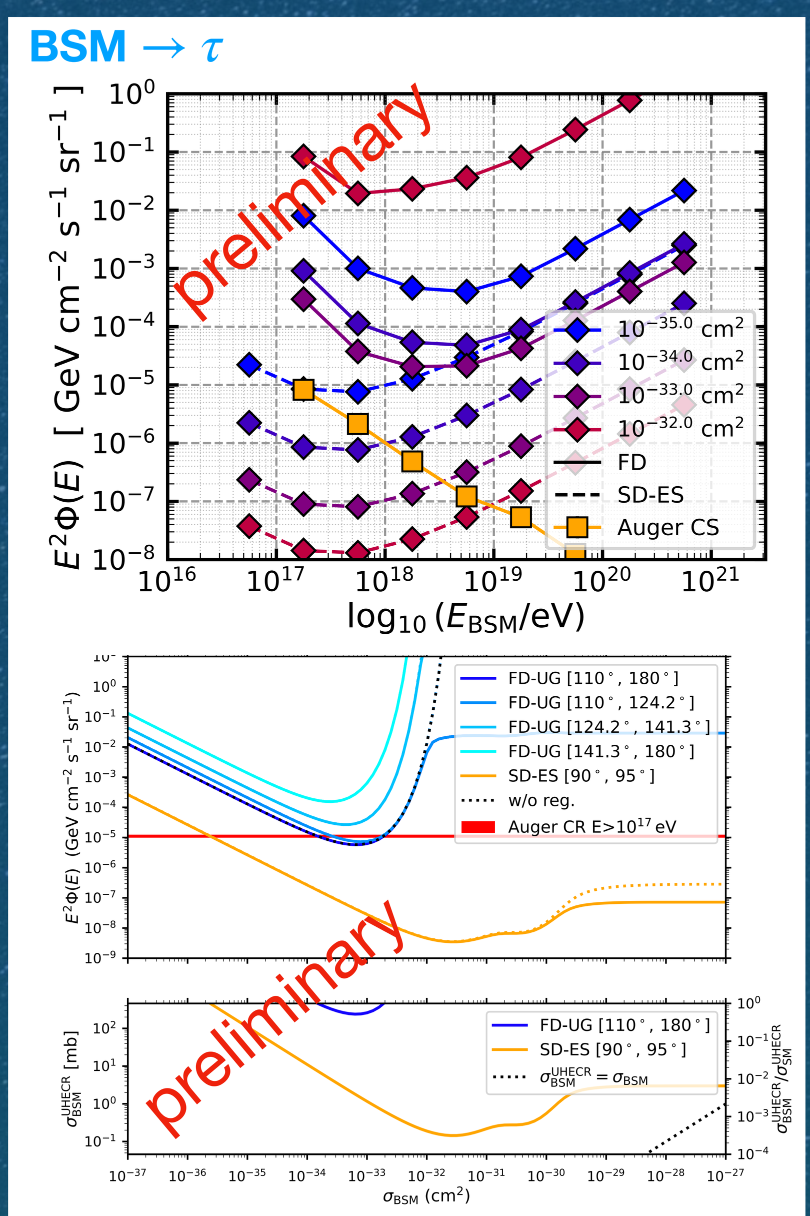
Exposure $\mathscr{E}(E_{BSM}) = \int_{E_\tau}\int_{H_{dec}}\int_{\Omega}\int_{A}\int_{T} |\cos\theta| \cdot P_{exit}^{BSM} \cdot P_{dec} \cdot \varepsilon_\tau \, dE_\tau dH_{dec} d\Omega dA dt$

Prediction $N_{evt} = \int_{E_{BSM}} \mathscr{E} \cdot \Phi_{BSM} \, dE_{BSM}$ — Null-observation → **Upper limits**

Monte Carlo
ν_τ and τ propagation: NuTauSim [3]
τ decay: TAUOLA [4]
τ decay products first interaction depth: CONEX [5]
FD-UG and SD-ES exposure: Off̲line [6]

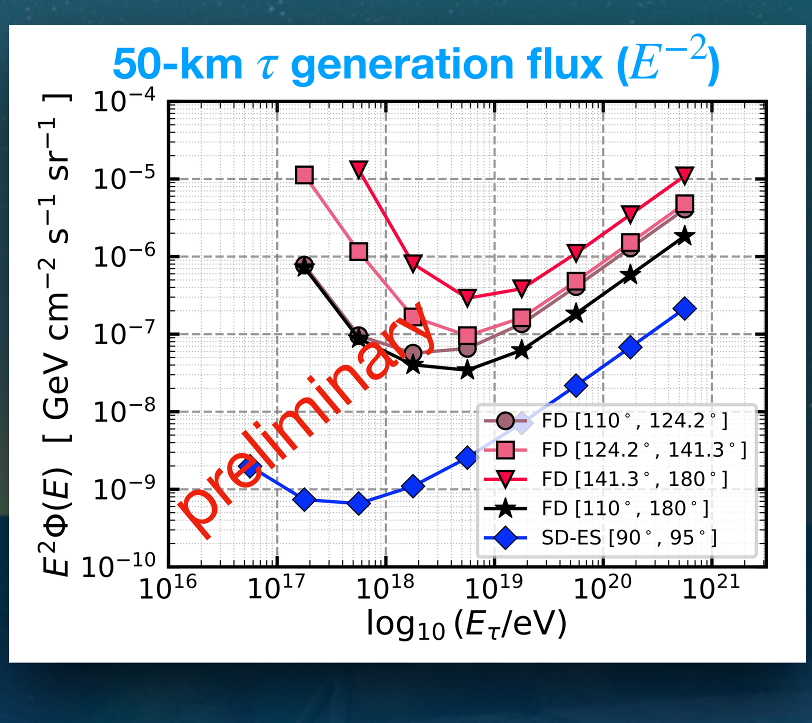
BSM → ν_τ/τ scenario constraint

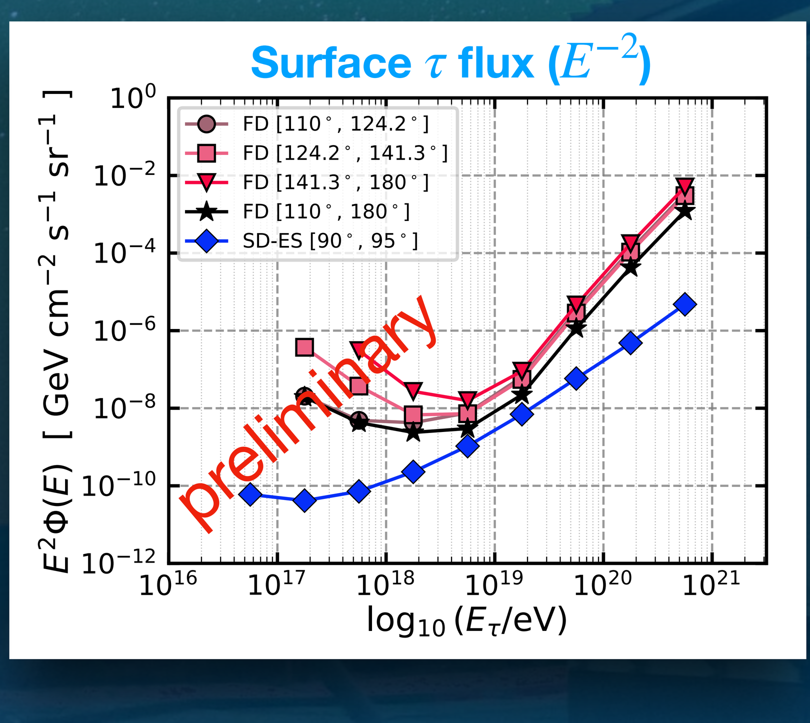




- FD can set the strongest integral flux constraint to BSM flux about 7×10^{-5} GeV cm^{-2} s^{-1} sr^{-1} (E^{-2}) at σ_{BSM} ~ 10^{-33} cm². SD can reduce the integral upper limit to 6×10^{-9} GeV cm^{-2} s^{-1} sr^{-1} (E^{-2}) at $\sigma_{BSM} \gtrsim 10^{-32}$ cm², which is 3.5 orders of magnitude below the measured UHECR flux in the same range of energies (E>0.1 EeV), thereby constraining also the production $\sigma_{BSM}^{UHECR} \lesssim 0.2$ mb (0.1 mb) for the case of BSM → ν_τ (BSM → τ) at 90% C.L.

τ related scenarios

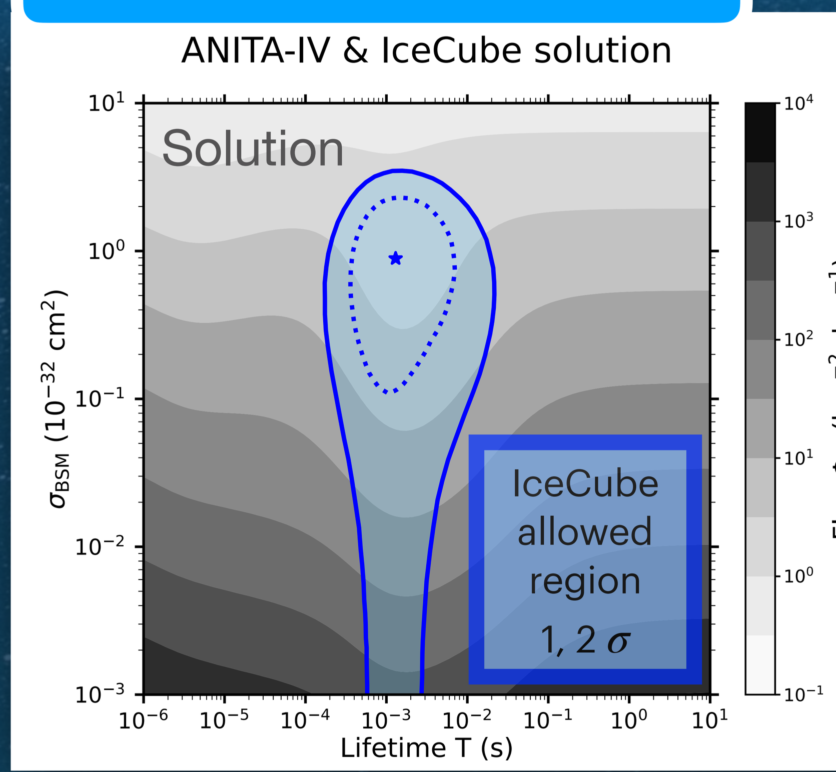




- 50-km τ generation flux: τ generated more than 50 km underground can't escape the Earth.
- Surface τ flux: upper limits of τ flux on the ground.
- These upper limits can be converted to any τ related scenarios.

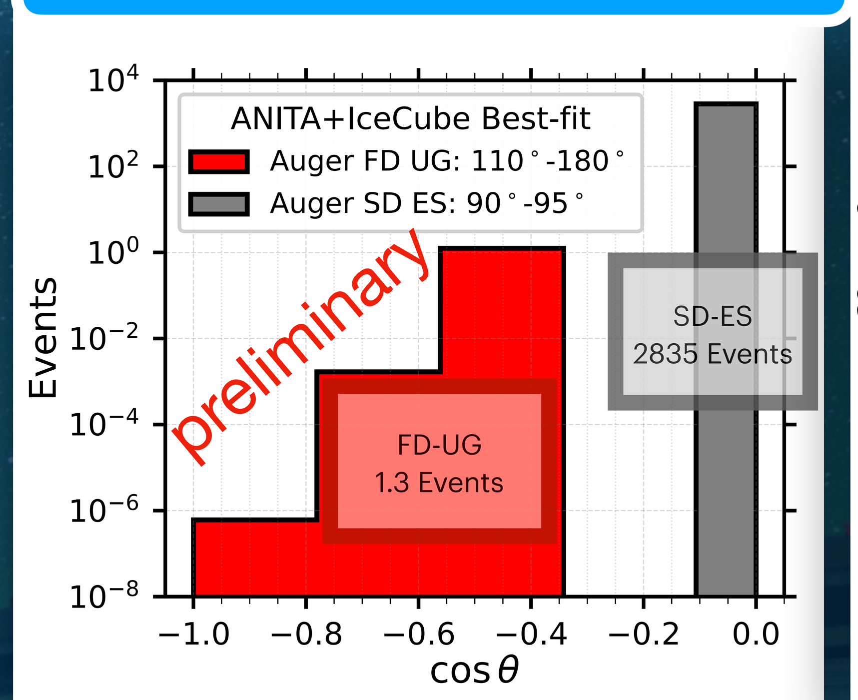
BSM → τ-like scenario

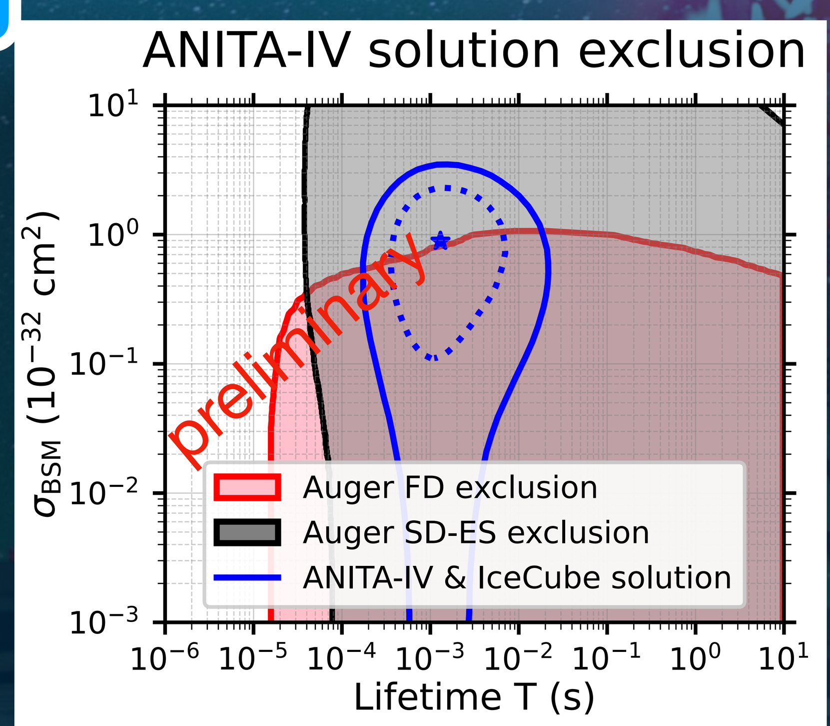
ANITA-IV anomalous events



- [7] propose to explain ANITA-IV events by introducing BSM → τ-like model (1-100 EeV).
- BSM particle can generate a long-lived particle, like τ, which can decay (energy-independent T) and doesn't have energy loss.
- The null-observation at IceCube set a constraint to the parameter space with an allowed region.
- Regeneration (τ-like → BSM → τ-like, σ_{BSM}) is considered .
- Best fit: σ_{BSM}= 8.9×10^{-33} cm², T = 1.3×10^{-3} s, and Φ = 1.8 km^{-2} day^{-1}.

Auger predictions and exclusion





- The Null-observations of FD-UG and SD-ES exclude the allowed region of BSM → τ-like infered from the Null-observation of IceCube. :-)

Conclusion

- The Pierre Auger Observatory is sensitive to up-going showers in FD and SD.
- Recently, null-observations of UG shower in FD were found and are now extended to ES shower in SD.
- Model independent scenarios with BSM → ν_τ and BSM → τ have been well constrained.
- τ flux upper limits has been given: these limits can be converted to any τ related scenario.
- BSM → τ-like interpreted for the four anomalous events in ANITA-IV has been ruled out by using FD-UG and SD-ES data.

Reference

1. PoS(ICRC2023)1099
2. JCAP 10 (2019) 022
3. Rev. D 97, 023021 (2018)
4. Computer Physics Communications 183.3 (Mar. 2012), pp. 821–843
5. Nucl. Phys. B Proc. Suppl. 151 (2006)
6. Nucl.Instrum.Meth.A580: 1485-1496,2007
7. JHEP 07 (2023) 005