ANITA's Four Unsettle Events: Assessing Consistency Among Them and with IceCube Data

YOUNGST@RS - Interacting dark sectors in astrophysics, cosmology and the lab

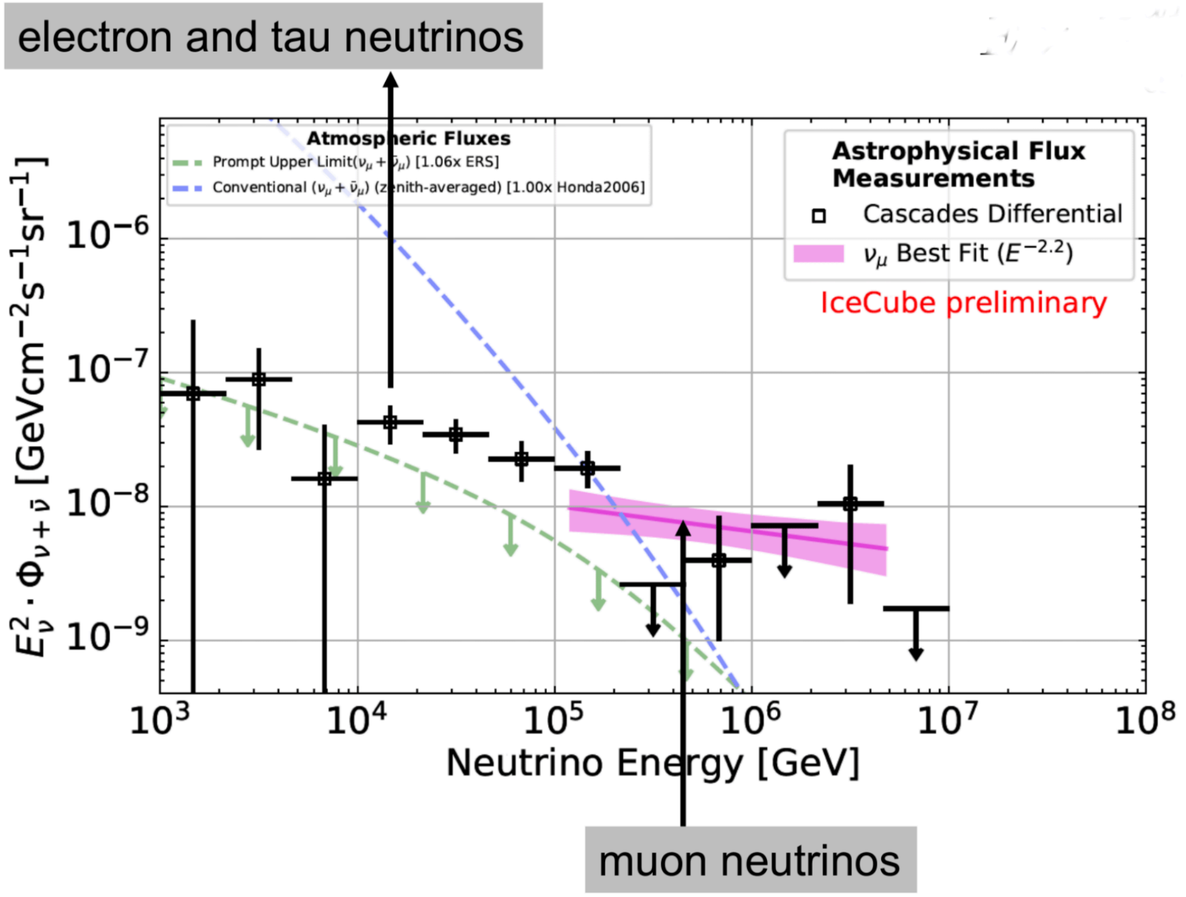
Ivan Martinez Soler

Based on: Esteban, et al., EPJC 80 (2020) 3, 259
Bertolez-Martinez, et al., JHEP 07 (2023) 005

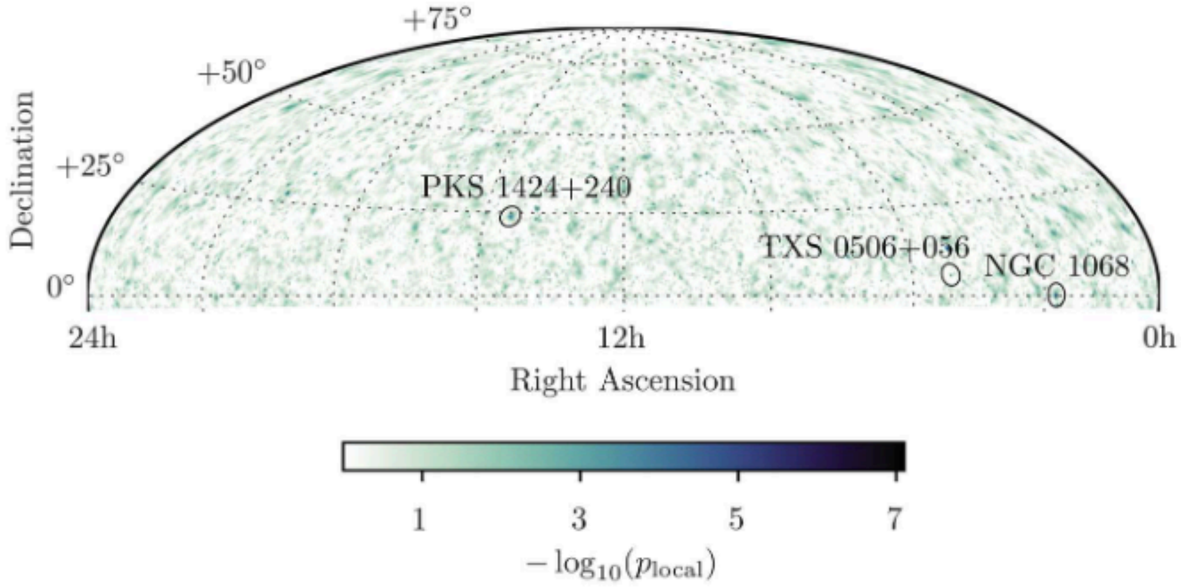
November 8, 2023

High-Energy Astrophysical Neutrinos

The detection of astrophysical events by IceCube has opened a new veneu to probe the Universe



Francis Halzen (Neutrino 2020)



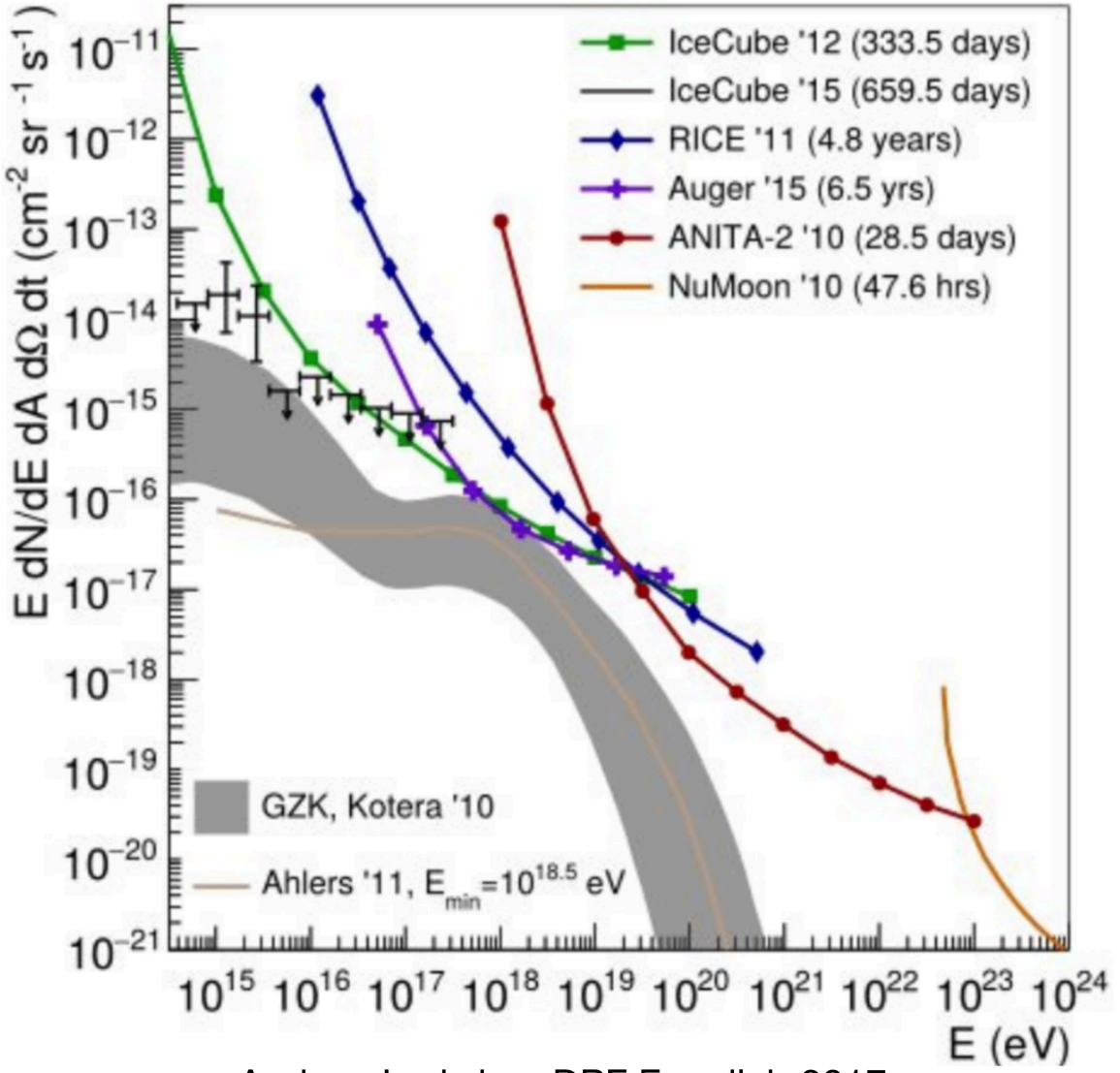
R. Abbasi et al. (IceCube) Science 378, 538 (2022)

High-Energy Astrophysical Neutrinos

- At the EeV scale, neutrinos are expected from cosmic rays (CRs) interaction with CMB photons (GZK neutrinos)

- The interaction occurs at very high center of mass energies (100-1000 TeV), enabling the testing of the SM beyond the TeV scale.

- Detecting this flux will require huge detectors ($\sim 1000\text{km}^3$)

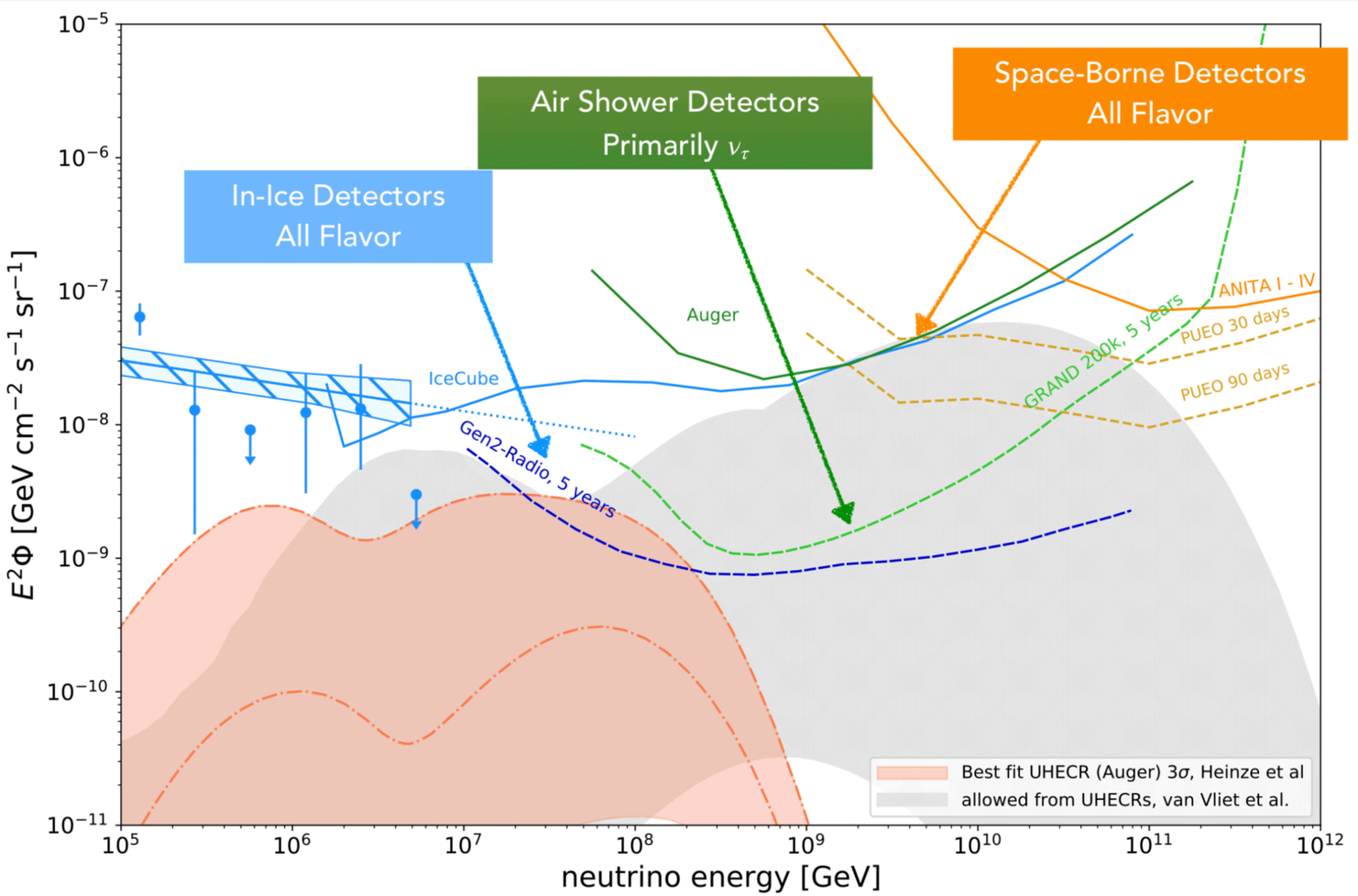


Andrew Ludwing, DPF Fermilab 2017

High-Energy Astrophysical Neutrinos

Several experiments are already looking for GZK neutrinos or they will do it in the near future.

- IceCube/Gen-2
- Auger
- ARIANNA
- GRAND
- **ANITA**/PUEO
- …



Stephanie Wissel (Neutrino 2020)

ANITA

- ANITA is a balloon experiment equipped with an array of antennas capable of detecting impulsive radio emissions.
- The flight altitude of the flight is approximately ~35 km.
- Measurements are conducted within the frequency band 200 - 1200 MHz
- The primary goal is the detection of ultra-high energy neutrinos using the Askaryan effect.
- ANITA searches for polarized signals measuring both the horizontal polarization (Hpol) and the vertical polarization (Vpol) of each impulse.

ANITA

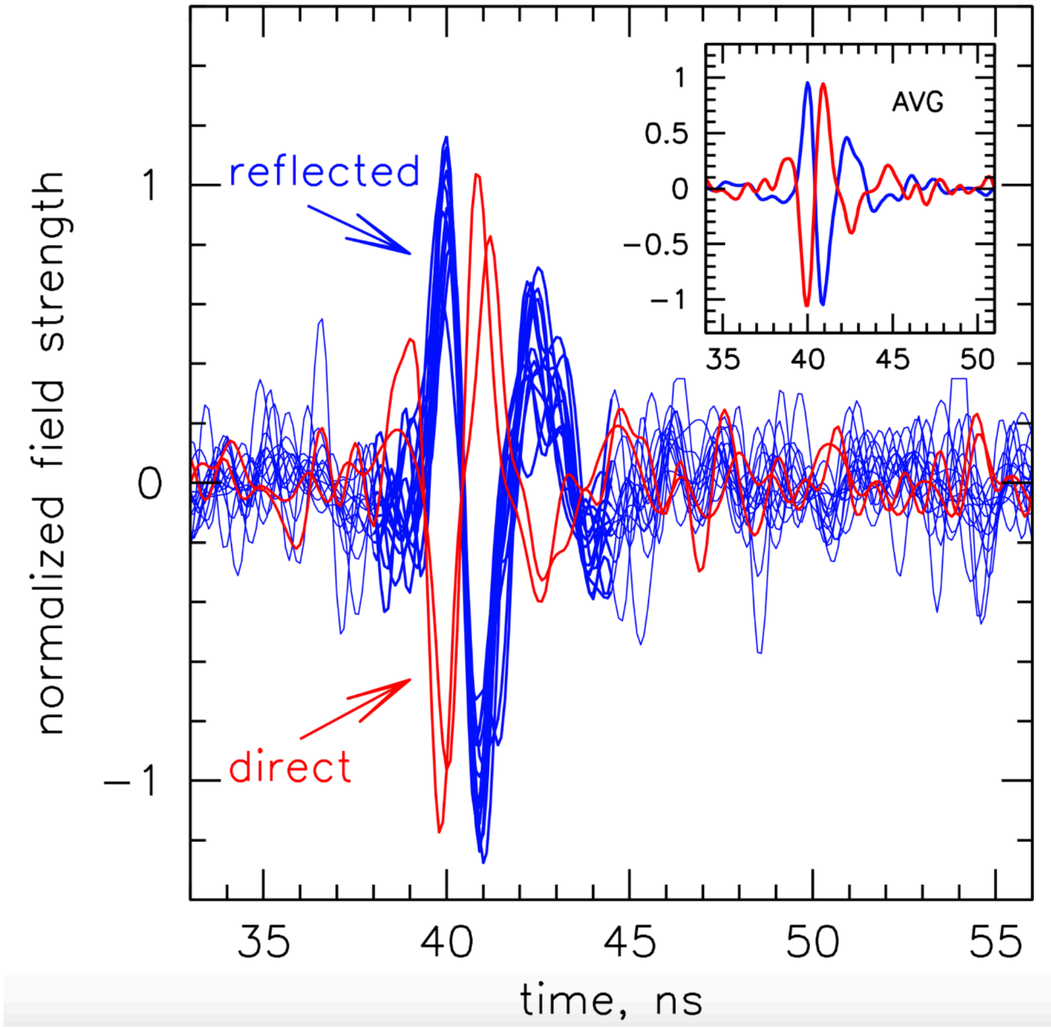
Which type of signals can be expected in ANITA?

Cosmic Rays:

- CRs generate extensive air showers.
- These events can be either direct (above the horizon) or reflected (below the horizon)
- In Antarctica, Earth's magnetic field produces Hpol events
- The direction of the event is reconstructed using the phase.

Neutrinos:

- Askaryan events: They appear as a Vpol signal
- Extensive air shower: Hpol signals created by the taus-decays



ANITA, PRL 105 (2010) 151101

ANITA

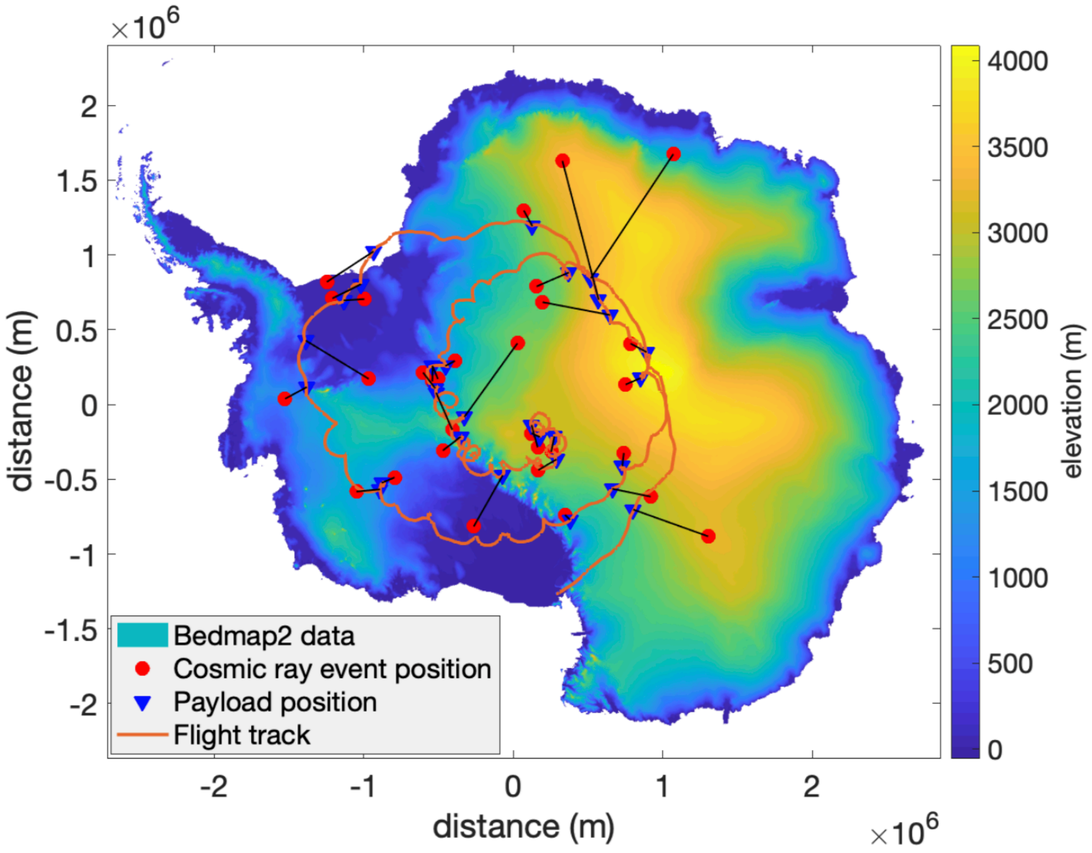
ANITA has conducted four flights, but has not detected any Askaryan events yet

ANITA I:
- 14 reflected CRs and 2 direct CRs
- 1 upward CR-like consistent with the emission from the surface.

ANITA II:
- 1 direct CRs
- Focused in neutrino detection via Askaryan effect.

ANITA III:
- 17 reflected CRs and 3 direct CRs
- 1 upward CR-like consistent with the emission from the surface.

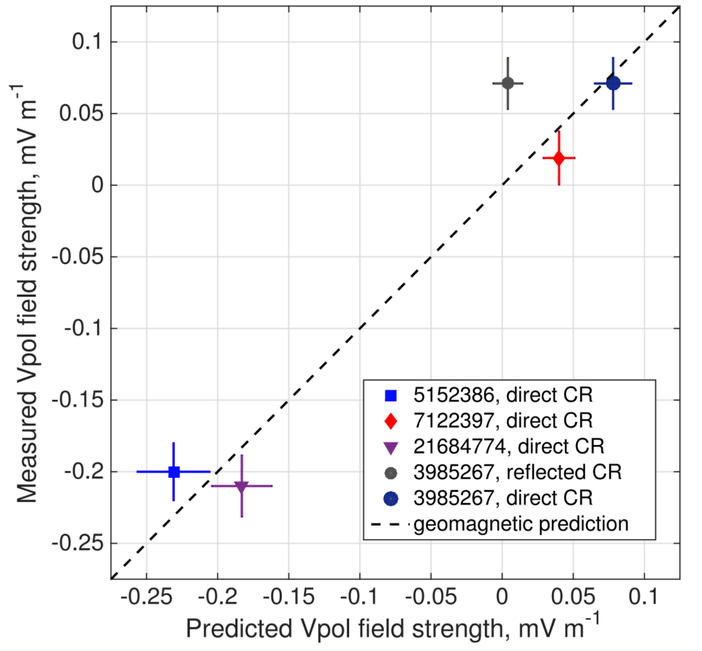
ANITA IV:
- 23 reflected CRs and 2 direct CRs
- 4 near-horizon CRs.

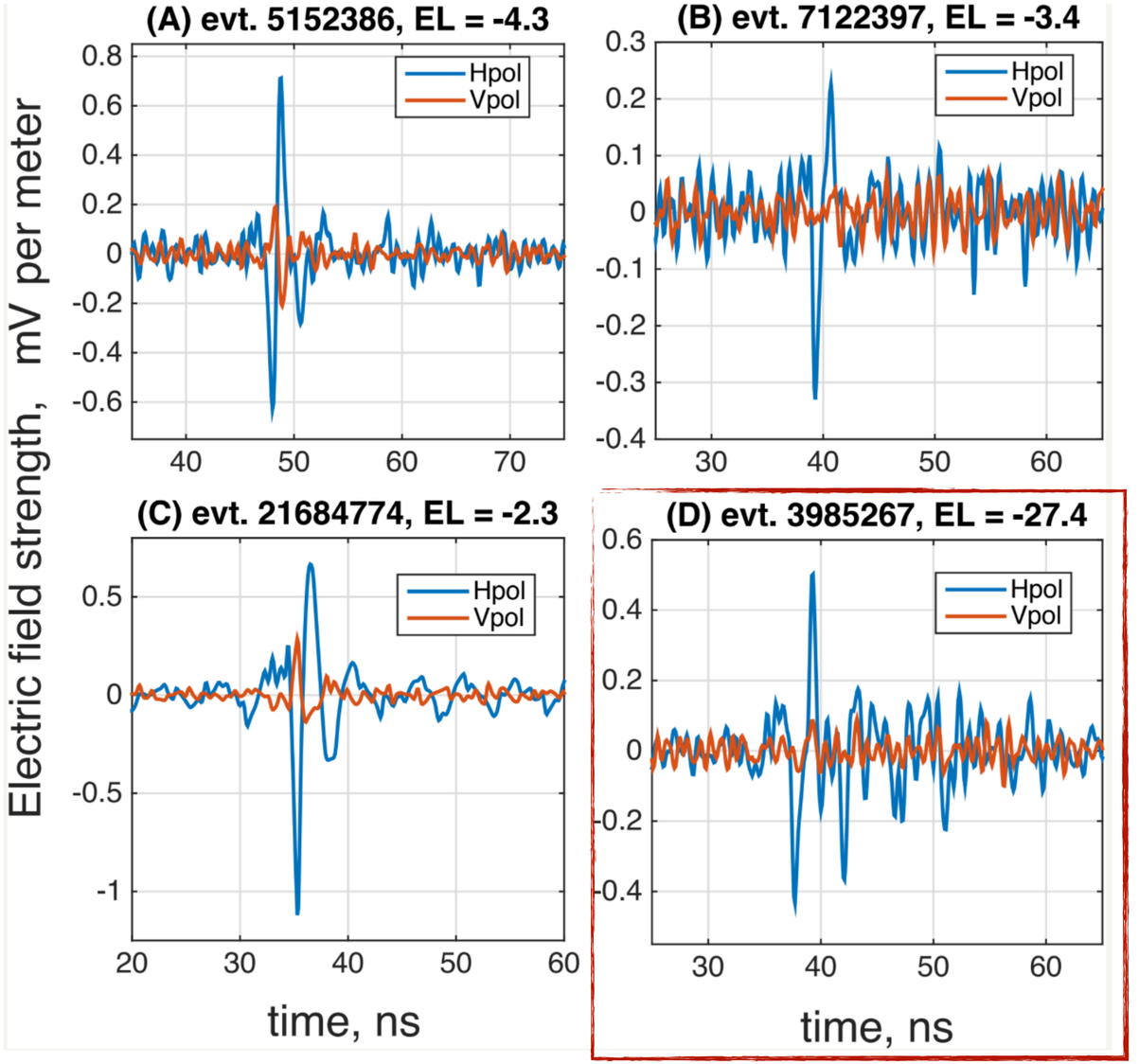


P.W. Gorham et al. (ANITA) PRL 126 (2021) 7, 071103

ANITA-I & III: anomalous events

- The events are polarized horizontally
- The elevation corresponds to -27° and -35°
- The phase is similar to other direct events (A, B, C)
- The polarization measured is correlated with the Geomagnetic field





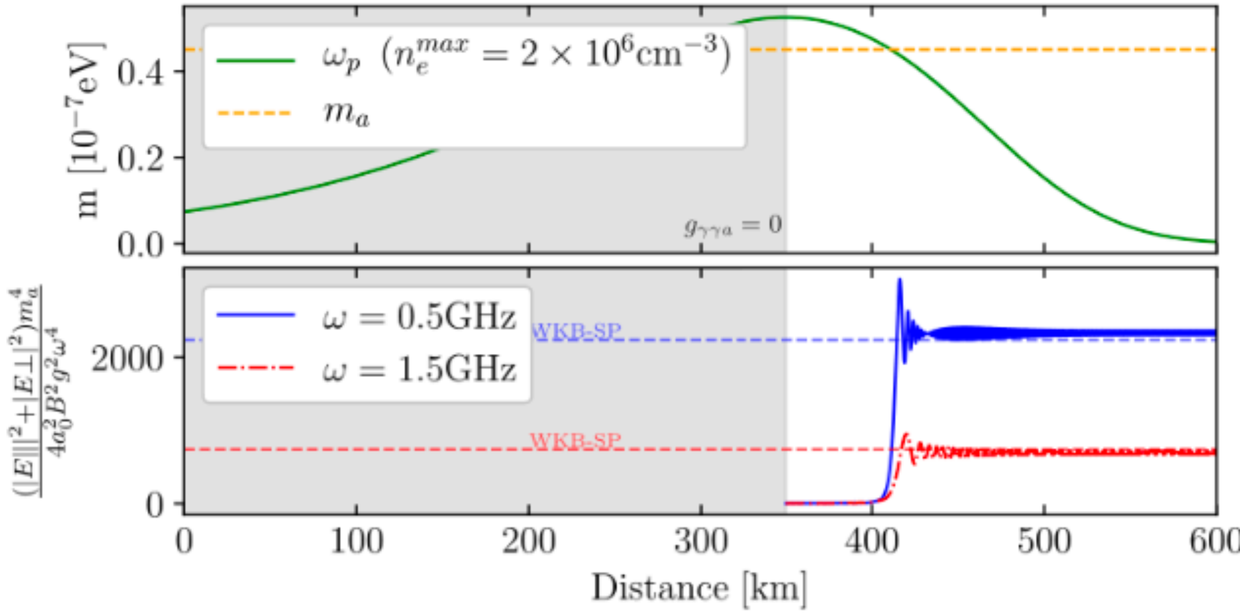
ANITA Collaboration, PRL 117 (2016) 7, 071101

ALP

Axions were proposed to address the strong CP problem, but they can solve various other questions in physics

$$\mathscr{L} \supset \frac{1}{2}\left(\partial_\mu a \partial^\mu a - m_a^2 a^2\right) - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{4}g_{a\gamma\gamma}aF_{\mu\nu}\tilde{F}^{\mu\nu}$$

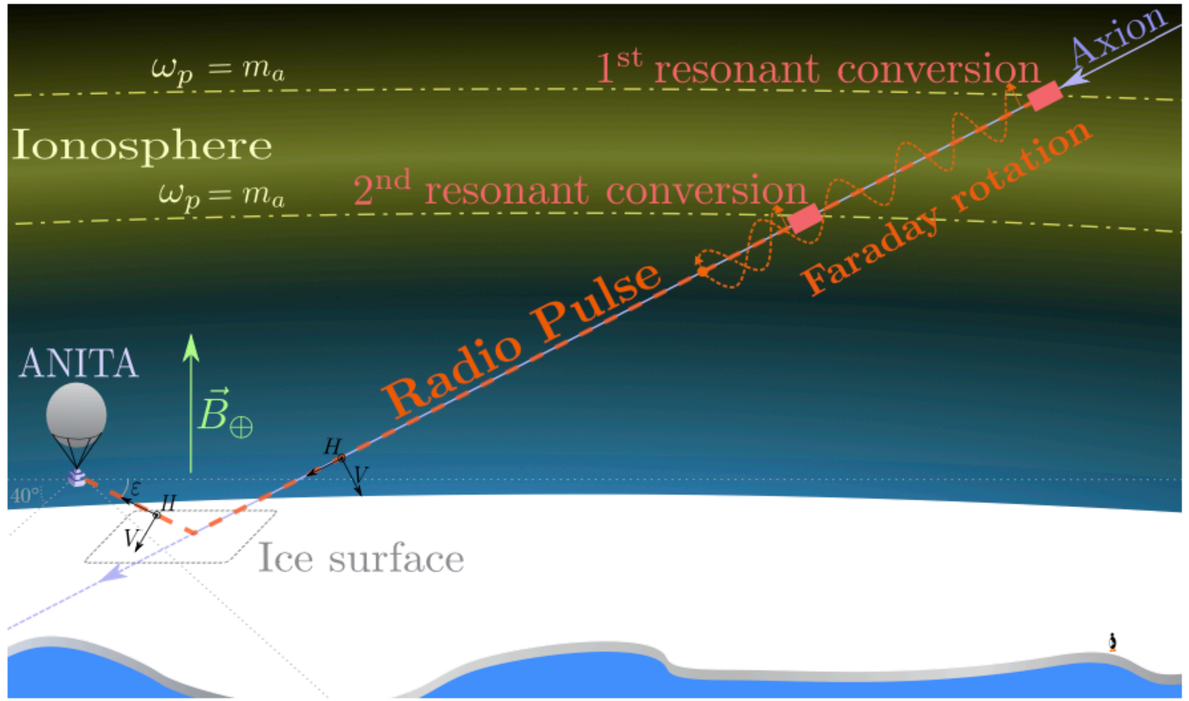
In the presence of a magnetic field (B), axions can undergo a resonant conversion into photons when the plasma frequency matches the axion mass.



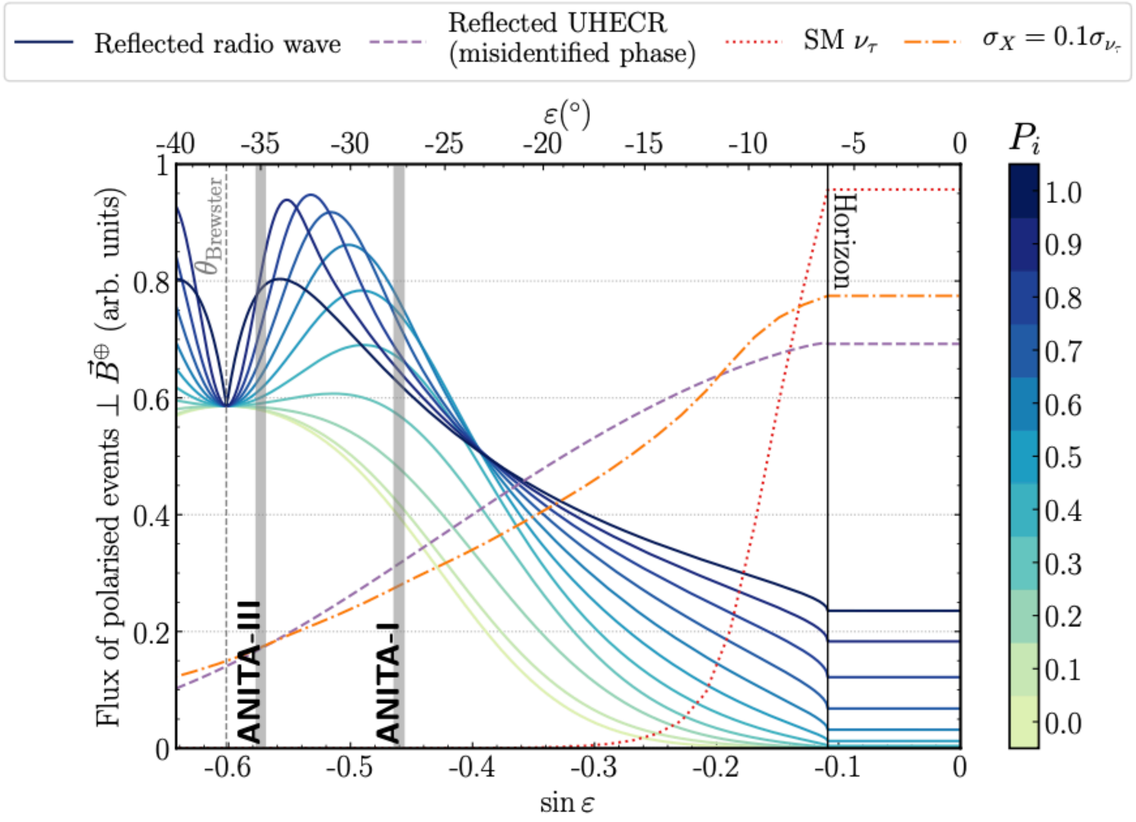
I Esteban, J Lopez-Pavon, IMS, J Salvado, EPJC 80 (2020) 3, 259

ALP

The interaction of an axion flux with $B_\oplus$ can generate a polarized radio pulse

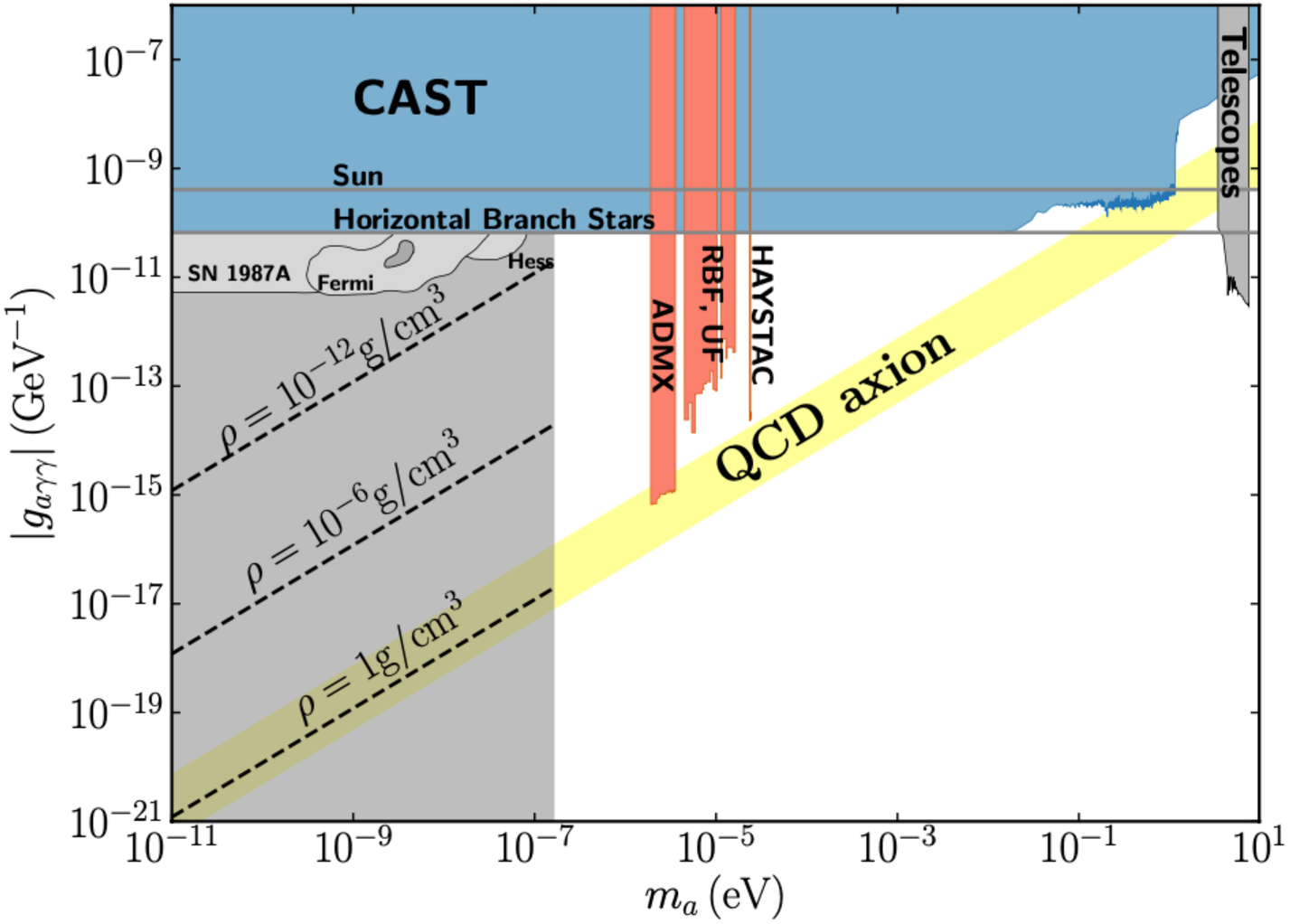


The elevation for both events is close to the Brewster angle, where the vertical component is nearly zero



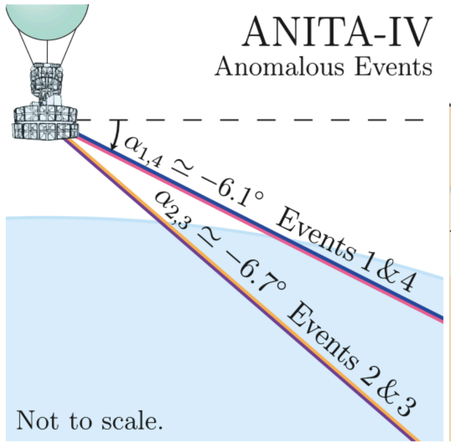
I Esteban, J Lopez-Pavon, IMS, J Salvado, EPJC 80 (2020) 3, 259

ALP

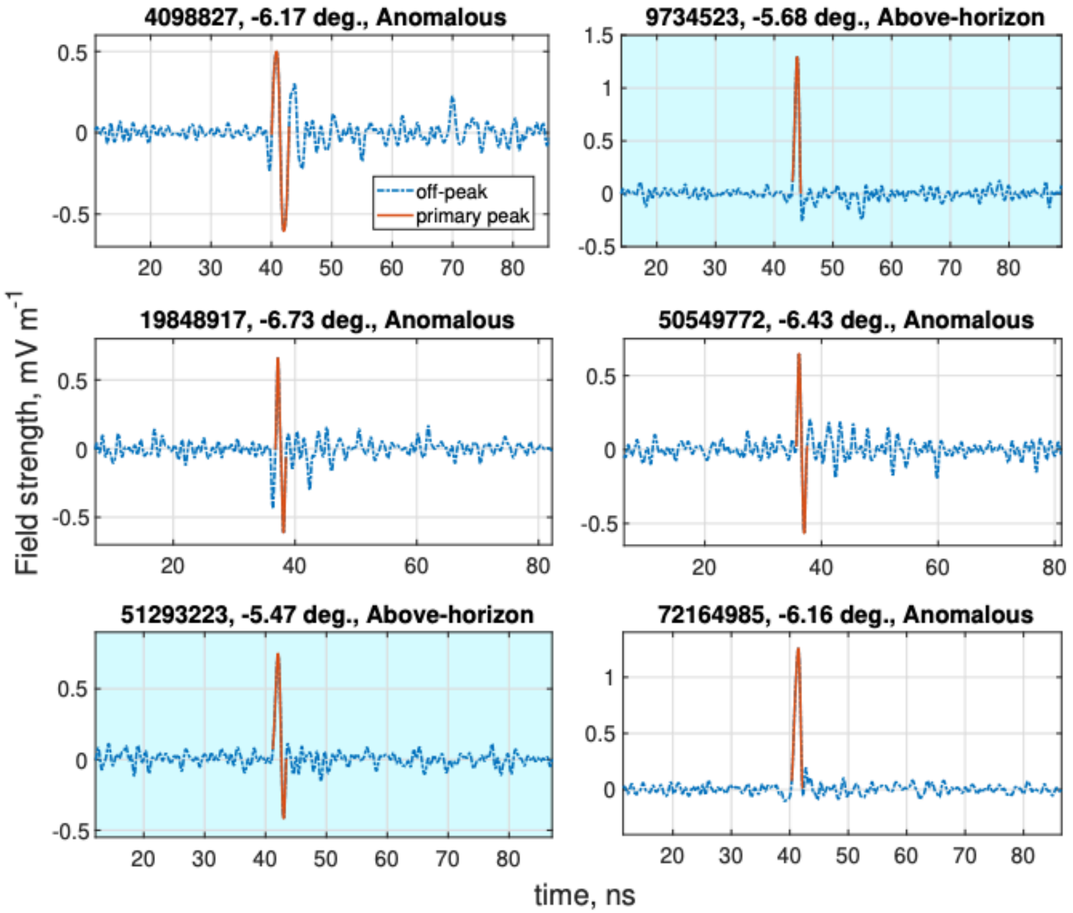


I Esteban, J Lopez-Pavon, IMS, J Salvado, EPJC 80 (2020) 3, 259

ANITA-IV: anomalous event



ANITA IV has observed **four** events coming **below the horizon** ($\sim 1°$) with energies around the EeV scale

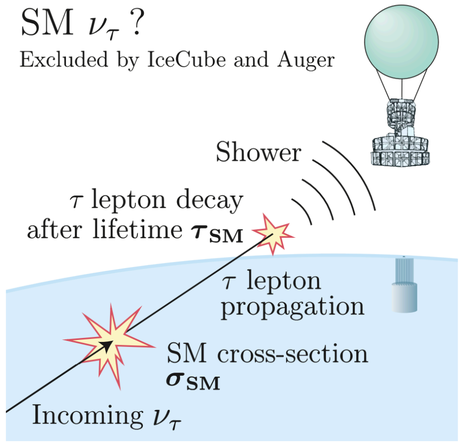


The events had a non-inverted polarity, which is inconsistent with reflected events

In case these events are indeed neutrinos, they would represent the highest-energy neutrinos ever observed.

P.W. Gorham et al. (ANITA) PRL 126 (2021) 7, 071103

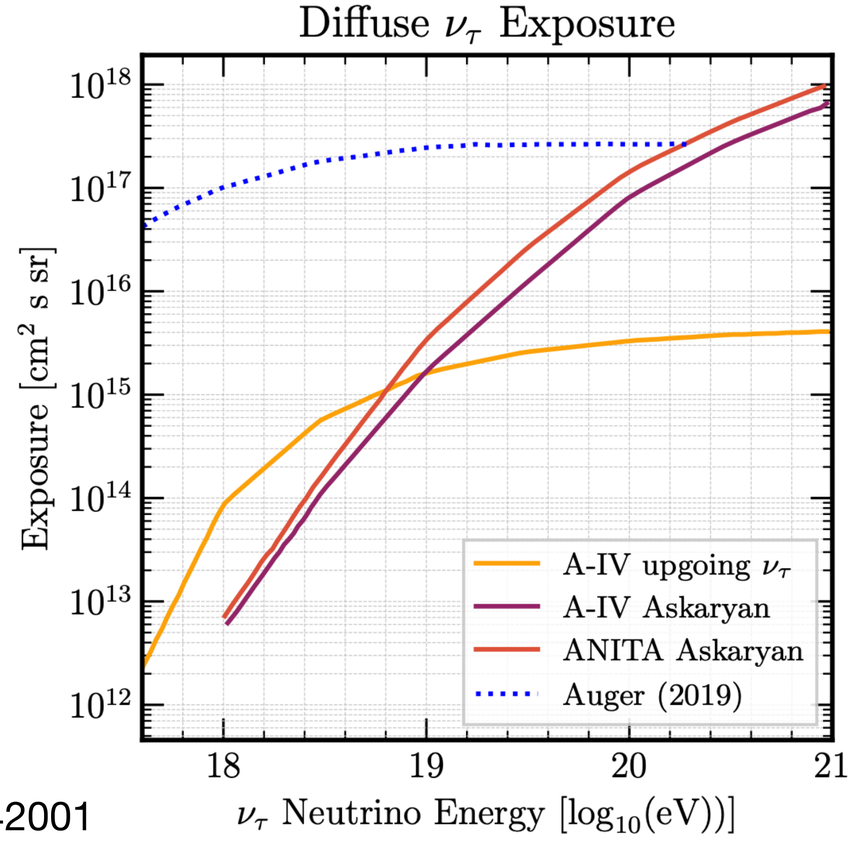
ANITA-IV: ν_τ?



The detector probability of ν_τ by ANITA is higher at horizontal directions

- An analysis carried away by the collaboration suggests that the four events are not incompatible with a tau origin

- Exposures from other experiments, such as Auger, which observe nothing, refute the interpretation in terms of ν_τ



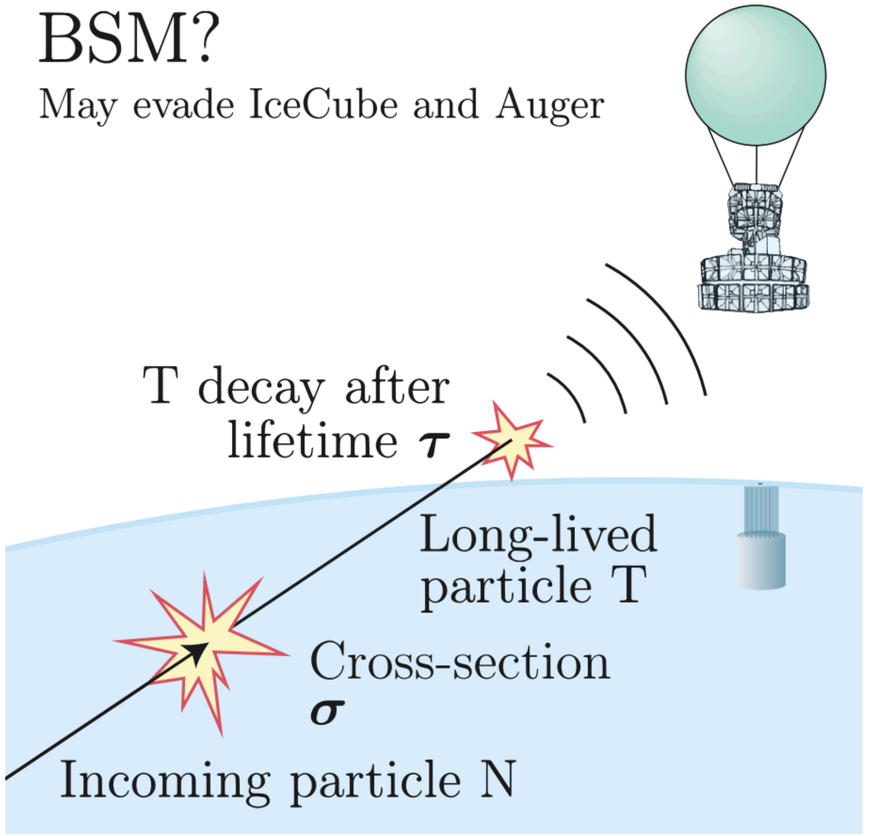
R. Prechelt et al. (ANITA) PRD 105 (2022) 4, 042001

ANITA-IV: BSM

The BSM scenario that we are going examine comprises three main components:

- An incoming flux of particles (N)
- The cross-section of those particles interacting with the Earth's nucleons (σ)
- The lifetime (τ) of the long-lived particles (T) produced after the interaction

The decay of T will generate the shower observed by ANITA

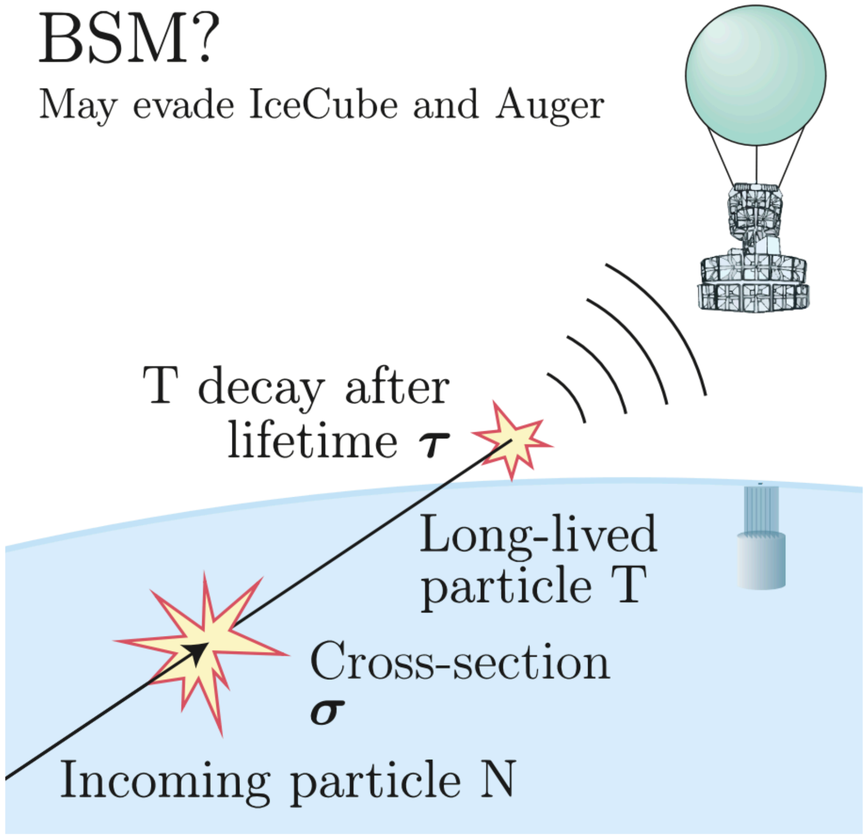


T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

ANITA-IV: BSM

Various BSM models can anticipate this signal:

- The SM can be expanded with an extra U(1) in the Dark Sector, two fermions χ_1, χ_2 , and a scalar (ϕ) acting as DM.
- The new boson mixes with the SM photo via kinetic mixing.
- The DM's decay into a stable fermion χ_1 will generate the initial flux.
- χ_2 will be generated by the interaction of χ_1 with Earth's nucleon via the new U(1) symmetry
- Considering χ_2 heavier than χ_1, we can have $\chi_2 \rightarrow \chi_1 +$ shower

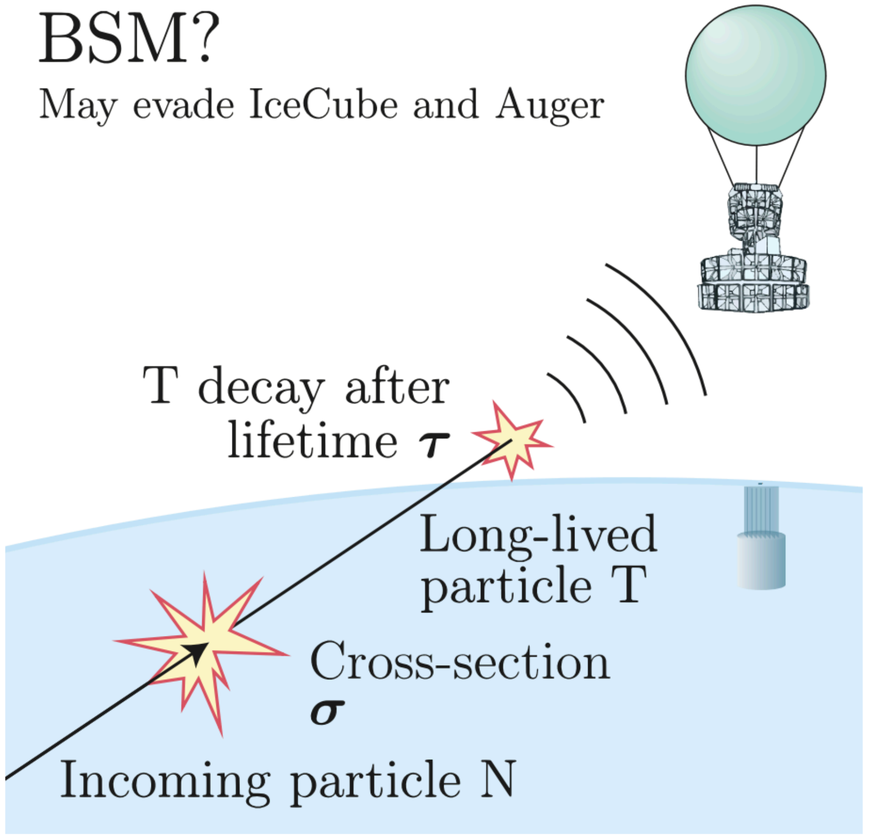


T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

ANITA-IV: BSM

Type of detectable signals that can be produced in this scenario:

- The decay of T will generate a shower.
- The interaction of the incoming flux will also generate a shower in the T production.
- The absorption of T by the Earth will also generate a shower.
- In the case of charged T, it can leave track-like events

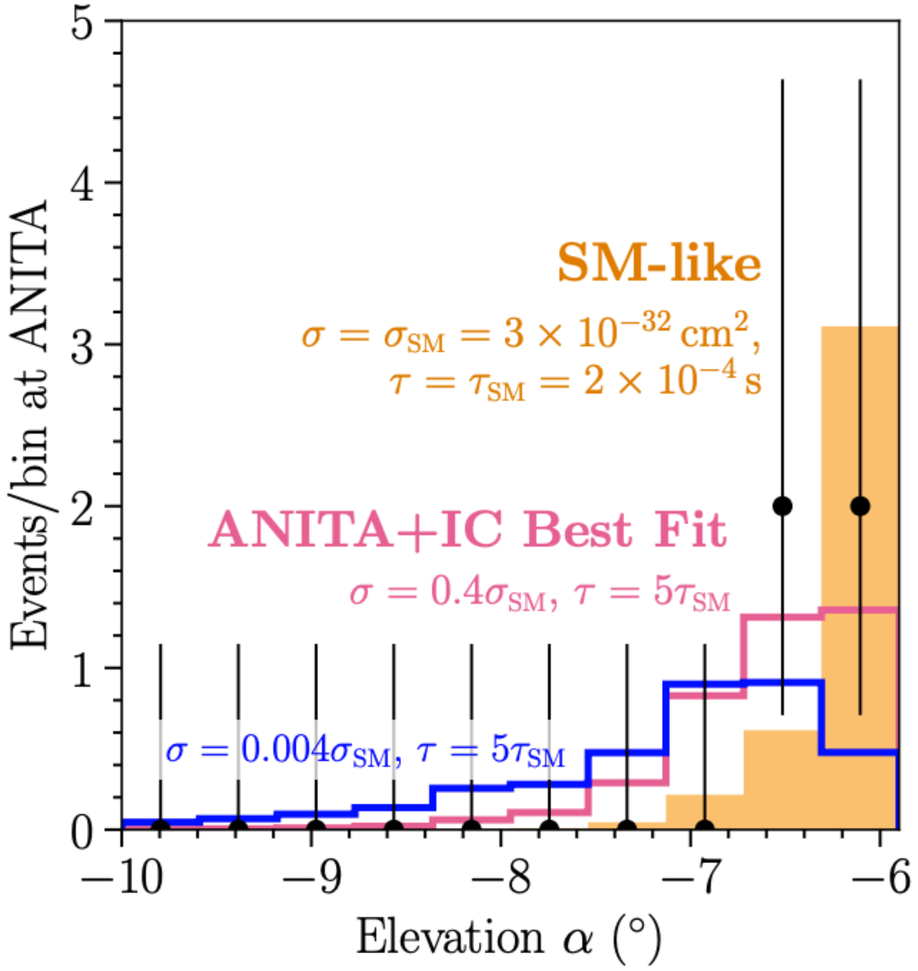


T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

ANITAIV: Angular dependence

The angular distribution observed in the four events constraints over the BSM model:

- The angular distribution depends on σ.
- Small values of σ leads to an isotropic distribution of T
- The lifetime of T can also affect the angular distribution.
- Very large values τ will favor an isotropic distribution.

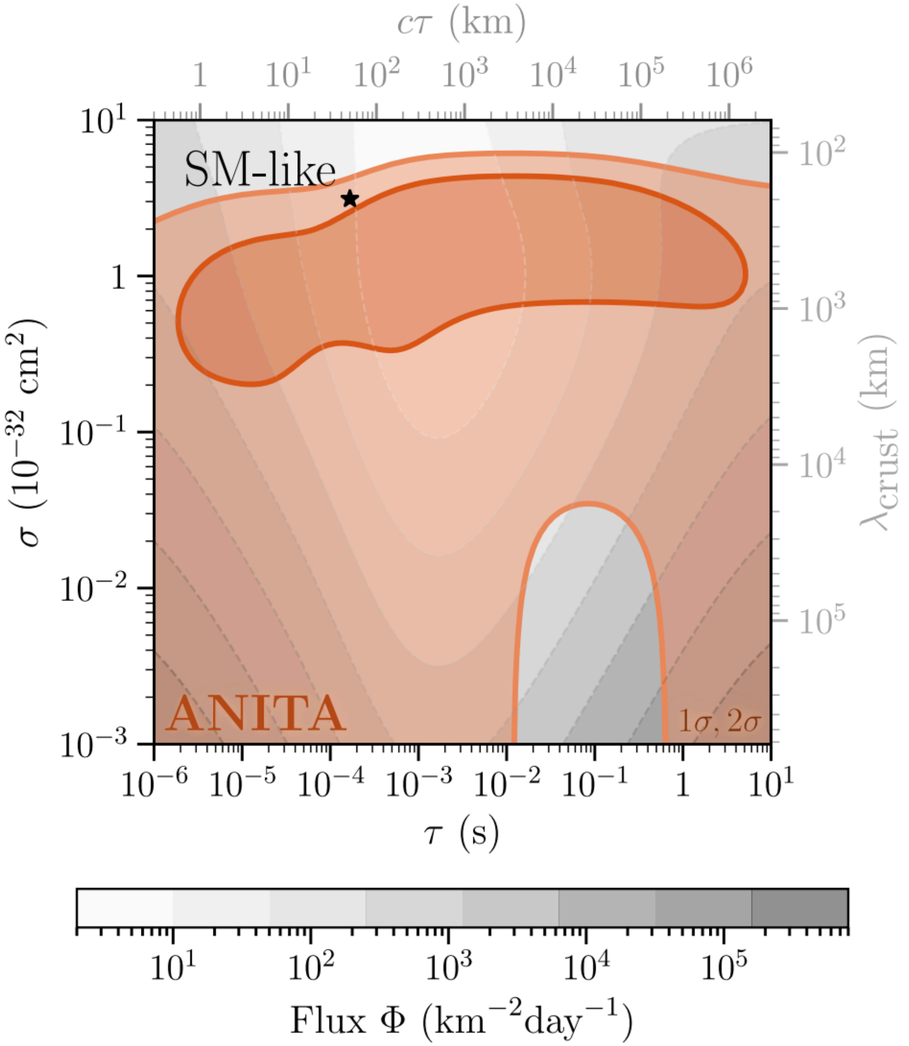


T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

ANITA IV: BSM region

A large region of the BSM parameter space is allowed by ANITA IV

- Large cross-section values predict a high number of events near the horizon
- With small cross-sections, the event distribution becomes very isotropic.
- When σ takes small values and $\tau > 1\text{s}$, the showers observed by ANITA are produced by the interaction of N with the atmosphere.
- An SM-like explanation of the events is consistent at 2σ
- The flux of BSM particles arriving at the Earth should exceed than the cosmic ray flux at EeV ($\sim 1\text{km}^{-2}\text{day}^{-1}$)

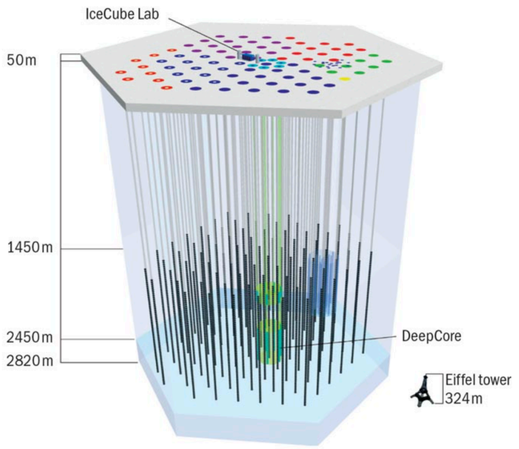


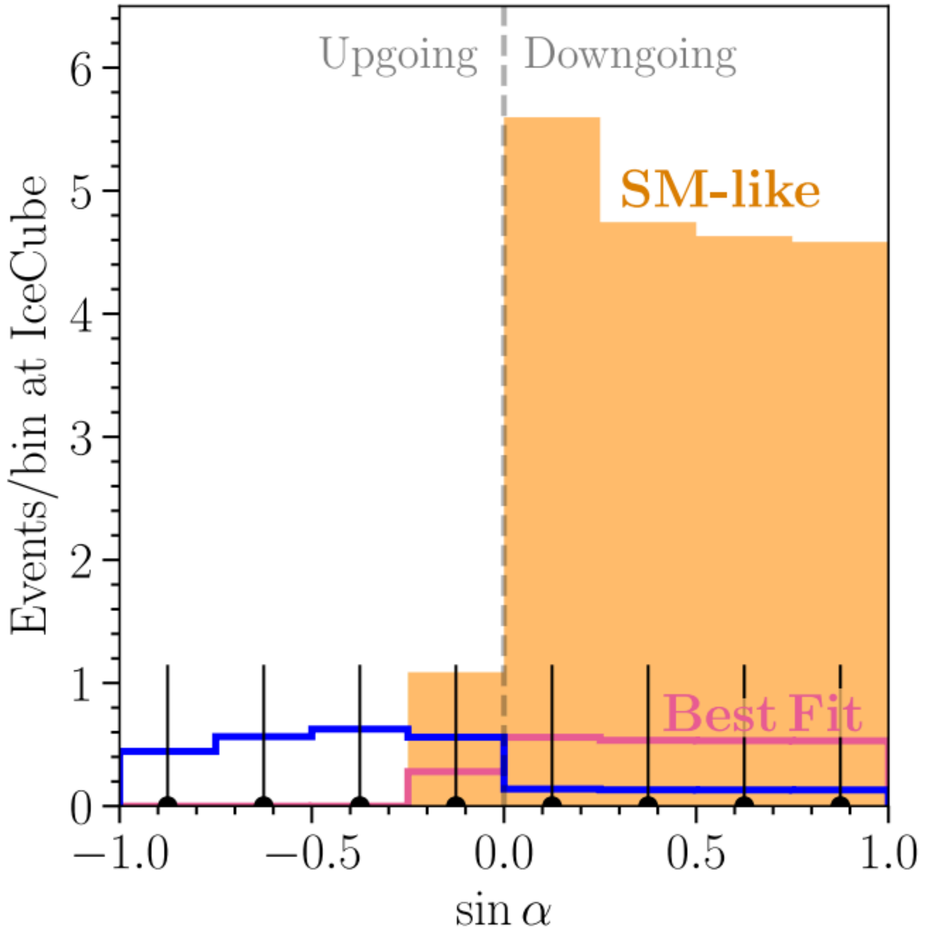
T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

ANITA IV: Interplay with IceCube

Other experiments, such as IceCube, are also sensitive to the BSM flux

- Despite its smaller volume, the extended observation time enables the testing of fluxes comparable to ANITA.
- The majority of the expected events are downgoing due to the Earth's absorption
- These events are generated by the interaction of N inside the detector.

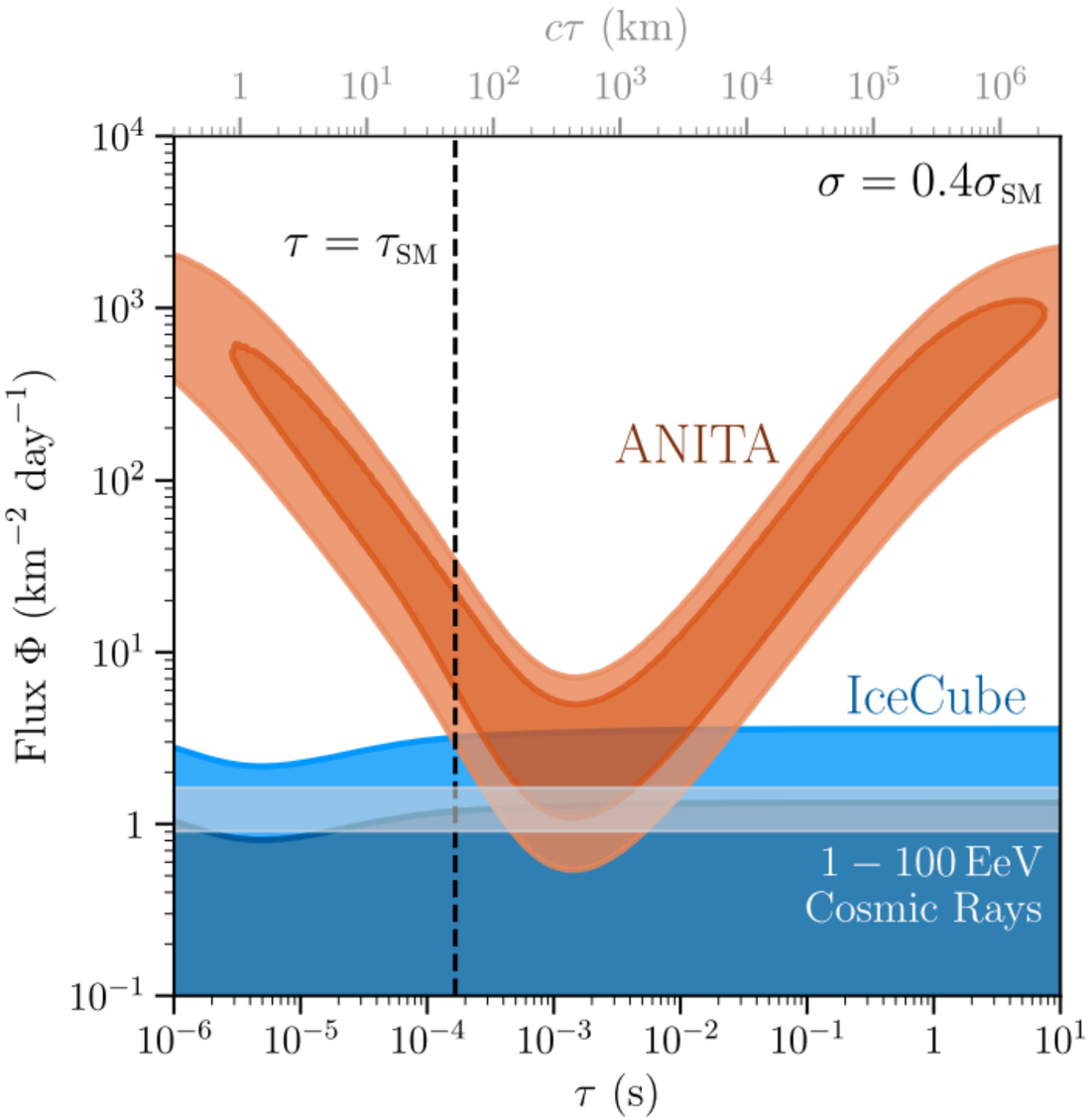




T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

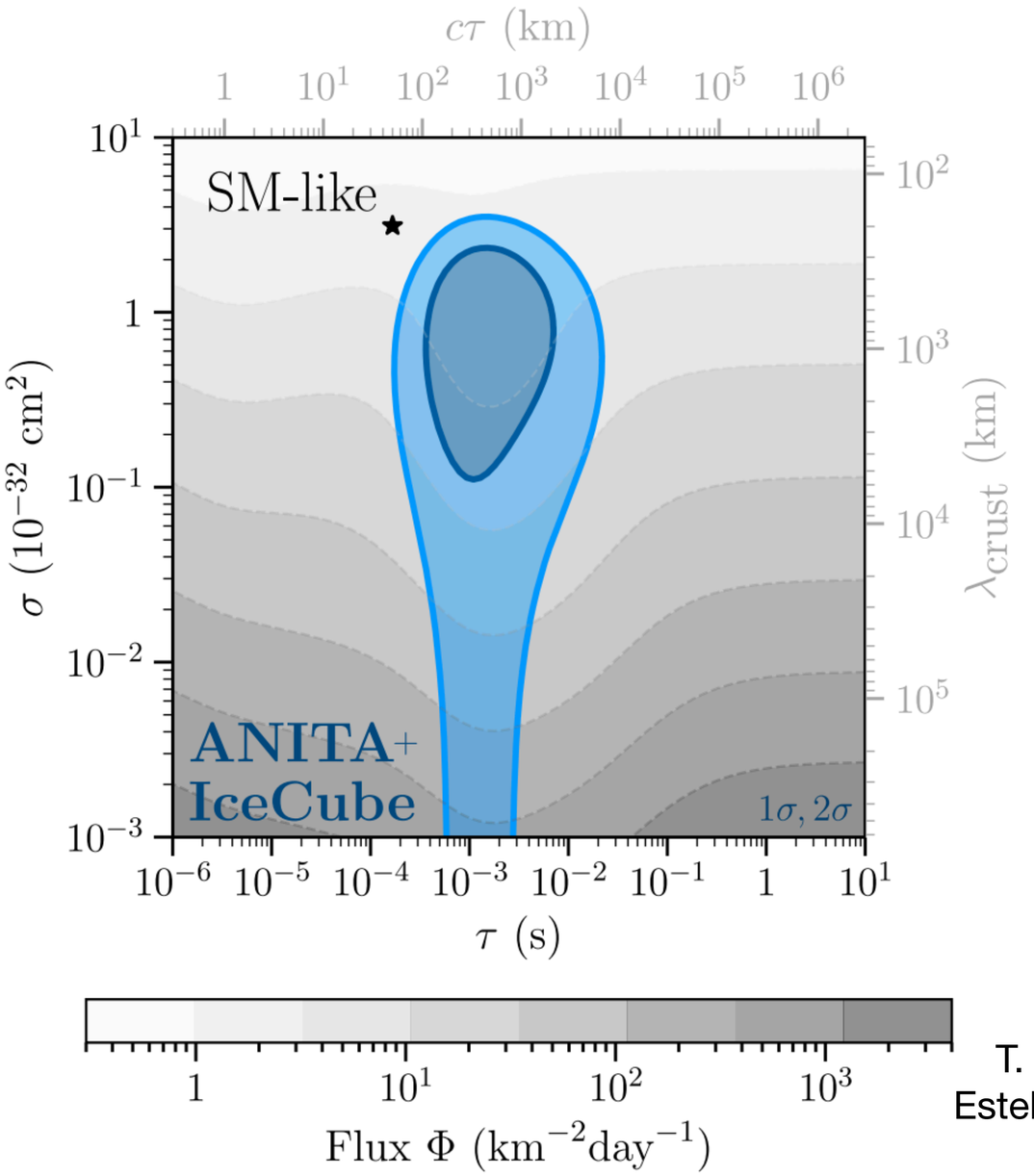
ANITA IV: Interplay with IceCube

For larger lifetimes than τ_{SM} and smaller cross-sections we can reconcile the observation of both experiments



T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

ANITA+IceCube analysis



T. Bertolez-Martinez, C. A. Arguelles, I Esteban, J. Lopez-Pavon, IMS, J. Salvado, JHEP 07 (2023) 005

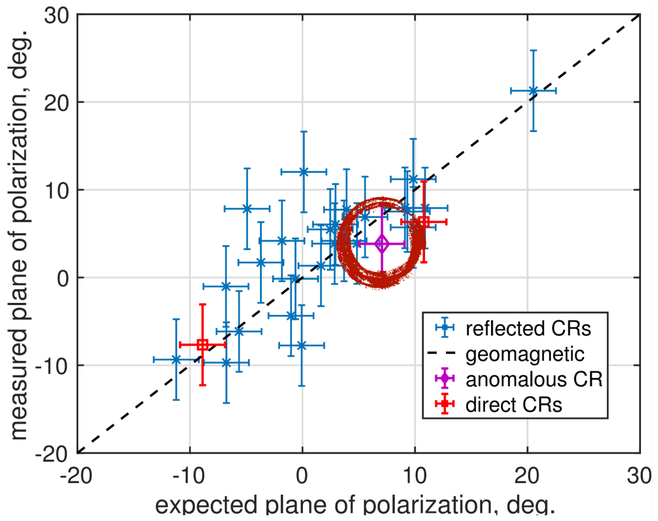
Conclusions

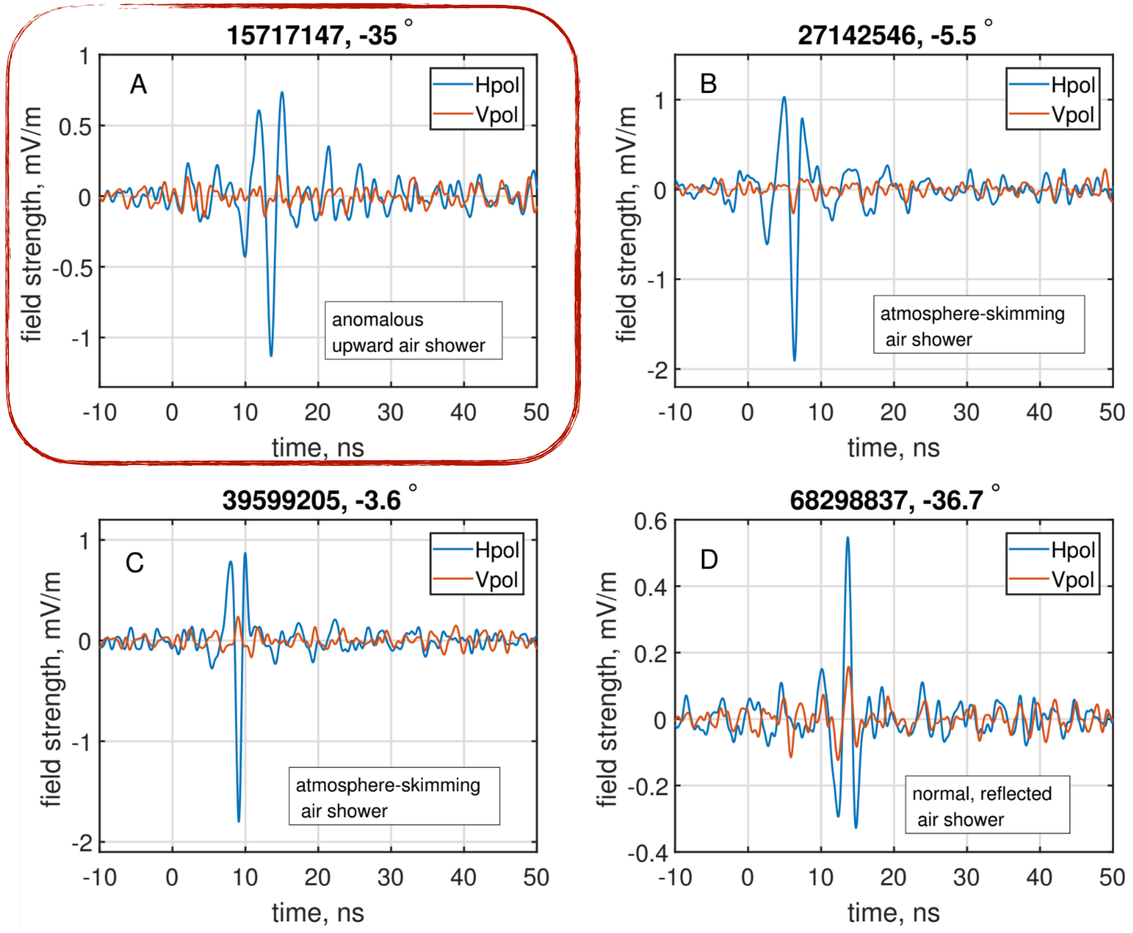
- ANITA has carried out four flights, finding anomalous events in three of them. The differences among those events suggest a different origin between them.
- In the case of ANITA I & III, the events come from very steep elevations -27° and -35°.
- We have explored the possibility that both events come from an axion-photon conversion in the atmosphere.
- In the case of ANITA-IV, the four events come from near the horizon.
- An interpretation in terms of ν_{τ} is inconsistent with the non-observation in Auger and IceCube.
- We have considered a BSM scenario that involves an incoming flux of N particles, its cross-section with nucleons (σ), and the lifetime (τ) of the secondary long-lived particles.
- Performing a statistical analysis, we found that $\sigma \sim 0.3\sigma_{SM}$ and $\tau \sim 10\tau_{SM}$ will make the observation of ANITA and IceCube compatible.
- BSM models that involve ultra-heavy scalar DM could originate this scenario

Thanks!

ANITA-III: anomalous event

- The event is polarized horizontally
- The elevation corresponds to -35°
- The phase is similar to other direct events. Events B and C are direct, while D is a reflected event.
- The polarization measured is correlated with the Geomagnetic field





ANITA Collaboration, PRL 121 (2018) 16, 161102