BSM interpretations of the ANITA events

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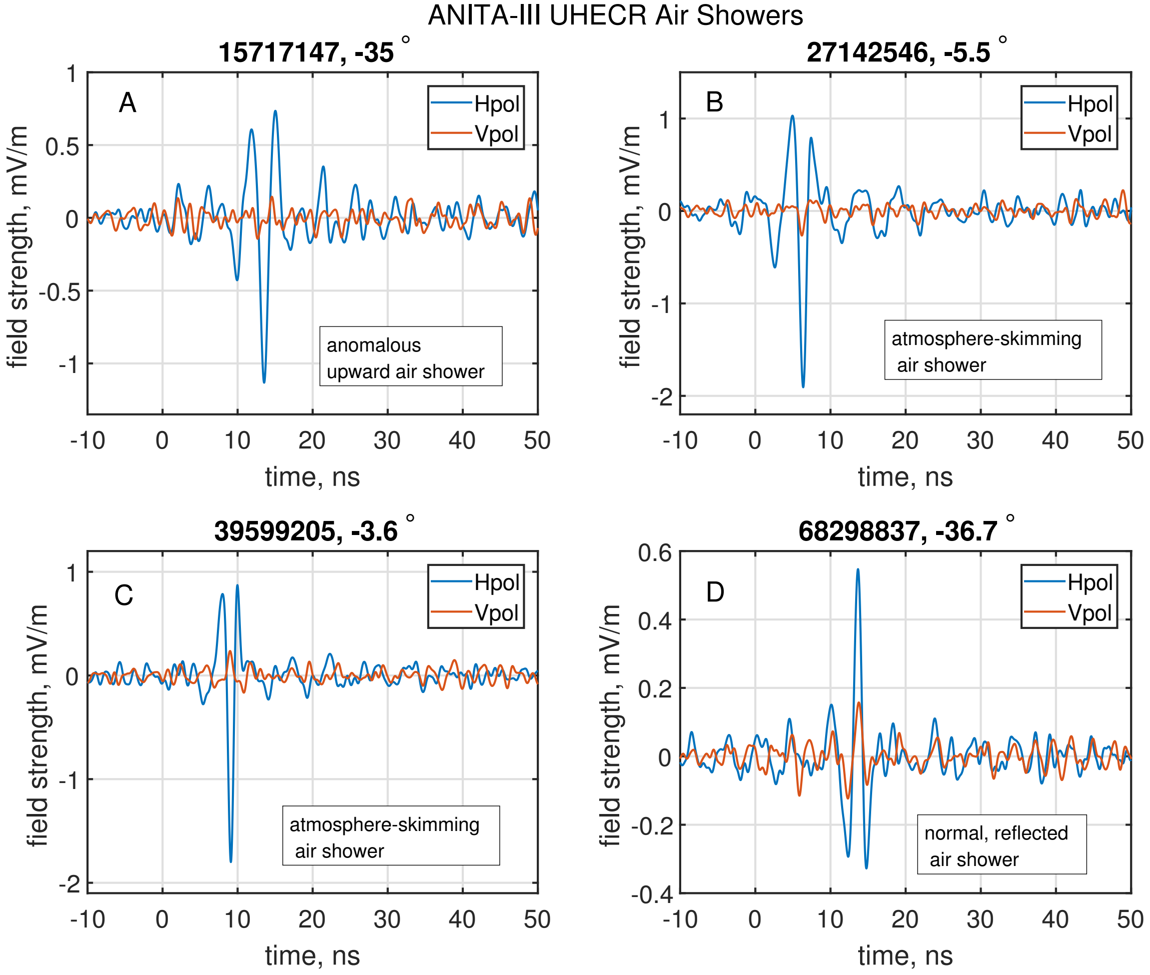
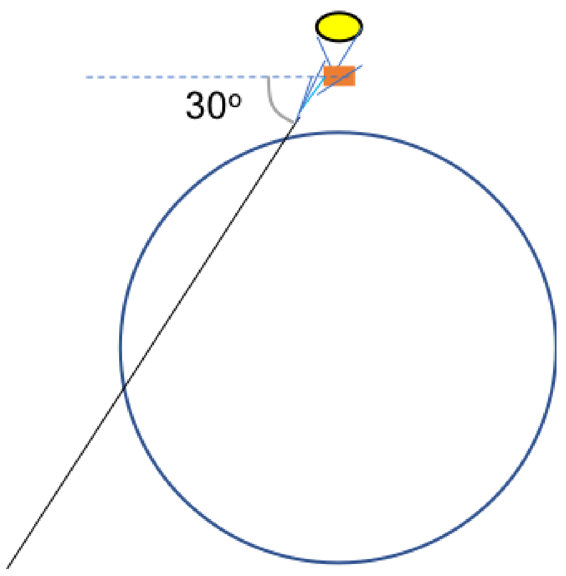
1. The (so far) two ANITA events
2. Neutral particles
3. Charged particles

Anchordoqui, Gutierrez, Masip, Palomares, Soriano, Weiler...
The pros and cons of BSM interpretations of the ANITA events
(to be presented in ICRC 2019)

15th MultiDark Workshop, 2019, Zaragoza

• ANITA has reported two anomalous events (inverted phase in the radio signal) during 85 days (flights I and III): Earth-emergent air showers of $E \approx 6 \times 10^8$ GeV and inclination $\theta = (27^\circ, 35^\circ)$ below the horizontal





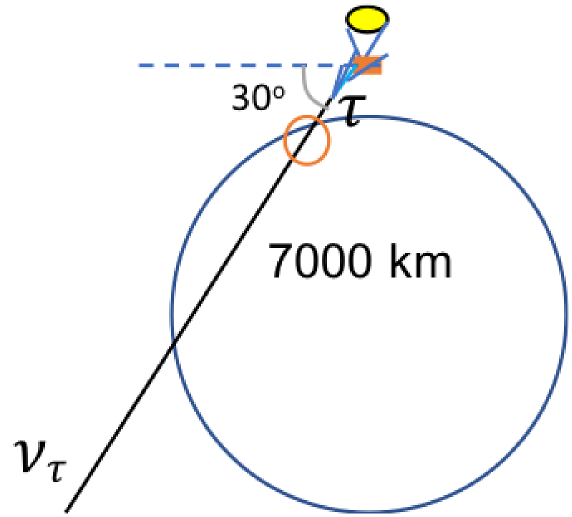
• Cosmogenic neutrinos have energies around 10^9 GeV...

$\lambda_\tau^{\rm dec} \approx 40$ km

chord distance $\approx$ 7000 km $\approx$ 16 int. lengths

The ν_τ flux is attenuated by a factor of 10^7!

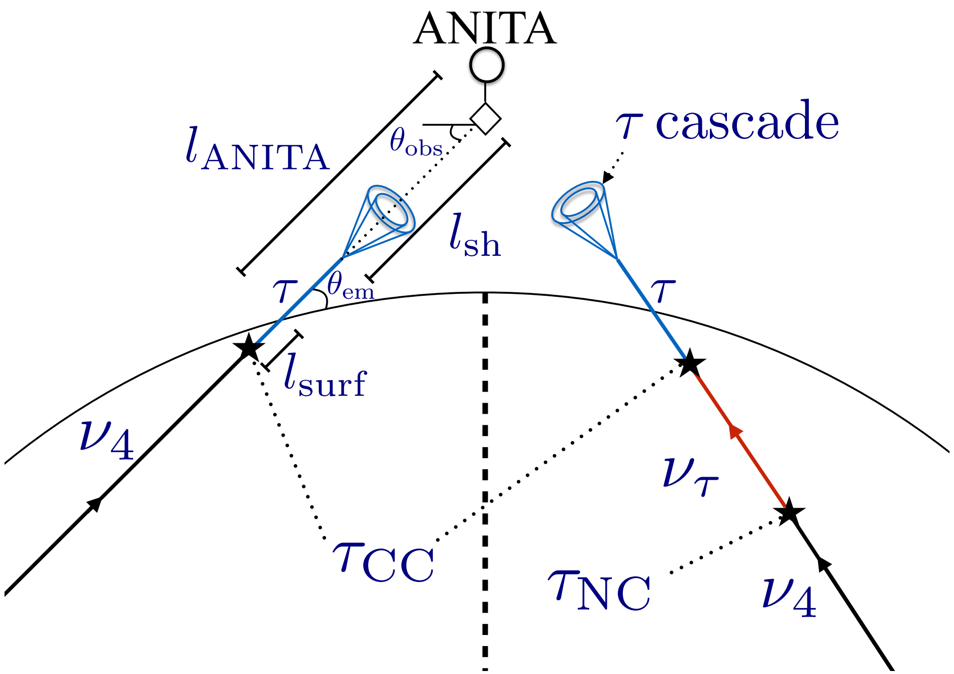
Signal more than 5σ away from the SM



ANITA does not see cascades from more horizontal directions (smaller chord distances are easier to cross...). The Earth is too opaque to all SM particles

• We need an exotic particle very penetrating, that could be created by CRs as they enter the atm, or by cosmogenic neutrinos when they reach the Earth, or by (extremely heavy!) dark matter decays, or...

• Let's just consider a flux of $E \approx 10^9$ GeV sterile neutrinos mixed with the tau flavor penetrating the Earth from all directions



- We need $l_{\rm surf} \approx \lambda_\tau^{\rm dec} \approx 40$ km
- If $\lambda_{\nu_4}^{\rm int} \approx L_{\rm chord}$, event rate suppressed by a factor of $\lambda_\tau^{\rm dec}/L_{\rm chord} \approx 0.006$
- Events emerging from more horizontal directions ($\theta_{\rm obs}$ from -6.5° to -35°) are equally probable

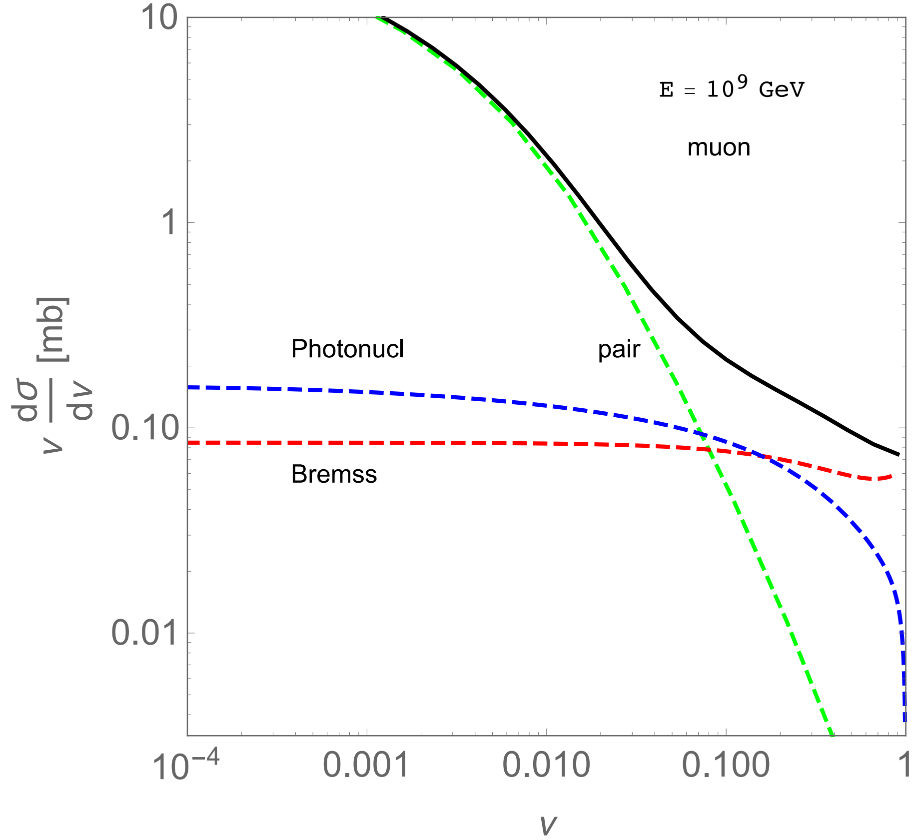
- Number of events at IceCube tends to be too large (Guo-yuan Huang 2018)

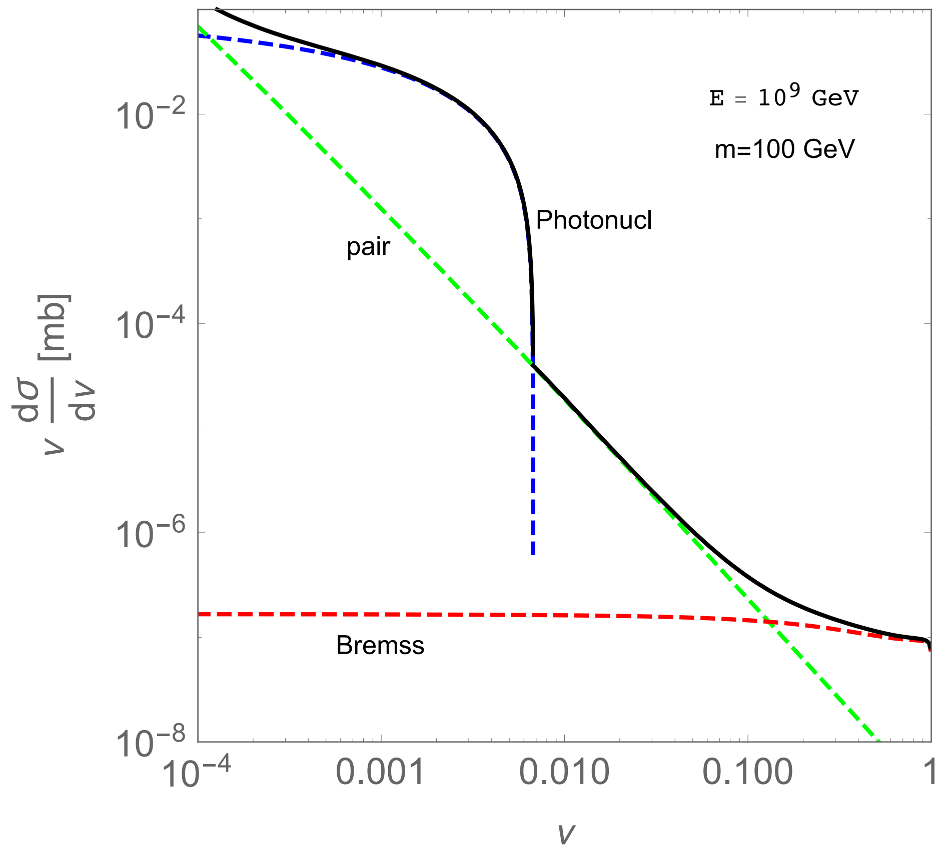
- How to produce a flux of sterile neutrinos slightly mixed with ν_τ without also producing active neutrinos? Dark matter (Mambrini et al 2019)

- Another scenario assumes the decay of a neutral heavy particle (R-parity violating bino) produced by cosmogenic neutrinos reaching the Earth (Collins et al 2019). Similar objections, if $\lambda_{\tilde{B}}^{\rm dec} \approx L_{\rm chord}$ the event rate is suppressed by $l_{\rm sh}/L_{\rm chord} \approx 0.002$

• Let us now consider a long-lived and very massive charged particle (aka a stau). Could it really cross 7000 km of rock? A muon is more penetrating than an electron, what happens when the mass is 100–1000 GeV?

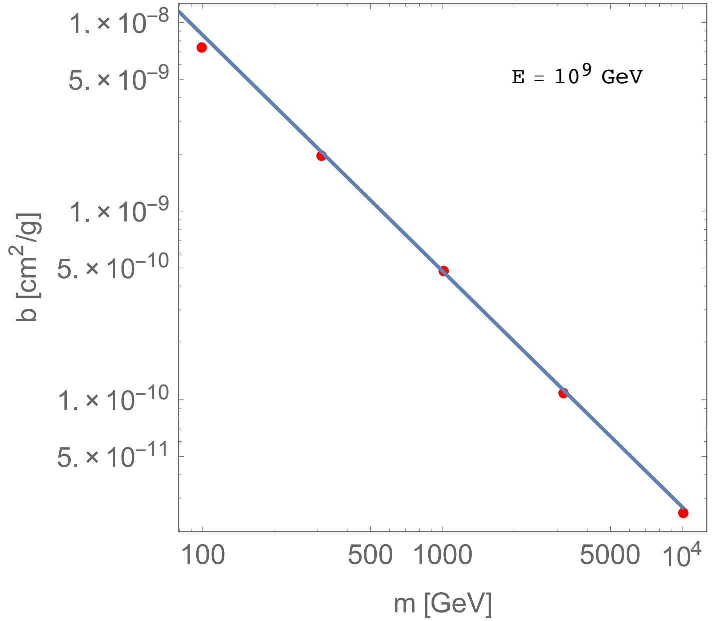
Energy loss occurs through 3 different processes: Bremsstrahlung ($\mu A \to \mu\gamma A$), pair production ($\mu A \to \mu e^+ e^- A$) and photonuclear collisions ($\mu A \to \mu\rho^* A \to \mu X$)

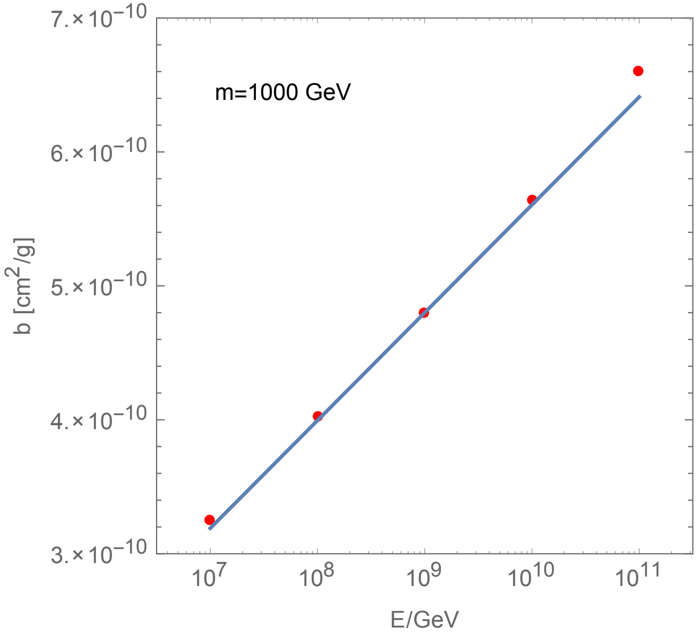




• If we neglect ionization and parametrize energy loss per unit depth in standard rock ($Z = 11$, $A = 22$)

$$\frac{\mathrm{d}E}{\mathrm{d}x} = -b(m, E)\, E\,, \qquad \text{then} \qquad b = \int_0^1 \mathrm{d}\nu\, \frac{\nu}{m_A} \frac{\mathrm{d}\sigma}{\mathrm{d}\nu}$$

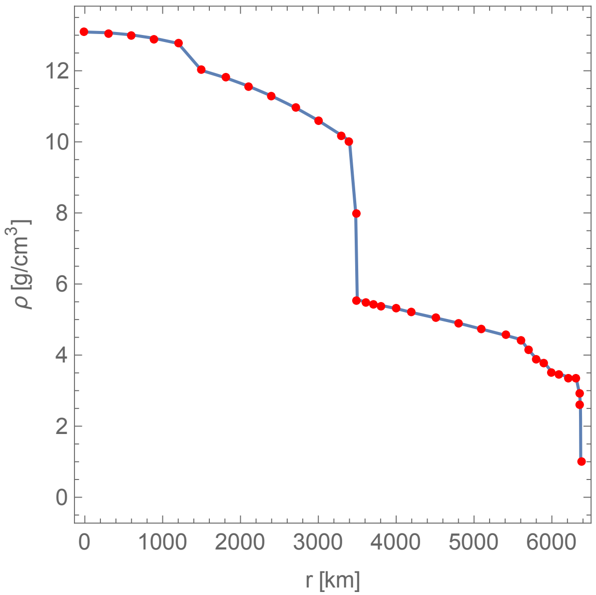


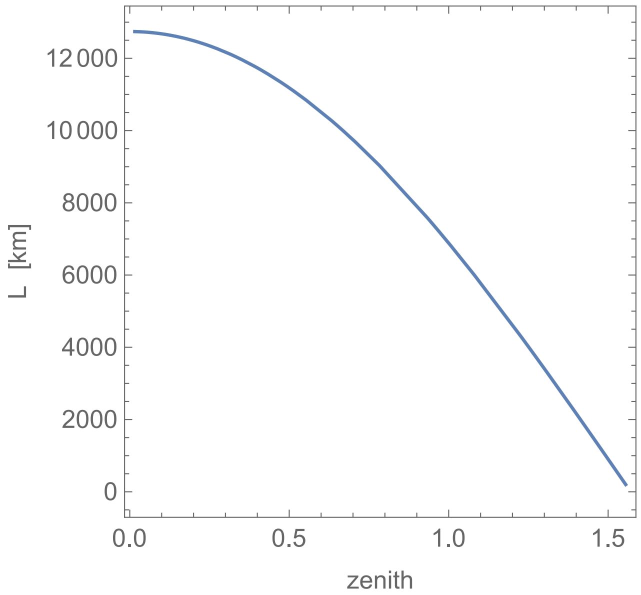


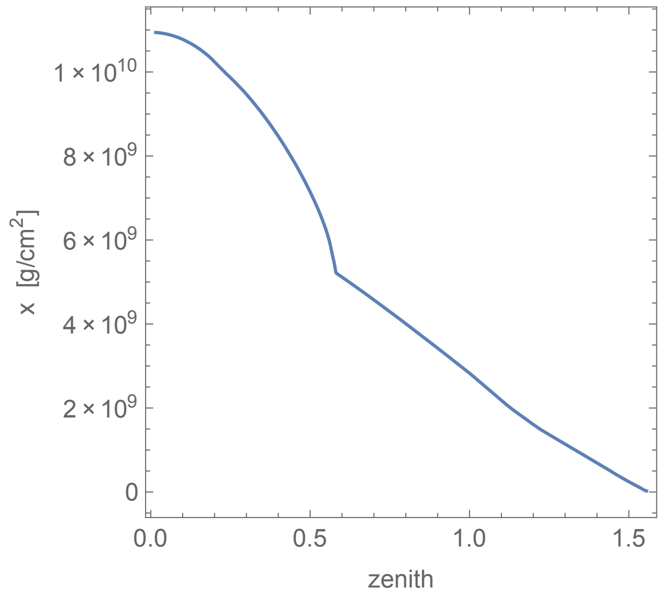
Fit : $$b(m, E) = 4.8 \times 10^{-10} \left(\frac{10^3\,\mathrm{GeV}}{m}\right)^{1.25} \left(1 + 0.073 \log \frac{E}{10^9\,\mathrm{GeV}}\right)\ \mathrm{cm}^2/\mathrm{g}$$

For a 10^9 GeV muon, $b = 8.0 \times 10^{-6}\ \mathrm{cm}^2/\mathrm{g}$

- The stau will face an r-dependent density of $1\text{–}13\ \mathrm{g/cm^3}$, a chord length of up to $2R_T$ and a total depth of up to $2\times 10^{10}\ \mathrm{g/cm^2}$



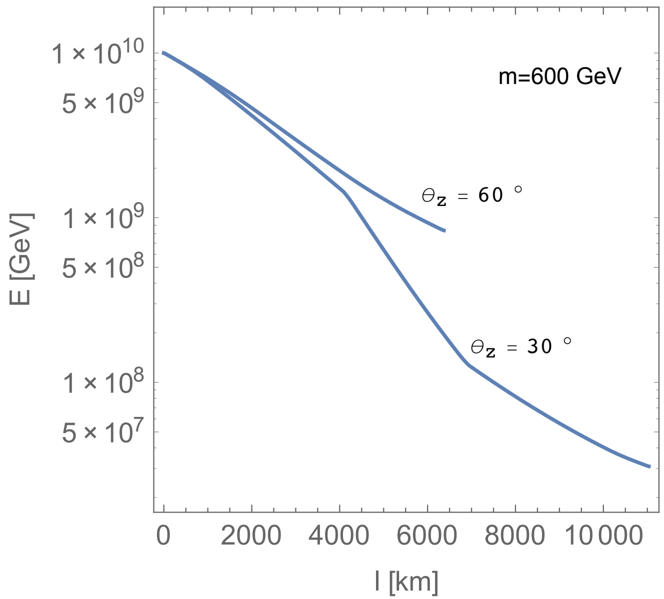




- Its energy changes

$$\frac{\mathrm{d}E}{\mathrm{d}\ell} = -\,b(m,E)\,\rho(\ell)\,E\,,$$

where ℓ goes from 0 to $L(\theta)$



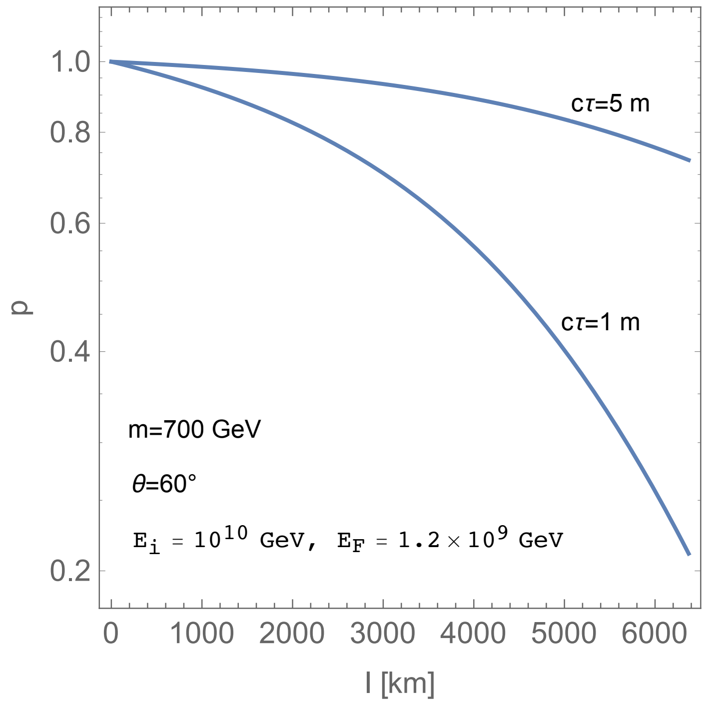
- As it propagates, the stau may decay. Its time-dilated decay length is

$$\lambda_{\rm dec}(\tau, m, E) = \frac{c\,\tau\,E}{m}\sqrt{1-\frac{m^2}{E^2}}\,.$$

The probability $p(\ell)$ that it survives along its trajectory satisfies

$$\frac{{\rm d}p}{{\rm d}\ell} = -\frac{p}{\lambda_{\rm dec}}\,.$$

Since we already know $E(\ell)$, we can integrate this equation and obtain the probability that the stau emerges:



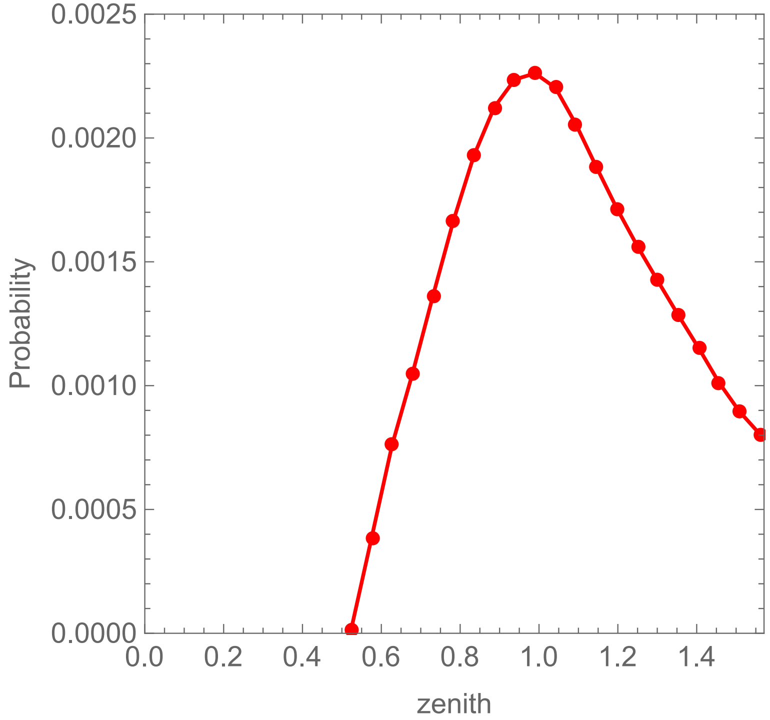
• To have an event the stau must decay in the air; the probability that it decays within 20 km is

$$p_{\text{event}} = 1 - \exp\left(\frac{20\,\text{km}}{\lambda_{\text{dec}}}\right) .$$

Notice that staus with large lifetimes will be able to cross the Earth, but they'll have a small probability to decay. Optimal case: charged particle that at 10^{10} GeV has a decay length similar to the observed chord (6000–7000 km) and loses energy as it propagates. The decay length becomes smaller and when the particle emerges has a significant probability to decay

$$m = 800 \text{ GeV}$$
$$c\tau = 4 \text{ m}$$
$$E_0 = 5 \times 10^9 \text{ GeV}$$
$$E_F = 7 \times 10^8 \text{ GeV}$$

$$\theta_{\text{obs}} \approx 34^\circ$$
$$p_{\text{event}} = 0.22\%$$



Conclusions

• ANITA uses a new technique that probably has yet to be fully understood but that seems promising at ultrahigh energies in the ice (vertical polarization) and the air (horizontal polarization)

• The two ANITA events are *unexpected*, they may be a sign of BSM physics. If caused by a new particle, the production (energy threshold? non-perturbative objects, DM annihilation or decay...) and the propagation (preference for $\theta_{\rm obs} \approx 30^\circ$? charged but very massive long-lived particle...) should be peculiar

• Long-lived massive particles are elusive at colliders, but there are other astroparticle experiments (IceCube, Auger, Magic?) that see nothing

• More data could confirm the anomaly. In that case, it will be interesting to see if the preferred energy and inclination persist