Upping the Reach for New Particles/Physics at JEM-EUSO (on the ISS)

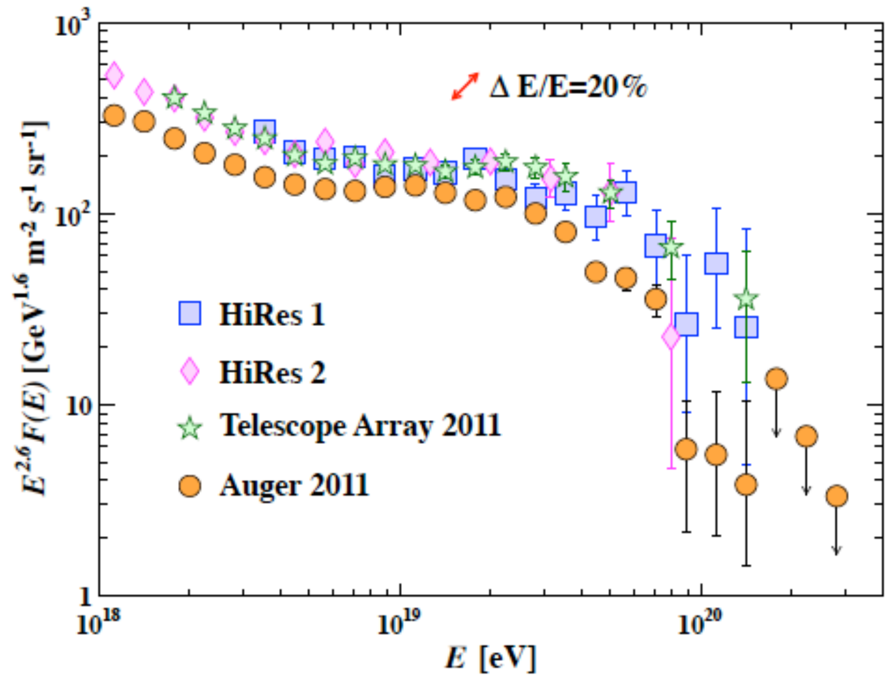


Figure 26.9: Expanded view of the highest energy portion of the cosmic-ray spectrum from data of HiRes 1&2 [101], the Telescope Array [103], and the Auger Observatory [104]. The HiRes stereo spectrum [112] is consistent with the HiRes 1&2 monocular results. The differential cosmic ray flux is multiplied by $E^{2.6}$. The red arrow indicates the change in the plotted data for a systematic shift in the energy scale of 20%.

The 10^{20} eV events have a

$$\sqrt{s} = \frac{1}{2}\ \text{PeV}$$

These PeV events contain
all of our accelerator physics,
and more if it exists.

Dipole anisotropy reach,
Space-Based versus Ground-Based

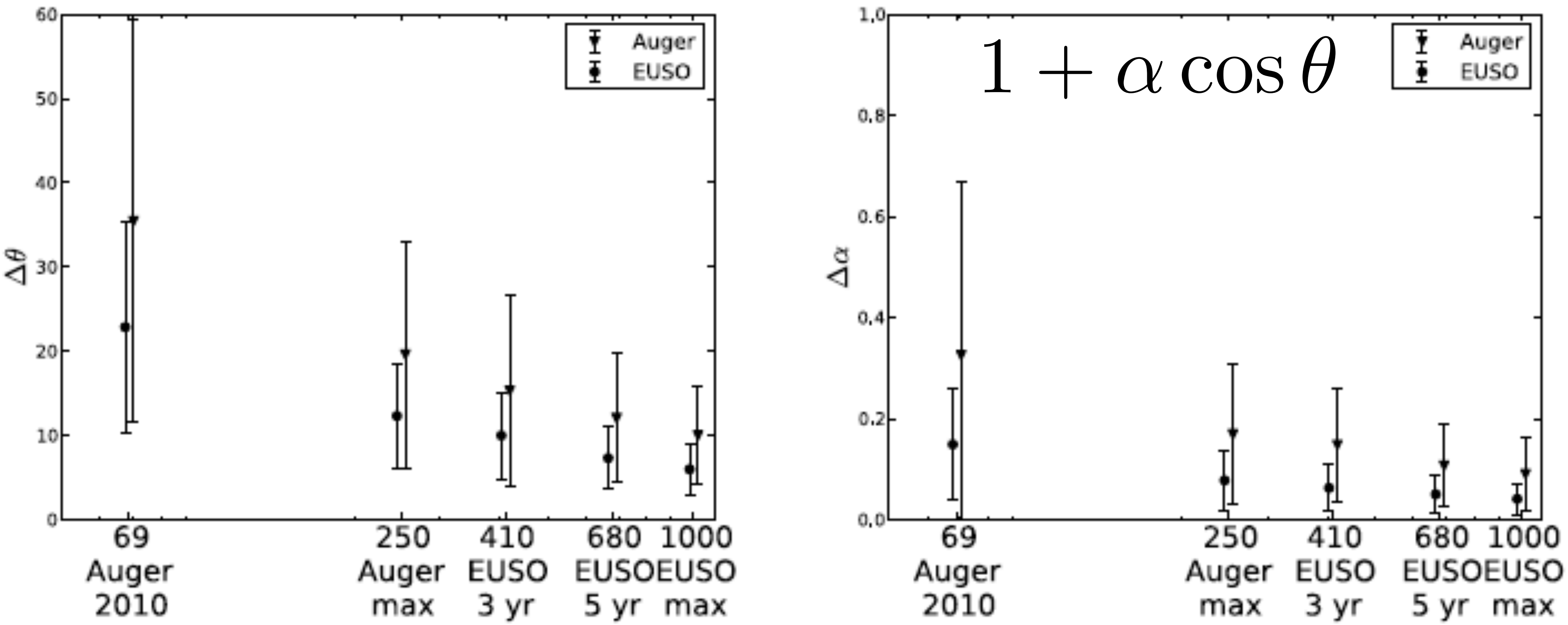


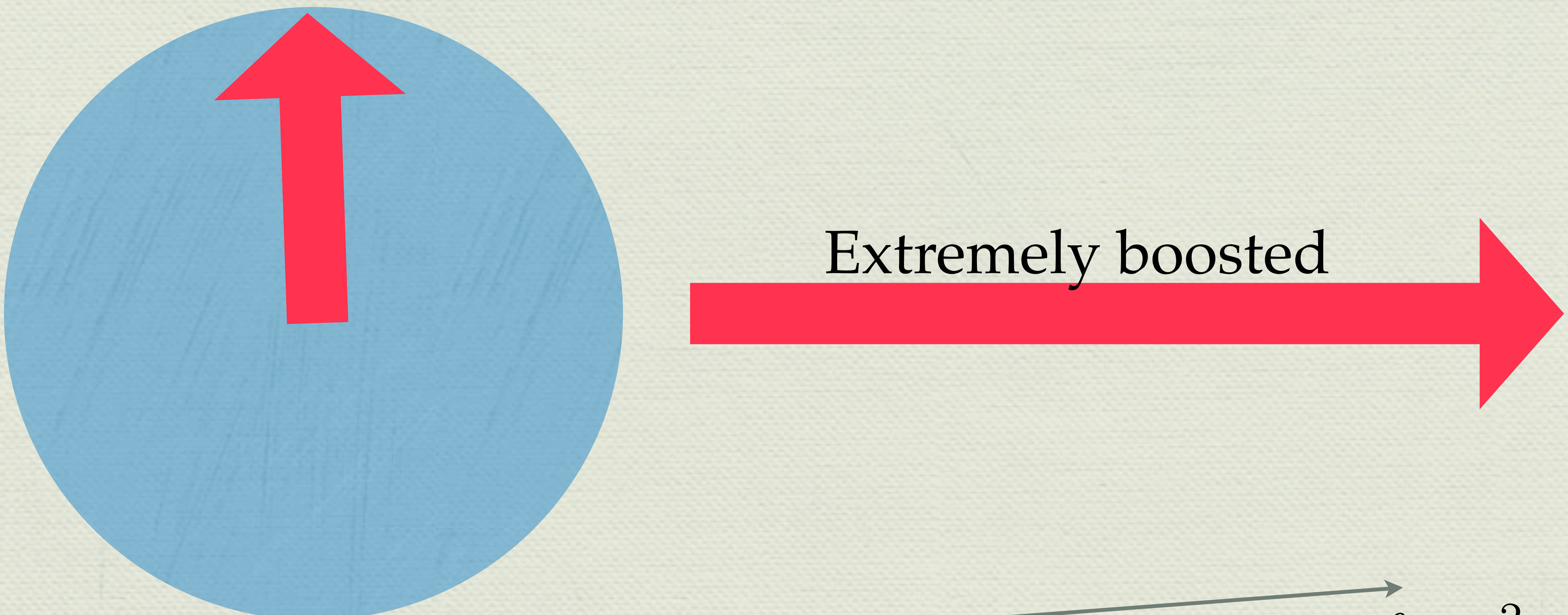
FIG. 1. **(Left)** Error in angular reconstruction of dipole direction, and **(Right)** error in reconstruction of dipole magnitude,each versus event number with simulated data sets and dipole magnitude $\alpha = 0.63$ [28].

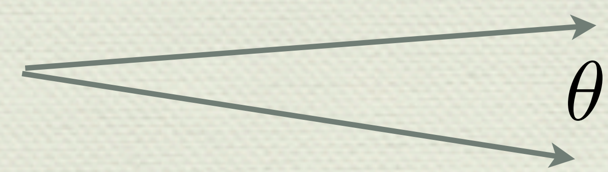
Anchordoqui, Denton, TJW

New Heavy Particles:

First, what does NOT provide a signature:

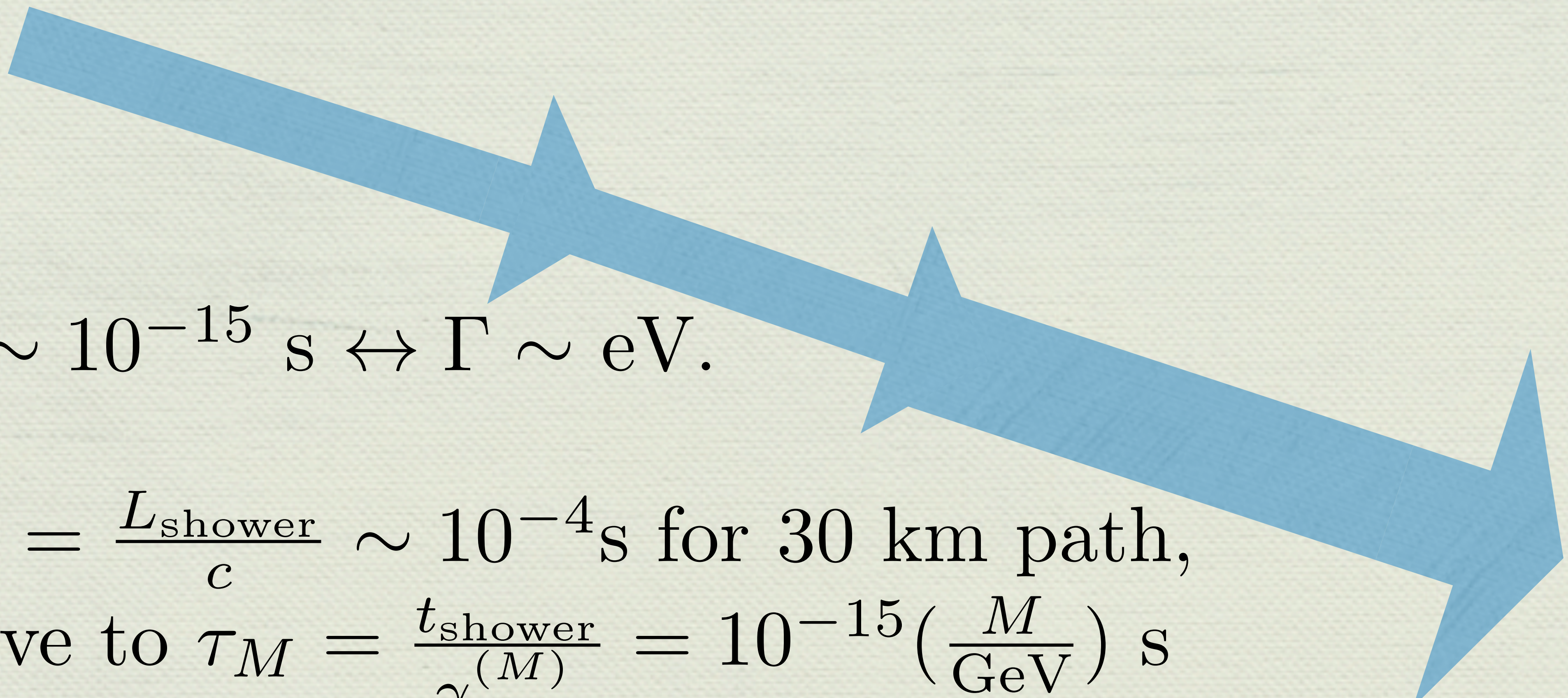
(a) high P_T decay





$$\gamma_{\mathrm{LAB}}^{(M)} \sim \frac{E_{\mathrm{CR}}}{M} \sim \frac{m_p}{M}\,\gamma_{\mathrm{LAB}}^{(\mathrm{CR})} \sim \frac{10^{11}}{(M/\mathrm{GeV})}$$

What else does not provide a signature:
(b) shower-brightening from decay



$$\tau \sim 10^{-15}\ \mathrm{s} \leftrightarrow \Gamma \sim \mathrm{eV}.$$

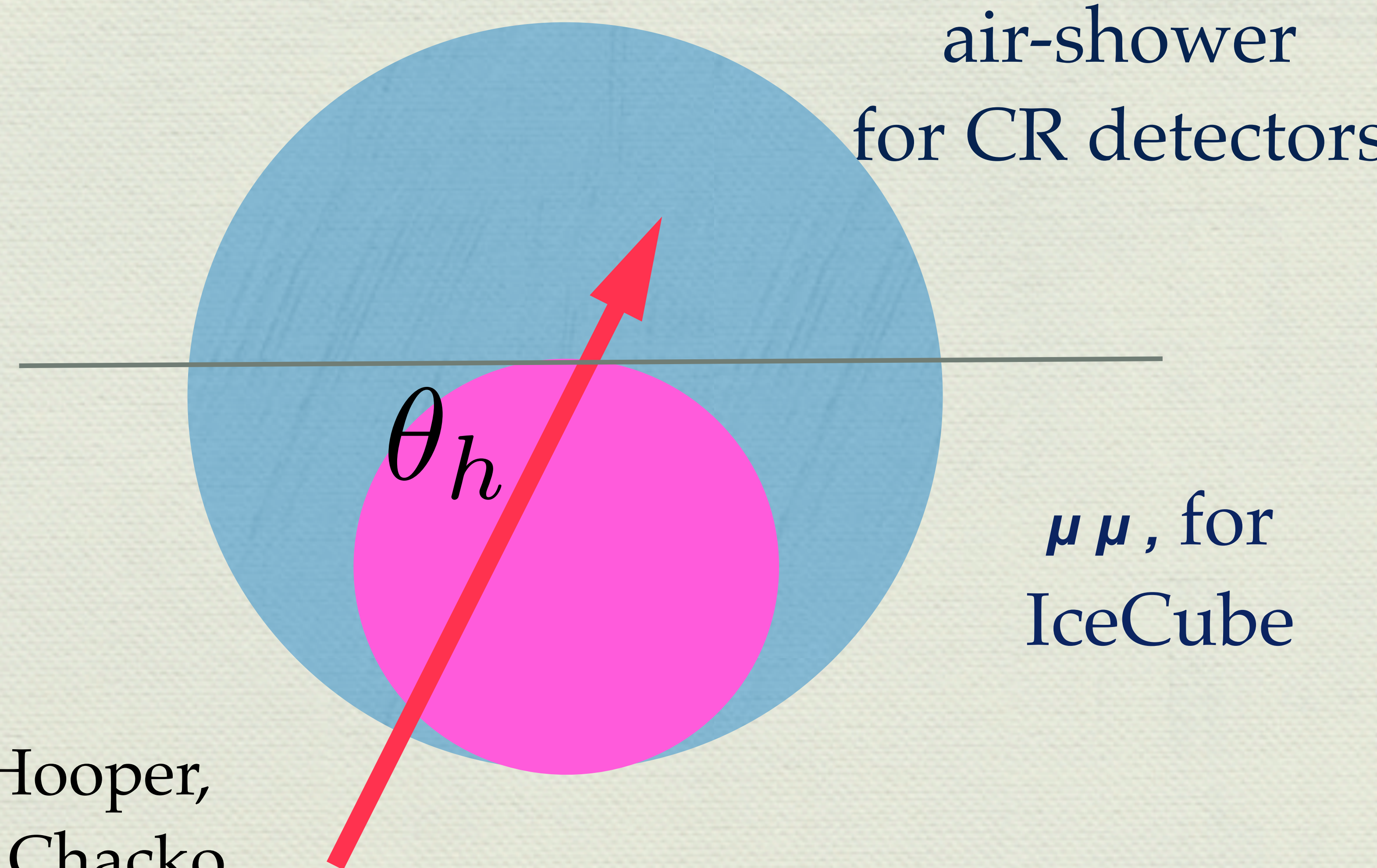
$t_{\rm shower} = \frac{L_{\rm shower}}{c} \sim 10^{-4}$s for 30 km path,
sensitive to $\tau_M = \frac{t_{\rm shower}}{\gamma_{\rm LAB}^{(M)}} = 10^{-15}(\frac{M}{\rm GeV})$ s

Versus natural unit $\frac{\hbar}{\rm GeV} = 0.7 \times 10^{-24}$ s

(e.g. W and Z bosons)

Put another way, $\tau \sim 10^{-15}$ s $\leftrightarrow \Gamma \sim$ eV.

What might/might not provide a signature:



Barbot, Drees, Halzen, Hooper,
Albuquerque, Burdman, Chacko,
Anchordoqui, Han, Sarkar, ...,
and most recently,
Albuquerque and Cavalcante de Souza

$$\text{Prob} = \frac{L-l}{\lambda}\, e^{-\frac{l}{\lambda}} \quad \text{Prob(air-shower develops)}$$

Rate maximized at chord length $L = \lambda$

(exponentials win over polynomials)

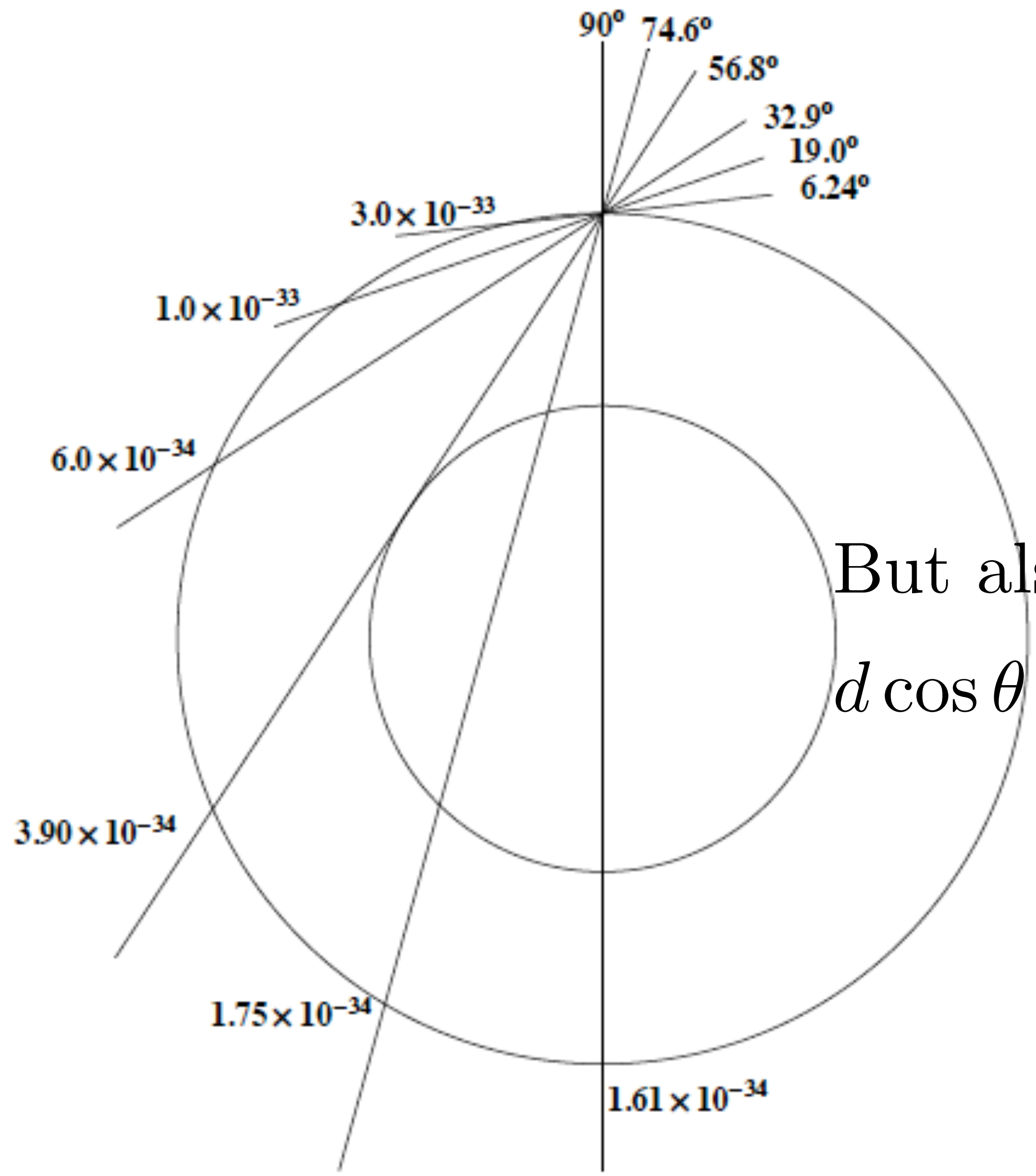


FIG. 1: Shown are neutrino trajectories for which the interaction MFP matches the chord length through the Earth. The various trajectories are parameterized values of the neutrino cross-section. Also shown is the trajectory's angle with respect to horizontal.

But also solid angle increases with θ as

$$d\cos\theta = \sin\theta\, d\theta = \frac{l}{R}\sqrt{1-\left(\frac{l}{2R}\right)^2}\, d\theta.$$

Needs more investigation
(Anchordoqui, Denton, TJW)

What else might/might not provide a signature: Time of Flight

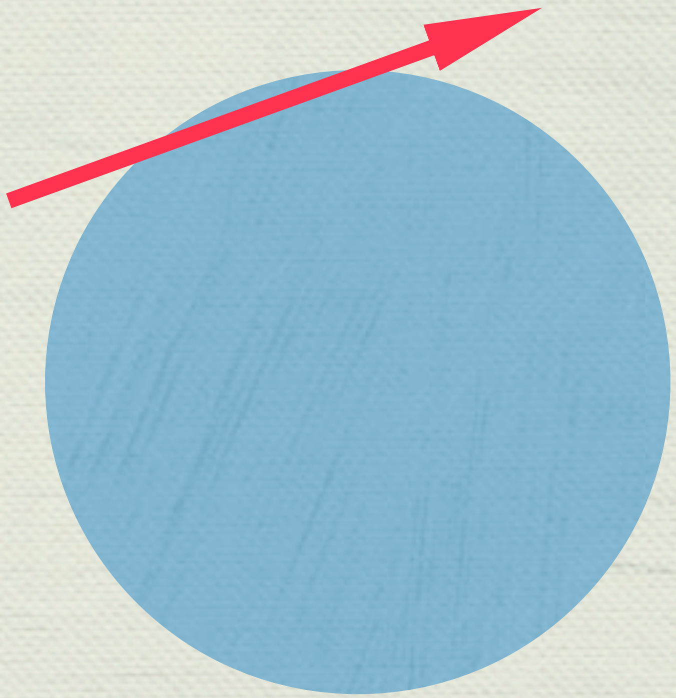
$$\frac{\delta t}{t} = \frac{\delta v}{v} = \frac{1}{2}\frac{\delta v^2}{v^2} \approx \frac{1}{2}\delta v^2 = \frac{1}{2}\frac{1}{\gamma_M^2} = \frac{M^2}{2E^2}$$

$$\text{So } \delta t = \frac{\left(\frac{D}{\text{kpc}}\right)}{\left(\frac{M}{\text{TeV}}\right)^2} \text{ seconds}$$

(early discussions with Lunardini)

Obvious drawback: limited flux of new, heavy particle

Earth-Skimming tau neutrinos



Detection enhanced
(but threshold energy raised)
by JEM-EUSO "tilt mode"

Kusenko-Weiler
(2002)

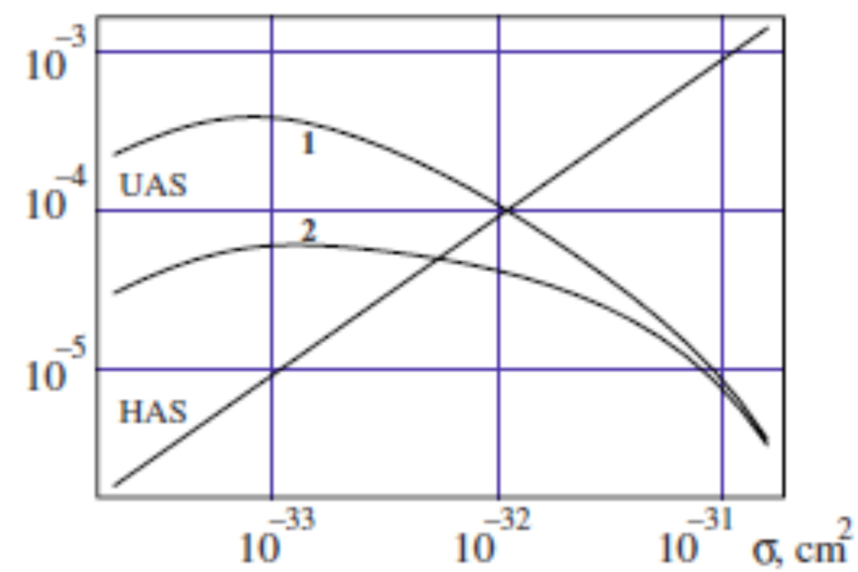
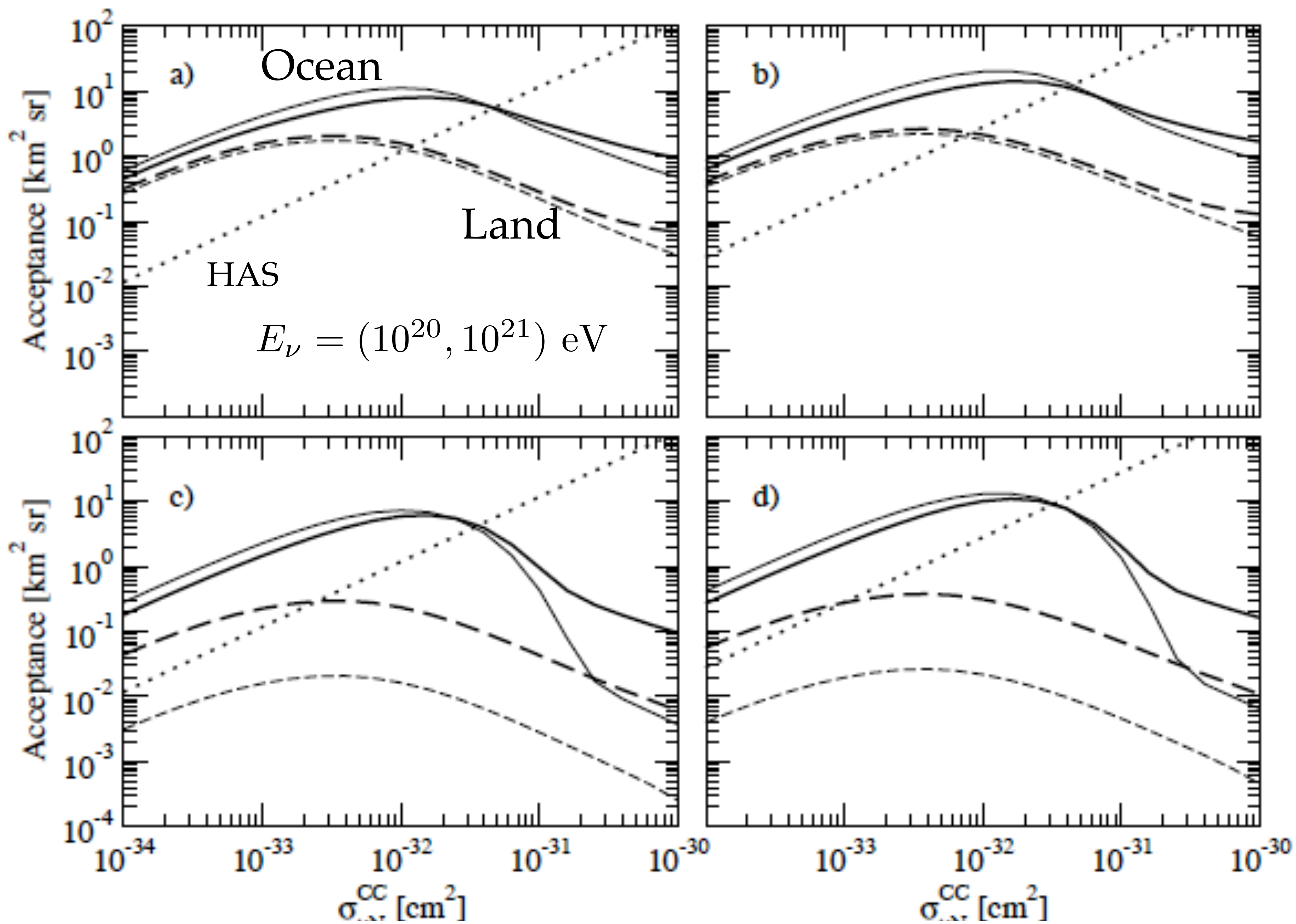


Fig. 2. The air shower probability per incident tau neutrino ($R_{UAS}/F_{\nu_\tau}\pi A$) as a function of the neutrino cross-section.[5] The incident neutrino energy is 10^{20} eV and the assumed energy threshold for detection of the UAS is $E_{th} = 10^{18}$ eV for curve 1 and 10^{19} eV for curve 2.

Ocean vs. Land, and dependence on E_{th}, air-shower length

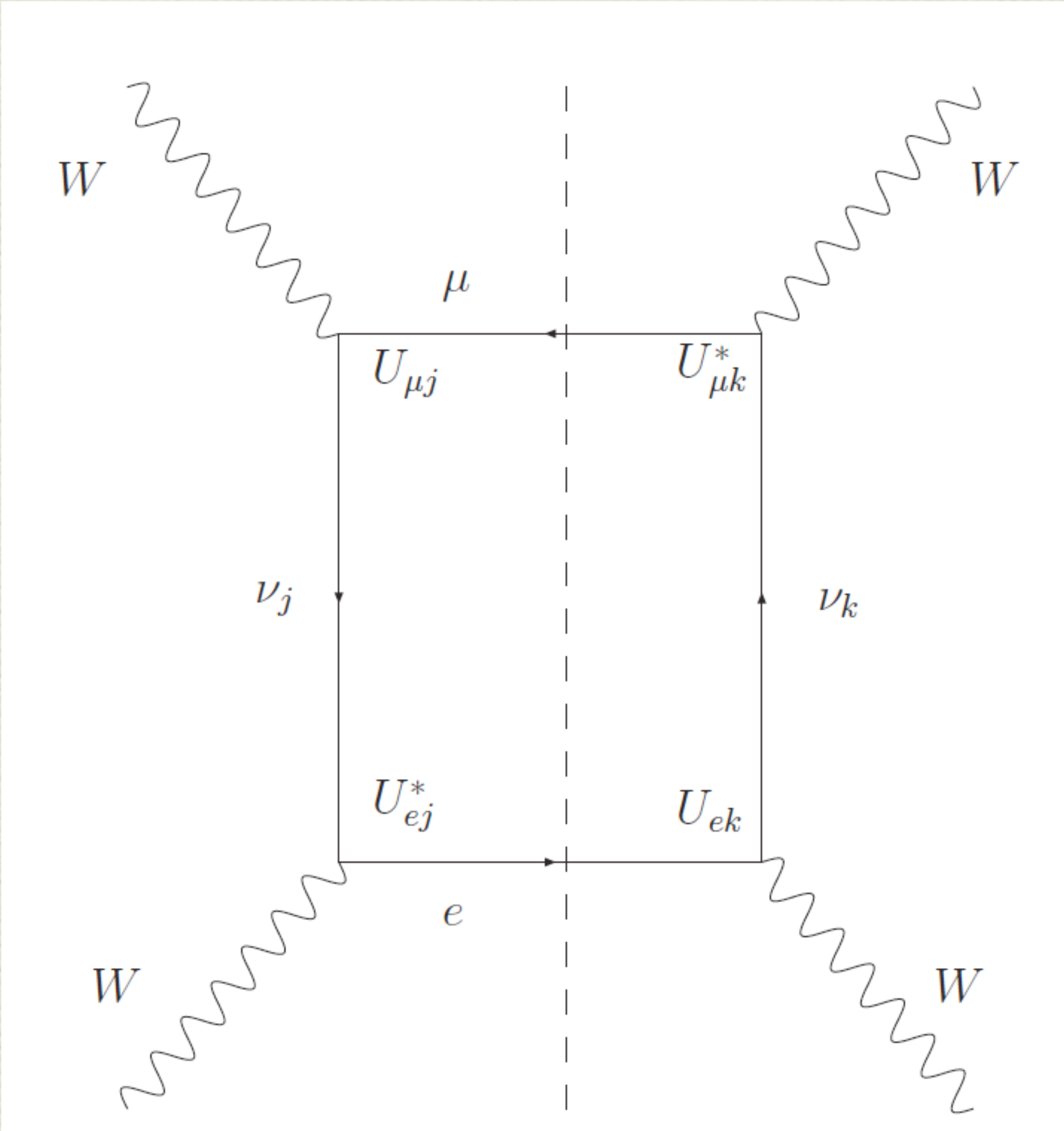
$l_{\min} = (10, 5)$ km

$E_{th} = (10, 50)$ EeV



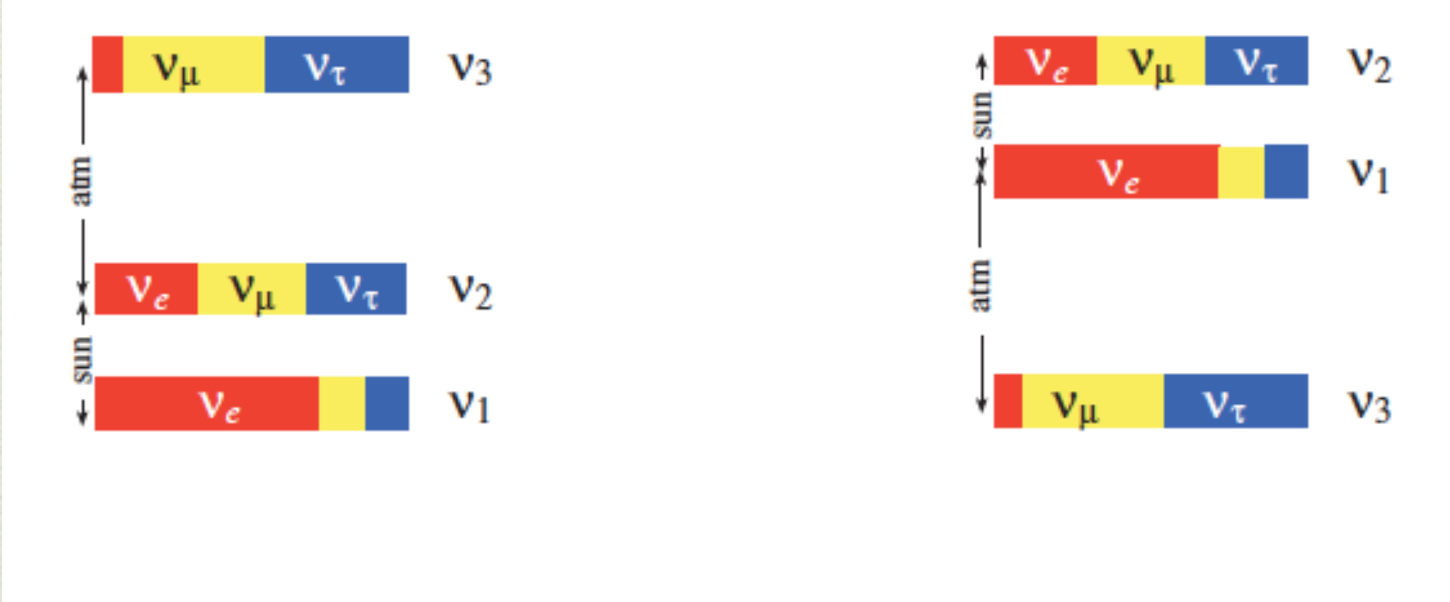
Palomares-Ruiz, Irimia, TJW (2005)

This Ocean/Land enhancement has yet to be seconded/simulated.



$$P_{\mu \to e} = \sum_j |U_{ej}|^2 \, |U_{j\mu}|^2$$

$$P_{\alpha \to \beta} = \sum_j |U_{\beta j}|^2 \, |U_{j\alpha}|^2$$



The Flavor Evolution Matrix: $\frac{1}{18}\begin{pmatrix} 10 & 4 & 4 \\ 4 & 7 & 7 \\ 4 & 7 & 7 \end{pmatrix}$

Working forward - guessing injection models, have:

Flavor Mix at Earth, $\sin\theta_{13} = 0$:

Beam type	Initial (input)	Final (output)
Conventional (pp,pγ)	1:2:0	1:1:1
Damped Muon	0:1:0	4:7:7
Beta Beam(n decay)	1:0:0	5:2:2
Prompt	1:1:0	14:11:11

Now we know that $\sin\theta_{13} = 0.16$

And spacetime foam/virtual black holes
democratize neutrino flavors to (1,1,1).

Summary:

Much particle and astro theory/simulation
to be done pre JEM-EUSO,

and much data to be analyzed post JEM-EUSO