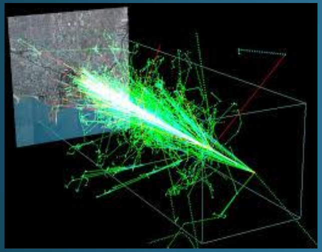
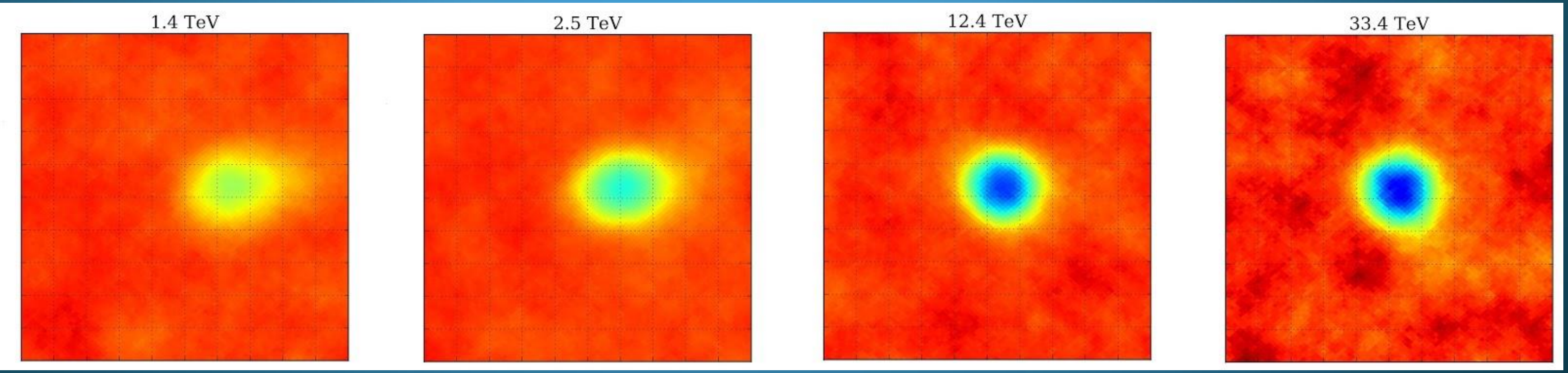
Surprising Muon and Tau Airshower from Earth edges and Moon shadows #175

D. Fargion, Pietro Oliva, P. G. De Sanctis Lucentini, M.Yu. Khlopov

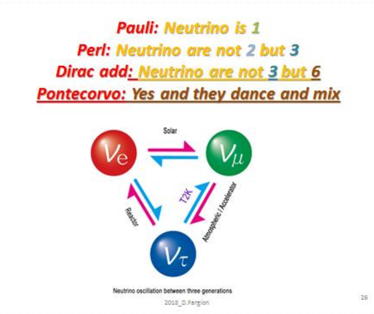




https://doi.org/10.1142/S021827181841002X

HOW DO WE SEE NEUTRINOS ?

- **Interaction with matter by their $e - \mu - \tau$ radiating signals (Cherenkov, secondaries shower, tracks, cascades or airshowers)**



- **$\nu, \bar{\nu}$: 3 flavors → 3x2 = 6 ν Astronomy**
- **e radiates a lot, lowest threshold→SHORT RANGE**
- **μ radiate less, higher mass →LONGER TRACKS →**

  β decay-> e , a Moon-far gamma-like air-showers
- **τ radiate much less; highest mass and most unstable →fast decay →SHORT to LONG TRACKS , decay in hadrons and leptons →most pions-> double bang in ice or water →**
- **τ airshower upward in Earth air.**

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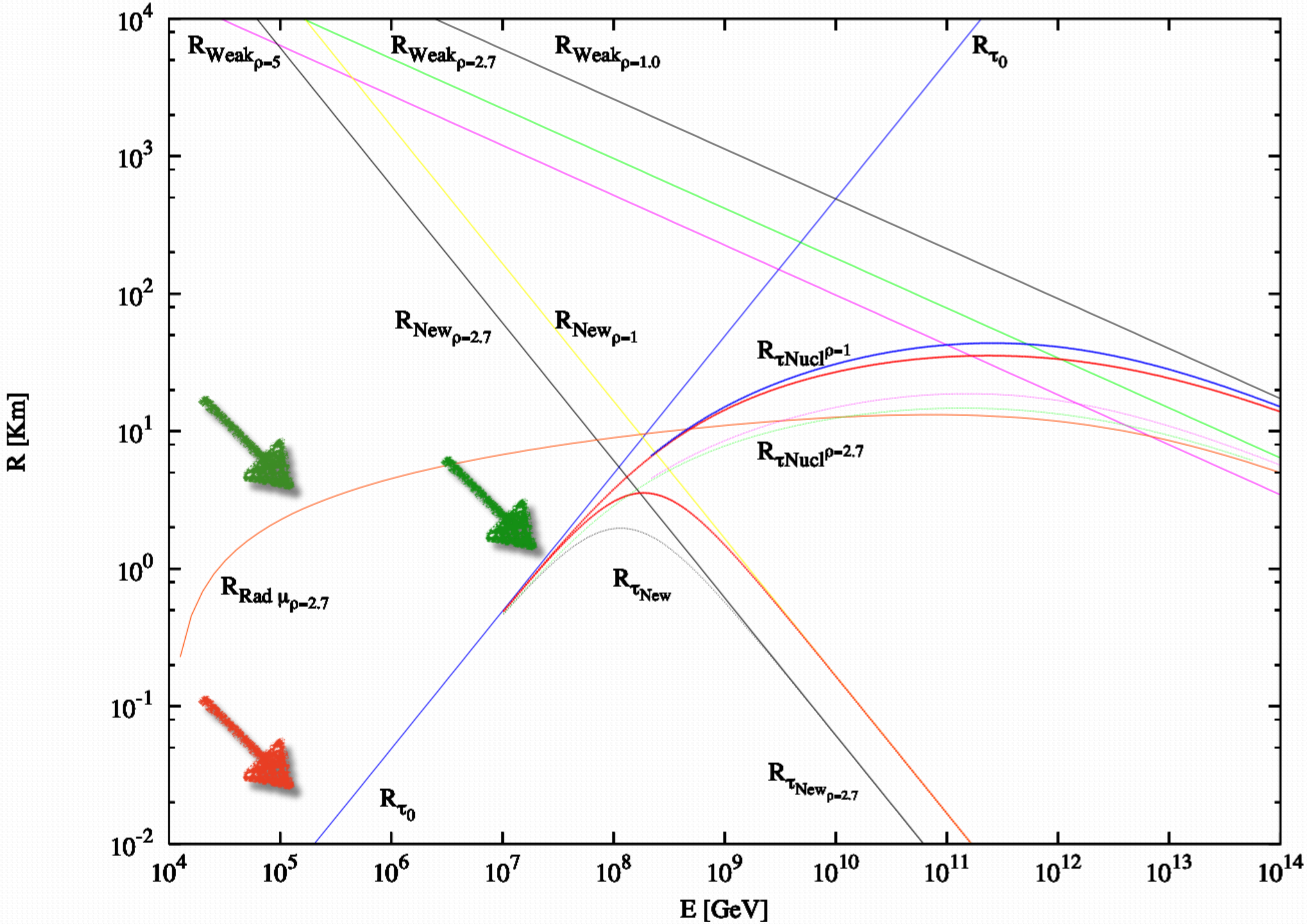
Electrons -> SK-HK cascades
Muon (and Tau) -> IceCube tracks
(and Tau double-cascades or Tau airshowers)

Also for $E\tau \gg$ PeVs, τ may decay in flight and produce largest τ-airshowers in large horizontal-upward areas

$$L_{\tau} = 49\text{m}\left(\frac{E}{\text{PeV}}\right)$$

Muon and Tau lenght penetrability favour muons but also tau at PeVs-EeVs



- ***Tau Airshower into space, see POEMMA and:***

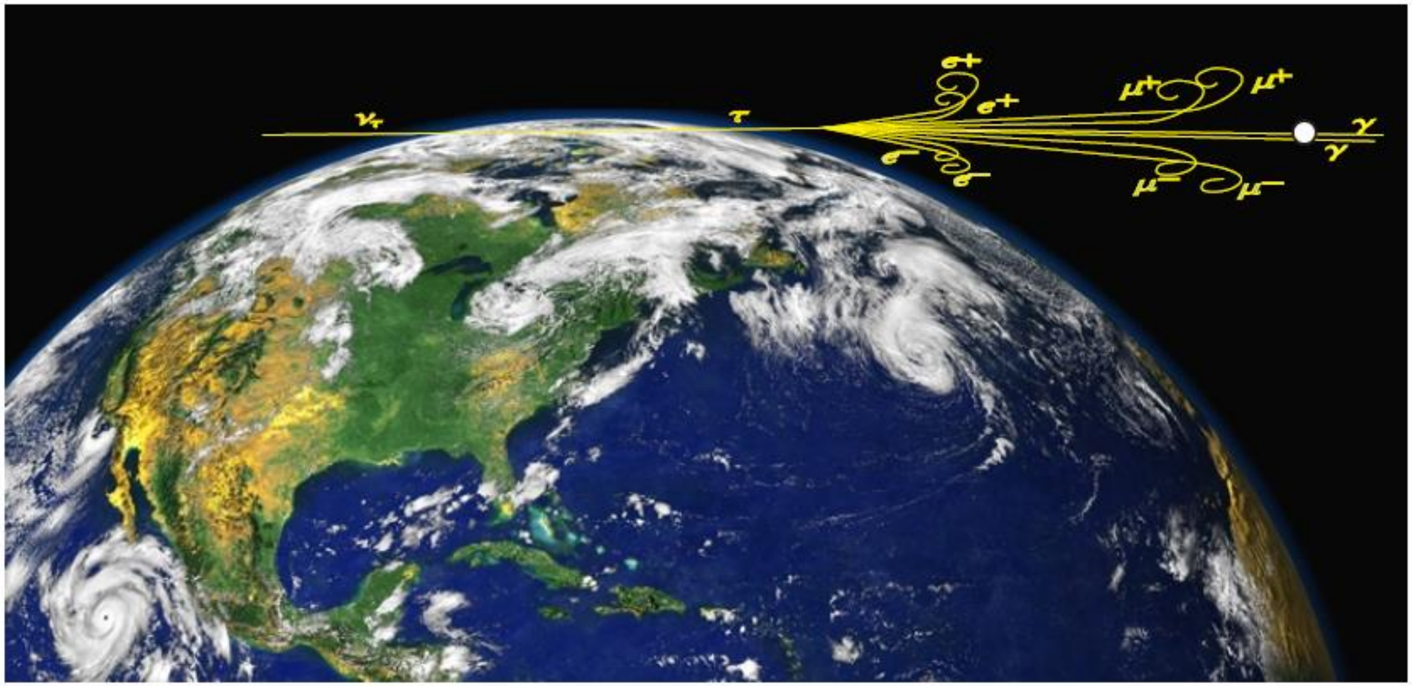
Discovering UHECR: D. Fargion 2002 ApJ 570, 909:

https://iopscience.iop.org/article/10.1086/339772

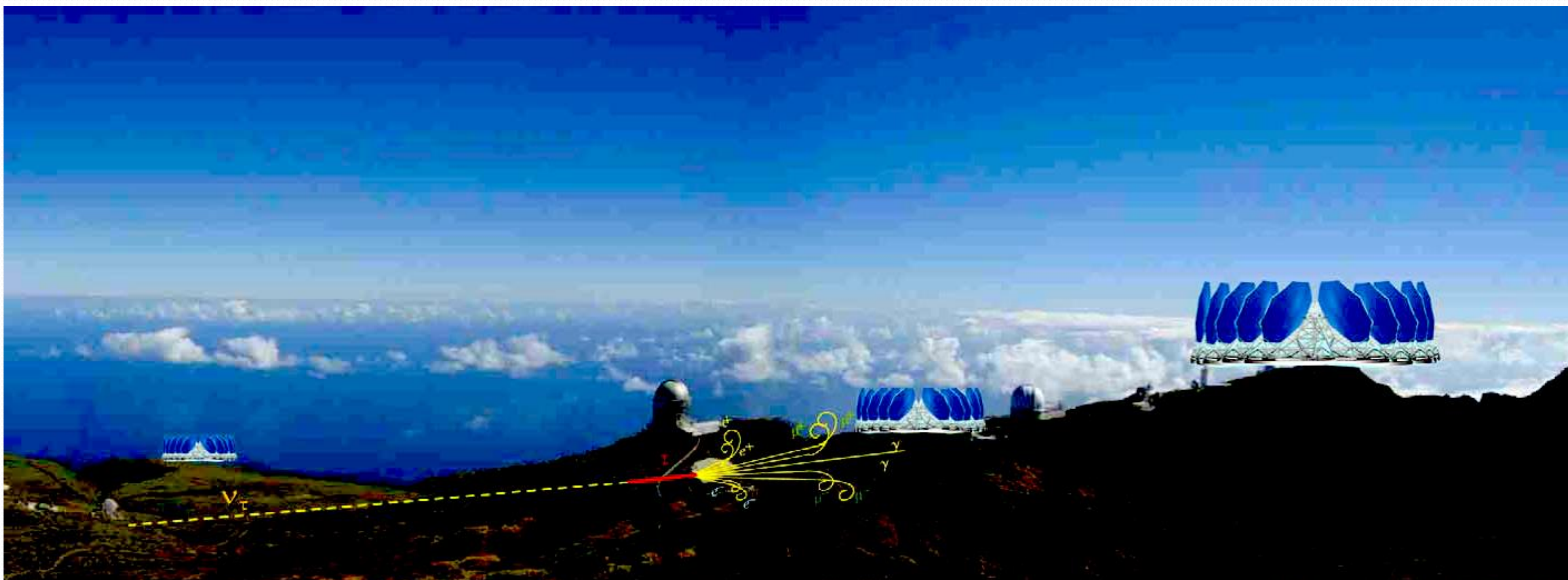
Tau from Earth: D. Fargion et al 2004 ApJ 613, 1285:

https://iopscience.iop.org/article/10.1086/423124

Because Earth opacity, best at Horizons (Skimming neutrino)



Tau Airshower from Mountains: ASHRA , MAGIC and CTA observing tau airshowers from Earth edges



The lifetime of a TeVs muon is too long to be *observable by its decay on Earth edges:* but it is *observable from the Moon*

$$L_\mu \simeq 6234{,}26\mathrm{km}\left(\frac{E_\mu}{1\mathrm{TeV}}\right)$$

Window of energies where TeVs muons *are* *nearly undeflected (from Moon shadows by terrestrial magnetic fields)* *a*nd they are mostly decaying in electrons along Moon-Earth flight:

$$61{,}66\ \mathrm{TeV} \gtrsim E_{\mu} \gtrsim 6{,}4\ \mathrm{TeV}$$

A very relevant astrophysical energy range

Muons from the Moon

Traces of highest energy astrophysical muon and tau neutrinos inside the Moon's shadow: arxiv 1706.09352

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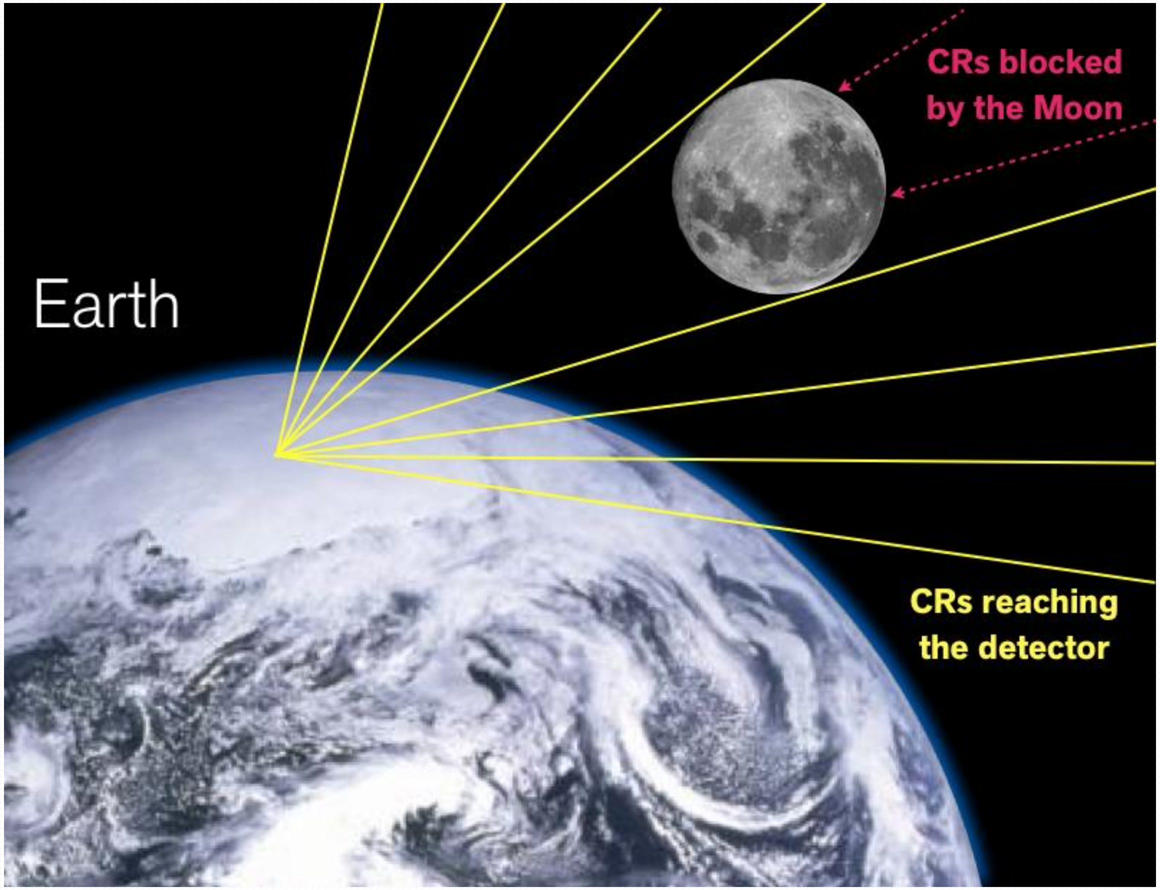
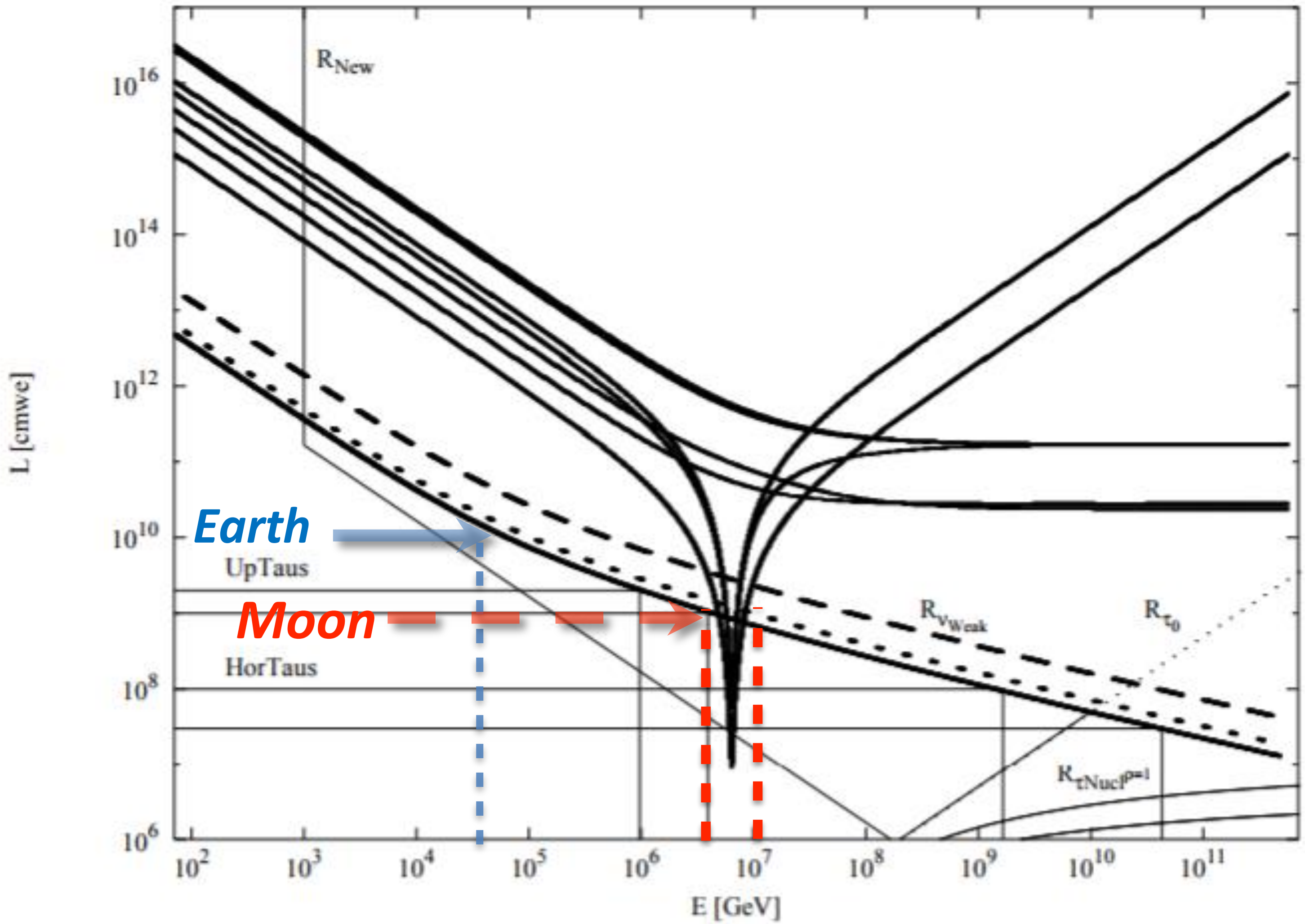
Moon Shadows already used for test CR composition and even anti-matter bending; positron and antiproton tests

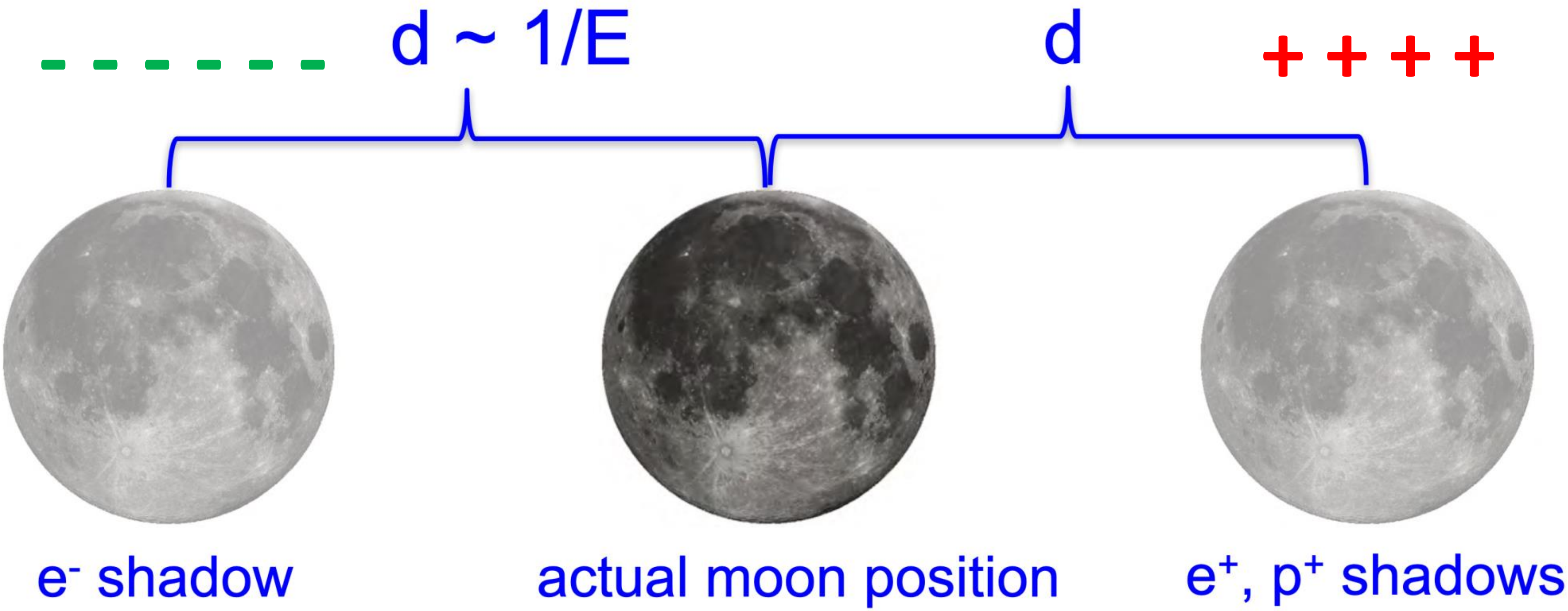


Earth Vs Moon neutrino opacity:

Moon transparent for upward tens PeVs ν



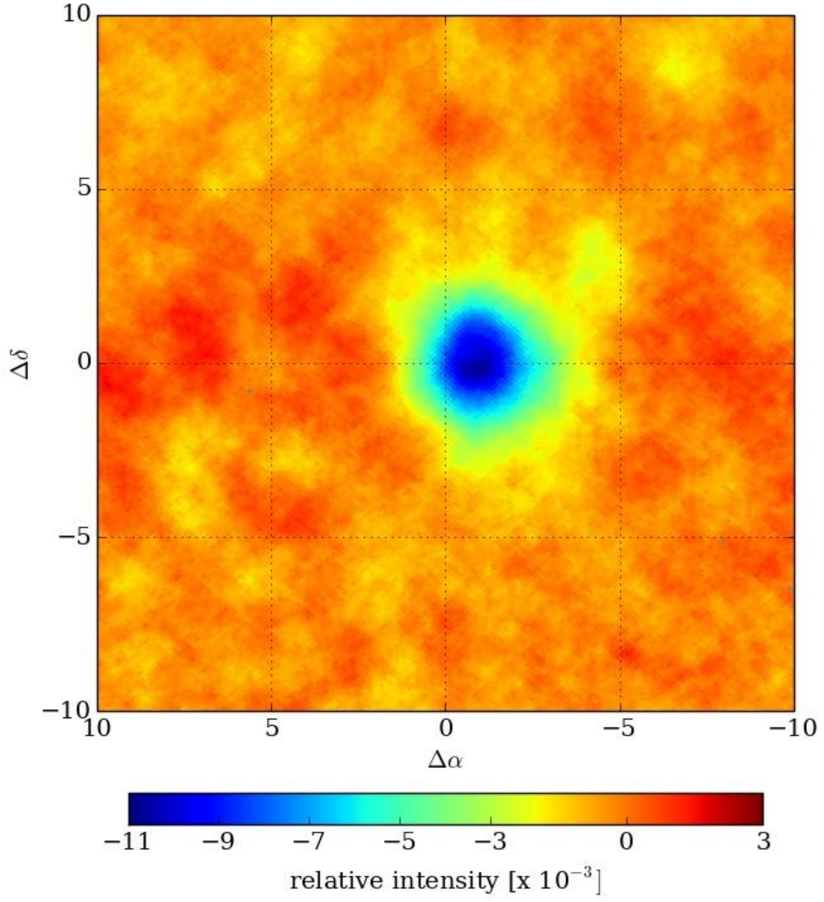
A remind: Moon shadows bending **both** charges by an ideal unidirectional field in twin sides



Magnetic deflection in Earth's field along trajectory from Moon is ~1.5°at 1TeV (depending on viewing direction and location on Earth)

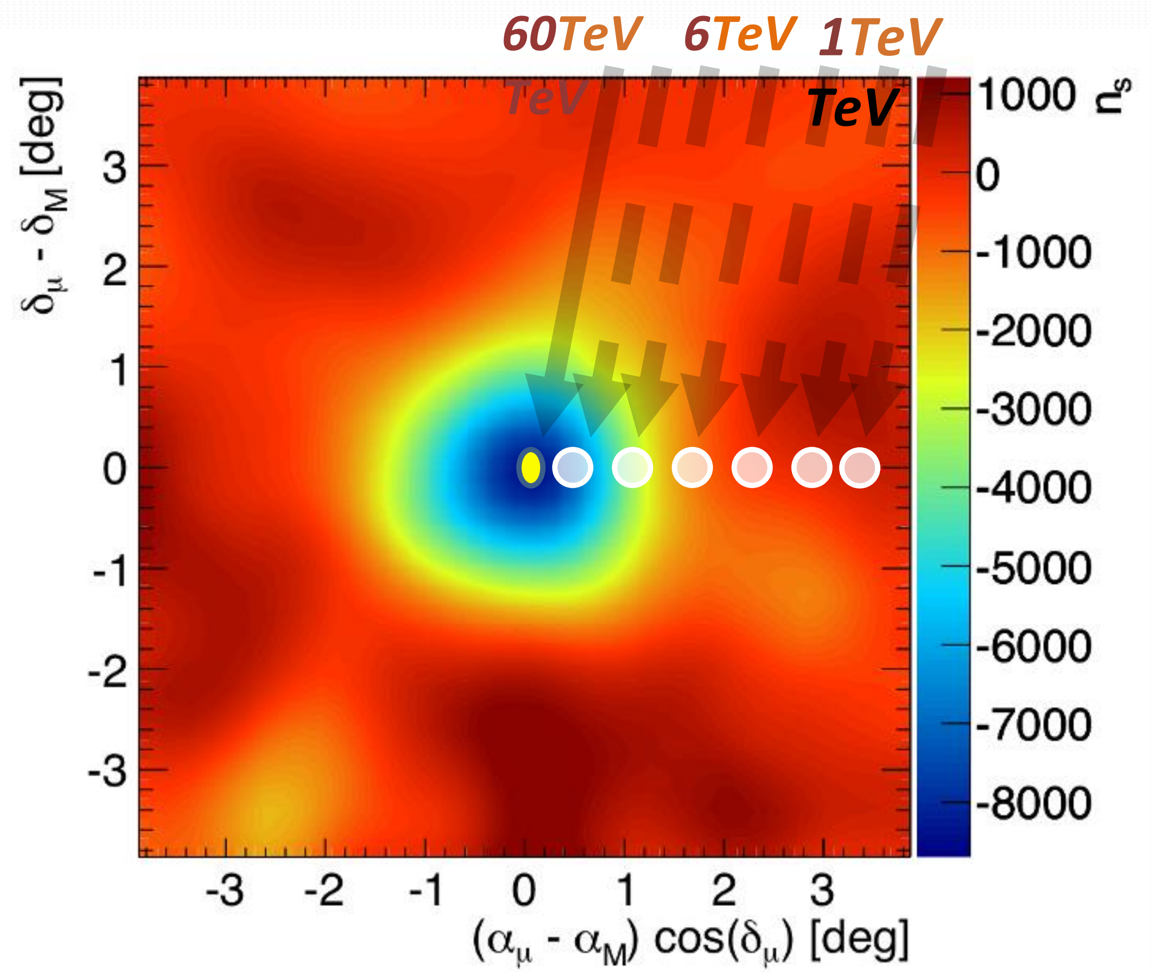
"Astrophysics with TeV particles" by Justin Vandenbroucke

Also the HAWC found Moon shadows at TeVs gamma sky but in a smooth area

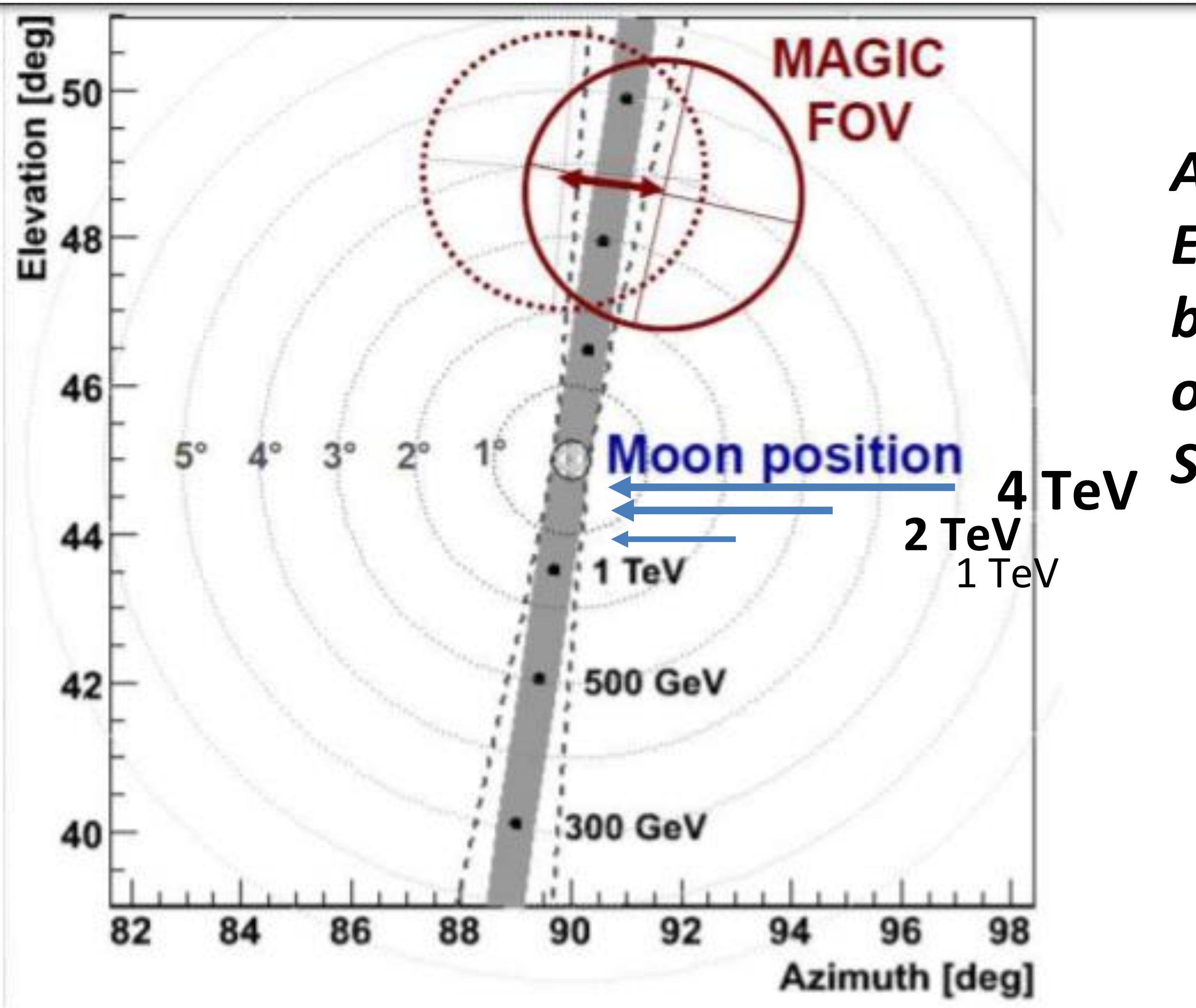


Even IceCube found by muons a TeVs Moon shadows.
It may have a rare inner gamma airshower by muon decay in flight

Physical Review D, arXiv:1305.6811



Magic using Moon Shadows for positrons; at 6 TeV CR bent inside Moon Shadows



At muon energy E>6TeV no more bending: muon track occur inside the Moon Shadows

Conclusions:

Why using filter Moon for tens TeV $\nu, \overline{\nu}$ muons and PeVs Taus?

- ***Moon has no atmosphere thus no noise of atmospheric neutrinos!***
- ***Moon is smaller than Earth = more transparence to ν up to several PeVs***
- **Signals not by single μs but their β-decay electron into wide and rich airshower as several TeVs gamma shower inside widest kms size array detectors**
- **(or thousands km PeVs-EeVs CR arrays)**

Conclusions:

MORE on Why using filter Moon for tens TeV muons and PeVs Taus?

- **Data from the Moon is already detectable or inside the present experiments measurements databases.**
- **At few TeVs-PeVs muon tracks are tens km long in Moon (probable showers in CTA and LHAASO TeV gamma in km-square array each once a year): they test huge depth mass calorimeter.**
- **Tau secondaries at hundred PeVs may also be present in moon shadows (play a role in future largest AUGER or GRAND ARRAY!)**

By the way: Moon shadows were more and more on big power attention! Since August 2017

THANK YOU!

BACKUP SLIDES

Price to pay for μ from the Moon?

There is a small solid angle of the Moon that make rare these muon escaping and arriving to us; but even a much thinner solid angle occurred for ZeV Askaryan ones in km radio antenna

$$\underline{\Delta\Omega_{\text{moon}}} \simeq 6{,}67 \times 10^{-5}\ \text{sr}$$

$$\frac{\Delta\Omega_{\text{moon}}}{\Delta\Omega_{2\pi}} \simeq 1{,}06 \times 10^{-5}$$

The life time of the charged pion

$$L_{\pi^\pm} = 55918 \cdot \left(\frac{E_{\pi^\pm}}{\text{PeV}}\right) \text{km}$$

Where pions by a PeVs tau decay may arrive on Earth and not make hadron but just a single unnoticed muons.
BUT neutral pions MAKE amazing PAIR PHOTON airshower

$$6,87\,\text{PeV} \gtrsim E_{\pi^\pm} \gtrsim 61\,\text{TeV}$$

For tau induce event (upward escaping from Moon to us) it may decay in flyght into a charged pion at energy E> 7 PeVs that do not decay but it makes an incredible hadron airshower inside the Moon shadows: DETECTING GZK EeVs neutrinos from Moon in AUGER or GRAND array detectors.

Earliest Askaryan Moon neutrino hunt: https://arxiv.org/abs/1608.02408

- The lunar Askaryan technique is a method to study the highest-energy cosmic rays, and their predicted counterparts, the ultra-high-energy neutrinos. By observing the Moon with a radio telescope, and searching for the characteristic nanosecond-scale Askaryan pulses emitted when a high-energy particle interacts in the outer layers of the Moon, the visible lunar surface can be used as a detection area. Several previous experiments, **at Parkes, Goldstone, Kalyazin, Westerbork, the ATCA, Lovell, LOFAR, and the VLA,** have developed the necessary techniques to search for these pulses, but existing instruments have lacked the necessary sensitivity to detect the known flux of cosmic rays from such a distance.
- **This will change with the advent of the SKA.**
- **The Square Kilometre Array (SKA) will be the world's most powerful radio telescope also as neutrinos.**

Conclusions 3

- **Muon and Tau neutrino traces in Moon disk**

There are several new and surprising signals arriving from theMoon as a huge calorimeter to Earth.

The analogous Askariyan [3] radio signal is competitive at ZeV energies, but the neutrino astronomy we offered here it is at tens TeV -PeVs energies, more at ICECUBE edges, both for muons and (at a much higher energy) for tau (GZK) EeV neutrinos. Detectable by LHAASO and maybe CTA

The complexity of the signal is rich and cannot be ignored. Particle physics and air-shower physics are building this new windows of astronomy.

Giant sq. km detector array in project maybe already at the detection threshold (by several event a year for an astrophysical neutrino flux comparable (20% – 5%)) of the terrestrial atmospheric flux ones, as suggested by ICECUBE.

A Short references list

- ***Tau Air Showers from Earth***

  D. Fargion *et al* (2004) *ApJ* **613** 1285
- https://doi.org/10.1086/423124;
- ***Discovering Tau Airshowers…***

  D. Fargion, *Astrophys. J.* **570** (2002) 909. Crossref, ISI, ADS, Google Scholar
- G. A. Askaryan, *Sov. Phys. J. Exp. Theor. Phys.* **14** (1962) 441. Google Scholar
- LHAASO Collab. (G. Di Sciascio), arXiv:1602.07600. Google Scholar
- D. Fargion, P. Oliva, F. Massa and G. Moreno, *Nucl. Instrum. Methods Phys. Res. A* **588** (2008) 146. Crossref, ISI, ADS, Google Scholar

  - ***Signals of HE atmospheric μ decay in flight …Moon shadow***
- **International Journal of Modern Physics DVol. 27, No. 06, 1841002 (2018)**

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https://doi.org/10.1142/S021827181841002X

Tau decay by pions

Neutral pion too

Major source of surprising gamma twin airshowers

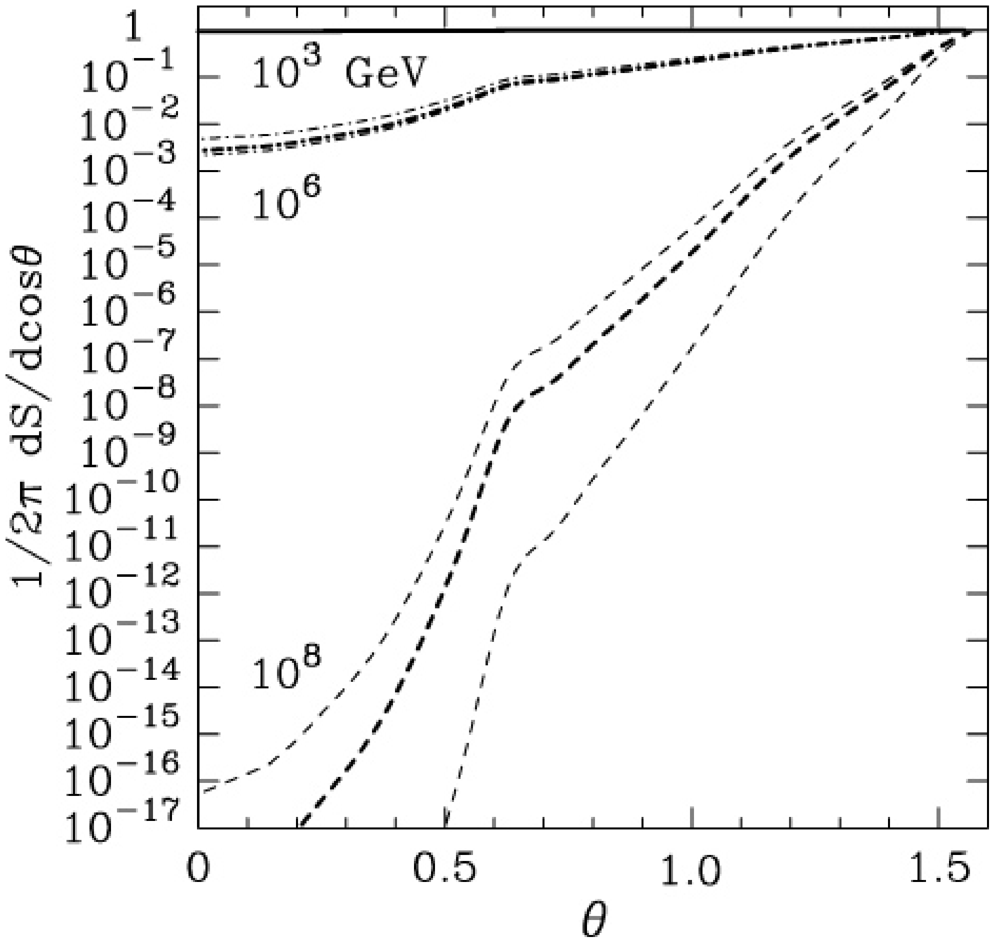
τ AIR SHOWER CHANNELS

Decay	Secondaries	Probability (%)	Air Shower
$\tau \to \mu^- \bar{\nu}_\mu \nu_\tau$	μ^-	~17.4	Unobservable
$\tau \to e^- \bar{\nu}_e \nu_\tau$	e^-	~17.8	One electromagnetic
$\tau \to \pi^- \nu_\tau$	π^-	~11.8	One hadronic
$\tau \to \pi^- \pi^0 \nu_\tau$	$\pi^-, \pi^0 \to 2\gamma$	~25.8	One hadronic, two electromagnetic
$\tau \to \pi^- 2\pi^0 \nu_\tau$	$\pi^-, 2\pi^0 \to 4\gamma$	~10.79	One hadronic, four electromagnetic
$\tau \to \pi^- 3\pi^0 \nu_\tau$	$\pi^-, 3\pi^0 \to 6\gamma$	~1.23	One hadronic, six electromagnetic
$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$	$2\pi^-, \pi^+$	~10	Three hadronic
$\tau \to \pi^- \pi^+ \pi^- \pi^0$	$2\pi^-, \pi^+, \pi^0 \to 2\gamma$	~5.18	Three hadronic, two electromagnetic

How many we should expect?

- **Because of nearly 2000 events above few TeV a year at km sq , because of larger crossing distance and depth in the Moon rock exit, (25 better than earth HESE one)**
- **We expect from the Moon nearly 50000 TeV muons events a year and within a sq.km and the Moon shadows only one astrophysical event every 4 years in SKA (Square km Array) . The huge gamma telescope array as the GRAND one,(arXiv:1508.01919) imagined for tau airshowers, of 20000-200.000 km sq would possibly record hundreds or thousands of them each a year in a far future array at lowest tens- hundred TeV energies up to several events at few PeVs ones .**

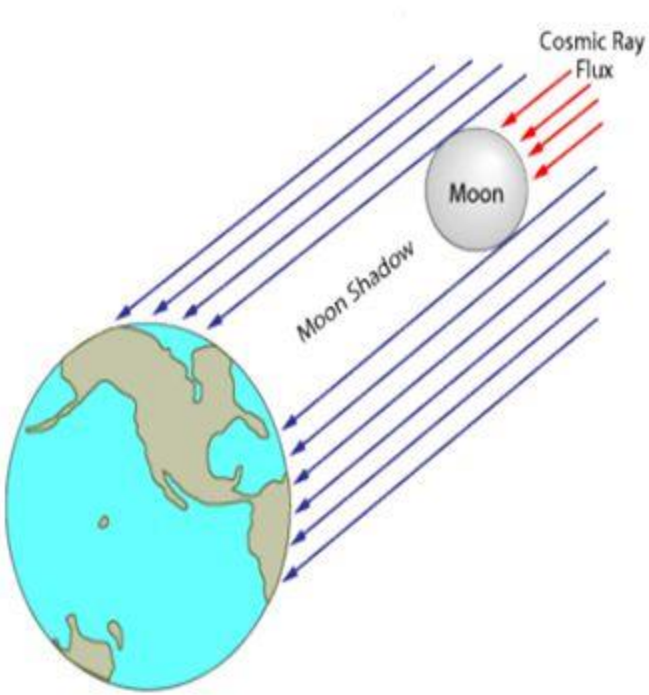
Moon it is much transparent than Earth; it may allow to cross inside up PeVs or even to EeVs neutrinos

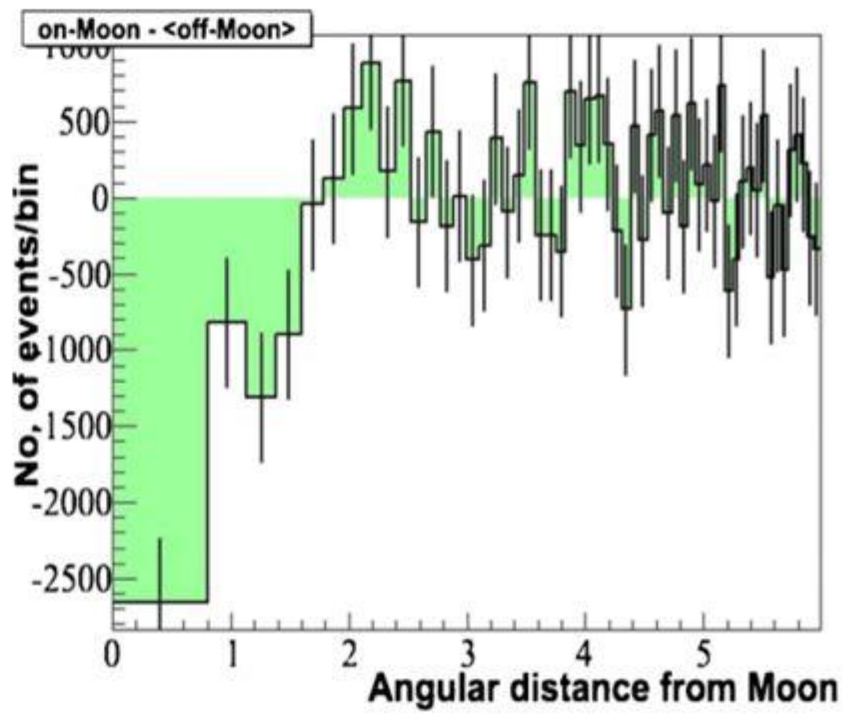


Earth Opacity
From Apj
Ghandi et all 1998

A standard yet beautiful angular resolution measurement (IceCube)

- Measure the moon shadow in the C.R. muon sky!





Our Moons shadows on Earth as filter for several TeVs neutrino μ

- ***Let us now consider the very realistic case of an ultra-relativistic μ, ¯μ+ neutrinos crossing the Moon at TeV energies pointing***

  the Earth: its possible interaction within the Moon surface skin facing the Earth may lead to an escaping ∼TeV muon whose flight is

  still toward our planet Earth. Now a unique muon track (within the Moon shadow) is mostly useless, but its decayed electron airshowering on atmosphere is a much amplified trace. These rare gamma like air-shower are of lunar origination inside its shadows and these air-showers may spread in wide areas.

  Unfortunately any CR bending angle due to the solar magnetic field along the Moon-Earth trajectory might be able to deflect

- ***any charged particle (of charge Z and energy E) by a quantity***

- $\simeq 1,6^{\circ}$ *(E/TeV)^(-1) * Z*

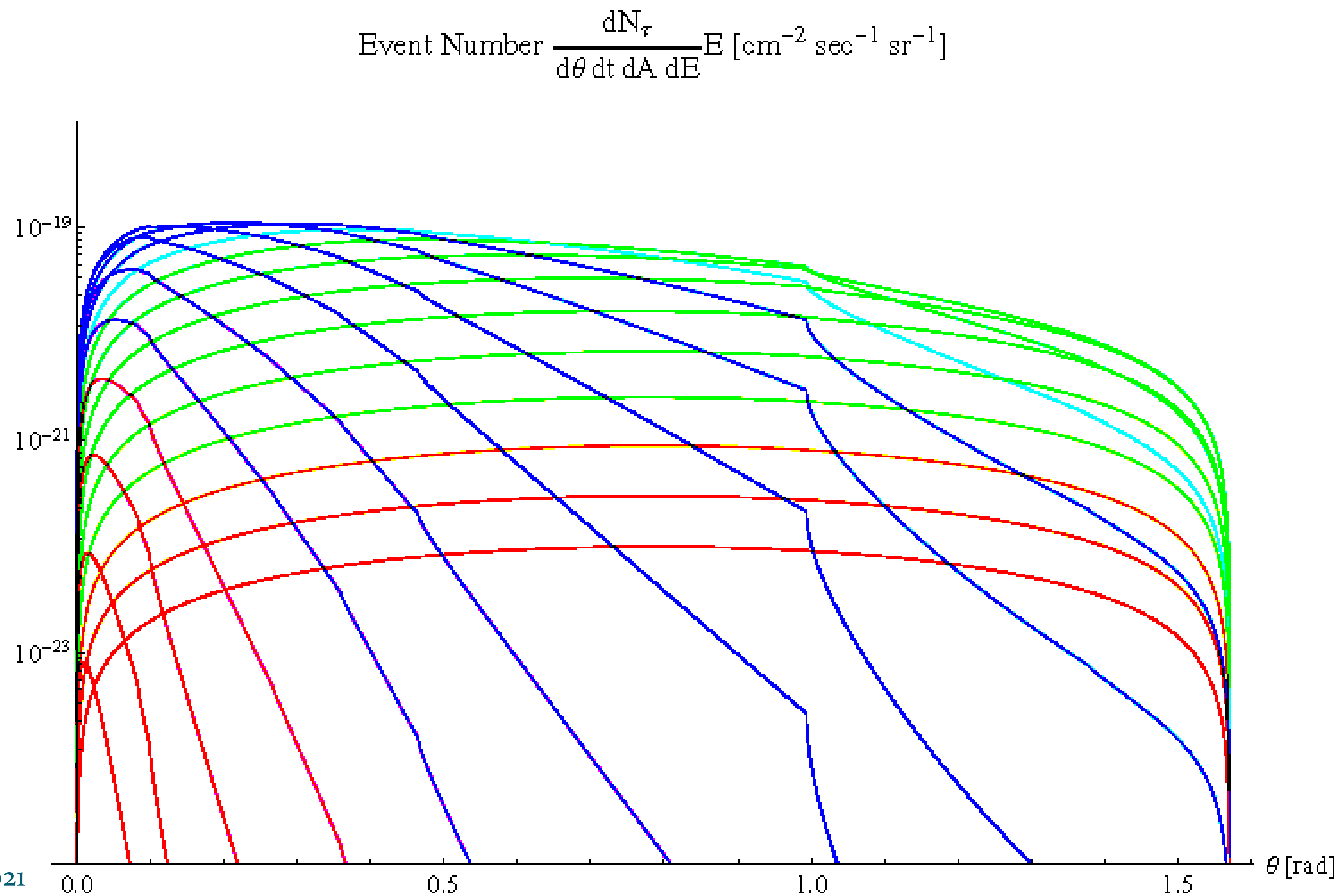
Why Horizontal – Upward Tau Showering is so much linked to neutrino mass and mixing ?

Because mixing, even for minimal masses guarantee the flavour transformation from Muon Neutrinos to the Tau Neutrinos.

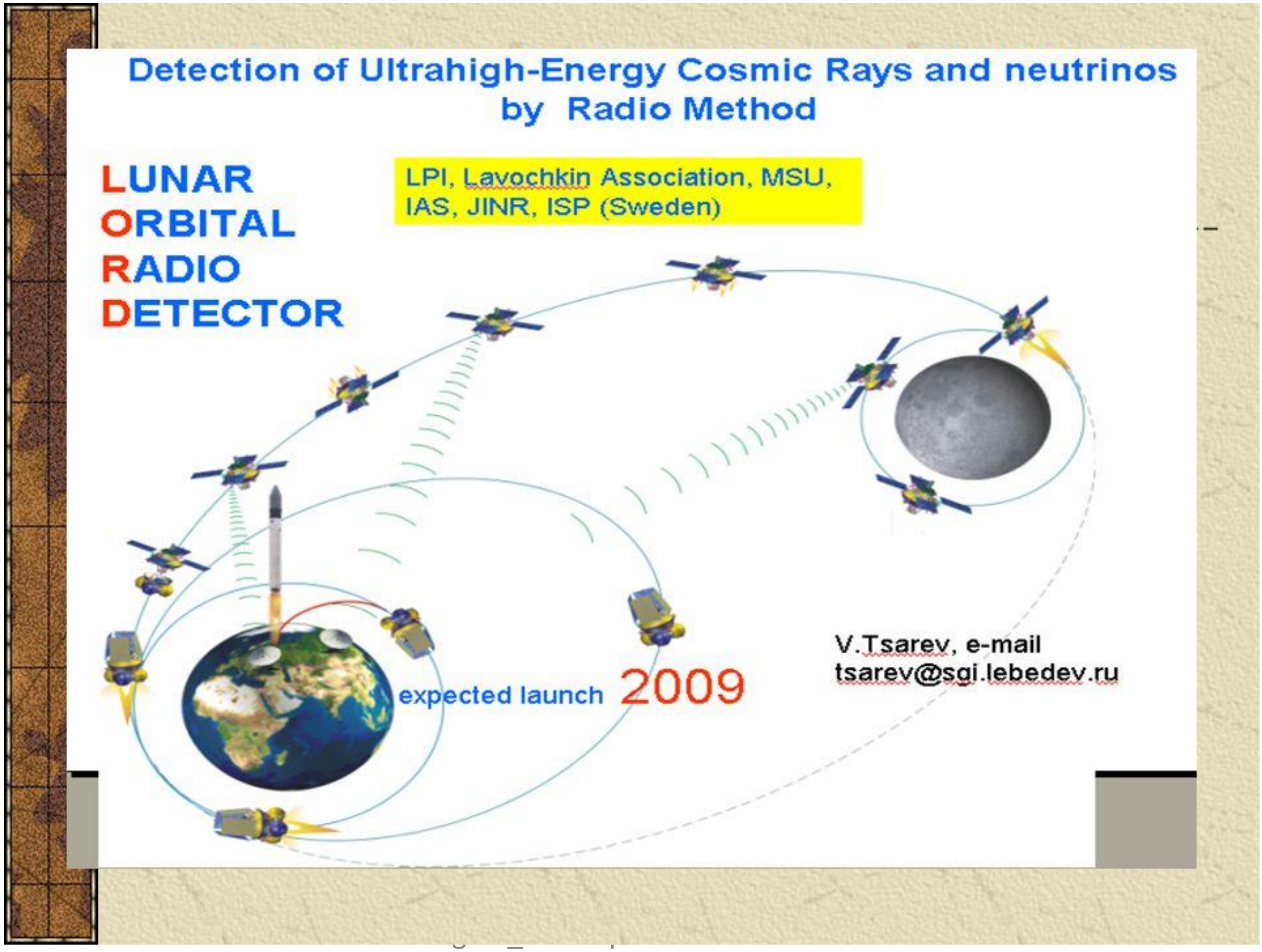
Galactic and cosmic distances are huge respect oscillation lenghts.

$$L_{\nu_\mu - \nu_\tau} = \boxed{8.3\,\mathrm{pc}} \left(\frac{E_\nu}{10^{19} eV} \right) \left(\frac{\Delta m_{ij}^2}{(10^{-2} eV)^2} \right)^{-1}$$

Differential event rate for energy and skimming angle 10 GeV eV up to 0.1 ZeV energy: tau rate for WB flux at 20 eV cm^-2 s^-1 sr^-1



Other proposal: future Russian-Chinese or American Orbital Station orbit around the Moon: the distances are Smaller, the solid angle of the moon is million times bigger. Upward cascades made by UHE neutrinos may be observed by smaller areas.



Gamma like Electron air shower, made by muon decay or (by tau and pion decay into) Twin photon gammas hit while reaching Earth atmoshere and while airshowering inside the Moon Shadows. Their gamma nature differ radiacally from any hadronic (CR) one.