

# Tau Now

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*Tau Now 25'*

PeV neutrino has been found in ICECUBE. The mixing along galactic distance guarantee the presence of PeV Tau neutrinos among astrophysical signals, whose direct detection is subject of deep research since a decade at different UHECR experiments , mostly at EeV energies; these UHE tau neutrino while skimming the Earth (Horizontal Tau airshowers) may shower upward to the sky. The EeV tau neutrino are a guaranteed GZK signal if UHECR are nucleons: But if they are mostly light nuclei as we advocated since 2008 , the expected photo nuclear dissociation (GZK He) signals is at PeVs. Therefore, knowing their angular distribution and rate, we propose here a novel detection signature that has not been yet considered. The signal, may be already recorded in AUGER and TA records.

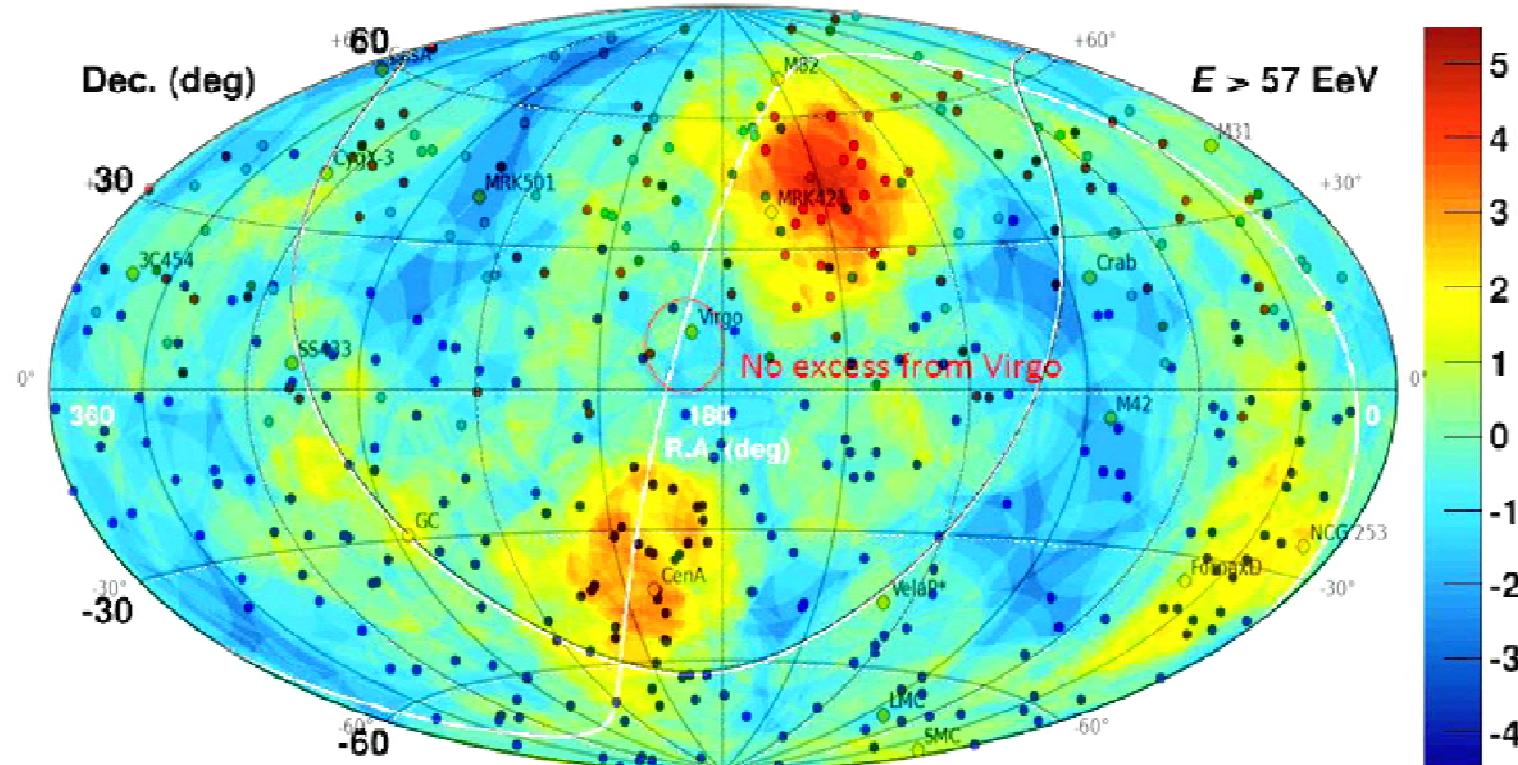
## History and UHECR connections

# North and South at 50 EeV

## The PERSISTENT SCANDAL (celestial coordinates) of VIRGO ABSENCE

TA 6 Years + Auger 10 Years

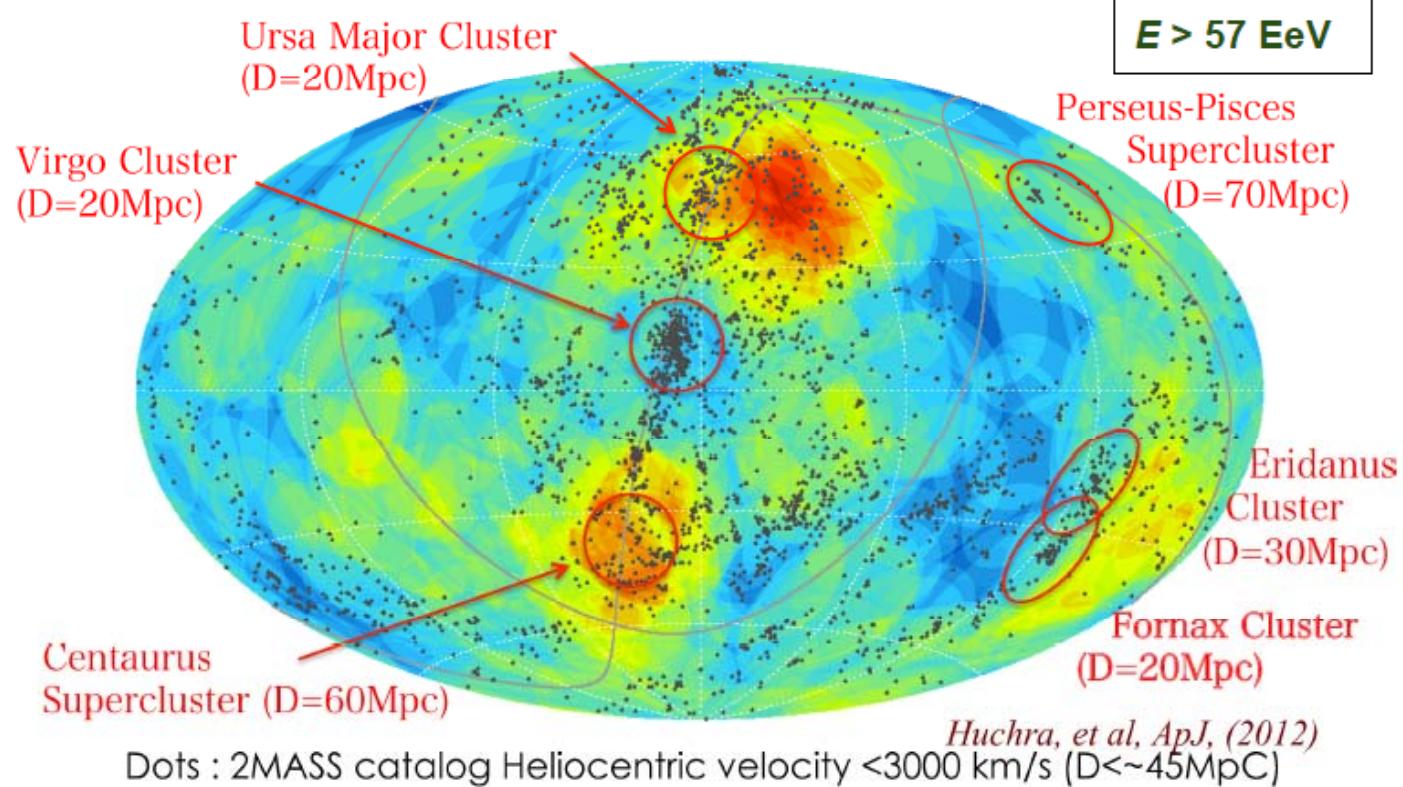
ATTENTION: MOLWEIDE versus HADER—Celestial HADER here-GALACTIC LATER



North:  $S_{MAX} = 5.19\sigma$ , (R.A, Dec.) =  $(148.4^\circ, 44.5^\circ)$   
South:  $S_{MAX} = 3.57\sigma$ , (R.A, Dec.) =  $(210.9^\circ, -48.2^\circ)$

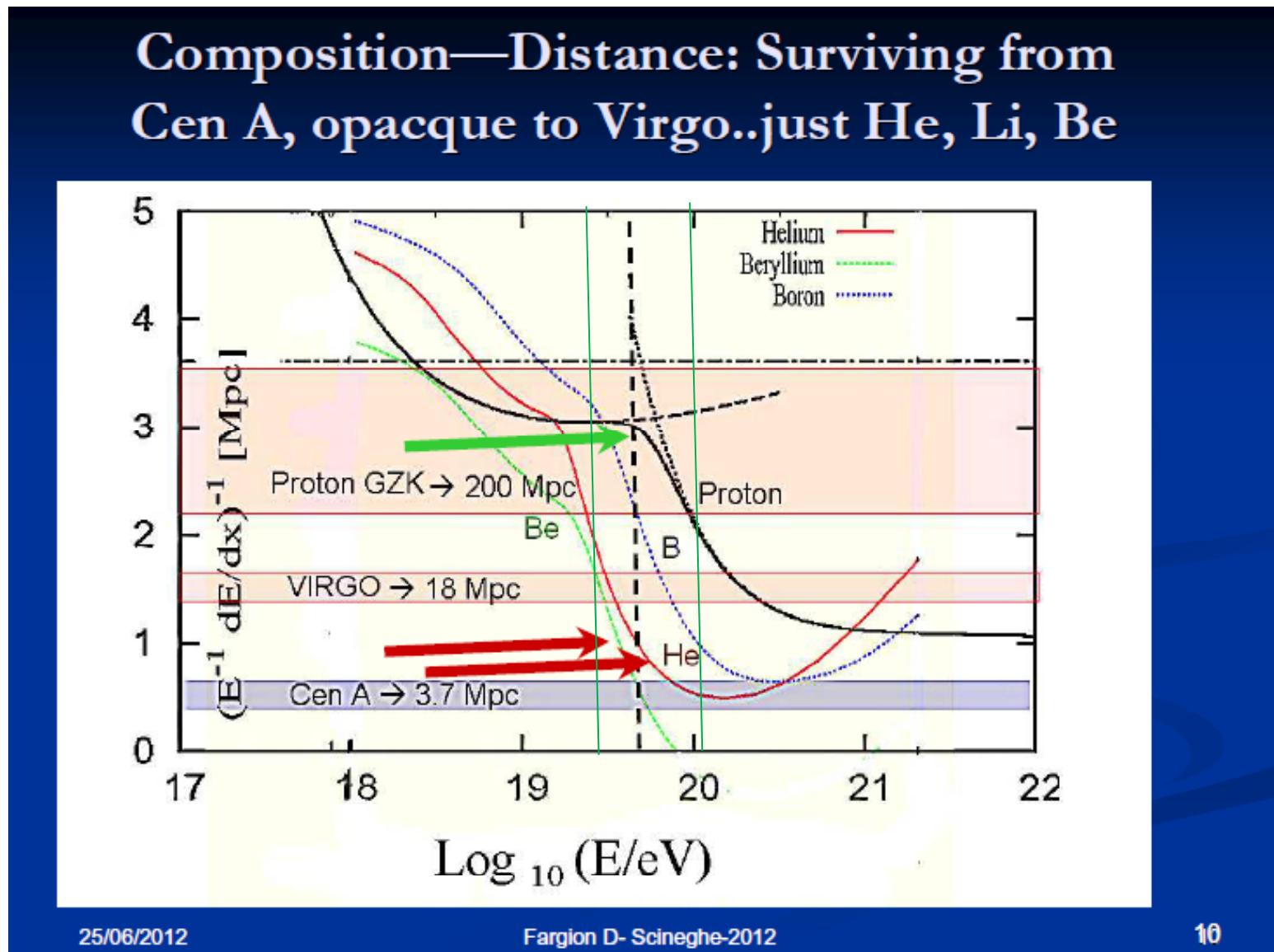
# UHECR..UHE neutrino astronomy : The Virgo scandal

## TA Anisotropy - Nearby Galaxy Clusters



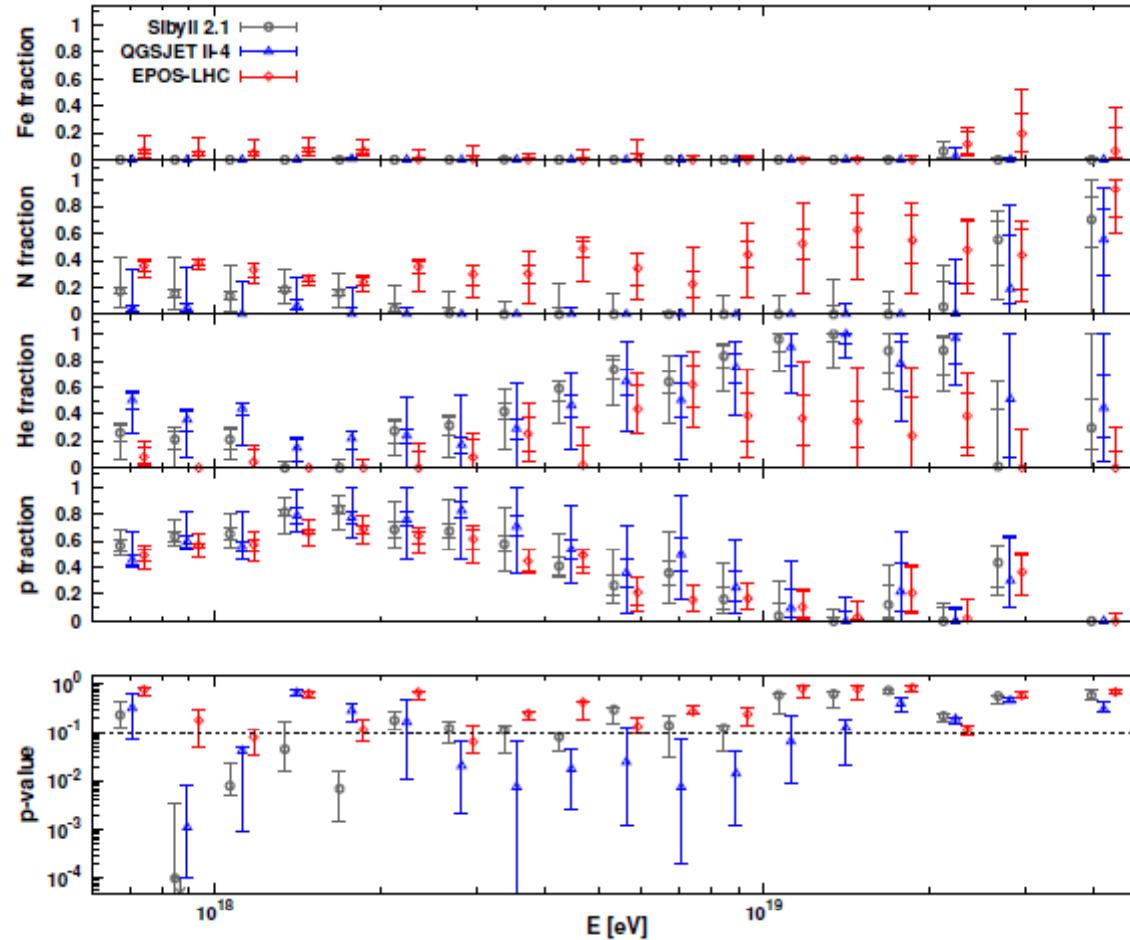
All-sky significance: TA Northern and PAO southern.  
No energy scale correction between TA & PAO.

# *The lightest nuclei: the best filter to mask Virgo*



# Composition by AUGER 2015

## Composition Fit ( $X_{\max}$ distribution)



# Bending By Random or Coherent B into smeared HOT SPOT: Photonuclear dissociation feed PeVs neutrinos

**Random Deflections inside our Galaxy and along  
horizontal Galactic Plane in vertical axis toward Cen A  
by LIGHTEST NUCLEI: He, Li, Be**

same Super-Galactic Arm , just apparently from far 80 Mpc Centaurs Cluster. The mean random angle bending  $He_4^2, Li_6^3, Be_8^4$ , ( . . . ) by spiral galactic magnetic fields along the plane is  $\delta_{rm} \geq$ :

$$\rightarrow 11.3^\circ \cdot \frac{Z}{Z_{He^2}} \cdot \left( \frac{6 \cdot 10^{19} eV}{E_{CR}} \right) \left( \frac{B}{3 \cdot \mu G} \right) \sqrt{\frac{L}{20 kpc}} \sqrt{\frac{l_c}{kpc}} \quad (1)$$

$$16.95^\circ \cdot \frac{Z}{Z_{Li^3}} \cdot \left( \frac{6 \cdot 10^{19} eV}{E_{CR}} \right) \left( \frac{B}{3 \cdot \mu G} \right) \sqrt{\frac{L}{20 kpc}} \sqrt{\frac{l_c}{kpc}} \quad (2)$$

$$22.6^\circ \cdot \frac{Z}{Z_{Be^4}} \cdot \left( \frac{6 \cdot 10^{19} eV}{E_{CR}} \right) \left( \frac{B}{3 \cdot \mu G} \right) \sqrt{\frac{L}{20 kpc}} \sqrt{\frac{l_c}{kpc}} \quad (3)$$

This *Lightest Nuclei for Highest Cosmic Rays* model implies and foresees among the other, additional clustering of UHECR events around the nearest AGN Cen-A

# *Tau Birth dates : the Tau Time is very running..*

- Perl, M. L.; et al. (1975). "Evidence for Anomalous Lepton Production in e+e- Annihilation". Physical Review Letters **35** (22): 1489..
- **Martin Perl** shared the 1995 Nobel Prize in Physics with Frederick Reines

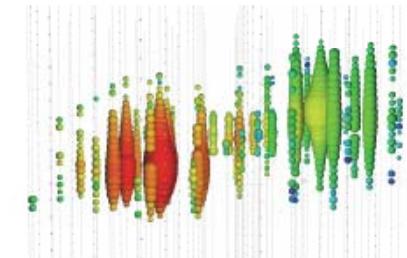
# 1995-2000: Tau Airshower

- [\*\*1994-1995 Tau Double Bang\*\*](#) : Detecting Nutau Oscillations as PeV Energies
- hep-ph/9405296, di JG Learned - **1994** -  
Should see the first Tau soon!
- [\*\*astro-ph/9906450\*\*](#) Horizontal Tau air showers  
from mountains in deep valley.
- Traces of UHECR neutrino tau
- [Daniele Fargion, Andrea Aiello, Roberto Conversano](#)
- 26th ICRC, He 6.1.09, p.396-398. **1999**.
- [\*\*astro-ph/0002453, DF, Discovering Ultra High E\*\*](#)  
Neutrinos by Horizontal and Upward tau
- Air-Showers: Evidences in Terrestrial Gamma Fl
- **Astrophys.J.570:909-925,2002**
- D. F., [P.G. De Sanctis Lucentini, M. De Santis. M.Grossi](#)
- **Upward Tau Air Showers from Earth**
- Journal-ref: **Astrophys.J. 613 (2004) 1285-1301**

Charged Current tau neutrino:

$$\nu_\tau + N \rightarrow \tau + X$$

Double-bang signature from decaying tau,  
 $l_\tau = \gamma c_\tau \sim 50 (E_\tau / \text{PeV}) \text{ m}$   
Can identify double bang above  $\sim \text{PeV}$   
Lower energy id more limited possibilities.



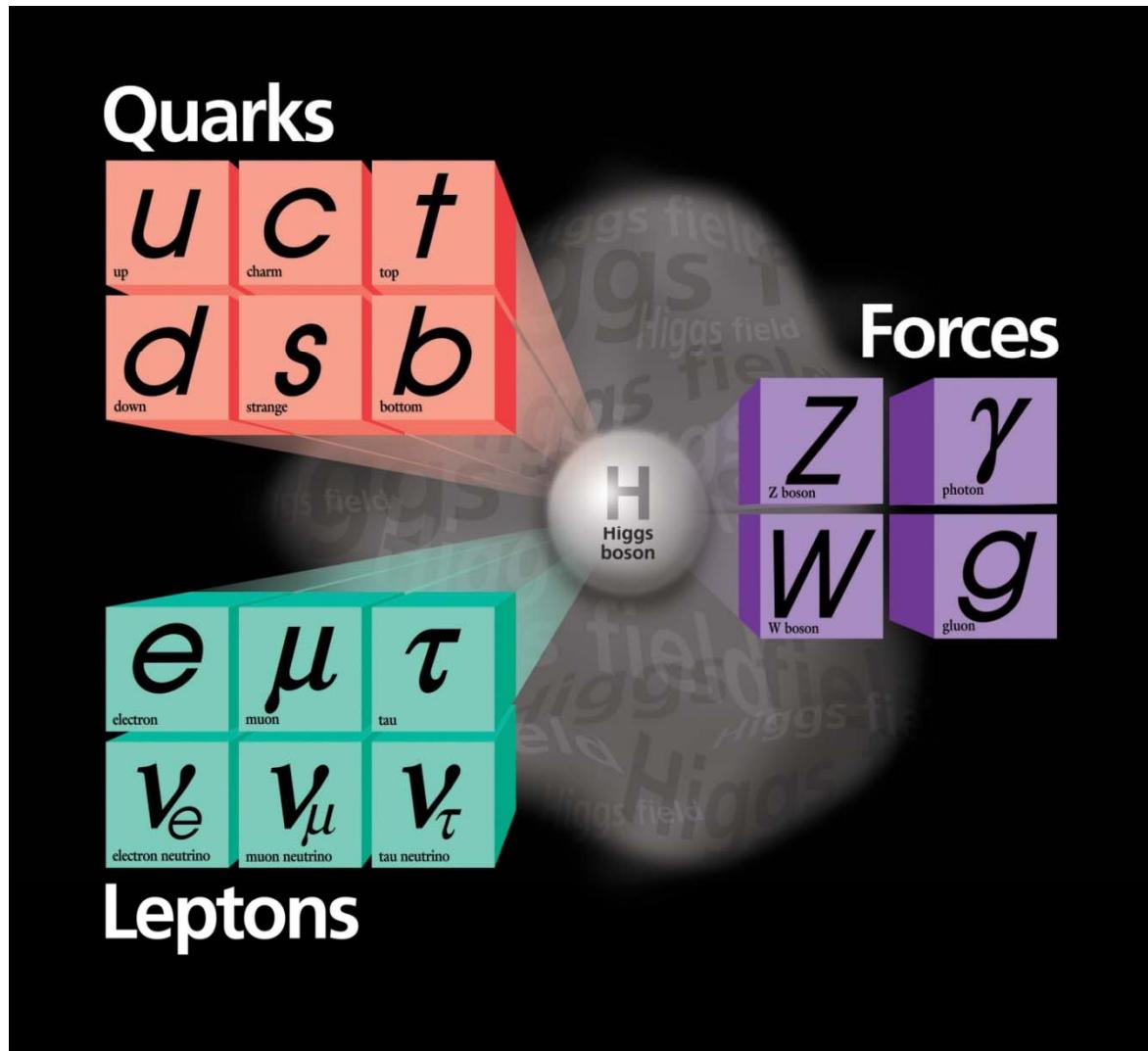
Event with longer decay length

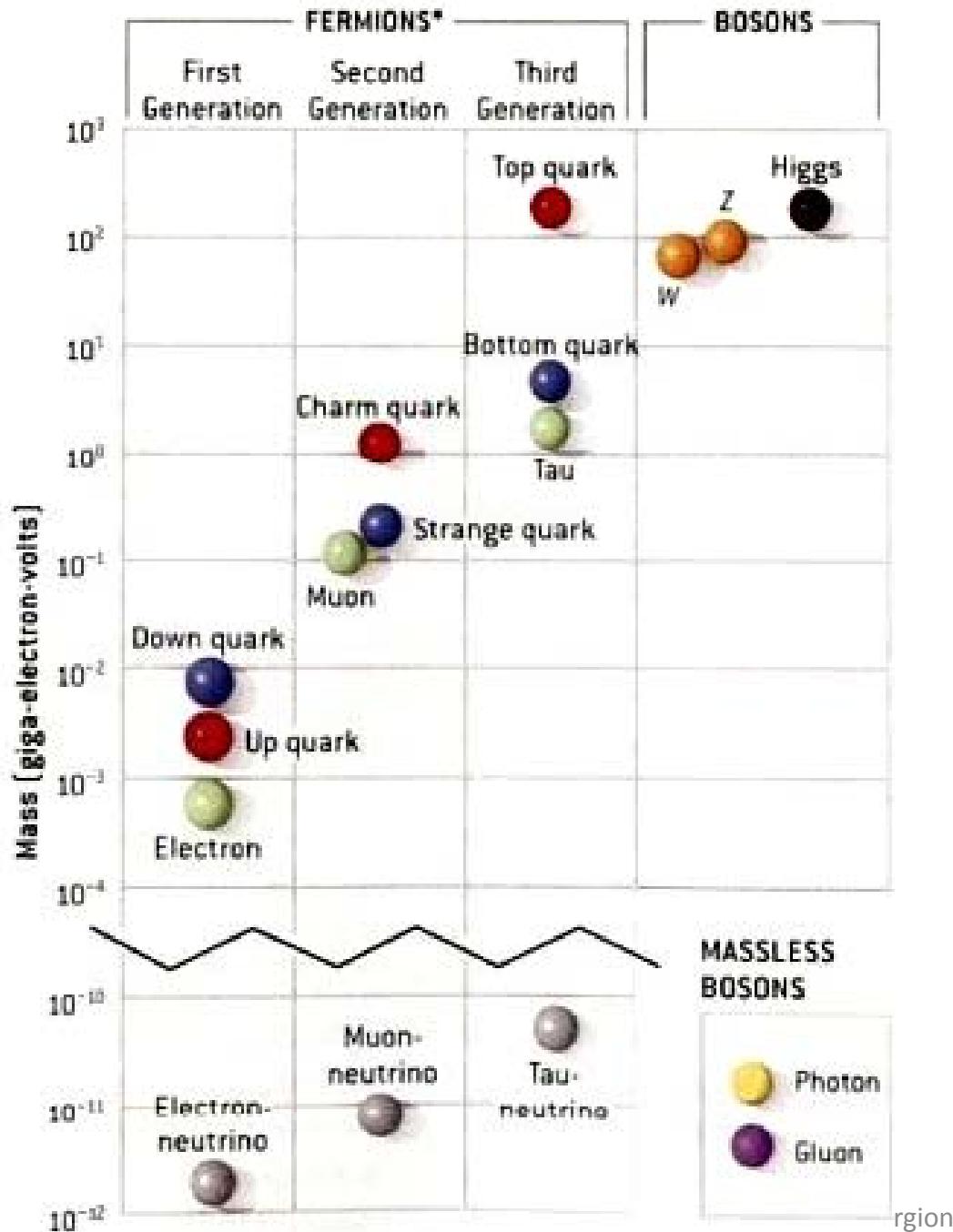
# The real theoretical tool

- The Astrophysical Journal, 613:1285-1301, 2004 October 1
- **Tau Air Showers from Earth**
- D. Fargion ,<sup>1,2</sup> P. G. De Sanctis Lucentini ,<sup>1</sup> M. De Santis ,<sup>1</sup> and M. Grossi <sup>1</sup>

# Leptons and Neutrinos Now

- [https://en.wikipedia.org/wiki/Tau\\_\(particle\)zzzz](https://en.wikipedia.org/wiki/Tau_(particle)zzzz)





# The Yukawa puzzle and the neutrino mass splitting and their mix angle

# Pontecorvo-Maki-Nakagawa-Sakata Matrix

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix}
 \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{bmatrix}
 \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}
 = 
 \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{CP}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{CP}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{CP}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{CP}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{CP}} & c_{23}c_{13} \end{bmatrix}$$

# SK MIXING (1997-98) OFFERING to TAU a chance

The Astrophysical Journal, 570:909-925, 2002 May 10.

Discovering Ultra High Energy Neutrinos  
Through Horizontal and Upward  
Air Showers: Evidence in Terrestrial Gamma Flashes?

D. Fargion<sup>1,2</sup>

*Received 1997 November 11; arxiv Feb 2000*

*accepted 2002 January 22*

*2002: Tau by AUGER Bertou; 2002*

*Skimming neutrino by Feng, Wilzeck..*

# Tau Neutrino Astronomy

- Why Tau is better? A fine tuned gift by Nature...

- Neutrino electron do not leave long trace+ atmospheric
- Muon is very penetrating, but unique (**no-shower**) + atmospheric
- Both electron and muon are mainly atmospheric
- Tau , even with mixing, is not atmospheric **above 100GeV**

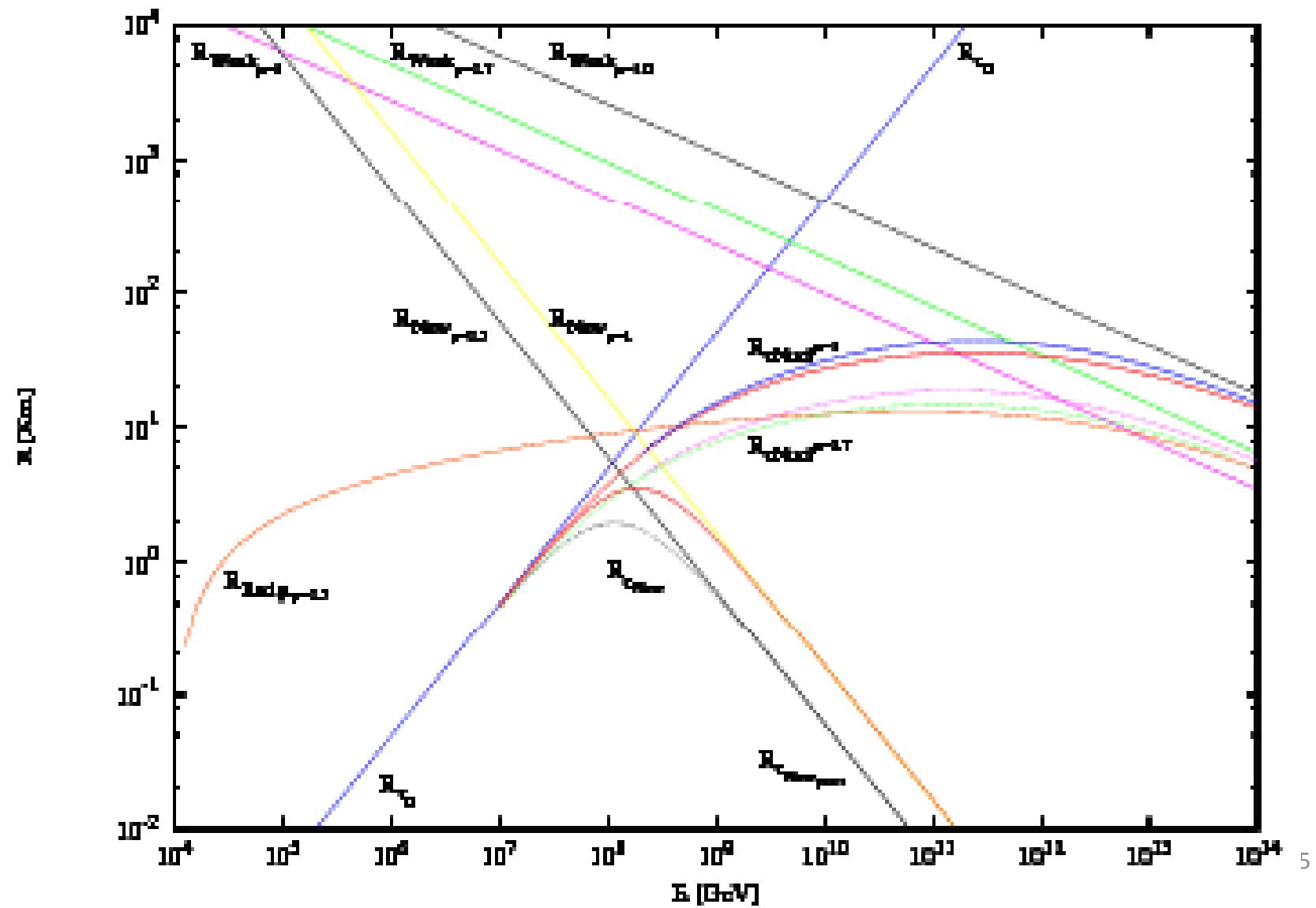
**..tau is longer and longer ..overcoming muon track**

**and once in air it makes tau AIR-SHOWER:: A NATURAL neutrino AMPLIFIER , BOTH IN NUMBER AND IN SIZE...making easy the detection.**

**Tau neutrino may naturally be born by muon or electron by random oscillation and mix along interstellar and galactic distances: possible by Tiny neutrino mass splitting...(if neutrino mass splitting was larger or much small, or if tau was much or less heavier..no such**

**A tau Airshower possibility)..a miracle....a gift**

# Tau EeV winning lengths



# Updated tau Propagation lenght

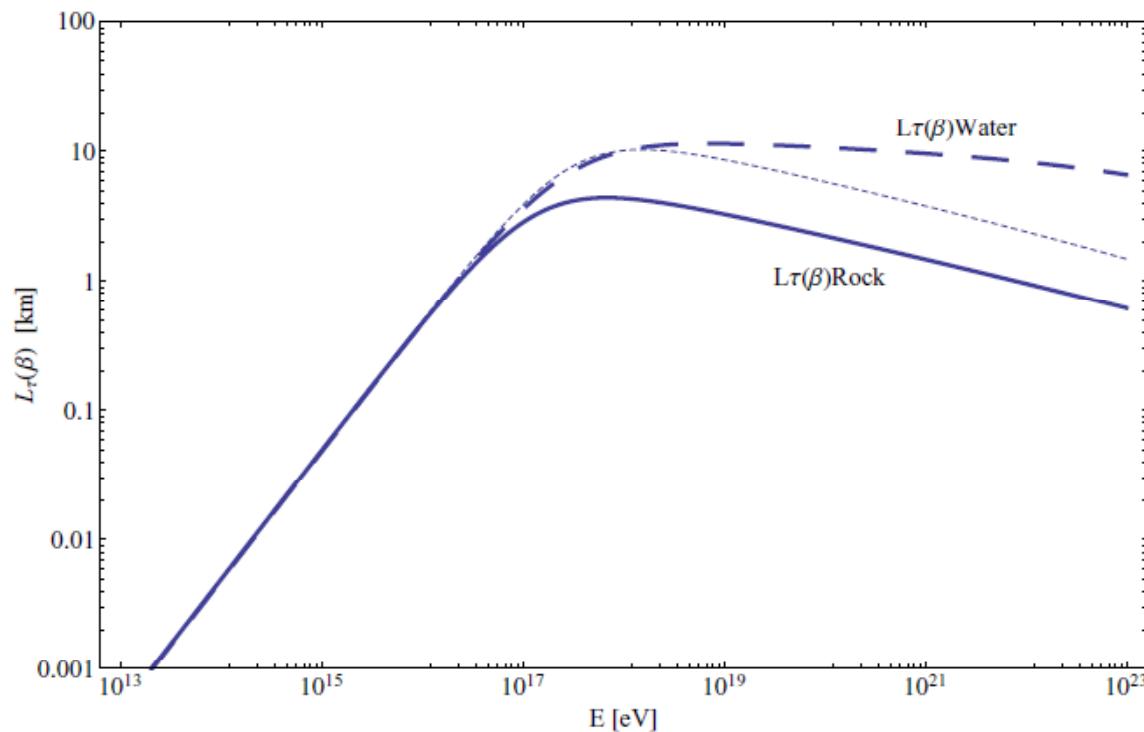


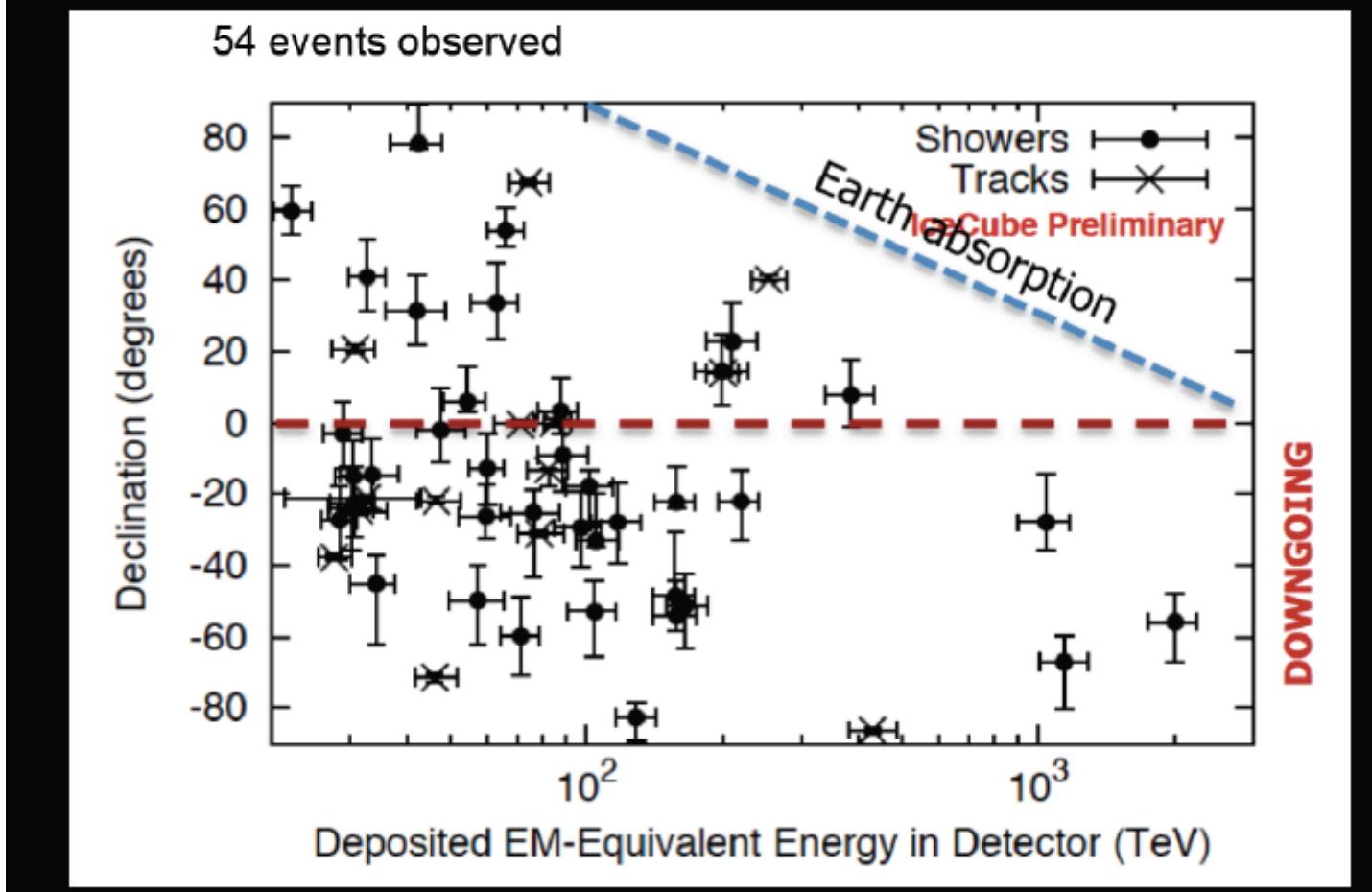
Figura 6.15: Lunghezze di propagazione  $L_{\tau(\beta)}$  nei casi in cui l'ultimo strato attraversato sia roccia o acqua. La curva a punti è relativa al calcolo sovrastimato presente in [70] per la roccia, e qui corretto.  
cris\_2015\_fargion

# Other Tau AUGER estimate based on Montecarlo, AUGER Surface detector

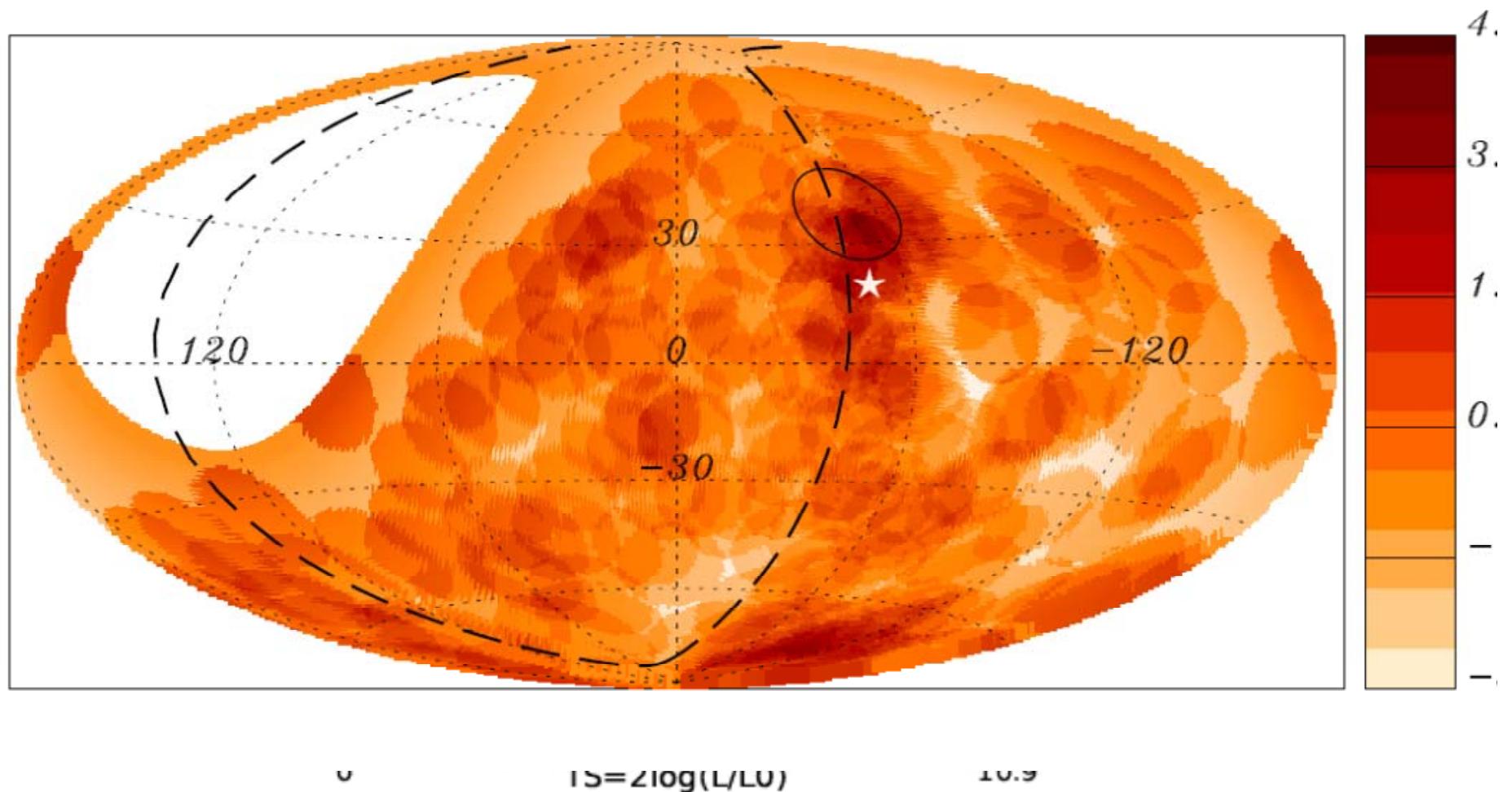
- [Earth-skimming UHE tau neutrinos at the fluorescence ...](#)  
di C Aramo - 2005
- [The aperture for UHE tau neutrinos of the Auger ...](#)
- di G Miele - 2006
- **An improved limit to the diffuse flux of ultra-high energy neutrinos from the Pierre Auger Observatory**
- ***Phys. Rev. D 91, 092008 (2015)***
- **D.F., Coherent and random UHECR Spectroscopy of Lightest Nuclei along CenA: Shadows on GZK Tau Neutrinos spread in a near sky and time**  
**NIMA , 51778 PII: S0168-9002(10)01230-1, 2010**

# ICECUBE 4 years

## High Energy Starting Events (4 yr)

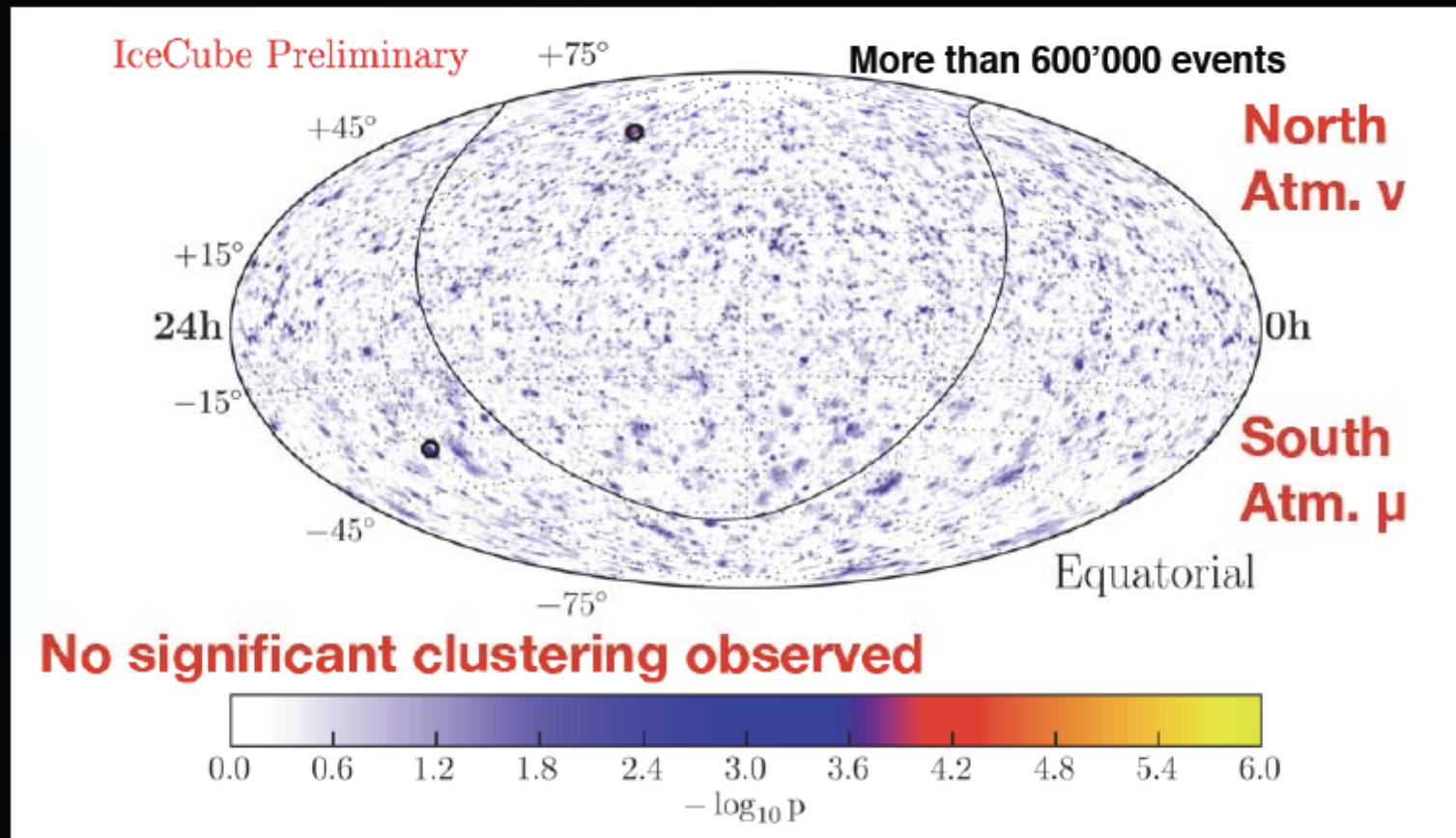


# Overlapping Highest and Lower UHECR part of UHECR fragment in neutrinos?



# Atmosphere noise ruling

6 yr (1700 d) of point source searches



ASHRA at the top in Hawaii-2005-2015  
PeVs Cherenkov, see also Gora et all, 2015. and  
DF 2007-8



# ICECUBE 2011-2015

## UHE astrophysical neutrinos

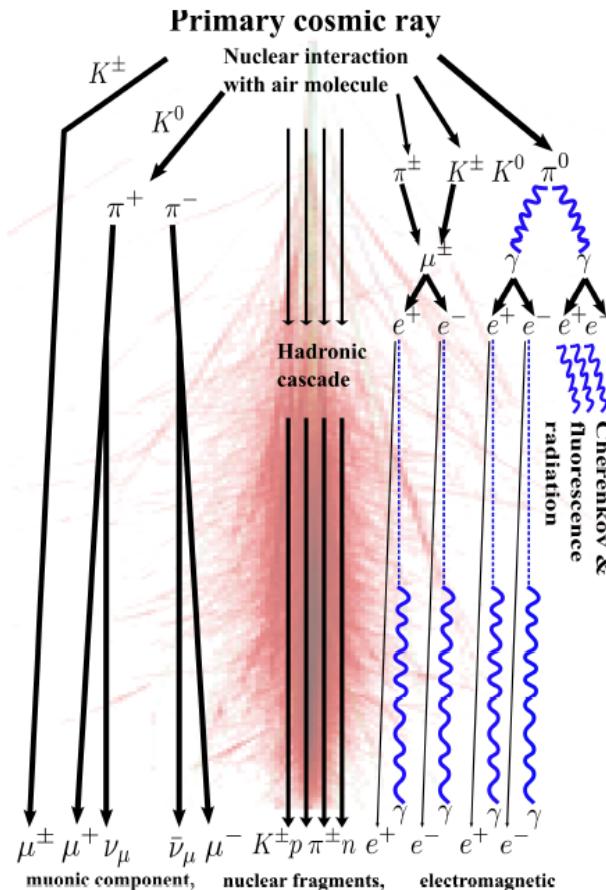
- **Neutrino Telescope Array Letter of Intent: A Large Array of High Resolution Imaging Atmospheric Cherenkov and Fluorescence Detectors for Survey of Air-showers from Cosmic Tau Neutrinos in the PeV-EeV Energy Range; [Makoto Sasaki](#), [George Wei-Shu Hou](#)**

Neutrino by Sun and CR: atmospheric neutrino..

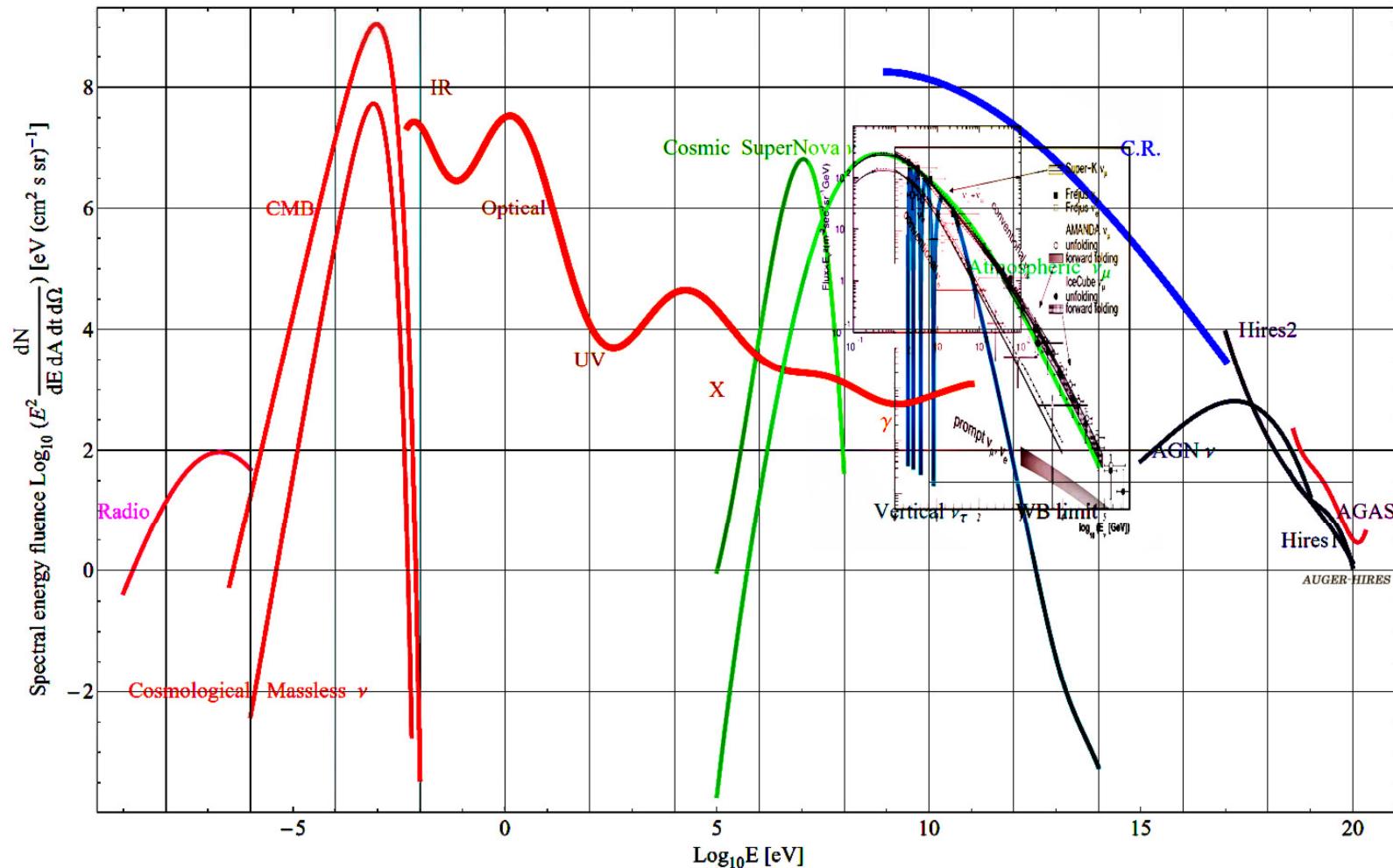
Remember: tau mass energy threshold 4 GeV

Remember: tau oscillation max across the Earth

See: Beaming Neutrino across the Earth



# Energy fluence



# Tau appearance 2015

- Discovery of the TAU Neutrino appearance

The first tau neutrino was observed in 2010. The second and third events were reported in 2012 and 2013, respectively, while the fourth one was published in 2014. The last ***fifth 2015***

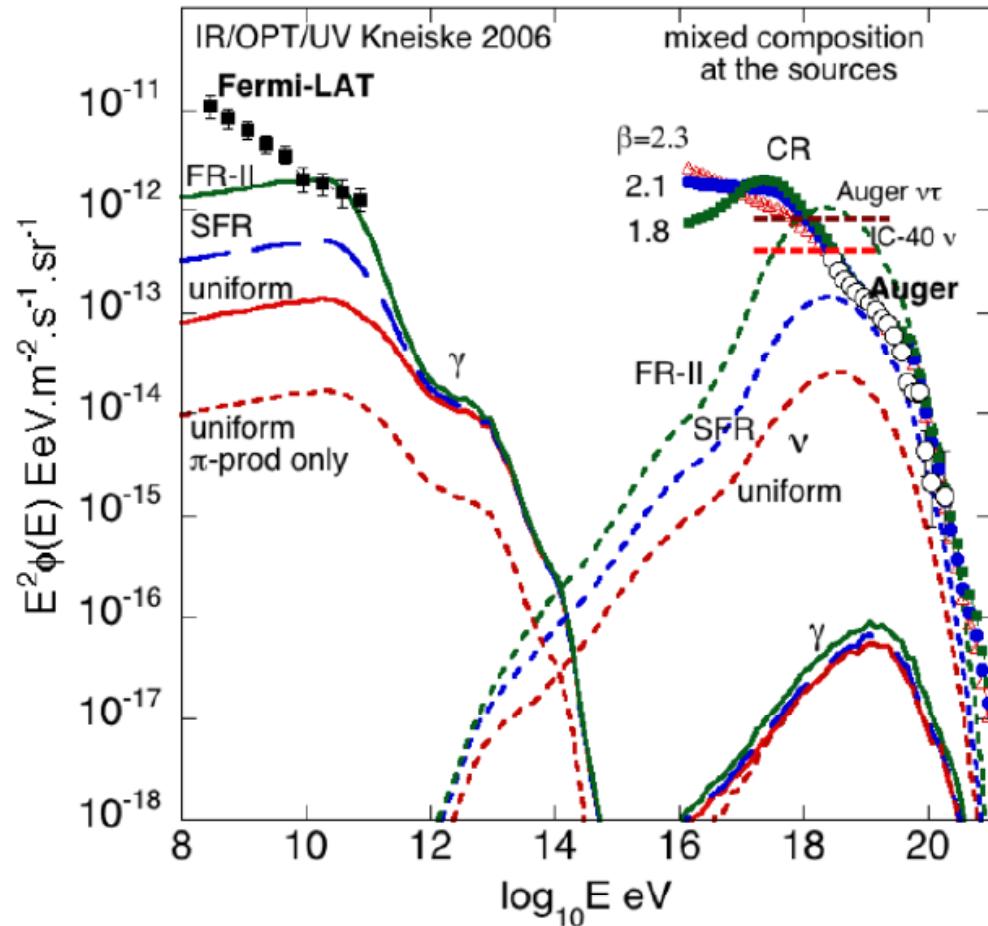
By OPERA-CERN.

*Much interesting a Beaming neutrino across  
The Earth for tau and anti-tau appearance test*

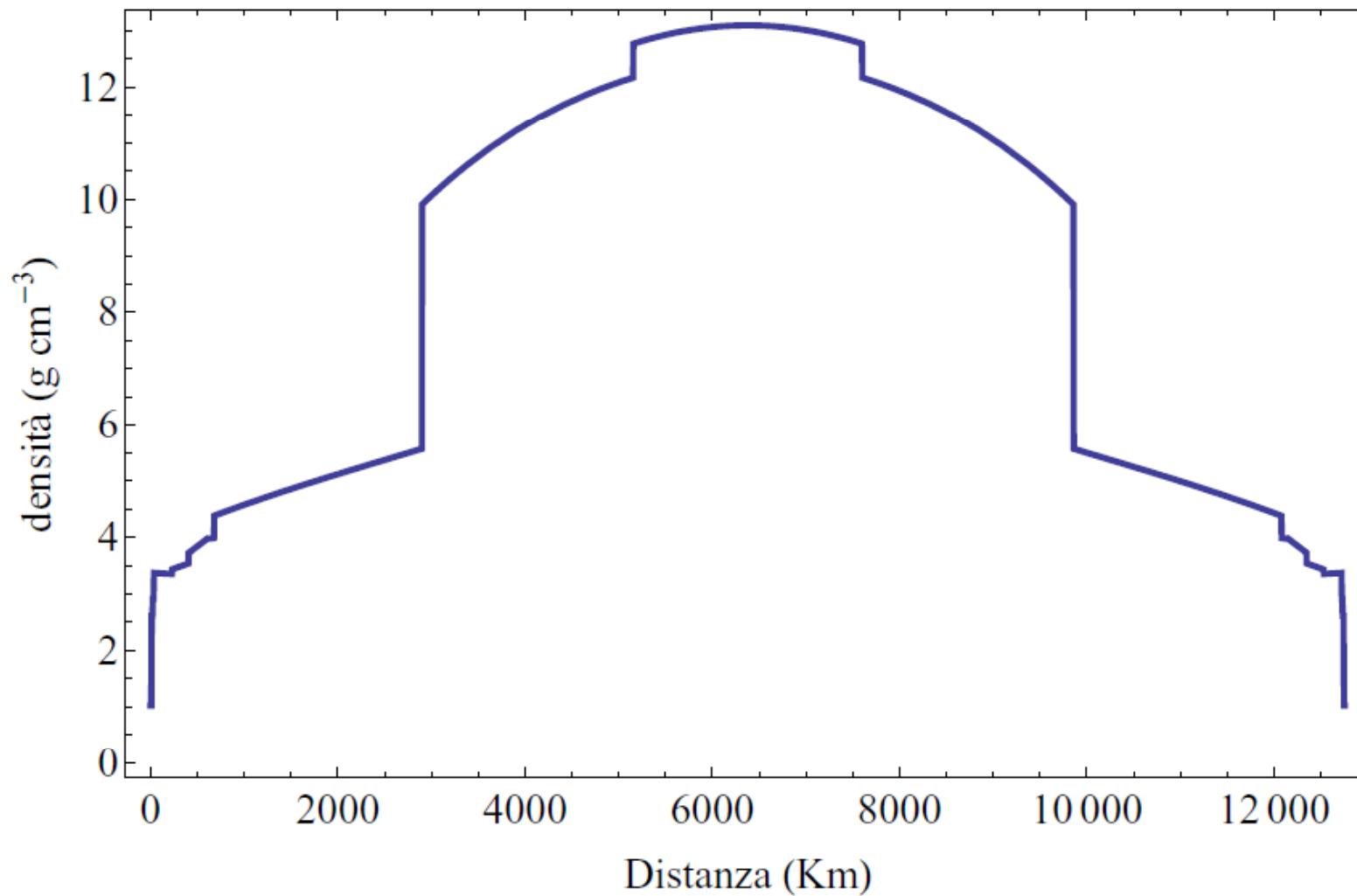
*DF et al Apj 2012*

# UHECR GZK proton and neutrino..

## An old 2011 expectation..today forgot



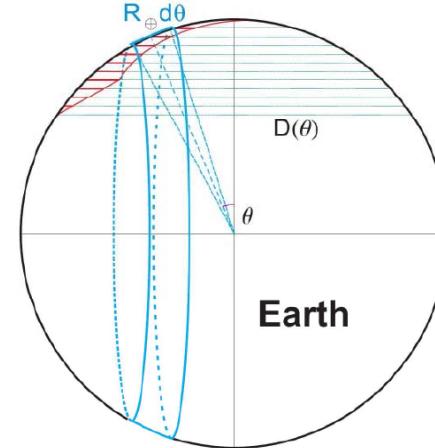
# Earth density profile: The Earth Shadow



# UHE Tau Airshower anisotropy



# Earth skin by skimming nu tau



Il volume efficace viene calcolato per unità di superficie di rivelazione a terra, così da poterlo estendere a qualsiasi esperimento: [70]

$$\frac{V_{tot}(E_\nu)}{A} = \frac{V_{tot\oplus}(E_\nu)}{2\pi R_\oplus^2} = \int_0^{\pi/2} \int_0^{D(\theta)} e^{-\frac{(D(\theta)-x)}{L_{\nu CC}(E_\nu)}} e^{-\frac{x}{l_\tau(E_\tau)}} \cos(\theta) \sin(\theta) d\theta dx \quad (6.2)$$

e corrisponde al prodotto delle probabilità di interazione del neutrino e di sopravvivenza del leptone, per i fattori che descrivono la geometria del problema. Integrando nella distanza, si ottiene:

$$\frac{V_{tot}(E_\nu)}{A} = \left( \frac{l_\tau(E_\tau)}{1 - \frac{l_\tau(E_\tau)}{L_\nu(\eta E_\tau)}} \right) \int_0^{\pi/2} e^{-\frac{(D(\theta))}{L_{\nu CC}(\eta E_\tau)}} - e^{-\frac{x}{l_\tau(E_\tau)}} \cos(\theta) \sin(\theta) d\theta \quad (6.3)$$

# Earth Shadow

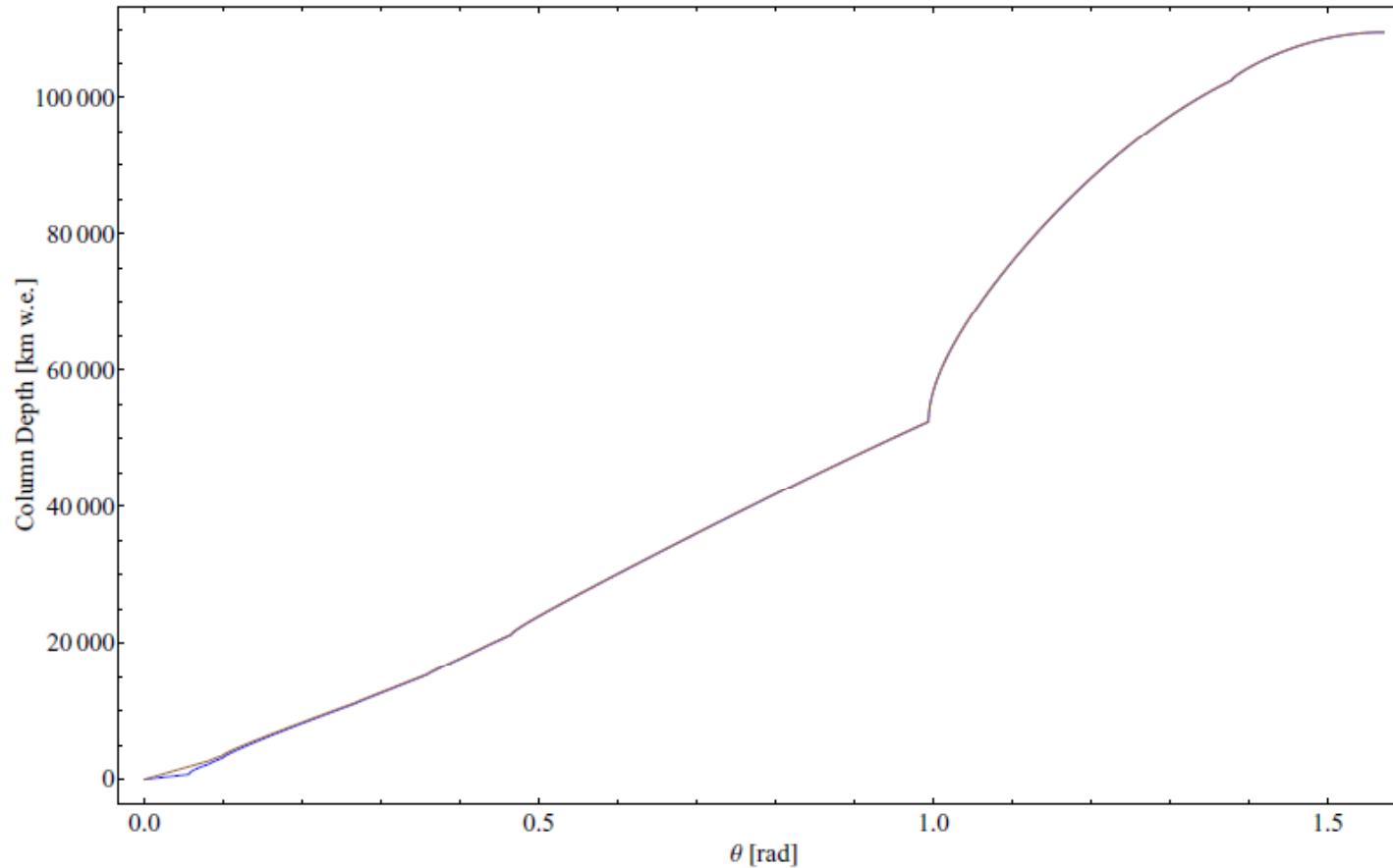


Figura 6.9: Spessore di massa in funzione dell'angolo di arrivo  $\theta$ , ricavata dal modello [63], espresso in km equivalenti d'acqua.

# Rock or water?

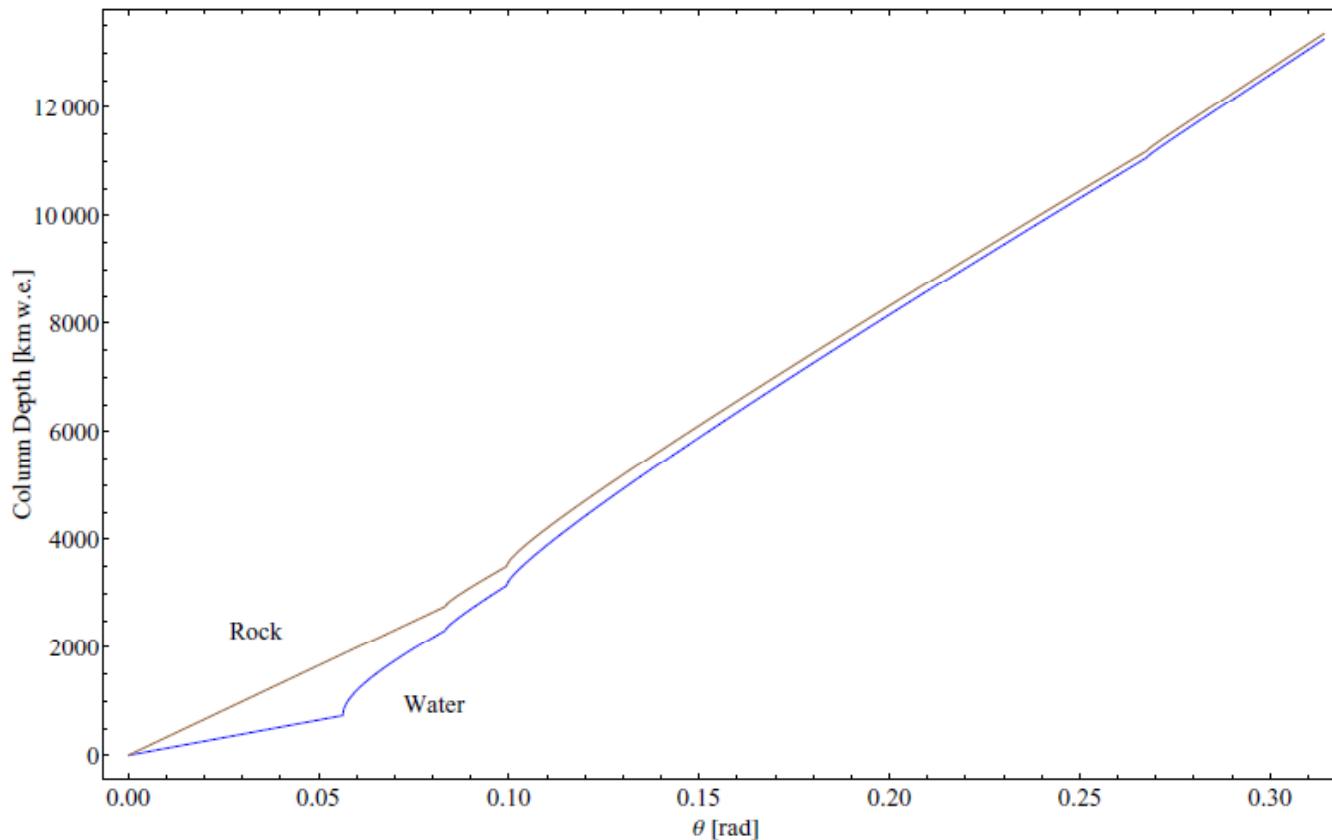


Figura 6.10: Ingrandimento della fig. 6.9 a piccoli angoli. Da osservare la differenza dovuta all'ultimo strato attraversato dal  $\tau$ .

# Cross sections

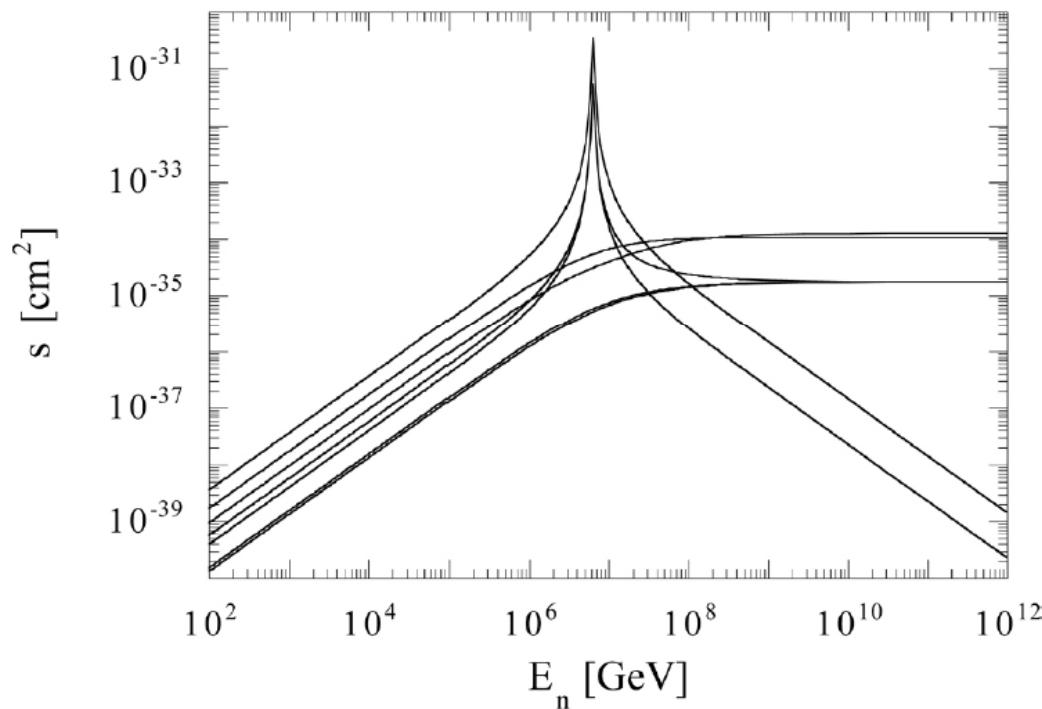


Figura 6.12: Sezione d'urto di interazione CC di neutrino su elettrone, [68]. A basse energie, dalla più grande alla più piccola sezione d'urto, i processi sono: (1)  $\bar{\nu}_e + e \rightarrow \text{adroni}$ , (2)  $\nu_\mu + e \rightarrow \mu + \nu_e$ , (3)  $\nu_e + e \rightarrow \nu_e + e$ , (4)  $\bar{\nu}_e + e \rightarrow \bar{\nu}_\mu + \mu$ , (5)  $\bar{\nu}_e + e \rightarrow \bar{\nu}_e + e$ , (6)  $\nu_\mu + e \rightarrow \nu_\mu + e$ , (7)  $\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$

# Hadron and lepton interactions

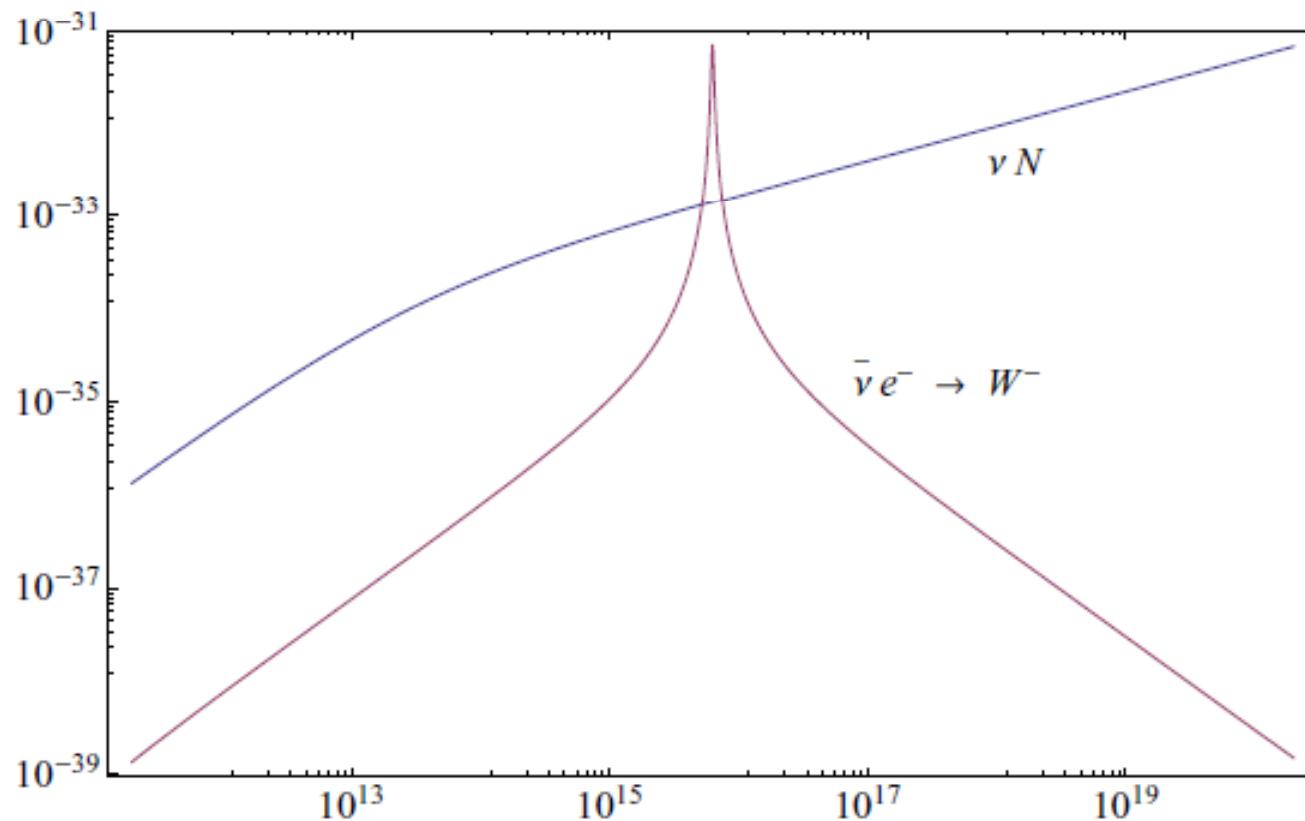


Figura 6.13: Confronto tra le sezioni d'urto  $\nu + N$  e  $\nu + e^-$ .

# Energy losses

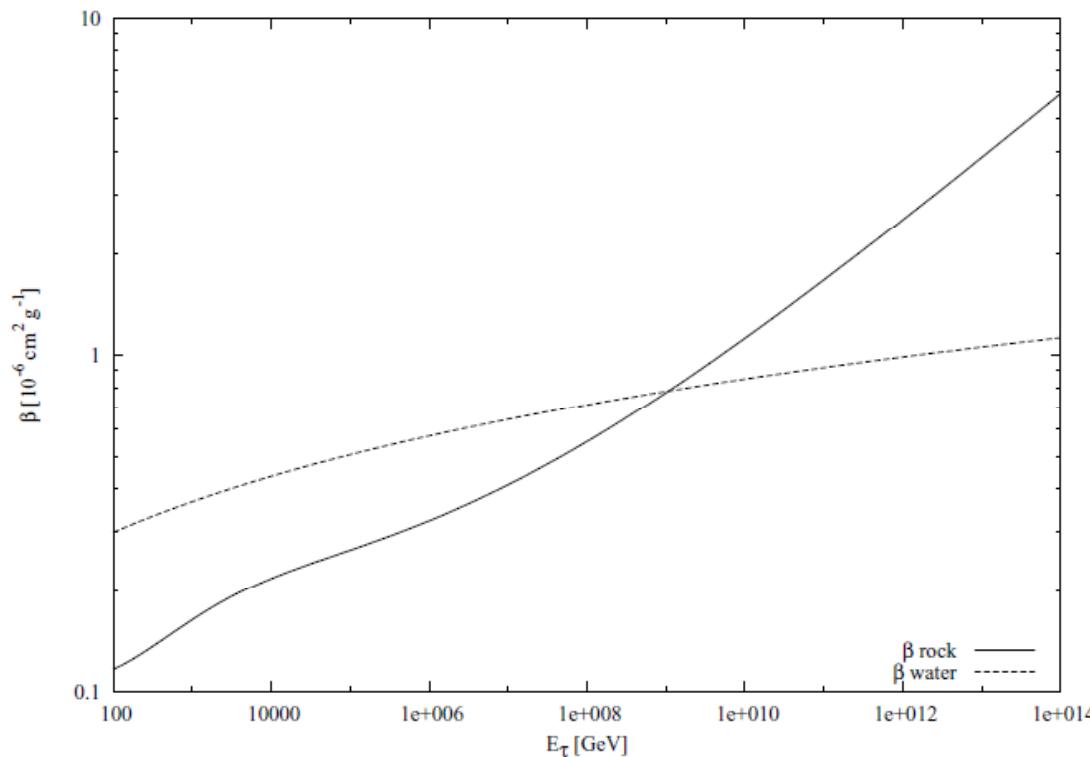


Figura 6.14: Perdita di energia per il leptone  $\tau$  dovuta a reazioni foto-nucleari, produzione di coppie e bremsstrahlung  $\beta$ , in funzione dell'energia, in roccia e in acqua [70]. Ad alte energie, superiori a  $10^{18} \text{ eV}$  è fatta un'estrapolazione rispetto alle formule descritte in [70], come descritto in [82], da cui la presente figura.

# Propagation lenght

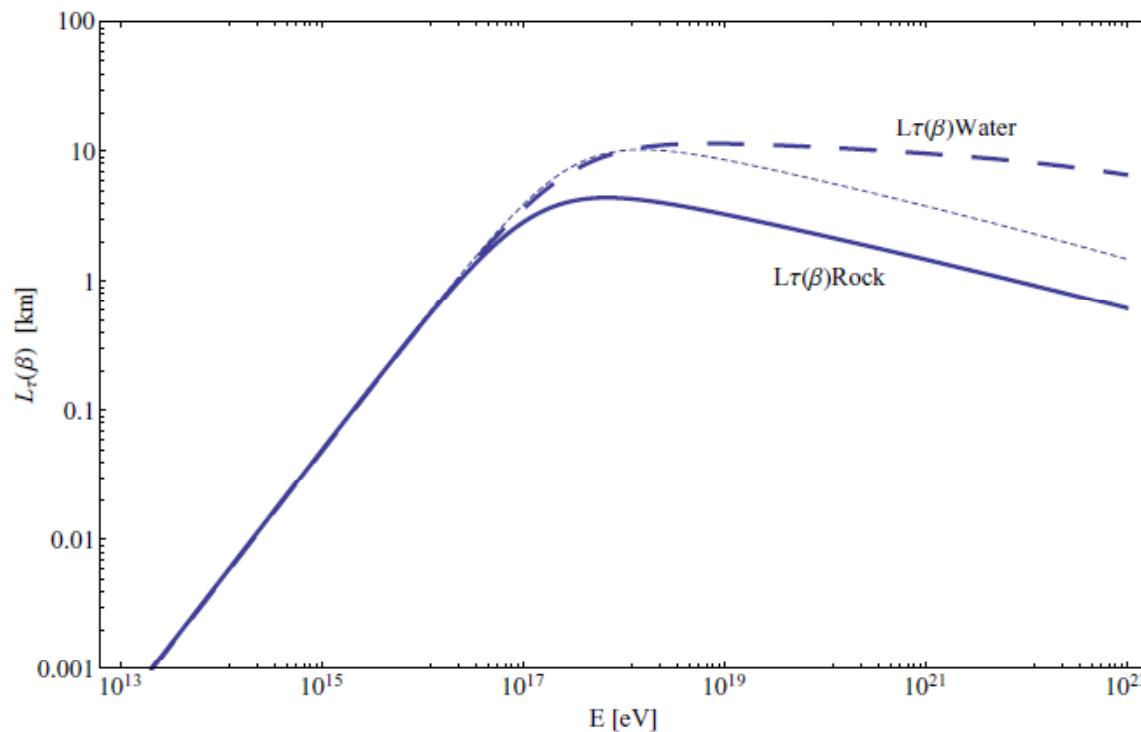


Figura 6.15: Lunghezze di propagazione  $L_{\tau(\beta)}$  nei casi in cui l'ultimo strato attraversato sia roccia o acqua. La curva a punti è relativa al calcolo sovrastimato presente in [70] per la roccia, e qui corretto.  
cris\_2015\_fargion

# Propagation lenght of tau

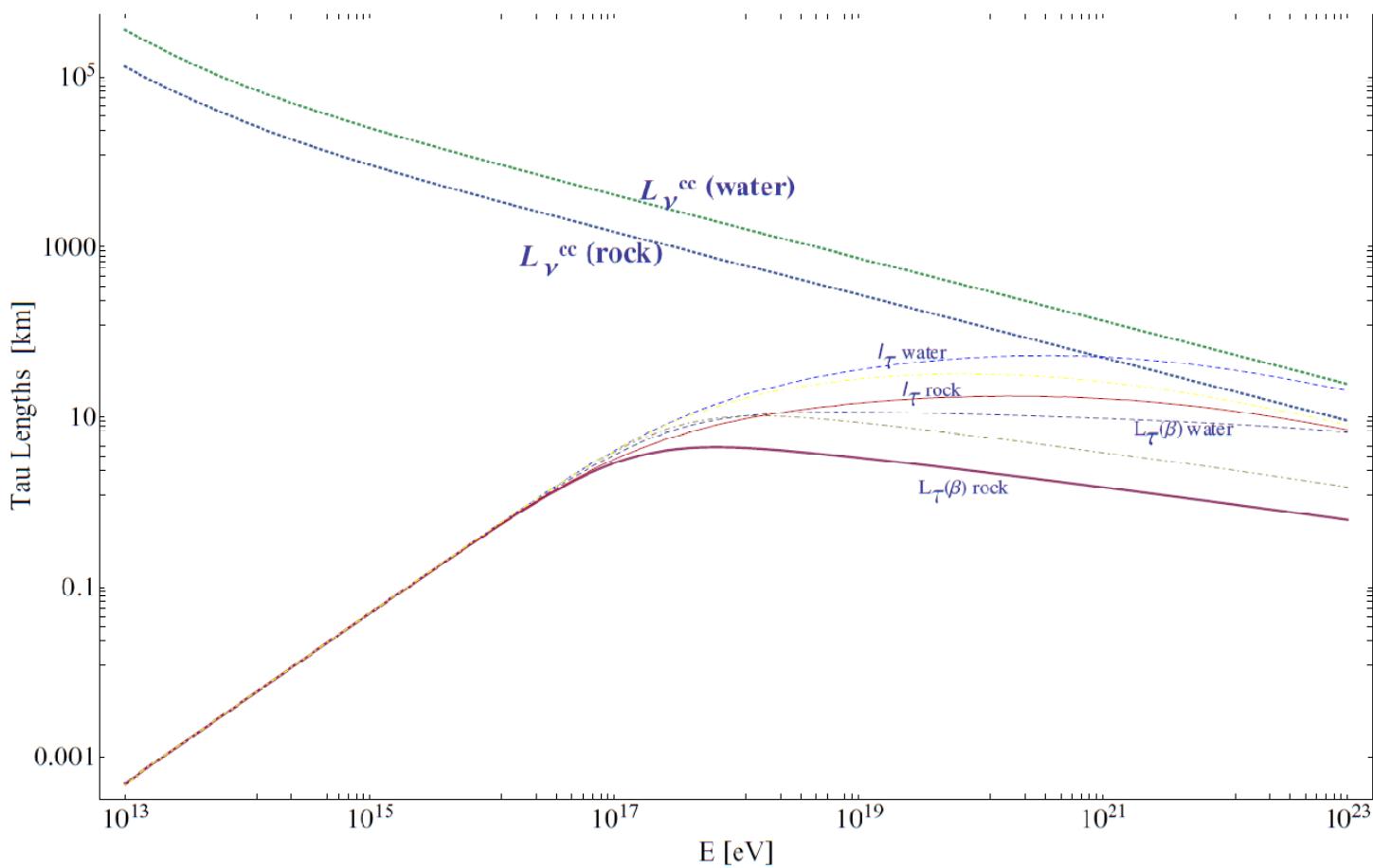


Figura 6.16: Lunghezze di propagazione del  $\tau$ :  $L_{\tau(\beta)}$ ,  $l_\tau$  e le lunghezze caratteristiche di interazione CC  $L_{\nu^{CC}}$ .

# Updated effective volume estimate-water-rock

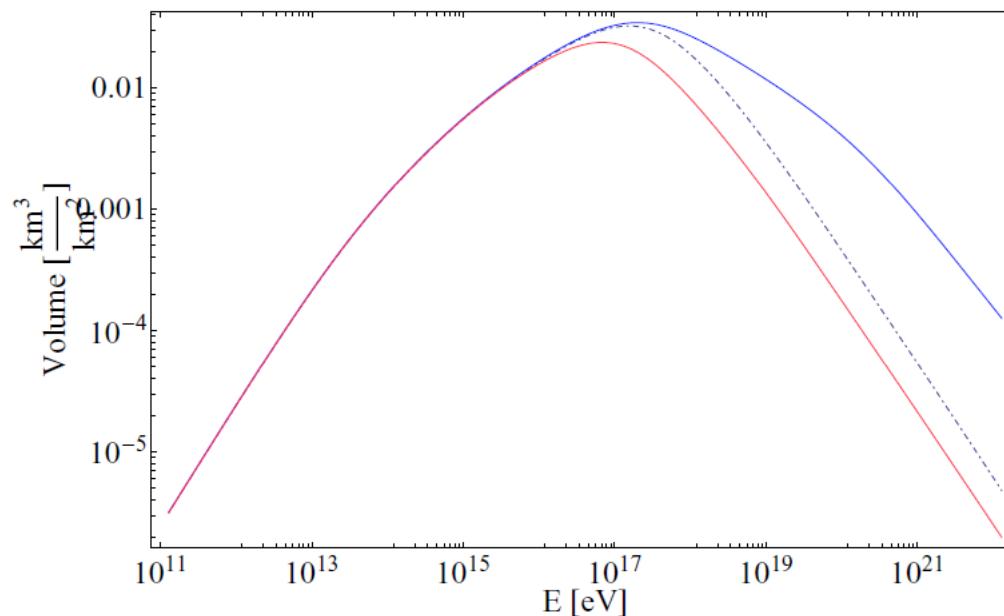


Figura 6.17: Volume effettivo di interazione del  $\tau$ , in funzione dell'energia finale  $E_{\tau f}$  per unità di area. Viene riportato in tratteggio la curva riferita all'ultimo strato di roccia [70], ed in rosso il nuovo calcolo corretto. In blu è il volume corrispondente al caso in cui l'ultimo strato è d'acqua.

CMS\_2013\_Rapporto

# Area Volume effective mass

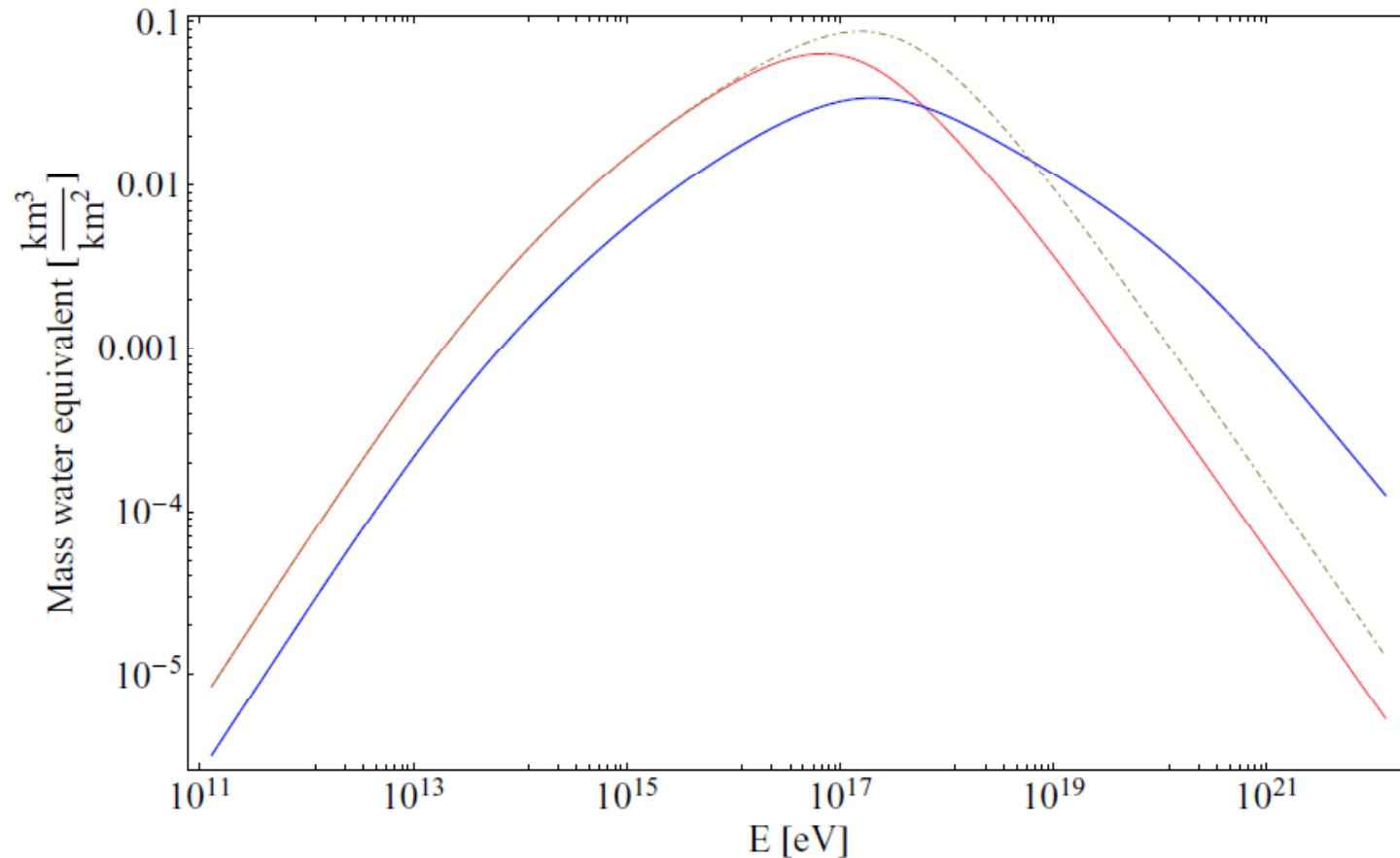


Figura 6.18: Massa effettiva d'interazione, in  $\text{Km}^3/\text{Km}^2$  quivalenti d'acqua.

# Neutrino Flux and interactions

Il numero di eventi da  $\nu_\tau$ , si stima al solito con:

$$\frac{dN}{d\Omega dt} = \int \frac{dN_\nu}{dE_{\eta\nu} d\Omega dA dt} \sigma_{\nu N}(\eta E_\tau) n \rho_r V_{tot}(E_\tau) dE_\tau \quad (7.1)$$

# Rates in 3 years WB

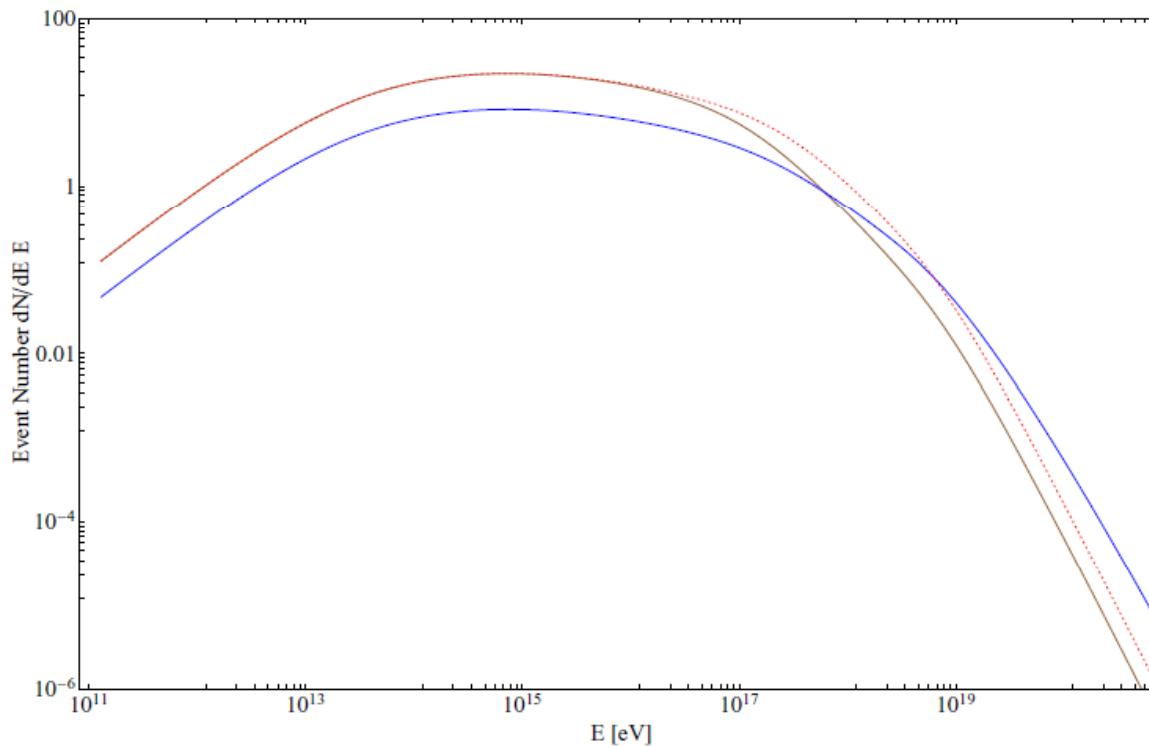


Figura 7.1: Numero di eventi da  $\nu_\tau$  in 3 anni per una superficie totale di rivelazione di  $3000 \text{ km}^2$ . In tratteggio è il calcolo per l'ultimo strato costituito da roccia, da [70], qui corretto. In marrone è l'ultimo strato di roccia, in blu d'acqua.

# The real rate: Ground and Fluorescence

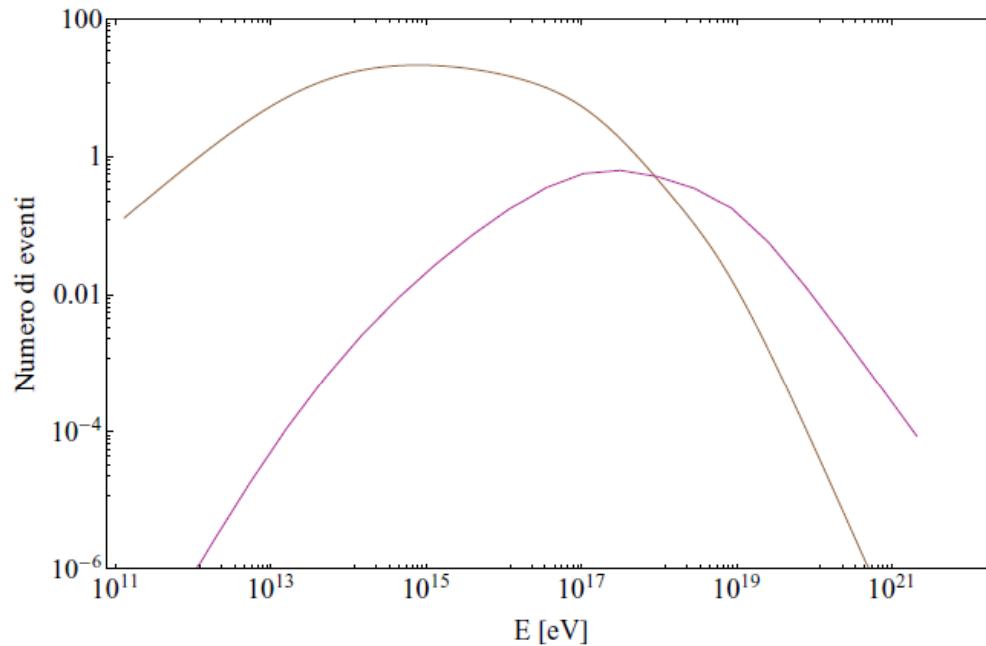


Figura 7.3: Numero di eventi da  $\nu_\tau$  come in fig. 7.1 per l'ultimo strato di roccia. La curva più bassa è riferita al numero di eventi osservabili da telescopi fluorescenza, (già soppressi del 10%), la curva marrone più alta è riferita al numero osservabili dal Surfare Detector, in funzione dell'energia.

# Angular distribution

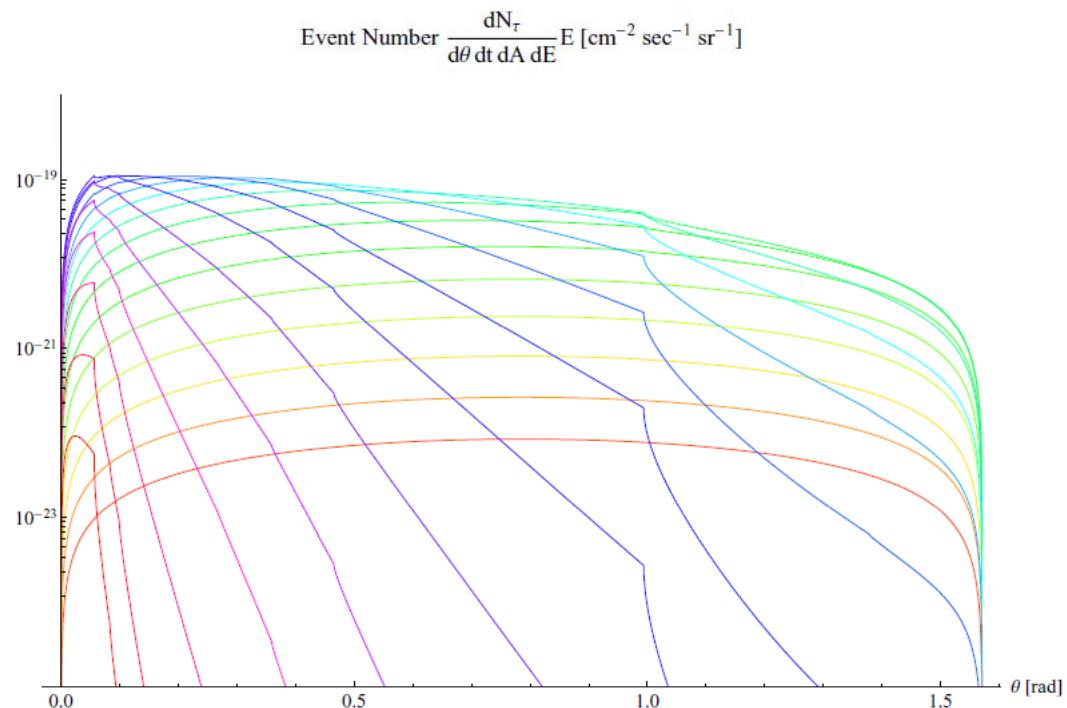


Figura 7.4: Eventi differenziali, in funzione dell'angolo di osservazione sotto l'orizzonte, in cui l'ultimo strato è di acqua. Le curve coprono un intervallo di energia che va da  $10^{11}$  a  $10^{21}$  eV, e sono distanziate da mezzo ordine di grandezza l'una dall'altra.

# Rock soil

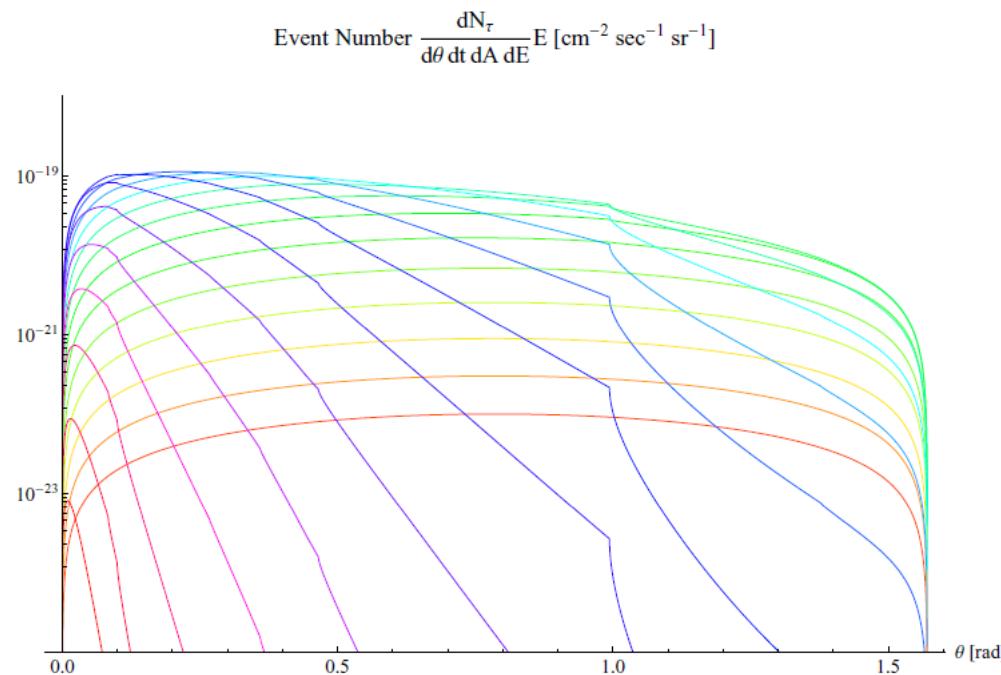


Figura 7.5: Eventi differenziali, in funzione dell'angolo di osservazione sotto l'orizzonte, in cui l'ultimo strato è di roccia. Le curve coprono un intervallo di energia che va da  $10^{11}$  a  $10^{21}$  eV.

# Fluorescence

Energia media	$6.3 \cdot 10^{15}$	$1.18 \cdot 10^{16}$	$3.54 \cdot 10^{16}$	$1.06 \cdot 10^{17}$	$3.2 \cdot 10^{17}$	$9.5 \cdot 10^{17}$	$2.87 \cdot 10^{18}$
Eventi	0.07	0.08	0.18	0.28	0.32	0.26	0.17

Tabella 7.1: Numero di eventi nel rivelatore a fluorescenza di Auger, integrati in 3 anni, da  $6.3 \cdot 10^{15}$  a  $2.87 \cdot 10^{18}$  eV.

La somma degli eventi nell'intervallo da  $6.3 \cdot 10^{15}$  a  $2.87 \cdot 10^{18}$  eV è quindi circa 1.3, in 3 anni. Gli eventi ad altri valori di energia sono trascurabili.

# Glashow resonance events

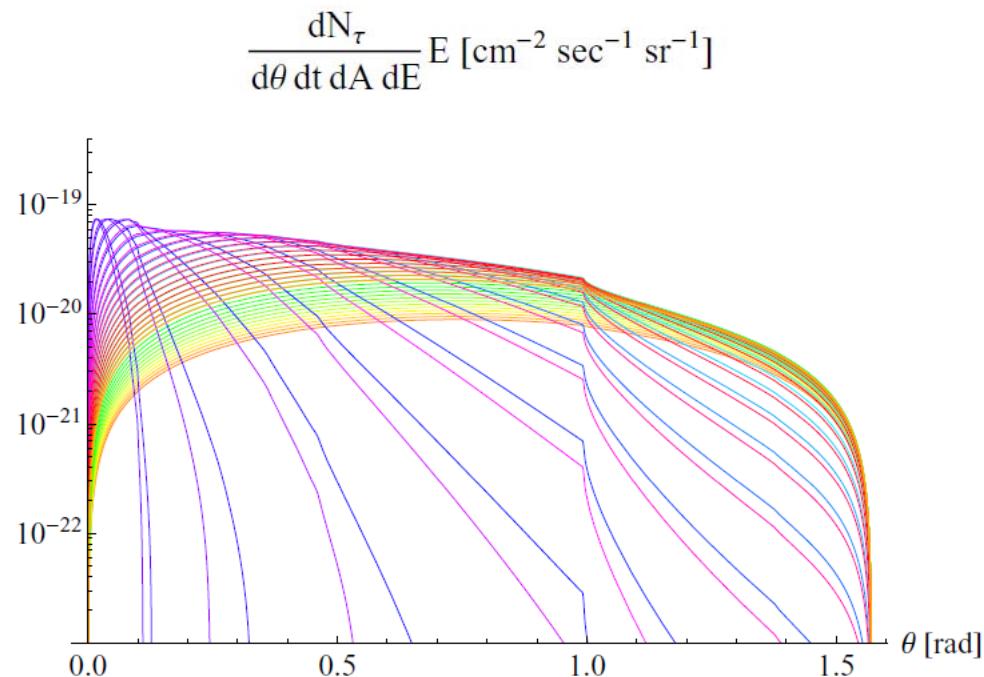


Figura 7.7: Eventi differenziali prodotti dalla risonanza  $\bar{\nu}_e e^- \rightarrow W^- \rightarrow \tau \nu_\tau$ , in funzione dell'angolo sotto l'orizzonte. Le curve coprono un intervallo di energia che va da  $3.15 \cdot 10^{15} \text{ eV}$ .

# All event flux for square Km

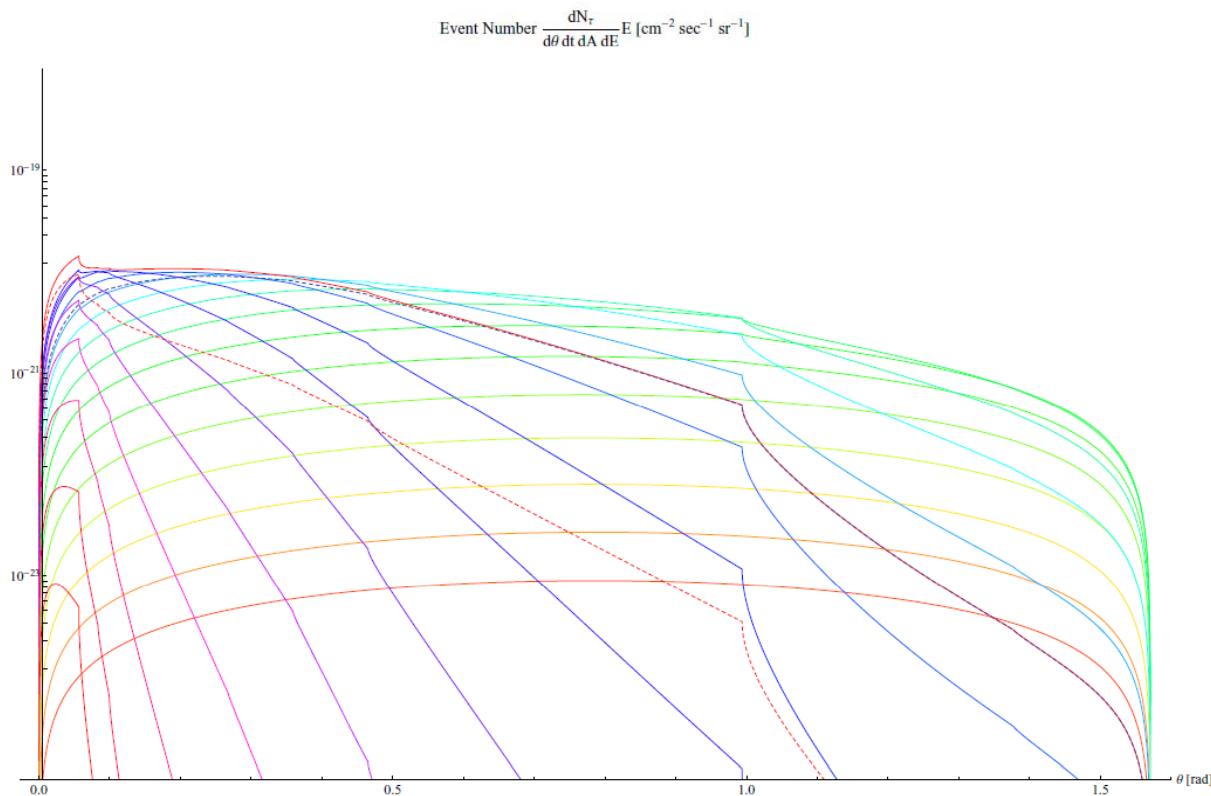


Figura 7.8: Eventi differenziali, in funzione dell'angolo sotto l'orizzonte, dove si può notare il contributo della risonanza  $\bar{\nu}_e e^- \rightarrow W^- \rightarrow \tau \bar{\nu}_\tau$ , in tratteggio rosso, e la somma degli eventi con e senza gli eventi di risonanza. Le curve coprono un intervallo di energia che va da  $10^{11}$  a  $10^{21}$  eV.

# Rate for 3 years in AUGER

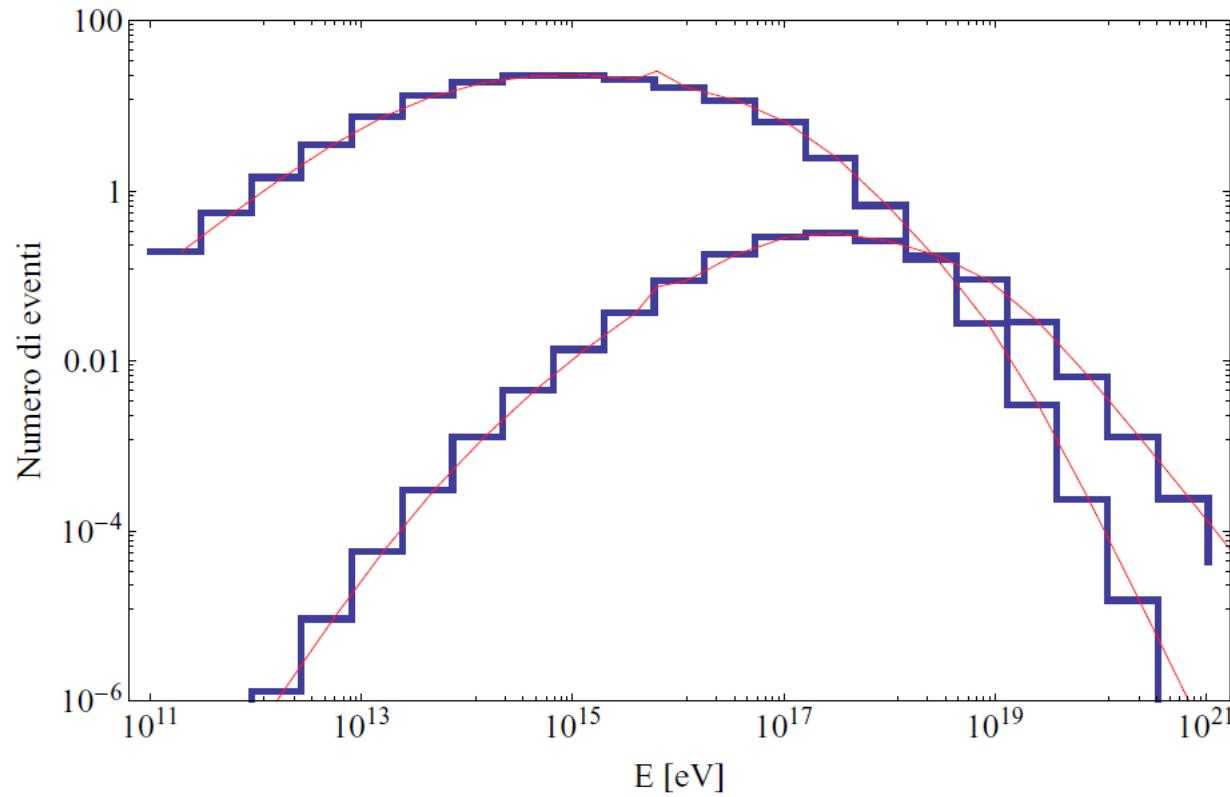
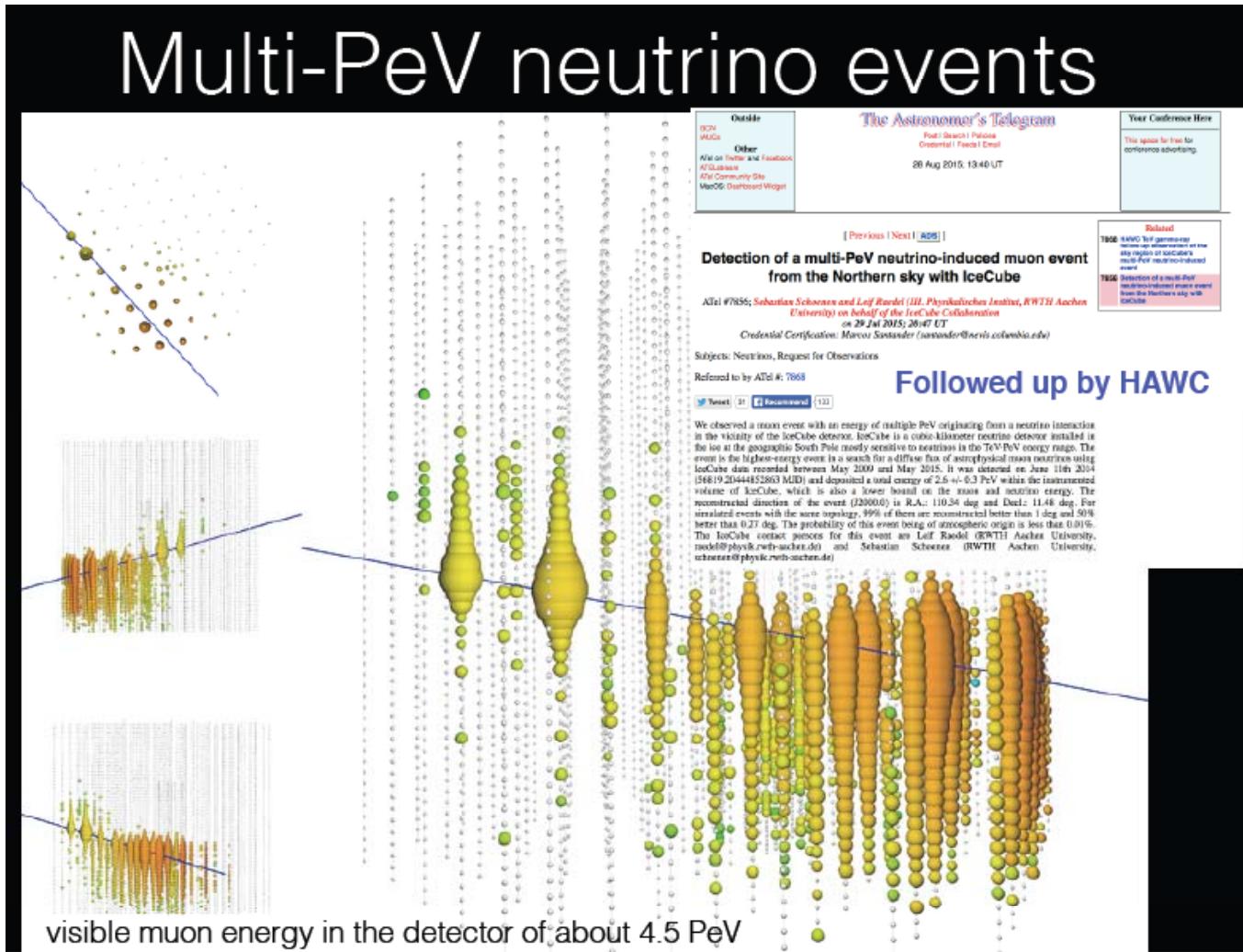


Figura 7.9: Numero di eventi, in funzione dell'energia, dove si può notare il contributo della risonanza  $\bar{\nu}_e e^- \rightarrow W^- \rightarrow \tau \nu_\tau$ , all'energia di  $6.3 \cdot 10^{15} eV$ . In blu sono gli stessi eventi visualizzati nei relativi intervalli di energia, di larghezza pari all'energia media, come descritto nel testo. La curva più alta è relativa al rivelatore di superficie SD, e quella più bassa ai rivelatori a fluorescenza, come in fig. 7.3.

# ICECUBE neutrino updated: Finally an 4.5 PeV neutrino



# Part of the subject REFLECTING tau PeV airshower



# Cloud screen



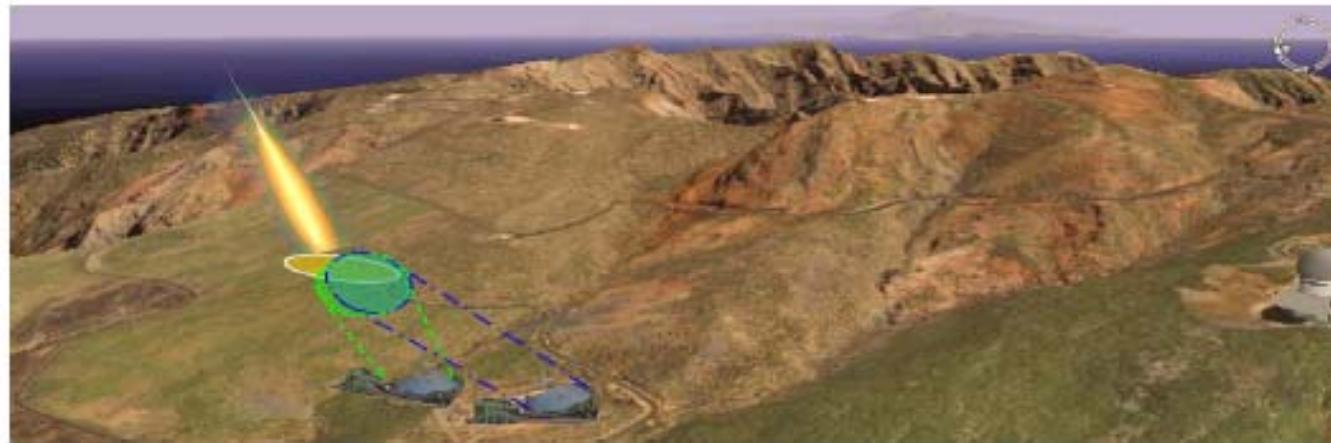
# Up going tau Cherenkov flash every three years

- *Nearly or above 20 events skimming upward by tau each year in AUGER area*
- *Nearly 2000 or more at PeV energy muons escape upward*
- *Nearly or above 100 million (500 GeV) muons escape each year from AUGER upward*
- *No muon might shine detectable only a small TeV fraction on the clouds*  
*Fluorescence detector may observe 30 % of cloudy days nights, at least 10% are ideal to see reflected Cherenkov flash of upward tau*

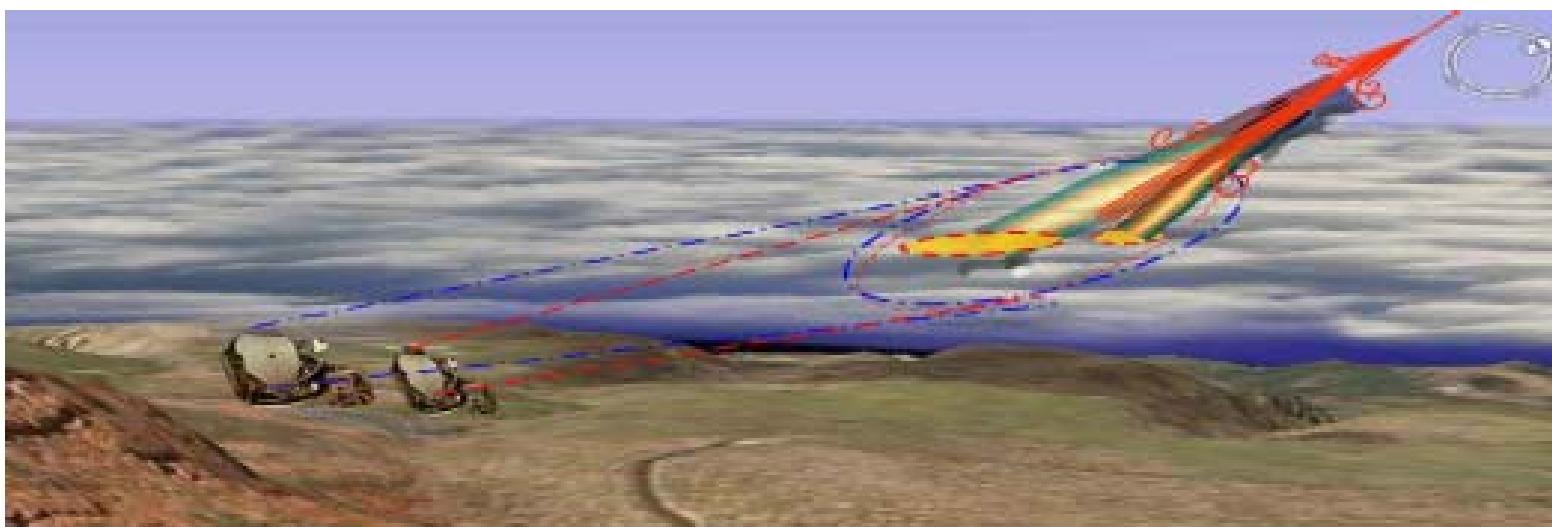
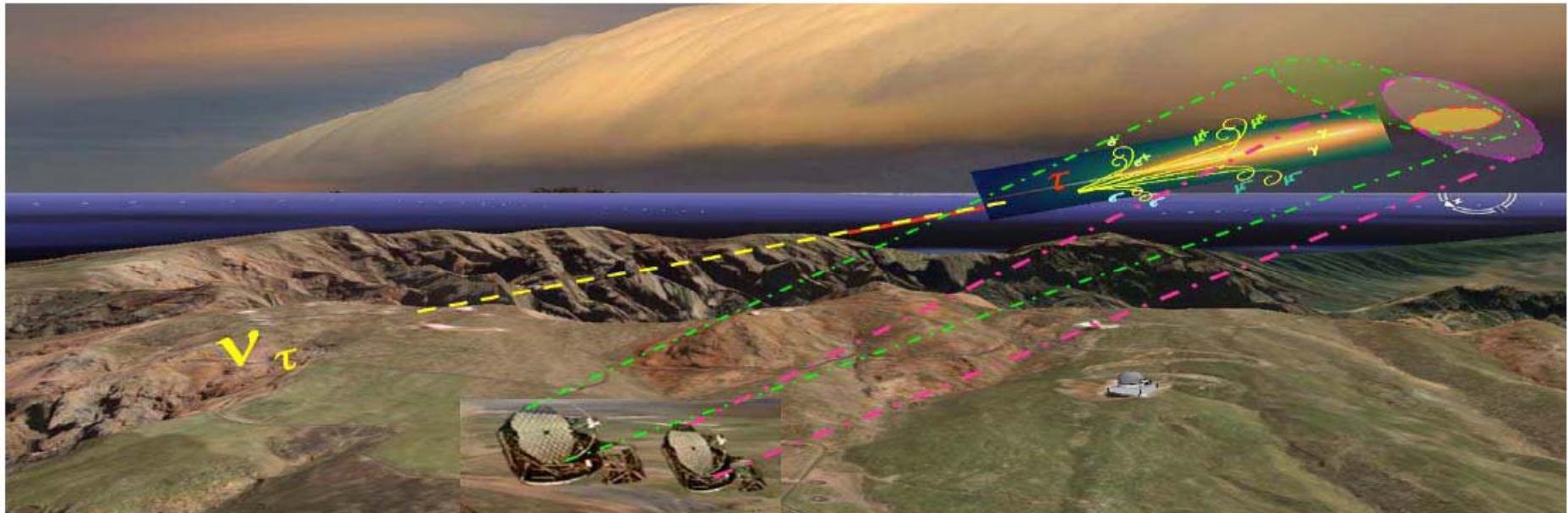
# Conclusions

- *Tau at PeVs should be seen by Cherenkov flashes at horizons in the night on clouds*
- *The AUGER area observed by PeV a Cherenkov reflected event on clouds is comparable with the area of a EeV fluorescence event: at least two events a year might be observed as a Tau PeV event each year (if they did record it they may have the AUGER signal record). TA might be able to observe one tau every two years. CTA and other array too.*
- *Tau might be observed by multi water tank or air telescope array in mountains or better, vulcanos, making the X-muon-radiography of mountain and the up-tau airshower search from Earth.*  
*AUGER fluorescence telescope array, as well CTA and any telescope might inspect clouds in the nights, discovering rare upgoing airshower reflections as a first road to tau neutrino astronomy*

# Thank you for the kind attention



# Up Tau Airshower



ref

## Cherenkov Flashes and Fluorescence Flares on Telescopes: New lights on UHECR Spectroscopy while unveiling Neutrinos Astronomy

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## Reflecting on Čerenkov Reflections

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# MSW effect: Beaming neutrino across the Earth DF , Apj 2012

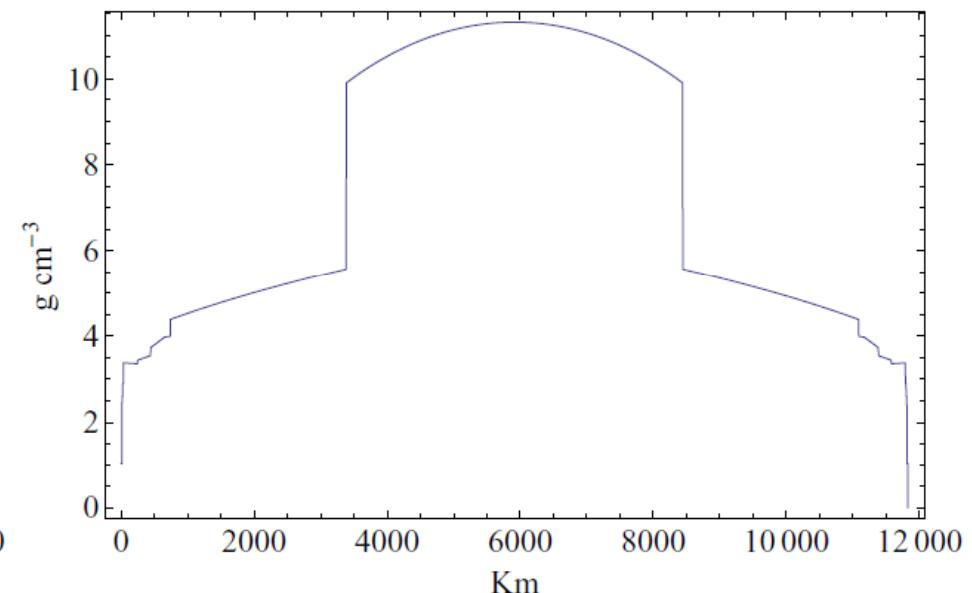
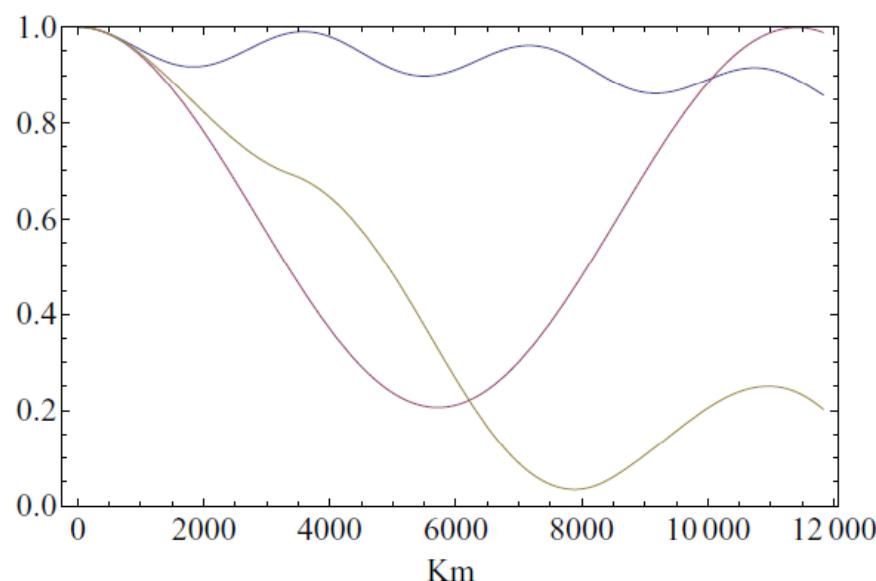


Figura 3.4: Probabilità di sopravvivenza per  $\nu_e$ , ad energia di 3.4 GeV, nel vuoto (blu), nella materia a densità costante di  $7.33 \text{ g cm}^{-3}$  (rosso), e nel profilo di

# Mixing and MSW inside the Earth

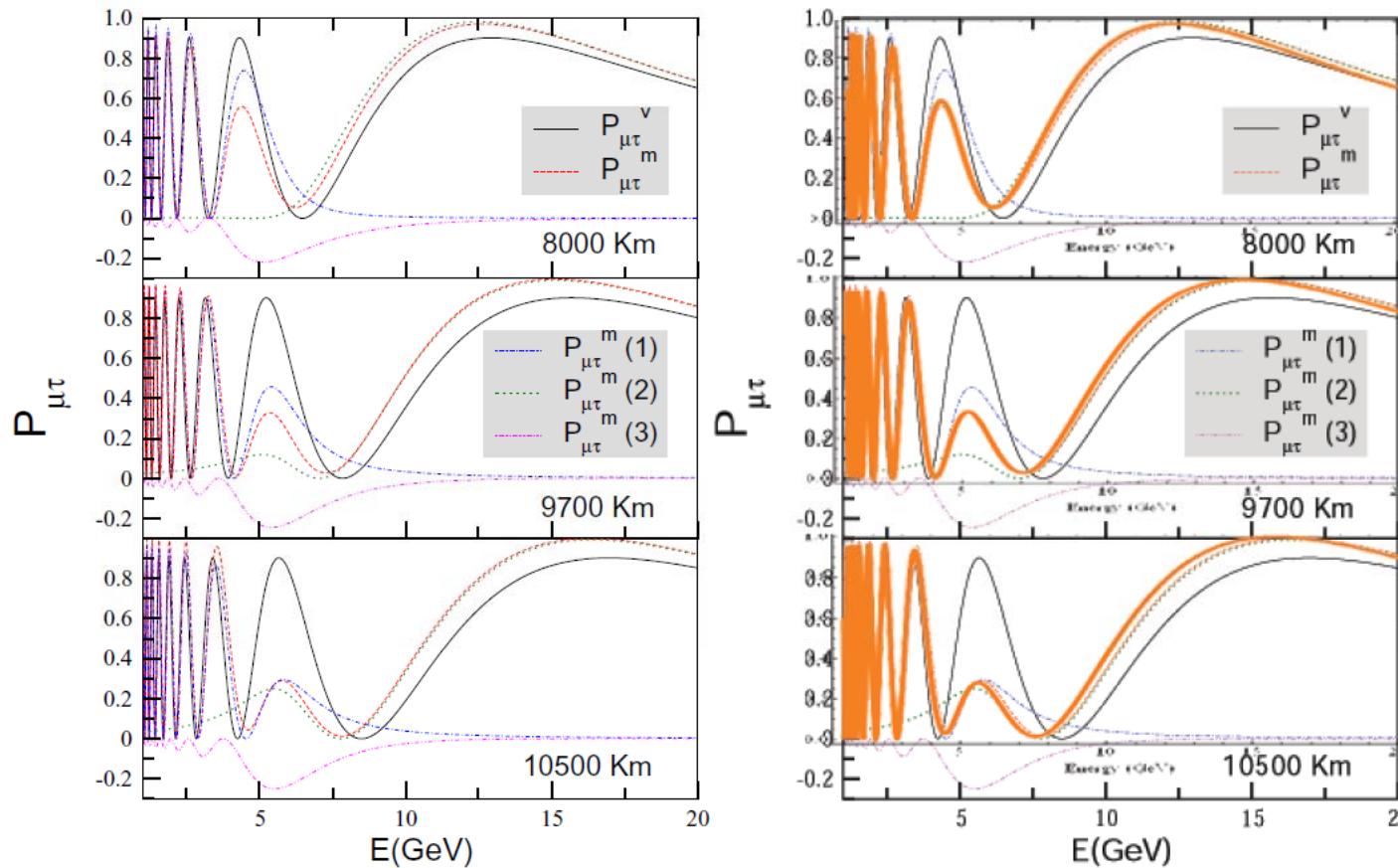


Figura 3.6: Grafici a sinistra: probabilità di oscillazione dalla referenza [35], e a destra: confronto sovrapposto con la stessa probabilità da noi calcolata a densità costate. I parametri usati da [35] sono:  $\Delta m_{21} = 8 \cdot 10^{-5}$ ,  $\Delta m_{31} = 2 \cdot 10^{-3}$ ,  $\sin^2 2\theta_{23} = 1$ ,  $\sin^2 \theta_{12} = 0.27$ ,  $\sin^2 \theta_{13} = 0.1$ . Il valore per la densità costante è  $4.5 \text{ g cm}^{-3}$ . Come si può vedere le due curve sono in pieno accordo.

# Cross sections (Reno et all)

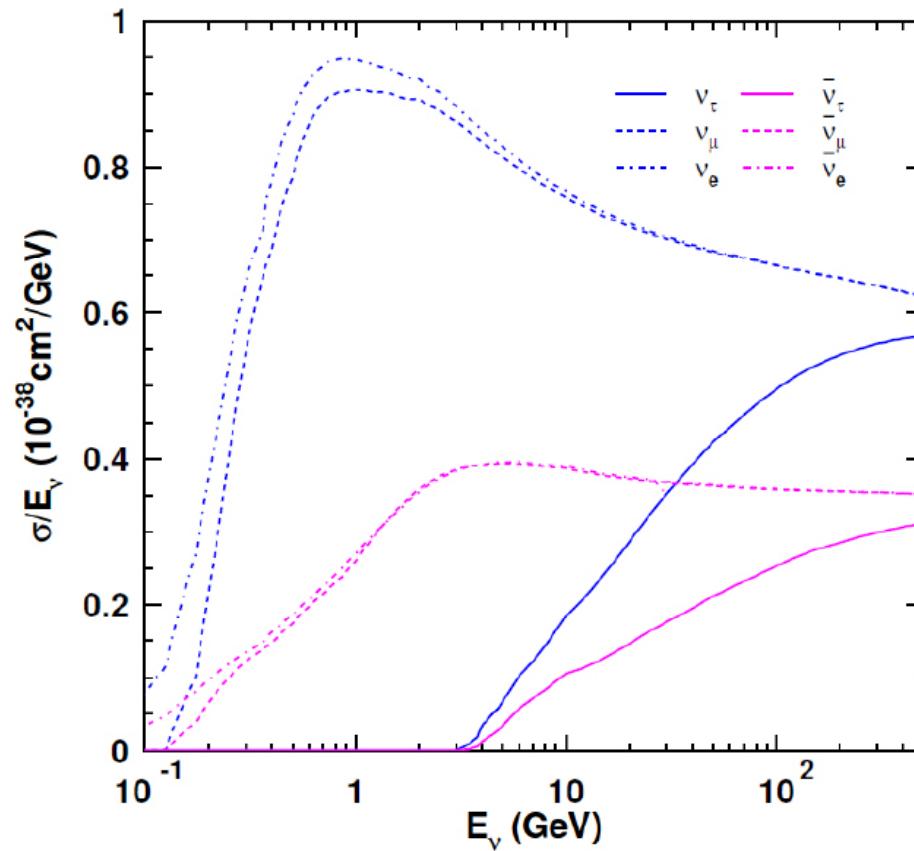


Figura 5.7: Sezione d'urto totale di Corrente Carica  $\sigma_{CC}$  dei neutrini in funzione dell'energia [53].

# Beaming across the Earth

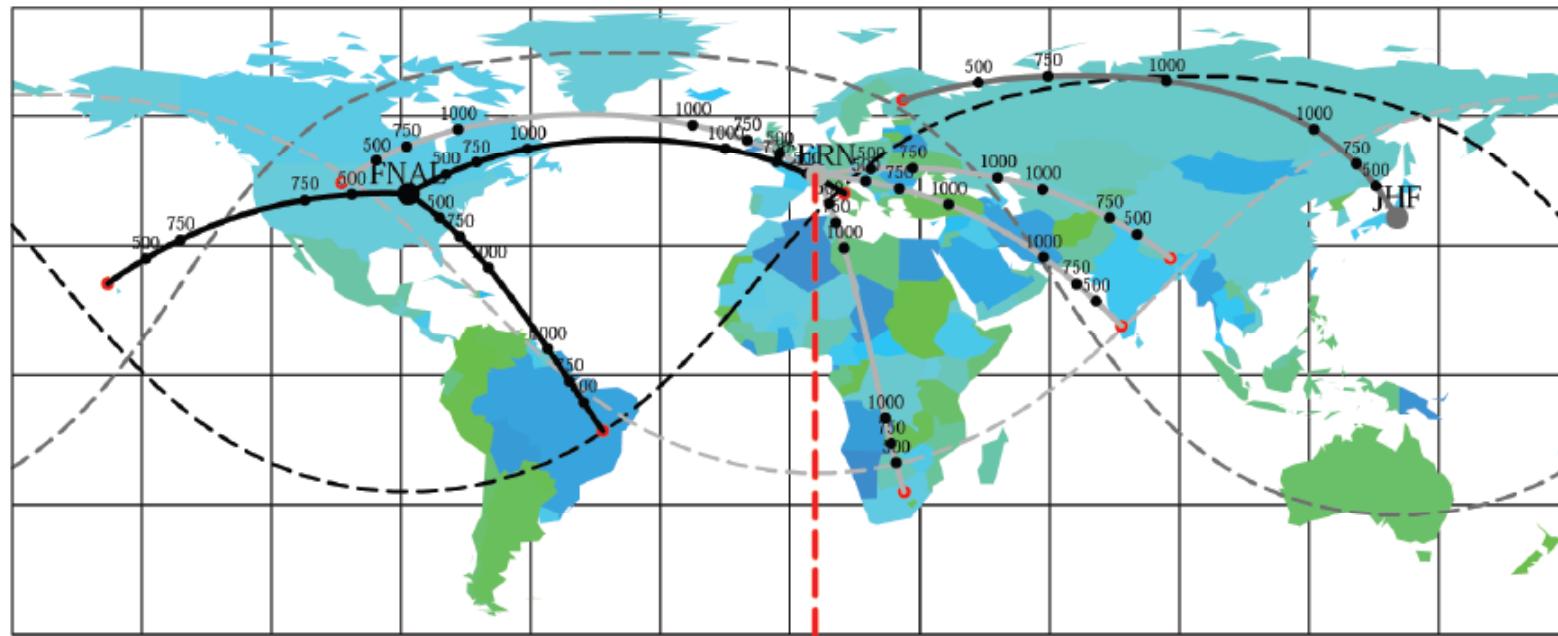


Figura 4.2: Alcune potenziali baseline per oscillazione di neutrino [44]. La nostra proposta (baseline in tratteggio rosso) è nuova, è la più lunga baseline, per la quale tra l'altro esistono già la sorgente del fascio e il rivelatore. La nostra proposta è stata recentemente analizzata da [45].

# Old limits by AUGER 2009-2011

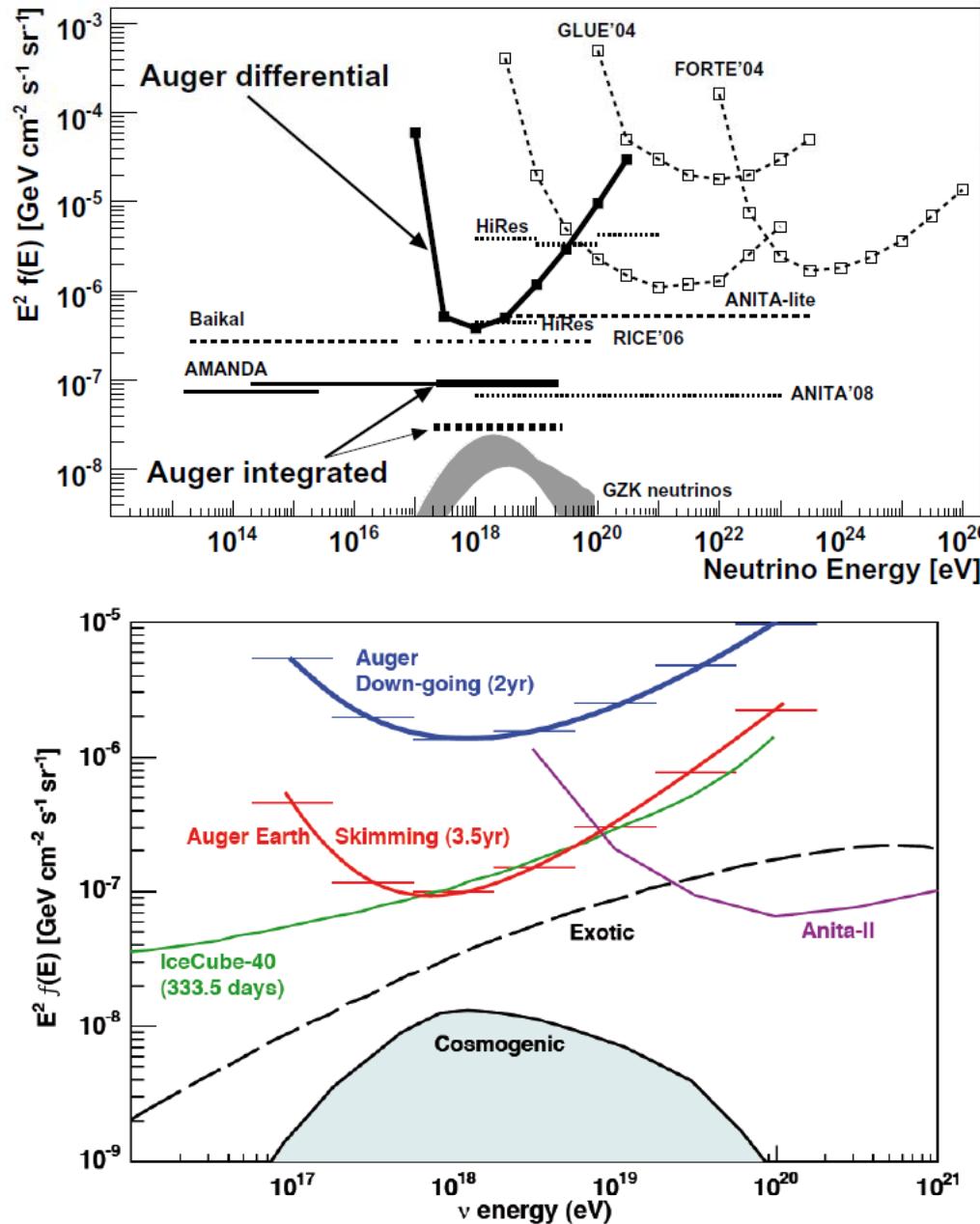
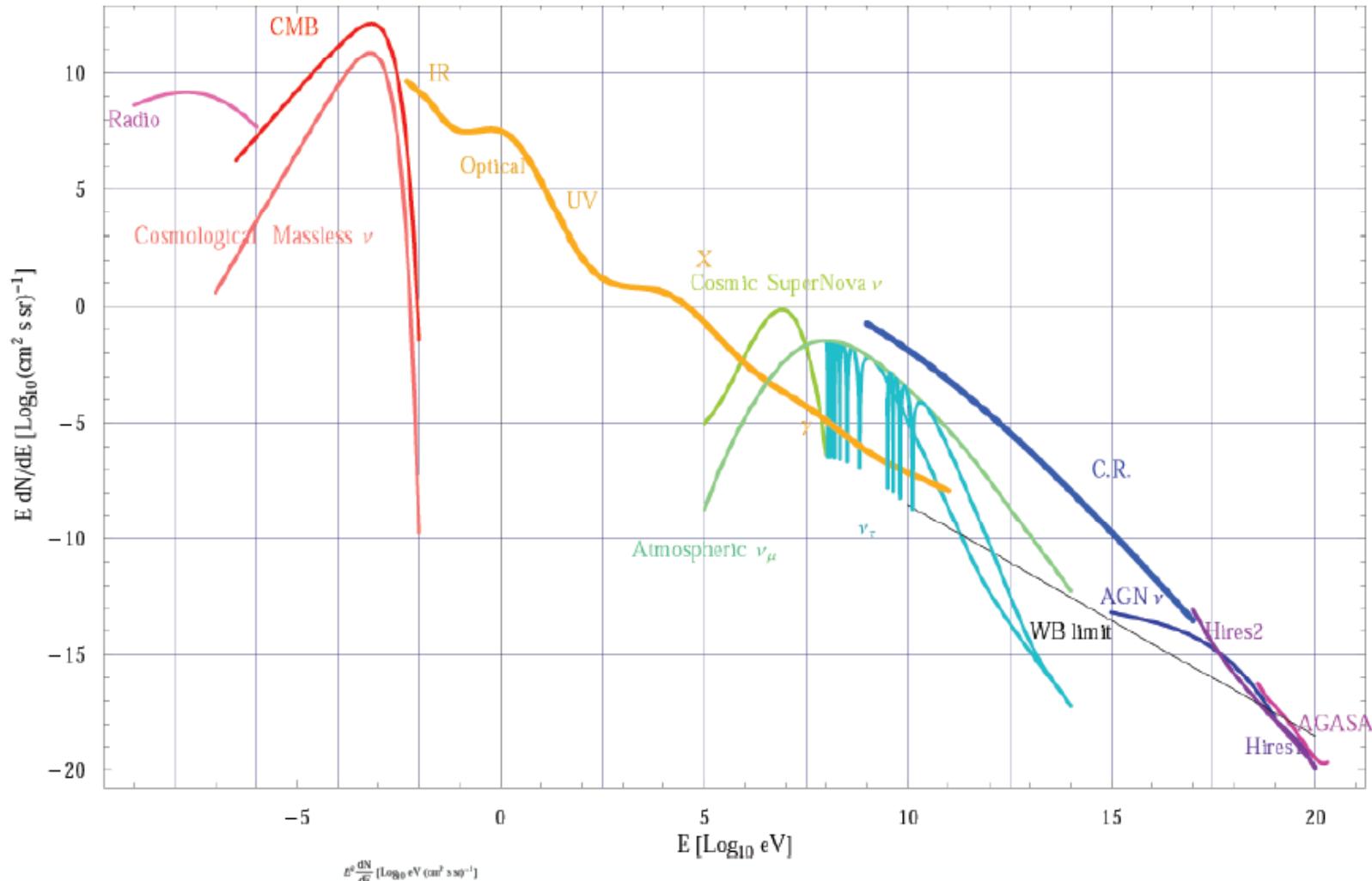


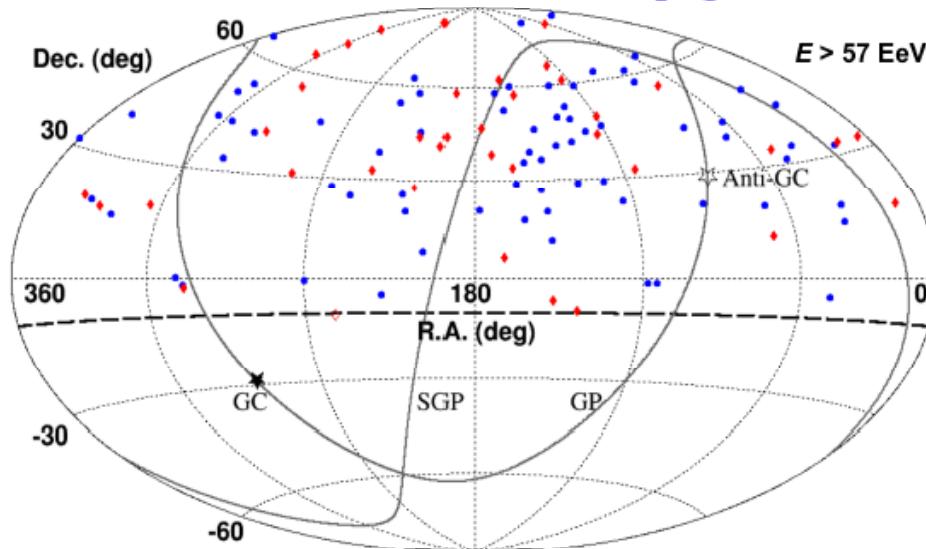
Figura 6.6: Limite superiore posto da Auger per il flusso di neutrini nel 2009, sopra [87], e nel 2011, sotto [86, 91].

# A wide view



# UHECR

## TA Anisotropy - Hotspot (7 yr update)



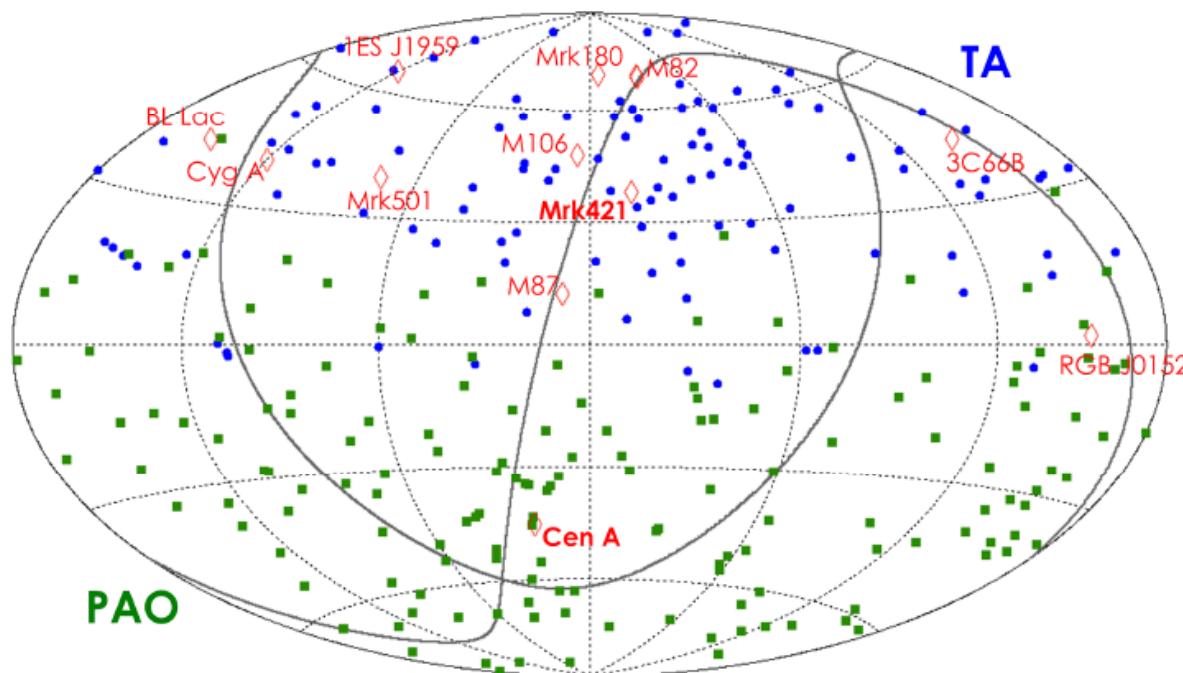
First 5 year data → 72 events,  $3.4 \sigma$  [ApJ 790 L21 (2014)]

New 2 year data → +37 events,  $3.4 \sigma$

Total 109 events (7 years SD, 2008 May 11 - 2015 May 11)

# Anisotropy

## *TA Anisotropy - Nearby Prominent Sources*



Suggested possible sources near Ursa Major cluster:  
Blazar Mrk 421 (134 Mpc)  
Blazar Mrk 180 (192 Mpc)  
Starburst galaxy M82 (3.4 Mpc)

K. Fang et al., ApJ 794, 126 (2014)  
H.-N. He et al., arXiv:1411.5273 (2014)

# Overlap maps

## UHECR-neutrinos



231 events ( $E > 52$  EeV, zenith angle  $< 80^\circ$ , ang. res.  $\leq 0.9^\circ$ ) between 01/01/2004 to 31/03/2014<sup>o</sup>

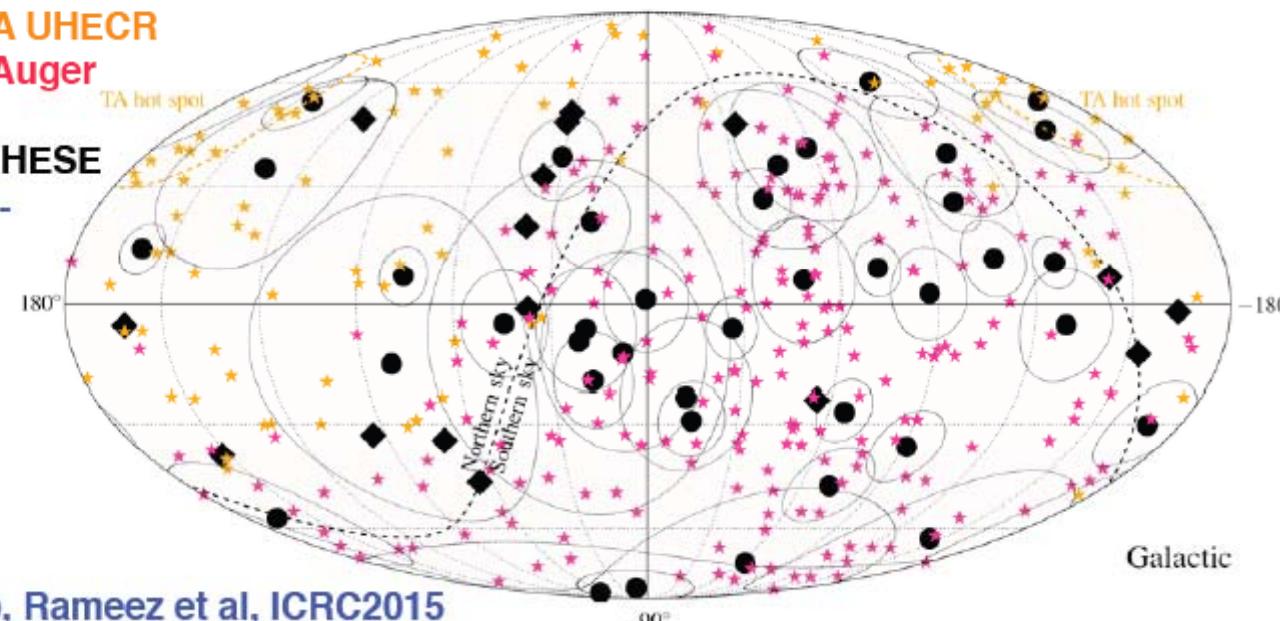
87 events ( $E > 57$  EeV, zenith angle  $< 55^\circ$ , ang. res.  $\leq 1.5^\circ$ ) between 11/05/2008 to 01/05/2014<sup>o</sup>

The Pierre Auger Collaboration, *Astrophys. J.* 804 (2015) 1 and PoS(ICRC2015)310.  
The Telescope Array Collaboration, *Astrophys. J. Lett.* 790 (2014) L21.

Orange stars: TA UHECR  
Magenta stars: Auger

Black symbols: HESE

Blue: diffuse  $\nu_\mu$ -induced tracks



Christov, Golup, Rameez et al, ICRC2015

HESE 4 yr ( $> 30$  TeV): 39 cascades (ang. res.  $\sim 20^\circ$ ) + 7 tracks (ang. res.  $\sim 1^\circ$ )



ICRC 2015, PoS 1081, PRL 113 (2014) 101101

9  $\nu_\mu$  induced upgoing muons with  $E > 100$  TeV (PRL 115 (2015) 081102)

