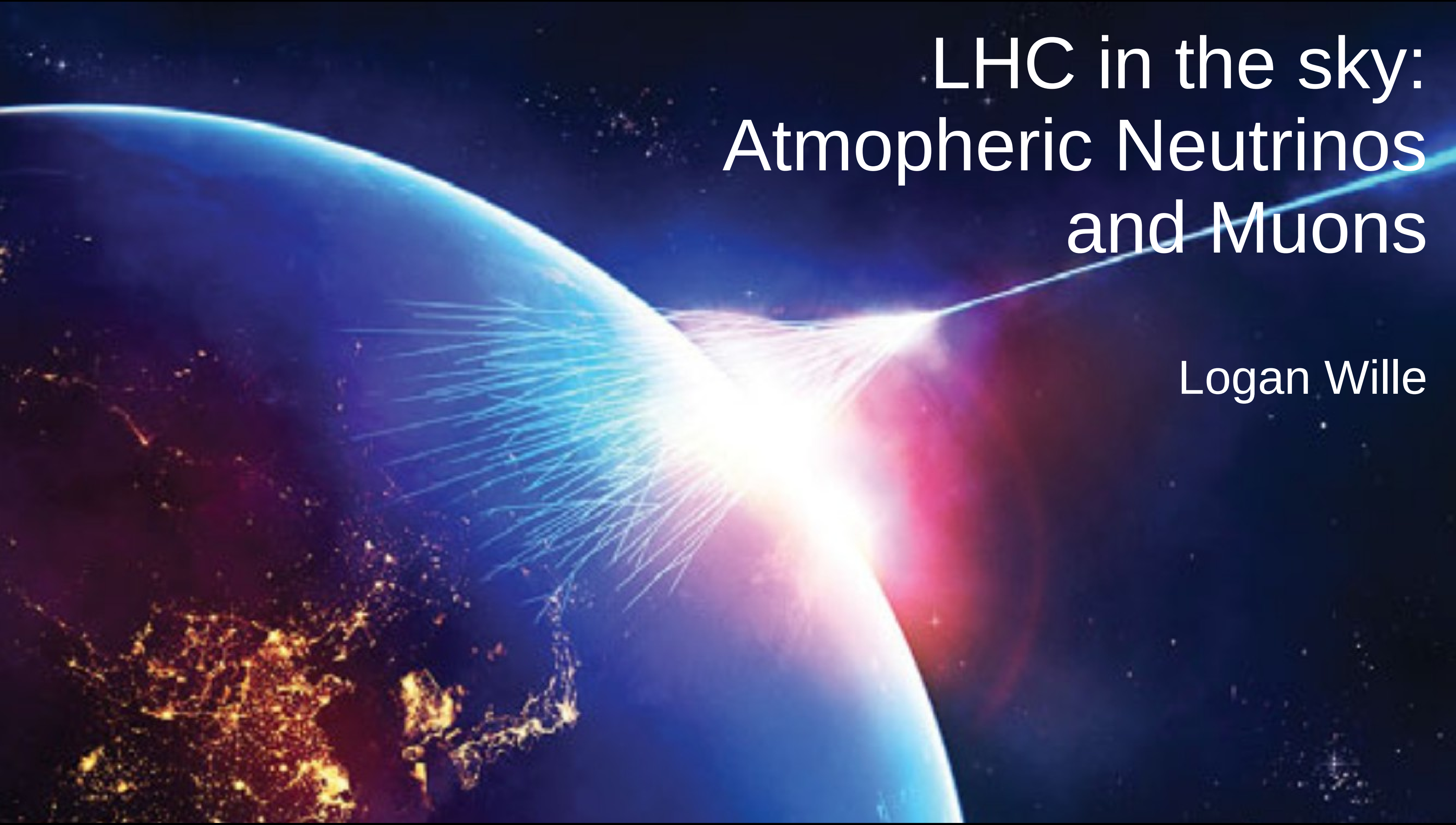
LHC in the sky: Atmopheric Neutrinos and Muons

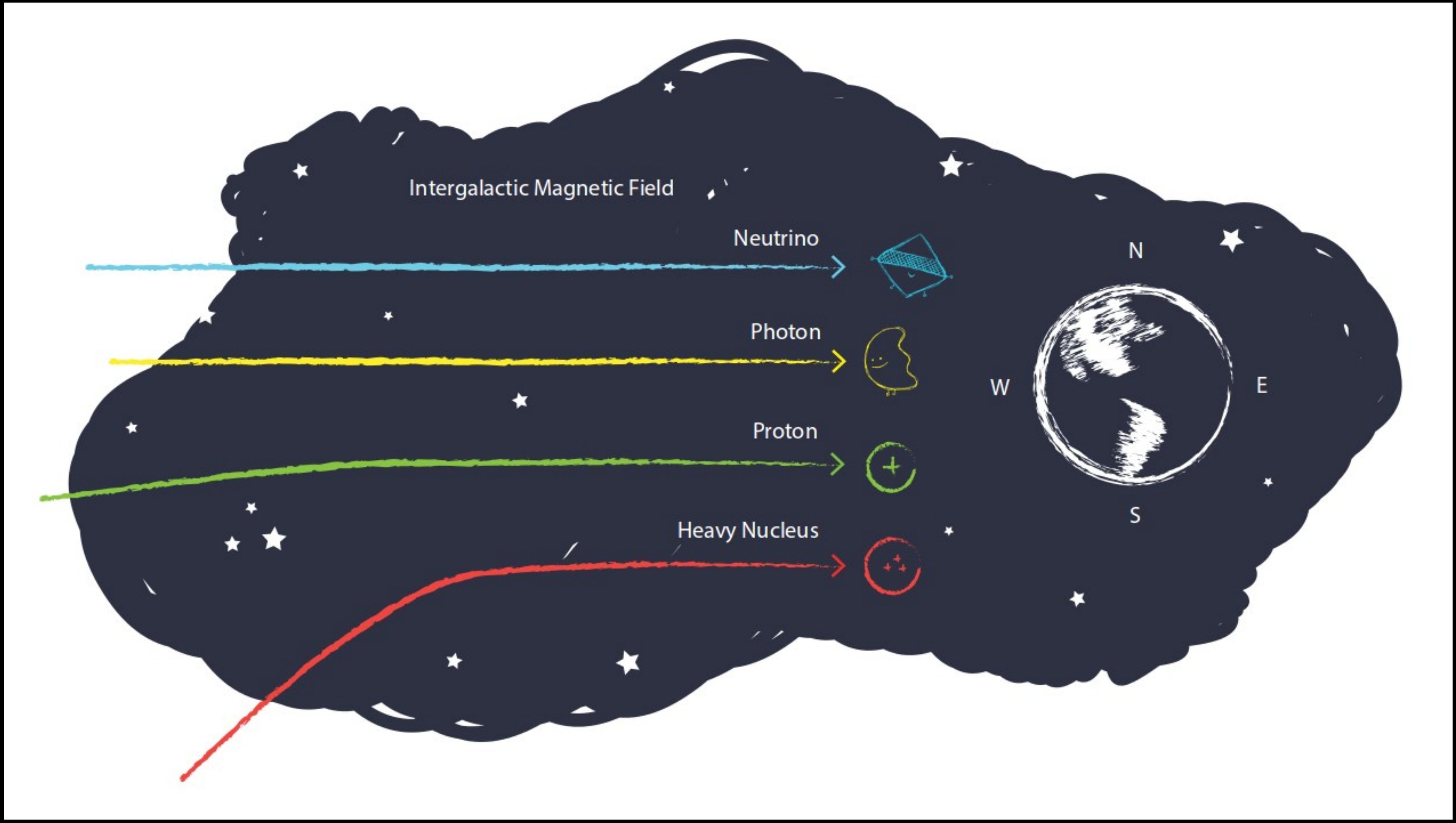
Logan Wille

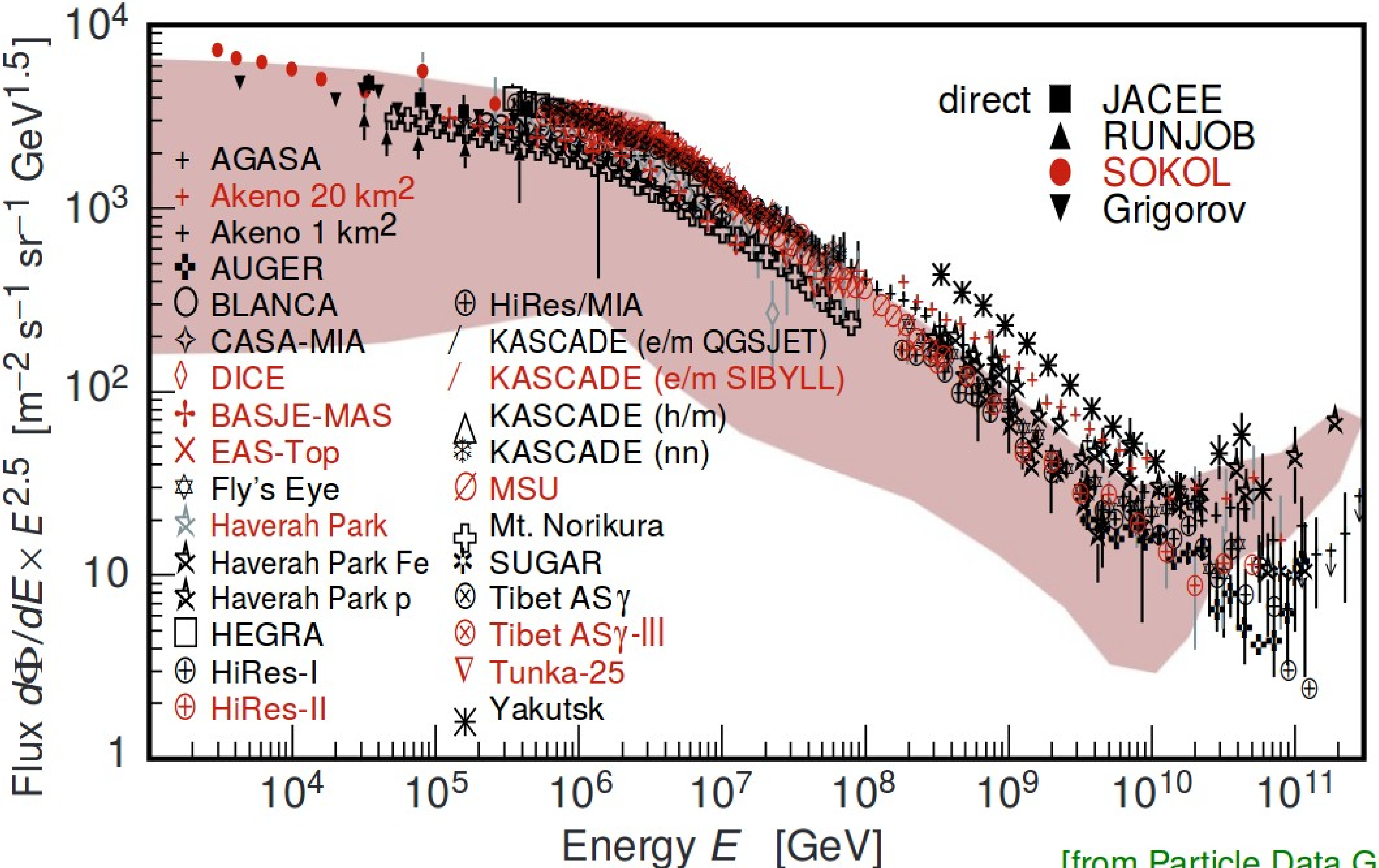


[CERN/Asimmetrie/Infn]

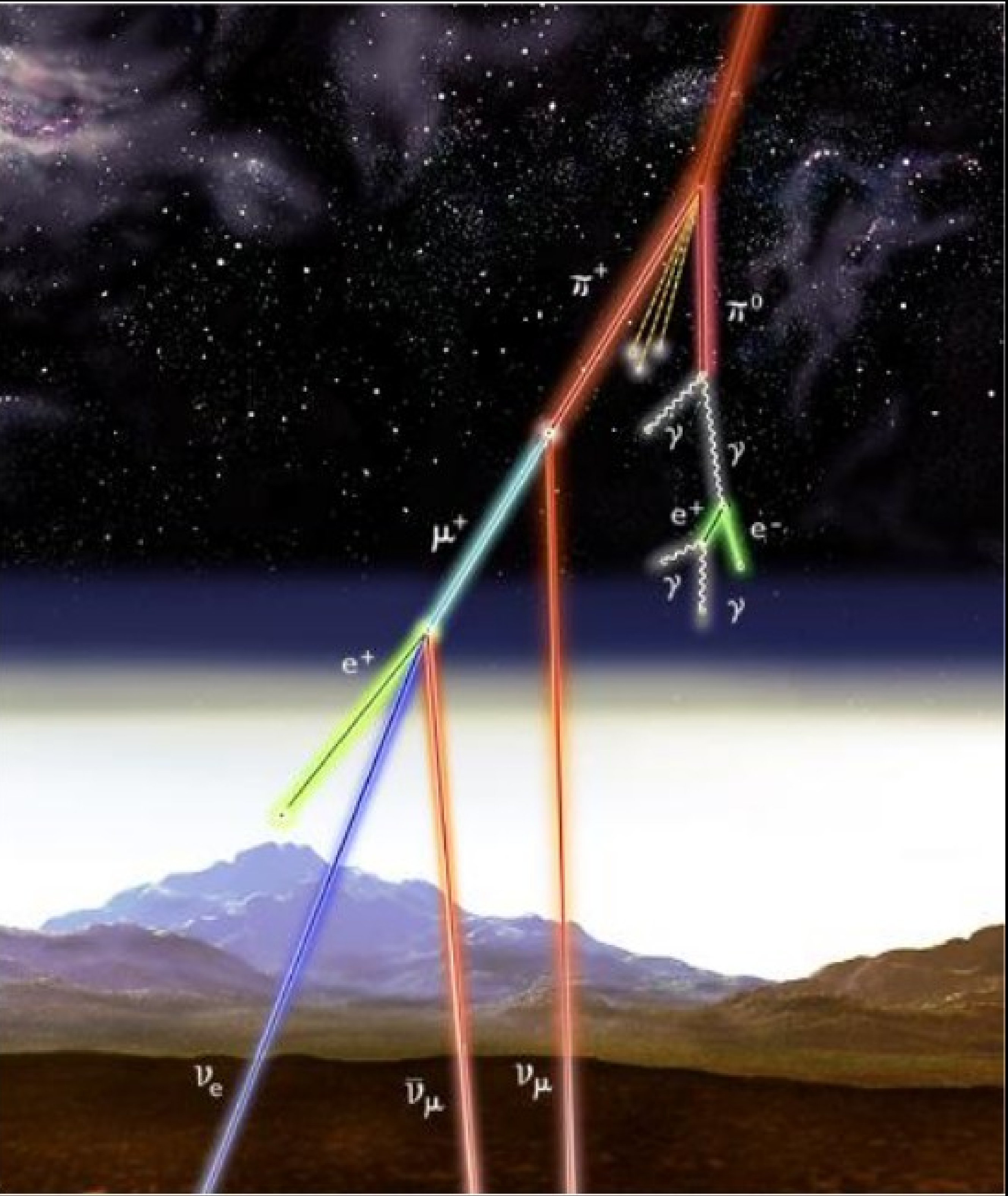
Cosmic Rays

- Just like high energy neutrinos are created in cosmic sources, high energy ions are produced too. These are called Cosmic rays.



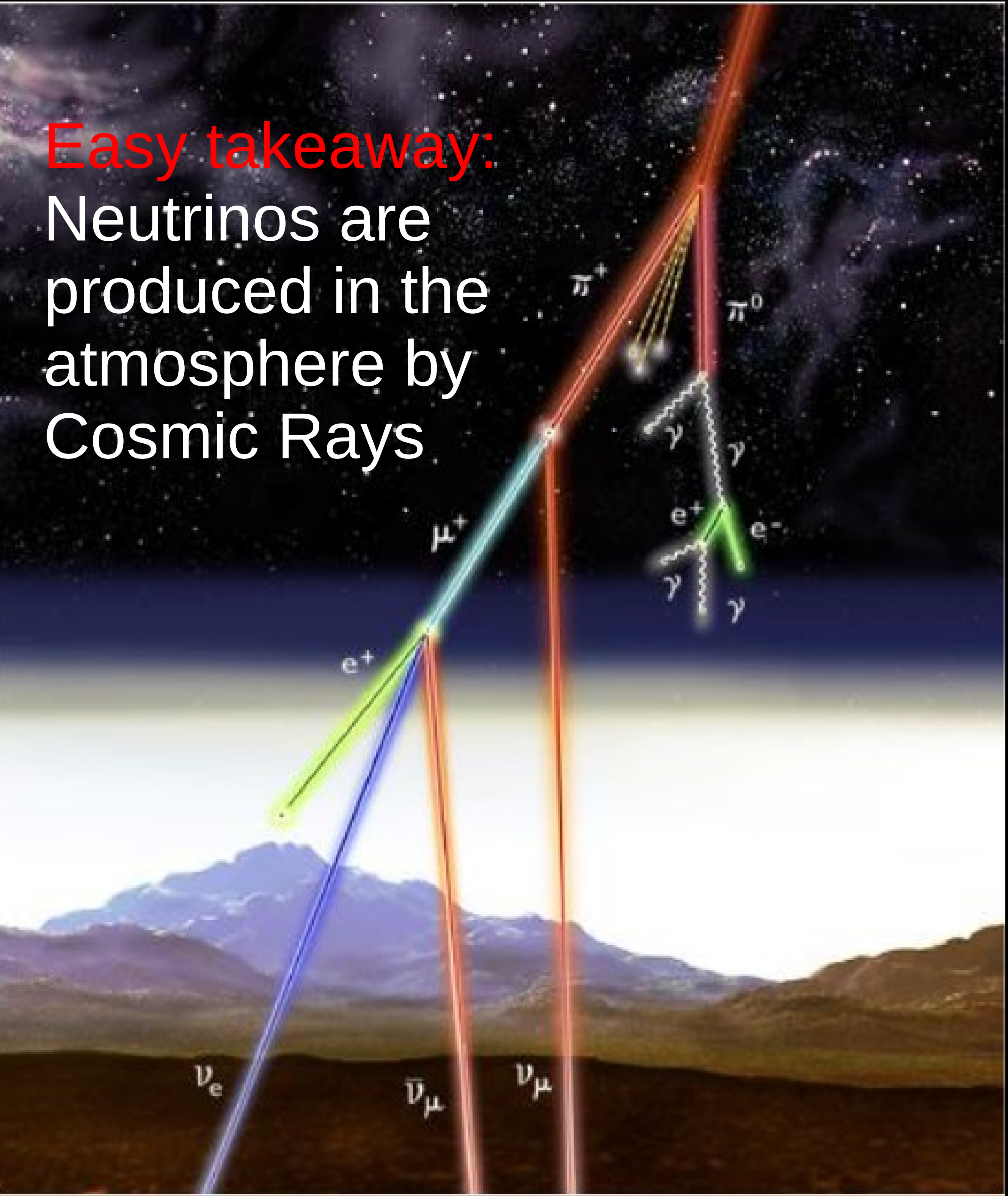


[from Particle Data Group '05]



LHC vs. Airshowers

$$\sqrt{s} = 8\ \mathrm{TeV}$$
$$s = 2m_p E_p$$
$$E_p = 34\ \mathrm{PeV}$$



Easy takeaway:

Neutrinos are produced in the atmosphere by Cosmic Rays

Atmospheric Neutrinos have two sources: Conventional and Prompt

Conventional Atmospheric Neutrinos

- These come from pion, kaon, and muon decays.
- If someone is talking about atmospheric neutrinos, it's probably this type.

$$p + p \rightarrow \pi^+ + X$$
$$\hookrightarrow \mu^+ + \nu_\mu$$
$$\hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$\pi^\pm$ MEAN LIFE

VALUE (10^{-8} s)	
2.6033 ±0.0005	**OUR AVERAGE**

π^+ DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Conf
Γ_1	$\mu^+\nu_\mu$	[a]	(99.98770±0.00004) %	

$K^\pm$ MEAN LIFE

VALUE (10^{-8} s)	*EVTS*
1.2380±0.0021 OUR FIT	

K^+ DECAY MODES

Leptonic and semileptonic modes	
$e^+\nu_e$	(1.581±0.008) × 10^{-5}
$\mu^+\nu_\mu$	(63.55 ±0.11) %
$\pi^0 e^+\nu_e$	(5.07 ±0.04) %
Called K^+_{e3}.	
$\pi^0\mu^+\nu_\mu$	(3.353±0.034) %

[PDG '15]

Cascade Equation

Particle Flux

Interaction

Decay

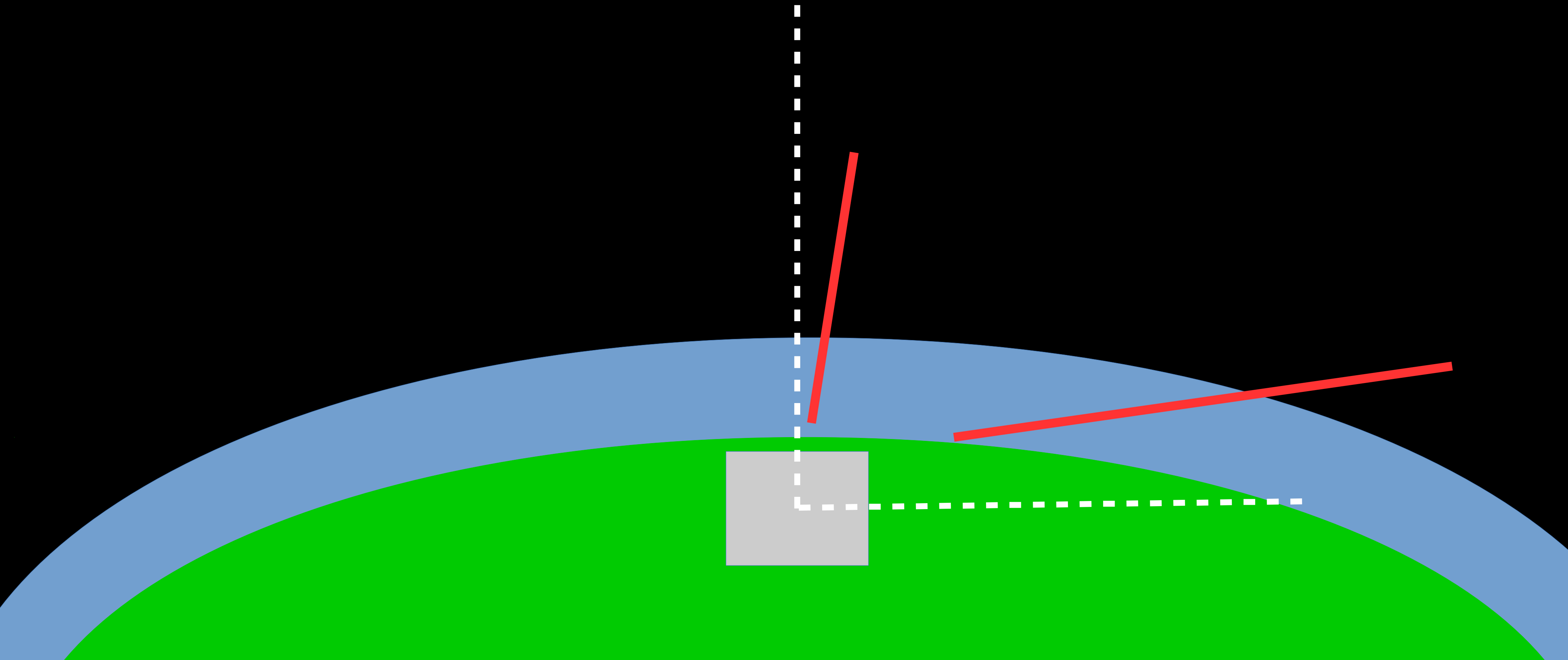
$$\frac{\mathrm{d}N_i(E_i,X)}{\mathrm{d}X} = -\frac{N_i(E_i,X)}{\lambda_i} - \frac{N_i(E_i,X)}{d_i}$$

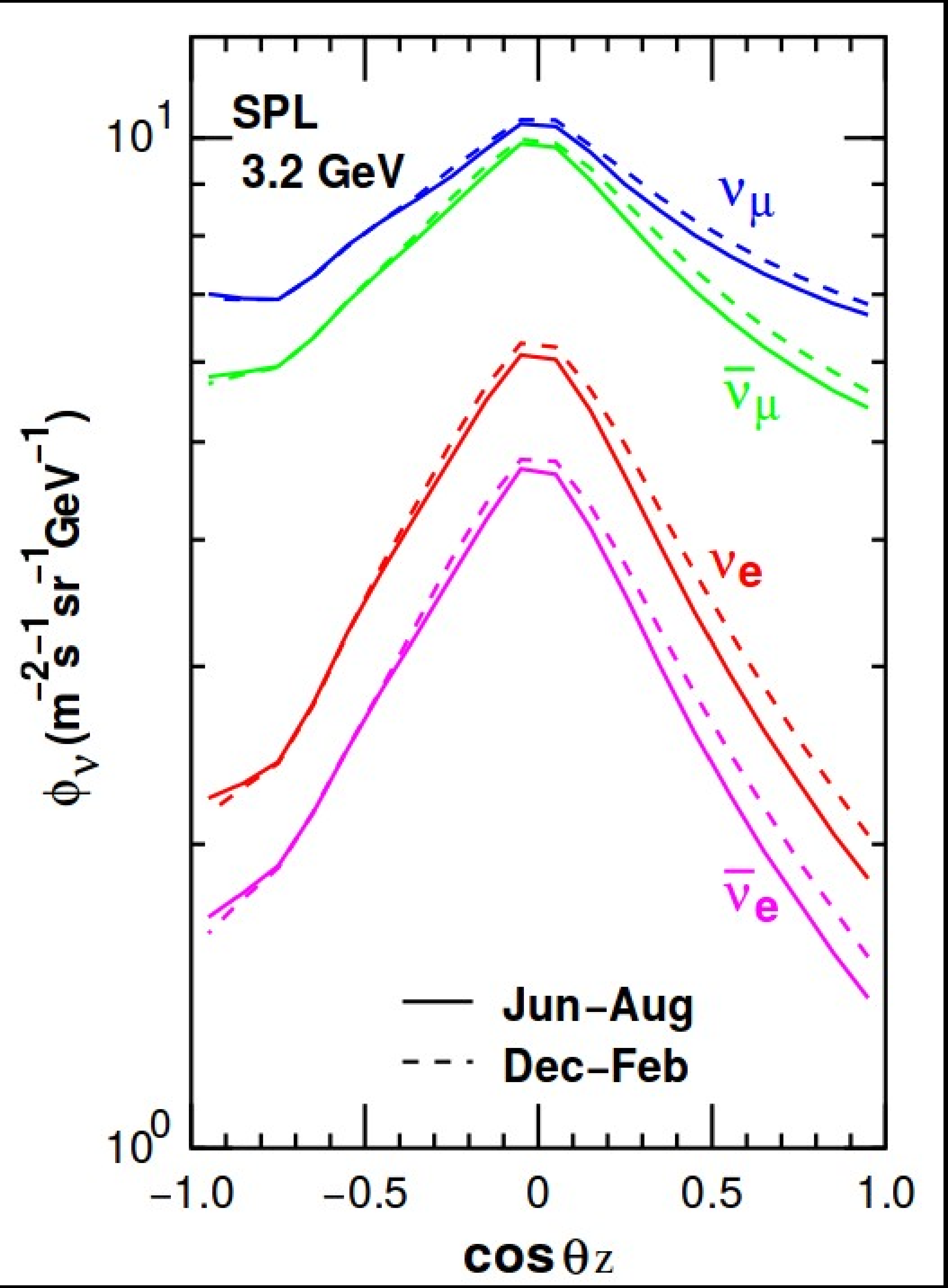
$$+\Sigma_{j=i}^{J}\int_E^\infty \frac{F_{ji}(E_i,E_j)}{E_i}\frac{N_j(E_j,X)}{\lambda_j}\,\mathrm{d}E_j$$

Parent Particle
cross term

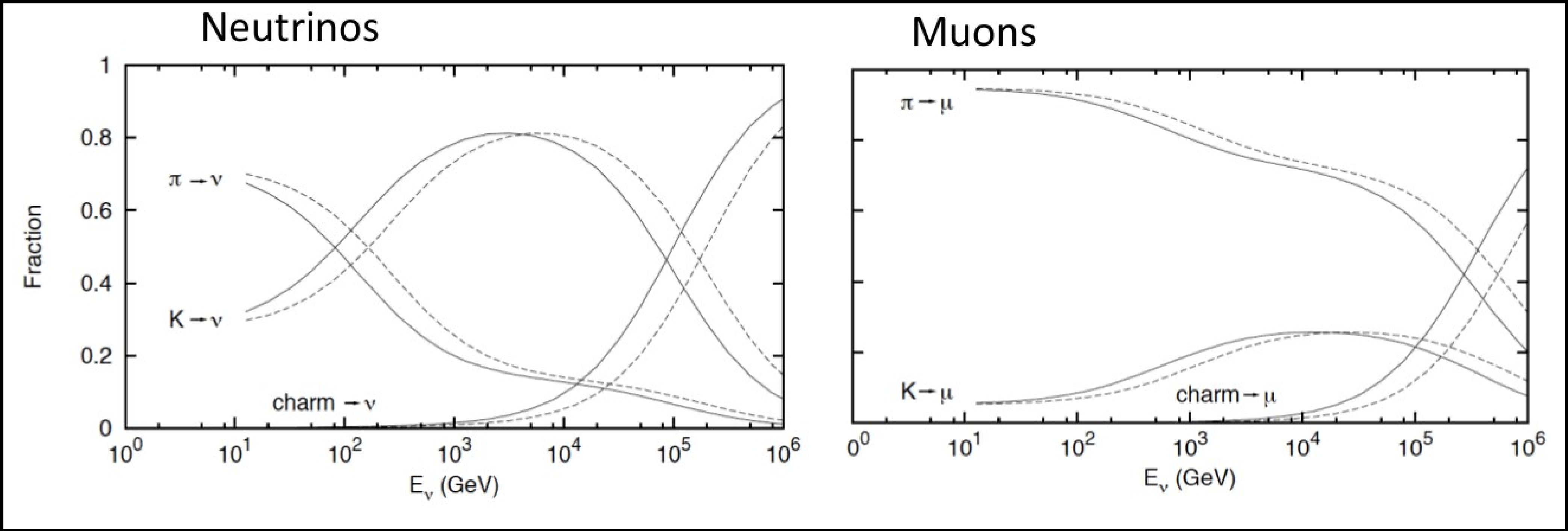
Parent Particle
Interaction/Decay

Slant Depth and Zenith Angle





M. Honda et. al. 1502.03916

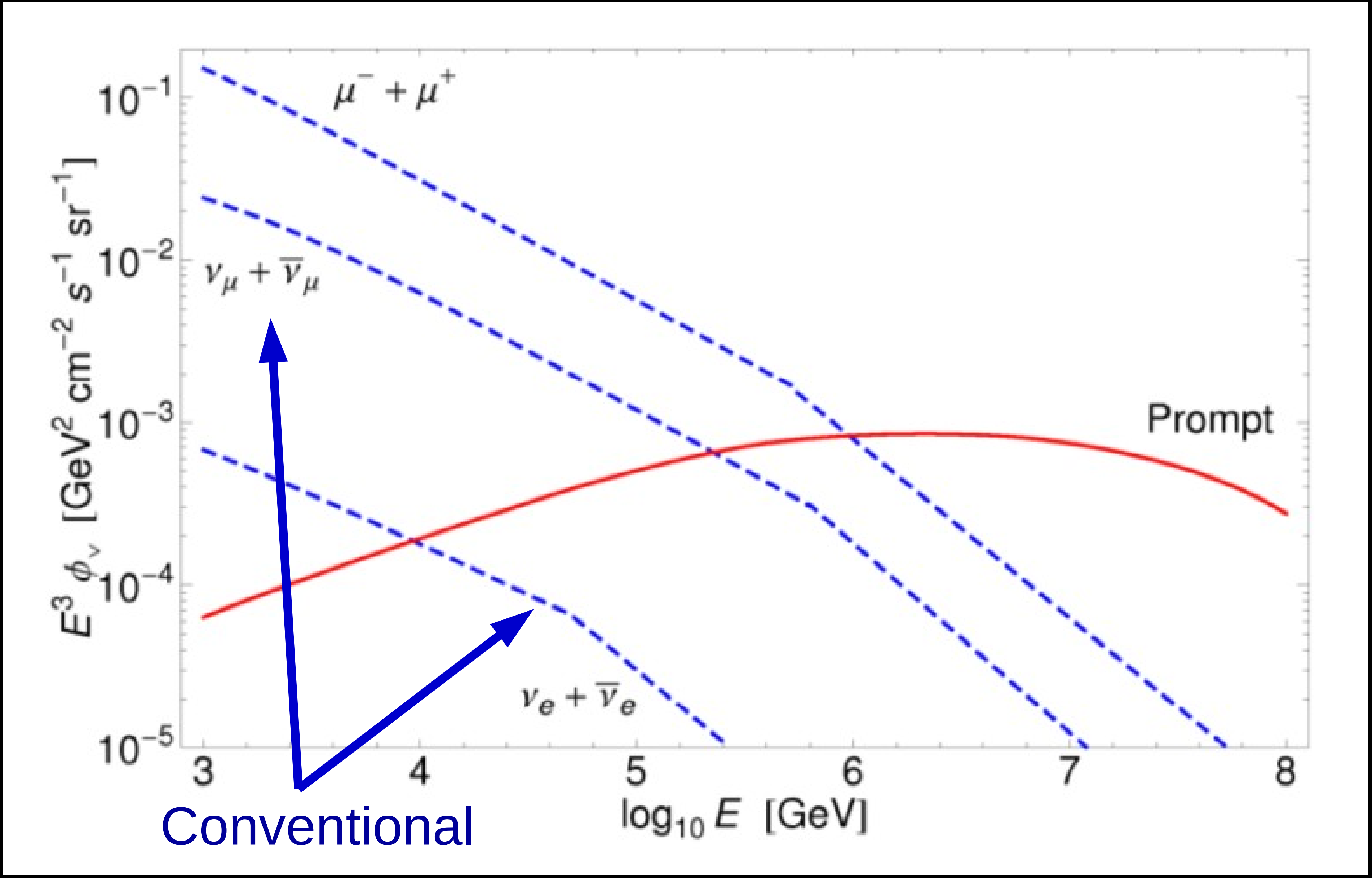


Neutrino production channel changes with energy due to parent particle life times

Tom Gaisser


Let's see some Atmospheric Fluxes

Atmospheric Neutrino flux on Earth



Prompt Neutrinos

- Come from decay of charm hadrons (D mesons, Lambda c's)
- Charm hadrons decay 'promptly' compared to pions and kaons

$\pi^{\pm}$ MEAN LIFE

VALUE (10^{-8} s)
2.6033 ±0.0005 OUR AVERAGE

$K^{\pm}$ MEAN LIFE

VALUE (10^{-8} s)	*EVTS*
1.2380±0.0021 OUR FIT	

CHARMED MESONS
($C = \pm 1$)

$D^+ = c\overline{d}$, $D^0 = c\overline{u}$, $\overline{D}^0 = \overline{c}\,u$, $D^- = \overline{c}\,d$, similarly for D^*'s

Mean life $\tau = (1040 \pm 7) \times 10^{-15}$ s

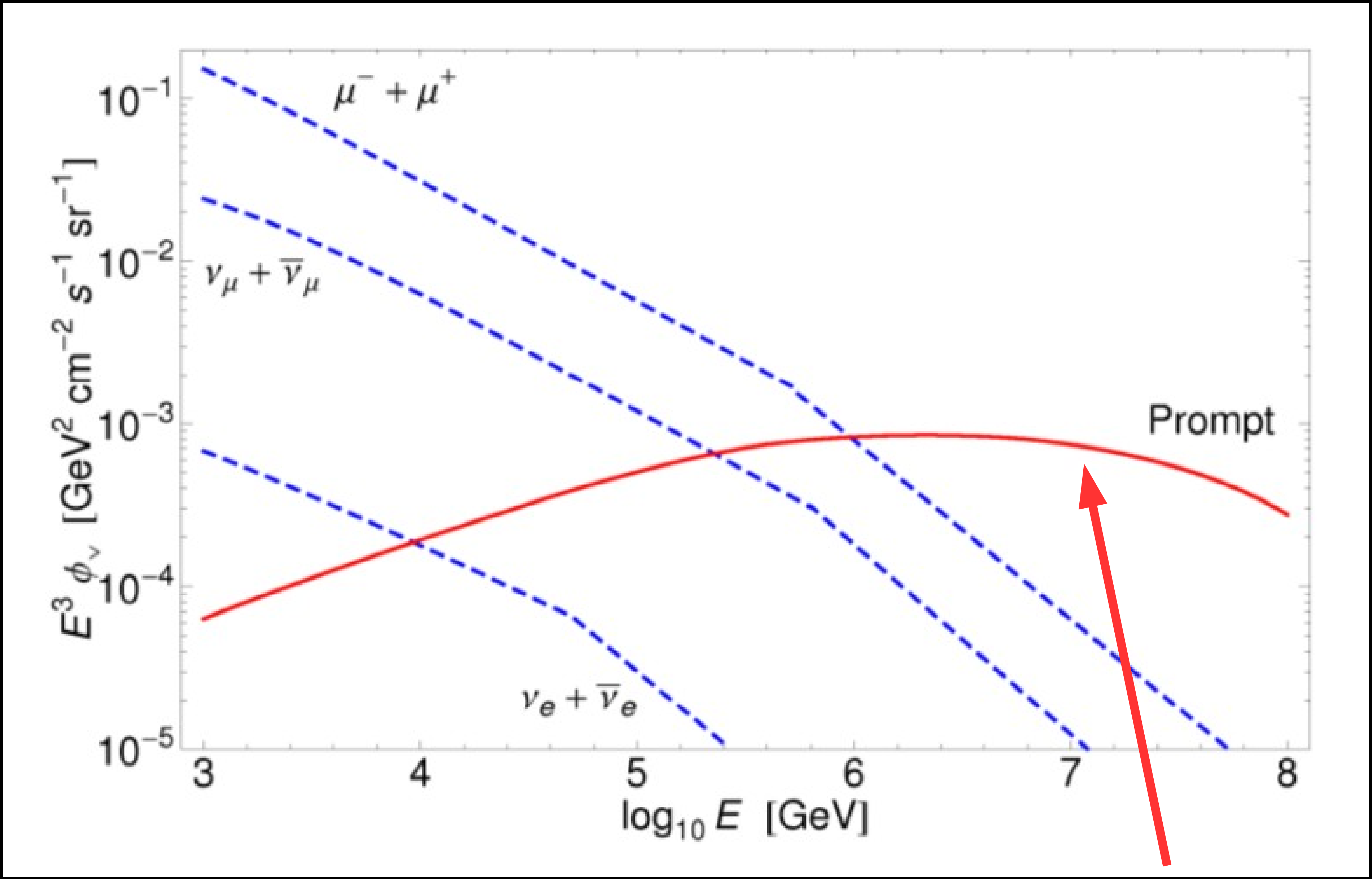
CHARMED MESONS
($C = \pm 1$)

$D^+ = c\overline{d}$, $D^0 = c\overline{u}$, $\overline{D}^0 = \overline{c}\,u$, $D^- = \overline{c}\,d$, similarly for D^*'s

Mean life $\tau = (1040 \pm 7) \times 10^{-15}$ s

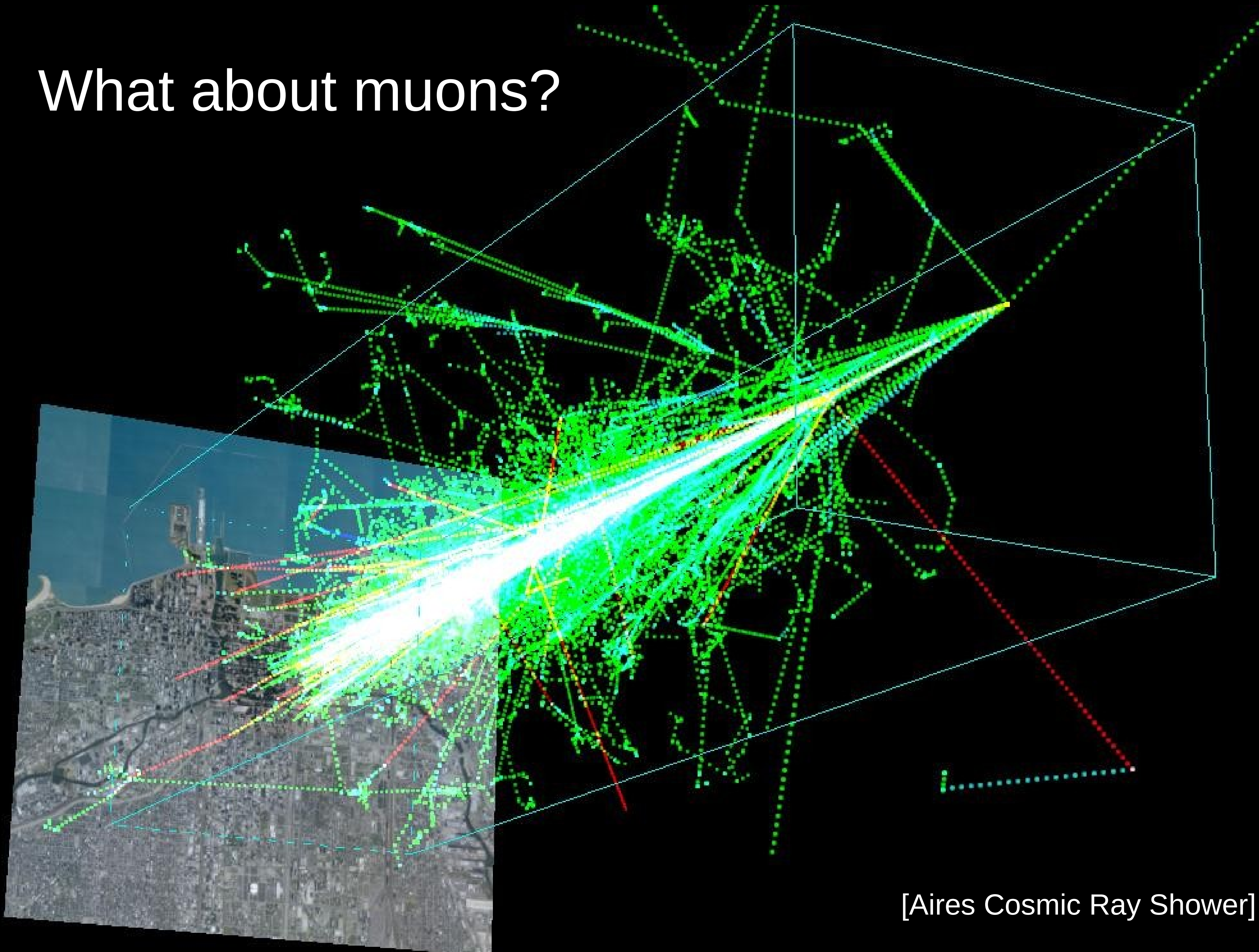
D^+ DECAY MODES	Fraction (Γ_i/Γ)
	Inclusive modes
e^+ semileptonic	(16.07 ± 0.30) %
μ^+ anything	(17.6 ± 3.2) %

However, charm quarks are produced less often and don't always decay to neutrinos



Very fast decay, no chance for the meson to lose energy.

What about muons?



[Aires Cosmic Ray Shower]

$$p + p \rightarrow \pi^+ + X$$

$$\hookrightarrow \mu^+ + \nu_\mu$$

$$\hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

μ MEAN LIFE τ

Measurements with an error > 0.001×10^{-6} s have been omitted.

VALUE (10^{-6} s)	*DOCUMENT ID*	*TECN*	*CHG*	*COMMENT*
2.1969811±0.0000022 OUR AVERAGE				

Muons live a long time, reaching the detector.

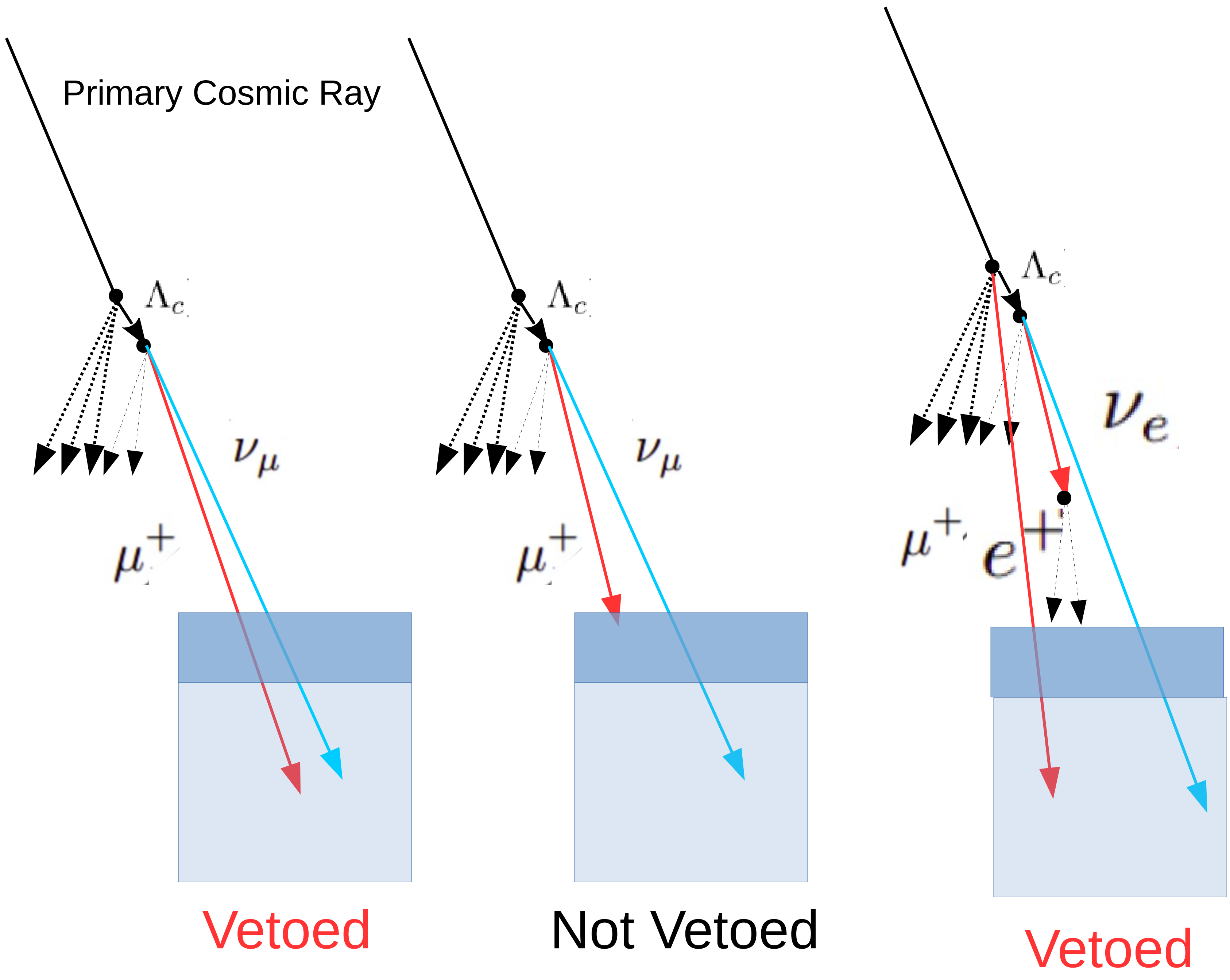
Several muons can be produced in a single shower, these are called muon bundles.

Muons vs. Neutrinos

- Atmospheric muons flood the IceCube detector because their interaction likelyhood is *very* large compared to a neutrino's
- ~10^6 muon events per neutrino event in IceCube, even though the flux is only ~10 larger

Reducing the muon events

- In IceCube, we always have to remove muon background to see the neutrinos. One common way to do it is the veto.
- However, when we add a veto to remove muon events, we also remove atmospheric neutrino events. This is called the 'self-veto' effect.



Primary Cosmic Ray
Λ_c
ν_μ
μ^+
Λ_c
ν_μ
μ^+
Λ_c
ν_e
μ^+
e^+
Vetoed
Not Vetoed
Vetoed

Calculating self-veto probability

- To understand self-veto, we need to simulate the entire airshower.
- The best tool for simulating airshowers is called CORSIKA
- CORSIKA is a monte-carlo program where you can use many different interaction models, atmospheres, and cosmic ray models.

Further Reading

General review : arxiv:1412.6424

Tom Gaisser's textbook : Cosmic Rays and Particle Physics

Detailed calculation of Atmospheric neutrinos : arxiv:1210.5154