The Effect of a Maximum Lepton Energy on the Stability of Pions and Cosmic Ray Physics

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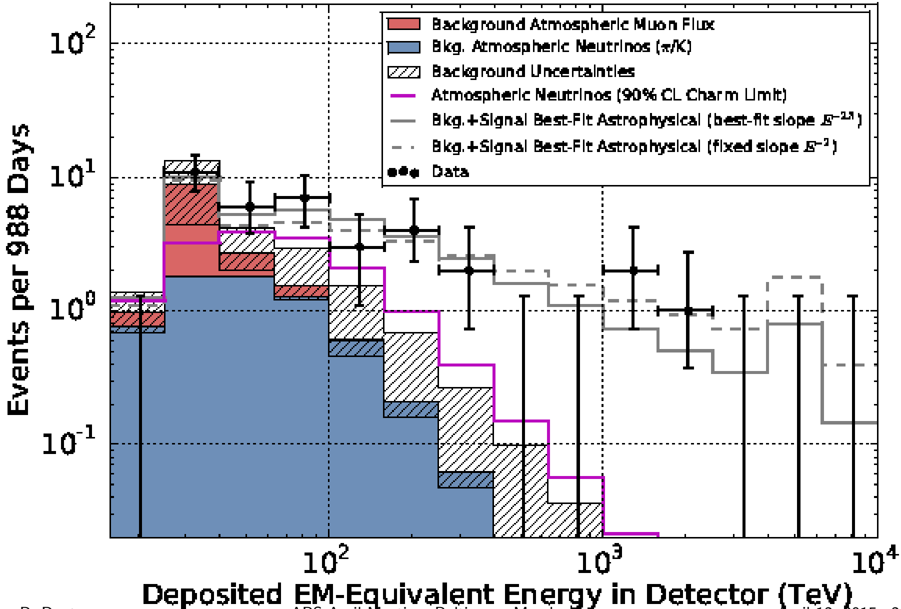
Astrophysical Neutrinos



Glashow Resonance

At $E_\nu = 6.3$ PeV $\bar{\nu}_e$ resonantly creates a W.

Several events should have been seen at $E_\nu \sim 6.3$ PeV.

The spectrum appears to cut off around 2 PeV.

An absolute maximum energy of the neutrino has been proposed.

We extend the cutoff to the charged lepton sector as well.

The GZK process produces π^0, π^+ with $E_\pi \gtrsim 10$ EeV.

Pion Decay: Observed Processes

Main decays are two body,

$$\mu + \nu, \qquad e + \nu\,.$$

There is one very rare four body decay,

$$3e + \nu\,.$$

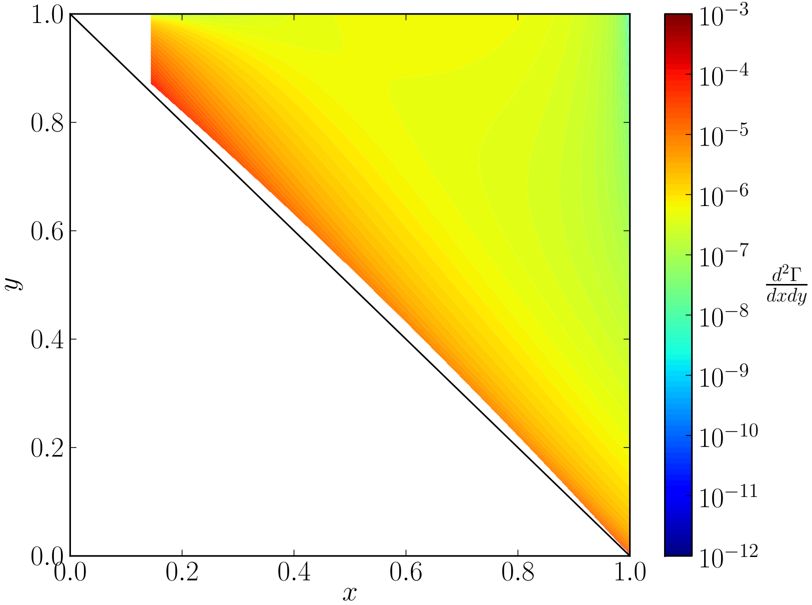
Charged pions decay to three three body processes,

$$\mu + \nu + \gamma, \qquad e + \nu + \pi^0, \qquad e + \nu + \gamma\,.$$

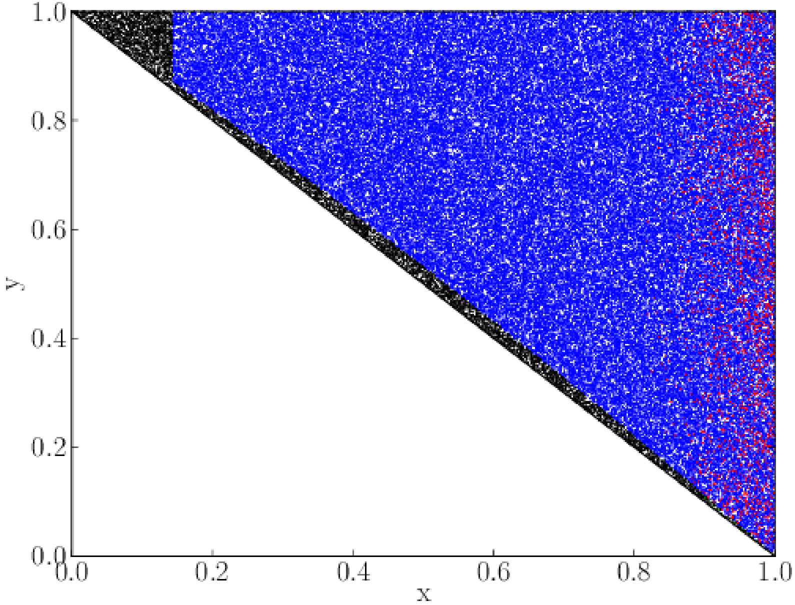
At $E_{\pi^\pm} = 10$ EeV and $E^{\ell}_{\max} = E^{\nu}_{\max} = 2$ PeV,

all but the last two are forbidden.

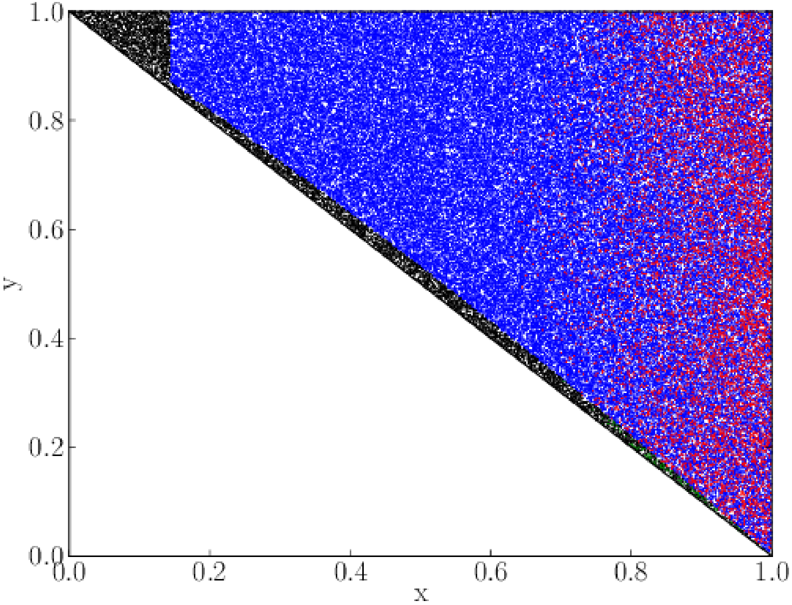
$\pi \to e + \nu + \gamma$: Width



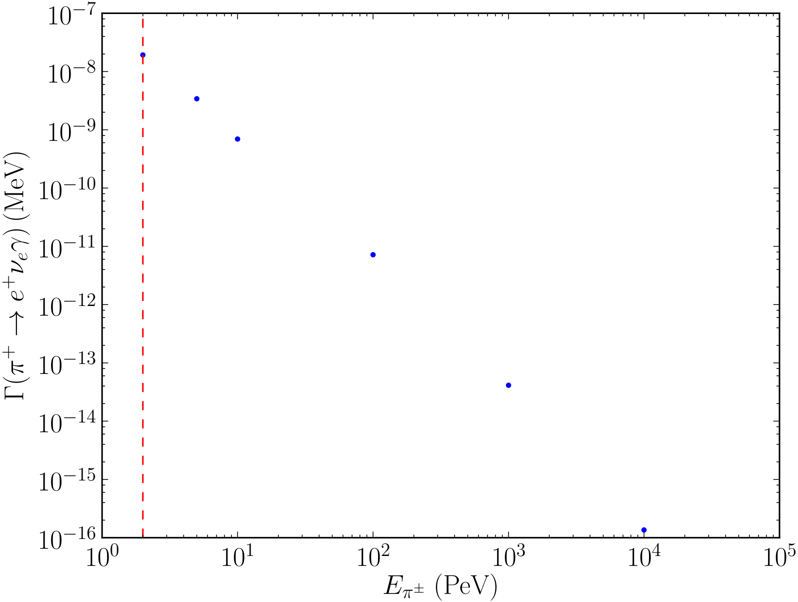
$\pi \to e + \nu + \gamma$: $E_{\max} = 1$ EeV, $E_\pi = 10$ EeV



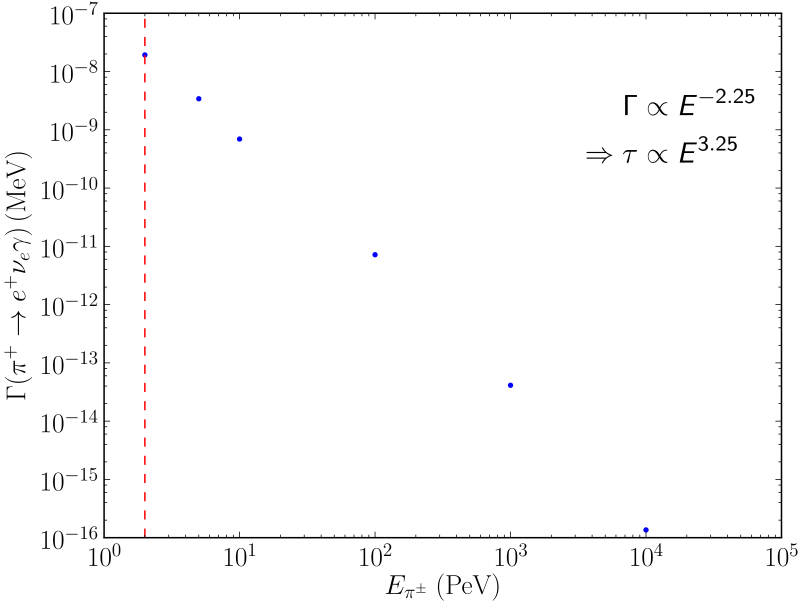
$\pi \to e + \nu + \gamma$: $E_{\max} = 2$ EeV, $E_\pi = 10$ EeV



$\pi \to e + \nu + \gamma$: $E_{\max} = 2$ PeV



$\pi \to e + \nu + \gamma$: $E_{\max} = 2$ PeV



Pion Lifetime

In the SM, at rest, $\tau = 26$ ns.

By removing all but two channels, at $E_{\pi^\pm} = 10$ EeV, $c\tau = 25$ pc.

Including the matrix element and the reduced phase space:

$$c\tau = 4 \text{ Gpc}$$

at $E_{\pi^\pm} = 10$ EeV.

Pion Horizon

Photopion production could limit this horizon.

The process is $\pi^\pm + \gamma_{\rm CMB} \to \rho^\pm \to \pi^\pm + \pi^0$.

Averaged over the CMB photon energies and directions,

the threshold energy is $E_{\pi^\pm,\rm tr} = 14$ EeV,

the resonant energy is $\langle E_{\pi^\pm,\rm res}\rangle_{\rm CMB} = 291$ EeV.

For the standard GZK with the proton, the corresponding values:

$E_{p,\rm tr} = 68$ EeV, $\langle E_{p,\rm res}\rangle_{\rm CMB} = 319$ EeV.

Photopion Production From Pions

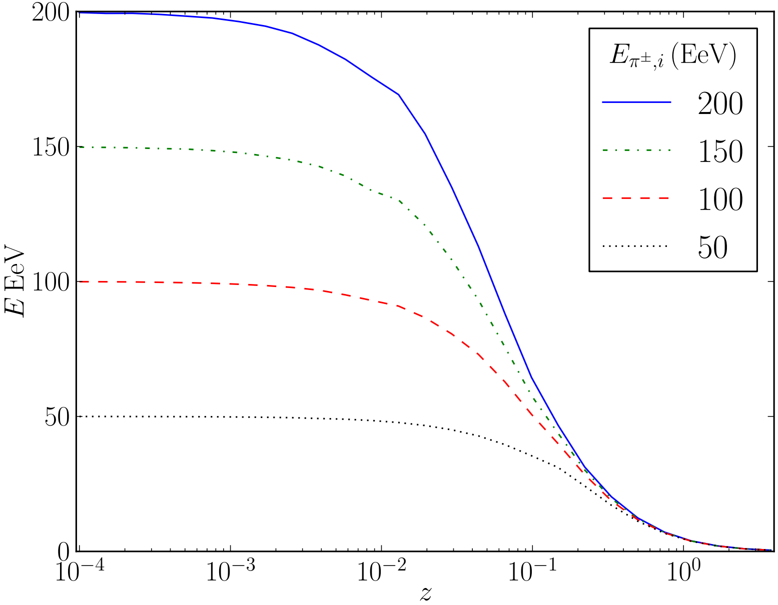
$\sigma(\pi+\gamma)$ has not been measured,

$\Gamma(\rho\to\pi\gamma)$ and $\Gamma(\rho\to\pi\pi)$ have both been measured.

We use a Breit-Wigner approximation for the cross section,

$$\sigma(s)=\frac{2J_\rho+1}{(2S_\pi+1)(2S_\gamma+1)}\frac{4\pi}{|\hat{\mathbf{p}}_i|^2}\frac{m_\rho^2\Gamma_\rho^2}{(s-m_\rho^2)^2+m_\rho^2\Gamma_\rho^2}$$
$$\times\,\mathrm{BR}(\rho\to\pi\gamma)\,\mathrm{BR}(\rho\to\pi\pi)\,.$$

Pion Energy Loss via Photopion Production



Proton + Pion Secondaries Spectrum

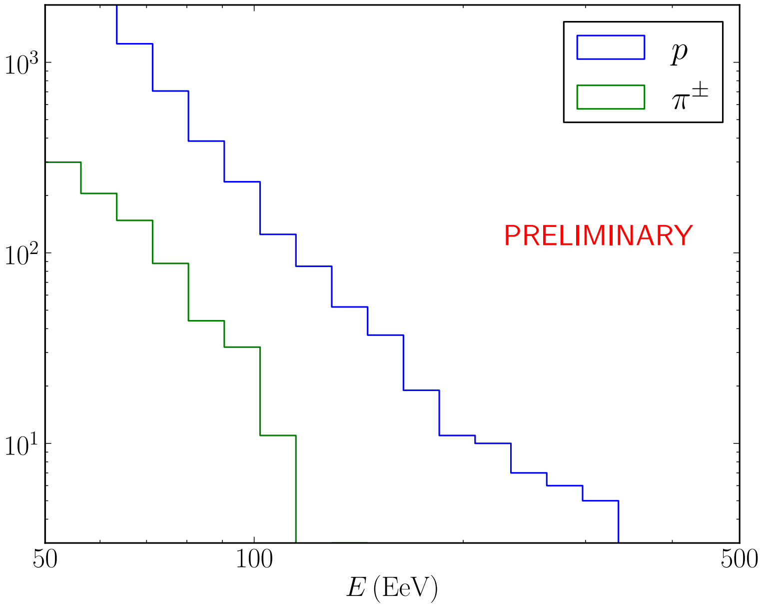
We propagated protons with photopion and redshift effects.

Charged pion secondaries were also propagated.

Used a source evolution of the form,

$$\propto \begin{cases} (1+z)^3 & z < 1.9 \\ (1+1.9)^3 & 1.9 < z < 2.7 \\ (1+1.9)^3 \exp\left(\frac{2.7-z}{2.7}\right) & z > 2.7 \end{cases}$$

Proton + Pion Secondaries Spectrum



Pion Conclusions

Lack of Glashow events suggests an end to the neutrino spectrum.

A maximum energy in the lepton sector effectively stabilizes a $\pi^\pm$.

$\pi^\pm$ can propagate cosmological distances,

and may contribute to the UHECR flux.

Bibliography

References

- PDG, Chin.Phys. C38 (2014) 090001 (2014).
- PBD, T. Weiler, Phys.Rev. D89 (2014) 035013.
- IceCube Collaboration, Phys.Rev.Lett. 113 (2014) 101101.
- S. Glashow, Phys.Rev. 118 (1960) 316-317.
- L. Anchordoqui, et. al., Phys.Lett. B739 (2014) 99-101.