A multi-component model for the observed astrophysical neutrinos

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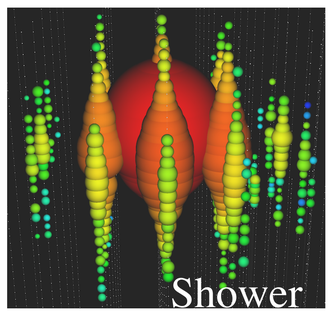
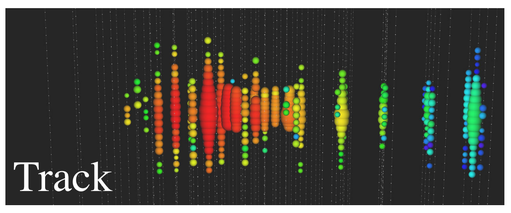
Detection: HESE and TGM

High Energy Starting Events (**HESE**): neutrino-nucleon interaction, inside the detector (tracks and showers, all neutrinos involved)

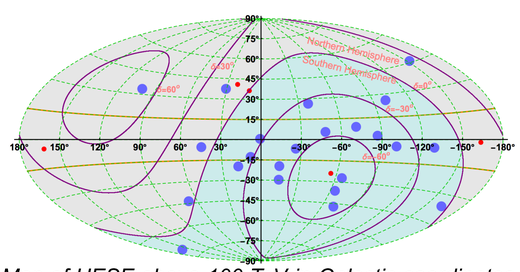
Throughgoing muons (**TGM**): interaction outside the detector (tracks, only muon neutrinos involved)





Astrophysical neutrinos: IceCube observations

	HESE	TGM
Measured power law	$\sim E^{-2.7}$	$\sim E^{-2}$
Energy threshold	30 TeV	200 TeV
Angular sensitivity	mainly Southern hemisphere	Northern hemisphere



Map of HESE above 100 TeV in Galactic coordinates. The blue points denote shower-like events while the red points denote track-like events. The angular resolution is not represented.

Open questions

How can we explain:
- different spectral indices observed by HESE and TGM ?
- slight accumulation of events close to the Galactic plane ?
- lack of correlations between neutrinos and known gamma-ray sources ?
- very energetic track of 4.5 PeV ?

A single power law flux is unable to solve all the issues at the same time

The ingredients of the model

The flux of astrophysical neutrinos can be the result of the contribution of different sources:
- **residual atmospheric background**: it can affect HESE below 100 TeV;
- **galactic neutrinos**: neutrinos produced by the interaction between accelerated protons and the gas contained in our Galactic disk;
- **extragalactic pp neutrinos (Xpp):** the diffuse energy spectrum suggested by TGM is almost flat between 200 TeV and 5 PeV and it is in agreement with HESE measurements in this energy range. This suggest that neutrinos in this energy range can be generated by proton-proton interaction in extragalactic sources;
- **extragalactic p-gamma (Xpg):** 3 HESE have been detected above PeV energy. These events are compatible with neutrinos originated by proton-gamma interaction in an extragalactic source, but the statistics is low

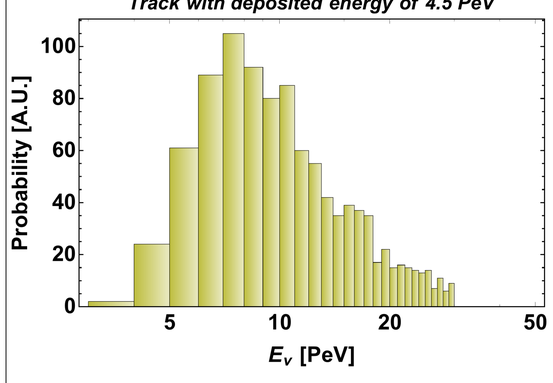
Reconstructed energy

In order to include the atmospheric background we need to reconstruct the initial energy of the full dataset (both HESE and TGM), since in the experimental points, released by IceCube, the background has been already subtracted in a not reproducible way.

Showers: the reconstructed energy is close to the deposited energy

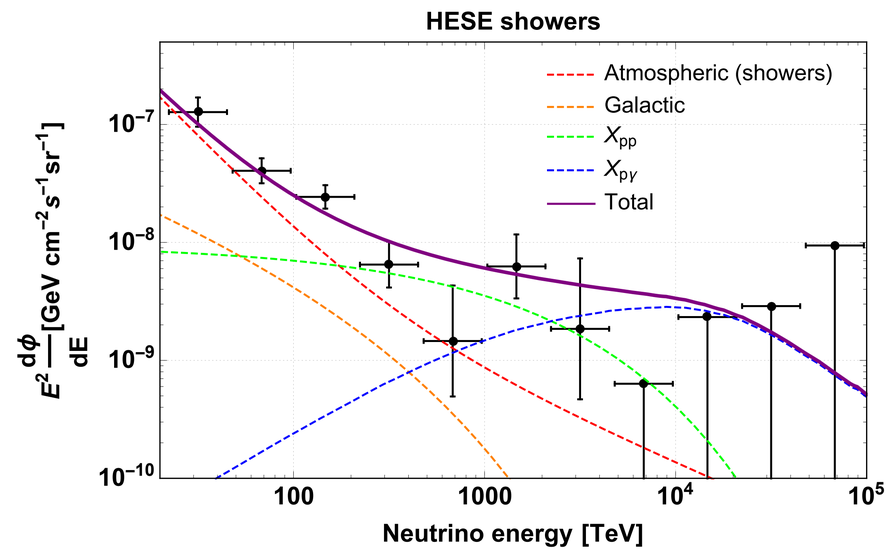
Tracks: the reconstructed energy is very different compared to the deposited one. It can be 2-3 times larger, with a large uncertainty.

Track with deposited energy of 4.5 PeV



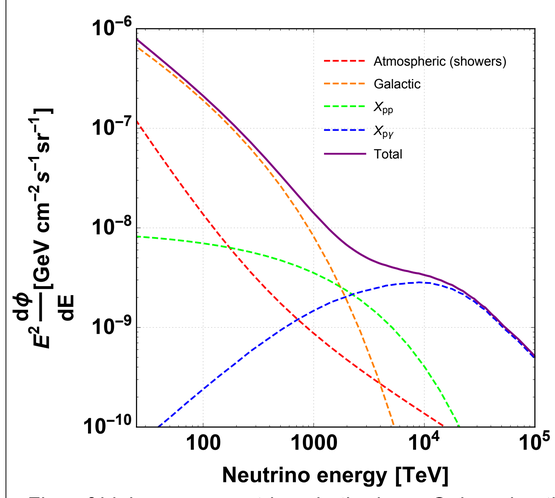
Main results

With the multi-component model we are able to interpret the diffuse flux of astrophysical neutrinos



Diffuse neutrino spectrum obtained using the multi-component model compared with the reconstructed data points. The deficit of neutrinos observed between 500 TeV and 1 PeV is present in the HESE dataset but not in the TGM one; therefore it is likely to be a statistical fluctuation. The point at 6.5 PeV is related to the non observation of resonant events (Glashow resonance) and it is strictly related to the production mechanism. Assuming p-gamma mechanism it would be at least 2 times higher, removing any tension.

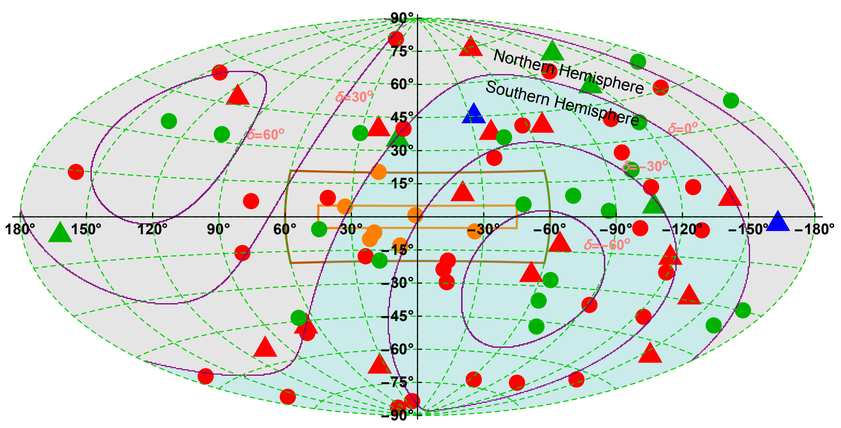
On the Galactic component



Flux of high energy neutrinos in the inner Galaxy, i.e. the region having Galactic latitude $|b|<5°$ and Galactic longitude $|l|<45°$

Although it is plausible that the flux of Galactic neutrinos is characterized by a cutoff (or at least by a softening) around 150 TeV, the contribution of Galactic neutrinos in the inner Galaxy can be the dominant one up to PeV energies.

Discussion and conclusions



Map of HESE in Galactic coordinates. The possible counterpart are represented, namely: in red atmospheric neutrinos, in orange Galactic neutrinos, in green extragalactic neutrinos from pp interaction, in blue extragalactic neutrinos from p-gamma interaction.

A multi-component model can reconcile the numerous observations related to astrophysical neutrinos, solving the main issues:

- **tension between HESE and TGM:** can be due to a Galactic component (present in HESE-South) + residual atmospheric background in HESE. TGM are not affected by them, due to the position and to the higher energy threshold;
- **accumulation of neutrinos above 100 TeV on the Galactic plane:** at this energy the atmospheric background becomes sub-dominant while the Galactic component is still important in the "inner Galaxy"
- **lack of correlation with known sources:** the most important contribution to the IceCube signal (50%-60%) is provided by pp sources, like Starburst Galaxies. Those sources are not bright in gamma-rays;
- **the very energetic PeV track**: a p-gamma source (TDEs, not resolved blazars, …) can explain neutrinos above PeV, since the flux of neutrinos from p-gamma interaction is expected to peak at PeV energies.

References

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