

New Constraints on Neutrino Velocities

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”.....we refute the superluminal interpretation of the OPERA result. Furthermore, we appeal to Super-Kamiokande and IceCube data to establish strong new limits on the superluminal propagation of high-energy neutrinos.”

”As in all cases of superluminal propagation, certain otherwise forbidden processes are kinematically permitted, even in vacuum. In particular, we focus on the following analogs to Cherenkov radiation:

$$\nu_{\mu} \longrightarrow \begin{cases} \nu_{\mu} + \gamma & (a) \\ \nu_{\mu} + \nu_e + \bar{\nu}_e & (b) \\ \nu_{\mu} + e^+ + e^- & (c) \end{cases}$$

Process (c), pair bremsstrahlung, proceeds through the neutral current weak interaction. The threshold energy for this process is

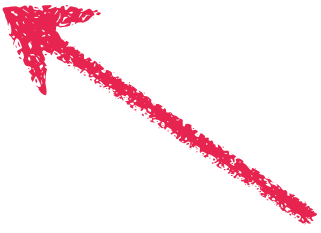
$$E_0 = 2m_e / \sqrt{v_\nu^2 - v_e^2}$$

where v_e is the maximal attainable velocity of an electron and m_e its mass.

However, we know that $v_e = 1$ to a precision of at least 10^{-15} .

Thus we may write $E_0 = 2m_e / \sqrt{\delta}$

Its value is about 140 MeV for the OPERA value of δ .



Otherwise CR photons would decay to e^+e^- pairs. Limit comes from observation of CR photons above 20 TeV

We have computed both Γ , the rate of pair emission by an energetic superluminal neutrino, and dE/dx , the rate at which it loses energy in the high energy limit where the electron and neutrino masses may be neglected¹:

$$\Gamma = k' \frac{G_F^2}{192\pi^3} E^5 \delta^3$$
$$\frac{dE}{dx} = -k \frac{G_F^2}{192\pi^3} E^6 \delta^3$$

¹ These expressions are leading order in δ . We have also neglected the vector-current coupling of the electron: $c_V = 0$ and $c_A = -1/2$.

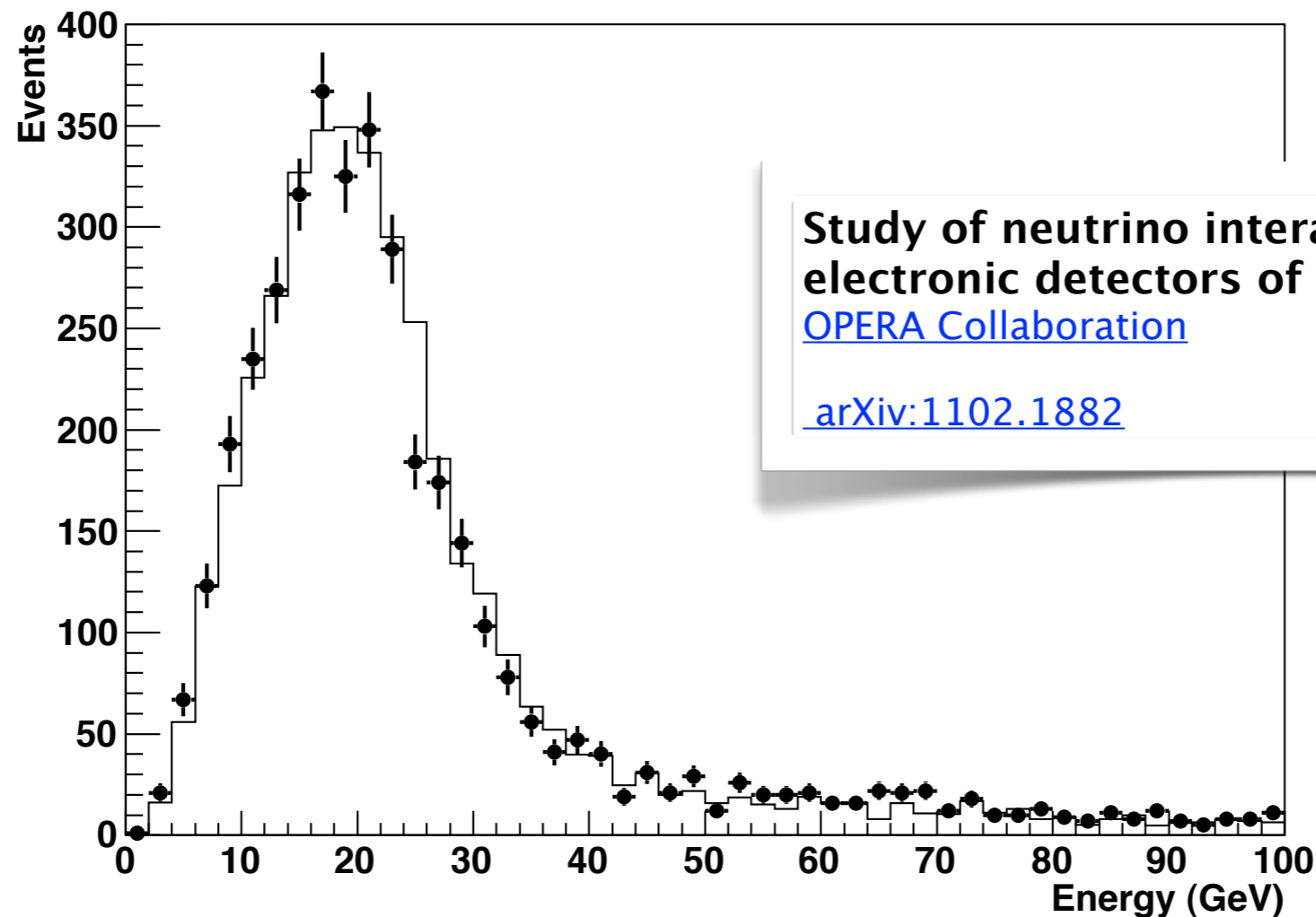
We integrate dE/dx assuming δ not to vary significantly in the relevant energy interval.
We find that neutrinos with initial energy E_0 , after traveling a distance L , will have energy E as given by:

$$E^{-5} - E_0^{-5} = 5k\delta^3 \frac{G_F^2}{192\pi^3} L \equiv E_T^{-5}$$

The steeply falling (with energy) form of dE/dx means that neutrinos with initial energy greater than E_T rapidly approach a terminal energy, E_T , which is essentially independent of the initial neutrino energy.

Adopting the OPERA result $\delta = 5 \times 10^{-5}$ and using the OPERA baseline of 730 km we find a terminal energy of about 12.5 GeV.

..we may also establish that any superluminal neutrino with the velocity claimed by OPERA of any specific initial energy much greater than 12.5 GeV has a negligible probability of arriving at the Gran Sasso without having lost most of its energy.



The IceCube collaboration has reported the observation of upward-going showers with reconstructed shower energies above 16 TeV. Using a neutrino energy of 16 TeV and a minimum baseline of 500 km (which would be appropriate for a horizontal neutrino) we obtain a more stringent limit $\delta < 3.75 \times 10^{-10}$, superior to the SN1987a constraint by an order of magnitude.

Finally IceCube has also reported events with energies in excess of 100 TeV. Observation of neutrinos with this energy and a baseline of at least 500 km implies a limit of $\delta < 1.7 \times 10^{-11}$.

While $\delta < 1.7 \times 10^{-11}$ is significantly better than previous bounds, a more careful analysis of the pathlengths and energies of the highest energy events from Super-Kamiokande, IceCube and other neutrino telescopes may enable an even stronger constraint.