Neutrino time-of-flight from GRB's

A proposed direct measurement of neutrino mass

M. G. Greene, D. F. Cowen

mgreene@phys.psu.edu

Department of Physics

Pennsylvania State University

Time-of-flight

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\begin{aligned}
t &= \frac{L}{v} \\
&= \frac{L}{\sqrt{1-(m/E)^2}} \\
&\approx L\left[1+\frac{1}{2}\left(\frac{m}{E}\right)^2\right]
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Measure t, L, E, get m.

F. Halzen and G. Jaczko, Phys. Rev. D **54**, 2779 (1996).

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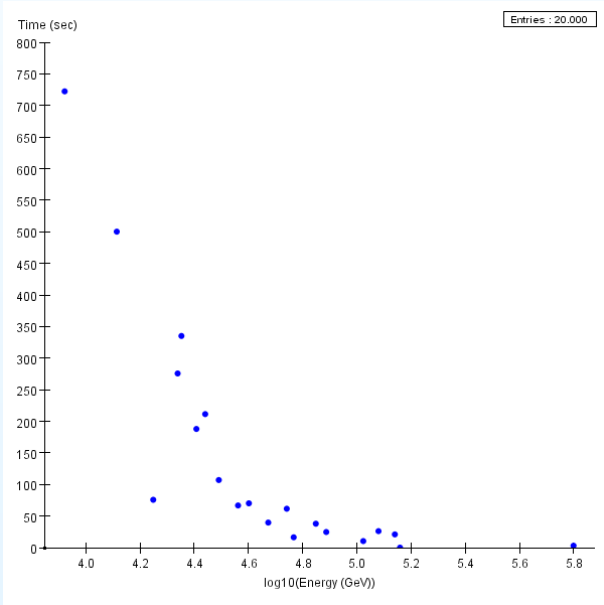
- *But neutrinos may not have been emitted simultaneously with photons!*
  P. Meszaros and E. Waxman, Phys. Rev. Lett. **87**, 171102 (2001) [astro-ph/0103275].

Don’t use photons for start time

$$t_i = L - t_0 + \frac{L\,m^2}{2\,E_i^2}\ .$$



S. Choubey and S. F. King, Phys. Rev. D **67**, 073005 (2003) [hep-ph/0207260].

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- Also, one supernova-associated burst could induce as many as 300 detected neutrinos!
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- Only need to detect two neutrinos from one GRB *(in principle!)*

Two neutrinos from a single GRB

Assume both neutrinos have the same mass:

$$m = E_1 \, E_2 \left[\frac{2 \, (t_2 - t_1)}{L \, \left(E_1^2 - E_2^2 \right)} \right]^{\frac{1}{2}} .$$

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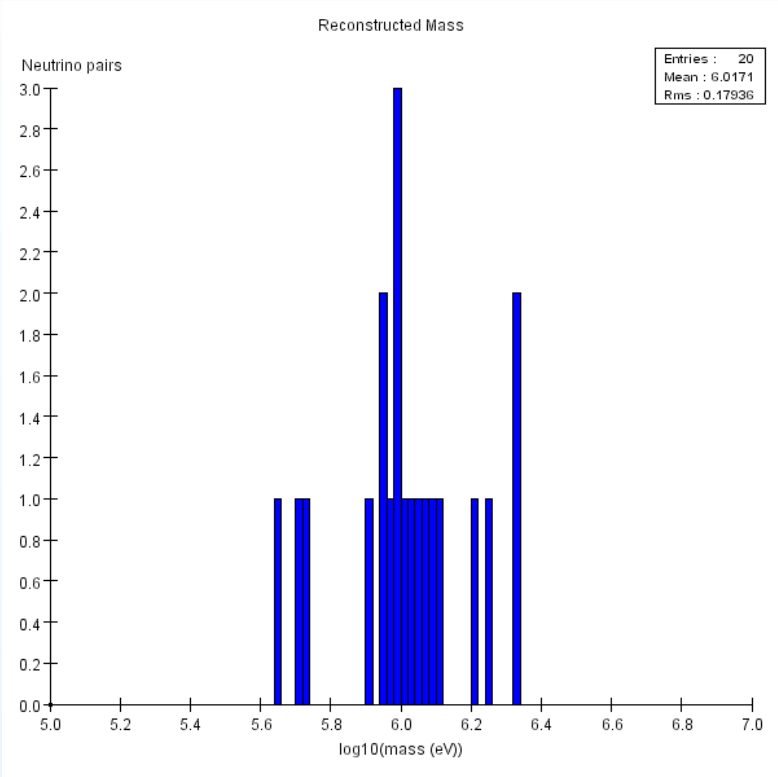
Or, place an upper limit two orders of magnitude lower than current PDG value for τ neutrino (18 MeV)

HOWEVER: Indirect upper limit on maximum neutrino mass is less than the limit on electron neutrino plus the (small) delta m^2

Many neutrino pairs (from different GRB's)



$N_f = 1$

20 detected pairs

MC Truth: $m_\nu = 1.0$ MeV, mean GRB duration = 10 seconds, mean GRB distance = 8.3×10^9 ly

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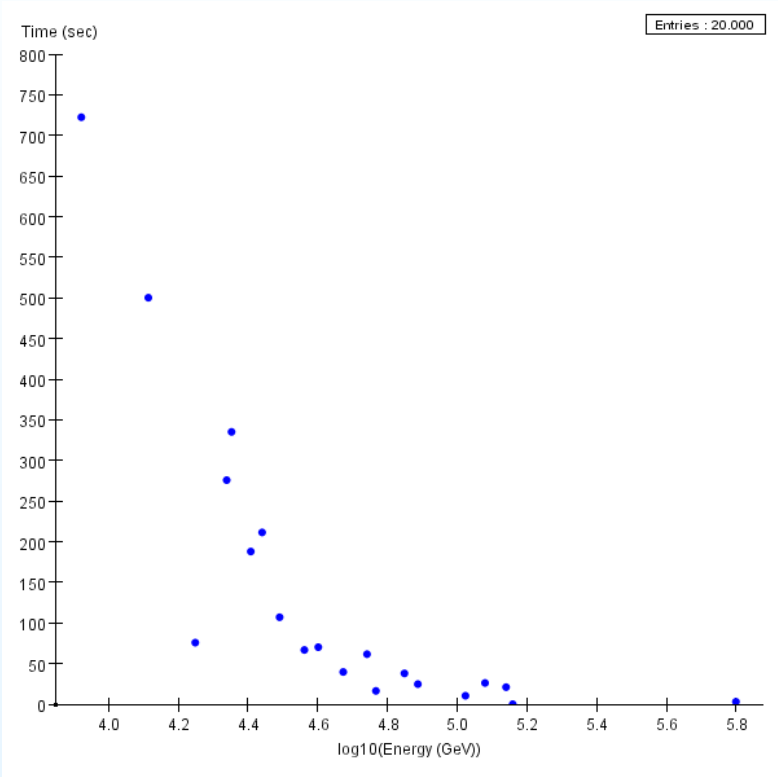

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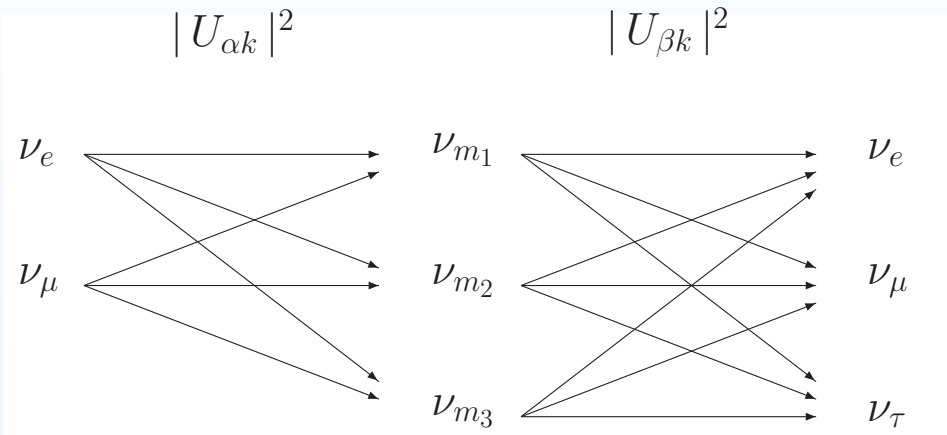
Neutrino mixing



Neutrino emitted as $|\alpha\rangle$, detected as $|\beta\rangle$

$N_f = 3$ *clusters*

Neutrinos from pion decay: $f_\alpha = (1/3,\ 2/3,\ 0)$

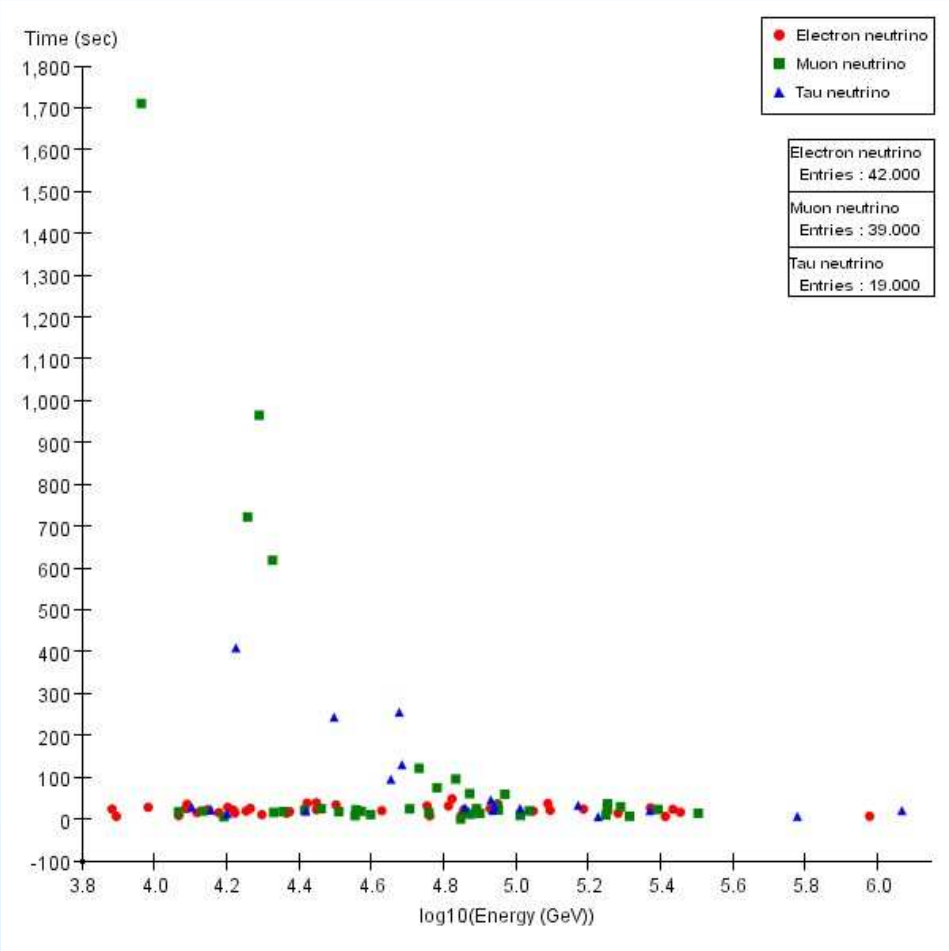
Neutrino mixing (cont.)

The next two slides –

Monte Carlo Truth:

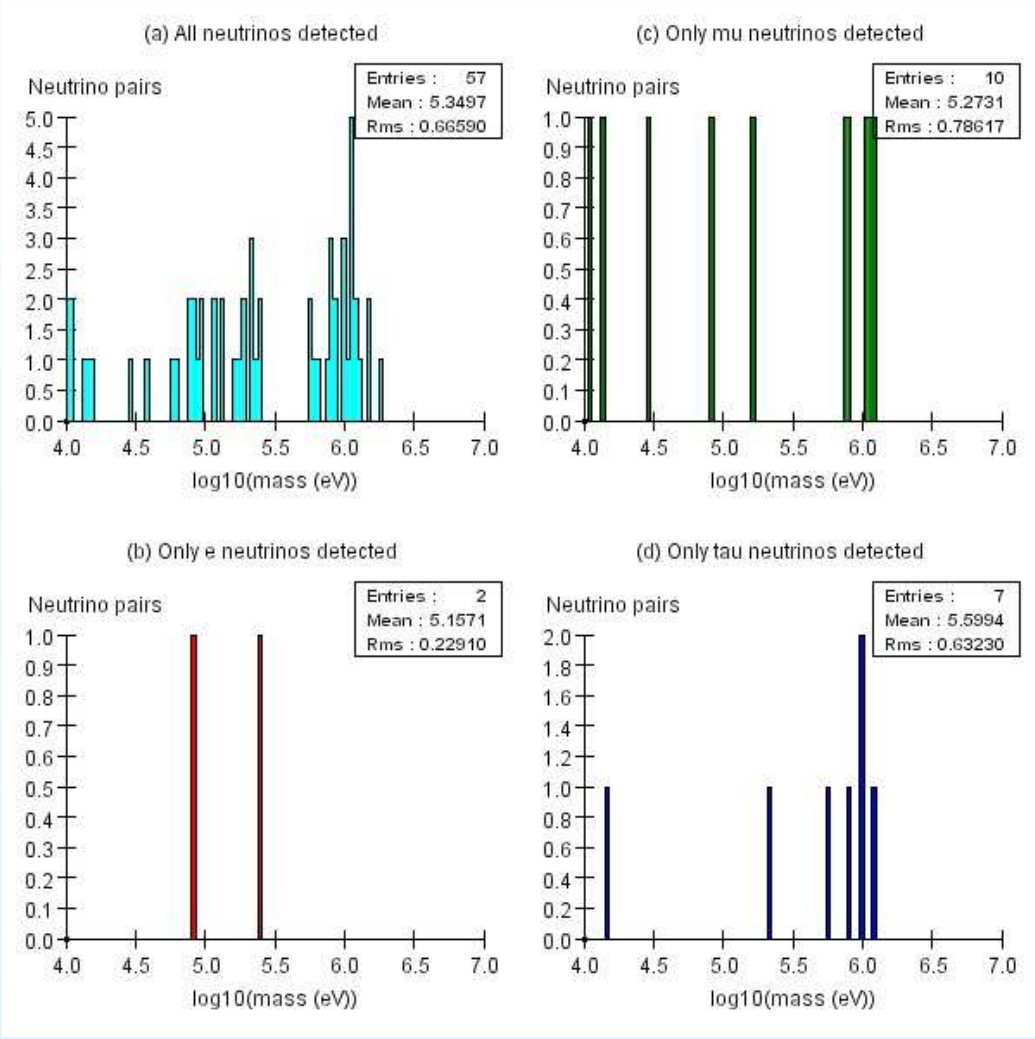
- MNS matrix based on “large mixing MSW” solution.
- Emission probabilities $f_e = 1/3,\ f_\mu = 2/3,\ f_\tau = 0$.
- $m_1 = 1$ eV, $m_2 = 1 \times 10^3$ eV, $m_3 = 1 \times 10^6$ eV.
- Mean GRB duration = 10 seconds.
- Mean GRB distance $= 8.3 \times 10^9$ ly.

100 neutrinos detected from one GRB



Markers indicate *detected* flavor.

100 neutrino pairs (from different GRB's)



Unanswered questions

- What's the best way to fit the data?
  - How to assign neutrinos to clusters?
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- What's the best way to fit the data?
  - How to assign neutrinos to clusters?
  - What assumptions should to be made about mixing matrix?
- If no correlation between neutrino arrival time and energy is observed, how to place an upper limit?

More things to think about

- Cosmological expansion
  L. Stodolsky, Phys. Lett. B **473**, 61 (2000) [astro-ph/9911167].

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- Neutrino decay in flight

Conclusions:

If we get multiple neutrinos from a GRB, we will certainly want to look at them with this kind of technique, looking at the energies and arrival times of the neutrinos.

Can get as low as roughly 1 MeV in neutrino mass with this technique
- About 2 orders of magnitude better than current direct limit
- About 2 orders of magnitude worse than current indirect limit from electron neutrino and delta-m^2's

Are there other ways that neutrinos can experience neutrino-mass-dependent dispersion?

More details

Docushare:

icecube-phys/0503141 v1