Tutorial Question #99

Deborah Harris

Borrowing heavily from

INSS 2012 problem presentation
R. Castillo, M. Reeves, C. Sun, L. Yang

Advice: title slide with all the names of the people in your group
Advice: Plan for a 10 minute presentation, <10 slides if you can

If no one in your group has a laptop

- You can still present your answer to a question, you can just use a whiteboard instead

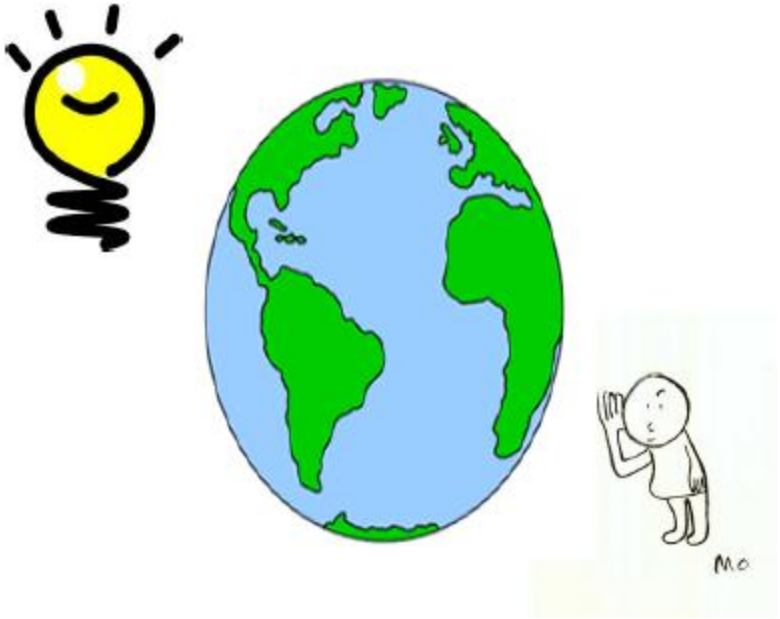
- Please let us know in advance if this is the case
  - We have more whiteboards if needed!

Advice: state the question

- Imagine you were trying to set up a fast communications link using neutrinos to do insider trading (see http://www.forbes.com/sites/brucedorminey/2012/04/30/neutrinos-to-give-high-frequency-traders-the-millisecond-edge/
- What kind of neutrino detector and neutrino source would you need for this to work (imagine that money is no object)?

From INSS 2012 tutorials

Advice: start with the big picture



Take advantage of the fact that neutrinos can go through the earth directly, without the need for a satellite

"... High-frequency traders are notoriously secretive about divulging trading times even to colleagues within their own firms, since any such time-dependent trading edge can be fleeting. But many programmed trades are now known to take place within milliseconds or less.

"Thirty milliseconds is a lot of time in high-velocity trading," said former J.P. Morgan Chase options trader Espen Gaarder Haug, an expert in automated high-frequency trading, and a professor of finance at the Norwegian University of Life Sciences near Oslo. ..." http://www.forbes.com/sites/brucedorminey/2012/04/30/neutrinos-to-give-high-frequency-traders-the-millisecond-edge/2/

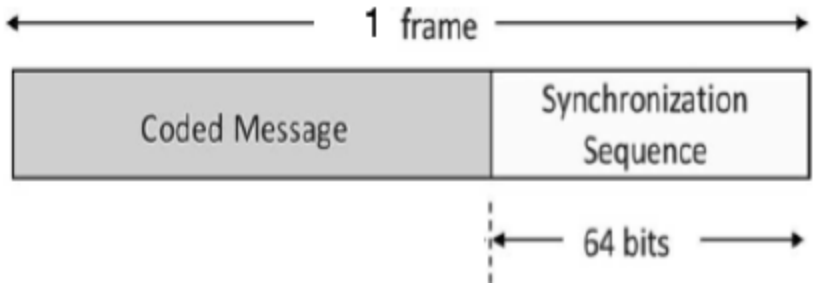
Communicating with neutrinos

- If you can turn on and off a pulsed neutrino beam then you can send a signal
  - A demonstration of this was done with the NuMI beamline in 2010

ASCII (American Standard Code for Information Interchange)

- only use capital A (~~01~~000001) to Z (~~01~~011010)
- A (Ø1000001) to Z (Ø1011010) and 0 (Ø0110000) to 9 (Ø0111001)
- the word 'INSS' is coded as 20 bits '001001/ 001110/ 010011/ 010011' and being encapsulated as 84 with control sequence

Assume need 100 bits to send the message:
Which stock to trade



refer to 'Demonstration of Communication Using Neutrinos', (arXiv: 1203.2847v2 [hep-ex])

Time differences

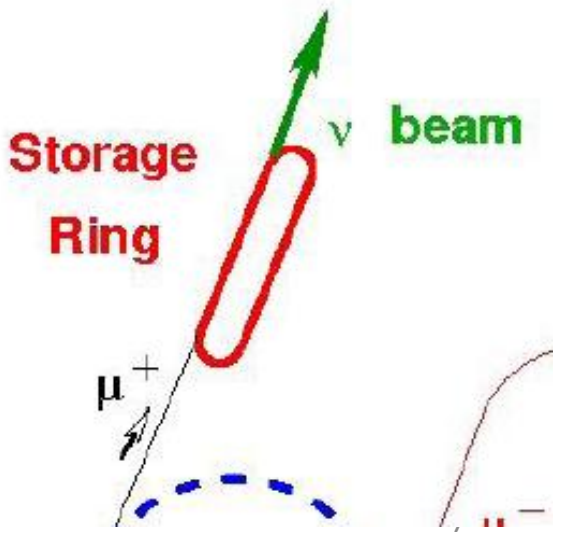
	Distance Earth Surface	Distance Through Earth	Time Surface Fiber optics	Time Surface Air	Time Through Earth	Time saved Through Earth versus Fiber	Time saved Through Earth versus Air
New York London	3,465	3,337	28.2	18.6	17.9	10.3	0.7
New York Tokyo	6,749	5,817	54.9	36.3	31.2	23.7	5.0
London Tokyo	5,946	5,394	48.4	31.9	29.0	19.4	3.0
New York Hong Kong	8,054	6,630	65.5	43.3	35.6	29.9	7.7
London Hong Kong	5,979	5,423	48.6	32.1	29.1	19.5	3.0
London Sydney	10,572	7,691	86.0	56.8	41.3	44.7	15.5
New York Sydney	10,377	7,487	84.4	55.7	40.2	44.2	15.5

Distances in miles, time in milliseconds, calculations by professor Espen Gaarder Haug
Optical fiber assumed 66% speed of light. Neutrino speed assumed approximately speed of light.

New York to Hong Kong: Save 8msec with a neutrino interaction

Beam: Neutrino Factory

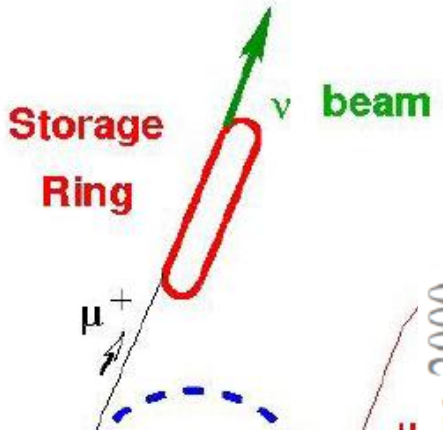
- Created by decays of muons that have been focused and accelerated and put into race-track like storage ring (Soler advice: can quote professors here)
- Opening angle of neutrino beam: $1/\gamma$
  - Where γ is the boost of the muon (E_μ/m_μ)
  - Show that flux is α to $(1/\gamma)^2$
  - Show that flux is α to $(1/L(km))^2$
- Average Neutrino Energy is $\alpha\ \gamma$
  - Can derive some version of event rate per muon decay



Neutrino Factory Event Rates:

$$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$$

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



Total neutrino and anti-neutrino interaction rates per muon decay:

$$N_\nu = 1.2 \times 10^{-14} \left[\frac{(E_\mu, \mathrm{GeV})^3}{(L, km)^2}\right] \times C(\nu) \text{ events per kt}$$

$$N_{\bar{\nu}} = 0.6 \times 10^{-14} \left[\frac{(E_\mu, \mathrm{GeV})^3}{(L, km)^2}\right] \times C(\nu) \text{ events per kt}$$

$$C(\nu_\mu) = \frac{7}{10} + P_\mu \frac{3}{10}, \quad C(\nu_e) = \frac{6}{10} - P_\mu \frac{6}{10}$$

Assume Polarization (P_μ) is zero

Plugging in Numbers

- For 100GeV neutrinos, 7000km:

$$N_\nu = 1.2 \times 10^{-14} \left[\frac{(E_\mu, \mathrm{GeV})^3}{(L, km)^2}\right] \times C(\nu) \text{ events per kt}$$

$$N_{\bar{\nu}} = 0.6 \times 10^{-14} \left[\frac{(E_\mu, \mathrm{GeV})^3}{(L, km)^2}\right] \times C(\nu) \text{ events per kt}$$

$$C(\nu_\mu) = \frac{7}{10} + P_\mu \frac{3}{10}, \quad C(\nu_e) = \frac{6}{10} - P_\mu \frac{6}{10}$$

Advice: don't need to show every step of math

Assume: 10^{21} muon decays/year,
Or 10^{14} decays per second
10^{11} decays per ms
and 100 kton: get

$N_\nu = 1.2 \times 10^{-3} \, (1/49)*(7/10)*100$ ~1 CC ν_μ/ms

Advantage of using Neutrinos only for communication

- Since this is not an oscillation or cross section measurement
  - We don't care if it's a neutrino or antineutrino
  - We don't care if the interaction is charged current or neutral current
  - So 1 ν_μ Charged Current/msec really means closer to 2 or 3 total neutral lepton interactions per msec
- But will need to reduce backgrounds if we accept all these kinds of events
  - Put detector underground, no big mountains in NYC

Effects not considered in today's example but could be considered

- Neutrino Absorption in earth
  - Interaction length of neutrino: $L_{\text{int}} = \frac{1}{\sigma \rho N_A} \sim 10^{15} m$
  - Conversion probability: 10^{-8}
- Neutrino Oscillations
  - Would change muon neutrinos to tau neutrinos
  - Would change some electron neutrinos to μ/τ neutrinos
- Earth's matter effect
  - Would change electron neutrino transition probability

Advice: can mention effects that you didn't calculate exactly and explain if they matter

Advice: end with Conclusion slide

- With neutrino factory beam
  - of 100GeV muons
  - With 10^{21} muon decays per year in straight section
- With neutrino detector of 100kton
  - 2x Super-Kamiokande
  - 20x MINOS
  - 7x NOvA
  - 5000 Daya Bay modules
- Can just get 3 ν's per msec in a communication link, to take advantage of the 8msec speed advantage of going from Hong Kong to New York City
- Moral of the story: Forbes magazine isn't reviewed by physicists

Tutorial Schedule

- Today: meet your group, discuss which question you want to answer
- Tomorrow: sign up
- Rest of the time: work on questions
  - Professors/Tutors will be here from 2-4PM if you have questions
- Give your slides to Deborah or Wei before presentation session
- Lecturers will be the jurors for presentations
- Wednesday July 14: 1st set of presentations during tutorials (half the groups present)
- Thursday July 15: 2nd set of group presentations during tutorials (second half)
- Thursday night: Award Ceremony at Banquet