Double Chooz: REU at Nevis 2013

*a study on neutrino directionality and brief overview of neutrino physics*

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Standard Model

-initial assumption: lepton flavour is permanent
-experiment by Ray Davis (Homestake experiment) observes about 1/3 as many as predicted neutrinos from the sun are detected
-explained by the notion that neutrinos can oscillate but because of quantum mechanics...

-implies that there are also mass eigenstates mass eigenstate [not equal] flavour eigenstate .... thus:

Neutrinos oscillate
Neutrinos have small mass
Neutrinos Oscillate

Pontecorvo-Maki-Nakagawa-Sakata Matrix (PMNS)
flavour eigenstates NOT EQUAL mass eigenstates
flavour eigenstates = U-PMNS * mass eigenstates
Neutrino oscillation

\[ P(\nu_\mu \rightarrow \nu_e) = \sin^2(2\theta) \sin^2\left(\frac{1.27\Delta m^2 L}{E}\right) \]

- 2 neutrino model and three neutrino model

- \text{theta}13: mixing angle (from the PMNS matrix)

- \text{delta m}^2: difference of masses squared between the neutrino flavours

- \text{L}: distance neutrino has traveled (from emission to detection)

- \text{E}: is the energy of the neutrino beam
Neutrino oscillation

\[ P(\nu_\mu \rightarrow \nu_e) = \sin^2(2\theta) \sin^2\left(\frac{1.27 \Delta m^2 L}{E}\right) \]

- \( \theta_{13} \): mixing angle
- \( \Delta m^2 \): difference of masses
- \( L \): baseline
- \( E \): is the energy of the neutrino beam (3.5 MeV)
Neutrinos: Theory

-mixing angle \( \theta_{12} \) and \( \theta_{23} \) are known because they were circumstantially easier to measure

-Solar angle (12): ~33 degrees

-Atmospheric angle (23): ~45 degrees

-Mass hierarchy problem

-search for mixing angle: \( \Theta_{13} \)
Neutrinos: Experiment

Methods of neutrino detection:
- appearance experiments: MicroBoone
- disappearance experiments: Double Chooz
  - located next to reactor: source of neutrinos
  - trying to measure $\theta_{13}$

* sometimes known as the small angle

-detection by way of inverse beta decay:

\[(\text{anti})\nu_e + p \rightarrow n + e^+\]

(anti electron neutrino and proton $\rightarrow$ neutron and positron)

***only method of detection, thus only can see anti electron neutrino
Double Chooz

-located in a town called Chooz in northern France, next to power station

-Uranium-235 or -238 (and sometimes Plutonium) fission emits anti neutrinos

**Reactor Oscillation Experiments**

\[ P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \left( \frac{1.27 \Delta m_{13}^2 L}{E_{\nu}} \right) \]

**Diagram:**

- Far detector: 1050 m
- Near detector: ~400 m
Far Detector

Target (blue ring)
Gamma Catcher (red ring)
Buffer (green ring)
1. Prompt Signal

2. Delayed signal
Double Chooz
{ in a nutshell}

Reactor
Near Detector or
MC prediction

(\text{ Flux})L^2

\begin{align*}
E_\nu & \sim 4 \text{ MeV} \\
\end{align*}

\begin{align*}
\text{No Oscillations} & \quad \text{Oscillated} \\
\text{\sim 1.5km} & \quad \text{\< 14\%} \\
\end{align*}
Looking for neutrino-like events
- prompt signal [.7, 12.2] MeV
- delayed signal 8 MeV if caught on Gd
  [6,12] MeV
- delayed signal 2.2 MeV if caught on H
  [1.5,3] MeV
- time separation between them
  [2, 100] us (Gd), [10,600]us (H)
Data from Double Chooz Publication, (IBD spectrum: Prompt signal)
Problematic neutrino-like events:
Lithium 9: also beta-n decays (cosmic ray muons)
Rock radioactivity: emit gamma rays
Fast neutrons (from cosmic ray muons)
Stopping muons: decay

muons + cosmic rays +Li9 +loose neutrons=coincidences and neutrino like events
-approximate how much that'll happen
More accuracy...?

- Directionality! unique to reactor neutrinos
  - direction of neutron displacement
  - displaced during thermalization
  - displacement vector:
    $<\text{position of delayed signal} - \text{position of prompt signal}>$

- predicted by neutrino wind
- distribution of theta
Neutrino wind in strong -y, slight -x
Neutron displacement (x component, y component)
PROMPT SIGNAL  DELAYED SIGNAL  COMPONENT

**DISPLACEMENT VECTOR**

**X**

- Entries: 8347
- Mean: -3.11
- RMS: 178.6

**Y**

- Entries: 8347
- Mean: -16.19
- RMS: 174.7

**Z**

- Entries: 8347
- Mean: 4.639
- RMS: 182.4
Ok, what of it?

- Analyse that data set and others
- based on n-displacement vectors (and cos(\theta) distributions)
- create a set of likelihoods, off of which create a set of weights
- apply weight to analysis
  - on premise of:
    - if within this angular distribution
    - then this much more likely to be a reactor neutrino event
Conclusions and Future

- Directionality is certainly useful analysis
  - extra feature distinguishing neutrino-like neutrino events from neutrino-like non-neutrino events
- The future of directionality depends on
  - position reconstruction

- Incorporating this analysis into the next publication
“There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is another theory which states that this has already happened.” - Douglas Adams

Special Thanks to...

Rachel Carr
Leslie Camilleri
Mike Shaevitz

for teaching me so much

and

Nevis Labs, the REU Program,
John Parsons and the NSF

for the opportunity and experience