NEUTRINO ASTRONOMY
MEASURING THE SUN’S CORE

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NEUTRINO ASTRONOMY

• In order to do astronomy with neutrinos we need to be able to work out where they are coming from in the sky.

• Interested in two cases: supernova neutrinos and solar neutrinos.

• If a supernova goes off in our galaxy and we detect its neutrinos, can we work out where in the galaxy it happened?

• Can we use neutrino directionality to probe the sun’s core?
DETECTION OF NEUTRINOS

• I will focus on water Cherenkov detectors such as Super Kamiokande (SK).
• Very large detectors such as SK mean that it is possible to obtain large statistics even though neutrinos interact weakly.
• They are good for solar and supernova neutrinos and they have directional sensitivity for incoming neutrinos.
DETECTION OF SOLAR NEUTRINOS

- An MeV-energy neutrino scatters elastically off an electron.
- The electron emits Cherenkov light, which is observed by photomultiplier tubes.

\[
\nu + e^- \rightarrow \nu + e^- \\
\text{In } H_2O \quad \text{Emits Cherenkov Light}
\]
DETECTION OF NEUTRINOS

- The elastic scattering cross section is strongly forward-peaked for MeV-scale neutrinos, especially for higher recoil energies.
- Hence the electron after scattering will point back towards the original direction of the neutrino.

THE ANGULAR RESOLUTION OF NEUTRINO DETECTORS

• Unfortunately the actual resolution is much worse, since the electron scatters in the water multiple times. Hence the observed electron direction is only weakly correlated with the incident neutrino direction.

• This multiple scattering contributes almost all of the angular resolution, and is well-understood due to calibration data.


\[ R(\ell) \]

\[
\begin{align*}
E=16.1\text{MeV} \\
E=6.8\text{MeV}
\end{align*}
\]

CASE STUDY: SUPERNOVA POINTING WITH NEUTRINOS

• Since the multiple-scattering of the electron is well-known, we can reconstruct the supernova direction.

• Obtain a simple approximate formula for the angular resolution for SN pointing:

\[ \delta \theta \approx \frac{25^\circ}{\sqrt{N_s}} \]


FIG. 4: Angular distribution of $\bar{\nu}_e p \rightarrow n e^+$ events (green) and elastic scattering events $\nu e^- \rightarrow \nu e^-$ (blue) of one simulated SN.
Solar neutrinos are produced via fusion reactions occurring in the Sun’s core.

- The solar core has a radius of 20% to 25% of the solar radius.
- Their energies and fluxes depend on the fusion reactions in which they are created.
WHERE ARE 8B NEUTRINOS PRODUCED IN THE CORE?

• Different fusion reactions should occur at different positions within the core.
• We focus on 8B neutrinos, which are predicted to be produced in a spherical region located at 5% of the solar radius from the core centre.

We need to generate the distribution of electrons in a water Cherenkov detector, given an assumption on the neutrino distribution in the solar core.

Start by generating initial angles of the neutrinos as they arrive at Earth, given a distribution in the core:
MAXIMUM LIKELIHOOD ANALYSIS – GENERATING SIGNAL DISTRIBUTIONS

- Combine the initial distribution of neutrinos, the differential cross section of electron-nu scattering and the distribution of electron multi-scattering in the detector.
- Repeat this process for different initial neutrino distributions within the solar core.
MAXIMUM LIKELIHOOD ANALYSIS – GENERATING SIGNAL DISTRIBUTIONS

Difference between profiles is about 200 events per bin.

The spectra are only just distinguishable above statistical noise.

Poisson uncertainty is roughly $\sqrt{31000} = 176$. 

Spectra of electrons from neutrino scattering assuming different values of $R_{SB}$.

2000 kton years exposure
MAXIMUM LIKELIHOOD ANALYSIS - RESULTS

95% confidence contours

4 years for a 500 kilo-tonne experiment

20 years for Super Kamiokande

CONCLUSION

• We can use solar neutrino experiments as telescopes of the solar interior.
• Super Kamiokande has 20 years of data so can already constrain the solar neutrino production region to be within the solar core.
• A 500 kton experiment, perhaps Hyper Kamiokande, could do much better, but it would need to keep background levels as small or smaller than for Super Kamiokande.

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