TeVPA – Columbus, Ohio, USA – 7th August 2017

NEUTRINO ASTRONOMY

MEASURING THE SUN'S CORE

Based on **J.H.Davis, Phys.Rev.Lett. 117 (2016) 211101**

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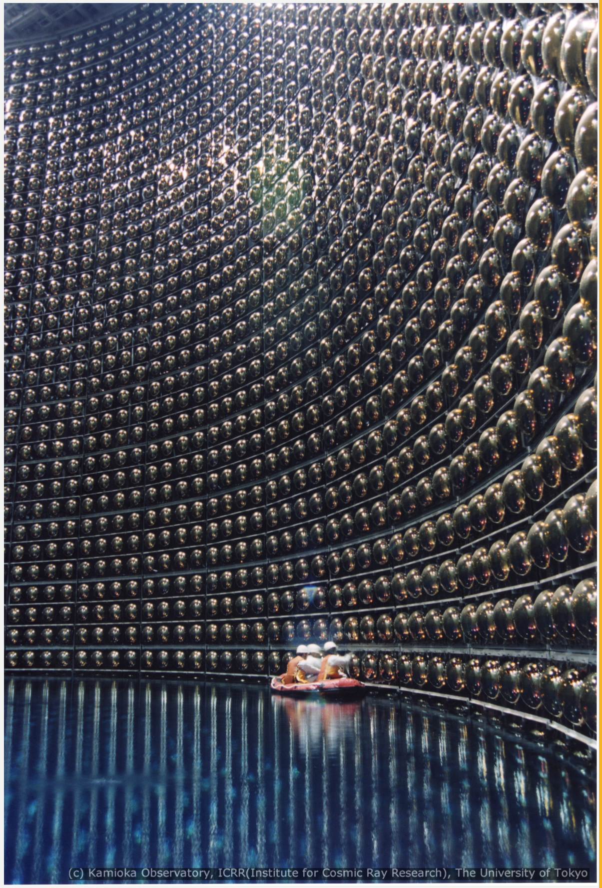
NEUTRINO ASTRONOMY

- 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**.



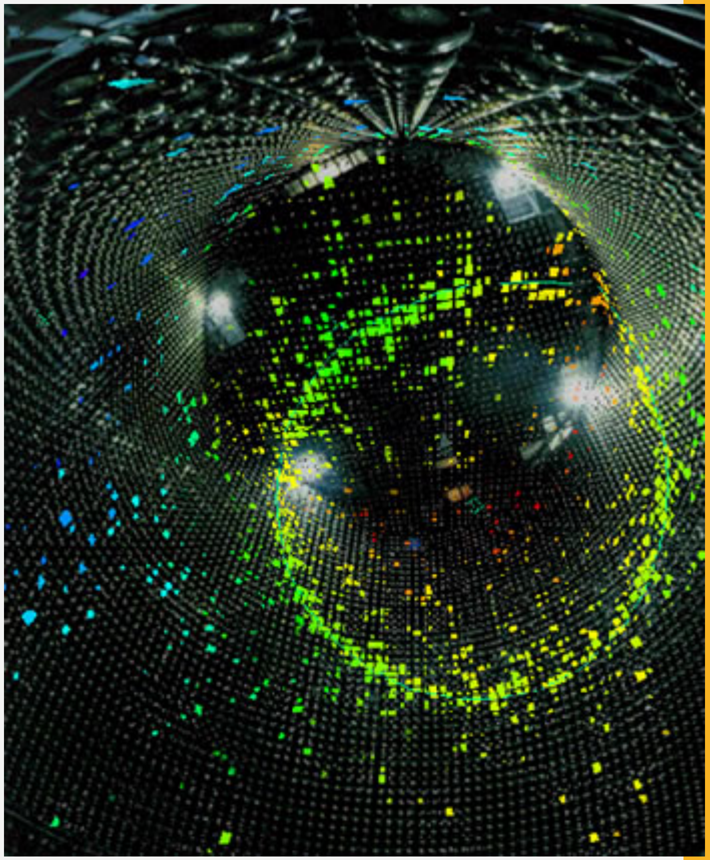
DETECTION OF SOLAR NEUTRINOS

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

$$\nu + e^- \rightarrow \nu + e^-$$

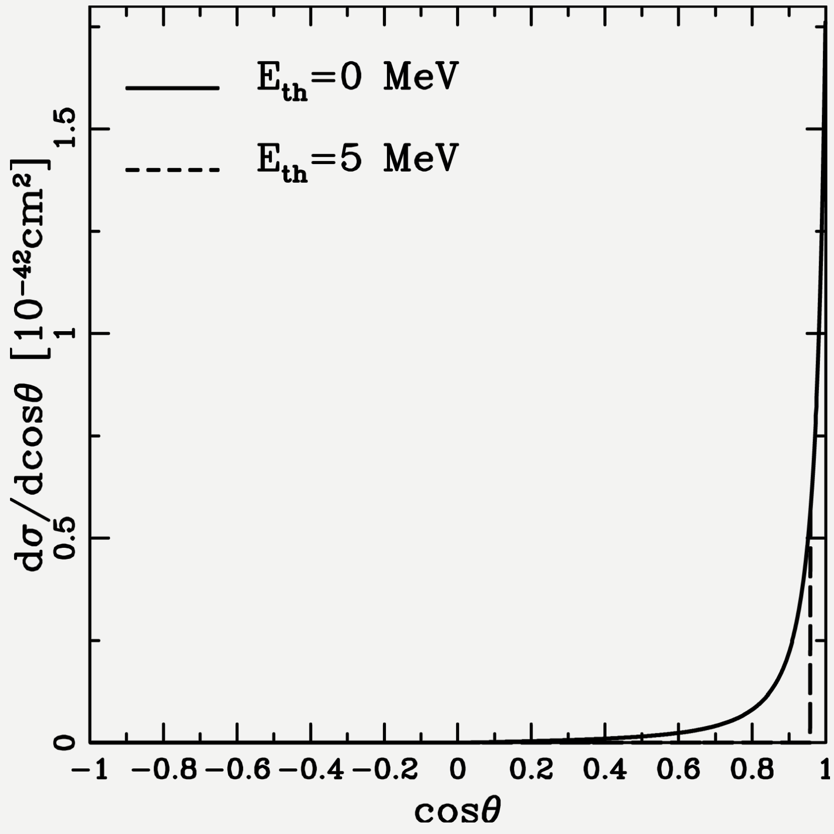
In H_2O

Emits Cherenkov Light



DETECTION OF NEUTRINOS

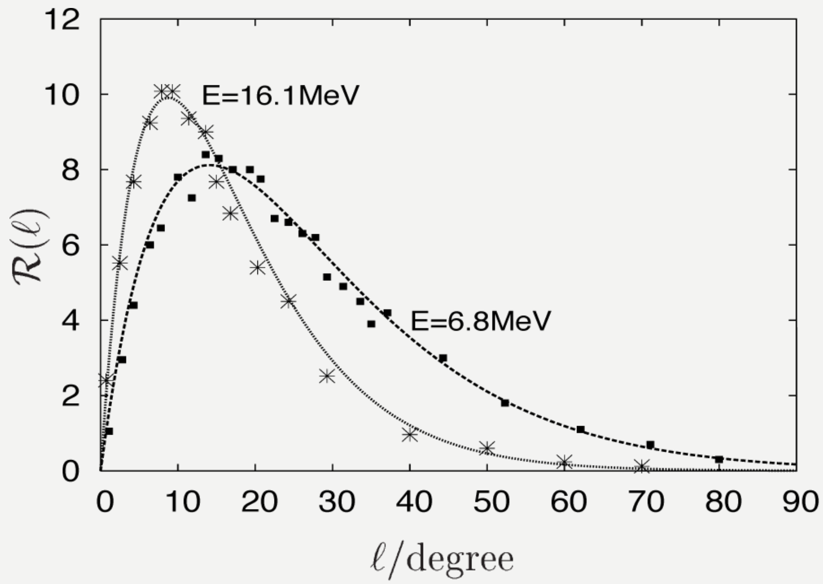
- The elastic scattering cross section is **strongly forward-peaked** for MeV-scale neutrinos, especially for higher recoil energies.
- Hence the electron after scattering will point back towards the original direction of the neutrino.



Ando and Sato, arXiv:hep-ph/0110187v4

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**.
- See e.g. Calibration of Super-Kamiokande using an electron LINAC, Nuclear Instruments and Methods in Physics Research A 421 (1999) 113-129.



R. Tomas et al. , Phys.Rev. D68 (2003) 093013

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:

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

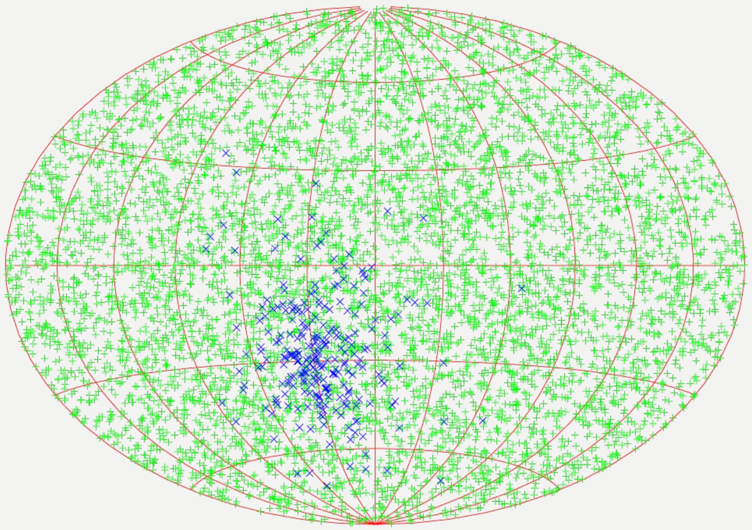
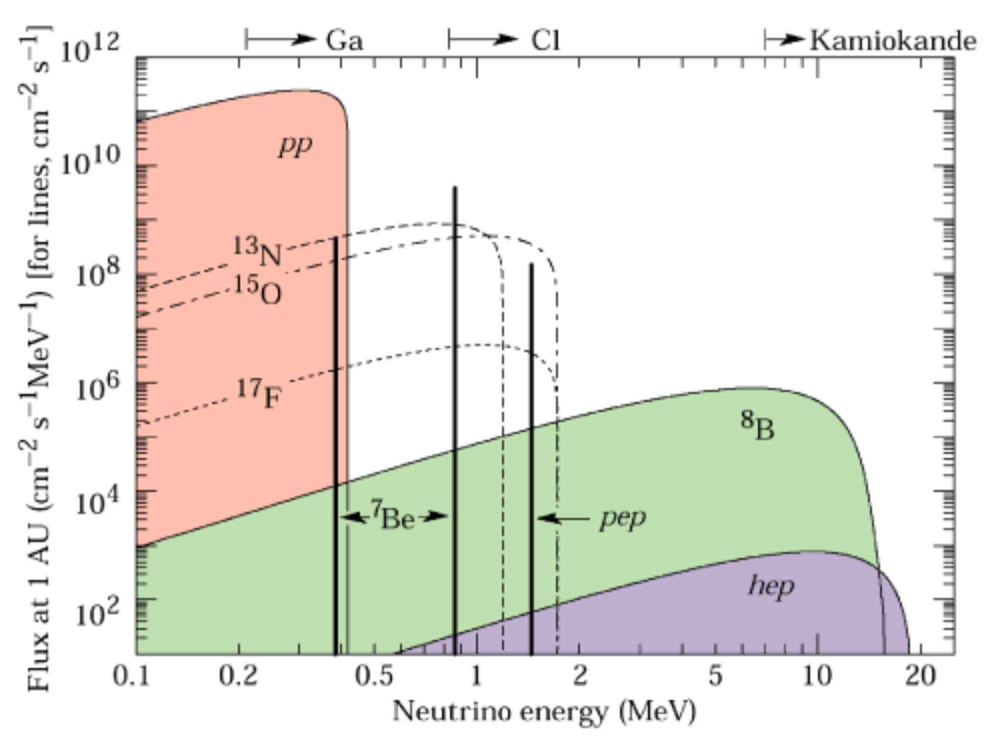


FIG. 4: Angular distribution of $\bar{\nu}_e p \to n e^+$ events (green) and elastic scattering events $\nu e^- \to \nu e^-$ (blue) of one simulated SN.

R. Tomas et al. , Phys.Rev. D68 (2003) 093013
S. Ando and K. Sato, Prog.Theor.Phys. 107 (2002) 957
J. Beacom and P. Vogel, Phys.Rev. D60 (1999) 033007

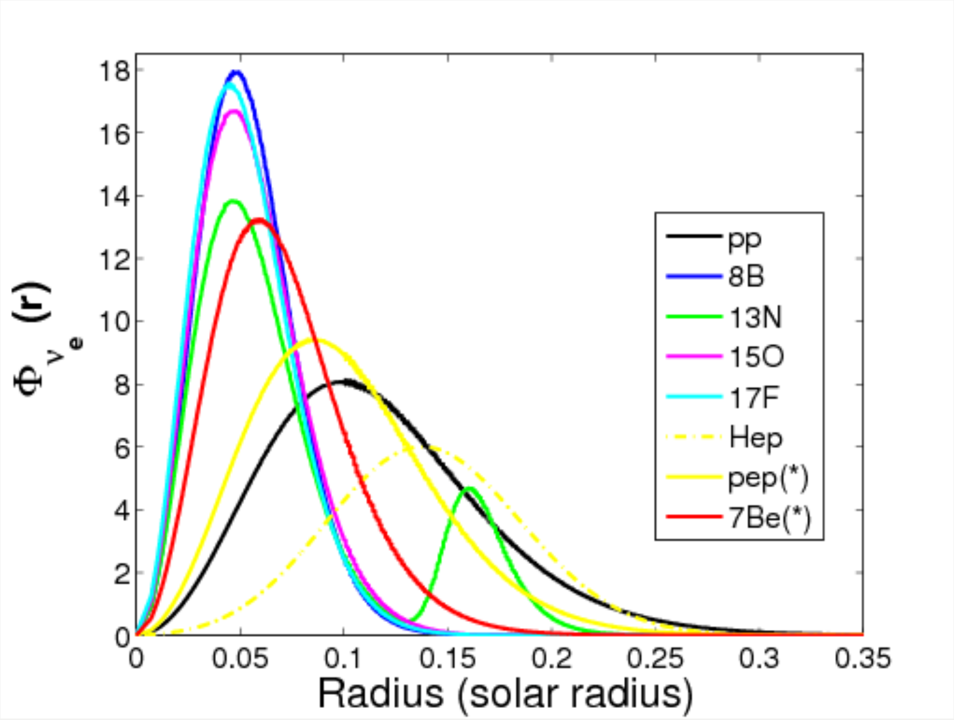
SOLAR NEUTRINOS

- 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?

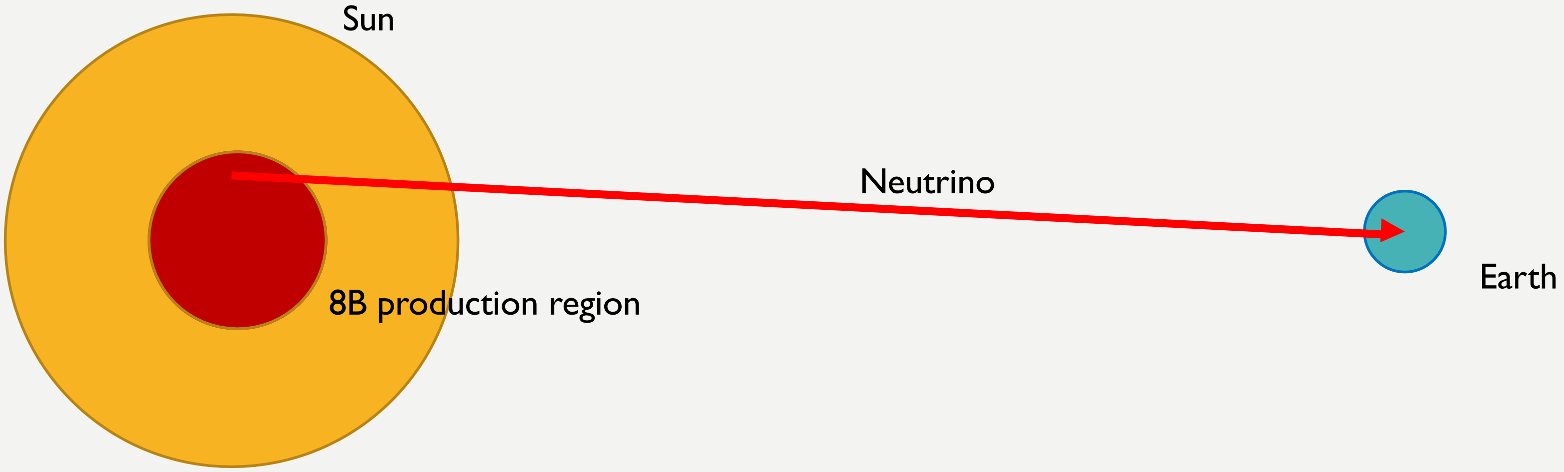
- Different fusion reactions should occur at different positions within the core.
- We focus on 8B neutrinos, which are predicted to be produced in a spherical region located at 5% of the solar radius from the core centre.



Lopes and Turck-Chièze, Astrophys.J. 765 (2013) 14

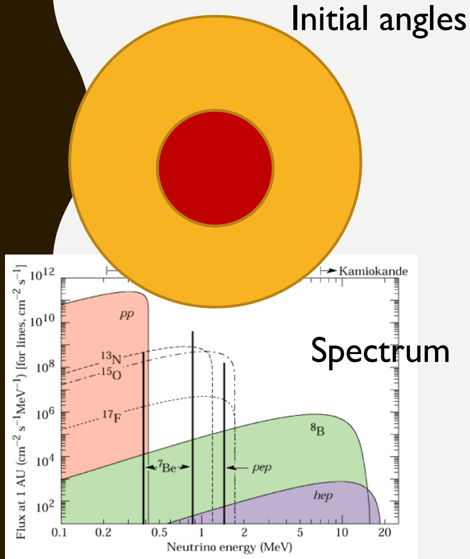
MAXIMUM LIKELIHOOD ANALYSIS – GENERATING SIGNAL DISTRIBUTIONS

- 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.



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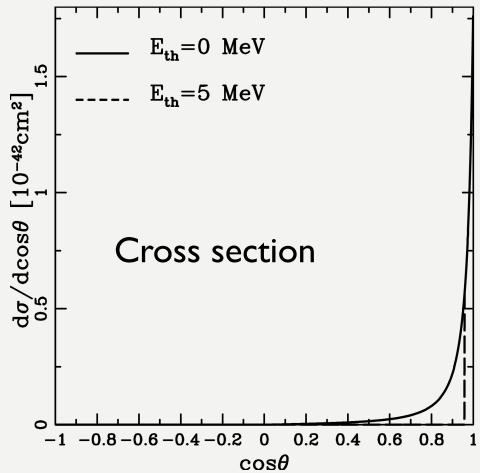

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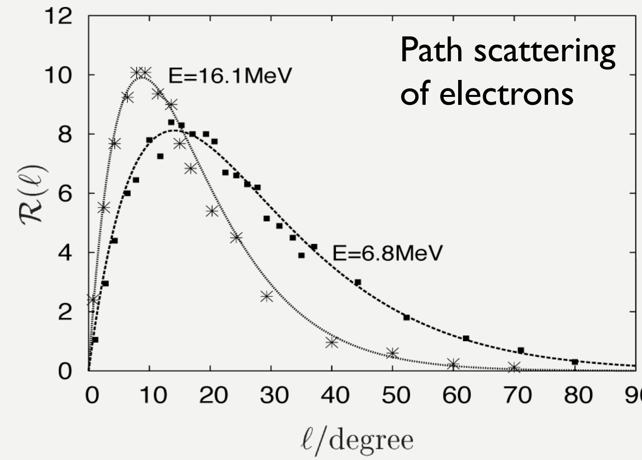
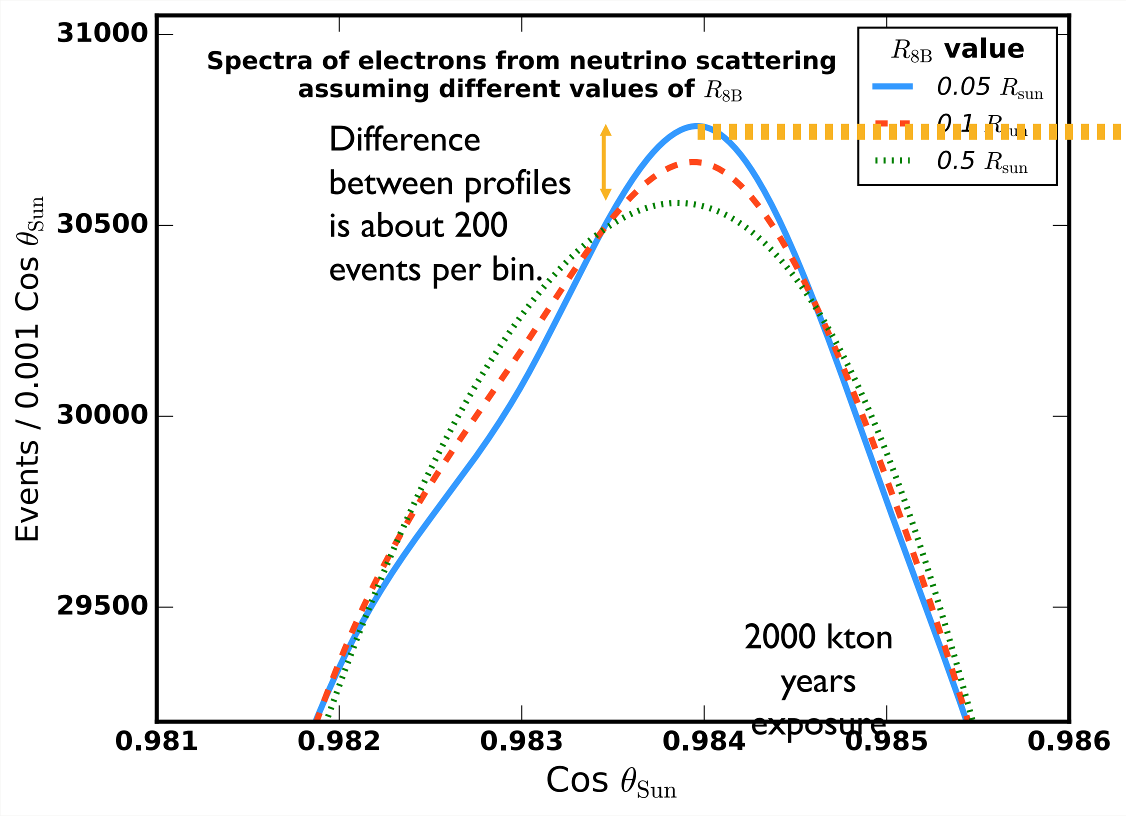


MAXIMUM LIKELIHOOD ANALYSIS – GENERATING SIGNAL DISTRIBUTIONS

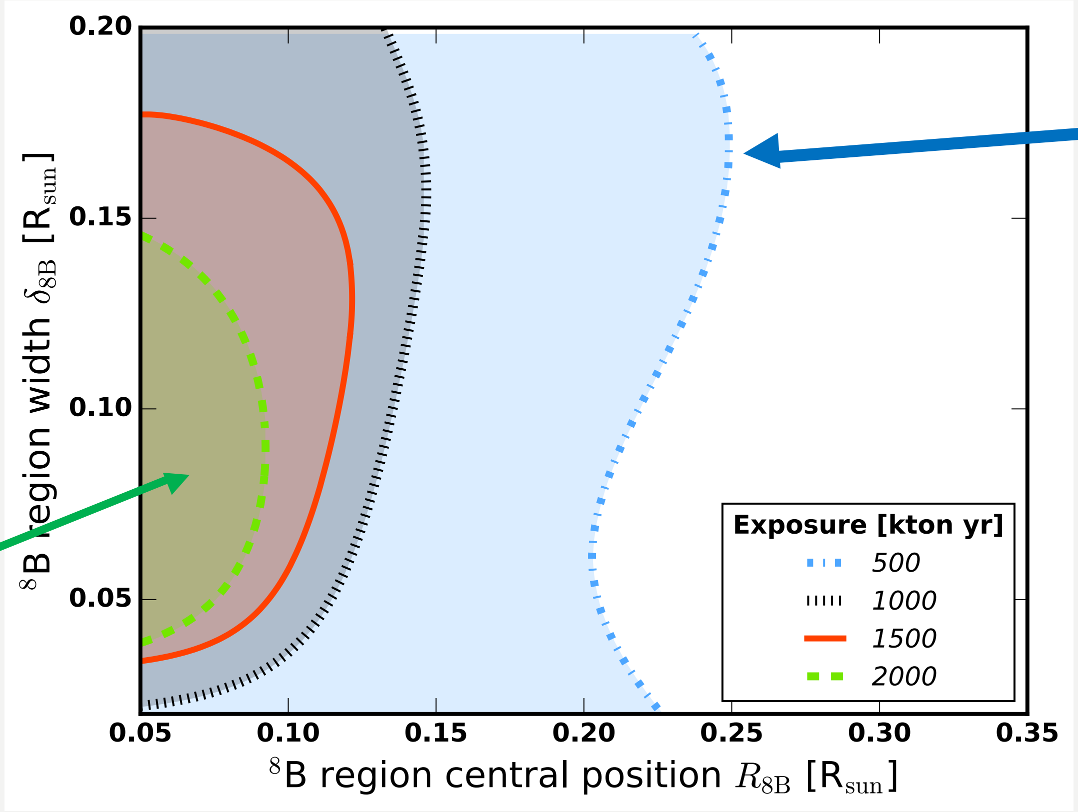


Poisson uncertainty is roughly Sqrt(31000) = 176.

The spectra are only just distinguishable above statistical noise.

MAXIMUM LIKELIHOOD ANALYSIS - RESULTS

95% confidence contours



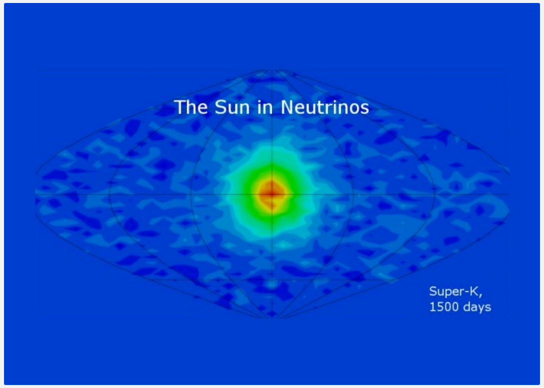
20 years for Super Kamiokande

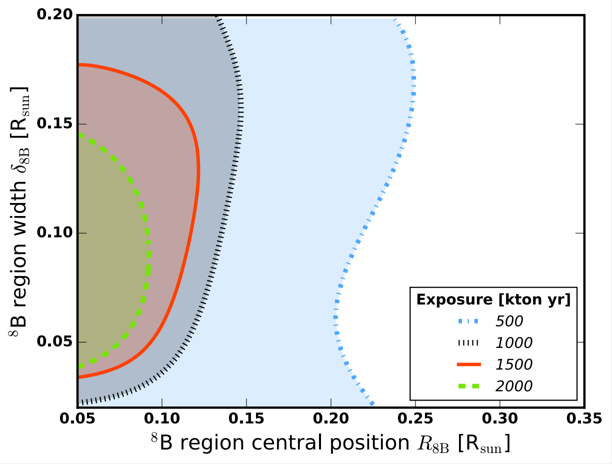
4 years for a 500 kilo-tonne experiment

J. H. Davis, Phys.Rev.Lett. 117 (2016) 211101

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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