Searching for Supernova Relic Neutrinos with SK-Gd

Jack Fannon jepfannon1@sheffield.ac.uk

The University Of Sheffield.

1 INTRODUCTION 1

- **Supernova Relic Neutrinos (SRN)** are created during the collapse of stars with a $m > 8$ solar masses.
- Gravitational energy stored in collapsing stars is converted to thermal energy during collapse.
  - Fuelling the production of (anti)neutrinos.
- SRN reveal information about the star's collapse, thus massive star formation rate.
- **Super-Kamiokande (SK)** has been doped with gadolinium to aid in **inverse beta decay (IBD)** detection.

2 SUPER-KAMIOKANDE 2

- Located in the Gifu prefecture of Japan underneath Mount Ikeno.
- Comprises of two volumes which make the inner detector and outer detector (figure 1).
- 50 kiloton water Cherenkov detector with a 22.5 kiloton fiducial volume.
- Used as a neutrino observatory for solar, atmospheric and reactor neutrinos, as well as the far detector in the **Tokai to Kamioka (T2K)** experiment.
- Data taking began in April 1996.
- Gd concentration: 0.01%

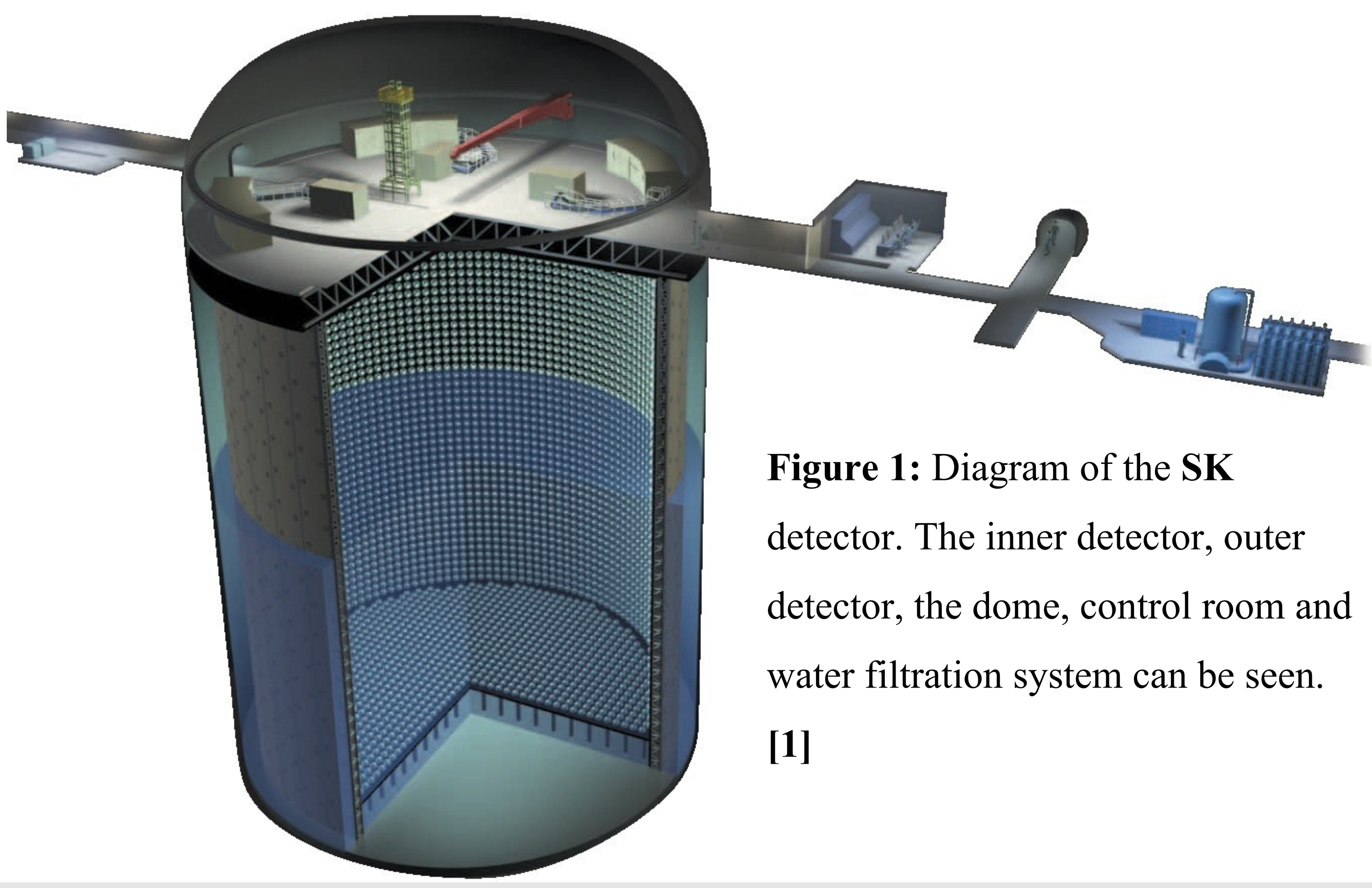
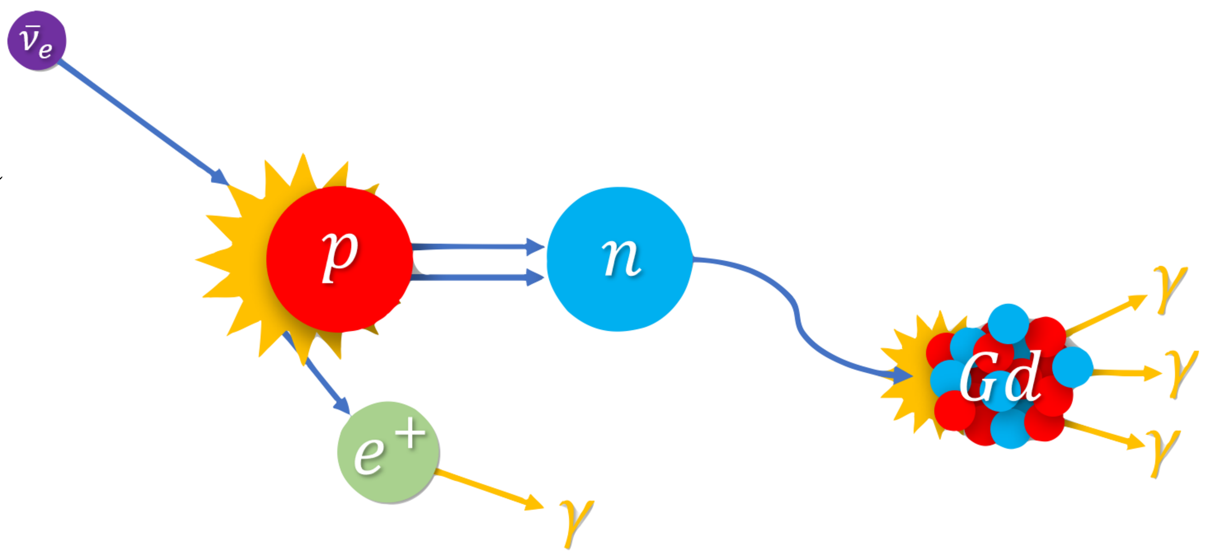


Figure 1: Diagram of the **SK** detector. The inner detector, outer detector, the dome, control room and water filtration system can be seen. **[1]**

3 INTERACTIONS 3

- IBD interactions produce positrons and neutrons in the final state.
- The neutron can capture on H or Gd in SK.
- Expected signal:
  - **Prompt Cherenkov ring** created by the positron.
  - **Delayed flash of light** from the neutron capture.

Figure 2: Diagram of an IBD interaction, creating a positron and neutron. The positron emits Cherenkov radiation and the neutron captures on a Gd nucleus.



4 BACKGROUNDS 4

Reactor neutrinos

Dominate $E_{e+} <\sim 10$ MeV.

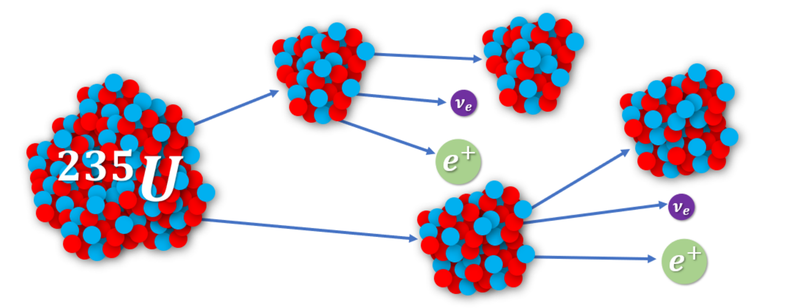


Figure 3: Reactor antineutrino production. Not to scale.

Solar neutrinos

Background caused by accidental pairing with fluctuations/other events.

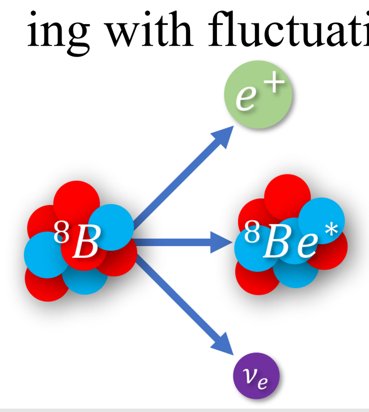


Figure 4: ^{8}B decay to ^{8}Be*, e^+ and ν_e.

Atmospheric neutrinos

Created by muon/pion decay. NCQE interactions dominate below ~ 20 MeV.

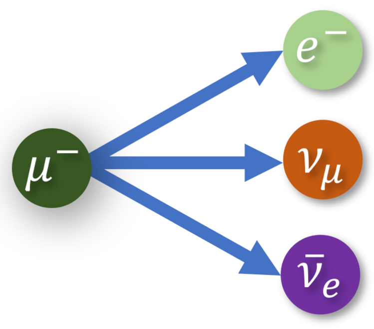


Figure 5: Muon decay creating an electron, electron neutrino and muon neutrino.

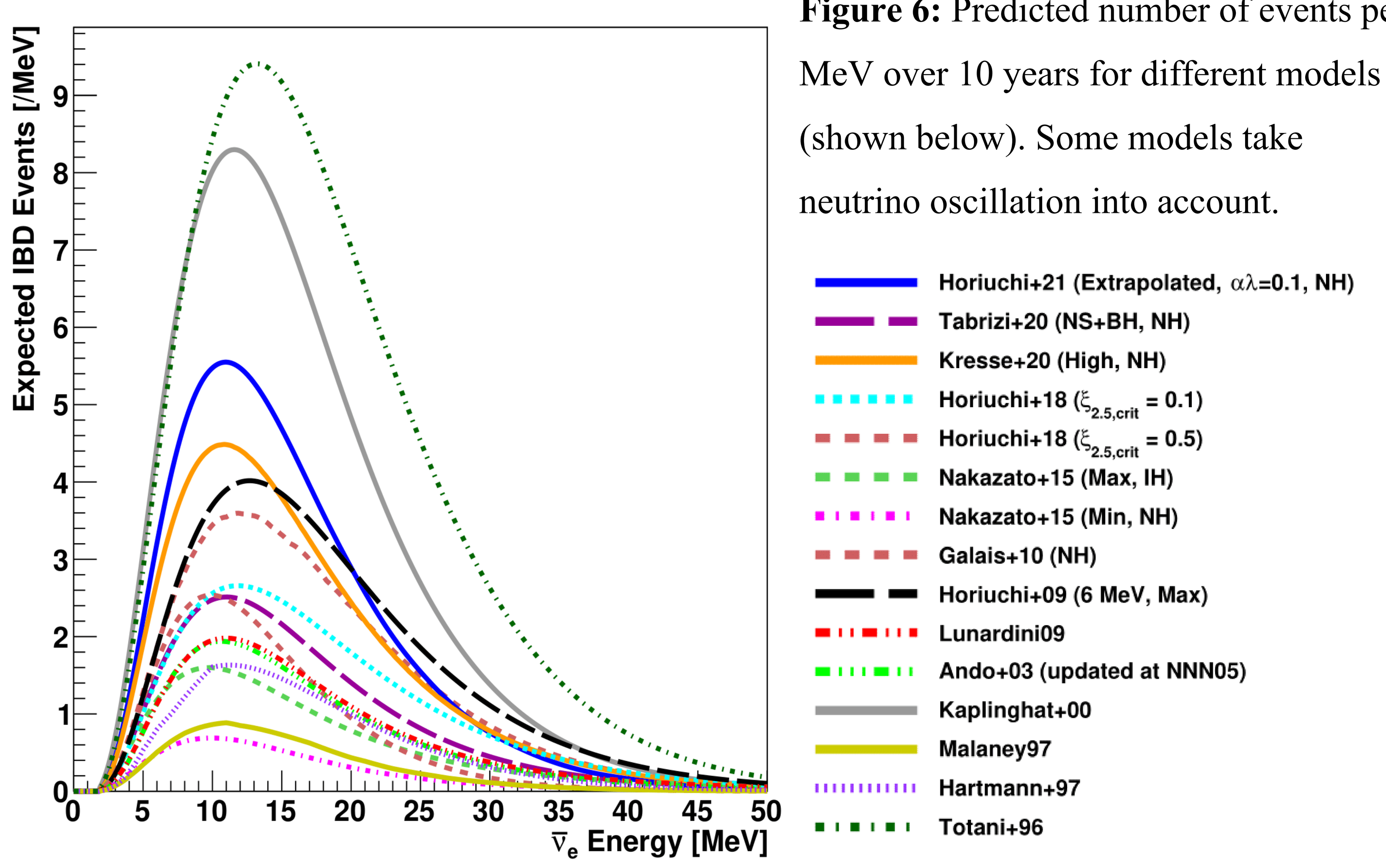
Cosmic ray muon spallation

- 10^6 times larger flux than the SRN at <~ 20 MeV **[2]**.
- Muons interacting with nuclei in the detector create unstable isotopes.
- Accidental tagging of these decays with other hits is a key background.

5 PREDICTED EVENTS 5

- Flux models are based on different star collapse rates and properties of the core collapse. They are used to:
  - Predict expected number of events.
  - Set upper and lower bounds on expected number of events.
- Expected events equation: $N_{SRN}(E_{\bar{\nu}_e}) = n_p \sigma_{IBD}(E_{\bar{\nu}_e}) T \Phi_{SRN}(E_{\bar{\nu}_e})$
  - T - time (s)

Figure 6: Predicted number of events per MeV over 10 years for different models (shown below). Some models take neutrino oscillation into account.



- Integrating and removing events where $E_{e+} < 10$ MeV (for reactor neutrino background) gives the prediction over 10 years:
  - **Maximum - Totani+96: 133 events.**
  - **Minimum - Nakazato (Min, NH): 7 events.**

6 SK-GD ADVANTAGES 6

- Neutron capture time:
  - 0% Gd - ~**200 μs**
  - 0.01% Gd - ~**115 μs** (current)
- Neutron capture energy:
  - Gd - ~8 MeV gamma cascade.
  - H - 2.2 MeV single photon.
- **Higher efficiency neutron tagging** using constrained capture time and capture energy cuts.
- **Reduce accidental backgrounds** that SK-IV could not.

7 ONGOING WORK 7

- Compare reconstruction between the neutron and positron.
- Constrain neutron tagging cuts.
- Revisit old cuts to see if any improvements can be made.

REFERENCES

[1] Kajita T, Kearns E, Shiozawa M, et al. (Super-Kamiokande Collaboration). Establishing atmospheric neutrino oscillations with Super-Kamiokande. Nuclear Physics B. 2016 Jul 1;908:14-29.

[2] Abe K, at al. (Super-Kamiokande Collaboration). Diffuse supernova neutrino background search at Super-Kamiokande. Physical Review D. 2021 Dec 10;104(12):122002.

CONTACT

www.linkedin.com/in/jackepfannon