Sensitivity of SNO+ to Supernova Neutrinos

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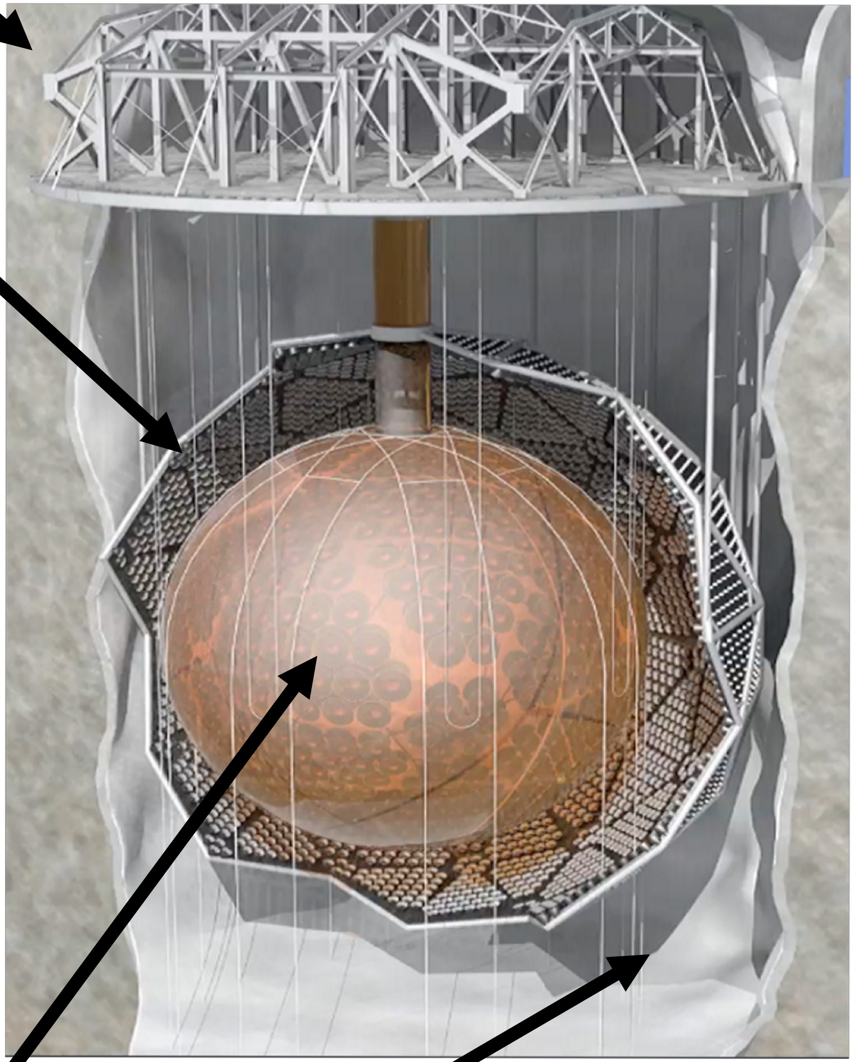
SN at the Crossroads : ECT* Workshop

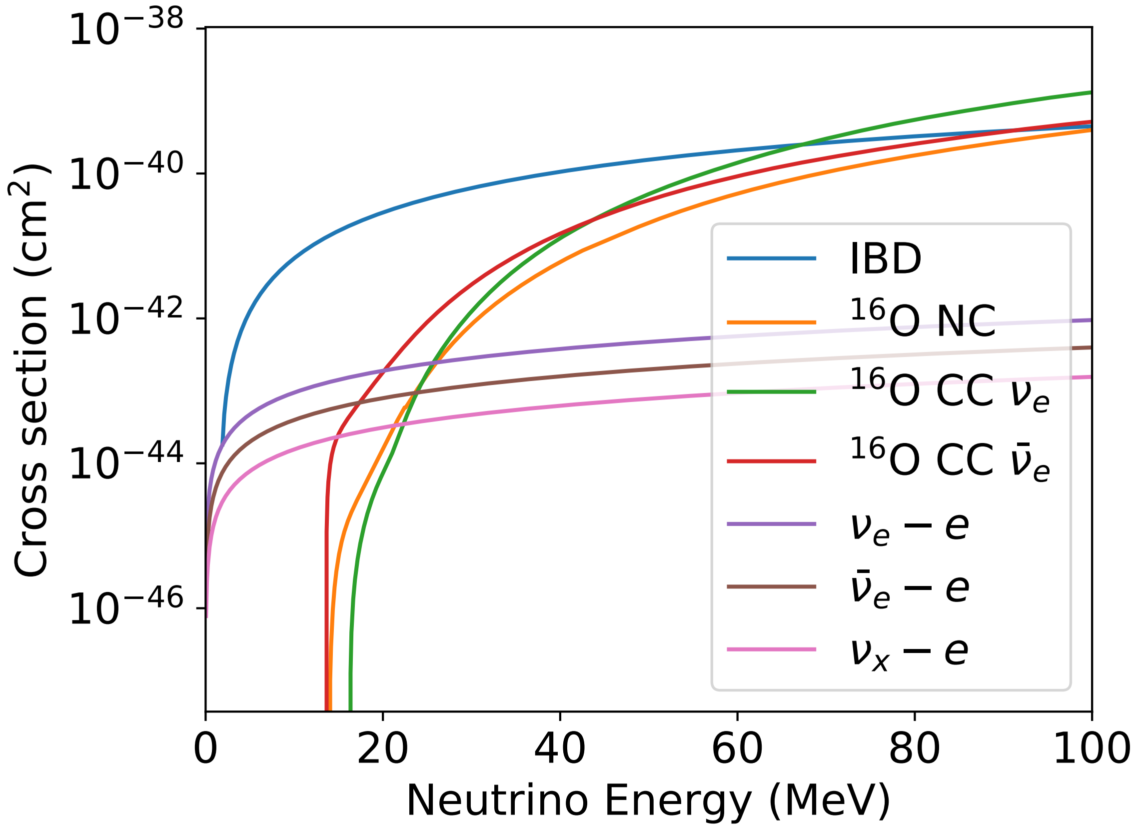
The SNO+ Detector

- General Purpose neutrino experiment.
- Main focus on the search for 0νββ.
- Water phase currently wrapping up.
- Scintillator filling taking place now.
    - Scintillator fill scheduled to complete in September.
    - Te loading to start in December.
    - Te loading complete (0.5%) in 2020.



Interaction channels (Water Phase)

- Water phase
  - ν-e scattering
  - Inverse beta decay[1] (Tagging efficiency ranges from 30 – 45 % depending on position within the detector.)
  - Interactions with ^{16}O nuclei[2]



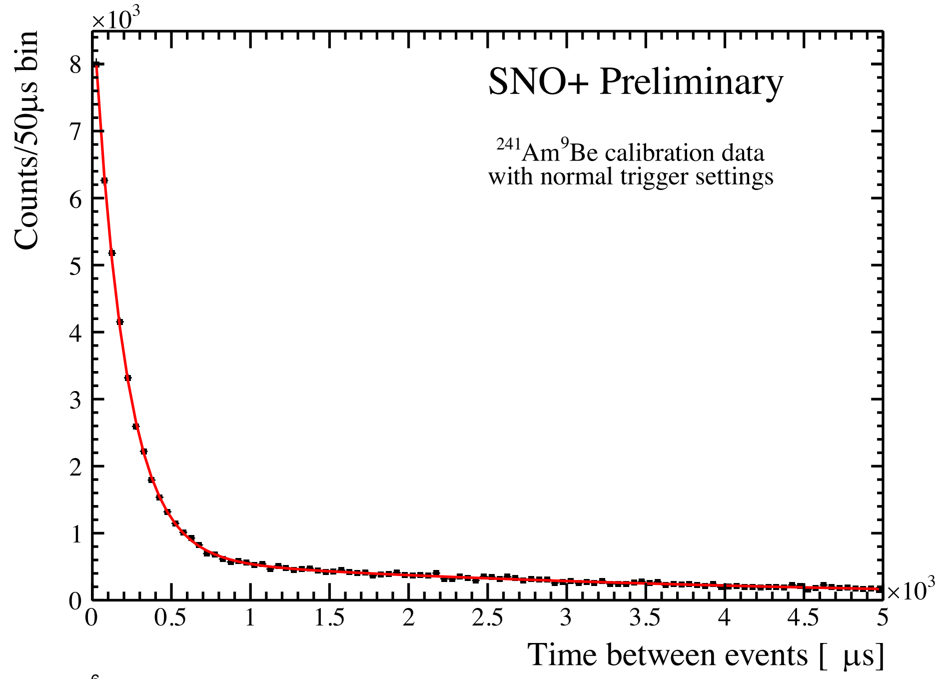
1 arxiv:astro-ph/0302055
2 Phys. Rev., D66:013007

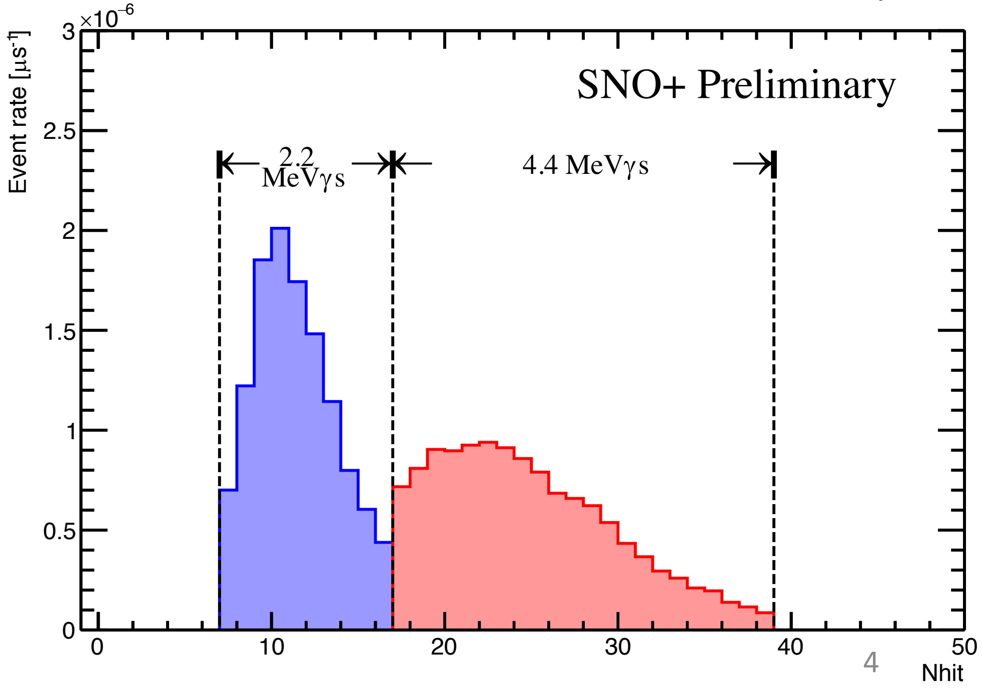
Neutron capture efficiency (In water)

- AmBe source deployed in water:
  - $\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n$
  - ${}^{12}C^{*} \rightarrow {}^{12}C + \gamma$ (4.4 MeV prompt)
  - $n + p \rightarrow d + \gamma$ (2.2 MeV delayed)
- Measured capture time is:

  208.2 ± 2.1 μs
- Measured neutron detection efficiency

  46.5 ± 0.4 %





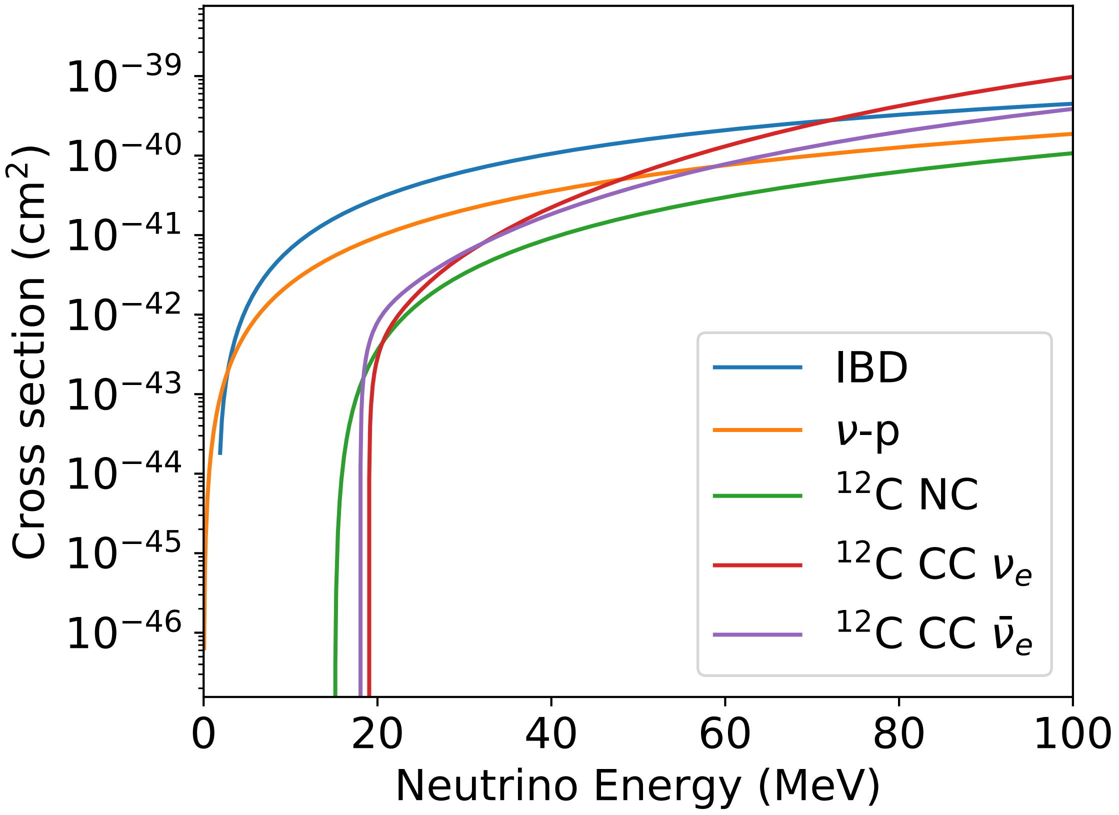
Event Counts in Water Phase

Model	IBD	ν-e	$\nu_e + ^{16}O$ (CC)	$\overline{\nu}_e + ^{16}O$ (CC)	$\nu + ^{16}O$ (NC)
11.2 $M_\odot$	24.0	3.9	0.1	0.2	0.4
17.6 $M_\odot$	41.2	5.7	0.3	0.6	1.1
20.0 $M_\odot$	36.3	5.2	0.2	0.5	0.9
27.0 $M_\odot$	48.1	6.5	0.3	0.8	1.4
Analytical	133.1	15.9	0.9	1.3	7.6

- Results from 1D Garching models (arxiv:1111.4483)
- Simulated between -0.015 and 0.45 seconds
- Analytical fluence reflects neutrino emission from entire burst. (arxiv:1103.2768)
- SN at a distance of 10 kpc.
- Assumes a 5 m fiducial volume corresponding to a fiducial mass of 0.51 kT.
  - It is likely we can extend the fiducial volume beyond the AV for higher energy events which would more than double our fiducial mass.

Interaction channels (Scintillator Phase)

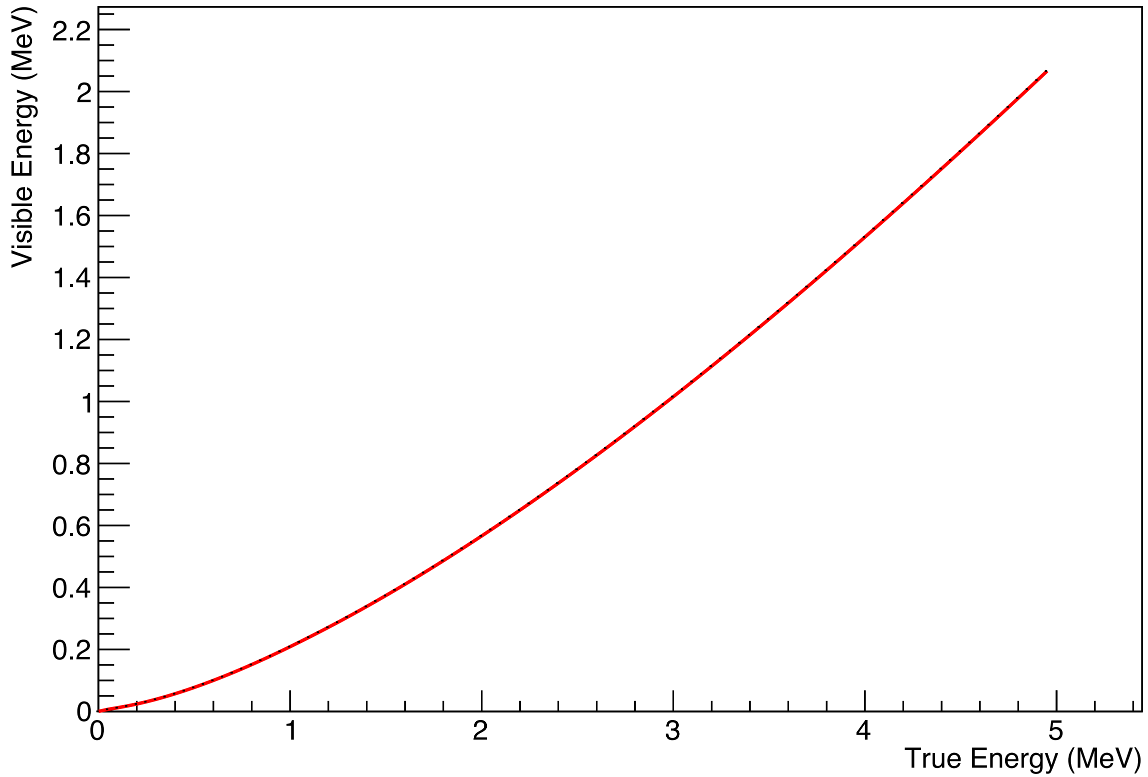
- Scintillator and Scintillator + Te phases
  - ν-p scattering[1]
  - Inverse beta decay
  - Interactions with ^{12}C nuclei[2]

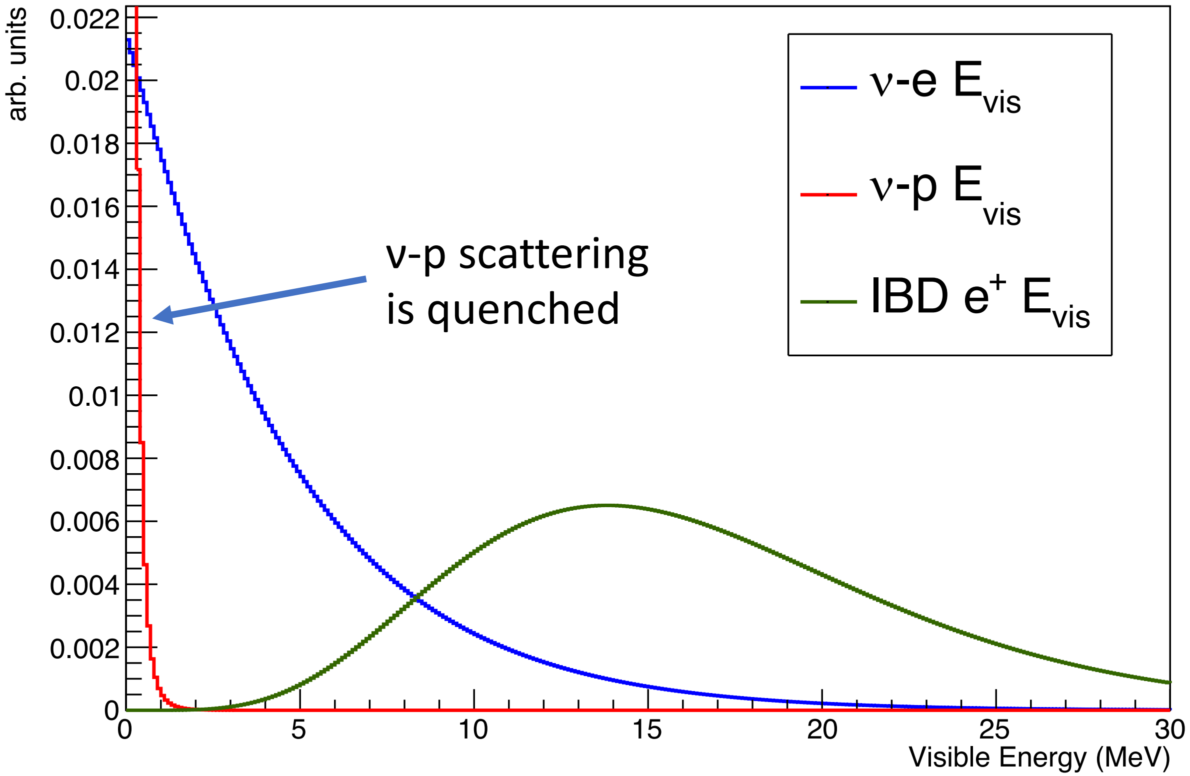


1 Phys. Rev., D66:033001
2 arxiv:nucl-th-9903022

Interaction energy spectra

- In scintillator phase SNO+ will have a threshold of ~0.2 MeV
- LAB ex-situ measurement of Birks' parameter made k_B=0.0096±0.0003 cm/MeV[1]





Total visible energy

Energy deposited per unit distance

$$E_{\mathrm{vis}} = \int \frac{\frac{dE}{dx}}{1 + k_B \frac{dE}{dx}} \, dx$$

[1]arxiv:1301.6403

Event Counts in Scintillator Phase

Model	IBD	ν-p	ν-e	$\nu_e + ^{12}C$ (CC)	$\overline{\nu}_e + ^{12}C$ (CC)	$\nu + ^{12}C$ (NC)
11.2 $M_\odot$	21.6	38.0 (5.7)	3.1	0.2	0.5	1.3
17.6 $M_\odot$	37.1	58.7 (11.7)	4.6	0.6	1.1	2.5
20.0 $M_\odot$	32.7	52.4 (9.8)	4.2	0.5	0.9	2.1
27.0 $M_\odot$	43.2	67.5 (14.4)	5.2	0.8	1.3	3.1
Analytical	119.7	262.9 (74.0)	12.5	1.1	3.5	15.4

- Results from 1D Garching models (arxiv:1111.4483)
- Simulated between -0.015 and 0.45 seconds
- Analytical fluence reflects neutrino emission from entire burst (arxiv:1103.2768).
- SN at a distance of 10 kpc.
- Assumes a 5 m fiducial volume corresponding to a fiducial mass of 0.45 kT.
- Terms in brackets for ν-p scattering represent the number of events above a 0.2 MeV threshold after quenching.

Predicted Backgrounds in Scintillator

- Backgrounds above ~1 MeV in a 5 m fiducial volume are negligible
  - The only channel that will be significantly effected by backgrounds is ν-p scattering.
  - IBD events will essentially be background free due to neutron tagging.

- Two dominant backgrounds for a 5 m fiducial volume
  - ^{14}C and ^{222}Rn daughters.

- **^{14}C**

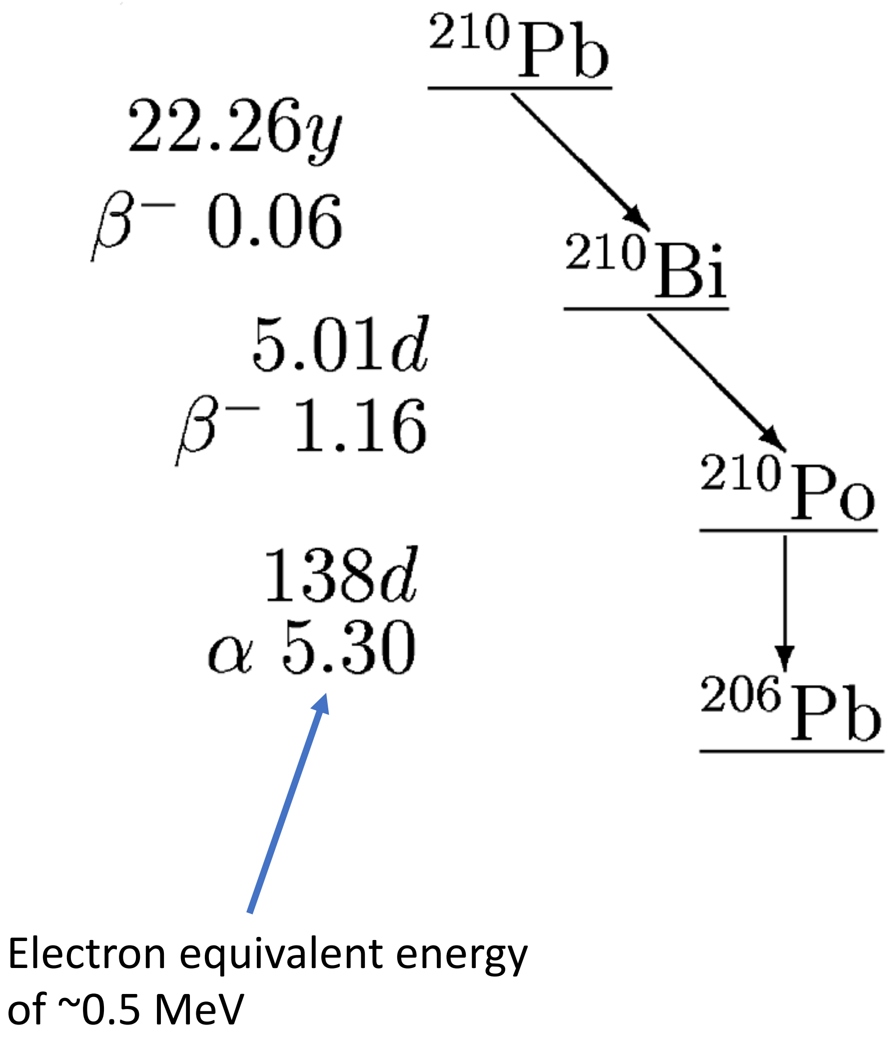
$$^{14}\mathrm{C} \rightarrow ^{14}\mathrm{N} + e^{-} + \bar{\nu}_e (Q = 0.16\ \mathrm{MeV})$$

  - Naturally present in liquid scintillator.
    - $^{14}C/^{12}C = O(10^{-18})$
  - Predicted raw rate of O(100 Hz) in 0.78 kT scintillator volume.

- External backgrounds (PMTs/Ropes/external water) negligible for a 5 m fiducial volume.

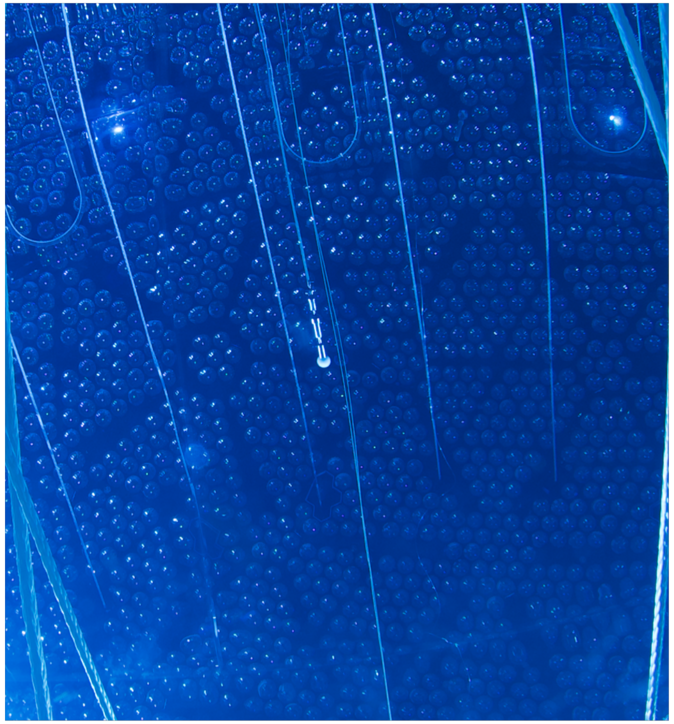
Radon daughter background

- During construction of SNO and commissioning of SNO+ radon daughters became embedded in surface of acrylic vessel.
- Long half life of ^{210}Pb means throughout lifetime of SNO+ decays of ^{210}Pb daughters will form a background in the experiment.
- Decay rate of O(1 KHz) on inner AV surface.
- A small fraction of the daughters are expected to leach into the scintillator volume throughout the lifetime of SNO+
  - Leaching rate will be measured during the scintillator phase of the experiment.



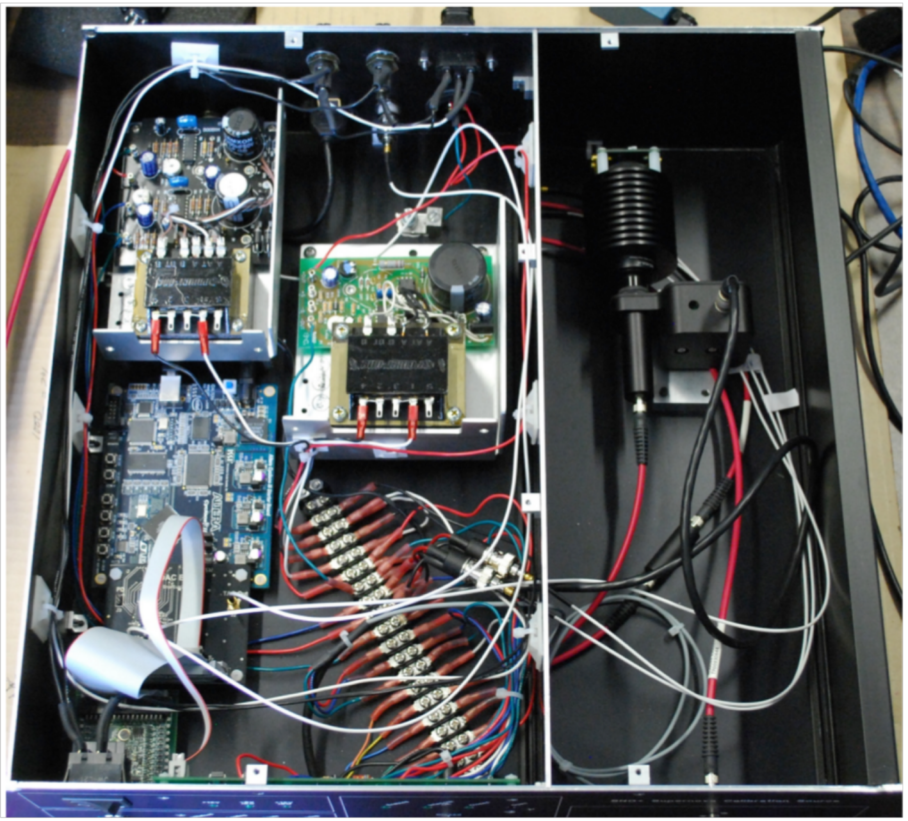
The Supernova Calibration Source

- Dedicated hardware designed to test the response of the detector to a supernova, and the ability to test the DAQ resilience to a nearby supernova.
- 406 nm peak wavelength laser diode
- Can produce light pulses with intensities up to the equivalent of 60 MeV deposited in liquid scintillator.
- Attaches to an existing optical calibration source.



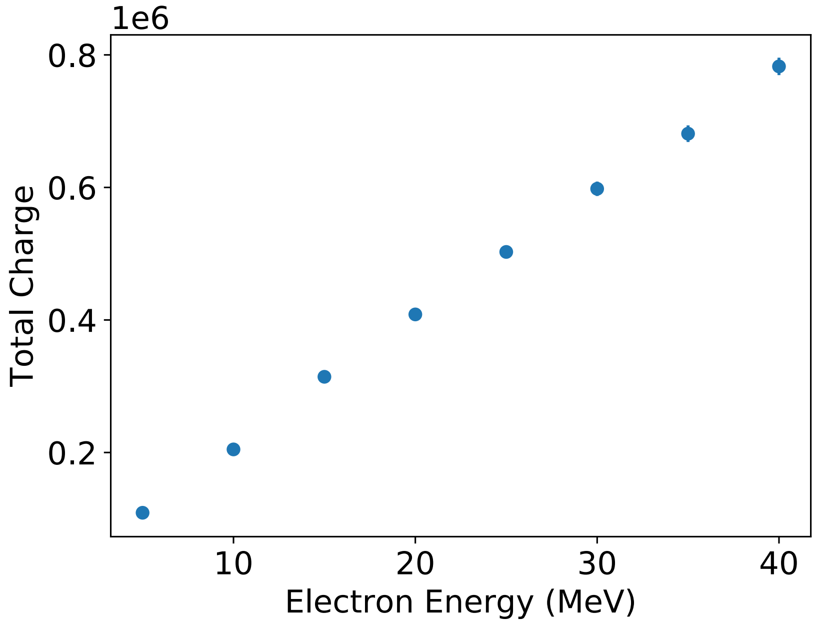
The Supernova Calibration Source

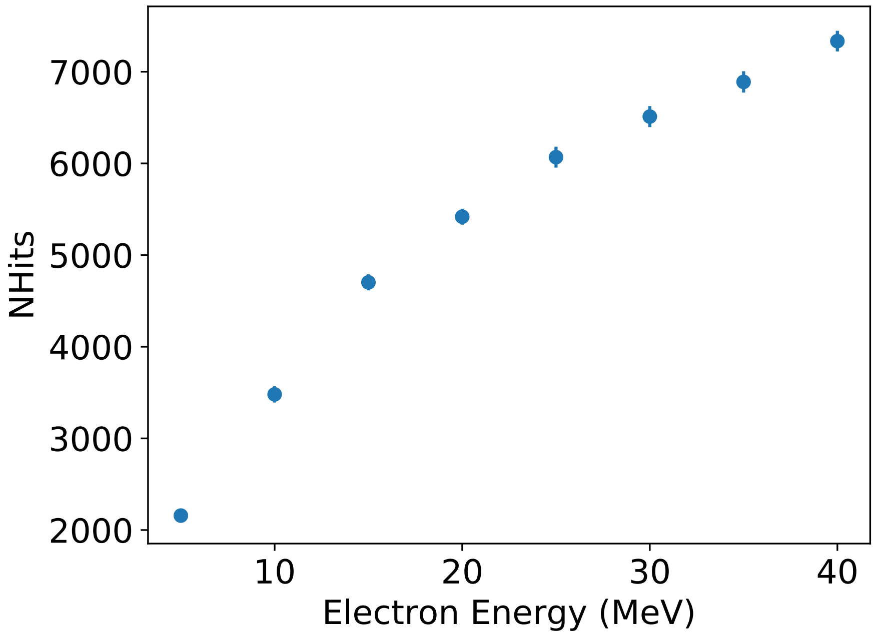
- Calibration source contains programable FPGA.
- Simulations can be used as input
  - Currently using Garching 1D models in NH and IH (MSW only)
- Pulse intensity and frequency will match the input energy spectrum and event rate.



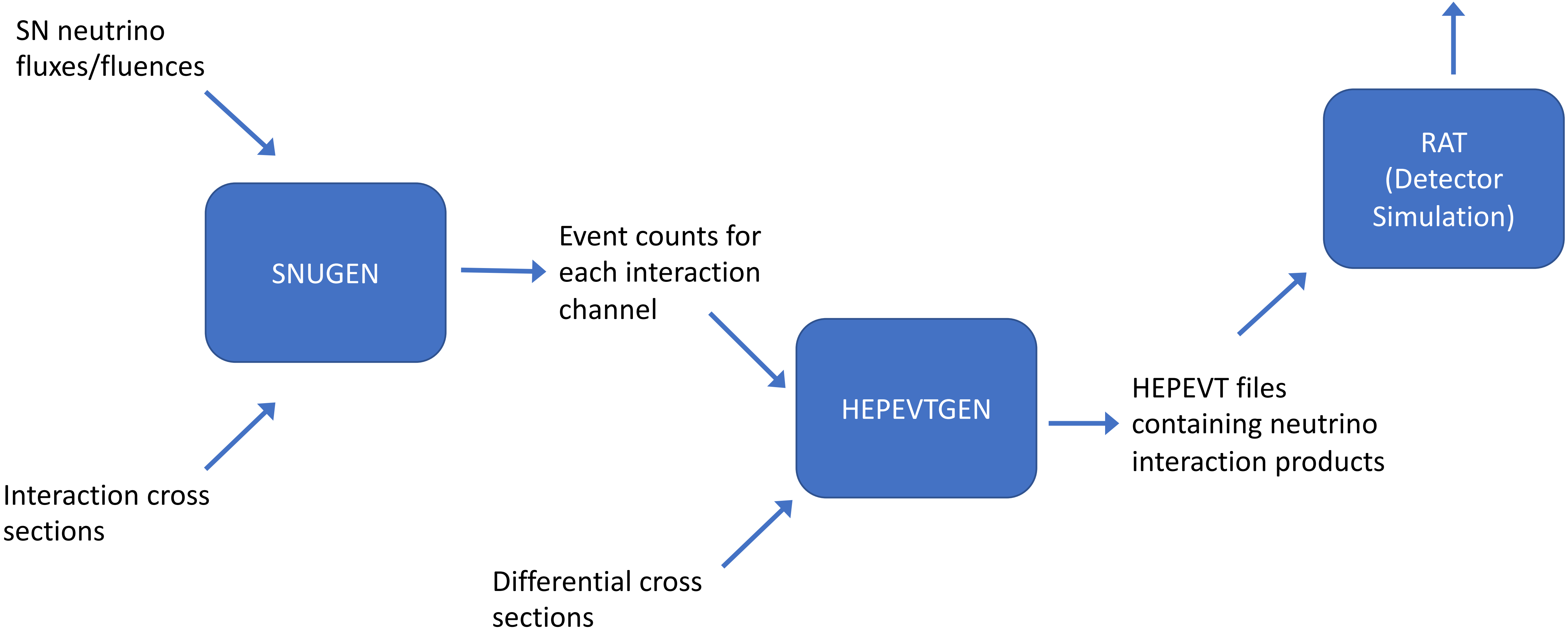
Reconstruction of high energy events.

- Standard energy reconstruction routines based on the number of PMTs which are triggered in an event (NHit).
- For higher energy events counting the number of triggered PMTs to reconstruct the energies is no longer optimal.
- Triggered PMTs also record the charge deposited (Proportional to the number of photons observed by the PMT).
- The total charge can be used to reconstruct events at higher energies.





SNO+ Supernova Simulation Framework



SN Trigger for SNO+

L1 Trigger
The L1 trigger searches for bursts of events with given NHit cuts

File containing events in the burst

L2 Trigger
The L2 trigger cuts any events associated with detector effects, for example PMT flashers.

File containing remaining events in the burst

L3 Trigger
The L3 checks the number of events in the burst if this is above some threshold an alert is sent to the SN group.

Plots and an alert message.

Supernova Group
The group then decides whether to issue a SNEWS alert based on the plots

SNEWS alert if appropriate

Conclusions

- SNO+ is sensitive to neutrinos from a supernova in all phases of the experiment.
- A calibration source has been developed to specifically test the response of the detector in the case of a supernova.
  - Both the response of the detector to high energy events and the DAQ systems ability to handle the data rate.
- Reconstruction routines have been developed to handle higher energy events which would be relevant to a supernova.
- Burst trigger development currently underway
  - Aim to be incorporated with SNEWS

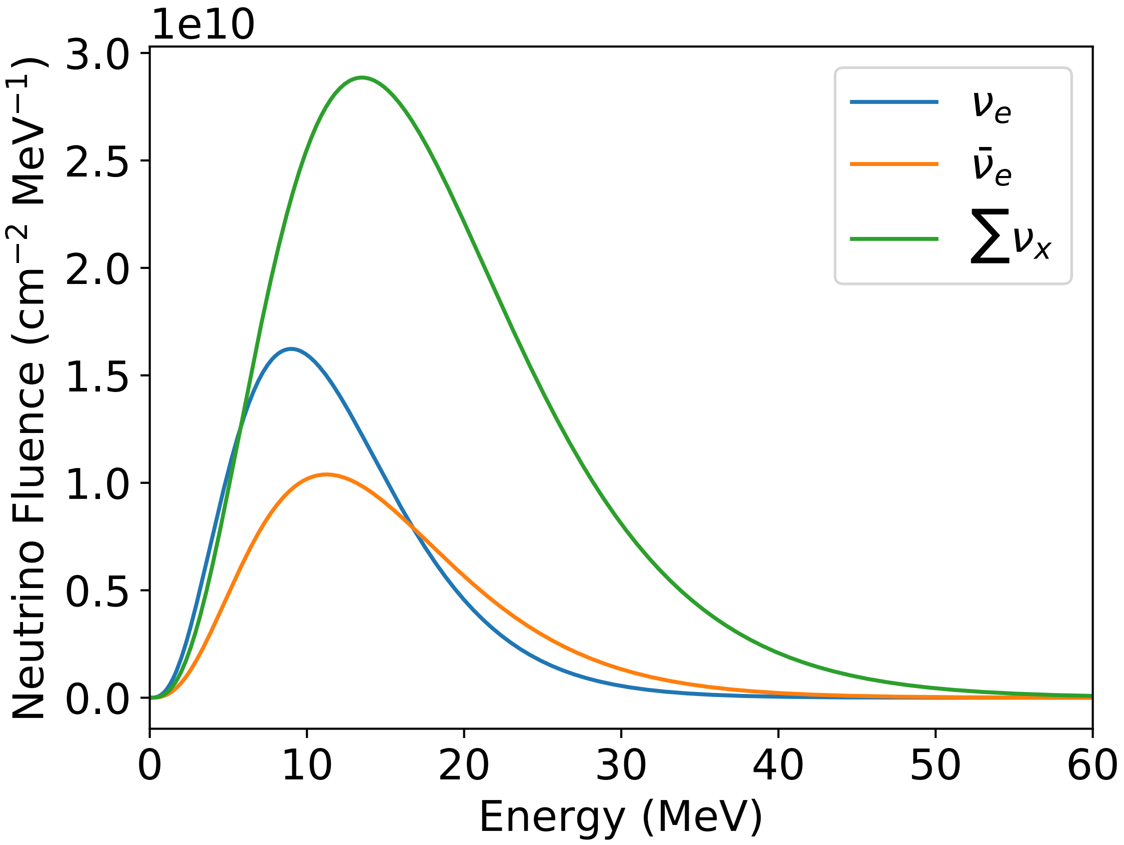
Backup Slides

Analytical SN spectra

Flavour	L_0 (10^{51} ergs)	$\langle E \rangle$ (MeV)	β
ν_e	50	12.0	3.0
ν_μ	50	15.0	3.0
ν_x	50	18.0	3.0

Average energies obtained from arxiv:1103.2768.

$$\frac{dL}{dE} = L_0 \frac{1.0}{\langle E \rangle^2} \frac{(1+\beta)^{1+\beta}}{\Gamma(1+\beta)} \frac{E}{\langle E \rangle}^{\beta} e^{\frac{-(1+\beta)E}{\langle E \rangle}}$$



Neutrino fluence at 10 kpc