Search for solar neutrino absorption with ^{40}Ar in DEAP-3600

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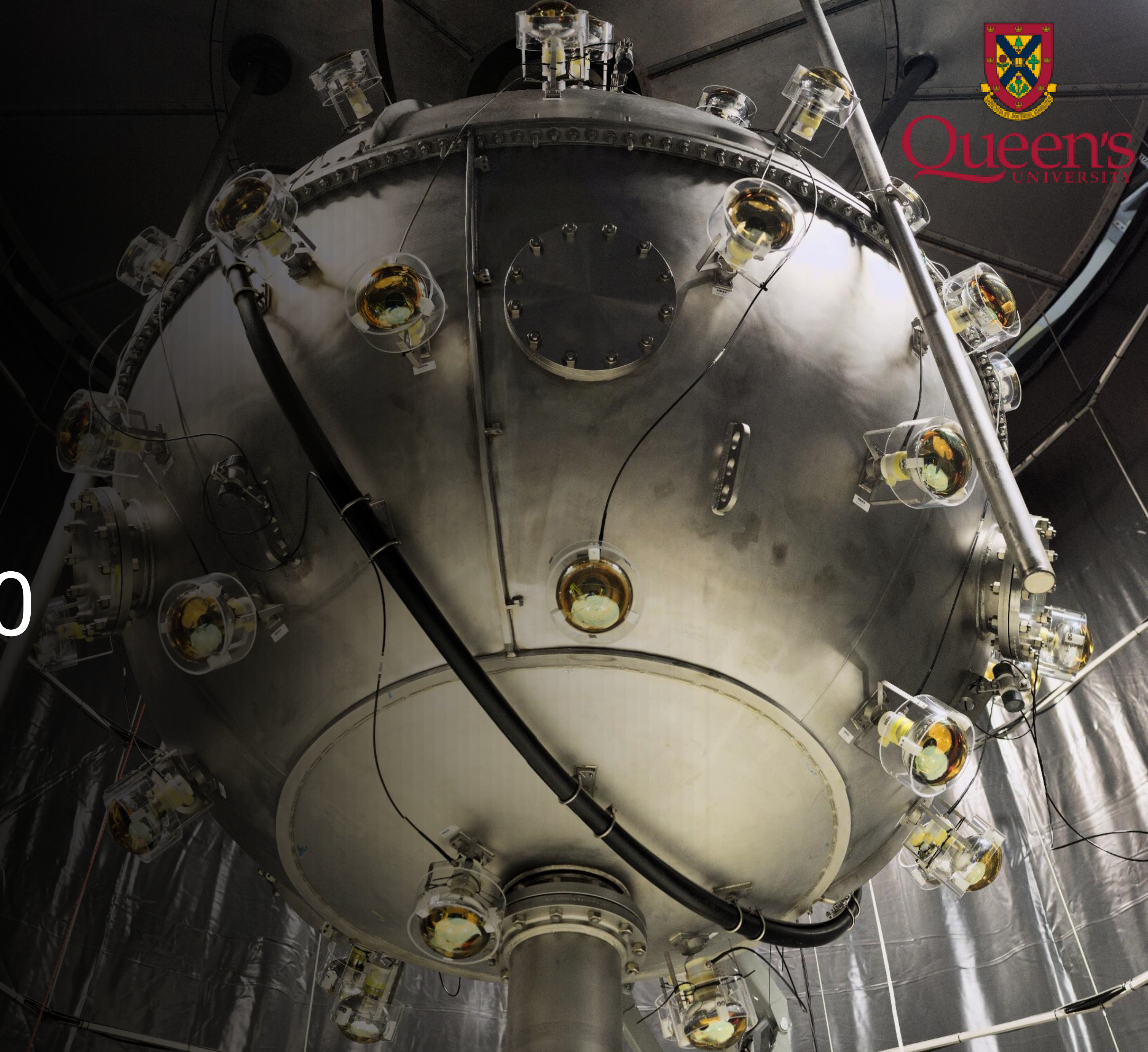
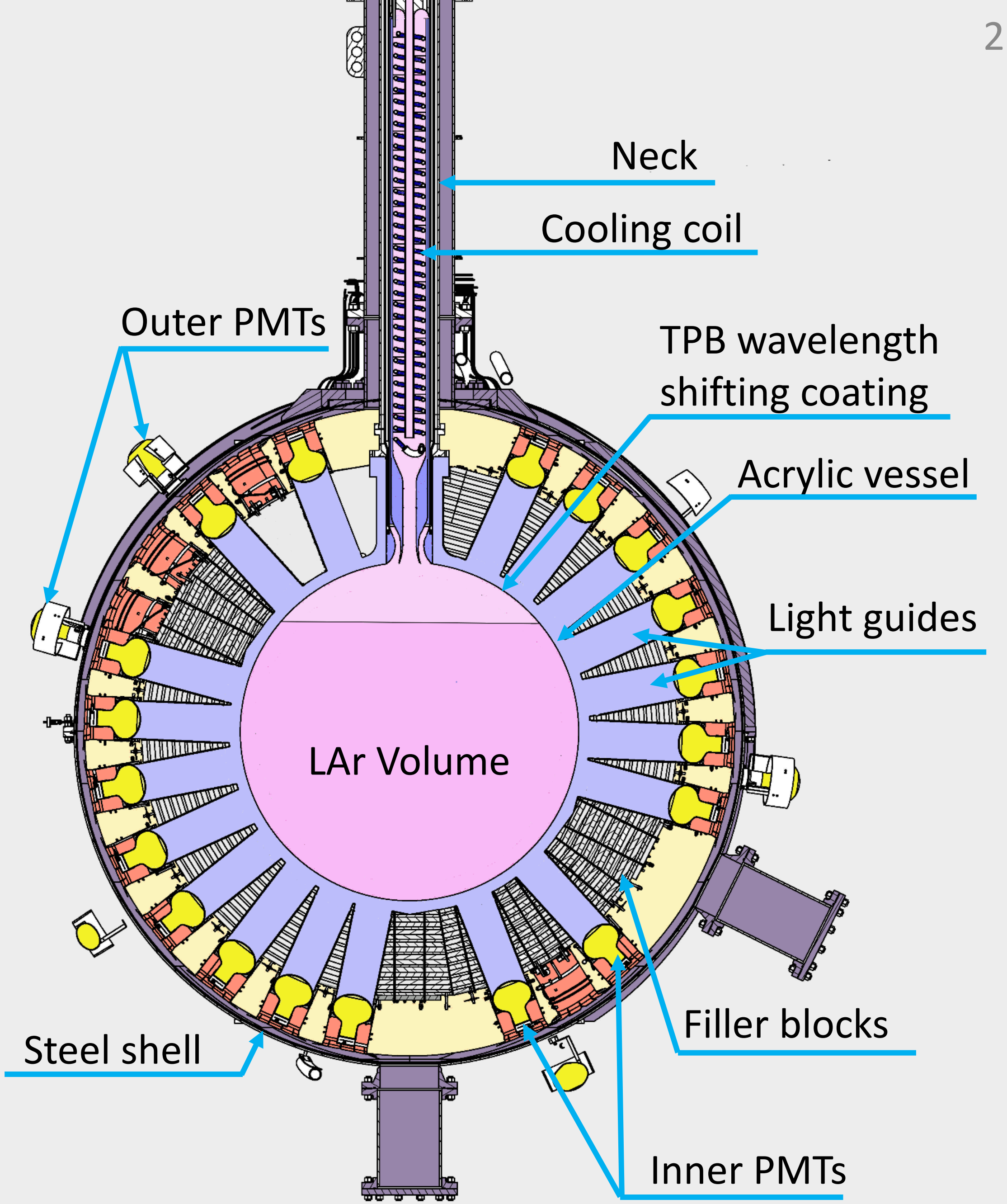


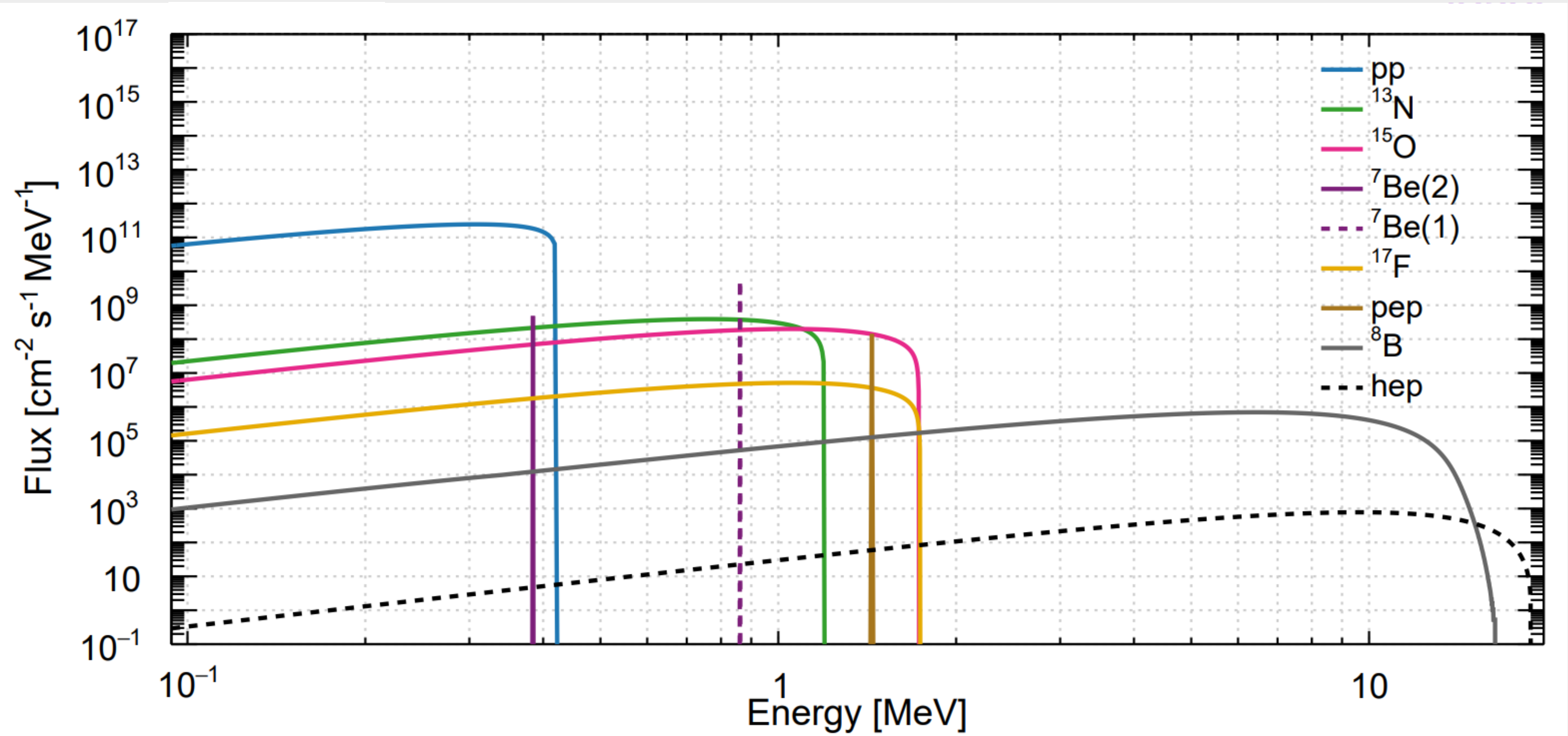
DEAP-3600

- Dark matter Experiment using Argon Pulse shape discrimination
- Single-phase dark matter direct detection experiment at SNOLAB.
- Particle interactions with LAr produce 128nm scintillation light wavelength shifted by TPB coating on acrylic vessel to ~420 nm and detected by PMTs.
- Difference in time constants for LAr singlet and triplet states makes it possible to distinguish nuclear and electron recoils.



Solar Neutrino Spectrum

$$p + p \rightarrow d + e^+ + \nu_e$$
$$^{13}N \rightarrow {}^{13}C + e^+ + \nu_e$$
$$^{15}O \rightarrow {}^{15}N + e^+ + \nu_e$$
$$^{7}Be + e^- \rightarrow {}^{7}Li + \nu_e$$
$$^{17}F \rightarrow {}^{17}O + e^+ + \nu_e$$
$$p + e + p \rightarrow d + \nu_e$$
$$^{8}B \rightarrow {}^{8}Be^* + e^+ + \nu_e$$
$$^{3}He + p \rightarrow {}^{4}He + e^+ + \nu_e$$



From SNO measurements[1] the expected integral flux of ^{8}B neutrinos is

$$\phi(\nu_e)_{SNO} = 1.76\,^{+0.05}_{-0.05}(stat.)\,^{+0.09}_{-0.09}(sys.) \times 10^6\, cm^{-2} s^{-1}$$

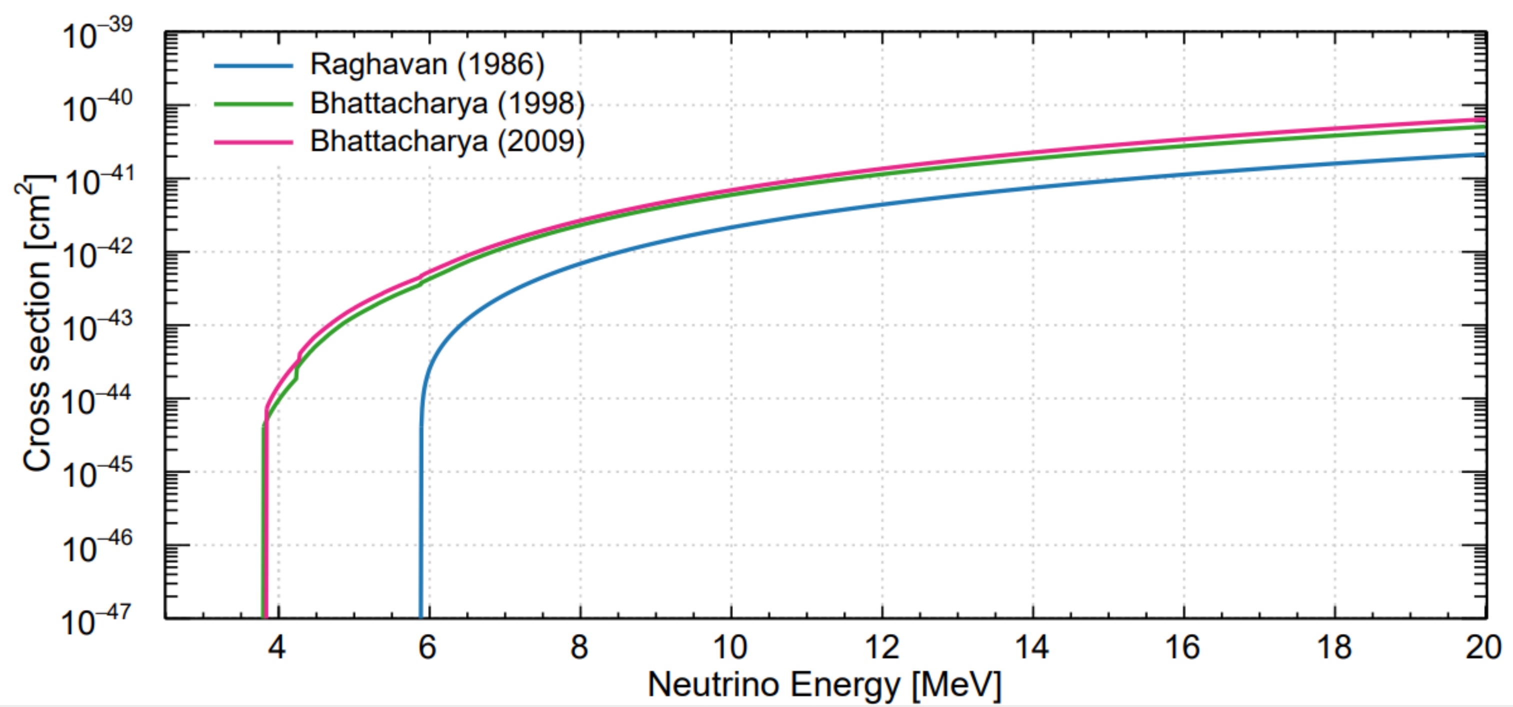
Neutrino Absorption

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$$

- R. S. Raghavan (1986)[2] proposed that it could be possible to observe low energy neutrino interactions via the super-allowed $0^+ \rightarrow 0^+$ Fermi transition from the ground state of ^{40}Ar to an excited state of ^{40}K.
- This excited ^{40}K state would decay through characteristic gamma rays to the ground state.
- Energy threshold of 5.885 MeV to observe neutrinos for this process.

$$E_\nu = E_e + \sum E_\gamma + 1.5\ MeV$$

Neutrino Absorption



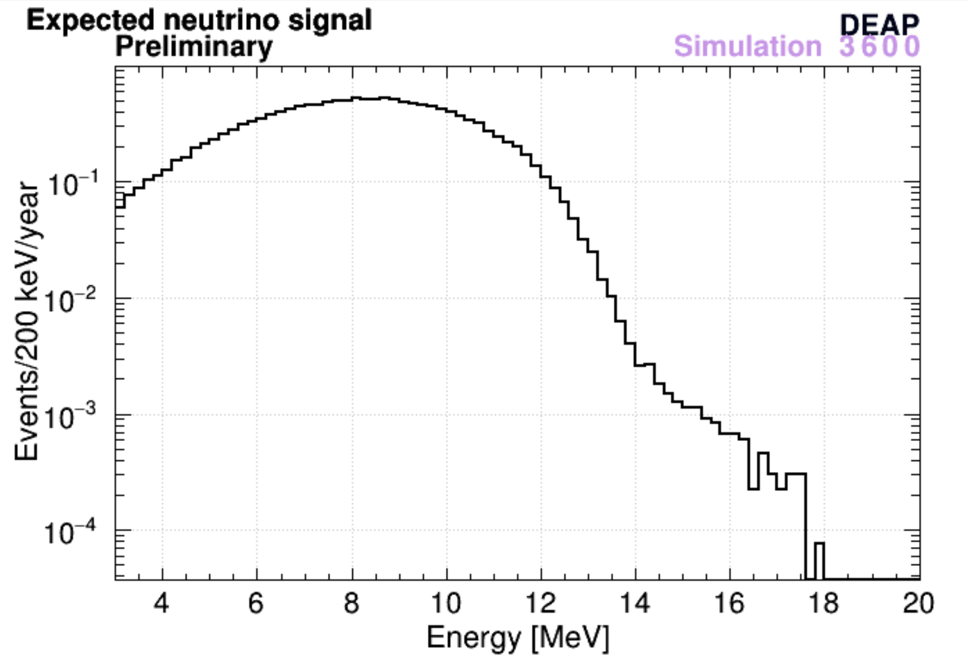
Based on the cross-section of neutrino interactions from various nuclear models and the normalized neutrino flux we expect

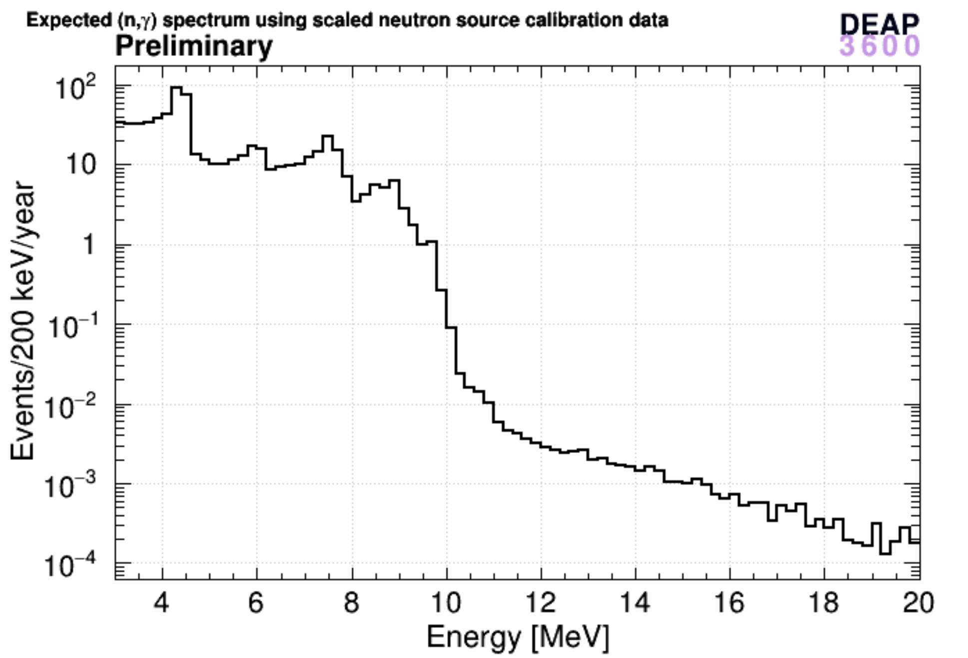
Γ = 2.2 events/tonne-year

- M. Bhattacharya et al.[3,4] measured Gamow-Teller (GT) strength for transitions from ^{40}Ar to excited states in ^{40}K.
- Shows that other gamma transitions, besides the super-allowed Fermi transition are allowed for this state.
- Reaction threshold lowers to 3.9 MeV.

Neutrino Study Search Regions

- Study split into two energy regions with different signatures of neutrino absorption with their own distinct backgrounds.
    - Delayed coincidence region
    - High-energy region
- Boundary between the two regions depends on the drop in the neutron capture spectrum.





Neutrino Study Search Regions

BiPo = Bismuth – Polonium delayed coincidence

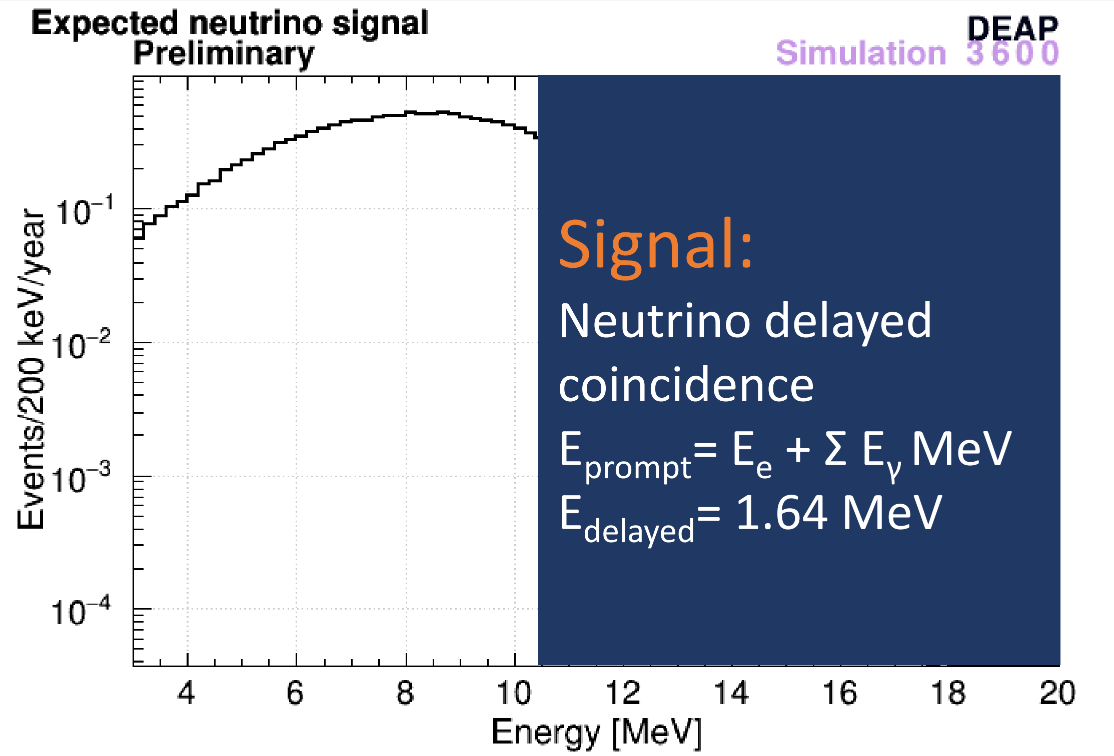
^{238}U chain:

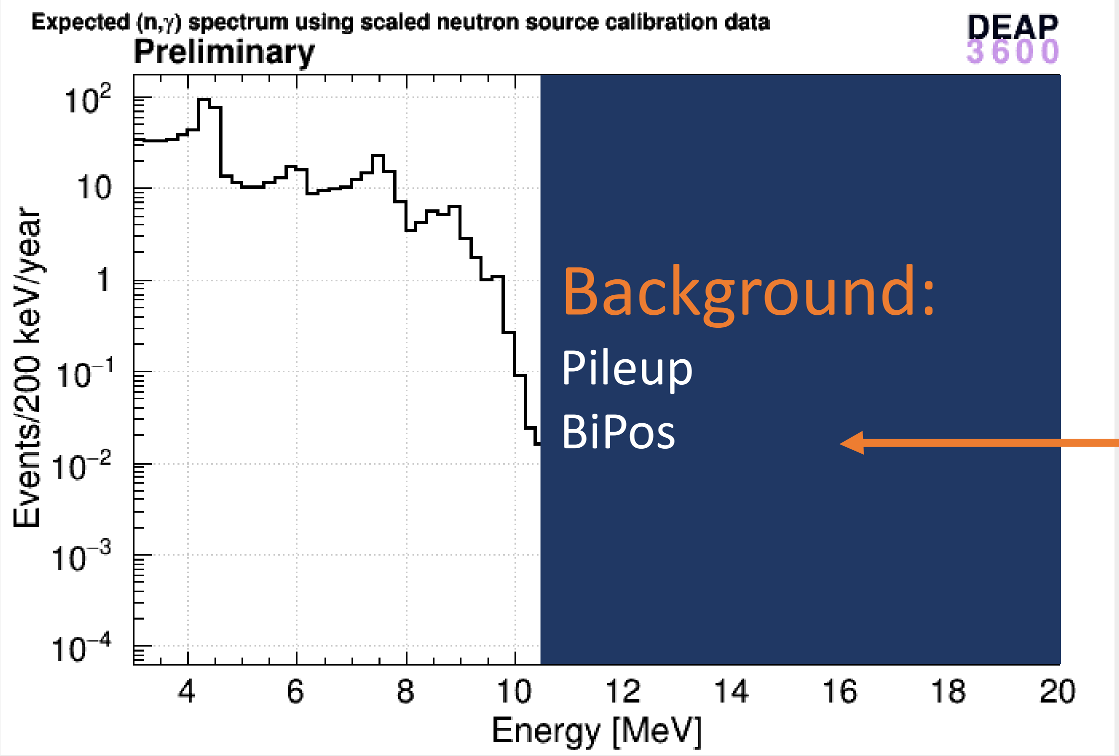
^{214}Bi →β→ ^{214}Po (τ=236 us) →α→ ^{210}Pb

^{232}Th chain:

^{212}Bi →β→ ^{212}Po (τ=432 ns) →α→ ^{208}Pb

Delayed Coincidence Region





Expected Signal

Delayed Coincidence Region

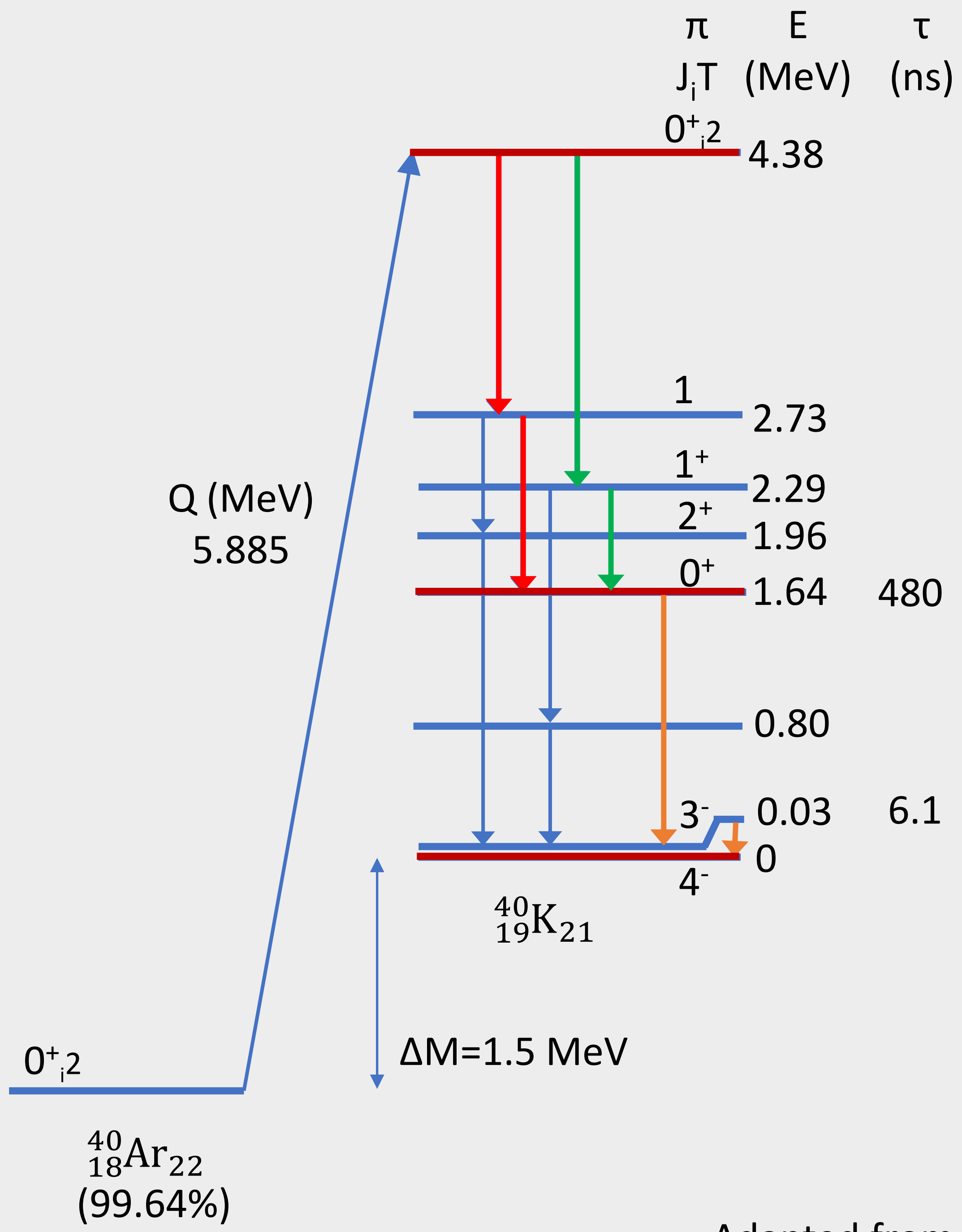
- Prompt peak from the electron and from multiple gammas from the excited state to the 1.64 MeV metastable state.

$$E_{prompt} = E_e + \sum E_\gamma$$

- The metastable state has a time constant of 480 ns.
- Delayed signal is a 1.64 MeV gamma signal to the ground state.

$$E_{delayed} = 1.64\ MeV$$

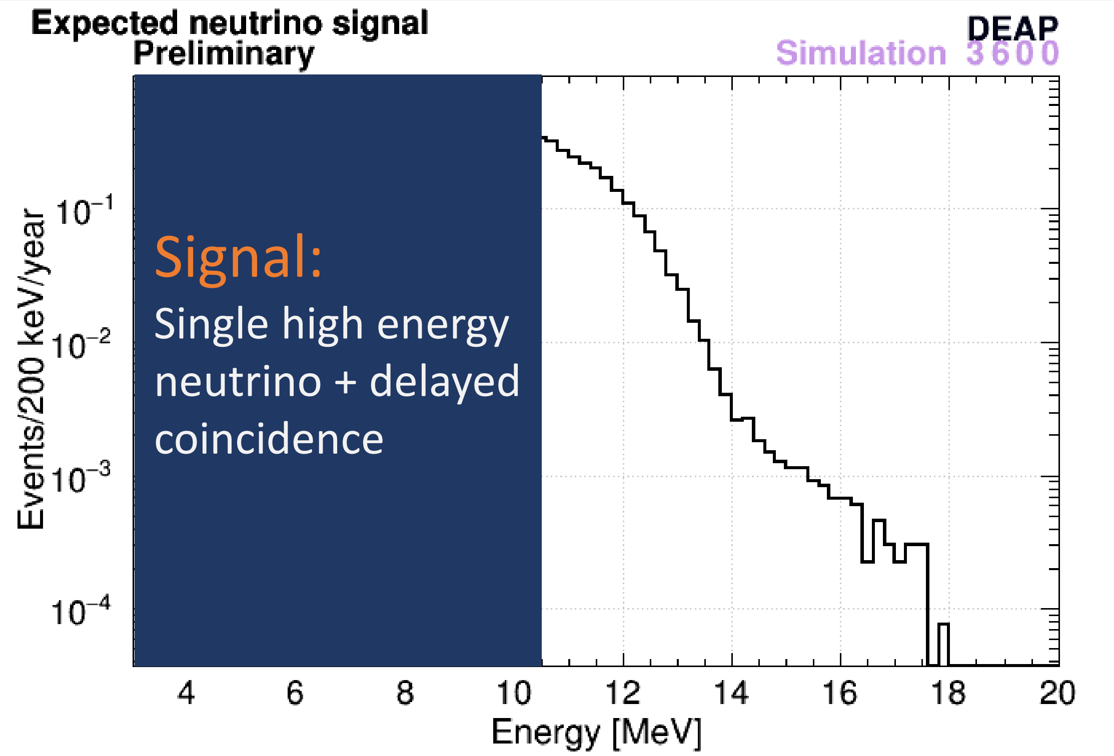
$$E_\nu = E_{prompt} + E_{delayed} + 1.5\ MeV$$

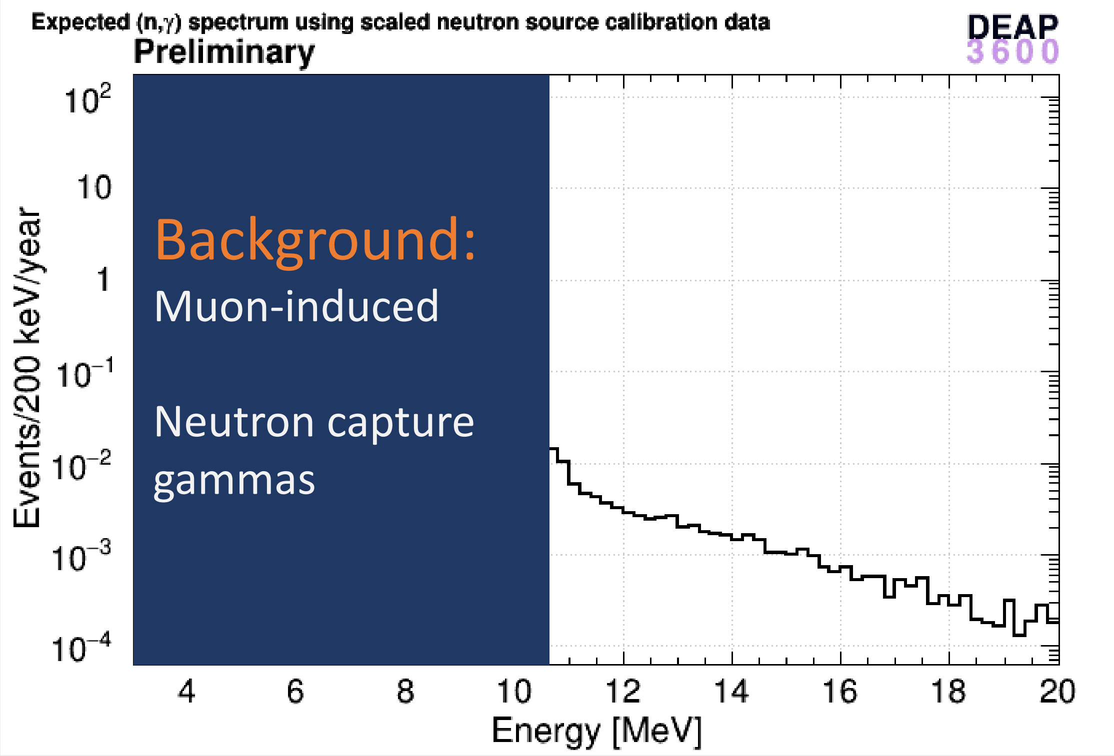


Adapted from [1]

Neutrino Study Search Regions

High Energy Region





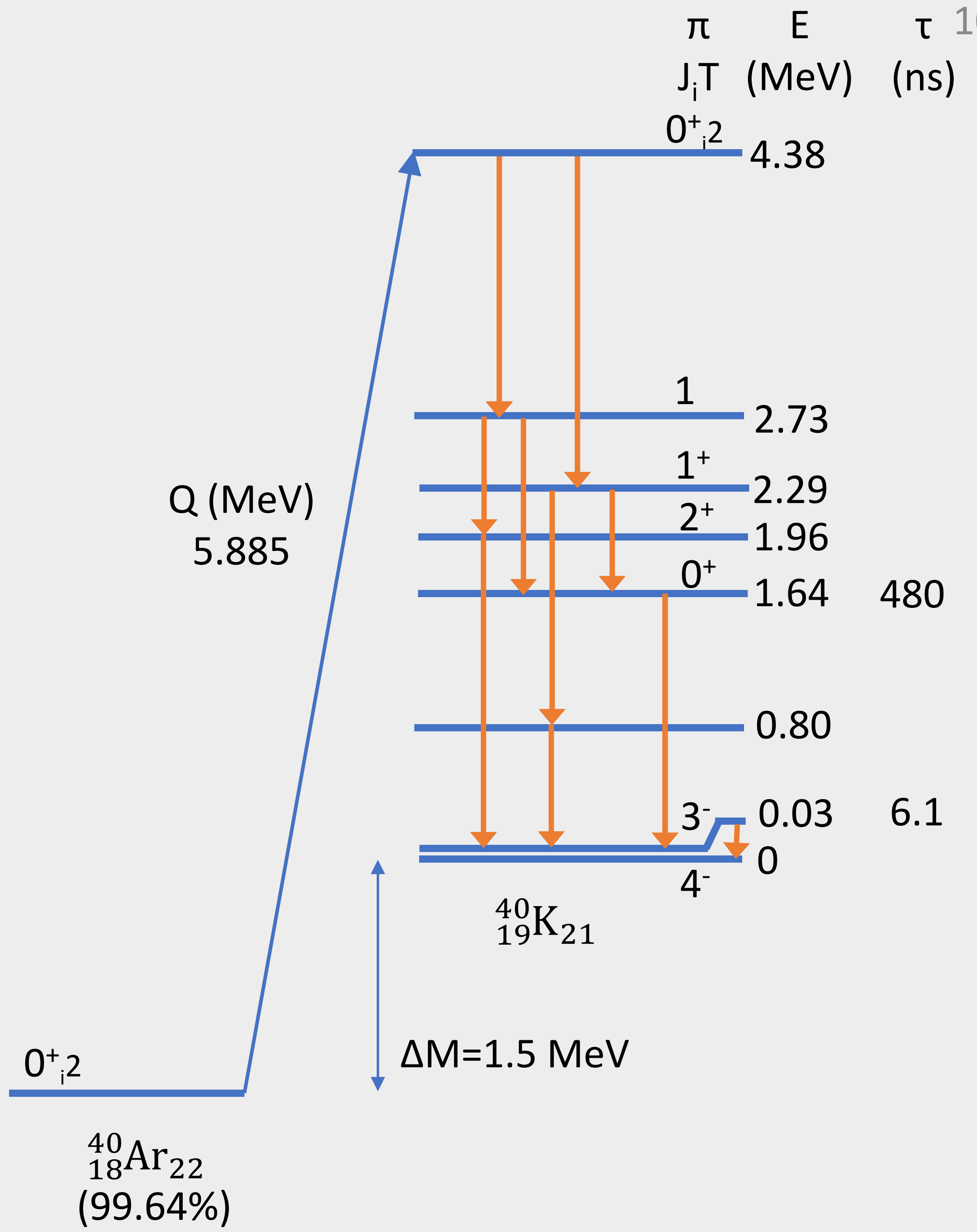
Expected Signal

High Energy Region

- Signal will be a count of excess high energy events over a carefully calculated background.

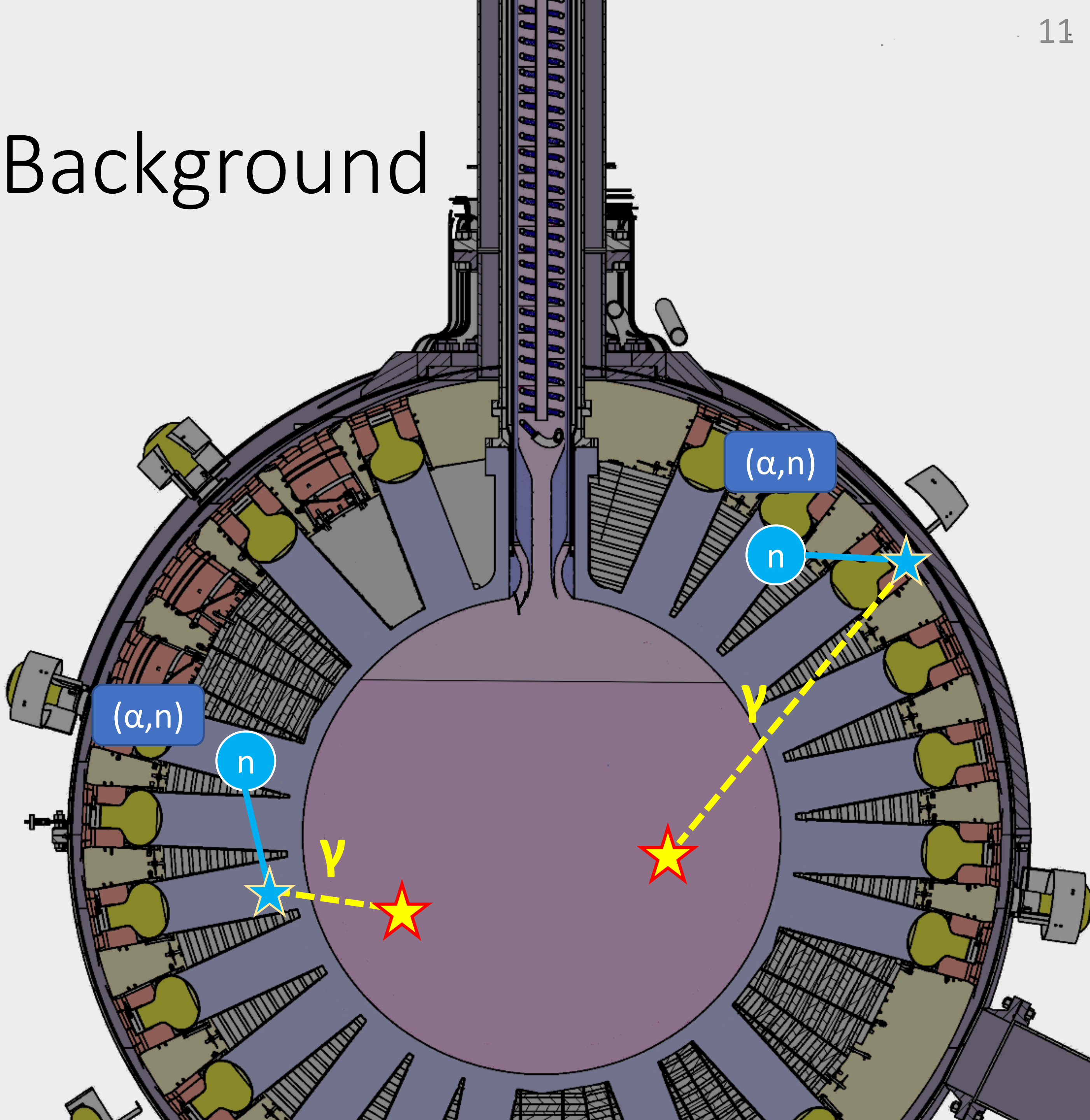
$$E_\nu = E_e + \sum E_\gamma + 1.5\ MeV$$

$$E_\nu = E_{obs} + 1.5\ MeV$$



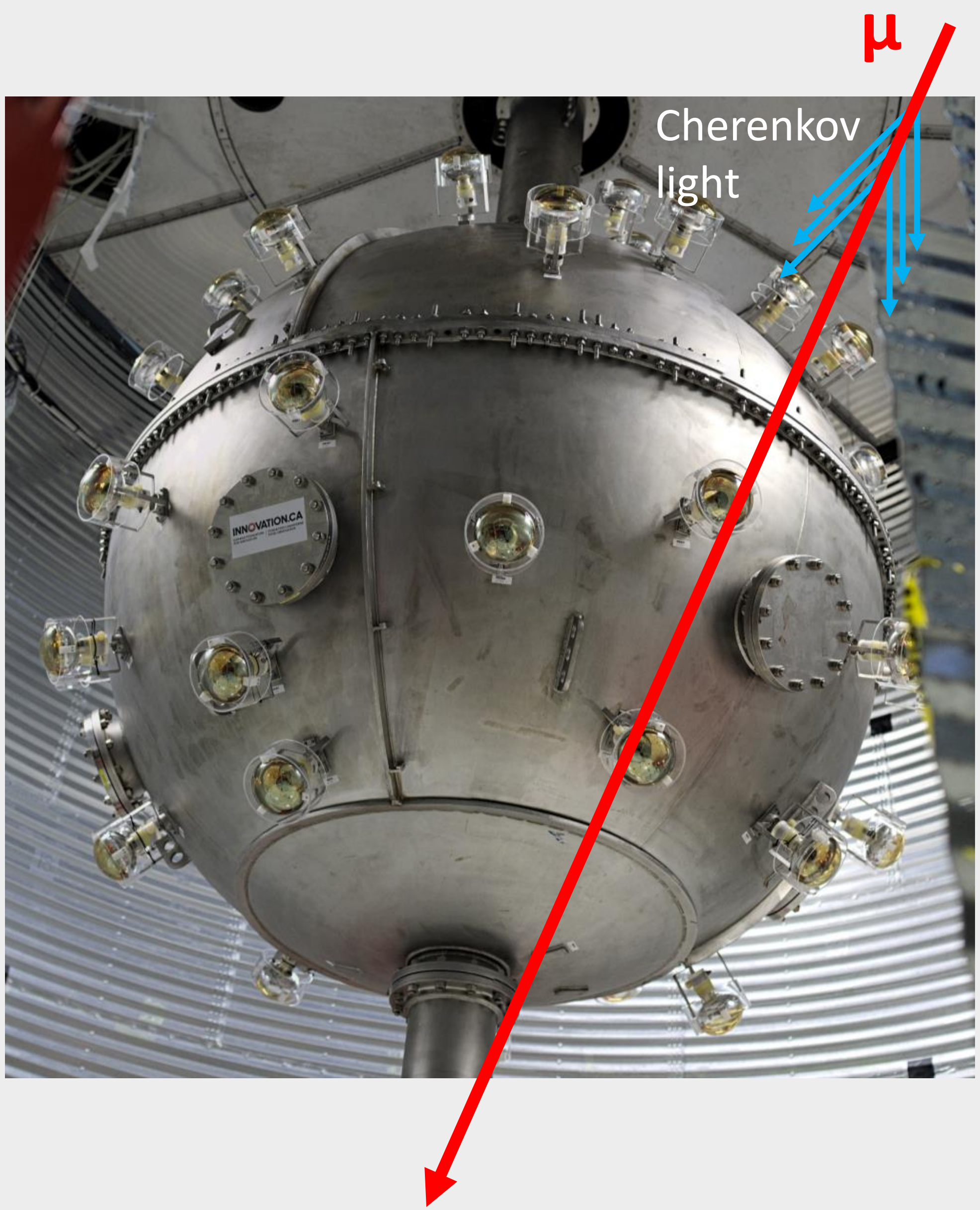
Radiogenic Neutron Background

- Main source of backgrounds are neutron capture events initiated by ^{238}U decay in the PMT glass.
- Undergoes an (α, n) reaction producing a neutron.
- Neutrons captured by material in the detector producing gammas.
- The gammas produced can have different energies depending on the capturing element.
- Highest energy neutron capture defines the separation in study energy ROIs.



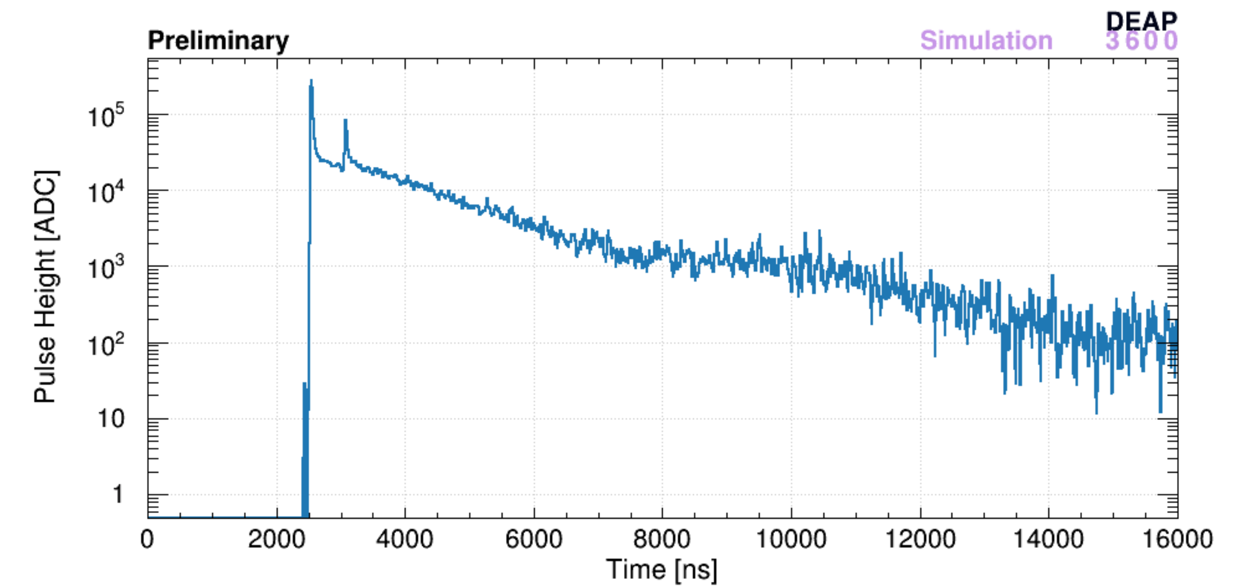
Cosmogenic Background

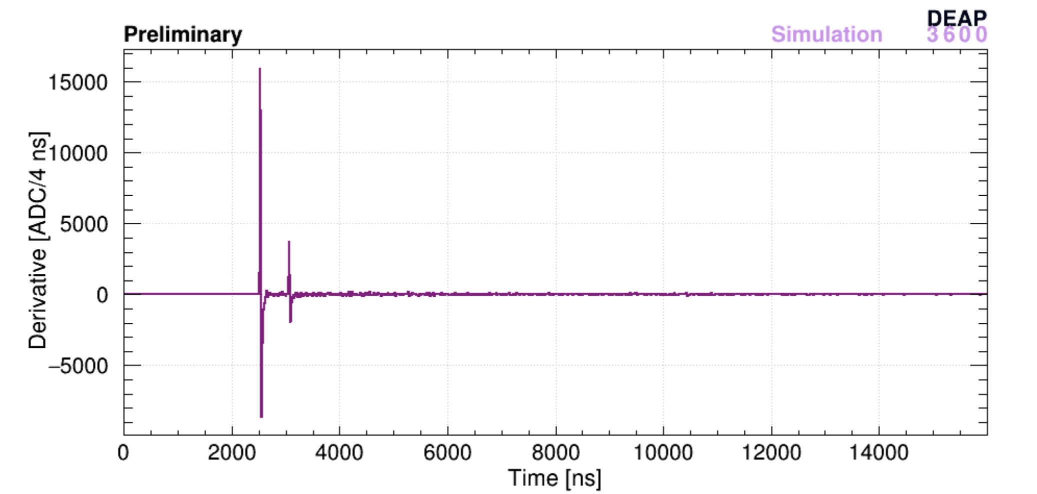
- Picking out events in LAr in prompt coincidence with muons either passing through or near the water tank where there are muon veto PMTs.
- Simulated with both Geant4 and FLUKA



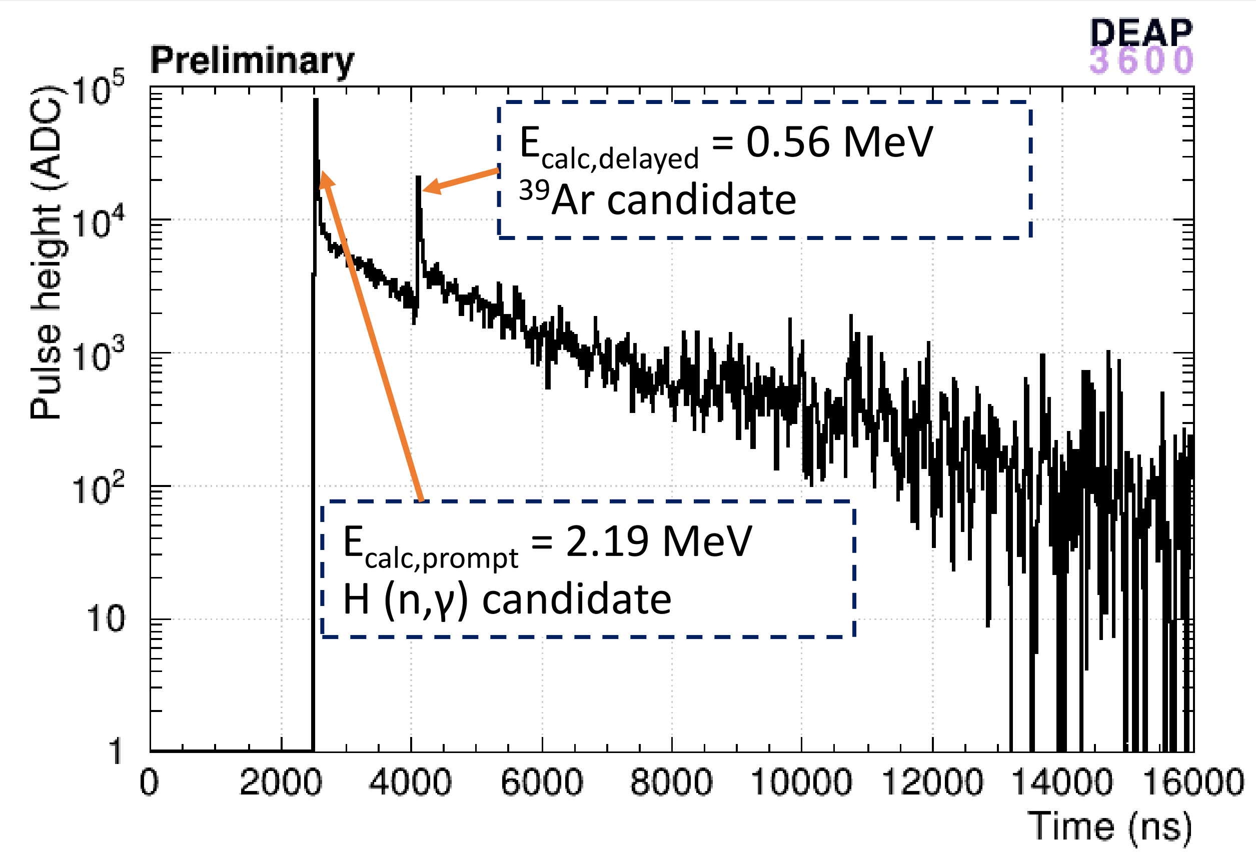
Delayed Coincidence High Energy Pileup Algorithm

- Used to identify high energy pile up events.
- Identify peaks by when the waveform derivative passes a certain threshold.
- Then looks forward in the waveform for the zero crossing indicating a peak.





Delayed Coincidence Energy Response Model



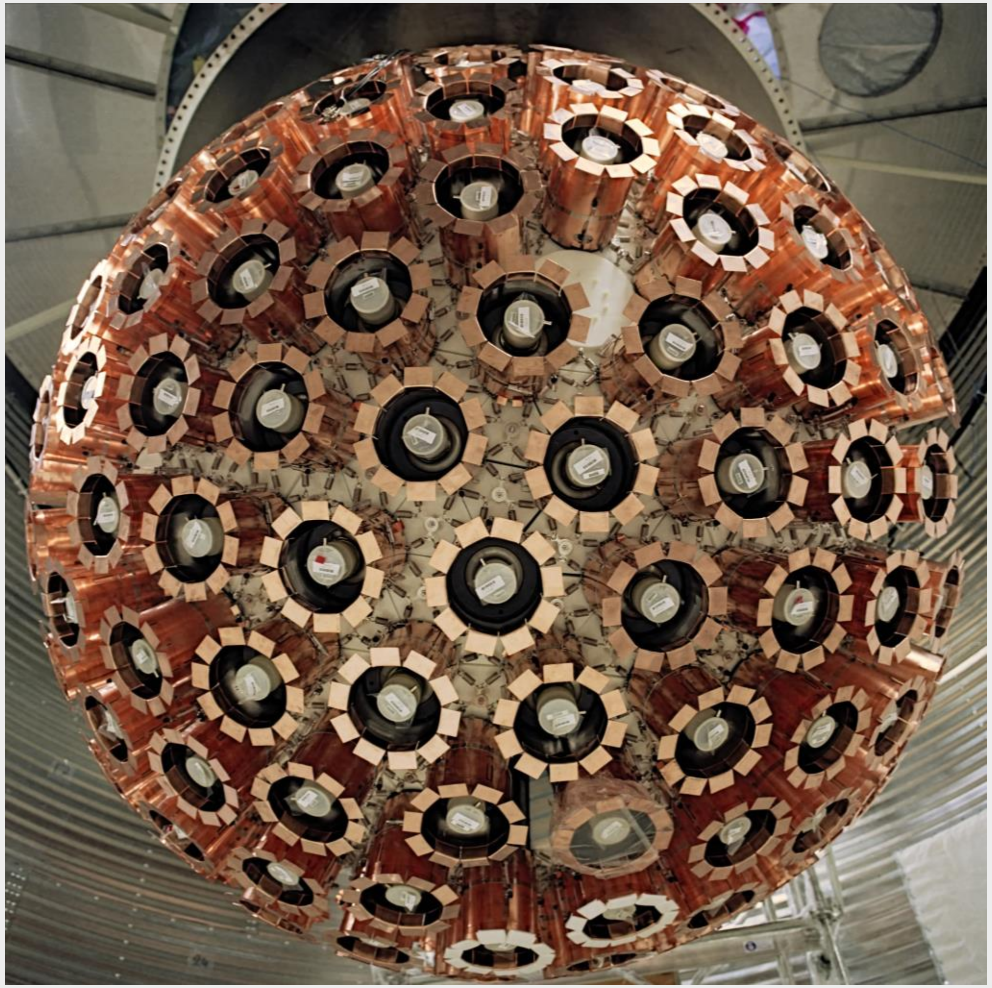
- Data-driven energy response model using gammas in physics and neutron source calibration data.
- Trying to determine the energy of prompt and delayed events in a single waveforms.
- Uses well calibrated single peak energy response model for DEAP for the prompt peak to estimate the energy of the delayed peak.

Delayed Coincidence Monte Carlo Pileup Model

- Using non-pileup background to make an MC of random pileup.
- Studying the efficiency of the algorithm at identifying pileup as a function of time between pileup peaks for different combinations of E_{prompt} and $E_{delayed}$.

Summary

- Literature suggests it is possible to observe neutrinos in a LAr detector by neutrino absorption with ^{40}Ar.
- Neutrino search split into a delayed coincidence region and a high energy region.
- This project is still ongoing.



References

[1] B. Aharmim, et al. Determination of the ν_e and total ^{8}B solar neutrino fluxes using the Sudbury Neutrino Observatory Phase I data set. Phys. Rev. C, 75:045502, Apr 2007.

[2] R. S. Raghavan. Inverse β^- decay of ^{40}Ar: A new approach for observing MeV neutrinos from laboratory and astrophysical sources. Phys. Rev. D, 34:2088-2091, Oct 1986.

[3] M. Bhattacharya, et al. Neutrino absorption efficiency of an ^{40}Ar detector from the β decay of ^{40}Ti. Phys. Rev. C, 58:3677-3687, Dec 1998.

[4] M. Bhattacharya, C. D. Goodman and A. García. Weak-interaction strength from charge-exchange reactions versus β decay in the A=40 isoquintet. Phys. Rev. C, 80:069901, Nov 2009.