Backgrounds in the Measurement of θ_{13} with Hydrogen Neutron Capture at Daya Bay

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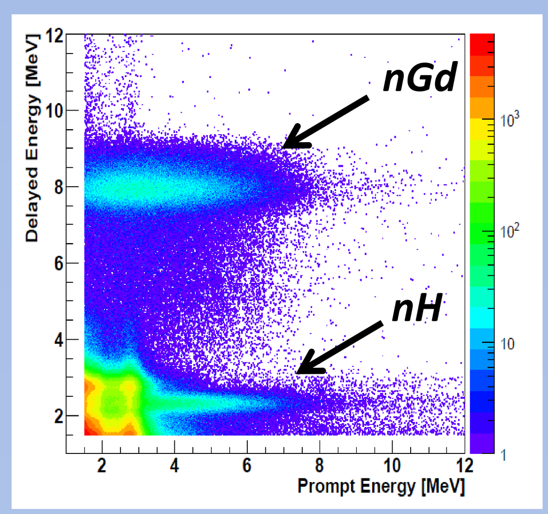
① Introduction

Recently, the Daya Bay Experiment has made substantial progress in understanding reactor electron-antineutrino disappearance with their neutron capture on gadolinium (nGd) sample. Here, we discuss the study of neutrino survival probability with a new neutron capture on hydrogen (nH) sample at Daya Bay. The backgrounds (accidental, fast neutron, ^{9}Li/^{8}He and Am-C) could contaminate the nH correlated prompt-delayed signals. Background studies are important for extracting a clean nH sample for a precision measurement of θ_{13}.



- **Detection of Antineutrinos**

Inverse beta decay (IBD)

$\bar{\nu}_e + p \rightarrow e^+ + n$

prompt signal: e+ annihilation,
delayed signal: neutron capture

Hydrogen Neutron Capture

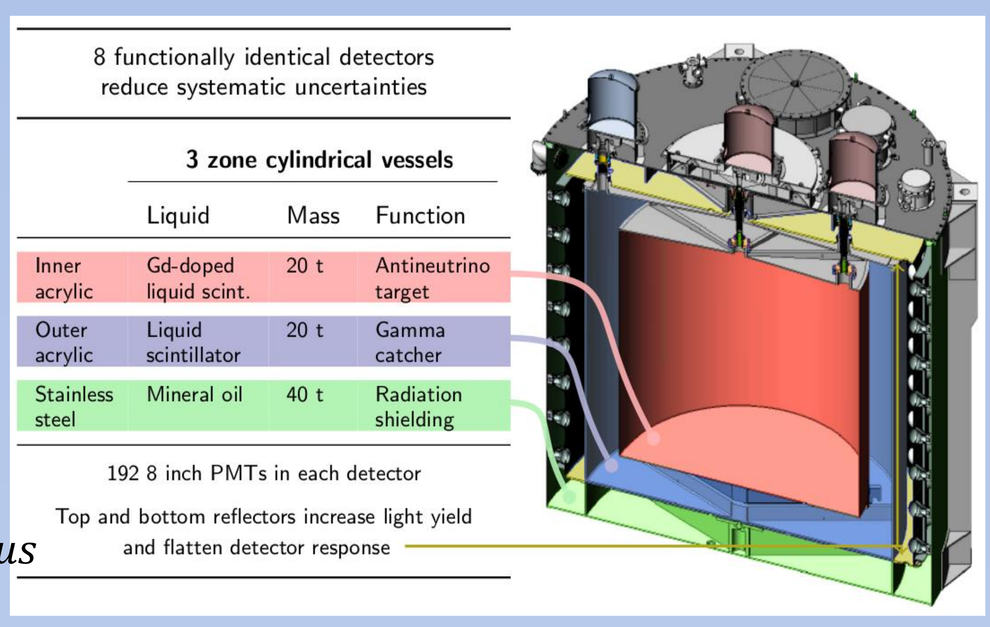
$n + p \rightarrow D + \gamma(2.2MeV), \tau{\sim}180\mu s$

Antineutrino target: LS and Gd-LS

Gadolinium Neutron Capture

$n + Gd \rightarrow Gd^* + \gamma's(8MeV), \tau{\sim}30\mu s$

Antineutrino target: Gd-LS

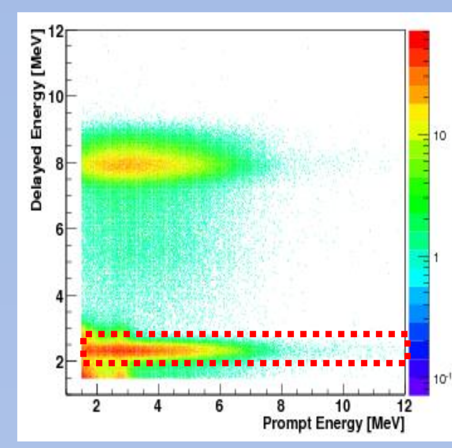


Antineutrino events: prompt and delayed signals coincident in time and energy.

② Antineutrino Event Selection (nH)

- Prompt signal (p) energy cut: $1.5 < E_p < 12.0$ MeV
- Delayed signal (d) energy cut: (nH peak energy $\pm$ 3σ range)
- Time correlation cut (delayed time cut): $1 < \Delta t_{d\text{-}p} < 400$ μs
- Reject spontaneous PMT light emission ("flashers")
- Distance cut: $\text{Distance}_{dp} < 0.5$ m
- Muon veto

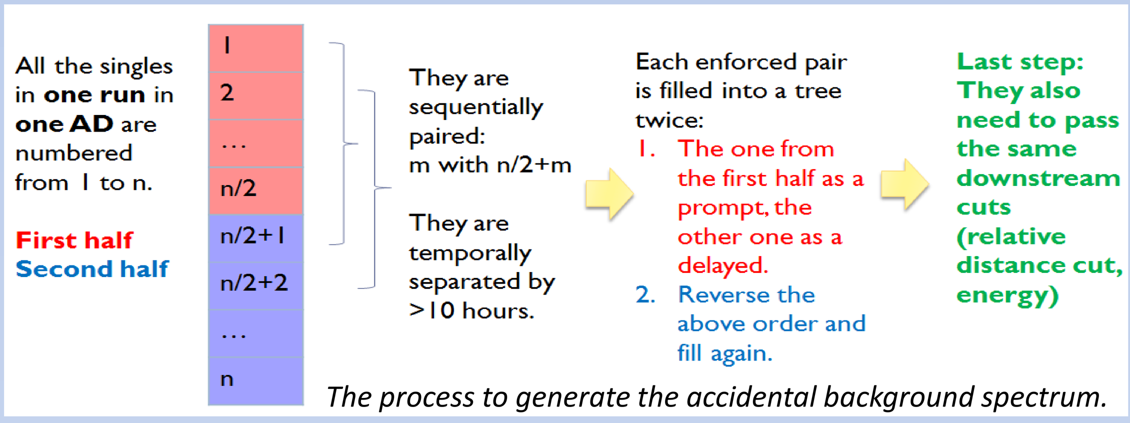
Water pool muon (inner water shield > 12 hit PMTs or outer water shield > 15 hit PMTs), reject signals in (-400, 400 μs)
AD muon (Energy > 20 MeV), reject signals in (-400, 800 μs) to the muon
AD shower muon (Energy > 2.5 GeV), reject signals in (-400 μs, 1 s) to the muon



③ Accidental Backgrounds

The accidental background is caused by the random coincidence of a prompt-type single event ($1.5 < E_p < 12$ MeV) and a delayed-type single event (E_d in the nH peak $\pm$3σ range).

Method: The accidental background spectrum is generated from singles data, and subtracted from the coincidence pairs that passed the antineutrino event selection in ②.



The process to generate the accidental background spectrum.

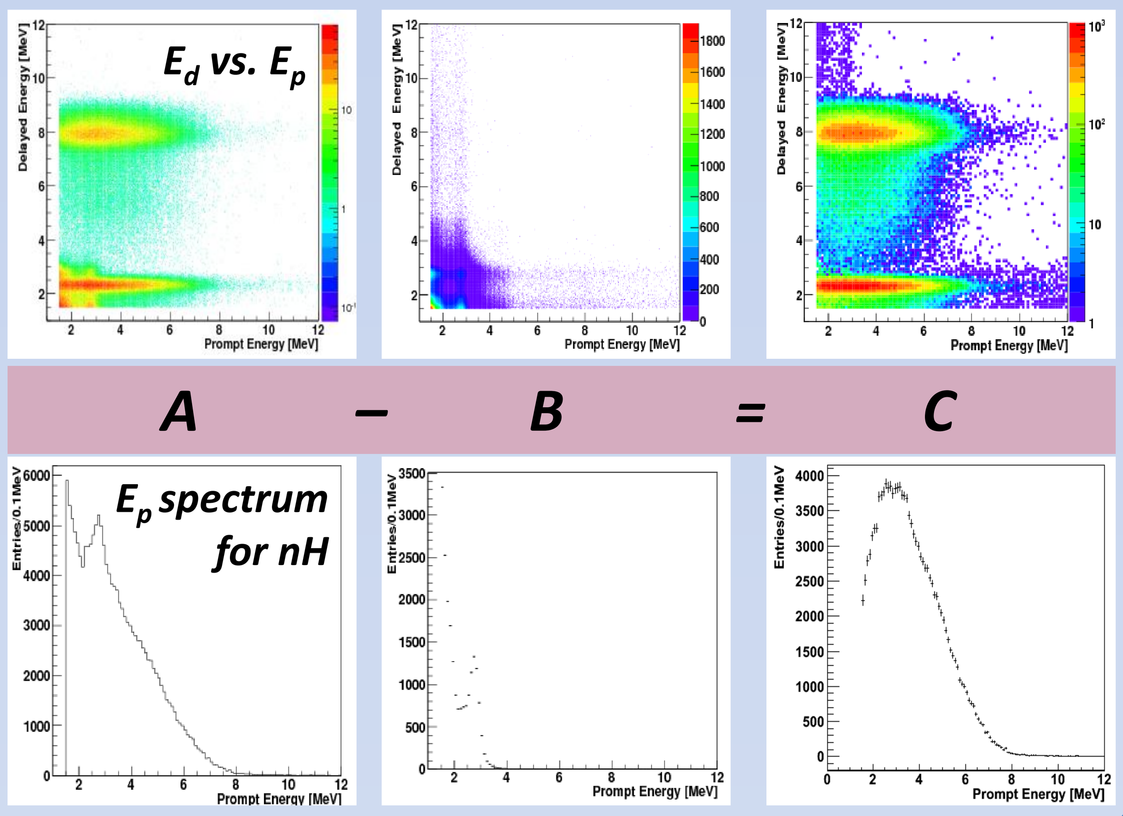
Validation:

- Long distance accidental events, and long delayed time accidental events.

The left graphs:
Coincidence pairs that passed the selection in ②. (before the accidental background subtraction)

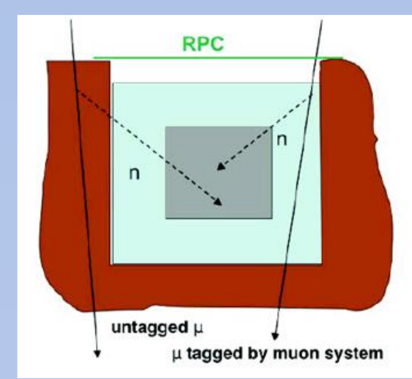
The middle graphs:
The accidental background spectrum

The right graphs:
The correlated signal pairs after the accidental background subtraction

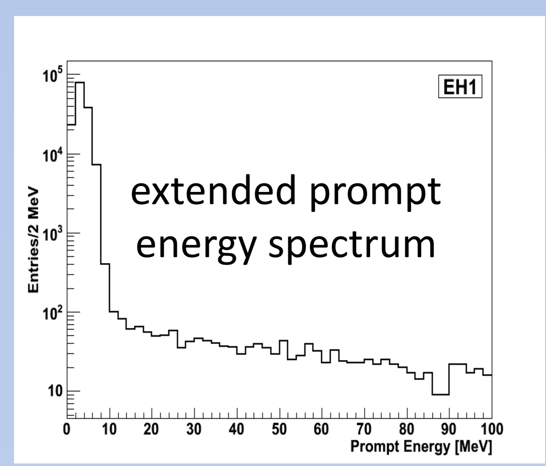


④ Fast Neutron Backgrounds

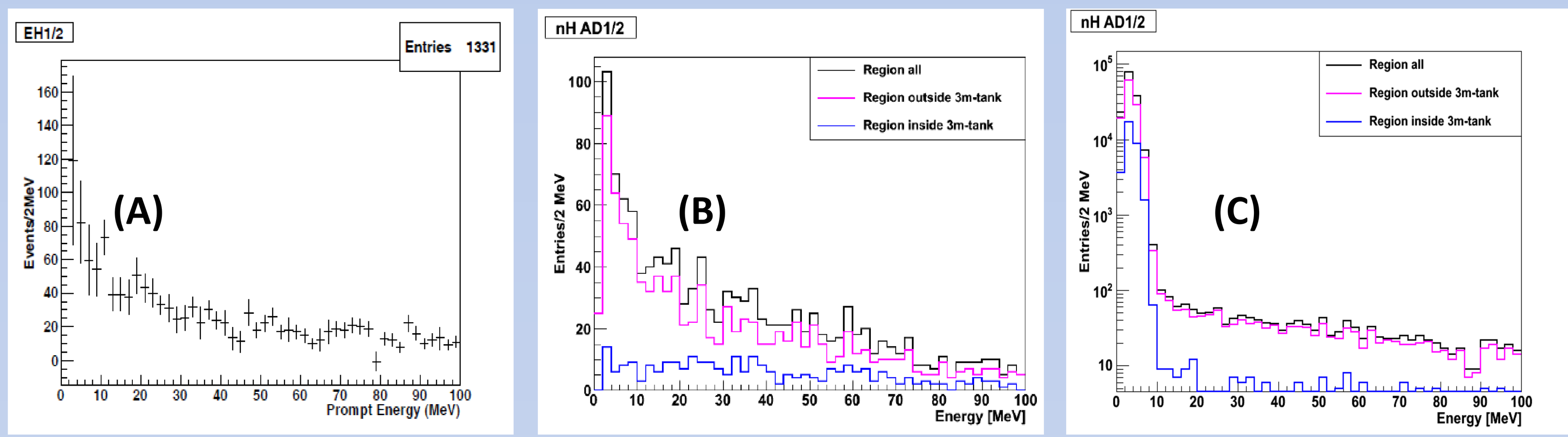
Energetic neutrons created by cosmic ray muons entering an antineutrino detector (AD) could mimic IBD events by recoiling off a proton before being captured on hydrogen.



Method: By relaxing the $E_p < 12$ MeV criterion in IBD selection, E_p distribution is studied up to 100MeV. Extrapolation into the IBD energy region gives an estimate for the fast neutron backgrounds.

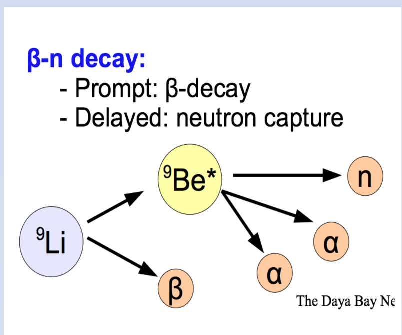


The spectrum rises at low energy due to insufficient enclosure of the prompt recoil signal (**geometry effect**). It is validated by fast neutron spectra from **(A)** outer water shield (OWS) tagged muons, **(B)** simulation results with geometry-cuts, confining the delayed signals in the "3m-tank" (Gd-LS) and outside of the "3m-tank" (LS), and **(C)** extending the prompt energy with geometry-cuts.



⑤ ^{9}Li/^{8}He Backgrounds

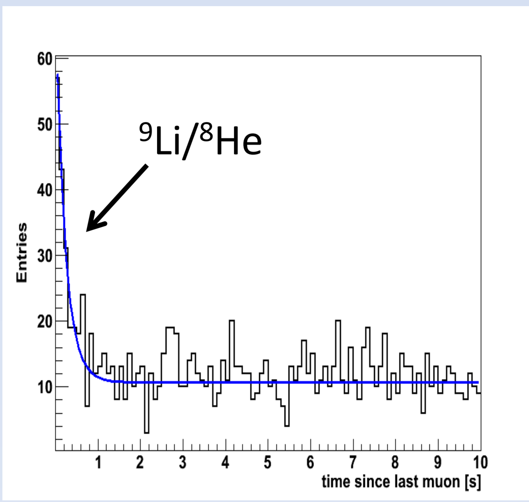
^{9}Li ($\tau_{1/2}$=178 ms, Q=13.6 MeV) and ^{8}He ($\tau_{1/2}$=119 ms, Q=10.6 MeV) are long-lived isotopes produced by cosmic ray muon interactions with nuclei of the liquid scintillator. The ^{9}Li/^{8}He can undergo beta-neutron decay. This gives a correlated beta-neutron pair and mimics IBD events.



Method: The correlated background from the β-n cascade was evaluated from the distribution of the time since the last muon (requiring a neutron detected within (10, 200 μs) after the muon), which can be described as

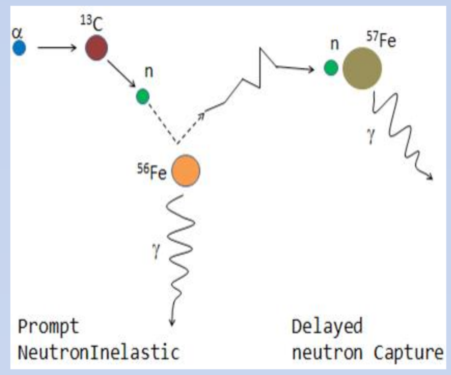
$$f(t) = \sum_{i}^{Li,He} N_i \cdot (\lambda_i + \lambda_\mu) e^{-(\lambda_i+\lambda_\mu)t} + N_{IBD} \cdot \lambda_\mu e^{-\lambda_\mu t}$$

λ_μ: the muon rate dependent on the muon selection criteria
λ_i: the decay time of ^{9}Li and ^{8}He, respectively
N_i: the number of β-n events for ^{9}Li and ^{8}He, respectively



⑥ ^{241}Am-^{13}C Backgrounds

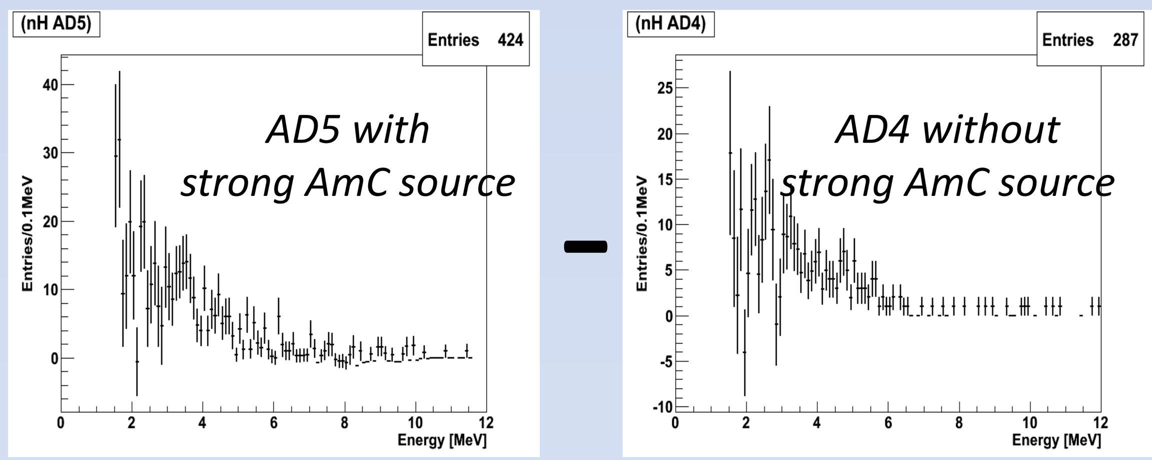
Am-C neutron sources sat inside the ACUs on the top of each AD and caused correlated backgrounds. An IBD was mimicked if both gamma-rays from the scattering and capture process on stainless steel entered the scintillating region.



Method: The background was studied by using a special x80 stronger Am-C source (the strong Am-C source) placed on AD5 in Summer 2012. The Am-C correlated background was estimated by the strong Am-C's normalization with the Am-C caused delayed-type single events (n-like events).

Validation: Normal Am-C and strong Am-C results from Monte Carlo simulation.

$$Bkgs(Normal\ AmC) = Bkgs(stong\ AmC) \cdot \frac{N_{n-like}(Normal\ AmC)}{N_{n-like}(strong\ AmC)}$$

$Bkgs\ (strong\ AmC) =$ 

(Prompt spectra of correlated pairs after accidental background subtraction. AD5 and AD4 are in one site.)

⑦ Summary

- The backgrounds (accidental, fast neutron, ^{9}Li/^{8}He and ^{241}Am-^{13}C) in the hydrogen neutron capture signals are studied. The study methods are validated by various techniques.
- The background rates/spectra are estimated from the study methods.
- A precision measurement of θ_{13} with hydrogen neutron capture will come in the near future.

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