Background Estimation

in the Daya Bay Reactor Antineutrino Experiment

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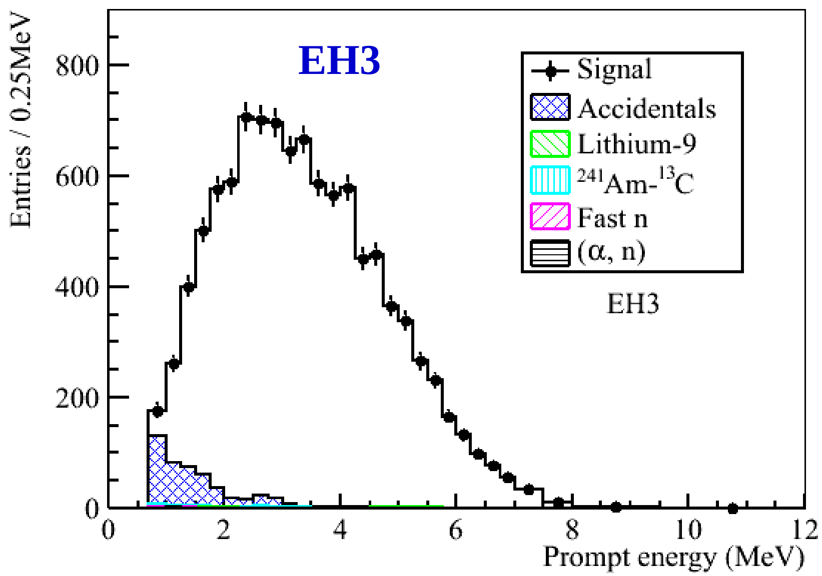
Background Sources

- Accidental background

  Two unrelated signals mimic an IBD

- Correlated background
  - Muon spallation products
    - $^{9}Li/^{8}He$
    - Fast neutron
  - (α,n)
  - $^{241}Am^{13}C$



Formation of Accidental Background

Two unrelated signals can accidentally mimic an IBD:

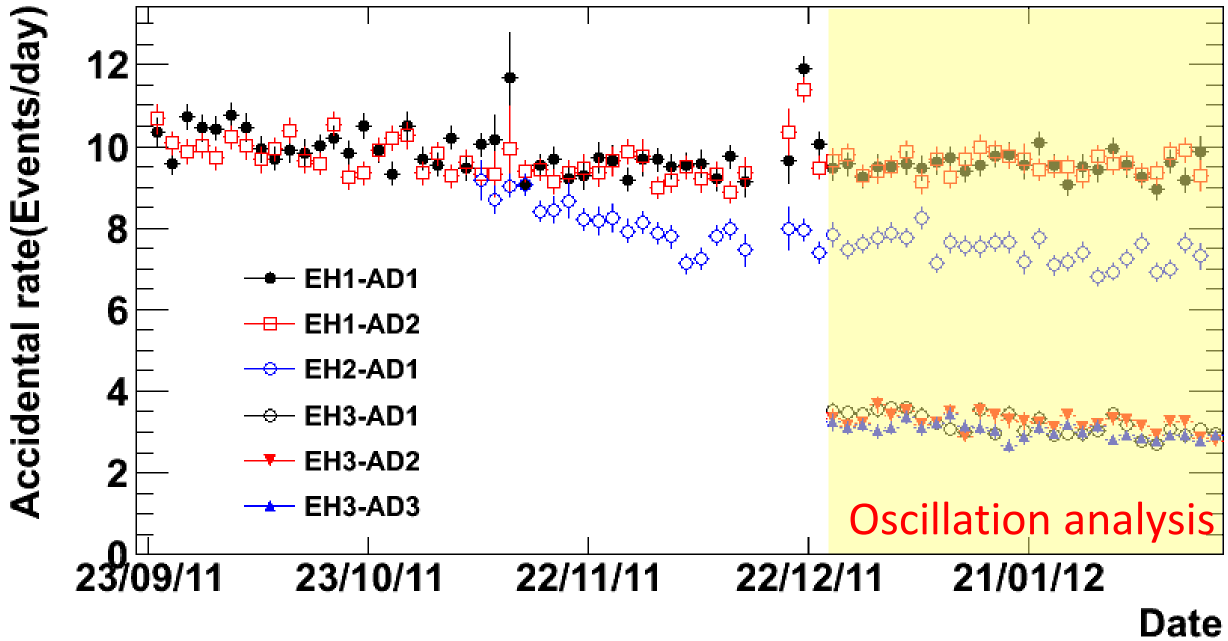
$\gamma\gamma, \gamma n, nn$

- γ: Liquid Scintillator/PMT/SS tank/rock natural radioactivity/ AmC
- n: spallation neutron/long-lived cosmogenic isotopes(B/N/Li/C)/ (α,n)

Main source of n-like singles*	**Rate of singles(/day/AD)**	**Fraction(%)**
AmC sources	~250	~18.2
$^{12}B/^{12}N$	~648	~47.3
$^{8}Li/^{8}B$	~270	~19.7
^{9}C	~50	~3.6

$*n-like\ single\colon\ uncorrelated\ signal\ in\ neutron\ energy\ region$

Accidental Backgrounds Evaluation



$$N_{\text{accBkg}} = \sum_i N^i_{\text{n-like singles}} \bullet \left(1 - e^{-R^i_{e^+\text{-like triggers}} \cdot 200\,\mu s} \right) \pm \frac{N_{\text{accBkg}}}{\sqrt{\sum_i N^i_{\text{n-like singles}}}}$$

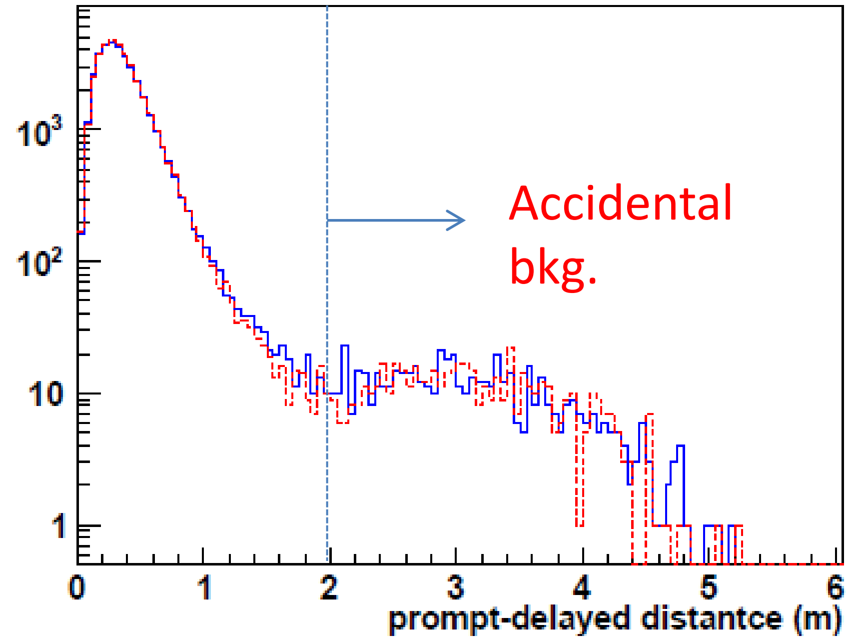
Random coincidence in 200μs

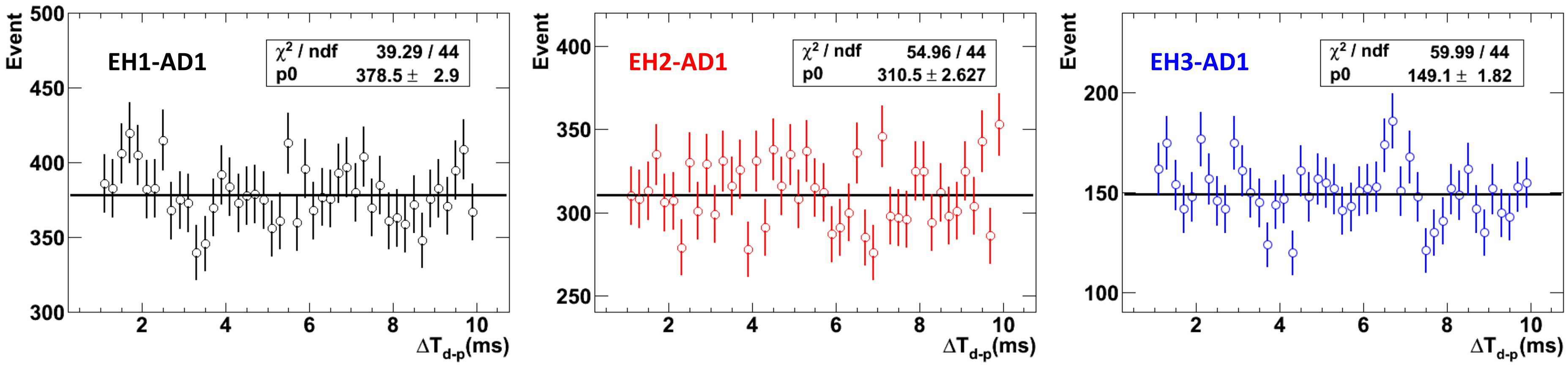
$N^i_{n-like\ singles}$: *number of singles in neutron energy region*

$R^i_{e^+-like\ triggers}$: *rate of the triggers in prompt energy region*

Accidental Backgrounds: Cross Checks

- Prompt-delayed distance distribution. Check the fraction of prompt-delayed pair with distance>2m
- Off-window coincidence → 'measure' the accidental background
- Results in agreement within 1%.



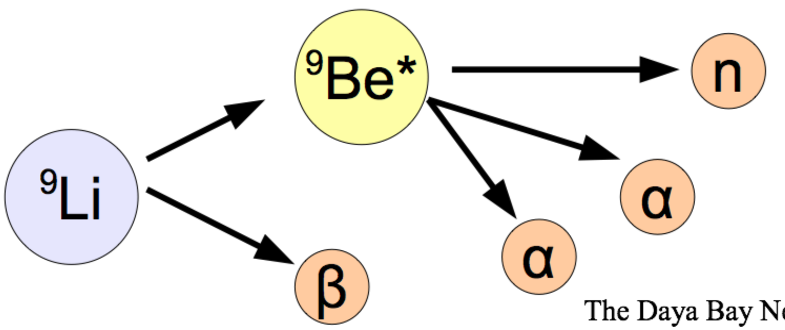


^{9}Li/^{8}He: β-n decay

Muon interactions in LS produce radioactive isotopes.
^{9}Li and ^{8}He are long-lived β,n emitters that can fake the IBD signature

β-n decay:

- Prompt: β-decay
- Delayed: neutron capture



The Daya Bay Ne

^{9}Li: $\tau_{½}$ = 178 ms, Q = 13. 6 MeV

^{8}He: $\tau_{½}$ = 119 ms, Q = 10.6 MeV

Time since last muon fit

NIM A 564 (2006) 471-474

$$f(t) = \sum_i N_i \cdot \lambda_i \exp(-\lambda_i t) + N_\mu \cdot R_\mu \cdot \exp(-R_\mu t)$$

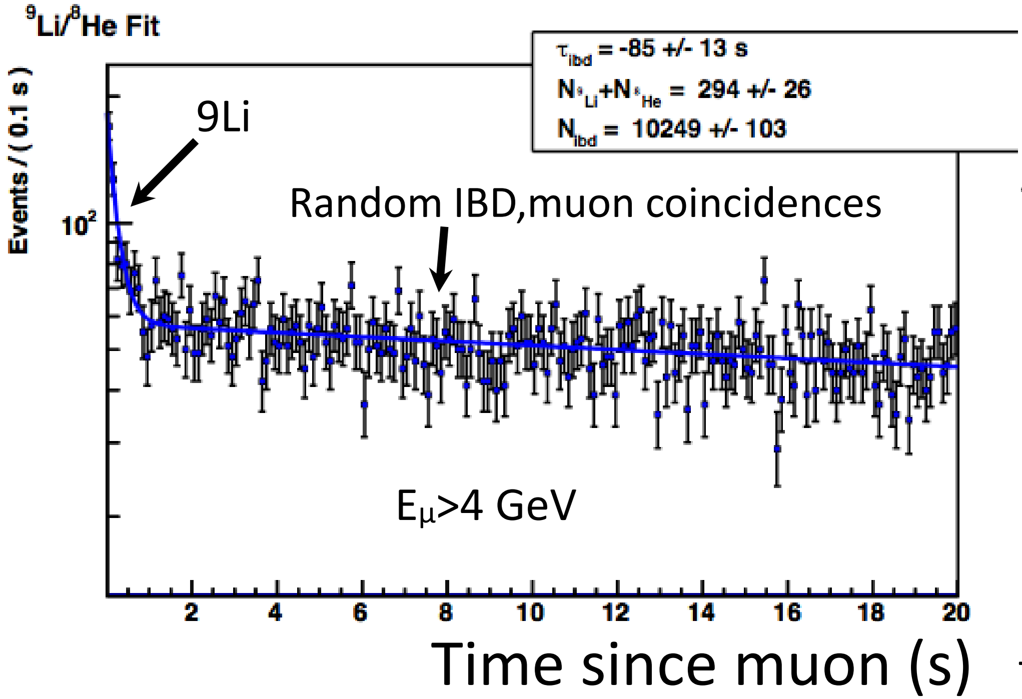
R_μ: muon rate

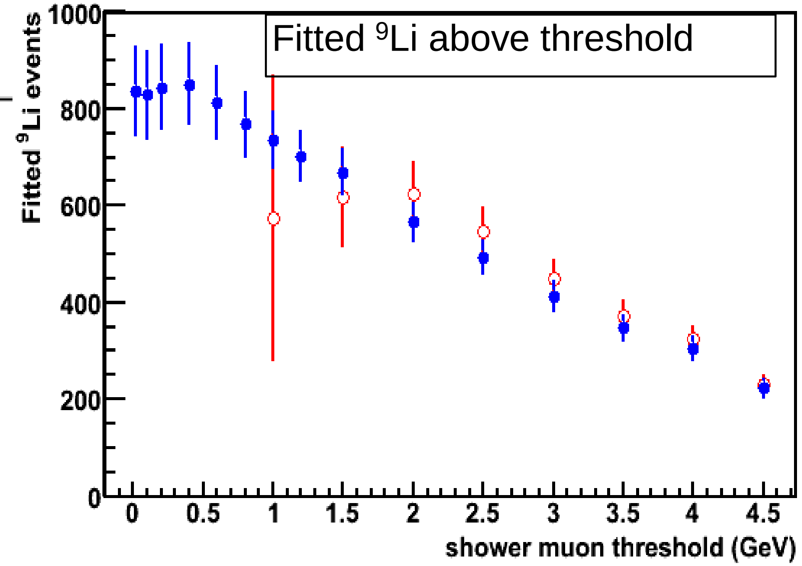
$$\lambda_i = R_\mu + \frac{1}{\tau_i^{isotope}}$$

N_i: counts of the specific kind of isotopes

$\tau_i^{isotope}$: life time of the specific kind of isotopes

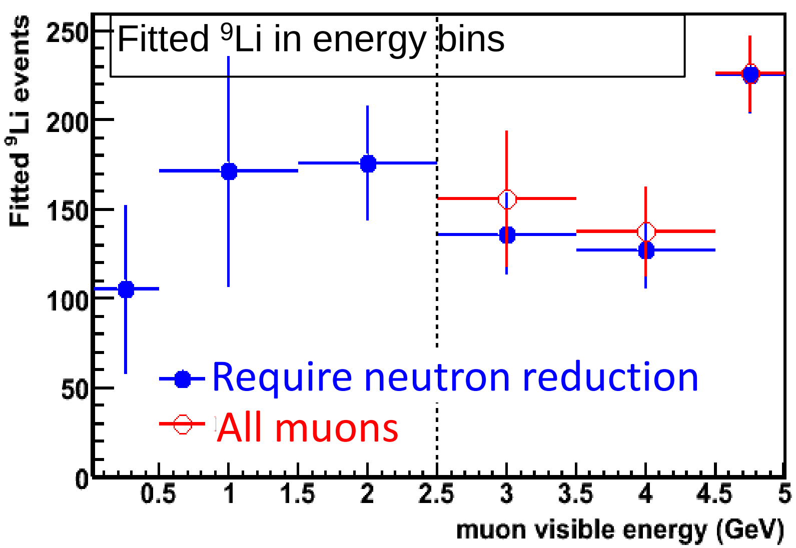
When R_μ is close to or greater than $\frac{1}{\tau_i^{isotope}}$





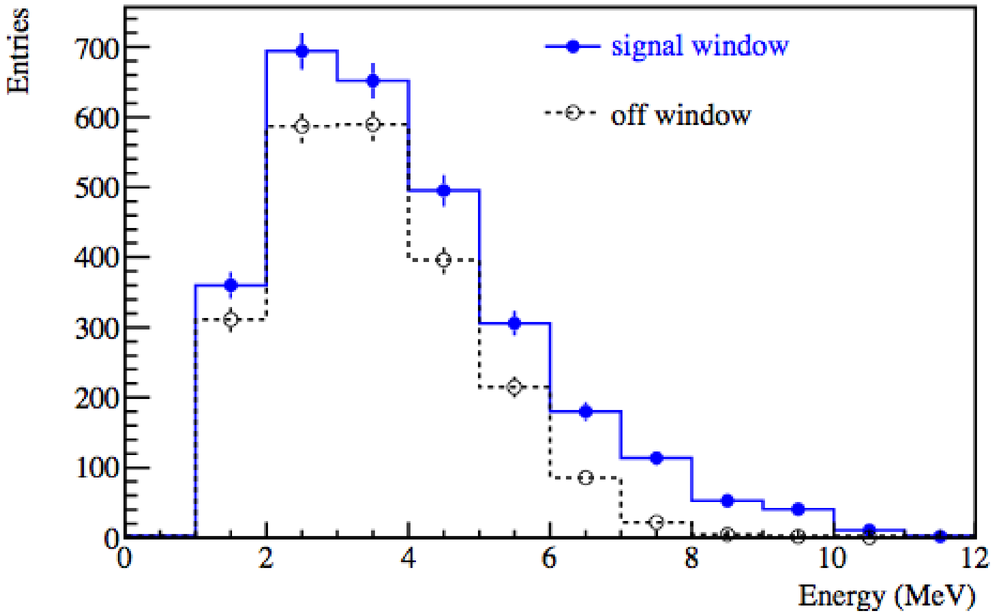
The precision of the fitted ^{9}Li rate is given by

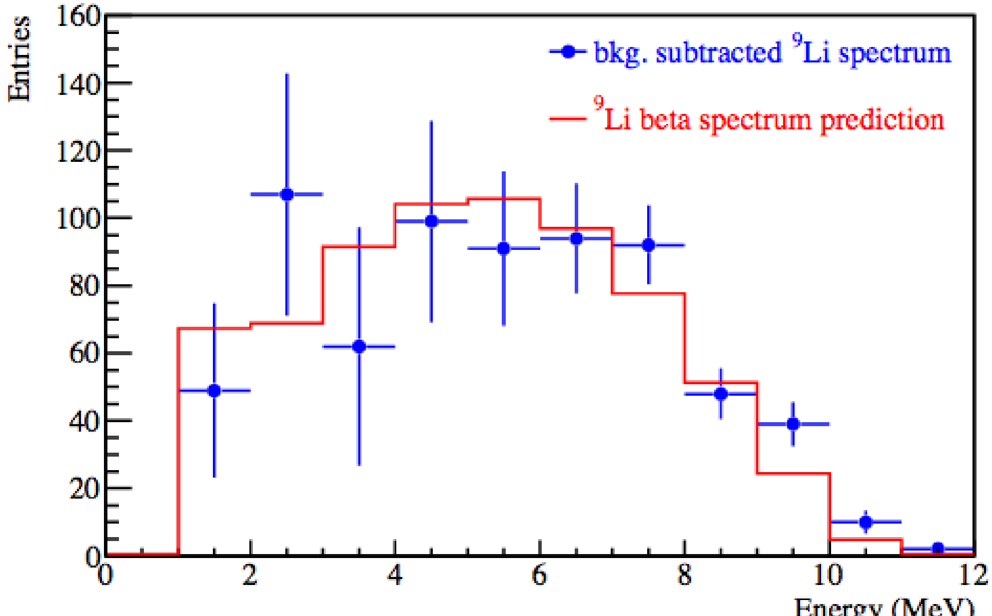
$$\sigma_b = \frac{1}{N} \cdot \sqrt{(1 + \tau R_\mu)^2 - 1}$$



Measure 9Li with two selection methods based on the **energy deposited** in the AD and the detected **co-production of neutrons**. The neutron co- production requirement reduces the muon rate and allows a measurement of the ^{9}Li rate. Comparison of rates allows uncertainty estimate.

Compare measured and expected ^{9}Li spectra





Data from all ADs with >2.5 GeV muon energy cut

Signal window: (1ms, 1s)
Off window: (1s, 2s)

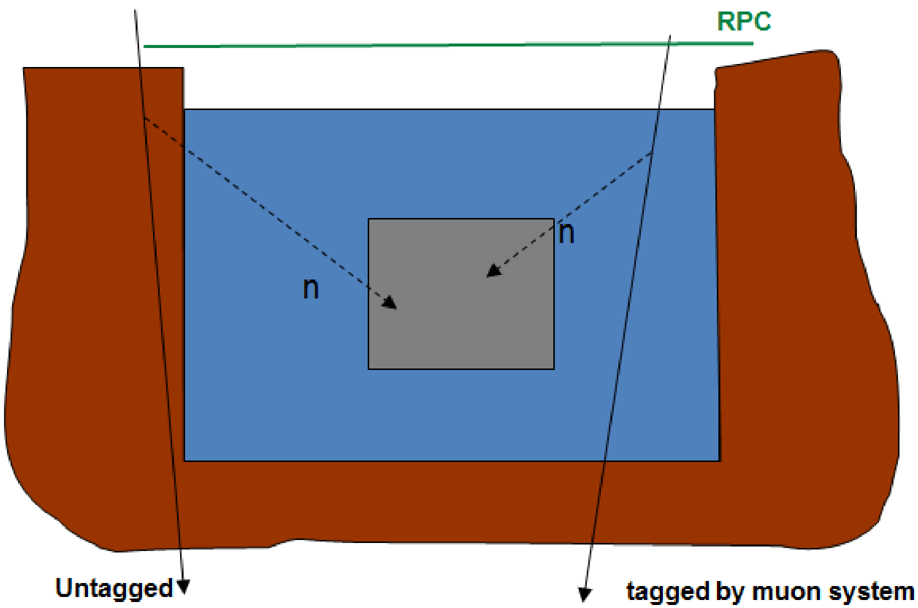
Require distance between prompt and delayed <1m

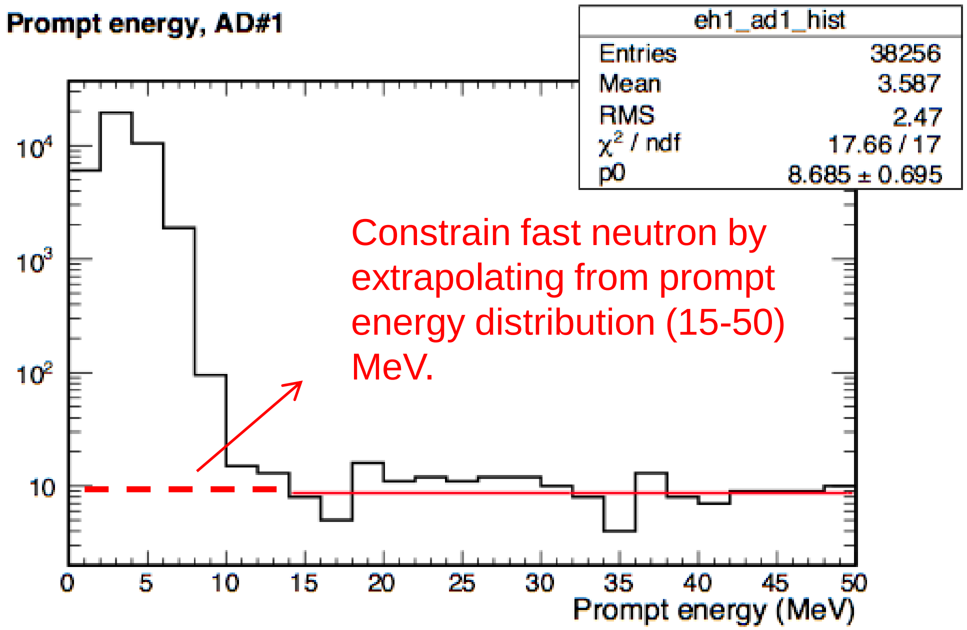
Fast neutron

"Fast" neutrons produced by cosmic muons external to the AD can enter the AD, slow and be captured.

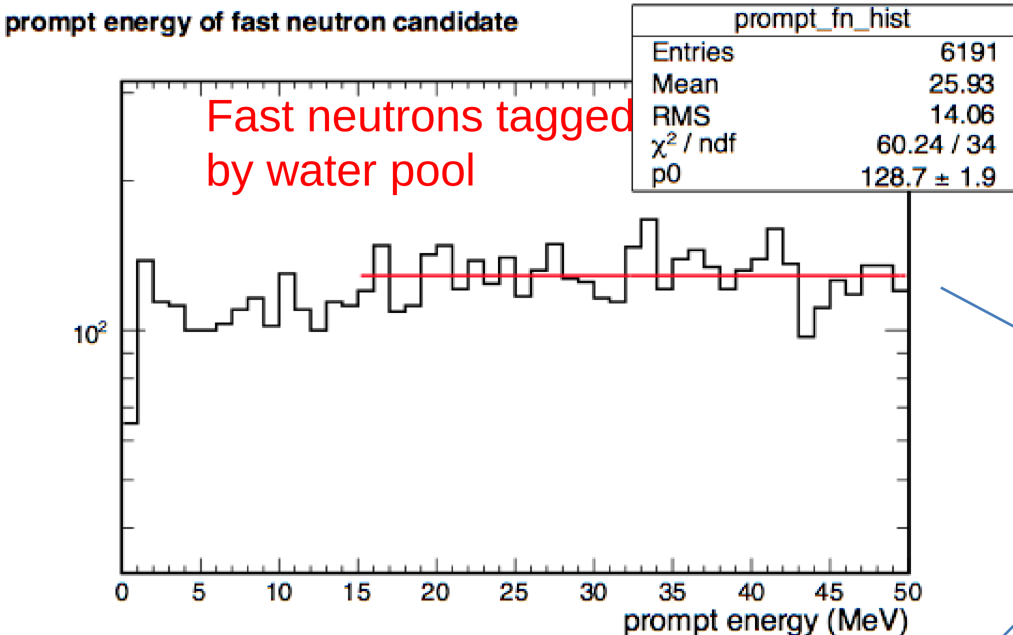
It can fake IBD events via:

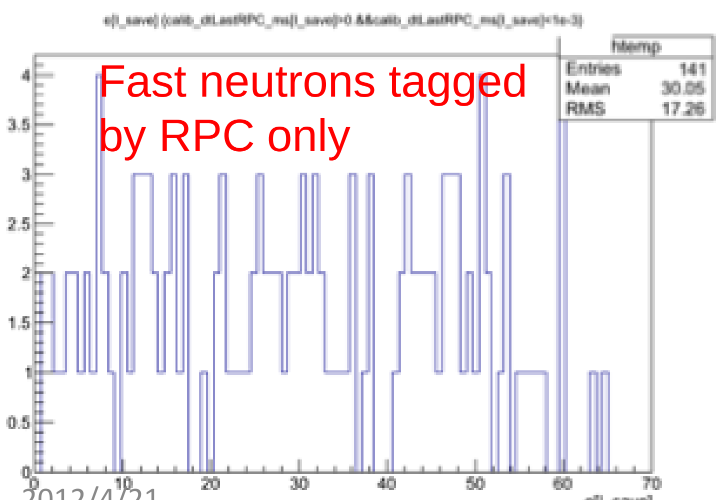
- Prompt: proton recoil in antineutrino detector
- Delayed: neutron captured on Gd





Validate extrapolation method





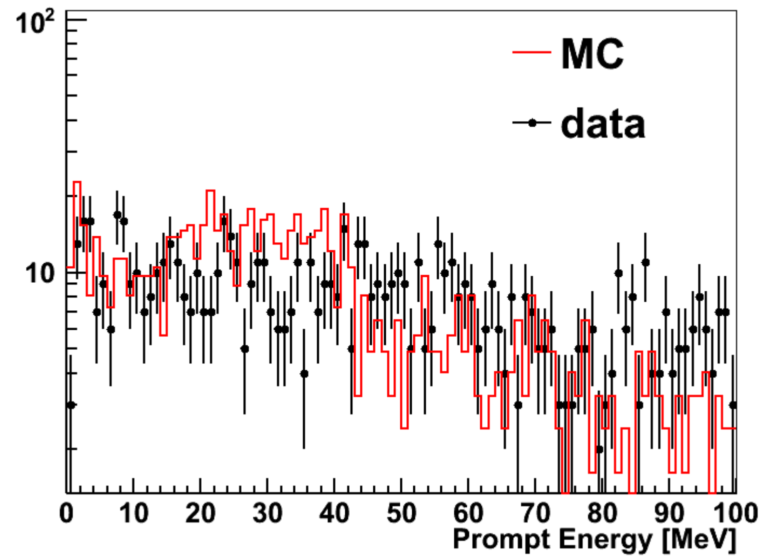
Check validity of extrapolation by tagging fast neutrons using the water pool and RPCs.

Both spectra are flat

Approximately 30% of fast neutrons untaggable by the water pool can be tagged by the RPCs based on MC and data.

Cross Checks

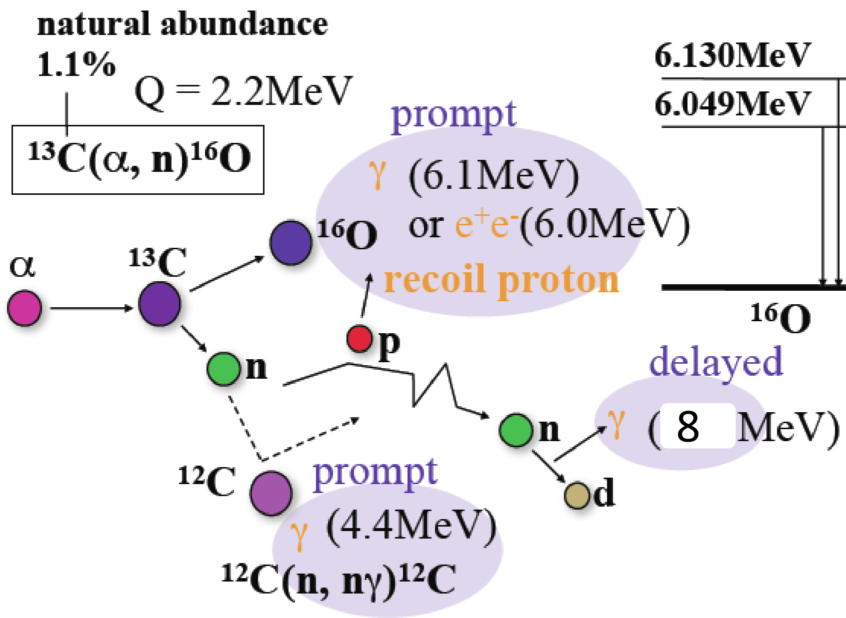
- Fast neutrons from water pools
  - Obtain the rate and energy spectrum of fast neutrons by tagged muons in water pool. Consistent with MC simulation.
  - Estimate the untagged fast neutron by using water pool inefficiency
- Fast neutrons from nearby rock
  - Estimated based on MC simulation

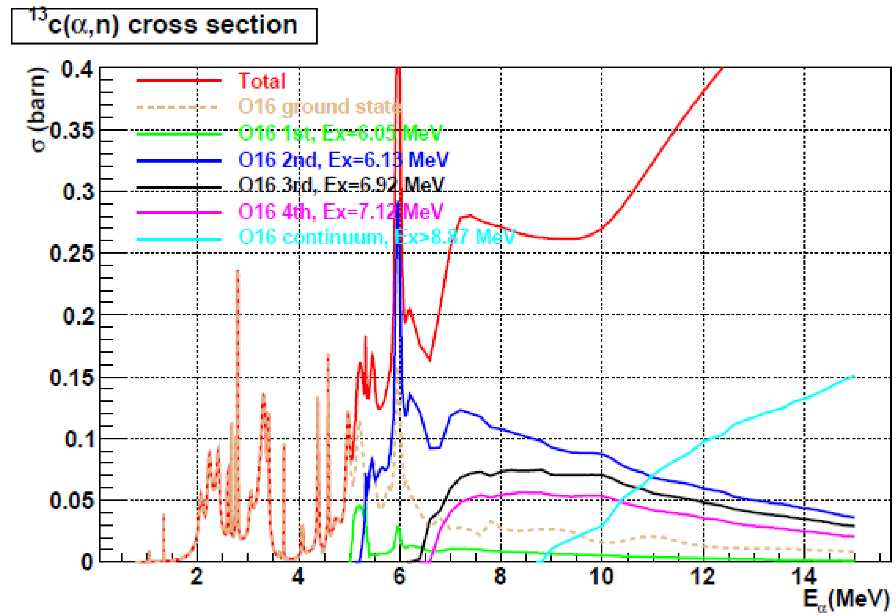


	Fast neutron (event/day)	Cross checks(event/day)
AD1	0.84±0.28	0.6±0.4
AD2	0.84±0.28	0.6±0.4
AD3	0.74±0.44	0.6±0.4
AD4	0.04±0.04	0.04±0.04
AD5	0.04±0.04	0.04±0.04
AD6	0.04±0.04	0.04±0.04

Results are consistent

Background $^{13}C(\alpha,n)^{16}O$





Two kinds of $^{13}C(\alpha,n)^{16}O$ bkg.

- ^{16}O excited states:

  $\gamma + n\ cpature$
- ^{16}O ground state:

  $p\ recoil\ +\ n\ capture$

Neutron yield calculated from α rate and (α,n) cross section analytically

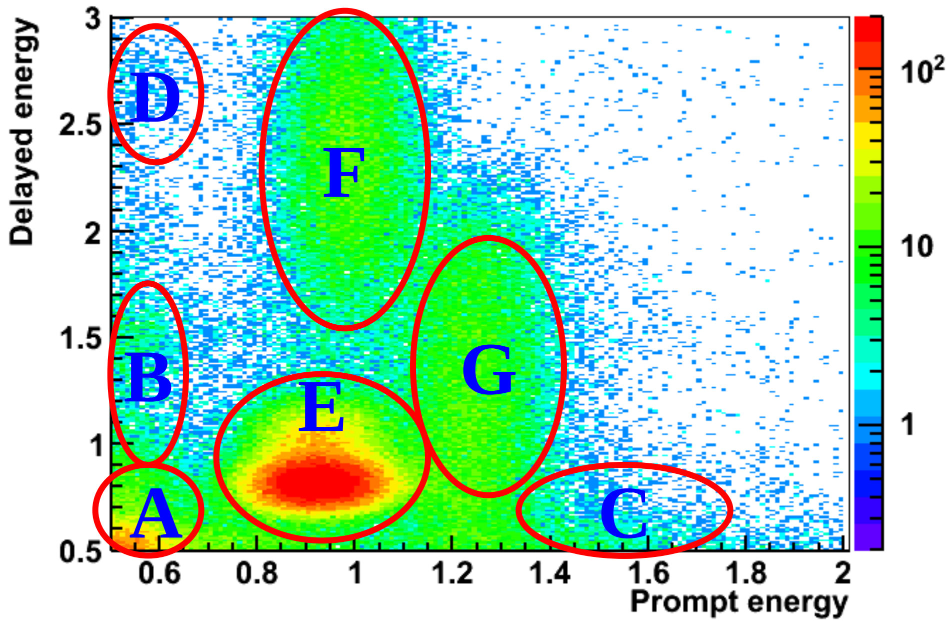
Alpha rate determination

Alpha rate determined from cascade decays in
^{238}U, ^{232}Th, ^{227}Ac, ^{210}Po

^{238}U: $^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Po$

^{232}Th: $^{212}Bi \xrightarrow{\beta} {}^{212}Po \xrightarrow{\alpha} {}^{208}Pb$

^{227}Ac: $^{219}Rn \xrightarrow{\alpha} {}^{215}Po \xrightarrow{\alpha} {}^{211}Pb$

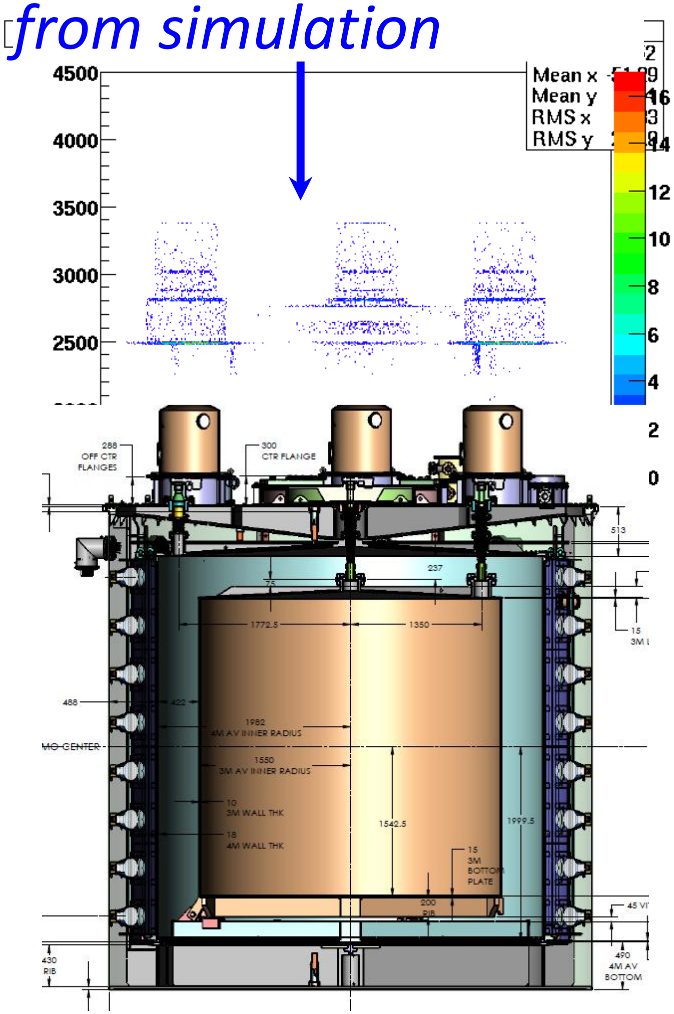


Uncertainty: 50%

	Components	Total α rate	BG rate
Region A	Acc. Coincidence of ^{210}Po&^{210}Po	^{210}Po: 10Hz at DYB 8Hz at LA 6Hz at Far	0.02/day at DYB 0.015/day at LA 0.01/day at Far
Region B	Acc. Coincidence of ^{210}Po&^{40}K		
Region C	Acc. Coincidence of ^{40}K&^{210}Po		
Region D	Acc. Coincidence of ^{208}Tl&^{210}Po		
Region E	Cascade decay in ^{227}Ac chain	1.4 Bq	0.01/day
Region F	Cascade decay in ^{238}U chain	0.07Bq	0.001/day
Region G	Cascade decay in ^{232}Th chain	1.2Bq	0.01/day

^{241}Am-^{13}C background

Position of neutron capture from simulation



~ 0.5 Hz ^{241}Am^{13}C source

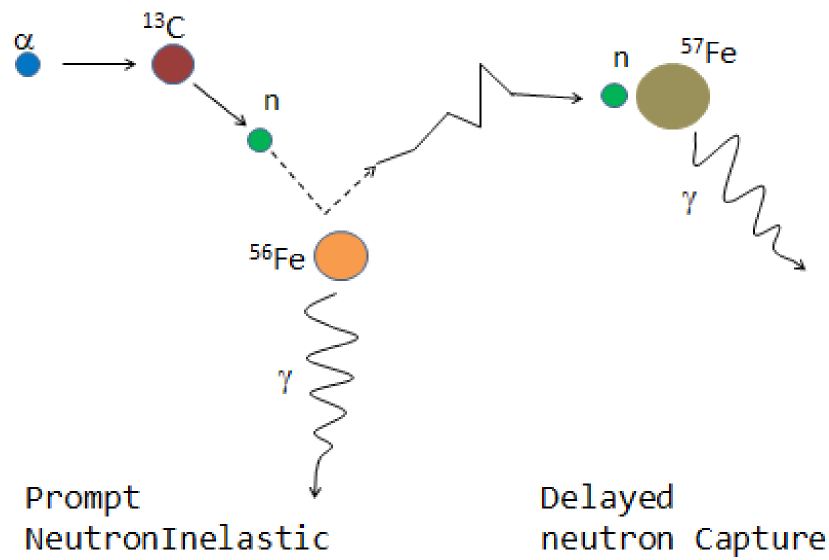
During physics data-taking, nearly no AmC neutron leak into AD, but gamma from neutron will.

n capture:

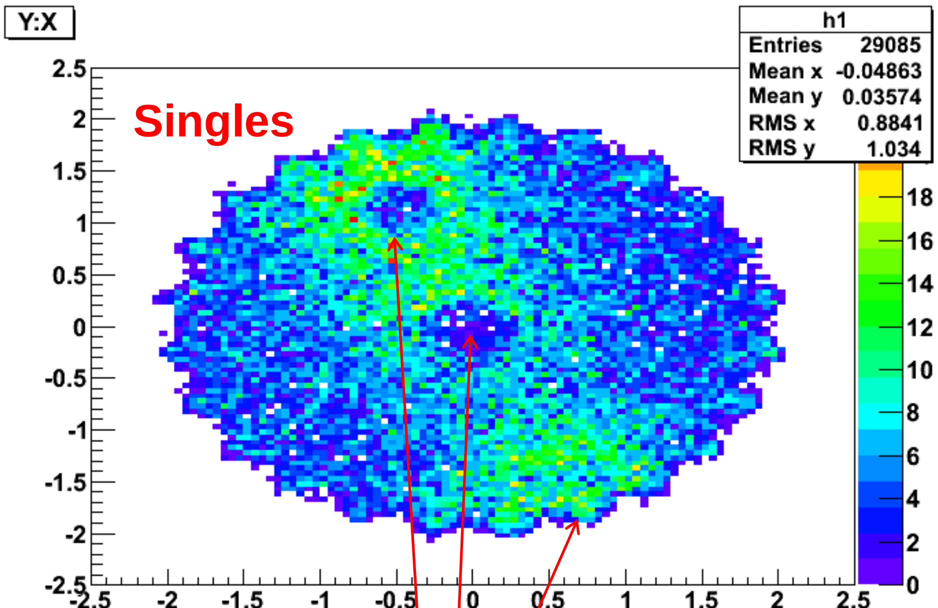
- contribute to accidental bkg.

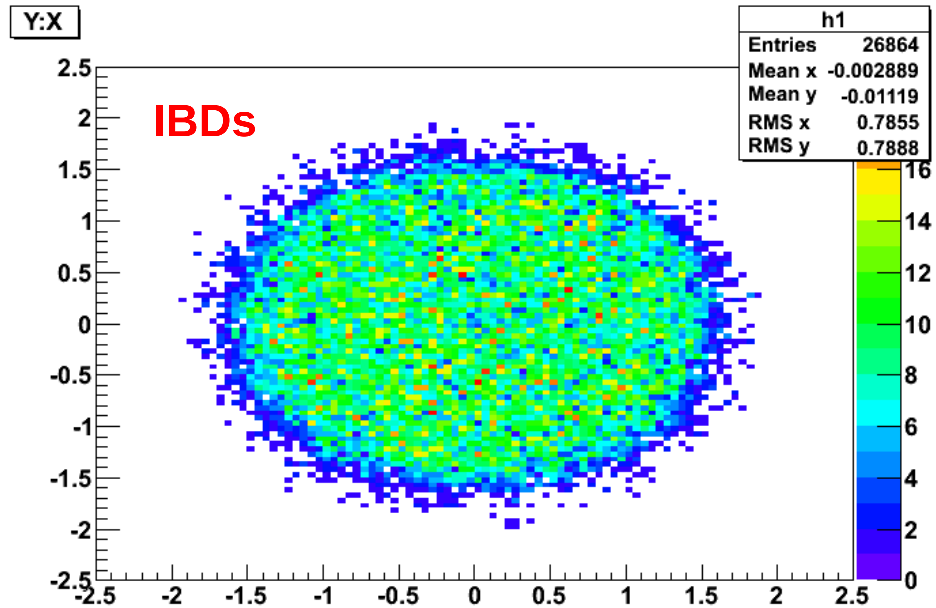
n inelastic scattering + n capture:

- contribute to correlated bkg.



Far site ADs Y vs X for delayed candidates



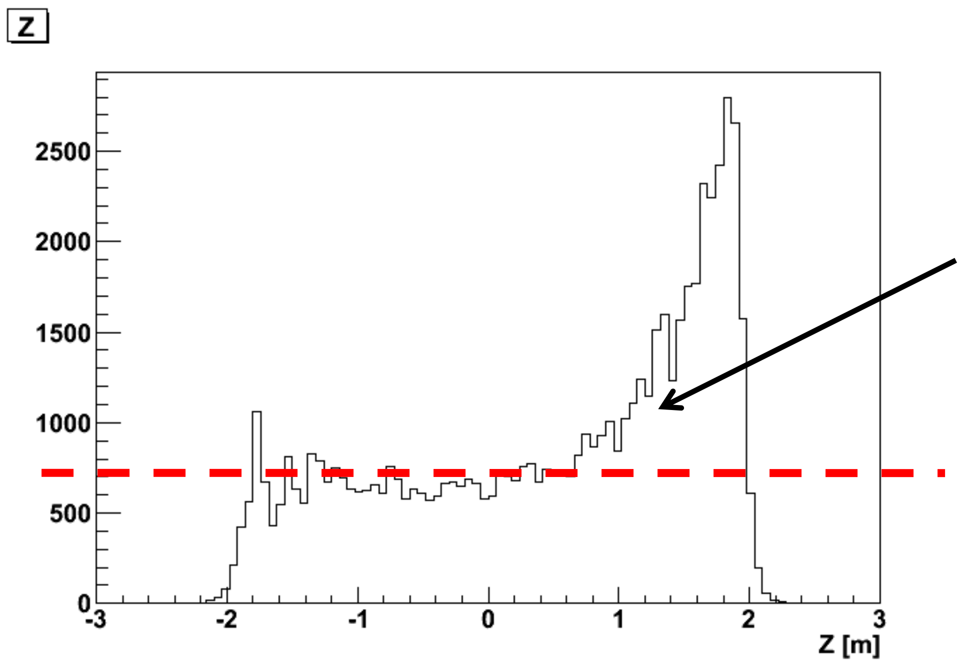


Singles with E_d>6 MeV
in top half of AD

IBD candidates
(prompt, delayed pairs)

ACUs

Am-C background rate



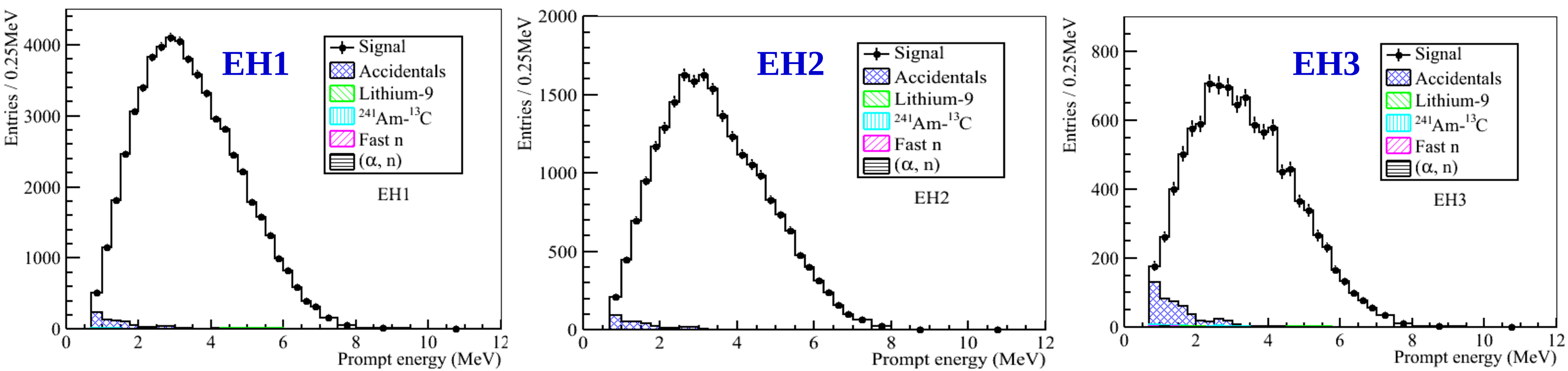
Z [m]

- Measured single neutron background due to AmC ~ 230±40 /day/module
- Agrees well with Monte Carlo prediction 285 /day/module

Estimate ratio of correlated/uncorrelated rate using Monte Carlo, which predicts a 0.2/day/module correlated background from AmC source (we take it with 100% uncertainty)

Summary of Backgrounds

Background	Near	Far	Fractional Accuracy (%)
Accidental	~1.4 %	~4.5 %	<1%
Fast Neutrons	~0.1%	~0.06%	<100%
$^{8}He/^{9}Li$	~0.4%	~0.2%	<70%
Am-C	~0.03%	~0.3%	100%
(α-n)	~0.01%	~0.04%	<70%



谢谢！