Production Yield of Muon-induced Radioactive Isotopes

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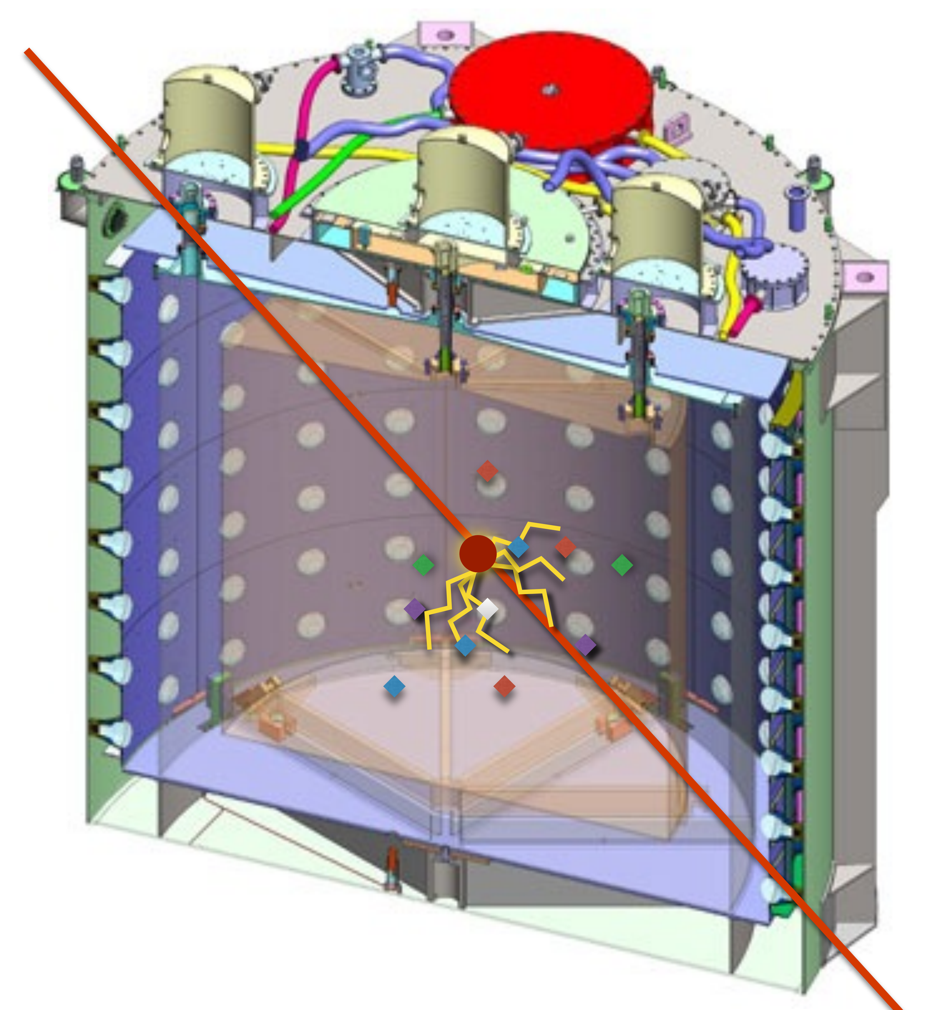
Cosmic-ray muon-induced radioactive isotopes are common backgrounds to rare-event experiments, such as neutrino oscillation experiments, double beta-decay experiments and dark matter searches. We present data selection criteria and fitting method on the production yields of muon induced radioactive isotopes.



A muon passing through an anti-neutrino detector generating radioactive isotopes

	C	H	O	N	Gd
Gd-LS	87.22%	11.77%	0.91%	0.02%	0.1%
LS	87.36%	11.79%	0.85%	0.02%	

Composition of Gd-doped liquid scintillator in the Daya Bay antineutrino detectors

	Overburden	R_μ	E_μ
EH1	250	1.27	57
EH2	265	0.95	58
EH3	860	0.056	137

Vertical overburden (m.w.e.), muon rate R_μ (Hz/m^2), and average muon energy E_μ (GeV) of the three Ehs.

Isotope	^{12}B	^{12}N	^{9}Li	^{8}He	^{9}C
Half-life	20.2ms	11ms	178.3ms	119.0ms	126.5ms
Q Value(MeV)	13.37	17.34	13.61	10.65	16.5
Isotope	**^{8}Li**	**^{8}B**	**^{11}C**	**^{10}C**	**^{11}Be**
Half-life	838ms	770ms	20.39ms	19.255s	13.81s
Q Value(MeV)	16	17.98	1.98	3.648	11.51

Some isotopes resulting from muon spallation and their half lives

Radioactive Isotopes Selection Criteria

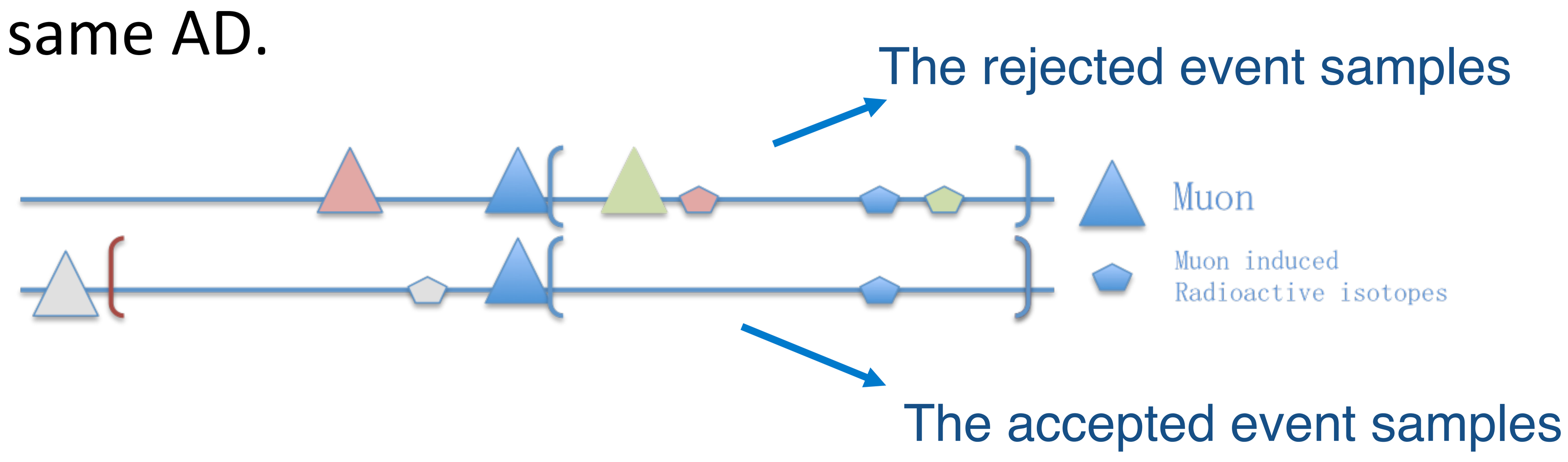
Flasher cut

Water pool Muon veto:

Water pool muon veto time window is (-20 μs, 200 μs) from any IWS or OWS muon trigger time.

Muon Isolation cut

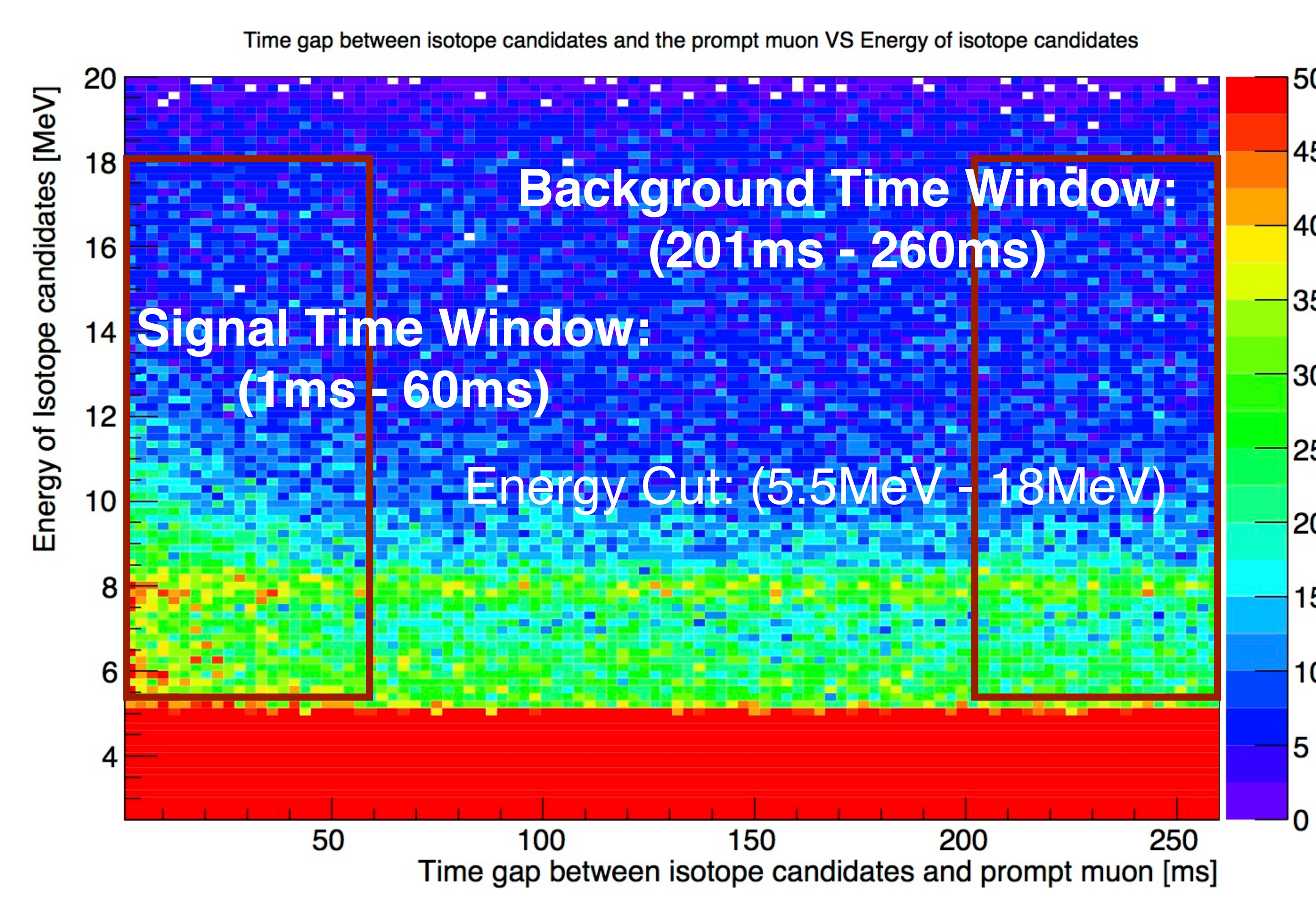
No other trigger muon existed in the time window (-260ms, 260ms) from current trigger muon time in the same AD.



Vertex cut: |x+y|<2.0 m and |z|<2.0 m

To ensure no energy escape at the edge of our detector

Muon AD energy cut: E > 20 MeV



Energy-Time Gap 2D Fit and the Production Yield Calculation

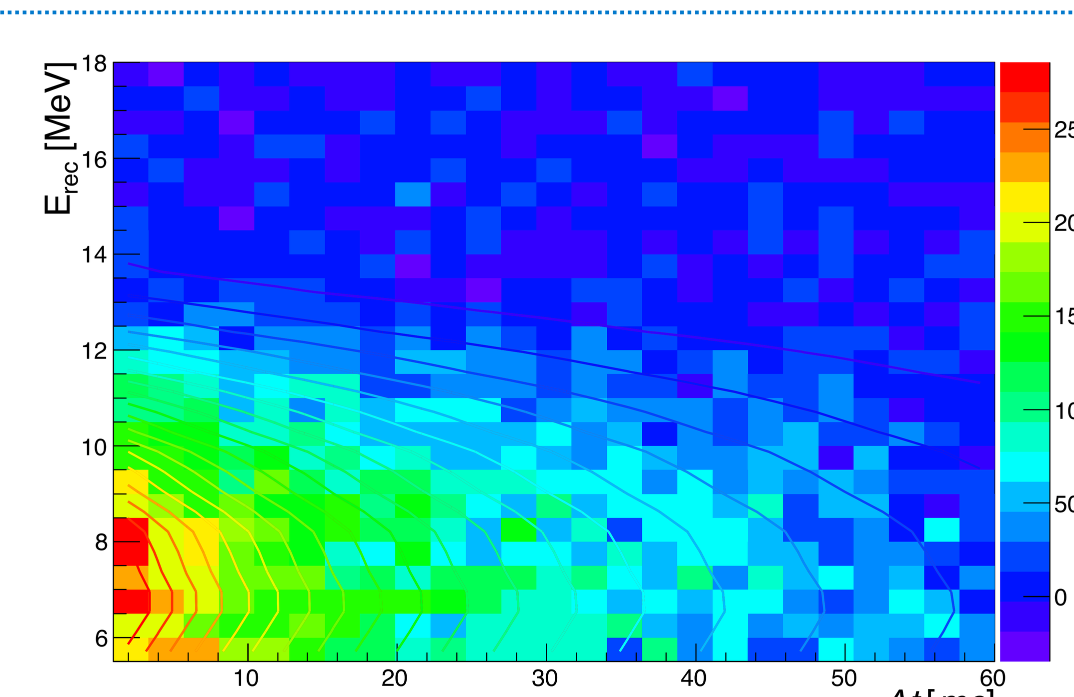
$$P(E,\Delta t)=\sum_m N_m\cdot f_m(\Delta t)\cdot g_m(E)+R_{bkg}$$

$$=\sum_m N_m\cdot \varepsilon_m\cdot\left(\frac{1}{\tau_m}\cdot e^{-\Delta t/\tau_m}\right)\cdot g_m(E)+R_{bkg}$$

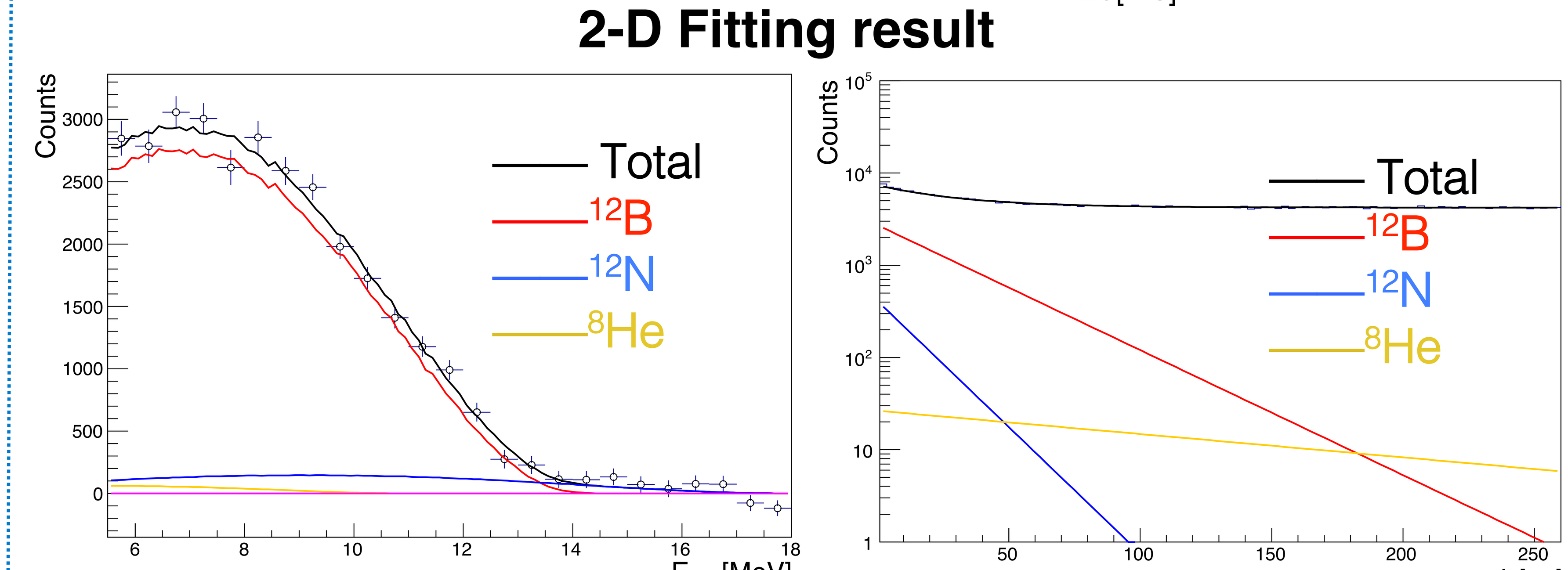
$$\varepsilon_m=\varepsilon_{veto}\cdot\varepsilon_{bkgsub}\cdot\varepsilon_{flasher}$$

$$Y_{m/\mu}=\frac{N_m}{N_\mu\cdot\rho\cdot\langle L_\mu\rangle}$$

- N_m : the true number of isotope decays
- τ_m : the lifetime of isotope being fitted
- ε_m : the total efficiency
- g_m : the pdf of energy spectrum
- R_{bkg} : the uncorrelated background rate
- N_μ : prompt muon number
- ε_{bgsub} : background subtraction efficiency
- ε_{veto} : water pool muon veto efficiency
- $\varepsilon_{flasher}$: flasher cut efficiency
- $\langle L_\mu\rangle$: muon track lenth
- ρ : density of LS



2-D Fitting result



Comparison between fitting result and the selected data

	^{12}B	^{12}N	^{9}Li	^{8}He	^{9}C
Simulation true value	8.70E+07	3.48E+06	2.61E+06	5.22E+6	1.74E+6
Fitting result	8.68E+07	3.49E+06	2.00E+06	5.74E+6	1.66E+6

The comparison between toy MC true value and fitting result to cross check our 2-D fitting method

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