Muon-induced backgrounds for MeV neutrinos

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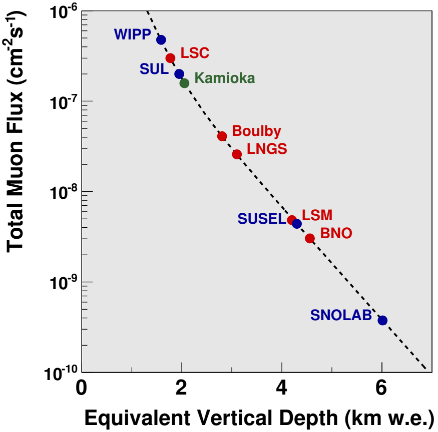
2015 IPA

Cosmic-ray muons produce low-energy backgrounds

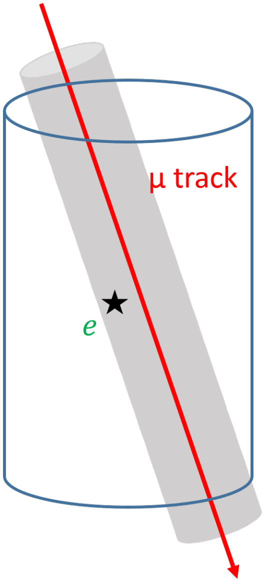
- Cosmic-ray muons are high-energy events
- Muons penetrate rock, interacting with detecting/detector material
- Muons themselves can easily be detected and vetoed
- Muons make **beta-decay isotopes**, and **neutrons**
- keV-MeV experiments, neutrino, dark matter, $\nu 0\beta\beta$, etc



Gomez-Cadenas *et al.*, 2012

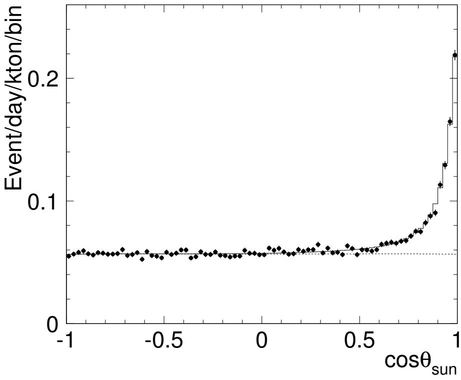
What are spallation backgrounds?

- $\mu + X \to \mu + X'$,
  $X' \to \boldsymbol{e} +$ others
- MeV neutrino detection,
  $\nu + e \to \nu + \boldsymbol{e}$
- The competition is between X' lifetimes and muon rate
- Most isotopes have lifetimes $\sim$ seconds to minutes
- Muon rate: Super-K 0.5 Hz, SNO 3 per hour



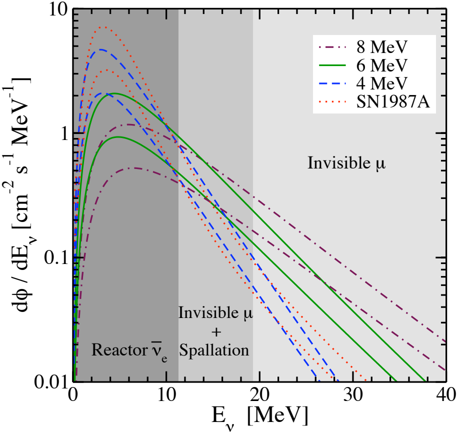
Why spallation backgrounds? Why Super-K?

Solar neutrino



Abe *et al.* (Super-K Collaboration), 2011

DSNB

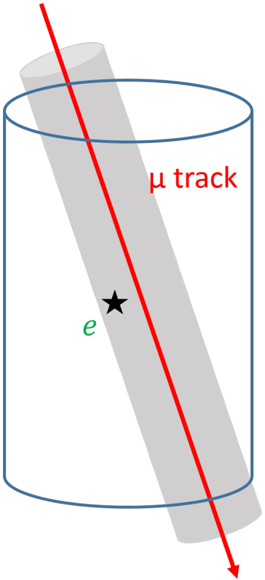


Horiuchi *et al.*, 2009

Super-K spallation cuts

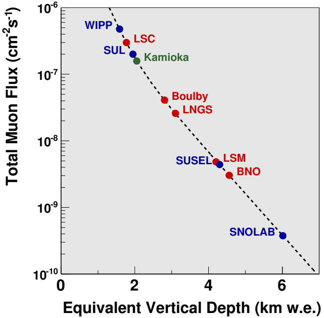
Super-K cuts

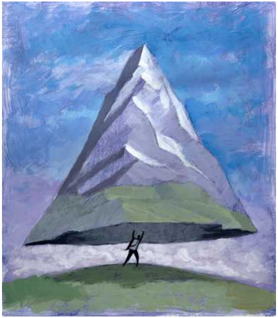
- Empirically developed
- Cylinder cut around muon track (a few meters and a few seconds)
- Likelihood function of ΔL, Δt, and muon energy loss



Our goal

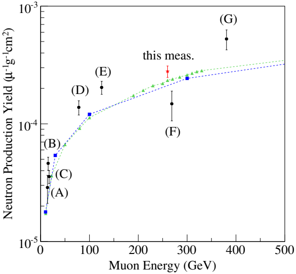
- Model the background production theoretically
- Understand the production features of these spallations
- Find better ways to reject them





Other studies

- No such studies in water
- Lots of works on neutron production, $\sim 30\%$ uncertainties
- Several studies on theory simulation vs. experimental measurement in scintillator detectors ($\mu + ^{12}$C)
- Effort from theory side on improving these calculations

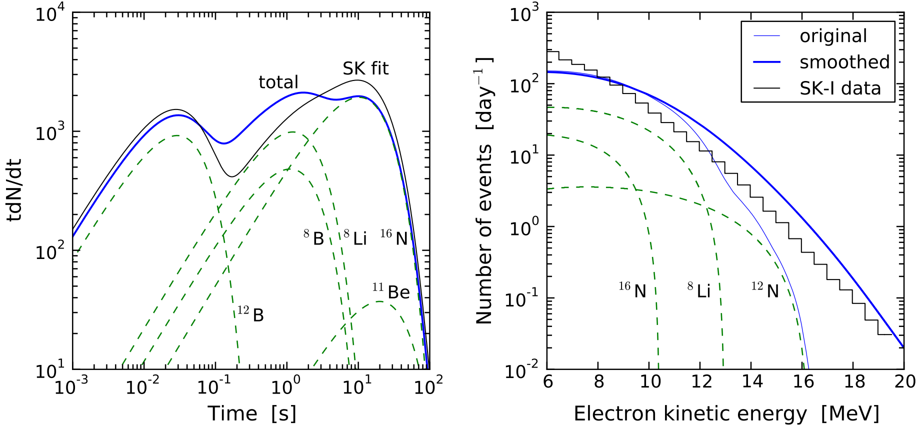


Abe *et al.* (KamLAND Collaboration), 2010

	GEANT4 Model III	GEANT4 Model IV	FLUKA	Borexino	KamLAND
	— $\langle E_\mu \rangle = 283 \pm 19$ GeV —				$\langle E_\mu \rangle = 260 \pm 8$ GeV
Isotopes	Yield $[10^{-7} (\mu\, g/cm^2)^{-1}]$				
^{12}N	1.11 ± 0.13	3.0 ± 0.2	0.5 ± 0.2	< 1.1	1.8 ± 0.4
^{12}B	30.1 ± 0.7	29.7 ± 0.7	28.8 ± 1.9	56 ± 3	42.9 ± 3.3
^{8}He	< 0.04	0.18 ± 0.05	0.30 ± 0.15	< 1.5	0.7 ± 0.4
^{9}Li	0.6 ± 0.1	1.68 ± 0.16	3.1 ± 0.4	2.9 ± 0.3	2.2 ± 0.2
^{8}B	0.52 ± 0.09	1.44 ± 0.15	6.6 ± 0.6	14 ± 6	8.4 ± 2.4
^{6}He	18.5 ± 0.5	8.9 ± 0.4	17.3 ± 1.1	38 ± 15	not reported
^{8}Li	27.7 ± 0.7	7.8 ± 0.4	28.8 ± 1.0	7 ± 7	12.2 ± 2.6
^{9}C	0.16 ± 0.05	0.99 ± 0.13	0.91 ± 0.10	< 16	3.0 ± 1.2
^{11}Be	0.24 ± 0.06	0.45 ± 0.09	0.59 ± 0.12	< 7.0	1.1 ± 0.2
^{10}C	15.0 ± 0.5	41.1 ± 0.8	14.1 ± 0.7	18 ± 5	16.5 ± 1.9
^{11}C	315 ± 2	415 ± 3	467 ± 23	886 ± 115	866 ± 153
Neutrons	Yield $[10^{-4} (\mu\, g/cm^2)^{-1}]$				
	3.01 ± 0.05	2.99 ± 0.03	2.46 ± 0.12	3.10 ± 0.11	2.79 ± 0.31

Bellini *et al.* (Borexino Collaboration), 2013

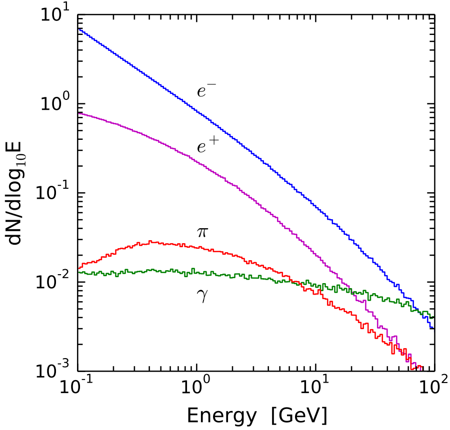
Our calculation of the backgrounds



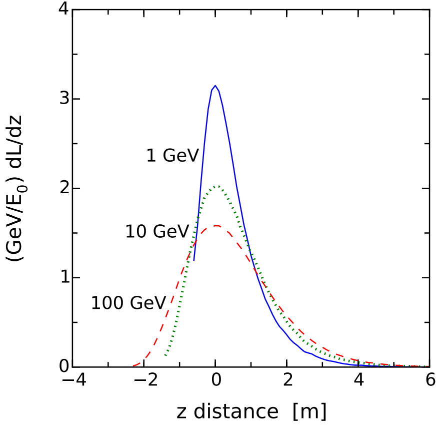
Li and Beacom, 2014

Isotopes are made by secondary particles.

Muons make bursts of showers

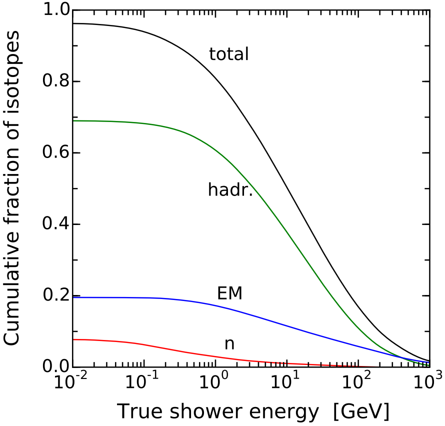


Li and Beacom, 2015

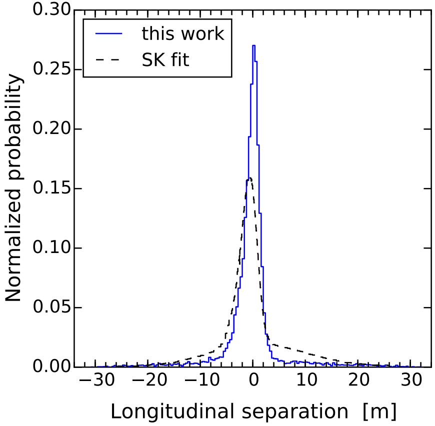


Li and Beacom, 2015

Spallations are made in these showers

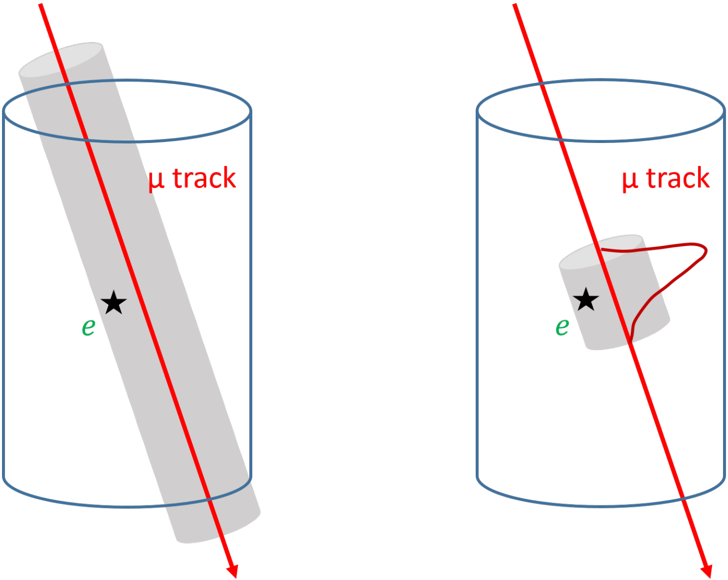


Li and Beacom, 2015



Li and Beacom, 2015

A new way to tag these backgrounds!



Conclusion

- Muon-made spallation backgrounds are important
- Theoretical calculations of spallation are possible
- Spallations are made in showers
- Showers can tag background
- arXiv: 1402.4687, 1503.04823