First calculation of cosmic-ray muon spallation backgrounds for MeV astrophysical neutrino signals in Super-Kamiokande

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Neutrino astrophysics opportunities in 6-30 MeV

Solar day-night effect

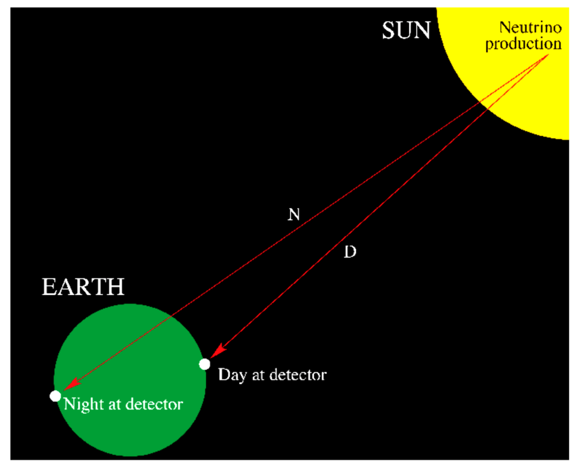


Figure taken from M. Blennow talk[1]

Diffuse supernova neutrino background

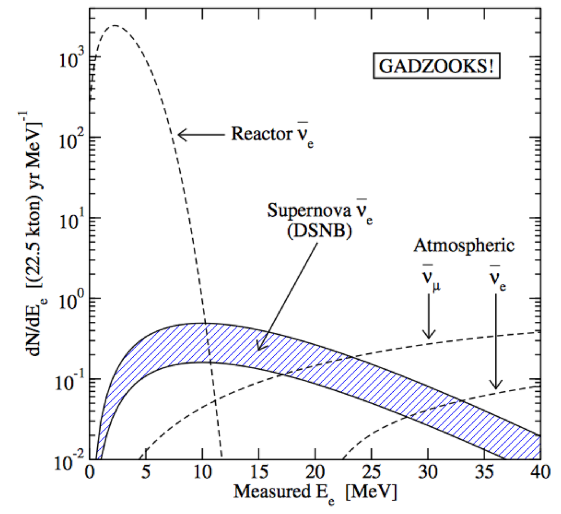


Figure taken from Beacom and Vagins[2]

Spallation backgrounds are overwhelming

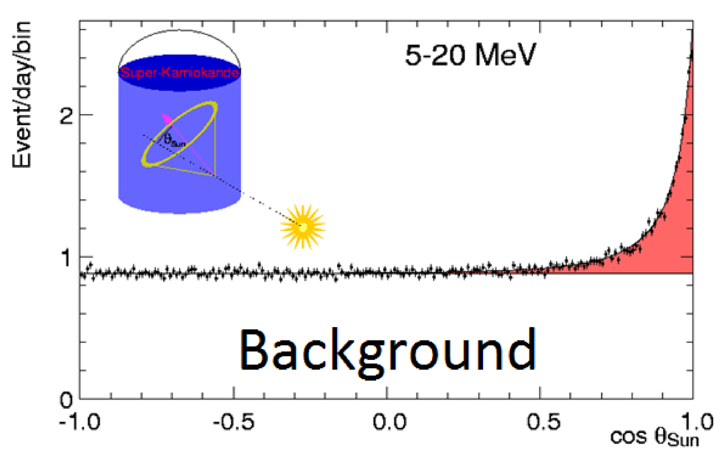


Figure taken from Super-K website[3]

Signal: $\nu + e \rightarrow \nu + e$

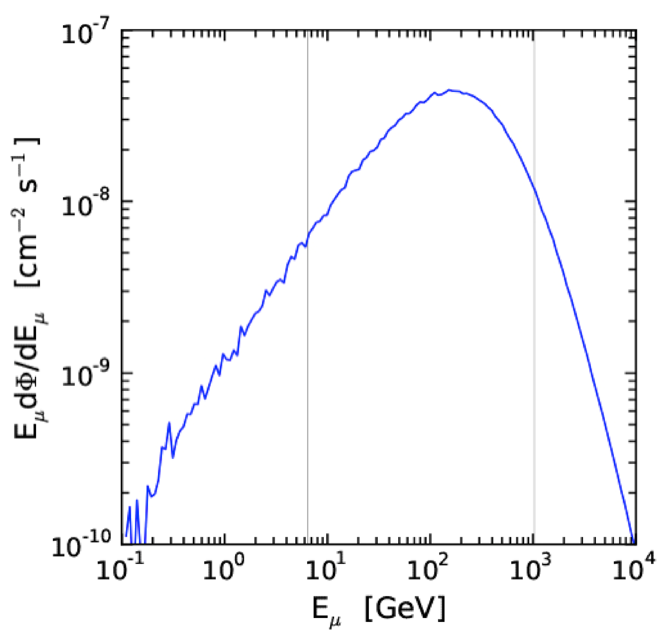
Background:

Muons break nuclei,
Nuclei beta decay.

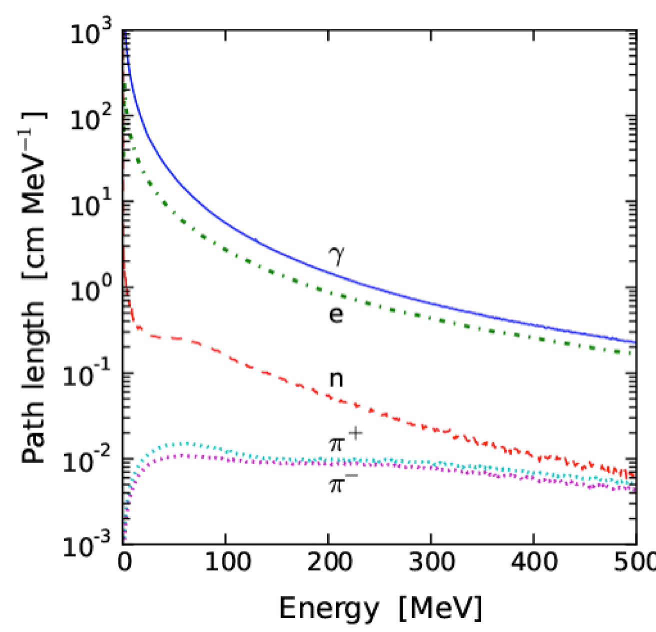
Above 6 MeV, the backgrounds are dominated by cosmic-ray muon induced spallation.

Cosmic-ray muons lose energy and produce secondaries

The average muon energy in Super-K is 270 GeV.



Muons make lots of secondary particles through pair production, bremsstrahlung, ionization, and photonuclear interaction.



Secondary particles make spallation isotopes

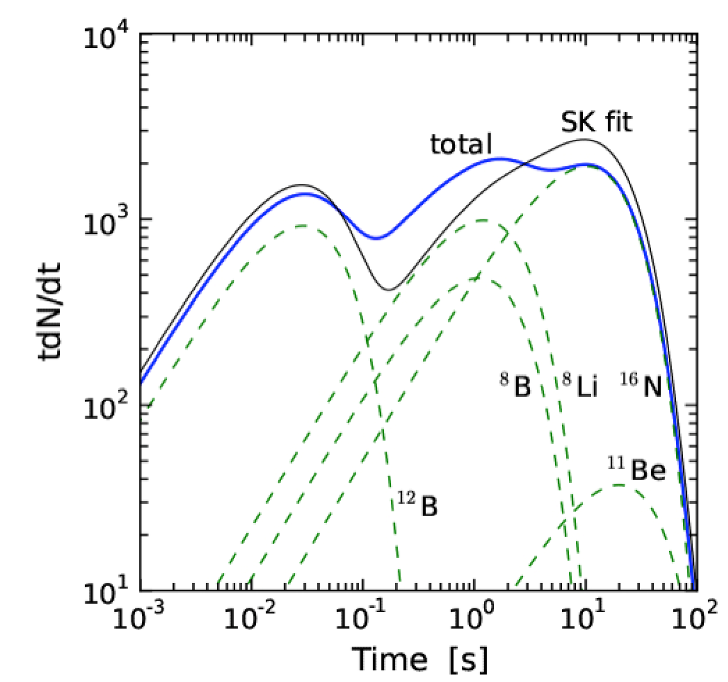
We calculated the isotope yields using FLUKA

Calculated isotope yields

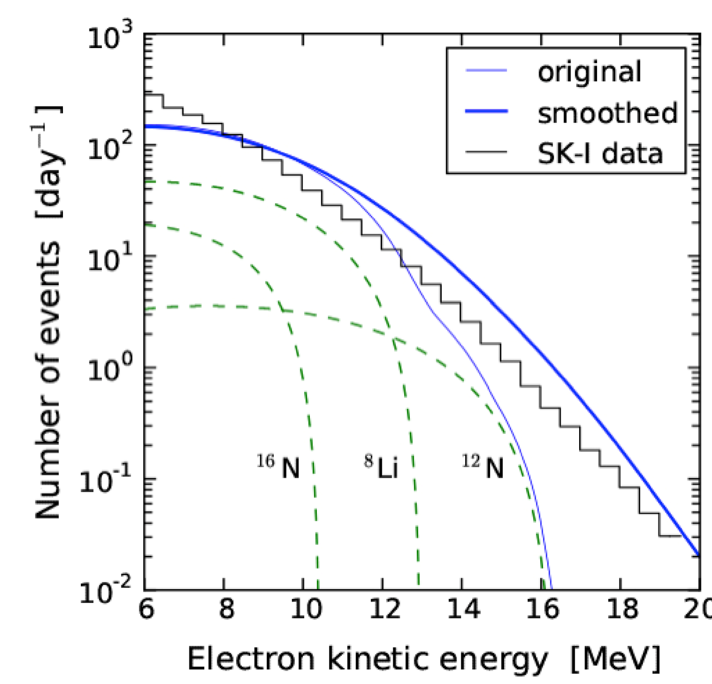
Isotope	Half-life (s)	Decay mode	Yield (total) $(\times 10^{-7} \mu^{-1} g^{-1} cm^2)$	Primary process
n			2030	
^{16}N	7.13	$\beta^- \gamma$ (66%), β^- (28%)	18	(n,p)
^{15}C	2.449	$\beta^- \gamma$ (63%), β^- (37%)	0.82	(n,2p)
^{13}B	0.0174	β^-	1.9	(π^-,2p+n)
^{12}B	0.0202	β^-	12	(n,α+p)
^{11}Be	13.8	β^- (55%), $\beta^- \gamma$ (31%)	0.81	(n,α+2p)
^{11}Li	0.0085	$\beta^- n$	0.01	(π^+,5p+π^++π^0)
^{9}C	0.127	β^+	0.89	(n,α+4n)
^{9}Li	0.178	$\beta^- n$ (51%), β^- (49%)	1.9	(π^-,α+2p+n)
^{8}B	0.77	β^+	5.8	(π^+,α+2p+2n)
^{8}Li	0.838	β^-	13	(π^-,α+^{2}H+p+n)
^{8}He	0.119	$\beta^- \gamma$ (84%), $\beta^- n$ (16%)	0.23	(π^-,^{3}H+4p+n)
^{15}O			351	(γ,n)
^{15}N			773	(γ,p)
^{14}O			13	(n,3n)
^{14}N			295	(γ,n+p)
^{14}C			64	(n,n+2p)
^{13}N			19	(γ,^{3}H)
sum			3015	

Yields compared to Super-K measurements

Good agreement with spallation background time distribution.



Good agreement with spallation background energy spectrum.

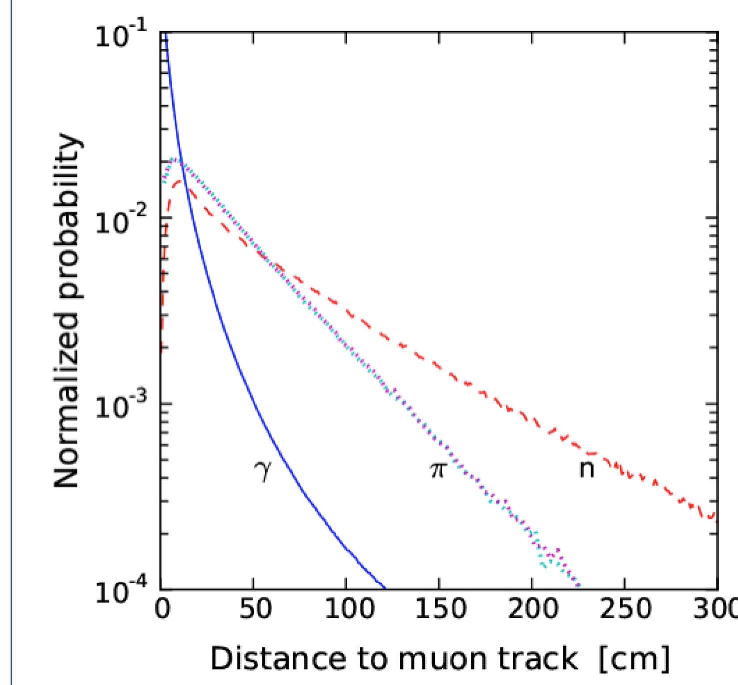


The fact that our results match BOTH the time and energy distributions is a powerful indication that they are accurate.

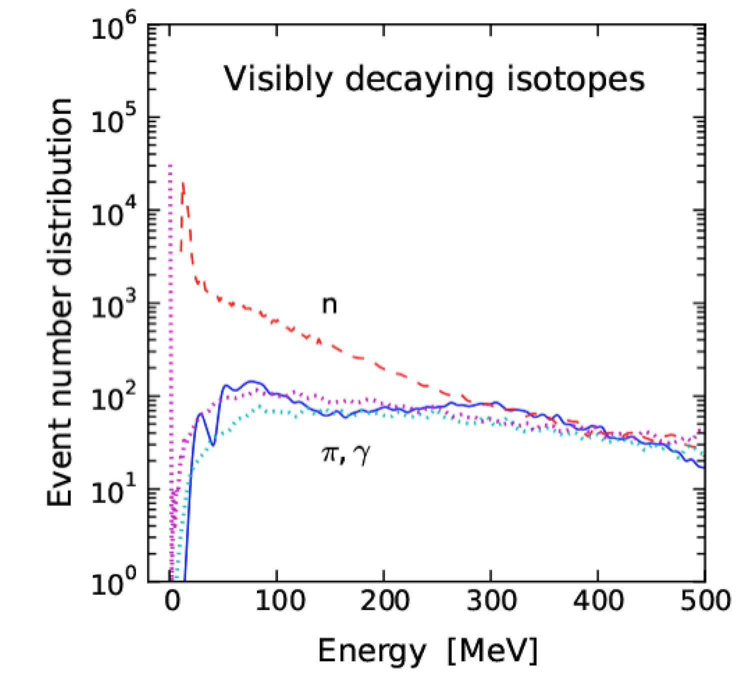
Time distribution: tests the relative yields among isotopes.
Energy spectrum: tests the overall normalization.

Different isotopes are made by different secondaries

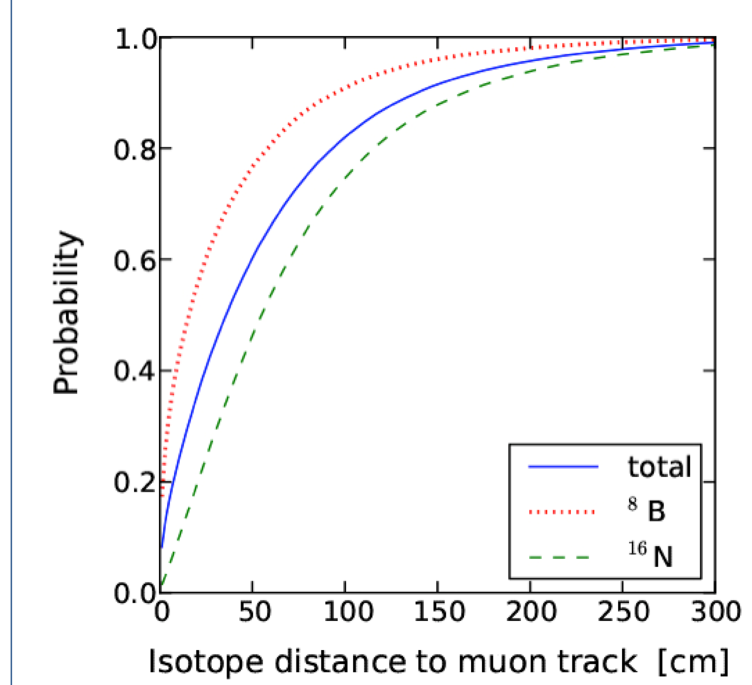
The secondaries reach different distances.



The secondaries interact at different energies.



Because different isotopes are made by different secondary particles, they have different distance distributions.



^{8}B is dominant at higher energies, and is primarily made by pions.

^{16}N is dominant at lower energies, and is primarily made by neutrons.

They differ by a factor of 1.7 in radius, which is a factor of 3 in cylindrical volume, which affects cut efficiency.

Conclusions

We demonstrated that a theoretical calculation of spallation is possible, with an accuracy of a factor of 2, while the yields vary by orders of magnitude.

There are correlations among secondary particles and isotopes, and among different isotopes. Using this information can lead to stronger cuts.

There is more information to be gained by separating each isotope, instead of combining all of them together.

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References

1. M. Blennow, "The homepage of Mattias Blennow", http://theophys.kth.se/~mbl/daynight.pdf, [Online; accessed 2014-05-16].
2. J. F. Beacom and M. R. Vagins, Phys. Rev. Lett. **93**, 171101 (2004).
3. Super-Kamiokande 10 day plot data as of December 2002; Super-Kamiokande collaboration, Phys. Rev. Lett. **86**, 5651 (2001); Phys. Lett. B **539**, 179 (2002).
4. S. W. Li and J. F. Beacom, Phys. Rev. C **89**, 045801 (2014) [arXiv:1402.4687].