Developing the MeV Potential of DUNE: What are the Backgrounds?

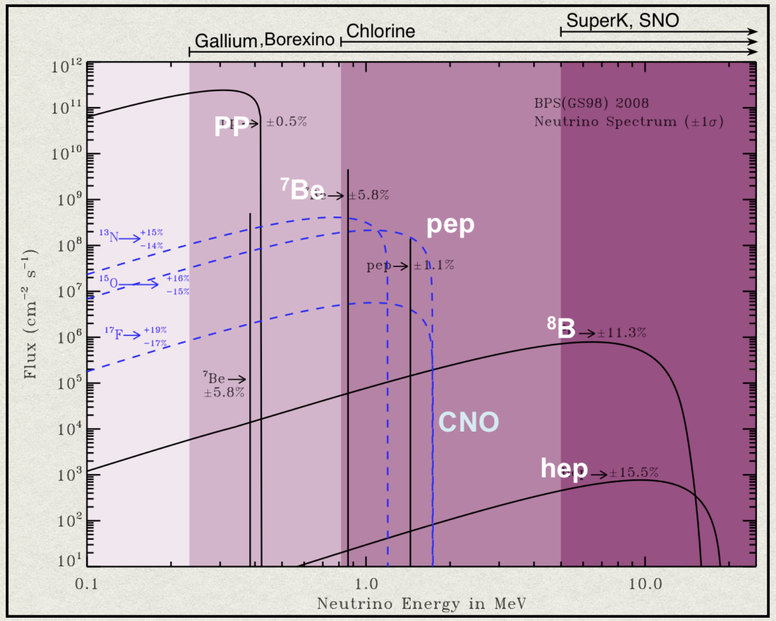
Guanying Zhu

[arXiv: 1808.08232] F. Capozzi, S. Li, G. Zhu, J. Beacom, "DUNE as the Next-Generation Solar Neutrino Experiment"
[arXiv: 1811.07912] G. Zhu, S. Li, J. Beacom, "Developing the MeV Potential of DUNE: Detailed Considerations of Muon-Induced Spallation Backgrounds and More"

THE OHIO STATE UNIVERSITY

MeV astrophysical neutrinos

Solar neutrinos



arXiv: 1211.5359

Supernova neutrinos

Anglo-Australian Observatory

DSNB

$$\frac{d\phi}{dE_\nu}(E_\nu) = \int_0^\infty [(1+z)\varphi[E_\nu(1+z)]]\,[R_{SN}(z)]\left[\left|\frac{c\,dt}{dz}\right| dz\right].$$

Spectrum per SN

SN rate

Space volume

arXiv: 1004.3311

Our goal: understand detector backgrounds

Neutrino signals

- Elastic-scattering channel

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

- Charged-current channel

$$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^* \hookrightarrow \gamma$$

arXiv: 1810.06502

Demonstration of MeV-Scale Physics in Liquid Argon Time Projection Chambers Using ArgoNeuT 🎉

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(The ArgoNeuT Collaboration)

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MeV-scale energy depositions by low-energy photons produced in neutrino-argon interactions have been identified and reconstructed in ArgoNeuT liquid argon time projection chamber (LArTPC) data. ArgoNeuT data collected on the NuMI beam at Fermilab were analyzed to select isolated low-energy depositions in the TPC volume. The total number, reconstructed energies and positions of these depositions have been compared to those from simulations of neutrino-argon interactions using the FLUKA Monte Carlo generator. Measured features are consistent with energy depositions from photons produced by de-excitation of the neutrino's target nucleus and by inelastic scattering of primary neutrons produced by neutrino-argon interactions. This study represents a successful reconstruction of physics at the MeV-scale in a LArTPC, a capability of crucial importance for detection and reconstruction of supernova and solar neutrino interactions in future large LArTPCs.

Our goal: understand detector backgrounds

Neutrino signals

- Elastic-scattering channel

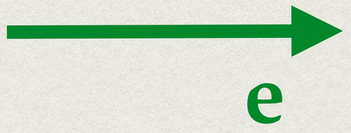
$$\nu_x + e^- \rightarrow \nu_x + e^-$$

- Charged-current channel

$$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$$

Backgrounds

(to be conservative)

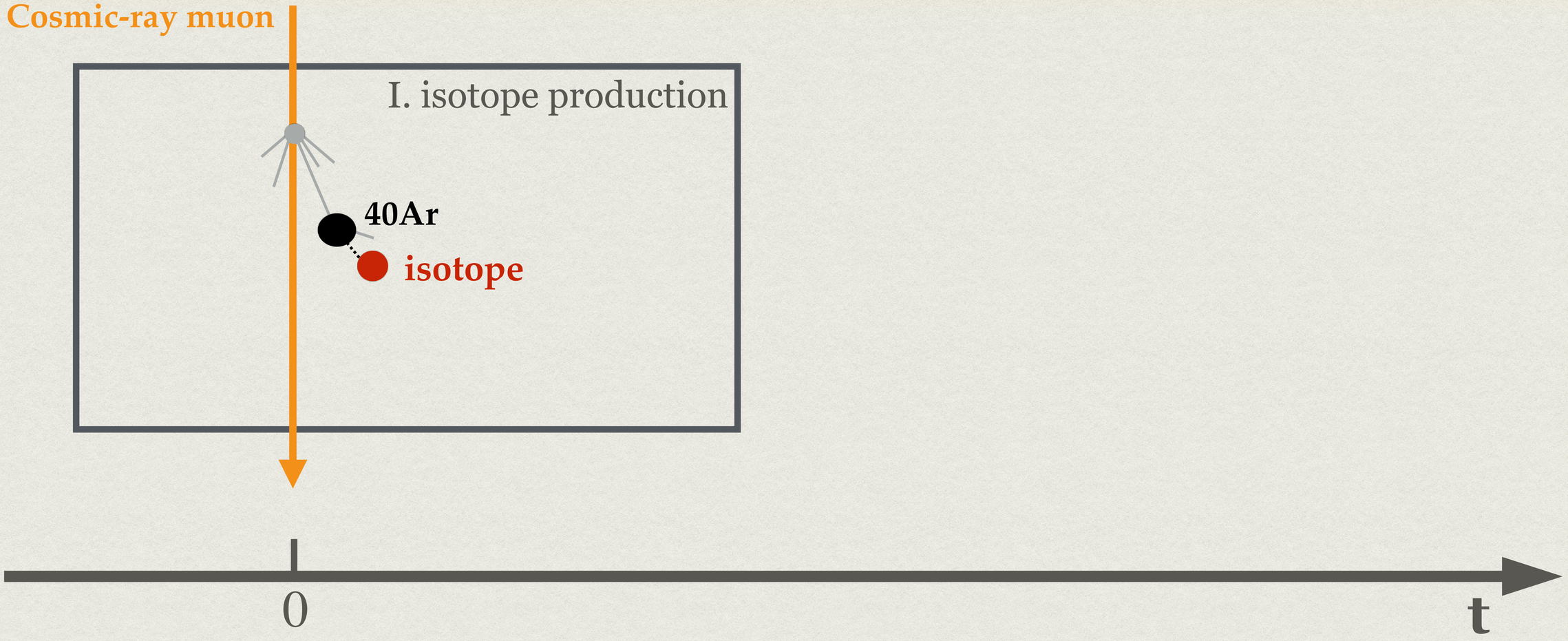


Outline

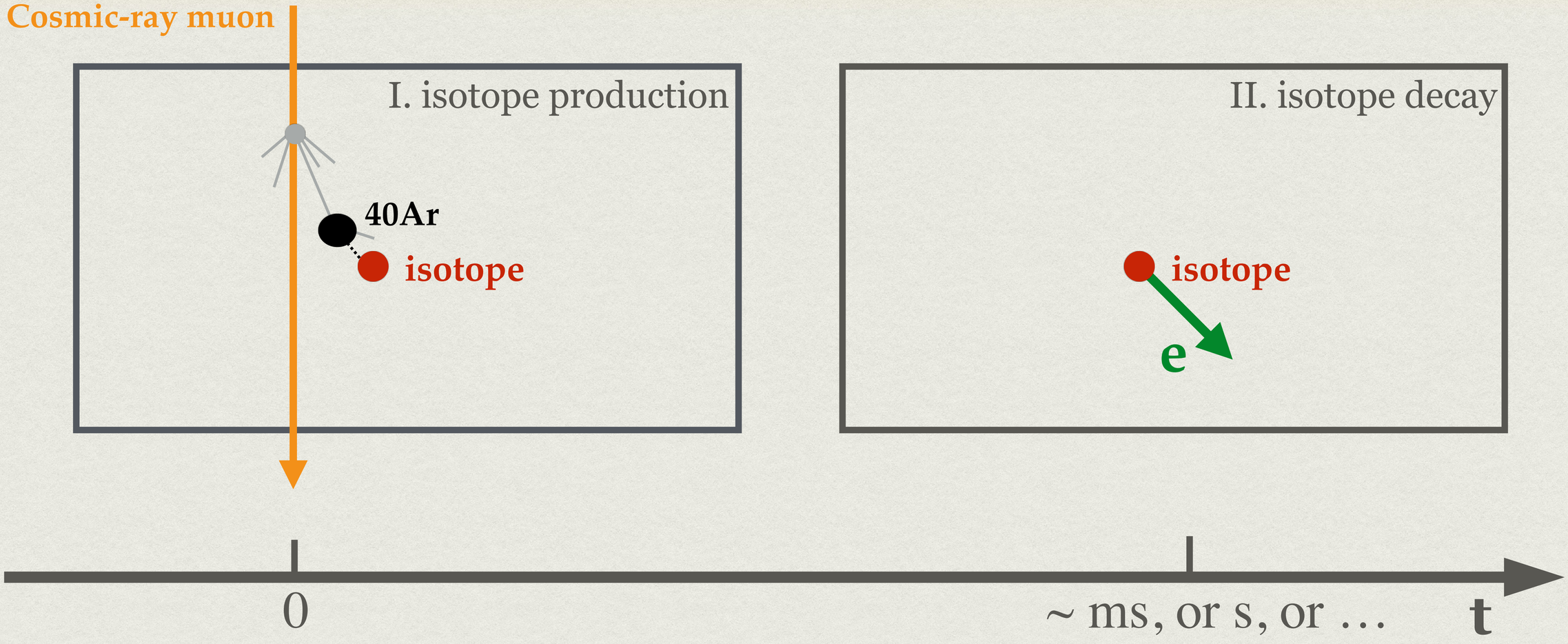
- Background I: Muon-induced spallation
- Background II: Neutron capture
- Background III: Sub-threshold events pileup

Background I: Muon-induced spallation

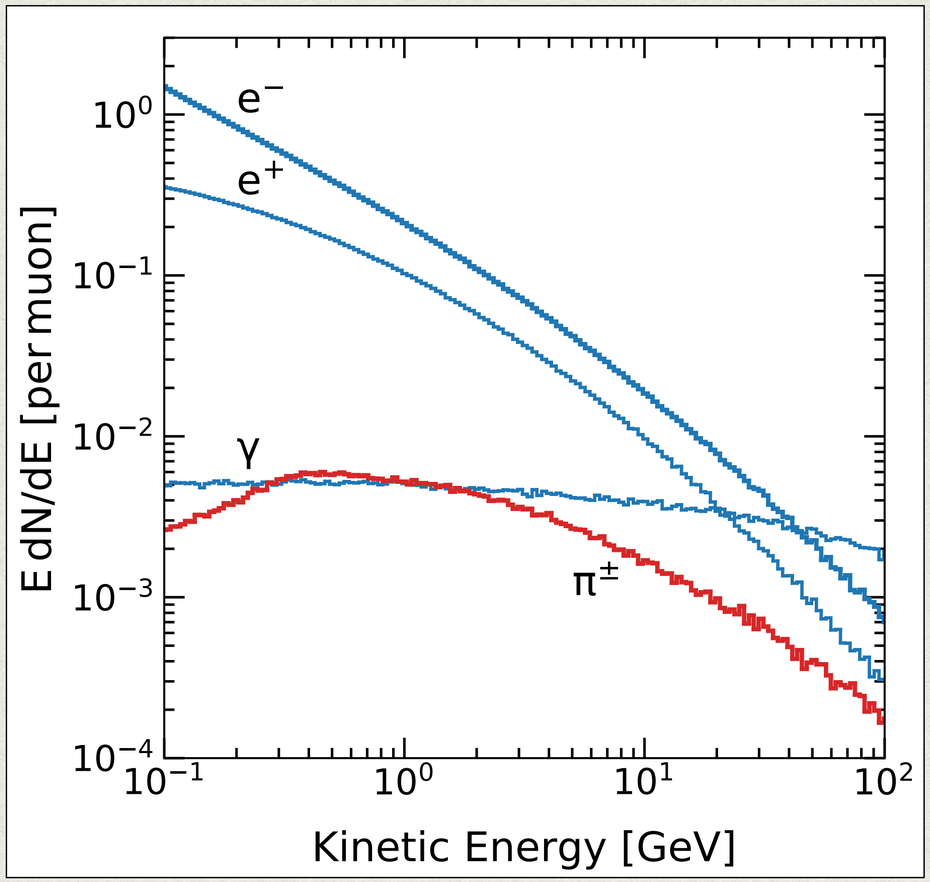
What are spallation backgrounds?



What are spallation backgrounds?



Muons → 1st-generation particles

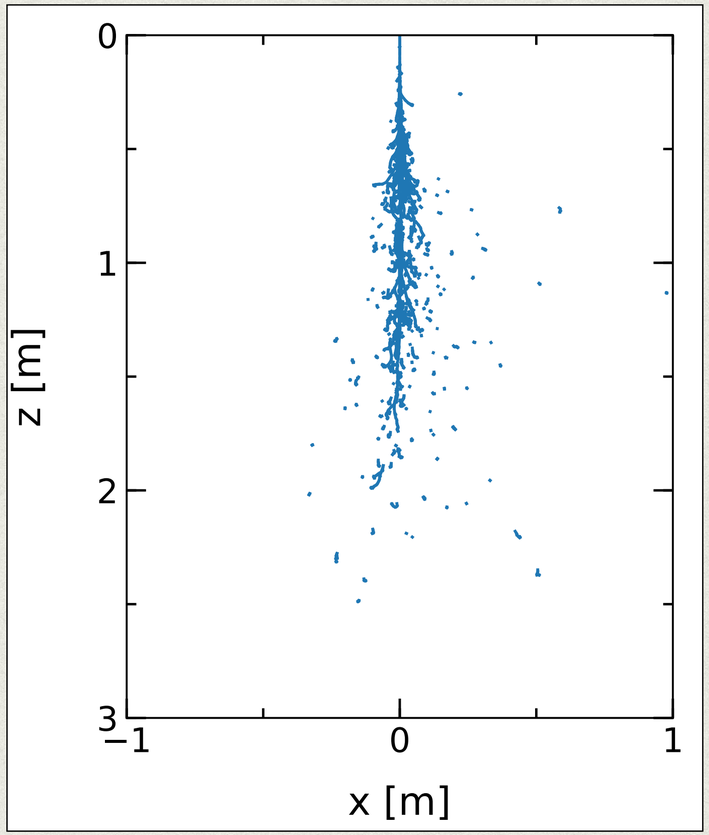


Muon energy loss

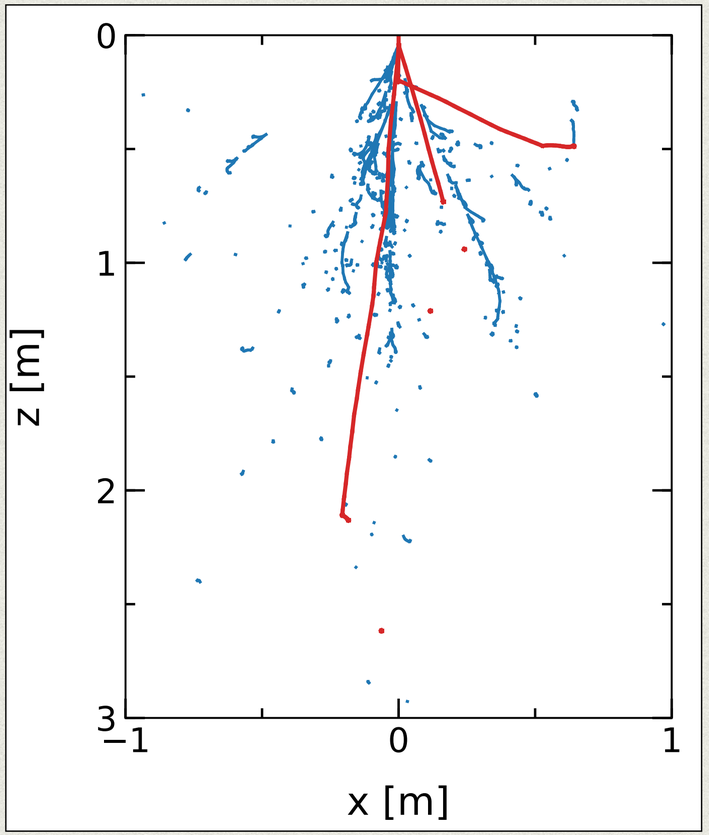
- Ionization: muon + atomic electrons
  - Restricted energy loss; Delta-ray
- Radiative process: muon + nuclei
  - Pair production
  - Bremsstrahlung
  - Photonuclear interactions

1st-generation particles → showers

5-GeV electron —> EM shower

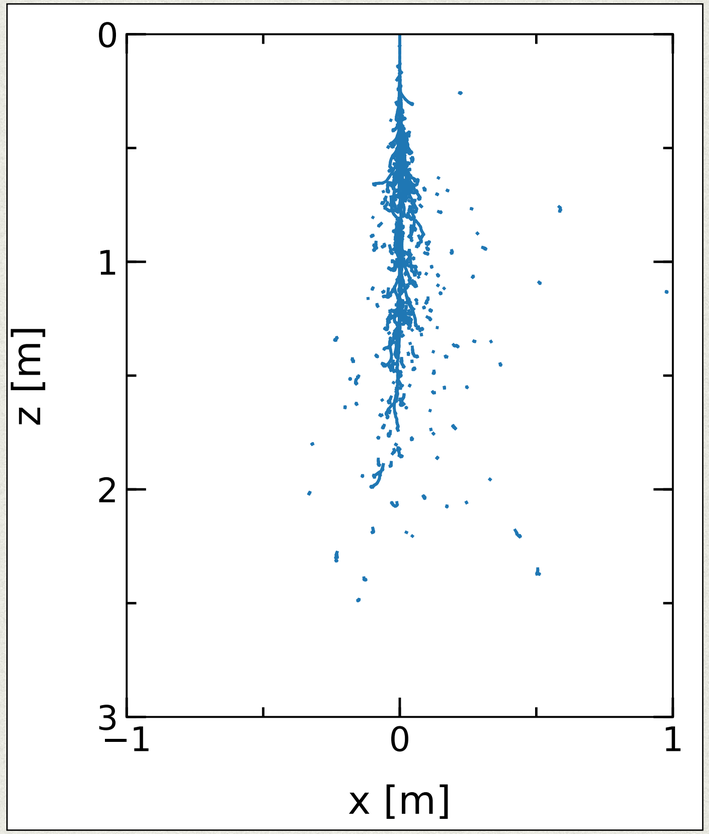


5-GeV pion —> hadronic shower

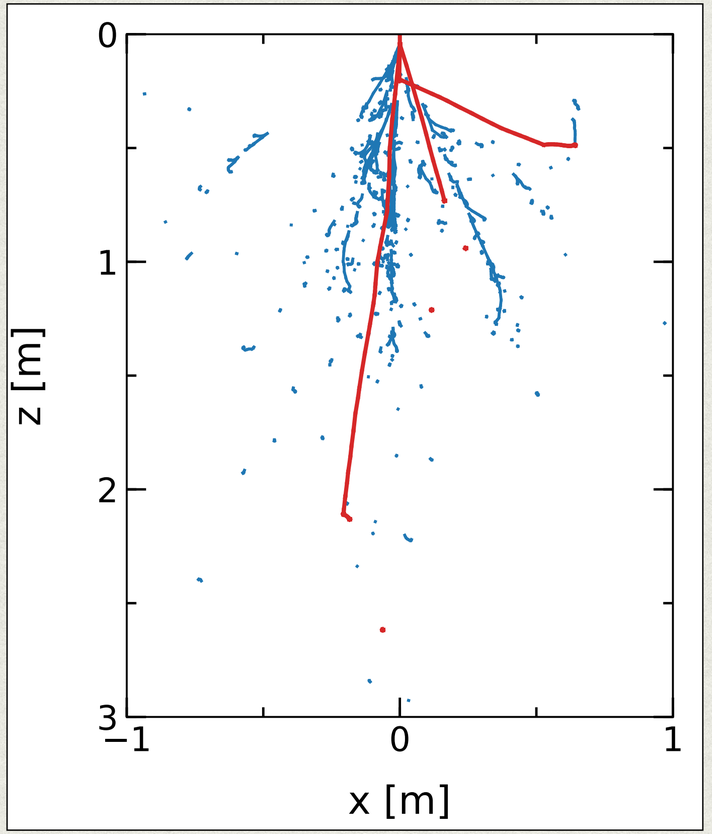


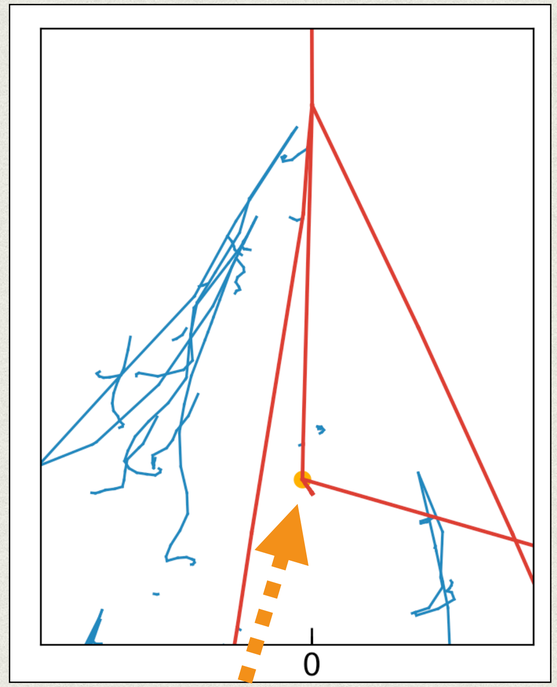
Isotopes @ showers

5-GeV electron —> EM shower



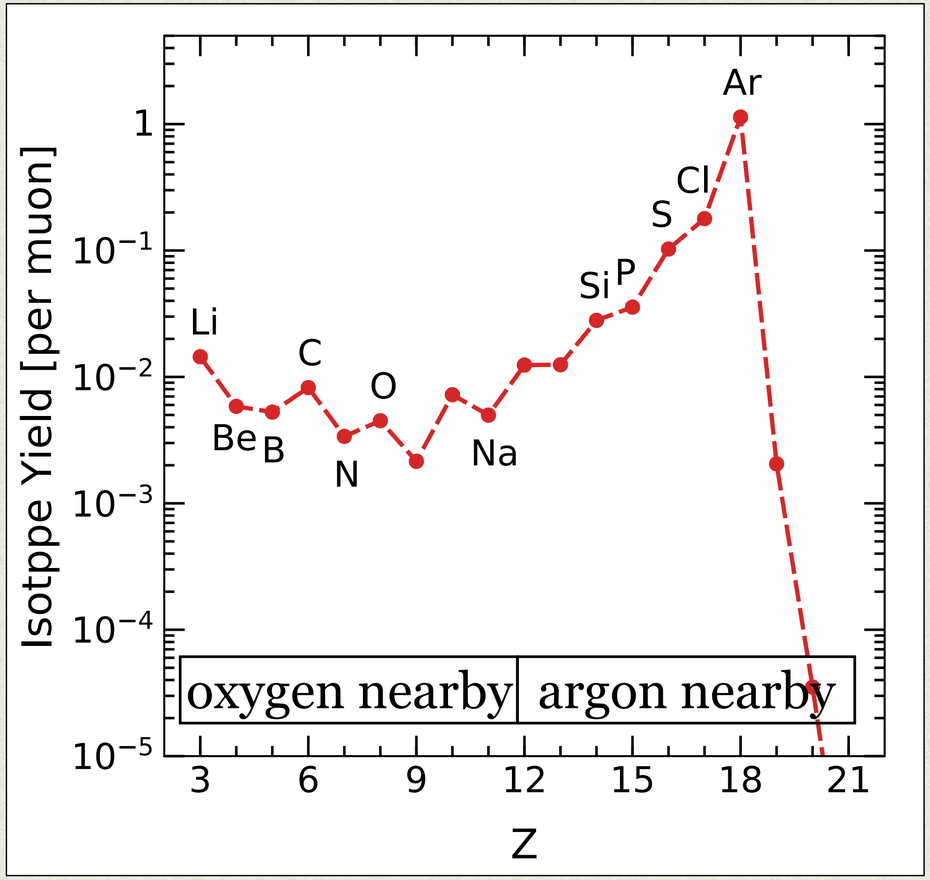
5-GeV pion —> hadronic shower





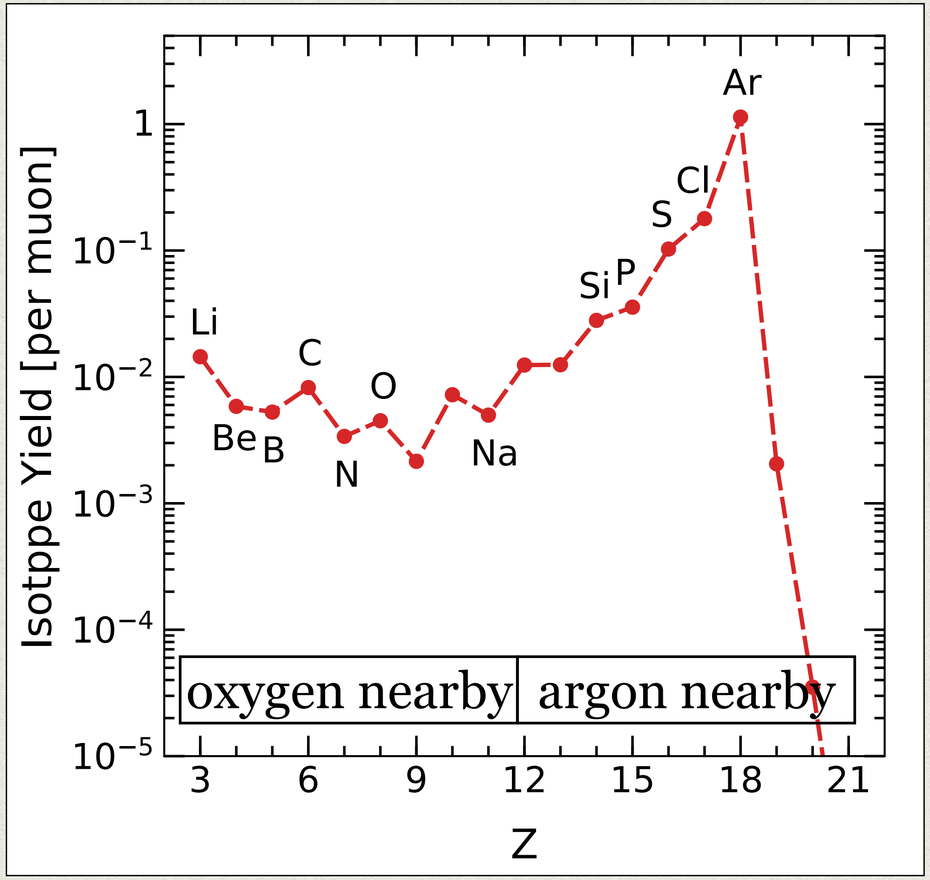
$^{40}Ar(\pi^+, \pi^+ p\, \pi^0 n)^{38}Cl$

Isotope production yields in DUNE



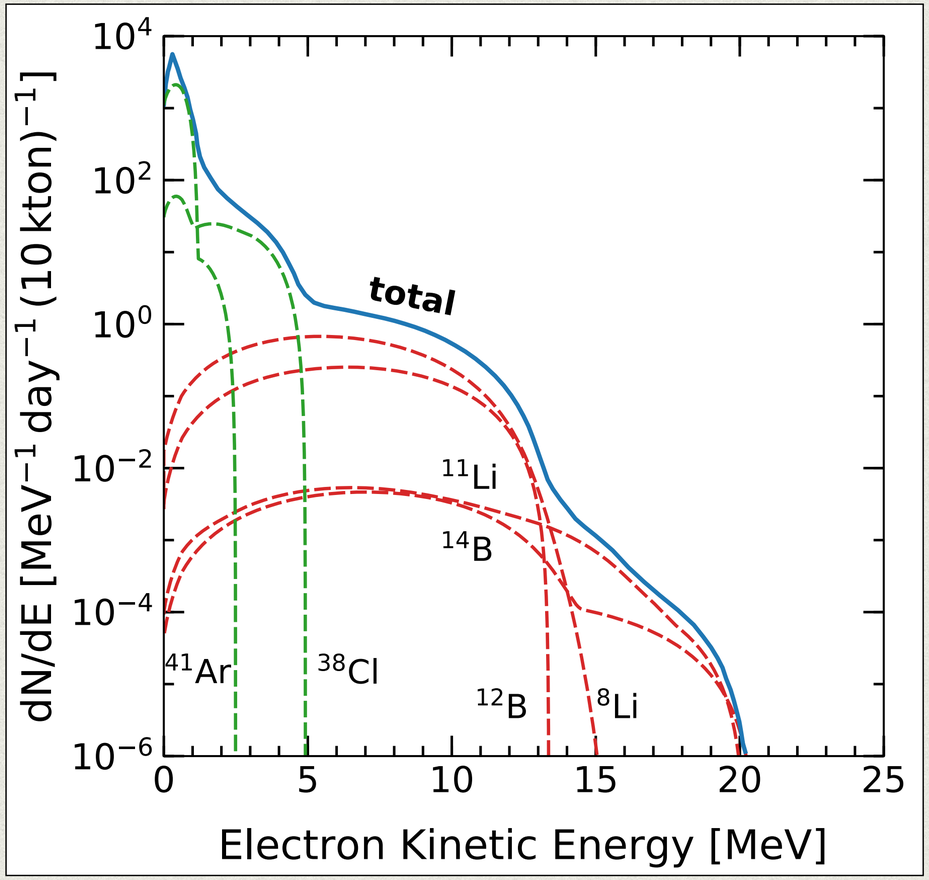
- Average isotope yield: 1.4 per muon
- 90% isotope yield: S, Cl, Ar
- Yield uncertainty: a factor of ~ 2

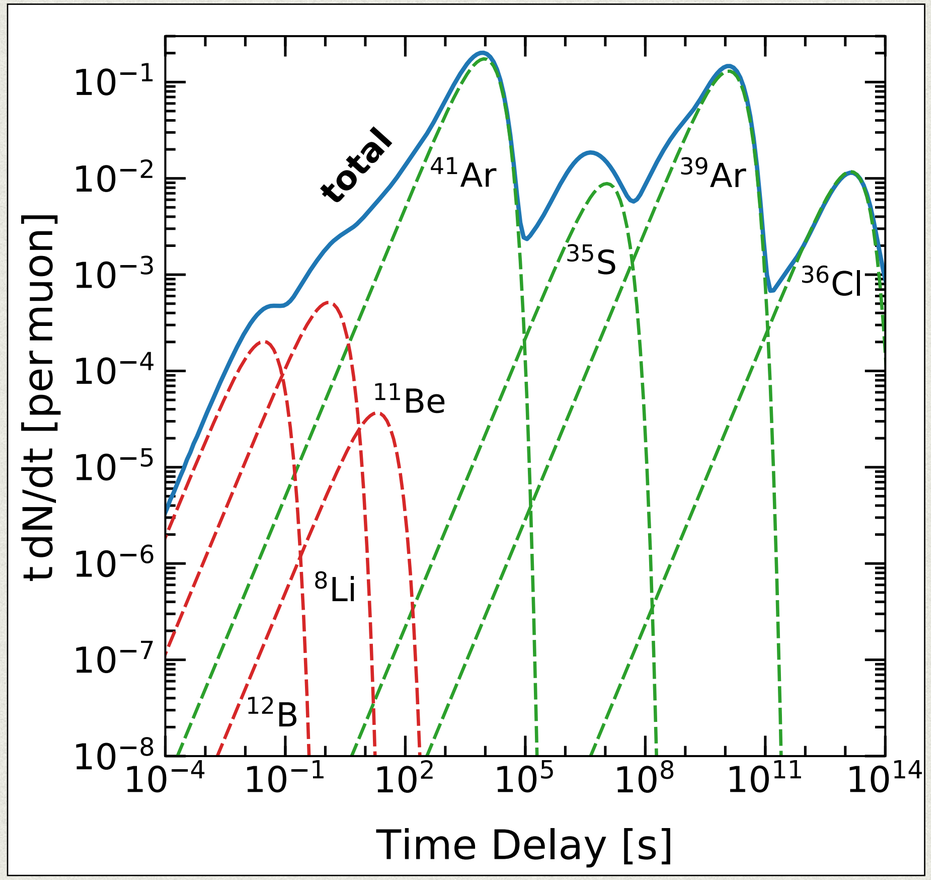
What are important isotopes?



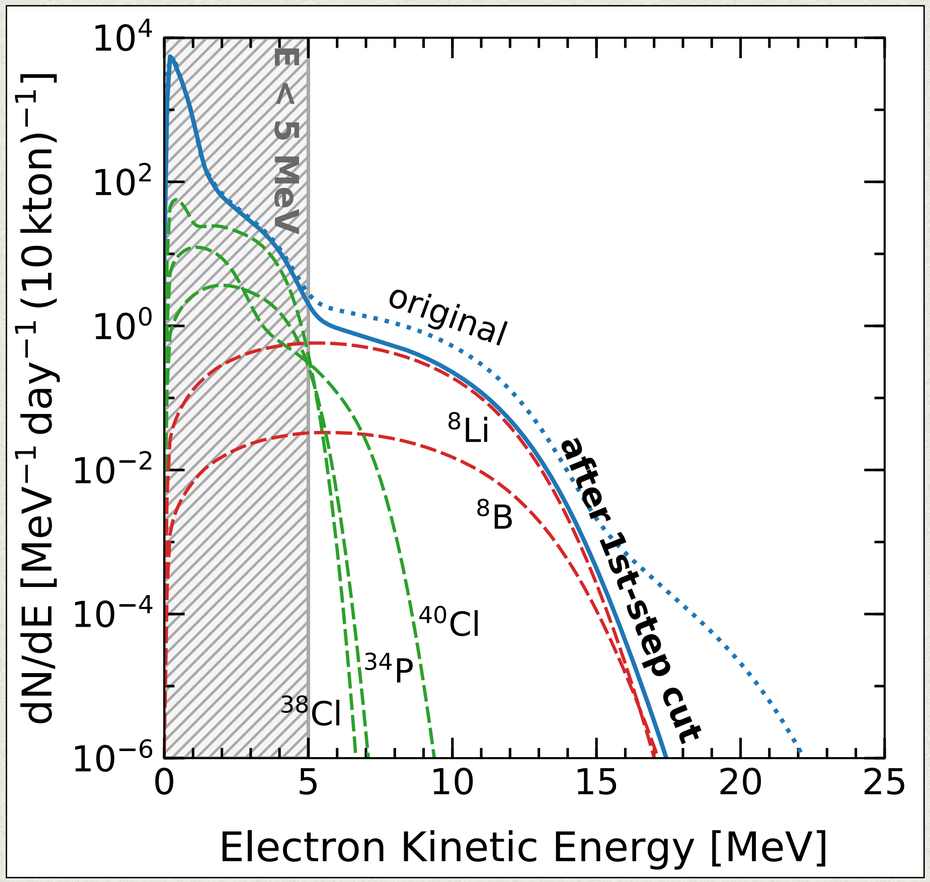
Production yields + Decay properties

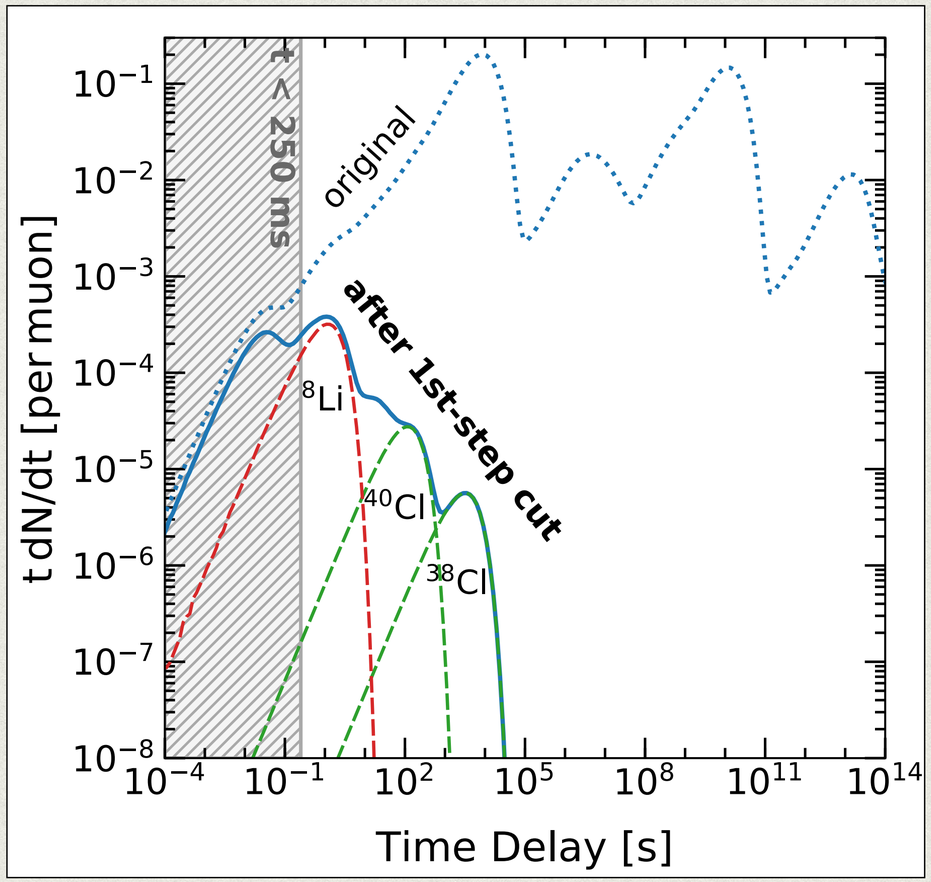
DUNE spallation backgrounds



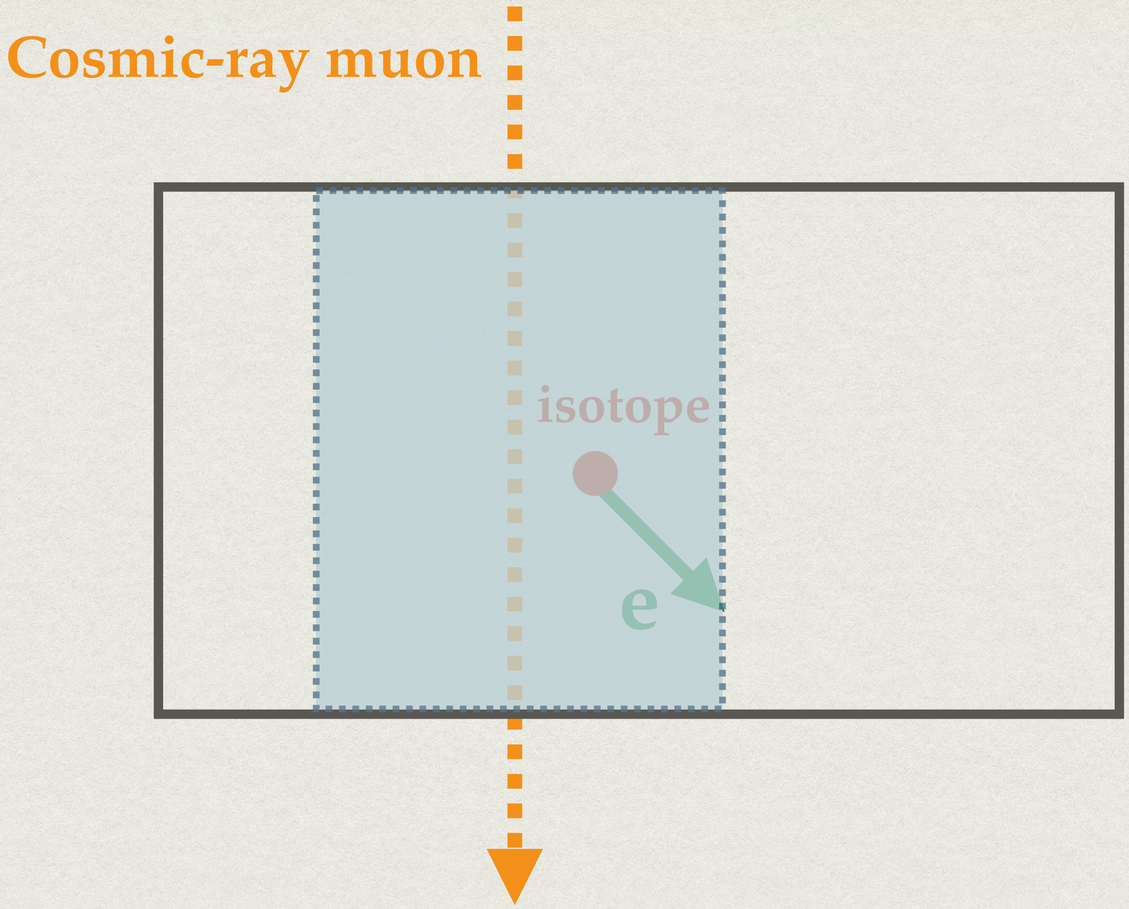


DUNE spallation backgrounds, after 1st-step cut





2nd step — a cylinder cut



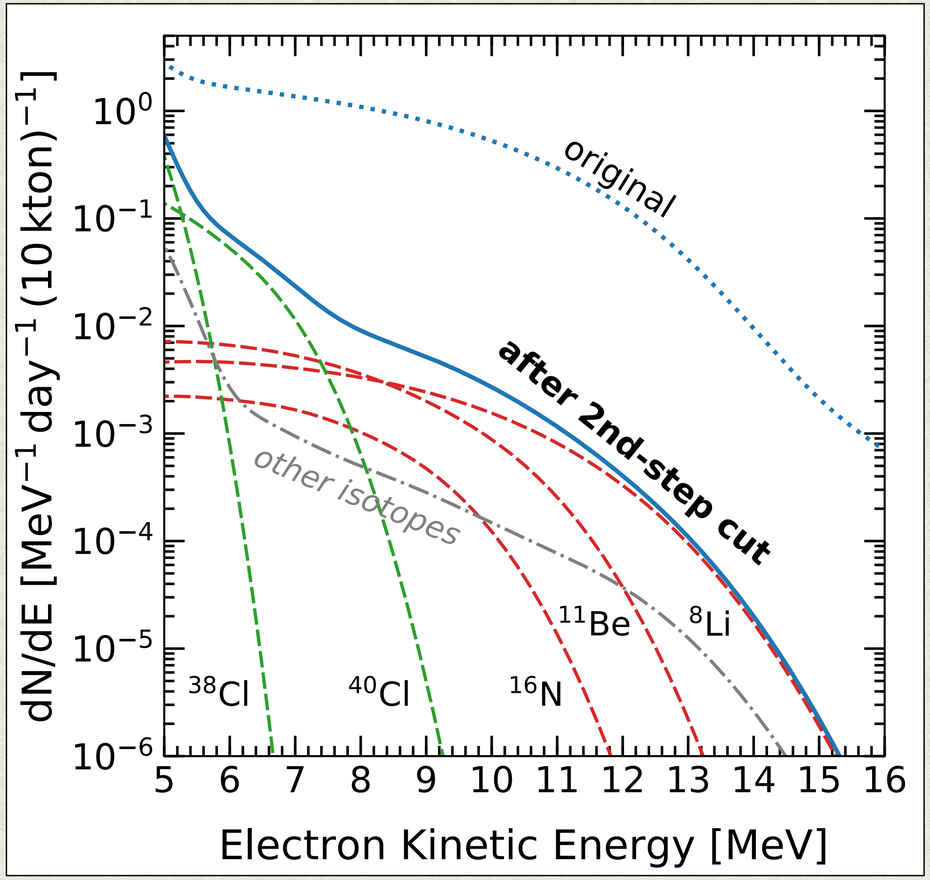
- Remaining background:

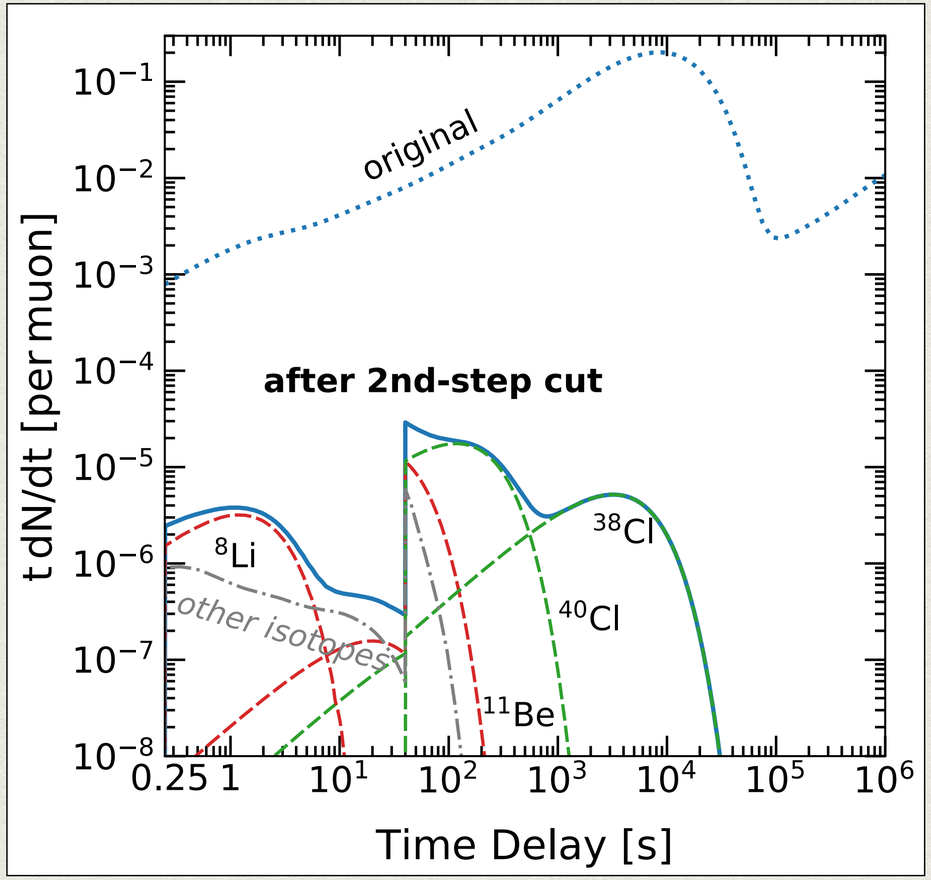
$$\frac{dN'}{dE}(E) = \sum_i \frac{dN_i}{dE}(E) \times \left(P_i\left(D > R\right) + P_i\left(D < R\right) \times P_i\left(t > \Delta t\right)\right), \quad (1)$$

- Resulting deadtime:

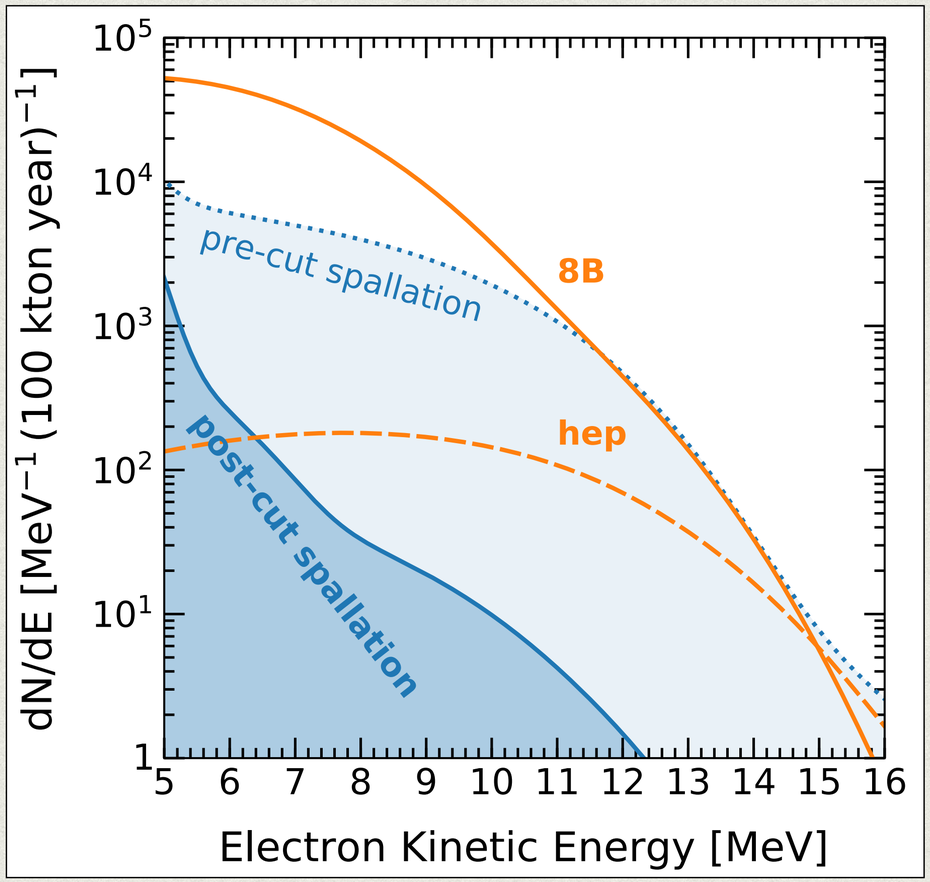
$$f(R, \Delta t) \simeq \Phi_\mu \, \pi \, R^2 \, \Delta t \simeq 1.8 \times 10^{-4} \left(\frac{R}{1\,\mathrm{m}}\right)^2 \left(\frac{\Delta t}{1\,\mathrm{s}}\right). \quad (2)$$

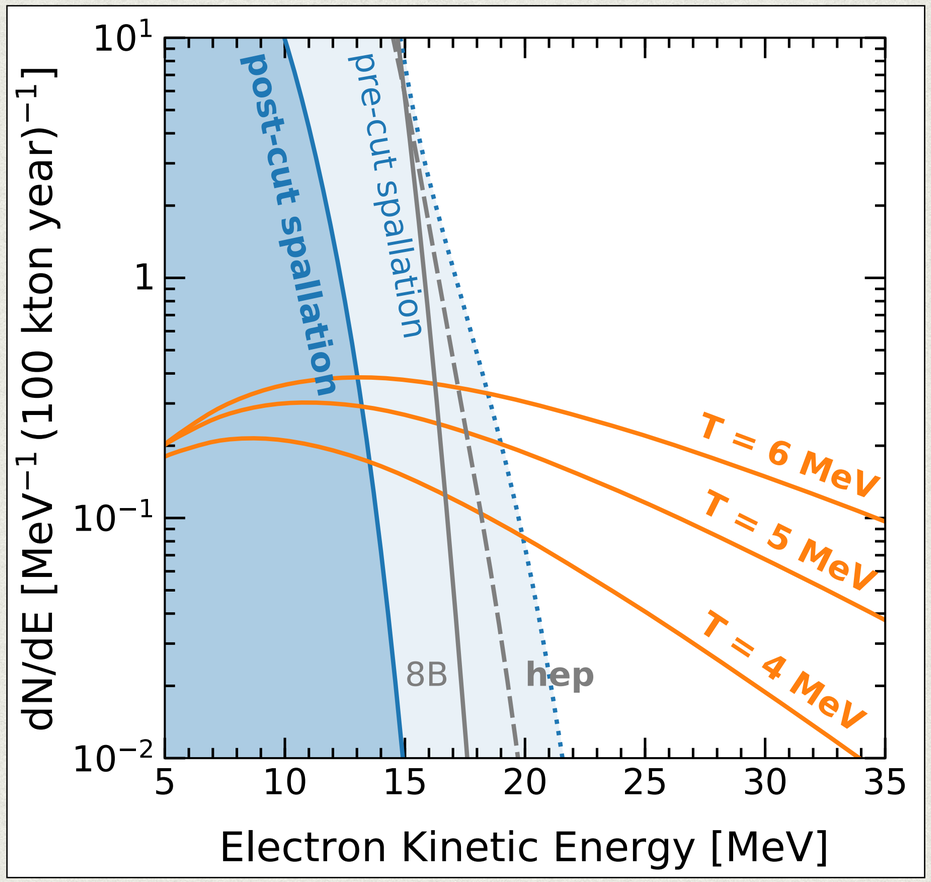
DUNE spallation backgrounds, after 2nd-step cut





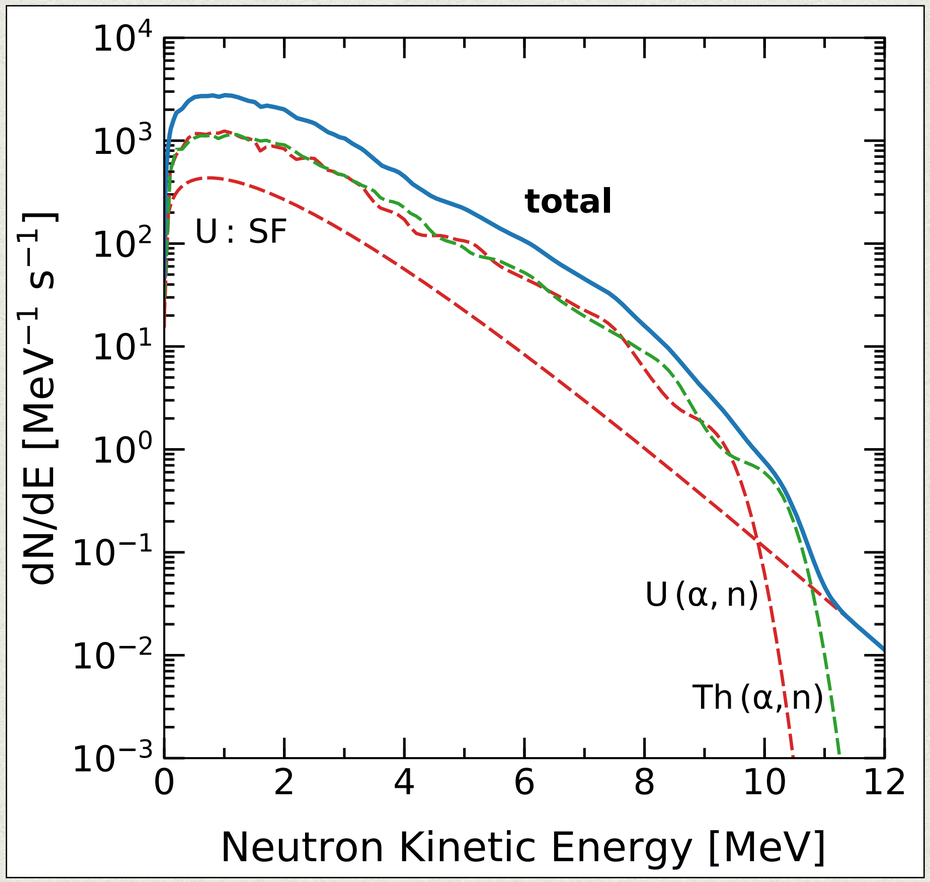
Spallation backgrounds vs. MeV signals





Background II: Neutron capture

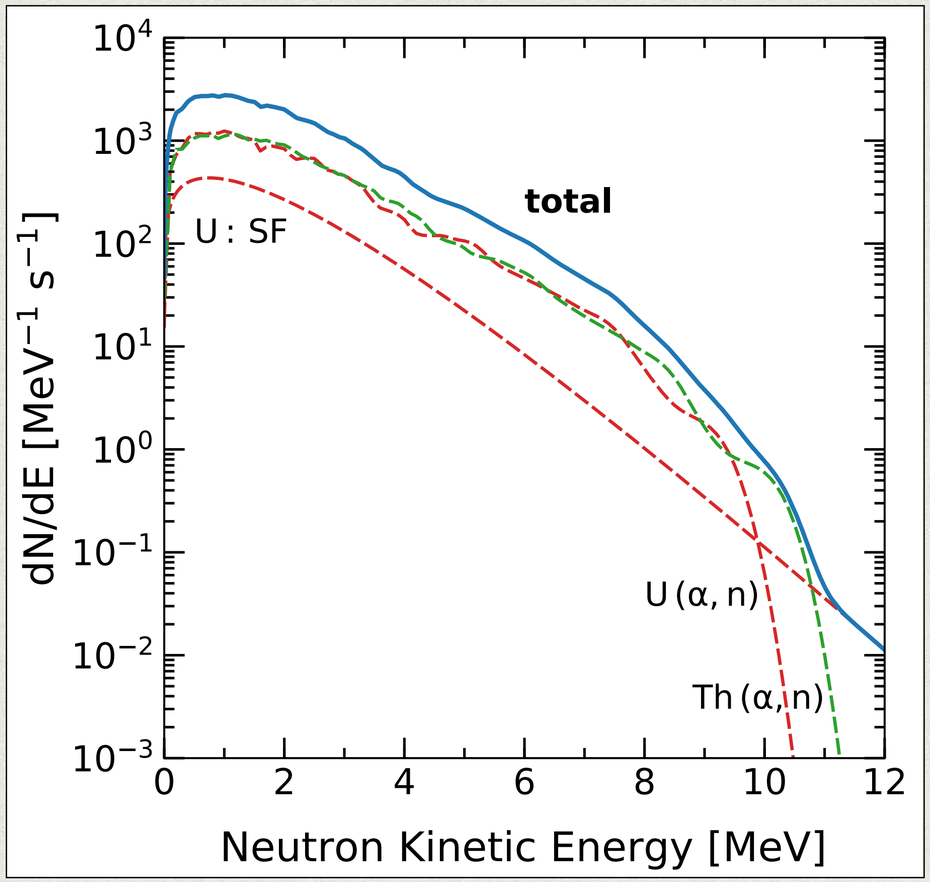
Radioactivity neutrons produced in rock

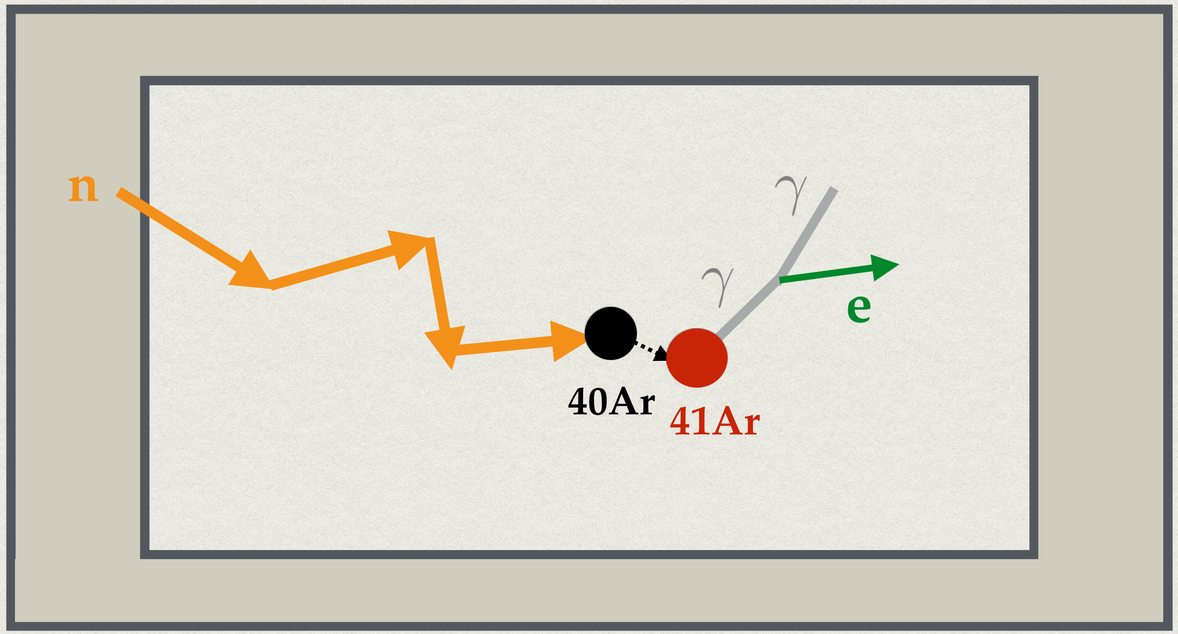


Neutron productions in 2 m rock:

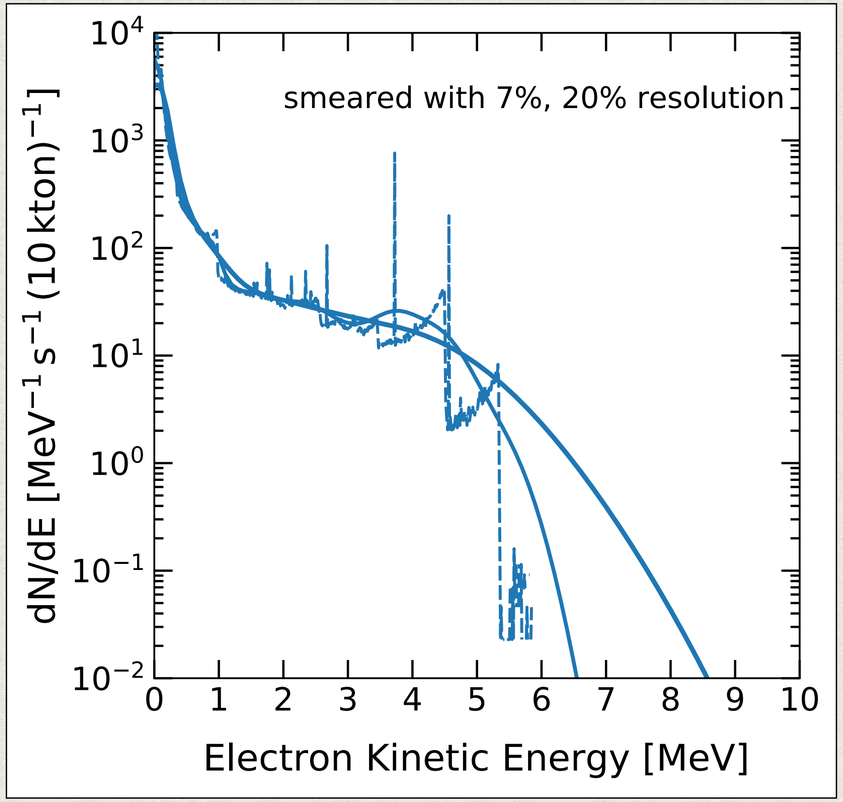
- 7.11 ppm 232Th & 3.43 ppm 238U
  - **Th, U** -> alpha; alpha + rock -> **n**
  - **U** -> **n**, through spontaneous fission

Radioactivity neutrons captured in DUNE



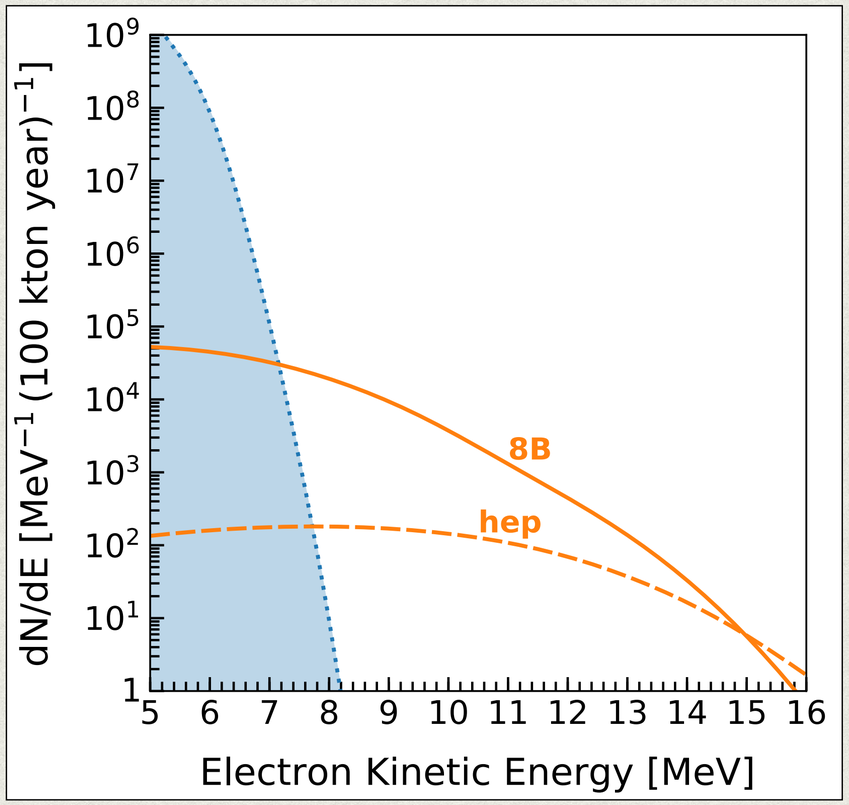


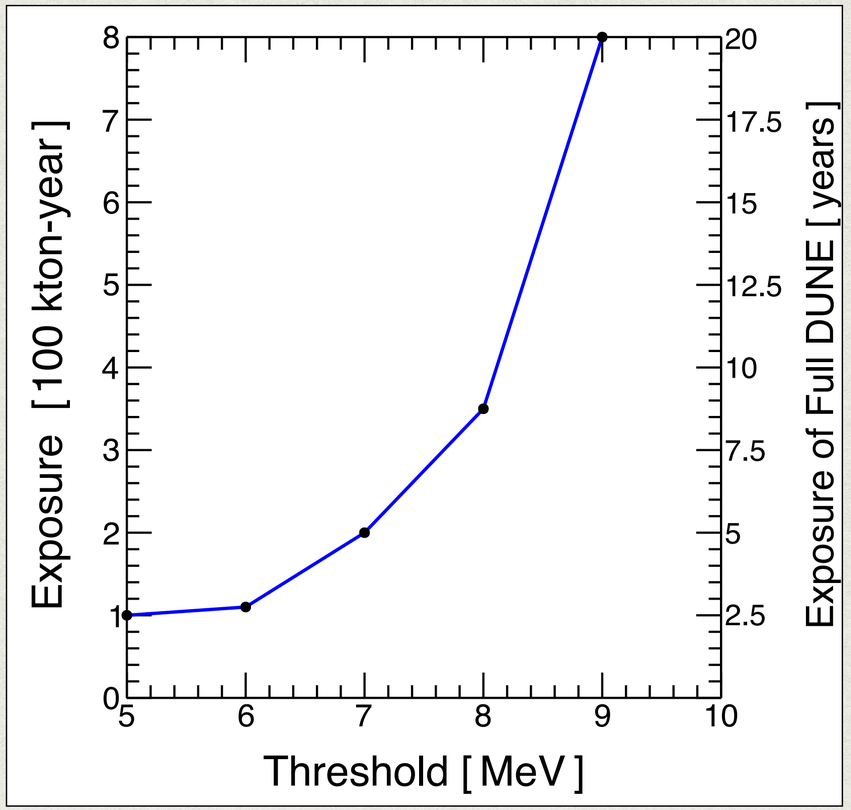
Neutron background in DUNE



- Neutron capture rate: 81 s-1
- Background electron rate (> 5 MeV):
  - with 7% energy resolution: 1.2 Hz
  - with 20% energy resolution: 5 Hz

Neutron background vs. Solar neutrinos

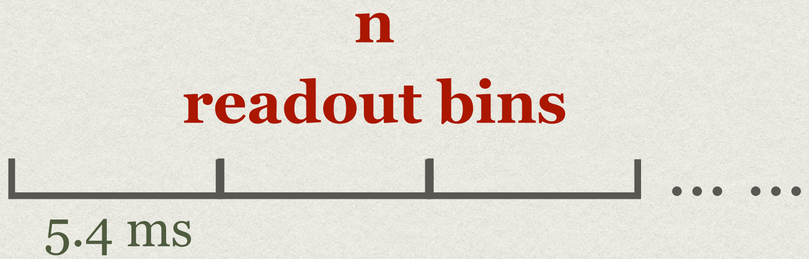




Neutron background vs. Supernova neutrinos

Trigger considerations

- Type I:

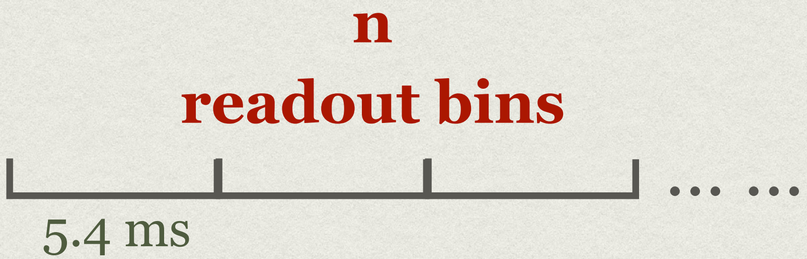


- Type II:

Neutron background vs. Supernova neutrinos

Trigger considerations

- Type I:



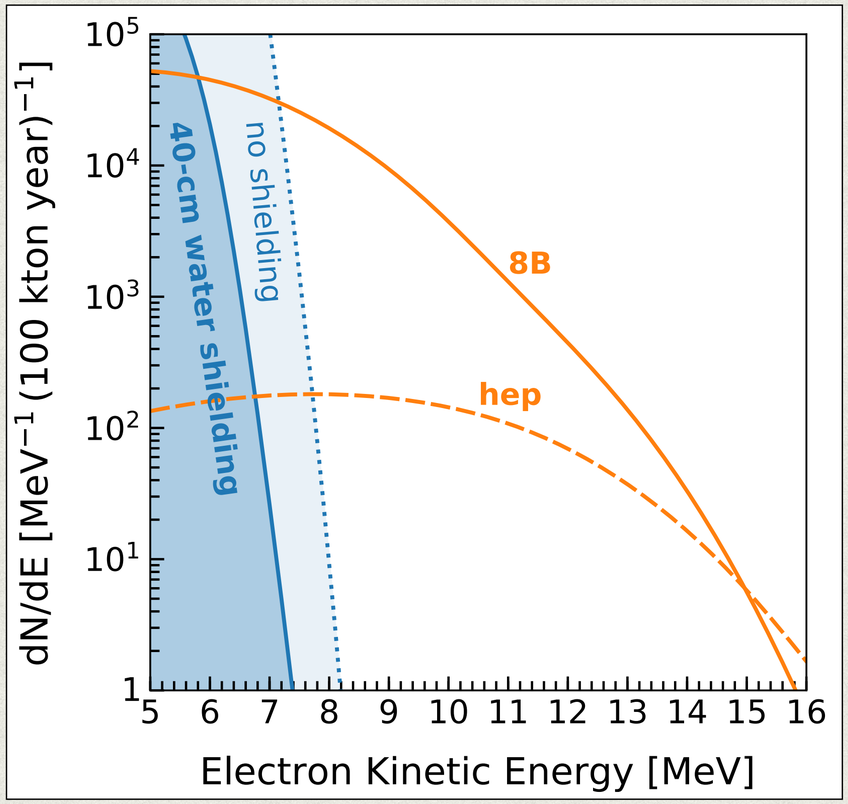
- Type II:

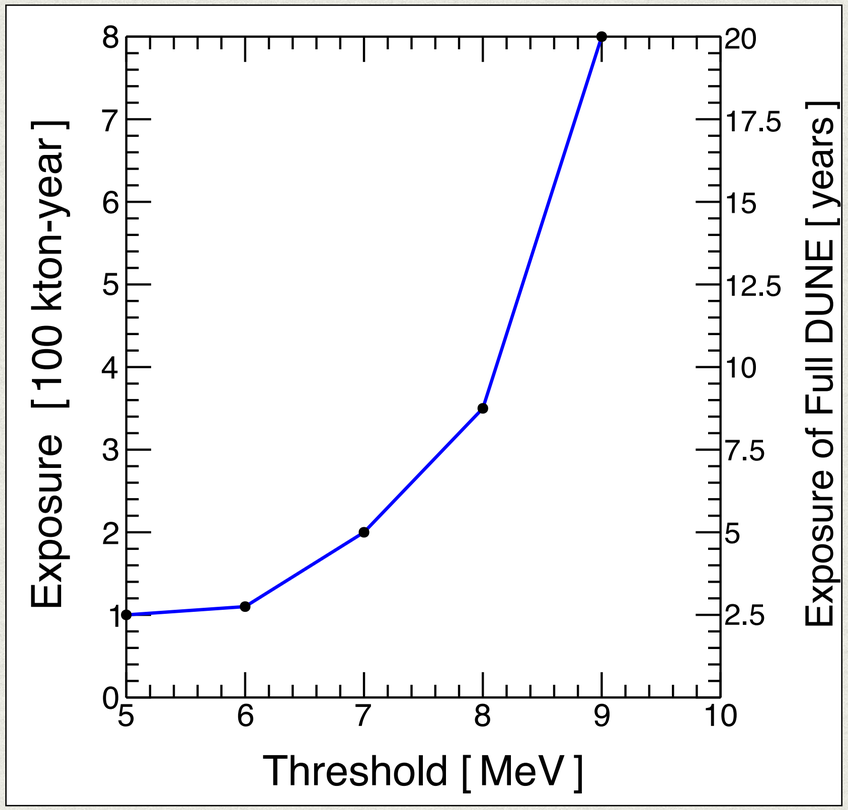
E_{thr} [MeV]	Number of 5.4-ms bins			
	1	2	3	4
5	1×10^{7}	4×10^{5}	1×10^{4}	300
6	3×10^{6}	1×10^{4}	90	0.5
7	4×10^{5}	300	0.2	–
8	3×10^{4}	2	–	–
9	2×10^{3}	–	–	–
10	60	–	–	–

E_{thr} [MeV]	Number of electrons in 5.4 ms			
	1	2	3	4
5	1×10^{7}	2×10^{5}	2×10^{3}	10
6	3×10^{6}	8×10^{3}	20	0.02
7	4×10^{5}	100	0.04	–
8	3×10^{4}	1	–	–
9	2×10^{3}	–	–	–
10	60	–	–	–

Reject neutron background for solar neutrinos

Add moderate water/oil/plastic shielding

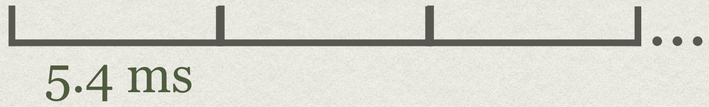




Reject neutron background for supernova neutrinos

Add moderate water/oil/plastic shielding

- Type I trigger: **n readout bins**



- Type II trigger: **n events**

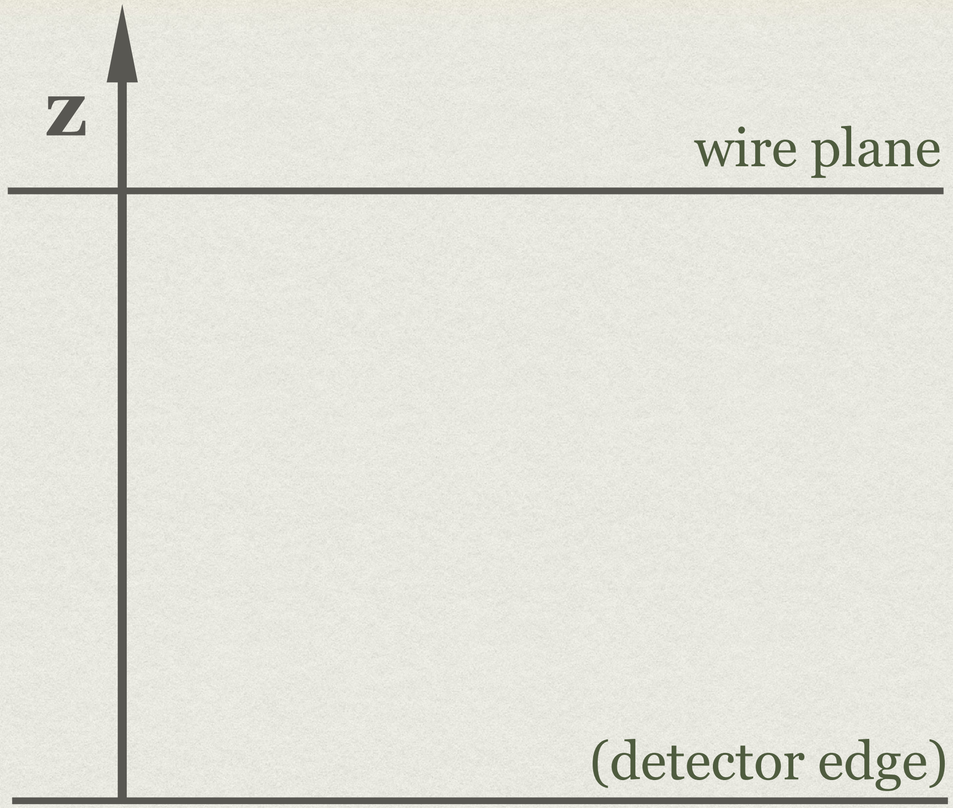
Shielding [cm]	E_{thr} [MeV]	Number of 5.4-ms bins 1	2	3	4
0 cm	5	1×10^{7}	4×10^{5}	1×10^{4}	300
	6	3×10^{6}	1×10^{4}	90	0.5
	7	4×10^{5}	300	0.2	–
	8	3×10^{4}	2	–	–
	9	2×10^{3}	–	–	–
	10	60	–	–	–
20 cm	5	1×10^{5}	30	–	–
	6	2×10^{4}	1	–	–
	7	3×10^{3}	0.02	–	–
	8	300	–	–	–
	9	20	–	–	–
	10	0.5	–	–	–
40 cm	5	3×10^{3}	0.02	–	–
	6	700	–	–	–
	7	90	–	–	–
	8	8	–	–	–
	9	0.4	–	–	–
	10	0.01	–	–	–

Shielding [cm]	E_{thr} [MeV]	Number of electrons in 5.4 ms 1	2	3	4
0 cm	5	1×10^{7}	2×10^{5}	2×10^{3}	10
	6	3×10^{6}	8×10^{3}	20	0.02
	7	4×10^{5}	100	0.04	–
	8	3×10^{4}	1	–	–
	9	2×10^{3}	–	–	–
	10	60	–	–	–
20 cm	5	1×10^{5}	20	–	–
	6	2×10^{4}	0.6	–	–
	7	3×10^{3}	0.01	–	–
	8	300	–	–	–
	9	20	–	–	–
	10	0.5	–	–	–
40 cm	5	3×10^{3}	0.01	–	–
	6	700	–	–	–
	7	90	–	–	–
	8	8	–	–	–
	9	0.4	–	–	–
	10	0.01	–	–	–

Background III: Sub-threshold events pileup

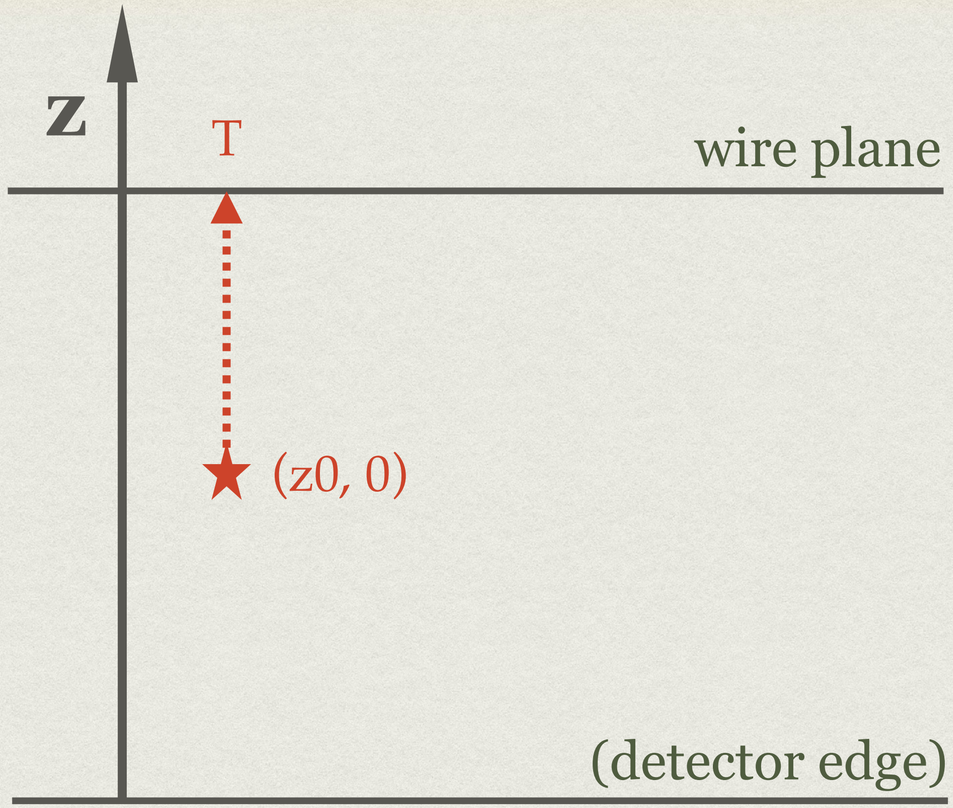
Calculation framework

- 2-event pileup
  - dx = dy = 5 cm



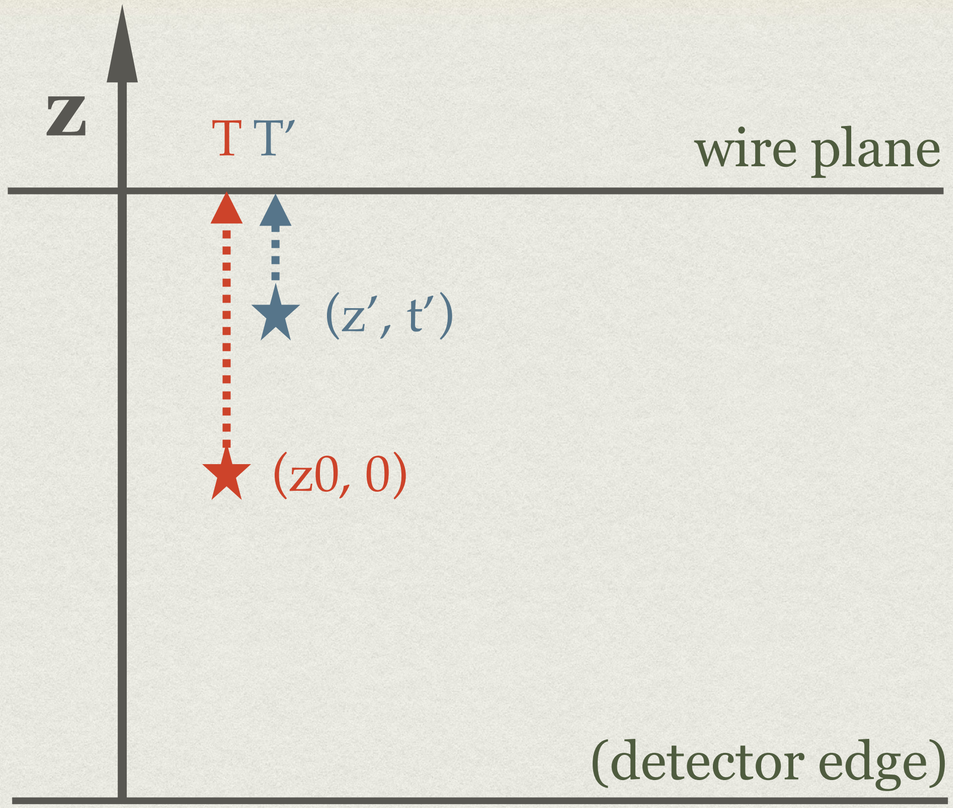
Calculation framework

- 2-event pileup
  - dx = dy = 5 cm
  - 1st event at (z0, t0 = 0)



Calculation framework

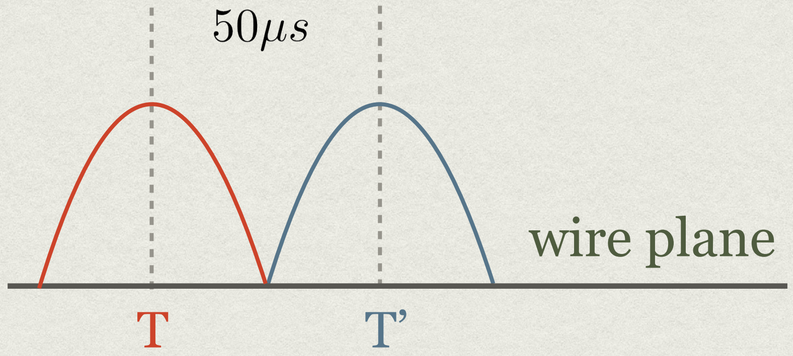
- 2-event pileup
  - dx = dy = 5 cm
  - 1st event at (z0, t0 = 0)
  - 2nd event at (z', t' > 0)

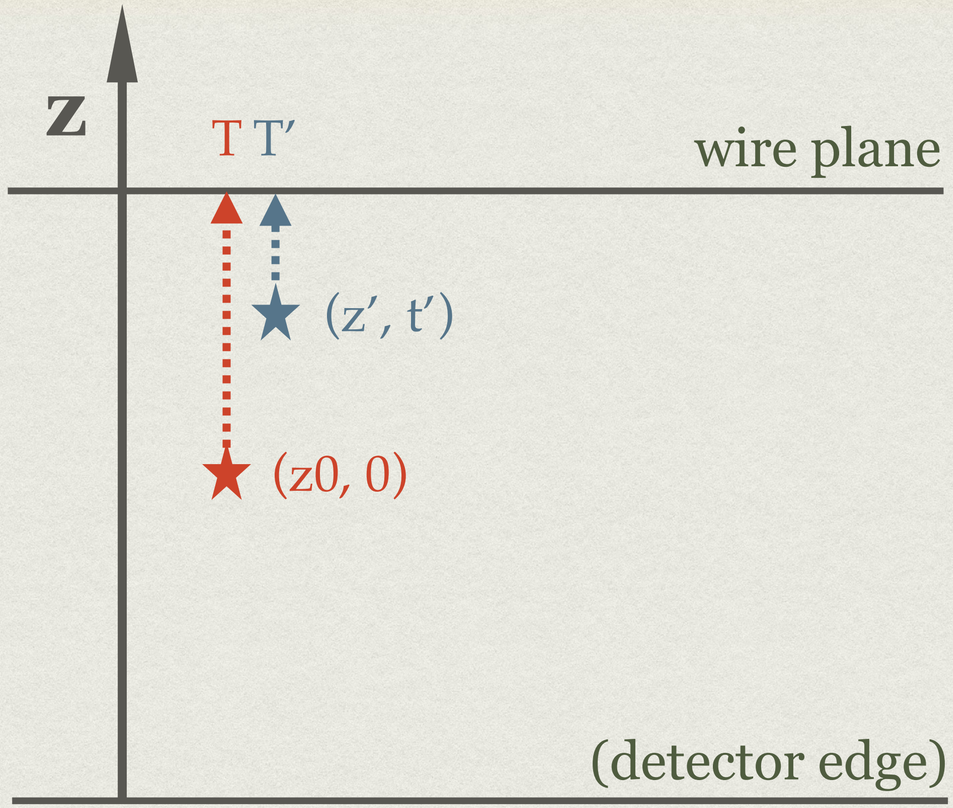


Calculation framework

- 2-event pileup
  - dx = dy = 5 cm
  - 1st event at (z0, t0 = 0)
  - 2nd event at (z', t' > 0)

  such that: | T - T' | < 50 us





Pileup sources

	39Ar (in atm argon)	42Ar (in atm argon)	42K (42Ar decay)	214Bi (222Rn, 10 mBq/m3, decay)	neutron (U/Th in rock)
Ee [MeV]	0.6	0.6	3.5	3.5	3
Rate [Hz]	10^7	10^3	10^3	10^2	10^2

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Pileup rates << neutron rates above 5 MeV

	39Ar **(in atm argon)**	**42K** **(42Ar decay)**
Ee [MeV]	**0.6**	**3.5**
Rate [Hz]	**10^7**	**10^3**

- Pileup among 39Ar, 42K themselves
  - 10 decays of 39Ar: **10^-15 Hz**
  - 2 decays of 42K: **10^-4 Hz**
- Pileup between 39Ar and 42K
  - 3 decays of 39Ar with 1 decay of 42K: **10^-5 Hz**
- Neutron background > 5 MeV: **5 Hz**

Conclusions

	Solar neutrinos	Supernova neutrinos (trigger)	DSNB
Spallation	😊	😊	😊
Neutron No shielding	🤔	🤔	😊
Neutron After shielding	😊	😊	
Pileup	😊	😊	😊

GEOLOGY OF PRECAMBRIAN ROCKS IN THE POORMAN ANTICLINORIUM AND HOMESTAKE MINE, BLACK HILLS, SOUTH DAKOTA

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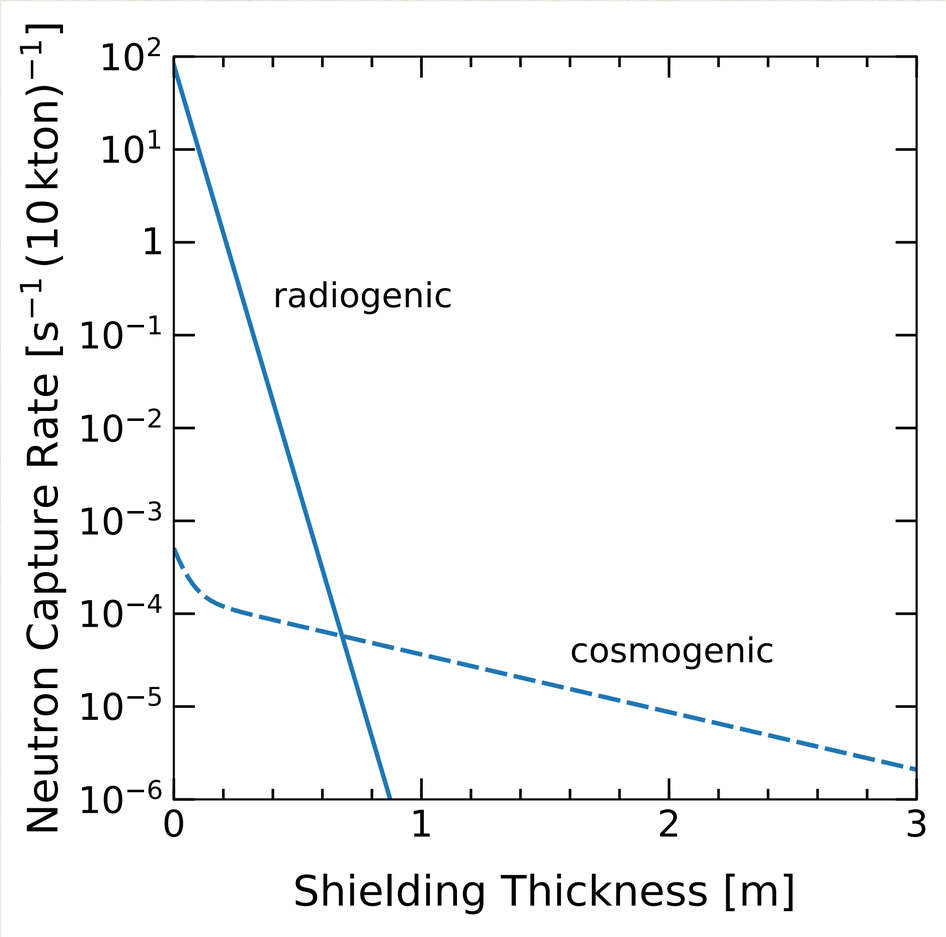
INTRODUCTION

Previous work on Precambrian rocks from the Lead window (Noble and Harder, 1948) concentrated on the stratigraphy and structure of rocks exposed along the Lead Anticlinorium and at the Homestake gold mine. This paper focuses on lithologies, geochemistry, and paleoenvironments of mostly unmineralized metasediments exposed in the Poorman anticlinorium.


Neutron Capture Rate [s^{-1} (10 kton)$^{-1}$]
10^{2}
10^{1}
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
1
2
3
Shielding Thickness [m]
radiogenic
cosmogenic