Cosmogenic Neutron Production in SNO/SNO+

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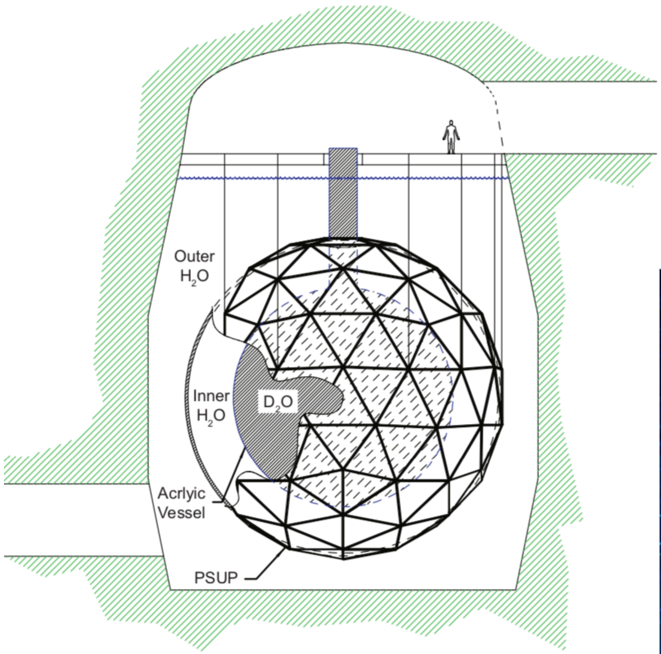
8th November 2019, KCL

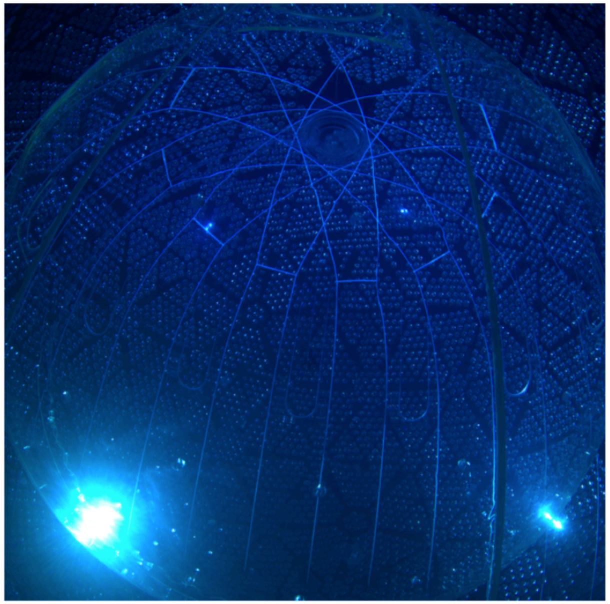
Outline

- Experimental Overview – SNO, SNO+
- Cosmogenic Neutrons
  - Motivation
  - SNO results
  - SNO+ measurement status

Experimental Overview

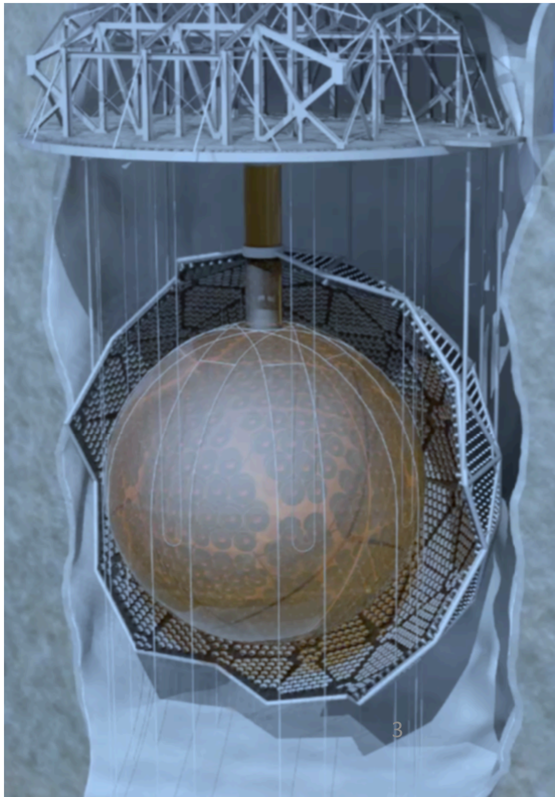


SNO – D2O target

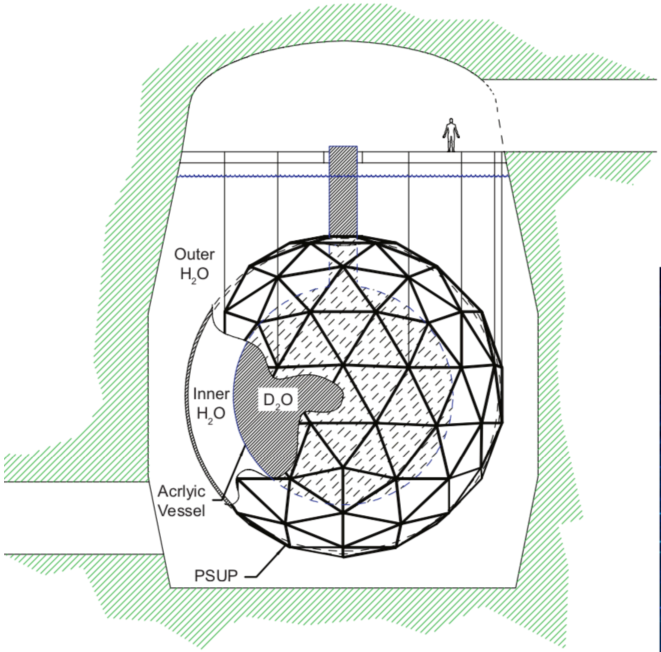


SNO+ commissioning
– H2O target

SNO+ scintillator target

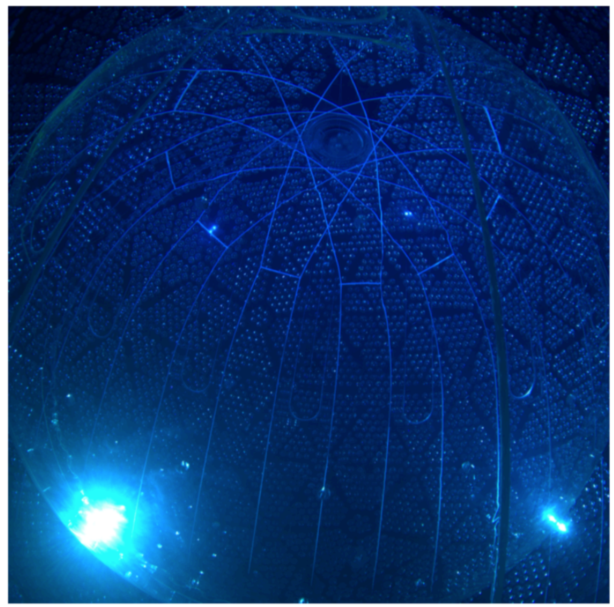


Neutron capture Overview



SNO – D2O target (+ salt)

n capture on ^{2}H
→ 6.25MeV γ, 10s of ms
n capture on ^{35}Cl
→ 8.6MeV γs, few ms

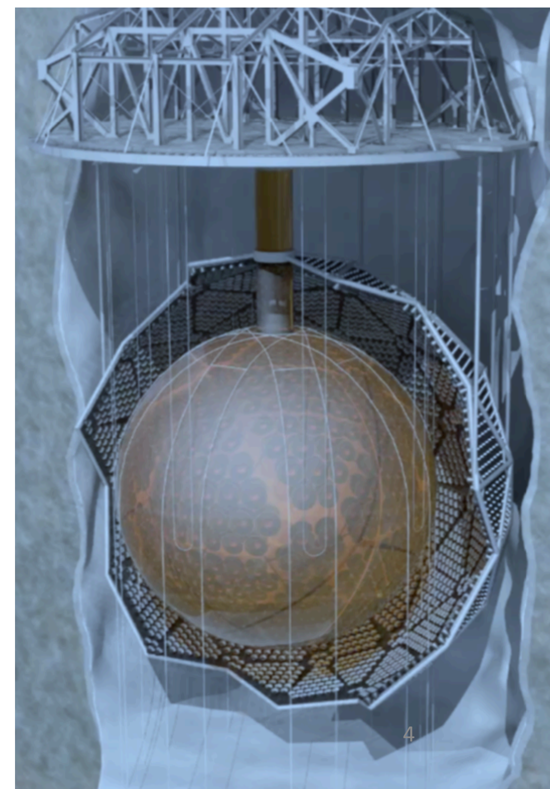


SNO+ commissioning
– H2O target

n capture on ^{1}H
→ 2.2MeV γ, 0.2ms

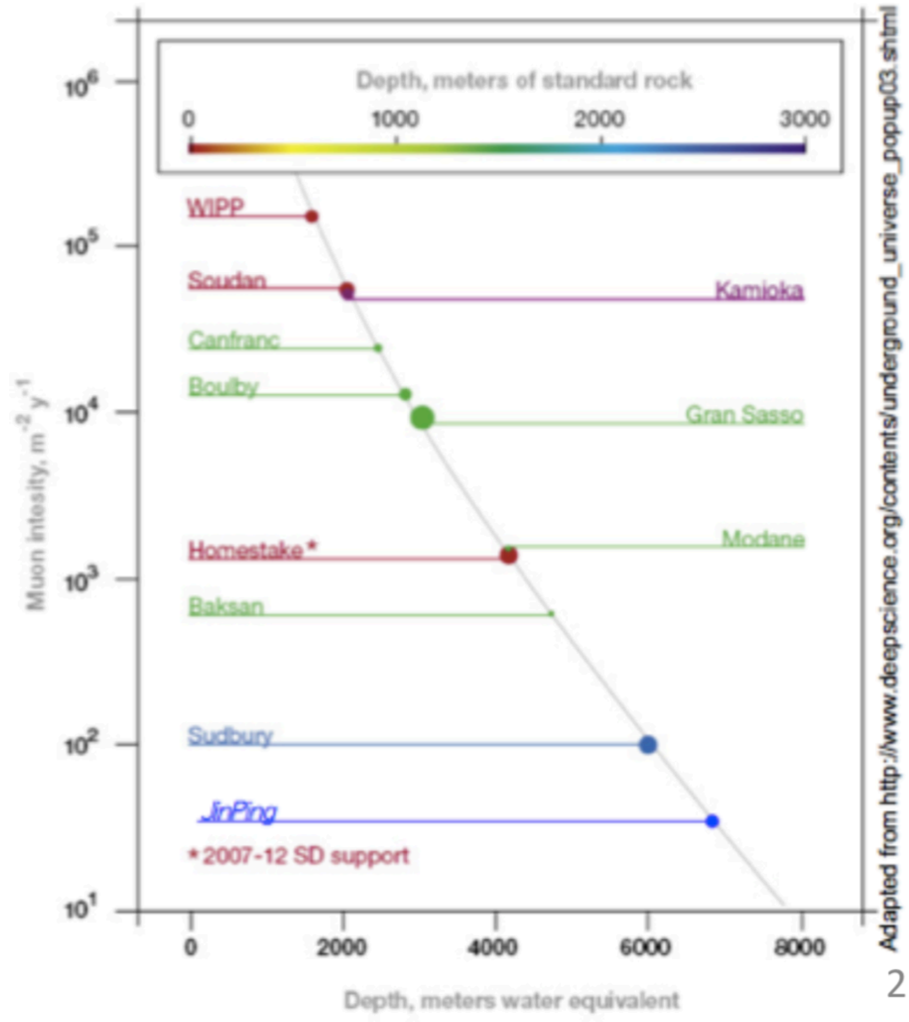
SNO+ scintillator target

n capture on ^{1}H
→ 2.2MeV γ, 0.2ms

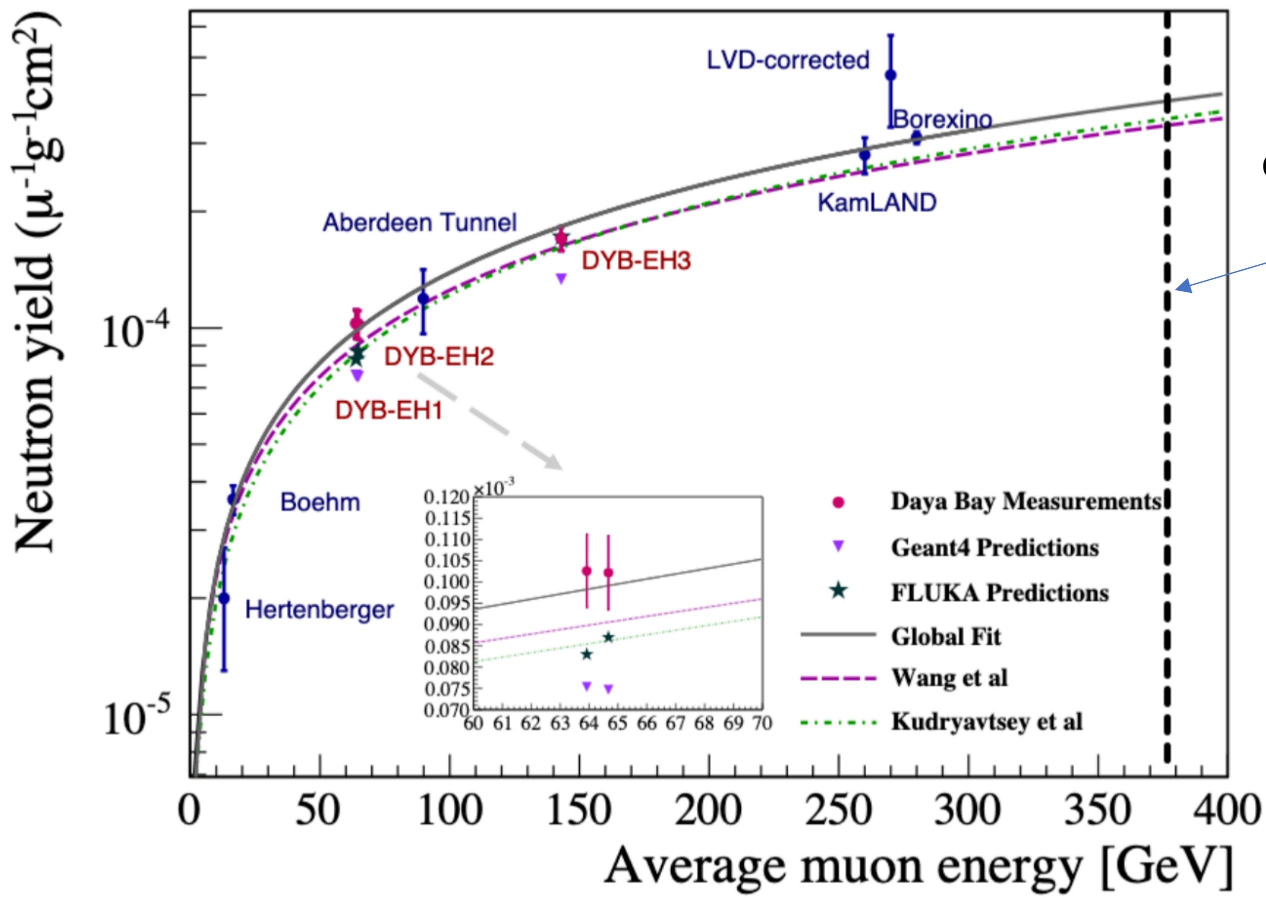


Why bother?

- Muons penetrate even to deep underground laboratories
- Cosmic Muon spallation products present a background for many weak signal searches
  - Long lived products – time veto results in detector dead time
  - Neutron spallation cross section 2 orders of magnitude higher than the other long lived spallation daughters.
- SNOLAB has access to a low rate high energy cosmic muon flux for which neutron production yield is not well studied.
- Unique opportunity to measure same flux with same detector and 3 different media



Cosmogenic Neutron production knowledge so far



Average muon energy at SNOLAB depth

F. An et al, Cosmogenic neutron production at Daya Bay, Phys Rev D 7, 052009, Mar 2018

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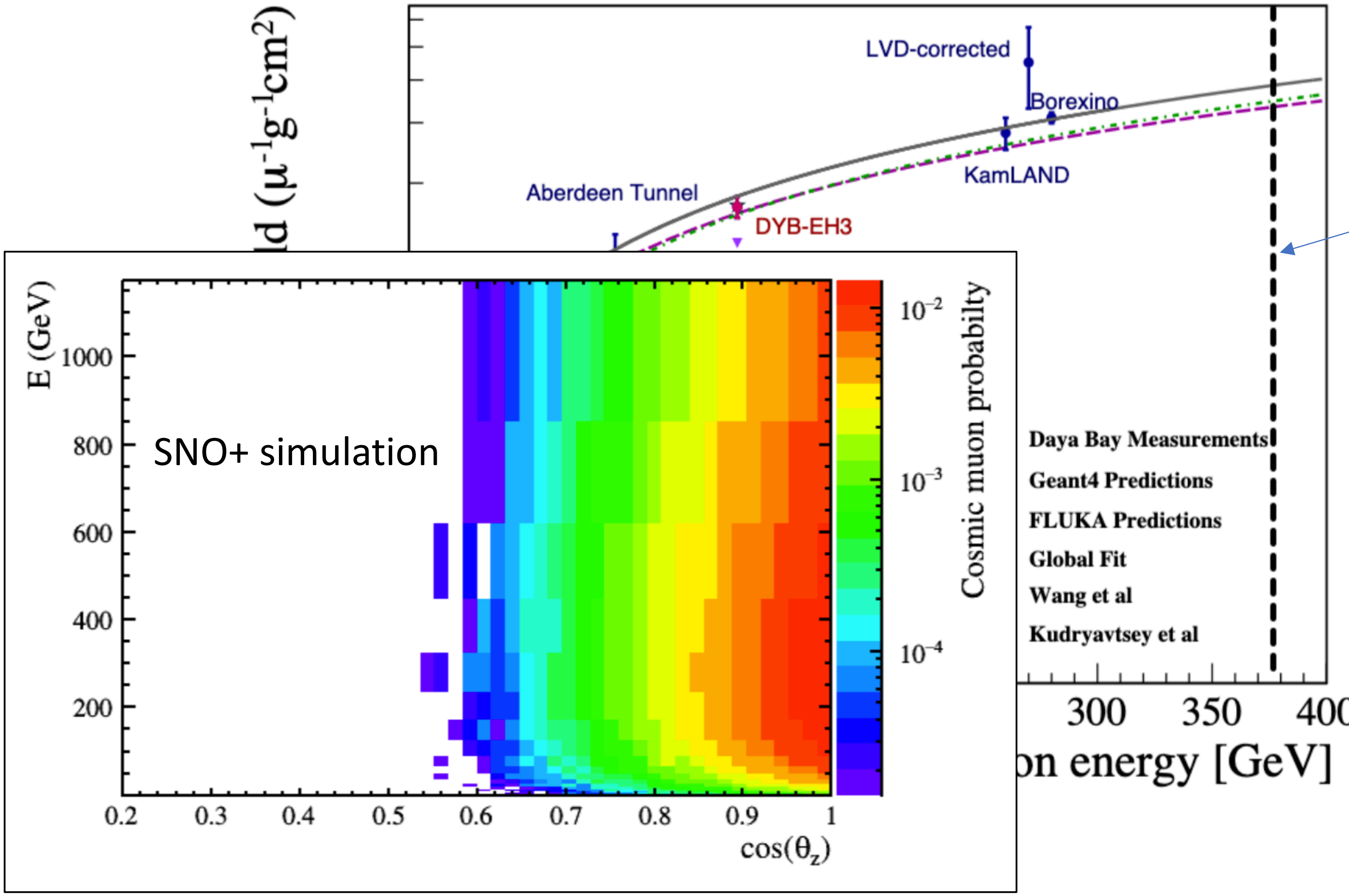

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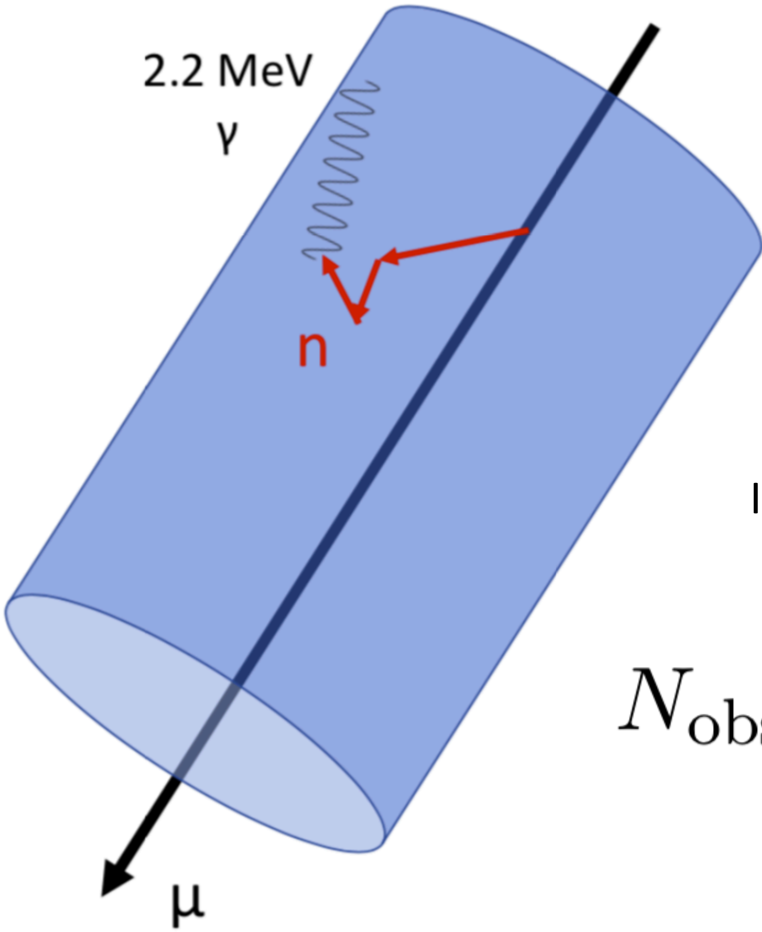
Cosmogenic Neutrons



Muon passes through detector,

track length, L_μ

Count N_{obs} neutrons in window after muon

Impurity correction

efficiency

Muon correlated backgrounds

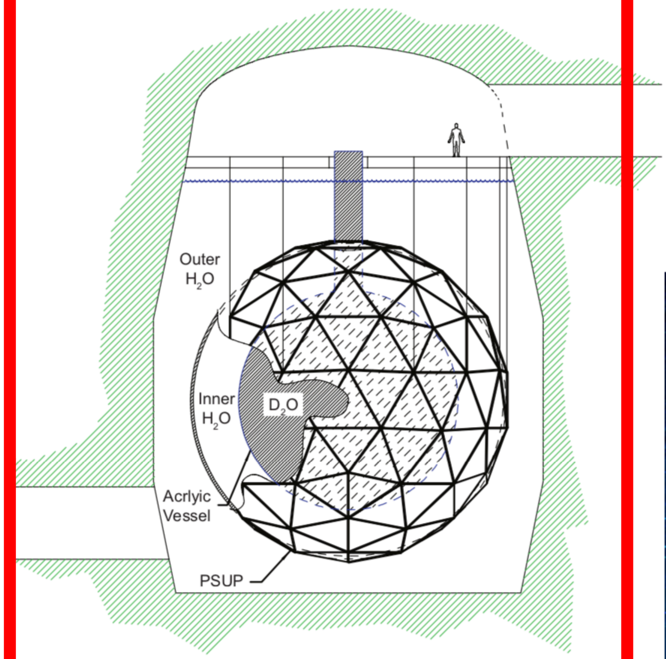
Random backgrounds

$$N_{\rm obs} = (\zeta + \epsilon) \cdot N_n + B_\mu + B_{\rm R}$$

$$Y_n = \frac{1}{\rho} \frac{\sum_\mu N_n^\mu}{\sum_\mu L_\mu} \qquad Y_n^\mu = \frac{N_n^\mu}{L_\mu \rho}$$

Density of capture medium

Neutron capture Overview



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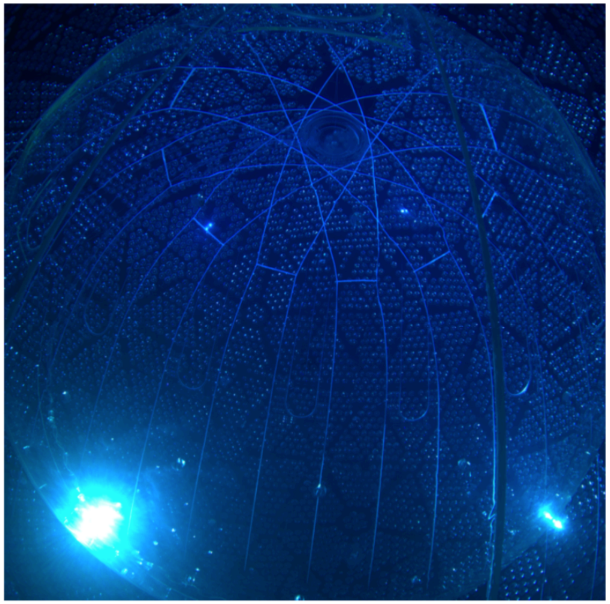

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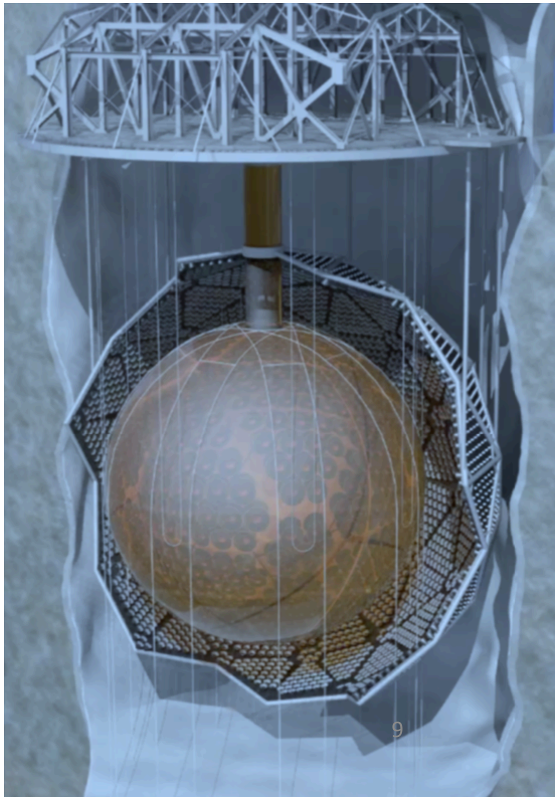
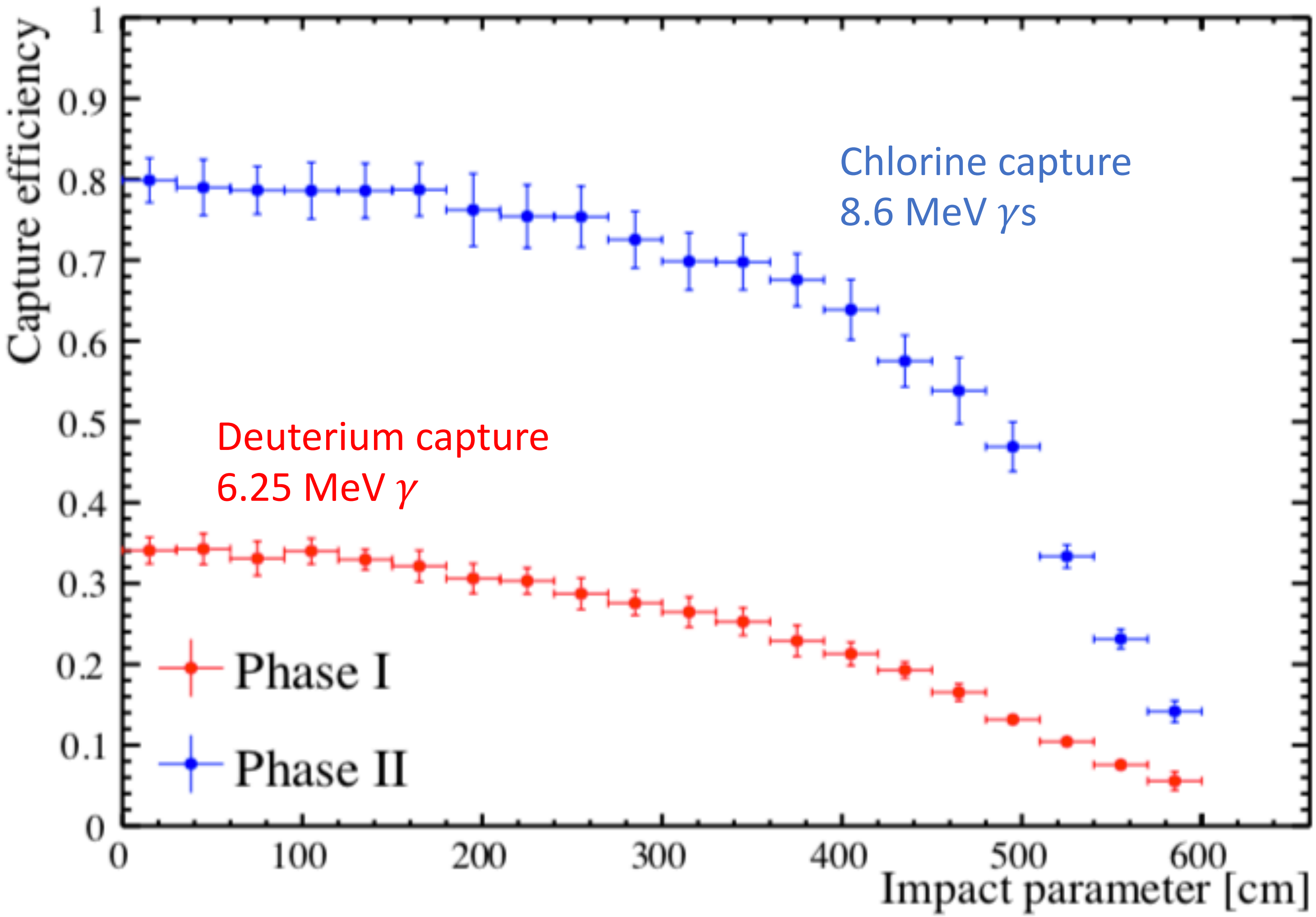
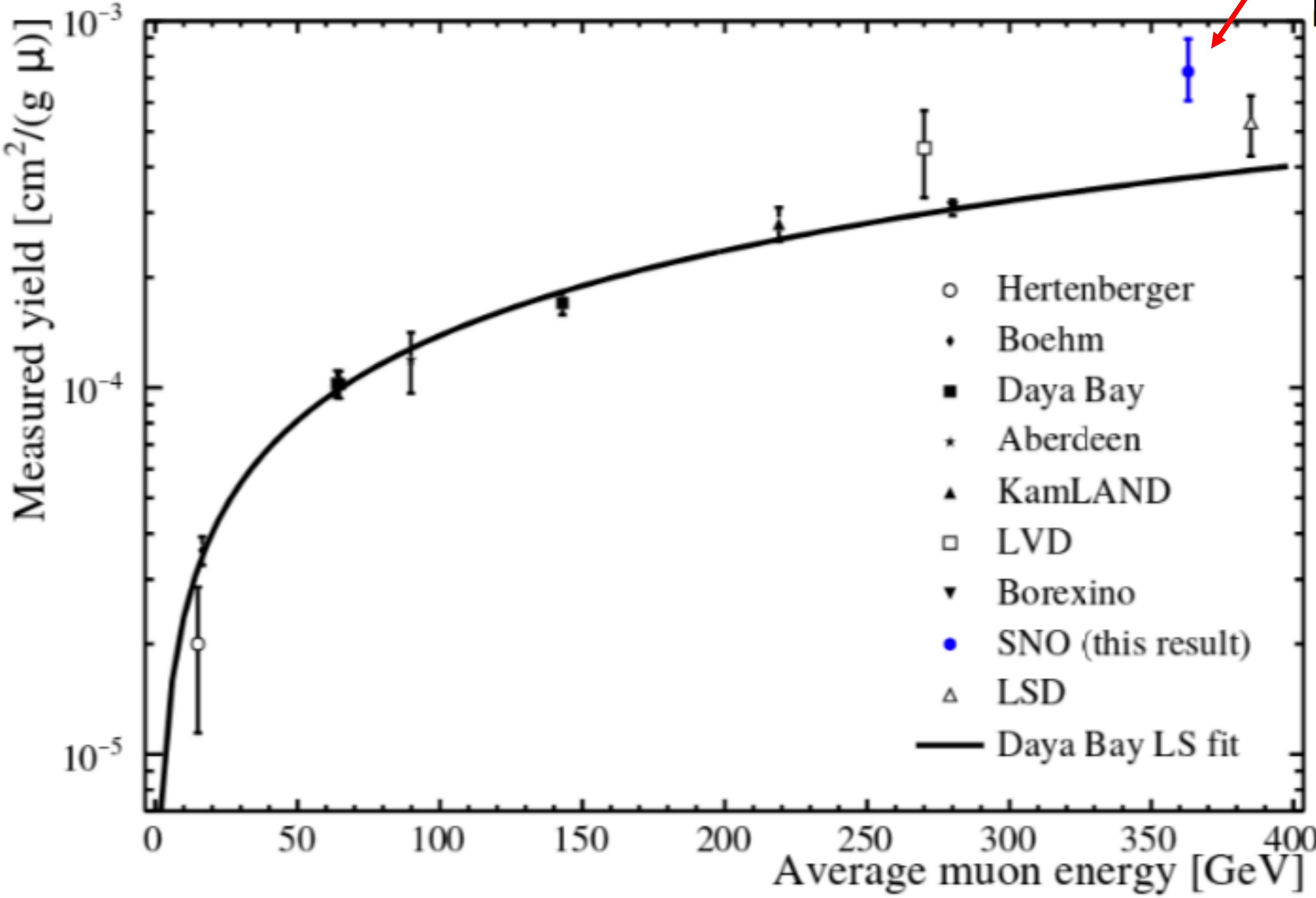


SNO neutron capture efficiencies



Cosmogenic neutron yield measurement



B. Aharmim et al. Cosmogenic neutron production at the Sudbury Neutrino Observatory, 595 2019, https://arxiv.org/abs/1909.11728

SNO – Tests of simulation model

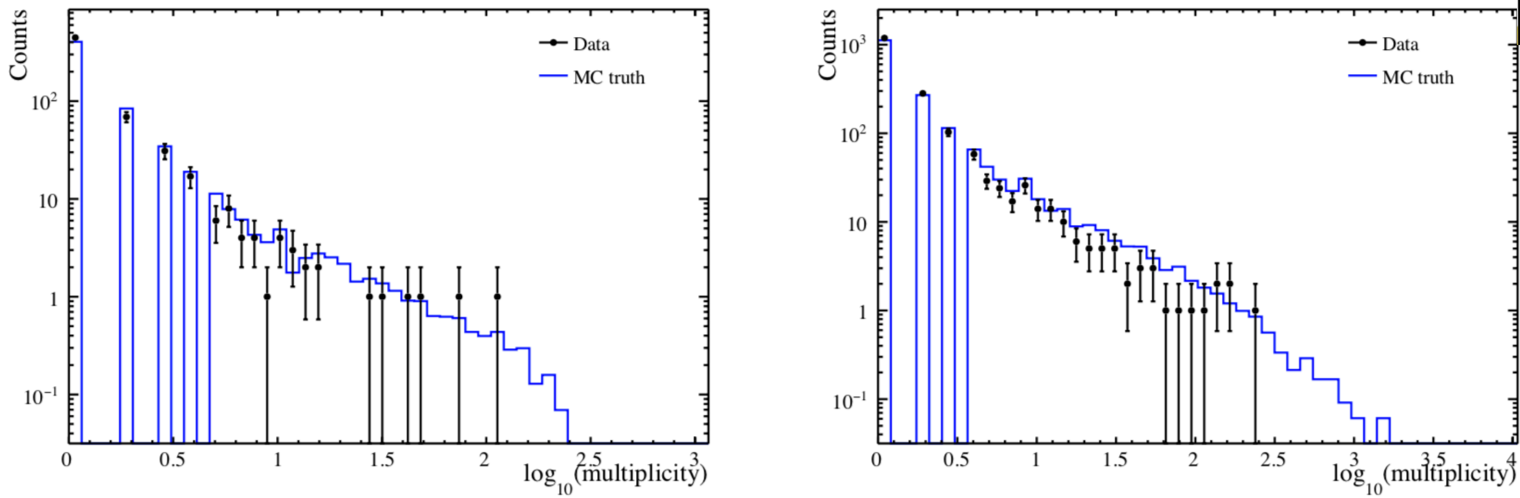


FIG. 8. (Color online) Number of detected neutron followers per muon, in Phases I (left) and II (right). Each entry to the histograms represents one muon.

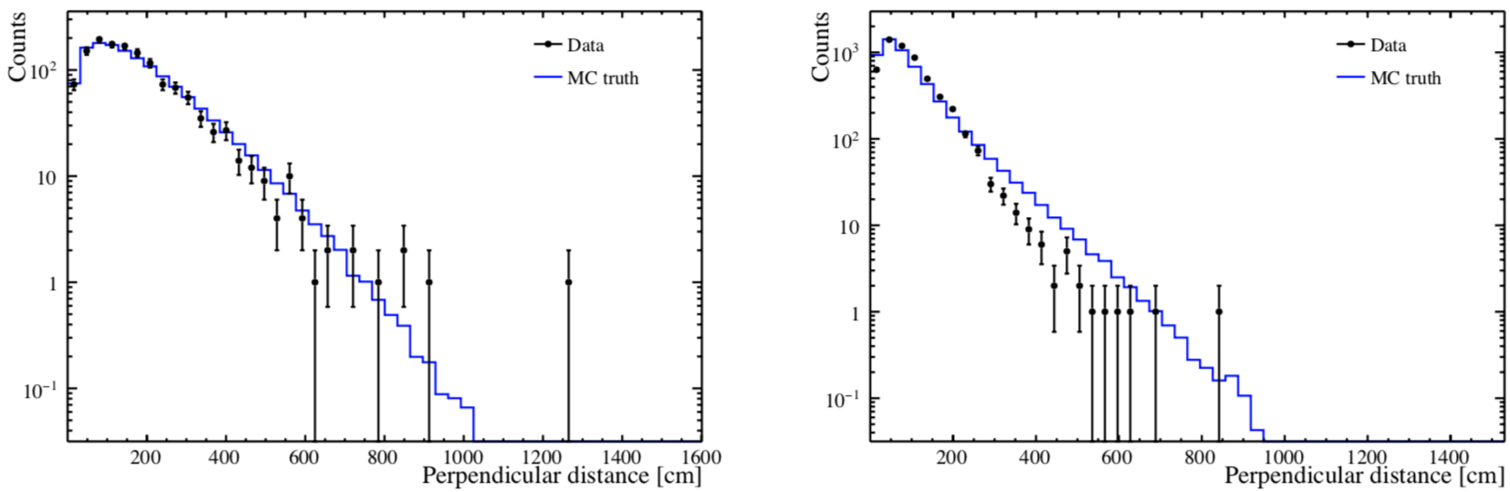
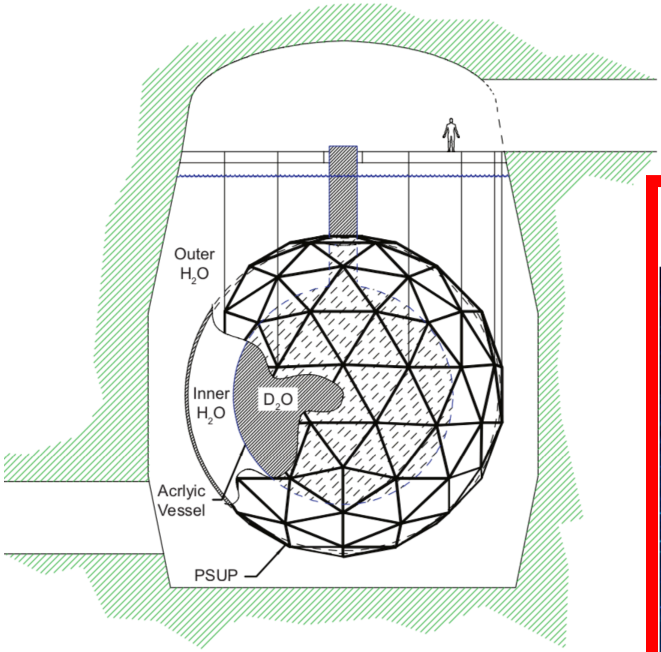


FIG. 11. (Color online) Lateral capture distances from track, in Phases I (left) and II (right).

n capture Overview



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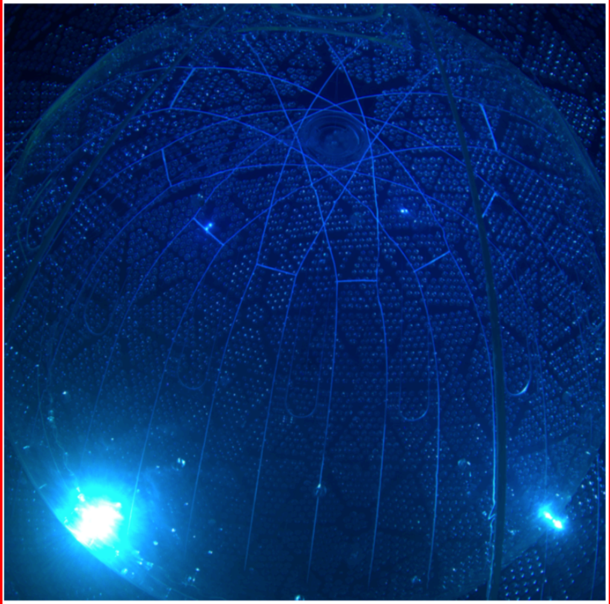

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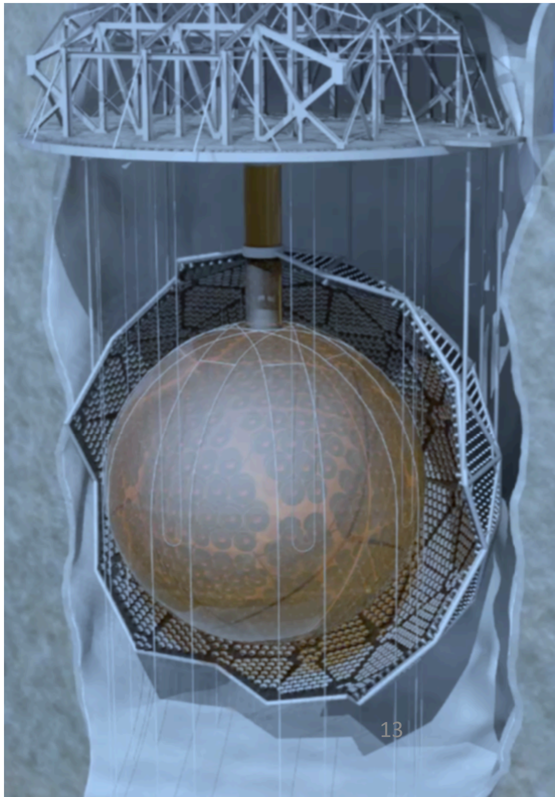
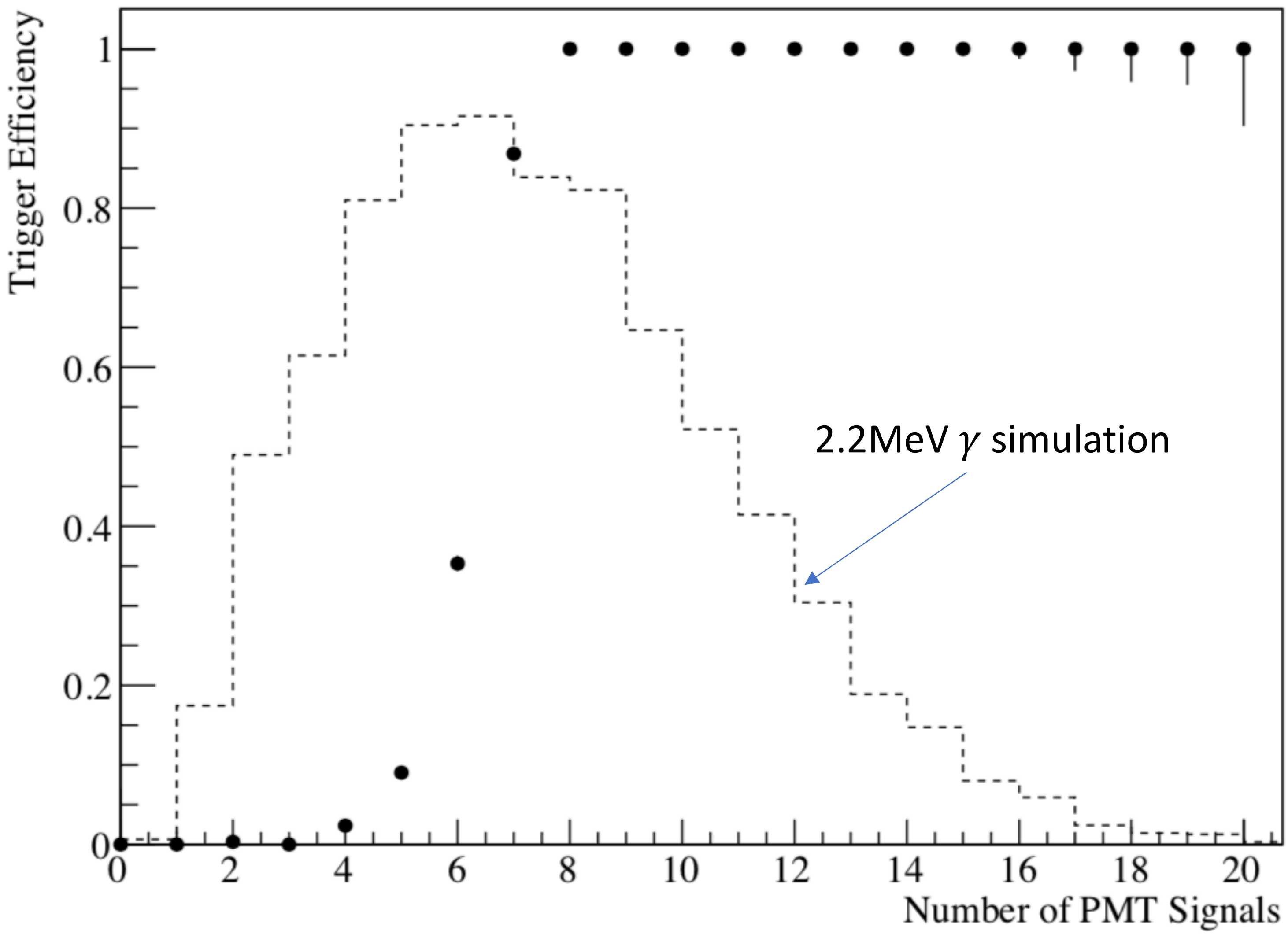


SNO+ Trigger Efficiency, Water phase

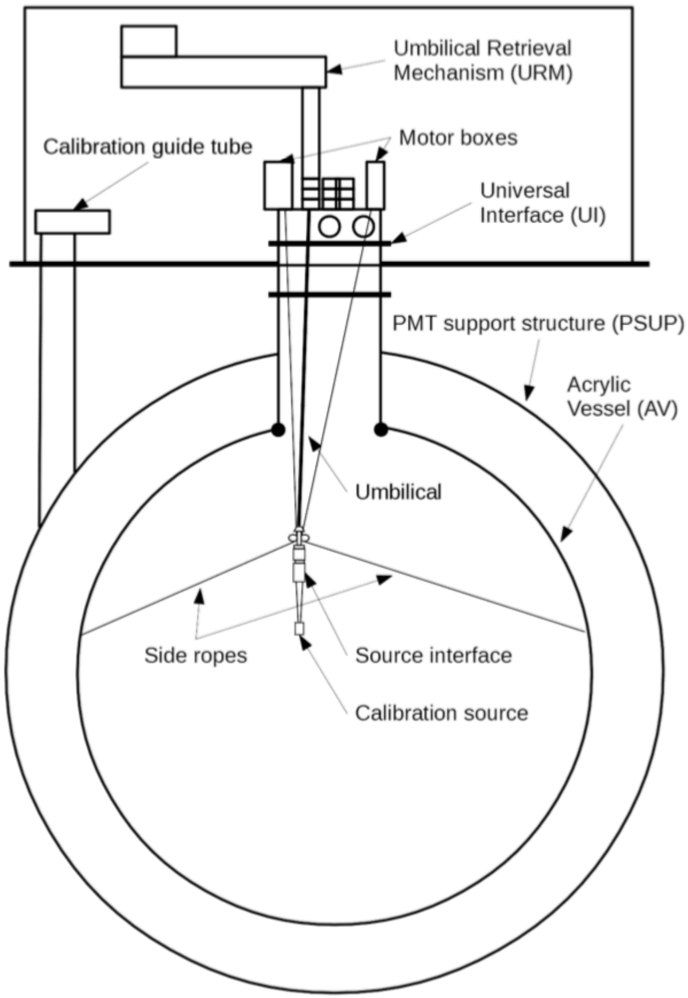


Trigger efficiency of N100 trigger (MC), paper in preparation

SNO+ AmBe calibration

$^{9}Be\ (\alpha,n)\ ^{12}C^*$ (60% time) Q = 1.261 MeV

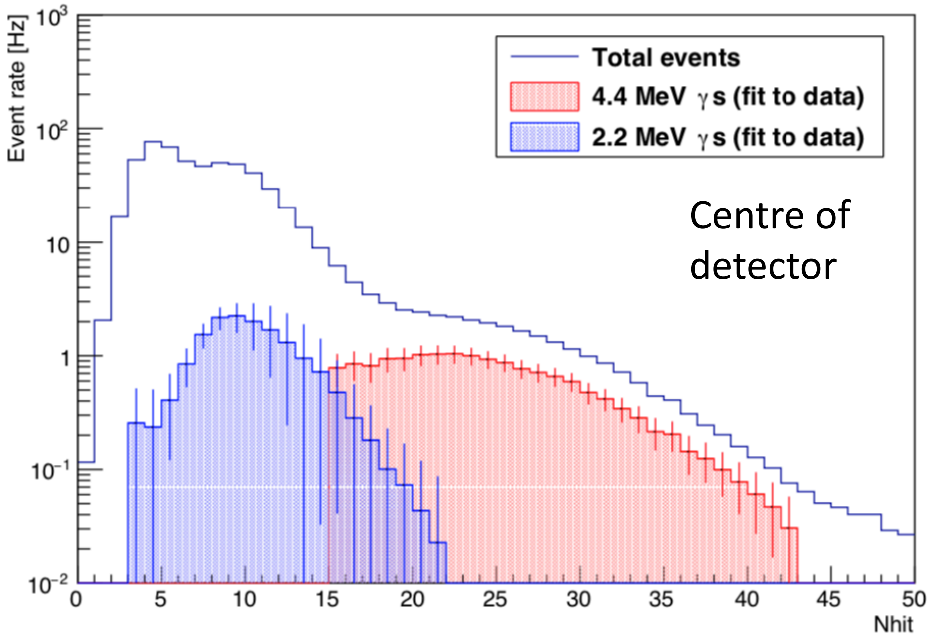
↳ $^{12}C + \gamma$ Q = 4.44 MeV

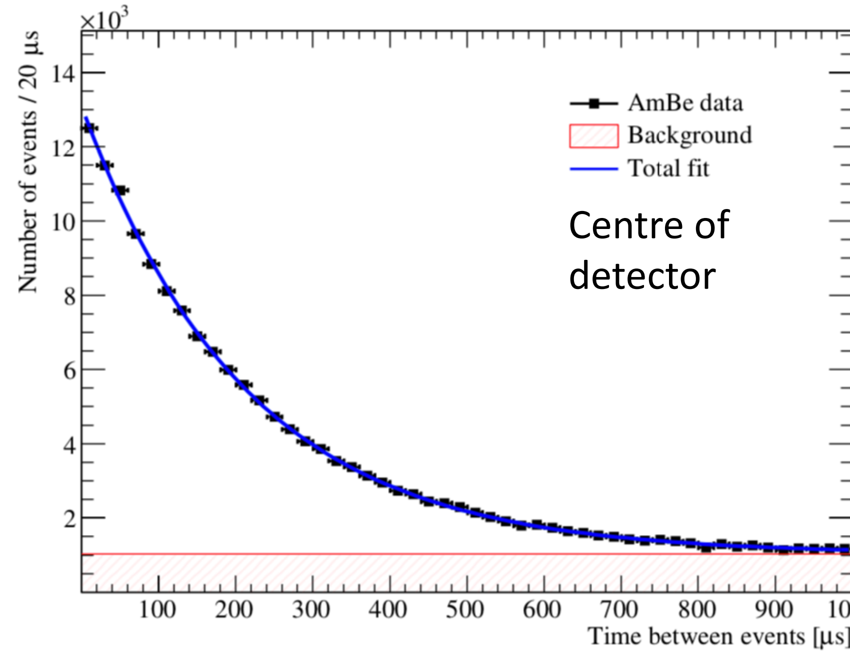


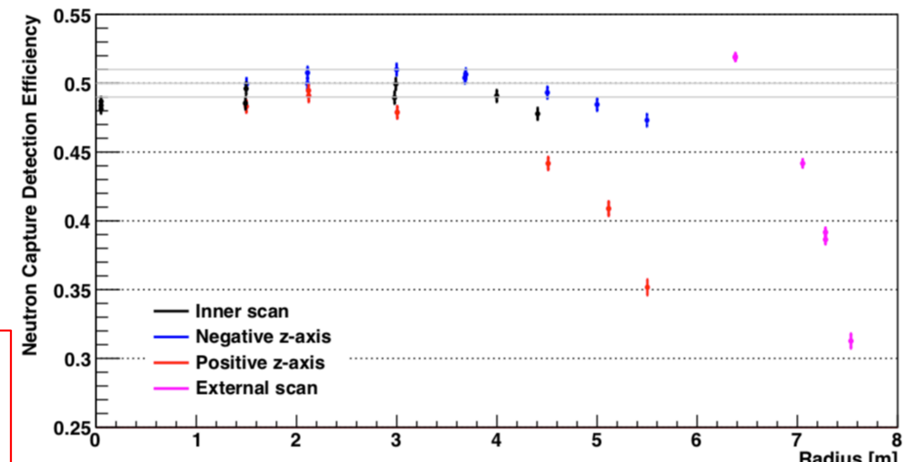
Source activity ~67n/s

SNO+ AmBe Calibration

Use standard detector trigger settings and low level analysis procedures
Select by timing coincidence of events: E1 > 15hits, E2> 4hits

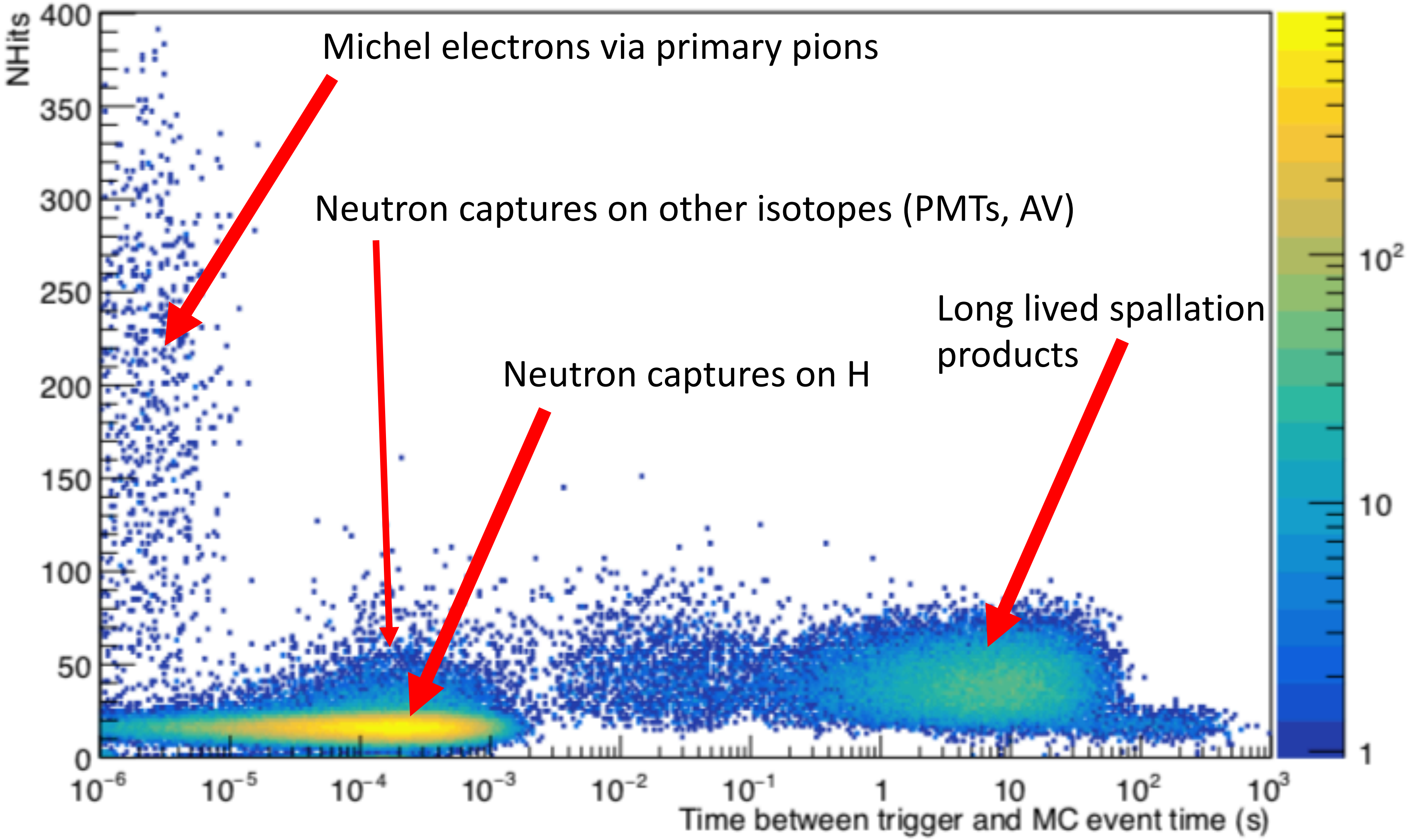






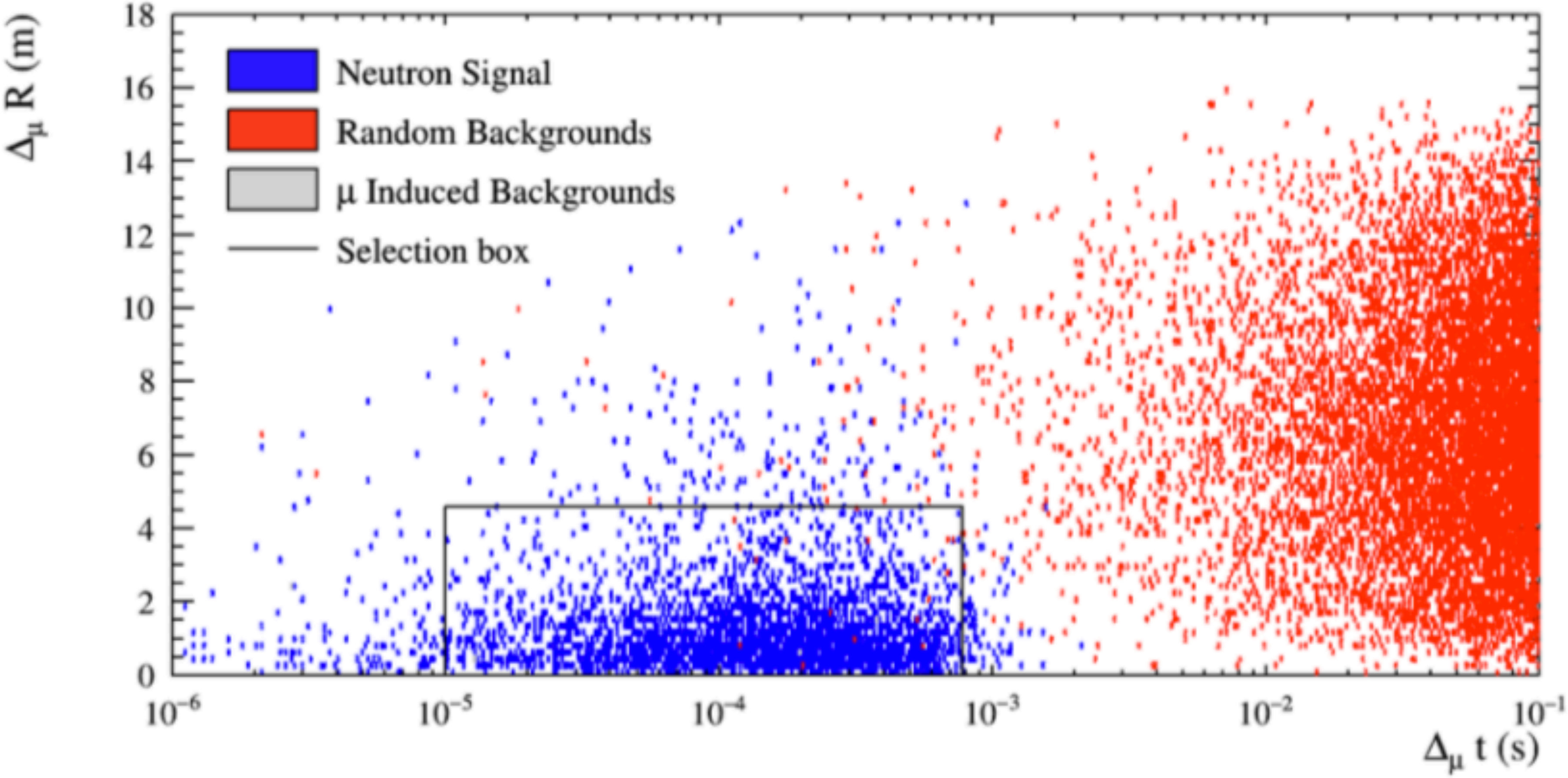
Trigger efficiency = 50% in central regions
Highest known in water Cherenkov detectors
Paper in preparation

Muon induced neutrons (SNO+ H_2O) - Simulation



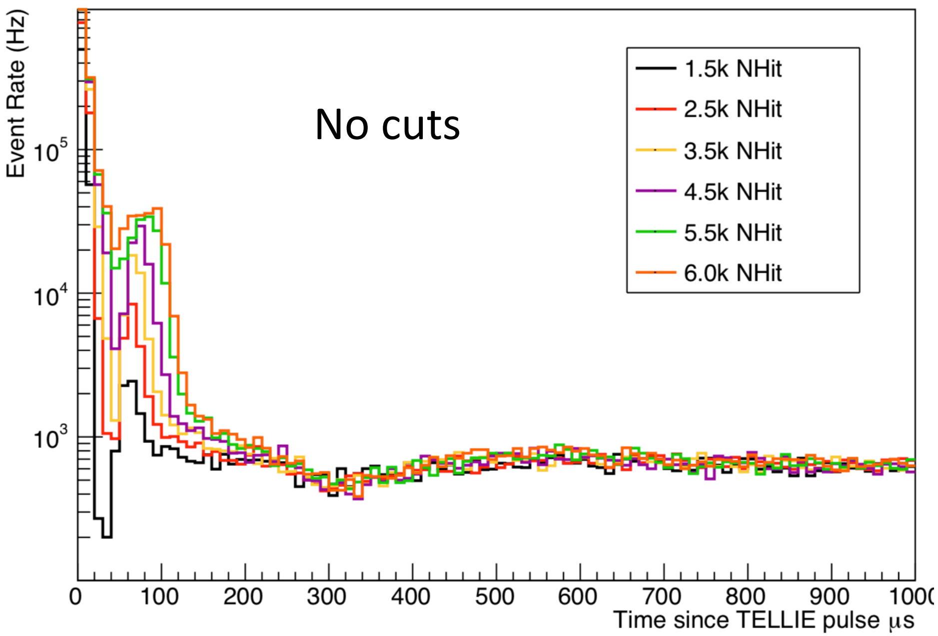
Plot by Mark Stringer, RAT MC

SNO+ optimized neutron selection



Plot by Billy Liggins, SNO+ thesis

Detector ringing after a muon

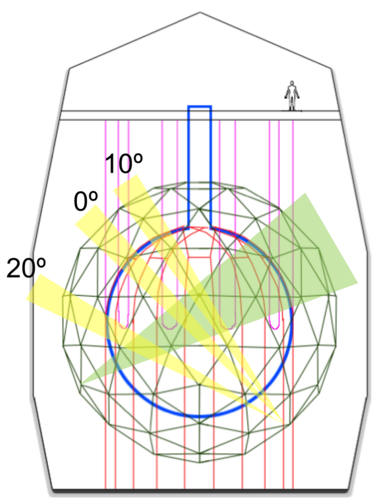


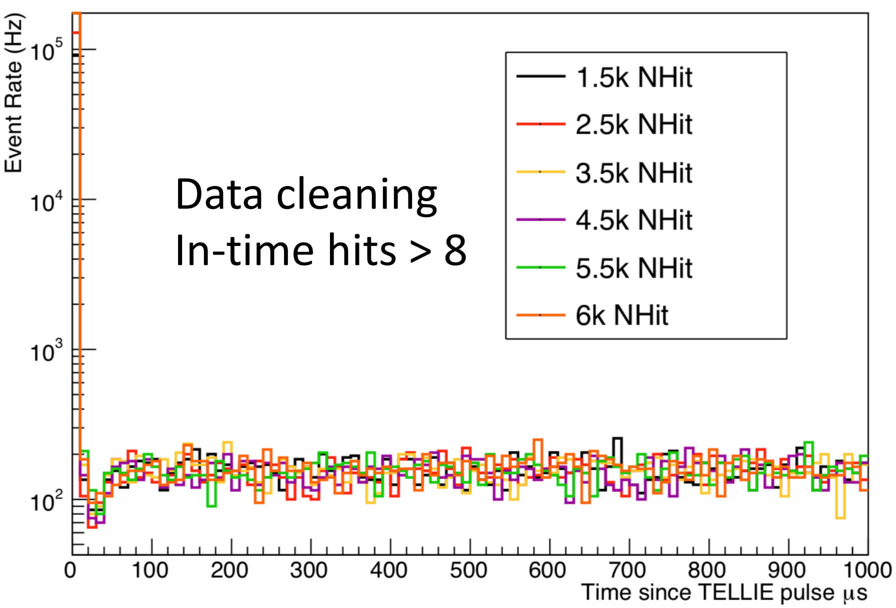
High charge deposit in detector, many channels railed

Initial PMT after-pulsing peak

Then channel baseline shifts for ~100s μs

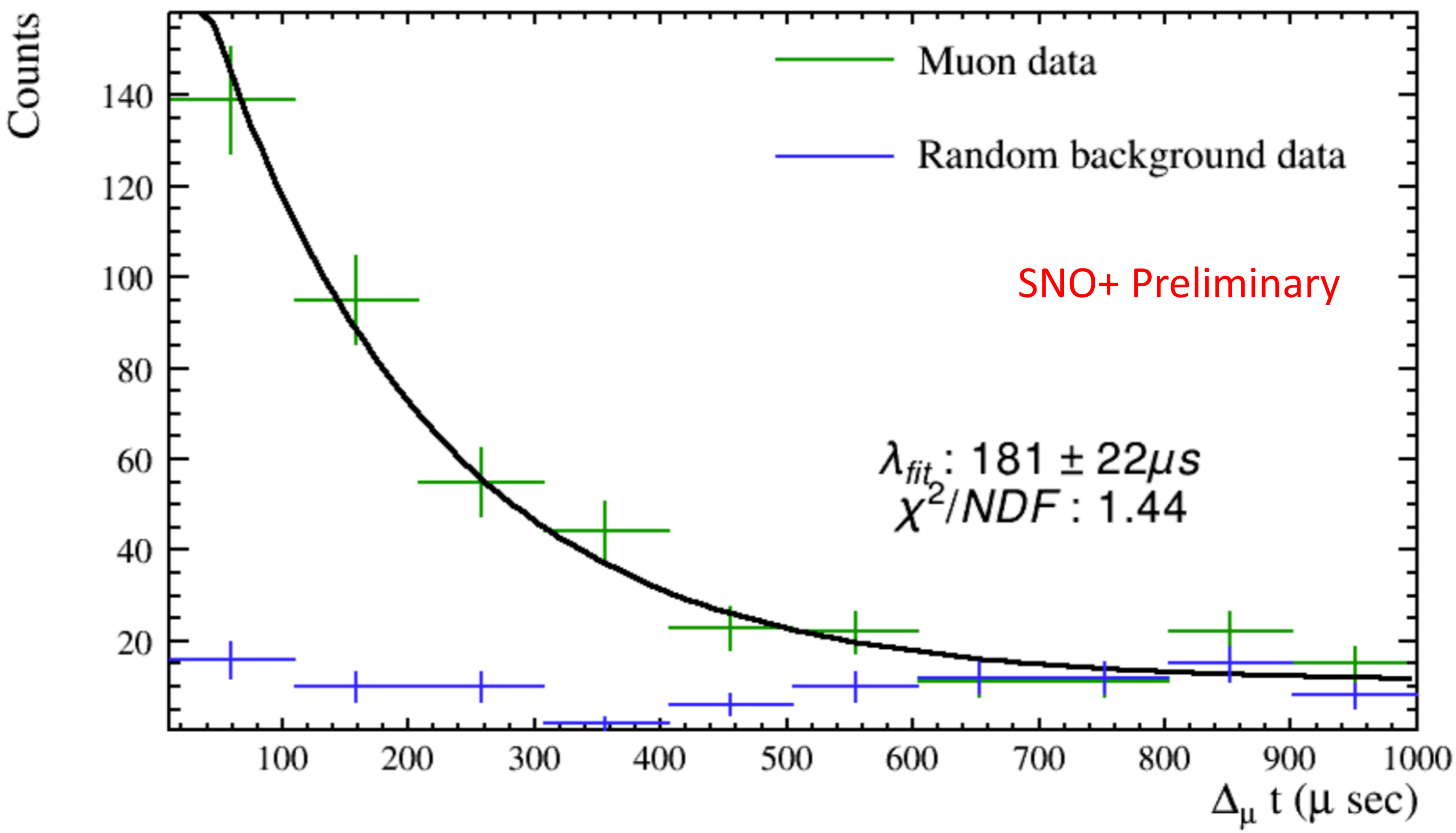
Test effect with high intensity light injection (TELLIE) runs.



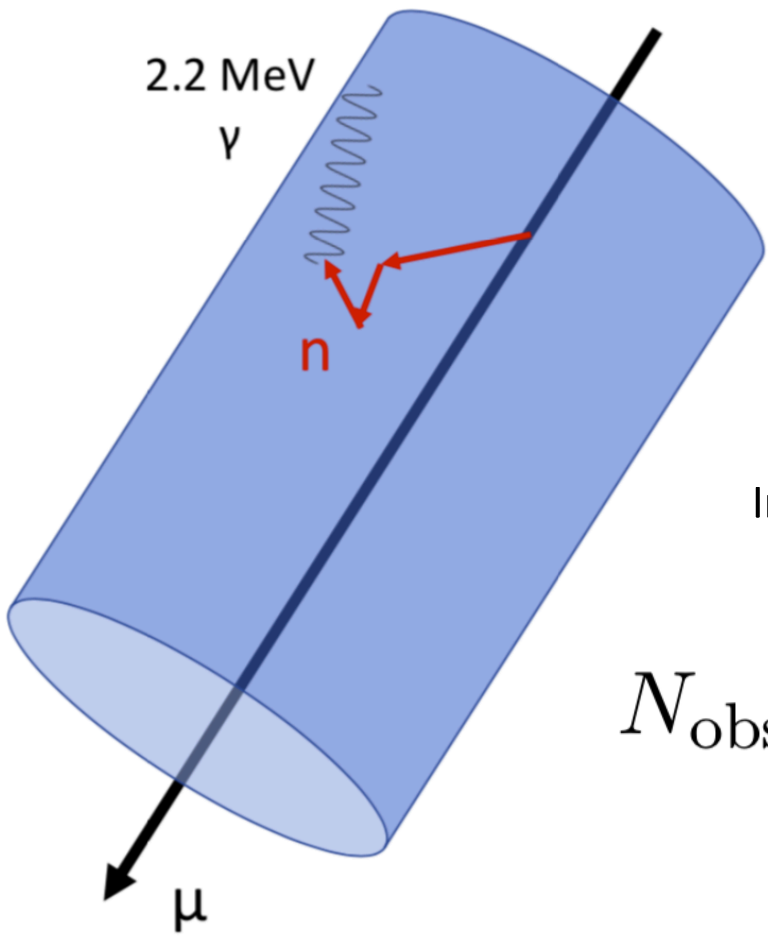


Neutrons confirmed

Cut	Value
In time N100 Cut	$9, 10 < N < 25$
Lower time cut	10 µs
Upper time cut	776 µs
Fit Valid	True
Lateral Fit Distance to Muon Track	4.6 m
Fit Radius	8 m
DC Word	`0x10000073ffe`



Cosmogenic Neutrons



Vary muon-by-muon
Evaluate from MC but very simulation intensive

Calibrate simulation against AmBe data
Still rely on Geant4 extrapolation to higher Energies

Impurity correction
efficiency
Muon correlated backgrounds
Random backgrounds

$$N_{\mathrm{obs}} = (\zeta + \epsilon) \cdot N_n + B_\mu + B_{\mathrm{R}}$$

Apply selection to non-muon following data

Analysis Outlook

SNO data:

	# Muons	% With followers in data	% With followers in MC
Phase I	21485	$(2.9 \pm 0.12)\,\%$	$(3.2 \pm 0.01)\,\%$
Phase II	31898	$(5.8 \pm 0.13)\,\%$	$(5.7 \pm 0.01)\,\%$

SNO+ data period much shorter so less muons,

but capture cross section on H much greater than on D or Cl

but neutron detection efficiency much lower

6110 muons examined so far, expect to at least double the data set

H_2O

In scintillator, we will have close to 100% efficiency to detect 2.2MeV γs

Will be able to use neutrons as part of three-fold coincidence tag to identify longer lived cosmogenic isotopes like ^{11}C.

LABPPO

Summary

- SNOLAB depths give access to low rate high energy cosmic muon flux
- Unique opportunity to measure cosmogenic neutrons on different targets (D_2O, H_2O, LAB) with same detector
- SNO has published cosmogenic neutron measurement
  - Large data sample allows tests of Monte Carlo models as well as yield measurement
- SNO+ calibrations show excellent neutron detection efficiency for H_2O Cherenkov detector
  - Cosmogenic neutron measurement underway.

Back up

Phase	Target	Live Time (d)
I	D_2O	306.4
II	D_2O + 0.2% NaCl	478.6
III	D_2O + NCDs	387.2

TABLE I. Duration and live time for each operational phase.