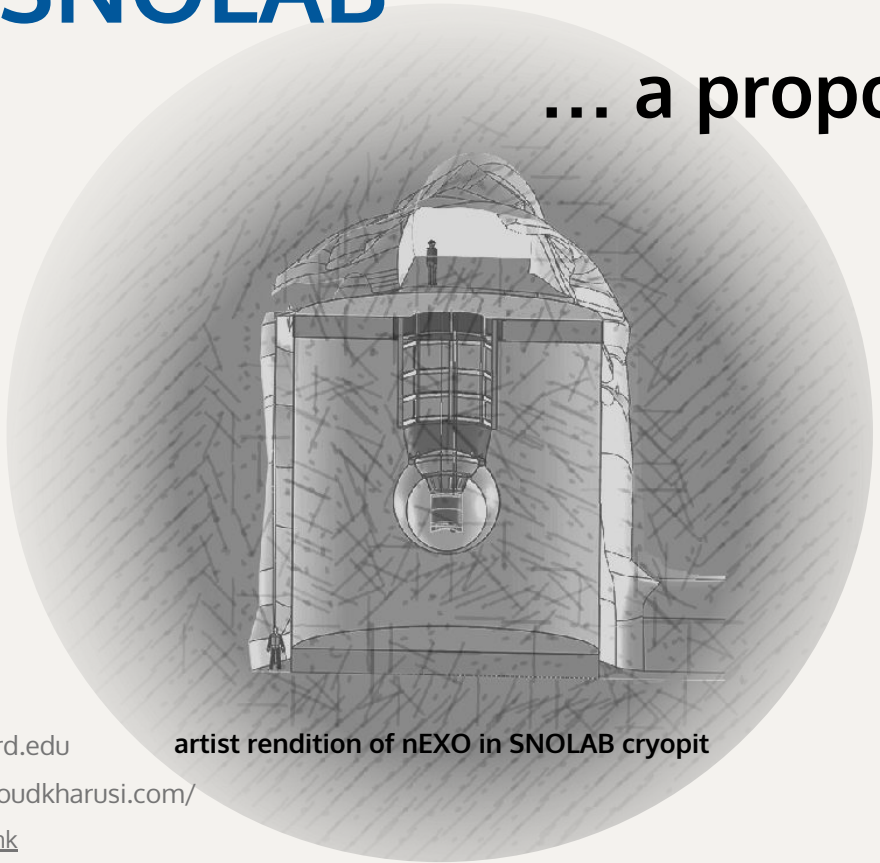
Harmonizing muon flux simulations for SNOLAB

… a proposal, or a call for help??



artist rendition of nEXO in SNOLAB cryopit

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SNOLAB User's Meeting
June 27th 2024

Google Slides link

All experiments at SNOLAB have the ~same muon flux

- All experiments at SNOLAB are at the same depth (~2 km rock, 6010 m.w.e.)
- SNOLAB has a flat overburden that lends itself to a **well parameterized muon flux** (e.g., Mei & Hime)

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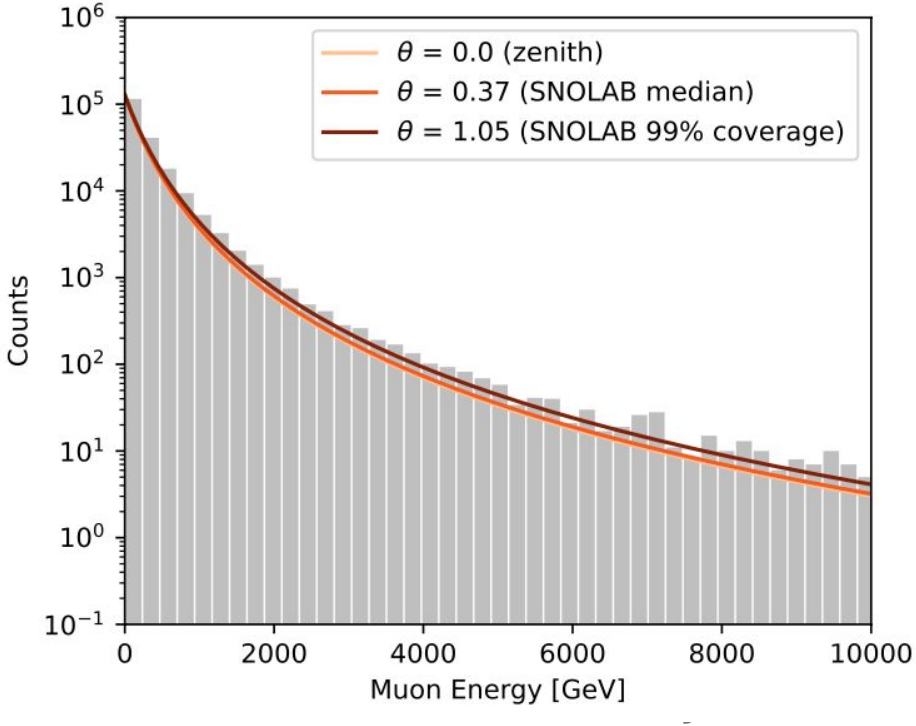
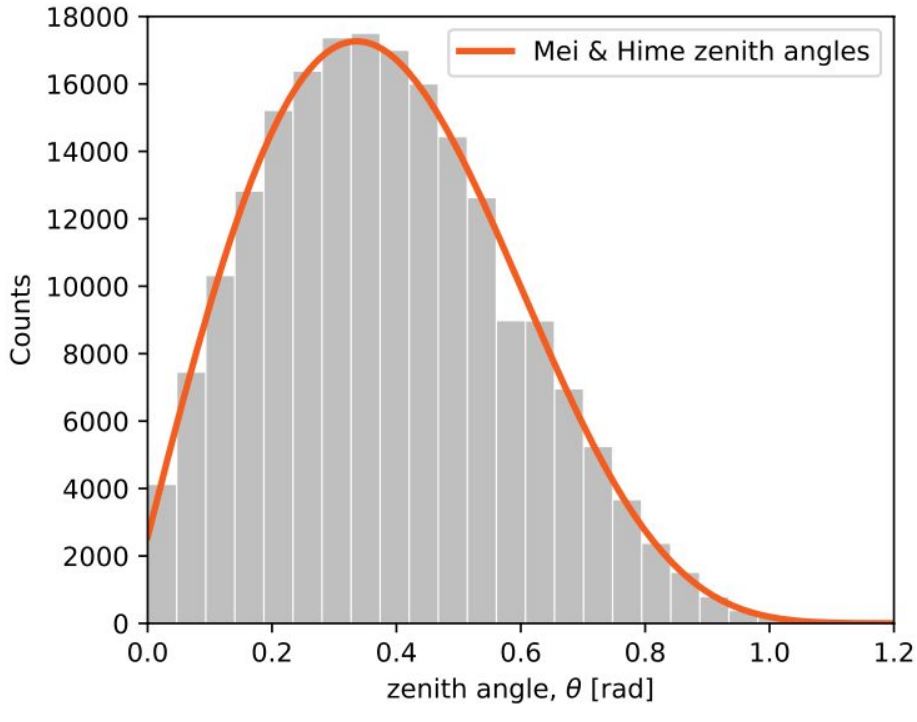
- SNOLAB has a flat overburden that lends itself to a **well parameterized muon flux** (e.g., Mei & Hime)
- Low-background experiments need to simulate this muon flux **in their preferred particle transport software**

SNOLAB (Mei & Hime) Muon Flux

(muon energies and angles are correlated)





Some old stuff

- Underground experiments since **SNO have measured and parameterized the flux at SNOLAB**
- Geant4 and FLUKA (among other softwares) are the “standard” bread-and-butter to perform cosmogenics simulations
  - see talk by R. Ross from earlier today
  - see also DARWIN (2024) and KamLAND-Zen (2023) cosmogenics papers
- Geant4v10.5+ and FLUKA now ~equivalent in activation estimates for nEXO
  - see EXO-200 Cosmogenics for an older comparison

Some new stuff

- Active development in Canada in getting more accurate underground muon fluxes, e.g., MUTE software (arXiv) which can include seasonal variation, etc...

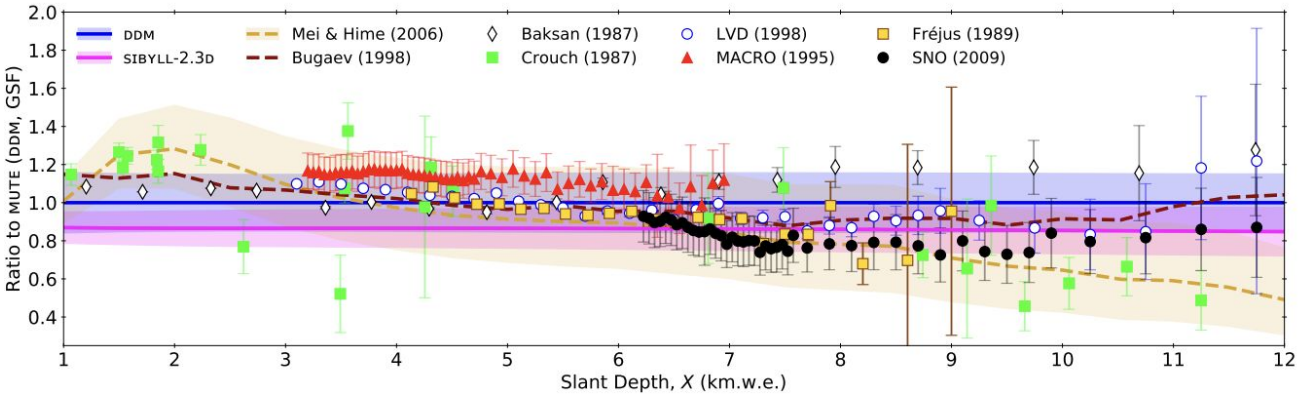
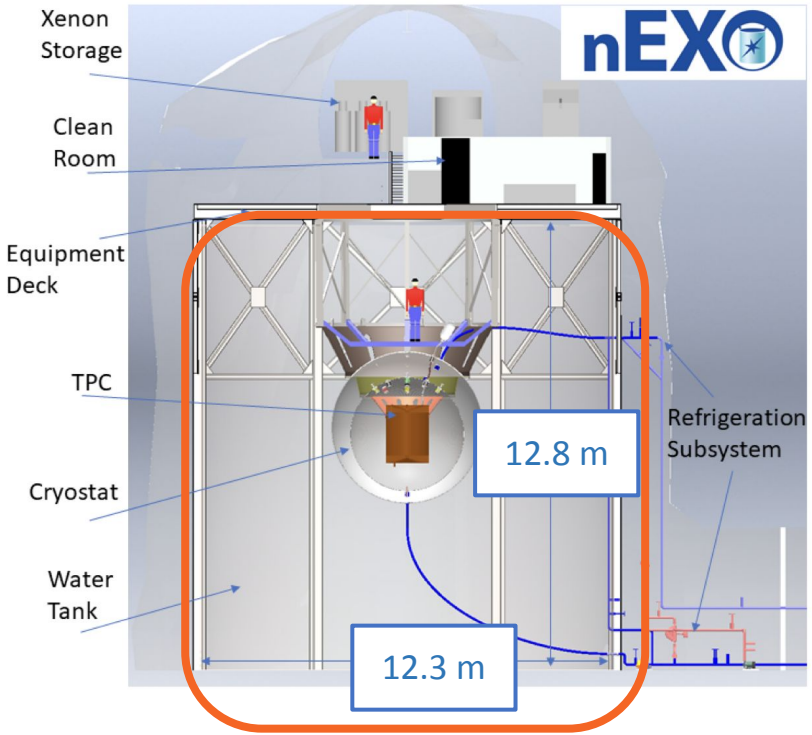


Figure 10. The ratio to MUTE results for standard rock using DDM and GSF of the experimental data and the predictions made with SIBYLL-2.3D with uncertainties computed using the *Bartol* method, the MH fit, and the BMN calculation. All experimental data are referenced in Figure 8. Systematic and statistical errors are geometrically summed for LVD, MACRO, and SNO. Other error bars denote solely statistical errors.

The nEXO $0\nu\beta\beta$ Experiment

- 5-tonnes of LXe is **enriched to 90% in the target isotope**, ^{136}Xe
- LXe in a single-phase liquid xenon Time Projection Chamber (**LXe TPC**)
- **Surrounded by a large water tank** for radioactive shielding and **muon tagging**

This is not unique to nEXO...



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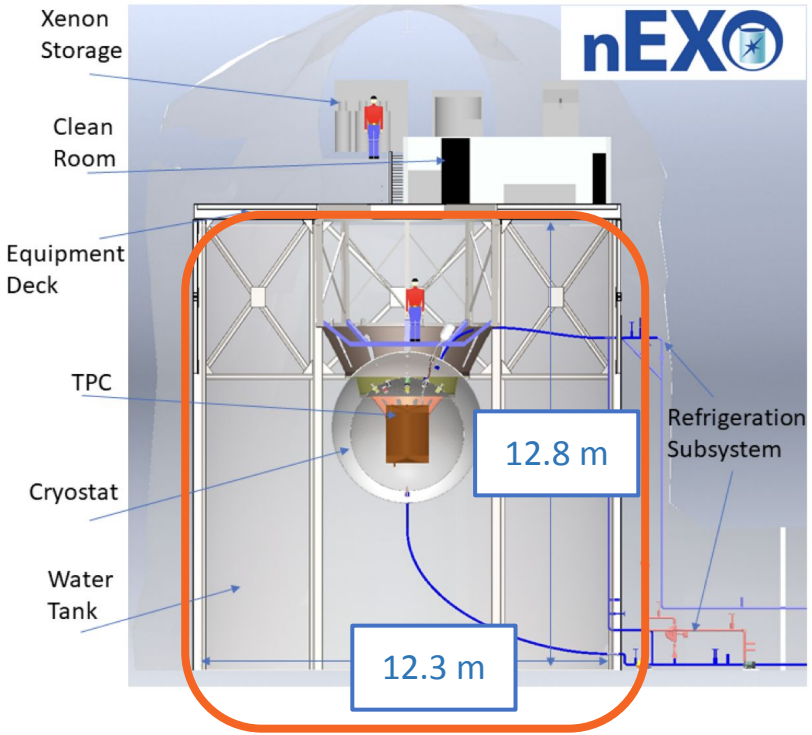
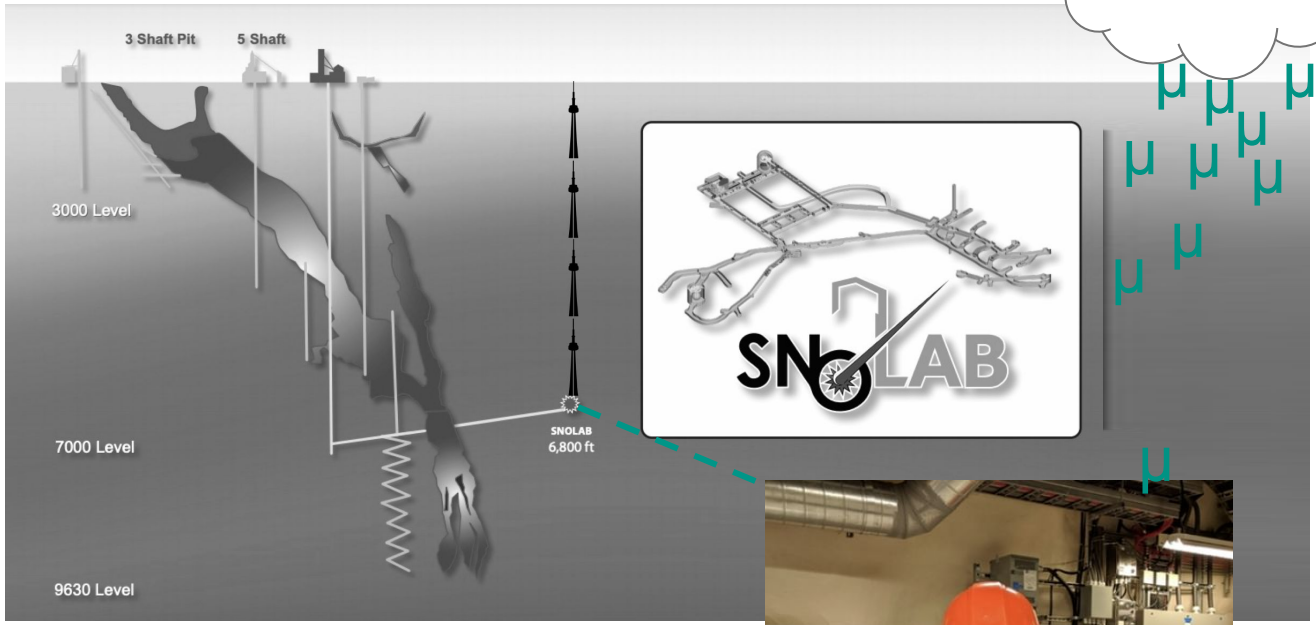
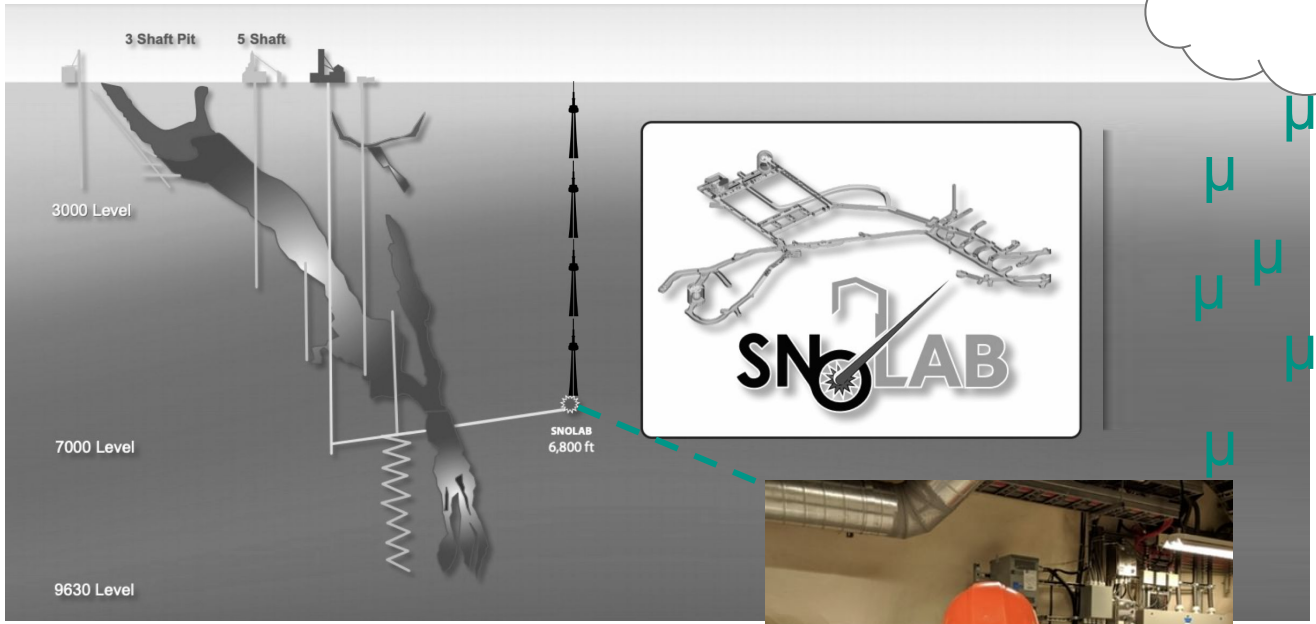


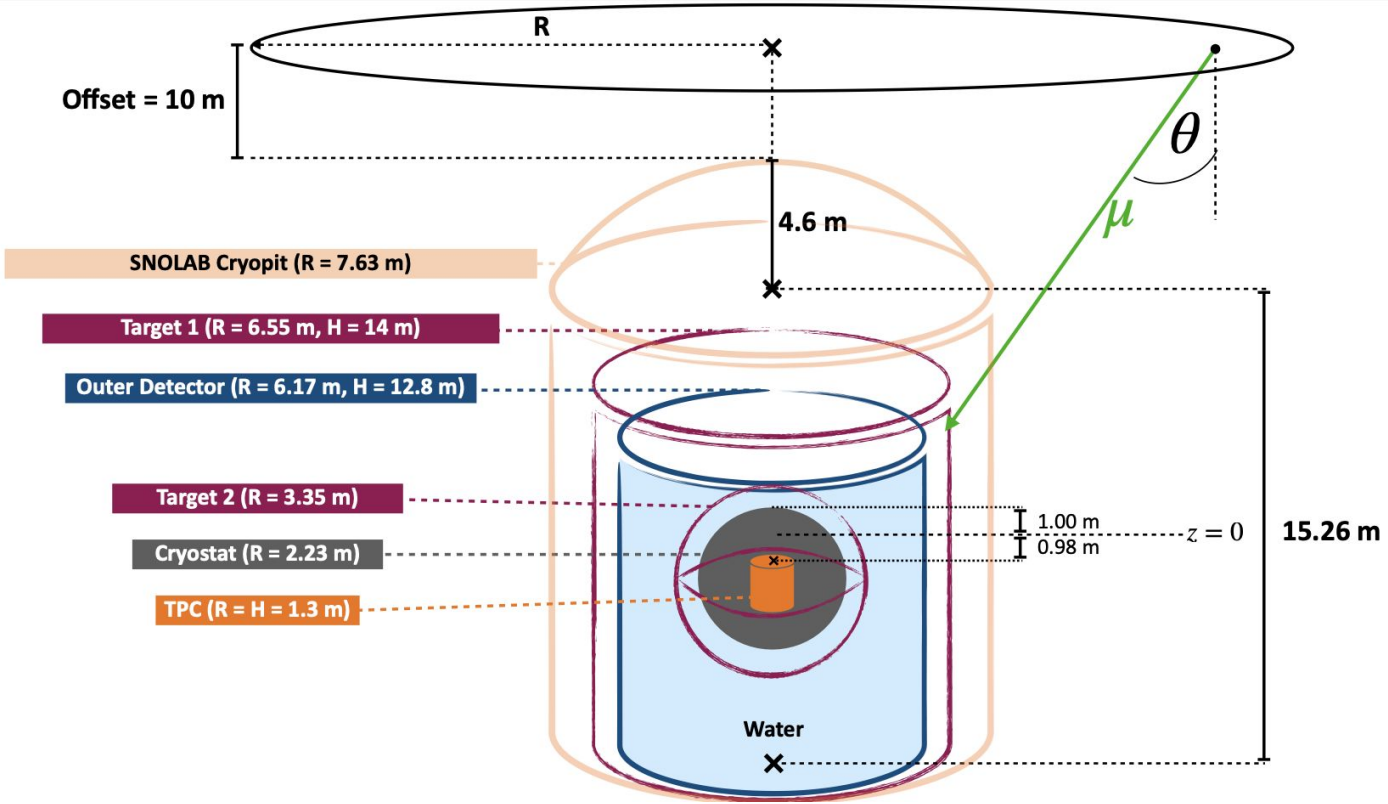
Tale of a graduate student



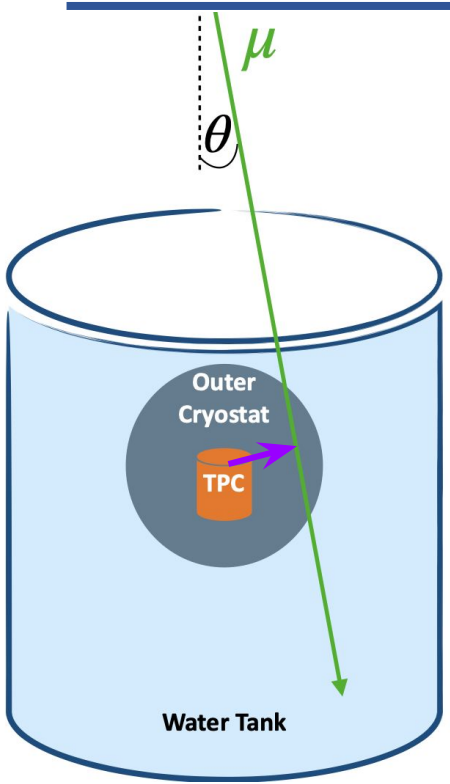
Realizing I have to remodel the flux…

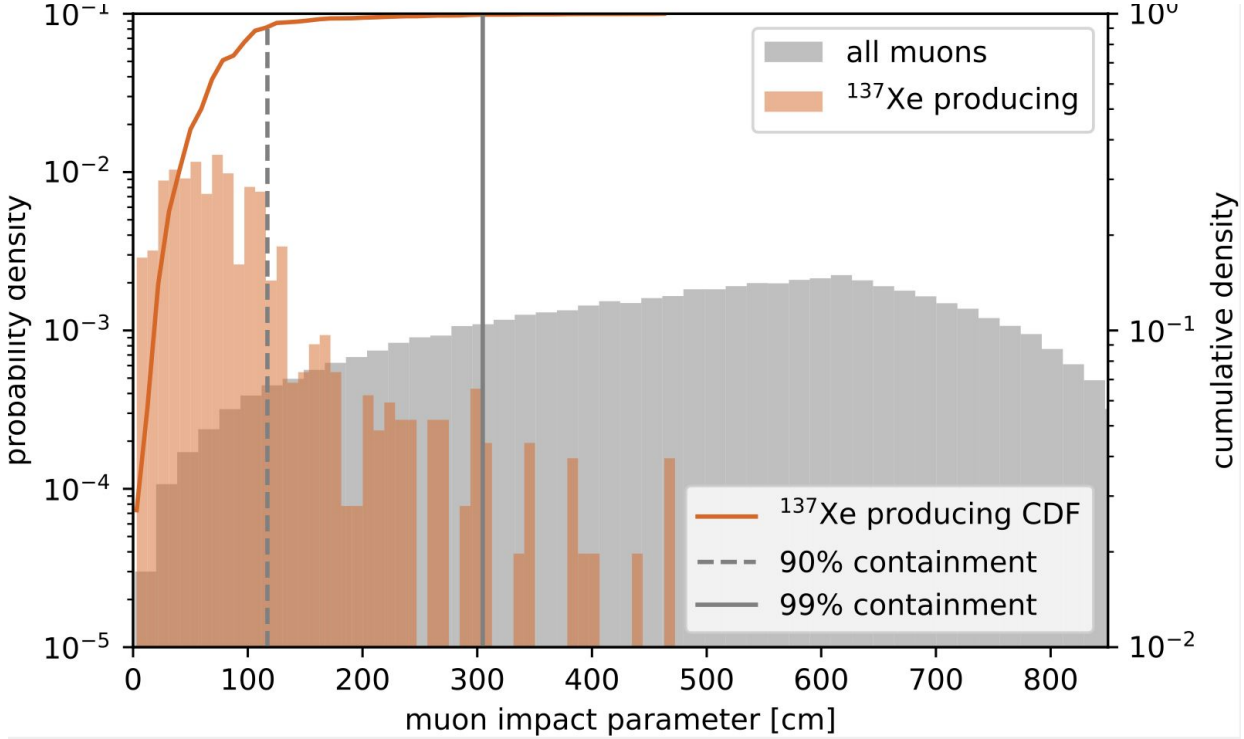


Modelling the underground muon flux



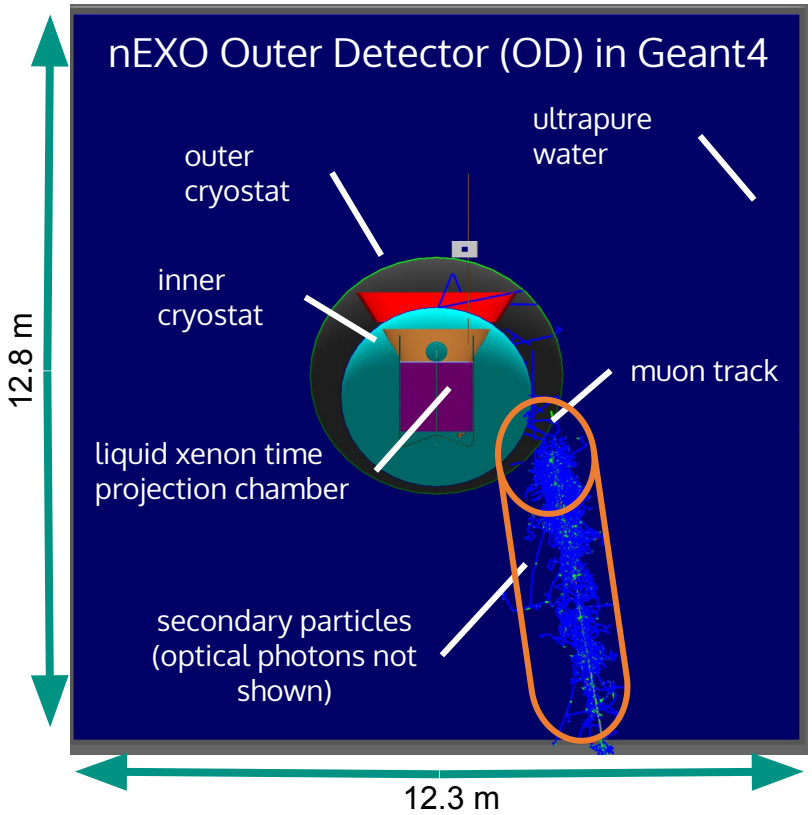
Low impact parameter → more background production

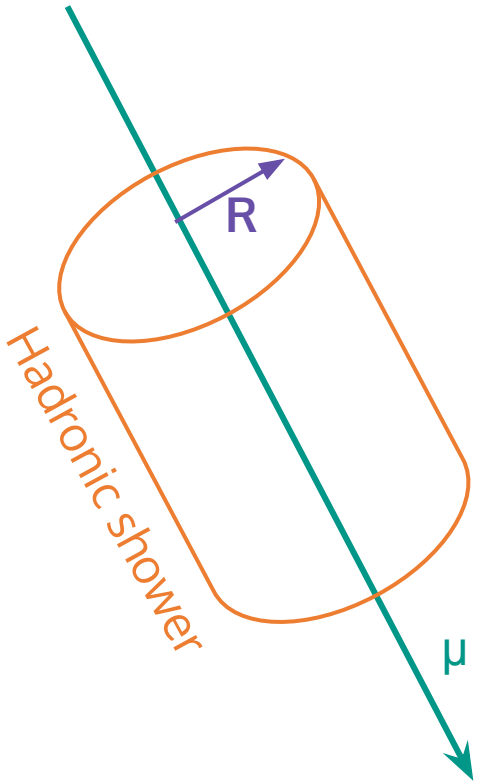




See also: [B. Aharmim et al (2019) "Cosmogenic Neutrino Production at the Sudbury Neutrino Observatory"]

Size scales of hadronic showers





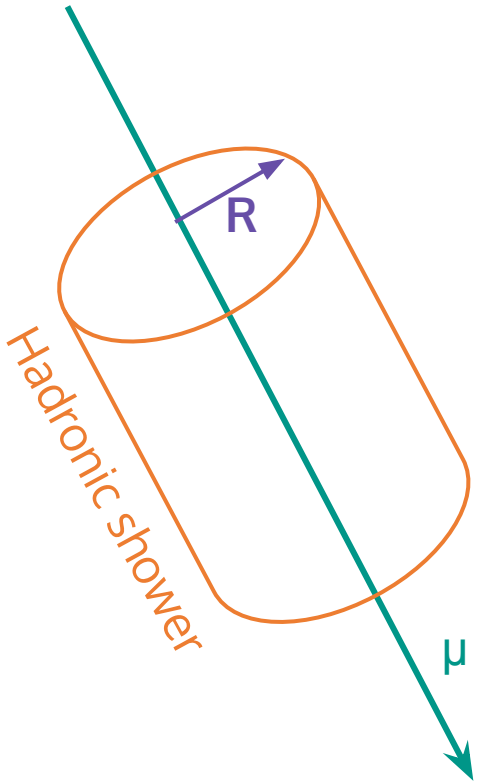
Size scales of hadronic showers

Super-K/DUNE studies from S.W. Li & J.F. Beacom:

1. spallation **backgrounds are associated with muon showers**, and are a **result of secondary particles**

2. Muon **showers are rare**, and so their occurrence and **localization can be used to define background rejection algorithms**.

3. Almost all **isotope-producing showers** (e.g., those leading to neutron captures) **are produced in hadronic and not EM showers**.

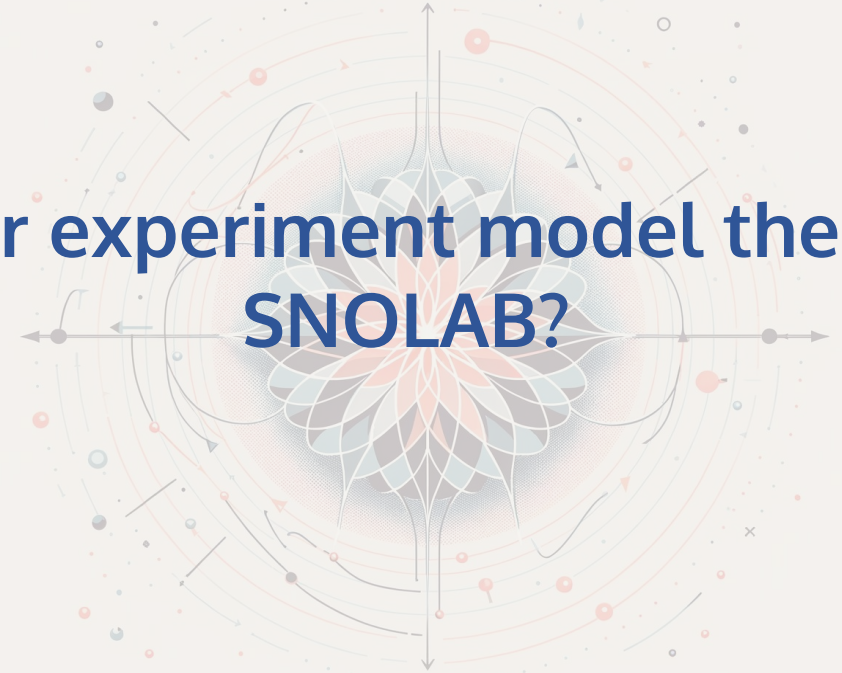


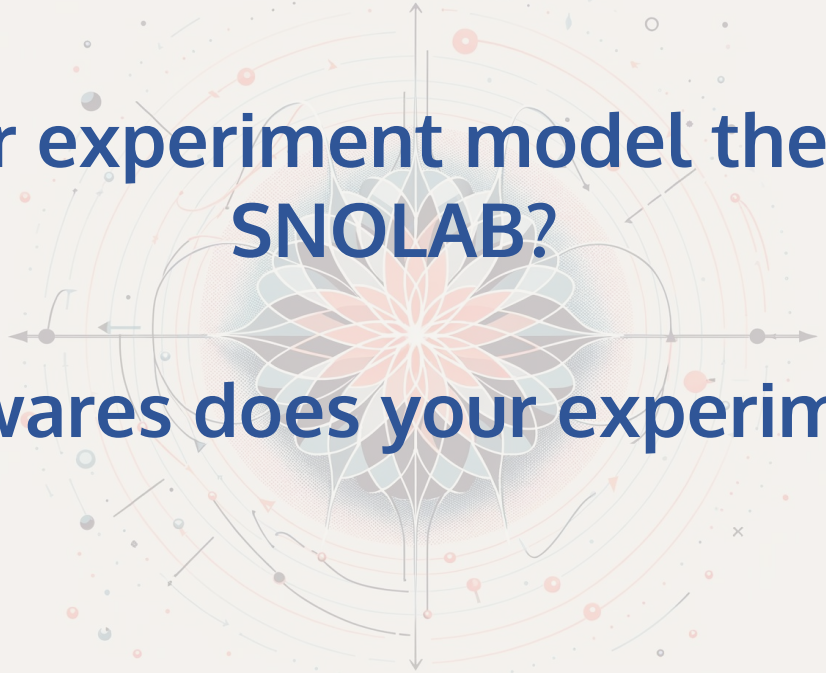
References:

- 10.1103/PhysRevC.89.045801
- 10.1103/PhysRevD.91.105005
- 10.1103/PhysRevD.92.105033
- 10.1103/ PhysRevC.99.055810

$R \sim 1m$ @ mean $E_\mu \sim 270$ GeV

How does your experiment model the muon flux at SNOLAB?





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How can we/have we validated the lower energy backgrounds, e.g., neutron scatters for DM experiments with a standard Geant4 physics list?

What we need from you…

- Put your experiment's experts on muon simulations/cosmogenics in touch with us so we can begin this conversation
- Help us decide on whether Geant4 modules are the way to go, or otherwise…
- Potential integration into "underground physics" Geant4's advanced example?

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