The Cosmogenic Neutron Multiplicity in Water at SNO+

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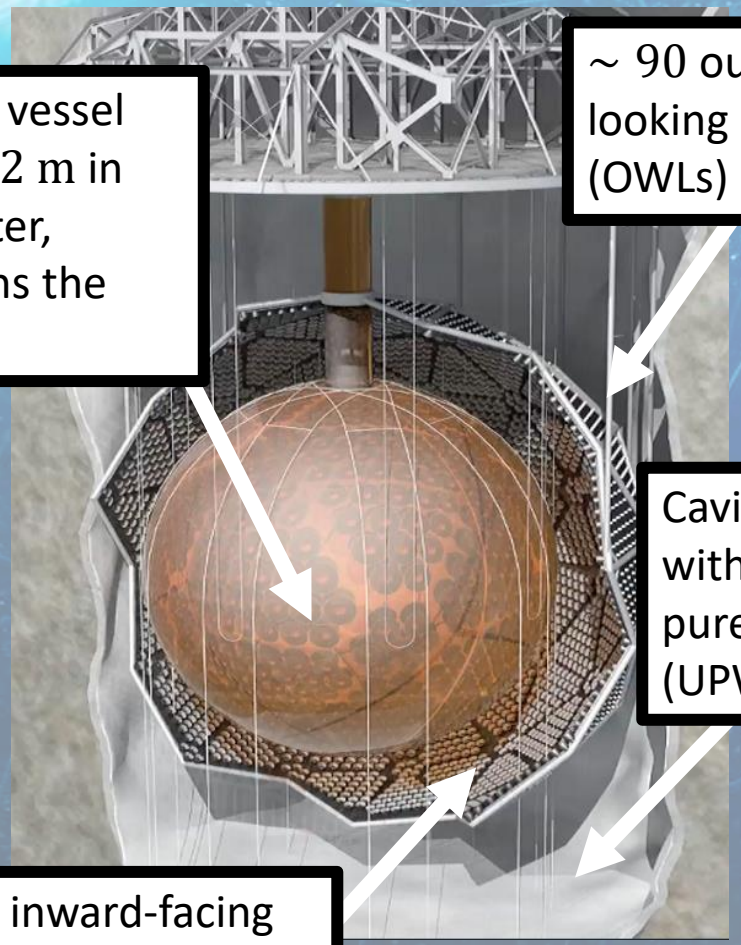
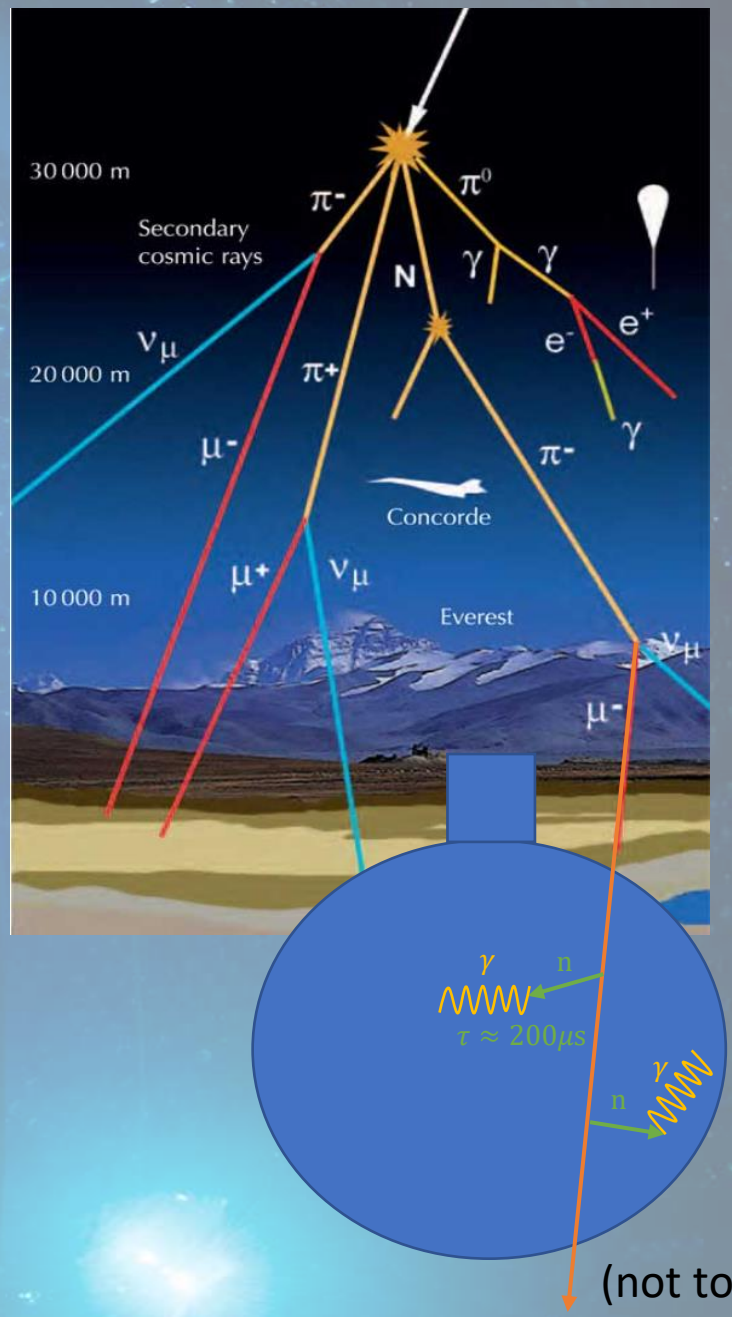
SNO+



- **The SNO+ detector is located 2070m underground in SNOLAB, Canada**
- **Three phases: water, scintillator, tellurium**
- **Main goal is the search for neutrinoless double beta decay ($0\nu\beta\beta$)**

Cosmogenic Neutrons

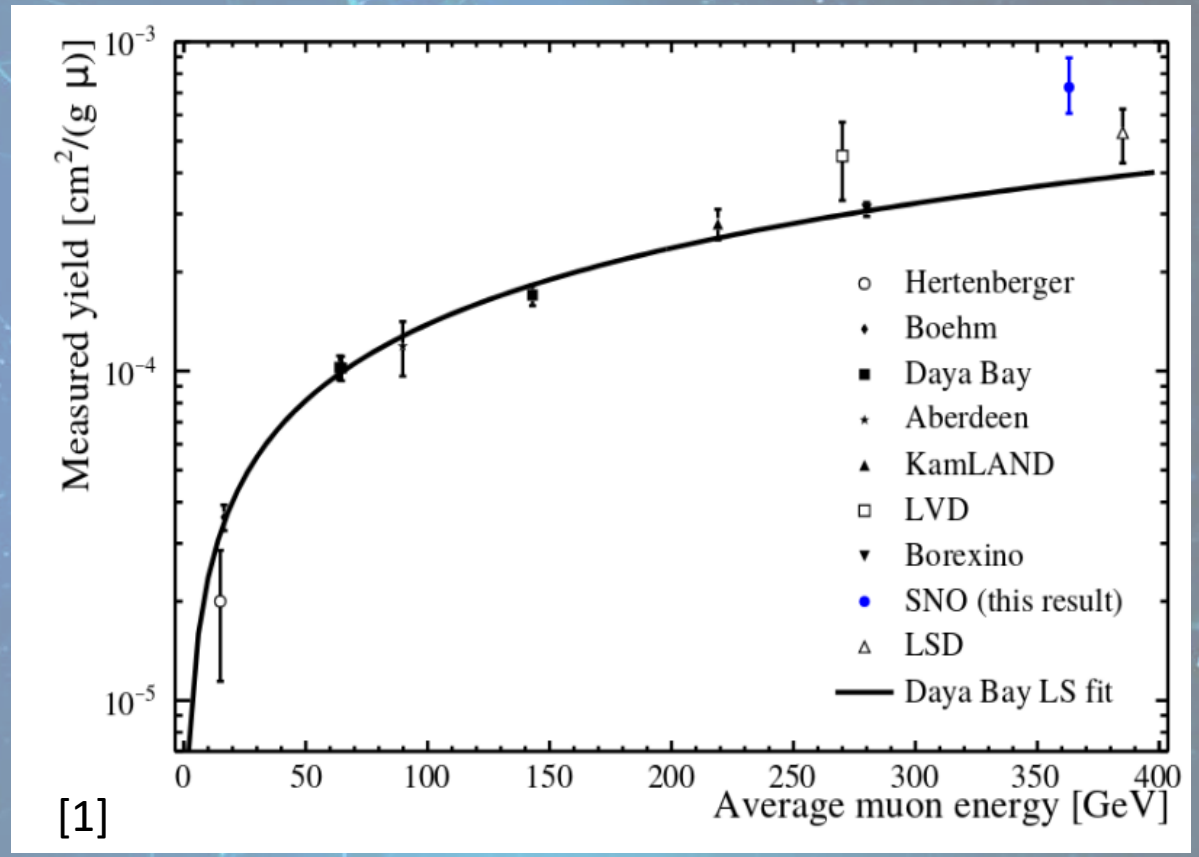
- **Approximately three high energy cosmic muons pass through the detector per hour**
- **The cosmic muons produce free neutrons which capture onto hydrogen atoms that will emit $2.2\mathrm{MeV}$ gammas**
- **Muon-induced neutrons pose as a background to many physics experiments which require very low backgrounds**



(not to scale)

Neutron Multiplicity

- **The number of neutrons produced changes with energy**
- **SNO has already made a measurement of the muon-induced neutron yield in heavy water**
- **SNO+ can measure this yield, with the same muon flux, in water and scintillator**



[1]

[1] Cosmogenic neutron production at the sudbury neutrino observatory, 2019

Measuring the Neutron Yield

Neutron multiplicity is determined through the measurement of the neutron yield:

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

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Number of neutrons produced by a given muon.

- Related to the number of observed neutrons…

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Density of the medium.

Number of neutrons per muon

The number of neutrons per muon is related to the number of neutrons observed per muon:

$$N_{\mathrm{obs}}^{\mu} = \varepsilon^{\mu} N_{n}^{\mu} + B_C + B_R$$

Backgrounds:

- B_C - other spallation products
- B_R - random detector backgrounds

Neutron selection efficiency:

- Number of selected neutrons of total number of neutrons produced in water

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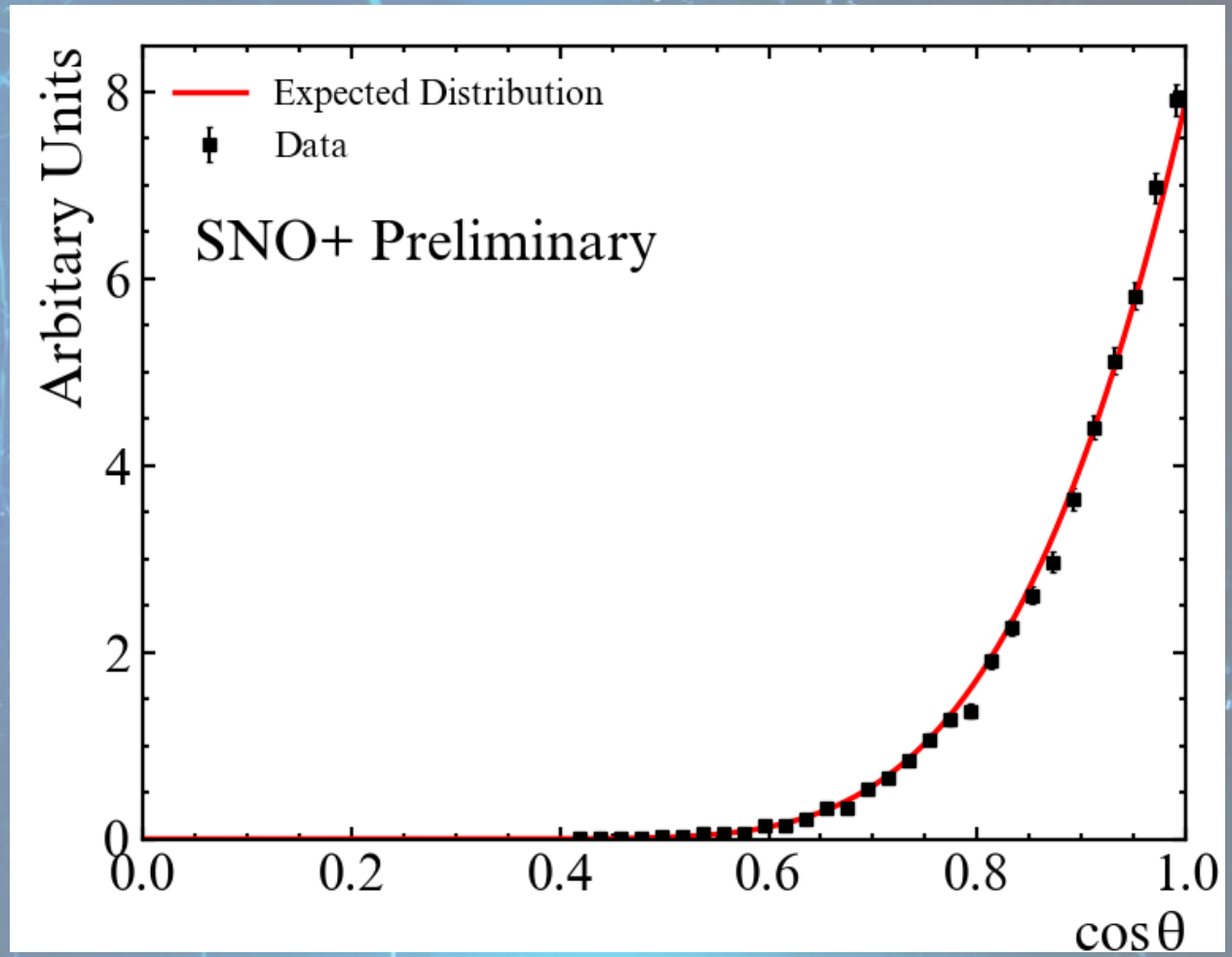
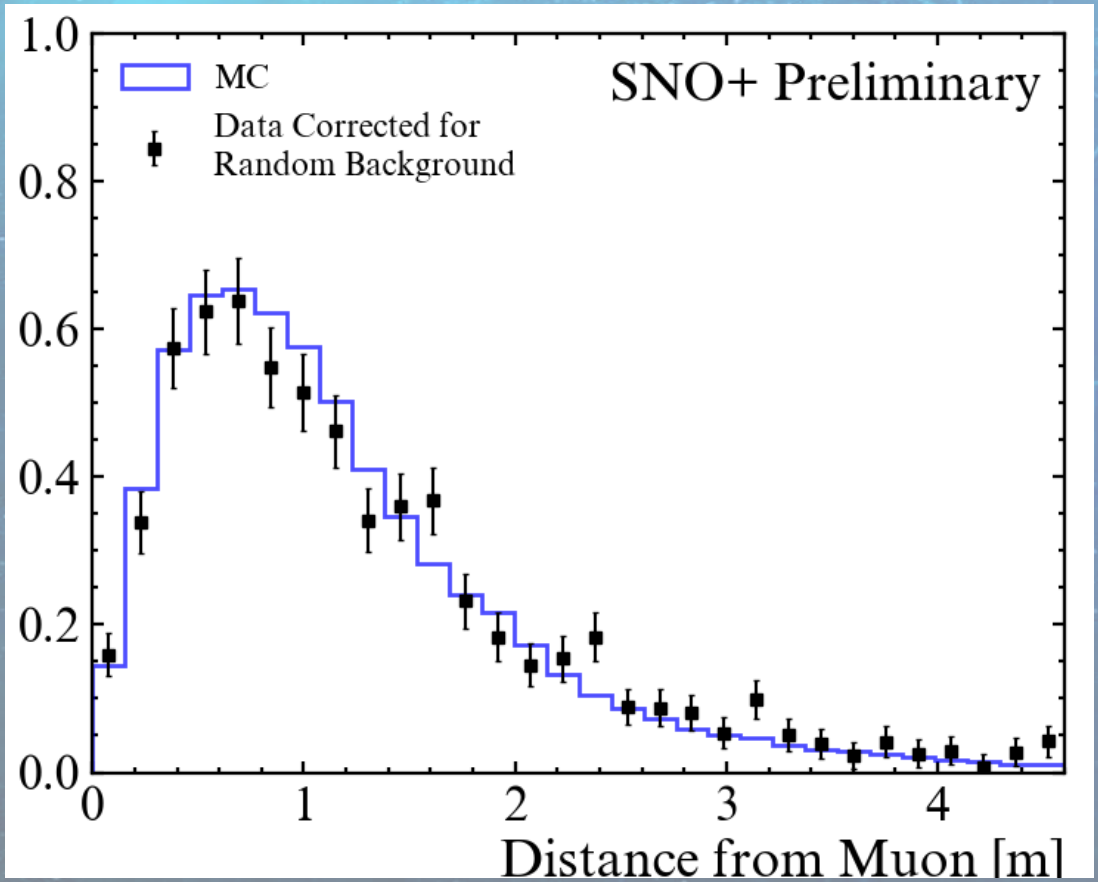
Muon Selection

- **This analysis requires a pure sample of muons**
- **Only down going muons with a track length of more than 10 m are selected**
- **The data matches the expected direction-intensity relation [2], at SNO+ depth, well**



[2] D.-M. Mei and A. Hime. “Muon-Induced Background Study for Underground Laboratories”.

Neutron Selection



- **Neutron selection criteria:**

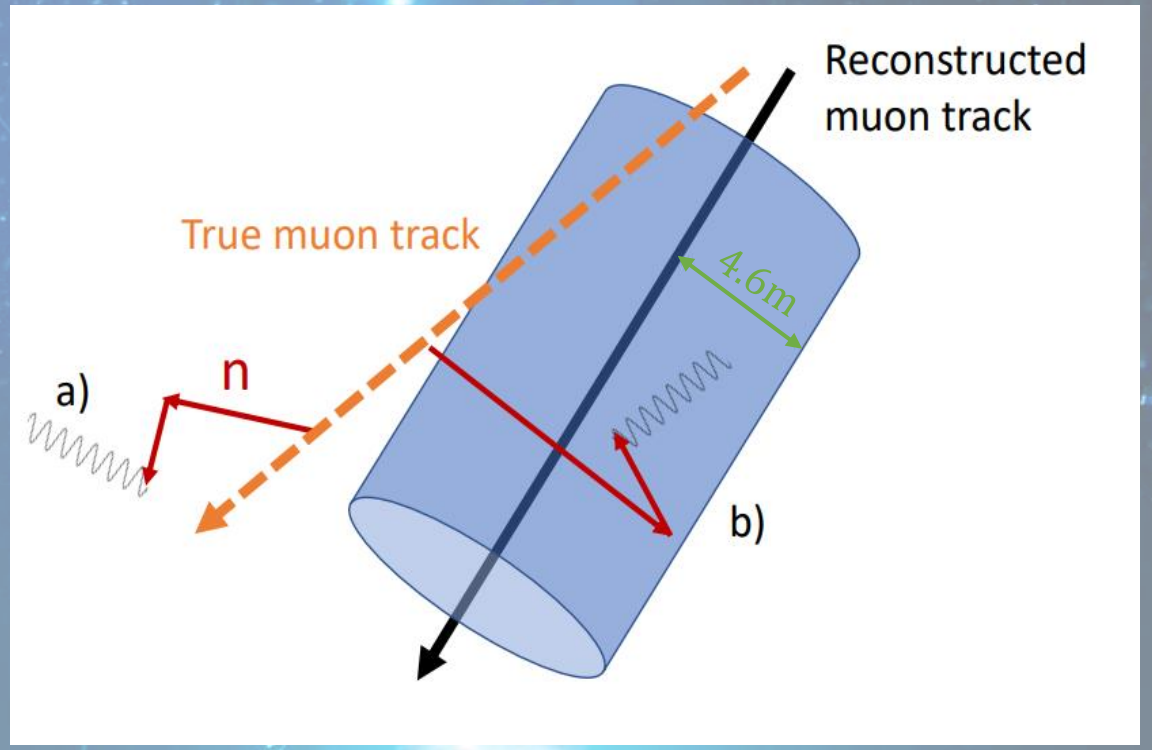
Parameter	Select if
Time since muon, t_μ	$10\ \mu s < t_\mu < 776\ \mu s$
PMT hits, H_{PMT}	$9 < H_{\mathrm{PMT}} < 25$
Distance from muon, d_μ	$d_\mu < 4.6$ m
Radius, R	$R < 8$ m

- **Data shows good agreement with simulation**

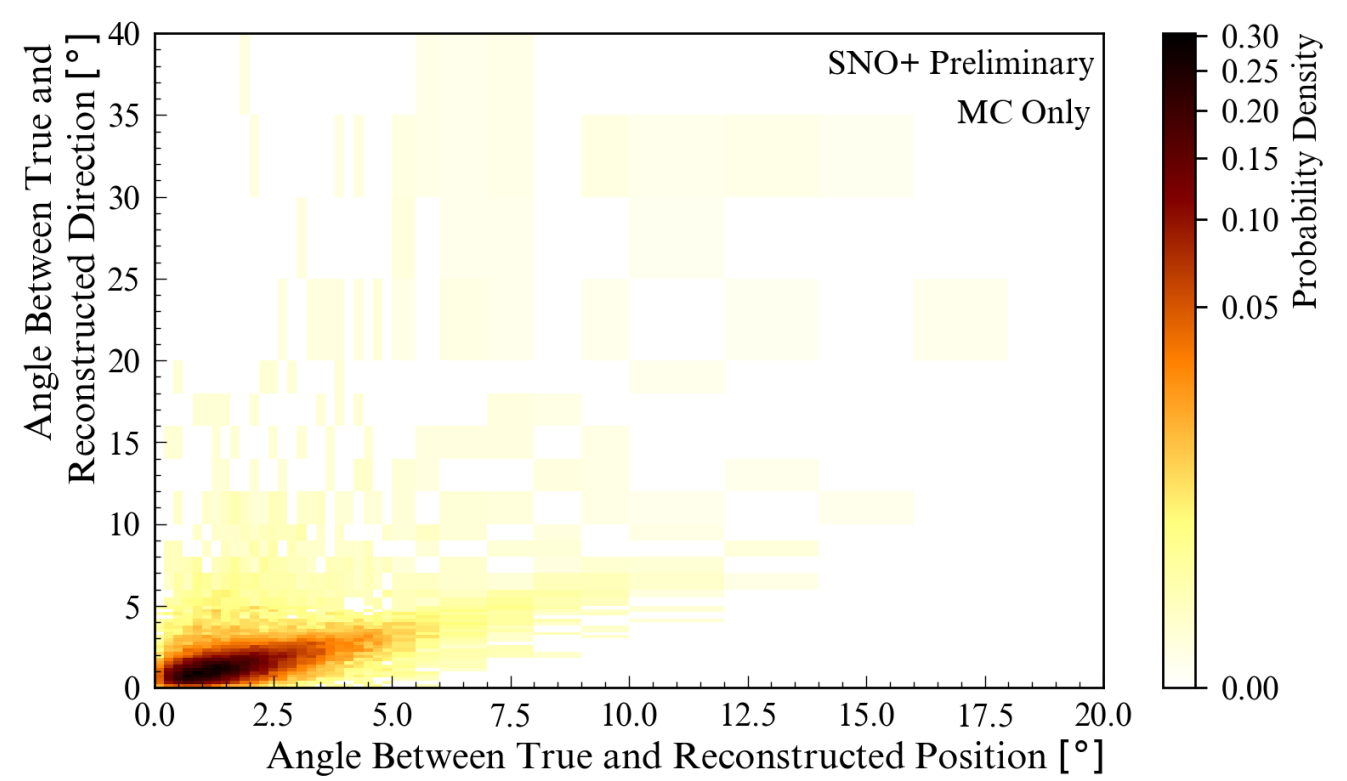
Neutron Selection Efficiency

$$\varepsilon = \frac{\text{number of neutrons which pass selection cuts}}{\text{number of neutrons generated along muon track in water}}$$

- **This is position dependent so must be evaluated for each individual muon**
- **The efficiency is low in water due to low energy - only 9-25 PMT hits per neutron capture event**
- **The misreconstruction of the muon track must also be taken into account**

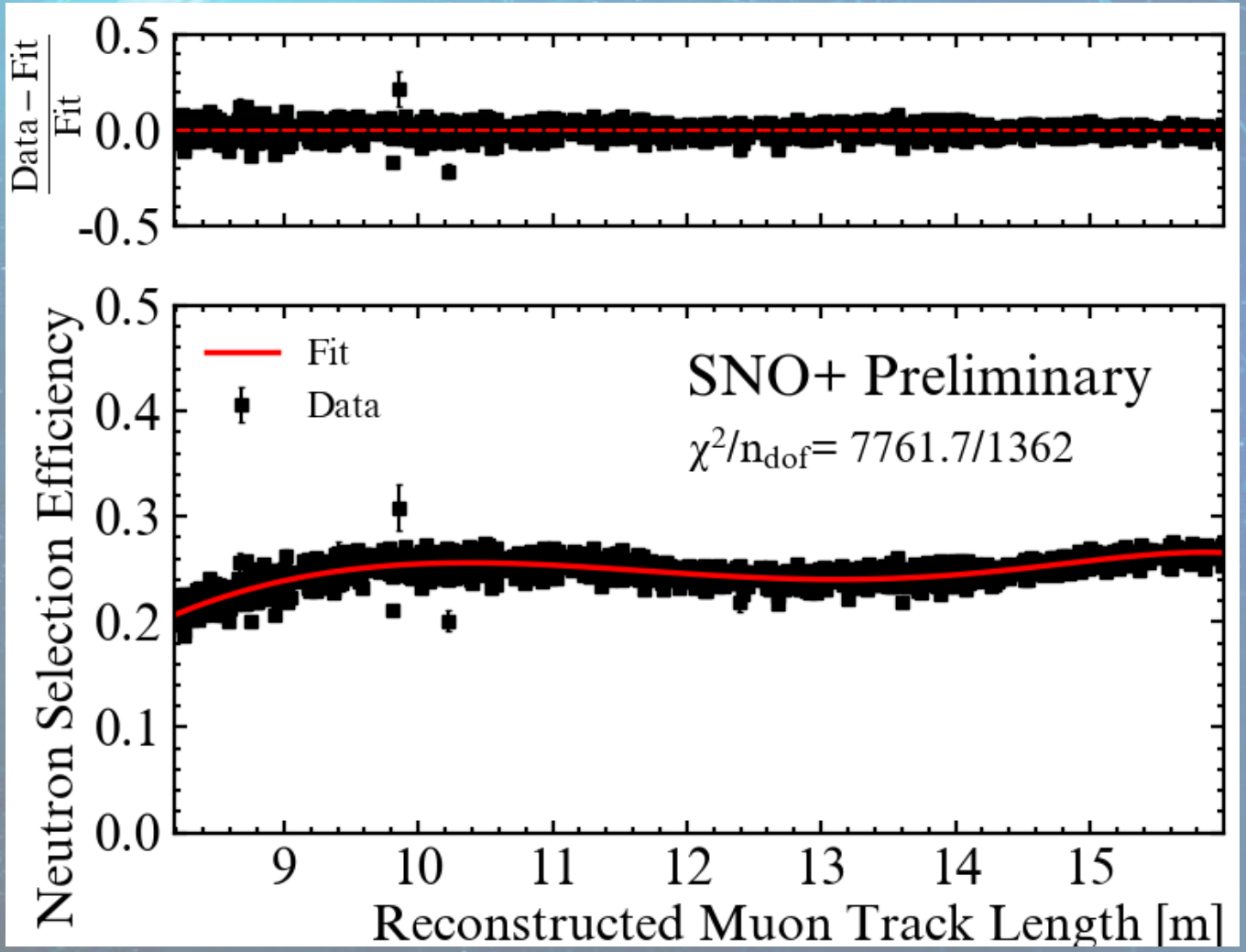


Muon Smearing



- The neutron selection efficiency is calculated using simulation
- Each muon in data is simulated with its initial position and direction smeared within the reconstruction uncertainty
- The average efficiency is calculated across all smears

Neutron Selection Efficiency Fit



- **The efficiency is calculated for a sample of data muons**
- **They can be fit as a function of track length**
- **The fit is extrapolated to get an efficiency for all muons in data**

Summary and Next Steps

- **The SNO+ detector allows for the measurement of neutron multiplicity in different media using the muon flux observed at SNOLAB**
- **Due to the low energy neutron signal, it is difficult to measure neutrons in water, putting great importance on the neutron selection efficiency**
- **The neutron selection efficiency has been found for each muon in data and the yield can now be calculated**
- **Result coming soon…**

Thank you for listening!