COHERENT Plans for D_2O at the Spallation Neutron Source

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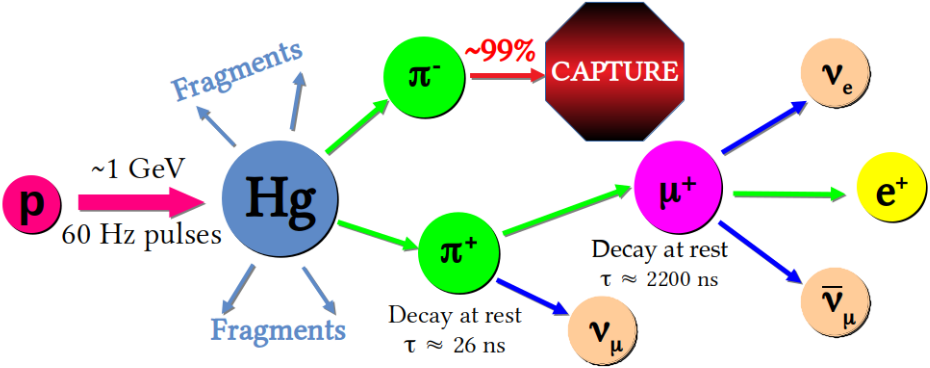
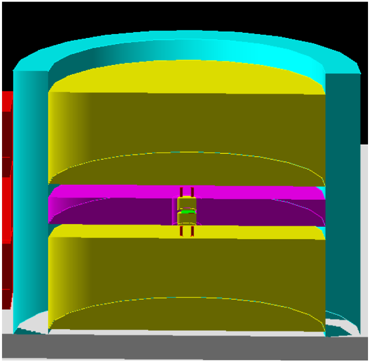
APS Division of Particles and Fields

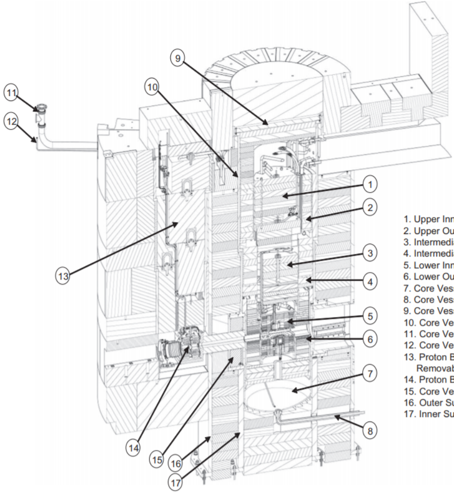
The Spallation Neutron/Neutrino Source



- ◇ π^+ decay chain produces ν_μ, ν_e, and $\bar{\nu}_\mu$
- ◇ π^- decay chain prevented: mostly captured!
- ◇ If π^- decay, μ^- decay produces $\bar{\nu}_e$

ν production doesn't need the full, complex geometry!





1. Upper Inner Reflector Plug
2. Upper Outer Reflector Plug
3. Intermediate Inner Reflector Plug
4. Intermediate Outer Reflector Plug
5. Lower Inner Reflector Plug
6. Lower Outer Reflector Plug
7. Core Vessel Ullage Volume
8. Core Vessel Drain Line
9. Core Vessel Lid
10. Core Vessel Chimney
11. Core Vessel Vacuum Line
12. Core Vessel Helium Suction Line
13. Proton Beam Window Removable Shielding
14. Proton Beam Window
15. Core Vessel Lower Section
16. Outer Support Cylinder
17. Inner Support Cylinder

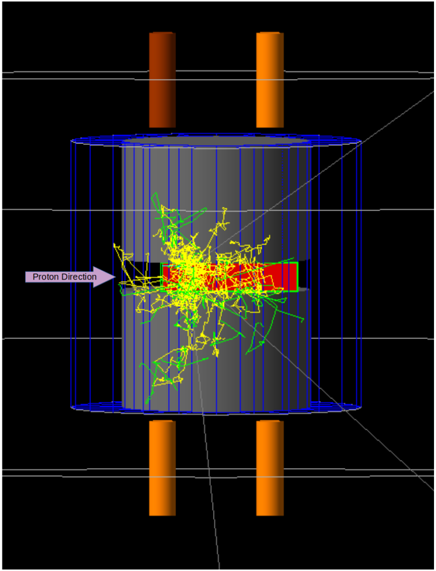
Simplified SNS to study:

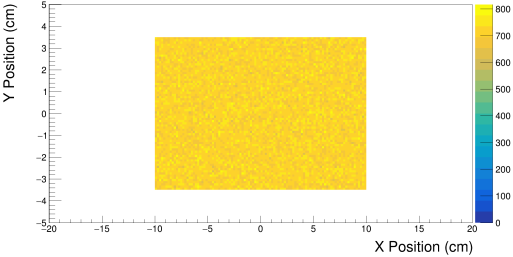
- ◇ ν production processes
- ◇ ν energy and timing

[1] J. Haines et al., "Spallation neutron source target station design, development, and commissioning", (2014).

((C HERENT SNS

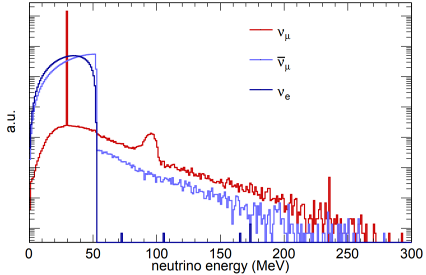
Generating Events

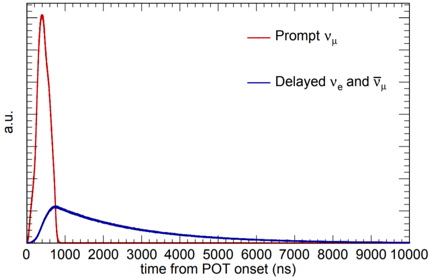




- Simulate single, 1 GeV protons
- Proton directed along $-z$
- $z = 20$ cm: edge of Hg target
- Distributed in xy across Hg target face
- Use QGSP_BERT physics list
- Track ν, π, μ, K, Λ, etc.

SNS ν Flux Calculation & Spectra





- SNS ν primarily have $0 < E_\nu < 50$ MeV
- "Prompt" and "Delayed" time windows
- Convolve timing with 695 ns beam spill
- $\sim$0.08 ν per flavor per 1 GeV POT
- 4.3×10^7 $\nu/\text{cm}^2/\text{s}$ at 20 m from target

- Advantages of using SNS ν:
  - Higher E_ν than reactor ν
    $\Longrightarrow$ Higher cross section
  - Steady-state rejection!
  - Background: beam-related neutrons

[2] D. Akimov et al., "COHERENT 2018 at the Spallation Neutron Source", arXiv:1803.09183v2, 2018.

The uncertainty in our calculation

- **No data exists for $\pi^{\pm}$ production from 1 GeV protons on Hg**
- LAHET also implemented Bertini cascade model
- Discrepancies were found between LAHET and world data
- Assigned conservative 10% systematic on our calculated SNS ν flux
- Strategies:
  - Update comparisons of our simulation to world data
  - Compare our simulation to LAHET predictions
  - Contribute to world data: measure SNS ν flux

Improving ν flux uncertainty: Simulation Validation Efforts

- HARP: measured $\pi^{\pm}$ production
  - Proton energies from 3 - 12 GeV
  - Limited $\pi^{\pm}$ momenta and production angle
  - Targets listed in righthand table
  - Comparisons to Geant4.7.1
  - Normalization between data/sim shown below

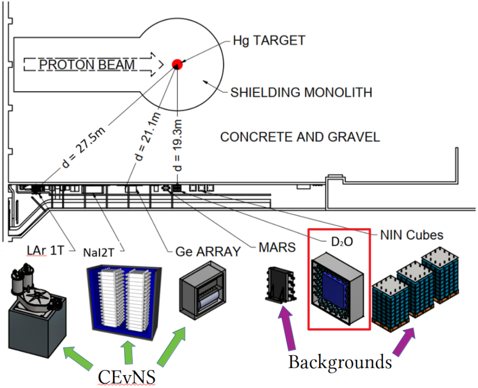
Beryllium
Carbon
Nitrogen
Oxygen
Aluminum
Copper
Tin
Tantalum
Lead

Model	Be (3 GeV)		Ta (3 GeV)		Be (5 GeV)		Ta (5 GeV)		Be (8 GeV)		Ta (8 GeV)		Be (12 GeV)		Ta (12 GeV)	
	π^+	π^-	π^+	π^-	π^+	π^-	π^+	π^-	π^+	π^-	π^+	π^-	π^+	π^-	π^+	π^-
Bertini	0.35	1.02	0.45	0.53	0.70	1.12	0.29	0.35	1.22	1.54	0.84	1.08	1.75	1.81	1.27	1.50

[3] M. Apollonio et al., "Forward production of charged pions with incident protons on nuclear targets at the CERN Proton Synchrotron", Phys. Rev. C **80** (2009).

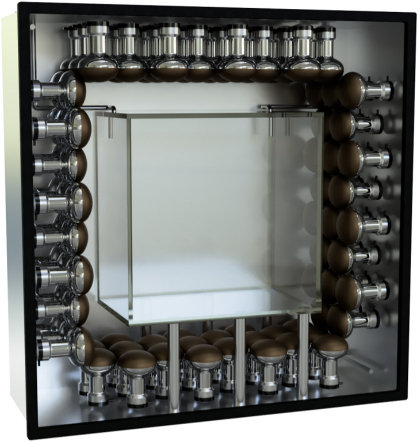
Improving ν flux uncertainty: Planned Experiment

The future of Neutrino Alley



- D$_2$O detector in Neutrino Alley
- Study $\nu_e + d \to p + p + e^-$
- Calculated 2-3% xscn uncertainty
- $\# \nu_e \implies \# \mu^+ \implies \# \pi^+$
- $3 \times (\# \nu_e) \approx \# \nu_{\text{TOTAL}}$
- Will normalize SNS ν flux!

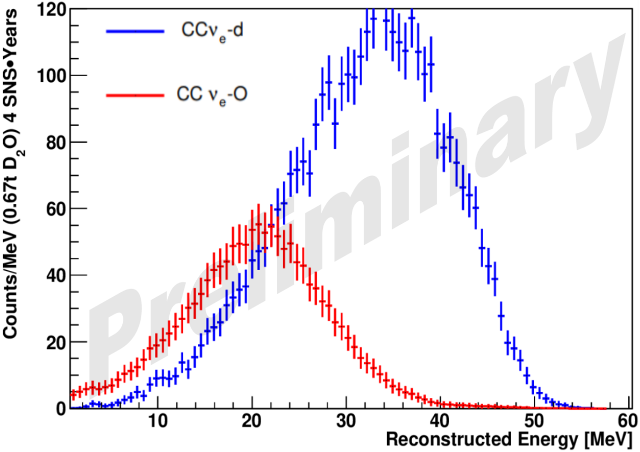
Plans for D_2O Detector in Neutrino Alley



Mockup from Eric Day, CMU

- 670-kg D_2O for inner acrylic vessel
- 10 cm H_2O tail-catcher region
- 80, 8” biakali PMTs
- Mockup of one possible configuration
- Available space limits PMT coverage
- Shielding for beam-related neutrons
- Muon vetos for cosmic backgrounds

Simulated D_2O Energy Reconstruction



Predicted 4 years run-time to get to few-% statistical precision

Figure from Jason Newby, ORNL

Effects of D_2O on COHERENT Physics Goals

Topic	CsI	Ar	NaI	Ge	Nubes	D_2O
Non-standard neutrino interactions	✓	✓	✓	✓		
Weak mixing angle	✓	✓	✓	✓		
Accelerator-produced dark matter	✓	✓	✓	✓		
Sterile oscillations	✓	✓	✓	✓		
Neutrino magnetic moment		✓	✓	✓		
Nuclear form factors	✓	✓	✓	✓		
Inelastic CC/NC cross-section for supernova		✓			✓	✓
Inelastic CC/NC cross-section for weak physics		✓	✓		✓	✓

Dominant CsI systematics

Quenching factor	25%
ν flux	10%
Nuclear form factor	5%
Analysis acceptance	5%
Total	$\pm$ 28 %

- ◇ ν flux will soon be dominant uncertainty
- ◇ Uncertainty shared by all detectors!

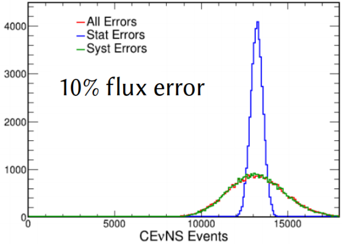
[4] D. Akimov et al., "Observation of coherent elastic neutrino-nucleus scattering", Science **357** (2017).

Effects of D_2O on LAr Pseudo-Experiment

Visualization of LAr uncertainties

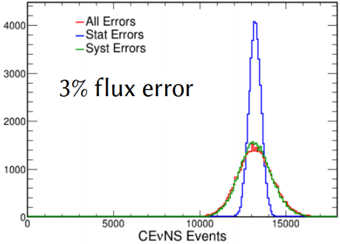
Without D_2O

Stat	358.1 (2.7%)
Syst	1600.9 (12.1%)
Total	1634.5 (12.4%)



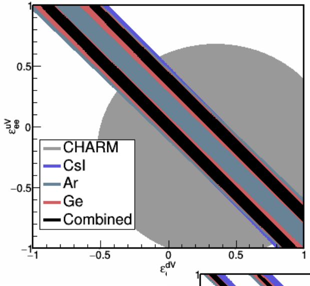
With D_2O

Stat	355.4 (2.7%)
Syst	951.1 (7.2%)
Total	1018.4 (7.7%)

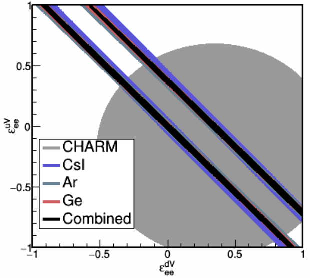


Figures from Dan Pershey, Duke

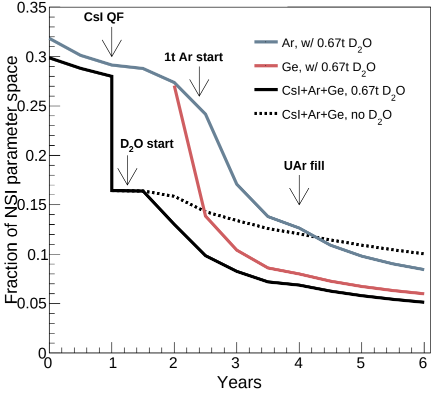
Effects of D_2O on predicted NSI constraints



← Without D_2O
10% flux error



With D_2O →
3% flux error



Figures from Kate Scholberg, Duke

Summary

- COHERENT is moving towards precision CEvNS measurements
- Efforts underway to validate simulation with updated world data
- *No world data for pion production from 1 GeV p + Hg!*
- To normalize ν flux, plans to deploy a D_2O detector in Neutrino Alley
- $\nu_e + d \rightarrow p + p + e^-$ cross section calculated to 2-3% uncertainty
- D_2O would immediately begin to reduce our flux uncertainty
- 4 years run-time to achieve few-% uncertainty on the ν flux

Thank You!

Backup Slides

ν flux depends on the proton energy