Flux Measurement at the SNS with a D_2O Detector

Jason Newby

for the COHERENT collaboration

Magnificent CEvNS 2019 Workshop
November 11, 2019
Chapel Hill, NC

SNS upgrades will accelerate scientific progress and deliver wholly new capabilities

PPU project: Double the power of the existing accelerator structure

- First Target Station (FTS) is optimized for thermal neutrons
- Increases the brightness of beams of pulsed neutrons
- Provides new science capabilities for atomic resolution and fast dynamics
- Provides a platform for STS

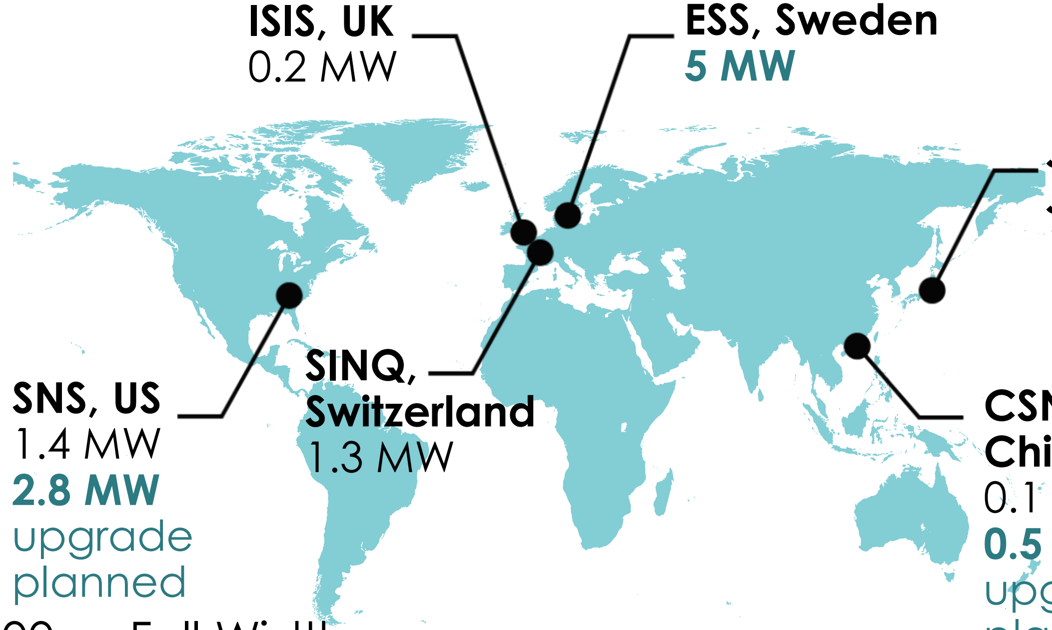
STS project: Build the second target station with initial suite of beam lines

- Optimized for cold neutrons
- World-leading peak brightness
- Provides new science capabilities for measurements across broader ranges of temporal and length scales, real-time, and smaller samples

Slide from Ken Herwig, Workshop on Fundamental Physics at the Second Target Station (FPSTS18)

SNS upgrades will provide world-leading neutron capabilities to US researchers

2.9 ms pulse width



ISIS, UK
0.2 MW

ESS, Sweden
5 MW

J-PARC, Japan
1 MW

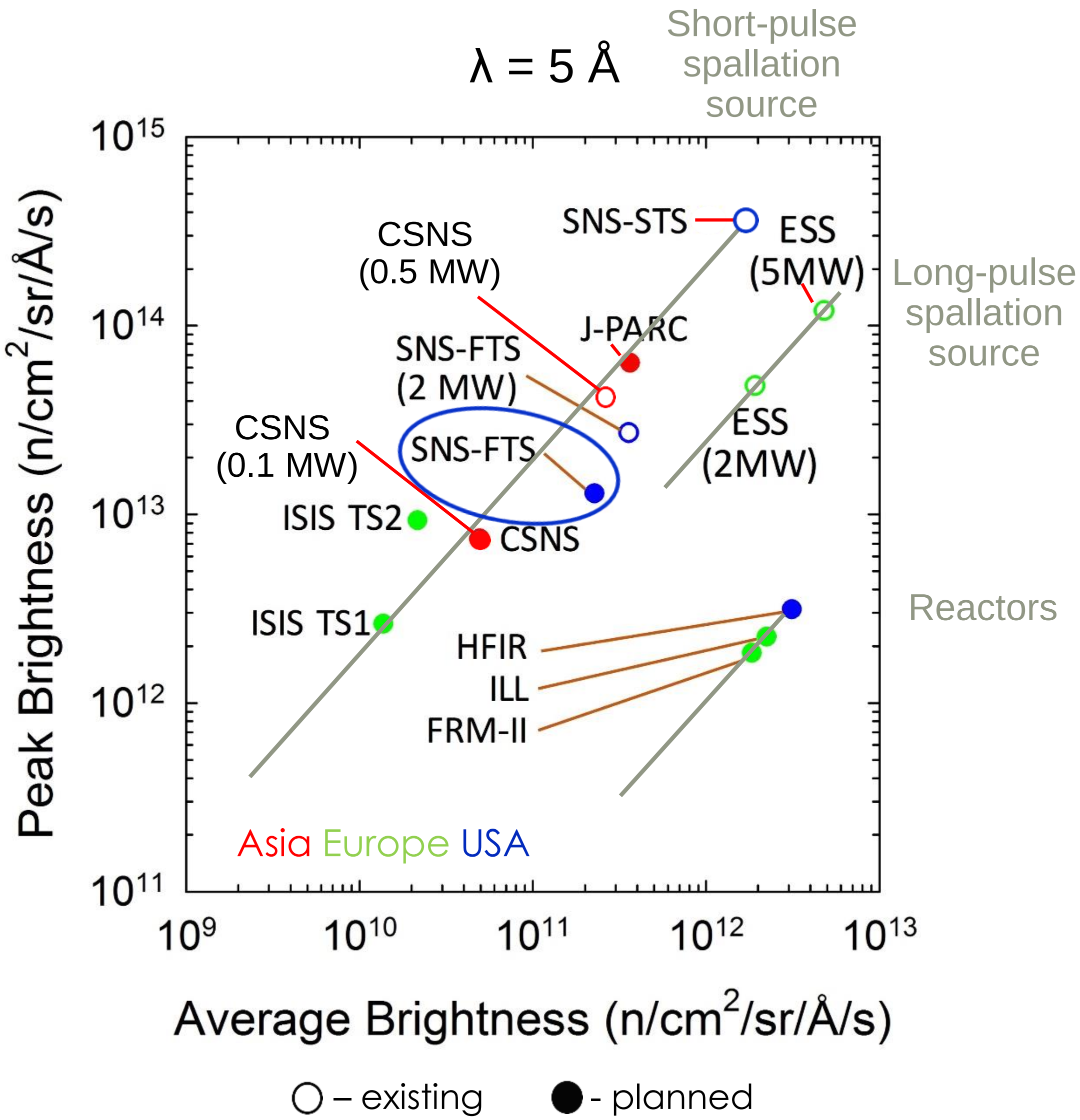
SNS, US
1.4 MW
2.8 MW
upgrade planned

SINQ, Switzerland
1.3 MW

CSNS, China
0.1 MW
0.5 MW
upgrade planned

700 ns Full Width

Global spallation neutron sources with general user programs



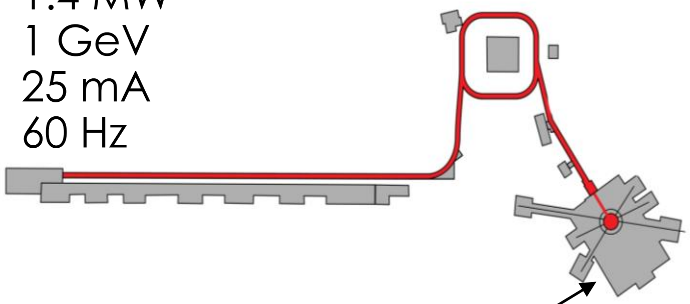
Slide from Ken Herwig, Workshop on Fundamental Physics at the Second Target Station (FPSTS18)

PPU and STS upgrades will ensure SNS remains the world’s brightest accelerator-based neutron source

Today

- 900 users
- Materials at atomic resolution and fast dynamics

1.4 MW
1 GeV
25 mA
60 Hz

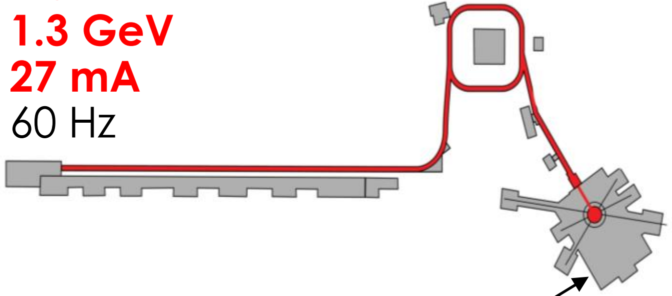


FTS
1.4 MW
60 Hz

2024 after PPU

- **1000+** users
- Enhanced capabilities

2.0 MW
1.3 GeV
27 mA
60 Hz



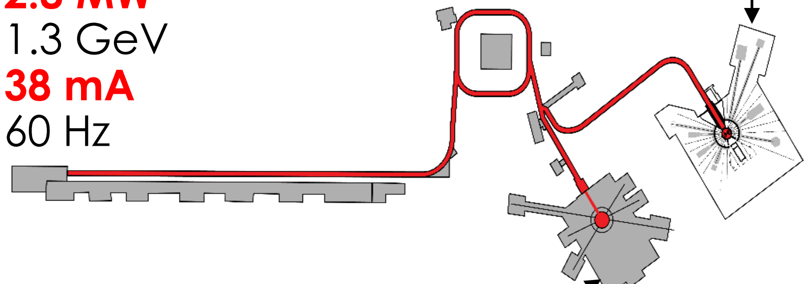
FTS
2 MW
60 Hz

2028 after STS

- **2000+** users
- Hierarchical materials, time-resolution and small samples

STS
0.7 MW
15 Hz

2.8 MW
1.3 GeV
38 mA
60 Hz



FTS
2 MW
45 pulses/sec

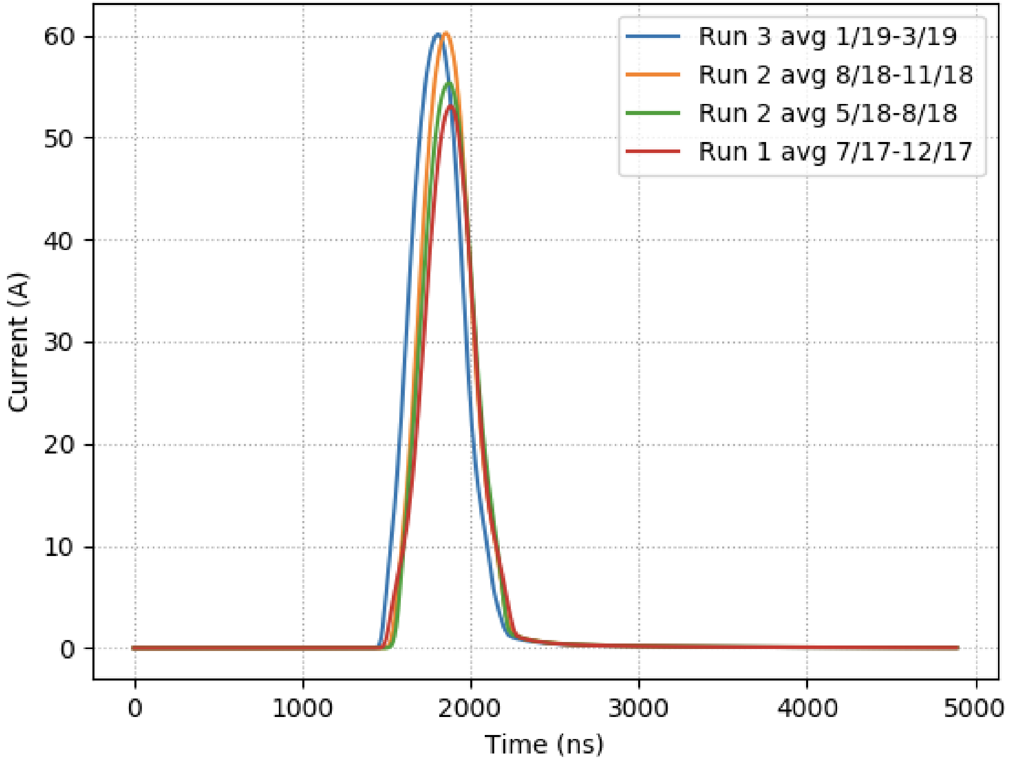
The choice of 15 Hz and 0.7 MW resulted from a detailed analysis of STS design (reviewed by a panel of experts in 2017) and optimizes performance of STS without impacting performance of FTS

Spallation Neutron Source Second Target Station Integrated Systems Update

April 2017

Oak Ridge National Laboratory

Beam Timing

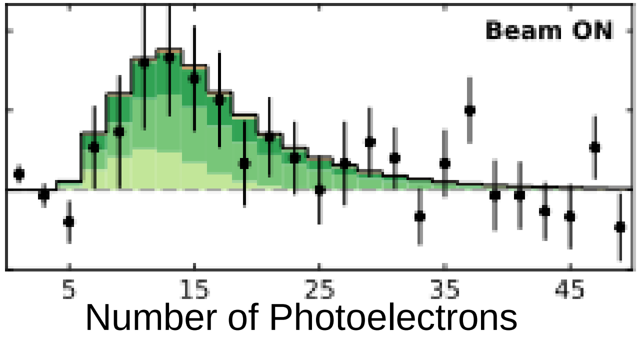


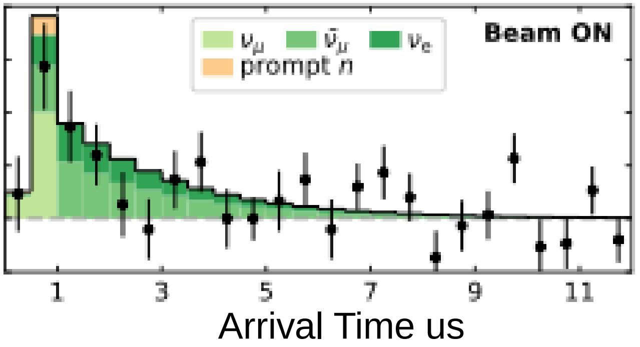
Lara Blokland

- COHERENT archives 1 in 60 proton beam longitudinal traces
- Beam width is 350 ns FWHM
- Peak intensity is 0.062 kJ/ns @ 1.4 MW average power
- New Master Timing Module reduces pulse-by-pulse jitter less than 32 ns

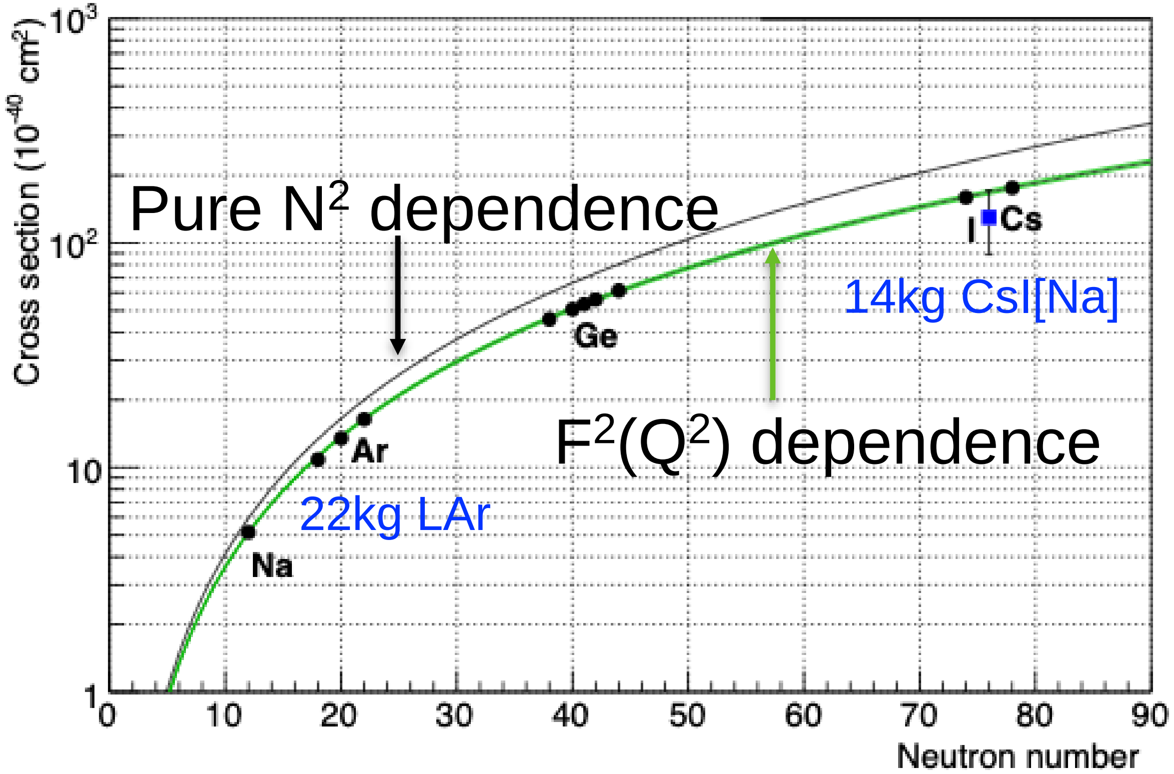
- See Rebecca Rapp’s talk on neutrino flux estimates

First Observation of CEvNS





Akimov et al. *Science*
Vol 357, Issue 6356
15 September 2017



Pure N^2 dependence

$F^2(Q^2)$ dependence

22kg LAr

14kg CsI[Na]

First light detectors deployed to measure neutron-squared dependence. (Na, Ge in 2020)

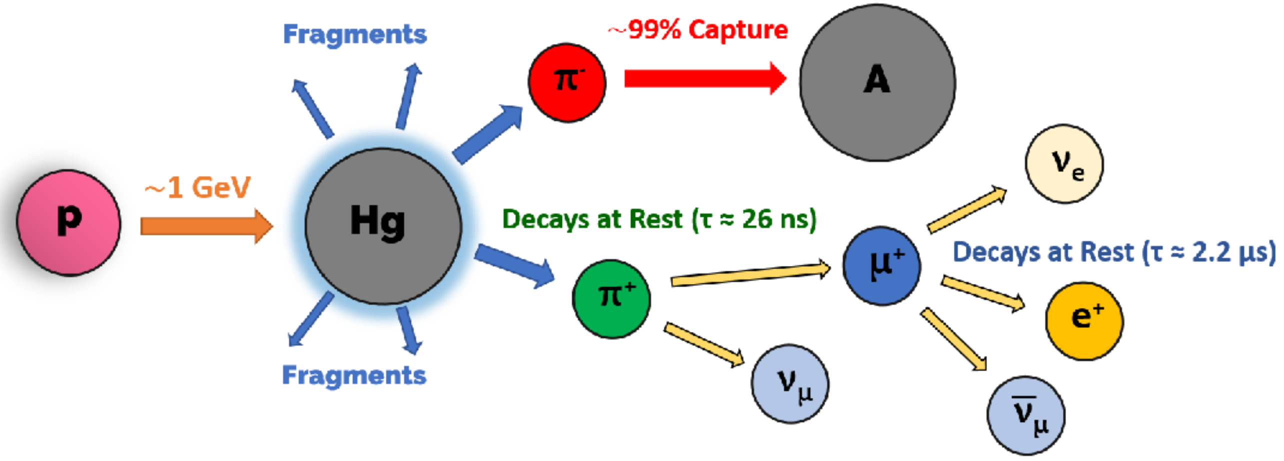
High precision measurements enable the full potential of CEvNS scientific impact.

Beyond First Light Measurements …

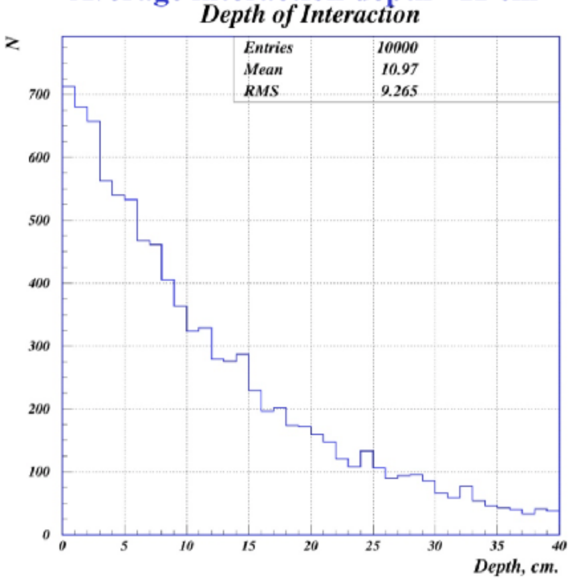
Uncertainties on CsI signal and background predictions	
Event selection (signal acceptance)	5%
Form Factor	5%
Neutrino Flux	10%
Quenching factor	25%
Total uncertainty on signal	**28%**

All uncertainties except neutrino flux are detector specific and could be much less for other technologies

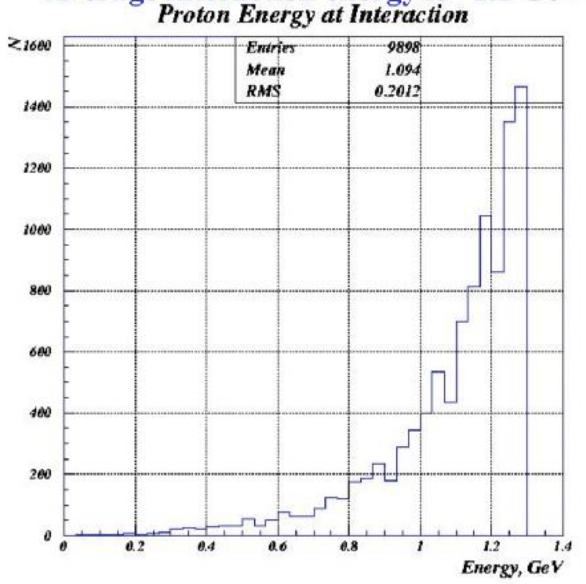
To unlock high precision CEvNS program, we need to calibrate SNS neutrino flux



Average interaction depth ~11 cm



Average interaction energy is ~1.1 GeV

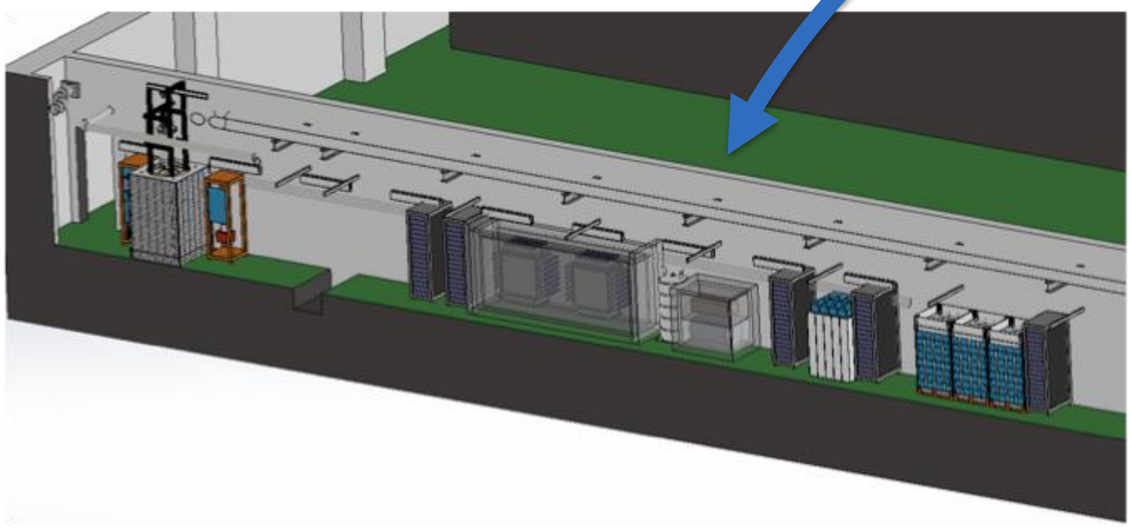


1-ton Heavy Water Detector

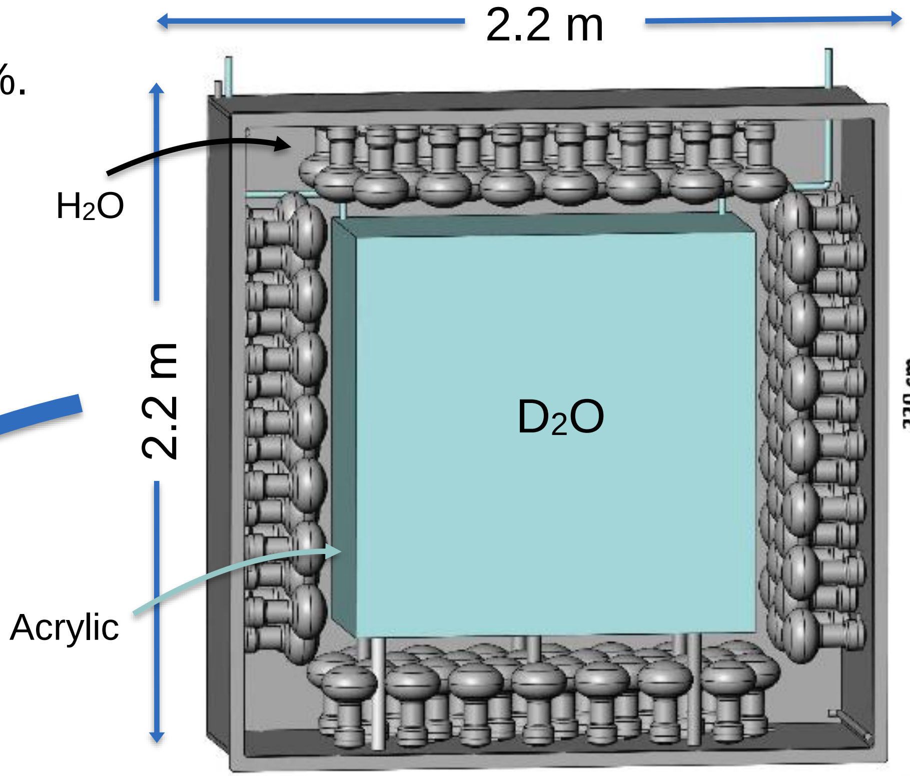
- Charged current ν_e-d cross section known to about 2-3%.

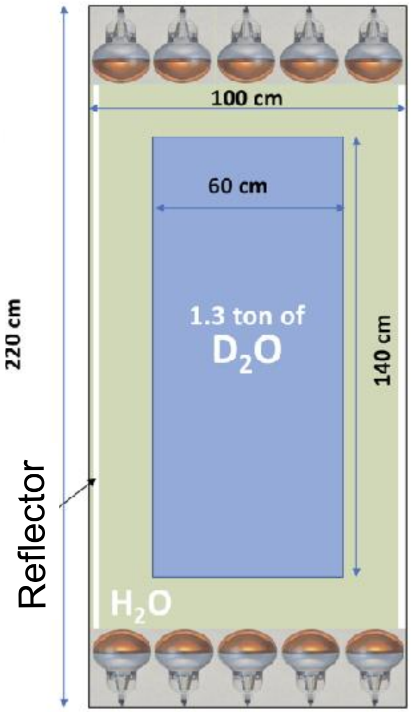
  S.Nakamura et. al. Nucl.Phys. A721(2003) 549
- Neutrino Alley space constraints:
  - 1 m depth x 2.3 m height x 3 m width
- Locations 20-29 meters from target
- Neutron shielding supplied by SNS

Neutrino Alley



Concept by Yuri Efremekno





Darryl Dowling, ORNL

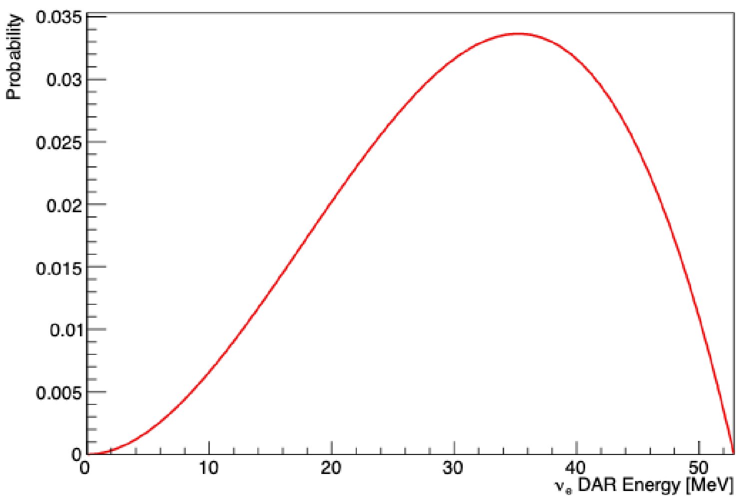
- 1.3 tons D_2O within acrylic inner vessel
- Water Cherenkov Calorimetry (no ring imaging)
- H_2O “tail catcher” for high energy e^-
- Outer light water vessel contains PMTs, PMT support structure, and optical reflector.
- Outer steel vessel to support shielding and veto

Interaction Rate is Sufficient for PPre

- Charged current ν_e-d cross section known to about 2-3%.

S.Nakamura et. al. Nucl.Phys. A721(2003) 549

$\nu_e + d \rightarrow p + p + e^-$ 5.5×10^{-41} cm^2



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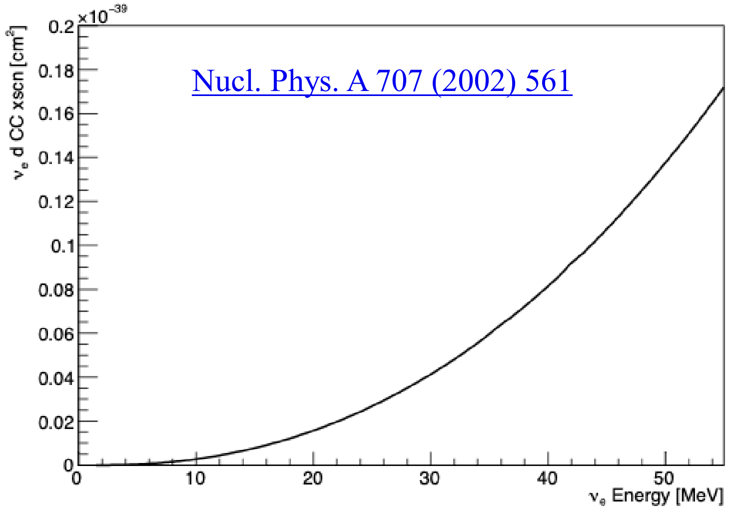


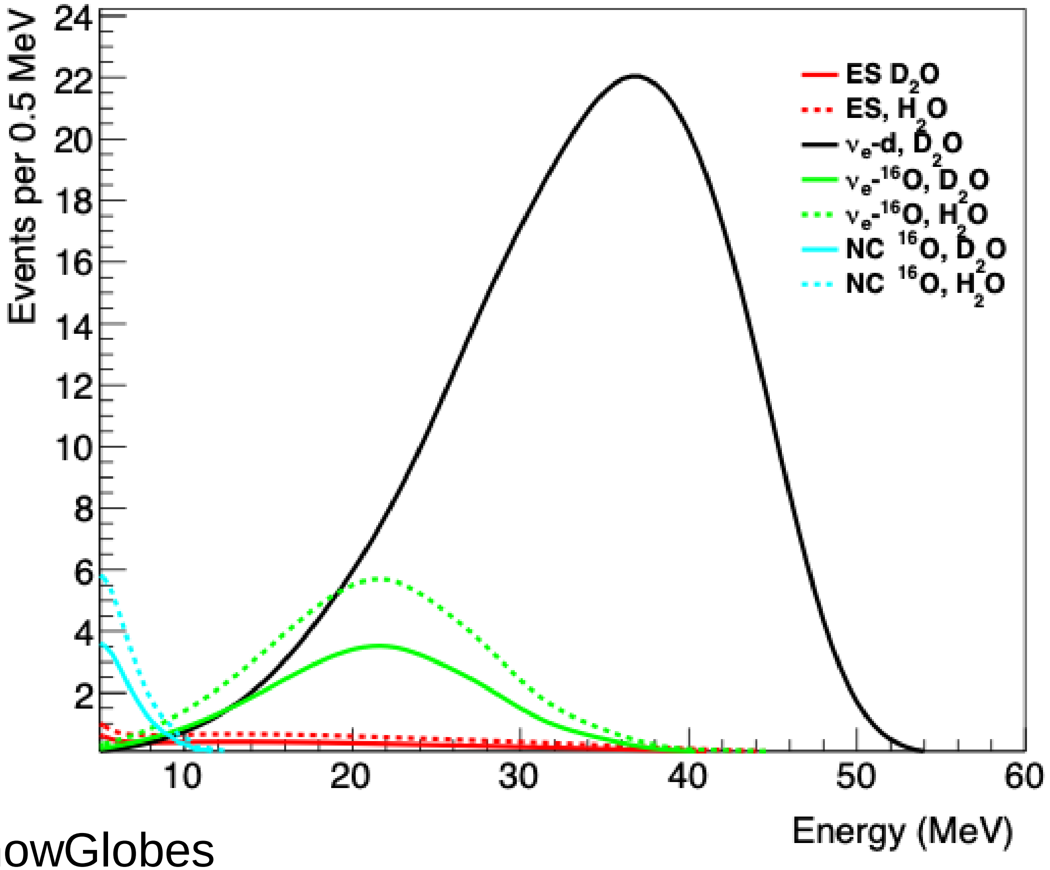
Nucl. Phys. A 707 (2002) 561

930 CC interactions per ton per SNS-year

5000 hrs/yr @ 1.4 MW
0.09 ν_e per proton

Dominant Beam Related Backgrounds?

- Updated SnowGlobes tool indicates largest beam related background is charged current on oxygen
- With a nominal 10cm tail catcher, 1.3 tons of D_2O requires 1.8 tons of H_2O which produces Cherenkov too.
- Full detector response model needed for accurate optimization.



SnowGlobes

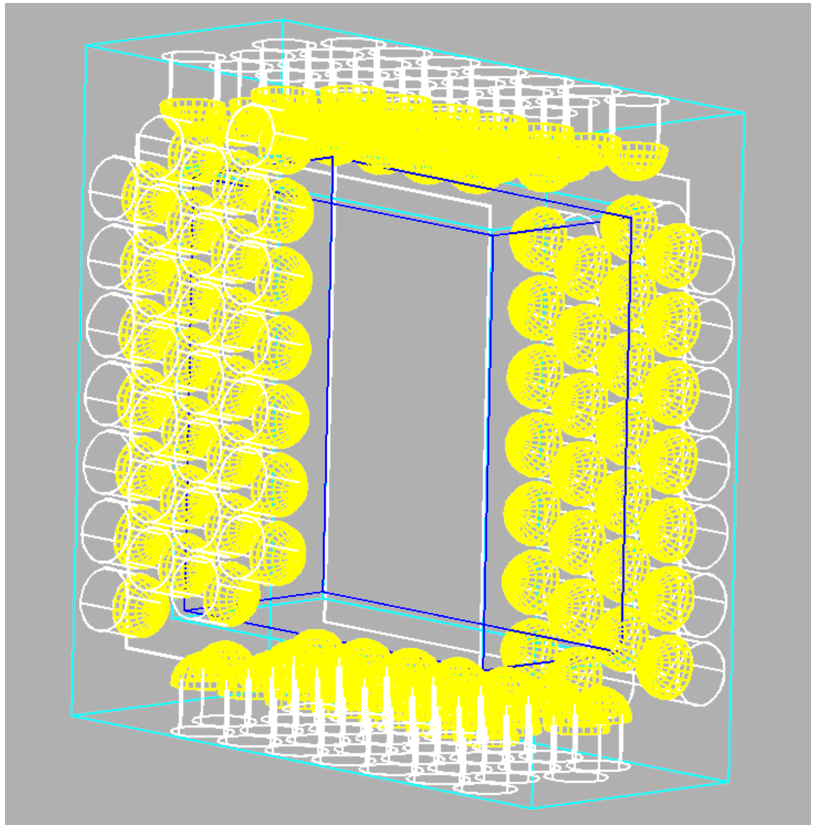
SNS flux weighted ν_e-d CC xscn by Jes Koros
SNS flux weighted ν_e-O CC xscn by Kate Scholberg

W. C. Haxton. Phys. Rev. C **37**, 2660

How much light water is optimal?

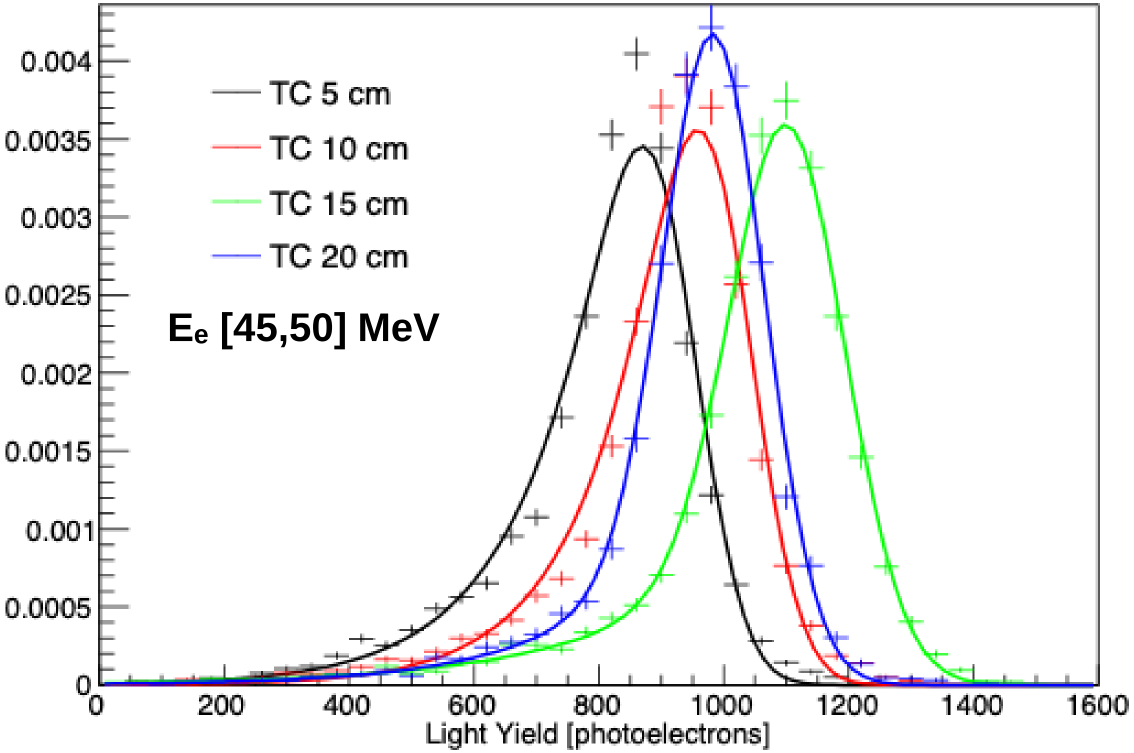
- G4 Simulation
  - 1.3 tons of D_2O (60×140×140 cm)
  - 1 inch acrylic tank
  - Light water gap to reflector/PMT {5,10,15,20} cm
  - 8 Inch Bialkali (25% peak QE) PMT on four sides
  - 0.25 Inch Teflon reflector on 2 sides
  - No reflector between PMTs

- 160 PMTs for H_2O Thickness of 15,20 cm
- 112 PMTs for H_2O Thickness of 5,10 cm

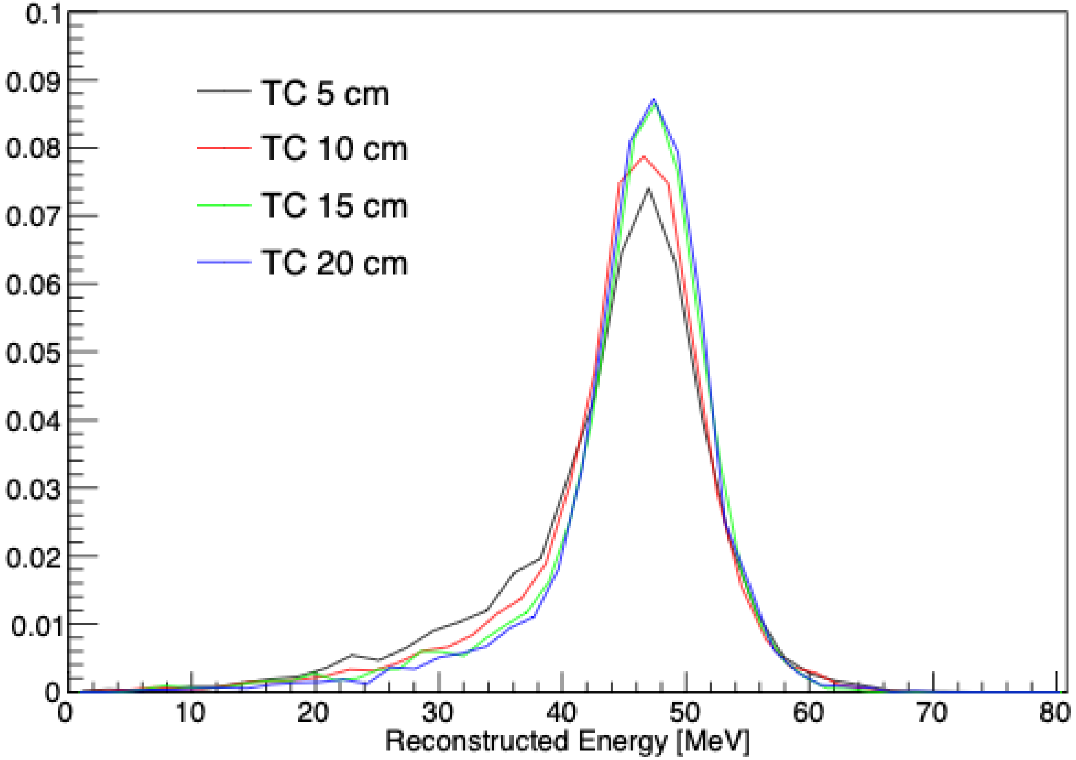


Geant4 Model
Matthew Blackston

Energy Resolution Improves only slightly with more H_2O

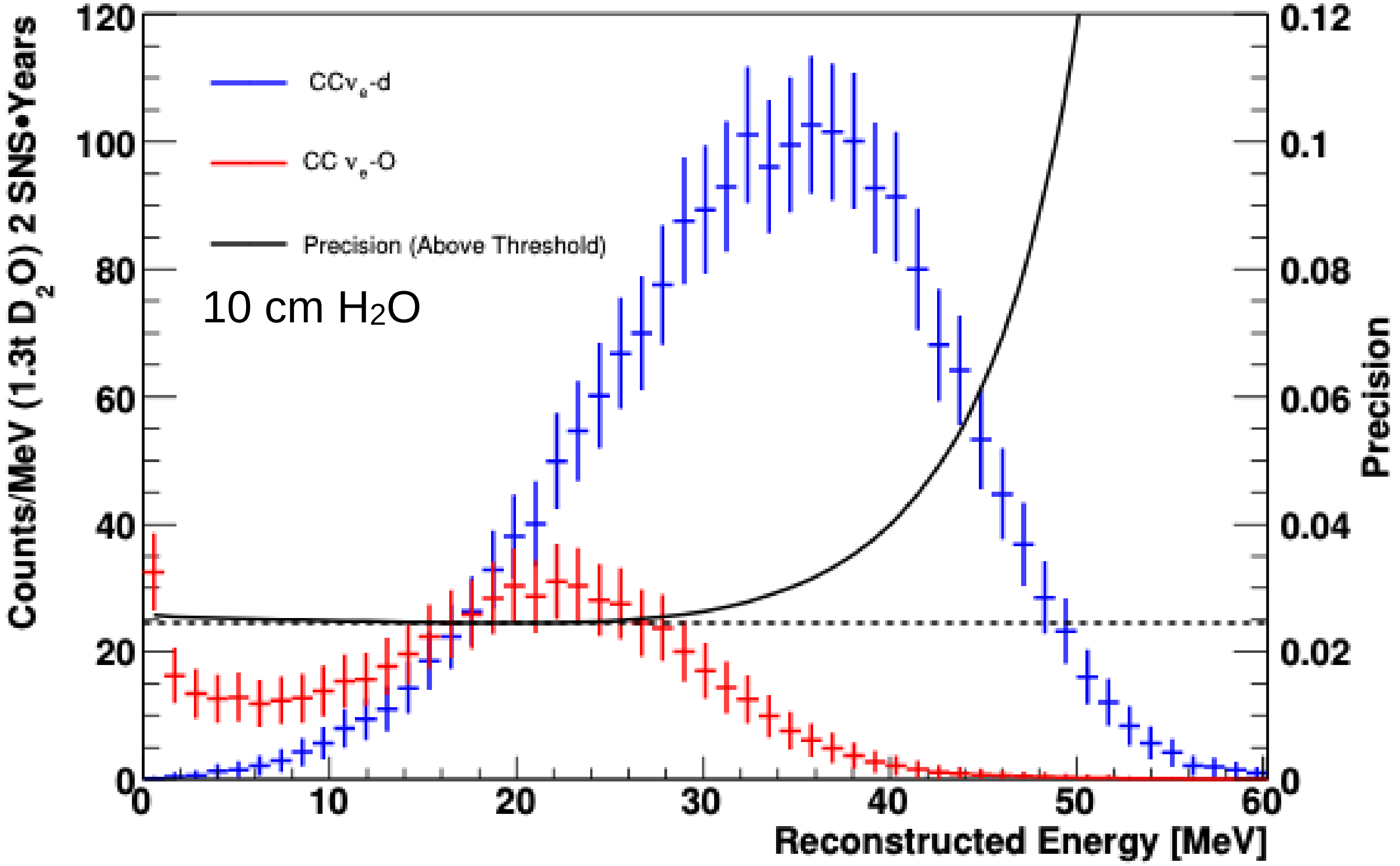


- 200k electron recoils thrown for each "tail catcher" (TC) thickness
- Wavelength dependent QE applied at PMT
- About 20 PE per MeV, 18% resolution at 50 MeV



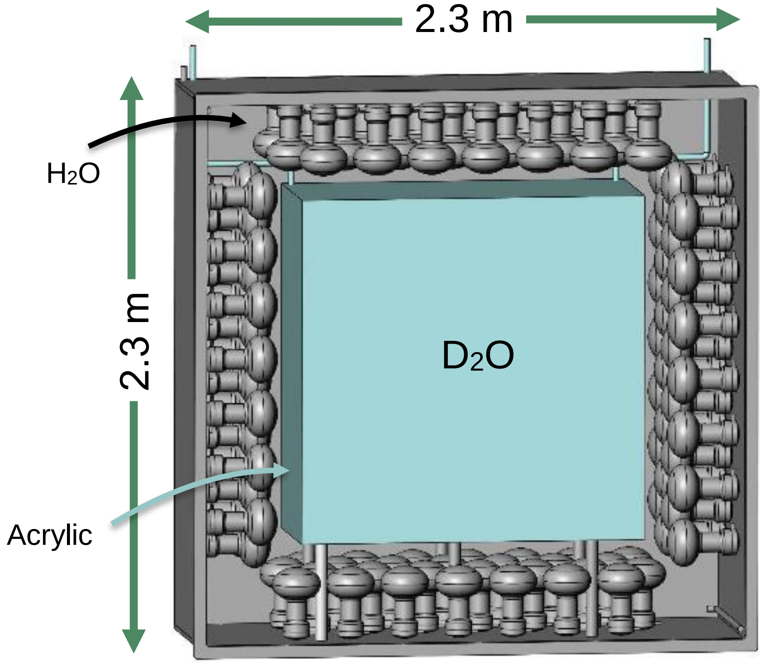
With thicker H_2O layer, more recoil electrons at the edges range out and deposit full energy.

Flux Normalization with Heavy Water Detector



2.5% Statistical Precision with 2 SNS years at 1.4 MW

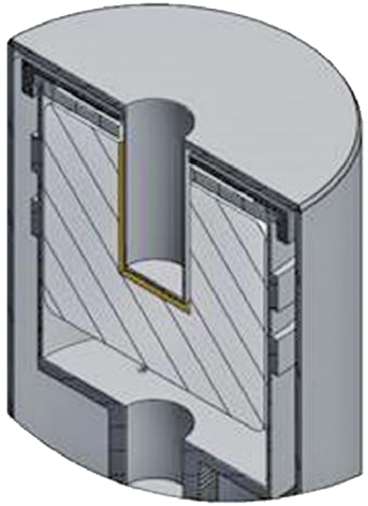
Maximum size for Neutrino Alley



Darryl Dowling, ORNL

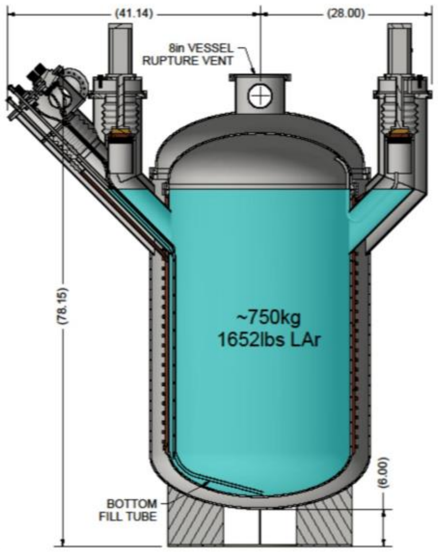
- 1.3 tons D_2O within acrylic inner vessel
- 10 cm H_2O “tail catcher” for high energy e^-
- 112 8” bialkali photomultipliers

D$_2$O Benefits All CEvNS Detectors



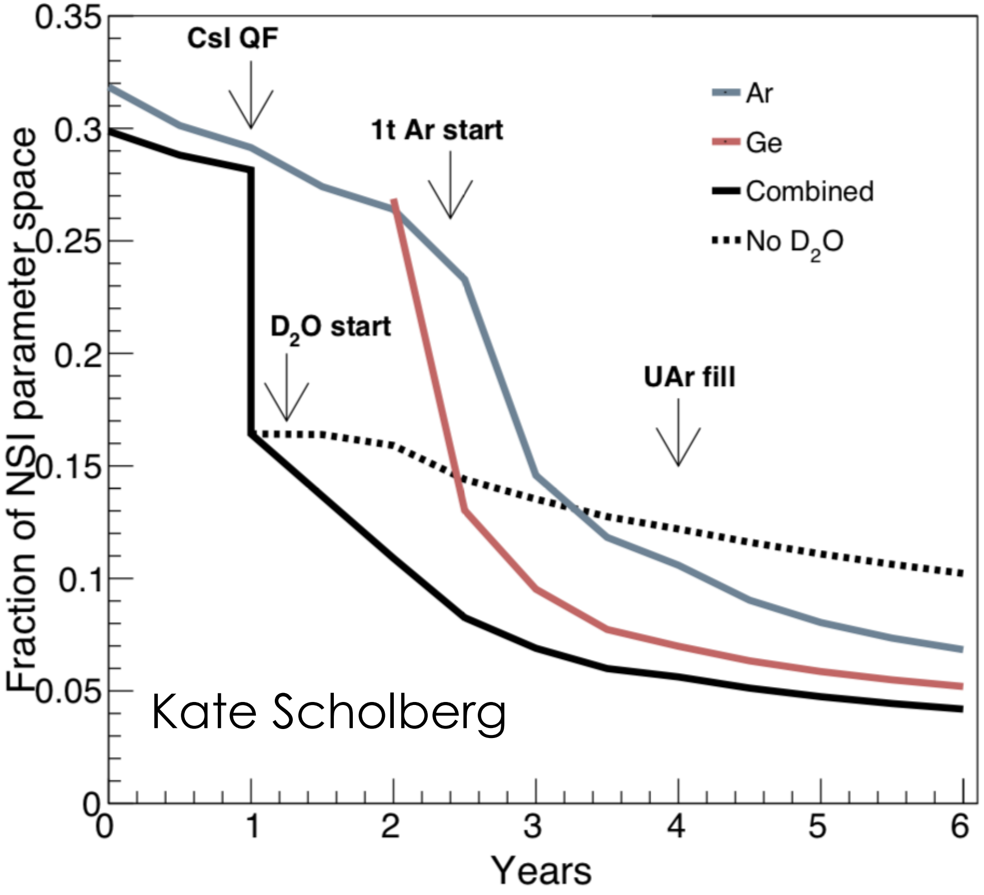
16 kg PPC HPGe
500-600 CEvNS/yr
Installation 2020
(NSF Funded)

3.4 ton NaI
3σ CEvNS/yr
Installation 2020
(DOE Funded)



750kg LAr
Single phase
~3000 CEvNS/yr

Reduction in allowed NSI

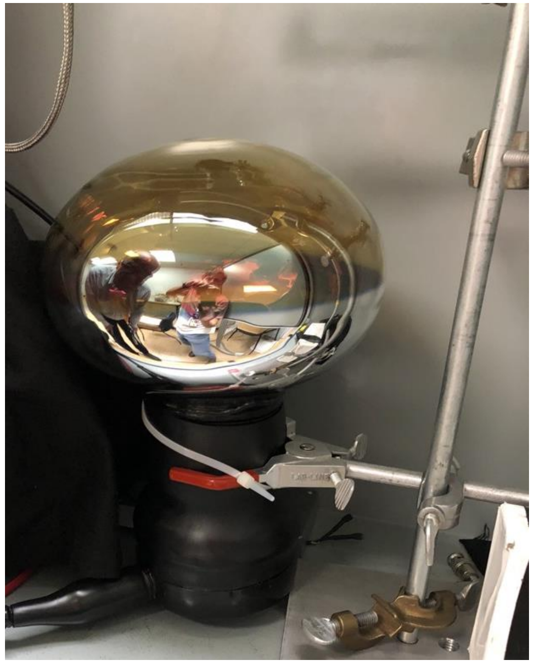


Kate Scholberg

- See also talks by Rex Tayloe and Dan Pershey on impact for precision CEvNS and DM searches

In the near term..

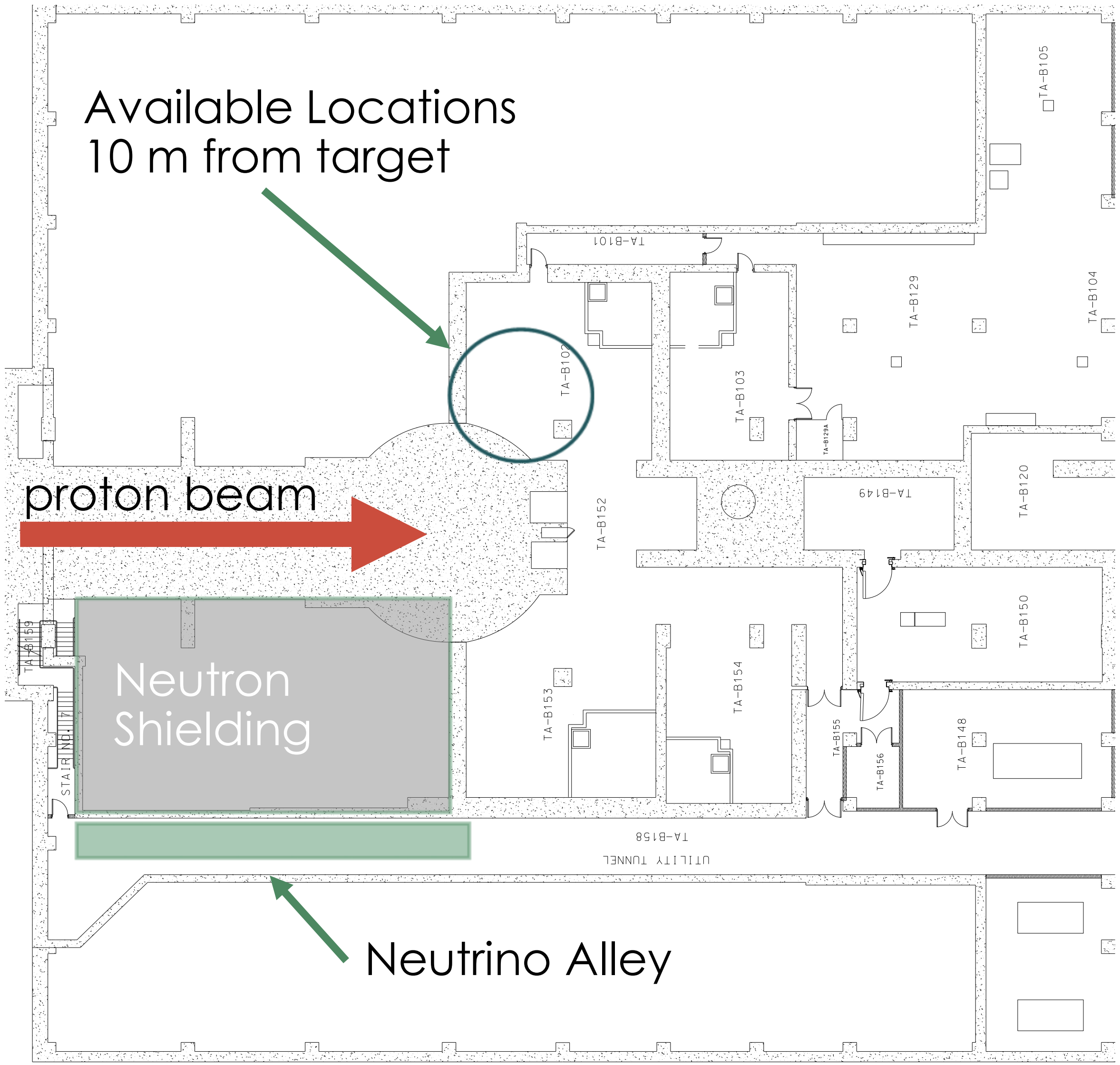
- Detector Optimizations via Simulations
  - Light Collection: Photocathode vs reflector
  - Detector geometry: cylindrical vs rectangular
  - Tail catcher: light water vs mineral oil
  - *See poster by Karla Tellez-Giron-Flores*
- Detector prototyping
  - PMT Testing
  - Light water prototype for in-situ backgrounds
- Hoard as much D_2O as possible
  - 110 kgs at ORNL, ~400 kgs at UC Irvine, ~400 kgs from BNL?
- Revisit siting options



Hamamatsu R5912-100
Water tight assemblies
(4 in hand)

Consider Additional Siting Options within FTS

- Neutrino Alley
  - 8 m.w.e. overburden
  - 8 m below target
  - 20 m of neutron shielding
  - 1 × 25 m^2 floor space
- Nearby Water Process Room
  - Less space constraints
  - Less intrinsic shielding
  - 1 Rad/hr Gamma Field
  - Location within 10m of target
  - Similar spaces available in STS


Available Locations
10 m from target

proton beam

Neutron
Shielding

Neutrino Alley

Summary

- The Spallation Neutron Source is currently the cleanest, most intense stopped pion neutrino source with stable operation planned for decades.
- Multiple targets (Ar, Ge, Na, Cs, I, D) deployed by the COHERENT collaboration in neutrino alley has created a rich neutrino physics program.

- Normalizing the neutrino flux is a critical to a precision program
- The 1-ton D_2O Detector can feasibly reach 2.5% statistical precision in 2 years

Acknowledgements

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