ORNL Neutrino Flux Simulations
FTS and STS

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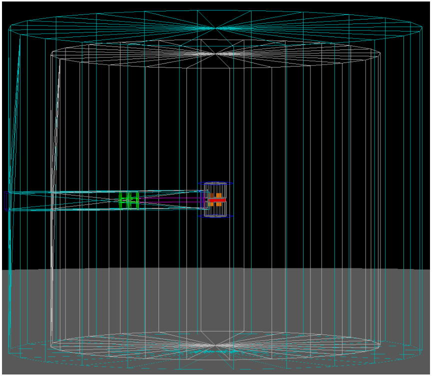
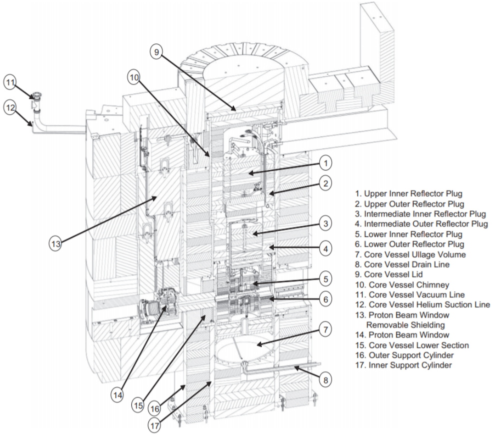
Monday, November 11
Magnificent CEvNS 2019

Goal: study ν production with simplified geometry

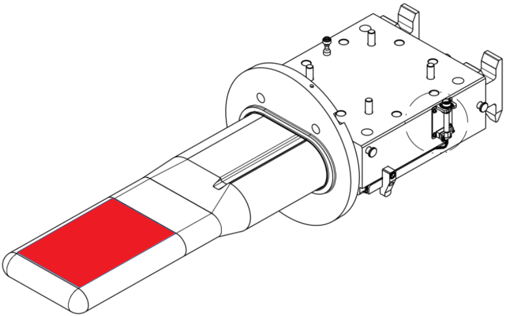


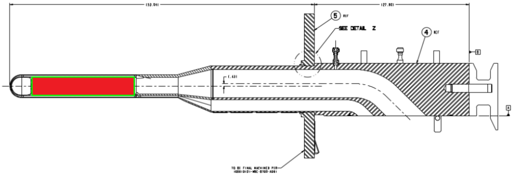


- ν energy and timing
- ν creation position, direction
- ν creation processes

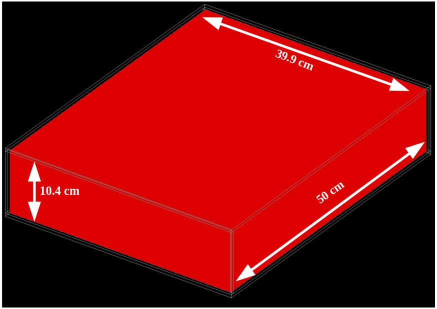
[1] J. Haines et al., "Spallation neutron source target station design, development, and commissioning", (2014).

Simulating the Target



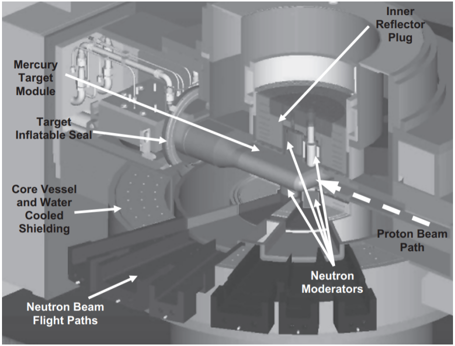


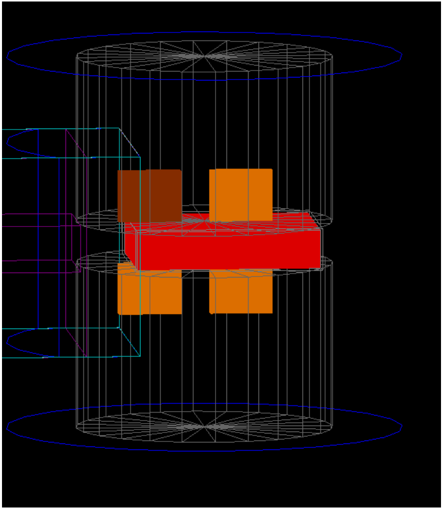
- Red: LHg target
- Gray: Steel (95% Fe, 5% C)



[2] *ORNL Technical Drawings*, 2005.

Simulating the Target – Adding moderator suite

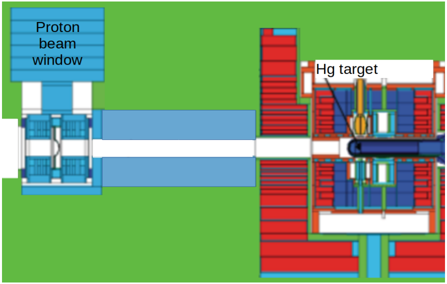


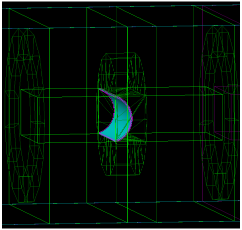


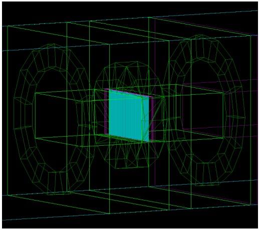
- Blue: 95% Steel, 5% D_2O Cylinder
- Gray: 90% Be, 10% D_2O plugs
- Orange: LH_2 Moderators
- Brown: H_2O Moderator

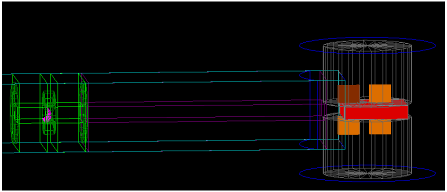
[3] J. Haines et al., "Spallation neutron source target station design, development, and commissioning", (2014).

Proton Beam Window





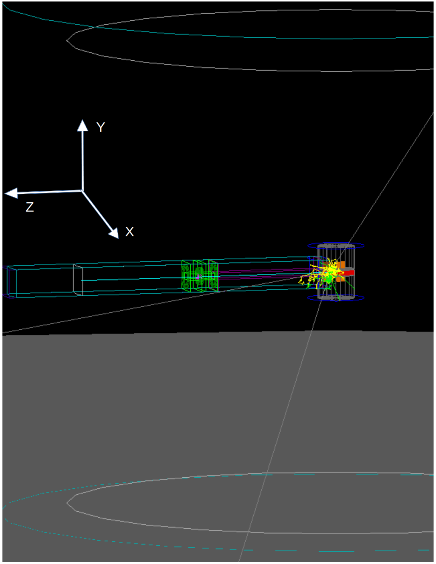


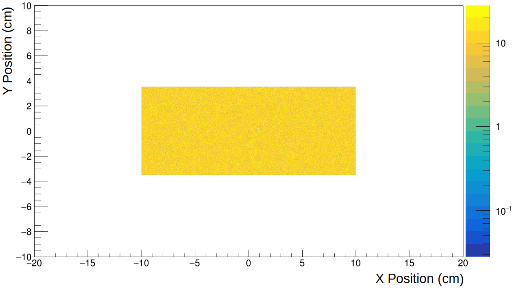


- ◇ Located ∼2.3m upstream from Hg
- ◇ $<$ 2017: Dual-layered Inconel films
- ◇ $\geq$ 2017: Aluminum plate
- ◇ Both PBW designs are water-cooled
- ◇ Also included for completeness:
  - ▷ Concrete floors/monolith
  - ▷ Steel reflectors outside target
  - ▷ Detector reference locations

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

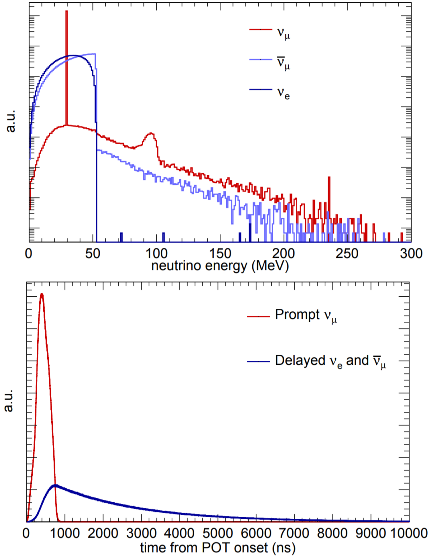
Generating Events





- Monoenergetic protons, $\hat{p} = -\hat{z}$
- Generated at $z = 5$ m, uniform in xy
- Use Geant4's QGSP_BERT physics list
- Store info about π, μ, ν, K, Λ, etc.

SNS ν Flux Calculation & Spectra



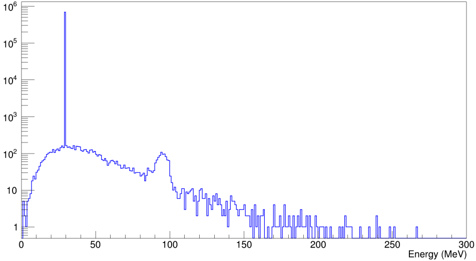
- SNS ν primarily have $0 < E_\nu < 50$ MeV
- "Prompt" and "Delayed" time windows
- Convolve timing with 695 ns beam spill
- $\sim$0.087 ν per flavor per 1 GeV POT
- No change with different beam window (within Poisson errors)
- 4.3×10^7 $\nu/\text{cm}^2/\text{s}$ at 20 m from target

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

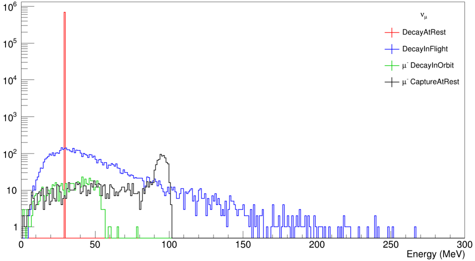
[5] D. Akimov et al., "COHERENT 2018 at the Spallation Neutron Source", arXiv:1803.09183v2, 2018.

Separating the ν Energy Spectrum

ν_μ Energy



E_{ν_μ} separated by creation process



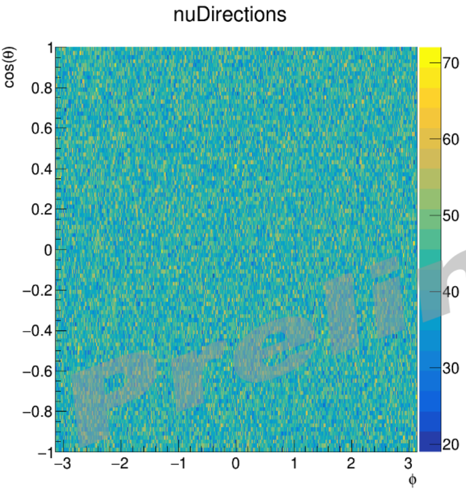
Particle	ν/POT	DAR	DIF	μ^- Capture	μ^- DIO
ν_μ	0.087	98.88%	0.82%	0.22%	0.08%
$\bar{\nu}_\mu$	0.087	99.70%	0.30%	–	–
ν_e	0.087	99.99%	0.01%	–	–

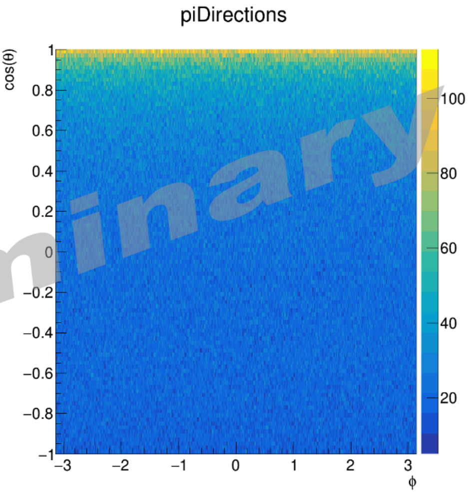
The uncertainty in our calculation

- **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

    $\rightarrow$ D_2O talk from Jason Newby

Recording Directional Information

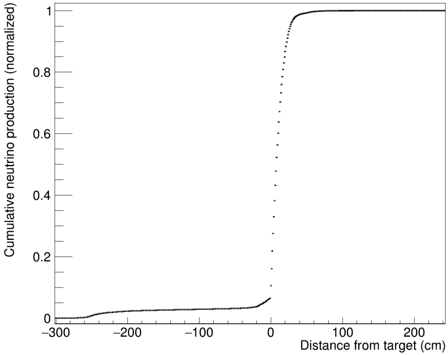


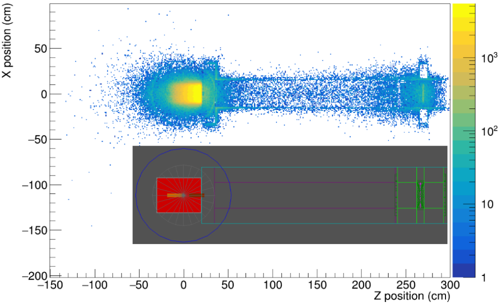


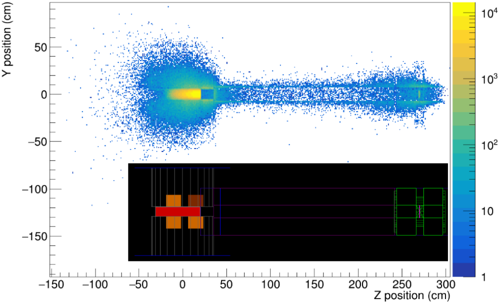
- Most ν created < 1 m from target – neglecting position effects (for now)
- **Goal:** Compare HARP data to Geant4.10.04 sim results

ν Production Positions

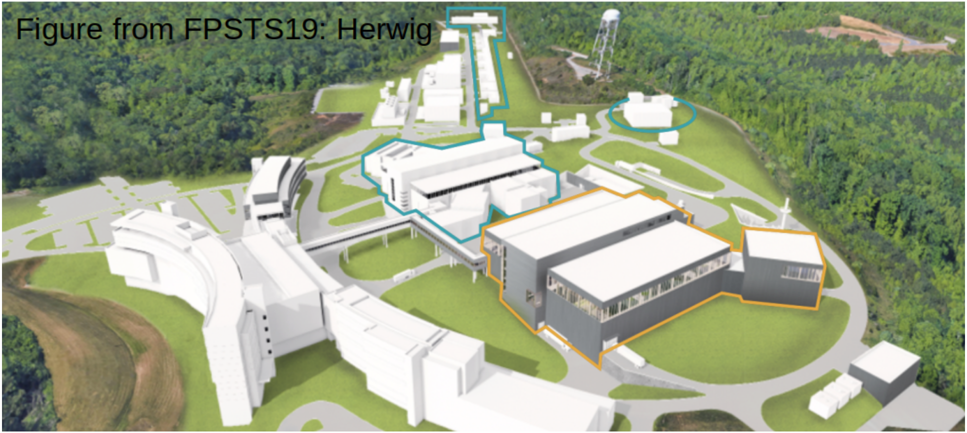
- ν produced primarily in Hg
- Some ν from the moderators
- Some ν produced before target







ORNL in Future



- Plan to upgrade SNS from 1.4 MW to 2.8 MW
- First Target Station optimized for thermal neutrons
- Second Target Station optimized for cold neutrons

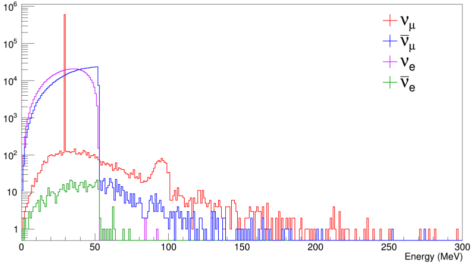
Proton Power Upgrade

- Upgrade from 1.4 MW to 1.7 MW in 2022
- Final increase to 2.0 MW in 2024
- By 2024, proton energy will be 1.3 GeV

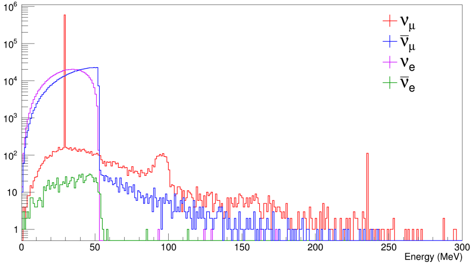
Second Target Station

- New user facility with dedicated experiments
- Proposed for use by 2028
- Power: 2.0 MW at FTS, 0.7 MW at STS
- Operations continue at 60 Hz
- Every 4th pulse to STS [15 Hz]

Proton Power Upgrade (2024)



ν Energy with 1 GeV protons



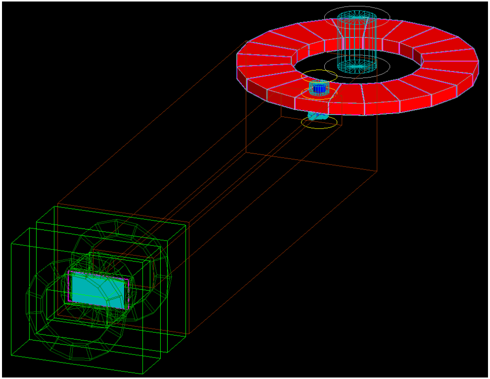
ν Energy with 1.3 GeV protons

Particle	ν/POT	DAR	DIF
ν_μ	0.087	98.88%	0.82%
$\bar{\nu}_\mu$	0.087	99.70%	0.30%
ν_e	0.087	99.99%	0.01%

Particle	ν/POT	DAR	DIF
ν_μ	0.119	98.60%	0.97%
$\bar{\nu}_\mu$	0.119	99.57%	0.43%
ν_e	0.118	99.99%	0.01%

STS Target Design

- FPSTS19 Workshop informed design
- Solid W instead of Liquid Hg
- 21 wedges; rotating assembly
- Compressed beam/moderator suite
- Assumed current PBW design



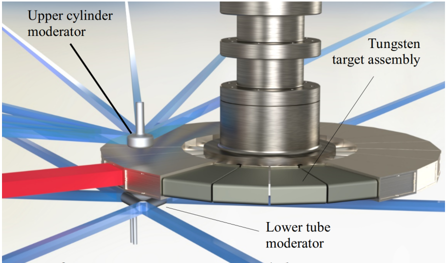


Figure from FPSTS19: Herwig workshop intro

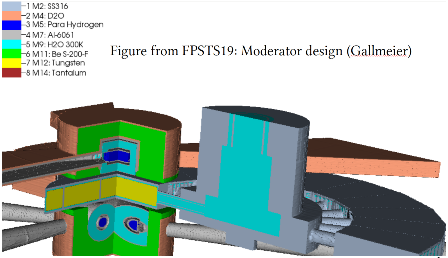


Figure from FPSTS19: Moderator design (Gallmeier)

A few details

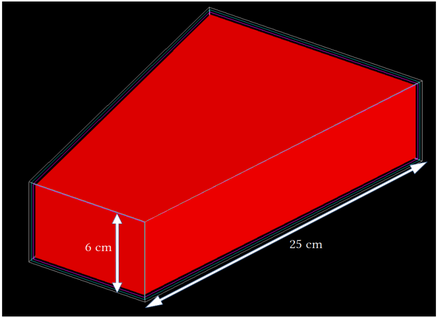
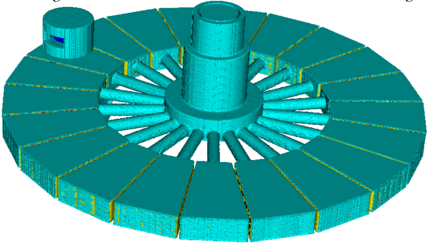
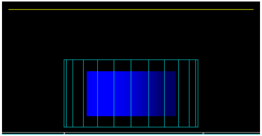


Figure from FPSTS19: Gallmeier Moderator Design

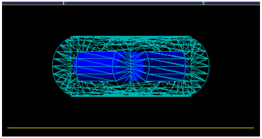


- ◇ Diameter of target assembly: 1.1 m
- ◇ 3 layers surround each wedge:
  - ▷ Tantalum coating
  - ▷ Water (edge cooling)
  - ▷ Steel casing
- ◇ Not all details are known:
  - ▷ Thickness of wedge layers
  - ▷ Gaps between wedges?
  - ▷ Exact moderator configurations
  - ▷ Shielding near target assembly

Above Target

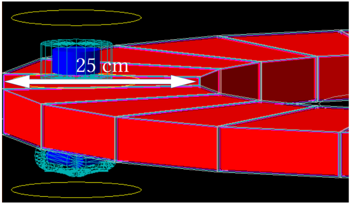


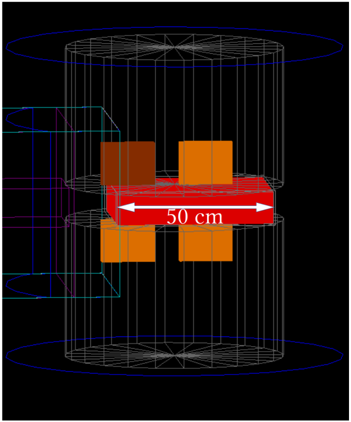
Below Target



Initial Estimates: FTS vs. STS

- ◇ STS is a pion decay-at-rest source of ν, but:
  - ▷ Small target, more decay-in-flight
  - ▷ Small moderators, more decay-in-flight
  - ▷ Shallow target, less ν produced in target
  - ▷ Immediate target surroundings unknown
- ◇ **Preliminary**: 0.14 ν/POT for ν_μ, $\bar{\nu}_\mu$, ν_e
- ◇ 15 Hz proton beam [3/4 pulses to FTS]
- ◇ STS monolith has denser shielding than FTS
- ◇ STS advantage: detector positioning





Summary

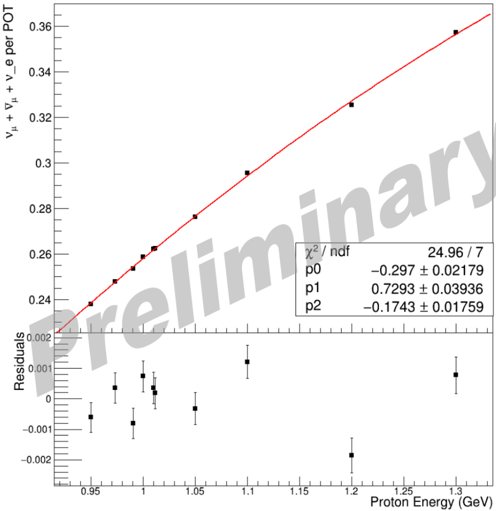
- ◇ Use simulation to monitor differences in SNS configurations
- ◇ 10% uncertainty from the model; simulation can't reduce alone!
- ◇ Improvements we've made to our flux simulation:
  - ▷ Neutrino creation positions and production angle
  - ▷ Breakdown flux by creation process
- ◇ Future of the simulation:
  - ▷ Determine position-related variations in ν flux
  - ▷ Compare newer Geant version with HARP data
  - ▷ Build up STS geometry as details become available
  - ▷ Compare simulation with results from planned D_2O

Thank you!

Carnegie Mellon University
The University of Chicago
Duke University
University of Florida
KAIST
Laurentian University / Université Laurentienne
Los Alamos National Laboratory EST. 1943
MEPhI
North Carolina Central University Founded 1910
NC State University
NM State University
Oak Ridge National Laboratory
Sandia National Laboratories
The University of Tennessee Knoxville
TUNL
University of Washington
Tufts University
University of South Dakota
Virginia Tech
CNEC Consortium for Nonproliferation Enabling Capabilities
KICP
NNSA National Nuclear Security Administration
NSF
U.S. Department of Energy

Backup Slides

Neutrino Production vs. Proton Energy



- 1 million POT per point
- Favors quadratic over linear