CEvNS at the Upgraded* SNS

*Proton Power Upgrade and Second Target Station

Diana Parno
Carnegie Mellon University

Neutrinos At ORNL Workshop – 1 December 2021

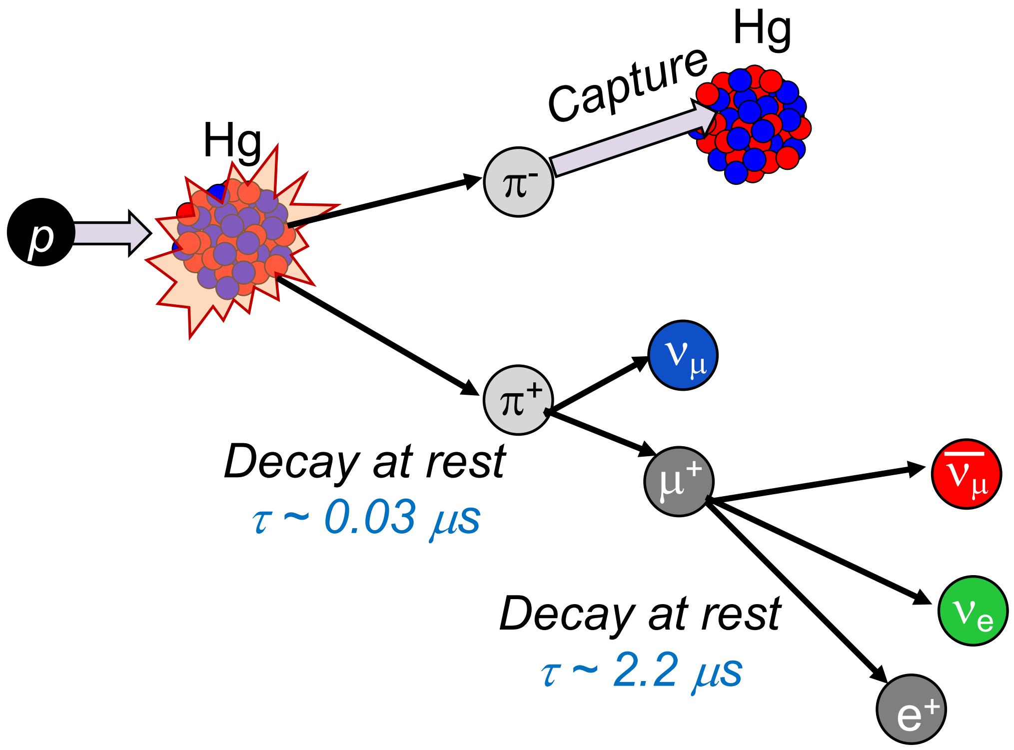
Acknowledgments

- COHERENT collaboration
- Neutrinos@STS working group
- DOE Office of Science Awards #DE-SC0010118 and #DE-SC0022125

Outline

- CEvNS at the Current SNS
- The Proton Power Upgrade
- The Second Target Station

Neutrinos at the SNS Right Now



Pion decay at rest

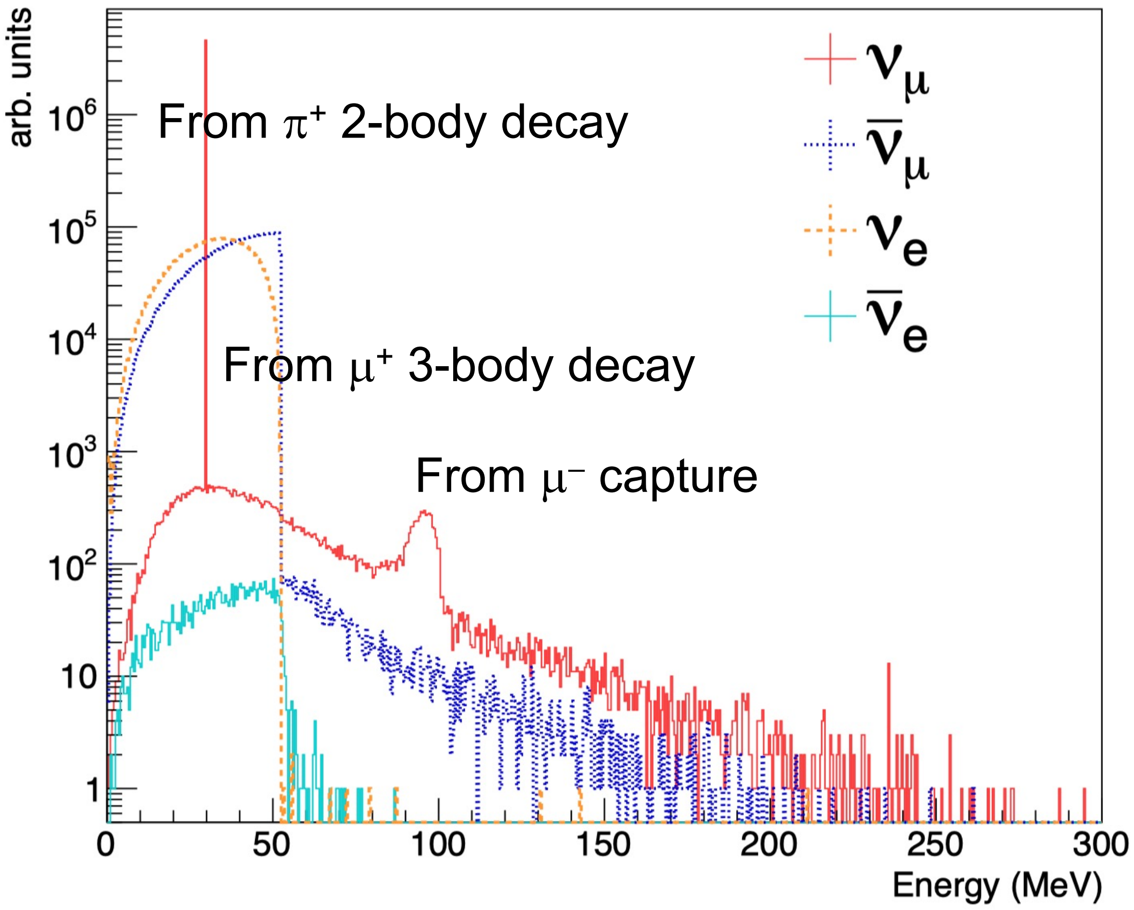
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

- A bunch of 1-GeV protons strikes a mercury target … and pions are born
  - π^- are captured on nuclei
  - π^+ stop in the dense target and then decay at rest
  - μ^+ decay products also stop, and decay at rest
- Proton bunches arrive at 60 Hz
- Via Geant4 simulations, we can predict the resulting neutrino flux to about 10% uncertainty

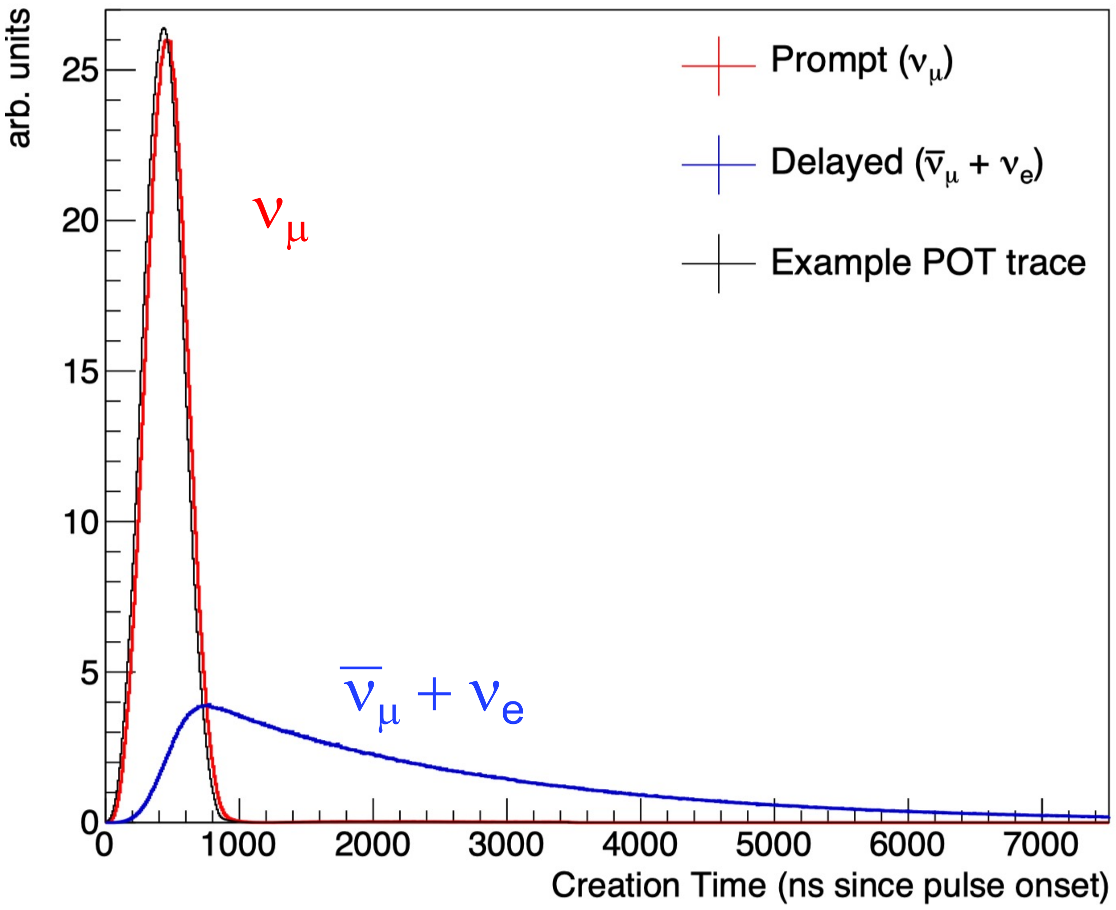
COHERENT, arXiv:2109.11049 [hep-ex]

SNS Neutrino Spectra

Energy



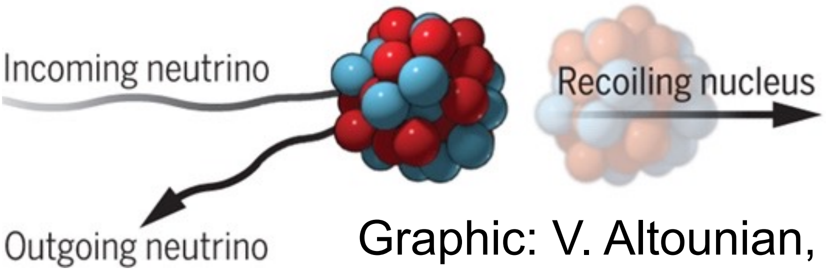
Timing



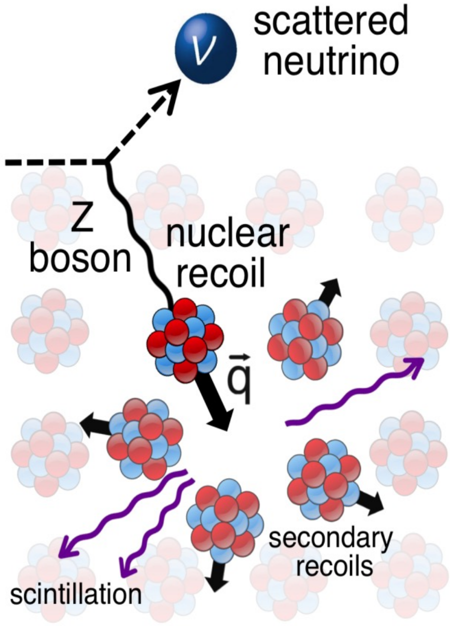
COHERENT, arXiv:2109.11049 [hep-ex]

Measuring CEvNS

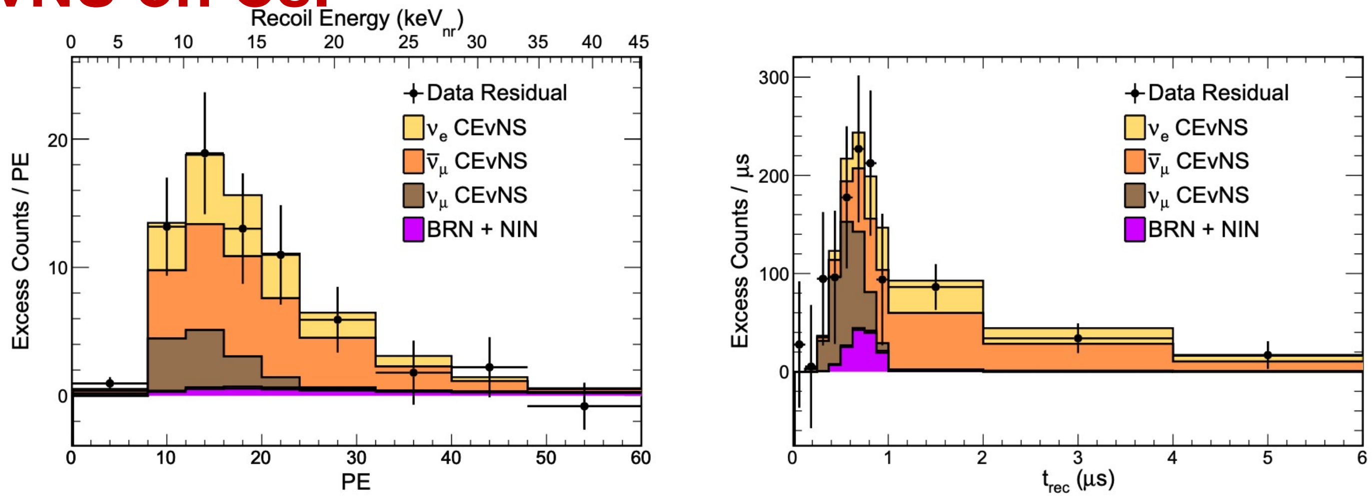
- Relatively large cross section
- Tiny nuclear-recoil signal



Graphic: V. Altounian, *Science*

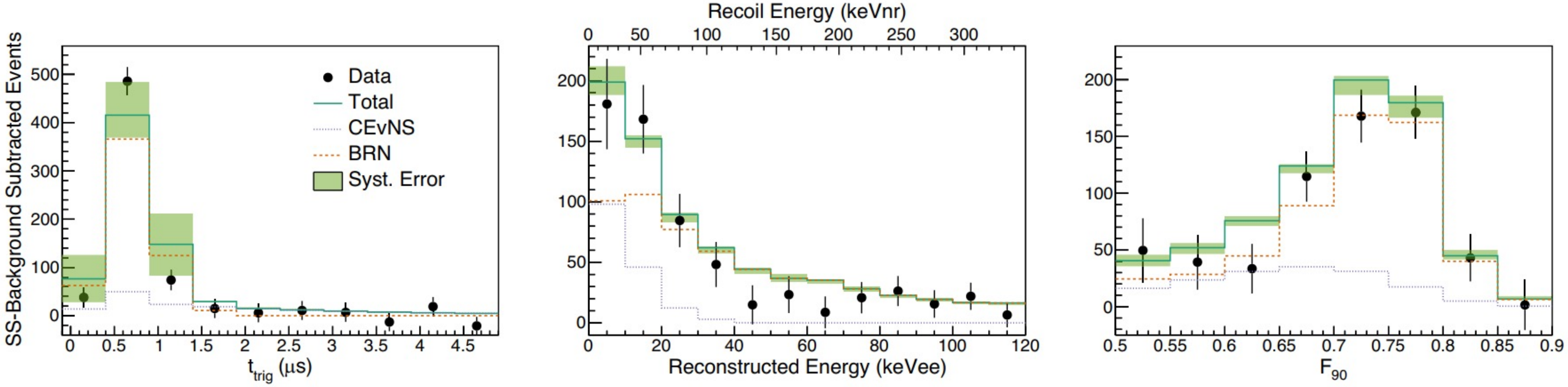


CEvNS on CsI



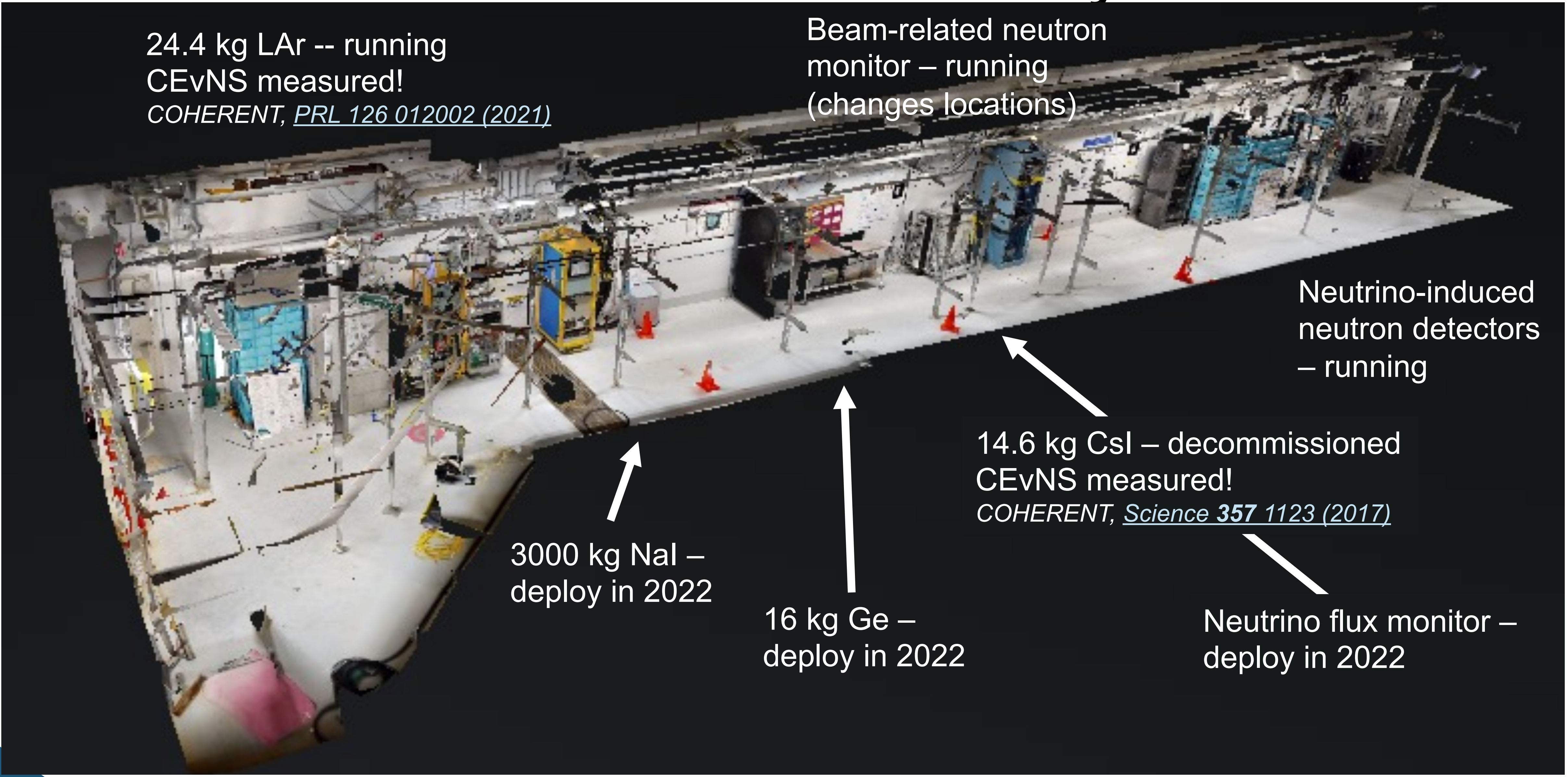
COHERENT, [arXiv:2110.07730 [hep-ex]]

CEvNS on Ar



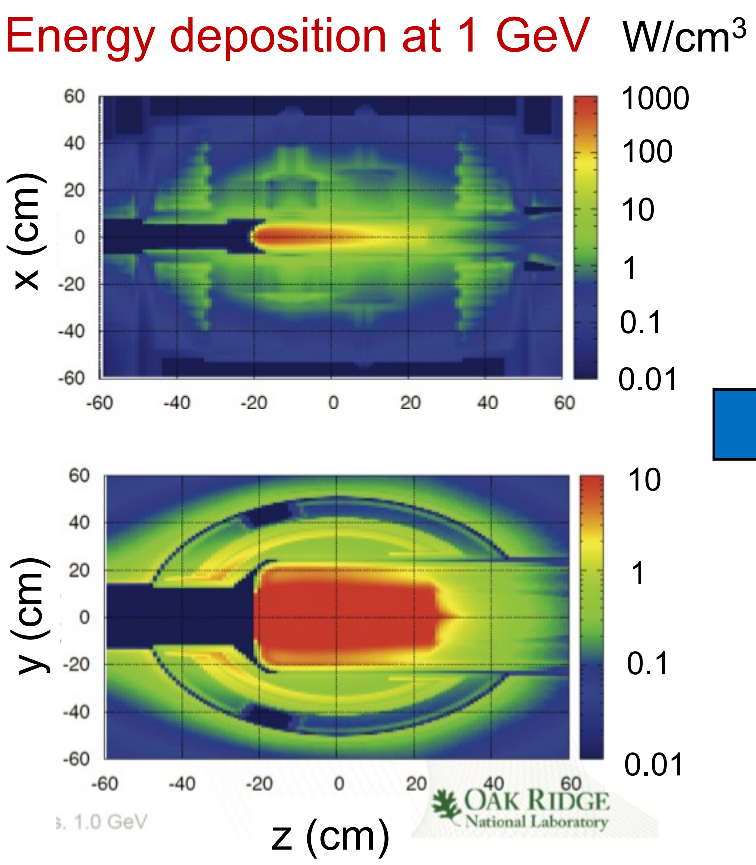
*COHERENT, [PRL **126** 012002 (2021)]*

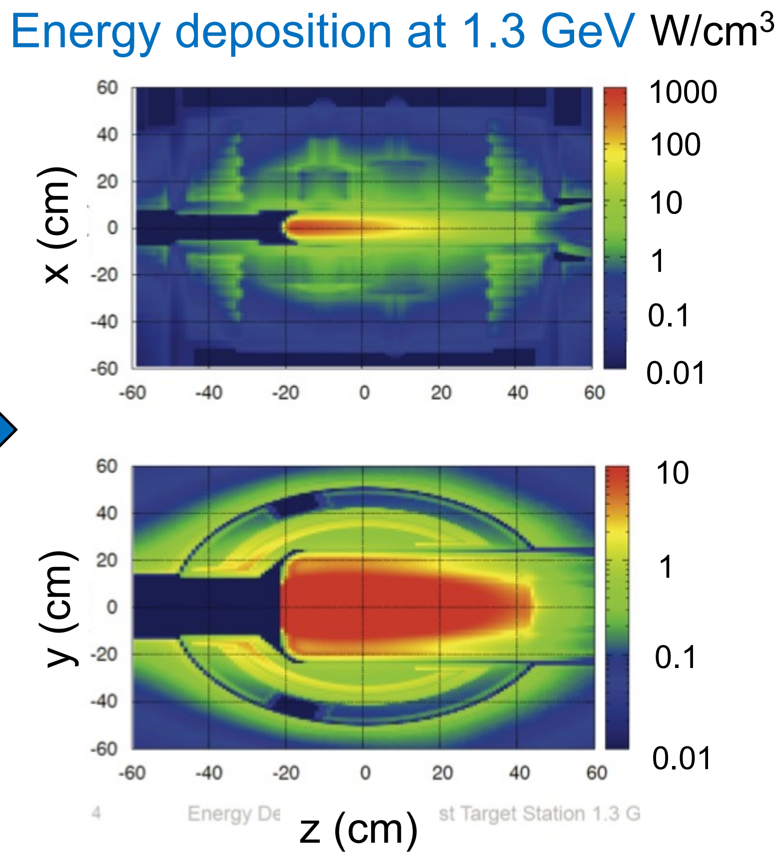
COHERENT in Neutrino Alley



Proton Power Upgrade: The Basics

- PPU will increase SNS power: 1.4 MW → **2.8 MW** by 2028
  - Average beam current: 26 mA → **38 mA**
  - Beam energy: 0.97 GeV → **1.3 GeV**

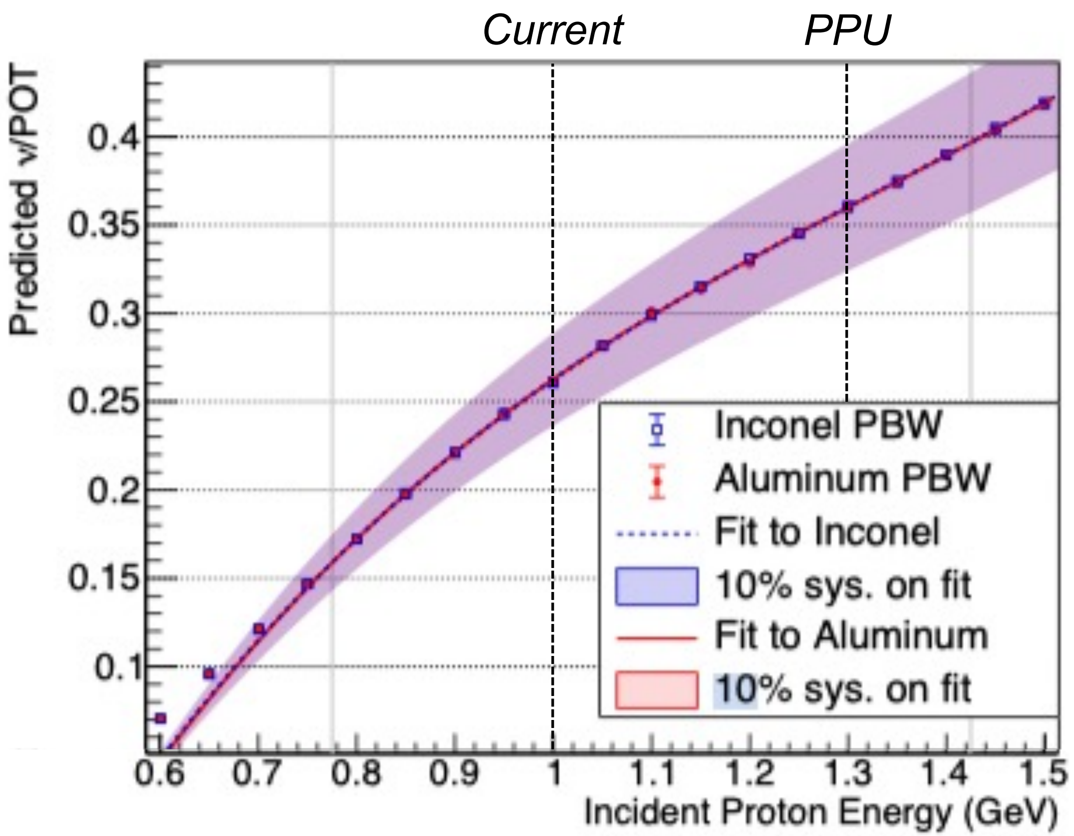




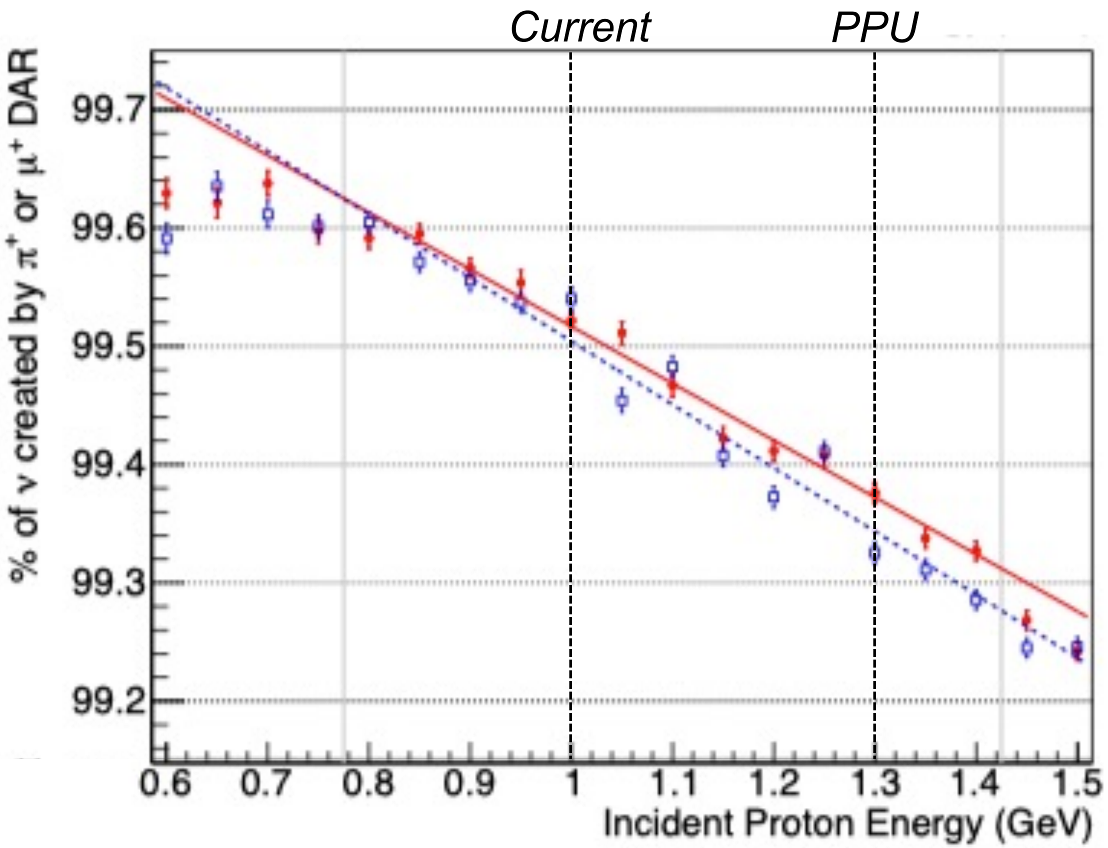
Simulations from J. Galambos et al., [PPU CDR (2017)]

Proton Power Upgrade: Neutrinos++

- Ratio of produced neutrinos to incident protons *increases* with E_p



- Fraction of decay-at-rest neutrinos *decreases* with E_p



COHERENT, arXiv:2109.11049 [hep-ex]

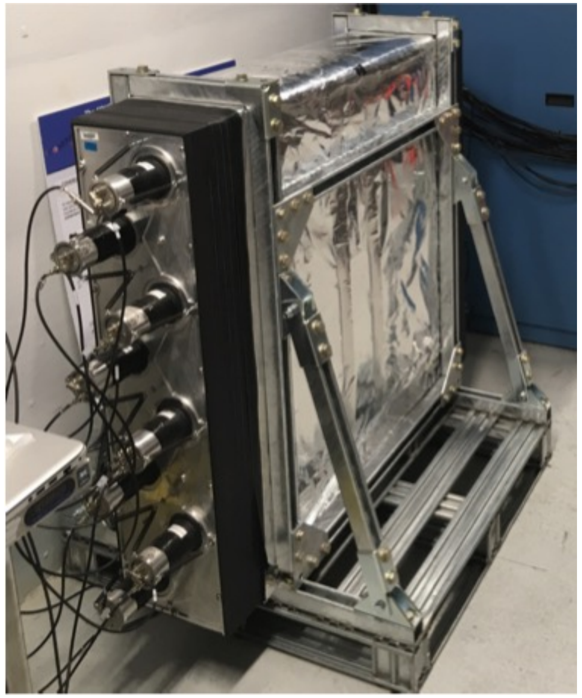
Proton Power Upgrade: Monitoring

- D_2O detector to benchmark ν flux

  - Use well-understood (2-3%) interaction $\nu_e + d \rightarrow p + p + e^-$
  - Avoid dominating uncertainty in pion-production cross sections
  - Deploy early in staged PPU process

*COHERENT, JINST **16** P08048 (2021)*

- MARS: Portable neutron detector



  - Monitor beam-related neutrons
  - Easily repositioned in Neutrino Alley
  - Measure backgrounds before, during and after PPU

*C. Roecker et al., NIM A **826** 21 (2016)*

Second Target Station: The Basics

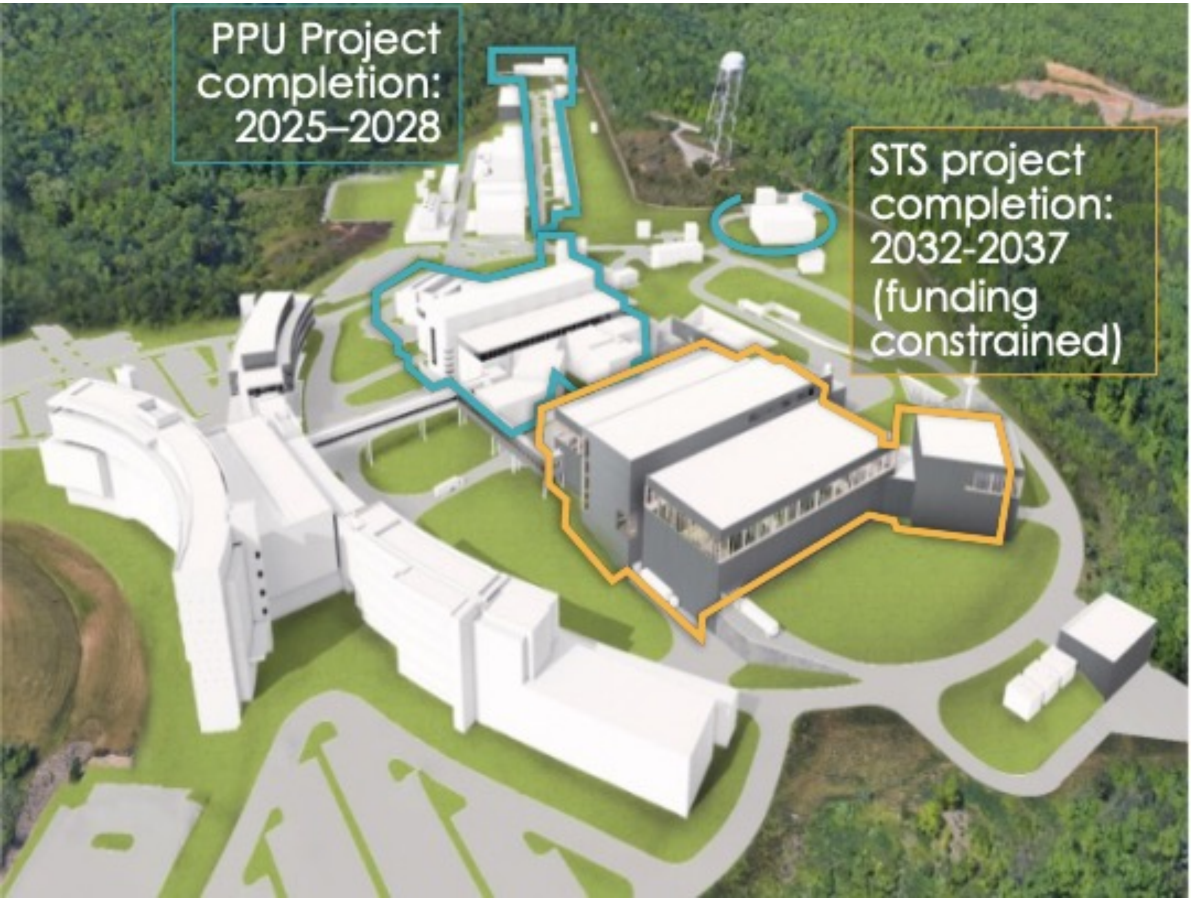
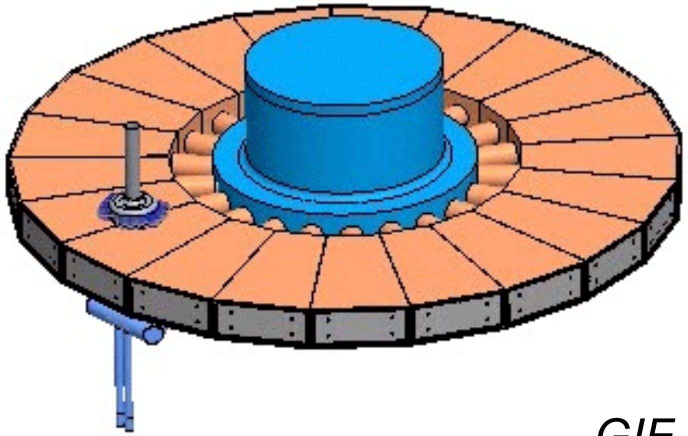


Image from Ken Herwig

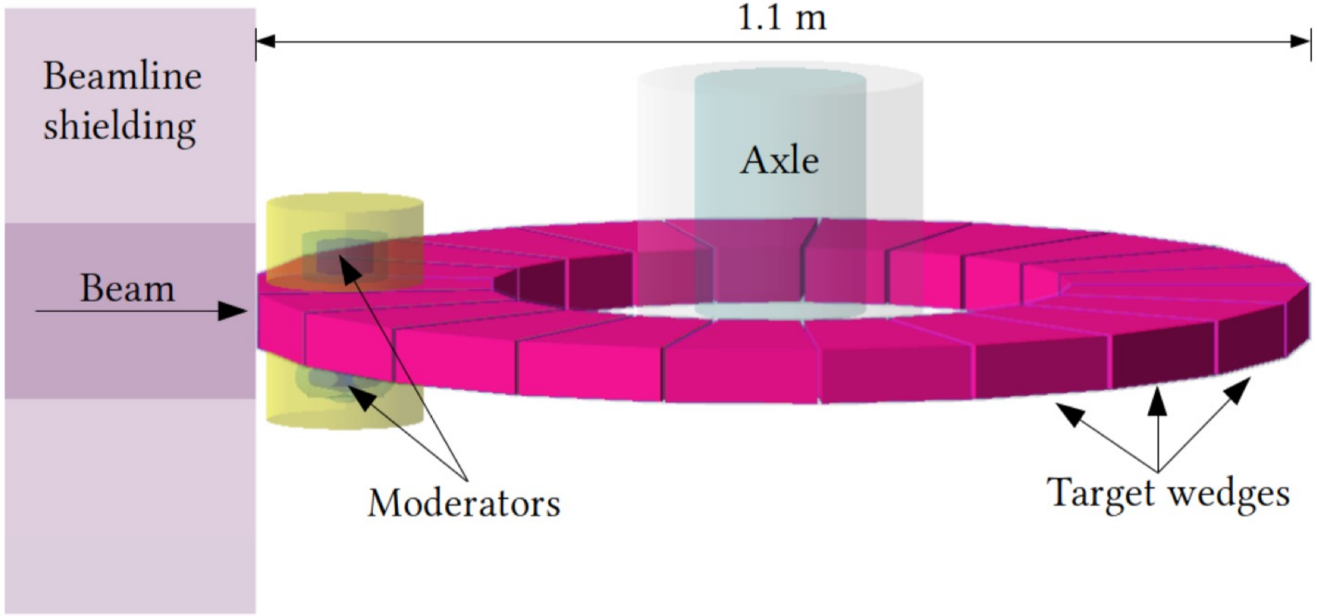
- Rotating wheel of tungsten wedges
- Receives ¼ proton pulses (15 Hz)
  - First target station gets ¾ proton pulses (45 Hz)
- Optimized to produce cold neutrons

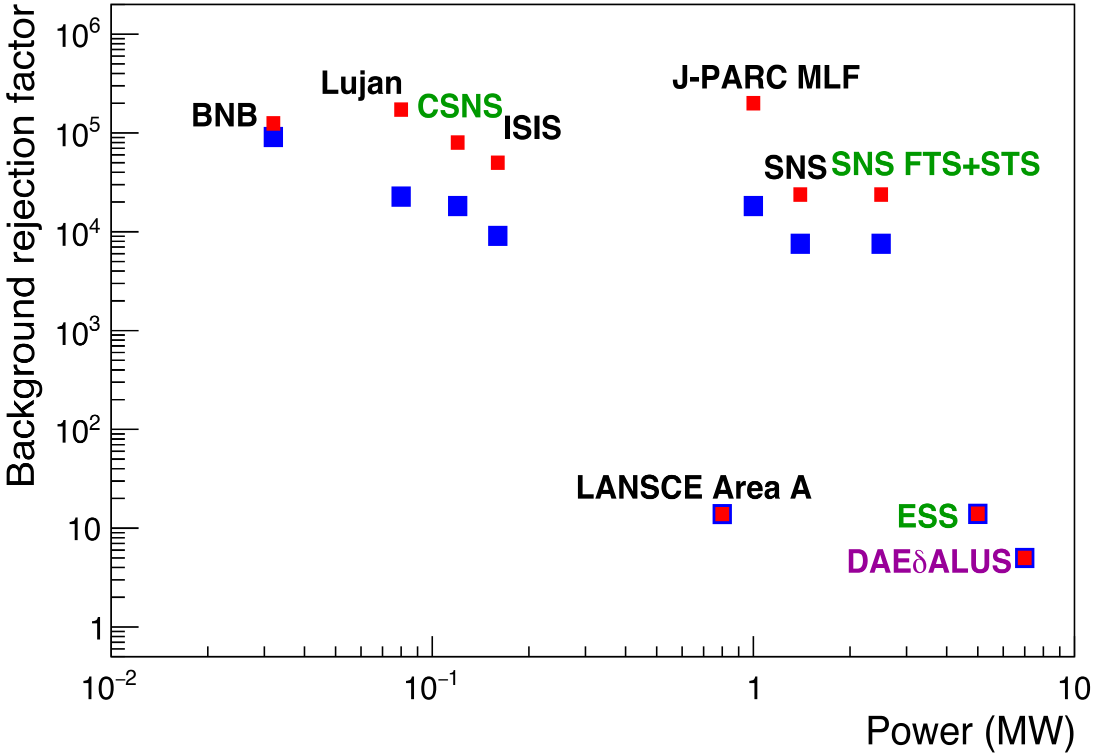


GIF from ORNL

Second Target Station: Neutrino Flux

- Preliminary simulation estimate: ~0.39 ν per proton on target
  - ~8% higher than for first target station (Hg) at same 1.3 GeV energy
- Decay-at-rest fraction depends on details of shielding structure



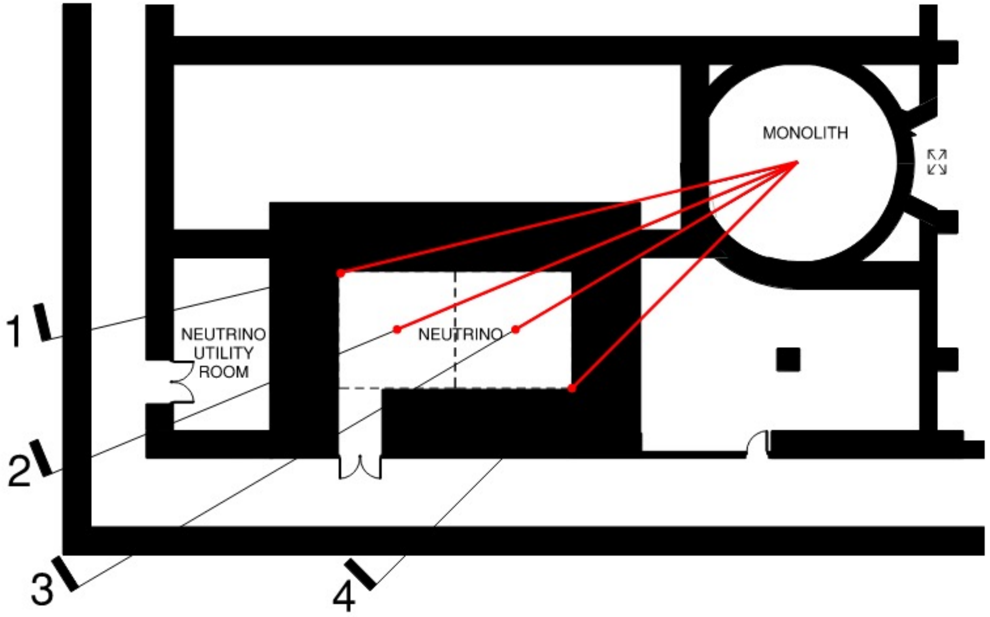


COHERENT, *[arXiv:2109.11049 [hep-ex]]*

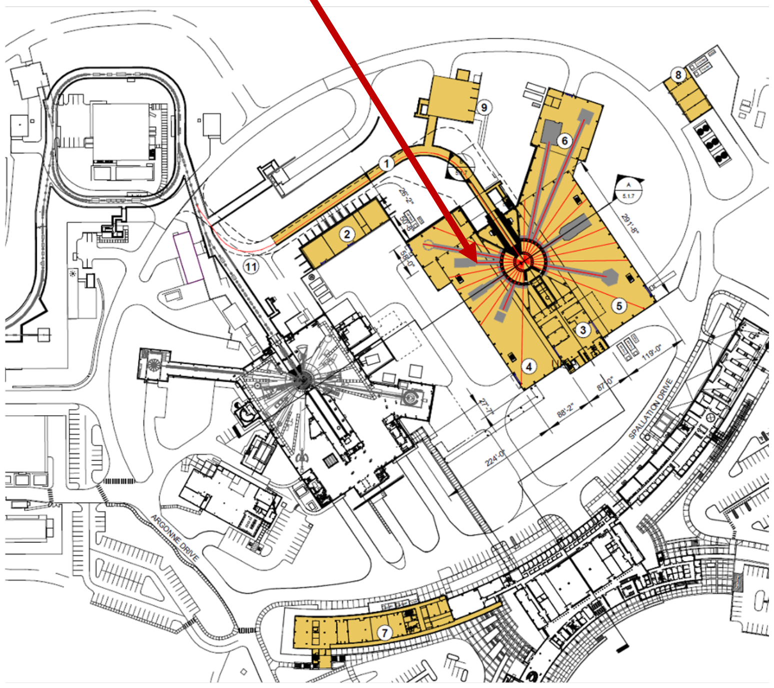
Second Target Station: Neutrino Alley++

- What do we need to measure CEvNS?
  - Space!
  - 20+ m of shielding
  - Overburden to reduce backgrounds
- Don't forget neutron and neutrino monitoring!

STS Basement Concept for Neutrinos



Ideal Basement Location

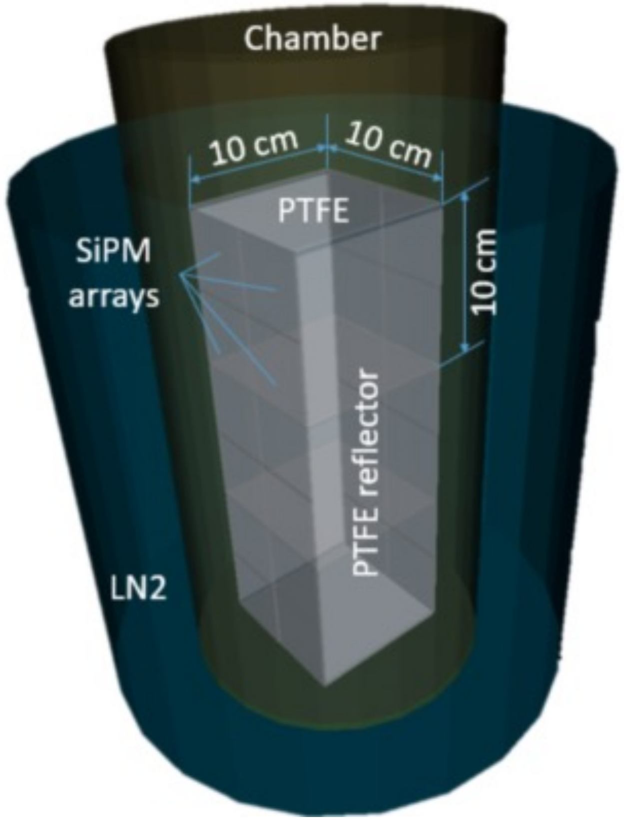


Images from Jason Newby

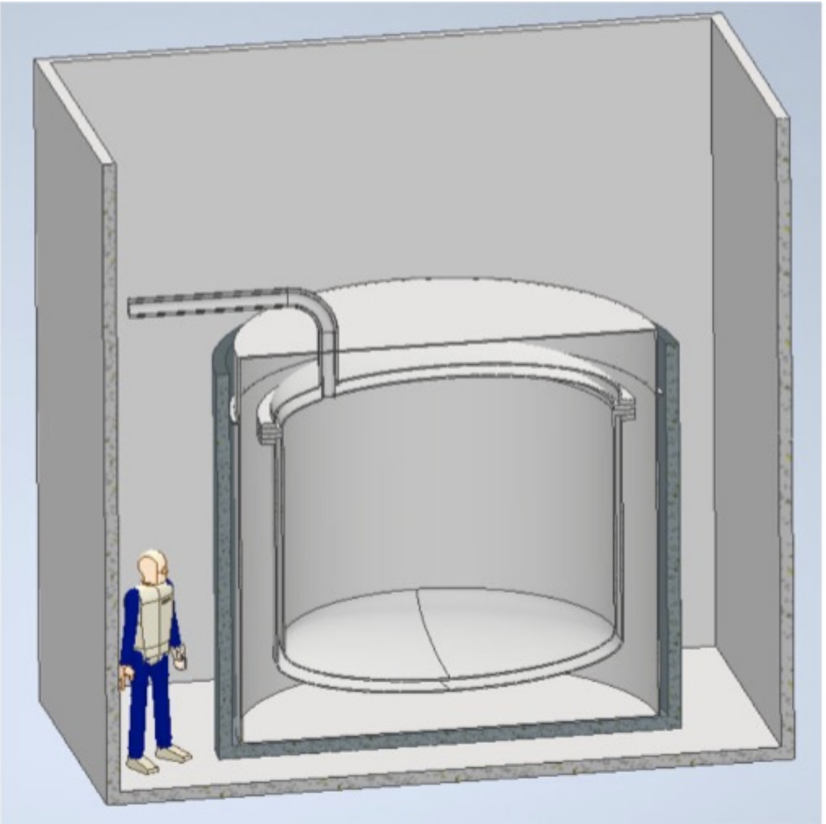
Second Target Station: Possibilities

- Room for two 10-ton-scale CEvNS detectors?

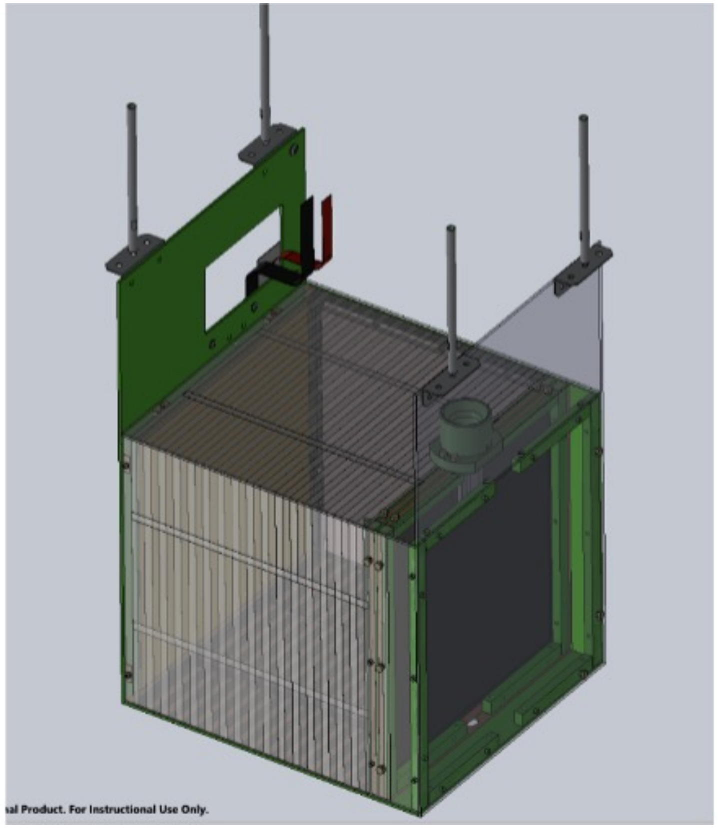
Cryogenic CsI detector



Single-phase LAr scint.



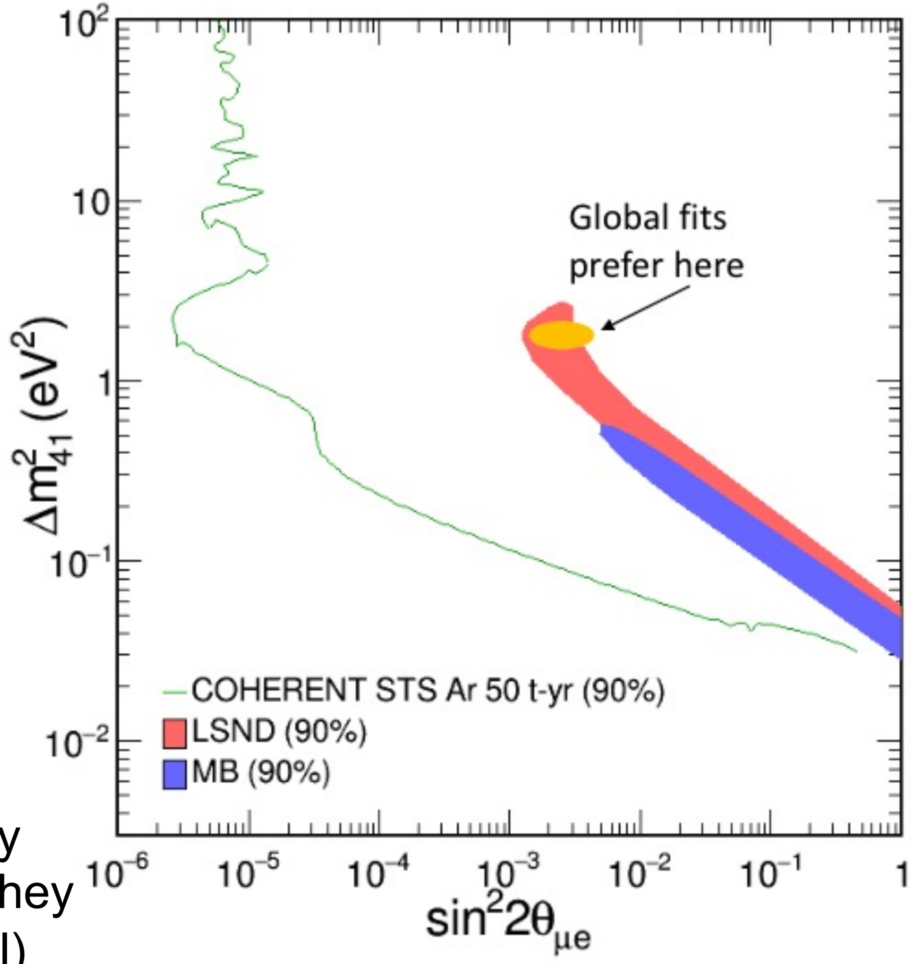
LAr TPC



- Immense Ge array? Two-phase Xe? Directional gas-phase detector? More?

Two Baselines at Once

- A large CEvNS detector will see neutrinos from both target stations
  - Distinguish sources via timing
  - Prompt neutrinos are (nearly) monoenergetic
  - Limit energy range of delayed neutrinos by requiring high recoil energies
  - … We can search for sterile neutrinos!
- Assumptions:
  - 10t depleted argon
  - 20m from STS and 121m from FTS
  - No neutrons in FTS beam spills
  - 1% uncorrelated normalization uncertainty



Preliminary sensitivity study from Dan Pershey (appearance channel)

Conclusion

- The SNS is already a premier facility for CEvNS detection and related physics
- PPU and STS upgrades hold great promise:
  - Increased neutrino flux (PPU)
  - Increased space → increased target mass, better optimized detector designs
  - Simultaneous measurement at 2 baselines
- Ongoing benchmarking of neutrino and beam-related neutron fluxes is crucial

Thank you!

Backup

PPU Staging

- Staged approach delivers more neutrons (and neutrinos) sooner

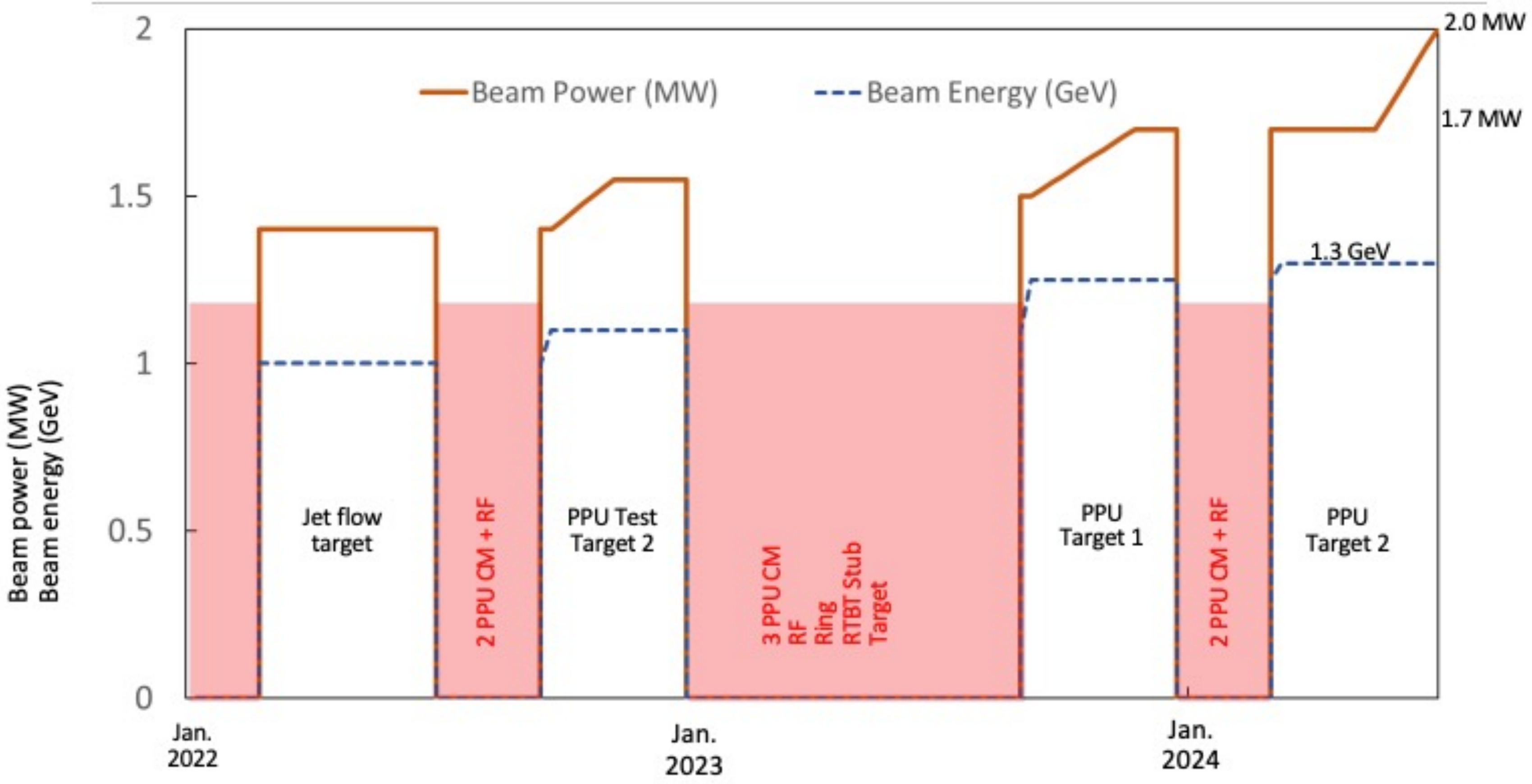


Figure from John Galambos