August 25 2023, Lomonosov-2023

TWENTY- FIRST
LOMONOSOV
CONFERENCE
ON
ELEMENTARY
PARTICLE
PHYSICS

Moscow, August 24 - 30, 2023

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1711-1765

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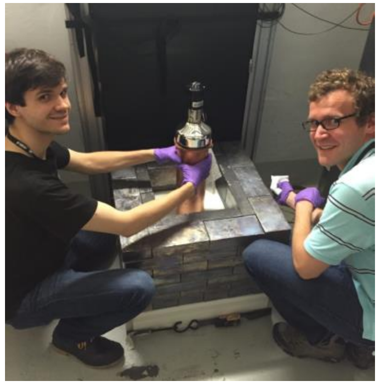
Status of COHERENT and new physics opportunities at SNS

Carnegie Mellon University · Duke University · UF University of Florida · Indiana University · ITEP · Laurentian University Université Laurentienne · Los Alamos National Laboratory · MEPhI · North Carolina Central University · NC State University · Oak Ridge National Laboratory · Sandia National Laboratories · 서울대학교 Seoul National University · SLAC · University of South Dakota · The University of Tennessee Knoxville · Tufts University · TUNL · Virginia Tech · University of Washington · Washington & Jefferson College

~85 people, 21 institutions from 4 countries

Looking for new physics using coherent elastic ν–nucleus scattering (CEvNS)

…but not only!



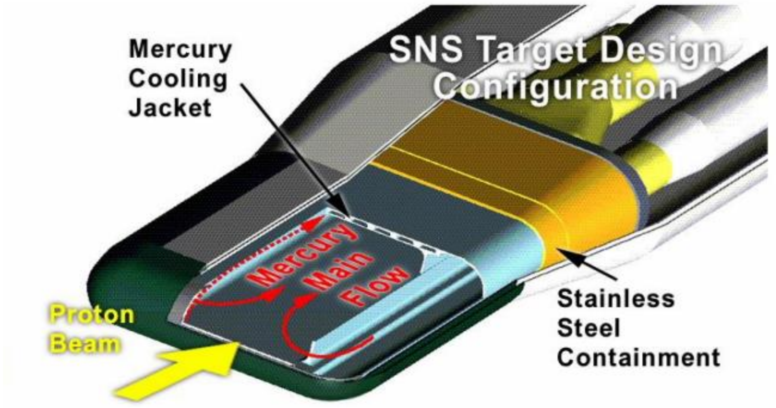


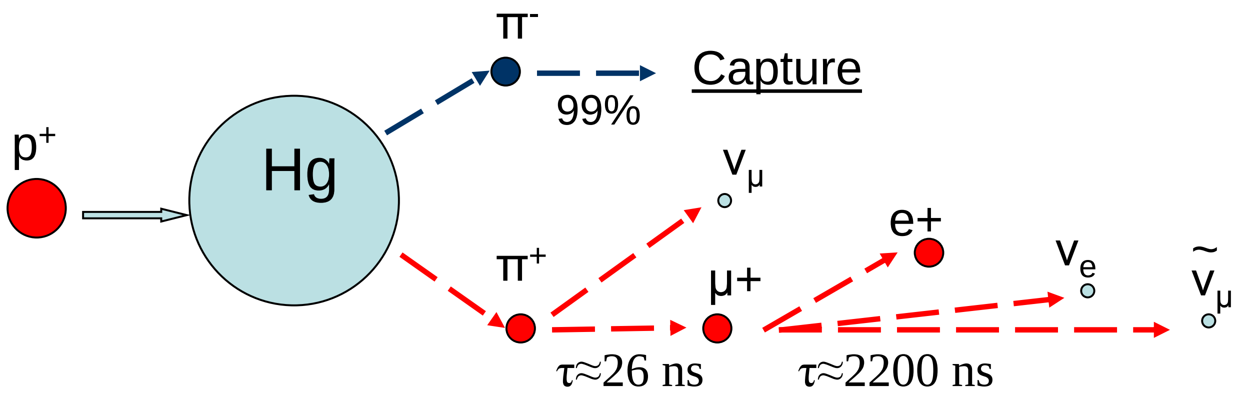
SNS facility at ORNL

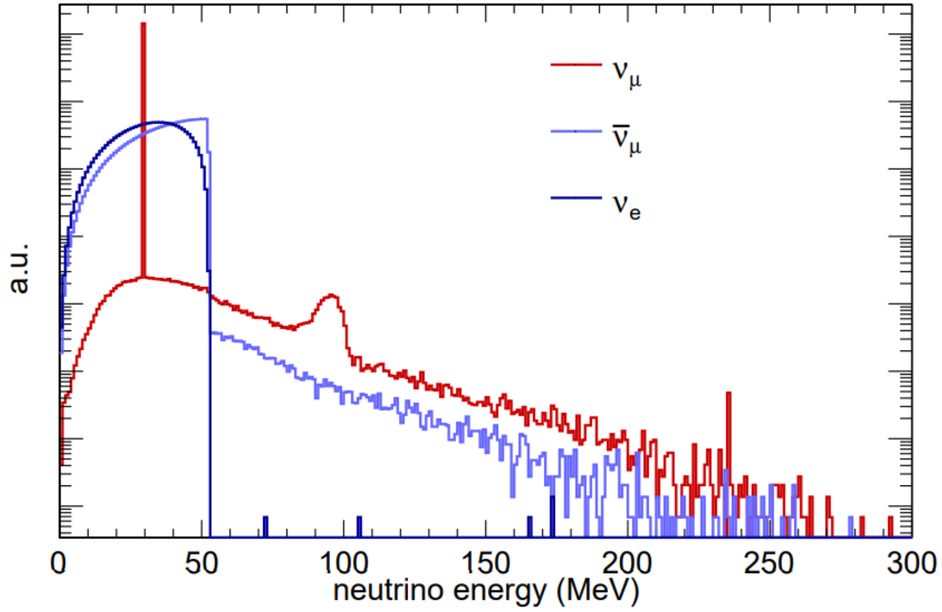
Bunches of ~1 GeV protons on the Hg target with 60 Hz frequency

Proton bunch time profile with FWHM of ~350 ns

Total neutrino flux of $4.3 \cdot 10^7$ $cm^{-2} * s^{-1}$ at 20m

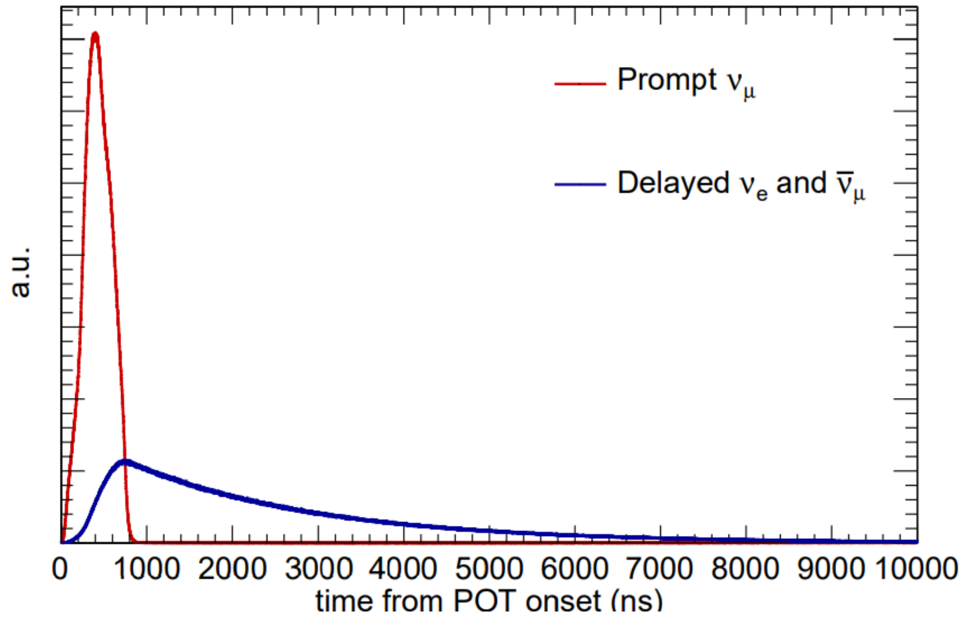




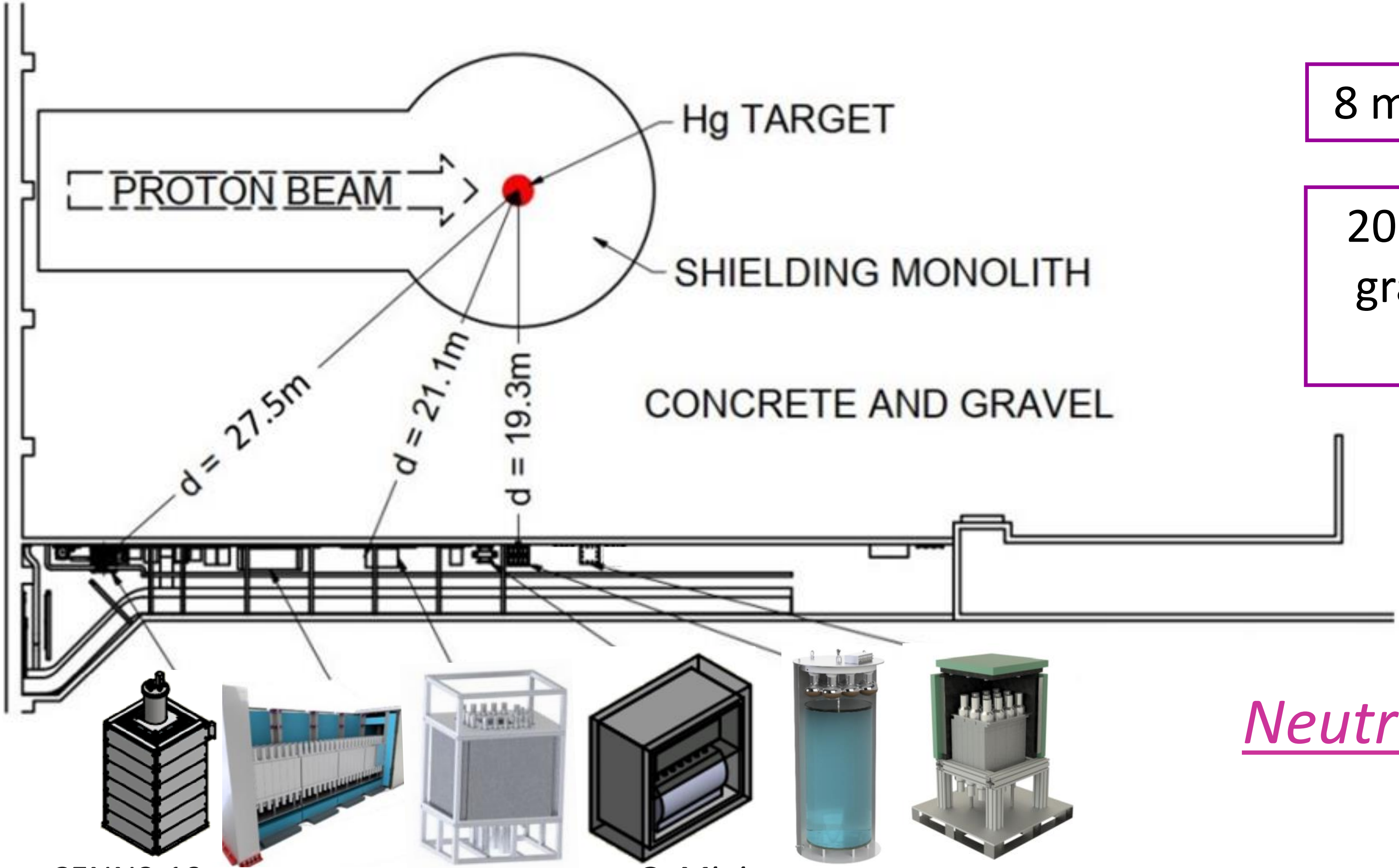


ν energy and timing suit well for CEνNS search

PRD 106, 032003 (2022)



COHERENT detectors are hosted by the target building basement



CENNS-10 (24 kg LAr)

NaI ~3T

NuThor

GeMini, (13 kg HPGe)

D2O

NaI, 185 kg

8 m.w.e. vertical overburden

20 m of steel, concrete and gravel with no voids in the direction of the target

Neutrino alley virtual tour (click me)

CEvNS detectors: pioneers

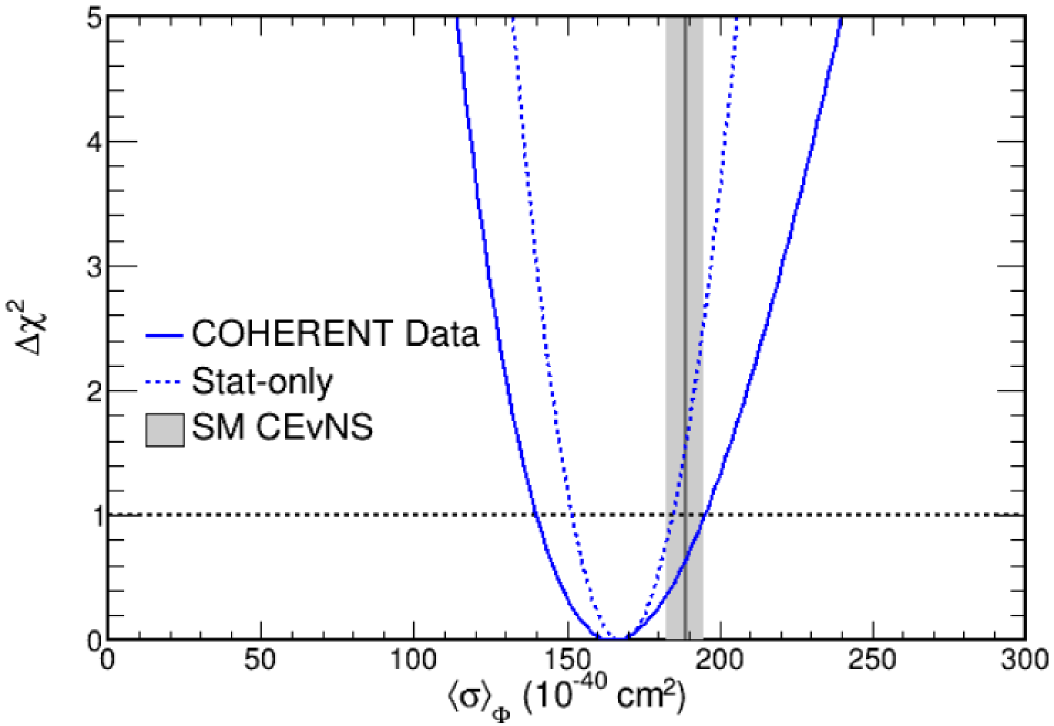
CsI[Na], 14.6 kg

2015-2017: Science vol. 357 iss. 6456 (2017)

6.7σ first observation

2015-2019: PRL vol. 129 081801 (2022)

11.6σ at full statistics



The end of exposure in 2019

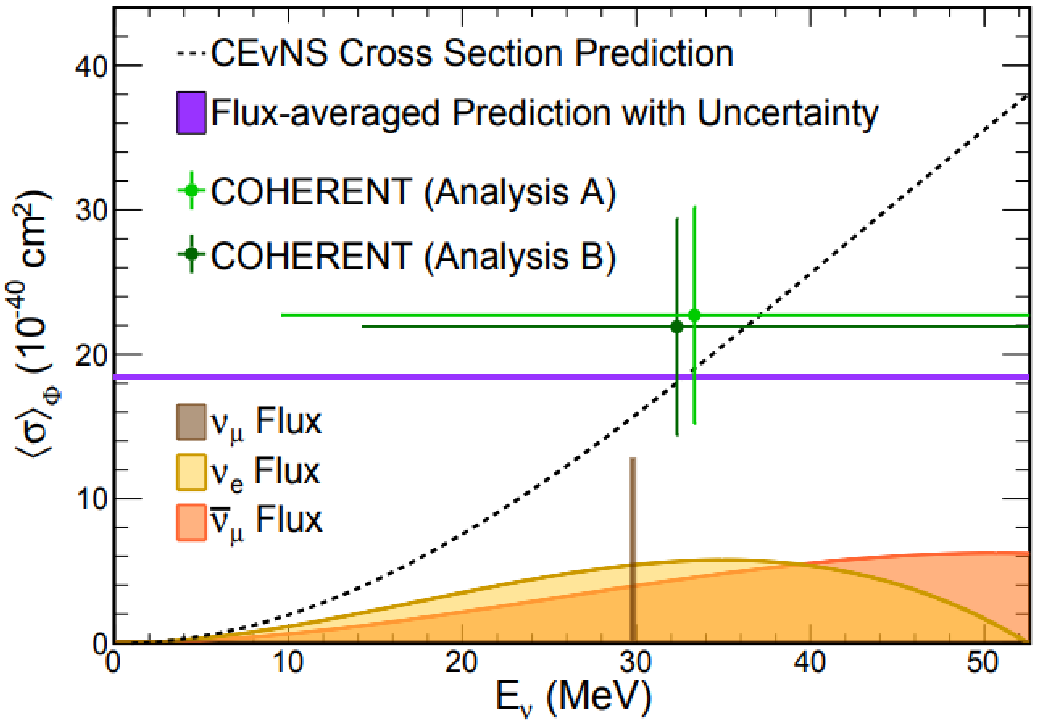
LAr, 24 kg (CENNS-10)

2017: PRD vol. 100 115020 (2019)

limit ~4 times SM (90% CL)

2017-2018: PRL vol. 126 012002 (2021)

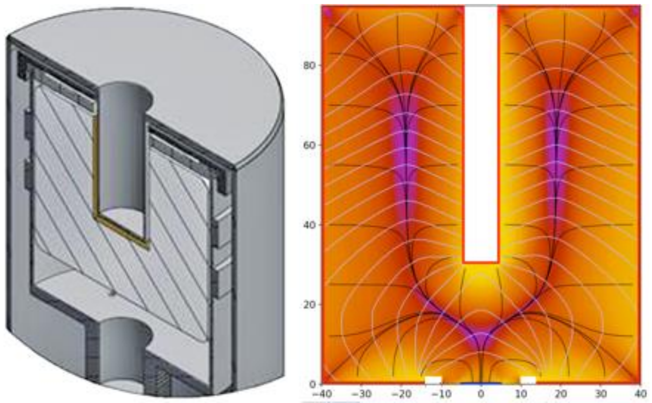
observation at 3.1σ

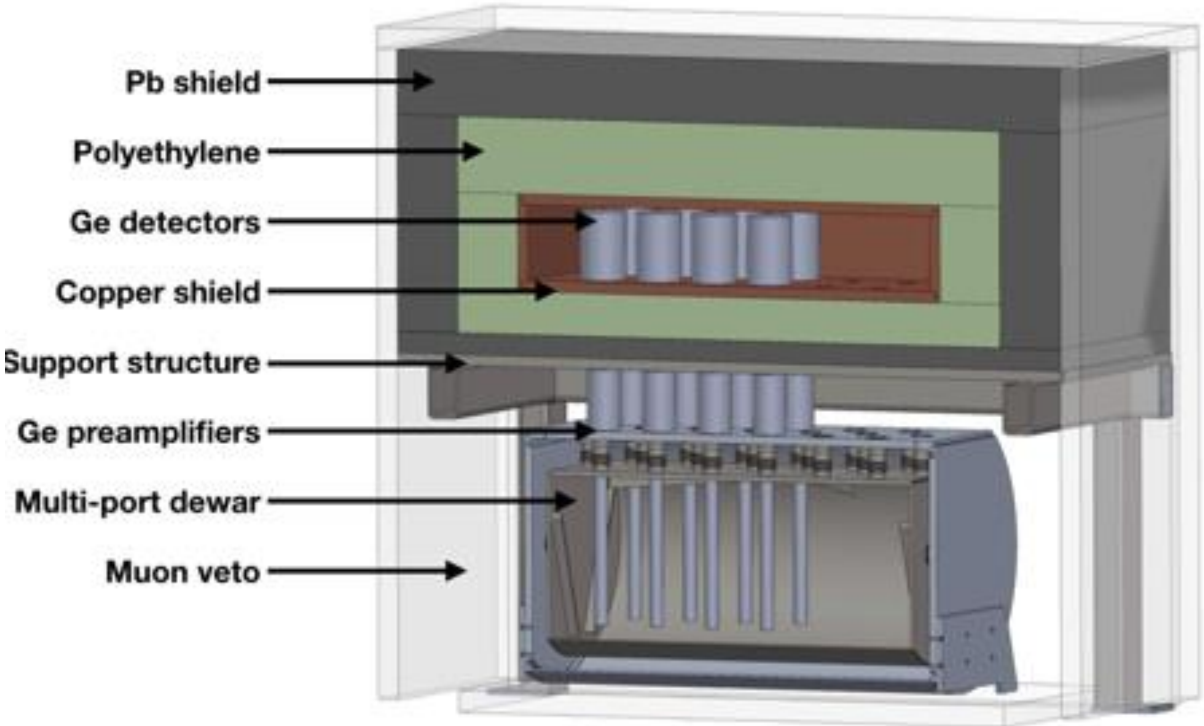


The full data (2017-2021) analysis is ongoing

CEvNS detectors: Ge-Mini

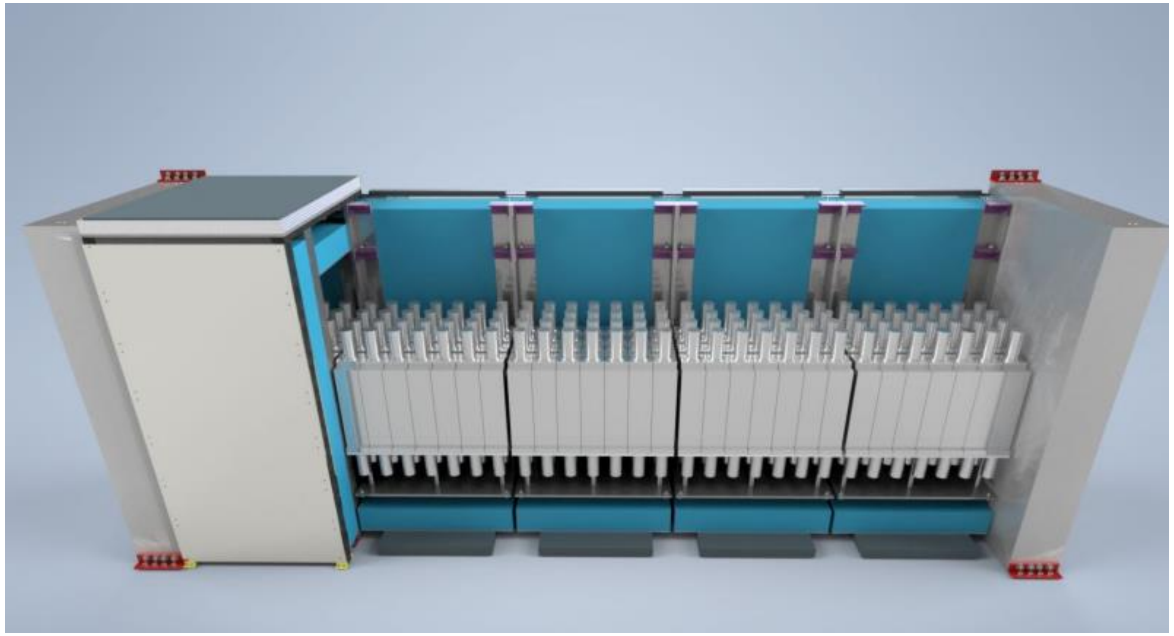
HPGe PPC
6 detectors deployed, ~13 kg active mass,
100-150 eV FWHM pulser resolution,
expected threshold of 2.5 keV$_{nr}$≈ 0.4 keV$_{ee}$





<u>About a month of BEAM ON data acquired -> Initial results this fall</u>

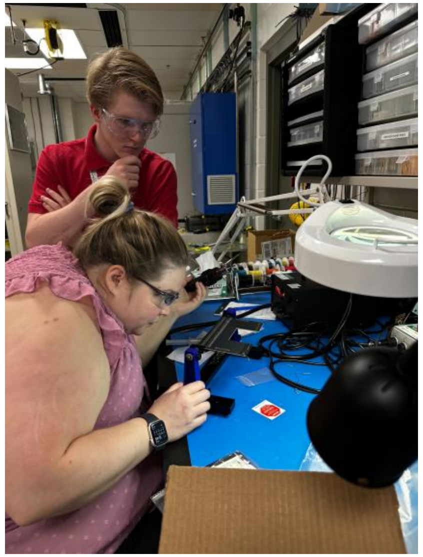
CEvNS detectors: NaIvETe

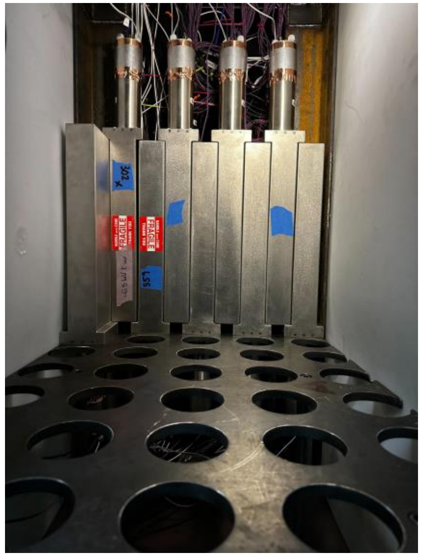


NaI[Tl]: 2.4T→3.4T

1 crystal = 7.7 kg,
1 module = 63 crystals,
5->7 modules planned [3 deployed ATM]

Sensitivity: 3σ per year (3.4 T), E_{thr}=13 keV_{nr}

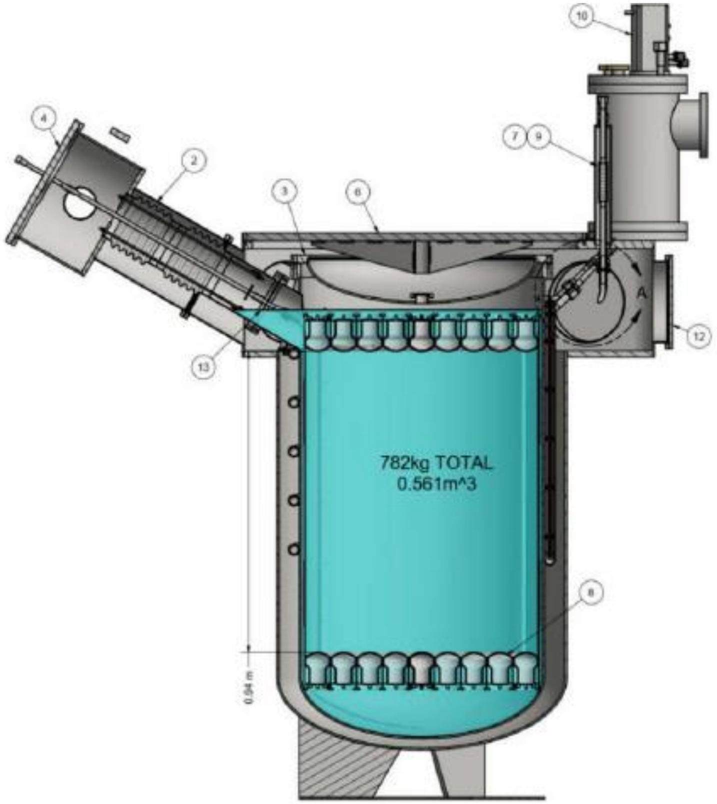


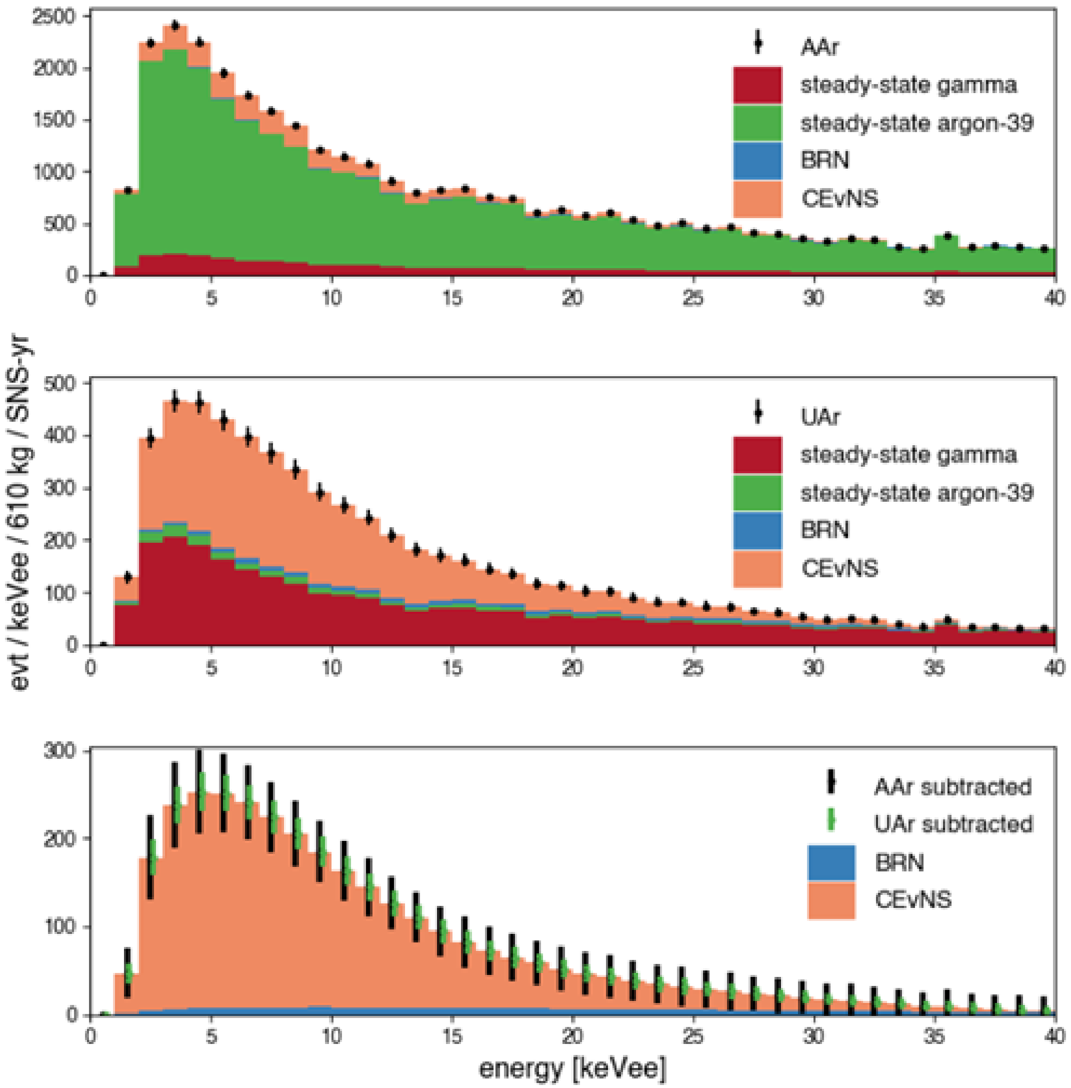


CEvNS detectors: future – CENNS-750 (LAr)

750 kg total (610 kg fid.), 3000 CEvNS/year

128 PMTs, TPB for wavelength shifting

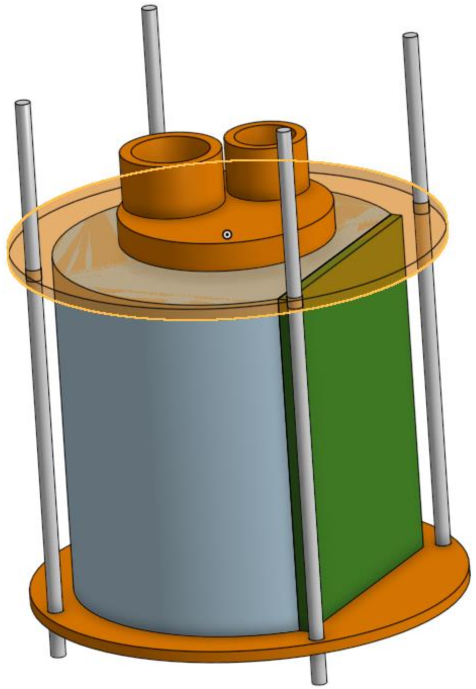




Cryostat nearly complete, PMTs acquired

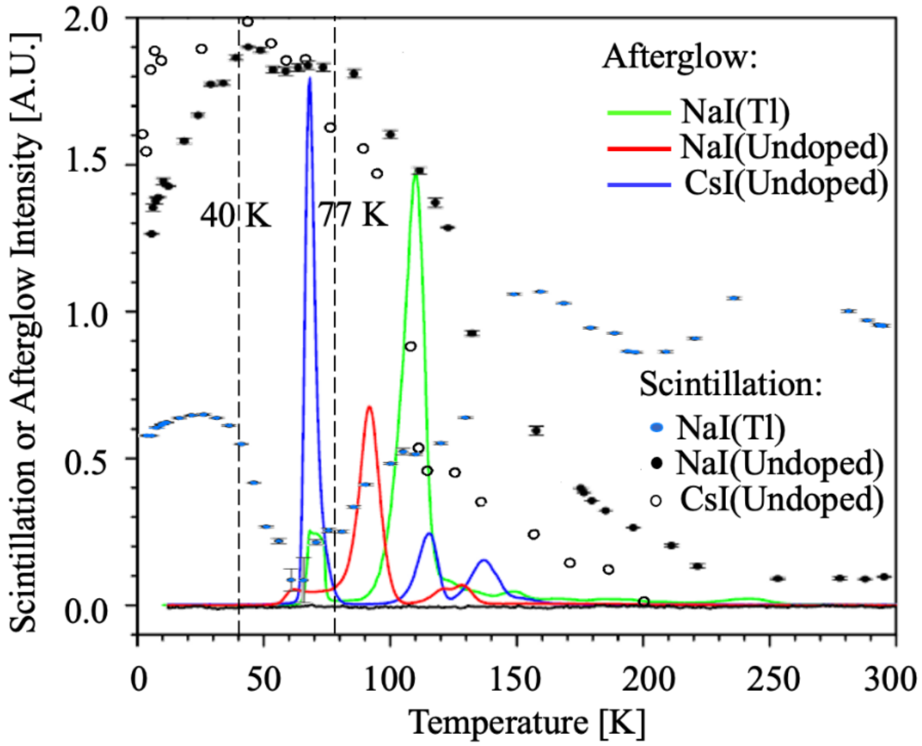
Planned to be deployed and running by 2025

CEvNS detectors: future – cryogenic undoped CsI



Like CsI[Na], but better:

1. *Higher light yield at or below 77 K*
2. *SiPMs:*
   - *high QE*
   - *no Cherenkov radiation*
   - *low dark count rate (low T)*



R&D: - detector shape and size: ~10 kg, 6"x 6" cylinder

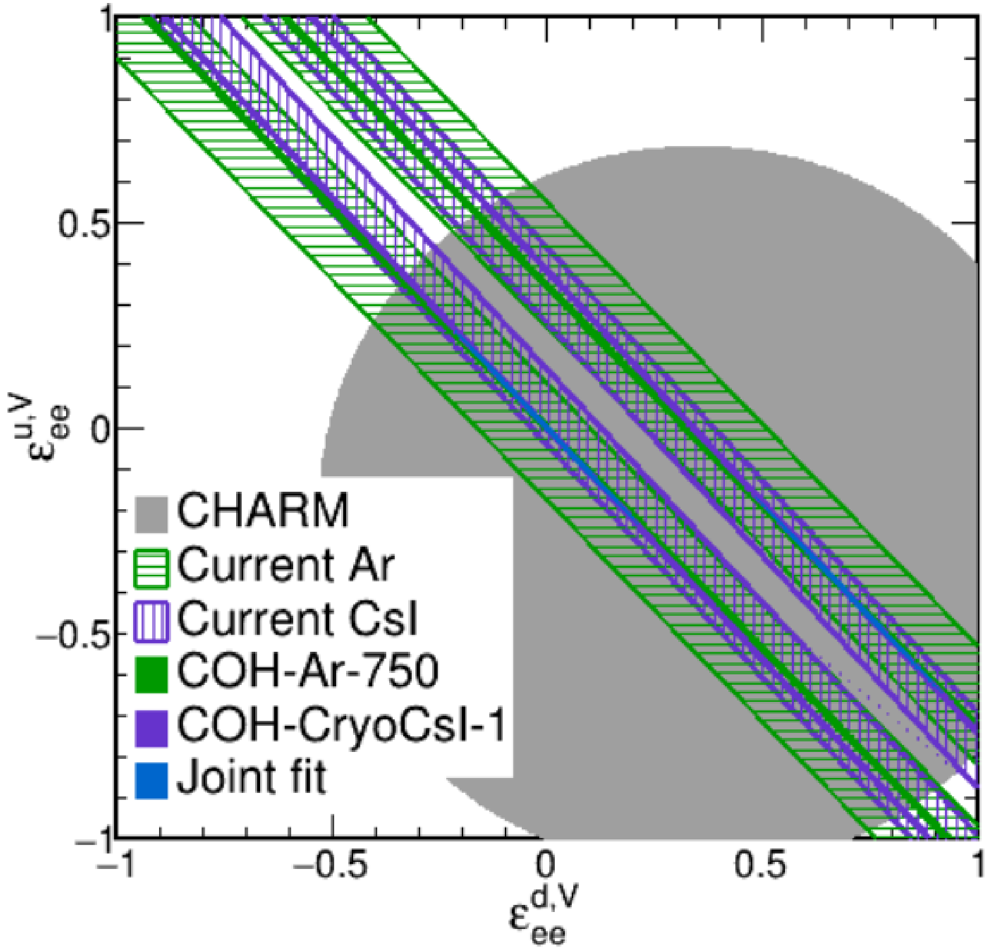
- cooling: LN or cryocooler

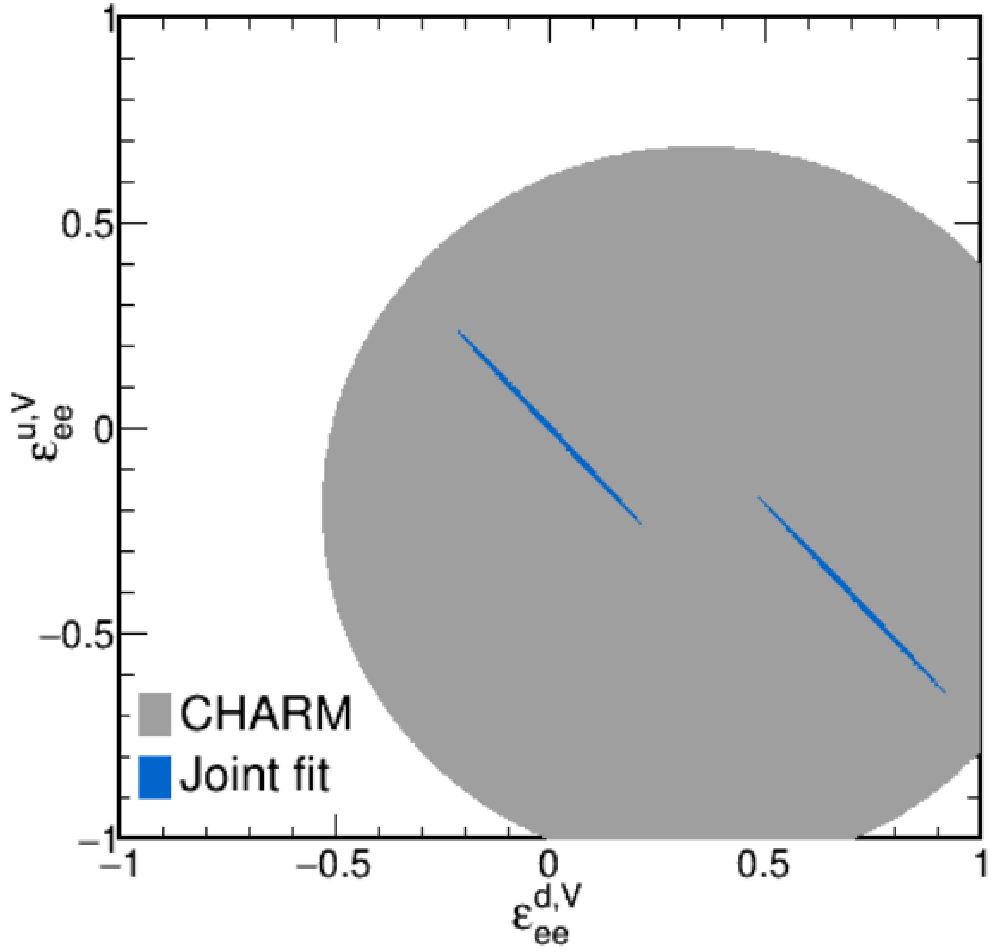
- QF measurements at TUNL

- about 1.4 keV$_{nr}$ threshold planned

Vector-like ν-q NSI, $Q_\alpha^2 = \left[Z\left(g_p^V + 2\varepsilon_{\alpha\alpha}^u + \varepsilon_{\alpha\alpha}^d\right) + N\left(g_n^V + \varepsilon_{\alpha\alpha}^u + 2\varepsilon_{\alpha\alpha}^d\right)\right]^2$ *, see JHEP 12 (2005) 021*

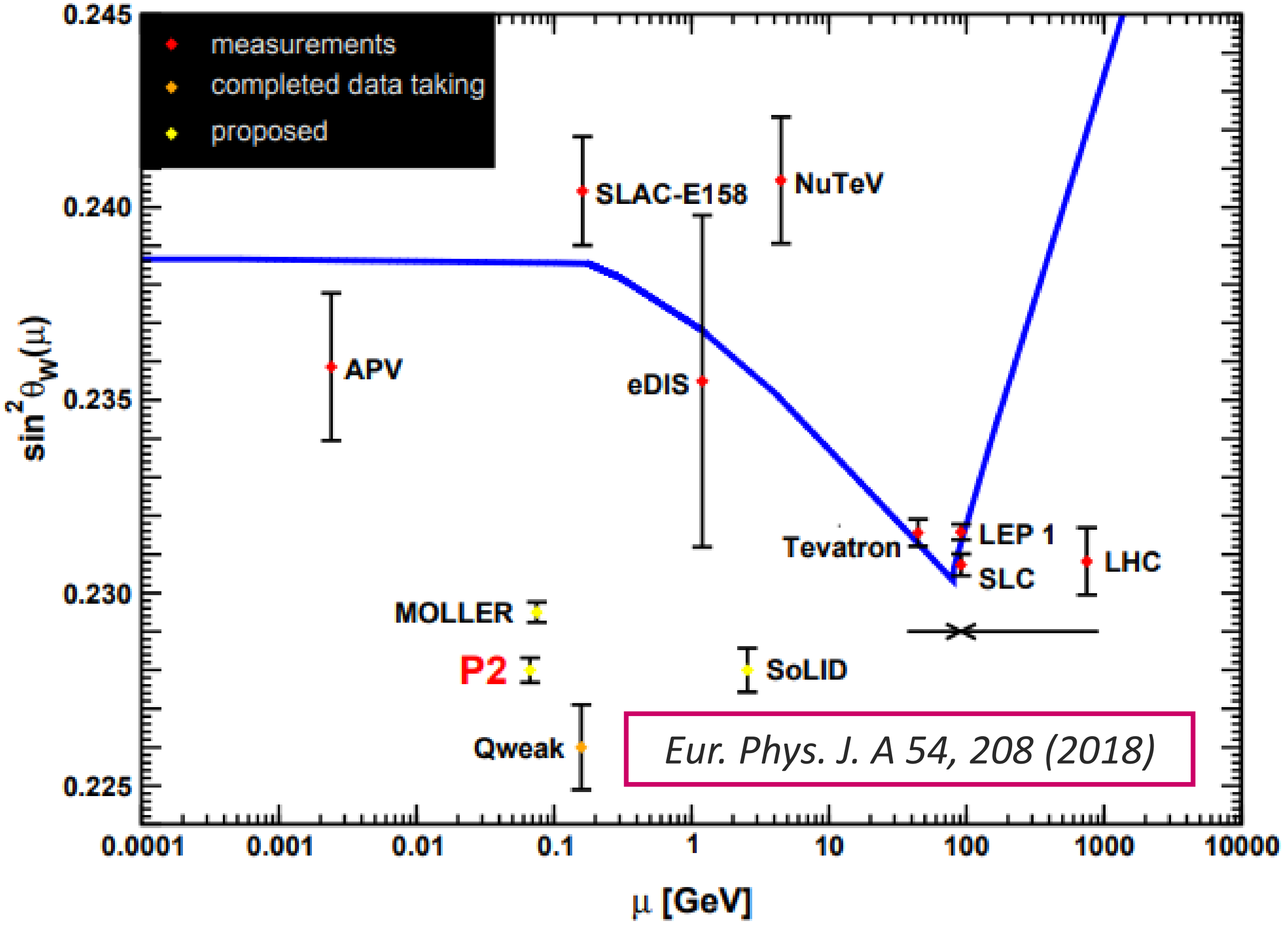
Different nuclei -> Different Z/N = Different u to d quark ratio





Testing multiple techniques to identify optimal: sensitivity/scalability/price

Physics reach: $\sin^2\theta_W$

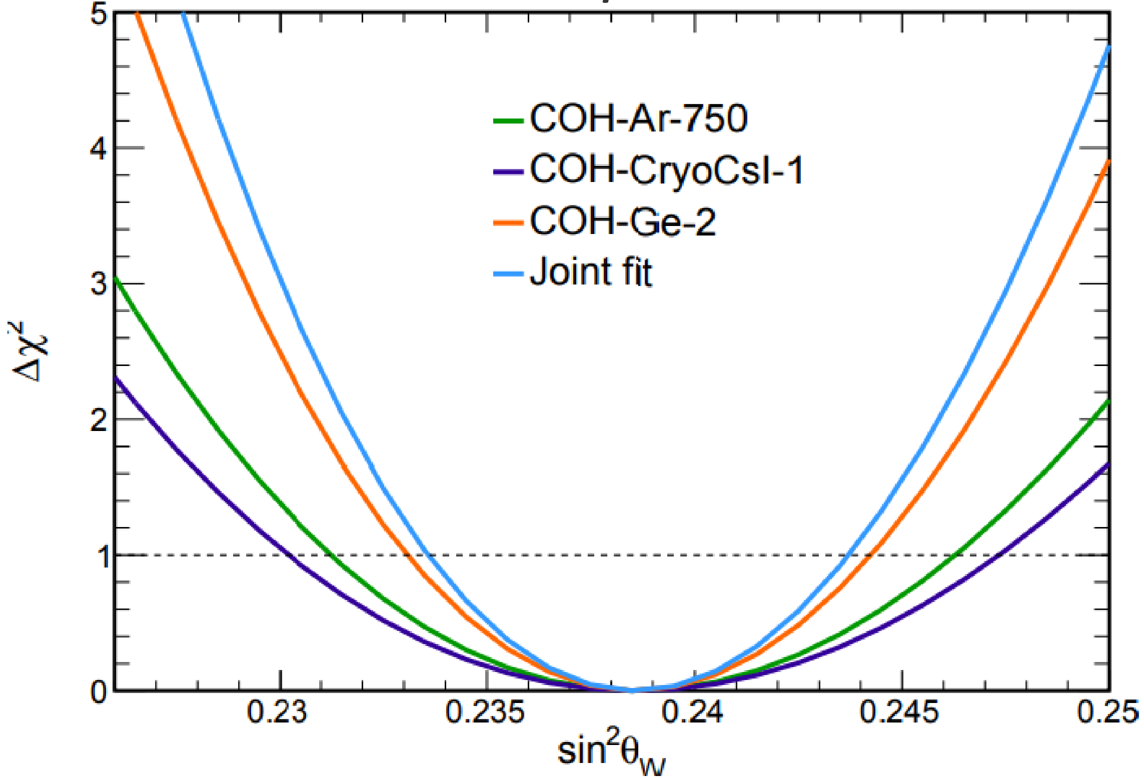


EW couplings running with the scale

From CsI[Na]

$$\sin^2\theta_W = 0.220^{+0.028}_{-0.026}$$

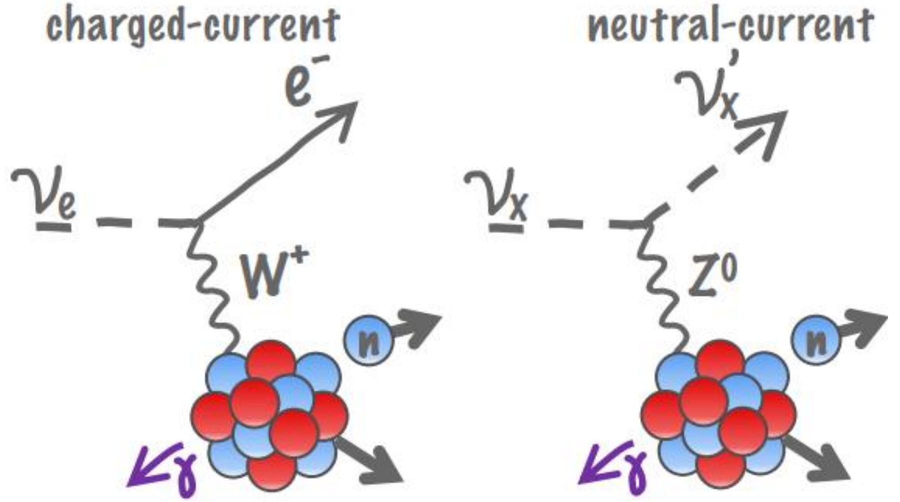
Future: ~2% comparable to PV



Low energy inelastic ν-N scattering

An interesting alternative way of ν detection:

- *larger cross sections (vs. IBD & ν-e)*
- *denser targets*
- *different detector technologies*



List of <300 MeV neutrino-nucleus measurements with terrestrial sources

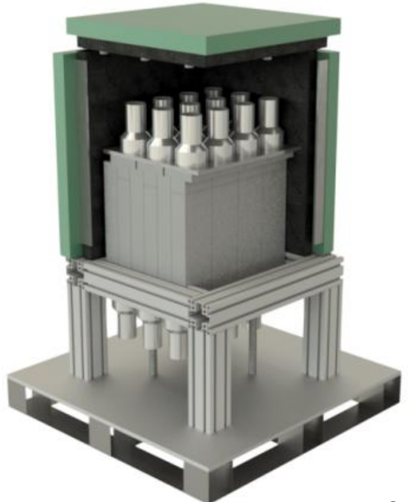
Isotope	Reaction Channel	Source	Experiment	Measurement (10^{-42} cm^2)	Theory (10^{-42} cm^2)
^{2}H	^{2}H(ν_e, e^-)pp	Stopped π/μ	LAMPF	52 ± 18(tot)	54 (IA) (Tatara *et al.*, 1990)
^{12}C	^{12}C$(\nu_e, e^-)^{12}$N$_{g.s.}$	Stopped π/μ	KARMEN	9.1 ± 0.5(stat) ± 0.8(sys)	9.4 [Multipole](Donnelly and Peccei, 1979)
		Stopped π/μ	E225	10.5 ± 1.0(stat) ± 1.0(sys)	9.2 [EPT] (Fukugita *et al.*, 1988).
		Stopped π/μ	LSND	8.9 ± 0.3(stat) ± 0.9(sys)	8.9 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C$(\nu_e, e^-)^{12}$N*	Stopped π/μ	KARMEN	5.1 ± 0.6(stat) ± 0.5(sys)	5.4-5.6 [CRPA] (Kolbe *et al.*, 1999b)
		Stopped π/μ	E225	3.6 ± 2.0(tot)	4.1 [Shell] (Hayes and S, 2000)
		Stopped π/μ	LSND	4.3 ± 0.4(stat) ± 0.6(sys)	
	^{12}C$(\nu_\mu, \nu_\mu)^{12}$C*	Stopped π/μ	KARMEN	3.2 ± 0.5(stat) ± 0.4(sys)	2.8 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C$(\nu, \nu)^{12}$C*	Stopped π/μ	KARMEN	10.5 ± 1.0(stat) ± 0.9(sys)	10.5 [CRPA] (Kolbe *et al.*, 1999b)
	^{12}C(ν_μ, μ^-)X	Decay in Flight	LSND	1060 ± 30(stat) ± 180(sys)	1750-1780 [CRPA] (Kolbe *et al.*, 1999b)
					1380 [Shell] (Hayes and S, 2000)
					1115 [Green's Function] (Meucci *et al.*, 2004)
	^{12}C$(\nu_\mu, \mu^-)^{12}$N$_{g.s.}$	Decay in Flight	LSND	56 ± 8(stat) ± 10(sys)	68-73 [CRPA] (Kolbe *et al.*, 1999b)
					56 [Shell] (Hayes and S, 2000)
^{56}Fe	^{56}Fe$(\nu_e, e^-)^{56}$Co	Stopped π/μ	KARMEN	256 ± 108(stat) ± 43(sys)	264 [Shell] (Kolbe *et al.*, 1999a)
^{71}Ga	^{71}Ga$(\nu_e, e^-)^{71}$Ge	^{51}Cr source	GALLEX, ave.	0.0054 ± 0.0009(tot)	0.0058 [Shell] (Haxton, 1998)
		^{51}Cr	SAGE	0.0055 ± 0.0007(tot)	
		^{37}Ar source	SAGE	0.0055 ± 0.0006(tot)	0.0070 [Shell] (Bahcall, 1997)
^{127}I	^{127}I$(\nu_e, e^-)^{127}$Xe	Stopped π/μ	LAMPF	284 ± 91(stat) ± 25(sys)	210-310 [Quasi-particle] (Engel *et al.*, 1994)

[J. A. Formaggio & G. P. Zeller, Rev. Mod. Phys **84** (2012)]

SNS gives an opportunity to test this alternative channel!

Inelastic neutrino interactions: inclusive ν_e CC on ^{127}I

arXiv: 2305.19594



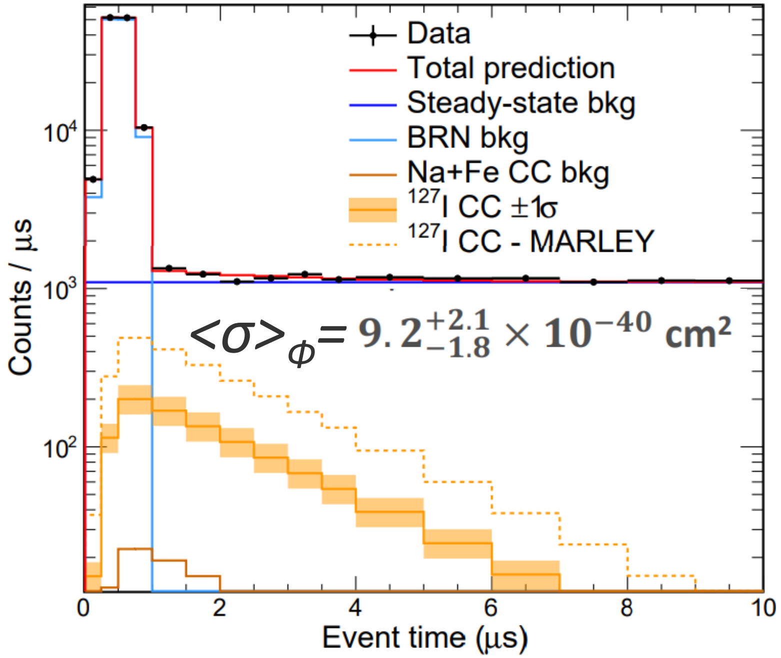
Motivation:

1. *Initial: $\nu_e + {}^{127}I \rightarrow e^- + {}^{127}Xe^*$ for solar ^7Be ν_e*
2. *Cross section depends on g_A (at ~10s MeV Q)*

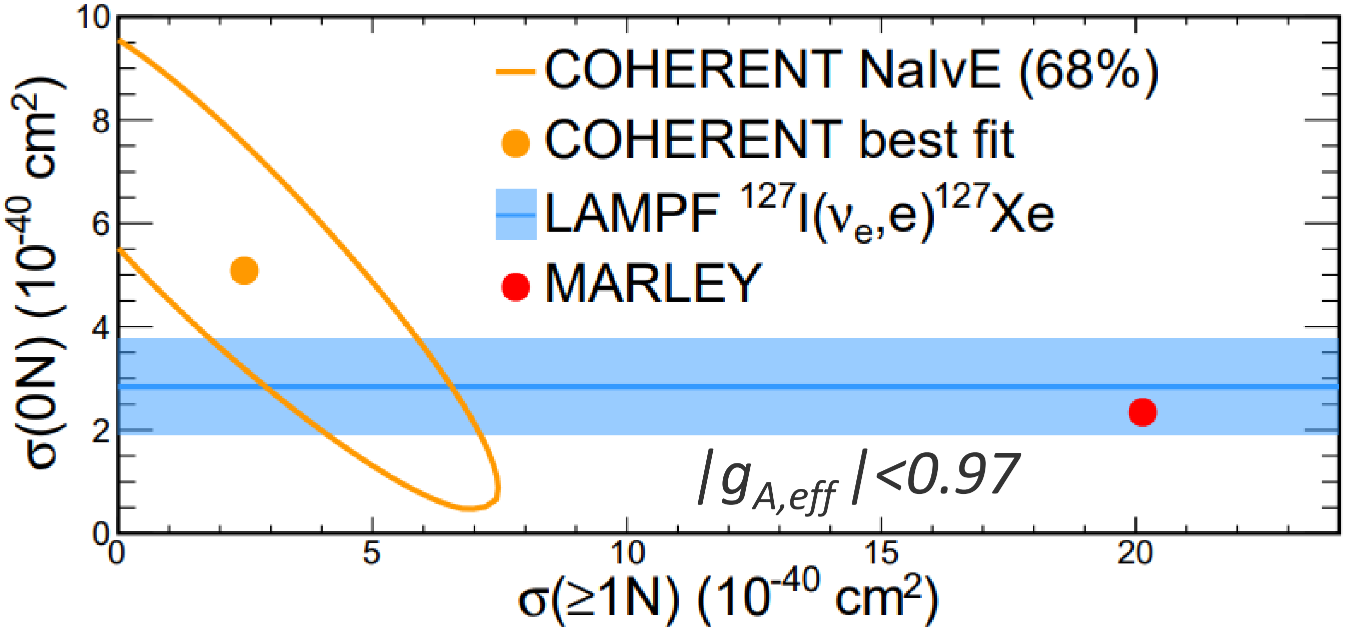
Detector: 24×7.7 kg NaI[Tl] crystals *Exposure: ~5 years*

Signal: 10-55 MeV electrons in the delayed neutrino window

5.8σ CC signal (541 events), but 41% lower than MARLEY prediction



If deconvolved to 0N and ≥1N by energy deposition, data suggests lack of events with neutron emission



900 kg lead

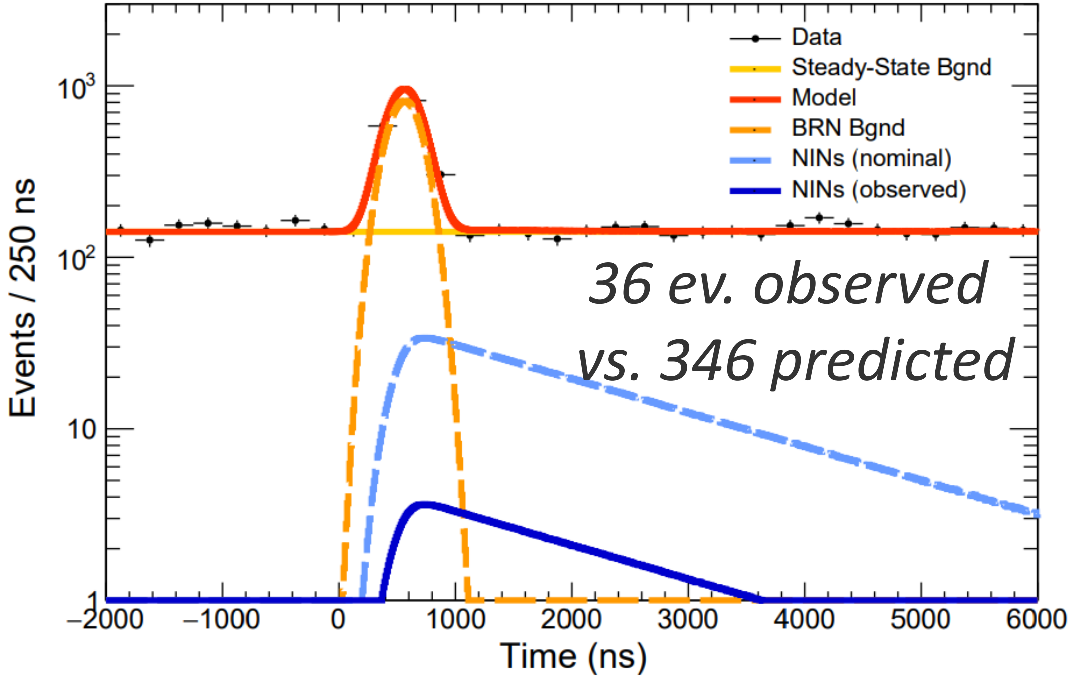
$\nu_e + {}^{208}Pb \rightarrow e^- + {}^{208}Bi^*$, + decay of a nucleus with

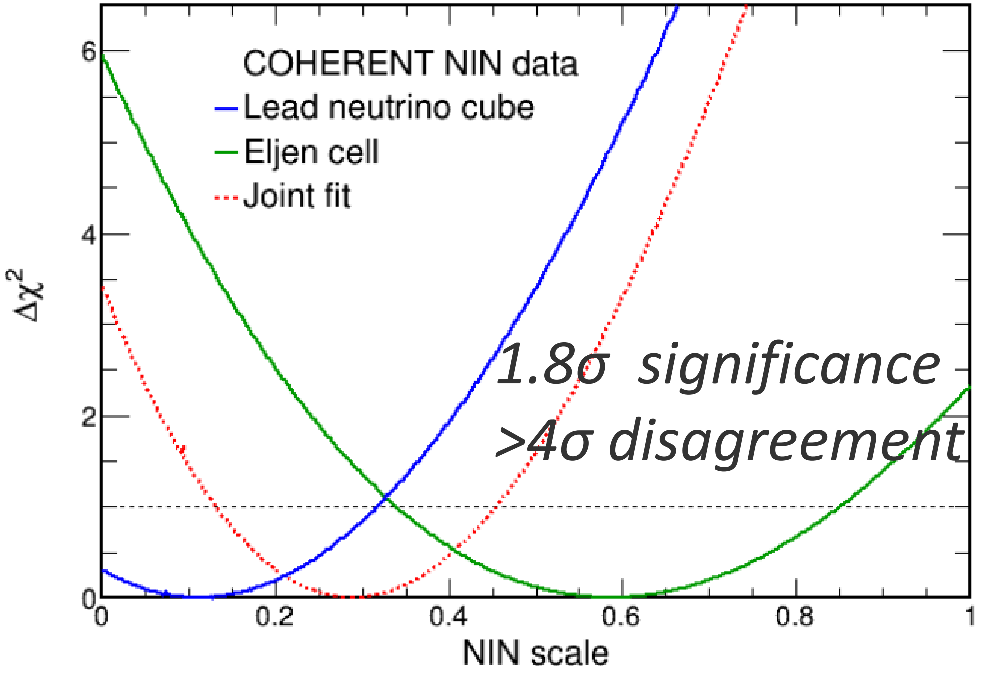
$\nu + {}^{208}Pb \rightarrow \nu + {}^{208}Pb^*$ neutrons in the final state

Motivation:

1. Can be a background for CEvNS ($M_{shield} >> M_{det}$)
2. Can be used for supernova neutrino detection (HALO)

factor $0.29^{+0.17}_{-0.17}$ suppression vs. MARLEY in combination with LS in the CsI shielding

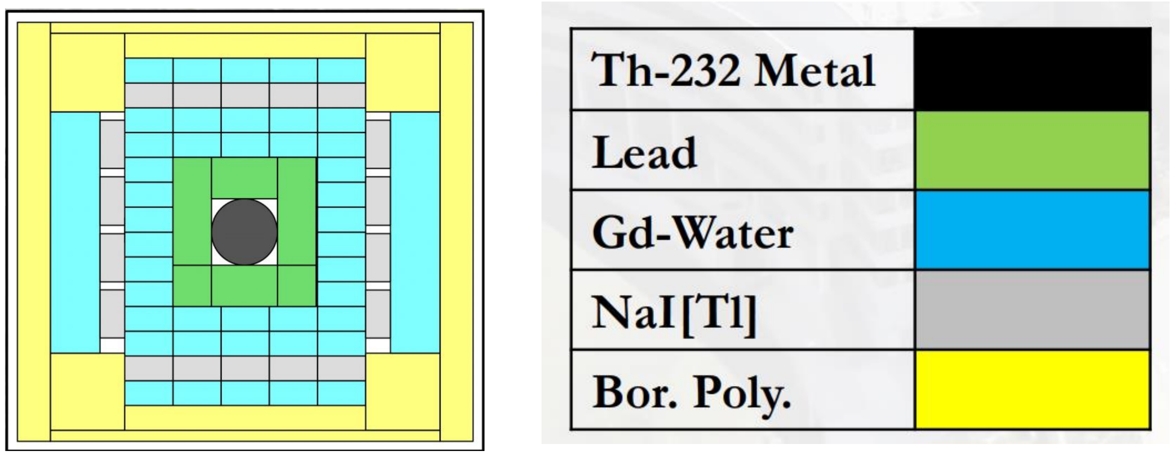




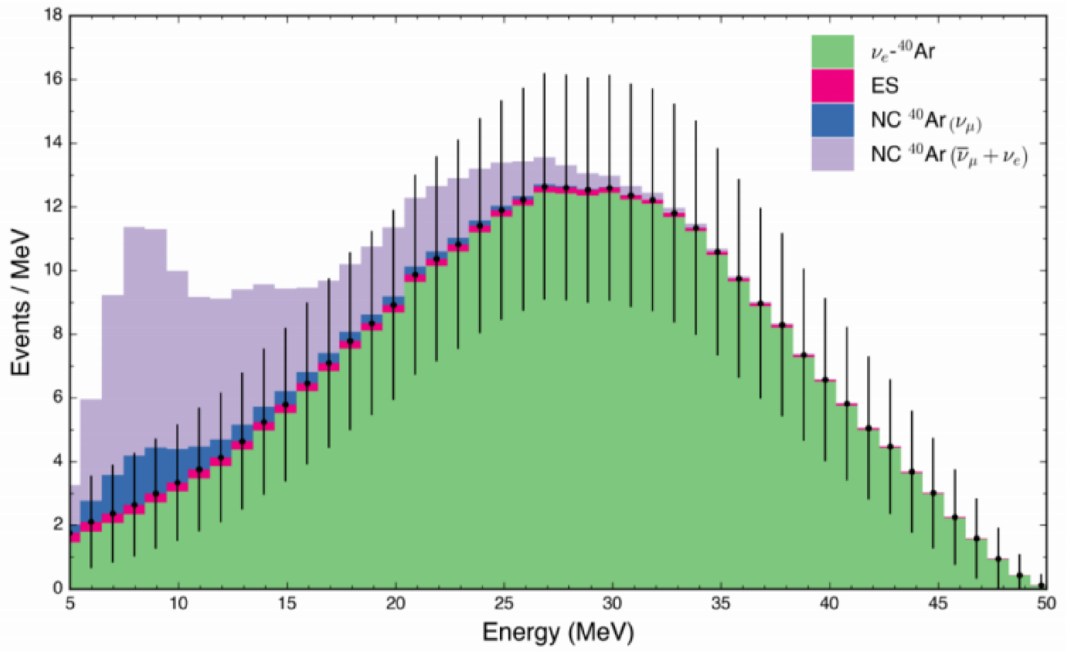
NuThor and plans for LAr

Looking for neutrino-induced thorium fission – predicted in 1971, but not observed yet

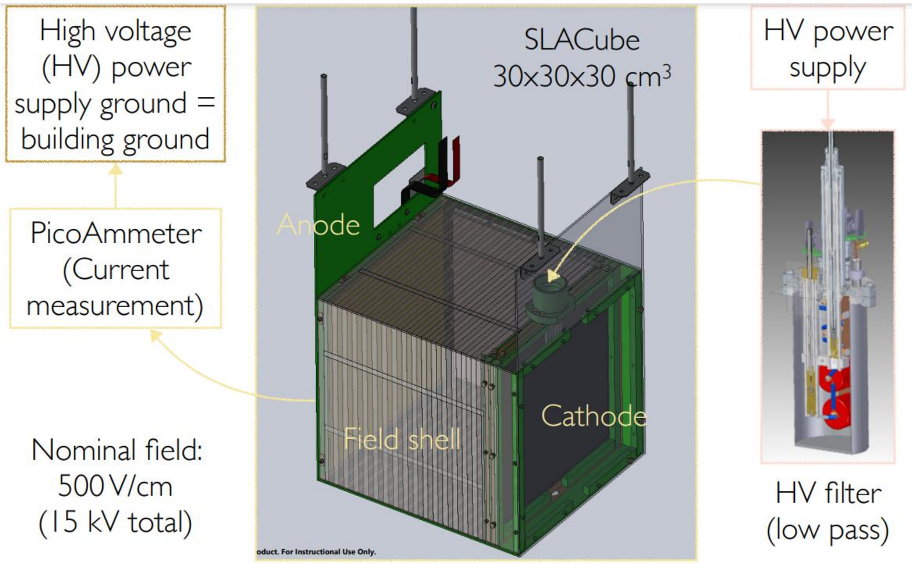
52 kg metal Thorium deployed,
looking for high neutron multiplicity events



CENNS-750: ~340 ν CC and 100 NC per SNS year



LAr TPC: 250 kg LAr to for DUNE-like CC detection

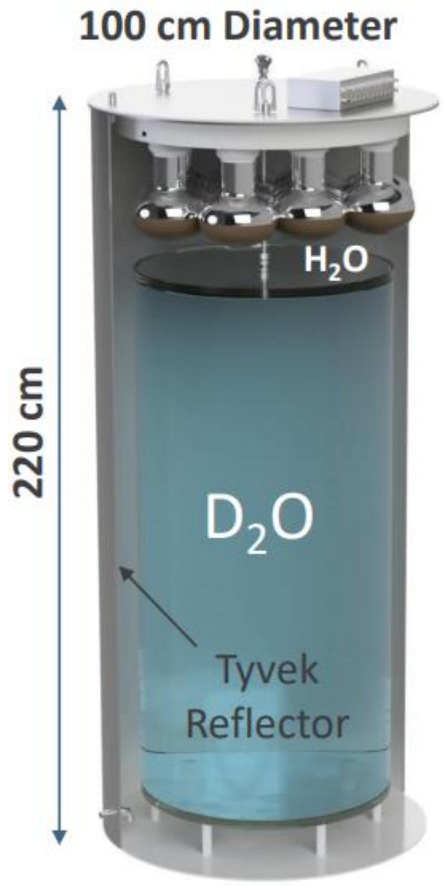


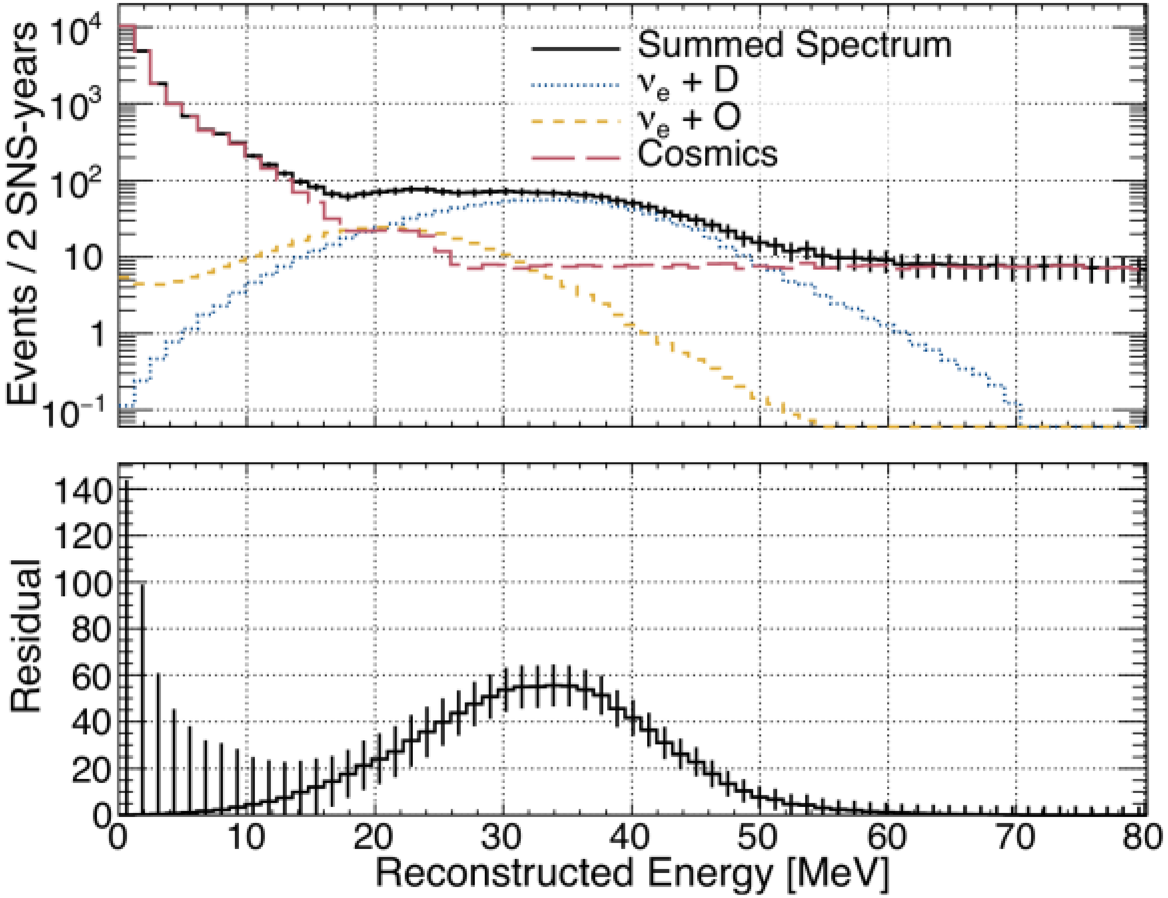
R&D, prototype operation

Leading syst. right now: ±10% on the neutrino flux

PRD 106, 032003 (2022)

Idea: measure flux with $\nu_e + d \rightarrow p + p + e$





Two modules,
592 kg D_2O each

Down to ~5% flux unc-ty with a single module for 2 SNS-years of operation

First module deployed!

JINST 16 P08048 (2021)

Bonus: charge current (CC) on oxygen for supernova ν in Super/Hyper-Kamiokande

SNS schedule

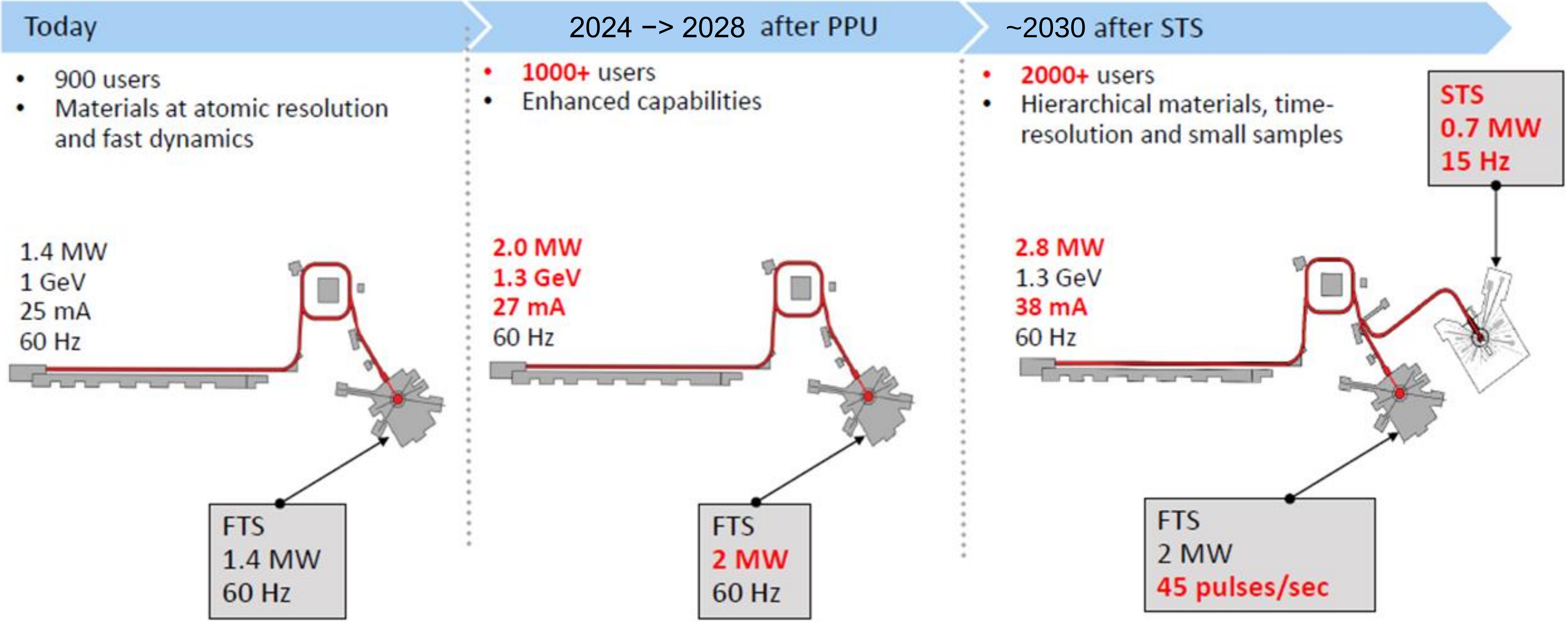
FY23

	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23
SNS	FY22C		T31 - PPU Test Target 2 (MTX-029) 1992 hours - ramp up to 1.55 MW @ 1.05 GeV			FY23A			(PPU 2MW Target) 1288 hours - ramp to 1.6/1.7 MW @ 1.05 GeV		FY24A	
HFIR	499 EOC 499	500	EOC 500					501	EOC 501	502	EOC 502	503

FY24

	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24
SNS	FY24A									PPU 2MW Target Ramp to 1.7 MW @ 1.3 GeV for 1250 hr KPP		
HFIR	EOC 503		504		EOC 504 505	EOC 505	506 EOC 506		507	EOC 507 508	EOC 508	509

Upgrades



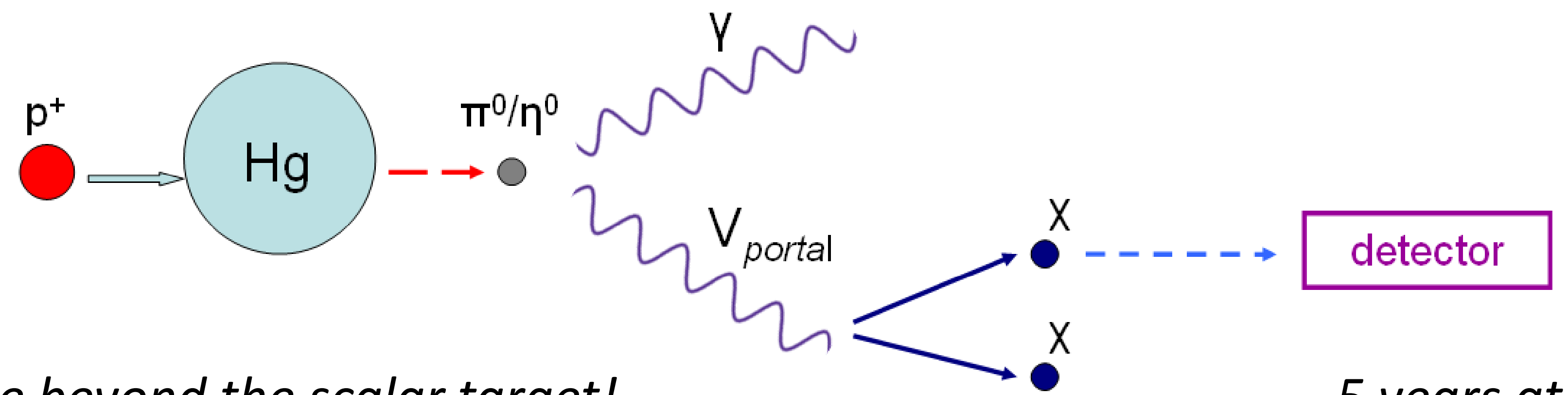
The Second Target Station (STS) provides more dedicated neutrino physics space

COHERENT is in contact with ORNL on this matter (space/background level optimization)

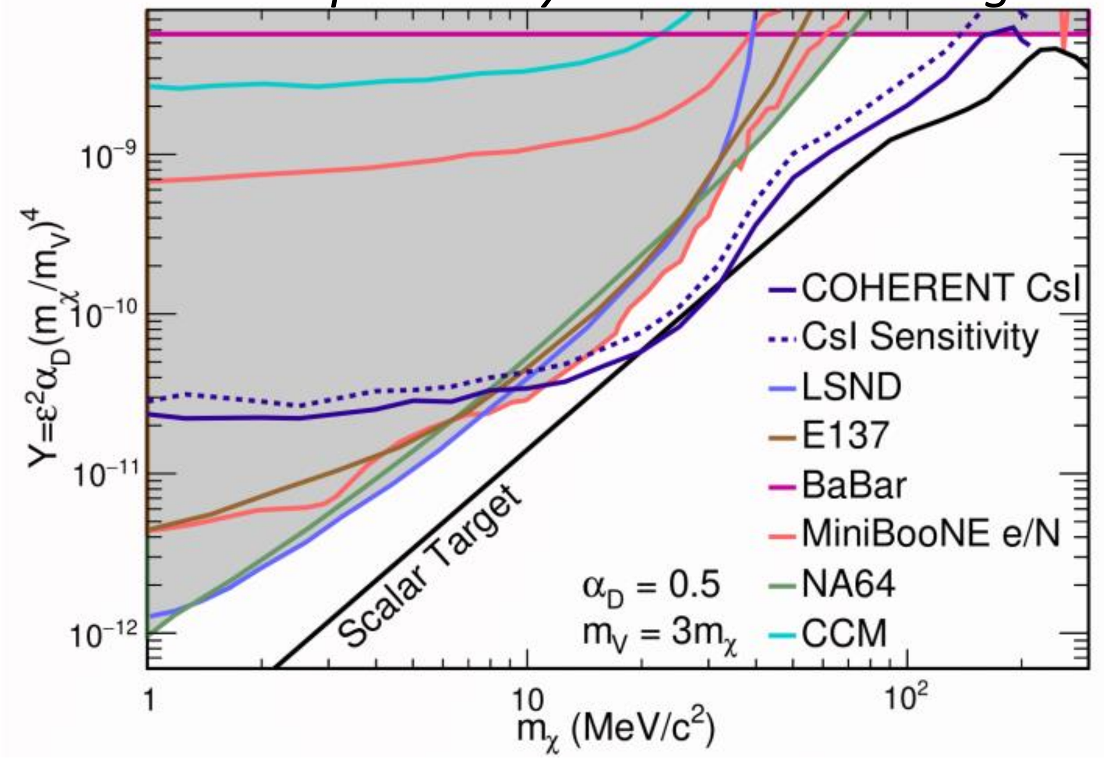
Physics reach: the dark matter of Oak Ridge

«V kinetic mixing with γ» PRL 130, 051803 (2023)

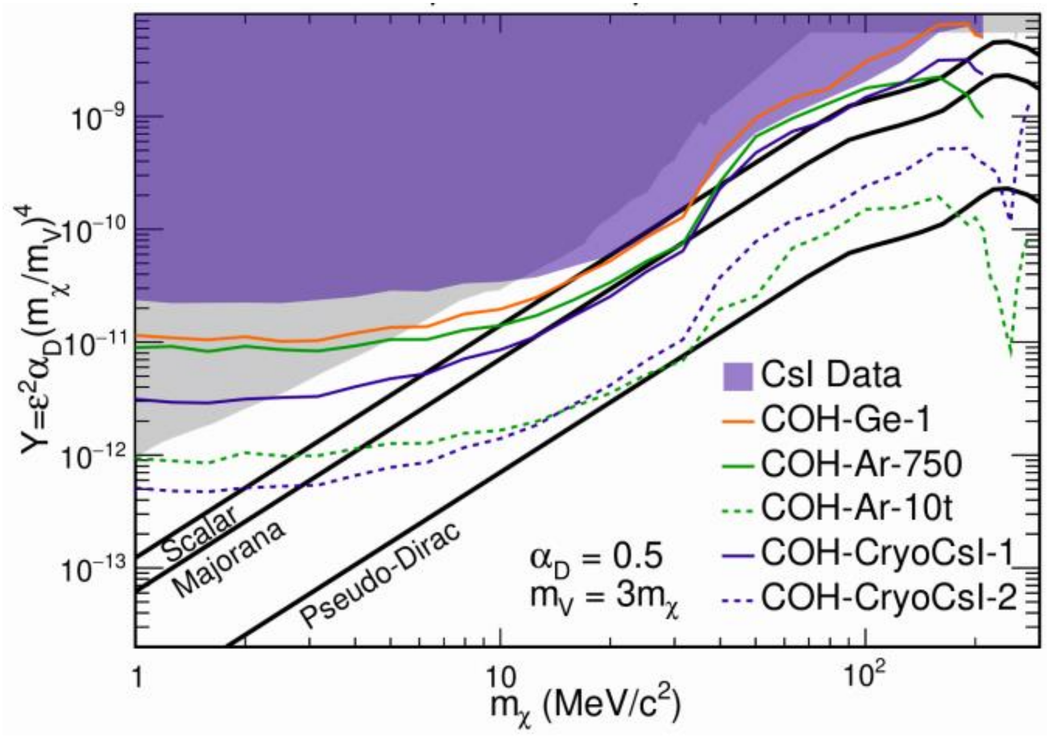
«leptophobic» PRD 106, 052004 (2022)



First to probe beyond the scalar target!



5 years at STS



Physics reach: sterile neutrino

Consider disappearance:

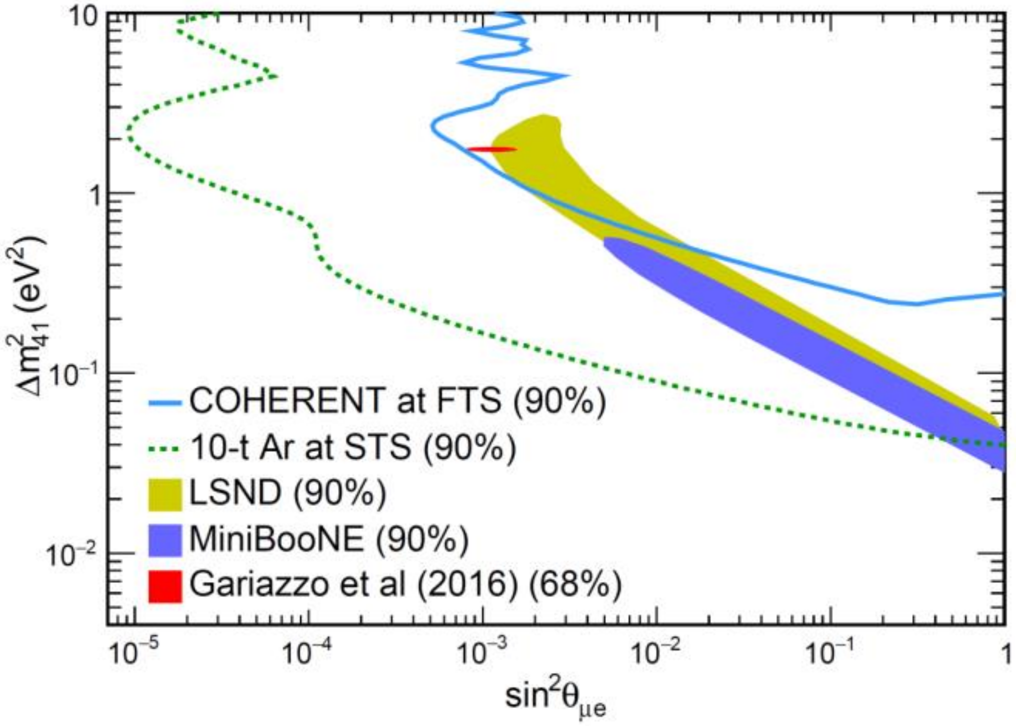
$$1 - P(\nu_e \to \nu_s) = 1 - \sin^2 2\theta_{14} \cos^2 \theta_{24} \cos^2 \theta_{34} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

$$1 - P(\nu_\mu \to \nu_s) = 1 - \cos^4 \theta_{14} \sin^2 2\theta_{24} \cos^2 \theta_{34} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

We need a prior constraint on θ_{34}, take from 3-flavor oscillations

Neutrino energy from 10 to 53 MeV, distances from 19 to 28 m ⇒ Δm^2_{41} between 0.4 and 3.4 eV^2

Sensitivity estimates (FTS - 3 years, STS - 5years)

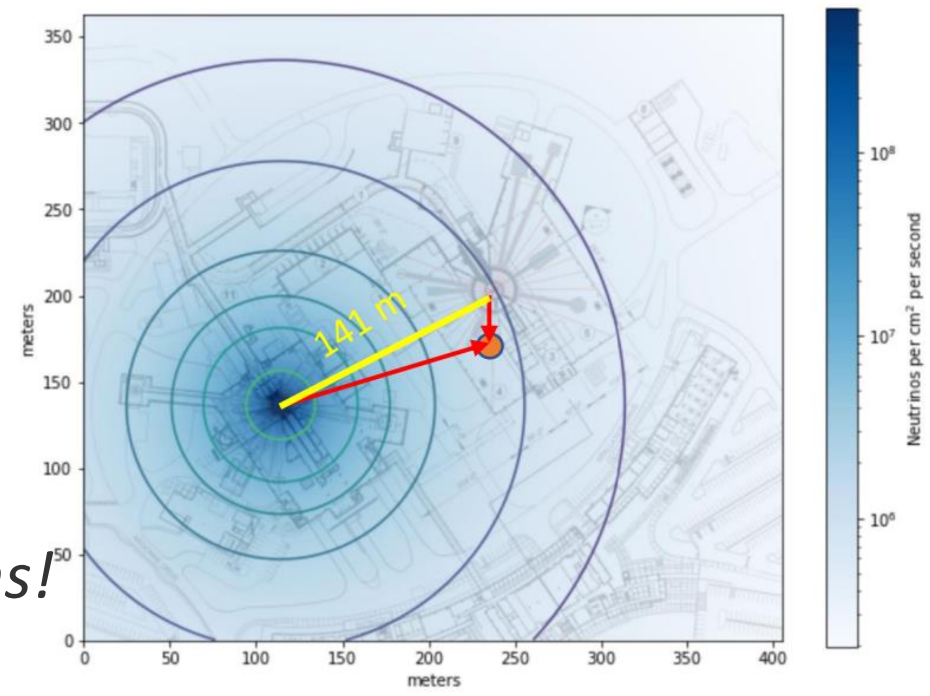


Consider 10T LAr

L_{STS} = 20m,

L_{FTS} = 121m

1 detector, 2 beams!



Collaboration operates multiple detectors in the «Neutrino Alley» at SNS

Wide physics reach

- *CEvNS*
- *$\sin^2\theta_W$*
- *Nuclear FF*
- *Inelastic ν interactions (CC, NC)*
- *ν-q NSI*
- *DM*
- *Steriles*

COHERENT SNS

Thank you for your attention!

Backup: calculations for inelastics