



EOS@SNS

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UC Berkeley and Lawrence Berkeley National Lab

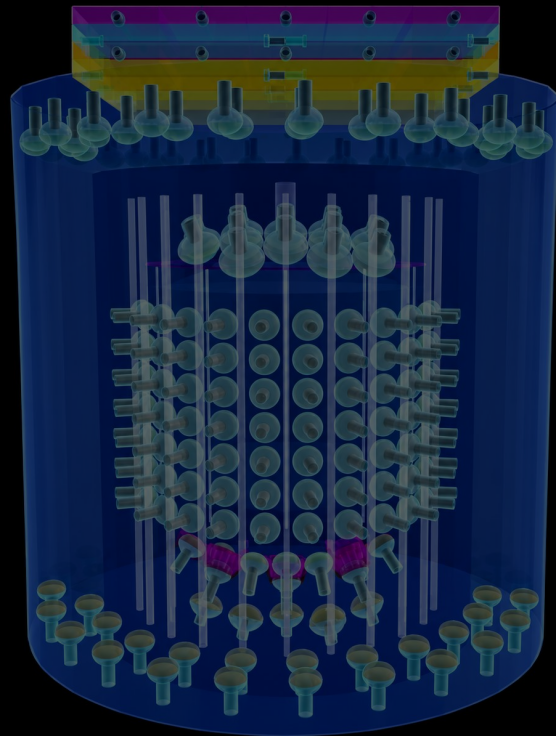
On behalf of the Eos collaboration

CPAD 2026

October 20, Seattle, Washington

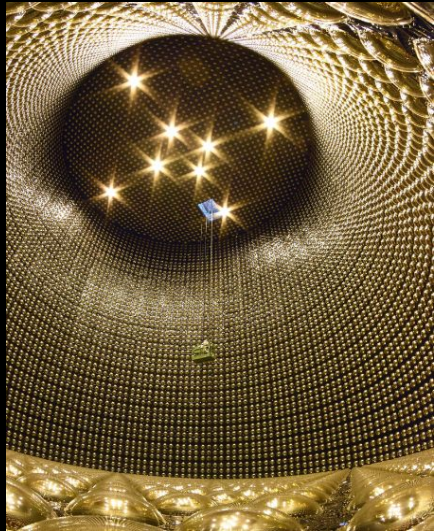
Outline

- Overview of hybrid neutrino detector concept
- THEIA & supernova neutrinos
- EoS @ Berkeley
- Plans for EoS @ SNS

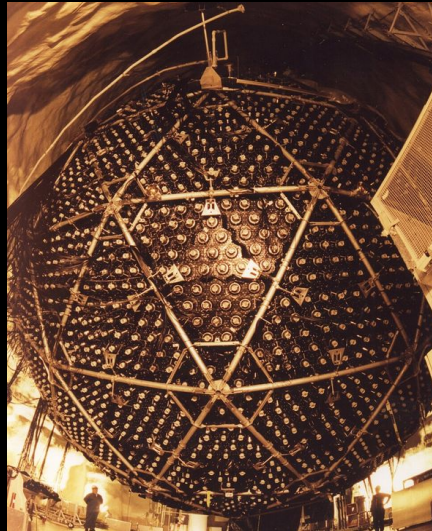


Neutrino Detectors

Water Cherenkov



Super-Kamiokande



SNO

Directional, high threshold

Liquid Scintillator



Borexino



KamLAND

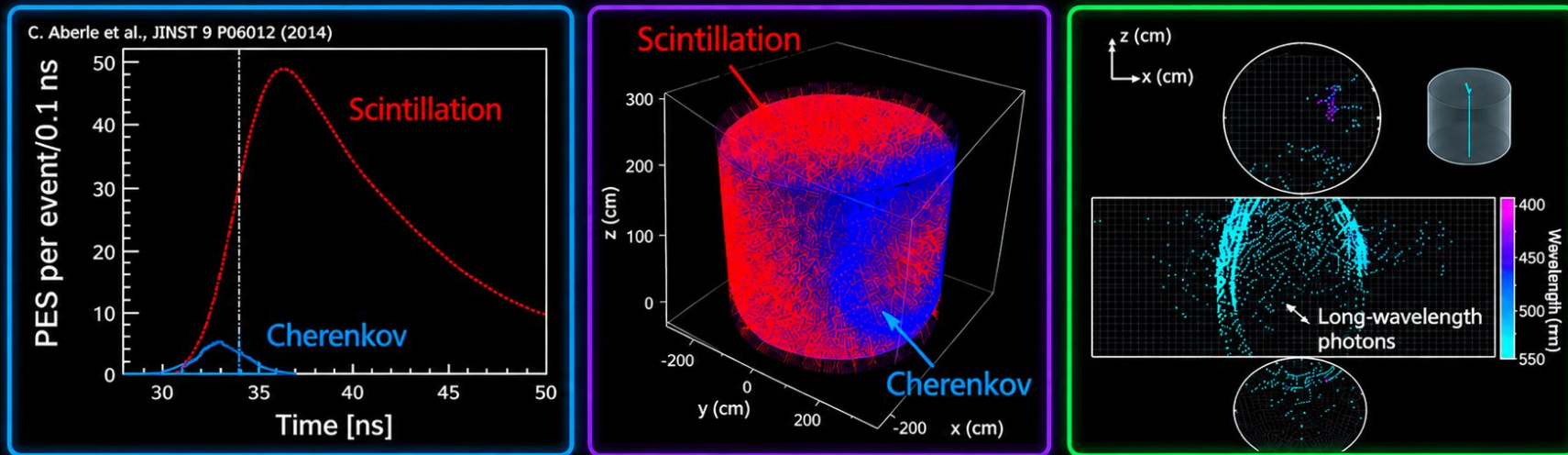
Non-directional, low threshold, good res.

Hybrid Detectors

Can we build on the success of water Cherenkov & liquid scintillator detector to maximize future physics impact?

Hybrid Detectors

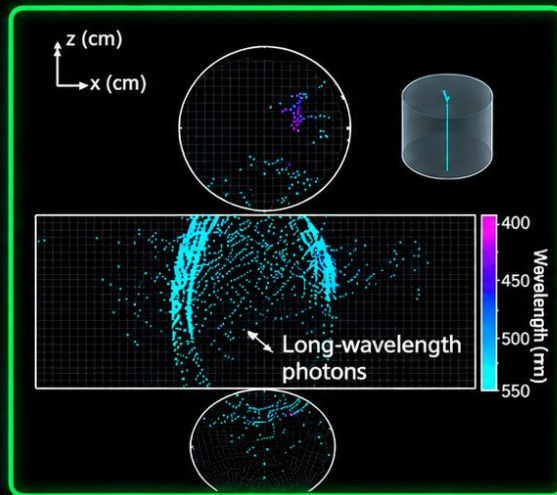
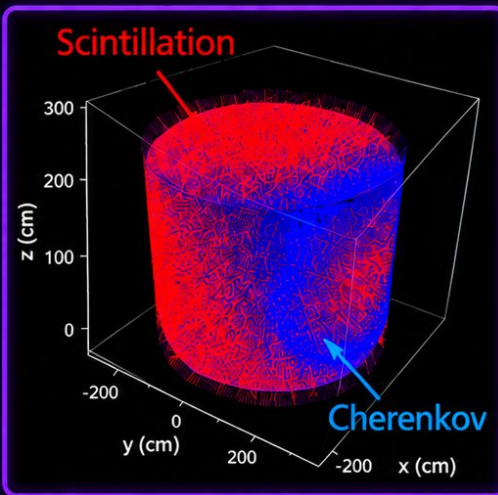
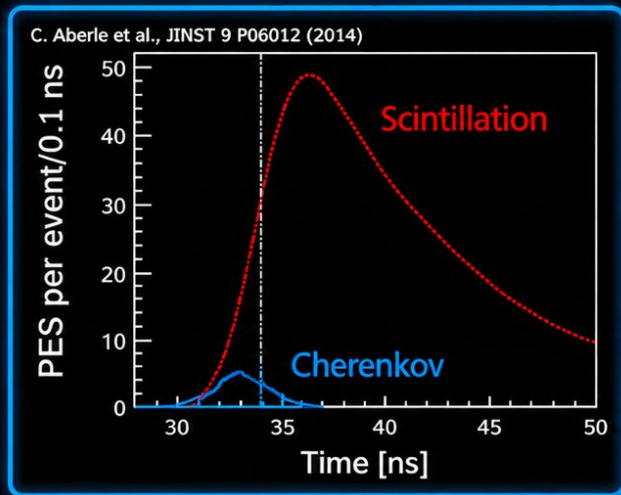
Can we build on the success of water Cherenkov & liquid scintillator detector to maximize future physics impact?



Utilize both the Cherenkov and scintillation signals

Hybrid Detectors

Can we build on the success of water Cherenkov & liquid scintillator detector to maximize future physics impact?



Utilize both the Cherenkov and scintillation signals

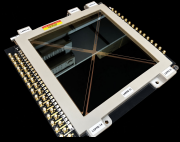
A high light yield, low threshold, directional detector with excellent PID

Challenge: Overwhelming scintillation light drowns the Cherenkov signal

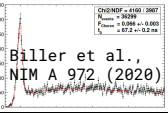
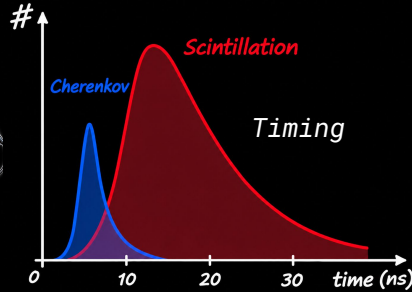
Instrumentation

Key for hybrid detectors

LAPPD for ANNIE



Fast PMTs in EOS



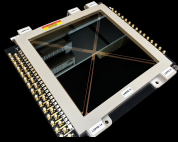
Slow LS

- Fast PMTs
- LAPPDs
- Slow scintillator

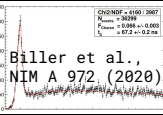
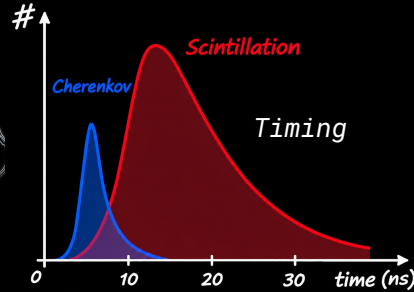
Instrumentation

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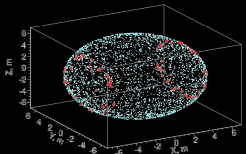


Fast PMTs in EOS

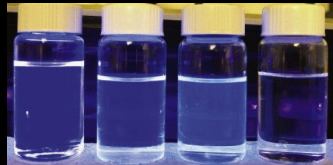


Slow LS

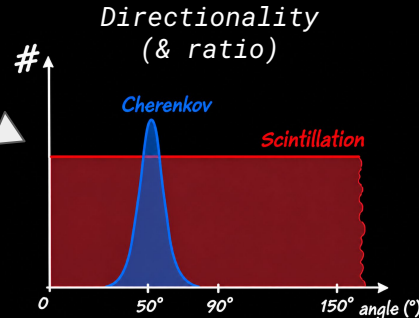
- Fast PMTs
- LAPPDs
- Slow scintillator



Original version in A.Elagin, et al., NIM A 849 (2017)



WbLS at BNL



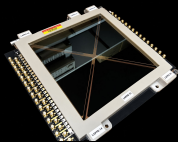
- Water-based scintillator (WbLS)
- Advanced reconstruction techniques

Instrumentation

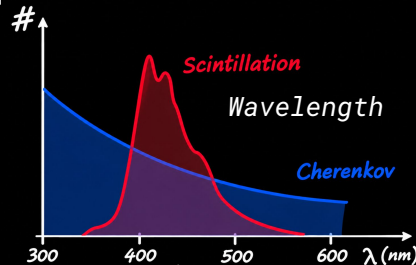
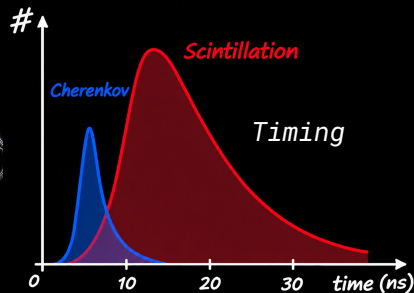
Key for hybrid detectors

- Dichroicons
- Filtering
- Red-sensitive PMTs

LAPPD for ANNIE



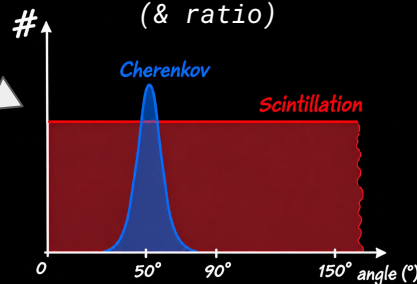
Fast PMTs in EOS



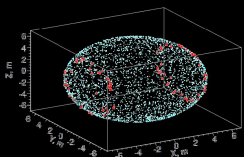
Dichroicon for Eos

- Fast PMTs
- LAPPDs
- Slow scintillator

Directionality
(& ratio)



- Water-based scintillator (WbLS)
- Advanced reconstruction techniques



Original version in A.Elagin, et al., NIM A 849 (2017)



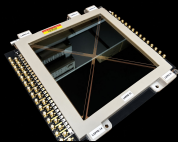
WbLS at BNL

Instrumentation

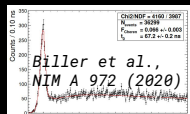
Key for hybrid detectors

- Dichroicons
- Filtering
- Red-sensitive PMTs

LAPPD for ANNI

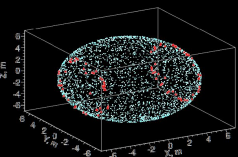


Fast PMTs in EOS

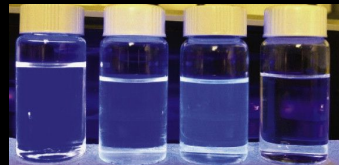


Slow LS

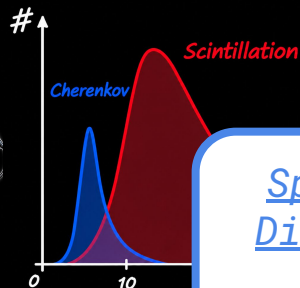
- Fast PMTs
- LAPPDs
- Slow scintillator



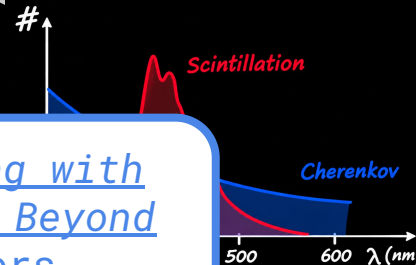
Original version in A. Elagin, et al., NIM A 849 (2017)



WbLS at BNL



Spectral Photon Sorting with
Dichroicons in Eos and Beyond
RDC 2 Photodetectors
S. Naugle



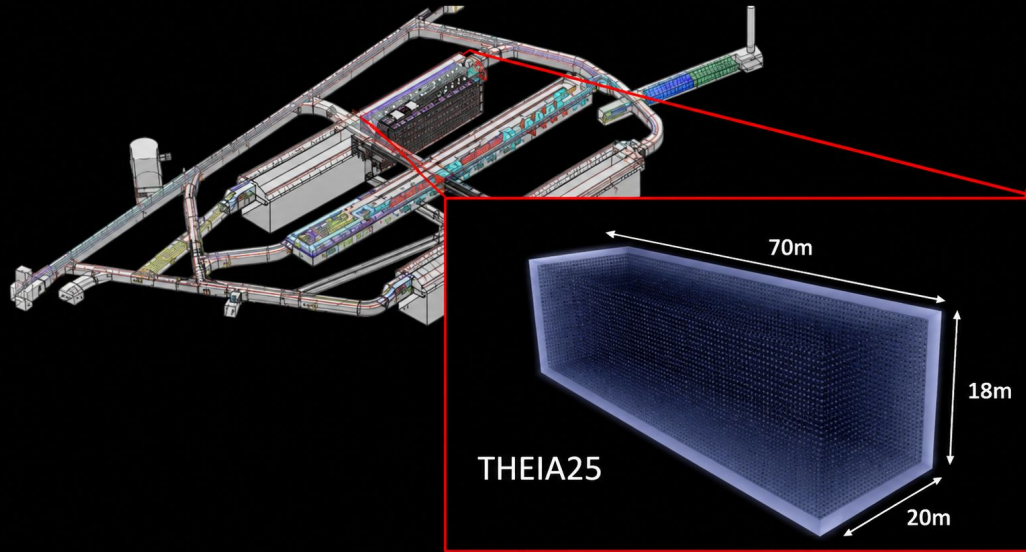
Dichroicon for Eos



- Water-based scintillator (WbLS)
- Advanced reconstruction techniques

THEIA

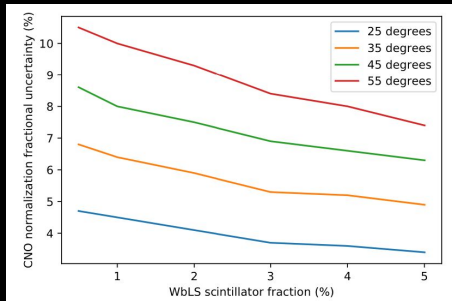
Ultimately, the goal is to deploy this technology in a much larger detector, THEIA, with broad physics applications.



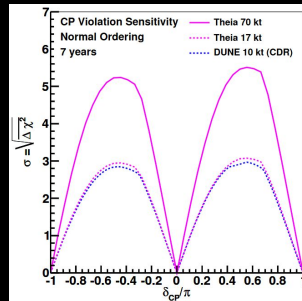
Schematic of THEIA as DUNE module 4
THEIA collaboration, EPJC 80 416 (2020)

THEIA has an extremely broad physics program

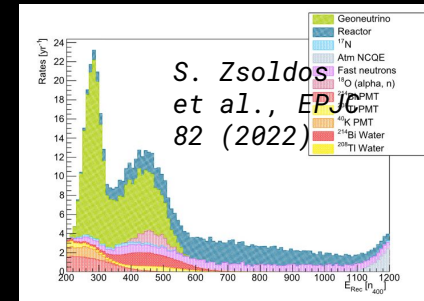
THEIA collaboration, EPJC 80 416 (2020)



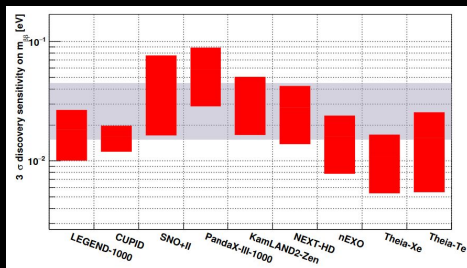
Solar neutrinos (CNO, ^8B upturn)



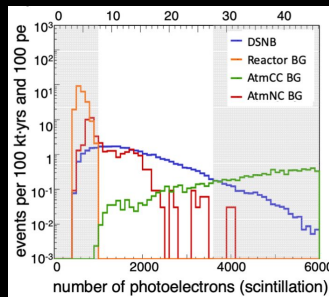
Long baseline (e.g., δ_{CP})



Geoneutrinos



$0\nu\beta\beta$



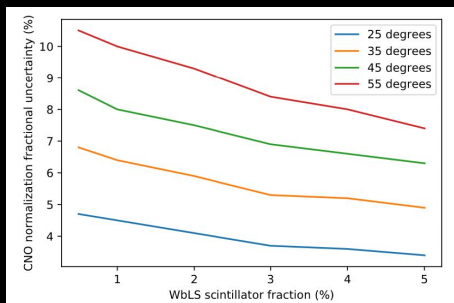
DSNB



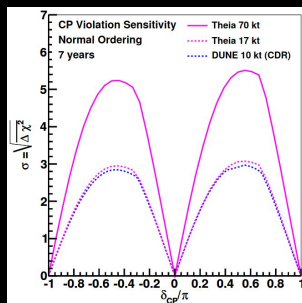
Supernova burst neutrinos

THEIA has an extremely broad physics program

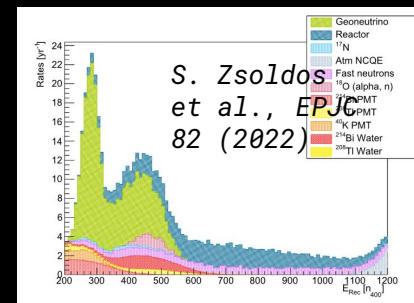
THEIA collaboration, EPJC 80 416 (2020)



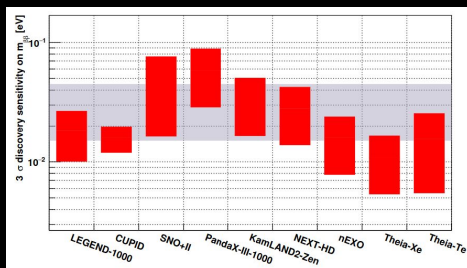
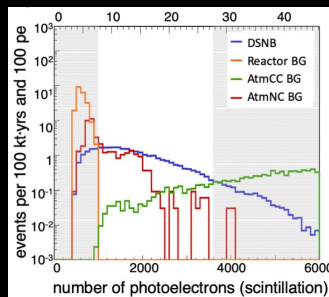
Solar neutrinos (CNO, ^8B upturn)



Long baseline (e.g., δ_{cp})



Geoneutrinos

 $\theta \sim \beta \beta$ 

DSNB



Supernova burst neutrinos

THEIA

THEIA could play important role in supernova detection

- High statistics IBD signal
- Supernova pointing ($<1^\circ$)
- Complementary to DUNE:
co-detection of $\nu_e/\bar{\nu}_e$
- Complementary to HK & JUNO:
 $\bar{\nu}_e$ on opposite side of earth

Reaction		Rate
(IBD)	$\bar{\nu}_e + p \rightarrow n + e^+$	19,800
(ES)	$\nu + e \rightarrow e + \nu$	960
(ν_e O)	$^{16}\text{O}(\nu_e, e^-)^{16}\text{F}$	340
($\bar{\nu}_e$ O)	$^{16}\text{O}(\bar{\nu}_e, e^+)^{16}\text{N}$	440
(NCO)	$^{16}\text{O}(\nu, \nu)^{16}\text{O}^*$	1,100

Event rates in 100 kt THEIA
for SN at 10 kpc (GVKM model)

THEIA

THEIA could play important role in supernova detection

- Flavor resolved ν_e spectrum from (CC $\nu_e - {}^{16}\text{O}$)
- During the prompt neutronization burst (first ~25 ms) core-collapse supernovae emit mainly ν_e s

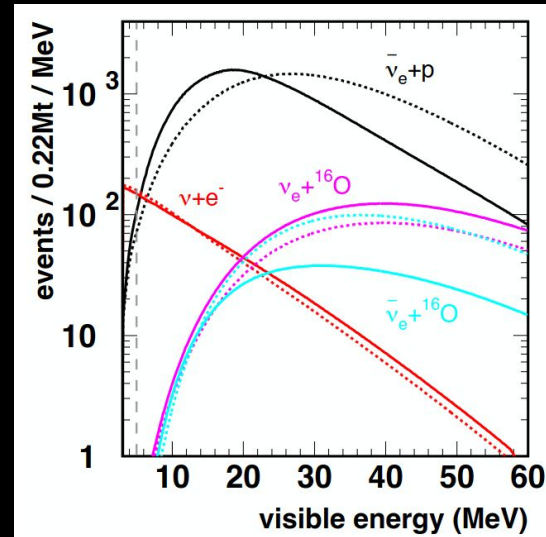
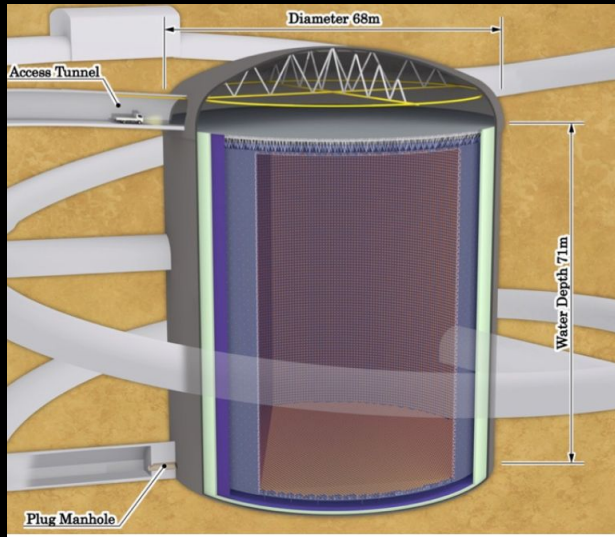
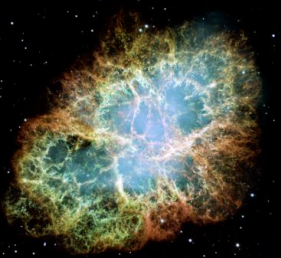
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Event rates in 100 kt THEIA
for SN at 10 kpc (GVKM model)

cross-section has not been measured

Charged Current $\nu_e - {}^{16}\text{O}$

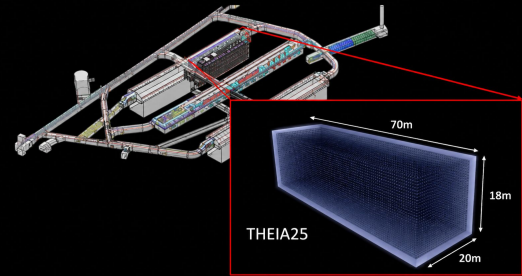
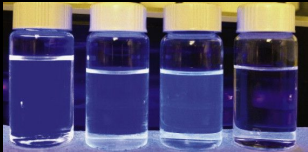
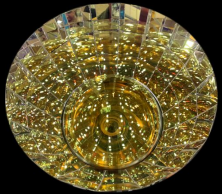
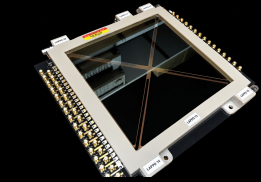
Cross-section measurement of (CC $\nu_e - {}^{16}\text{O}$) important for THEIA, Hyper-Kamiokande (& SK) in order to interpret supernova data.



Hyper-Kamiokande collaboration,
Astrophys.J. 916 (2021) 15

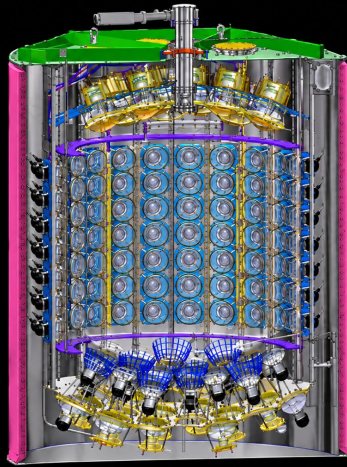
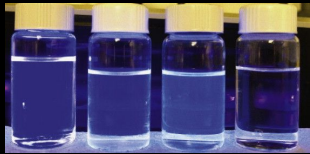
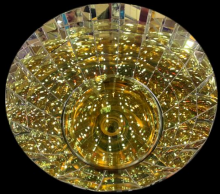
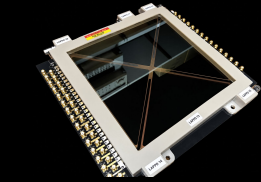
Scaling Up

How do we scale from benchtop to 25+ ktonnes?

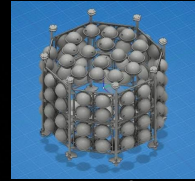


Scaling Up

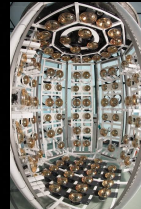
How do we scale from benchtop to 25+ ktonnes?



EOS



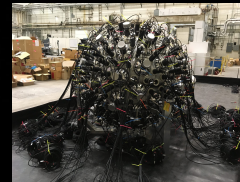
BUTTON



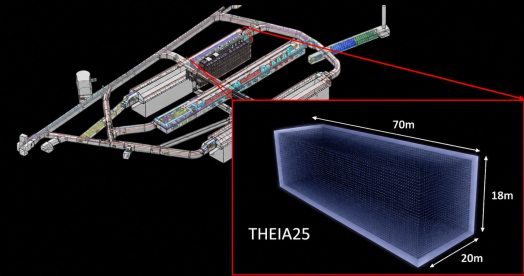
ANNIE



BNL-30t



NuDot



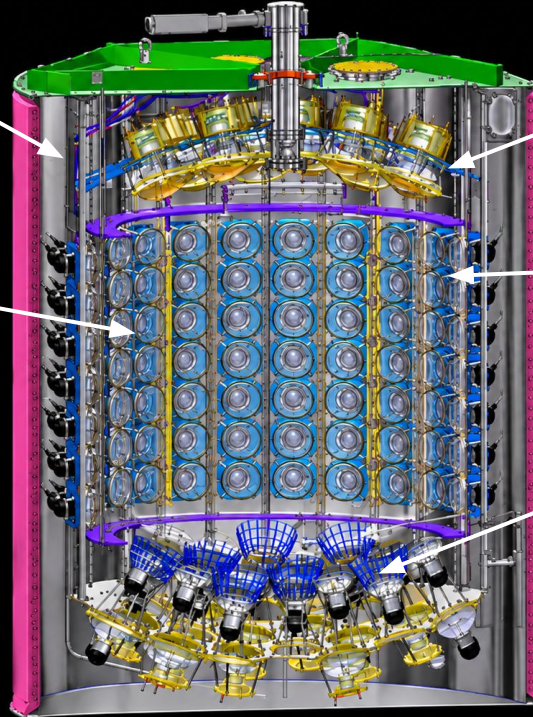
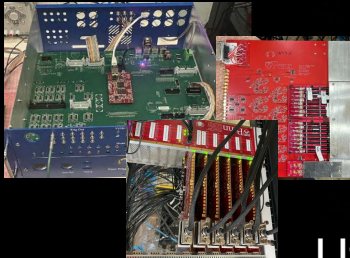
Suite of tonne-scale experiments

Central axis calibration system

30-tonne outer vessel filled with water

4-tonne acrylic inner vessel filled with target fluid

Suite of custom electronics



24x R11780 HQE
12-inch PMTs

200x R14688-100
fast 8-inch PMTs

12x dichroicons
for spectral
sorting



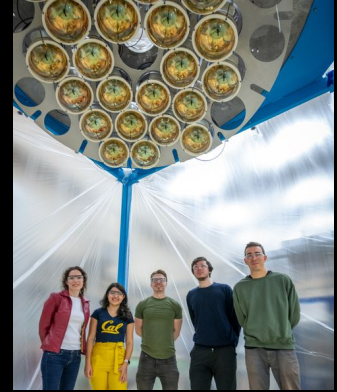
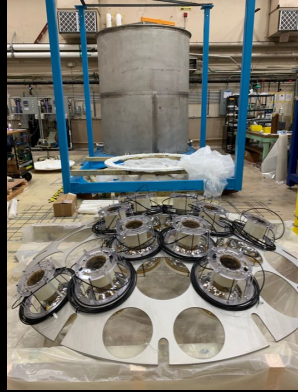
Utilizes all facets of the hybrid neutrino detector technology

EOS Construction



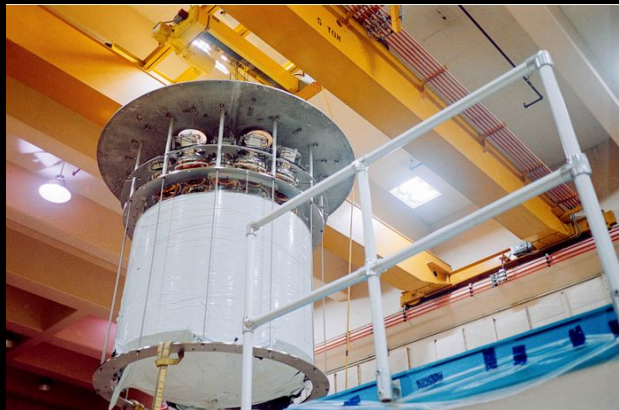
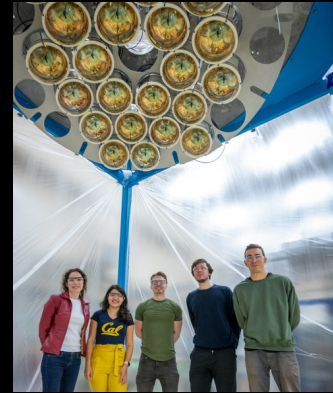
First components arrive to
Berkeley (Sept. 2023)

EOS Construction



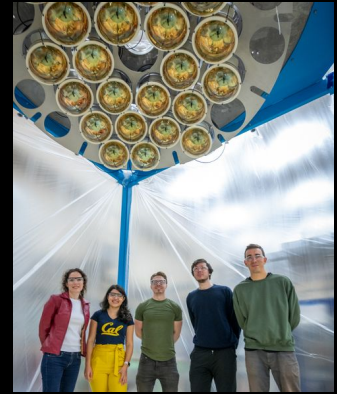
First PMTs installed (Oct. 2023)

EOS Construction



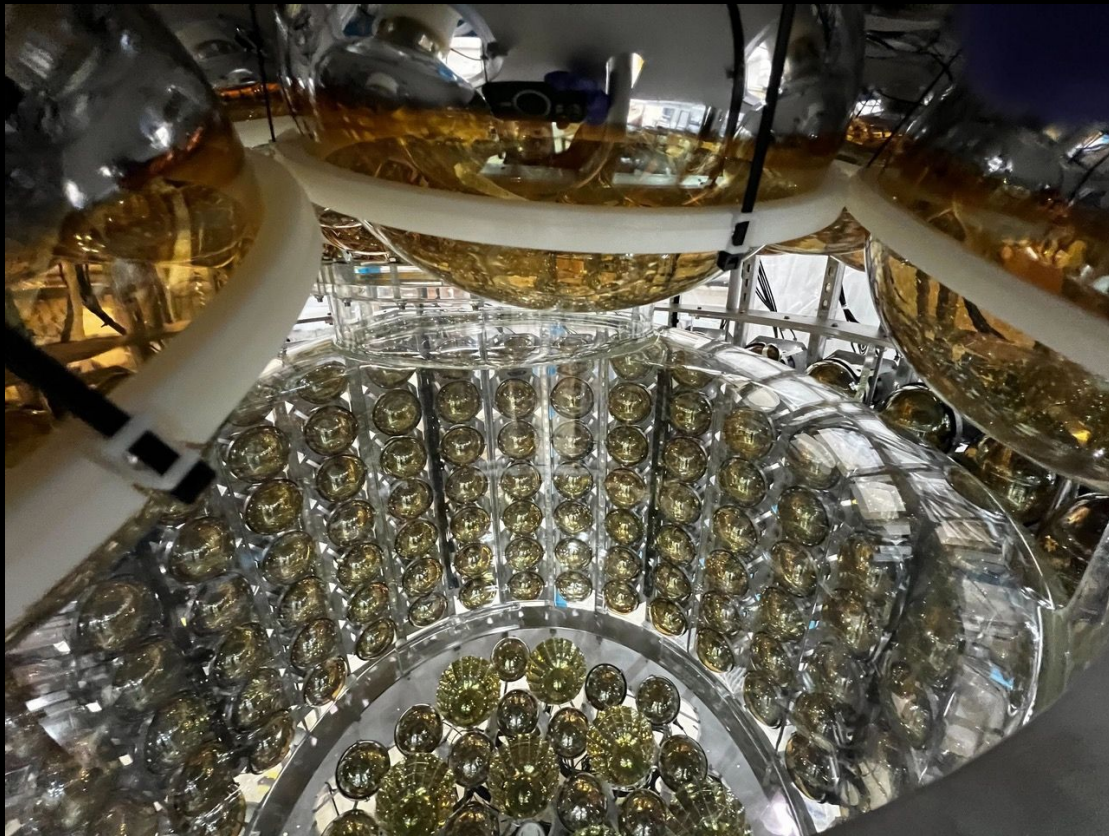
Acrylic vessel installed, dichroicons installed (Nov. 2023)

EOS Construction



Construction completed and inner vessel deployed (Jan. 2024)

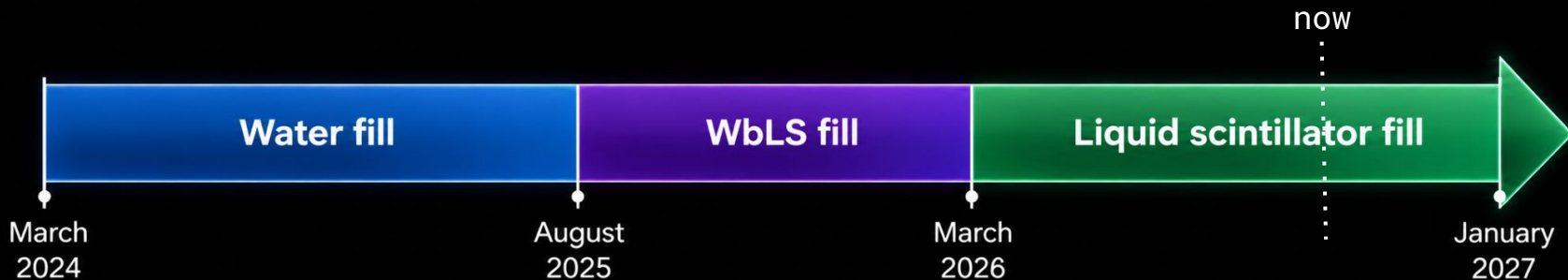
Eos Construction



EoS Data Collection

- Significant data collection campaign with several different target materials
- Suite of deployed radioactive and optical calibration sources and tagged cosemics

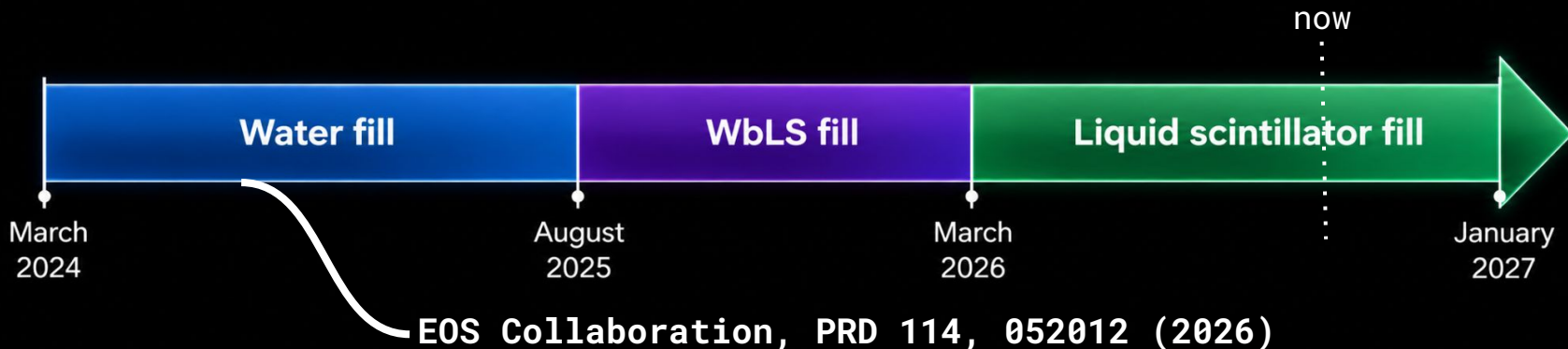
Several of the EoS calibration sources



EOS Data Collection

- Significant data collection campaign with several different target materials
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Several of the EOS calibration sources



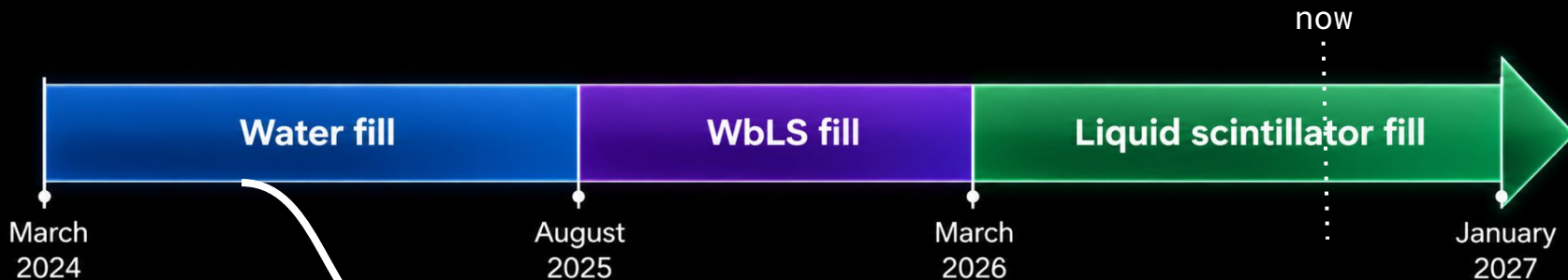
EOS Data Collection

- Significant data collection campaign with several different target materials
- Suite of deep optical calibration using tagged cosmic

Several of the EOS calibration sources



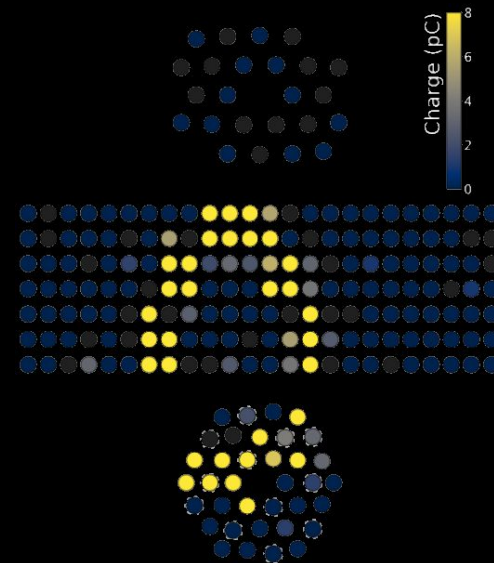
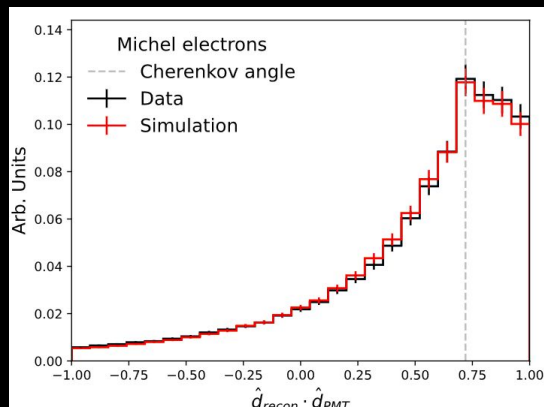
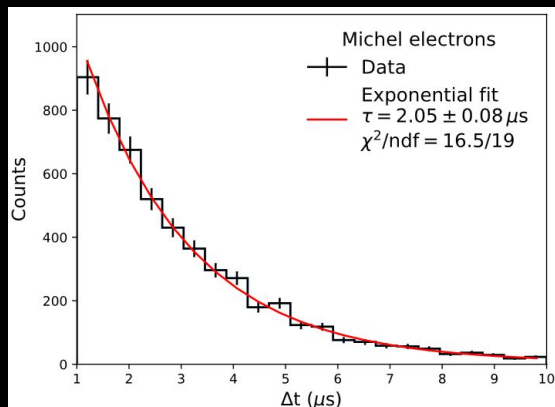
Performance of the EOS Detector
RDC 2 Photodetectors
L. Ren



EOS Collaboration, PRD 114, 052012 (2026)

EOS Water Results

- Significant calibration campaign during water phase
- Tagged Michel electrons show excellent data-MC agreement in a variety of observables



Unique environment for neutrino physics

- Spallation neutron source (SNS) at Oak Ridge National Lab
- 1.3 GeV protons @ 2 MW @ 60 Hz produces $3.5 \times 10^{15} \nu/s$

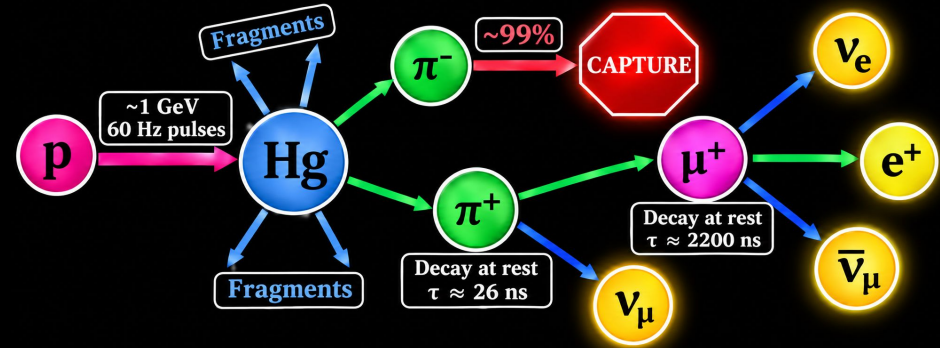
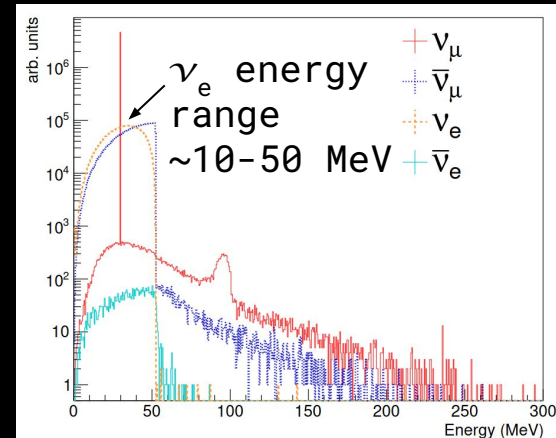
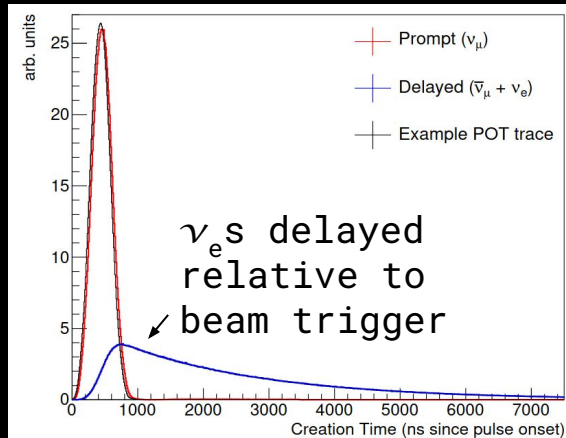


Image based on:
<https://rappr1.github.io/research/nuFlux>

Unique environment for neutrino physics

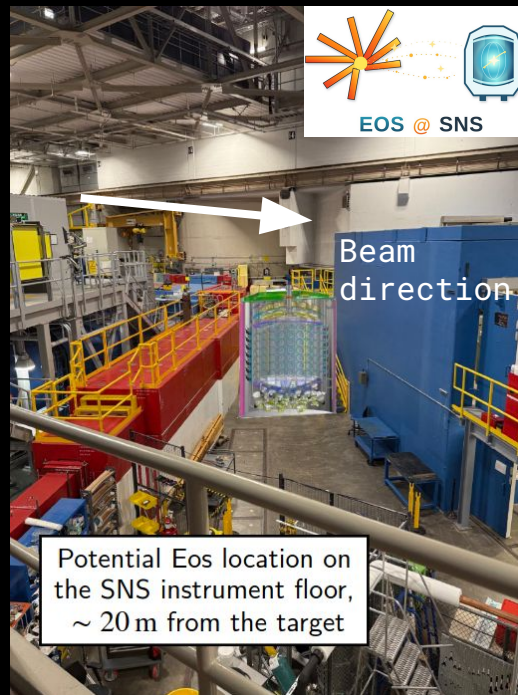
- ν_e s produced with delayed timing and energies $\sim 10\text{--}50$ MeV
- Neutrino energy aligns with expected core collapse supernova energy spectrum



Eos @ SNS

Leveraging Eos for high-impact neutrino physics

- Plan to deploy EOS about ~20 m from the target, in Beamline 8. Using water target.
- Moving to SNS in 2027, preparations underway
- Key goal: Precision measurement of CC ν_e - ^{16}O cross-section
- Many other possible physics topics (see backup slides)

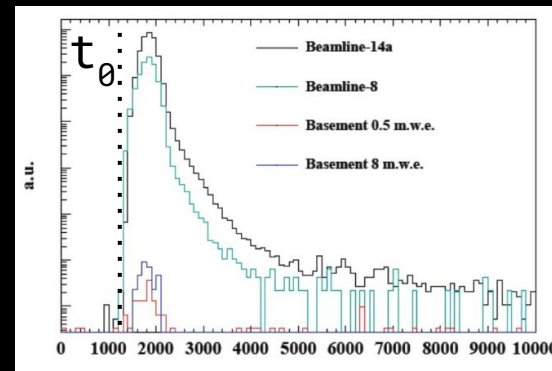
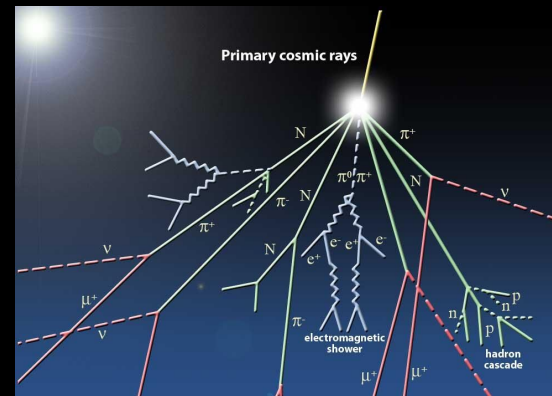


Backgrounds

- **Cosmics:** Michel electrons, gamma-rays, and neutrons produced in cosmic muon interactions
- **Beam neutrons:** Fast neutrons produced by the SNS beam

Neutron rate, energy, and timing measured by COHERENT collaboration in Beamline 8

- **Neutrinos:** Small background from other channels (e.g., elastic scattering)



Upgrades

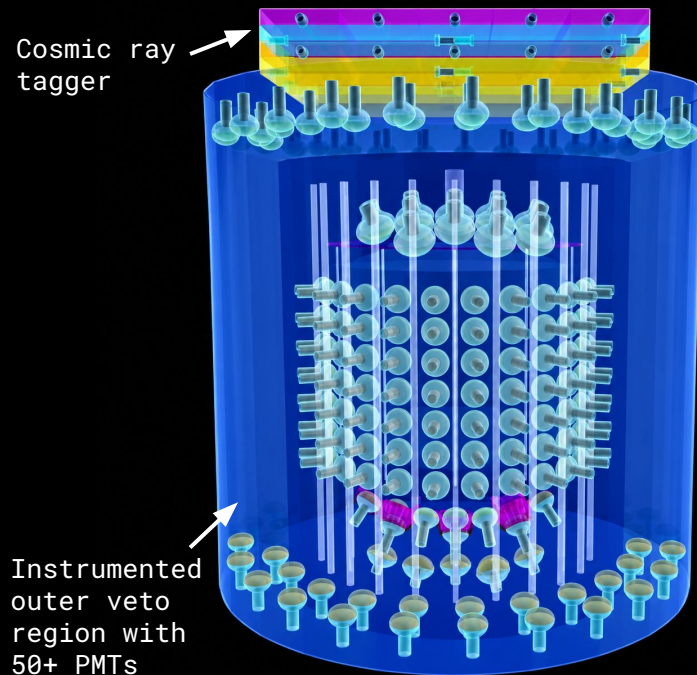
1. Instrumented, tyvek-coated, water-filled outer veto tank

Shielding & tagging of cosmic-ray particles and beam neutrons

2. Top cosmic-ray tagger: scintillator panels

Tagging of cosmic muons

3. Additional PMTs and potential for upgraded electronics

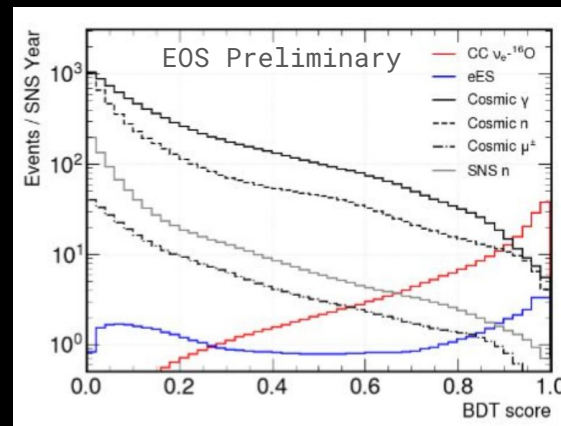
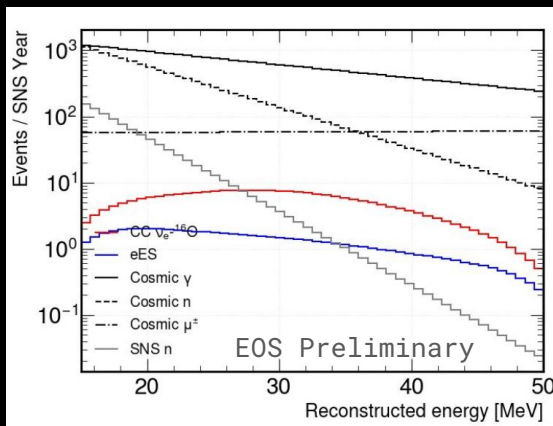
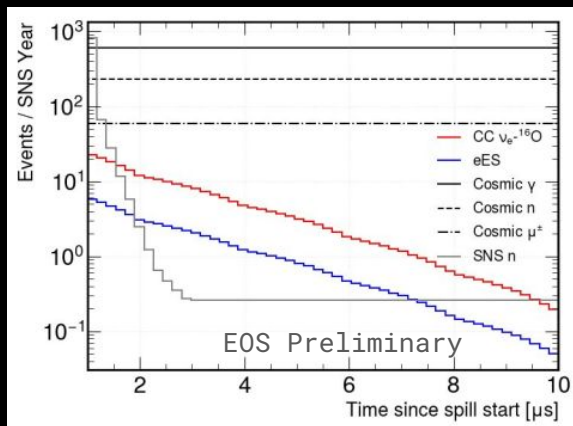


ratpac-two model

<https://github.com/rat-pac/ratpac-two>

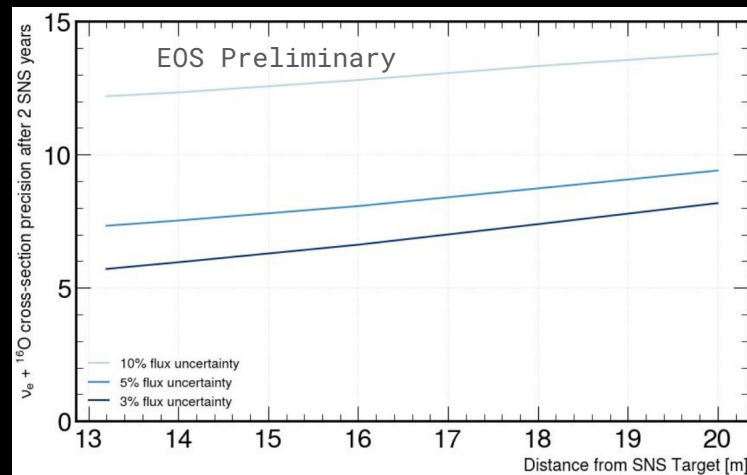
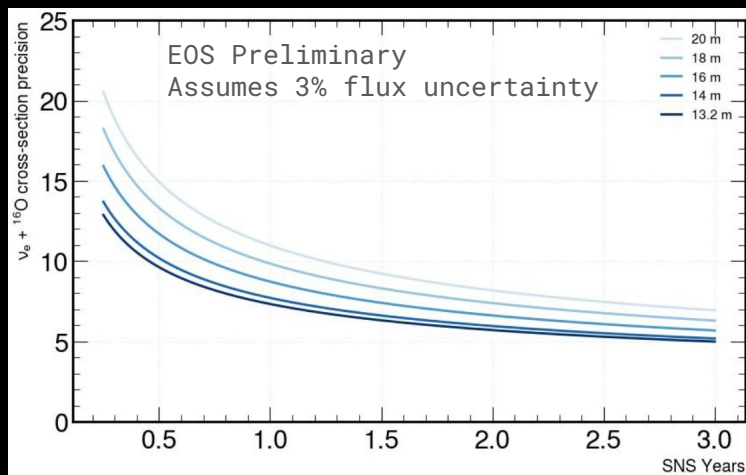
Background Rejection

- Discriminate untagged backgrounds using the time, energy, multiplicity, and reconstructed position & direction.
- Combine observables into BDT score:
Background rejection >99.99% for signal efficiency ~20%



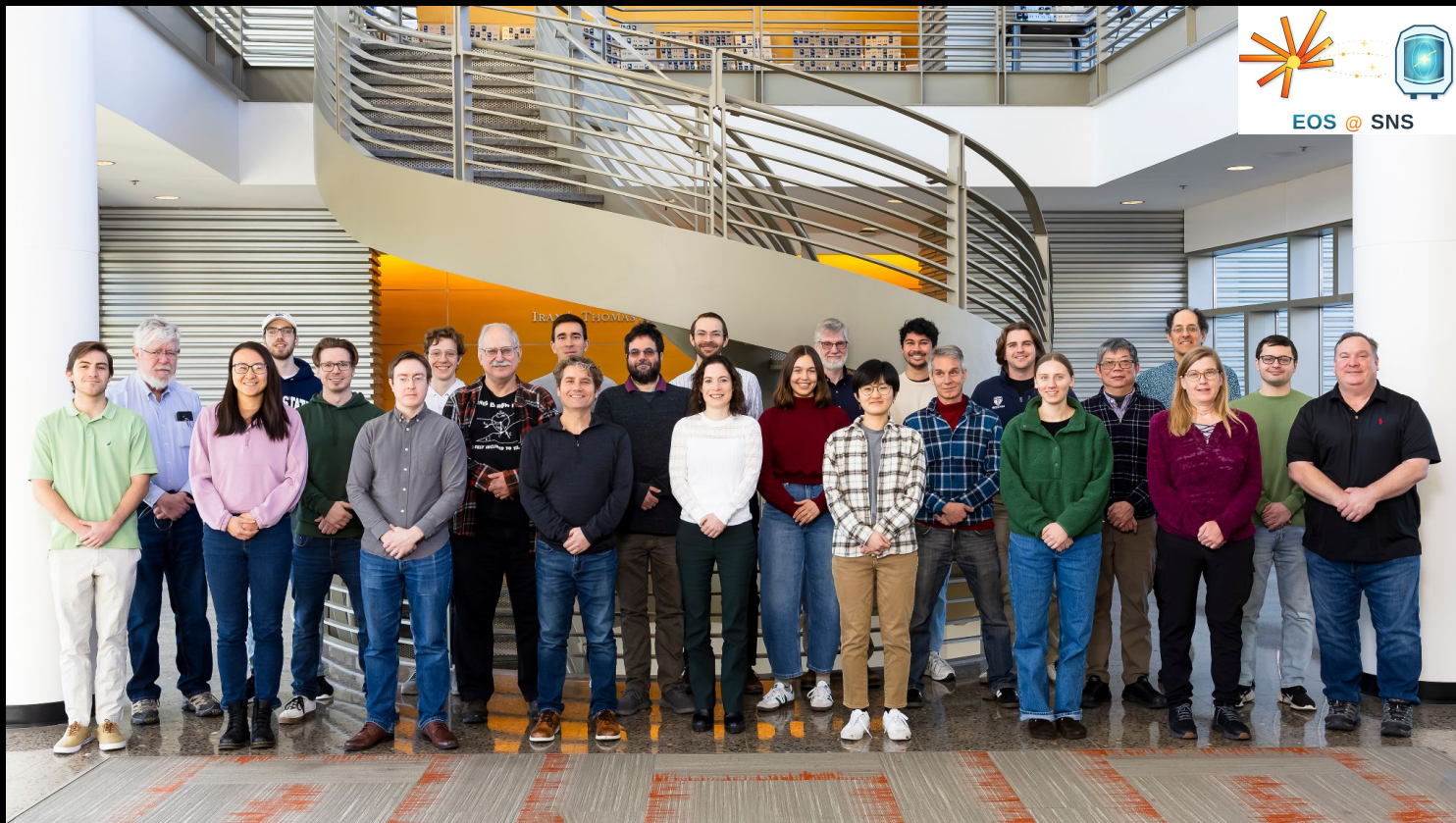
Sensitivity

- $< 10\%$ measurement of CC $\nu_e - {}^{16}\text{O}$ cross-section in 3 yrs
- Primary systematic is uncertainty in the neutrino flux (currently 10%, expect better from COHERENT measurements*)



* For more information see here: <https://arxiv.org/abs/1910.00630>

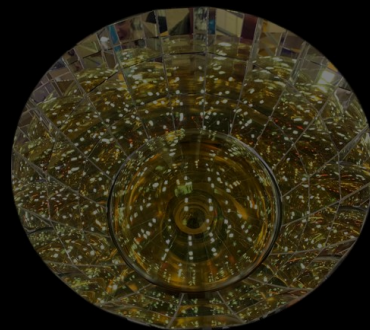
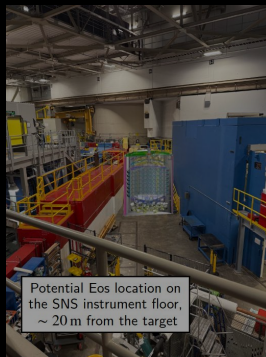
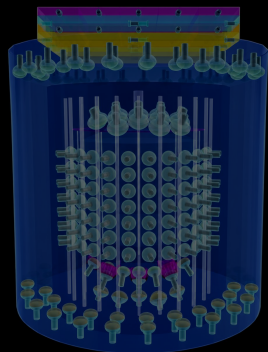
Acknowledgements



Oak Ridge National Lab, 2025

Conclusion

- The EoS collaboration plans to utilize existing, highly capable detector to perform impactful physics measurements
- Expect better than 10% measurement of CC ν_e - ^{16}O when deployed at the SNS



Backup

Other Physics Topics

EOS @ SNS has broad physics potential

- With liquid scintillator, measure CC ν_e interactions on carbon
- With Te-loaded scintillator, measure CC ν_e -Te cross-section, relevant for future $0\nu\beta\beta$ searches
- With gallium loading, opportunity to test gallium anomaly
- Exotics searches: light sterile neutrinos, variety of BSM particles (ideal for searches for low mass, low coupling particles)