OAK RIDGE National Laboratory

Neutrinos at ORNL

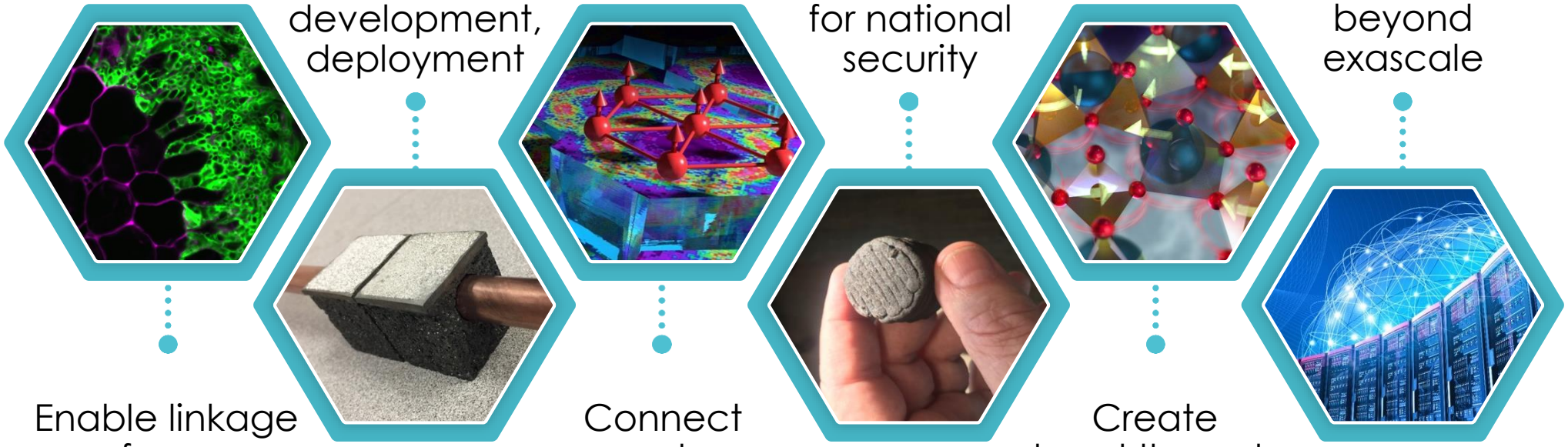
Marcel Demarteau
Division Director
Physics Division

Magnificent CEvNS 2019 Workshop
November 11, 2019

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

ORNL Science opportunities … official lab plan



Enable linkage of gene function to ecosystems: BioScales

Advance fusion energy: Science, development, deployment

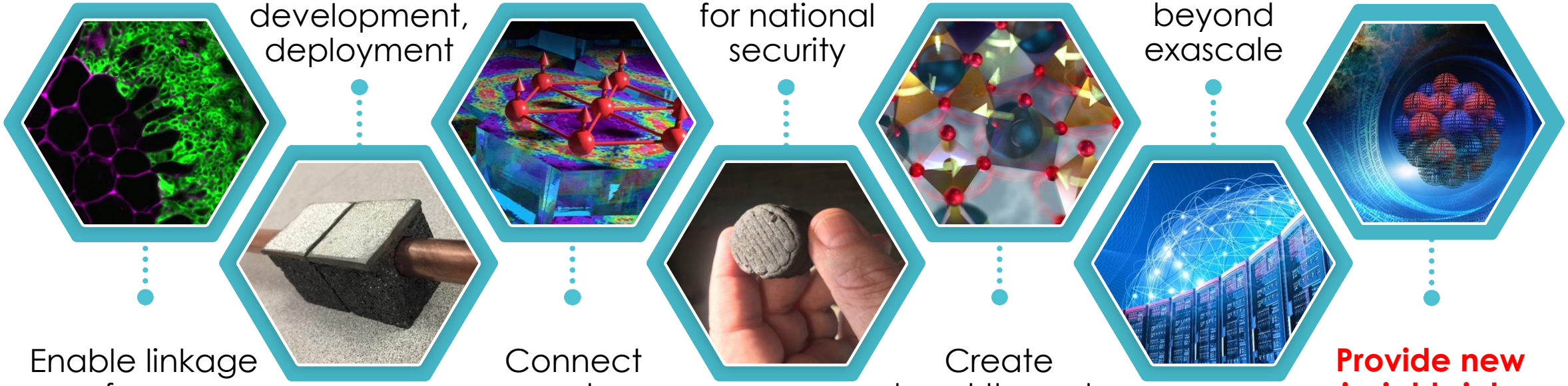
Connect quantum materials to quantum information

Drive a manufacturing revolution for national security

Create breakthrough capabilities for neutron scattering with STS

Advance toward computing and data analytics beyond exascale

ORNL Science opportunities +



Enable linkage of gene function to ecosystems: BioScales

Advance fusion energy: Science, development, deployment

Connect quantum materials to quantum information

Drive a manufacturing revolution for national security

Create breakthrough capabilities for neutron scattering with STS

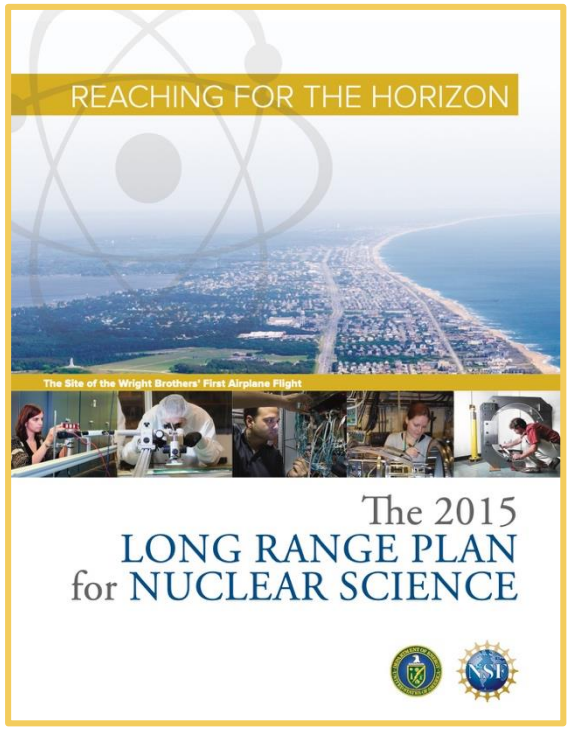
Advance toward computing and data analytics beyond exascale

Provide new insights into the structure and evolution of the universe

Fundamental discovery science and neutrinos

- Two major neutrino efforts: one ongoing and one being built falling under two SC offices

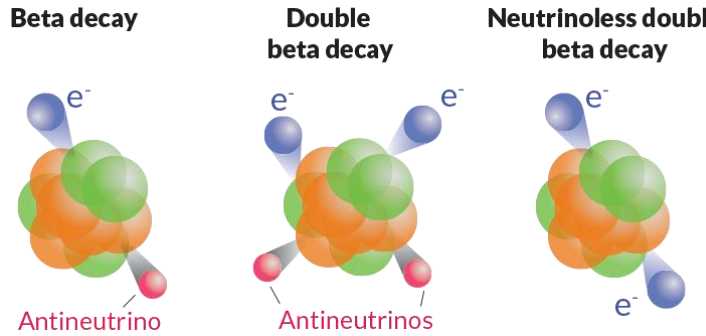
Nuclear Physics

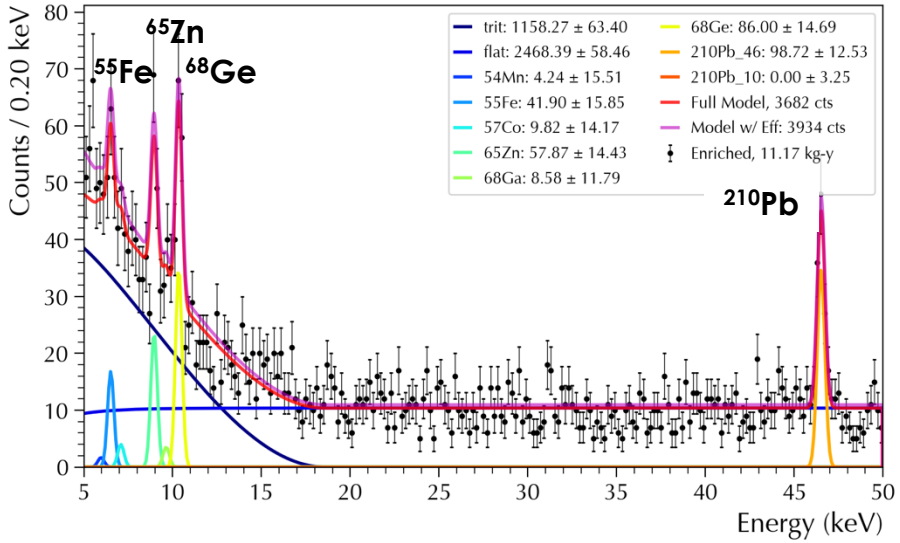


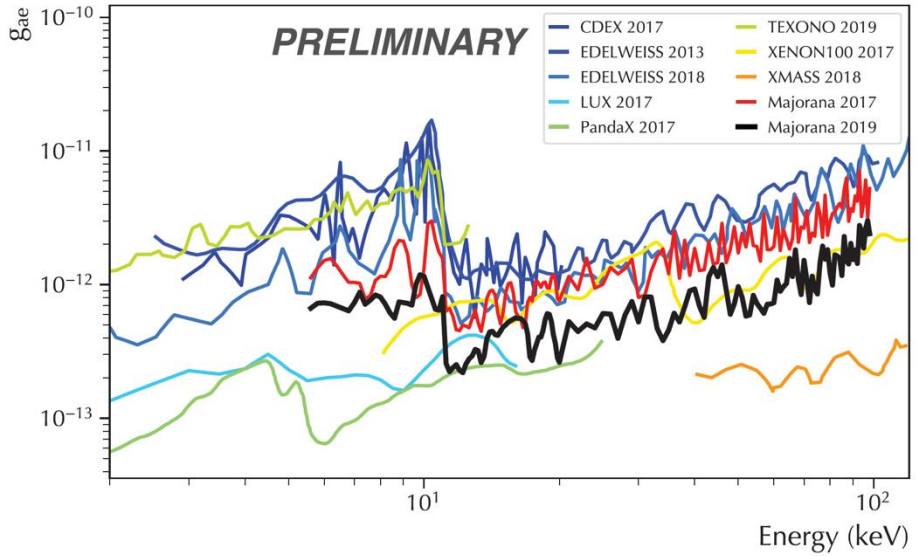
Particle Physics

The Majorana Demonstrator Experiment (MJD)

- Observation of 0νββ-Decay would prove the nature of the neutrino and provide clues to the matter-antimatter asymmetry in the universe
- The Majorana Demonstrator Experiment based on ^{76}Ge
  - 29.7 kg, 88% enriched, p-type point contact, ^{76}Ge crystals,
  - Energy resolution: 2.5 keV FWHM @ 2039 keV
- **ORNL is the lead lab for MJD**







PRL 118, 161801 (2017)
http://taup2019.icrr.u-tokyo.ac.jp/

OAK RIDGE National Laboratory

Next Generation 0νββ-Decay Experiment

- The timely development and deployment of a U.S.-led ton-scale neutrino-less double beta decay experiment is a high-priority of the DOE NP Long-Range Plan.
- Two main competing technologies:
  - ^{76}Ge, 1000 kg, crystal based, underground: LEGEND experiment
  - ^{136}Xe, 5 tons, liquid based, underground: nEXO experiment
- The next-generation 0νββ is all about ***background*** and ***energy resolution***
  - Latest 0νββ ROI background performance ~ 3x our UPP goal
- "Demonstrator" experiments for scale-up: Majorana Demonstrator and GERDA
- State of the art in the key performance parameters: lowest background and best resolution of all 0νββ experiments
- Next generation experiment will deploy LAr as a shield ….. synergies

MJD = Majorana Demonstrator
GERDA = GERmanium Detector Array
LEGEND = Large Enriched GErmanium Neutrinoless Decay
nEXO = next Enriched Xenon Observatory

Large Enriched Germanium Experiment for 0νββ Decay

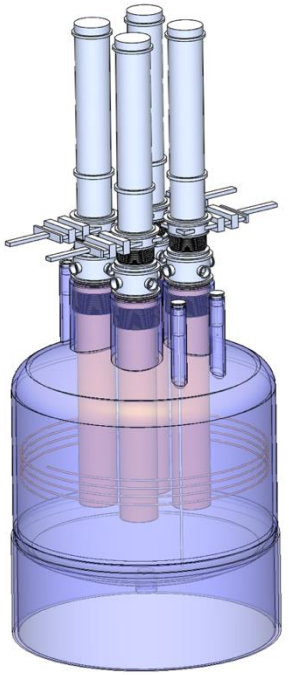
- LEGEND: the merger of MJD and GERDA is the LEGEND Collaboration to develop a ^{76}Ge-based double-beta decay experiment with discovery potential at a half-life approaching or at 10^{28} years of the universe is ~10^{10} years!)

First phase (LEGEND-200):

- 200 kg ^{76}Ge
- Modification of existing GERDA infrastructure at LNGS
- BG goal (x5 lower) 0.6 c /(FWHM t-y)
- "Module" and R&D for ton scale
- Start by 2021
- NSF midscale funding for US component (UNC)

Ton stage (LEGEND-1000):

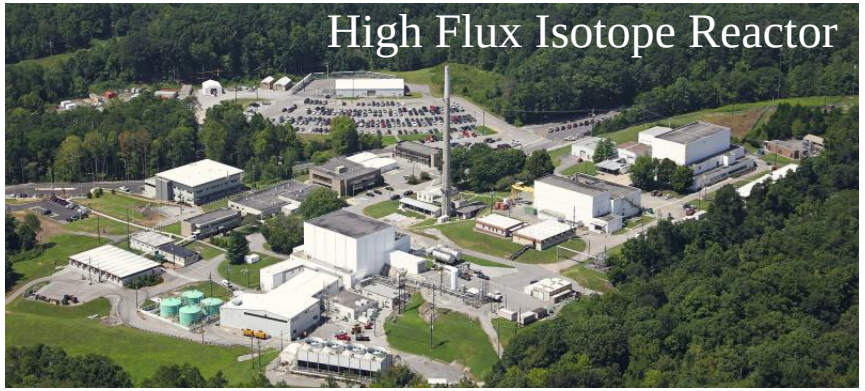
- 1000 kg (staged)
- Timeline connected to U.S. DOE down select process
- BG: goal (at least x30 lower) 0.1 c /(FWHM t-y)
- Location: TBD
- LDRD supported: FY17-19: $1.5M

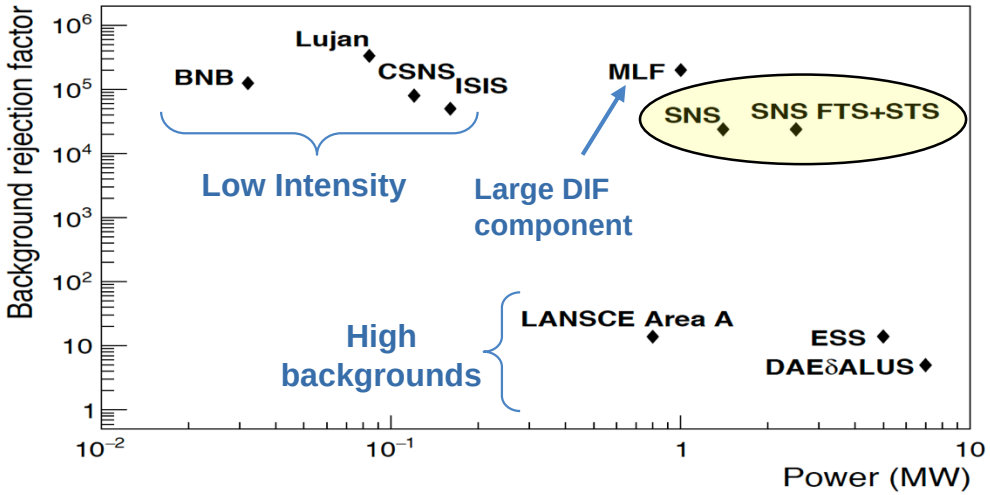


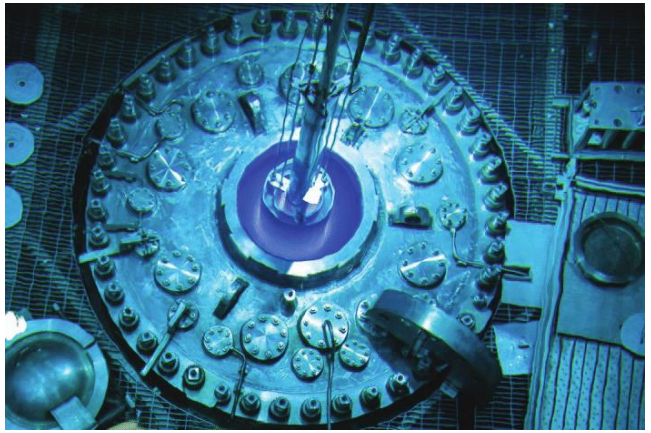
MJD = Majorana Demonstrator
GERDA = GERmanium Detector Array
LEGEND = Large Enriched GErmanium Neutrinoless Decay
LGNS = Laboratori Nazionali del Gran Sasso

Experimental Neutrino Facilities at ORNL

The most intense pulsed neutrino source in the world







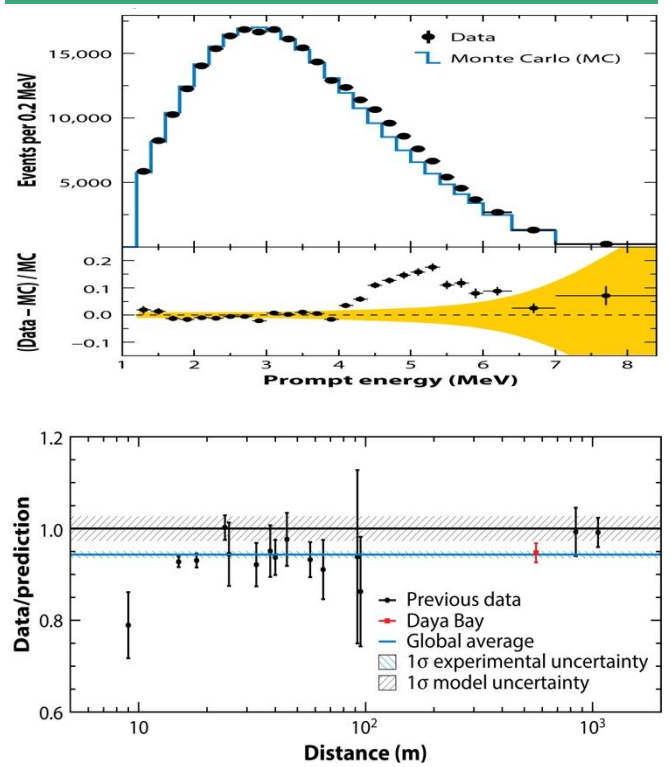
Powerful Compact Core.

PROSPECT

- First above-ground measurement of neutrino energy spectrum of ^{235}U reactor core with the Precision Reactor Oscillation and SPECTrum Experiment (PROSPECT)

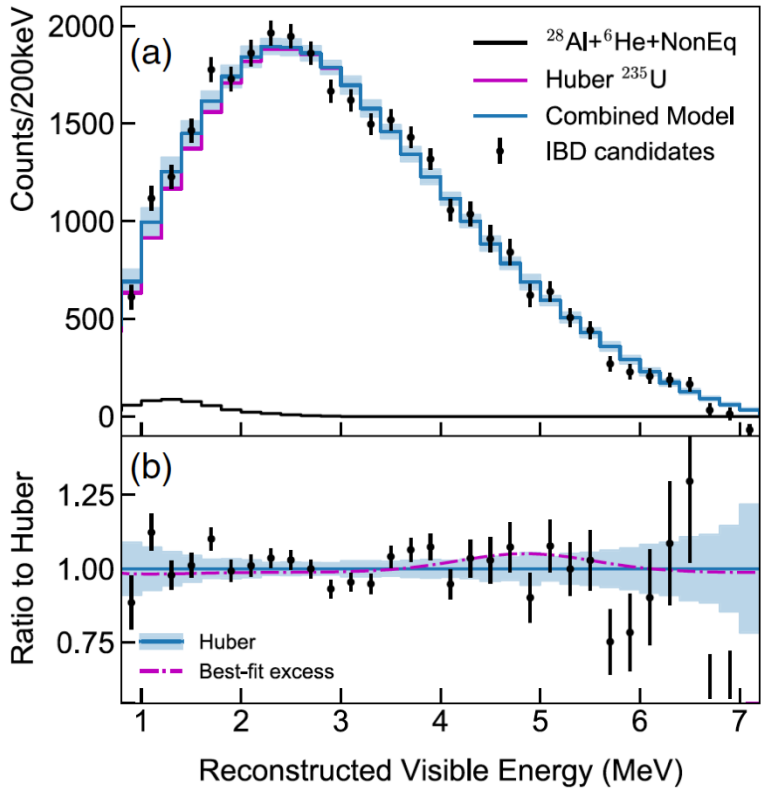
Experiment

Motivation



Hayes AC, Vogel P. 2016.
Annu. Rev. Nucl. Part. Sci. 66:219–44

Result



J. Ashenfelter et al., Phys. Rev. Lett. 122 (2019) 251801

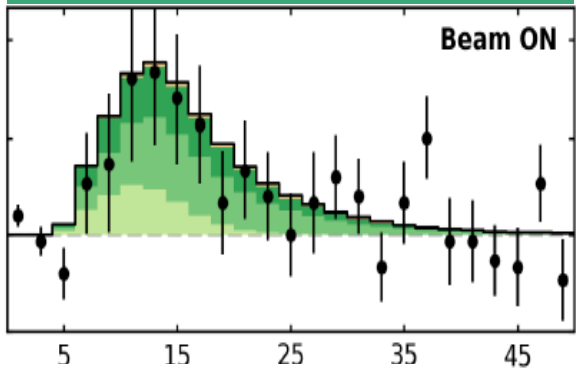
OAK RIDGE National Laboratory

Coherent Elastic Neutrino Nucleus Scattering

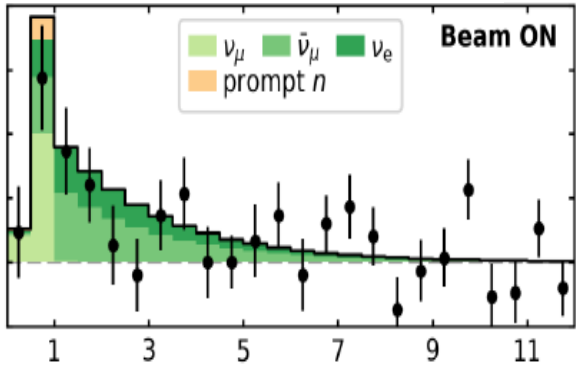
Scientific achievement

Akimov et al. Science
Vol 357 (6356), Sept. 2017

Measurement



Number of Photoelectrons (PE)

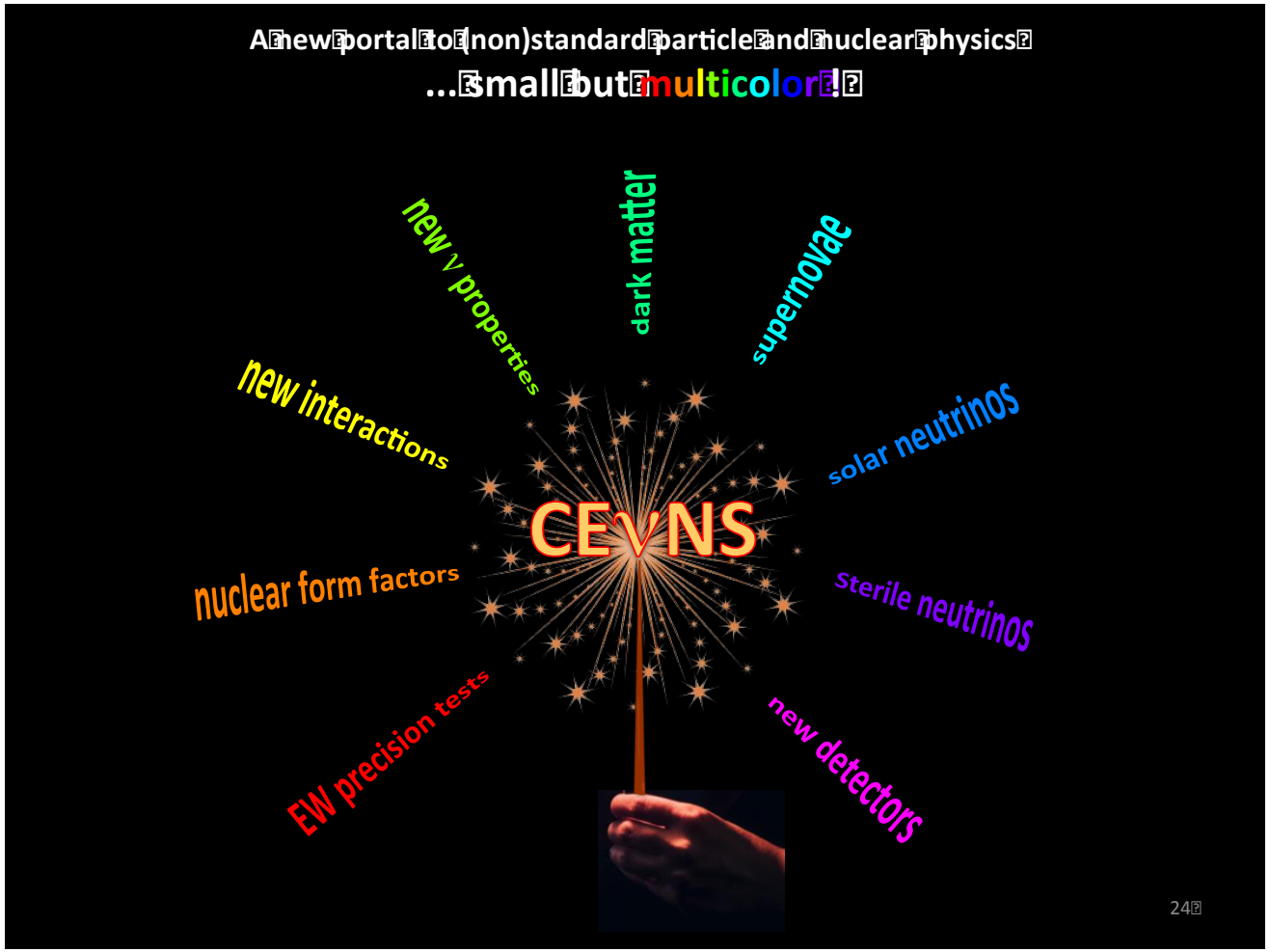


Arrival time (μs)

Methodology at SNS

- SNS is an intense source of neutrinos from pion decay at rest (DAR)
  - π^+: ν_μ ; ν_e , $\bar{\nu}_\mu$
  - π^- decay chain mostly captured!
  - A neutrino scatters on a nucleus that recoils as a whole; **coherent** up to $E_\nu \sim 50$ MeV, proportional to the number of neutrons.
- NSF MRI for HPGe awarded for 2020

Neutrinos at ORNL: A Complementary Portal

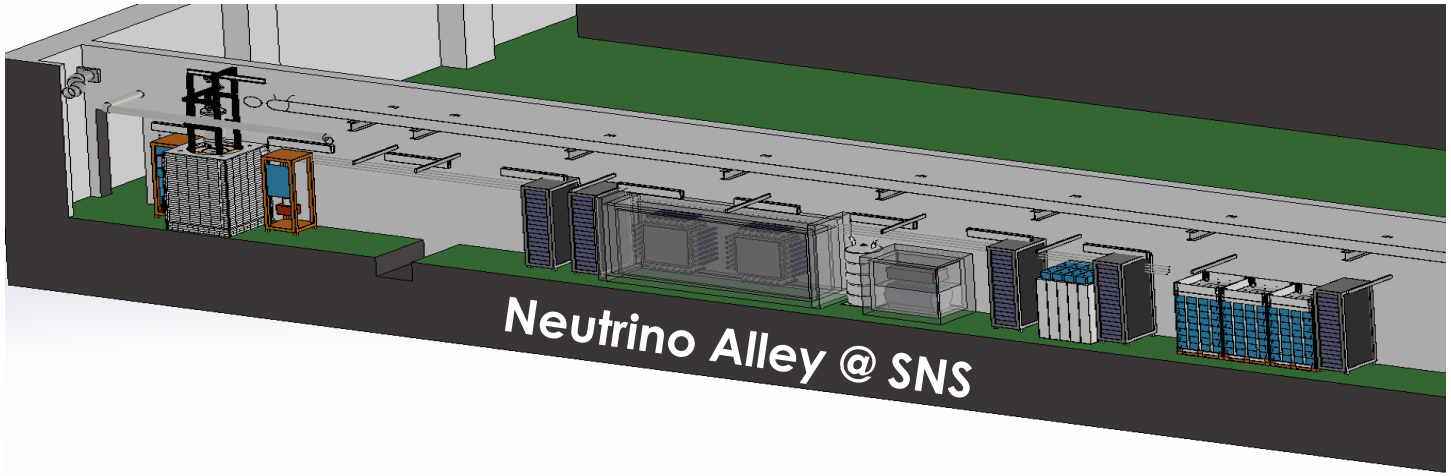


Slide from opening plenary talk by Eligio Lisi at NuInt 2018
https://indico.cern.ch/event/703880/

As the Higgs is a tool for discovery CEvNS is a tool for probing a broad spectrum of unique physics complementary and supportive of the LBNF/DUNE program

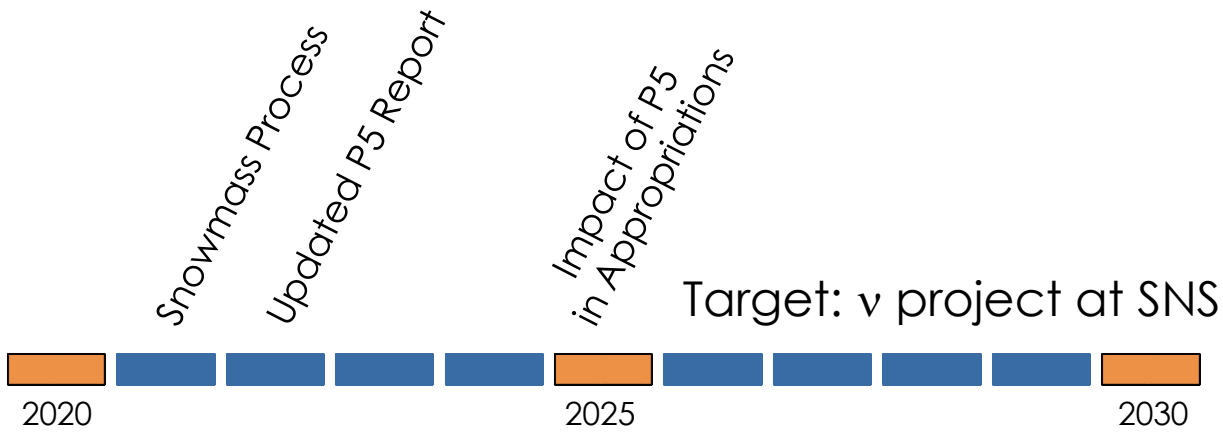
Goal: a lab supported research program to develop an OHEP supported neutrino science program at the FTS and STS

Goal: Neutrino Program at the SNS (FTS and STS) and HFIR

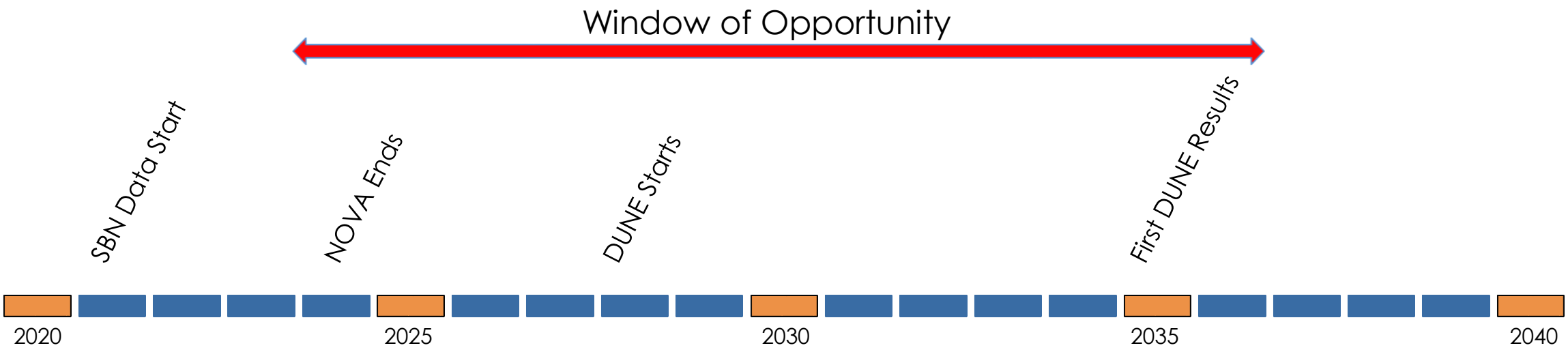


- Neutrinos at ORNL address three of the five P5 science drivers:
  - Pursue the physics associated with neutrino mass.
  - Identify the new physics of dark matter.
  - Explore the unknown: new particles, interactions, & physical principles.

- Integrate with the P5 process through strategic LDRD



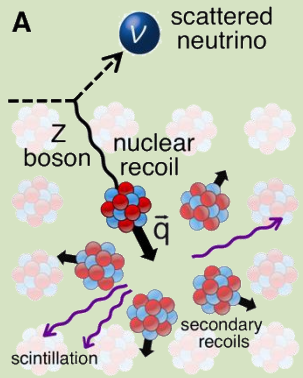
Neutrino Program at the SNS (FTS and STS) and HFIR



- The physics associated with neutrinos is the highest priority of the national HEP program and vigorously pursued in China and Japan (HyperKamiokande – Japan; JUNO – China)
  - Worldwide investment in new projects close to $5B in US accounting
- An SNS – HFIR neutrino program uniquely probes fundamental physics, the 'neutrino anomalies', dark matter, delivers a continuous stream of high-profile neutrino physics results, provides a test bed for detector development and provides critical input to the Deep Underground Neutrino Experiment (DUNE)

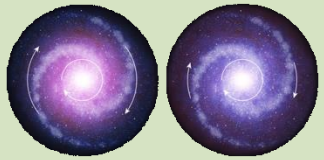
Neutrinos: Window to New Physics

CEvNS



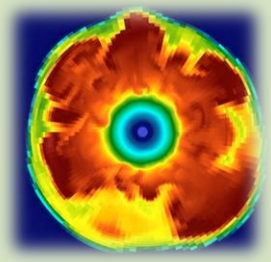
- Cross section measurements LAr, Ge
- Resolve neutrino mass ordering degeneracy
- Precision electroweak measurements
- Beyond the SM searches; non-standard interactions

Dark Matter



- Probe neutrino floor for WIMP search
- Search for accelerator produced dark matter

Foundational



- Foundational neutrino interaction measurements for DUNE, Hyper-K
- Supernovae dynamics
- Flux normalization
- Sterile neutrino oscillations
- Low threshold LAr detector development
- Non-standard interaction couplings

Nuclear non-proliferation

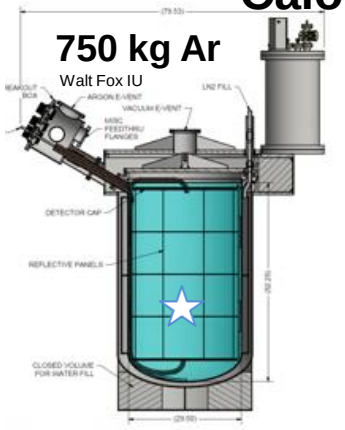
- Best calibrated neutrino source
- Reactor monitoring

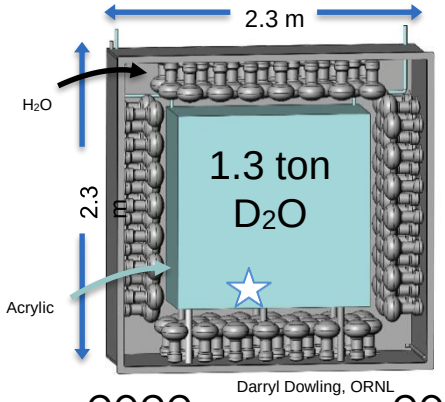
SNS (FTS+STS)

HFIR

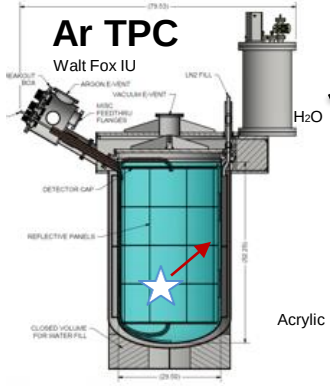
Neutrinos: Window to New Physics

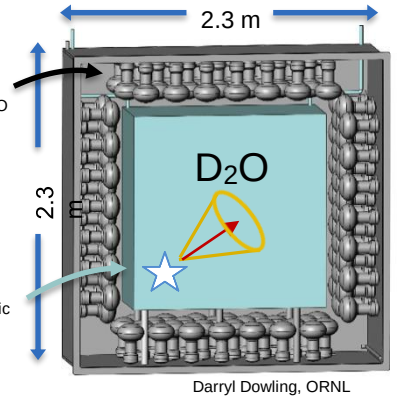
Calorimetry



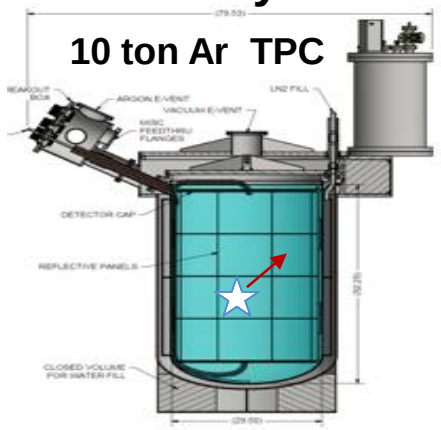


Directionality





Discovery Scale



FTS 2021 2022 2023 2024 2025 STS

Ton-Scale Argon Calorimetry
ORNL LDRD
- CEvNS studies
- Dark Matter searches
- Limits on quark-lepton couplings for DUNE mass ordering degeneracy
- Supernovae neutrino cross sections for DUNE

COHERENT "First Light" Program
HEP and NSF
- Heavy Water Flux Normalization of FTS
- CEvNS with HPGe, NaI
- Low Threshold Detector R&D: Quantum Enhanced Light Collection, Xenon Doping, SiPM

Ton-Scale Directionality with Low Threshold Detector R&D

Heavy Water Ring Imaging Design
- Improved Flux Normalization
- Neutrino oxygen Interactions for Super-K, Hyper-K

Argon Detector R&D for STS
- Simultaneous Low threshold Light and Time Projection Readout of Charge

Exact time evolution of program to be determined by the collaboration →

HEP Program at STS

Argon TPC
- Dark Matter searches
- Precision CEvNS studies
- Precision Ar cross sections for DUNE
- Weak Mixing Angle
- Neutrino EM properties

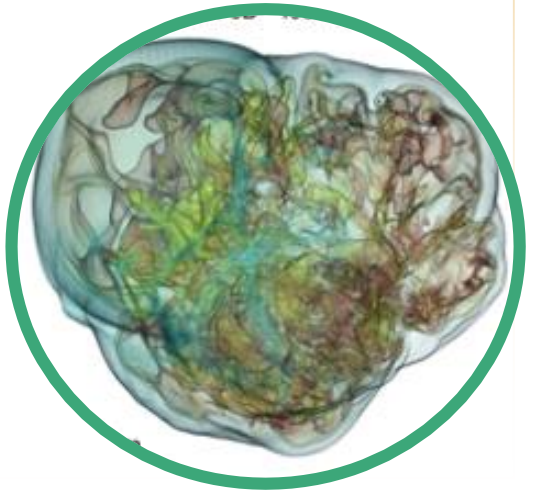
Heavy Water Ring Imaging
- Flux Normalization of STS
- Precision oxygen cross sections for Super-K, Hyper-K

Aim: part of next P5

Synergy with Nuclear Theory Program

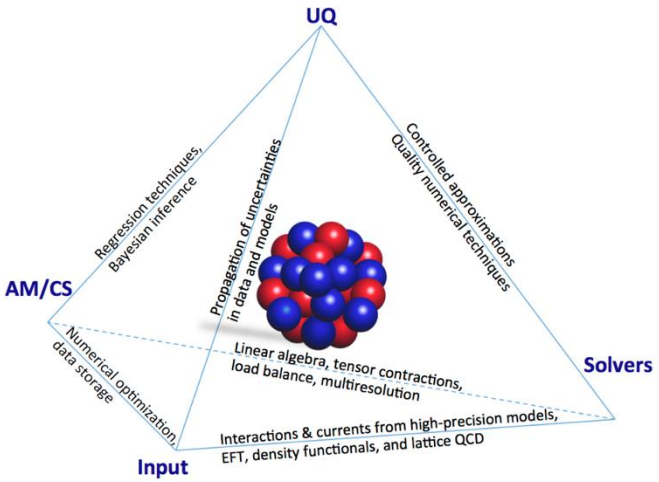
- The Nuclear Theory group of the Physics Division has four key research thrusts with strong links to OLCF.

Nuclear Structure	Astrophysics	Neutrinos	Computational
• Nuclear structure for experimental facilities • Properties of nuclei (Coupled Cluster and Halo EFT) • Unification of nuclear structure and reactions • Uncertainty quantification	• Mechanism and nucleosynthesis of core-collapse supernovae • Nucleosynthesis process in compact objects • Neutron star structure and dynamics • Identification of astrophysical reactions	• Neutrino response in nuclei relevant for detectors and simulations • Neutrinoless double beta decay	• Development of codes using latest hardware and algorithms

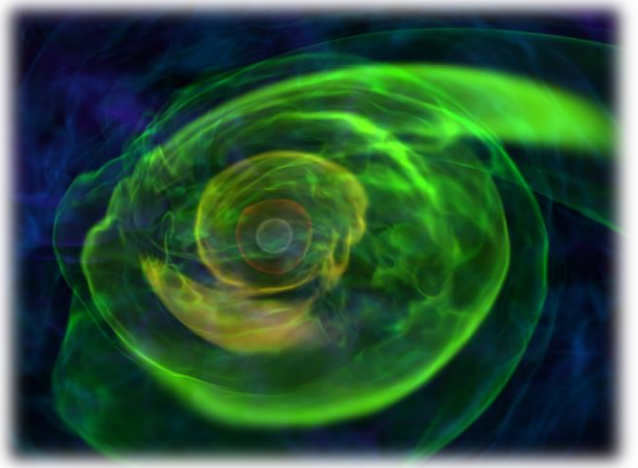


Synergy with OLCF

- Nuclear Computational Low Energy Initiative (NUCLEI):
  - INCITE project to calculate properties and reactions of atomic nuclei for accelerator-based experiments and for thermonuclear reactions occurring in stars



- Towards Exascale Astrophysics of Mergers and Supernovae (TEAMS)
  - The current supernova and neutron star merger simulation code, CHIMERA (ORNL), is among the **highest physical fidelity in the world**. Successor codes being developed:
  - **GenASiS:** cell-by-cell adaptive mesh refinement.
  - **CLASH:** simulate the coupled hydrodynamics, radiation transport, thermonuclear kinetics, and nuclear microphysics at play in stellar explosions; Supported by ECP and SciDAC



White dwarf merger,
P. Katz et al, 2016, ApJ, 819 94

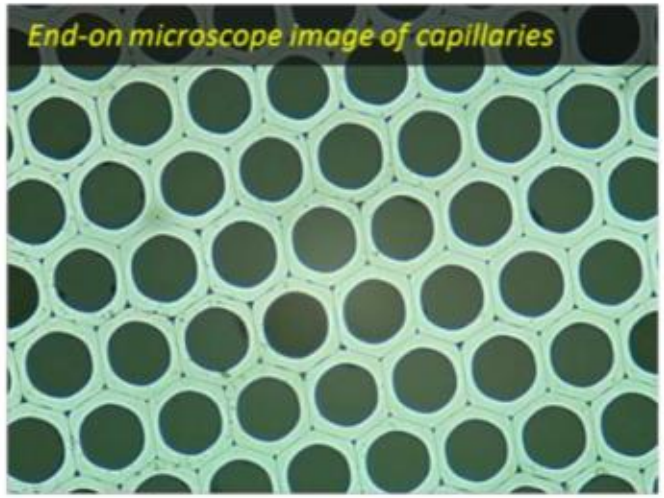
- Projects very synergistic with ORNL core capabilities and strong links with the experimental program

Synergy with Detector Development

Scintillator

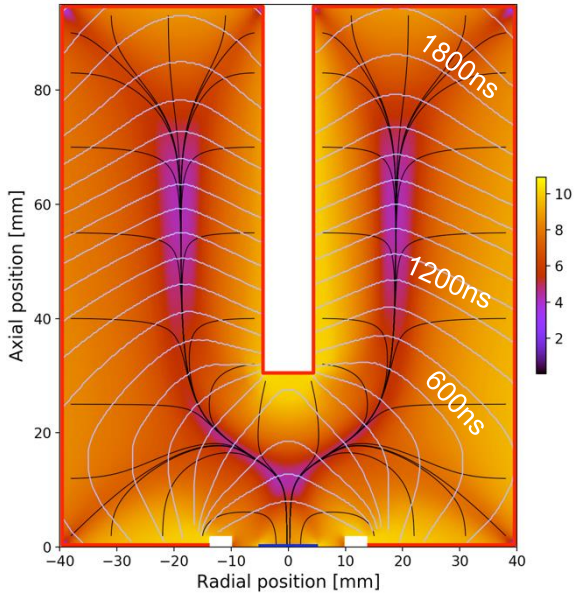
- Synthesis of low-background Polyethylenenaphthalate (PEN) scintillator to replace inactive structural components with scintillating materials

Neutron Detection



- Directional neutron detection with glass capillary plates filled with scintillator (patented)

Germanium



- Improved inverted coaxial point-contact Ge detectors

Physical Sciences Directorate

SCIENTIFIC ADVISORY COMMITTEE MEETING

November 5-7, 2019

OAK RIDGE National Laboratory

- The science advisory committee of the PSD directorate met last week.
- A plan for a fundamental neutrino program at the SNS was presented.
- The advice of the committee to the lab director at the close-out was: “must do”.

Concluding Remarks

- The Neutrino (and Neutron) physics at ORNL is exceedingly compelling.
- The First and Second Target Station provide a world leading neutrino physics program that
  - Addresses **three of the P5 science drivers**
  - Provides a **continuous broad stream of neutrino physics results** over the next two decades (at close to zero operational cost)
  - Provides **foundational measurements** for LBNF/DUNE
  - Provides a **test bed for new detector** development
- **Thank you all very much for helping build a strong science case!**
- **I am committed to help building a strong neutrino science program at the SN²S!**

DISCUSSION