Nuclear Physics & Nuclear Data

Barbara Jacak
Physics Department
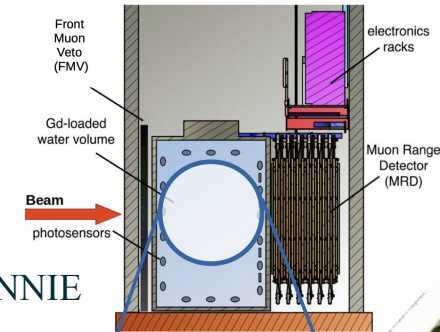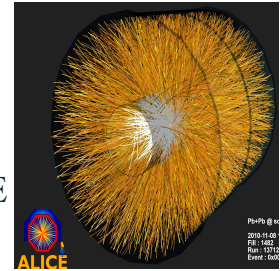**UC Berkeley**

NSSC3 Kickoff Meeting and Advisory Board Review
April 19-20, 2022

Projects: Nuclear fission, structure and astrophysics; Nuclear reaction and decay data; Quark gluon plasma at extreme energy and density; Neutrino nuclear physics and noble liquid detectors; Reactor monitoring with neutrinos.
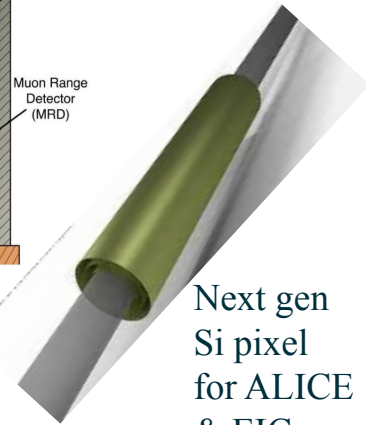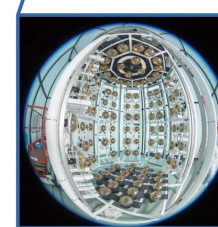
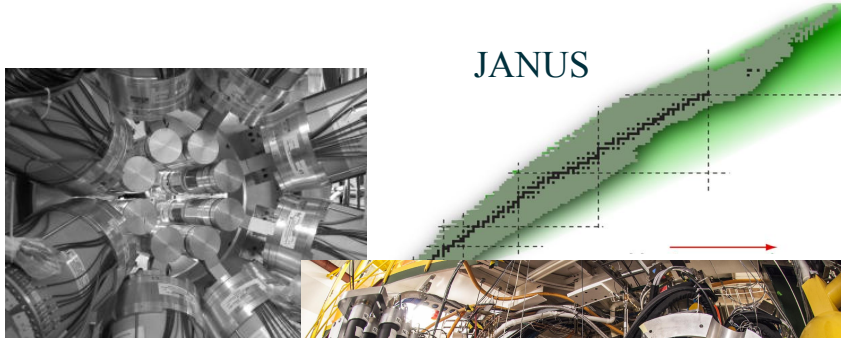*Mission: understand fundamental workings of the universe & publish results*

ALICE
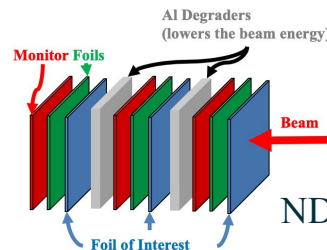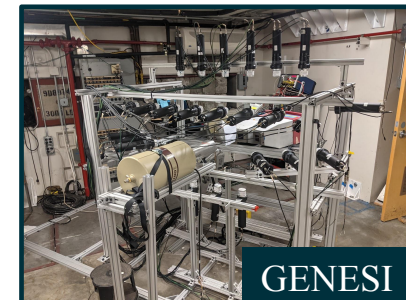

ANNIE

Front Muon Veto (FMV)
electronics racks
Gd-loaded water volume
Muon Range Detector (MRD)
Beam
photosensors

Next gen Si pixel for ALICE & EIC

JANUS

GRETINA @ S800

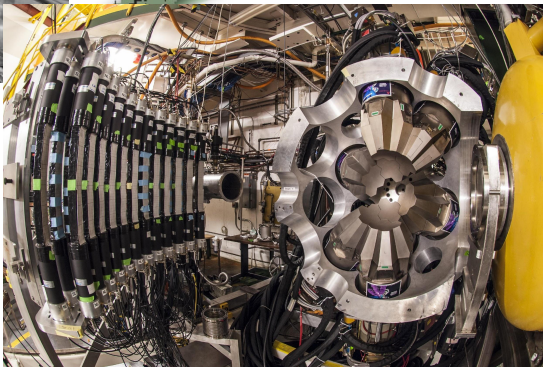Al Degraders (lowers the beam energy)
Monitor Foils
Beam
Foil of Interest

ND at Crocker Lab

GENESI

- **Address key questions in Nuclear Physics**
– What are the limits of exotic nuclei: how is balance between neutrons and protons achieved? What is the structure of exotic nuclei?
– With new facilities and detectors, how much better can we understand nuclear reactions and decay properties? Feed into nuclear data knowledge.
– How do neutrinos work and can reactors be monitored with anti-neutrinos?
– Can dark matter be detected?
– What is the nature of matter at high temperature and density?

- **Develop and train students in new detection methods**   *Synergy*
– Particle/gamma ray/fission fragment detectors and techniques   *with*
– Modeling and database development for nuclear data   *radiation*
– Monolithic active pixel sensors for multiple charged particles   *detection!*

- **Train students in experimental techniques**
– Acquisition and analysis of data (from precise spectroscopy to >1 Pb of data)
– Detailed detector simulations
– Work in large (5 - 1005 scientists) and distributed teams

Deliverables: answers, <u>people</u>, publications, technologies

Key for the National Laboratories

- Skill set obtained by students in Nuclear Physics/Data are highly desirable by the national laboratories
  - Large multivariate data analysis and Petabyte data sets
  - Novel applications of Machine Learning to big data
  - Measurements in small signal-to-background environments
  - Development of state-of-the-art detection systems
  - Experience in geographically distributed collaborations
  - Ability to critically evaluate nuclear data and identify gaps
- NSSC gives students exposure to mission of the labs
  - Students have transitioned into the labs from a variety of programs
  - Helps them link basic and more applied research
- Fundamental science is a strong recruiting tool
- Furthermore, NSSC trains future faculty members in applied-basic research connection

University Key Personnel

Berkeley — UNIVERSITY OF CALIFORNIA

Barbara Jacak, Lee Bernstein, Bethany Goldblum, Dan McKinsey

MICHIGAN STATE UNIVERSITY

Sean Liddick, Alexandra Gade, Hironori Iwasaki, Greg Severin, Jaideep Singh, Artemis Spyrou

UCDAVIS — UNIVERSITY OF CALIFORNIA

Emilija Pantic, Eric Prebys, Robert Svoboda, Mani Tripathi

AFIT — AIR FORCE INSTITUTE OF TECHNOLOGY

Juan Manfredi

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Vladimir Sobes, Jason Hayward

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Laboratory Partners

Melynda Brooks, Cesar da Silva, A. Couture, S. Mosby, H.Y. Lee, M. Devlin, S. Gollapinni, J. Ullmann, D. Neudecker, R. Van der Water, C. Vermeulen, E. Birnbaum, M. Fassbender, T. Kawano, T. Ito

Nikki Apadula, S. Fiorucci, A. Manalaysay, G. Orebi Gann

A. Angerami, M. Bergevin, A. Bernstein, D. Bleuel, B. Canion, S. Dazeley, S. Friedrich, S. Labov, J. Mitrani, J.J. Ressler, N. Scielzo, J. Silano, R. Soltz, J. Verbeke, R. Vogt, J. Xu

M. Blackston, S. McConchie, C. Romano

Nuclear Data

Expand nuclear databases for broad use.
Added data for interpretation of pre- & post-detonation signatures

FPY covariance database*
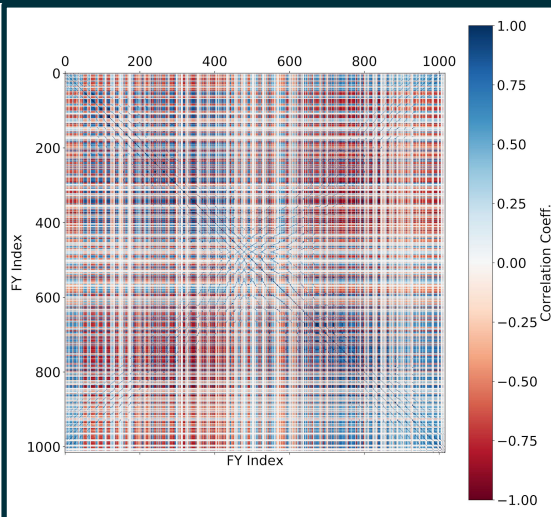
| $_{90}$Th | $_{91}$Pa | $_{92}$U | $_{93}$Np | $_{94}$Pu |
| $_{95}$Am | $_{96}$Cm | $_{97}$Bk | $_{98}$Cf | $_{99}$Es | $_{100}$Fm |

Coincident γ+X-ray database for post-det forensics (joint w/DTRA)

ARES Detector

B. Pierson (PNNL)
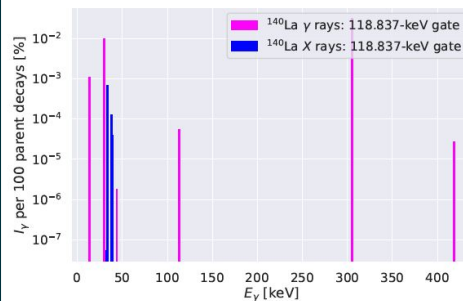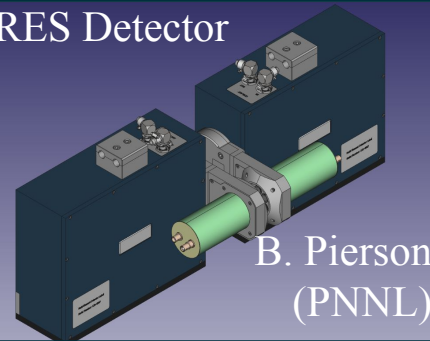
$(n_{fast}, n'γ)$ benchmark database (joint w/USNDP)

ATLAS OF GAMMA-RAY SPECTRA FROM THE INELASTIC SCATTERING OF REACTOR FAST NEUTRONS

$^{56}Fe(n,n'γ)$
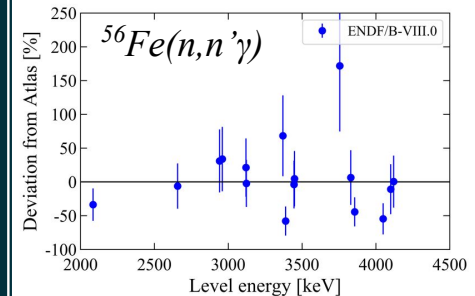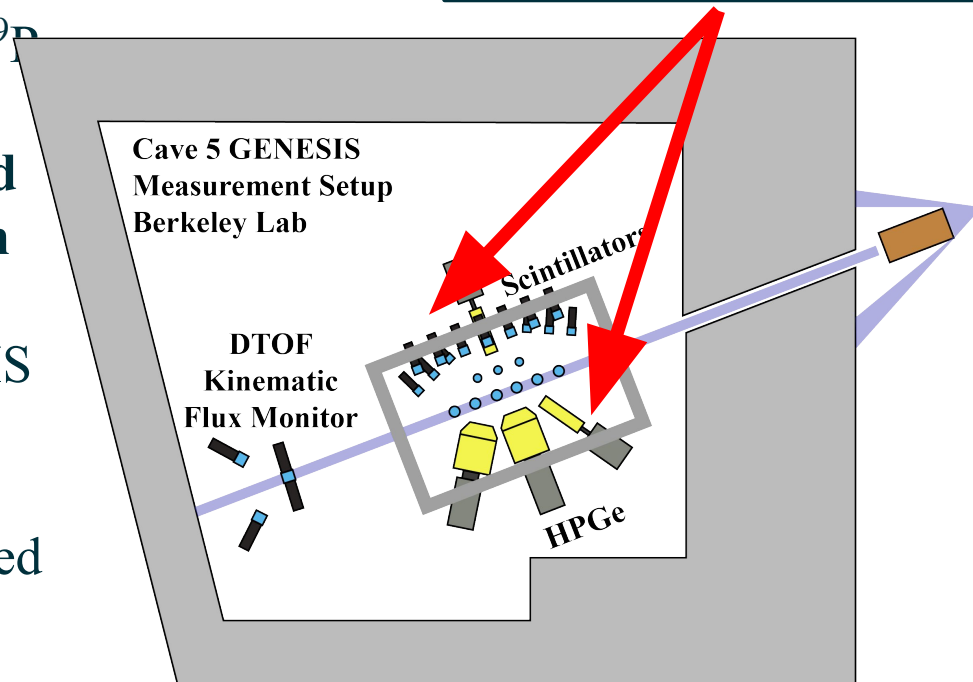

Work highly-leveraged by DOE Nuclear Physics distributed at https://nucleardata.berkeley.edu

Nuclear Data: ≤100 ms β-delayed neutron fission fragment measurements

P. Awedisean

F\ER ◄ n+γ Coincidences with GENESIS scintillators and HPGe

Improved β-delayed fission yield data
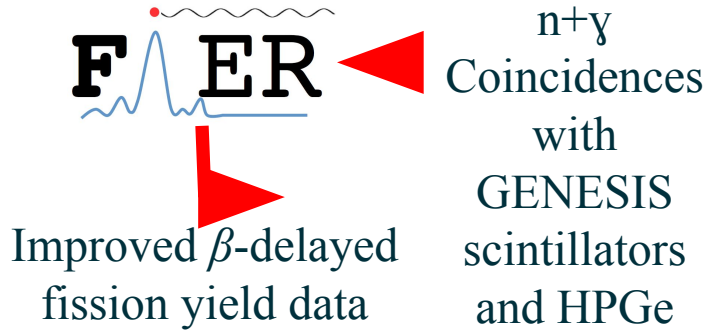
GENESIS

- **PhD student Preston Awedisean:** ^{239}Pu $t_{irradiation} = 1\ s$ data analysis.
- Preston's thesis: measuring **β-delayed neutrons in coincidence with fission** product gammas using $t_{irradiation} < 100\ ms$ pulsed beams in the new GENESIS array at LBNL's 88-inch cyclotron
- **FIER analysis tools** developed in NSSC2 will be modified and employed to determine absolute yields from specific β-delayed fission products.

Cave 5 GENESIS Measurement Setup Berkeley Lab

DTOF Kinematic Flux Monitor

Scintillators

HPGe

Neutron Inelastic Scattering on ^{16}O with GENESIS

PhD Student: Capt Molly Wakeling (AFIT)

LLNL Mentor: Dr. Darren Bleuel
LBNL Mentors: Dr. Lee Bernstein, Dr. Bethany Goldblum

Goal: Measure **triple-differential inelastic neutron scattering** cross sections on ^{16}O
- GENESIS: Gamma Energy Neutron Energy Spectrometer for Inelastic Scattering located at the 88-Inch Cyclotron at LBNL
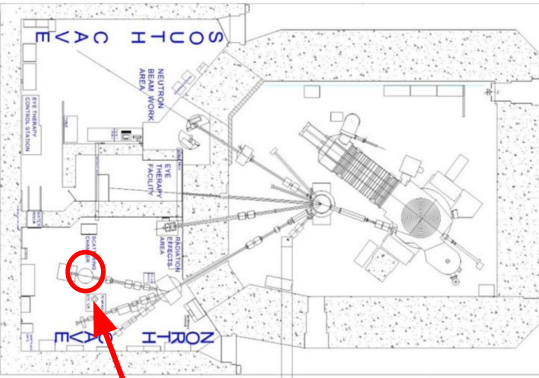- Main experimental run took place earlier this year, analysis in progress
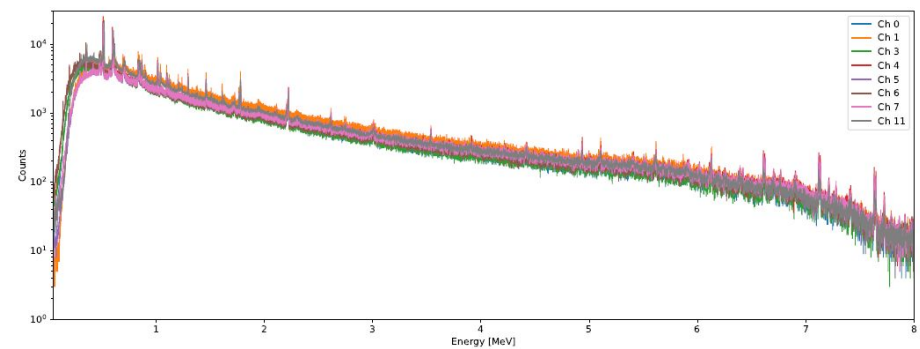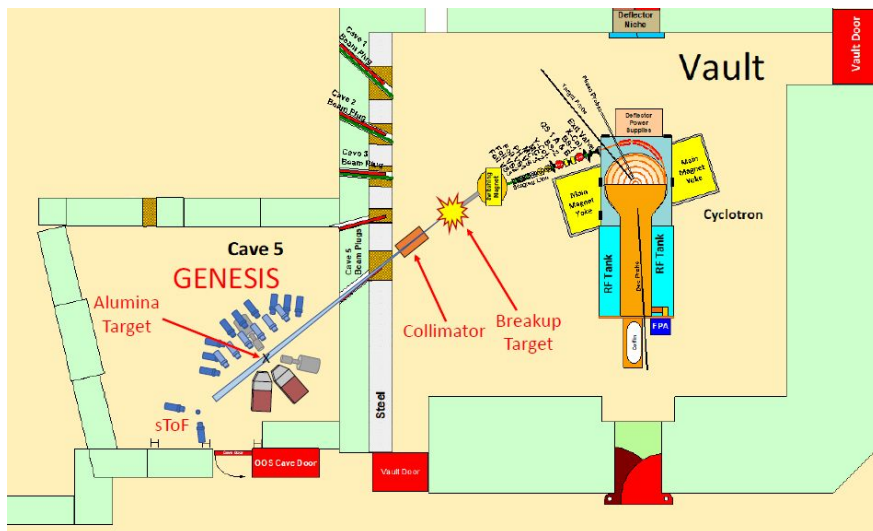
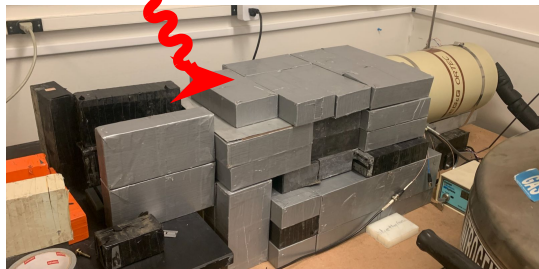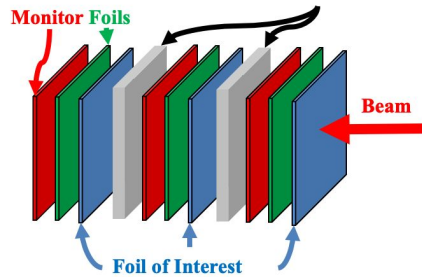*Future candidates for measurement include C, N, Na, and many more*

Nuclear Cross Sections at Davis

Irradiate stacked foils with proton and deuteron beams from the Crocker Nuclear Lab cyclotron.

CROCKER NUCLEAR LABORATORY
University of California, Davis

Generate missing data for the National Nuclear Database, as well as test nuclear physics models.

Collaborating with Lee Bernstein at LBNL/UC Berkeley. This work is complementary to work his is doing at the Berkeley 88" Cyclotron.

Al Degraders
(lowers the beam energy)

Monitor Foils

Beam

Foil of Interest

^{152}Eu calibration source
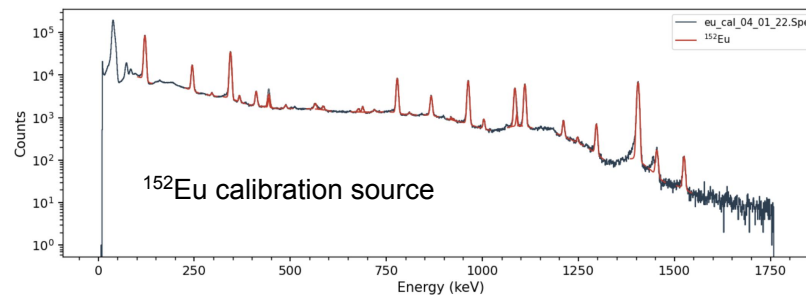
Lena Korkeila, UC Davis Ph.D. student Advisor: Eric Prebys

Artificial Intelligence-based Identification of Nuclear Resonances

UTK Student: Noah Walton
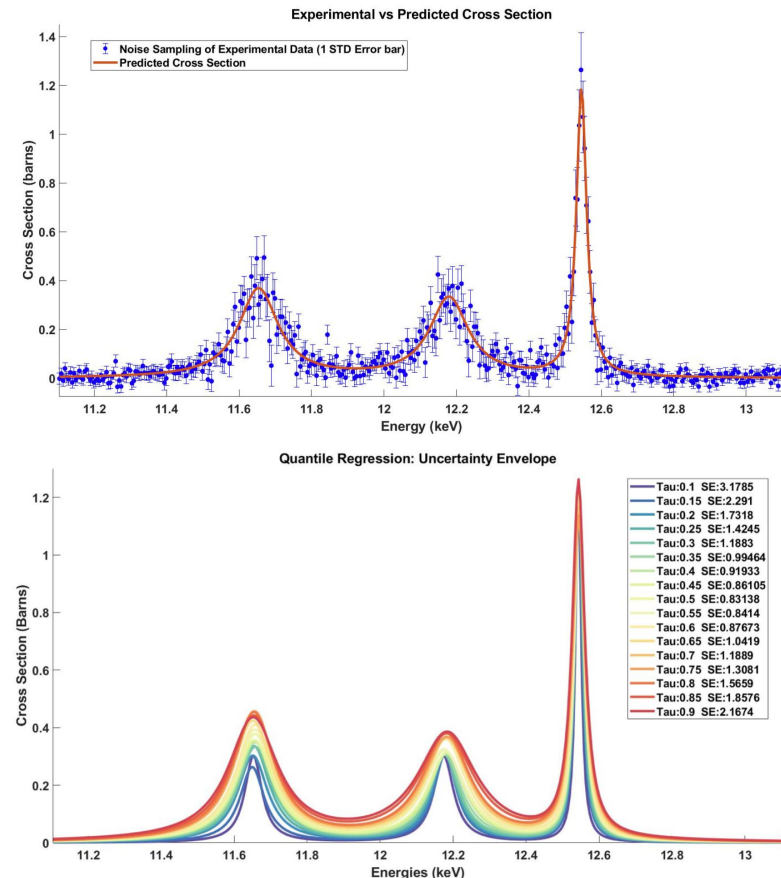**UTK Advisor: Vladimir Sobes**
ORNL Mentor: Jesse Brown

Scientific Objective

Develop a **targeted Artificial Intelligence (AI) algorithm that will identify nuclear resonances**.

Outcomes

1) Automate evaluation of the Nuclear Data Pipeline, make it fast, systematic, reproducible.

2) Allow expert nuclear data evaluators to focus on identifying and understanding relevant experimental measurements and developing new theory, rather than spend time identifying resonances in experimental data.

3) Produce quantitative and defendable uncertainty estimates to calculate confidence intervals for predictive radiation transport modeling for all NNSA applications.

Experimental vs Predicted Cross Section

Quantile Regression: Uncertainty Envelope

- **Neutron capture cross sections** (σ_n) for nuclear energy calculations, reaction networks; nuclear structure and astrophysics
- Hard to directly measure σ_n of short-lived nuclei
- Use indirect methods for short-lived, neutron-rich nuclei
- Properties explored through β decay:
  Nuclear level densities,
  Gamma-ray strength functions
 Decay feedings
  Average e_-/γ energies

$^{103}Mo(n,\gamma)^{104}Mo$
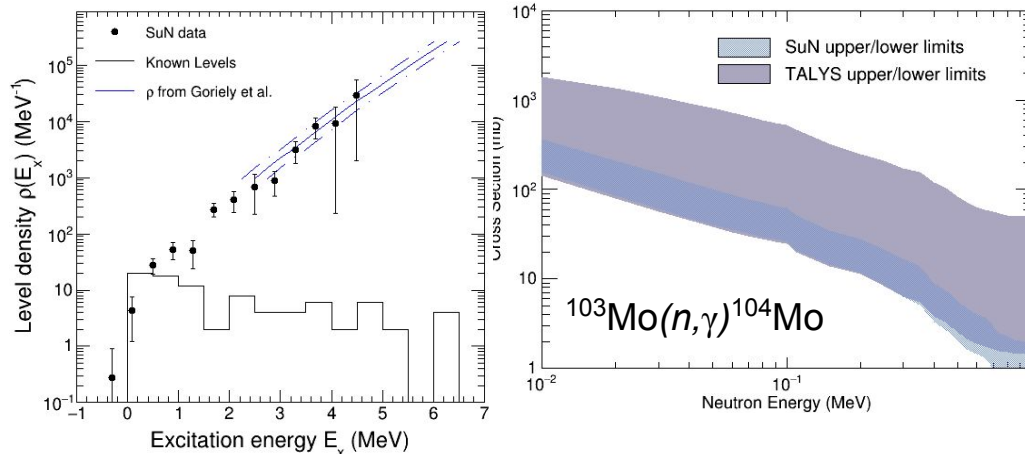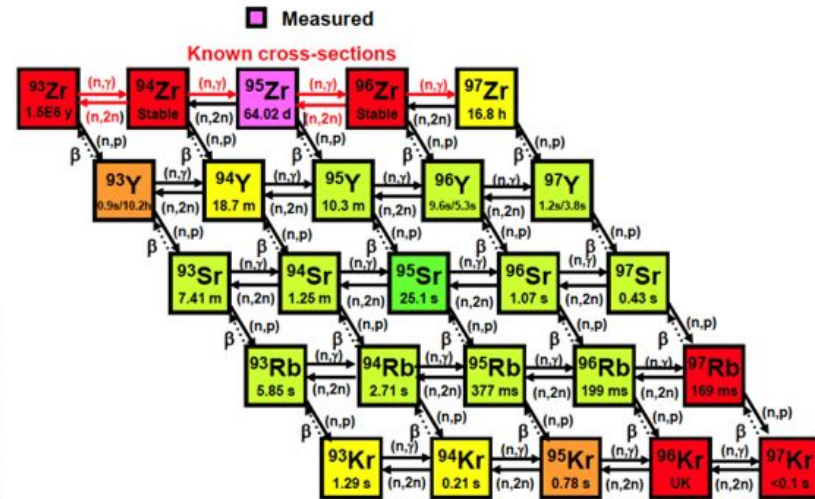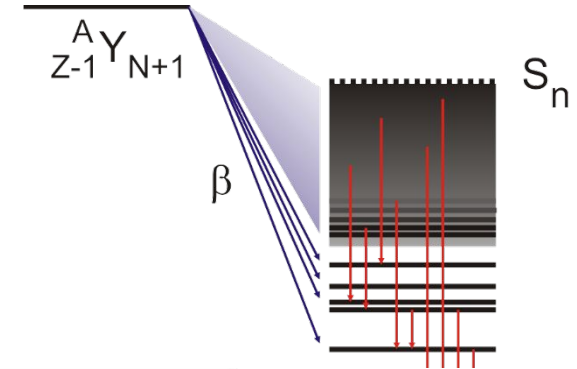
**A. Richard (former Liddick group postdoc, now at LLNL)**

- **J**oint **A**rray for **NU**clear **S**tructure designed and built by MSU & LLNL
- **Coulomb excitation with rare isotope beams**; Ge and Si detectors for γ-ray and particle detection
- Operates at NSCL since 2018; 5 publications + several manuscripts.

- We have an FRIB PAC1 experiment approved!

- **Quadrupole collectivity and deformation** are important nuclear physics data for a number applications   See Ava's talk in this meeting for an example
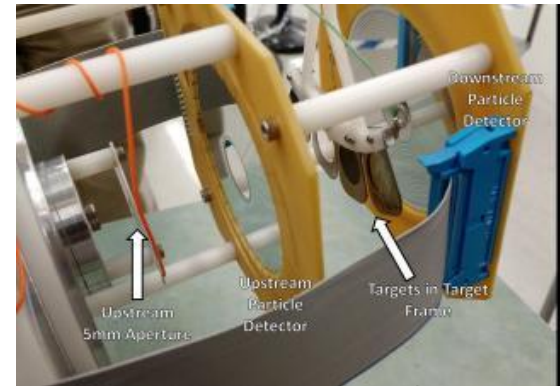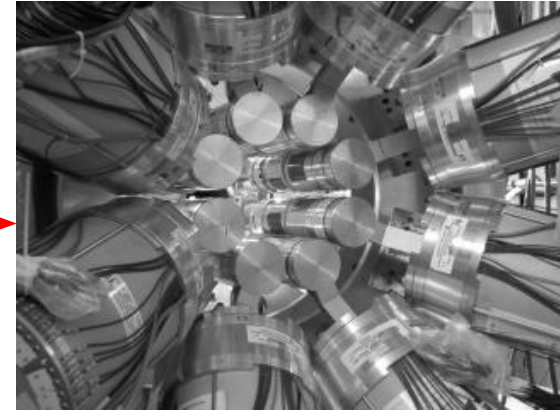
E. M. Lunderberg et al., NIM A 885, 30 (2018)
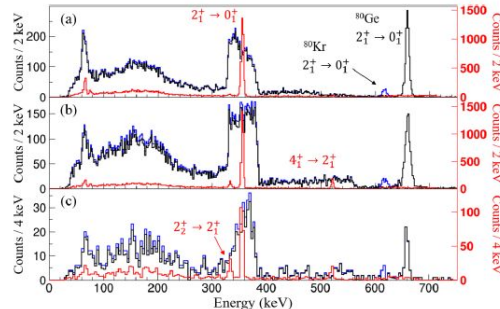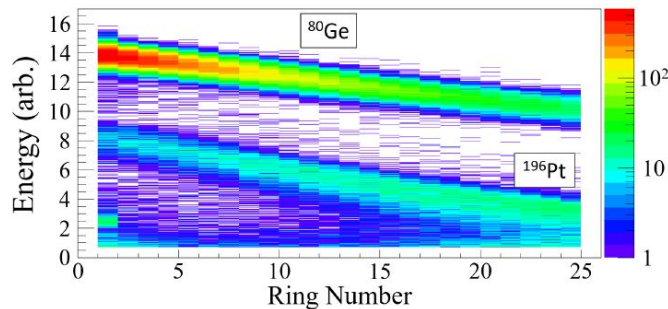
PhD student: Ava Hill Advisor: Alex Gade

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Gamma ray tracking at MSU

- Gamma-ray tracking array **GRETINA** at MSU S800 spectrograph

- GRETINA returns to MSU this May/June to begin FRIB PAC1 experiments

- Gade and Iwasaki groups work on set up, operation, data taking, and analysis

- Hands-on work with one of the most advanced γ-ray detectors in the world; precursor to full GRETA array

- Broad program of **nuclear structure physics, nuclear astrophysics and the study of weak interactions**
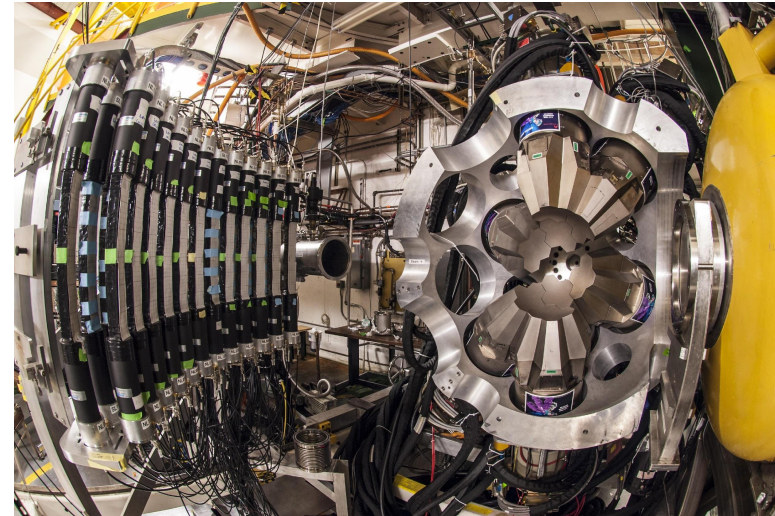
Picture: GRETINA set up in front of the S800 entrance quadrupole with the low-energy neutron array LENDA under backward angles
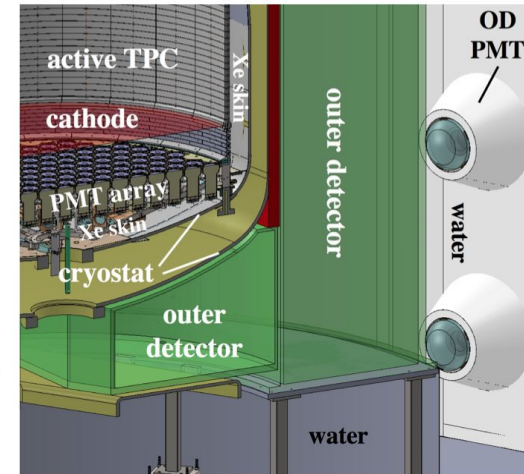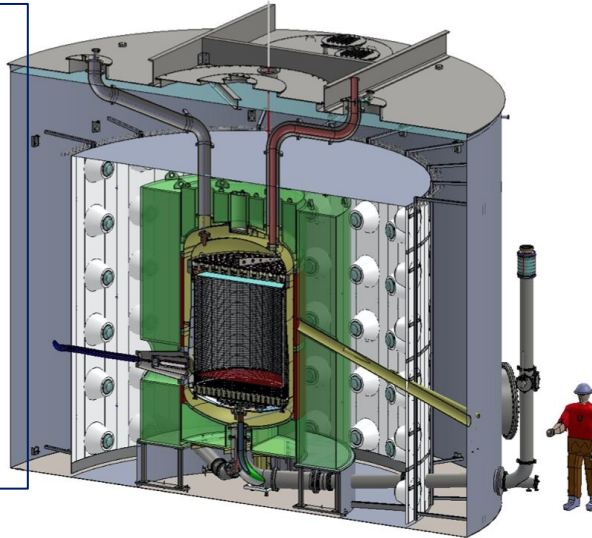
~ 10 MSU-NSSC graduate students and postdocs have been involved in this effort throughout the MSU campaigns

Search for Dark Matter – The LUX-ZEPLIN Experiment

LBNL scientists: Kevin Lesko, Aaron Manalaysay, Jingke Xu (LLNL)

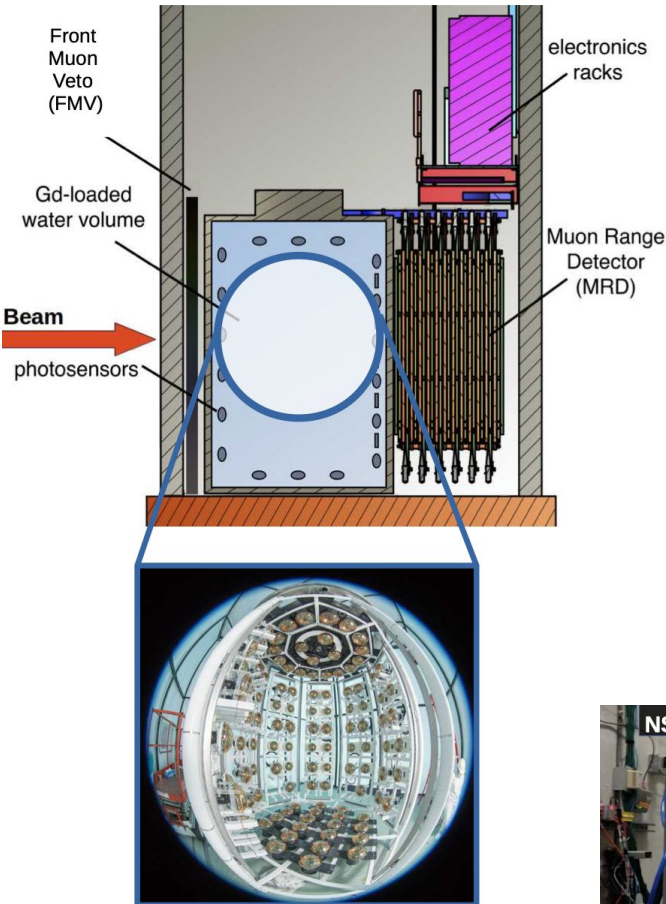**PhD students: James Kingston, Jyothis Johnson (UC Davis) Ryan Smith (UC Berkeley)**

Faculty: Mani Tripathi (UCD), Dan McKinsey (UCB)
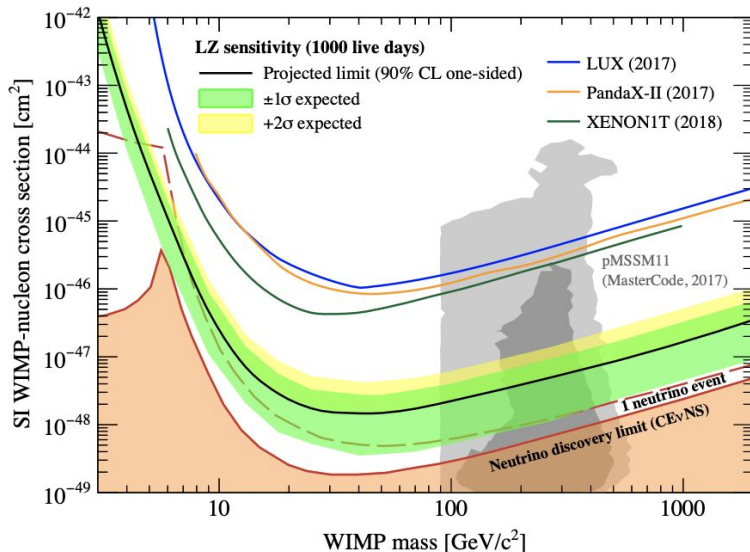
- LZ is the world's largest two-phase xenon time projection chamber (TPC), led by UCB & LBNL

- UC, Davis provided the front-end electronics for 3 sub-systems of the detector

- Effective target mass of 5.6 tons gives much improved sensitivity to dark matter above 10 GeV

- First science run is in progress. Results expected in summer 2022

Accelerator Neutrino Neutron Interaction Experiment

Front Muon Veto (FMV)

Gd-loaded water volume

Beam

photosensors

electronics racks

Muon Range Detector (MRD)

ANNIE Investigates **nuclear effects in neutrino interactions** – now operational

First major use of Large Area Picosecond PhotoDetector (LAPPD) - deployed and being commissioned
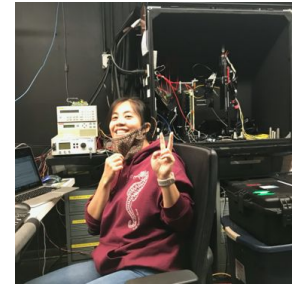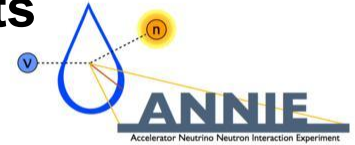
UC Davis collaborating with LLNL on calibrations, tagged radioactive source fabrication; BNL on Water-based Liquid Scintillator for future deployment

NSSC fellows adding gadolinium in ANNIE

T. Pershing – NSSC Fellow, now at LLNL
J. He – NSSC Fellow, LAPPD software
L. Pickard - NSSC Fellow, Calibrations
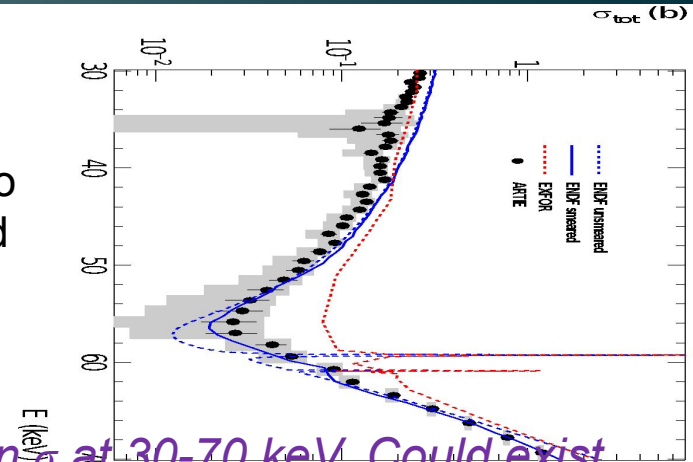**V. Fischer - NSSC Fellow, now at FNAL**

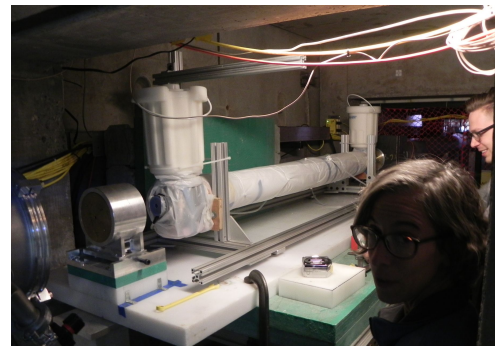**A**rgon **R**esonant **T**ransport and **I**nteraction **E**xperiment

FP14 station at LANSCE

ARTIE σ compared to EXFOR and ENDF

total argon-neutron σ at 30-70 keV. Could exist an anti-resonance affecting the transport distance of neutrons in the DUNE far detector.

Objective: **Measure the neutron-argon total cross-section in the resonance region** below 70 keV at Los Alamos

*NSSC Fellows @ UC Davis: T. Erjavec, J. He, L. Pickard Advisor: Robert Svoboda*

Matter under extreme conditions
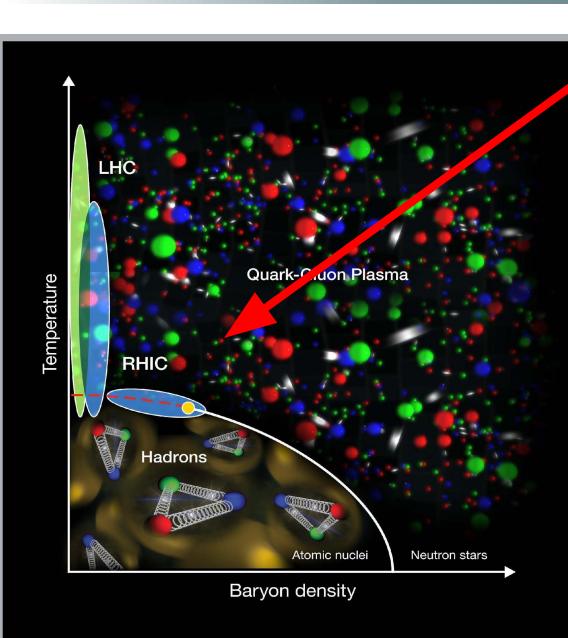
T > 10^{12} K

What are quark gluon plasma properties?

**Deep inside nucleus have dense gluon gas. How does that work?**

Dixit: probe gluons in Pb with QCD Compton scattering

Next student: design tracker to study in electron-ion collisions

Silicon pixel tracker concept for EIC: low mass & power new sensor

Develop w/ LANL P-25
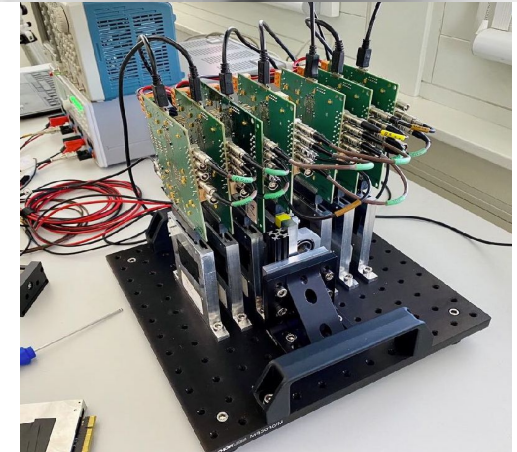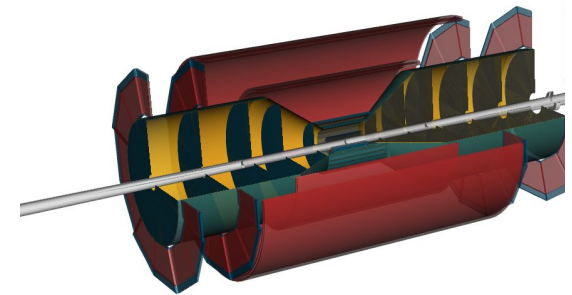
UCB PhD student Dhruv Dixit
Advisor: Barbara Jacak
LBNL mentor: M. Ploskon

ALICE at LHC sPHENIX @ RHIC

ALI-PREL-516818

An NSSC Fellow Success Story
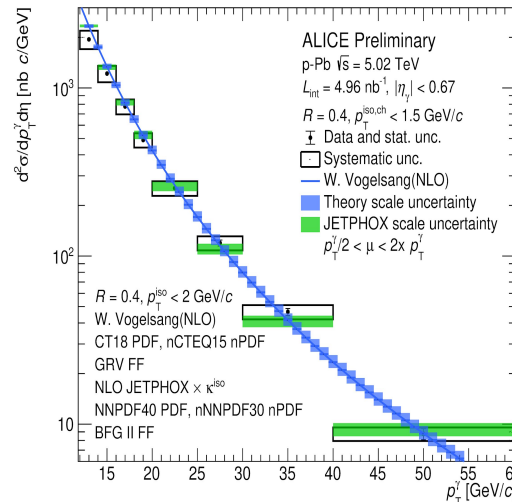
- ***Brenden Longfellow*** graduated from MSU in 2020.

- Currently, a LLNL postdoc, at the brink of conversion to staff (Nuclear and Chemical Science Division)
- Works in the same group he did his NSSC internship

- At MSU, he performed experiments with scintillator arrays and high-purity Ge detectors and left with 6 first-author papers (1 PRL, 1 PRC rapid, 3 PRC and 1 NIM A).

- For his PhD thesis, he was awarded MSU's 2020 Sherwood K. Haynes Award for Outstanding Ph.D. Student

Acknowledgements

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number **DE-NA0003996.**