NSSC 8
NUCLEAR SCIENCE and SECURITY CONSORTIUM

National Nuclear Security Administration

Nuclear Science and Security Consortium

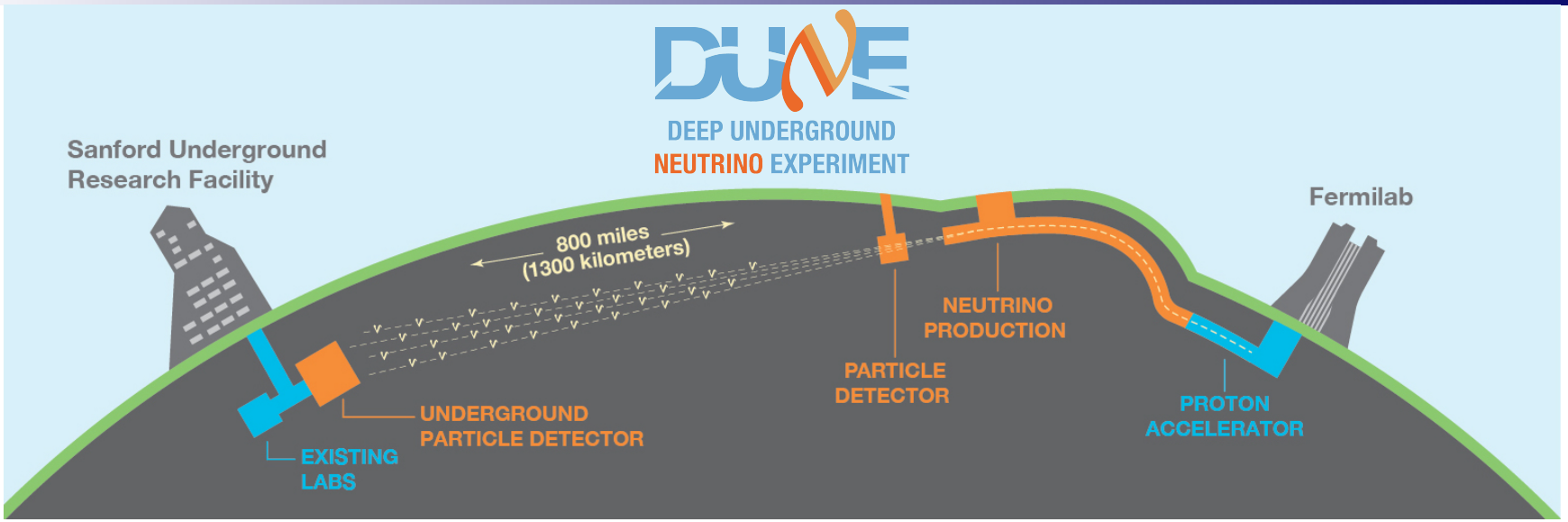
September Workshop and Advisory Board Meeting

ACED: Argon Capture Experiment at DANCE

September 11, 2017

Steven Gardiner
University of California, Davis
Nuclear and Particle Physics

Deep Underground Neutrino Experiment (DUNE)



- The DUNE detector is a 40 kton liquid argon time projection chamber
- Flagship domestic project for DOE Office of High Energy Physics
- More than 1,000 collaborators from 176 institutions around the world

Physics goals

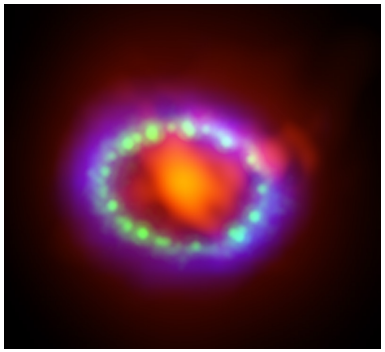
- Test leading theory of the matter/antimatter imbalance in the universe (neutrino CP violation)
- **Observe neutrinos from a nearby core-collapse supernova**
- Search for proton decays
- Many others

Supernova neutrinos in DUNE

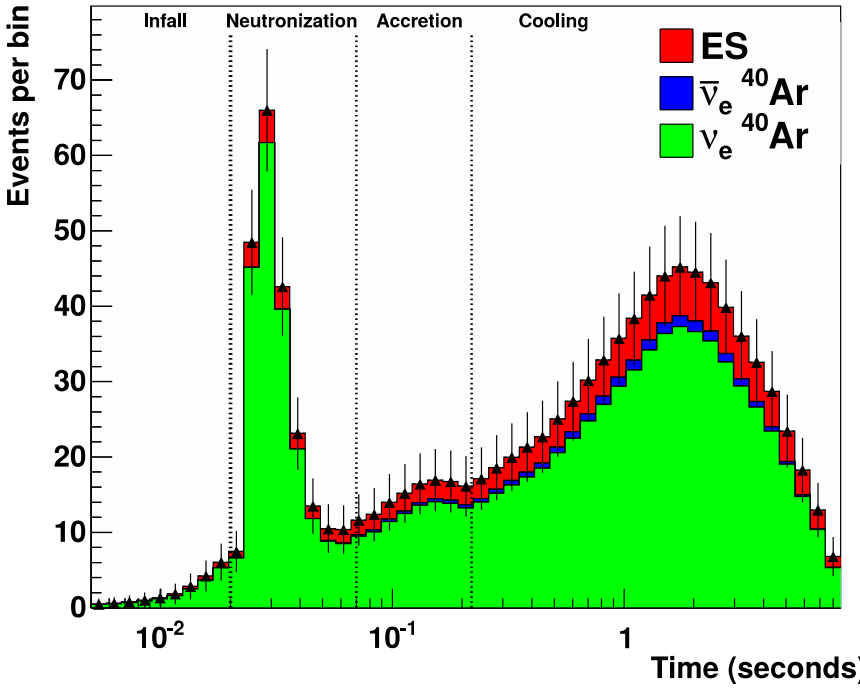
- Core-collapse supernovae produce tremendous numbers (~10^{58}) of neutrinos
- DUNE will be uniquely sensitive to ν_e from a galactic SN
- Observation would be scientifically interesting
  - Supernova dynamics
  - Nucleosynthesis
  - Exotic physics (e.g., quantum gravity effects, axions)
- Complementary to optical and gravitational wave astronomy

SN1987A

(the only observation of SN neutrinos so far)



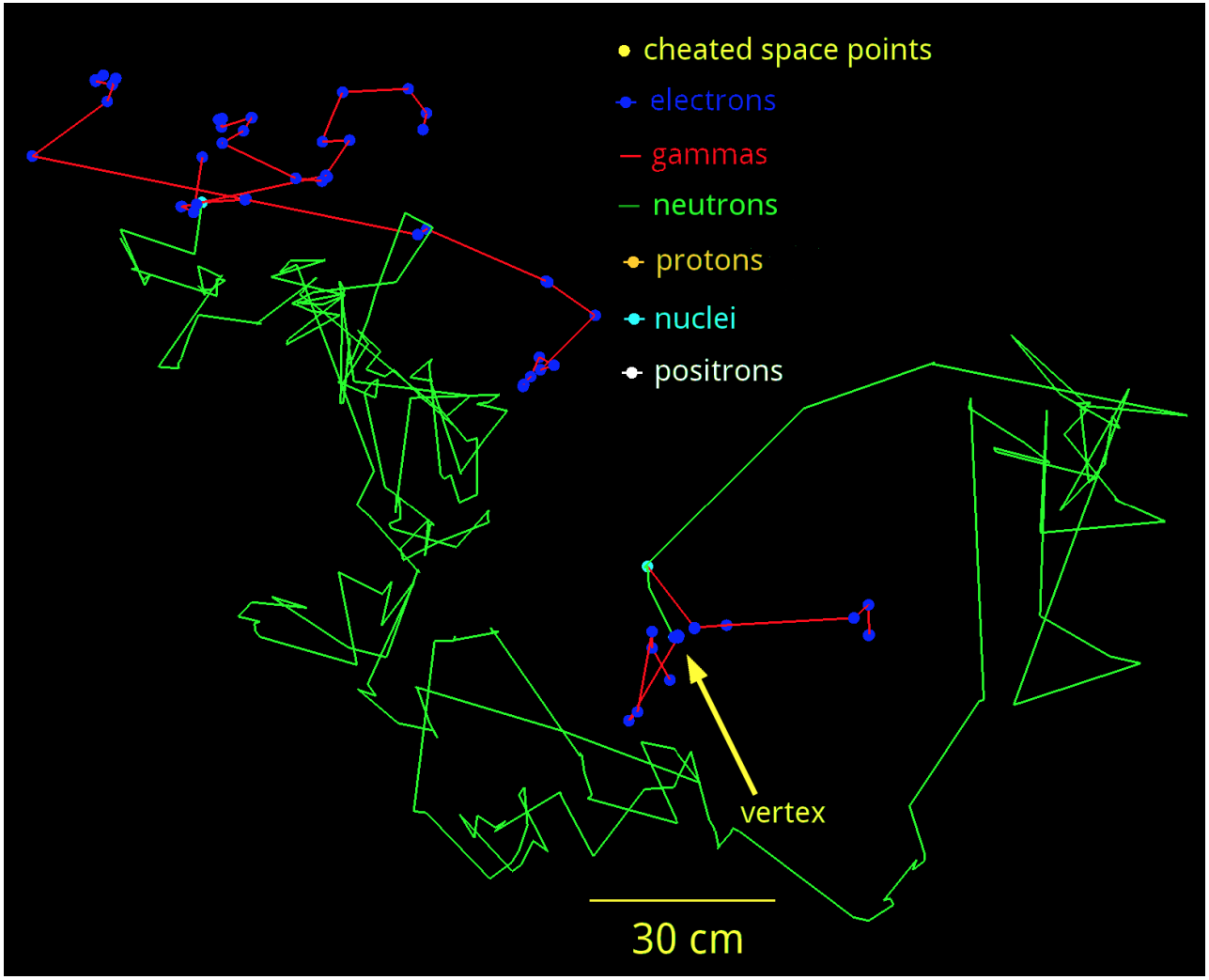
Simulated supernova neutrino events in DUNE



Motivation for ACED: Neutrons from Supernova Neutrinos

- Calculations performed by our group suggest that a significant fraction of SN events in DUNE will involve **neutron emission**
- Missing the emitted neutron leads to a large error on the reconstructed neutrino energy
- The **event-by-event capture γ-ray distributions** are unmeasured (would be valuable to tag these neutrons)
- The **thermal (n,γ) cross section** is poorly measured

Particle trajectories from a simulated SN event in DUNE



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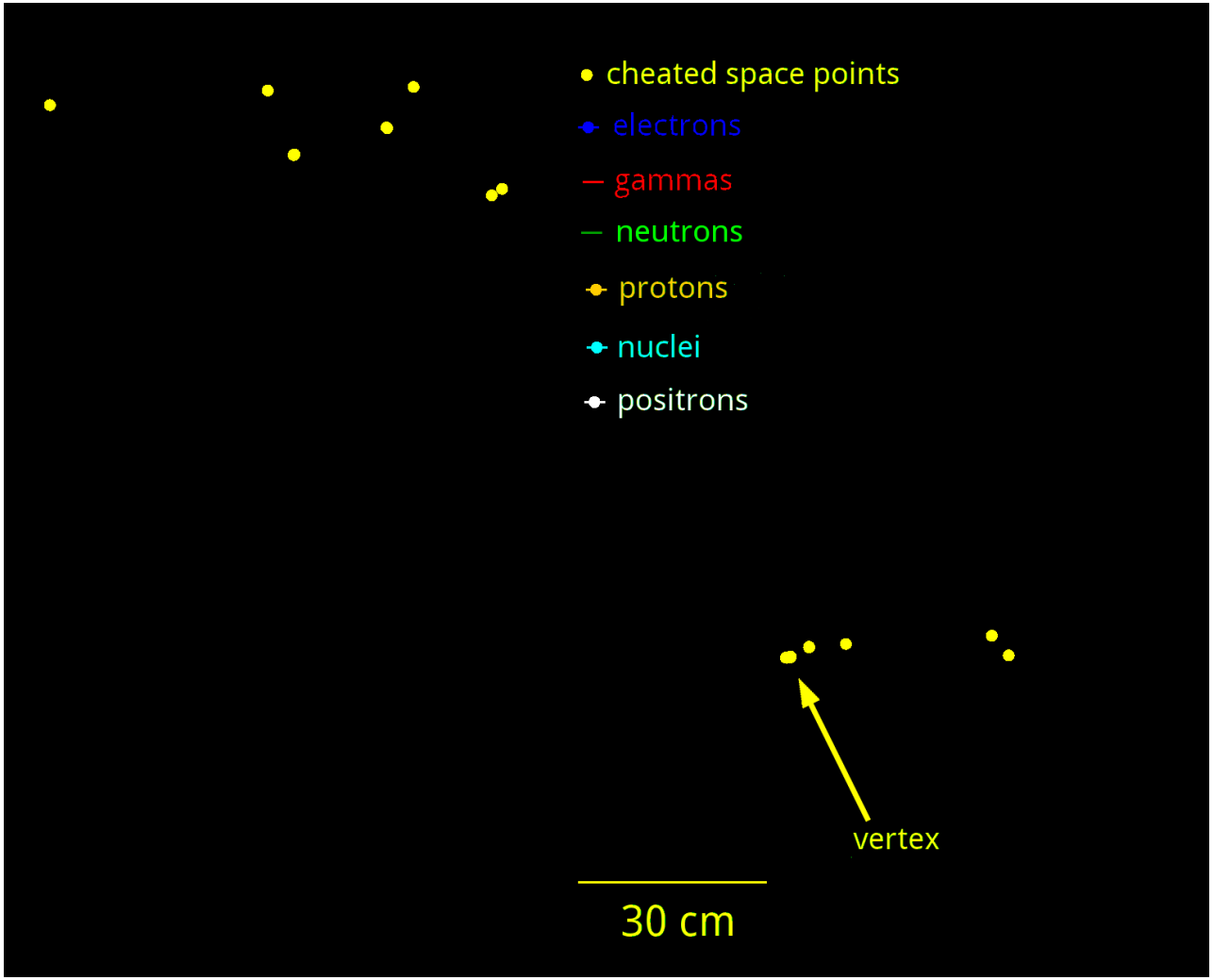
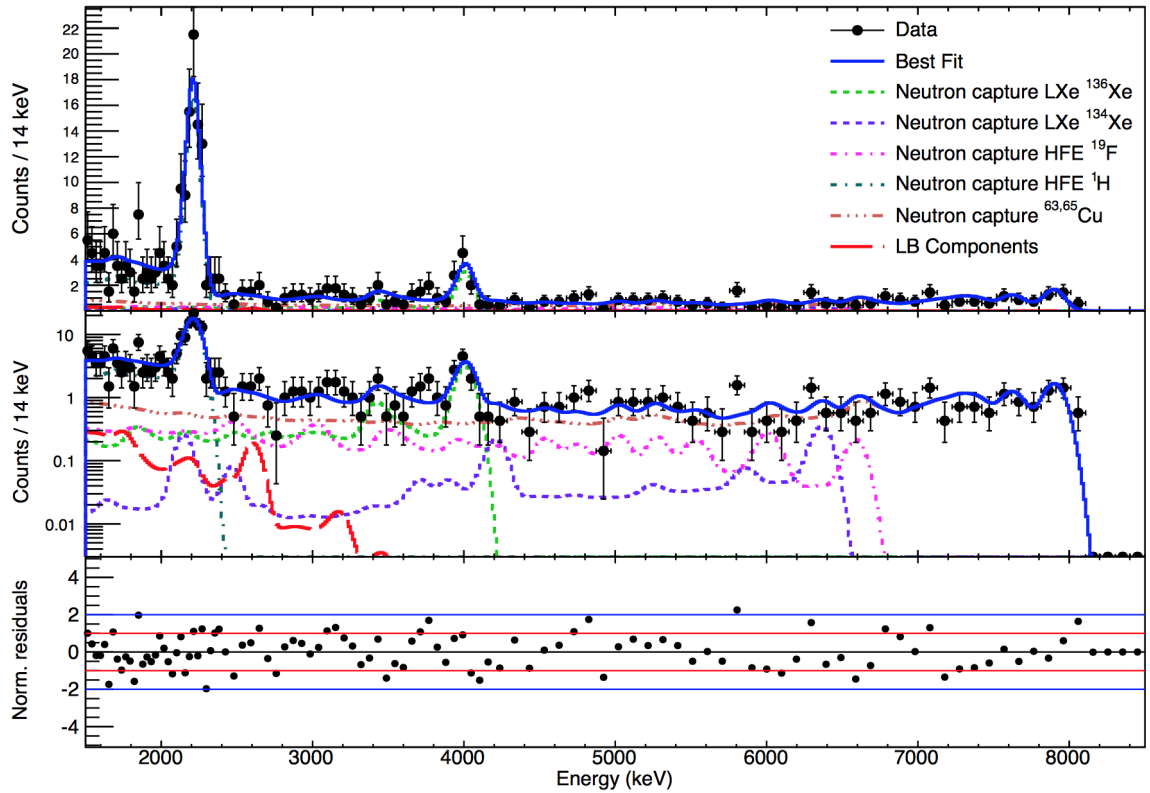


Motivation for ACED: Low Background Experiments

- Determining the neutron flux within an argon-based low background detector
- Vetoing neutron scatters (dark matter experiments) or neutron capture gammas (0νββ experiments)
- **Low background detectors using liquid argon**



- DarkSide-50 / DarkSide-20k
- DEAP-3600 / DEAP-50T
- MiniCLEAN
- GERDA (active shield)

EXO-200 measured the flux of neutrons in a xenon detector by fitting correlated γ capture spectra on xenon and surrounding materials

No Need to "Reinvent the Wheel"

- Previous measurement on ^{136}Xe had 7% uncertainty
- We can use a nearly identical technique to obtain similar information for argon
- Xe paper coauthor Tessa Johnson now a post-doc at UC Davis
- Reuse many tools from Xe measurement
  - Data acquisition software
  - Geant4 simulation geometry
  - Gas holding vessel

Measurement of neutron capture on ^{136}Xe

J. B. Albert,[a] S. J. Daugherty, T. N. Johnson,[b] T. O'Conner, and L. J. Kaufman
Physics Department and CEEM, Indiana University, Bloomington, Indiana 47405, USA

A. Couture and J. L. Ullmann
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

M. Krtička
Faculty of Mathematics and Physics, Charles University in Prague, V Holešovičkách 2, CZ-180 00 Prague 8, Czech Republic

(Dated: September 30, 2016)

^{136}Xe is a $0\nu\beta\beta$ decay candidate isotope, and is used in multiple experiments searching for this hypothetical decay mode. These experiments require precise information about neutron capture for their background characterization and minimization. Thermal and resonant neutron capture on ^{136}Xe have been measured at the Detector for Advanced Neutron Capture Experiments (DANCE) at the Los Alamos Neutron Science Center. A neutron beam ranging from thermal energy to greater than 100 keV was incident on a gas cell filled with isotopically pure ^{136}Xe. The relative neutron capture cross sections for neutrons at thermal energies and the first resonance at 2.154 keV have been measured, yielding a new absolute measurement of 0.238 ± 0.019 b for the thermal neutron capture cross section. Additionally, the γ cascades for captures at both energies have been measured, and cascade models have been developed which may be used by $0\nu\beta\beta$ experiments using ^{136}Xe.

Phys. Rev. C **94**, 034617 (2016)
arXiv:1605.05794v3

ACED: Argon Capture Experiment at DANCE

- **Planned measurements**

  - Thermal neutron capture cross section of natural argon
  - Event-by-event correlated γ-ray cascades

- **The ACED team**

  - **UC Davis**: Bob Svoboda, Emilija Pantic, Tessa Johnson, Vincent Fischer, Leon Pickard, Jingbo Wang, Steven Gardiner
  - **LANL**: John Ullman
  - **Boston University**: Chris Grant

Existing σ(n,γ) Measurements

$E_{neutron}$ [MeV]	σ(n,γ) [barns]	uncertainty [barns]	year	author
2.53E-08	**0.51**	**0.025**	**1969**	**N.Ranakumar+**
2.53E-08	**0.723**	**0.025**	**1965**	**R.L.D.French+**
2.53E-08	**0.63**	**0.02**	**1963**	**W.Koehler**
0.005	0.0032	0.00018	1989	R.L.Macklin+
0.01751	0.01702	0.02442	1989	R.L.Macklin+
0.136	0.0022	0.0008	1959	N.A.Bostrom+
0.37	0.00119	6.00E-05	2014	M.Bhike+
0.03	0.00254	0.0001	2000	Z.Y.Bao+
0.03	0.00245	0	2006	S.F.Mughabghab
0.0234	0.00255	0.00015	2002	H.Beer+

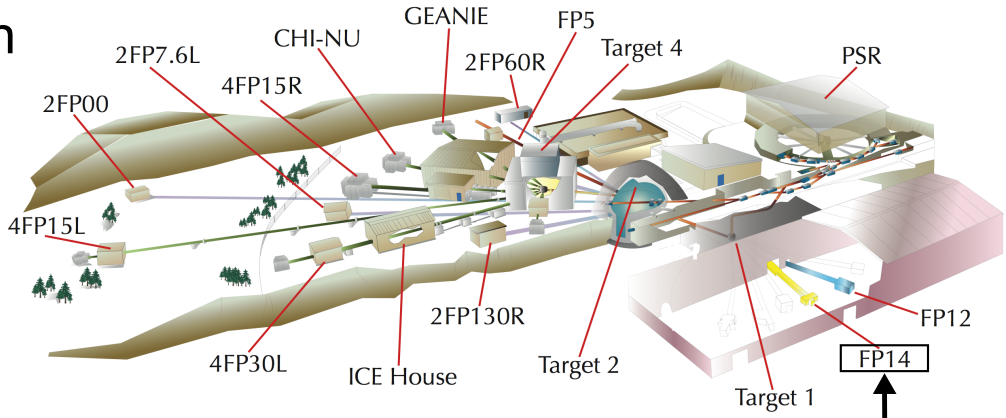
Published measurements of the neutron capture cross section on argon (list compiled by J. Wang).

Thermal measurements are shown in **blue**.

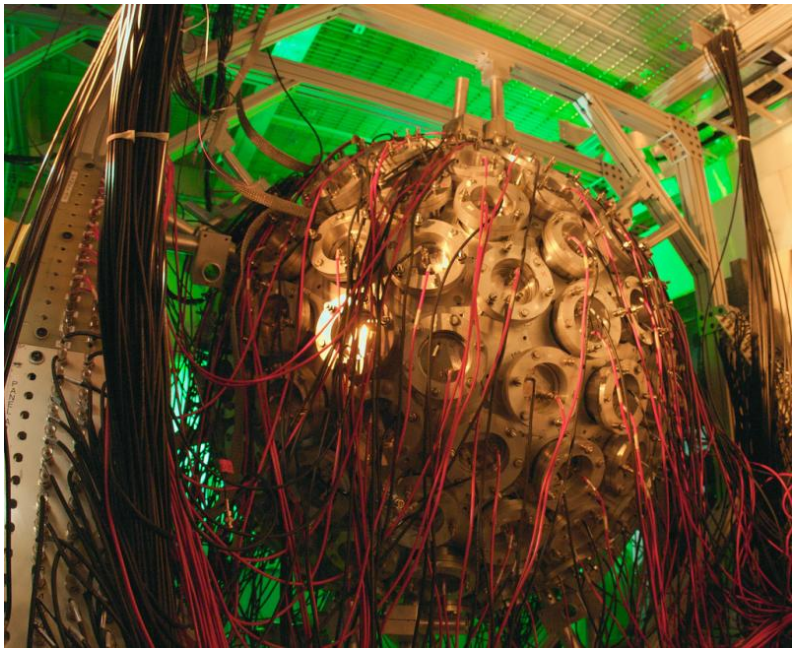
DANCE: Detector for Advanced Neutron Capture Experiments

- Sphere of 160 BaF_2 crystals, each coupled to its own photomultiplier tube
- Nearly 4π coverage
- Inner ^{6}LiH shell shields crystals from scattered neutrons
- Neutron energies obtained using time-of-flight
- Segmentation allows γ multiplicity measurements
- Downstream monitors measure energy-dependent neutron beam flux

The Los Alamos Neutron Science Center

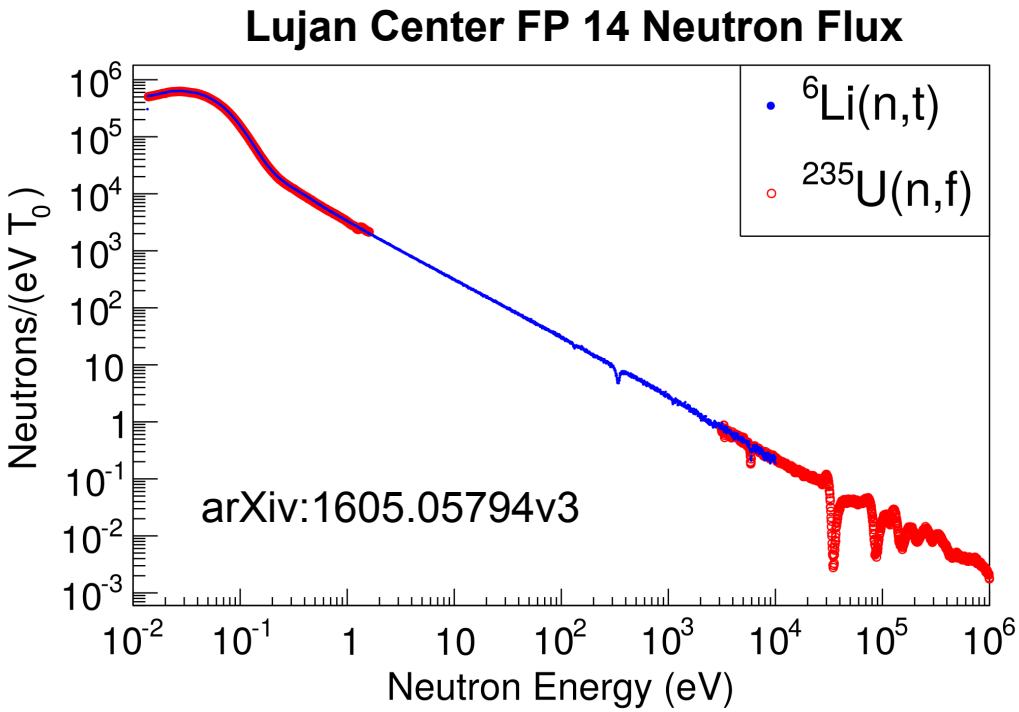


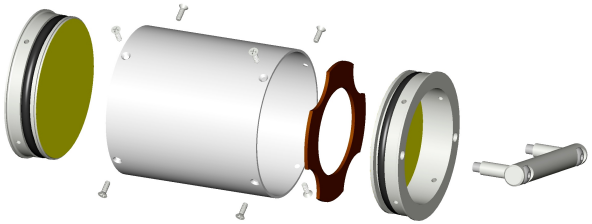
Home of DANCE

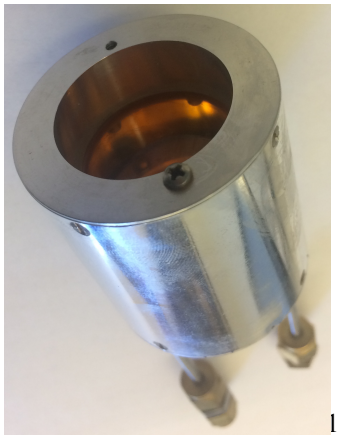


Data Taking Plan

- Expose natural argon gas (99.6% ^{40}Ar) to neutron flux in Lujan Center flight path 14
- Argon target contained in aluminum vessel with kapton windows (borrowed from Indiana U)
- Measure flux using independent beam monitors (^{3}He, ^{6}Li, ^{235}U)
- DANCE data provide γ multiplicity and energy
- Measure backgrounds using beam-off and empty-vessel data
- Calibrate DANCE crystals by activating a gold foil in the beam

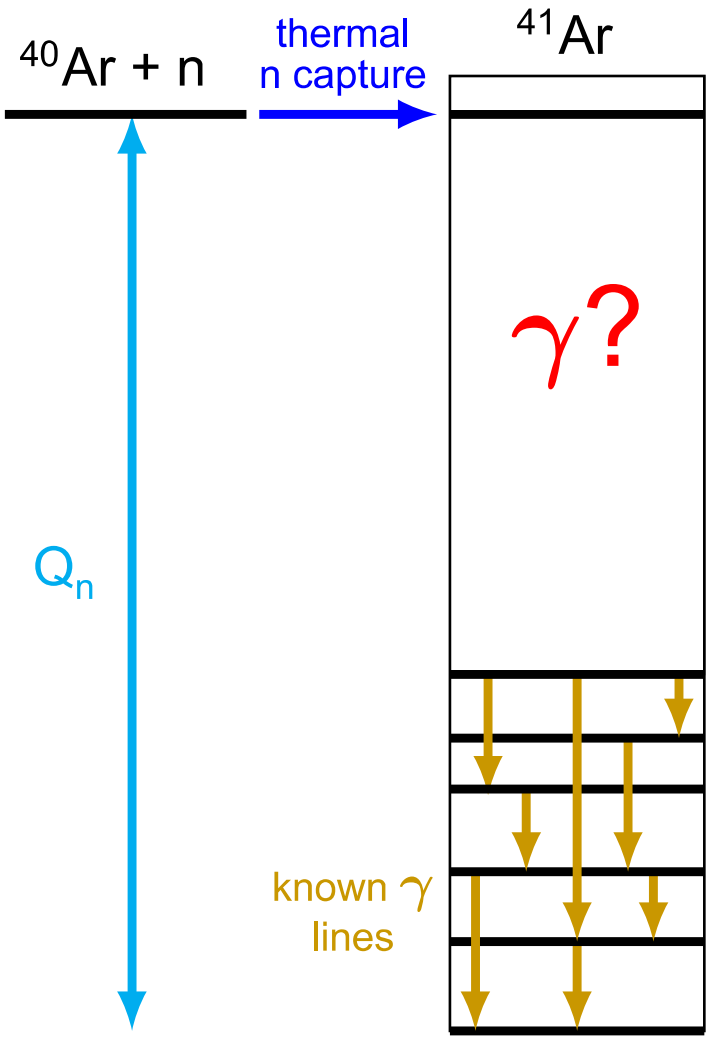






Analysis Plan: Gamma Cascades

- Subtleties in detector response make it difficult to obtain γ cascades directly
  - Multiple scatters in crystals
  - Absorption by ^{6}LiH shield
- Extract γ decay scheme by comparing predicted and measured event spectra
- **Problem:** high-lying levels and γ-rays are numerous, unknown, and difficult to determine theoretically



Analysis Plan: Gamma Cascades

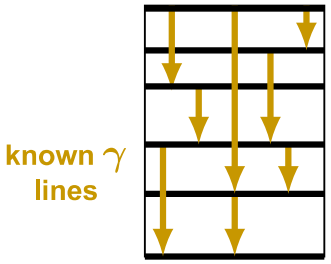
- Statistical *distributions* of level spacings, γ intensities are well-modeled
- The DICEBOX code produces Monte Carlo "nuclear realizations" of these distributions (complete decay schemes)
- Many realizations are compatible with input parameters

$S_{\gamma}^{(XL)}(E_{\gamma})$

photon strength functions

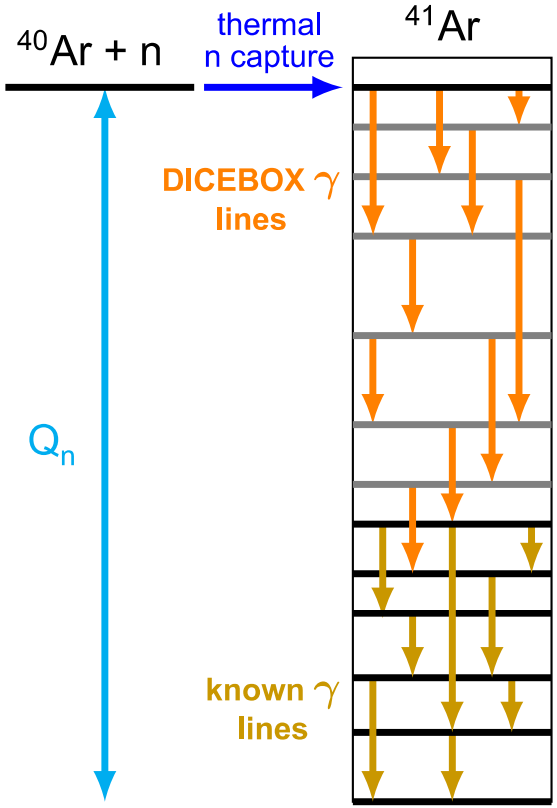
$\rho(E_x, J^{\pi})$

nuclear level density



DICEBOX

Nucl. Instrum. Meth. A **417** (1998) 434-449



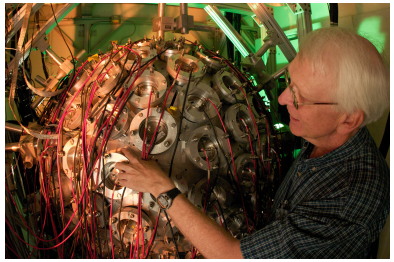
Analysis Plan: Gamma Cascades

Extraction Strategy

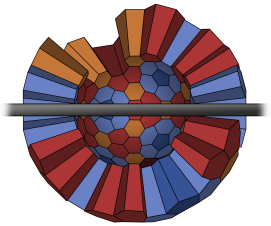
- Generate many nuclear realizations with DICEBOX
- Use γ distributions from each realization to simulate DANCE response
- Compare each simulation result to the measured data
- Minimize χ^2 to find best-fit nuclear realization

DICEBOX

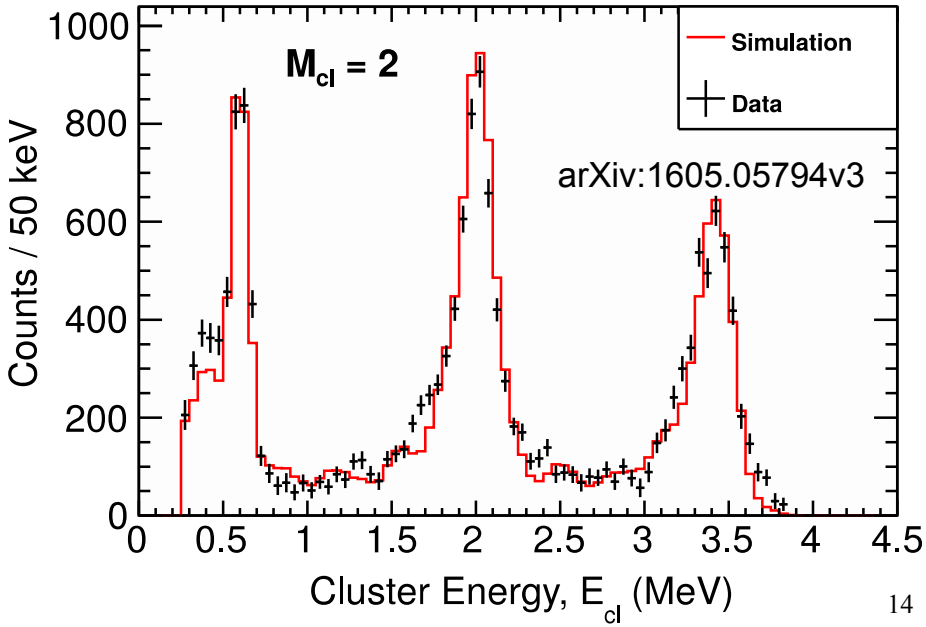
DANCE



Geant4



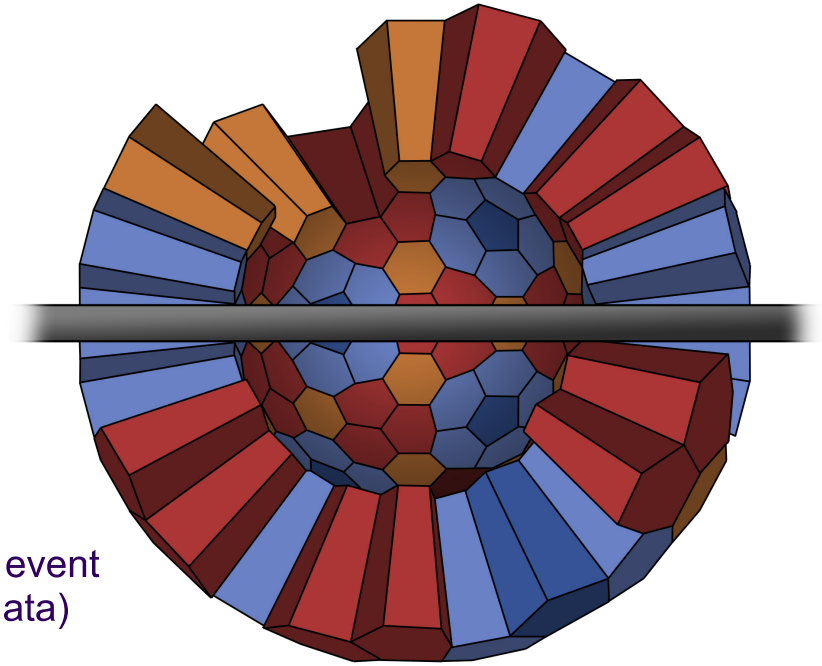
χ^2 optimization



Analysis Plan: Capture Cross Section

- Implement best-fit γ decay scheme within Geant4
- Calculate detector efficiency for thermal $^{40}Ar(n,\gamma)^{41}Ar$ events
  - Use same analysis cuts as the data
- Combine with experimental measurements to obtain the cross section:

Geant4 model of DANCE crystals and beam pipe



thermal ($E_n \approx 0.025$ eV) neutron capture cross section

background-subtracted event count (from DANCE data)

$$\sigma(E_n) = \alpha \frac{N(E_n)}{\epsilon(E_n)\Phi(E_n)}$$

energy-independent factors (e.g., argon density)

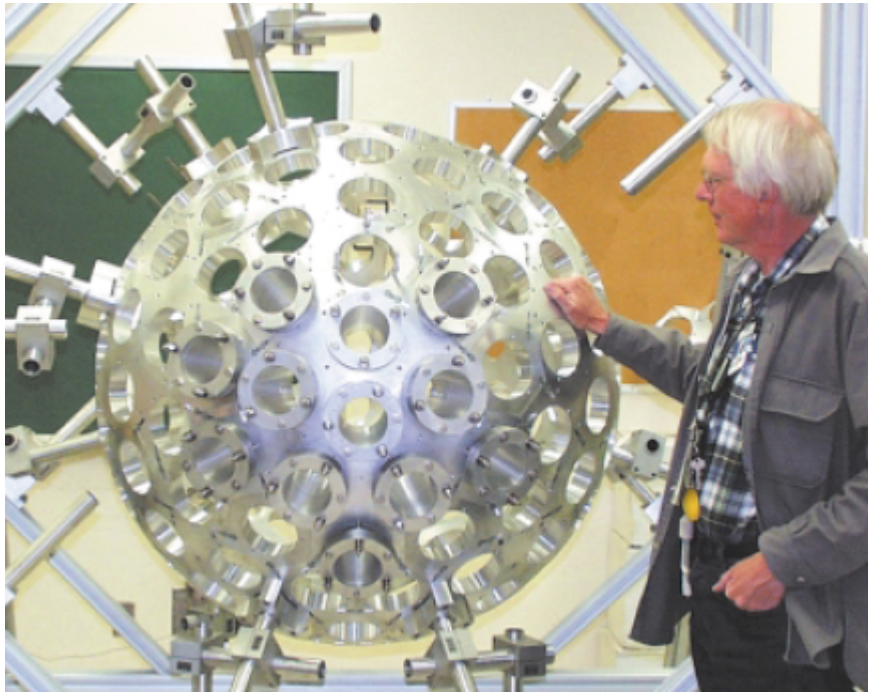
detector efficiency (from Geant4)

neutron flux (from beam monitors)

Summary

- A better understanding of neutron captures in argon would be helpful for state-of-the-art physics measurements
  - DUNE supernova neutrino signal
  - Backgrounds for neutrino and dark matter experiments

- ACED will measure σ(n,γ) and the correlated γ-ray cascades for thermal neutrons this fall at LANL
  - Testing of ACED components:
    - 3–4 October
  - Beam data taking:
    - First two weeks of November



Disclaimer

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003180.

Backup

Liquid Argon Time Projection Chambers

- Uniform electric field applied to volume of liquid argon
- Charged products from neutrino interactions create ionization tracks
- Drifting electrons create hits on wire planes
- Separate photon detection system allows t_0 determination (needed for z coordinate)