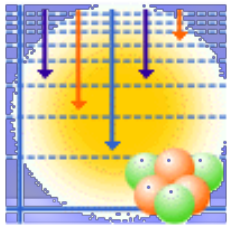
Argonne NATIONAL LABORATORY



Member of the US Nuclear Data Program

Improving Nuclear Data for Antineutrino Spectra Predictions for Nonproliferation Applications

F.G. Kondev

Physics Division, Argonne National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

FOA-LAB17-1763

National Nuclear Security Administration

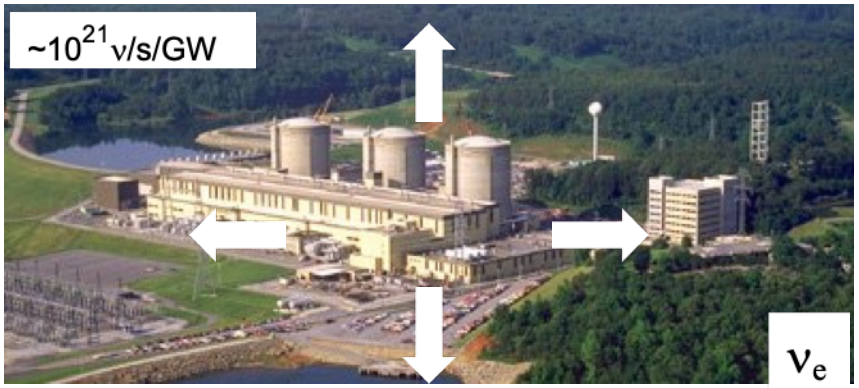
Nuclear Physics

NA-22

WANDA2022 (virtual) meeting, March 4, 2022

U.S. DEPARTMENT OF ENERGY

Objective: improve Nuclear Data for key nuclei relevant to antineutrino spectra predictions



compelling physics

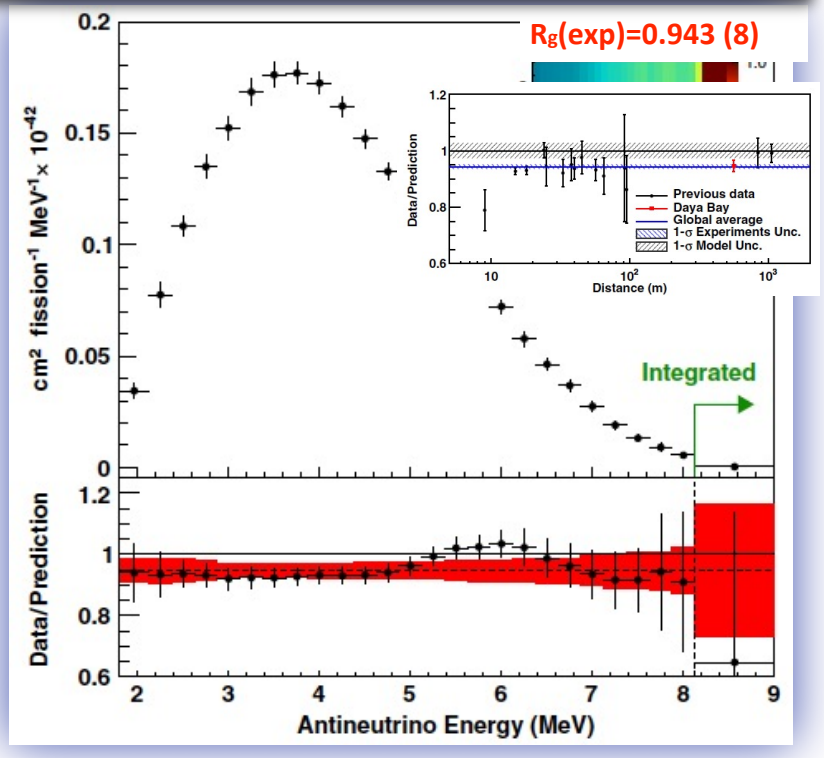
- physics beyond the Standard Model
- astrophysics - supernovae core collapse & big bang nucleosynthesis
- neutrinoless double beta decay
- reactor anomaly & ν oscillations

applications

- detection of fissile materials from peaceful & military program
- remote safeguards and monitoring of operation status and power levels of reactors
- remote fission inventories in operating reactors

PRL 116, 061801 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Measurement of the Reactor Antineutrino Flux and Spectrum at Daya Bay



The New York Times

How to Spot a Nuclear Bomb Program? Look for Ghostly Particles

By Kenneth Chang March 27, 2018

Nuclear Data Needs

International Atomic Energy Agency
Nuclear Data Services
Provided by the Nuclear Data Section

INDC(NDS)-0676
Distr. EN, ND

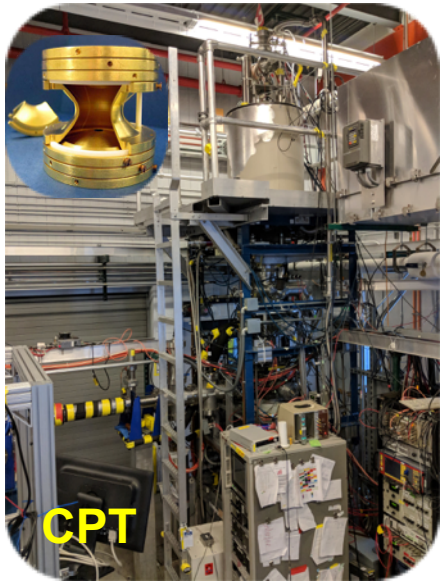
INDC International Nuclear Data Committee

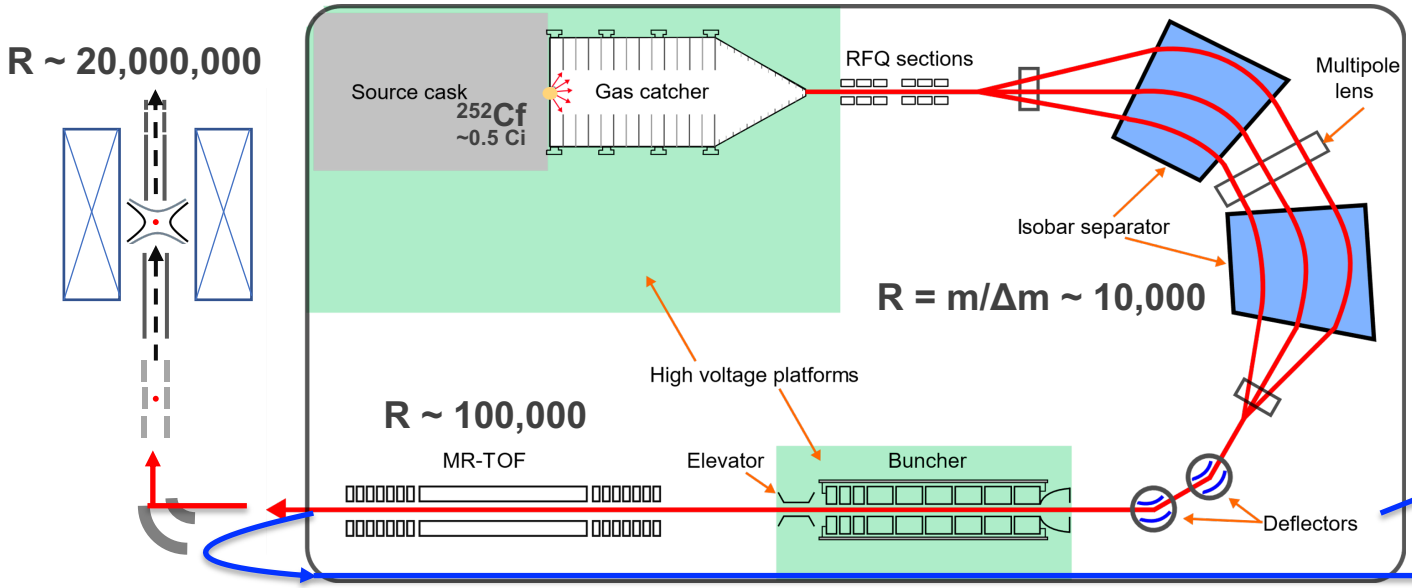
~30 FP radionuclides grouped into priority I and II

How to improve the needed ND?

- unique capabilities of ***CARIBU@ANL*** (DOE/SC/NP National User Facility) to produce high-purity beams of essentially all fission products – no stop-overs for refractory elements
- state-of-the-art detector equipment - ***Gammasphere***

CARIBU @ ANL

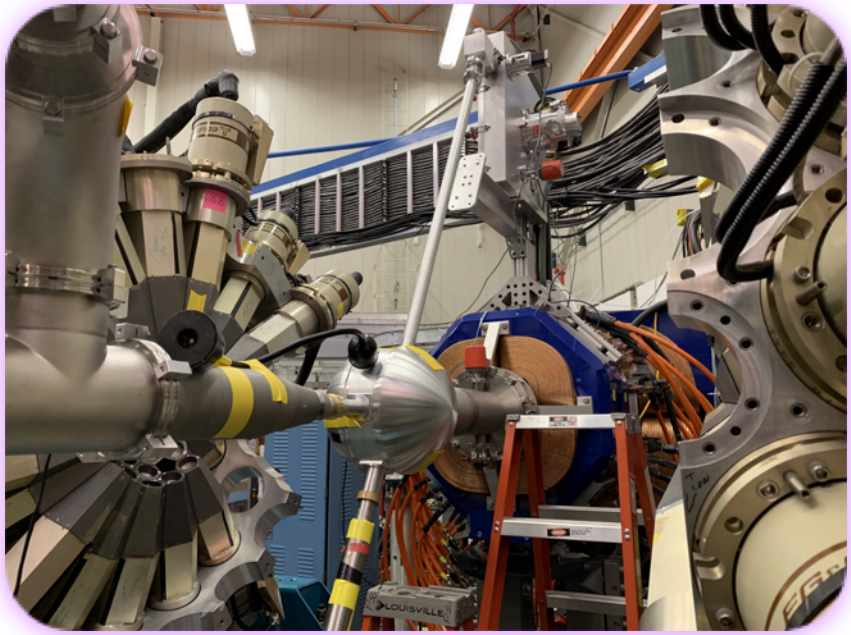

CPT

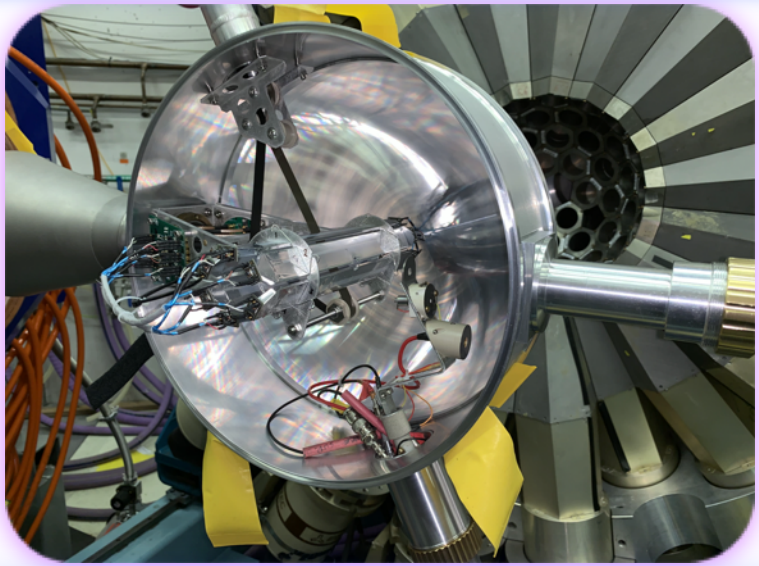

R ~ 20,000,000
Source cask
252Cf
~0.5 Ci
Gas catcher
RFQ sections
Multipole lens
Isobar separator
R = m/Δm ~ 10,000
High voltage platforms
R ~ 100,000
MR-TOF
Elevator
Buncher
Deflectors
to ATLAS
to area 1

Gammasphere decay data station

Advantages

- **discrete & calorimetry** γ-ray spectroscopy techniques within a single device
- **high granularity** & **resolving power** ($\Delta E\gamma$=2 keV, P/T~60% and ε_γ~85%) - ability to resolve week γ-ray cascades (10^{-5}-10^{-6} %)
- **complete decay schemes** - angular correlations for transition multipolarities & Jπ assignments - end game in nuclear spectroscopy

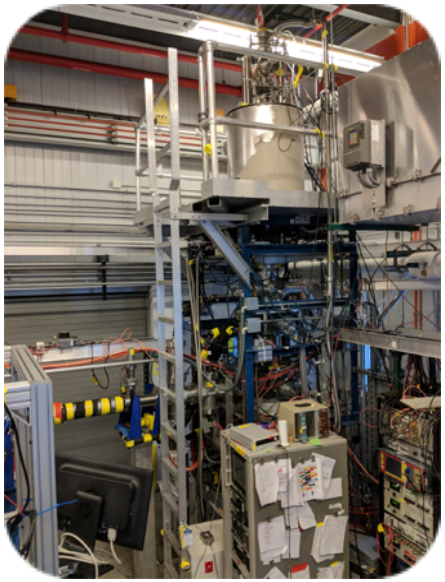




- **HEART** - HExagonal ARray for Triggering
  - ✓ 6 EJ-204 plastic scint. & 12 SiPM
  - ✓ ε_β~75% from β-γ singles & coin.
- powerful γ-γ-β-t coincidence device

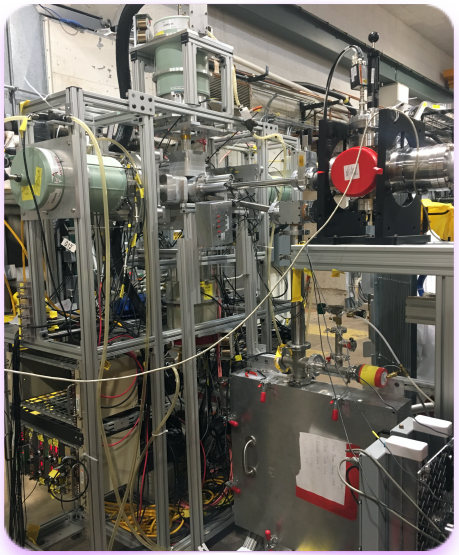
Project status: experiments

- Designed and built a new decay data station at Gammasphere (**FY18**)
- Completed three experimental campaigns:
  - ✓ **December 2018 (FY19)** – aimed at transitional (weakly-deformed) ^{144}La, ^{146g,m}La, ^{144}Ba, ^{146}Ba and ^{146}Ce nuclei
  - ✓ **December 2019 (FY20)** – aimed at well-deformed ^{102g,m}Nb, ^{104g,m}Nb, ^{102}Zr, ^{104}Zr, ^{102}Mo and ^{104}Mo nuclei
  - ✓ **December 2021 (FY22)** – aimed at ^{98}Y & ^{98}Nb
- Complementary nuclear data were obtained using the Canadian Penning Trap (CPT) & the X array (5 Ge CLOVER detectors)



CPT

X array



Project status: data analysis

- analysis of experimental data - extensive time-correlated, multi-parameter gamma-ray data analysis with the main aim at constructing complete decay schemes with associated level energies, quantum numbers and lifetimes, and determination of gamma- and beta-ray branching ratios:
  - ✓ partial analysis of **^{144}Ba** and **^{146}Ba** data is completed & published; analysis of **^{102}Mo, ^{104}Mo, ^{102}Zr** and **^{104}Zr** data is continuing
  - ✓ analysis of **^{160m,g}Eu** data is completed & published
  - ✓ analysis of **^{144}La** data is completed – no isomer was observed in this nuclide and the nuclear data was considerably improved
  - ✓ analysis of **^{146m,g}La** data is completed – we were able to separate for the first time the decay of the ground state and the isomer
  - ✓ analysis of **^{102m,g}Nb** and **^{104m,g}Nb** data is continuing
  - ✓ analysis of the newly collected data on **^{98}Y** and **^{98}Nb** just started

Recent publications:

EPJ Web of Conferences **223**, 01028 (2019)

Masses and Beta-decay Studies of Neutron-rich Nuclei using the X-array and Gammasphere

F.G. Kondev[1,*], *D.J.* Hartley[2], *R.* Orford[1,3], *J.A.* Clark[1,4], *G.* Savard[1,5], *K.* Auranen[1], *A.D.* Ayangeakaa[1,2], *S.* Bottoni[1,6], *M.P.* Carpenter[1], *P.* Copp[1], *K.* Hicks[2], *C.R.* Hoffman[1], *R.V.F.* Janssens[7], *B.P.* Kay[1], *T.* Lauritsen[1], *J.* Li[1], *S.T.* Marley[8], *G.E.* Morgan[8], *G.* Mukherjee[9], *S.* Nandi[9], *W.* Reviol[1,10], *J.* Sethi[1,11], *D.* Seweryniak[1], *S.* Stolze[1], *J.* Wu[1], *R.* Yadav[12], and *S.* Zhu[1]

PHYSICAL REVIEW C **101**, 044301 (2020)

High-K, two-quasiparticle states in ^{160}Gd

D. J. Hartley,[1] F. G. Kondev,[2] G. Savard,[2] J. A. Clark,[2] A. D. Ayangeakaa,[2,*] S. Bottoni,[2,†] M. P. Carpenter,[2] P. Copp,[2,3] K. Hicks,[1] C. R. Hoffman,[2] R. V. F. Janssens,[4,5] T. Lauritsen,[2] R. Orford,[6,‡] J. Sethi,[2,7] and S. Zhu[2,§]

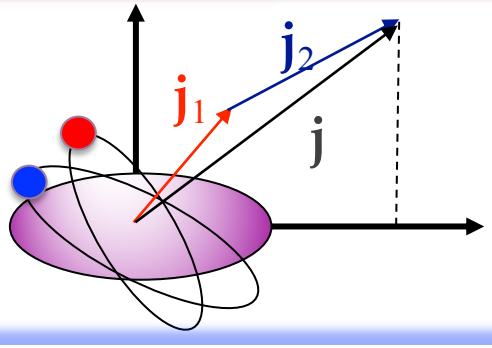
PHYSICAL REVIEW C **102**, 011303(R) (2020)

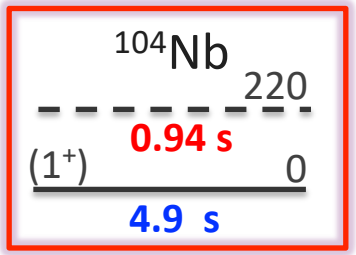
Rapid Communications

Spin-trap isomers in deformed, odd-odd nuclei in the light rare-earth region near $N = 98$

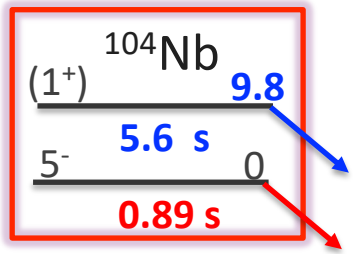
R. Orford,[1,2,*] F. G. Kondev,[1] G. Savard,[1,3] J. A. Clark,[1,4] W. S. Porter,[1,†] D. Ray,[1,4] F. Buchinger,[2] M. T. Burkey,[1,3,‡] D. A. Gorelov,[1,4] D. J. Hartley,[5] J. W. Klimes,[1,§] K. S. Sharma,[4] A. A. Valverde,[1,4] and X. L. Yan[1,6]

Project status: data analysis - cont.





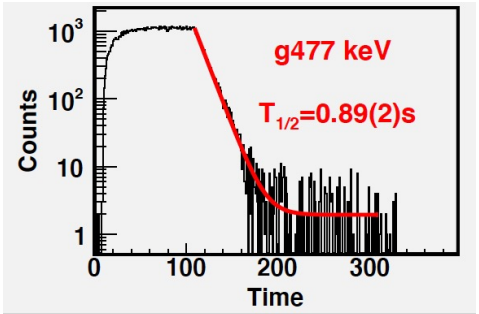
J. Blachot, NDS 108 (2007) 2035

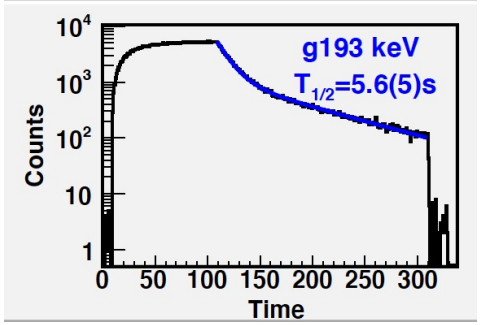


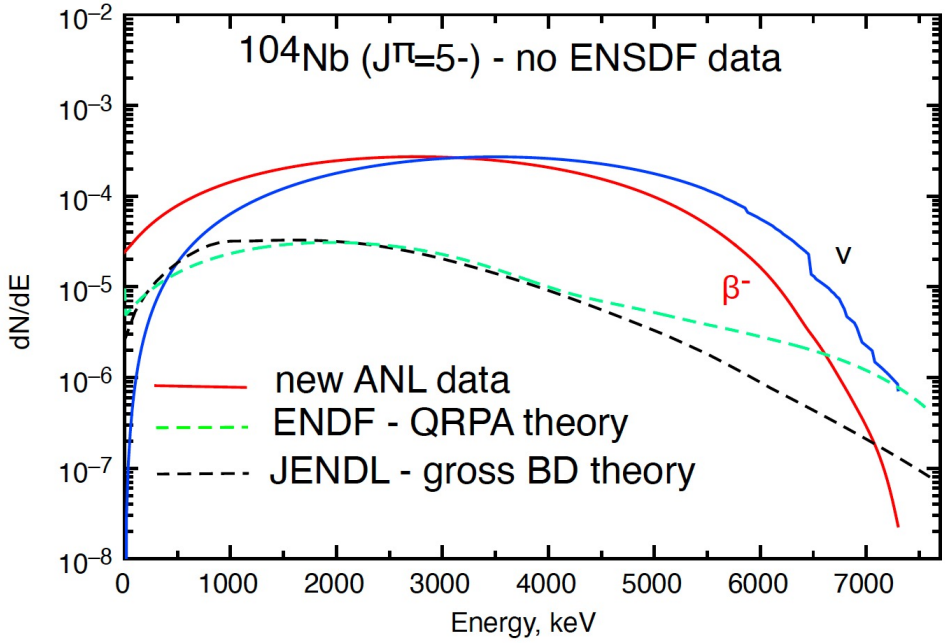
present data

spin-traps isomers in deformed nuclei resulting from the residual π–ν interactions

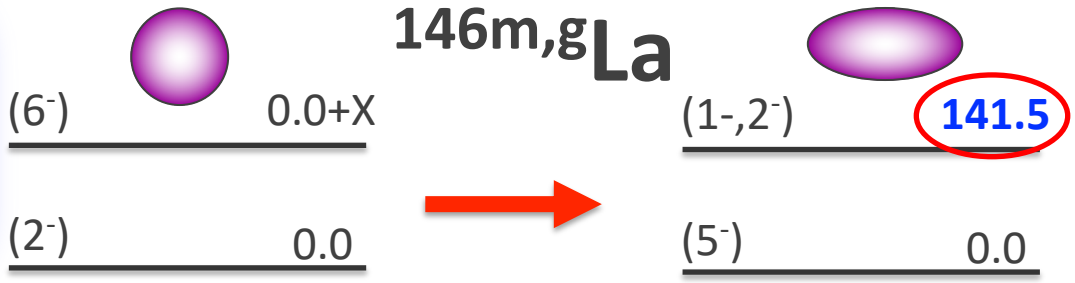
- unique capabilities at ANL to study long-lived, beta-decaying isomeric states
  - ✓ direct mass-spectrometric techniques – excitation energy of the isomer
  - ✓ comprehensive β–γγ(CE)-*time* coincidence studies with Gammasphere decay station



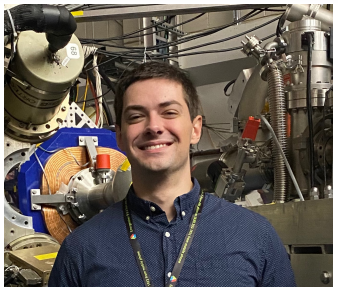




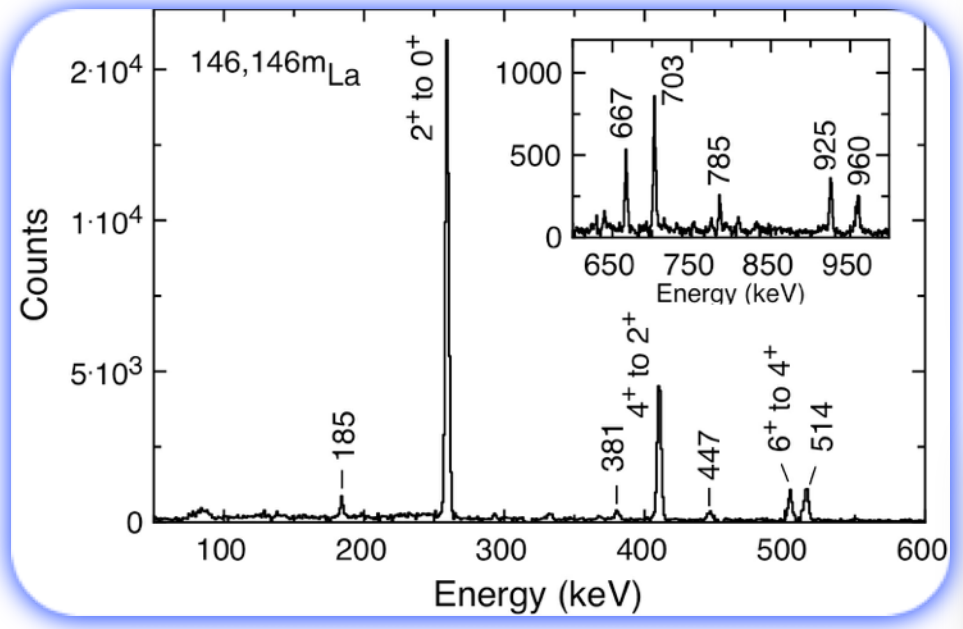
Project status: data analysis - cont.



Y. Khazov et al., NDS **136** (2016) 163



N. Giha, University of Michigan
PhD student (summer of 2021)



- resolved gs and isomer decays
- new levels and transitions
- new Jπ and configurations
- new nuclear structure interpretation - deformed shell model

analysis is completed – results were presented at the 2021 APS/DNP meeting (October 2021) & are prepared for publication in the journal **Physical Review C**

Collaborators

Argonne National Laboratory:
M.P. Carpenter, J. Clark, **P. Copp**, F.G. Kondev, T. Lauritsen, **S. Nandi**, W. Reviol, D. Santiago-Gonzalez, G. Savard, D. Seweryniak, F. Tovesson, M. Oberling, J. Anderson, R. Knaak, & B. DiGiovane

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