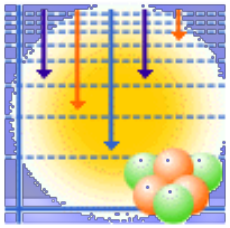
Argonne NATIONAL LABORATORY



*Member of the US Nuclear Data Program*

# Novel Approach for Improving Nuclear Data for Antineutrino Spectra Predictions

**FOA-LAB17-1763**

U.S. DEPARTMENT OF ENERGY | Office of Science

National Nuclear Security Administration

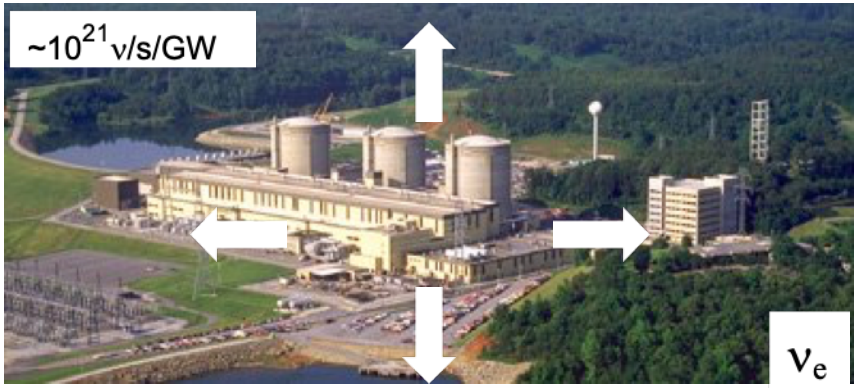
Nuclear Physics

NA-22

**WANDA2021 February 3, 2021**

U.S. DEPARTMENT OF ENERGY

# Introduction

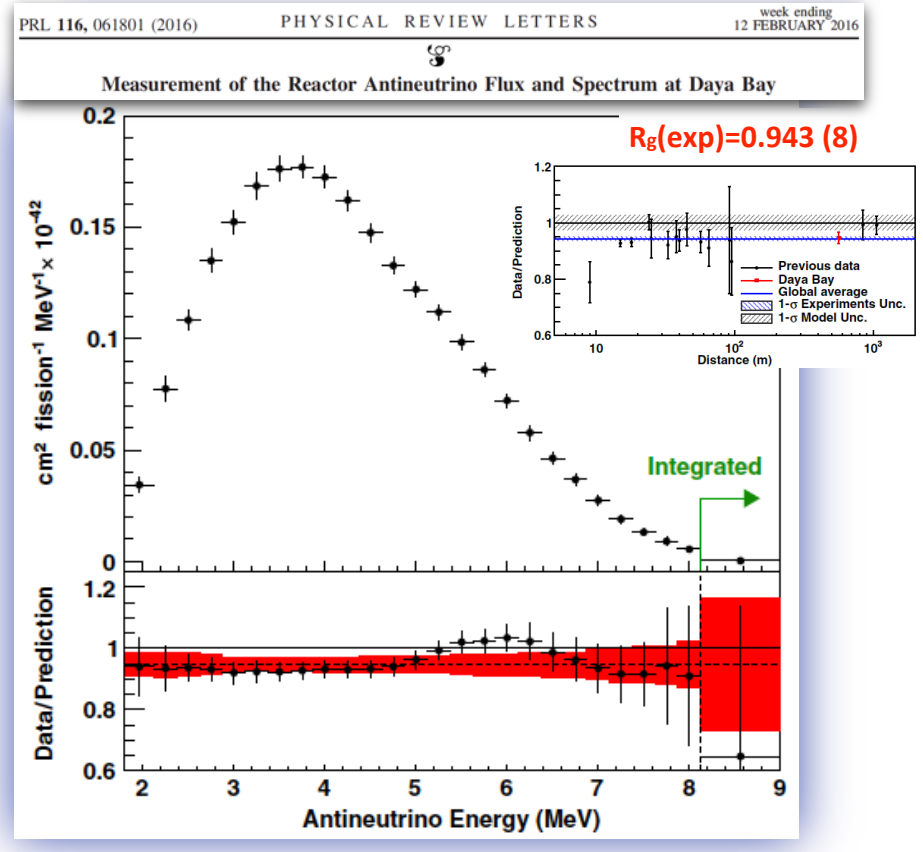



**compelling physics**

- 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




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 priority I and II nuclides

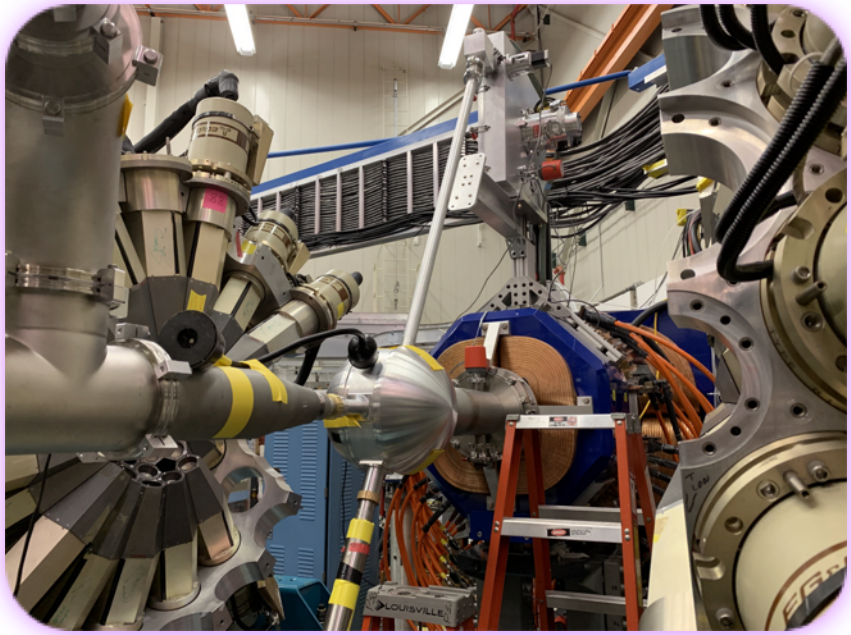
## How to improve the needed ND?

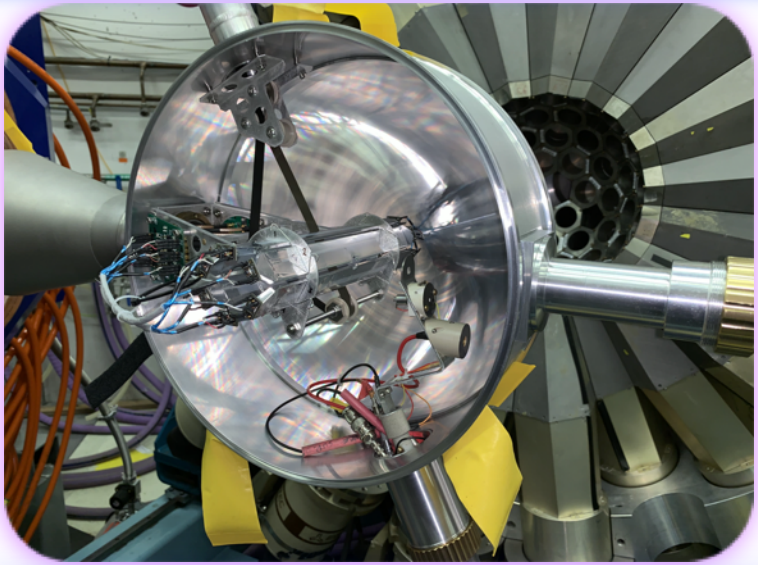
- unique capabilities of ***CARIBU@ANL*** (DOE/SC/NP National User Facility) to produce high-purity beams of essentially all fission products
- state-of-the-art detector equipment - ***Gammasphere***

# Gammasphere decay 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 $\varepsilon_\gamma$~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

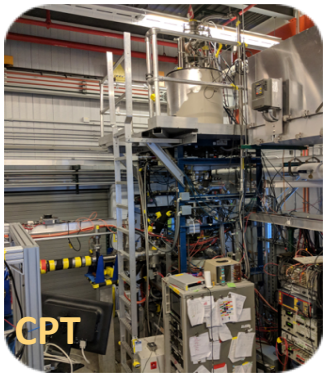


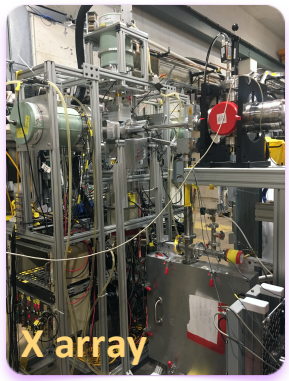


- **HEART** - HExagonal ARray for Triggering
  - ✓ 6 EJ-204 plastic scint. & 12 SiPM
  - ✓ $\varepsilon_\beta$~75% from β-γ singles & coin.
- powerful γ-γ-β-t coincidence device

# Current status

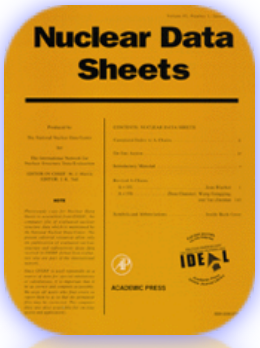
- Completed two experimental campaigns:
  - ✓ **December 2018** – aimed at transitional (weakly-deformed) $^{144}$La, $^{146g,m}$La, $^{144}$Ba, $^{146}$Ba, $^{146}$Ce nuclei
  - ✓ **December 2019** – aimed at well-deformed $^{102g,m}$Nb, $^{104g,m}$Nb, $^{102}$Zr, $^{104}$Zr, $^{102}$Mo, $^{104}$Mo nuclei
- Additional nuclear data were obtained by implementing the Canadian Penning Trap (CPT) & X array (5 Ge CLOVER detectors)



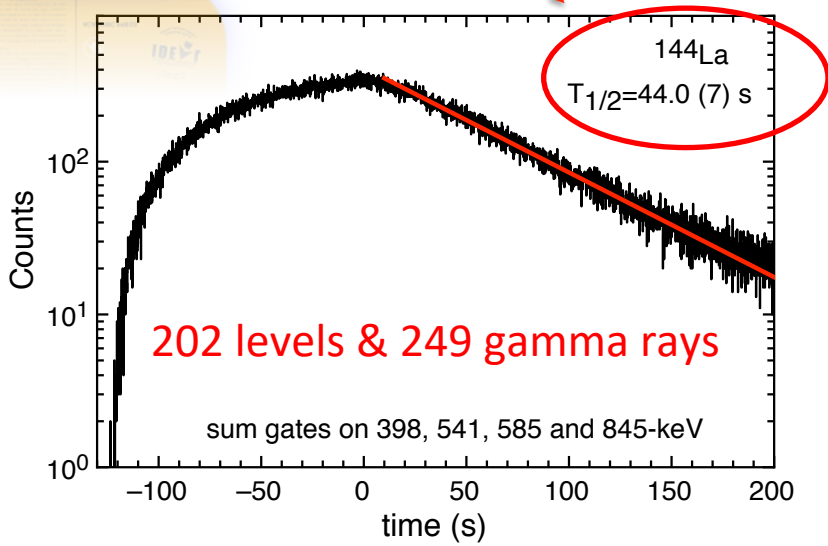

- A new campaign was approved by the ATLAS Program Advisory Committee - delayed to later this year due to COVID-19

$^{144}$La




$(3^-)$ 0.0

**40.8 (4) s**

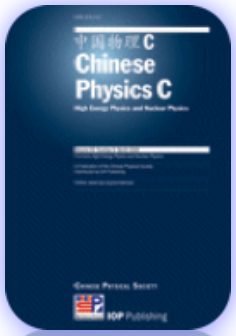


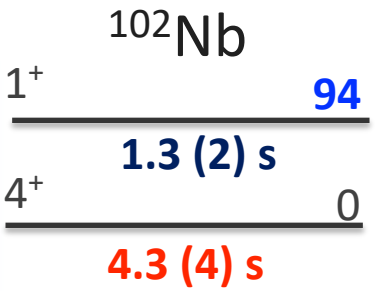

10% difference - purity of the source in previous experiments

$^{144}$Ba(11.7 s) -> $^{144}$La(44 s)->$^{144}$Ce(285 d)

F.G. Kondev *et al.* EPJ **223** (2019) 01028

# Deformed nuclei & isomers




Chinese Physics C Vol. 45, No.3 (2021) 030001

**The NUBASE2020 evaluation of nuclear physics properties**

F.G. Kondev [1, *], M. Wang (王猛)[2, *], W.J. Huang (黄文嘉)[2,3,4], S. Naimi[5], G. Audi (欧乔治)[6]

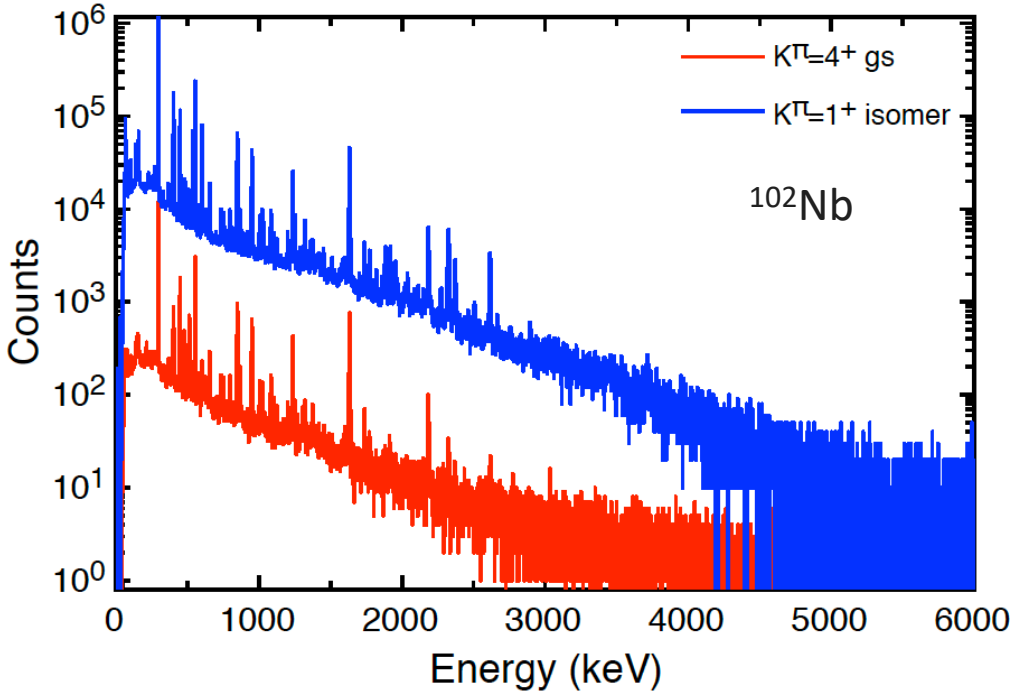
Chinese Physics C Vol. 45, No. 3 (2021) 030002

**The AME2020 atomic mass evaluation**

W.J. Huang (黄文嘉)[1,2,3] Meng Wang (王猛)[1,4;1)] F.G. Kondev[5] G. Audi (欧乔治)[2] S. Naimi[6]

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

- very complex decay schemes with overlapping decay paths between the ground state and isomer
- unambiguously resolved the isomer from the ground state
- for the first time a comprehensive decay schemes for the ground state and the isomer were established



# 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]

- data on $^{144}$La are being prepared for publication in **PHYSICAL REVIEW C**

# Conclusions & Outlook

- **Gammasphere** was converted into a powerful spectrometer for beta-decay studies of nuclei in the fission product region - state-of-the-art decay spectroscopy with **CARIBU** beams
  - ✓ ***compelling physics*** - structure of neutron-rich nuclei in the FP region - great discovery potential & detailed spectroscopy studies (resolving isomer decays)
  - ✓ ***valuable data for applications*** - antineutrino spectra, fission product yields (presentations by K. Kolos & G. Savard), decay heat, safeguards and others
- first results on $^{144}$La & $^{146,146m}$La ($^{144,146}$Ba & $^{146}$Ce) & deformed $^{102,102m,104,104m}$Nb ($^{102,104}$Zr & $^{102,104}$Mo) – resolved differences between previous studies & existing ND evaluations
- targeted experiments will continue during FY21-FY22 for other nuclei on the IAEA priority list

# Collaborators

**Argonne National Laboratory:**
K. Auranen, M.P. Carpenter, J. Clark, **P. Copp**, F.G. Kondev, T. Lauritsen, J. Lee, W. Reviol, D. Santiago-Gonzalez, G. Savard, D. Seweryniak, S. Stolze, S. Zhu, J. Wu, M. Oberling, J. Anderson, R. Knaak, J. Roher & B. DiGiovane

**LSU:**
S. Marley, E. Zganjar, G.E. Morgan, G. Willson

**US Naval Academy:**
D.J. Hartley

**VECC, Kolkata**
G. Mukharjee & **S. Nandi**