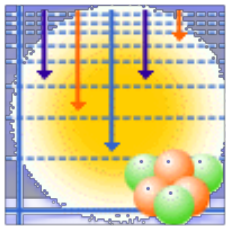
Argonne NATIONAL LABORATORY



Member of the US Nuclear Data Program

Novel Approach for Improving Antineutrino Spectra Predictions

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U.S. DEPARTMENT OF ENERGY | Office of Science

Nuclear Physics

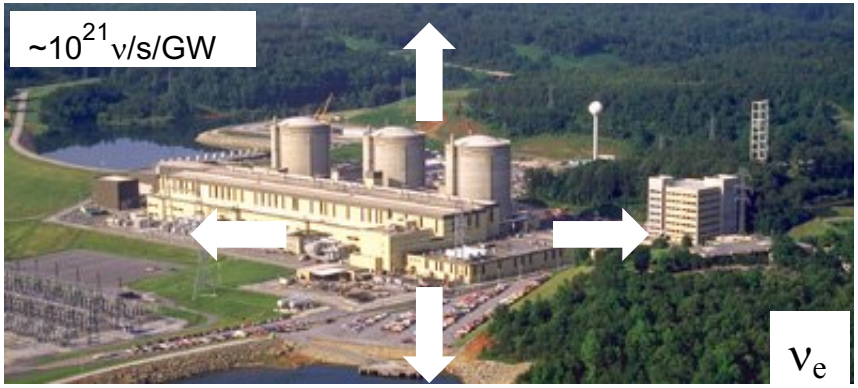
National Nuclear Security Administration

NA-22

WANDA, George Washington University, Washington DC, January 22-24, 2019

U.S. DEPARTMENT OF ENERGY | Office of Science

Introduction



compelling physics

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

applications

- detection of fissile activities from peaceful & military programs
- ***remote*** safeguards, monitoring and fission inventory of nuclear reactors

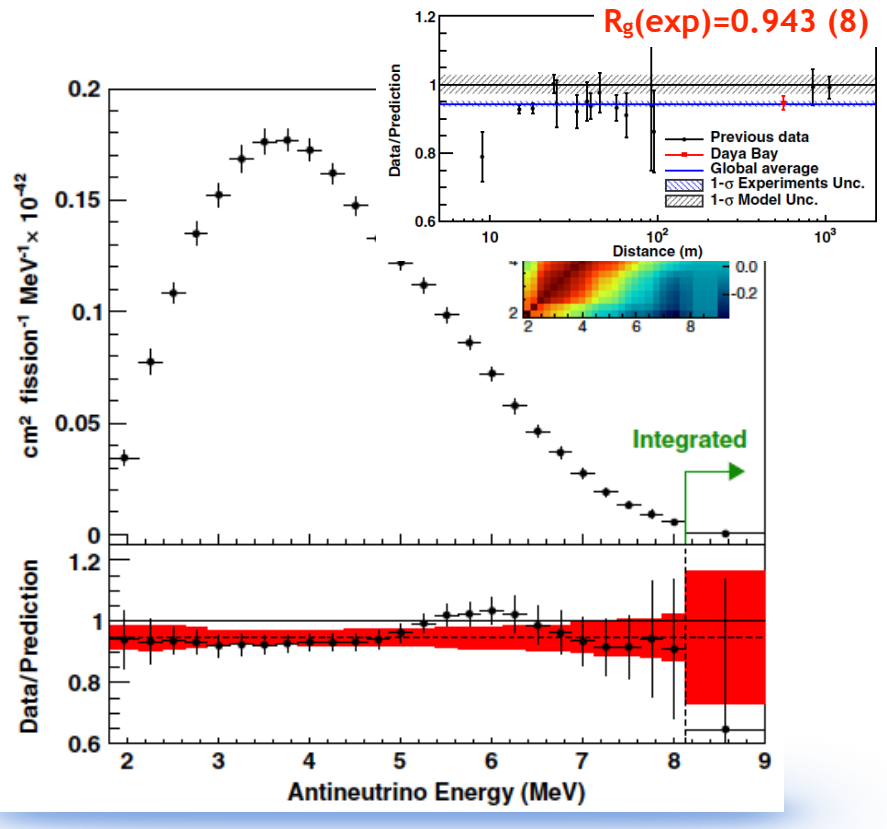
The New York Times

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

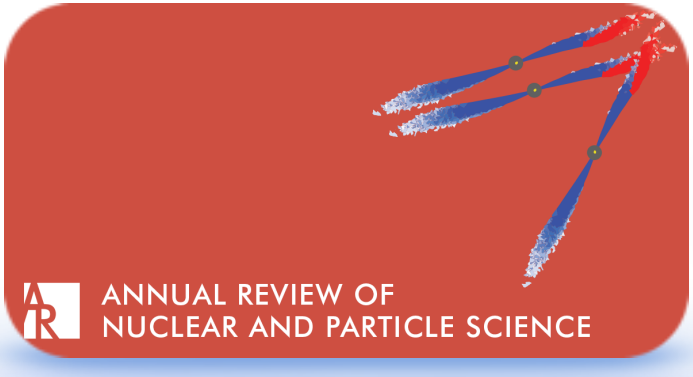
By Kenneth Chang March 27, 2018

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

Measurement of the Reactor Antineutrino Flux and Spectrum at Daya Bay



Introduction - cont.



Reactor Neutrino Spectra

Anna C. Hayes[1] and Petr Vogel[2]

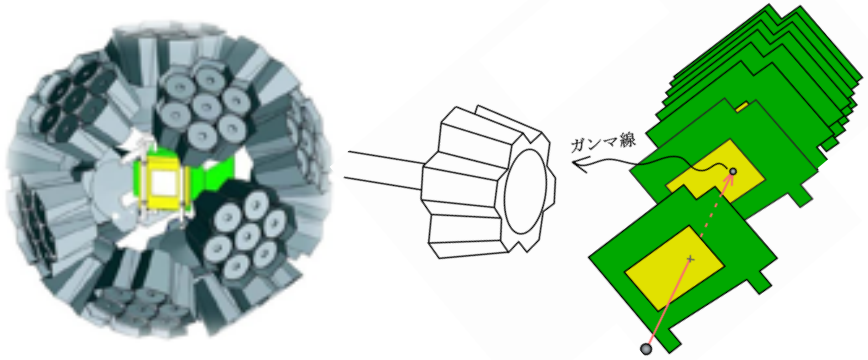
vol. **66**: 219-244 (2016)

Quantity	Type	ΔJ^π	Uncertainty
Unknown branching and J^π	Allowed and forbidden	All	50%
Finite size correction	Allowed	1^+	50%
Finite size correction	Forbidden	$0^-, 1^-, 2^-$	100%
Weak magnetism	Allowed	1^+	20%
Weak magnetism	Forbidden	0^-	None
Weak magnetism	Forbidden	2^-	20%
Weak magnetism	Forbidden	1^-	25%
Shape factor	Allowed	1^+	None
Shape factor	Forbidden	2^-	None
Shape factor	Forbidden	$0^-, 1-$	30%
Fission yields	Allowed and forbidden	All	10%
Missing spectra	Allowed and forbidden	All	50%

- ***key needs:*** improved experimental & evaluated nuclear physics data

Experimental Approaches

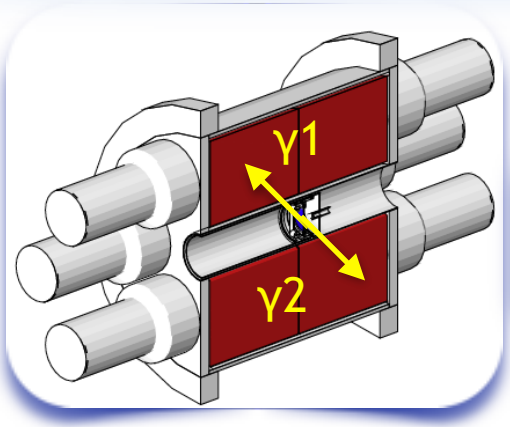
discrete ß-γ-γ spectroscopy with HPGe detectors

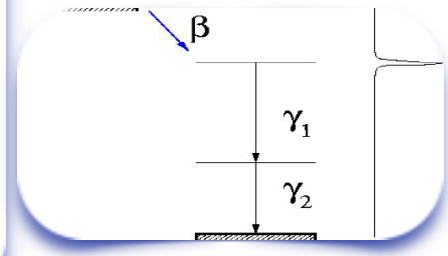


Pros
- determination of detailed decay scheme
- state-of-the-art detector equipment - problematic in the past - current deficiency in ENSDF/ENDF

Cons
- reduced HPGe efficiency for high-energy γ rays

Total Absorption Gamma-ray Spectroscopy calorimetry with NaI detectors



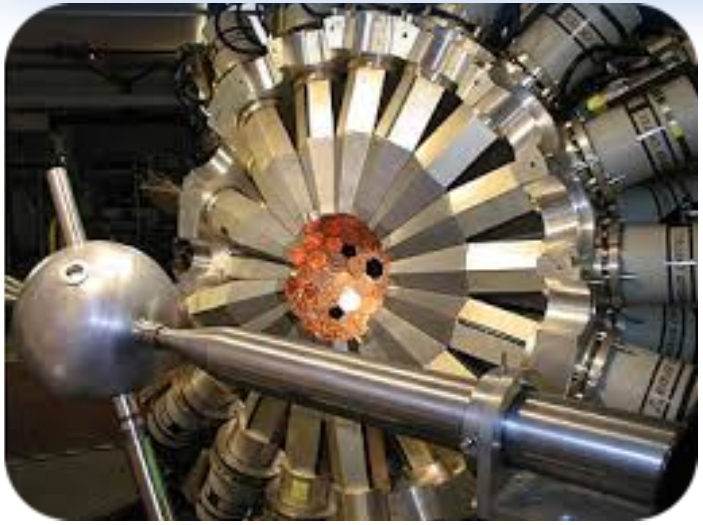


Pros
- large γ-ray singles efficiency

Cons
- low energy resolution and resolving power
- must know details of the decay scheme - often this is not the case - simulations
- complicated unfolding procedure - often non-unique solutions exist - unreliable uncertainties

Decay Spectroscopy with Gammasphere

Combine GAMMASPHERE the **most powerful** gamma-ray spectrometer in the WORLD with the unique **beam capabilities of** CARIBU (all fission products are available as high purity beams - no stopovers for refractory elements)



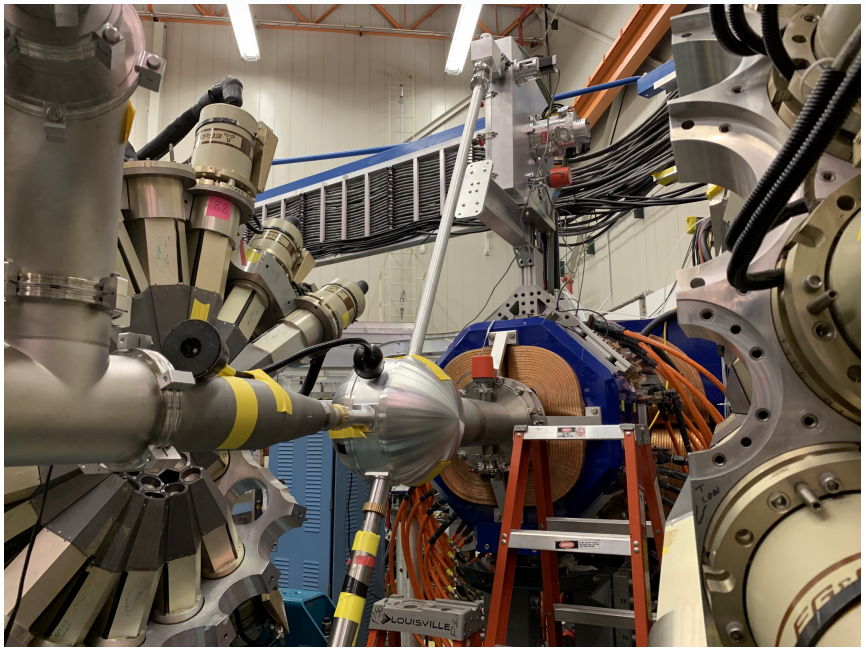
100 HpGe detectors with BGO shields in a close (~4π) geometry

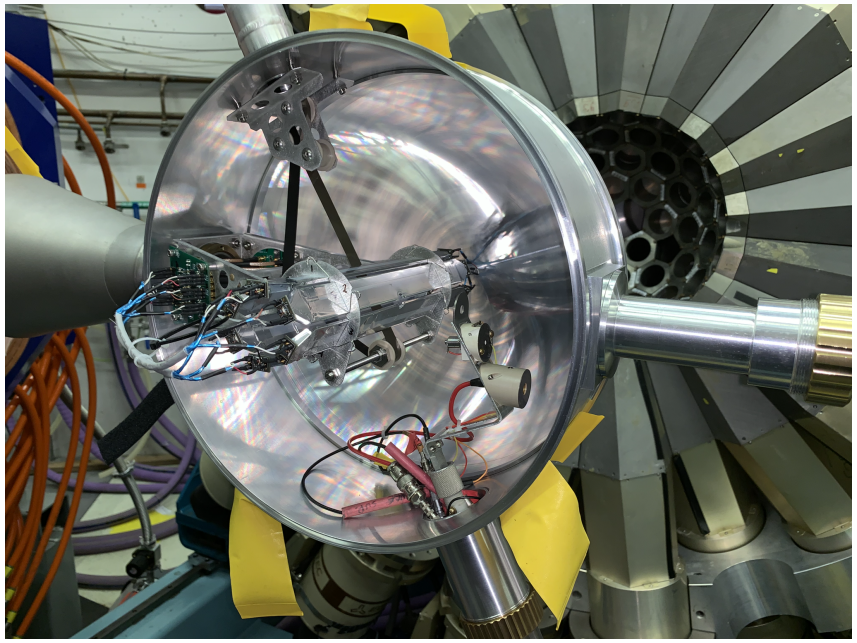
Advantages

- **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} %) - unprecedented sensitivity!
- **establish complete decay schemes** - angular correlations for transition multipolarities & Jπ assignments - end-game in nuclear spectroscopy

Commission Experiment - Dec. 17-21, 2018

new Decay Data Station at Gammasphere - commissioned in December 17-22, 2018
target chamber (WUSL), moving tape (LSU) and ß- particle detector arrays (ANL)

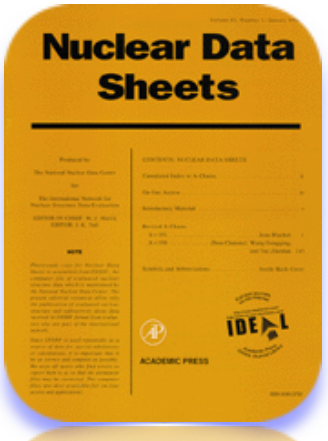




- flexible selection of different growth & decay cycles
- increased sensitivity for fast-decaying nuclei (down to 100s of ms); resolving isomers

- **HEART** - Hexagonal Array for Triggering
  - ✓ 6 EJ-204 plastic scint. & 12 SiPM
  - ✓ ε_{β}=75 (2)% from ß-γ singles & coin.
  - ✓ determine the direction of ß part.
- **powerful γ-γ-ß-t coincidence device**

First Results - ^{144}La & ^{146,146m}La



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

structure & Jπ based on shell-model

^{146}La

9.8 (4) s

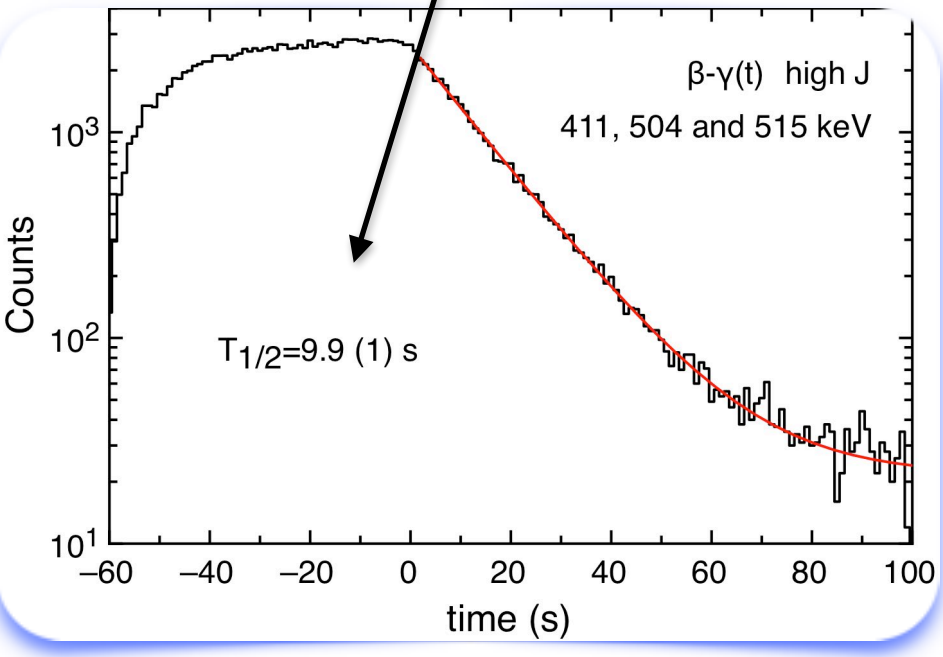
(6$^-$) 0.0+X

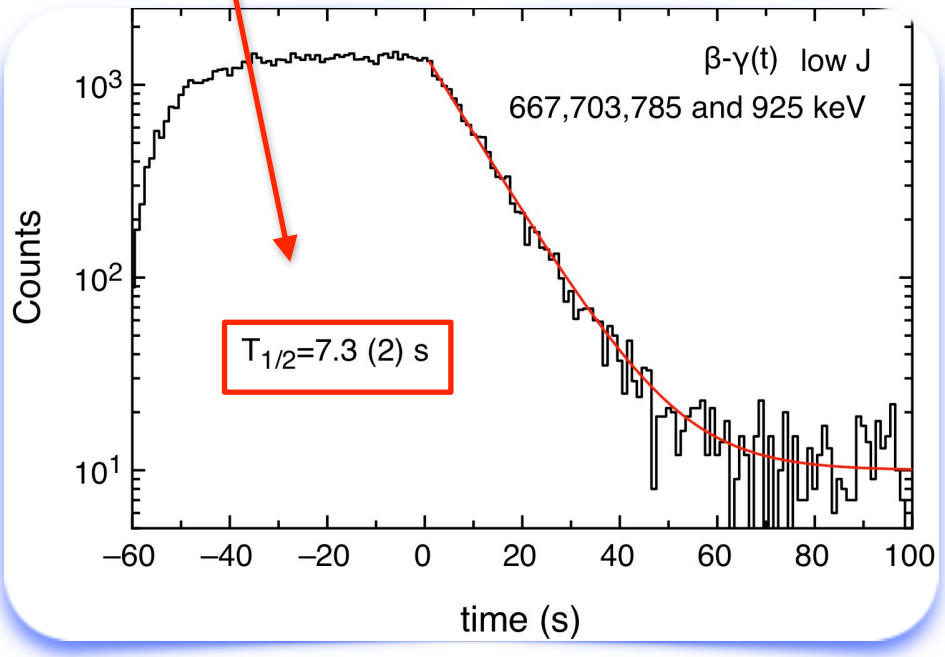
(2$^-$) 0.0

6.1 (3) s

good!

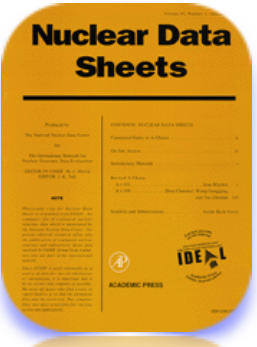
discrepant



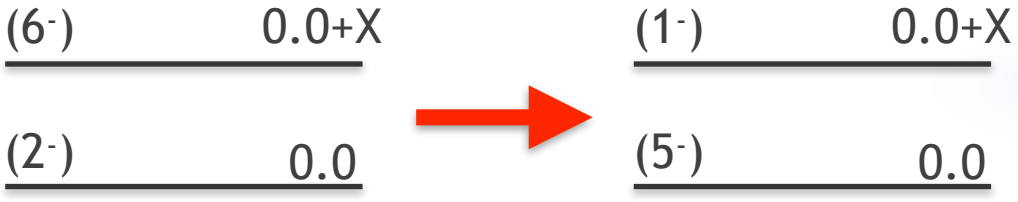


gating on selecting γ rays associated with the low- and high-spin β-decaying states

First Results - cont.



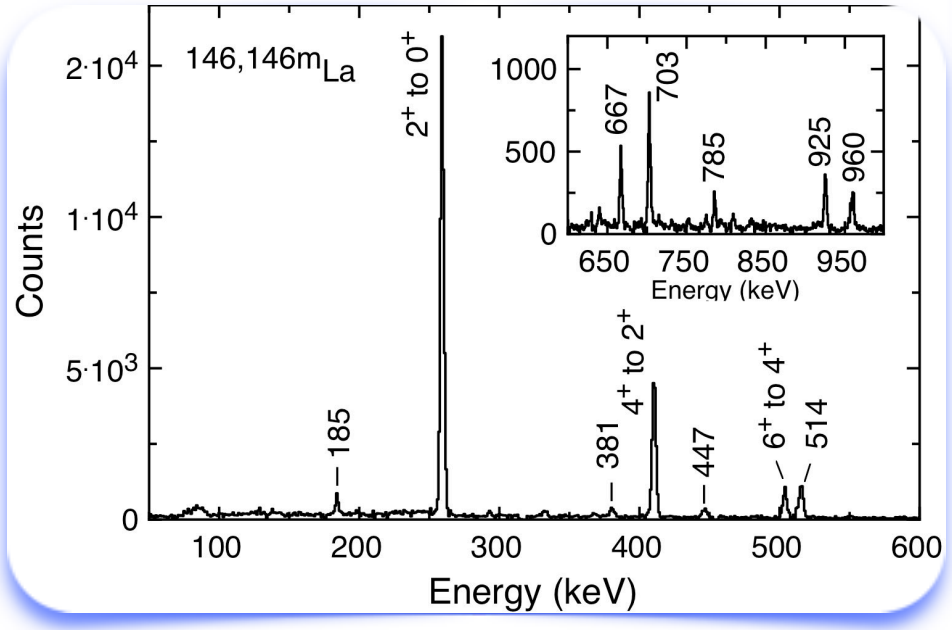
^{146}La



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

transitional region
deformation changes

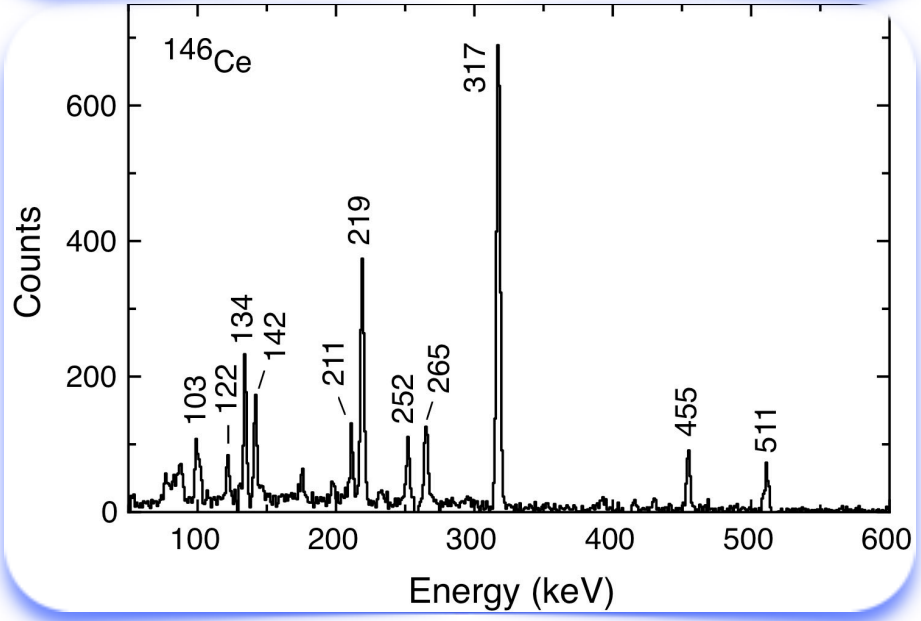
π5/2+[413] ν5/2[523]
Nilsson assignment



^{146}Ce β- decay

- differs significantly from previous TAGS (calorimetric) studies

R.C. Greenwood et al. NIM **A390** (1997) 95



What Next?

a list of ~30 nuclides, based on recent recommendations by IAEA-NDS

INDC(NDS)-0676
Distr. EN, ND

INDC International Nuclear Data Committee

Technical Meeting on "Nuclear Data for Anti-neutrino Spectra Calculations and Their Applications", April 2019 (tentative)

- 3 days allocated in March 2019 - ^{102,102m}Nb and ^{104,104m}Nb
  - ✓ role played by deformation
- new proposals to the ATLAS-PAC for campaigns in FY19 & FY20

Conclusions & Outlook

- **Gammasphere** was converted to a powerful spectrometer for beta-decay studies - state-of-the-art decay spectroscopy with **CARIBU** beams
  - ✓ **compelling physics** - structure of neutron-rich nuclei into FP region - great discovery potential & detailed spectroscopy studies - in many cases better compared to what the other RIB facilities can offer
  - ✓ **high-value data for applications** - antineutrino spectra, decay heat, fission yields, safeguards, etc.

- new decay data station at **Gammsphere** was successfully commissioned in December 2018 **-** first data taken on ^{144}La & ^{146,146m}La (^{146}Ba and ^{146}Ce) - notable differences with previous studies & evaluations - new physics!

- targeted experiments for nuclei on the IAEA list of priority nuclides - several experimental campaigns planned during FY19 and FY20

- **ANL Decay Data Factory**: moving GS to the new LE area (close to CARIBU) - no interference with ATLAS operation - running continuously for 6-10 months
  - ✓ a wealth of new data for both science & applications
  - ✓ a new way of data storage, analysis & dissemination

Collaborators

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