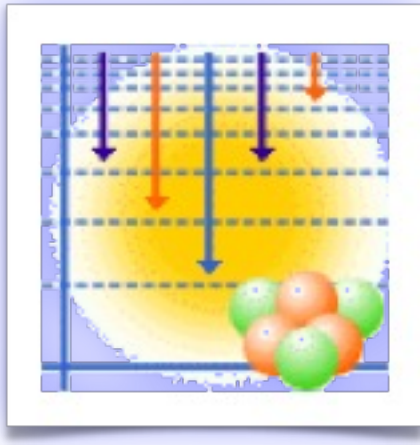
Decay Spectroscopy Studies at CARIBU@ANL Relevant to Antineutrino Spectra Reconstruction

F.G. Kondev
Physics Division, Argonne National Laboratory



U.S. DEPARTMENT OF ENERGY | Office of Science

TM on Nuclear Data Needs for Antineutrino Spectra Applications, January 16-20,2023, Vienna

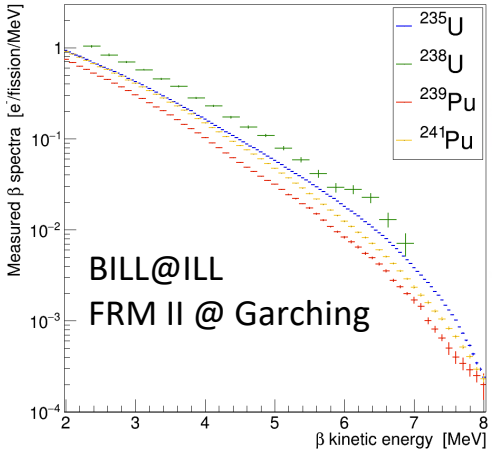
Introduction

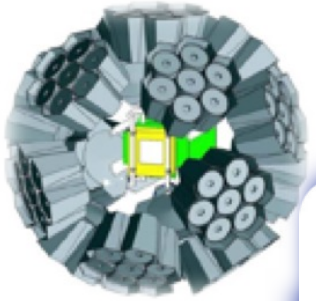
High Energy Physics Opportunities Using Reactor Antineutrinos

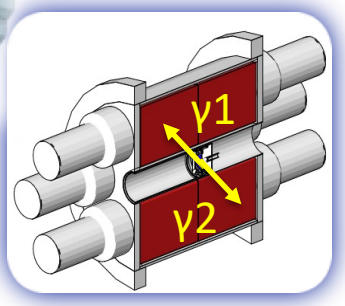
O. A. Akindele, J. M. Berryman, N. S. Bowden, R. Carr, A. J. Conant, P. Huber, T. J. Langford, J. M. Link, B. R. Littlejohn, G. Fernandez-Moroni, J. P. Ochoa-Ricoux, C. Roca, S. Schoppmann, L. Strigari, J. Xu, C. Zhang, X. Zhang

arXiv:2203.07214

- **Direct measurements**
  ⇒ several presentations at this meeting



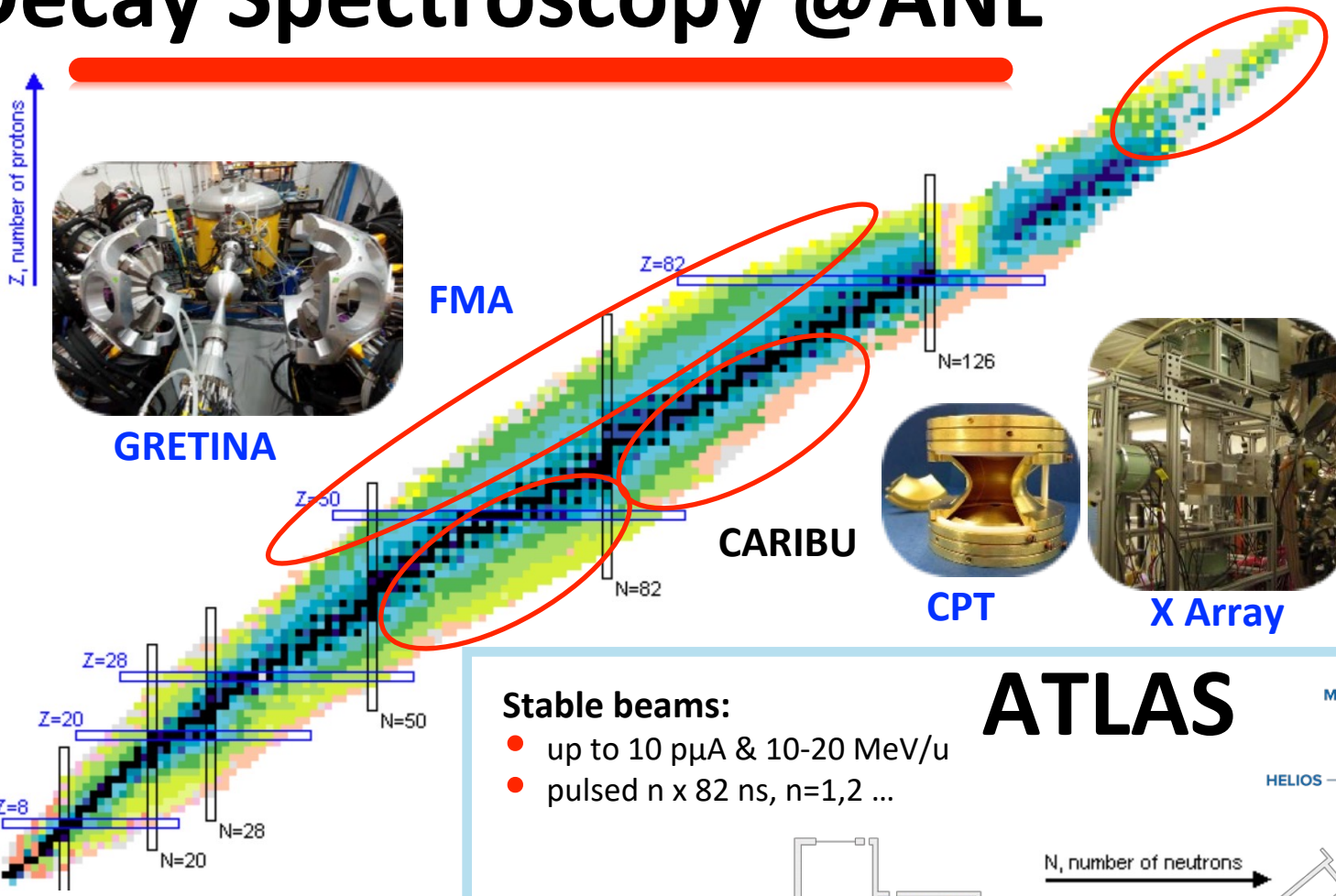




- **Indirect measurements**
  ⇒ measurements of betas
  ⇒ measurements of gammas

a wealth of LE NP data are needed - the design and execution of experiments & in their interpretation -> better theoretical understanding & modeling

Decay Spectroscopy @ANL



AGFA

FMA

GRETINA

CARIBU

CPT

X Array

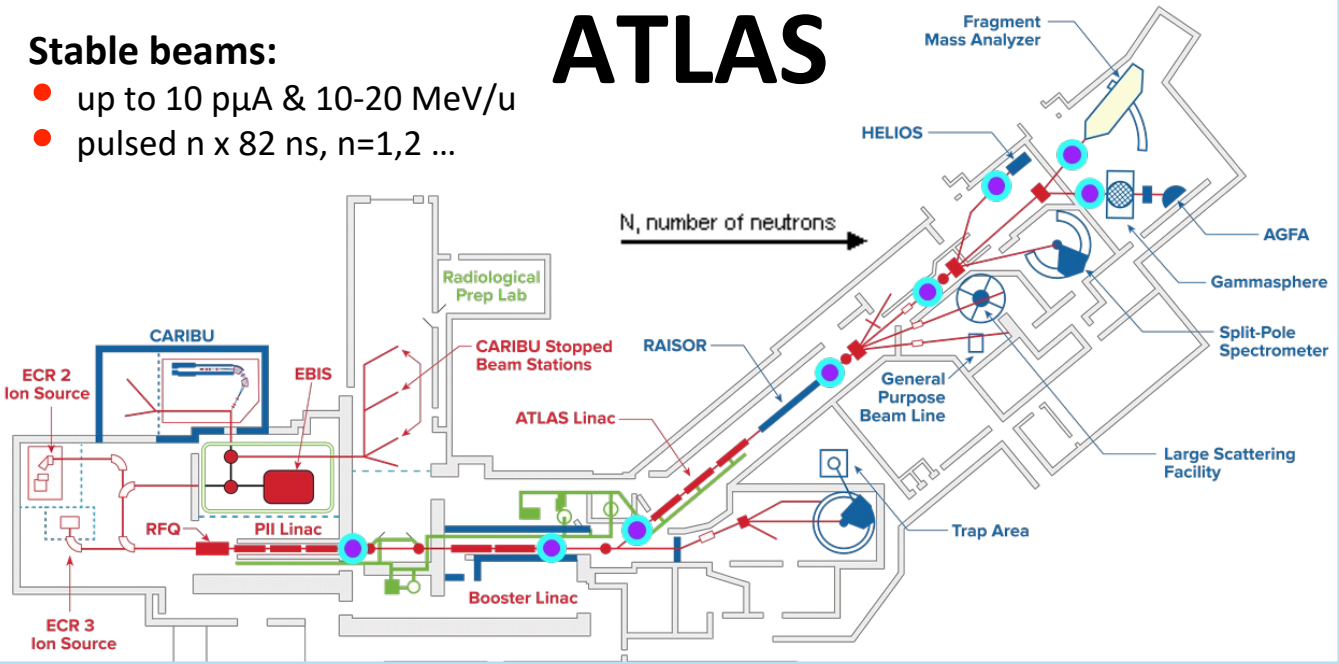
Gammasphere

- Nuclear Structure
- Nuclear Astrophysics
- ND & Applications

ATLAS

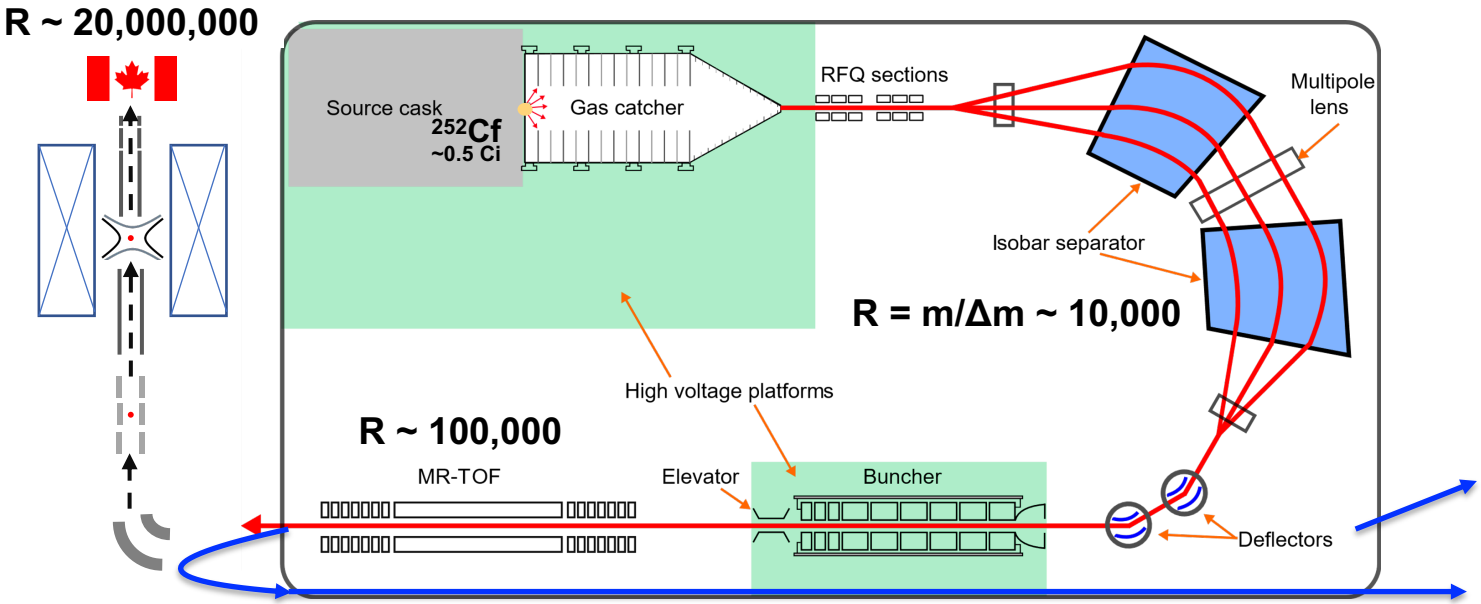
Stable beams:

- up to 10 pμA & 10-20 MeV/u
- pulsed n x 82 ns, n=1,2 …

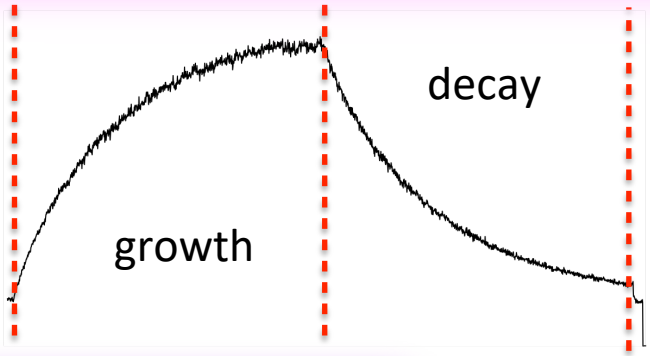


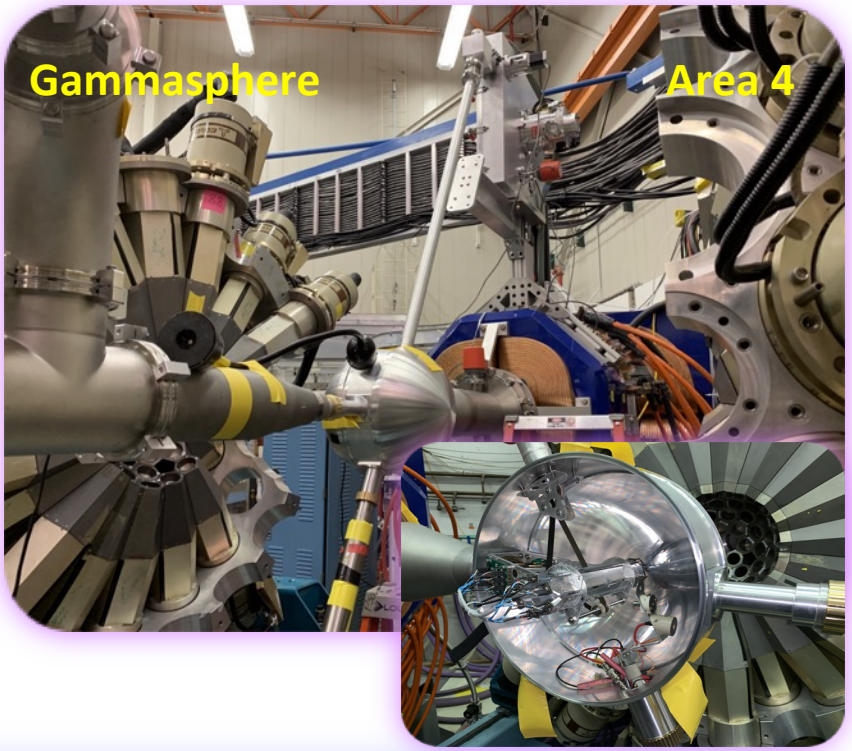
CARIBU @ ANL

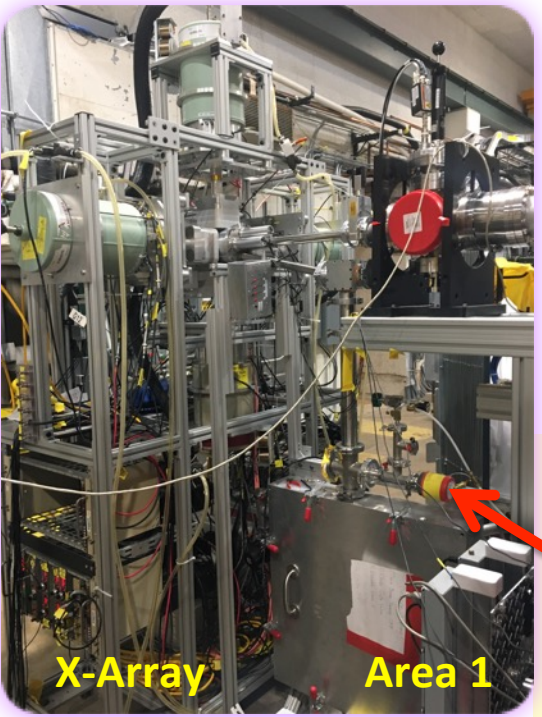

CPT


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

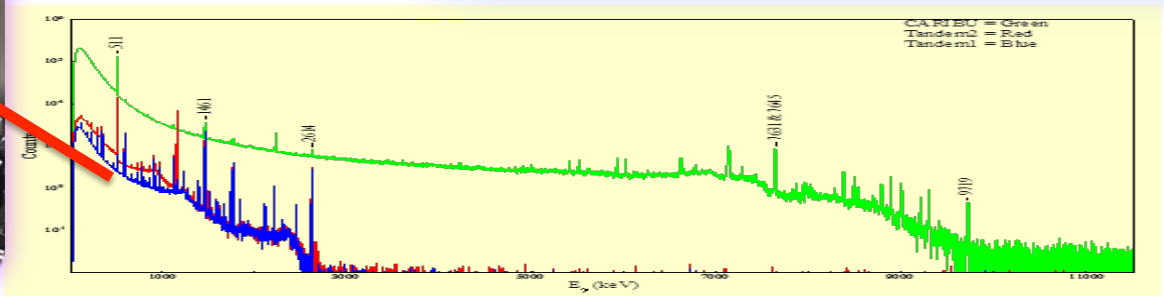
- direct implantation on the tape
- control the growth & decay times
  - selectivity by $T_{1/2}$
- β-γ-γ(t) coincidences



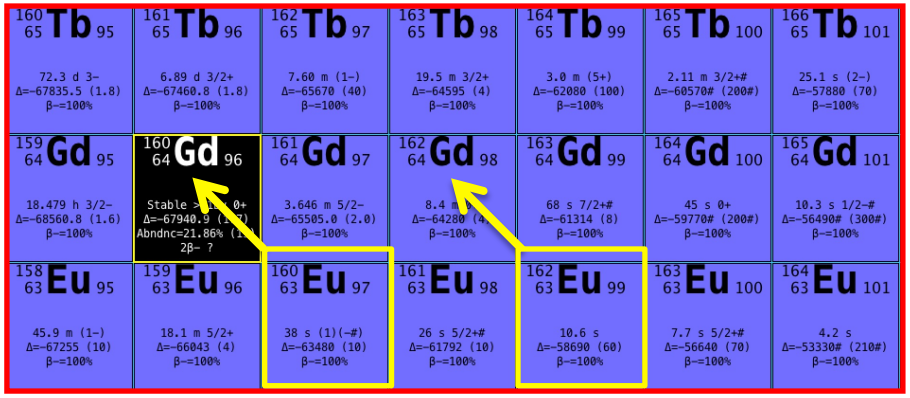




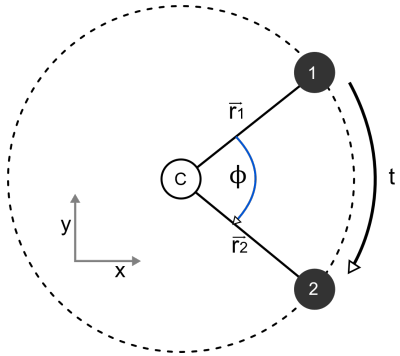
- **HEART** - HExagonal ARray for Triggering
  - ✓ 6 EJ-204 plastic scint. & 12 SiPM
  - ✓ ε_β~75% from β-γ singles & coin.
- powerful γ-γ-β-t coincidence device

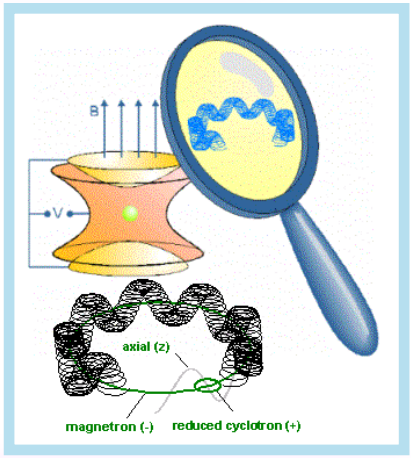


Isomers in $^{160}Eu_{63}$ (N=97) & $^{162}Eu_{63}$ (N=99)



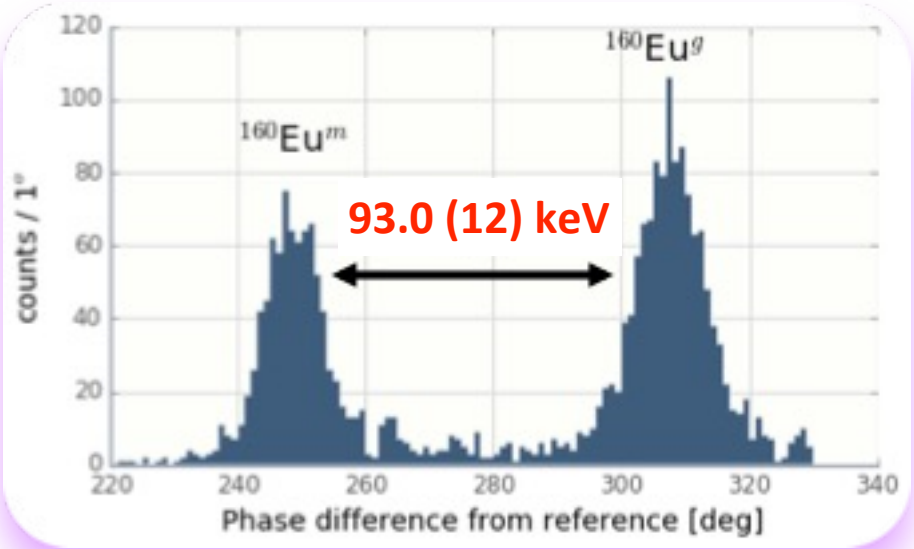
CPT: mass measurements

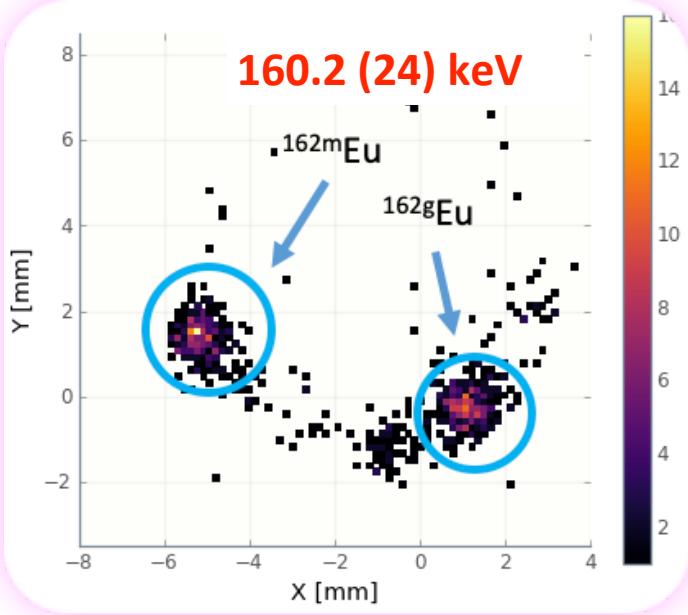




phase-imaging ion-cyclotron-resonance (PI-ICR) technique

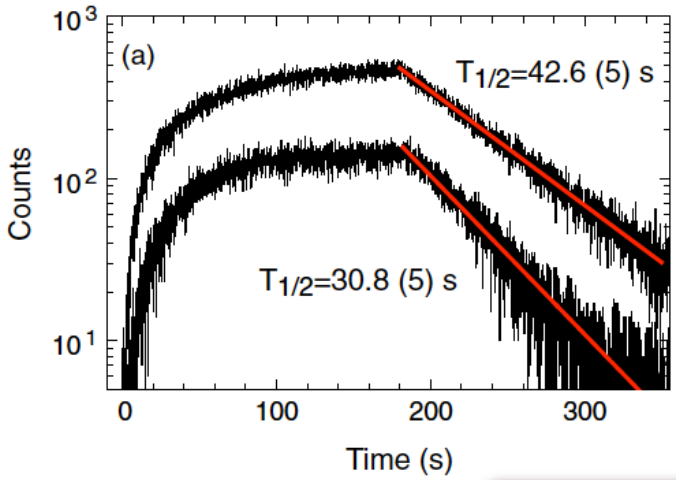
- faster measurements - nuclei with shorter lifetimes
- improved sensitivity & accuracy - resolving isomers





D.J. Hartley et al. PRL120 182502 (2018)

$^{160}Eu_{63}$ (N=97)



$K^{\pi}=0^-$

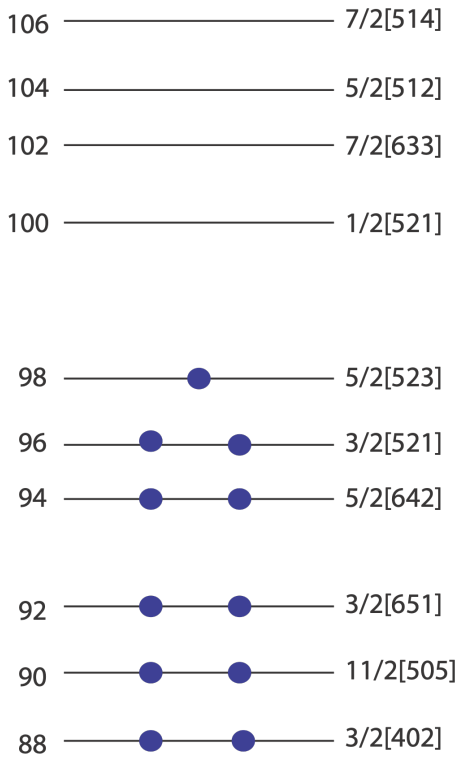
$K^{\pi}=5^-$

π5/2[413] ν5/2[523]

60%

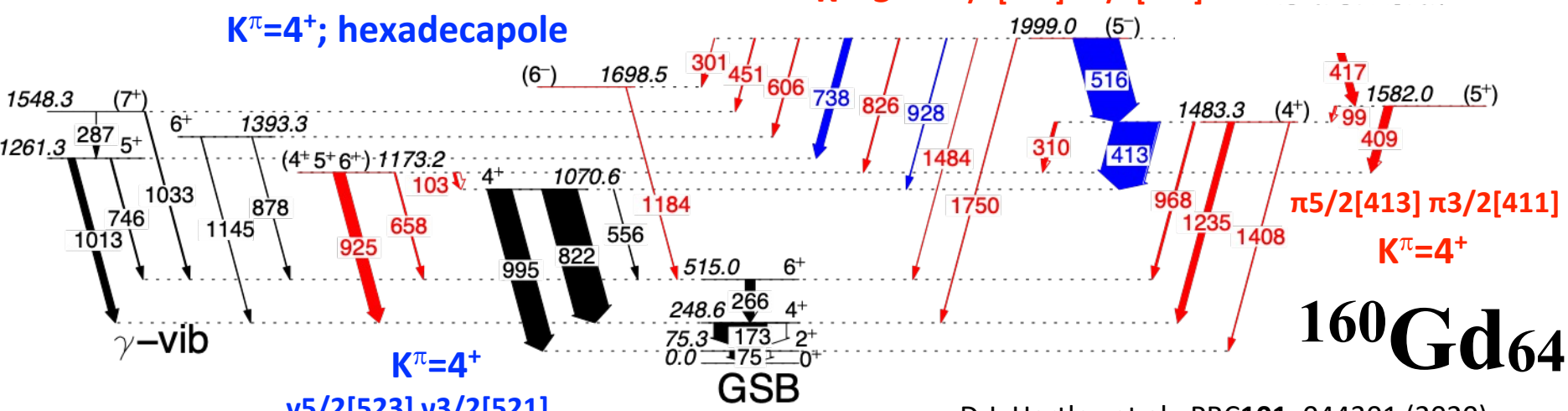
log *ft* ≈ 5.1

ΔN=0, $\Delta n_z=\Delta\Lambda=0,+/-1$



$K^{\pi}=5^-$ π5/2[413] π5/2[532]

$K^{\pi}=4^+$; hexadecapole



$K^{\pi}=4^+$

ν5/2[523] ν3/2[411]

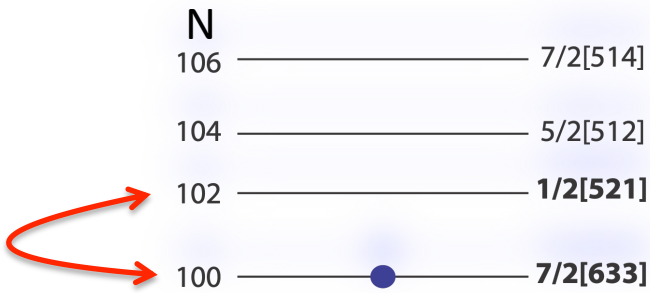
π5/2[413] π3/2[411]

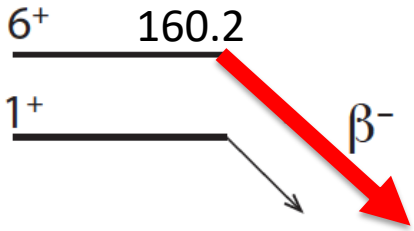
$K^{\pi}=4^+$

$^{160}Gd_{64}$

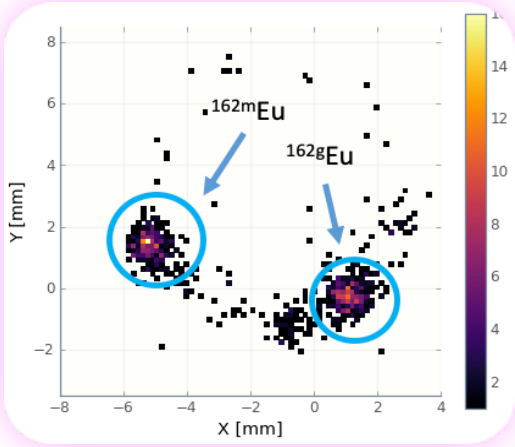
D.J. Hartley et al., PRC**101**, 044301 (2020)

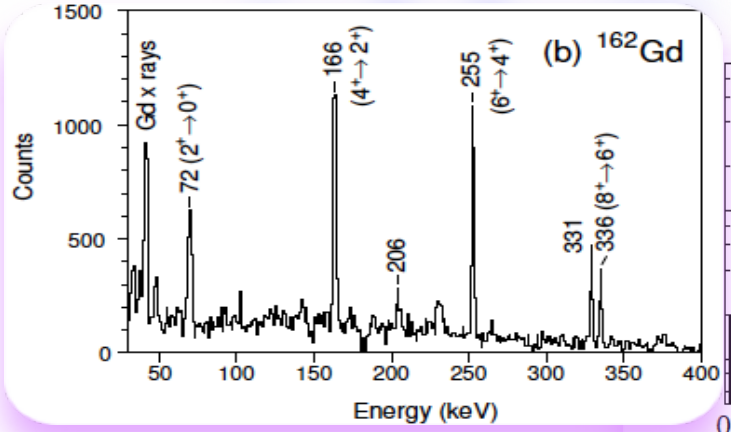
^{162}Eu (N=99)

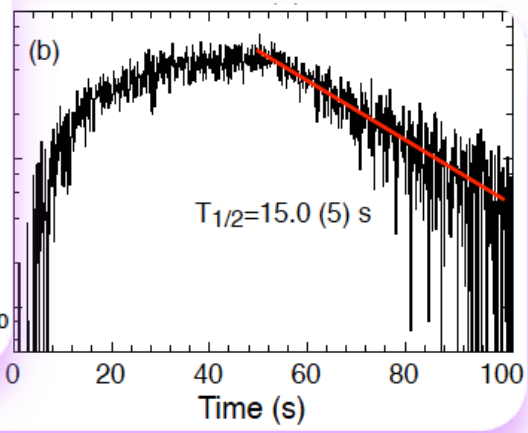


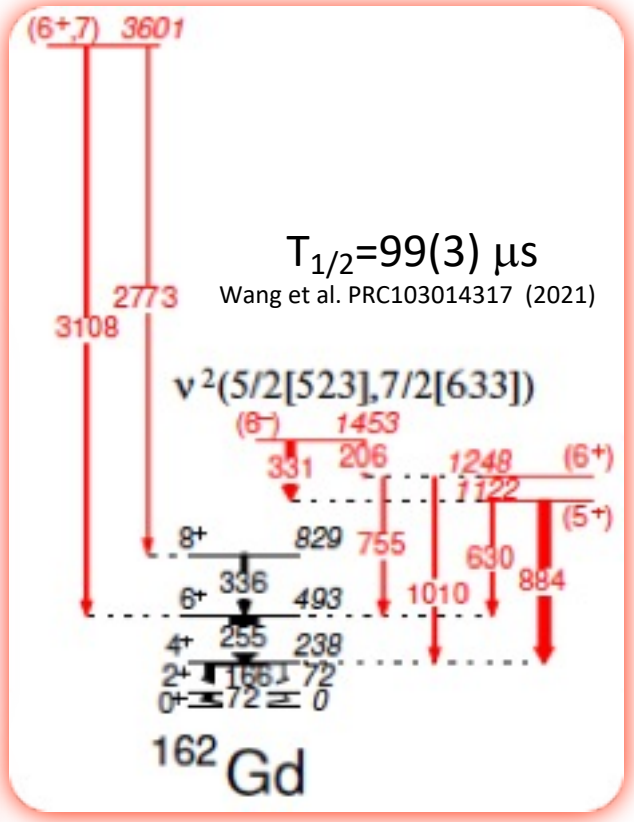


N=99 π5/2[413] ν7/2[633]





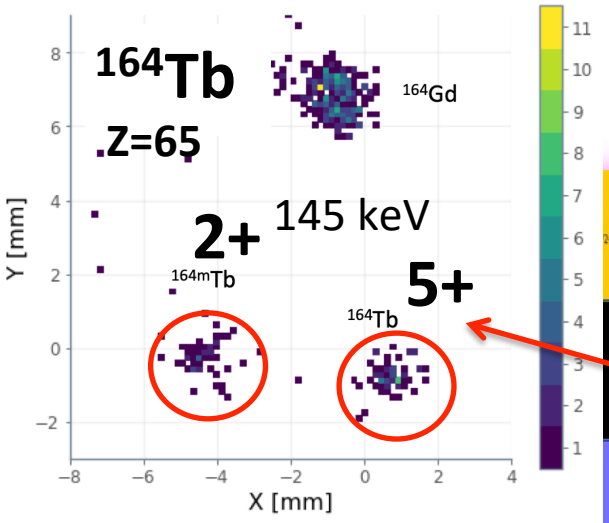


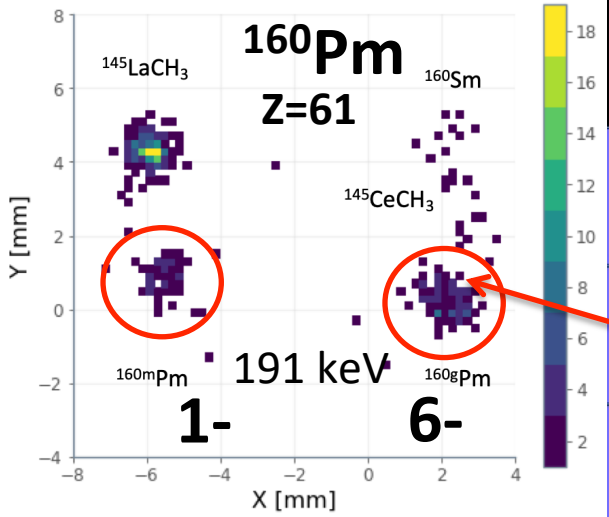


deviations from WS, Nilsson & folded-Yukawa ordering of the 1/2[521] and 7/2[633] neutron orbitals

D.J. Hartley et al. PRL120 182502 (2018)

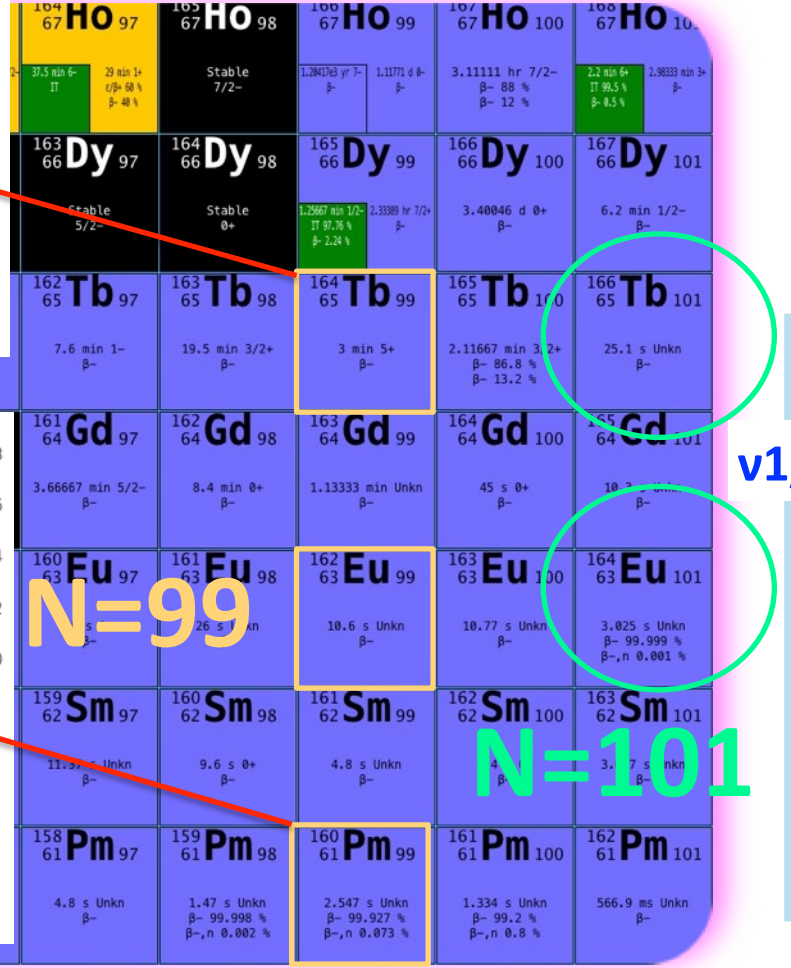
Spin-trap Isomers in Pm, Eu and Tb





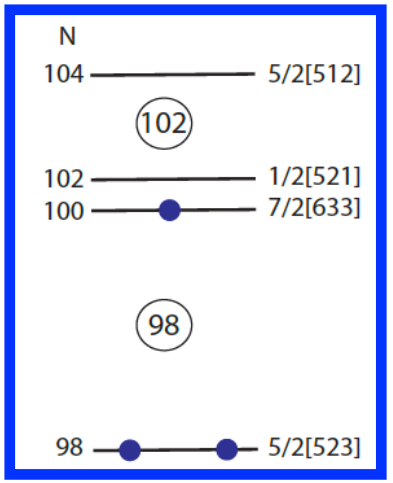
π3/2[411] ν7/2[633]

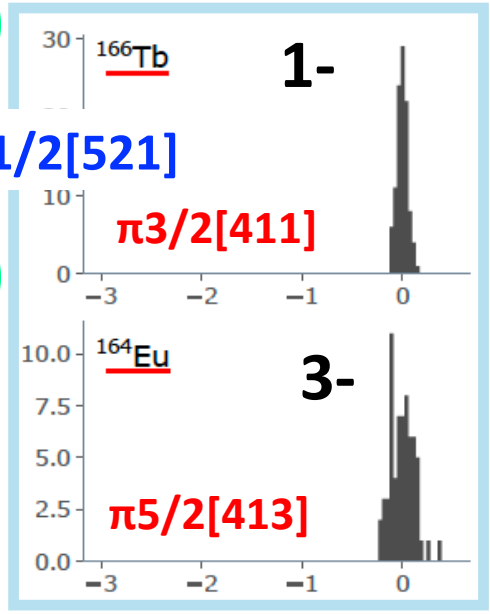
Kπ=5+ & 2+



π5/2[532] ν7/2[633]

Kπ=6- & 1-





R. Orford et al., PRC**102**, 011303(R) (2020)

FP campaign at CARIBU

U.S. DEPARTMENT OF ENERGY | Office of Science

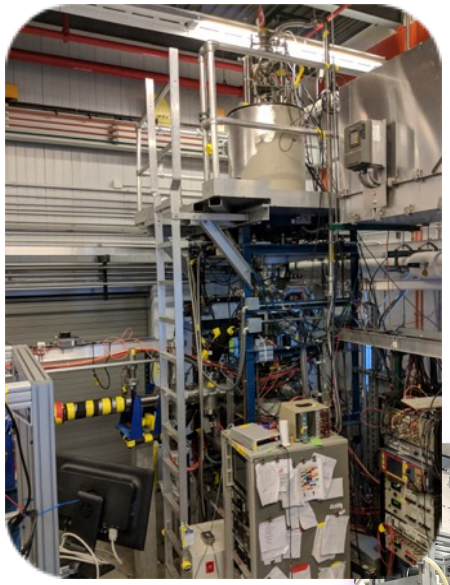
FOA-LAB17-1763

National Nuclear Security Administration

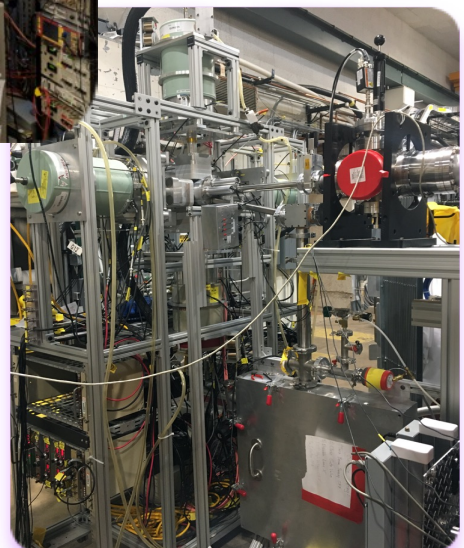
Nuclear Physics

NA-22

- Designed and built a new decay station at Gammasphere (**FY18**)
- Completed two 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
- Additional nuclear data were obtained in **FY20-21** using the Canadian Penning Trap (CPT) & the X array (5 Ge CLOVER detectors) – ^{98}Y & ^{98}Nb

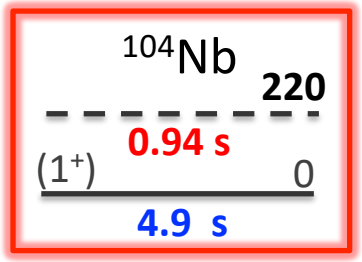


CPT

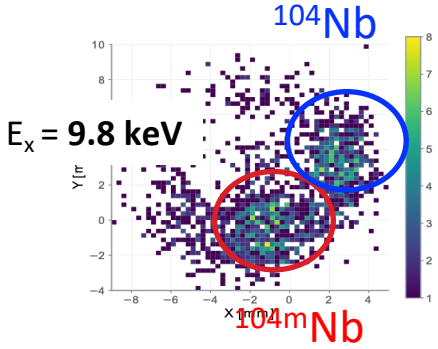


X array

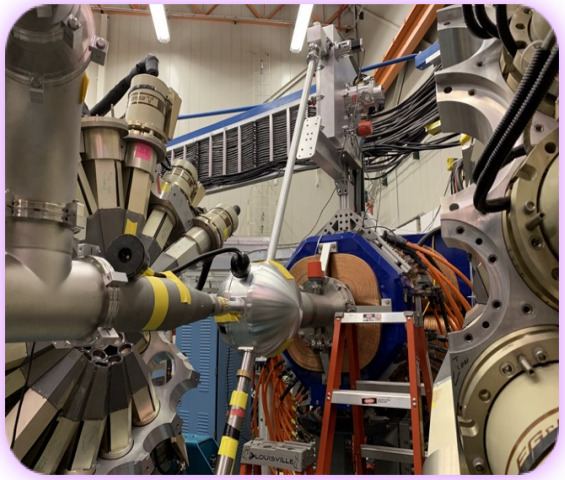
A=100 deformed region



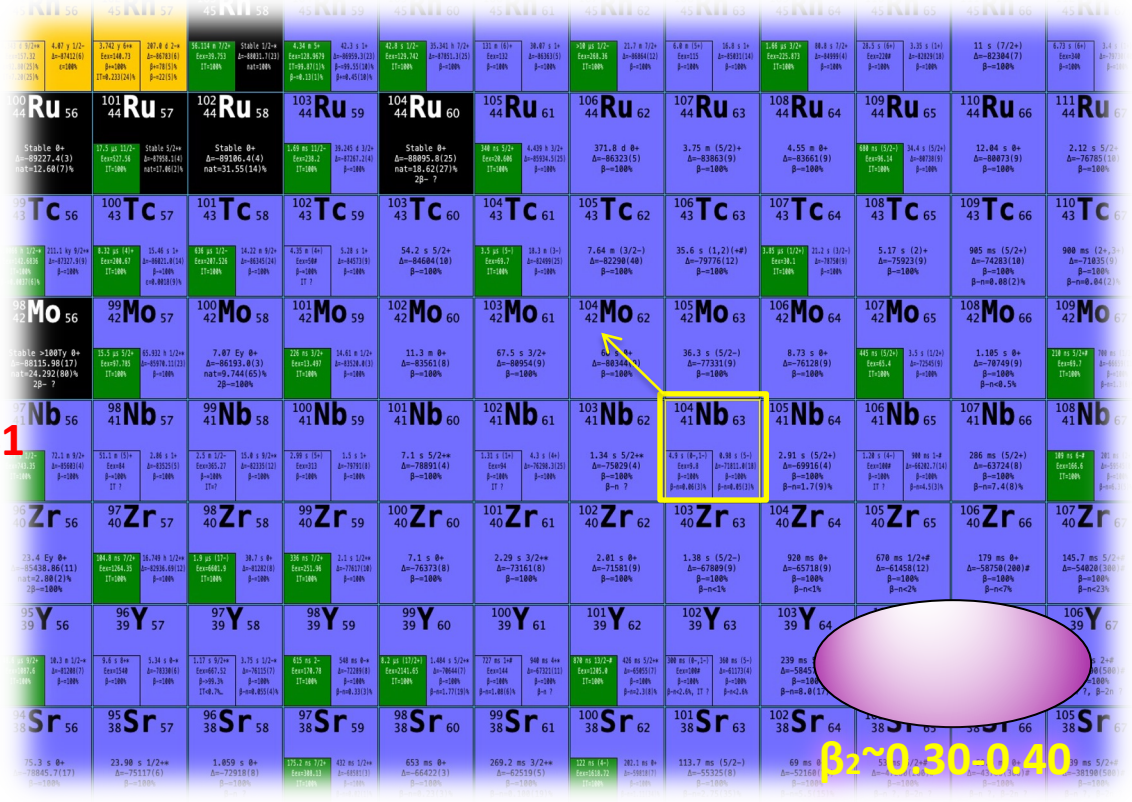
J. Blachot, NDS 108 (2007) 2035

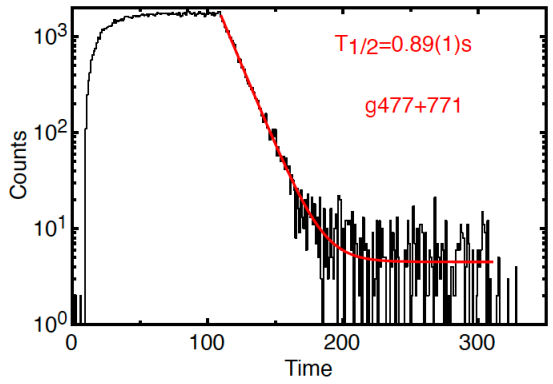


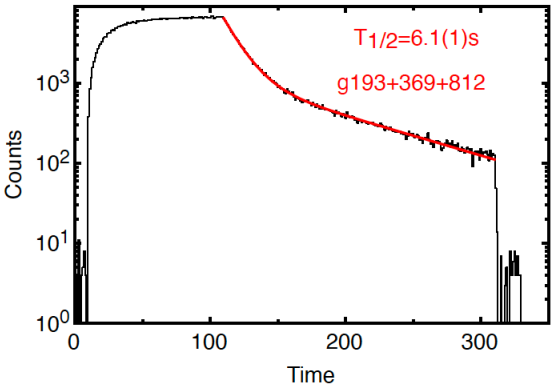
R. Orford, PhD thesis 2021



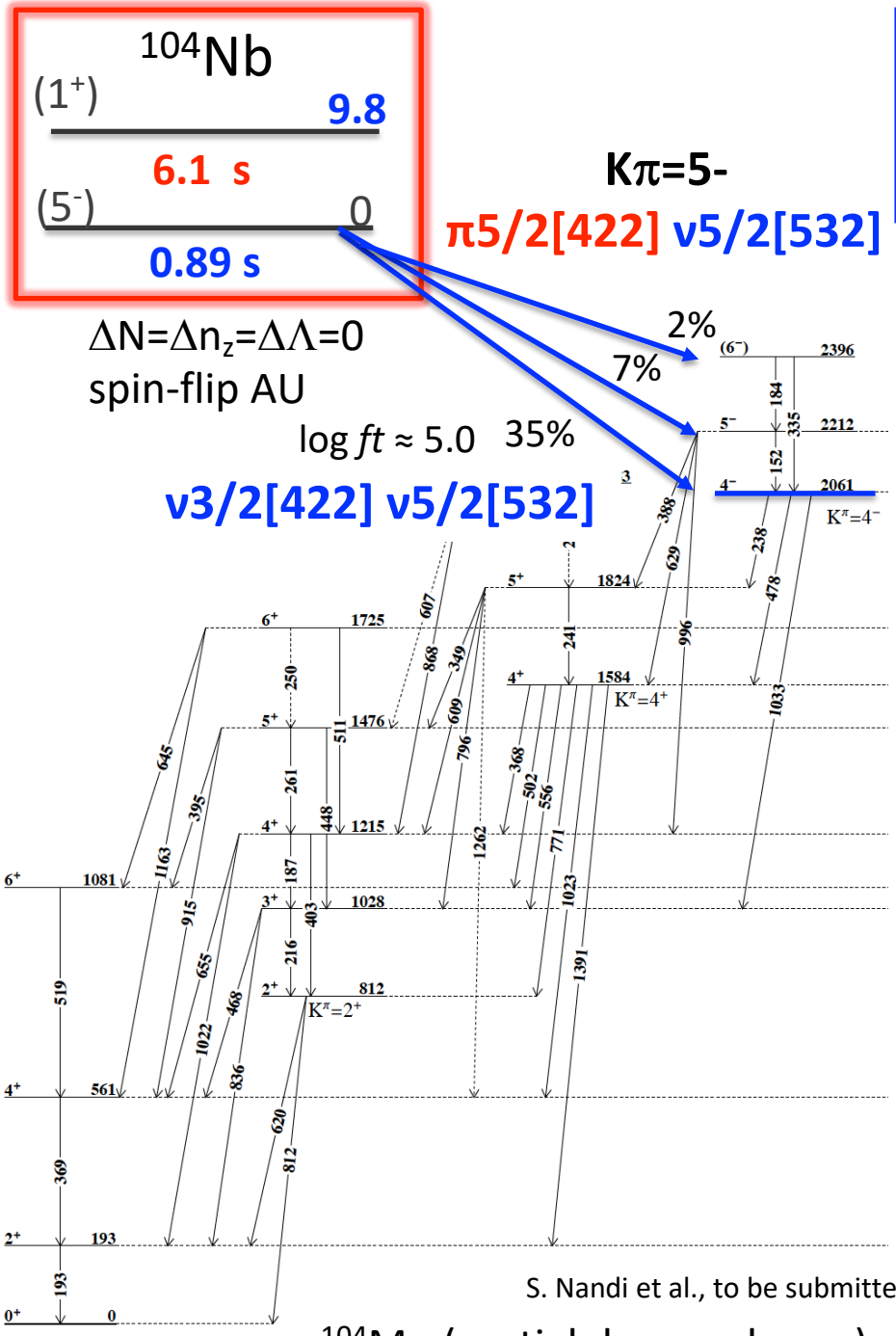
CARIBU @Gammasphere







S. Nandi et al., to be submitted



S. Nandi et al., to be submitted

^{104}Mo (partial decay scheme)

PHYSICAL REVIEW C **103**, 035803 (2021)

β-decay feeding intensity distributions for ^{103,104m}Nb

J. Gombas,[1,2,*] P. A. DeYoung,[1,†] A. Spyrou,[2,3,4,‡] A. C. Dombos,[2,3,4] A. Algora,[5,6] T. Baumann,[3] B. Crider,[3] J. Engel,[7] T. Ginter,[3] E. Kwan,[3] S. N. Liddick,[3,4,8] S. Lyons,[3,4,§] F. Naqvi,[3,4] E. M. Ney,[7] J. Pereira,[3,4] C. Prokop,[3,8] W. Ong,[3,2,4] S. Quinn,[2,3,4] D. P. Scriven,[2] A. Simon,[9] and C. Sumithrarachchi[3]

TAGS measurement using SUN at NSCL/MSU

- ^{104m}Nb is associated with 0.9 s the decaying state
- no decay scheme was established
- data discrepancy & different interpretation

TABLE III. $I_\beta(E)$ for ^{104m}Nb. All intensity values that were below 10^{-3}% were set to 0.

Energy (keV)	Intensity (%)	Error (±)	Energy (keV)	Intensity (%)	Error (±)
0	5.6	1.3			
192	0				
561	2.9	0.6	3210	1.4	0.4
812	2.2	0.7	3290	0	
886	0				
1028	0				
1080	0				
1215	0				
1275	0.02	0.06			
1469	0.4	0.3			
1475	1.7	0.4			
1545	0		4030	1.65	0.23
1583	1.9	0.3	4130	0.0	0.3
1607	0		4230	3.4	0.5
1611	0		4330	0.00	0.21
1624	0.3	0.3	4430	0	
1790	1.0	0.3	4530	0.00	0.08
1882	0		4730	2.3	0.3
2061	28.8	1.5	4930	0.84	0.21
2317	0		5130	0.40	0.11
2656	17.5	1.5	5330	1.0	0.3
2671	1.3	1.0	5530	0.7	0.3
2685	4.6	0.7	5730	0.8	0.3
2792	3.6	0.8	5930	0.6	0.5
2888	0		6030	0.02	0.07
2890	3.9	0.6	6530	1.6	0.3
2970	7.4	1.1	7030	2.2	0.5

0+

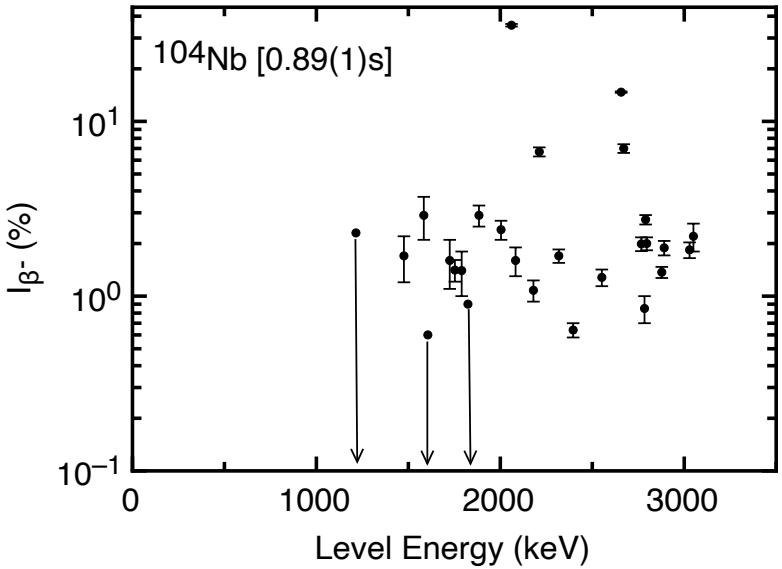
4+

5- to 0+; ΔJ=5 transition??

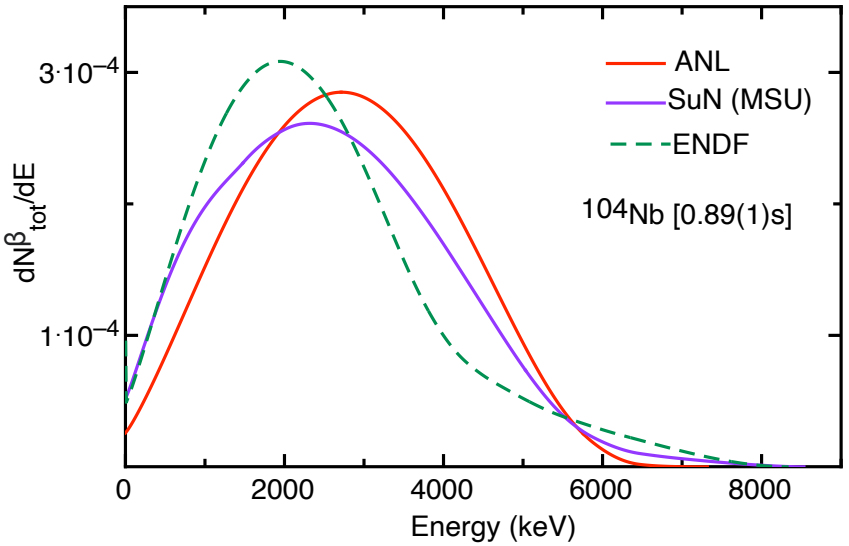
5- to 4+; ΔJ=1 transition
log *ft (exp)*=**7.4**, but
log *ft* ~ **12** for ΔK=5

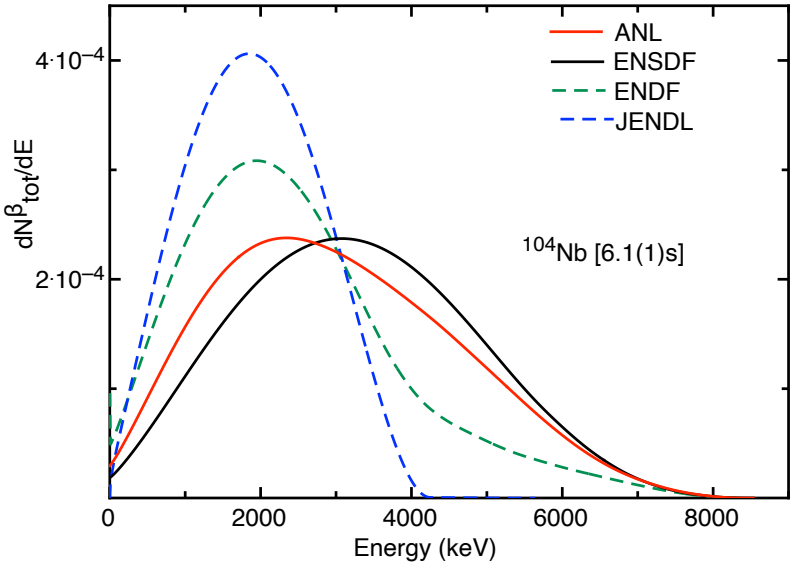
^{104}Nb - beta-decaying states

S. Nandi et al., to be submitted

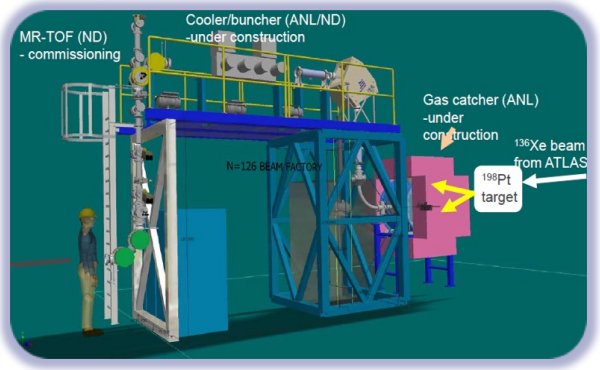


conversion using BETASHAPE, X. Mougeot

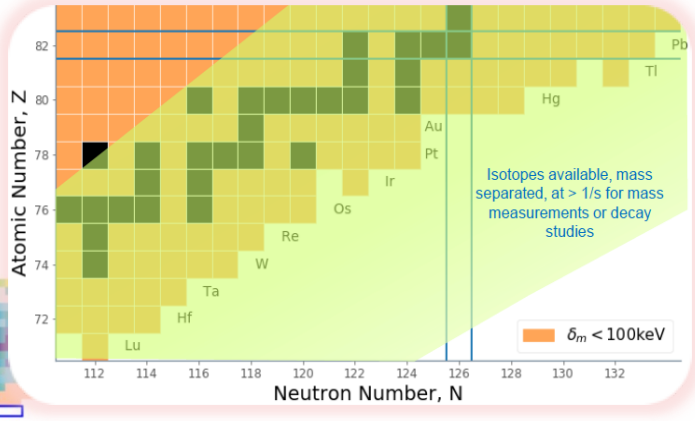




Outlook



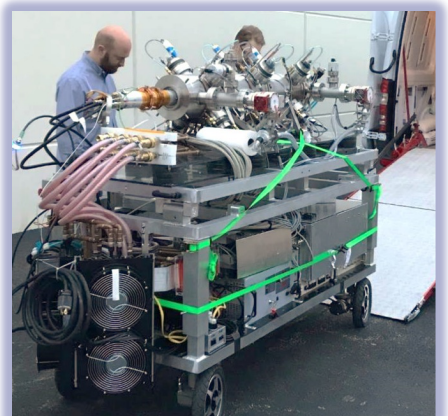
multi-nucleon transfer reactions



N=126 FACTORY
^{136}Xe + ^{198}Pt

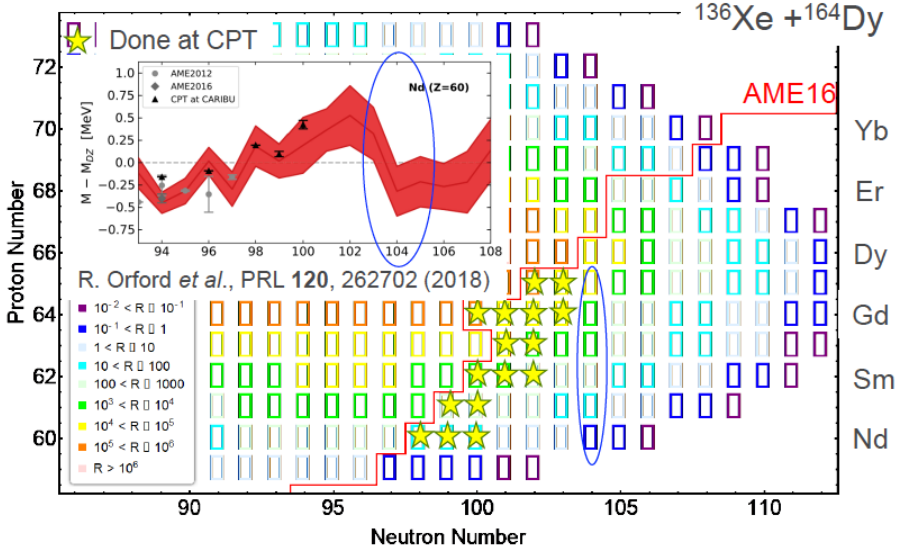
Rare-Earth FACTORY
^{136}Xe + ^{164}Dy

nuCARIBU



p+^{6,7}Li
6 MeV@0.5 mA

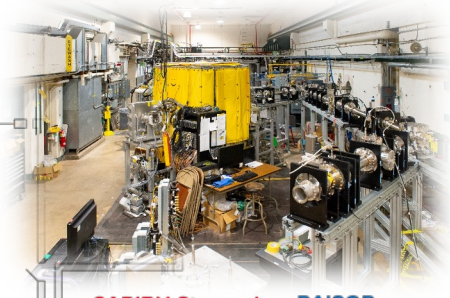
Best Cyclotron Systems

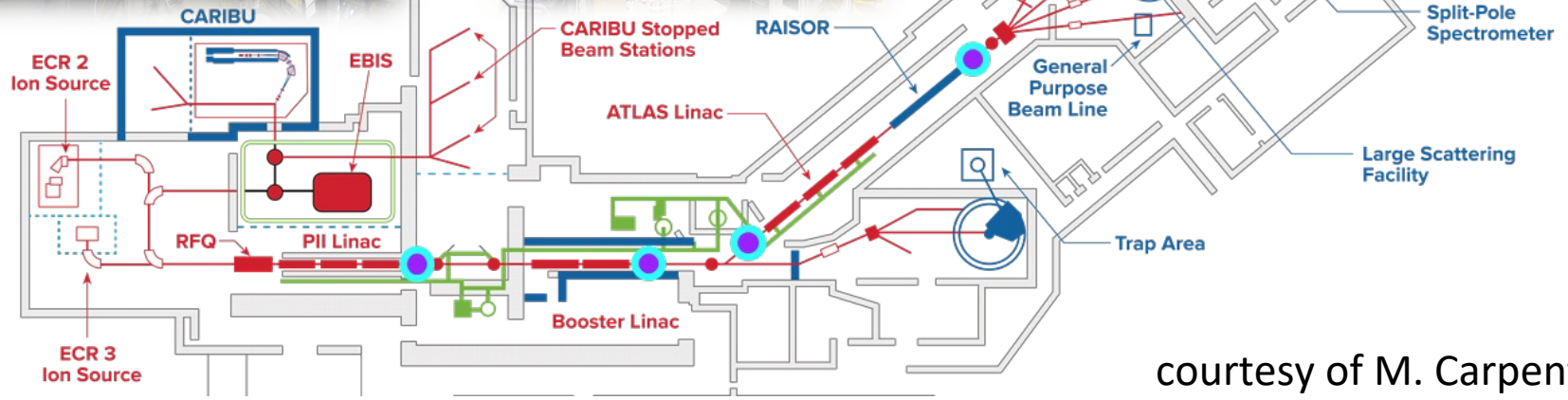


courtesy of G. Savard

- **Current status:** Gammasphere is located in area 4 – reacceleration of the CARIBU beam through the ATLAS facility is needed
  - ✓ loss of beam intensity – 10-100
  - ✓ unable to use the unique MR-TOF capabilities – loss of unambiguous separation of isobars
  - ✓ competition for beam time with the main research programs at ATLAS

- **What we plan to do:** move Gammsphere to area 1 and perform dedicated studies of high-priority cases – FP decay data factory





courtesy of M. Carpenter

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The β-decay Paul trap: A radiofrequency-quadrupole ion trap for precision β-decay studies

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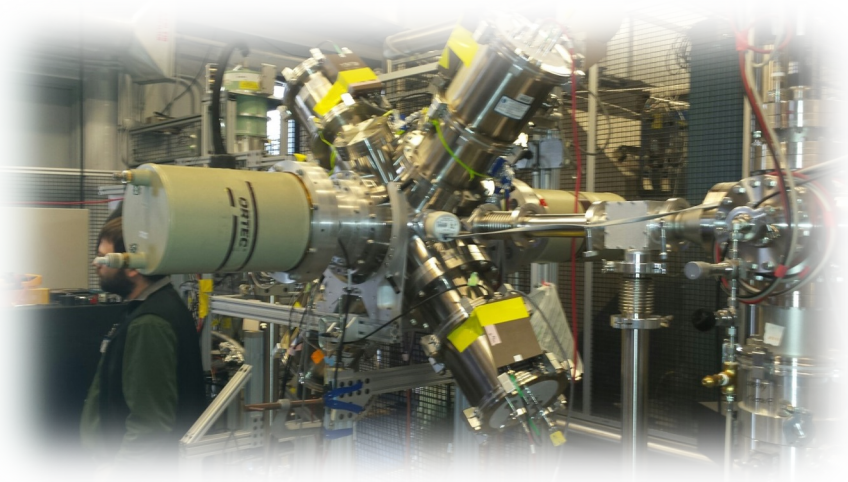
direct beta spectra measurements for selected (important) nuclei

- Beta detector system adapted from our ^{8}Li and ^{8}B beta-neutrino correlation measurements setup using beta-decay Paul trap

⇒ obtained one of the best low-energy limits on tensor currents, by fully reconstructed each events and obtained the full beta response function up to ~14 MeV

- The system will incorporate a tape transport system to move in activity and an array of HPGe detectors to obtained gamma-gated spectra of the lower energy branches



courtesy of G. Savard

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