# Structure of Neutron-Rich Nuclei in the A~160 Region via Beta Decay & Mass Measurements

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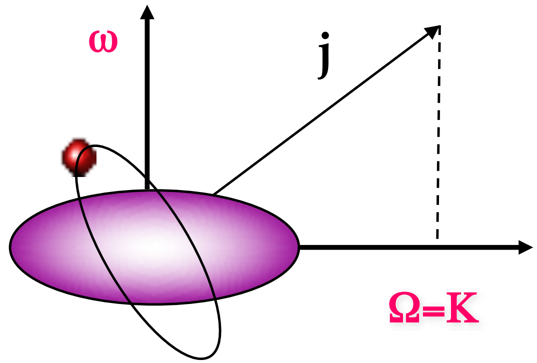
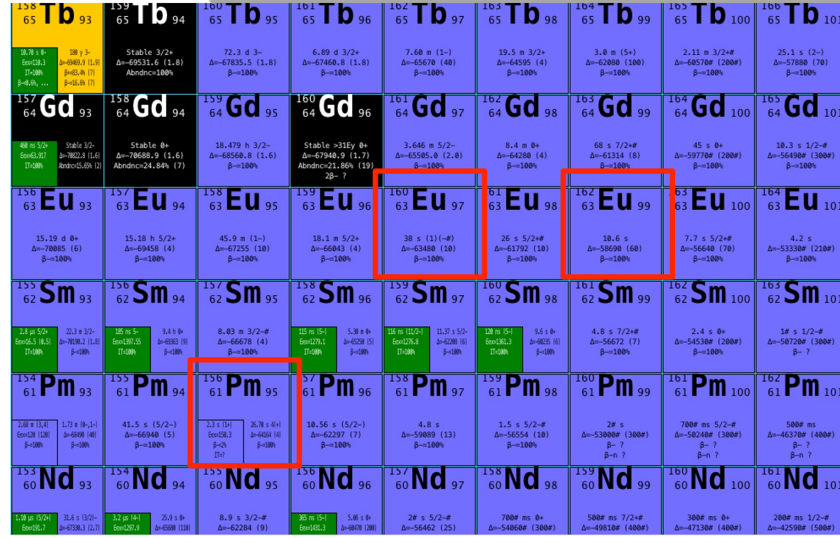
U.S. DEPARTMENT OF ENERGY | Office of Science

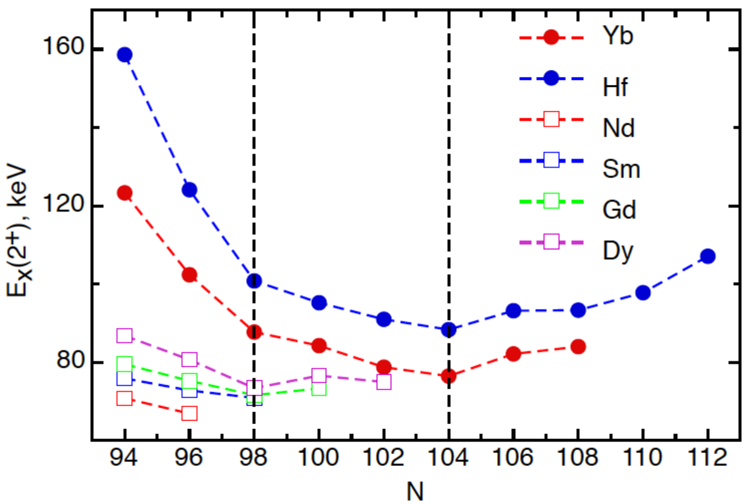
# Motivation



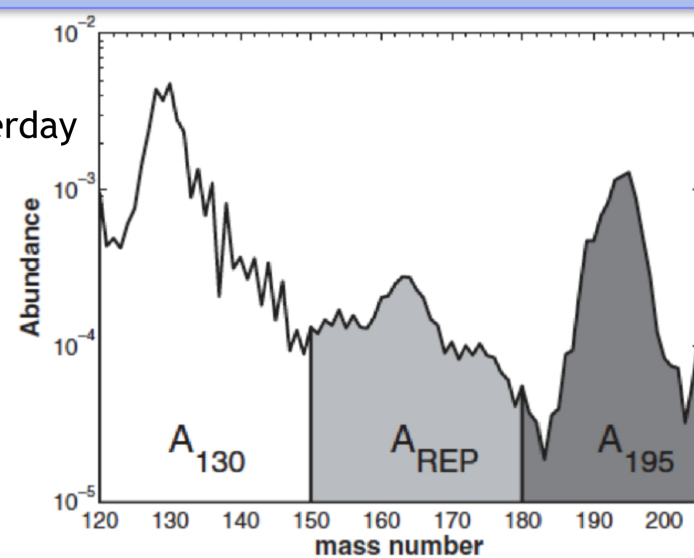



unusual structure behavior near N= 98

understanding the pygmy rare-earth peak depends on nuclear structure input




R. Surman (ND)
plenary talk yesterday




M.R. Mumpower, G.C. McLaughlin, R. Surman, PRC **86**, 035803 (2012)

- single-particle structure; size of deformation; pairing and residual interactions

- basic nuclear data: masses, $T_{1/2}$, Pn
- role of deformation on stellar rates

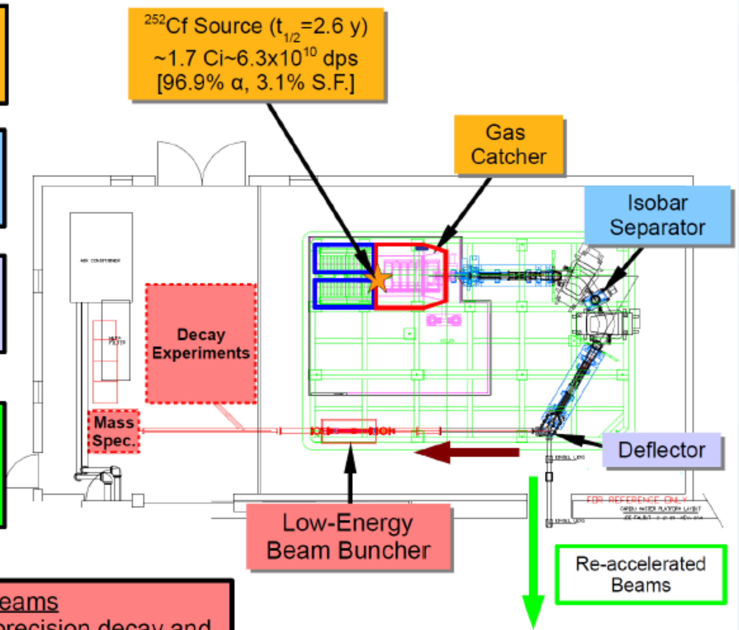
# CARIBU & ANL

$^{252}$Cf fission fragments are slowed and focused in a helium-gas catcher

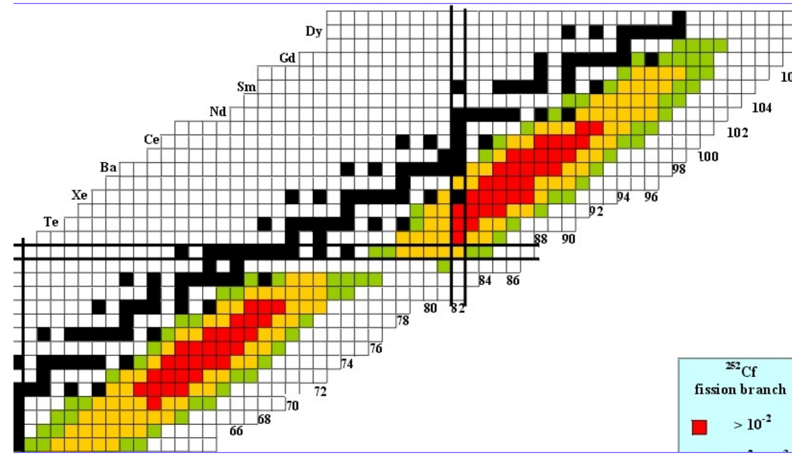
Beams of a desired mass are selected by a 120º magnetic isobar separator

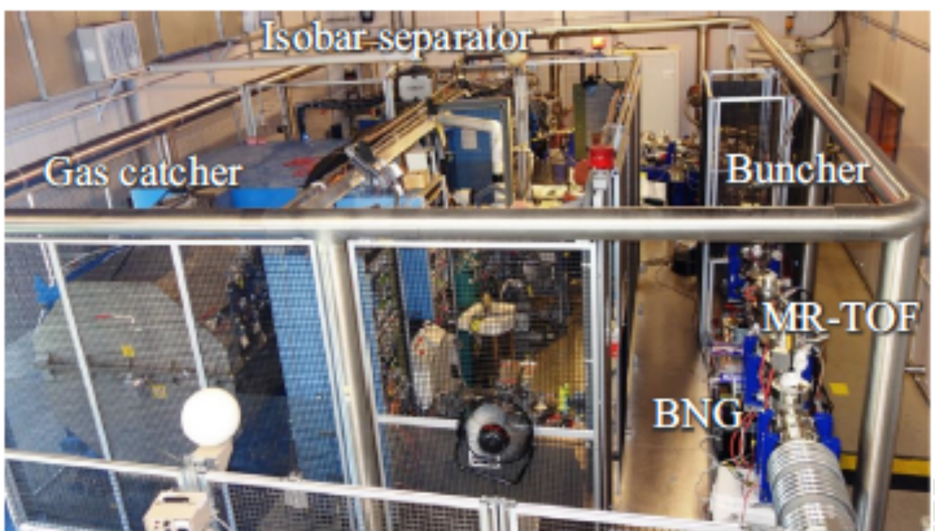
The neutron-rich beams can be deflected to low-energy or re-accelerated beam lines

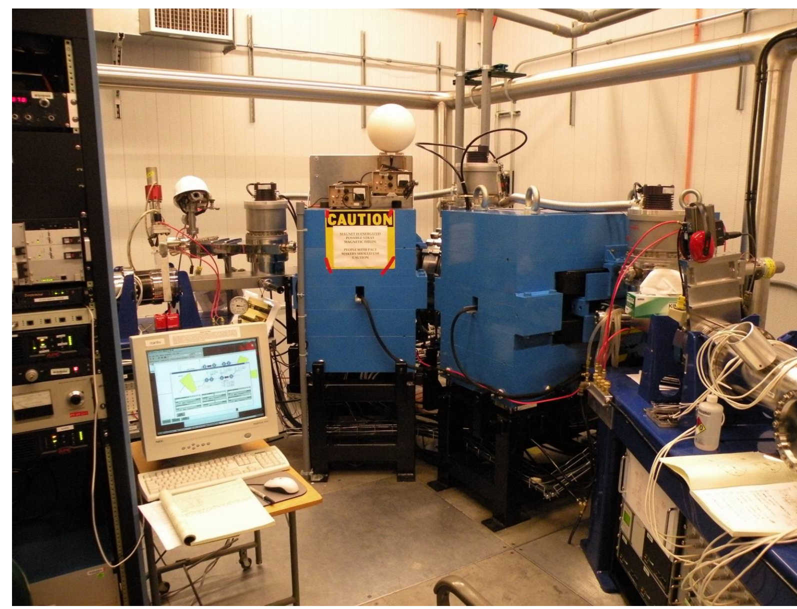
<u>Re-accelerated beams</u>
Charge bred and injected into ATLAS resulting in energies up to ~15 MeV/A




<u>Low Energy Beams</u>
Beams bunched for use in precision decay and mass spectrometry experiments




mass resolving power R~10000

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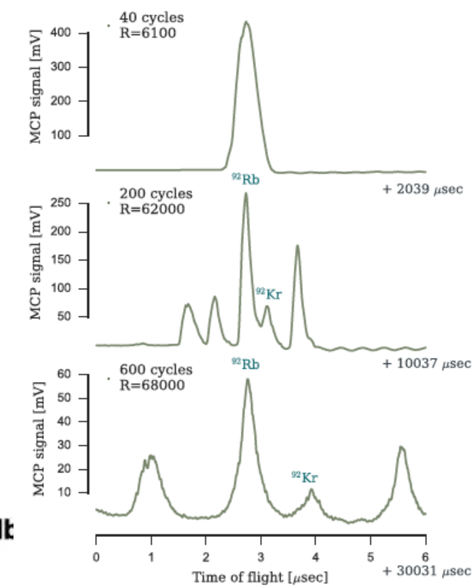
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

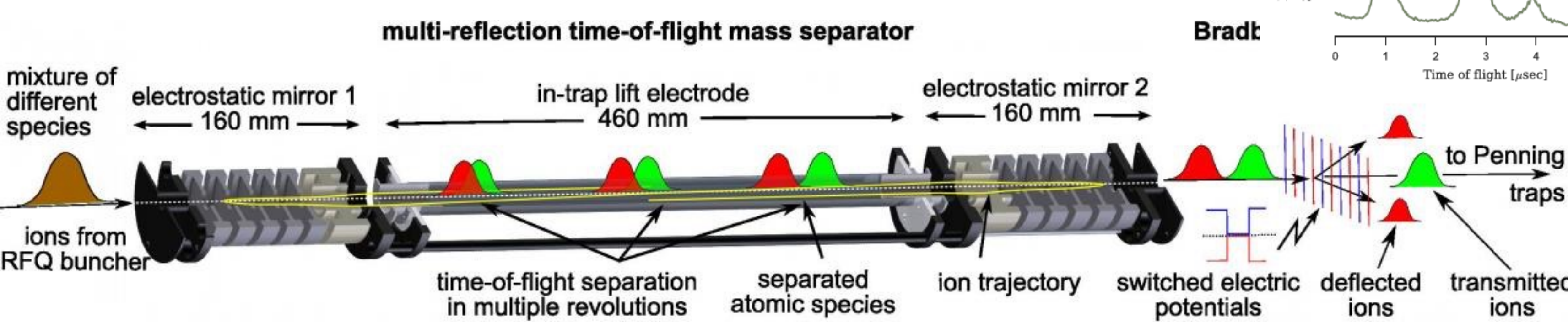
# First operation and mass separation with the CARIBU MR-TOF

Tsviki Y. Hirsh [a,b,*], Nancy Paul [b,c], Mary Burkey [b,d], Ani Aprahamian [c], Fritz Buchinger [e], Shane Caldwell [b,d], Jason A. Clark [b], Anthony F. Levand [b], Lin Ling Ying [b], Scott T. Marley [c], Graeme E. Morgan [a,b], Andrew Nystrom [b,c], Rodney Orford [b,e], Adrian Pérez Galván [b,a], John Rohrer [b], Guy Savard [b,d], Kumar S. Sharma [a], Kevin Siegl [b,c]




'Fast' isobar separator:

- based on ISOLTRAP/ISOLDE design
- ~ 1.3 m long MR-TOF
- currently mass resolving power, R~50,000 with ~50% transmission in ~15 ms



# CARIBU low-energy experimental area

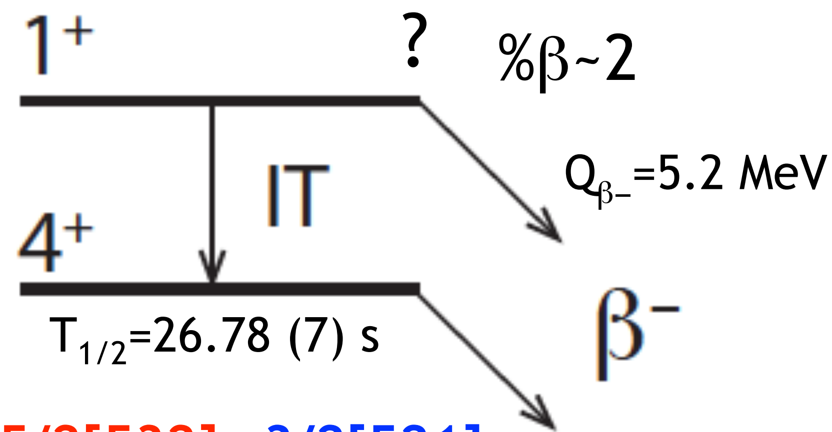
- Delivers 1.5 kV to 10 kV beam to experimental stations
- Pulsed beams with rates from ~ 50 ms to seconds
- Low emittance

**CPT**

**TAPE STATION**

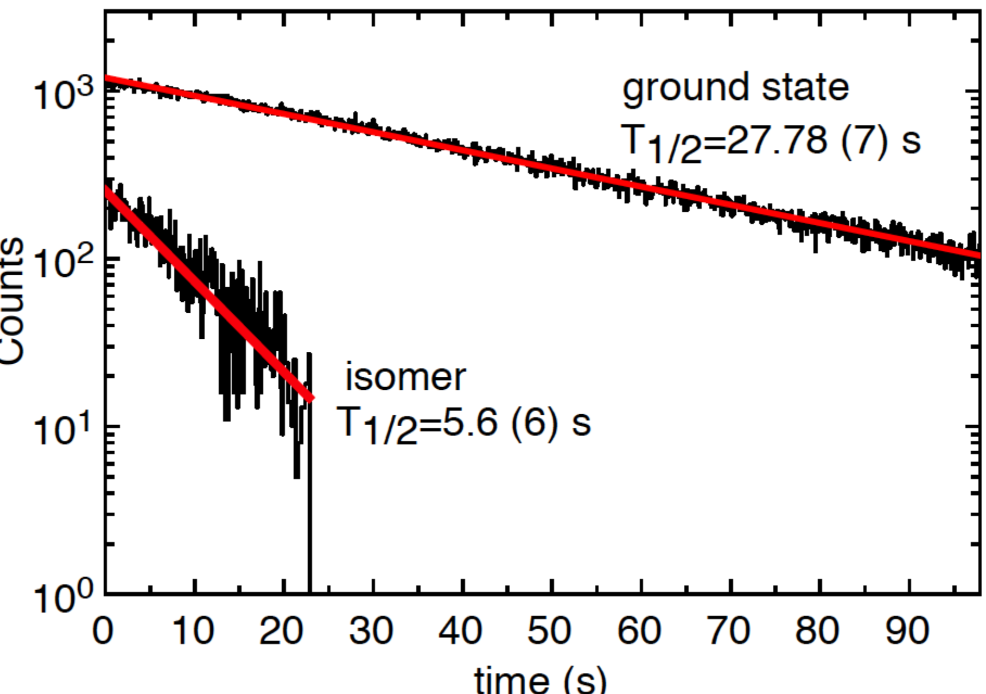
**X-ARRAY**

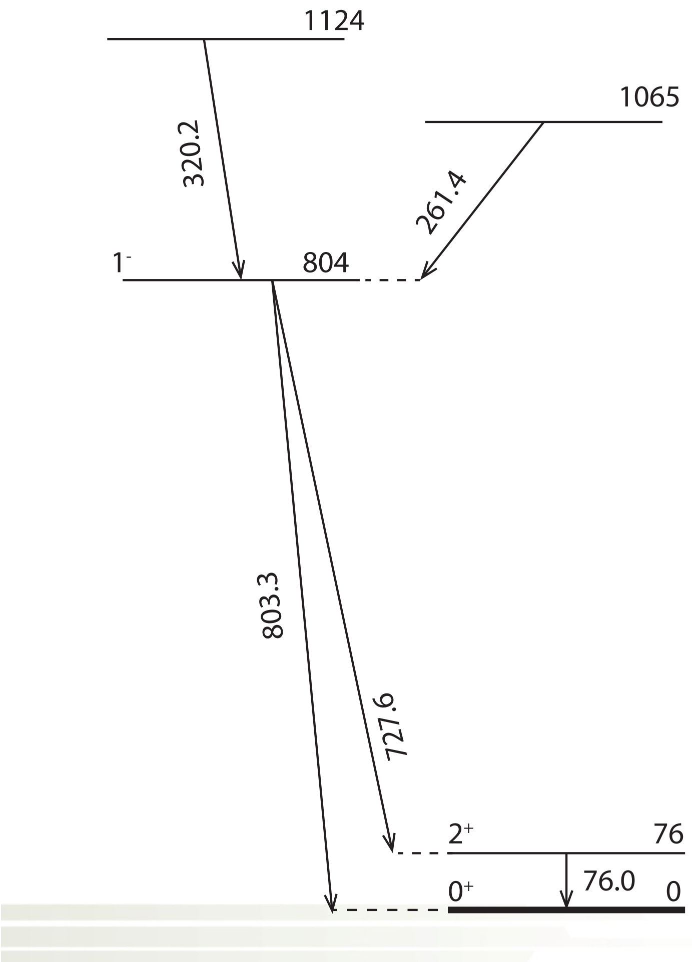
# Studies of $^{156}$Pm (N=95): low-spin isomer




π5/2[532] ν3/2[521]

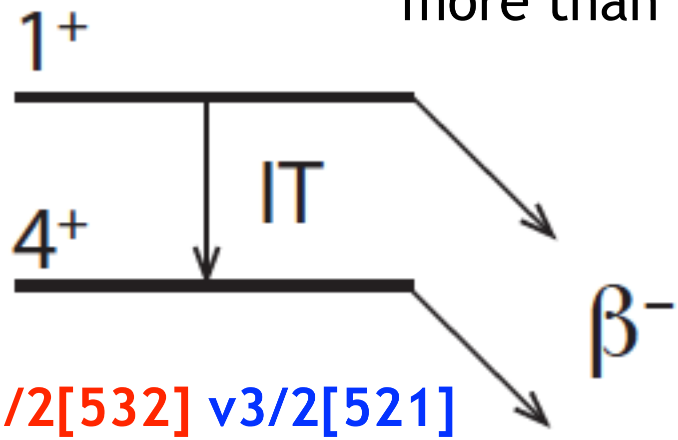
- speculations about the Jπ and the structure of the g.s. and isomer
- unknown $T_{1/2}$ for the isomer



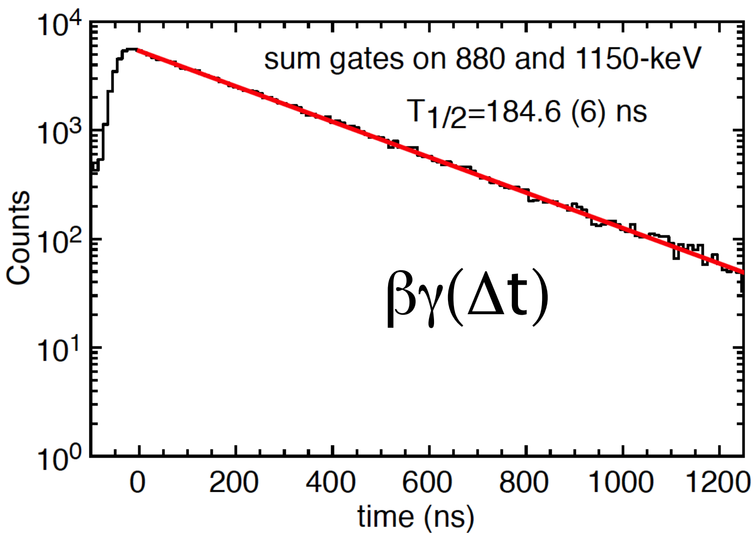



# Studies of $^{156}$Pm(N=95): high-K states

more than 50 levels & 200 γ-ray transitions



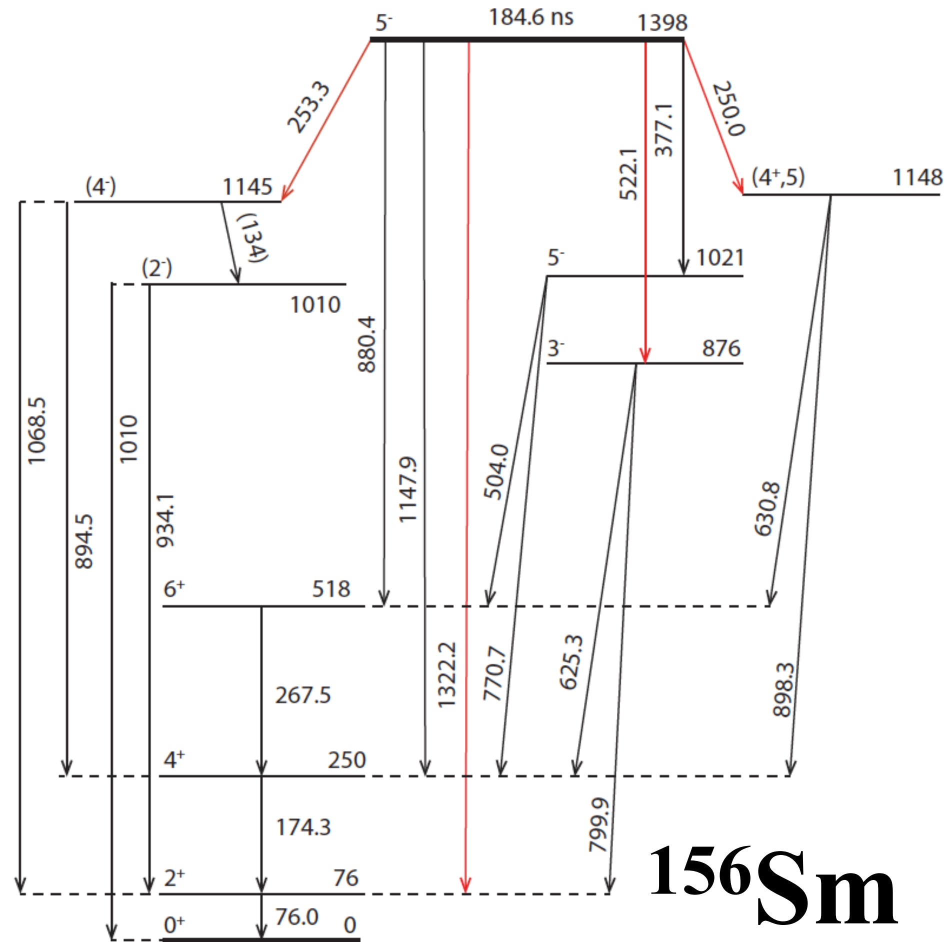

π5/2[532] ν3/2[521]




B(E3)=0.0100 (6) W.u.

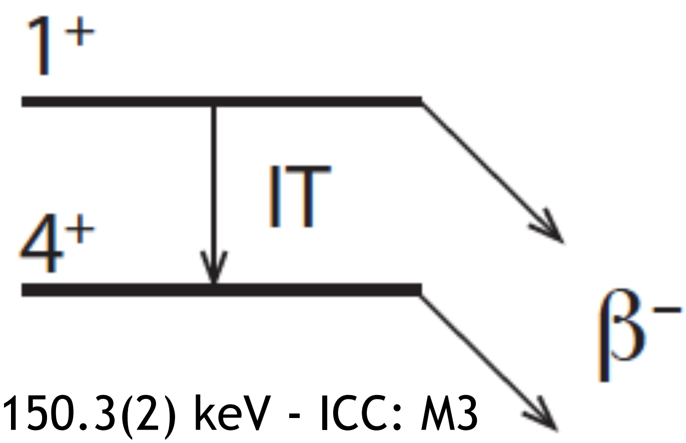
F.G. Kondev, G.D. Dracoulis & T.X. Kibedi, ADNDT **103-104** (2015) 50

π5/2[532] π5/2[413] **K$^{\pi}$=5- isomer**




... significant differences with the TAGS data of Greenwood ...

# Studies of $^{156}$Pm: isomer excitation energy



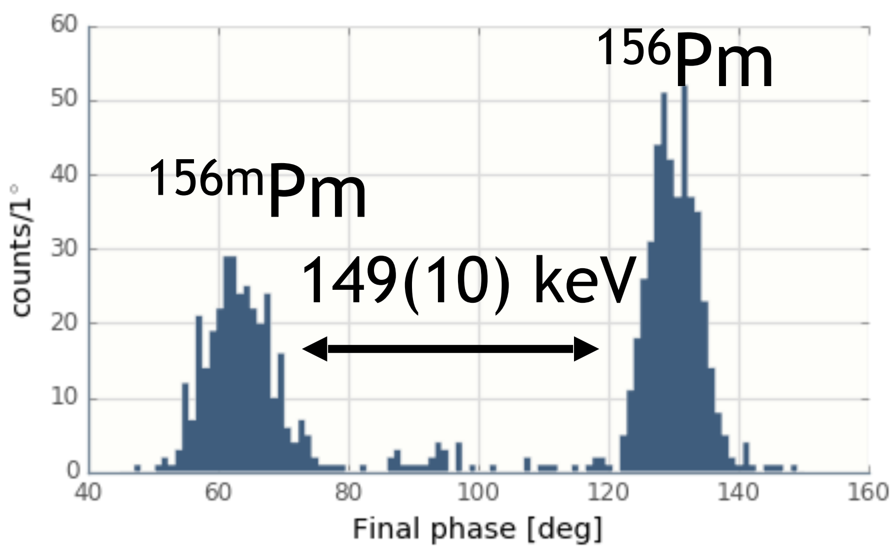

$\Delta E = 150.3(2)$ keV - ICC: M3

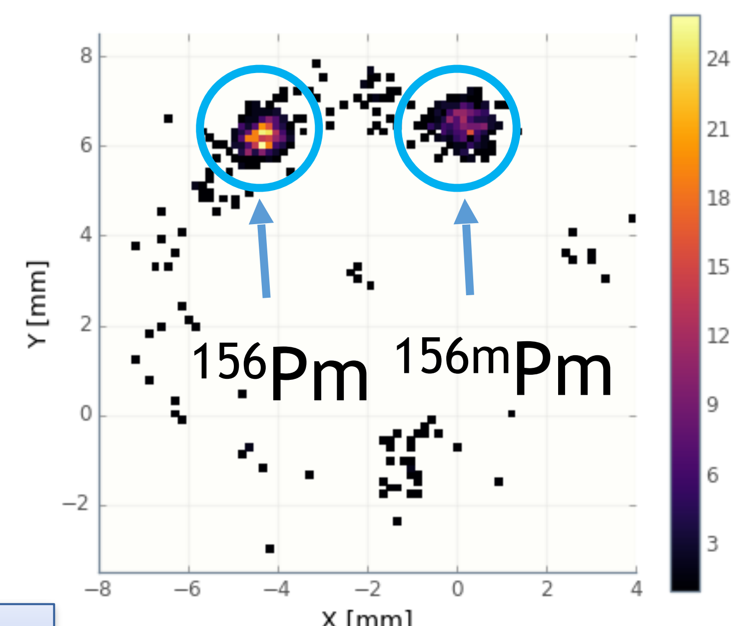
M. Shibata et al., EPJ A31, 171 (2007)

**π5/2[532] ν3/2[521]**

$\Delta E_x =$
- 50 keV - δ force
- 118 keV - central force + spin polarization
- 140 keV - + tensor and long-range force

J.P. Boisson et al., Phys. Rep. **26**, 99 (1976)

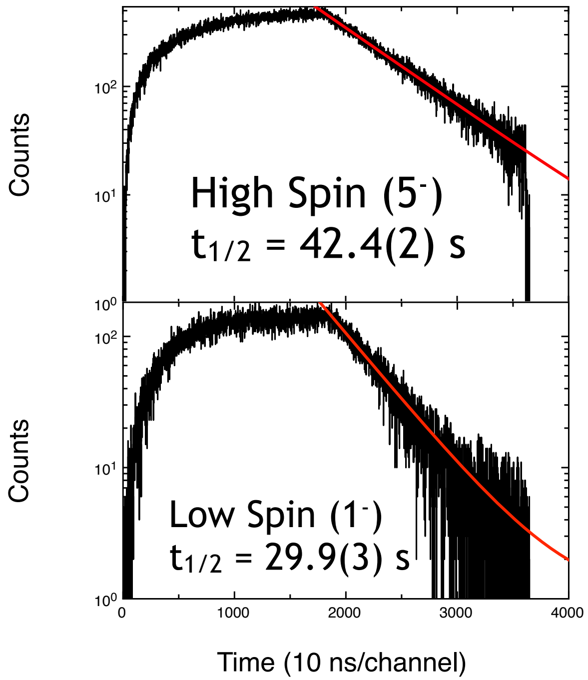



phase-imaging ion-cyclotron-resonance technique

S. Eliseev *et al.*, Phys. Rev. Lett. **110**, 082501 (2013)

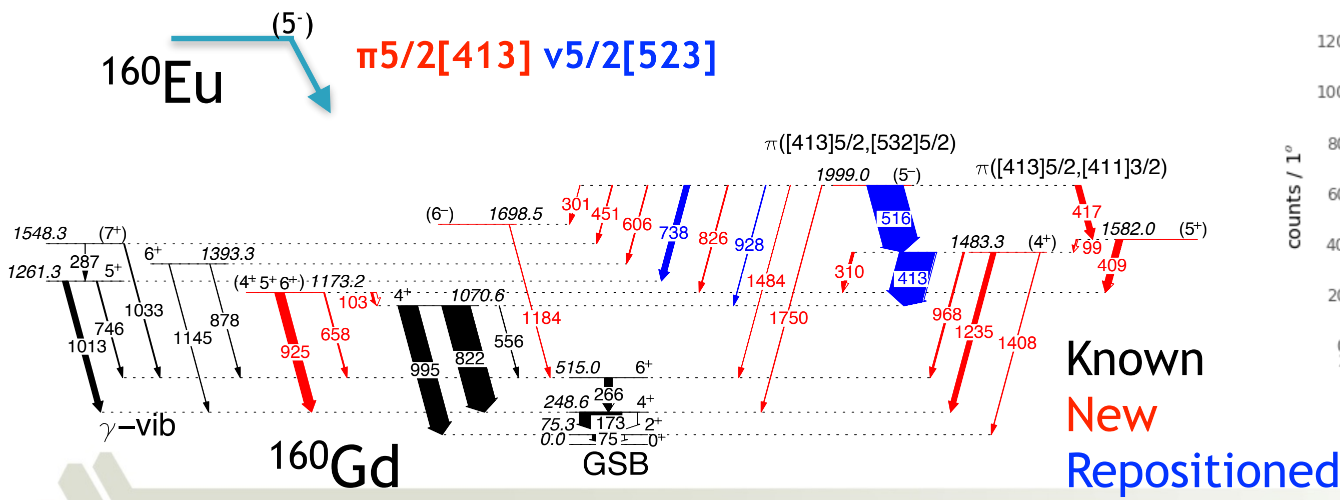
# Studies of $^{160}$Eu (N=97)

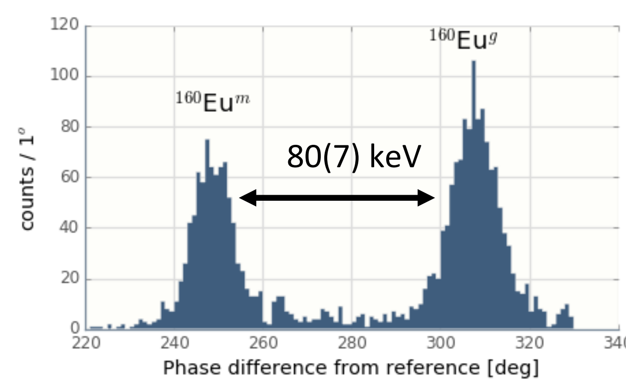



**Previous $t_{1/2}$:** 31(4) s, 41(4) s, 50(10)s, 53(10)s, assuming a single (low-spin) β-decaying state
**Present:** lifetimes of γ's fell into 2 values (2 isomers)

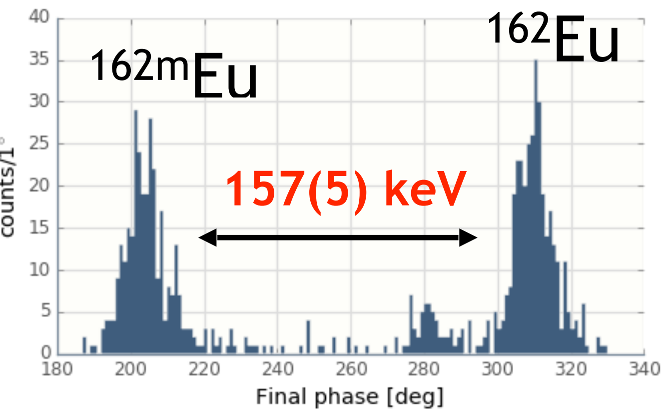
**π5/2[413] ν5/2[523] -> $K^{\pi}$ = $5^-$ & $0^-$**

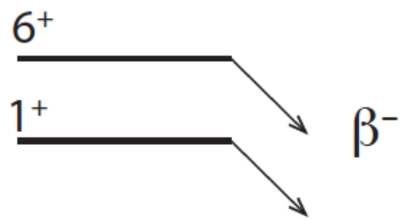
Two different decay schemes proposed for $^{160}$Gd, ours differs from both!
1999-keV state most strongly fed by $K^{\pi}$ = $5^-$, $t_{1/2}$=42 s isomer; log*ft* ≈ 5.0 -> related configurations



# Studies of $^{162}$Eu (N=99)

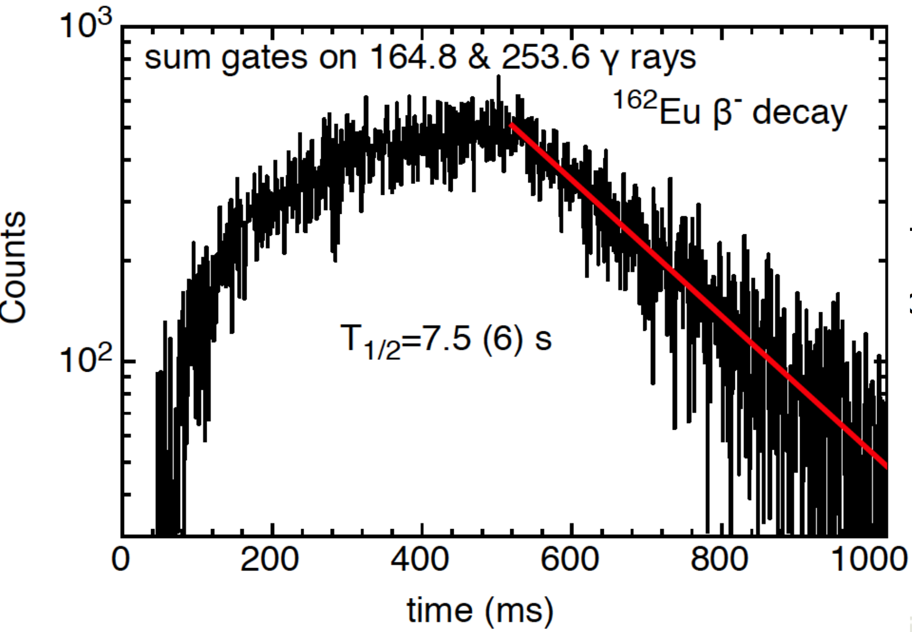


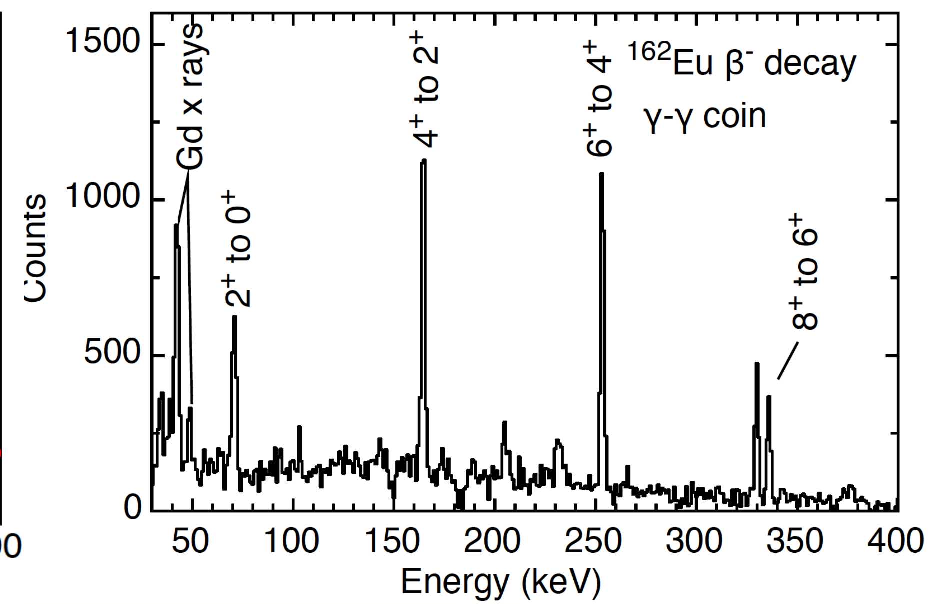




**π5/2[413] ν7/2[633]**

10.6 (1) s from Gd X-rays
Greenwood et al. PRC 35 (1987) 1065

deviations from WS predictions (ordering of the 1/2[521] and 7/2[633] neutron orbitals): **ν$p_{3/2}$** higher compared to **ν$i_{13/2}$**



# Outlook & Conclusions

- direct mass measurements in conjunction with detailed ß-decay studies are powerful tool to elucidate properties of neutron-rich nuclei

- CARIBU produces high-quality LE beams with sufficient yield for detailed spectroscopy - examples on $^{156}$Pm, $^{160,162}$Eu - decay properties, isomers, excitation energies …

- limitations - the high background in the LE area - a new beam line has been built and will be operational early next year

- future DIC & MNT using Gammasphere ($^{160}$Gd beam on $^{154}$Sm and $^{164}$Dy targets) to look for in-beam structures

Ning Wang and Lu Guo, Phys. Lett. **B 760**, 236 (2016)