Enhanced octupole collectivity in ^{148}Dy

Pietro Spagnoletti

GRIFFIN Collaboration

IOP Brighton 2026

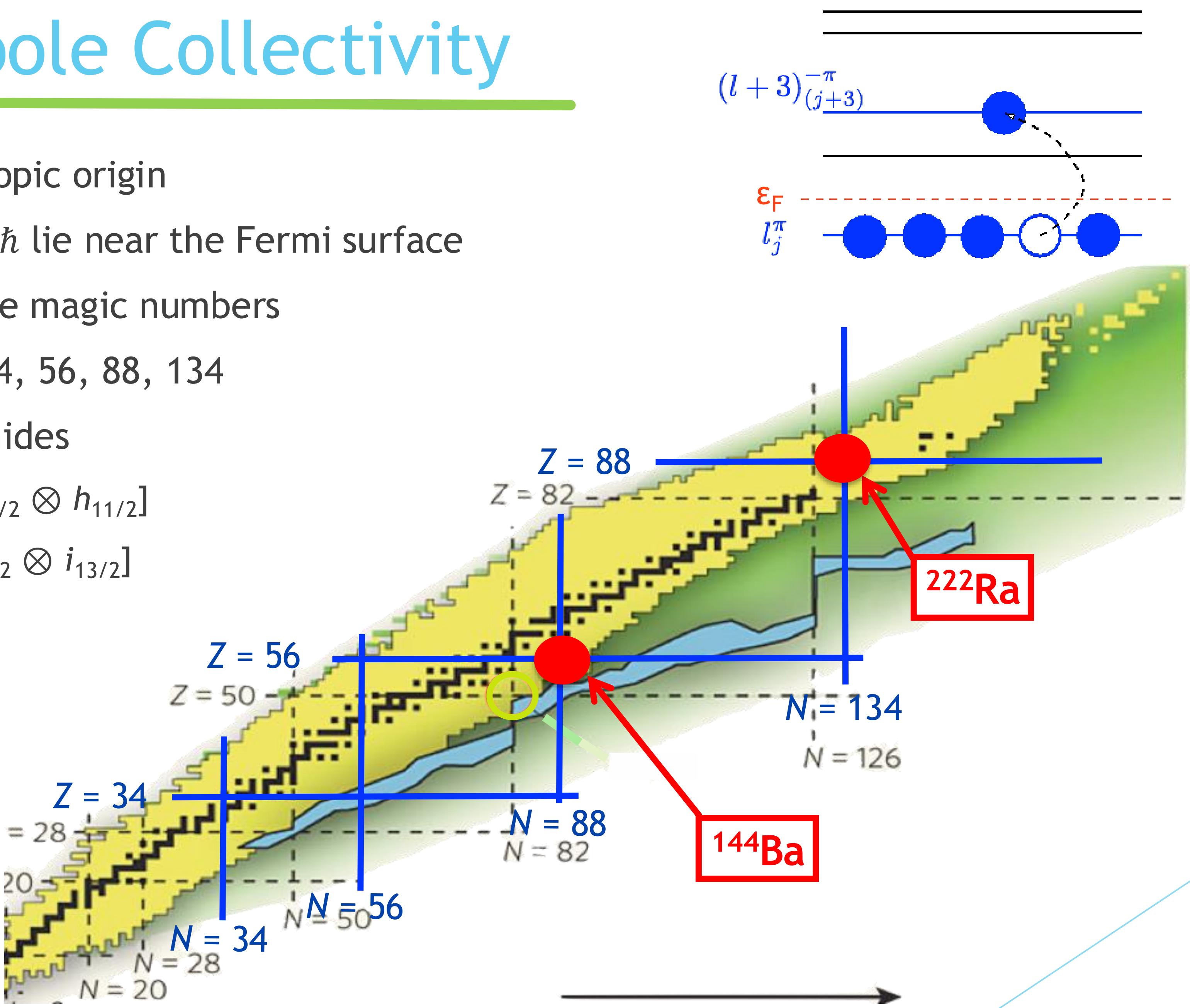
GRIFFIN

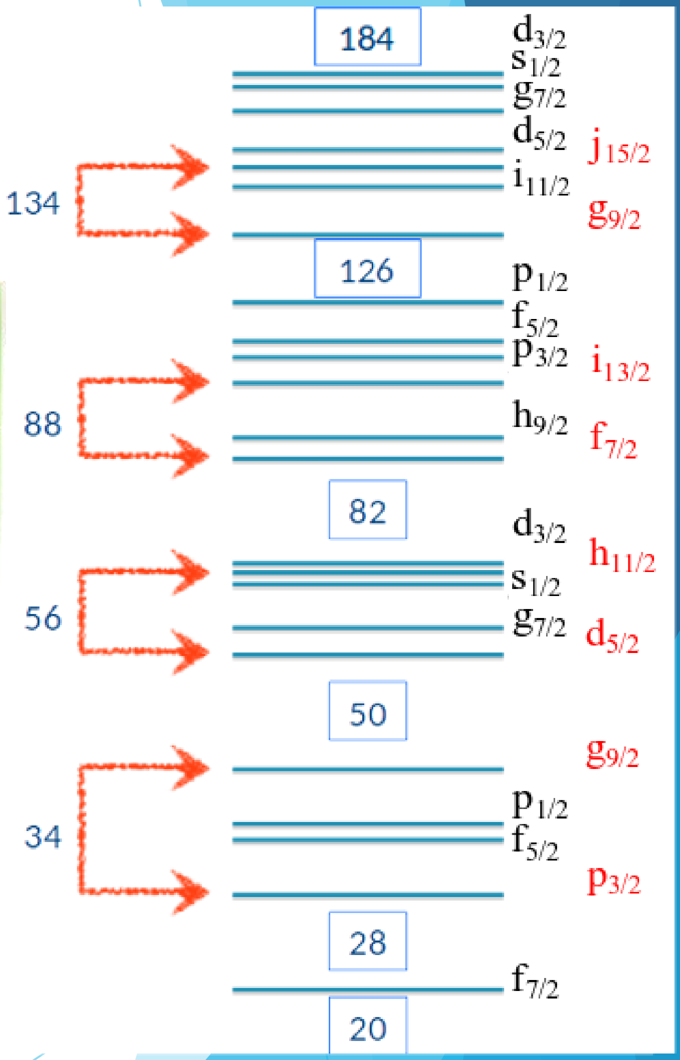
UNIVERSITY OF LIVERPOOL

TRIUMF

Octupole Collectivity

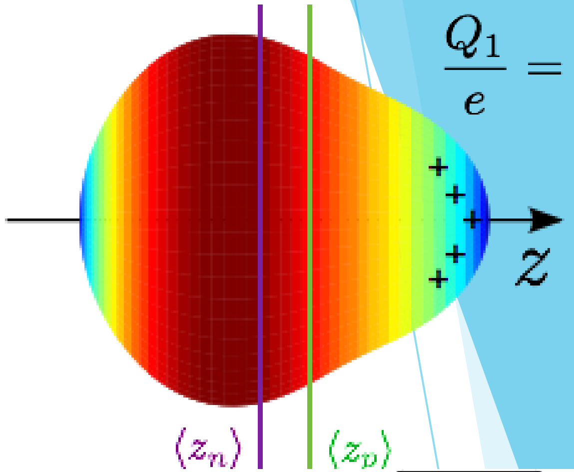
- Microscopic origin
- $\Delta j=\Delta l=3\hbar$ lie near the Fermi surface
- Octupole magic numbers
- N,Z ≈ 34, 56, 88, 134
- Lanthanides
  - $\pi[d_{5/2} \otimes h_{11/2}]$
  - $\upsilon[f_{7/2} \otimes i_{13/2}]$





Measuring Octupole Collectivity

$$\frac{Q_1}{e} = \frac{N}{A}\langle z_p \rangle - \frac{Z}{A}\langle z_n \rangle$$

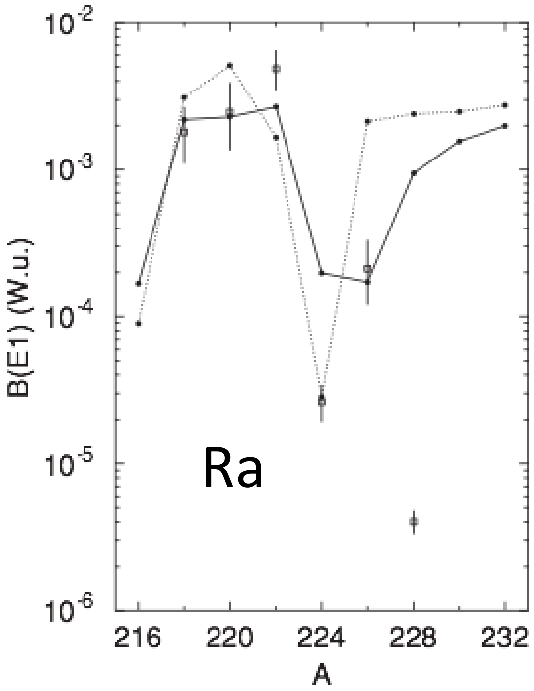


B(E1)

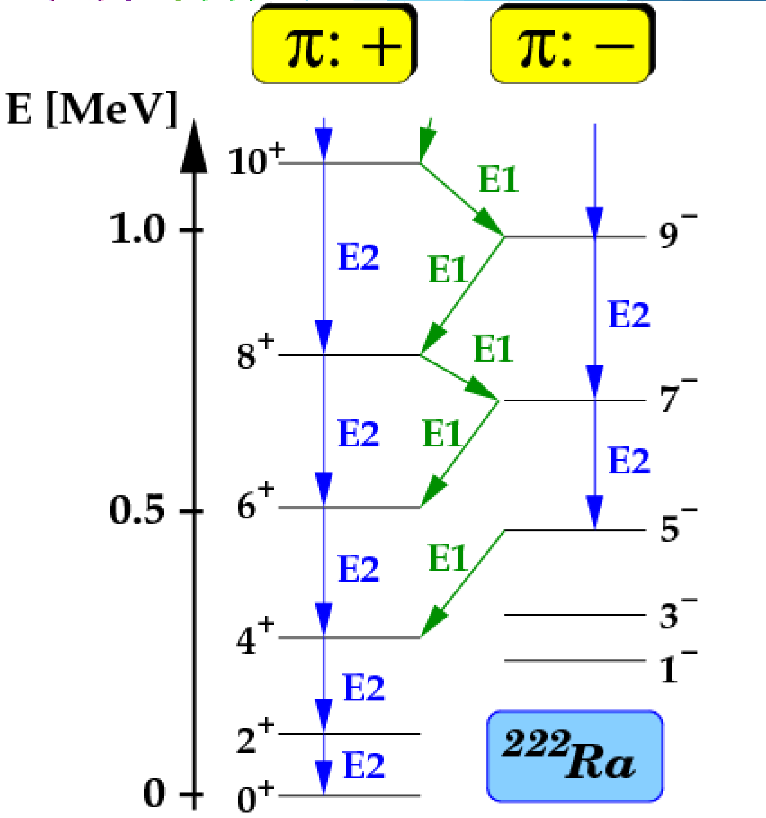
- Nuclear pear shape gives rise to electric dipole moment
  - Enhanced B(E1) transitions.
- Dipole moment has microscopic and macroscopic contributions.

B(E3)

- Less sensitive to single particle effects
- Direct measure of octupole collectivity
- Difficult to access E3 transitions
  - E3 competes weakly against E1/E2
- Coulomb Excitation usually best.
  - This work: beta-decay



L.M. Robledo et al., Phys. Rev. C ***81**, 034315 (2010)*



J.F.Cocks et al., PRL 78, 2920 (1997)

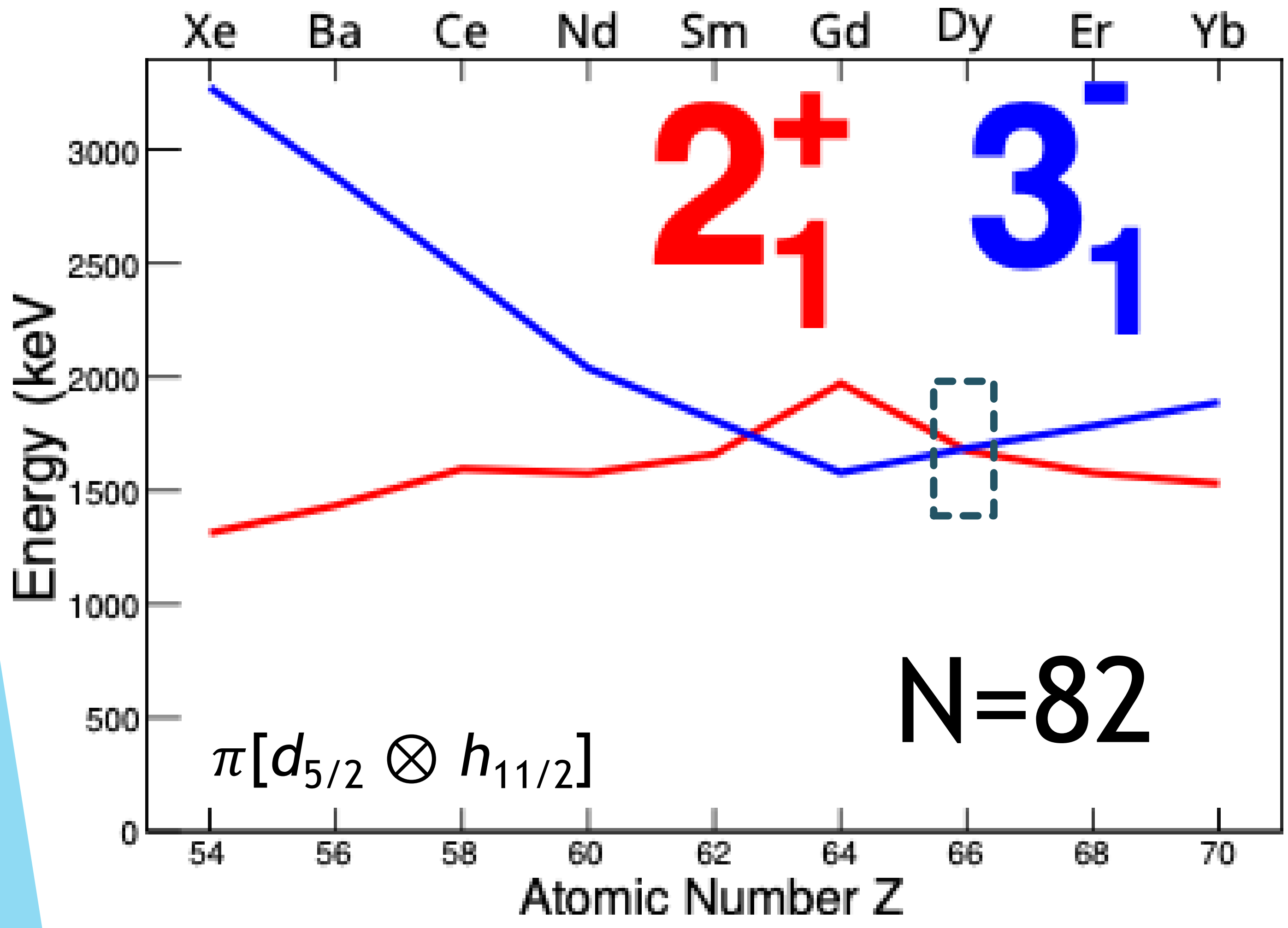
Evolution at N = 82

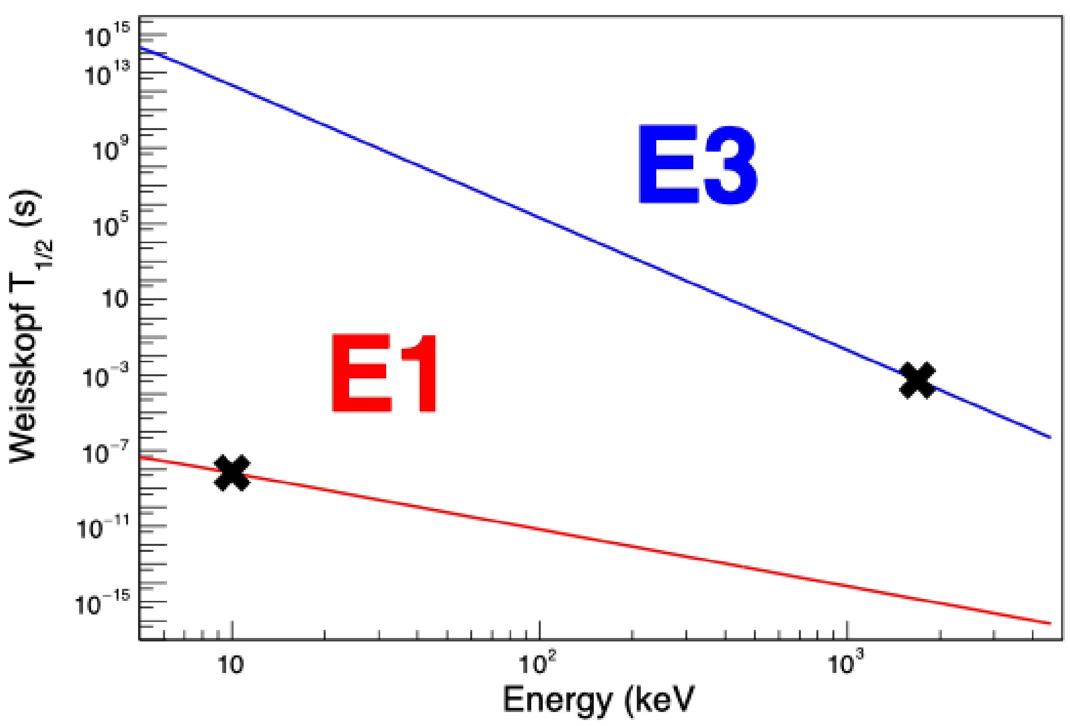
$E_x(3_1^-) = 1687\ keV$

$E_x(2_1^+) = 1677\ keV$

$E_\gamma(3_1^- \rightarrow 0_1^+) = 1687\ keV$

$E_\gamma(3_1^- \rightarrow 2_1^+) = 10\ keV$





E3 Collective ~10s W.u.

E1 Suppressed 10^{-6} - 10^{-3} W.u.

Rare-earth region
Z=56, N=88

- Best studied region!
- Missing puzzle pieces.
- Increasing B(E3) with Z!
- Drop in B(E3) at N=90
- How to measure B(E3) in ^{148}Dy?

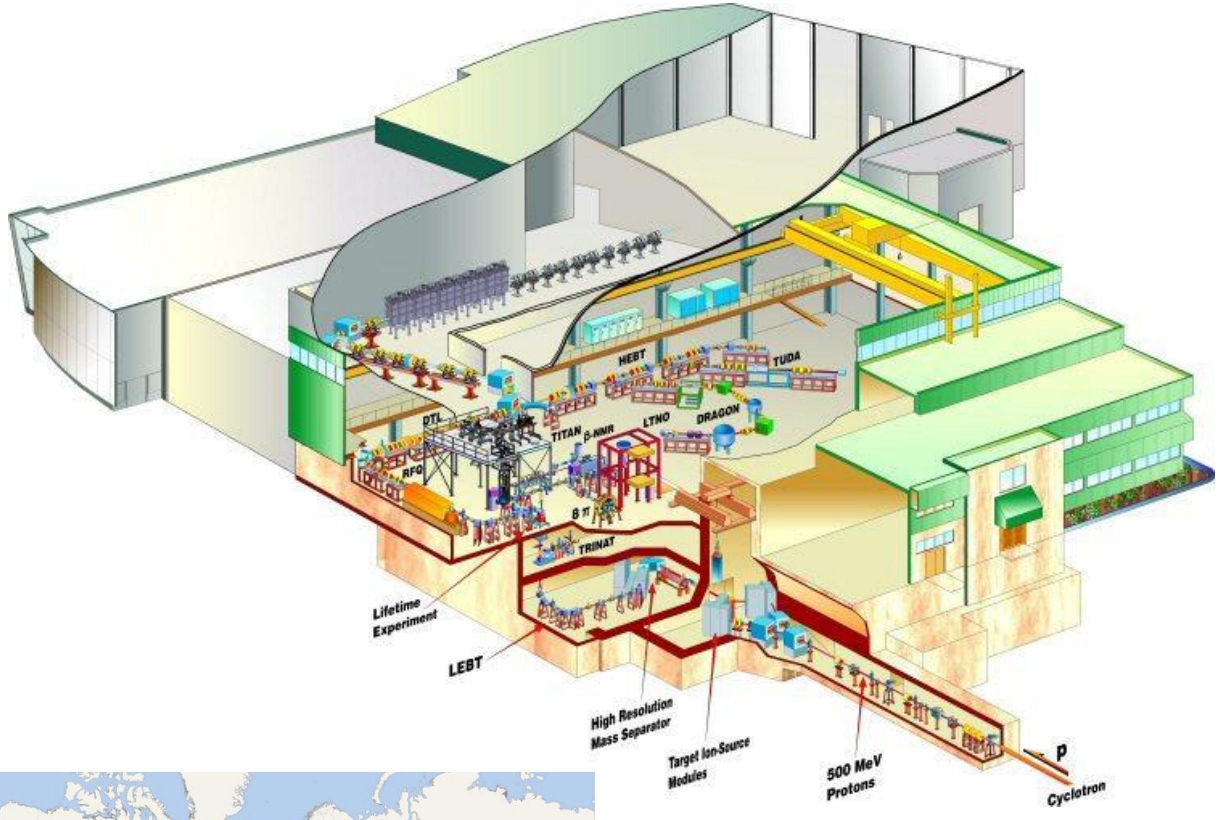
$$B(E3;3_1^- \rightarrow 0_1^+) = \frac{0.02947}{E_\gamma^7 \boldsymbol{\tau_{E3}} A^2}$$

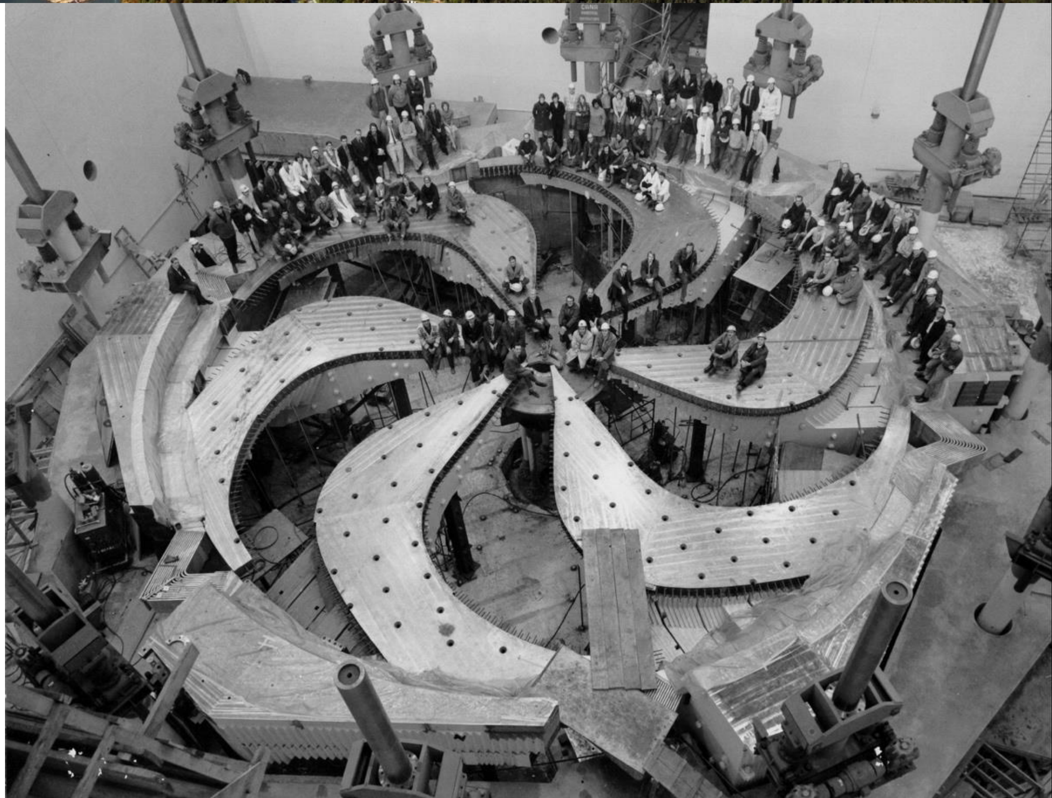
$$\tau_{E3} = \frac{\tau(3_1^-)}{BR_\gamma^{Abs}(E3;3_1^- \rightarrow 0_1^+)}$$

Z \ N	82	84	86	88	90	92	94	96	
68							17 ±4	13 ±3	Er
66	★				22 ±7	22 ±5	16.1 ±0.9	9.5 ±0.6	Dy
64	37 ±5	42 ±6	45 ±5	52 ±17	21 ±5	16.9 ±0.7	11.9 ±0.7	11.4 ±0.7	Gd
62	36 ±3		39 ±3	33 ±3	14.2 ±1.6	10 ±2			Sm
60	30 ±3	30.5 ±1.2	30 ±3	34 ±3	19 ±2				Nd
58	24.8 ±1.6	24.0 ±1.6							Ce
56	16.8 ±1.7		22*	48^{+25}_{-34}	48^{+21}_{-29}				Ba
54	17 ±6			5^{+8}_{-5}					Xe

$B(E3;3_1^- \rightarrow 0_1^+)$

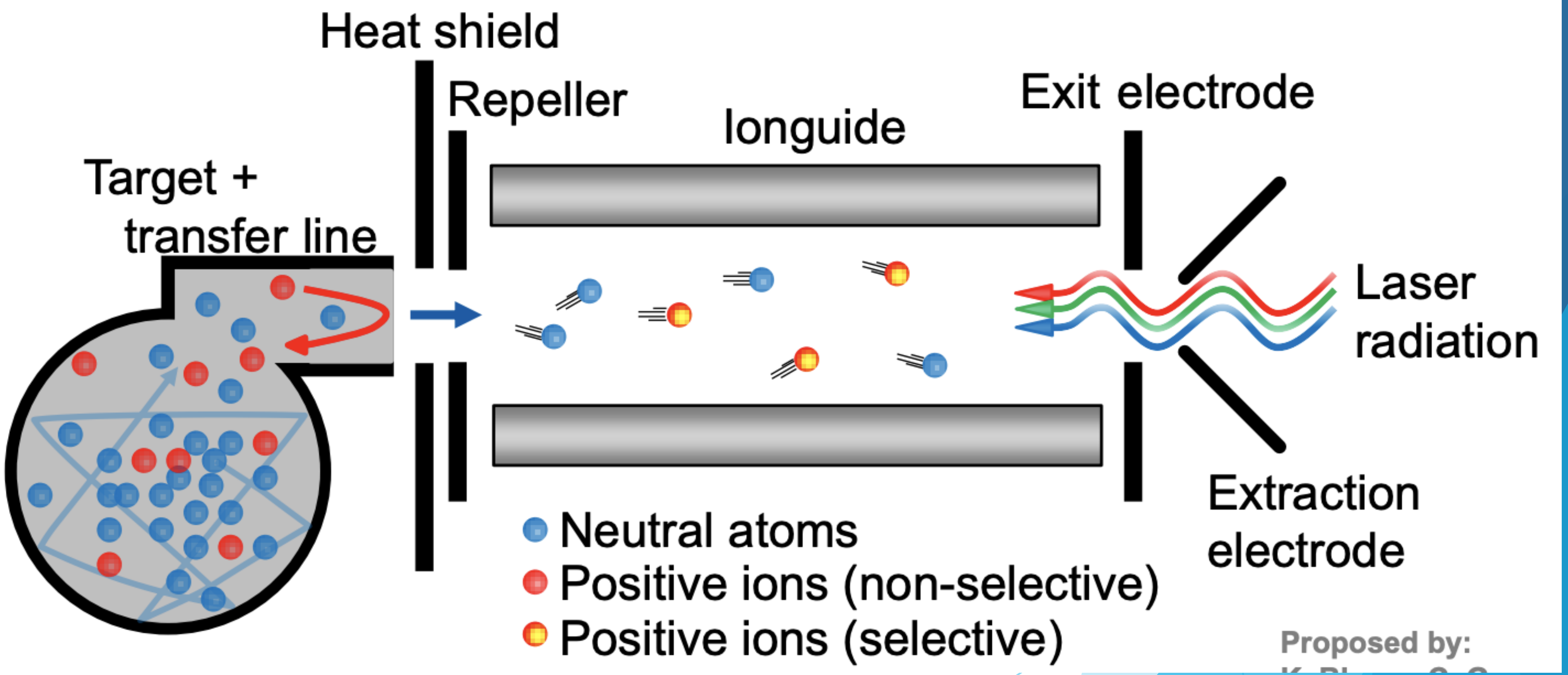
TRIUMF


HEBT
TUDA
DTL
TITAN
β-NMR
LTNO
DRAGON
RFQ
8π
TRINAT
Lifetime Experiment
LEBT
High Resolution Mass Separator
Target Ion-Source Modules
500 MeV Protons
p
Cyclotron



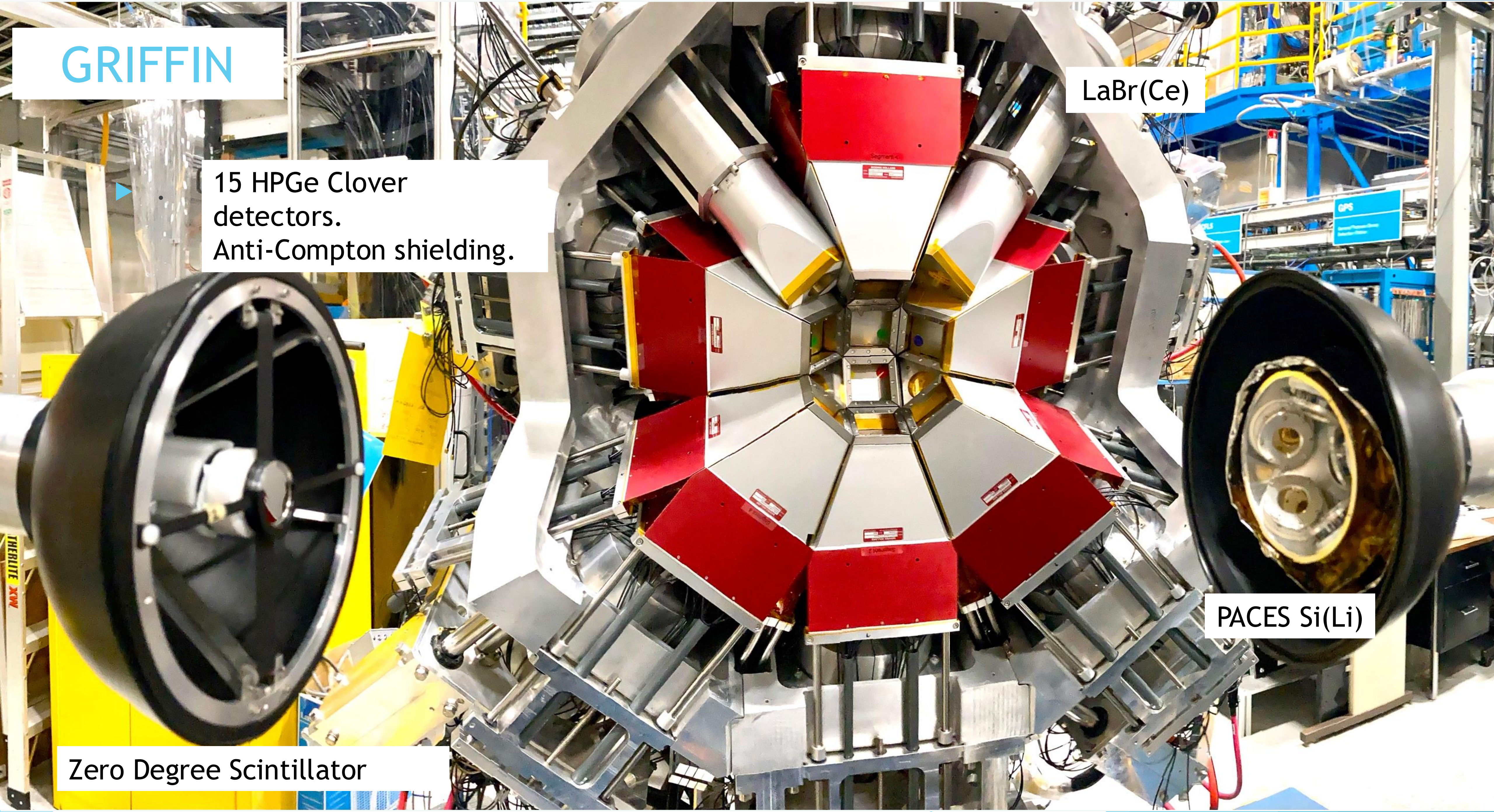
Ion-Guide Laser Ion Source IGLIS

- ^{148}Ho yield
  - $> 10^6$ pps
  - Good 😊
- Dy, Tb, Gd, Eu
  - Yields ~10^7 pps
  - Bad ☹
- Must suppress isobars
  - IGLIS!
  - εff ~ 1%
  - 10^6 suppression!



GRIFFIN

- 15 HPGe Clover detectors.
  Anti-Compton shielding.

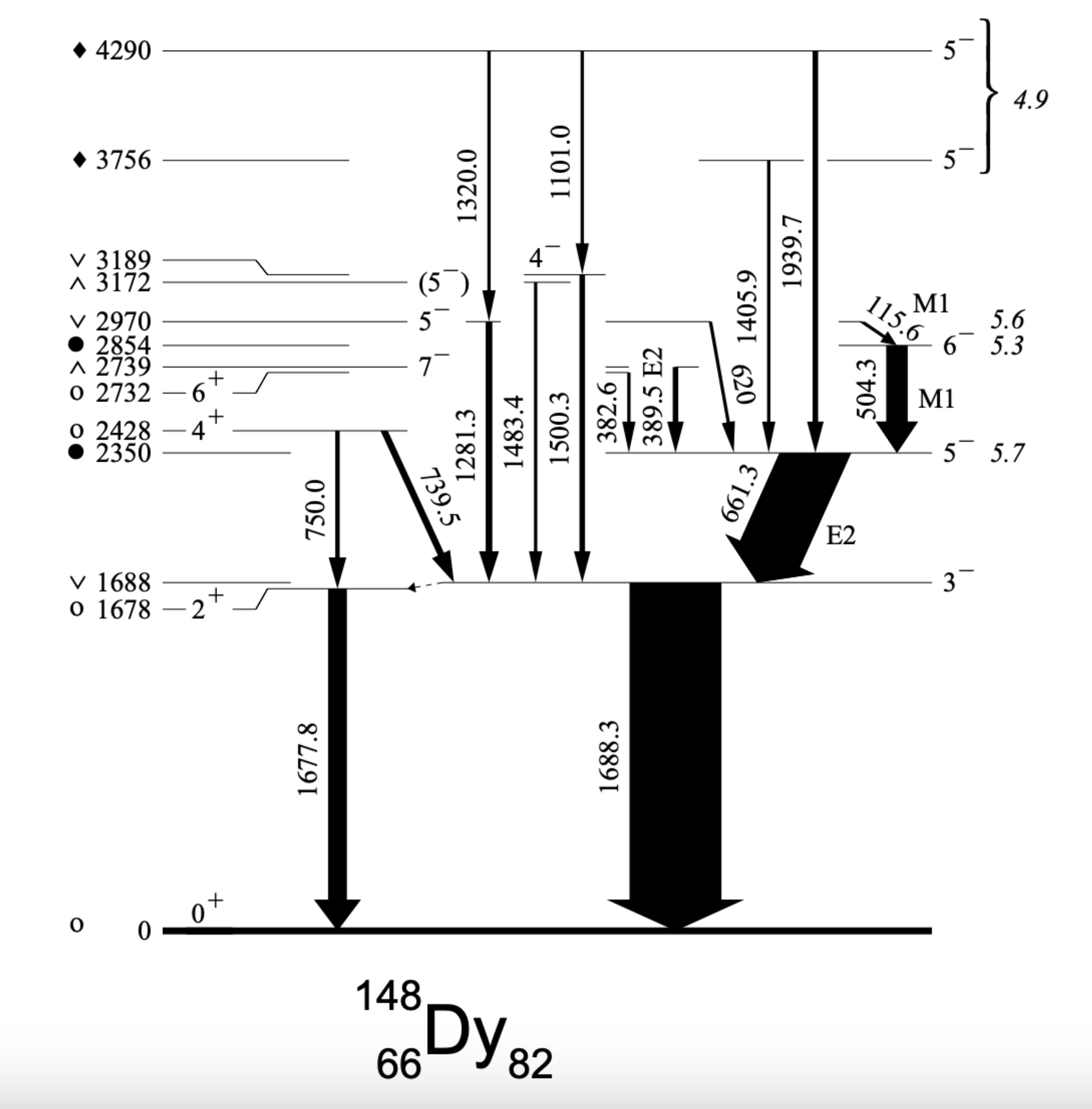


Exp. Details

Beam: ^{148m}Ho, $J^{\pi} = 5^{-}$
Rate: ~ 5000 pps
Time: ~ 6 hours

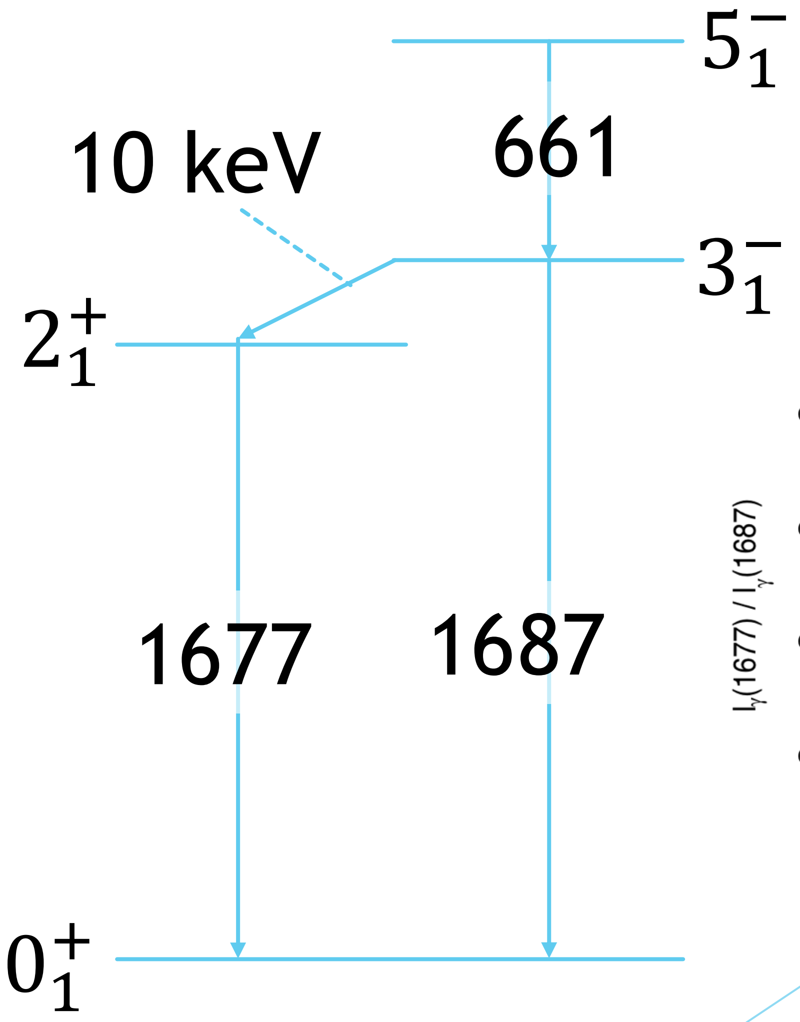
^{148m}Ho: $\beta^{+}/EC \rightarrow$ ^{148}Dy

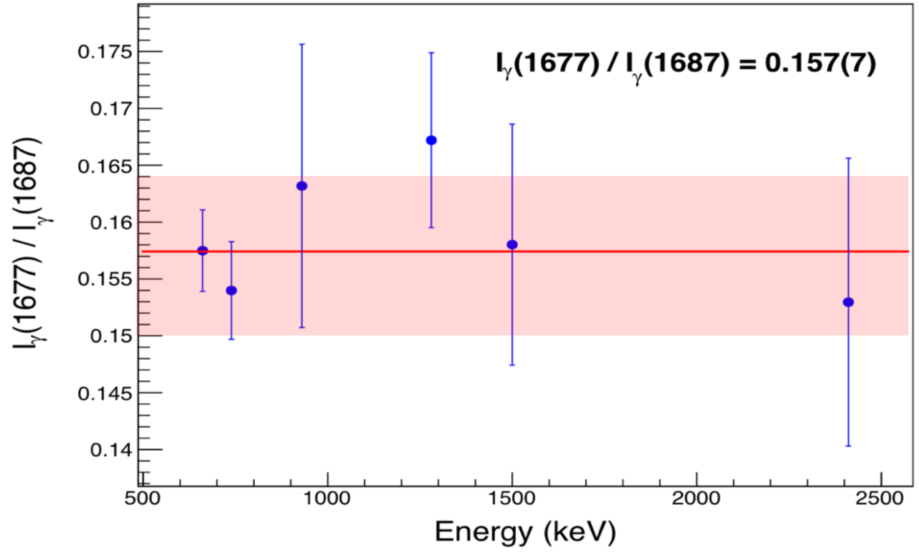
Goal: Two measurements
1. Branching ratio $3_1^- \rightarrow 0_1^+$
2. 3^- lifetime



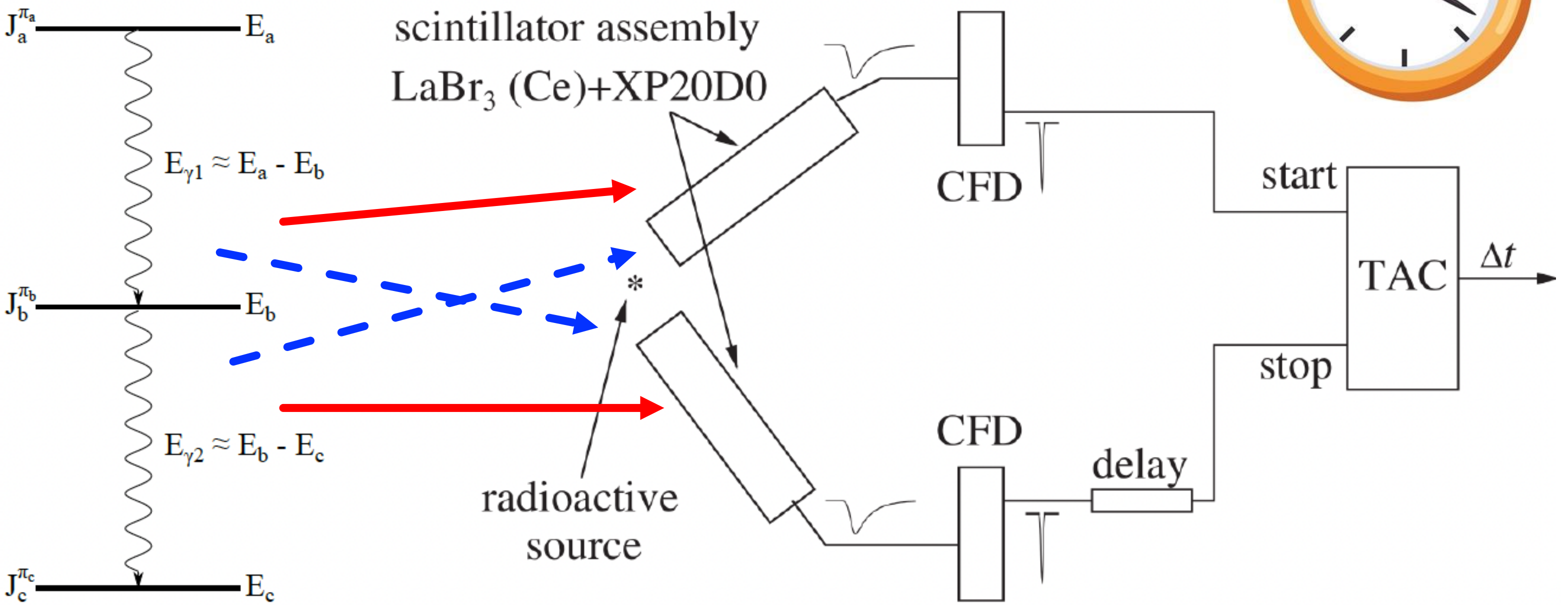
E3 $3_1^- \rightarrow 0_1^+$ Branching ratio

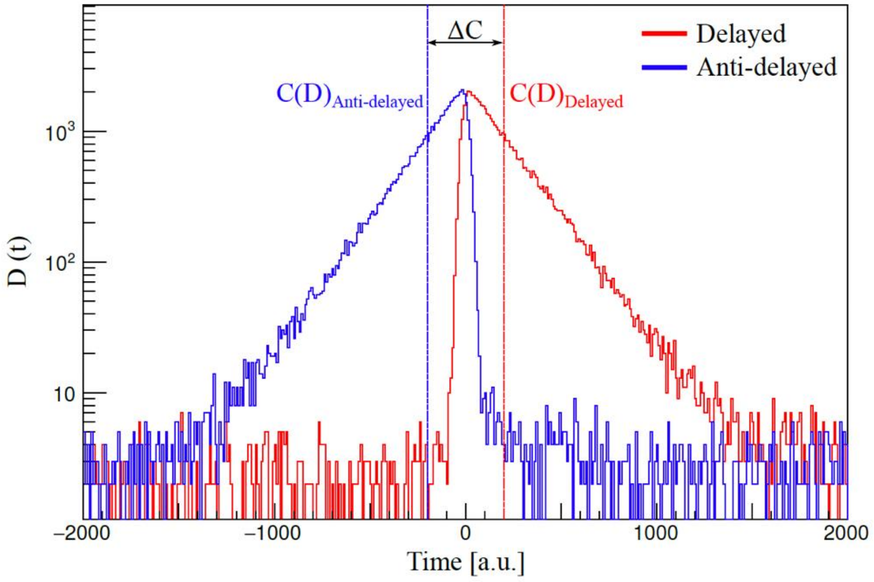
- Can't observe $3_1^- \rightarrow 2_1^+$
  - 10 keV gamma ray!
  - Internal conversion= 27
- Exploit $2_1^+ \rightarrow 0_1^+$
- Measure $\frac{I_\gamma(2_1^+ \rightarrow 0_1^+)}{I_\gamma(3_1^- \rightarrow 0_1^+)}$
  - $\gamma(E_x \rightarrow 3_1^-) - \gamma$
- $BR_{Abs}(3_1^- \rightarrow 0_1^+) = 0.862(11)$
- Goal 1: Success!
- Next: Measure lifetime





Fast Timing
Mirror Symmetric Centroid Difference

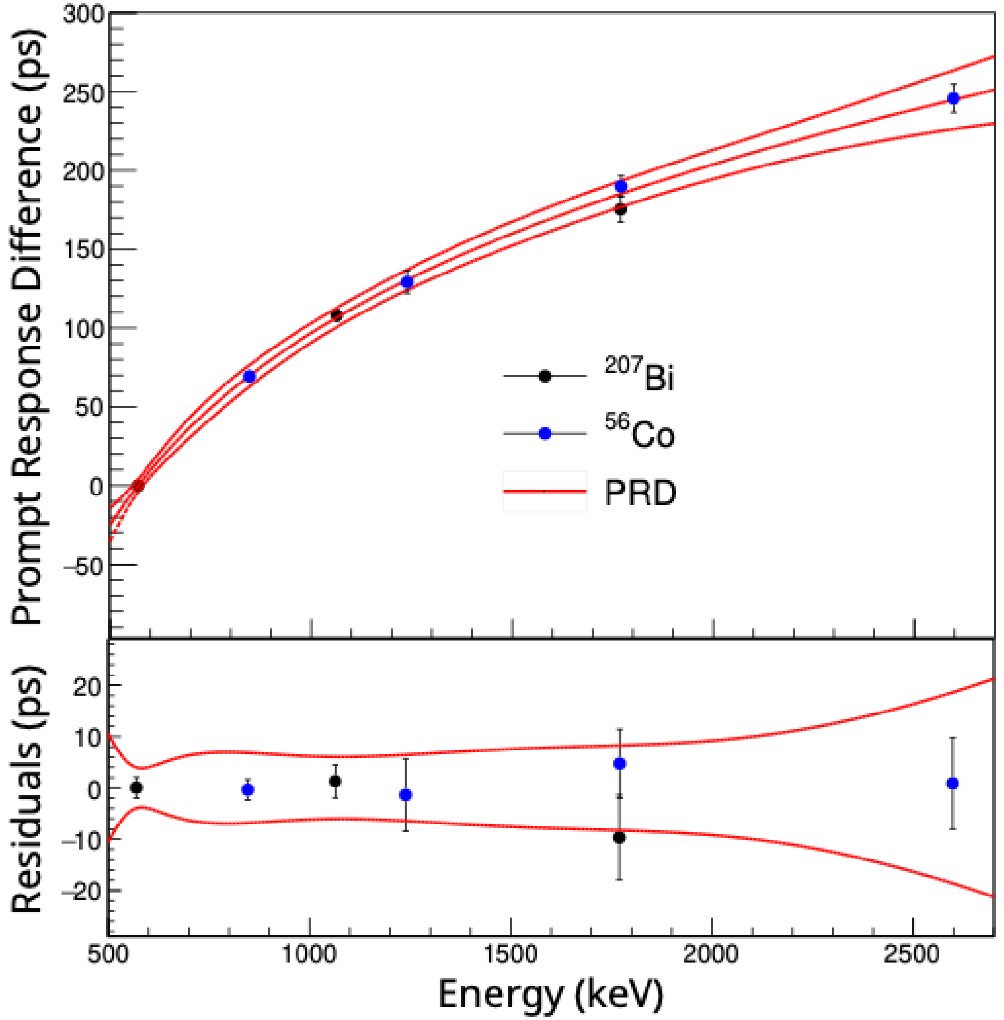


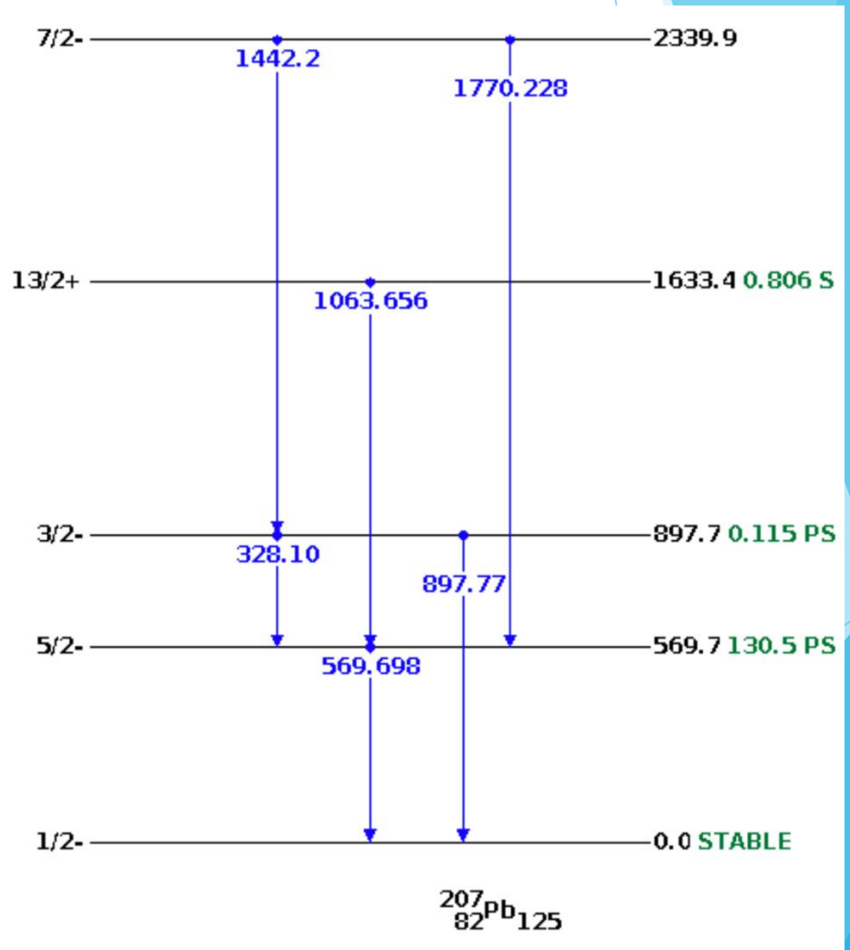


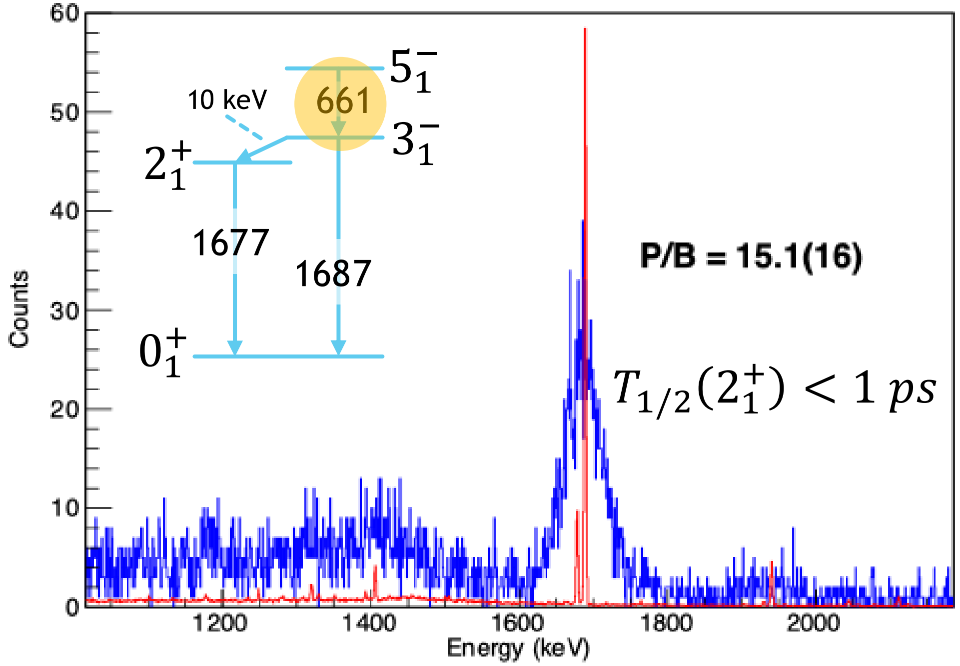
$$\Delta C = 2\tau + \mathrm{PRD}(\gamma_1, \gamma_2)$$

PRD = Prompt Response Difference

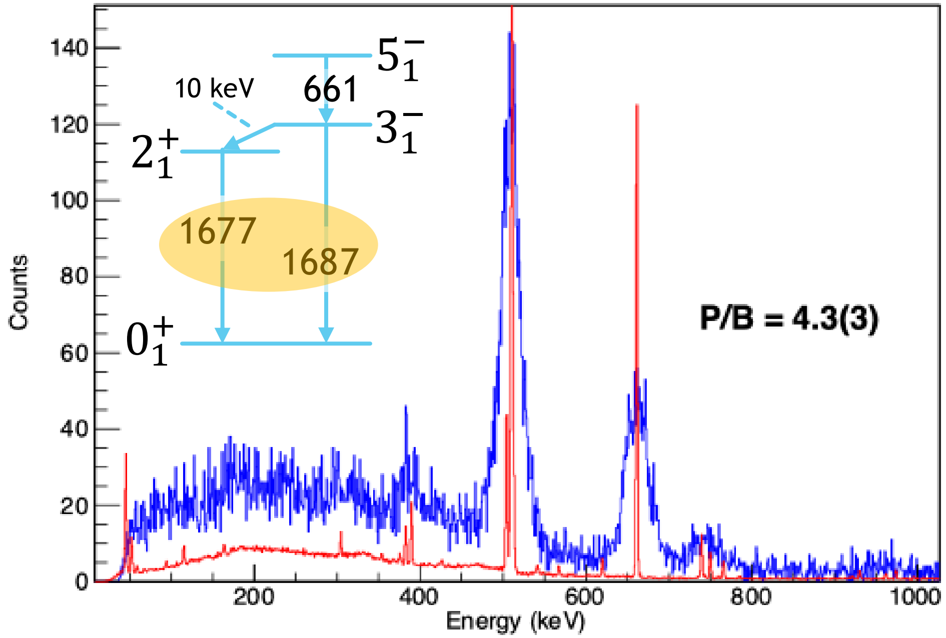
PRD calibration: $PRD(\gamma_1, \gamma_2) = \Delta C - 2\tau$



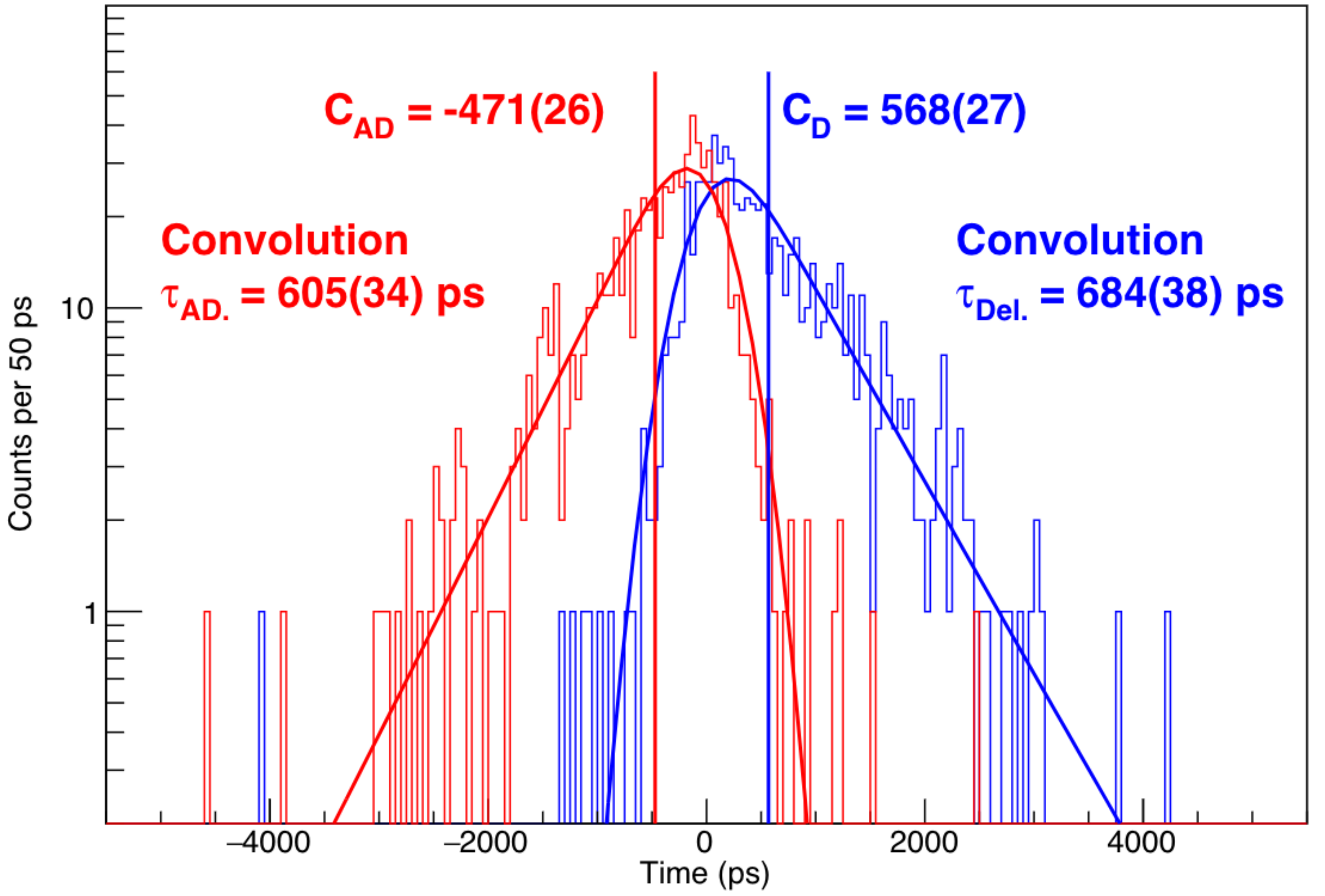




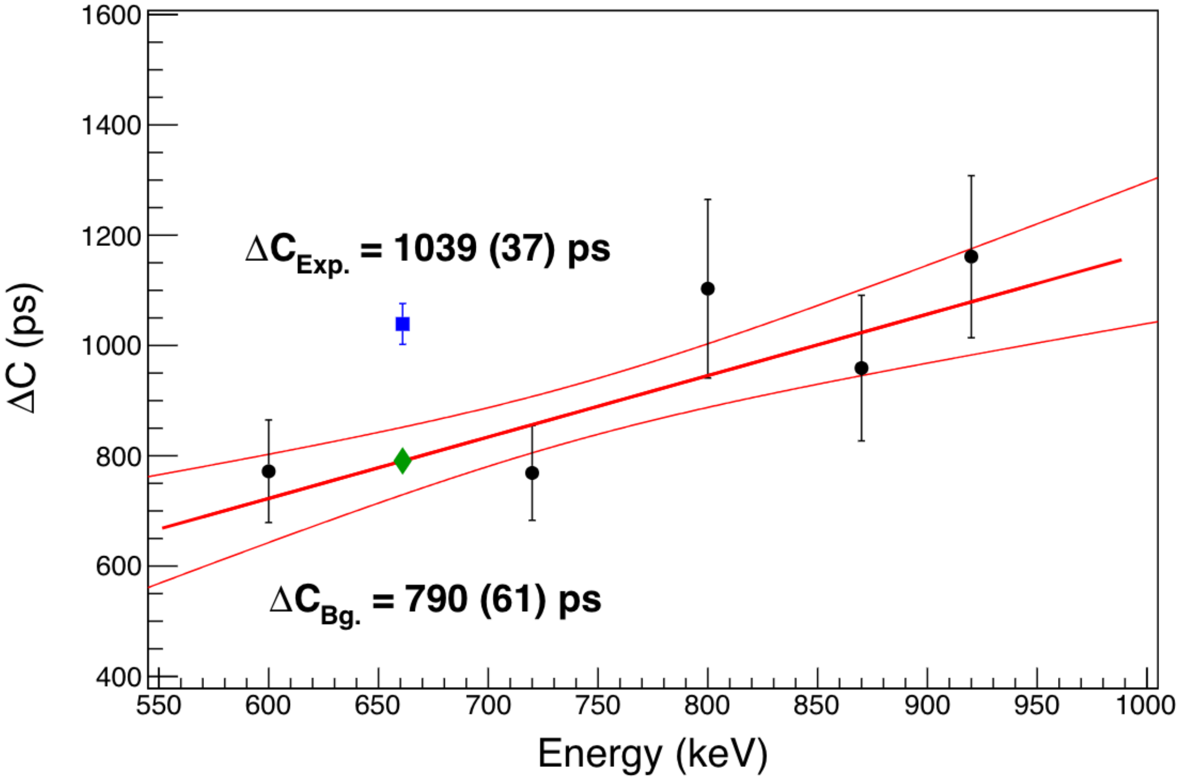
10 keV
661
1677
1687
P/B = 15.1(16)
$T_{1/2}(2_1^+) < 1\ ps$
Counts
Energy (keV)

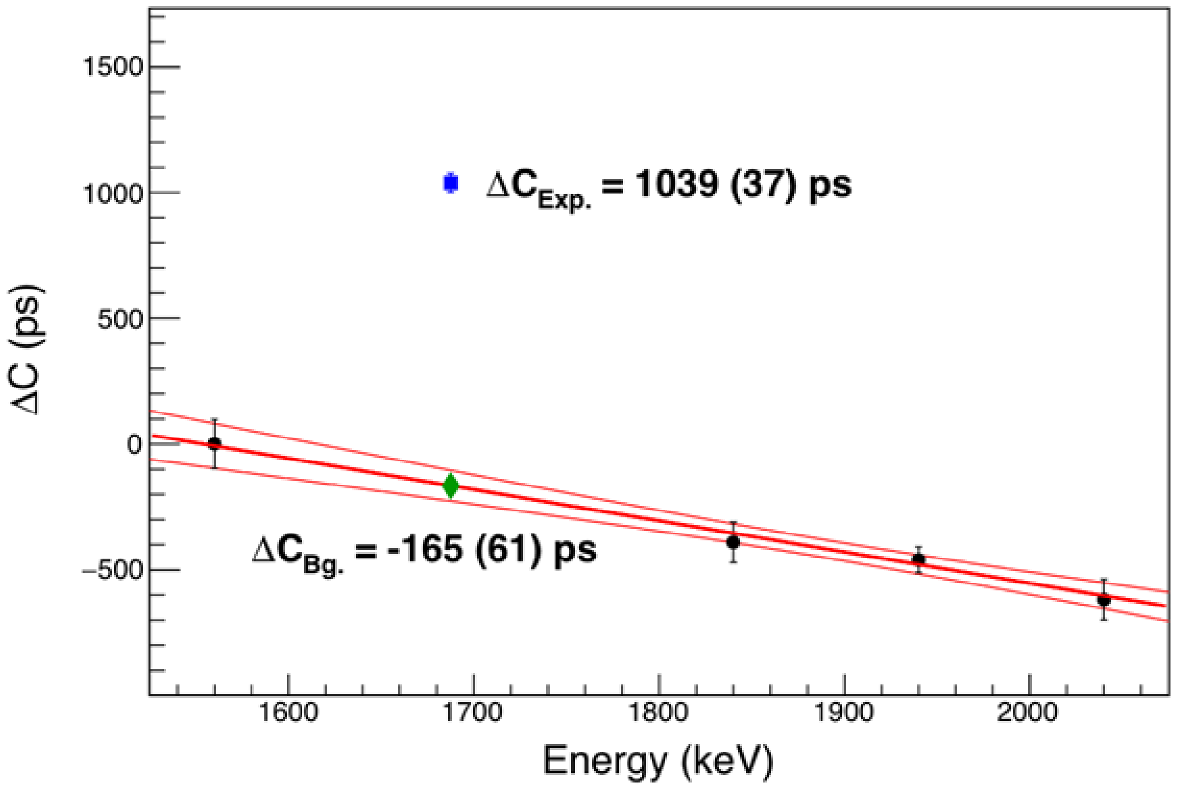


10 keV
661
1677
1687
P/B = 4.3(3)
Counts
Energy (keV)



C_{AD} = -471(26)
C_D = 568(27)
Convolution
$\tau_{AD.}$ = 605(34) ps
Convolution
$\tau_{Del.}$ = 684(38) ps
Counts per 50 ps
Time (ps)





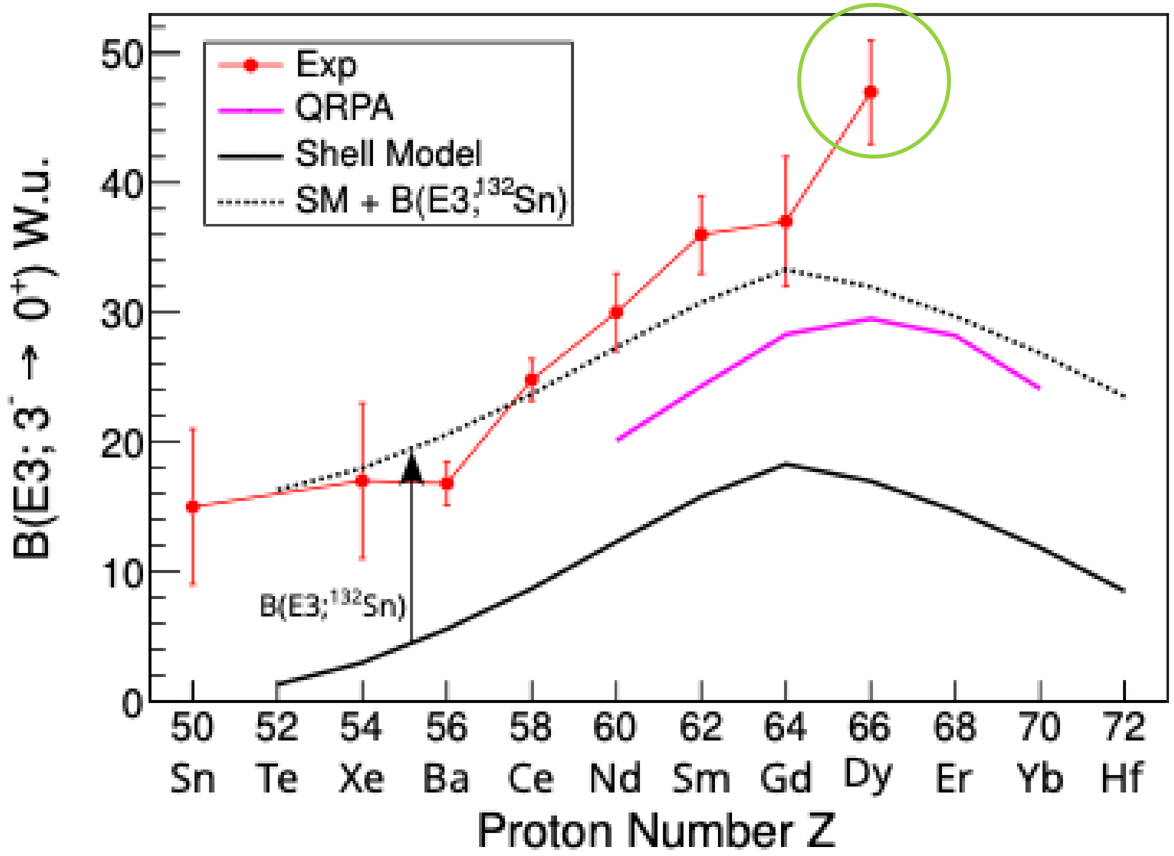
$$C_{PP} = C_{Exp} + \tilde{t}_{corr}$$

$$t_{corr} = \frac{C_{Exp} - C_{Bg}(E)}{P/B(E)}$$

$$\tilde{t}_{corr} = \frac{P/B(E_f)t_{corr}(E_i) + P/B(E_i)t_{corr}(E_f)}{P/B(E_i) + P/B(E_f)}$$

$$\tau = \frac{\Delta C_{Exp} + \tilde{t}_{corr} - PRD(661, 1687)}{2}$$
$$= \frac{1039(37) + 63(27) - -152(15)}{2}$$
$$= 627(24) \text{ ps}$$

Results & Future



Z \ N	82	84	86	88	90	92	94	96	
68							17 ±4	13 ±3	Er
66	45 ±3				22 ±7	22 ±5	16.1 ±0.9	9.5 ±0.6	Dy
64	37 ±5	42 ±6	45 ±5	52 ±17	21 ±5	16.9 ±0.7	11.9 ±0.7	11.4 ±0.7	Gd
62	36 ±3		39 ±3	33 ±3	14.2 ±1.6	10 ±2			Sm
60	30 ±3	30.5 ±1.2	30 ±3	34 ±3	19 ±2				Nd
58	24.8 ±1.6	24.0 ±1.6							Ce
56	16.8 ±1.7		22*	48^{+25}_{-34}	48^{+21}_{-29}				Ba
54	17 ±6			5^{+8}_{-5}					Xe

- $B(E3; 3_1^- \rightarrow 0_1^+)$ ~ **45 W.u.**
- Largest B(E3) at N=82!

QRPA: Esra Yuksel (Surrey)
Shell Model: Y.X. Yu & G.J.Fu

Future

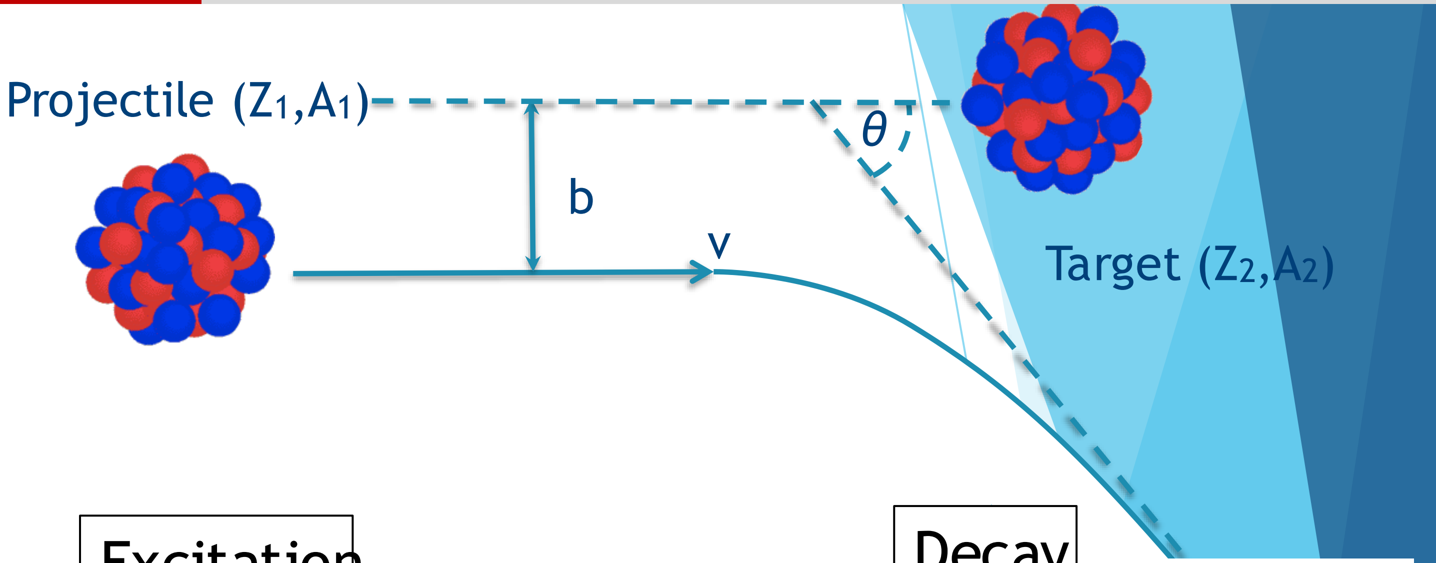
- Can we go to higher Z?
- When will B(E3) reduce?
- Can we extend to heavier Dy isotopes?
- Should we revisit ^{136}Xe & ^{132}Sn?

Collaborators

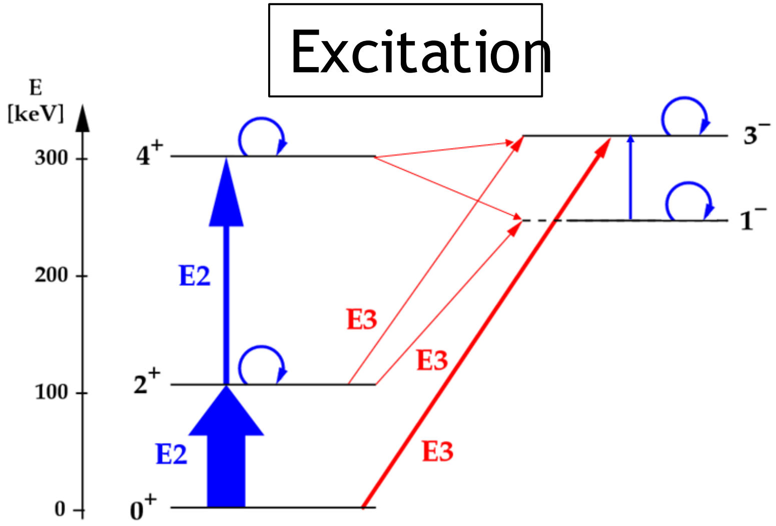
- University of Liverpool
  - P. Spagnoletti
- CERN
  - **V. Vedia (spokesperson)**
- TRIUMF
  - **A. Garnsworthy (sp)**, S. Murillo, A.A. Avaa, R. Umashankar, I. Dillmann, J. Liu, G. Ball, J. Williams, A. Ludlam
- University of Guelph
  - V. Bildstein, S. Buck, G. Colombi, C. Svensson
- Simon Fraser University
  - C. Andreou, F. Wu, M. Madhu
- University of Regina
  - A. Tsantiri, E. Cantacuzene, G. Grinyer
- University of Surrey
  - P. Regan
- University of Padova & INFN
  - G. Andreetta, D. Stramaccioni, R.N. del Alamo
- Tennessee Technological University
  - M. Rajabali, S. Sekal, J. Seger
- CEA Saclay
  - L.L Luperi
- INFN Firenze
  - M. Rocchini, T. La Marca
- CSIC, IEM
  - D. Movilla

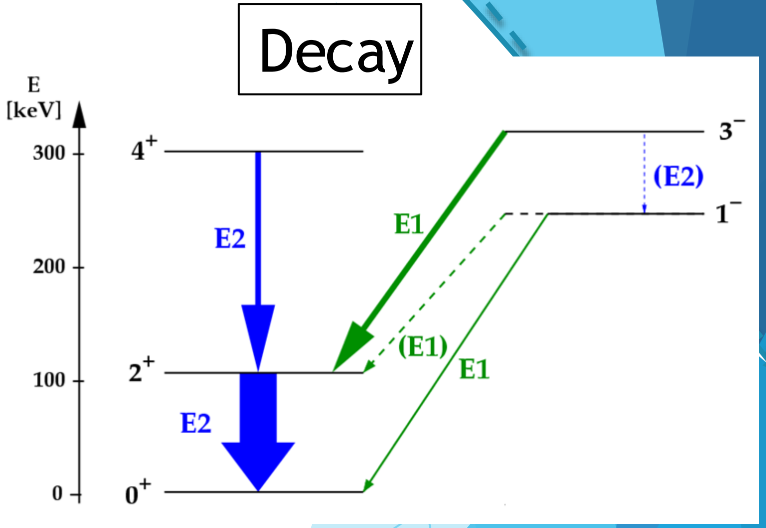
Extra slides

Coulomb Excitation



- High energy projectiles bombard target nuclei.
- Purely EM interaction.
  - Cline safe energy.
- Excitation sensitive to E2 and E3 matrix elements.
- γ-ray decay
  - M1, E1, E2
- Access to diagonal matrix elements.
  - E.g. $\langle 2_1^+ \| E2 \| 2_1^+ \rangle$
- Determine sign of Q_1
  - Relative phase $Q_1 Q_3$
- Multi-step excitation sensitive to Z_p-Z_t combination.
- M.E determined with GOSIA





$$\frac{\sigma(E3)}{\sigma(E2)} \propto \left(\frac{R_0}{a}\right)^2 \frac{B(E3)}{B(E2)} f \approx 10^{-2}$$

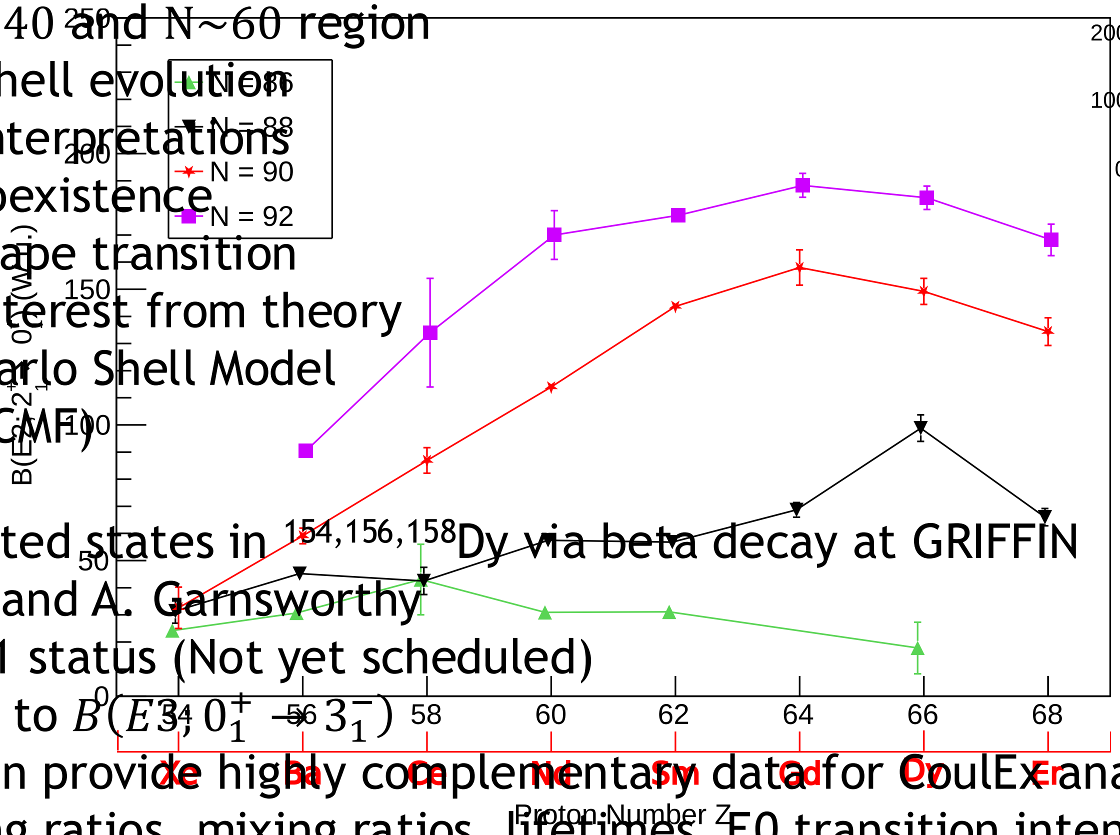
$$\frac{\lambda(E3)}{\lambda(E2)} \propto \left(\frac{R_0}{\lambda}\right)^2 \frac{B(E3)}{B(E2)} f \approx 10^{-4}$$

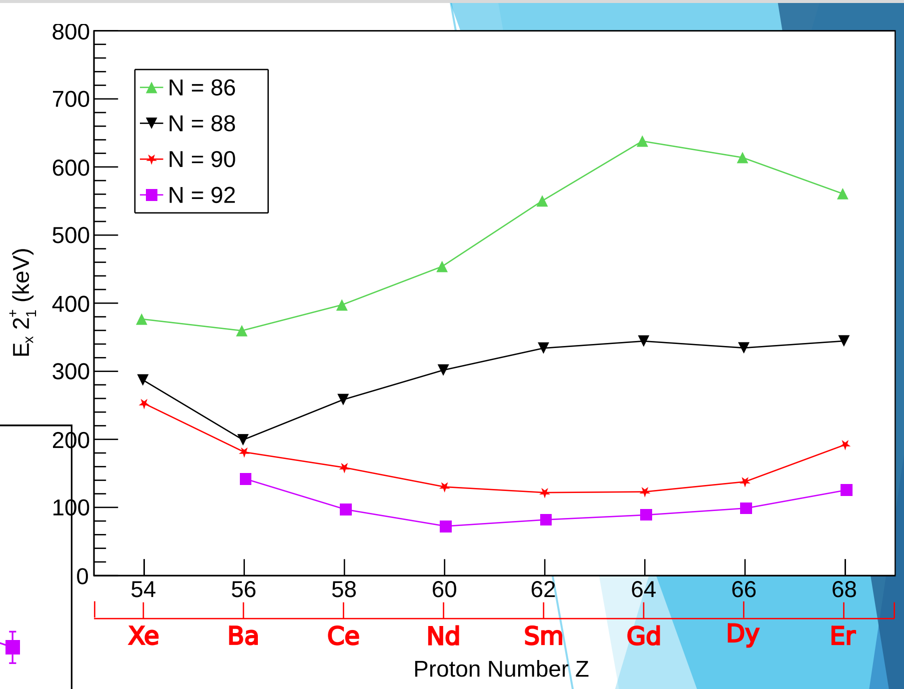
Transitional region N~90

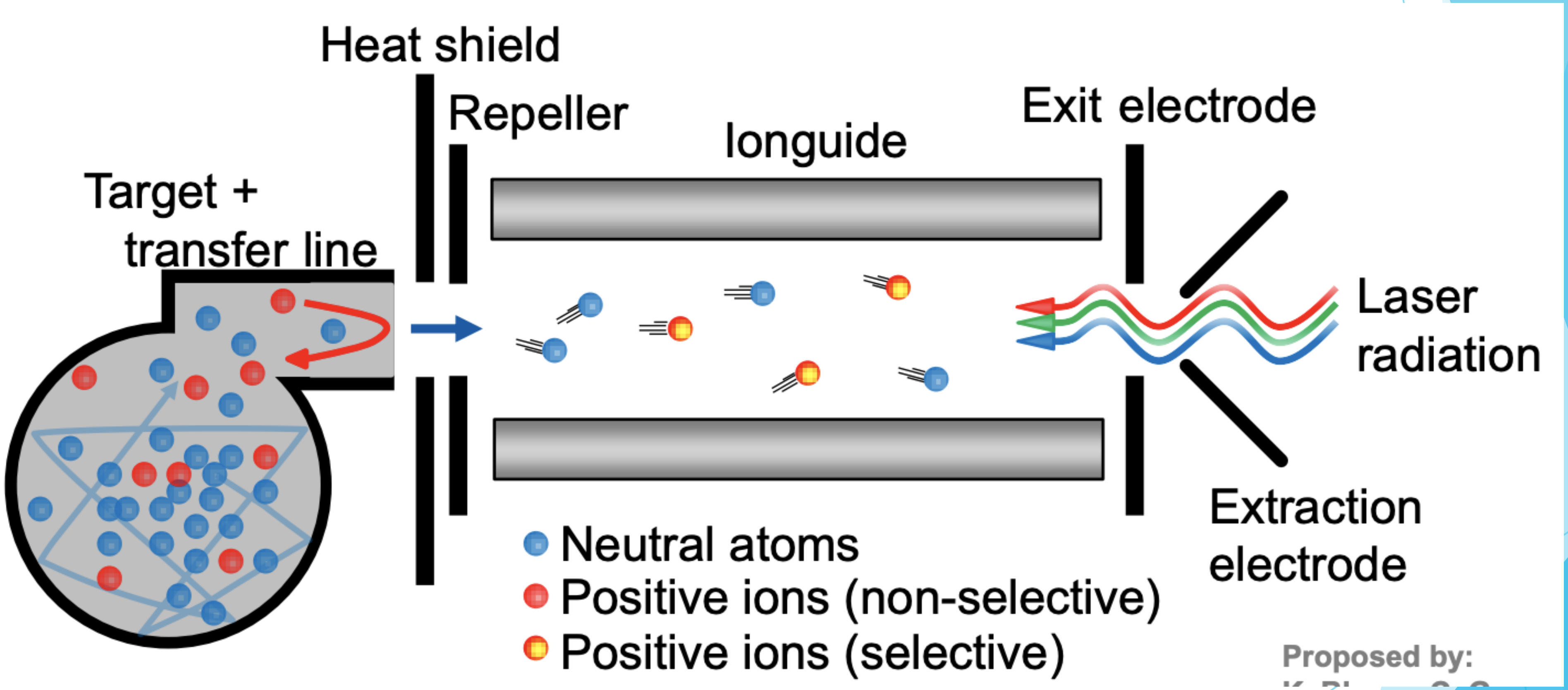
- Clear change in behaviour between N=88 and N=90 isotones
- Rapid changes in $E_x(2_1^+)$ and $B(E2; 0_1^+ \rightarrow 2_1^+)$
- Similar to Z~40 and N~60 region
  - Type-II shell evolution
- Competing interpretations
  - Shape coexistence
  - Phase shape transition
- Significant interest from theory
  - Monte-Carlo Shell Model
  - IBM-2 (SCMF)

<u>S2209</u>

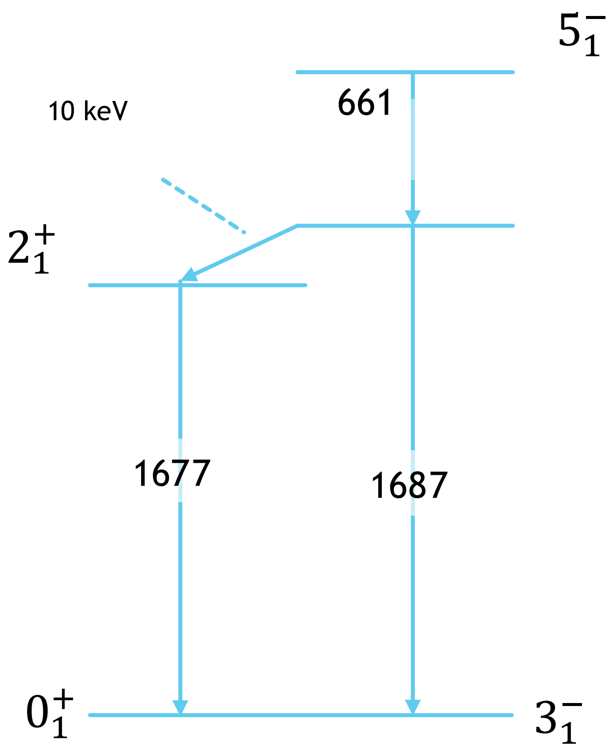
- Study of excited states in ^{154,156,158}Dy via beta decay at GRIFFIN
  - V. Vedia and A. Garnsworthy
  - Priority 1 status (Not yet scheduled)
- Not sensitive to $B(E3; 0_1^+ \rightarrow 3_1^-)$
- This study can provide highly complementary data for CoulEx analysis.
  - Branching ratios, mixing ratios, lifetimes, E0 transition intensities.







- Suppress surface ions with electro static potential barrier
- Extract ions created by laser ionization in cold environment behind the barrier
- Ion guide to confine the diverging laser ions and guide them toward the extraction



5_1^-
10 keV
661
2_1^+
1677
1687
0_1^+
3_1^-