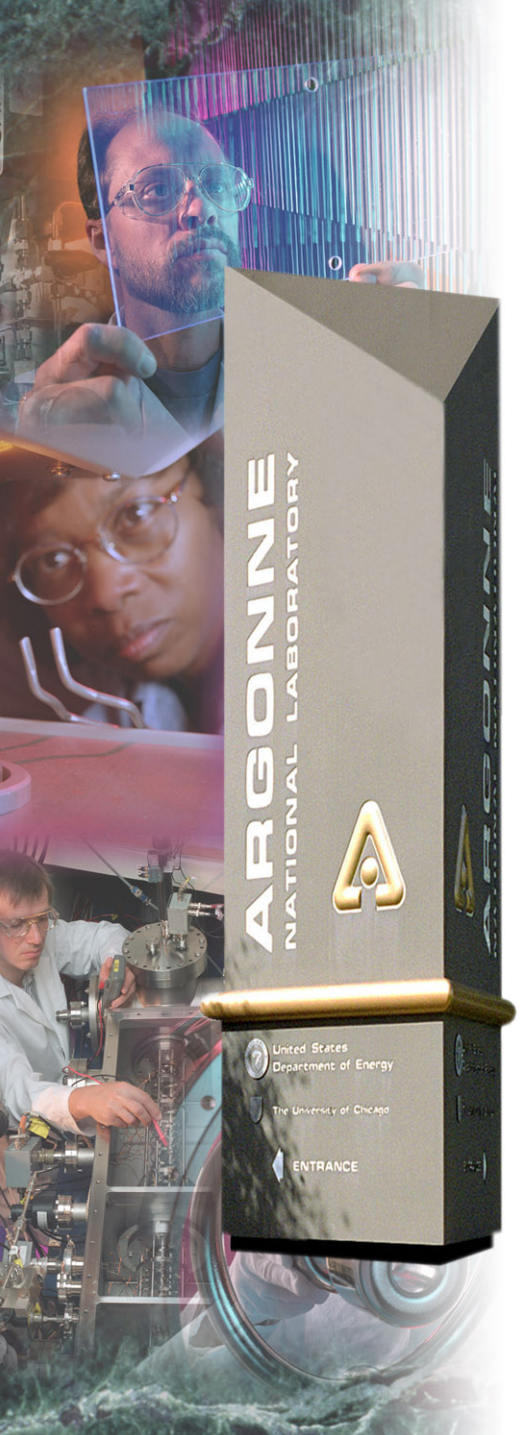


The Study of Proton-Rich Nuclei in the Pb Region: A Tale of Three Shapes

- Introduction.
- Experimental Setup at Gammasphere.
- Results from ^{90}Zr + ^{92}Mo experiment @ GS + FMA
- Current Status of Mid-Shell Pb nuclei
- Future Studies

M.P. Carpenter

Argonne National Laboratory

November 9, 2005

Office of Science
U.S. Department of Energy

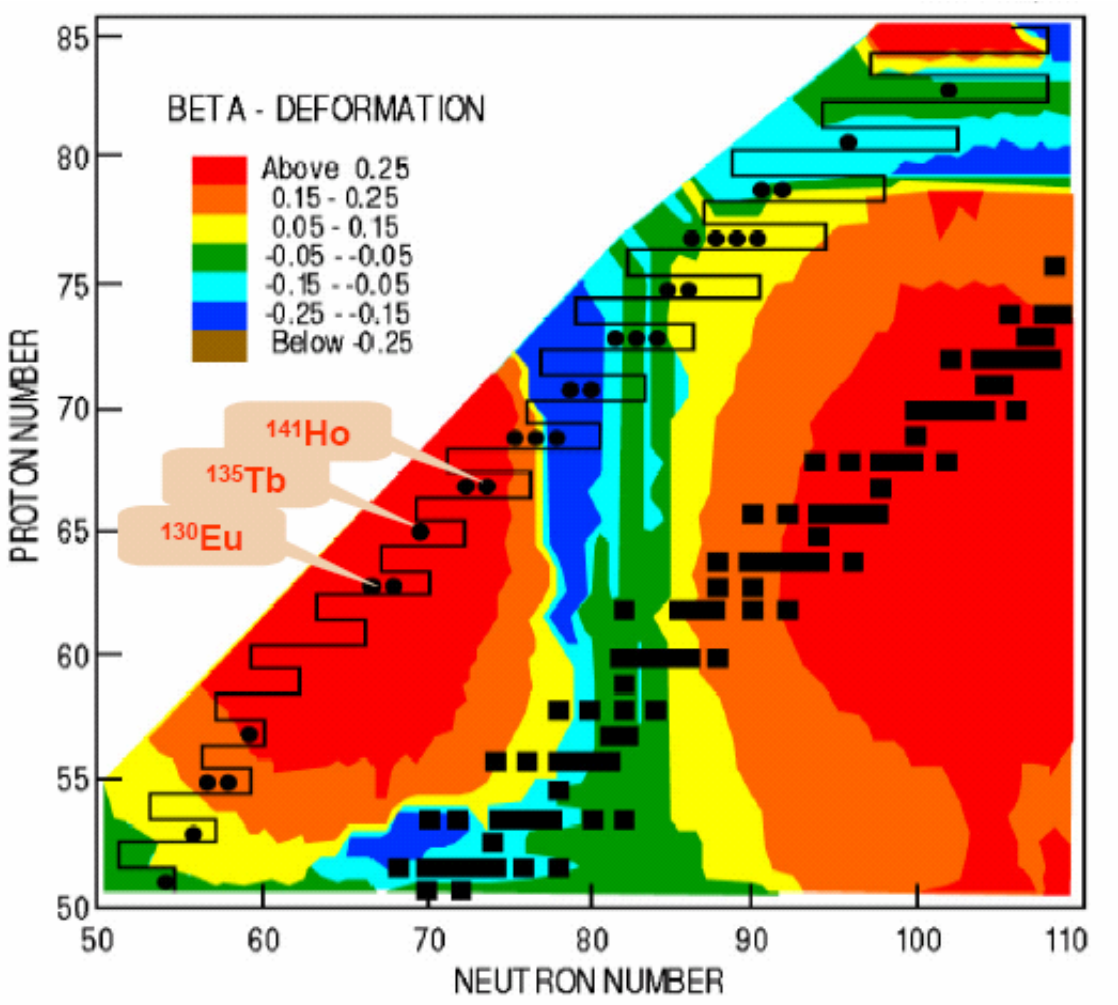
A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Gammasphere at the proton drip-line

One of the major programs of Gammasphere when coupled with the Fragment Mass Analyzer (FMA) has been to study excited states in nuclei beyond the proton drip line.

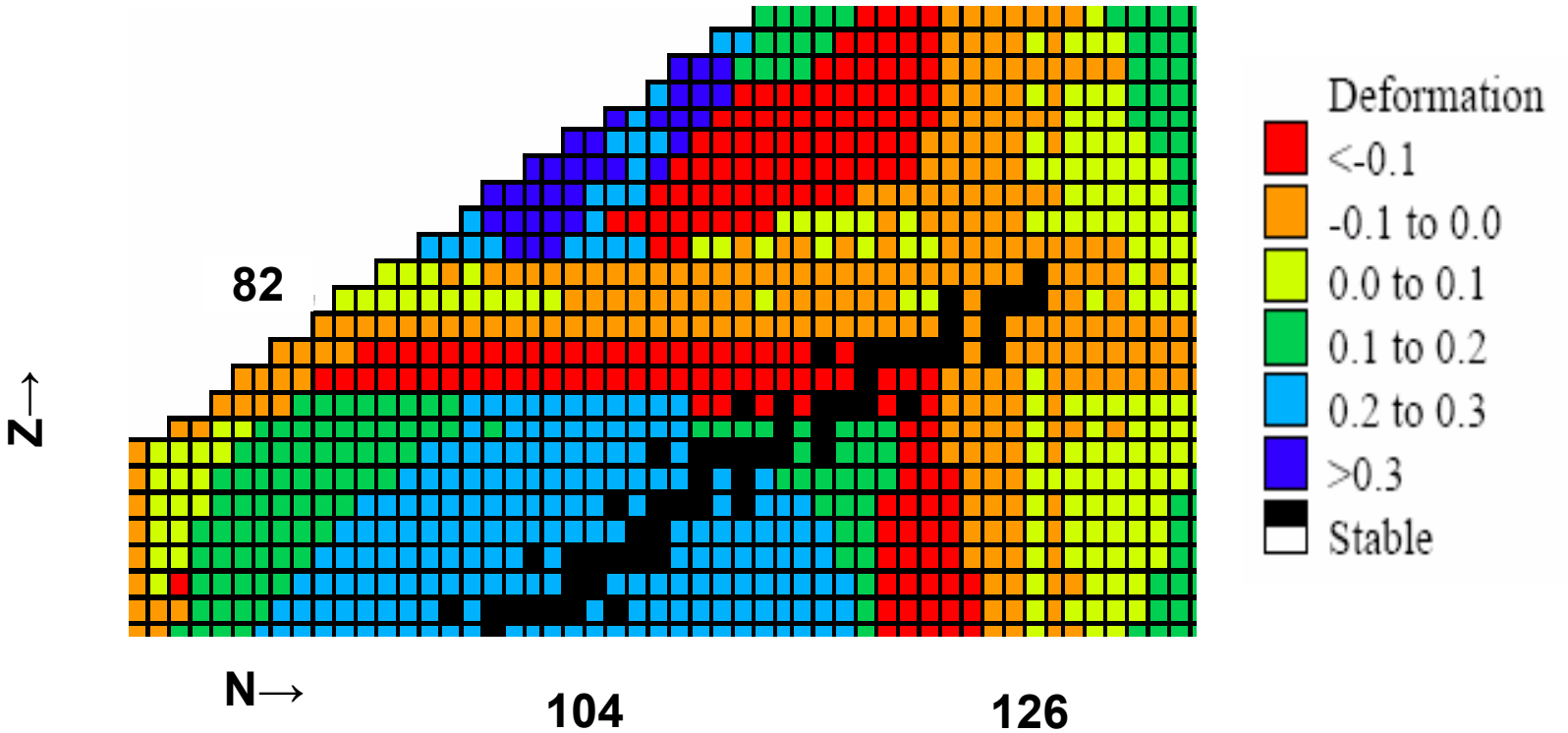
Examples:

- Excited states on top of deformed proton emitters
- Shape co-existence in the Pb region.

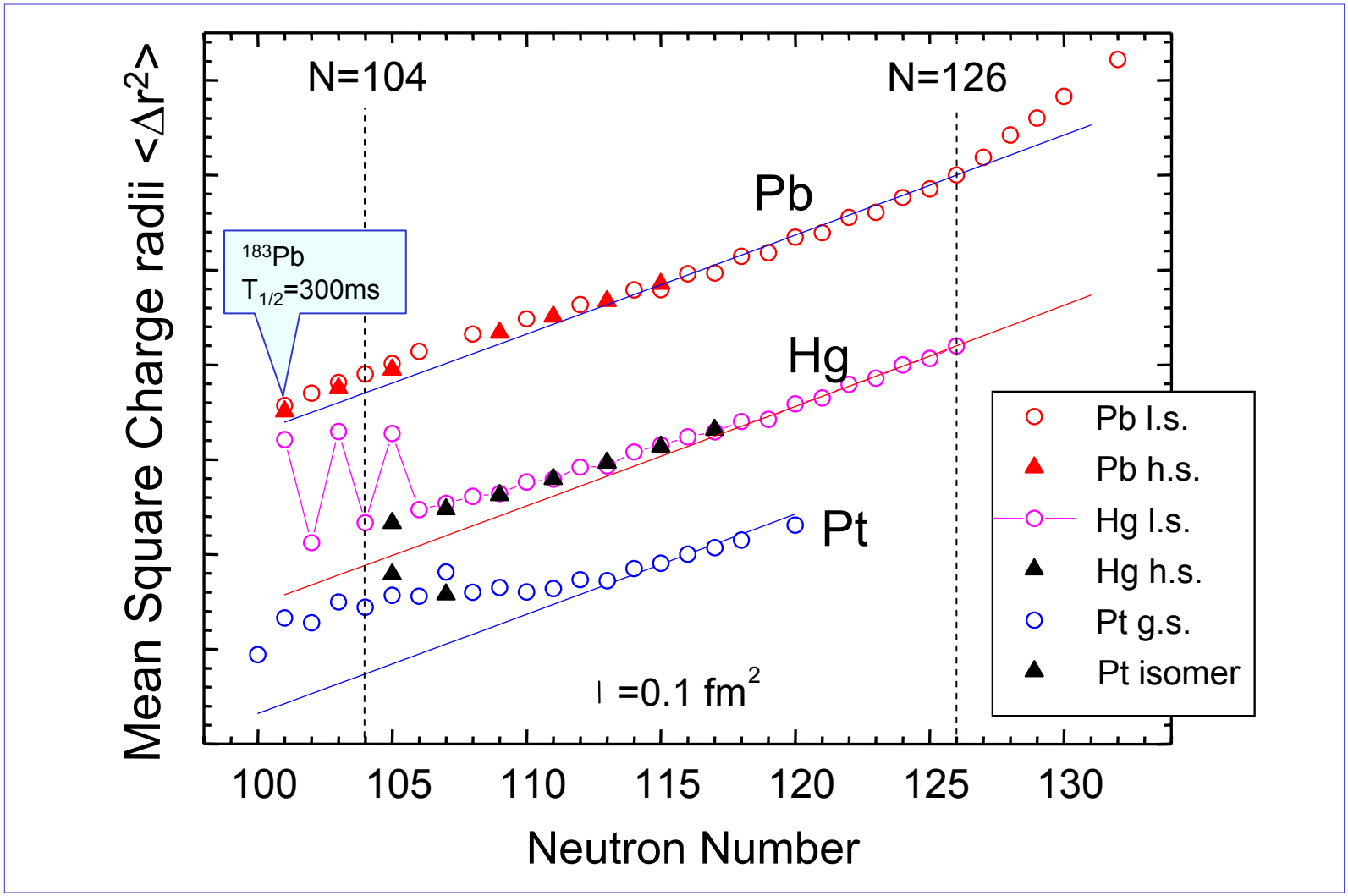


Moller-Nix Ground State Deformations

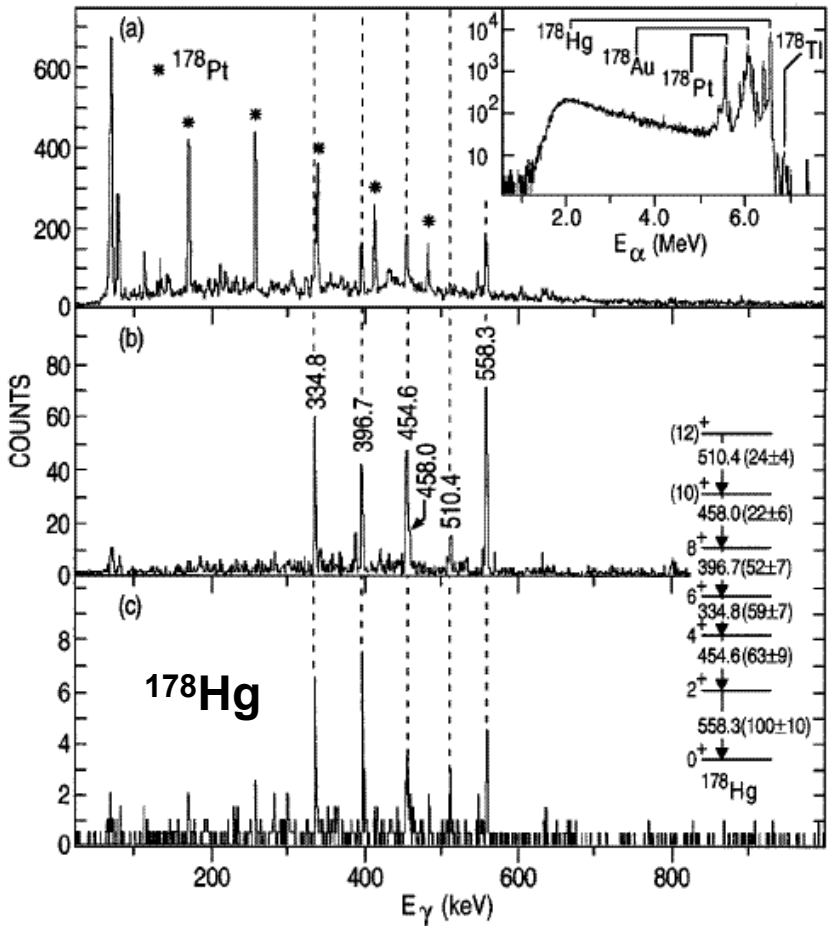
- Large shape variations in predicted ground state deformations as function of Z around N~104.
- N~104 Po, Rn, Ra ground states predicted to be β_2>0.3
- Moller-Nix Predictions ^{192,193}Po oblate, $^{186\text{-}191}$Po prolate.



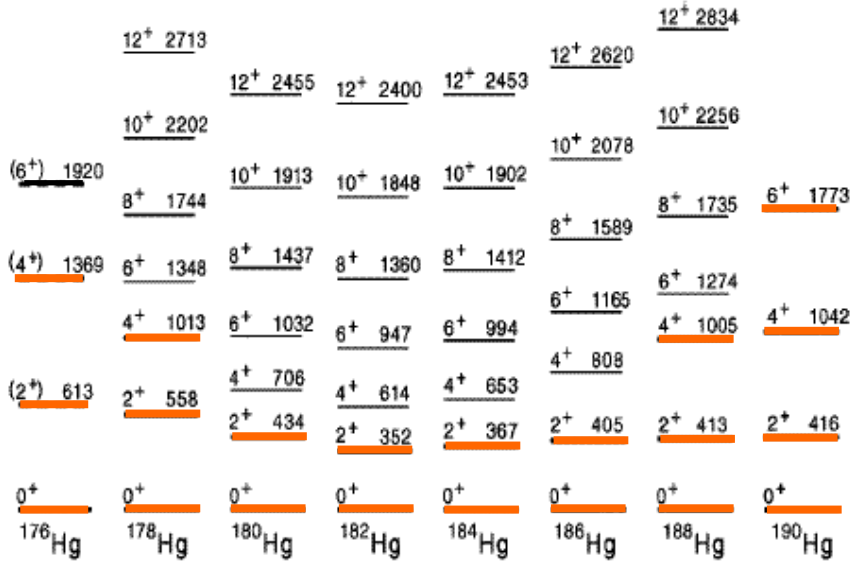
Evidence for Shape Coexistence



Yrast Bands in mid-Shell Hg Isotopes



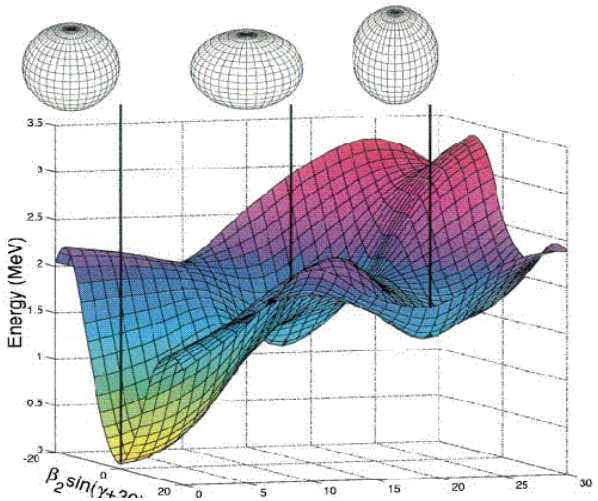
Systematics of Yrast Bands in Hg Isotopes

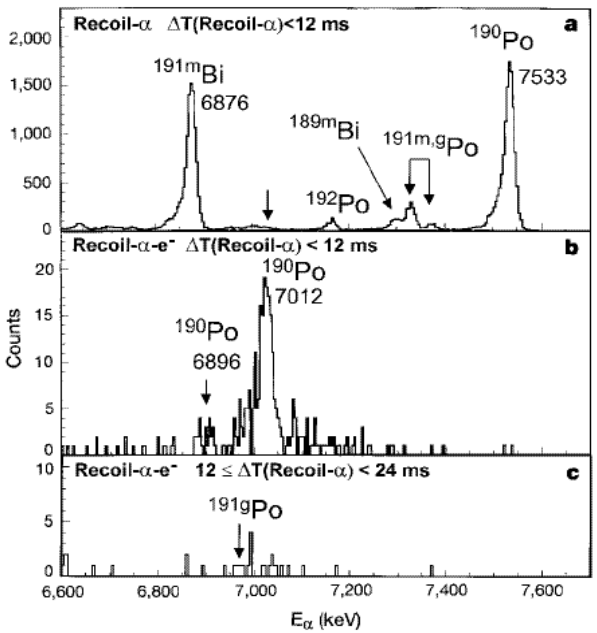


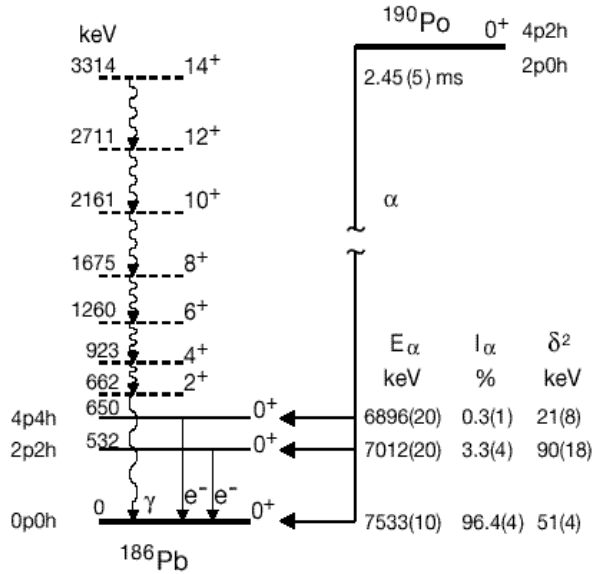
M.P. Carpenter et al., Phys. Rev. Lett. 78 (1997) 3650.

A Triplet of Differently Shaped 0^+ States in ^{186}Pb

- 3 shapes in mid-shell Pb nuclei predicted for some time (*e.g. R. Bengtsson and W. Nazarewicz, Z. Phys. A334 (1989) 269*).
- Established in ^{186}Pb by measuring coincidences between a-decays and K-x rays. (*A.N. Andreyev et al., Nature 405 (2000) 430*)

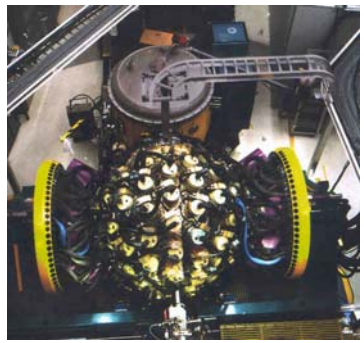




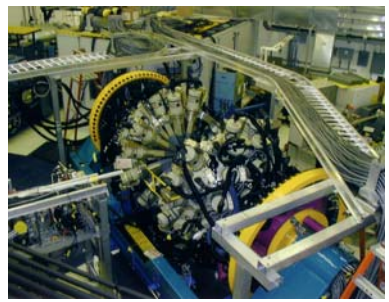


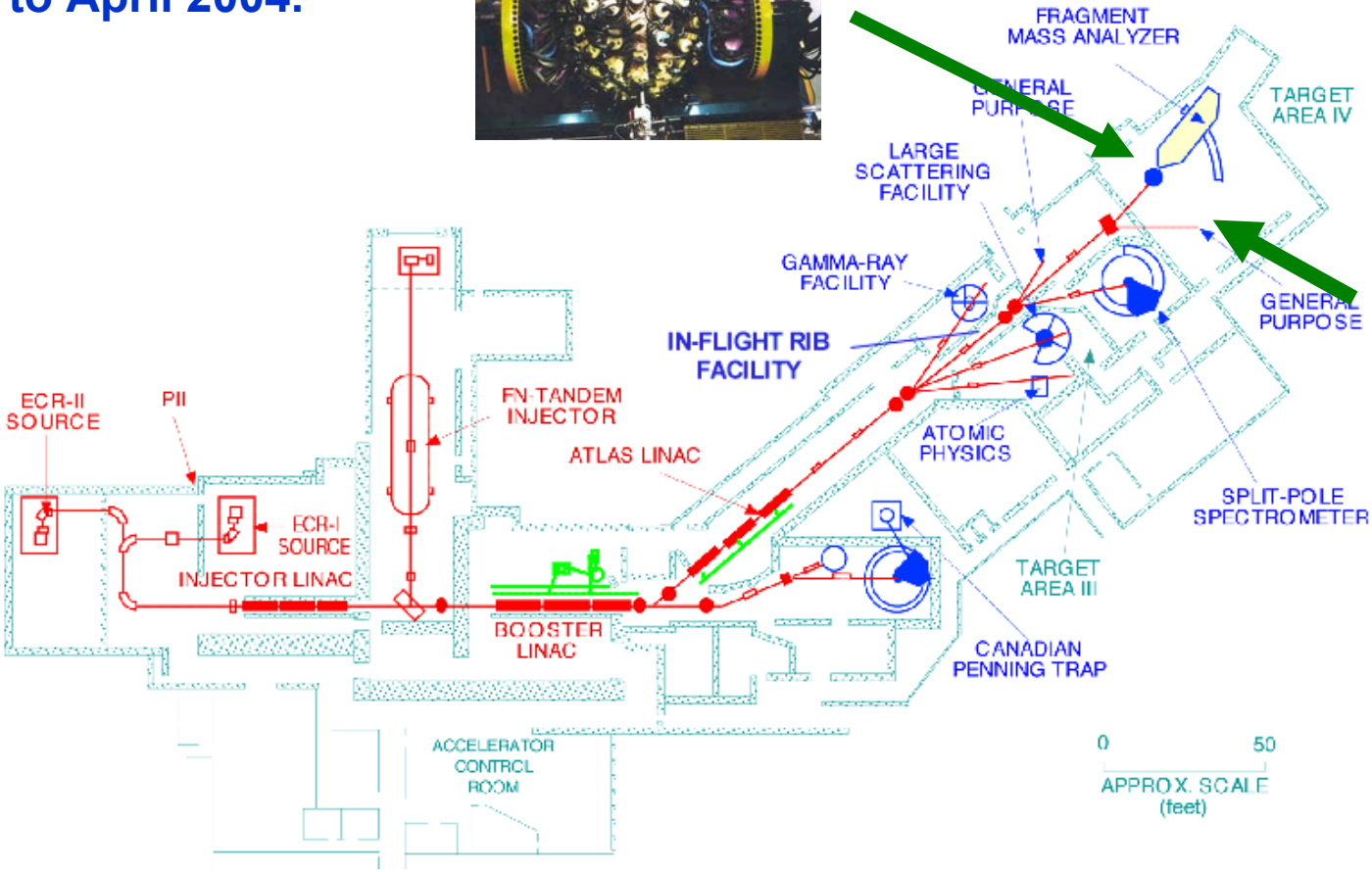
ATLAS Facility at Argonne National Laboratory

Operated at FMA from March 2003 to April 2004.



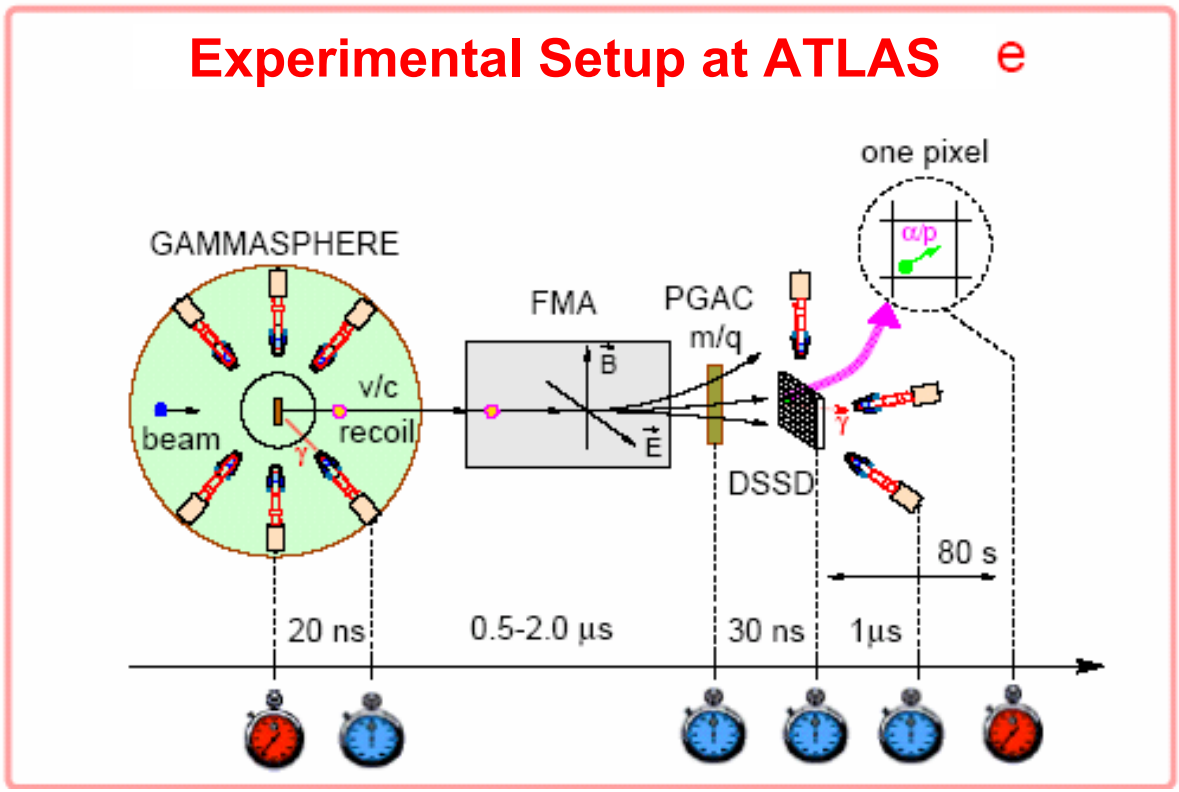
Operating in standalone position since May 2004.



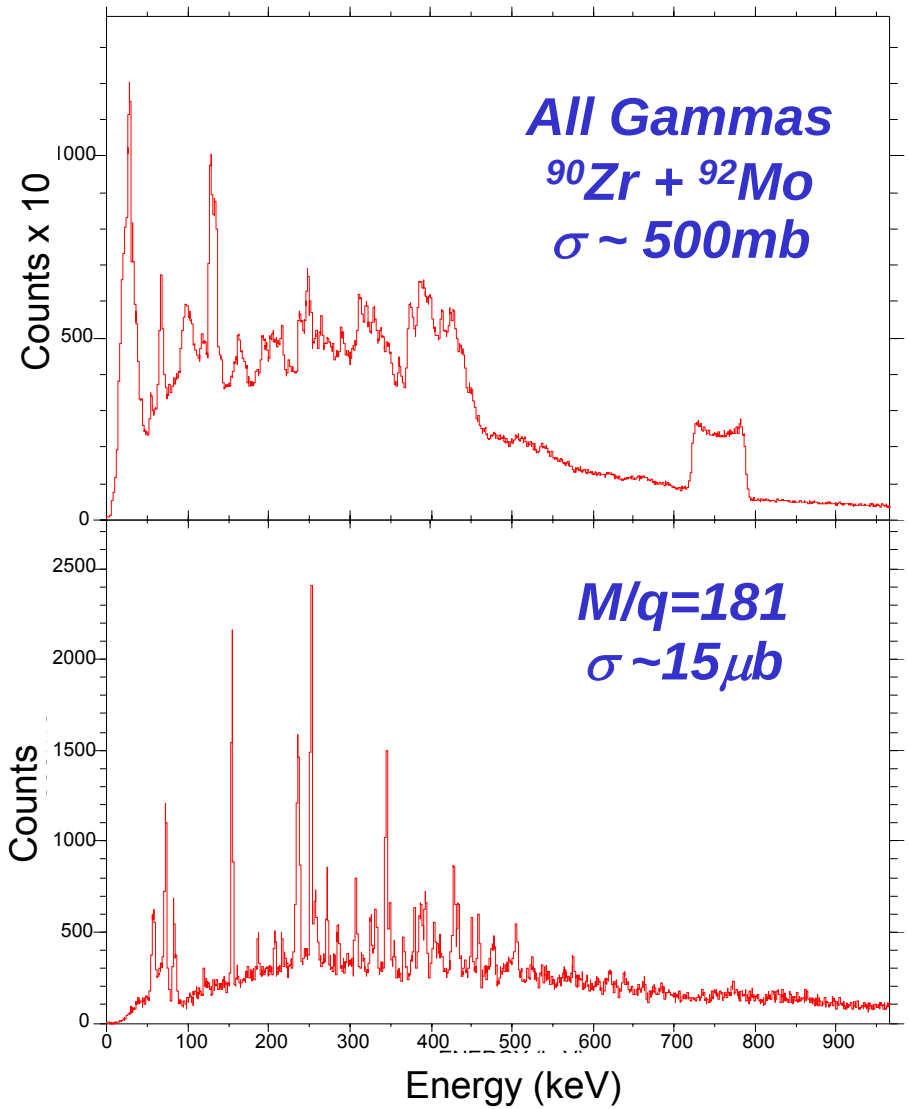


Recent Experiment:

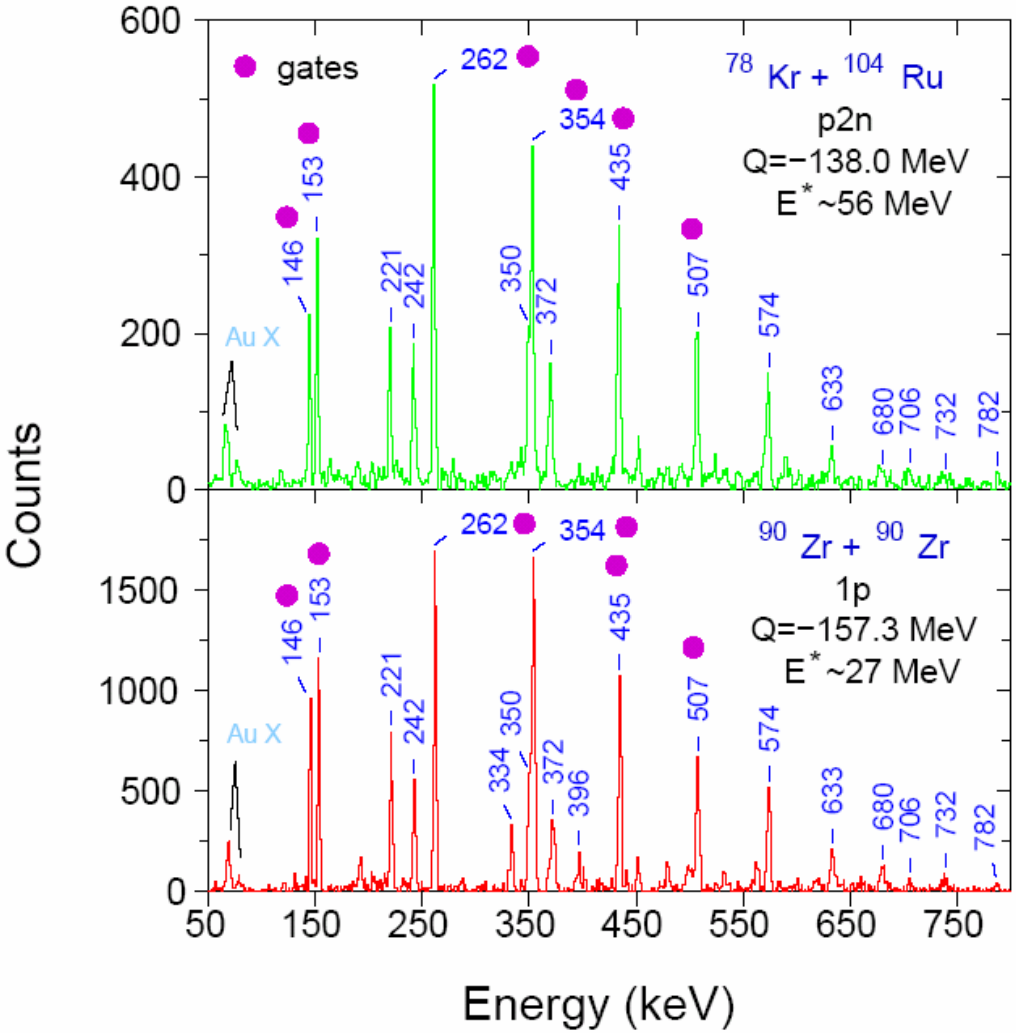
- ^{90}Zr + ^{92}Mo reaction at 385 MeV to study ^{181}Tl and ^{181}Pb via the 1*p* and 1*n* evaporation channel.
- ^{181}Tl (N=100) lies both beyond the proton drip line and the neutron mid-shell.
- ^{181}Pb (N=99) is the most neutron deficient odd-A Pb isotope identified thus far.



Why do we need the FMA?

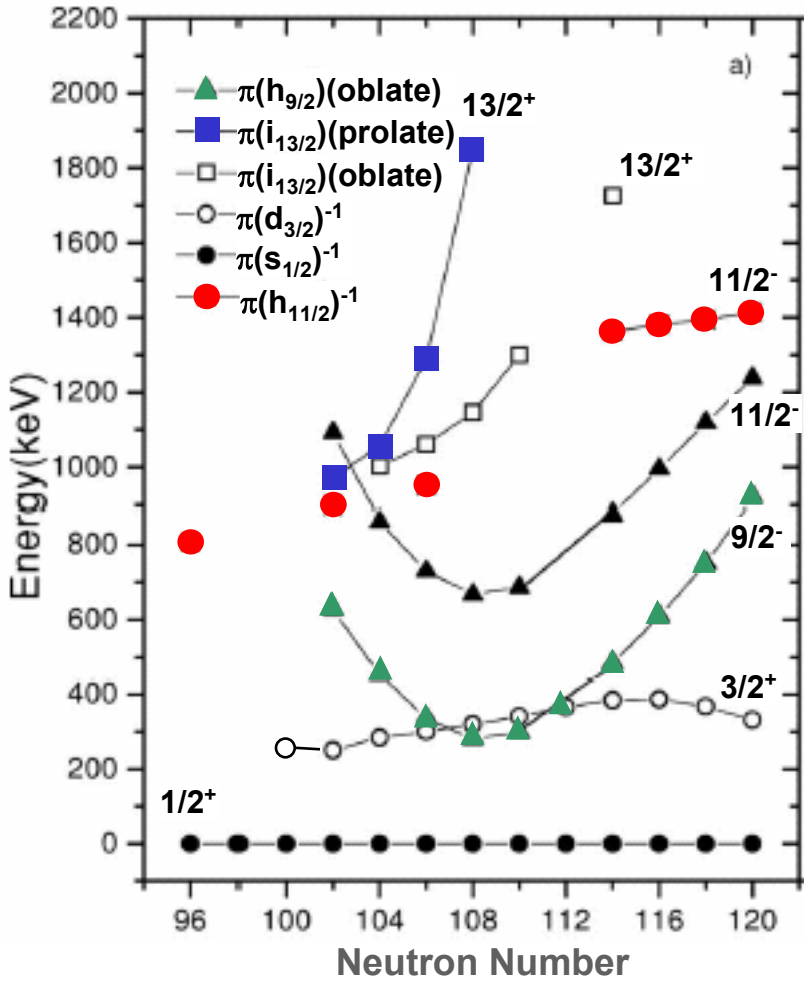


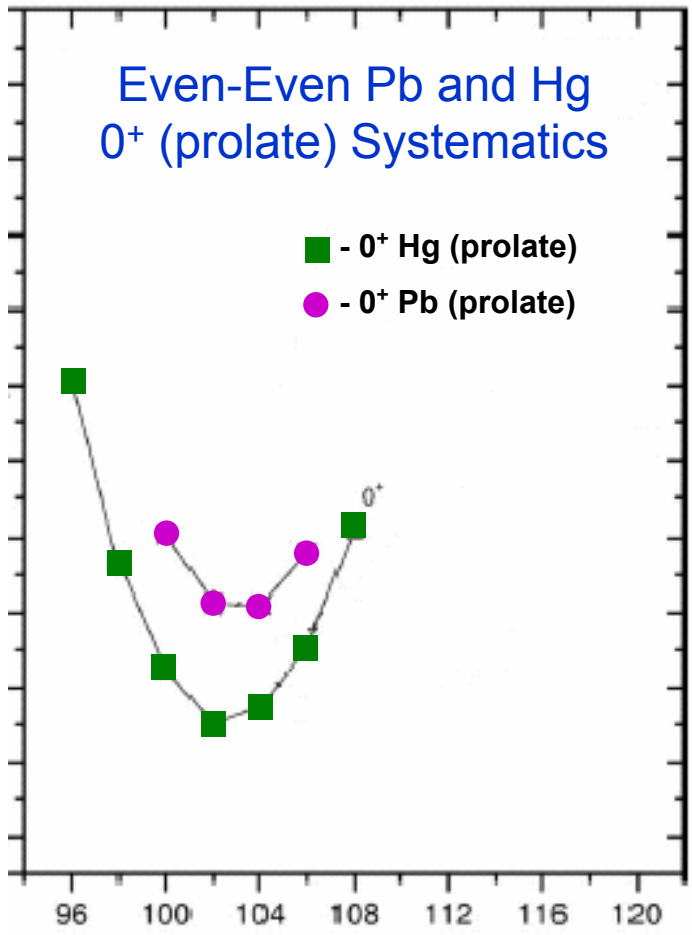
Near Barrier Reactions for In-Beam Studies



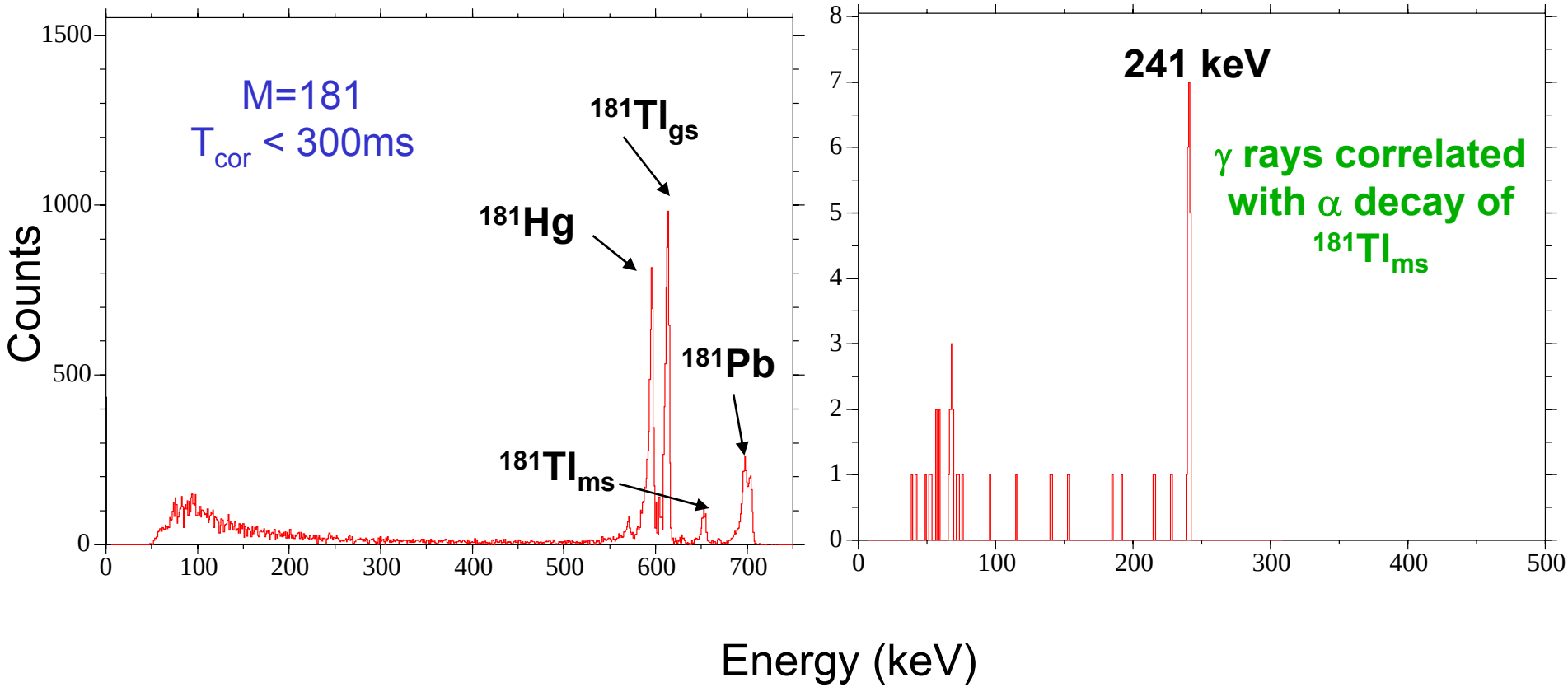
- Due to large, negative Q-value, the compound system is left with relatively low excitation energy when using bombarding energies near the Coulomb barrier.
- **Minimizes** fission probability.
- **Minimizes** fragmentation of reaction channel (1 and 2 particle evaporation).
- **Maximizes** FMA efficiency
- **Allows**:
  - More beam on target.
  - Less restrictive gating.
- **Bottom line**: you make more of the stuff you want.

Motivation: Push Beyond mid-shell in Tl isotopes



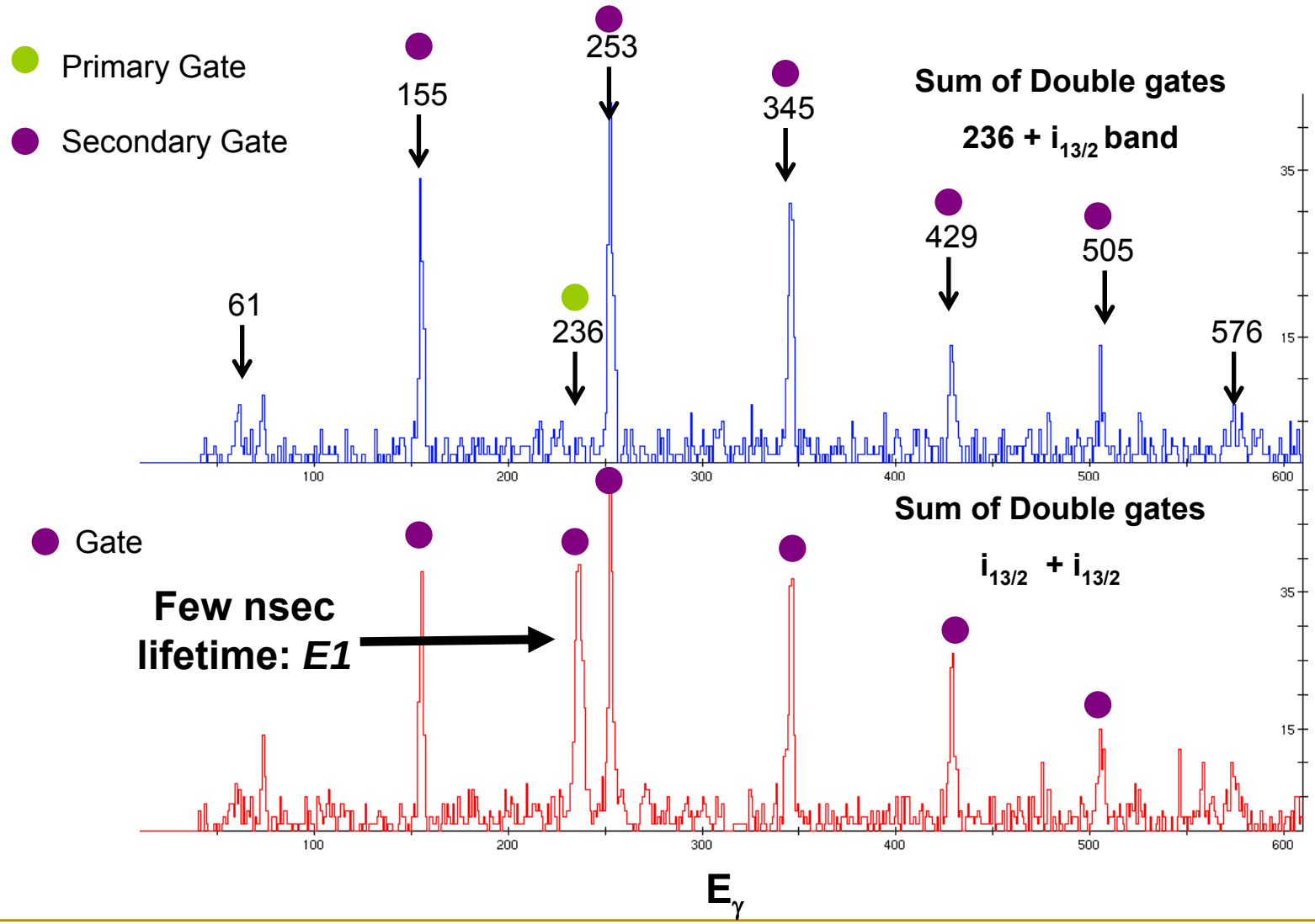


Alpha Decay of ^{181}Tl



- $^{181}Tl_{gs}$ ($T_{1/2}$ = 3.2 sec) correlated with gs decay of ^{177}Au.
- $^{181}Tl_{ms}$ ($T_{1/2}$ = 1.5 ms) feeds 9/2$^-$ state in ^{177}Au and correlates with $^{177}Au_{ms}$ α decay.

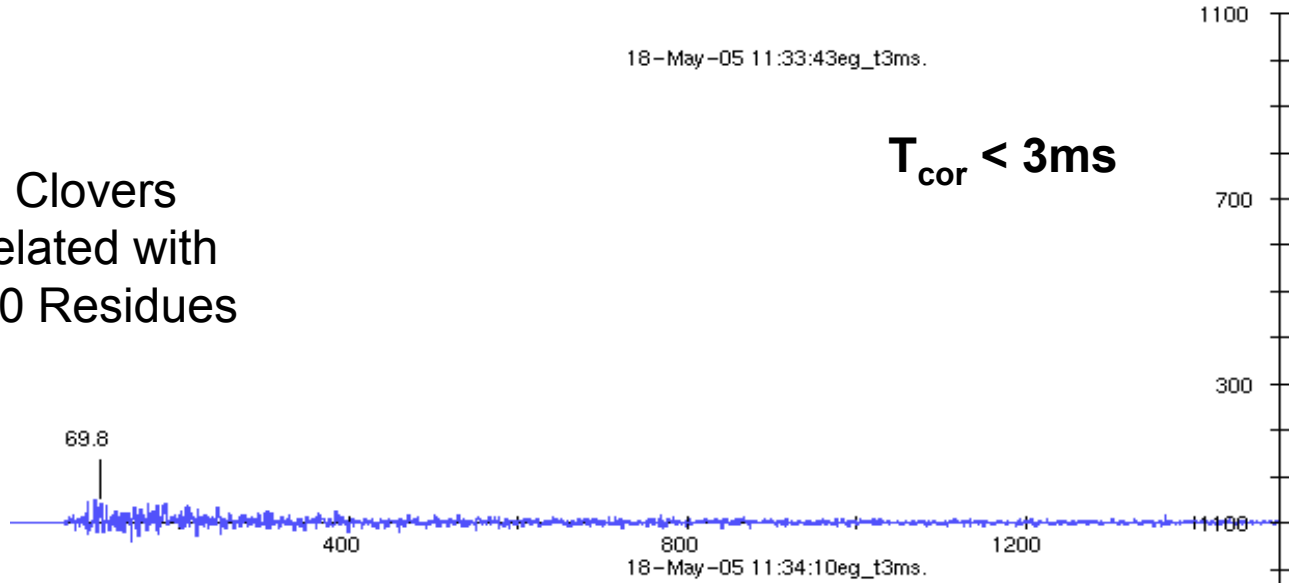
In-Beam Gamma Rays for ^{181}Tl (mass gated)



FMA Only Experiment

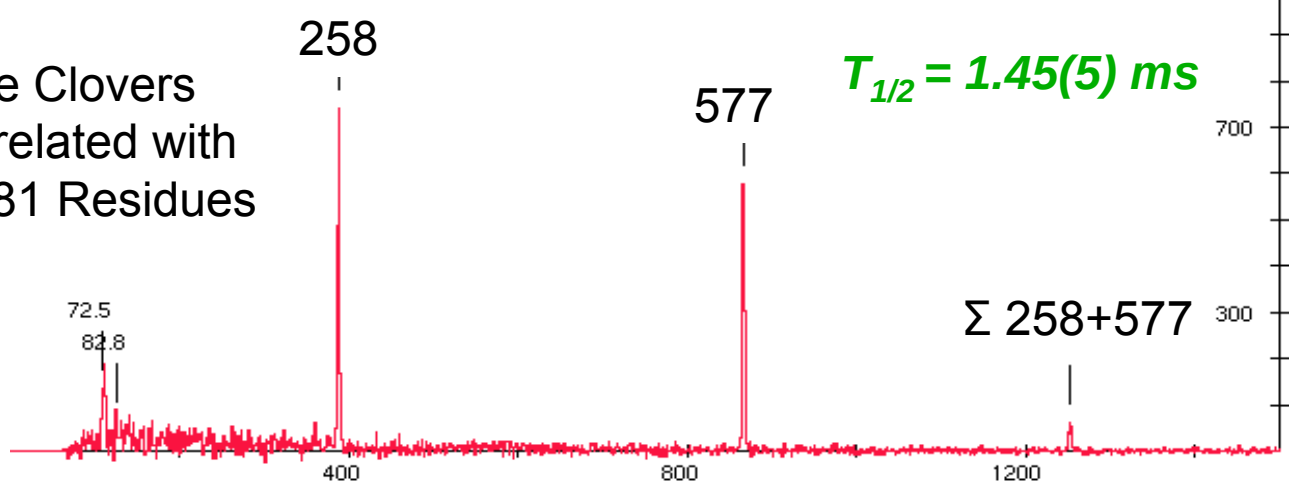
Ge Clovers
Correlated with
M=180 Residues

T_{cor} < 3ms

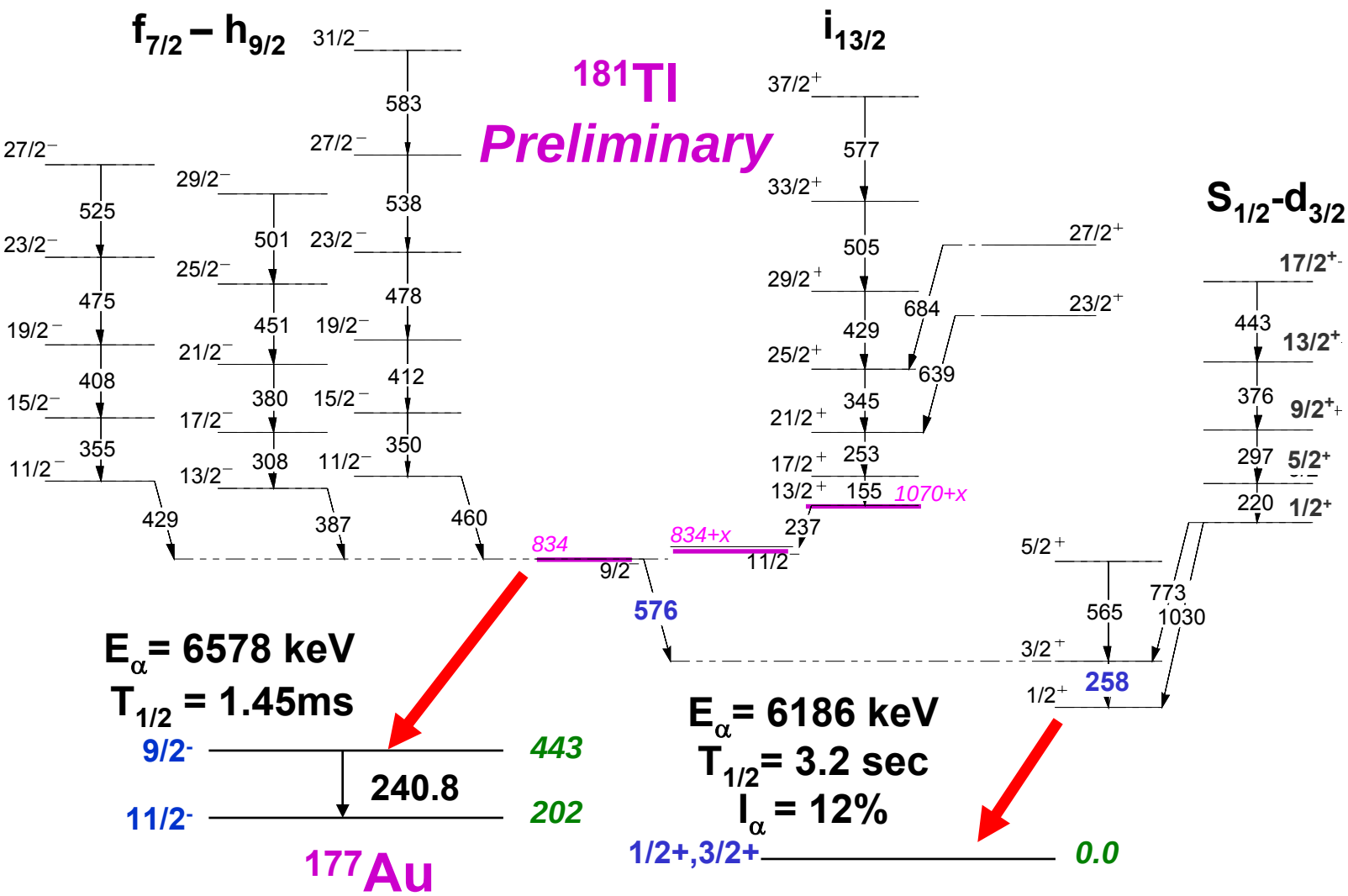


Ge Clovers
Correlated with
M=181 Residues

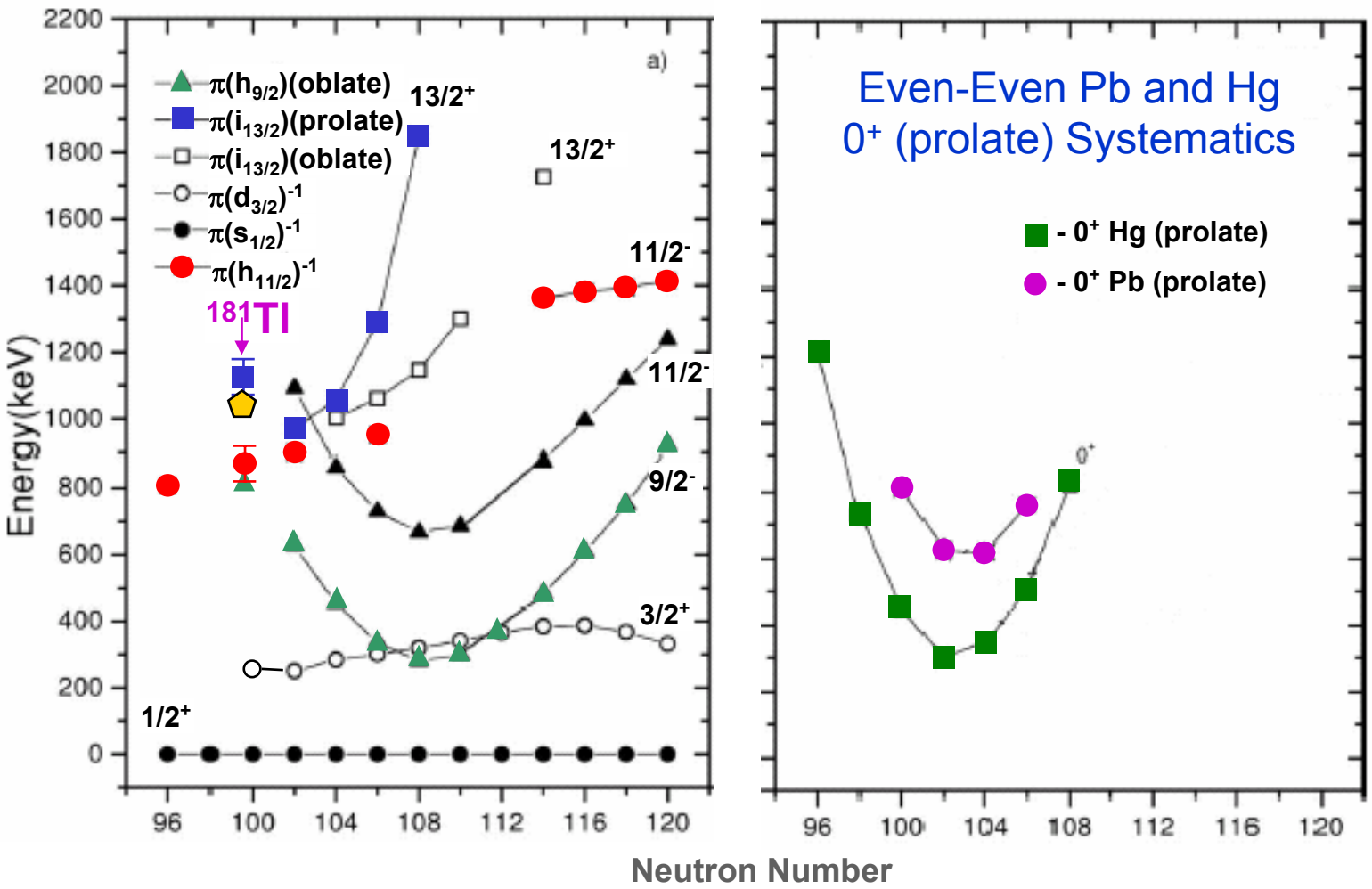
$T_{1/2}$ = 1.45(5) ms



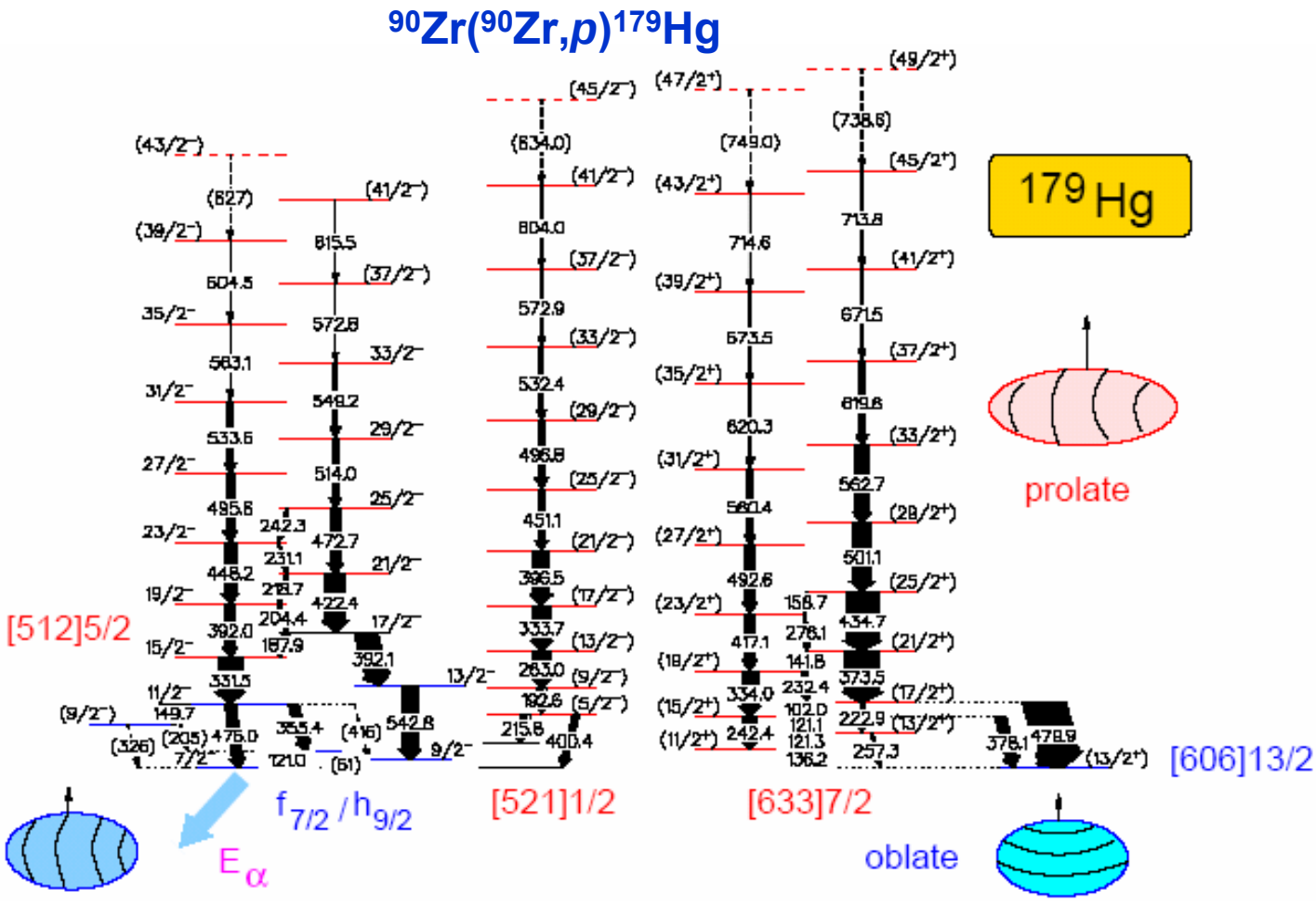
^{181}Tl Level Scheme: ^{92}Mo(^{90}Zr,p)^{181}Tl ($\sigma \sim 15\mu b$)



Tl level systematics



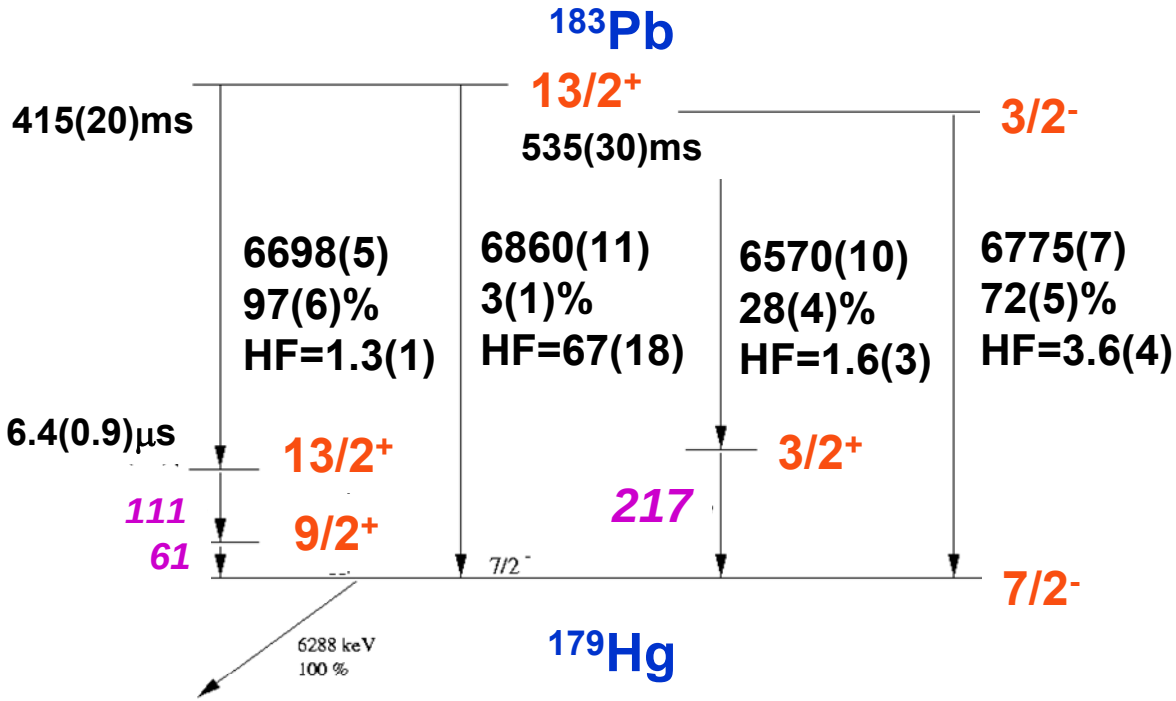
Triple Shape Coexistence in ^{179}Hg



F.G. Kondev et al., Phys Lett. B 528 (2002) 221.

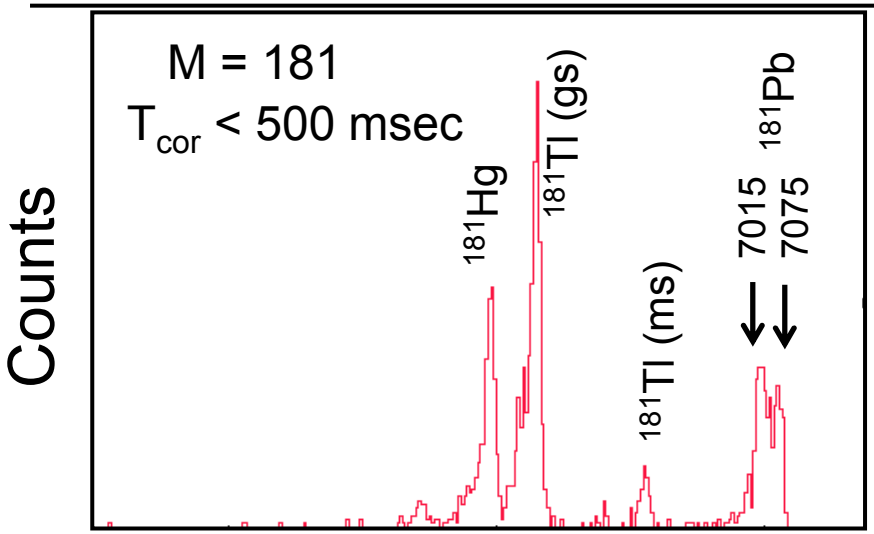
^{183}Pb α-Decay

D.J. Jenkins et al., PRC 66 (2002) 011301(R).



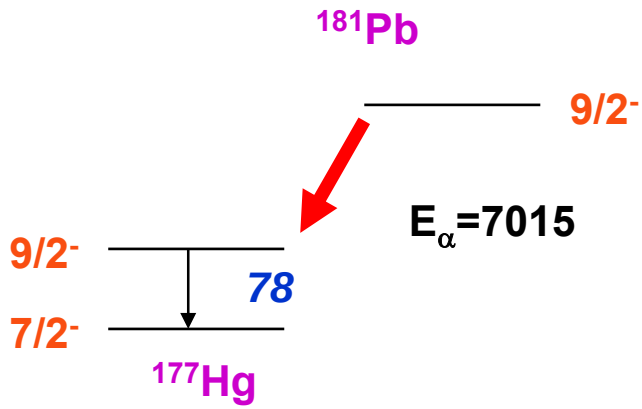
- $13/2^+$ isomer feeds the $13/2^+$ oblate state in ^{179}Hg with $T_{1/2}$=6.4 ms and establishes the excitation energy of the isomer at 172 keV.
- Alpha decays in ^{183}Pb established to come from a ground and isomeric state. The $3/2^-$ ($3p_{3/2}$) ground state continues the trend starting at ^{199}Pb.
- Hindrance factors for α decays to the ground state of ^{179}Hg support near spherical interpretation for the shape of the g.s.

Results: ^{181}Pb α decay

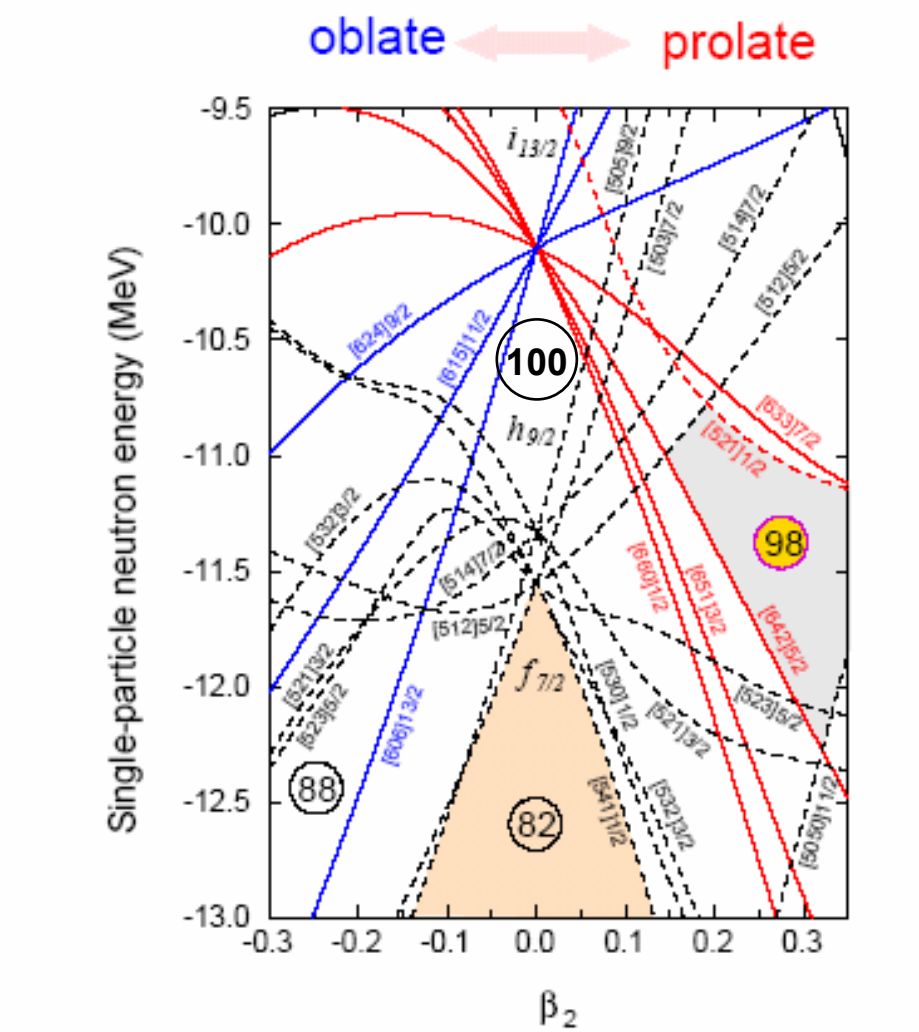


- Interpret the higher line as sum of *l*-converted electron (~60 keV) and the 7015 keV α decay.
- Ground state of ^{181}Pb is $9/2^-$ not $3/2^-$ as in heavier odd-A Pb isotopes.

- Two α lines are observed to be correlated with the α decay of ^{177}Hg.
- Both α-lines have same lifetime ($T_{1/2}$=40ms)
- The 7015 keV line is in coincidence with a 78 keV gamma-ray.



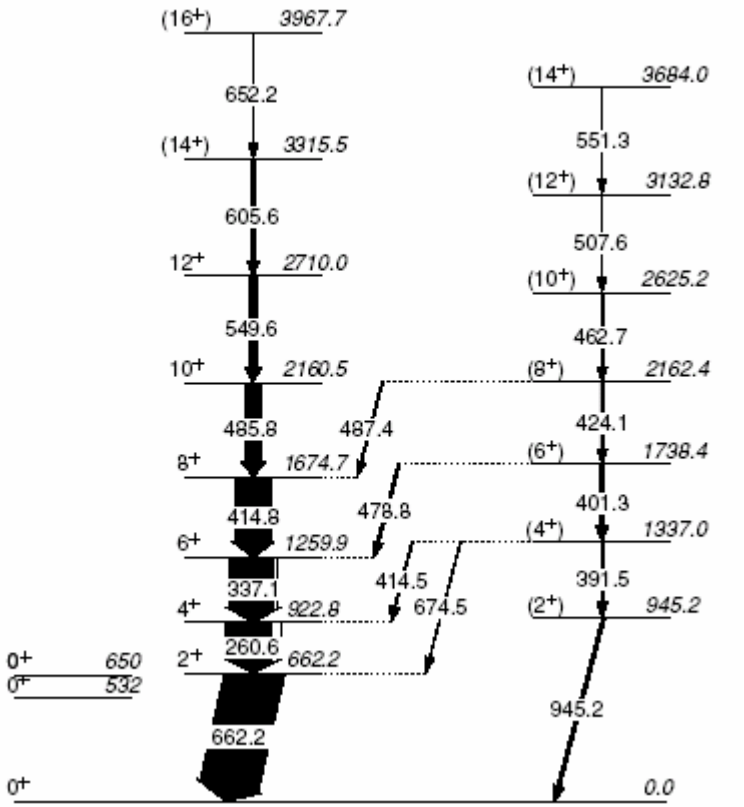
Change in structure of ^{181}Pb ground state



- Occupy states below N=100 sub-shell $h_{9/2}$ and $f_{7/2}$.
- $9/2^-$ assignment to ground state, indicates an $h_{9/2}$ configuration.
- Sub-shell gap probably responsible for the near spherical ground states in Pt and Hg isotopes for N<100.
- The $7/2^-$ ground states in ^{177,179}Hg (also ^{175}Pt) indicates a weakly deformed shape as opposed to spherical.

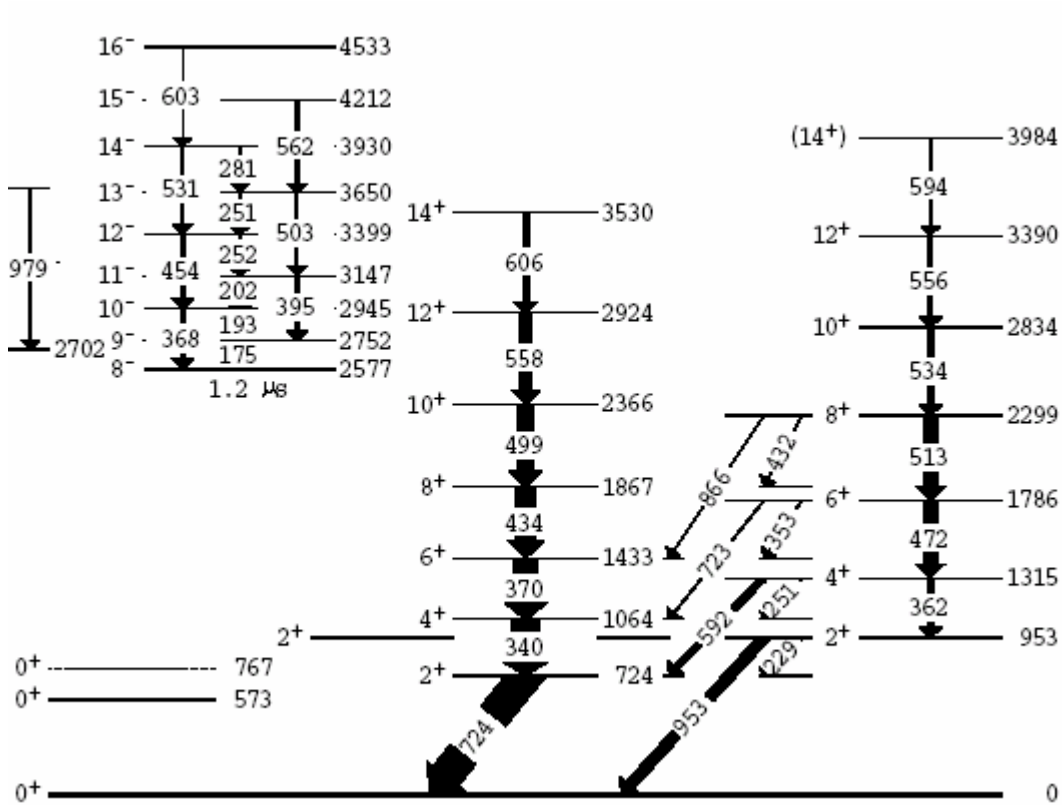
New Results on Pb Nuclei

^{186}Pb



J. Pakarinen *et al*., Phy. Rev. C **72**, 011304(R) (2005)

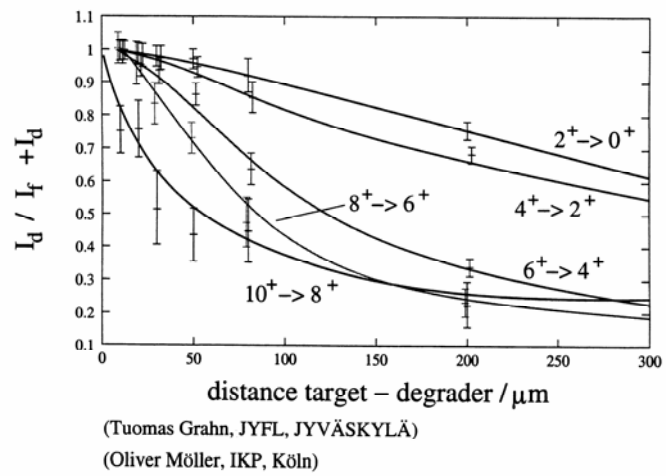
^{188}Pb



G. Dracoulis *et al*., Phy. Rev. C **67**, 051301(R) (2003)

A. Dewald: Plunger+JUROGAM+RITU+GREAT

Reaction: ^{108}Pd(^{83}Kr,3n)^{188}Pb @ 352 MeV , σ~470 μb

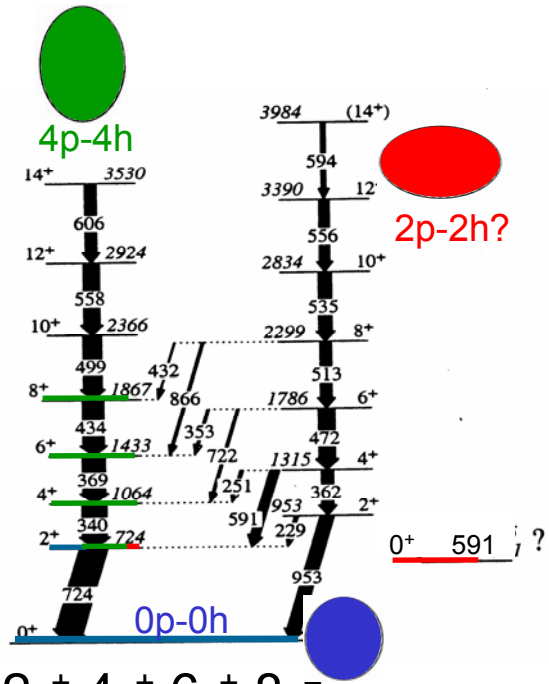


preliminary results:

(Tuomas Grahn, JYFL, JYVÄSKYLÄ)

(Oliver Möller, IKP, KÖLN)

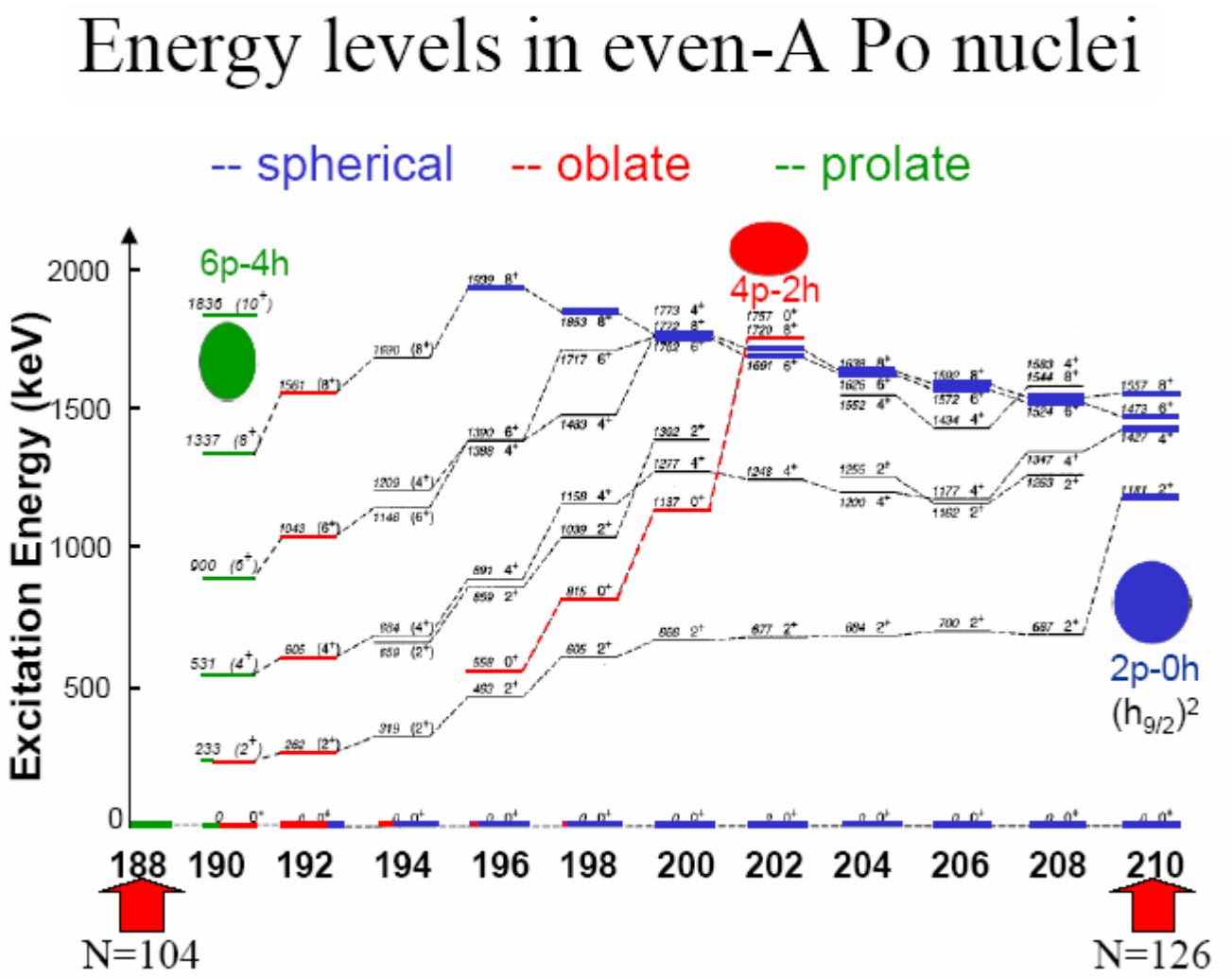
τ/ ps	Q_t /eb	B(E2)/W.u.
2.1(10)	8.5(20)	378(180)
4.0(15)	9.3(18)	429(161)
12(3)	6.9(8)	213(53)
7(2)	1.7(2)	9.1(26)



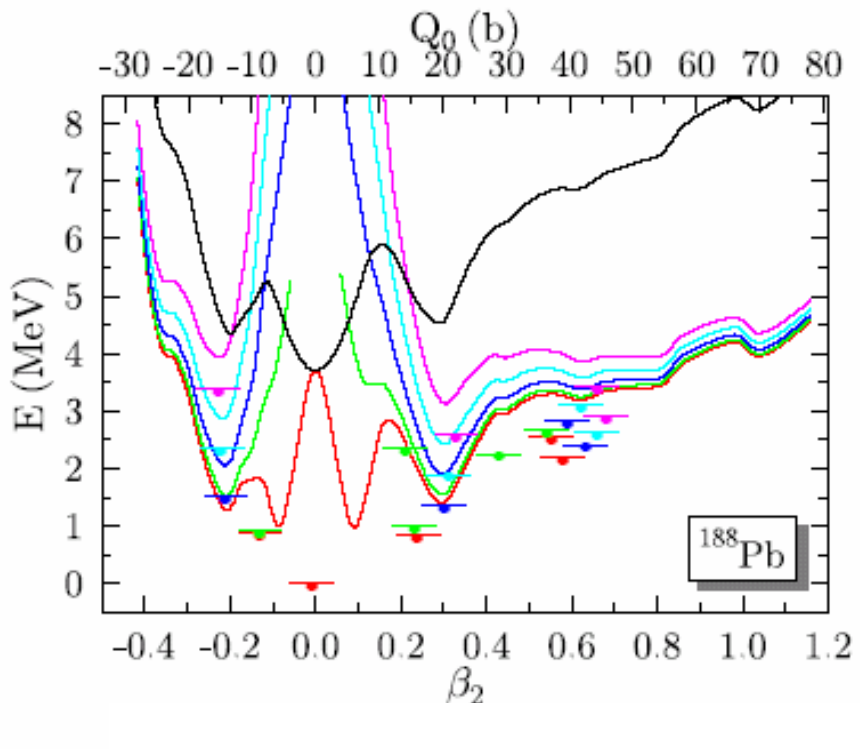
- Deformed yrast prolate band (half-lives of 2_1^+,4_1^+,6_1^+,8_1^+
- Mixed 2_1^+ state! (a^2_{prol}~ 50-70%)
- ^{186}Pb $B(E2)_{4-2}$ = 480, $B(E2)_{6-4}$ = 438, $B(E2)_{8-6}$ = 246

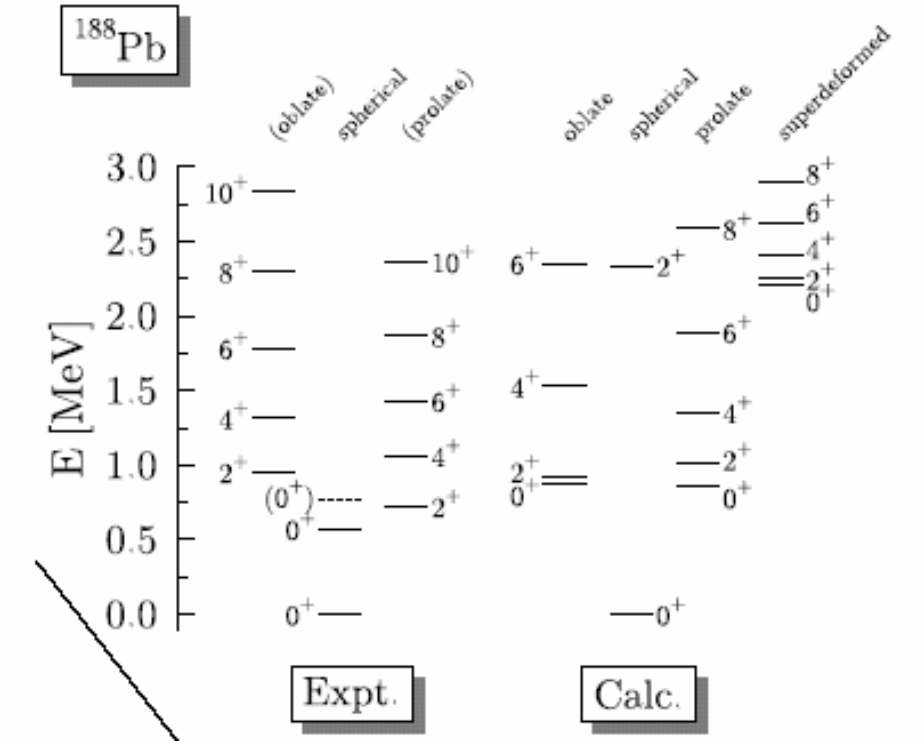
first plunger measurement for ^{188}Pb : A. Dewald et al., PRC68, 034314 (2003) (Gammasphere+FMA)

Shape Co-existence in Po Isotopes



Theoretical Calculations (Beyond Mean Field)





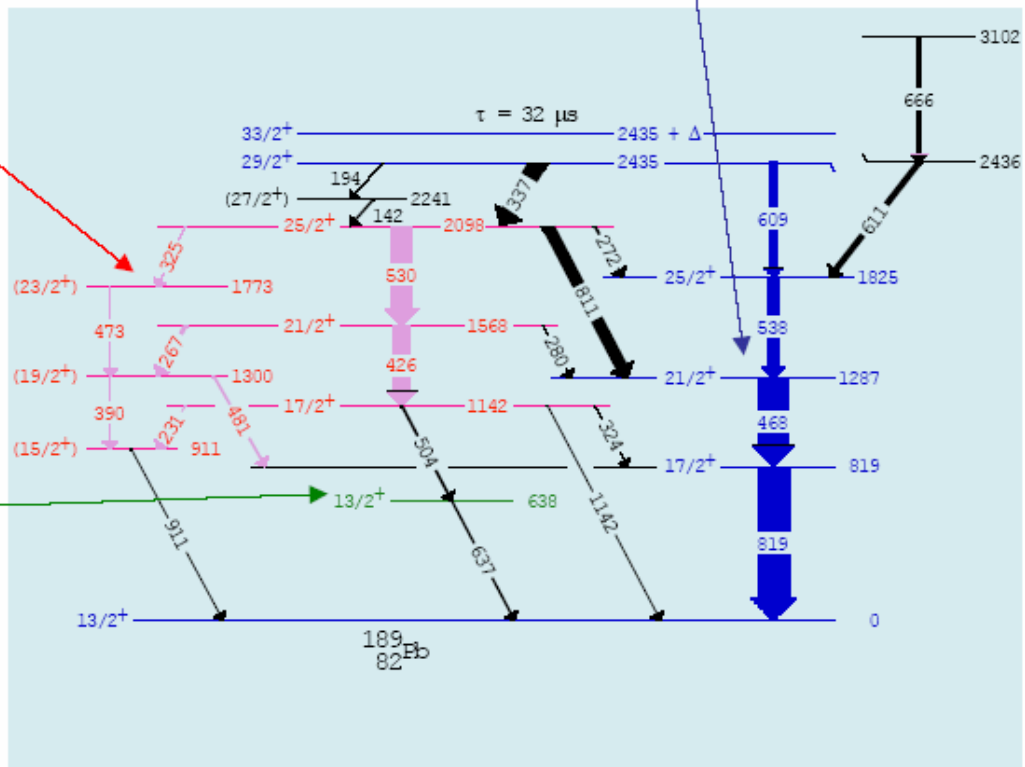
- Skyrme Interaction: M. Bender *et al.*, Phys. Rev. C69, 064303 (2004).
- Gogny Interaction : R. Rodriguez Guzman *et al.*, Phys. Rev. C69, 054319 (2004).

^{189}Pb – *A.M. Baxter et al., Phys. Rev. C 71 (2005) 054301*

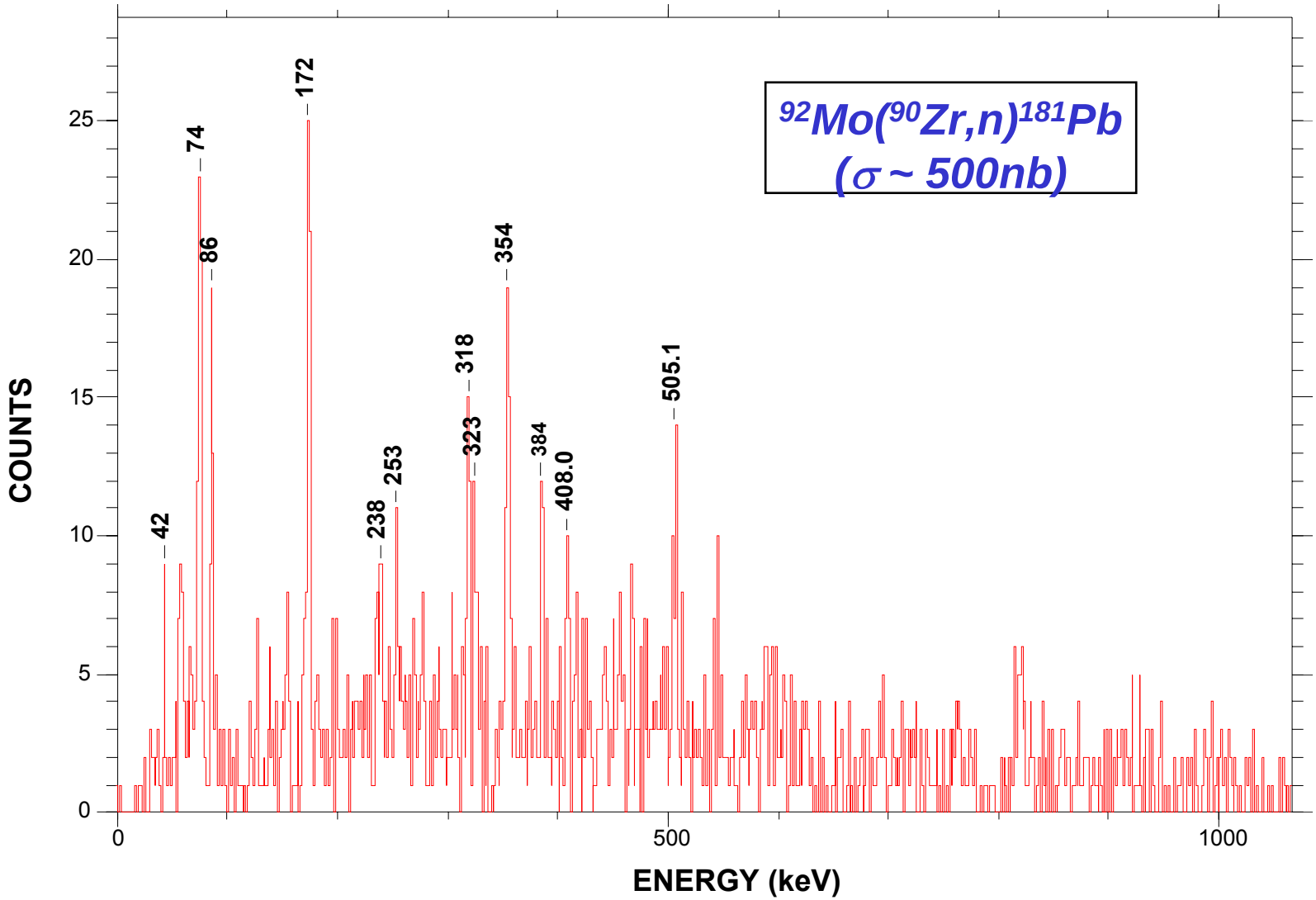
Prolate band
From similarity to "mixed $i_{13/2}$" band in ^{187}Hg

Spherical states
From systematics in odd-A Pb isotopes

Oblate state
$\nu(i_{13/2})$ coupled to $\pi(2p\text{-}2h)$ oblate intruder



^{181}Pb In-Beam γ spectrum: RDT gated



Future Plans

- In-beam spectroscopy of odd-A mid-shell Pb nuclei (^{183,185,187}Pb) – identify excitation energies of oblate and prolate deformed single-particle states.
- Search for the the 4th minimum, superdeformed states in mid-shell Pb isotopes.
- Measure lifetimes in the so-called oblate deformed bands in the Pb isotopes.
- Waiting for theorists to calculate odd-A cases.

Collaborators on ^{181}Tl Studies

M.P. Carpenter, F.G. Kondev, R.V.F. Janssens, C.J. Lister, T.L. Khoo, I. Ahmad, C.N. Davids, T. Lauritsen,, D. Seweryniak, S. Zhu
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