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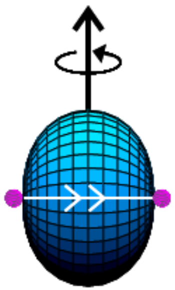
Oblate Deformation and Metastable States in Pt and Hg isotopes



Sujit Tandel

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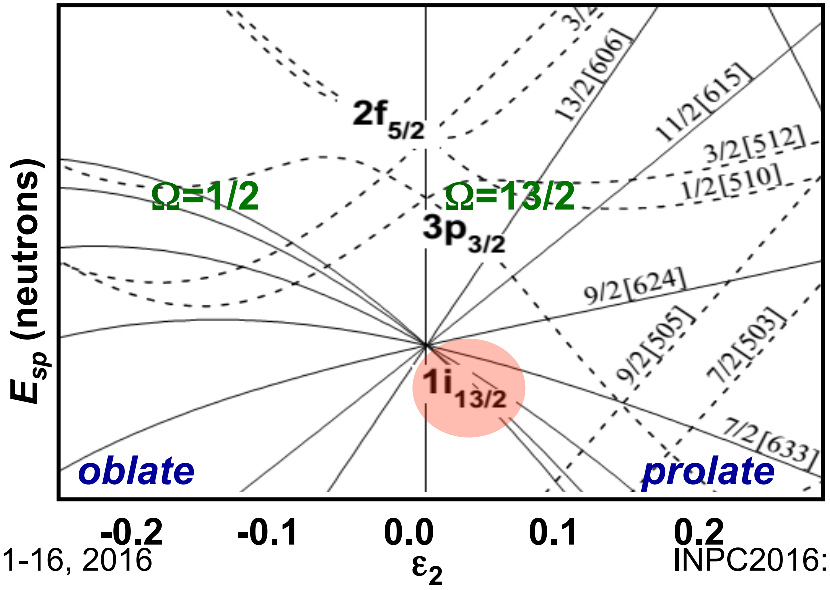
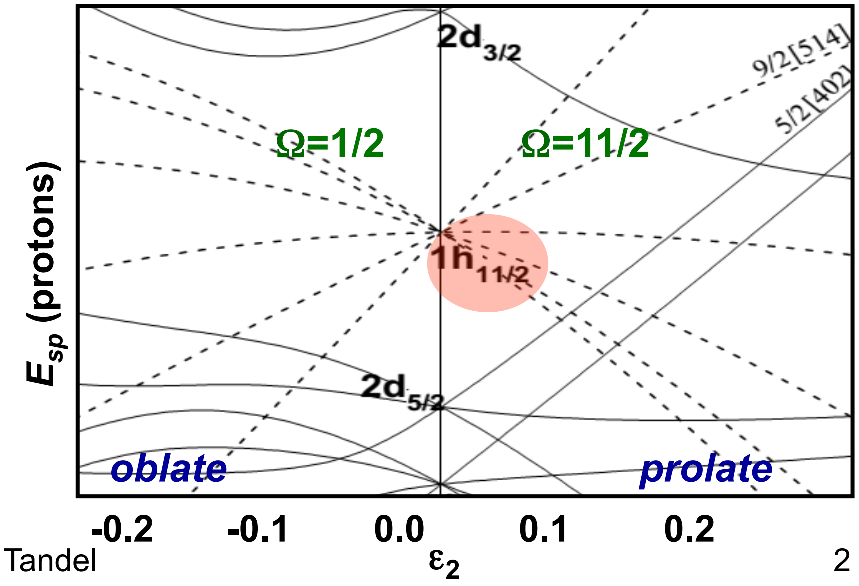
Shape competition at high spin in A≈190 region

- Prolate to oblate shape transition with increasing *Z*, *N* and spin

- Valence $i_{13/2}$ neutrons and $h_{11/2}$ protons:
Prolate shapes: high-Ω orbitals near the Fermi surface
Oblate deformation: low-Ω orbitals near the Fermi surface

- Rotation alignment of low-Ω orbitals at smaller frequencies ⇒ oblate rotation-aligned structures (with higher moments of inertia) can be favored in energy over prolate structures with no alignments (for similar ε_2)





Prolate to oblate shape transition in ^{180}Hf

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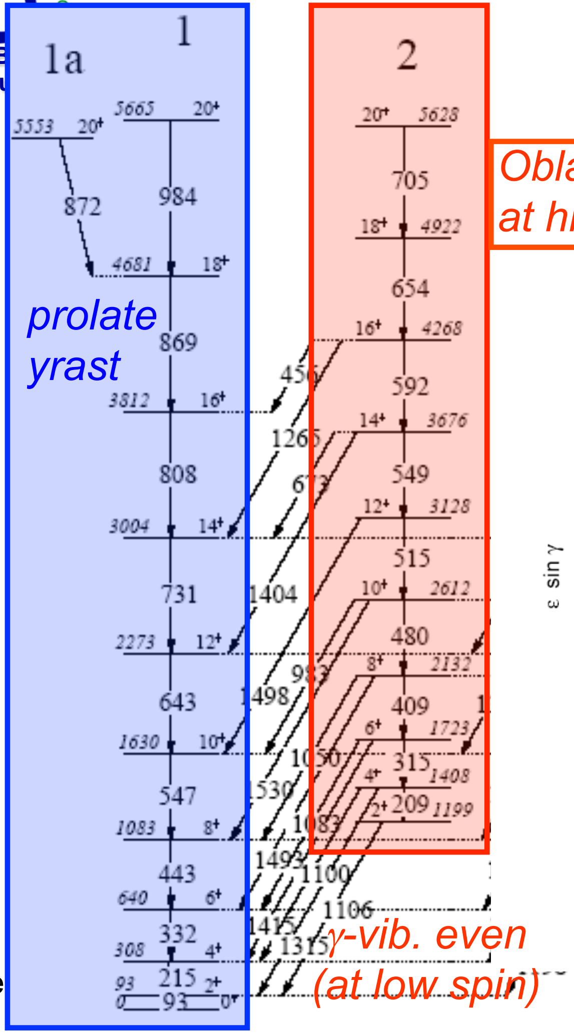
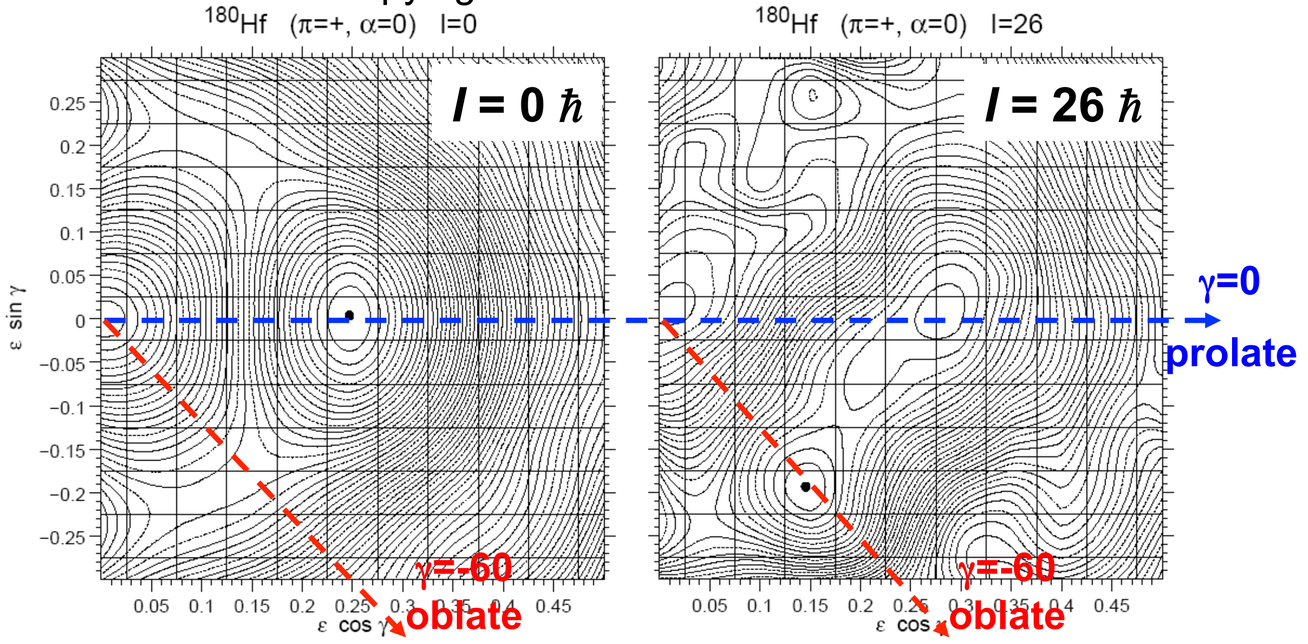


- **^{180}Hf**: classic example of prolate deformed rotor near the ground state (*cf.* Bohr's Nobel lecture)
- Prolate to oblate shape transition at high spin due to the rotation alignment of nucleons occupying low-Ω orbitals at oblate deformation



[Tandel et al., Phys. Rev. Lett. 101, 182503 (2008)]

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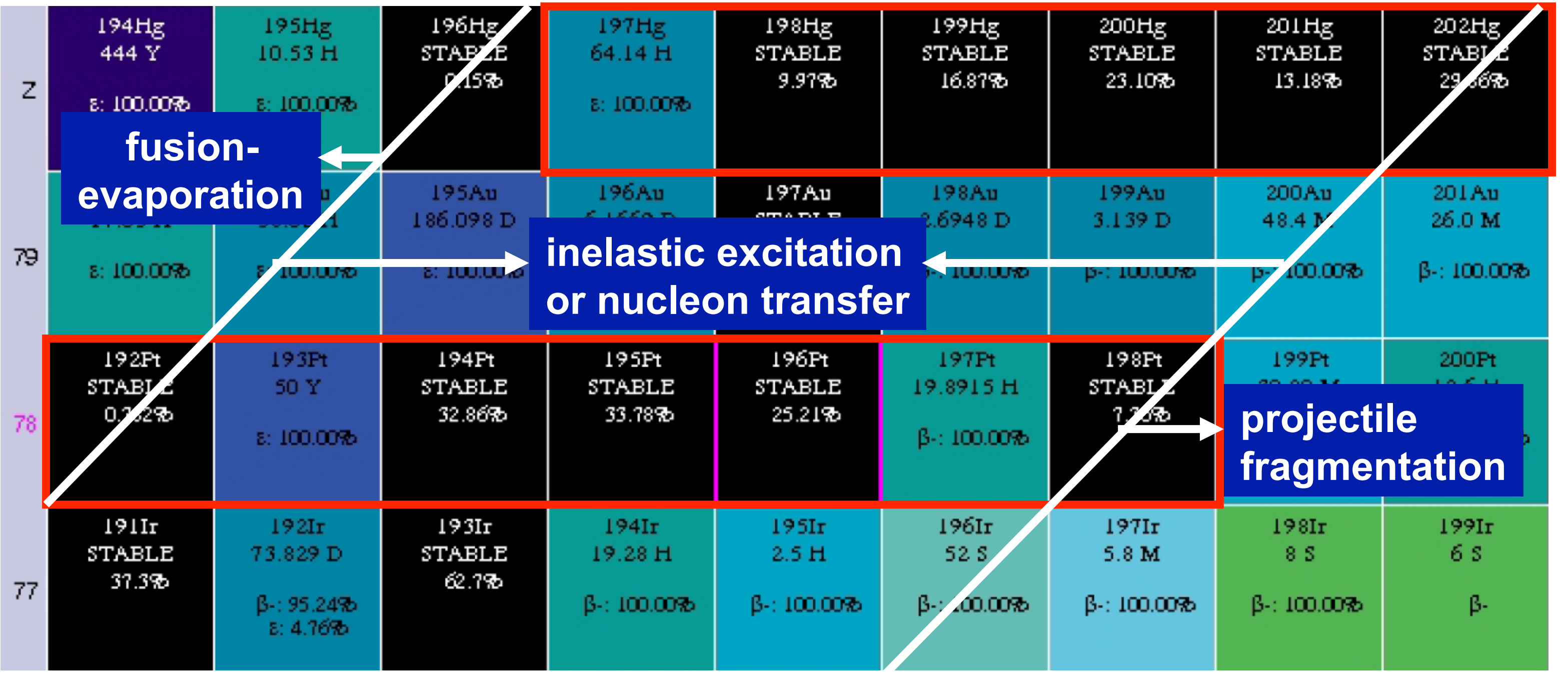
Spectroscopy of stable Pt and Hg isotopes



Proton-rich isotopes well studied through fusion-evaporation reactions; limited information on stable and neutron-rich isotopes through inelastic excitation/multi-nucleon transfer and projectile fragmentation reactions

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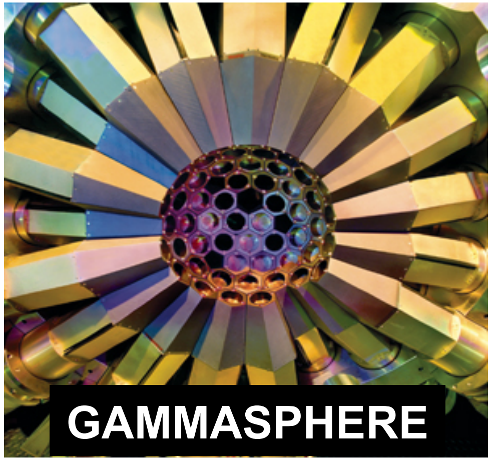
Experiment and data analysis



- Heavy-ion induced multi-nucleon transfer reactions
  ^{197}Au (^{209}Bi, ±1pxn) $^{192\text{-}198}$Pt , $^{198\text{-}202}$Hg

- Thick ^{197}Au target (≈50 mg/cm^2),
  1450 MeV ^{209}Bi beam
  from ATLAS accelerator at Argonne National Laboratory

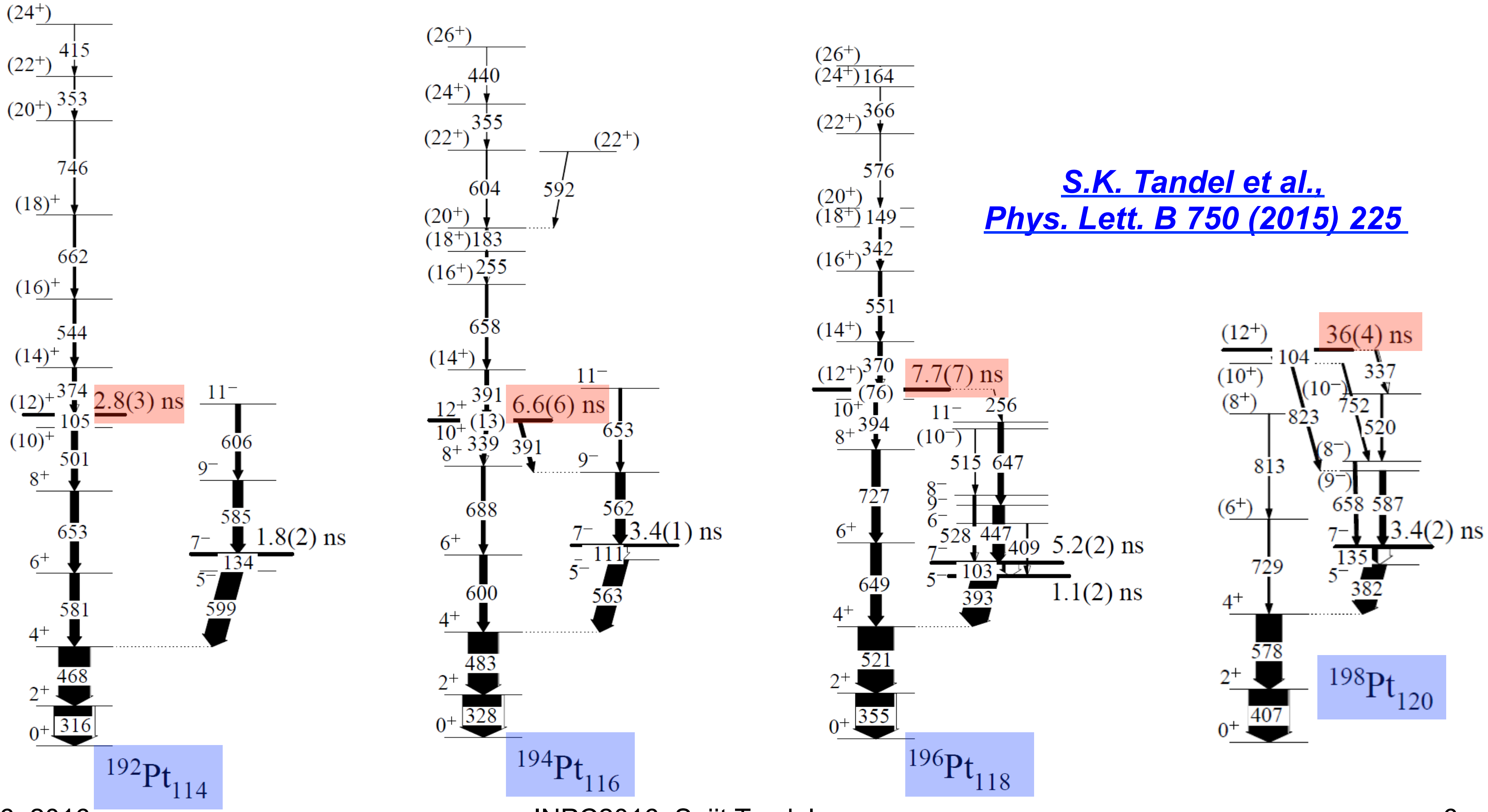
- **GAMMASPHERE**: 100 Compton-suppressed high-purity Ge detectors

- **γ-ray coincidence measurements**

i. 2-, 3-, 4-dimensional symmetric γ-energy histograms (RADWARE)
ii. Energy-energy-time difference histograms (isomers: $T_{1/2}$ < 10 ns)
iii. Time-gated, triple-γ coincidence histograms (isomers: $T_{1/2} \geq$ 10 ns)
iv. Prompt-delayed 2- and 3-dimensional γ-energy histograms
v. Angle-sorted γ-energy histograms for determination of transition multipolarity

Metastable states and rotation-aligned structures in even Pt isotopes

from present work



S.K. Tandel et al., Phys. Lett. B 750 (2015) 225

Structure of ^{196}Pt (N=118)

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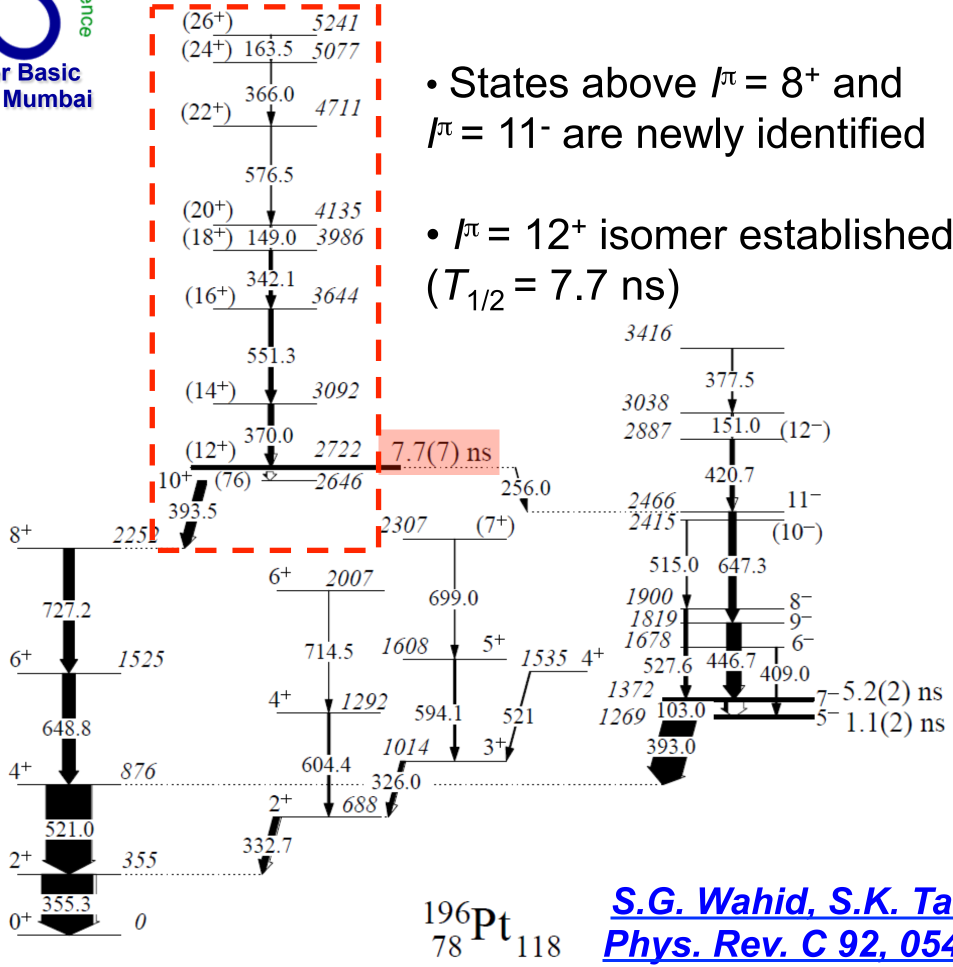
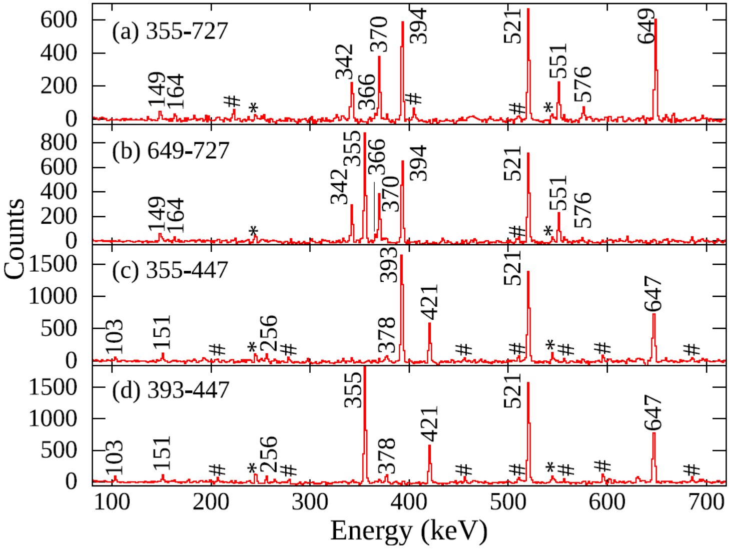
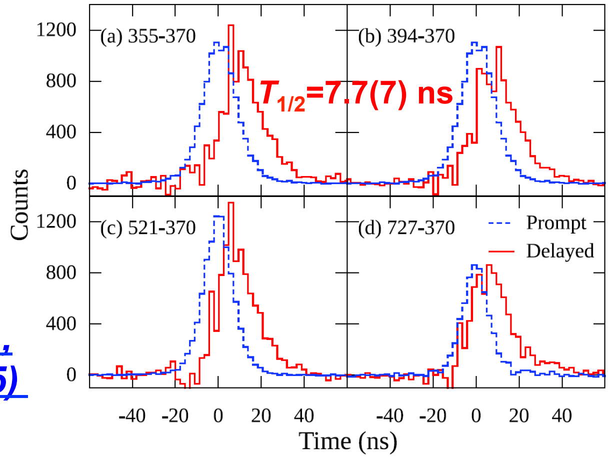
- States above I^{π} = 8^{+} and I^{π} = 11^{-} are newly identified

- I^{π} = 12^{+} isomer established: ($T_{1/2}$ = 7.7 ns)







[S.G. Wahid, S.K. Tandel et al., Phys. Rev. C 92, 054323 (2015)]

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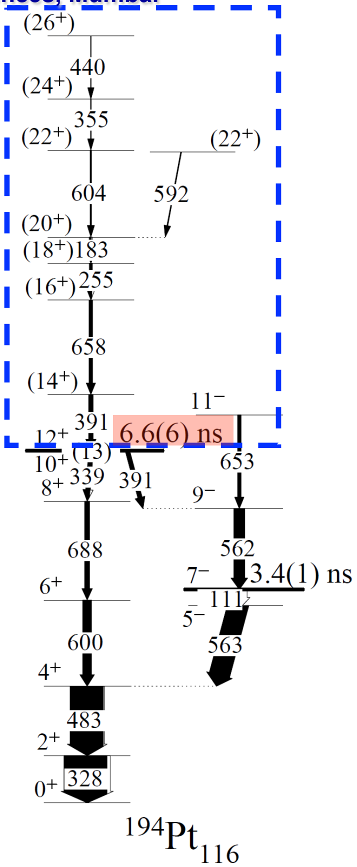
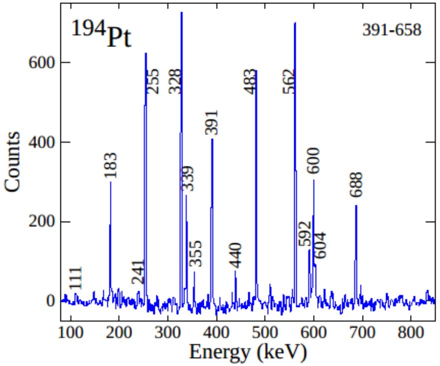
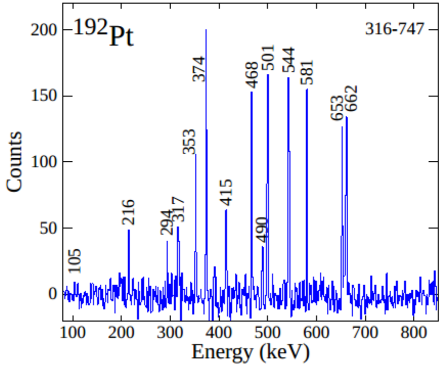
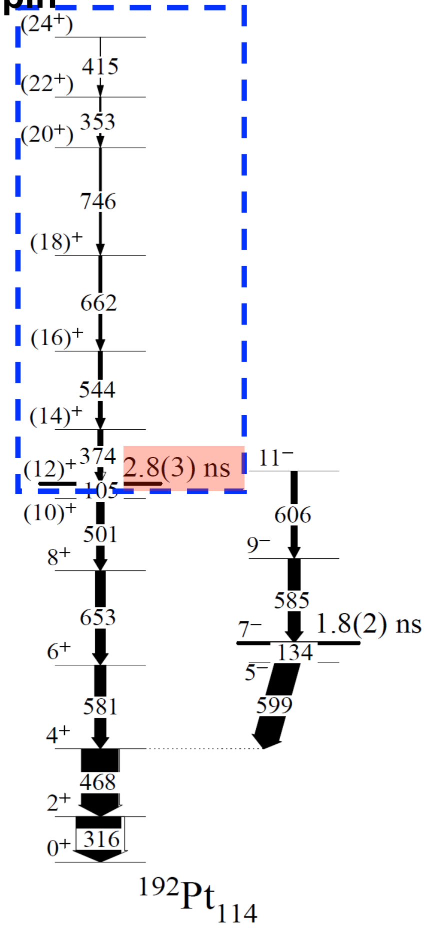
Structure of ^{192,194}Pt (N=114,116)

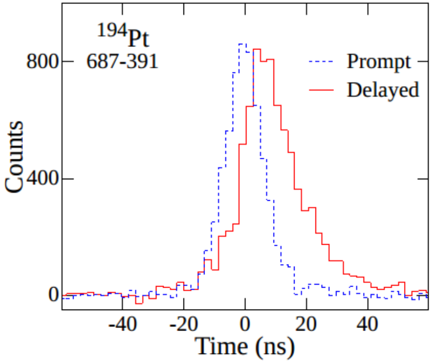
Yrast positive parity structures in ^{192,194}Pt extended to high spin



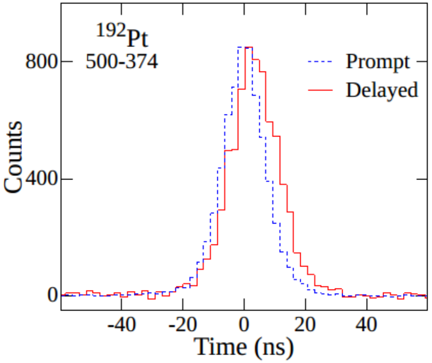








$T_{1/2}$=6.6(6) ns



$T_{1/2}$=2.8(3) ns

S.K. Tandel et al., Phys. Lett. B 750 (2015) 225

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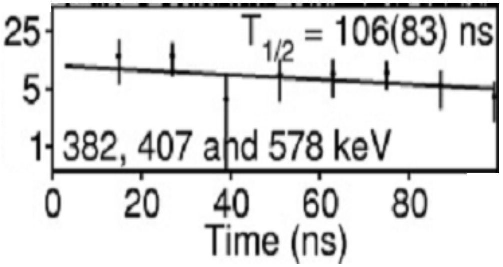
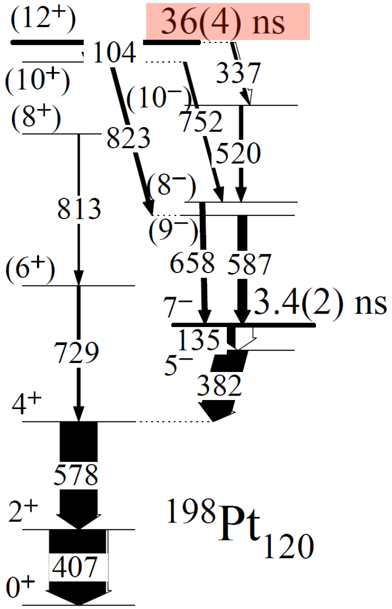
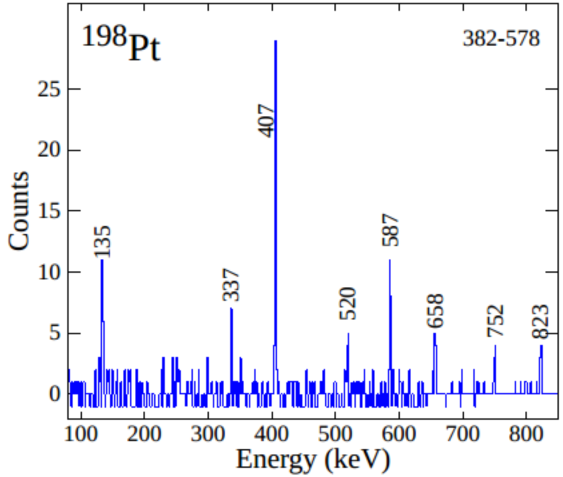
Metastable state in ^{198}Pt (N=120)

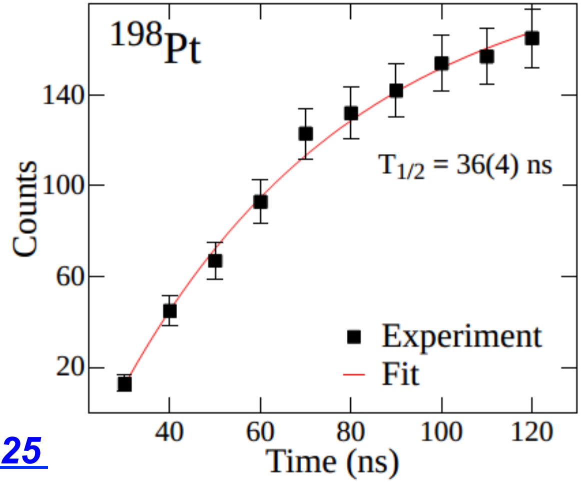
- Information on excited states in ^{198}Pt primarily from the de-excitation of $I^{\pi}=12^{+}$ isomer
- $T_{1/2}$ = 36(4) ns firmly established for the 12^{+} state
- Spin-parity assignments revised from earlier ones



S.J. Steer et al., PRC 84, 044313 (2011)



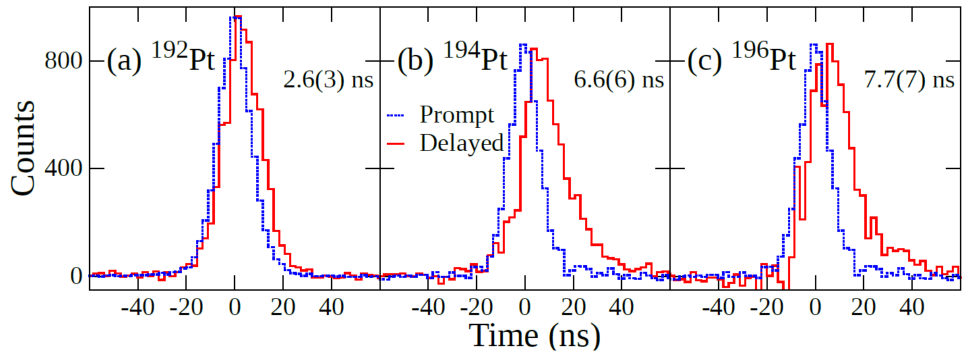




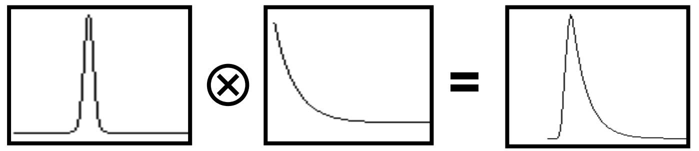
[S.K. Tandel et al., Phys. Lett. B 750 (2015) 225](#)

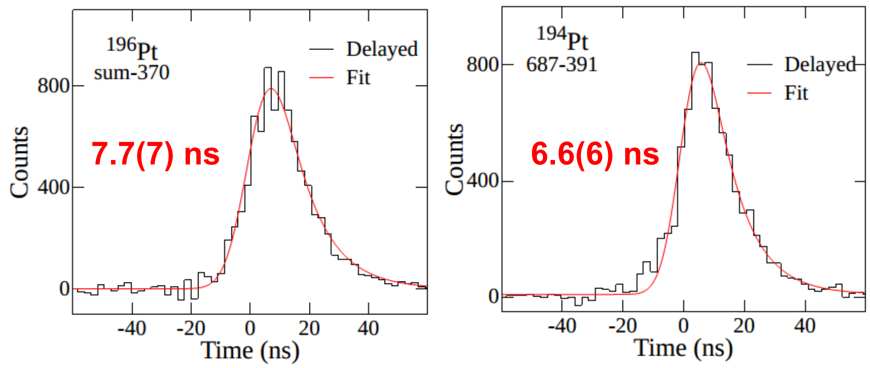
Lifetimes of metastable states in Pt isotopes

- $T_{1/2}$ ~ 1-10 ns (comparable to prompt response time for HPGe detectors)
- Histogram of time difference between transitions feeding and de-exciting isomeric states
- Centroid of time distribution for transitions from isomeric states shifted in comparison to that from prompt levels (for γ rays of similar energy)
- Magnitude of centroid shift is equal to the mean life of the isomeric state



Observed time spectrum:
Convolution of prompt (Gaussian) and exponential decay





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Evolution of collectivity in Pt isotopes

Near ground states

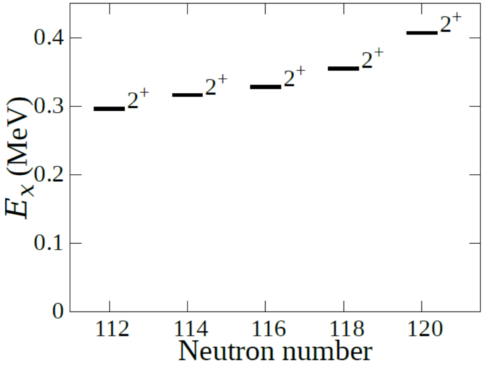
- Gradual increase in E(2+) approaching N = 126 spherical shell gap
- Steady decrease in kinematic moment of inertia of ground state band

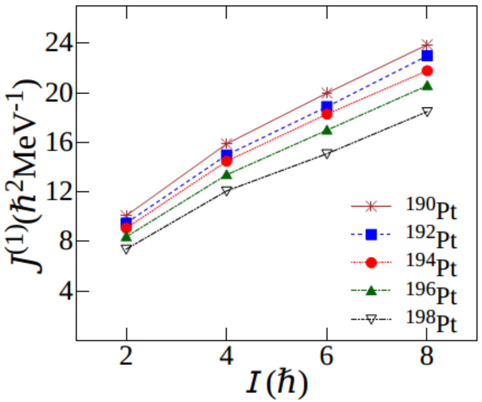
Indicative of progressive reduction in deformation of prolate ground state band

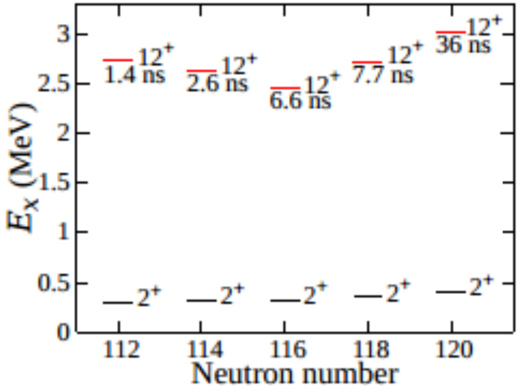
12^+ metastable states

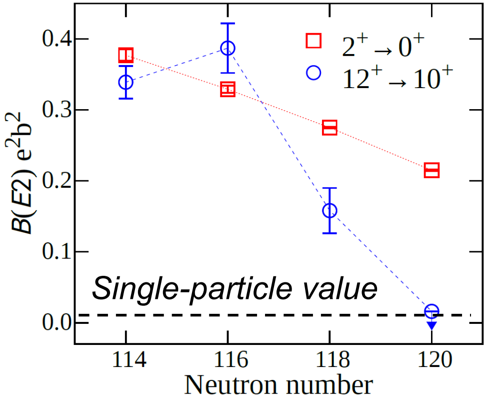
- Substantial collectivity indicated by $B(E2;\, 2^+ \rightarrow 0^+)$ being ~30-50 times the single-particle value from ^{198}Pt to ^{192}Pt
- Lifetimes of 12^+ isomers increase with neutron number

Sharp decrease of $B(E2;\, 12^+ \rightarrow 10^+)$ in ^{196,198}Pt: approaching the single-particle value, indicating abrupt quenching of collectivity









[S.K. Tandel et al., Phys. Lett. B 750 (2015) 225]

$$B(E2) = \frac{0.08156 B_\gamma}{E_\gamma^5 \tau [1 + \alpha_t(E2)]} \; e^2 b^2$$

Prescription for cranking calculations

Approaches

i. Woods-Saxon potential with universal parameterization
ii. Ultimate Cranker, with Modified Oscillator potential (standard Nilsson parameters)

- Extended grid in deformation space employed to include all possible shapes ranging between prolate non-collective to oblate non-collective (including collective prolate/oblate and triaxial)

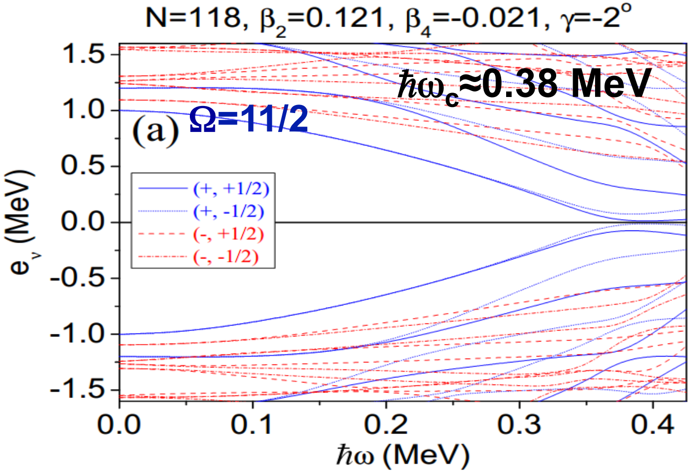
- Empirical pair-gap energies from 5-point odd-even mass differences

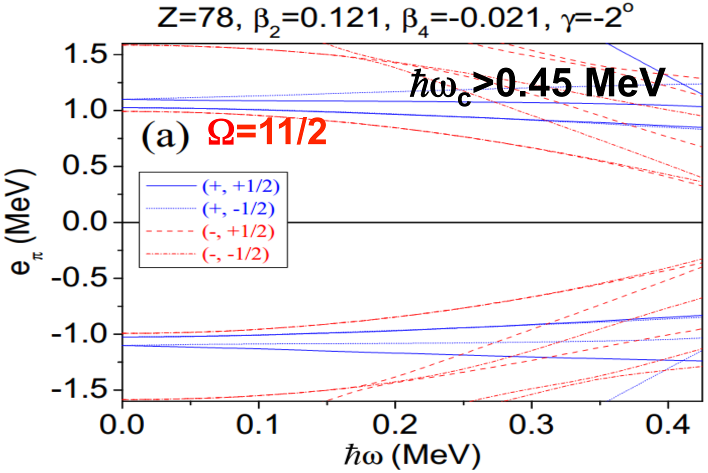
- Calculated shape evolution, excitation energies, crossing frequencies, aligned angular momentum…

- Systematic calculations for range of even Os (Z=76), Pt (Z=78) and Hg (Z=80) isotopes

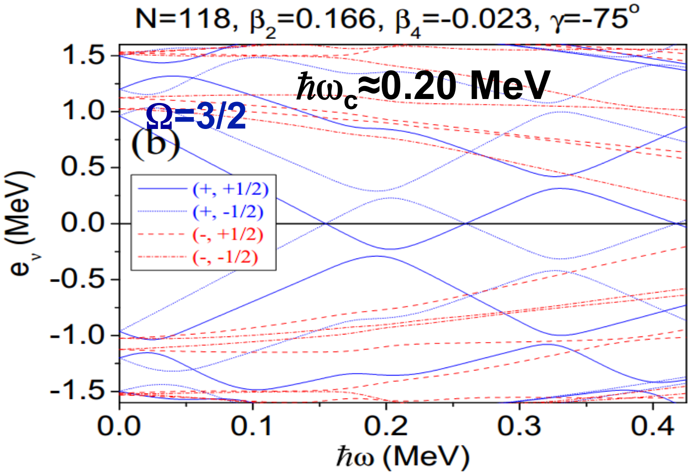
Nucleon alignments in ^{196}Pt

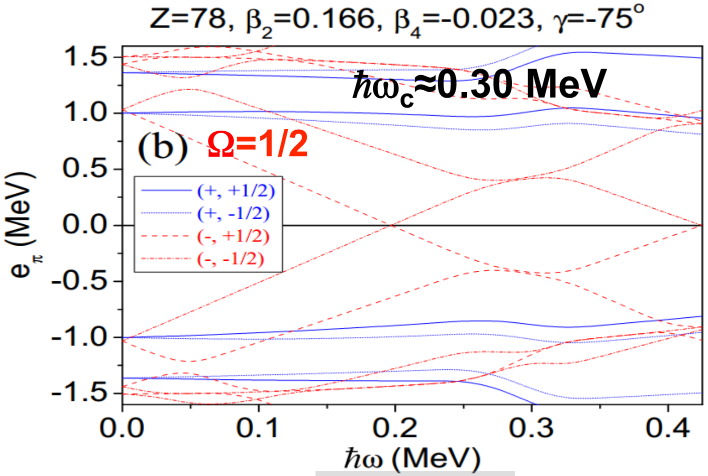
Prolate →





Oblate →





Neutrons

Protons

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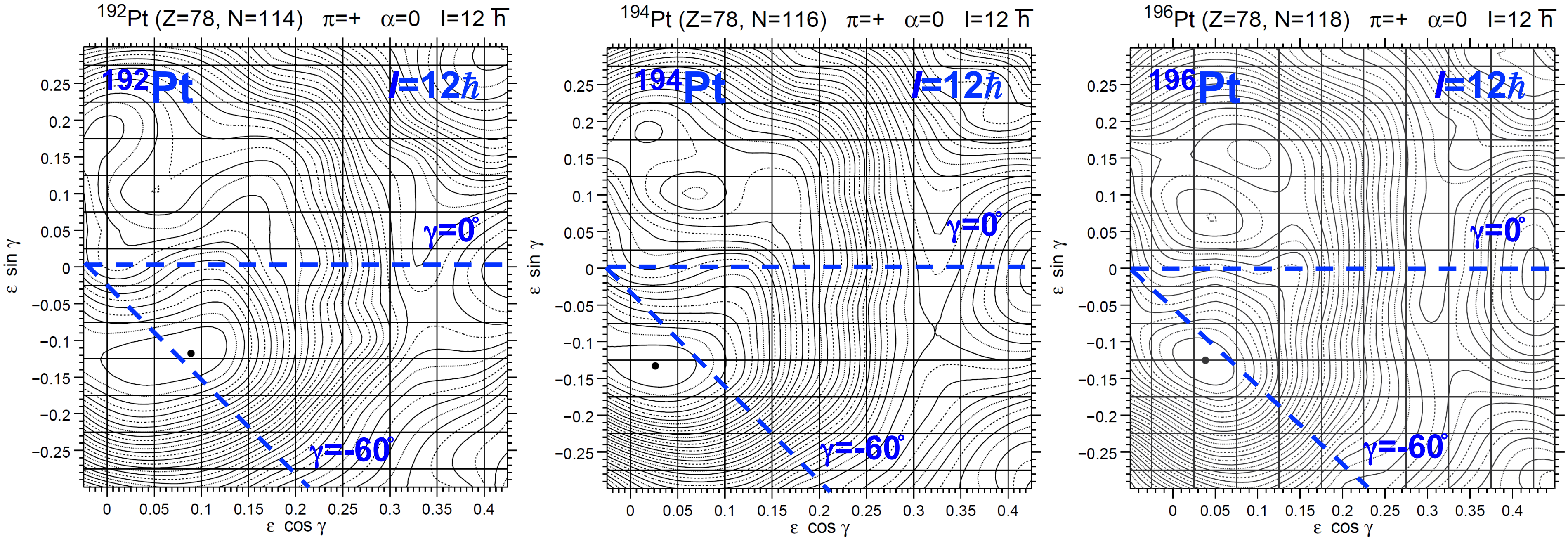
Shapes: metastable states in Pt isotopes

- **Ultimate Cranker:** Collective oblate minimum ($\gamma \approx -60^o$) near $I^\pi = 12^+$ (metastable states)
- Energy minimum moves towards more negative γ values with increase in *N*
- Oblate minimum persists beyond $I = 20\ \hbar$

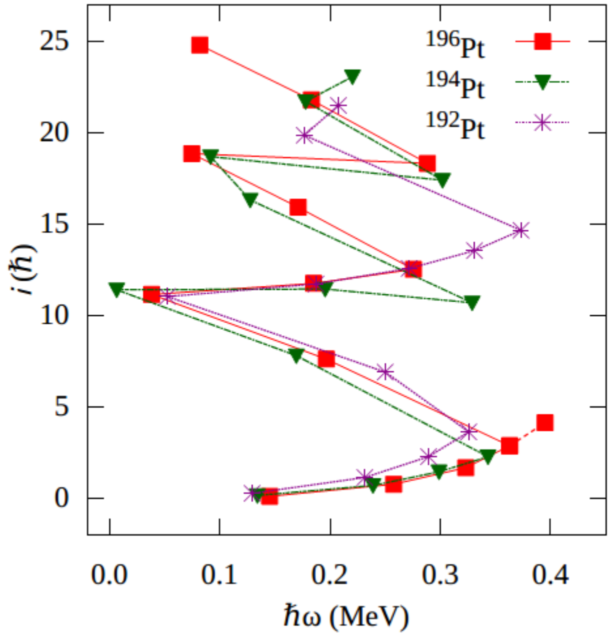


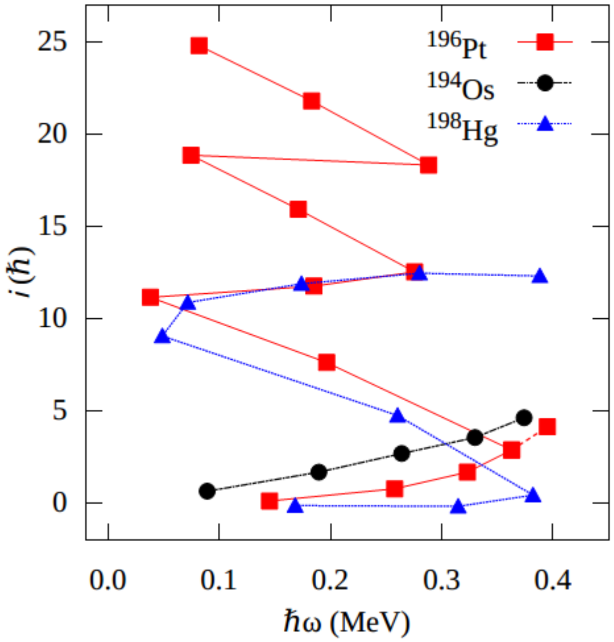
Rotation-aligned angular momentum (experimental)

• First rotation alignment at $\hbar\omega \approx 0.2$ MeV in Pt isotopes due to $i_{13/2}$ (*AB*) neutrons (~12 $\hbar$); compare with predicted alignment frequency for prolate (0.38 MeV), and that for oblate (0.2 MeV)

• Second alignment due to either $i_{13/2}$ (*CD*) neutrons or $h_{11/2}$ protons; delay in ^{192}Pt possibly due to involvement of higher-Ω neutron orbitals

• Isotones of ^{196}Pt: $i_{13/2}$ *AB* neutron alignment identified in ^{198}Hg; only prolate ground state band known in ^{194}Os





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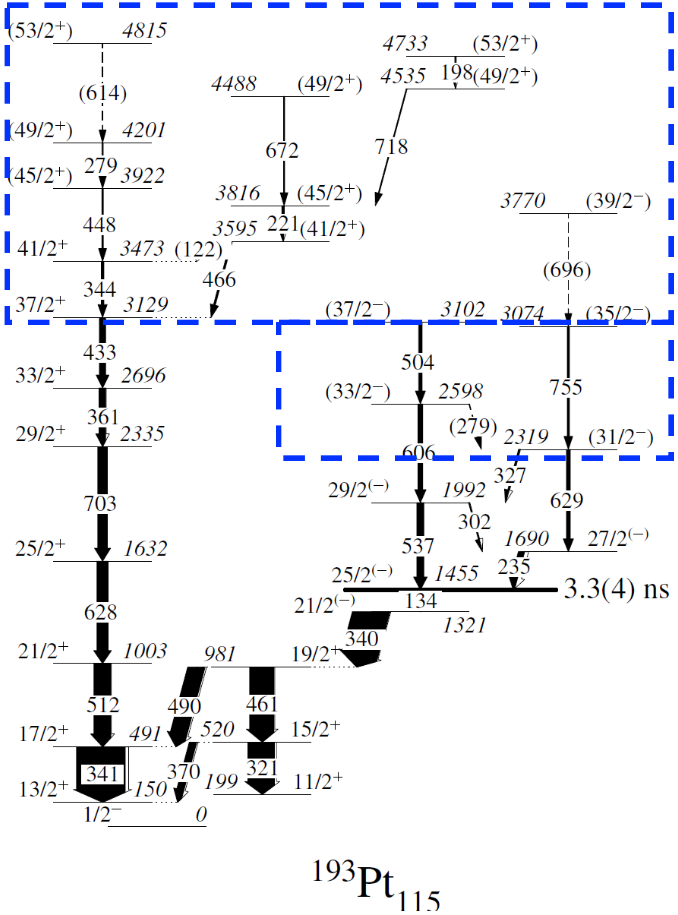
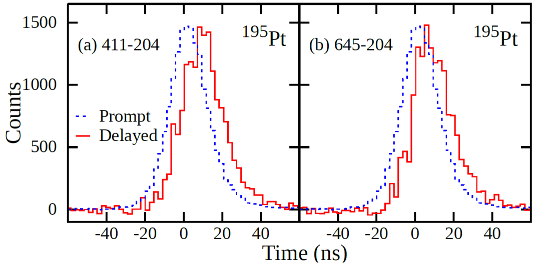
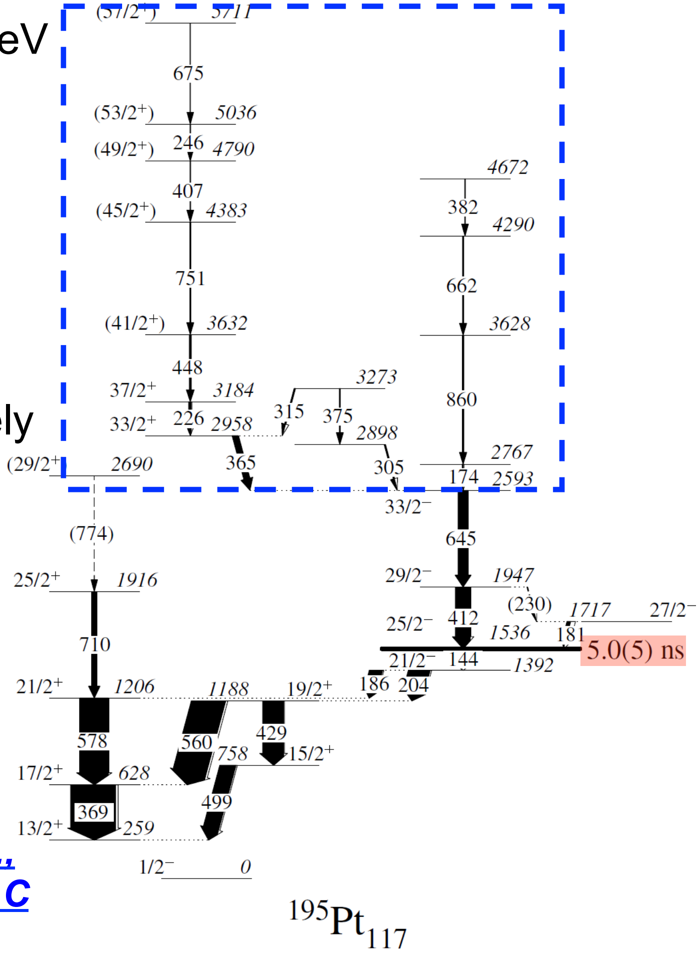
Structure of odd-A Pt isotopes: ^{193,195}Pt



- Excited states up to E_x~ 5 MeV and I^{π}~25 $\hbar$ established
- I^{π} = 25/2$^-$ metastable state identified in ^{195}Pt
- Band crossings in ^{193,195}Pt: *AB* neutron crossing blocked; *BC* neutron crossing most likely responsible for first alignment





S.G. Wahid, S.K. Tandel et al., for submission to Phys. Rev. C

INPC2016: Sujit Tandel

Structure of odd-A Pt isotopes: ^{193,195}Pt

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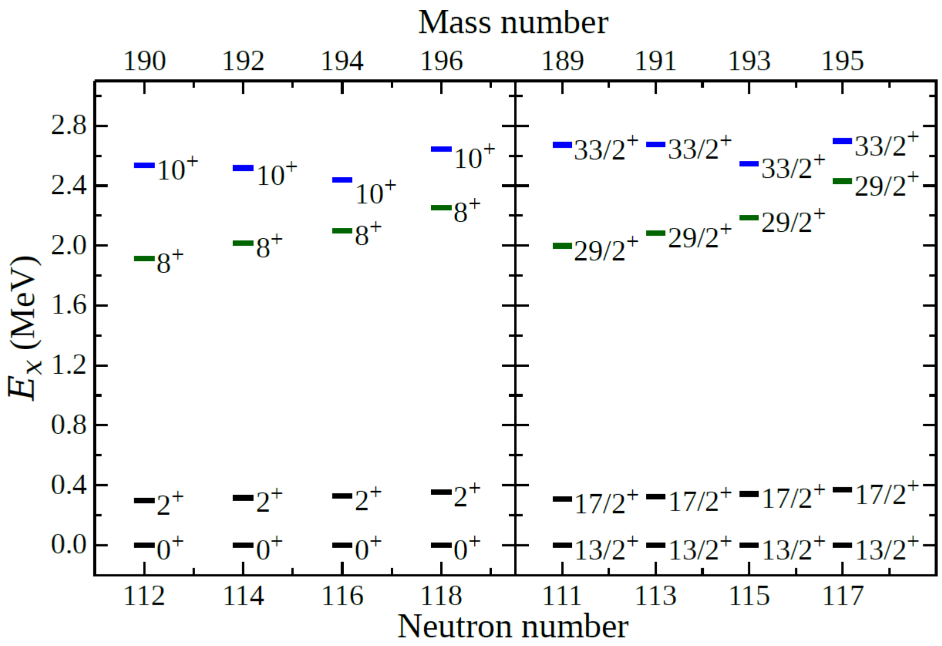
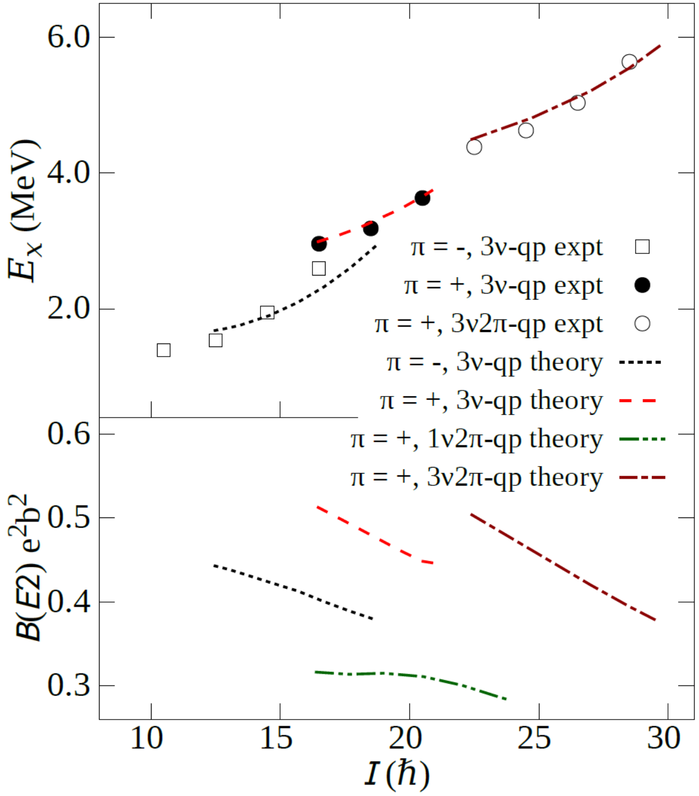
- TAC-CDFT calculations satisfactorily reproduce experimental energies
- Calculated *B(E2)* values can be used to distinguish between possible configurations



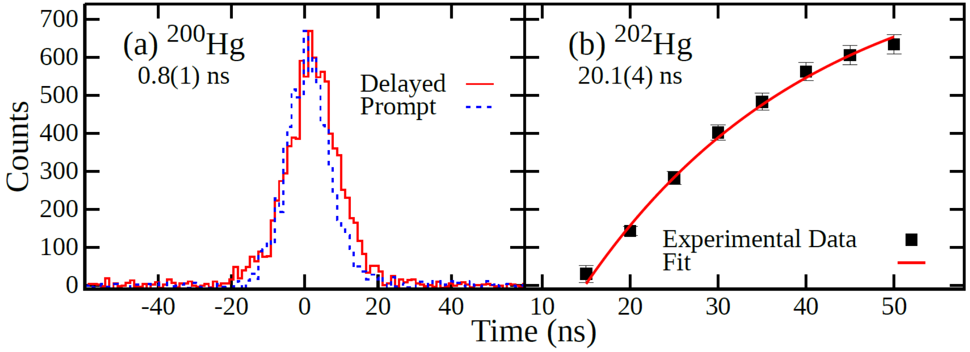
Excitation energies in even-A and odd-A Pt isotopes



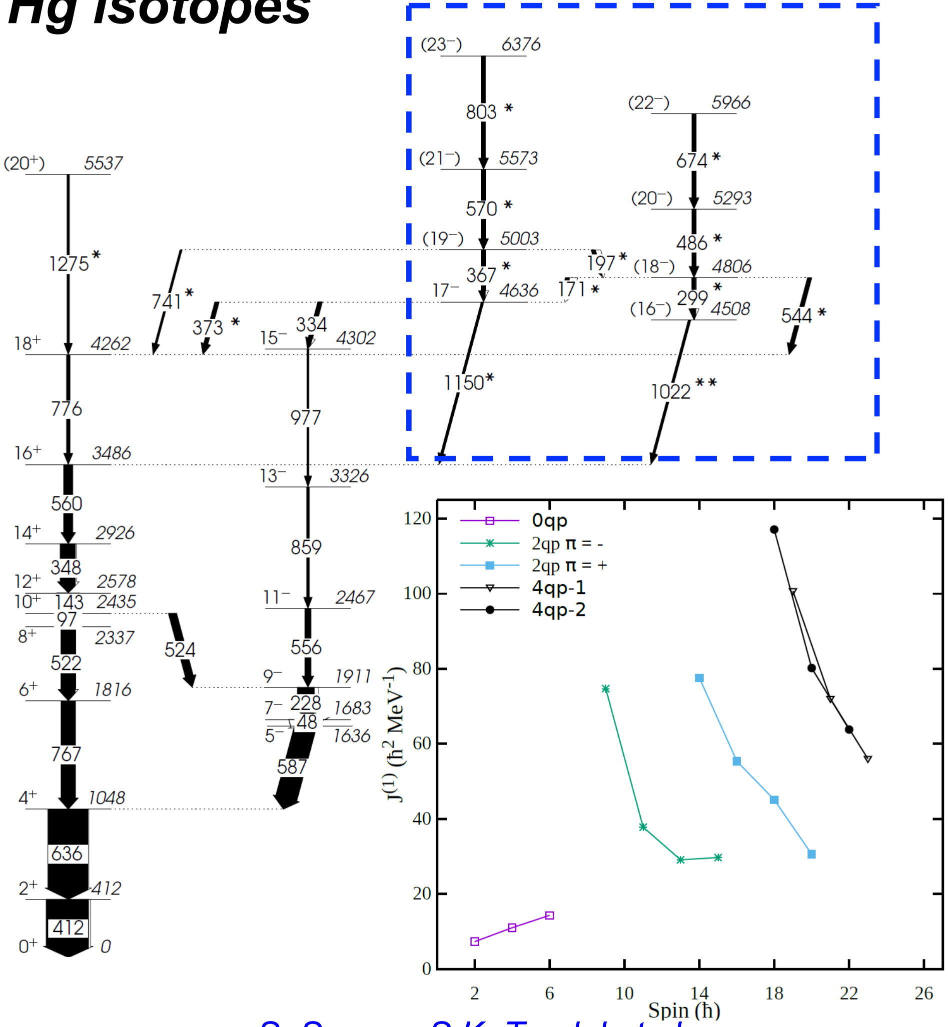
Q.B. Chen, J. Meng et al., priv. comm.
J. Meng et al., Front. Phys. 8, 55 (2013)

Structure of even Hg isotopes

- *Four-quasiparticle band structure established in ^{198}Hg*
- *Lifetime measurement of $I^{\pi}=12^{+}$ state in ^{200}Hg*
- *New metastable state ($I^{\pi}=7^{-}$) identified in ^{202}Hg*



[A. Kumawat, S.K. Tandel et al., to be published]



[S. Suman, S.K. Tandel et al., to be published]

Summary

• Pt and Hg isotopes along the line of stability populated through multi-nucleon transfer reactions; sensitive spectroscopic measurements (including lifetimes) using Gammasphere

• Rotation-induced excitations of valence high-*j* nucleons play a central role in the competition between prolate and oblate potential wells and in generating high spin

• Oblate collectivity at high spin explored through transition probabilities deduced from decay of metastable states and the nature of rotational sequences

• Different rotation alignments identified by studying even-even and even-odd isotopes

• Abrupt quenching of oblate collectivity at high spin around N=120 evident from deduced $E2$ transition probabilities; in stark contrast to the gradual decrease in collectivity near the ground states

Collaboration

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