



Shape coexistence in neutron-deficient Pb isotopes: Recent results from Jyväskylä

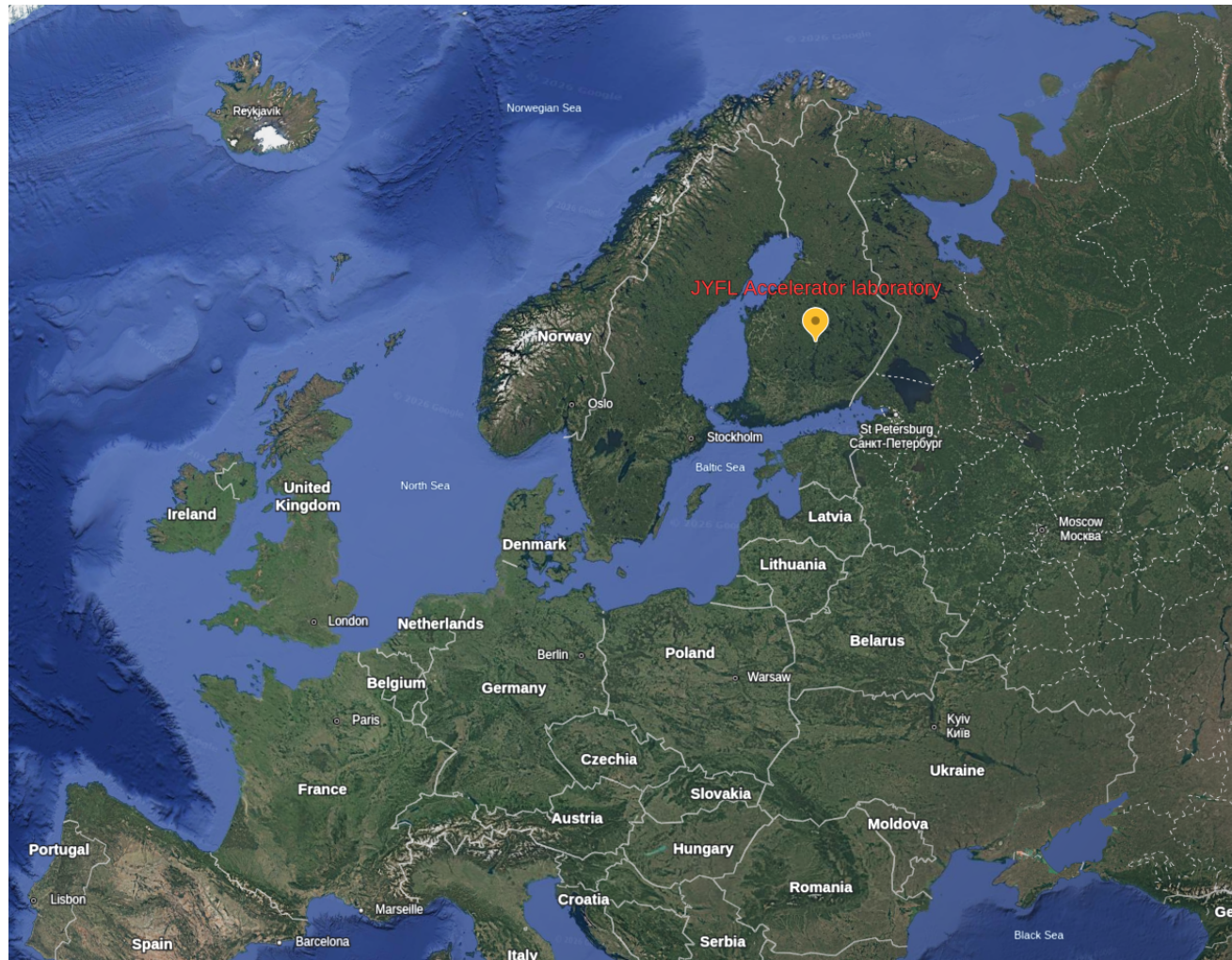
Joonas Ojala

Content

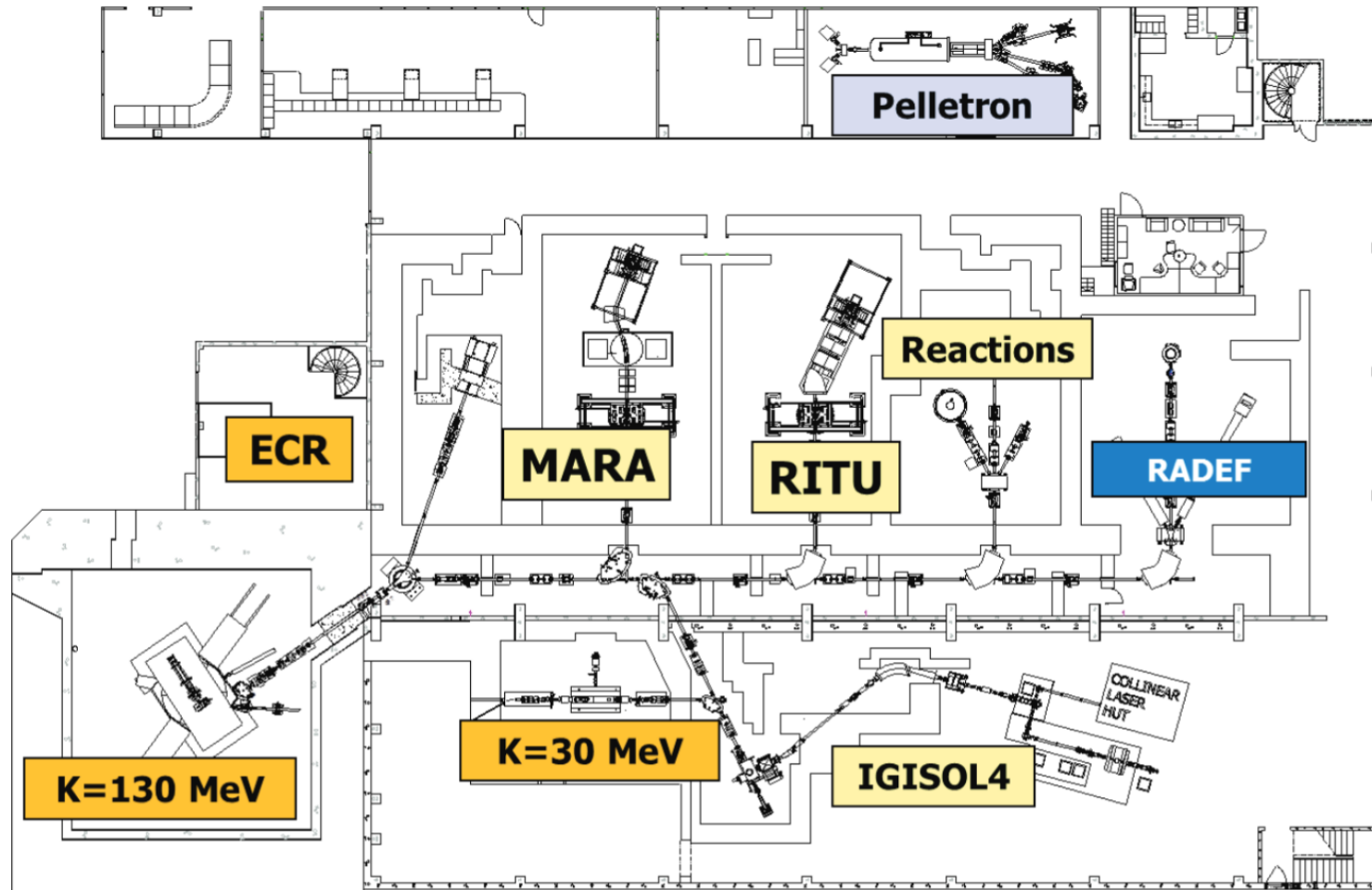


- Overview of experimental setups
- Introduction to topic
- Results for the neutron-deficient Pb region

Accelerator laboratory of Jyväskylä



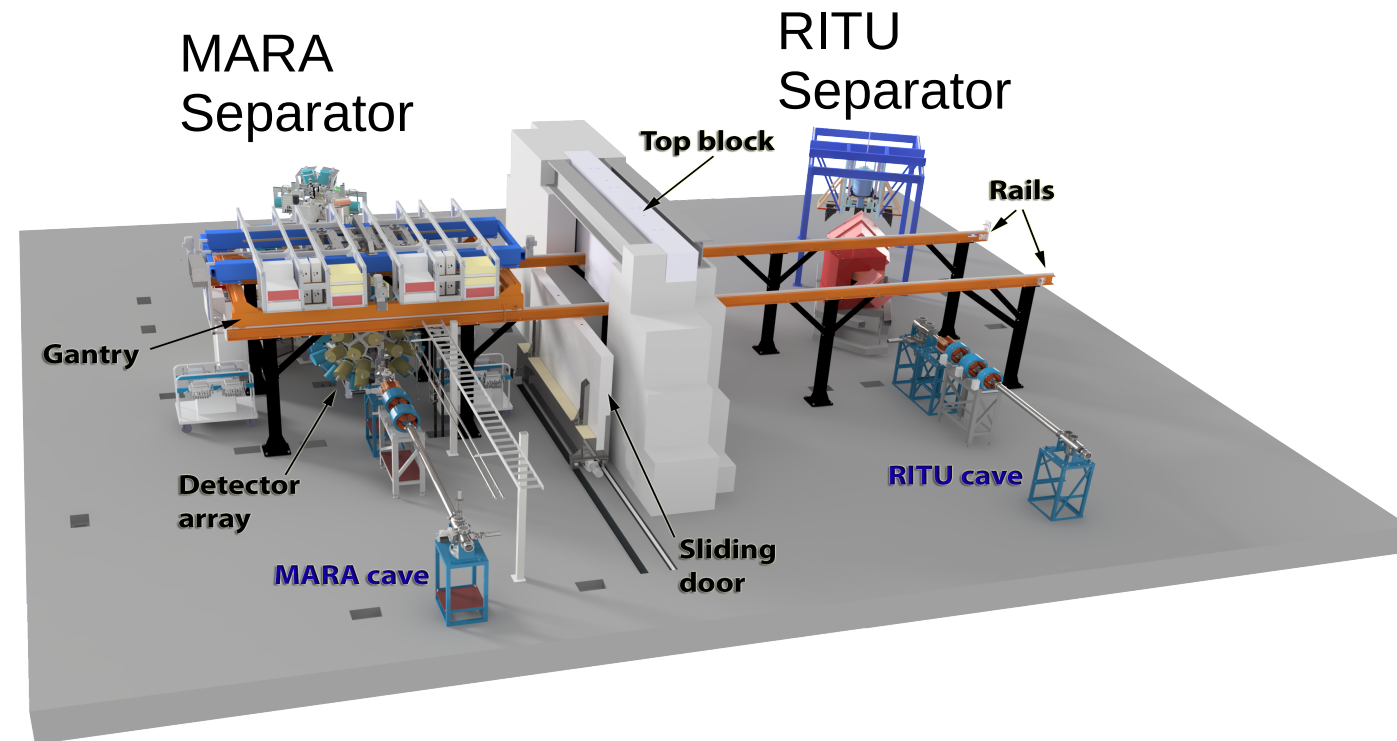
Accelerator laboratory of Jyväskylä



Nuclear spectroscopy group

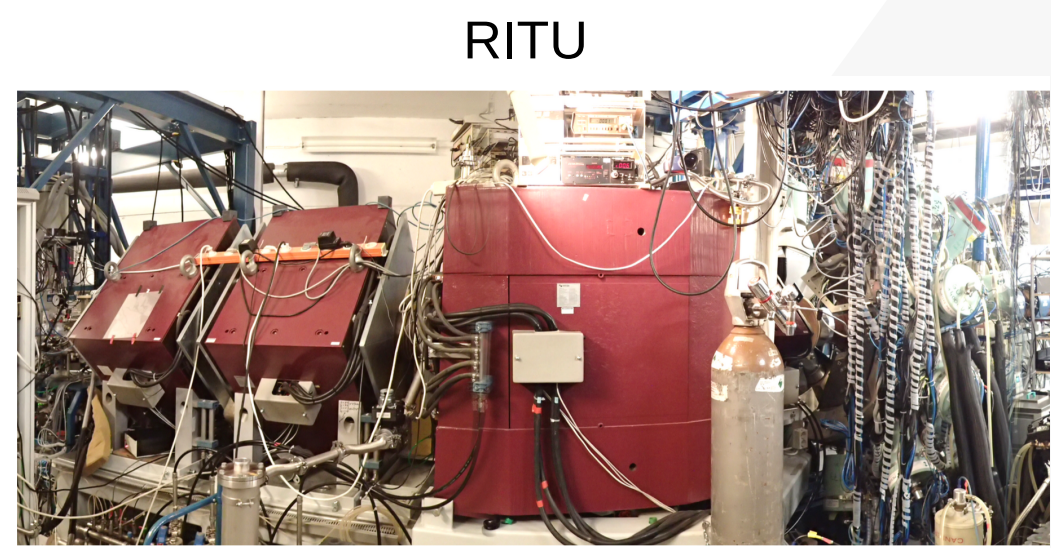
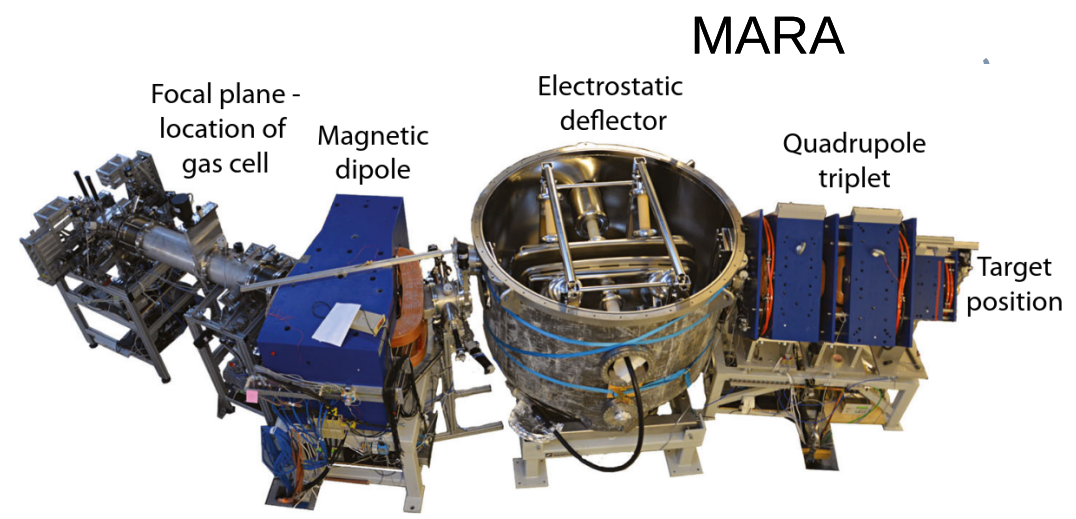
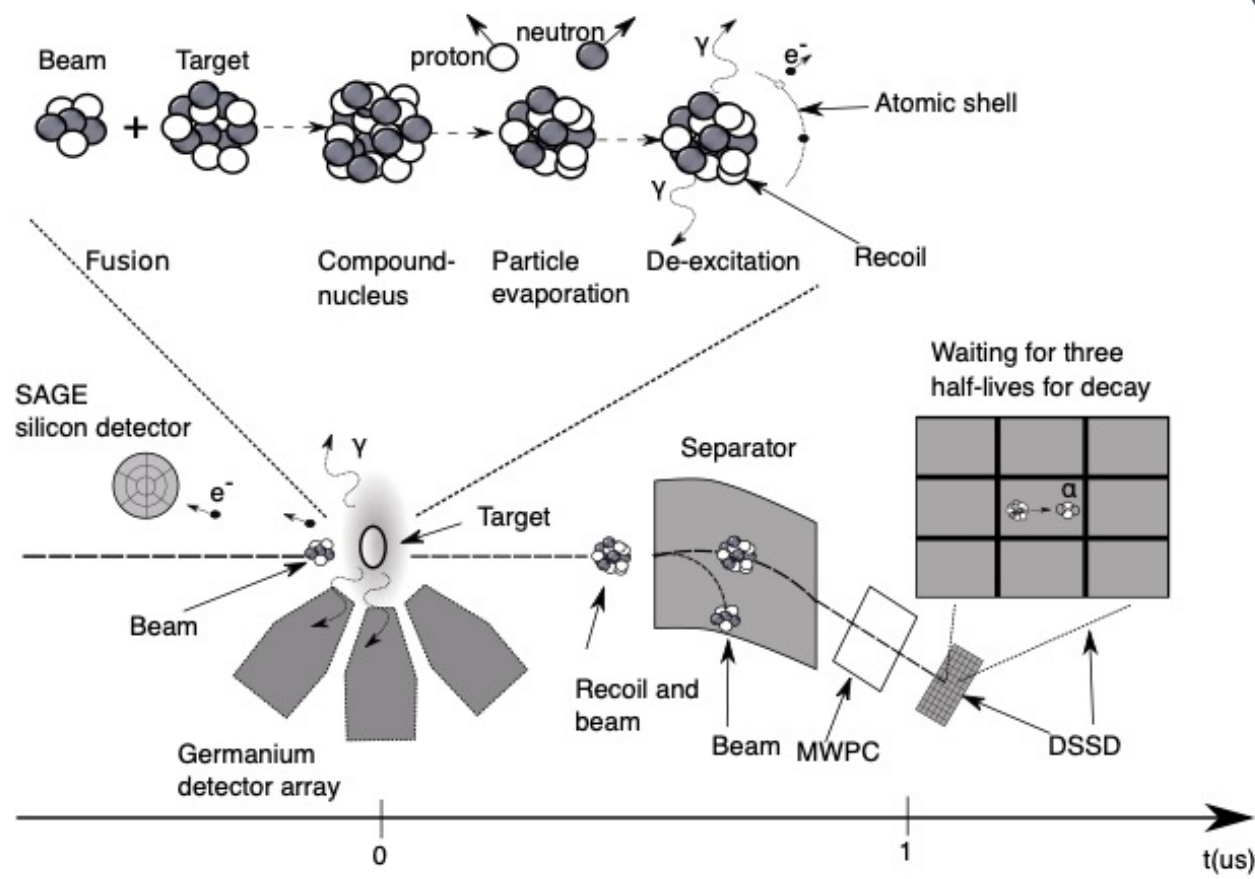


- Stable beams from the K-130 accelerator
- Fusion-evaporation reactions → neutron-deficient nuclei
- JUROGAM3 germanium array for detecting prompt gamma rays
- The MARA/RITU separator separates fusion-evaporation products (recoil) from beam
- Focal plane at the end of beam line for recoil identification and decay spectroscopy
- Proton drip line, heavy nuclei, $N \sim Z$, shape coexistence...
- MARA: $N \sim Z$, medium mass-nuclei
RITU: heavier nuclei



Recoil-decay tagging(RDT)

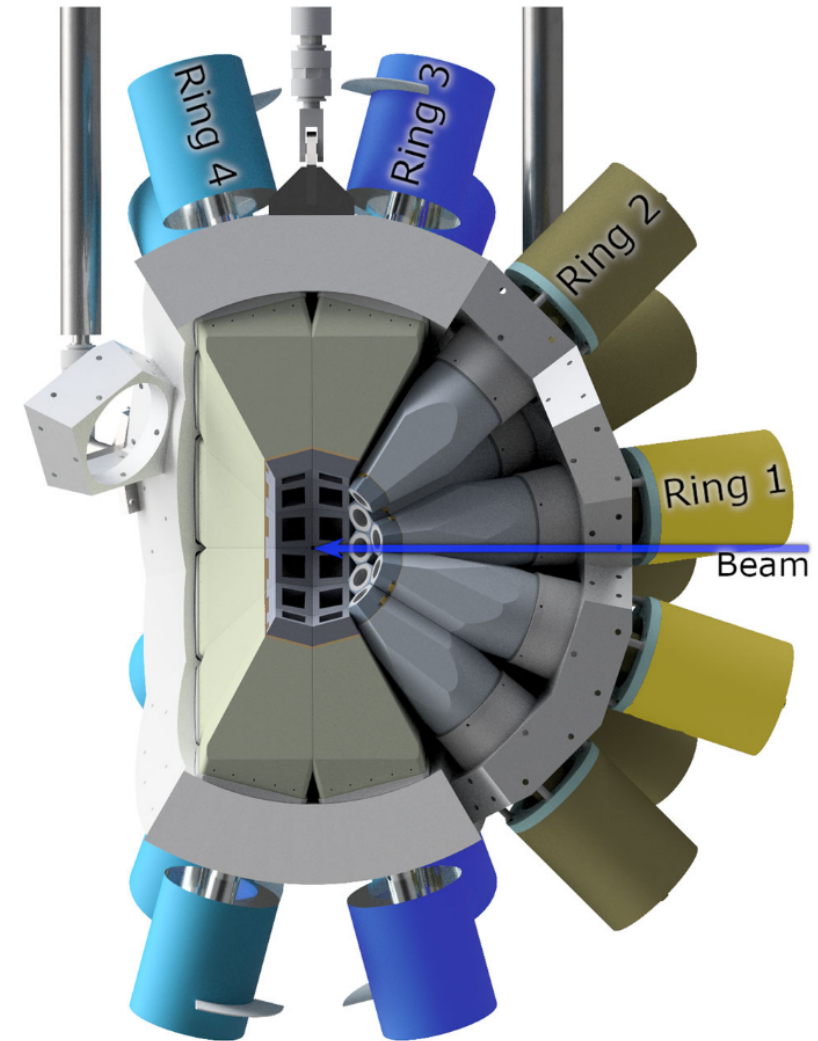
Recoil tagging(RT)



JUROGAM3 germanium array



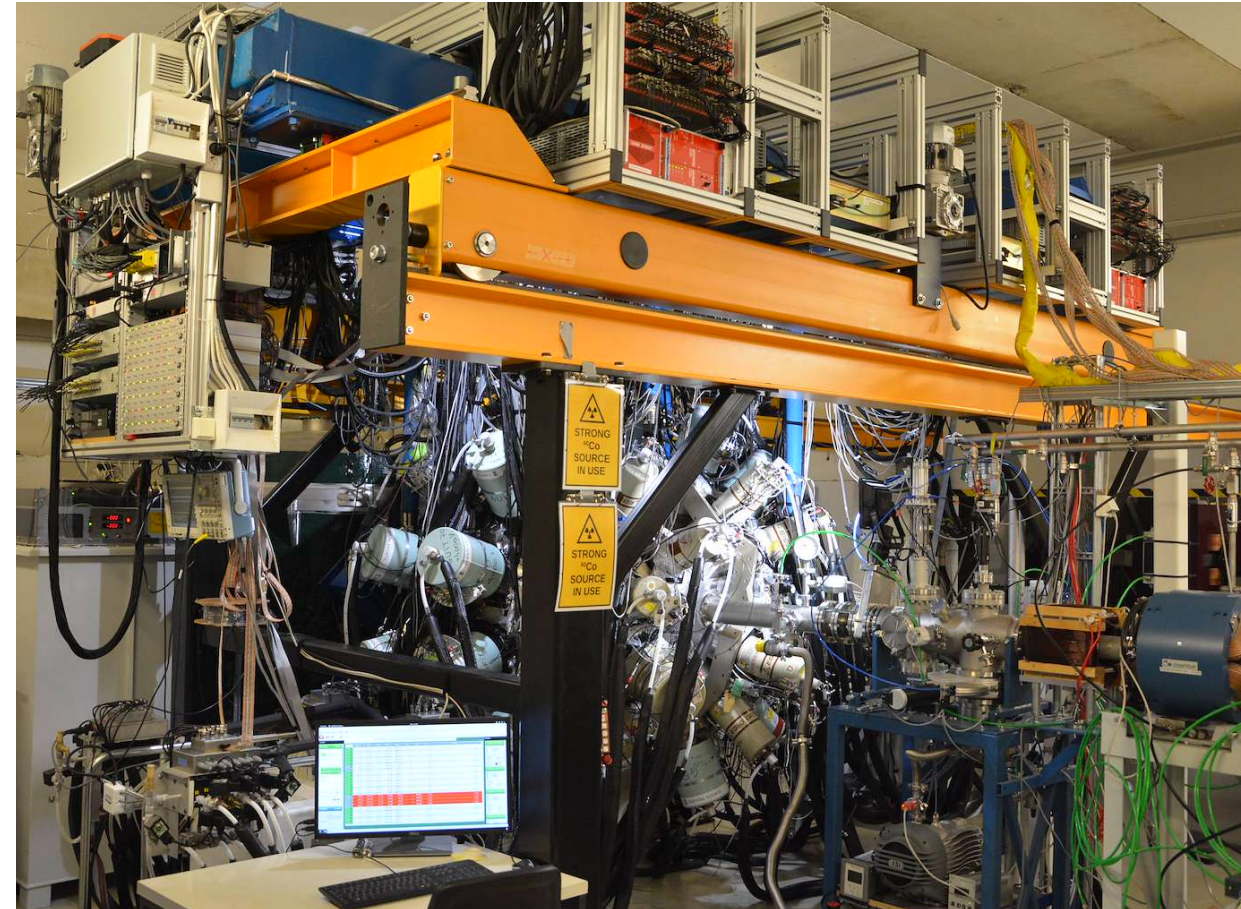
- 24 4-crystal (clover) germanium detectors
- 15 single-crystal (tapered) germanium detectors
- The detectors are arranged in four different rings with respect to the beam axis.
- BGO-shields to veto the Compton scattering events
- Array is located at the target position where fusion-evaporation reaction is induced.



JUROGAM3 germanium array

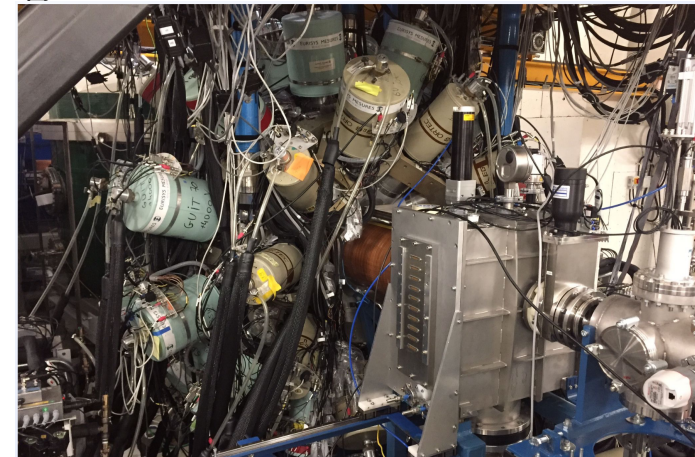
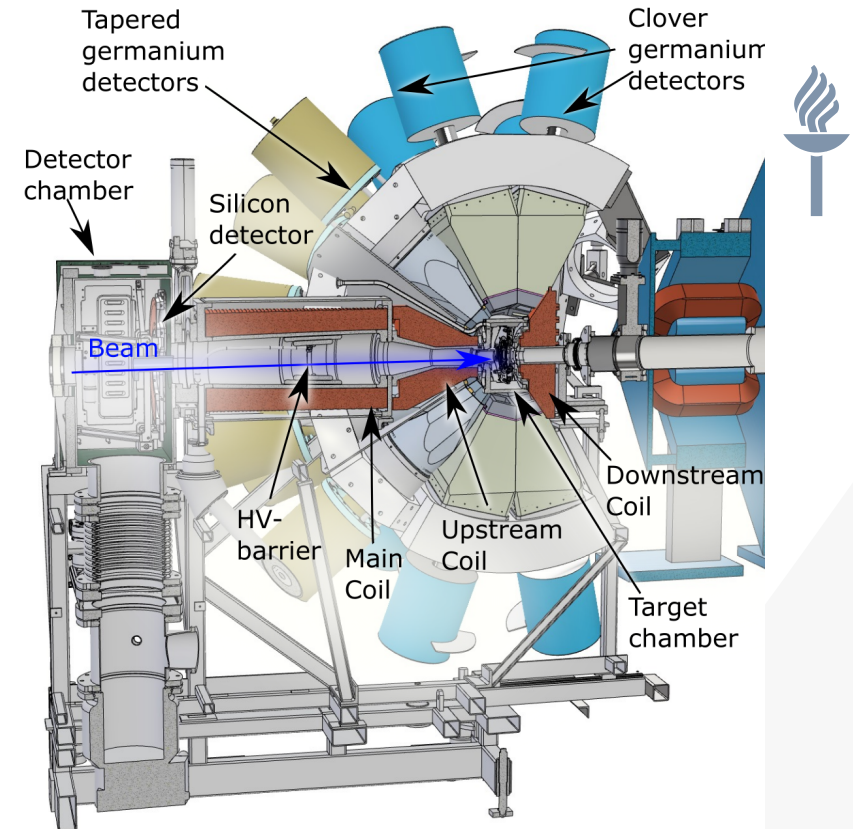


- 24 4-crystal (clover) germanium detectors
- 15 single-crystal (tapered) germanium detectors
- The detectors are arranged in four different rings with respect to the beam axis.
- BGO-shields to veto the Compton scattering events
- Array is located at the target position where fusion-evaporation reaction is induced.



Simultaneous γ -ray and conversion-electron spectrometer SAGE

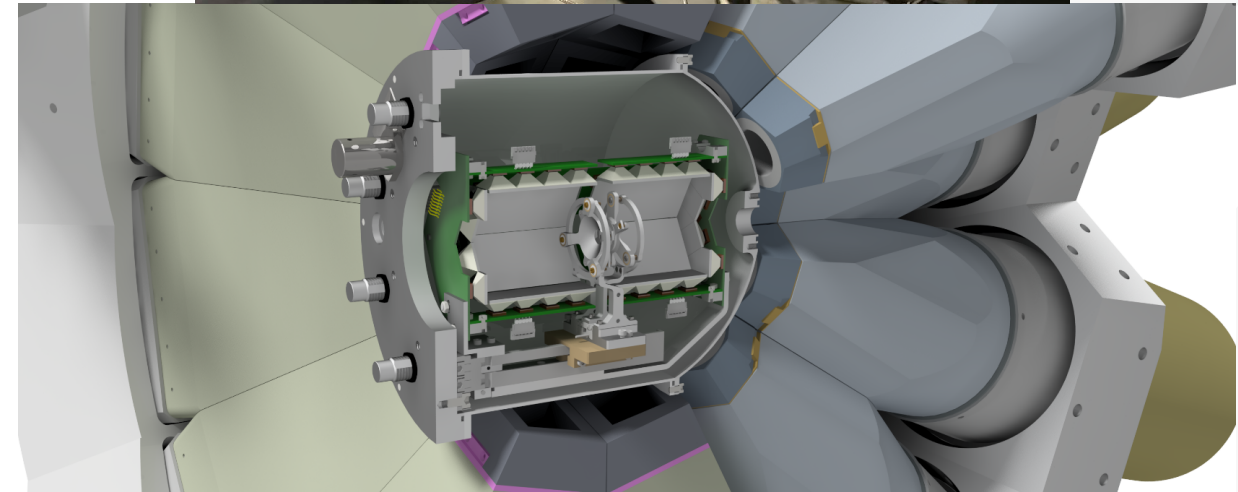
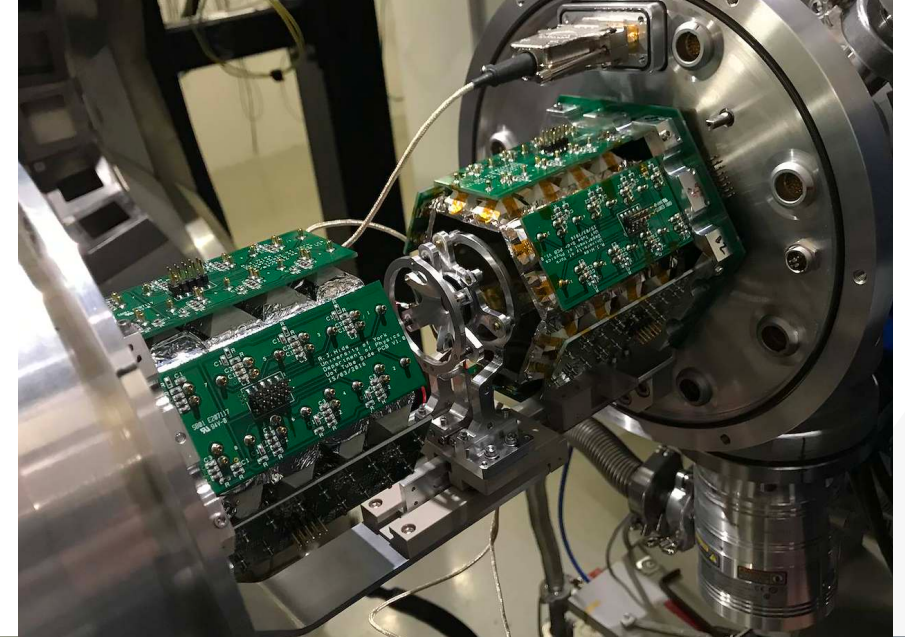
- 10 Tapered and 24 Clover type germanium detectors
- The SAGE silicon detector is positioned upstream of the target
- Conversion electrons are transported using the solenoid magnets from the target to the silicon detector (800A)
- HV-barrier inside solenoid is needed to prevent the low-energy delta-electrons reaching the silicon detector



Advanced Plunger-Particle detector Array (APPA)



- Contains target and movable degrader foil
- Is used in conjunction of the JUROGAM3 spectrometer
- Can be combined with JYUTube charged-particle detector array
- The distances below 100 μm are measured capacitance method
- The distances above 100 μm are measured with step motor

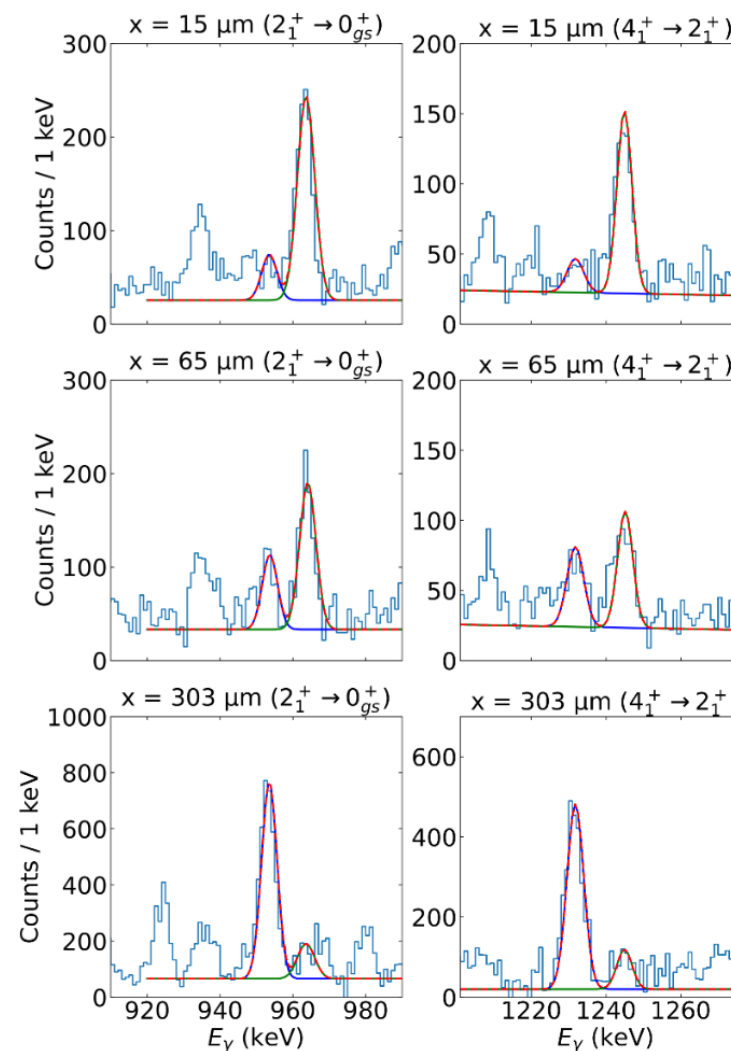


Advanced Plunger-Particle detector Array (APPA)



- These spectra are collected from Ring 1.
- Lifetimes can be determined by using Recoil-Distance Doppler-Shift method (RDDS).
- Alternatively Differential Decay Curve Method (DDCM) can be used for the gamma-gamma coincidence data.
- APPA can be used to determine the picosecond lifetime of levels

Uusikylä, E, submitted to EPJA



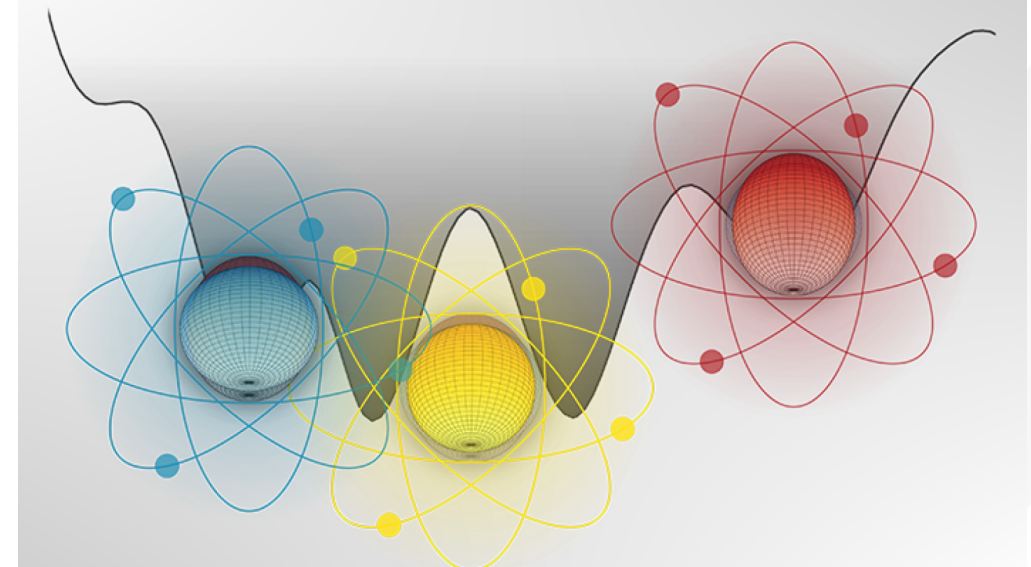


Shape coexistence in neutron-deficient Pb region

Shape coexistence in neutron-deficient Pb isotopes



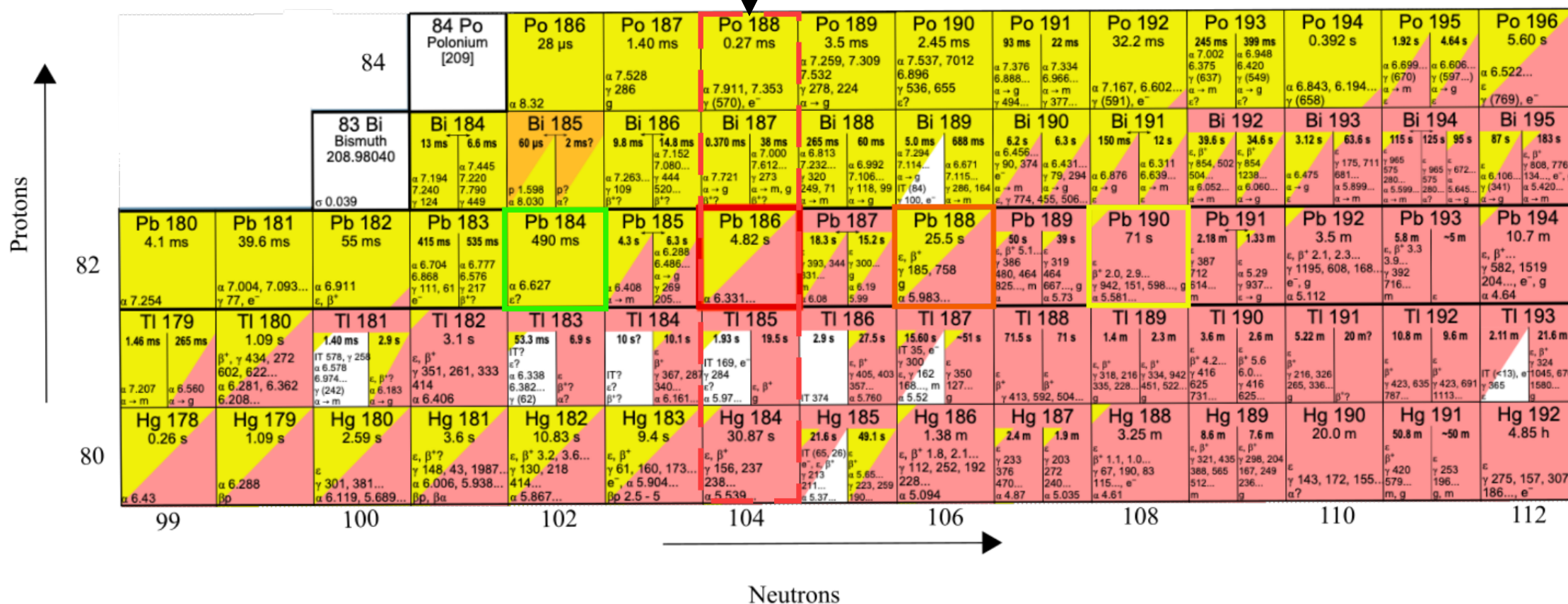
- The shape coexistence phenomenon has been under study for several decades in Pb region
- Shape coexistence appears close to the neutron-midshell $N \approx 104$
- In addition to the spherical ground state, the intruder structures have been identified to be as following shapes, prolate $\pi(4p-4h)$ and oblate $\pi(2p-2h)$, in neutron-deficient Pb isotopes



Shape coexistence in neutron-deficient Pb isotopes



N=104





<https://doi.org/10.1038/s42005-022-00990-4>

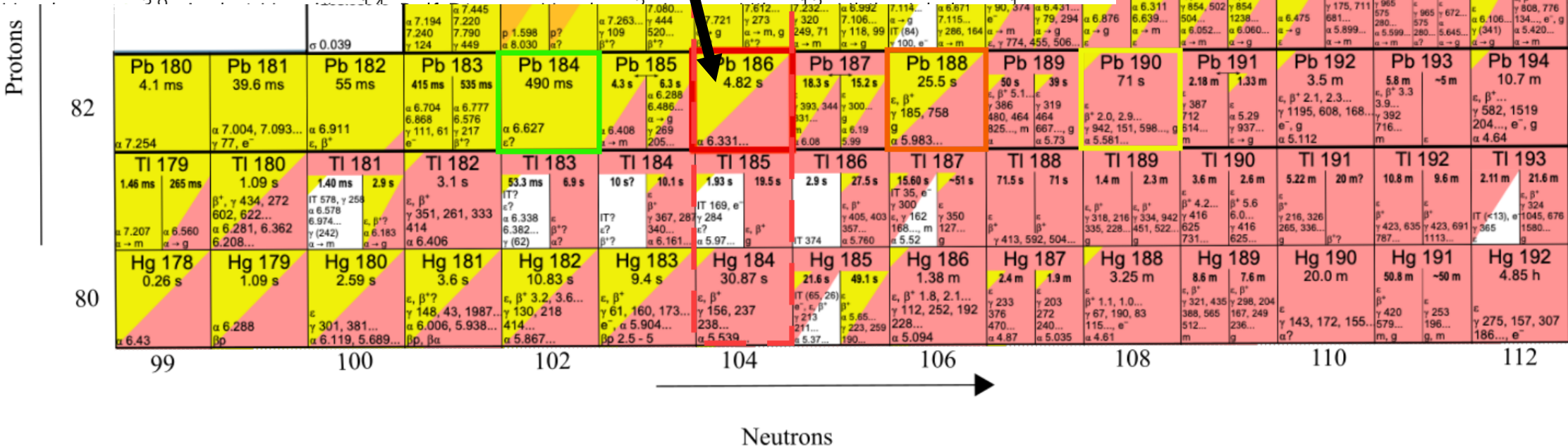
OPEN



2022

Reassigning the shapes of the 0^+ states in the ^{186}Pb nucleus

Joonas Ojala¹, Janne Pakarinen¹, Philippos Papadakis^{1,6}, Juha Sorri^{1,7}, Mikael Sandzelius¹, Daniel M. Cox^{1,2,8}, Kalle Auranen¹, Hussam Badran¹, Paul J. Davies³, Tuomas Grahn¹, Paul T. Greenlees¹





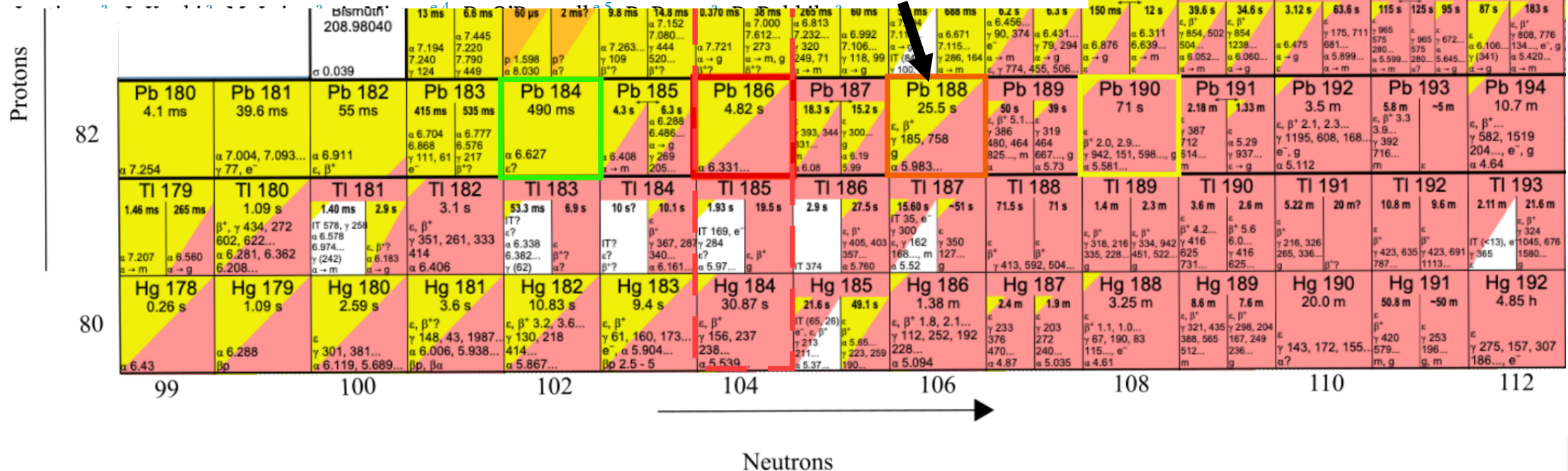
efficient Pb 2024



Letter

Direct observation of $E0$ transitions in ^{188}Pb through in-beam spectroscopy

P. Papadakis^{a,b,*}, J. Pakarinen^{a,*}, A.D. Briscoe^{a,2}, D.M. Cox^a, R. Julin^a, K. Auranen^a,
T. Grahn^a, P.T. Greenlees^a, K. Hadyńska-Klek^c, A. Herzán^{a,d}, R.-D. Herzberg^c, U. Jakobsson^{a,3}





<https://doi.org/10.1038/s42005-024-01928-8>

deficient Pb

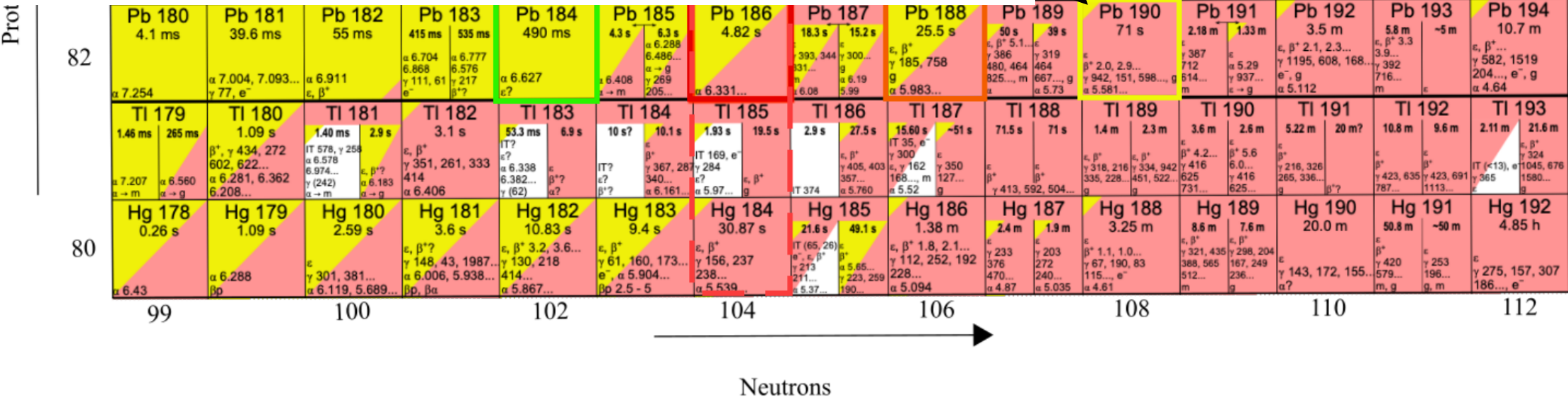
2025



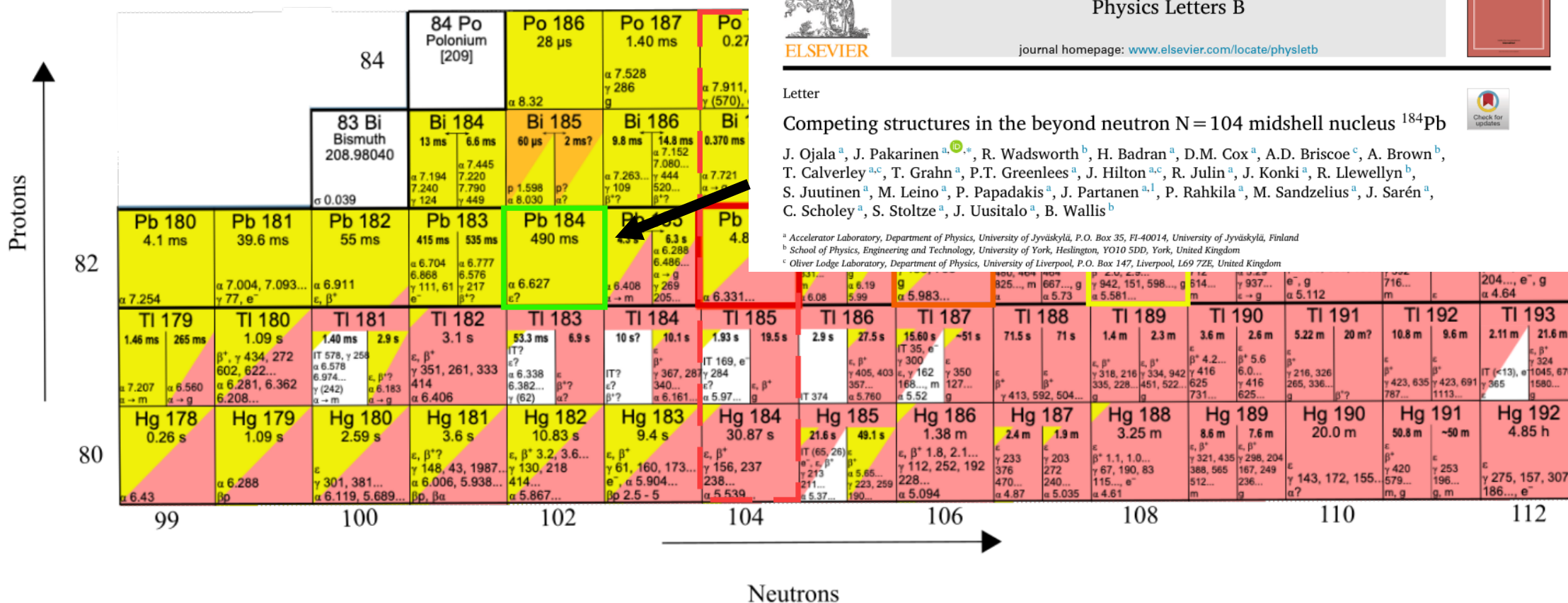
Direct measurement of three different deformations near the ground state in an atomic nucleus



Adrian Montes Plaza^{1,2}, Janne Pakarinen²✉, Philippos Papadakis³, Rolf-Dietmar Herzberg¹, Rauno Julin², Tomás R. Rodríguez⁴, Andrew D. Briscoe^{2,11}, Andrés Illana^{2,4}, Joonas Ojala²,



2025



Phys. Lett. B 867 (2025) 139601

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Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

Letter

Competing structures in the beyond neutron $N=104$ midshell nucleus ^{184}Pb

J. Ojala ^a, J. Pakarinen ^{a,10,*}, R. Wadsworth ^b, H. Badran ^a, D.M. Cox ^a, A.D. Briscoe ^c, A. Brown ^b, T. Calverley ^{a,c}, T. Grahn ^a, P.T. Greenlees ^a, J. Hilton ^{a,c}, R. Julin ^a, J. Konki ^a, R. Llewellyn ^b, S. Juutinen ^a, M. Leino ^a, P. Papadakis ^a, J. Partanen ^{a,1}, P. Rakkila ^a, M. Sandzelius ^a, J. Sarén ^a, C. Scholey ^a, S. Stoltze ^a, J. Uusitalo ^a, B. Wallis ^b

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Shape coexistence in neutron-deficient Pb isotopes



Phys. Lett. B 870 (2025) 139906



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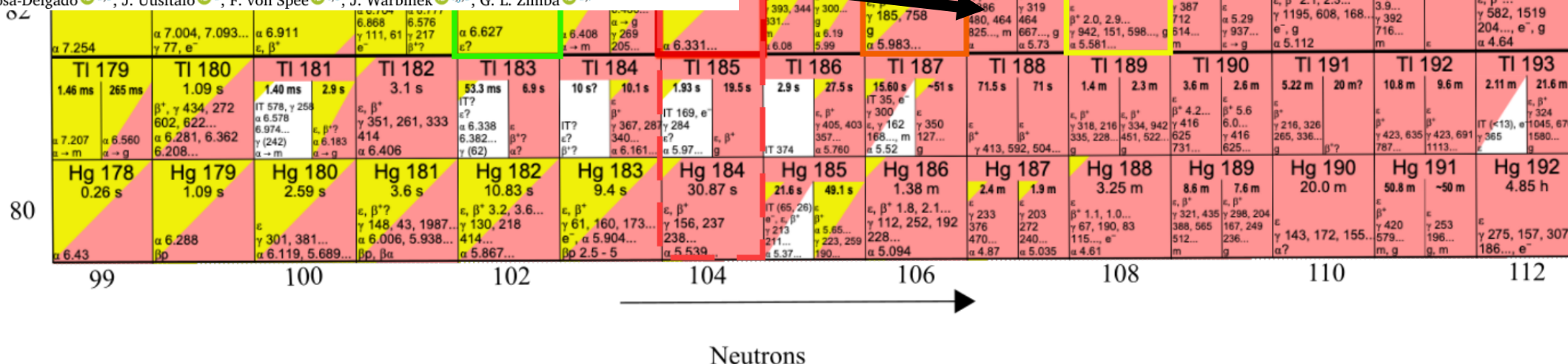
journal homepage: www.elsevier.com/locate/physletb



2025

Shape coexistence and particle-core coupling in ^{189}Pb and ^{191}Pb nuclei

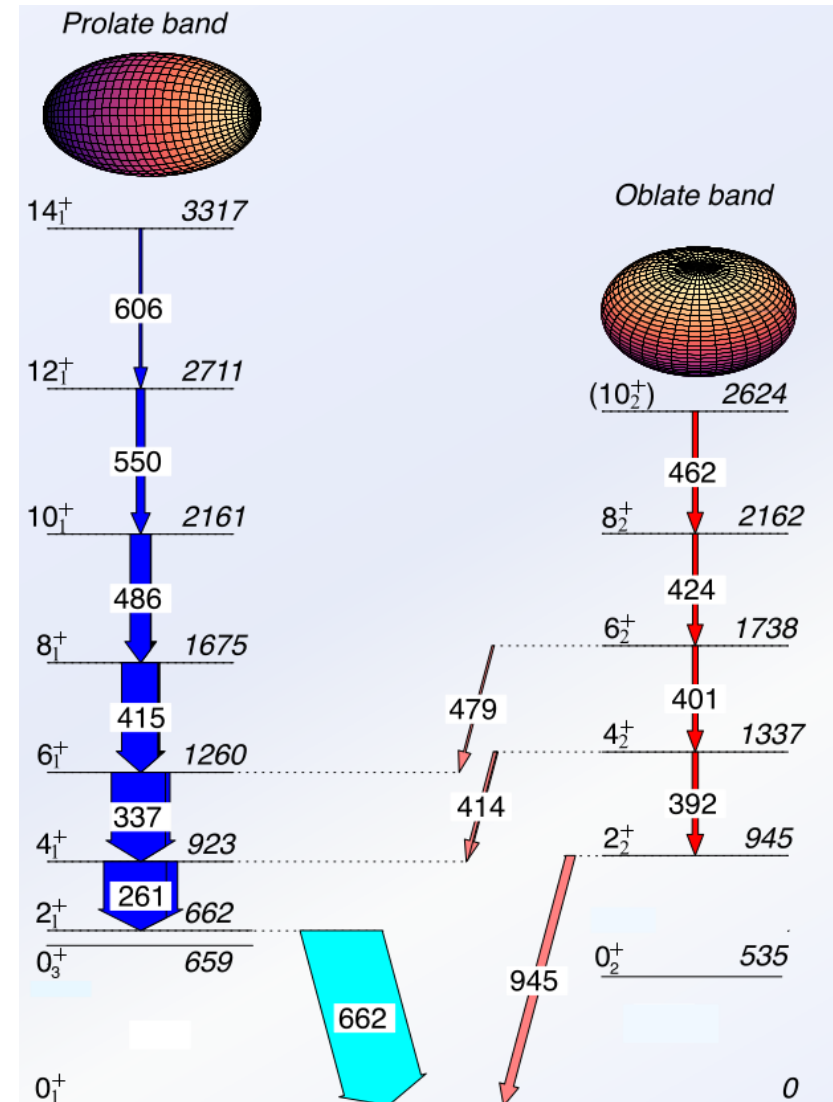
A. M. Plaza ^{a,b,1}, J. Pakarinen ^{b,*}, R. Julin ^b, P. Papadakis ^c, R.-D. Herzberg ^{b,a}, A. D. Briscoe ^{b,2}, A. Illana ^{b,d}, J. Ojala ^{b,a,b}, P. Ruotsalainen ^b, E. Uusikylä ^b, B. Alayed ^{e,a}, A. Alharbi ^{c,a}, O. Alonso-Saáudo ^d, K. Auranen ^b, V. Bogdanoff ^b, J. Chadderton ^a, A. Esmaylzadeh ^f, C. Fransen ^f, T. Grahn ^b, P. T. Greenlees ^b, J. Jolie ^f, H. Joukainen ^b, H. Jutila ^b, C. Lakenbrink ^f, M. Leino ^b, J. Louko ^b, M. Luoma ^{b,g}, A. McCarter ^a, B. S. Nara Singh ^h, P. Rahkila ^b, A. Raggio ^{b,3}, J. Romero ^b, J. Sarén ^b, M.-M. Satrazani ^{a,3}, M. Stryczyk ^{b,4}, C. M. Sullivan ^a, Á. Tolosa-Delgado ^{b,5}, J. Uusitalo ^b, F. von Spee ^{f,6}, J. Warbinek ^{i,j,5}, G. L. Zimba ^{b,7}



Previously known about ^{186}Pb



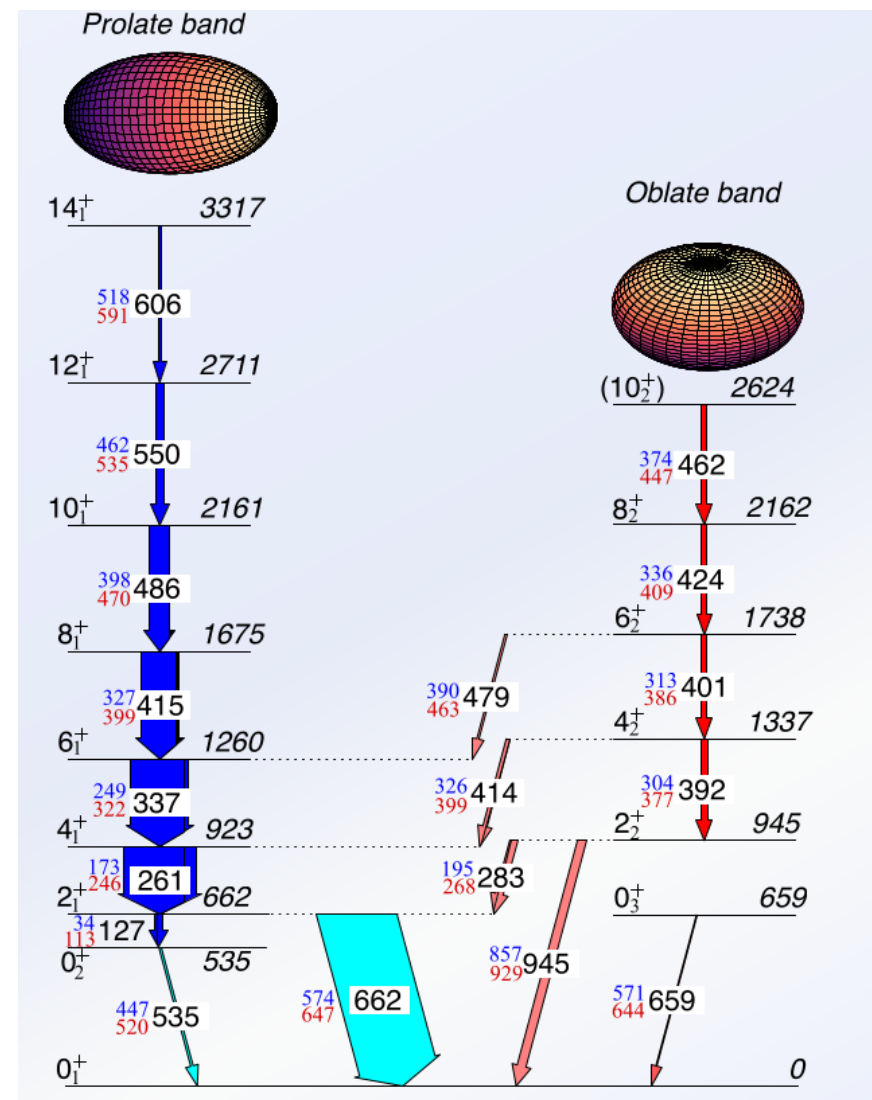
- The excited 0^+ states were observed for the first time at α -decay study of ^{190}Po
- The γ -ray spectroscopy study has shown rotational yrast and non-yrast band
- The lifetime measurement has been performed for the yrast band



SAGE experiment for ^{186}Pb



- Performed in the Accelerator laboratory of Jyväskylä
- SAGE+RITU+GREAT+TDR
- $^{106}\text{Pd}(^{83}\text{Kr}, 3n)^{186}\text{Pb}$
- Recoil-decay tagging method
- Observed feeding of 0_2^+ state
- $0_2^+ \rightarrow 0_1^+$ and $0_3^+ \rightarrow 0_1^+$ transitions were observed
- $2_2^+ \rightarrow 2_1^+$ and $4_2^+ \rightarrow 4_1^+$ interband transitions' E0 component were identified



SAGE experiment for ^{186}Pb



Main results:

- The $B(E2; 2_1^+ \rightarrow 0_2^+) = 190(80)$ transition and $Q_t = 7.7$ eb shows collectivity and implies a predominant prolate component for the 0_2^+ state $\rightarrow$ originally it was associated being part of the oblate band-head state
- For inter-band transition $\Delta I = 0$, it determine the monopole strengths

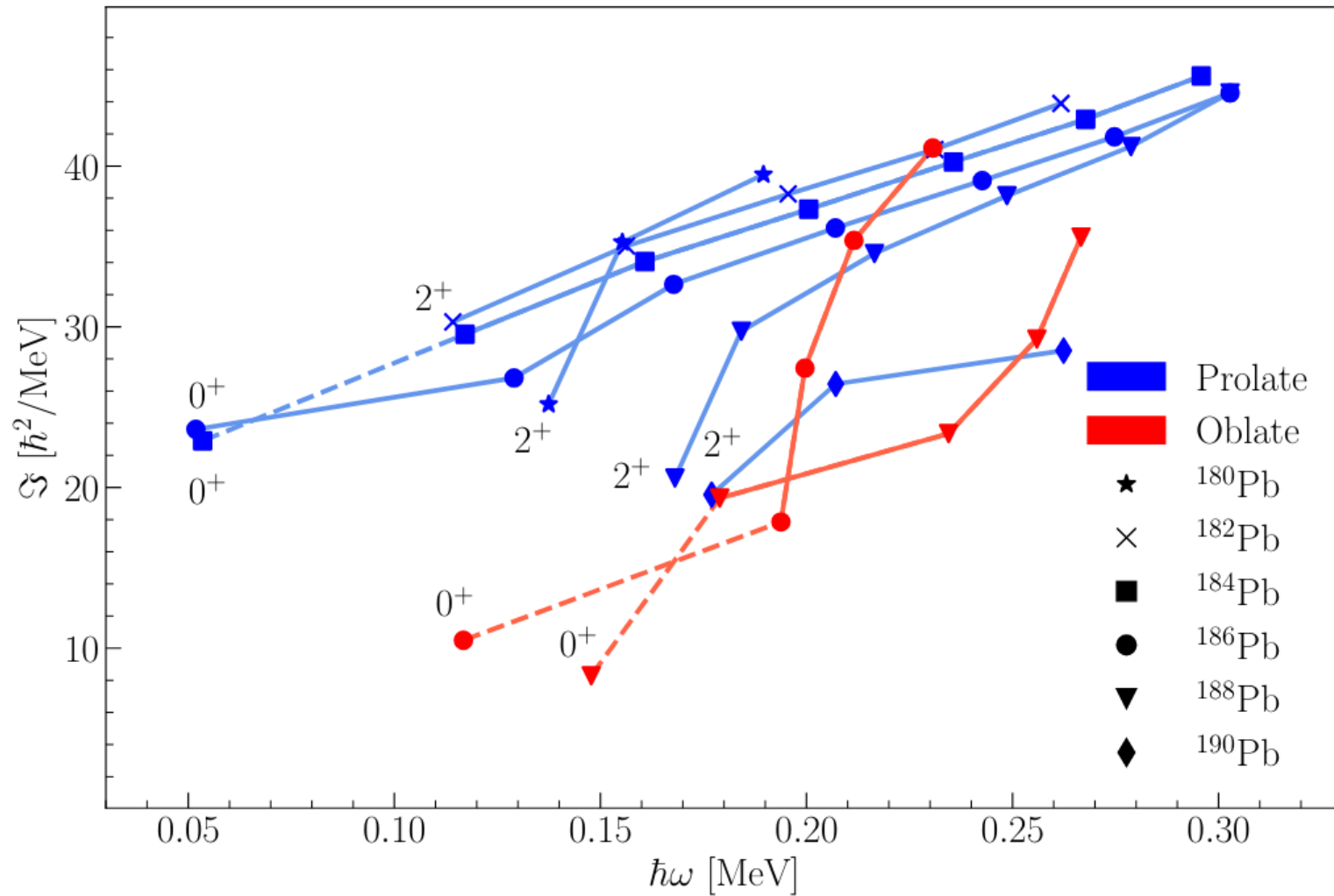
$$\rho^2 = \frac{I_K(E0)W_y(E2)}{I_y(E2)\Omega(E0)}$$

- The mixing of states can be estimate via ρ^2 and using two-level mixing mode

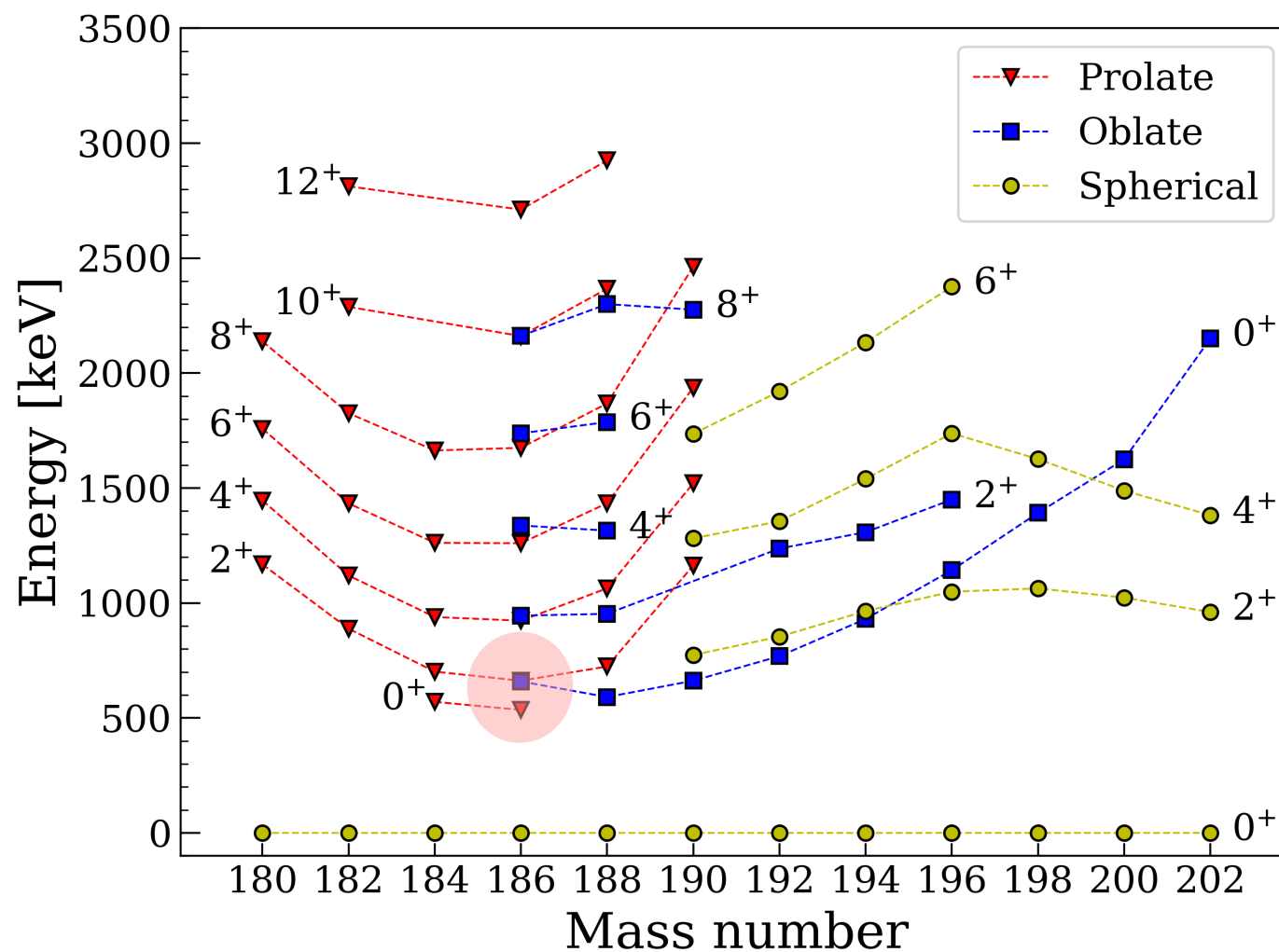
$$\rho^2 = \left(\frac{3}{4\pi}Z\right)^2 a^2 b^2 [\beta_1^2 - \beta_2^2]^2$$

- The oblate deformation parameter $\beta_2 = 0.17$ was taken from lifetime experiment of ^{194}Po and similar $B(E2)$ values were assumed for intra-band transitions of were assumed for non-yrast structure in ^{186}Pb
- The prolate deformation $\beta_2 = 0.29$ was taken from lifetime experiment of ^{194}Po
- Mixing parameter was estimated $a^2 = 0.9 - 0.96$ for prolate band $\rightarrow$ relatively pure prolate band
- Similar mixing was also concluded in life time experiment
- Word of warning: These are very crude estimates about mixing

SAGE experiment for ^{186}Pb



SAGE experiment: Pb-186



Previously known about ^{188}Pb



Dracoulis, G. D. Phys. Rev C 69, 054318
(2004)

- The excited 0^+ state was observed by α -decay of ^{192}Po
- The γ -ray spectroscopy study has shown rotational yrast and non-yrast band
- The lifetime measurement has been performed for the yrast band

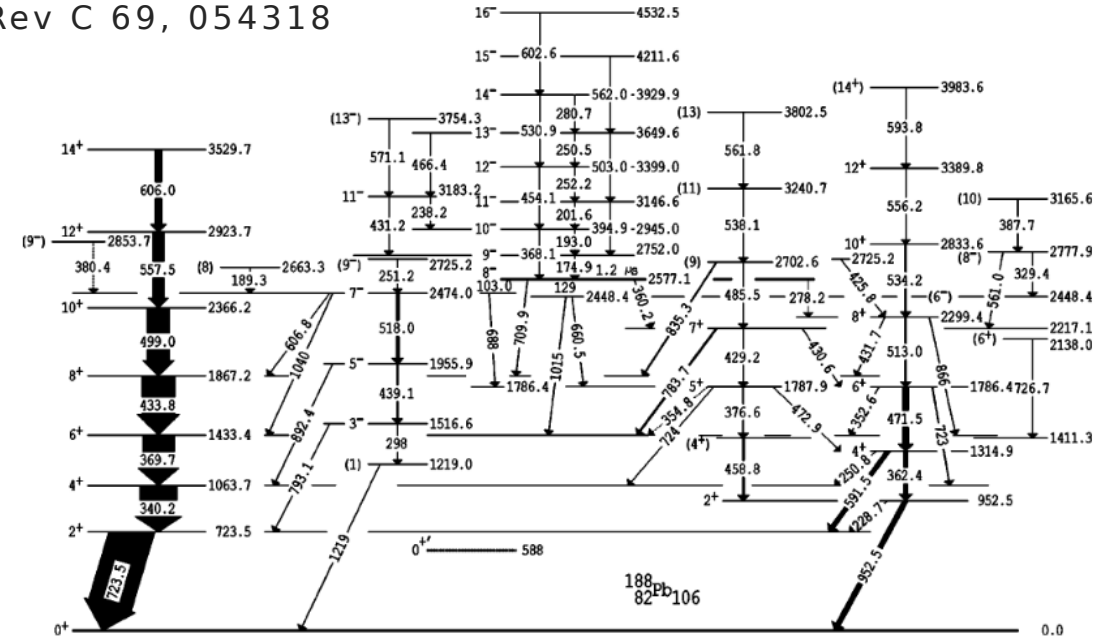


FIG. 2. Level scheme of ^{188}Pb in two parts; part II.

Dracoulis, G. D. Phys. Rev C 69, 054318 (2004)

- The excited 0^+ state was observed by α -decay of ^{192}Po
- The γ -ray spectroscopy study has shown rotational yrast and non-yrast band
- The lifetime measurement has been performed for the yrast band
- (Second excited 0^+ states has been identified)

Le Coz, Y, EP|direct A3, 1-6 (1999)

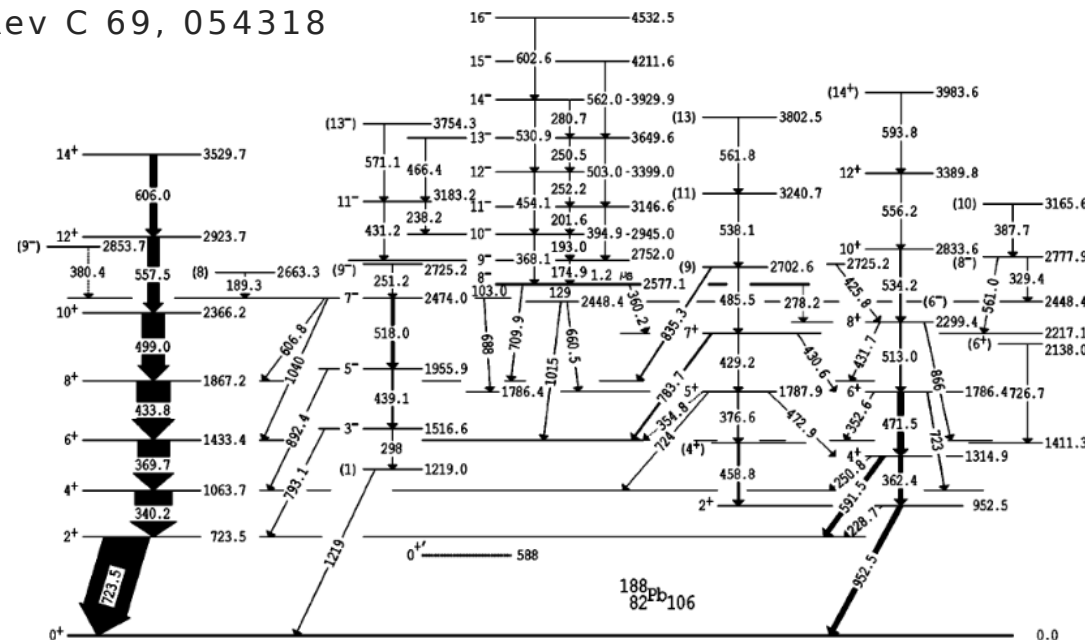
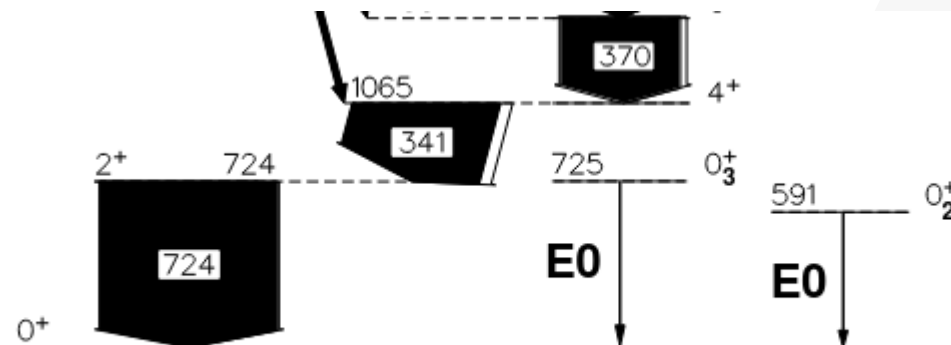


FIG. 2. Level scheme of ^{188}Pb in two parts; part II.



Previously known about ^{188}Pb



Dracoulis, G. D. Phys. Rev C 69, 054318 (2004)

- The excited 0^+ state was observed by α -decay of ^{192}Po
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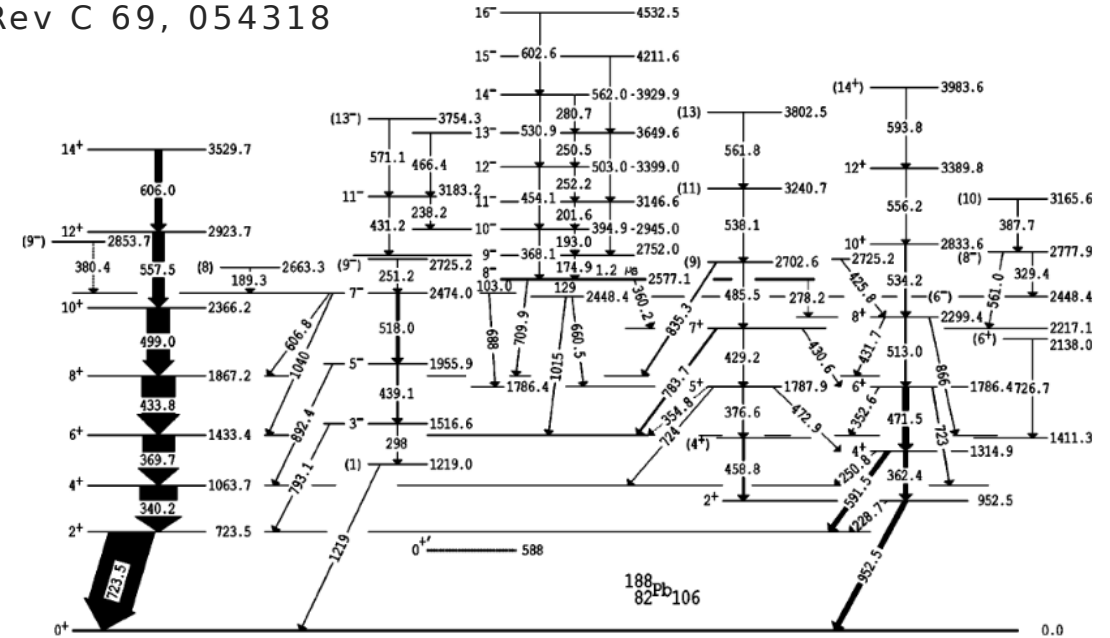
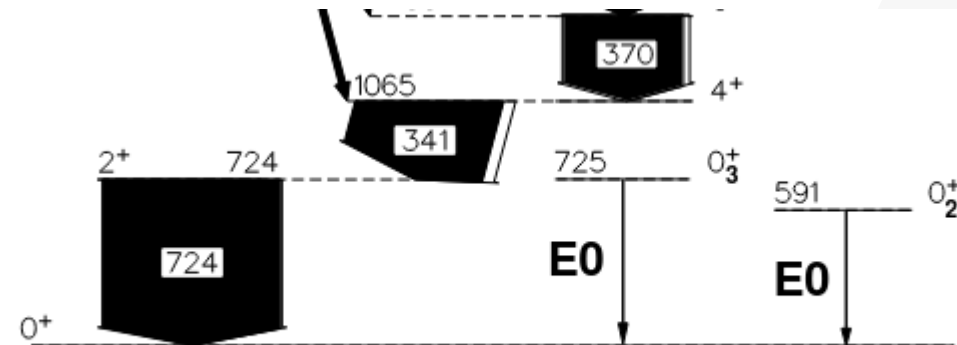


FIG. 2. Level scheme of ^{188}Pb in two parts; part II.

- (Second excited 0^+ states has been identified)

?

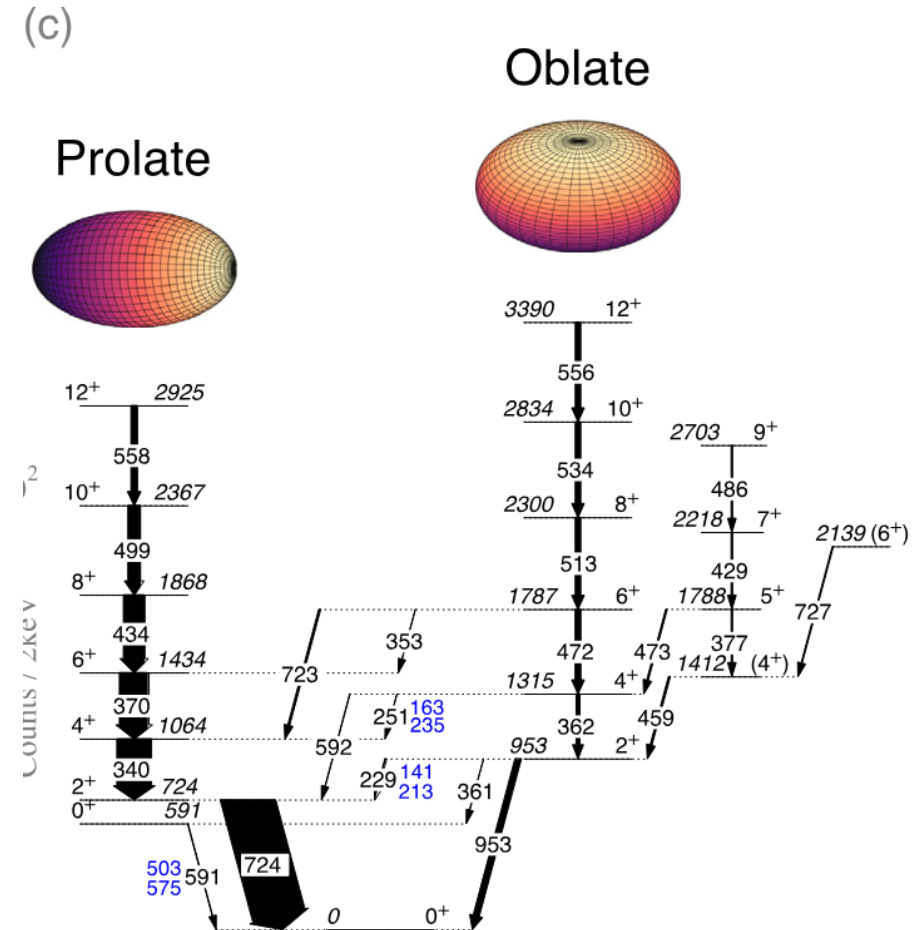
Le Coz, Y, EPJdirect A3, 1-6 (1999)



SAGE experiment ^{188}Pb



- Performed in the Accelerator laboratory of Jyväskylä
- SAGE+RITU+GREAT+TDR
- $^{160}\text{Dy}(^{32}\text{S}, 4n)^{188}\text{Pb}$
- Recoil-tagging method
- $0_2^+ \rightarrow 0_1^+$ was observed
- $2_2^+ \rightarrow 2_1^+$ and $4_2^+ \rightarrow 4_1^+$ interband transitions' E0 component were identified
- No sign for 0_3^+ state



SAGE experiment ^{188}Pb

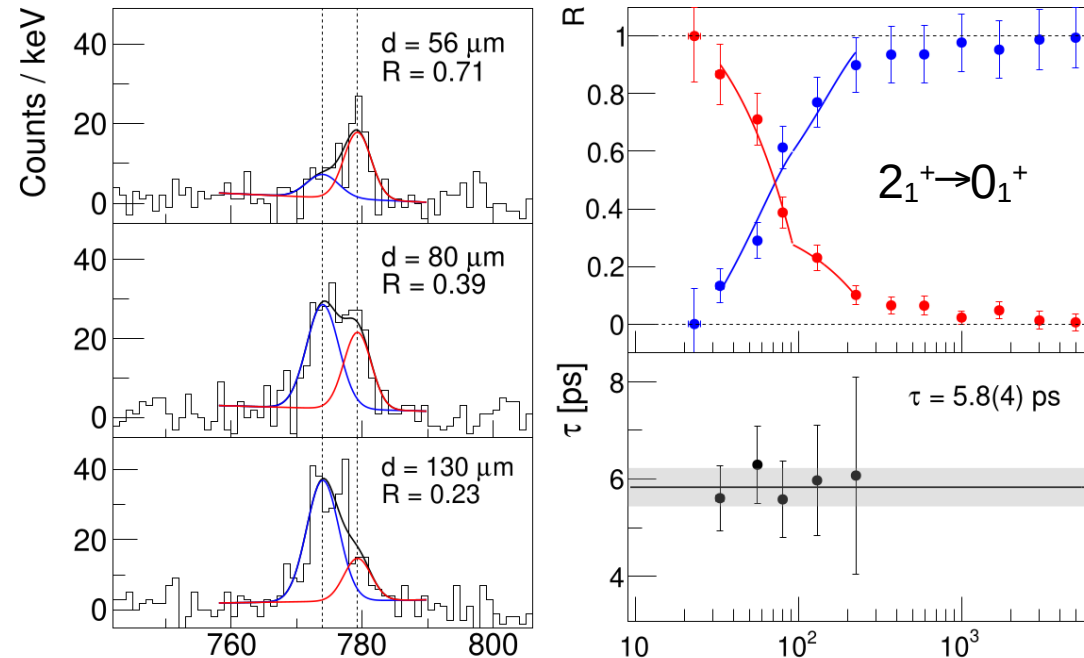
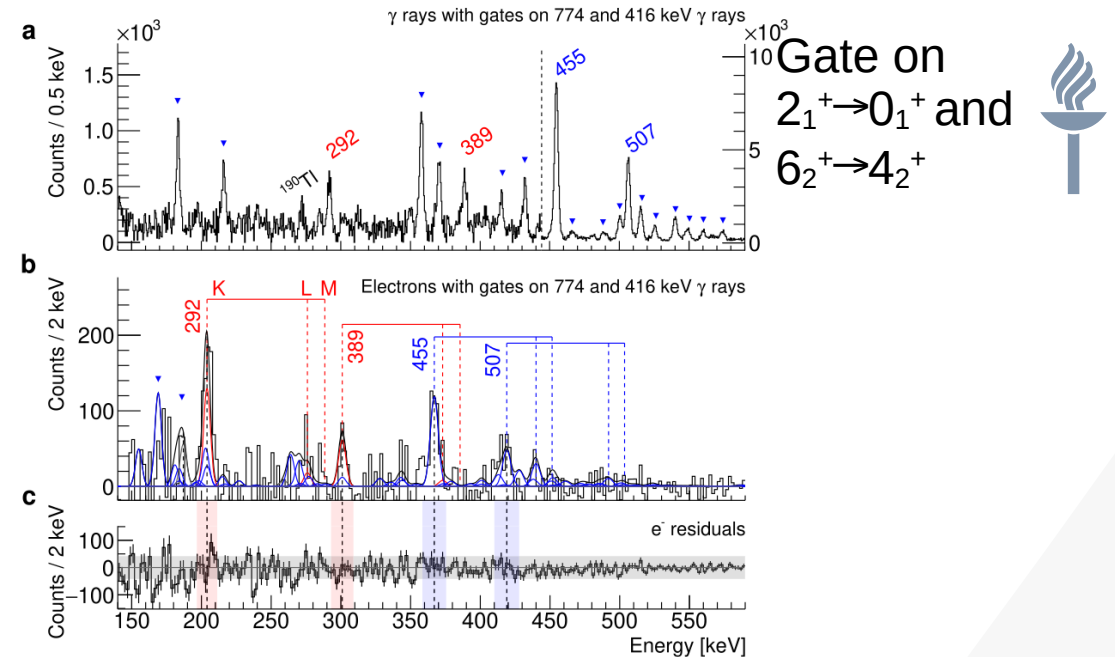


- Earlier the 0_2^+ state was associated with oblate. In current experiment, the obtained intensity ratio between $2_2^+ \rightarrow 0_2^+$ and $2_2^+ \rightarrow 2_1^+$ gives reason to reassign the 0_2^+ state as band head of prolate band
- With similar type of assumption as in ^{186}Pb , it was possible to estimate the mixing between two configuration $a^2=0.8$ for a prolate band
- ^{188}Pb prolate band seems to be more mixed compared to ^{186}Pb . Similar feature are also hinted by kinematic moment of inertia plot and estimates based on on the transition strength

SAGE+APPA experiment: ^{190}Pb

- SAGE:
 - Utilising the MARA separator
 - $^{159}\text{Tb}(^{35}\text{Cl},4n)^{190}\text{Pb}$ reaction
- APPA Plunger experiment
 - 15 tapered detector
 - $^{108}\text{Pd}(^{86}\text{Kr},4n)^{190}\text{Pb}$
- RT-method was used

Montes Plaza, A., et al., *Comm. Phys.*, 8(8) (2025).

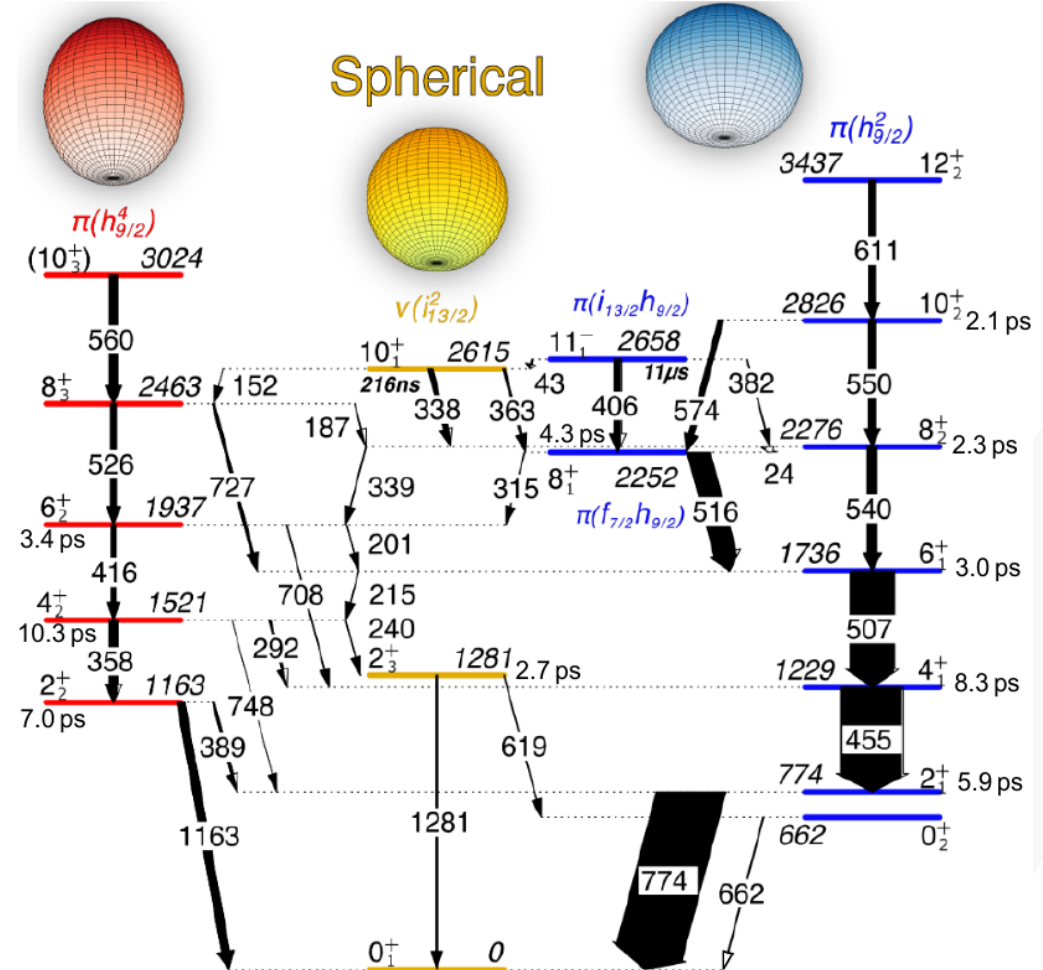


SAGE+APPA experiment: ^{190}Pb

- The yrast band was associated with predominantly oblate shape
- The non-yrast band has been assigned a predominantly prolate character
- The measurement of $E0(0_2^+ \rightarrow 0_1^+)$ allowed to assign first excited 0^+ state to oblate band
- Discovery of a spherical 2_3^+ state

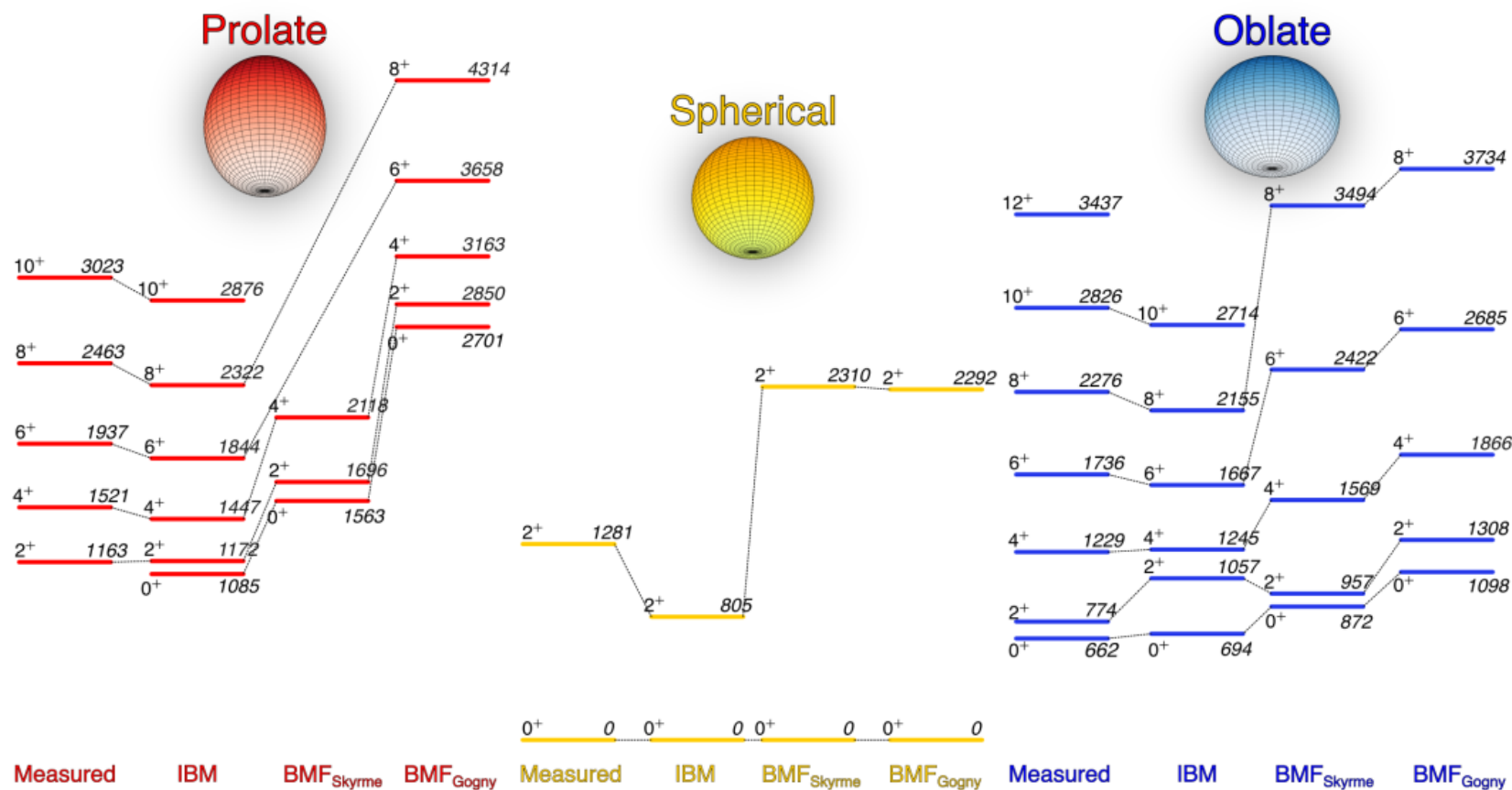
Prolate

Oblate

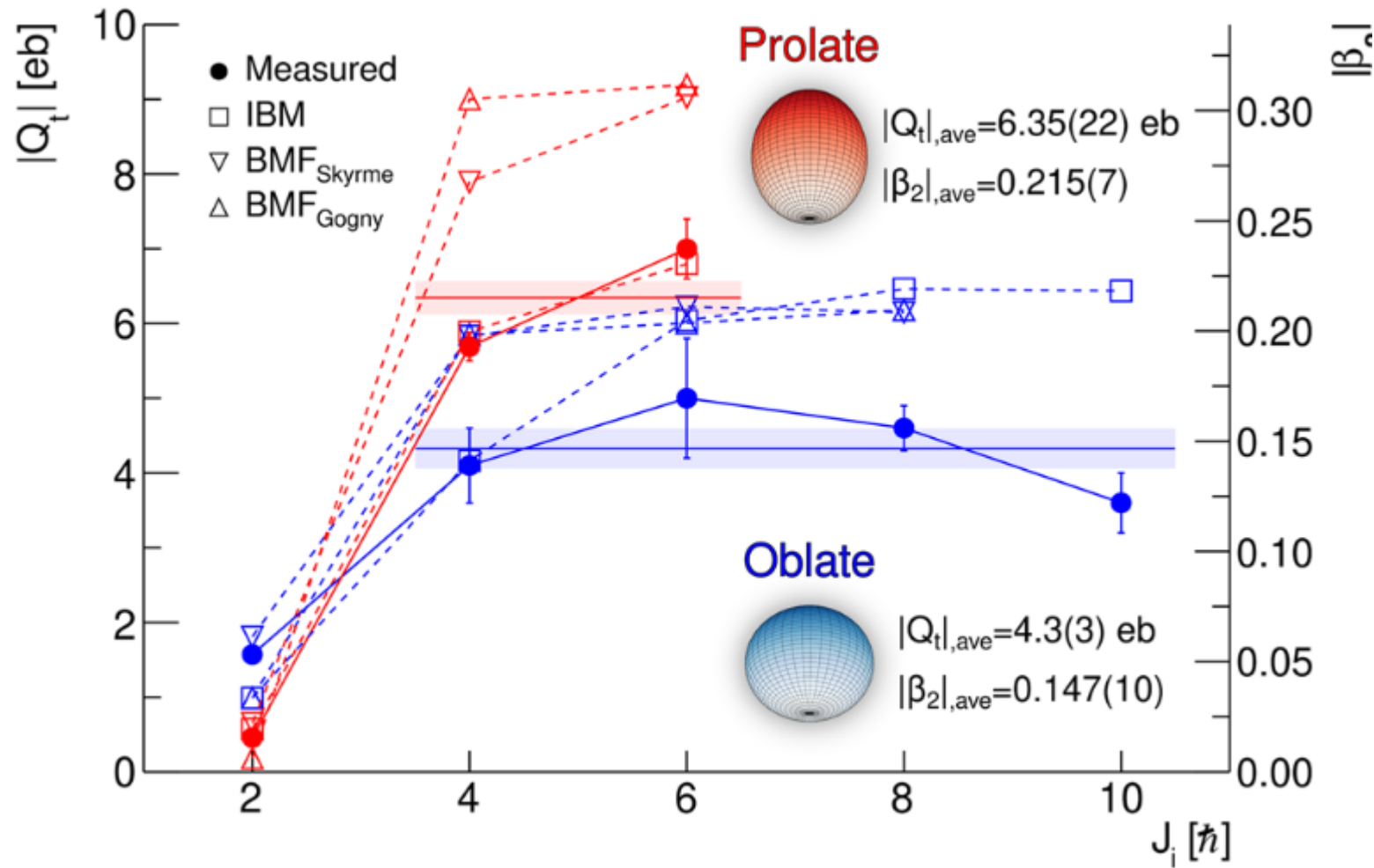


Montes Plaza, A., et al., *Comm. Phys.*, 8(8) (2025).

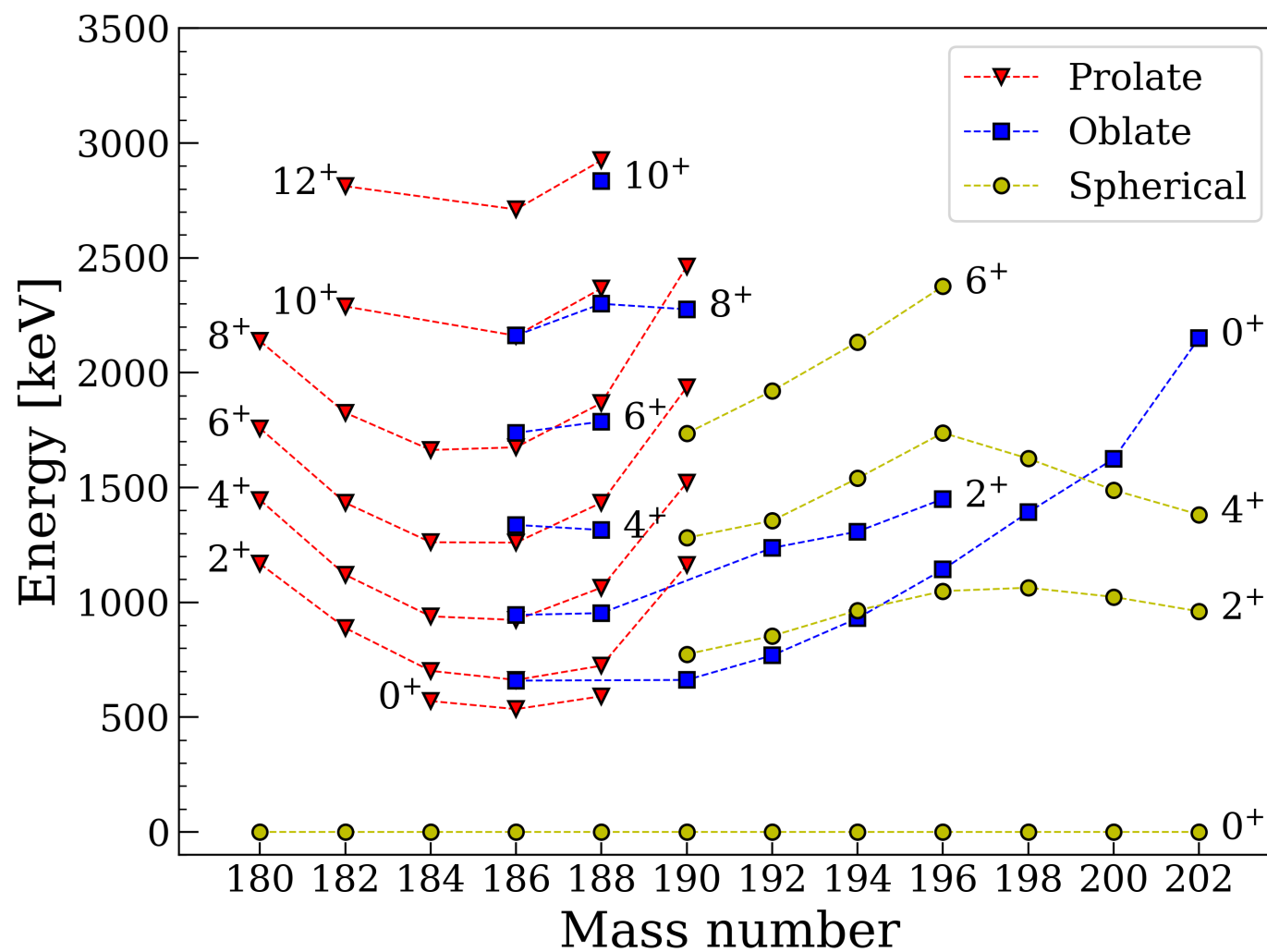
Pb-190 Theory comparison



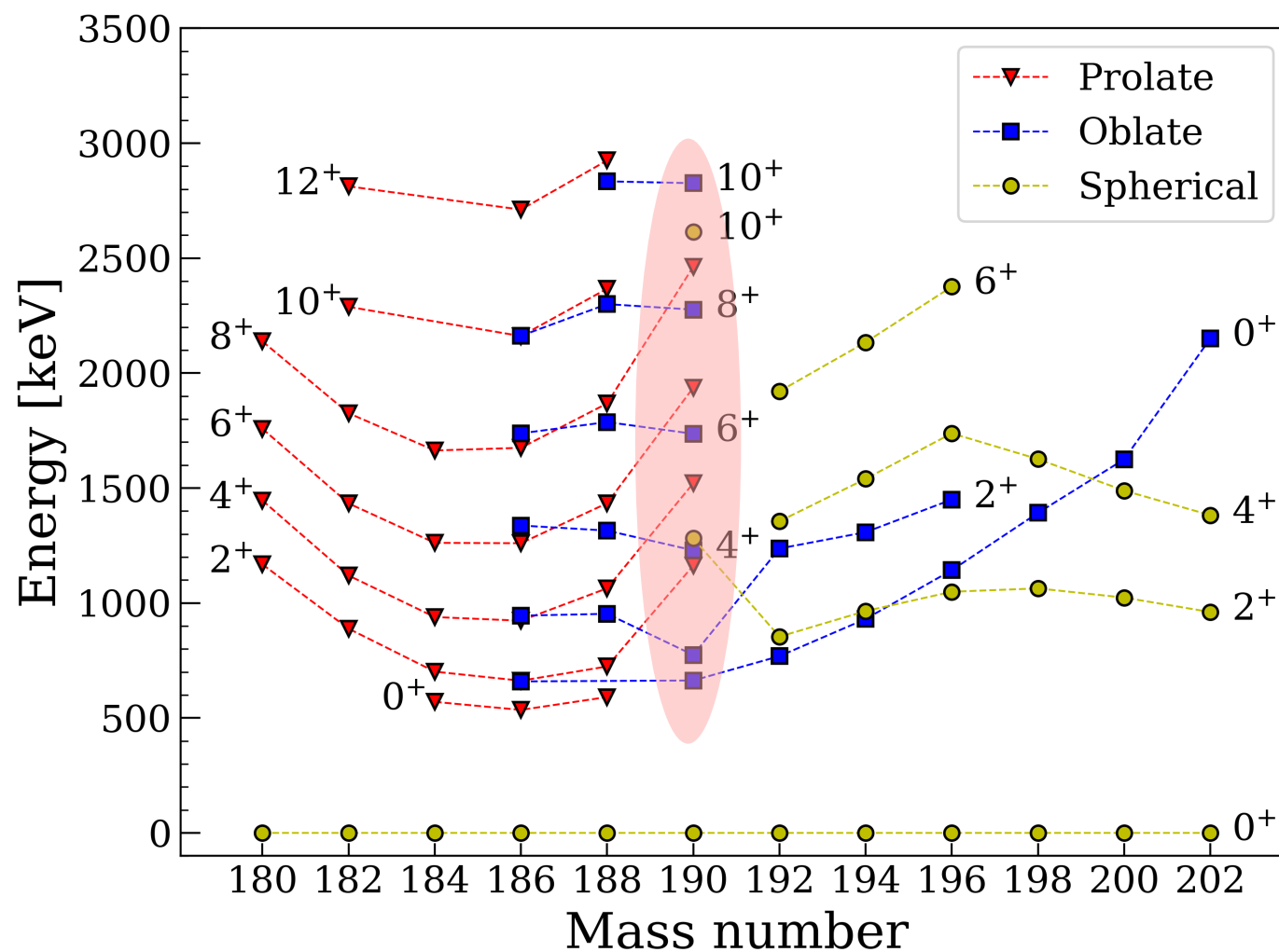
Pb-190 Transitional quadrupole moment



SAGE / APPA experiment: Pb-190



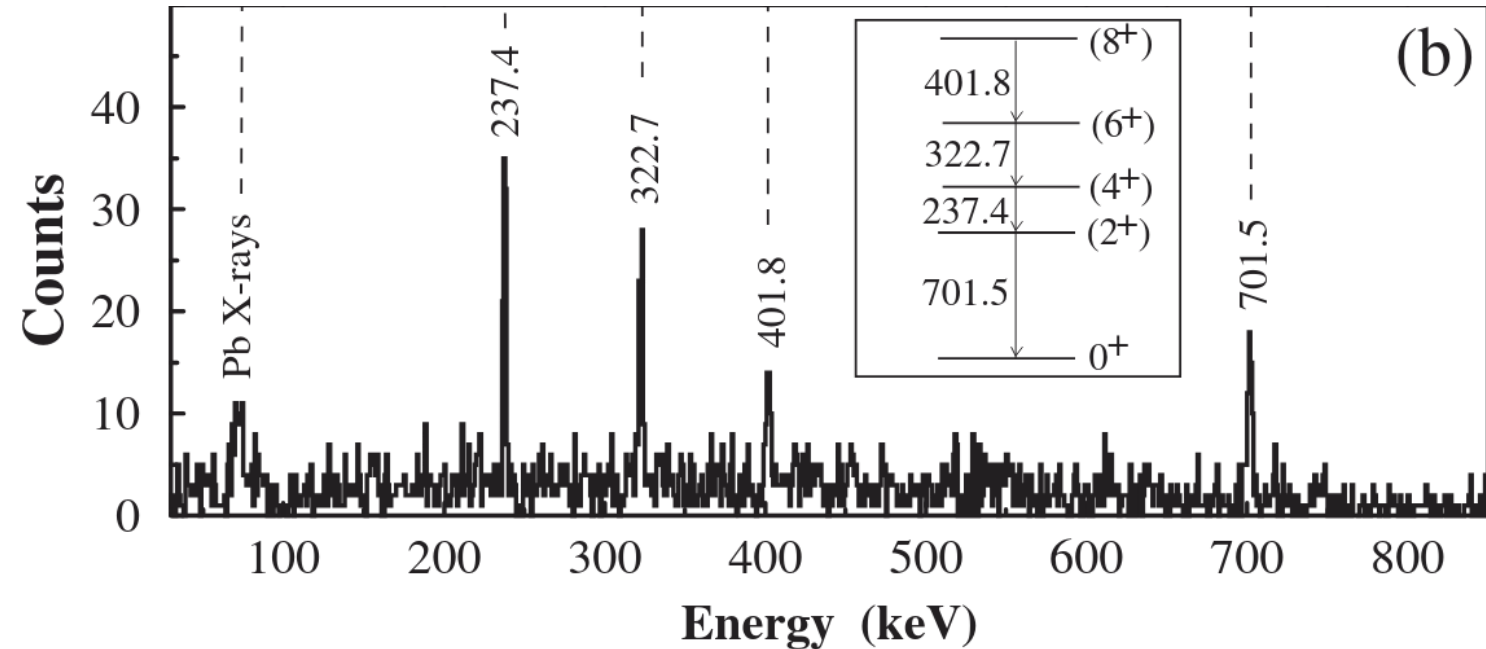
SAGE / APPA experiment: Pb-190



Previously known about ^{184}Pb



- The excited 0^+ state at 570(30) keV were observed for the first time at α -decay study of ^{188}Po
- The γ -ray spectroscopy study has shown yrast states up to 8^+ state.



Cocks, J.F. C., et al., *EPJA* 3 17-20 (1998)

JUROGAM II experiment: ^{184}Pb



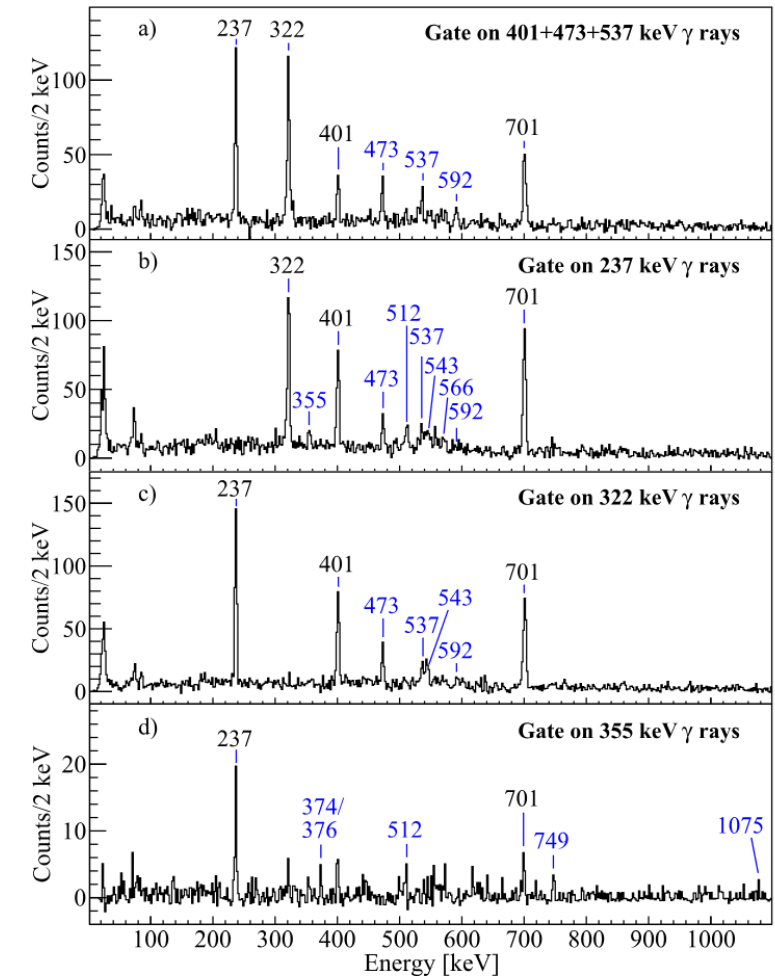
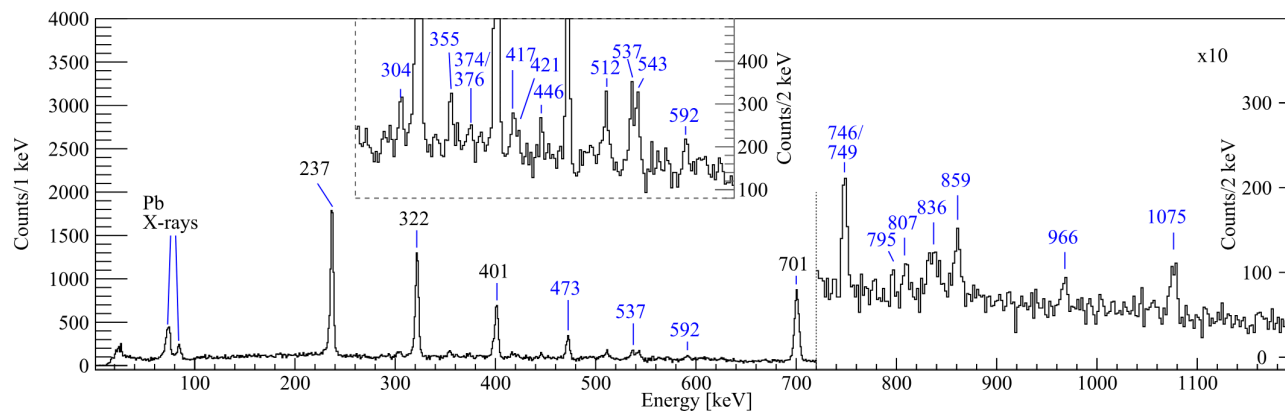
- JUROGAMII+RITU+GREAT+TDR

- $^{104}\text{Pd}(^{83}\text{Kr}, 3n)^{184}\text{Pb}$

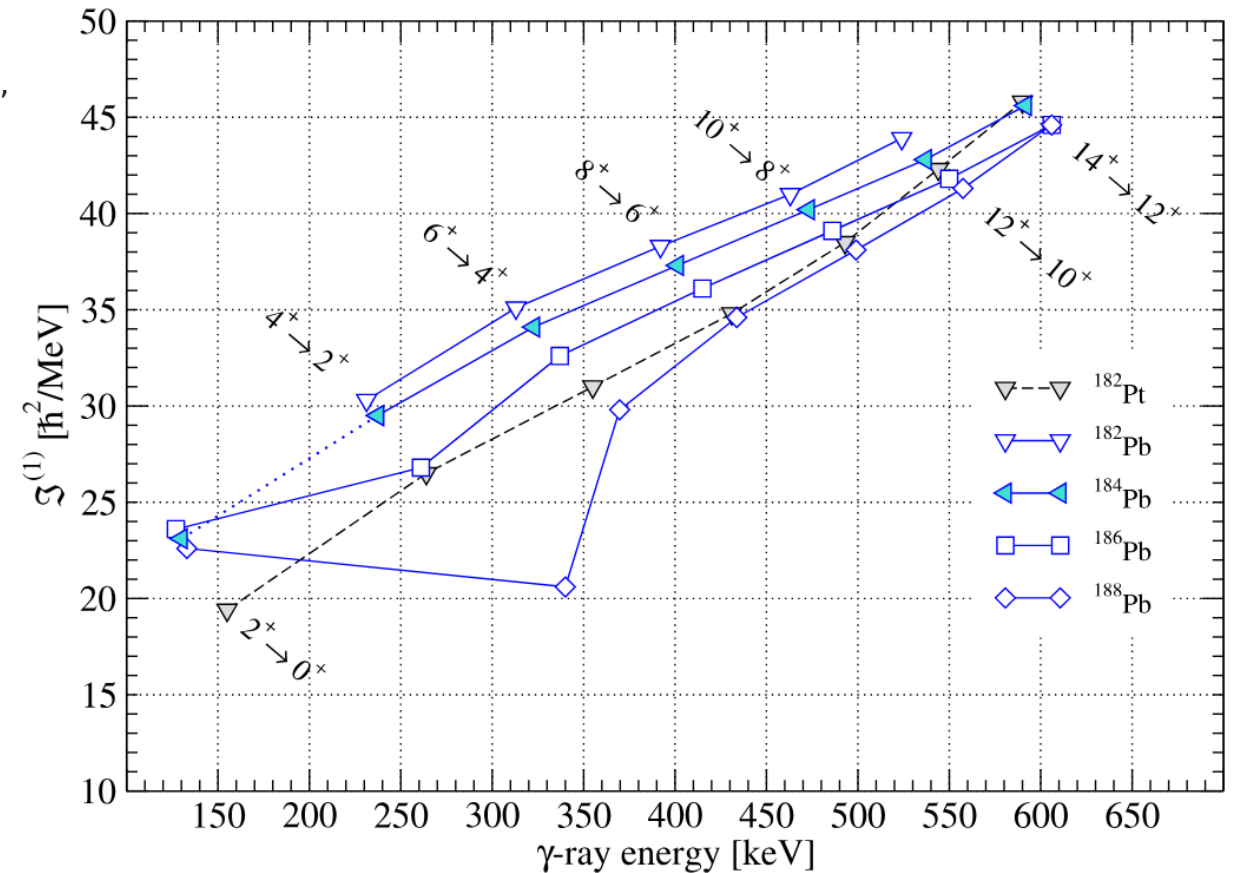
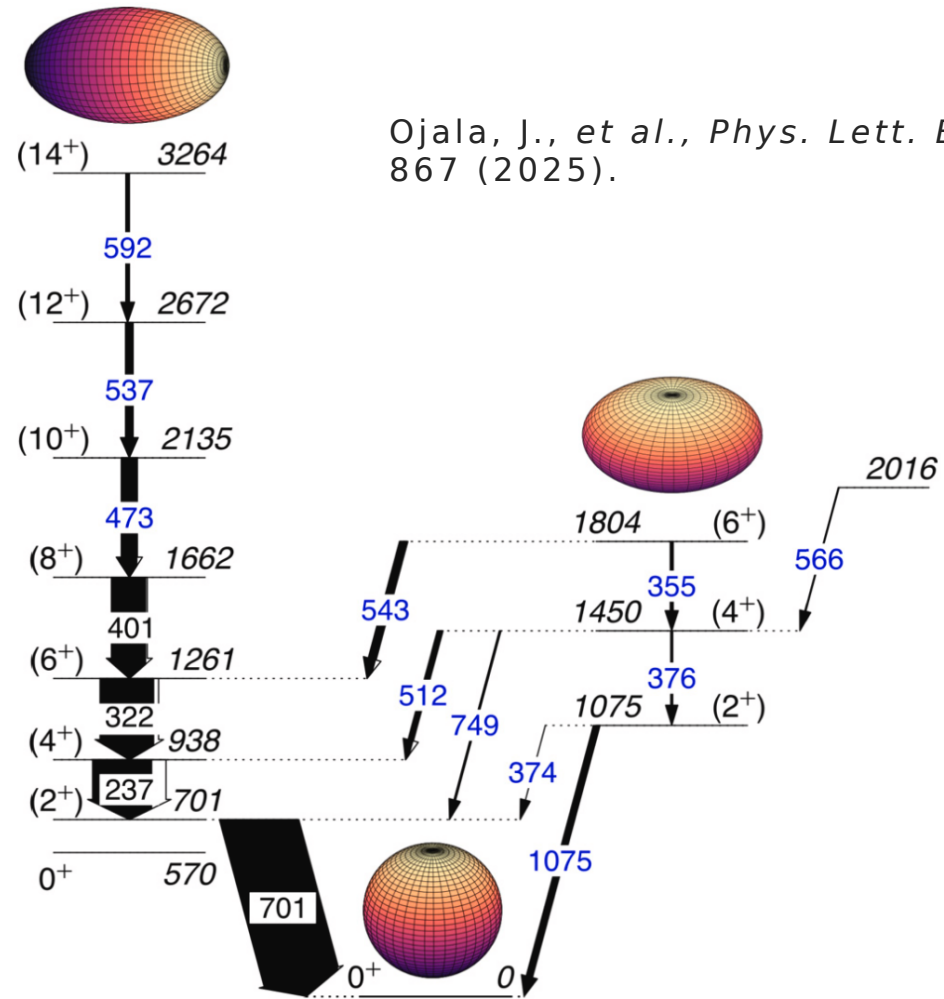
- RDT-method was used

Ojala, J., et al., *Phys. Lett. B*,
867 (2025).

- Were able to identify
candidates for non-yrast
structure



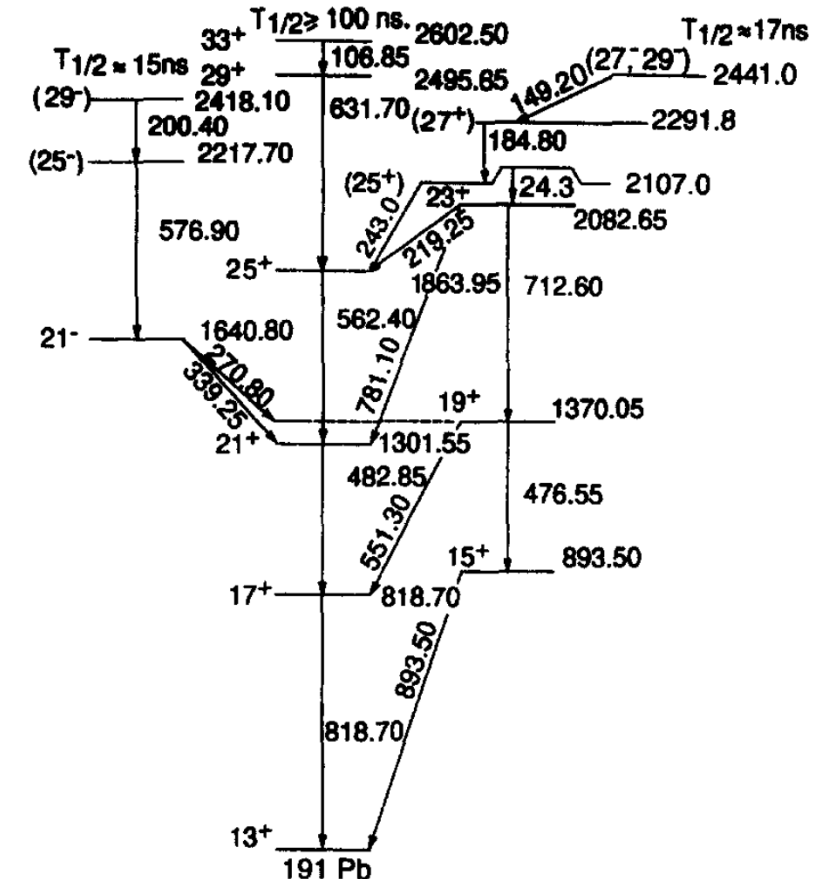
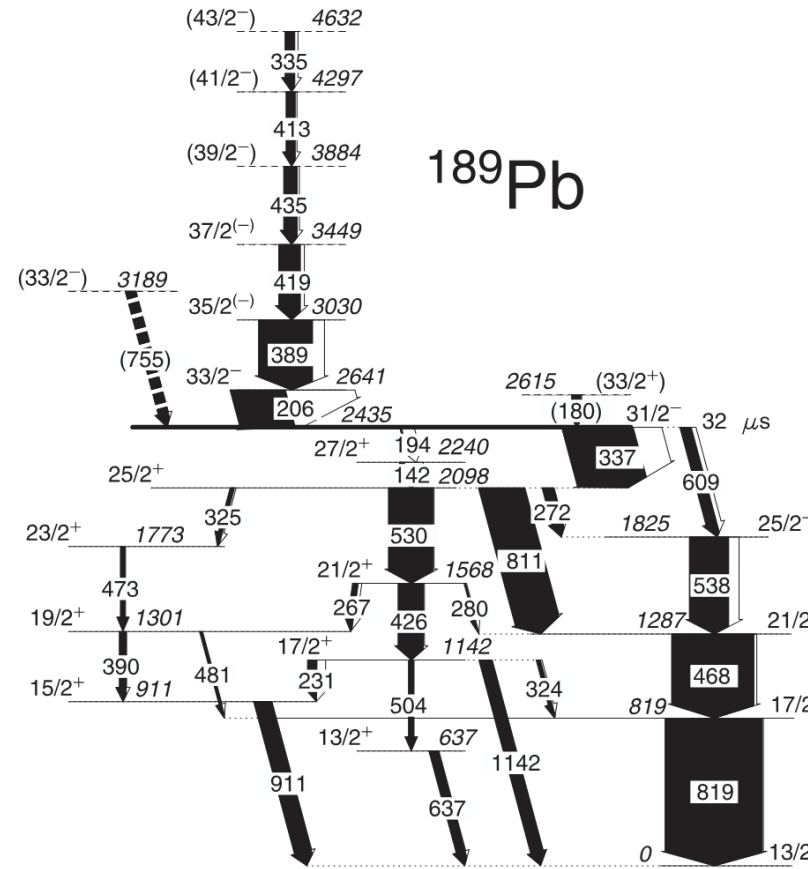
JUROGAM II experiment: ^{184}Pb



Previously known about ^{189}Pb and ^{191}Pb



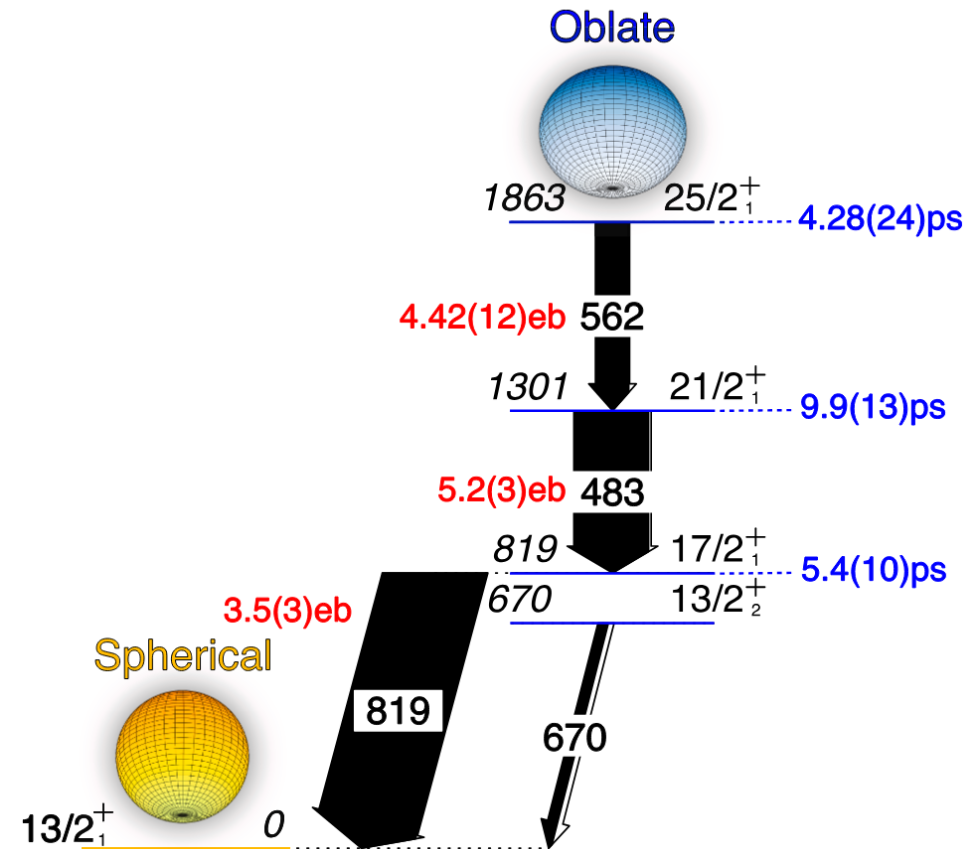
- For both of these nuclei, the level schemes are known above the $13/2^+$ state
- The second $13/2^+$ state is known for ^{191}Pb via beta-decay studies
- Conversion coefficient has been obtained by Baxter et al for several transitions for ^{189}Pb



Lifetime experiment: ^{191}Pb



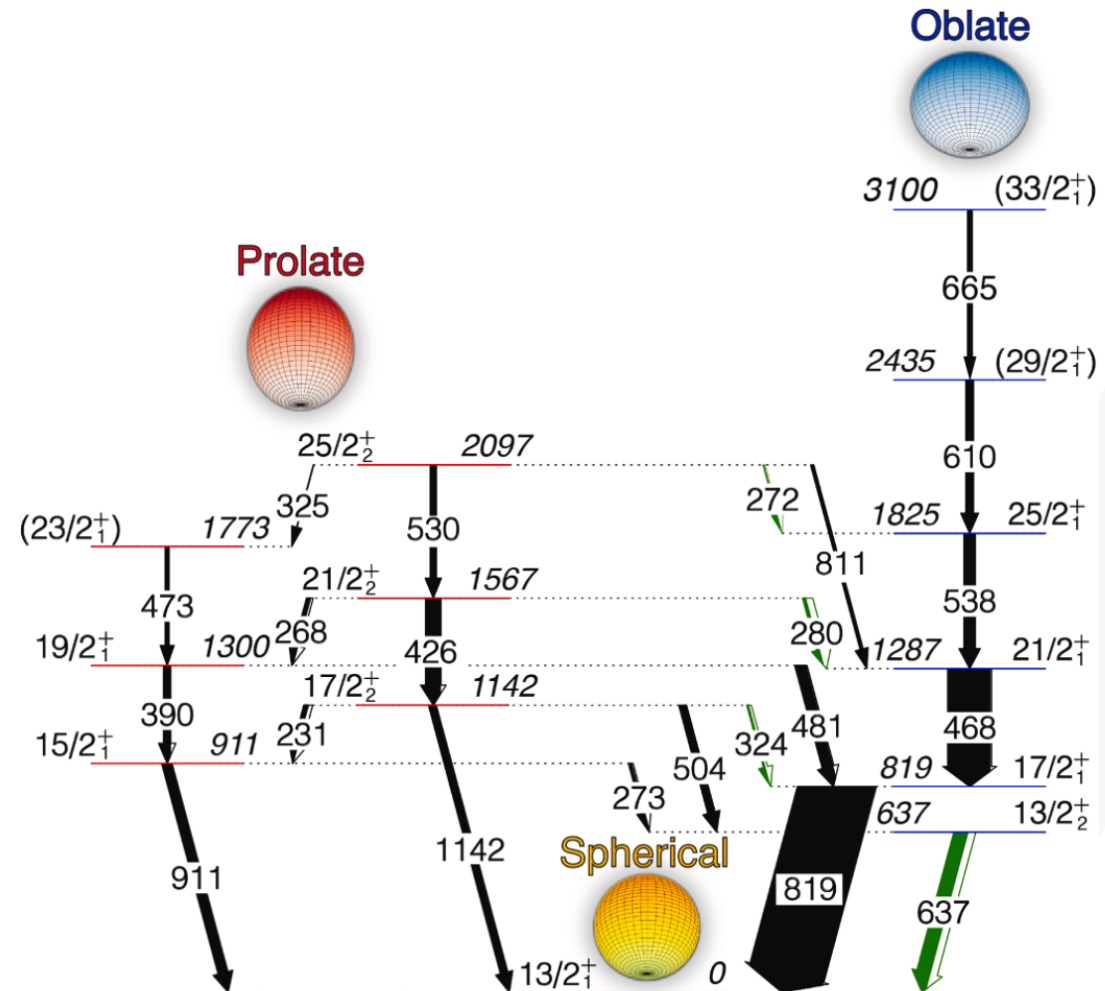
- The lifetime has been obtained for the structure build above $13/2_1^+$ state
- Obtained transitional quadrupole moment values corresponds values that are oblate deformation (for example ^{194}Po)



SAGE experiment: ^{189}Pb



- For both of these nuclei, the level schemes are known above the $13/2^+$ state
- The second $13/2^+$ state is known for ^{191}Pb via beta decay studies



Conclusions



- $^{186,188,190,189}\text{Pb}$ was measured using combined γ -ray and conversion electron spectroscopy
- APPA device was used for measure lifetimes for $^{190,191}\text{Pb}$ states
- ^{184}Pb was measured with the JUROGAMII spectrometer
- The systematic picture has become more clear with these experiments
- More still to come!



PROCON2027

7.6.-11.6.2027, Jyväskylä, Finland



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UNIVERSITY OF JYVÄSKYLÄ



THANK YOU!