UNIVERSITY OF LIVERPOOL

Prompt and delayed spectroscopy of ^{196}At – installation of the novel detector SIGMA in the focal plane

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The 5th early-career researcher (ECR) forum
University of Brighton
April 2026

Outline

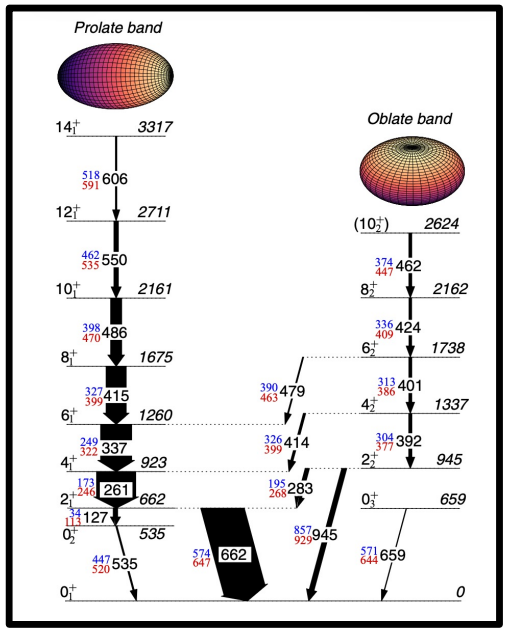
- Introduction
- Physics motivation for neutron-deficient ^{196}At
- Earlier reported works for ^{196}At
- Experimental details
- Results
- Installation of a new detector SIGMA in the focal plane
- Applications of SIGMA in this experiment
- Summary and future plan

Introduction

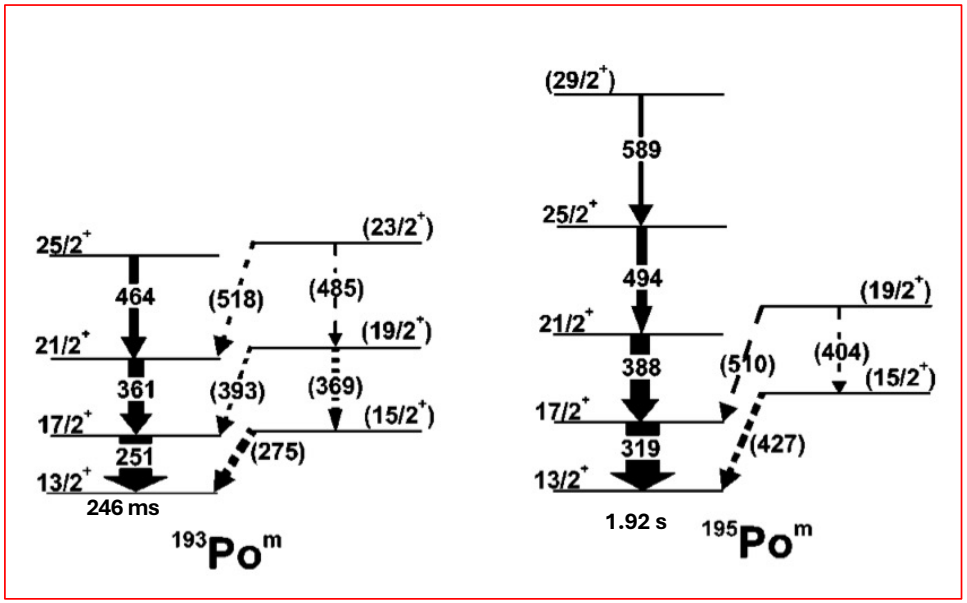
The neutron-deficient nuclei in the Pb region

Presence of deformation-driving intruder orbitals
→ shape co-existence

Presence of unique-parity orbitals →Long-lived isomers
The lowest unique-parity states in the odd-A nuclei in Pb(Z=82) region are often **isomeric- arising from ($\nu i_{13/2}$)**



^{186}Pb (J. Ojala et al., *Commun Phys* **5**, 213 (2022))



Andreyev et al., PRC **66**, 014313 (2002)

Introduction: Odd Z nuclei in A~ 190 region

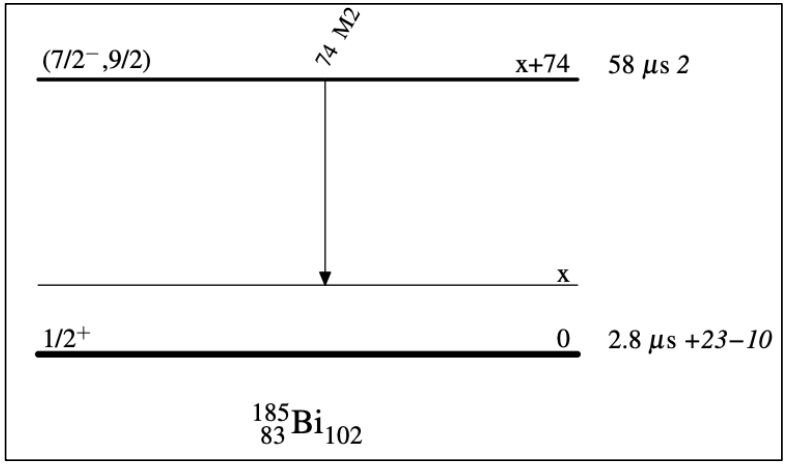
Neutron deficient odd mass Bi (Z = 83), At (Z = 85) isotopes

Change of ground state configuration :

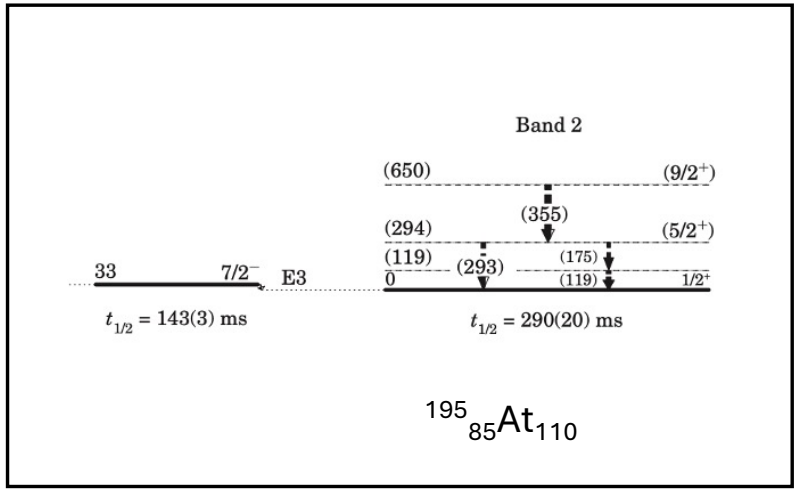
Neutron number decreases towards the mid-shell

- Heavy mass nuclei → $\pi h_{9/2}$
- Light mass nuclei → $\pi s_{1/2}^{-1}$
- Bi : N 104 →102.
- At: N 112 → 110

→ Interpreted as the change of nuclear shape from spherical or near spherical to oblate



Doherty et al., PRL 127 202501(2021)

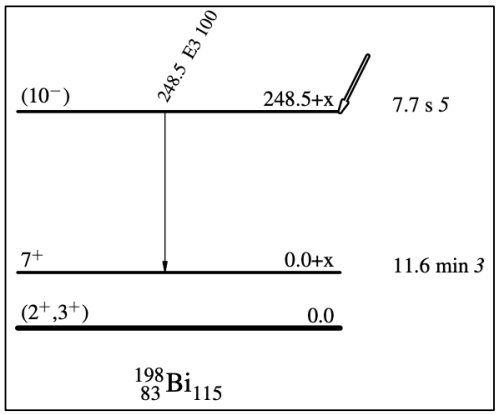


M. Nyman et. Al., PRC **88**, 054320 (2013)

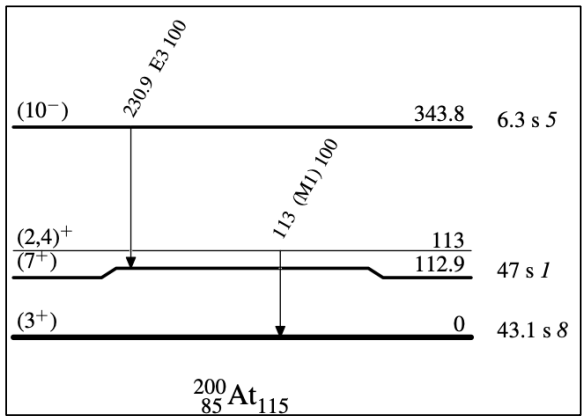
Introduction: Odd-odd nuclei in A~ 190 region

Neutron deficient odd-odd Bi (Z = 83), At (Z = 85) isotopes

- The effect of mid-shell neutron coupling with the protons
- Several possible configurations : multiparticle and multi-hole coupling across the shell closure
- In the neutron-deficient nuclei – 3^+ → α–decaying ground state
  7^+, 10^- → 2 α-decaying states – interconnected by E3



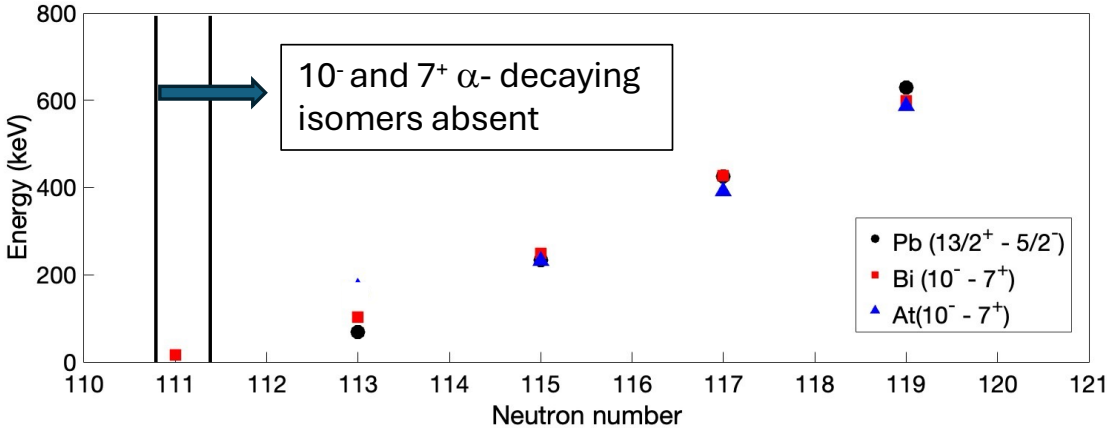
U. Hagemann et al, NPA 197, 1(1972)



M. Huyse et al, PRC **46**, 1209 (1992)

Physics motivation for neutron deficient ^{196}At

The 10^- → 7^+ E3 transition energy of odd-odd Bi, At isotopes ($13/2^+$ → $5/2^-$) Exc. Energy difference of odd Pb isotopes
→ Proton coupling only acts as spectator

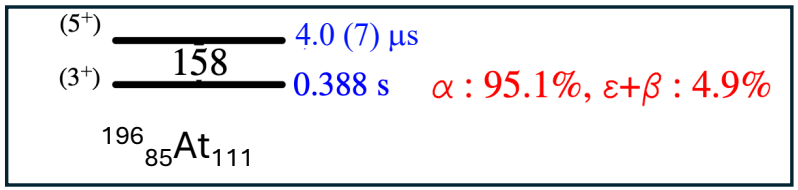


The high spin α-decaying isomers are absent for N = 111 of At isotope – ^{196}At

- Some other spin multiplets become favorable
- Allows γ transitions over α-decay

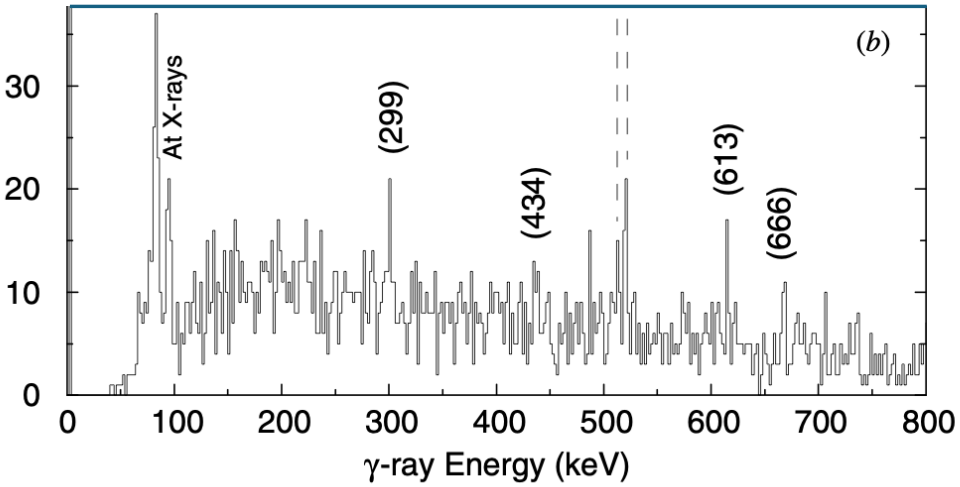
Change of structural configuration of the lower excited state around Neutron number N = 111

Earlier reported works on ^{196}At



^{165}Ho(^{36}Ar, 5n) ^{196}At @ 178MeV, σ ~ 15 μb

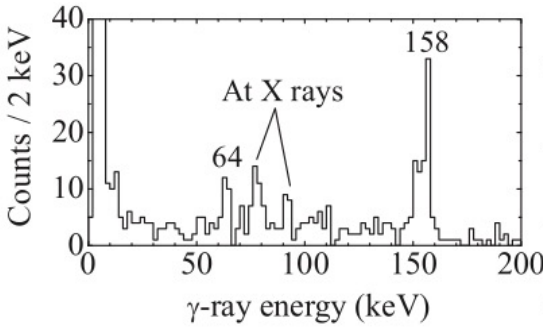
M.B. Smith et al., JPG Nucl. Part. Phys. 26(2000) 787



- 158 and 64 keV observed in the focal plane
- Few prompt gammas observed

^{147}Sm(^{51}V,3n)^{196}At @ 224 MeV , σ ~ 230 nb

M. Nyman et al., PRC **88**, 054320 (2013)

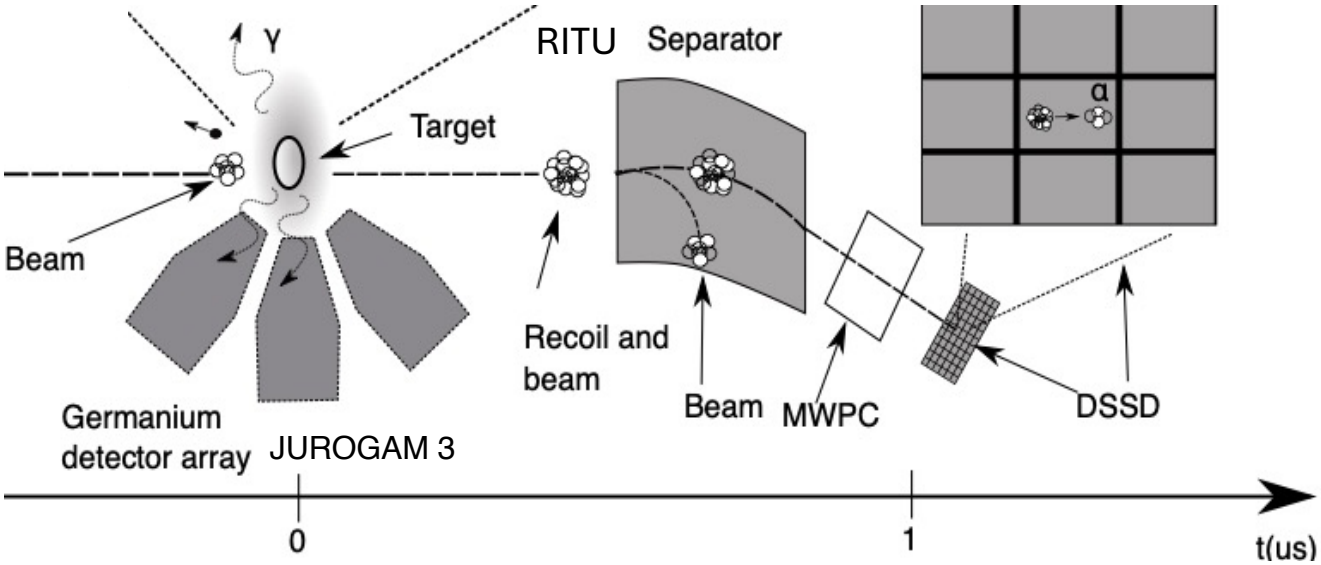


Primary focus of experiment

- ❑ The level structure above μs isomer (5^+) state
- ❑ The connection of coincident prompt gammas with the 5^+ and 3^+ state
- ❑ Search for the decay path of the isomer which involves 64 keV delayed-γ transition

Experimental details

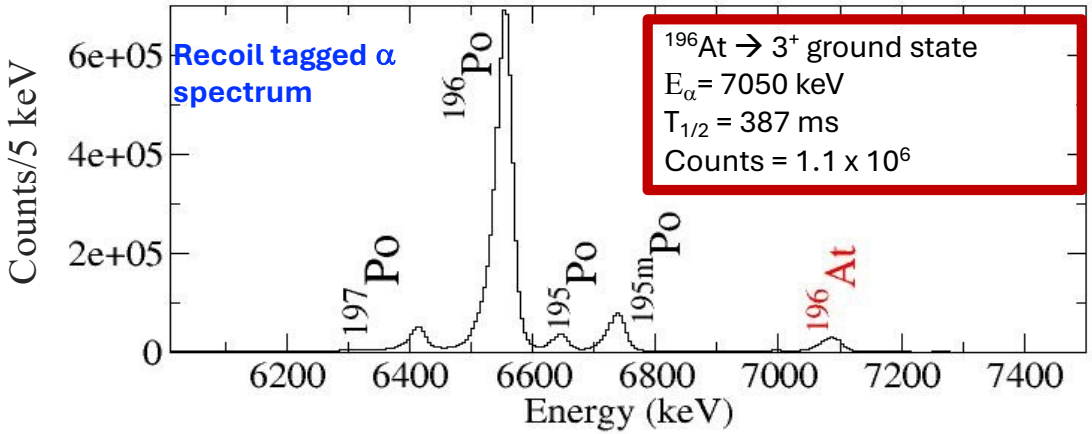
Accelerator Laboratory of the University of Jyväskylä



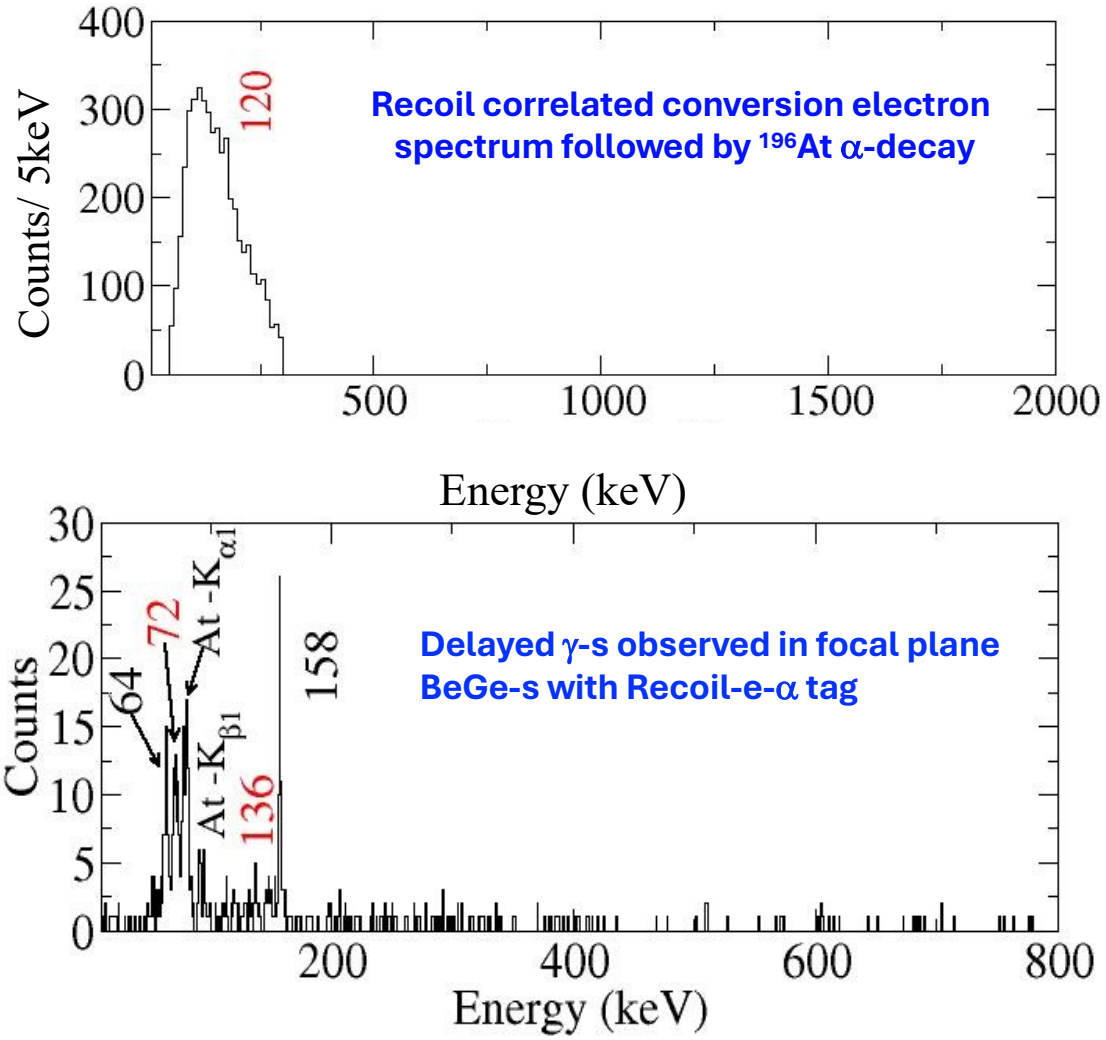
- Recoil products separated using Gas filled recoil Separator -RITU
- Implanted recoils in DSSD
- Correlated with subsequent α-decay

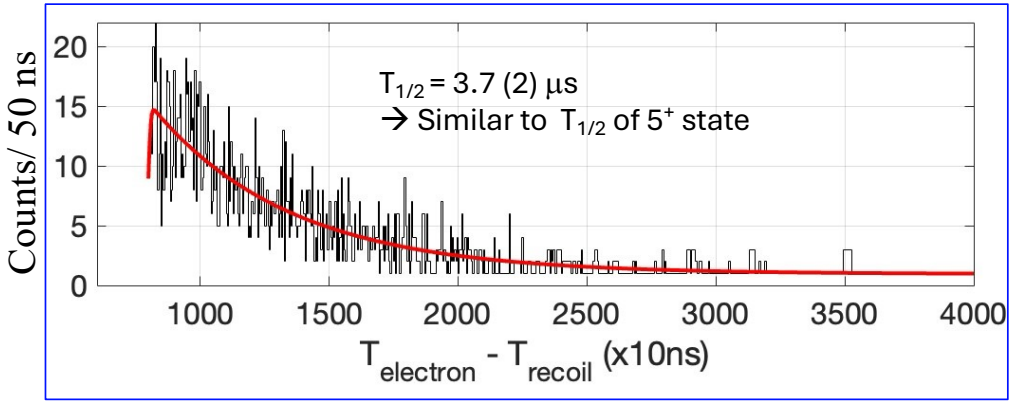
→ Recoil-decay tagging (RDT)

- ✓ **Reaction: ^{165}Ho(^{36}Ar, 5n)^{196}At**
- ✓ Beam energy: 186 MeV
- ✓ Beam intensity : 20 pnA
- ✓ Target thickness : 350 μg/cm^2
- ✓ Cross section: ≈ 30 μb
- ✓ Beam-Time: ≈ 10 days



Results: Conversion electron and delayed γ-s in the focal plane



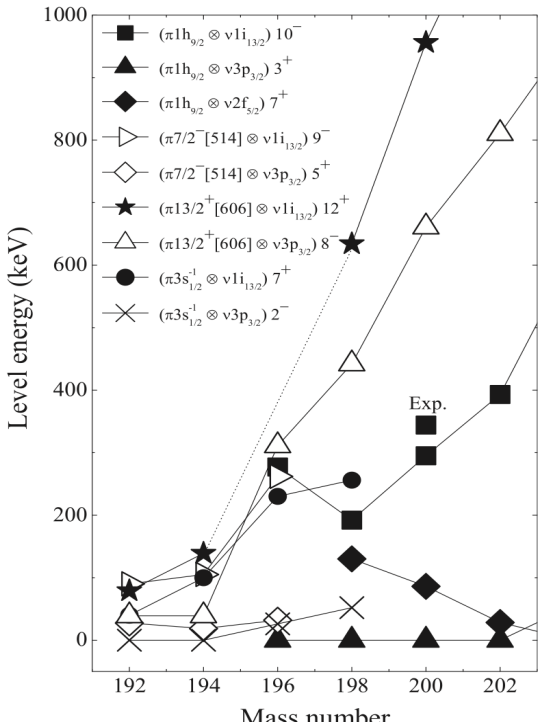


- → Similar $T_{1/2}$ values obtained for the 64, 72, 136 and 158 keV
- → DSSD conversion electron spectrum is the sum of L+M+... peaks of 64, 72, 136 and 158 keV
- → They belong from the same cascade following from one isomeric state

Results: decay path of the isomer

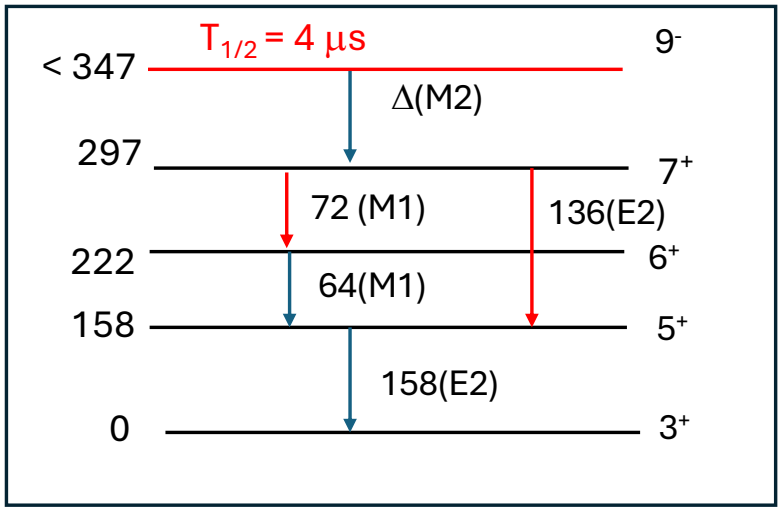
Shell model calculation from ***Nyman et al, PRC 88, 054320 (2013)***

- Existence of deformed 7^+ state
- Existence of 9^- state instead of 10^- α-decaying state
- Existence of 9^- to 7^+ M2 transition of low energy



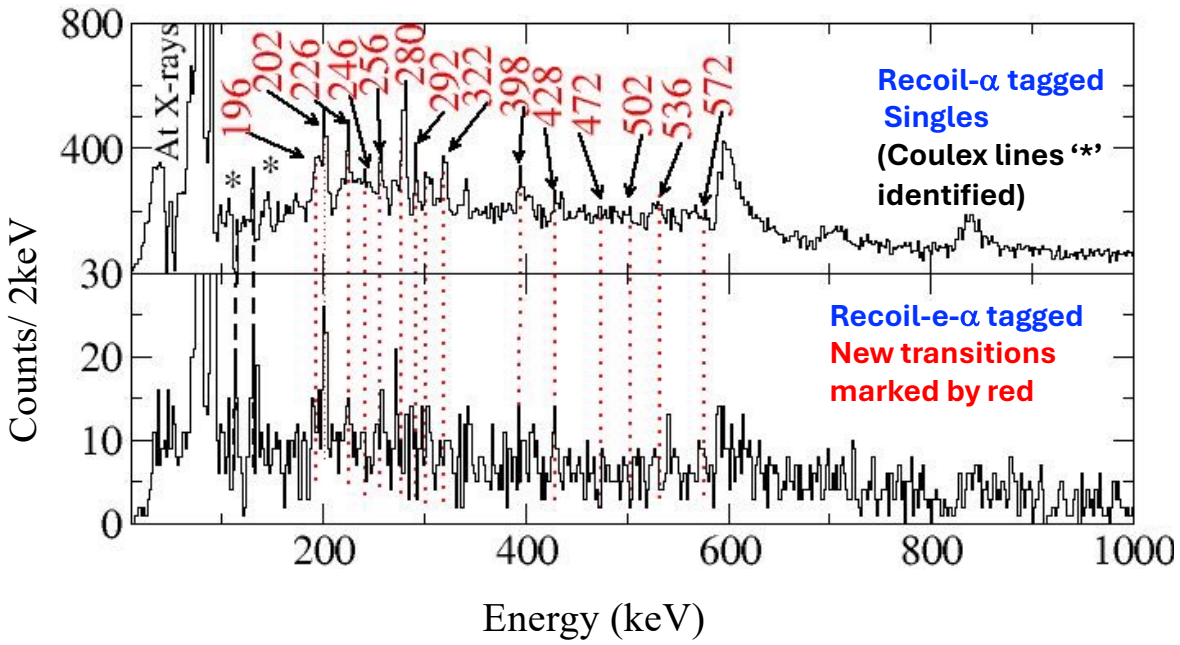
Nyman et al, PRC 88, 054320 (2013)

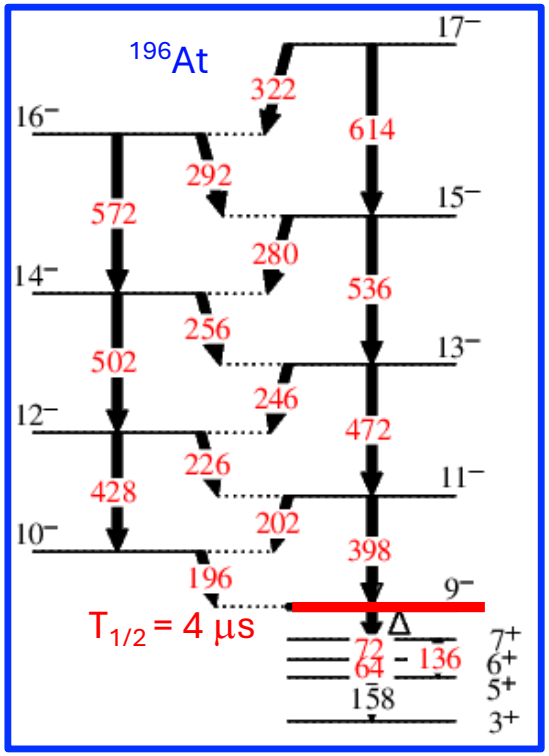
Energy (E_γ)	$T_{1/2}$ (Weisskpof estimates)
64(M1)	~ 10^{-12} s
72(M1)	~10^{-12} s
136(E2)	~ 100 ns
158(E2)	~ 50 ns
30(M2)(<50)	~ 5 µs



Results: High spin states above the isomer & preliminary level scheme

Prompt γ-rays observed in JUROGAM3 array





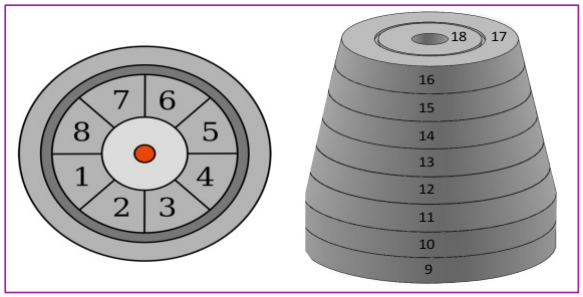
Most of the prompt and delayed γ–s observed in R-α tagged are also observed in R-e-α tagged spectra

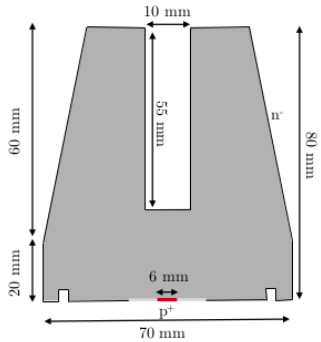
→ High spin structure is connected to the ground state via delayed γ -decays

Level scheme proposed from the present experiment(preliminary)

Installation of a new detector SIGMA in the focal plane

SIGMA (Segmented Inverted-coaxial GerMAnium) detector





Segmentation Scheme

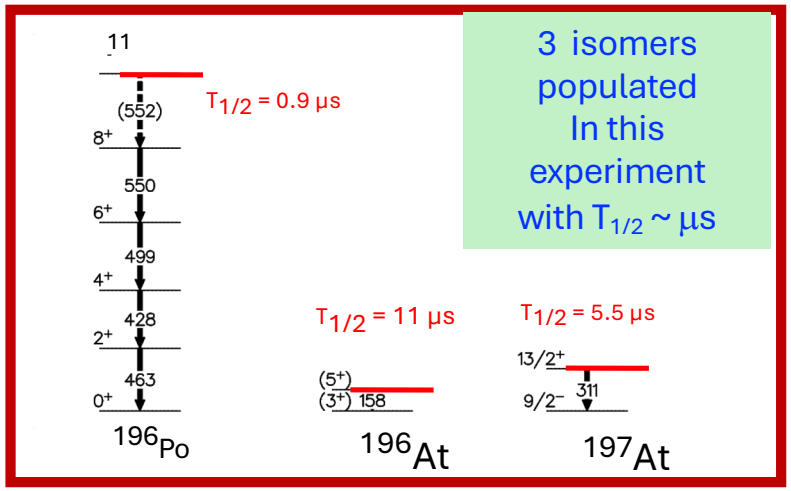
- 1- 8 azimuthal segments,
- 9-16 longitudinal segments
- 2 concentric segments (17, 18)
- 19 readout channels including the point contact(PC)

P-type germanium inverted-coaxial detector
Height – 80 mm
Diameter –70 mm
Volume ~ 240 cm^3

- The small size of the point contact - low capacitance – better energy resolution- 0.2% at 1.4 MeV
- Inverted Co-axial- much longer drift paths for the holes- ideal for good position resolution keeping the number of channels to lower

SIGMA installed in the focal plane in place of one BeGe detector

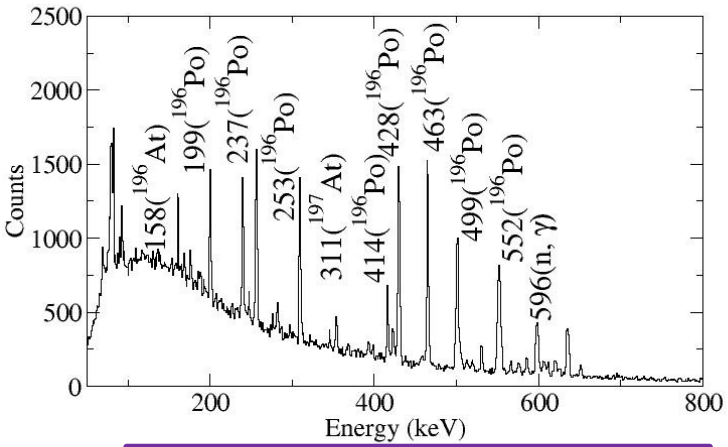
Applications of SIGMA in this experiment



3 isomers populated In this experiment with $T_{1/2}$ ~ µs

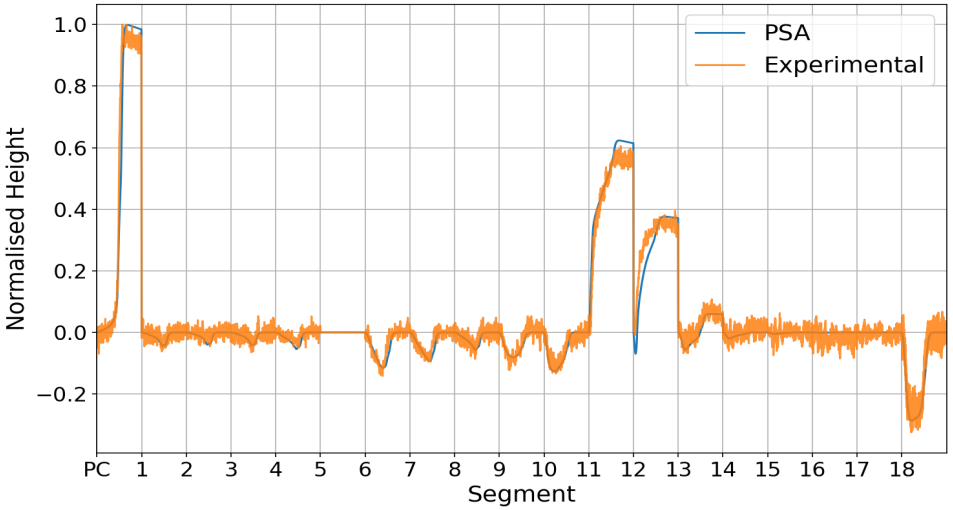
- Spectroscopic detector with promising energy resolution
- Gamma ray tracking and imaging device-
  - ✓ To track gamma rays back to the DSSD with Pulse Shape Analysis (PSA) technique
  - ✓ To correlate/veto-out the events generating from the isomeric decays of the implanted exotic ions.

SIGMA as spectroscopic detector



Recoil-correlated SIGMA spectrum

Comparison of the experimental signals to the validated simulated database



Summary & Future Plan

Summary

- Odd-odd neutron deficient exotic nucleus ^{196}At populated
- The level structure above 5^+ state & the internal decay path of the isomer investigated.
- As a commissioning experiment, the performance of novel detector SIGMA tested in the Jysväskylä Accelerator Laboratory (JYFL) selected as test site

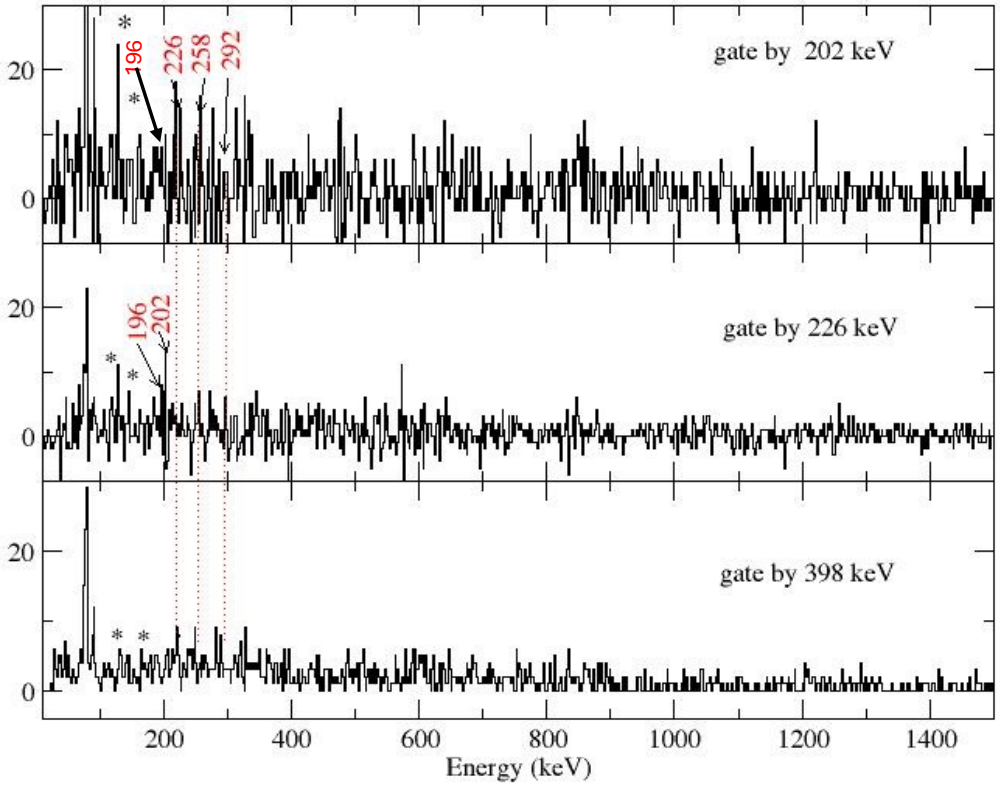
Future plan

- Finalization of level scheme of ^{196}At
- Next level analysis with saved SIGMA traces- to track gamma rays back to the DSSD to veto-out/ correlate isomeric decays using the results from PSA.

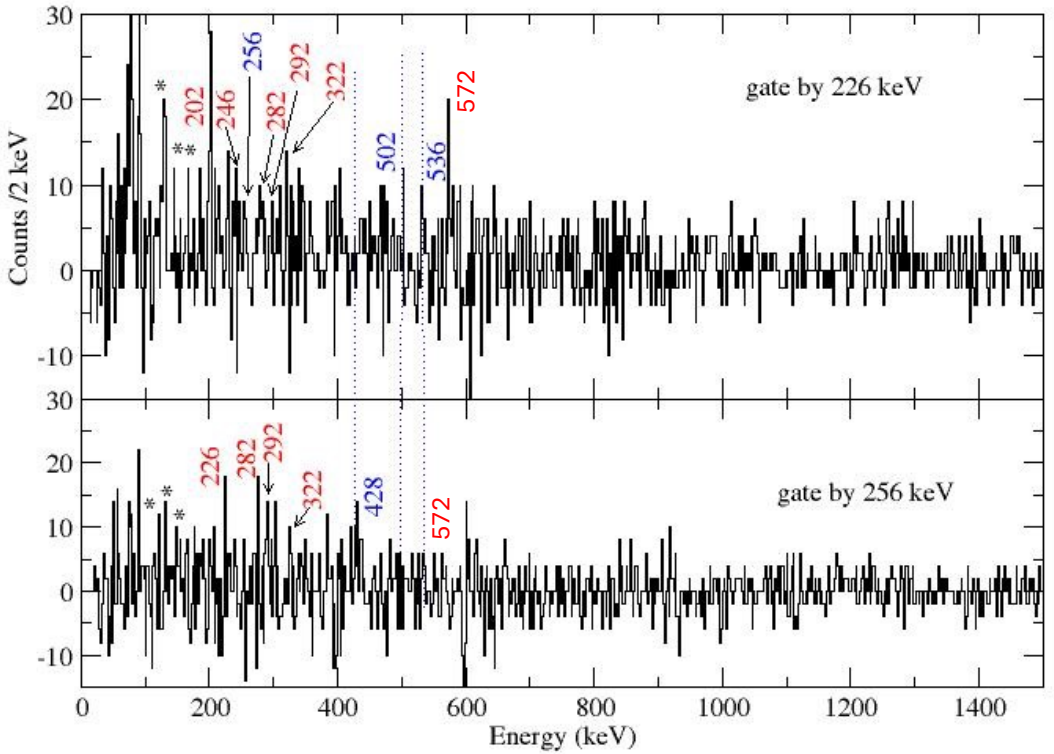
Thanks to Collaborators

Next --- Back-up Slides

Red dotted lines and energies → observed in all vertical panels
Blue dotted lines and energies → observed only in one panel
Asterisks → Coulex lines



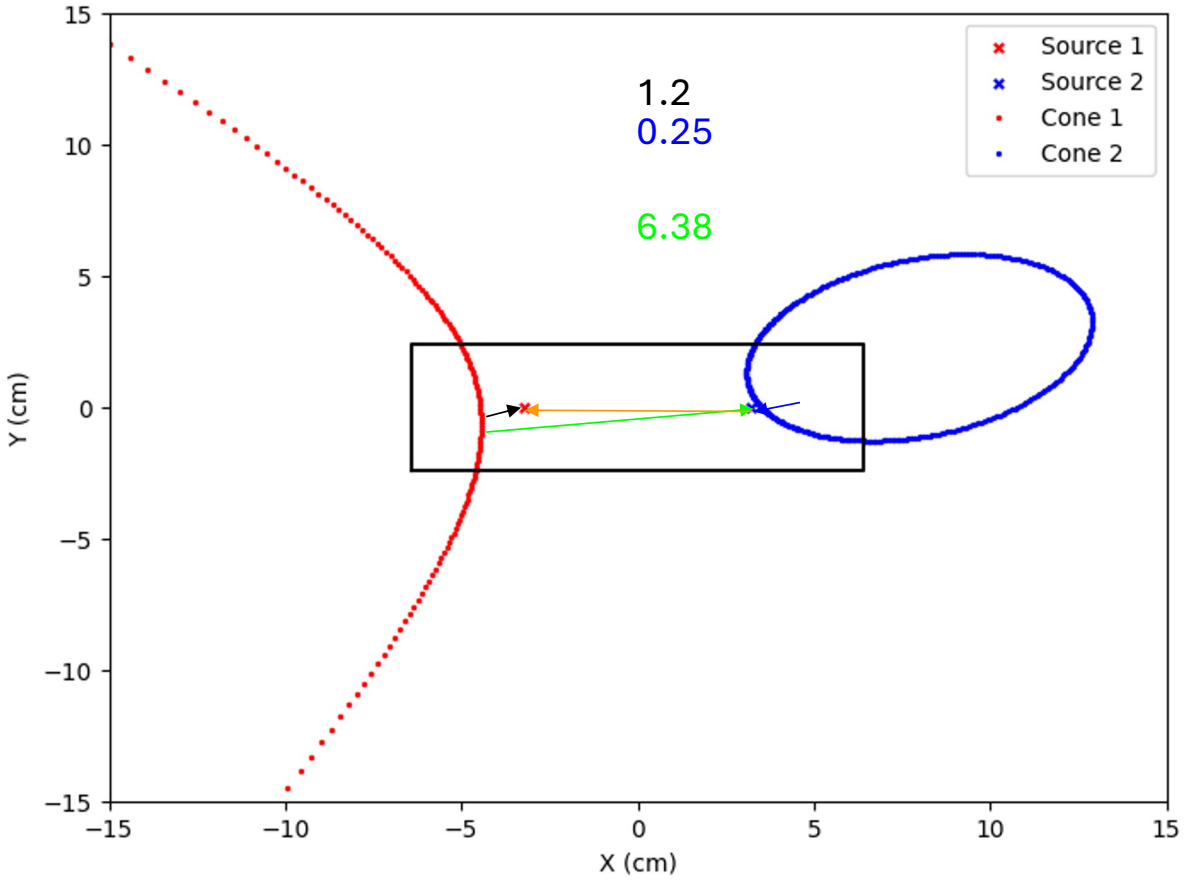
196, 202 are absent @398 keV



428 is absent @226 keV
502, 536 are absent @ 256 keV
572 is not that prominent in 256 gata !!

Back projection of cones at DSSD to find the emission point

- In the simulation, the emission points are distributed around all DSSD uniformly.
- Two points are chosen randomly as a coincidence
- The two points are then back-projected at the DSSD
- Now we calculate the d_{min} from each cone to each point



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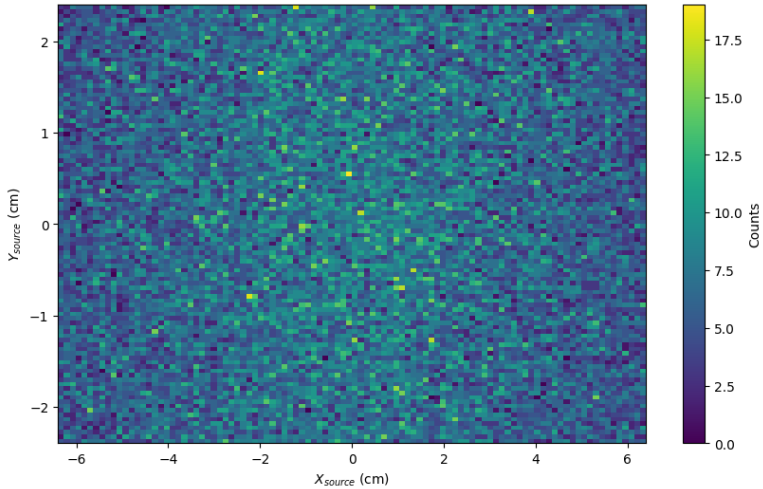
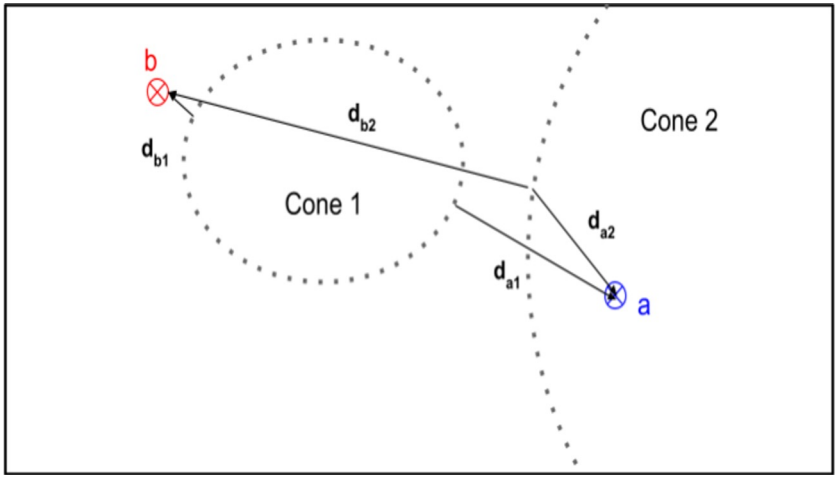
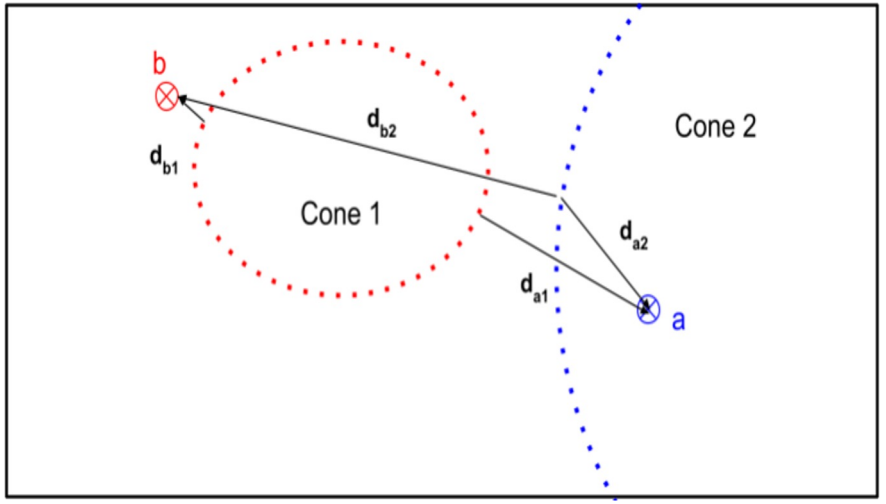


Before assignment



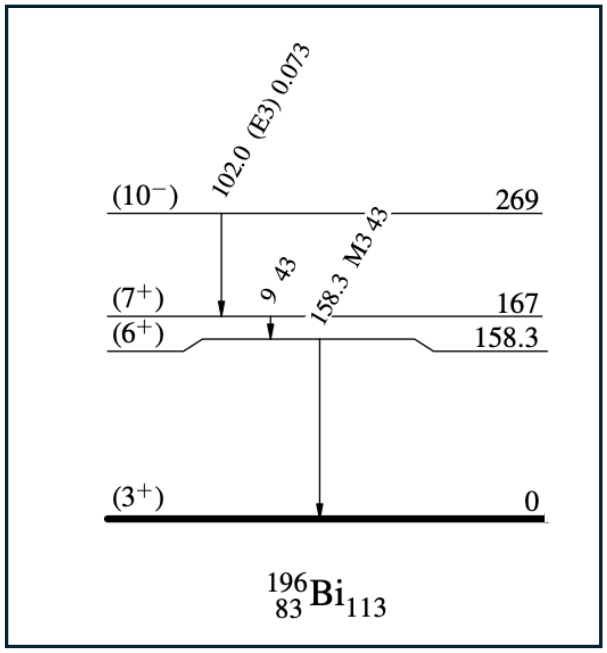
After assignment



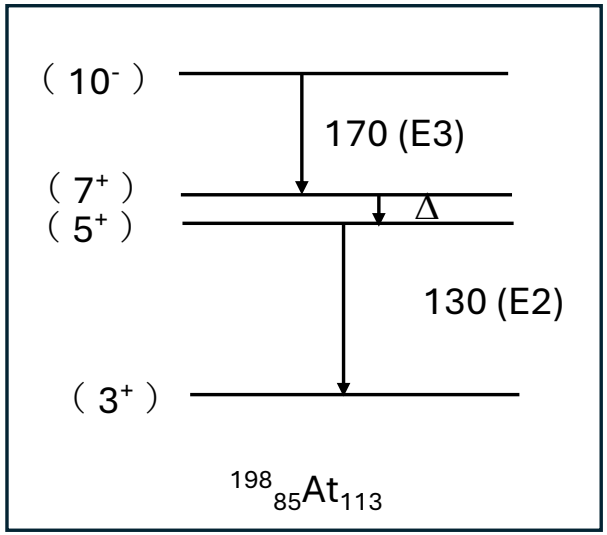
Neutron-deficient Odd-odd Bi (Z = 83), At (Z = 85) isotopes

For N = 113

The 10^- and 3^+ states are interconnected by 7^+ gamma-decaying isomers

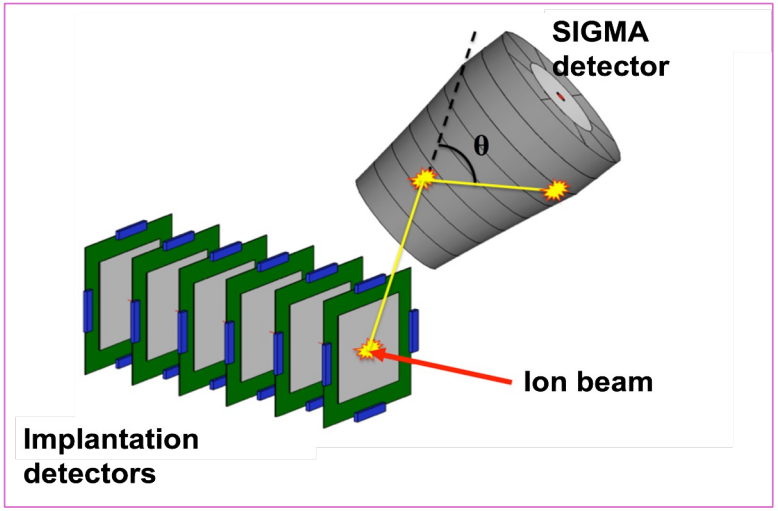


P. Van Duppen, et al., PRC 35, 5(1987)



From recent data analysis of ^{198}At

Applications



- Gamma ray tracking and imaging device-
  - ✓ To track gamma rays back to the DSSD with Pulse Shape Analysis (PSA) technique
  - ✓ To correlate isomeric decays and beta-delayed gamma rays from the implanted exotic ions.
- Spectroscopic detector with promising energy resolution
- Implementation of PSA technique for the improvement of intrinsic time resolution of the detector

Pulse Shape Analysis (PSA)

The position of a γ-ray interaction within SIGMA determined by comparing the experimental signals to the simulated database on an event-by-event basis using chi square minimisation approach