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Laser assisted studies of β-delayed fission in ^{178,176}Au and of the structure of ^{175}Au

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64th Meeting of the INTC

Outline

- Part 1: β-delayed fission (βDF) of ground and isomeric states in $^{178,176}Au$
- Detection setups
- Part 2: Laser spectroscopy of $^{175gs}Au$
- Beam request

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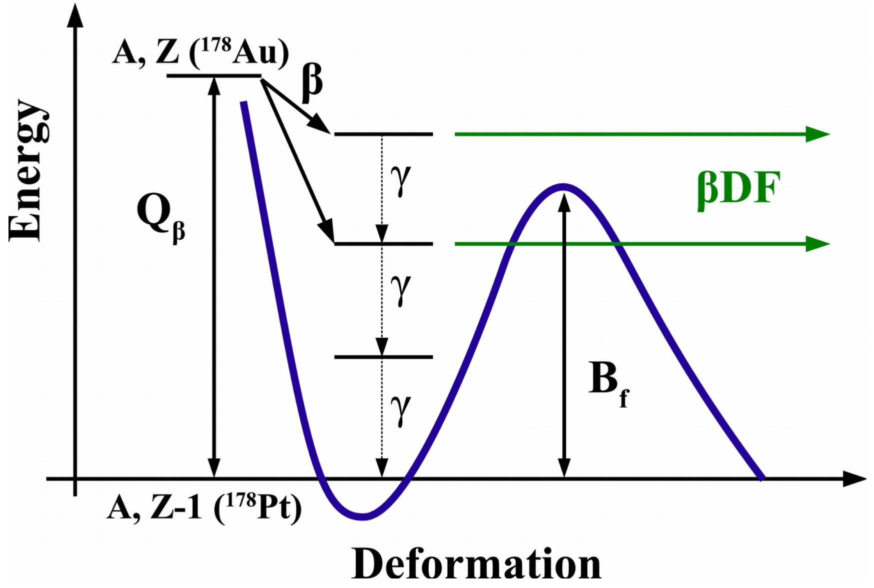
Part 1(βDF of ^{178gs,is,176gs,is}Au): Physics motivation

- typically $Q_\beta \leq 12$ MeV ⇒ low-energy fission properties of exotic isotopes (sensitive to shell effects)

- **in many cases impossible to determine βDF probability: mixture of two β-decaying states and/or unknown β-decay branching ratios**

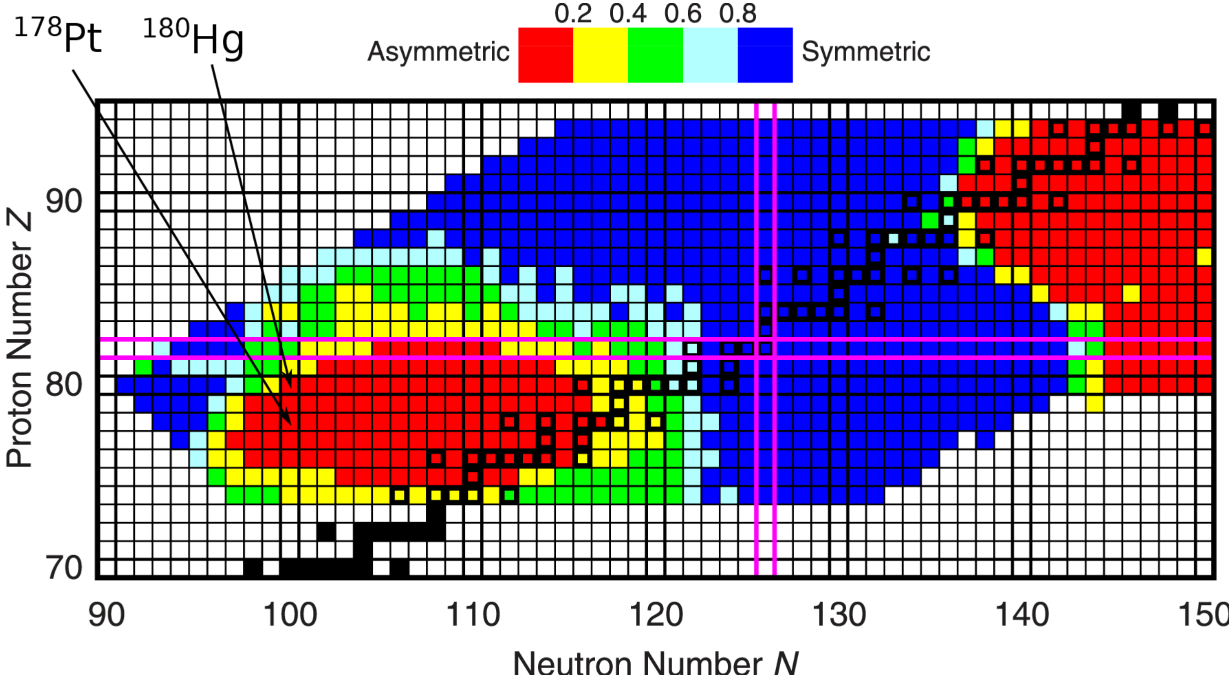


- **neither of these is an issue in our case (two states are in fact an opportunity to study spin dependence of fission)**

A. N. Andreyev, K. Nishio, and K.-H. Schmidt, Rep. Prog. Phys. 81, 016301 (2018).
A. N. Andreyev, M. Huyse, and P. Van Duppen, Rev. Mod. Phys. 85, 1541 (2013).

Part 1: Physics motivation

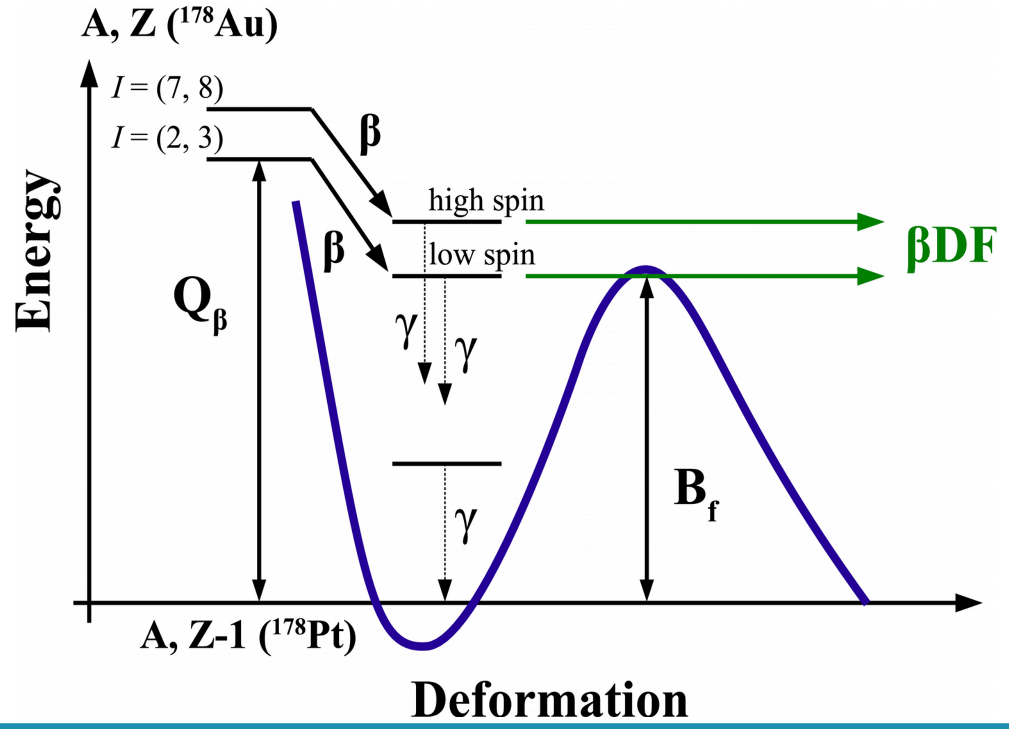
- discovery of asymmetric fission of ^{180}Hg in βDF of ^{180}Tl at ISOLDE [A. N. Andreyev et al., PRL 105, 252502 (2010).]
- followed by extensive studies towards symmetric fission in heavier nuclei [A. N. Andreyev, K. Nishio, and K.-H. Schmidt, Rep. Prog. Phys. 81, 016301 (2018); B. Andel et al, accepted in PRC (2020).]
- new island of asymmetric fission predicted in neutron-deficient region below *Z = 82*
- **experimentally, extent of island of asymmetry below mercury unknown**
- information on ^{178}Pt (β-decay daughter of ^{178}Au) only at higher excitation energies – mixture symmetric and asymmetric modes [I. Tsekhanovich et al., PLB 790, 583 (2019).]



Adapted from [P. Möller and J. Randrup, PRC 91, 044316 (2015).]

Part 1: Goals

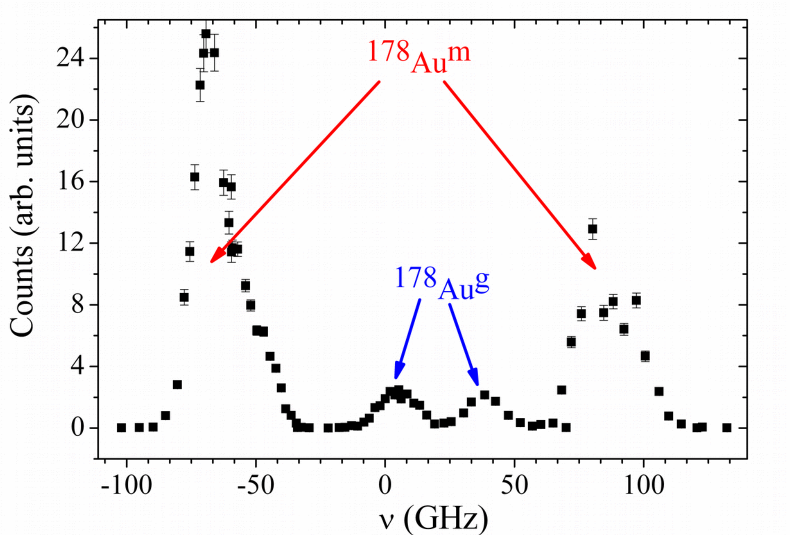
- **to probe the new island of asymmetry farther below mercury:** to determine asymmetric or symmetric character of fission for ^{178}Pt (βDF of ^{178}Au)
- **to identify βDF and determine βDF probability separately for ground and isomeric states in both ^{178}Au and ^{176}Au**
  (note: β-decay branching ratios measured in our IS534 exp. [J. G. Cubiss et al., ^{178}Au. In preparation; R. D. Harding et al., ^{176,177,179}Au. In preparation.])



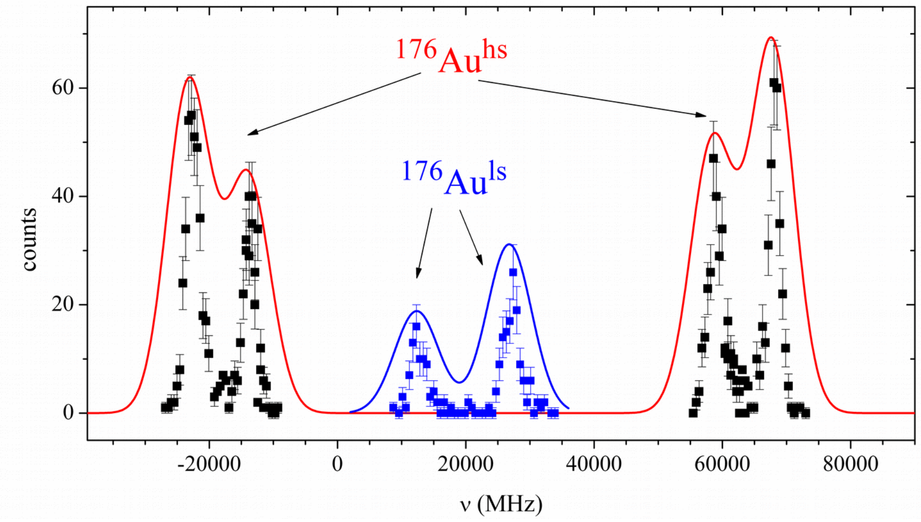
- **to investigate poorly-known spin dependence of fission properties**
- possibility to extract fission barriers from βDF probability, as was done for ^{178,180}Hg [M. Veselský et al., PRC 86, 024308 (2012).]

Part 1: Experimental method

- isomer-selective ionization by RILIS (similar study done in IS608 for ^{188gs,is}Bi [B. Andel et al, accepted in PRC (2020).])
- hyperfine spectra (hfs) of ^{178,176}Au are known from our IS534 experiment
- **isomer selectivity achieved already in broadband mode (BB), no loss of ionization efficiency related to narrowband mode**



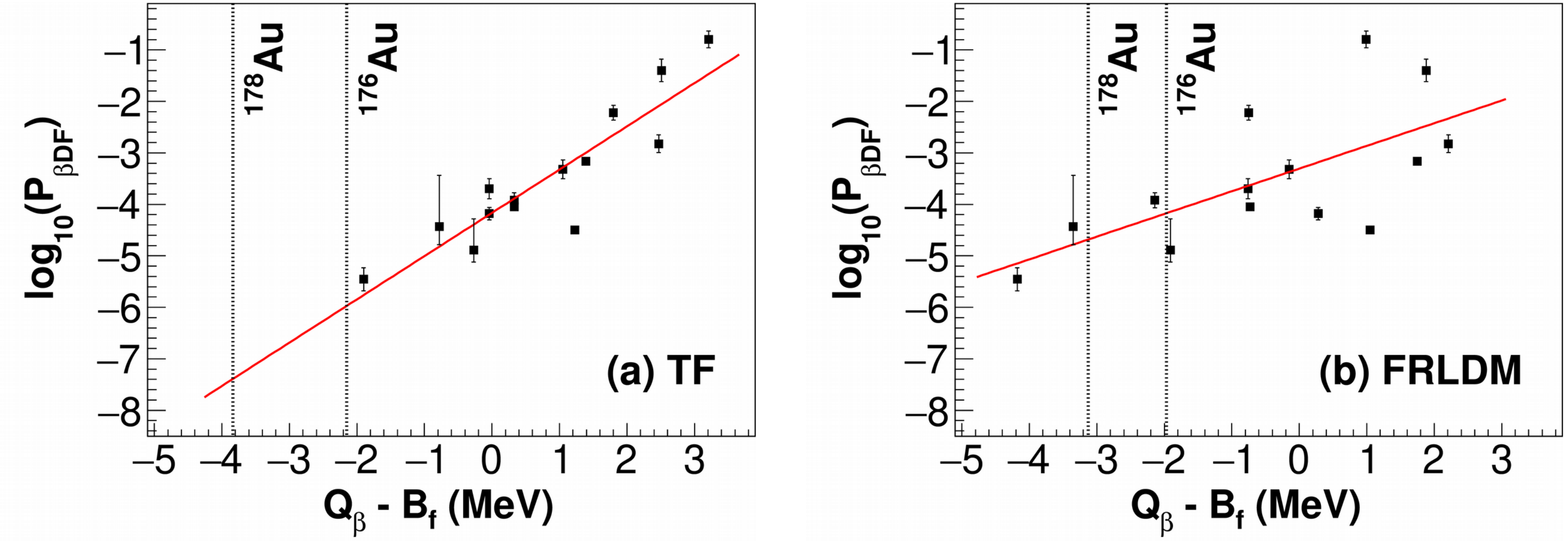
Hfs of ^{178}Au measured in BB mode.



Hfs of ^{176}Au measured in NB mode: solid line shows resolution in BB mode.

Part 1: Expected fission yields

- estimates based on measured yields of ^{178is,gs,176is,gs}Au in IS534 and systematics of βDF probabilities
- **orders of magnitude difference in estimates based on Thomas-Fermi (TF) model [1] and FRLDM [2] – test of predictive power**



Systematics of βDF probabilities as function of $Q_\beta - B_f$, where B_f are fission barriers from TF model [1] (a) and from FRLDM [2] (b).

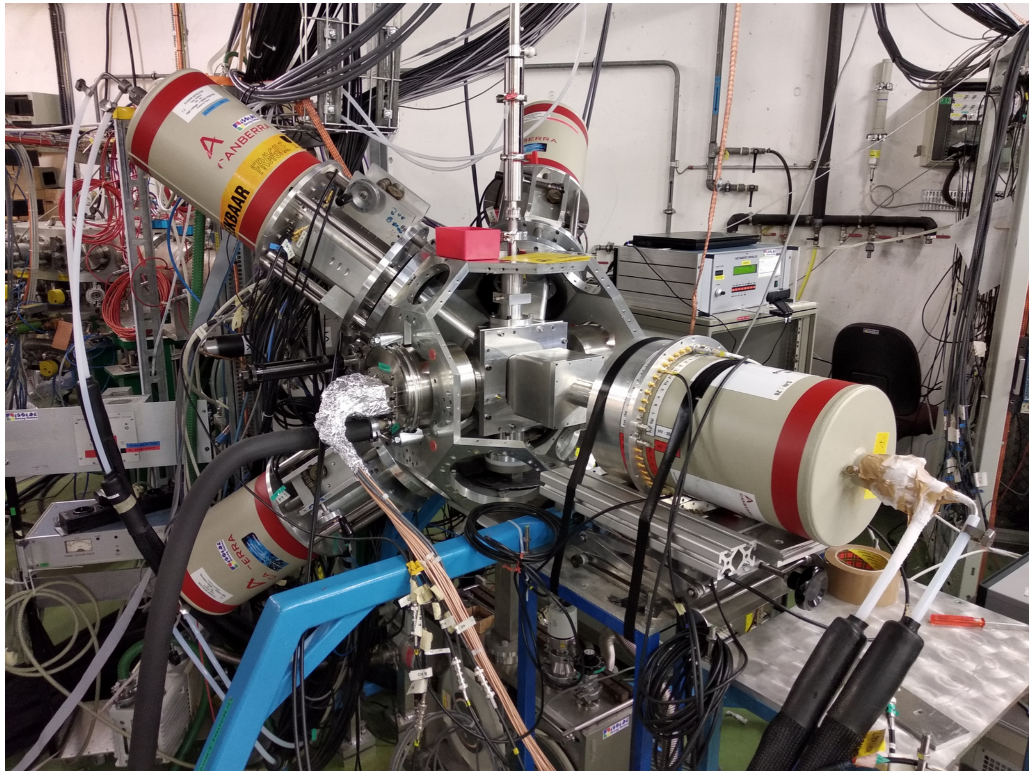
Expected implantation rate (ions/s) and rate of fission fragments per day.

	ions/s	FF/day	
		TF	FRLDM
^{178}Au^{gs}	2.4×10^3	3	1.4×10^3
^{178}Au^{is}	2.0×10^4	23	1.2×10^4
^{176}Au^{gs}	10	0.2	10
^{176}Au^{is}	20	0.5	31

[1] W. D. Myers and W. J. Światecki et al., PRC 60, 014606 (1999). [2] P. Möller et al., PRC 79, 064304 (2009).

Detection setups

- **IDS** (standard tape station and 4 HPGe Clovers) with additional annular Si detector in front of the tape for detection of α particles and fission fragments
- used for both Part 1 and Part 2
- setup complemented by detectors for lifetime measurements of levels populated in ^{178}Pt by ^{178}Au β decay (mainly 0^+_2 state) during βDF run (no extra beam time needed)



IDS during preparation for IS641 experiment.

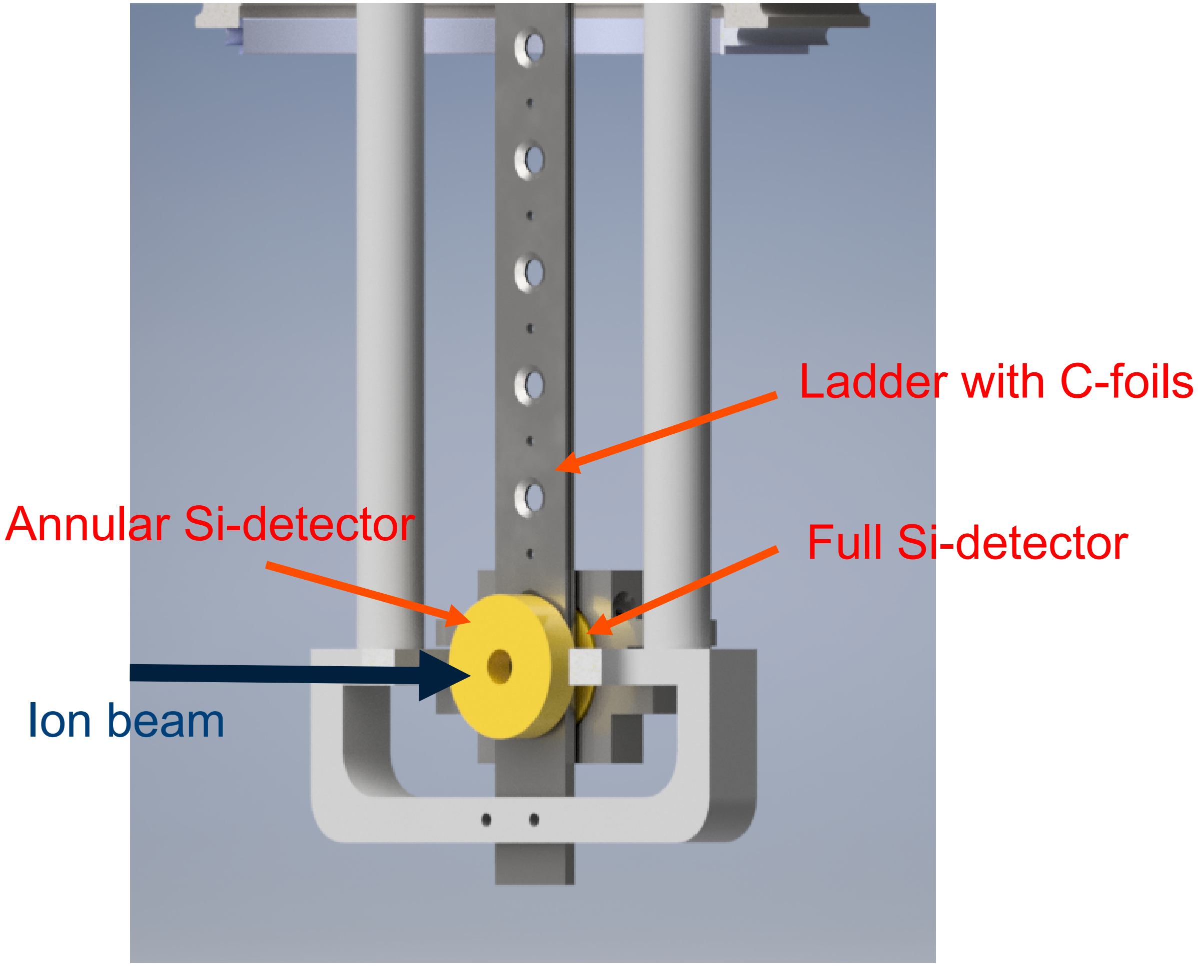
Detection setups

- **α decay setup** (employed in IS637)**:** will be used in the case of high fission yields in Part 1

- ladder with 10 carbon foils transparent to α particles and fission fragments (FF)

- foil at implantation position surrounded by annular and circular Si detectors (as in old Windmill setup)

- **enables to measure FF coincidences, and deduce masses (FFMD)**

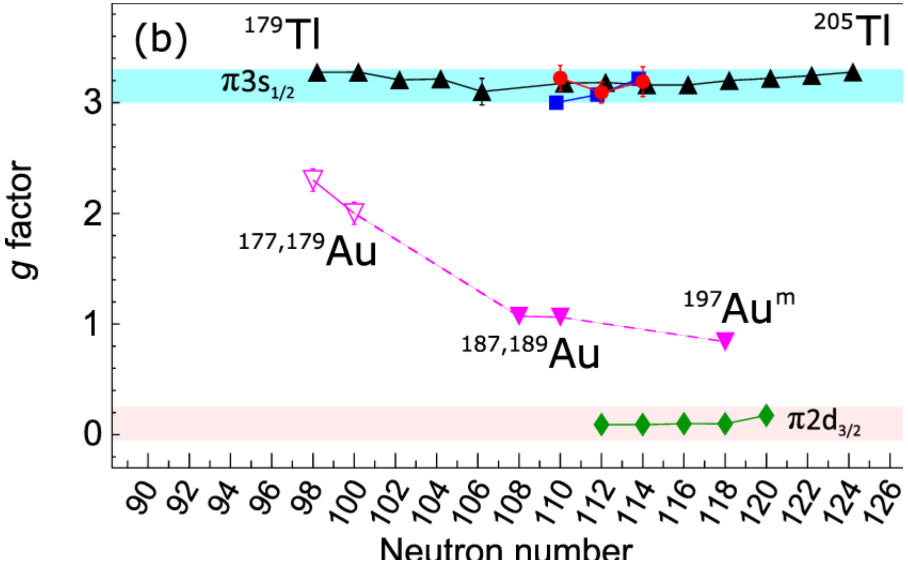


Part 2 (Laser spectroscopy of ^{175gs}Au): Physics motivation

- from IS534: *I* = 1/2 for ^{177,179gs}Au and mixed $\pi 3s_{1/2}/\pi 2d_{3/2}$ configuration with **hint of a trend towards pure $\pi 3s_{1/2}$** [1]

- **unhindered α decay ^{179}Tl (*I* = 1/2, $\pi 3s_{1/2}$) → ^{175gs}Au suggests pure $\pi 3s_{1/2}$ configuration for ^{175gs}Au** [2]

- this would mean rearranging of shell model states, as **$\pi 2d_{3/2}$ configuration is expected for ^{175gs}Au from shell model**

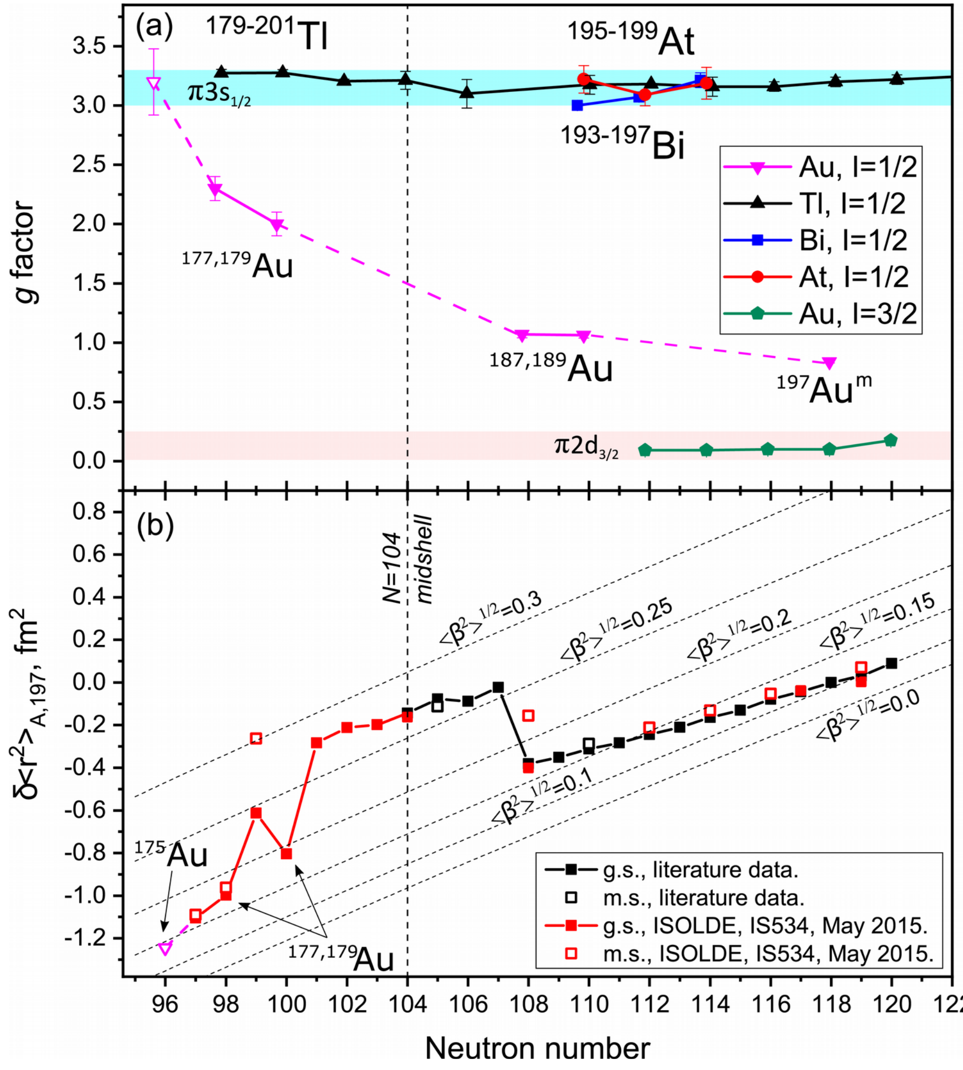


Trend in g-factors hinted by pink lines. Adapted from [1]

[1] J. G. Cubiss et al., PLB 786, 355 (2018).
[2] A. N. Andreyev et al., PRC 87, 054311 (2013).

Part 2: Goals

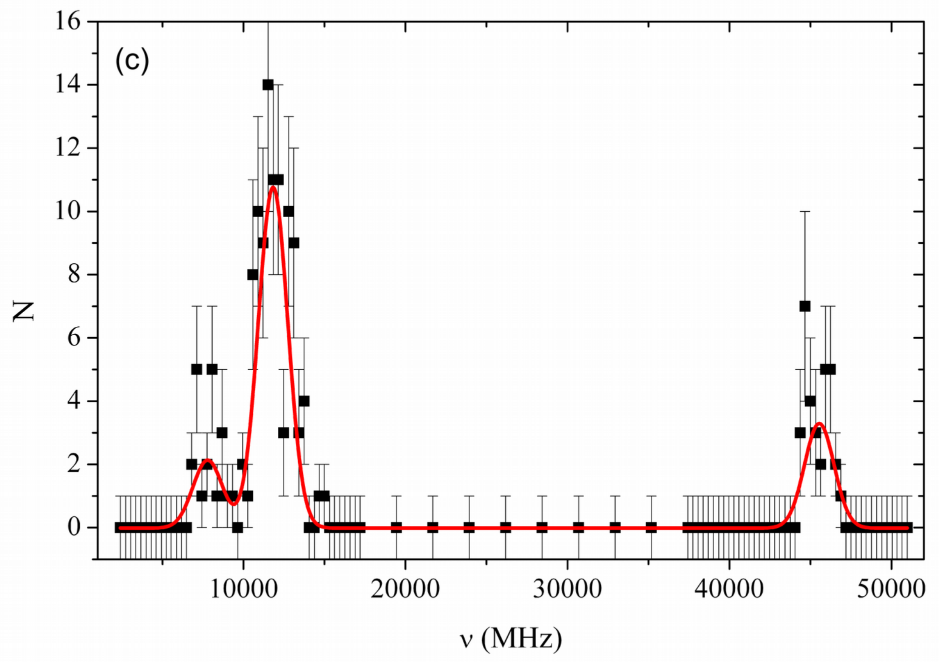
- **hfs and isotope shift (IS) measurement of ^{175gs}Au**
- **to determine *g*-factor and deduce the configuration**
- to determine change in mean-square charge radius to obtain information on the nuclear deformation



Adapted from [J. G. Cubiss et al., PLB 786, 355 (2018); R. D. Harding et al., Mean-square charge radii of gold isotopes. In preparation.]

Part 2: Experimental method and yield estimate

- laser scan using RILIS in narrow band mode
- **expected production yield in maximum is 0.3 ions/s** (based on extrapolation of measured yields of heavier Au isotopes (down to ^{176}Au) and considering half-life)
- **in the past, we successfully measured IS and hfs of ^{177}Hg with yield down to ≈0.1 ions/s** [B. Marsh et al., Nat. Phys. 14, 1163 (2018); S. Sels et al., PRC 99, 044306 (2019).]



Arbitrary subset of experimental hfs for ^{177gs}Au, where statistics is reduced to the level expected for ^{175gs}Au obtained in ≈ 4 hour scan.

Beam request

Expected ion and fission fragment yields.

	ions/s	FF/day	
		TF	FRLDM
$^{178}Au^{gs}$	2.4×10^3	3	1.4×10^3
$^{178}Au^{is}$	2.0×10^4	23	1.2×10^4
$^{176}Au^{gs}$	10	0.2	10
$^{176}Au^{is}$	20	0.5	31

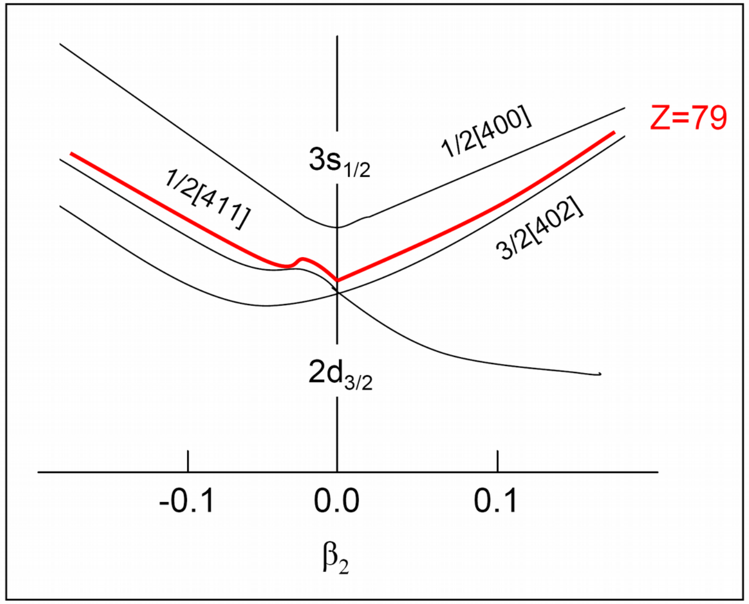
- Part 1:
- **10 shifts**: 5 shifts for βDF of ^{178gs}Au, 2 shifts for βDF of ^{178is}Au, 3 shifts βDF of ^{176gs,is}Au

- Part 2:
- estimated yield of ^{175gs}Au: 0.3 ions/s
- **4 shifts:** 1 shift setting up/optimization of lasers in NB mode and reference scans, 1 shift location of ^{175gs}Au hfs, 2 shifts scanning ^{175gs}Au

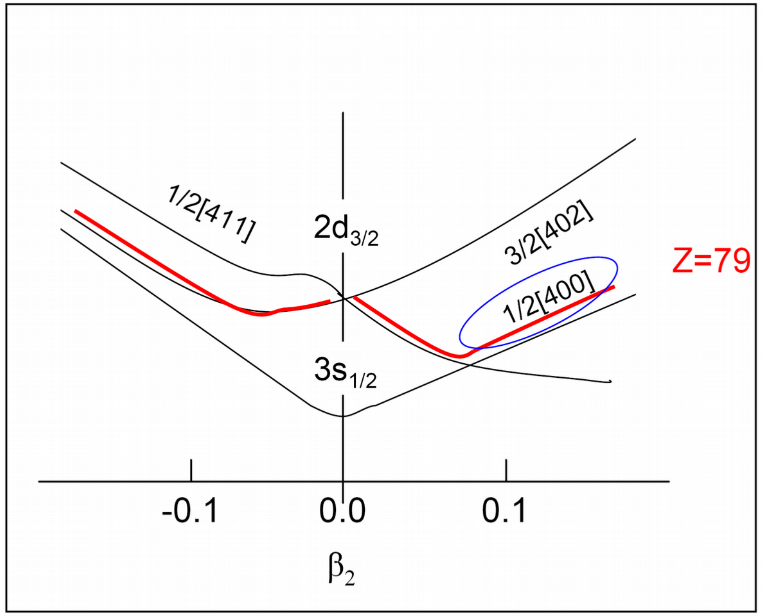
- **Total beam request: 14 shifts**

Spare slides

Nilsson diagram for protons around $Z = 79$

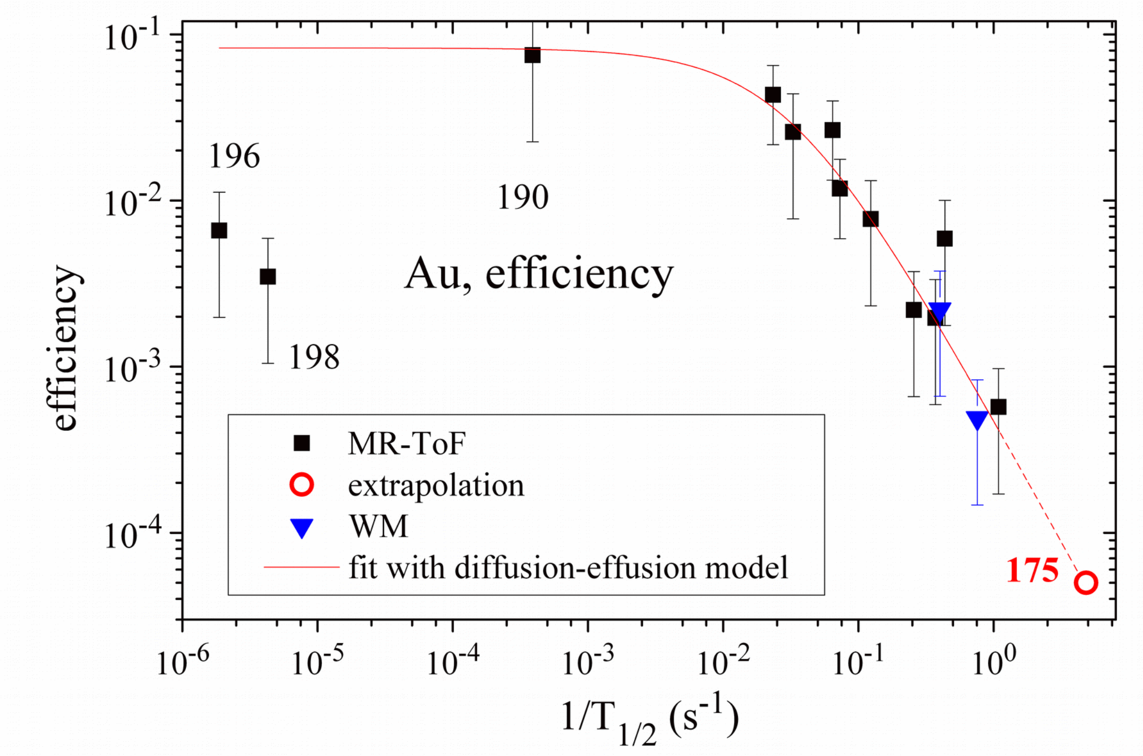


Original ordering of states.



Possible rearranging of $d_{3/2}$ and $s_{1/2}$ states to obtain $s_{1/2}$ configuration for $Z = 79$.

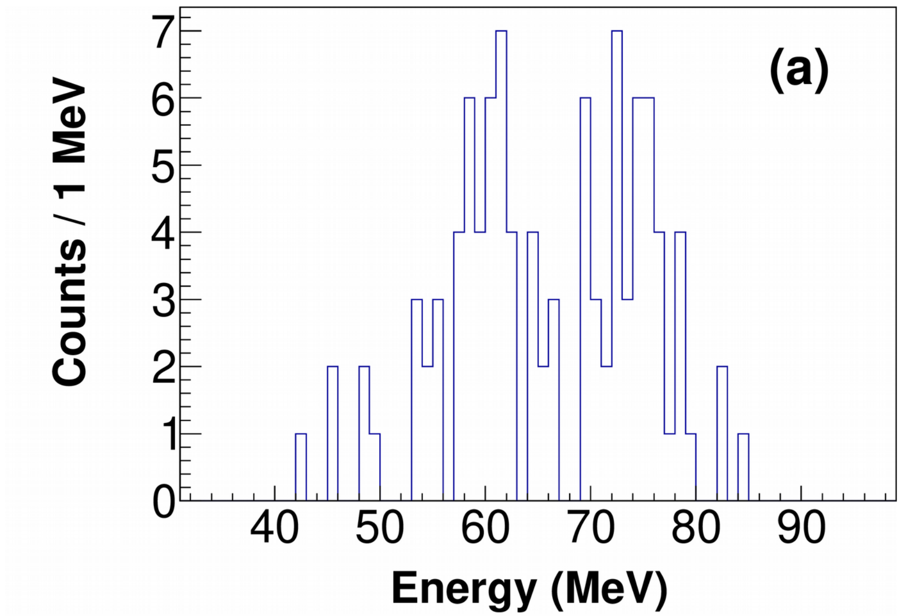
Yield estimate for ^{175}Au

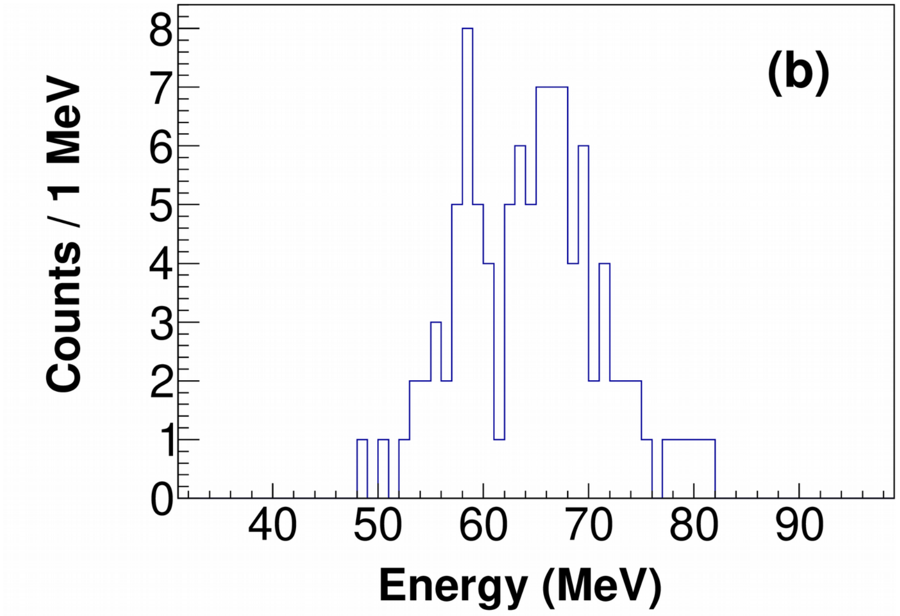


Efficiency: ratio of observed yield and in-target yield calculated by ABRABLA code.

Determination of symmetric/asymmetric fission at IDS

- 1 (annular) Si detector

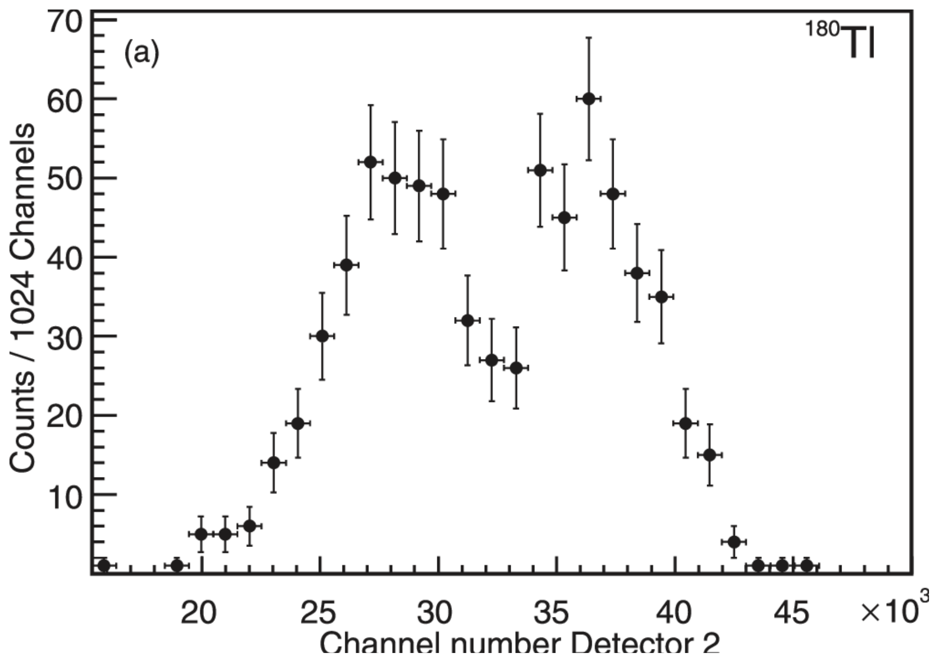


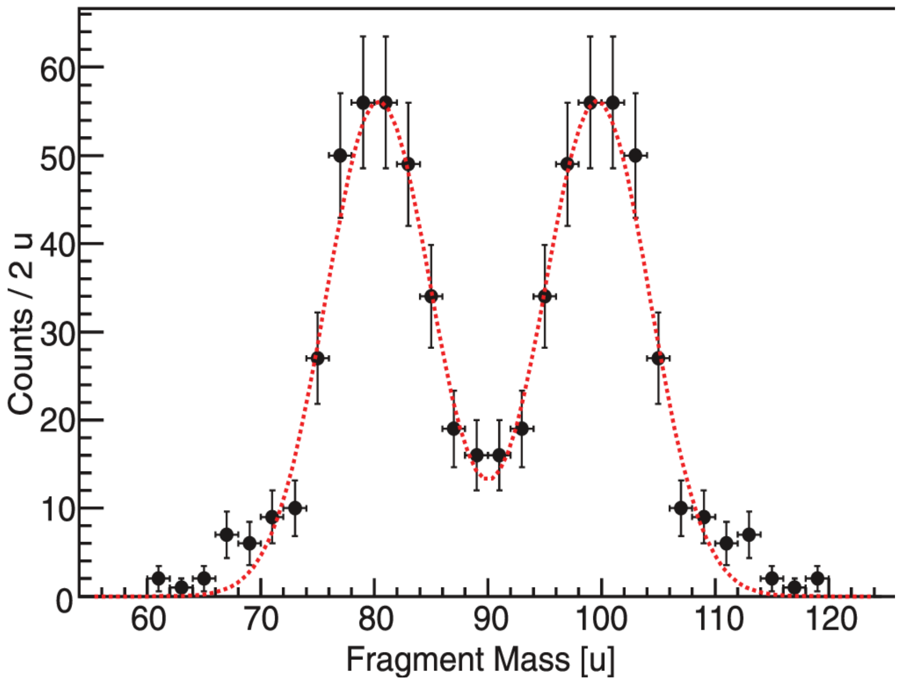


Energies of 100 fragments measured by single detector from asymmetric fission of ^{180}Hg (a) and 100 events from Gaussian distribution to simulate symmetric fission (b).

Fission fragment mass distribution using Windmill

- the same configuration of Si detectors is in the new α-decay setup





βDF of ^{180}Tl. Left: uncalibrated singles fission fragment energy spectrum from 1 Si detector. Right: fission fragment mass distribution deduced from calibrated fission fragment coincidences. [J. Elseviers et al., PRC 88, 044321 (2013).]