TATRA Decay Station at ISOLDE and Shape Coexistence in Odd-mass Au Nuclei

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On behalf of the IS521 collaboration (ISOLDE)

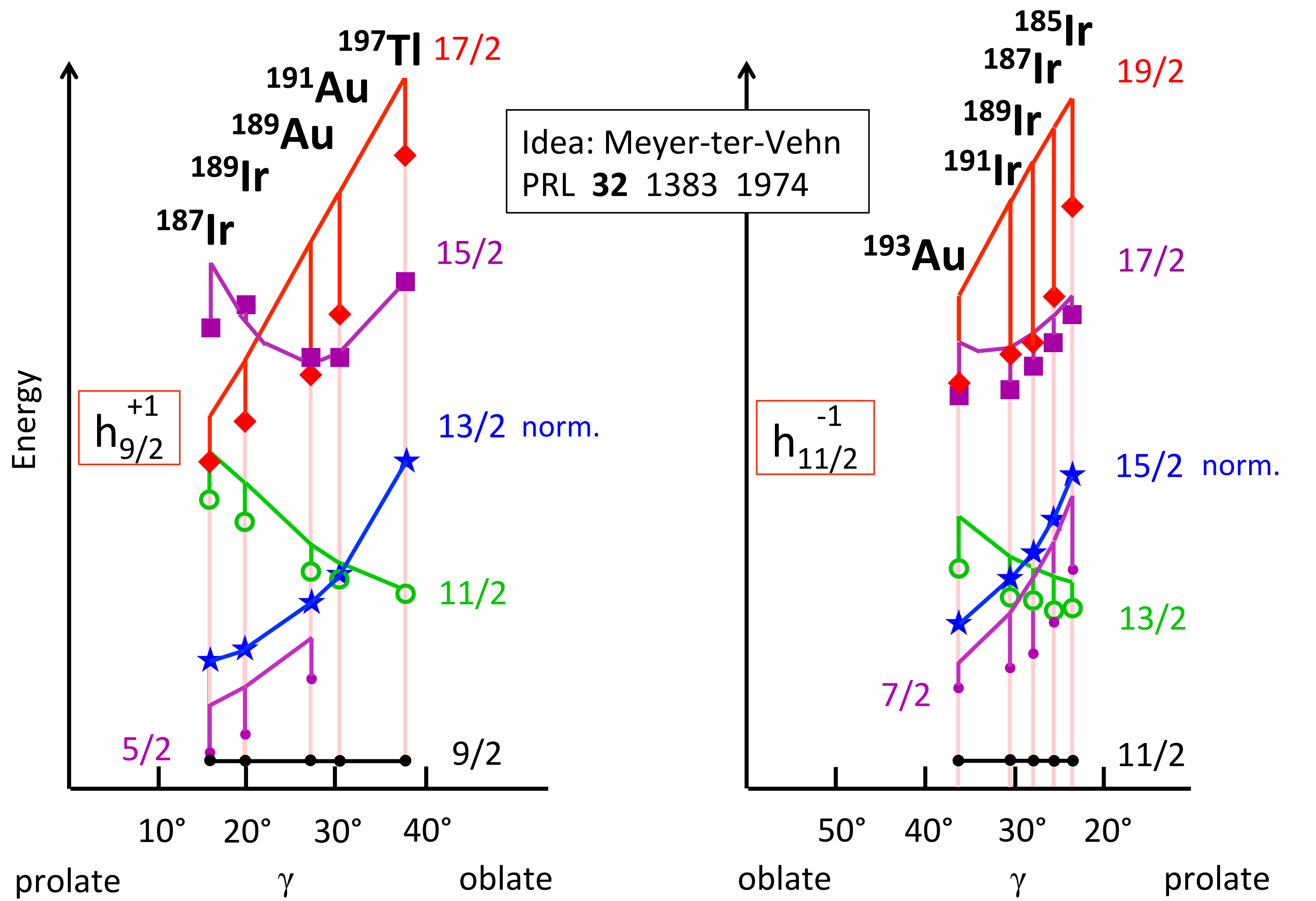
Why to study excited states of odd-Au nuclei?

- An odd particle acts as a probe of the core
    - Information on independent particle states
    - Information on deformation: axial and triaxial shapes
    - Information on pairing from blocking
    - Identification of intruder states free of mixing
    - Information on rotational collectivity
- Need of beta decay studies: in-beam experiments reveal almost only yrast cascades
- **Low-energy shape coexistence**

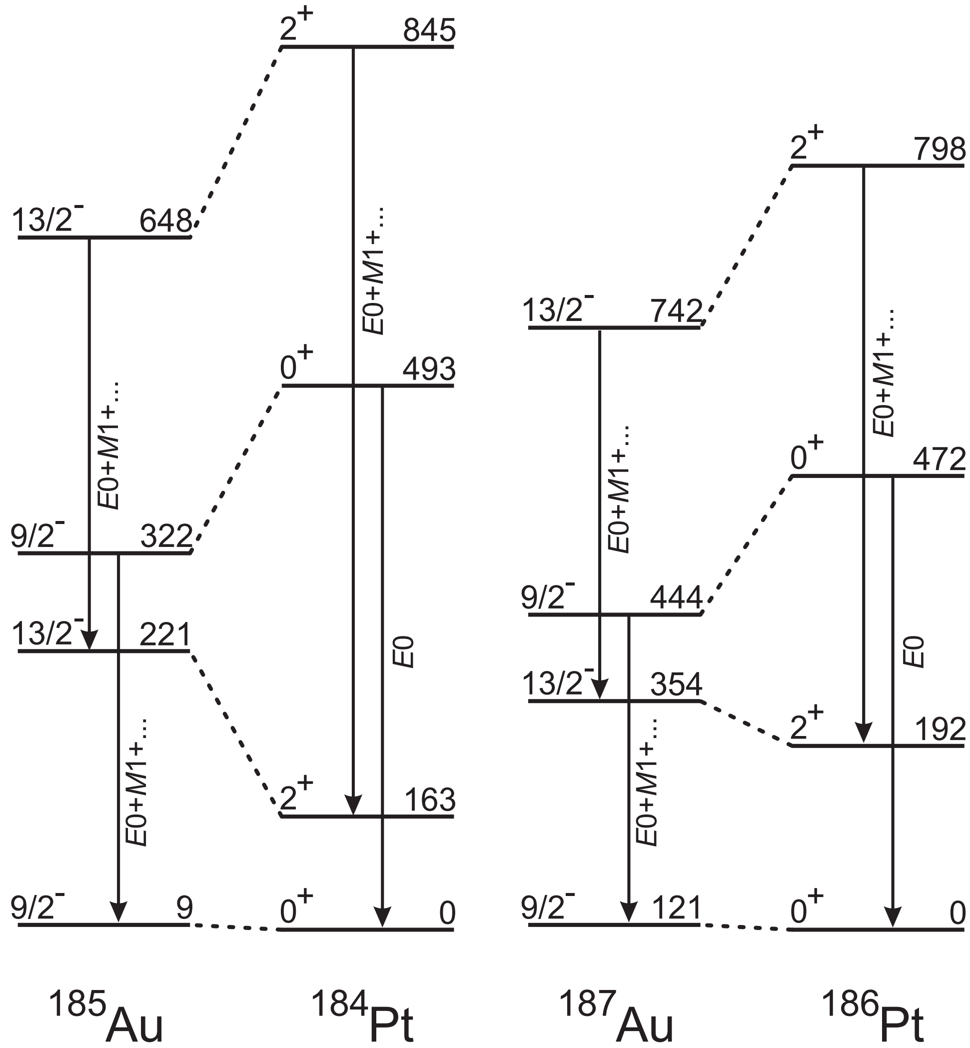
Problems encountered with odd-Au studies

- Complexity:
  - Multiple independent particle states coupling with core states: very high level density
  - Decay scheme spectroscopy involves multiple paths to the ground state (cf. even-even nuclei where most decay is through first 2^+ state)
  - Multipolarities not dominated by $E2$ ($M1$, $M1 + E2$)
  - Critical to identify $E1$ multipolarity (cf. even-even nuclei, where $E1$ decay is high energy)
  - Strong $E0$ components of transitions act as probe of the shape coexistence
  - **Spectra are very complex, therefore the energy resolution is critical**

Particle-core coupling approach



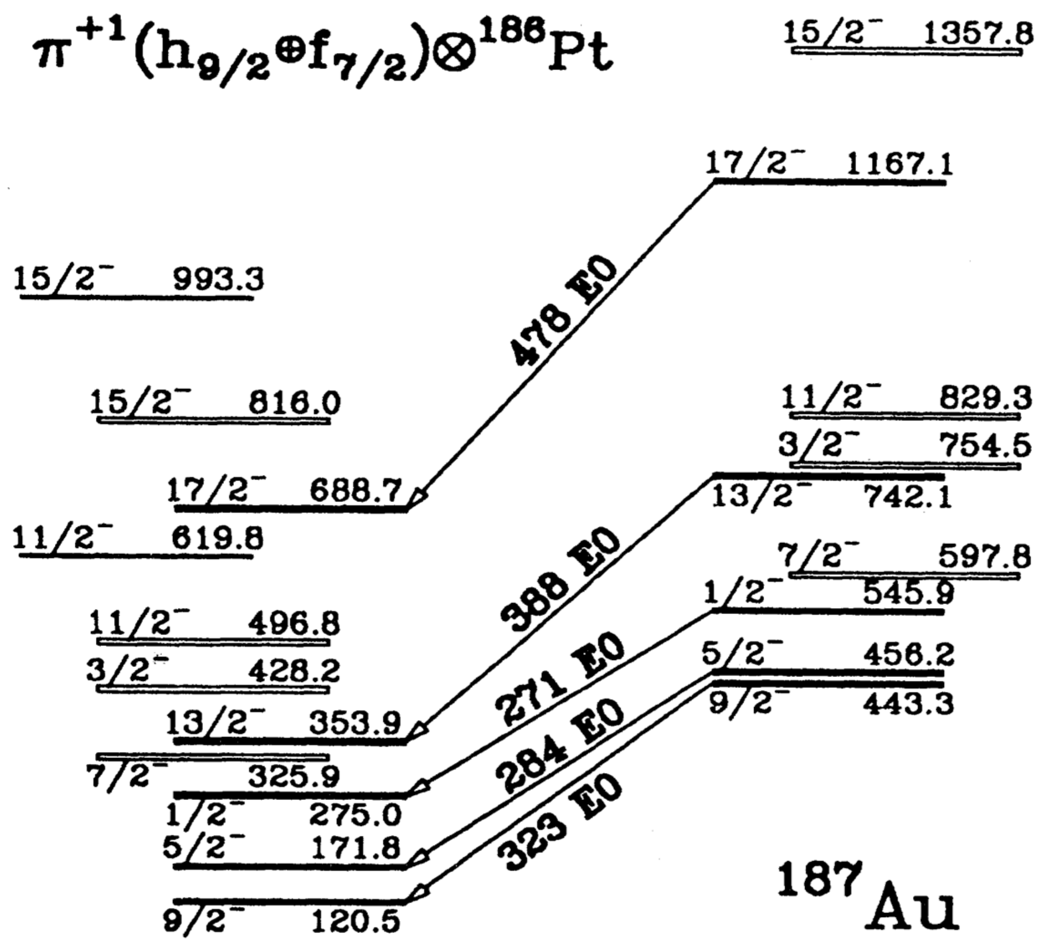
(At least) four types of excitations in odd-Au isotopes



C. D. Papanicolopoulos *et al.,* Z. Phys. A **330**, 371 (1988).

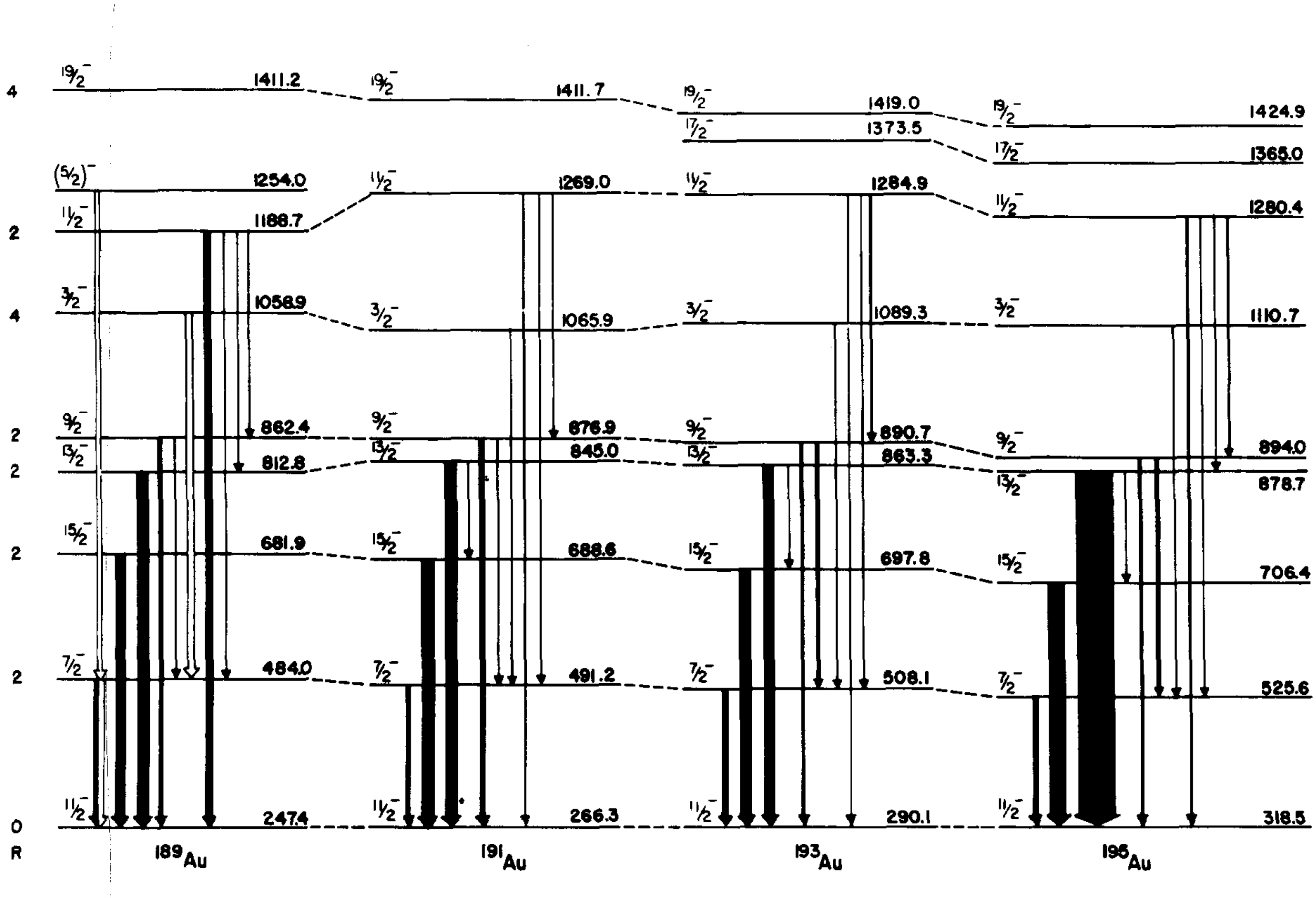
More detailed study: Pioneering experiment on ^{187}Hg decay

- UNISOR facility at ORNL (US)
- In total 9 transitions with *E*0 components were identified
- Both between positive and negative parity states
- Study that set the standards for odd-mass spectroscopy



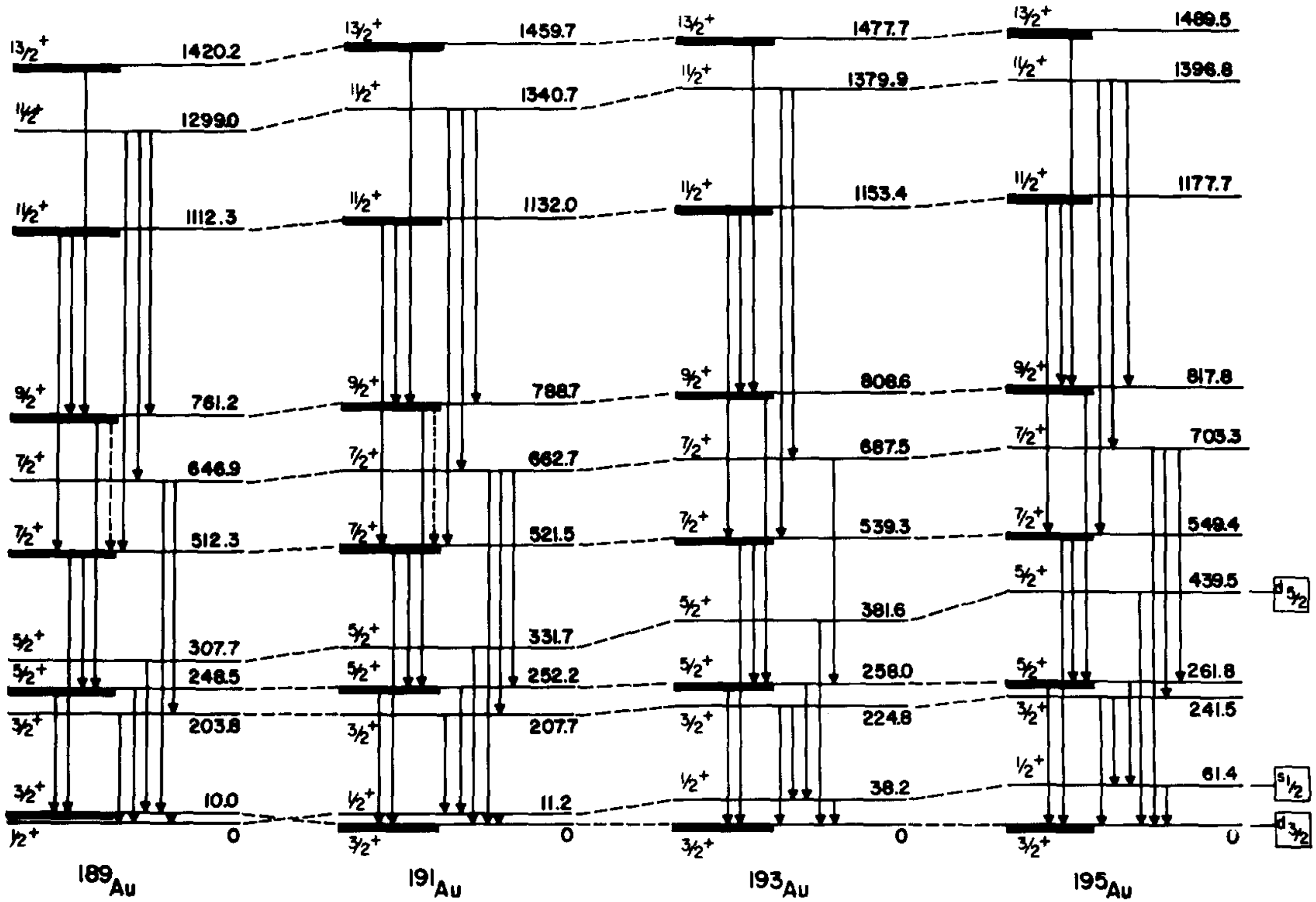
D. Rupnik *et al.*, Phys. Rev. C **58**, 771 (1998).

Road map to the Au structure: negative parity states



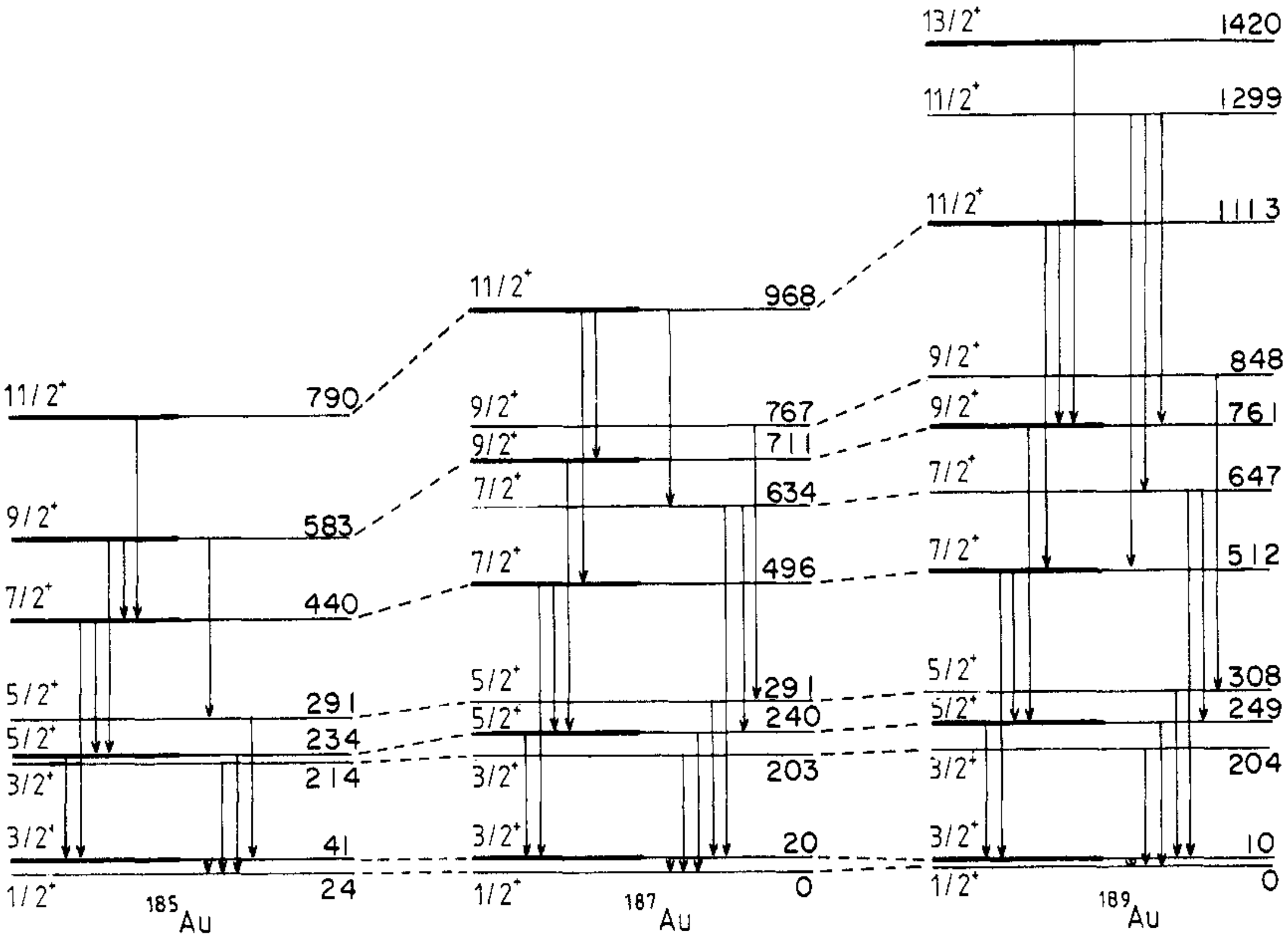
E. F. Zganjar *et al.*, Phys. Lett. B **58**, 159 (1975).

Road map to the Au structure: positive parity states



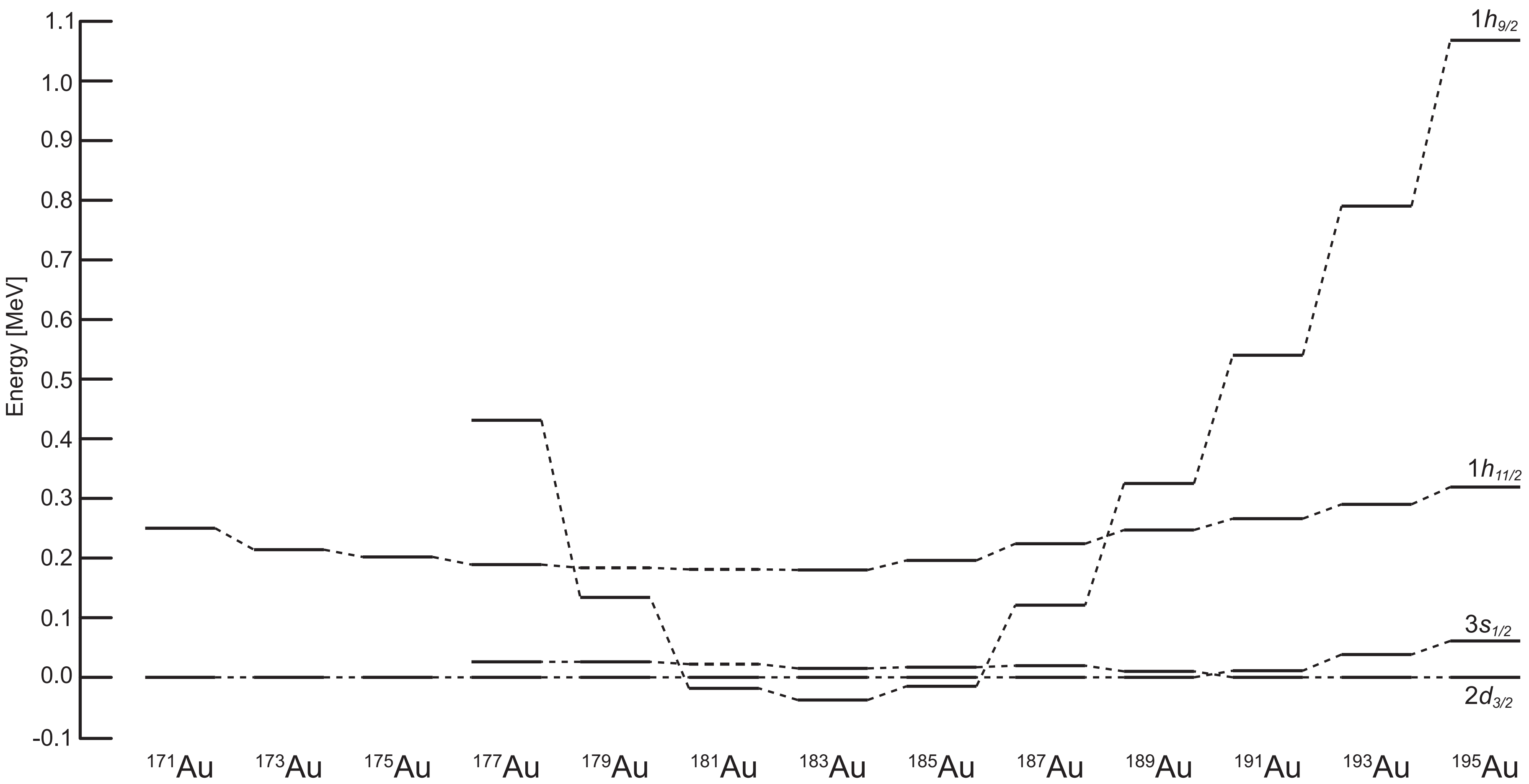
E. F. Zganjar *et al.*, Phys. Lett. B **58**, 159 (1975).

Road map to the Au structure: positive parity states



M. O. Kortelahti *et al.*, J. Phys. G **14**, 1361 (1988).

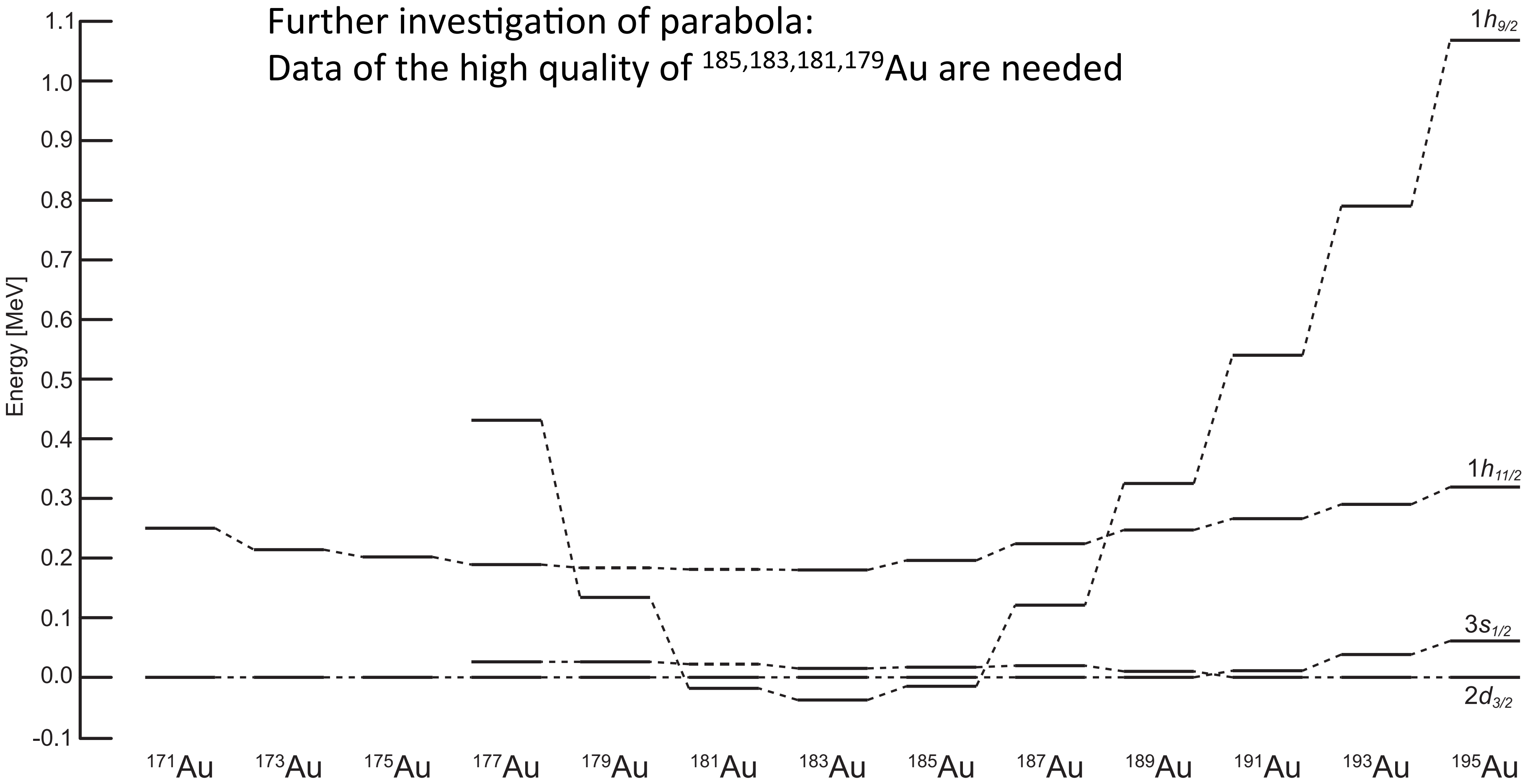
Intruder "parabola"



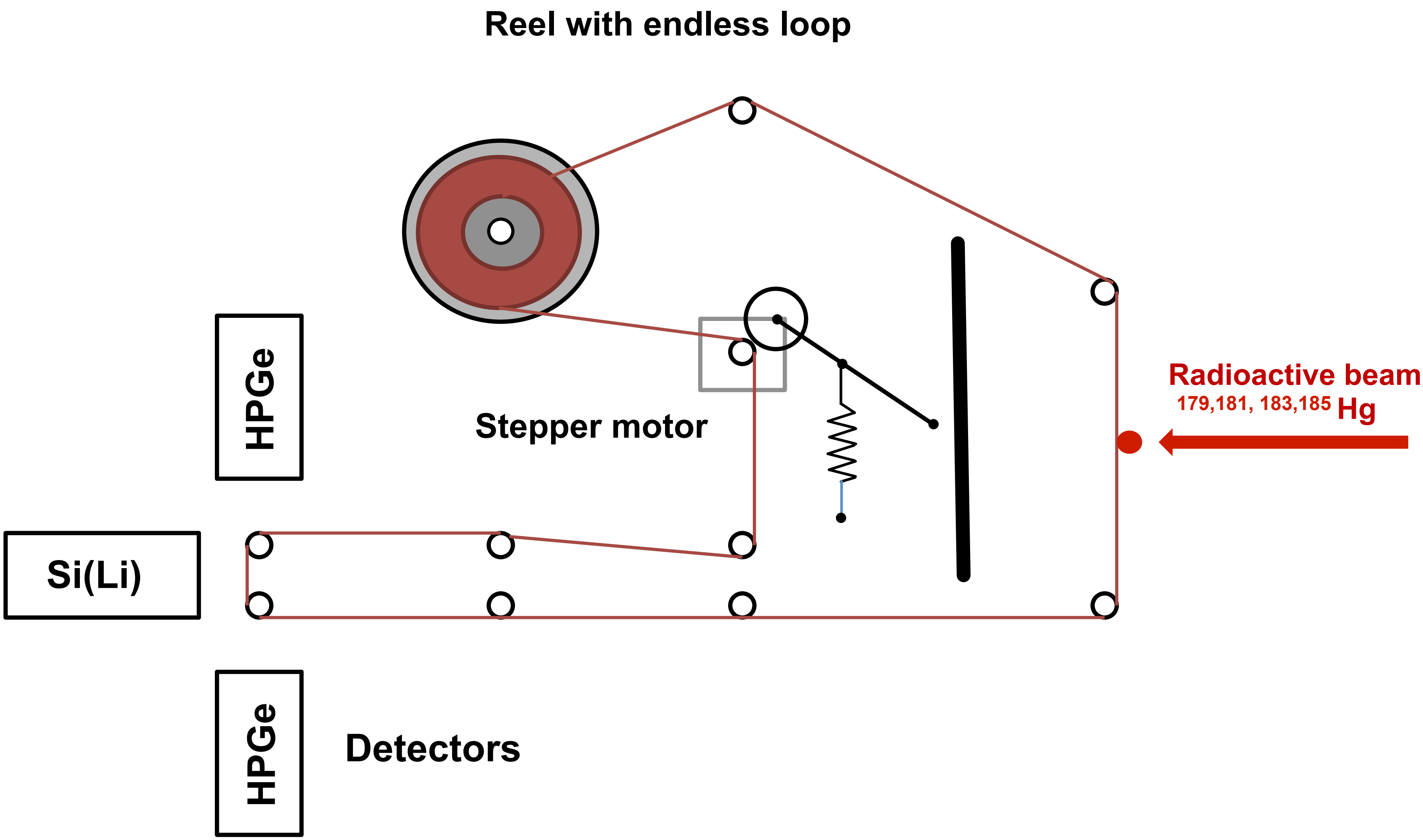
Intruder "parabola"

Further investigation of parabola:

Data of the high quality of ^{185,183,181,179}Au are needed



TATRA operation principle



8-track tape design

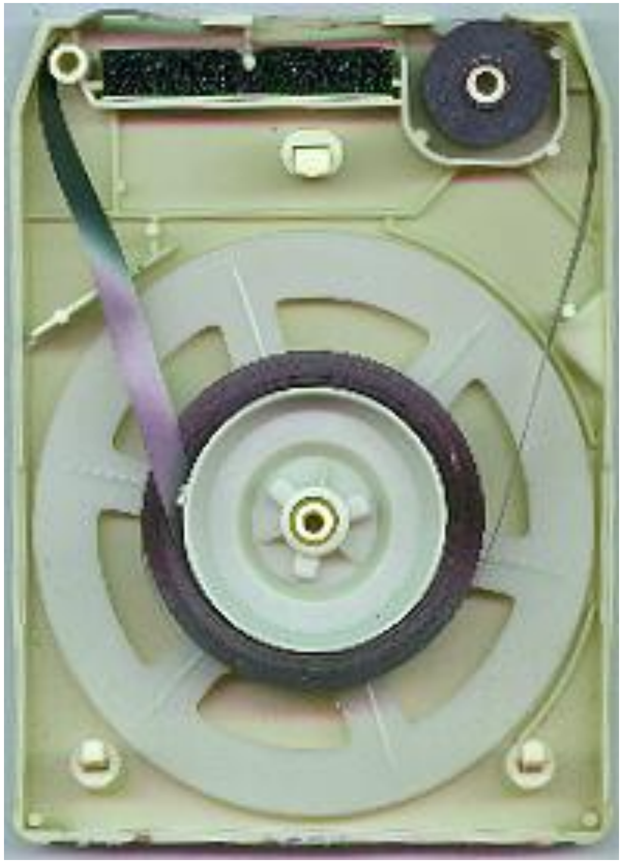
- Design inspired by Ed Zganjar

- Ed: “If you can tune beam to 6 mm wide tape, go for it, they are the best!”

- Single reel tapes with endless loop of magnetic tape

- Production ceased in 1980

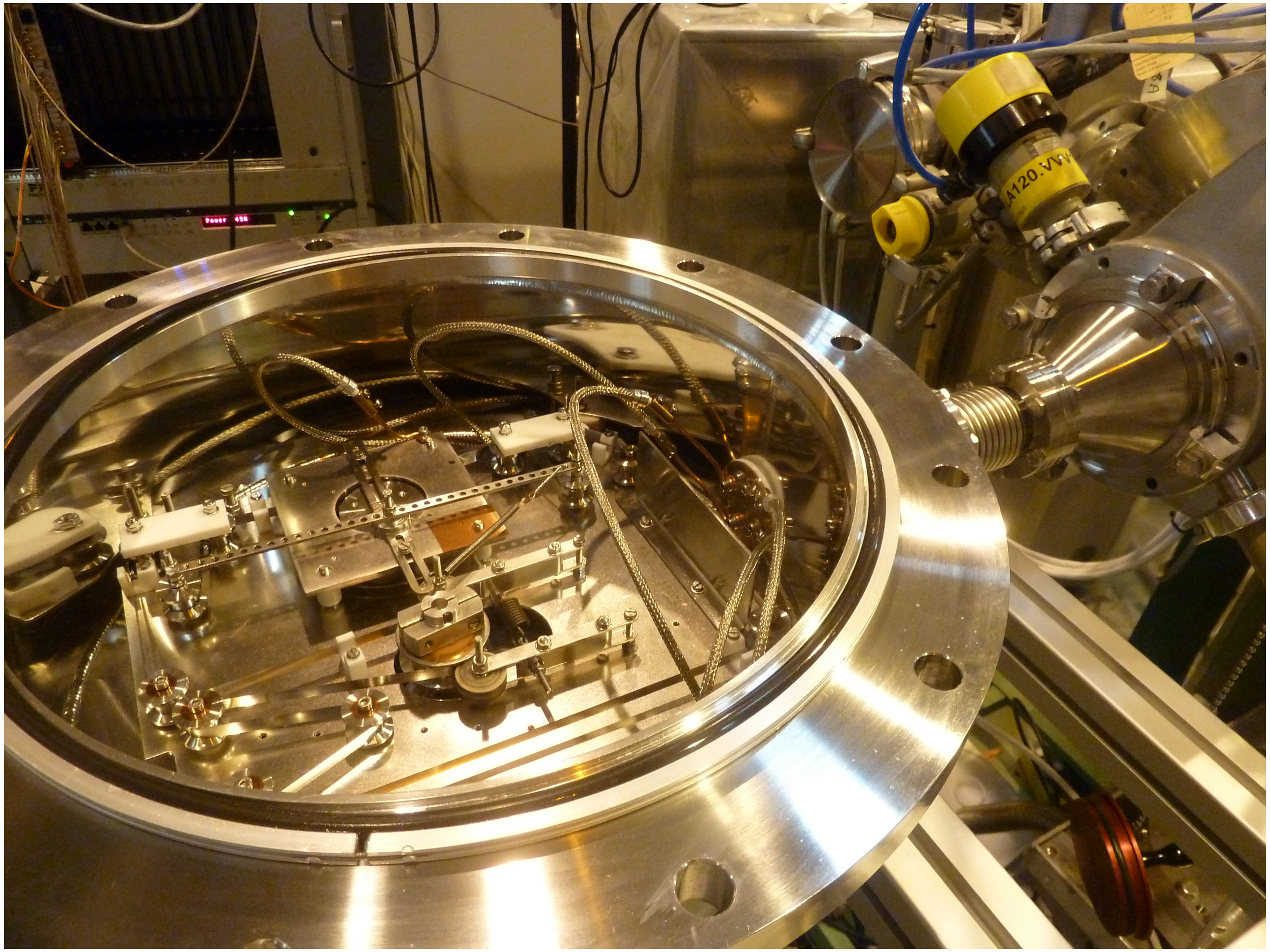
- Original tapes do not work well after 35+ years of storage



Amorphous metallic tape (courtesy of Metal physics Dept.)

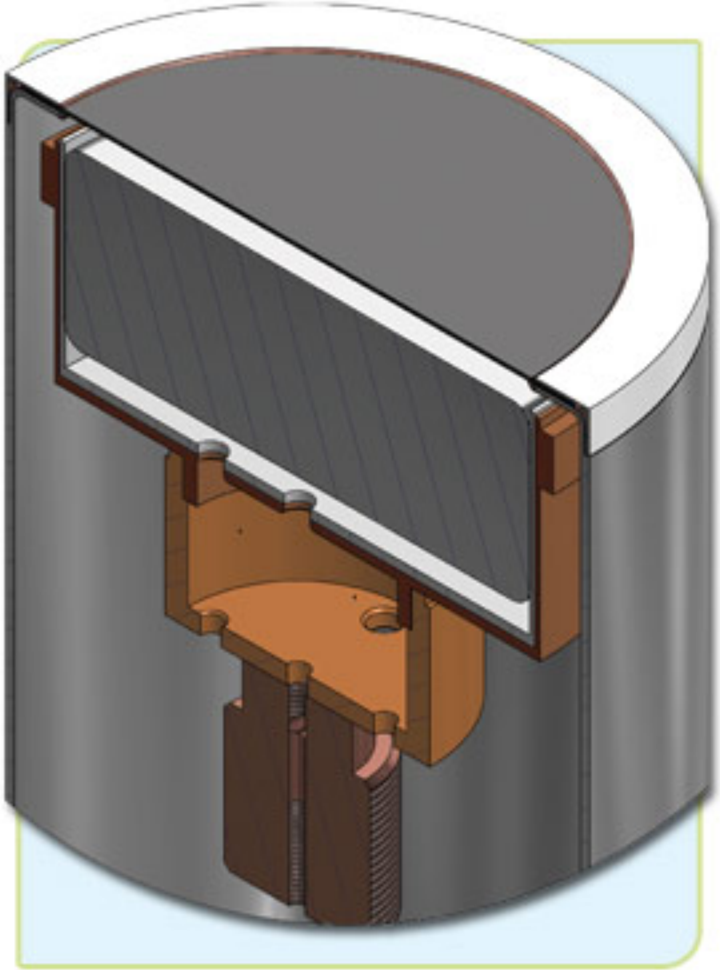
- Amorphous metallic tape produced by rapid quenching of an alloy
- Rapid = 10^6 K per second
- To operate in 8-track mode: alloy of 7 elements is used
- Welding of amorphous metal is a challenge: new methods need to be developed
- Tape keeps metallic properties: suitable for use in high-vacuum environment
- TATRA can be operated at pressures below 10^{-7} mbar in whole system
- Windowless Si(Li) detector operated at LN_2 temperature can be used

TATRA online: August 2014 – IS521 experiment

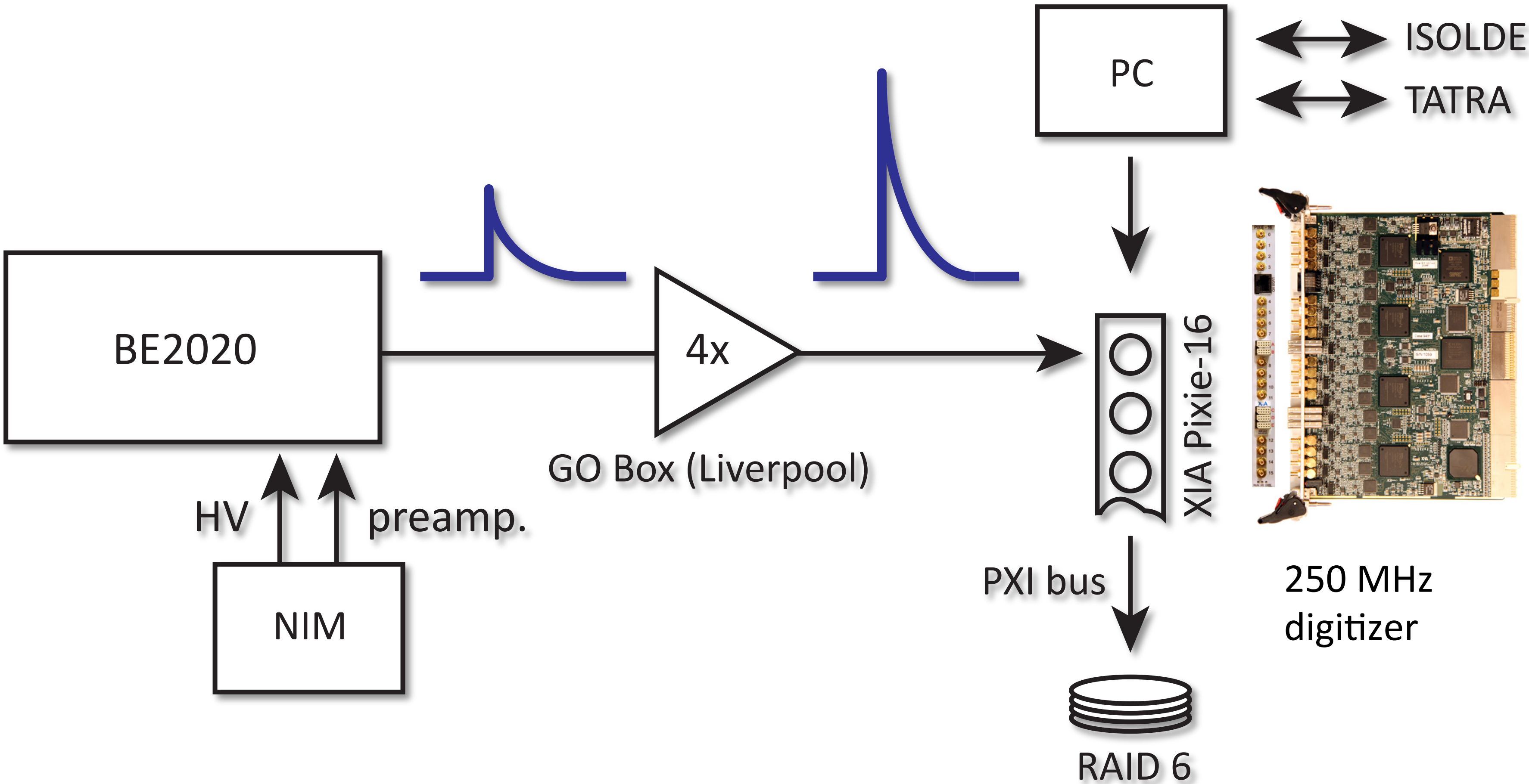


BE2020 Broad Energy Germanium Detector

- p-type HPGe detector
- Active diameter 51 mm and thickness 20 mm
- Relative efficiency of approximately 9 %
- Designed for environmental applications
- IS521 – (one of) the first nuclear structure experiments
- Detector provided by the University of Liverpool
- Very promising gamma-detector for future
- Operated at high gain: one ADC channel = 27 eV



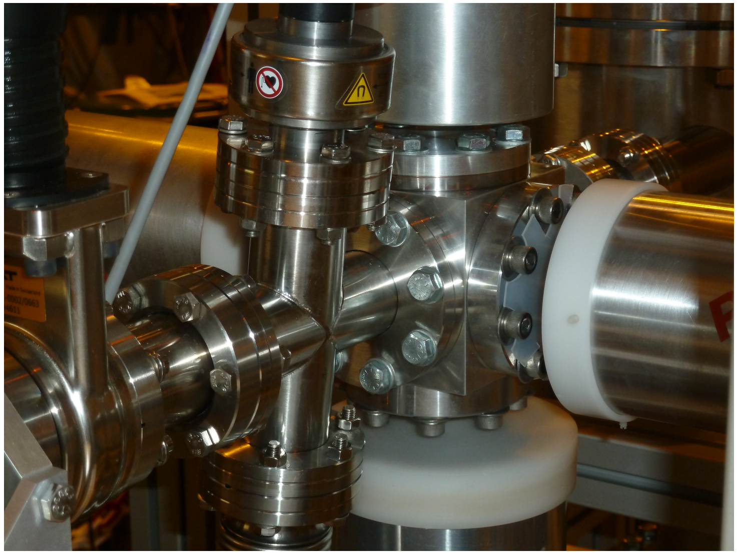
Experiment instumentation

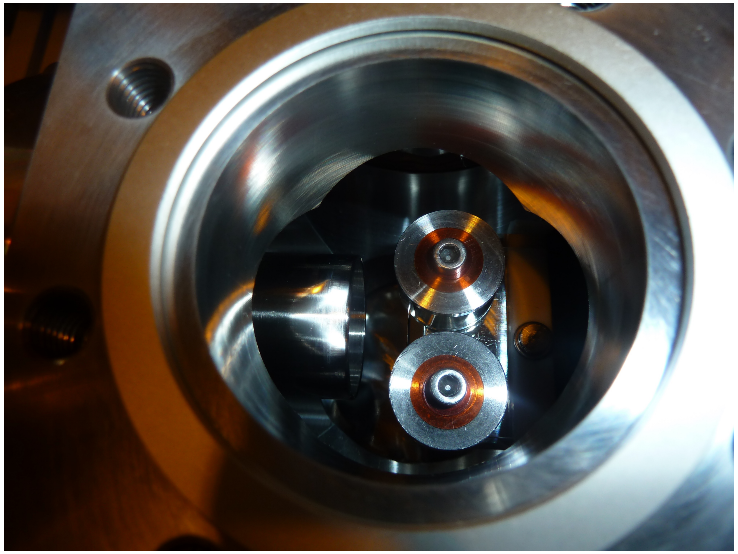


GO box crucial: allows to use full dynamical range of the digitizer

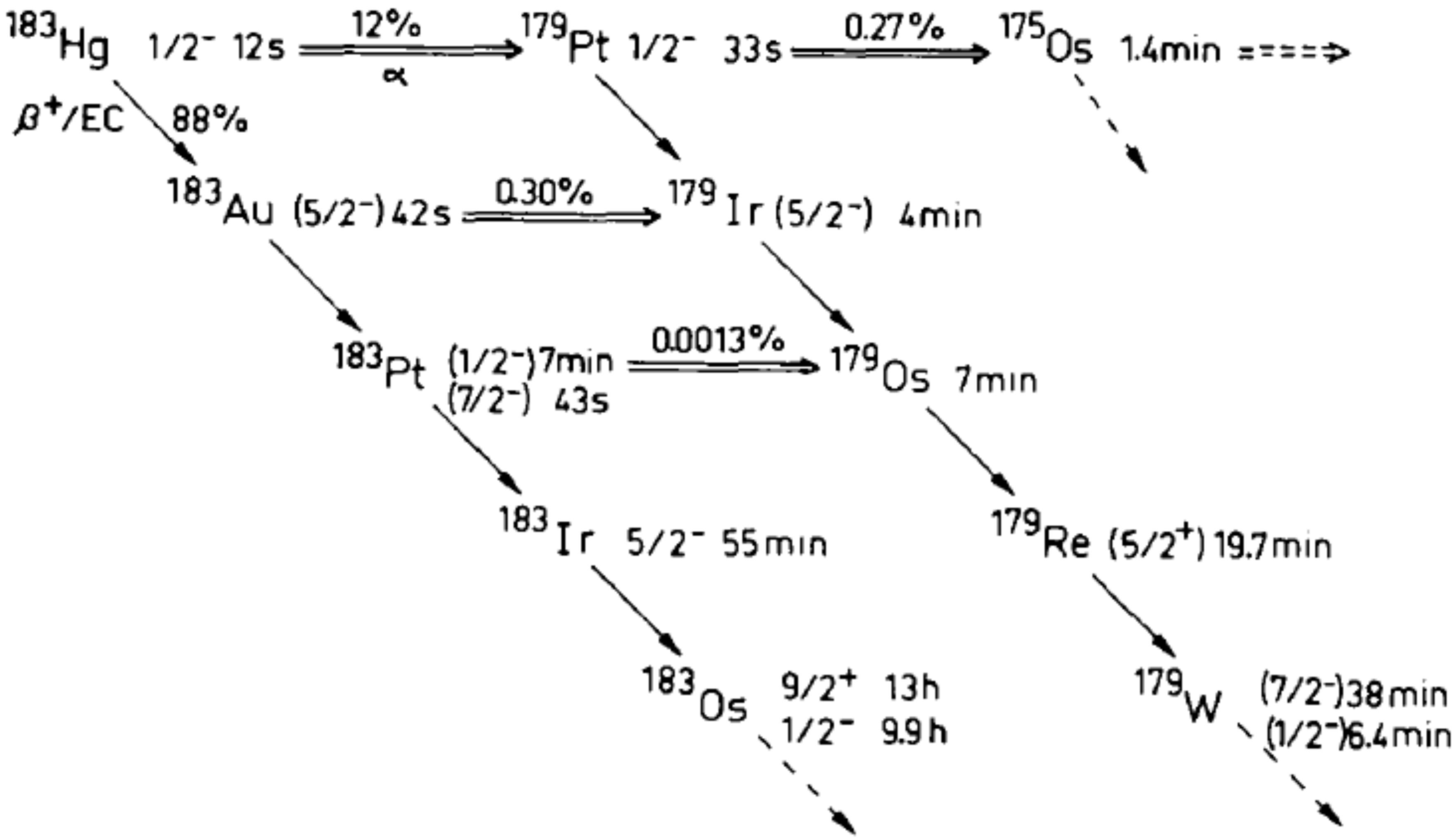
BEGe detects gamma rays up to 1 MeV, i.e., one channel is ~30 eV

TATRA in 2016: 3 coaxial detectors, 1 BEGe and Si(Li)





^{183}Hg decay spectrum detected with BE2020



M. I. Macias-Marques *et al.*, Nucl. Phys. A **427**, 205 (1984)

^{183}Hg decay scheme construction

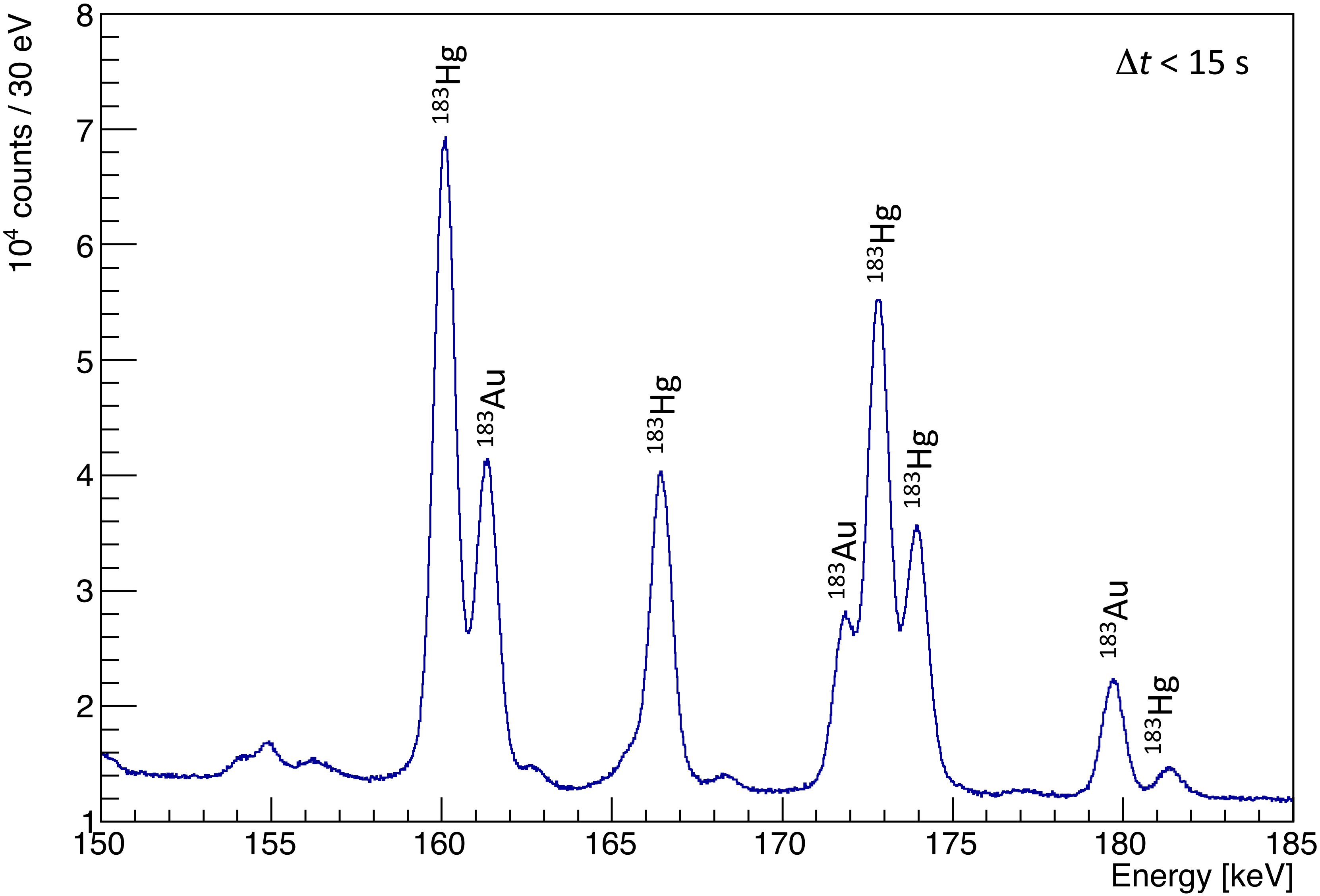
1. Identification of the lines due to mother decay using the timestamped stream of the data

2. Determination of precise energies using gamma-ray singles spectrom from the BEGe

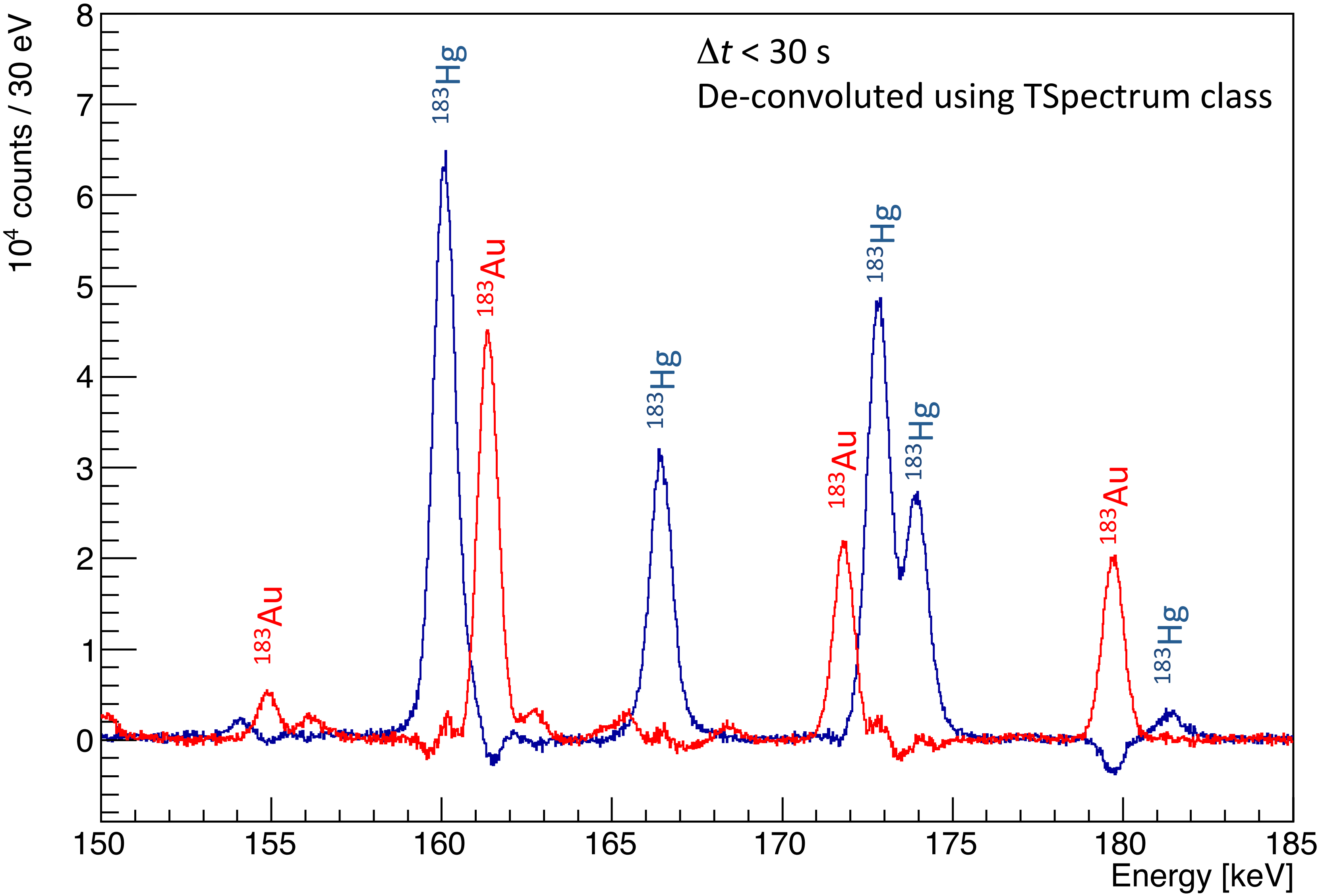
3. Standard gamma-gamma coincidence analysis

4. Rydberg-Ritz combination principle can be used (be careful about the doublets!)

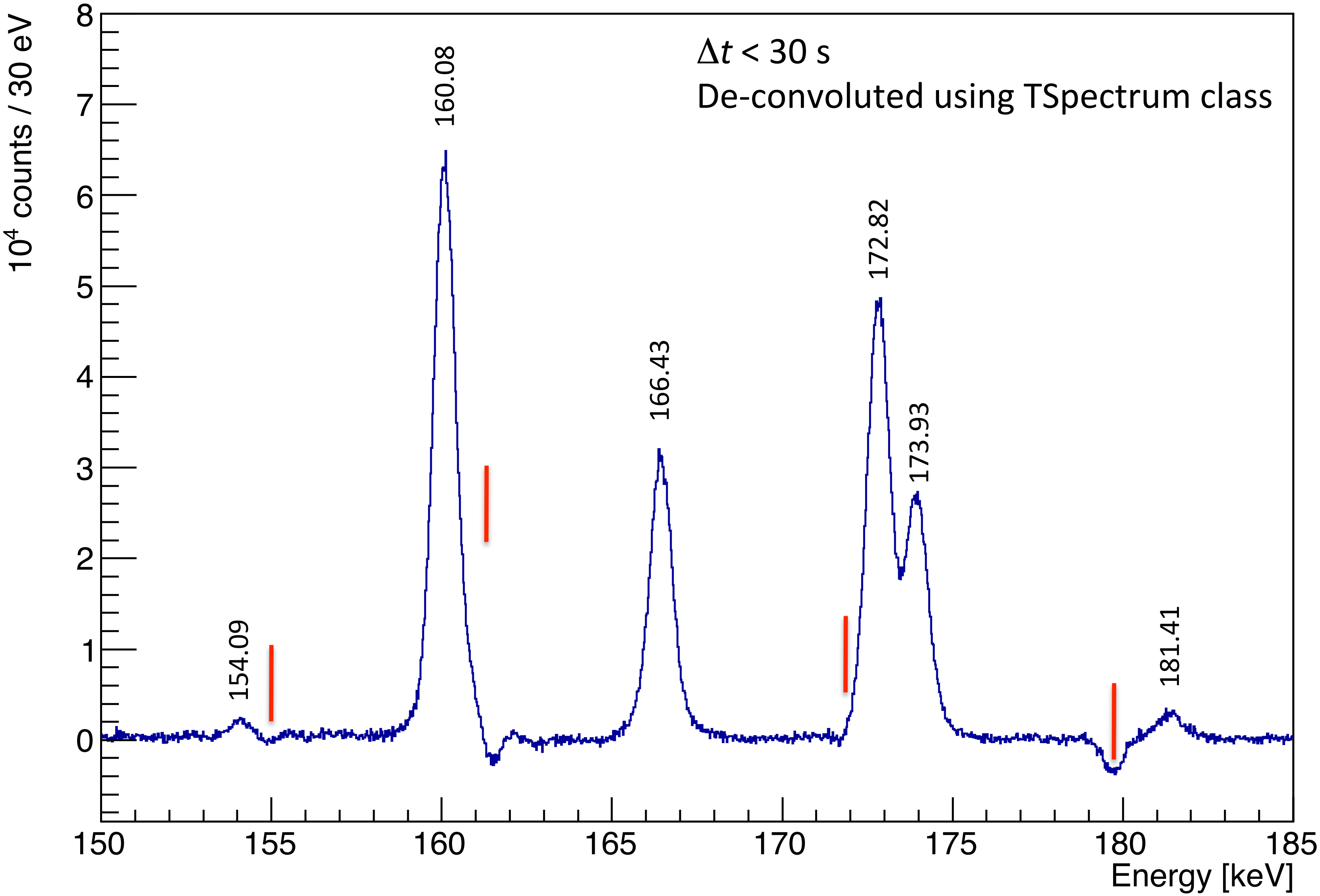
^{183}Hg -> ^{183}Au decay: Example of BE2020 spectrum



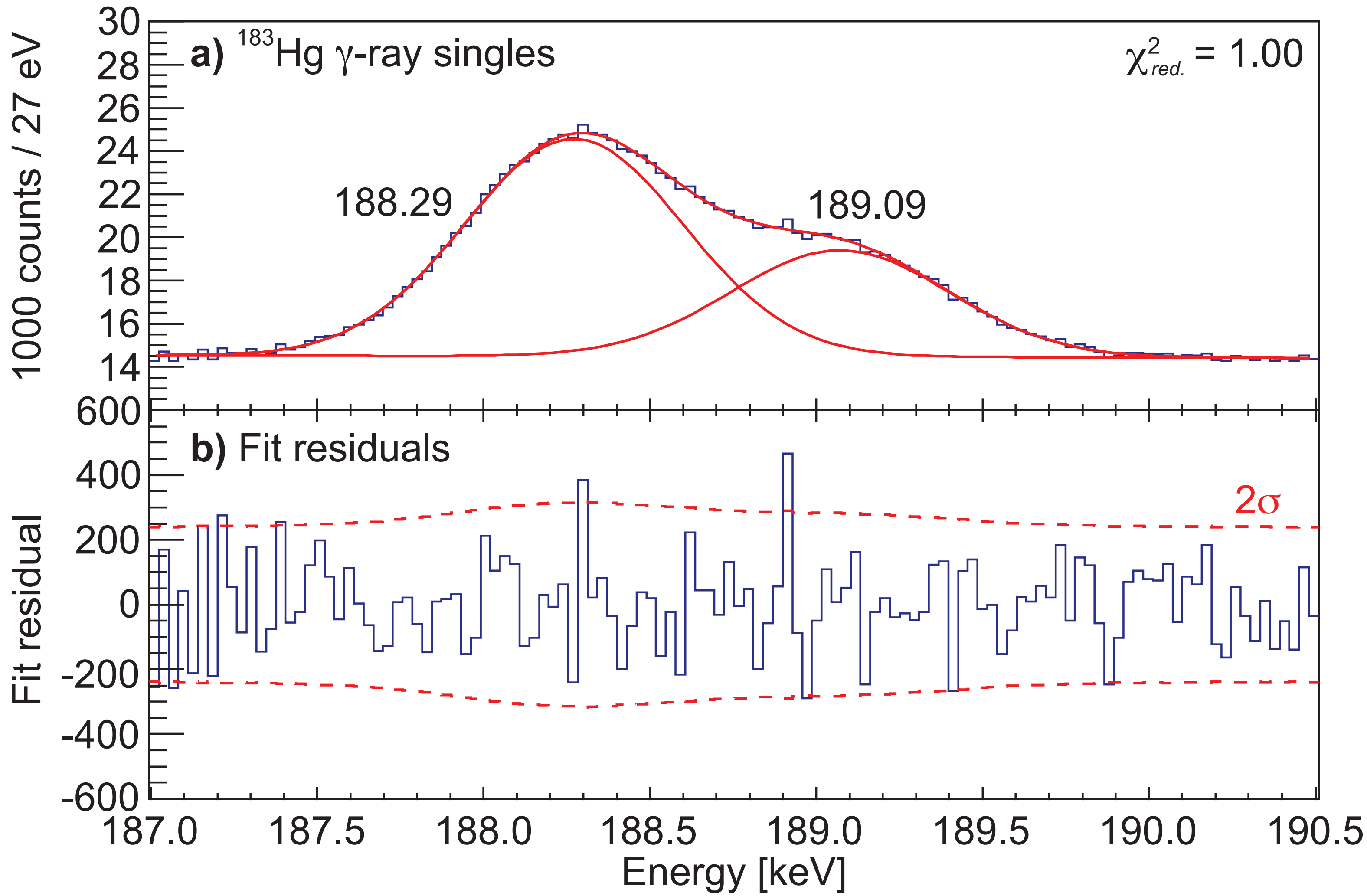
^{183}Hg -> ^{183}Au decay: Identification of peaks using timing



^{183}Hg -> ^{183}Au decay: Identification of peaks using timing

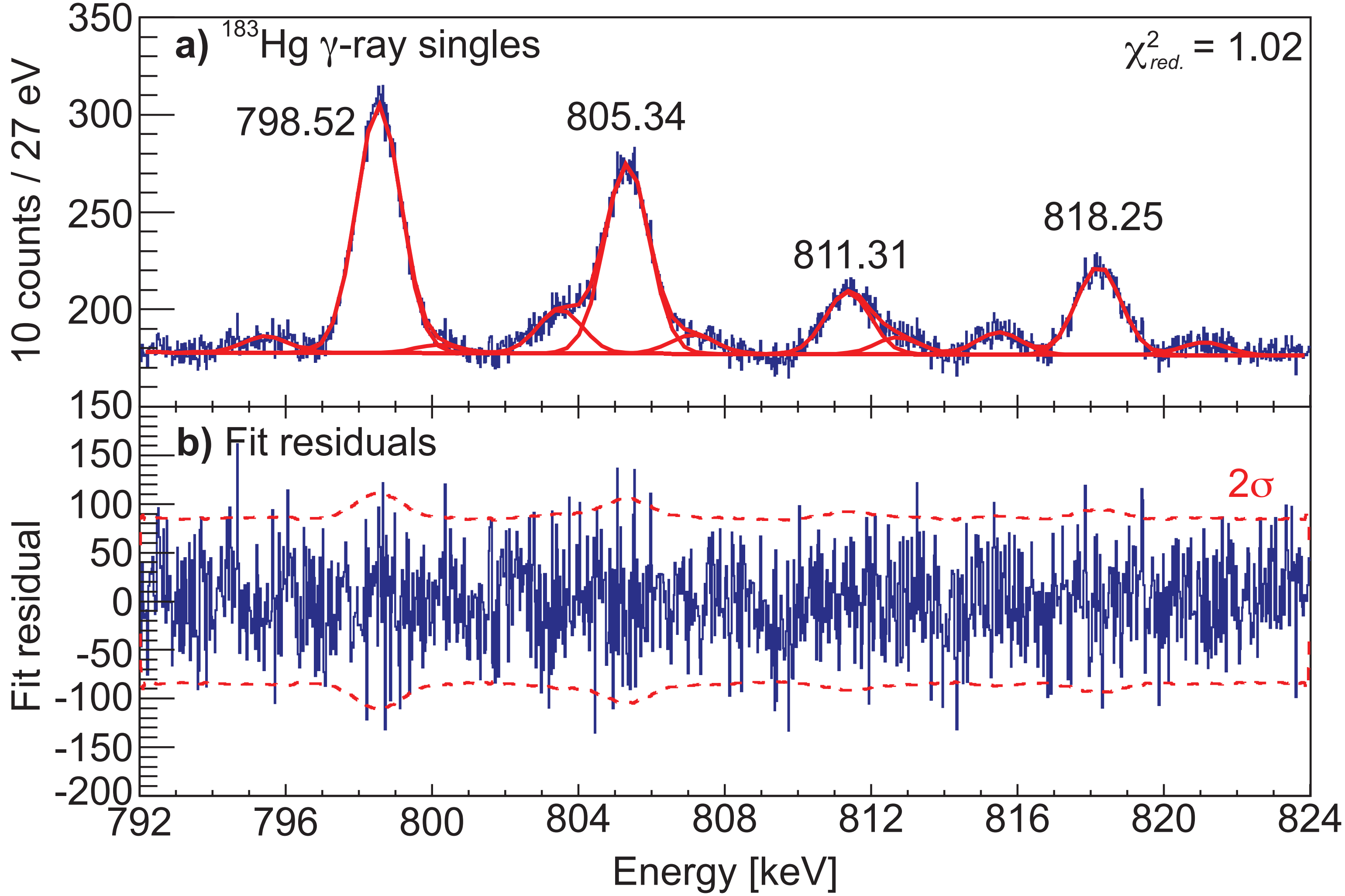


BE2020 Broad Energy Germanium Detector



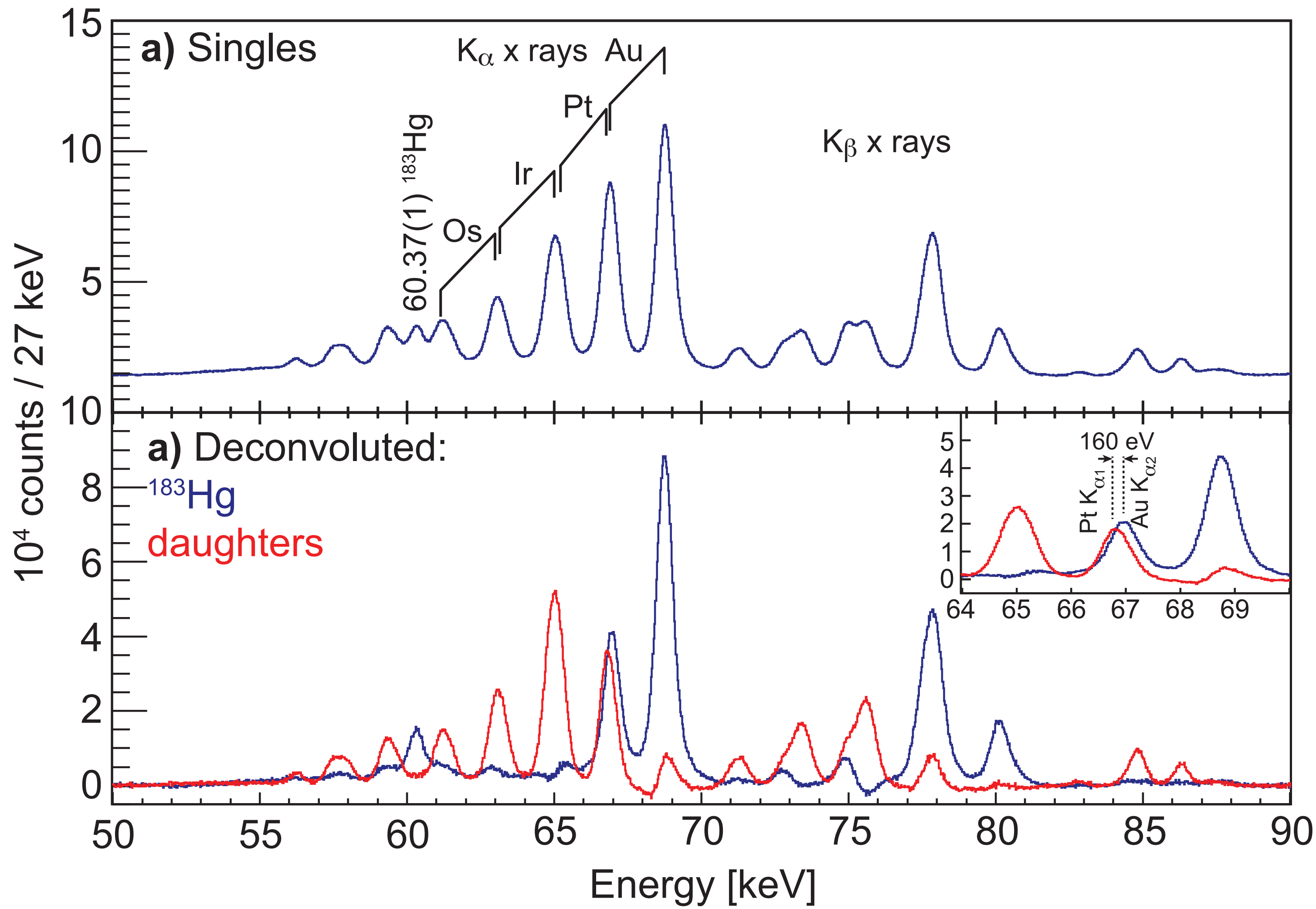
M. Venhart *et al.*, Nucl. Instrum. and Methods in Phys. Res. **849**, 112 (2017).

BE2020 Broad Energy Germanium Detector



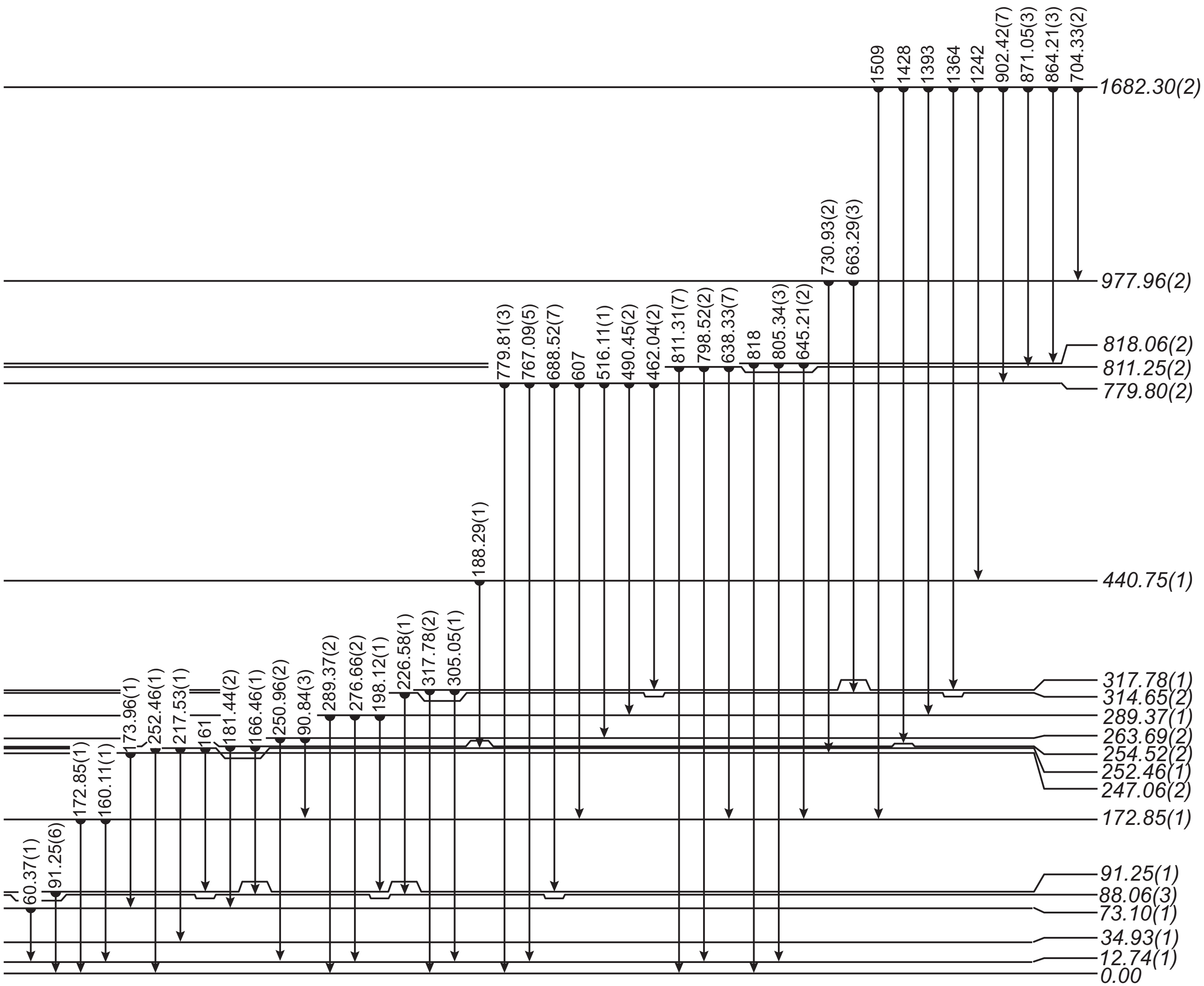
M. Venhart *et al.*, Nucl. Instrum. and Methods in Phys. Res. **849**, 112 (2017).

Deconvolution using the timestamped data



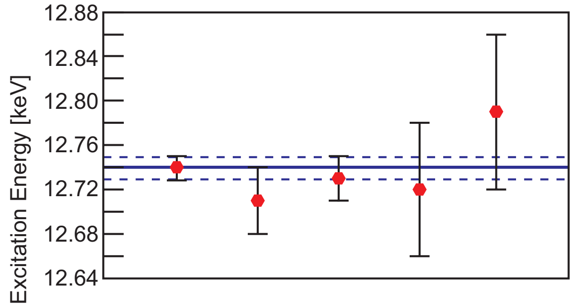
M. Venhart *et al.*, Nucl. Instrum. and Methods in Phys. Res. **849**, 112 (2017).

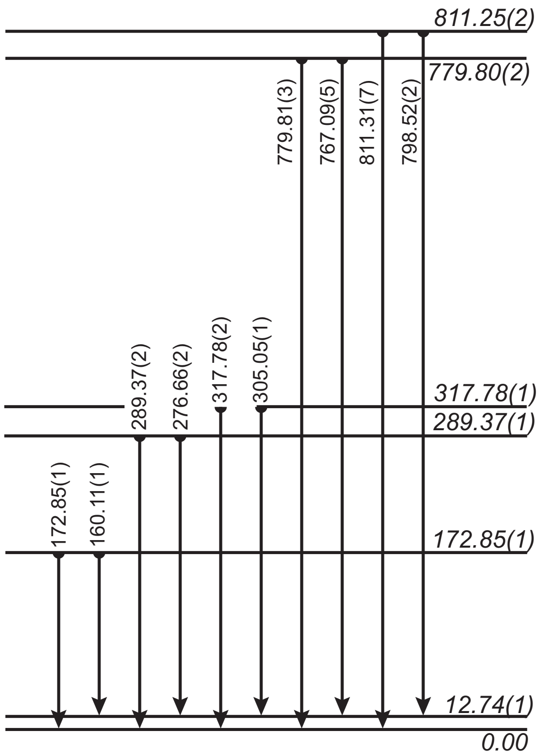
Building of the level scheme: Rydberg-Ritz combination principle



M. Venhart *et al.*, Nucl. Instrum. and Methods in Phys. Res. **849**, 112 (2017).

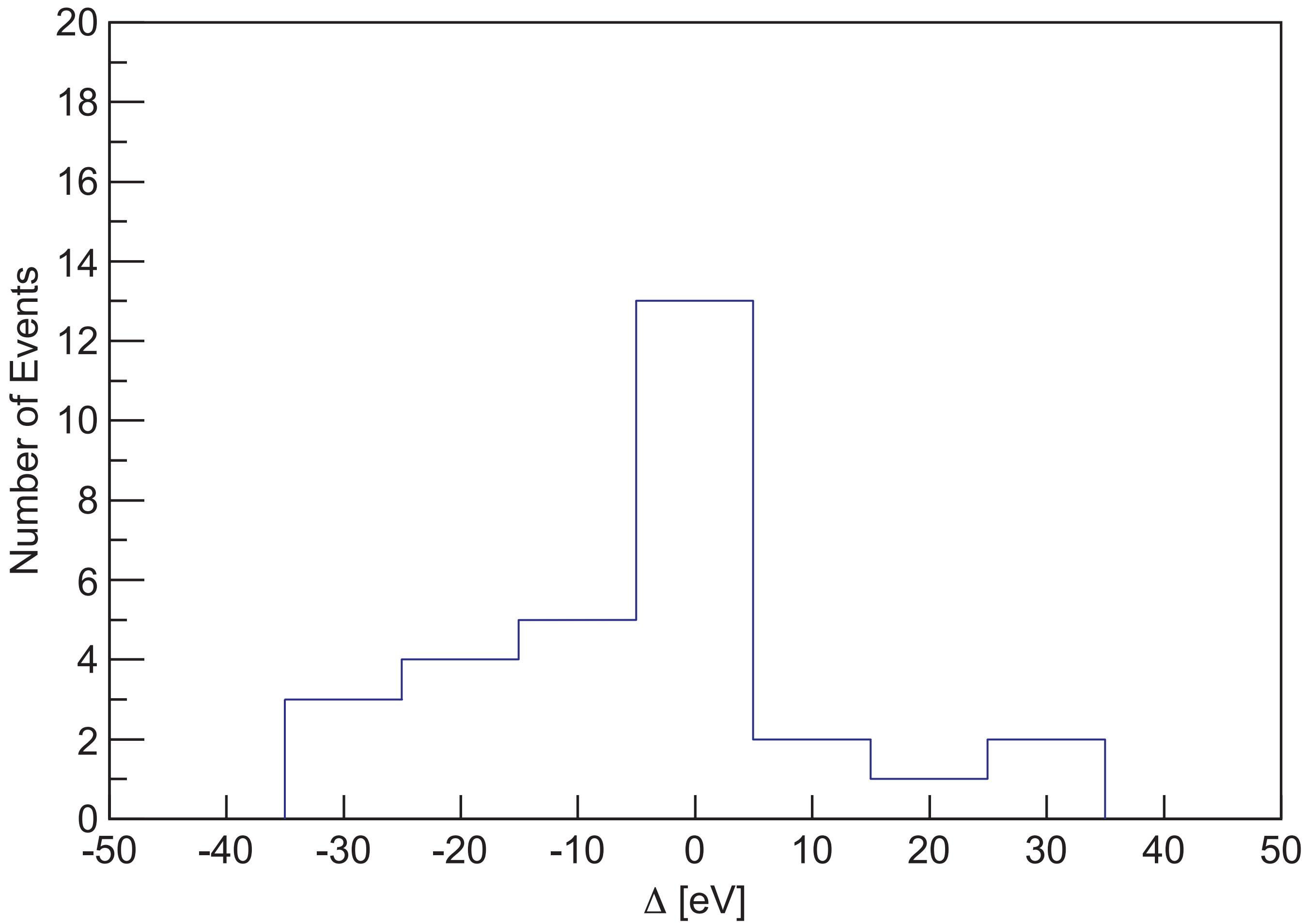
Determination of the excitation energy of first excited state



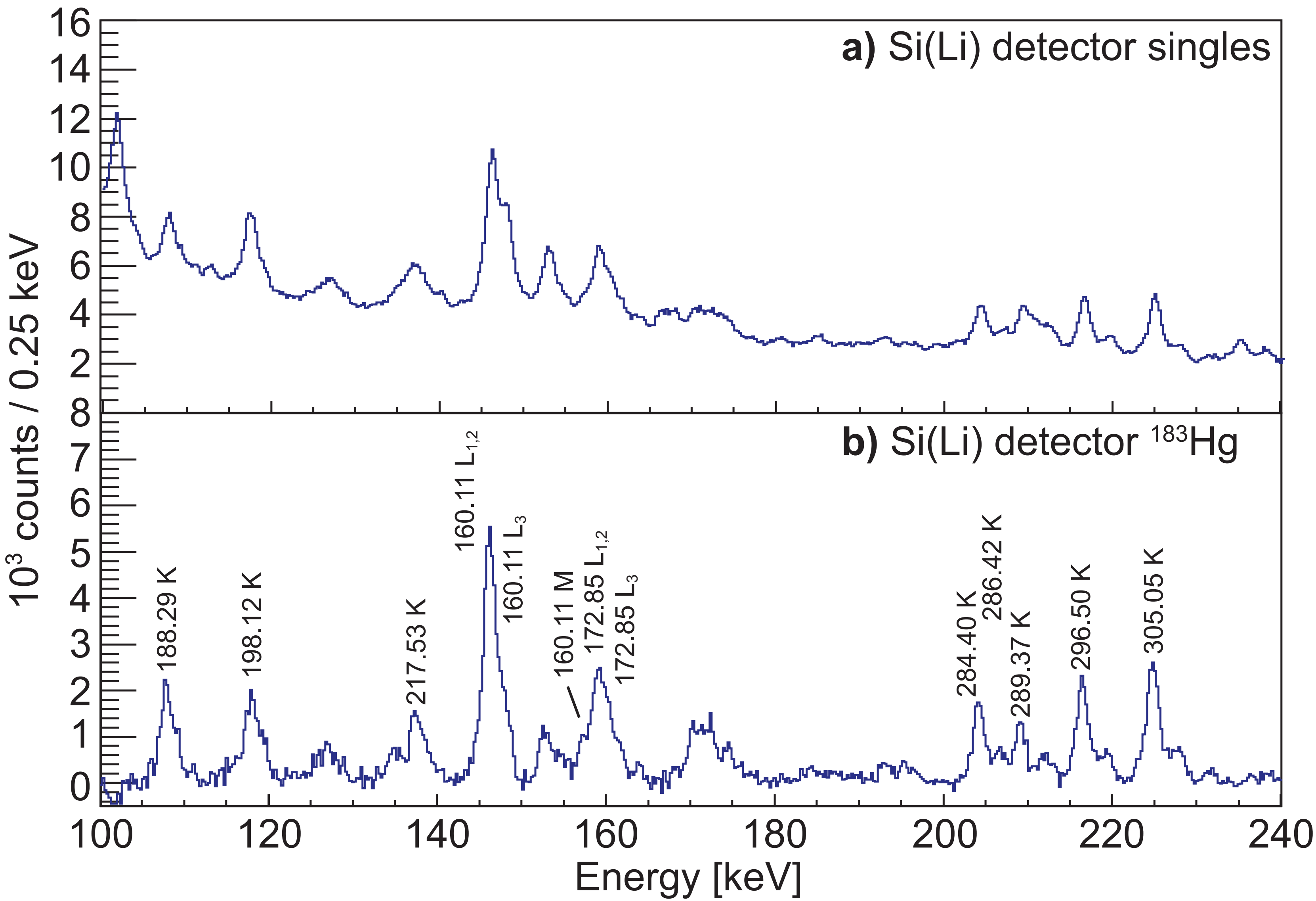


M. Venhart *et al.*, Nucl. Instrum. and Methods in Phys. Res. **849**, 112 (2017).

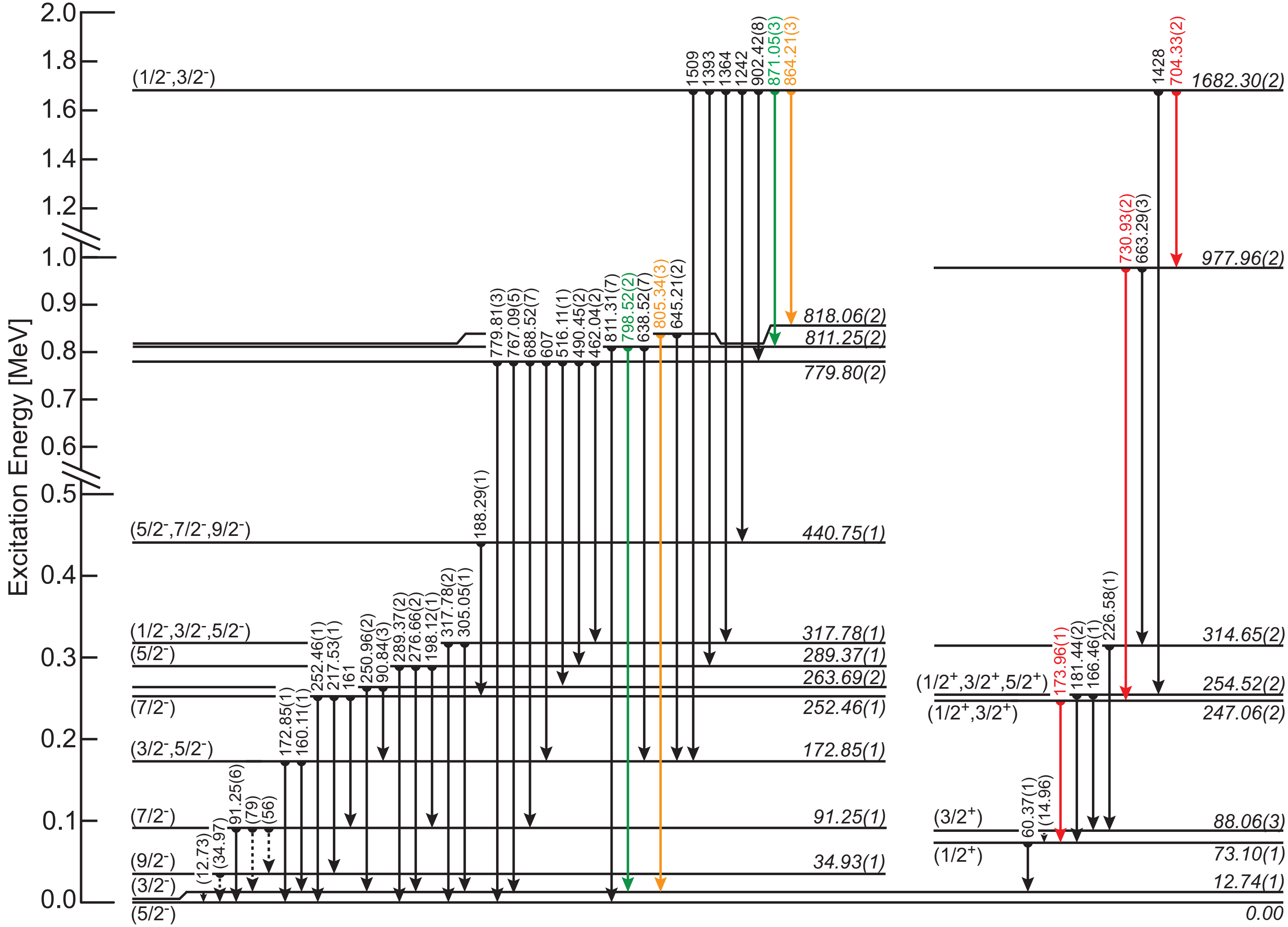
Distribution of Rydberg-Ritz combinations



Conversion-electron spectrum: 1.5 keV resolution



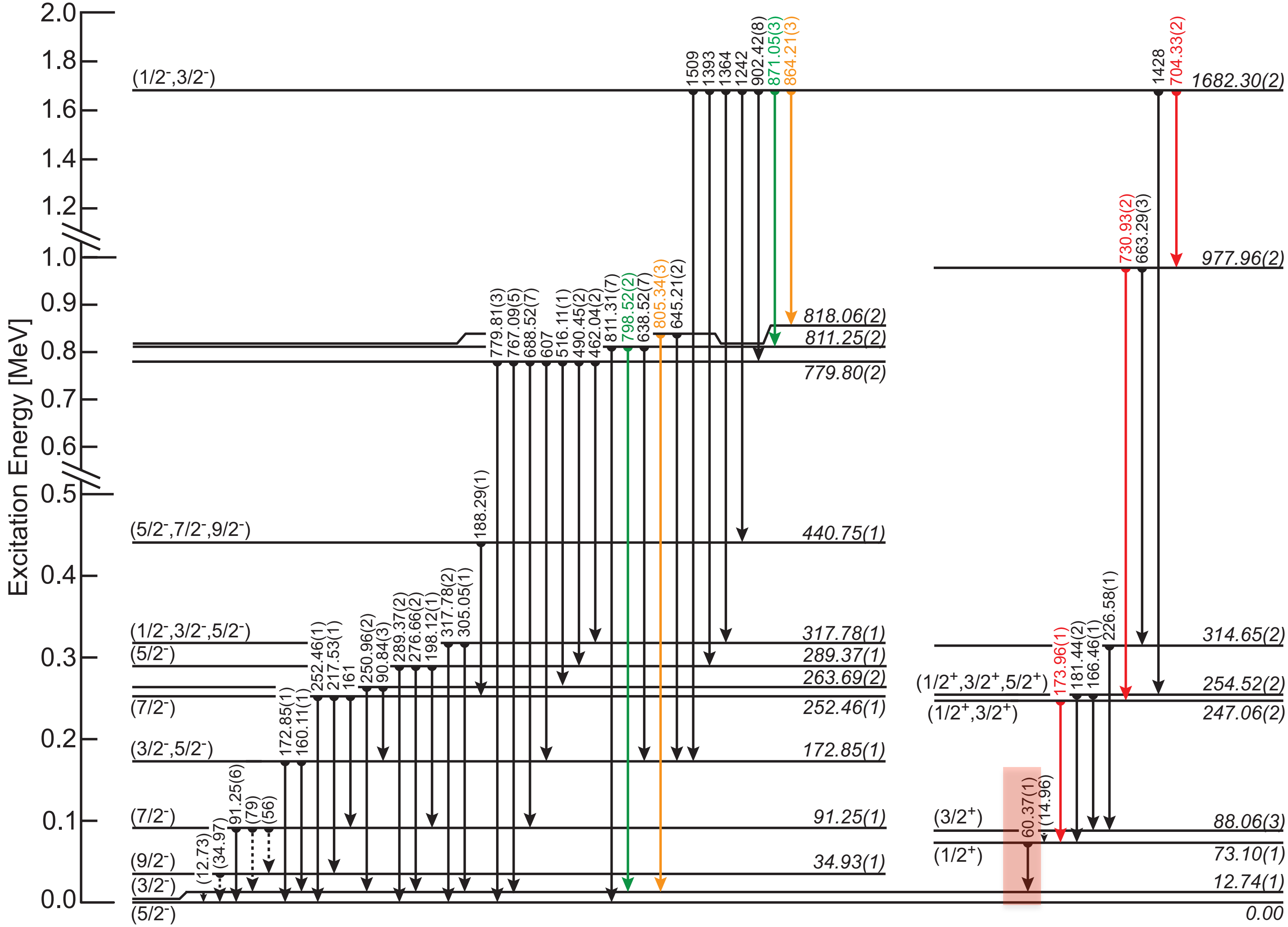
Decay of ^{183}Hg: excited states of ^{183}Au



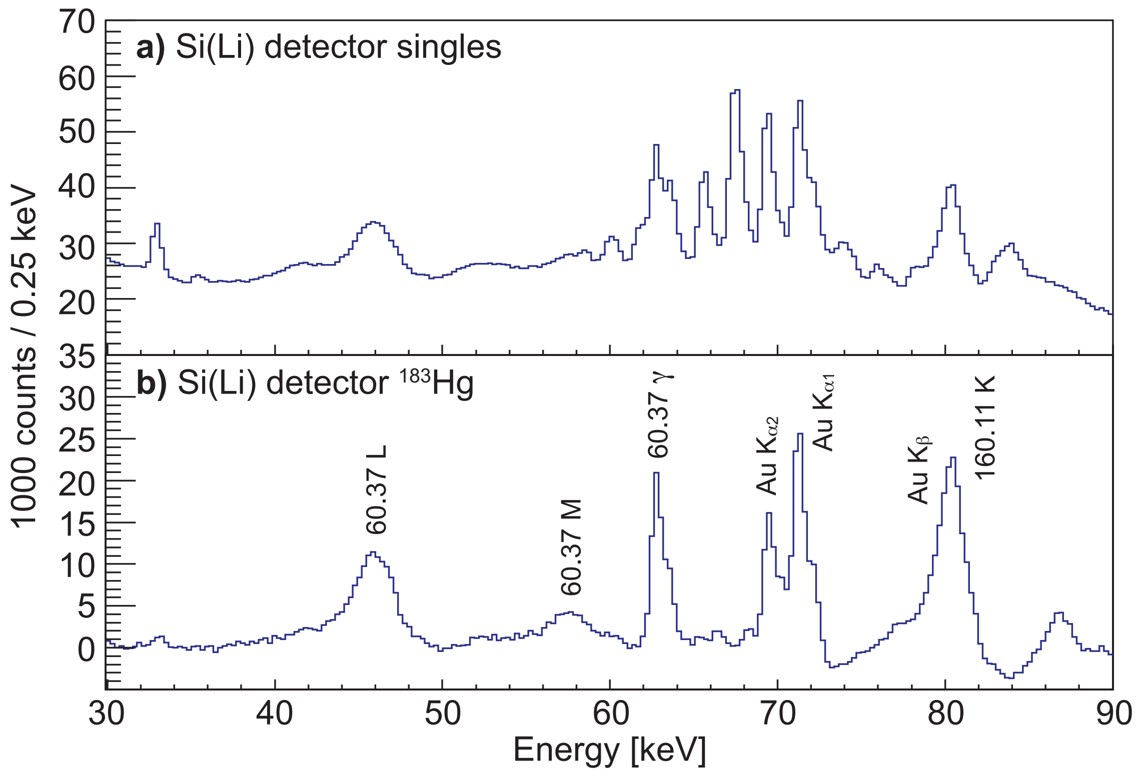
Martin Venhart: TATRA decay station at ISOLDE and shape coexistence in odd-mass Au nuclei

Shape coexistence and electric monopole transitions in atomic nuclei, 23-27 October 2017, CEA-Saclay

Decay of ^{183}Hg: excited states of ^{183}Au



^{183}Au partial level scheme: Placement of the 60.37 keV transition



The 60.37 keV transition:

$\alpha_L = 0.22(4)$
$\alpha_M = 0.04(2)$

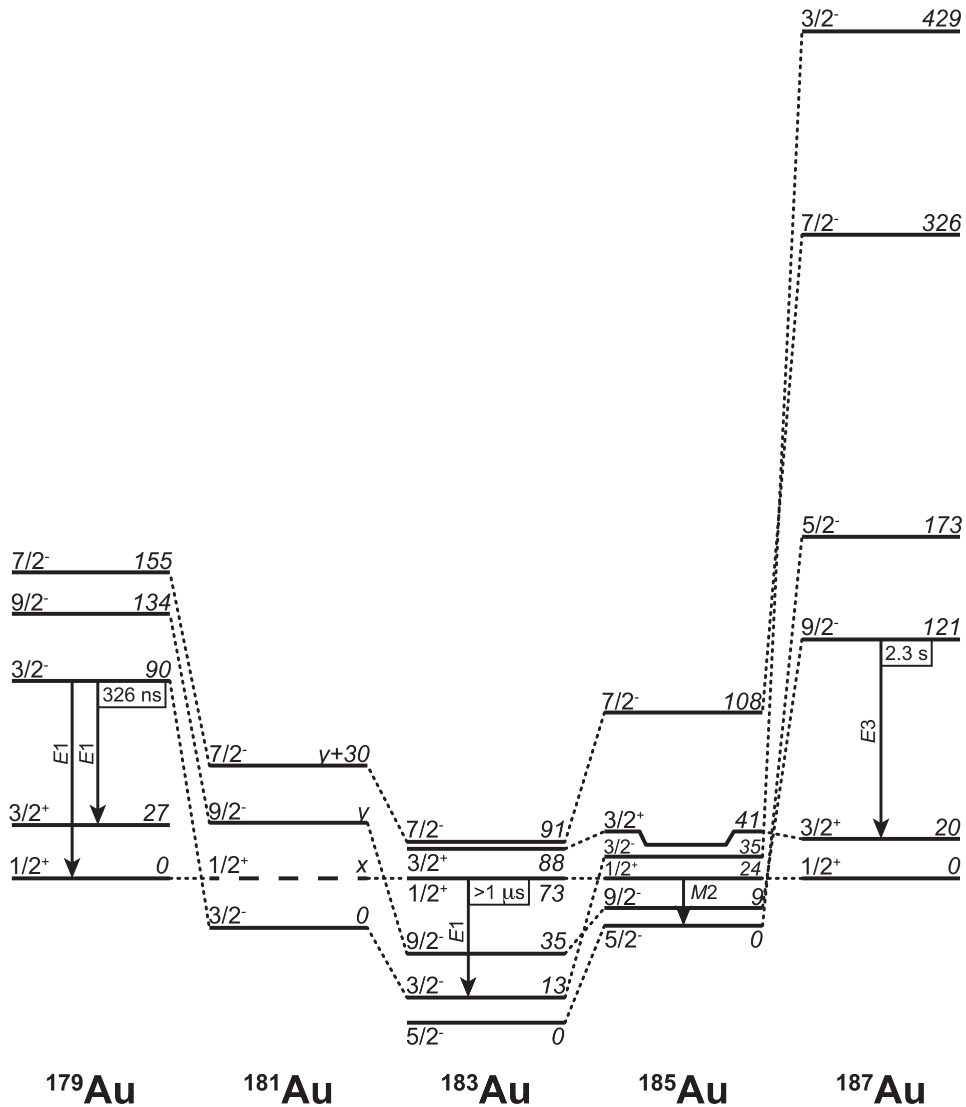
Compared with BrIcc code: E1

The 60.37 keV is isomeric hole-to-intruder transition

BrIccS v2.3 (9-Dec-2011)
Z=79 (Au, Gold)
γ-energy: 60.37 keV
Data Sets: BrIccFO

Shell	E1	M1	E2	M2	E3	M3	E4	M4	E5	M5
Tot	3.254E-01	5.667E+00	5.024E+01	1.869E+02	2.307E+03	6.720E+03	5.843E+04	1.877E+05	1.256E+06	4.400E+06
L-tot	2.500E-01	4.355E+00	3.768E+01	1.394E+02	1.670E+03	4.805E+03	3.816E+04	1.249E+05	6.714E+05	2.622E+06
M-tot	5.868E-02	1.011E+00	9.782E+00	3.648E+01	4.932E+02	1.473E+03	1.563E+04	4.805E+04	4.483E+05	1.352E+06

Intruder parabola

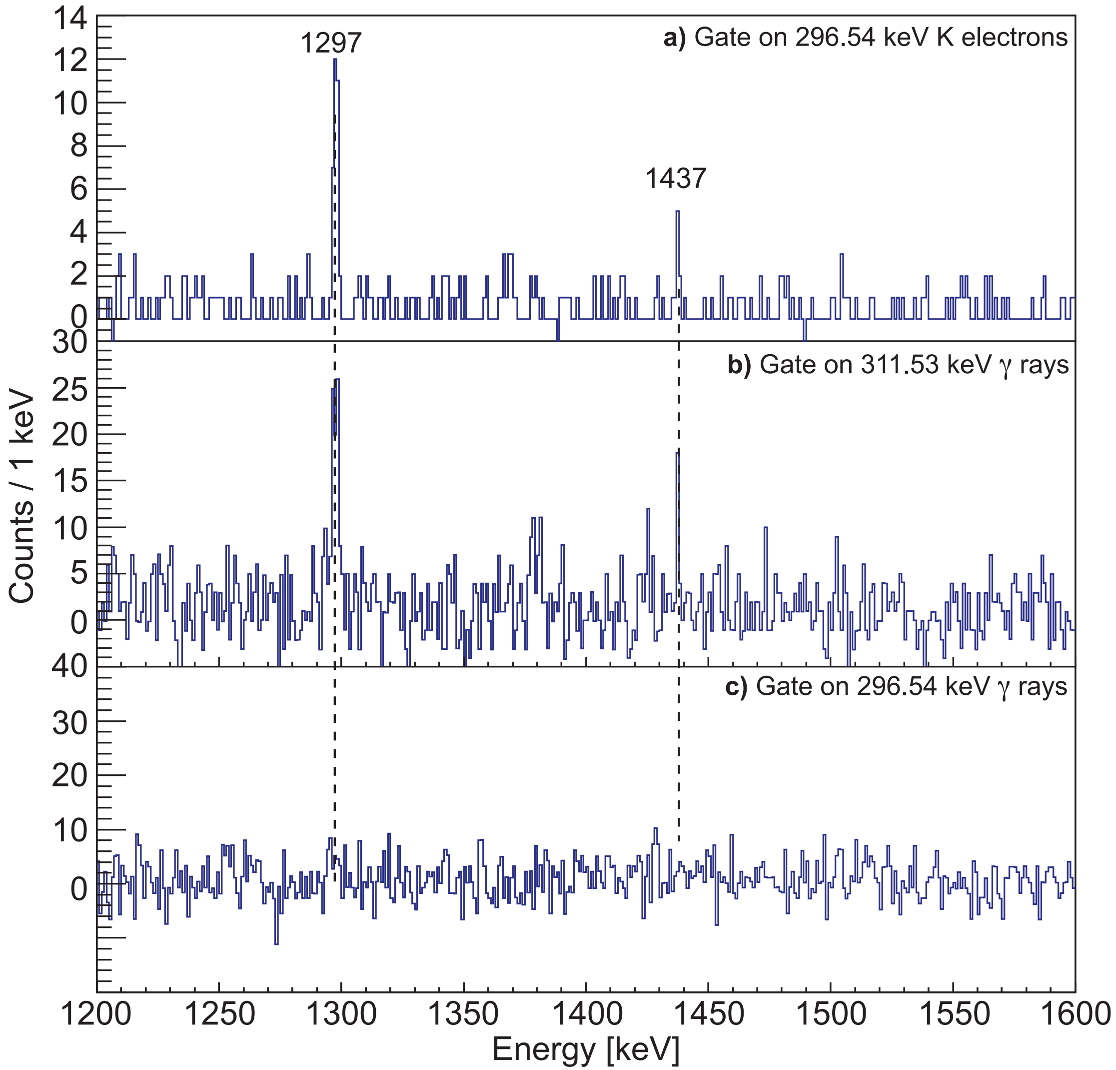


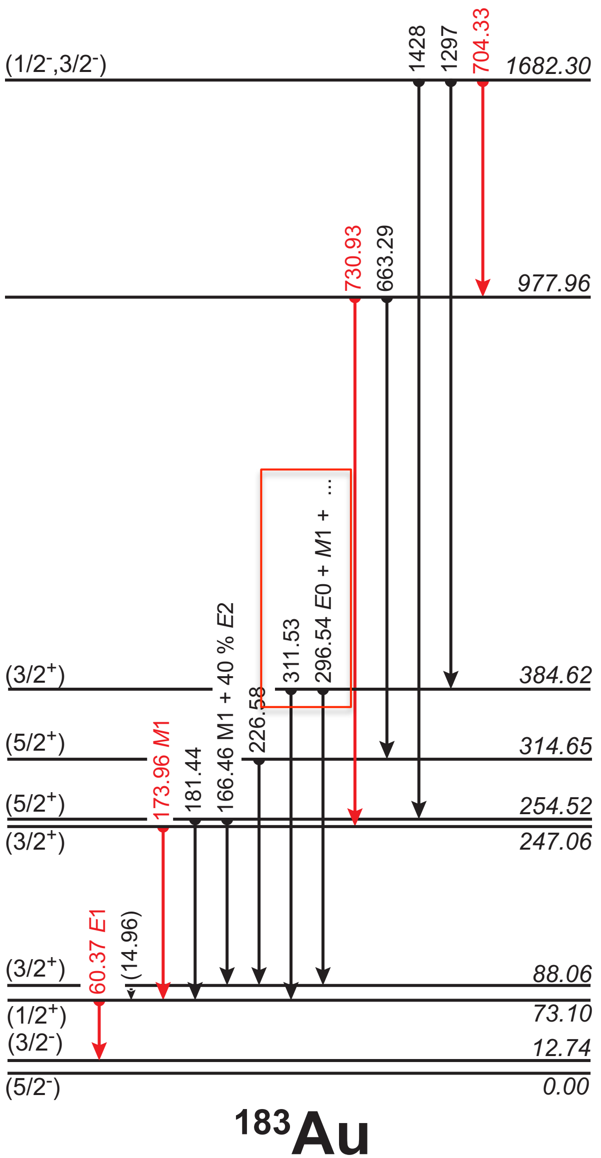
- Spectroscopy at minimum of intruder parabola in odd-Au isotopes
- Laser measurements are in agreement conclusions based on excited states

Internal conversion coefficients: two $E0$ transition identified

E_γ [keV]	Experimental value	BrIcc ($M1$)	BrIcc ($E2$)	Multipolarity
60.37	$\alpha_L = 0.22(4)$	4.355	37.68	$E1$
	$\alpha_M = 0.04(2)$	1.011	9.782	
160.11	$\alpha_K/\alpha_L = 4.7(18)$	5.99	0.72	$M1$ (+ $E2$)
166.46	$\alpha_K/\alpha_L = 3.4(5)$	5.994	0.782	$M1$ + 40(10) % $E2$
	$\alpha_L = 0.24(5)$	0.233	0.338	
172.85	$\alpha_K = 1.25(28)$	1.257	0.242	$M1$
173.96	$\alpha_K = 1.25(28)$	1.234	0.238	$M1$
188.29	$\alpha_K = 0.87(20)$	0.989	0.197	$M1$ (+ $E2$)
198.12	$\alpha_K = 0.88(20)$	0.858	0.174	$M1$
217.53	$\alpha_K = 0.54(13)$	0.661	0.138	$M1$ (+ $E2$)
284.40	$\alpha_K = 1.21(33)$	0.316	0.071	$E0$ + $M1$ + ...
289.37	$\alpha_K = 0.25(6)$	0.302	0.068	$M1$ + $E2$
296.54	$\alpha_K = 2.84(74)$	0.282	0.064	$E0$ + $M1$ + ...
305.05	$\alpha_K = 0.26(6)$	0.261	0.060	$M1$
	$\alpha_L = 0.04(1)$	0.043	0.029	

Placement of 296.54 keV *E*0 transition: coincidences



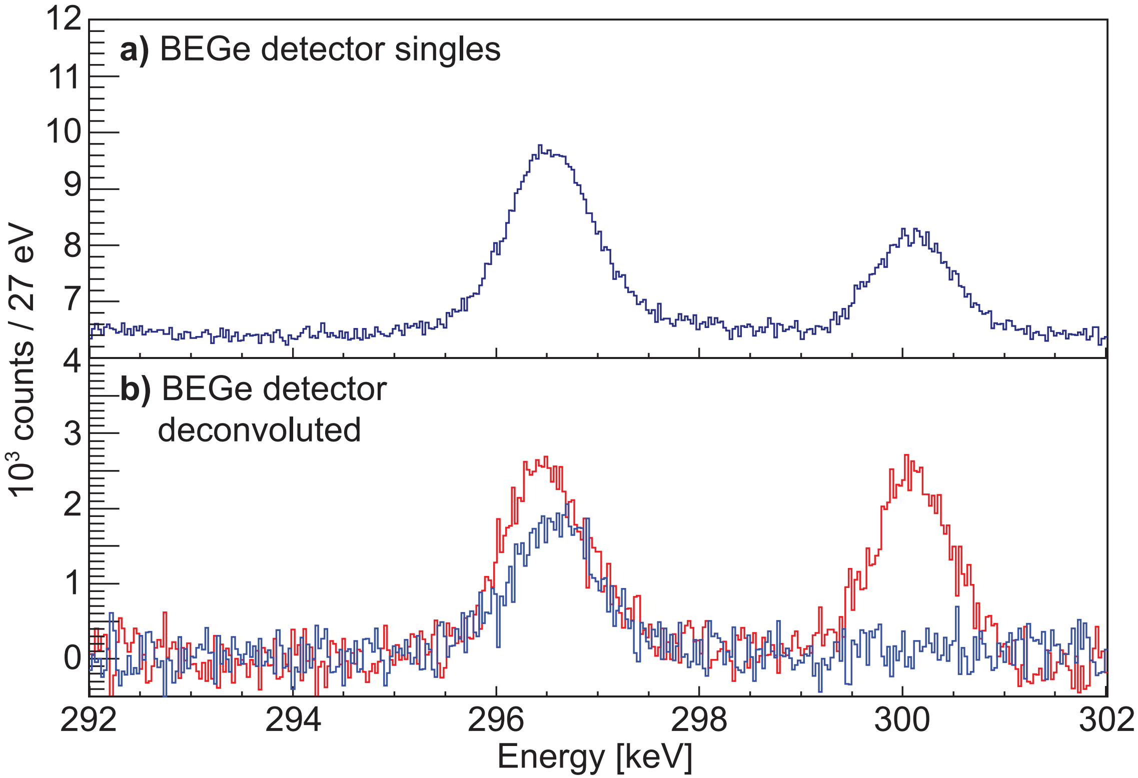


Placement of 296.54 keV *E*0 transition: Rydberg-Ritz

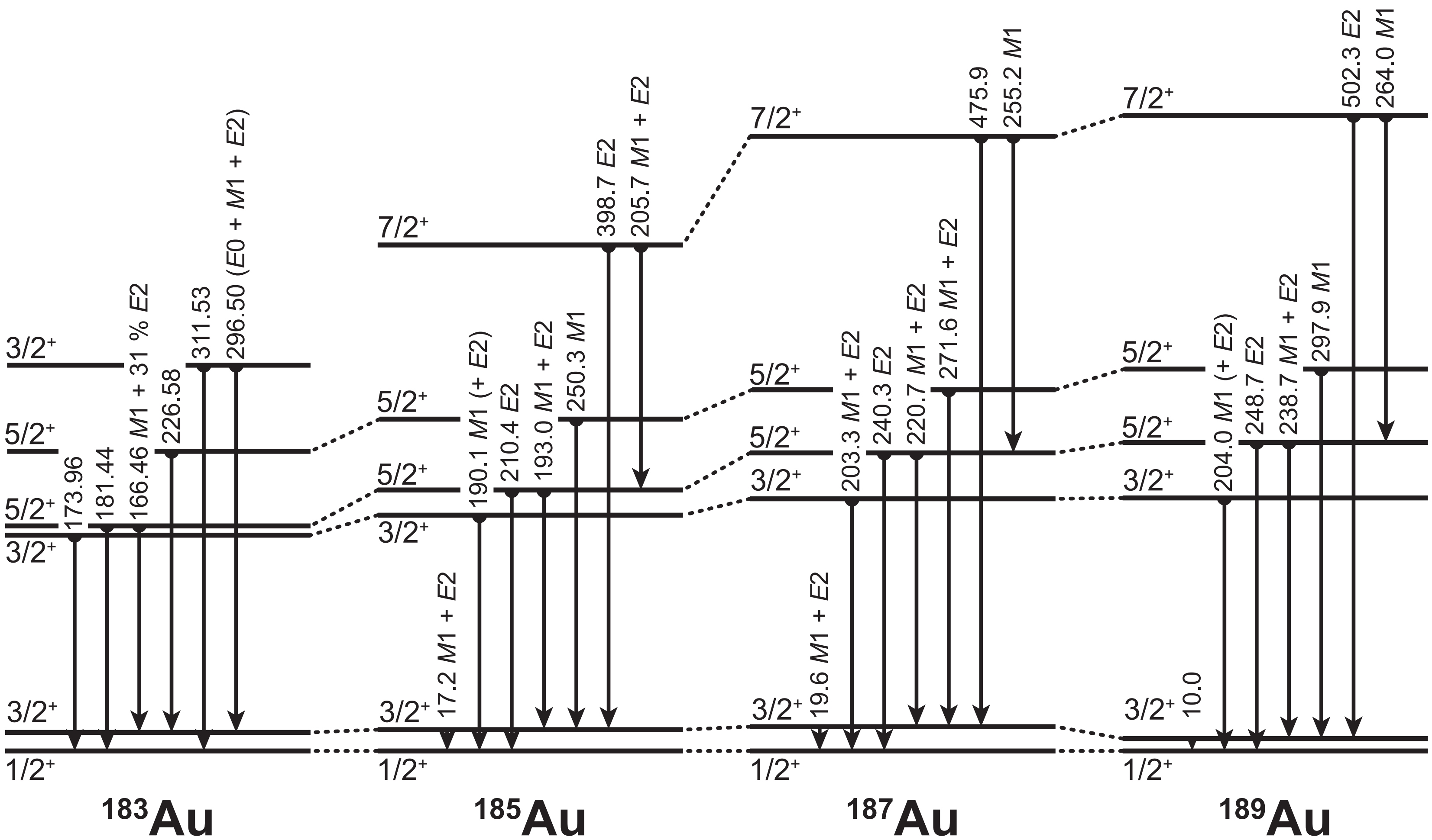
- Initial analysis (singles spectrum): 50 eV difference for Rydberg-Ritz combination
- What is wrong?

Placement of 296.54 keV *E*0 transition: Rydberg-Ritz

- Initial analysis (singles spectrum): 50 eV difference for Rydberg-Ritz combination
- What is wrong?
- 296.54 keV line is a doublet!



Systematics of positive-parity states extended

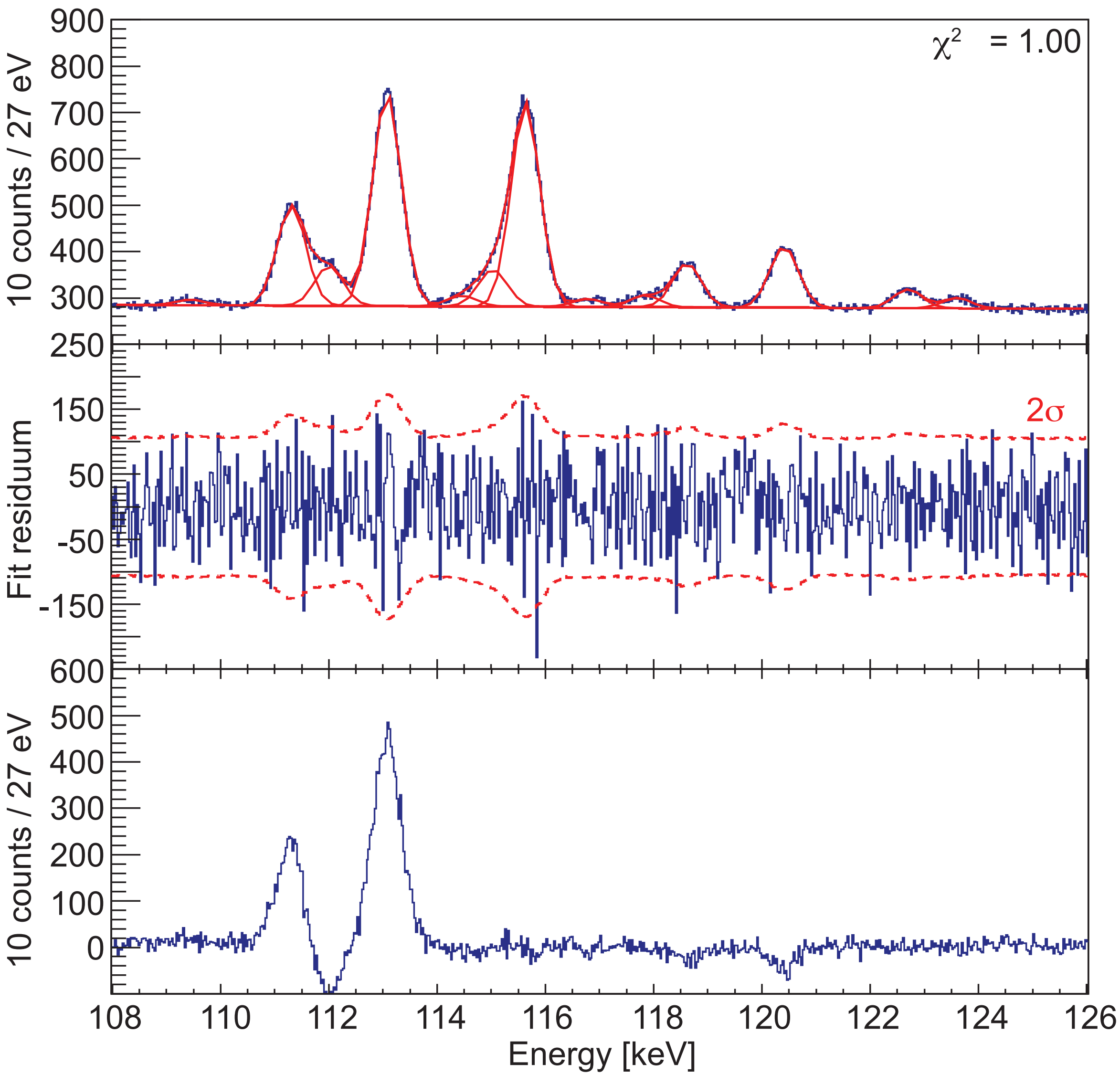


^{181}Hg decay: limit β^+/EC decay studies

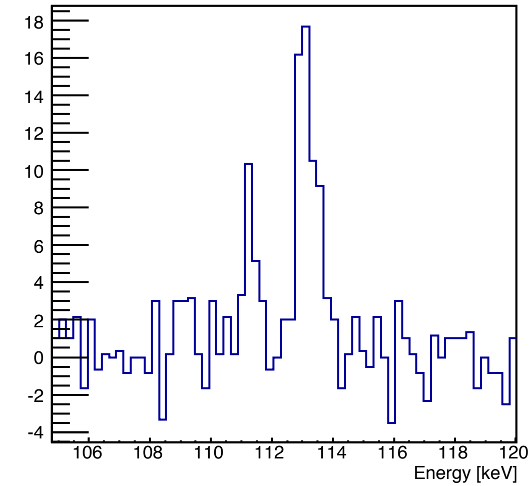
- Lighter isotopes dominantly decay via α decay
- Yield of ISOLDE is limited
- Previous data: ISOCELE in beginning of 80's
- Only list of gamma rays is given, no level scheme

- IS521: first (limited) level scheme constructed
- Great benefit from the time structured data and BEGe detector
- Analysis of the data is not finished yet
- Dedicated study will be needed in the future

Manifestation of the resolving power of BEGe



Gate on 1908 keV

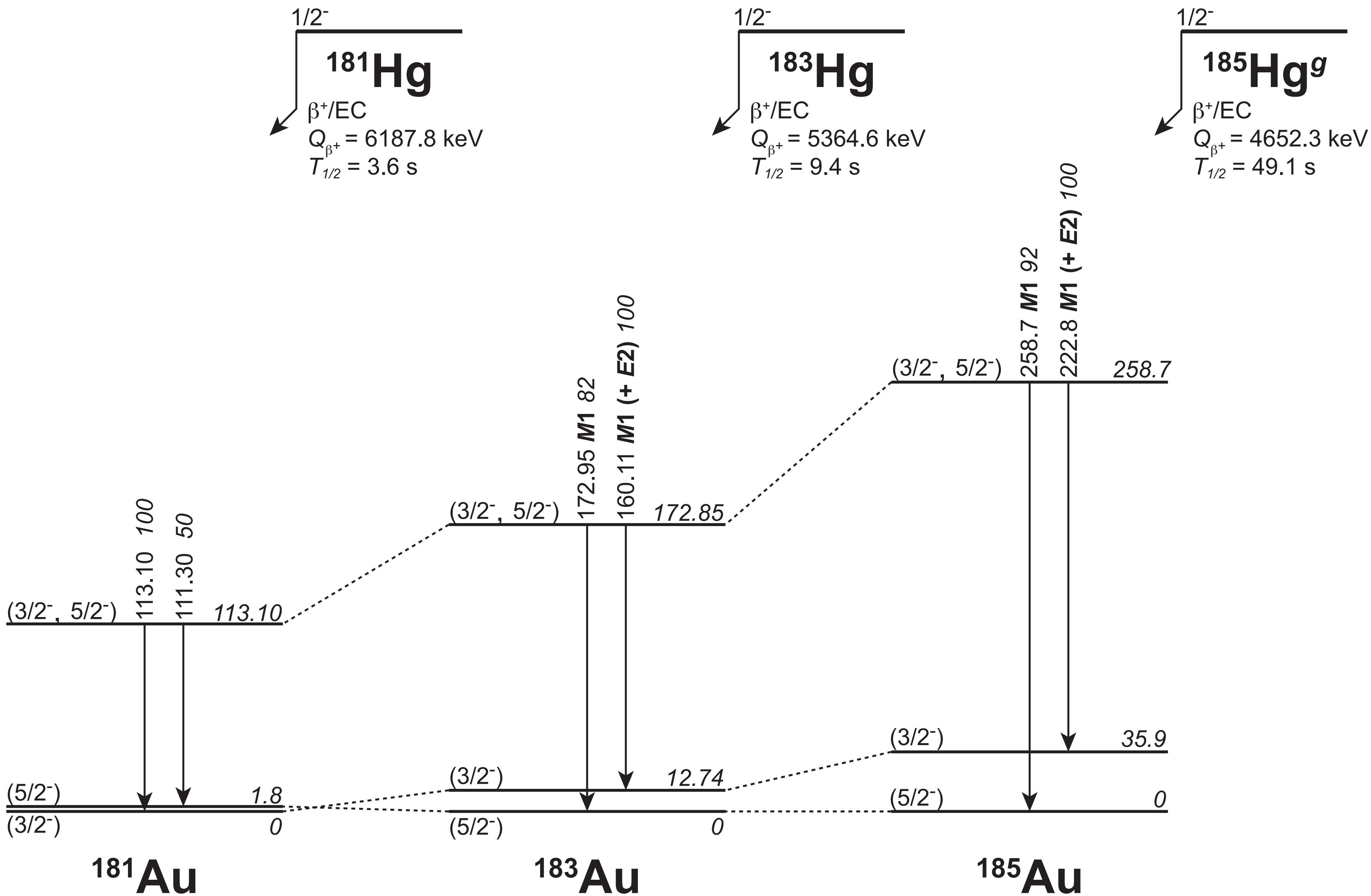


111.30 and 113.10 keV lines are the strongest

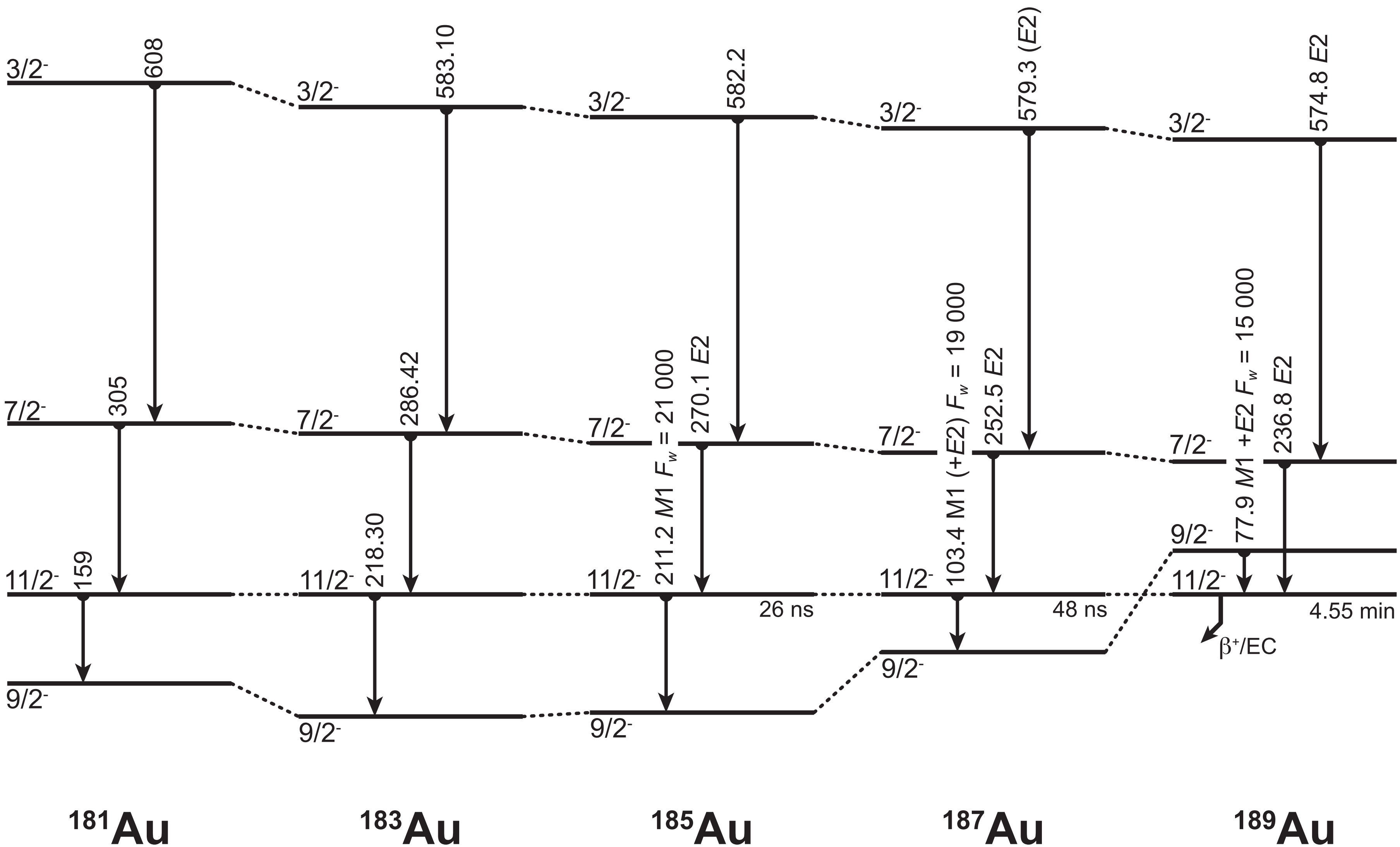
No observed by Orsay group

Reason: ^{181}Pt has strong 112 keV line: unresolved

^{181}Hg decay: Feeding from 1/2$^-$ ground state



^{181}Hg decay: idenfication of lines due to 1$h_{11/2}$ configuration



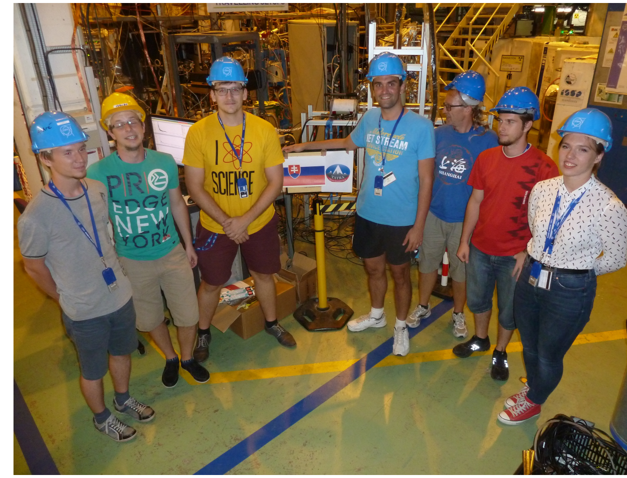
Excellent young team

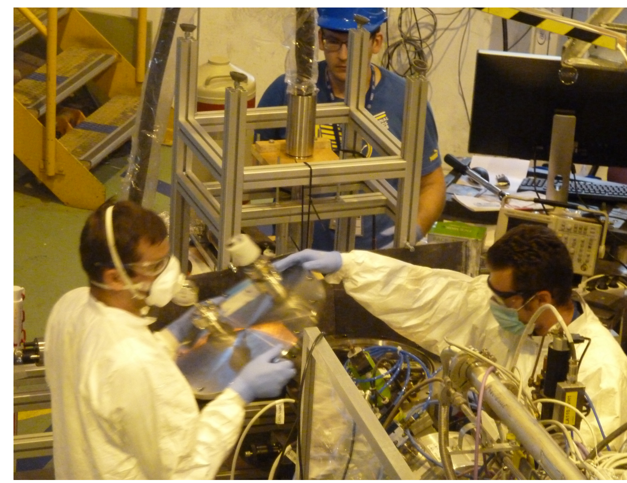
- Martin Veselský
- Ján Kliman
- Stanislav Hlaváč
- Vladislav Matoušek
- Peter Švec, Sr.

- Paresh Prajapati
- Anton Repko
- Kristian Petrík
- Peter Švec
- Štefan Motyčák
- Dušan Janičkovič

- Matúš Sedlák
- Matúš Balogh
- Jozef Klimo
- Robert Urban
- Jakub Krajňák

- Monika Bírová
- Andrej Špaček
- Jakub Lietavec
- Jakub Lušnák
- Lukáš Holub





- Slovakia member state of ISOLDE since 2015

ISOLDE

Conclusion

- TATRA system was used to identify E0 transitions in ^{183}Au
- To our knowledge the BEGe detector was used for the first time for nuclear spectroscopy experiment
- Conversion electrons with 1.5 keV resolution (above 100 keV) were detected
- TATRA can be operated
- Lot of work is still ahead of us: the system is very fragile and sensitive for presise tuning
- The tape is very difficult to produce and to weld