PEKING UNIVERSITY

CRIS Collaboration Meeting 2025

Summary of neutron-deficient gold (IS737)

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Supervisors: Xiaofei Yang, Gerda Neyens

Outline

Motivation

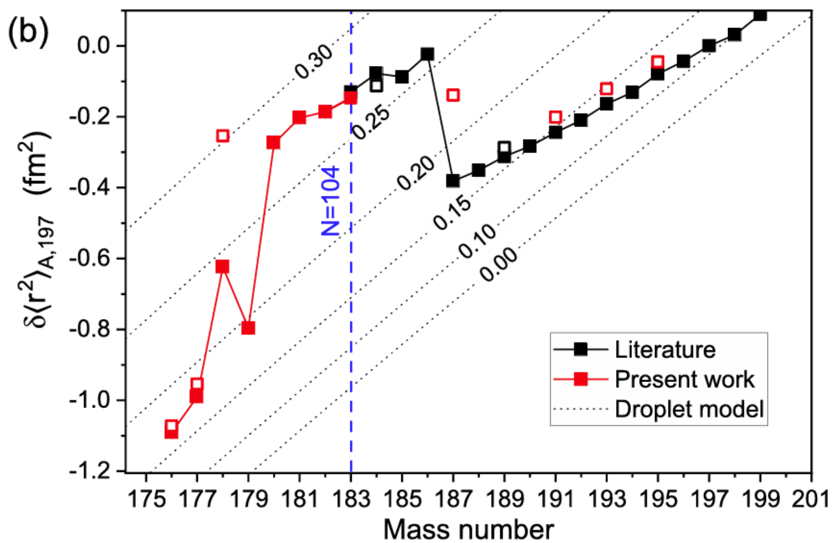
Quadrupole moments of neutron-deficient gold (Z = 79)

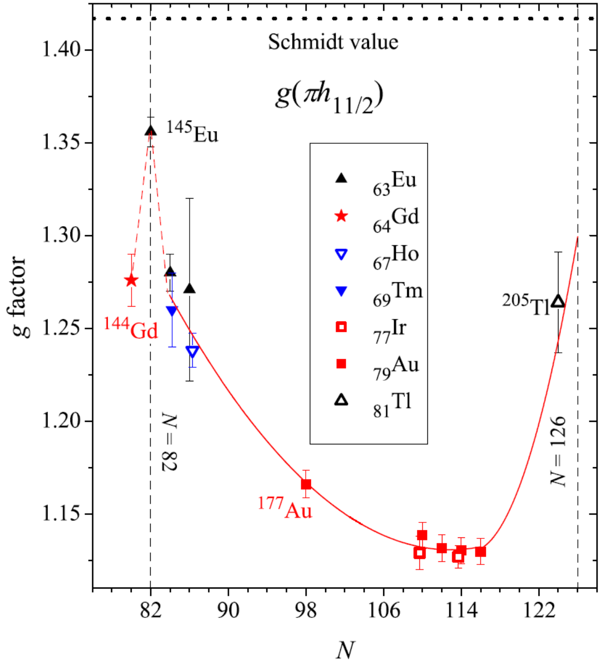
For:

- Island of deformation (180-186g)
- Shape coexistence (187m, 178m)
- 11/2- isomers (177m, 189m, 191m, 193m,195m,197m)
- …

*: this work

#: literature values available





Experiment

Production: 1.4 GeV P + UC_X

Laser scheme: D2 line for 1st

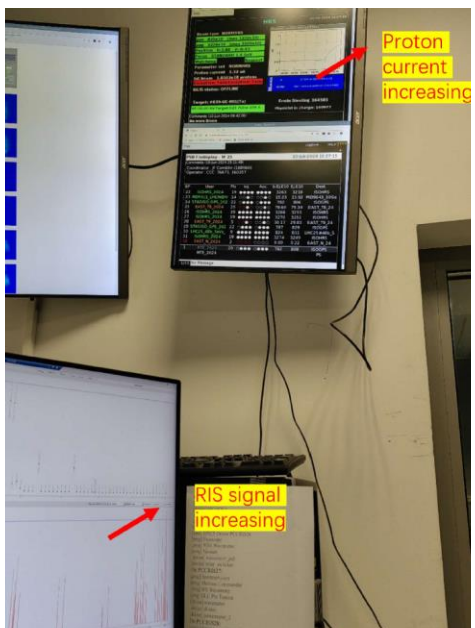
Scan strategy: V scan for 2 sides

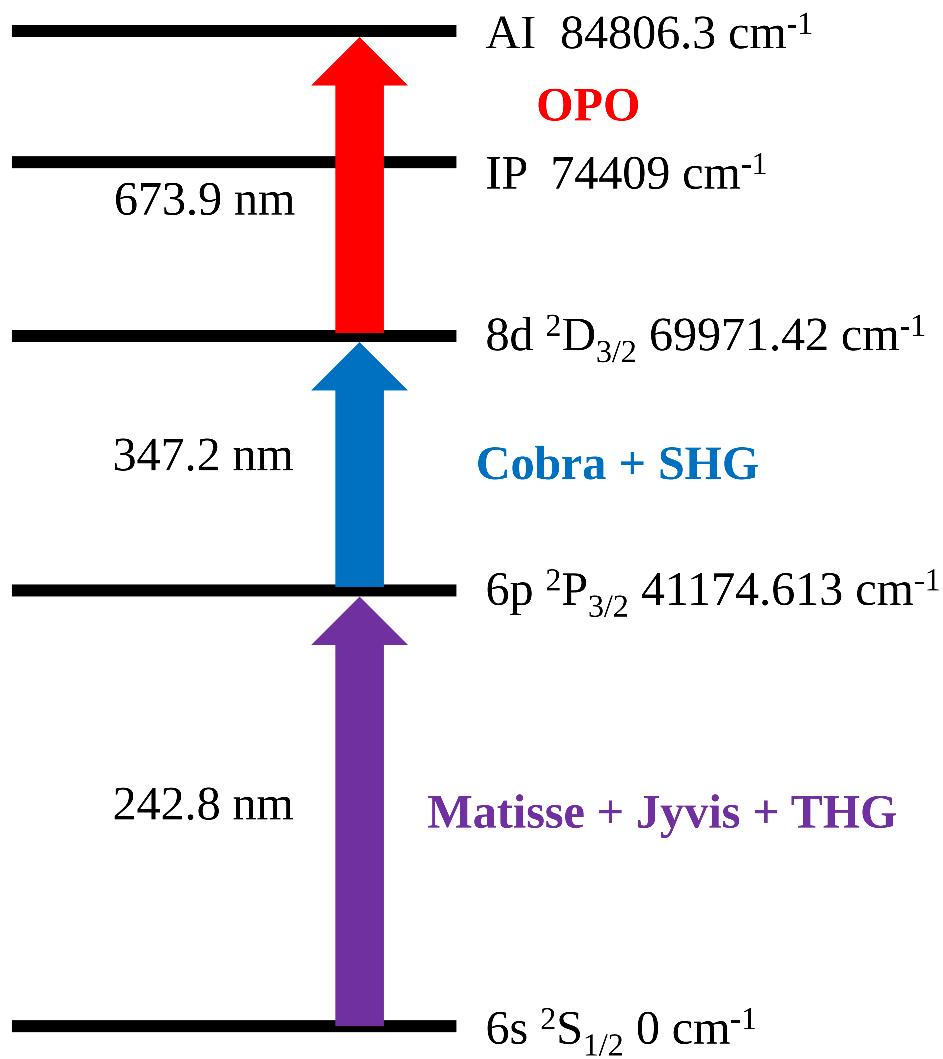
Ref isotope: 197

Isotopes: 180, 181, 182, 183, 185, 187g&m, 188, 189g&m, 190, 191, 192, 193, 195

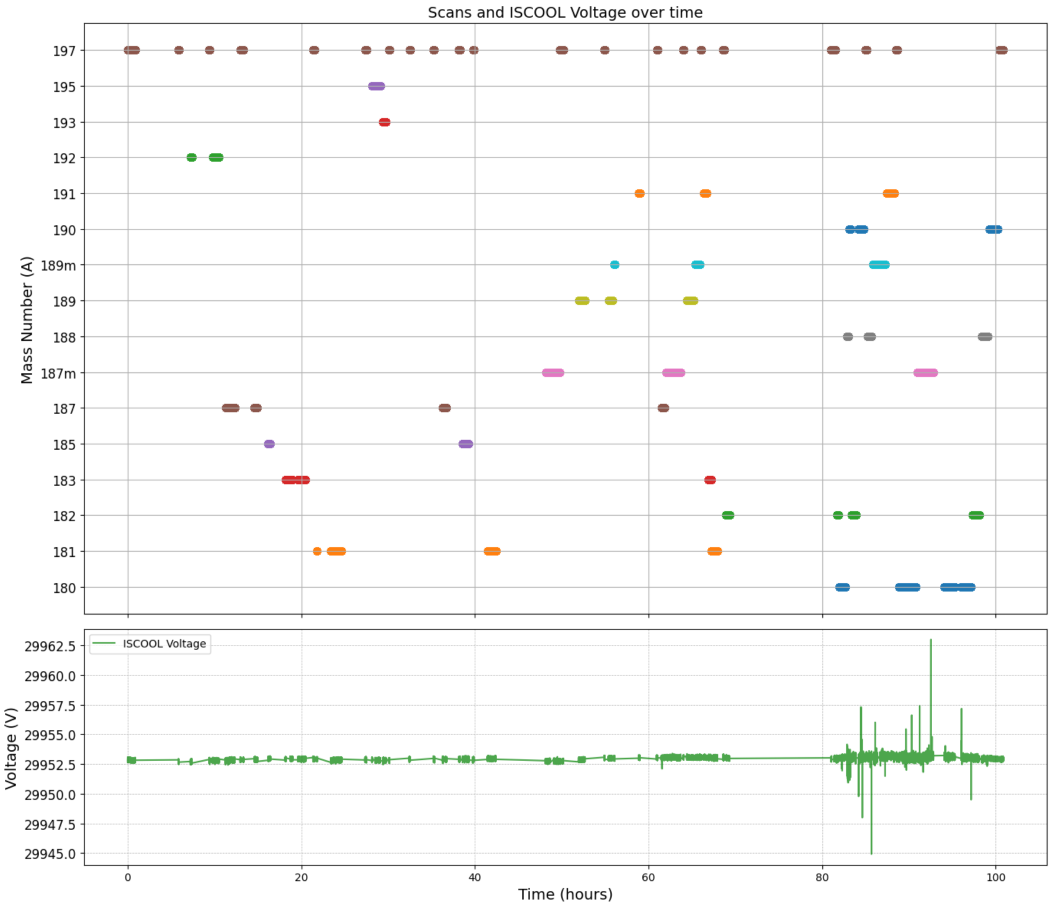
Main issues:

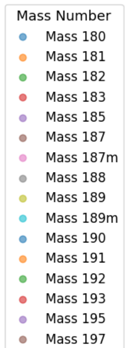
- Mass marker;
- Contamination;
- Shared proton beam intensity;
- Seeking for isomers…





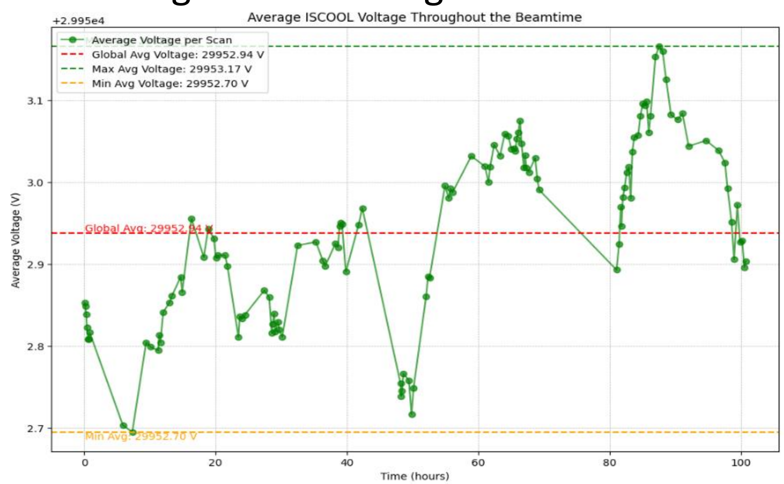
Experiment





Plots and contents thanks to Osama!

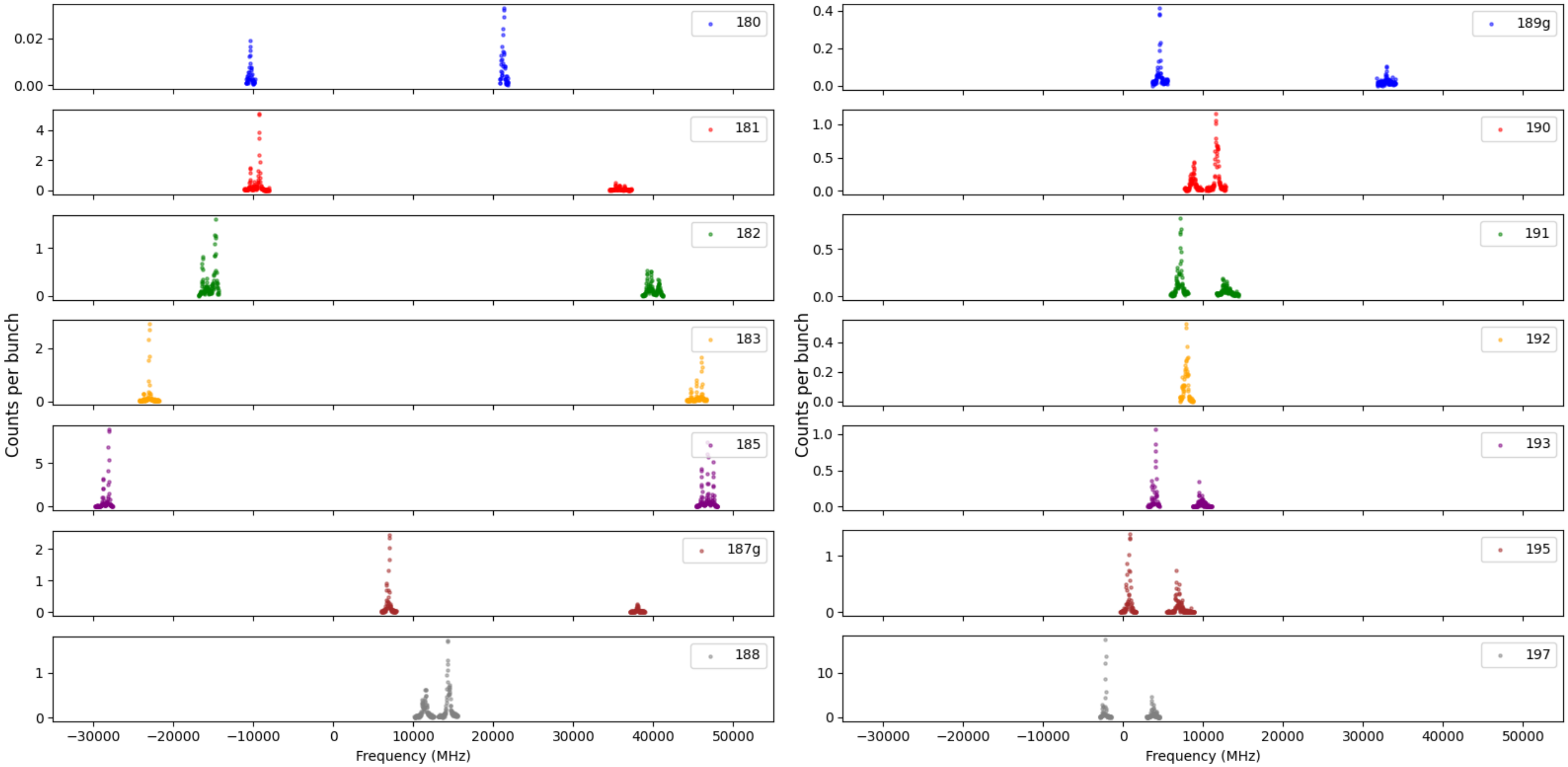
Avg ISCOOL voltage = 29952.94 V



Max and Min ISCOOL Voltage fluctuation throughout the beamtime was 18V.

Avg max and min ISCOOL Voltage fluctuation throughout the beamtime was ~ 0.5V.

HFS Spectrum



14 ground states + 2 isomers

Data analysis

Diode correction:

$$\nu_{\mathrm{T}} = \nu_{\mathrm{T}}^{\mathrm{read}} - (\nu_{\mathrm{T}}^{\mathrm{diode}} - \nu_{\mathrm{T=0}}^{\mathrm{diode}}).$$

vs

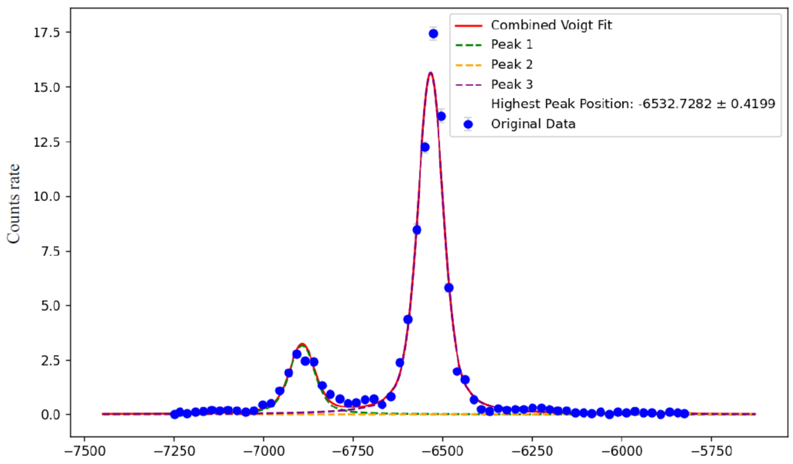
$$\nu_{\mathrm{T}} = \left(\alpha \frac{\nu_{\mathrm{T}}^{\mathrm{diode}} - \nu_{\mathrm{T=0}}^{\mathrm{diode}}}{\nu_{\mathrm{T=0}}^{\mathrm{diode}}} + 1\right) \nu_{\mathrm{T}}^{\mathrm{read}}$$

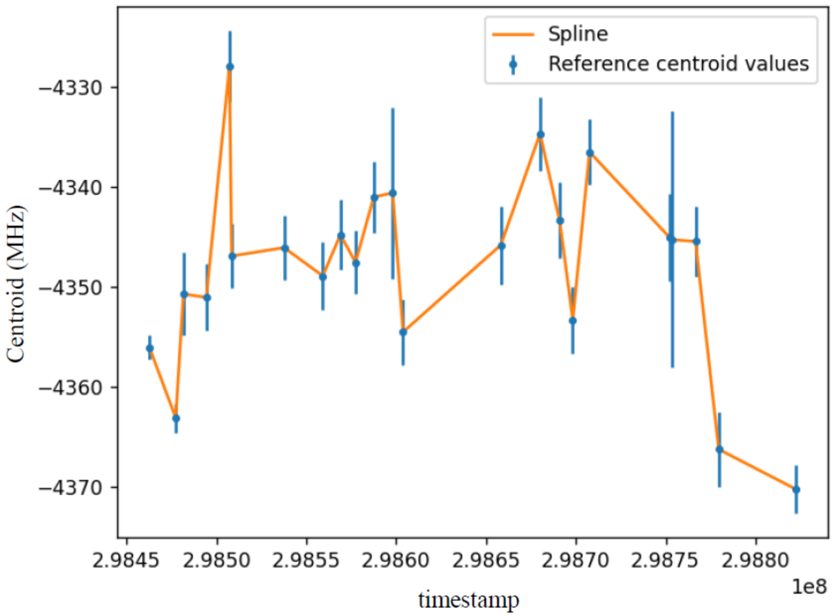
Reference scan: only LHS for most cases

Strategy I: fix Al (Au), fit Bu, centroid, fitting with 3 (overlapped) peaks on LHS;
→ saw relatively large ref errors (compare with CRIS 2023 experiments)

Strategy II:
fit all full ref scans to get a offset (Δ) from highest peak to centroid;
use Voigt fitting for LHS highest peak (P);
deduce centroid from P and Δ.

Reference correction only affects isotope shift!





Data analysis

isotope	spin	IS	A_l	A_u	B_u	Data sets
195	1.5	3036.6(14)	3099.1(20)	14.8(8)	361.9(18)	2
193	1.5	6143.6(27)	2939(4)	17.1(17)	396(4)	1
192	1	7827.5(28)	-251(4)	-3.9(27)	-127.8(21)	2
191	1.5	9221.2(24)	2889(4)	15.7(17)	429(5)	2
190	1	10662(13)	-2004(6)	-10.3(20)	-169(28)	2
189	5.5(m)	10865(7)	32540.6(13)	178.8(6)	1348(14)	2
189	0.5(g)	11618(9)	28654(10)	164(6)	/	2
188	1	13358(8)	-2008(5)	-13.9(24)	-184(3)	2
187	4.5(m)	5318(8)	22510.9(13)	122.1(9)	-1510(11)	2
187	0.5(g)	14692.6(23)	31338(4)	169.0(10)	/	4
185	2.5	3083.4(11)	25183.7(6)	134.7(5)	-623.2(19)	3
183	2.5	5469(6)	23020.6(19)	126.1(25)	-560(8)	2
182	2	6770(7)	22213.5(21)	122.1(18)	1301(6)	2
181	1.5	7394(3)	22808.8(25)	123.9(10)	765(5)	2
180	(1)	10562(6)	-21289(19)	-130(5)	32(13)	2

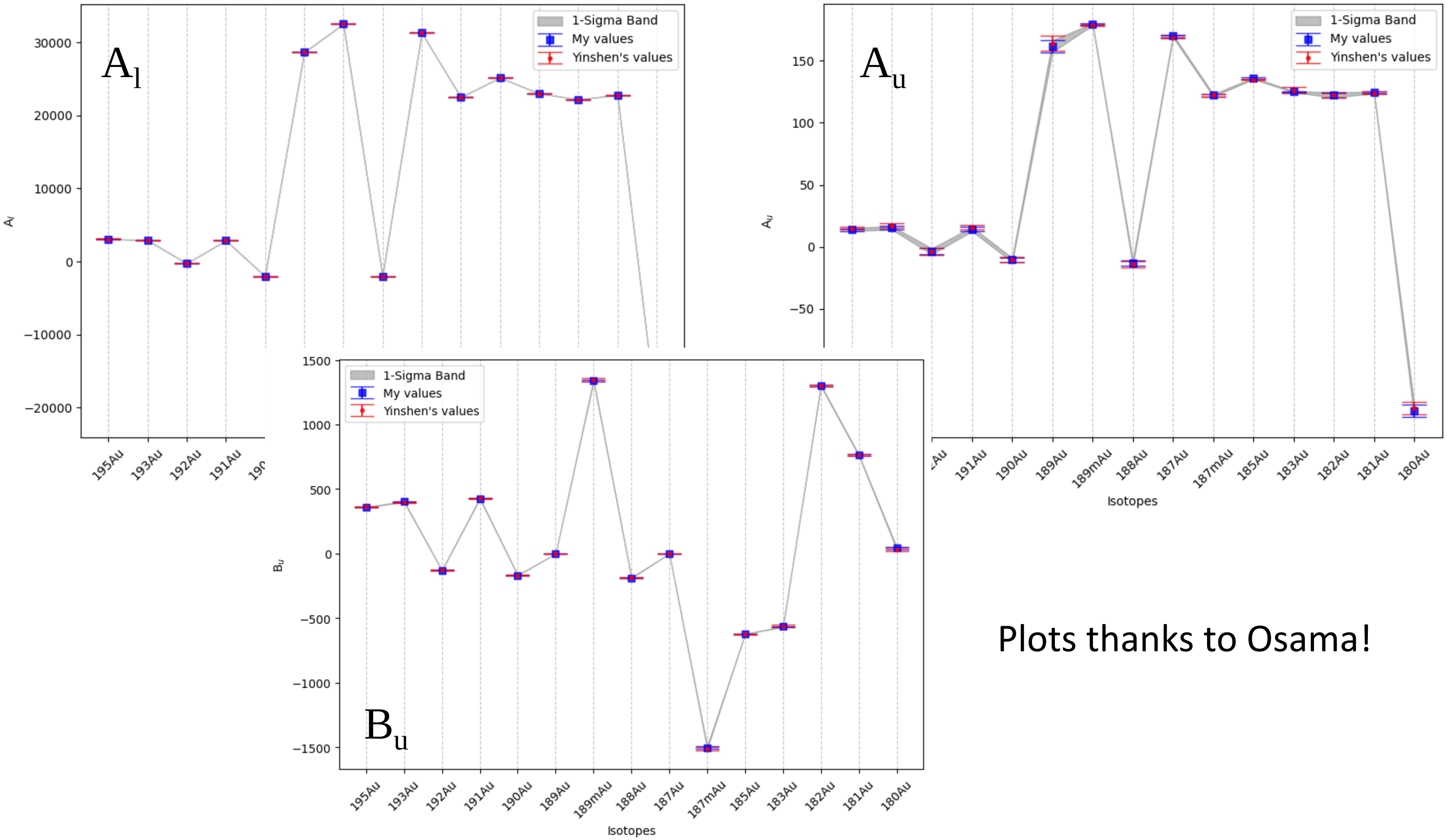
Satlas2 analysis result by Yinshen

A_l	A_u	B_u
3098.4 (21)	13.8(12)	360.4(17)
2935.4(31)	15.4(14)	402.4(36)
-251.9(38)	-3.6(24)	-128.7(19)
2890.7(33)	14.2(17)	427.7(45)
-1998.6(94)	-10.5(17)	-167.3(22)
28654.8(93)	161.7(48)	
32540.5(8)	179.2(7)	1339.2(87)
-2004.8(45)	-12.9(22)	-187.0(32)
31341.8(56)	169.9(11)	
22511.8(11)	122.08(9)	-1502(12)
25183.09(39)	135.63(65)	-621.6(12)
23021.5(13)	125.01(47)	-566.2(26)
22214.1(24)	122.3(21)	1300.9(62)
22809.7(17)	124.42(68)	763.5(52)
-21308(18)	-132.2(51)	42(9)

analysis result by Osama

Analysis parallelly and independently, all hfs constants are within 1-sigma!

Data analysis



Plots thanks to Osama!

Analysis parallelly and independently, all hfs constants are within 1-sigma!

Results

Spins:

^{181}Au: I = 3/2;

^{182}Au: I = 2;

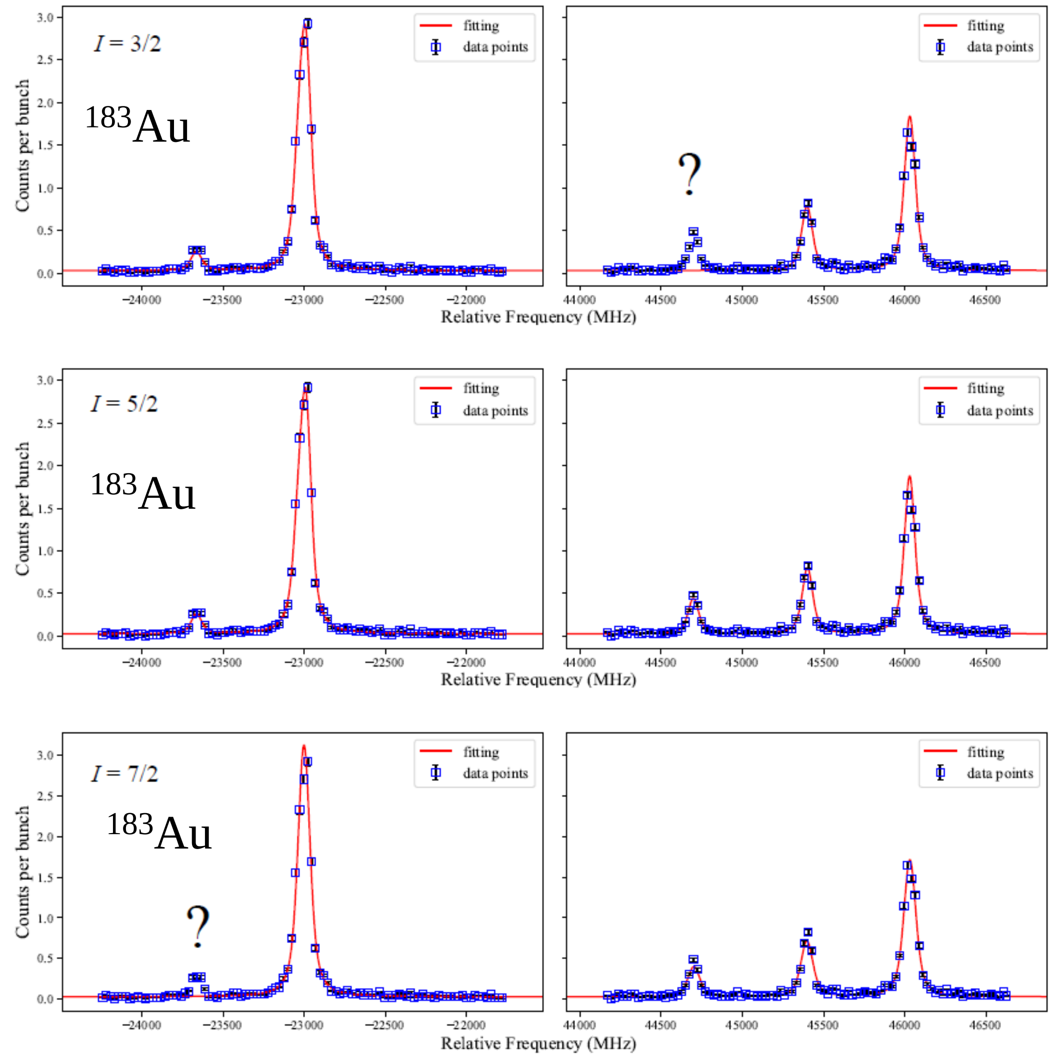
^{183}Au: I = 5/2;

Tentatively assigned in the literature,

Confirmed by us for the first time.

Isotope	Half-life	Spin
$^{181}Au_{101}$	13.7 s	$(3/2^-)$
$^{182}Au_{103}$	15.5 s	(2^+)
$^{183}Au_{104}$	42.8 s	$(5/2^-)$

^{180}Au: low statistic



Results

Charge radii

D2 line (King-plot):

$F = -39.6(6)\ \mathrm{GHz/fm^2}$,

$k = -1002(432)\ \mathrm{GHz\,u}$.

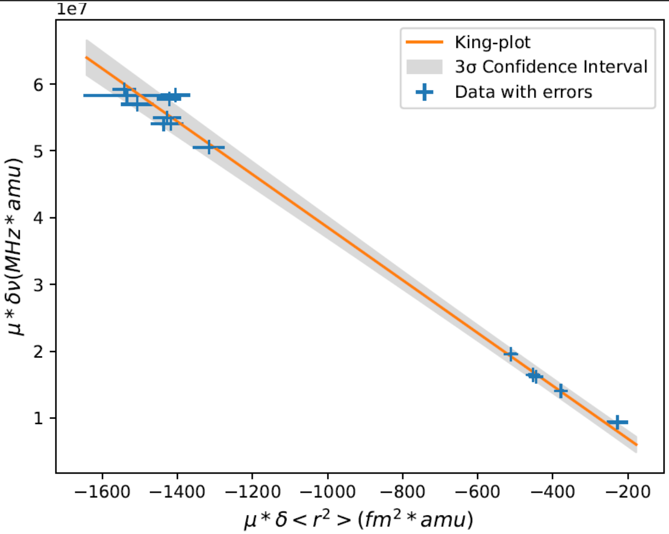
D1 line (atomic cal):

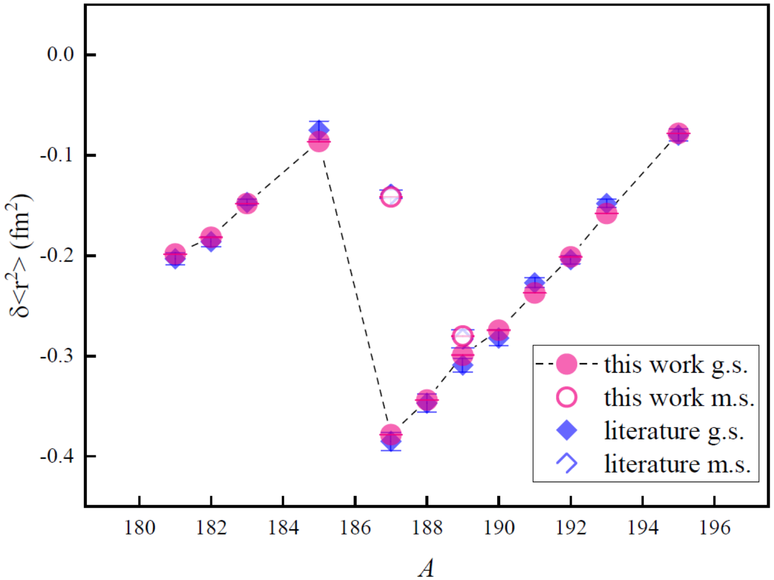
$F = -40.1(11)\ \mathrm{GHz/fm^2}$,

$k = 703(101)\ \mathrm{GHz\,u}$.

isotope	spin	Isotope Shift/MHz	$\delta\langle r^2\rangle/\mathrm{fm}^2$ (this work)	$\delta\langle r^2\rangle/\mathrm{fm}^2$ (literature)
195	1.5	3036.6(14)	-0.07808(4)[136]	-0.080(6)
193	1.5	6143.6(27)	-0.15797(7)[275]	-0.148(4)
192	1	7827.5(28)	-0.20122(7)[350]	-0.204(4)
191	1.5	9221.2(24)	-0.23714(6)[414]	-0.227(5)
190	1	10662(13)	-0.2743(3)[48]	-0.282(8)
189	5.5(m)	10865(7)	-0.28010(18)[502]	-0.283(9)
189	0.5(g)	11618(9)	-0.29913(23)[529]	-0.309(7)
188	1	13358(8)	-0.34383(20)[606]	-0.347(9)
187	4.5(m)	5318(8)	-0.14131(20)[372]	-0.139(4)
187	0.5(g)	14692.6(23)	-0.37829(6)[669]	-0.385(9)
185	2.5	3083.4(11)	-0.08628(3)[385]	-0.075(9)
183	2.5	5469(6)	-0.14808(15)[485]	-0.147(3)
182	2	6770(7)	-0.18173(18)[540]	-0.186(5)
181	1.5	7394(3)	-0.19827(8)[582]	-0.203(6)

(): statistical errors; []: systematic errors from F & k.





Results

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Magnetic moments:

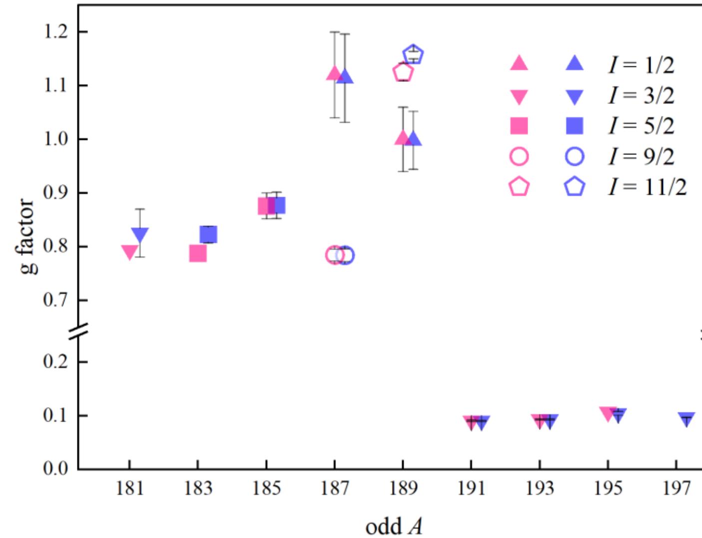
$$\mu_A = \mu_{ref} \frac{I_A}{I_{ref}} \frac{Al_A}{Al_{ref}} (1 + {}^{ref}\Delta^{A})$$

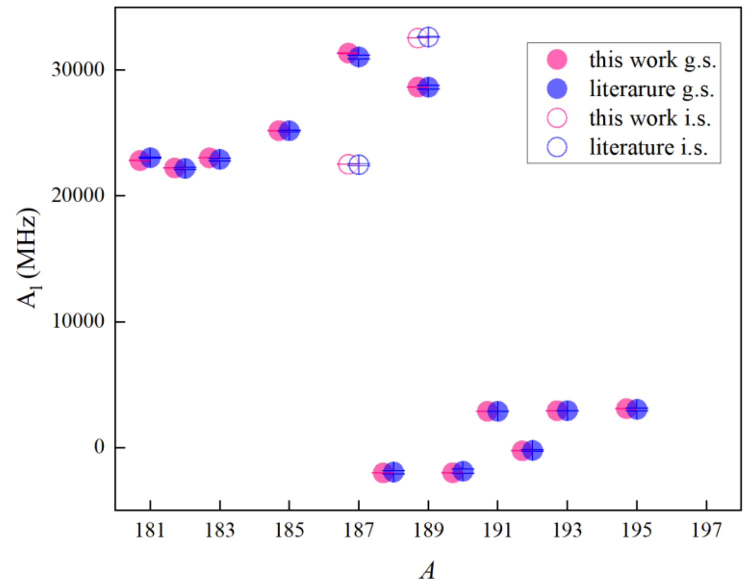
μ errors mainly come from relative hyperfine anomaly calculation (RHFA)

μ without available RHFA information are evaluated with empirical ML rule. In this case errors are not given.

$$\mu = A_l I / 29005 \pm 0.012,\ I = l \pm 1/2$$

isotope	spin	A_l/MHz	$A_{l\mathrm{ref}}$/MHz	RHFA	μ_A/μ_N (this work)	μ_A/μ_N (literature)
195	1.5	3099.1(20)	3040(90)		0.160	0.157(5)
193	1.5	2939(4)	2941(5)	-0.005(11)	0.1397(16)	0.1398(15)
192	1	-251(4)	-220(60)		-0.009	-0.0107(15)
191	1.5	2889(4)	2885(3)	-0.012(14)	0.1364(19)	0.1363(19)
190	1	-2004(6)	-1870(180)		-0.069	-0.065(7)
189	5.5(m)	32540.6(13)	32625(42)	0.086(16)	6.19(9)	6.365(38)
189	0.5	28654(10)	28632(128)	0.09(6)	0.499(27)	0.499(27)
188	1	-2008(5)	-1940(127)		-0.069	-0.07(3)
187	4.5(m)	22510.9(13)	22480(90)	0.095(16)	3.53(5)	3.529(53)
187	0.5	31338(4)	31032(168)	0.13(8)	0.56(4)	0.557(41)
185	2.5	25183.7(6)	25176(56)	0.09(3)	2.19(6)	2.193(61)
183	2.5	23020.6(19)	22900(100)		1.972	2.057(39)
182	2	22213.5(21)	22180(80)	0.17(7)	1.66(10)	1.664(91)
181	1.5	22808.8(25)	23037(40)		1.192	1.238(67)





Results

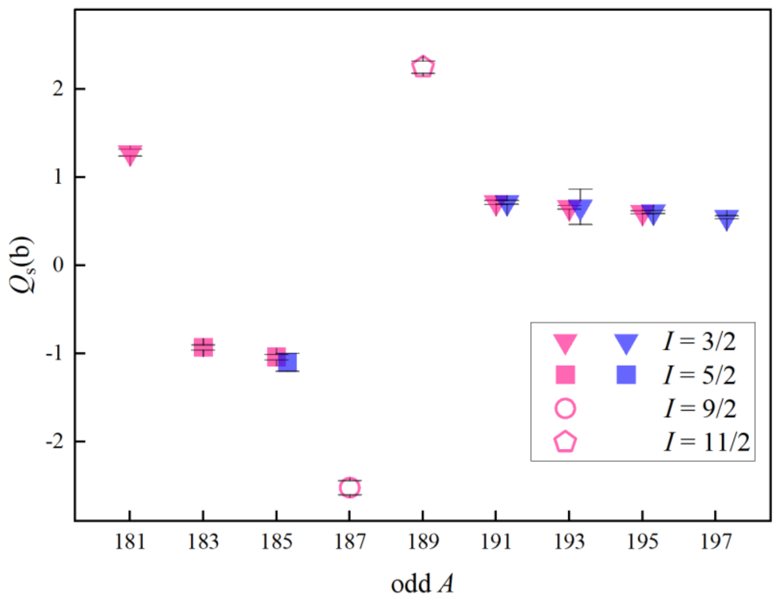
Quadrupole moments:

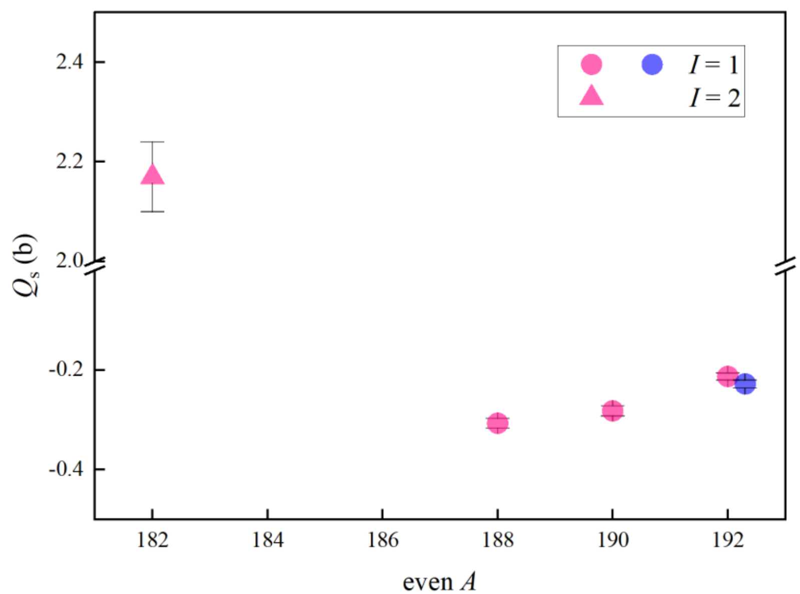
$$Q_A = Q_{197} \frac{Bu_A}{Bu_{197}}$$

$Bu_{197} = 328(2)$ MHz

$Q_{197} = 0.547(16)$ b

isotope	spin	B_u/MHz	Q/b (this work)	Q/b (literature)
195	1.5	361.9(18)	0.604(18)	0.607(18)
193	1.5	396(4)	0.660(21)	0.664(20)
192	1	-127.8(21)	-0.213(7)	-0.228(8)
191	1.5	429(5)	0.715(23)	0.716(21)
190	1	-169(28)	-0.282(10)	
189	5.5(m)	1348(14)	2.25(7)	
188	1	-184(30)	-0.307(10)	
187	4.5(m)	-1510(11)	-2.52(8)	
185	2.5	-623.2(19)	-1.04(3)	-1.10(10)
183	2.5	-560(8)	-0.93(3)	
182	2	1301(6)	2.17(7)	
181	1.5	765(5)	1.28(4)	



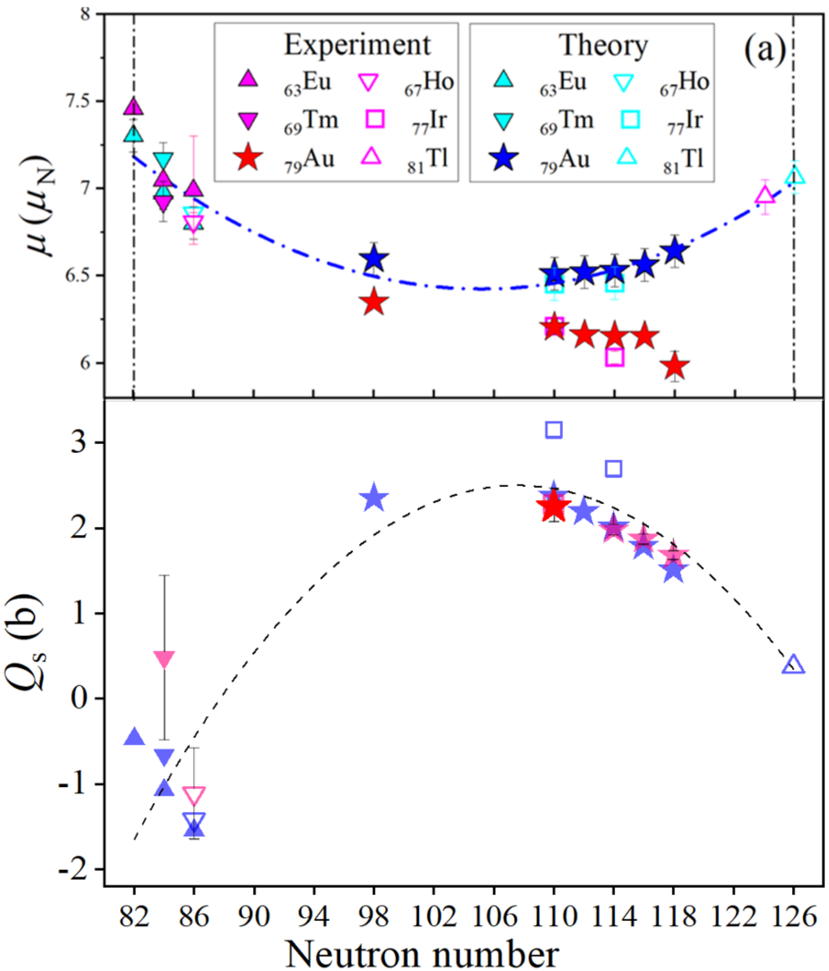


Results

189m: $\pi h_{11/2}$ state in odd Z even N $(63 \le Z \le 82, 82 \le N \le 126)$

Both μ and Q_s show the nearly parabolic trends;

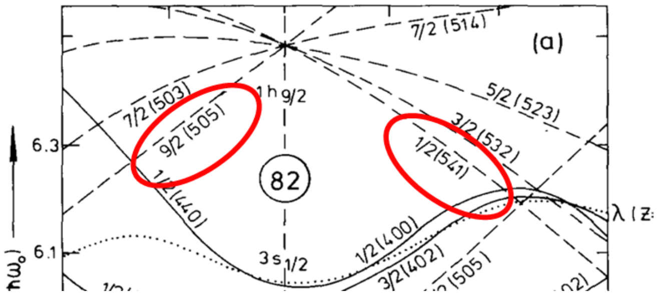
- Previous interpretation for μ: 1st order core-polarization correction due to $\nu f_{7/2} \rightarrow \nu f_{5/2}$
- DFT calculations reproduced μ and spectroscopic Q_s without using effective charges, including the ^{189m}Au (this work), and 193,195,197 gold isomers (literature)
- time-reversal symmetry breaking impacts very little (<1%) on Q_s, while Angular Momentum Projection plays a vital role in spectroscopic Q_s calculation;
- effective test for the validity of DFT.

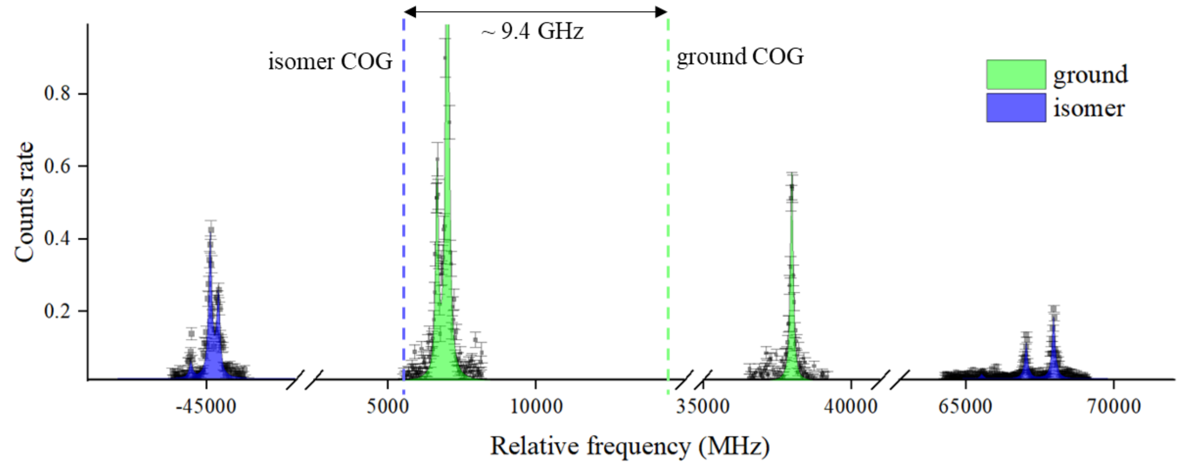


J. Bonnard, et al. Phys. Lett. B, 843 (2023) 138014

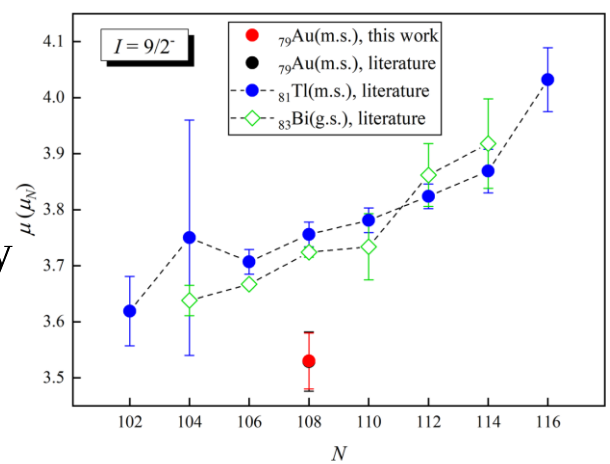
Results

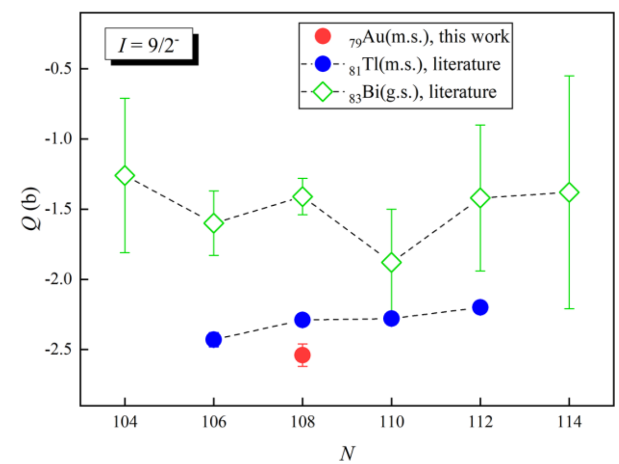
187m: shape coexistence





- Previous interpretation based on μ suggested a rotation band build on 1/2[541], e.g. prolate deformation;
- $Q_s < 0$, the 9/2- isomer is likely to be formed as 9/2[505] at moderate oblate deformation just like nearby Tl isomer;





A. E. Barzakh et al., Phys. Rev. C, 101, 064321 (2020)

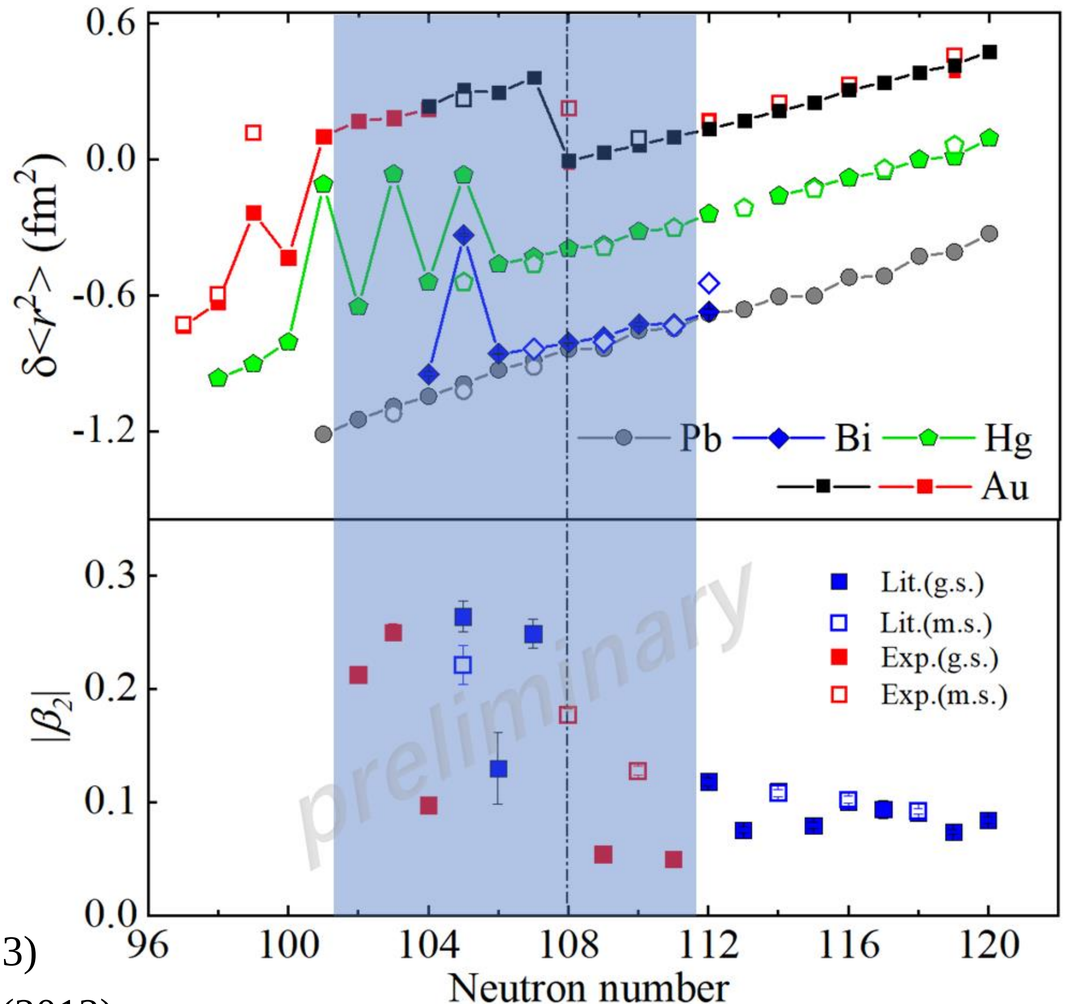
Results

Island of deformation

$$Q_s = \frac{3K^2 - I(I+1)}{(2I+3)(I+1)} Q_{intr.}$$

$$Q_{intr.} = \frac{3}{\sqrt{5\pi}} Z R_0^2 \beta_2 (1 + 0.36\beta_2).$$

- For now the strong coupling assumption ($K = I$) is used in β_2 extraction;
- potential of nonaxial deformation?
- …



B. Bally, et al., Eur. Phys. J. A 59, 58 (2023)

Y. Oktem et al., Phys. Rev. C, 86, 054305 (2012)

L. K. Peker et al., Phys. Rev. C, 20, 855 (1979)

Summary:

- Firmly determine the spins of 181-183;
- Quadrupole moments of 7 states;
- 3 physics cases are (partially) investigated;

Outlook:

- ☐ Approaching more neutron-deficient side (e.g. 176-180) and isomers in the next gold run (13 shifts remaining);
- ☐ Calculation and interpretation for Q_s and deformation parameters;
- ☐ …

Thanks for your attention!

Shift schedule: original

"Due to the technical stop, our run will be divided into 2 parts:
1st: 06/06(Thur) afternoon- 11/06(Tue) morning
2nd: 14/06(Fri) afternoon- 18/06(Tue) afternoon"

Thursday	06-06	night								
		AM			8:30 Continue with setup	GPS				
					Proton scan + yield checks		8:30 #834M			
		PM	Au		Stable beam to CRIS	HRS	Direct (-10,-63)	MEDICIS		
Friday	07-06	night								
		AM					11:00 Change trolley			
		PM			IS737 - 177-188Au - 30 keV		Indirect (0,0)			
Saturday	08-06	night								
		AM			IS737 - 177-188Au - 30 keV			NORMHRS		
		PM								
Sunday	09-06	night								
		AM			IS737 - 177-188Au - 30 keV					
		PM								
Monday	10-06	night								
		AM		9:30 #534-Sn-VD7				8:30 - 10:30		
					IS737 - 177-188Au - 30 keV			NORMHRS		
		PM								

Summary: On GPS, IDS and ECSLI finish on Thursday 8:30. Short interruption for target change on Tuesday afternoon. On HRS, setup for CRIS on Thursday, in the evening, 3 shifts of stable beam to CRIS. Protons for CRIS on Friday afternoon.

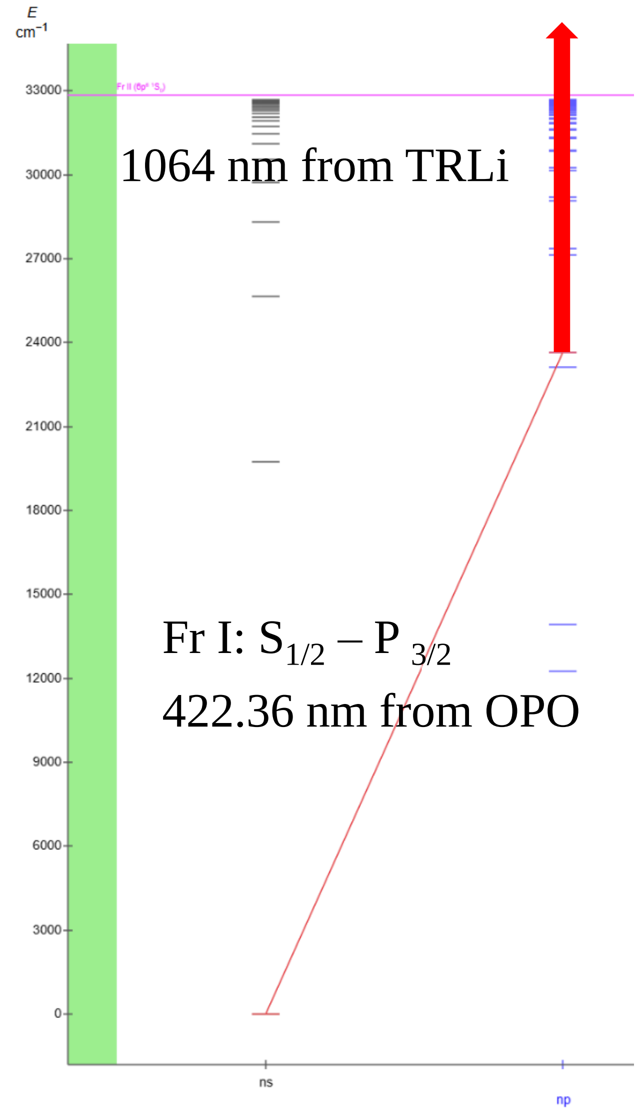
11 shifts with protons at 1st half according to the plan

Failed to see any gold RIS signal before the end of 1st half
Mainly due to ISOLDE side ☹:
No gold mass marker;
Contamination.

1st half summary

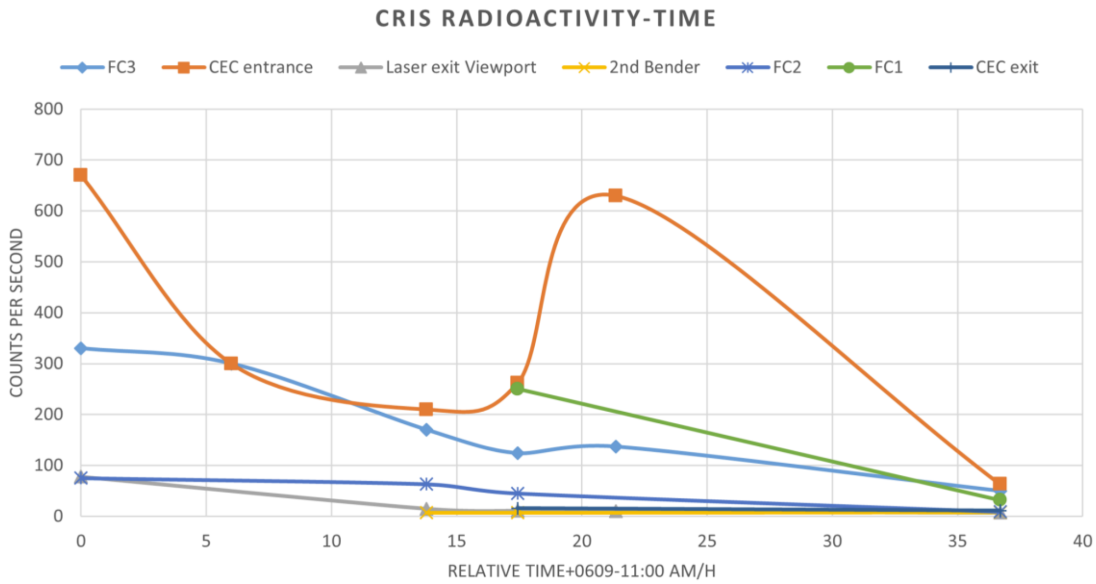
What we managed to achieve:

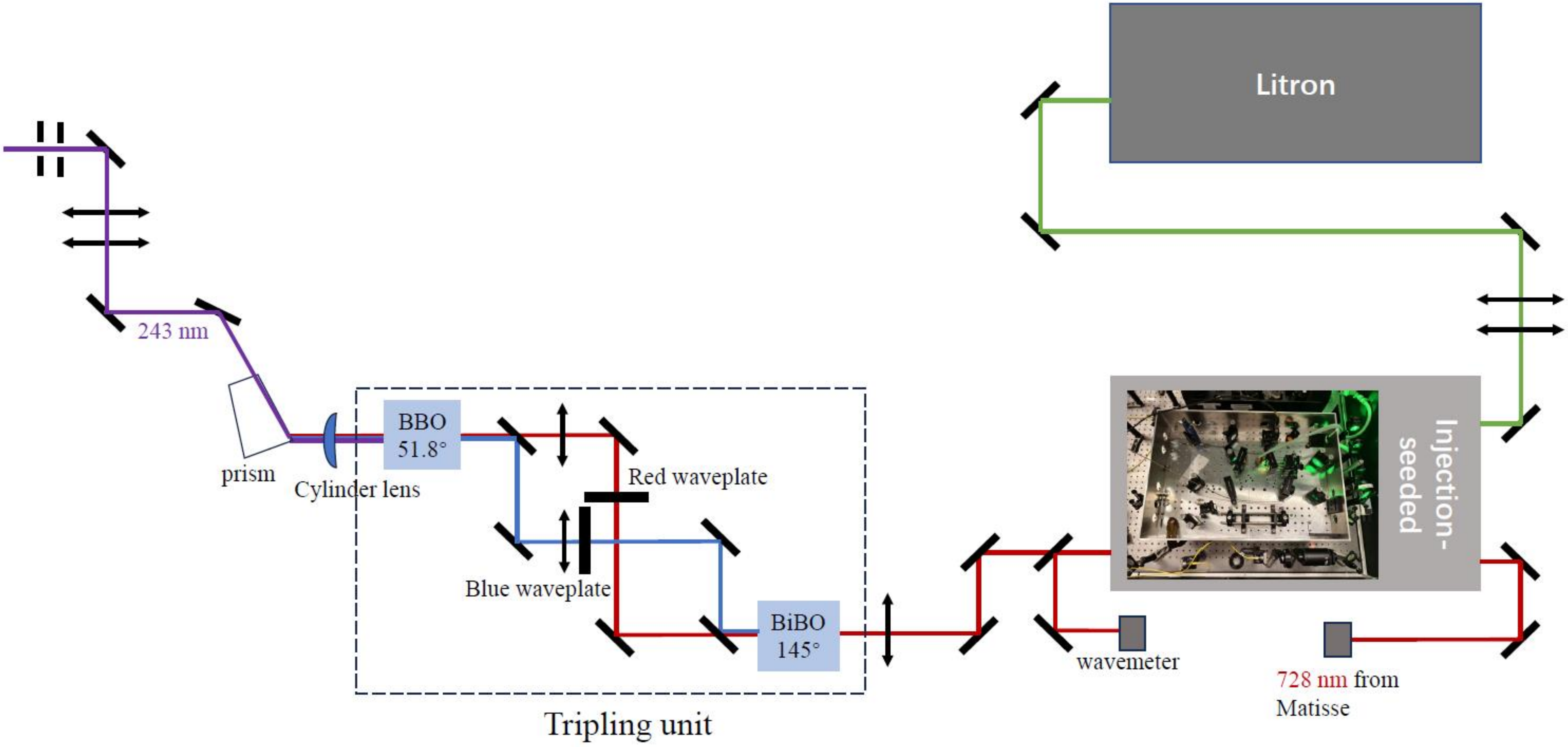
- **Successfully find out ^{221}Fr RIS signal** to make sure our setup is working ideally and a beneficial training for fresh blood
- Beamtune with stable K&U
- Set up correct laser/beam timing, prepare proton beamgate
- Locate the source of heating up downstairs laser tent which cause unstable OPO

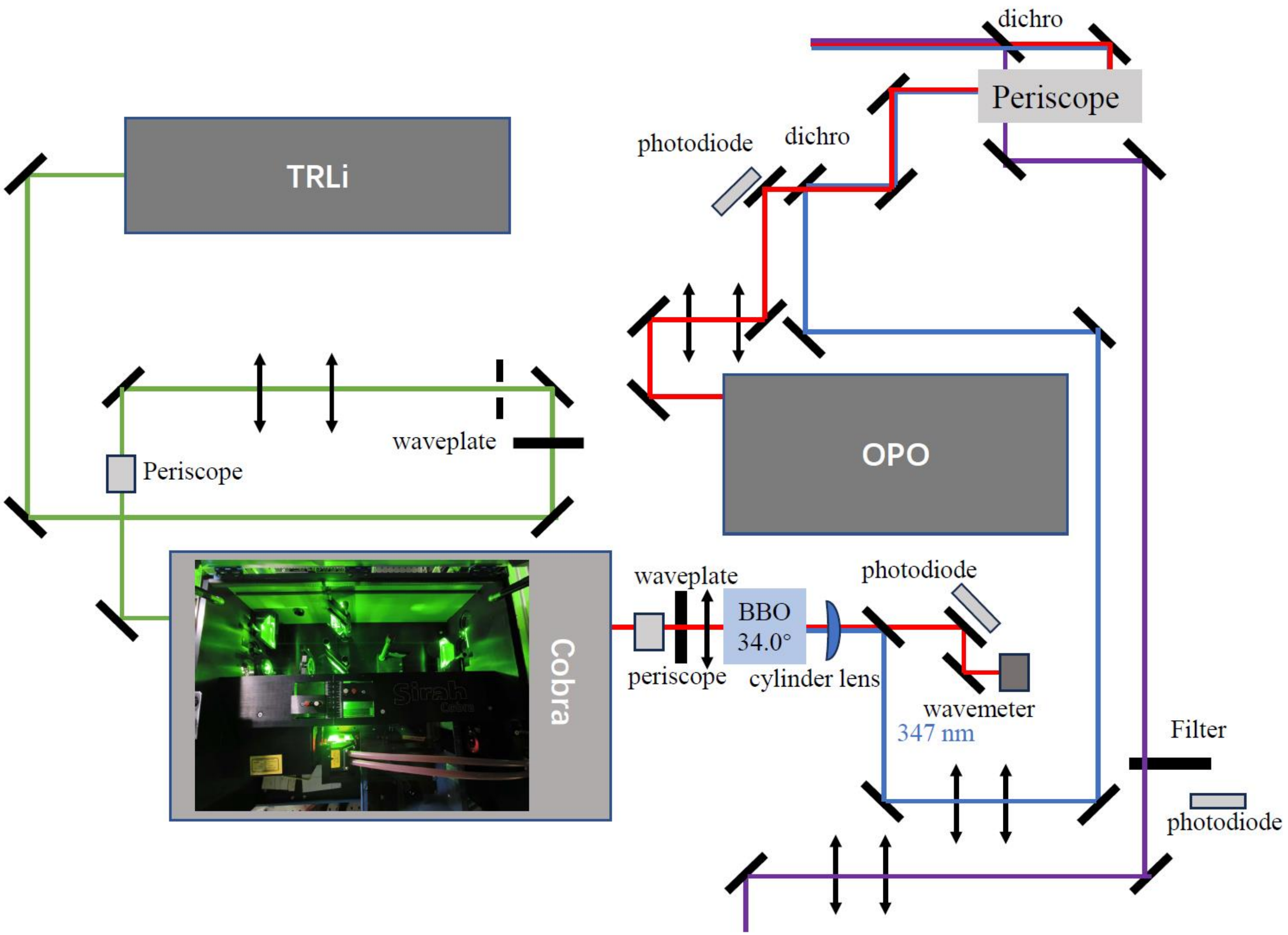


2nd part preparation

- New gold target with mass marker (#839-UC-MI1(Ta)), “pure” gold beam from mass marker&RILIS
- Beam time extended (stable beam started at Fri. afternoon, gave proton to ISOLTRAP next Thur. afternoon)
- Proton sharing with solid physics
- …




Litron
243 nm
prism
Cylinder lens
BBO
51.8°
Red waveplate
Blue waveplate
BiBO
145°
Tripling unit
Injection-
seeded
wavemeter
728 nm from
Matisse


dichro
Periscope
photodiode
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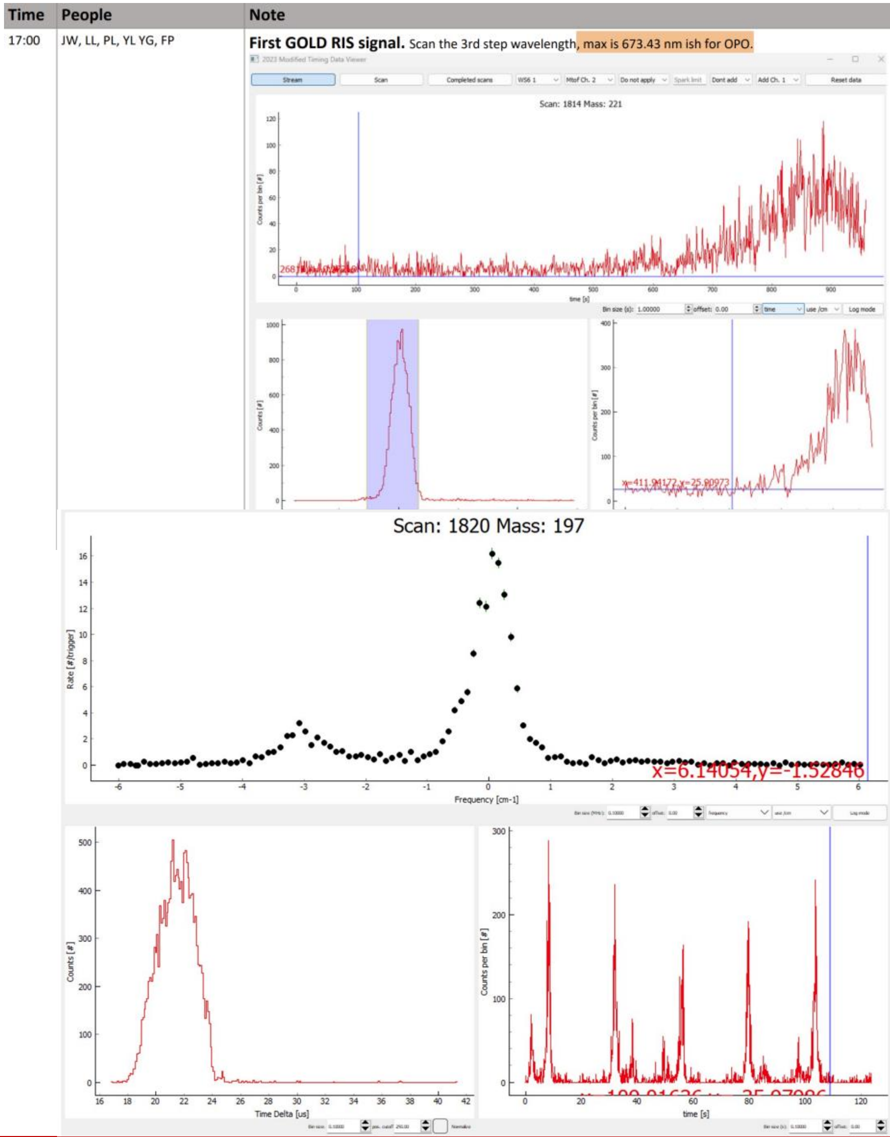
TRLi
waveplate
Periscope
OPO
Cobra
waveplate
BBO
34.0°
photodiode
periscope
cylinder lens
wavemeter
347 nm
Filter
photodiode

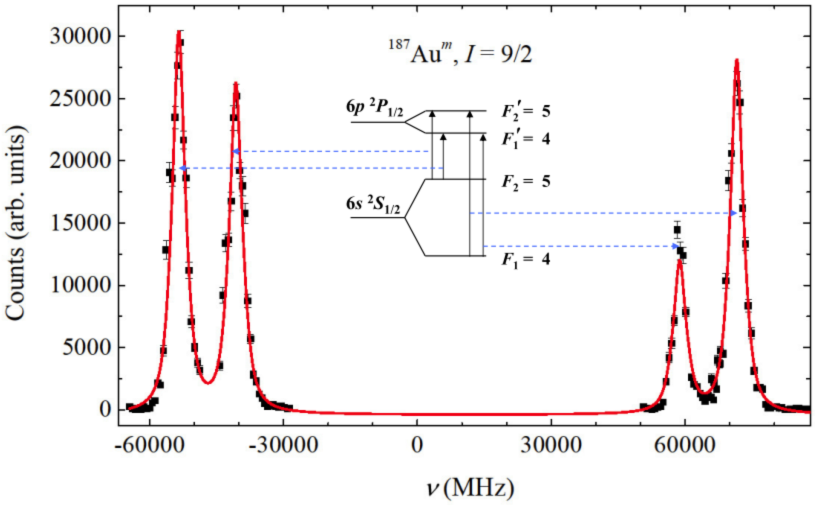
1st gold RIS and 1st scan

- Strange TOF (multipole peaks) – overfilled ISCOOL by wrong QC setting
- 1st RIS signal of gold when optimizing laser frequency.
- Reshaped laser profile, optimized timing (ISCOOL, lasers) and laser position, beamtuning
- Saturation curve. Efficiency (best 1:800) vs linewidth (best ~ 100 MHz). Laser on/off = 800:1 (versus collisional bkg)
- After located every peak position, 1st voltage scan: scan 1820 (LHS of 197g)

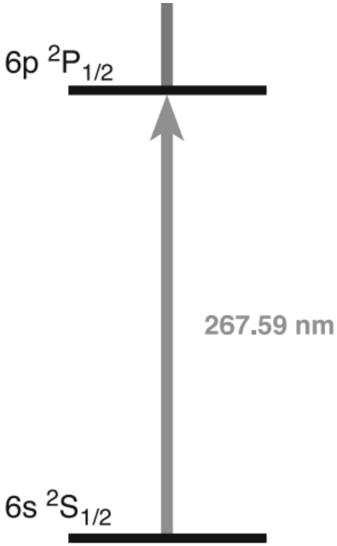


Searching for g.s & i.s.

- Used 197&192 to adjust prediction, almost every g.s. could be easily located around predicted value (off by ~ 0.004 cm^{-1})
- But we could not see even one single isomer with scanning 1st & 2nd steps.



- RILIS 1st step is broad but may not be broad enough. Especially for isomers with large spins (e.g. 9/2-, 11/2-) we are expecting over 100 GHz for D1 transition.
- Shifted 1st step of RILIS and we saw our 1st isomer at predicted wavenumber!

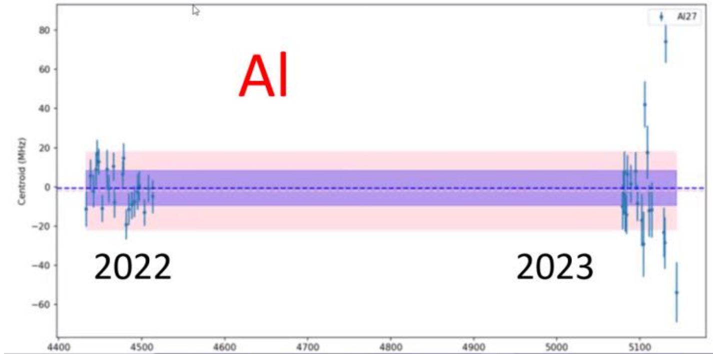


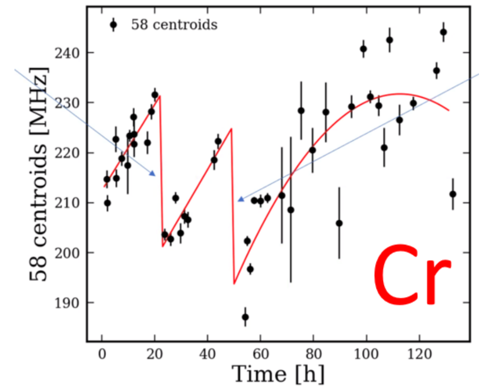
Details in reference analysis

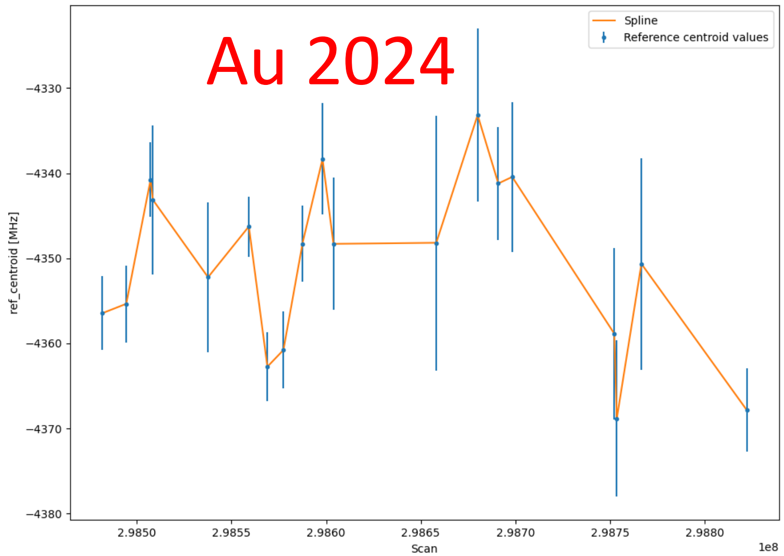
Ref scans: only LHS for most cases

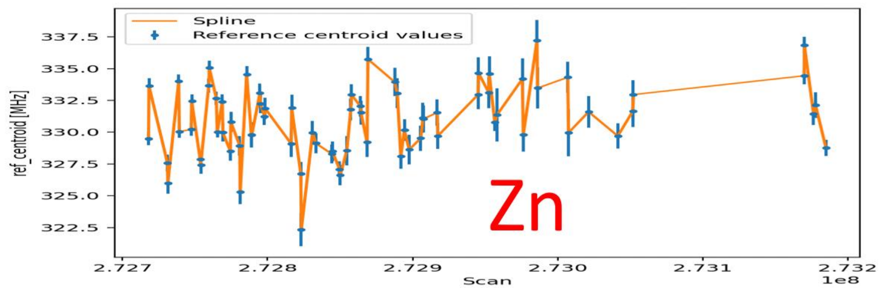
Strategy in Round I: fix Al (Au), fit Bu, centroid with 3 (overlapped) peaks

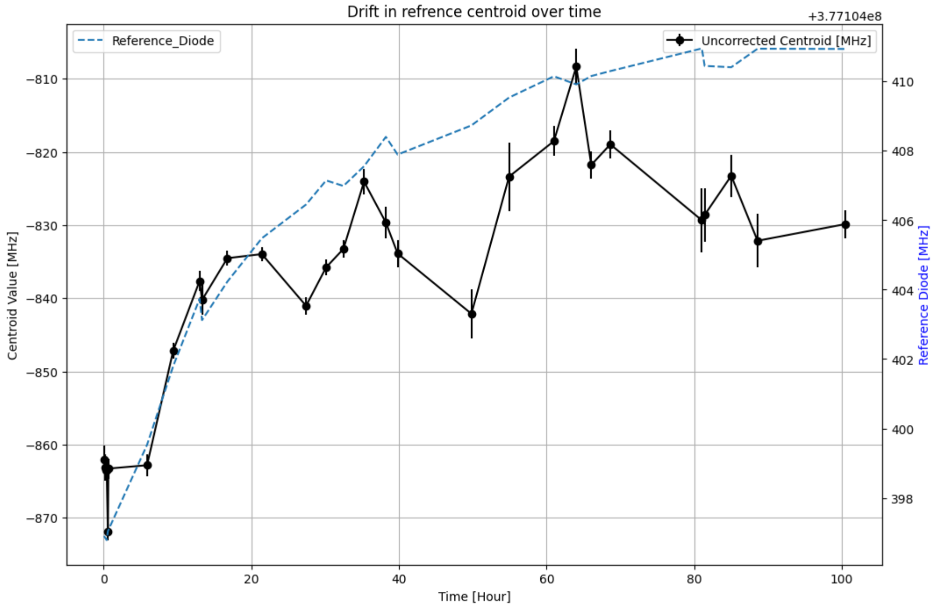
Comments: large ref errors (compare with CRIS 2023 experiments)

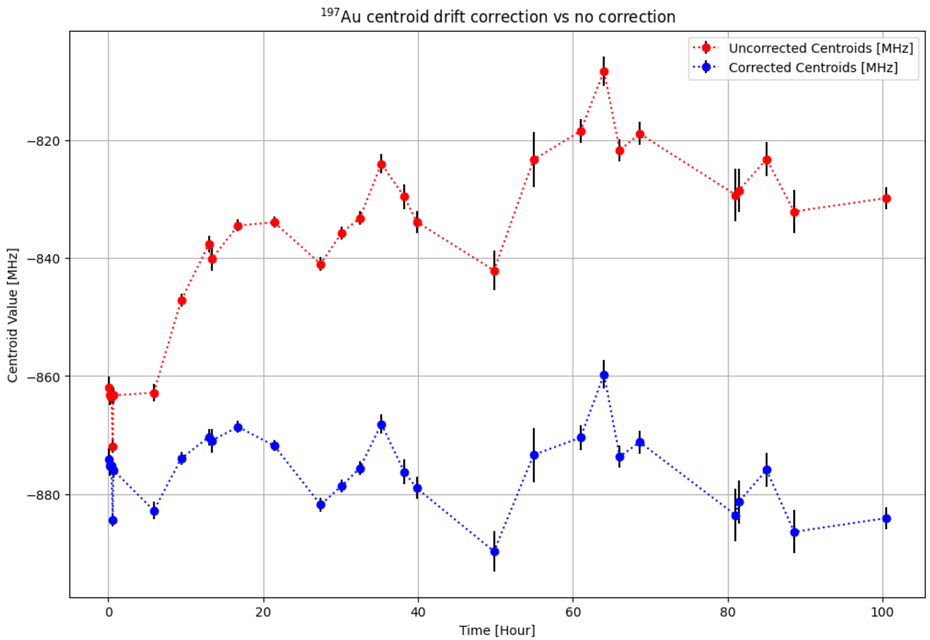








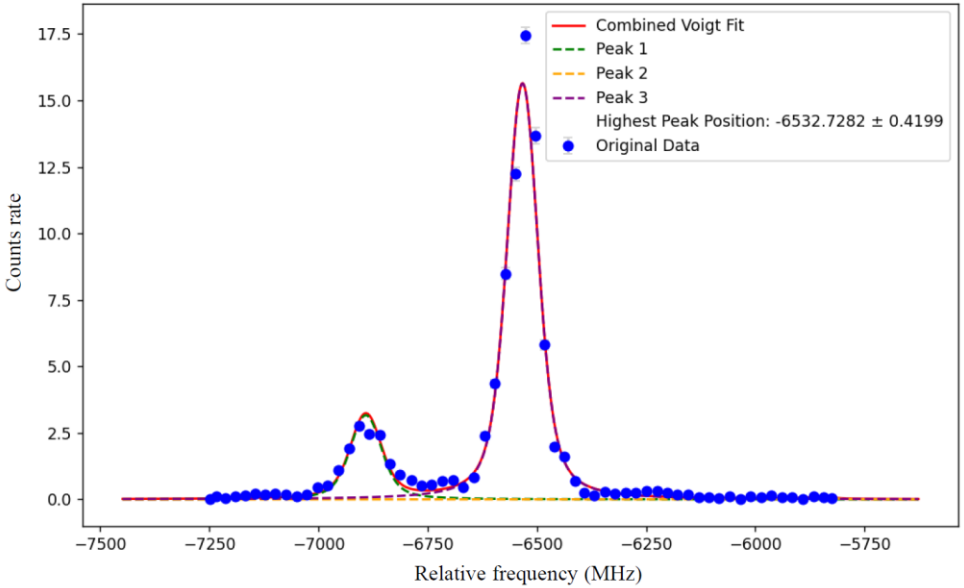

Drift in refrence centroid over time
+3.77104e8
Reference_Diode
Uncorrected Centroid [MHz]
Centroid Value [MHz]
Reference Diode [MHz]
Time [Hour]

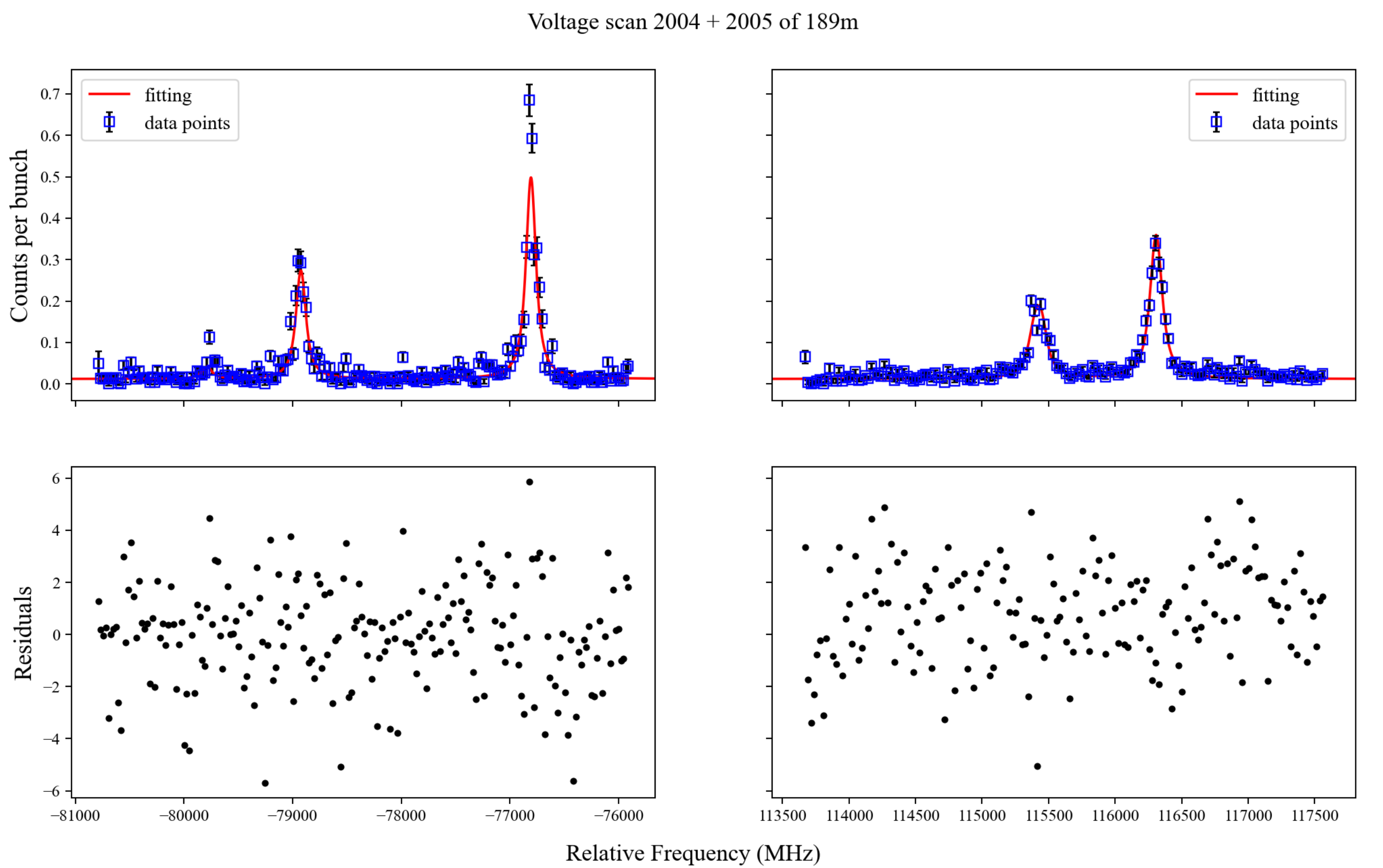

197Au centroid drift correction vs no correction
Uncorrected Centroids [MHz]
Corrected Centroids [MHz]
Centroid Value [MHz]
Time [Hour]

reference analysis

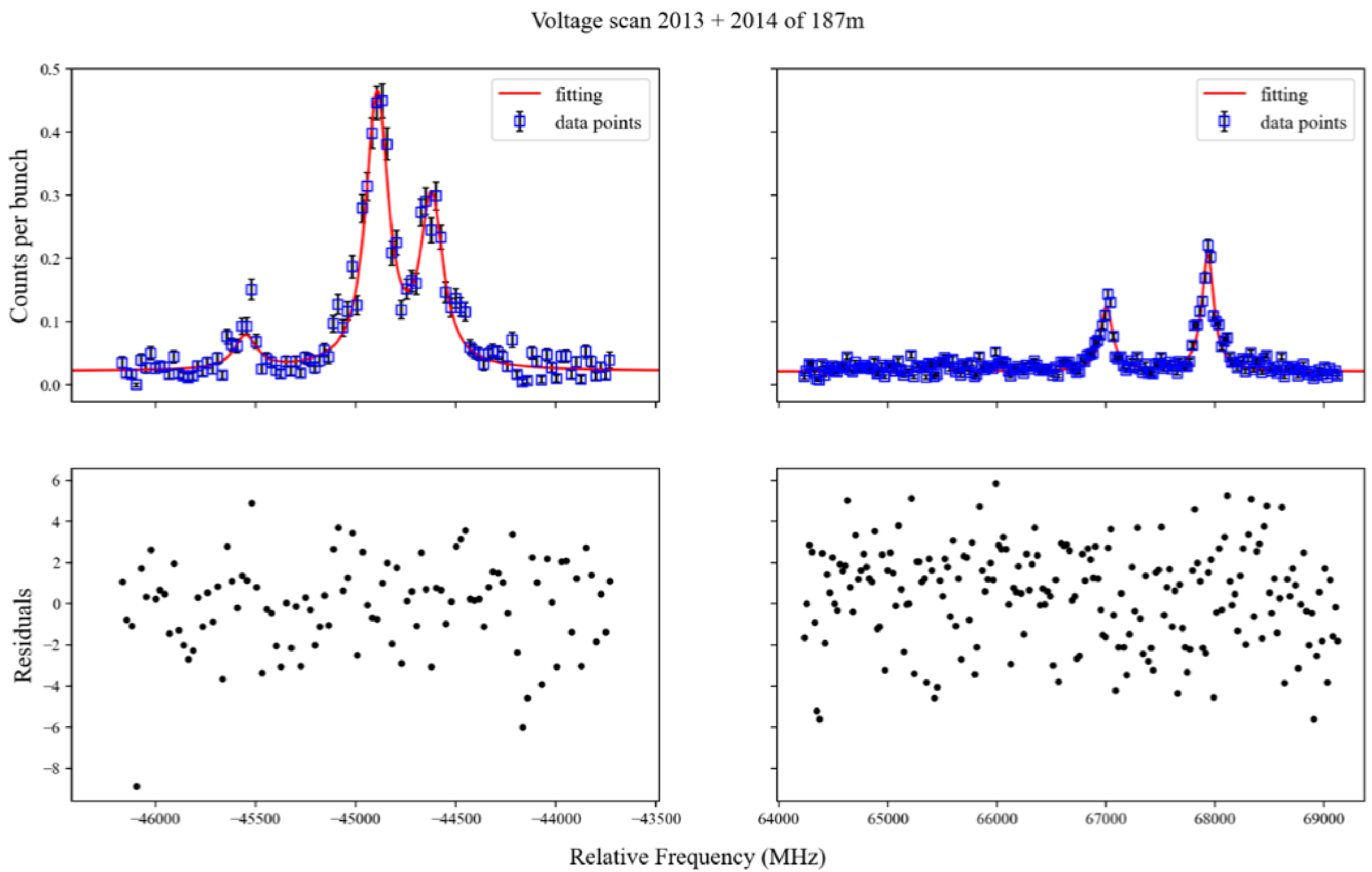
scan number	centroid	error	P	error	$\Delta =$ COG $- P$	error
1820+1821	−4356.1	1.2	−6532.7	0.4	2176.6	1.3
1822	−4363.1	1.4	−6548.0	0.9	2184.8	1.7
1939+1940	−4390.2	4.0	−6523.8	3.4	2133.7	5.3
2030+2031	−4370.3	2.4	−6541.5	2.1	2171.3	3.2

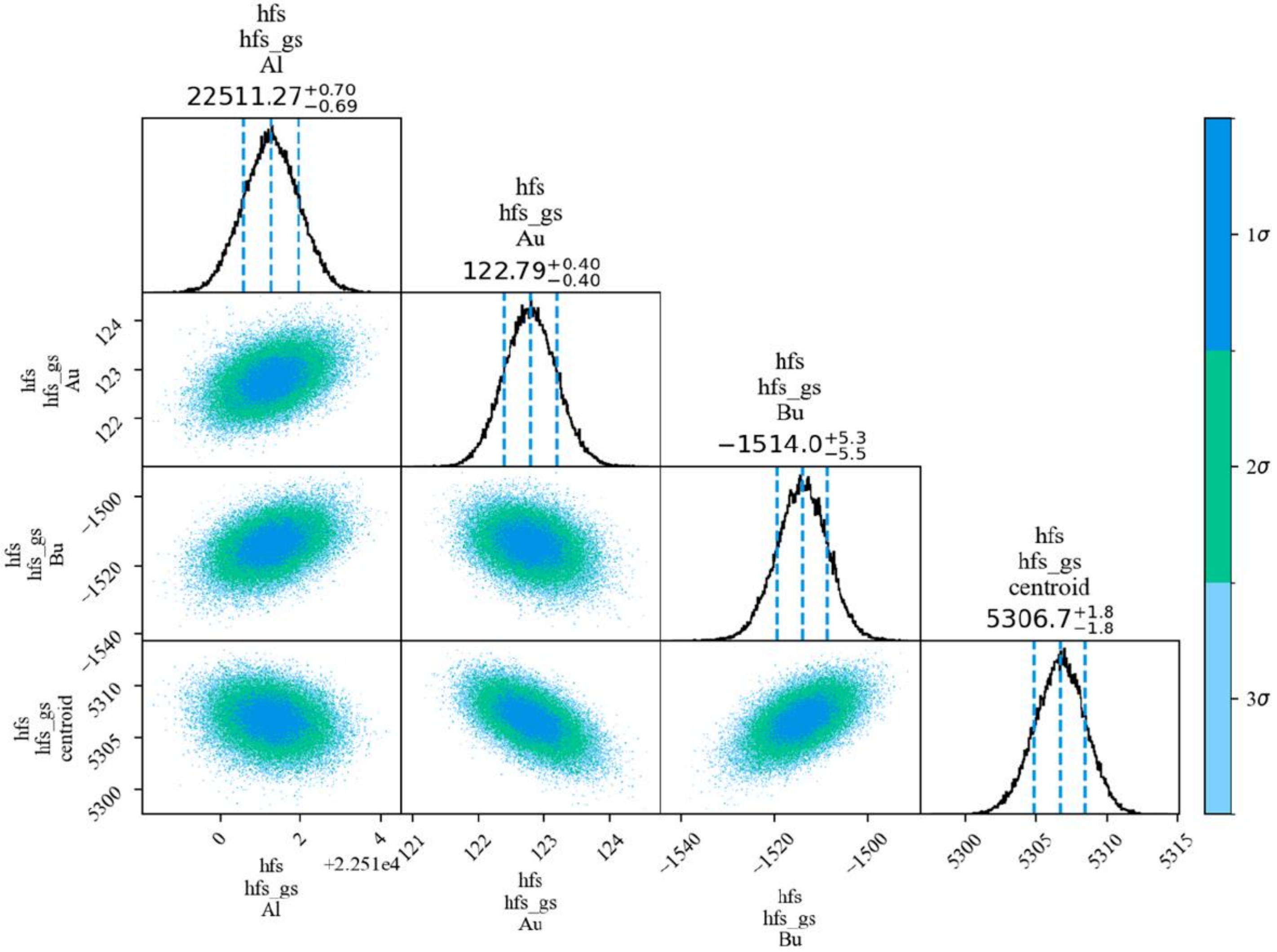
$$\Delta = \text{centroid} - P = 2178.8(31)\ \text{MHz},$$





Voltage scan 2004 + 2005 of 189m
fitting
data points
Counts per bunch
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Residuals
6
4
2
0
−2
−4
−6
−81000
−80000
−79000
−78000
−77000
−76000
113500
114000
114500
115000
115500
116000
116500
117000
117500
Relative Frequency (MHz)


Voltage scan 2013 + 2014 of 187m
Counts per bunch
Residuals
fitting
data points
Relative Frequency (MHz)
-46000
-45500
-45000
-44500
-44000
-43500
64000
65000
66000
67000
68000
69000


hfs
hfs_gs
Al
22511.27$^{+0.70}_{-0.69}$
hfs
hfs_gs
Au
122.79$^{+0.40}_{-0.40}$
hfs
hfs_gs
Bu
−1514.0$^{+5.3}_{-5.5}$
hfs
hfs_gs
centroid
5306.7$^{+1.8}_{-1.8}$
1σ
2σ
3σ
+2.251e4