High-resolution laser spectroscopy of light gold isotopes: investigation of “**island of deformation**” and **shape coexistence**

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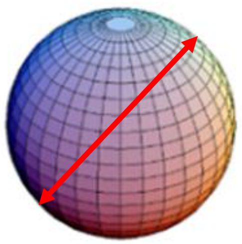
Contents

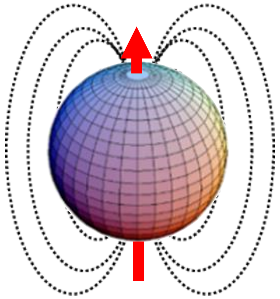
Research context

Laser spectroscopy of exotic nuclei → aimed to investigate **nuclear structure** and **nuclear force**

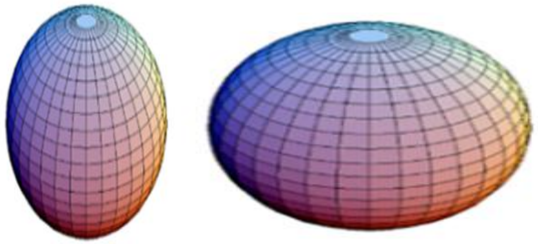
The *nuclear charge radius* and the *nuclear electromagnetic moments* are important observables to study the **nucleon-nucleon** interaction:



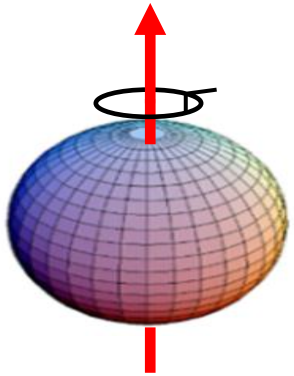
charge radius
(R)



Magnetic dipole moment
(μ)



electric quadrupole moment
(Q_s)

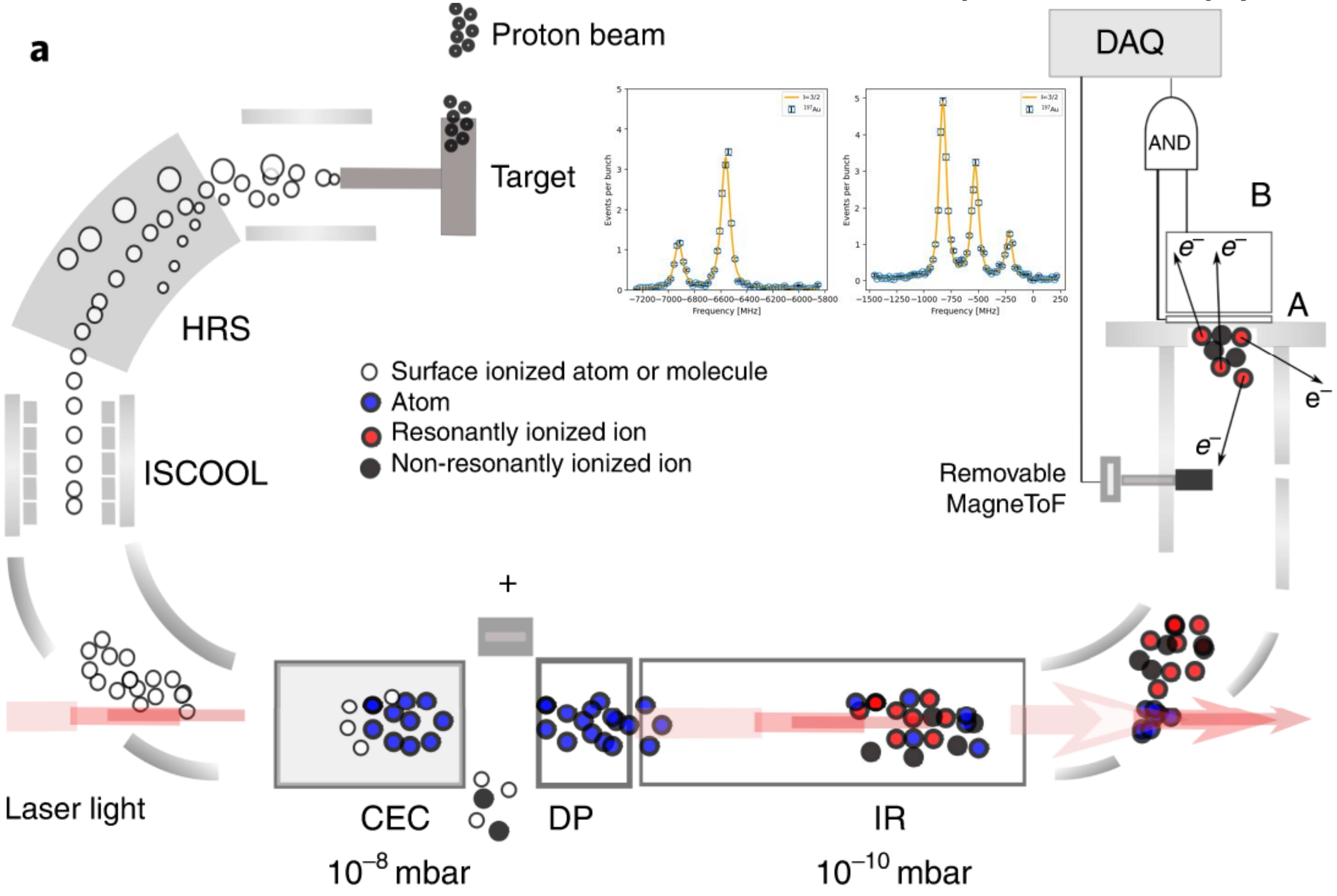


Nuclear spin
(I)

With laser spectroscopy, we can probe these observables in a **nuclear model independent method**.

CRIS @ ISOLDE

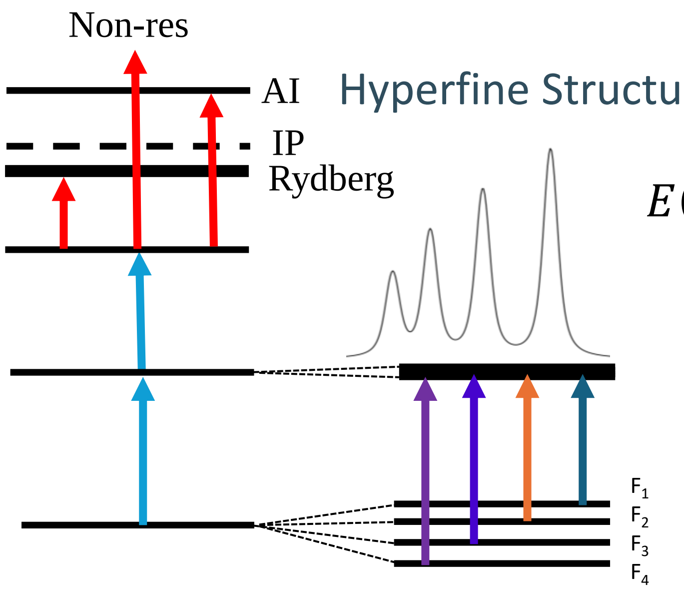
CRIS : Collinear Resonance Ionization Spectroscopy



✓ High sensitivity : > few 10 ions/s

✓ High resolution : > 20 MHz

✓ Versatility



Hyperfine Structure (HFS) :

$$E(F) = kA + k'B$$

$$A = \frac{\mu\, Be(0)}{I.J}$$

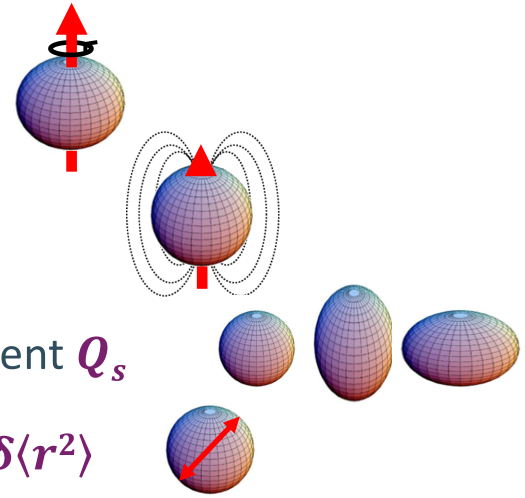
$$B = e\, \boldsymbol{Q_s}\, V(0)$$

Isotope shift : shift of HFS between two isotopes A and A'

$$\delta\nu_i^{A,A'} = \frac{A - A'}{AA'} M_i + F_i\, \delta\langle r^2\rangle^{AA'}$$

Measuring the HFS :

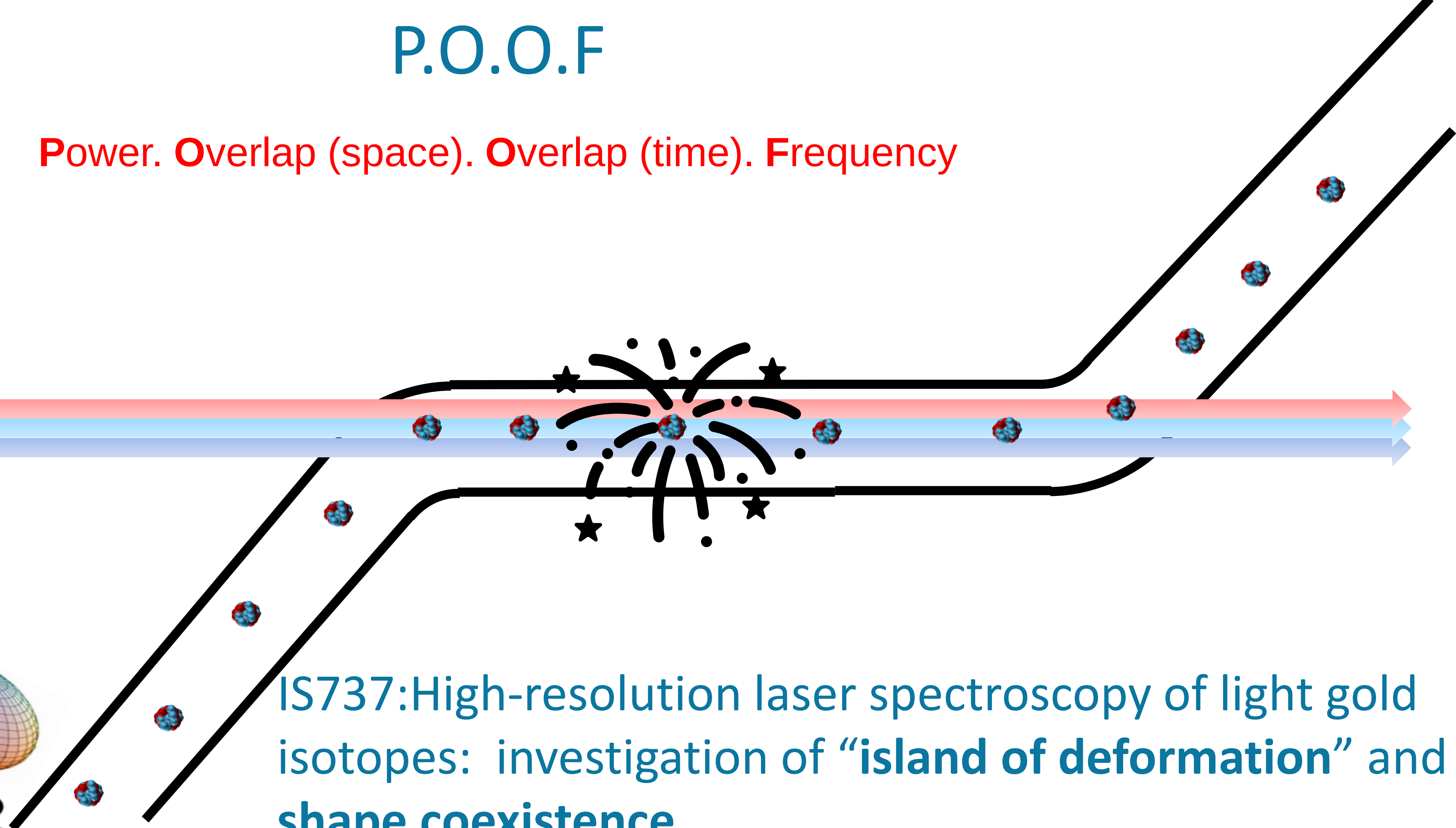
- Nuclear Spin I
- Magnetic dipole moment μ
- Electric quadrupole moment $\boldsymbol{Q_s}$
- Changes of charge radii $\boldsymbol{\delta\langle r^2\rangle}$

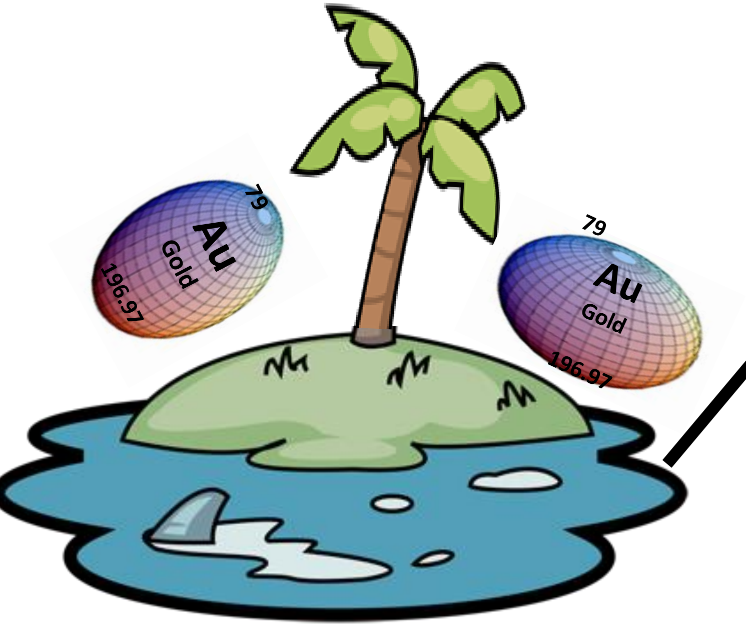


Slide courtesy: Louis Lallane

P.O.O.F

Power. **O**verlap (space). **O**verlap (time). **F**requency

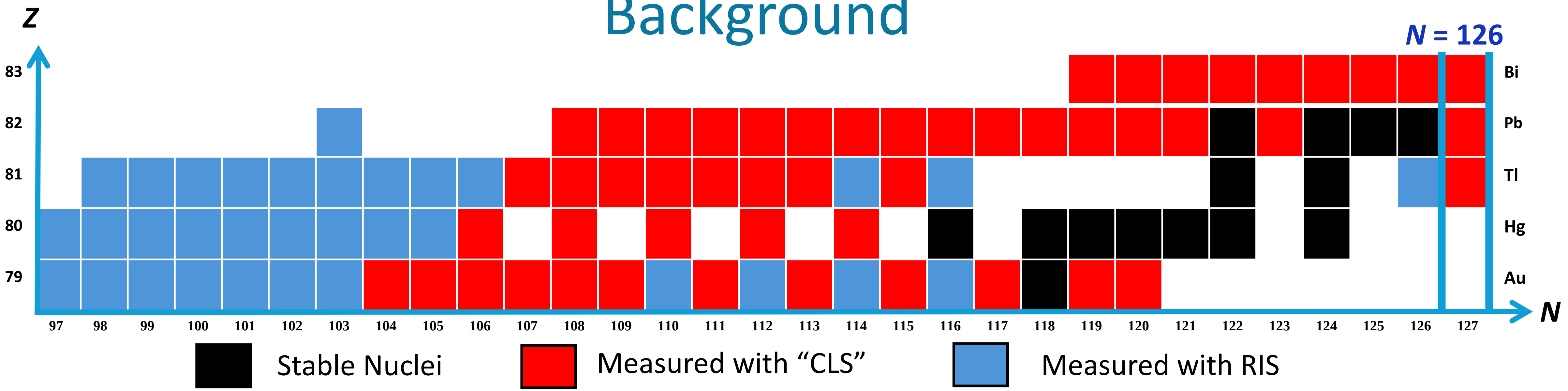


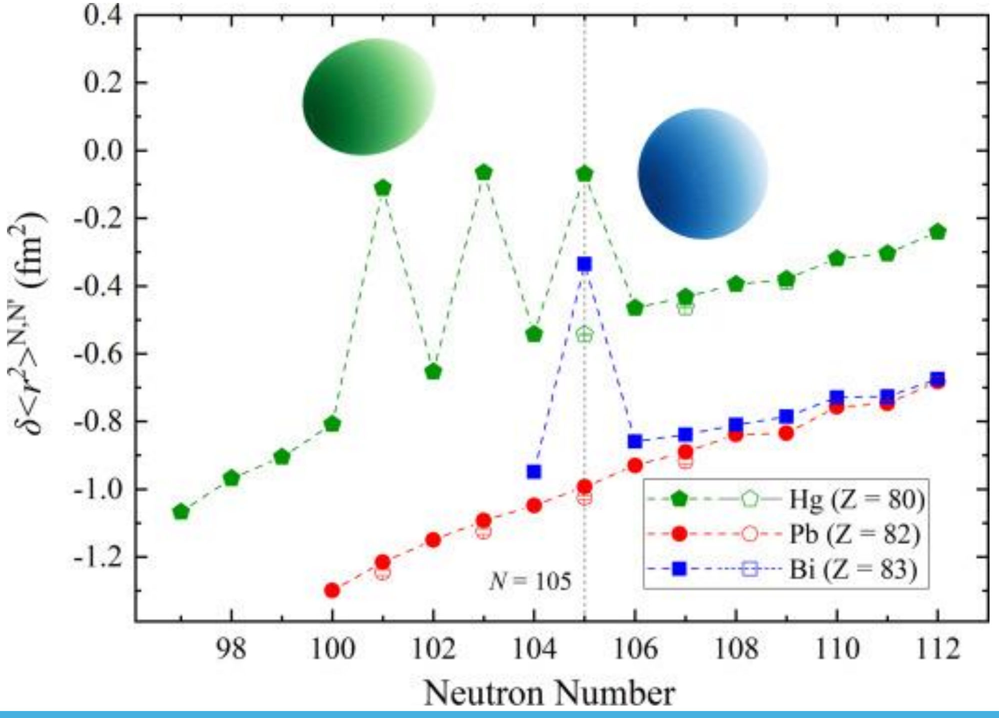


IS737:High-resolution laser spectroscopy of light gold isotopes: investigation of "**island of deformation**" and **shape coexistence**

Spokesperson: Xiaofei Yang
Co-spokesperson: Gerda Neyens, Shiwei Bai

Background



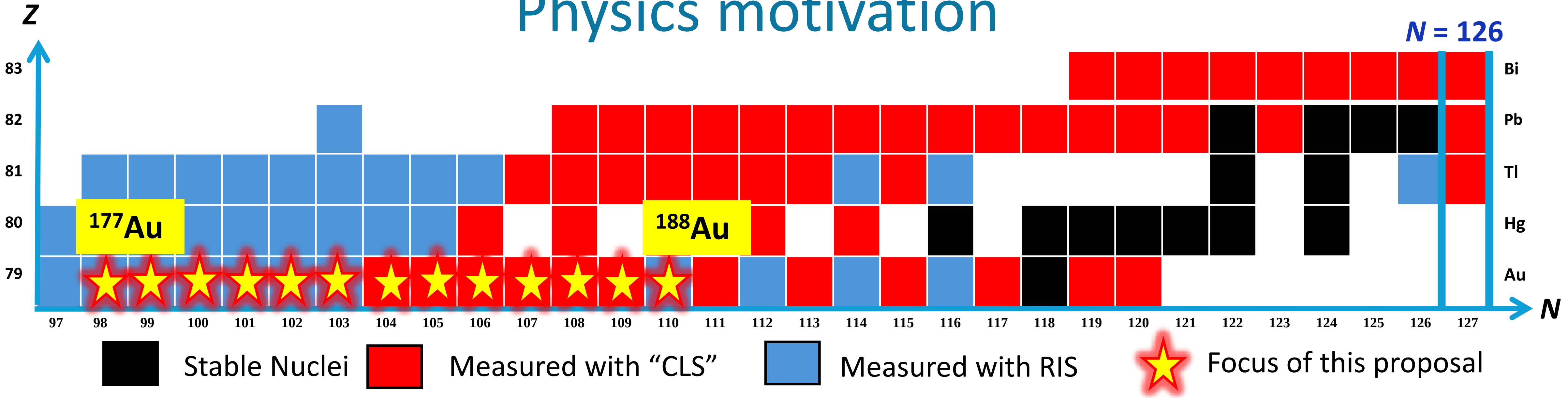


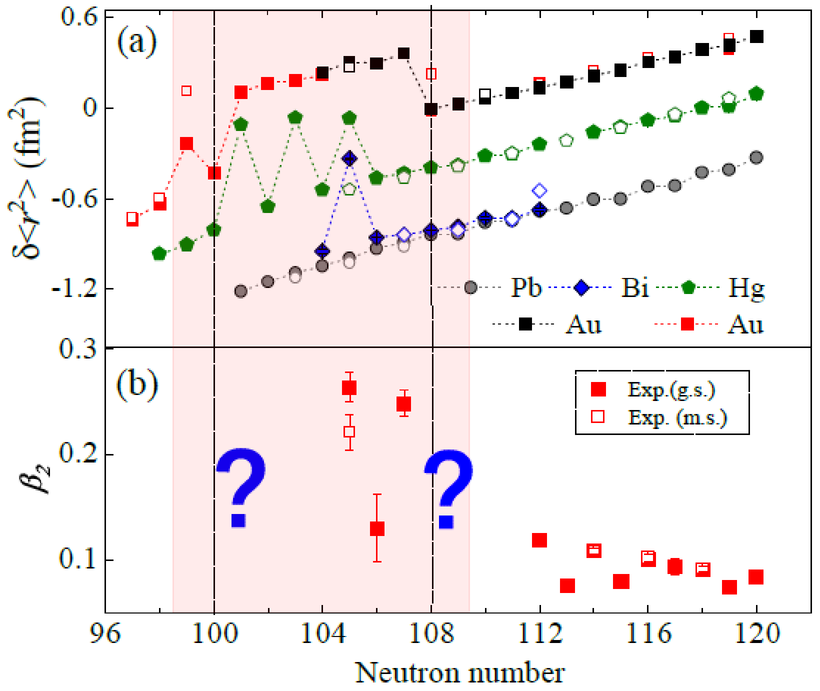
- Large **shape staggering** in **Hg** (Z=80) from N = 105 to 100
- Same phenomenon in **Bi** (Z=83) exactly at N = 105 and similar magnitude as Hg [1]
- In contrast, Pb (Z=82) isotopes **remain spherical** down to N = 101 [2]

1.H. De. Witte et al., Phys. Rev. Lett., 98,112502 (2007)
2.A. Barzakh, et al. Phys. Rev. Lett. 127, 192501(2021)

Slide courtesy: Xiaofei Yang

Physics motivation





The scenario is very different in Au (Z=79)

- Strong deformation is observed at N = 107 [3]
- Deformation remains constant until N = 101 “**Island of deformation**”
- At N=99 & N=108 (^{178}Au,^{187}Au), **shape coexistence**

3. J.G Cubiss et. al ., Phys. Rev. Lett., **131**,202501 (2023)

Proposed measurements

Isotope	Half-life	J^{π}	μ (μ_N)	Q_s (b)
$^{177}Au_{98}$	1.53 (s)	$1/2^+$	1.15 (5)	
$^{177m}Au_{98}$	1 (s)	**$11/2^-$**	6.348 (6)	-
$^{178}Au_{99}$	3.4 (s)	**(2,3)**	?	-
$^{178m}Au_{99}$	2.7 (s)	**(7,8)**	?	-
$^{179}Au_{100}$	7.1 (s)	**$1/2^+$**	1.01 (5)	
$^{180}Au_{101}$	8.4 (s)	**1^+**	-0.83 (9)	-
$^{181}Au_{102}$	13.7 (s)	**$3/2^-$**	?	-
$^{182}Au_{103}$	15.5 (s)	**2^+**	1.66 (9)	-
$^{183}Au_{104}$	42.8 (s)	**$5/2^-$**	1.972 (23)	-
$^{184}Au_{105}$	20.6 (s)	5^+	2.07 (2)	4.65 (26)
$^{184m}Au_{105}$	47.6 (s)	2^+	1.44 (2)	1.90 (16)
$^{185}Au_{106}$	4.25 (m)	$5/2^-$	2.193 (61)	-1.10 (10)
$^{186}Au_{107}$	10.7 (m)	3^-	-1.202 (60)	3.10 (6)
$^{187}Au_{108}$	8.2 (m)	$1/2^+$	0.557 (41)	
$^{187m}Au_{108}$	2.3 (s)	$9/2^-$	3.529 (53)	-
$^{188}Au_{109}$	8.84 (m)	1^-	-0.07 (3)	-

'Shape coexistence'

'Island of deformation'

'Shape coexistence'

Q_s :mostly unknown around the beginning of 'island of deformation'

$^{177-183}$Au: Spin assignment is tentative

I,Q +known μ

- Probing the configuration of the nuclear states

Q_s $^{177-188}$Au + known $\langle r^2 \rangle$

- Information on the nature of the deformation and the degree to which these nuclei are statically deformed.

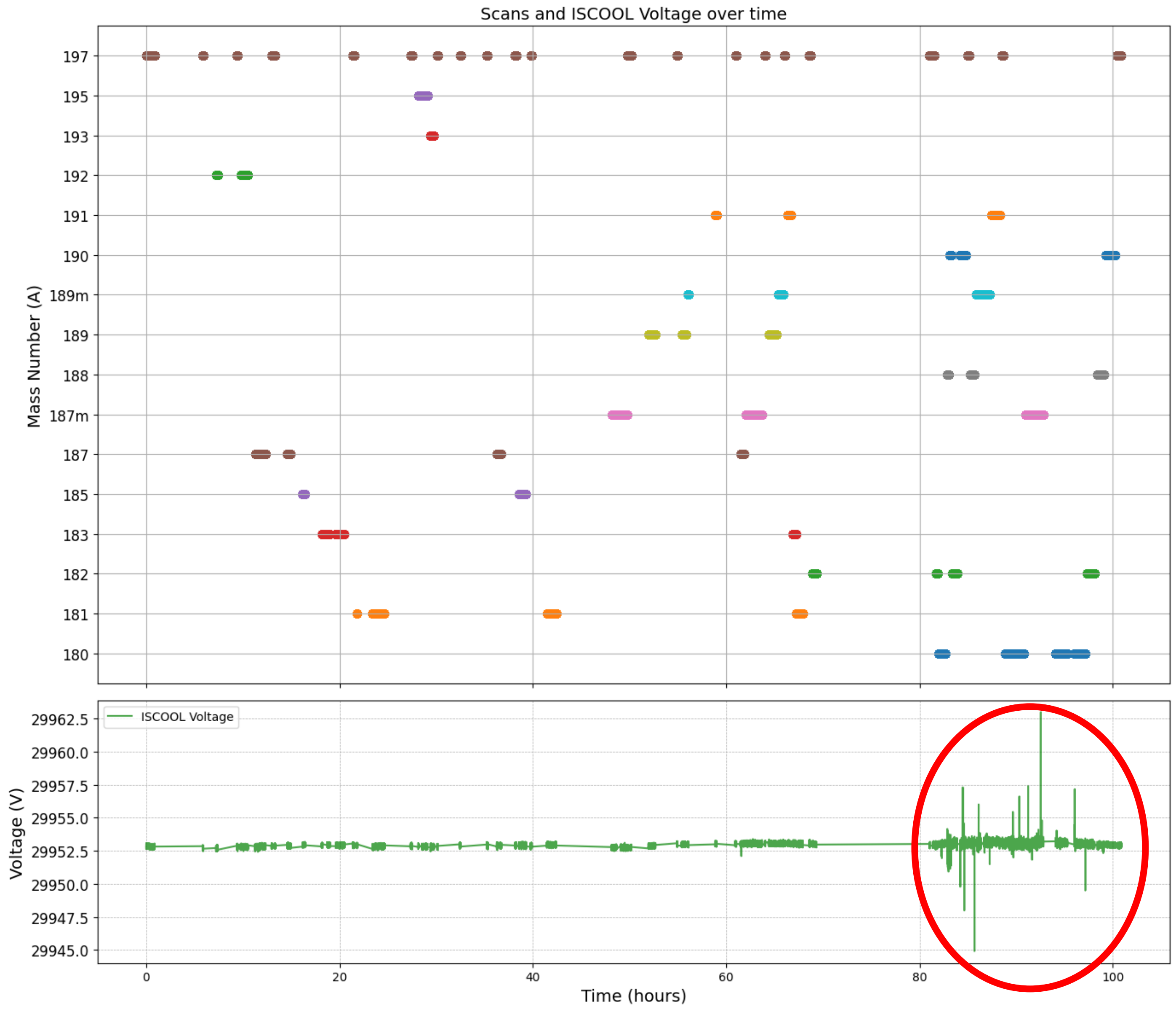
$$Q_{\text{intr.}} = \frac{3}{\sqrt{5\pi}} Z R_0^2 \beta_2 (1 + 0.36\beta_2).$$

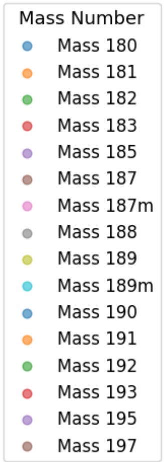
$$Q_s = \frac{3K^2 - I(I+1)}{(2I+3)(I+1)} Q_{\text{intr.}}$$

Newly measured I,Q

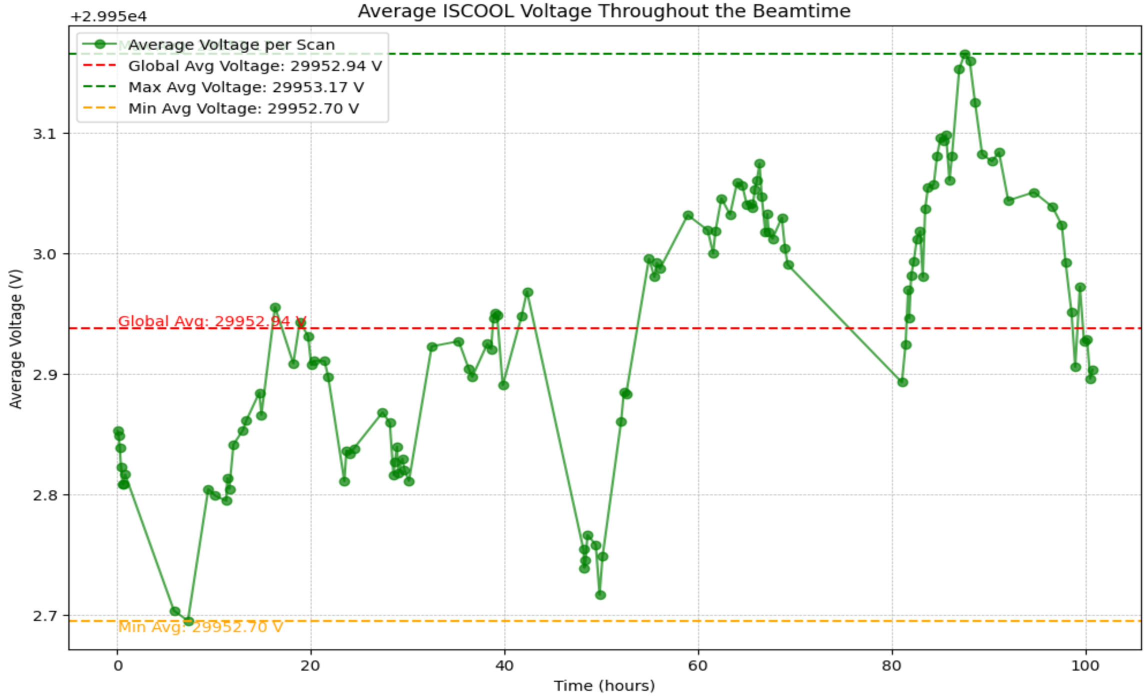
- Benchmark theoretical models*:* Monte Carlo Shell Model, HFB & DFT

Experimental campaign

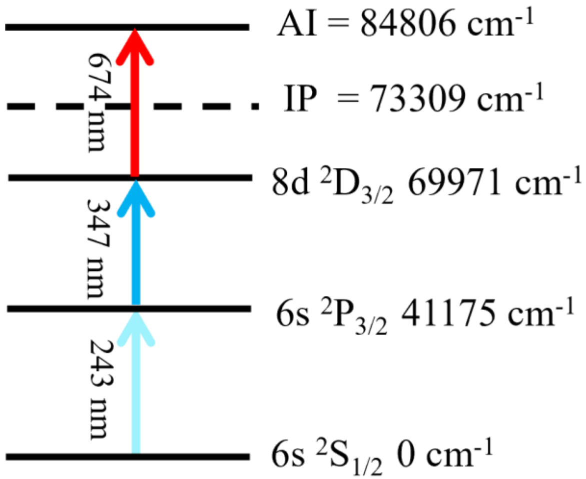




Avg max and min ISCOOL Voltage fluctuation throughout the beamtime was ~ 0.5V.



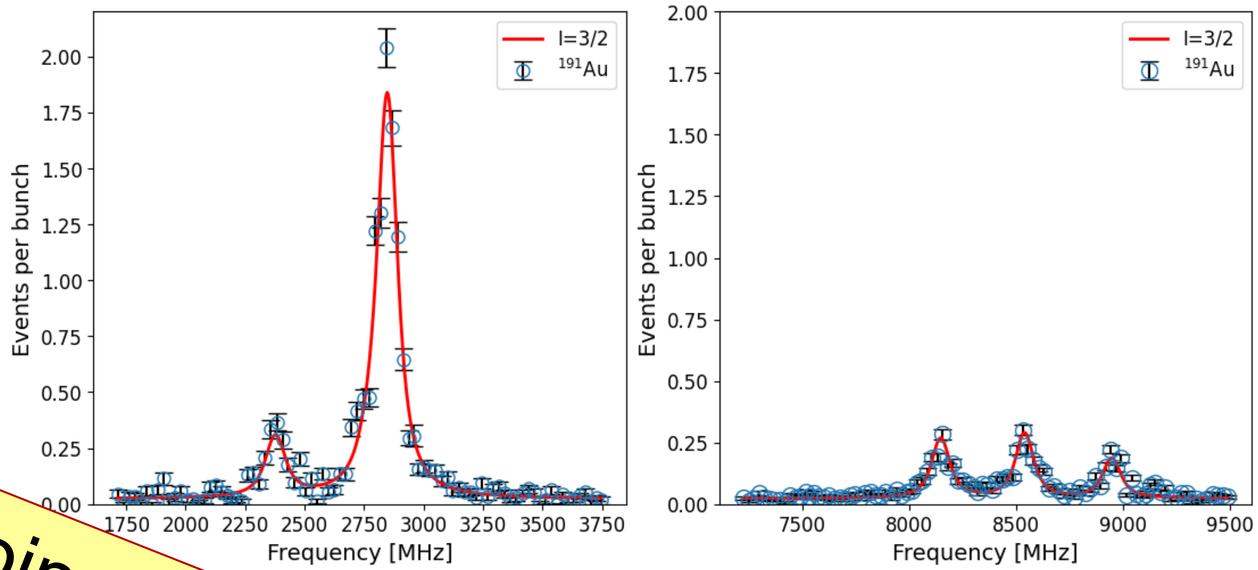
Preliminary analysis

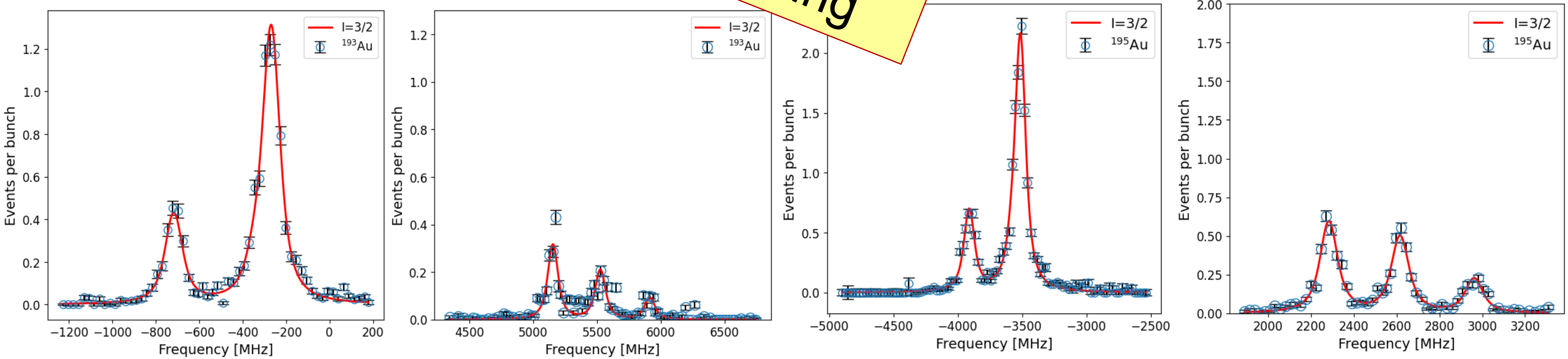


Gold laser scheme

- Voltage scanning employed
- Scans recorded in two parts

Analysis ongoing





Department of Physics and Astronomy (IKS)

KU LEUVEN

Beamtime summary

- 100 hours of scanning time (~ 4 days).
- 126 scans in total (14 isotopes and 2 isomers)
- Voltage scanning was mostly used throughout the beamtime. Therefore, due to the large splitting(~ 3 GHz) in the hyperfine structure of gold, the scans of each hyperfine structure was recorded in two parts as left and right (branches).
- Issues encountered with production of gold isotopes.
- Most of the shifts available to (re)visit ^{178}Au and ^{178,m}Au

No.	Isotope	Scans	LHS	RHS
1	180	7	4	3
2	181	9	5	4
3	182	8	5	3
4	183	7	5	2
5	185	5	2	3
6	187	10	5	5
7	187m	9	6	3

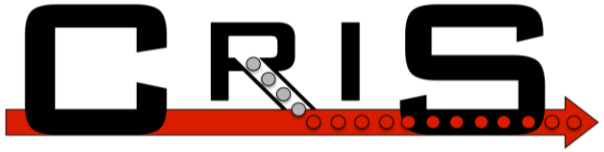
"Island of deformation" & shape coexistence

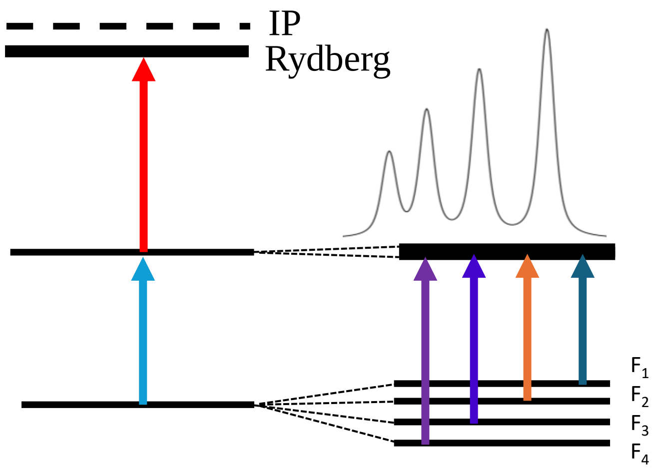
No.	Isotope	Scans	LHS	RHS
8	188	5 + 1(both)	3	3
9	189	7	5	2
10	189m	7	5	2
11	190	6	4	2
12	191	5	3	2
13	192	2	2	
14	193	2	1	1
15	195	5	3	2
16	197 (ref)	31	29	2

Benchmarking and quadrupole moments

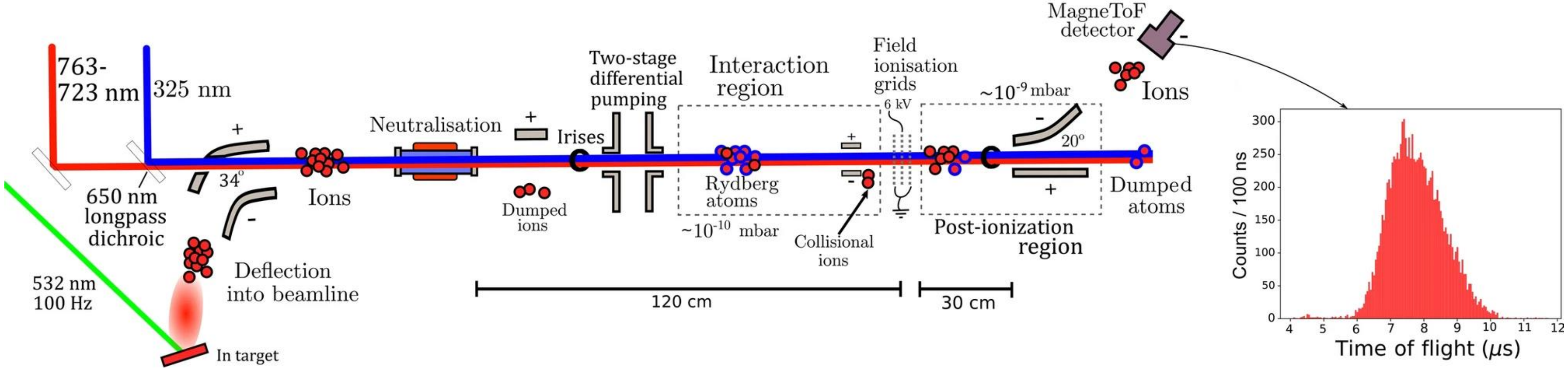
Hey CRIS!! What's new??

FIU
(Field Ionization Unit)





- Electric field ionization of Rydberg states in a collinear geometry.
- Increased sensitivity for isotope separation and measurement of atomic parameters over previous non-resonant laser ionization methods
- Reduction of Ionization volume.



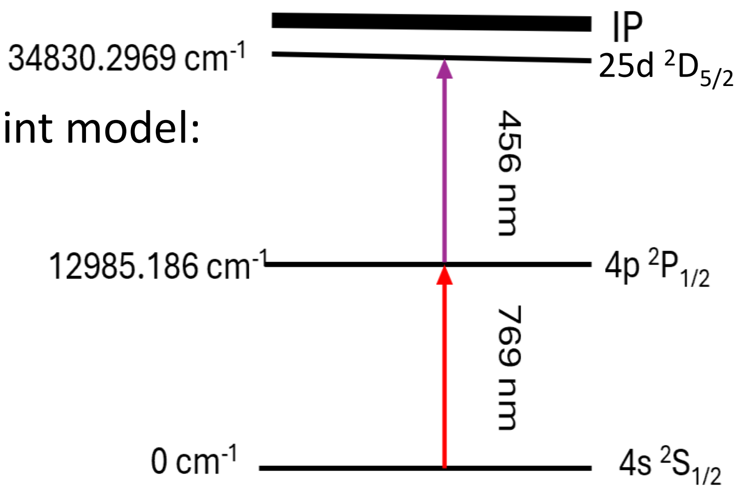
Pictures: Vernon, A.R. et al. Laser spectroscopy of indium Rydberg atom bunches by electric field ionization. Sci Rep 10, 12306 (2020).

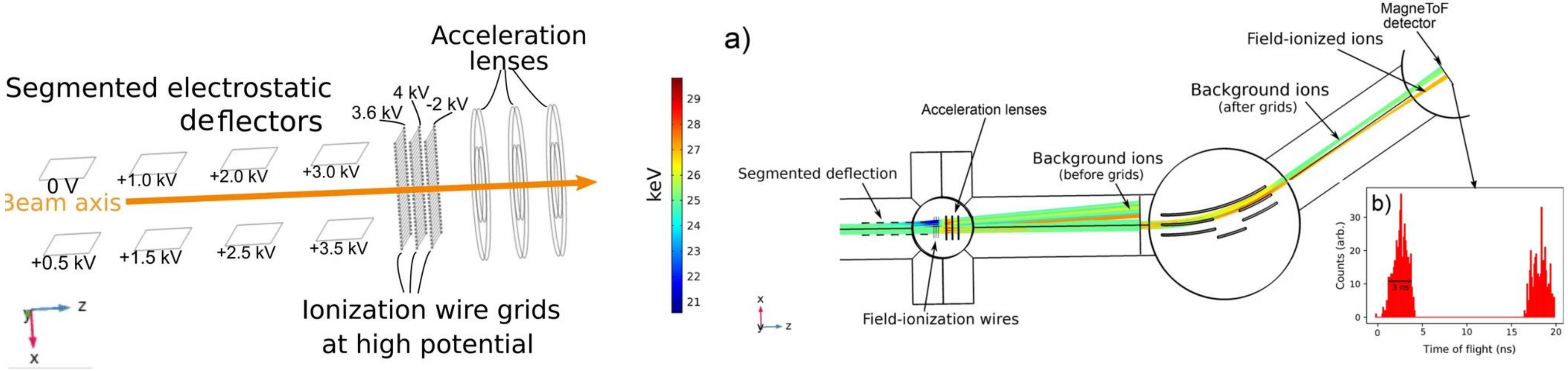
Commissioning

- Commissioning was done in May, 2024.
- ^{39}K used to populate the Rydberg state 25d
- Electric field gradient required to ionize a Rydberg state is calculated using saddle point model:

$$E_{ionisation} = E_{IP} - 2\sqrt{\frac{Z_{eff}\, e^3}{4\pi\varepsilon_0}}\sqrt{E}$$

- ~ 450 V/0.5 cm gradient required to ionize the e^- in 25d Rydberg state

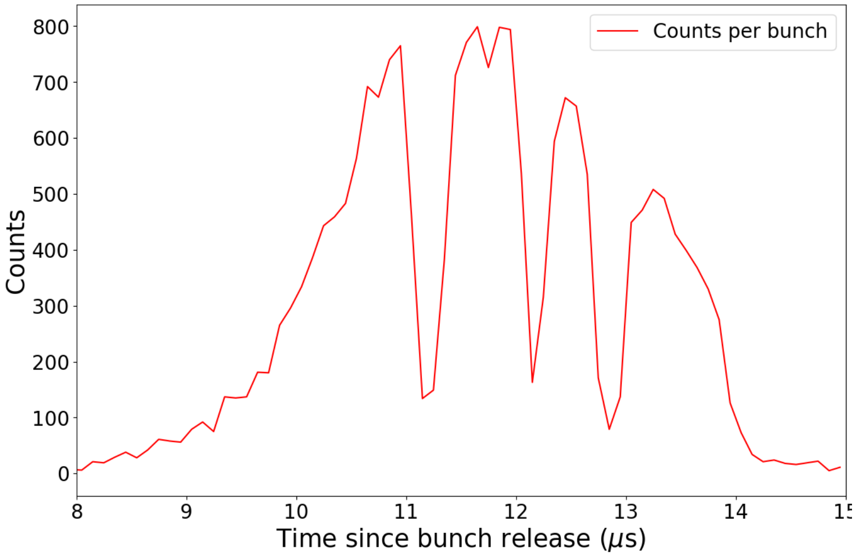


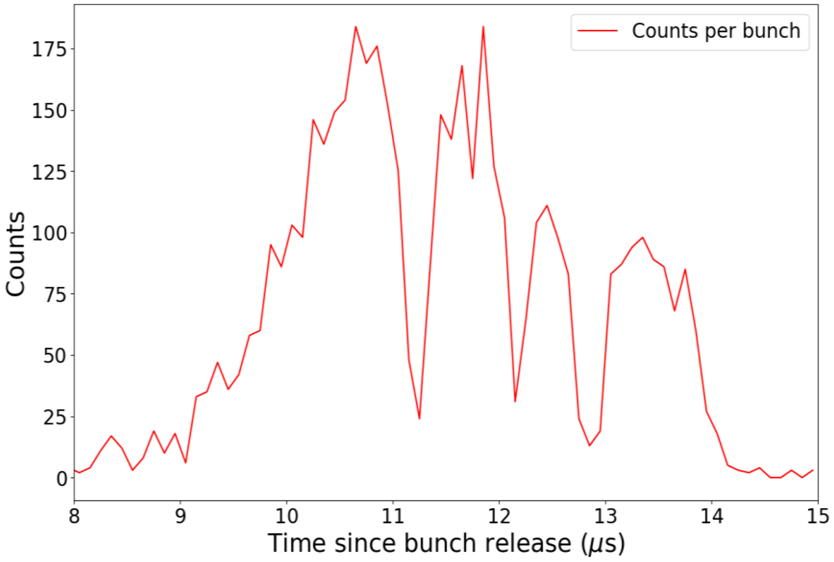


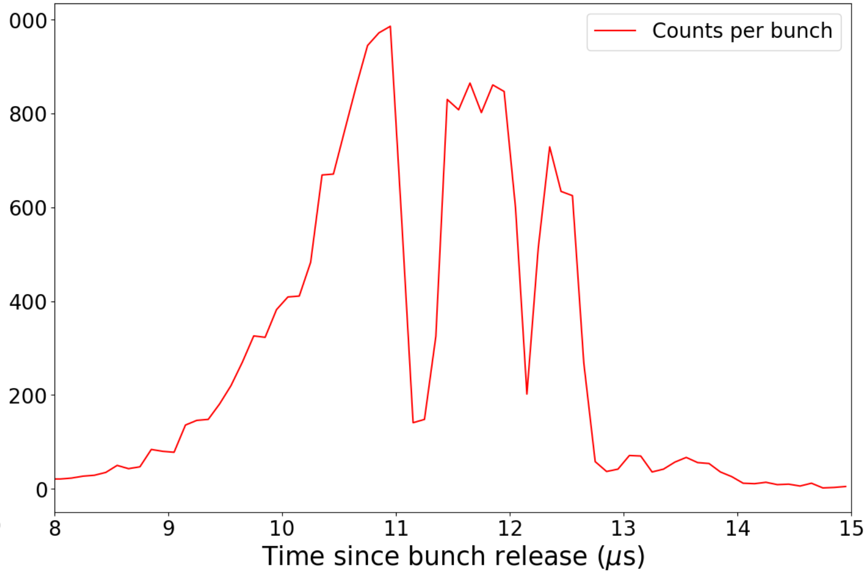
Pictures: Vernon, A.R. et al. Laser spectroscopy of indium Rydberg atom bunches by electric field ionization. Sci Rep 10, 12306 (2020).

Summary

- Multiple ToF peaks in the MagneToF
- Rydbergs being ionized by collisions at different sites in the beamline. (CEC, IR, FIU & bender).







CEC deflectors ON

- Field Ionization Unit successfully installed.
- More time needed to do a systematic study.
- Populating low lying Rydberg states (e.g. n = 10) to lower the collisionals.
- DAQ improved to record voltages as a function of counts on MagneToF.
- OPO laser to be used to easily tune to various Rydberg states.

THANK YOU

KU LEUVEN

Centroid drift of reference isotopes ^{197}Au