

GANIL SCIENTIFIC COUNCIL 2025

FEBRUARY 4<sup>TH</sup>, 2025

# Laser Resonance Chromatography @ GANIL

*M. Laatiaoui (GANIL)  
on behalf of the LRC project & collaboration*



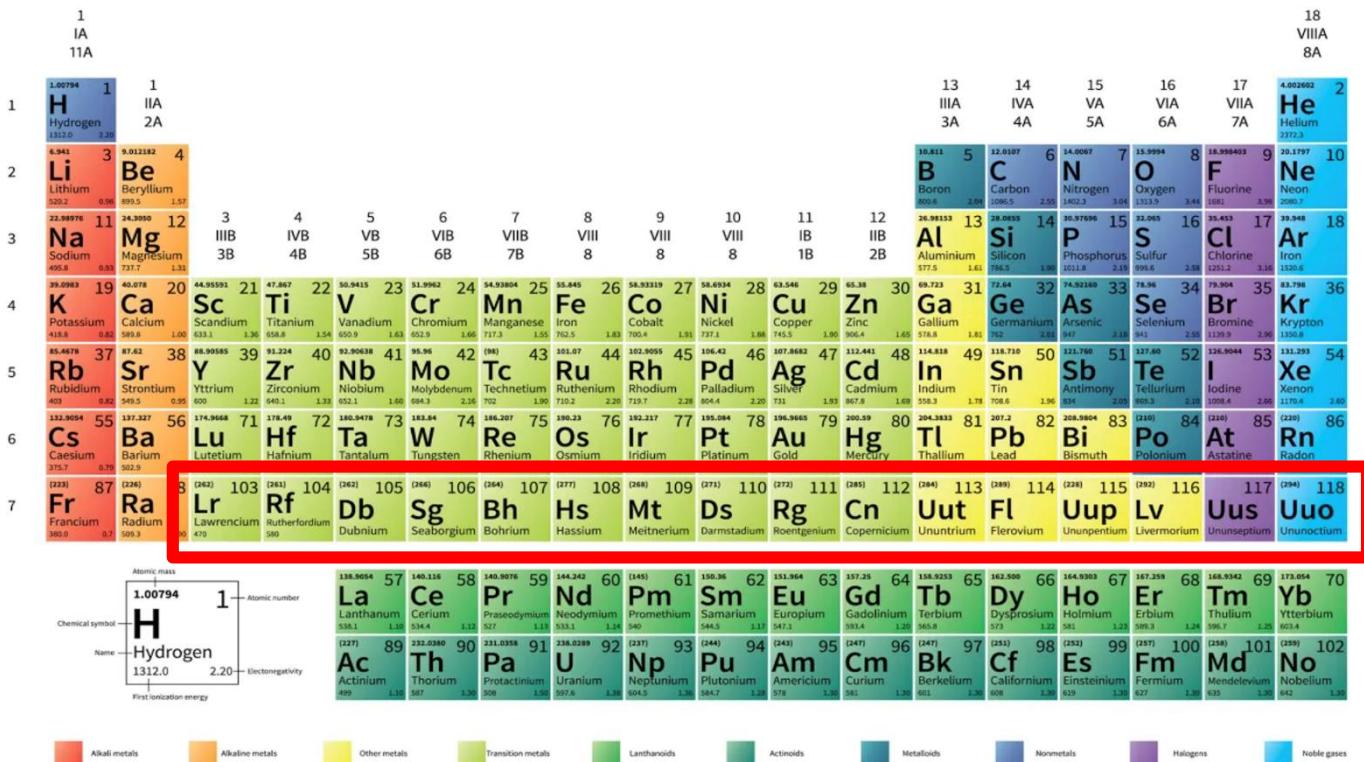
The LRC project has received funding for the period 2019-2024 from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 819957)

# Outline

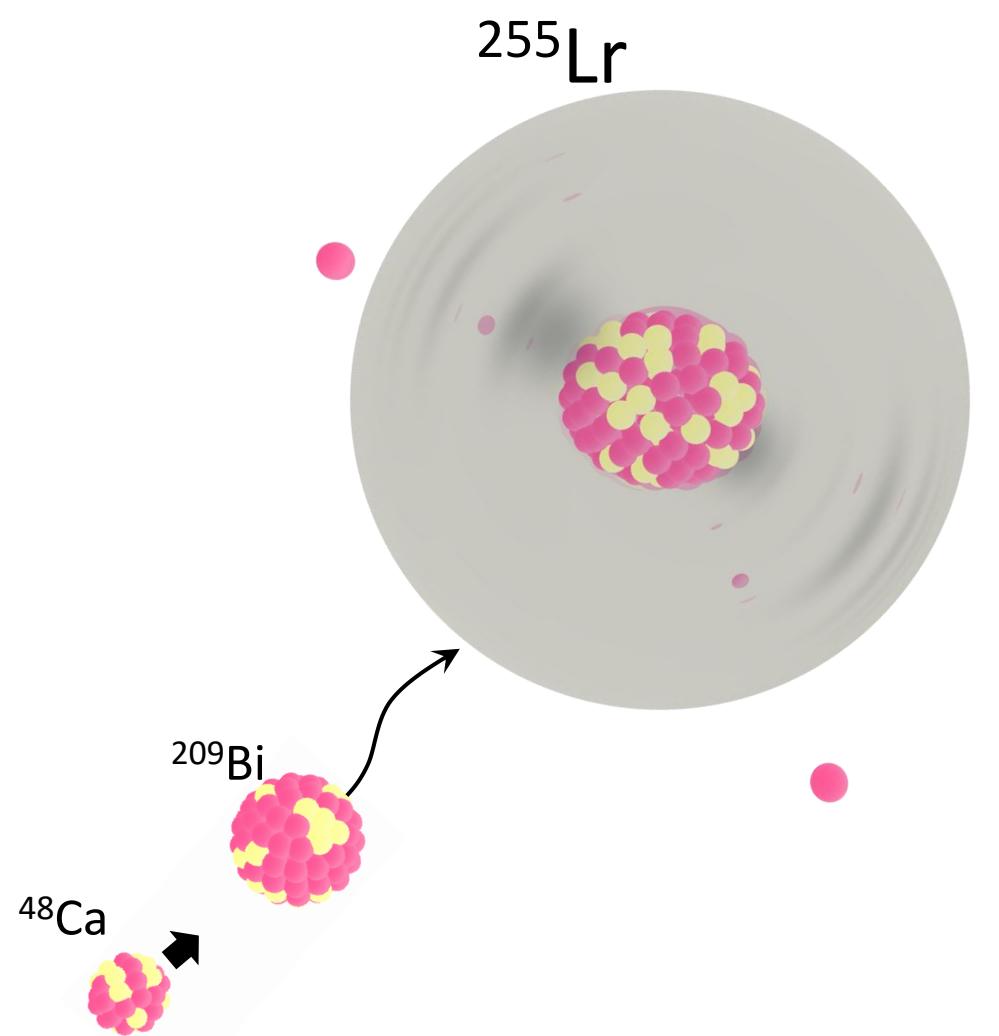
- Motivation
- Objectives
- Laser Resonance Chromatography (LRC)
  - The LRC technique
  - Proof-of-principle results
- Towards LRC on actinium & lawrencium
- Start-up phase program

# Motivation

$^{255}\text{Lr}$



- Which radionuclides can exist?
- What chemical, atomic & nuclear properties do they have?
- How robust is our understanding of atomic & nuclear structure?
- Are these radionuclides being produced in the universe?

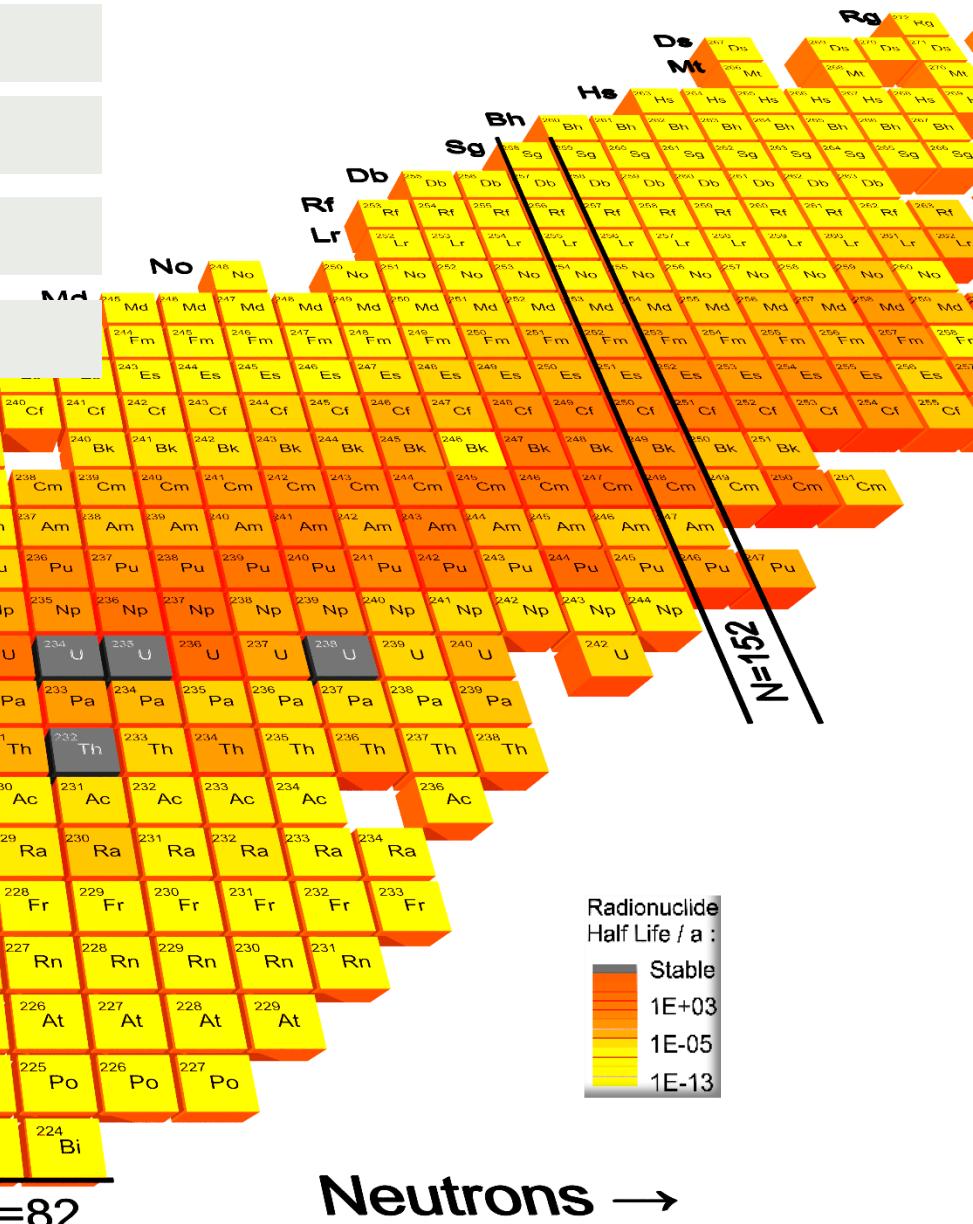
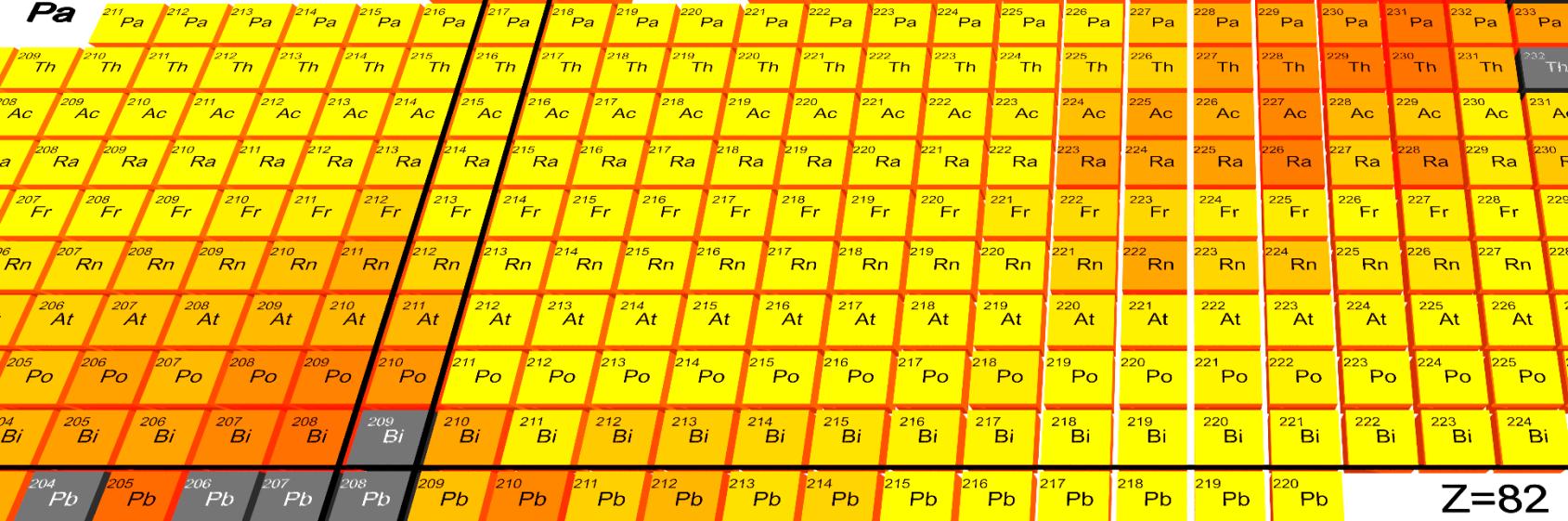


# Main objectives

- Explore the atomic structure of the heaviest chemical elements
- Delineate optical spectral lines for observational astronomy
- Generate powerful benchmarks for atomic modeling
- Extract nuclear properties independent of nuclear models

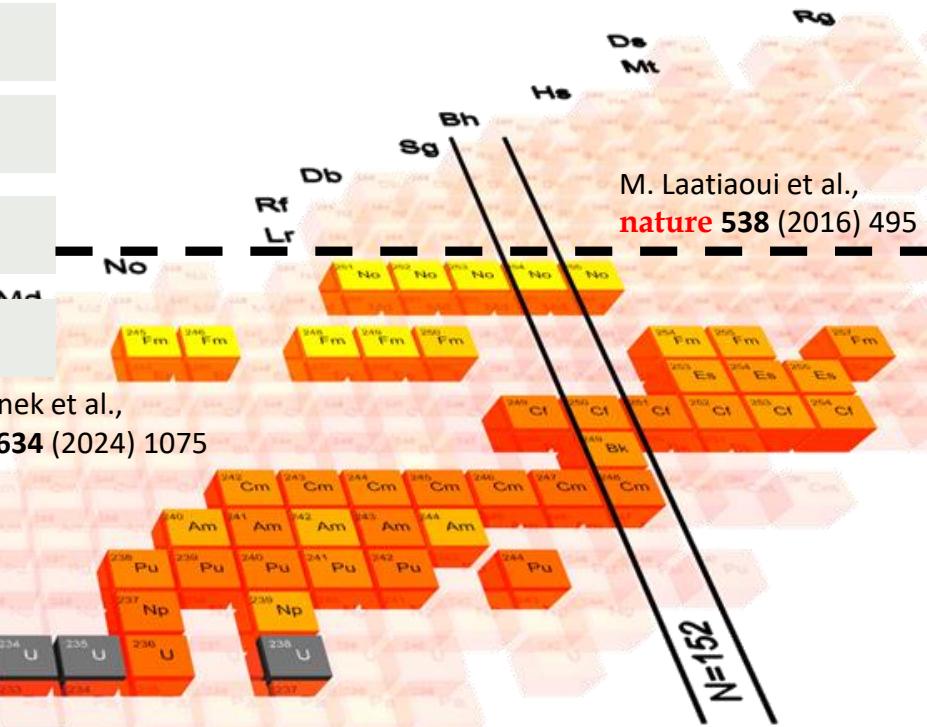
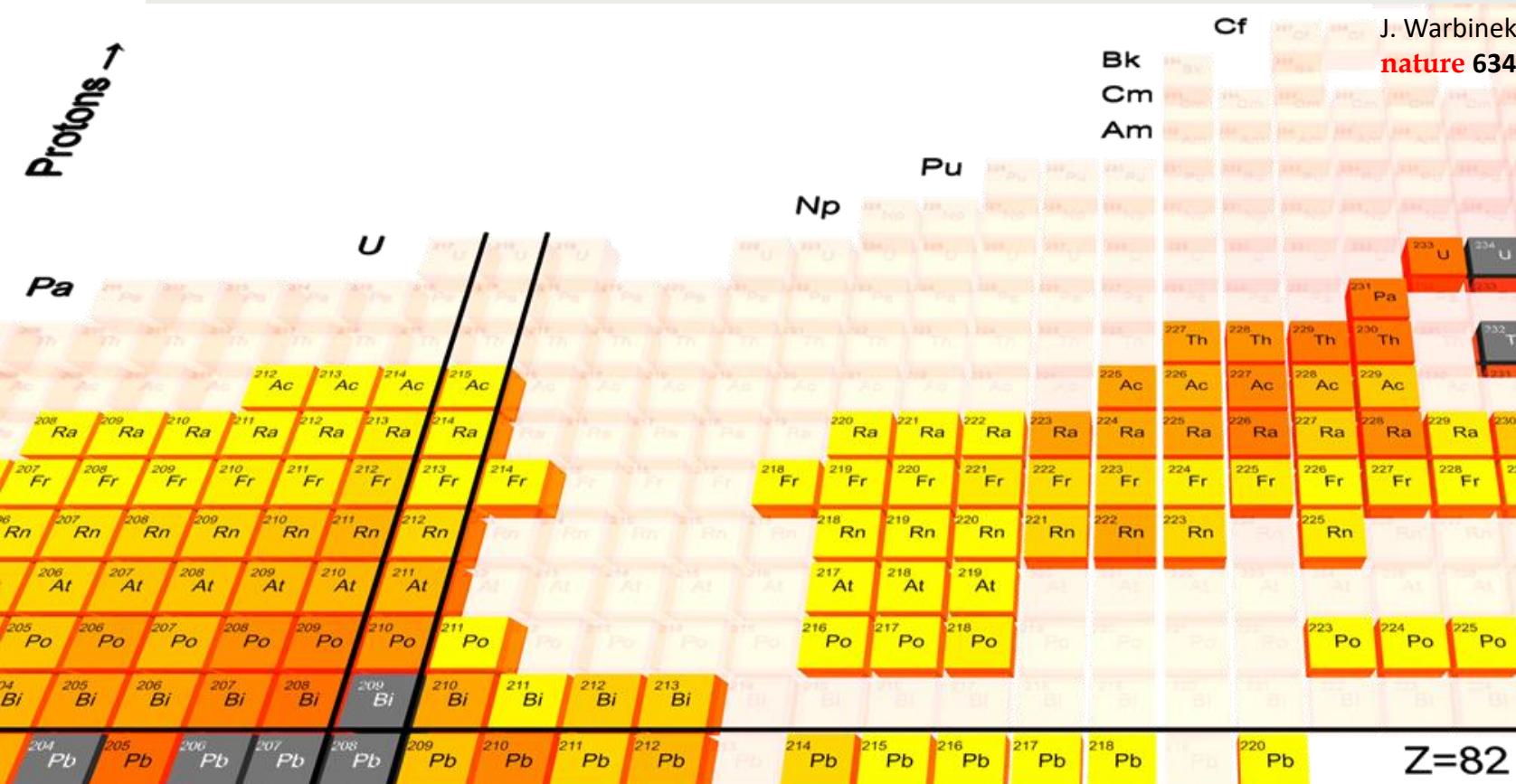
Protons ↑

Z=82



# Main objectives

- Explore the atomic structure of the heaviest chemical elements
- Delineate optical spectral lines for observational astronomy
- Generate powerful benchmarks for atomic modeling
- Extract nuclear properties independent of nuclear models



Neutrons →

Radionuclide  
Half Life / a :  
Stable  
1E+03  
1E-05  
1E-13

M. Laatiaoui et al.,  
*nature* 538 (2016) 495

J. Warbinek et al.,  
*nature* 634 (2024) 1075

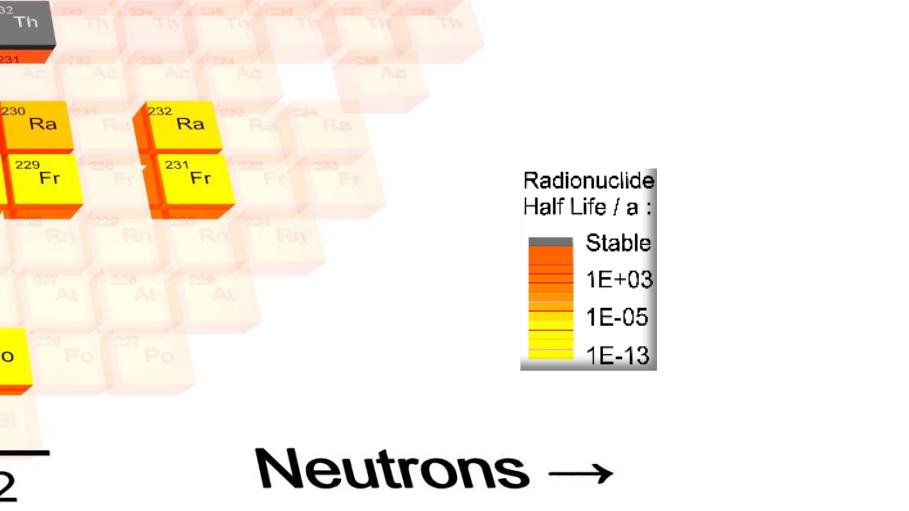
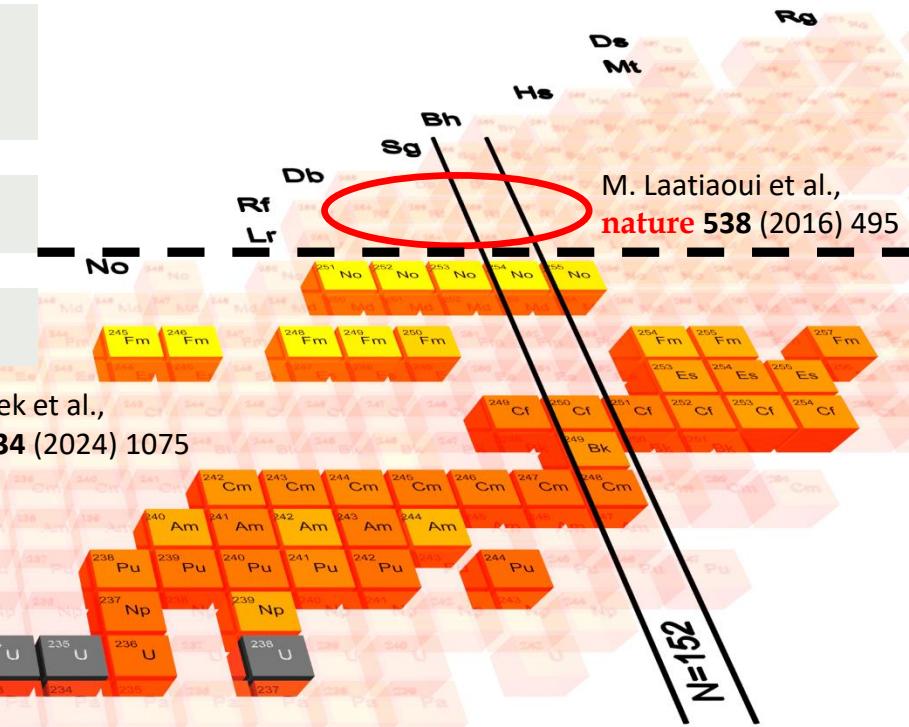
# More specific

1) LRC-based level search in lawrencium cations,  $^{254,255}\text{Lr}^+$

→ Develop a corresponding Online Chromatography Setup (OCS)

2) LRC-based hfs & isotope shift studies on short-lived  $^{208-215,220}\text{Ac}^+$  isotopes

3) Optimize LRC in offline experiments



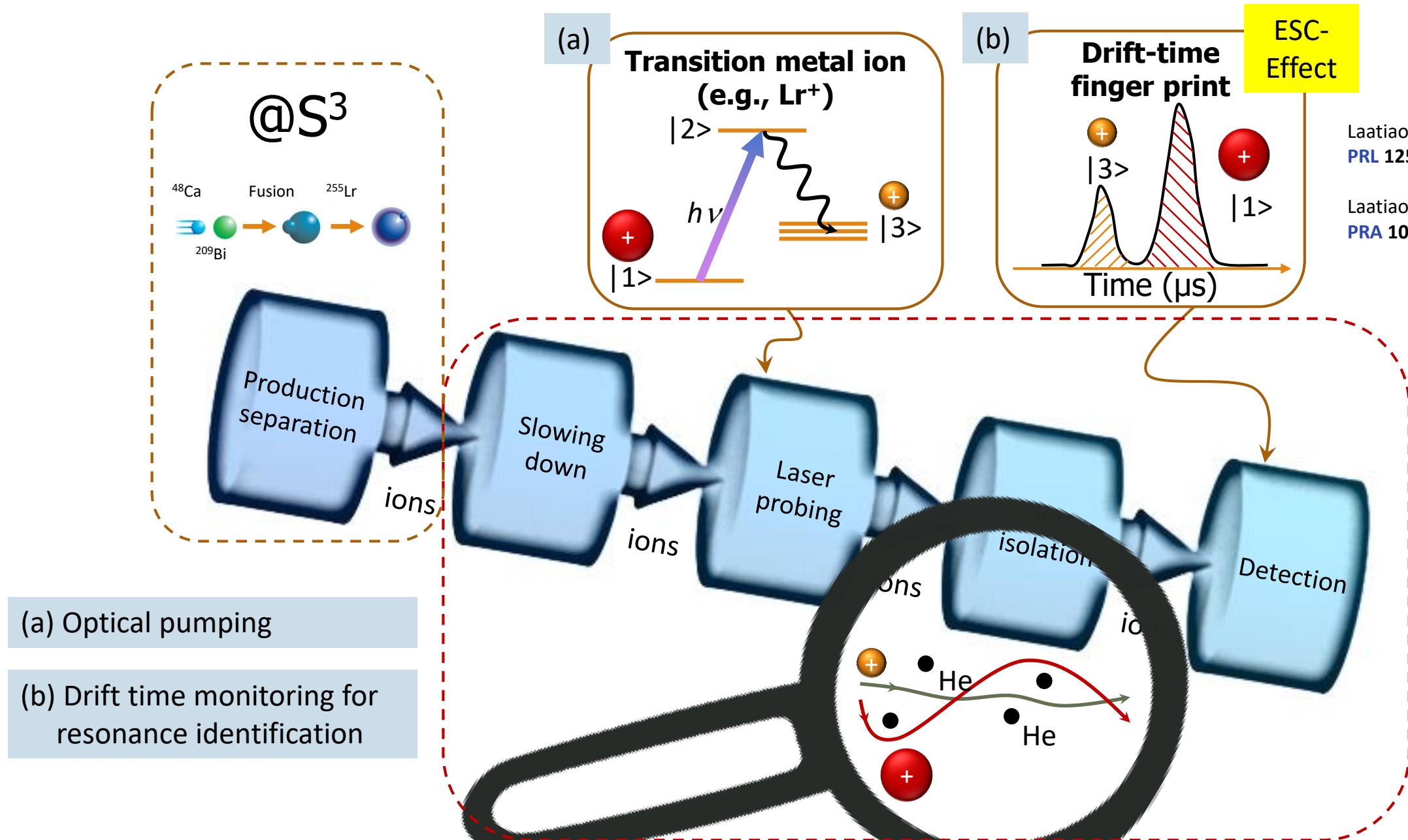
# Laser Resonance Chromatography (LRC)



European Research Council  
Established by the European Commission

Laatiaoui *et al.*,  
**PRL** **125** (2020) 023002

Laatiaoui *et al.*,  
**PRA** **102** (2020) 013106



# Accessible elements



[www.lrc-project.eu](http://www.lrc-project.eu)



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		18 VIIIA 8A																		
		13 IIIA 3A																		
1 IA 11A		1 IIA 2A	14 IVA 4A																	
			15 VA 5A																	
			16 VIA 6A	17 VIIA 7A																
1	H Hydrogen	2	Li Lithium	3	Be Beryllium	4		5	6	7	8	9	10	11	12	B Boron	C Carbon	N Nitrogen	O Oxygen	He Helium
2	13.941 22.98776 24.30501 24.99468	3 Li Lithium	4 Be Beryllium	5 Mg Magnesium	6 VIB 4B	7 VIB 5B	8 VIIIB 6B	9 VIII 7B	10 VIII 8	11 IB 8	12 IIB 2B	13 III 3A	14 IV 4A	15 V 5A	16 VI 6A	17 VII 7A	18 VIIIA 8A	19 20.1797 20.9946 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 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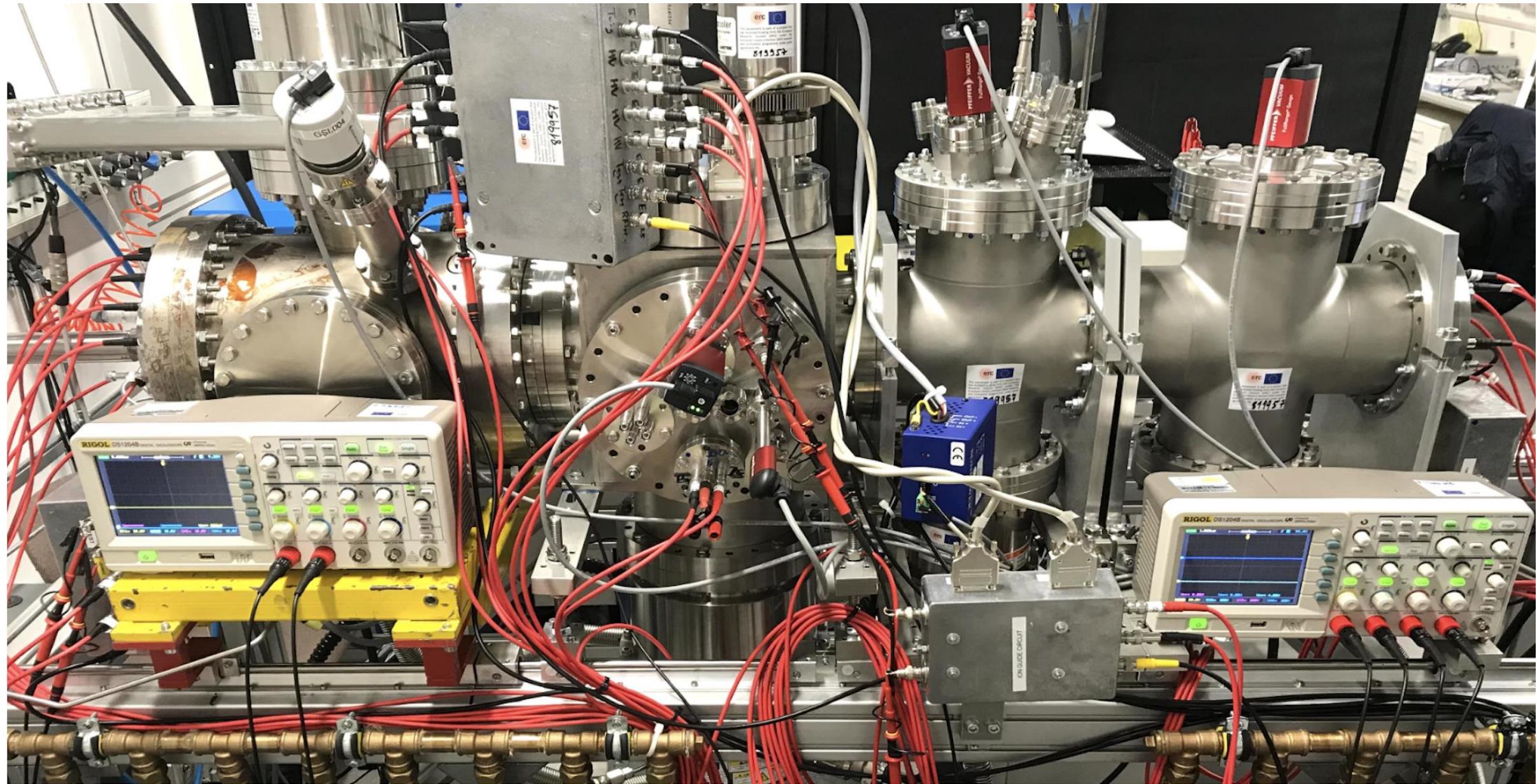
# LRC offline setup



[www.lrc-project.eu](http://www.lrc-project.eu)



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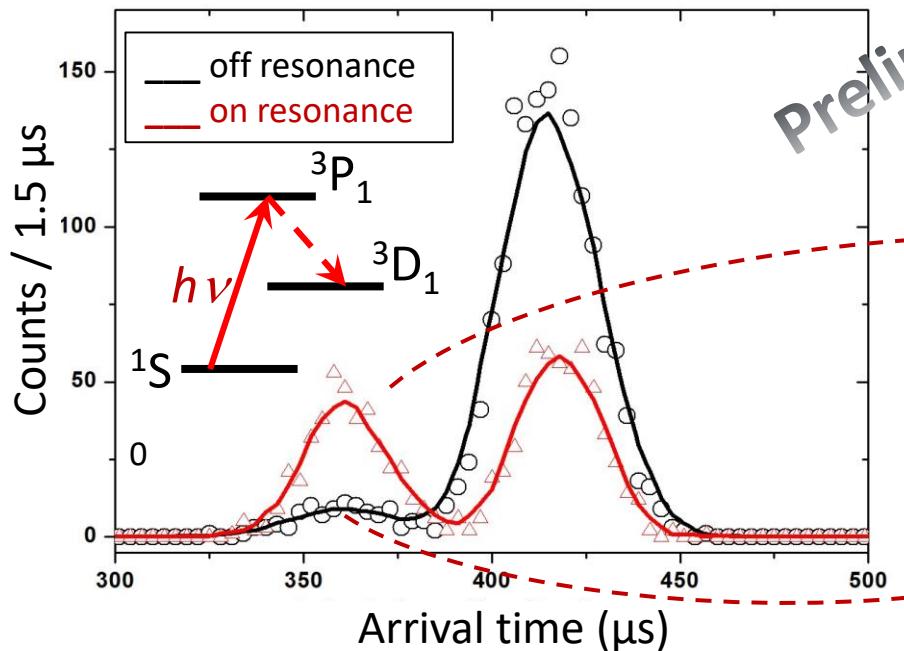
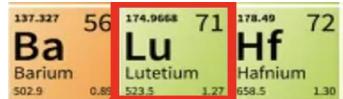
# Proof of principle for $^{175}\text{Lu}$



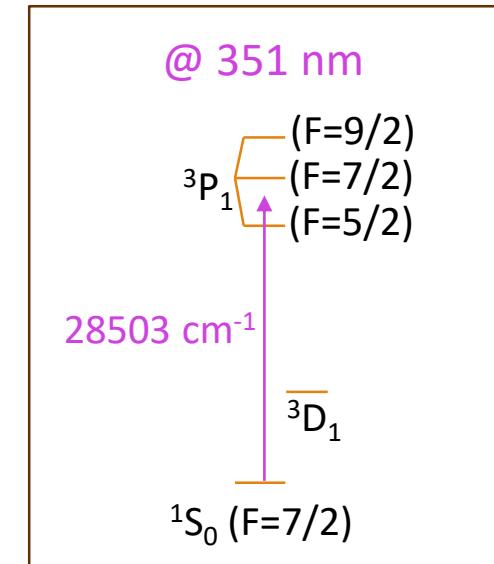
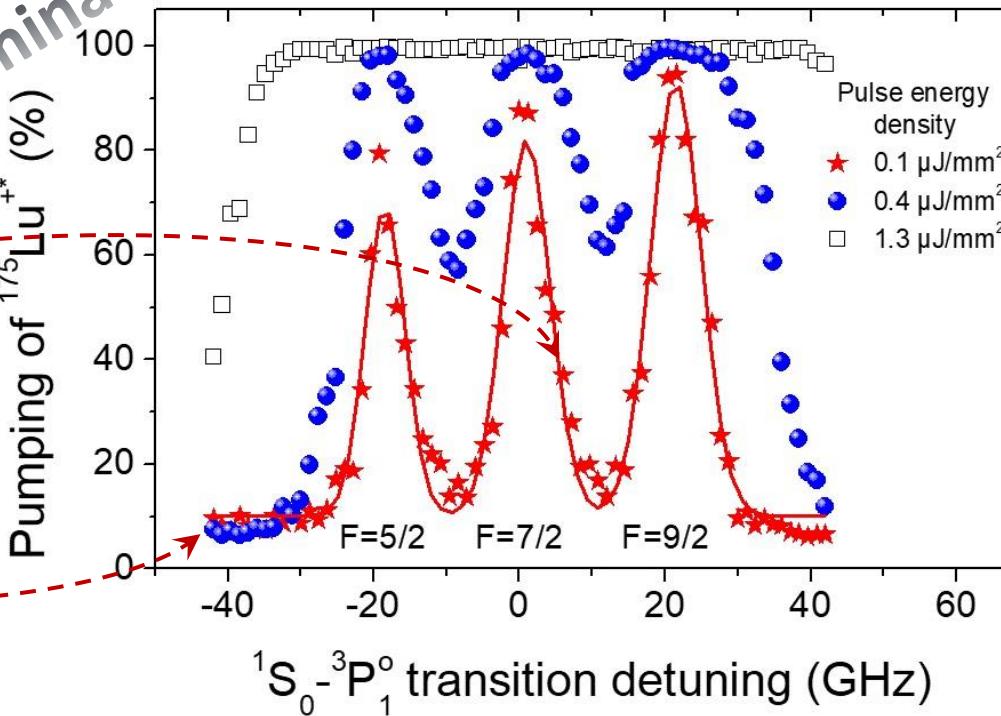
[www.lrc-project.eu](http://www.lrc-project.eu)



European Research Council  
Established by the European Commission



Preliminary



- Hyperfine structure studies possible at low laser power
- Power broadening beneficial for faster level search
- Measured overall-efficiency for ion transport: 0.6%

- E. Kahl et al., *PRA* **100** (2019) 062505  
 Laatiaoui et al., *PRL* **125** (2020) 023002  
 Laatiaoui et al., *PRA* **102** (2020) 013106  
 Ramanantoanina et al., *PRA* **104** (2021) 022813  
 Ramanantoanina et al., *Atoms* **10** (2022) 48  
 Romero-Romero et al., *Atoms* **10** (2022) 87  
 Ramanantoanina et al., *PRA* **108** (2023) 012802  
 Visentin et al., *PRA* **110** (2024) 012805  
 Kim et al., *NIMB* **555** (2024) 165461

# HFS & isotope shift studies



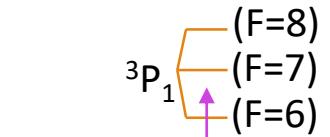
[www.lrc-project.eu](http://www.lrc-project.eu)



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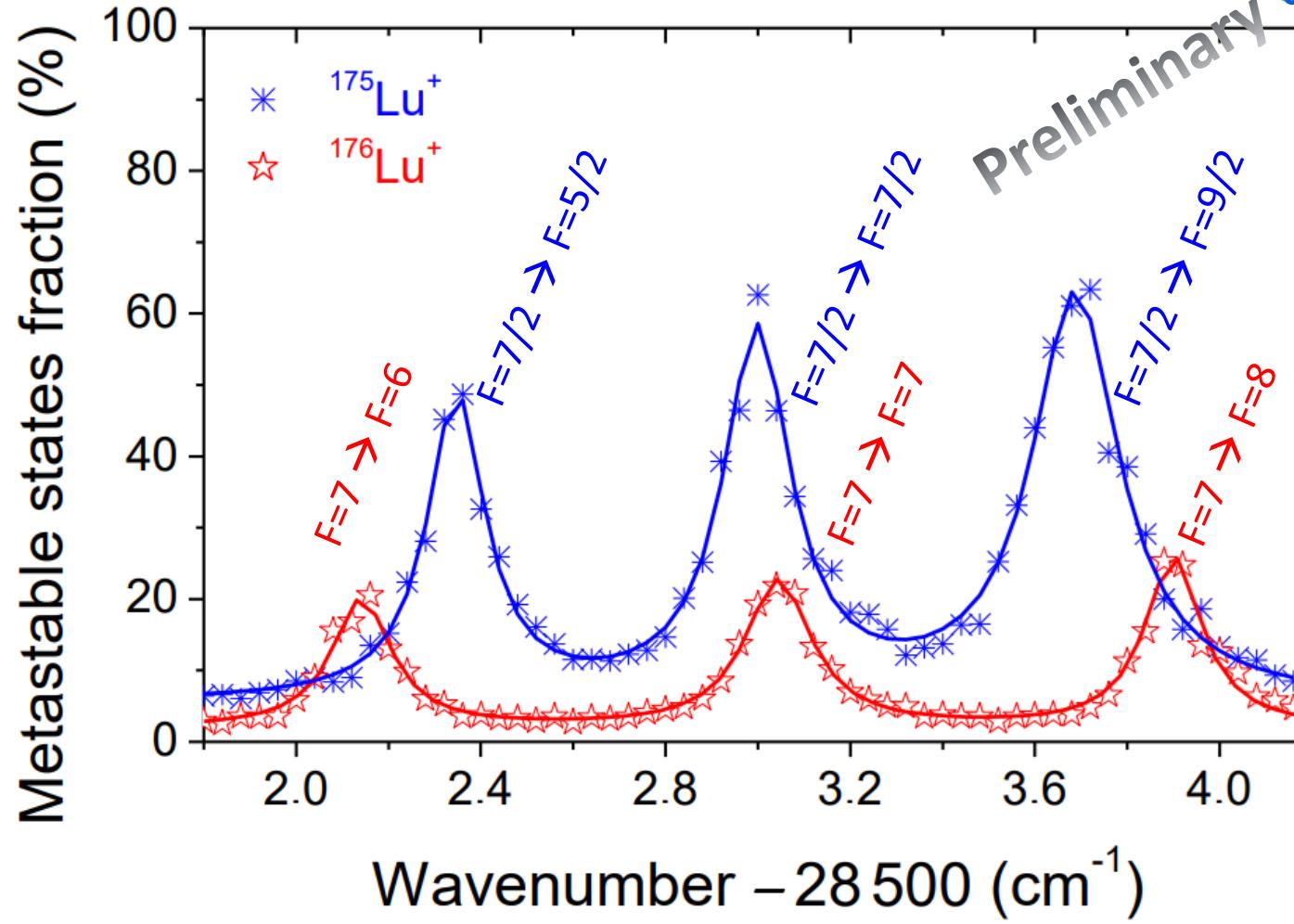
**$^{176}\text{Lu}$**

@ 351 nm



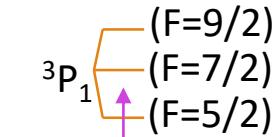
28503  $\text{cm}^{-1}$

$^1\text{S}_0$  ( $F=7$ )



**$^{175}\text{Lu}$**

@ 351 nm



28503  $\text{cm}^{-1}$

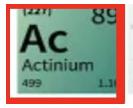
$^1\text{S}_0$  ( $F=7/2$ )

Species	A [MHz]		B [MHz]	
	this work	literature	this work	literature
$^{175}\text{Lu}$	+4,952 $\pm$ 16	+4,964 $\pm$ 9 <sup>a</sup>	-1,962 $\pm$ 94	-1,871 $\pm$ 30 <sup>a</sup>
$^{176}\text{Lu}$	+3,494 $\pm$ 8	3,502.6838 $\pm$ 0.0017 <sup>b</sup>	-2,604 $\pm$ 115	-2,602.291 $\pm$ 0.024 <sup>b</sup>

a: Hartog D. et al.,  
AJSS **248** (2020) 10

b: Kaewuam R. et al.,  
JMO **65** (2018) 592

# LRC on Ac<sup>+</sup> and Lr<sup>+</sup>



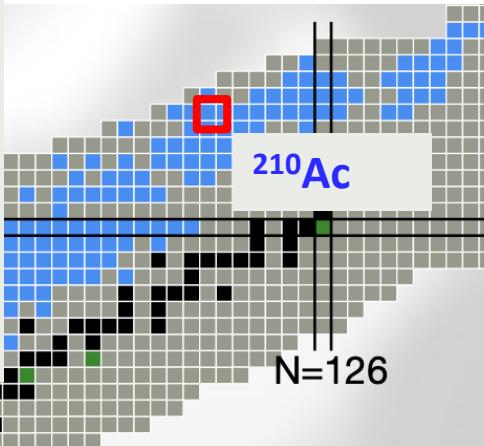
Evaporation residues:

$^{197}\text{Au}$  ( $^{20}\text{Ne}$ , 7n)  $^{210}\text{Ac}$

(5500 pps @ 20p $\mu$ A)

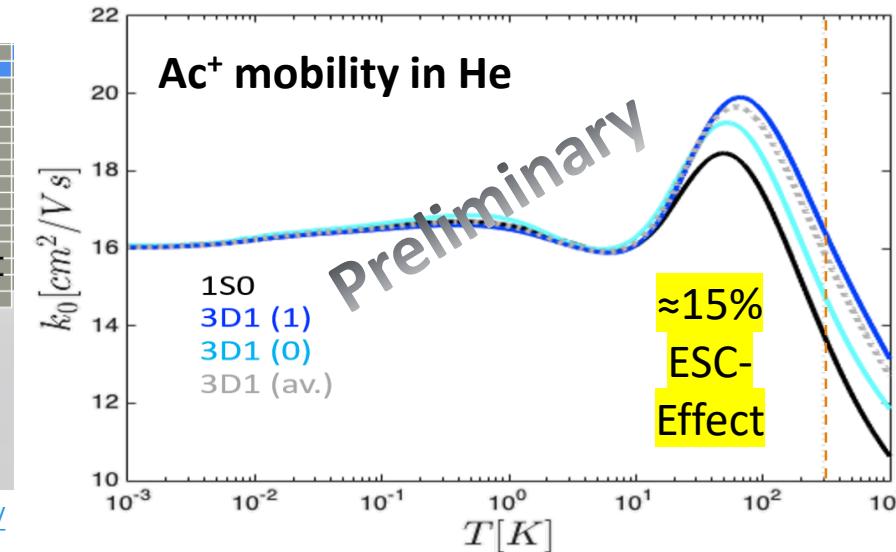
$^{197}\text{Au}$  ( $^{20}\text{Ne}$ , 8n)  $^{209}\text{Ac}$

(60 pps @ 20p $\mu$ A)



<https://u.ganil-spiral2.eu/chartbeams/>

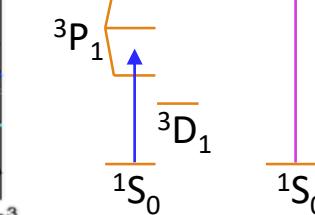
Courtesy H. Ramanantoanina



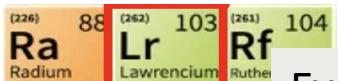
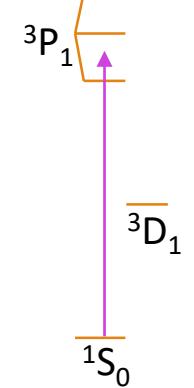
@ 342 nm



@ 451 nm



@ 317 nm



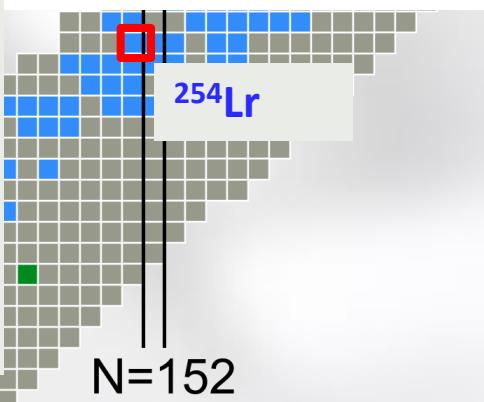
Evaporation residues:

$^{208}\text{Pb}$  ( $^{48}\text{Ti}$ , pn)  $^{254}\text{Lr}$

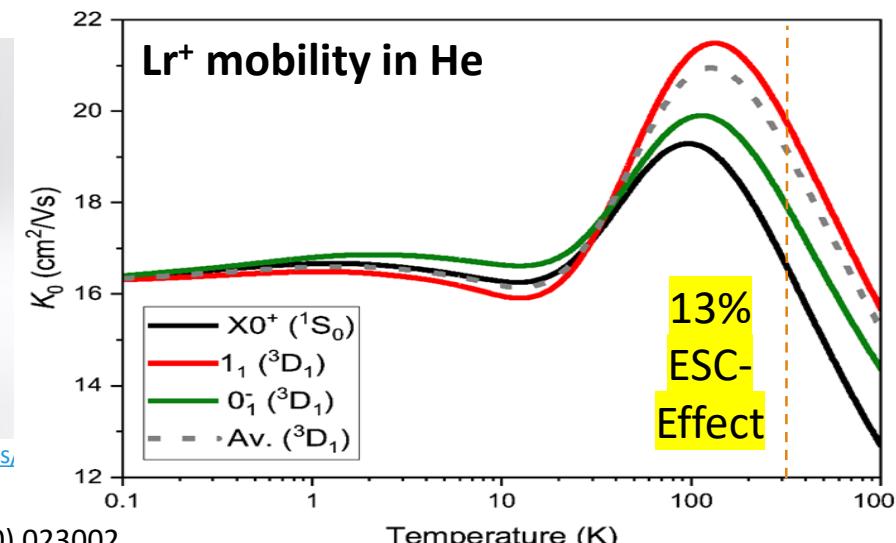
(3.2 pps @ 3p $\mu$ A)

$^{209}\text{Bi}$  ( $^{48}\text{Ca}$ , 2n)  $^{255}\text{Lr}$

(0.4 pps @ 3p $\mu$ A)



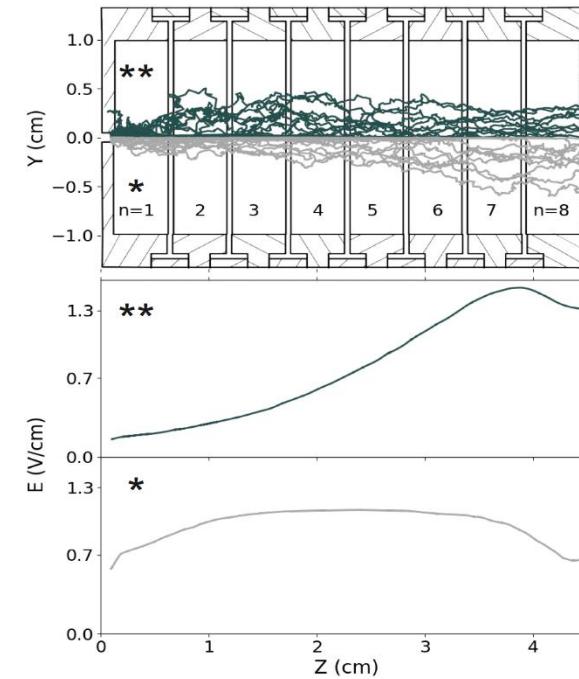
<https://u.ganil-spiral2.eu/chartbeams/>



# Start-up phase @GANIL

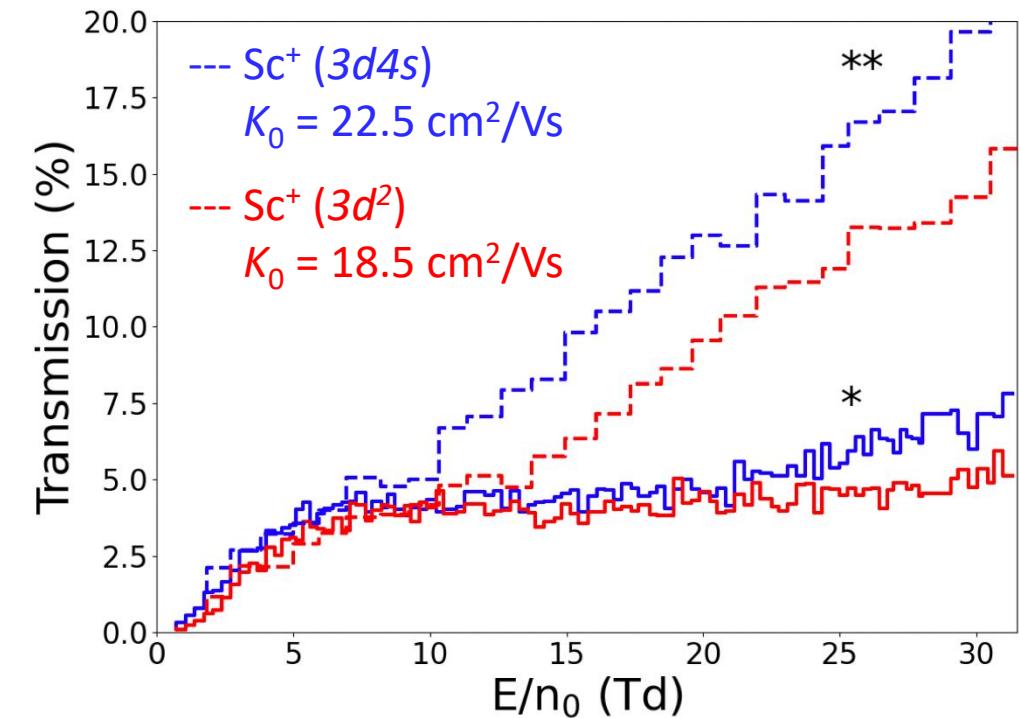
# Enhancing the efficiency

- Optimization of the drift field & pressure
  - while preventing electric discharge
  - & suppressing collisional quenching
- Exploiting synergies with GISELE/FRIENDS3 (Hall D)



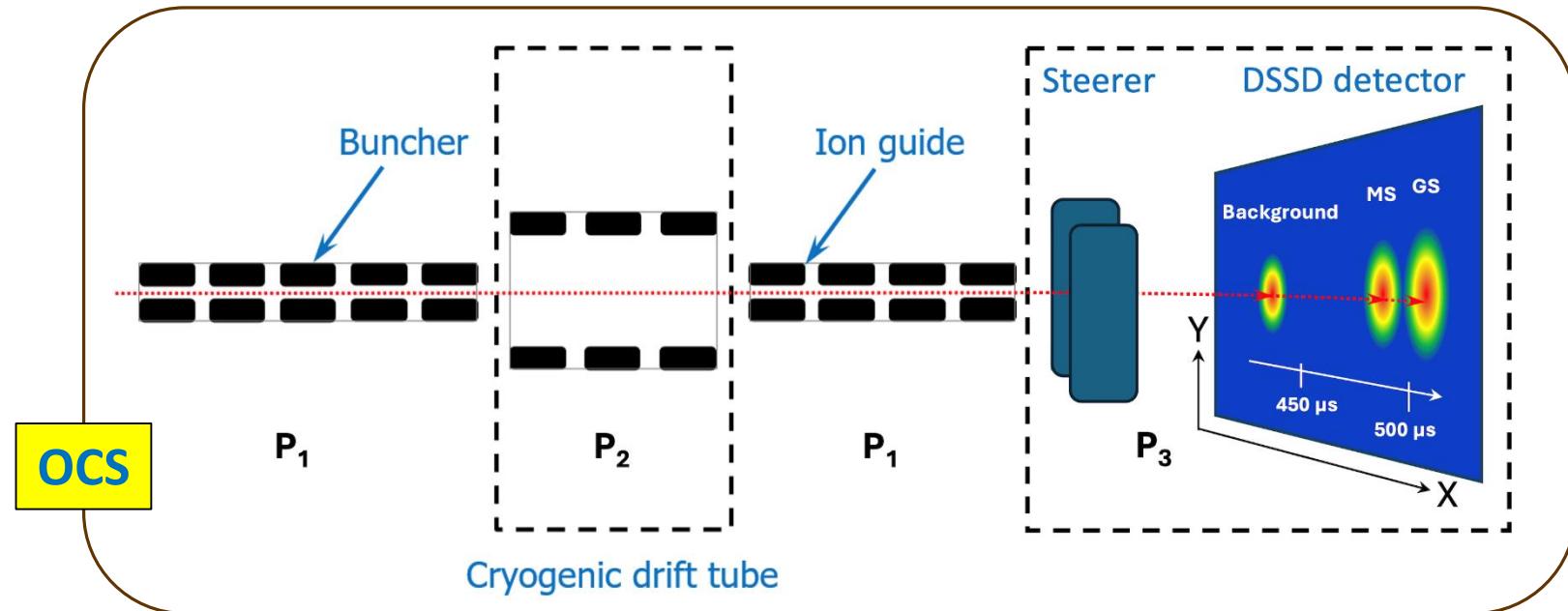
SIMION simulations  
(SDS model) for  
**Sc<sup>+</sup>** drifting in He

Romero-Romero *et al.*,  
*Atoms* **10** (2022) 87



# Enhancing the sensitivity

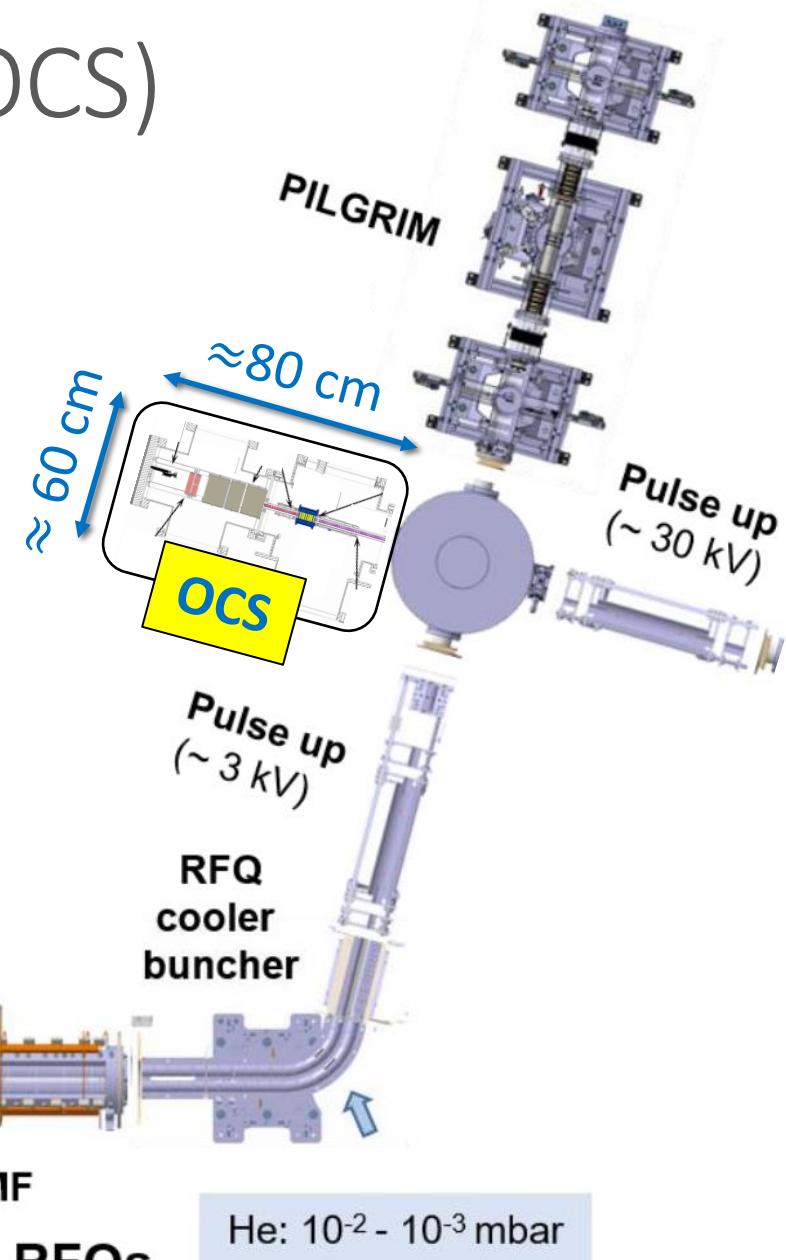
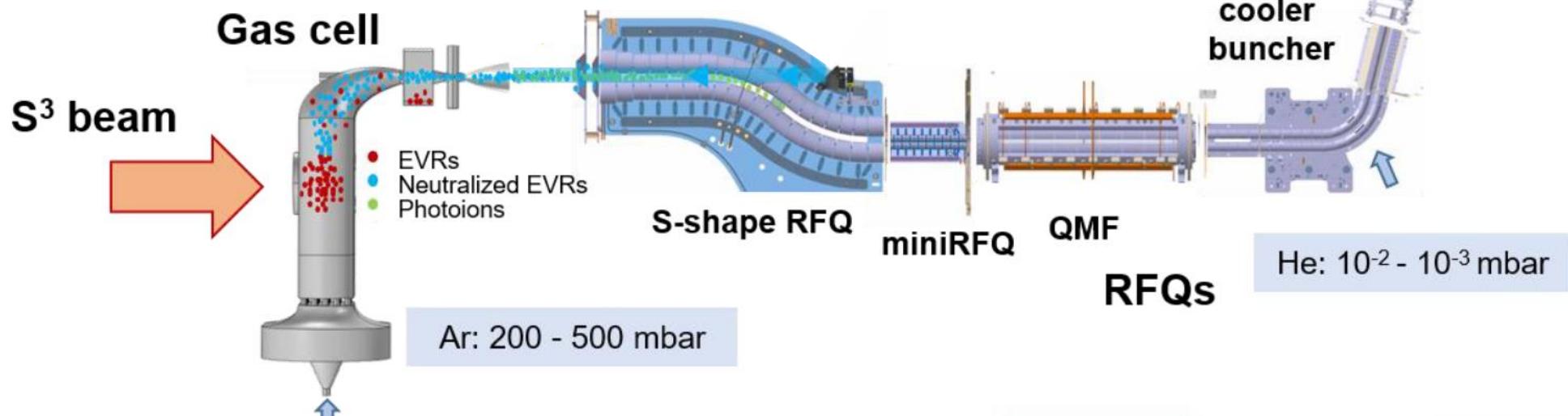
- Development of an Online Chromatography Setup (OCS)



- Increased sensitivity by registering alpha decay events
  - Deflection of ions at the right moment
  - Centroids of radioactivity hotspots correspond to distinct arrival times
- Balky molecules are slow-moving, thus easy to discriminate
  - No mass filter required for alpha emitters

# Online Chromatography Setup (OCS)

- First phase: Integration behind Q-deflector @ S3-LEB
- Compact setup ( $\approx 80$  cm length)
- Inauguration in parasitic mode ( $^{214}\text{Ac}^+$ )



# Start-up phase program (overview)

- Work packages (2025-2028):

- (WP1): Online experimental program including the development of the OCS

[CaeSAR PhD]

- (WP2): Offline experimental program with the existing LRC setup

[CNRS Postdoc]

- (WP3): Proof-of-concept activities for grant applications

[Prepare funding application for a new stopping cell]

[Prepare funding application for LRC setup @DESIR]

Description	2025												2026												2027												2028											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
WP1: Online experimental program																																																
Task-1.1 Simulations, design, & construction	x	x						x	x	x	x	x																																				
Task-1.2 Equipment procurement	x	x	x					x	x																																							
Task-1.3 DAQ inauguration																																																
Task-1.4 Offline calibration/optimization																																																
Task-1.5 Online inauguration with Ac isotopes (parasitic)																																																
Task-1.6 Beamtime proposals																																																
Task-1.7 Level search in lawrencium																																																
Task-1.8 Online HFS of Li isotopes																																																
Task-1.9 Online HFS of Ac isotopes																																																
WP2: Offline experimental program								x	x																																							
Task-2.1 LRC setup transport and storage	x	x						x	x	x	x	x																																				
Task-2.2 Setup installation in HALL D								x	x	x	x	x																																				
Task-2.3 Study transition strengths & quenching effects								x	x	x	x	x																																				
Task-2.4 Enhance ion transmission efficiency								x	x	x	x	x																																				
Task-2.5 Enhance LRC spectral precision								x	x	x	x	x																																				
WP3: Proof-of-concept activities																																																
Task-3.1 Simulations & design of the cryogenic stopping cell	x	x	x	x																																												
Task-3.2 Gas dynamic simulations for the nozzle	x	x	x	x																																												
Task-3.3 Ion trajectory simulations for collinear LRC								x	x	x	x	x																																				
Task-3.4 Preparation of grant applications	x	x	x	x																																												

Cost category	Total (kEUR)
Online Chromatography Setup (Tab. A.1)	131
Carrying amount for LRC equipment (Tab. A.2)	45
Resumption of LRC operation at GANIL (Tab. A.3)	45
<b>Total costs</b>	<b>221</b>
Duties	FTE
Technical referent for OCS	0.2
Support for the OCS at S <sup>3</sup> -LEB	0.7
Technical referent for the offline setup (coordination)	0.2
Support for the offline setup in Hall D	1.2
Support for the cryogenic buffer-gas stopping cell (design)	0.2
<b>Total</b>	<b>2.5</b>



# Distinct ion mobilities ( $K_0$ )

