

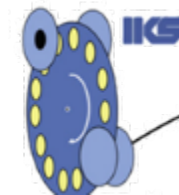
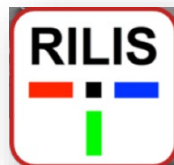
Combining mass spectrometry with laser spectroscopy at ISOLDE

David Lunney (CNRS, France)

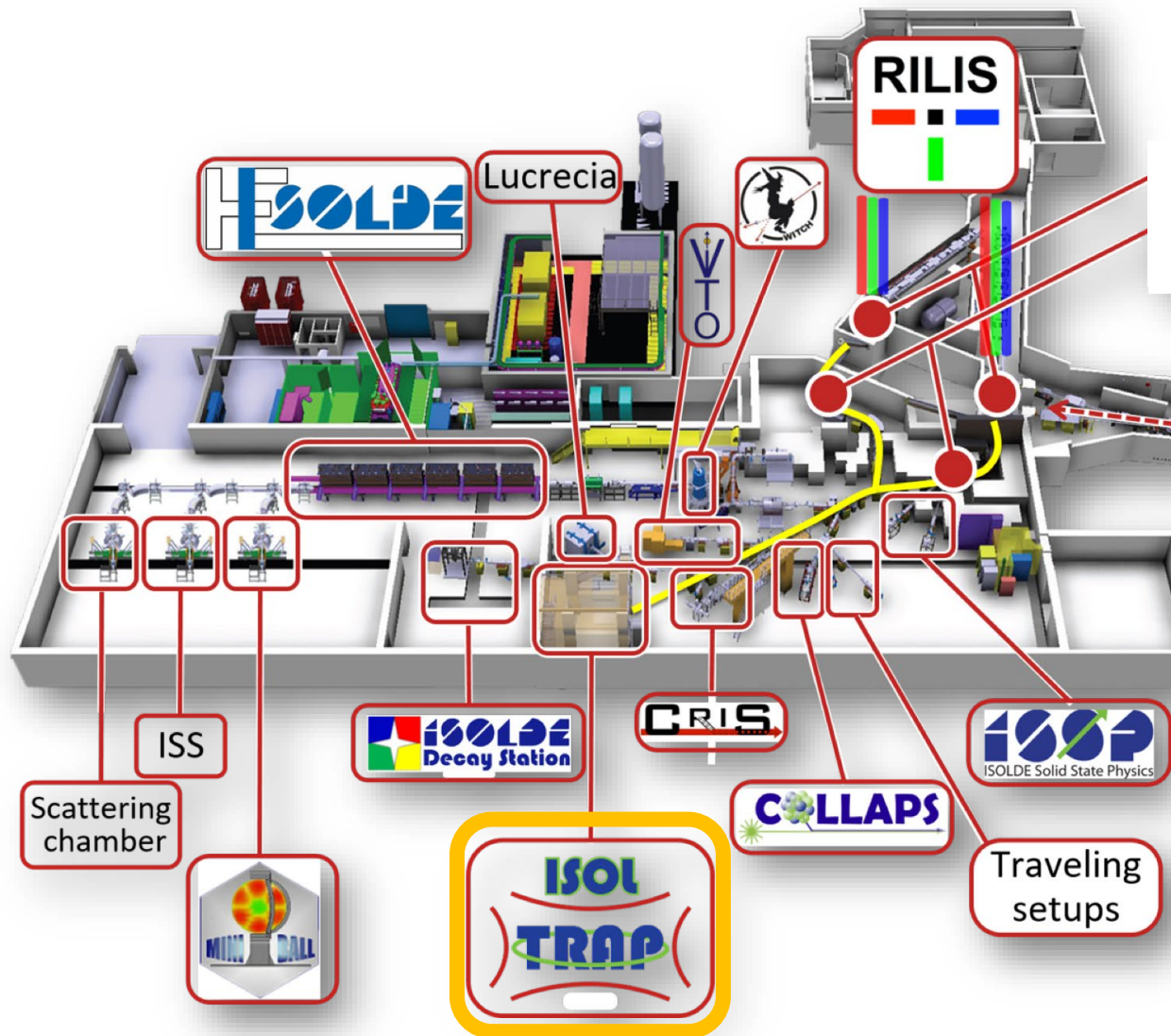
with the ISOLTRAP, RILIS and WINDMILL/IDS collaborations



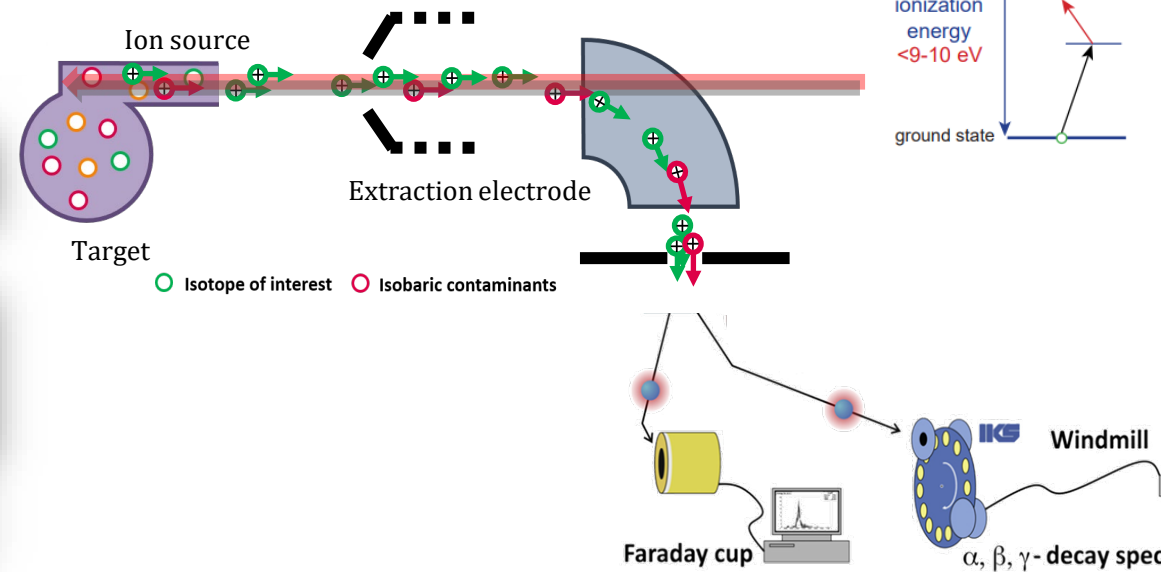
NUCLÉAIRE
& PARTICULES



ISOLDE – needs no introduction!



Neither does RILIS



- F. Scheerer et al., *Rev. Sci. Instrum.* (1992)
- A.E. Barzakh et al. *Phys. Rev. C* (2000)
- V.N. Fedosseev et al. *NIM B* (2003)

- H. De Witte et al., *Phys. Rev. Lett.* (2007)
- T.E. Cocolios et al. *Phys. Rev. Lett.* (2011)
- ...

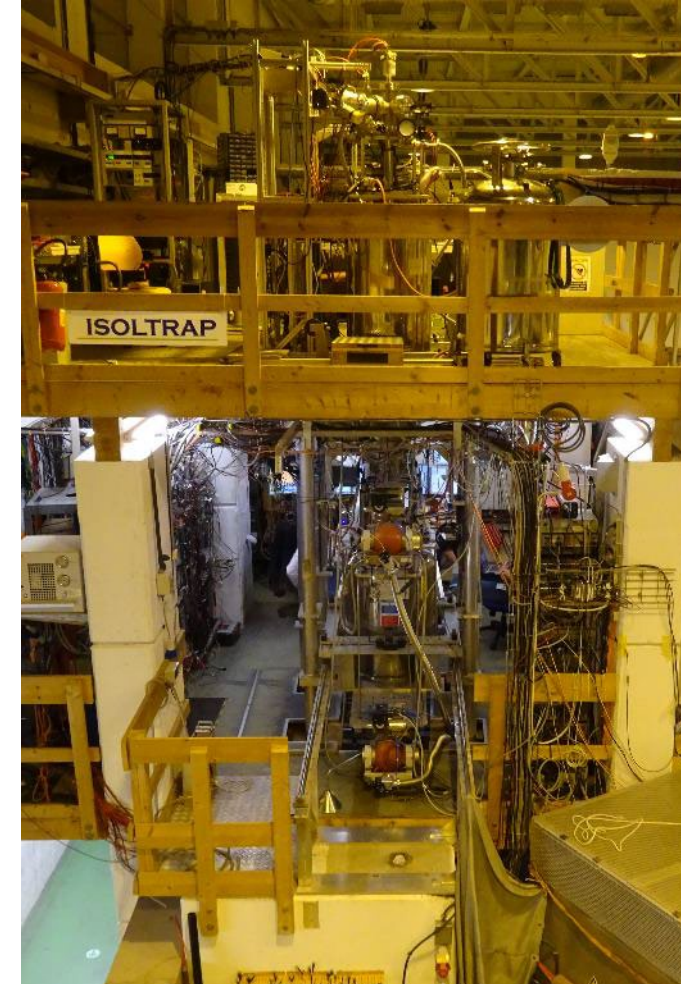
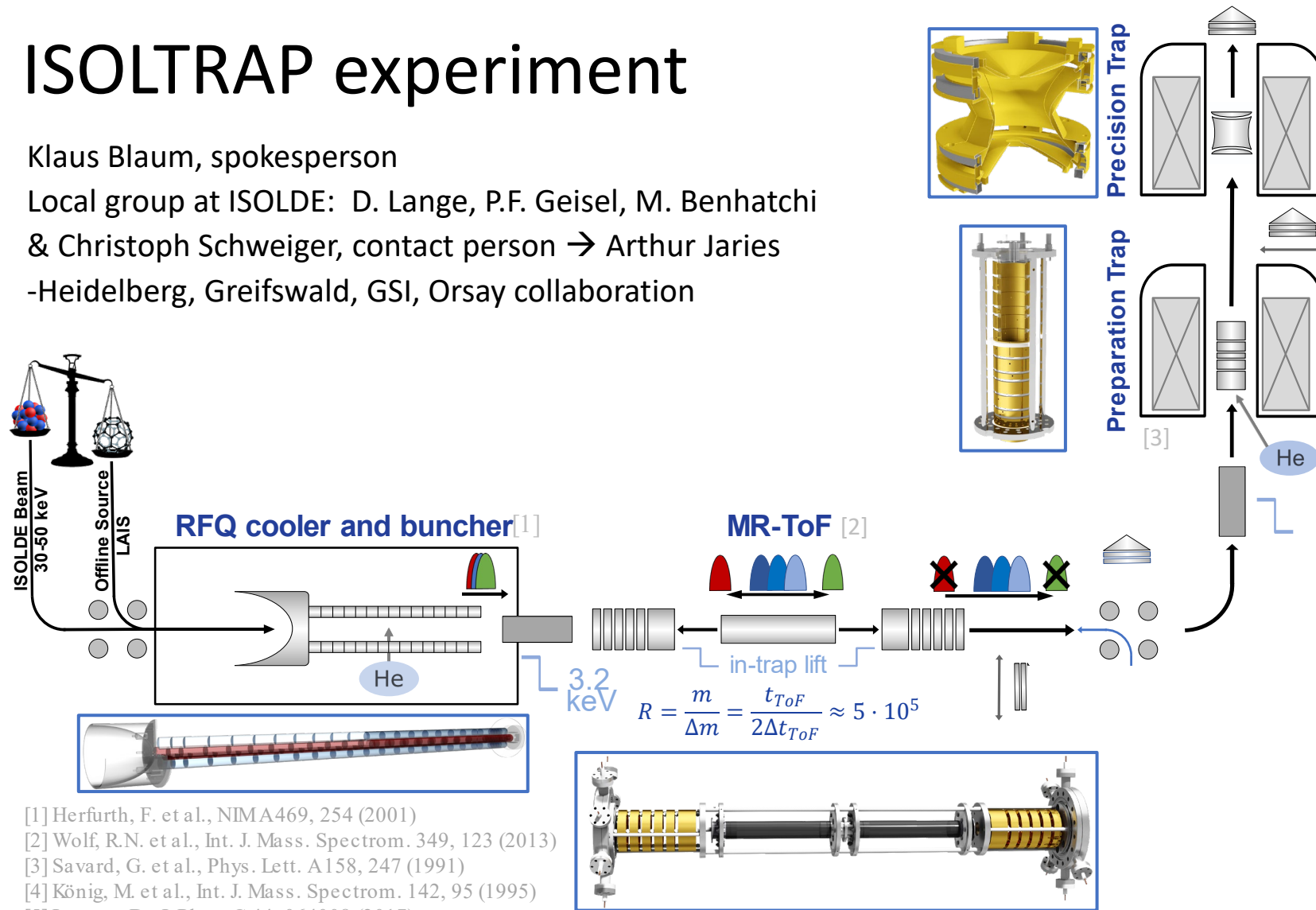
ISOLTRAP experiment

Klaus Blaum, spokesperson

Local group at ISOLDE: D. Lange, P.F. Geisel, M. Benhatchi

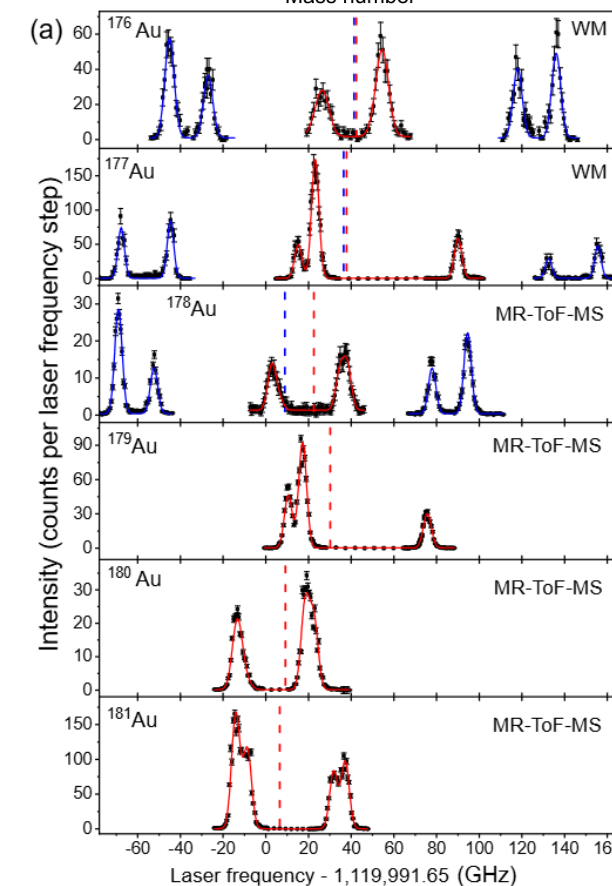
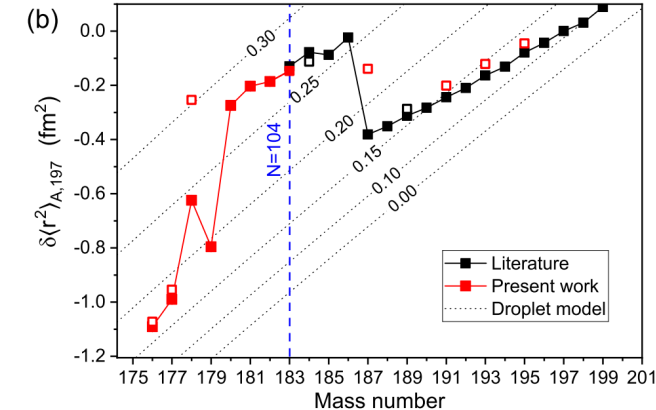
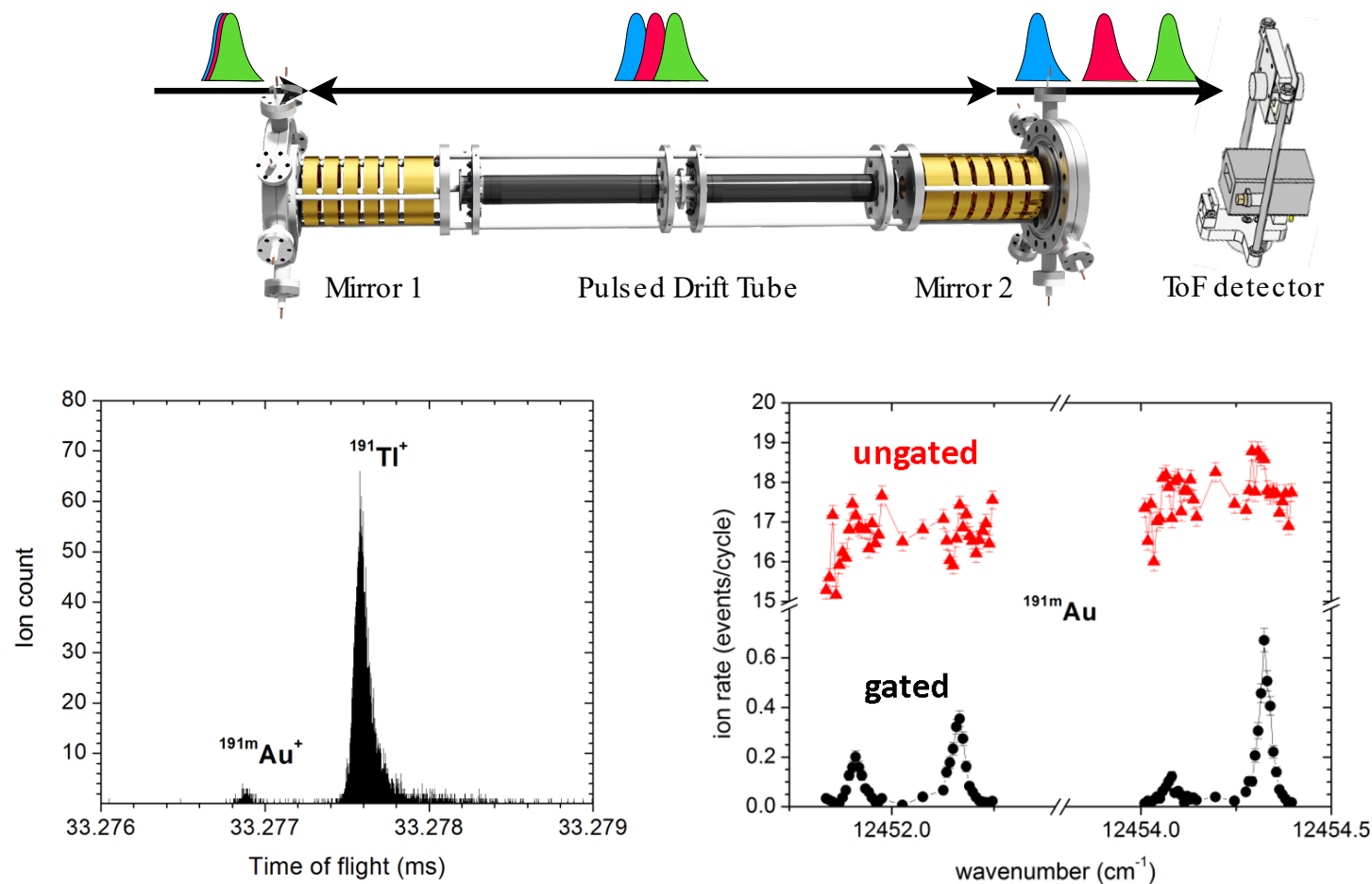
& Christoph Schweiger, contact person → Arthur Jaries

-Heidelberg, Greifswald, GSI, Orsay collaboration



- [1] Herfurth, F. et al., NIMA469, 254 (2001)
- [2] Wolf, R.N. et al., Int. J. Mass. Spectrom. 349, 123 (2013)
- [3] Savard, G. et al., Phys. Lett. A158, 247 (1991)
- [4] König, M. et al., Int. J. Mass. Spectrom. 142, 95 (1995)
- [5] Lunney, D., J. Phys. G 44, 064008 (2017)

Multi-Reflection Time-of-Flight MS

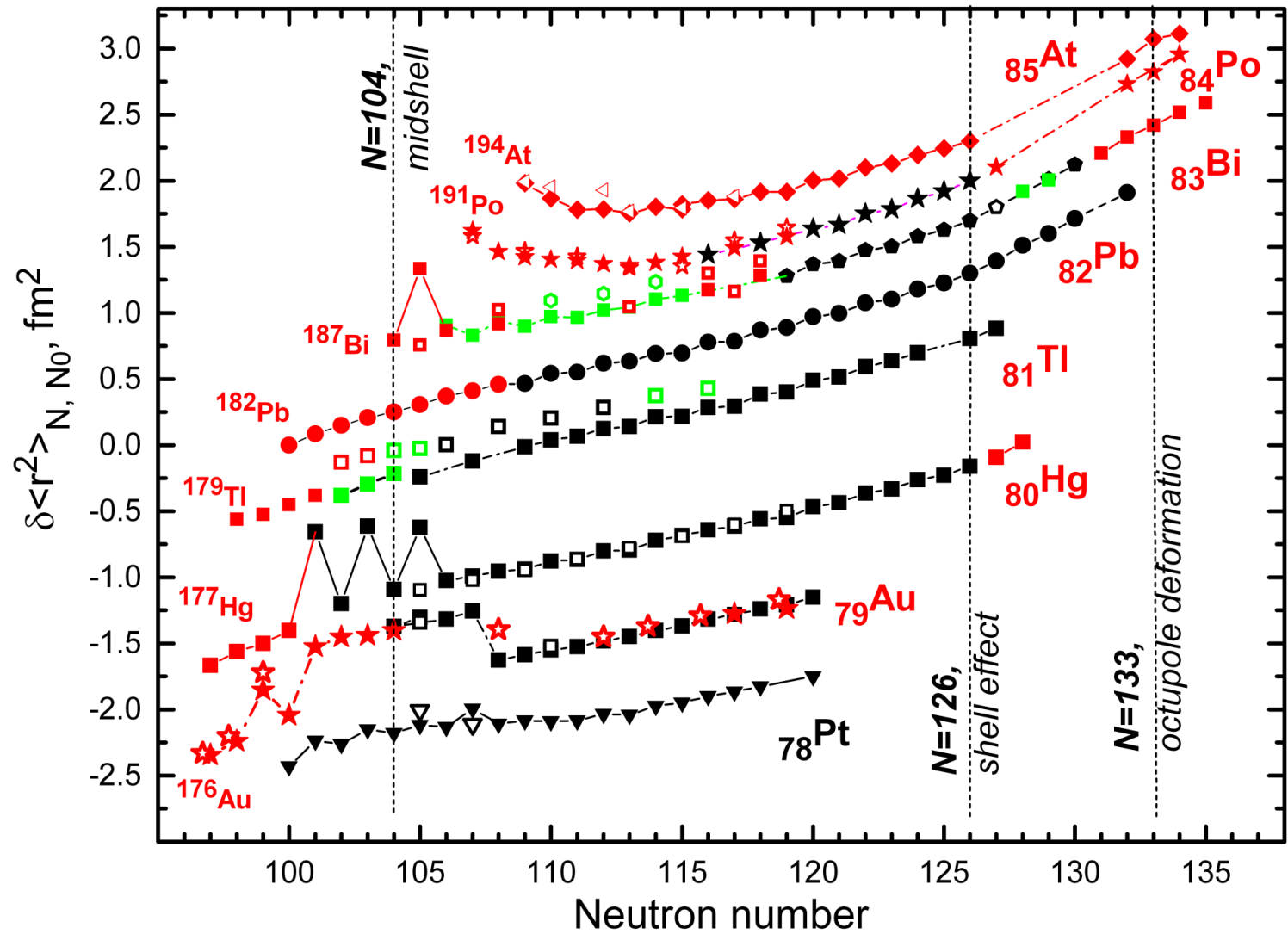
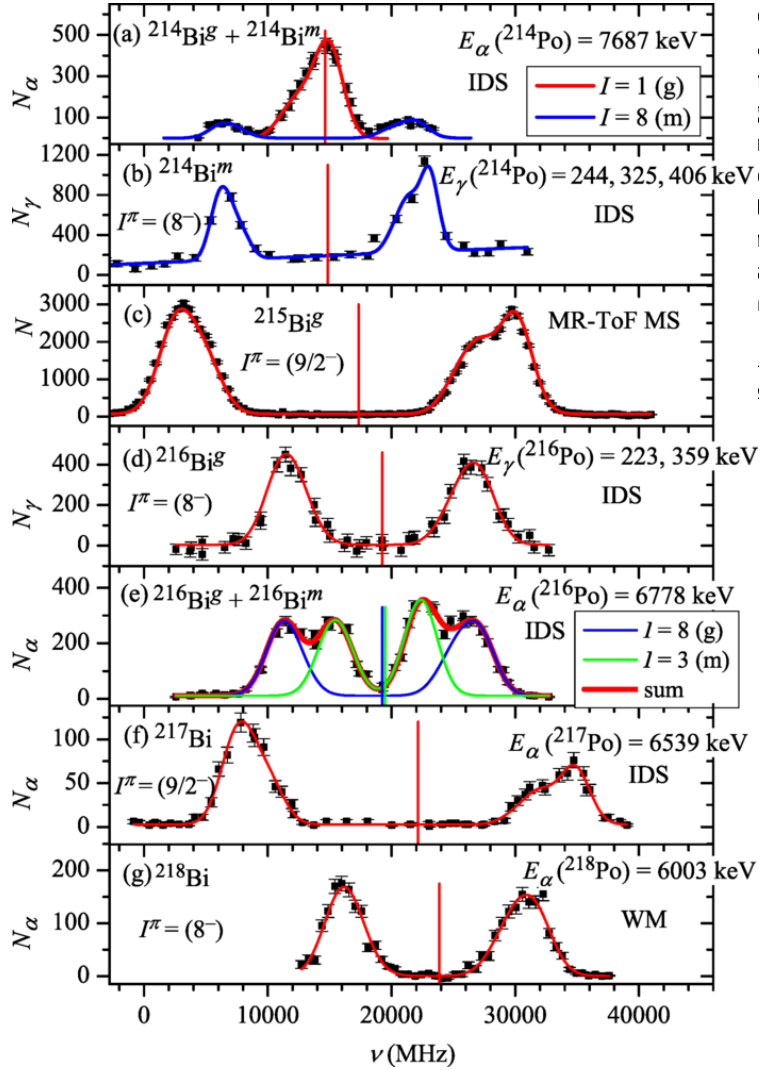


Deformation versus Sphericity in the Ground States Lightest Gold Isotopes

J. G. Cubiss *et al.*
Phys. Rev. Lett. **131**, 202501 (2023) – Published 14 November 2023

Bibliography of the WINDMILL/IDS + RILIS + ISOLTRAP results (so far!)

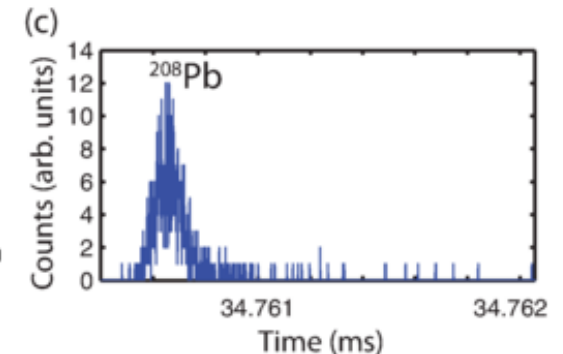
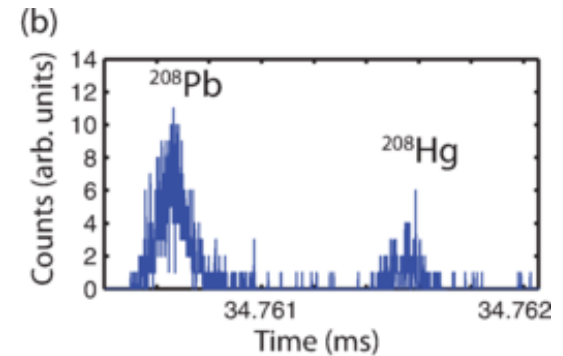
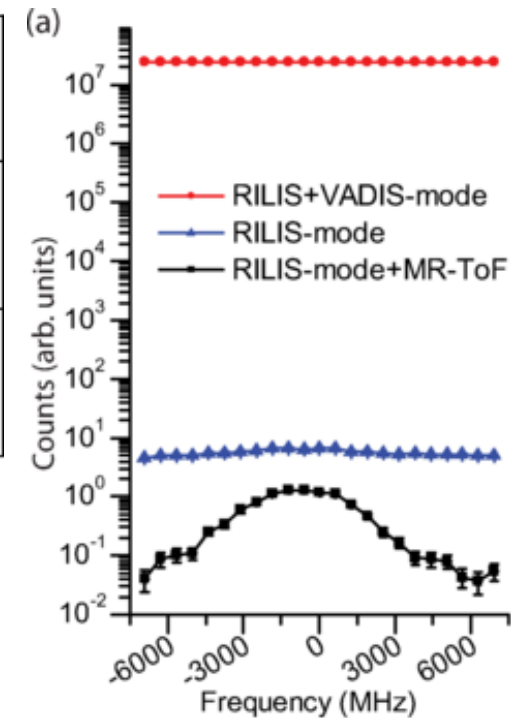
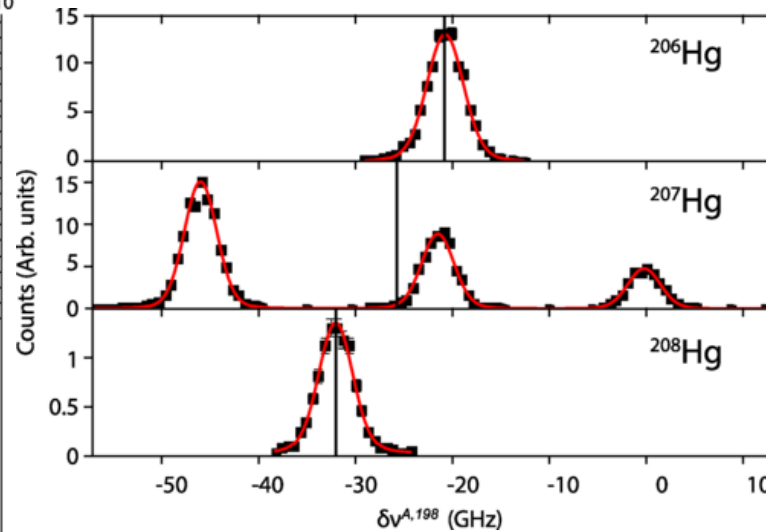
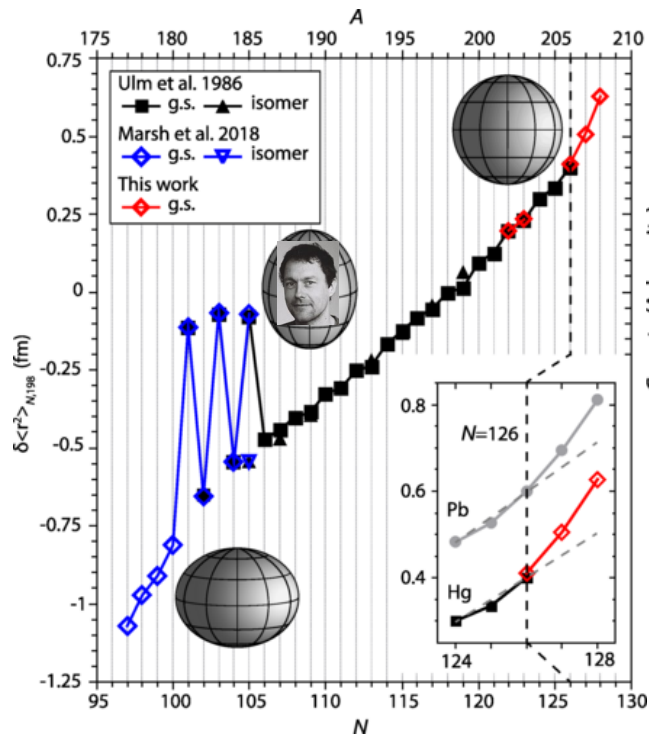
• A. Barzakh et al. "Charge radii and moments of $^{214-218}\text{Bi}$: Exploring the "southern" border of the $Z > 82$ octupole-deformation region," *Physical Review C* 112, 034304 (2025)



Red data = our data from ISOLDE campaign; Green points = Gatchina; Black points = literature

Bibliography of the WINDMILL/IDS + RILIS + ISOLTRAP results (so far!)

- **A. Barzakh et al. "Charge radii and moments of $^{214-218}\text{Bi}$: Exploring the "southern" border of the $Z > 82$ octupole-deformation region," *Physical Review C* 112, 034304 (2025)**
- J. Cubiss et al. "Deformation versus sphericity in the ground states of the lightest gold isotopes," *Physical Review Letters* 131, 202501 (2023)
- A.E. Barzakh et al. "Producing gold at ISOLDE," *Nuclear Instruments & Methods in Physics Research B* 513, 26 (2022)
- **T. Day Goodacre et al "Charge radii, moments and masses of mercury isotopes across the $N = 126$ shell closure," *Physical Review C* 104, 054322 (2021)**
- **T. Day Goodacre et al. "Laser Spectroscopy of Neutron-Rich $^{207,208}\text{Hg}$ Isotopes: Illuminating the Kink and Odd-Even Staggering across the $N = 126$ Shell Closure," *Physics Review Letters* 126, 032502 (2021)**
- J. Cubiss et al. "Laser-assisted decay spectroscopy and mass spectrometry of ^{178}Au ," *Physics Review C* 102, 044332 (2020)
- R.D. Harding et al. "Laser-assisted decay spectroscopy for the ground states of $^{180,192}\text{Au}$," *Physical Review C*, 102, 024312 (2020)
- A.E. Barzakh et al. "Shape coexistence in ^{187}Au studied by laser spectroscopy," *Physics Review C* 101, 064321 (2020)
- A.E. Barzakh et al. "Hyperfine anomaly in gold and magnetic moments of $11/2^-$ gold isomers," *Physics Review C* 101, 034308 (2020)
- A.E. Barzakh et al., "Inverse odd-even staggering in nuclear charge radii and possible octupole collectivity in $^{217,218,219}\text{At}$ revealed by in-source laser spectroscopy," *Physical Review C* 99, 054317 (2019)
- S. Sels et al. "Shape staggering of mid-shell mercury isotopes compared with EDF and MCSM calculations," *Physical Review C* 99, 044306 (2019) – **Editor's Suggestion**
- **B.A. Marsh et al. "Characterization of the shape-staggering effect in mercury nuclei," *Nature Physics* 14, 1163 (2018)**
- J.G. Cubiss et al. "Change in structure between the $I = 1/2$ states in ^{181}Tl and $^{177,179}\text{Au}$," *Physics Letters B* 786, 355 (2018)
- J.G. Cubiss et al. "Charge radii and electromagnetic moments of $^{195-211}\text{At}$ isotopes," *Physical Review C* 97, 054327 (2018)



INTC-I-244 to develop Hg beams → CERN-INTC-2024-019; INTC-P-698

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

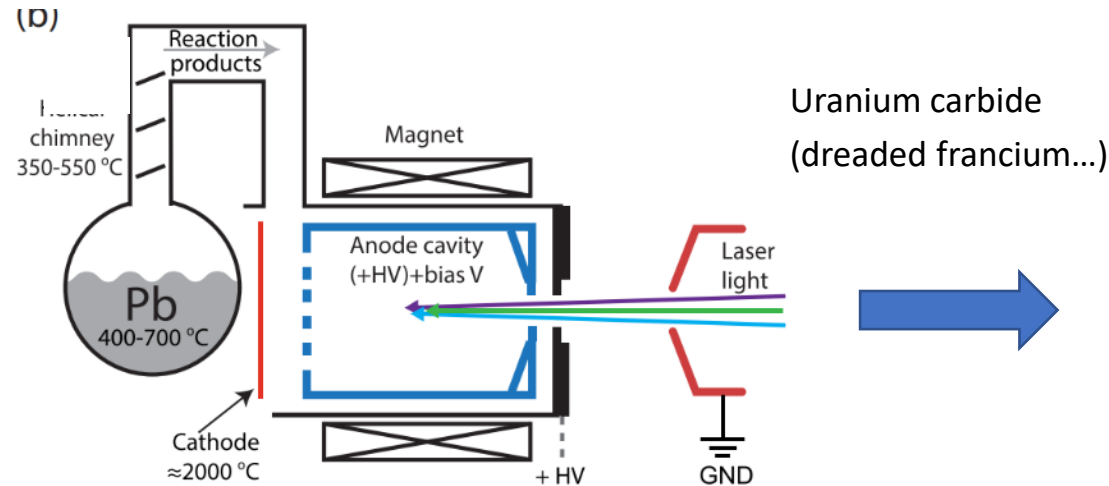
Laser & decay spectroscopy and mass spectrometry of neutron-rich mercury isotopes south-east of ^{208}Pb

10th January 2024

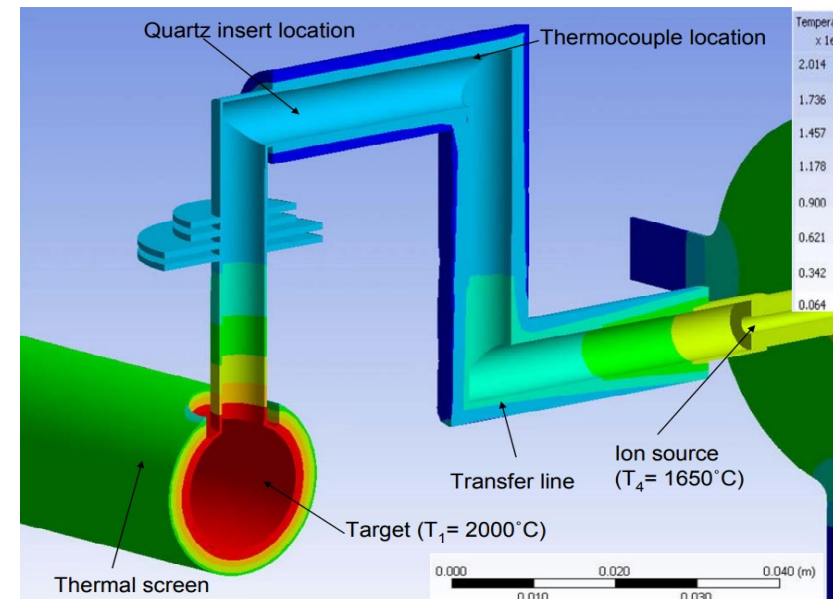
A. Algora¹, B. Andel², A. N. Andreyev³, S. Antalic², D. Balabanski⁴, M. Benhatchi⁵, J. Benito⁶, C. Bernerd⁷, K. Blaum⁸, J. A. Briz⁶, R. B. Cakirli⁹, K. Chrysalidis⁷, T. Coccolios¹⁰, J. G. Cubiss³, T. Day Goodacre¹¹, V. N. Fedosseev⁷, L. M. Fraile⁶, L. P. Gaffney¹², G. Georgiev⁵, P. F. Giesel¹³, K. Gladnishki¹⁴, R. Heinke⁷, Y. Hirayama¹⁵, A. Illana⁶, D. Kocheva¹⁴, U. Köster¹⁶, D. Lange⁸, R. Lica¹⁷, Yu. A. Litvinov¹⁸, D. Lunney⁵, B. A. Marsh⁷, A. McFarlane³, J. Mišt², A. Morales¹, M. Mukai¹⁹, S. Naimi⁵, L. Nies⁷, T. Niwase¹⁵, J. Ojala¹², B. Olaizola²⁰, C. Page³, R. D. Page¹², J. Pakarinen²¹, Z. Podolyak²², G. Rainovski¹⁴, M. Rosenbusch¹⁵, S. Rothe⁷, P. Schury¹⁵, Ch. Schweiger⁸, L. Schweikhard¹³, S. Sharma²³, A. Sitarčik², P. Srivastava²³, K. Stoychev⁷, M. Stryczyński²¹, P. Van Duppen¹⁰, Y. Watanabe¹⁵, J. Wilson³, Z. Yue^{3,7} + IDS collaboration

Spokesperson: J. G. Cubiss [james.cubiss@york.ac.uk], D. Lange [daniel.lange@cern.ch], A. N. Andreyev [andrei.andreyev@york.ac.uk], U. Köster [koester@ill.fr]

Contact person: Ch. Schweiger [christoph.schweiger@cern.ch], Z. Yue [zixuan.yue@york.ac.uk]

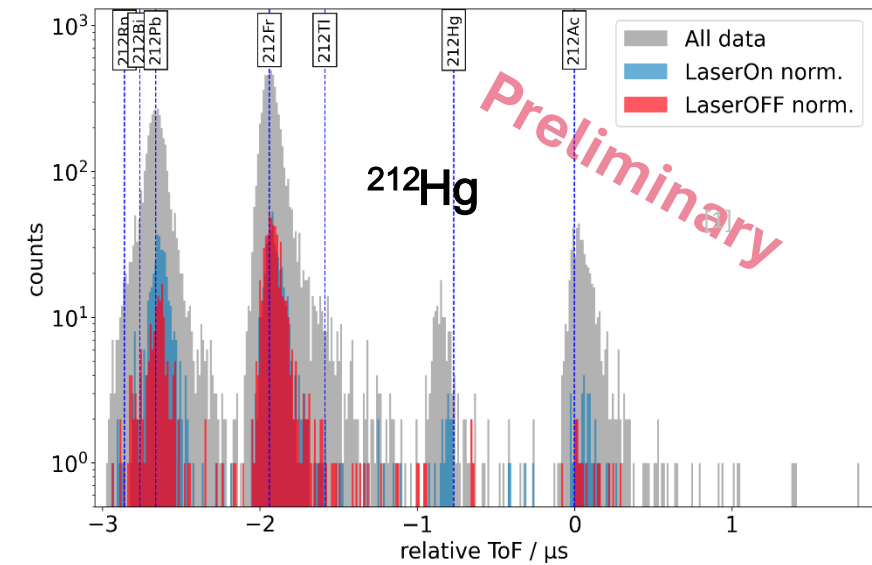
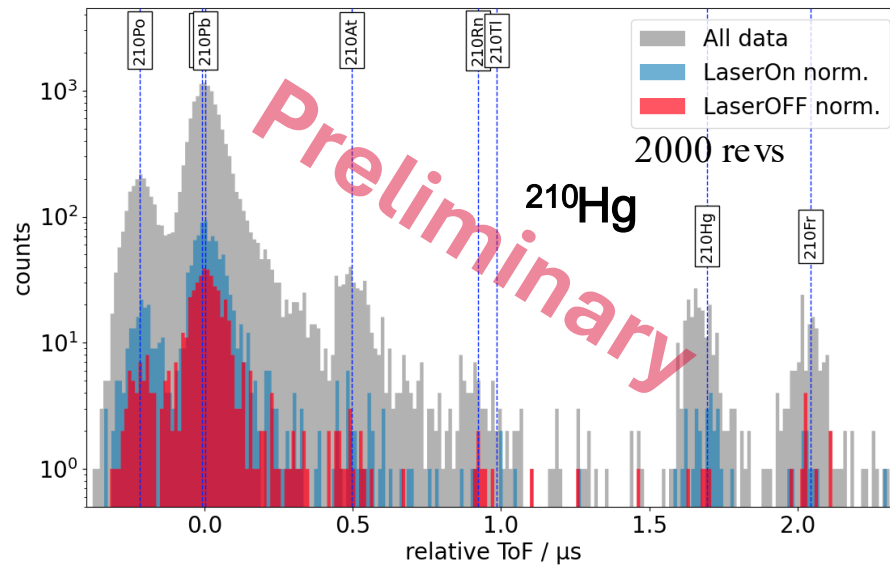
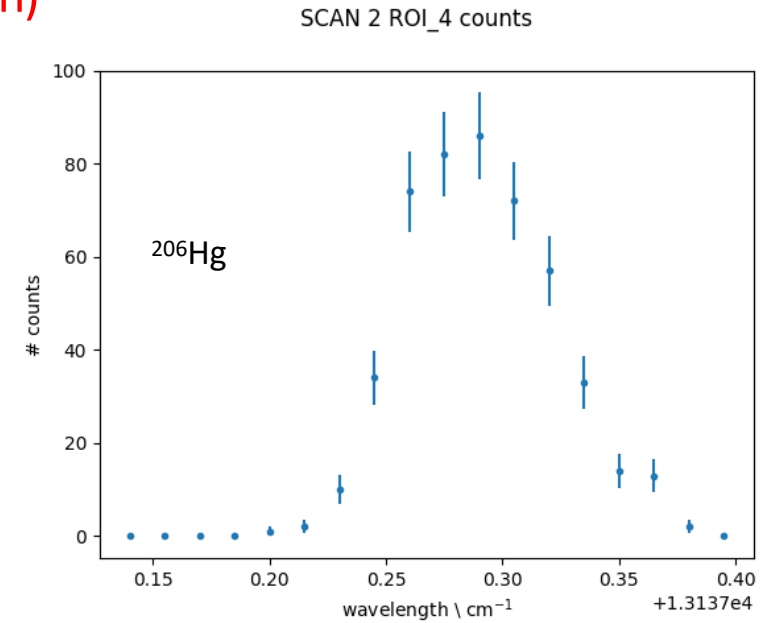
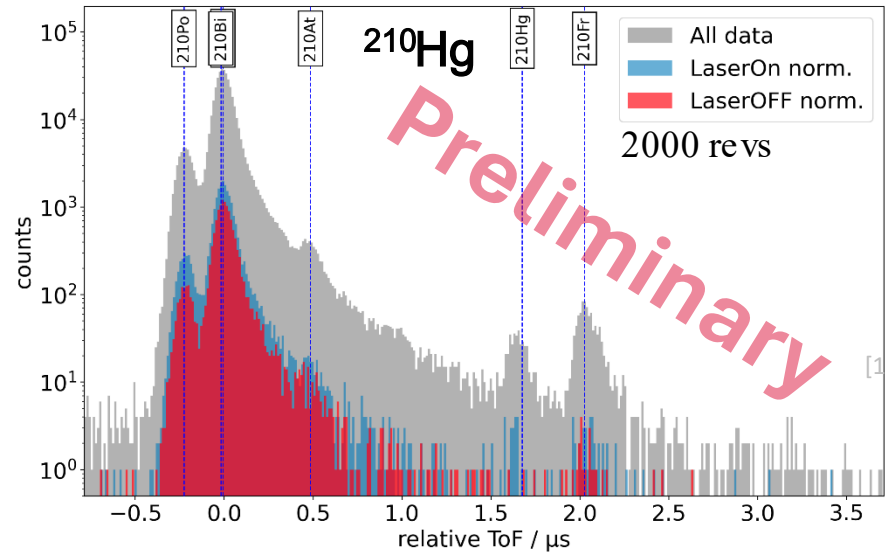


208 Pb 82 Pb 126 500 ns 10 ⁺ Ex 488.22 (0.05) IT=100% stable 0 ⁺ M 21745.6 (1.1) Ex 100% α?	209 Pb 82 Pb 127 3.234 h 9/2 ⁺ M 17614.6 (1.7) β ⁻ =100%	210 Pb 82 Pb 128 201 ns 8 ⁺ Ex 1278 (5) IT=100% 22.20 y 0 ⁺ M 14220.5 (1.4) Ex 100% α=1.9e-5 (4%)	211 Pb 82 Pb 129 159 ns (27) Ex 104 (15) IT=100% 35.164 m 9/2 ⁺ M 10482.9 (2.3) β ⁻ =100%	212 Pb 82 Pb 130 6.0 us 8 ⁺ Ex 1335 (2) IT=100% 10.64 h 0 ⁺ M 7948.8 (1.8) β ⁻ =100%	213 Pb 82 Pb 131 10.2 m (9/2 ⁺) M 3204 (7) β ⁻ =100%	214 Pb 82 Pb 132 6.2 us 8 ⁺ Ex 1420 (20) IT=100% 27.06 m 0 ⁺ M 182.8 (2.0) β ⁻ =100%	215 Pb 82 Pb 133 2.34 m 9/2 ⁺ M 4340 (50) β ⁻ =100%
207 Tl 81 Tl 126 1.33 s 11/2 ⁺ Ex 136 (0.05) IT=100% 4.77 m 1/2 ⁺ M 21034 (5) β ⁻ =100%	208 Tl 81 Tl 127 3.053 m 5 ⁺ M 16750.1 (1.9) β ⁻ =100%	209 Tl 81 Tl 128 2.162 m 1/2 ⁺ M 13645 (6) β ⁻ =100%	210 Tl 81 Tl 129 1.30 m 5 ⁺ M 9247 (12) β ⁻ =100% β ⁻ n=0.009 (6%)	211 Tl 81 Tl 130 80 s 1/2 ⁺ M 6080 (40) β ⁻ =100% β ⁻ n=2.2 (22)%	212 Tl 81 Tl 131 31 s (5 ⁺) M 1550# (200#) β ⁻ =100% β ⁻ n=1.8 (18)%	213 Tl 81 Tl 132 24 s 1/2 ⁺ M 1784 (27) β ⁻ =100% β ⁻ n=7.6 (34)%	214 Tl 81 Tl 133 11 s 5 ⁺ M 6470# (200#) β ⁻ =100% β ⁻ n=34 (12)%
206 Hg 80 Hg 126 18 ns 10 ⁺ Ex 102 (1) IT=100% 2.09 us 5 ⁺ Ex 102 (1) IT=100% 32 m 0 ⁺ M 2046 (20) β ⁻ =100%	207 Hg 80 Hg 127 2.9 m 9/2 ⁺ M 16487 (30) β ⁻ =100%	208 Hg 80 Hg 128 99 ns (8 ⁺) Ex 138 (24) IT=100% 42 m 0 ⁺ M 13270 (30) β ⁻ =100%	209 Hg 80 Hg 129 38 s 9/2 ⁺ M 8640# (150#) β ⁻ =100% β ⁻ n=0#%	210 Hg 80 Hg 130 1 us 3 ⁺ Ex 142 (2) IT=100% 21 us 3 ⁺ Ex 142 (2) IT=100% 64 s 0 ⁺ M 379 (20#) β ⁻ =100% β ⁻ n=2.2 (22)%	211 Hg 80 Hg 131 26 s 9/2 ⁺ M 620# (200#) β ⁻ =100% β ⁻ n=6.3 (63)%	212 Hg 80 Hg 132 1# m 0 ⁺ M 2760# (300#) β ⁻ ? β ⁻ n=6#%	213 Hg 80 Hg 133 1# s 5/2 ⁺ M 7670# (300#) β ⁻ ? β ⁻ n=30#%
205 Au 79 Au 126 13 ns 10 ⁺ Ex 102 (1) IT=100% 5 s 11/2 ⁺ Ex 102 (1) IT=100% 33 s 3/2 ⁺ M 979 (20#) β ⁻ =100%	206 Au 79 Au 127 47 s (5 ⁺ , 6 ⁺) M 14220# (300#) β ⁻ =100%	207 Au 79 Au 128 10# s 3/2 ⁺ M 10810# (300#) β ⁻ ? β ⁻ n=0.4#%	208 Au 79 Au 129 10# s M 6100# (300#) β ⁻ ? β ⁻ n=5#%	209 Au 79 Au 130 1# s 3/2 ⁺ M 2540# (400#) β ⁻ ? β ⁻ n=90#%	210 Au 79 Au 131 1# s M 2330# (400#) β ⁻ ? β ⁻ n=10#%		



Quartz transfer line:
Lower negative
adsorption enthalpy
of Hg vs. Fr ! ☺

New Hg masses (D. Lange, in preparation)

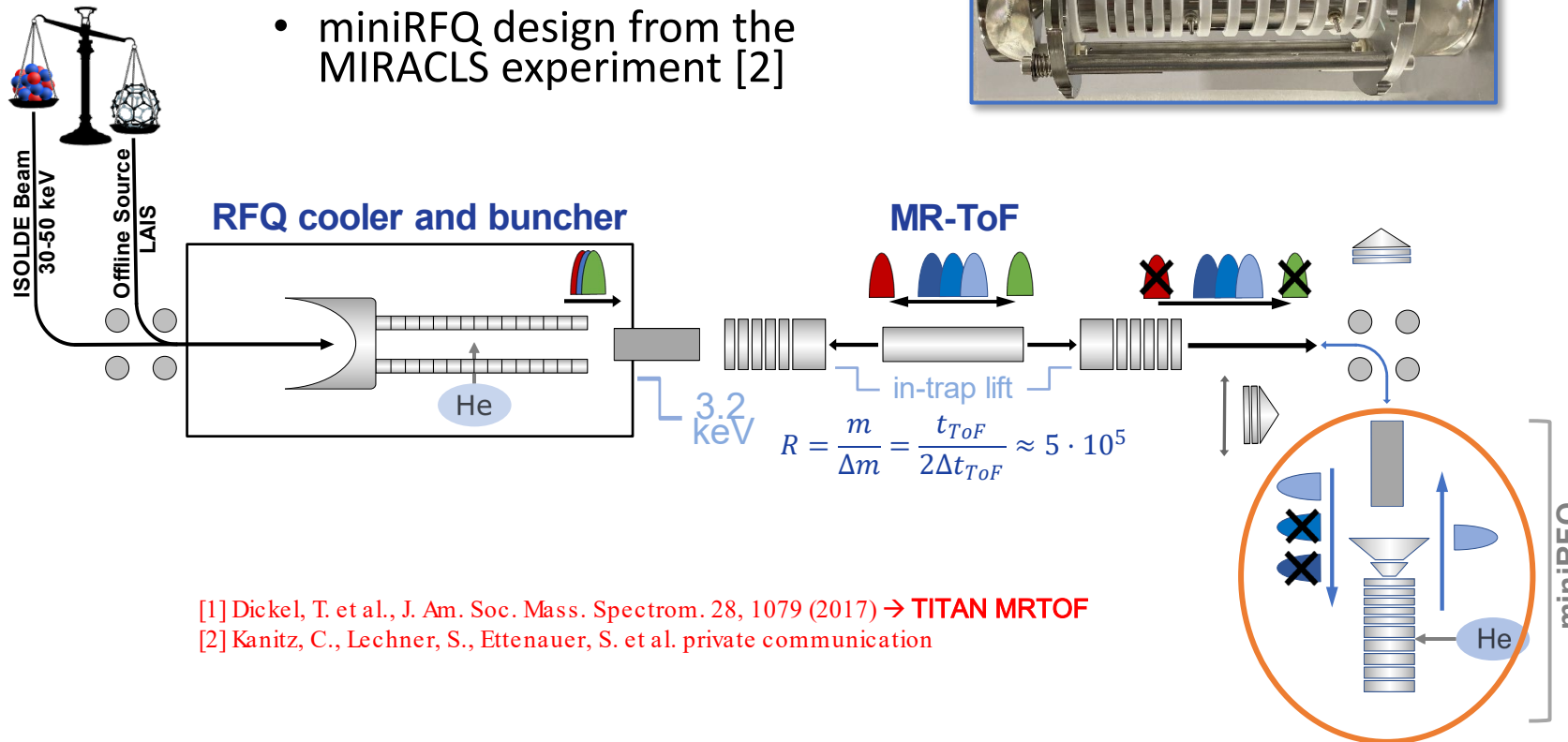
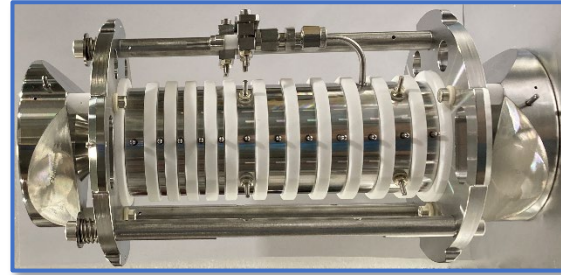


Reduction
of target
and line
heating

MiniRFQ: Mass-selective re-trapping [1]

(part of the PhD work of **Daniel Lange**, U. Heidelberg)

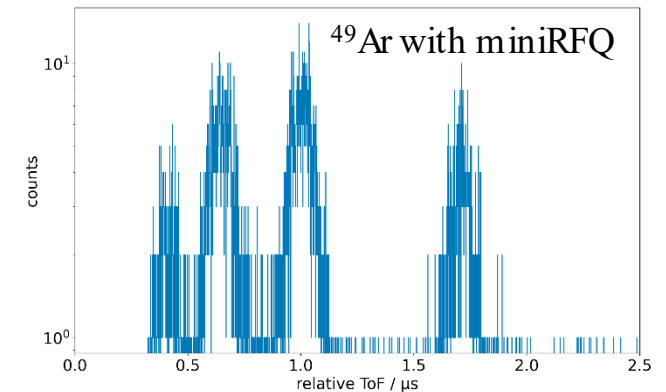
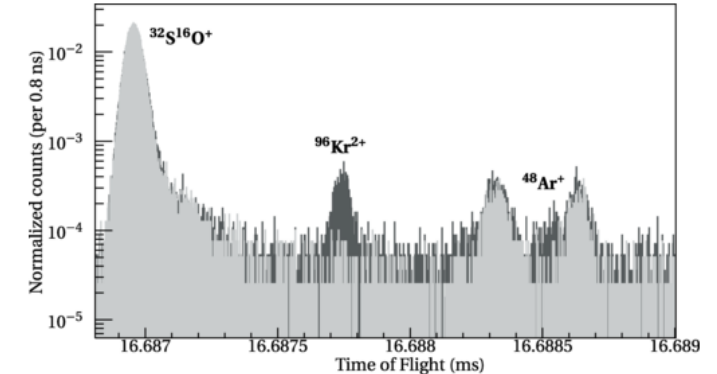
- Low production cross section combined with isobaric and molecular contamination
- miniRFQ design from the MIRACLIS experiment [2]



[1] Dickel, T. et al., J. Am. Soc. Mass. Spectrom. 28, 1079 (2017) → **TITAN MRTOF**

[2] Kanitz, C., Lechner, S., Ettenauer, S. et al. private communication

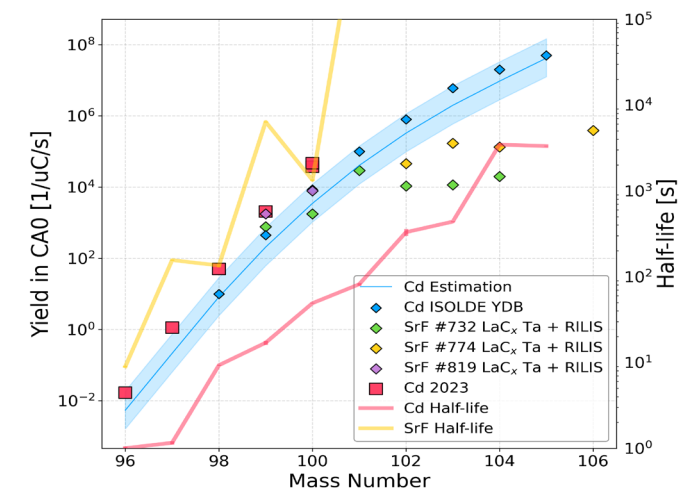
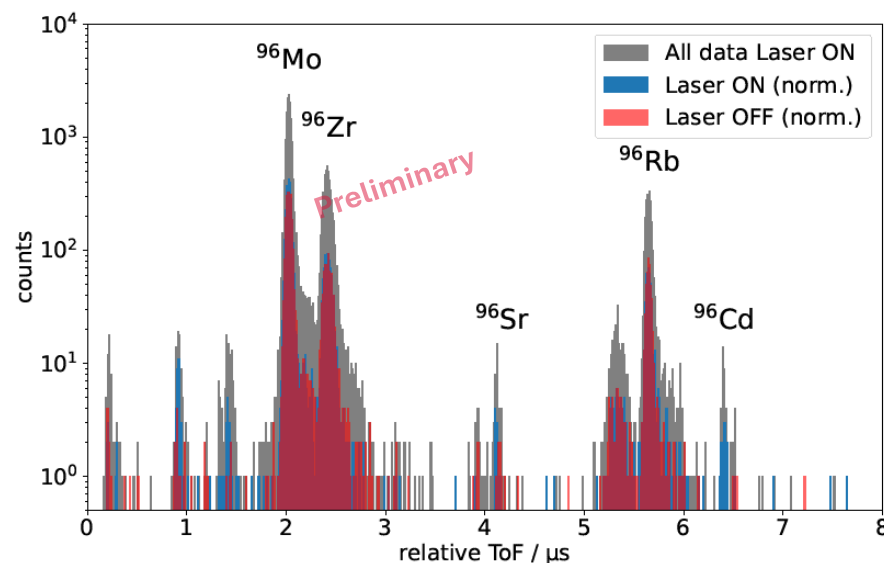
M. Mougeot et al., Phys. Rev. C (2020)



D. Lange et al., under analysis

Other measurements (not related to charge radii)

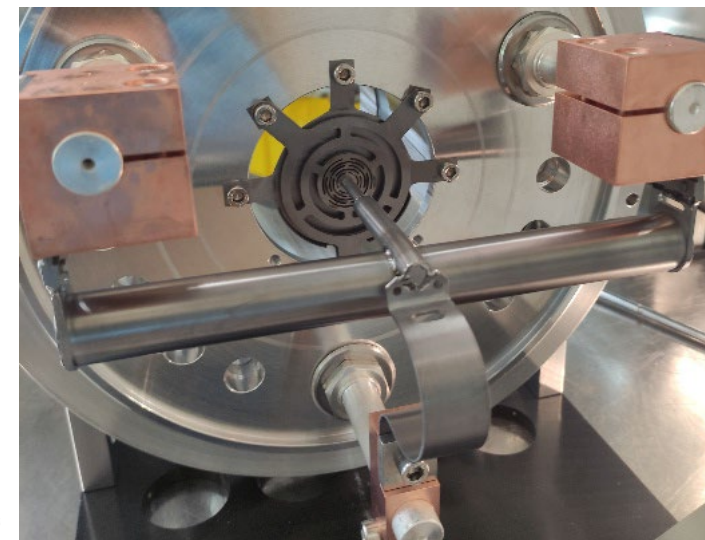
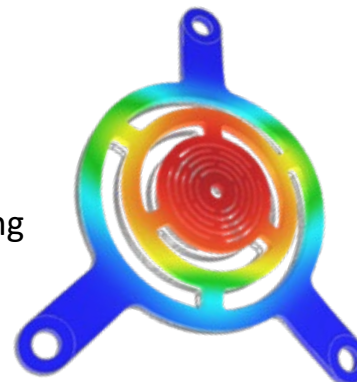
	99Sn 24 ms $\epsilon+\beta+=100\%$ $\epsilon p=3.9\%$	100Sn 1.18 s $\epsilon+\beta+=100\%$ $\epsilon p<17\%$	101Sn 2.2 s $\epsilon+\beta+=100\%$ $\epsilon p=23\%$
96In $\epsilon+\beta+?$ $\epsilon p?$ $p?$	97In 36 ms $\epsilon+\beta+=100\%$ $\epsilon p=1.7\%$	98In 30 ms $\epsilon+\beta+=100\%$ $\epsilon p<0.13\%$	99In 3.11 s $\epsilon+\beta+=100\%$ $\epsilon p=0.29\%$
95Cd 32 ms $\epsilon+\beta+=100\%$ $\epsilon p=4.5\%$	96Cd 1.01 s $\epsilon+\beta+=100\%$ $\epsilon p=1.6\%$	97Cd 1.16 s $\epsilon+\beta+=100\%$ $\epsilon p=9.7\%$	98Cd 9.3 s $\epsilon+\beta+=100\%$ $\epsilon p<0.029\%$
94Ag 27 ms $\epsilon+\beta+=100\%$ $\epsilon p<0.2\%$	95Ag 1.81 s $\epsilon+\beta+=100\%$ $\epsilon p=2.3\%$	96Ag 4.435 s $\epsilon+\beta+=100\%$ $\epsilon p=4.8\%$	97Ag 25.5 s $\epsilon+\beta+=100\%$
			98Ag 47.5 s $\epsilon+\beta+=100\%$ $\epsilon p=1.1e-3\%$



M. Benhatchi (IJCLab, Orsay)
and D. Lange (MPIK),
under analysis

Prototype LaC_x target
(A. Koliatos, ISOLDE)

- Improved heat shielding
- Spider-web ion source



Developments at ISOLTRAP

PicoDAQ [part of PhD work of M. Benhatchi]

Current DAQ - MCS6A :

Scaler TDC type that converts raw data into histogram

- good for low intensity beams
- amount of data is reduced
- but all raw data is lost $\rightarrow$ bias

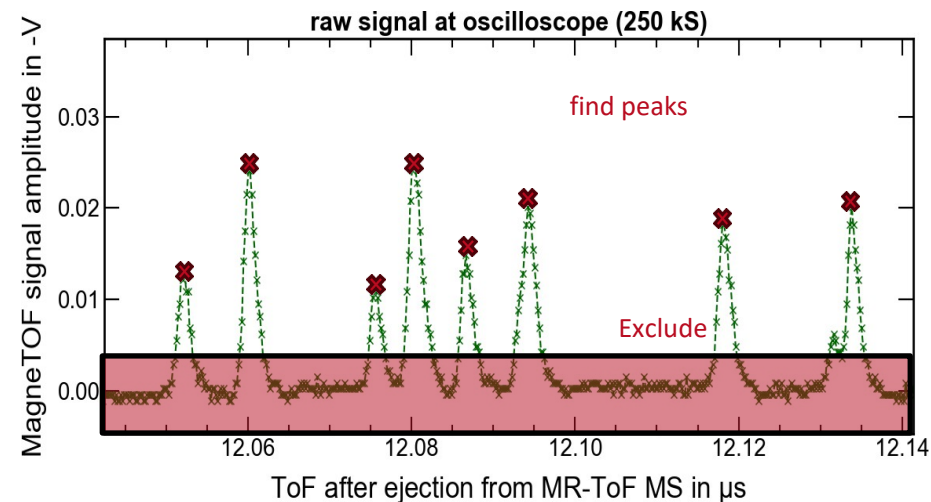
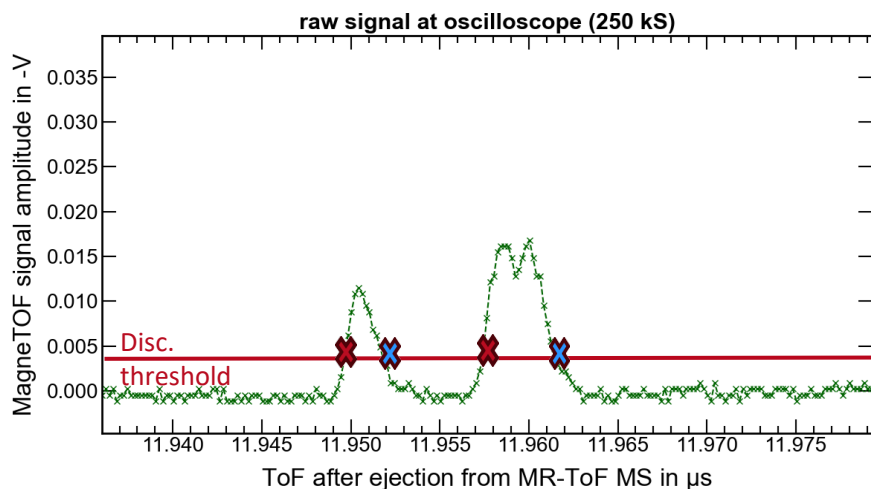


New DAQ - Picoscope 6428A :

Oscilloscope + python codes



- raw data $\Rightarrow$ one spectrum saved for each shot
- python to control scope and conversion



Acknowledgements:

D. Antanasov, M. Benhatchi,
K. Blaum, R. B. Cakirli,
P. F. Giesel, P. Fischer,
D. Lange, Yu. Litvinov,
D. Lunney, V. Manea,
S. Naimi, L. Nies,
Ch. Schweiger, L. Schweikhard,
F. Wienholtz, *et al.*
for the ISOLTRAP collaboration

**WINDMILL/IDS Collaboration,
ISOLDE OPERATIONS TEAM,
RILIS TEAM, TARGET TEAM,
& the ISOLDE Collaboration**



Slides from: Ch. Schweiger, D. Lange, M. Benhatchi, J. Cubiss
A. Andreyev and A.E. Barzakh

