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

Measuring the electron affinity of polonium

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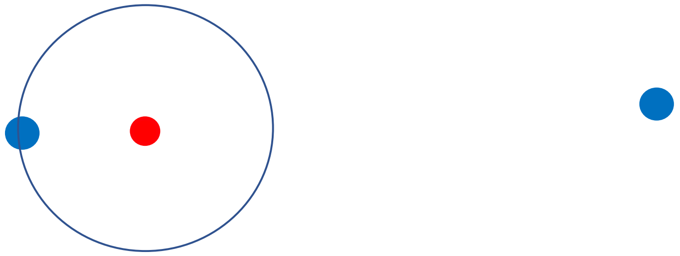
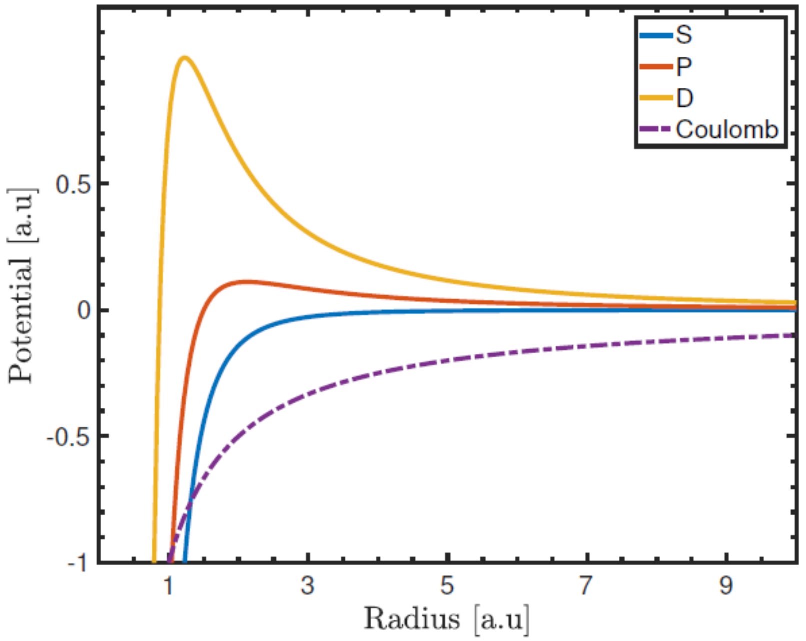
for the CRIS Collaboration

.

INTC meeting 8th of February 2023

Properties of Negative ions

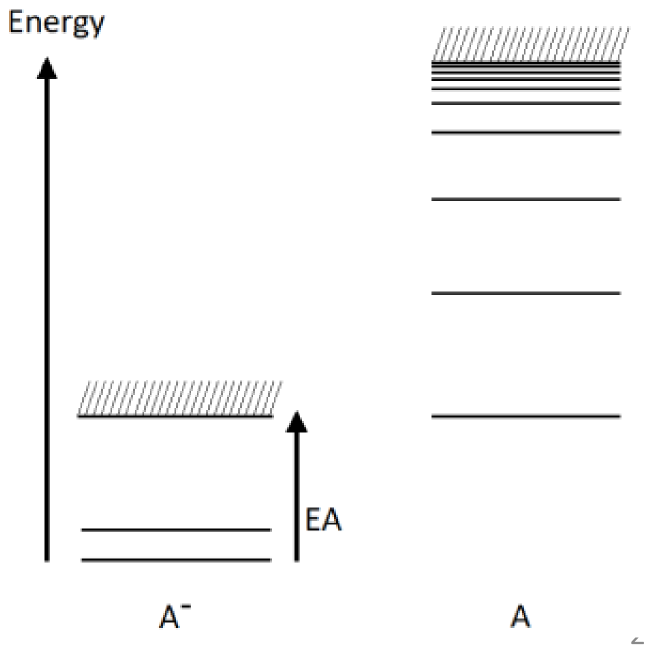




- **Electron correlation dominated** binding allows probing of theory beyond Hartree-Fock approximation

- **Electron affinity (EA)** is the binding energy of the additional electron (in the order of ~1eV)

- **Almost no bound states** with opposite parity existing (except e.g. La, Os, Ce, Th,…)



Why study negative ions?

Fundemantal research

- Benchmark electron correlation calculations
- Info about chemical properties
- Lasercooling enabeling sympathetic cooling of antiprotons

Applications

- Astrophysics
- Mass spectrometry
- Plasmas
- Heating of Tocamacs
- Radiochemistry

Why study Po^-?

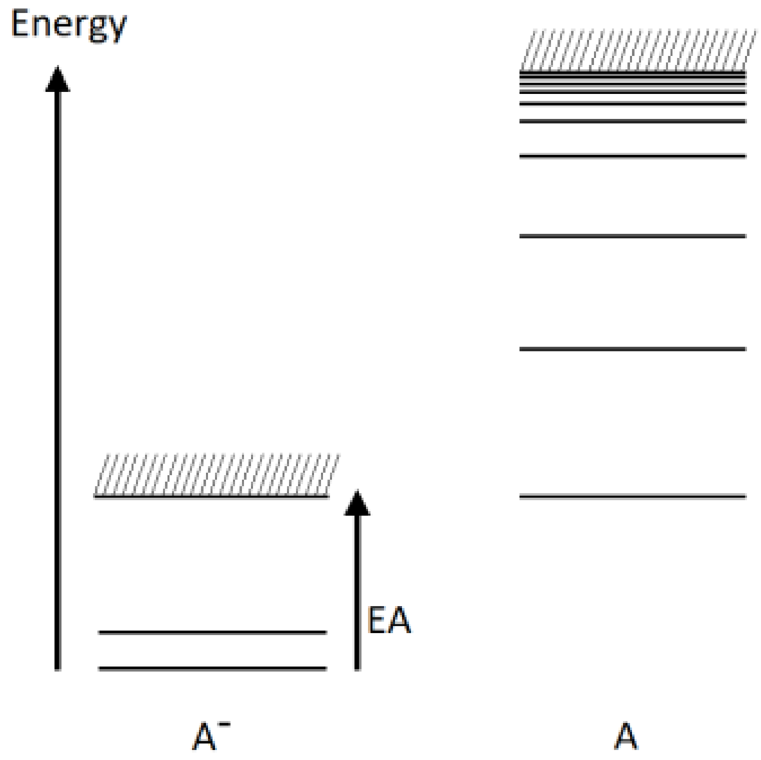
Fundemantals research

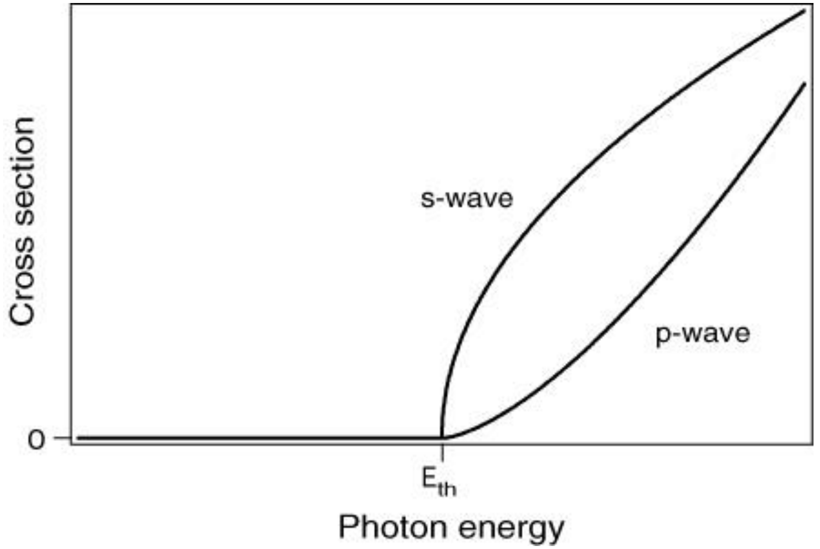
- Test of relativistic electron correlation calculation
- More complex electronic structure than previously studied At^- which was a closed shell
- Lack of knowledge about chemical behavior
- Route towards superheavy elements

Applications

- Environmental/toxic element
- Management of abonnended Uranium mines
- Produced in Gen IV reactors
- MYRRHA Belgian nuclear reactor

Laser Photodetachment $hf + X^{-} \rightarrow X + e^{-}$

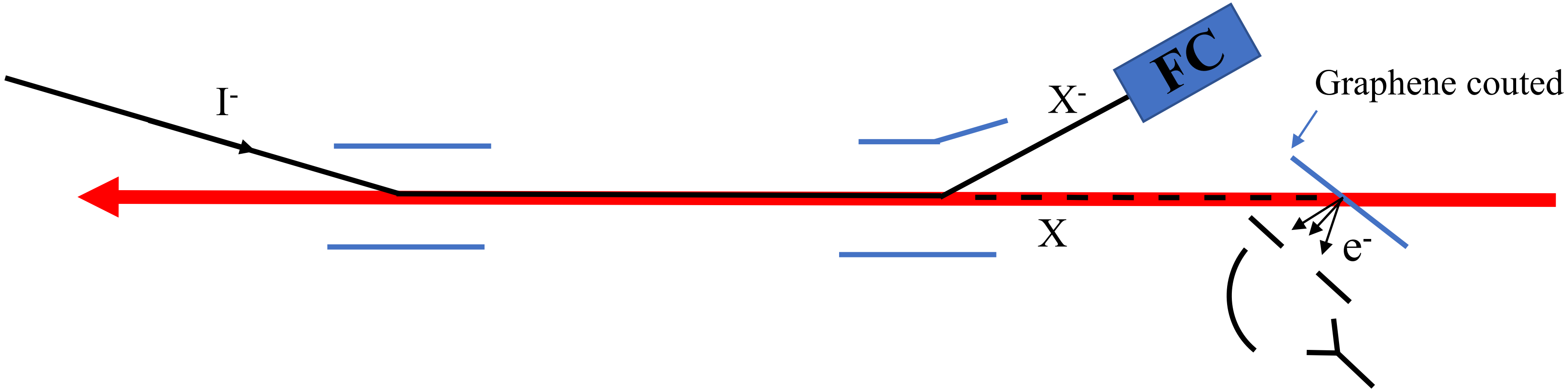


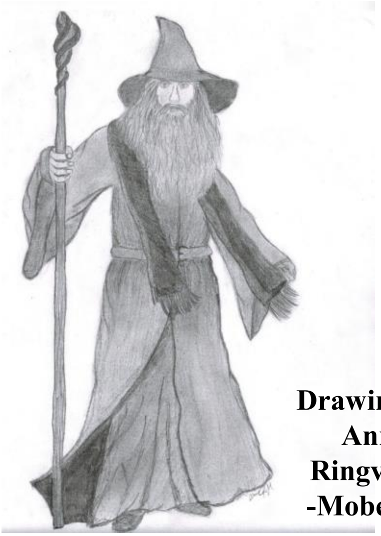


- Cross section given by the **Wigner threshold law**:

$$\sigma(E) = (E_{\gamma} - E_{th})^{l+\frac{1}{2}}$$

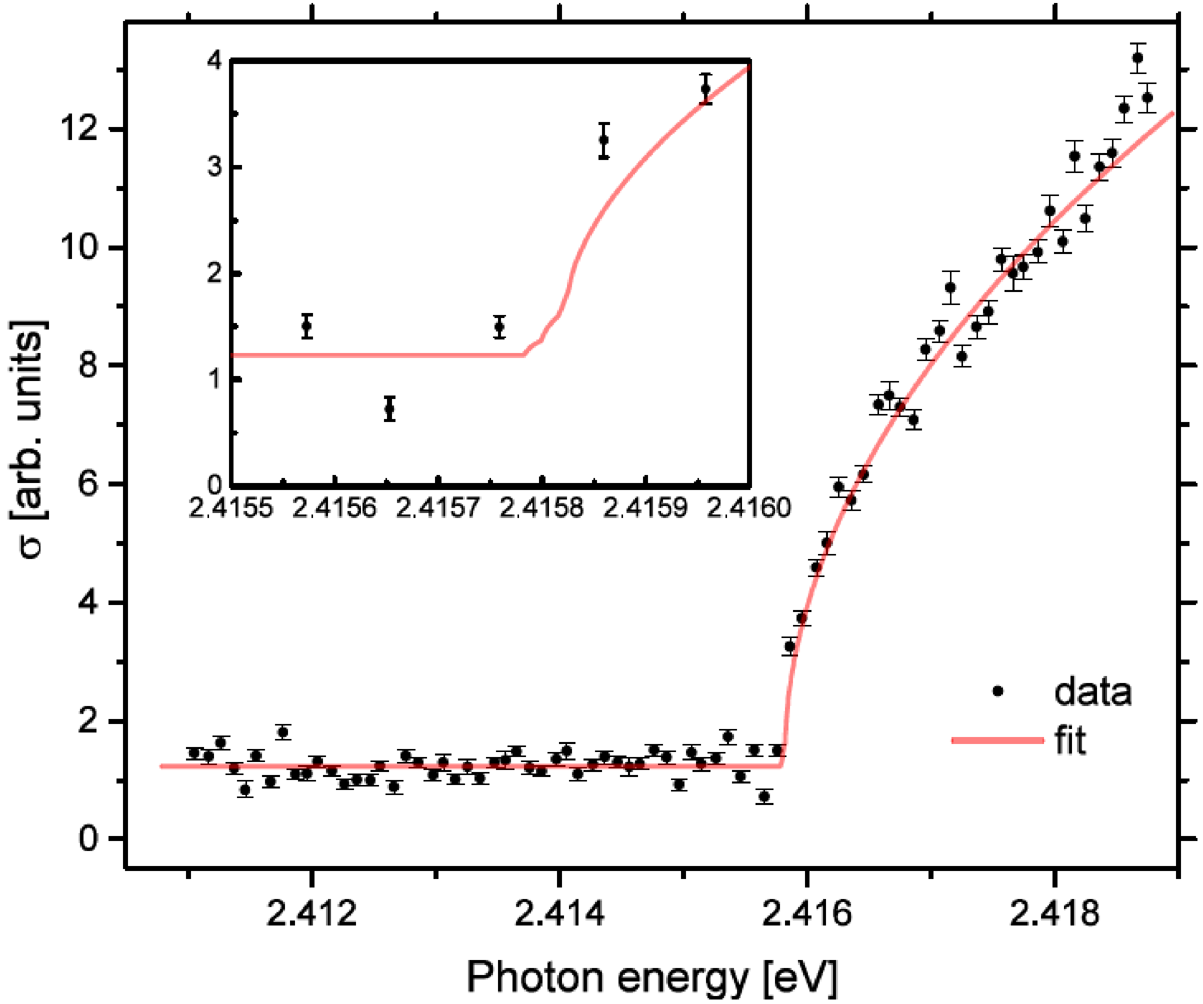
GANDALPH





Drawing: Annie Ringvall -Moberg

The electron affinity of Astatine



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ARTICLE

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Check for updates

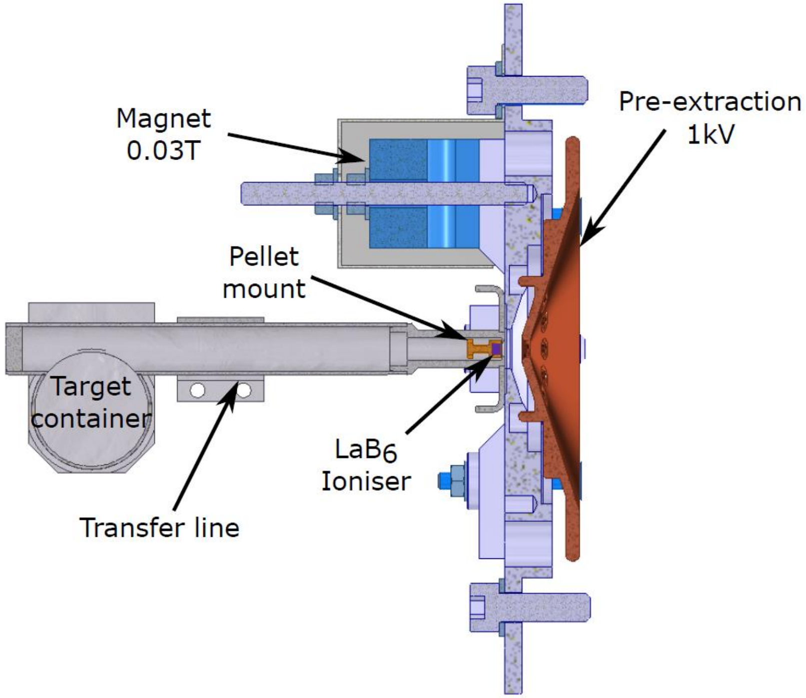
The electron affinity of astatine

David Leimbach[1,2,3✉], Julia Karls[2], Yangyang Guo[4], Rizwan Ahmed[5], Jochen Ballof[1,6], Lars Bengtsson[2], Ferran Boix Pamies[1], Anastasia Borschevsky[4], Katerina Chrysalidis[1,3], Ephraim Eliav[7], Dmitry Fedorov[8], Valentin Fedosseev[1], Oliver Forstner[9,10], Nicolas Galland[11], Ronald Fernando Garcia Ruiz[1,12], Camilo Granados[1], Reinhard Heinke[3], Karl Johnston[1], Agota Koszorus[13], Ulli Köster[14], Moa K. Kristiansson[15], Yuan Liu[16], Bruce Marsh[1], Pavel Molkanov[8], Lukáš F. Pašteka[17], João Pedro Ramos[20], Eric Renault[11], Mikael Reponen[18], Annie Ringvall-Moberg[1,2], Ralf Erik Rossel[1], Dominik Studer[3], Adam Vernon[19], Jessica Warbinek[2,3], Jakob Welander[2], Klaus Wendt[3], Shane Wilkins[1], Dag Hanstorp[2] & Sebastian Rothe[1]

Nature Communications **11**, Article number: 3824 (2020)

- **EA_{exp}: 2.41578(7)eV**
- **EA_{theory}: 2.414(16)eV**

ISOLDE- Negative ion production



I^- and At^- produced with negative surface ion source

- [1] M. Menna, R. Catherall, J. Lettry, E. Noah, and T. Stora, *R&D for the Development of Negative Ion Beams of Halogens*, Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms **266**, 4391 (2008).
- [2] Y. Liu, D. W. Stracener, and T. Stora, *Production of Negatively Charged Radioactive Ion Beams*, New J. Phys. **19**, (2017).
- [3] U. Köster, *ISOLDE Target and Ion Source Chemistry*, Radiochim. Acta **89**, 749 (2001).

This will not suffice for Po^- production (as found in At-211 EA study)

- S. Rothe, J. Champion, K. Chrysalidis, T. D. Goodacre, V. Fedosseev, N. Galland, D. Hanstorp, R. Heinke, T. Kron, B. Marsh, G. Montavon, E. Renault, R. Rossel, C. Seiffert, J. Sundberg, J. Welander, and K. Wendt, *Determination of the Electron Affinity of Astatine and Polonium by Laser Photodetachment*, 1 (2016).

Alternative production method: Charge exchange

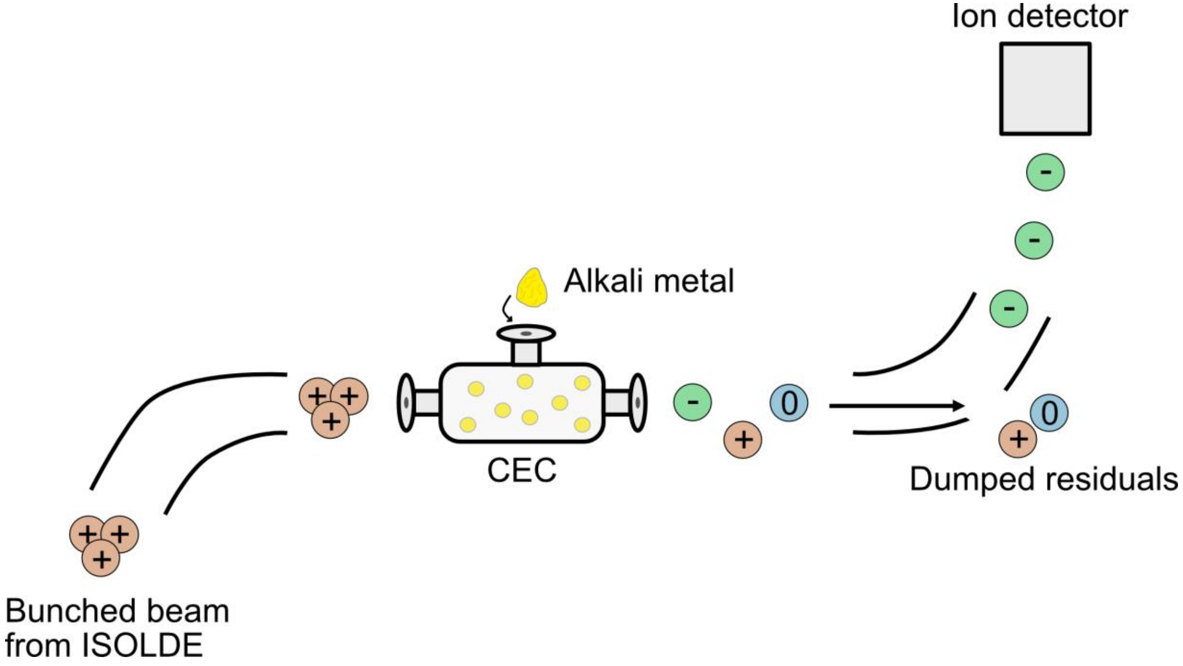
$$X^+ + Y \rightarrow X + Y^+ + \Delta E_1$$

$$X + Y \rightarrow X^- + Y^+ + \Delta E_2$$

- Has been studied extensively but with only stable projectiles

- E.g. [1] J. Heinemeier and P. Hvelplund, *Production of 10-80 KeV Negative Heavy Ions by Charge Exchange in Na Vapour*, Nucl. Instruments Methods **148**, 425 (1978).
- [2] J. Heinemeier and P. Hvelplund, *Production of 15-90 KeV Negative Heavy Ions by Charge Exchange with Mg Vapour*, Nucl. Instruments Methods **148**, 65 (1978).
- [3] A. S. Schlachter, *Formation of Negative Ions by Charge Transfer: He- to Cl-**, AIP Conf. Proc. **300**, 300 (1984).

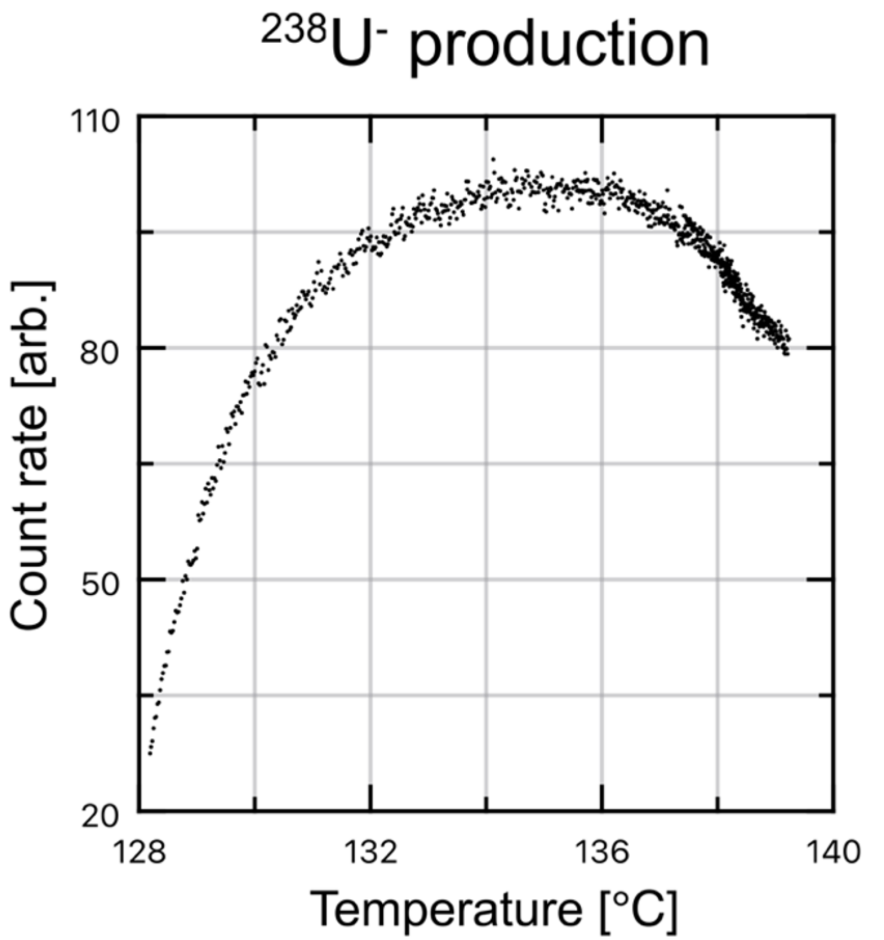
LOI225 Results



$$X^{+} + Y \rightarrow X + Y^{+} + \Delta E_1$$

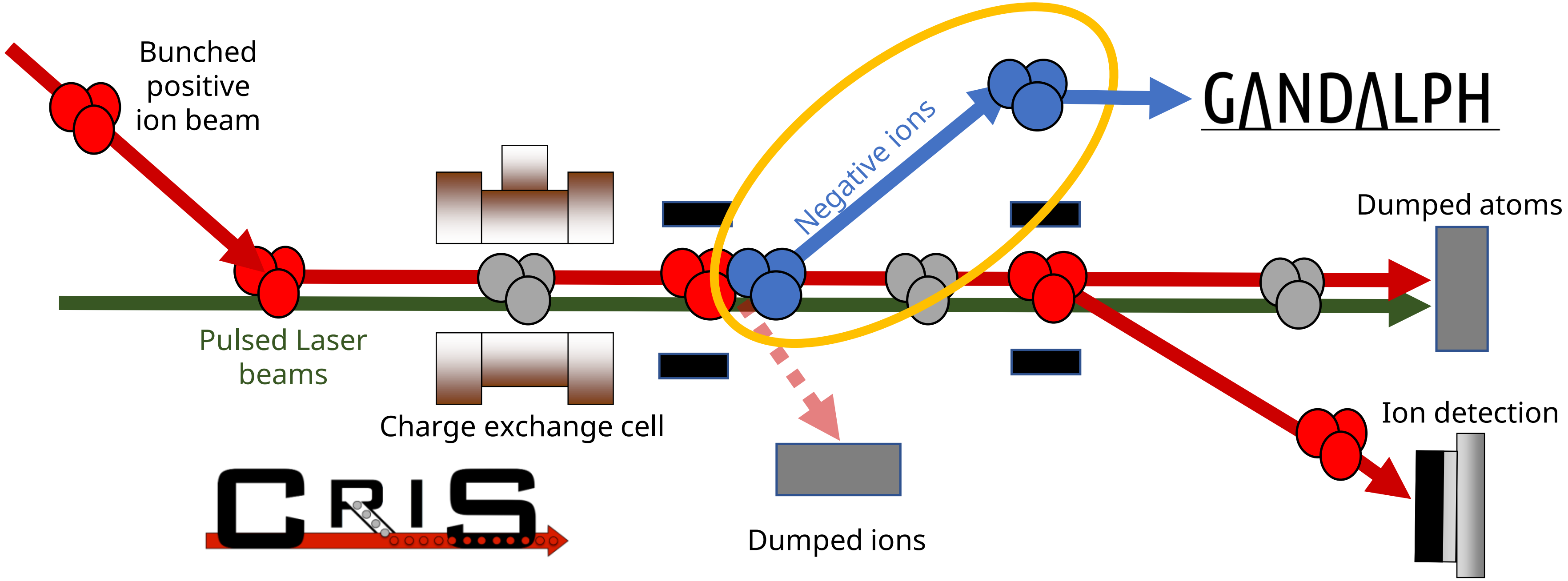
$$X + Y \rightarrow X^{-} + Y^{+} + \Delta E_2$$

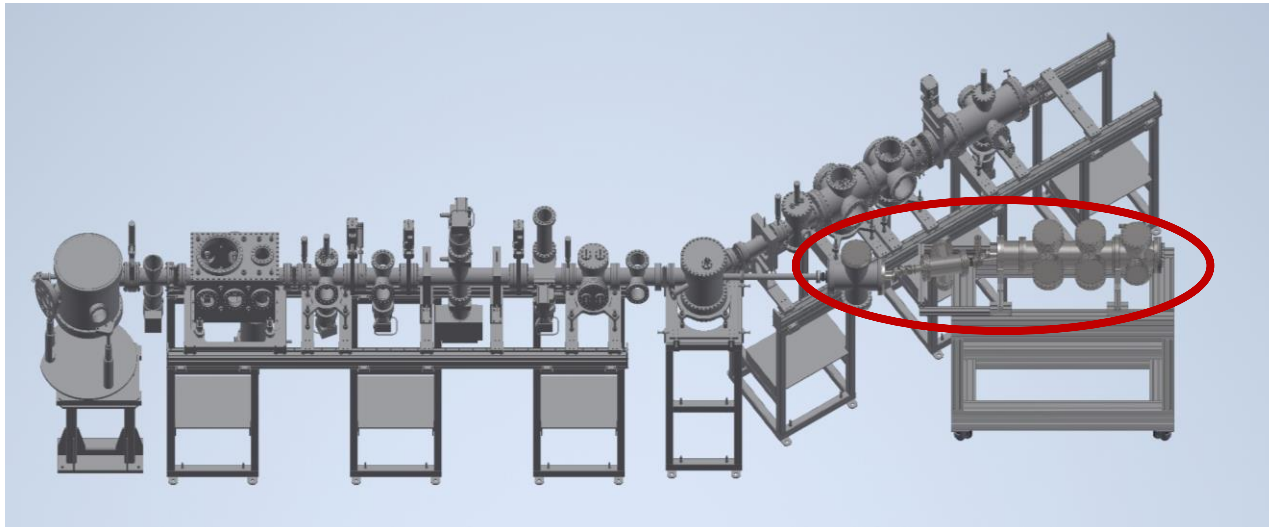
$$X^{-} + Y \rightarrow X + Y + e^{-}$$



This temperature dependence has also been seen by Alton *el al.* for Ca- production using a Li target

G. D. Alton, T. J. Kvale, R. N. Compton, D. J. Pegg, and J. S. Thompson, *The Production of Ca- through Sequential Charge Exchange with Li Vapor*, Nucl. Instruments Methods Phys. Res. A **244**, 142 (1986).


Bunched
positive
ion beam
Pulsed Laser
beams
Charge exchange cell
Negative ions
GANDALPH
Dumped atoms
Dumped ions
Ion detection
CRIS



Proposed experiment

- Laser photodetachment of Po^- around threshold of 844 nm
- Atomic property investigated → results independent of isotope
- Ideal laser wavelength using Ti:Saph laser

Requested shifts

Description	*Element*	*Number of shifts*
Online		
Producing and detecting negative ions	Po	3
Determining threshold region	Po	3
Co- & counter-propagating scans	Po	9
Offline		
Beam tuning and setup	^{238}U	3
Above threshold measurement	^{238}U	1
Producing and detecting negative ions	Fr	1

15 (+5 shifts of stable beam)

Comments from TAC

Is the presence of Fr an issue which needs to be dealt with?

- Suppression of Fr using LIST source
- Fr has a much smaller EA than Po → gives smaller negative ion productions

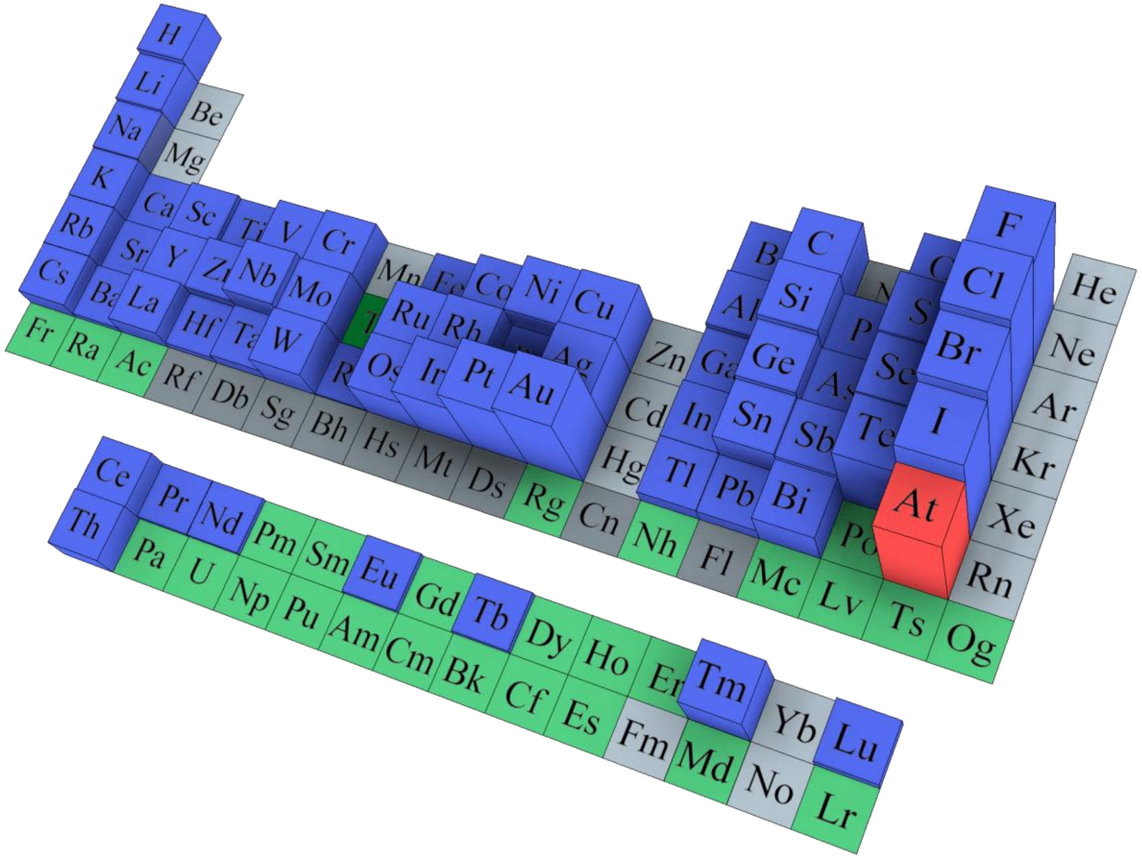
The feasibility test from 2022 which is mentioned seems to concern only U, whereas the production of Po^- wasn't yet achieved. Could this be addressed in the presentation with regard to what is still needed to produce these ions?

- Po^- not tested during LoI due to technical problems
- Asked for beamtime for remaining three shifts to make Po^- test
- EA(U) << EA (Po) → more difficult to produce U^- in charge exchange

Outlook

- Fr^-
- Actinides
- Superheavy elements

- Of interest for the PUMA project



Thank you for your attention!

Why was Po- not measured?

- Current beamline configuration made it extremely difficult to separate negatives from residual positives at 40 keV
- Started with Po-202 but quickly realized that we could not do that because of Bi-202 decay contamination on MagneToF detector ($t_{1/2}$ = 1.72 hr) (Fr/Ra-202 contamination was not an issue due to ms half lives)
- Moved to Po-211 because it decays to stable Pb-207
  - With LIST supression, IDS was able to confirm that we had a relatively pure beam with ~14 000 cps.
  - But estimated yields are around E4/uC which is too low for efficient exchange