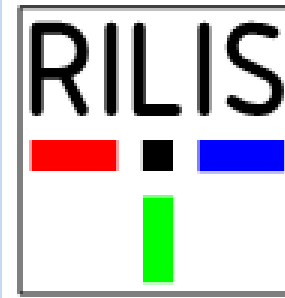




UNIVERSITY OF
GOTHENBURG



Dag Hanstorp

Determination of the electron affinity of astatine and polonium by laser photodetachment

S. Rothe, J. Champion, K. Chrysalidis, T. Day Goodacre, V. Fedosseev, N. Galland, D. Hanstorp, R. Heinke, U. Köster, T. Kron, Y. Liu, B. Marsh, G. Montavon, E. Renault, A. Ringwall-Moberg, R. Rossel, C. Seiffert, J. Sundberg, J. Welander and K. Wendt

INTC meeting 3-4 February 2016

Follow up of Letter of Intent (LOI) INTC-I-148

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

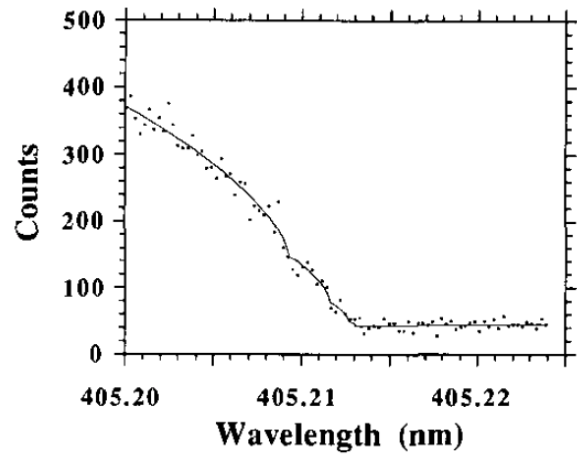
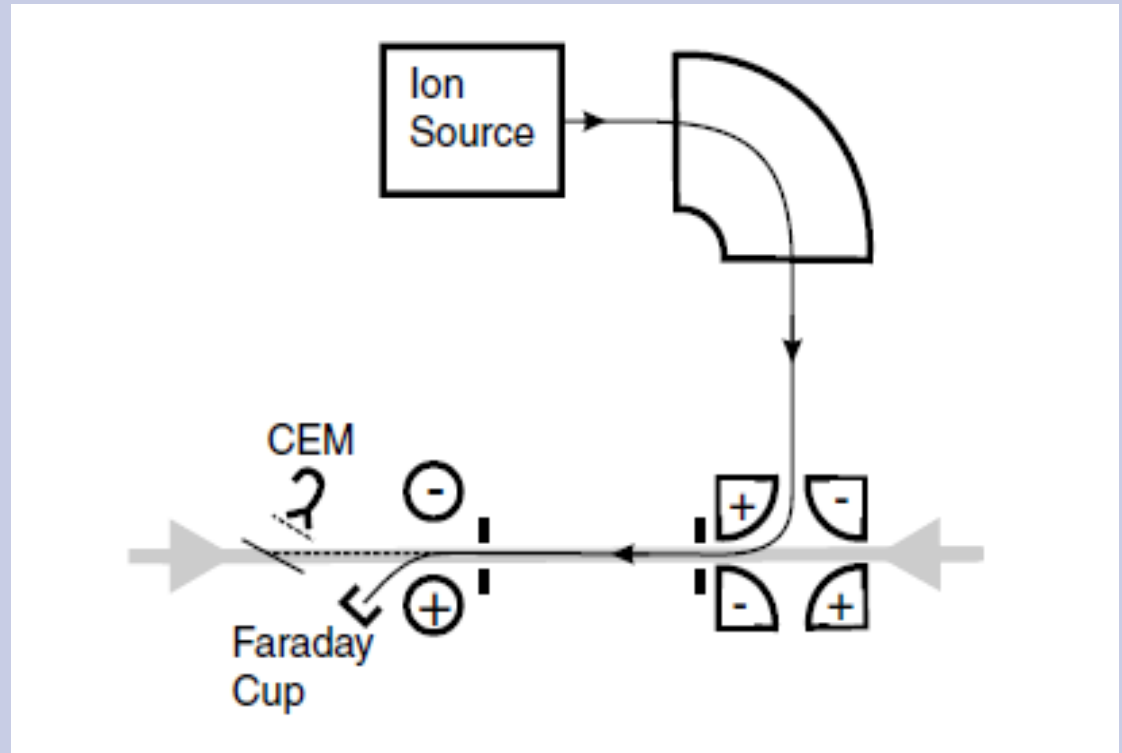
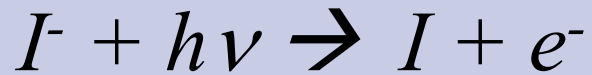
Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

Preparation of negative ion beams for the determination of the
electron affinity of polonium and astatine by laser
photodetachment

25.09.2013

S. Rothe¹, M. Bissell², T. Day Goodacre^{1,3}, V. Fedosseev¹, K. Flanagan³,
N. Galland⁴, T. Giles¹, A. Gottberg¹, D. Hanstorp⁵, U. Köster⁶, T. Kron⁷,
Yu. Kudryavtsev², B. Marsh¹, G. Montavon⁸, G. Neyens², S. Raeder², E. Renault⁴,
R. Rossel^{1,9}, M. Stachura¹, T. Stora¹, K. Wendt⁷

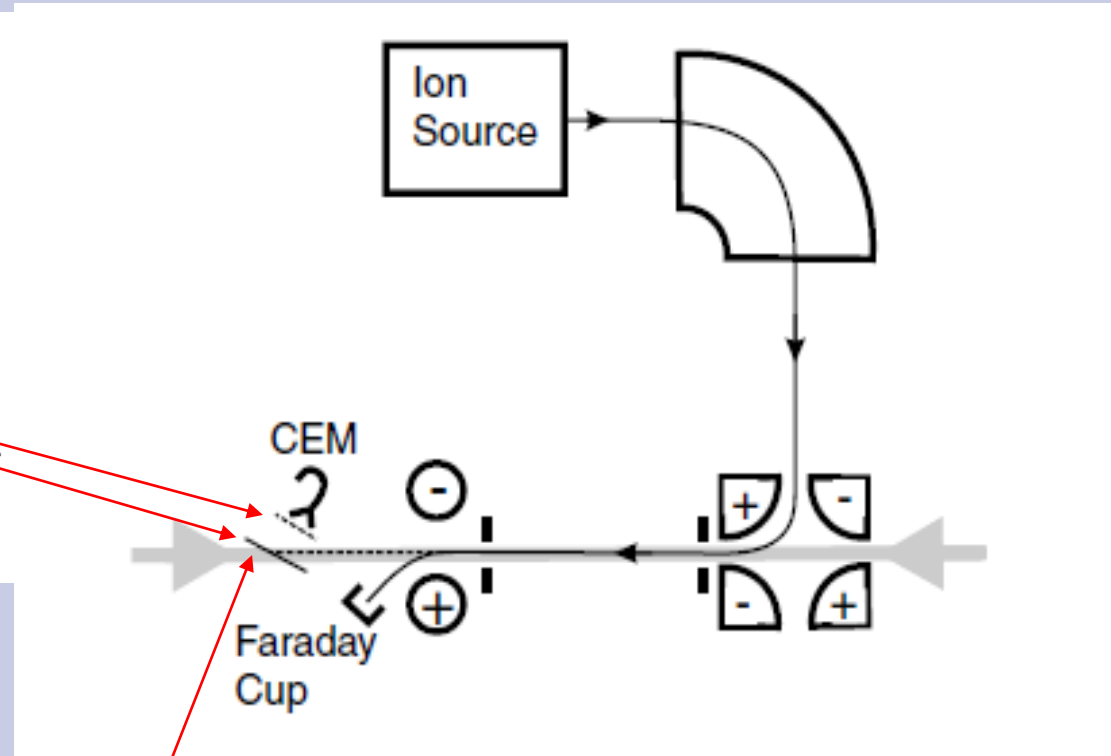
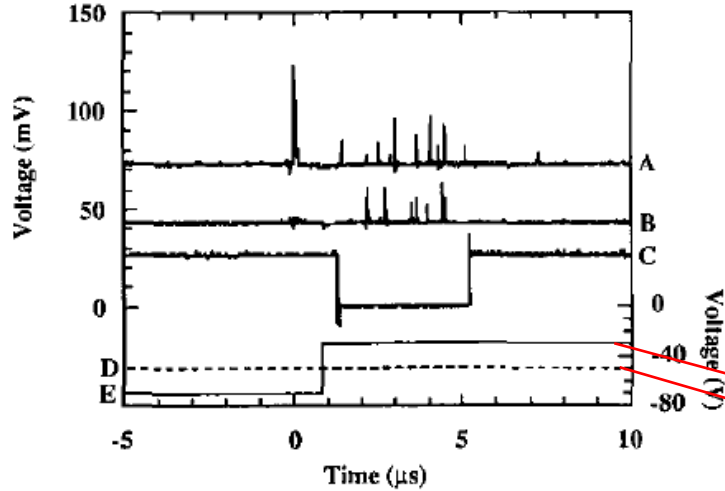
Collinear photodetachment spectroscopy



Wigner law:

$$\sigma = k (E - E_0)^{l+1/2}$$

Neutral particle detection in collinear laser spectroscopy



For each laser pulse:

Signal:

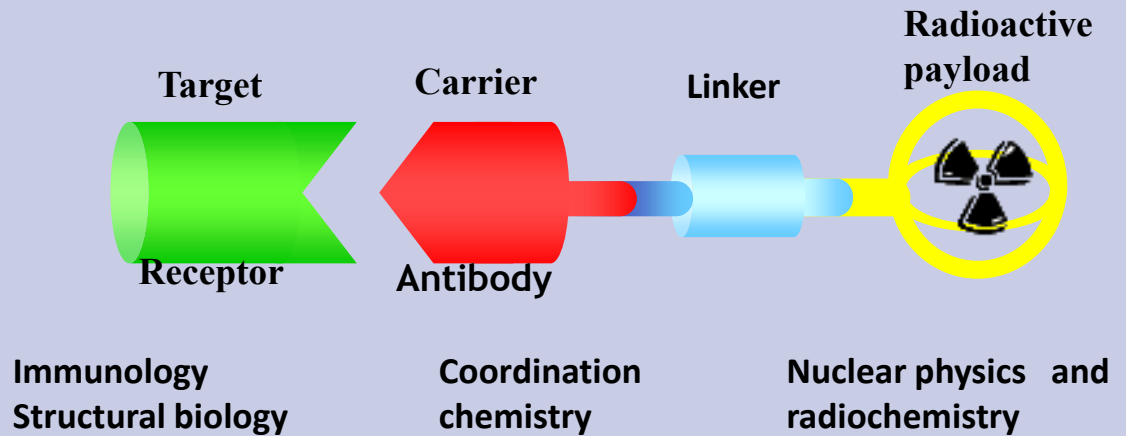
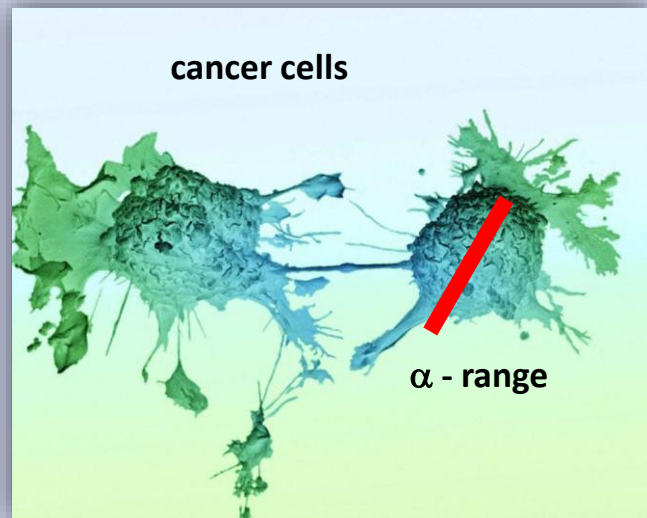
0.01 atom

Background:

10^{14} photons

Glass plate coated with ITO (In₂O₃:Sn)

Targeted Alpha Therapy (TAT)



^{211}At particularly suitable isotope

- 7 h lifetime
- No long lived daughters
- Non-toxic daughters
- Suitable α energy

Astatine

- Least abundant element on earth
- 70 mg in the crust of the earth (1 atom per 100 kg mass)
- Small knowledge about chemical and physical properties
- Halogen or metal?

Periodic Table of Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.00794																	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182															10 Ne Neon 20.1797	
5 Na Sodium 22.98976928	12 Mg Magnesium 24.304															18 Ar Argon 39.948	
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933194	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (97.906287)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.90545	54 Xe Xenon 131.29
55 Cs Cesium 132.90545196	56 Ba Barium 137.327	57-71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.222	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (285)	111 Rg Roentgenium (286)	112 Uub Ununbium (288)	113 Uut Ununtrium (289)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (289)	116 Uuh Ununhexium (289)	117 Uuq Ununseptium (289)	118 Uuo Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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ASTATINE 70mg

R
I
S
I
S
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S

1 x per Planet

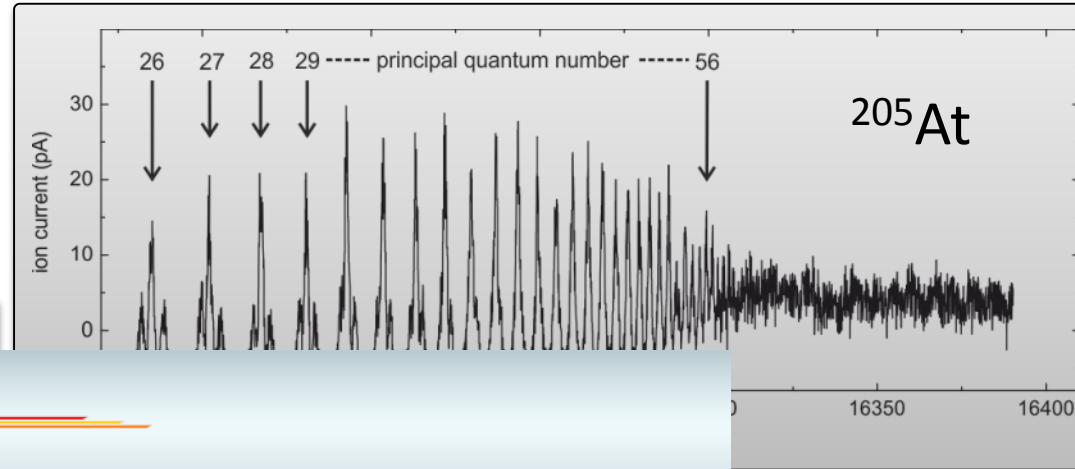
(Apply to crust)

218 At



Spectroscopy of Rydberg levels

- $IP_{\text{Threshold}}$ allowed choice of laser dye
- High resolution laser scan across the IP
- ^{205}At measured on Faraday cup
- 50 Rydberg levels found



nature COMMUNICATIONS

ARTICLE

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Measurement of the first ionization potential of astatine by laser ionization spectroscopy

S. Rothe^{1,2}, A.N. Andreyev^{3,4,5,6}, S. Antalic⁷, A. Borschevsky^{8,9}, L. Capponi^{4,5}, T.E. Cocolios¹, H. De Witte¹⁰, E. Eliav¹¹, D.V. Fedorov¹², V.N. Fedosseev¹, D.A. Fink^{1,13}, S. Fritzsche^{14,15,†}, L. Ghys^{10,16}, M. Huyse¹⁰, N. Imai^{1,17}, U. Kaldor¹¹, Yuri Kudryavtsev¹⁰, U. Köster¹⁸, J.F.W. Lane^{4,5}, J. Lassen¹⁹, V. Liberati^{4,5}, K.M. Lynch^{1,20}, B.A. Marsh¹, K. Nishio⁶, D. Pauwels¹⁶, V. Pershina¹⁴, L. Popescu¹⁶, T.J. Procter²⁰, D. Radulov¹⁰, S. Raeder^{2,19}, M.M. Rajabali¹⁰, E. Rapisarda¹⁰, R.E. Rossel², K. Sandhu^{4,5}, M.D. Seliverstov^{1,4,5,12,10}, A.M. Sjödin¹, P. Van den Bergh¹⁰, P. Van Duppen¹⁰, M. Venhart²¹, Y. Wakabayashi⁶ & K.D.A. Wendt²

ds versus n
meters)
es

berg-Ritz formula

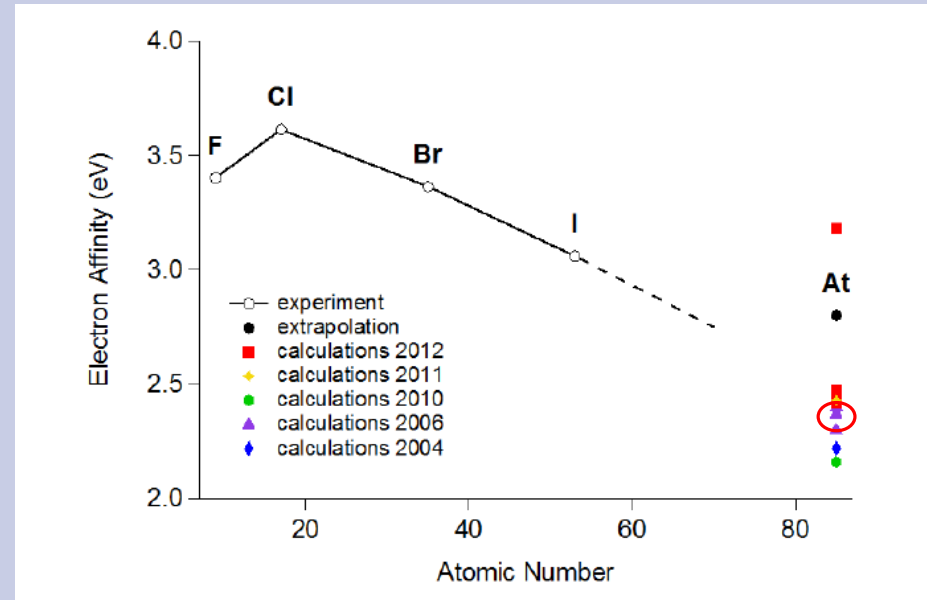
$$= \square \square - \frac{\square}{E \square - \square F}$$

$$IP_{\text{Rydberg}}(\text{At}) = 75150.8(7) \text{ cm}^{-1}$$

Motivation for EA measurement of At and Po

Astatine

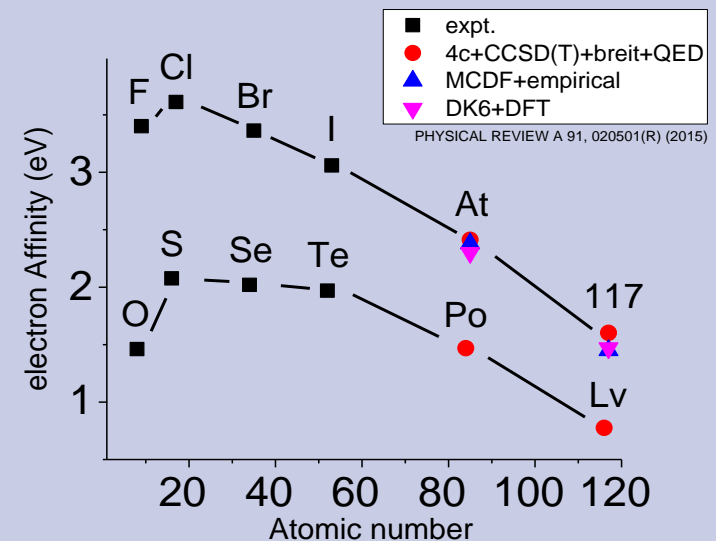
- EA equally important as the IP
 - determine electronegativity
 - nature of chemical bonds
- Important for computer simulations for binding of At to receptor
- No experimental value for EA(At) yet
- Scattering of theoretical predictions ~ 1 eV



○ PHYSICAL REVIEW A 91, 020501(R) (2015)

Polonium

- Po is considered important component of the natural radiation affecting humans
- Physico-chemical properties need to be understood to develop decorporation treatments



GANDALPH

Gothenburg ANion Detector for Affinity measurements by Laser PHotodetachment

Built in spring 2015 in Gothenburg

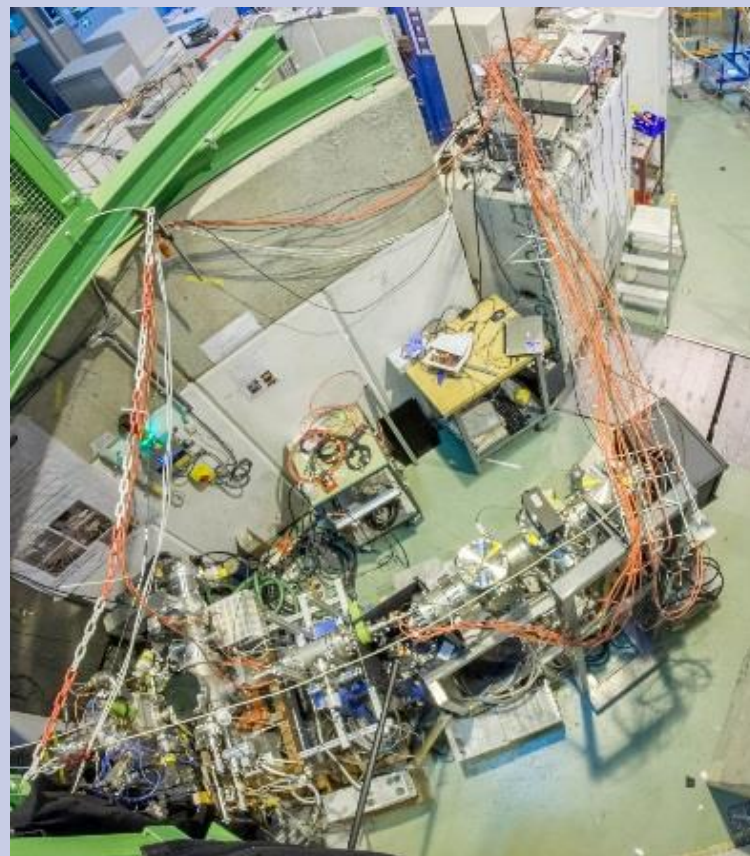
Moved to ISOLDE, June 2015

Installed and put into operation at GLM

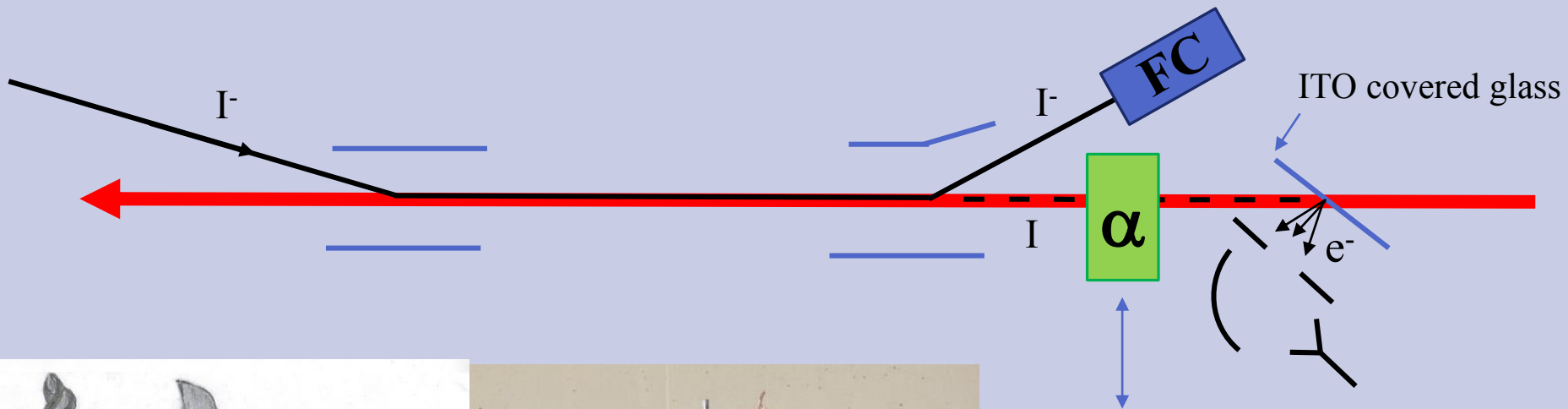
full control of system

Laser transport from RILIS

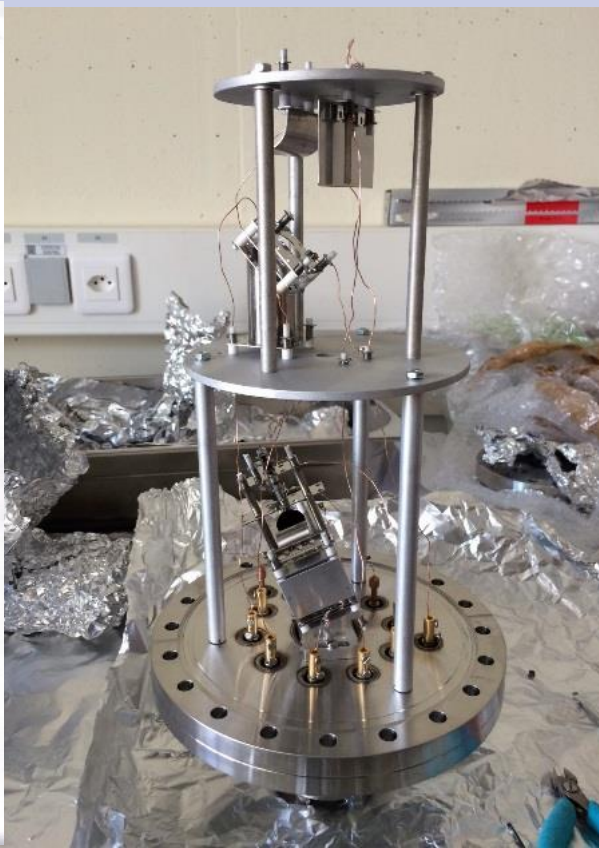
Photodetachment of I⁻, July 2015



GANDALPH



Drawing:
Annie
Ringvall
-Moberg



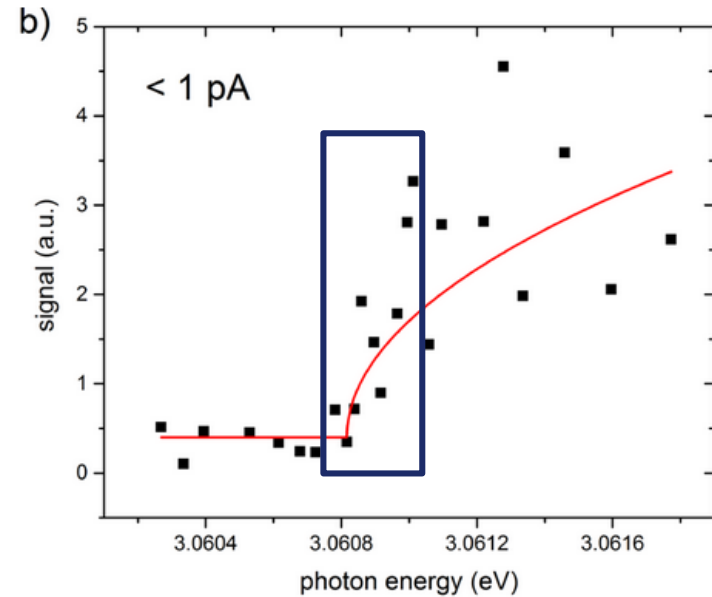
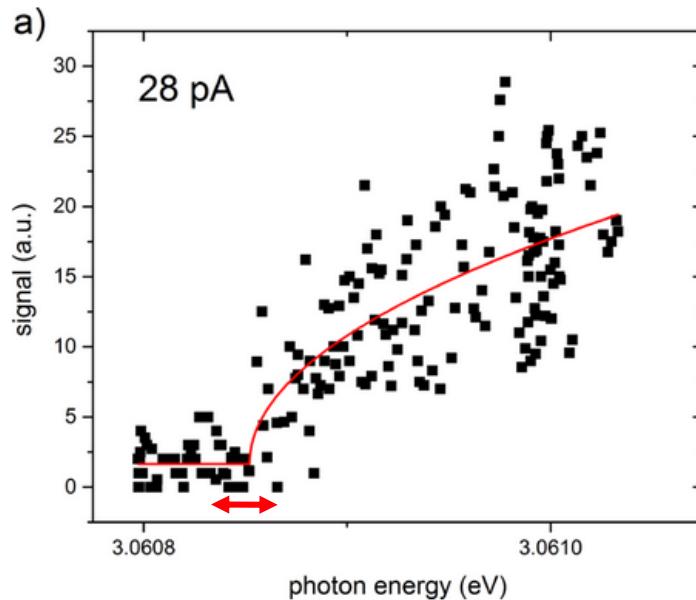
Test of GANDALH: Photodetachment of stable I⁻

Low 10^{-8} mbar vacuum

~ 8% transmission to the neutral detector

Photodetachment signal of I⁻

Threshold still measurable at very low ion rates (<1 pA, FC noise)



Improvements prior to next run:

- Improve transmission → additional Einzel-lenses
- Low 10^{-8} mbar to high 10^{-10} mbar → new ion pump + baking
- Moveable α -detector → detection of selected At isotopes

BEAM TIME REQUEST

4.3 Summary of requested shifts

We request a total number of 16 shifts preceded by 4 shifts for the offline setup and initial reference scans.

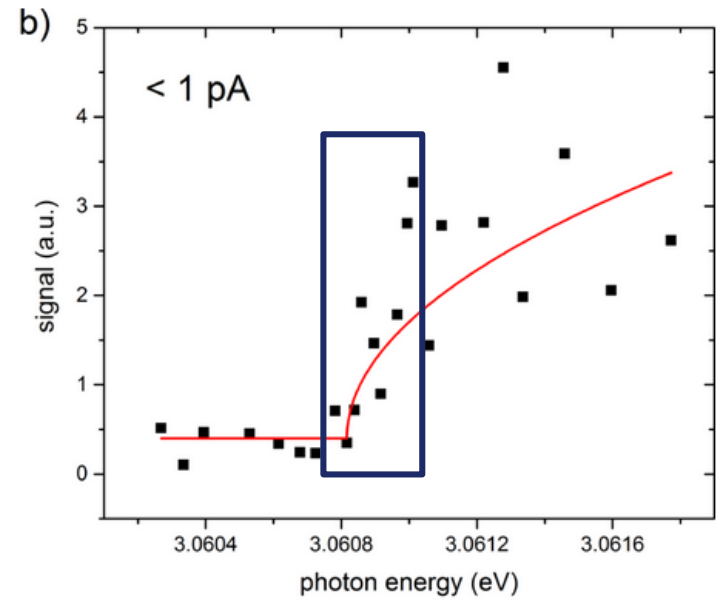
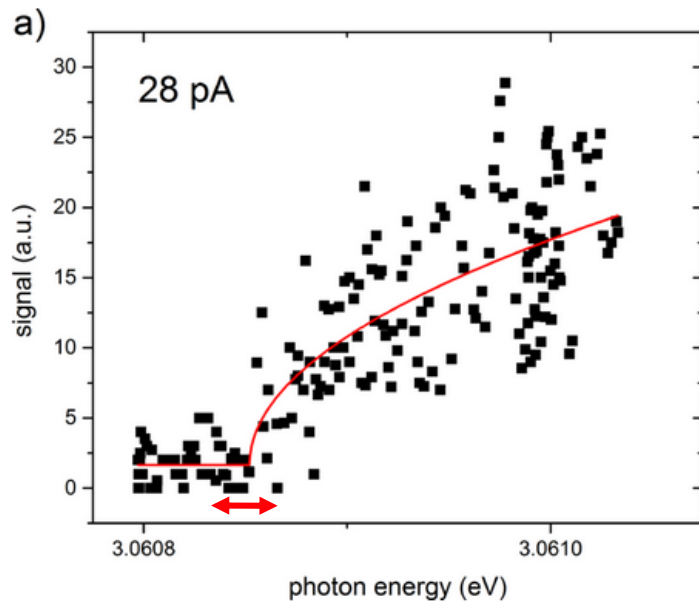
Description	Element	Number of shifts (offline)	Protons
Stable beam tuning	iodine	(4)	no
determining threshold region	astatine	4	yes
fine scan collinear	astatine	3.5	yes
reference scans	iodine	1	no
fine scan anticollinear	astatine	3.5	yes
attempt threshold region	polonium	4	yes

~We can select the most suitable isotope
(Any isotope could be used to determine EA)

Experiment possible with $3 \cdot 10^5$ ions (but with lower resolution)

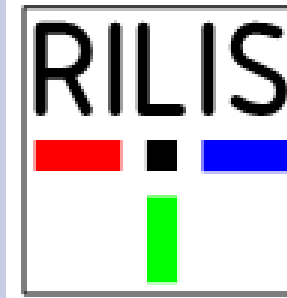
Requested $3 \cdot 10^7$ ions but experiment possible also with $3 \cdot 10^5$

- The background (collisions) proportional to ion beam intensity
 - Lower current compensated with increased acquisition time
- Pressure down $\times 20$ → $\times 20$ reduction in background
- Photodetachment is a threshold process:
 - Lower current compensated with larger steps in photon energy
 - threshold measurement but with lower resolution
- Goal: Determine EA with resolution of $40 \mu\text{eV}$
 - but: **today is today completely unknown!**
 - Even resolution 10 meV is very important result





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Thank you for your attention!

