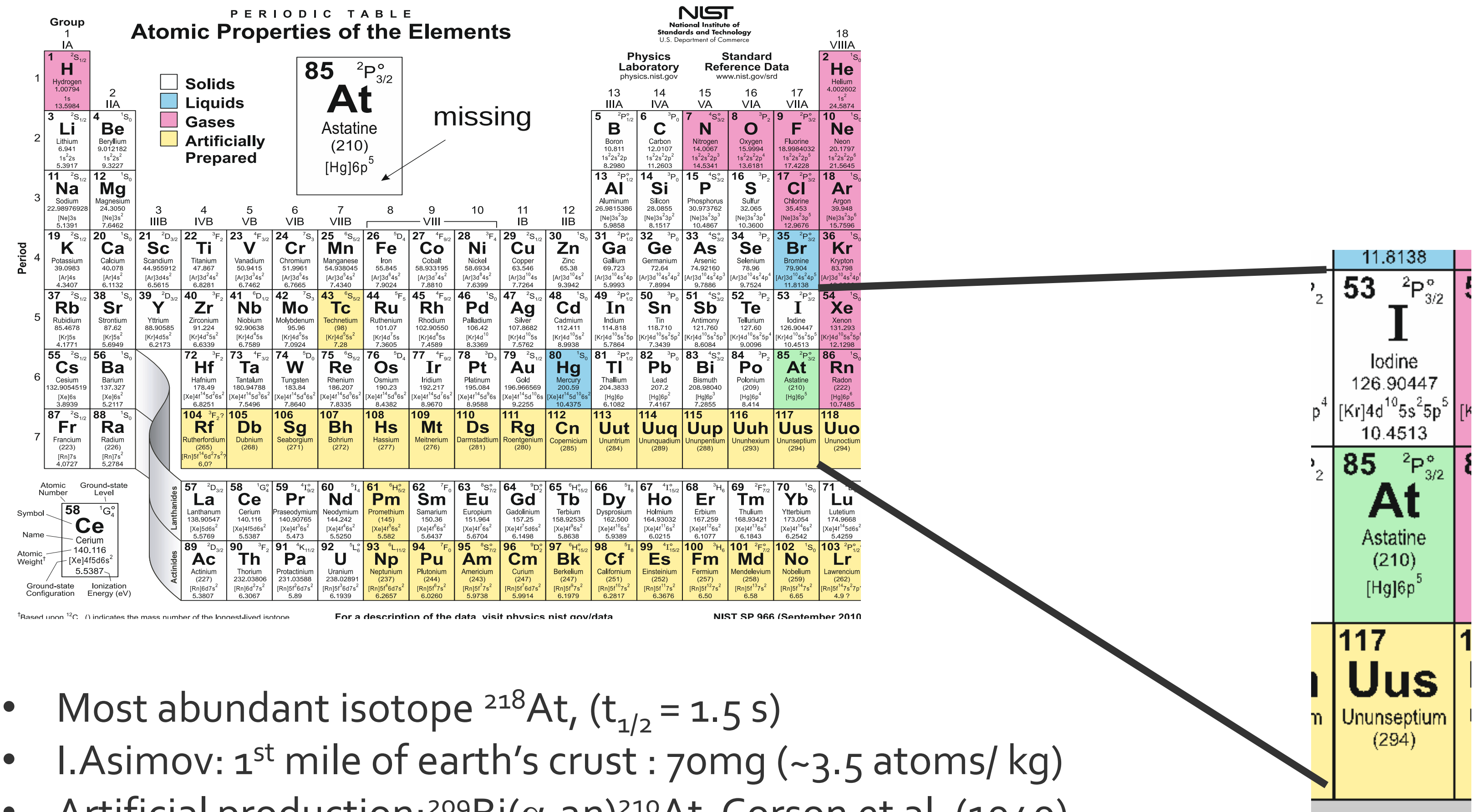
First photodetachment studies on radioactive negative ions

Towards the electron affinity measurement of astatine

S.Rothe for the I-148 Collaboration

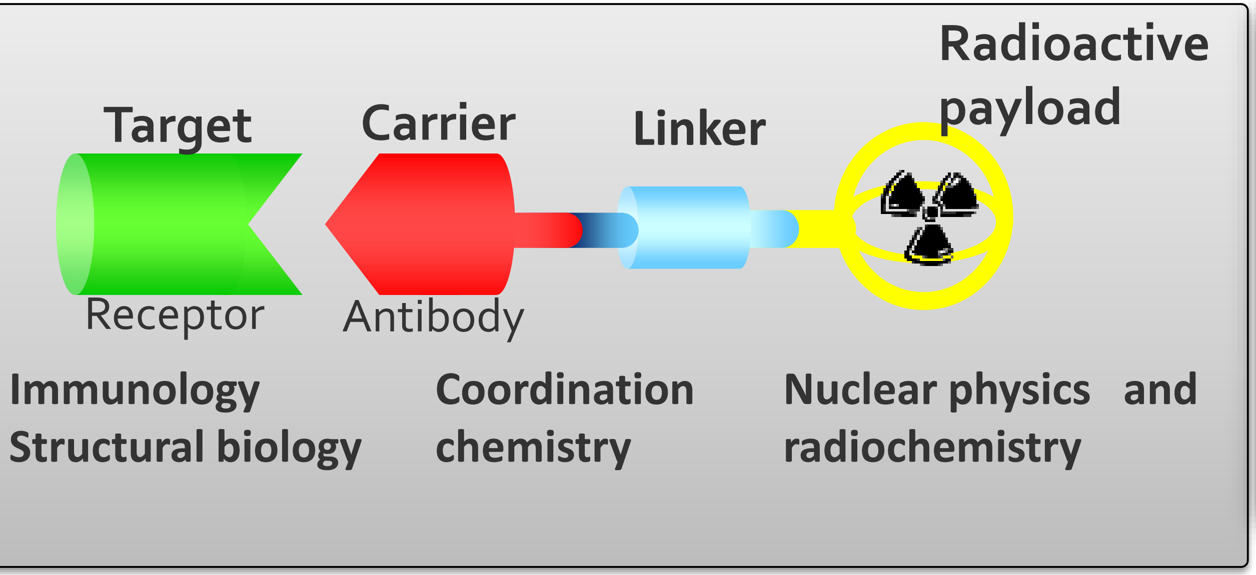
ENGINEERING DEPARTMENT

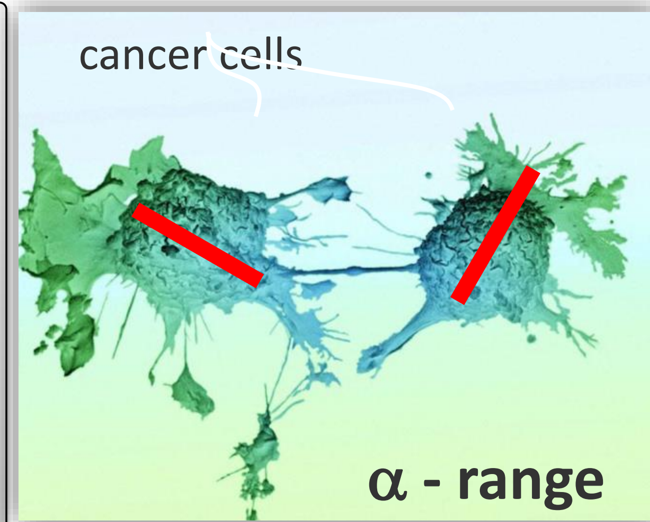
The rarest element on Earth: Astatine



- Most abundant isotope ^{218}At, ($t_{1/2}$ = 1.5 s)
- I.Asimov: 1st mile of earth's crust : 70mg (~3.5 atoms/ kg)
- Artificial production: ^{209}Bi(α,2n)^{210}At, Corson et al. (1940)
- Physical and chemical properties hard to investigate

Astatine for targeted alpha therapy (TAT)





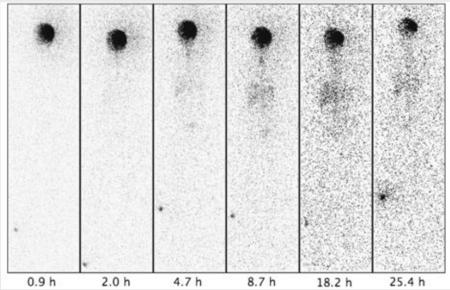
- Cancer cells have specific receptors
- Can be targeted by antibodies which carry radionuclides
- Alpha particles have ideal range to kill individual cancer cells

- Astatine is a good candidate for TAT (half life, α-energy)
- But At behaves sometimes like a metalloid sometimes like halogen - a **chemical hybrid**

A zorse (zebra-horse hybrid)

With material from *U.Köster, INPC 2013*

Astatine biochemistry studies

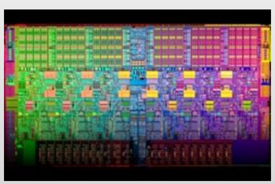


73 MBq 211At-ch81C6
γ ray image of full body

in vivo
M. Zalutsky et al., J. Nucl. Med. 49 (2008) 30.

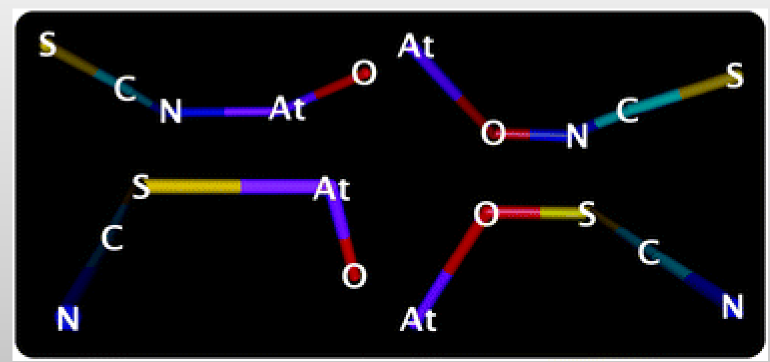
- Slow process due to absence of a long lived tracer

in vitro
S.H. Cunningham et al., Br. J. Cancer 77 (1998) 2061.
S.H.L. Frost et al., Cancer 116 (2010) 1101.
J. Champion et al., J. Chem. Phys. A114 (2010) 576.



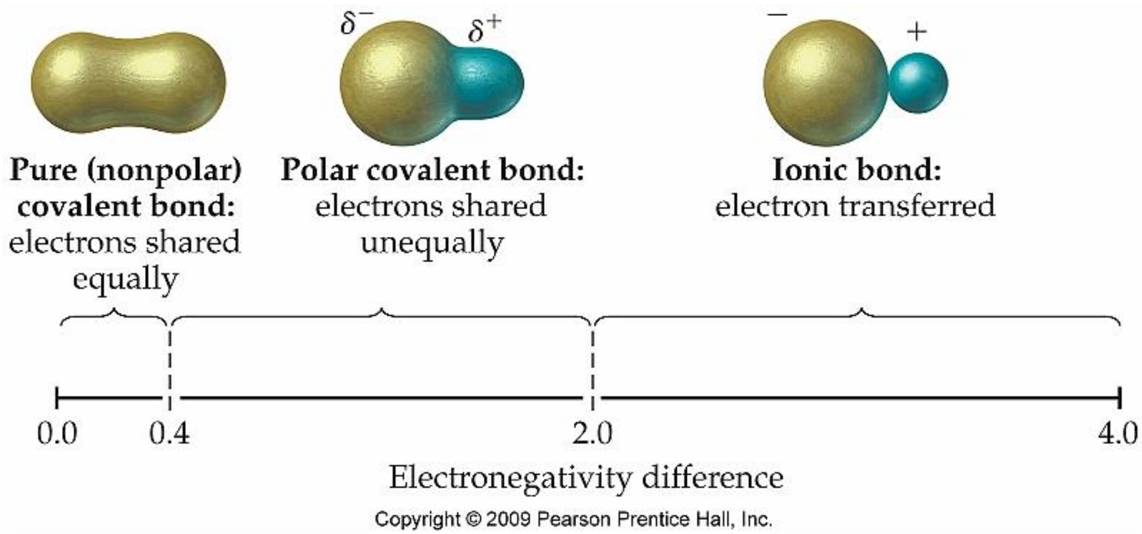
in silico
J. Champion et al., PCCP 13 (2011) 14984.

- 'In silico' calculations can predict behavior of compounds before synthesis
- **Needs experimental references: such as the IP and EA**



With material from *U.Köster, INPC 2013*

Electronegativity



Pauling scale (empirical)

- Electron Affinity (EA)
  = Binding energy of the negative ion

- Ionization Potential
  = Binding energy of the positive ion

- IP + EA determine the chemical reactivity type of chemical bonds.

Mulliken electronegativity scale

$$X^M = \frac{IP + EA}{2}$$

Can be connected to Pauling scale:
DOI: 10.1021/ct049942a

Contents

The ionization potential of astatine

nature COMMUNICATIONS

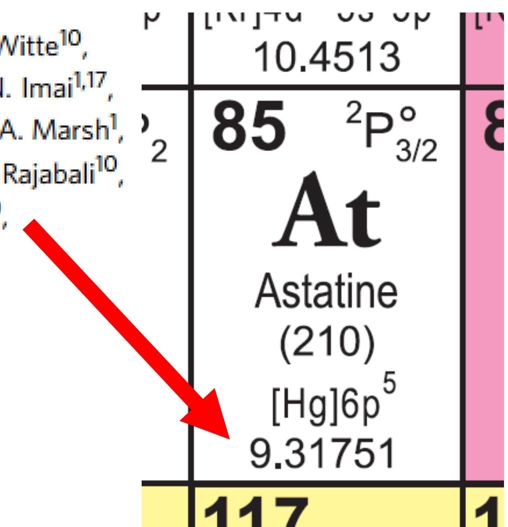
ARTICLE

Received 21 Aug 2012 | Accepted 27 Mar 2013 | Published 14 May 2013 DOI: 10.1038/ncomms2819 OPEN

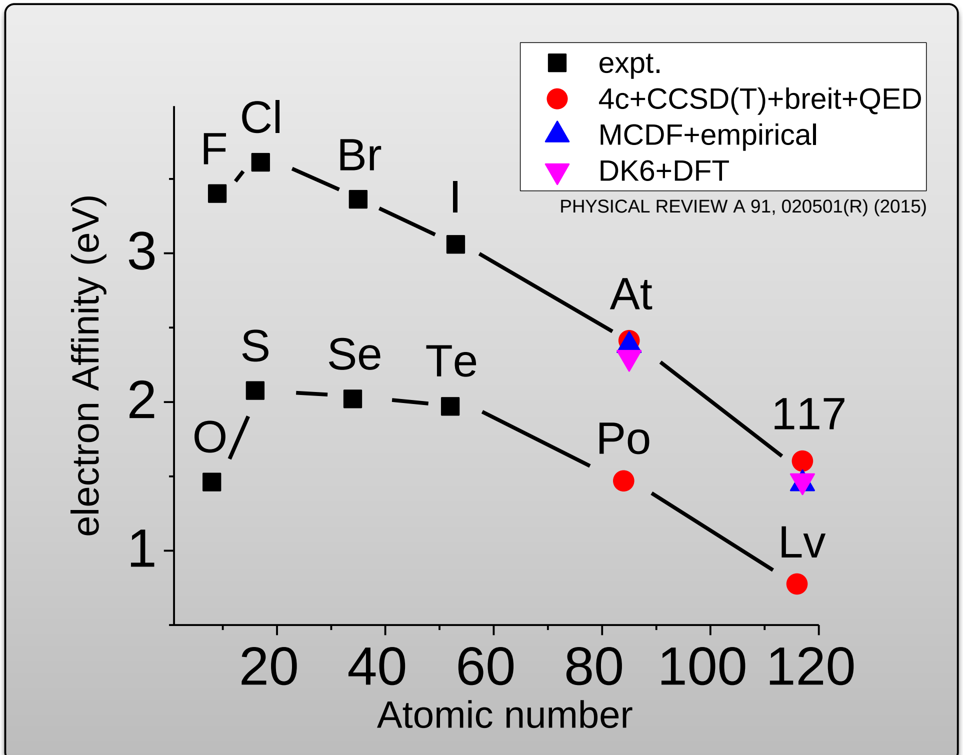
Measurement of the first ionization potential of astatine by laser ionization spectroscopy

S. Rothe[1,2], A.N. Andreyev[3,4,5,6], S. Antalic[7], A. Borschevsky[8,9], L. Capponi[4,5], T.E. Cocolios[1], H. De Witte[10], E. Eliav[11], D.V. Fedorov[12], V.N. Fedosseev[1], D.A. Fink[1,13], S. Fritzsche[14,15,†], L. Ghys[10,16], M. Huyse[10], N. Imai[1,17], U. Kaldor[11], Yuri Kudryavtsev[10], U. Köster[18], J.F.W. Lane[4,5], J. Lassen[19], V. Liberati[4,5], K.M. Lynch[1,20], B.A. Marsh[1], K. Nishio[6], D. Pauwels[16], V. Pershina[14], L. Popescu[16], T.J. Procter[20], D. Radulov[10], S. Raeder[2,19], M.M. Rajabali[10], E. Rapisarda[10], R.E. Rossel[2], K. Sandhu[4,5], M.D. Seliverstov[1,4,5,12,10], A.M. Sjödin[1], P. Van den Bergh[10], P. Van Duppen[10], M. Venhart[21], Y. Wakabayashi[6] & K.D.A. Wendt[2]

IP (At) = 9.31751(8) eV



The electron affinity of astatine



- No experimental value for EA(At) yet
- Scattering of all theoretical predictions and extrapolations ~1 eV

Letter of Intent 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. Rothe[1], M. Bissell[2], T. Day Goodacre[1,3], V. Fedosseev[1], K. Flanagan[3], N. Galland[4], T. Giles[1], A. Gottberg[1], D. Hanstorp[5], U. Köster[6], T. Kron[7], Yu. Kudryavtsev[2], B. Marsh[1], G. Montavon[8], G. Neyens[2], S. Raeder[2], E. Renault[4], R. Rossel[1,9], M. Stachura[1], T. Stora[1], K. Wendt[7]

Proposal INTC-P-462

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

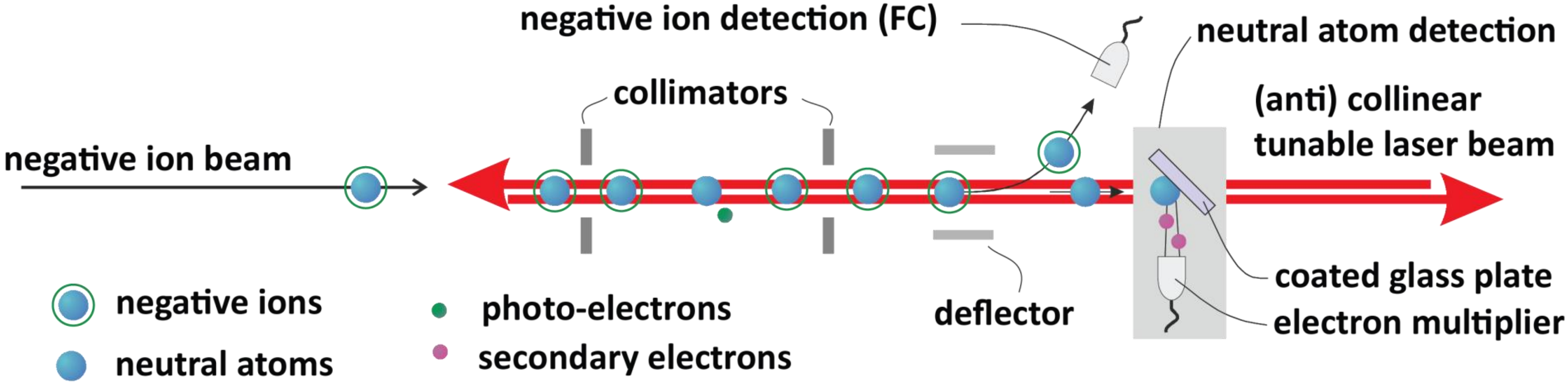
(Following ISOLDE Letter of Intent I-148)

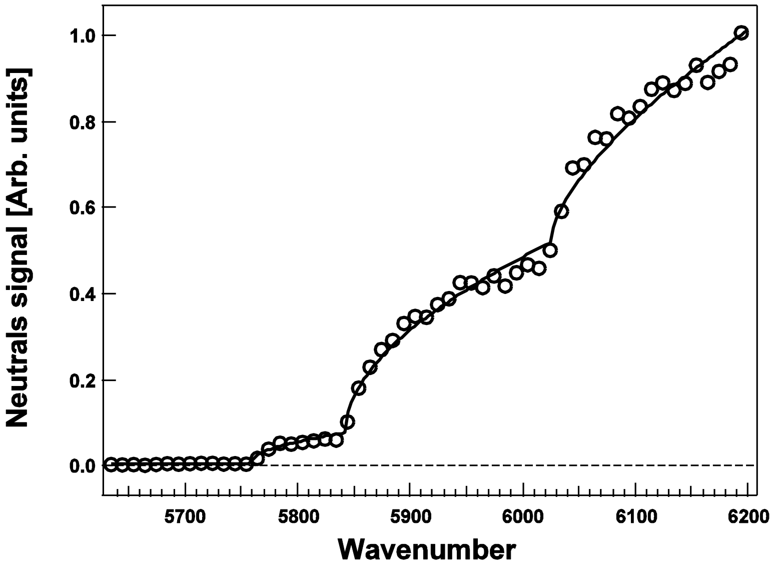
Determination of the electron affinity of astatine and polonium by laser photodetachment

January 12, 2016

S. Rothe[1,2,3], J. Champion[4], K. Chrysalidis[1,5], T. Day Goodacre[1,3], V. Fedosseev[1], N. Galland[6], D. Hanstorp[2], R. Heinke[5], U. Köster[7], T. Kron[5], Y .Liu[8], B. Marsh[1], G. Montavon[4], E. Renault[6], A. Ringwall-Moberg[2], R. Rossel[5], C. Seiffert[1], J. Sundberg[1,2], J. Welander[2], and K. Wendt[5]

The Method: Collinear laser photodetachment





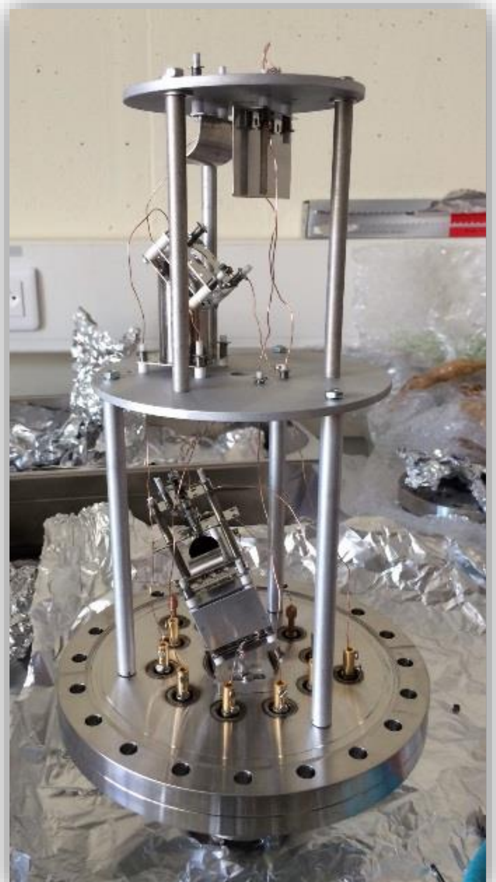
$$At^{-} + h\nu \rightarrow At + e^{-}$$

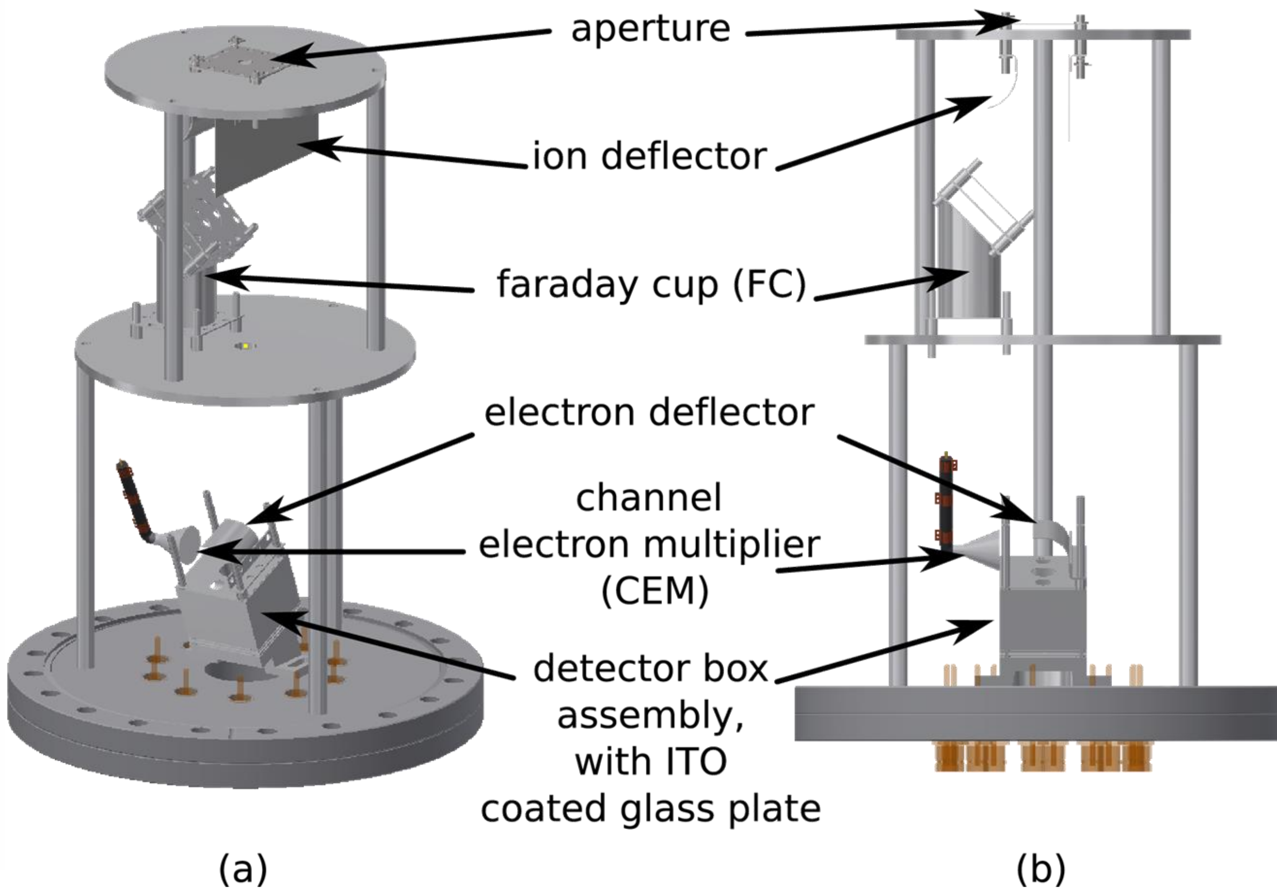
Wigner law:

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

l = 0 for s-wave outgoing electron

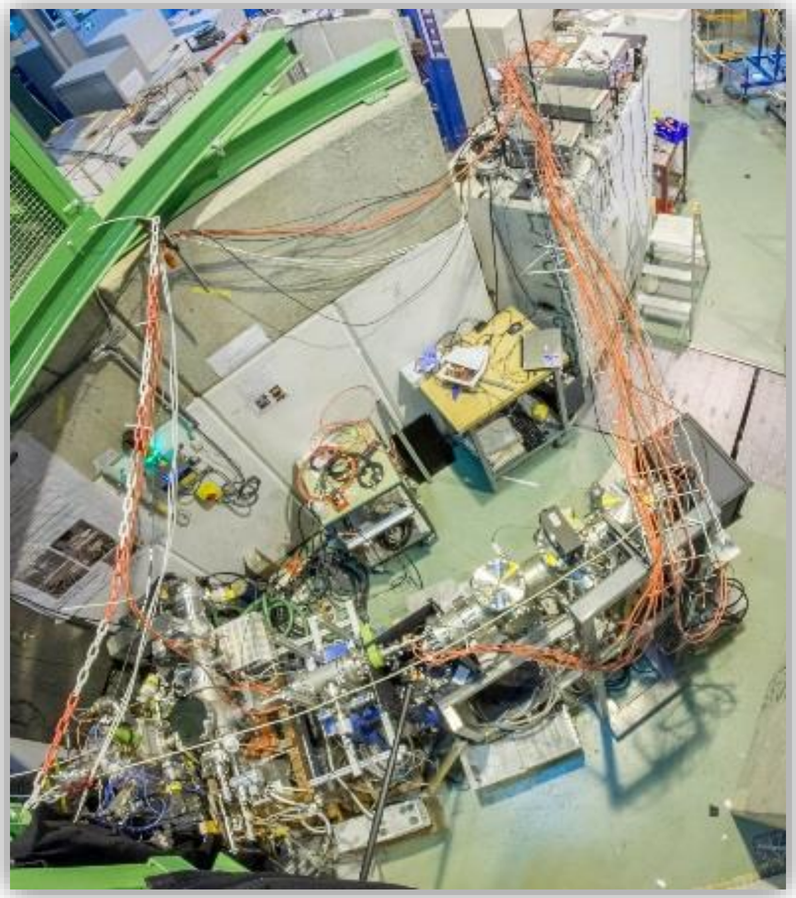
The neutral atom detector





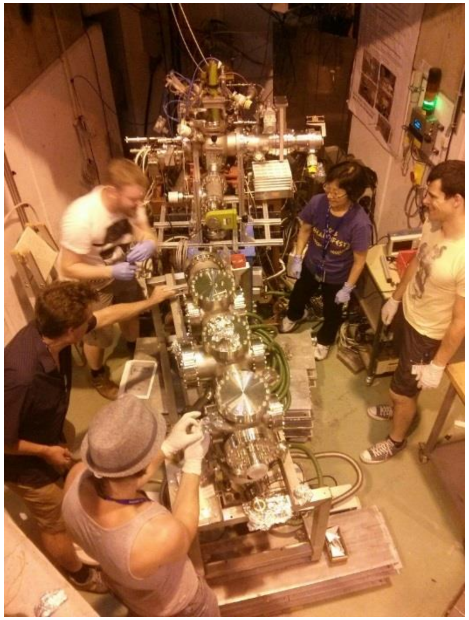
A new apparatus: GANDALPH 2015

Gothenburg **AN**ion **D**etector for **A**ffinity measurements by **L**aser **PH**otodetachment

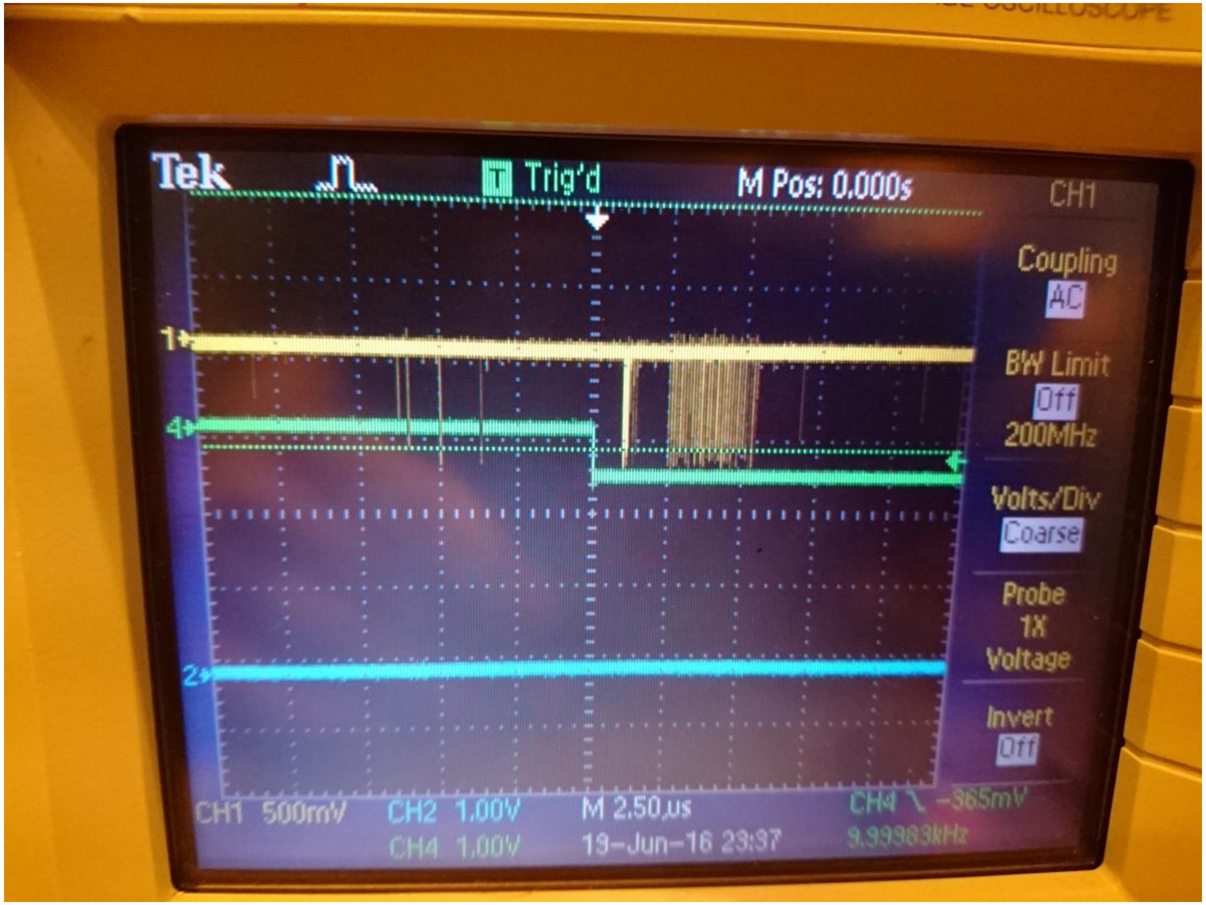


- Built in spring 2015 in Gothenburg
- Moved to ISOLDE, June 2015

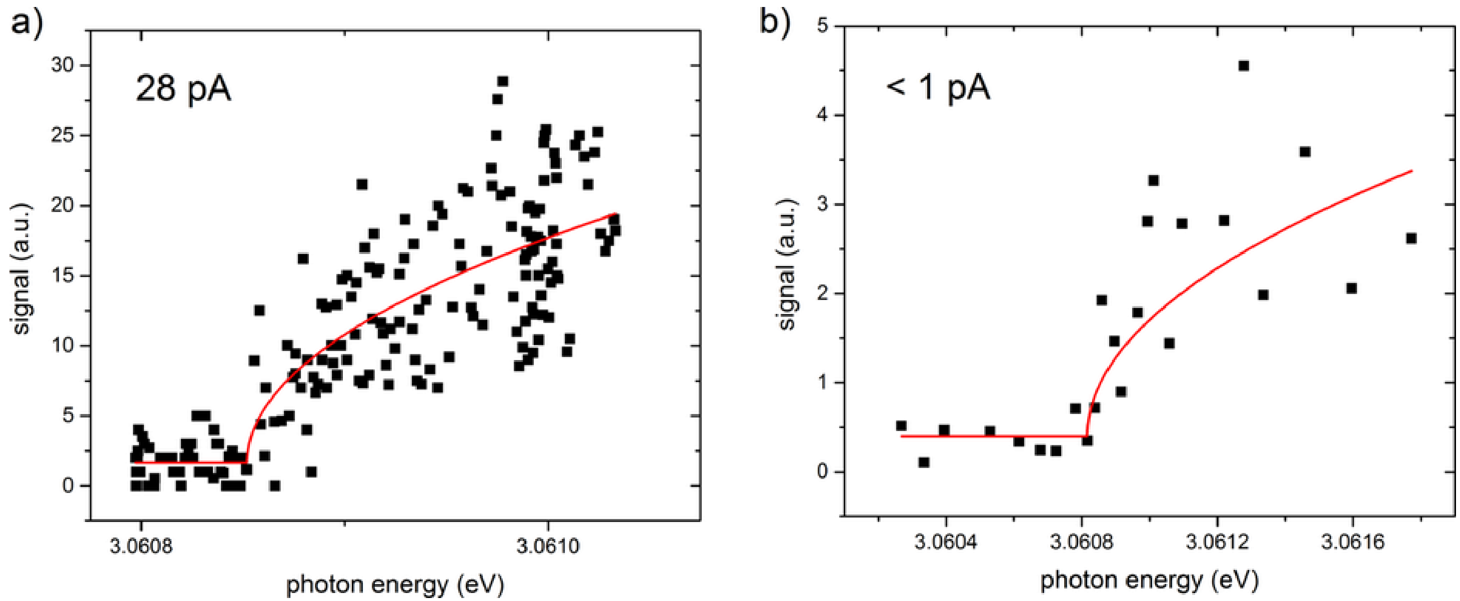
GANDALPH 2015



The signal


Tek
Trig'd
M Pos: 0.000s
CH1
Coupling
AC
BW Limit
Off
200MHz
Volts/Div
Coarse
Probe
1X
Voltage
Invert
Off
CH1 500mV
CH2 1.00V
CH4 1.00V
M 2.50µs
19-Jun-16 23:37

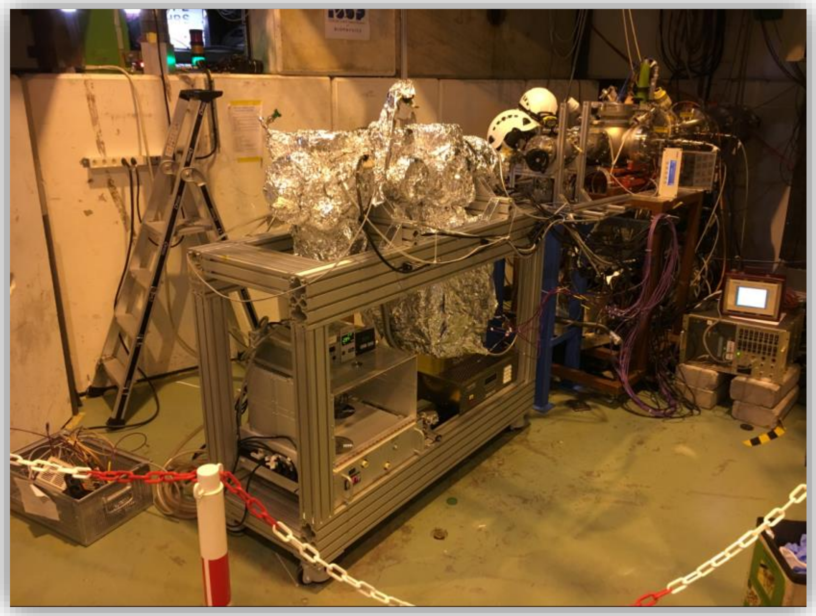
Results 2015: photodetachment of stable 127-iodine



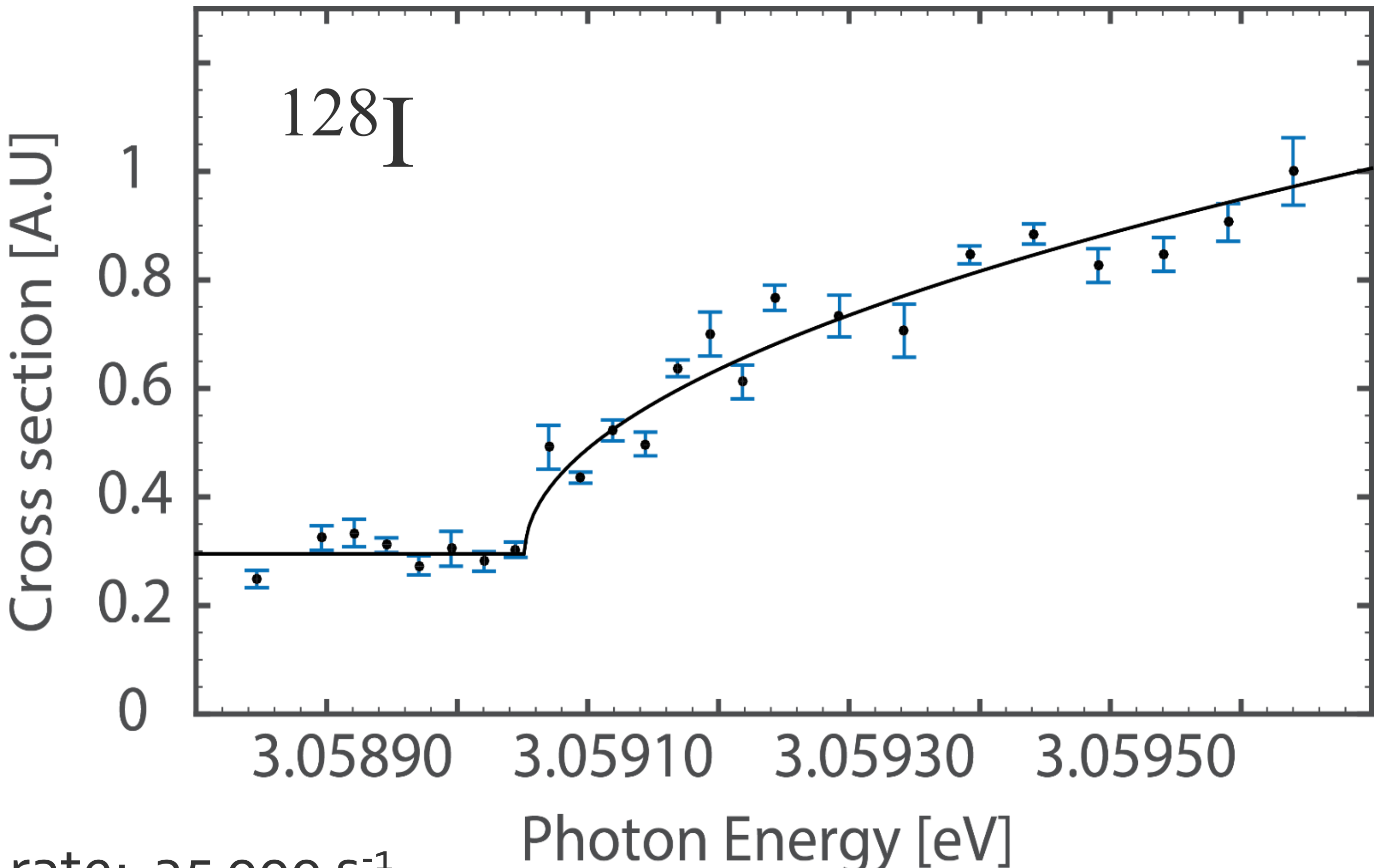
- First photodetachment signal of I^- at ISOLDE
- Threshold still measurable at very low ion rates (<1 pA, FC noise)
- No radiogenic iodine or astatine beams for LOI I-148

Upgraded GANDALPH 2016 vs 2015

	2015	2016
Baking	no	yes
Vacuum	2 x 10^{-8} mBar	<10^{-10} mBar
DAQ	Lecroy	SRS Photon Counter
Transmission	8%	25%
Frame	Bricolage	ITEM profiles



2016 – first affinity measurement on radioactive ions



- Ion rate: 35 000 s^{-1}
- Measurement time: 39 min
- Extracted EA: 3.059 052(38) eV

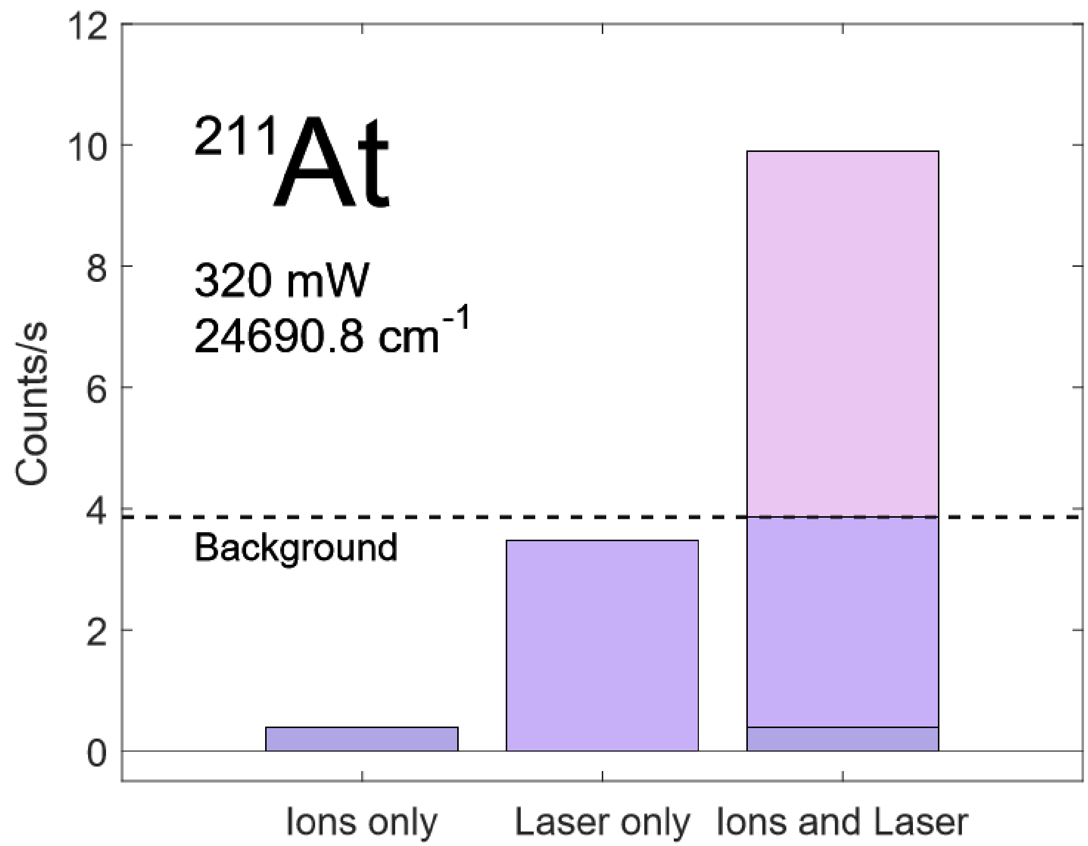
2016 - astatine yields

Mass	Signal (cps)	Background (cps)
204	2000	200
206	2500	170
208	1700	170
209	4000	150
210	4800	150
211	6200	170
212	about 800	170
213	170	170
217	170	170
218	170	170
219	170	170
204	2900	200

- 1.6uA p on target
- Signal = secondary electrons from ion beam on glass plate
- Increased background

- ^{211}At most intense beam

First photodetachment signal of astatine



- Ion rate ($^{211}At^{-}$): 6 200 s^{-1}
- Measurement time: ~1 h
- Upper limit for EA(At): < 3.06 eV

Conclusion

- GANDALPH has been upgraded – better vacuum better ergonomics
- First electron affinity measurement on a radioactive ion performed
- First laser photodetachment of astatine negative ions achieved

Outlook: GANDALPH 201x

- Improved beam diagnostics
  - Dedicated ion detector for tuning
  - Segmented collimators
- Re-condition the ion pump
- Fix broken vacuum feed-troughs
- File a beam time request for P-462

Astatine EA team (2015)

I-148 Collaboration

Laser photodetachment of radioactive $^{128}I^-$

Sebastian Rothe[1,2,3], Julia Sundberg[1,2], Jakob Welander[2], Katerina Chrysalidis[1,4], Thomas Day Goodacre[1,3], Valentin Fedosseev[1], Oliver Forstner[5], Reinhard Heinke[4], Karl Johnston[1], Tobias Kron[4], Ulli Köster[6], Yuan Liu[7], Bruce Marsh[1], Annie Ringvall-Moberg[1,2], Ralf Erik Rossel[1,4], Christoph Seiffert[1], Dominik Studer[4], Klaus Wendt[4], and Dag Hanstorp[2]

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[2] Department of Physics, Gothenburg University, Gothenburg, Sweden
[3] School of Physics and Astronomy, The University of Manchester, Manchester, UK
[4] Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany
[5] Friedrich Schiller Universität, Jena, Germany
[6] Institut Laue-Langevin (ILL), Grenoble, France
[7] Physics Division, Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, USA

Submitted to J. Phys. G

ISOLDE RILIS MANCHESTER 1824 The University of Manchester UNIVERSITY OF GOTHENBURG JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Thanks

- Isolde technical team for intense ion source tests and swapping ISOLDE to negative mode
- ISOLDE experimental setups (CRIS,COLLAPS,ISOLTRAP,SSP, …) for helping out with equipment – especially for GANDALPH 1.0
- Vacuum group for assistance with baking of GANDALPH 2.0

/eof