NUSPRASEN Workshop 2019

Towards Ion Mobility Studies of Actinides

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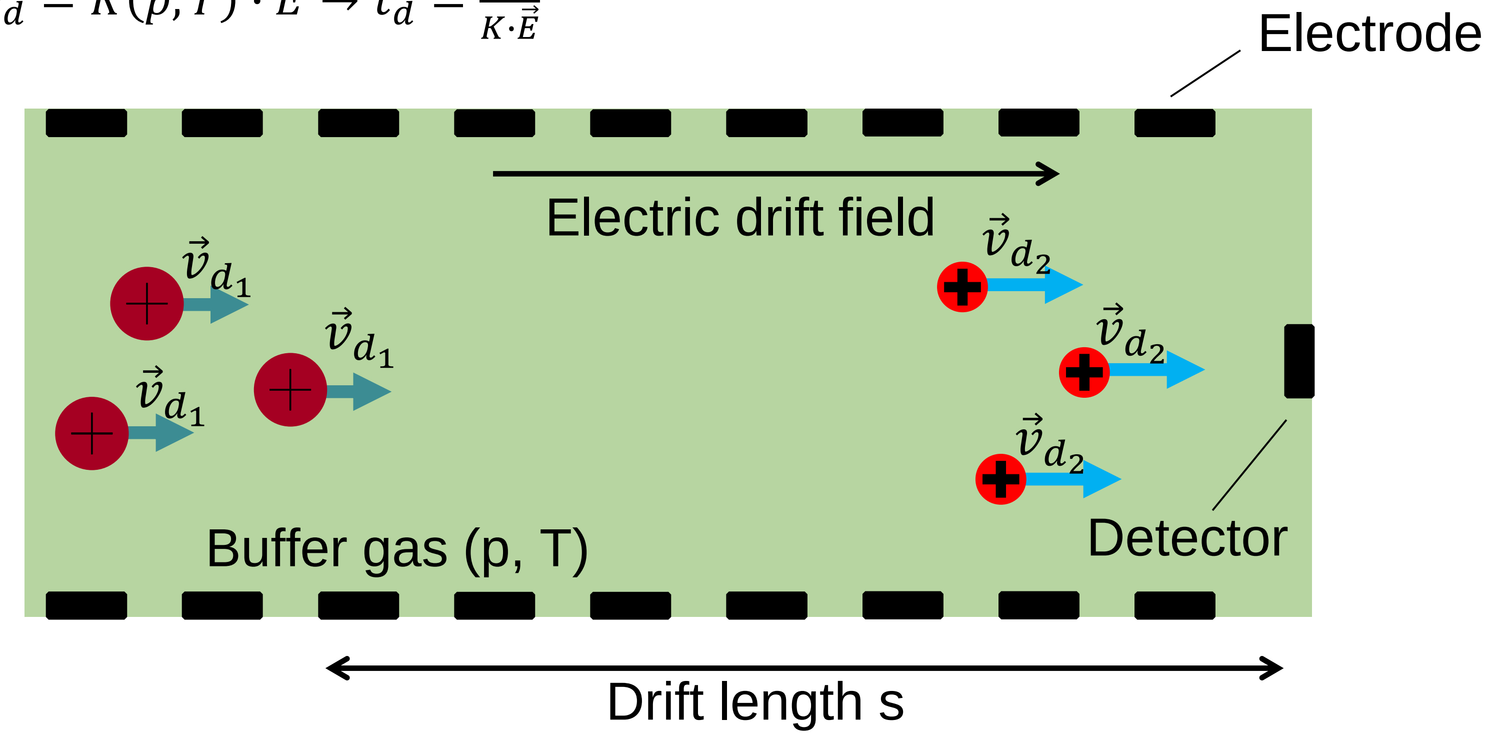
Motivation

- $v_d = K(p,T) \cdot \vec{E} \rightarrow t_d = \frac{s}{K \cdot \vec{E}}$



- Ion mobility K
  - Ion mass, size, shape
  - Ion-atom interaction potential

Motivation

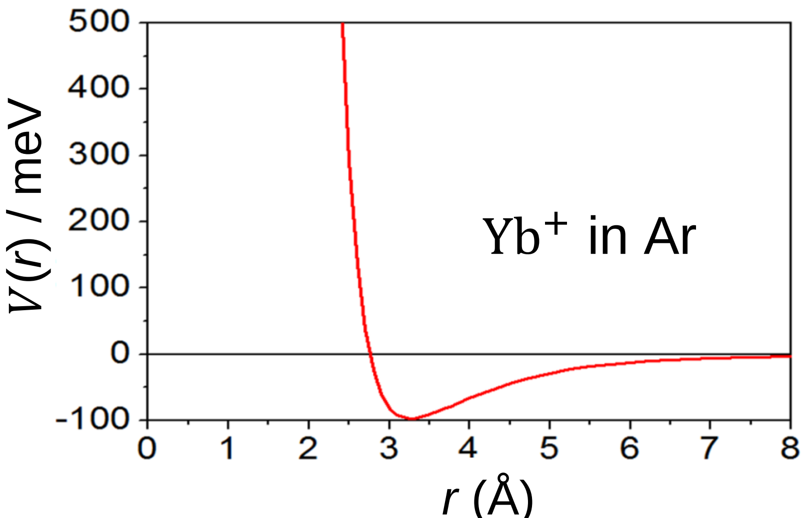
- $K \leftrightarrow$ Collision cross section $\Omega \leftrightarrow$ Ion-neutral interaction potential *V*(*r*) [1]
  - reduced mass $\mu = \frac{mM}{m+M}$
  - ion-atom interaction potential
    - $V(r) = {}^{C_n}/_{r^n} - {}^{C_6}/_{r^6} - {}^{C_4}/_{r^4}$

London dispersion & high order contributions

Pauli repulsion

Dipole attraction

- Ion-atom interaction potential $\leftrightarrow$ electronic configuration $\leftrightarrow$ relativistic effects



[1] L.Viehland, E.Mason, Annals of Physics (1975) 91:499

Motivation

n=1	1 H																	2 He
n=2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
n=3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
n=4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
n=5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
n=6	55 Cs	56 Ba	57-71 La-Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rd
n=7	87 Fr	88 Ra	89-103 Ac-Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

Lanthanide

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu

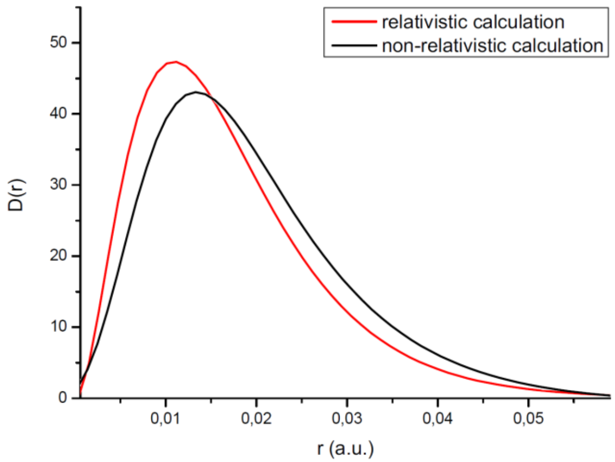
Actinide

89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cu	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

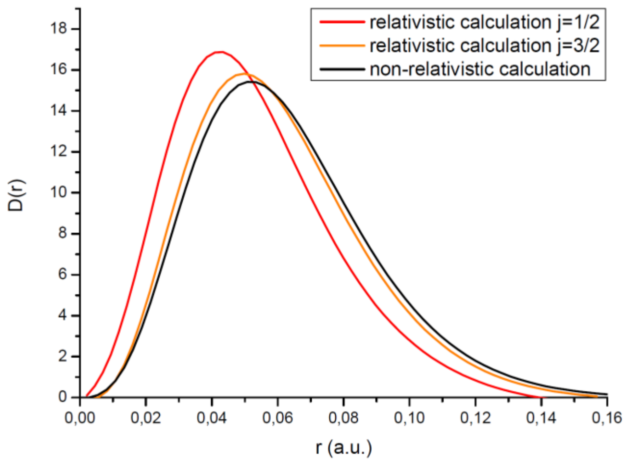
Motivation

- Relativistic effects increasingly important for high *Z*
- Electronic configuration
  - relativistic density profiles contracted
  - For increasing n relativistic contraction decreases
  - $\beta = \frac{v}{c} = \frac{Z}{137}$ a.u. $\rightarrow \beta = 0.58$ for hydrogen-like mercury (${}_{80}\mathrm{Hg}$)

1s



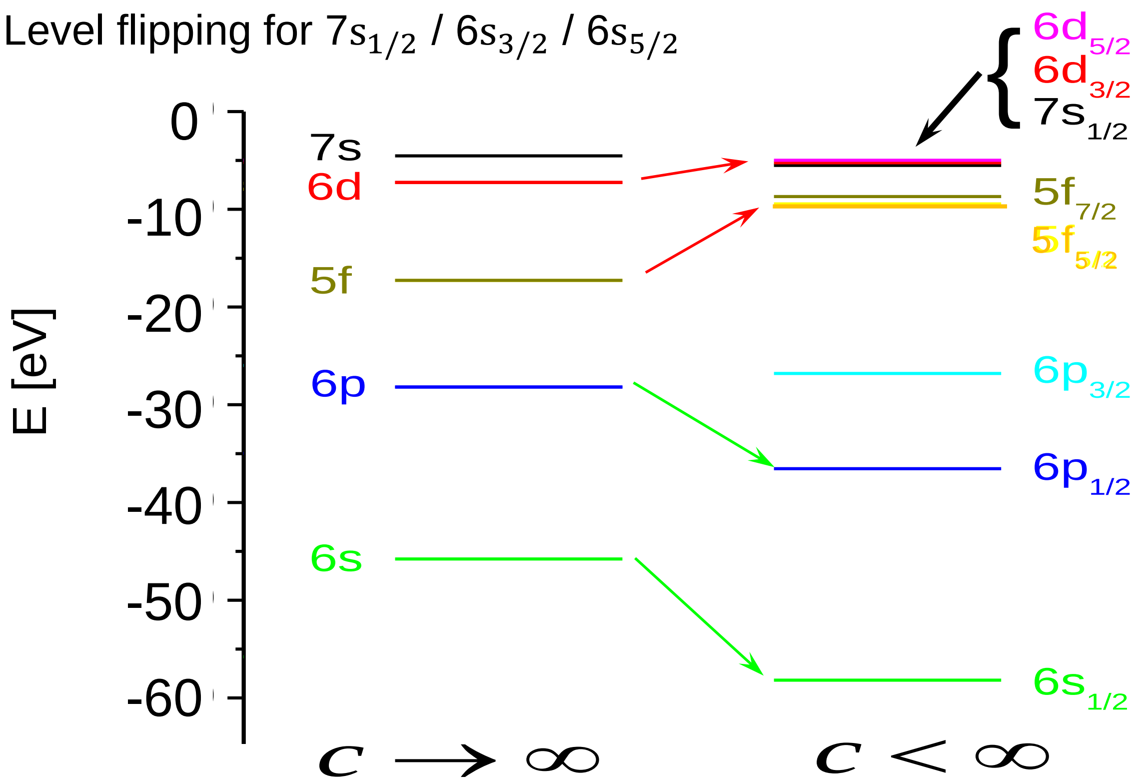
2p



Plots reproduced from data of [2] V. Burke et al., Proc. Phys. Soc. London, **90**, 297 (1967)

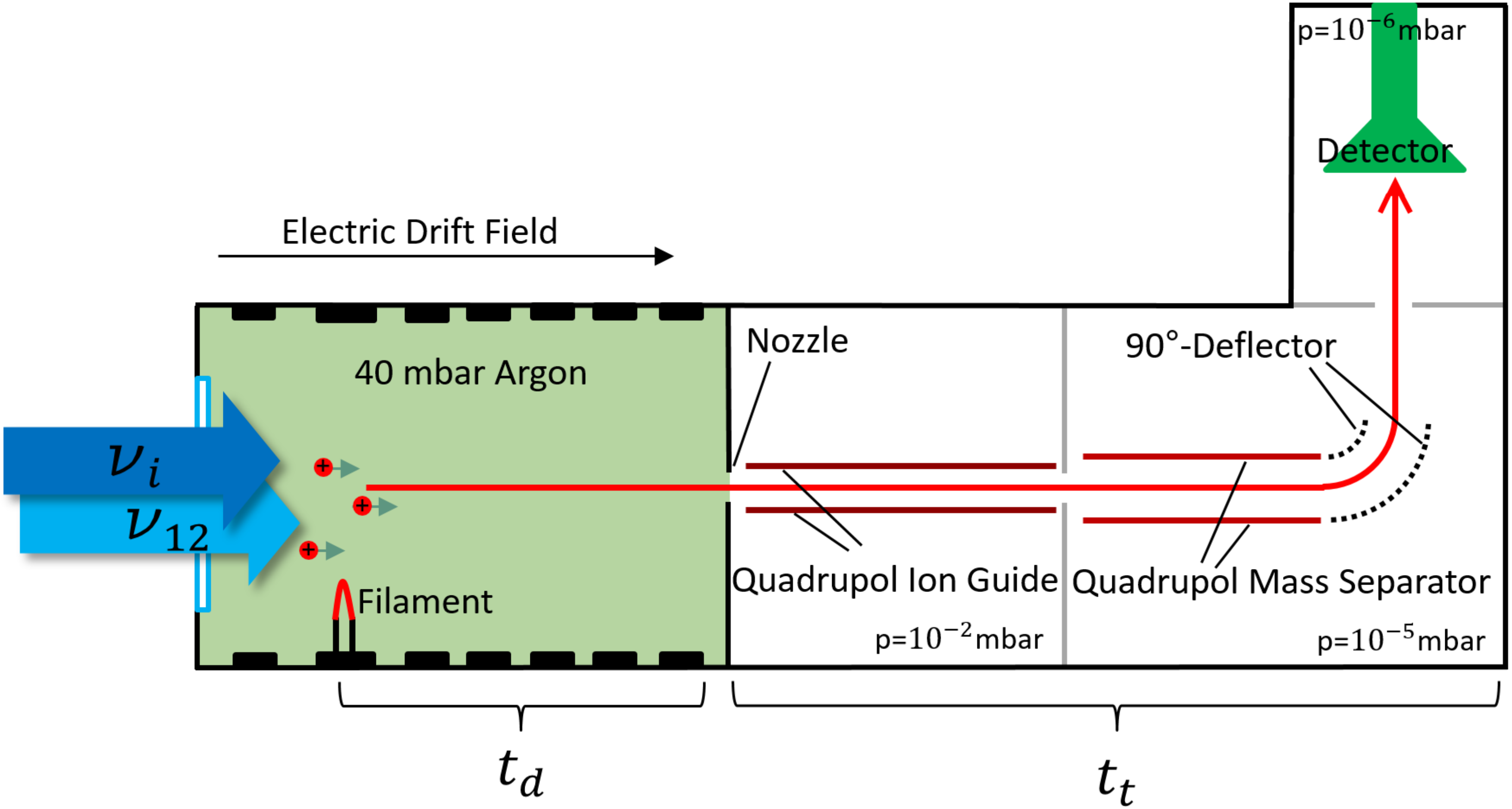
Motivation

- Shift of electronic energy levels
  - Level flipping for $7s_{1/2}$ / $6s_{3/2}$ / $6s_{5/2}$



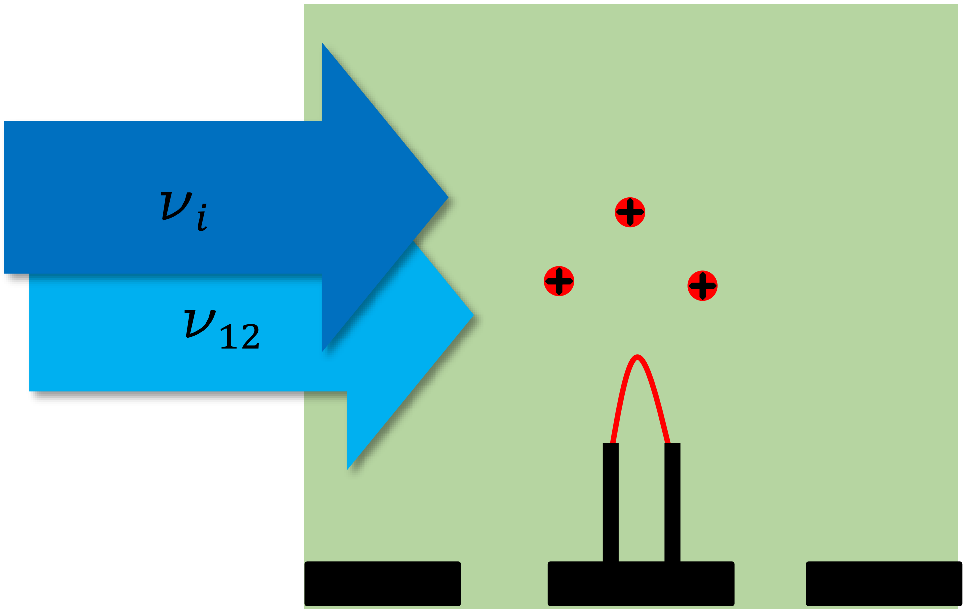
For Uranium (Z=92)

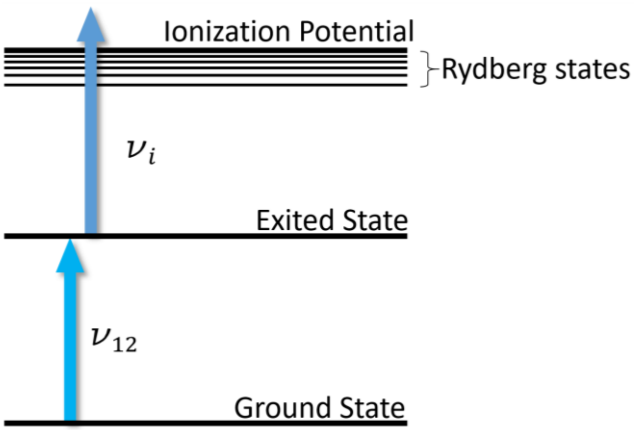
IMS Apparatus



Measurement Principle

- Two-step photo-ionization
- Fixed starting time and starting position
- Register arrival time $t_a = t_d + t_t$ at channeltron detector





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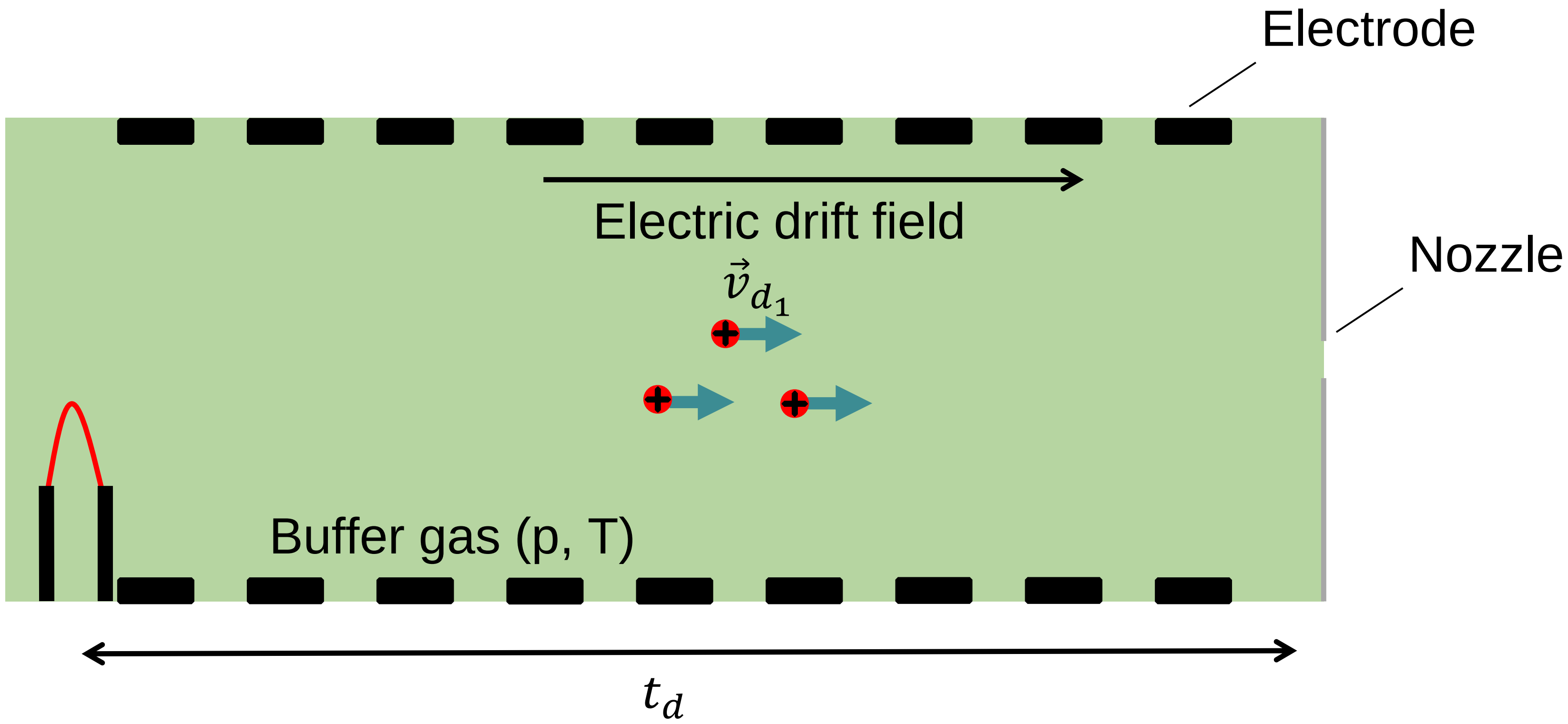
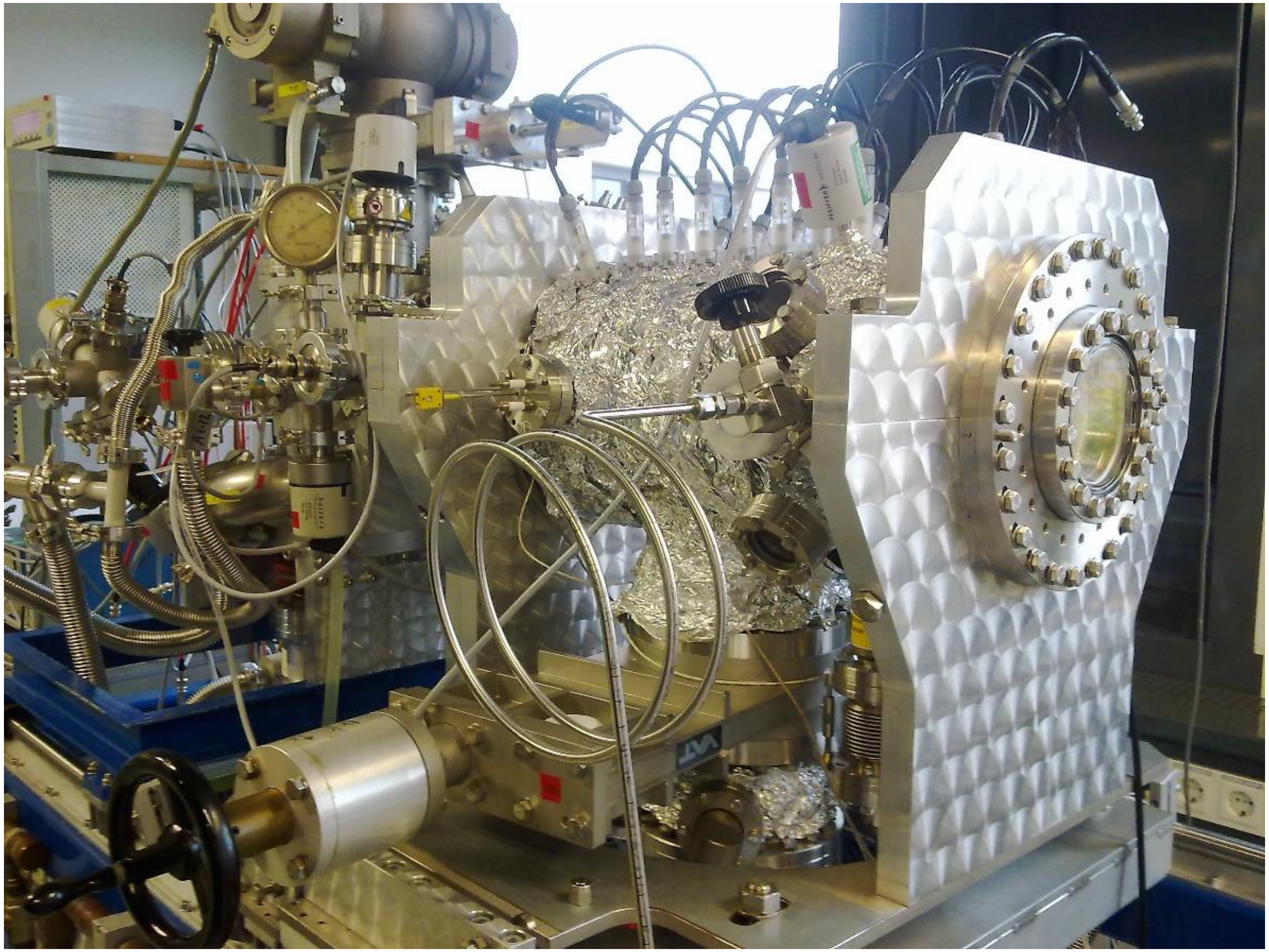
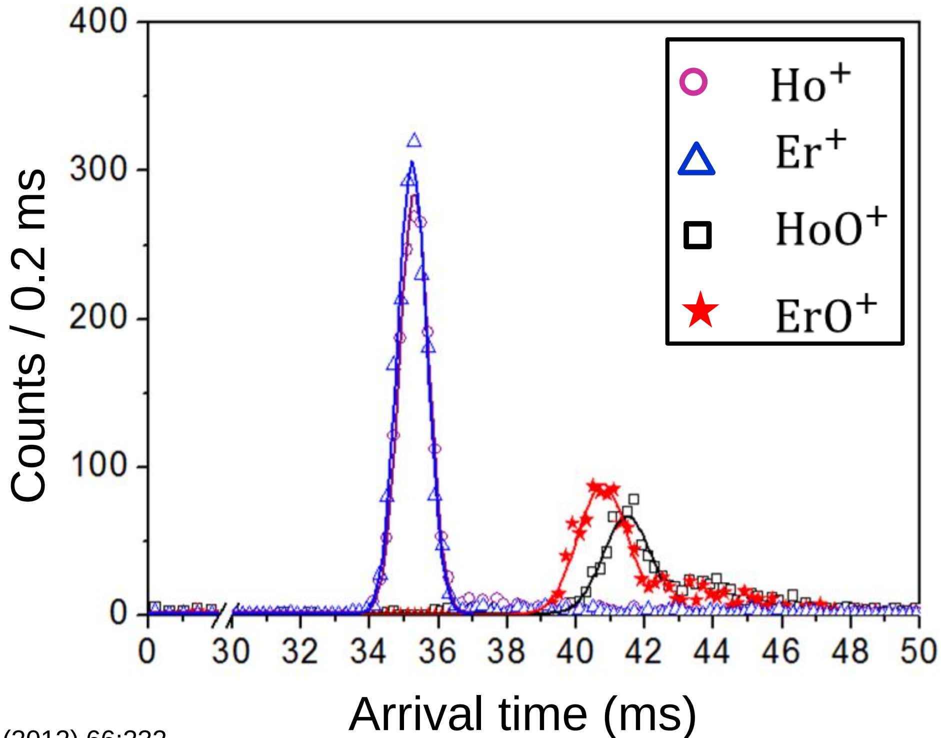


IMS Apparatus



Lanthanide Results

- Systematic IMS studies of several Lanthanides in 2009 [3]
- $^{151}_{63}Eu^+$, $^{156}_{64}Gd^+$, $^{159}_{65}Tb^+$, $^{156}_{66}Dy^+$, $^{165}_{67}Ho^+$, $^{168}_{68}Er^+$, $^{174}_{70}Yb^+$
- Arrival time spectra of Lanthanide ions indistinguishable



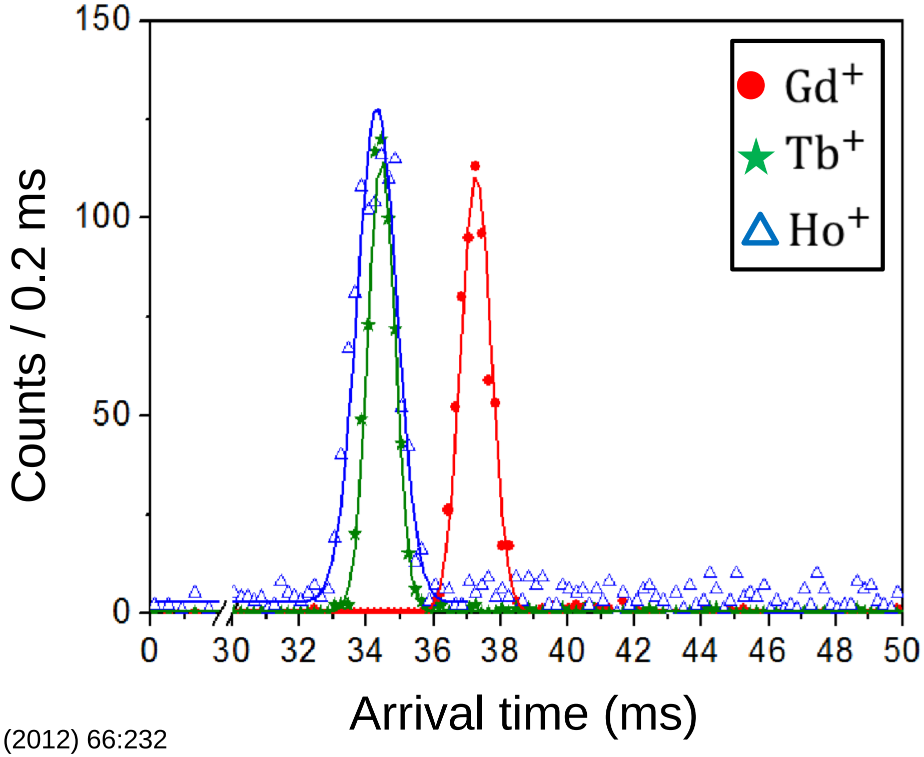
[3] M. Laatiaoui et al., EPJD (2012) 66:232

Lanthanide Results

- Arrival time spectra of Lanthanide ions indistinguishable EXCEPT Gd^+

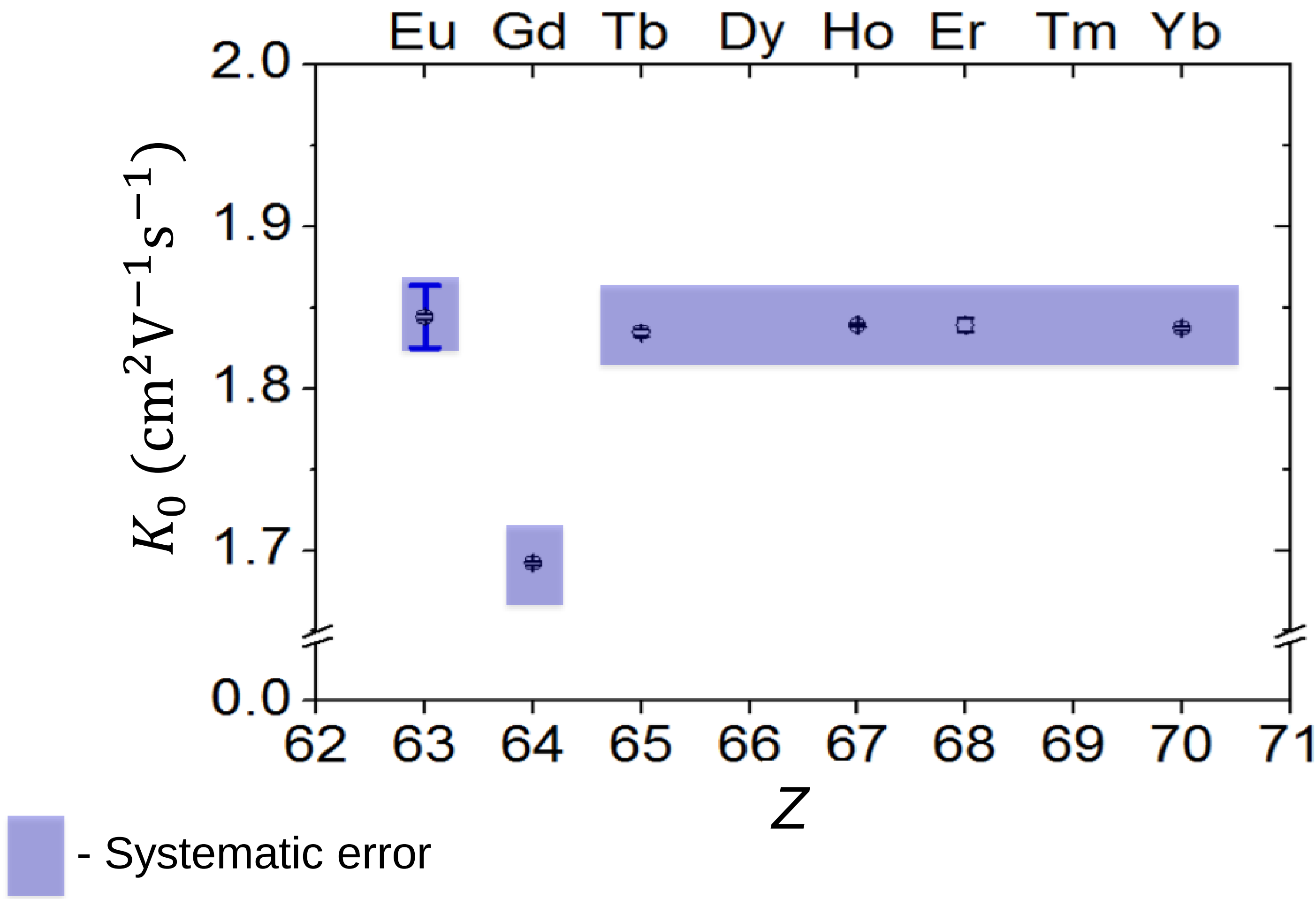
  → occupied 5d-shell leads to reduced mobility

→ Impact of electronic configuration on distinct ion mobilities proven



[3] M. Laatiaoui et al., EPJD (2012) 66:232

Lanthanide Results



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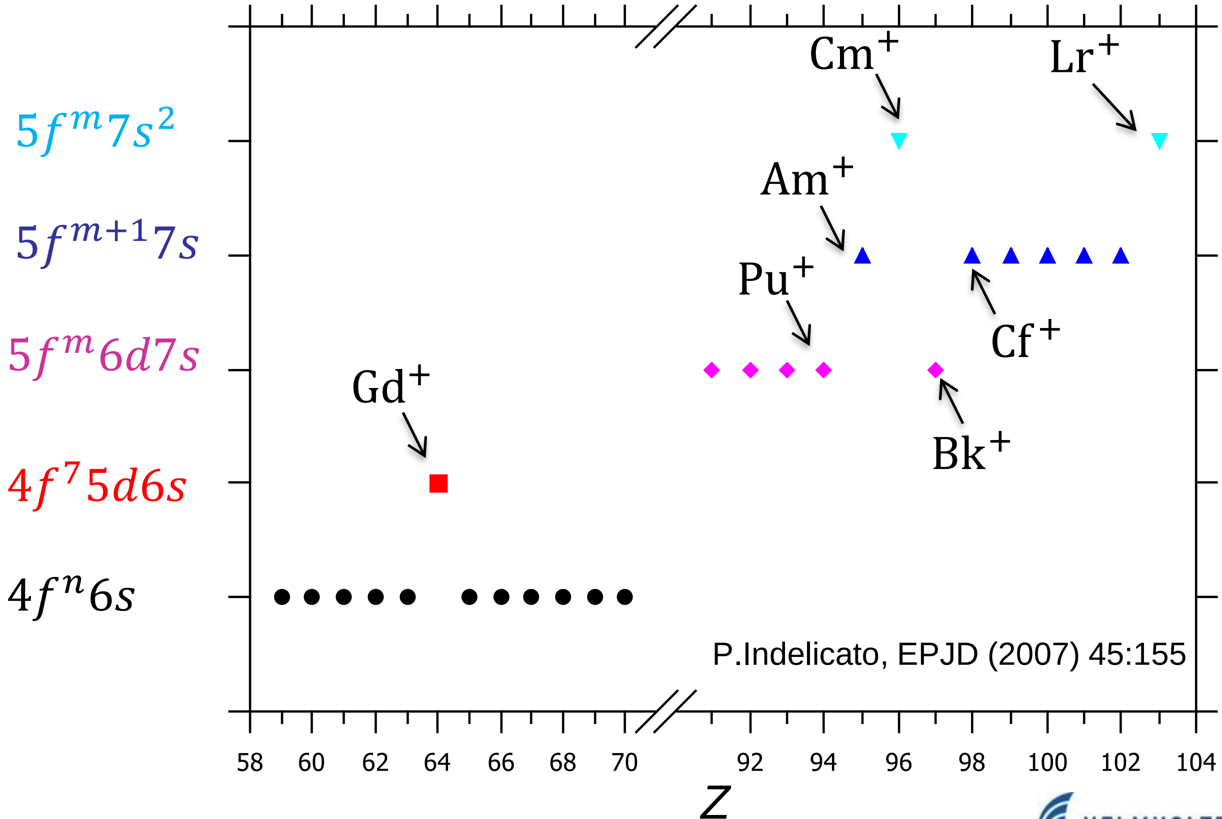
Actinide Expectations

- Similar drift behaviour for actinide series
- Mobility variations due to different electronic configurations
  - reduced K_0 for ${}_{94}\mathrm{Pu}^+$?



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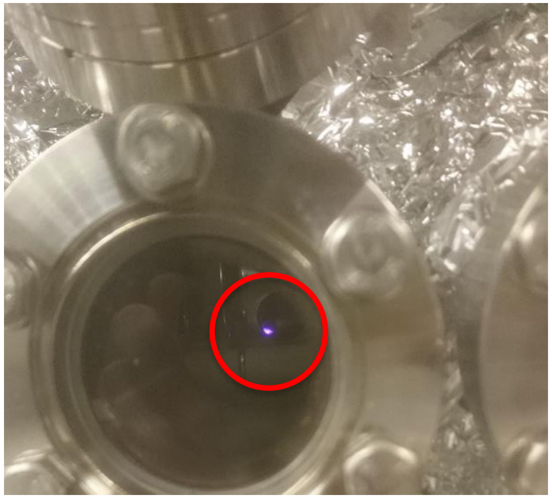
First steps

- Voltage divider installed to provide voltages for the drift cage
- First signals for argon ions from argon discharge



<u>Next steps</u>

- Test ion production via two-step photo-ionization with inactive metal foils
- Acquire data for ions from inactive printed targets
- Install active printed targets for ion mobility studies of Actinides

Thank you for your attention!

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