Ion Beam Analysis in the Helium Ion Microscope

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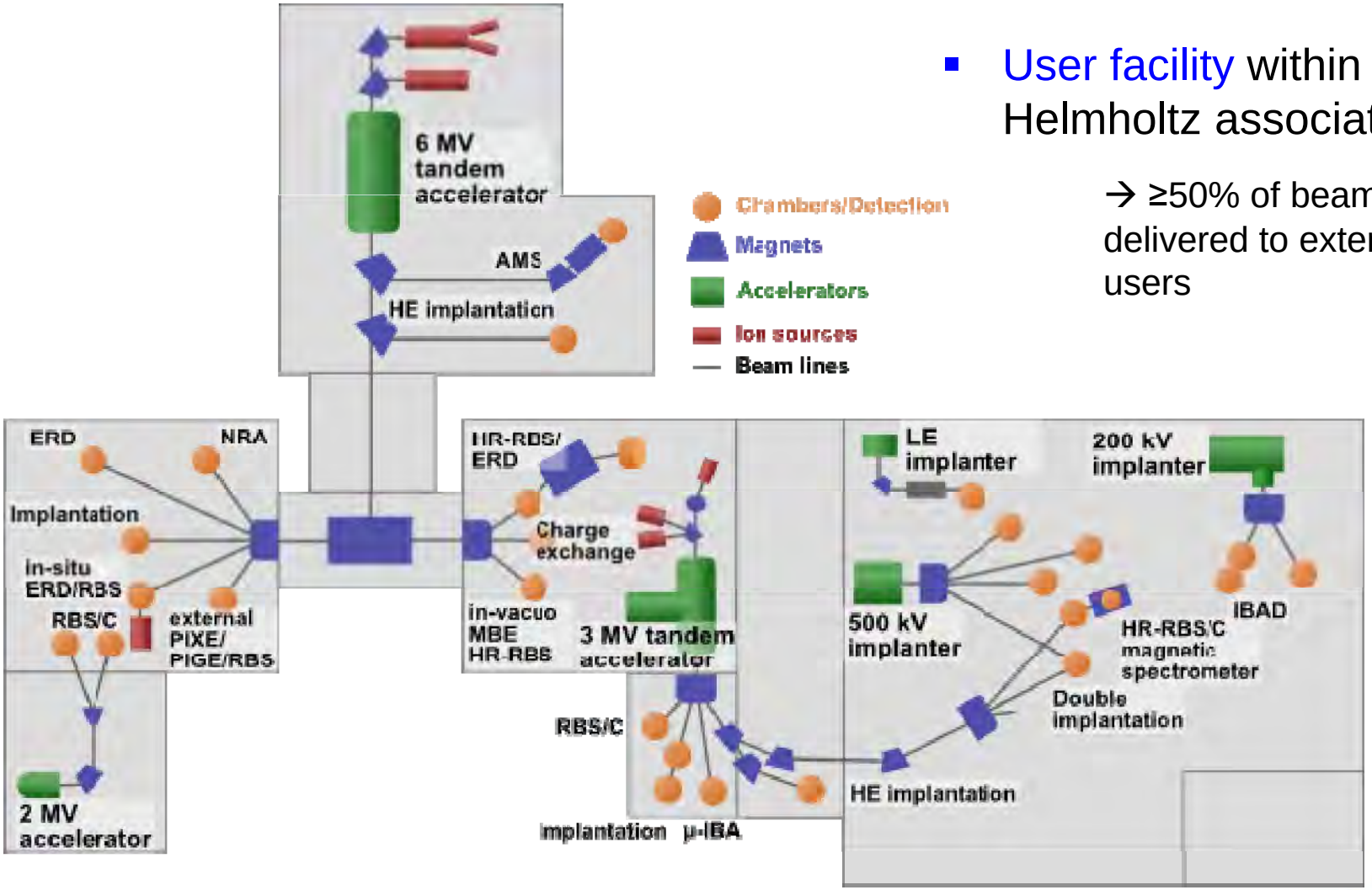
HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Mitglied der Helmholtz-Gemeinschaft

The Ion Beam Center



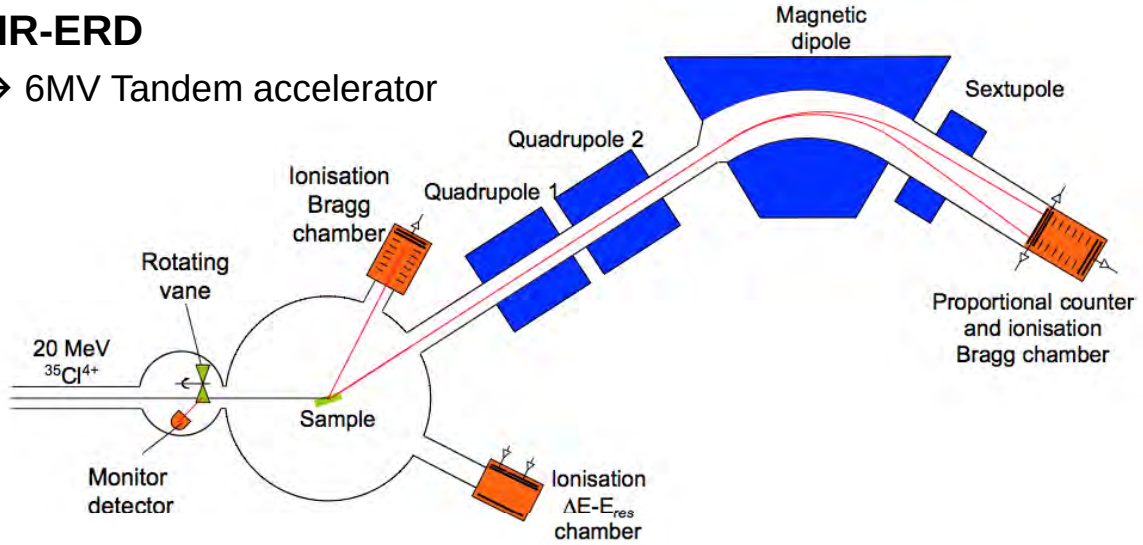
- User facility within the Helmholtz association

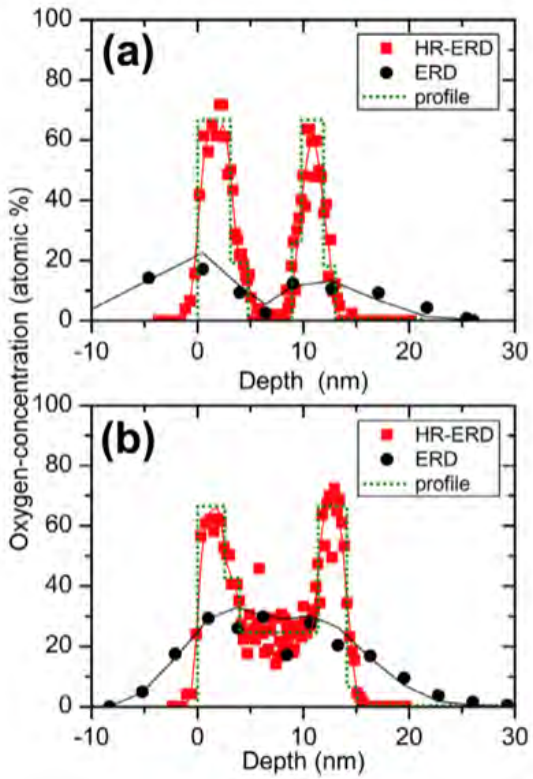
  → ≥50% of beam time delivered to external users

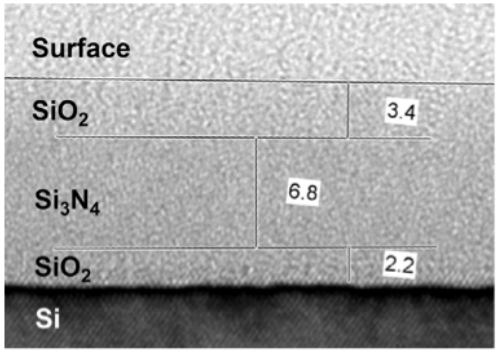
Motivation

HR-ERD

→ 6MV Tandem accelerator





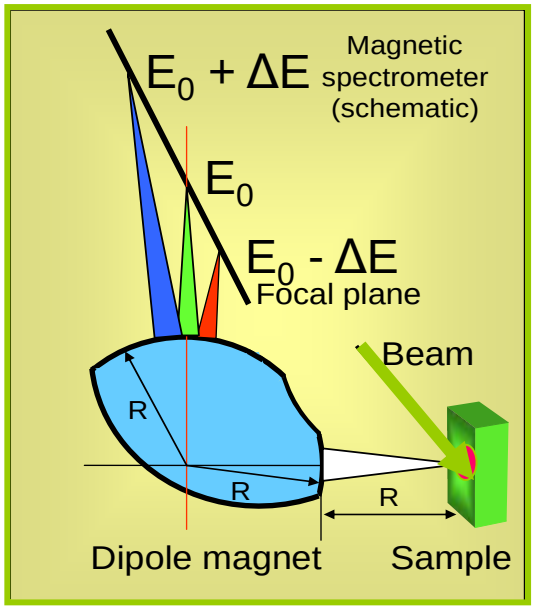


Kosmata *et al.*, NIMB **337** (2014) 27

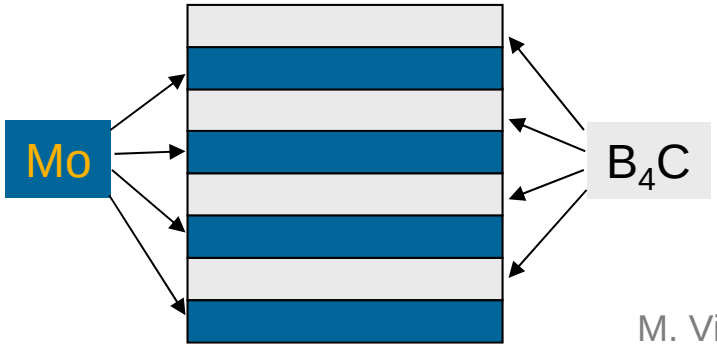
Motivation

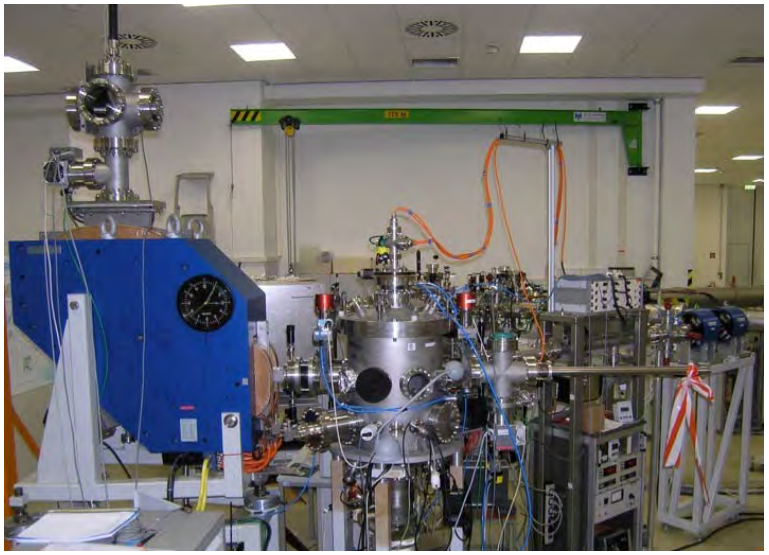
HR-RBS

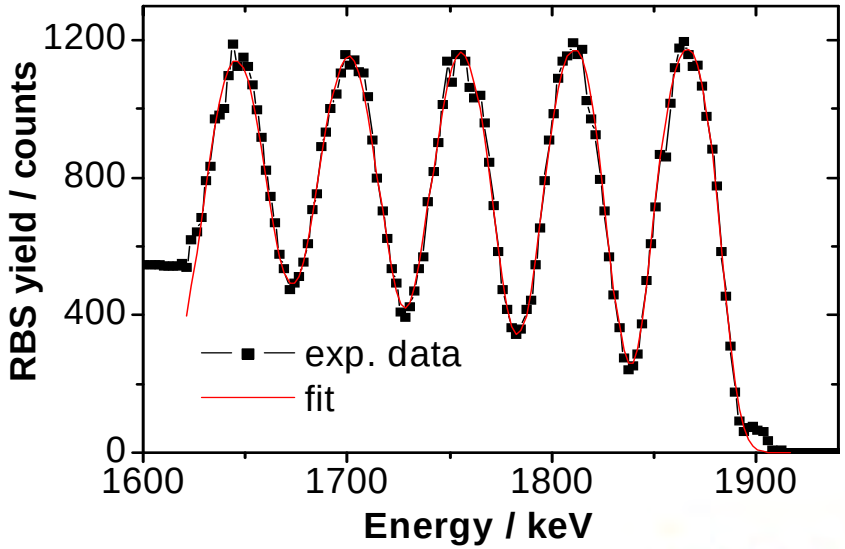
→ 3MV Tandem accelerator



n x 2.33 nm B_4C / 1.9 nm Mo

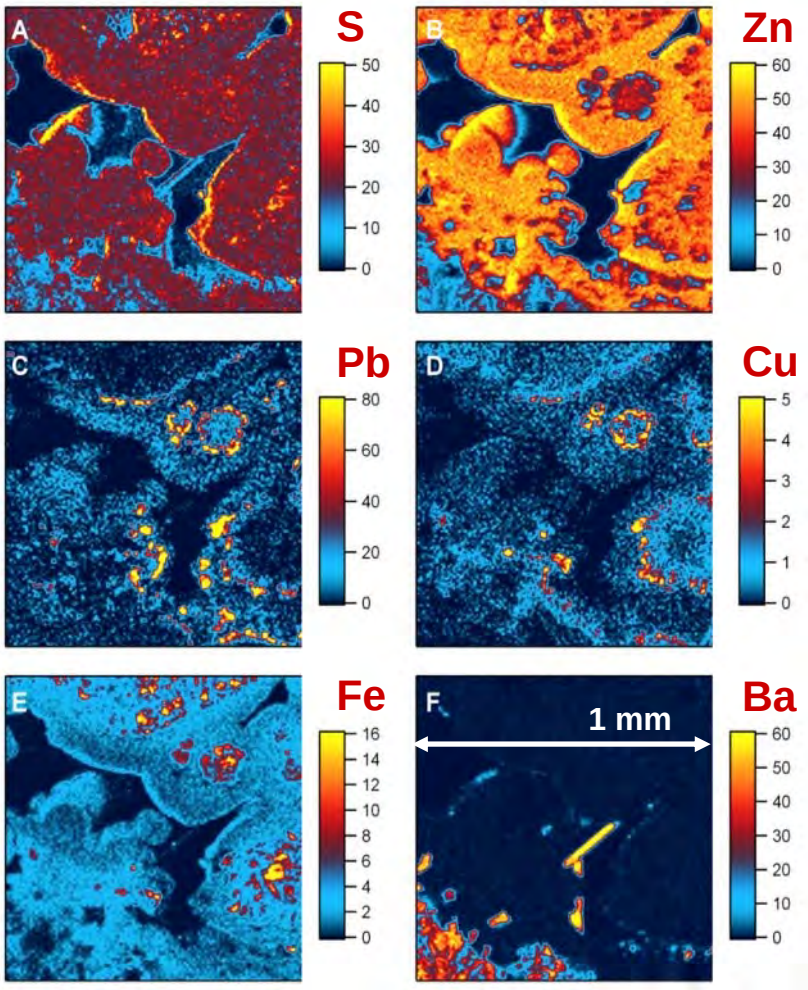






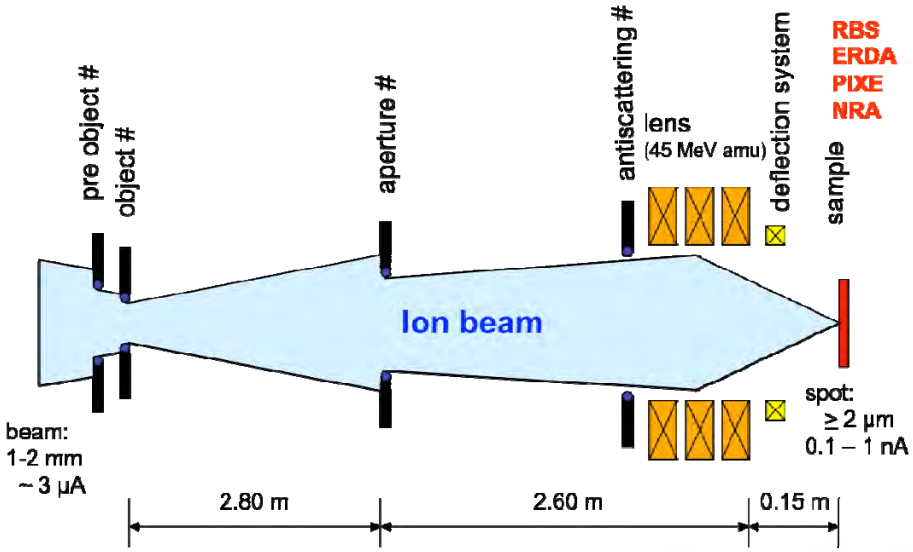
M. Vieluf *et al*, Thin Solid Films **520** (2012) 5900

Motivation



Ion Micro Probe

- → 3MV Tandem accelerator
- → lateral resolution approx. 3µm
- → Limited depth profiling / resolution

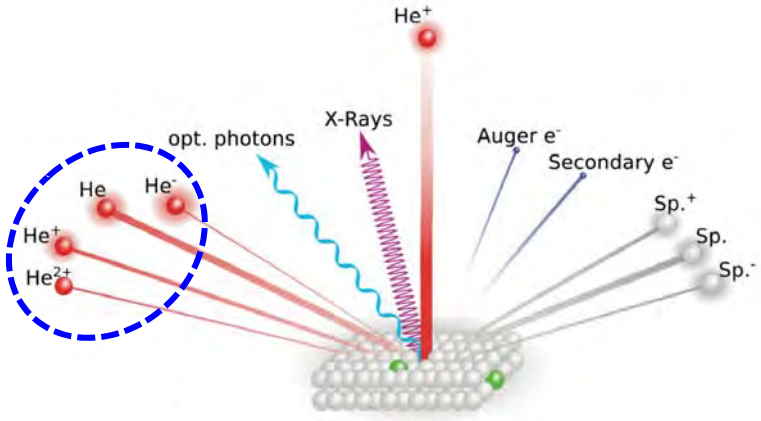


Motivation

Helium Ion Microscope

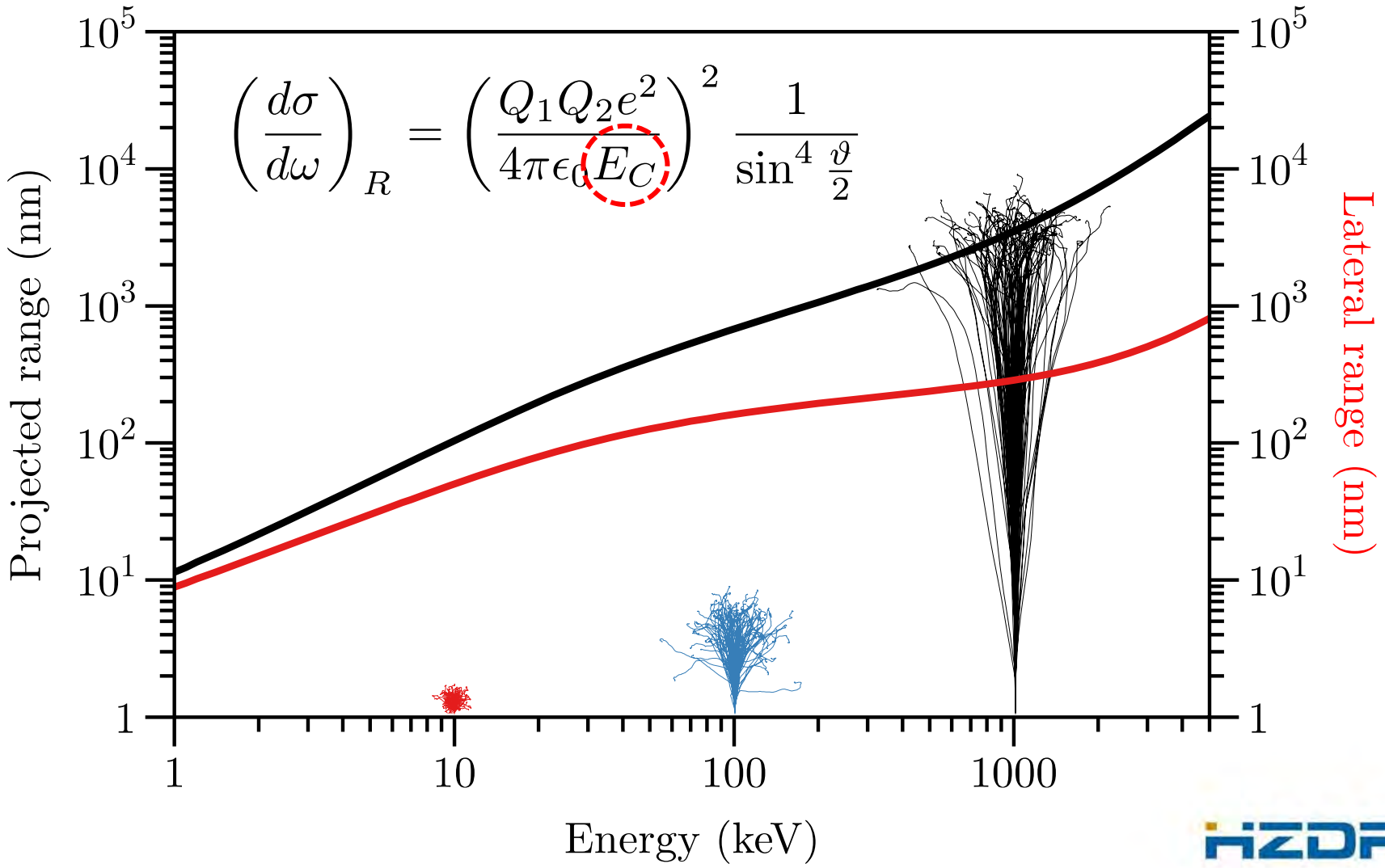
- 10 - 35keV He^+ beam
- Beam spot ~ 0,3nm
- 0.1–0.5pA beam current
- Contrast generation by number of secondary electrons

No chemical analysis available!? Why?



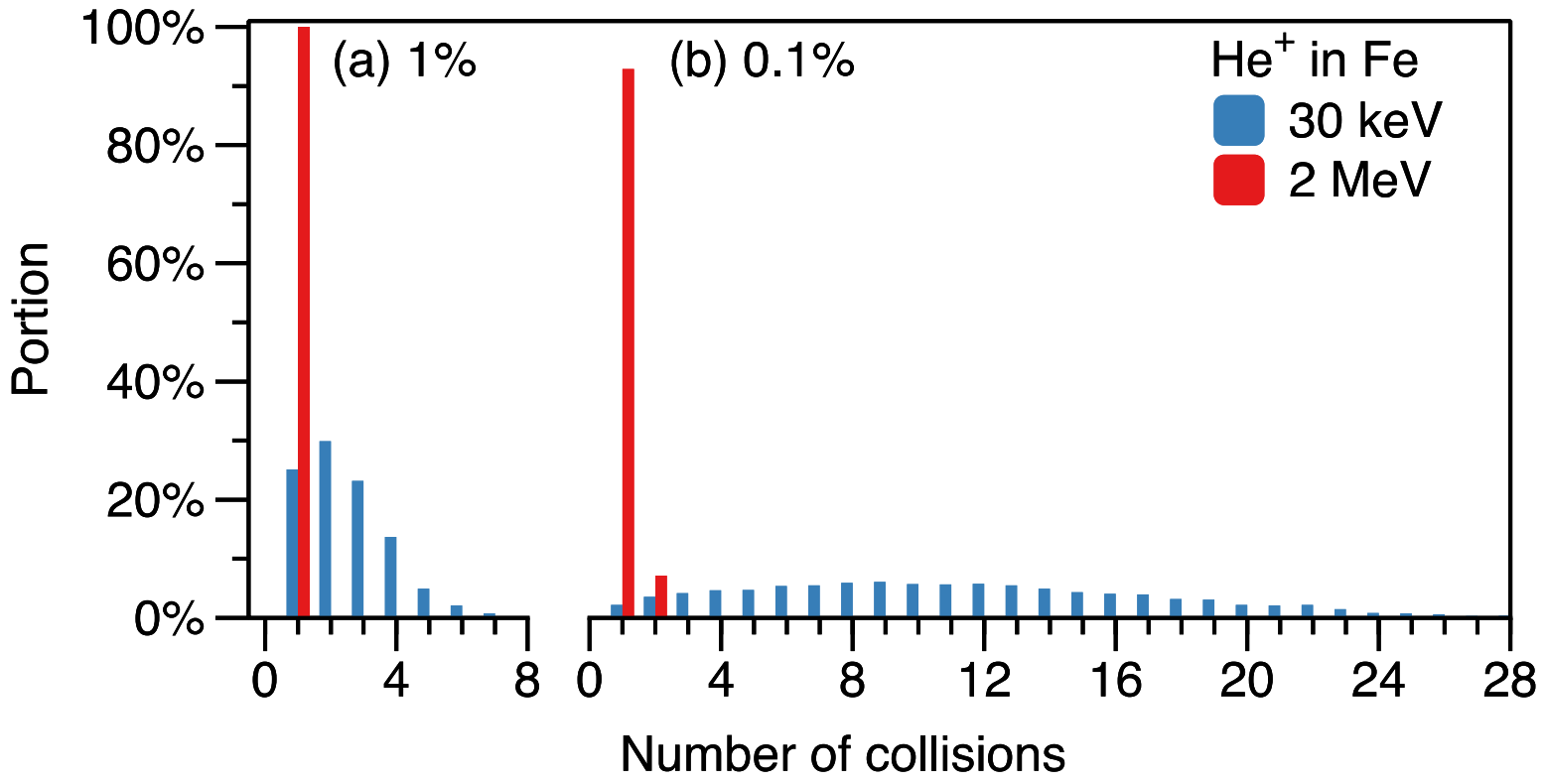
Motivation

Interaction volume & cross sections



Challenges and Limitations

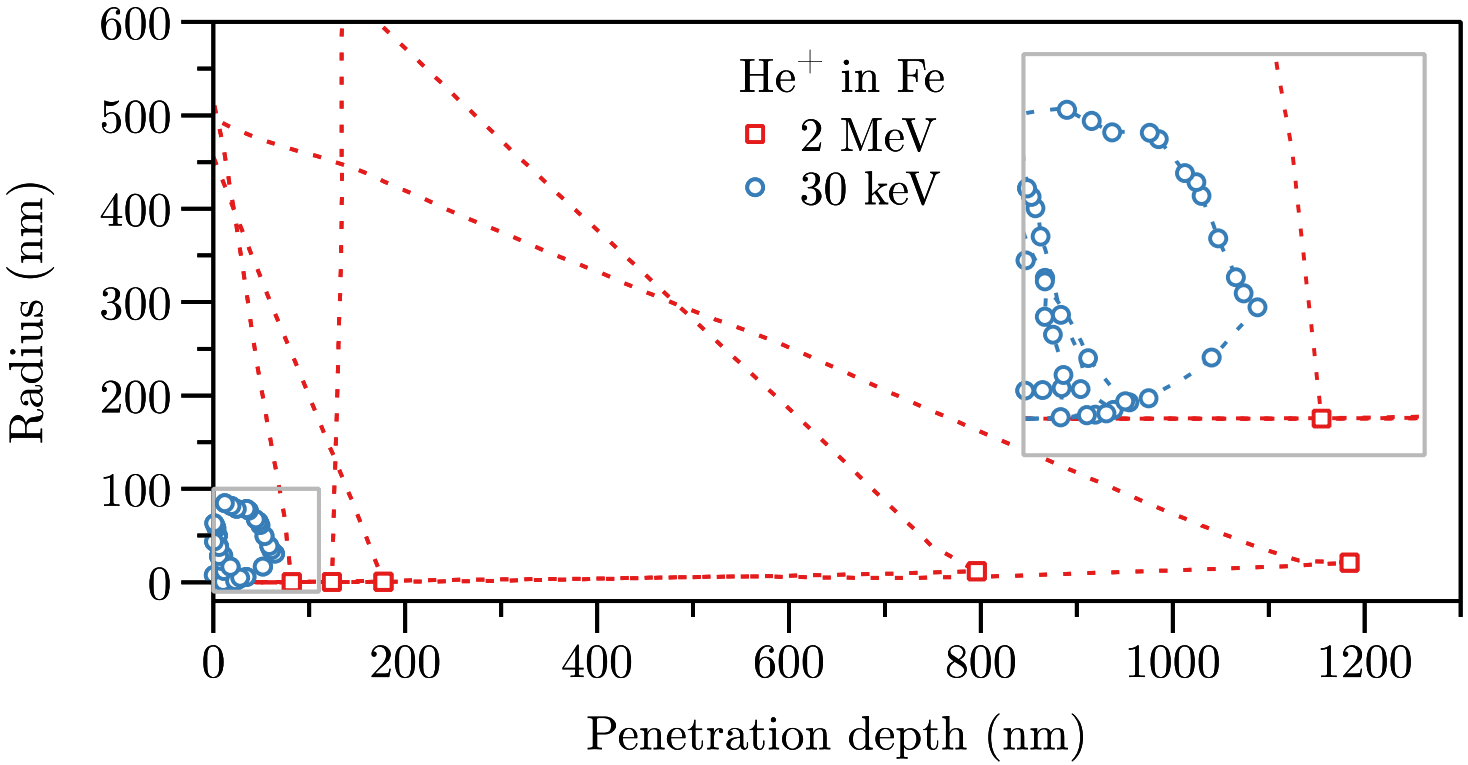
Multiple scattering



- Multiple scattering becomes highly dominant in the keV energy range
- Analytical simulations fail to reveal measured spectra
  → Binary Collision Monte Carlo simulations necessary

Challenges and Limitations

Multiple scattering



- Multiple scattering becomes highly dominant in the keV energy range
- Analytical simulations fail to reveal measured spectra
  → Binary Collision Monte Carlo simulations necessary

Challenges and Limitations

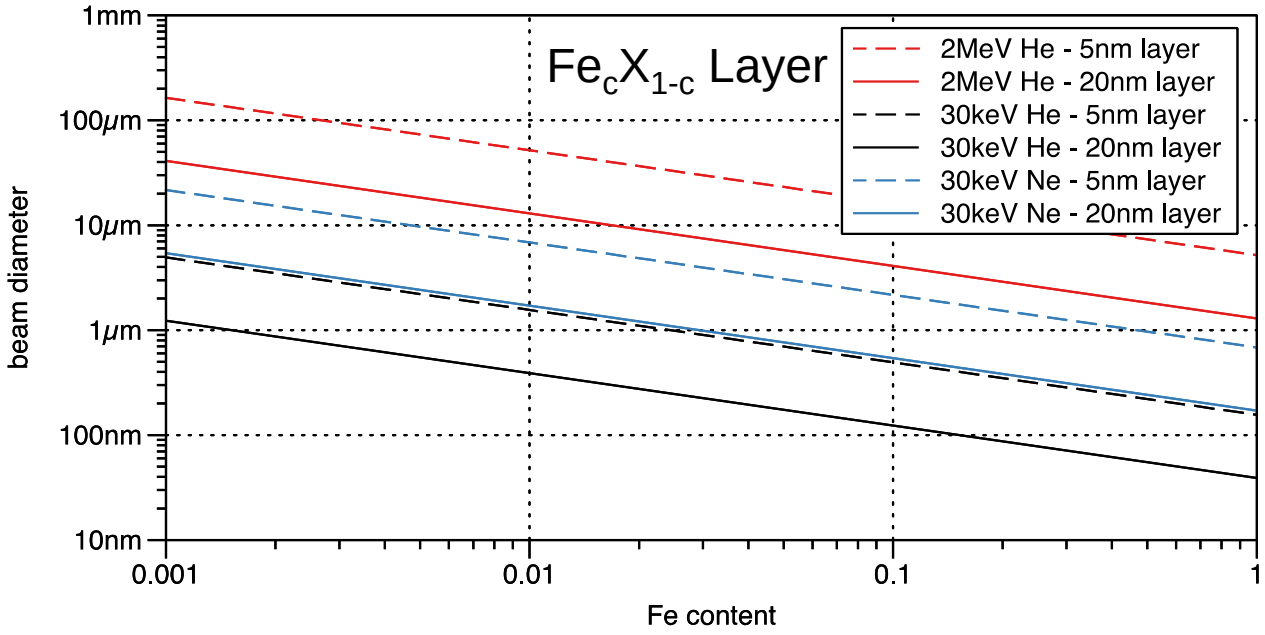
Sputtering and detection/resolution limits

- Smallest observable feature size strongly correlated to the detection limit and feature thickness → no general statement possible

$$N_{det} = \sigma_R \cdot \Omega \cdot Q \cdot A_D \cdot c$$

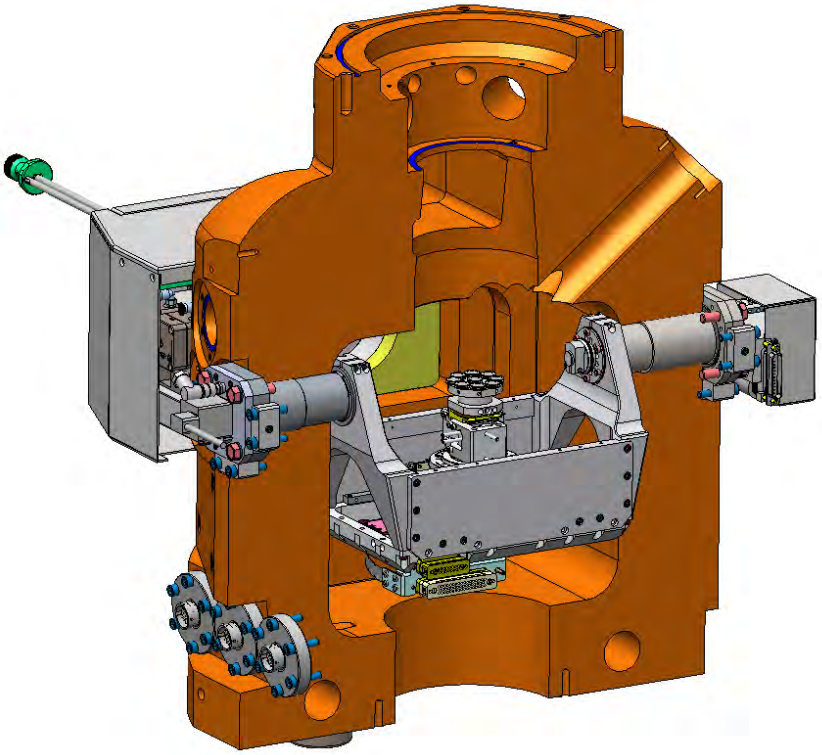
$$N_{sp} = Y \cdot \frac{Q}{F}$$

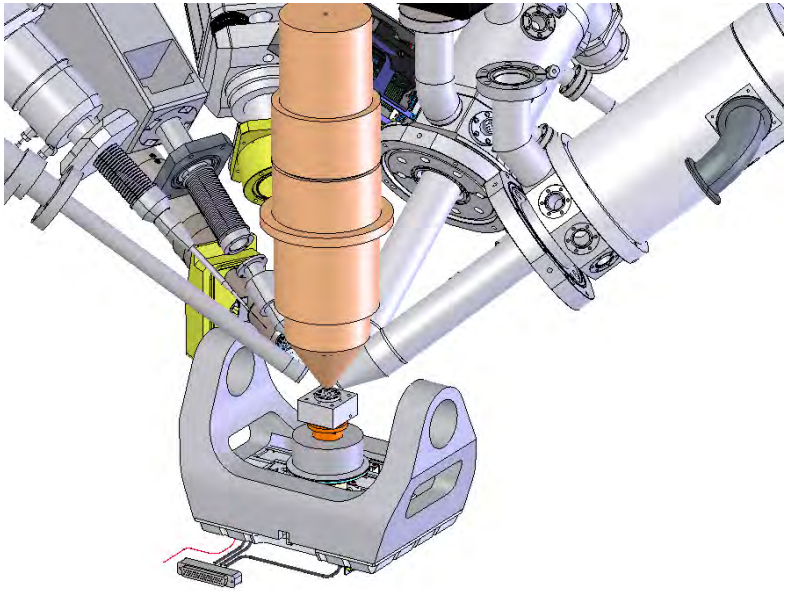
$$d > \sqrt{\frac{2 \cdot Y \cdot N_{det}}{\pi \cdot \sigma_R \cdot \Omega \cdot A_D^2 \cdot c}}$$



Challenges and Limitations

Geometrical constrains



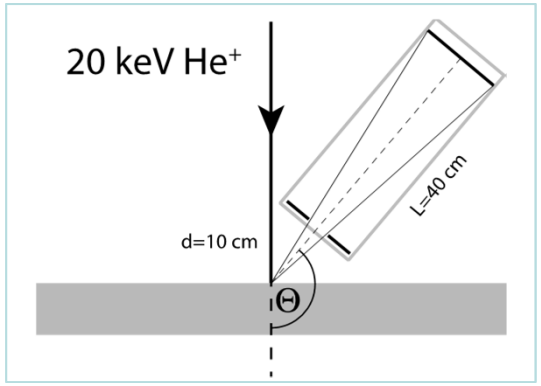


→ Limited space & sensitive ion optics

Possible Approaches

TOF

(Time of Flight)



Neutral & Ions

Resolution

ΔE/E = 2 Δt/t (≈600eV)

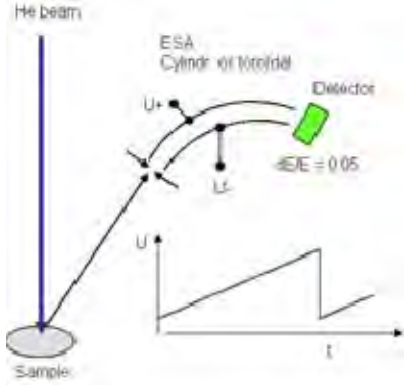
Rel. Intensity

1 … 0.1

(large solid angle)

ESA

(Electrostatic Analyzer)



Ions only

Resolution

ΔE/E < 10^{-3}

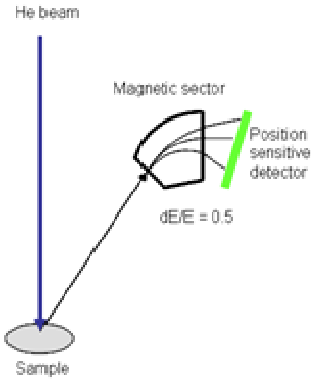
Rel. Intensity

<10^{-2}

(sequential)

MA

(Magnetic Analyzer)



Ions only

Resolution

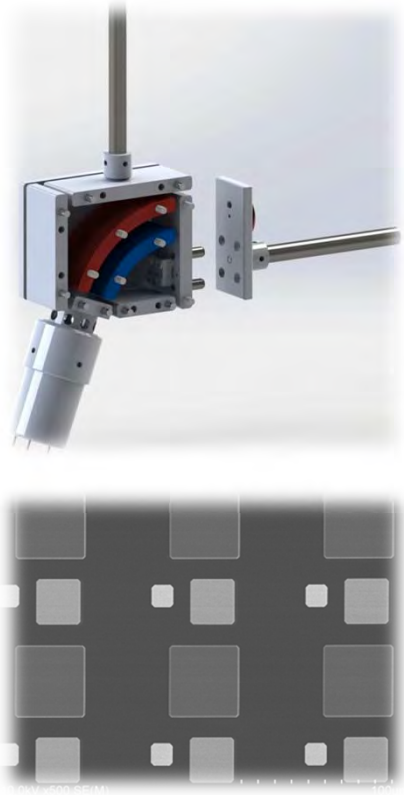
ΔE/E < 10^{-2}

Rel. Intensity

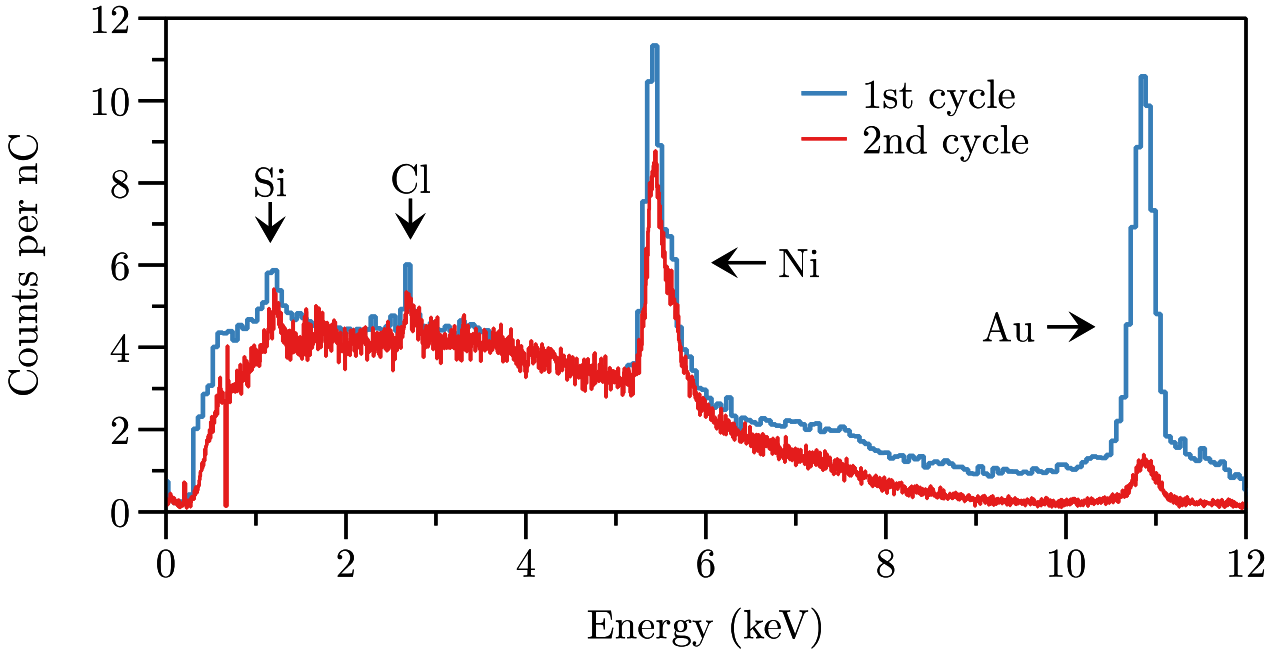
<10^{-2}

(sequential)

Electrostatic Analyser

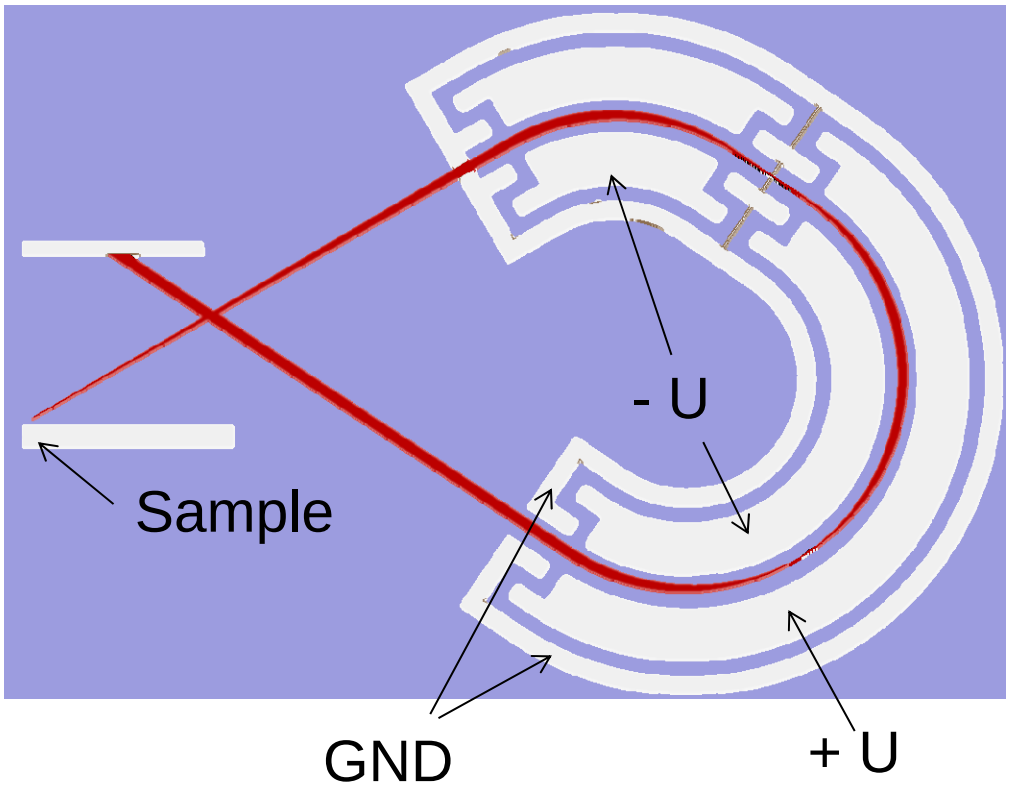


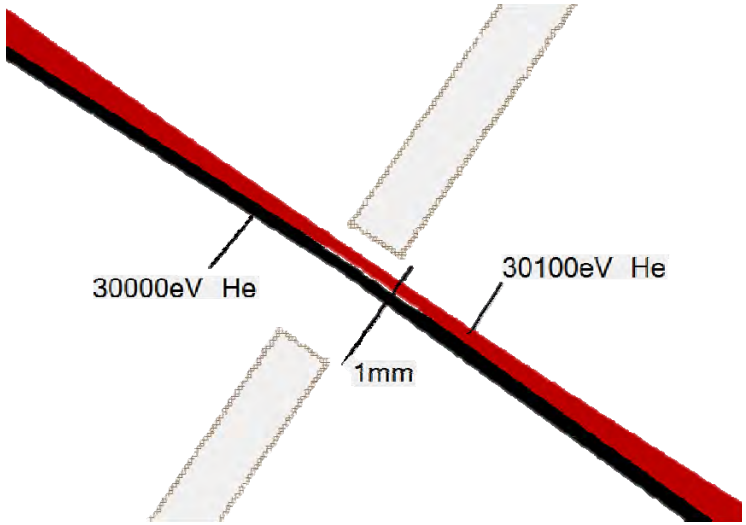
Au/Ni/Si/C test sample

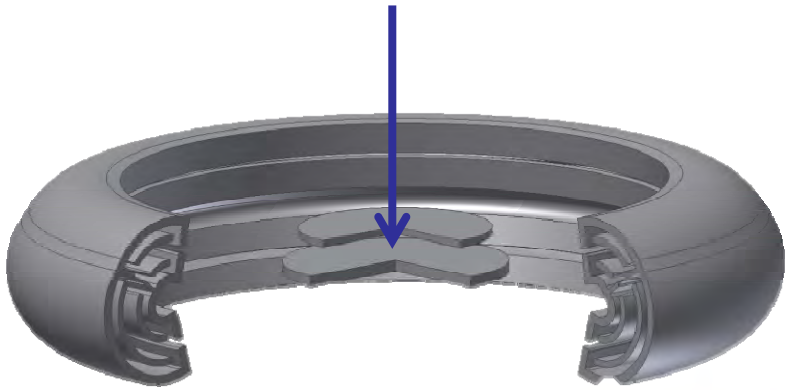


- **ΔE ≤ 1keV**
- **Small solid angle, charge fraction & sequential measurement lead to not-acceptable efficiency**

Toroidal Electrostatic Analyser



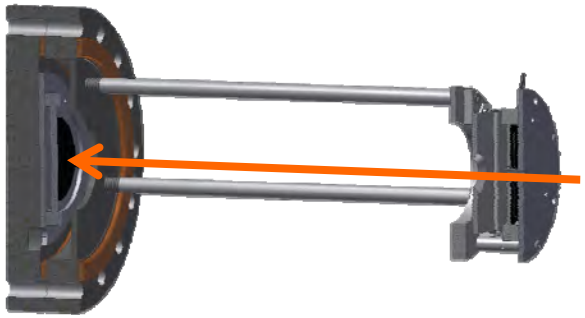


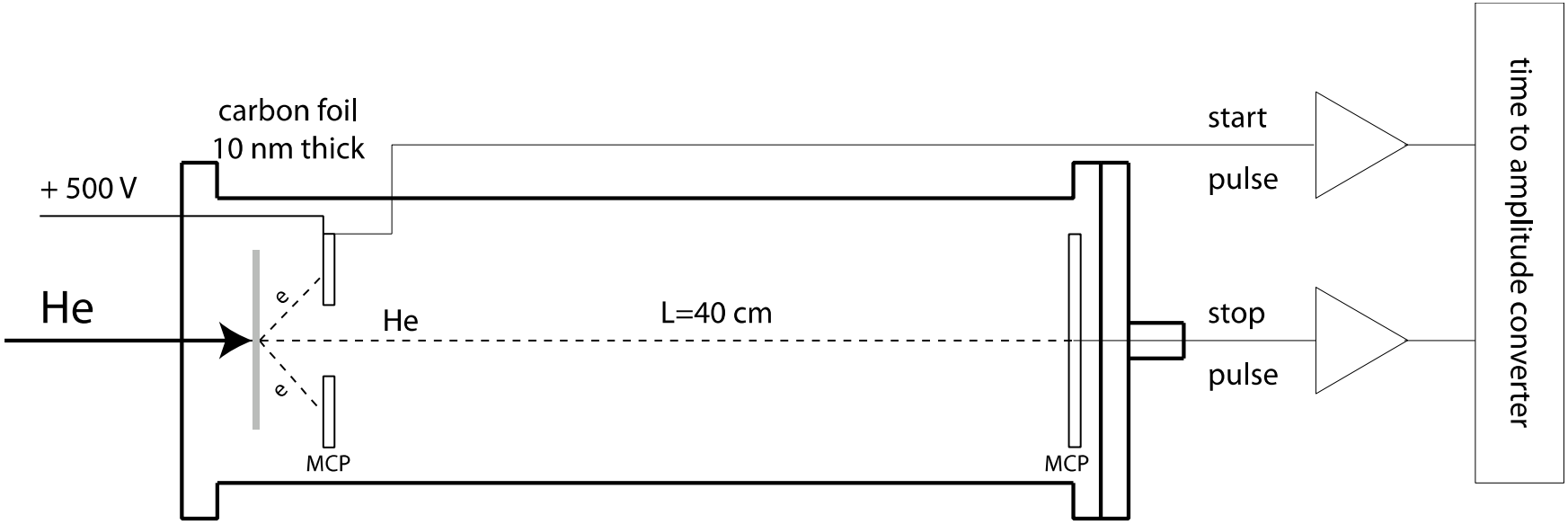


- **Huge solid angle**
- **Geometrical constraints**

Time of Flight RBS

- Get start signal from electrons emitted from He ions passing a thin Carbon foil
- Stop signal from He ions hitting on MCP

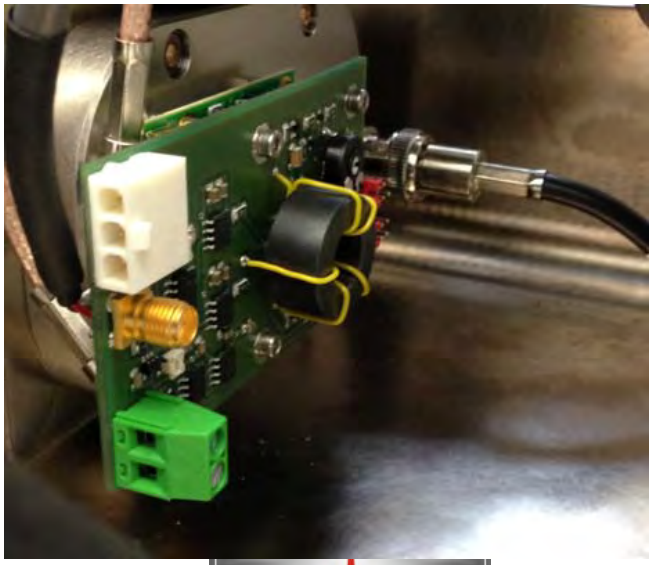


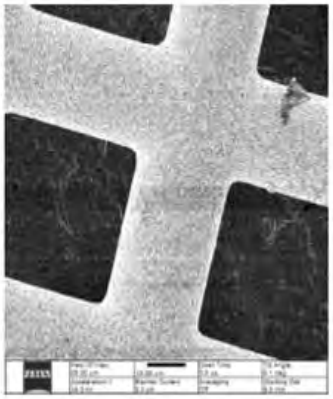


→ SE yield of <30keV He ions passing a <10nm Carbon foil by far to low to be used as a reliable start signal

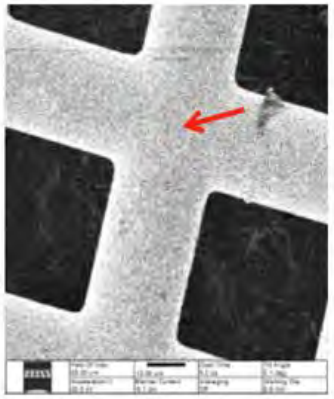
Time of Flight RBS

- Pulsing primary beam to generate start signal & detect BS particles with MCP detector (stop signal)
- Large solid angle
- Detect both: neutral & charged BS particles
- Minimum changes to the device
- Blanking has to be realized with care to not disturb imaging!



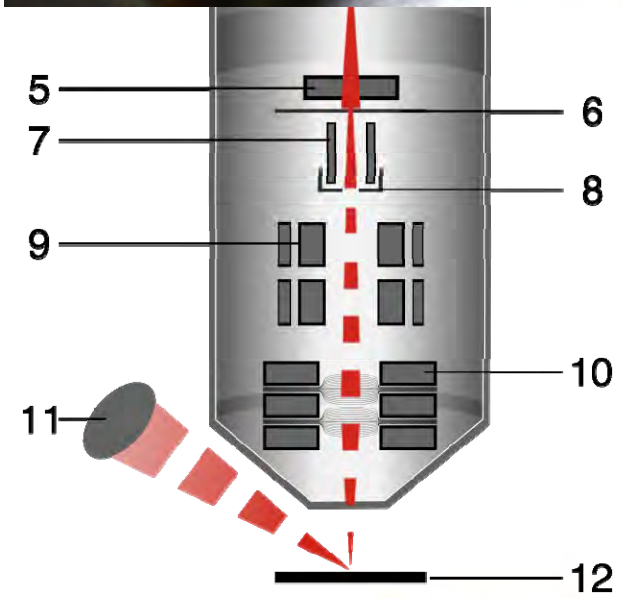


0 V (un-blanked)



5 V – 2µm shift

30 V – blanked

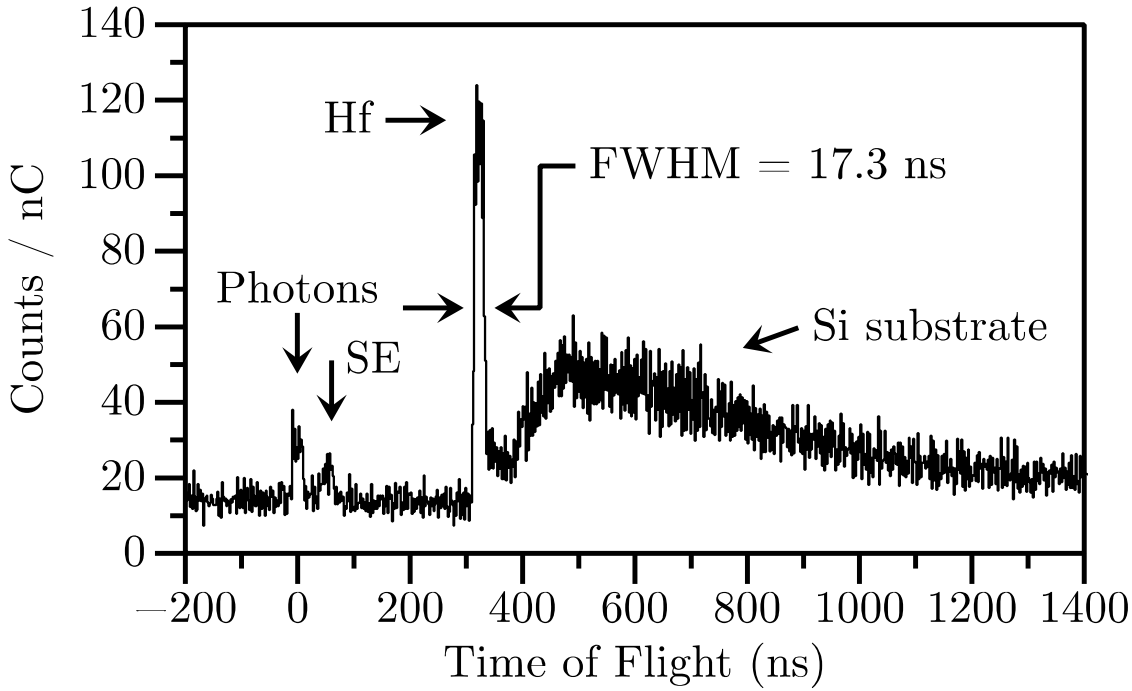


Time of Flight RBS

ToF-RBS spectrum of 2nm HfO on Si

- 30keV He
- Solid angle = 10.8msr
- Rep. rate 350kHz
- I_{ion} = 15pA (I_{eff}=42fA)
- t_{meas} = 120s

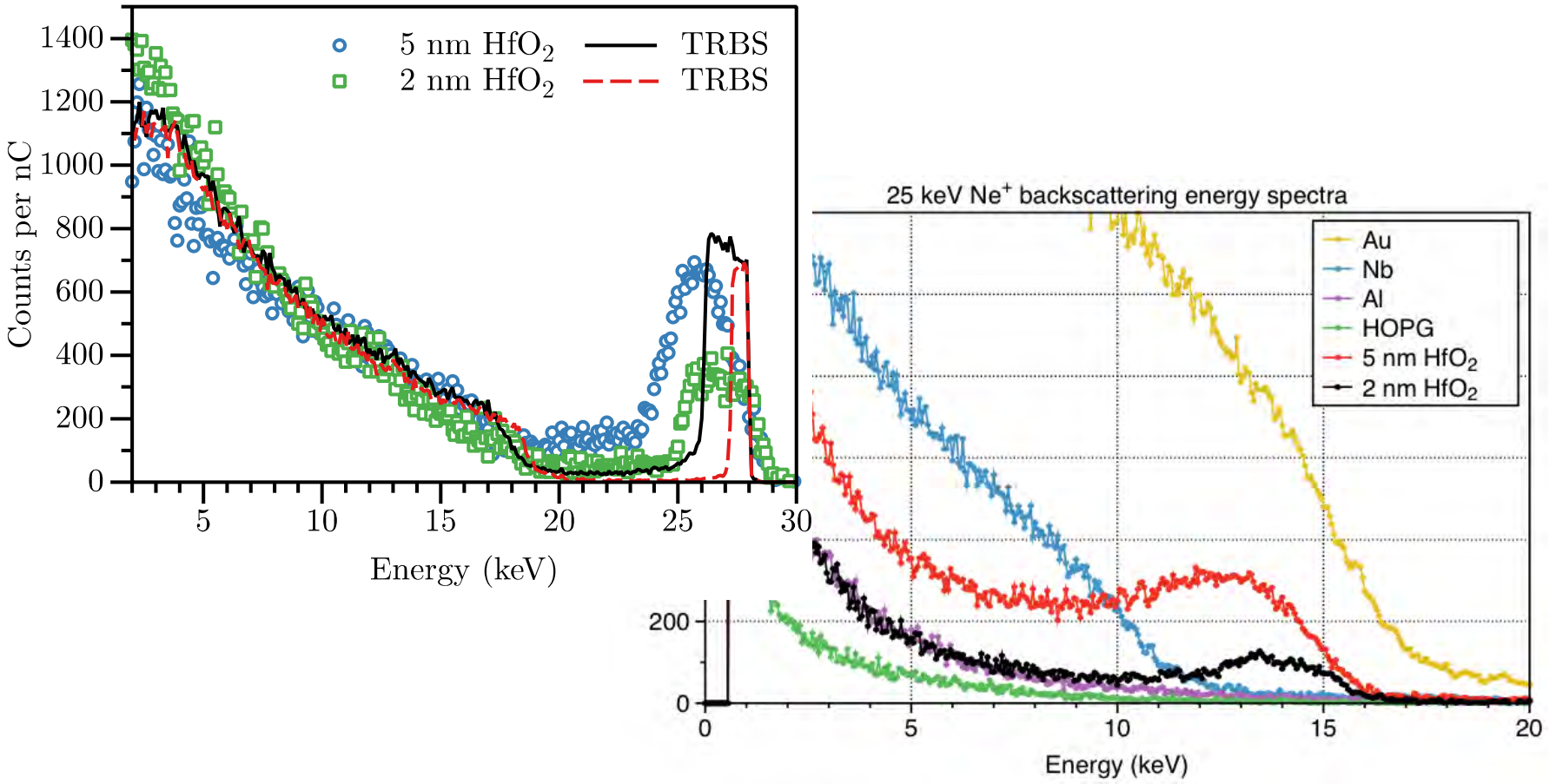
Q = 5pC



N. Klingner, R. Heller *et al*, Ultramicroscopy **162** (2016) 91

Time of Flight RBS

Performance: mass & depth resolution



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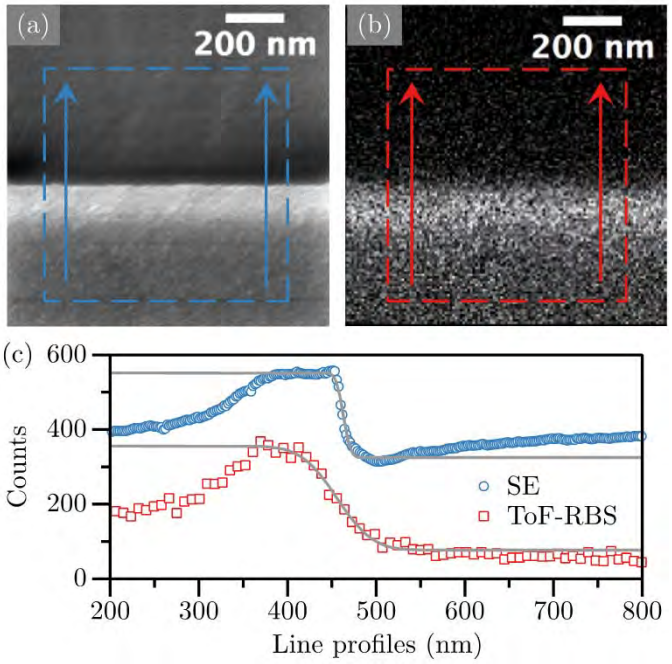
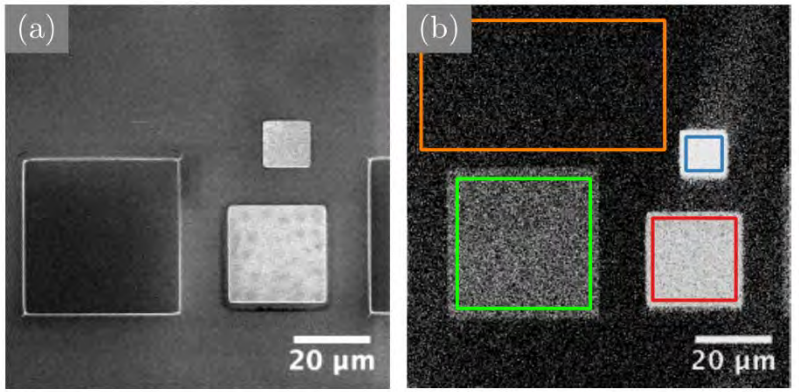
Time of Flight RBS

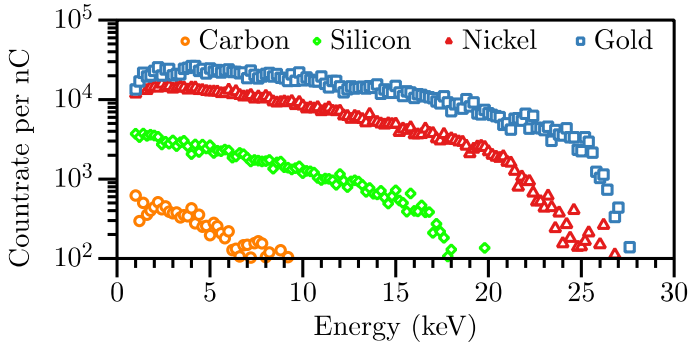
Performance: imaging

- **Lateral resolution < 55nm**

  Mainly limited by the ions transient time through the blanker unit & information volume





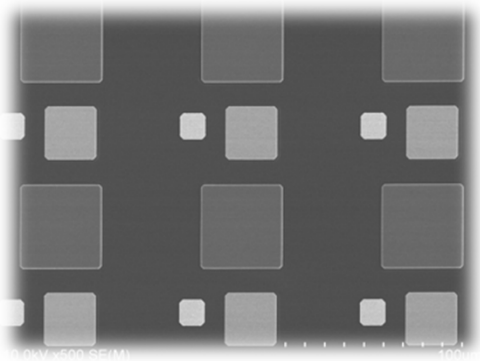


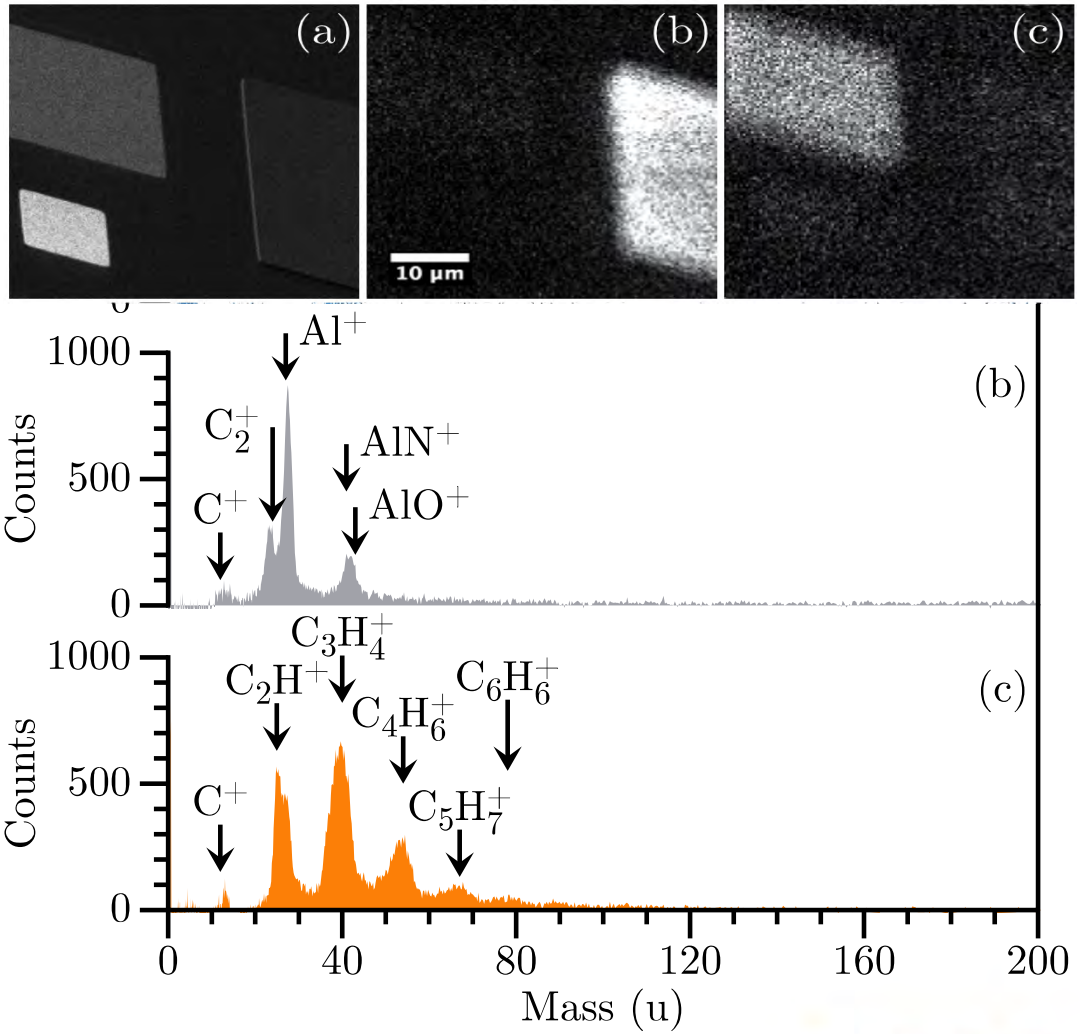
- **Post analysis in list mode**

  Each pixel contains a RBS spectrum
  → post selection of ROI allows elemental mapping

Time of Flight SIMS

Au/Ni/Si/C test sample





- Enabled by just biasing sample and increase measured flight time scale
- Lateral resolution down to <50 nm possible.

Conclusions

- Preforming RBS analysis within a Helium ion microscope could be demonstrated with lateral resolutions down to <55nm
- Time-of-Flight approach seems to be the best choice for particle detection and most gentle in terms of sample damage
- Still space for improvements by modification of blanking unit
- Minor adjustments of the setup enable ToF-SIMS on the nm scale
- The complete setup requires just a minimum amount of changes to the device

Thank your for your attention!