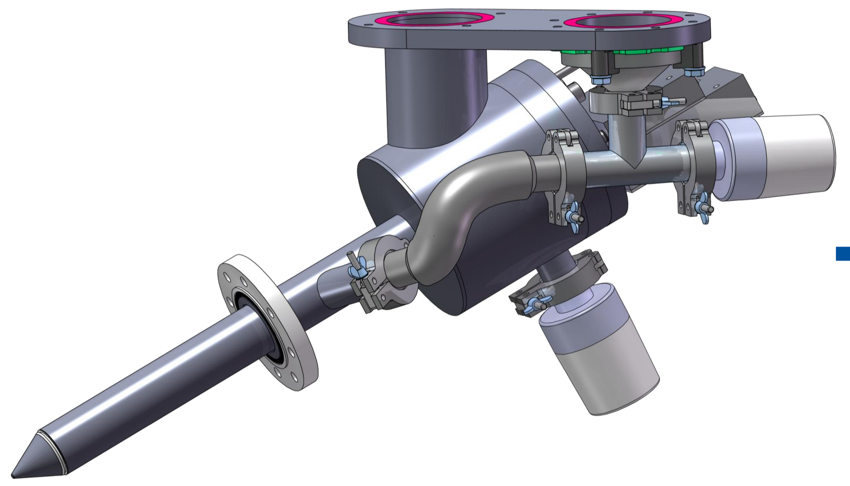

Highly efficient and compact Quadrupole Ion Transfer Guides in planar technology for space-limited applications

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Introduction

Overview:

In many applications the combination of high resolution optical and analytical imaging of the same target at the same time is desirable.

Modern electron microscopes are often equipped with a primary focused ion beam (FIB) for nano-scale surface manipulation. During surface-processing, a small amount of secondary ions are produced, which can be use for spatially resolved mass spectrometry.

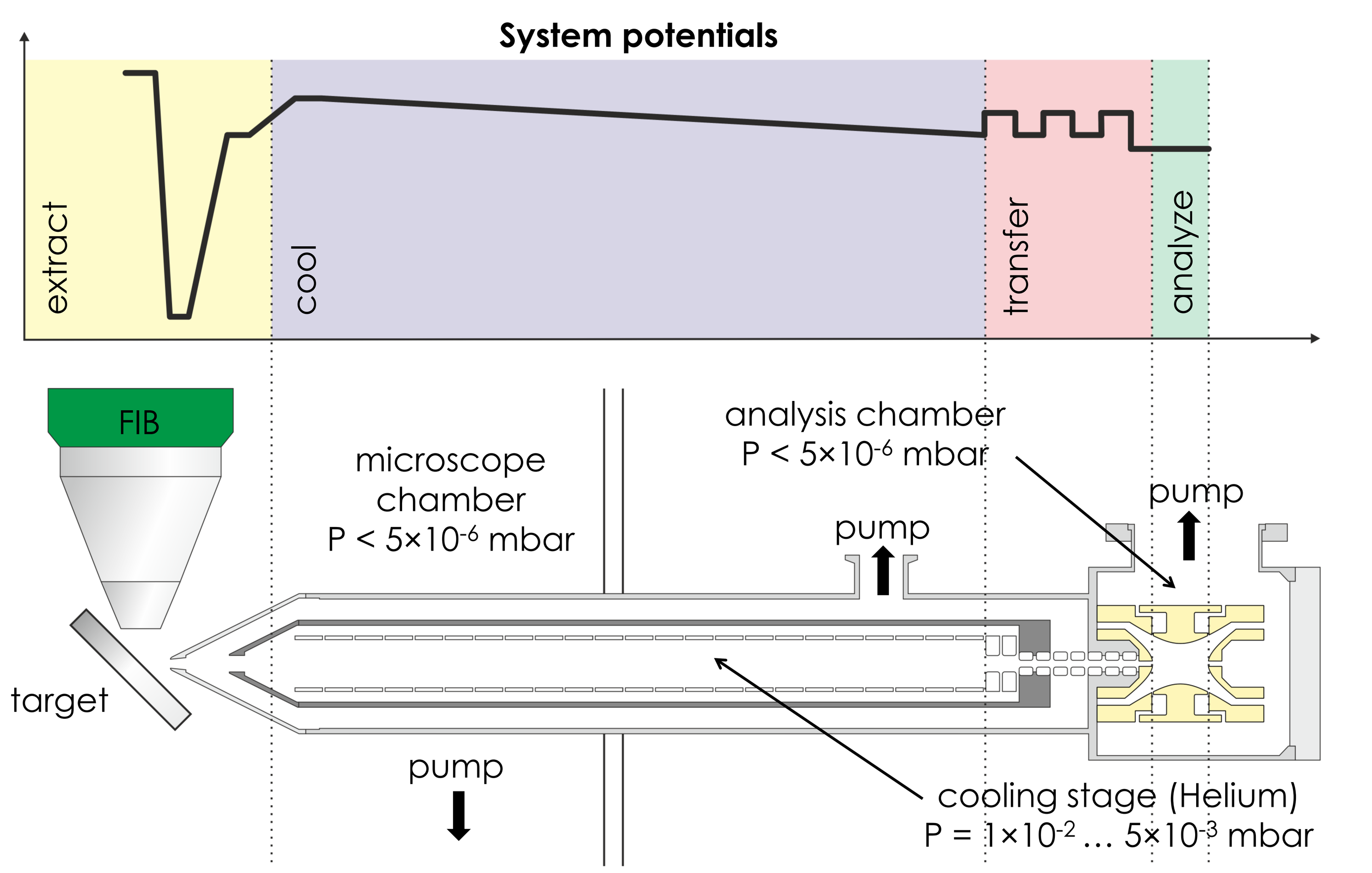
Due to small secondary ion beam currents, high energy distribution of the secondary ions, limited space and hard vacuum conditions new approaches for high efficient ion transfer optics are required.

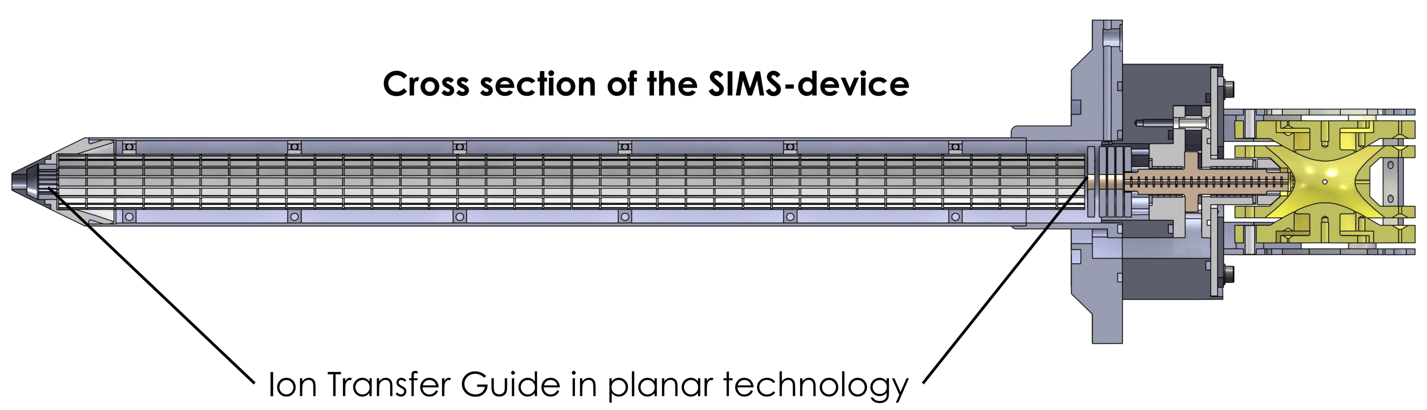
Challenges for Ion Transfer Optics:

- Limited space
- Low secondary ion beam currents (typical 1 … 5 pA)
- Broad kinetic energy distribution of the secondary ions (Thompson distribution)
- Difficult vacuum conditions

Principle of Operation (complete SIMS)

I. Secondary ions are continuously generated by the FIB
II. Secondary ions are accelerated into the SIMS orifice [1]
III. Ions are cooled and bunched in the Ion Transfer Guide
IV. Ions are accumulated and sequentially transferred/pulsed into the mass analyzer.
V. Ions are analyzed [3], [4]





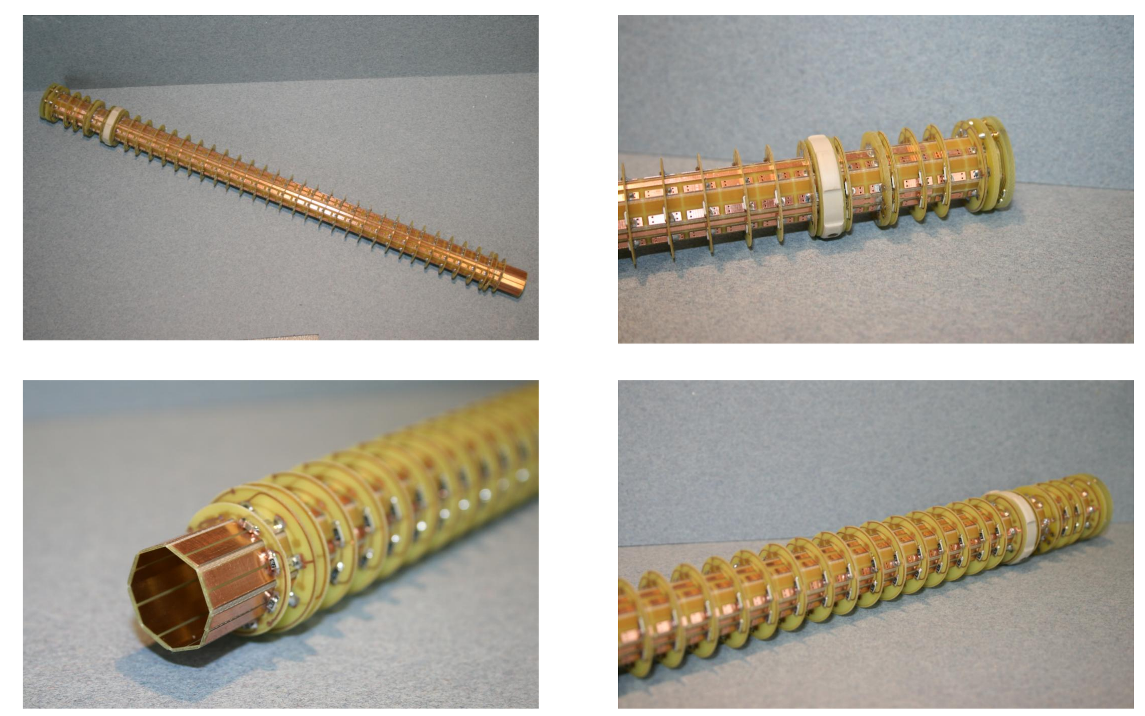
Ion Transfer Guide in planar technology

Requirements:

- High transfer efficiency
  - ⇨ Capable for low to medium mass range (10 – 200 amu)
- Largest possible cross section for ion trapping relative to given SIMS flange diameter
- Ion cooling to reduce energy distribution of the secondary ions
  - ⇨ Collisions induced cooling by helium buffer gas
  - ⇨ DC gradient along ion transfer axis for a forced ion transfer (avoiding ion plugging)
  - ⇨ Quadrupole storage field for efficient ion bunching and storing
- Cost efficiency

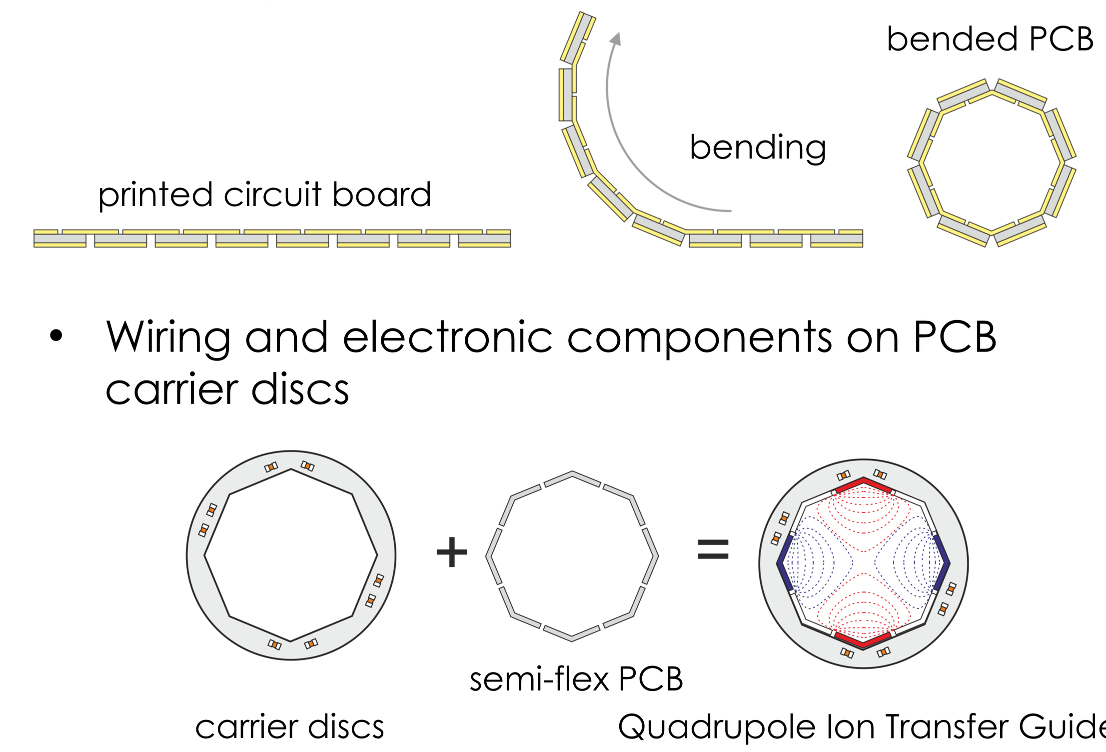
Complete setup:

- Full assembled Ion Transfer Guide with 36 axial segments and an overall length of 342 mm, core diameter 16 mm



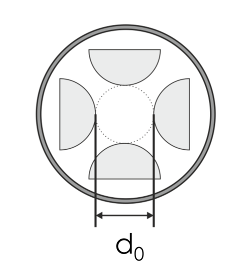
Planar technology (PCB):

- Semi-flex printed circuit board with grooves for bending
- Wiring and electronic components on PCB carrier discs

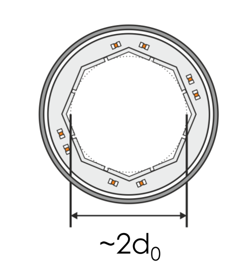


Advantages :

- Large ion trapping cross section



With half rods 1/3 of tube diameter can be used for ion trapping.



With planar solution at least 2/3 of tube diameter can be used.

- Easy and fast manufacturing and assembling
- High precision combined with low manufacturing costs due to standard high reliability PCB technology

Conclusions

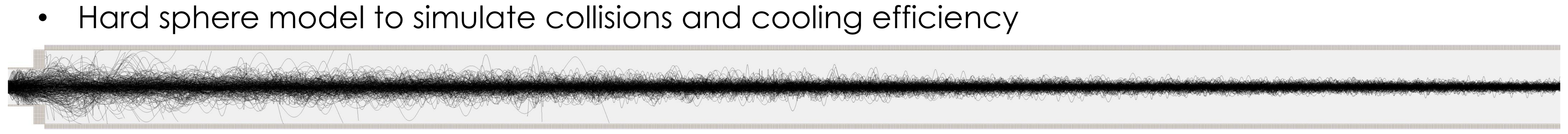
- A full functional Ion Transfer Guide in planar technology has been built and evaluated
- The Ion Transfer Guide enables to transfer, cool and bunch ions in an efficient manner
- The kinetic energy distribution of sputtered secondary ions can be minimized using helium damping gas
- The kinetic energy equilibrium depends on the dc gradient of the Ion Transfer Guide
- High transfer efficiency was demonstrated
- Planar technology enables to manufacture high efficient, inexpensive Ion Transfer Guides
- Ion Transfer Guides in planar technology maximize ion trapping cross section in space limited applications

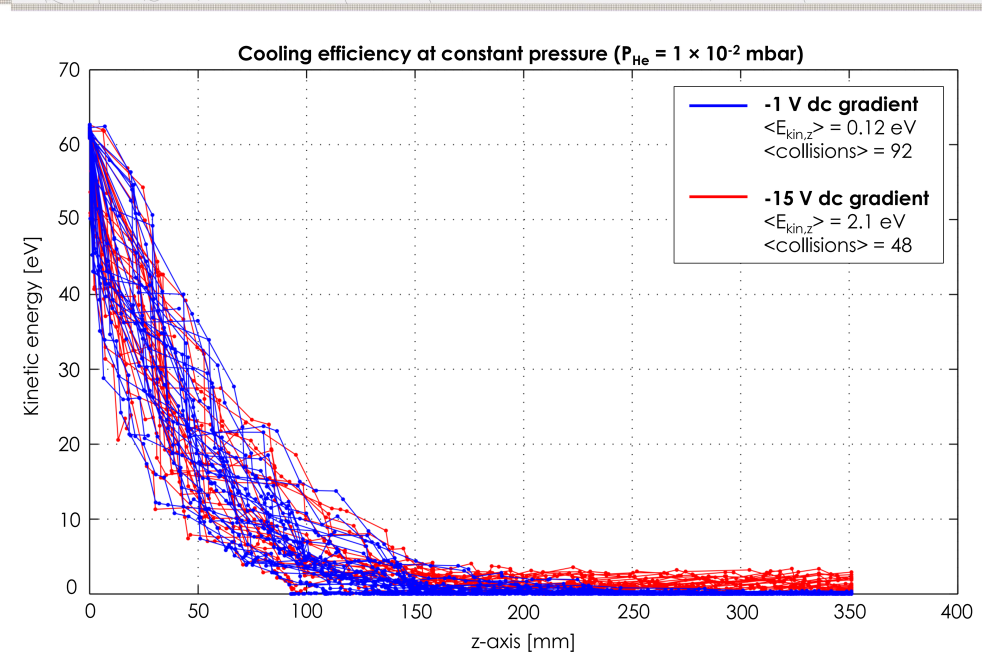
Future work:

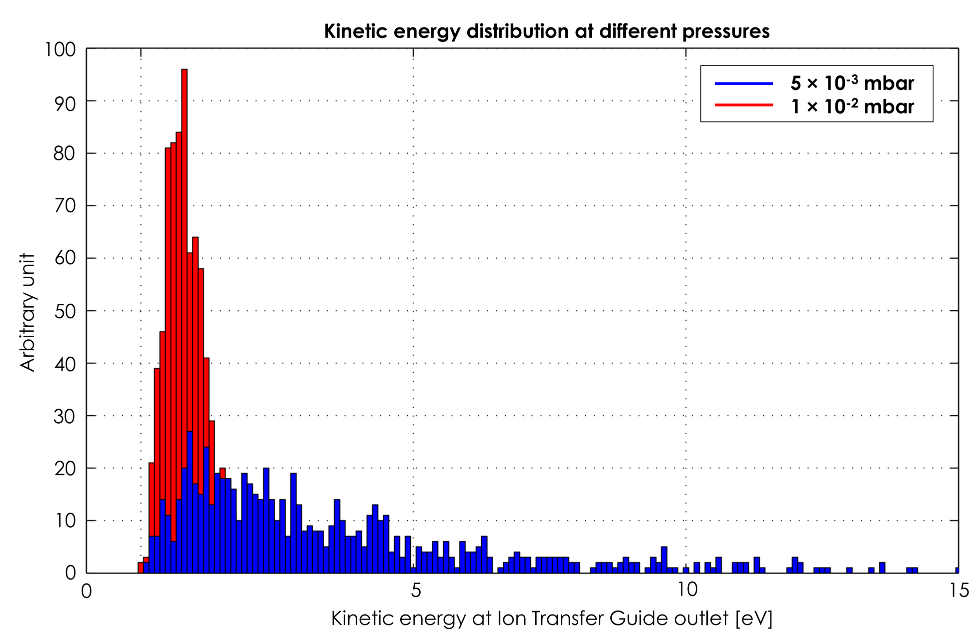
- Improved and extended low mass range
- Evaluation of different segment length for improved dc gradient characteristic

Simulation

- System design of the complete transfer chain using SimIon
- Hard sphere model to simulate collisions and cooling efficiency





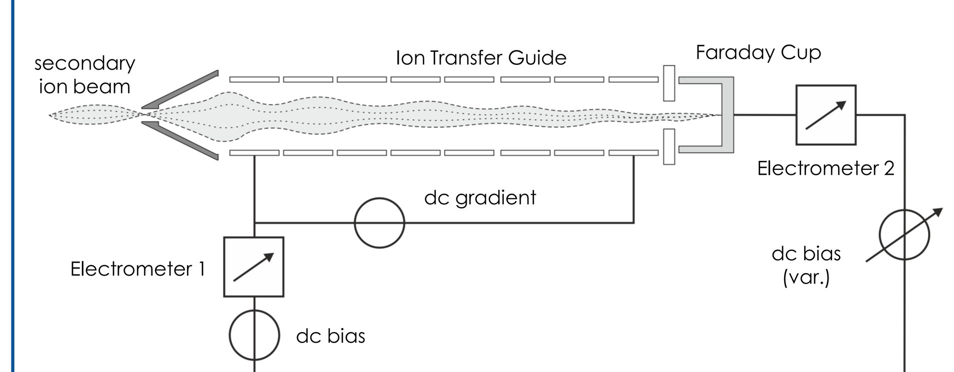


Measurement

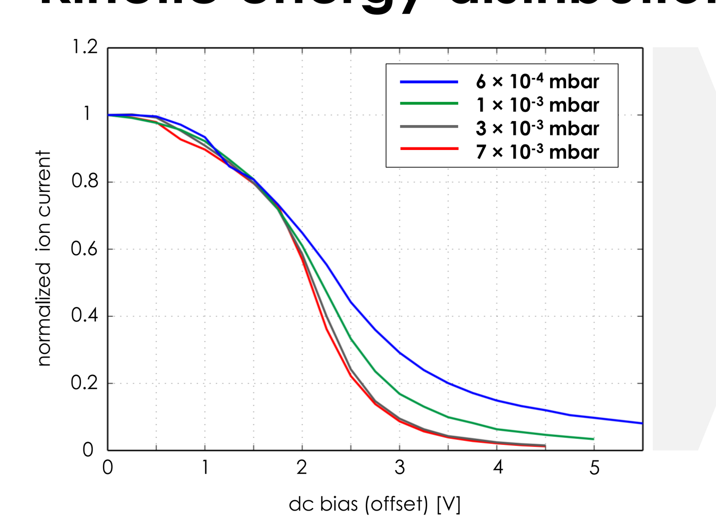
Measurement setup:

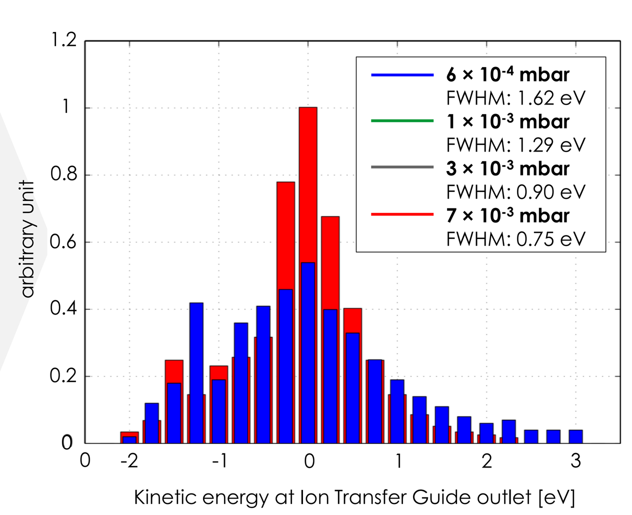
All measurements were carried out with the following parameters:

rf-voltage:	420 Vpp
rf-frequency:	1 MHz
dc gradient:	-7.5V
$E_{Kin,Start,Ion}$:	0 … 60 eV



Kinetic energy distribution:





Transfer efficiency:

Ion beam current at Ion Transfer Guide entrance compared to ion beam current at Faraday Cup:

40 amu: 48 %
86 amu: 29 % (increases with larger rf-voltage)

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[2] Glasmachers, A.; Laue, A.; Brockhaus, A.; Puwey, A.; Aliman, M. *Planar technologies for optimized realizations of quadrupole ion guides and quadrupole ion wave guides*, **58th ASMS Conference**, 2010

[3] Laue, A.; Glasmachers, A. *New Design of a Compact Fourier-Transform Quadrupole Ion Trap for High Sensitivity Applications*, **57th ASMS Conference**, 2009

[4] Laue, A.; Glasmachers, A. *Metrological Characterization of a Sensitive Secondary Ion Mass Spectrometer for Electron Microscopes to Combine Optical/Structural and Analytical Imaging*, **59th ASMS Conference**, 2011

[5] **Patent application EP11152379.1 – 1232:** *Apparatus for focusing and for storage of ions and for separation of pressure areas*, 2011

[6] **Patent application EP11152420.3 – 2208:** *Apparatus for transmission of energy and/or for transportation of an ion as well as particle beam device having an apparatus such as this*, 2011