Developments towards a transversal electron target for CRYRING

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for the SPARC working group “Electron Targets“,
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und Forschung

Justus-Liebig-University Giessen/GSI Darmstadt

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Outline

- Concept and Physics Case
- Tests with a Multi-Electrode Target Optimized for the Giessen Low-Energy Single-Pass Setup
- Status and Outlook

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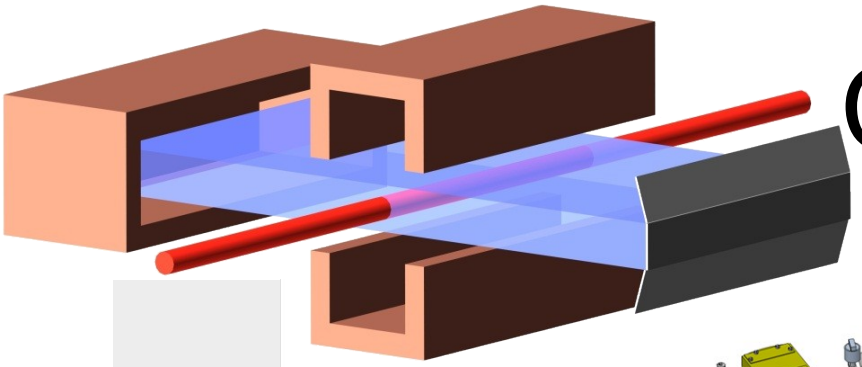
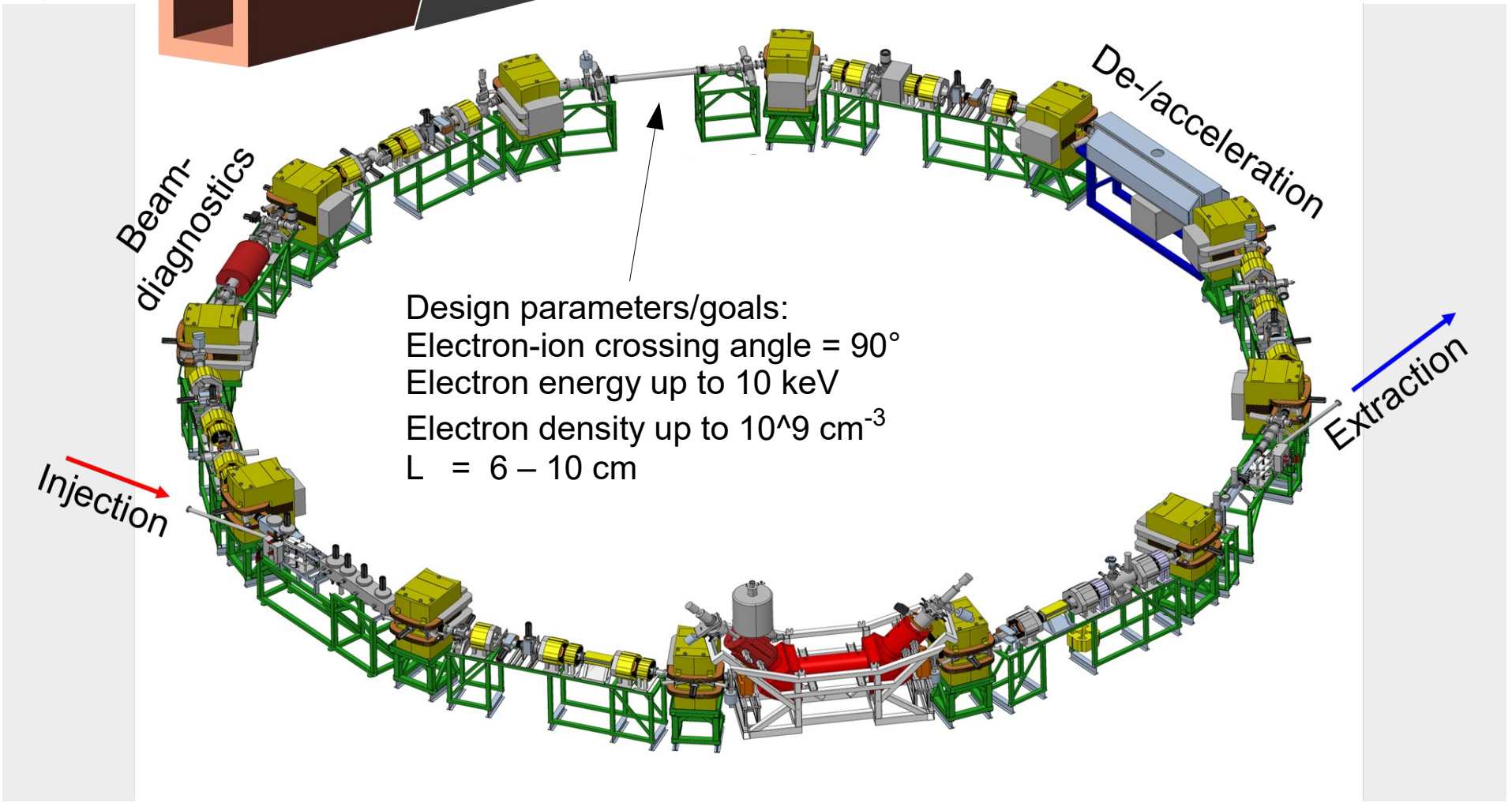


Concept

Transversal target with electron beam formed like a **sheet/ribbon**



Design parameters/goals:
Electron-ion crossing angle = 90°
Electron energy up to 10 keV
Electron density up to 10^9 cm^{-3}
L = 6 – 10 cm

Physics Case

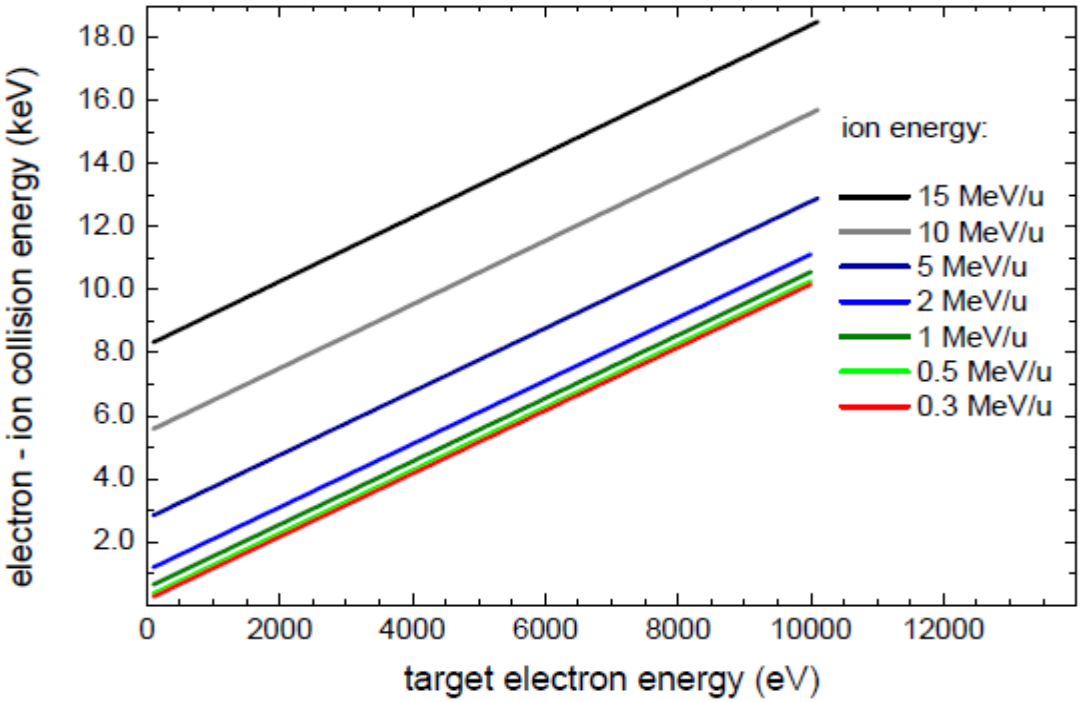
- Main advantages:
  - Free electrons (no target nucleus)

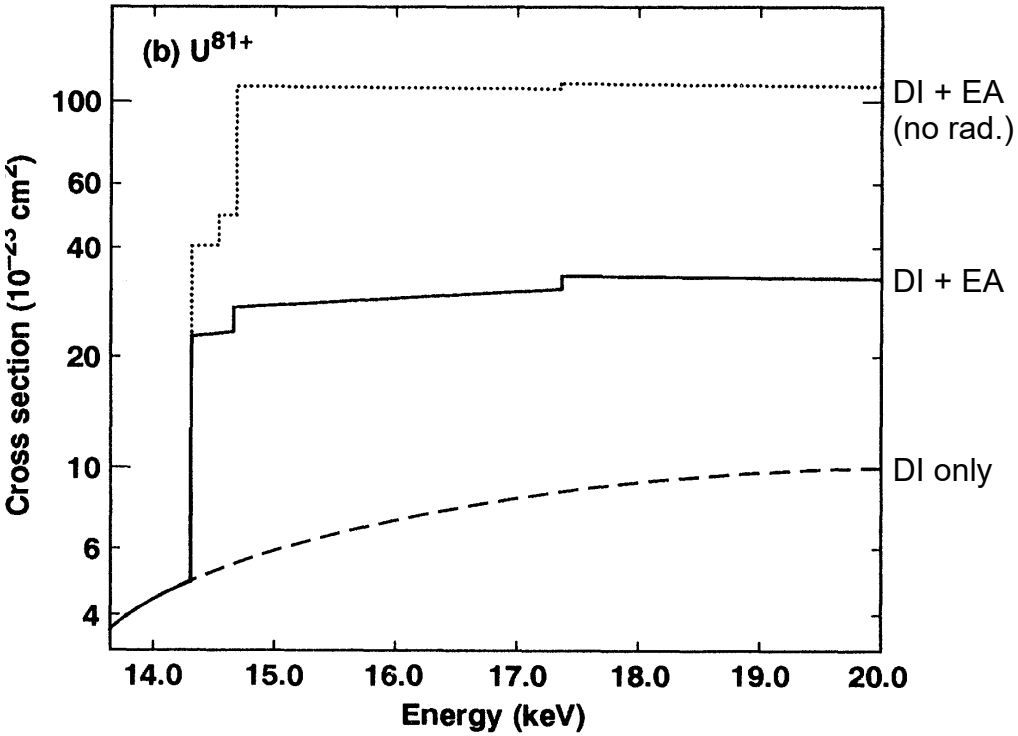
    → High energy resolution, no NRC, no excitations due to the nucleus
  - Well localized interaction region

    → Spectroscopy with large solid angles
  - Easy and precise tunable collision energy
- Possible experiments:
  - Photon spectroscopy (REC) at low ion energies
  - Electron-impact excitation (EIE) and ionization (EII)

    → Indirect and/or resonant contributions
  - 2^{nd} generation: Nuclear excitation by electron capture (NEEC) and resonant electron scattering (RES)

Physics Case Example: EII of HCI

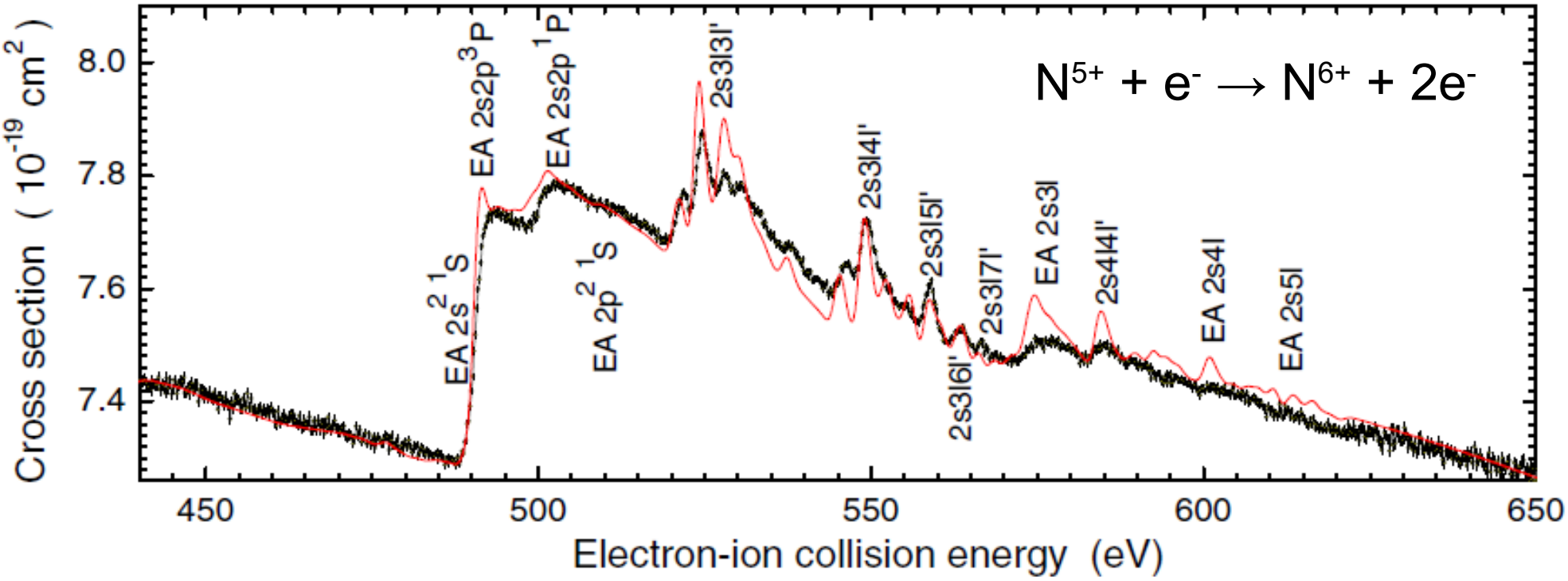




Distorted-wave calculations from
Reed, Chen and Moores, Phys. Rev. A
44, 4336 (1991)

- Investigation of heavy and highly charged ions, e.g. U^{81+}
- Will importance of indirect processes (such as EA, log-scale for U^{81+}) increase further?

Example From the Giessen Single-Pass Setup: EII of N^{5+}



A. Müller et al., PRA **90** (2014) 010701(R).

- High-resolution cross section measurements with fine-step energy-scan method
- Measurement of accurate absolute cross sections (Giessen: ~ 6 %)

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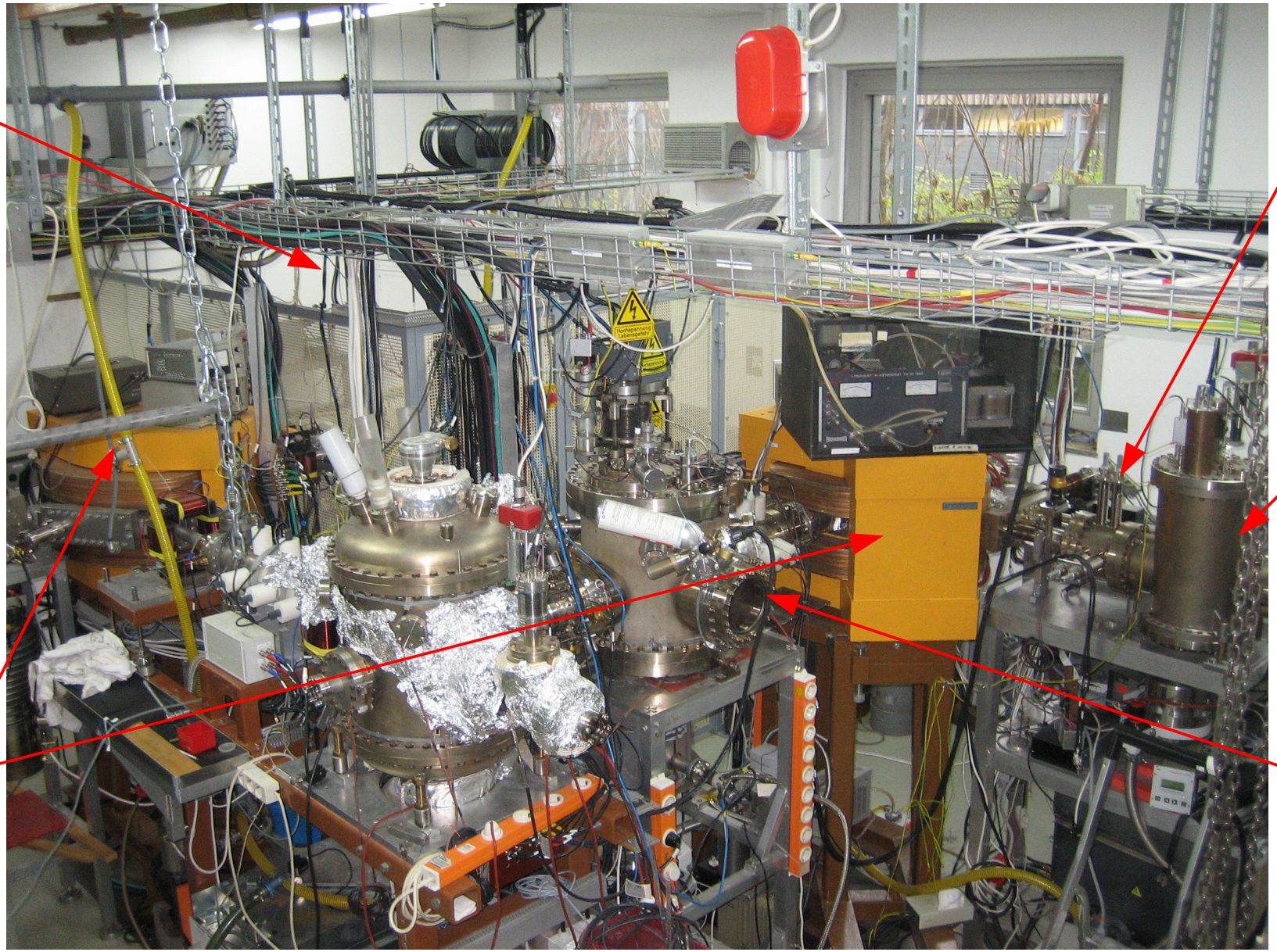
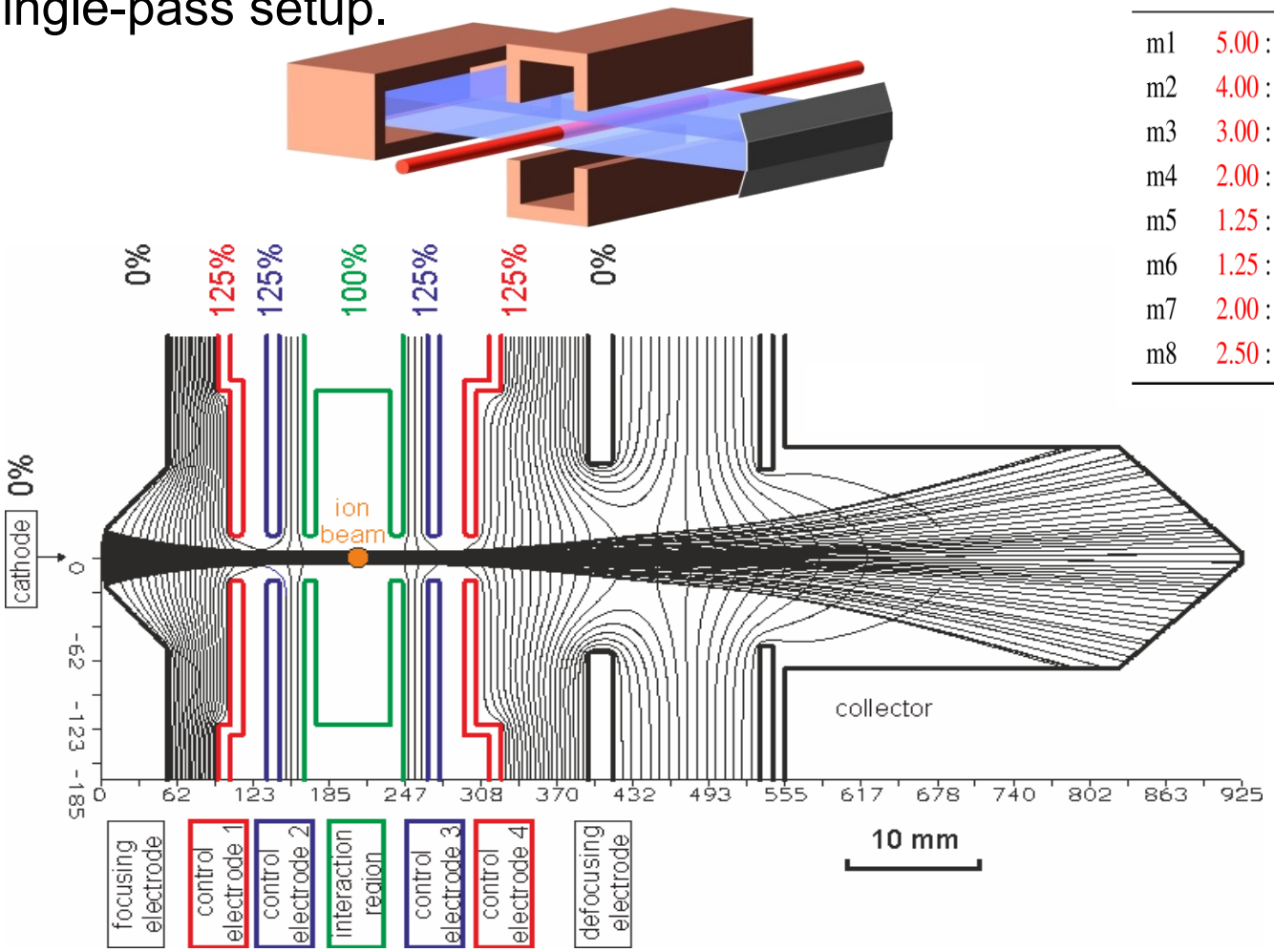
Giessen Low-Energy Single-Pass Setup



Electron Target at Giessen

Note: The numbers are optimized for the Giessen single-pass setup.

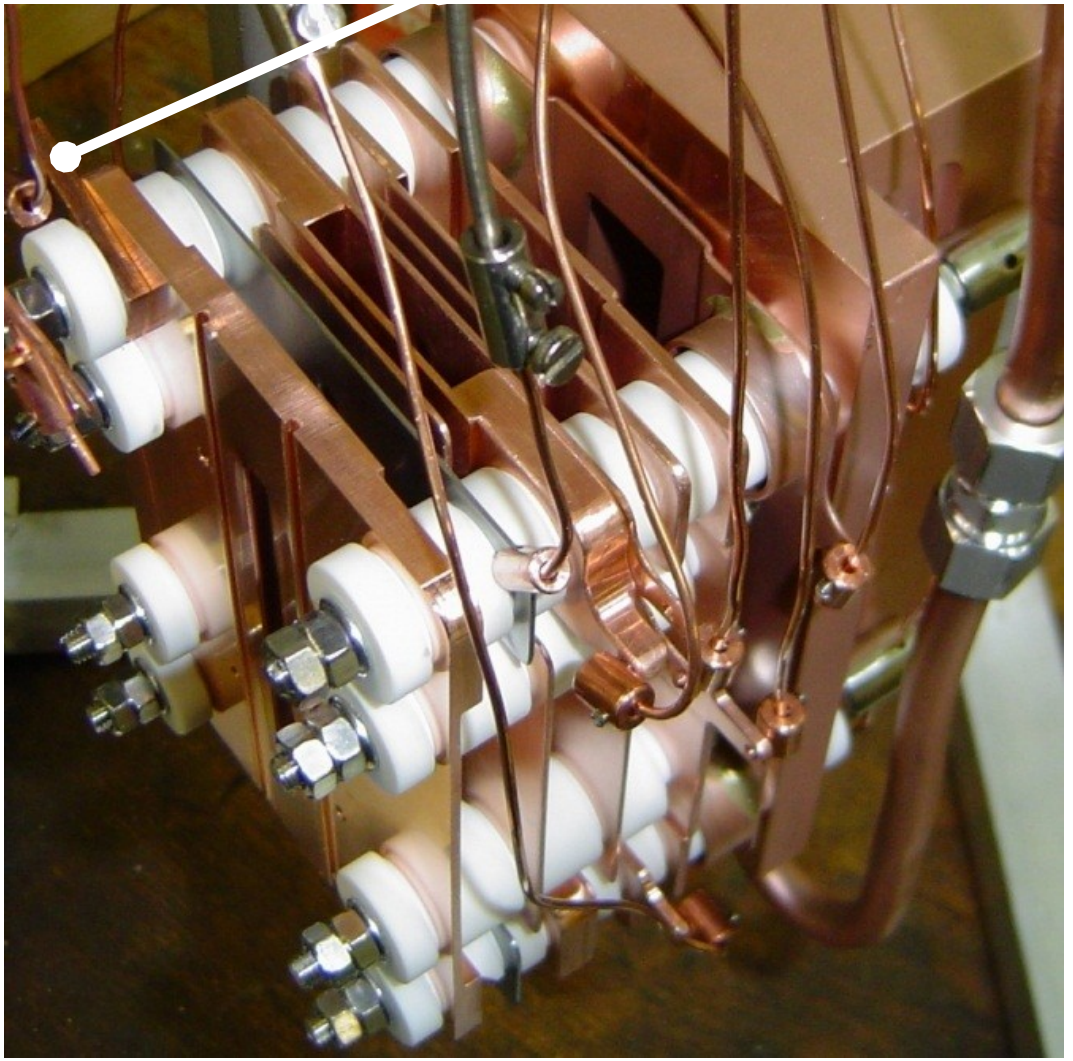
Mode	Electrode voltage ratio	Lower limit	Effect. perveance $10^{-6}AV^{-3/2}$	Trap
m1	5.00 : 1.25 : 1 : 1.25 : 5.00	$\gtrsim$ 10 eV	31.1	Yes
m2	4.00 : 1.25 : 1 : 1.25 : 4.00	$\gtrsim$ 30 eV	22.3	Yes
m3	3.00 : 1.25 : 1 : 1.25 : 3.00	$\gtrsim$ 50 eV	14.5	Yes
m4	2.00 : 1.25 : 1 : 1.25 : 2.00	$\gtrsim$ 70 eV	7.9	Yes
m5	1.25 : 1.25 : 1 : 1.25 : 1.25	$\gtrsim$ 100 eV	3.9	Yes
m6	1.25 : 0.85 : 1 : 0.85 : 1.25	$\gtrsim$ 100 eV	3.9	No
m7	2.00 : 0.65 : 1 : 0.65 : 2.00	$\gtrsim$ 100 eV	7.9	No
m8	2.50 : 0.45 : 1 : 0.45 : 2.50	$\gtrsim$ 50 eV	11.0	No



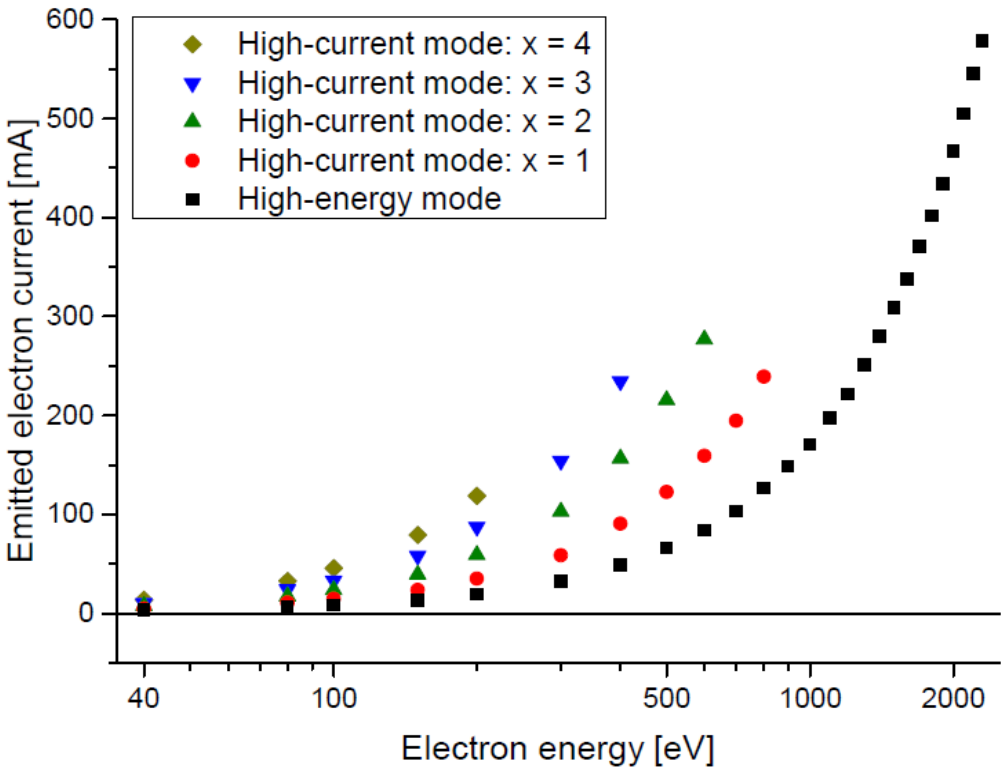
- Several modes for a flexible operation: e.g. high-current, high-energy and without a potential trap

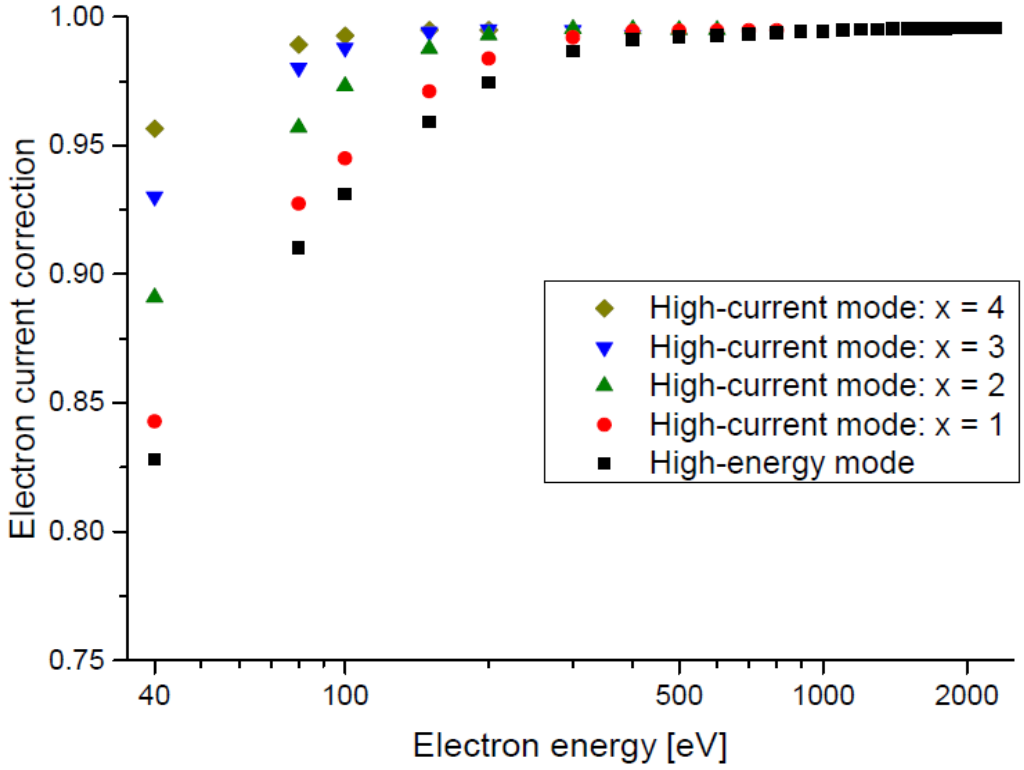
- Successful operation of measurement principles at the Giessen single-pass setup since the 1980's

Electron Target at Giessen



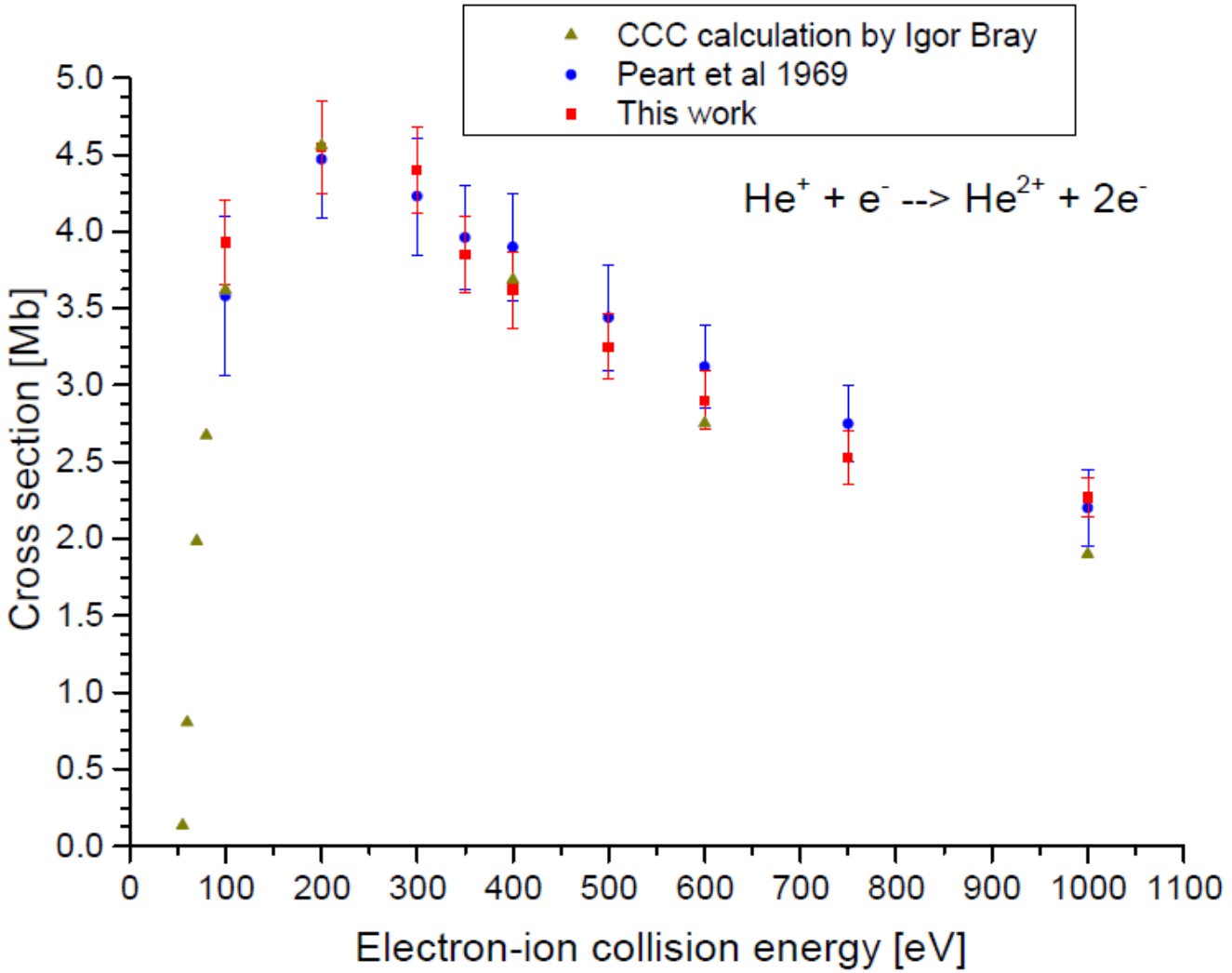
Tests at Giessen Single-Pass Setup





- Different modes do work as expected

Tests at Giessen Single-Pass Setup



- Excellent match to literature values
- For higher energies: field correction electrodes needed

  → Under testing

Theory: atom.curtin.edu.au/CCC-WWW/index.html
Experiment: Peart et al., J. Phys. B 2 (1969) 1347-1352

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Status

- Tasks towards a dedicated transversal target for CRYRING (ongoing work):
  - Improvement of the UHV capability (goal: few 10^{-11} mbar)
  - Improvement of the high-voltage resistance
  - Larger aperture for ion beam
  - Improved collector design
  - Free view to interaction region (for spectroscopy)

    → New electron optics calculations optimized for CRYRING
  - Storage ring integration (vacuum layout and mechanical design drafted)
  - Development of a new control and data acquisition system

    → Working on integration into CRYRING/FAIR system

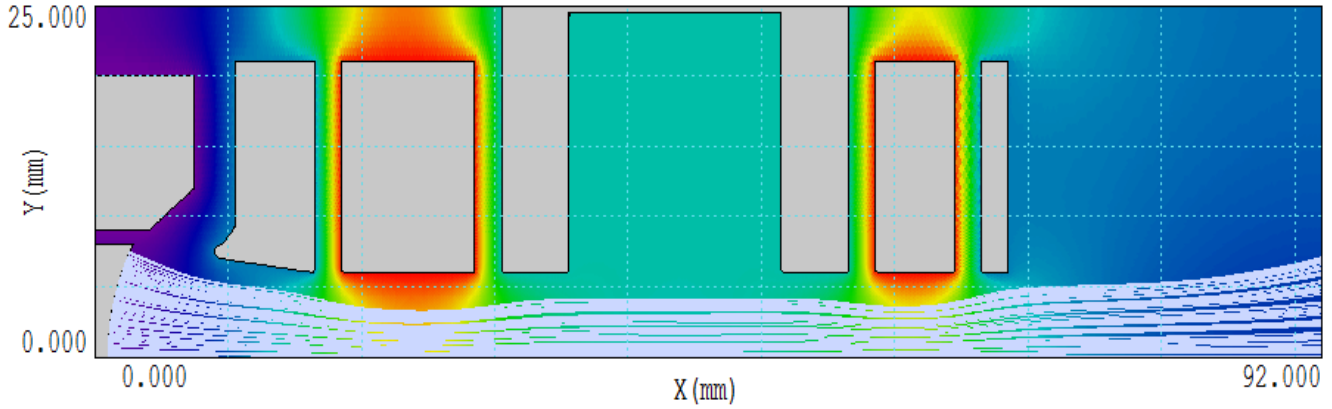
Calculations

- Electron energy can be varied over a wide range (by a factor of 3) by changing just one parameter and still obtaining an acceptable beam quality

  → Well behaving electron beam, non-problematic handling

- Typically synchronous changing of voltages on all electrodes

Settings:
Cathode: 0 V Wehnelt: -80 V Int. region: 1200 V
1st Electrode: 900 V 2nd Electrode: 3200 V



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Vert. grid: 5.000
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Filter 3:

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Maximum: 3.200E+03

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	2.714E+02
	5.057E+02
	7.400E+02
	9.743E+02
	1.209E+03
	1.443E+03
	1.677E+03
	1.911E+03
	2.146E+03
	2.380E+03
	2.614E+03
	2.849E+03
	3.083E+03

Electron density of several 10^8 cm^{-3}

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Settings:
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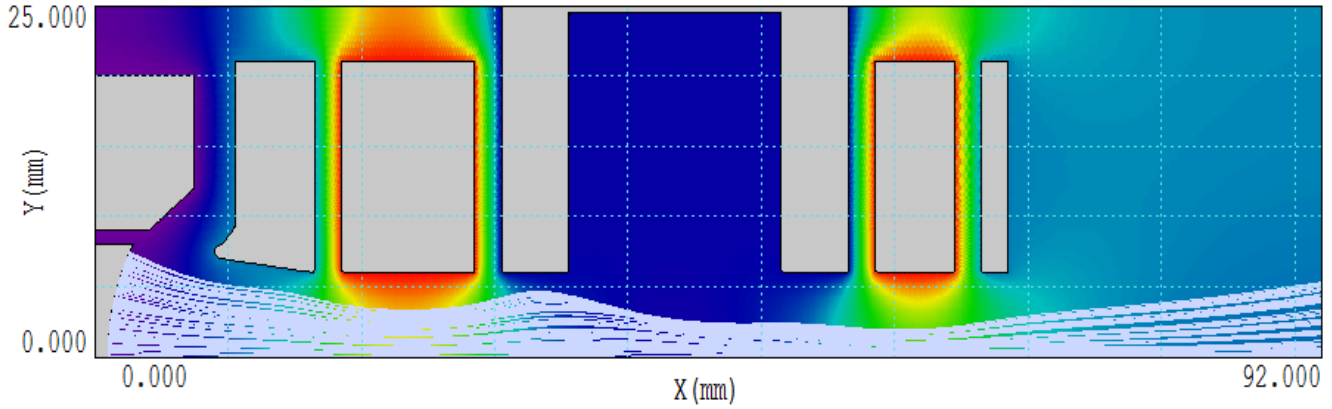
1st Electrode: 900 V 2nd Electrode: 3200 V



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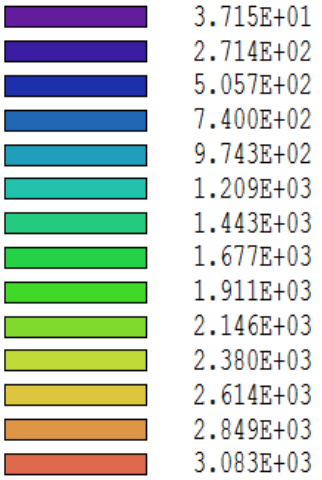

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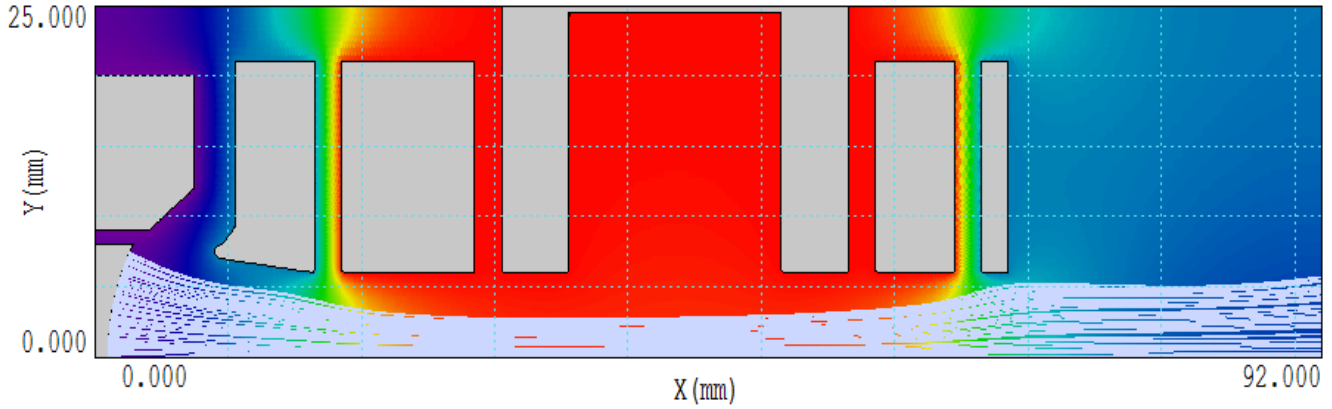
1st Electrode: 900 V 2nd Electrode: 3200 V



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Settings:
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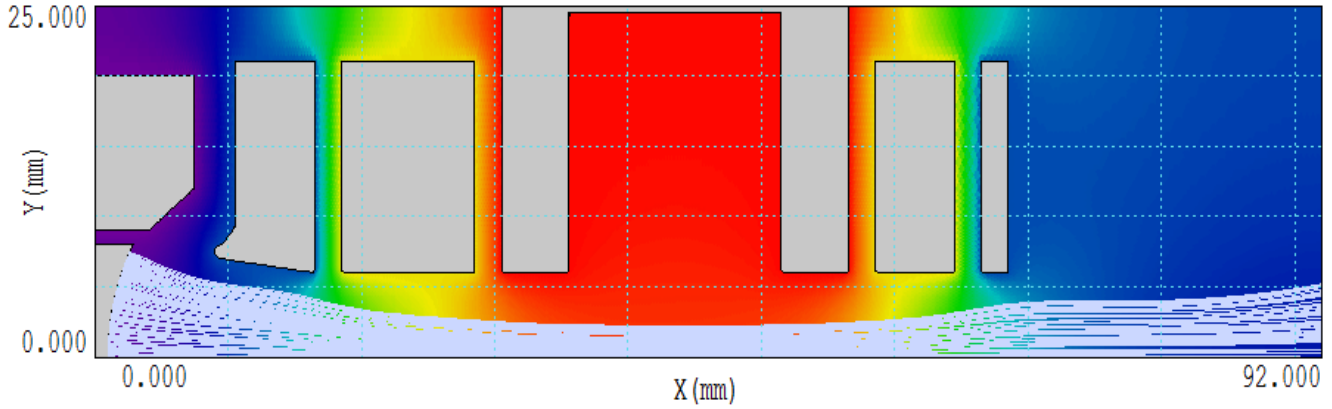
1st Electrode: 900 V 2nd Electrode: 3200 V



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	9.400E+02
	1.231E+03
	1.523E+03
	1.814E+03
	2.106E+03
	2.397E+03
	2.689E+03
	2.980E+03
	3.271E+03
	3.563E+03
	3.854E+03

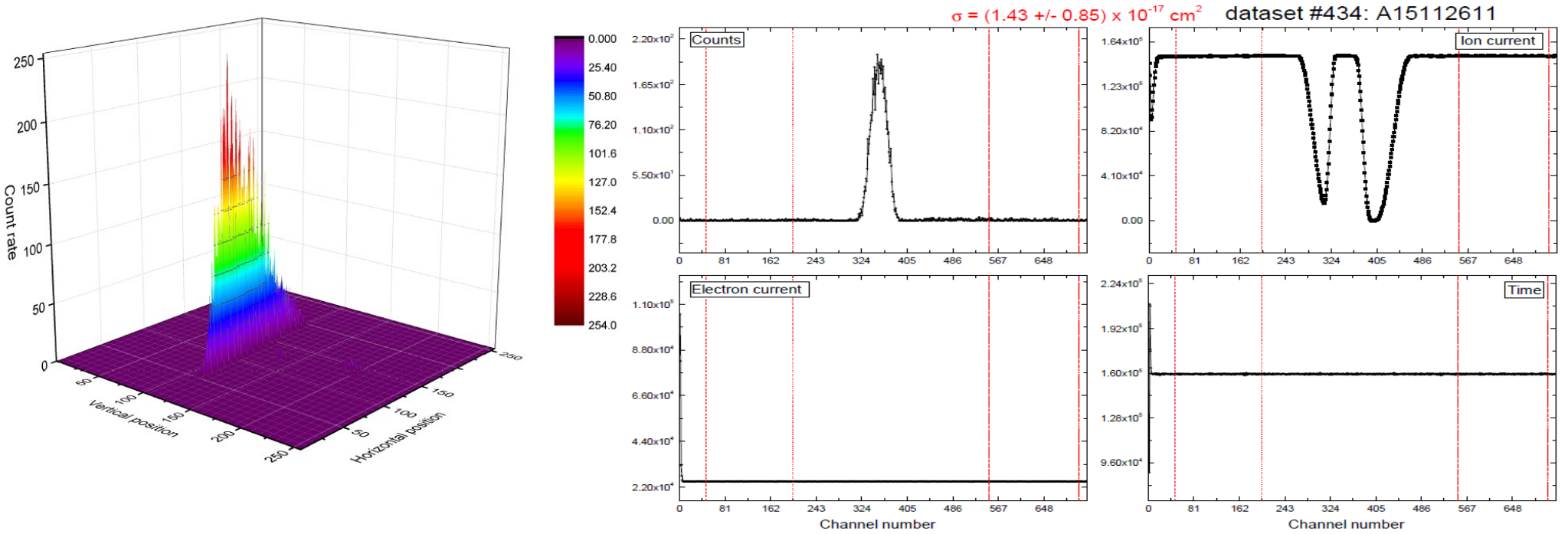
Electron density of several 10^8 cm^{-3}

Summary

- A transversal free-electron target dedicated for experiments at CRYRING is being developed
- Enables the investigation of a long list of electron-ion collision phenomena that were not accessible until now → see CRYRING Physics Book (in print) or Instrumentation TDR (http://www.fair-center.eu/fileadmin/fair/publications_exp/TDR_CRYRING_Experimental_Instrumentation.pdf)
- Test measurements with the Giessen electron target yield valuable information for the optimization of the CRYRING target
- Work on optimizations and modifications for the CRYRING target is in progress

Thank you for your attention!

Tests at Giessen Single-Pass Setup

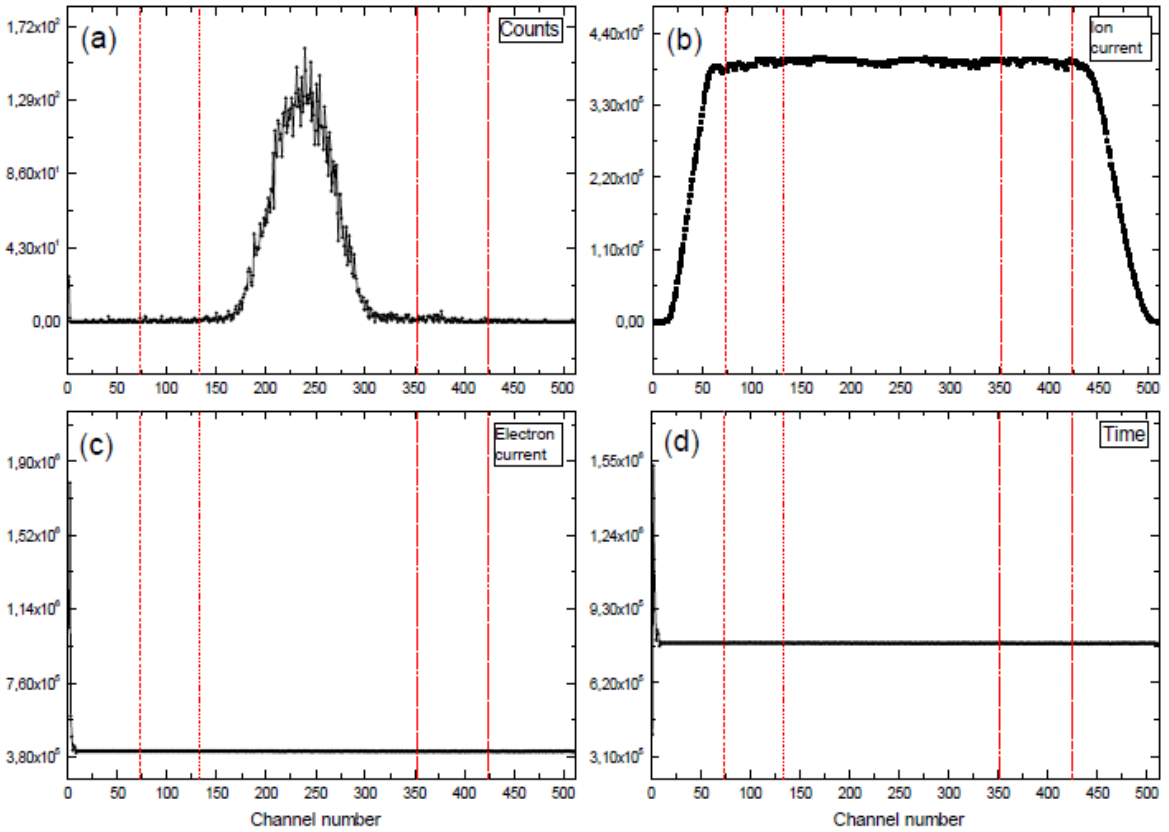


- Ion beam is influenced (deflected, splitted up) by electric field → Appropriate voltage settings on electrodes and field correction electrodes

Experimental Setup: Methods of Measurement

- Absolute measurements:
  - Deliver absolute ionization cross sections
  - To accurately know the quantity of the cross section
  - By sweeping the electron beam mechanically through the ion beam (animated crossed-beams)
- Relative measurements:
  - Deliver only relative cross section values
  - To accurately know the qualitative behavior of the cross section
  - By scanning the electron energy in very fine steps (fixed beam positions)
  - Can be fitted to absolute measurements

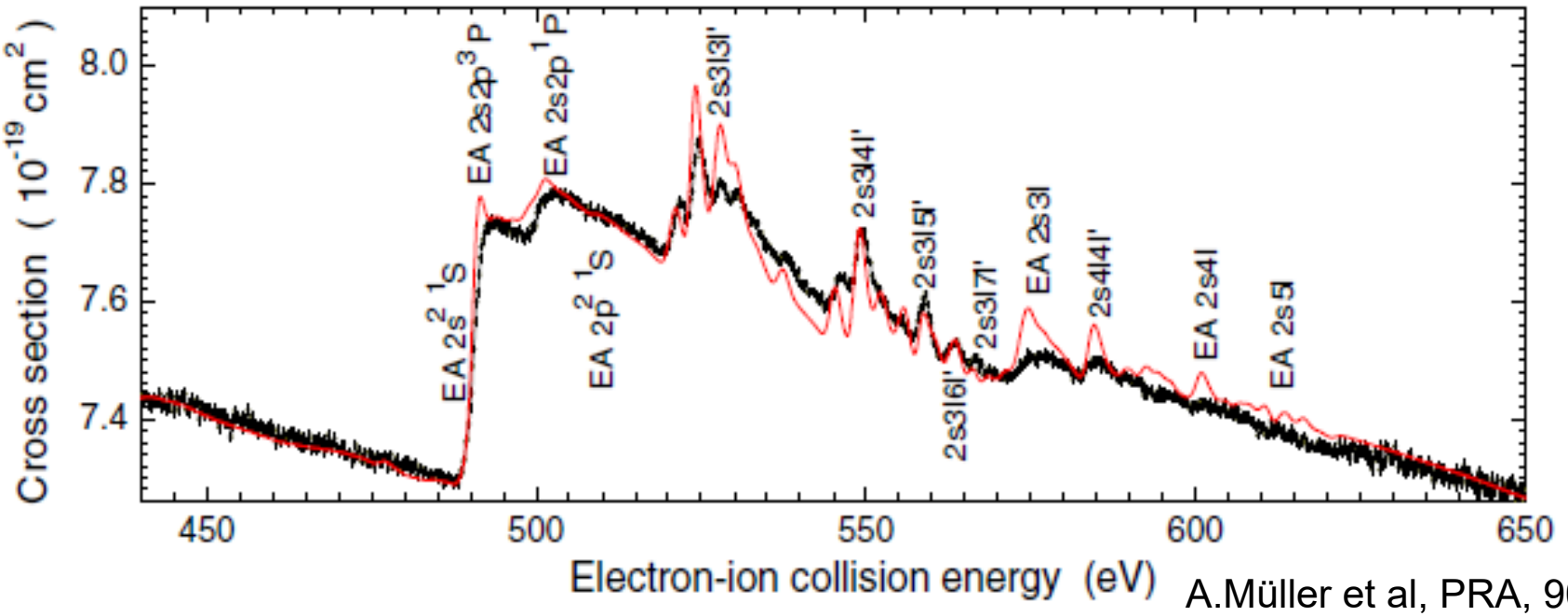
Exp. Setup: Absolute Measurements



- Not a trivial task at all
- Animated-beams make it a lot easier → Overlap and profile of beams get measured simultaneously with signal
- Still need to measure electron and ion current accurately as well as detect all product ions → Counting efficiency of detector

- Systematic uncertainty can be brought down to about 6 %
- Typically steps of several up to 50 eV → No structures can be observed

Exp. Setup: Scan Measurements



N^{5+}-ions

Black: Experiment

Red: Theory

A.Müller et al, PRA, 90, 010701 (2014)

- Fine-steps of typically ~ 0.2 eV
- Ion and electron beam are fixed to the maximum overlap the entire time
- Low statistic uncertainty can be achieved in a short time as measurement is operated automatically
- Ionization threshold as well as positions of EA-thresholds and REDA/READI-processes can be determined