



MEDeGUN

an electron gun for a high intensity C^{6+} source

M. Breitenfeldt



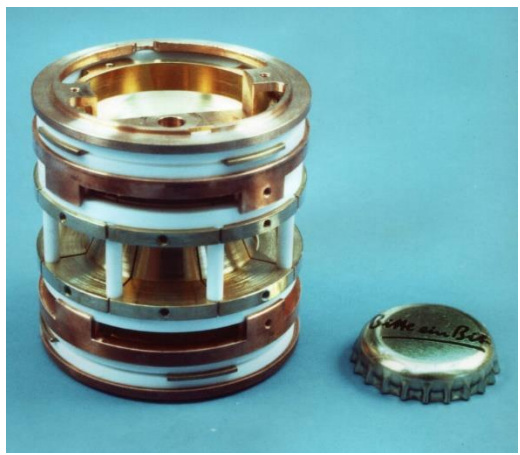
Short CV



Down to single ions in a Penning trap for mass measurements @ ISOLTRAP



Up to 10^6 ions in a Penning trap for weak interaction studies @ WITCH



isoltrap.web.cern.ch



Electron Beam Ion Source for charge breeding of up to 10^8 ions with an extraction frequency of 400Hz

Strong (several T) **magnetic** fields and **electrostatic** fields for confinement of **charged particles**



Samuel Morier-Genoud/CERN



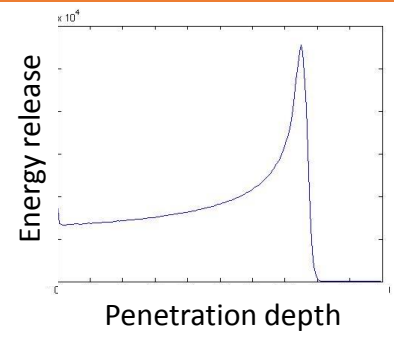
Outline

- 1. Heavy ion cancer therapy**
2. EBIS as injector
3. MEDeGUN design and assembly
4. Commissioning



Why heavy ions?

- **Heavier ions** deposit **more energy** than protons in the Bragg peak
- Higher relative biological effect due to double-strand DNA break-ups → choice for radiation-resistant tumors
- In a population of 10 millions 4500 cases per year
→ ~ 6 facilities a 750 patients/year/10million people
→ require **300 facilities** in EU

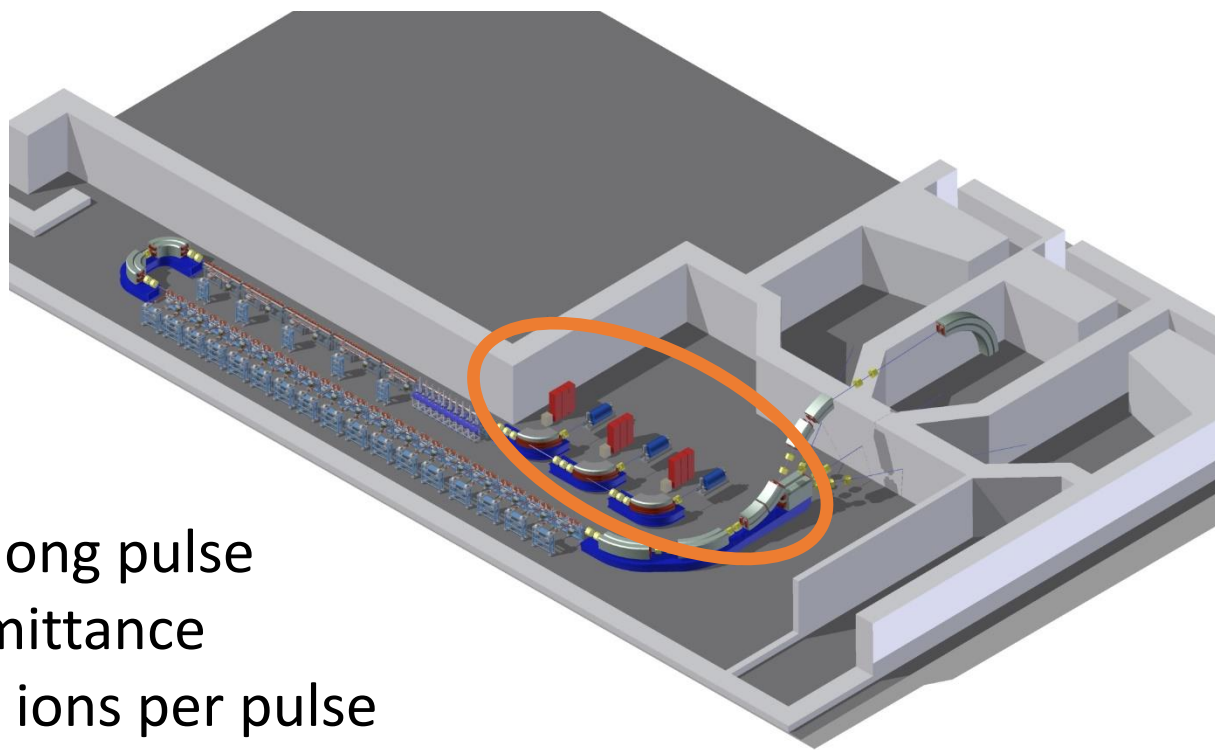




Requirements for 2nd generation IBT

e.g. CABOTO

CARbon **B**Ooster for **T**herapy in **O**ncology



- 400 Hz
- < 5 us long pulse
- Low emittance
- 10^8 C⁶⁺ ions per pulse

S. Verdu-Andres et al., Journal of Radiation Research 54 (2013) il55

S. Benedetti 2016 (talk) Update on TULIP and CABOTO projects



Outline

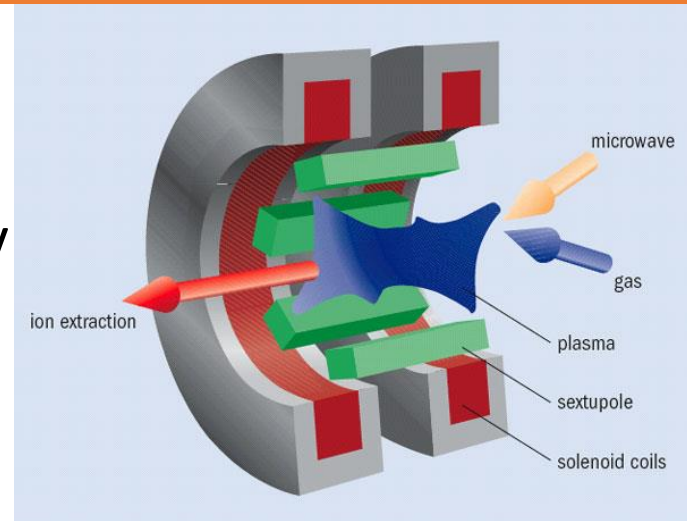
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EBIS vs ECRIS

Electron Cyclotron Resonance Ion Source

- Long ion pulse, even with afterglow
- Only 4^+ produced with sufficient intensity
→ Stripper foil
- Large transverse emittance



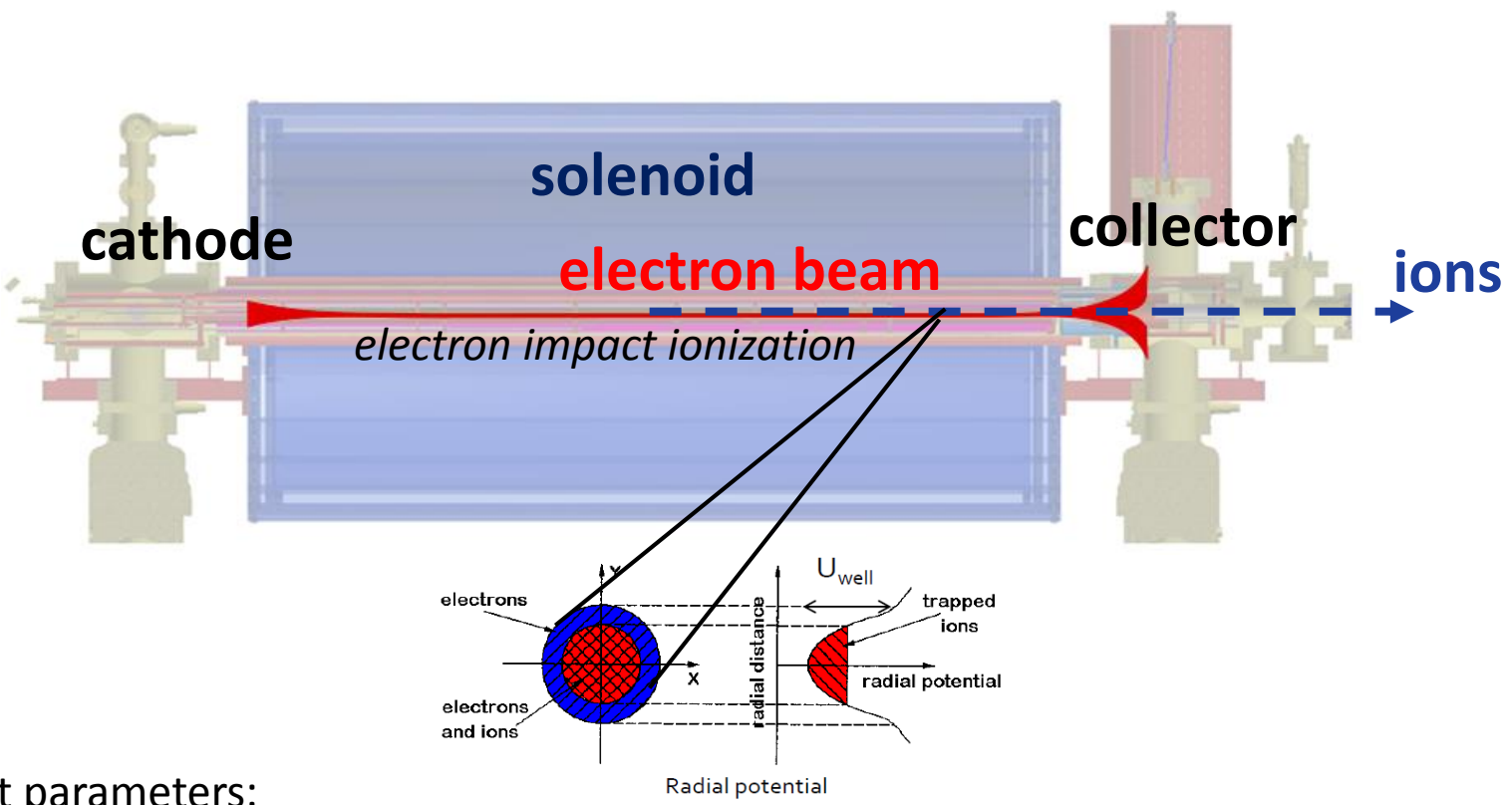
Electron Beam Ion Source

- Clean (good vacuum)
- Short pulse are extracted
- Low transverse emittance
- **We have the expertise**





EBIS principle



Important parameters:

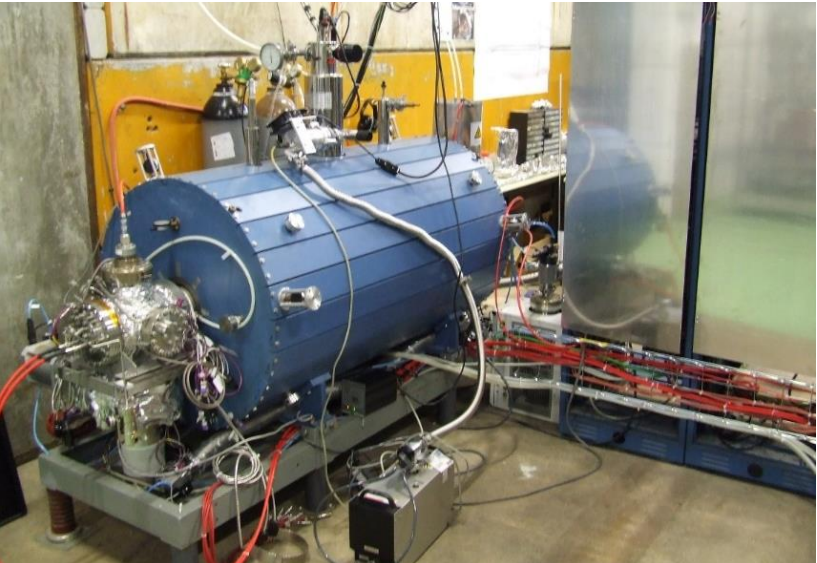
- Current density → charge breeding time
- Electron energy → cross section for ionization
- Current → ion capacity



Suggested MEDeGUN

High compression **Brillouin electron gun**
 (laminar beam, cathode sees no B-field)
 Low electron beam energy, **optimized for C⁶⁺**
 Vacuum **5*10⁻¹¹ mbar**
 Installation at TwinEBIS testbench

Design Parameter	MEDeGUN
Test site	TwinEBIS, CERN
Main magnet	2 T
Trap length	0.25 m
Electron current	1 A
Current density	1.5 kA/cm ²
Electron energy	7.5 - 10 keV
Capacity C ⁶⁺	1·10 ⁸ ions per pulse
Repetition rate C ⁶⁺	180 Hz



TwinEBIS test stand with 2 T superconducting solenoid
 M. Breitenfeldt et al., Nucl. Instrum. Methods A, 856 (2017) 139

Approved as
KT project in 2015:

- 1.) Design and build an electron gun
- 2.) Demonstrate transmission of 1A through a 2T magnetic field



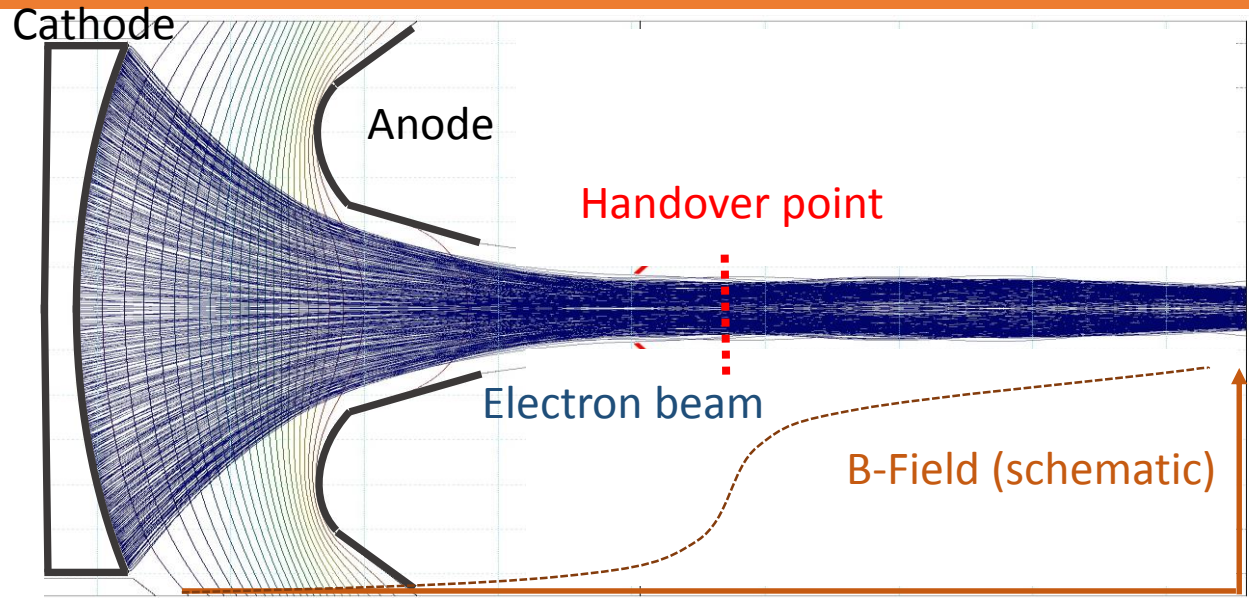
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MEDeGUN design challenges

Electron beam properties



Simulation: Electron trajectories as from cathode towards the hand over point (by R. Mertzig)

Repulsive Coulomb force → Magnetic field to reduce divergence of e^- beam

Magnetic mirror: too high relative transversal energy leads to reflection

1. Side emitted electrons
2. Temperature
3. Surface roughness
4. Work function distribution

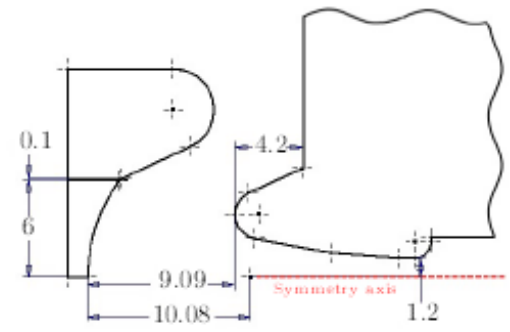
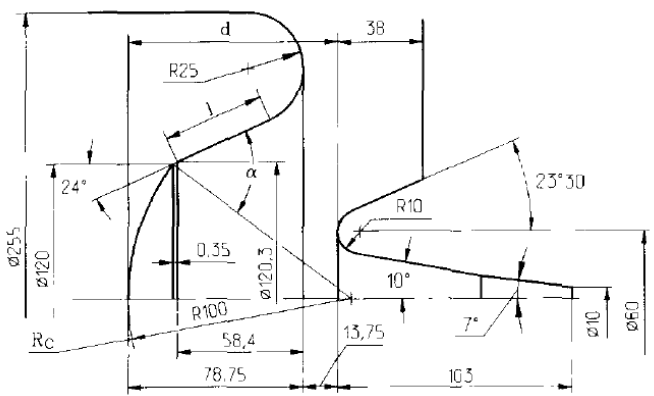
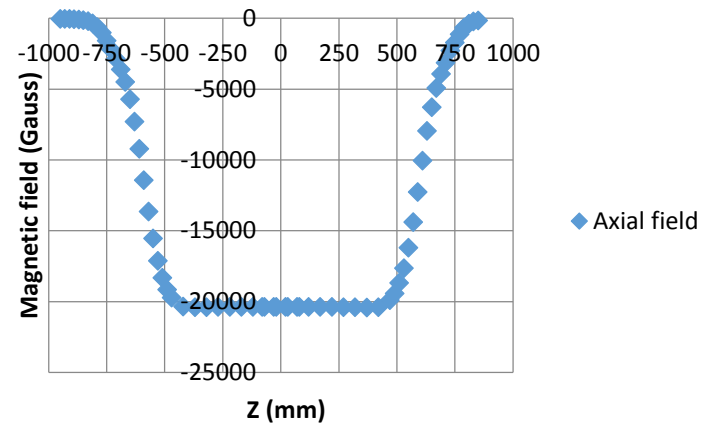


Design of the electromagnetic field

Magnetic field of the TWINEBIS test bench



Axial field

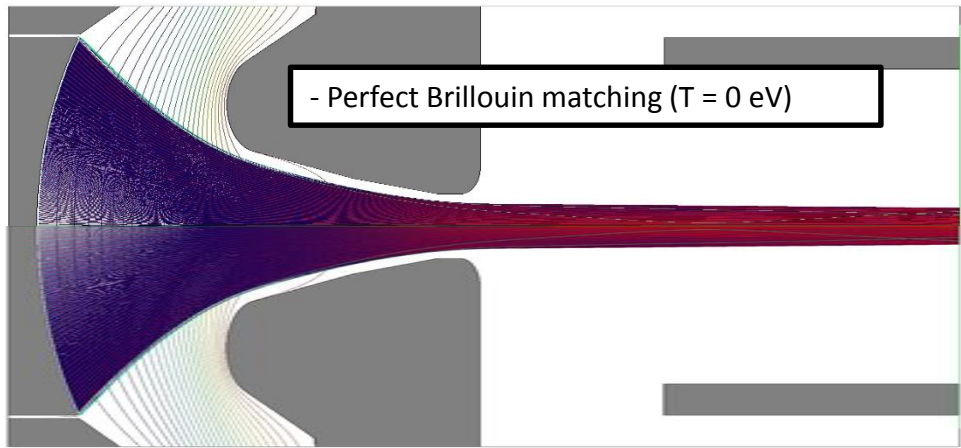


Y.V. Baryshev et al. Instr. Meth. Phys. Res., 340(2), 1994.

R. Mertzig, PhD thesis TU Dresden 2016

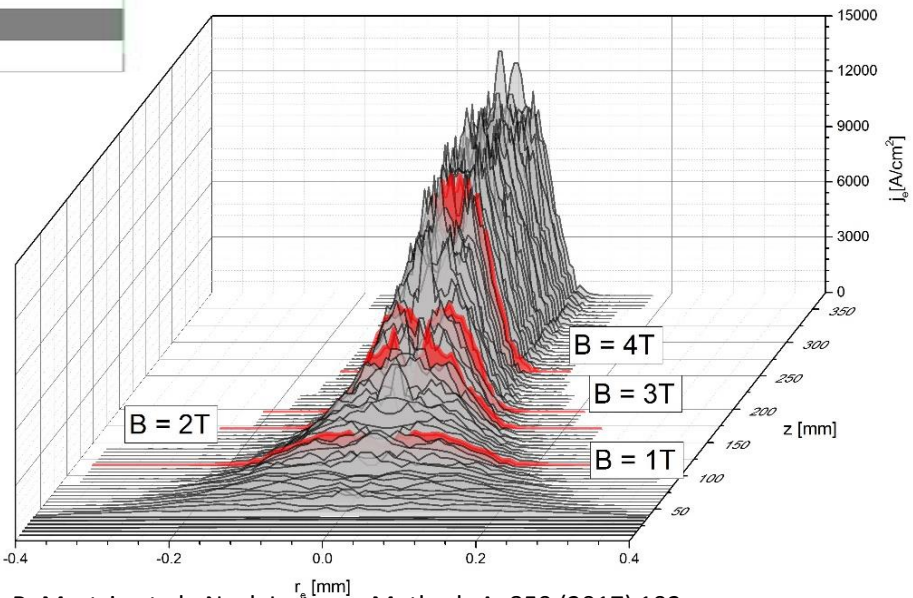


Simulation results



1st results using a cold beam looked promising

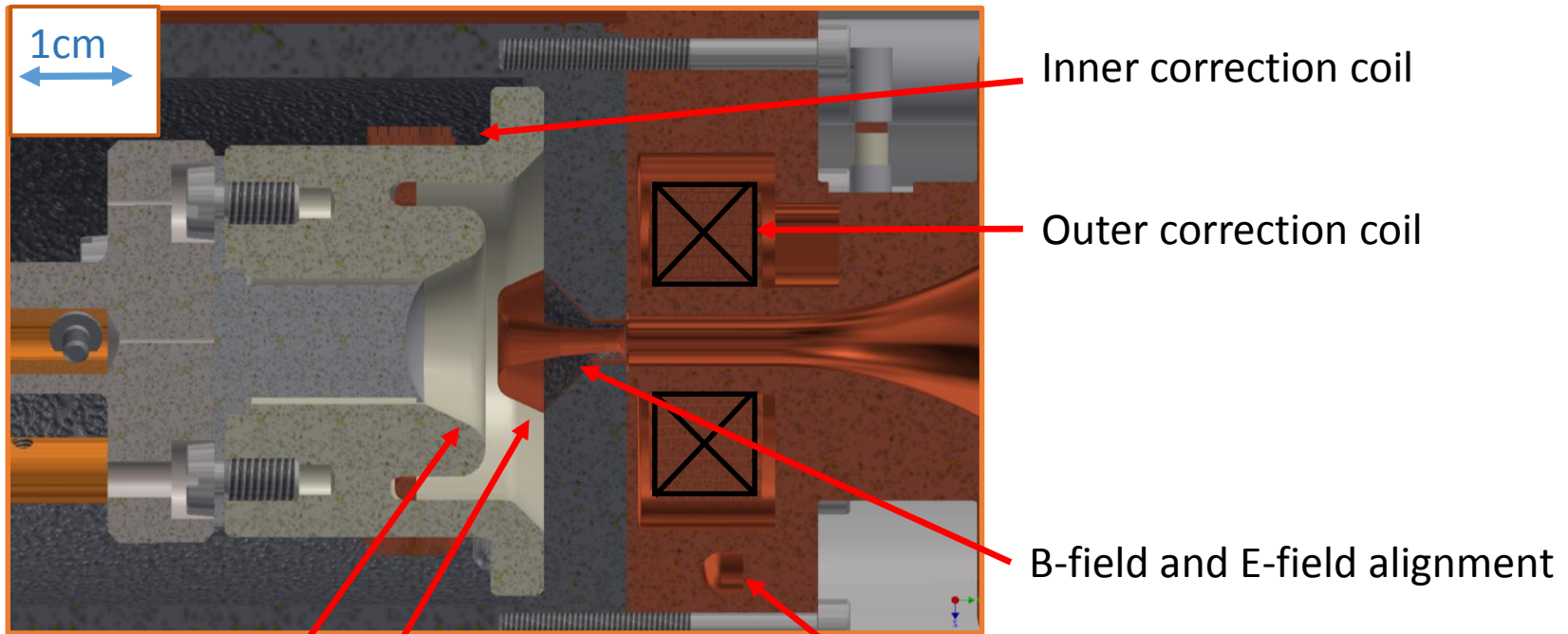
Minor optimization after adding a cathode temperature
→ Beam could be traced into the magnetic field



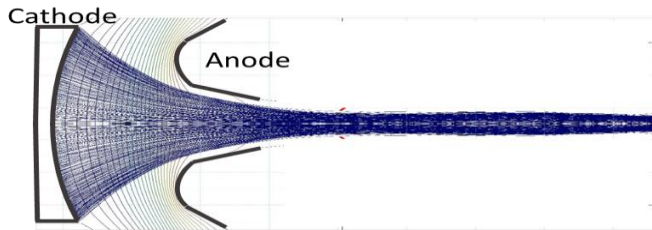


MEDeGUN design challenges

Machine boundaries



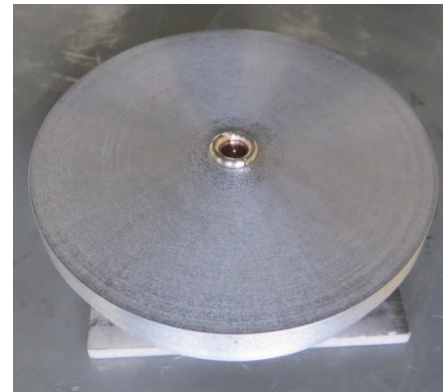
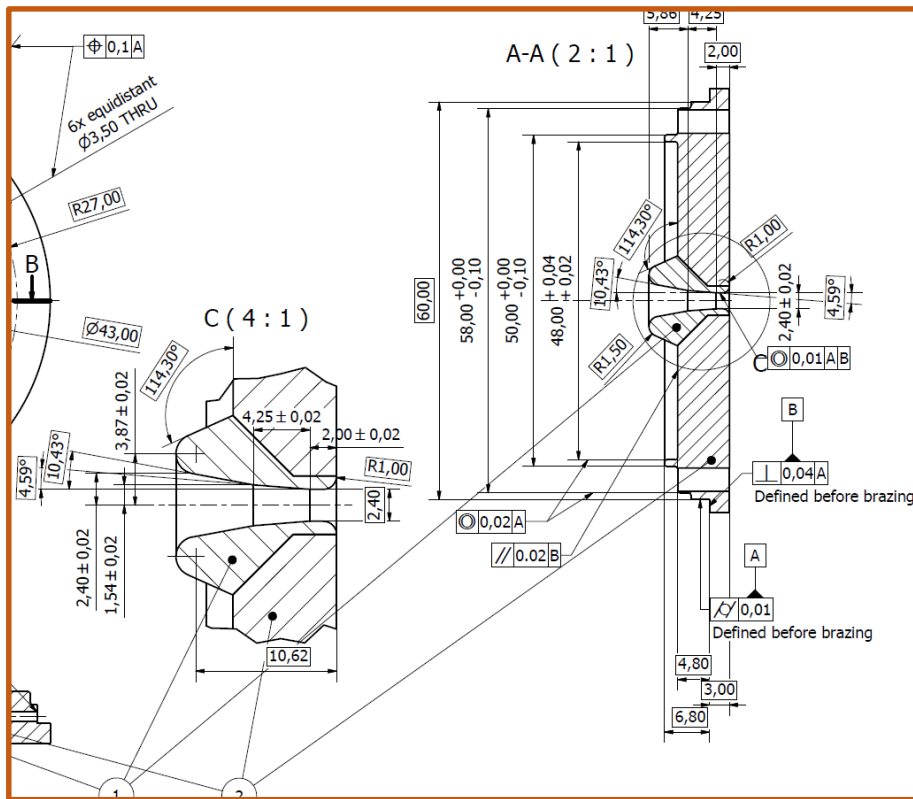
$\Delta U_{\max} = 15\text{kV}$ for extracting e^- beam





Production

Example: Production drawing for anode piece



Anode unmachined part:
Armco disc with copper piece



Finished anode piece: E-field and B-field

Surfaces for the E-field of the gun volume have tolerances of 20um!

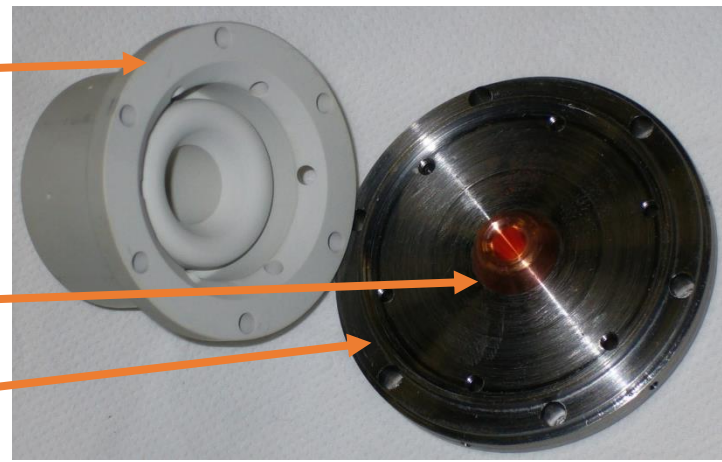
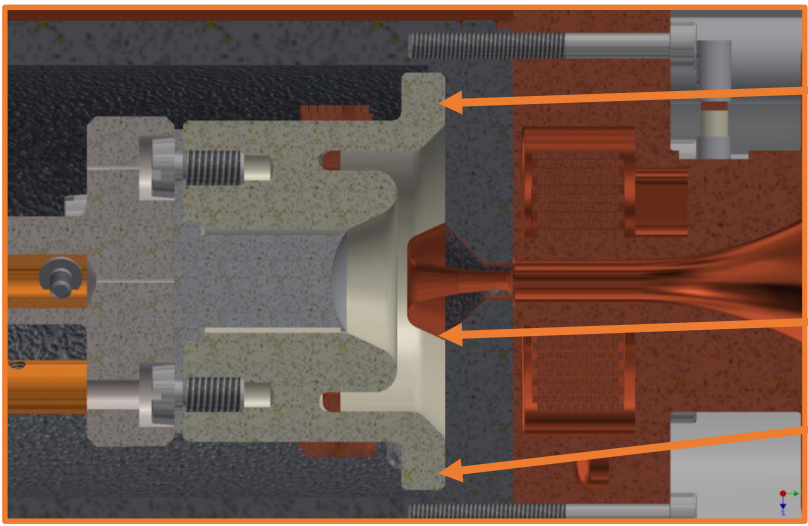
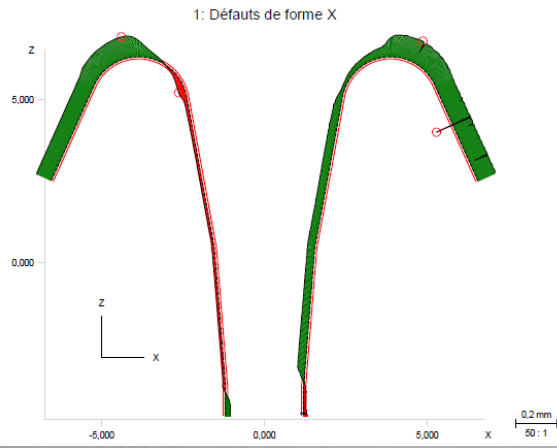


Quality control

Metrology measurements

	Rapport de controle			
Contrôleur Client Fournisseur MMT Incertitude Température Plan de contrôle	PUGNAT Dominique MARTIN BREITENFELDT Q_Inspect 1.9 µm + L/250 mm 20°C ±1°C EDMS.1722598-IRON FRONT PLATE ANODE	Nom du projet Numéro Pièce Nom de pièce N° de Plan N°EDMS Date	2 040216 1722598 1 Novembre 2016	

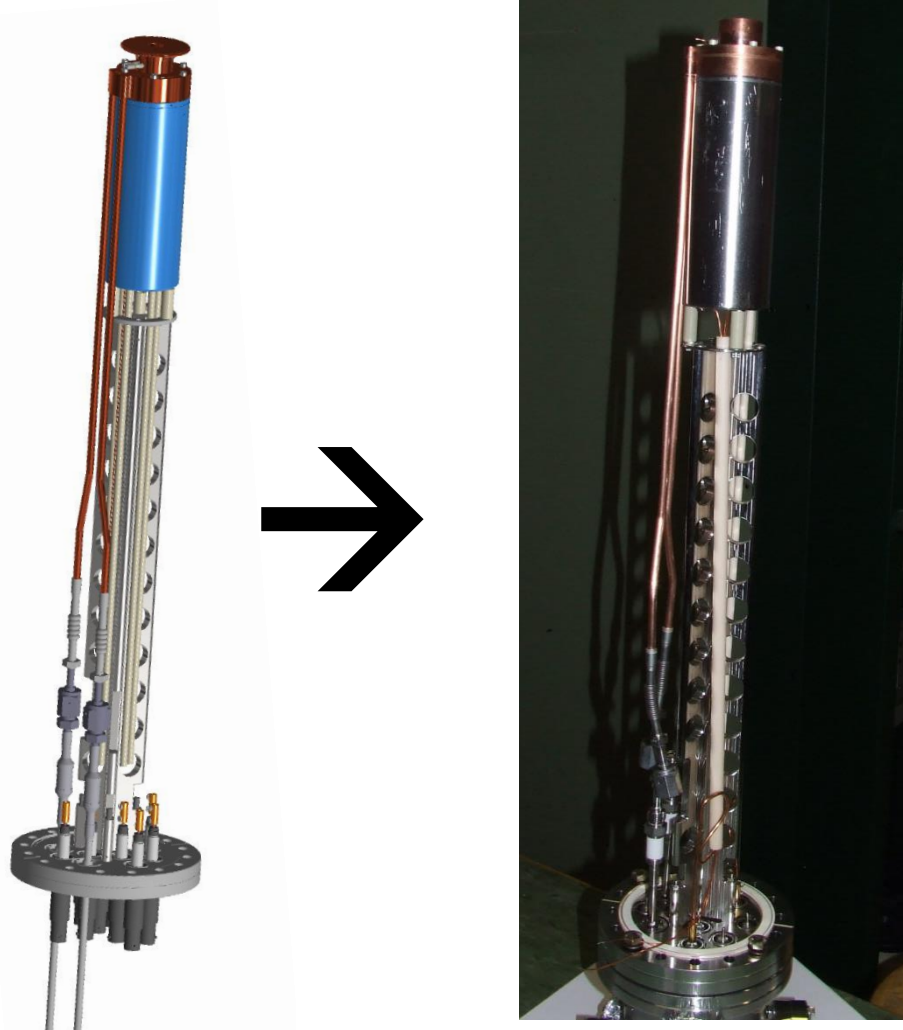
measurement anode profile



Wehnelt and Anode piece



And finally this spring...



- Installation finished
- Leak test
- HV tests
- Bake out
- Start of the electron beam

KT project:

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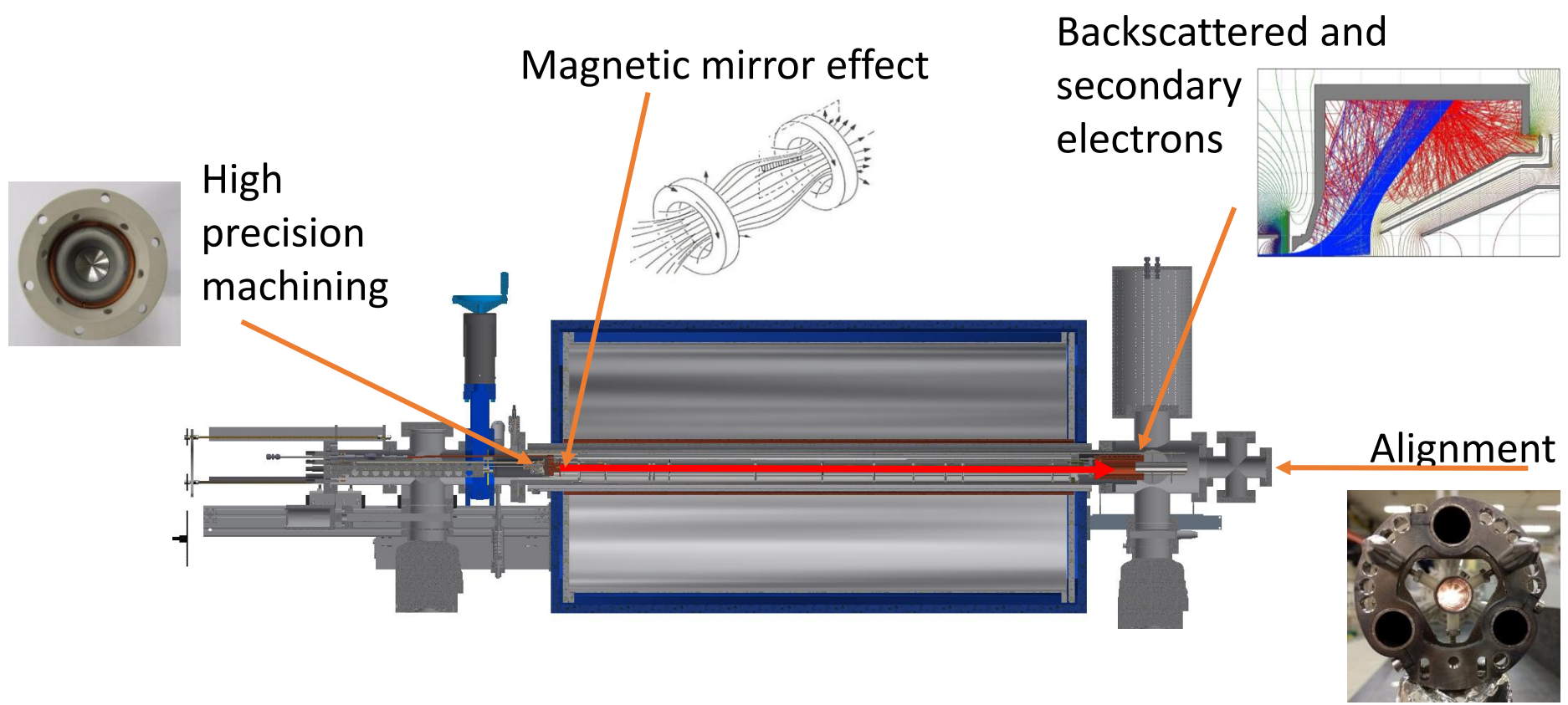


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MEDeGUN Commissioning: Challenges

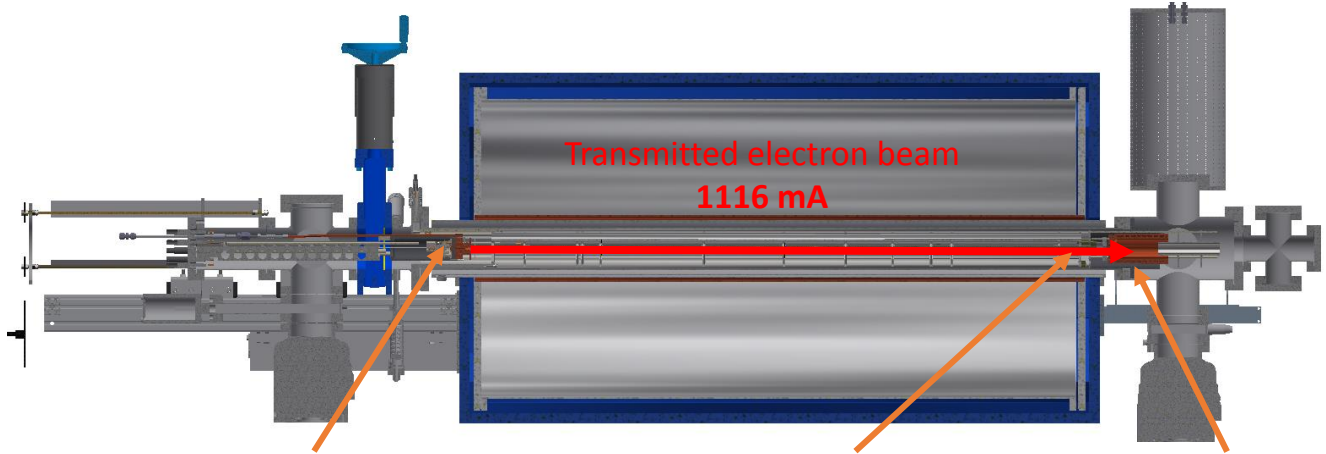
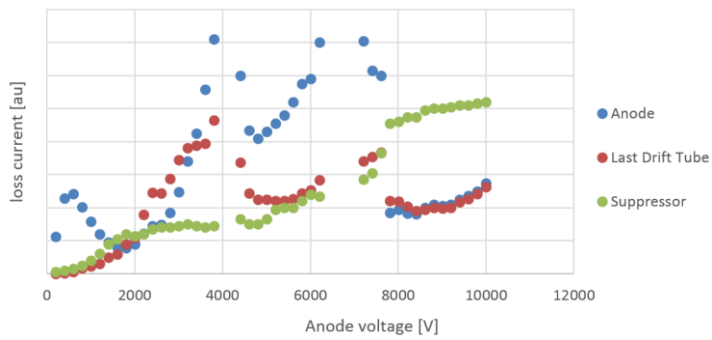


Minimizing loss currents on all electrodes while transmitting 1 A of electron beam



MEDeGUN Commissioning: Results

Typical transmission and loss currents
10 keV electron energy
10 kV extraction potential



Anode
0.55 mA

Last Drift Tube
0.13 mA

Suppressor
0.32 mA

Total losses
1 mA

Record current 1.5 A





MEDeGUN Commissioning: Results

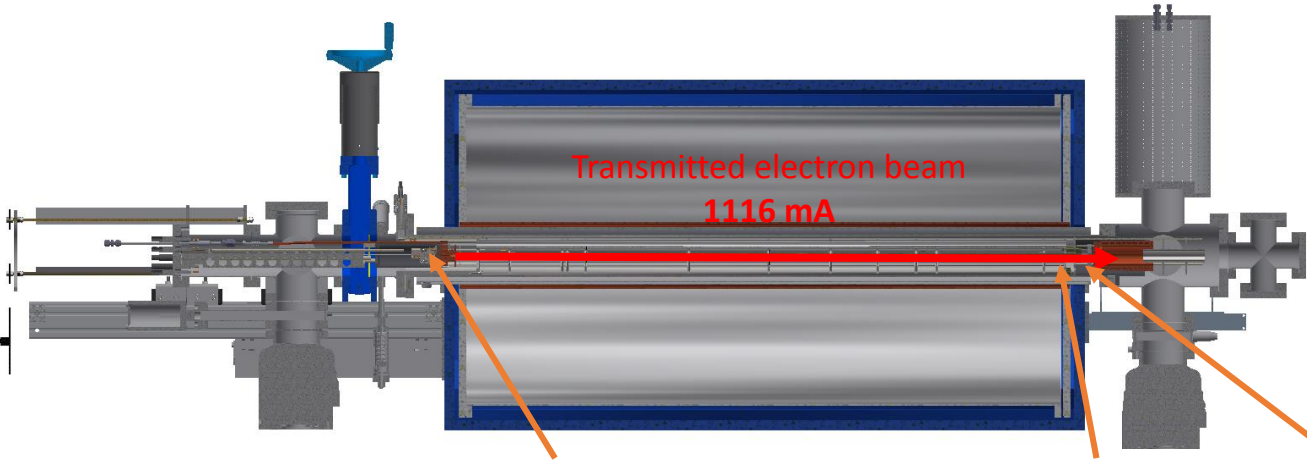
Typical transmission and loss currents
10 keV electron energy
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ON TIME



Anode
0.55 mA

Last Drift Tube
0.13 mA

Suppressor
0.32 mA

Total losses
1 mA

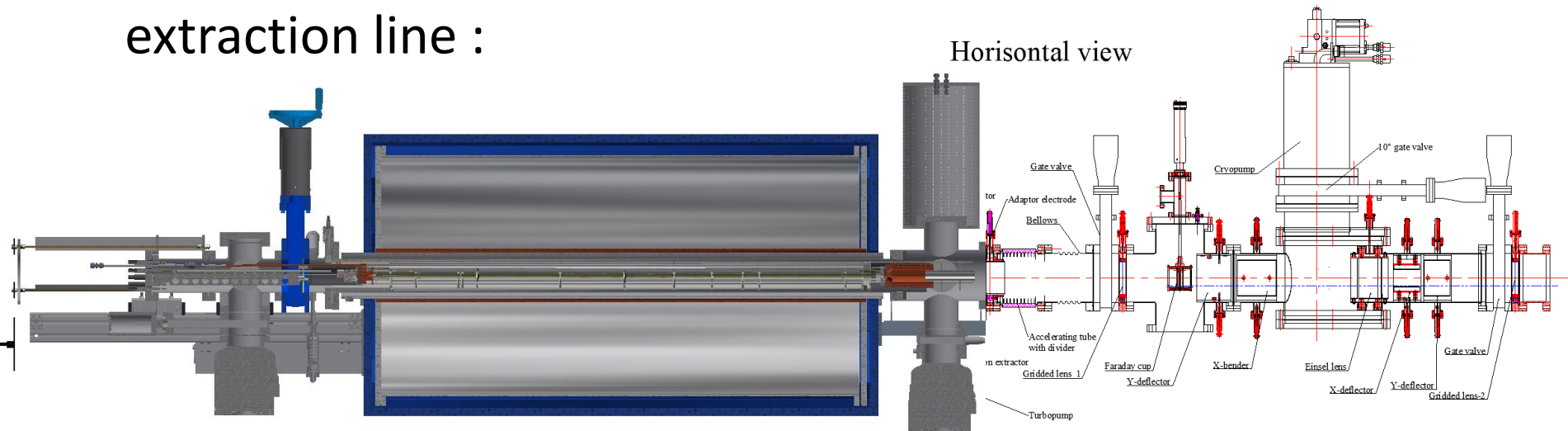
Record current 1.5 A





Outlook

Installation of an extraction line :



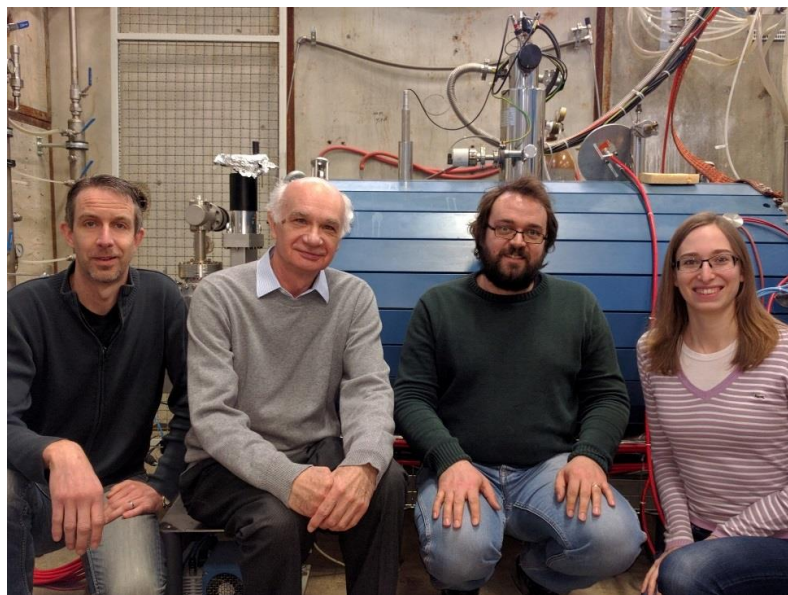
Why?

- Determine the current density - breeding time
- Verify amount of extracted C^{6+} - capacity of the EBIS

Given the resources: Can be realized by 06/2018



THANKS



Thanks to the EBIS team: F. Wenander, A. Pikin, J. Pitters, F. di Lorenzo
former members R. Mertzig, A. Shornikov,
and technical advisor S. Mathot

