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

Electron **B**eam **I**on **S**ource for charge breeding of up to 10^8 ions with an extraction frequency of 400Hz

isoltrap.web.cern.ch

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

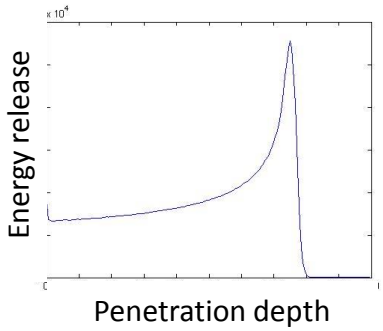
Samuel Morier-Genoud/CERN

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



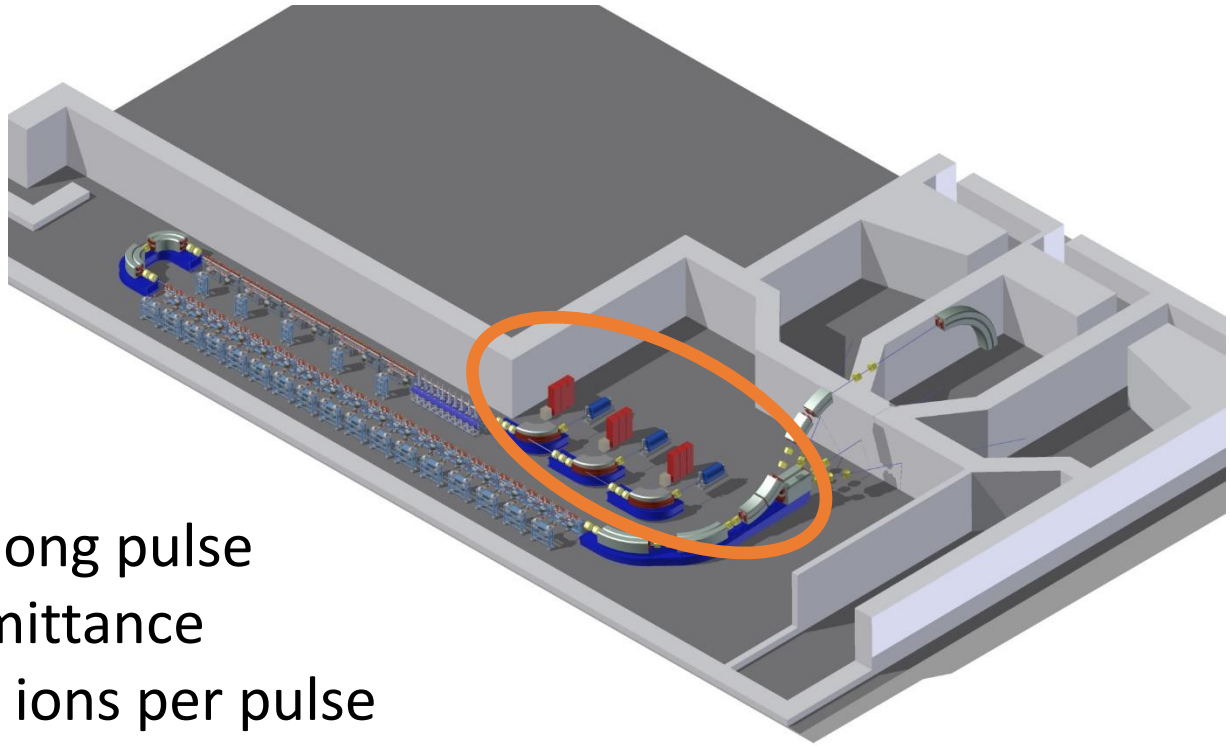
- Higher relative biological effect due to double-strand DNA break-ups → choice for radiation-resistant tumors

- In a population of 10 millions 4500 cases per year
  → ~ 6 facilities a 750 patients/year/10million people
  → require **300 facilities** in EU

A. Shornikov and F. Wenander,
http://dx.doi.org/10.1088/1748-0221/11/04/T04001

Requirements for 2nd generation IBT

e.g. CABOTO
CArbon **BO**oster for **T**herapy in **O**ncology



- 400 Hz
- < 5 us long pulse
- Low emittance
- 10^8 C^{6+} 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

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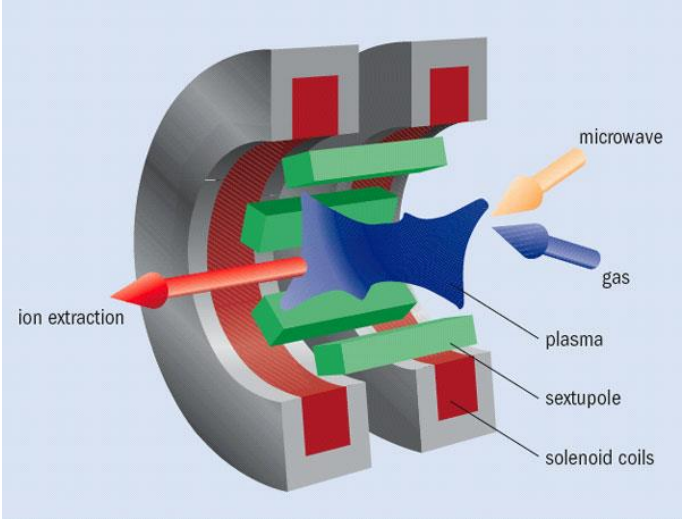
EBIS vs ECRIS

Electron **C**yclotron **R**esonance **I**on **S**ource

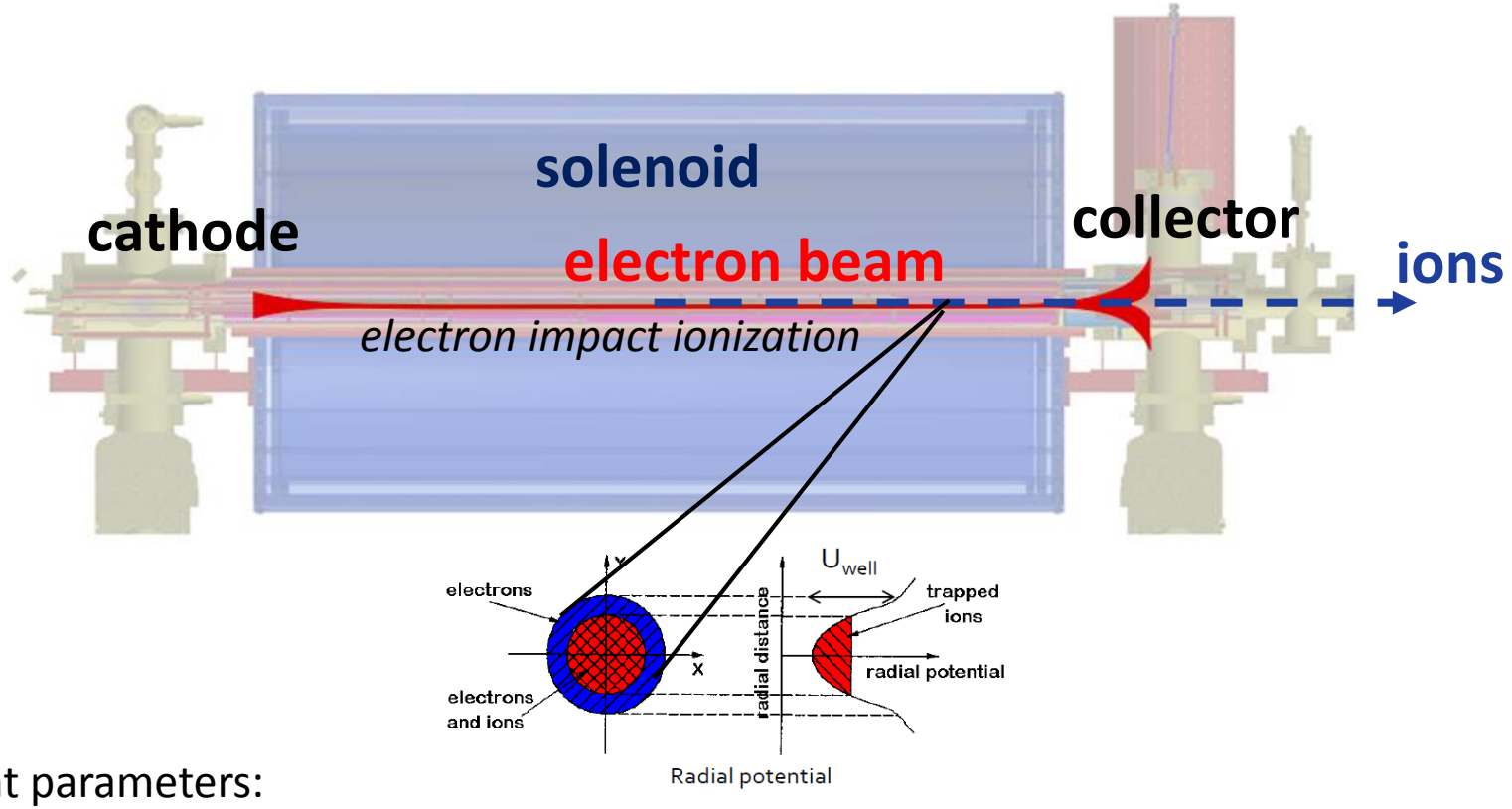
- Long ion pulse, even with afterglow
- Only 4^+ produced with sufficient intensity
  → Stripper foil
- Large transverse emittance



Electron **B**eam **I**on **S**ource

- 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 C^{6+}**

Vacuum **$5*10^{-11}$ mbar**

Installation at TwinEBIS testbench

TwinEBIS test stand with 2 T superconducting solenoid

M. Breitenfeldt et al., Nucl. Instrum. Methods A, 856 (2017) 139

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+}	$1 \cdot 10^8$ ions per pulse
Repetition rate C^{6+}	180 Hz

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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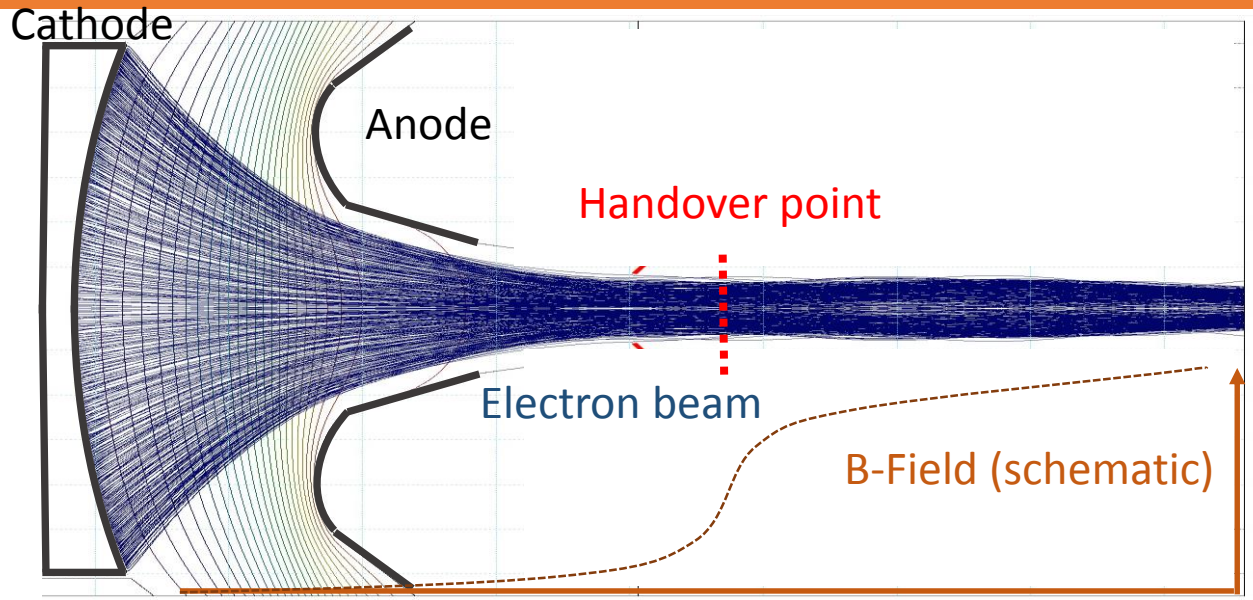
MEDeGUN design challenges
Electron beam properties



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

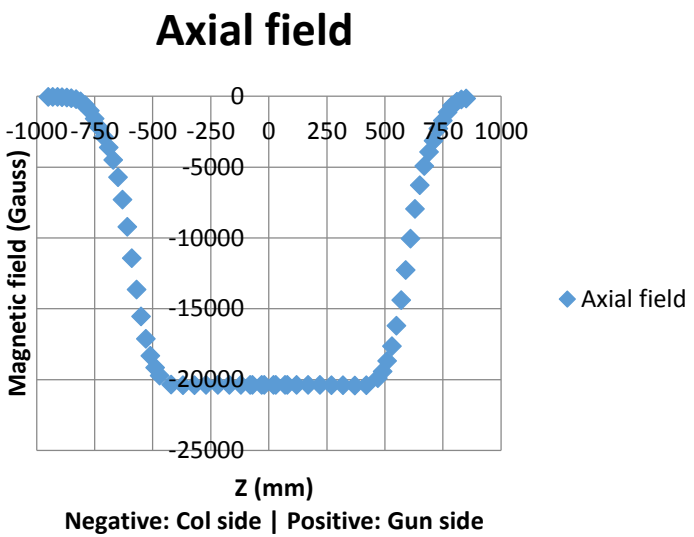
Repulsive Coulomb force → Magnetic field to reduce divergence of e^- beam

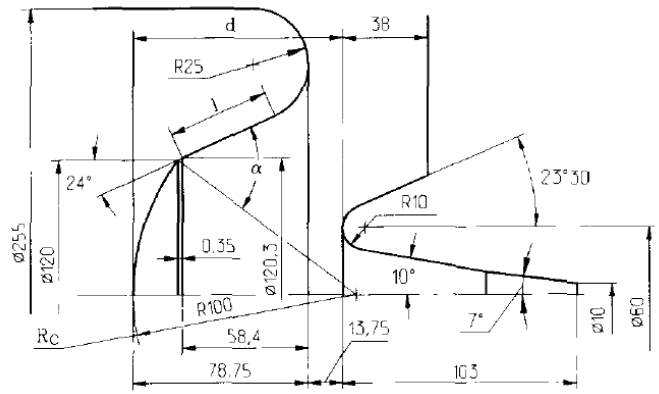
Magnetic mirror: too high relative transversal energy leads to reflection

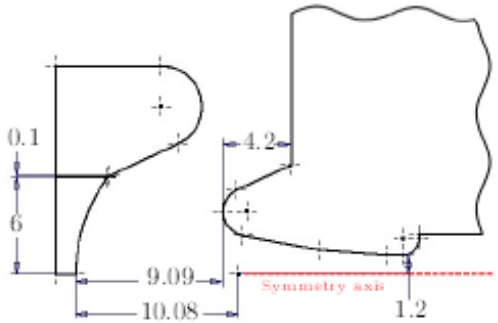
1. Side emitted electrons
2. Temperature
3. Surface roughness
4. Work function distribution

Design of the electromagnetic field

Magnetic field of the TWINEBIS test bench



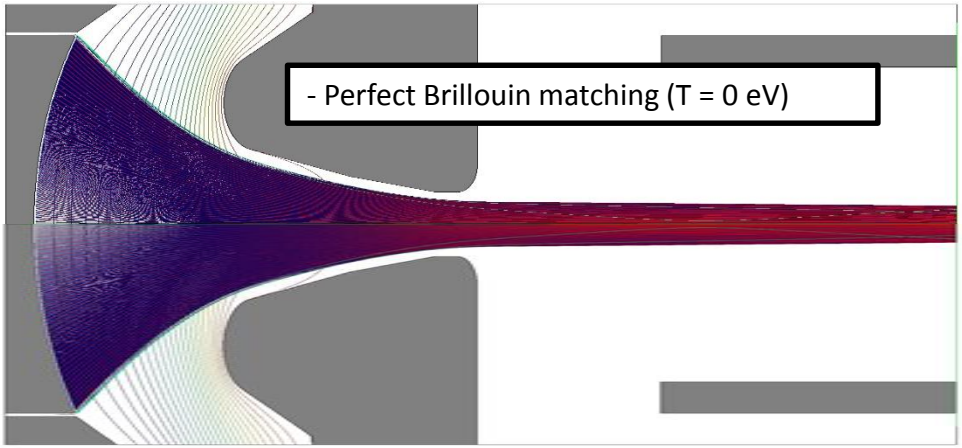




Y.V. Baryshev et al. Instr. Meth. Phys. Res., 340(2), 1994.

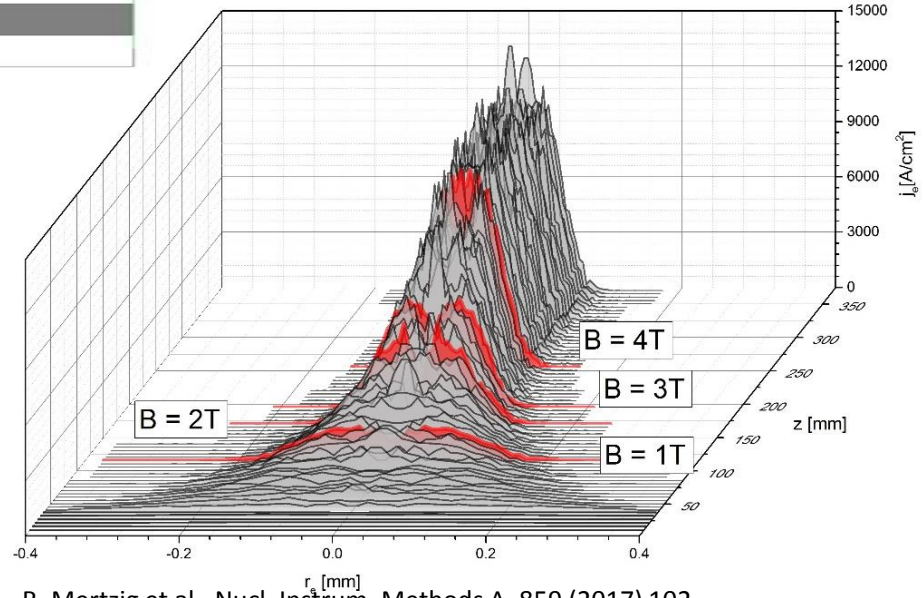
R. Mertzig, PhD thesis TU Dresden 2016

Simulation results



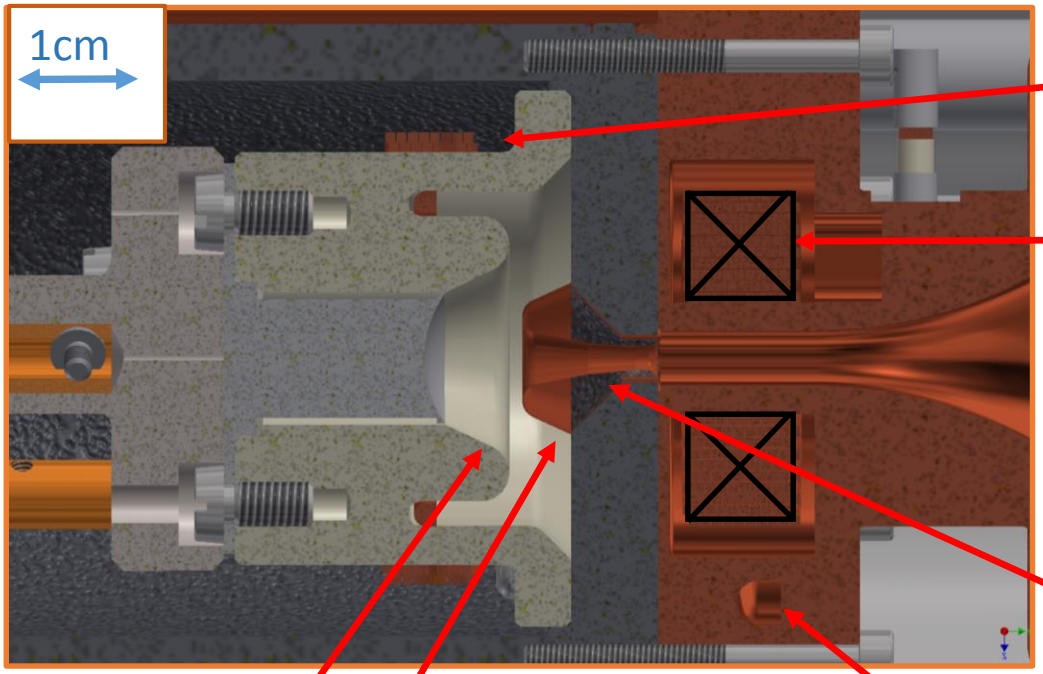
1st results using a cold beam looked promising

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



R. Mertzig et al., Nucl. Instrum. Methods A, 859 (2017) 102
R. Mertzig, PhD thesis TU Dresden 2016

MEDeGUN design challenges
Machine boundaries



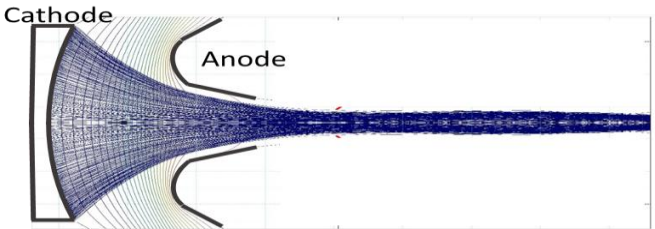
Inner correction coil

Outer correction coil

B-field and E-field alignment

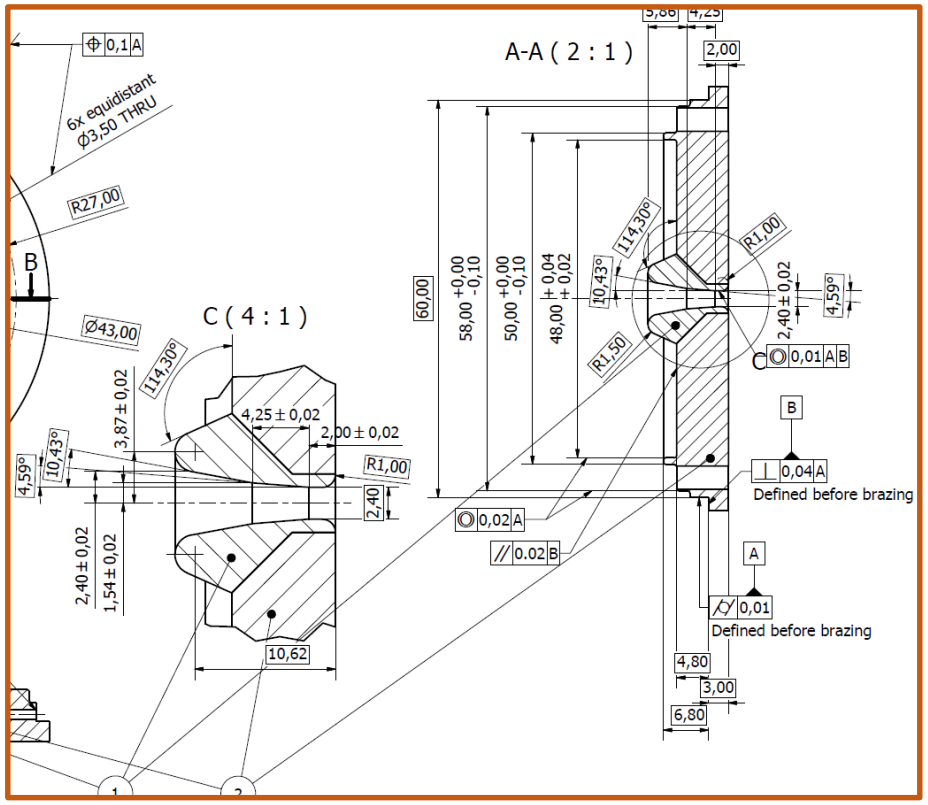
ΔU_{max} = 15kV for extracting e^- beam

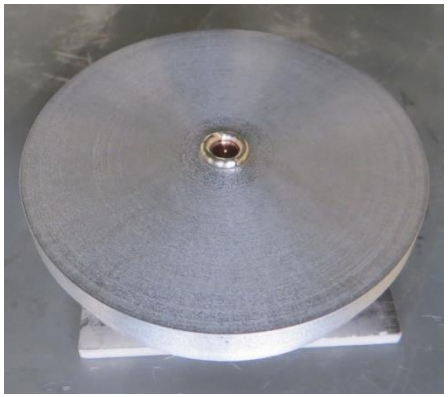
Cooling water channel



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!

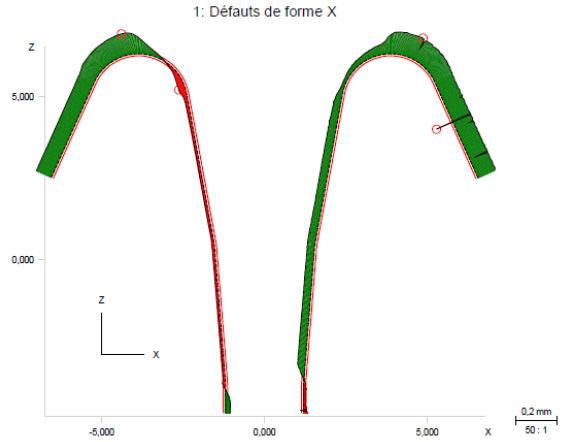
Quality control

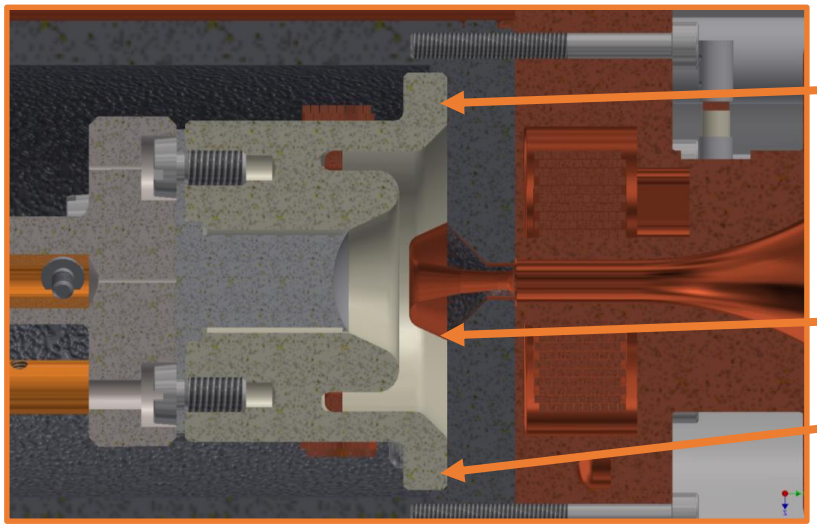
Metrology measurements

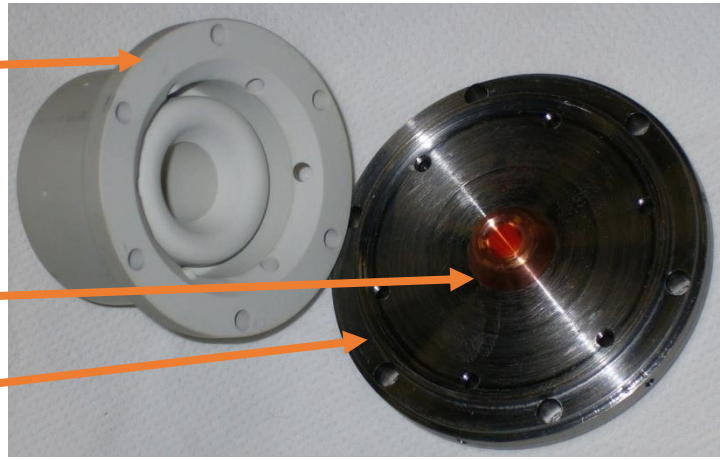
Rapport de controle

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

measurement anode profile

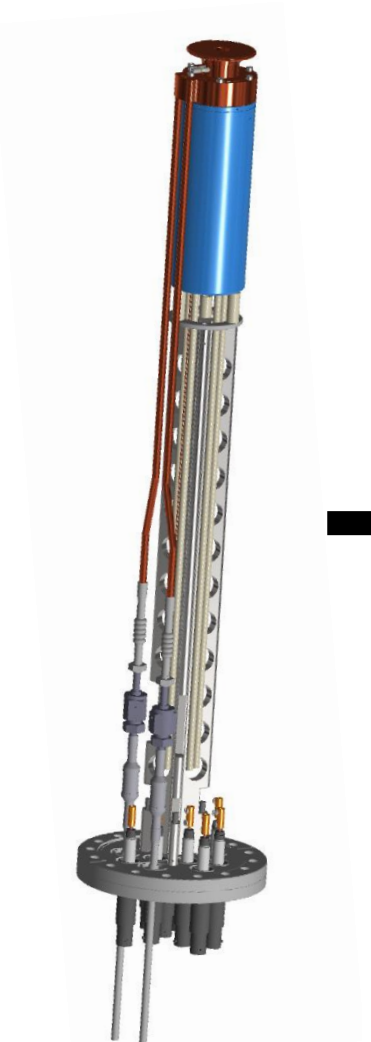


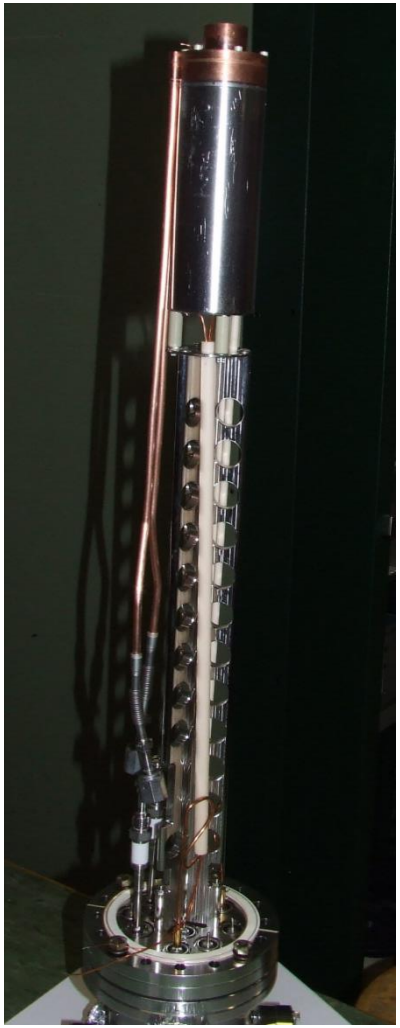




Wehnelt and Anode piece

And finally this spring…





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

KT project:
1.) Design and build an electron gun ☑
2.) Demonstrate transmission of 1A through a 2T magnetic field ☐

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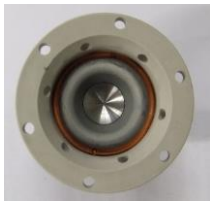
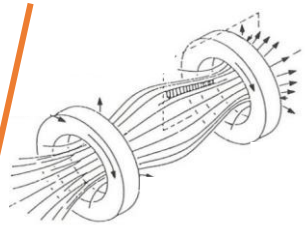
4. **Commissioning**

MEDeGUN Commissioning: Challenges

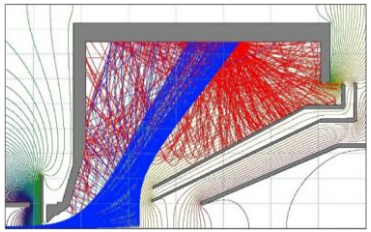


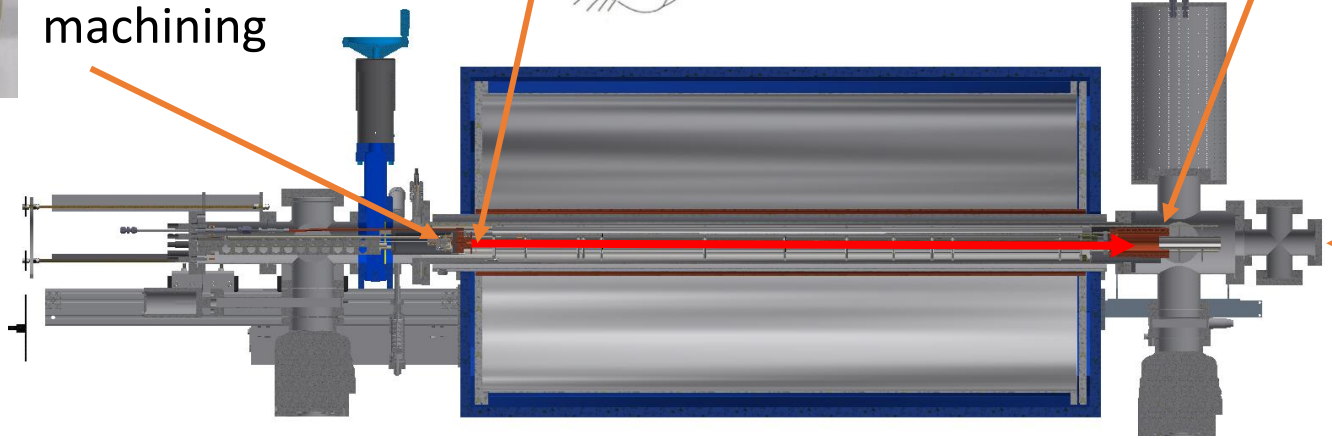
High precision machining

Magnetic mirror effect



Backscattered and secondary electrons



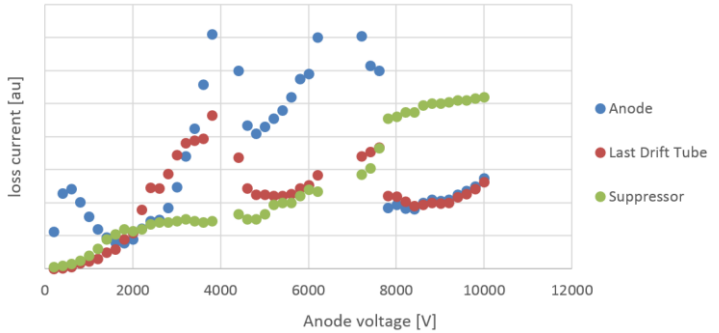


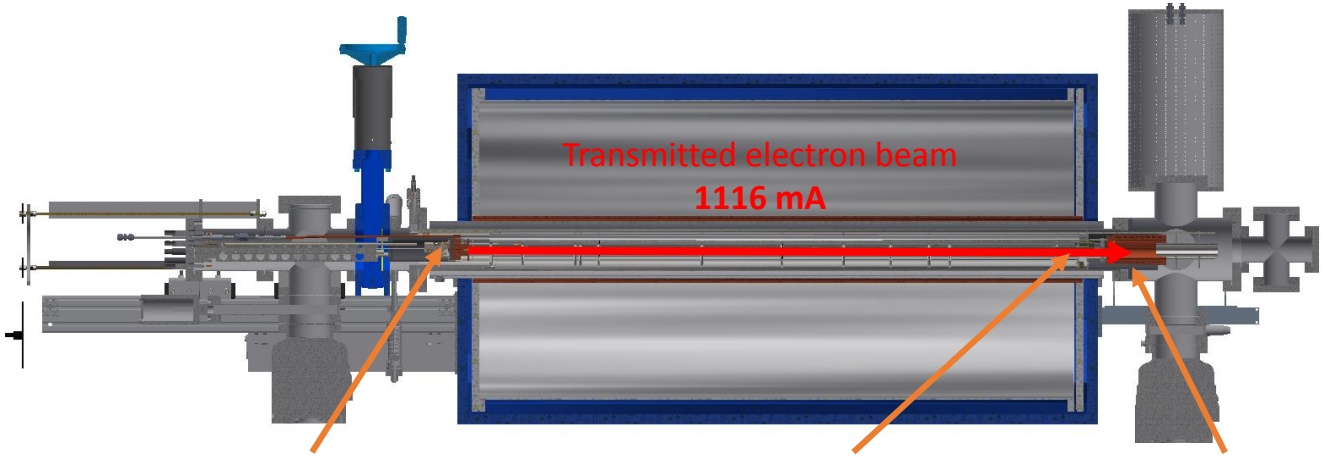
Alignment

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

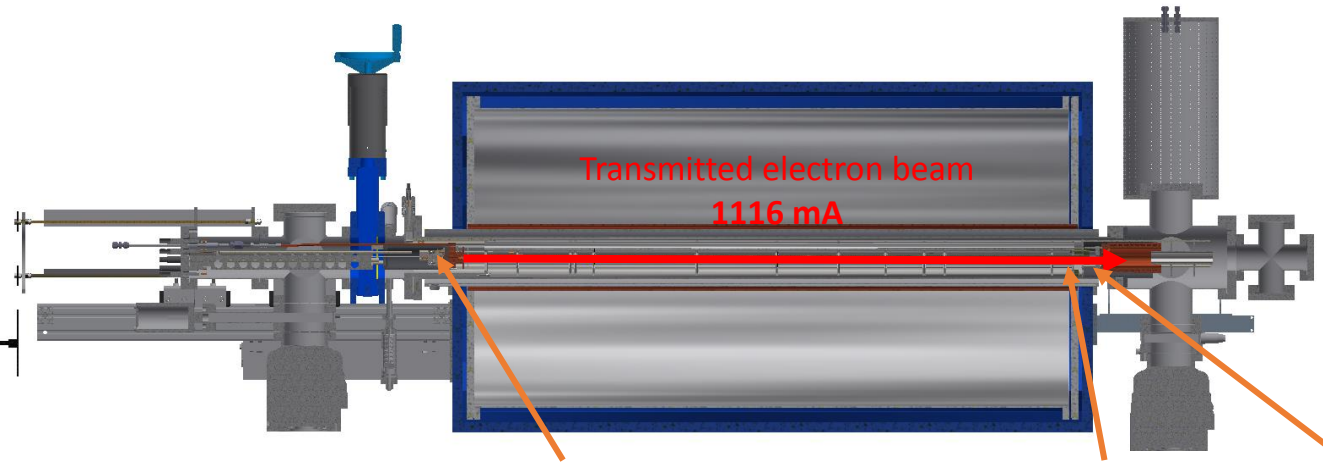
Total losses
1 mA

Record current 1.5 A

MEDeGUN Commissioning: Results

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

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



ON TIME

Anode
0.55 mA

Last Drift Tube
0.13 mA

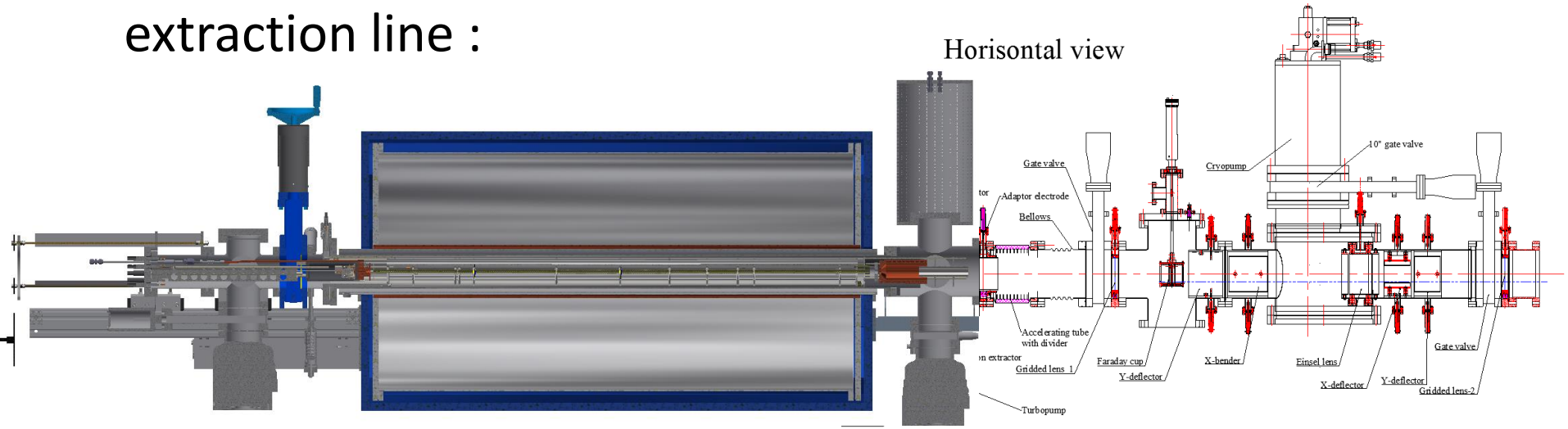
Suppressor
0.32 mA

Total losses
1 mA

Record current 1.5 A

Outlook

Installation of an extraction line :

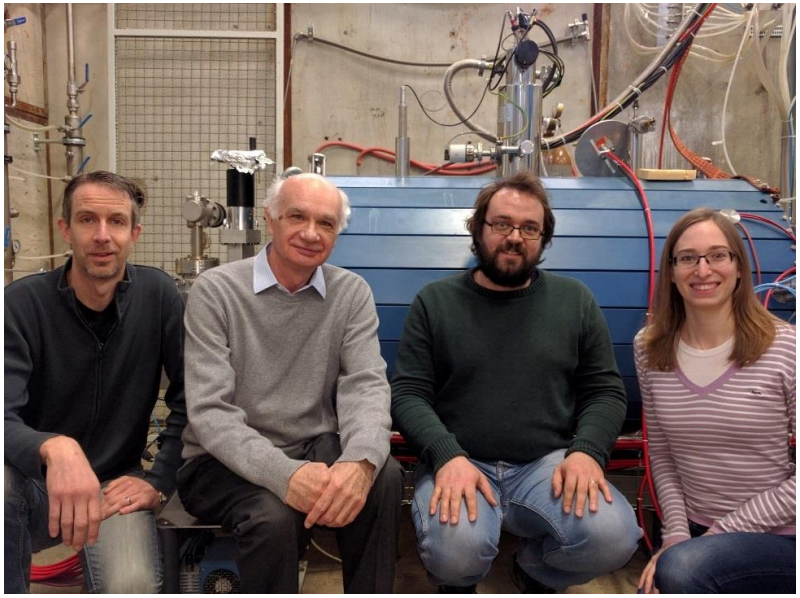


Why?

- 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


MED
GUN
e⁻