Injector and collector design details and developments

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International Review on the e-lens concept readiness for integration into the HL-LHC baseline

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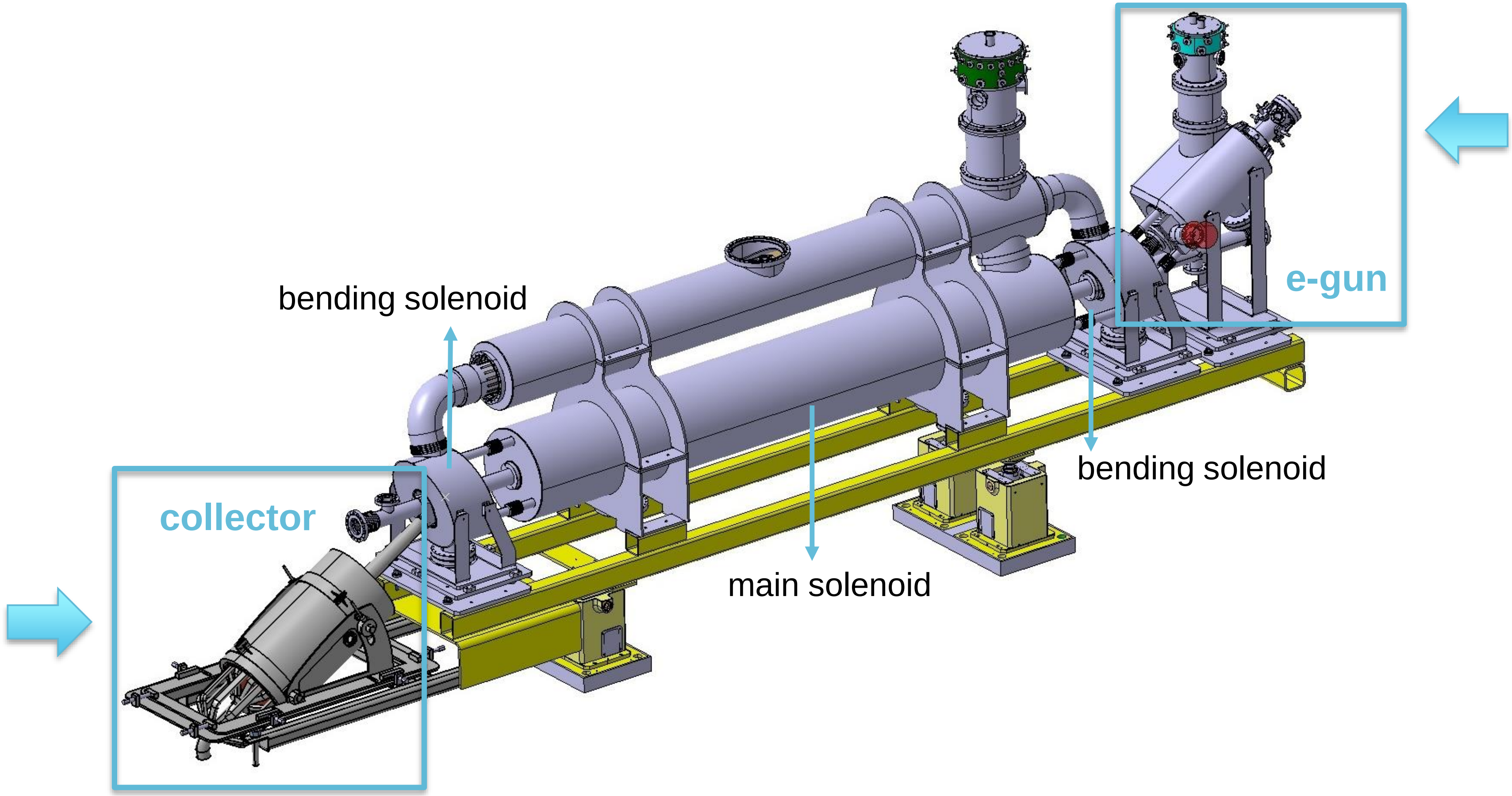
With the collaboration of: G. Stancari (FNAL), A. Rossi, S. Redaelli

Outline

- Introduction
- E-gun
  - Functioning - cathode
  - E-gun design development
  - FE Thermal analysis
- Collector
  - Design
  - FE Thermo-mechanical analysis
- Conclusions

Introduction



Aim: to present the state of art of the current design

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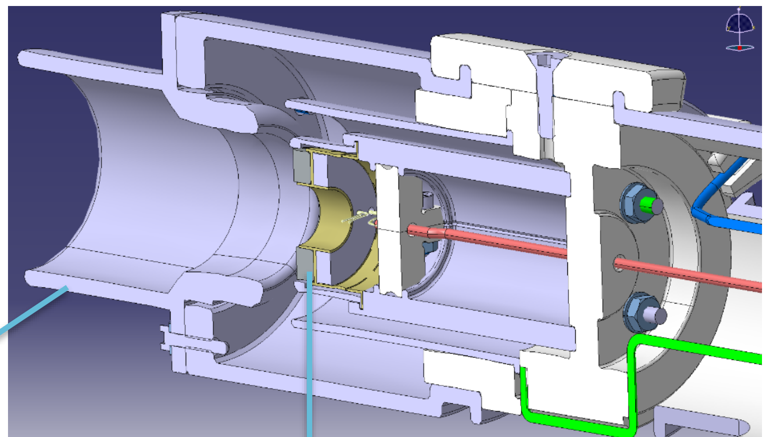
E-gun – Cathode



anode

cathode

- **Electron beam generated by hollow cathode**
- **Thermionic cathode**: electron emission T - activated

E-gun – Cathode parameters

HEL nominal parameter	
Magnetic field of the main solenoid $\mathbf{B_{MS}}$	4 T
Magnetic field in the e-gun $\mathbf{B_{GS}}$	0.2 T
Inner diameter of hollow electron beam	0.9 mm (3σ)
Outer diameter of hollow electron beam	1.8 mm (6σ)
Anode voltage **V**	10 kV
Current at cathode **I**	5 A

minimize field compression factor

$$\frac{R_{\text{beam,cathode}}}{R_{beam,MS}} = \sqrt{\frac{B_{MS}}{B_{GS}}}$$

A small cathode allows decreasing the field in main solenoid

Small cathode means **high current density**
→ material play a key role

BJUT (Beijing University of Technology)

Scandia-doped W cathode

D_e= 16.10 mm D_i = 8.05 mm

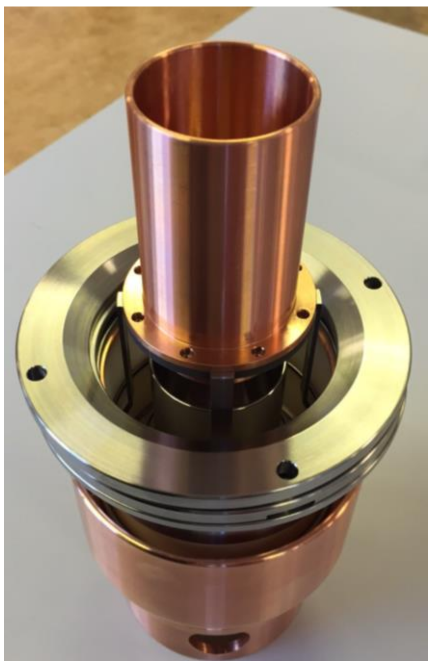
J = 3.3 A/cm^2

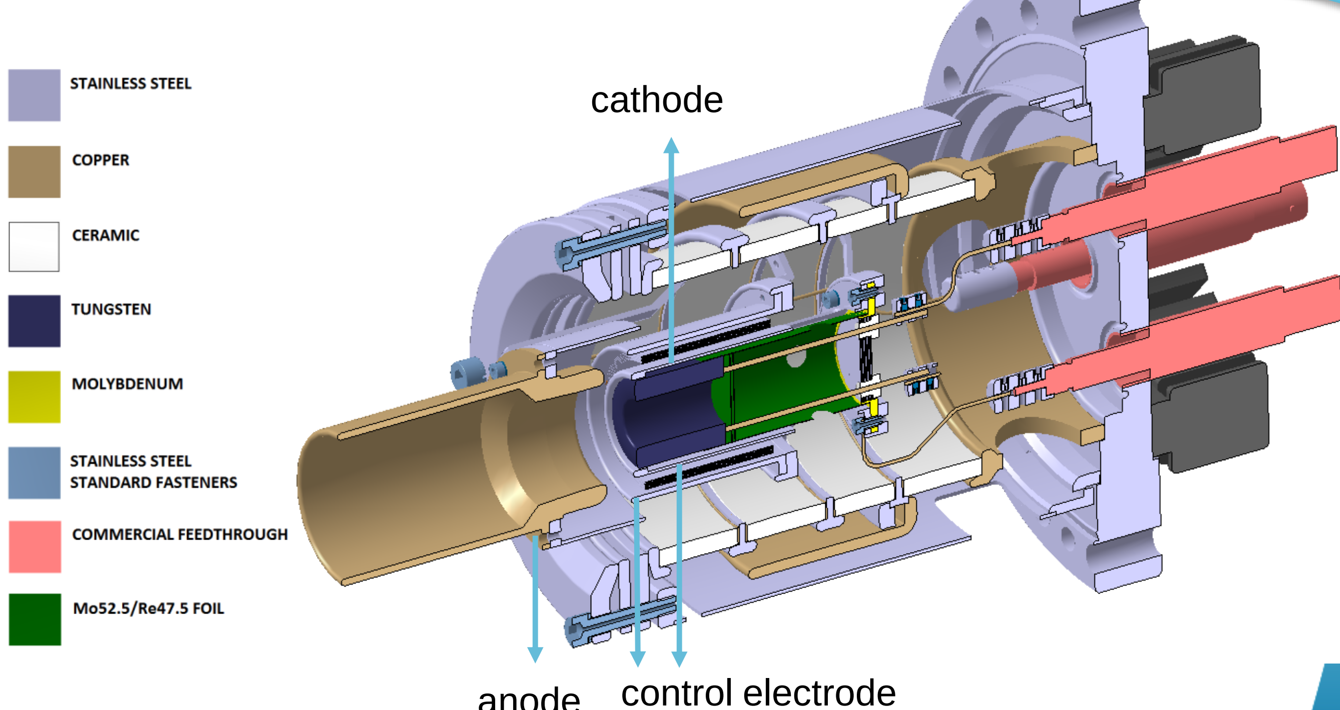
E-gun – FNAL e-gun design

First e-gun produced at CERN (EN-MME workshop)

- E-gun design: FNAL → few modifications added (different standards)
- Dispenser cathode HeatWave Labs (US)
- D_e = 25 mm D_i = 12.5 mm
- P = 6.14 μperv → 5.5 A @ 10kV

Successfully tested at FNAL

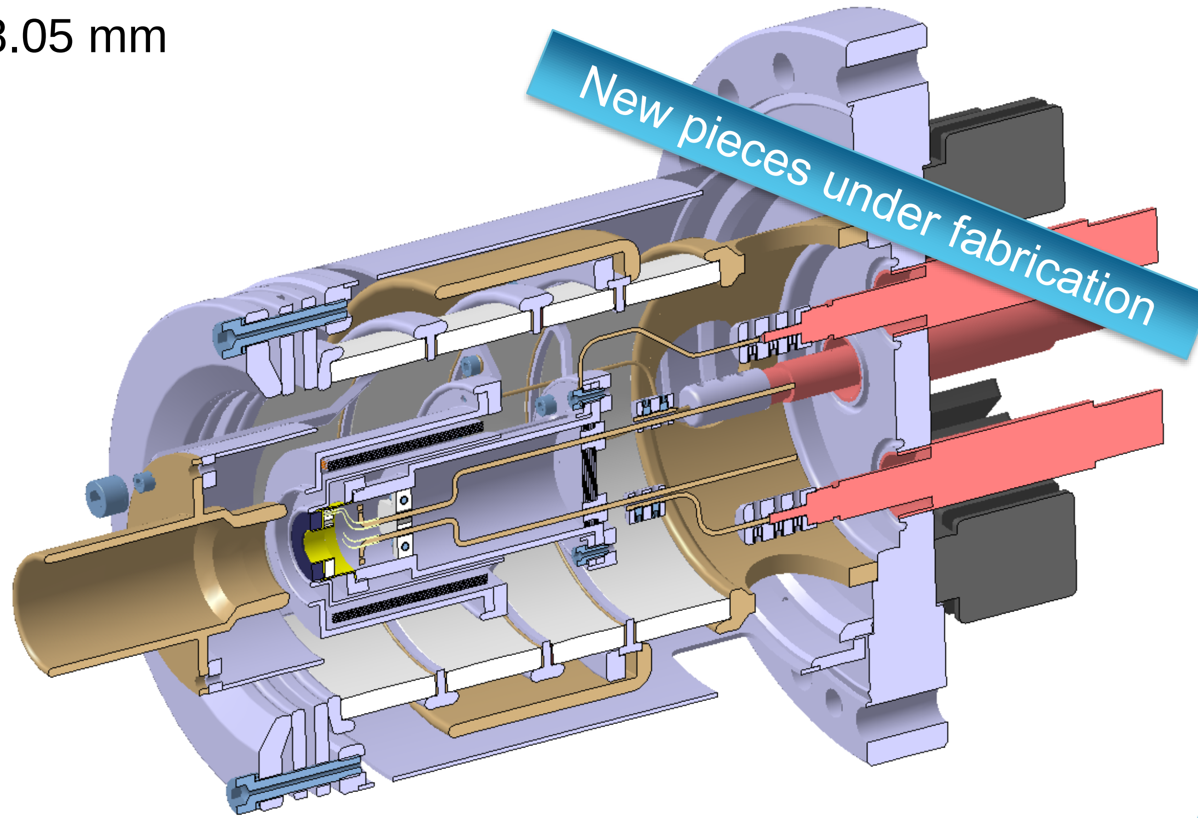




E-gun – HEL cathode dimension in FNAL design

Second e-gun: to adjust the design to fit in the HEL nominal dimension cathode by maintaining the same perveance (5 A – 10 kV)

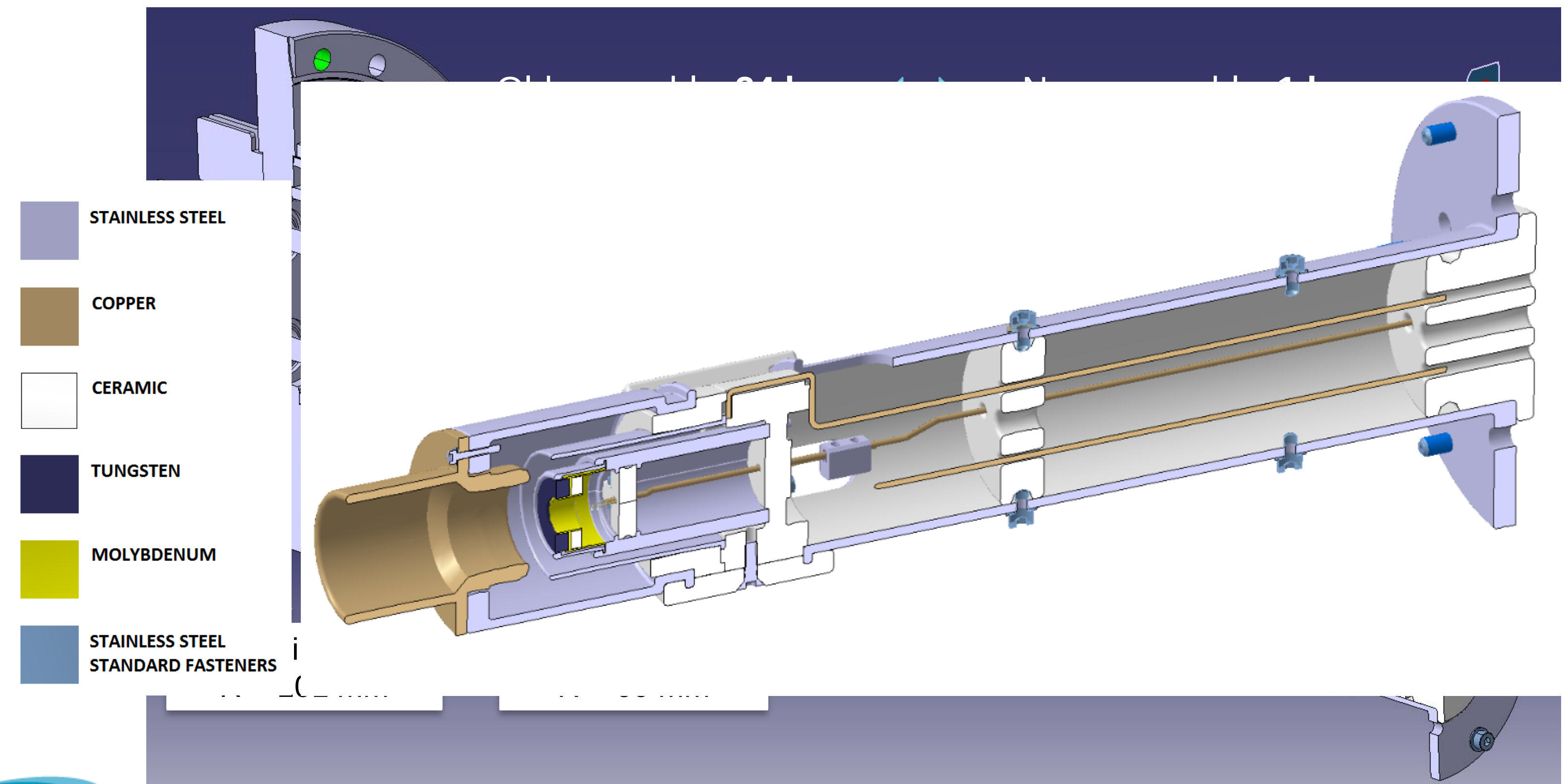
- E-gun design: FNAL
- Dispenser cathode BJUT (Beijing University of Technology)
- D_e = 16.10 mm D_i = 8.05 mm
- Not tested yet



E- gun – HEL nominal dimensions CERN design

Third e-gun: compact design with minimum number of components possible

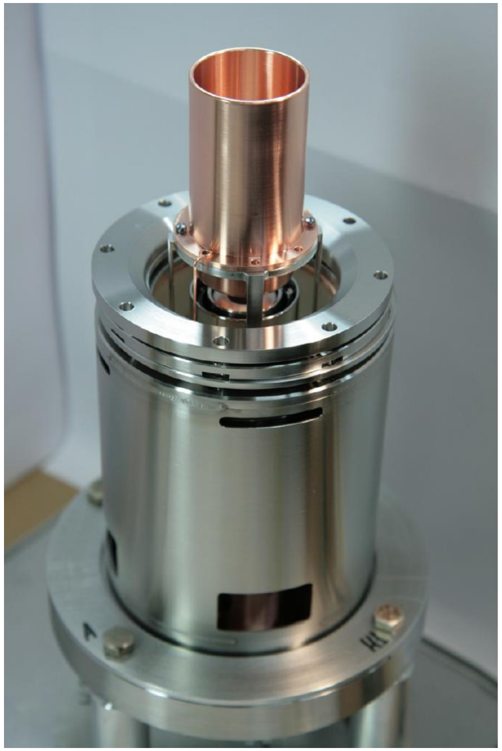
- E-gun design: CERN
- Dispenser cathode BJUT (Beijing University of Technology)
- D_e = 16.10 mm D_i = 8.05 mm

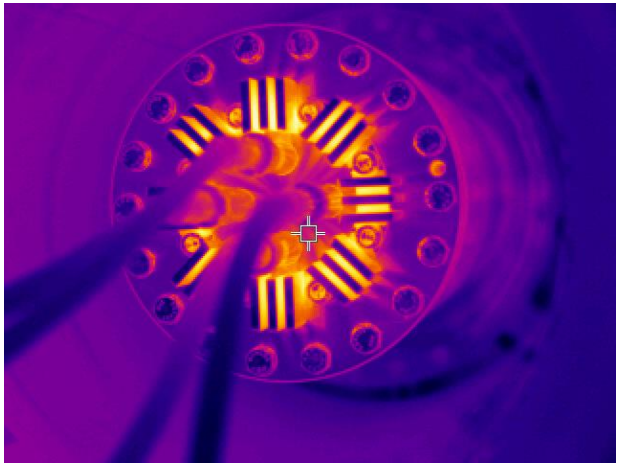


E-gun – FE thermal analysis

- Aim: FE thermal analysis to verify the thermal behavior of the materials inside the e-gun at high temperature
- Benchmark: outside temperature profile e-gun tested at FNAL

Model to be extended to the new CERN e-gun design





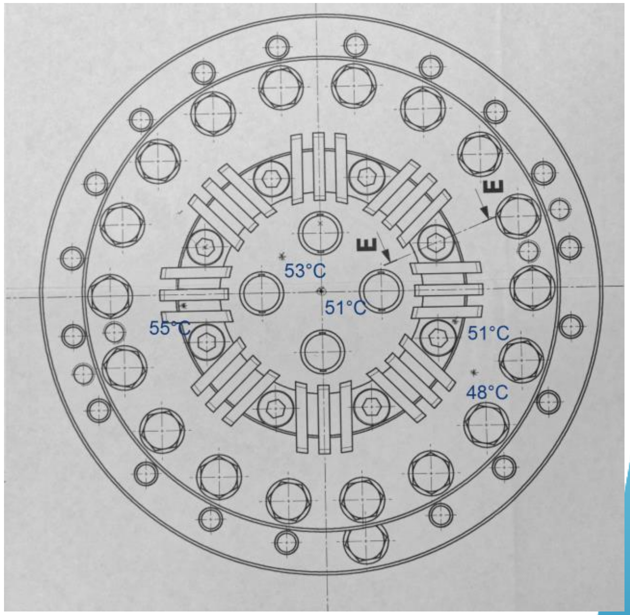
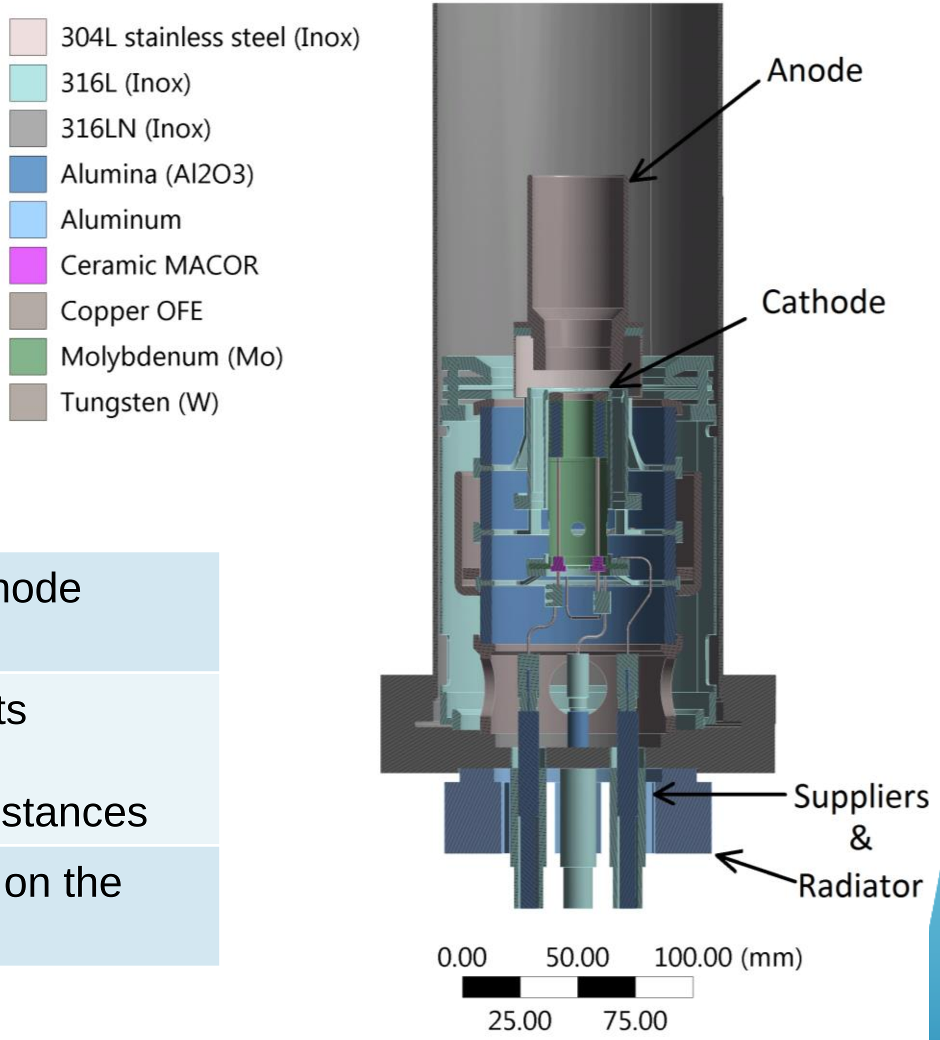


Photo Electron Gun from "Characterization of the CERN Hollow Electron Gun at the Fermilab electron-lens test stand" by Giulio Stancari

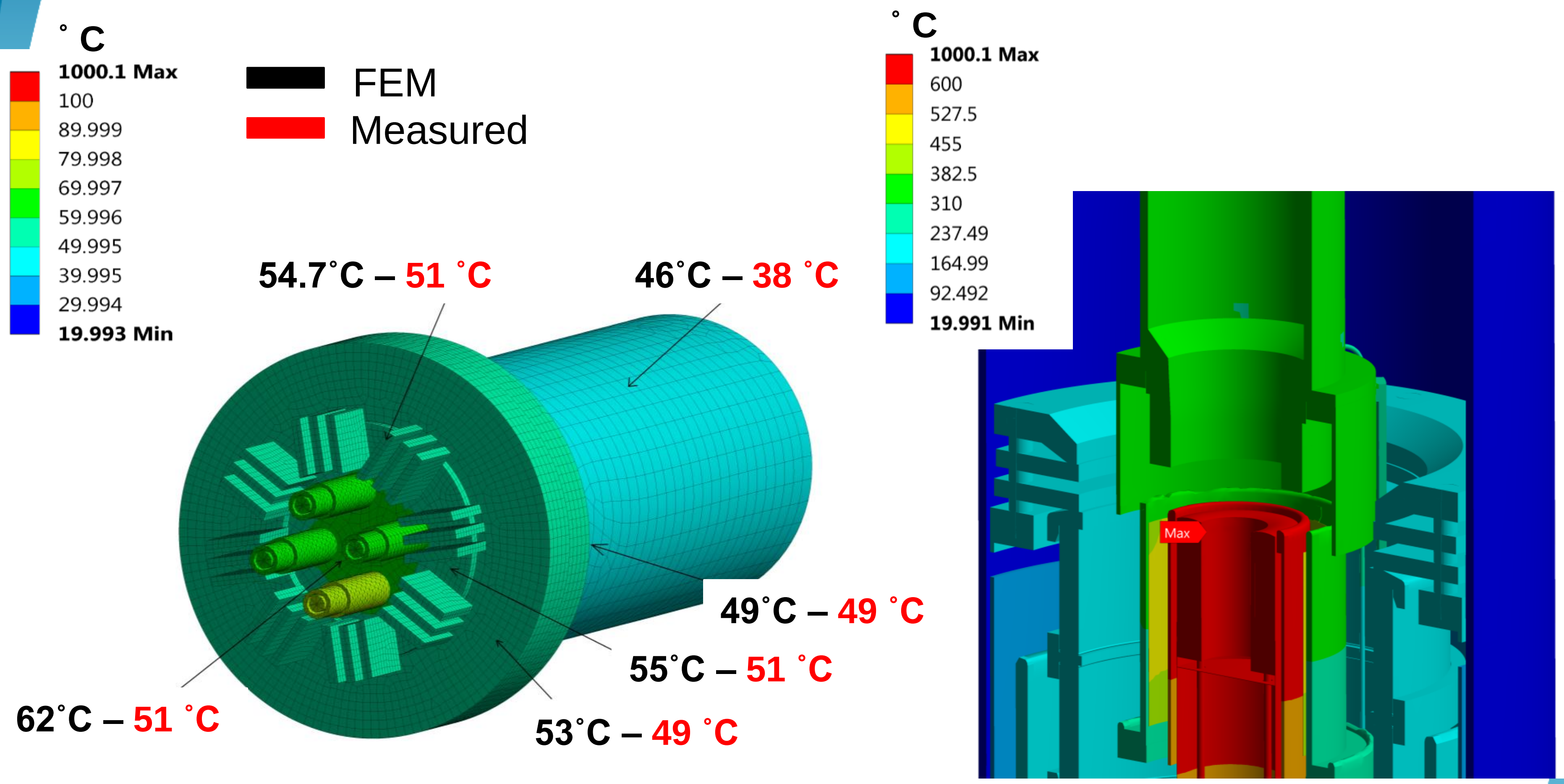
E-gun- FE thermal analysis

- Development of reliable thermal model to evaluate the behavior of different materials
- Sensitivity study of the model
- Outside temperature profile → benchmark



INPUT	1000 °C on tungsten cathode (~73 W)
PARAMETERS	• Convection coefficients • Materials Emissivity • Contact Thermal Resistances
OUTPUT	Temperatures measured on the outside cylinder

E-gun- FE thermal results



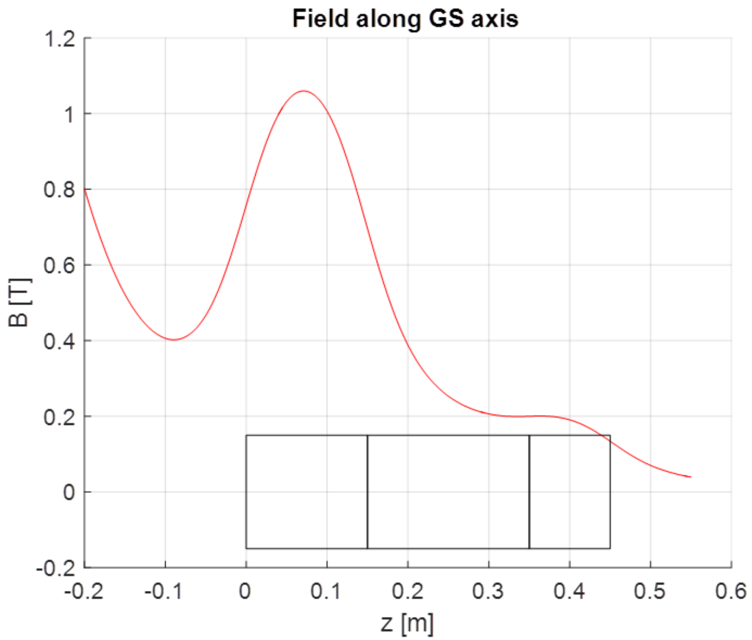
- Results within 5-10% with respect to experimental data
- Control electrode in Molybdenum

E-gun – Gun solenoid field

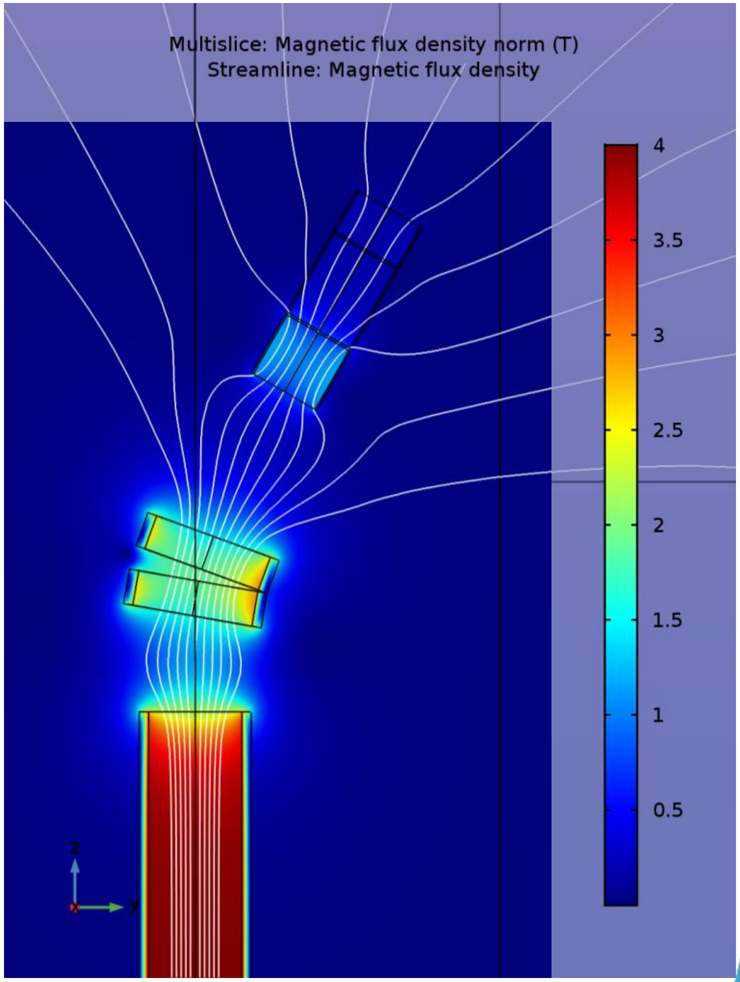
- Magnetic field around e-gun generated by **3 solenoids**

→ low sensitivity to cathode misalignment

→ increase electron beam stability



Currents optimized for flat axis field at cathode location



C. Zanoni COMSOL simulation

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  - Design evolution
  - Thermal analysis
- Collector
  - Design
  - Thermo-mechanical simulations
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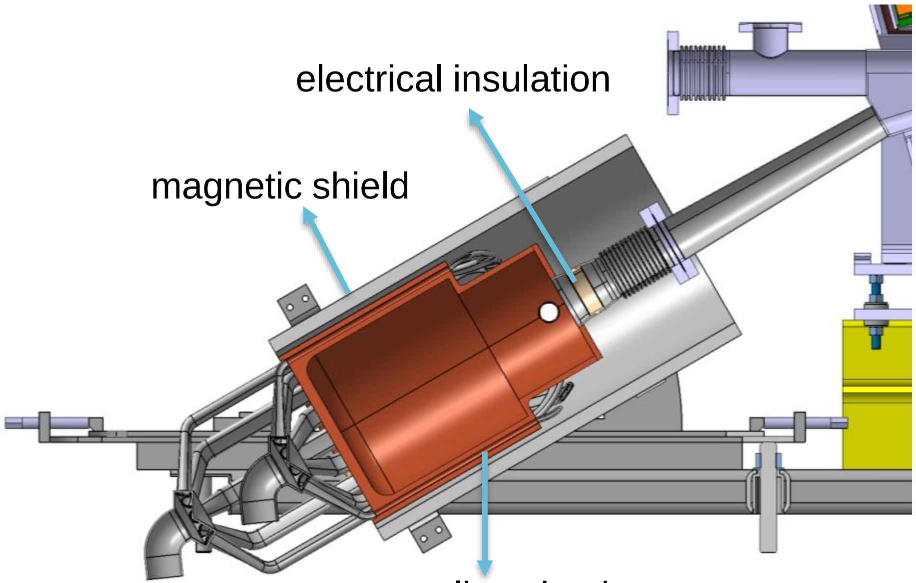
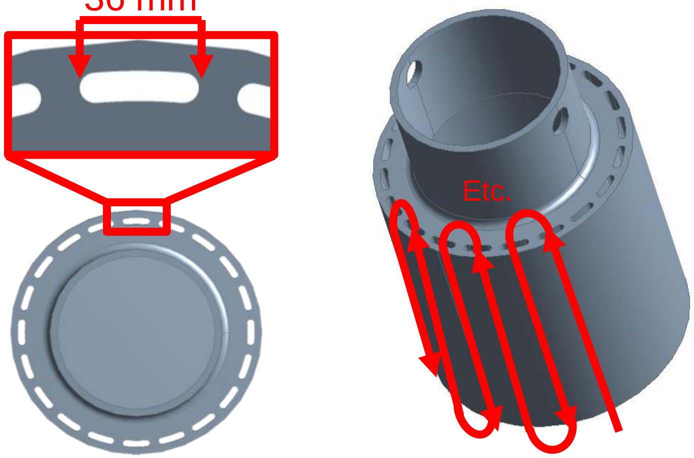
Collector – Functioning

- Collector: used to collect electron cloud and dissipate its energy
- Material: Cu alloy (e.g. ETP)
- Dimensions: 340xØ350 mm
- Power to absorb: **50 kW maximum value** (conservative)
  - →**Magnetic shield**
  - →**Electrical insulation**
- Active cooling via circulating water



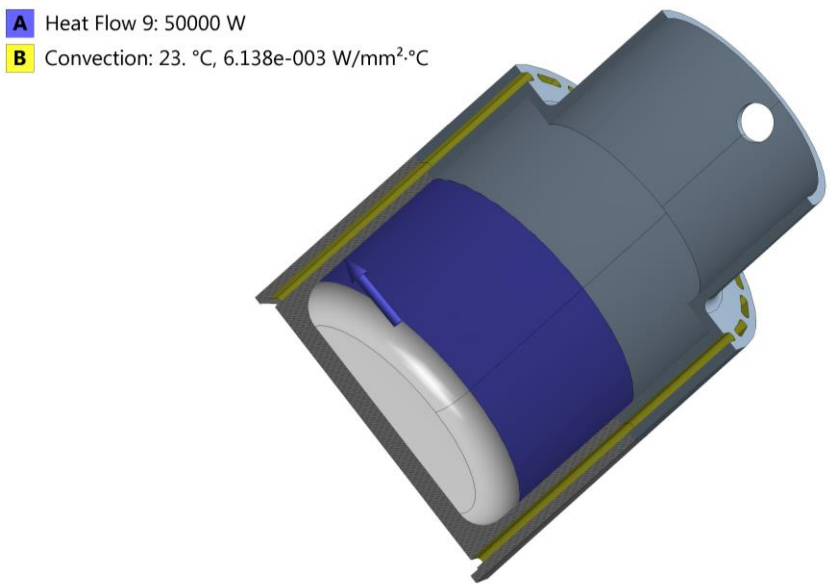
Restrictions:

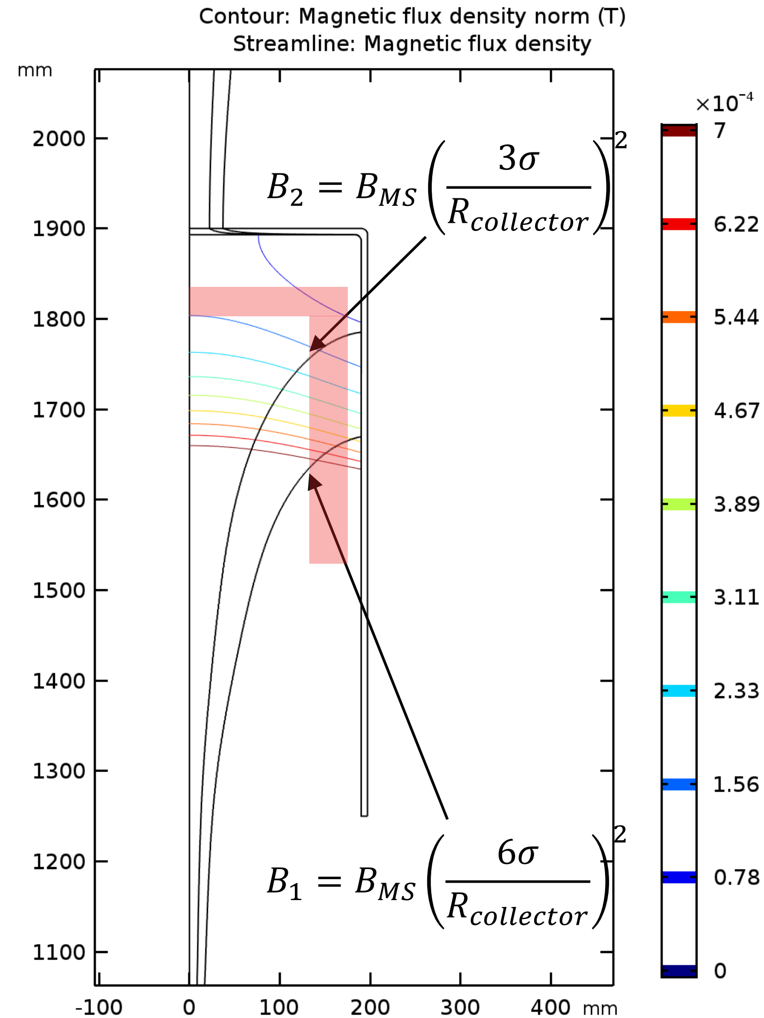
- Cu max temperature **< 90°C** for UHV compatibility
- Flow speed ≤ 1.5 m/s
- Size limitations



Collector – Load conditions

- All the power (50 kW) is dissipated in the collector → magnetic shield to open magnetic field
- A **7 mm mumetal shield** to deposit power deposited uniformly on a **150 mm long** cylinder





$\sigma \approx 0.3\ mm \quad B_{MS} = 4\ T \quad R_{collector} = 150\ mm$

C. Zanoni COMSOL simulation

Collector – FE thermal analysis

Load condition:

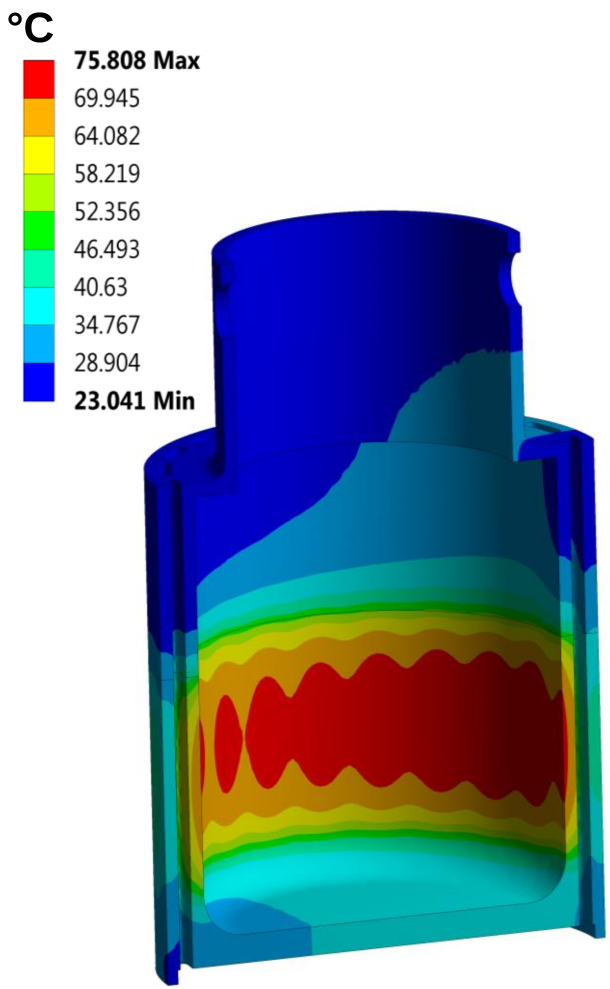
- Power 50 kW on 150 mm long collector portion

Boundary condition:

- Flow rate: 1.1 l/s
- Flow speed: 1.5 m/s
- Inlet temperature: 22°C
- Outlet temperature: 34°C

→ Maximum temperature: 76 °C

Cu T limit < 90°C ☑



Collector – FE structural analysis

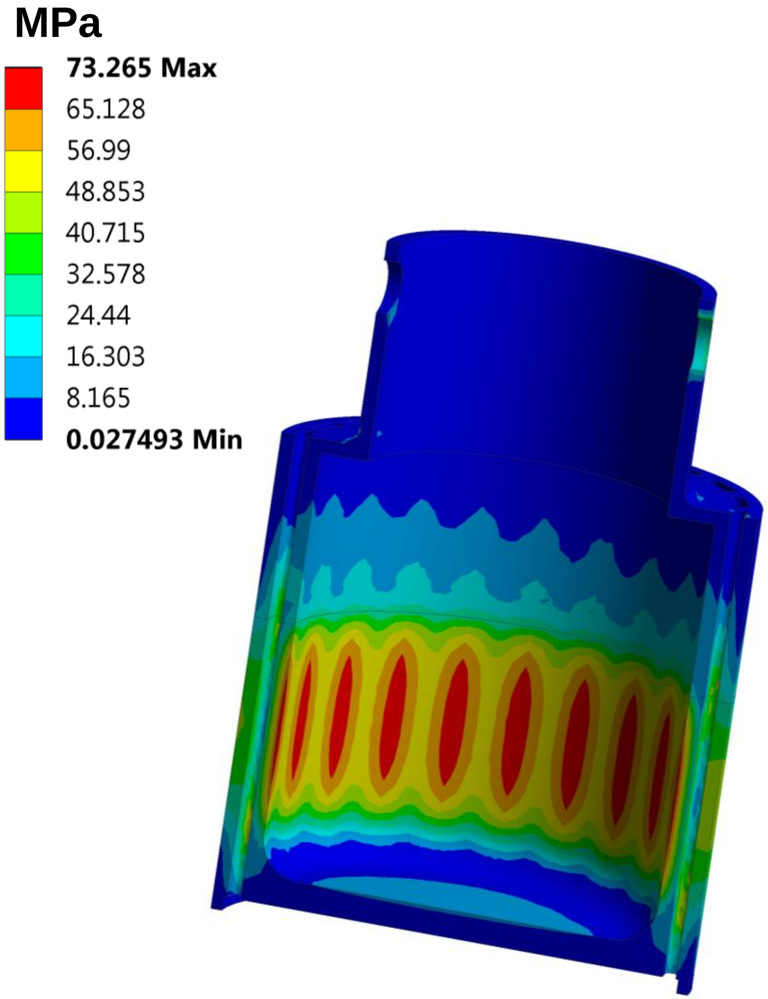
Load condition:

- Thermal gradient
- Vacuum
- Water pressure

Boundary condition:

- Flow rate: 1.1 l/s
- Flow speed: 1.5 m/s
- Inlet temperature: 22°C
- Outlet temperature: 34°C

→ Maximum stress 73 MPa ☑



Conclusions

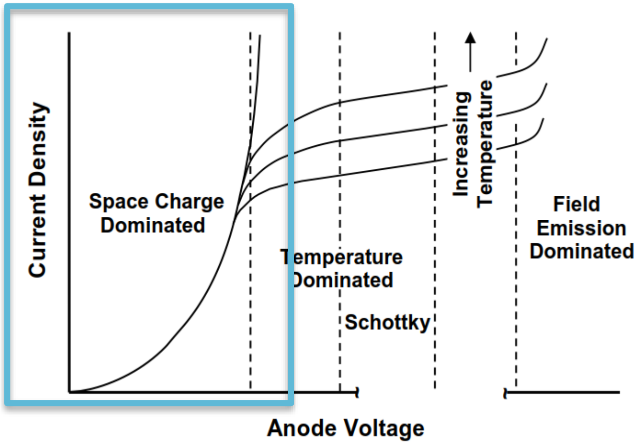
- **Know-how to built e-gun** transferred from FNAL to CERN → a first CERN e-gun successfully tested at FNAL
- An **optimization of the e-gun design** with HEL parameters proposed by CERN and to be tested in FNAL Test Stand
- The current design of the **collector is thermally and structurally verified**
- Further developments:
  - CERN design e-gun thermal analysis→ to validate design and materials
  - From full particle dynamics simulation outcome (A. Rossi)

    →Optimization of the cathode shape and dimensions

    →Update collector simulations with new load and position

Thank you for your attention

Perveance



Child-Langmuir law:

$$\mathrm{I} = \mathrm{P}V^{3/2}$$

$$I = JA \quad P = const \cdot \frac{A}{d^2}$$

A cathode area
d cathode-anode distance

Estimation of Nusselt Number

$$Nu_x = \frac{Total\ Heat\ Transfer}{Conductive\ Heat\ Transfer} = \frac{h_x x}{k}$$

- Value changes with flow temperature

1. ΔT is estimated

2. T_avg used to find fluid properties and Prandtl number

3. Using an estimation of flow speed, Reynolds number is calculated

4. Nusselt number is calculated using an appropriate correlation. In this case flow is turbulent so:

$$\mathrm{Nu} = 0.023 Re^{0.8} Pr^{0.4}$$

Ansys Detailed Iterative Estimation

- Model split into five sections
- Each section considered separately: