Update on LHC Electron Lens design

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Outlines

- Introduction
- Design of the main components
  - Main solenoid , cryostat
  - Gun and collector regions
- Conclusions

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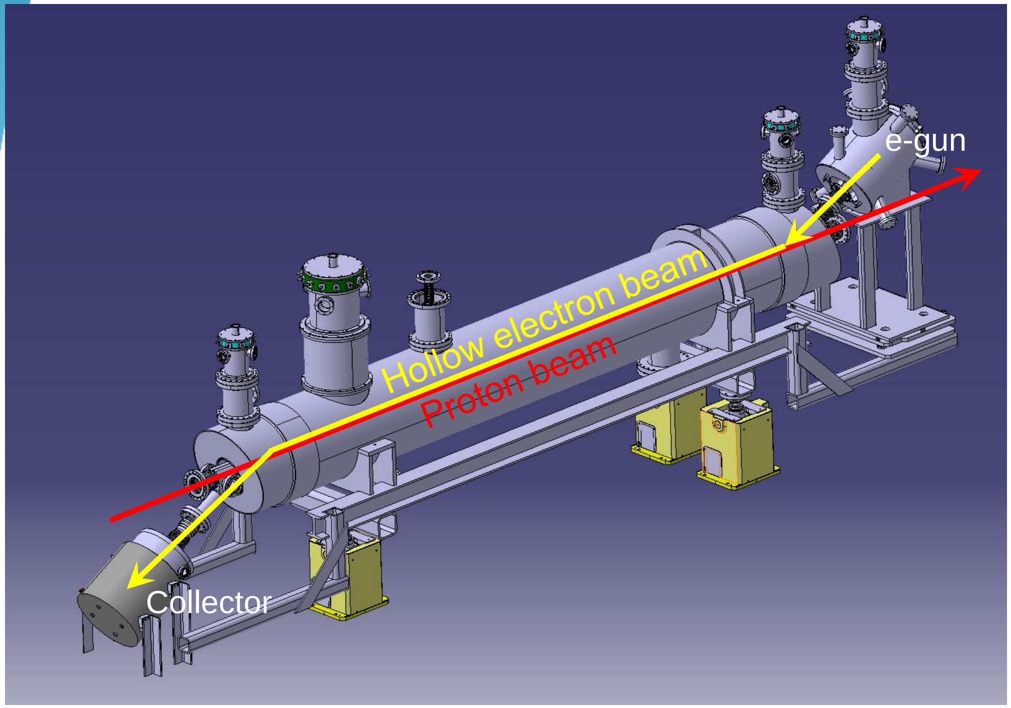
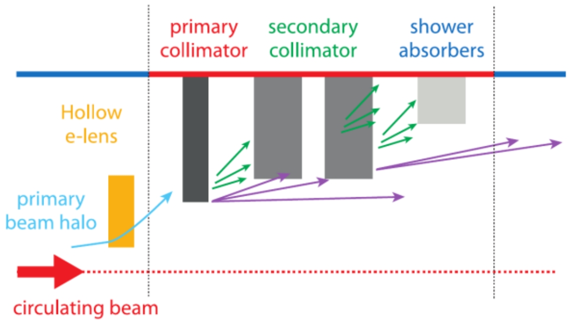
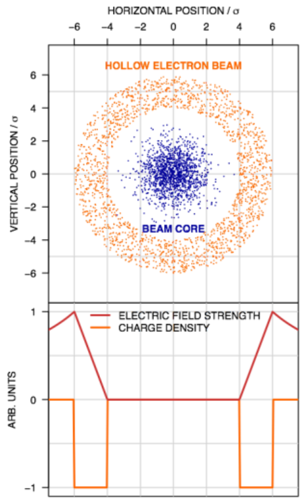
Introduction





The Hollow Electron Lenses will be integrated in the HL-LHC collimation system.
Halo particles are kicked to higher amplitudes by the electromagnetic field of the electron beam.

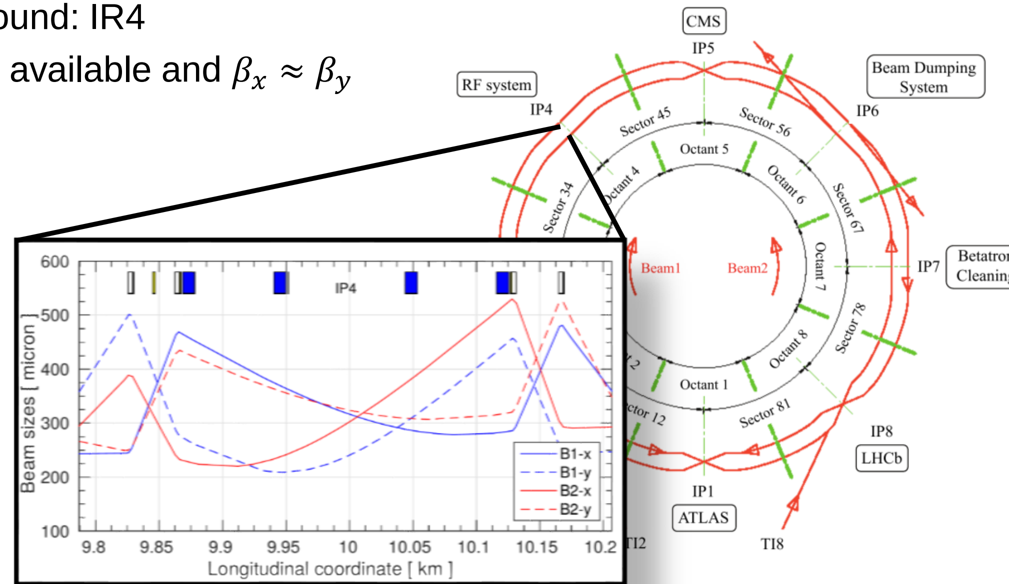


Electrons are generated by the cathode of an e-gun.
They travel along the proton beam
They are intercepted by the collector.
Superconducting solenoids cooled at 4.2 K generates the field to steer the electron trajectories.

Introduction

- Best place found: IR4
  - Space available and $\beta_x \approx \beta_y$

Candidate locations for the electron lenses are RB-44 and RB-46 at Point 4, on each side of the interaction region IR4.

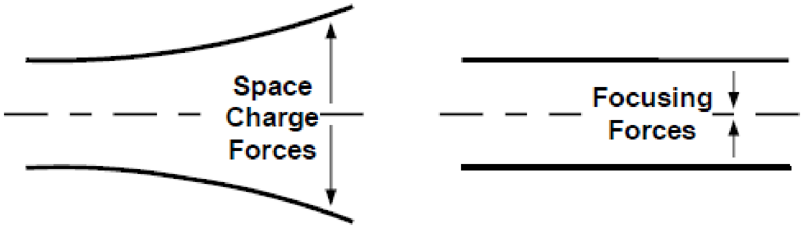


The beam to beam distance is 420 mm.
The longitudinal available space is limited

Compact design
Simple construction and maintenance.

Intensity and size of the e-beam required for HL-LHC are demanding

Introduction



The field level determines the radius of the e-beam. The dimensions of the electron beam in two points along its path follow the equation:

$$\frac{r_0}{r_1} = \sqrt{\frac{B_1}{B_0}}$$

Where r_0 and r_1 are the radii of the electron beam in point 0 (cathode) and 1 (main solenoid) and B_0 and B_1 are the magnetic field in points 0 and 1 respectively.

But:

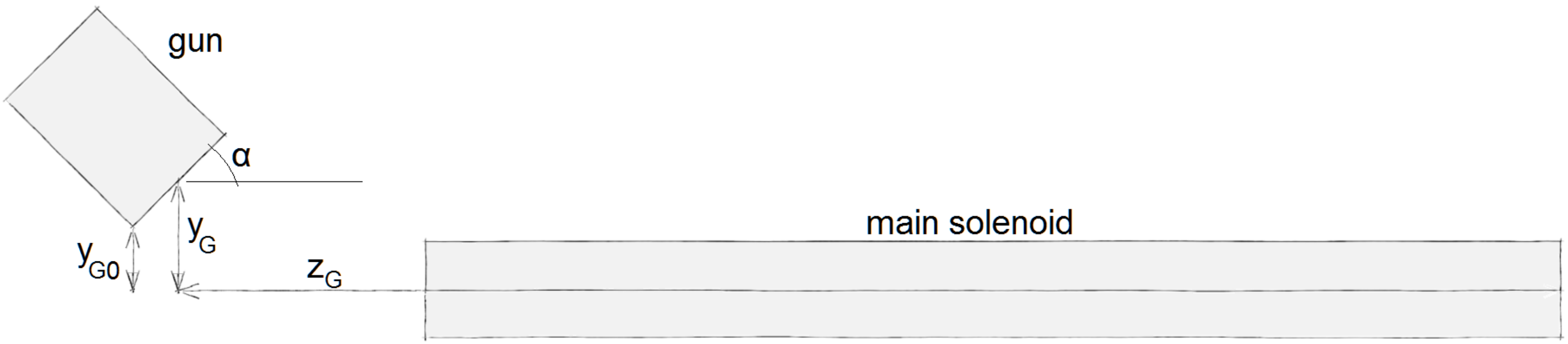
- The HEL must be compact, magnetic fields must be reasonable.
- Field seen by electrons must be always larger than 0.15 – 0.20 T.
- Dimensions of the cathode must be technically feasible.
- When the ratio of fields changes the relative position of the solenoids changes.

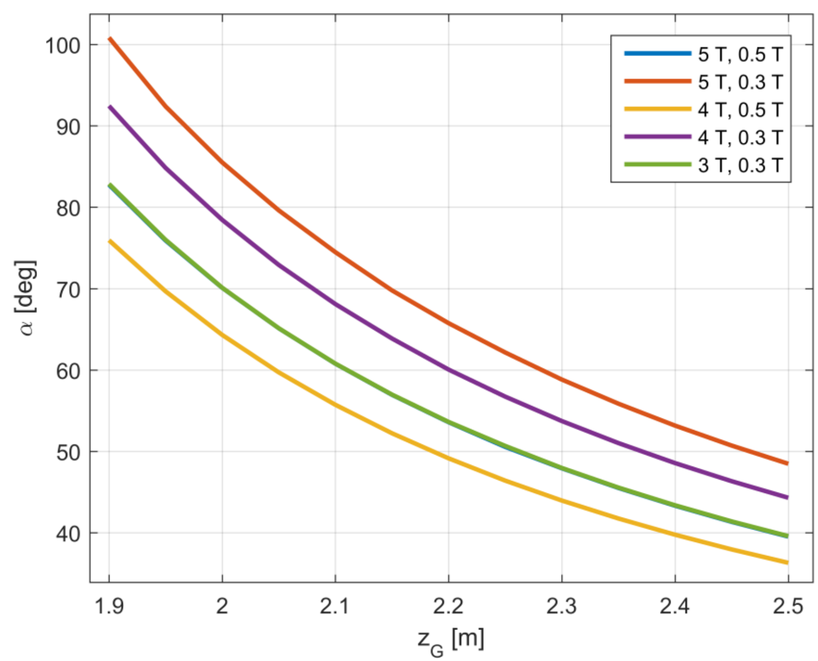
Despite the use of corrector and of an independent solenoid for the e-gun

The range of achievable field ratios is limited

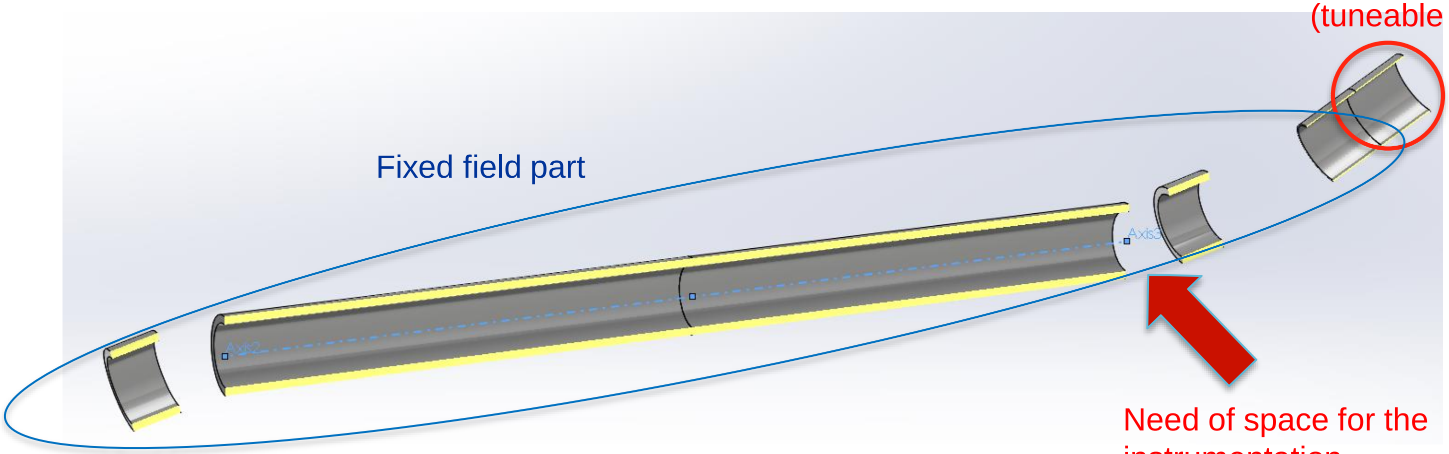
Introduction

The electrons travel along the e-gun solenoid longitudinal axis and must enter in the main solenoid along its longitudinal axis.
For different field ratios the optimal longitudinal position Z_G and the inclination angle α change.





Design of the main components



Nominal magnetic field of the main solenoid	4 T
Inner radius of the hollow electron beam @ nominal fields	0.9 mm
Outer radius of the hollow electron beam @ nominal fields	1.8 mm
Nominal magnetic field in the e-gun cathode	0.2 T
Inner diameter of the cathode	8.05 mm (*)
Outer diameter of the cathode	16.10 mm (*)
Inner radius of the hollow electron beam @ 4 T with 2 T @ cathode	5.7 mm
Outer radius of the hollow electron beam @ 4 T with 2 T @ cathode	11.4 mm
Nominal current at the cathode	5 A

Use at the injection.

(*) A 25 mm outer diameter cathode would require a 5T central solenoid and a 0.1 T at the e-gun cathode. 0.1 T is not enough.

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Design of the main components

Main parameters of the superconducting solenoids
(operating temperature 4.2 K)

All coils are wound using Nb-Ti wire. The insulated wire has a rectangular cross section of 1.65 mm x 1.05 mm with a copper to superconductor area ratio of 4. The critical current measured at 5 T and 4.2 K is at least 750 A.

Main solenoid	
Total length	3 m
Number of turns (per layer and per m of length)	606
Number of layers of superconductor	16
Total thickness of the coil (after curing)	~ 21 mm
Coil inner diameter	200 mm
Nominal field	4 T
Maximum operation field	5 T
Current at 4 T	330 A
Inductance (total for the 3 m)	3 x 3.71 H

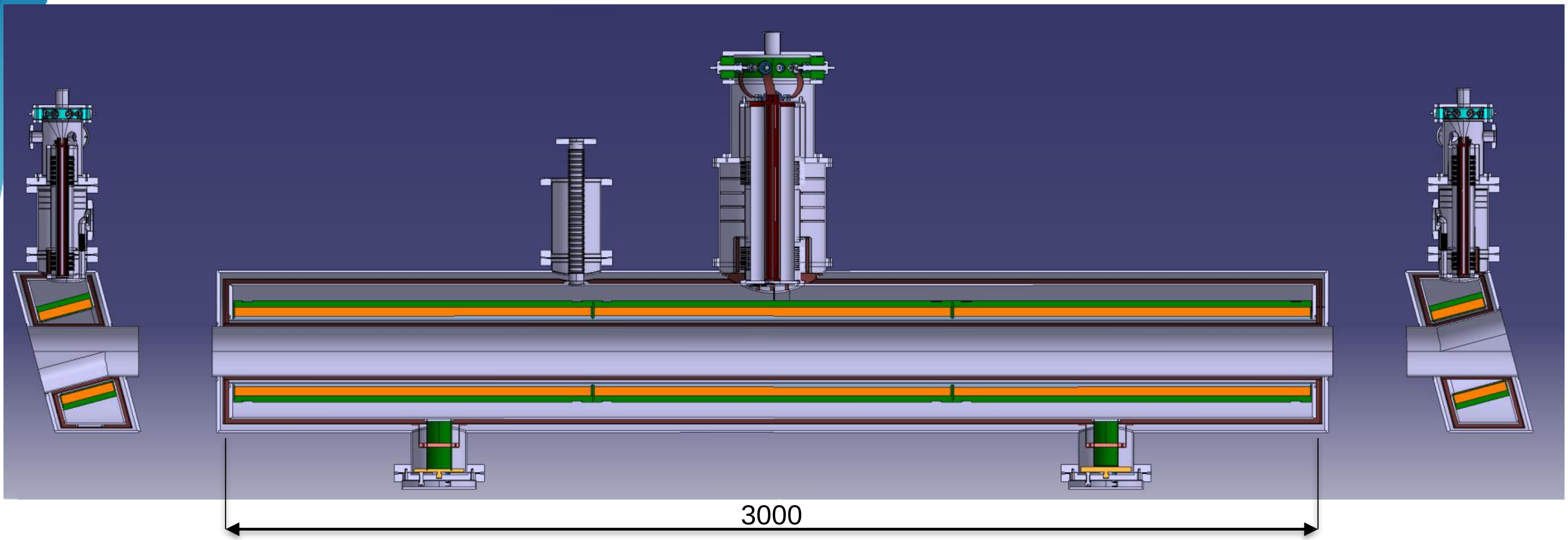
Bending solenoids (2 coils)	
Total length	0.15 m
Number of turns (per layer)	91
Number of layers of superconductor	16
Total thickness of the coil (after curing)	~ 21 mm
Coil inner diameter	220 mm
Current (with main solenoid at 4 T)	330 A
Inductance	0.66 H

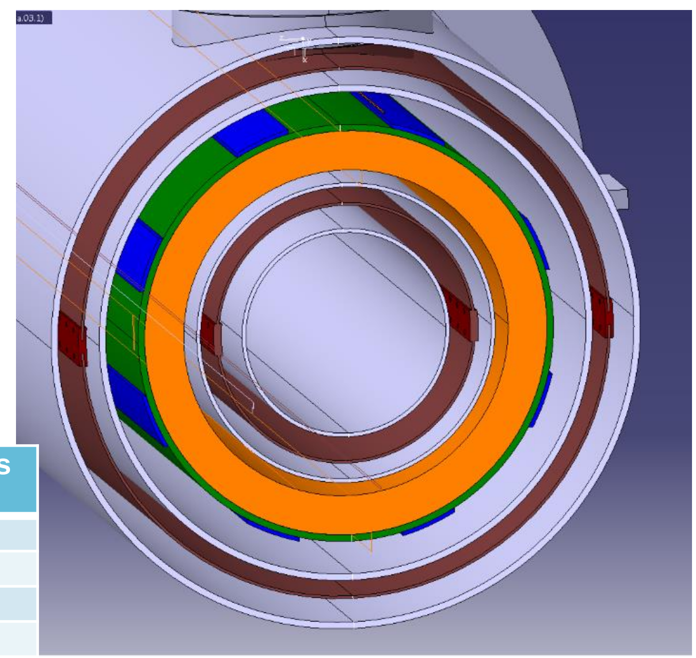
Gun solenoid - constant field part	
Total length	0.2 m
Number of turns (per layer)	121
Number of layers of superconductor	5
Total thickness of the coil (after curing)	~ 6 mm
Coil inner diameter	220 mm
Field with 94 A	0.4 T
Maximum operation field	0.6 T
Nominal current	106 A
Inductance	0.09 H

Gun solenoid – Cathode (tuneable part)	
Total length	0.2 m
Number of turns (per layer)	121
Number of layers of superconductor	5
Total thickness of the coil (after curing)	~ 6 mm
Coil inner diameter	220 mm
Nominal field	0.2 T
Maximum operation field	0.6 T
Current at 0.2 T	54 A
Inductance	0.09 H

Cable size, number of turns, nominal currents, inductances are reasonable achievable parameters. They could change in function of the industrial standards and the know how of the producer.

Design of the main components





Cross section of the HEL cryostat. In the centre there is the bore for the room temperature vacuum chamber (not shown here). The bore diameter is 135 mm. Then from inside to outside in grey the room temperature vacuum tank, in brown the thermal screen, in grey the helium tank wall, in orange the main solenoid, in blue the corrector coils generating a horizontal and a vertical dipole. Then follow the helium tank wall, the thermal screen and the vacuum tank. The overall external diameter is 454 mm.

Type	Heat On Cold Mass (4.2K)
G10 Supports	0.24 W
Radiation	0.68 W
Current Leads	4.51 W
Instrumentation	1.00 W

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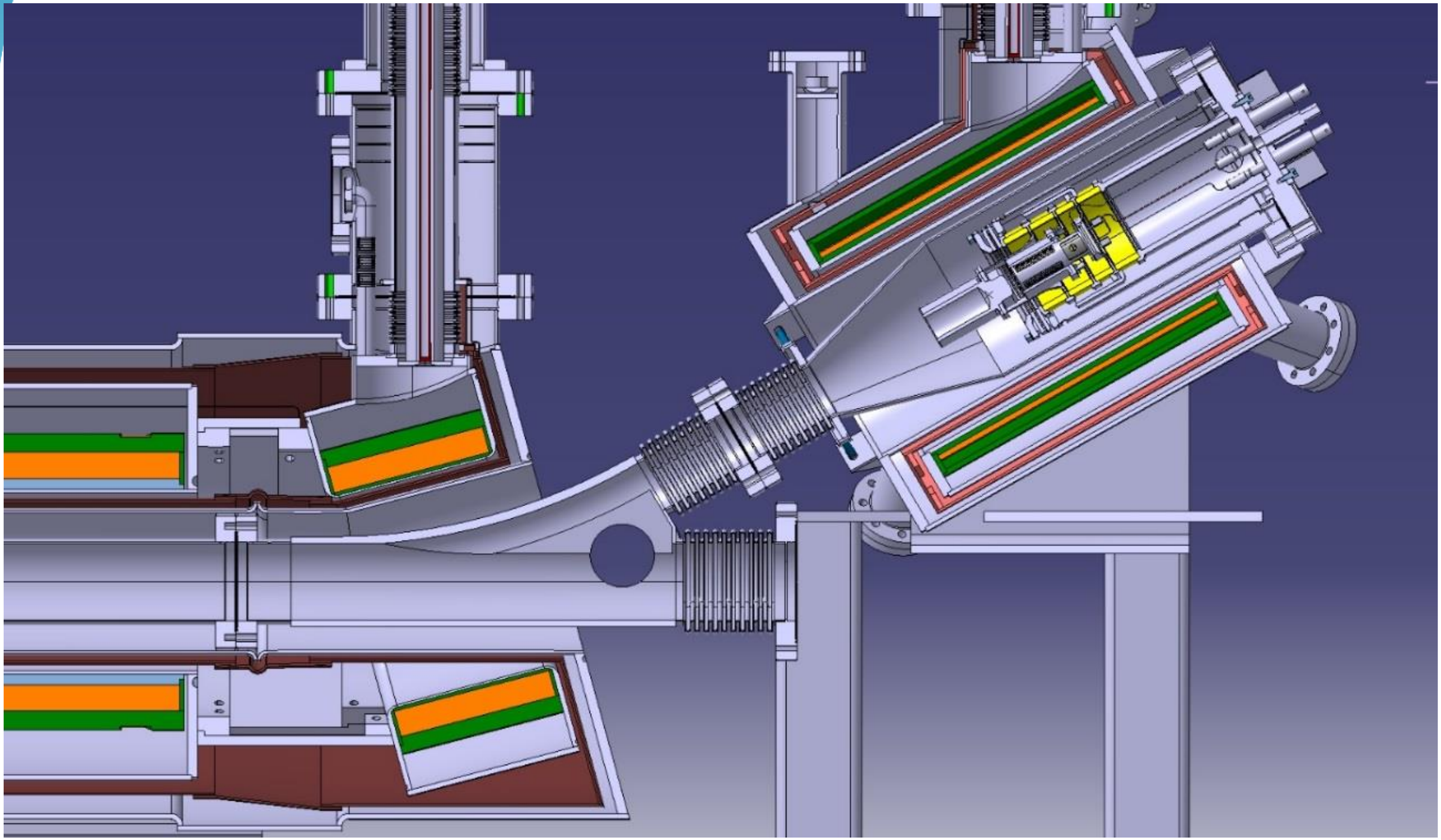
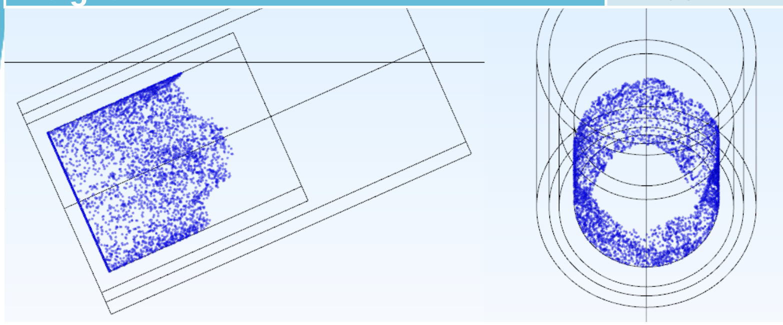
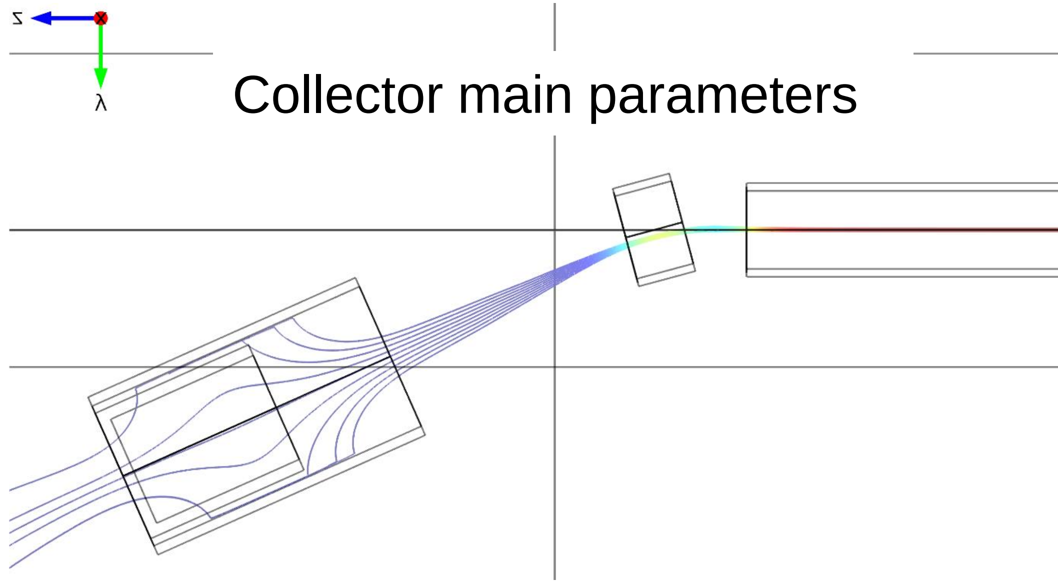


Design of the main components

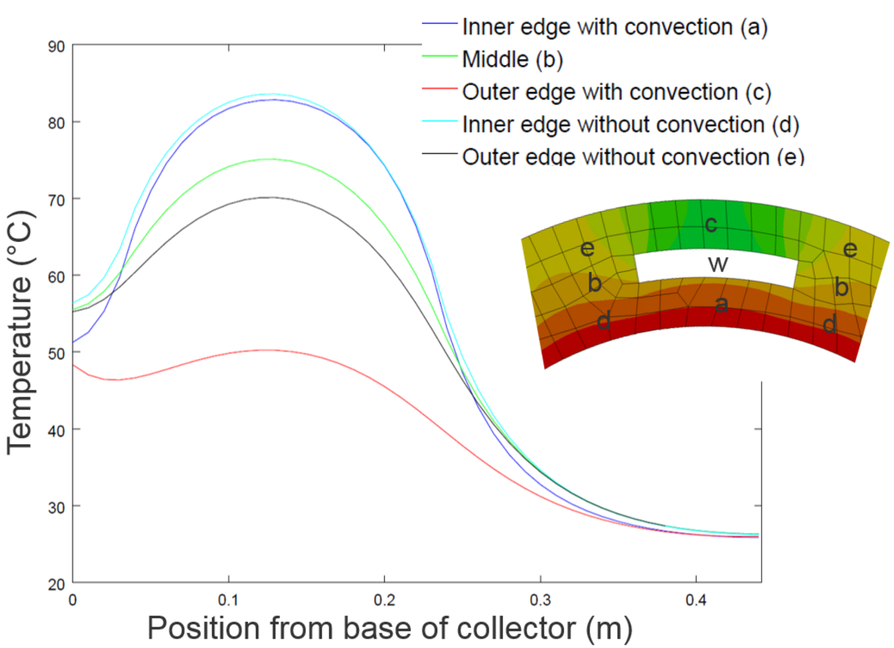
Collector in ETP copper	
Maximum power absorbed	50 kW
Maximum temperature	85ºC
Maximum speed of the cooling water	1 m/s
Water flux	8 l/s
Inner diameter	145 mm
External diameter	175 mm
Height	400 mm

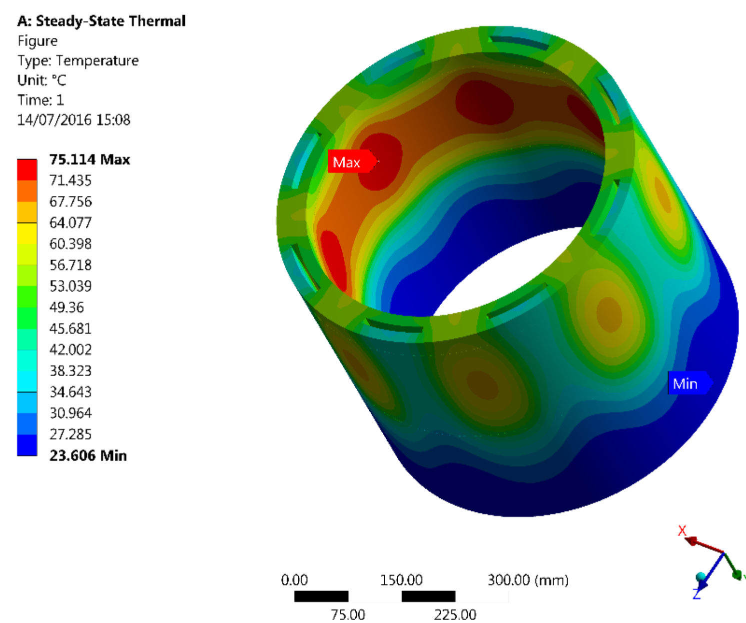


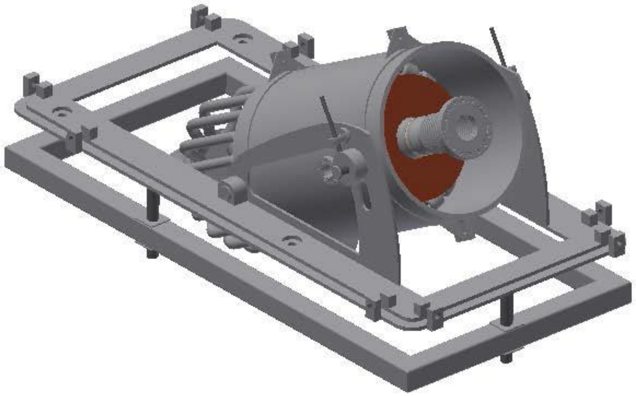
Collector main parameters



5 A , 10 kV => 50 kW of power to absorb

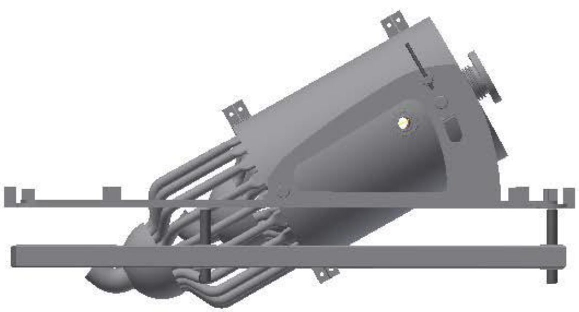


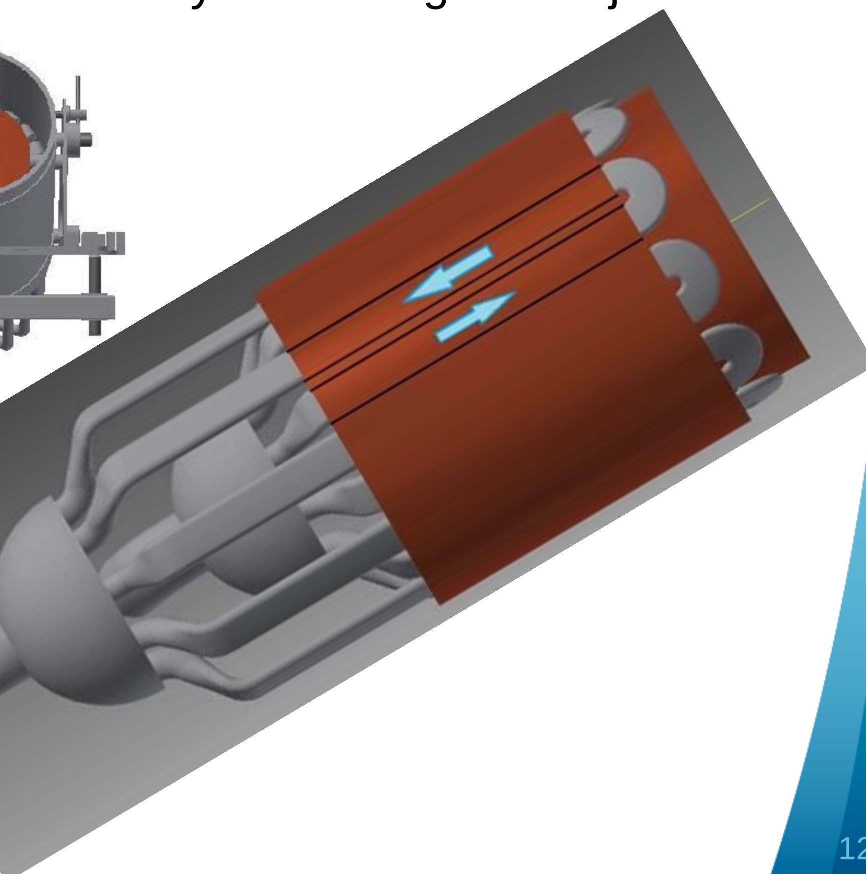




Collector and cooling circuit configuration (collaboration with LUAS Kemi).

Possibility of few degrees adjustment





Conclusions

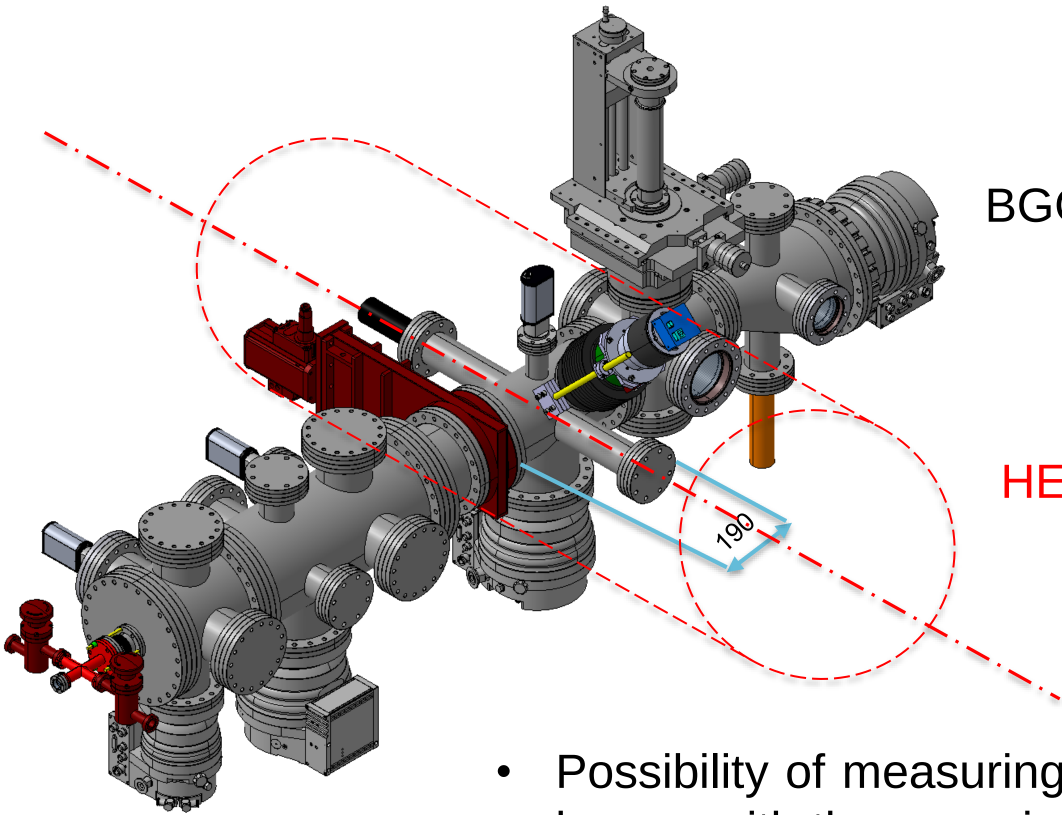
The situation today:

- The field configuration and consequently the magnet system is defined.
- We have a ‘reasonable’ solution that can be discussed with suppliers / in kind contributors. Drawings will be ready in few weeks.
- At this stage it is useless to go deeper into construction details. It is better to discuss these points with the manufacturers.

- The geometry has to be validated / approved from the beam dynamic view point. The computations we did do not consider the space charge effect.
- There is the possibility of tuning a bit some parameters (field, angles, cathode size) to fulfil the requirements coming from the previous point.
- This is final tuning of the mechanical structures, not re-design. It requires a few computations and we have all the analysis models ready.

Spare slides

Instrumentation:
Beam Gus Curtain (E. Barrios, G. Schneider, R. Veness)



BGC <u>test</u> layout.

- Possibility of measuring the position of the two beams with the same instrument.

- It will take time to develop the prototype.
- It has to be included / integrated in the HEL.

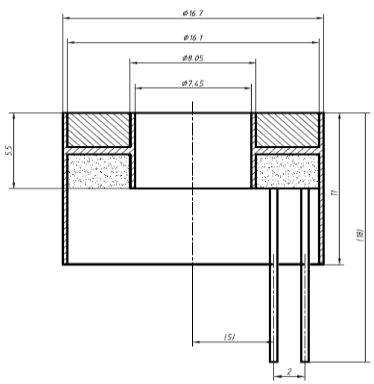
Test programme for guns and cathodes

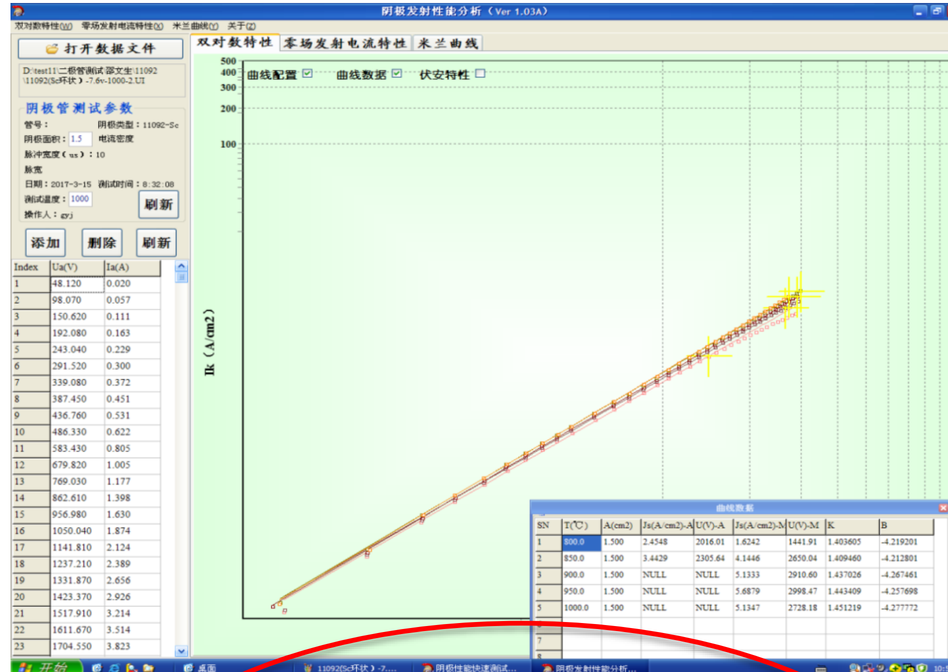
- ✓ Test of the e-gun with a 25 mm cathode from a Heatwave.
  Almost finished.
- ✓ Test of the e-gun with a 25 mm cathode from Ceradyne.
  Cathodes under production. Tests after summer.
- ✓ Test of the ‘minimum modification’ e-gun with a 16 mm cathode from BJUT/BVERI
  Cathodes ordered. Delivery end of the year.
  Drawings for gun modification ready.
  Gun parts will be produced soon.
- ✓ Test of a ‘small’ e-gun with a 16 mm cathode from BJUT/BVERI.
  Cathodes ordered. Delivery end of the year.
  Drawings of the gun ready.
  Gun designed and built by the end of the year.

- ✓ Test of a ‘small’ e-gum with a 9 mm cathode from BJUT.
  Cathodes ready by end of the year (coll. with BJUT)
  Gun designed and built by the end of the year

First nice results of the 16-mm test cathode obtained by BJUT / BVERI

Cathode No：001# Type：Scandate
Outer diameter: 16.1mm
Internal diameter：8.05mm Emission Area :1.5cm^2;





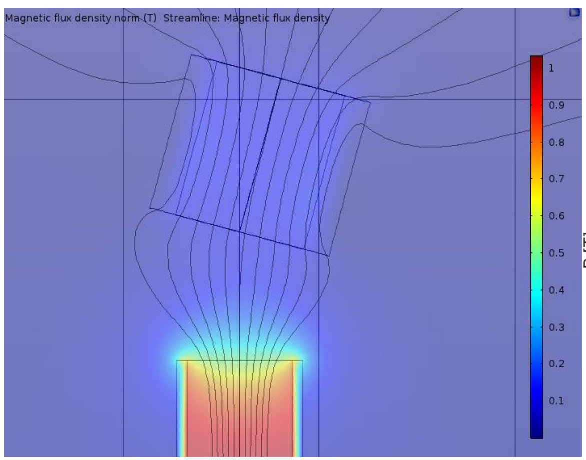
T(°Cb)	Saturation Current density J a（A/cm²）
800	1.6
850	>4.1
900	>5.1
950	>5.7
1000	>5.1

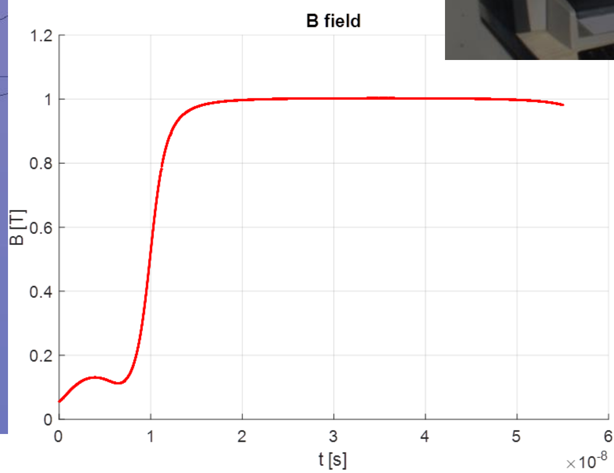
All pictures: courtesy of BVERI Beijing

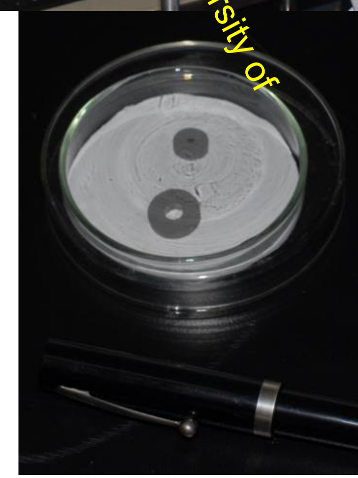
E-guns, cathodes, production tests

BJUT Beijing is developing a scandate cathode 4 mm / 8 mm. First test carried out on a 3 mm / 9 mm cathode shows that they have the necessary current density to reach 5 A.

Smaller cathodes means lower magnetic fields, simpler protection, less powerful power supplies and simpler construction.







This is not the baseline. But I think it can be useful to dedicate a bit of time to this possibility.

Thank you for your attention