HEL design, magnet system, e-beam generation and disposal

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

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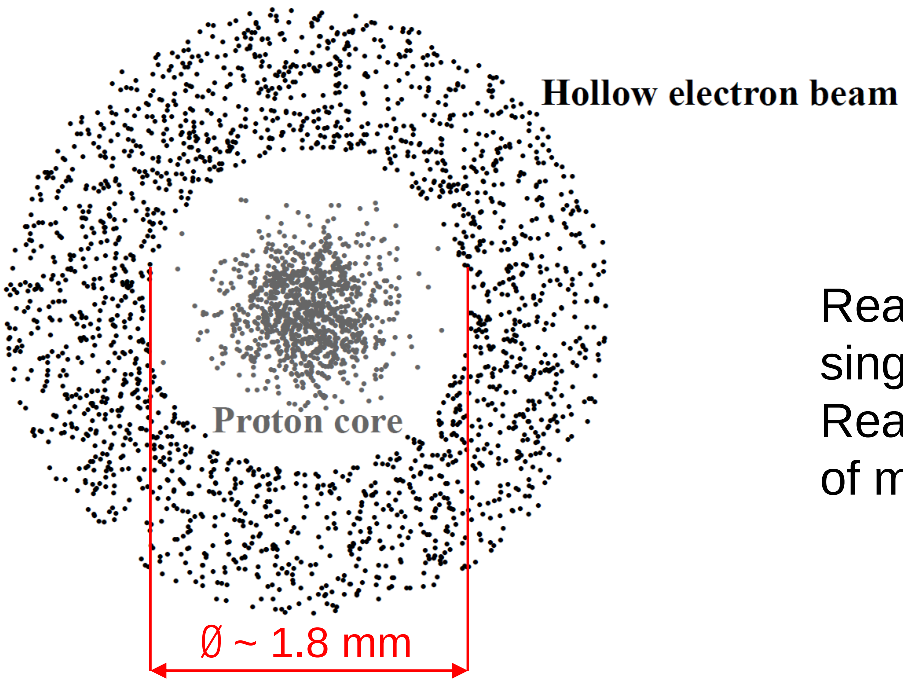
Giulio Stancari (FNAL)
Stefano Redaelli, Adriana Rossi, Glyn Kyrby, Giorgia Gobbi, Carlo Zanoni, Antti Kolehmainen (CERN).

Outlines

- Introduction
- Main parameters
- Design of the main components
  - Solenoids , cryostats
  - Gun and collector regions
- Conclusions

More details in the presentations of Glyn Kirby and Giorgia Gobbi in the afternoon

What do we want to do?



Off-centre of the ring ± 0.15 mm

Reasonable precision of a middle size single component: ± 0.05 mm.
Reasonable precision of an assembly of many components: ± 0.2-0.5 mm.

Beam-beam overlapping: ~3m , e current intensity: 5 A.
Use at injection and at collision level.

Where?

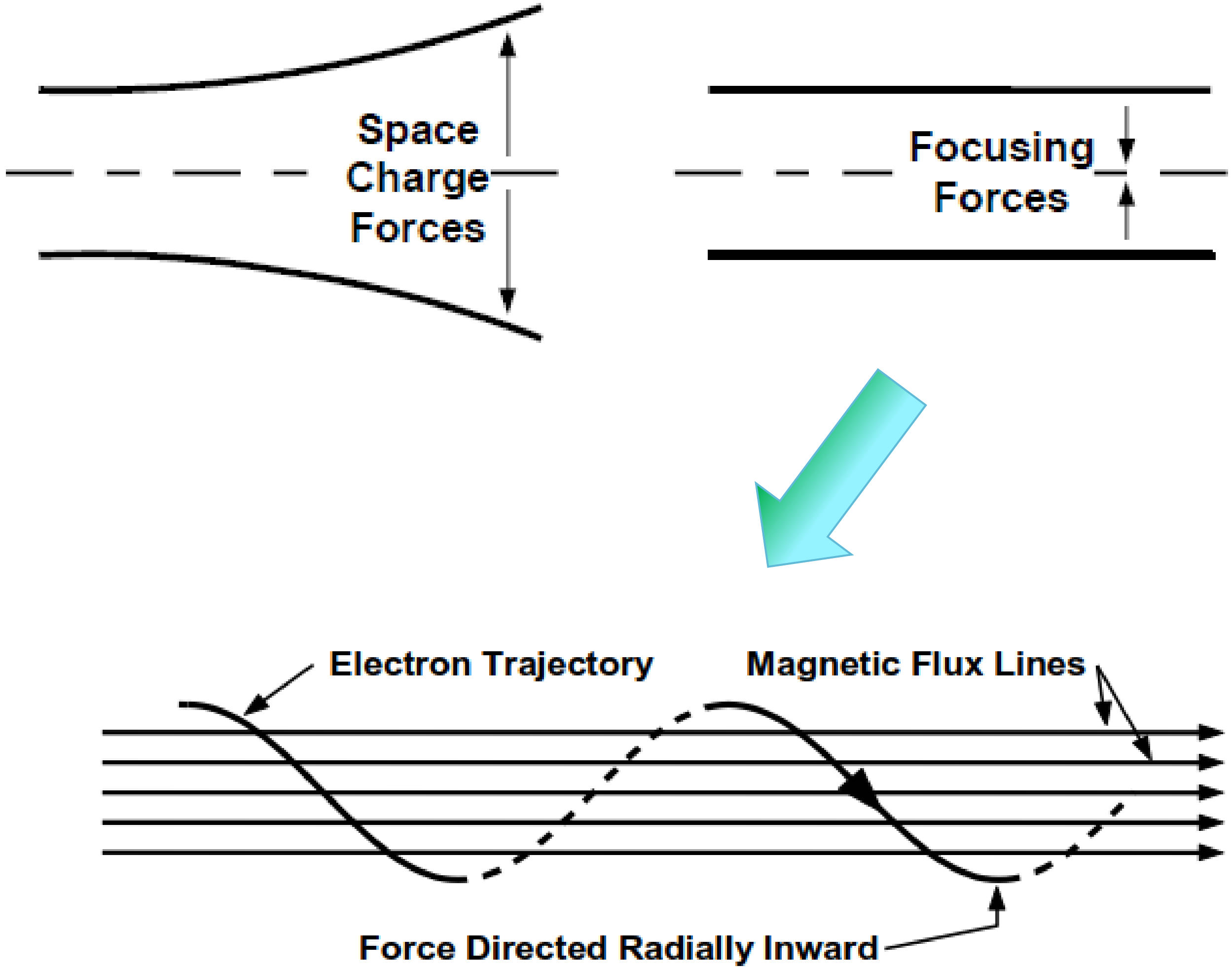
Candidate locations for the electron lenses are RB-44 and RB-46 at Point 4, on each side of the interaction region IR4

.

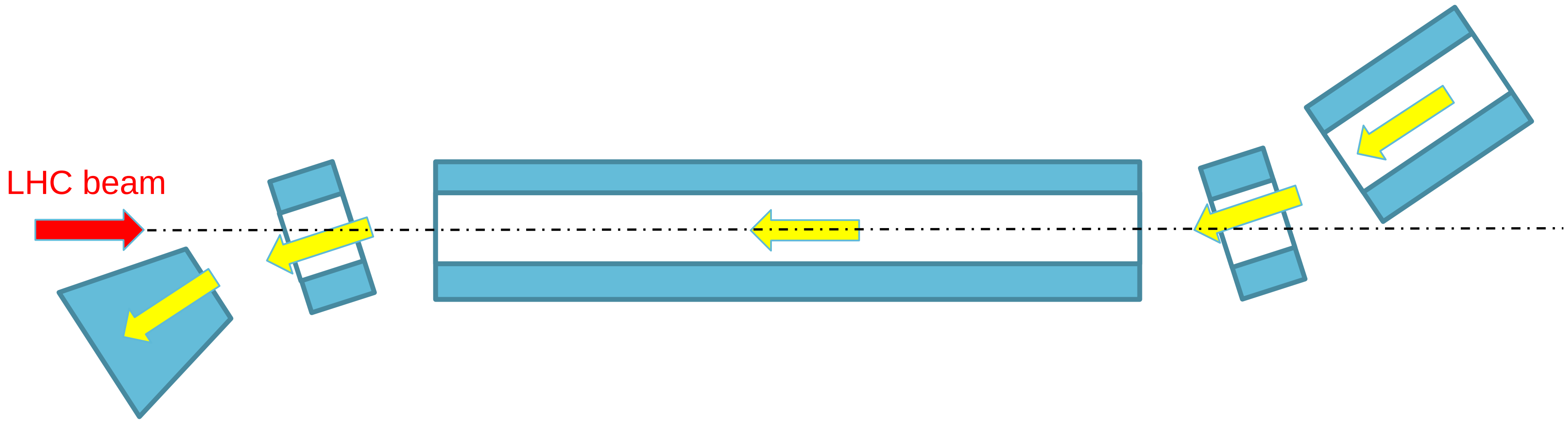
The beam to beam distance is 420 mm.
The longitudinal available space is limited.

→ Compact design

Confinement of an electron beam



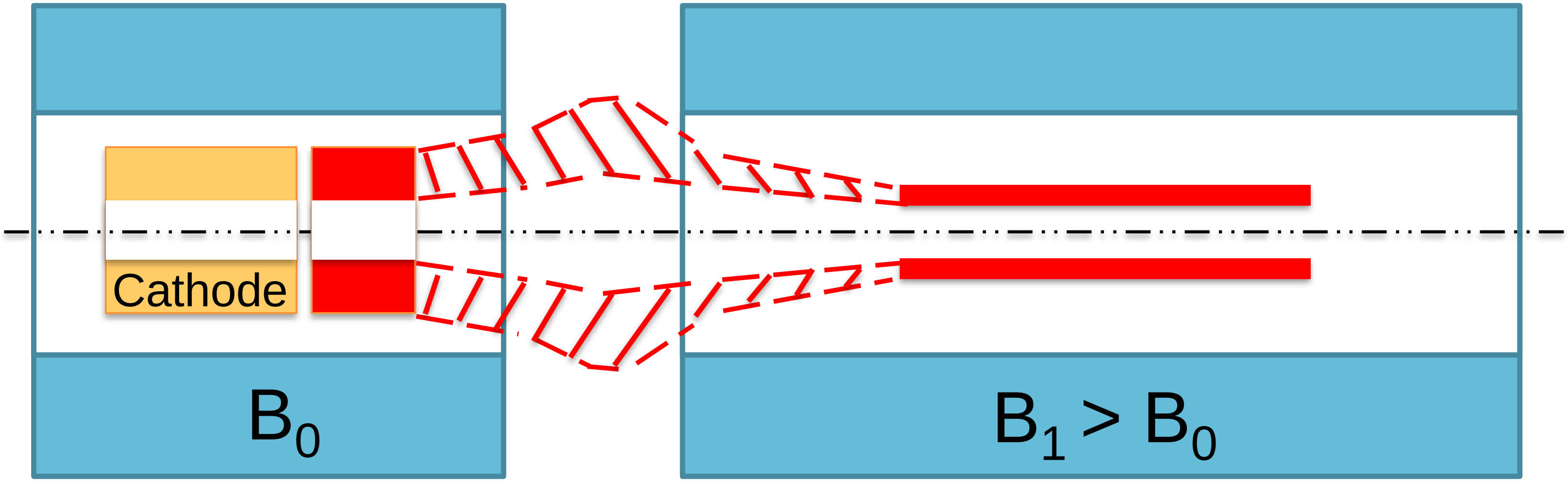
Elements of an Hollow Electron lens



- Electron gun solenoid and electron gun
- Bending solenoid(s)
- Main solenoid
- Bending solenoid(s)
- Collector
- Instrumentation, vacuum chamber, cryostats, supports etc.

Correctors

HiLumi HL-LHC PROJECT

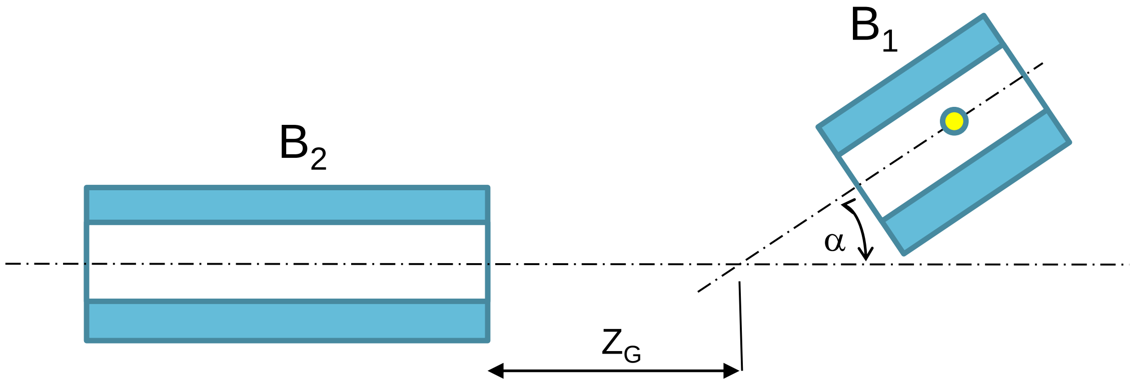


The field level determines the radius of the e-beam.
The dimensions of the electron beam in two points along its path follow the equation:

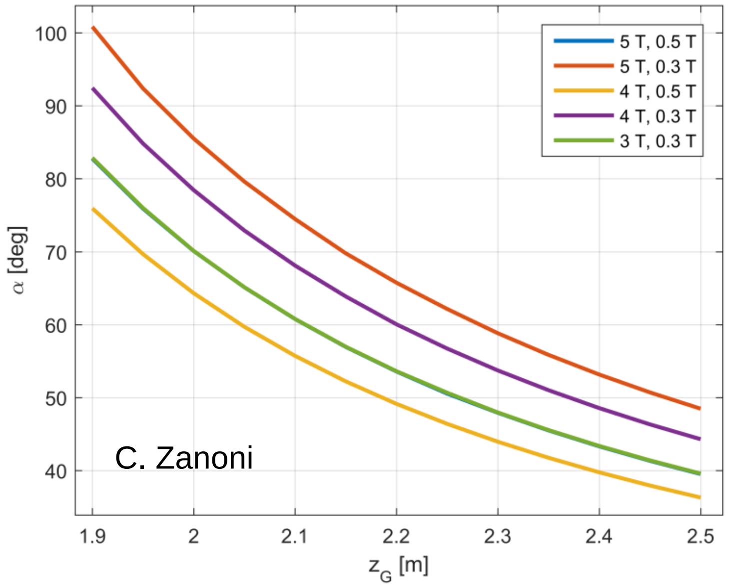
$$\frac{r_0}{r_1} = \sqrt{\frac{B_1}{B_0}}$$

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.

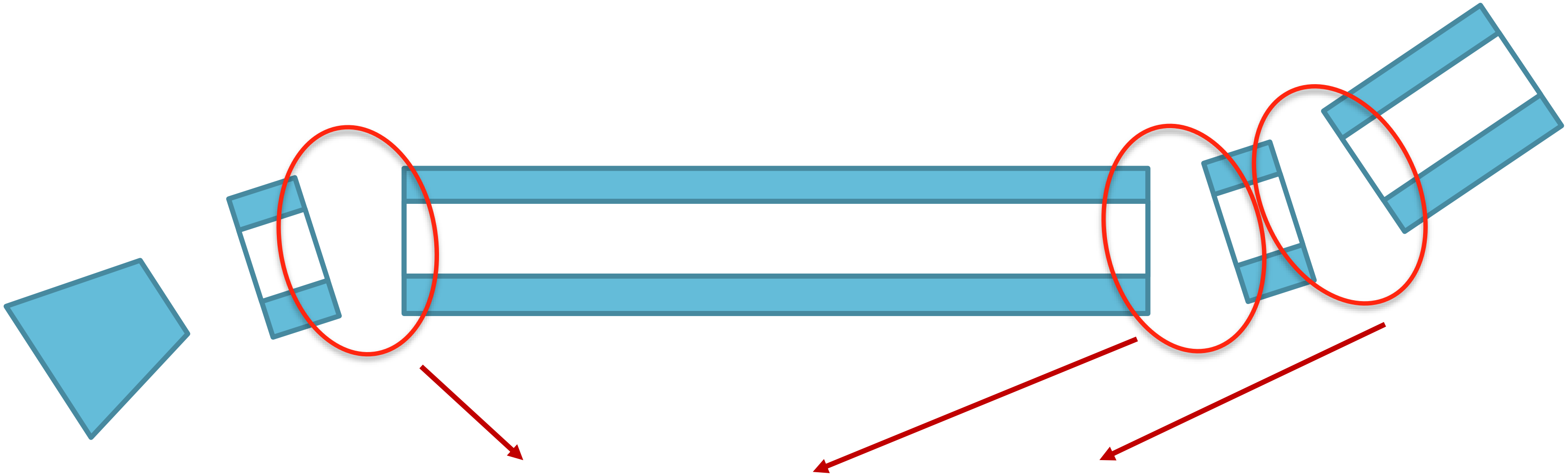
Why two solenoids are not enough?



Z_G, α, B_1 and B_2 are not independent parameters.
A change of the ratio B_1/B_2 calls for different Z_G and α



Critical regions



Lower field and bends

- Cryostats
- Valve
- Instrumentation
- ‘Y’ shaped vacuum chamber

It is necessary to iterate between mechanical design and simulations of e-beam dynamics.

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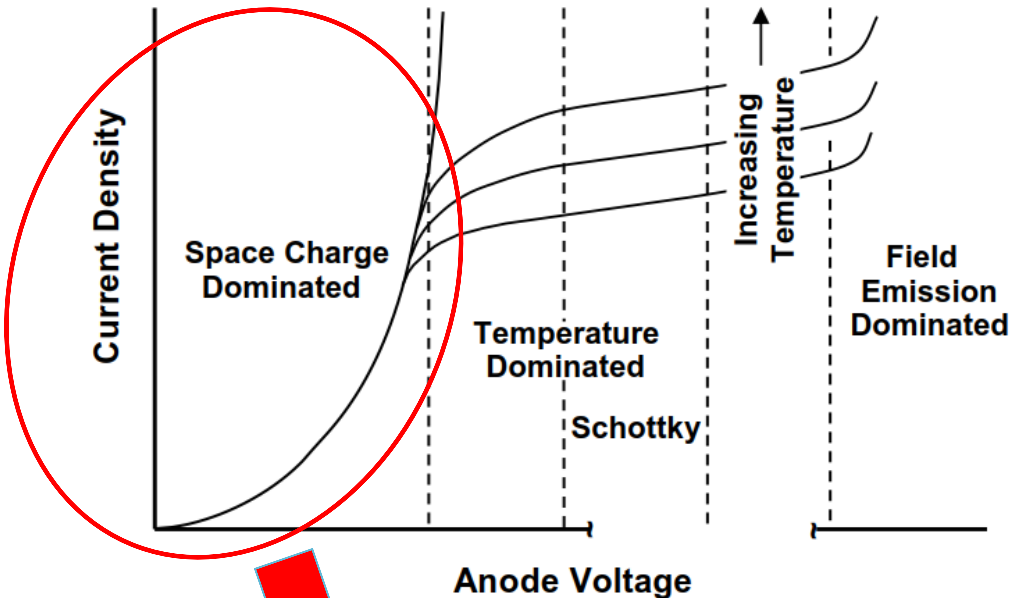
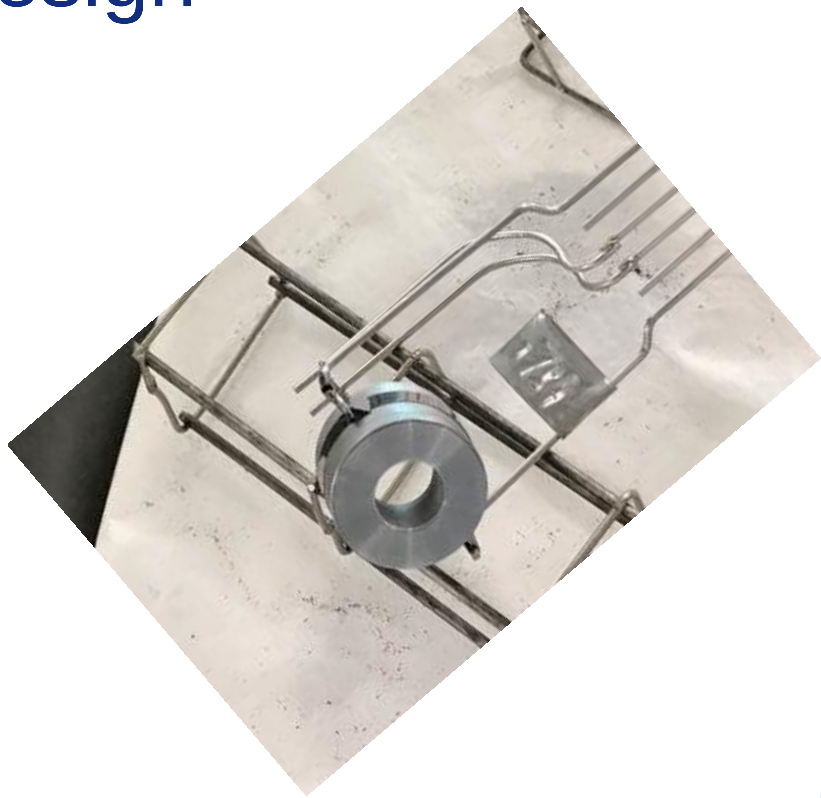
Cathode design





$I = P\,V^{3/2}$ $I = J\,A$

$P = K\,A/d^2$

Free parameters:

Cathode Surface: R_i , R_o

Cathode – Anode distance

Summary of the requirements

- The HEL must be compact.
- Magnetic fields in the solenoids must be reasonable.
- Magnetic fields in the transition regions must be smooth and high enough.
- Dimensions and current density of the cathode must be technically feasible.
- The HEL will be used at injection and at collision (very different e-beam size).

Important!

The today design is based on computations:

- of magnetic field flux lines
- of trajectories of single electrons.

This is a first good approximation but not perfect (in particular for high currents).

The computations of the displacement and stability of a ring of electrons under all the internal and external forces are going on.

Therefore there could be small changes of size and relative position of the main components and some adjustments of the level of magnetic fields.

The field of the main solenoid is the lowest possible under these approximations.

4T solenoid or more?

- Inductance: $L = \mu_0 n^2 A \ell$
- Magnetic field: $B = \mu_0 n I$
- Potential energy: $U = \frac{1}{2} L I^2 = \frac{1}{2\mu_0} B^2 (A\ell)$
- Volume of solenoid interior: $A\ell$
- Energy density of magnetic field: $u_B = \frac{U}{A\ell} = \frac{1}{2\mu_0} B^2$

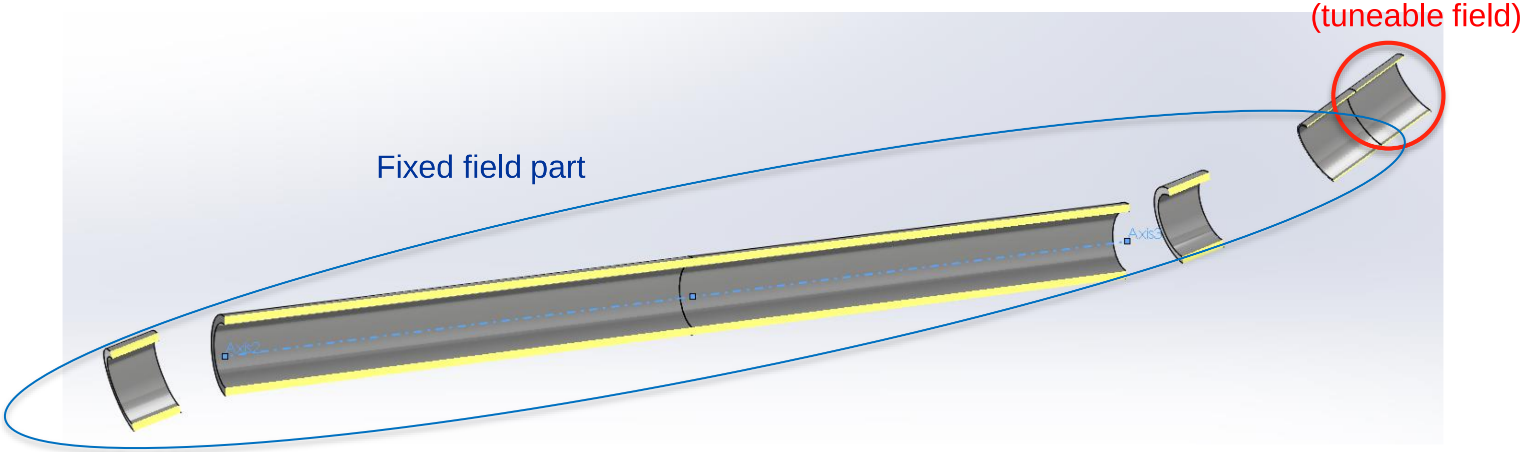
L is in Henries
μ_o is the Permeability of Free Space ($4.\pi.10^{-7}$)
n is the Number of turns
A is the Inner Core Area ($\pi.r^2$) in m^2
I is the current in Amperes
ℓ is the length of the Coil in metres

To increase the field one has either to increase the current or the number of turns or both.

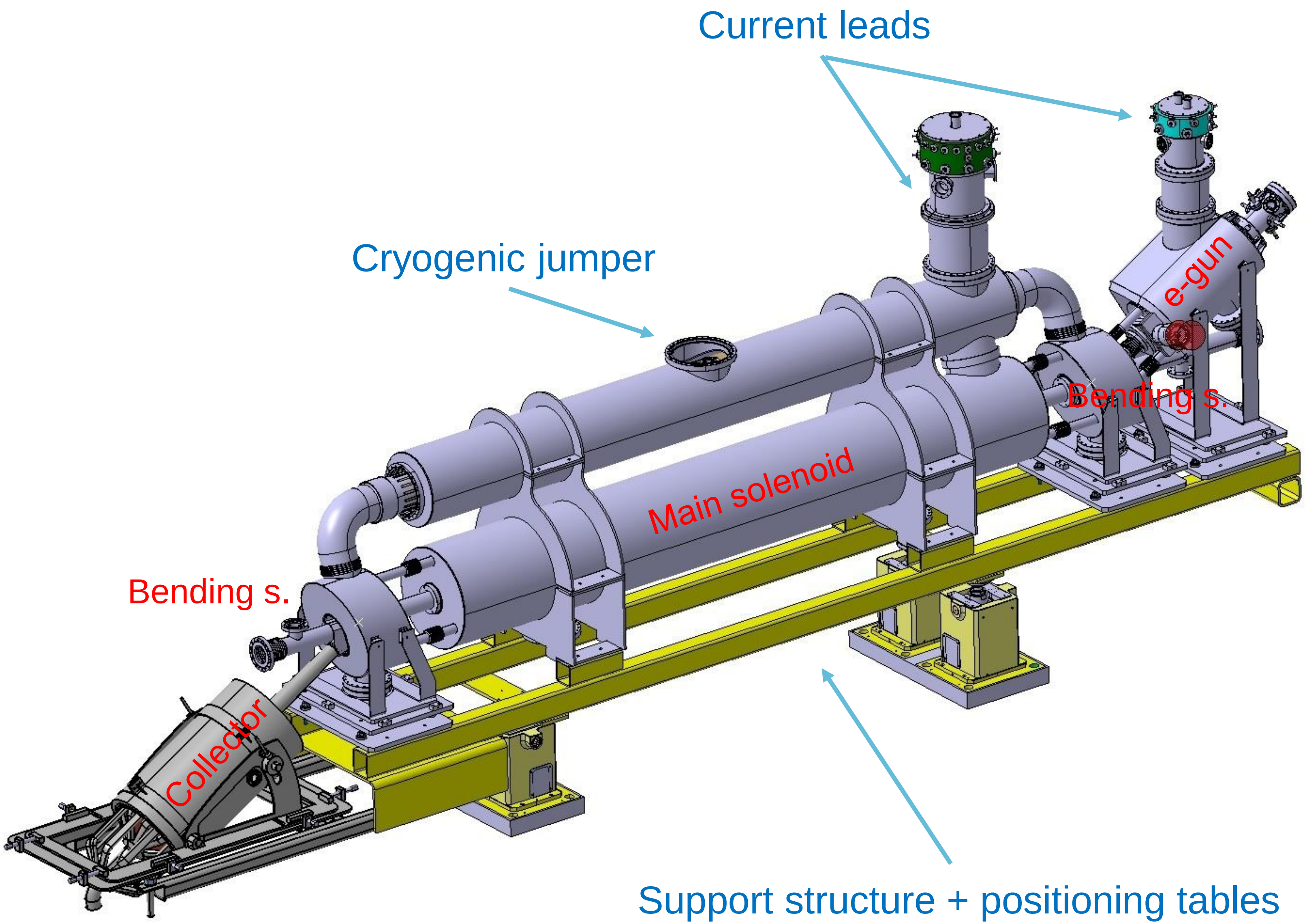
Consequences on:

- quench protection (stored energy, inductance)
- wire (cable) size, current lead size, heat load
- power supplies (including ramp time of the system).

Design of the main components

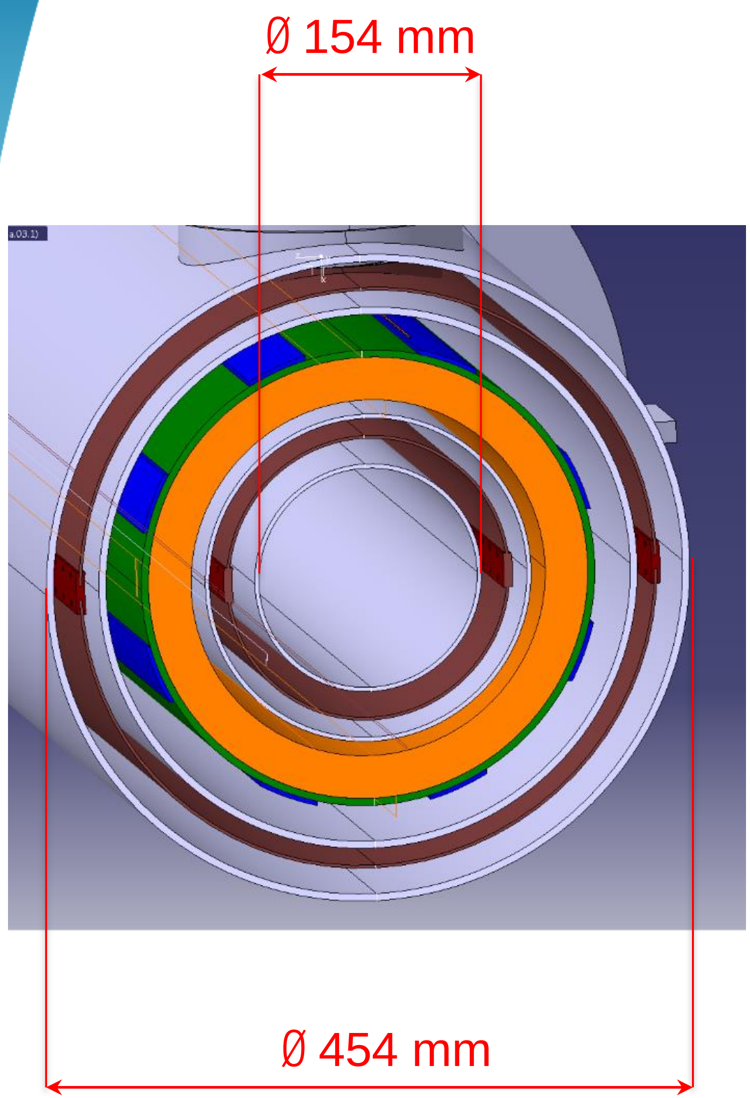


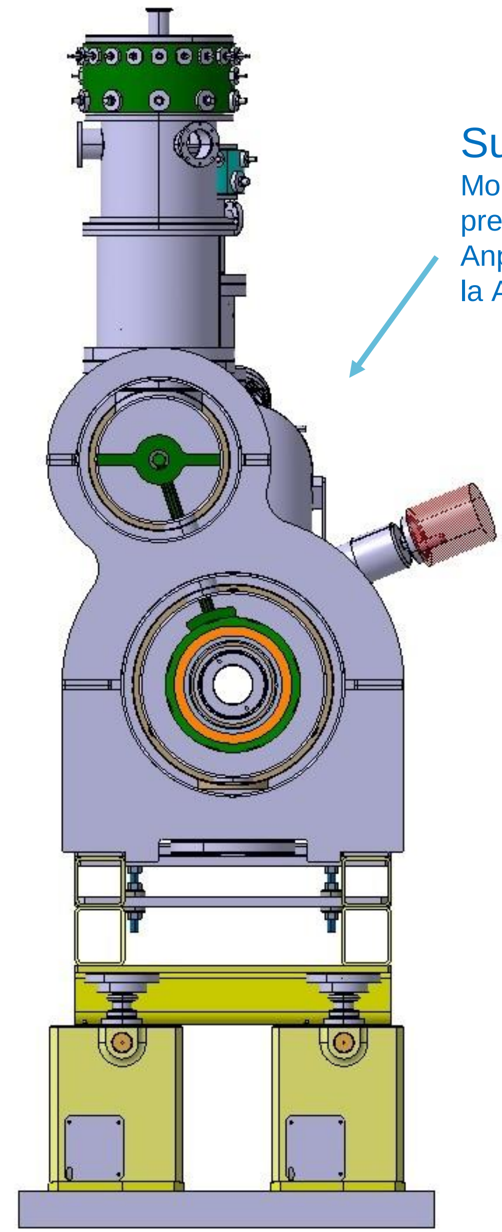
Nominal magnetic field of the main solenoid	**4 T**
Nominal magnetic field in the e-gun cathode	0.2 T
Inner radius of the hollow electron beam @ nominal fields	0.9 mm (3 σ)
Outer radius of the hollow electron beam @ nominal fields	1.8 mm (6 σ)
Inner diameter of the cathode	8.05 mm
Outer diameter of the cathode	16.10 mm
Inner radius of the hollow electron beam @ 4 T with 2 T @ cathode	5.67 mm
Outer radius of the hollow electron beam @ 4 T with 2 T @ cathode	11.34 mm
Nominal current at the cathode	5 A



Support structure + positioning tables

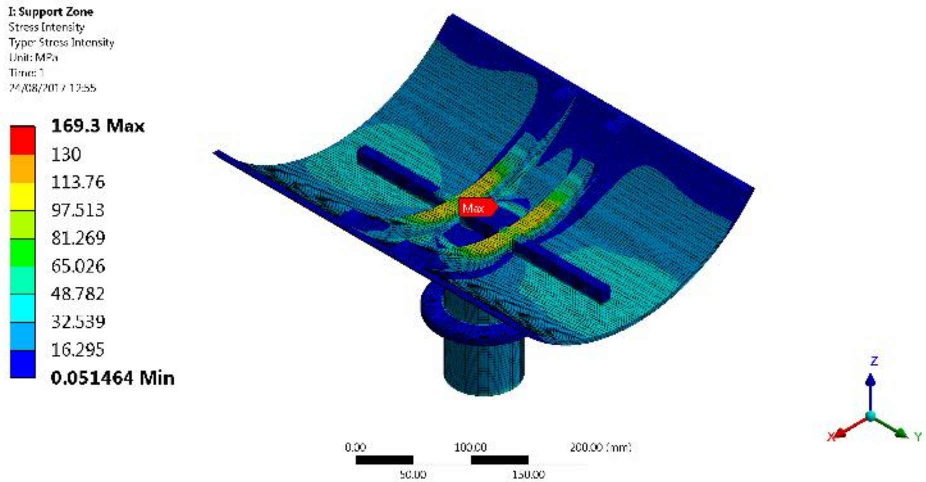
Discussions with the survey to define the position of their targets.

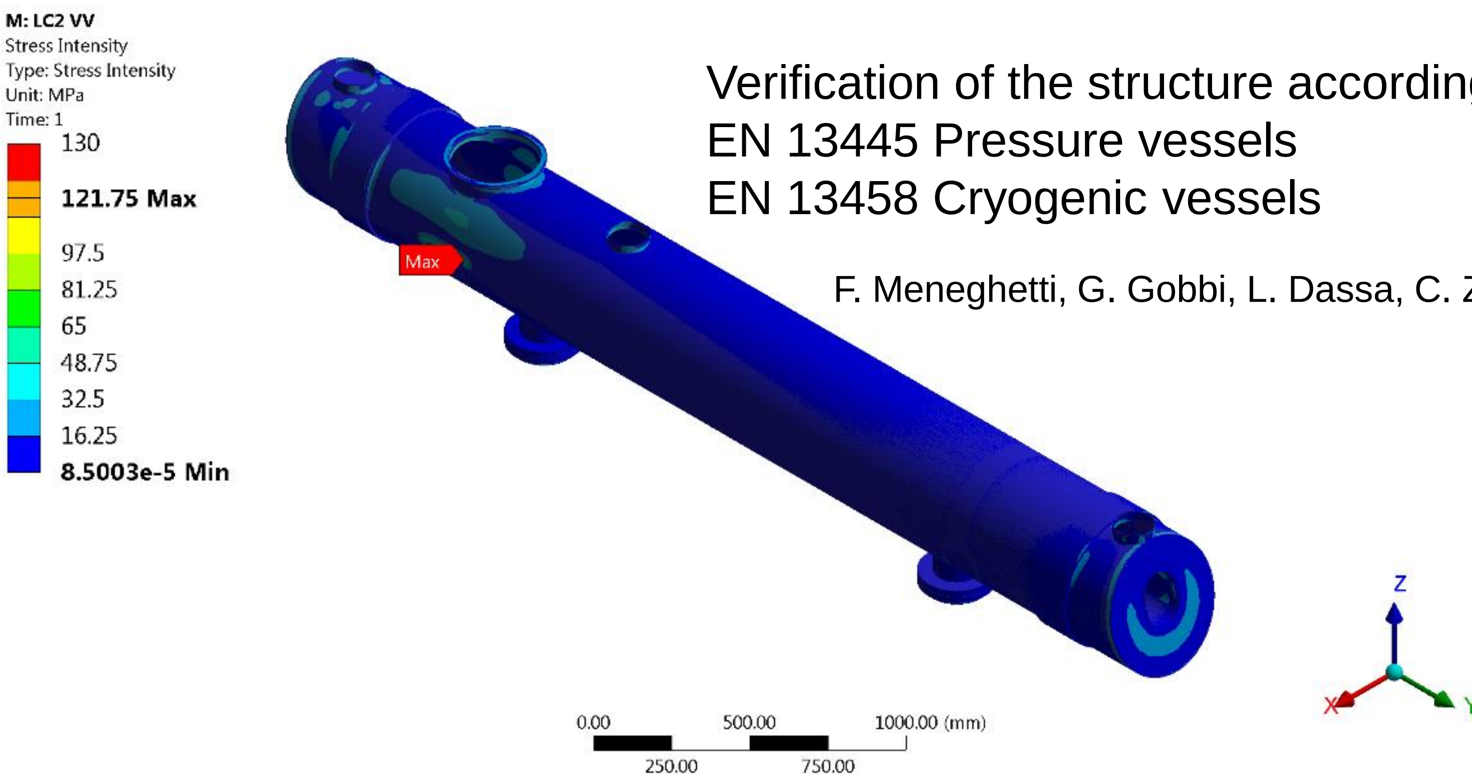




Survey space

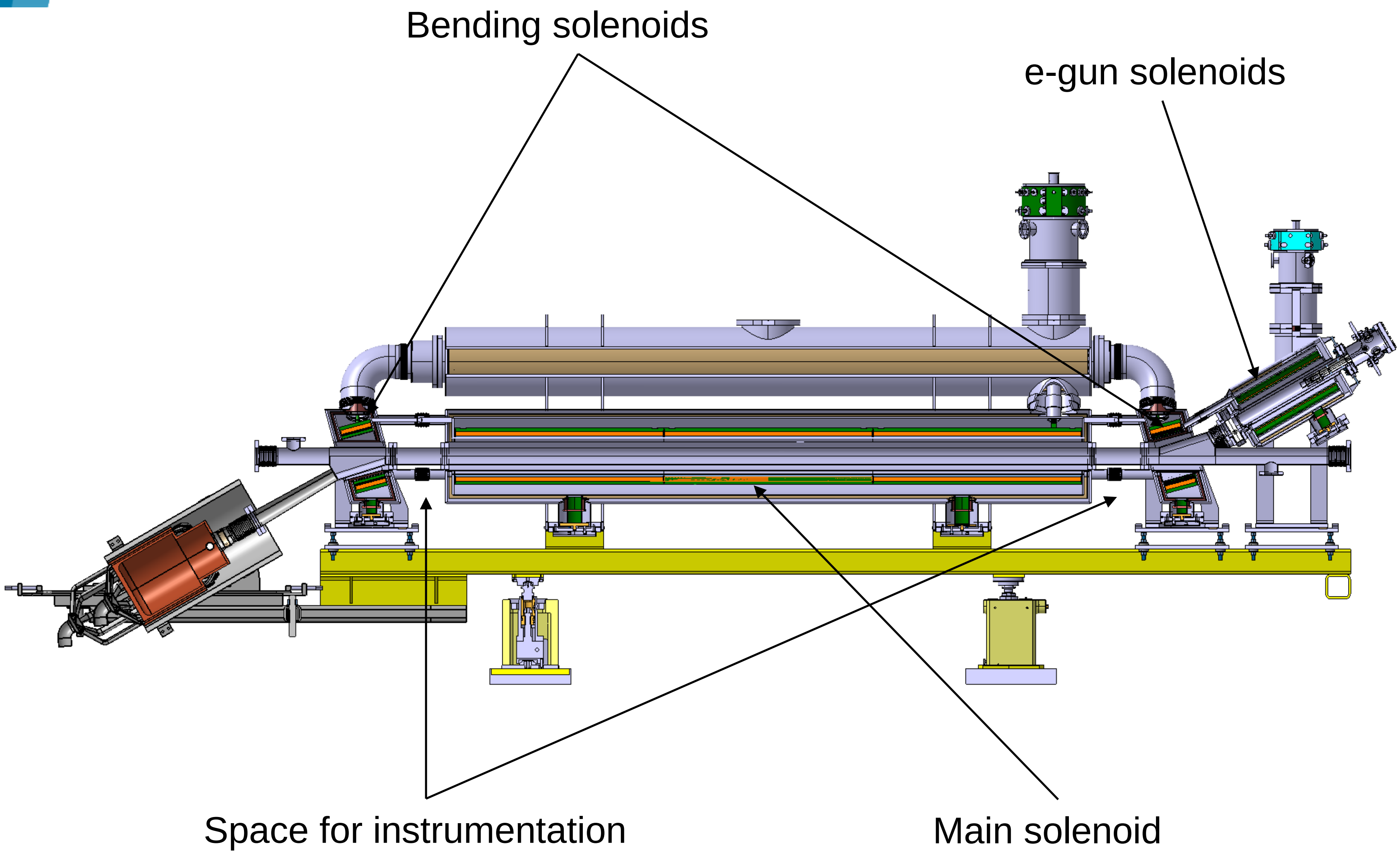
More details in the presentation of Maria Anparo Gonzalez de la Aleja Cabana.



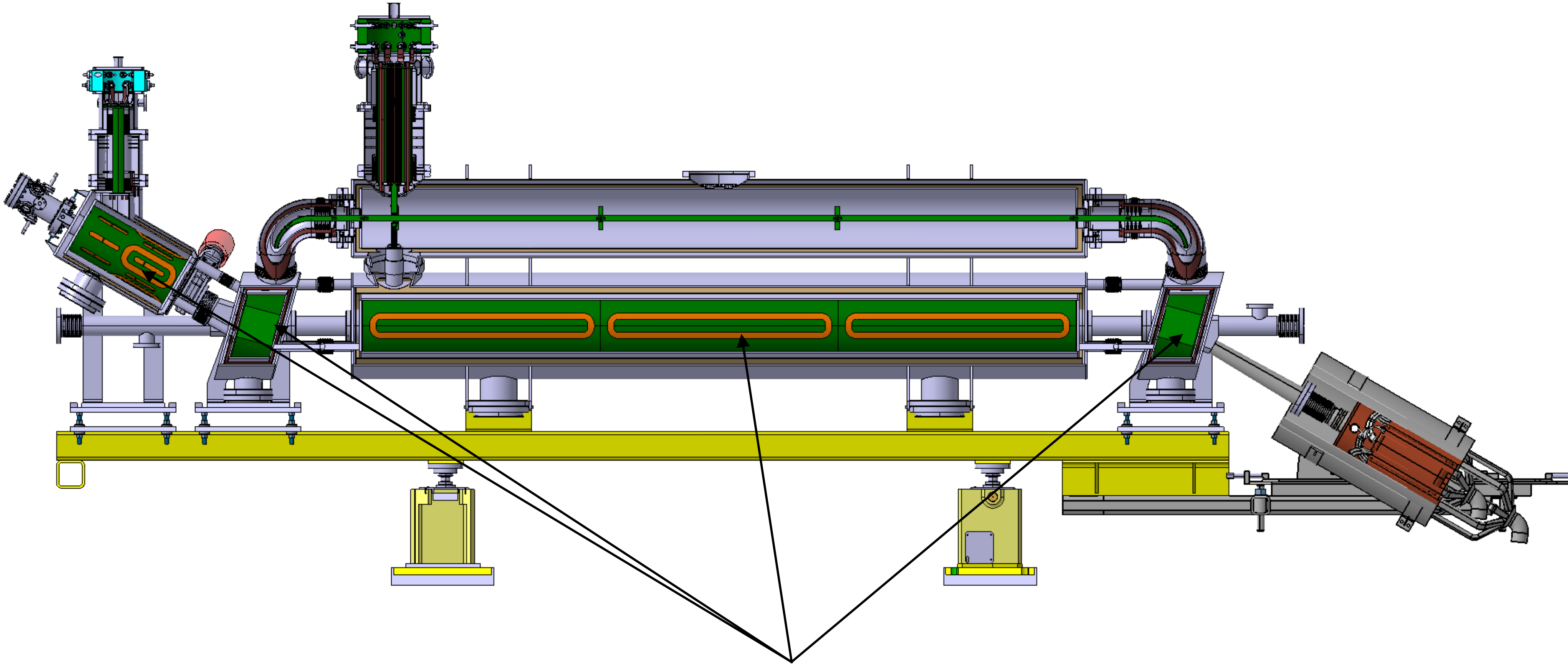


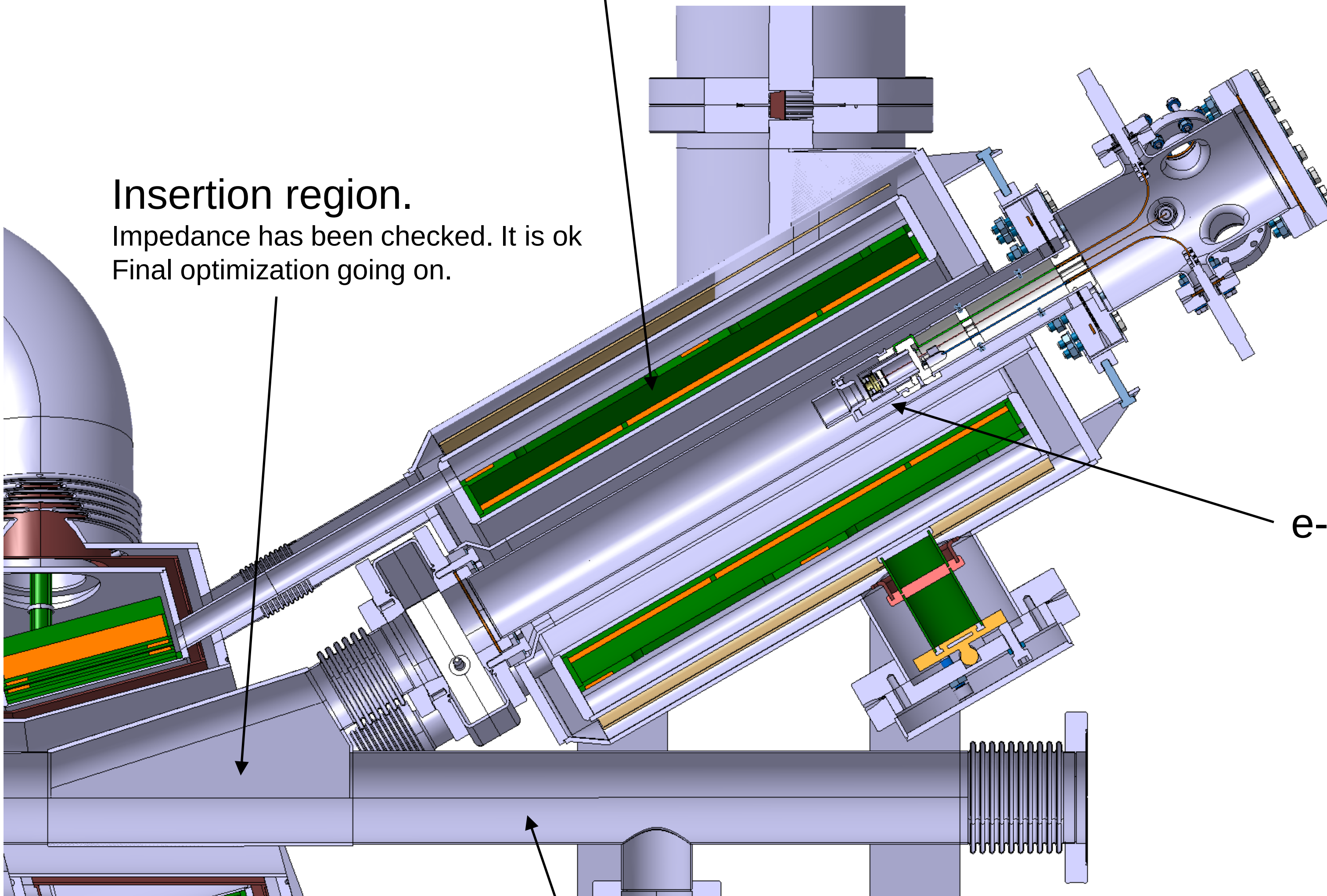
Verification of the structure according to:
EN 13445 Pressure vessels
EN 13458 Cryogenic vessels

F. Meneghetti, G. Gobbi, L. Dassa, C. Zanoni



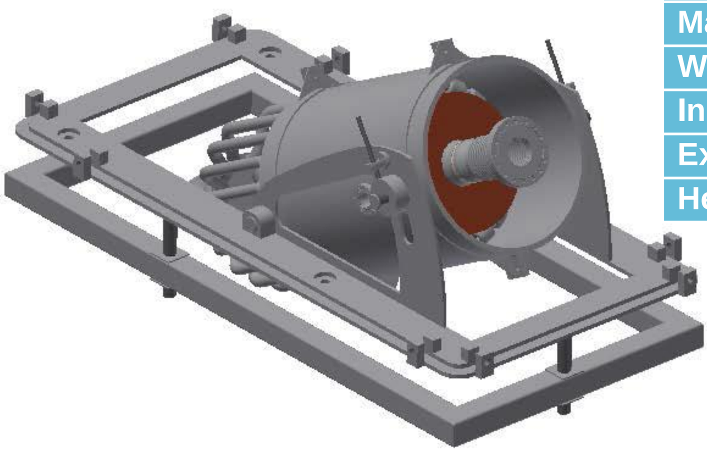
Bending solenoids
e-gun solenoids
Space for instrumentation
Main solenoid

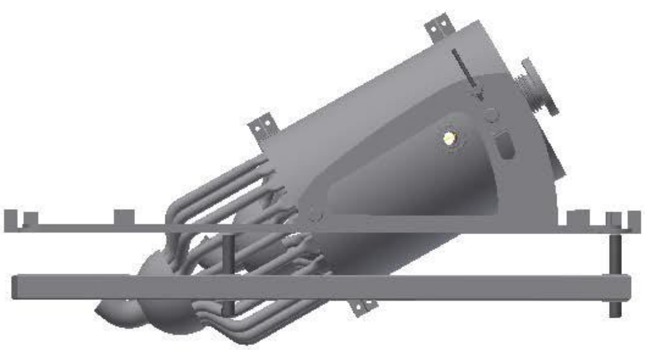

Corrector coils

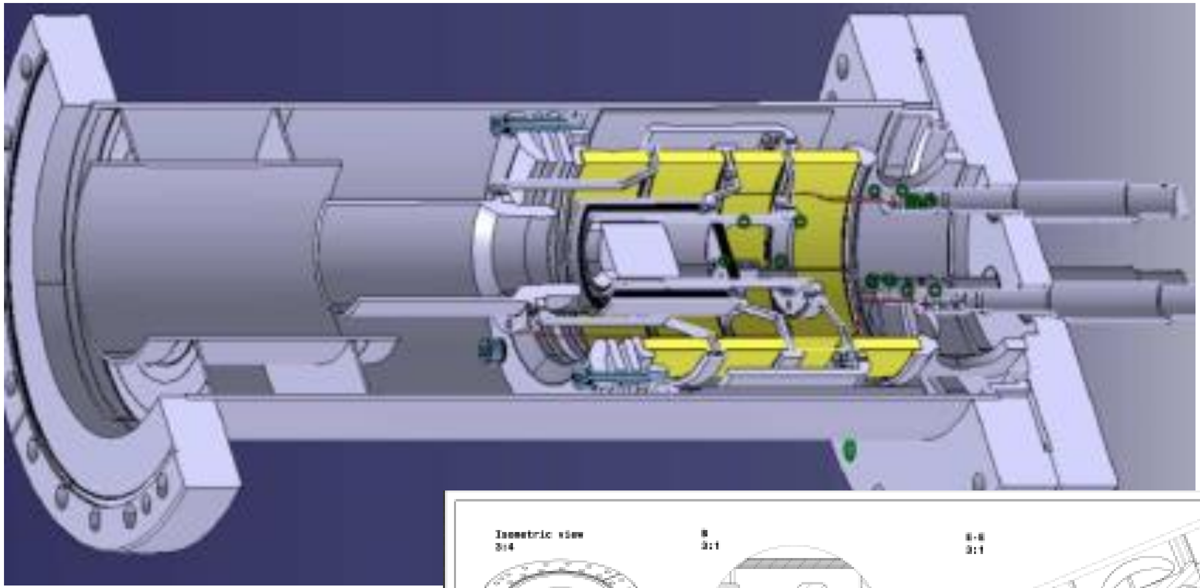

e-gun solenoids
Insertion region.
Impedance has been checked. It is ok
Final optimization going on.
e-gun
Vacuum chamber.
Discussions with vacuum group going on.

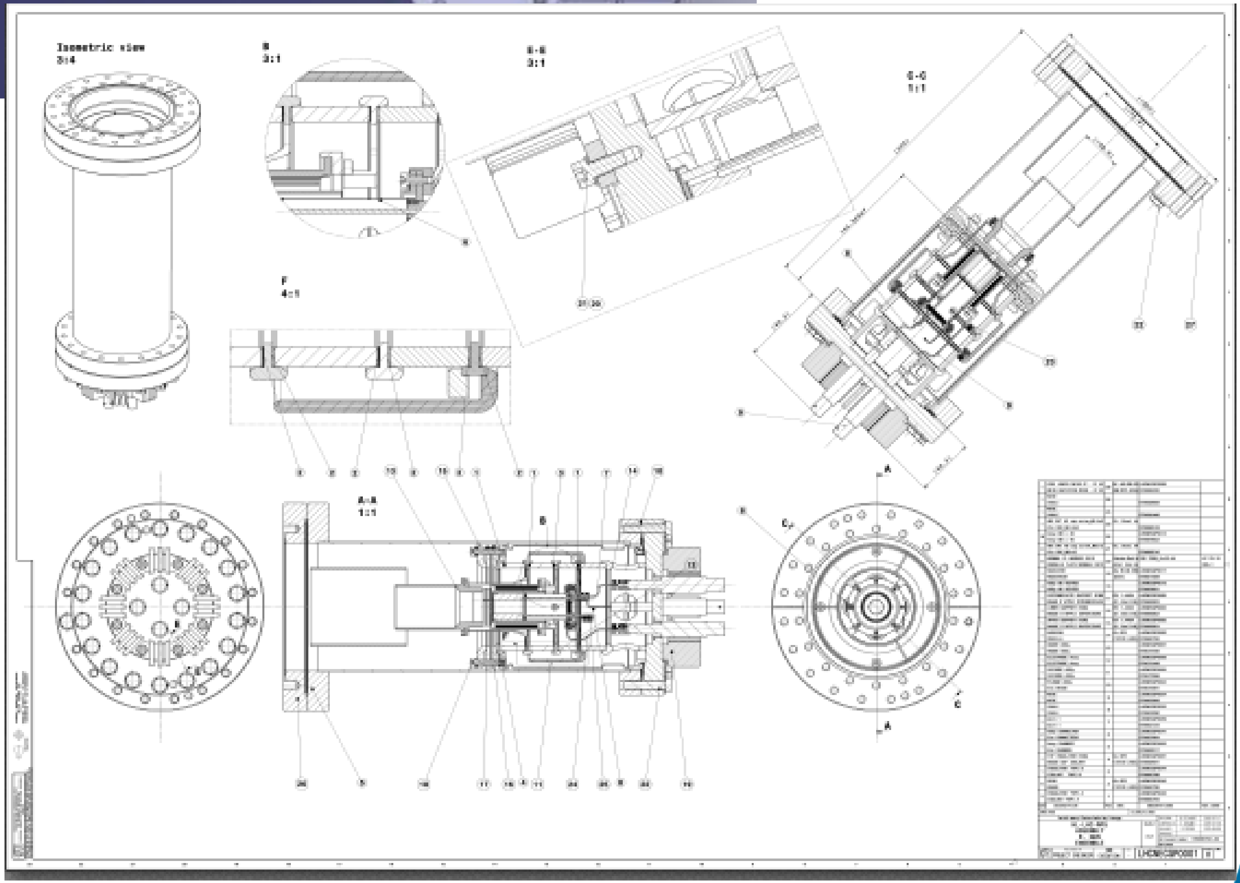
Collector

Collector in ETP copper	
Maximum power absorbed	50 kW
Maximum temperature	$85^{o}C$
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









Conclusions

- The Hollow Electron Lenses for HL-LHC are a complicate object with demanding performances (5 A current over a 3 m path, large range of e-ring sizes).

- We have a well advanced design and we are not far from the final configuration. We have a solid base to start discussions with the possible manufacturers.

- The HEL configuration will be frozen once the physic simulations will be completed and once the instrumentation will be defined.

Thank you for your attention

Existing electron lenses and HL-LHC hollow electron lenses

	RHIC EL	Tevatron EL	HL-LHC HEL
Effective length [m]	2.1	2	2.9
Current from cathode [A]	1	0.6-3	5
Main solenoid field [T]	6	3	4(*)
Solenoid inner bore [mm]	200	160	200
E-gun field [T]	0.2-0.8	0.3	0.2-2 (*)
Cathode radius [mm]	4.1 @250GeV 7.5 @100GeV	7.5	4 – 8.05 Hollow
Cathode surface* [cm^2]	0.53 @250GeV 1.77 @100GeV	1.77	1.53
Current density [A/cm^2]	1.89 @250GeV 0.53 @100GeV	1.69	3.27
E-beam compression	1.6-5.5	3.26	1.41-4.47

(*) to be confirmed, could change