Status of the HEL optics for the e-beam

A. Rossi with contributions from:

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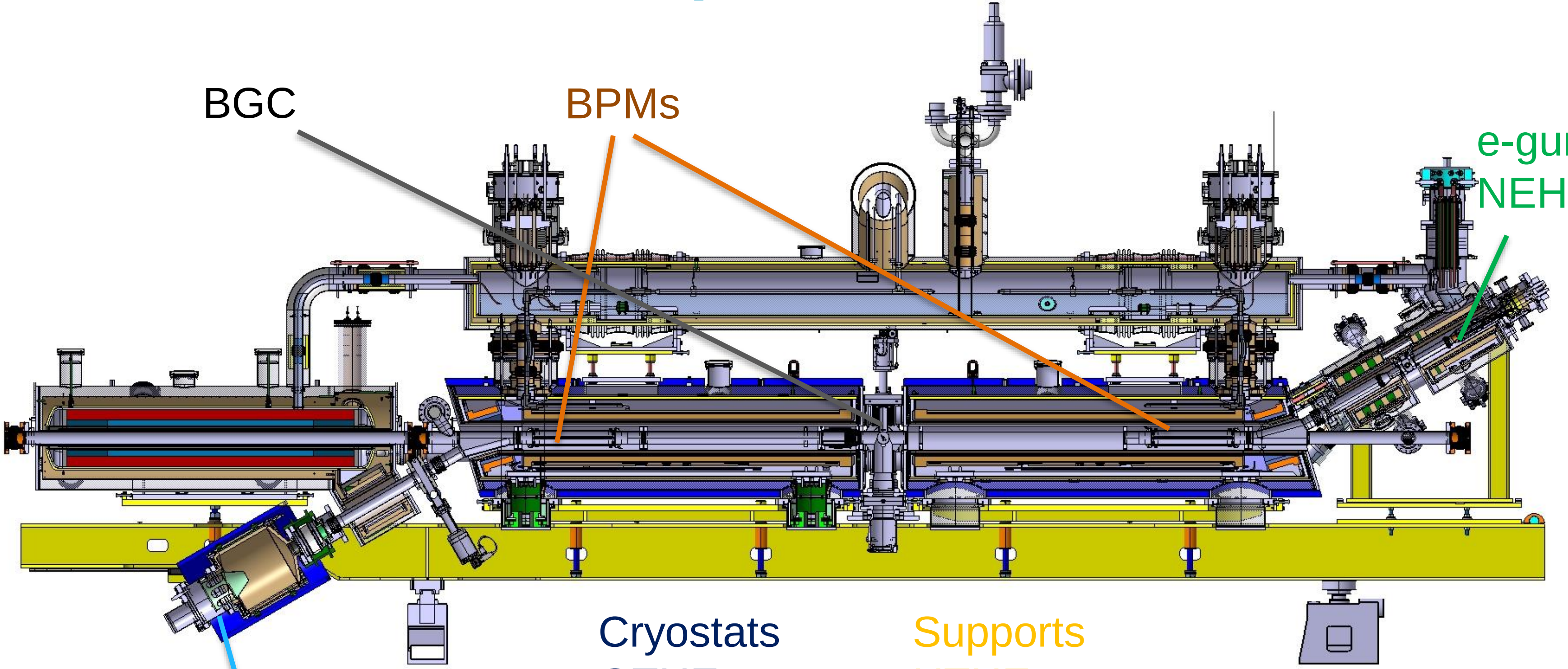
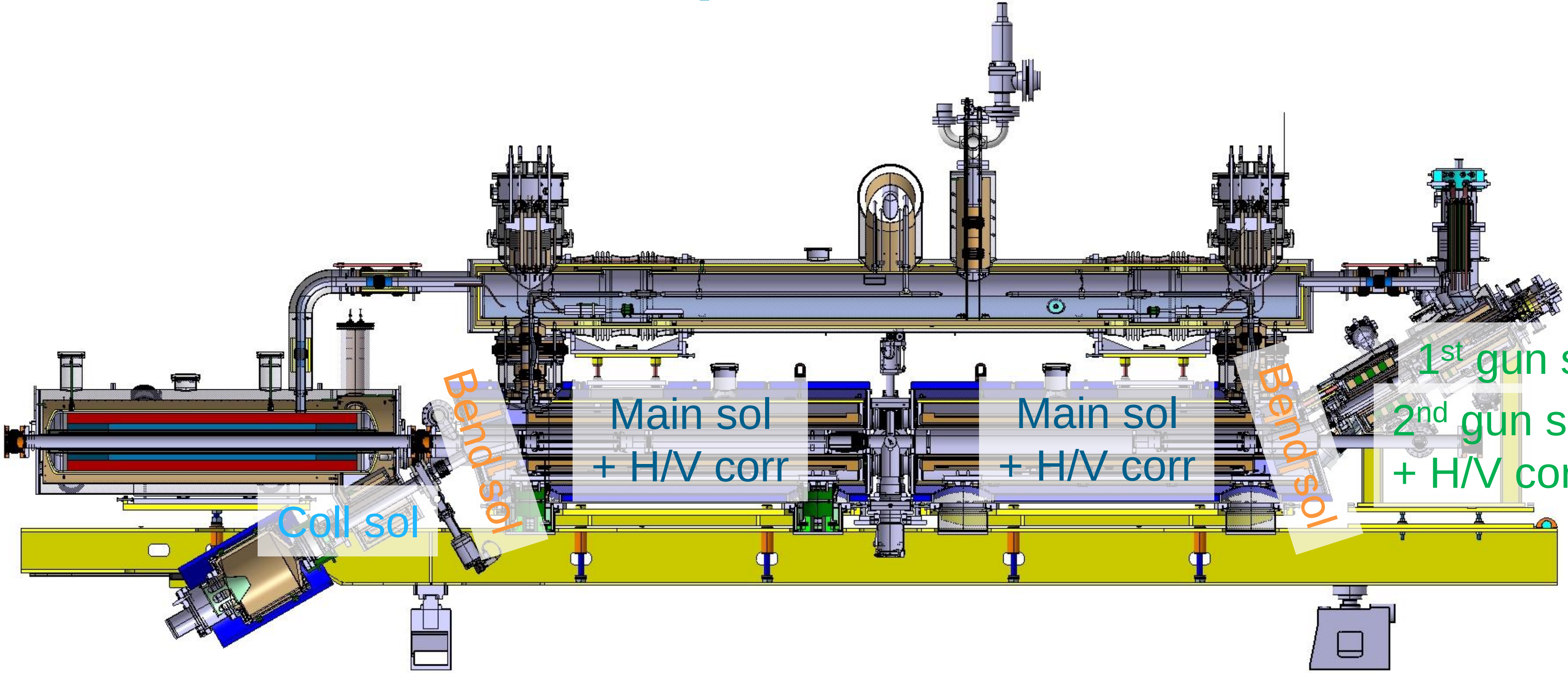
E-Beam - #12 Remote Working Group Meeting – HEL, 13 October '21

HEL components - THE



Courtesy of A. Kolehmainen, 2020
M. Zerlauth (MCF 13 July 2021)

HEL components - THE



Outline

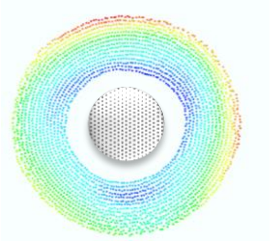
- Requirements for the hollow electron beam
- Evolution of the HEL design and simulations
- Current design and open points

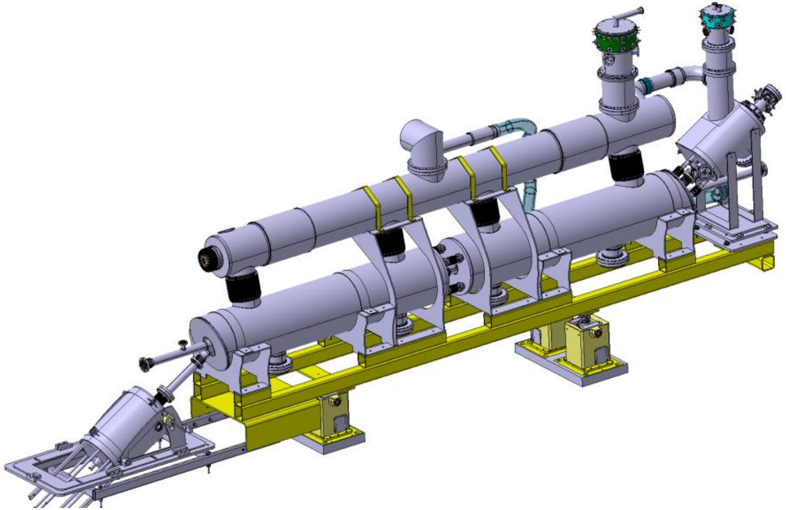
Requirements for the Hollow Electron beam

Property	Specification		Magnet system with ops @ const field
Design current (cathode 4/8 mm radii)	5.0 A ± 0.5 A	To achieve 90% depletion in 5 min	Main solenoid @ 5 T, overall coil length at least 3 m
Interaction region length (at min. inner beam radius)	3 m		
Min/max inner radius at 7 TeV	1.1/2.2 mm ± 0.01 mm	3.6/7.2 LHC beam sigma (280 m β) ± 1%	Tuneable (1st) gun solenoid field 0.37 T to 1.2 T (actual 0.2 T to 4 T)
Max inner radius at 450 GeV	3.6 mm		4T at gun and 5T at main
Electron beam position range	± 4 mm	± 2 mm for LHC orbit variations, + 2 mm for set up purposes	H/V Correctors at (2nd) gun solenoid and at main + at collector solenoid (under study)
Electron beam angle range	± 2 mm / 3 m	For LHC orbit variations	H/V Correctors at main
Position stability fill to fill and pulse to pulse	0.03 mm	1% of LHC beam sigma at 7 TeV	Magnetic field accuracy
Rate of position change	0.1 mm / s	-	Rate of change of field at correctors
Tolerated integrated dipole kick in the core	1 nrad	➔ Tight requirements on e-beam : • symmetry entrance / exit of e-beam trajectory • Electron density distribution • Smooth trajectory	

Reference design 2019

Review of hollow e-lenses, Feb. 2019





Acknowledgements:
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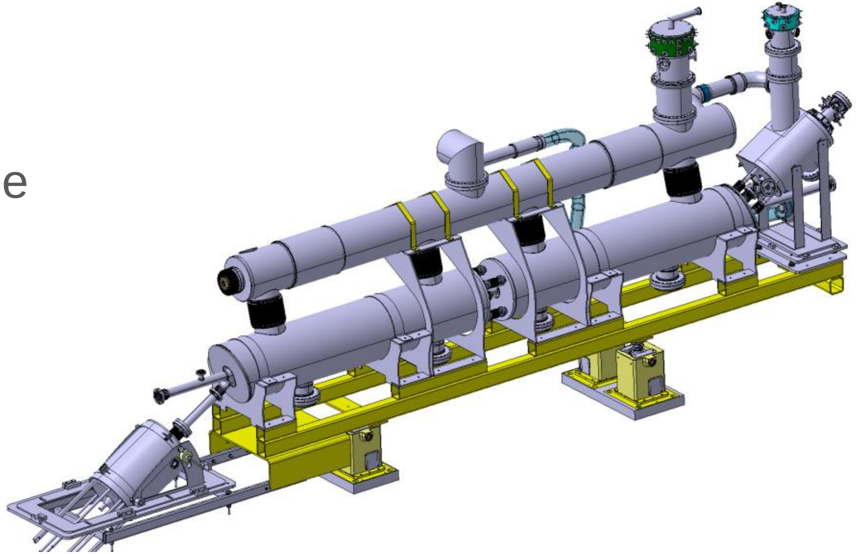
G. Stancari – FNAL
A. Levichev, M. Arsentyeva, A. Barnyakov, D. Nikiforov – BINP

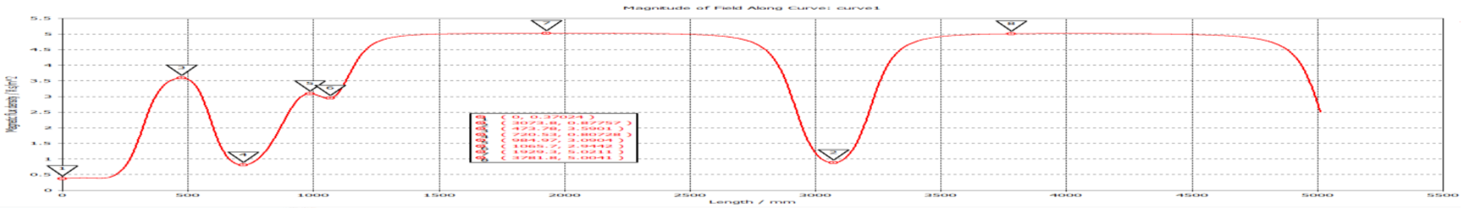
Reference design 2019

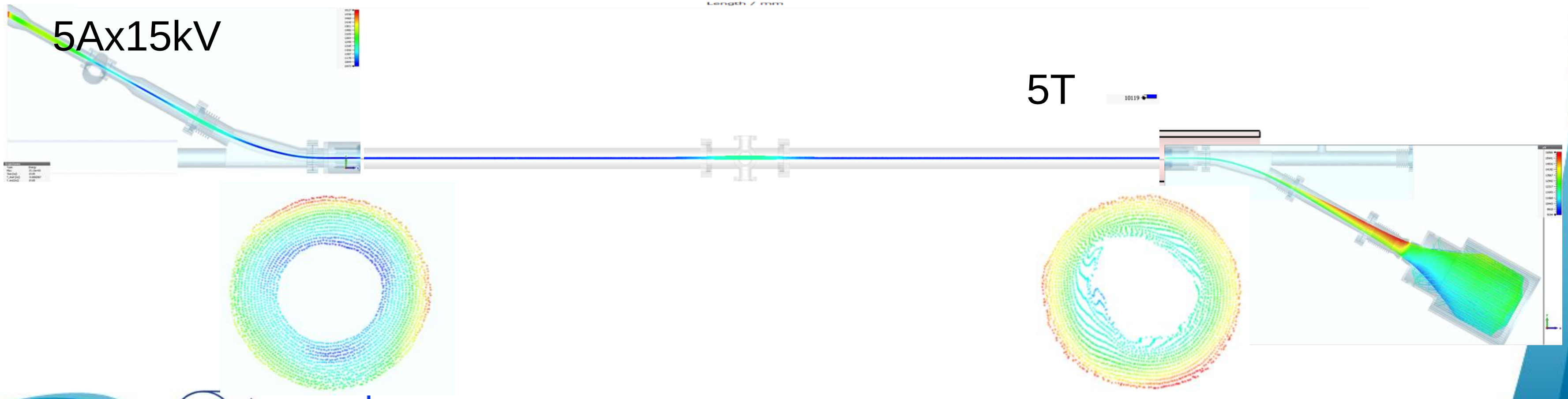
- 280 m β function at HEL = LHC beam sigma ~ 0.31 mm
- 15 keV e-beam acceleration
- 5 T main solenoid
- Vacuum chamber 60 mm
- Gap for instrumentation in the middle of the main
- No collector solenoid yet



Beam stability and shape at min radius

- CST Particle Studio simulation of the Hollow Electron Lens to feedback to thermomechanical design (here shown for 7TeV ops, 1.1mm inner e-radius)

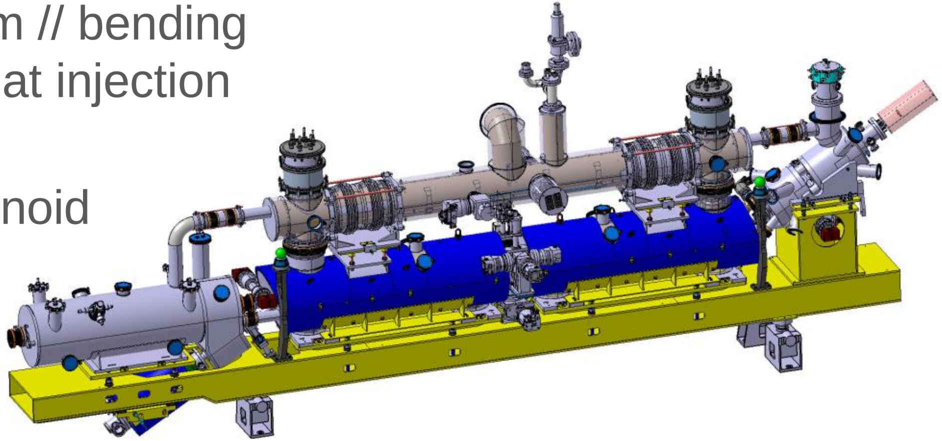




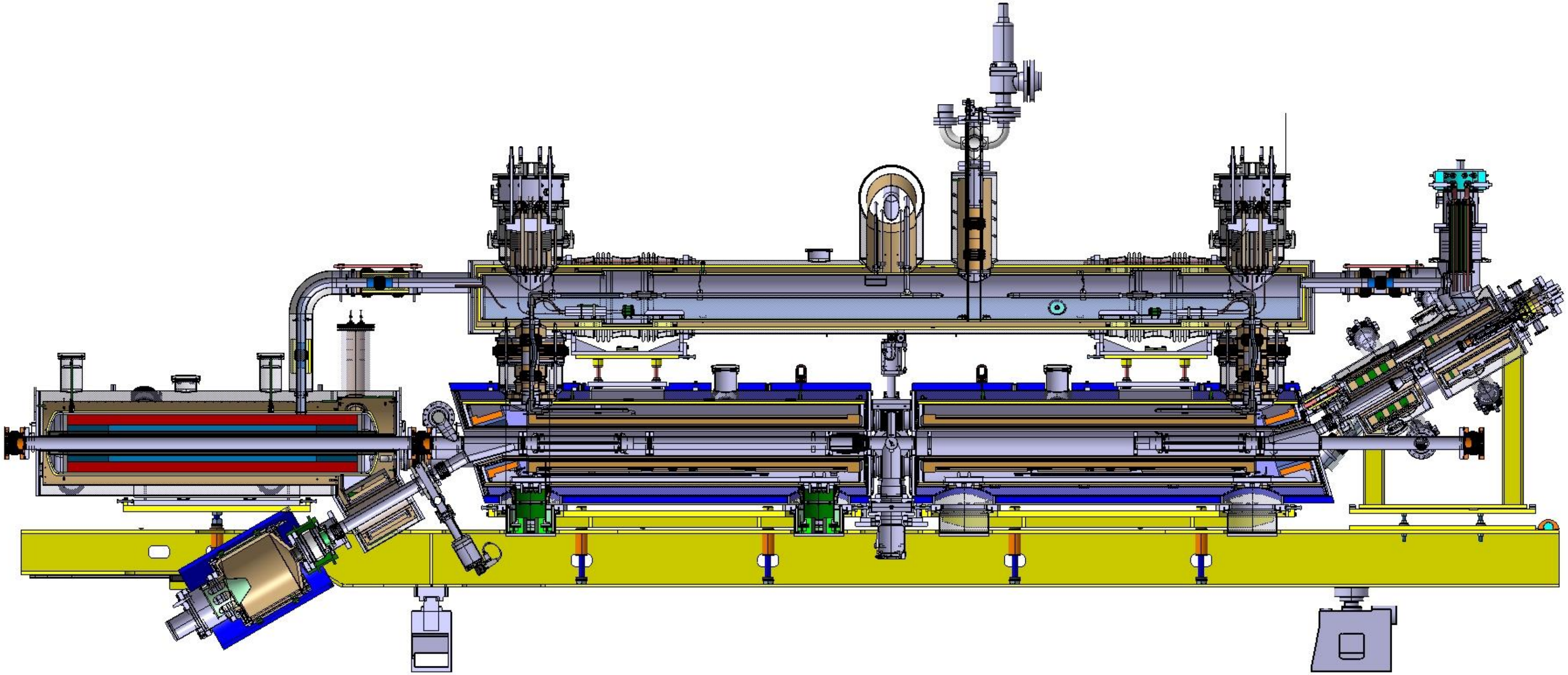
Current baseline design (see D. Perini's pres.)

- Addition of dipole compensator magnet for operations at low LHC energy (to compensate vertical dipolar component from // bending magnets, affecting LHC beam at injection energy)
- Addition of small collector solenoid (work ongoing)
- Integration of the BGC (to be completed)
- Addition of iron shielding (under evaluation, see Danila's presentation)

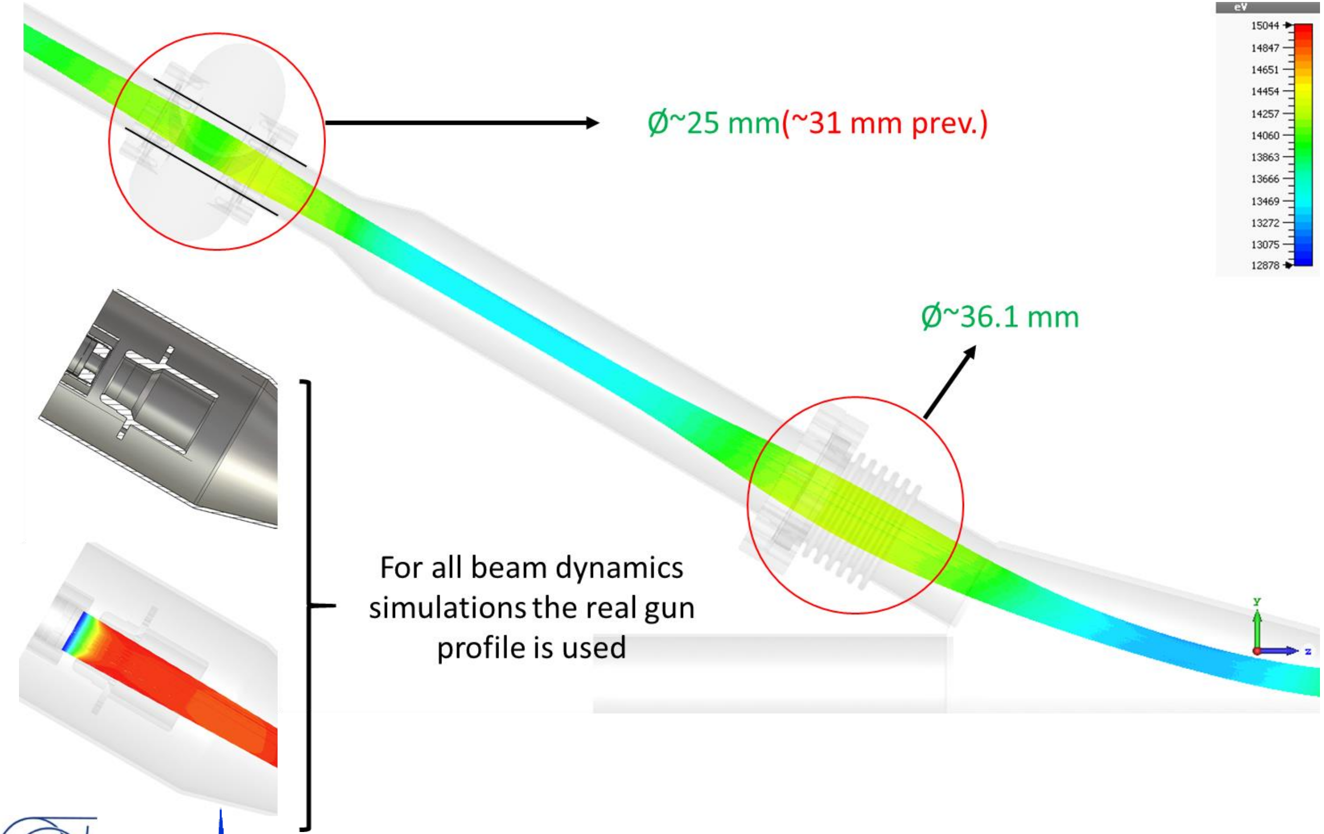
. . .



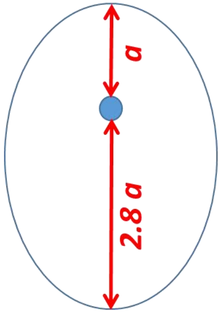
HEL 2021

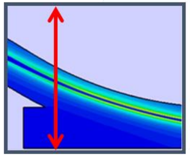


4 mm radius beam – injection aperture



Potential asymmetry at injection



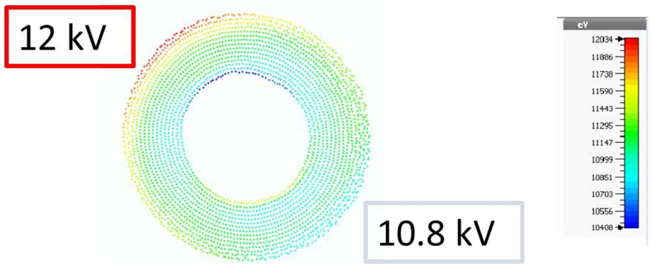


$$\Delta U_b \approx \frac{I}{2\pi v_b \varepsilon_0} \ln\frac{r_b}{a} - \frac{I}{2\pi v_b \varepsilon_0} \ln\frac{r_b}{2a+\sqrt{3}/2a} =$$

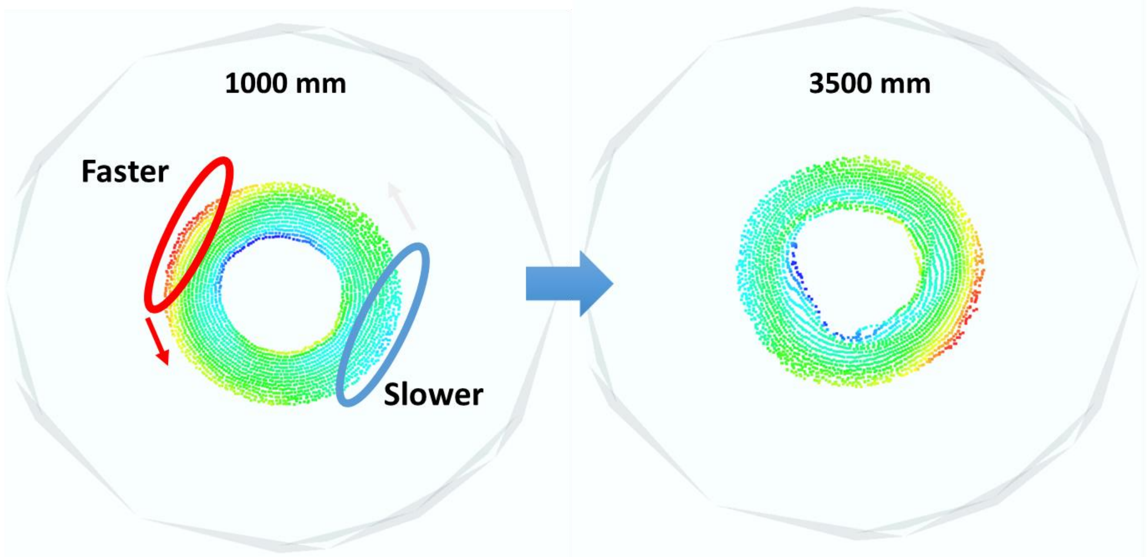
$$\frac{I}{2\pi v_b \varepsilon_0} \ln\frac{2a+\sqrt{3}/2a}{a}$$

If the beam was solid with parameters $U_0 = 15$ keV, $v_b = 0.2$ c
$I = 5$ A, $a = 30$ mm, $r_b = 1.8$ mm, potential difference is

$\Delta U_b \approx 1.3$ kV



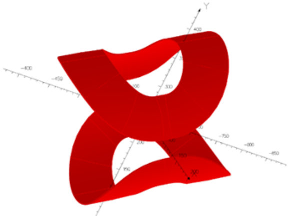
Consequence to e-beam shape

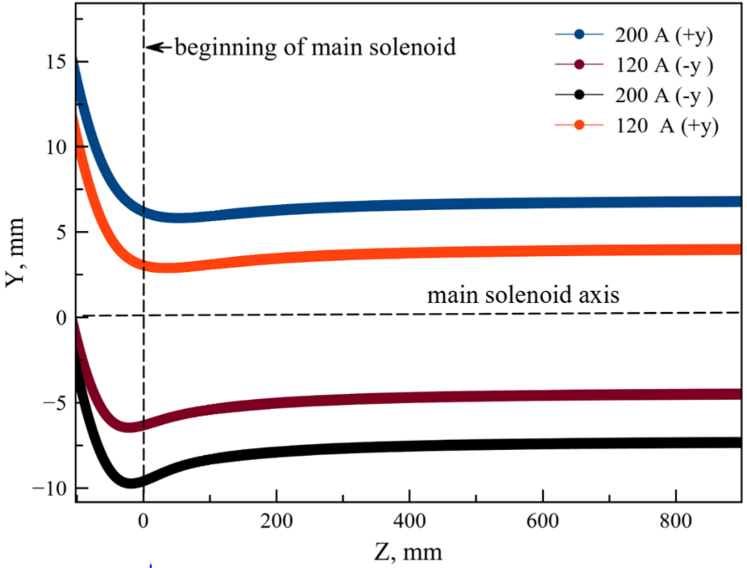


Particles starting from different azimuthal angles have different rotation velocity → Perturbation of the azimuthally uniform electron density → Non-zero electric field in the hollow increasing with the beam motion through the vacuum chamber

Gun corrector (max 120 A)

Current	By	Layers/wires (per layer)	Inductance	+y deflection	-y deflection
200 A	1570 Gs	2/70	0.0112 H	6.1 mm	9.5 mm
120 A	950 Gs	2/70	--//--	3.1 mm	6.5 mm

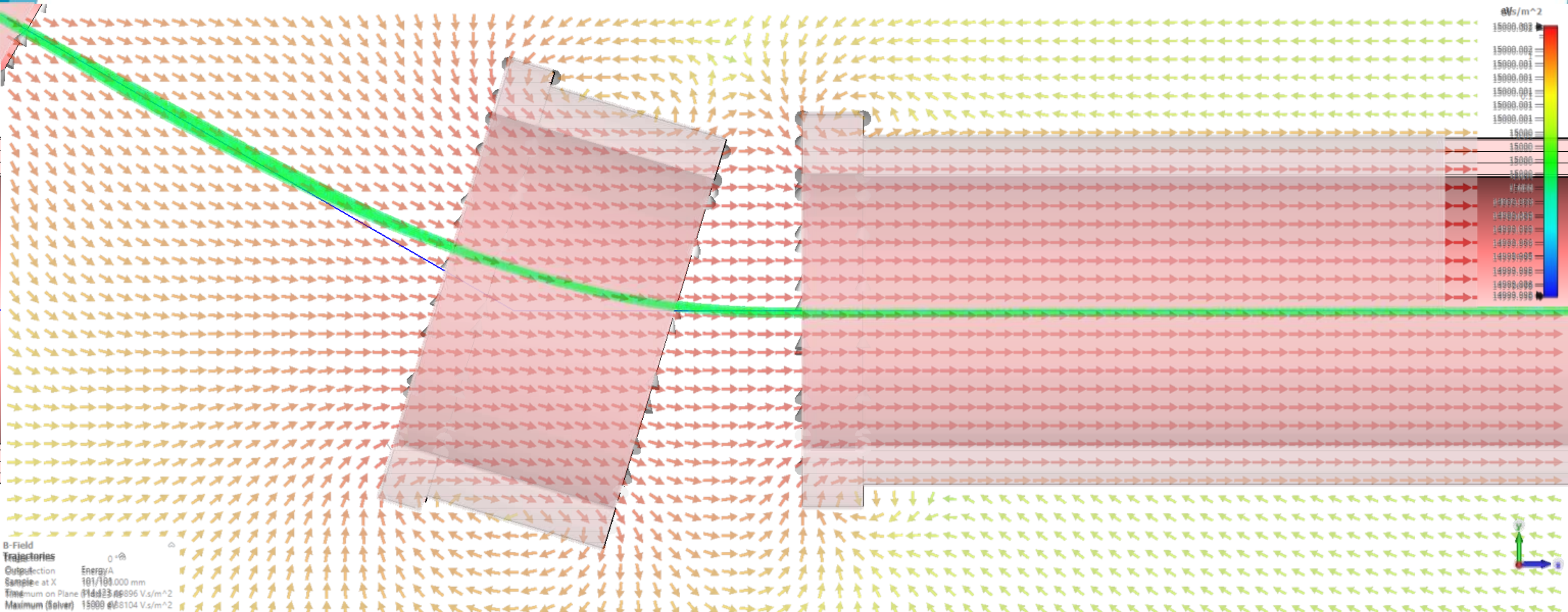




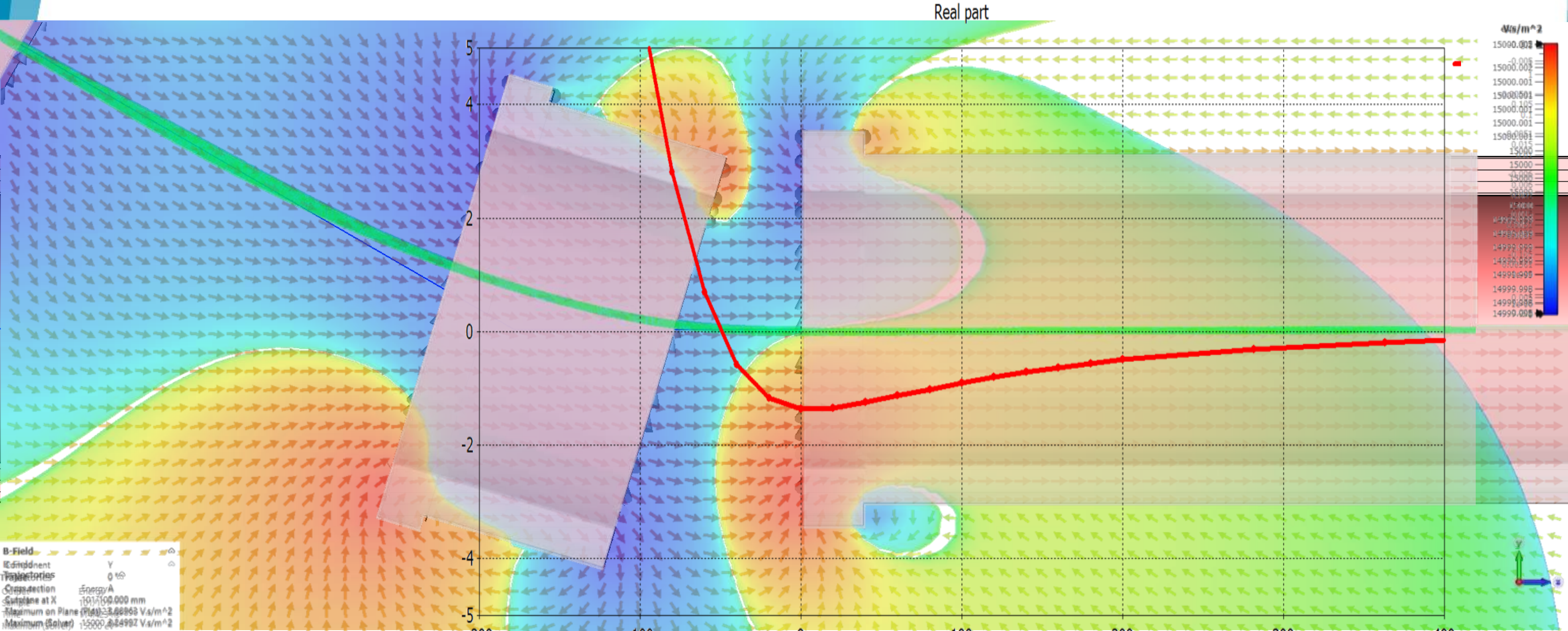
Maximum deflection of the e –beam trajectories in the entrance of the main solenoid vs. gun corrector current

See Danila's presentation

E-beam trajectory (1.1mm radius) with baseline design

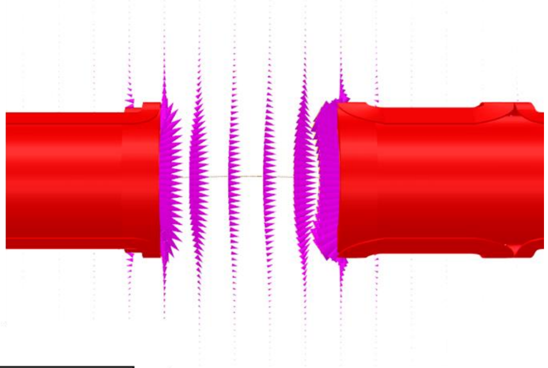


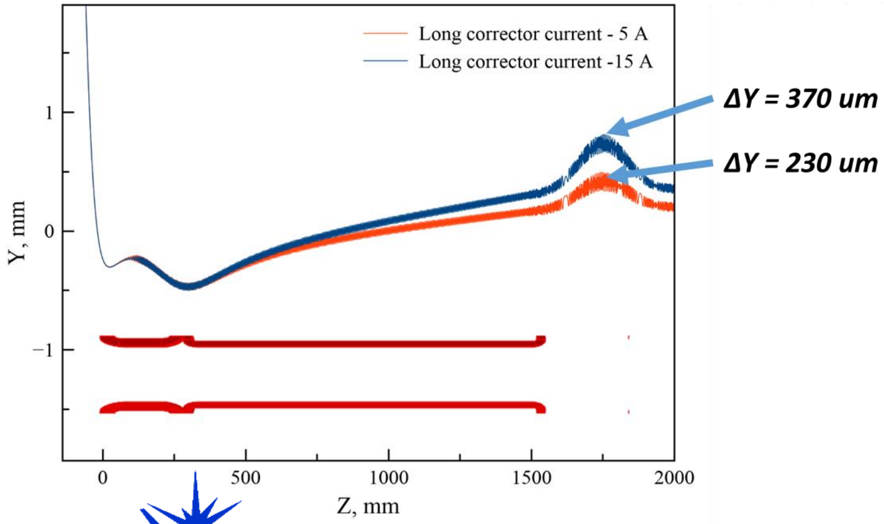
E-beam trajectory (1.1mm radius) and $B_Y > 0.005T$



Bump at BGC location

Due to magnetic field lines distortion in the middle gap, the full uncentered beam deflection was observed



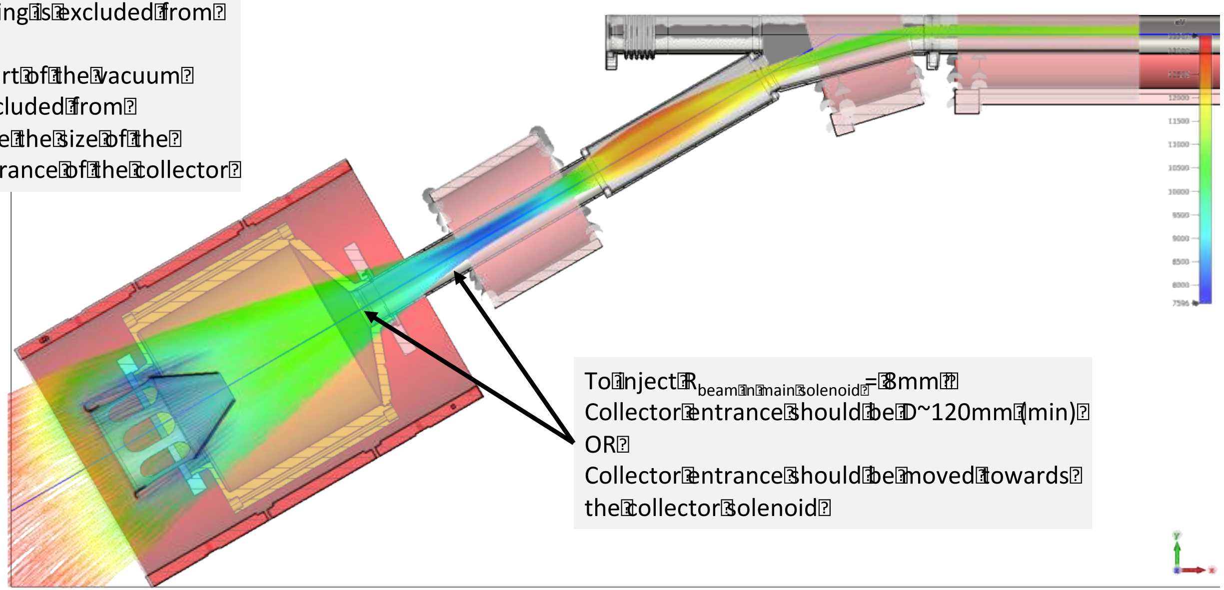


BINP

Rough simulation on collector side

EBeam trajectories, initial R_b=8mm

Magnetic shielding is excluded from simulation
Collector and part of the vacuum chamber are excluded from simulation to see the size of the beam at the entrance of the collector



To inject $R_{beam\ in\ main\ solenoid}$ = 8mm
Collector entrance should be D~120mm (min)
OR
Collector entrance should be moved towards the collector solenoid

Further open issues/studies

- Sensitivity of e-beam trajectory on mechanical errors/misalignments at different positions
- Sensitivity on powering ripple
- E-beam stability, shape (cross-section distribution) in new configurations, with e-beam centred and transversally displaced
- . . .
- Feed back to ABP for residual kick calculations

Summary and conclusions

- HEL electron beams have tight tolerances in terms of trajectory, size, uniformity.
- The HL-LHC Hollow Electron Lens is an in-kind contribution. The design is well advanced.
- The magnetic system is a ‘build to specs’ contribution, that is the CERN design is given as an example for BINP to take or …
- The magnetic layout is a chosen by CERN (in collaboration with BINP for e-beam simulation studies)
  - Studies addressing the ‘bump’ of the e-beam at injection/extraction, at the gap between main solenoids, and the aperture (or magnetic field) to the collector are progressing (in collaboration with BINP colleagues) and may bring modification to the HEL magnet layout.
- The parameters of the HEL magnet design are not expected to be affected by the possible changes, maybe marginally the current scope of the supply.
- Issues like integration and costs, will be taken into consideration.

Thank you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Power converters

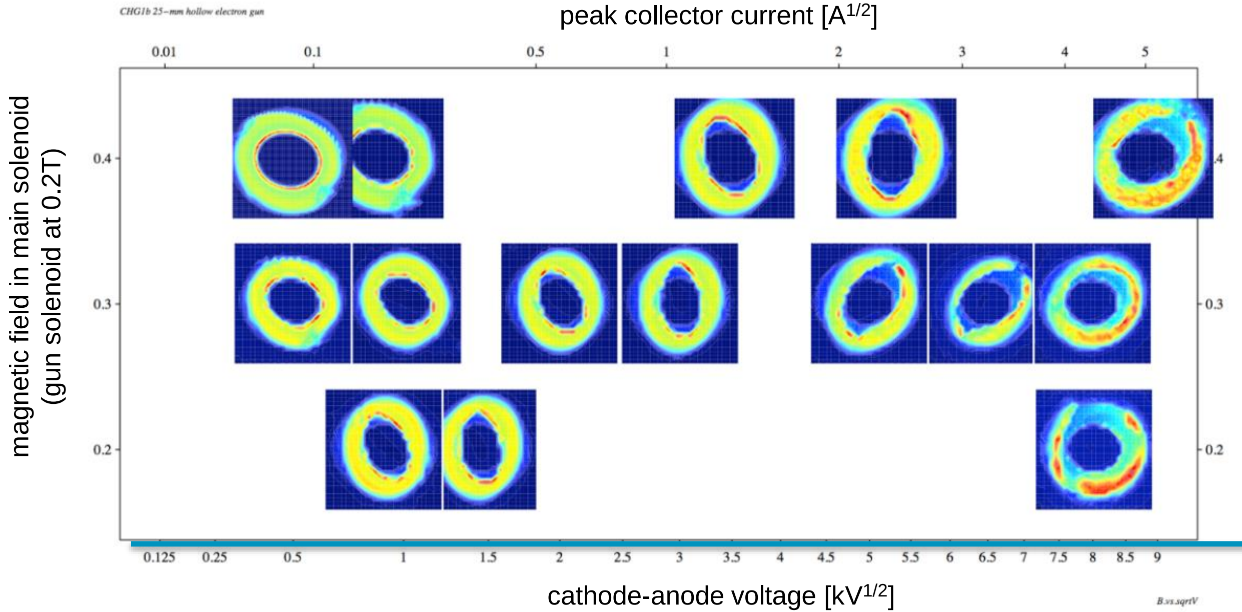
PC classe 3		10	ppm	of	600	A	0.006	A	
							RIPPLE		
main solenoid		5	T	nom. Current	330	A	0.09	mT	on axis
angle		0	deg						
V component		0.00	T				0.00	mT	V
H component		5.00	T				0.09	mT	H
PC classe 4		20	ppm	of	600	A	0.012	A	
							RIPPLE		
bend solenoid		3.5	T	nom. Current	335	A	0.13	mT	on axis
angle		16	deg						
V component		0.96	T				0.03	mT	V
H component		3.36	T				0.12	mT	H
2nd gun sol		3	T	nom. Current	320		0.11	mT	on axis
angle		30	deg						
V component		0.83	T				0.06	mT	V
H component		2.88	T				0.10	mT	H

Hollow Electron beam

LARP **Profile evolution**

HiLumi HL-LHC PROJECT

CHG1B Ø 25mm cathode – Ø 63mm chamber

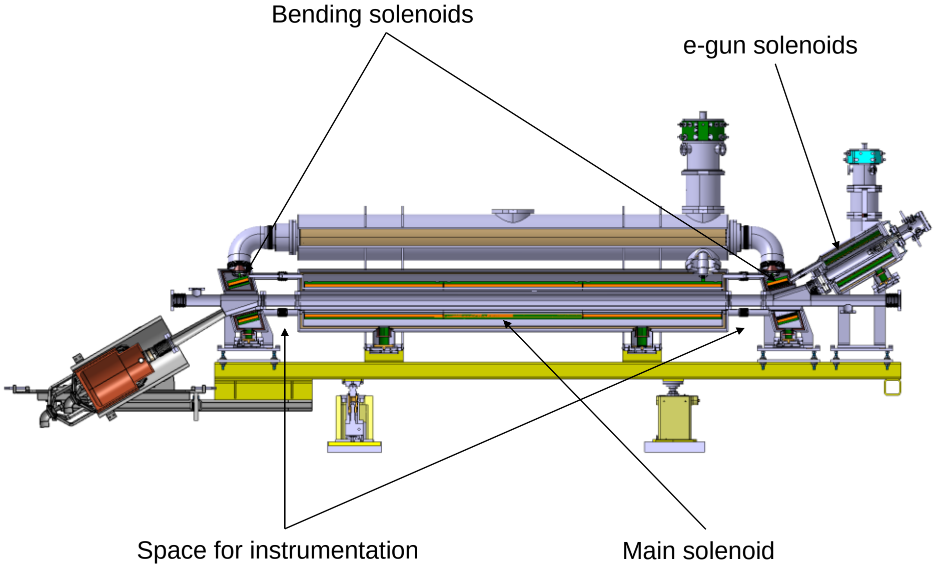


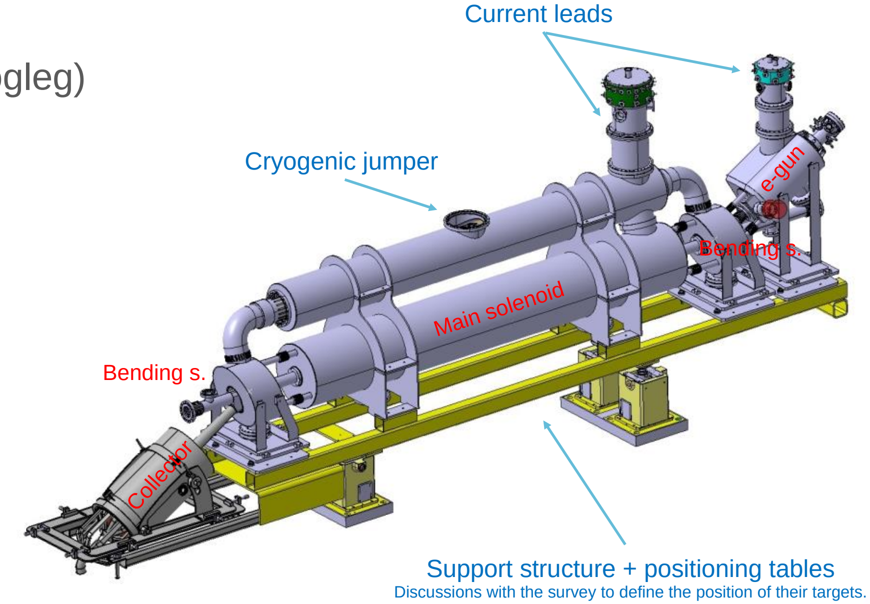
Increase in current density

Courtesy of Giulio Stancari

Reference design in Oct. 2017

- ~ 15% smaller e-beam (200 m against 280 m β at HEL)
- 5 A x 10 keV e-beam acceleration
- Tight space in IR4 (space available + cryo at dogleg)
- 4 T main solenoid
- Gap for instrumentation at ends of main

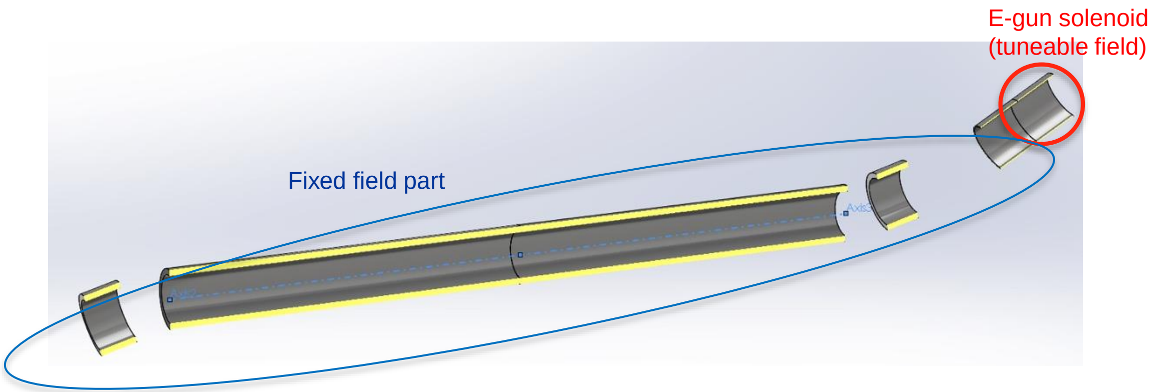




Courtesy of D. Perini, A. Kolehmainen

Electron transport simulations: parameters

Geometry and magnetic field as from current baseline

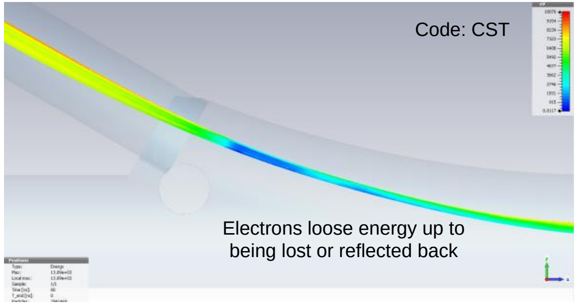


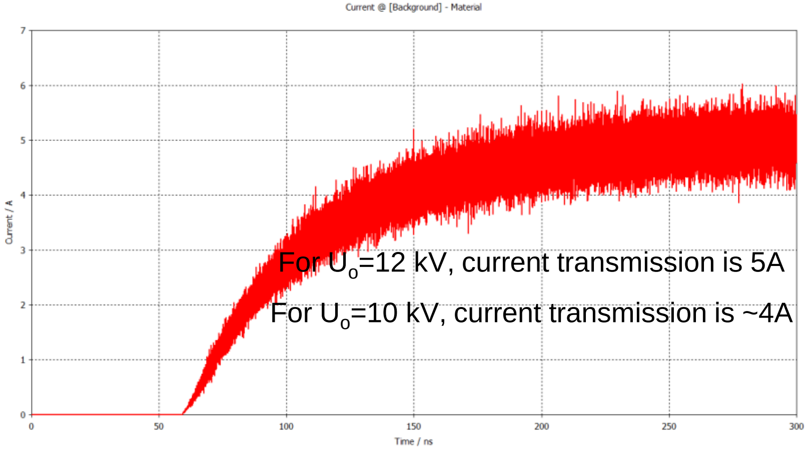
Courtesy of Diego Perini

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
Nominal current at the cathode	5 A

E-beam simulations

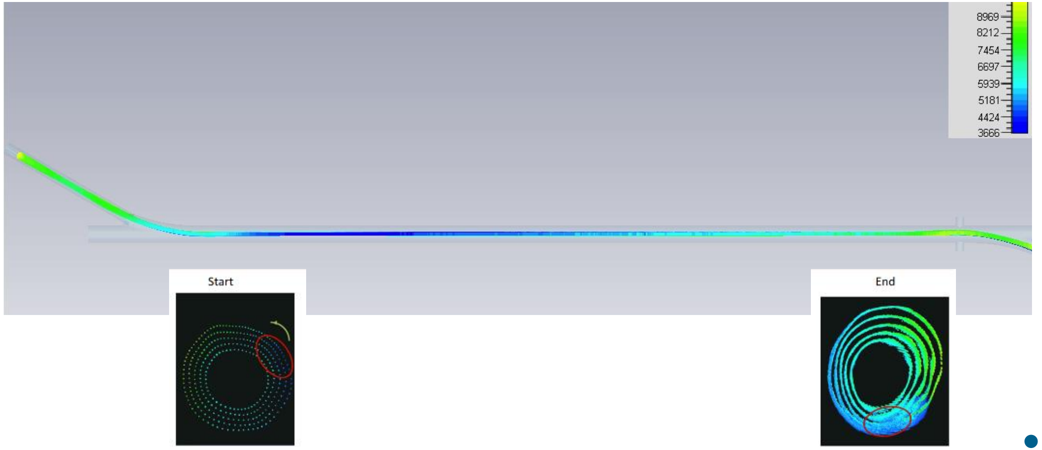
- Focusing on e-beam transmission
  - increase electron accelerating voltage to 15 kV





E-beam simulations

- Stability of the electron beam



- Increase of main field to 5T (proposed 6T but 5T for magnet considerations)