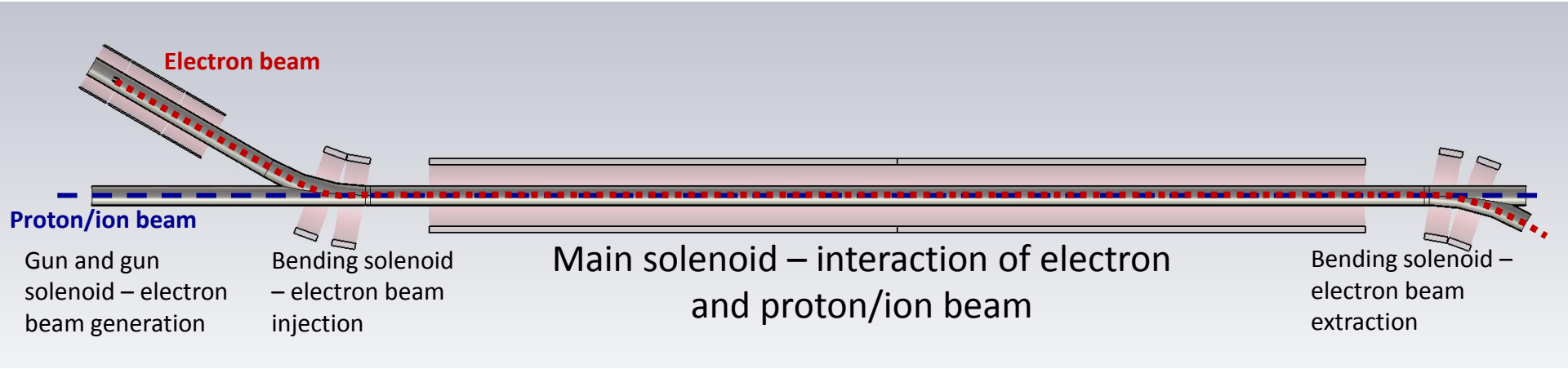
Design of the test stand for the CERN and GSI electron lenses

Outline

- Motivation
  - Electron lenses overview
  - Beam dynamics overview
- Test bench design
  - Solenoids
  - Electron gun
  - Beam diagnostics box
  - Measurements
- Summary and current status

Electron lenses (short overview)



Beam:

- appropriate beam current
- appropriate transverse and longitudinal profiles

Electron lens:

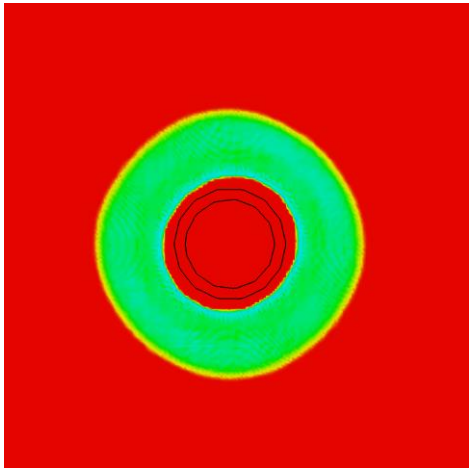
- magnetic field with appropriate configuration and uniformity
- diagnostic tools

Electron beam (5-10 A, 10-25 kV) dynamics in non uniform magnetic field over 5m

Electron beam dynamics (short overview)

- An electron in a uniform B field will gyrate along field lines with
  - *cyclotron frequency/Larmor radius*

$$w_c = \frac{|qB|}{m} \qquad r_g = \frac{v_\perp}{\omega_c} = \left|\frac{mv_\perp}{qB}\right|$$



- In the presence of an electric field (self field of e-beam), assuming that the induced B field change is << W_c^{-1}

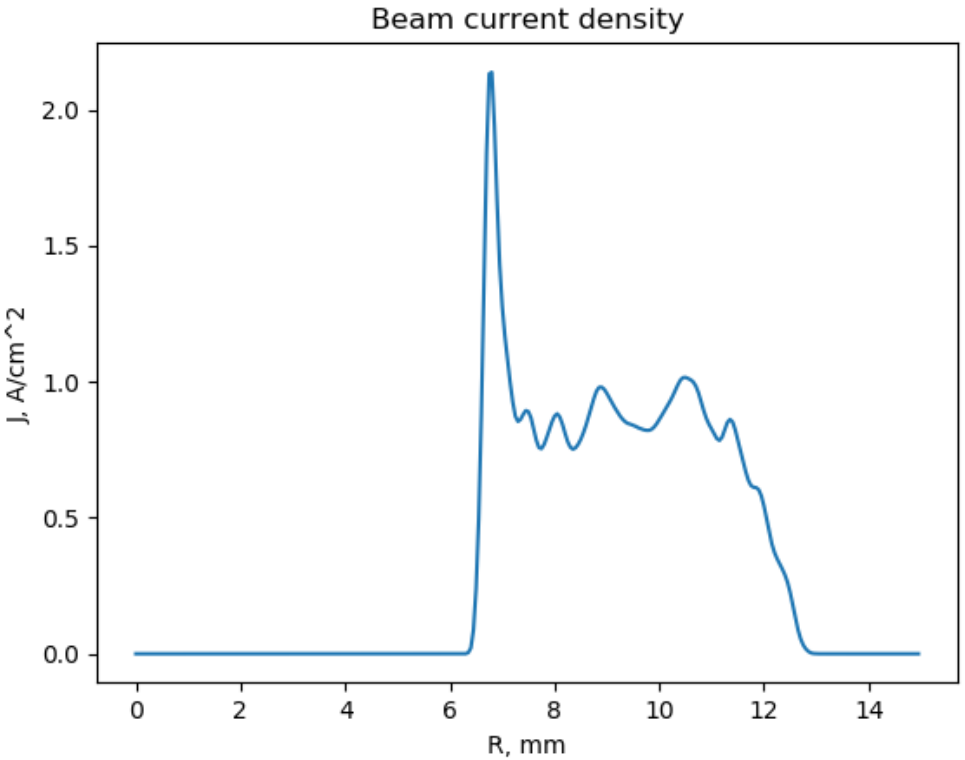
$$\frac{d\mathbf{r}_{\text{guiding centre}}}{dt} = v_{\parallel}\frac{\mathbf{B}}{|B|} + \frac{\mathbf{E}_\perp \times \mathbf{B}}{B^2}$$

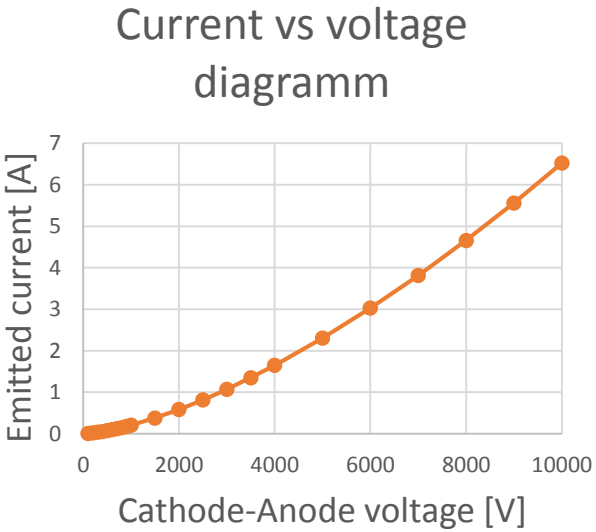
- In the presence of bent section:

$$\frac{d\mathbf{r}_{\text{guiding centre}}}{dt} = v_{\parallel}\frac{\mathbf{B}}{|B|} + \frac{\mathbf{E}_\perp \times \mathbf{B}}{B^2} + v_\perp \frac{\mathbf{B}\times\nabla\mathbf{B}}{B^2} - \frac{v_\parallel^2}{\omega_c}\frac{\mathbf{R}_C \times \mathbf{B}}{R^2|B|}$$

- In the presence of drift tube – possible formation of virtual cathode
- Intensity modulation – possible change of longitudinal profile

Electron gun (overview)



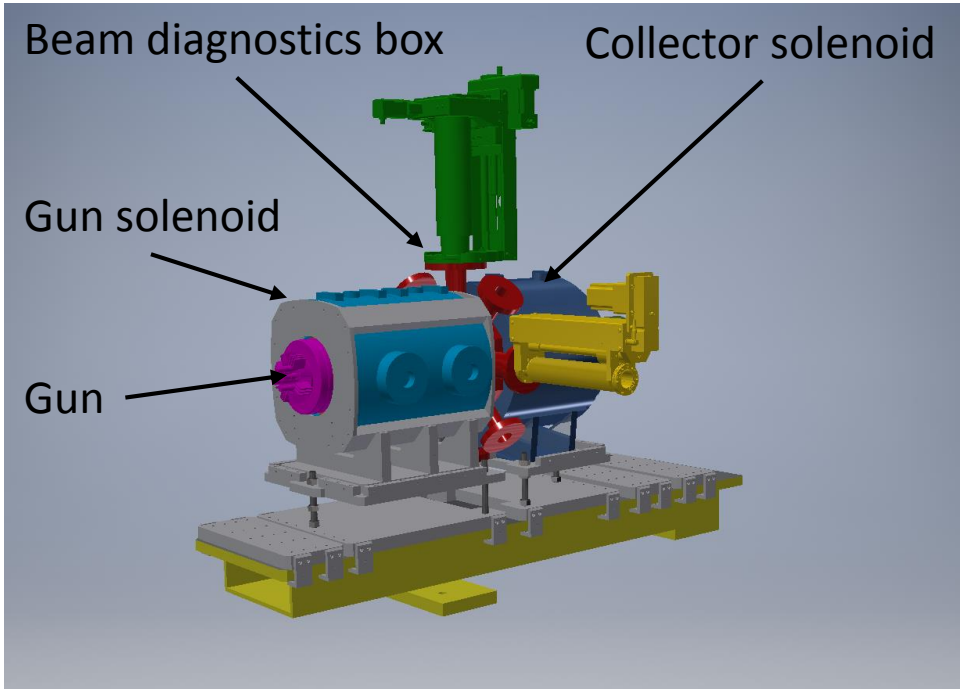


- Initial beam profile depends on current and magnetic field

Motivation of the test stand construction

- Foreseen for ARIES studies WP16 – **Intense, RF modulated E-beams (IRME):**
  - Design and build a test stand for testing gun including instrumentation suitable for measuring the transverse and longitudinal profiles of the RF modulated electron beam
  - Measure the properties of the RF modulated electron beam created by the gun using this test stand [50x70mm oval shape e-beam, 10A, 25kV]
- Can be used for:
  - Test diagnostics for electron beam:
    - Gas Curtain Monitor [https://indico.cern.ch/event/567704/]
    - Beam Position Monitors
  - If **HEL-HL-LHC** becomes baseline:
    - Characterise e-guns (5A, 15 kV, hollow beam, D=16.1mm)
    - Test and validate instrumentation and components (modulators, interlocks, etc.)
  - Benchmarking of electron beam dynamic simulations

Test stand: stage 1



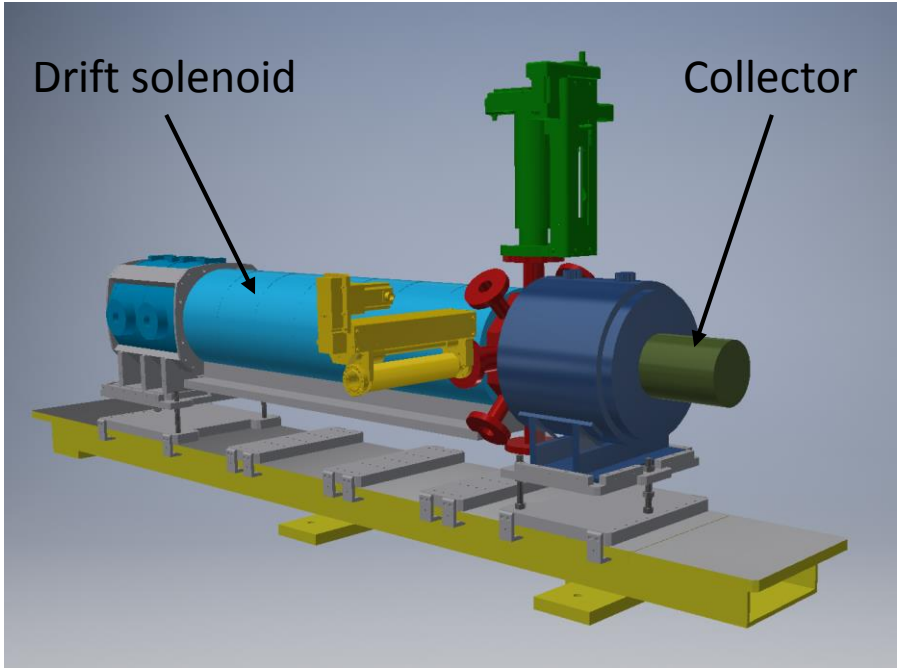
Purpose of first stage:

- Preparation:
  - Commissioning hardware (magnets, vacuum, HV system, control, etc.)
  - Safety and technical aspects of operation
  - Commissioning diagnostic procedures (current, profile, position)

- Measurements:
  - Electron gun tests: characterization
  - Electron gun: anode modular

Covered by HL-LHC

Test stand: stage 2.



Purpose and measurements of stage 2:

- Allow drift and see beam deformations/rotations/… computer model validation
- Study electron beam dynamics in regime close to virtual cathode
- Study electron beam dynamics with compression

- Test Beam Position Monitor ‘shoe-box’ or ‘strip-line’ with very HF modulation
- Test effect of very HF modulation (<10% current) on beam dynamics (microbunching?) for HEL

Simulations and computer codes

- Reliable and verified simulation techniques and models are required

- Computer codes that will be used for simulations (test bench, electron gun and beam dynamics):
  - CST particle studio [www.cst.com]
  - WARP [http://warp.lbl.gov]
  - TRAK [http://www.fieldp.com/trak.html]
  - UltraSAM [http://accelconf.web.cern.ch/accelconf/e02/papers/wepri050.pdf]
  - BENDER [https://www.researchgate.net/publication/274706602_The_Particle-in-Cell_Code_Bender_and_Its_Application_to_Non-Relativistic_Beam_Transport]

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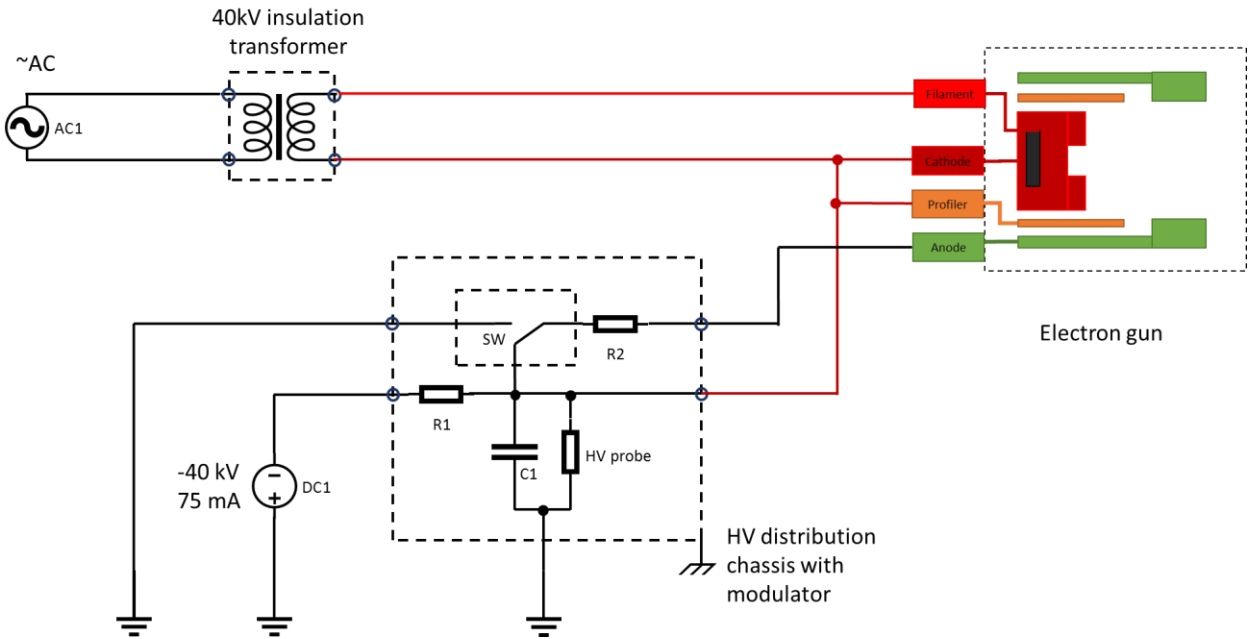
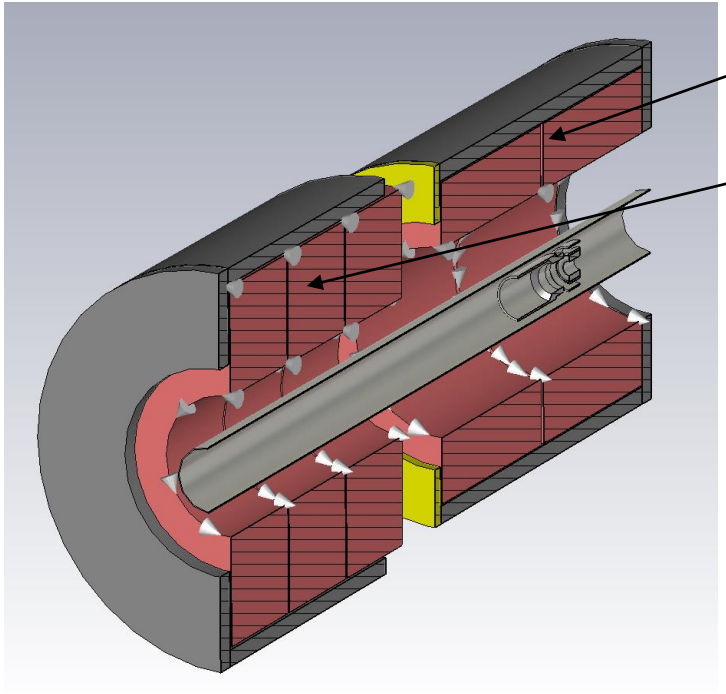
HV schematic (simplified)



- Operation in pulsed mode (up to 40kV extraction voltage)
- BELHKE HV switch (HTS 401-10-GSM) for anode modulation (10 Hz)
- Anode/grid modulator can be easily integrated

CST model of the solenoids



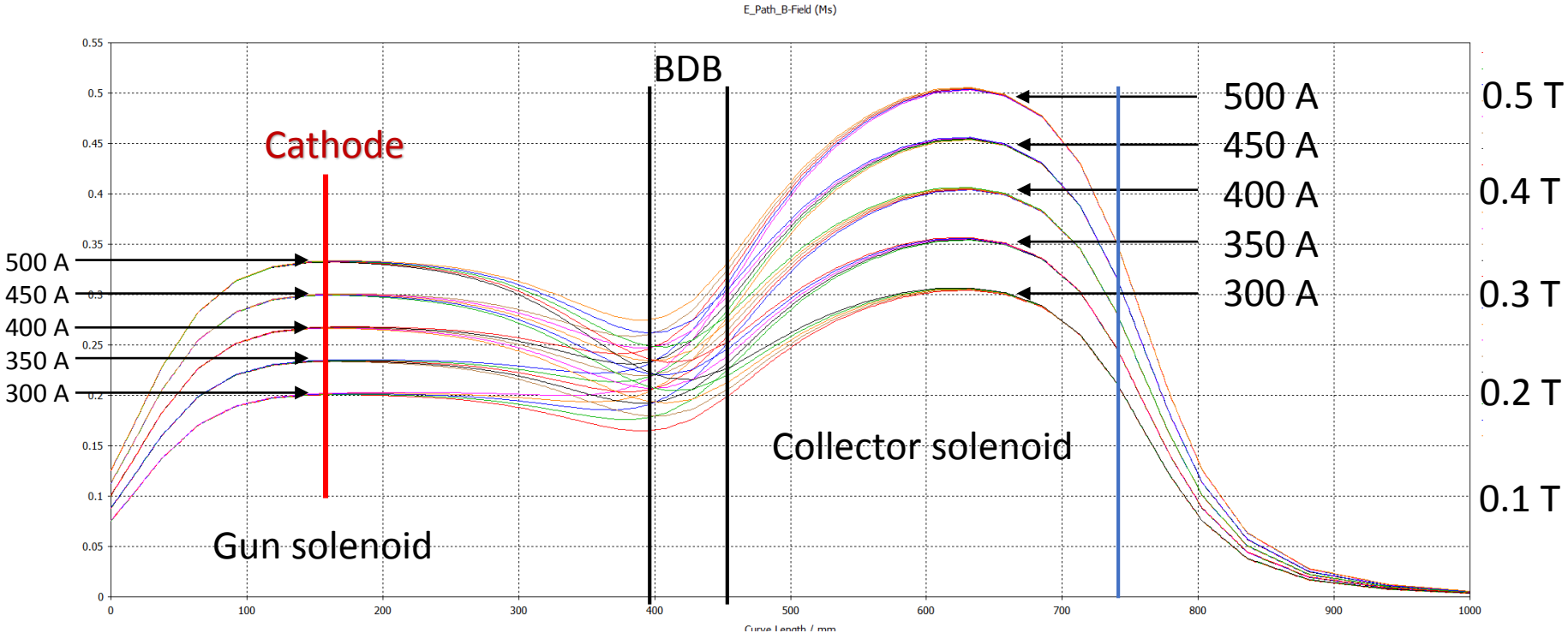
Gun solenoid (2 coils)

Collector solenoid (3 coils)

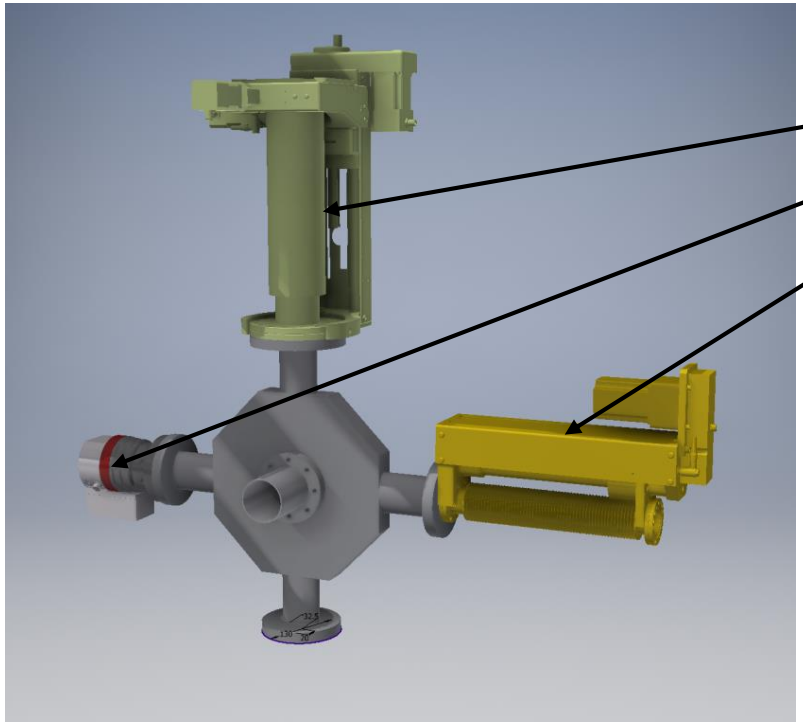
Calculations:

- B field depending on current in solenoids
- B field map (will be compared with measurements during solenoids commissioning)
- Beam dynamics for beam diagnostics
- Beam dynamics for collector design

Magnetic field along Z axis for different currents in the solenoids



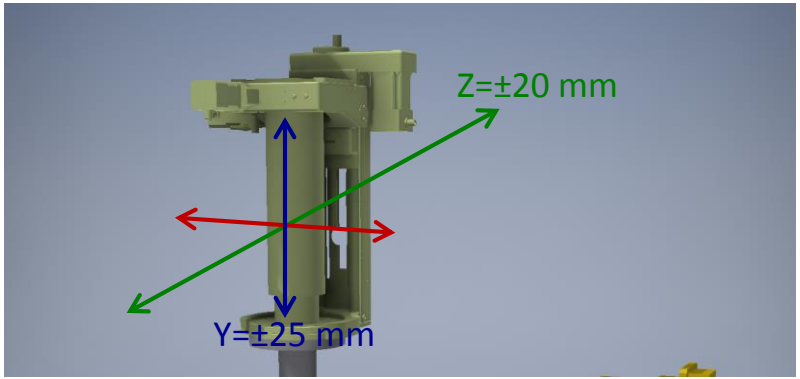
Beam diagnostics box

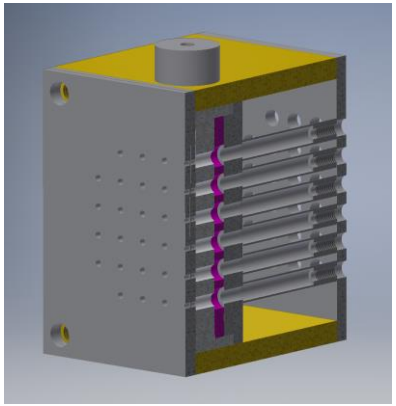


Beam diagnostic box includes:

- Movable pin-hole Faraday Cup
- Port for vacuum pump
- Yttrium aluminum garnet activate by cerium (YAG:Ce screen)

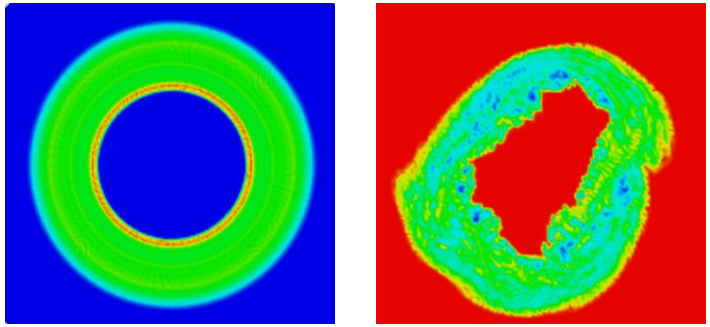
BDB: Faraday Cup





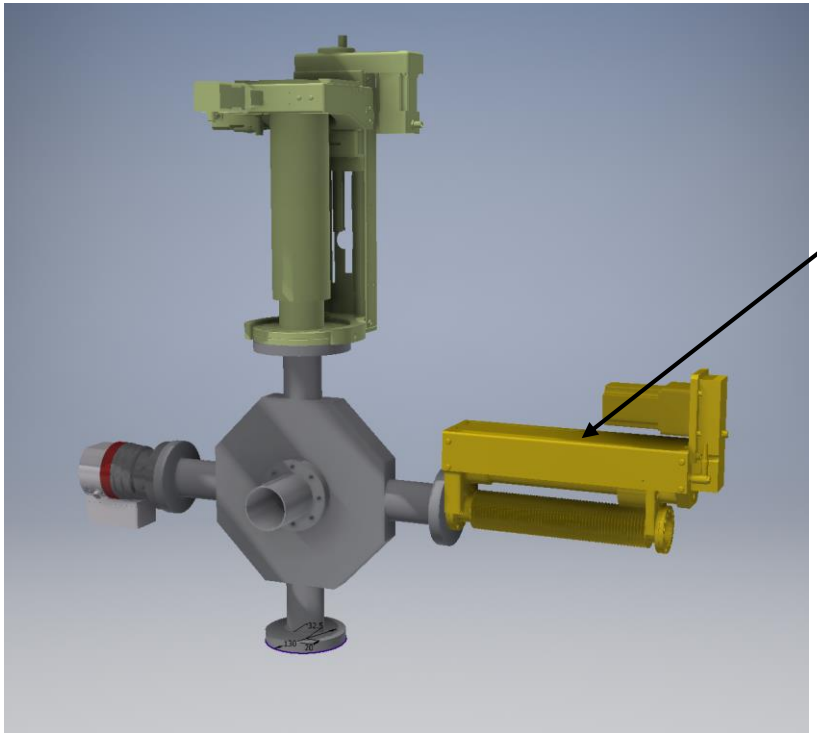
Pin-hole FC array:

- Faster scan
- Different apertures



Current density profile

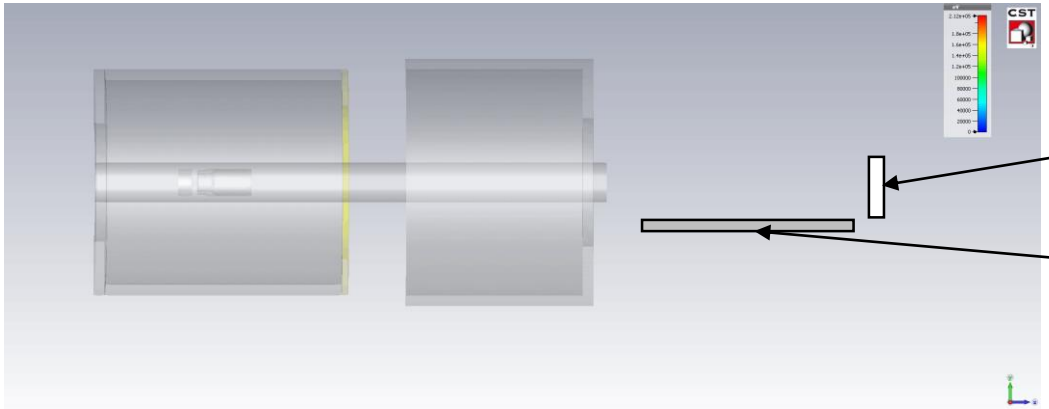
BDB: YAG:Ce screen



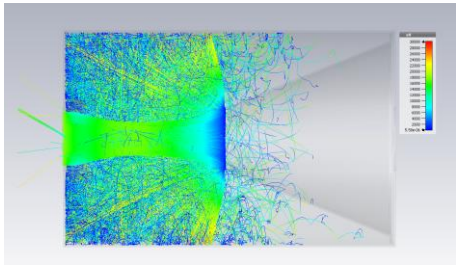
Movable actuator with YAG:Ce screen (scintillator)

- 3 screens (D=50 mm) are delivered at CERN
- Beam profile in one pulse
- Fragile (can be destroyed after one long pulse)
- Requires view port on the collector side

Collector



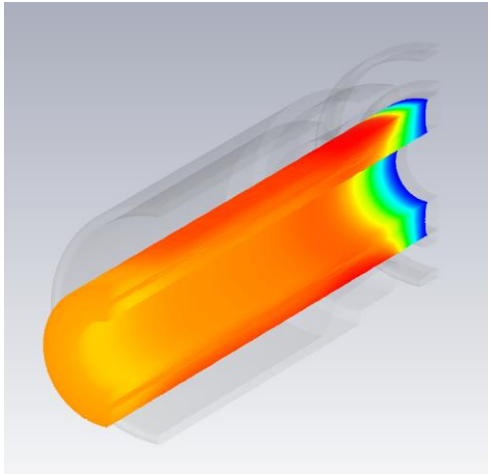
- View port for YAG:Ce screen
- Faraday Cup as collector (no water cooling)
  - Current measurement



- Preliminary design of the Faraday Cup is ready

Measurements at stage 1:

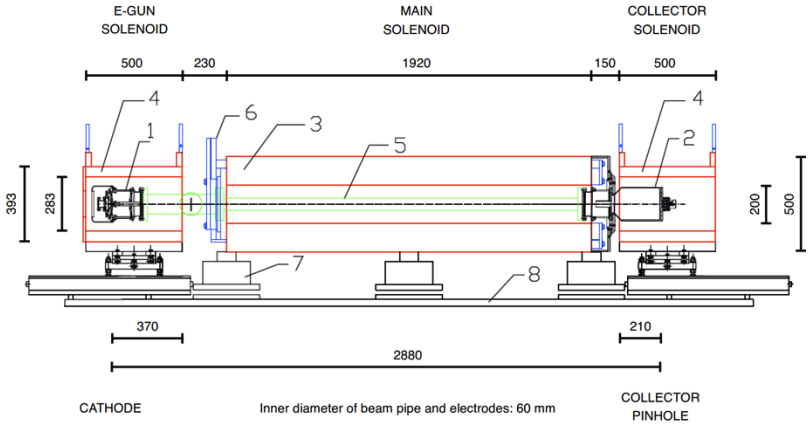
- Gun characterization
  - Current yield vs temperature of the cathode and extraction voltage applied
  - Beam profile measurements for different currents and magnetic field
  - Comparison of experimental results with CST/WARP/TRAK/UltraSAM (to use output beam profile distribution as inputs for beam dynamics simulation)



- Comparison with experimental results obtained in FNAL using identical electron guns

- Anode modulator
  - kHz at full range (0 V – -10kV)
    - HEL Gun: 200pF, 10kV
  - ~MHz at % level (beam modulation for BPM)
  - **Test modulator but not change of longitudinal profile of the beam*

E-lens test stand at FNAL



Operational, up to 10 kV, 8μs x 1Hz pulses (or higher at < 5A)

Used to test CERN guns, will be used for testing guns for space-charge compensation at IOTA ring.

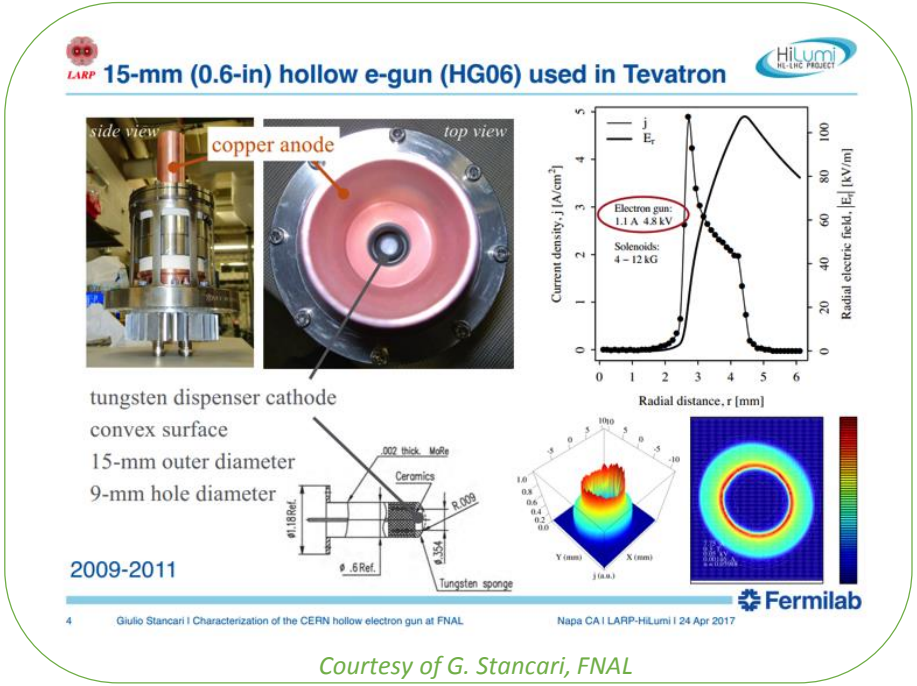
Could be used to test HF modulators.

Diagnostics: pin-hole FC in collector

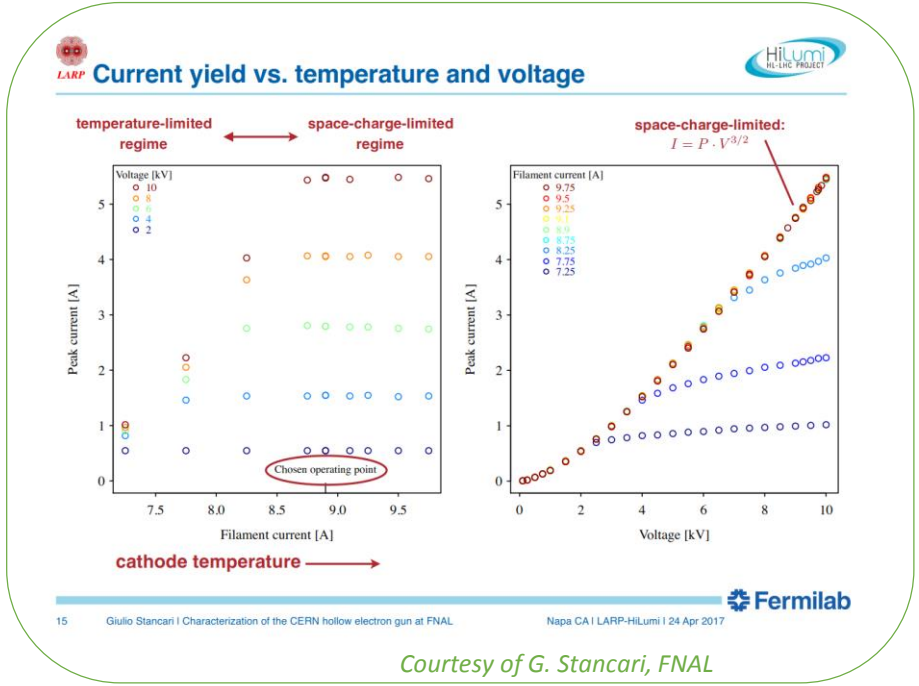
https://cdcvs.fnal.gov/redmine/projects/elens/wiki/Test_Stand

FNAL test stand: measurements

- Electron gun characterization



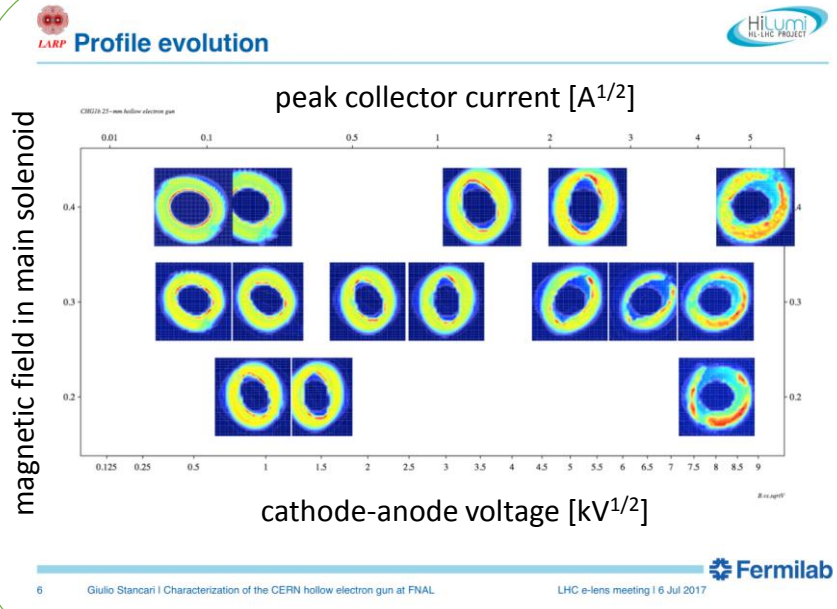
Courtesy of G. Stancari, FNAL



Courtesy of G. Stancari, FNAL

FNAL test stand: measurements

- Beam dynamics



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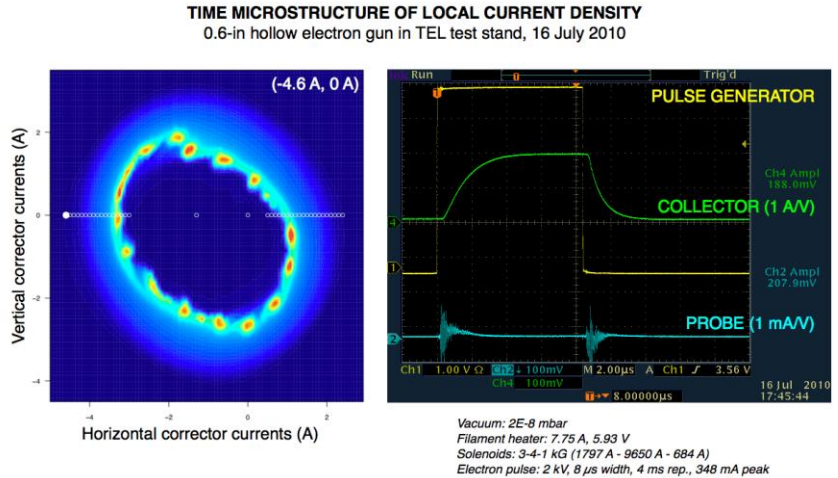

Courtesy of G. Stancari, FNAL
https://cdcvs.fnal.gov/redmine/projects/elens/wiki/Hollow_Electron_Beam_Collimator

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Summary and current status

A test stand at CERN is being constructed in a staged approach:

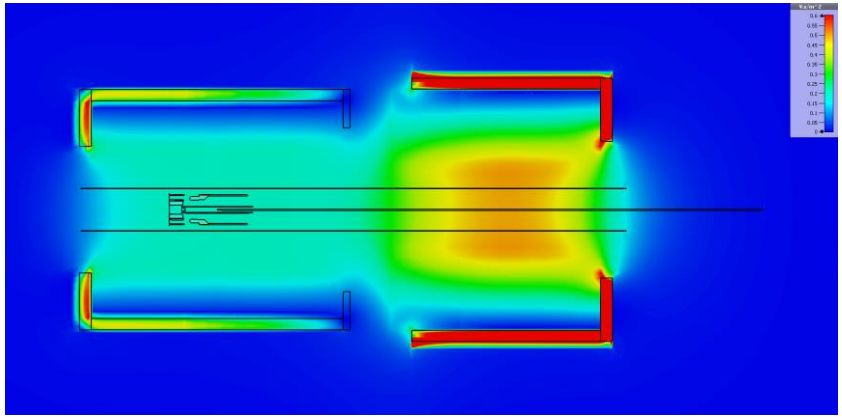
- The first stage of the test facility is planned to be installed by the end of 2018.
- The facility will then be commissioned and should be running in the first quarter of 2019.
- Measurements:
  - E-gun characterization both for SIS18 SCC lens and HEL-HL-LHC;
  - Benchmarking simulation codes (CST, WARP, TRAK, UltraSAM)
  - Initial tests of anode modulator
  - Test diagnostic tools like BGC

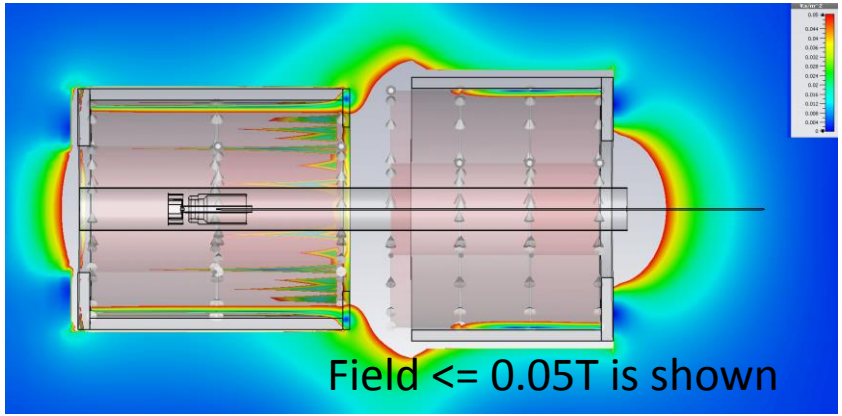
The current status is:

- Gun and collector solenoids were recuperated and commissioned at CERN.
- High current power supplies have been purchased and delivered at CERN, and will be commissioned during 2018.
- The preliminary design of the diagnostic box and diagnostic tools (pin-hole Faraday Cup, YAG screen) is completed.
- The beam dynamics through the entire stage one system (solenoids, vacuum chambers, hollow electron gun) have been modelled in CST STUDIO SUITE®.

The end

Magnetic field on plane X=0





I_{GS} = 300A
I_{CS} = 500A