This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

WP16: Intense, RF Modulated E-Beams

for Application in Pulsed Electron Lenses

4th Annual Meeting / 21.04.2021

David Ondreka / GSI

Outline

- WP16 Overview
- Covid-19 Issues
- Task Reports
  - 16.3: Gun and Modulator
  - 16.4: Test Stand
  - 16.2: System Integration
- Summary

WP16: Objectives

- JRA activity among four beneficiaries (CERN, GSI, IAP, RTU)

- Manufacturing of an RF modulated electron gun for application in electron lenses
  - High electron currents up to 10 A
  - RF modulated at 0.4 to 1 MHz with a bandwidth of up to 10 MHz
  - Elliptical beam cross section with adjustable aspect ratio
  - Different cathode shapes for matching beam dynamics requirements

- Operation of a test stand for the RF modulated electron gun
  - Normal conducting solenoids for beam transport
  - Instrumentation for probing transverse and longitudinal electron beam profiles

WP16: Covid-19 Issues

- WP16 hit hard by Covid-19
  - Pandemic started during hot phase of project
  - Severe impact for JRA due to lockdown of institutes
    - Labs and workshops closed
    - No personnel allowed on campus
    - Ordering of parts from companies delayed
  - Covid-19 measures not uniform over partners
    - Schedules got out of sync
- Consequences
  - Substantial delay of about one year for gun and modulator development (task 16.3)
  - Testing of SCC gun at CERN no longer possible, moved to IAP instead (task 16.4)
  - Focus on simulations (esp. task 16.2)
- WP16 very grateful for project extension until end of this year

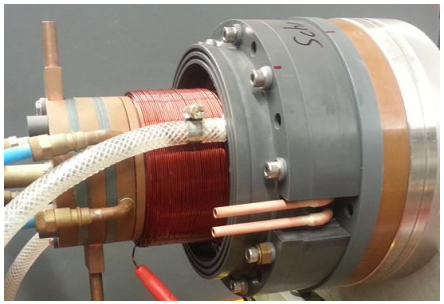
SCC Gun (16.3): Status

Partners: IAP, GSI

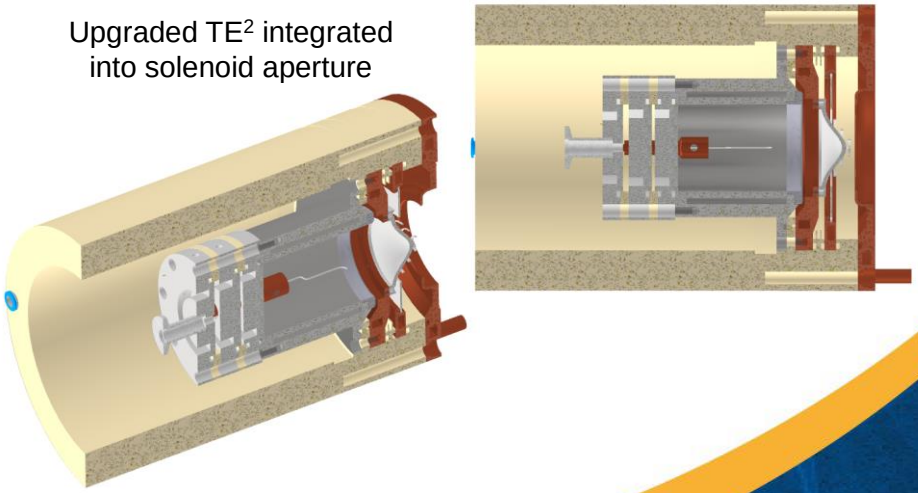
Code	Deliverable	Type	Due/m
D16.2	Gun and modulator	Demonstrator	46

- Upgrade of TE2 design
  - TE2 = Tungsten Electron Emitter
  - First prototype assembled one year ago
  - Design improvement by modification of
    - flange edges on grid and ground electrode
    - modulating grid (refined mesh)
    - anode (smoother shape)
  - Adaptations for integration into gun solenoid
    - Modifications of cooling connections
    - Insulating shield between gun and solenoid
  - Refined grid to be delivered soon
- Significant delay due to Covid-19 measures
  - Very limited access to IAP labs for almost one year
  - Lab works delayed due to university lock-down

First TE^2 prototype



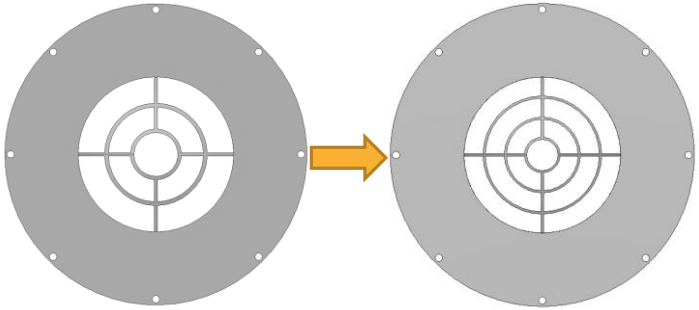
Upgraded TE^2 integrated into solenoid aperture



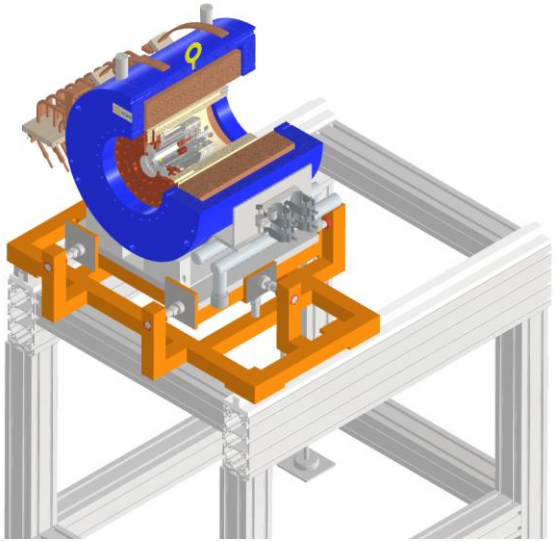
SCC Gun (16.3): Next Steps

- Implementation of upgraded TE^2 design
- Preparations for high current operation
- TE^2 measurement campaign
  - Extraction at few kV
  - Test of modulation with modulator prototype
  - Gun tuning for maximum current
  - Final gun tests at IAP (see task 16.4)

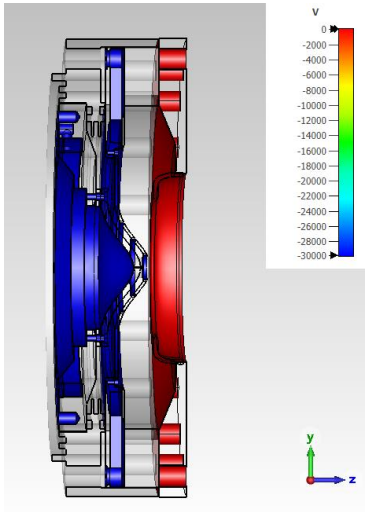
Original and refined grid



Gun integrated into solenoid



Upgraded design allowing adjustment of distances

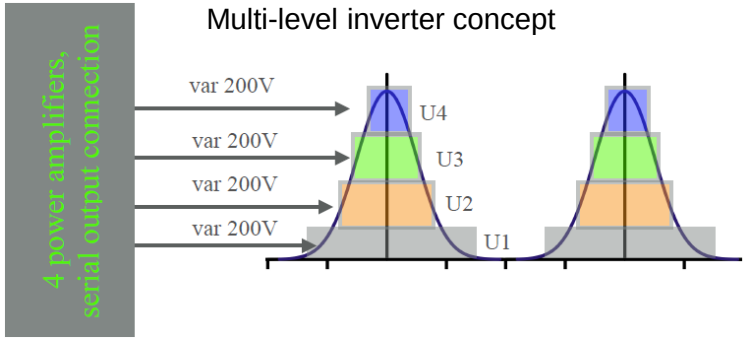


Modulator (16.3): Status and Next Steps

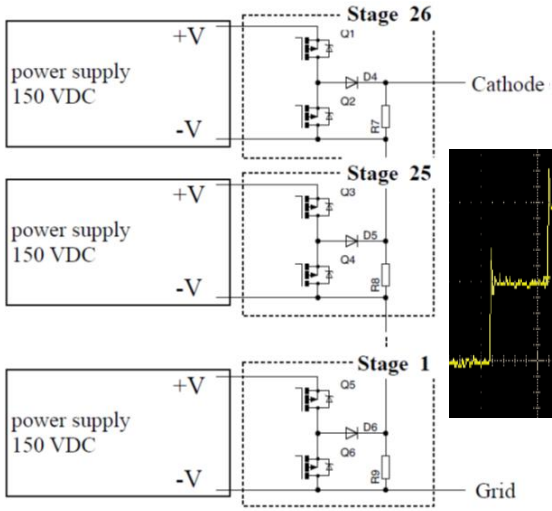
Partners: RTU

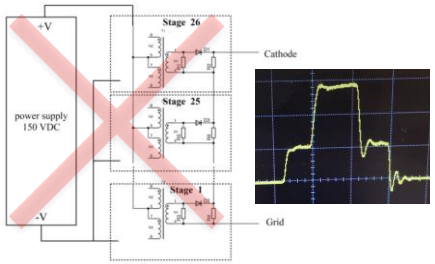
- Power supply for multi-level amplifier redesigned
  - Separation of stages by RF transformers lead to parasitic transients deteriorating pulse shape
  - New design with isolated individual power sources
    - Advantage: much better pulse shape
    - Disadvantage: much more complicated
  - 4-stage prototype under construction
    - Electronics parts received
    - Mechanical design work in progress
- Significant delay due to Covid-19 measures
  - RTU labs closed until beginning of April
  - No hardware work possible for almost one year
- Next steps
  - Completion of 4-stage prototype
  - Testing of prototype with TE^2 at IAP
  - Design and manufacturing of final amplifier with 26 stages
  - Commissioning of final amplifier for TE^2 gun tests

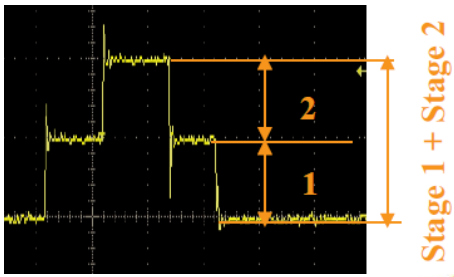
Multi-level inverter concept



New power supply topology







Test Stand (16.4): Status

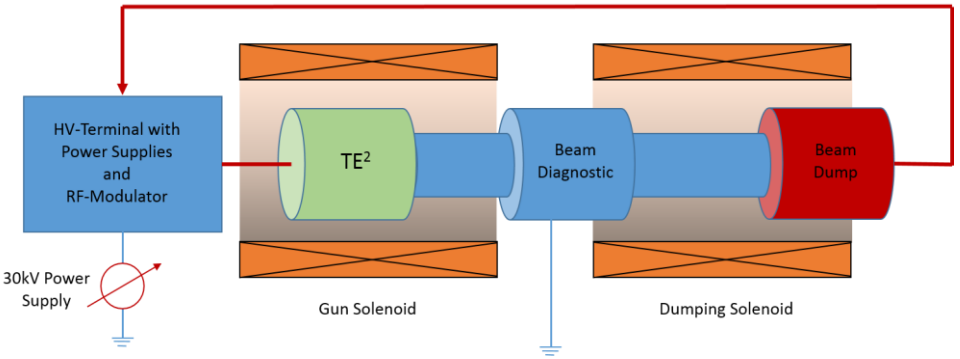
Partners: CERN, IAP

- Major change due to Covid-19
  - CERN test stand intended for both LHC HEL gun and ARIES SCC gun
  - HEL and SCC gun schedules out of sync due to Covid-19 effects at CERN and IAP
  - SCC gun can't be tested at CERN
- SCC gun tests moved to IAP
  - IAP provides equipment and assembly
  - Testing by personnel from both institutes
  - Final report D16.3 by CERN
  - Proposed new date for MS57: month 50
- Test stand at IAP under construction
  - Lab space for gun tests cleared
  - HV terminal up to 35 kV
  - Support structures
  - Controls infrastructure

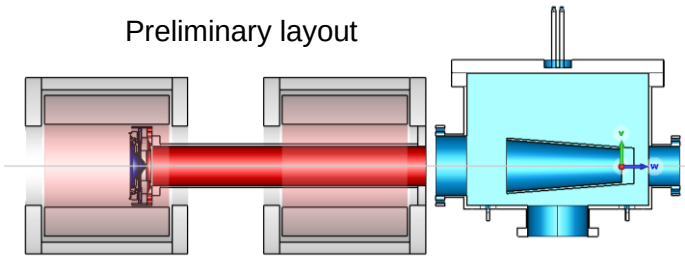
Code	Milestone	Type	Due/m
MS57	Assembly of test stand with diagnostics completed	Report	50 (47)

Code	Deliverable	Type	Due/m
D16.3	Test stand and gun tests	Demonstrator	53

Schematics of test stand at IAP



Preliminary layout

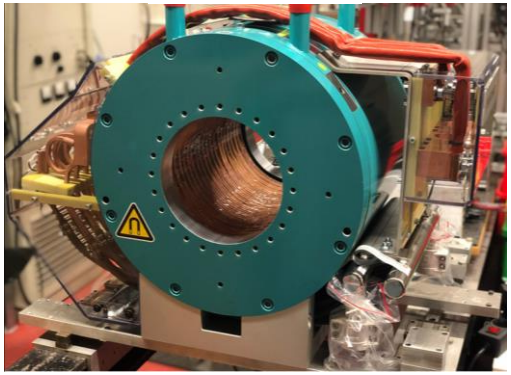


Test Stand (16.4): Next Steps

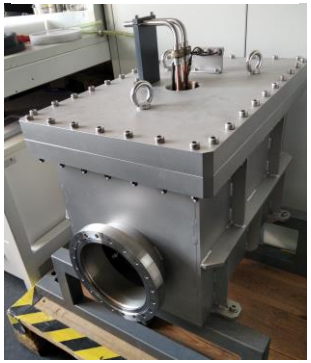
- Final decision on profile diagnostics
  - Difficult due to high power
- Completion of test stand (Q2/2021)
  - Installation of support structure
  - Infrastructure connections
- Integration of gun and modulator (Q2/2021)
- Commissioning of test stand (Q3/2021)
  - Controls for operation of gun
  - Safety measures and protection circuits
- Gun tests (Q3-Q4/2021)

Controls and HV terminal for test stand

Gun solenoid



27kW Faraday cup

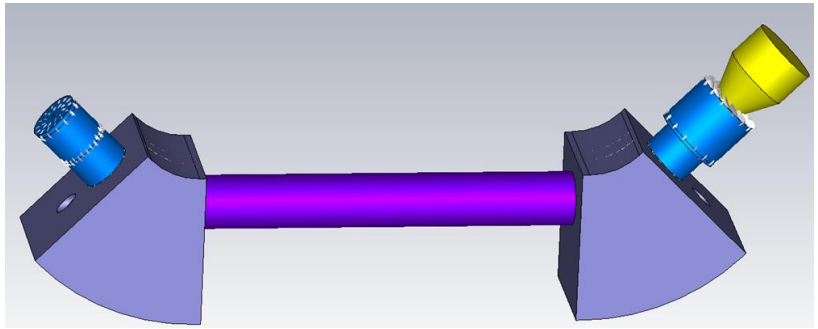


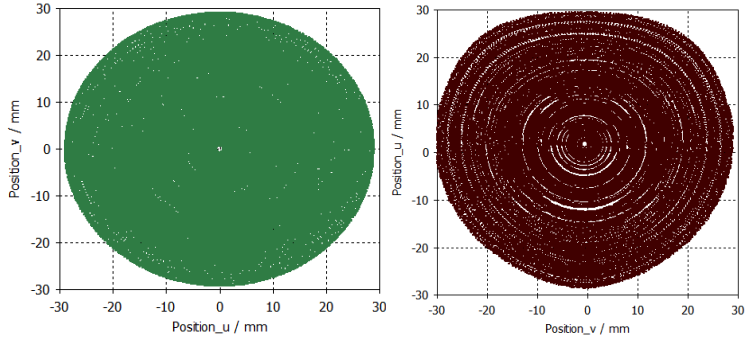
System Integration (16.2): Status

Partners: GSI

- Layout of major magnets completed
  - Toroids
  - Solenoids
  - Ion beam orbit correctors
- Preliminary collector design
- Electron beam transport simulations
  - Delay due to issues with simulation tool
  - Simulations now well progressed

Code	Deliverable	Type	Due/m
D16.1	Electron beam dynamics studies	Report	52

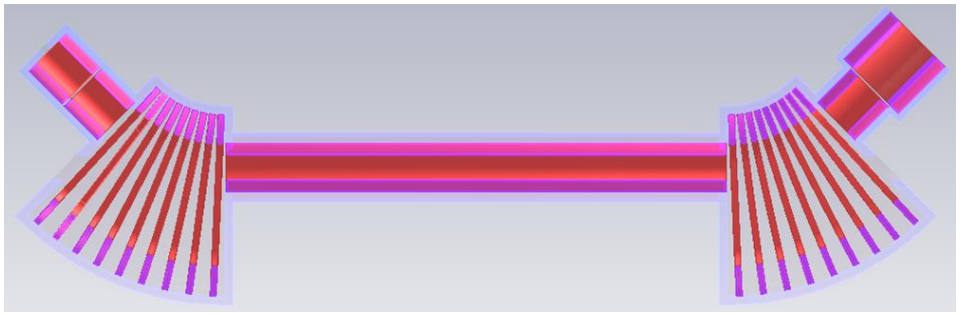




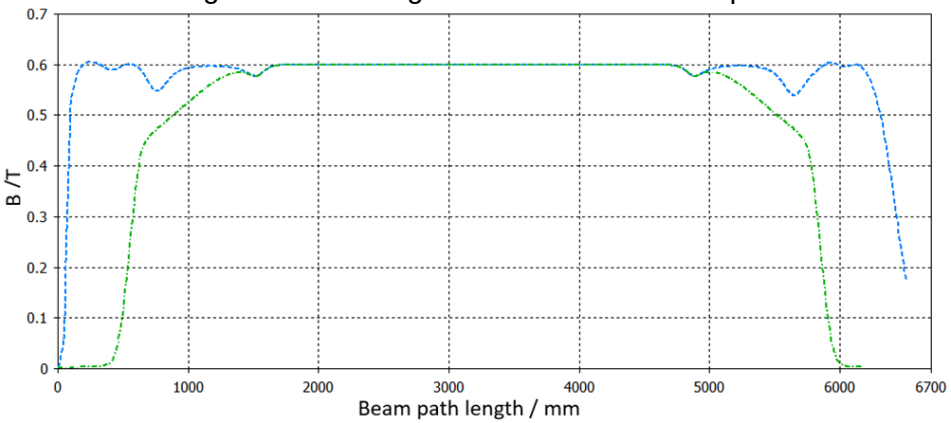
(16.2) Magnetic Layout

- System designed for 0.6 T longitudinal field
- Solenoids for guiding electron beam
  - Interaction solenoid of length 3.3m
  - Gun and two transport solenoids of length 0.4m
  - Collector solenoid of length 0.5m
- Toroids for bending beam onto ion beam path
  - Bending angle: 45 degree
  - Number of coils: 9
  - Coil outer dimensions: 0.94m x 1.2m
  - Coil cross section: 200mm x 40mm

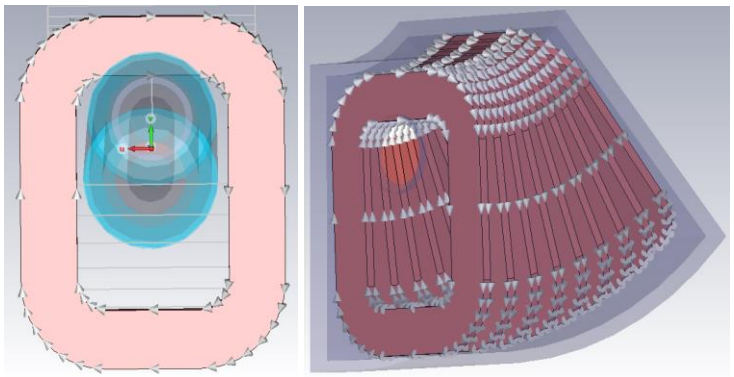
Coil system of the SCC electron lens



Magnetic field along electron and ion beam path



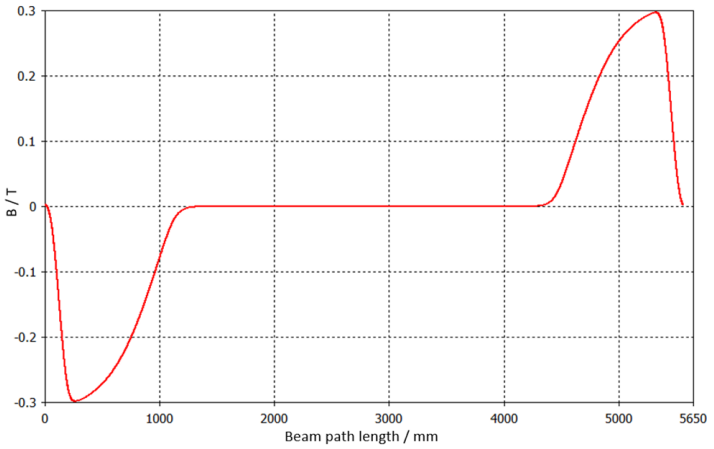
Toroid coils



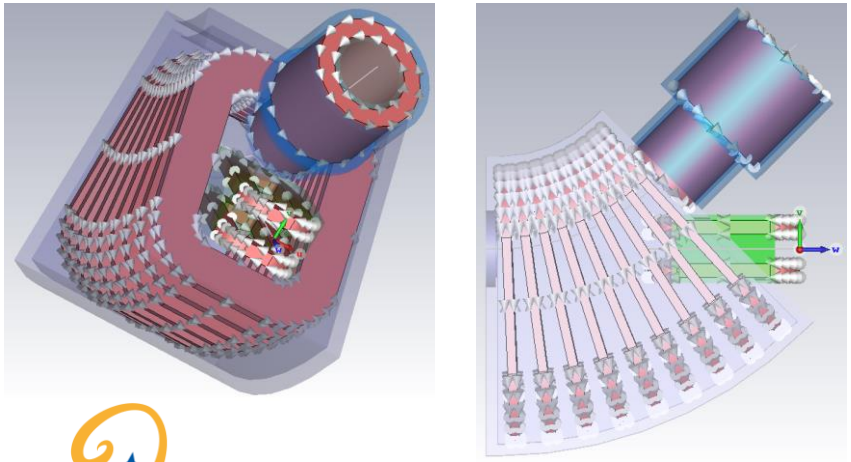
(16.2) Ion Orbit Correction

- Ion beam receives strong kick from toroids
  - Vertical field component creates horizontal deflection
  - Longitudinal field couples to vertical plane
  - Maximum effect for light ions (e.g. C^{6+}, 11.4MeV/u)
    - Total deflection angle almost 12 degree
    - Offsets at exit from toroid 100mm (h) and 11mm (v)
  - Correction required close to center of kick
- Integration of corrector dipoles into toroid
  - Challenging due to space constraints
  - Electron beam practically unaffected

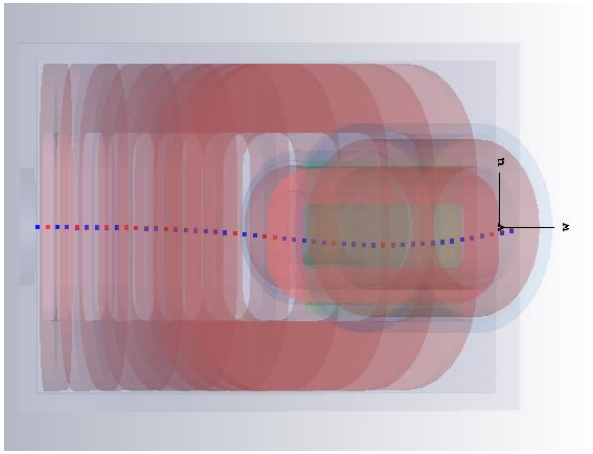
Vertical field along ion beam path



Corrector dipole integrated into toroid



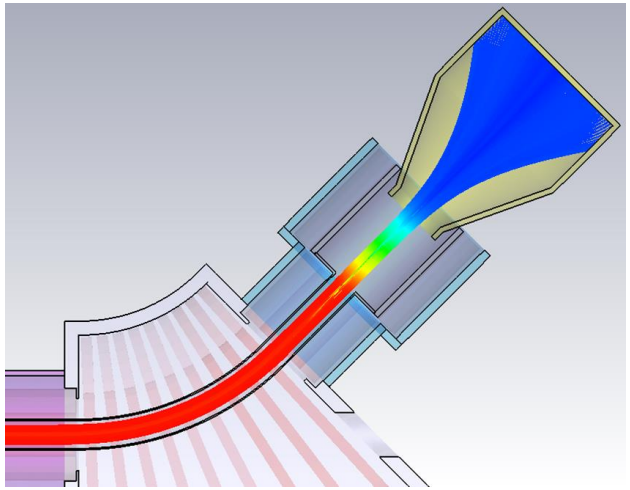
Corrected ion beam trajectory



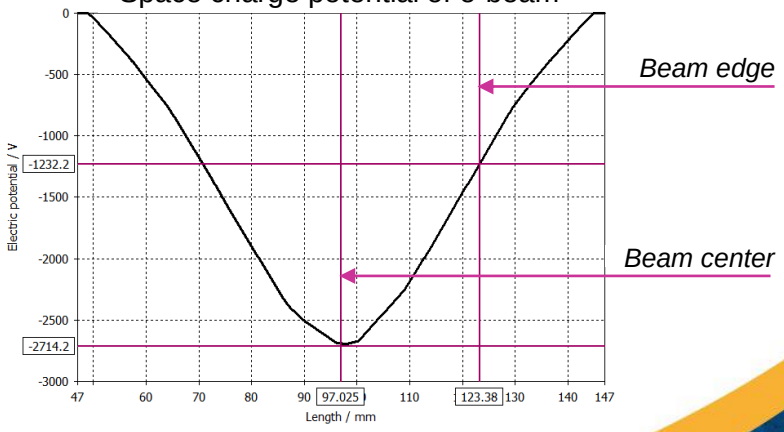
(16.2) Collector Design

- Collector as beam dump for high power e-beam
  - Minimize power by putting on cathode potential
  - Some positive bias required
    - Ensure high catching efficiency
    - Capture secondary electrons
    - Consider potential drop due to space charge
  - Dissipated power about 20kW at 10A current
  - Collector made from copper, water-cooled
- Special collector solenoid
  - Larger aperture to fit collector
  - Controlled beam expansion to increase surface
- Repeller electrode for secondary electrons
  - Prevents SEE electrons from entering the lens
  - Negative bias w.r.t. to cathode
  - Design work in progress

Present status of collector design



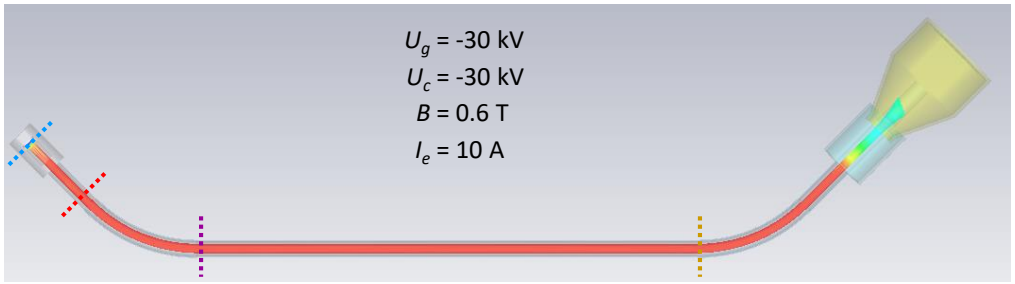
Space charge potential of e-beam



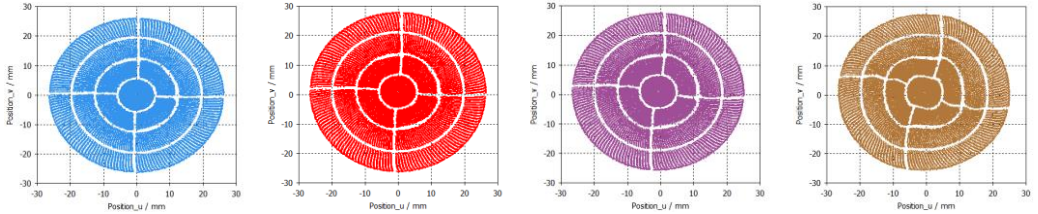
(16.2) Transport Simulations: Full Lens

- Simulations using CST
  - Long simulation times for full lens (days)
  - Definition of mesh challenging
  - Bending sections are an issue
- Different strategies used
  - Full simulation including field and beam
  - Separate simulation of magnetic field
  - Division into smaller subsections
- Results indicate robust design
  - Analytical results well reproduced
  - Excellent conservation of beam profile
- Studies ongoing
  - Impact of image fields from vacuum chambers
  - Influence of dipole correctors
  - Correction system

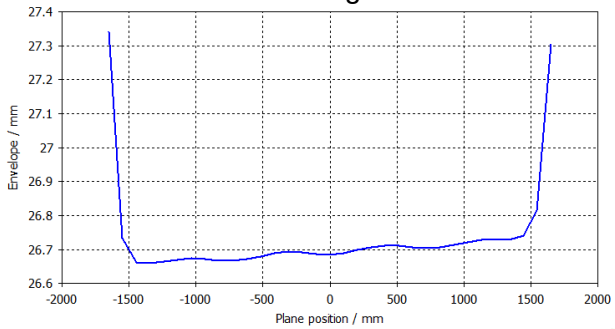
Simulation through whole SCC lens with imported external magnetic field



Transverse beam profiles along the SCC lens

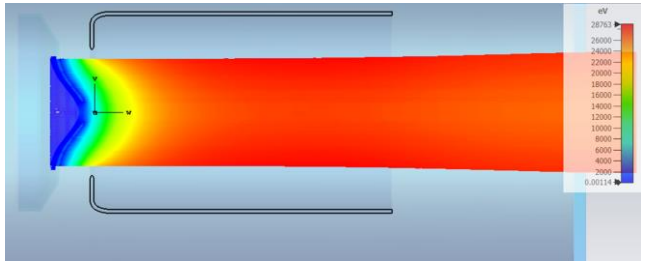


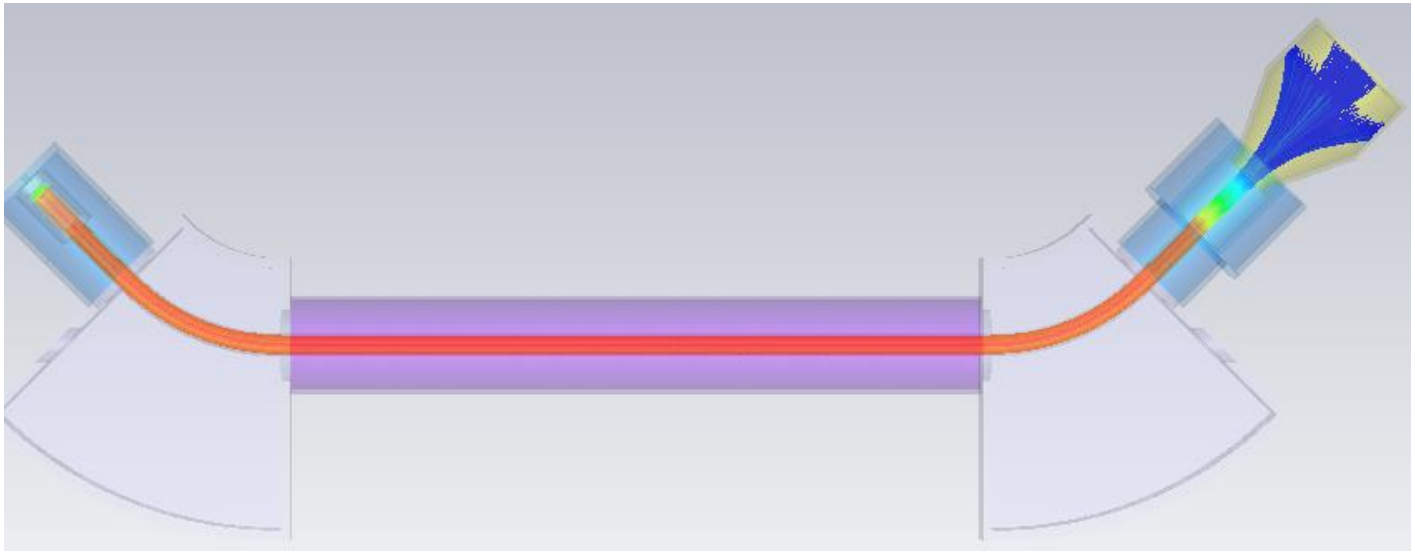
Beam radius along the SCC lens



System Integration (16.2): Next Steps

- Finalization of collector design
- Completion of beam transport simulations
- Outside ARIES
  - Mechanical design of electron lens for GSI/FAIR





Summary

- Gun development delayed due to Covid-19 situation
  - Operation of gun under preparation
  - Experiments expected to continue Q3/2021
- Gun testing moved to IAP due to Covid-19 situation
  - Test stand under construction
  - Completion expected by end of Q2/2021
- Lens design well advanced
  - Layout of main magnets completed
  - Collector design close to completion
  - Beam transport studies ongoing

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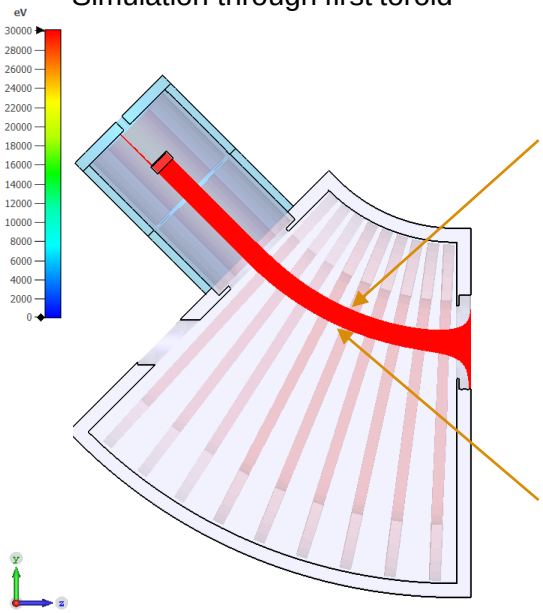
Oliver Meusel, Martin Droba, Katrin Thoma, Julian Rausch, Thomas Dönges (IAP)

Peteris Apse-Apsitis, Ingars Streiks, Johann Van De Pol (RTU)

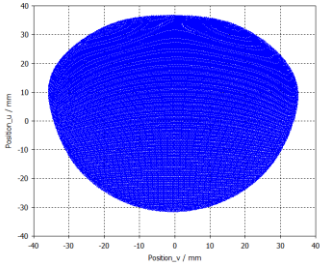
(16.2) Transport Simulations: Issues with Tool

- Observation of distorted beam profiles
  - Appeared in toroids, i.e. in a bent geometry
  - Bent chamber represented by PEC with μ=1
  - Calculation on HexMesh
  - Spurious high field regions (2T for 0.6T nominal)
  - Distortions present with and without space charge
  - No such distortions without chamber
  - Consulted with CST support
- Solutions
  - Different beam pipe design
  - Pre-calculation and import of magnetic field
    - Calculation with magneto-static solver
    - Import into particle tracking solver as external field

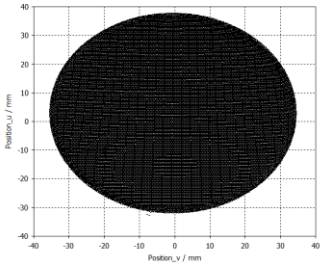
Simulation through first toroid



Distribution with pipe



Distribution w/o pipe



Spurious high-field regions in PEC chamber