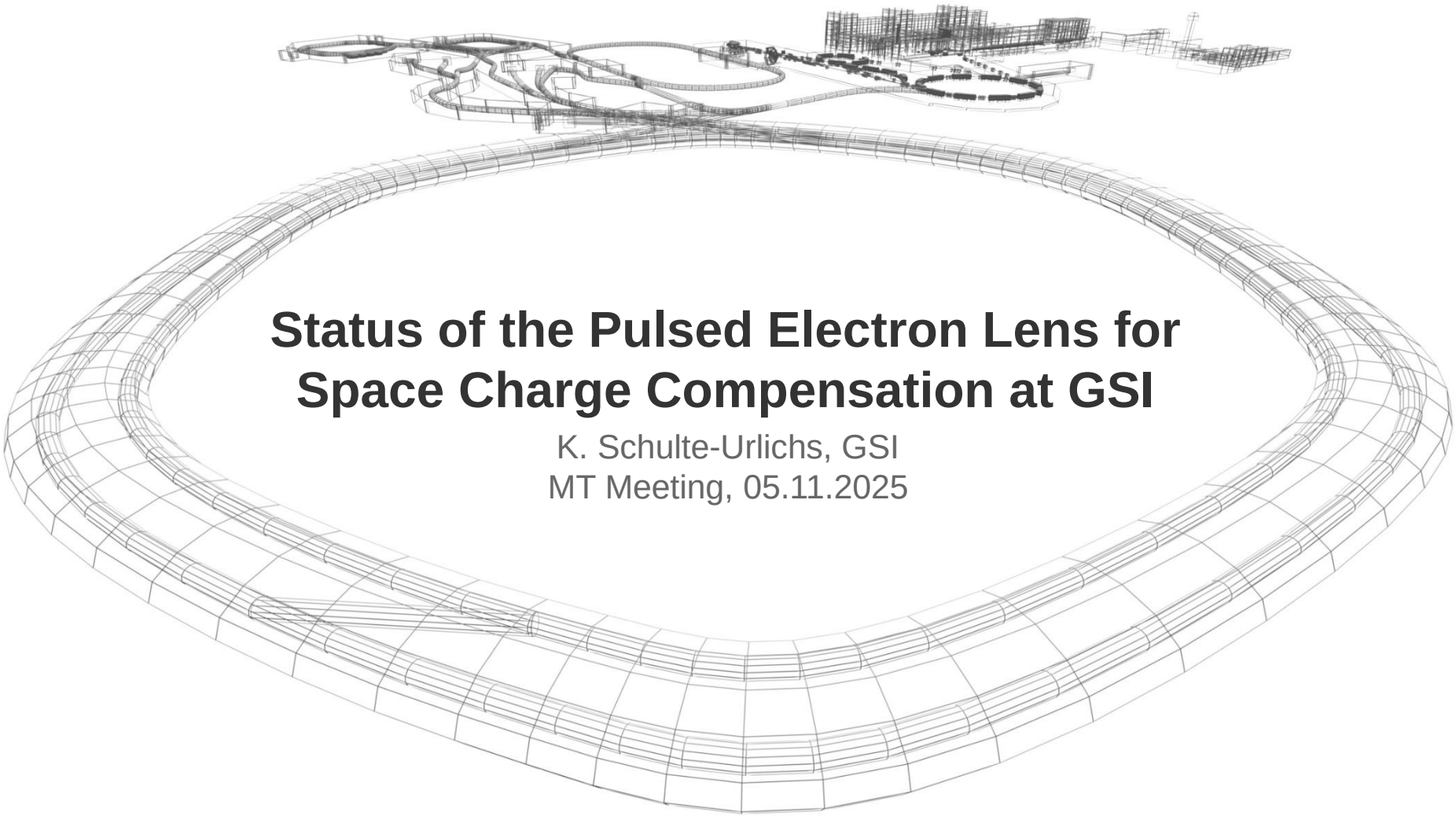
MATTER AND TECHNOLOGIES

FAIR GSI



Status of the Pulsed Electron Lens for Space Charge Compensation at GSI

K. Schulte-Urlichs, GSI

MT Meeting, 05.11.2025

Motivation

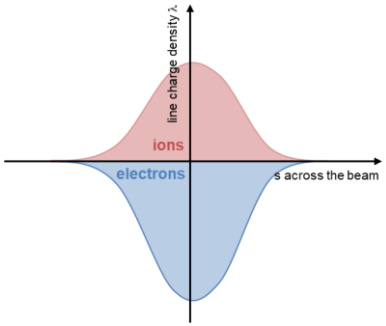
Electron Lens Prototype for Space Charge Compensation (SCC)

- Space charge represents a major intensity limitation in larger circular accelerators
- R&D to increase the primary beam intensity and thus accelerator efficiency for FAIR operation
- Electron Lens for SCC
  - Counter defocusing self-SC with electrons
  - Modulate e-beam to follow bunch profile
  - Linear compensation
    - Uniform transverse profile
    - linear fields avoiding resonance creation
  - Symmetry typically requires several lenses
- Strategy
  - Design of dedicated e-lens for SIS18
    - Design shall be compatible with SIS100
  - SIS18 e-cooler as test bed for e-gun and collector to demonstrate the concept

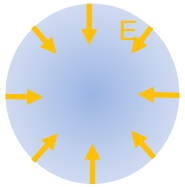
Synchrotron	dQ
PS Booster	up to -0.69
PS	up to -0.39
SPS	up to -0.21
AGS Booster	up to –0.3
AGS	up to -0.25
JPARC RCS Booster	up to -0.35
JPARC Main Ring	up to -0.4
ISIS SR	up to -0.4
SNS SR	up to -0.15
Fermilab Booster	up to -0.6
SIS18	up to -0.5
SIS100	up to -0.3 (planned)

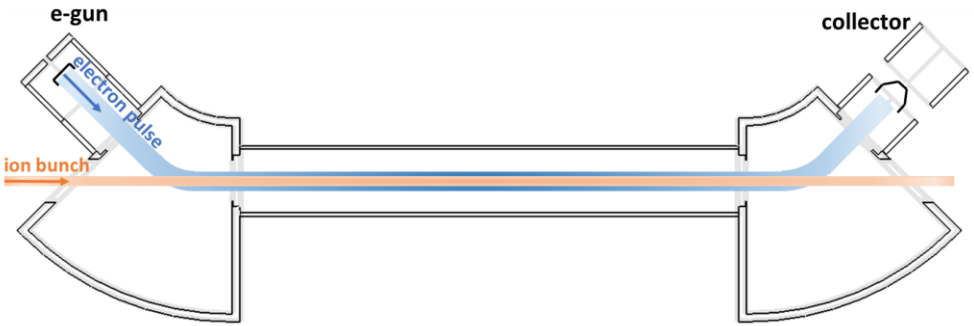
courtesy of P. Spiller, Talk, IPAC24, WEBD3

Modulation to match bunch profile



SCC scheme



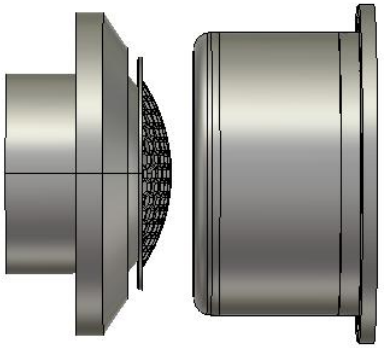


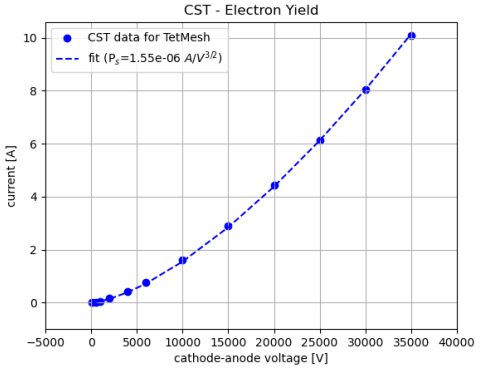
Design of Modulated Electron Gun

Requirements of design result from the SIS18 cycle:

- 400 kHz to 1 MHz to follow longitudinal bunch profile
  - grid modulation to reduce load, 3 kV on grid
  - two different types of modulation grid
- up to 15 A @ 35 kV for SCC
- modulator design
  - prototype within ARIES WP16
  - technical concept was developed
- transverse, homogeneous beam density profile
  - immersed in solenoidal field of up to 0.4 T
  - despite elliptical cross section of bunch, round cross section was chosen

Electrode design with honey comb grid

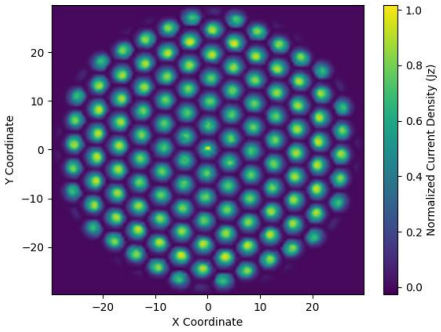




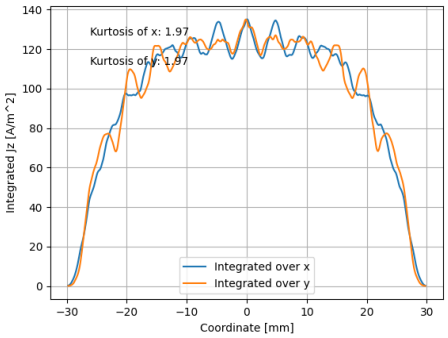
kurtosis: 1.97

Evaluation of transverse beam density profile

normalized current density

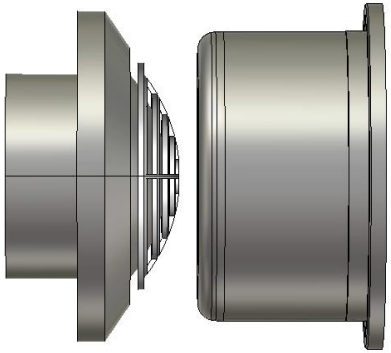


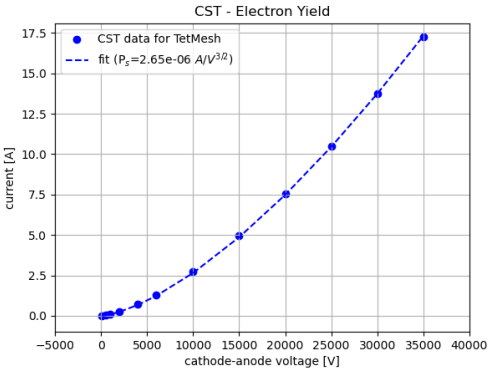
evaluation of kurtosis



kurtosis: $V_y = \frac{\langle y^4 \rangle}{\langle y^2 \rangle^2}$

Electrode design with target grid





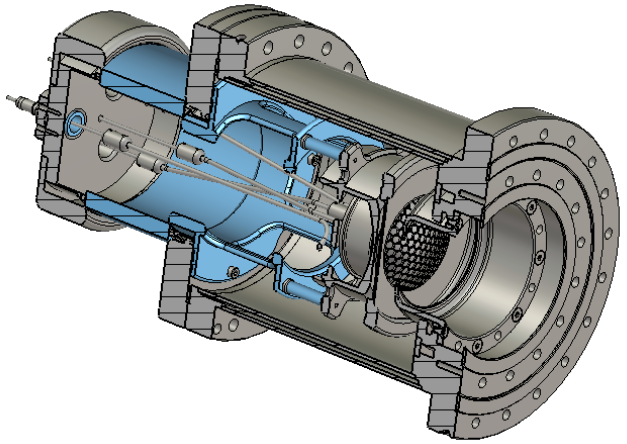
kurtosis: 1.99

Design of Modulated Electron Gun

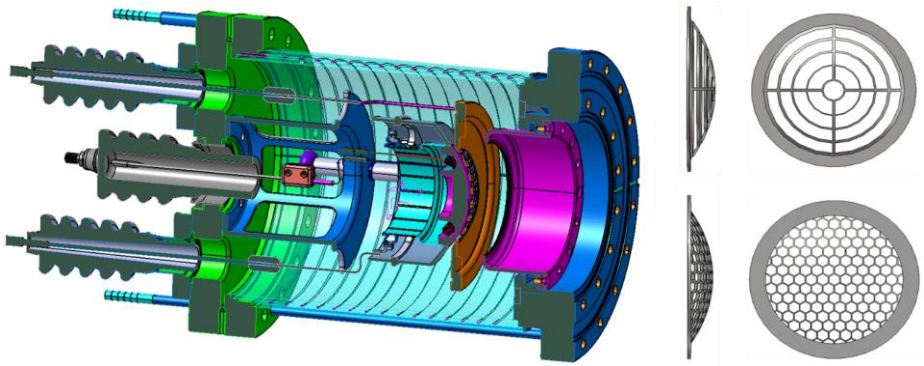
Status of rf-modulated E-Gun:

- Preparation of preliminary e-gun design with two different grids by GSI
  - flexible set-up to exchange grids
  - BaO dispenser cathode 311XM to meet current density requirements 4 A/cm^2
- Production contracted in April of this year
- E-gun is currently being redesigned by NTG
- Expected delivery in May 2026
- Commissioning at GSI test stand

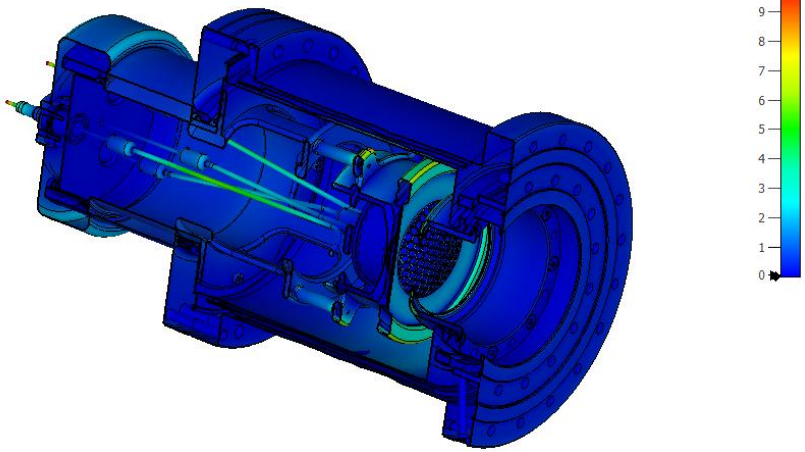
E-gun layout by NTG (current status)



E-gun design by GSI



Evaluation of dielectric strength

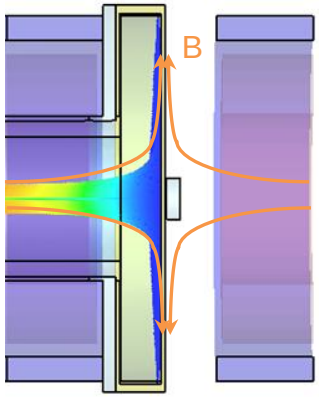


Design of Low Loss Collector

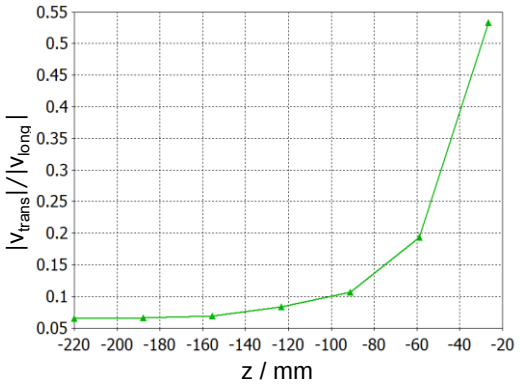
Design Challenges:

- collector is operated on a HV platform and has bias potential ΔU with respect to cathode to reduce power loss
- beam potential increases by deceleration
  - leads to reflection of beam for low ΔU between e-gun and collector
  - ΔU=10 kV required for conventional design
- magnetic cusp field helps to rapidly expand beam
  - reduce beam potential
  - distribute beam over large area
  - reduction of power deposition by ~50%

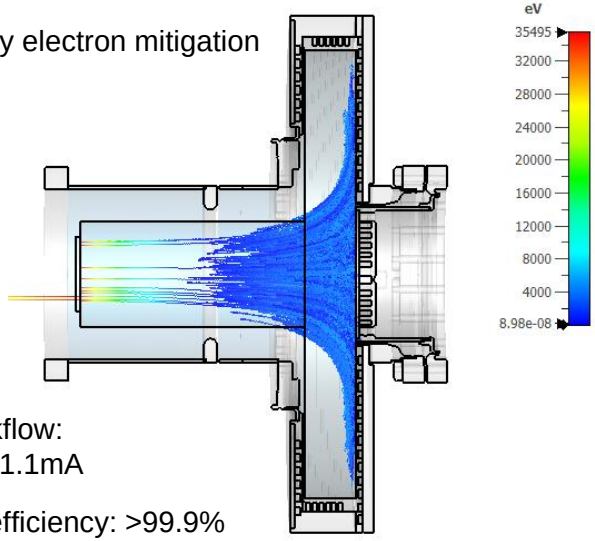
Collector integrated into cusp field



Velocity ratio of electrons in cusp field



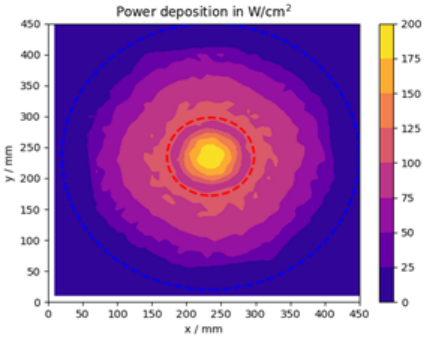
Secondary electron mitigation

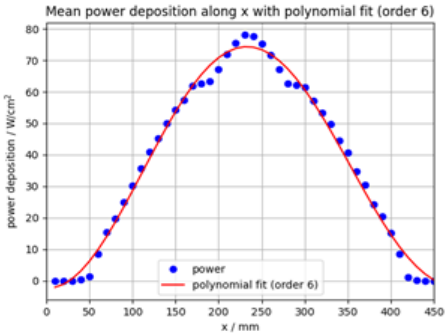


SEE backflow:
$I_{back,total}$=11.1mA

collector efficiency: >99.9%

Peak power deposition





E-lens is only used in the beginning of the SIS18 cycle, this reduced the power deposition by ~0.3.

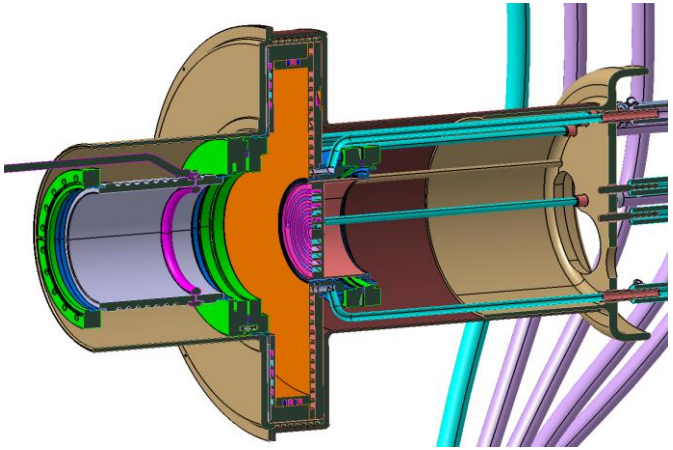
Design of Low Loss Collector

Technical Challenges:

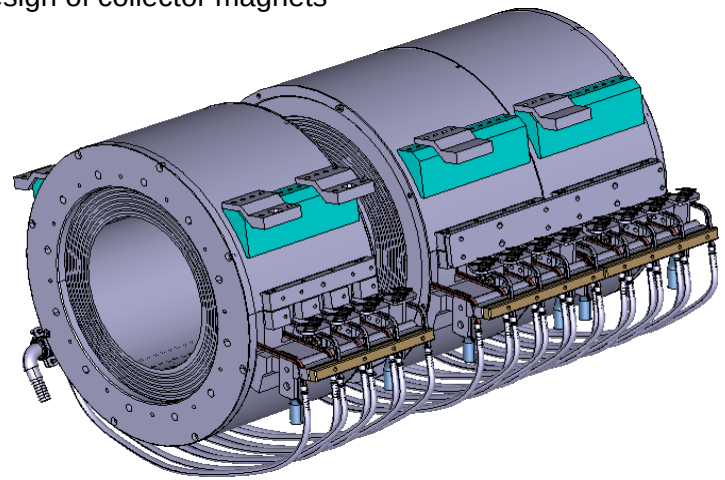
- chamber must have a small height compared to the diameter
- separate cooling channels are required to allow deducing beam power distribution from the temperature of the water backflow
- requires the use of advanced manufacturing methods

Collector Parameters		
Electron current max.	15	A
Collector bias potential max. (represents max. electron energy)	-5.5	kV
Beam modulation frequency	400 – 1000	kHz
Inner collector radius max.	215	mm
Outer collector radius	242	mm
Beam radius	≥ 215	mm
DC power deposition	82.5	kW
Power deposition within cycle, max.	20	kW
Collector area	1452	cm^2
Max. magnetic field	0.4	T
Collector chamber height	66	mm

Design of collector chamber



Design of collector magnets

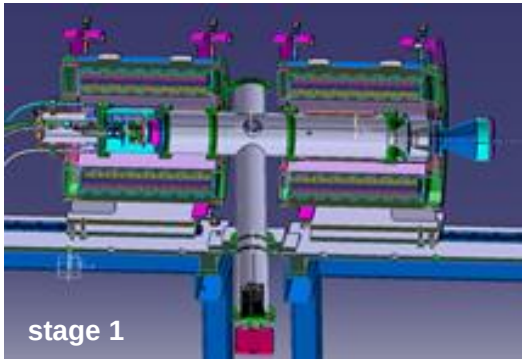


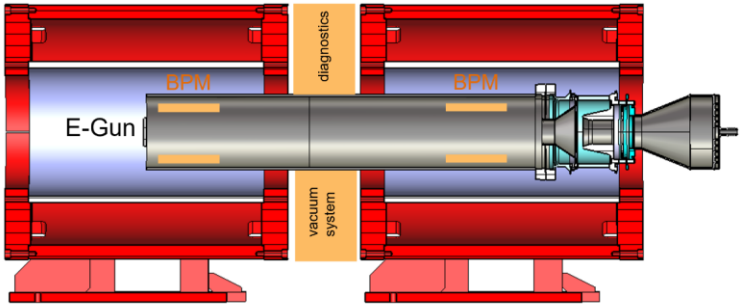
Test Bench at GSI

Test bench set-up:

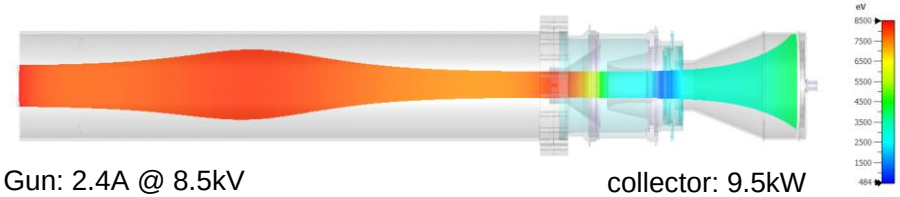
- commissioning of e-gun and collector
  - demonstration of extraction currents up to 15 A and beam profile
- reusage of equipment as power supplies, vacuum pumps and solenoids from 100 keV COSY e-cooler @ FZ Jülich

- used in different stages according to the experimental requirements
  - stage 1
    - existing collector with power depostion up to 10 kW and smaller aperture compared to beam diameter
    - preparation of transverse and longitudinal beam diagnostics
  - stage 2
    - commsioning of low loss collector
    - characterization of e-beam and operation modii



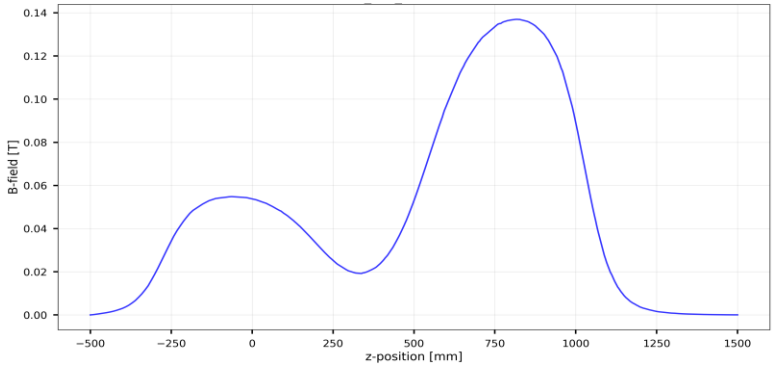


Electron beam trajectories



Gun: 2.4A @ 8.5kV

collector: 9.5kW

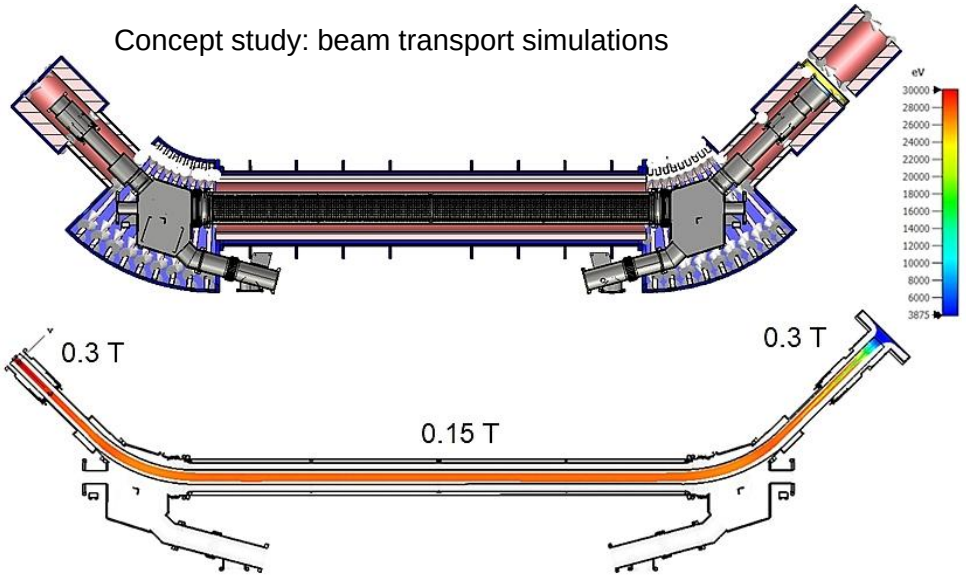


SIS18 E-Cooler as Test Bed

Modification of SIS18 E-Cooler:

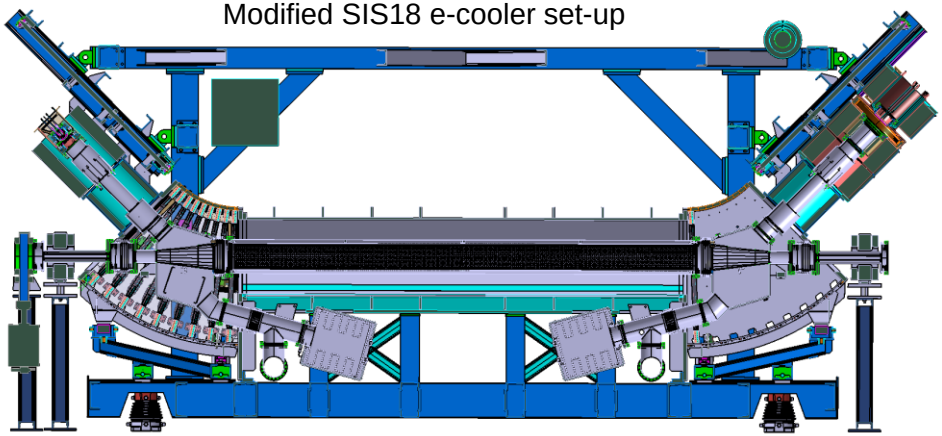
- E-Cooler is in Sector 10 of SIS18
- Electron cooler has a maximum B-field of 0.15 T in the interaction section and 0.4 T in the gun and collector branches
- simulations indicate that cooler field magnitude is feasible for demonstration experiments
- The design of the electron gun and collector has been adapted so that it can be integrated into the cooler.
  - An additional solenoid is provided to adjust the collector system to the length of the beam tube.
- next step: planning of demonstration experiments with “single lens”

Concept study: beam transport simulations



SIS18 e-cooler

Modified SIS18 e-cooler set-up



Outlook

- Preparation of demonstration experiments
- Set-up of test bench at GSI
- Commissioning of rf-modulated e-gun
- Construction of low loss collector
- Modification of SIS18 e-cooler and machine experiments

- Design of demonstrator electron lens is under preparation in parallel

Thanks for your attention!

Special thanks to all contributors to this project:

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