Low Energy Ion Beam Line for TwinEBIS

A. Pikin[1,2], M. Breitenfeldt[1], H. Pahl[1,3], J. Pitters[1] and F. Wenander[1]

[1] CERN, Geneva 23, CH-1211, Switzerland, [2] Brookhaven National Laboratory, Upton 11973, USA,
[3] Universität Heidelberg, D-69120 Heidelberg, Germany

Introduction

The **TwinEBIS** setup is being developed at CERN as a test bench for new types of electron guns and novel Electron Beam Ion Source (EBIS) concepts [1]. The primary goal is to improve the performance of EBISes as charge breeders for radioactive beam facilities like ISOLDE. Presently, TwinEBIS is featuring **MEDeGUN**, a Brillouin electron gun designed for applications in hadron therapy [2].

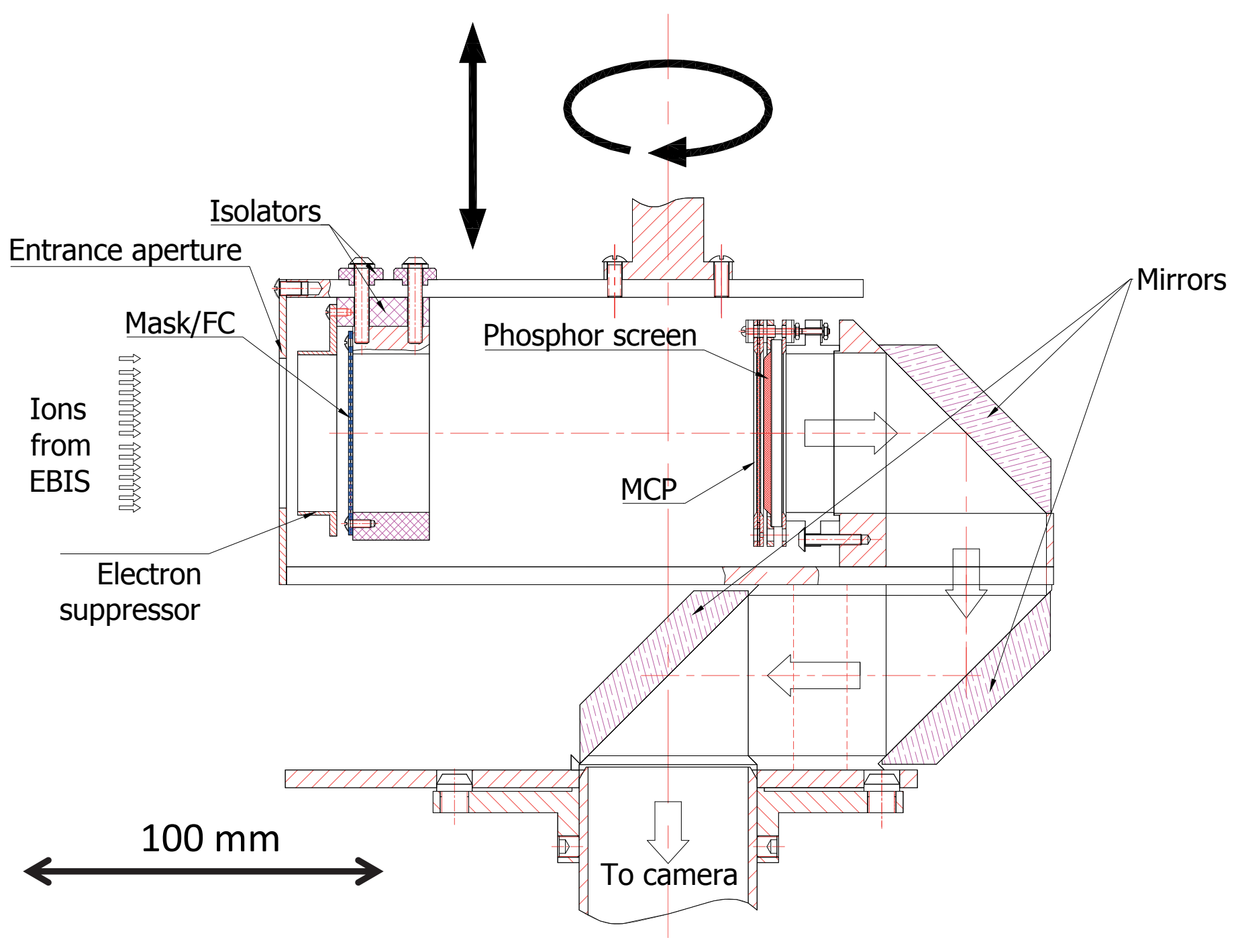
In order to extend the capabilities of the test bench an **ion beam line** is going to be installed at TwinEBIS, serving the following purposes:

- **Extraction** of highly charged ions into an **accelerating Radio Frequency Quadrupole (RFQ)**
- **Injection** of ions from an **external source**
- Ion beam **diagnostics**

In order to ensure an efficient injection into the small acceptance of a Brillouin electron beam inside the EBIS, and the extraction into the RFQ, the beam line was optimised to **minimise the emittance growth**.

Beam Diagnostic Tool

Based on a prototype built at Brookhaven National Laboratory [3].

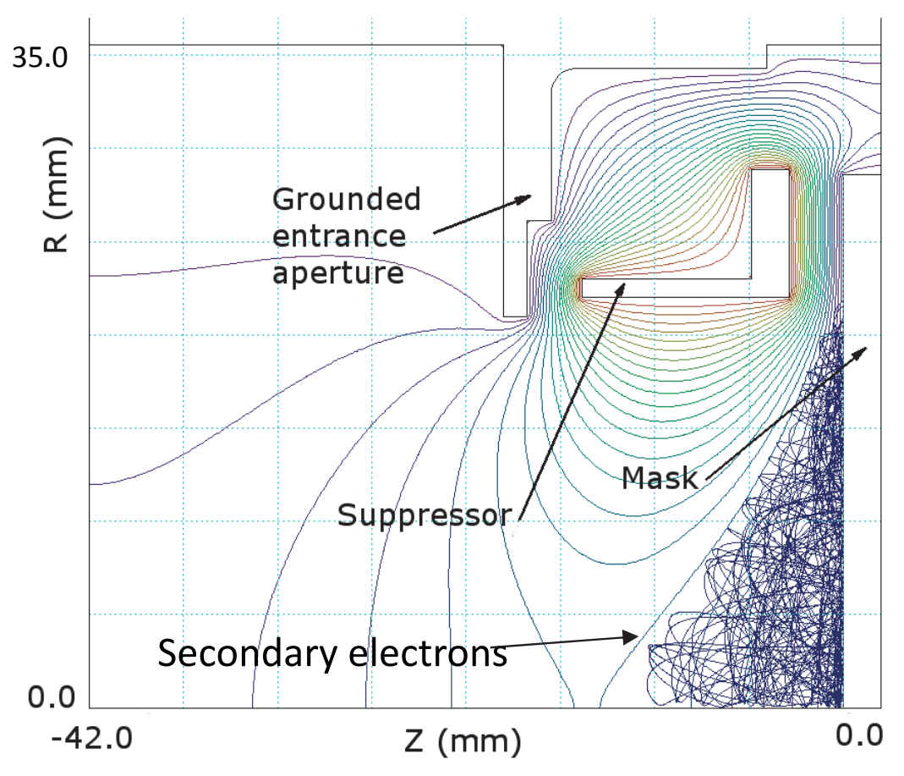


The device can be retracted and **rotated** using a vacuum feedthrough. During operation it is precisely locked in position, **oriented towards either the injected or the extracted beam**. This allows matching the Twiss parameters of incoming and outgoing beams.

Three combined functions:

- **Pepper pot emittance meter** (pinhole mask)
- **Beam current readout** (ions impinging on the mask)
- **Beam profile and position** (average profile)

Secondary electron suppression



Secondary electrons from the large diameter pinhole mask are actively suppressed for a precise current readout.

The suppressor electrode was simulated at a bias voltage of -200 V for secondary electrons from the mask with an energy of 50 eV emitted at random angles.

Beam Line Design

Deflector design

The electric field in the centre of the deflectors needs to be homogeneous to **minimise aberrations**. This is difficult to achieve for large apertures with flat electrodes, since the ground potential is leaking in from the vacuum chamber.

→ Electrodes are shaped to compensate for this effect.

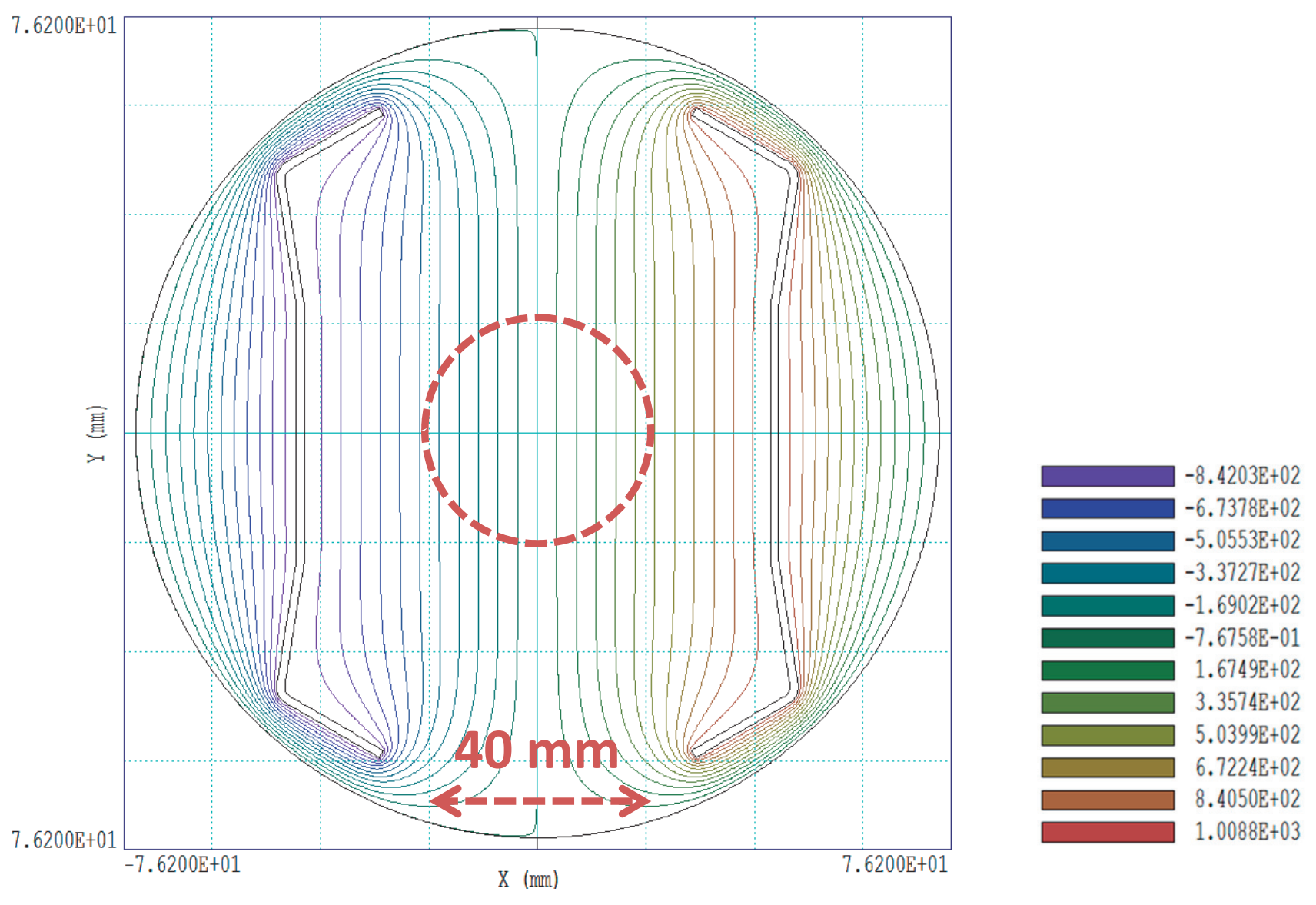
For the presented shape the electric field imperfections within a 20 mm radius around centre are (2D simulation):

→ Horizontal field strength deviation

$$\frac{\Delta E_x}{E_{x,0}} < 0.2\%$$

→ Residual vertical field strength

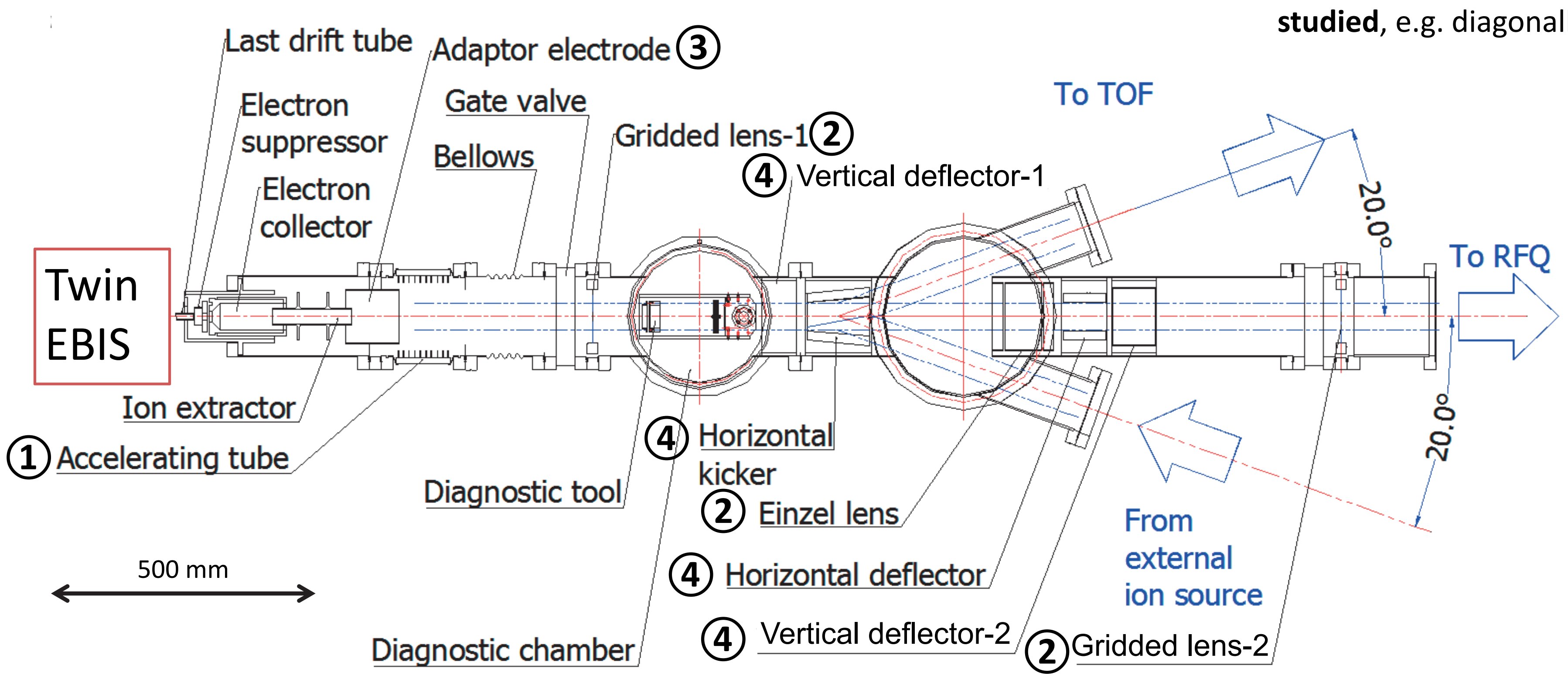
$$\left|\frac{E_{y,max}}{E_{x,0}}\right| < 0.2\%$$



Equipotential lines for a cross section of the optimised deflector shape according to a 2D simulation. Around the centre the potential is almost perfectly linear.

General layout

- TwinEBIS platform raised to approximately +30 kV
- RFQ line in straight direction for minimal steering of extracted beam
- Injection line and TOF accessible via a single electrostatic kicker
- Large physical apertures (≥ 40 mm mrad half aperture, except switchyard)
  → Minimise aberrations within a 20 mm radius around the beam axis (blue lines)
- Dedicated diagnostic chamber for the multipurpose beam measurement device



Main beam optics components

① **Acceleration tube**

- Multiple ring electrodes acting as potential dividers

② **Set of three lenses for matching into the RFQ**

- Two **gridded lenses** [4] as main focusing elements
  → Small aberrations, ability to defocus
  → Slightly reduced transmission (≈ 90%) due to grid
- Einzel lens for intermediate focusing

③ **Adaptor ring electrode**

- Between the EBIS ion extractor and the acceleration tube
- Focusing strength adjustment

④ **Two sets of horizontal and vertical deflectors in the RFQ direction**

- Electrode shape carefully adjusted to homogenise electric field
- First horizontal deflector is used as a **+/- 20° kicker** for the switchyard

Kicker design

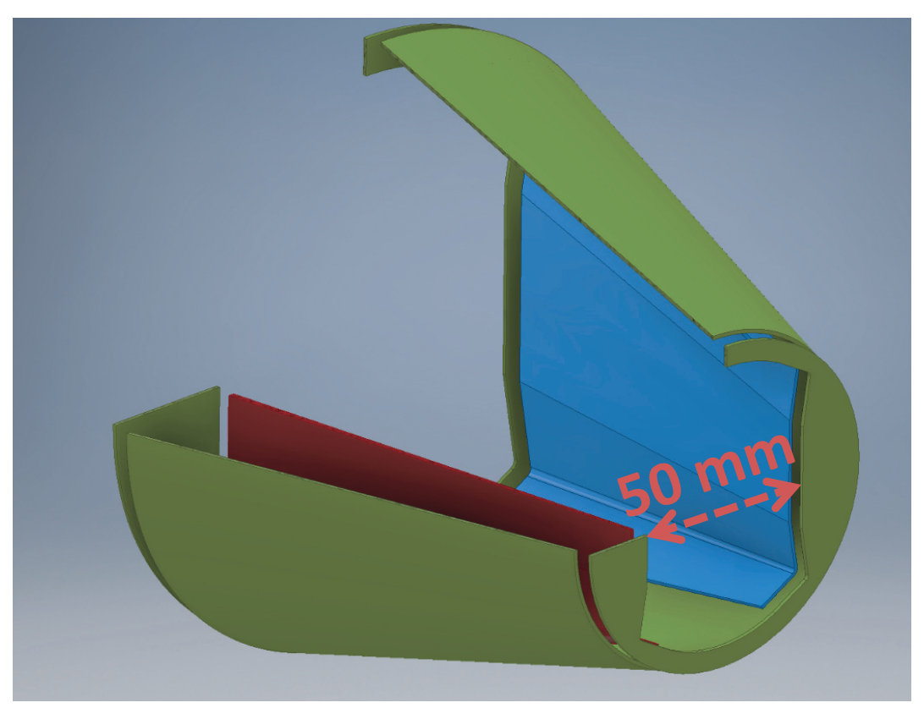
The design of the switchyard kicker is based on the deflector geometry. The kicker is tapered in order to grant enough space for the beam while limiting the effective gap size, which reduces the required voltages. Front and back shields are used to mitigate fringe fields.

Simulation parameters (CST):

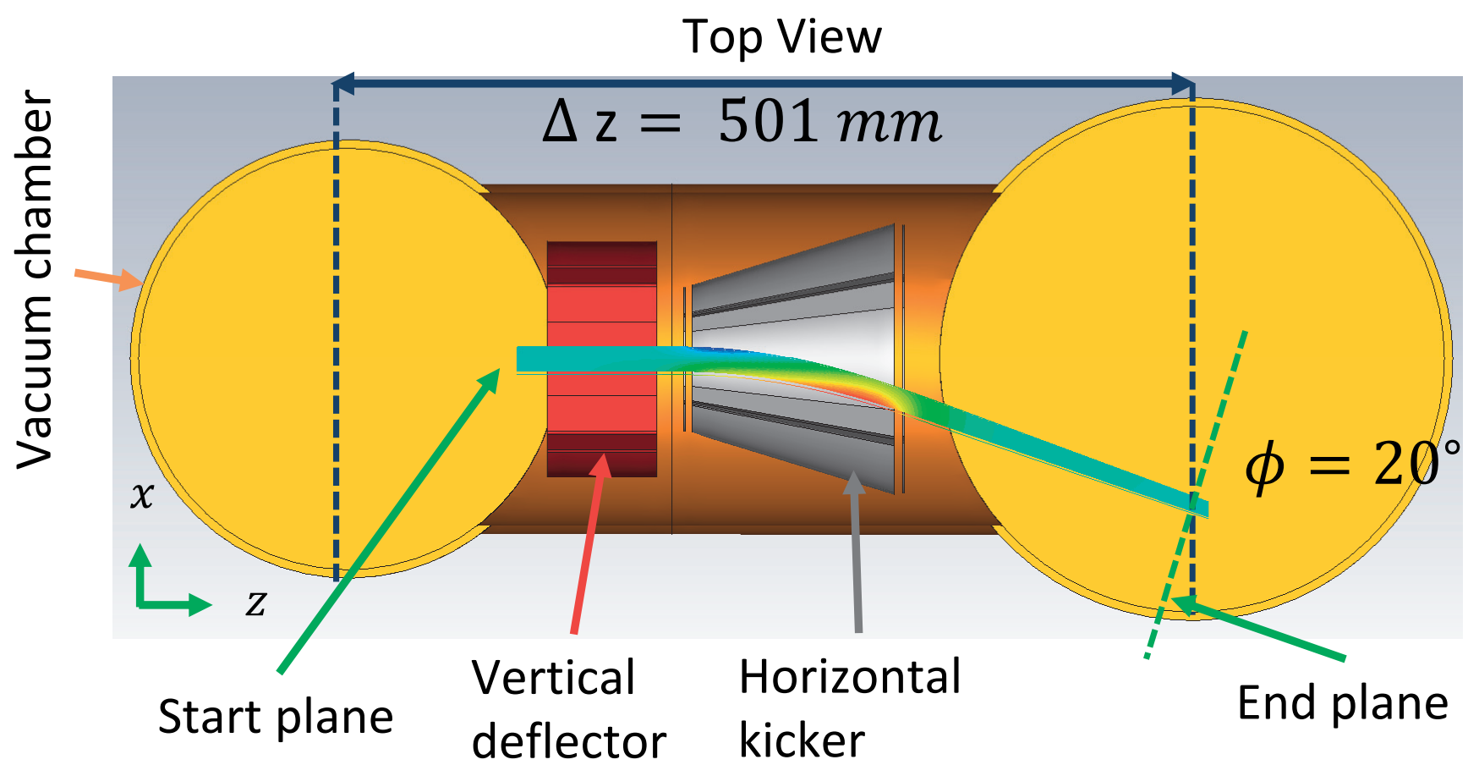
- Gaussian beam
- $\epsilon^{n}_{90\%}$ = 0.01 mm mrad
- 90%-diameter = 8 mm

3D simulations in CST Particle Studio [6] indicate that the **emittance growth in this kicker is insignificant** (< 5%) even for moderate beam displacements (+/- 10 mm).

At this point, the investigations are still ongoing and **other designs are studied**, e.g. diagonally segmented cylinder or flat electrodes.



Section view of the kicker geometry showing the two steering electrodes (blue / red) and the grounded field terminations (green). The minimum gap in the entrance plane is 50 mm wide.



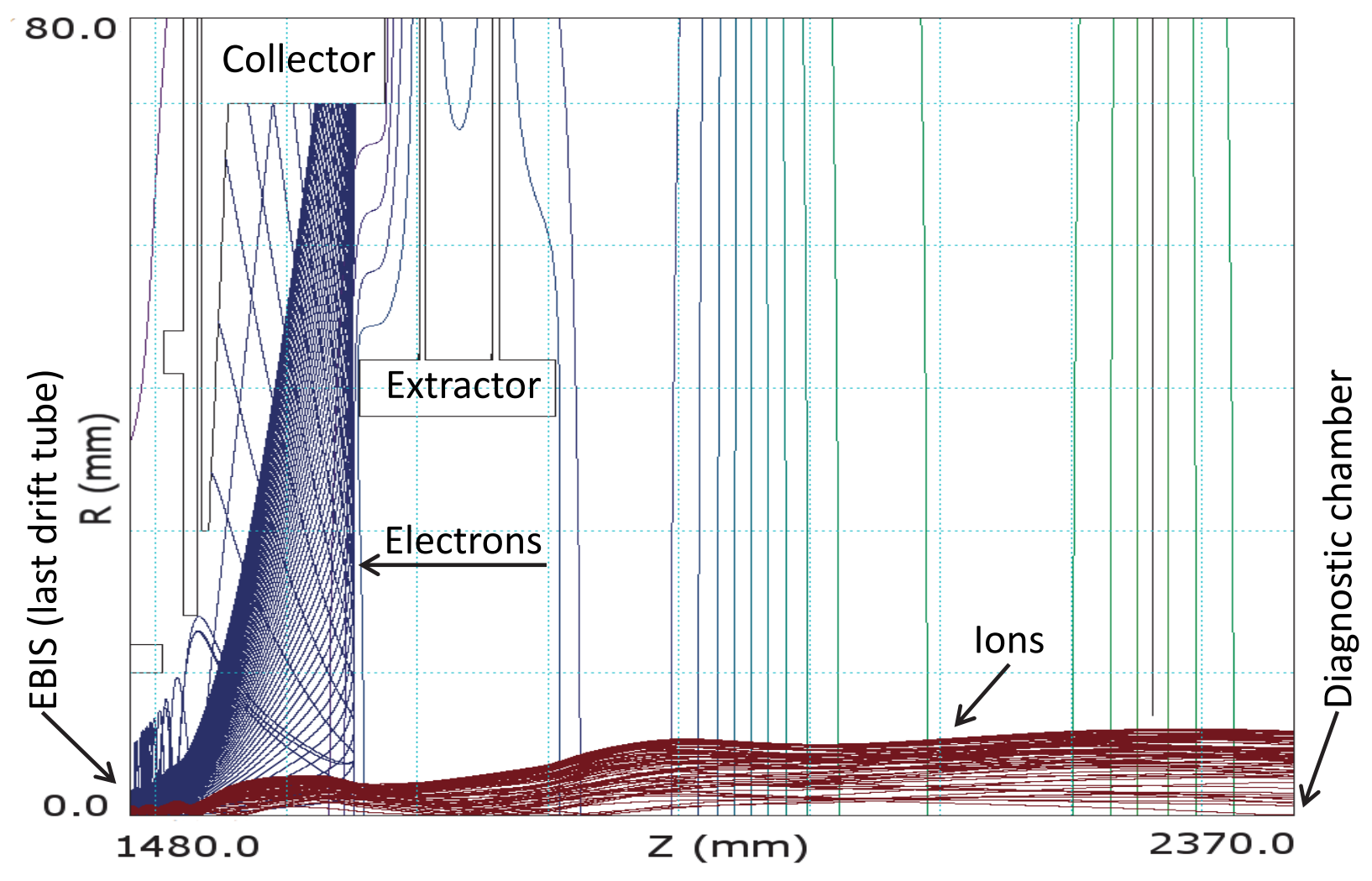
Simplified simulation model of the beam line from the diagnostic chamber to the switchyard chamber. The simulated trajectories of a 20° bend are shown. A voltage difference of approx. 11 kV is required for a 30 kV acceleration potential. The diameter of the vacuum chamber was increased for this geometry.

Ion Beam Simulations

Injection simulation

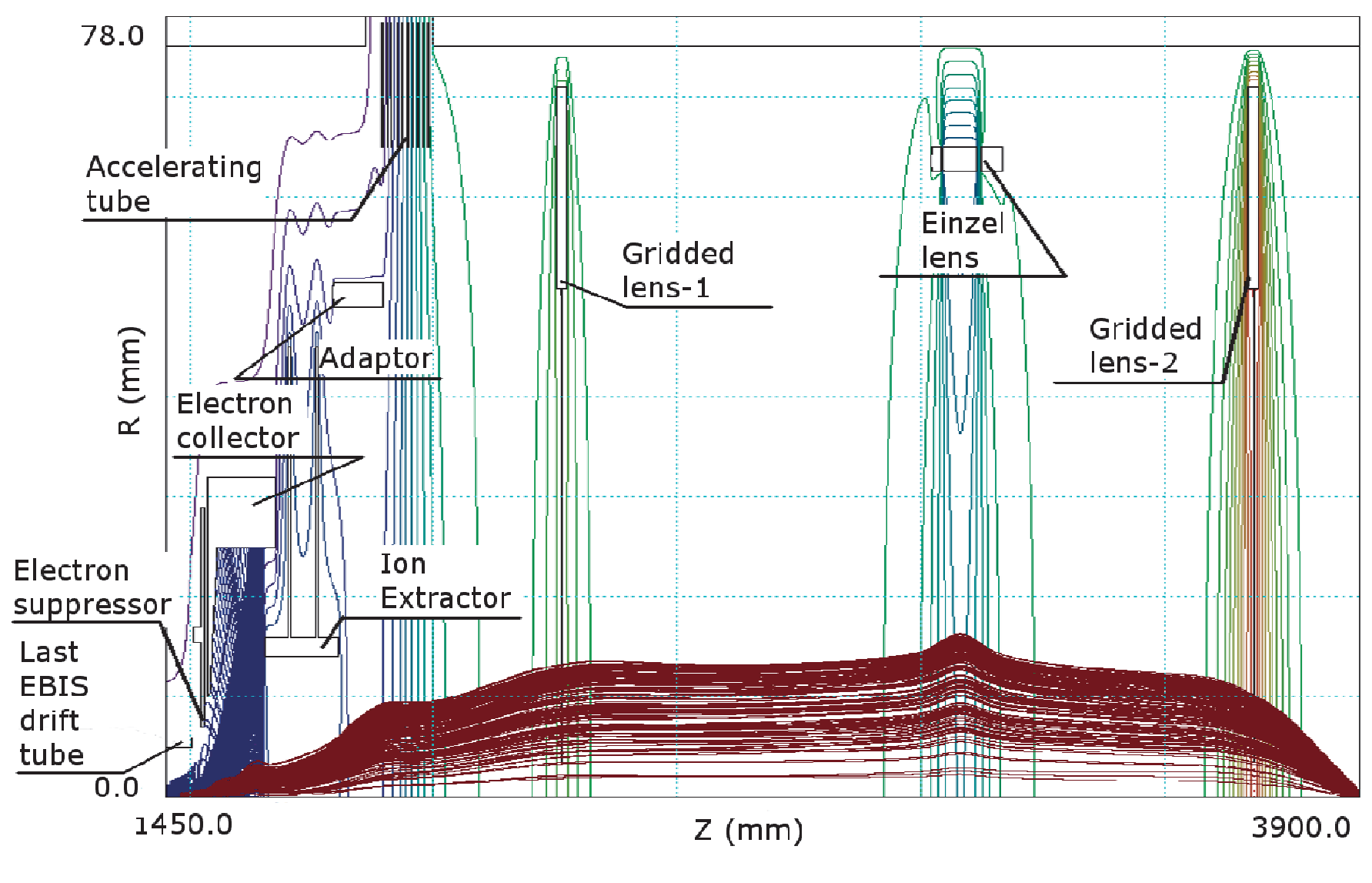
Ion tracking from the diagnostic chamber (where the beam parameters will be measurable in practice) into the electron beam. For efficient injection (A/q = 0.5) within the electron beam radius the normalised acceptance is only 0.011 mm mrad.

→ **Need to prevent growth of injection emittance**.



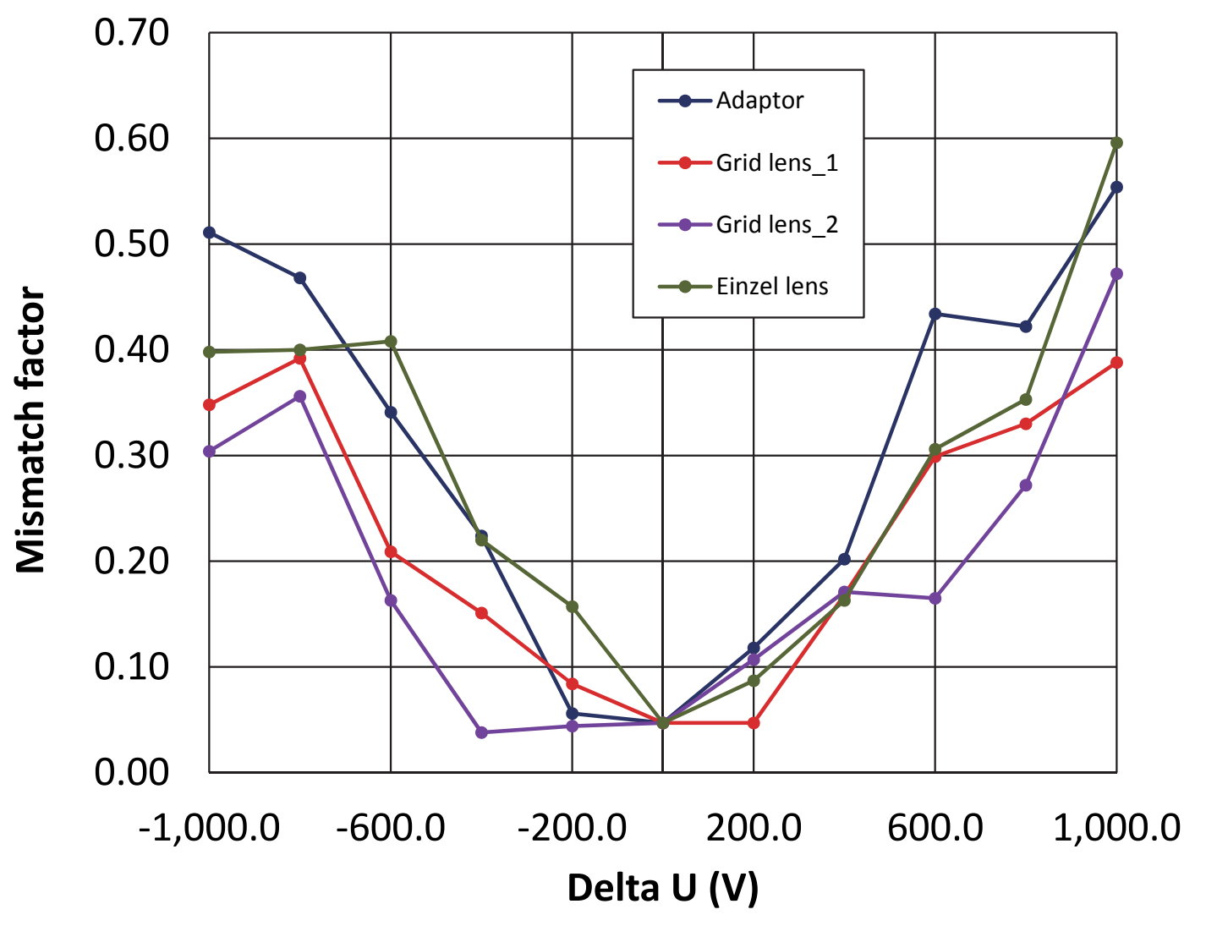
Extraction simulation

The ion beam transport from the EBIS into the RFQ has been simulated to determine the optimal settings of the electrostatic lenses.



Trajectory plot of the extraction simulation

The maximum beam radius is 15 mm. This is well below the 20 mm tolerance of the beam line design and should prevent aberrations.



Test of the matching stability

The potential of single elements was varied from the optimised value to investigate how the matching quality deteriorates.

→ For optimised matching the **mismatch factor is < 0.05**.

→ Matching into RFQ is **robust against a moderate detuning** of single elements.

Simulation parameters (TRAK [5]) :

- Starting plane in last EBIS drift tube
- Space charge compensation of ions and electrons is not negligible:
  → 300 electron beamlets
  → 500 ion beamlets
- Ion beam input distribution deducted from conservative assumptions for the central charge breeding region:
  → Ion beam radius 1.5 times larger than electron beam radius
  → Brillouin electron beam 1 A @ 10 keV
  → Magnetic field 2 T
  → Transverse ion energy determined by full potential well depth of 280 eV · q

Mismatch Factor:

$$MM = \sqrt{1/2\left(R + \sqrt{R^2 - 4}\right)} - 1$$

$$R = \beta\gamma^* + \beta^*\gamma - 2\alpha^*\alpha$$

where $(\alpha,\ \beta,\ \gamma)$ and $(\alpha^*,\ \beta^*,\ \gamma^*)$ are the Twiss parameters of the beam and the RFQ entrance. For perfect matching $MM = 0$.

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References

[1] M. Breitenfeldt et al., *Nucl. Instr. Meth. A*, 856, p. 139 (2017)
[2] R. Mertzig et al., *Nucl. Instr. Meth. A*, 859, p. 102 (2017)
[3] A. Pikin et al., *BNL Note*, C-A/AP/#244 (2006)
[4] A. Pikin and A. Kponou, *Rev. Sci. Instrum.*, 79, p. 123303 (2008)
[5] http://www.fieldp.com
[6] http://www.cst.com