Plasma Lens Experiment at the LIGHT Beamline

LIGHT Collaboration Meeting

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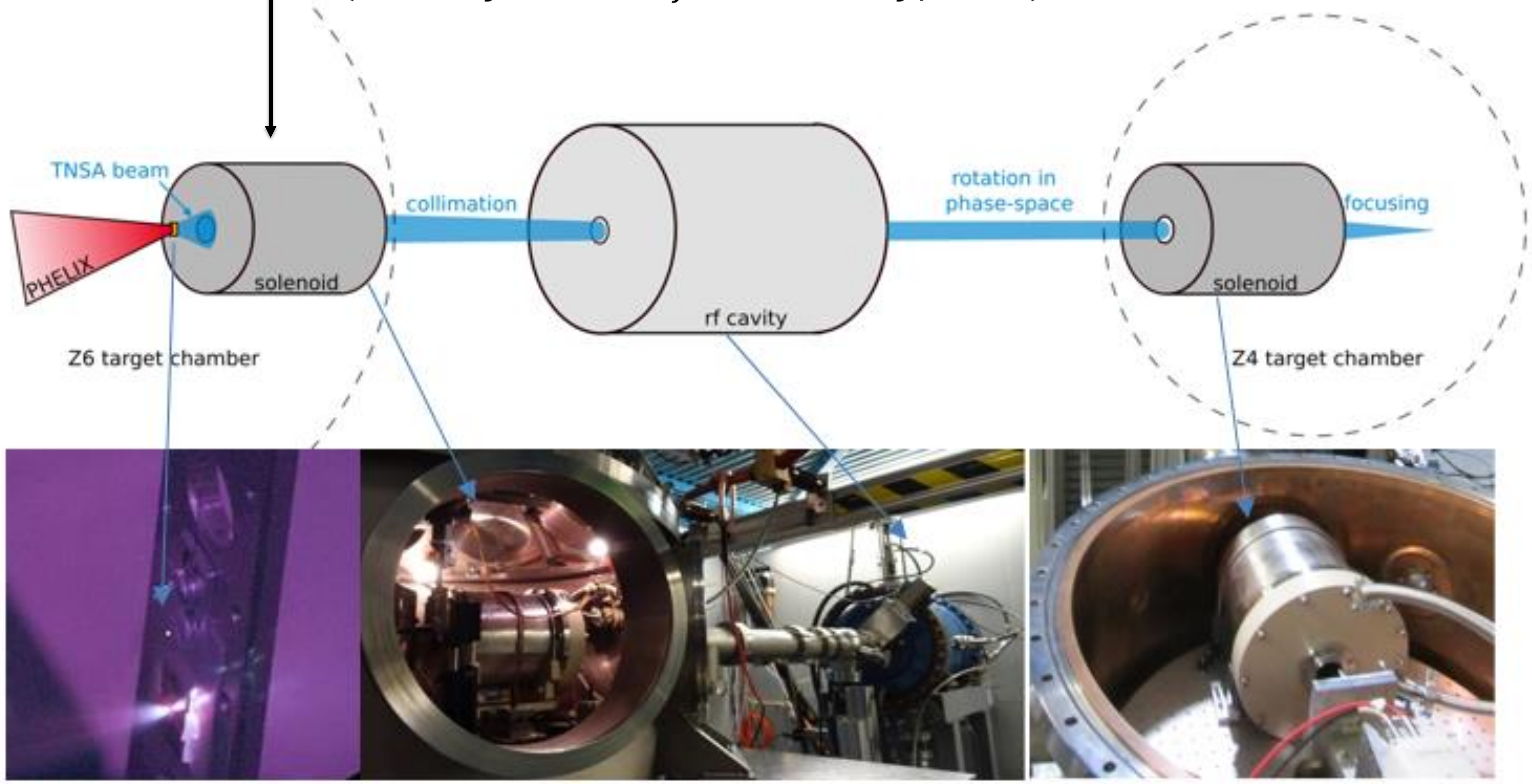
Current setup at LIGHT at FAIR

Plasma lens as a possible alternative to the solenoid in Z6

$(E < 25J, \tau = 500fs, I > 10^{19}\, J/cm\,2)$



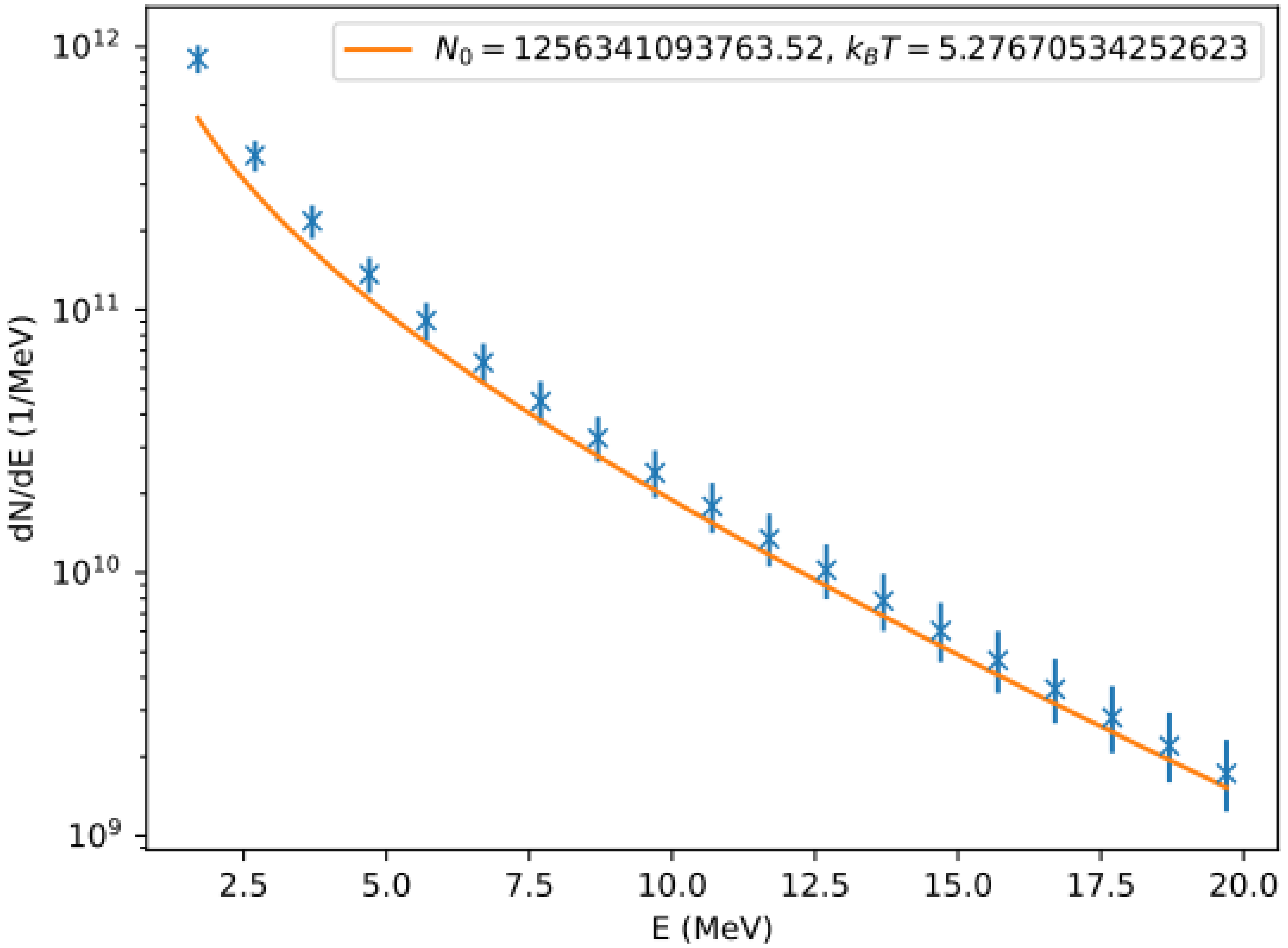
Source: GSI Helmholtzzentrum für Schwerionenforschung GmbH, PHELIX

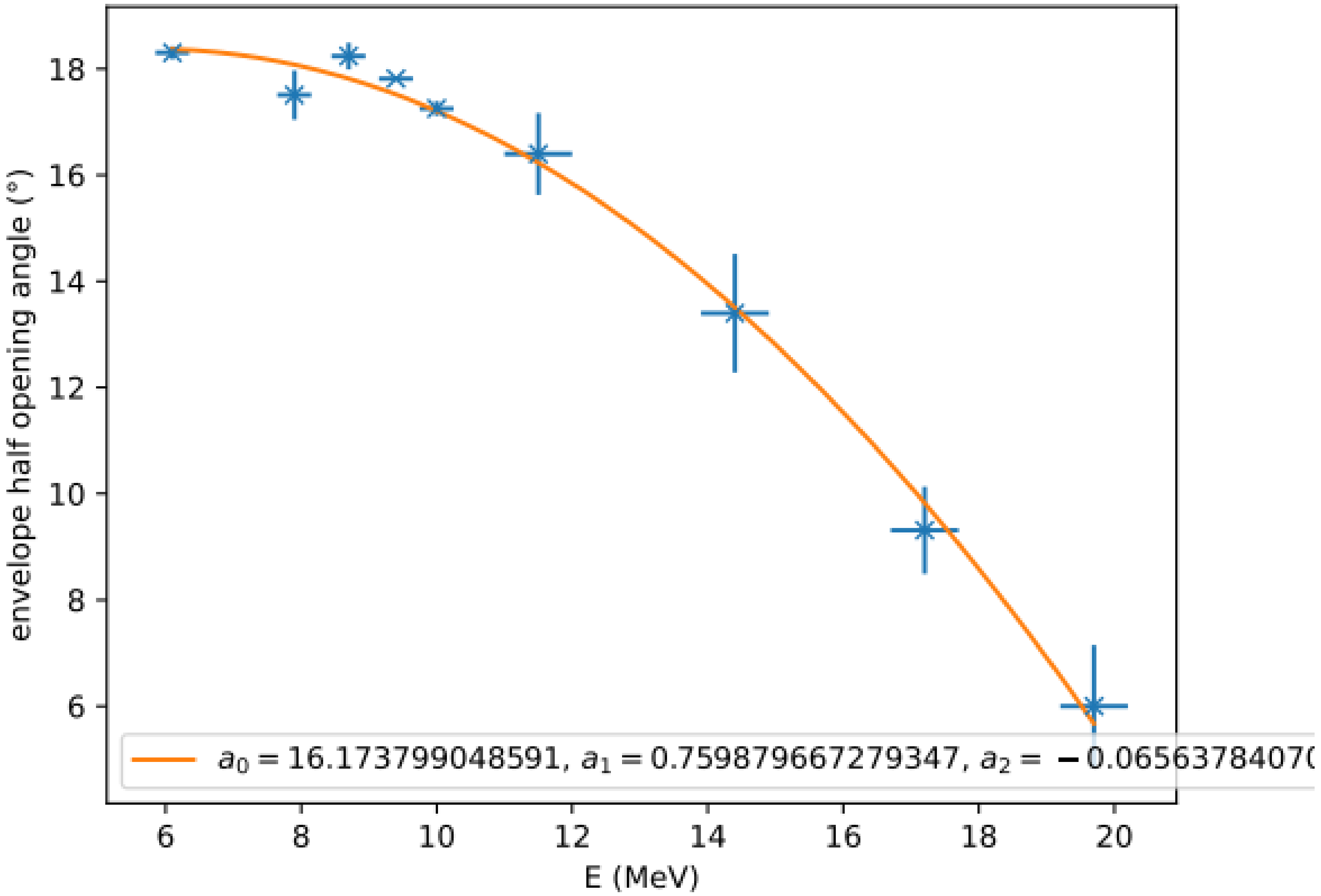
Marius Dehmer

Plasma Lens vs. Solenoid

Difficulty: Strongly divergent proton spectrum at energies <28 MeV

Solenoid	Plasma Lens
+ Existing system Reproducible results	+ Theoretically scalable to any extent<MT/m [2] No emittance growth (for homogeneous current distribution)
- Limited magnetic field gradient	- Difficult to handle (instabilities)



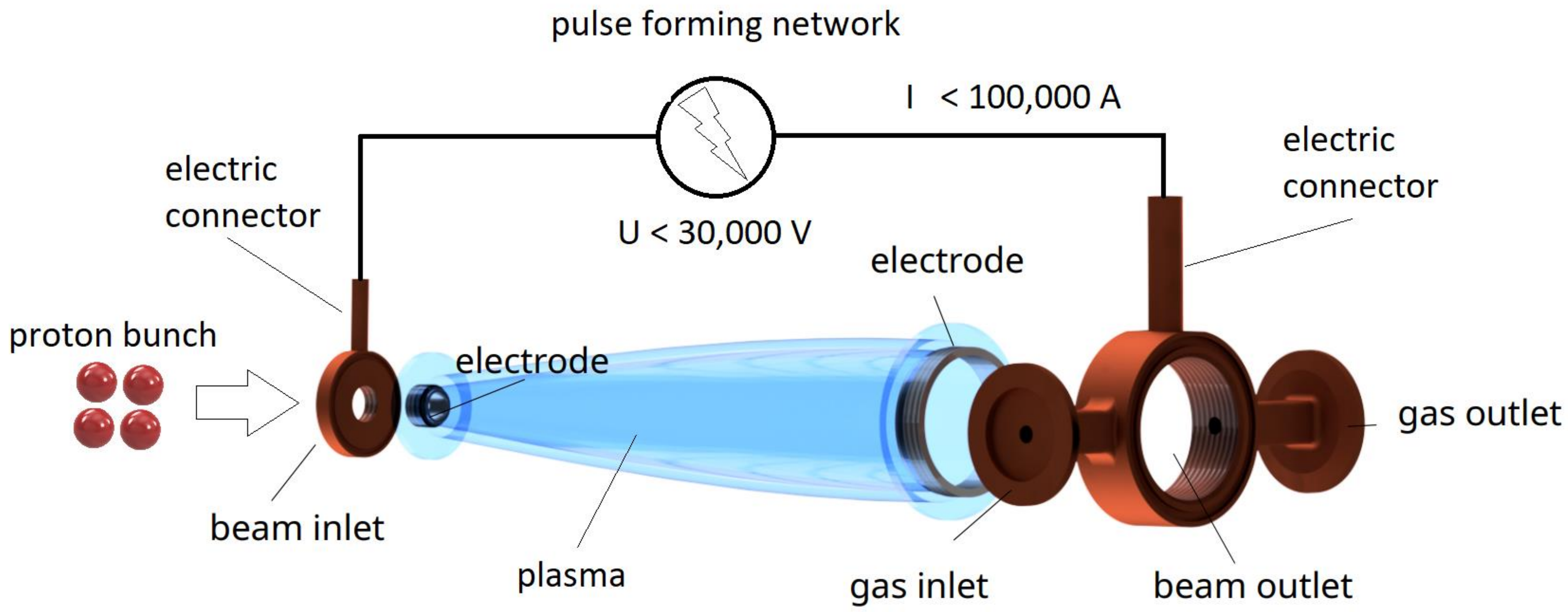


Source:[1] GSI Helmholtzzentrum für Schwerionenforschung GmbH, PHELIX, [2]Overview of plasma lens experiments and recent results at SPARC_LAB, C. A. Lindstrøm et al.

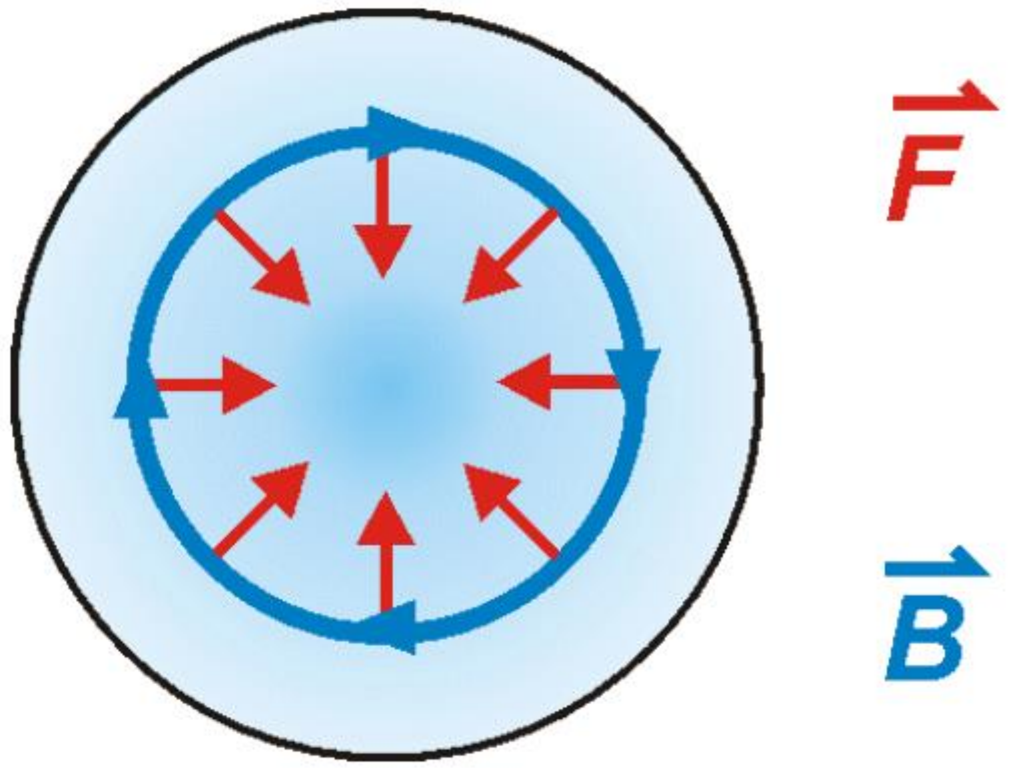
Gas discharge along the beam axis of a charged particle beam
Lorentz force acts on particle beam

$$F_{Lorentz} = q \cdot \vec{E} + q \cdot \vec{v} \times \vec{B}$$

$$B_{\phi,ideal}(r) = \mu_0 I_0 r / (2\pi R^2)$$



Technical drawing of the plasma lens in the pulse-forming network



Source: W. K. H. Panofsky and W. R. Baker , "A Focusing Device for the External 350-Mev Proton Beam of the 184-Inch Cyclotron at Berkeley", Review of Scientific Instruments 21, 445-447 (1950) https://doi.org/10.1063/1.1745611

Simulation of the Discharge Parameters

Given : Size (solenoid), particle energy (7.5-8.5 MeV)

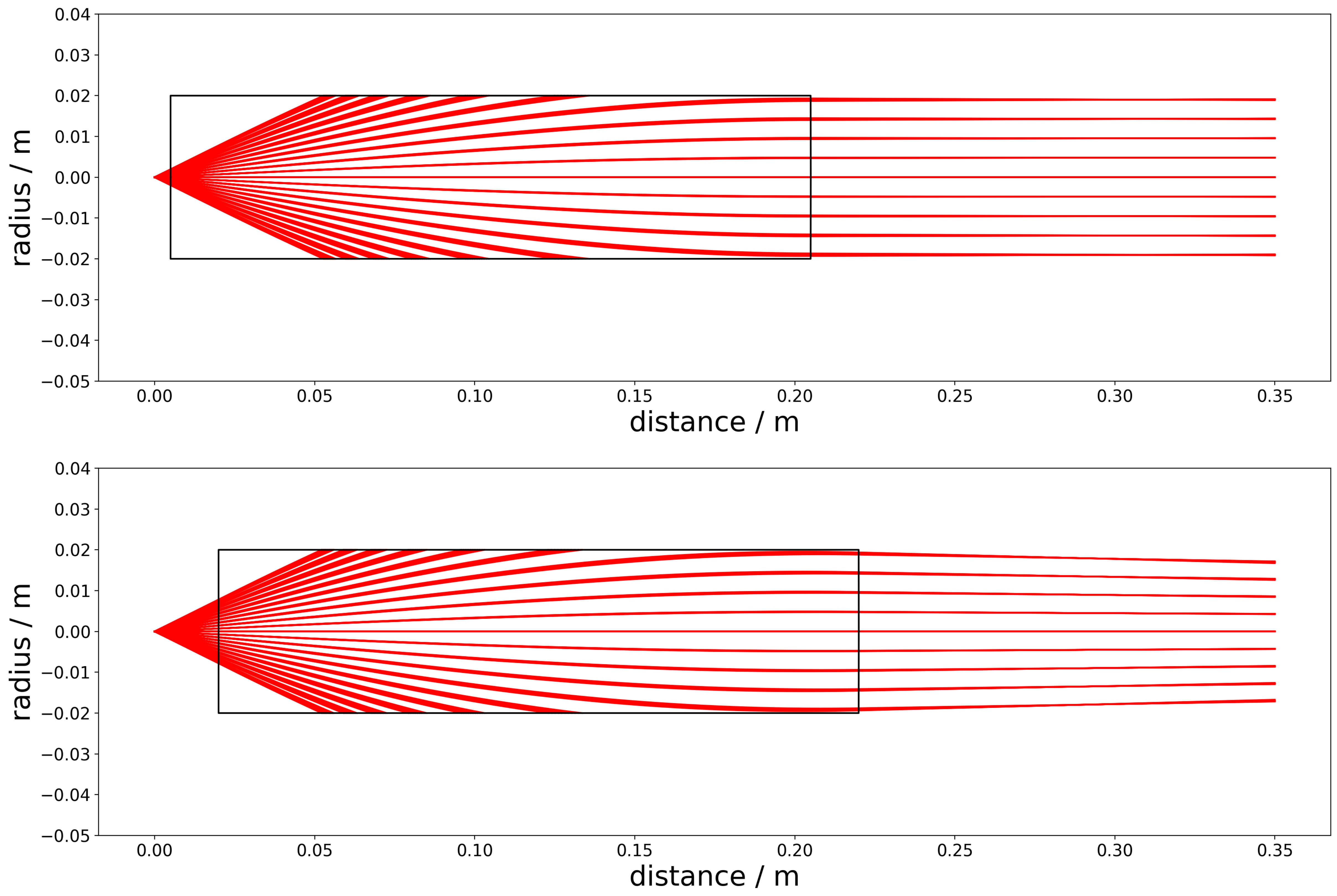
Goal : Maximize transmission, reach collimation

straight lens 0.5cm

- Ep= 7.5-8.5 MeV
- I= 50kA
- R1= 2cm
- R2= 2cm
- dsource= 0.5cm
- Llens= 20cm
- transmission= 43%

straight lens 4cm

- Ep= 7.5-8.5 MeV
- I= 50kA
- R1= 2cm
- R2= 2cm
- dsource= 4cm
- Llens= 20cm
- transmission= 42%



Simulated beam path of the averaged LIGHT spectrum for 7.5-8.5 MeV with specified lens parameters

Circuit Diagram of the Plasma Lens

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iAP Institut für Angewandte Physik

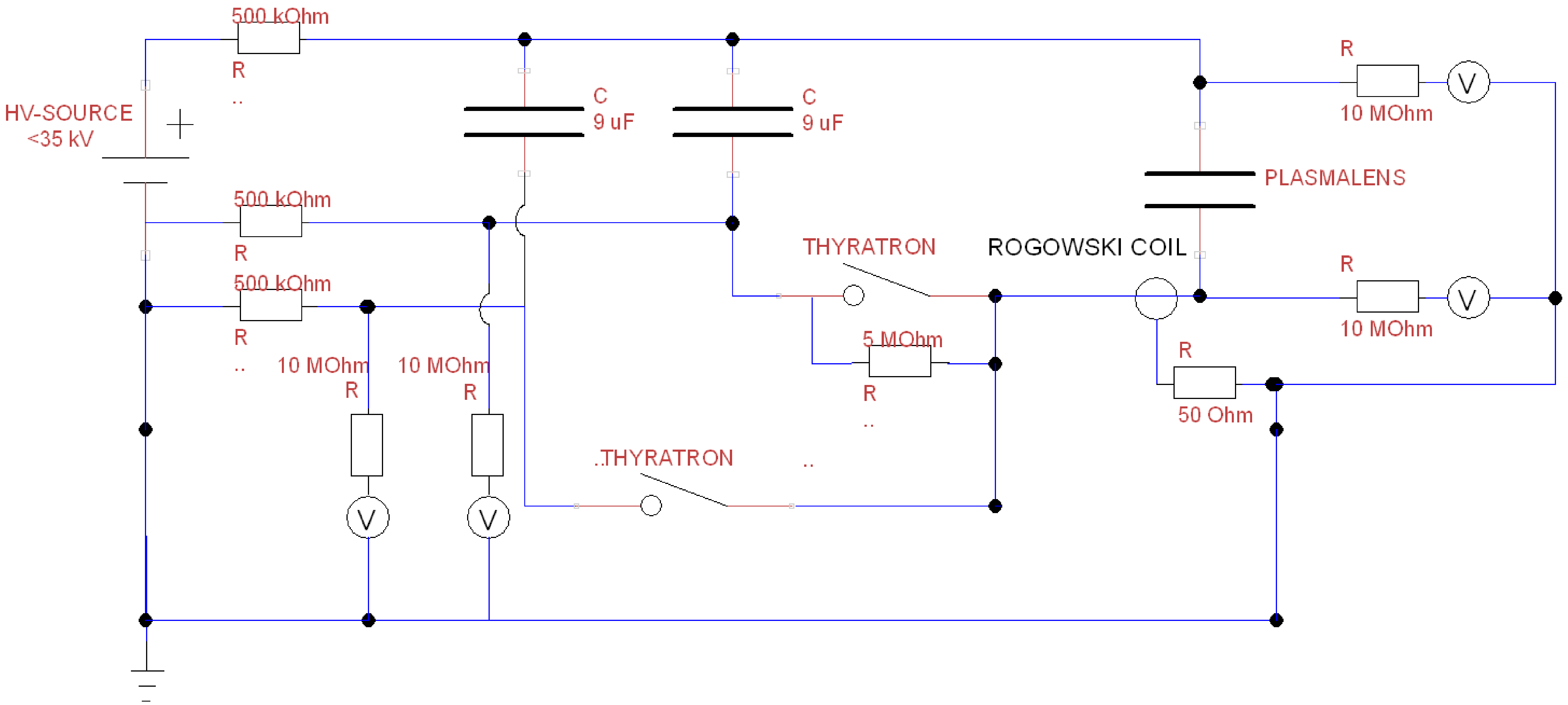
The circuit is designed to be quasi floating

- 500 kOhms to ground

$\longrightarrow \quad \sqrt{LC} \ll RC$

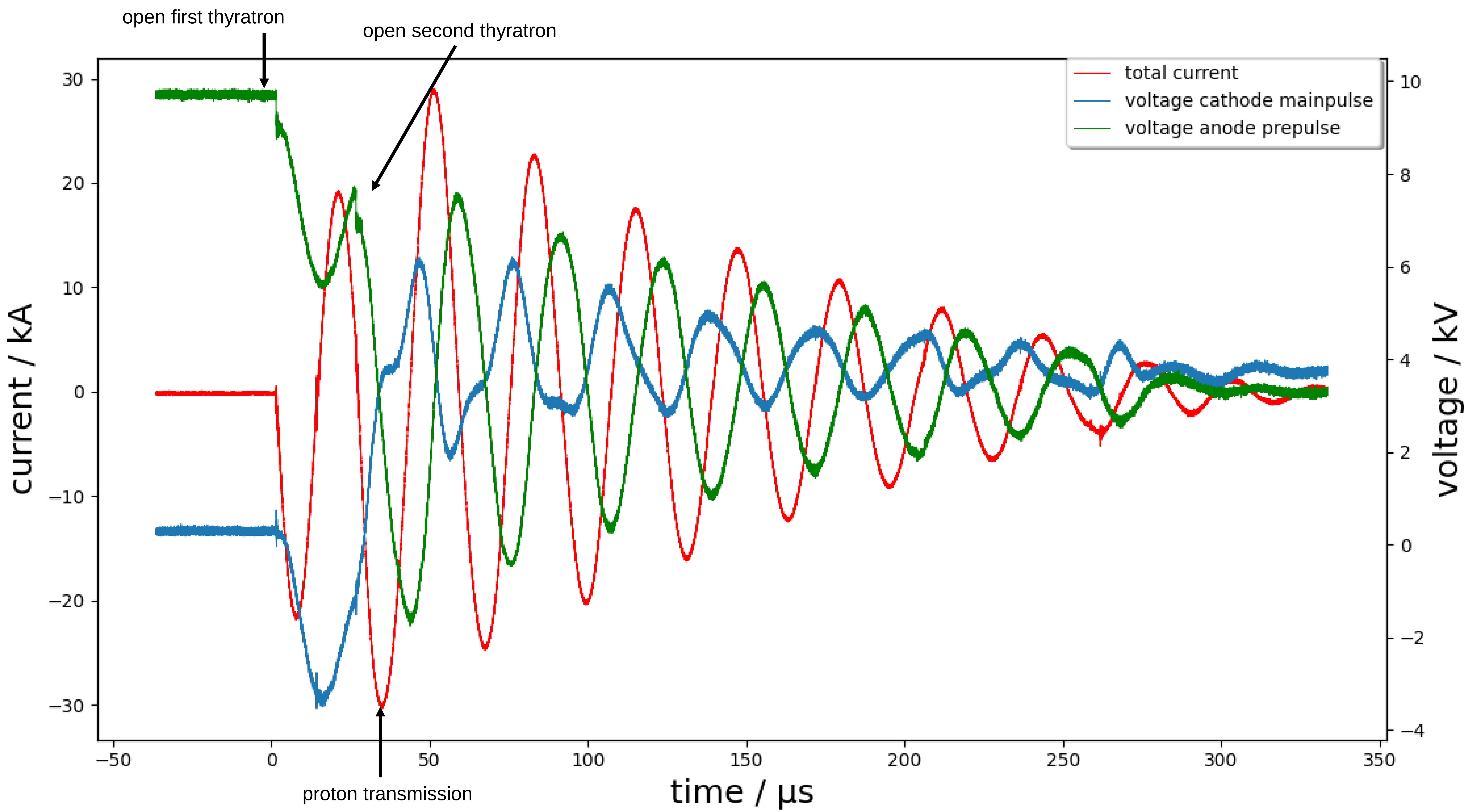
Pre-ionization to guarantee reproducible discharge by

- Bridging of the thyratron
- Pre-pulse 2π before main-pulse



Circuit diagram of the plasma lens

U-I-Diagram

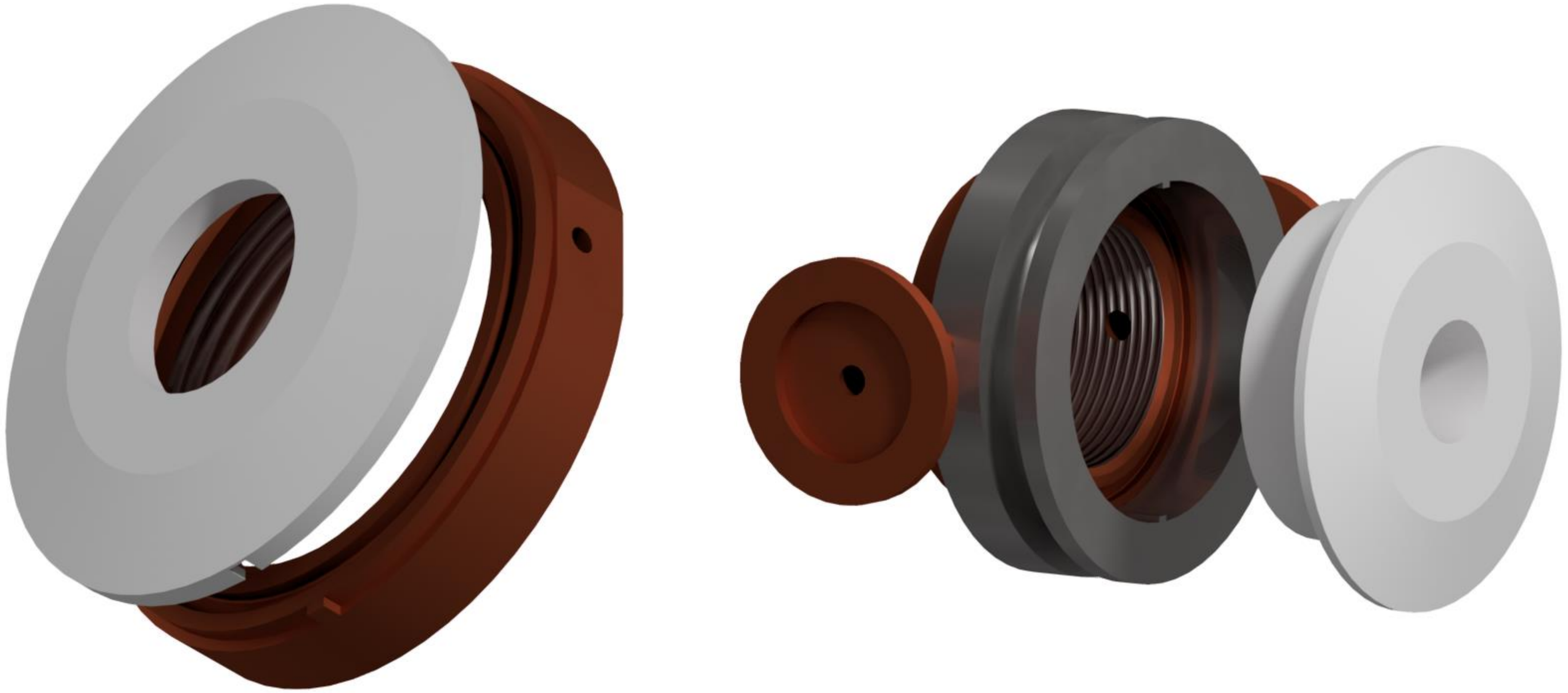

open first thyratron
open second thyratron
proton transmission
total current
voltage cathode mainpulse
voltage anode prepulse
current / kA
voltage / kV
time / µs
30
20
10
0
−10
−20
−30
10
8
6
4
2
0
−2
−4
−50
0
50
100
150
200
250
300
350

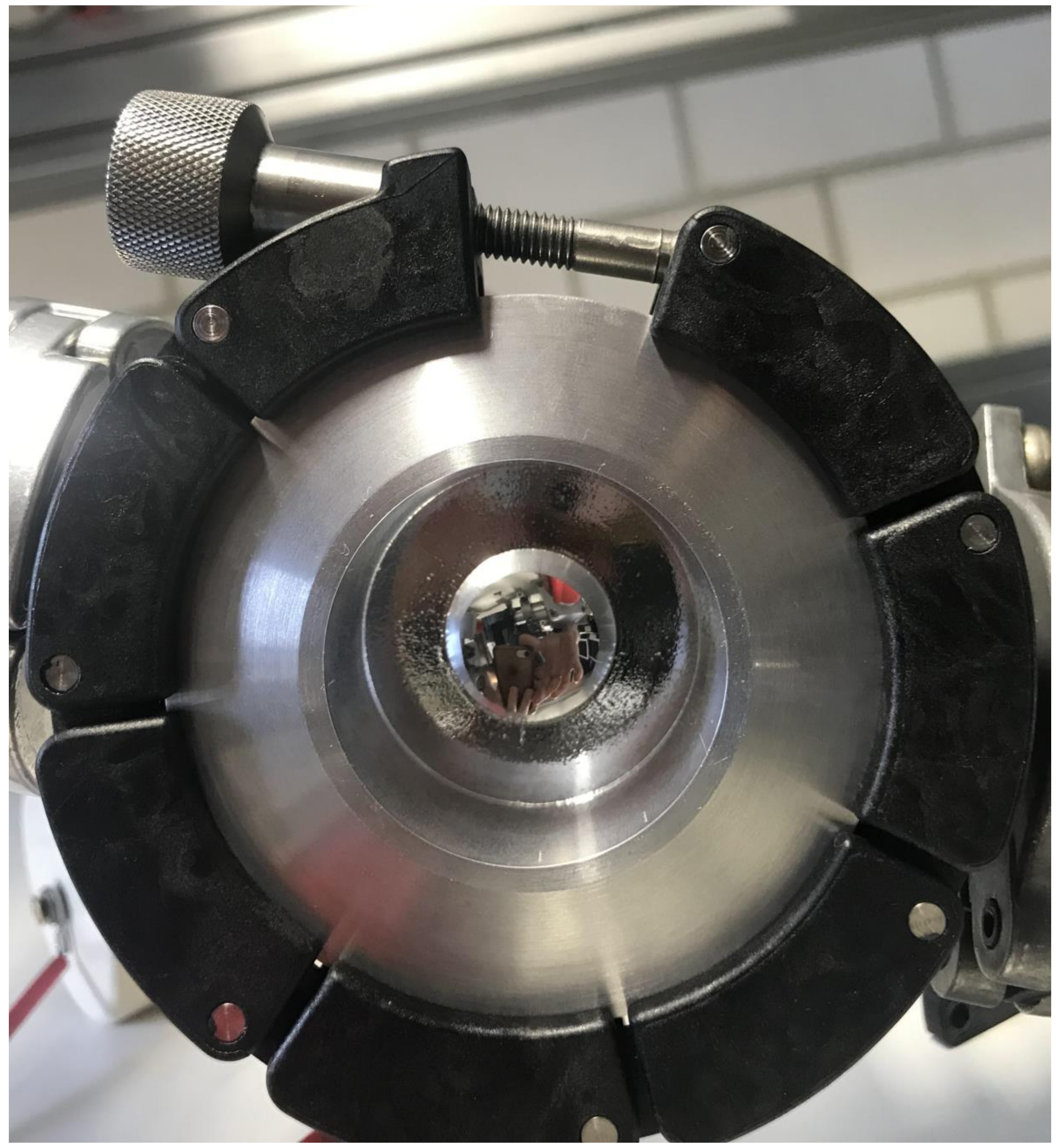
Goals:

Confine the working gas within the plasma lens
Allow the particle beam to propagate through the lens

Solution:

Foils ($25\mu m$ kapton)





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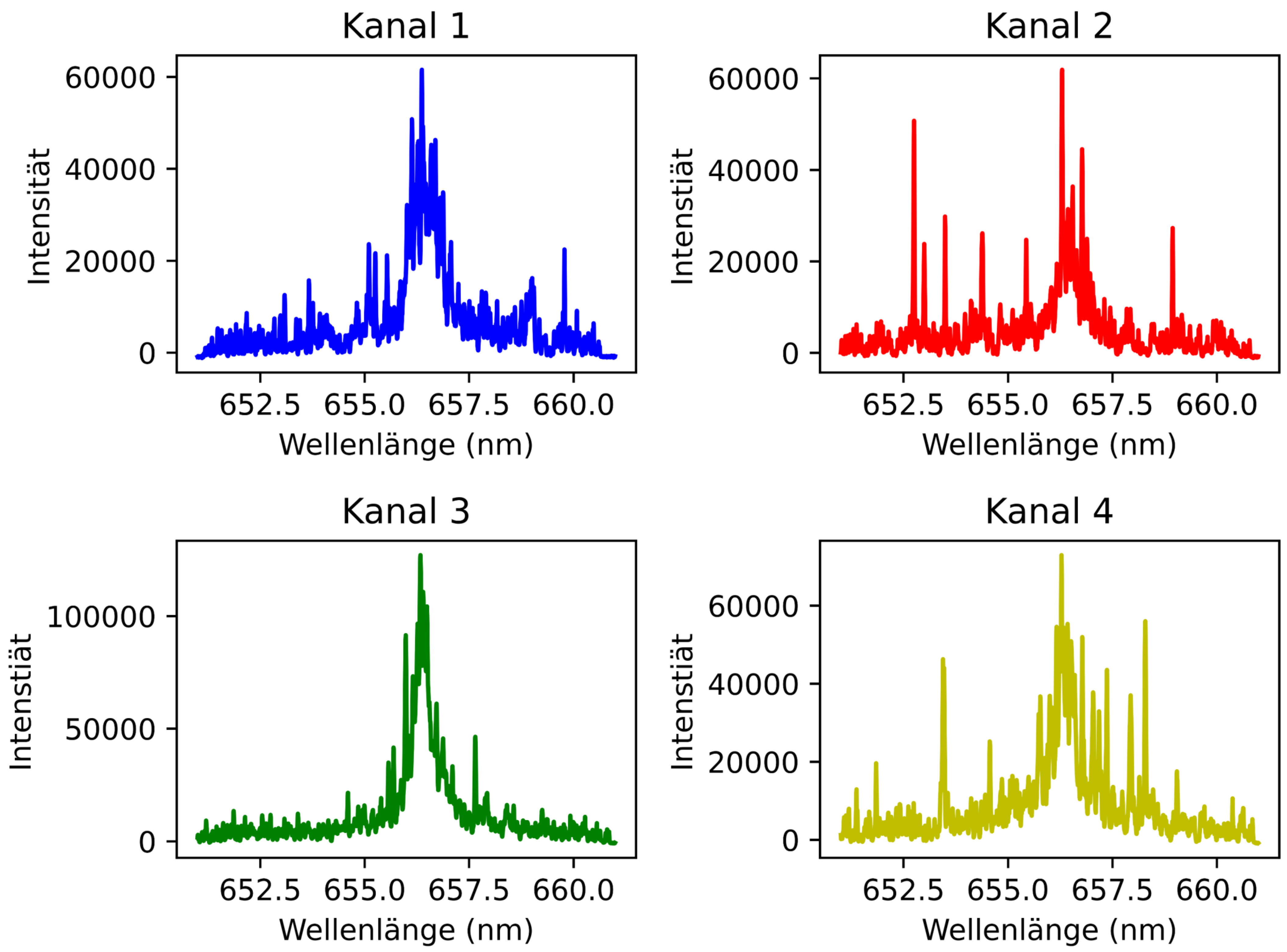
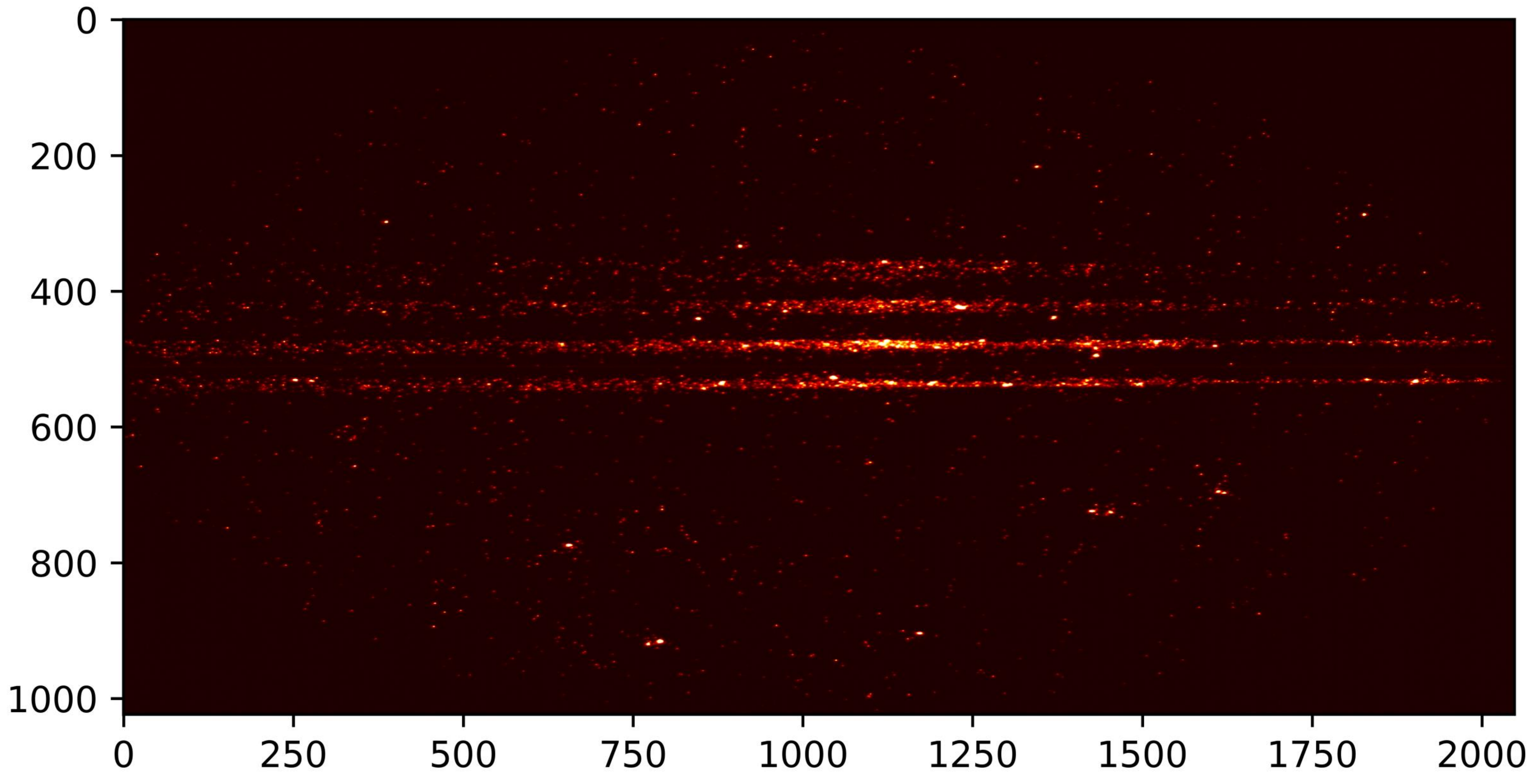
Examination of the symmetry of the discharge

Compare Spitzer resistivities $\eta(T_e, n_e, Z)$, $\eta \propto \frac{1}{I} \propto \frac{1}{B}$



Spectra of 4 different angles and the same radii and times along the beam axis

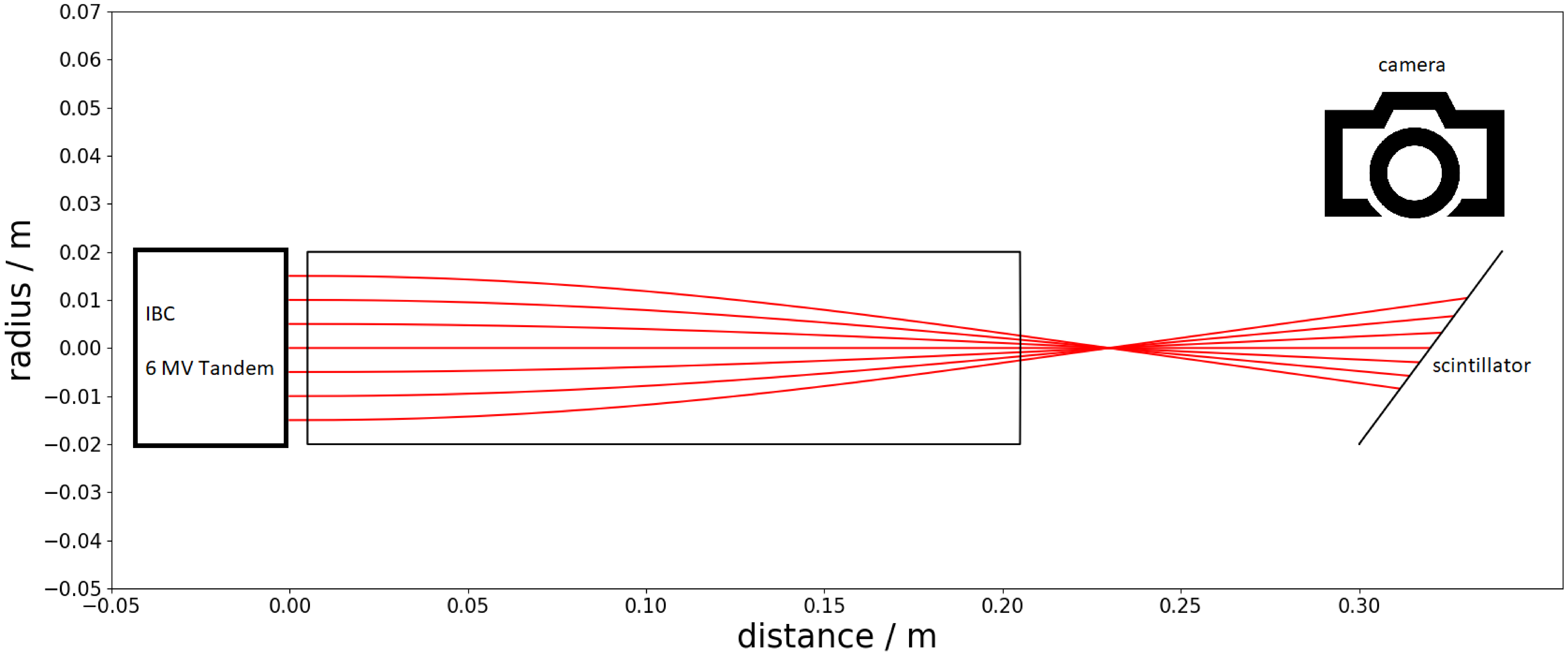


Heatmap of 4 spectra on one camera chip

Characterization Magnetic Field | Beamtime HZDR Dresden

Use high brilliance beam (6 MV Tandem)
Mask beam to define position and momentum

Beam detection by scintillator (Diagnostics by Florian Kroll and Joshua Schilz)



Schematic Drawing of the beamtime setup

Outlook

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Improve determination of plasma parameters in the laboratory

- Electron density and electron temperature by spectroscopy
  - Current density from the ratio of the two parameters
- Electron density by interferometry

Preparation for the beam

- Ignition in vacuum chamber to simulate conditions of Z6

Measurements at the beam (beamtime)

- Characterizing magnetic field at HZDR IBC (Dec. 2024)
- **Transmission and time of flight measurements at GSI LIGHT (May 2025)**

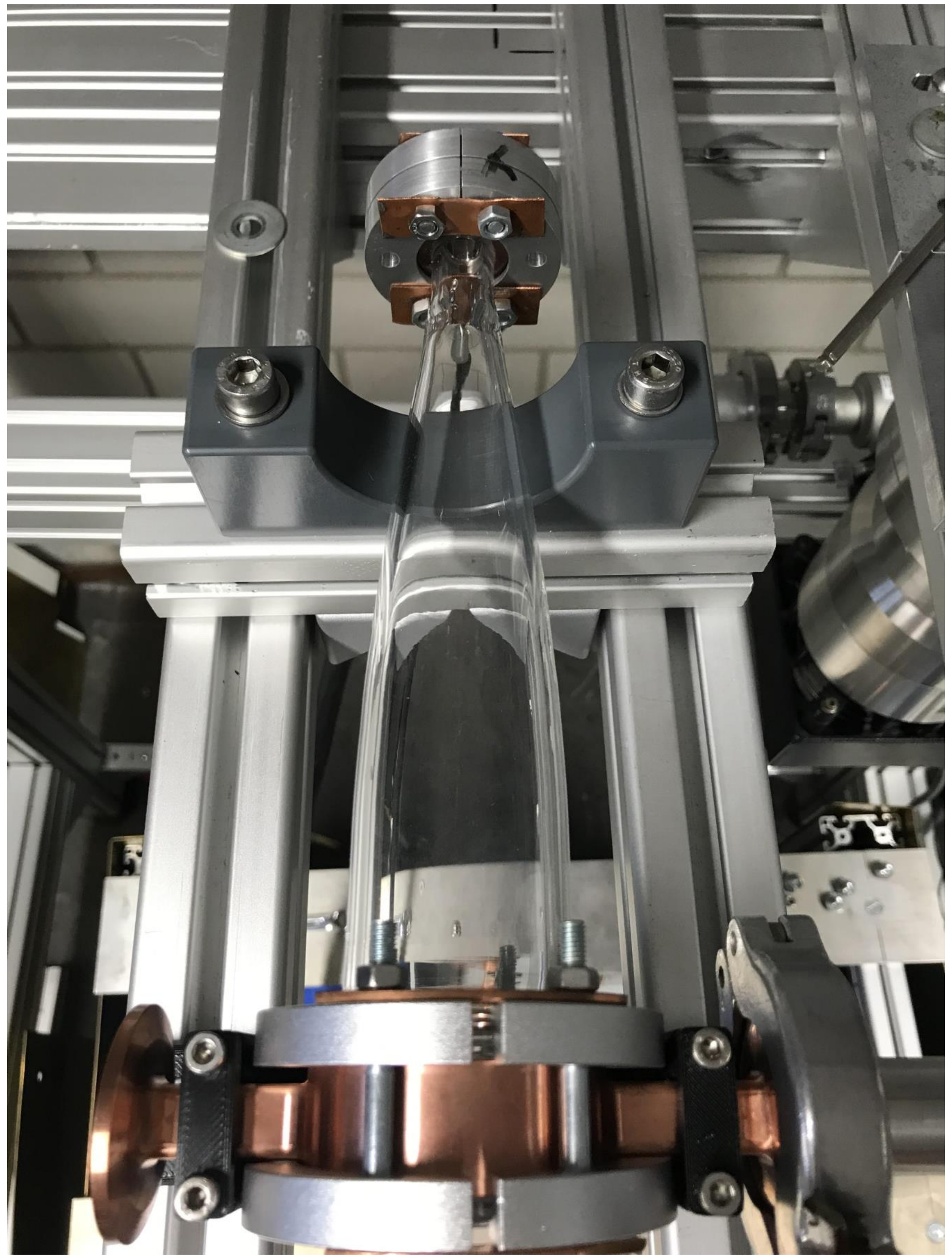

Image of the tapered plasma lens without electrical connection