Slit-Based Slice Emittance Measurements Optimization at PITZ.

Raffael Niemczyk et al.[1,2]

[1]DESY, Zeuthen Site, [2]University of Hamburg, Germany

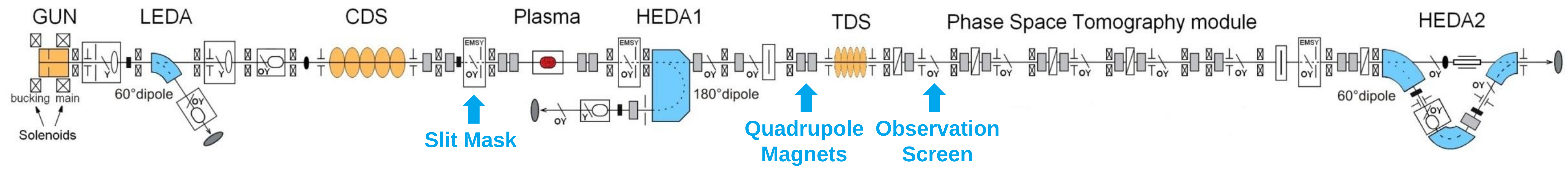
TUPP013

raffael.niemczyk@desy.de

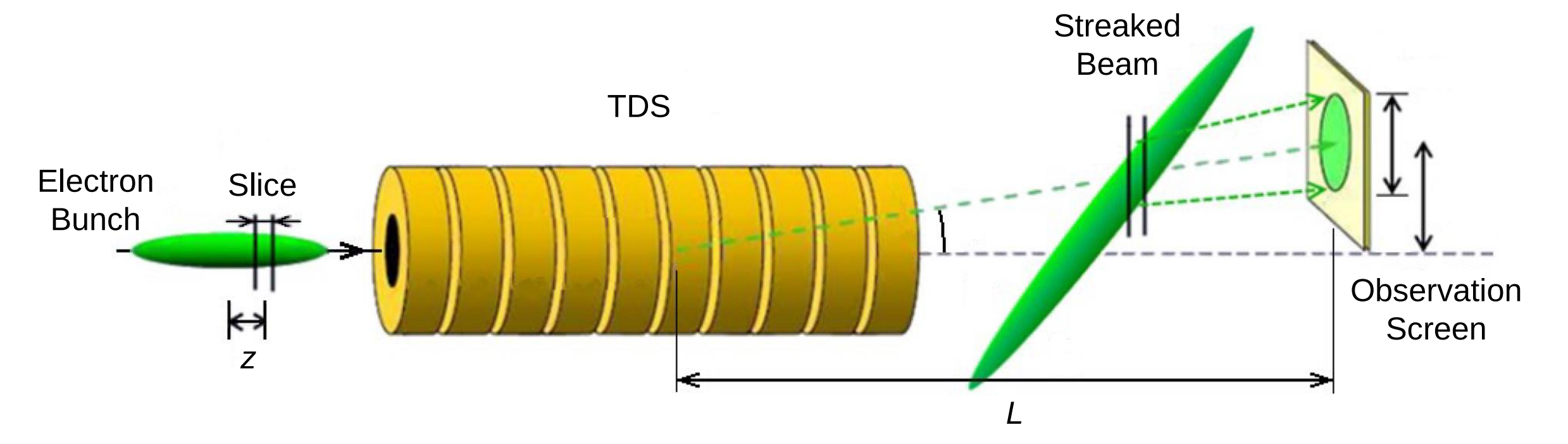
Photoinjector Test Facility at DESY in Zeuthen (PITZ)

Abstract: At the Photo Injector Test Facility at DESY in Zeuthen (PITZ) high-brightness electron sources are optimized for use at the X-ray free-electron lasers FLASH and European XFEL. Transverse projected emittance measurements are carried out by a single-slit scan technique in order to suppress space charge effects at an energy of ~20 MeV. Previous slice emittance measurements, which employed the emittance measurement in conjunction with a transverse deflecting structure, suffer from limited time resolution and low signal-to-noise ratio (SNR) due to a long drift space from the mask to the observation screen. Recent experimental studies at PITZ show improvement of the temporal resolution and SNR by utilizing quadrupole magnets between the mask and the screen.

PITZ Main Parameters	
Momentum	~ 24 MeV/*c*
Charge	20 pC … 6 nC
Bunch Length	2 ps … 24 ps
Emittance	~1 µm
Bunch spacing	1 µs
Bunches per Train	600 (max)
Bunch Train Rep. Rate	10 Hz



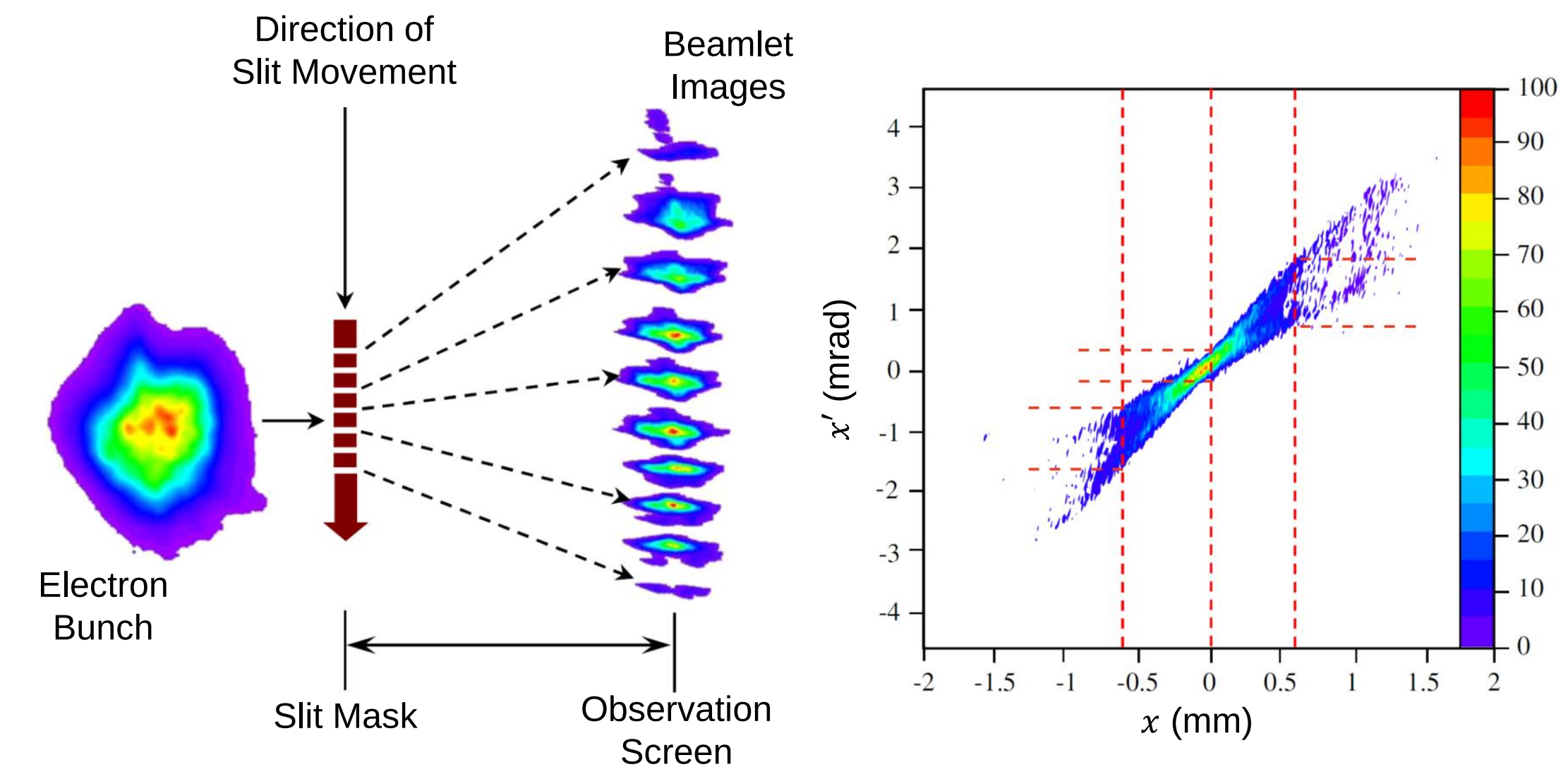
Transverse Deflecting Structure (TDS)



The TDS kicks the electrons depending on their longitudinal position within the electron bunch. This kick translates into vertical position after propagation through the following drift space.

This allows to correlate the vertical position on an observation screen with the longitudinal position within the bunch.

Slit-Based Emittance Measurement



The slit mask cuts out emittance-dominated beamlets from the whole beam. The angular spread of the electrons in each beamlet lead to widening of the beamlet in a following drift space.

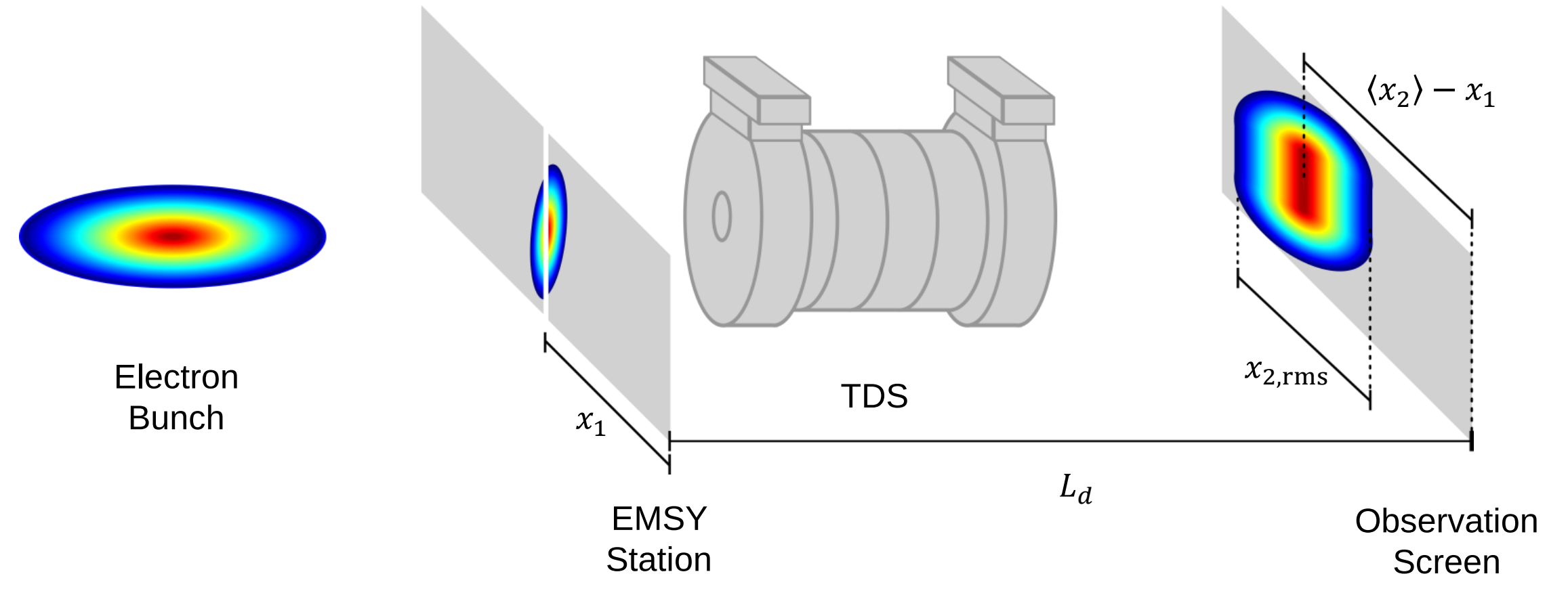
From the beamlet images the angular spread of the electron beam at the slit position is determined, allowing to reconstruct the transverse phase from beamlet images at different slit positions.

The normalized, (projected) emittance is calculated via

$$\epsilon = \beta\gamma\sqrt{\langle {x_0}^2\rangle\langle {x_0}'^2\rangle - \langle x_0 {x_0}'\rangle^2}$$

from the second-order moments of the phase space as well as the Lorentz factor γ and the electron speed β.

Slit-Based Slice Emittance Measurements

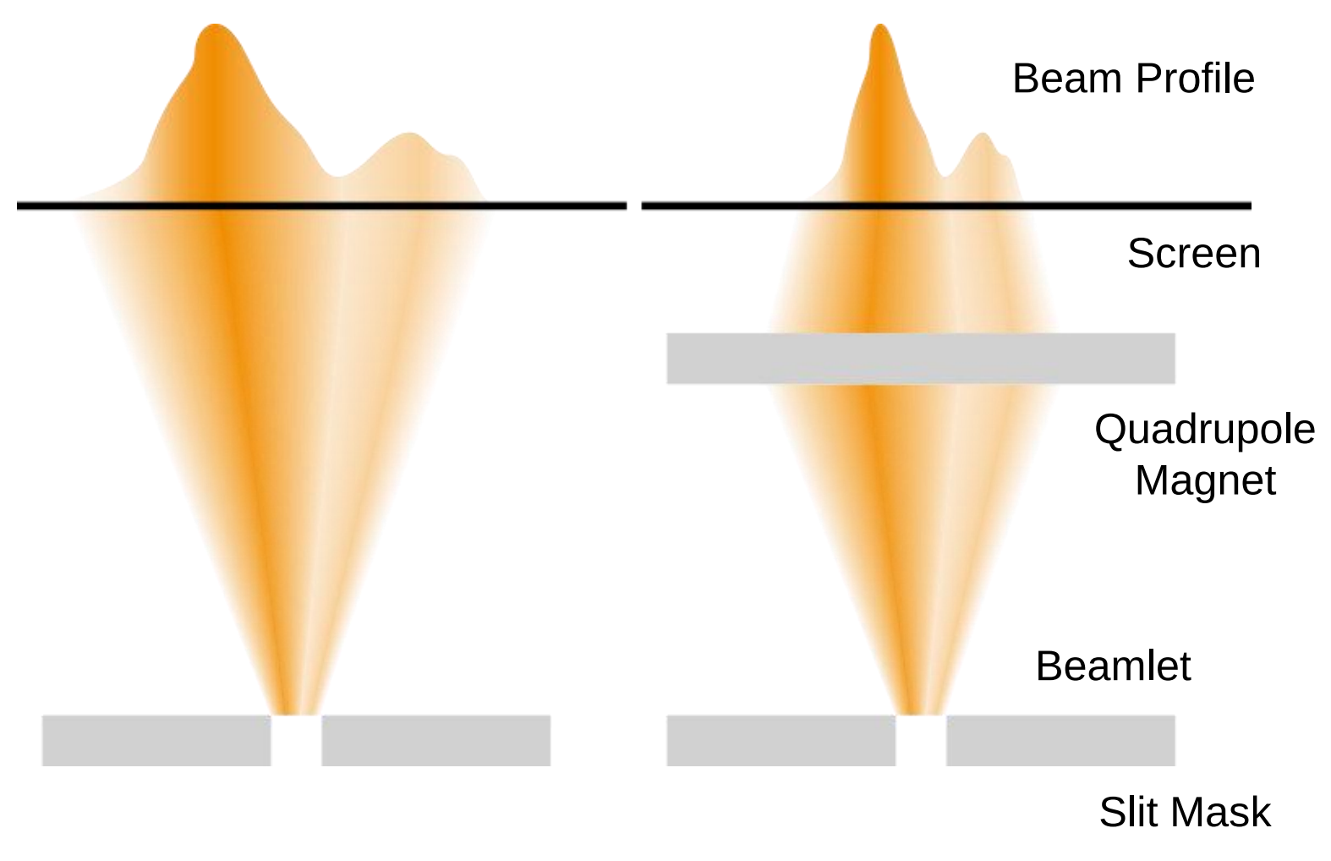


Combination of TDS and slit-based measurement
Combining the slit-based emittance measurement procedure with the TDS allows for measurements of the slice emittance.

The use of a slit mask, as well as the horizontal broadening due to the angular spread and the vertical streak in the rf deflector leads to a low signal-to-noise ratio of the image.

The low-intensity parts of the beamlets can't be recovered in the image processing, leading to an underestimation of the (slice) emittance.

Improving Beam Optics for higher SNR



In the drift after the slit mask the angular spread translates into spatial beam size, which makes it possible to determine the angular spread at the slit position. Due to the long drift the signal-to-noise ration (SNR) is small at the outer position.

As these parts can't be recovered during image processing the (slice) emittance is underestimated.

Slightly focusing of the beam increases the SNR, allowing to detect a higher fraction of the beam, yielding a higher emittance which is closer to the 100 % emittance.

Phase Space Reconstruction

Use of the quadrupole magnets to reduce the spatial broadening of the beamlets complicates the calculation of the angular spread. When the beam transport is linear between two points it can be written by means of the transport matrix **R** via

$$\begin{pmatrix} x_2 \\ x_2' \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_1' \end{pmatrix}$$

This yields for the angular spread at the slit mask the equation

$$x_1' = \frac{x_2 - R_{11}x_1}{R_{12}}$$

For a correct reconstruction of the phase space the transport matrix elements R_{11} and R_{12} have to be known. For a simple drift space from the slit to the screen $R_{11} = 1$ and $R_{12} = L$. When a more sophisticated optics is applied, these values change.

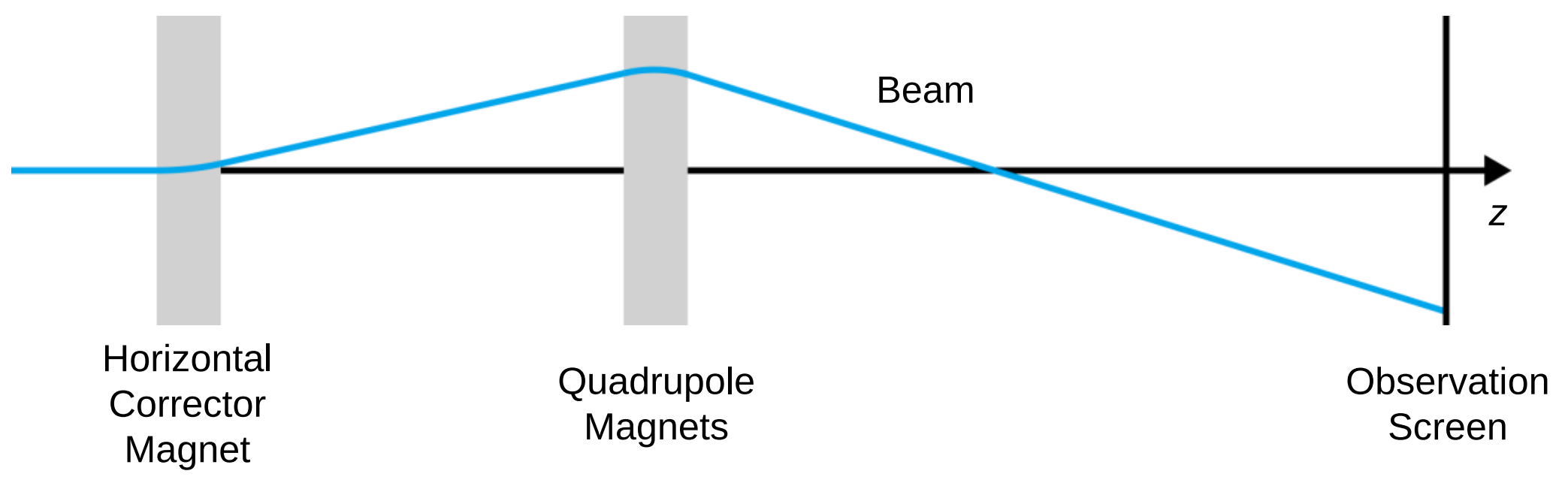
Online Measurement of Transport Matrix Elements

In order to determine the transport matrix elements trajectory response measurements are performed. A horizontal corrector magnet close to the slit position is used to deflect the electron beam while monitoring the beam position on a downstream screen.

The matrix element R_{12} is proportionality factor between the beam position on the screen and the angle at the center of the magnet according to

$$x_2 = R_{11}x_1 + R_{12}x_1'$$

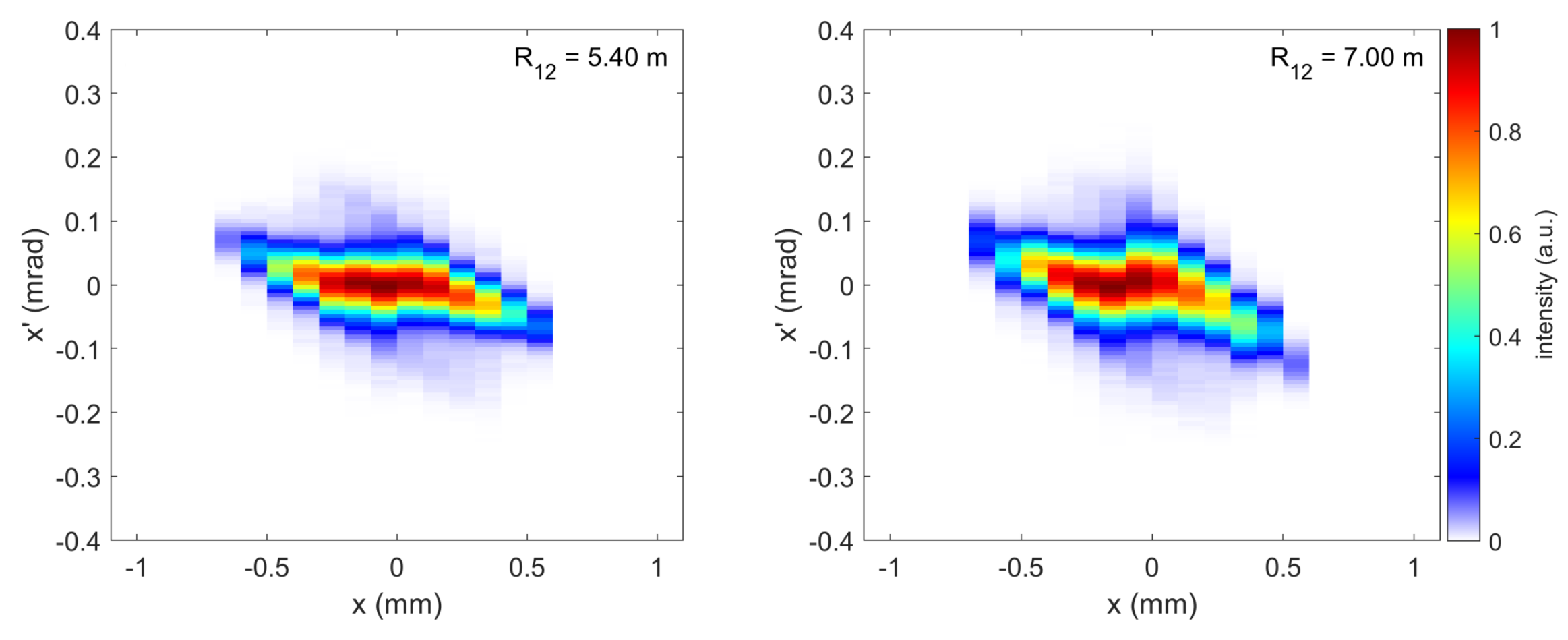
The same procedure is carried out beforehand the optics calibration in order to examine the corrector strength.



Correcting for space between corrector and slit
Nevertheless, the determined transport matrix element R_{12} is only valid from the center of the corrector magnet to the observation screen.

To calculate the transport matrix elements R_{11} and R_{12} from the slit mask to the observation screen a thin-lens model is applied. The focusing strength of the lens is calculated from the calibrated R_{12} from the corrector magnet to the screen. In a second step, the transport matrix elements are calculated based on the strength of the thin lens.

First Results

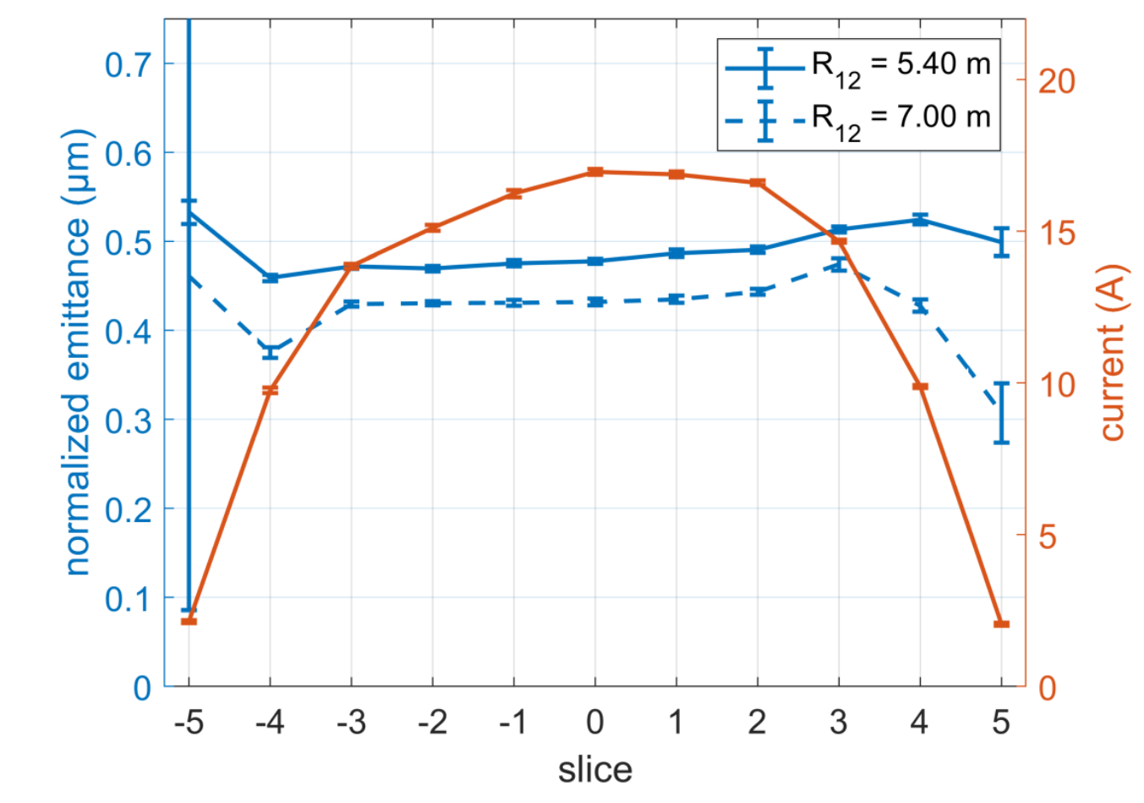


Measurement with and without quadrupoles
The center slice phase space, measured with quadrupole magnets behind the slit mask (left) and without (right) is shown above.

The similiar shapes indicate a proper phase space reconstruction despite the more sophisticated accelerator optics applied.

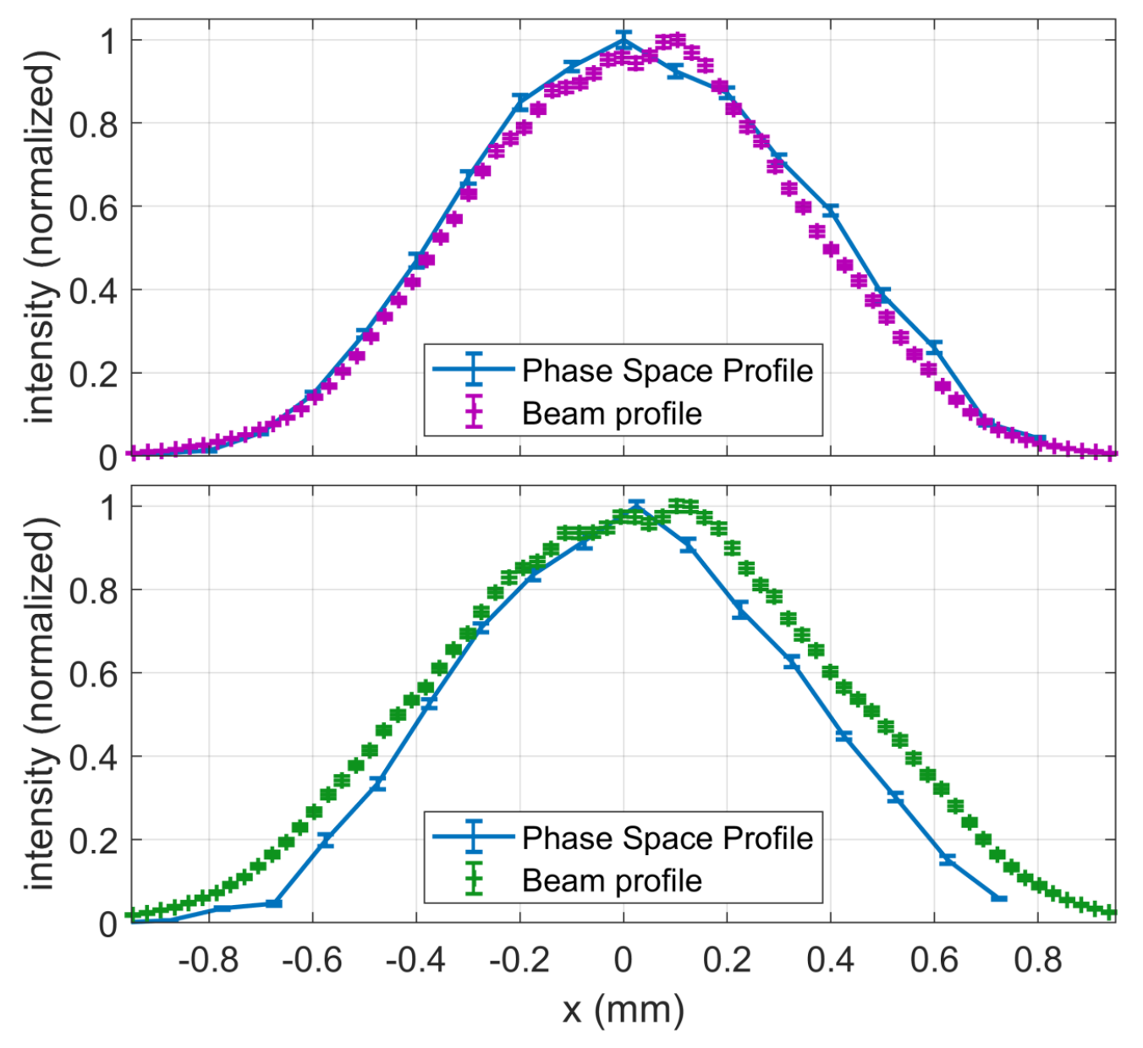
The left phase space has a normalized slice emittance of $\varepsilon_x = 0.48\ \mu\mathrm{m}$, the right one $\varepsilon_x = 0.43\ \mu\mathrm{m}$.

The difference in emittance values becomes more clear when comparing the slice emittance along the bunch, as well as the spatial profiles of the phase space and the beam at the slit mask, both right.



Slice emittance along longitudinal bunch axis
The slice emittance against the slice number, as well as the temporal bunch profile is shown above.

The slice emittance is systematically higher when measured with quadrupole magnets focusing the beam in the horizontal plane (solid blue line) compared to no quadrupole magnets used (dashed blue line). Due to the focus the signal-to-noise ratio increases, allowing to keep signal during image processing which otherwise would get lost in noise.



Beam and phase space profiles
Comparison of the horizontal profiles of the projected phase space with the horizontal beam profile at the slit mask shows the improvement in SNR.

The top image shows the horizontal phase space projection measured when focusing the beam with quadrupole magnets. The profile is very close to the beam profile.

The bottom image shows the phase space profile measured without quadrupole magnets. Signal loss during image processing is a possible explanation for the narrower profile, yielding a lower emittance.

Conclusion

A method to increase the signal-to-noise ratio during slit-based slice emittance measurements has been found and compared with a previous method. In a test it showed higher (slice) emittance values as a result of higher signal which is kept during image processing.

Aspects left to analyse
> Different quadrupole focusing strength
> Different TDS deflection voltages
> Detailed check of image processing
> Comparison of results with simulations

Application of slice emittance measurements
After the method for slice emittance measurements has been found the slice emittance for different temporal laser profiles, namely a long Gaussian and a Flattop profile can be measured.

It is also of interest to compare the slice emittance of a beam from a transversly uniform laser distribution with a transversly truncated Gaussian laser distribution.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES