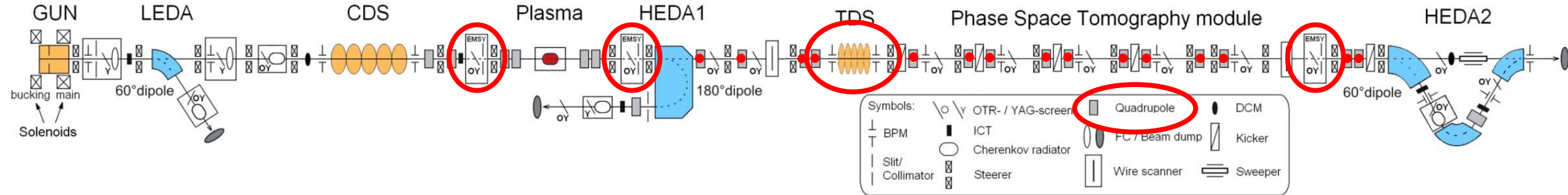


Progress towards slice emittance measurements at PITZ

Raffael Niemczyk for the PITZ team, Würzburg, March 20th 2018

PITZ Overview

Photo-Injector Test Facility at DESY, Zeuthen Site



> Three **E**mittance **M**easurement **S**ystems (EMSY)

- Standard measurement device for **normalized emittance**:

$$\epsilon = \beta\gamma \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2}$$

> Several quadrupoles and screens

- Enable multi-quadrupole scan

> Transverse Deflecting Structure (Cavity)

- Slice properties can be measured

Emittance Term
↓
Charge Term
↓

$$\text{beam envelope equation: } \sigma''_x = \frac{\epsilon_n^2}{\gamma^2 \sigma_x^3} + \frac{I}{\gamma^3 I_0 (\sigma_x + \sigma_y)}$$

PITZ Main Parameters

Momentum	~ 24 MeV/c
Charge	20 pC ... 2 nC
Bunch length	2 ps ... 24 ps
Emittance	~1 mm mrad

Slice emittance measurements for detailed characterisation of bunches

Transverse Deflecting Structure (TDS) at PITZ

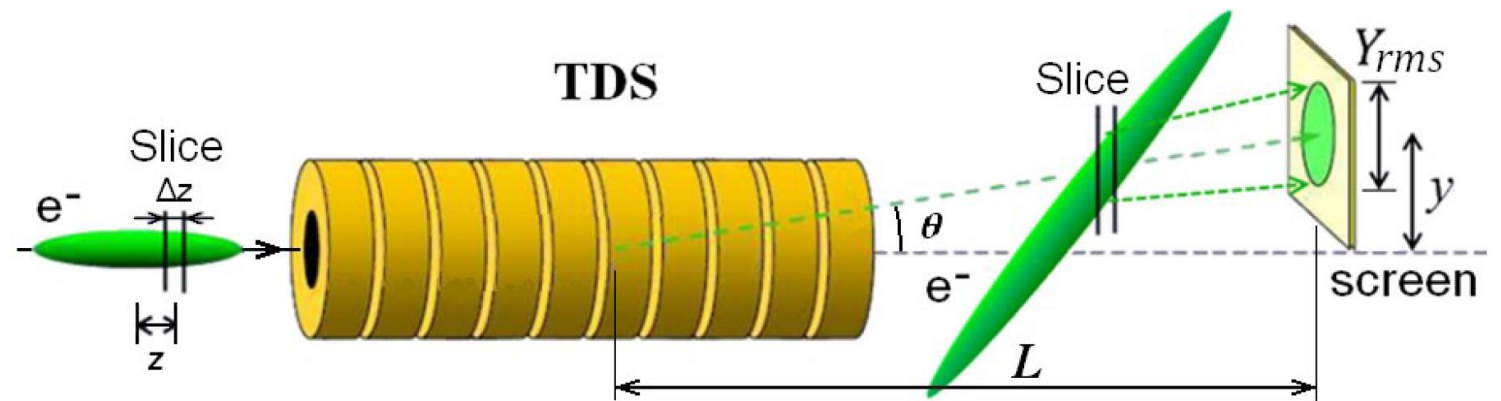
Photo-Injector Test Facility at DESY, Zeuthen Site

> Measurement possibilities with TDS Cavity:

- Longitudinal profile
- Longitudinal phase space
- Twiss parameters longitudinally resolved
 - > Slice emittance

> Properties:

- Frequency: 3 GHz (S band cavity)
- Resolution: ~ 200 fs
- Pulse length: up to $3 \mu\text{s}$



[1]

[1] D. Malyutin, PhD thesis, Universität Hamburg (2014).

Quadrupole Scan

Quadrupole scan based slice emittance measurement

- > Measure the beam size with different optics applied
- > Get the Twiss parameters from fit

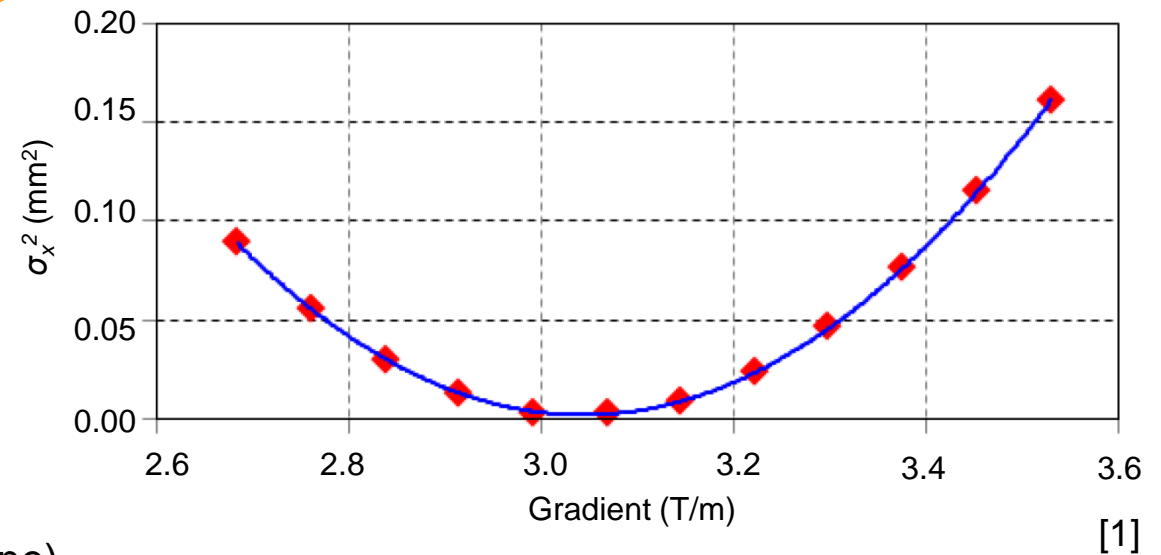
$$\langle x^2 \rangle = R_{11}^2 \langle x_0^2 \rangle + 2R_{11}R_{12} \langle x_0 x_0' \rangle + R_{12}^2 \langle x_0'^2 \rangle$$

- Calculate the emittance via

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

- > Constraints for slice emittance measurements:
 - Vert. beam size has to be small (Streaking plane)
 - Hor. beam size should be const. (Emittance measurement plane)
 - Transfer matrix element R_{12} should be big (strong streaking)

$$\begin{pmatrix} x \\ x' \end{pmatrix}_{s_2} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}_{s_1 \rightarrow s_2} \cdot \begin{pmatrix} x \\ x' \end{pmatrix}_{s_1}$$



[1] D. Malyutin, PhD thesis, Universität Hamburg (2014).

What has been done so far...

Quadrupole scan based slice emittance measurements

> Quadrupole scan performed

- Results unsatisfying
- Space charge forces disturb measurements (Solution: Slit Scan)
- Lattice was not properly optimized (sensitive to errors)

> Measurement of transport matrix (R_{12}) for whole optics and single quadrupoles

- Measurement weren't conclusive

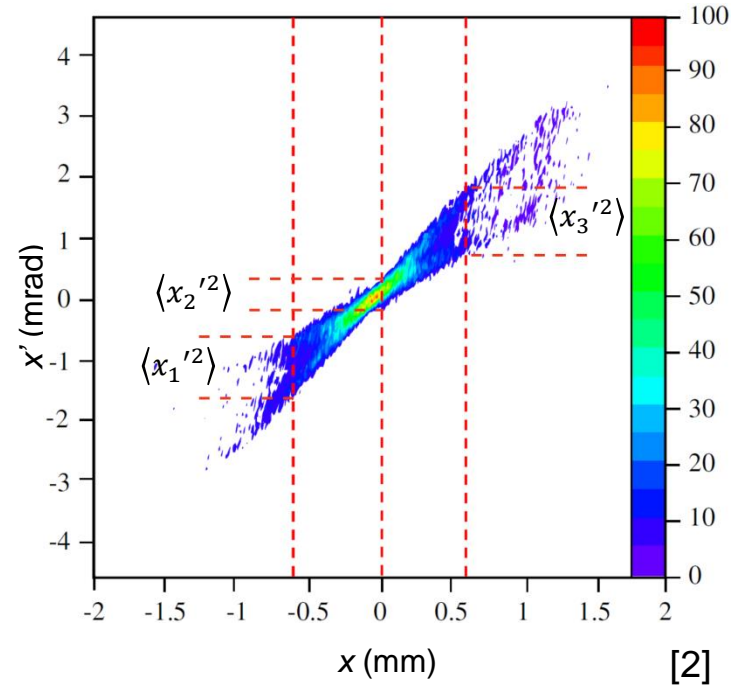
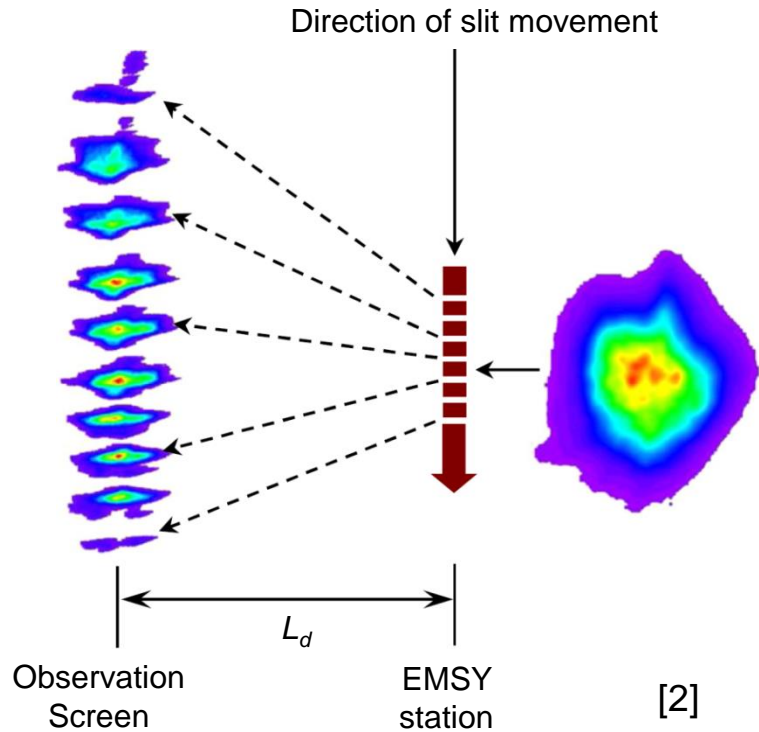
> More measurement required (next data in summer)

Quadrupole Scan: Different beam transport due to space charge forces for high charges

> For low-charged beams

Slit Scan Method

Slit-based slice emittance measurements



> Cut out **emittance-dominated beamlets** from **space charge-dominated beam** with a slit

- Measure the **size**, **position** and **intensity** of each beamlet on screen

> Reconstruct the phase space at slit position

- Emittance via $\epsilon = \beta\gamma \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \sqrt{\langle x_0'^2 \rangle \langle x_0^2 \rangle - \langle x_0 x_0' \rangle^2}$

[2] S. Rimjaem et al., Nucl. Instr. Meth. Phys. Res. A **671**, 62 – 75 (2012).

Slit Scan Data Filtering

Streaked beams lead to small Signal-to-Noise Ratio

Image Averaging

averaging of 10 images



Average Background Subtraction

subtract 10 background images



Convolution

with 2D-Gaus σ_{Conv}

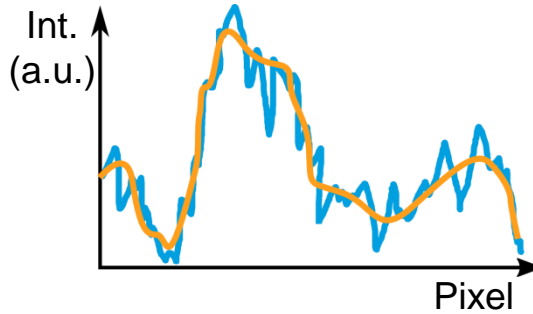
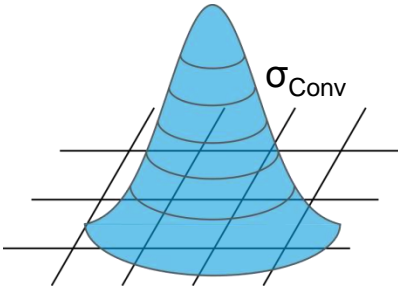


Noise cut

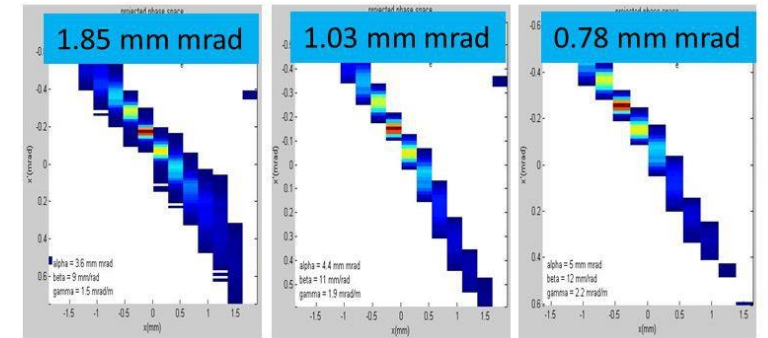
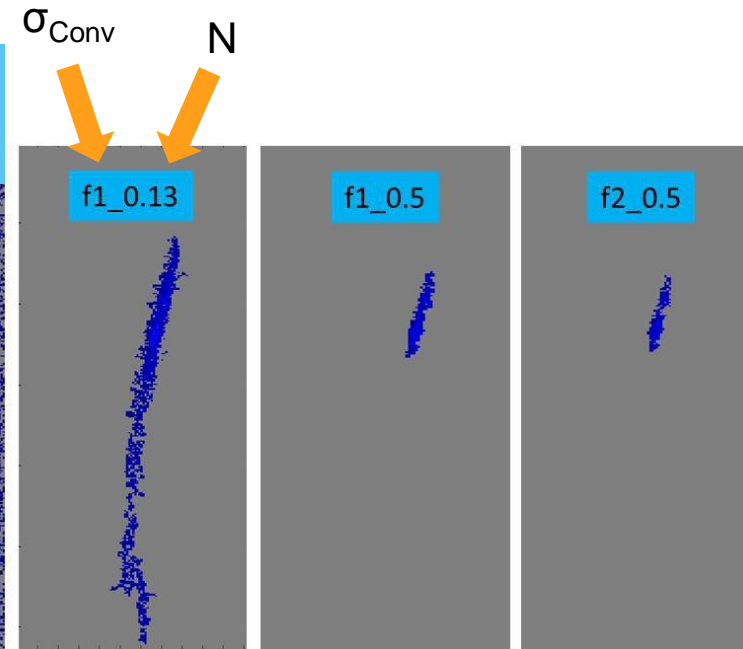
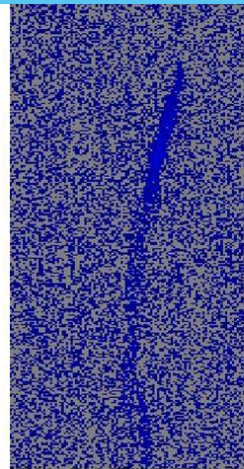
$N * \sigma_{Background}(x,y)$



Mask of Interest



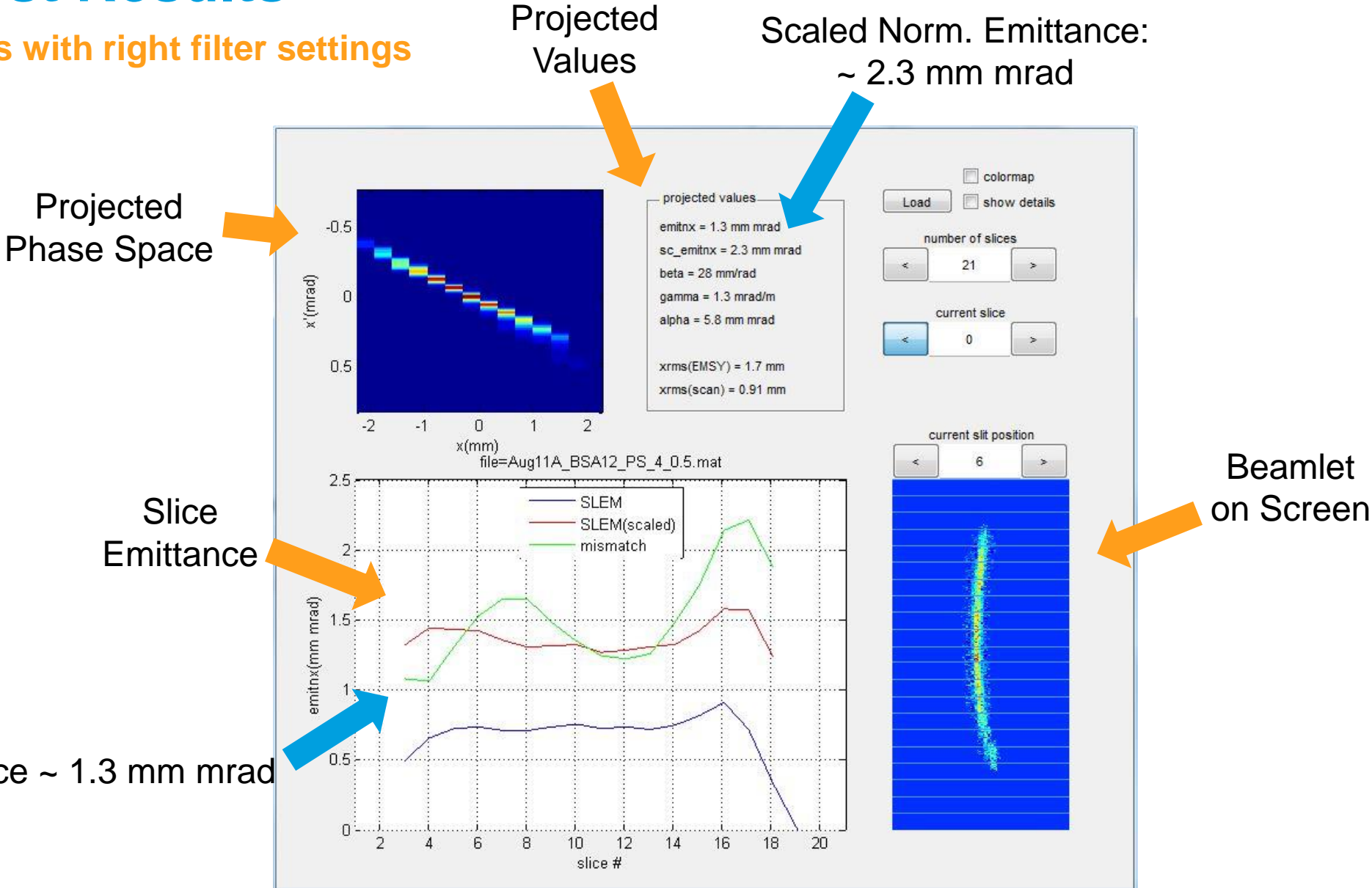
Background-subtracted Signal



Correct filtering and high Signal-to-Noise ratio important!

Slit Scan Test Results

Reasonable Results with right filter settings



Outlook

Further proceeding, next measurement program

> **Quadrupole-scan based SLEM: For low-charged beams**

- New calibration of quadrupole and steering magnets (repeat measurement)
- Robust optics have to be developed (small sensitivity to magnetic errors)

> **Slit-based SLEM: For high-charged beams**

- LYSO screens will increase sensitivity (in comparison to current YAG screens)
- Find best-suited set of filter parameters
- Improve tools for **online** slice emittance measurements

Literature list

- [1] D. Malyutin, *Time resolved transverse and longitudinal phase space measurements at the high brightness photo injector PITZ*, PhD thesis, Universität Hamburg (2014).
- [2] S. Rimjaem et al., *Optimizations of transverse projected emittance at the photo-injector test facility at DESY, location Zeuthen*, Nucl. Instr. Meth. Phys. Res. A **671**, 62 – 75 (2012).