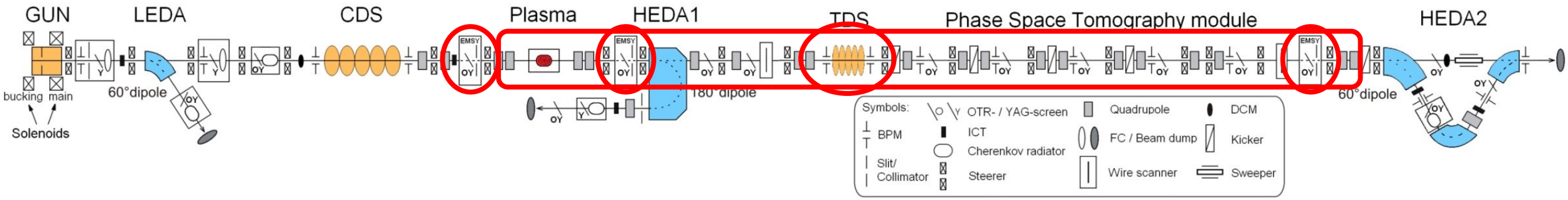
Progress towards slice emittance measurements at PITZ

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

- Slit-scan based slice emittance test measurements
- Beam Transport Studies as preparation of quadrupole-based slice emittance measurements

PITZ Overview

Photo-Injector Test Facility at DESY, Zeuthen Site

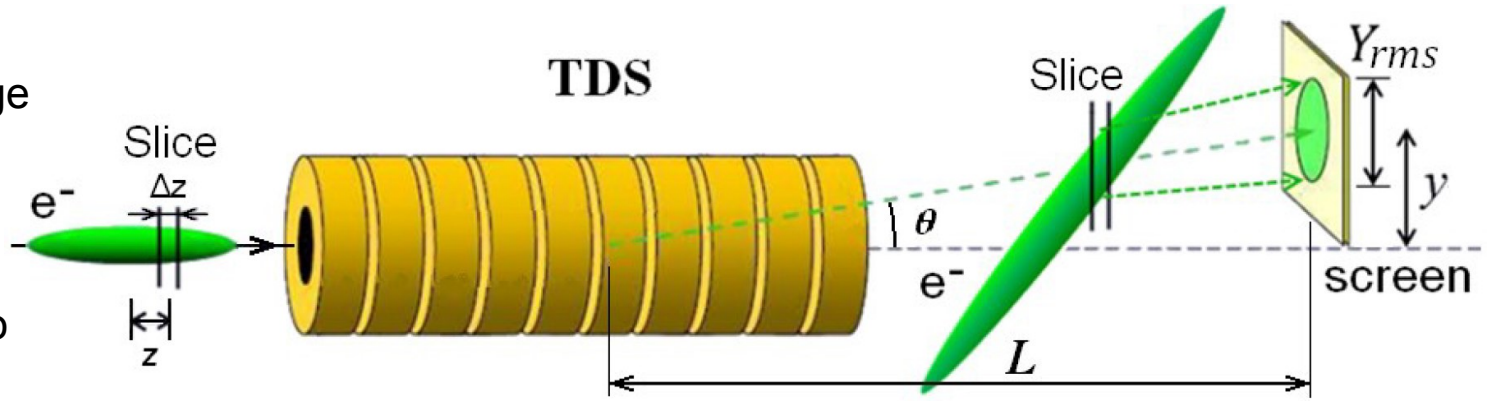


- **Three EMSY stations (movable slit)**
  - Two before and one after the TDS
  - Standard measurement device for **projected emittance**
- **Several quadrupoles and screens**
  - Different combinations of elements possible
  - Enable multi-quadrupole scan
- **TDS**
  - Measurement of longitudinal beam profile
  - Slice properties can be measured

Transverse Deflecting Structure (TDS) at PITZ

Photo-Injector Test Facility at DESY, Zeuthen Site

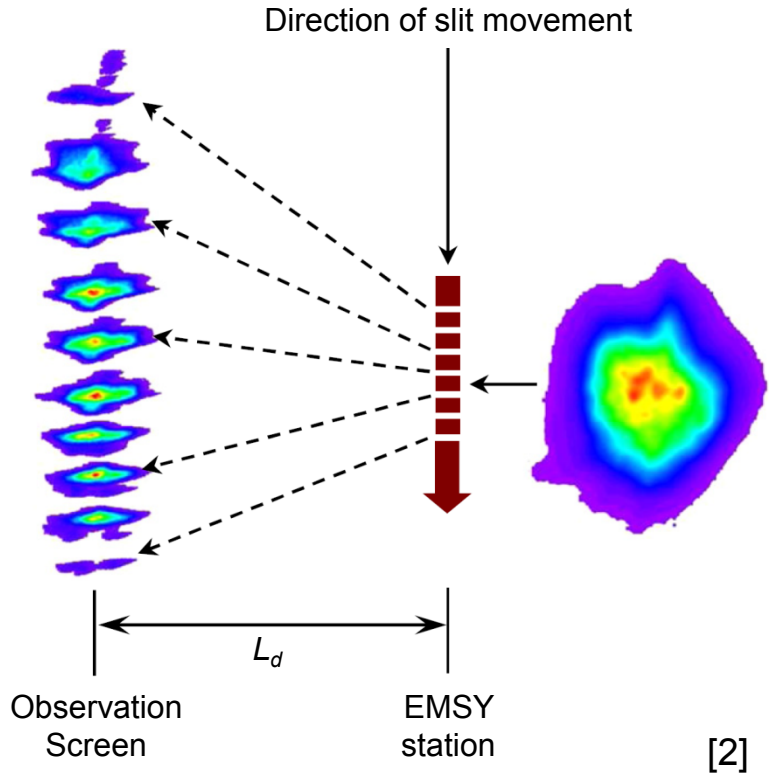
- **Measurement possibilities with TDS:**
  - Longitudinal profile
  - Longitudinal phase space
  - Twiss parameters longitudinally resolved
    - > Slice emittance
- **Properties:**
  - Frequency: 3 GHz (S band cavity)
  - Power: 2.1 MW → 1.7 MV deflection voltage
  - Pulse length: up to 3 µs
- **Hardware status**
  - Design parameters almost reached due to high reflectivity from wave guide
  - Small matching pieces mounted, but high power test to be done



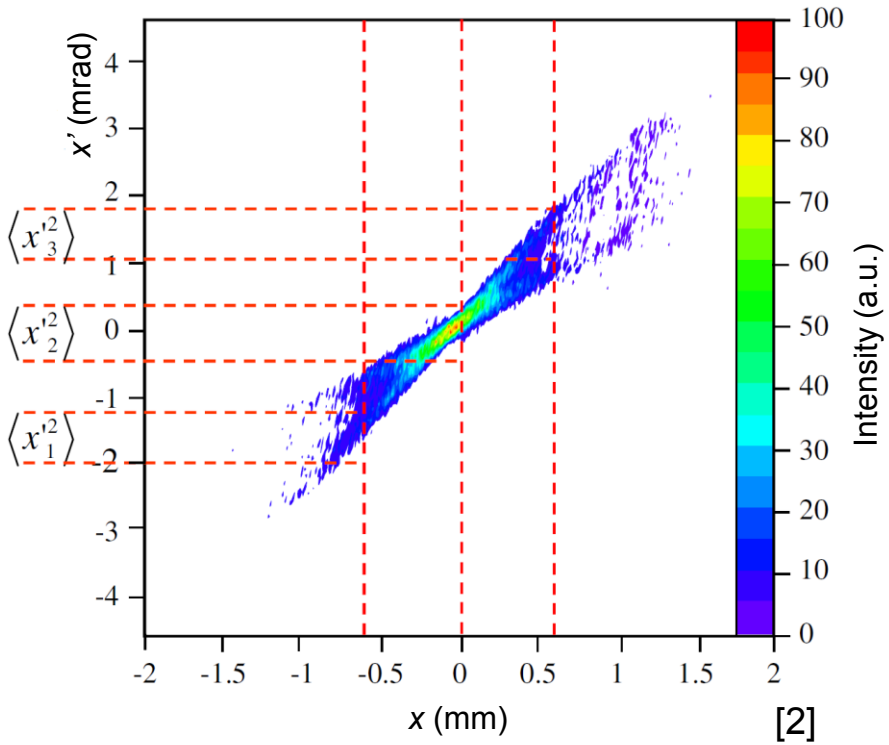
[1]

Slit-Scan Method

Slit-based slice emittance measurements



[2]



[2]

- **Cut out beamlets with a slit**
  - Measure the **size**, **position** and **intensity** of each beamlet on screen
- **Reconstruct the phase space at slit position**
  - Calculate the emittance in **one** plane via [3] $\epsilon = \sqrt{\langle x_0{}^2 \rangle \langle x_0{}'^2 \rangle - \langle x_0 x_0' \rangle}$

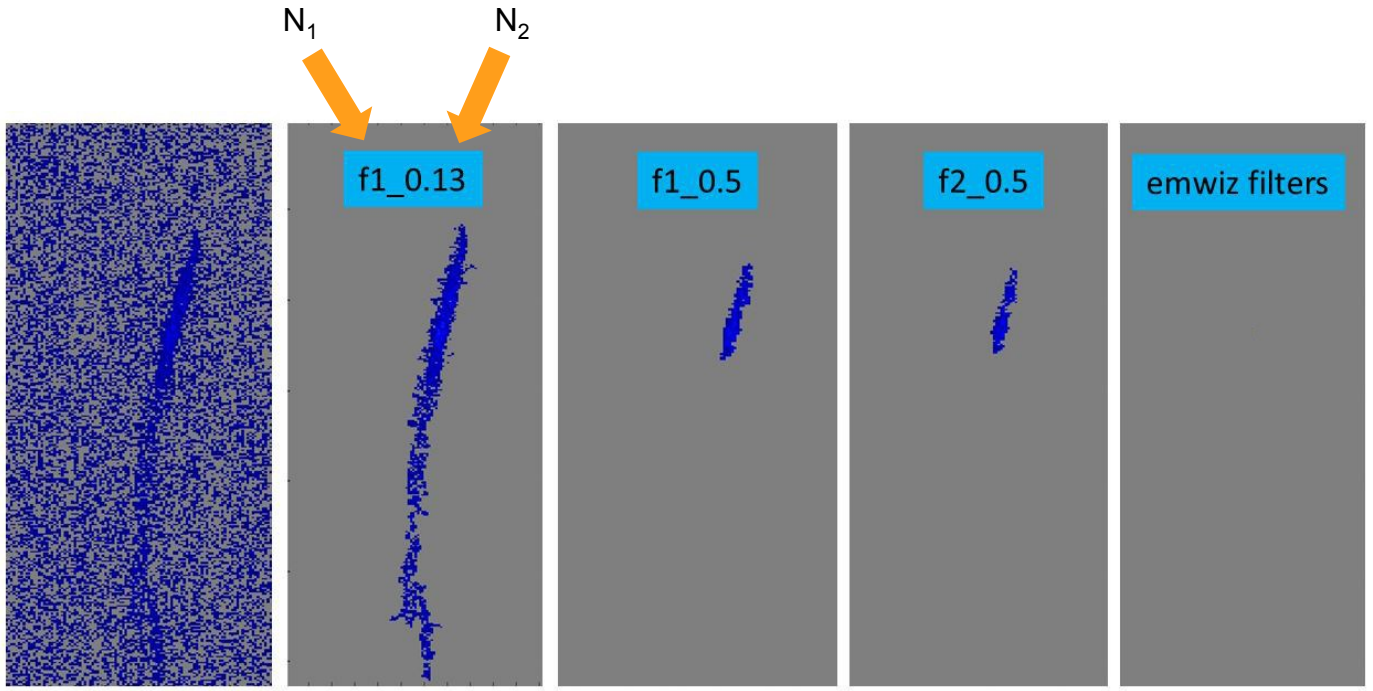
Slit-Scan Data Filtering

Testing influence of filter settings

Filter algorithm:

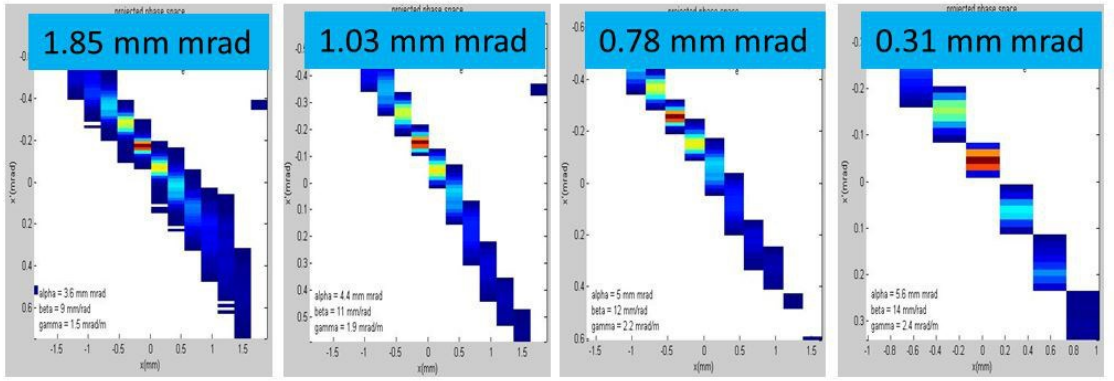
- Smoothing raw data with gauss
  - Parameter: **N_1 * RMS smoothing**
- Pixelwise: setting values to zero with

  value < N_2 * $RMS_{Background}$
  - Parameter: **N_2 * $RMS_{Background}$**



Observation:

- Signal very sensitive to parameter setting
- Reconstructed emittance values very sensitive



Quadrupole-Scan

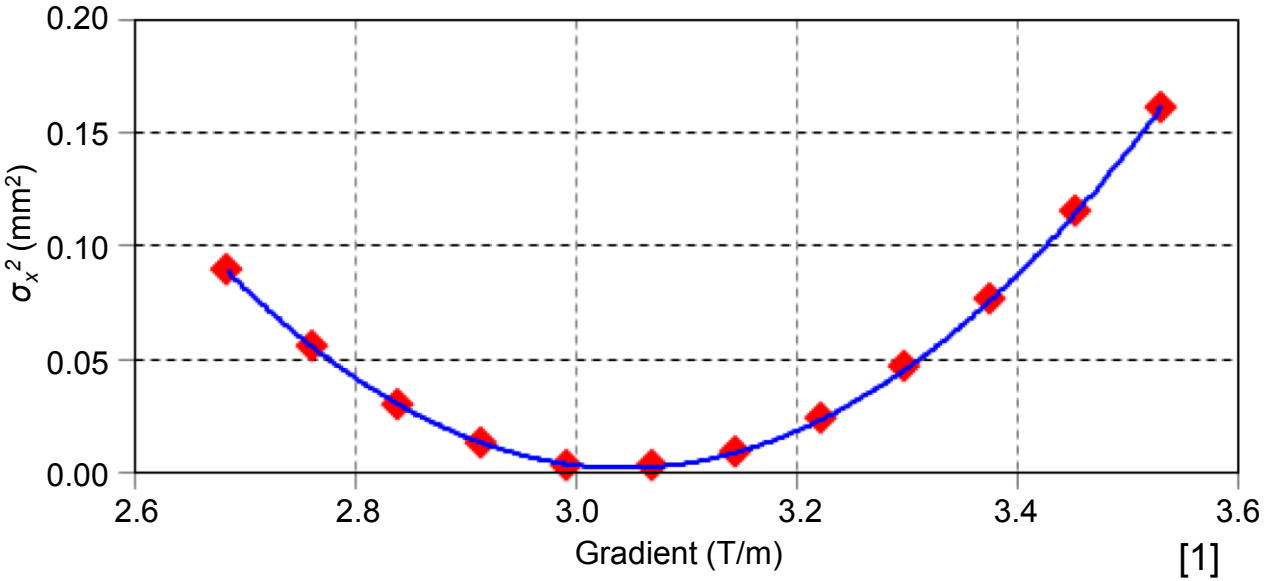
Quadrupole-scan based slice emittance measurement

- Measure the beam size with different optics applied
- Get the Twiss parameters from fit [3]

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

> Calculate the emittance [3] via

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



[1]

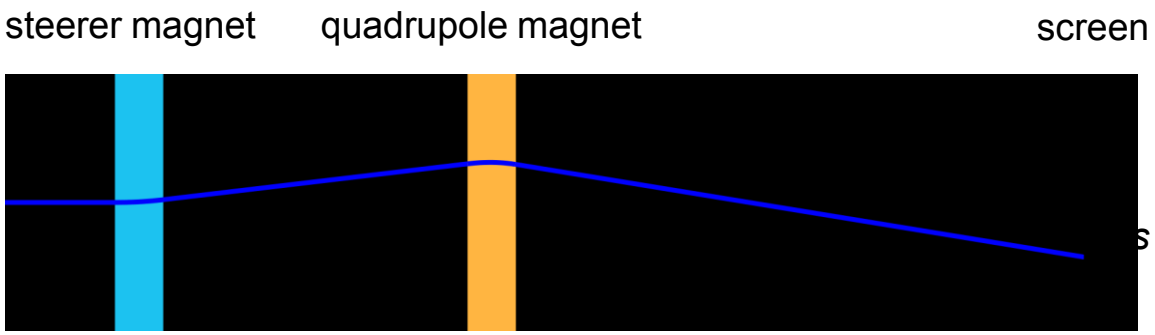
Beam Transport Studies

Calibrate the quadrupoles by beam transport

- **Method: Probe an optics by kicking the beam**
  - Kick the beam → change the angle at the beginning
  - Measure the beam position on screen
  - Get the transfer matrix element by linear fit

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

$$\Rightarrow x_{s_2} = \underbrace{R_{11} \cdot x_{s_1}}_{\text{const.}} + \underbrace{R_{12}}_{\text{slope}} \cdot x'_{s_1}$$

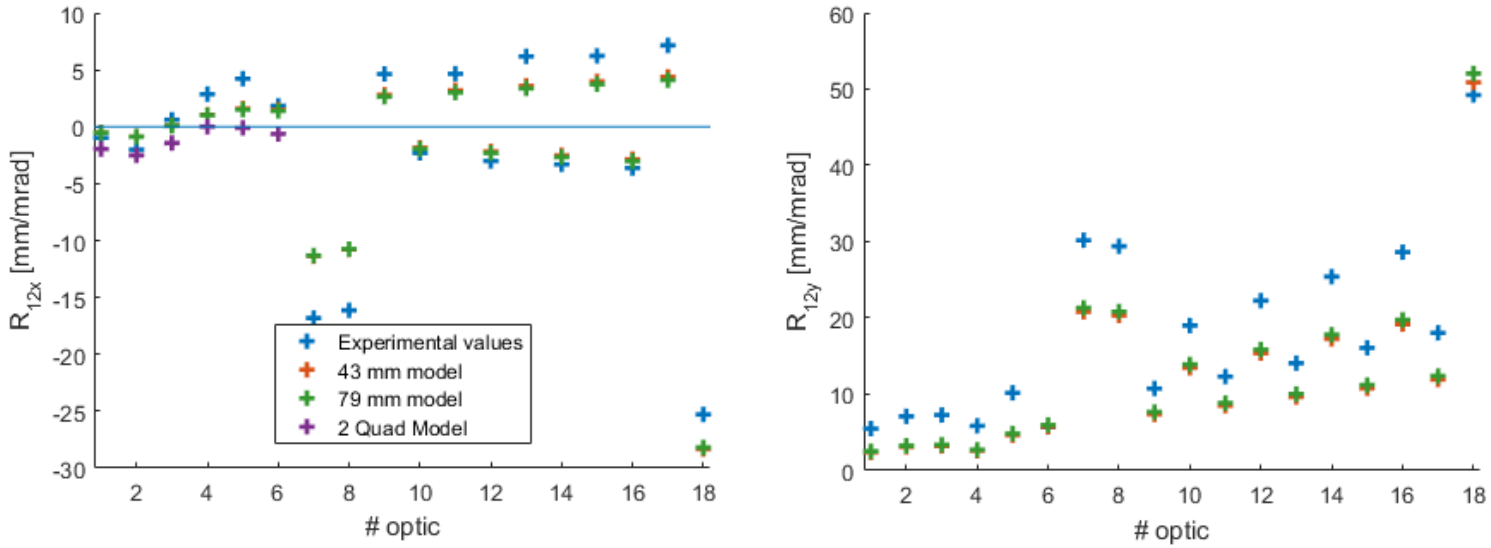


Beam Transport Studies

Calibrate the quadrupoles by beam transport

- **Results: Theoretical and experimental results don't match..**
  - Almost always deviation
  - Experimental values in general bigger than theoretical ones
  - Different quad models yield similar results

	June	Oct
Steerer Magnet	$\frac{dx'}{dI}$ $(\frac{\text{mrad}}{\text{A}})$	
HIGH1.St1	1.39	0.58
HIGH1.StA1	1.11	0.54
HIGH1.St2	-0.47	-0.35
HIGH1.StA2	-1.41	-1.79



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- **Results: Theoretical and experimental results don't match..**
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> **Try the analysis with the old steerer strength**

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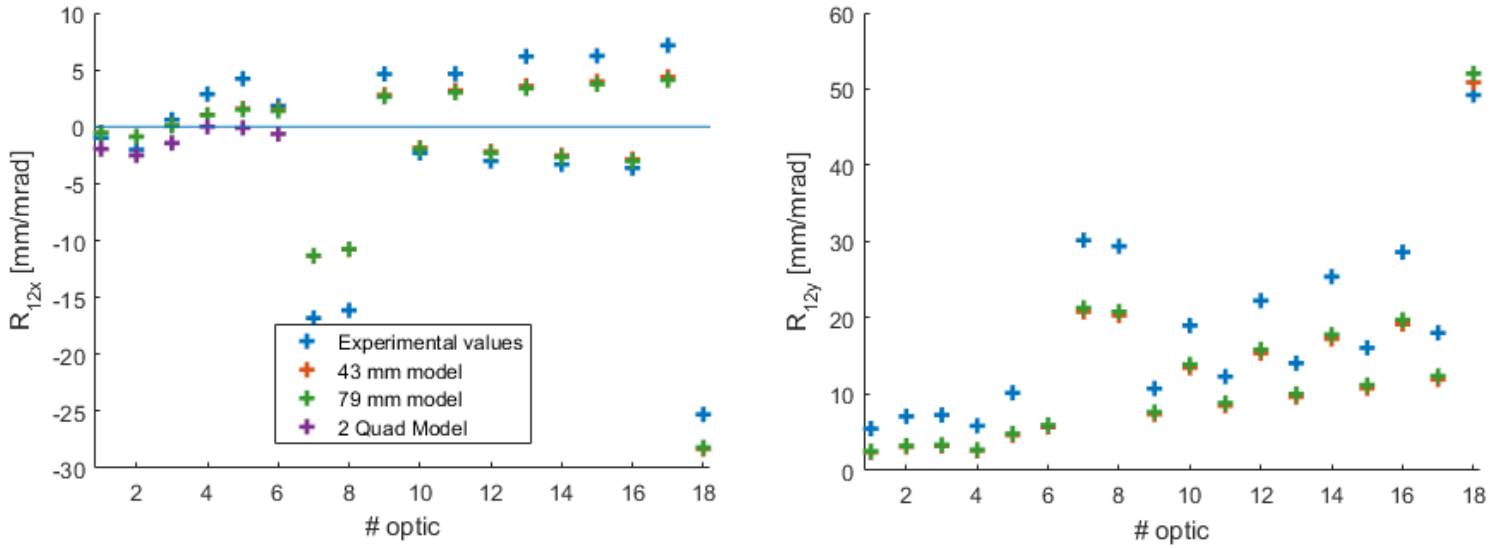

Beam Transport Studies

Use the steerer strength from June

- Much better matching, partially perfect results
- But: Other deviations grew bigger
- Different impact on different planes

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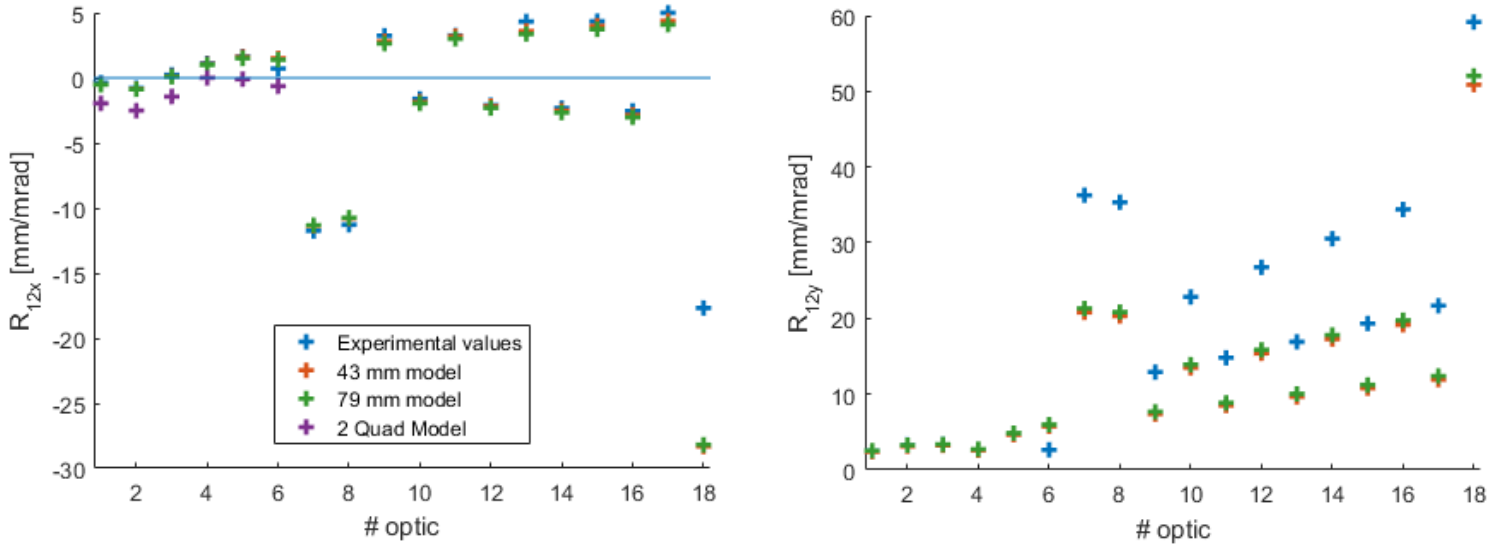

Beam Transport Studies

Use the steerer strength from June

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- But: Other deviations grew bigger
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> **Reason for (obviously) wrong calibration factors?**

- Beam momentum okay (cavity power was checked)
- Other magnets off? (has been considered)

➔**Reason for wrong calibration factors remains unknown**

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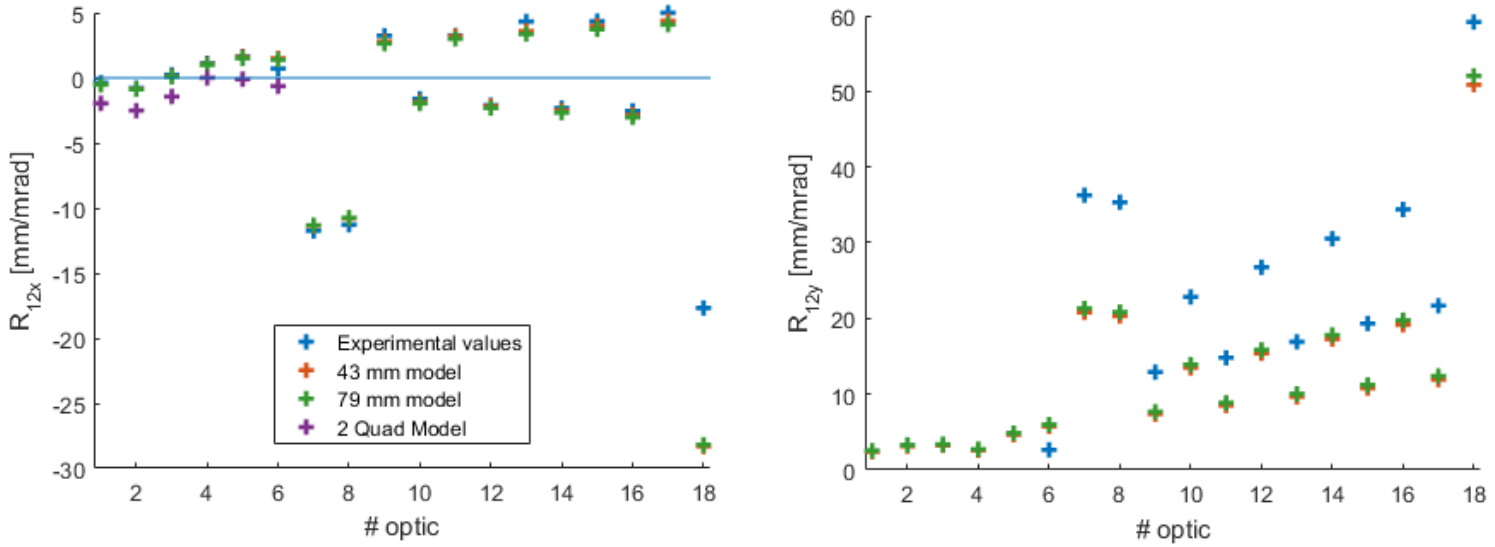

Outlook

Further proceeding, next measurement program

- **Slit-based SLEM**
  - LYSO screens will increase sensitivity
  - Improve tools for **online** slice emittance measurements
- **Quadrupole-scan based SLEM**
  - New calibration of quadrupole and steering magnets (repeat measurement)
  - Robust optics have to be developed (small sensitivity to magnetic errors)

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).

[3] M. Yan et al., *Comparison of quadrupole scan and multi-screen method for the measurement of projected and slice emittance at the SwissFEL injector test facility*, Proceedings of the 36th International Free Electron Laser Conference, Basel, Switzerland, 941 (2014).