Scaling factor for slice emittance

Measurement of the sliced scaling factor by imaging the beam from EMSY1 to PST.Scr1

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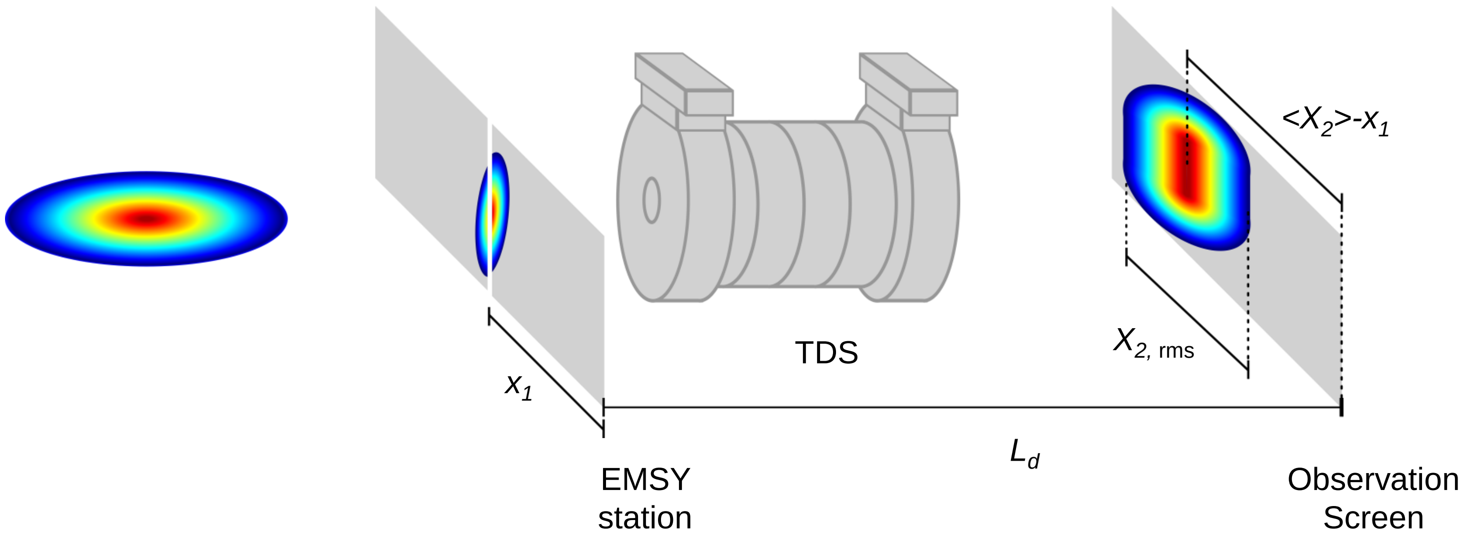
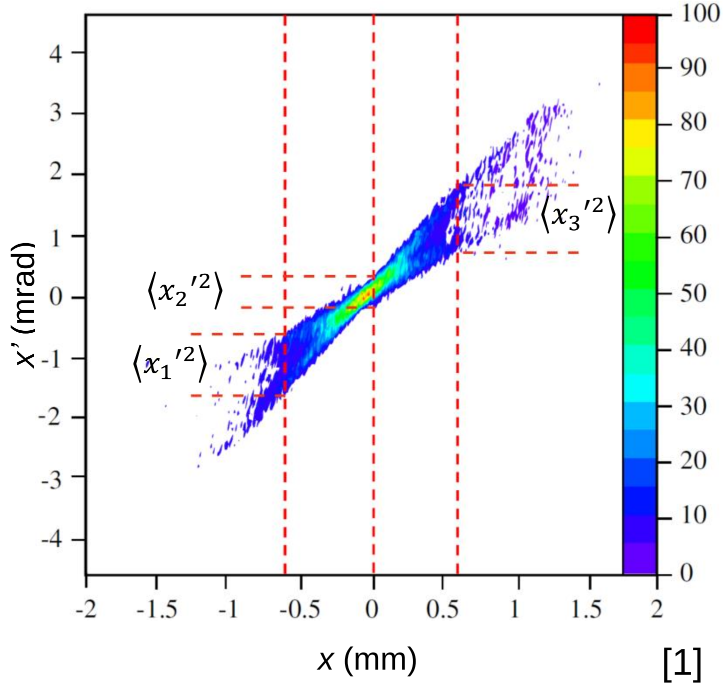
Recap: Slit Scan Method

Slit-Scan-based slice emittance measurements





[1]

- Cut out **emittance-dominated beamlets** from **space charge-dominated beam** with slit
  - Measure **size**, **position** and **intensity** of each beamlet on screen
- Reconstruct phase space at slit position
  - Emittance via $\epsilon = \beta\gamma \frac{\sigma_x}{\sqrt{<x^2>}} \sqrt{\langle {x_0}^2 \rangle \langle {x_0'}^2 \rangle - \langle x_0 x_0' \rangle^2}$

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

Slice emittance with intermediate quadrupoles (Q9/Q10)

Use of quadrupoles before TDS

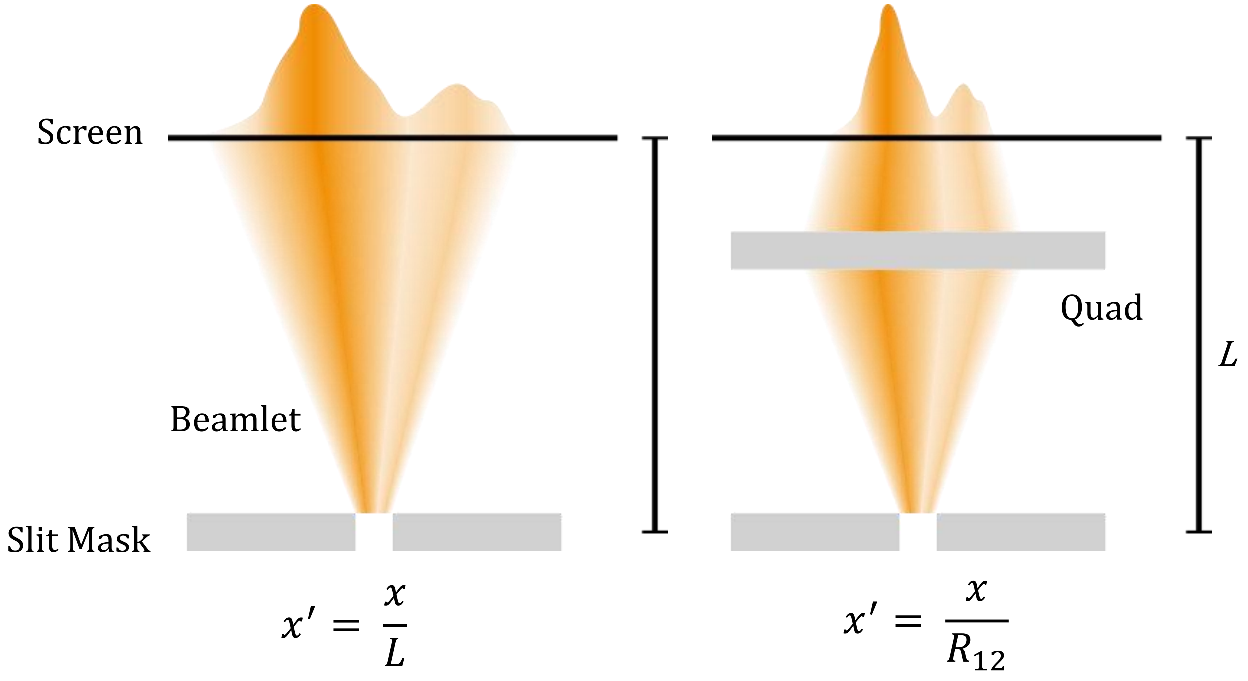
- High1.Q9/Q10 used
  - Higher S2N ratio
  - Better time resolution
- Phase space reconstruction changes

Beamline (z to scale)

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

$$\Rightarrow x_2 = R_{11} \cdot x_1 + R_{12} \cdot x'_1$$

$$\Rightarrow x'_1 = \frac{x_2 - R_{11} x_1}{R_{12}}$$



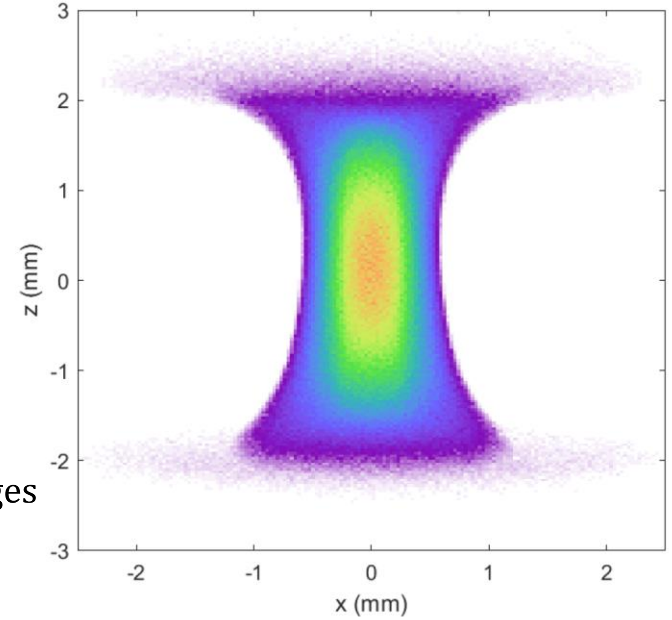
Problem: Missing EMSY-scaling factor

Due to missing time resolution at EMSY 1

- Scaling factor compares EMSY1 beam size & phase space beam size
  - Allows to estimate 100% rms emittance
  - But: EMSY yields only projected beam size
  - Beam size changes along slices
  - → Proj. scaling factor overestimates centre slice emittance

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

Beam size changes along beam



- Idea: Image beam from EMSY1 to PST.Scr1
  - TDS allows measurement of sliced beam size
  - Sliced beam size back calculated with magnification factor
- High1.Q09/Q10 create optics
  - Transfer matrix element R12 must vanish
  - Done experimentally, via optics response measurement
  - R12 = -0.15m

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

$$\Rightarrow x_2 = R_{11} \cdot x_1 + R_{12} \cdot x'_1$$

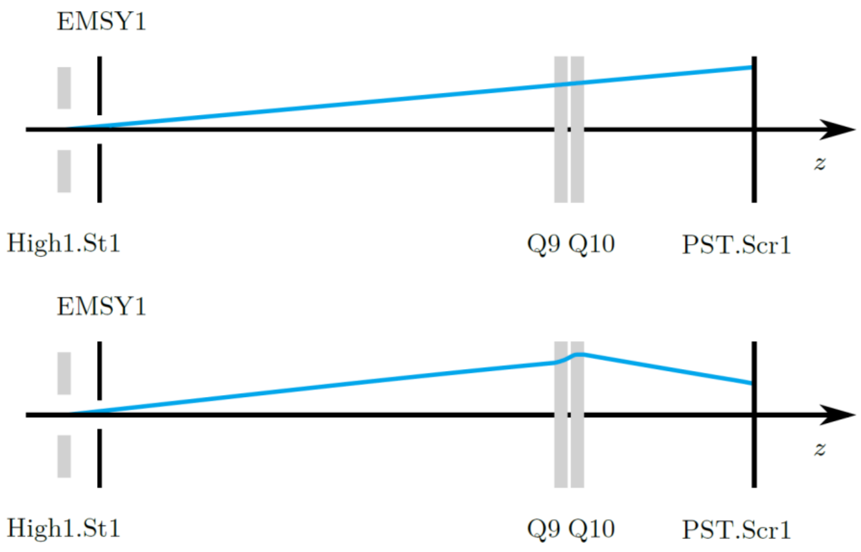
$$\Rightarrow x_1 = \frac{x_2}{R_{11}}$$

Preparation of imaging optics

Minimising transfer matrix element R12 from slit mask to observation screen

- Slice phase space reconstruction utilizes single-lens optics model
  - R11 calculated analytically from (remaining) R12 value
- R12 value determined from High1.St1 to PST.Scr1
  - Must be $R12_{Steerer \rightarrow Screen}$ = -0.15 m
  - Then R12 from slit to screen vanishes
- Applying a thin-lens model of Q09/Q10 allows R11 calculation
  - R11 = -0.394 for vanishing R12
- In experiment
  - R12 = -0.136 m
  - R11 = -0.392

  → Magnification M = 1/R11 = 2.55



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

$$\Rightarrow x_2 = R_{11} \cdot x_1 + R_{12} \cdot x'_1$$

$$\Rightarrow x_1 = \frac{x_2}{R_{11}}$$

Alternative way to determine R11

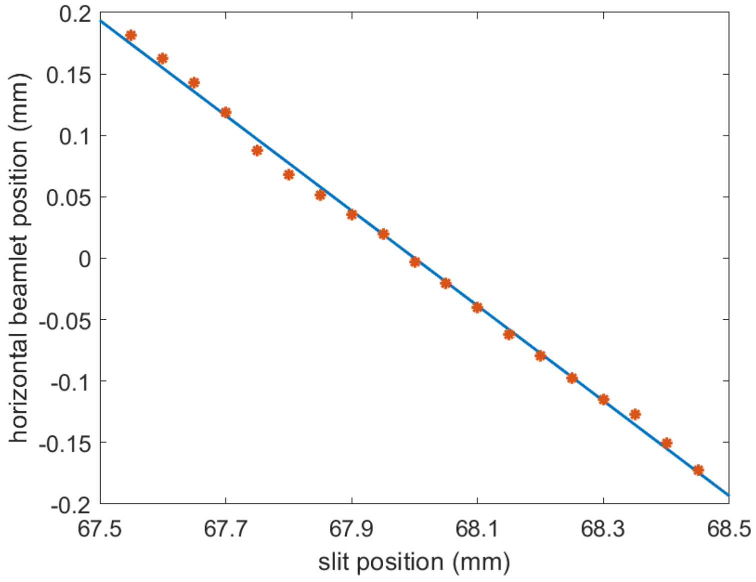
Allows to crosscheck value from single-lens optics model

- Beamlet position x_2 at PST.Scr1 depends linearly on slit position x_1
  - Plot x2 vs x1 (slit position), do linear fit, slope is R11
  - Fit shows good linearity
  - Slope = R11 = -0.387
  - Magnification M = 1/R11 = 2.58
  - Good agreement with thin-lens model

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

$$\Rightarrow x_2 = R_{11} \cdot x_1 + R_{12} \cdot x'_1$$

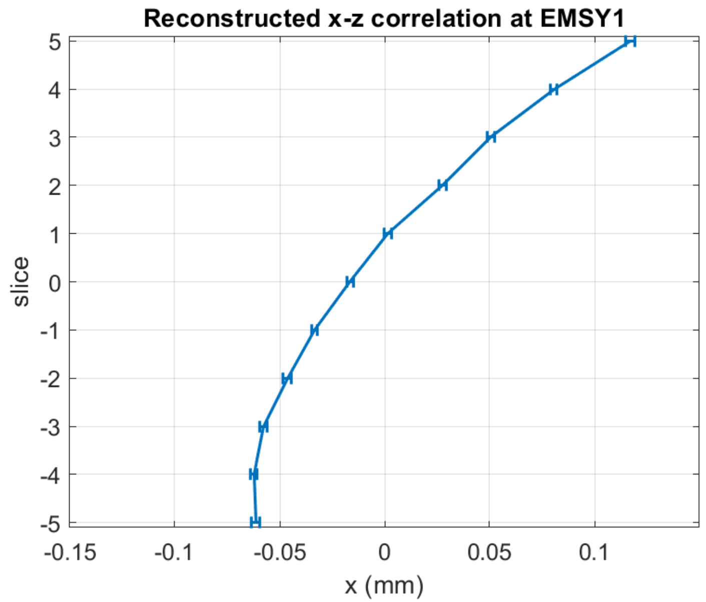
$$\Rightarrow x_2 = R_{11} x_1$$



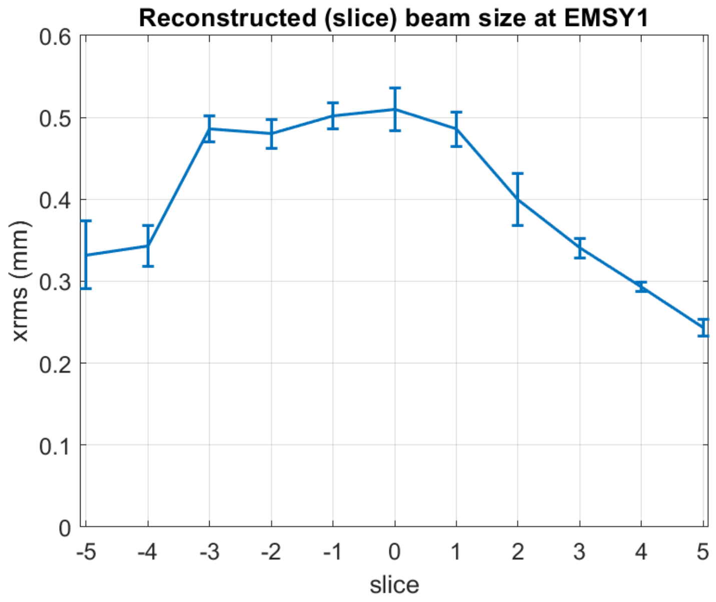
Calculation of slice beam size

Needed to determine EMSY scaling factor

- Slit scanned for optics R12 = 0
  - Removing space charge force
- Beamlets reassembled to beam at PST.Scr1
  - Allows to plot x-z correlation of beam



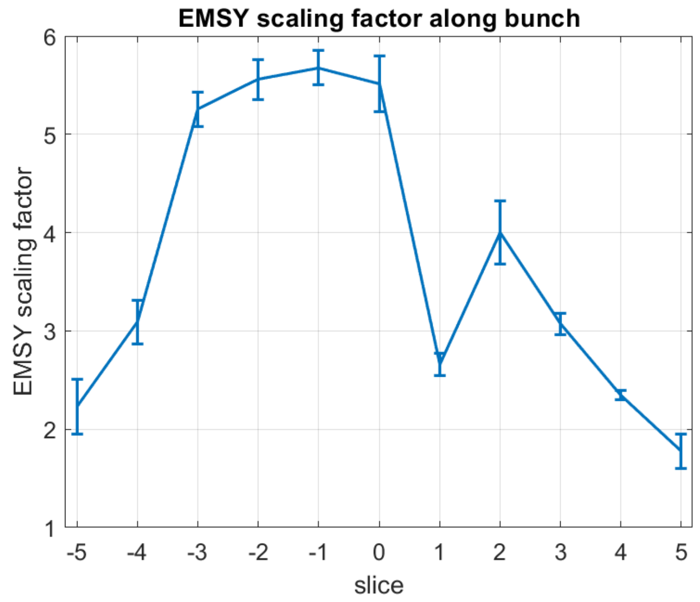
  - Calculation of sliced, horizontal beam size @ PST.Scr1
  - Magnification to get beam size @ EMSY1



Slice EMSY-scaling factor

Allows calculation of scaled slice emittance

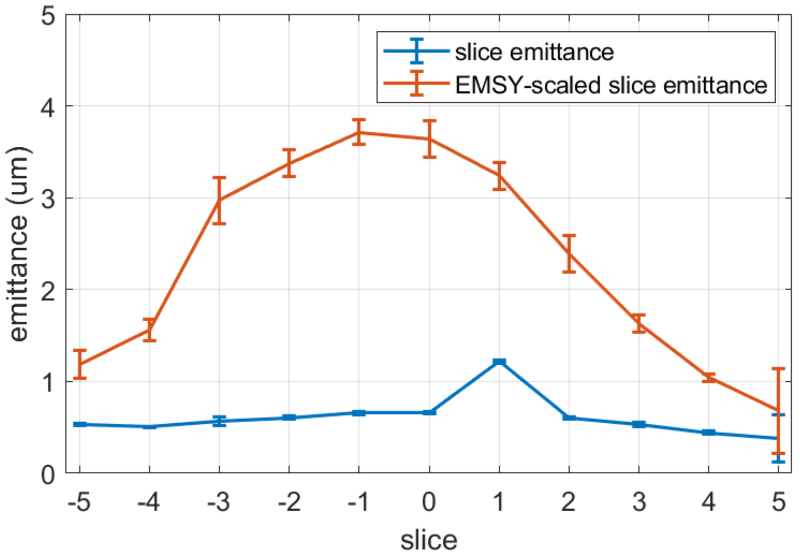
- EMSY scaling factor for each slice
- Slice #1 has small scaling factor
  - Due to screen defect, slice phase space is wider
  - Smaller scaling factor



- Slice emittance and scaled slice emittance plotted
- Slice #1: Increased slice emittance, due screen defect

- Projected scaling factor = 1.08

→ EMSY-scaled slice emittance far too high



Summary & Outlook

Future prospect of scaling factor for slice emittance

- Measured time-resolved EMSY scaling factor
- Far bigger than projected scaling factor
  - Beam transport linear in *x*, i.e. model justified
- High1.Q09/Q10 offer little flexibility in optics choice
  - Sophisticated optics allow other magnifications
  - Current magnification: Small spatial resolution at PST.Scr1
    - Beam size only 2 to 4 pixel on PST
    - Most probable error source