Analysis of slice emittance measurements

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> Presenting Methodology studies of slit-based slice emittance measurements

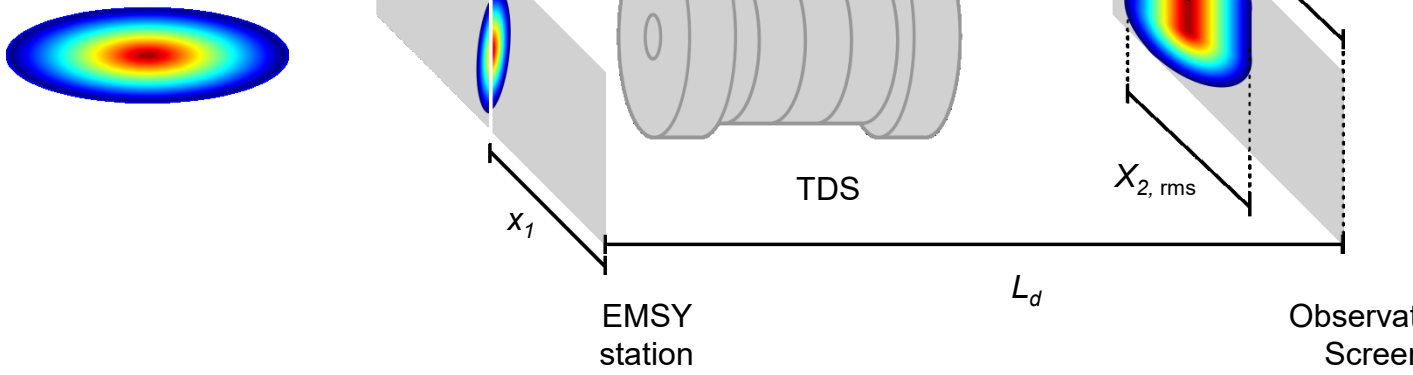
Methodology studies

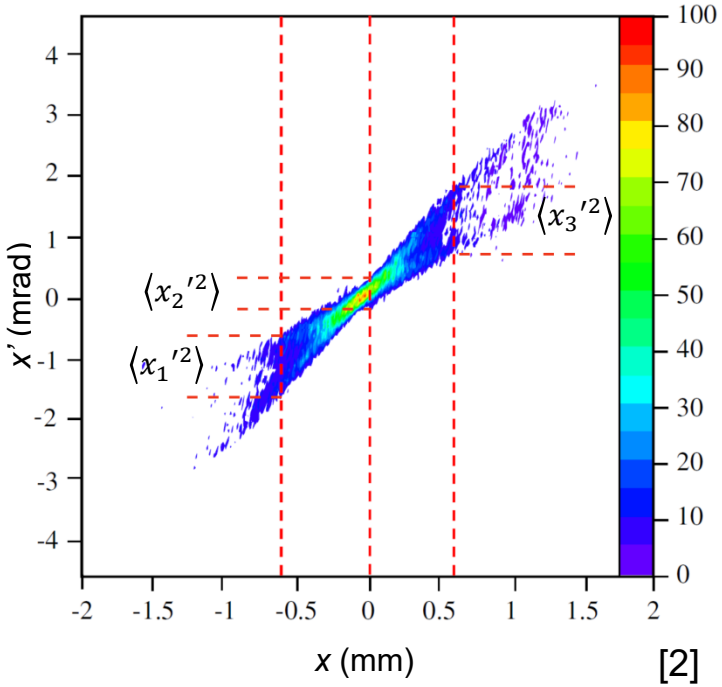
Methodology studies of slit-based slice emittance measurements

- Here presented:
  - Slice emittance measurements – changing number of bunches when intensity drops
  - Slice emittance measurements with High1.Q9 and High1.Q10
    - Quadrupoles **behind** slit mask (intermediate quadrupoles for focussing)

Recap: Slit Scan Method

Slit-Scan-based slice emittance measurements





[2]

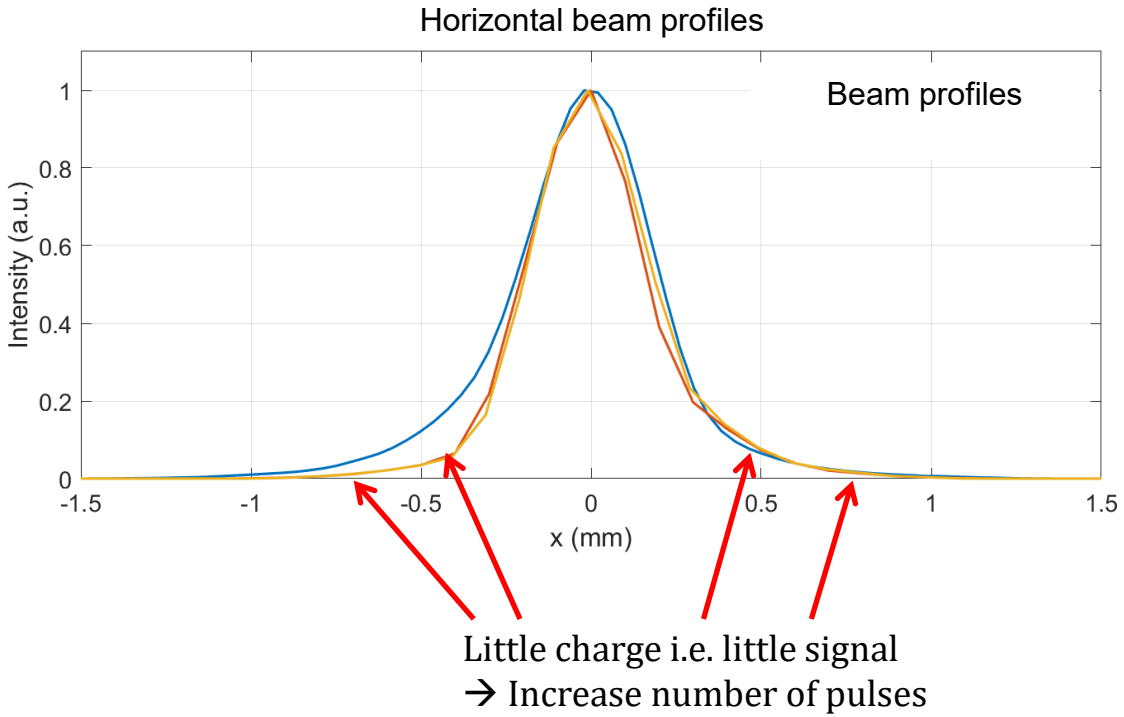
- Cut out **emittance-dominated beamlets** from **space charge-dominated beam** with slit
  - Measure **size**, **position** and **intensity** of each beamlet on screen
- Reconstruct phase space at slit position
  - Emittance via $\epsilon = \beta\gamma \frac{\sigma_x}{\sqrt{<x^2>}} \sqrt{\langle x_0{}^2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

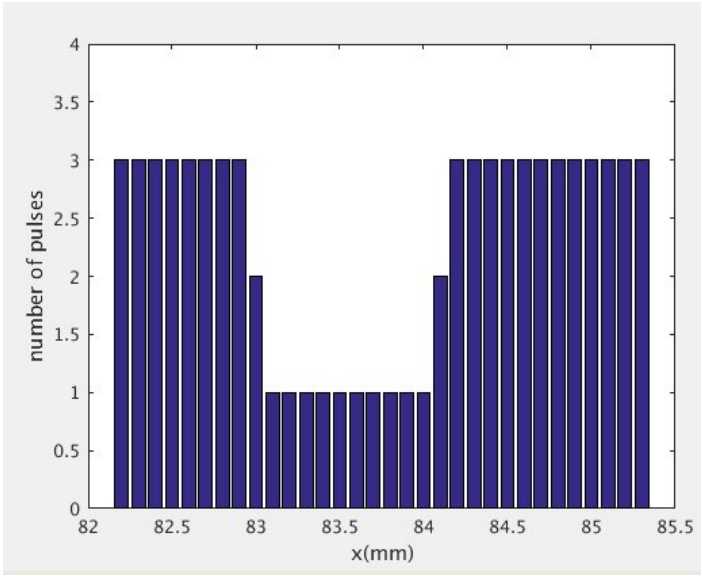
[2] S. Rimjaem et al., Nucl. Instr. Meth. Phys. Res. A **671**, 62 – 75 (2012).

Slice emittance versus pulse number

Measured on 2019-04-11

- Outer beamlets (slit positions) have low signal (signal from beam halo), see left
- Idea: Increase number of pulses for these beamlets, see right
- Result: high signal-to-noise ratio **in both core and tails**

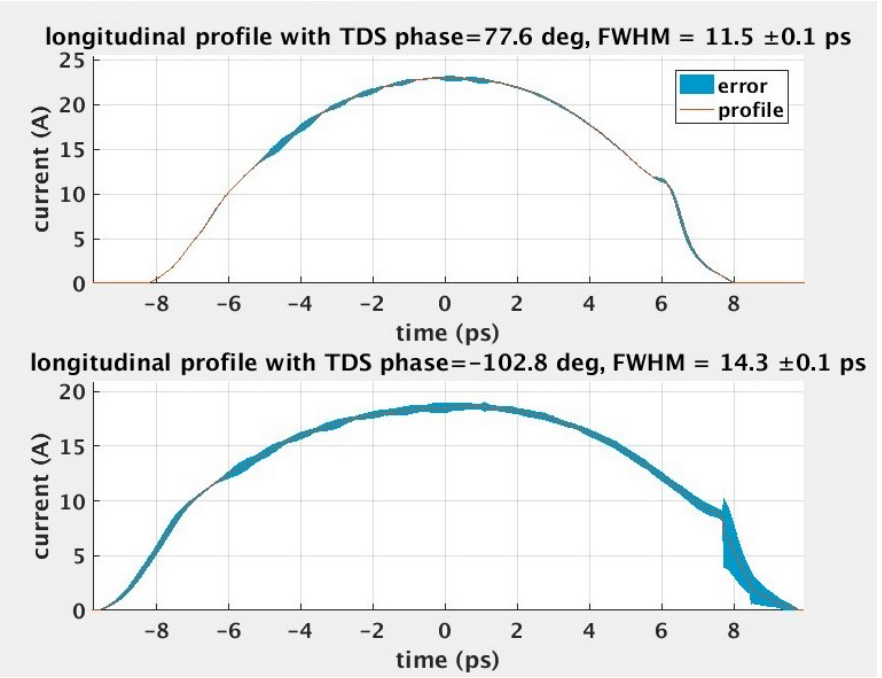




Slice emittance versus number of pulses

Measured on 2019-04-11

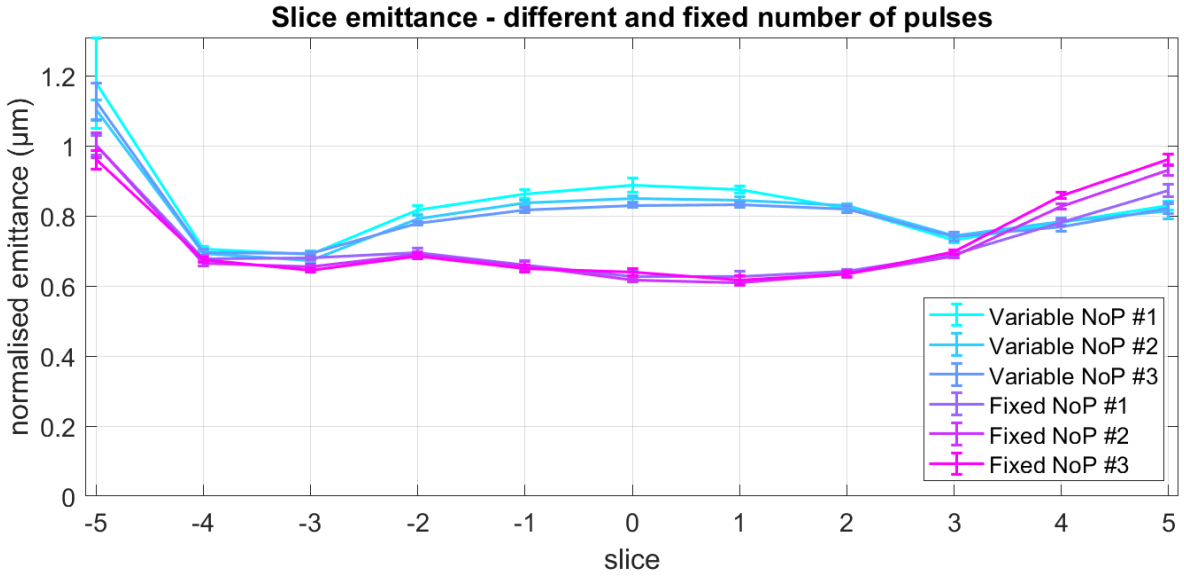
- BSA = 0.9 mm
- Q = 250 pC (LT = 21%)
- Imain = 370 A
- Gun quads set
- pGun = 6.3 MeV/*c* (MMMG phase)
- pBoo = 18.8 MeV/*c*
- TDS: 12.97 ps FWHM bunch length
- Done @ EMSY2
  - High1.Q5 and High1.Q6 used
  - Slit spacing = 100 um
  - Slit width = 50 um
  - 32 slit positions



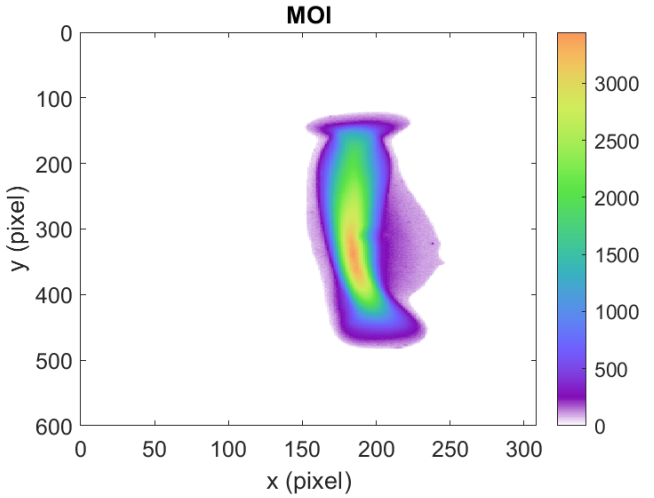
Slice emittance versus number of pulses: Beam #1

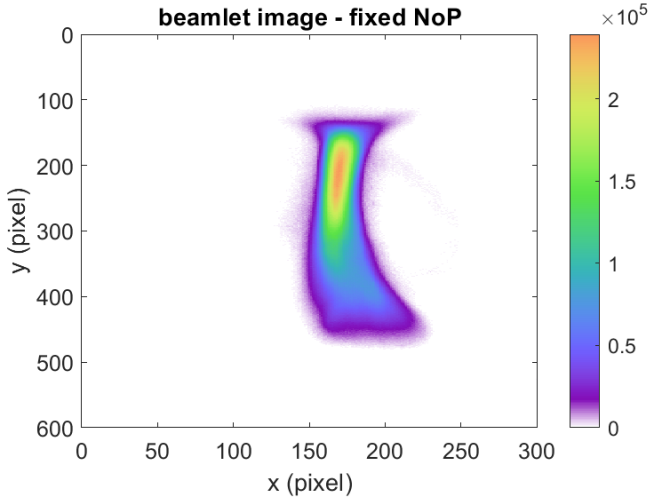
Measured on 2019-04-11

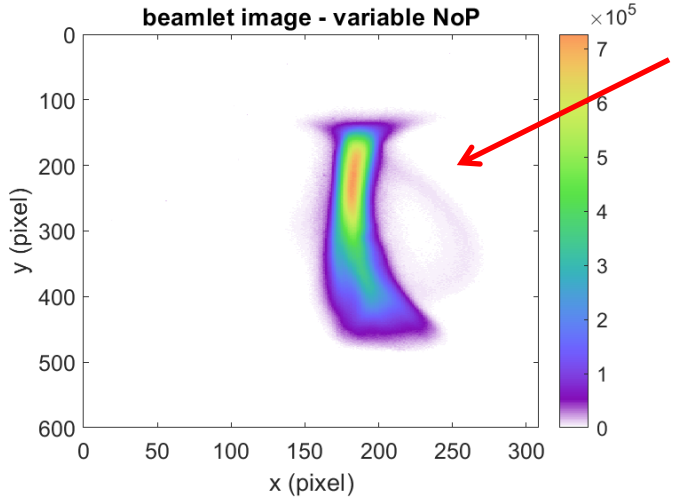
- Measured slice emittance with variable and fixed number of pulses
- Each measurement three times, for additional statistics



All beamlets:
- Filtered
- Summed up







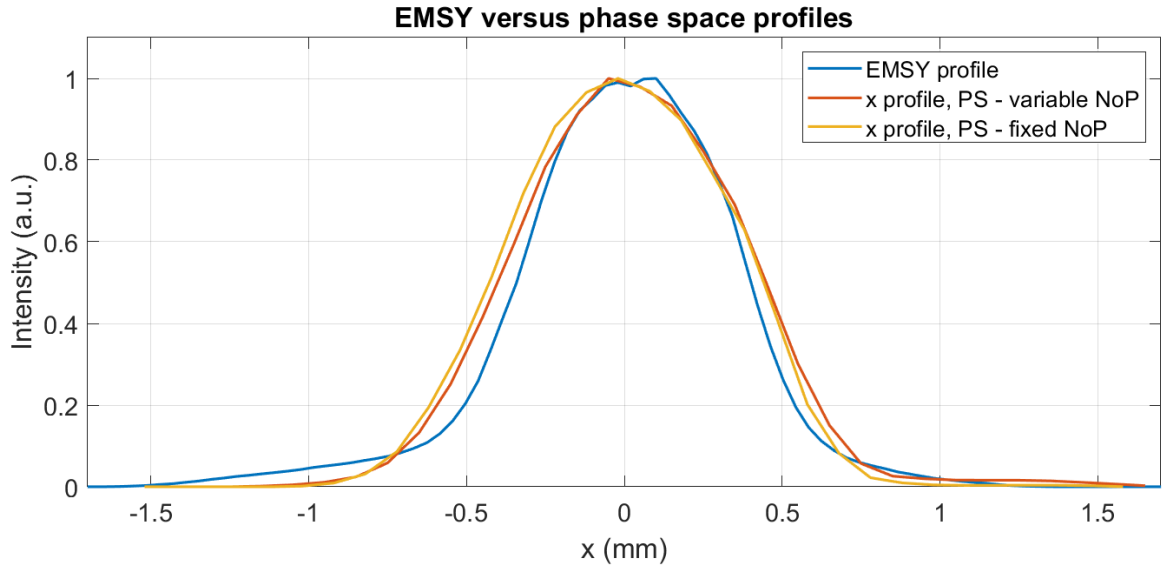
More beam is visible:
→ Higher emittance
However, not observed in MOI Image

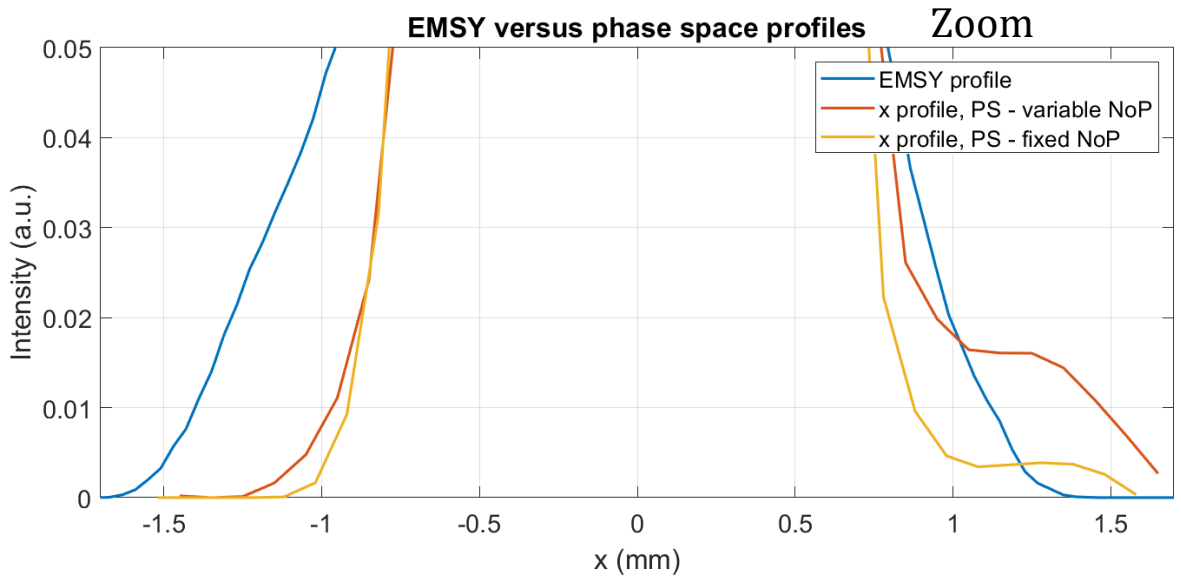
Slice emittance versus number of pulses: Beam #1

Measured on 2019-04-11

- EMSY Profile (blue)
- Horizontal projection of phase space
  - Variable pulse number (orange)
  - Fixed pulse number (yellow)

- All profiles normalised to 1
- Shifted left/right for optimum overlap

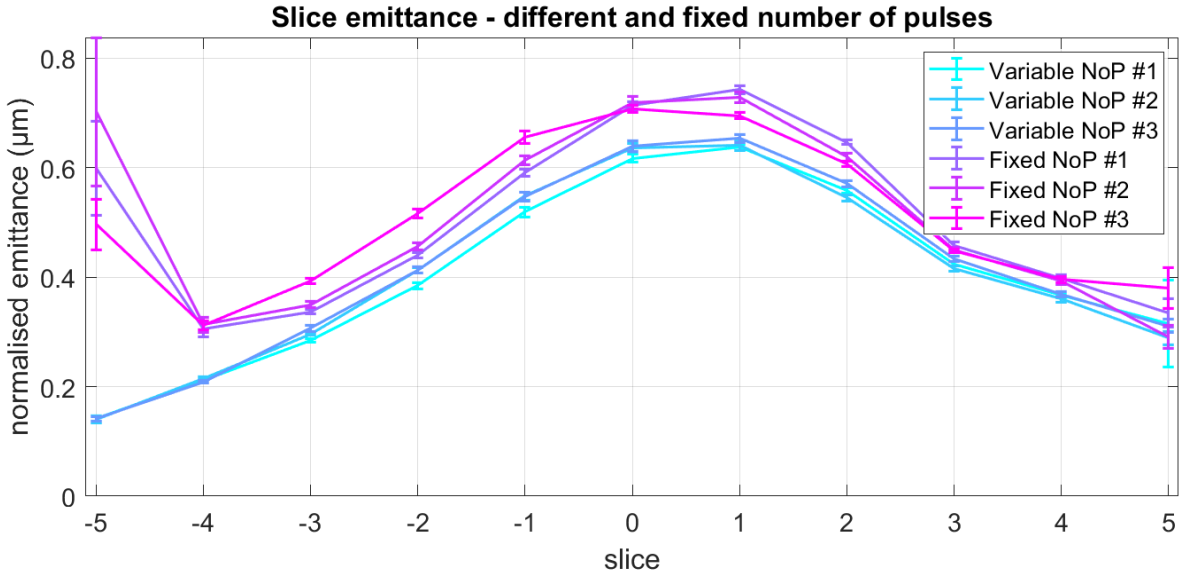




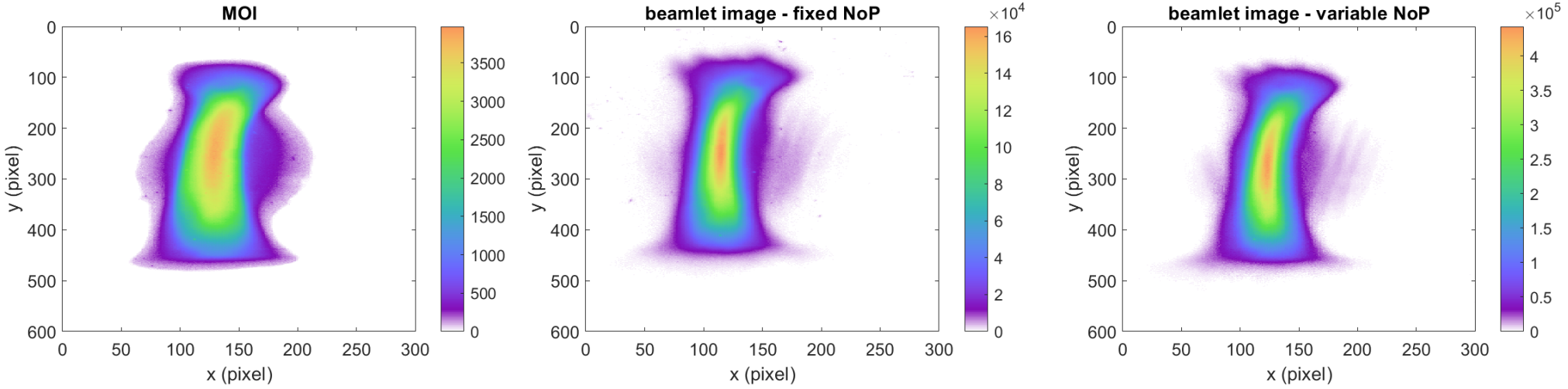
Slice emittance versus number of pulses: Beam #2

Measured on 2019-04-14

- Slightly varying injector
  - **Imain = 367 A**
  - **Q = 300 pC**



All beamlets:
- Filtered
- Summed up



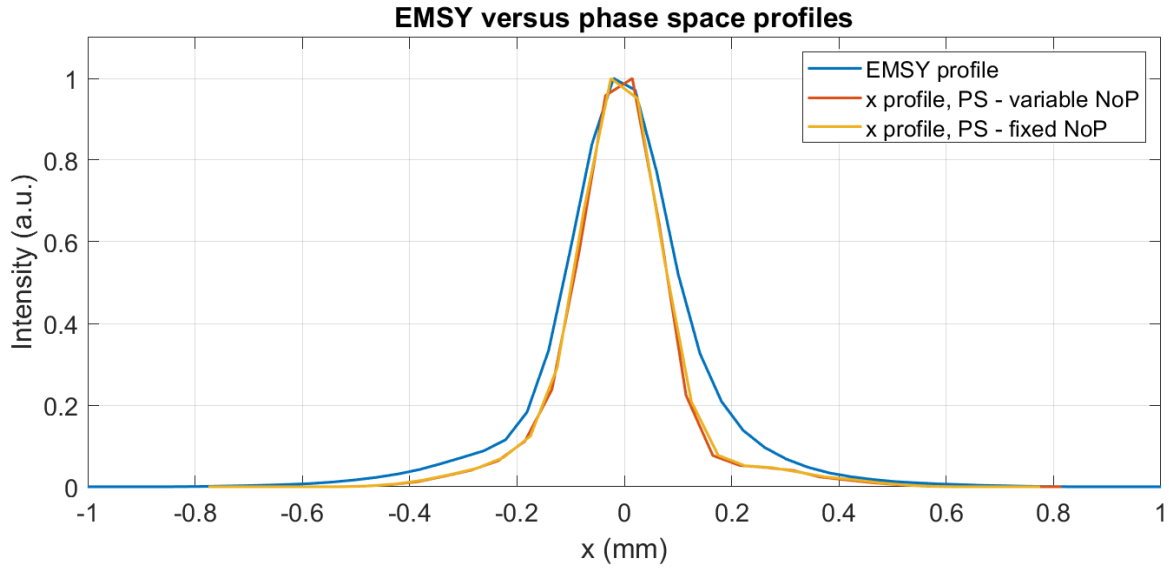
Here: Changing NoP yields smaller signal
→ Smaller emittance

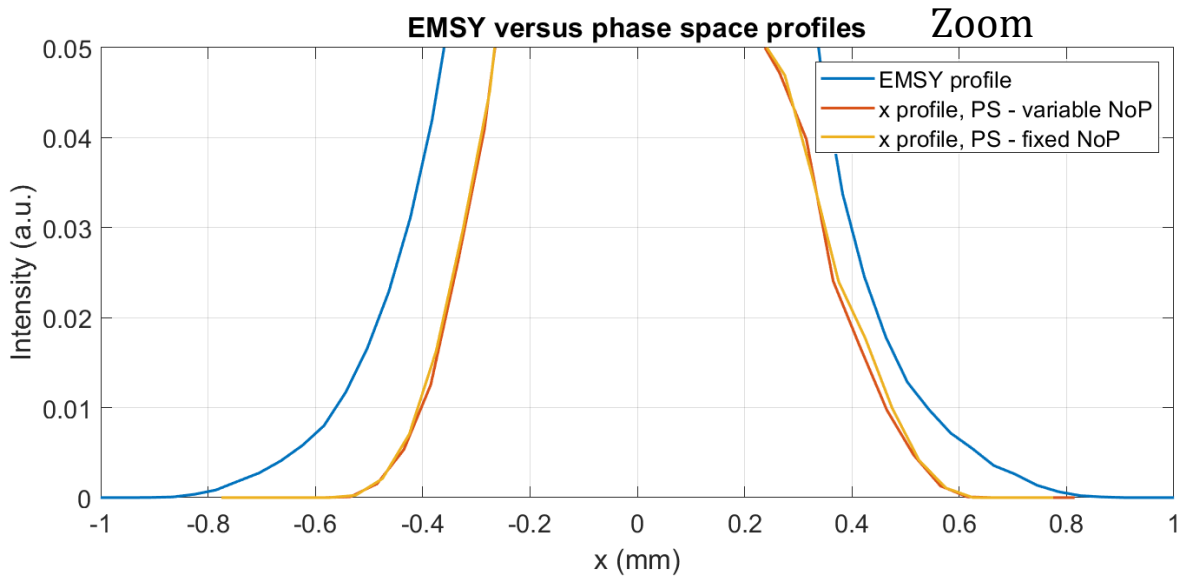
Slice emittance versus number of pulses: Beam #2

Measured on 2019-04-14

- EMSY Profile (blue)
- Horizontal projection of phase space
  - Variable pulse number (orange)
  - Fixed pulse number (yellow)

- All profiles normalised to 1
- Shifted left/right for optimum overlap

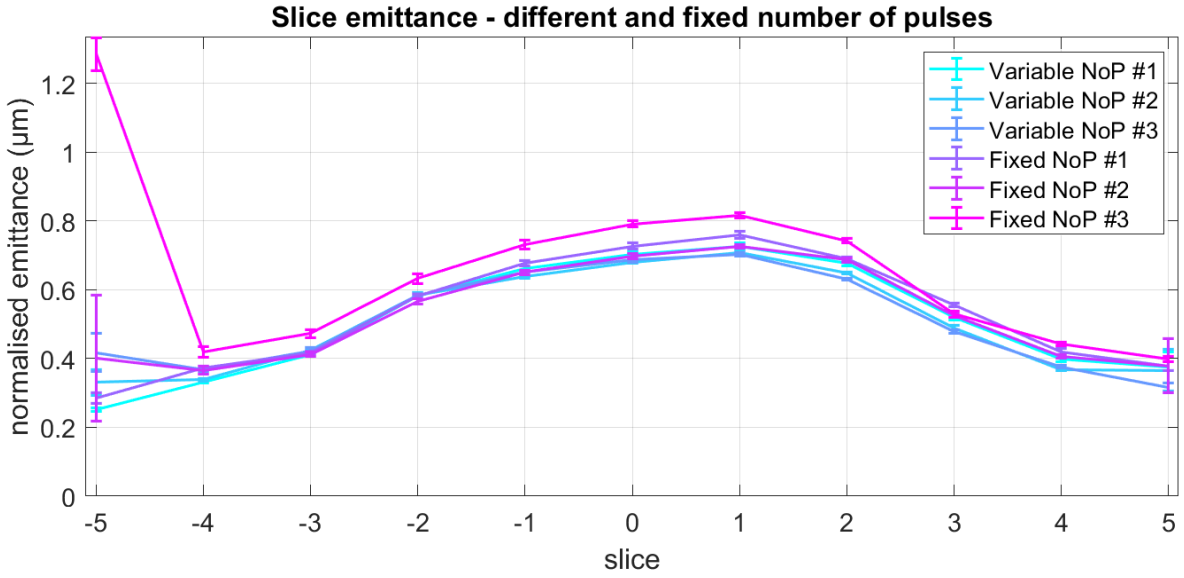




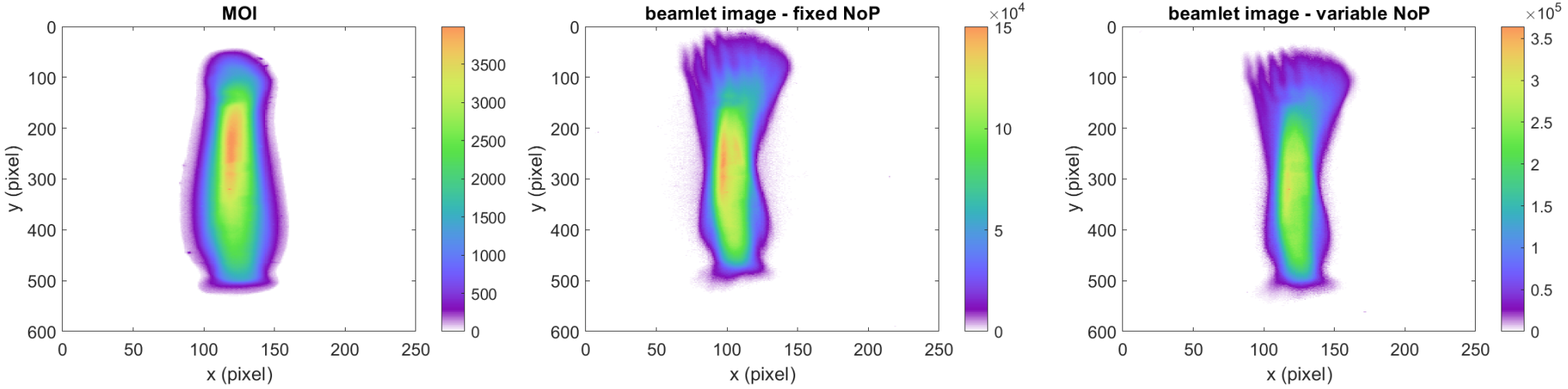
Slice emittance versus number of pulses: Beam #3

Measured on 2019-04-14

- Further varying injector
  - **Imain = 370 A**
  - **Q = 400 pC**



All beamlets:
- Filtered
- Summed up



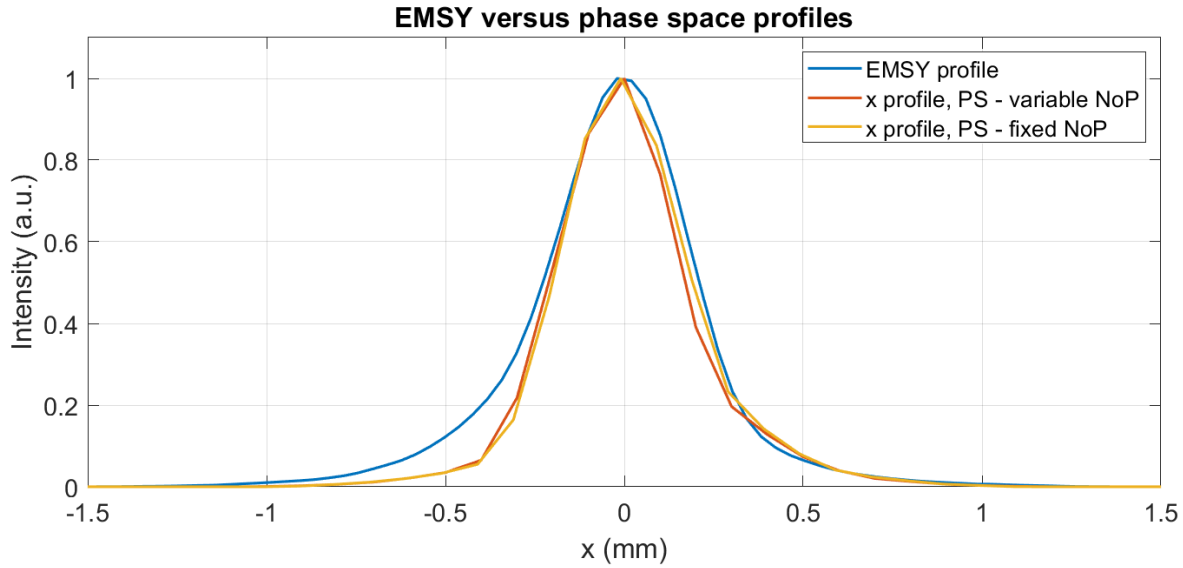
Here: Minor differences in beamlet image: Emittance ~ same

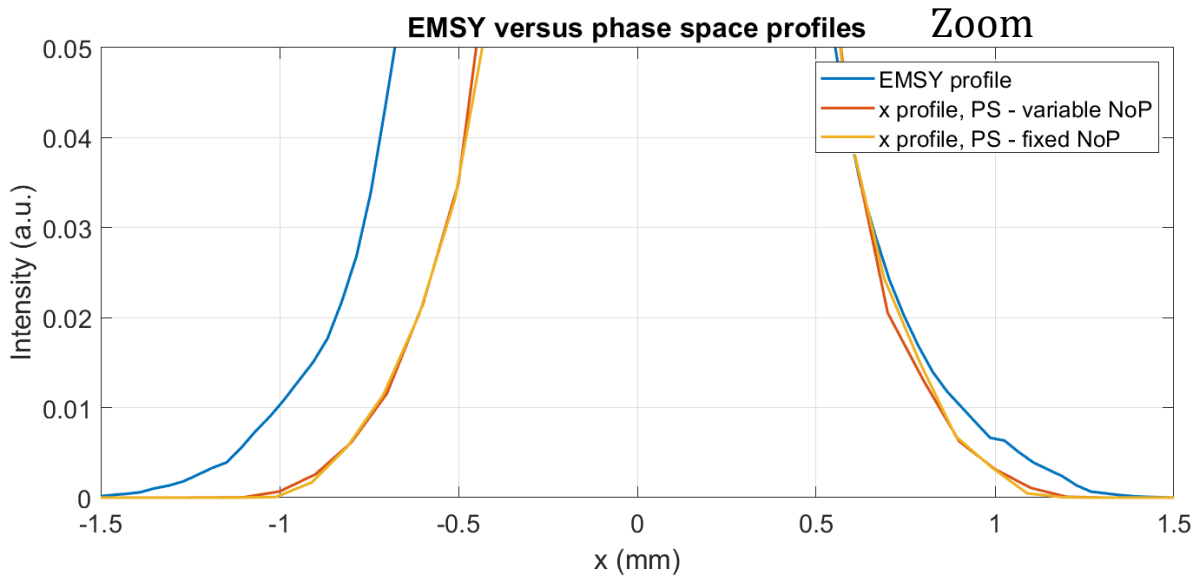
Slice emittance versus number of pulses: Beam #3

Measured on 2019-04-14

- EMSY Profile (blue)
- Horizontal projection of phase space
  - Variable pulse number (orange)
  - Fixed pulse number (yellow)

- All profiles normalised to 1
- Shifted left/right for optimum overlap





Slice emittance versus number of pulses

Increased number of pulses for higher signal to noise ratio

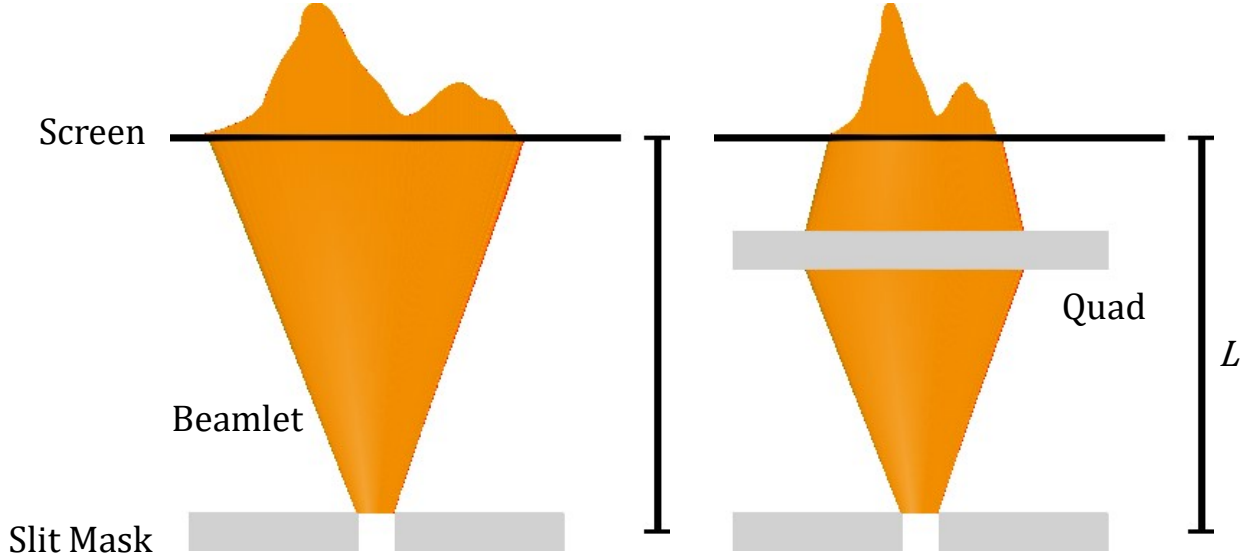
- Change of number: No systematic change in emittance results visible
  - Once emittance was higher, once same, once even lower
- We keep standard version: Fixed number of pulses (as in fastscan)

Slice emittance with intermediate quadrupoles (Q9/Q10)

Use of quadrupoles at different positions

- Conventional setup:
  - High1.Q1/High1.Q2 used
  - Drift from EMSY1 -> PST.Scr1
  - Simple PS reconstruction
- New setup:
  - No quads before slit used
  - Measurement EMSY1->PST.Scr1
  - High1.Q9/Q10 used
    - Higher S2N ratio
    - Better time resolution
  - **Phase space reconstruction changes**

Beamline (z to scale)



$$x' = \frac{x}{L} \qquad x' = \frac{x}{R_{12}}$$

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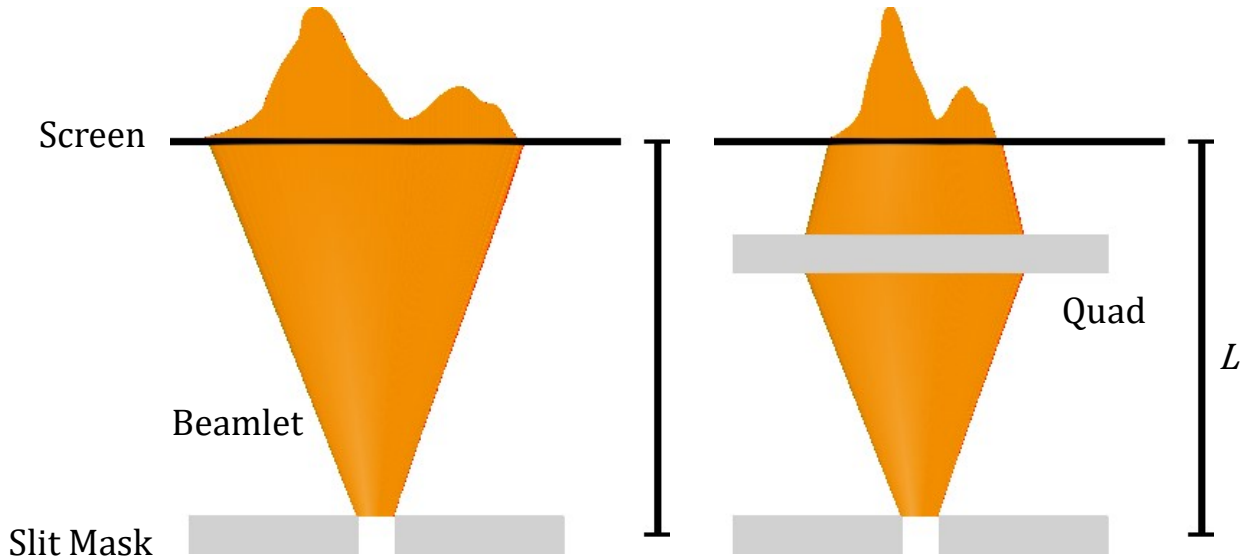


$$x' = \frac{x}{L} \qquad x' = \frac{x}{R_{12}}$$

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

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

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

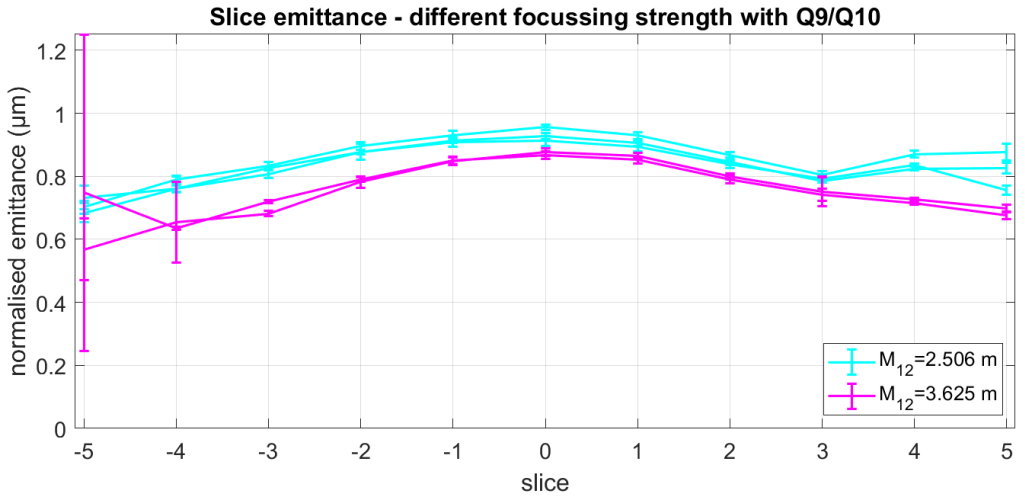
Experimentally determined

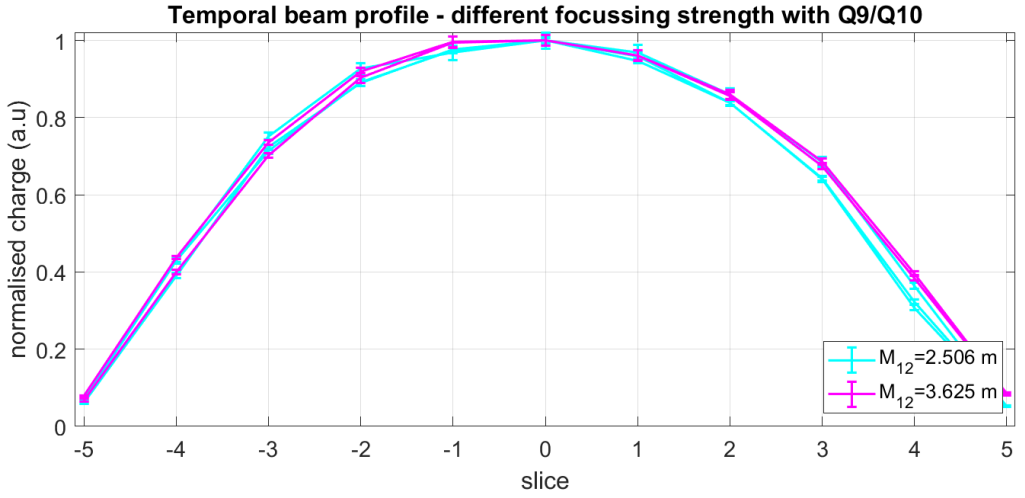
Slice emittance with intermediate quadrupoles (Q9/Q10)

First test with quadrupoles behind slit on 2019-05-10

- Comparison of slice emittance measurements
  - Different Q9/Q10 settings
  - R_11 and R_12 determined from quadrupole calibration
- Q = 250 pC
- BSA = 1.0 mm
- pGun = 6.3 MeV/c
- pBooster = 19.8 MeV/c
- Imain = 370 A
- (Slice) emittance difference for different optics: ~10%

- Here: (Slice) emittance high
  - Bucking solenoid was off





Slice emittance with intermediate quadrupoles (Q9/Q10)

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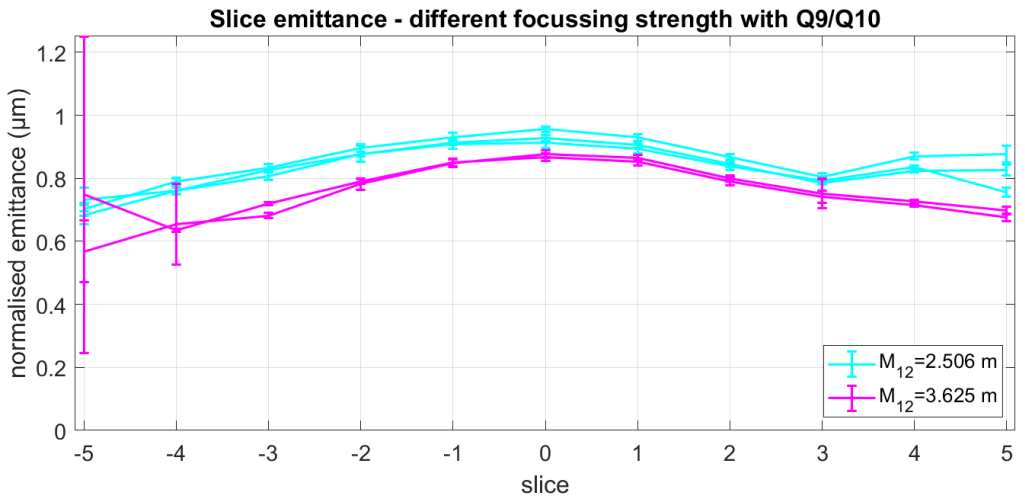
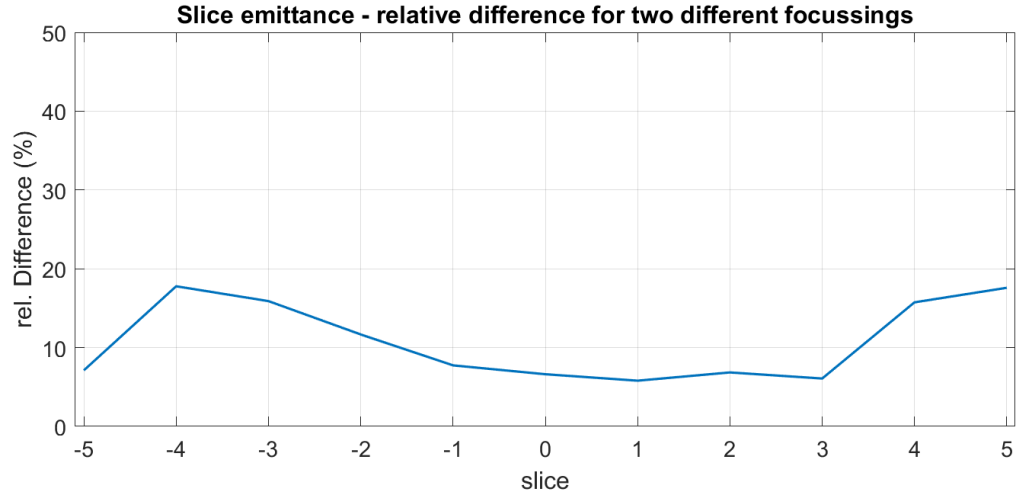
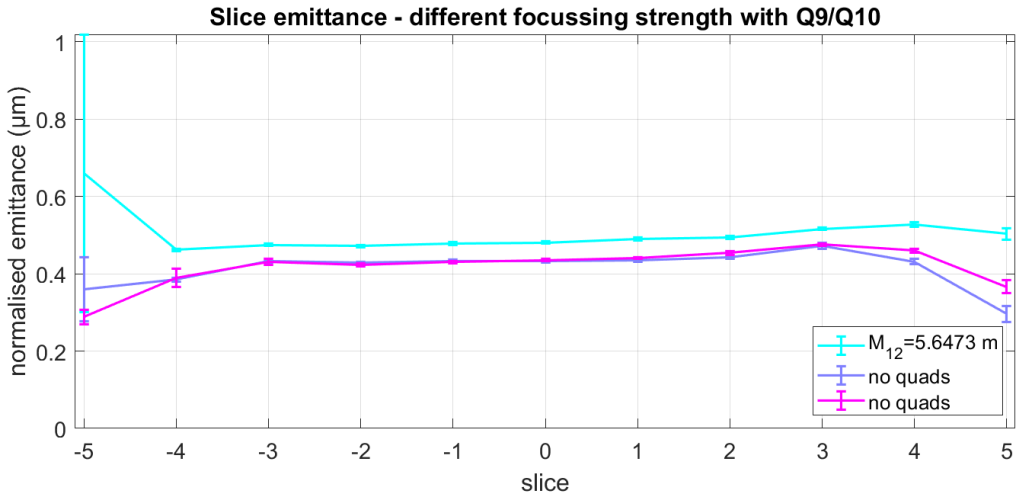




Slice emittance with intermediate quadrupoles (Q9/Q10)

Comparison of different settings – 2019-05-12

- Comparison of
  - Slice emittance for different optics (right)
  - Projected emittance for
    - TDS on/off
    - Different optics
    - Fastscan/SlitScanner.m



- Q = 250 pC, BSA = 1.0 mm
- pGun = 6.3 MeV/c
- pBooster = 19.8 MeV/c
- Imain = 370 A, bucking solenoid on

Results shown in paper

Slice emittance with intermediate quadrupoles (Q9/Q10)

Comparison of different settings – 2019-05-12

- Comparison of different settings
- In EmCalc, phase space reconstructed assuming pure drift

TDS	Quads		SlitScanner.m	Fastscan	
				nonscaled	scaled
On	On	R_12 = Drift	0.51	0.49	0.51
	Off				
off	On	R_12 = Drift	0.54	0.52	0.53
	off				

Assuming drift from EMSY to PST.Scr1

In SlitScanner.m, reconstruction can consider different optics

Slice emittance with intermediate quadrupoles (Q9/Q10)

Comparison of different settings – 2019-05-12

- Comparison of different settings
- In EmCalc, phase space reconstructed assuming pure drift
- Emittance values match ✓

TDS	Quads		SlitScanner.m	Fastscan	
				nonscaled	scaled
On	On	R_12 = Drift	0.51	0.49	0.51
		Optics corrected	0.66		
	Off				
off	On	R_12 = Drift	0.54	0.52	0.53
		Optics corrected	0.71		
	off				

Assuming drift from EMSY to PST.Scr1

In SlitScanner.m, reconstruction can consider different optics

Slice emittance with intermediate quadrupoles (Q9/Q10)

Comparison of different settings – 2019-05-12

- Comparison of different settings
- In EmCalc, phase space reconstructed assuming pure drift
- Emittance values match ✓

TDS	Quads		SlitScanner.m	Fastscan	
				nonscaled	scaled
On	On	R_12 = Drift	0.51	0.49	0.51
		Optics corrected	0.66		
	Off		0.57	0.52	0.57
off	On	R_12 = Drift	0.54	0.52	0.53
		Optics corrected	0.71		
	off		0.78	0.68	0.68

Assuming drift from EMSY to PST.Scr1

In SlitScanner.m, reconstruction can consider different optics

For comparison

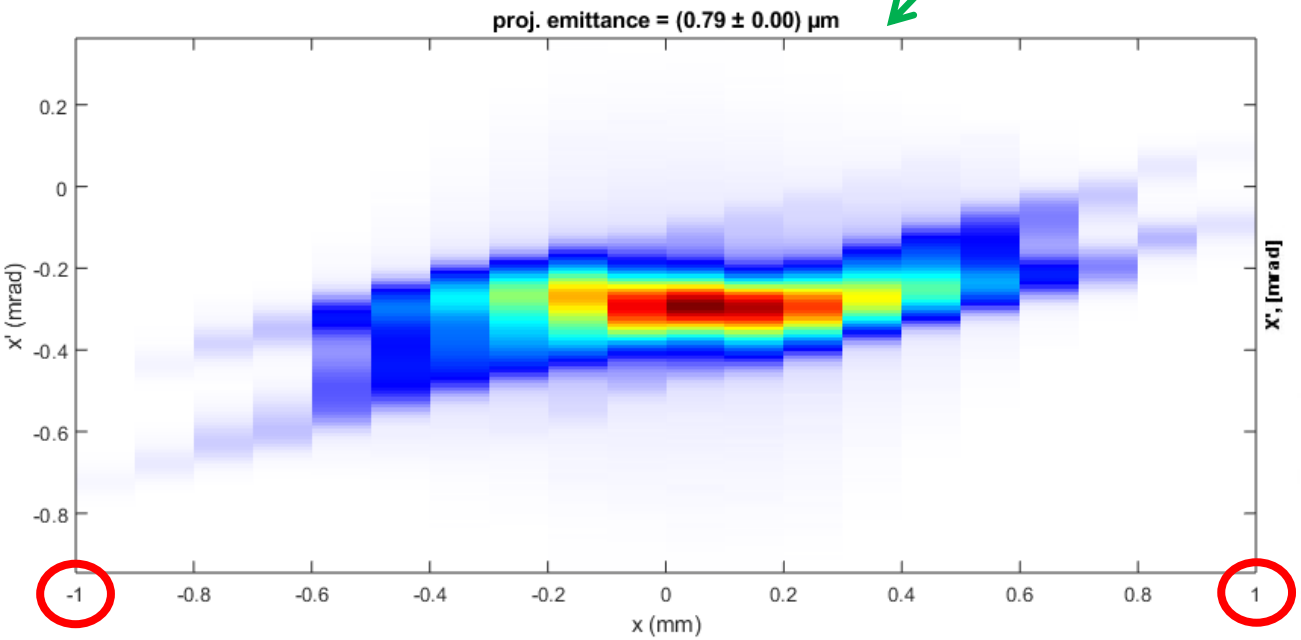
Slice emittance with intermediate quadrupoles (Q9/Q10)

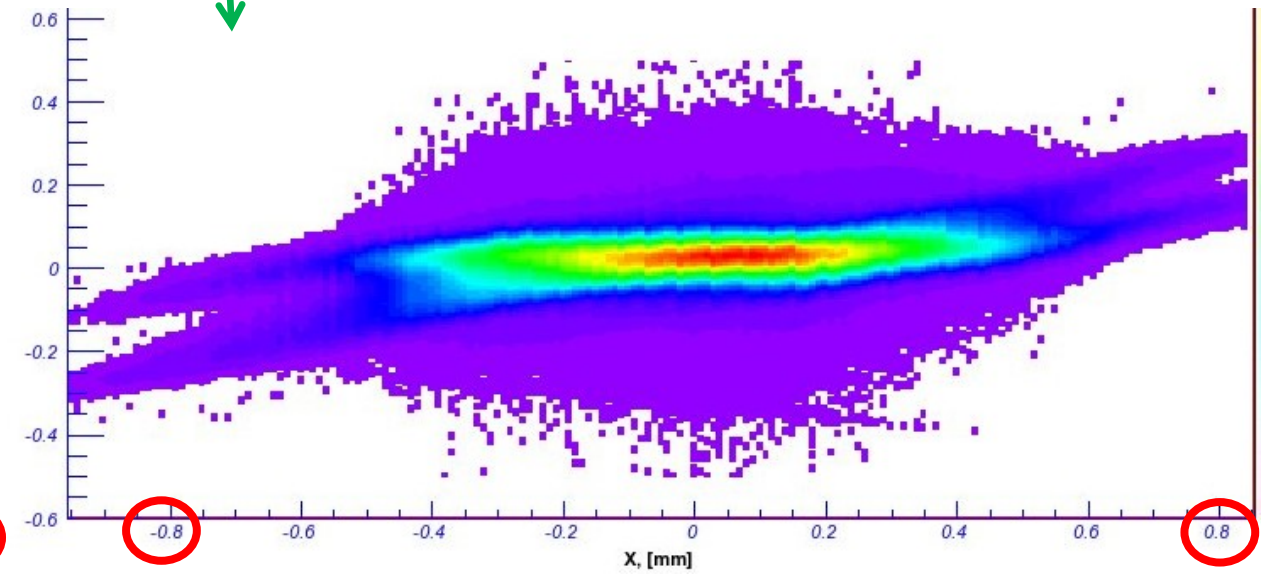
Comparison of different settings – 2019-05-12

> Let's look at last setting (TDS & Quads off)

TDS	Quads	SlitScanner.m	Fastscan	
			nonscaled	scaled
off	off	0.78	0.68	0.68

Beam looks narrower for Fastscan – different emittance results make sense





Outlook

Summary and Outlook

- **Methodology studies almost finished**
  - Change of number of pulses for higher SNR – not useful
  - Use of intermediate quadrupole magnets – increase of SNR, easier beam transport, higher time resolution possible
  - Systematic change of optics (intermediate quadrupoles) scheduled
    - Best optics to be identified
- **Improvement of PST.Scr1 btm (LYSO) done**
  - Moved camera closer to screen (higher light yield)
- **Slice emittance scans start soon**
  - Solenoid scans for slice emittance
    - Different BSA's, to find injector optimum for slice emittance
    - Compare long gaussian with flattop beam
    - At least one charge (e.g. 250 pC), XFEL working point
  - Estimation of systematic measurement error postponed
  - Detailed beam dynamics studies for measurement cases postponed