Slice emittance measurement methodology study

Scan of focusing strength (High1.Q09 & Q10, thus R12) to find optimum measurement setting

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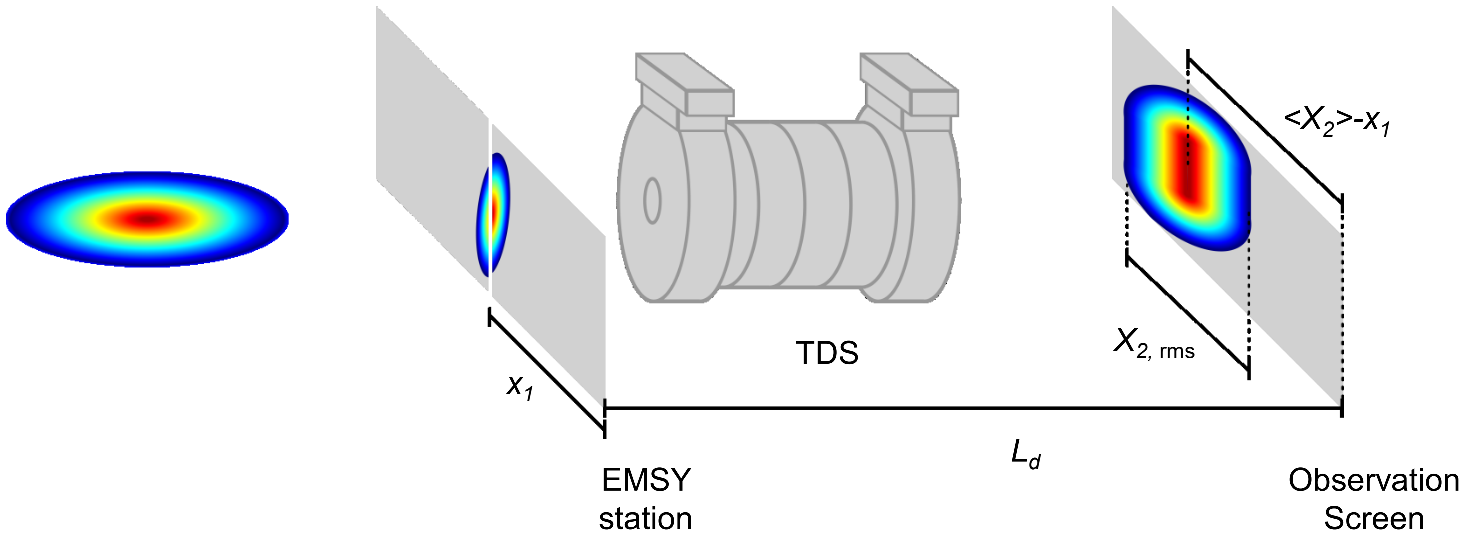
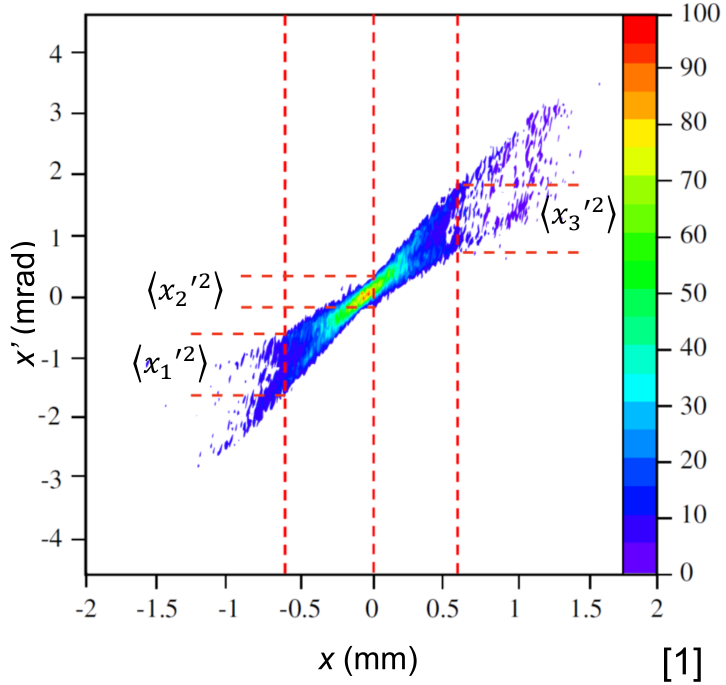
Recap: Slit Scan Method

Slit-Scan-based slice emittance measurements





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

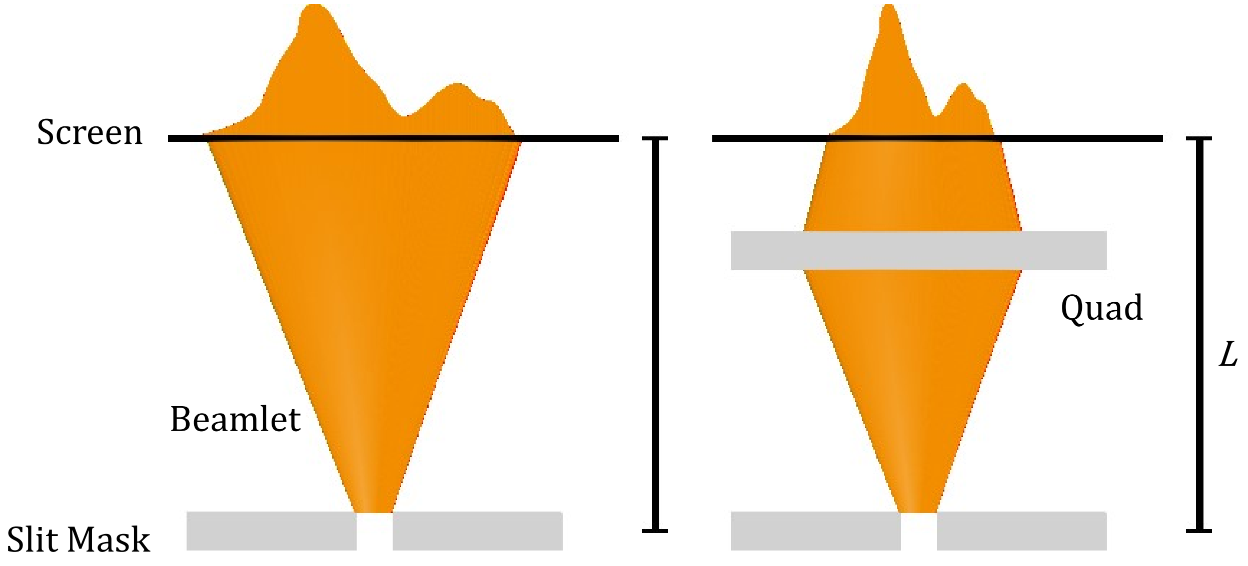
[1] S. Rimjaem et al., Nucl. Instr. Meth. Phys. Res. A **671**, 62 – 75 (2012).

Slice emittance with intermediate quadrupoles (Q9/Q10)

Use of quadrupoles before TDS

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

$$\begin{pmatrix} x \\ x' \end{pmatrix}_{s_2} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}_{s_1 \to s_2} \cdot \begin{pmatrix} x \\ x' \end{pmatrix}_{s_1}$$
$$\Rightarrow x_2 = R_{11} \cdot x_1 + R_{12} \cdot x'_1$$
$$\Rightarrow x'_1 = \frac{x_2 - R_{11} x_1}{R_{12}}$$



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

Slice emittance with intermediate quadrupoles (Q9/Q10)

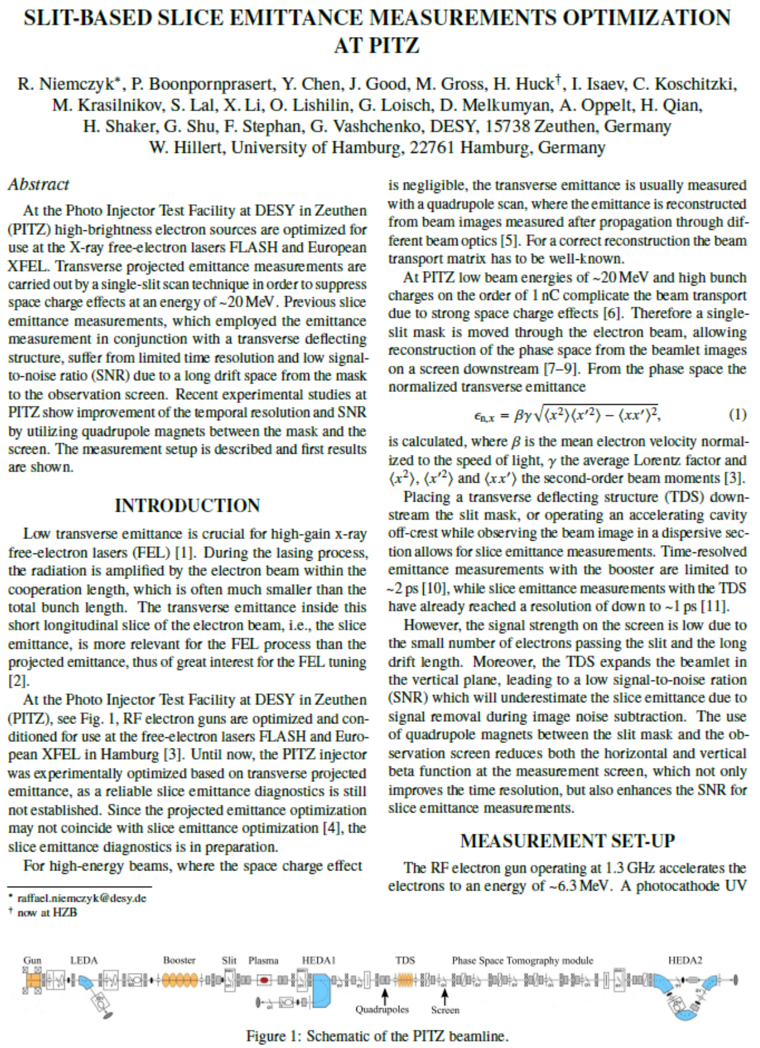
Tried first in May 2019

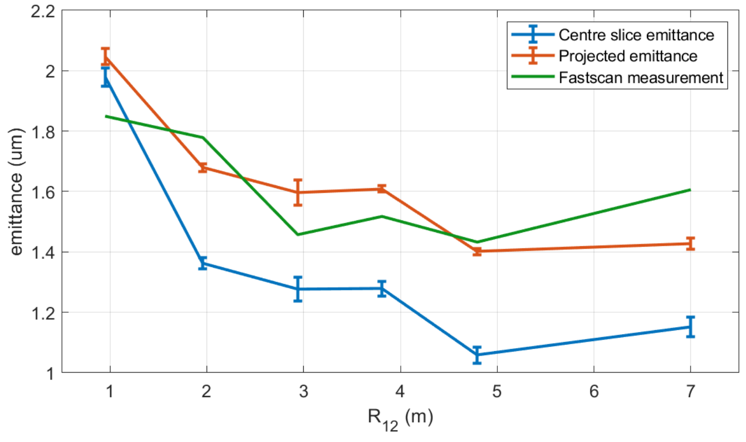
> Use of High1.Q09/Q10 published in IBIC'19 Proc.

> Increase of measured emittance observed

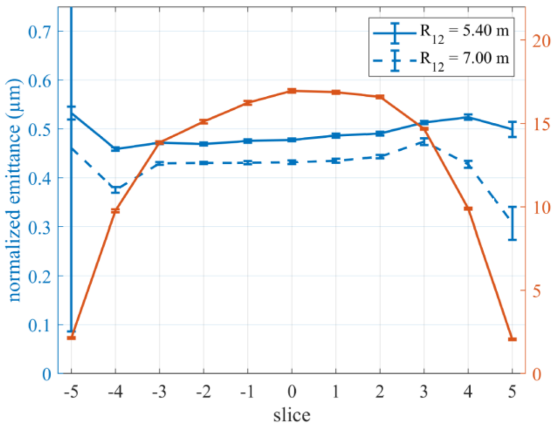
> Measurement with different focusing done, to find optimum focusing (August'19)

> Redone with better injector/more sample points





Measurement from 2019-08-16



Measurement from 2019-05-12

Scan of quadrupoles strength (R12 scan)

Different focusing strength (should) yield different SNR’s

- Measured on 2019-12-20_A
  - ~ 2.5h measurement time, without preparation

- Gun: 6.3 MeV/c, Booster 19.4 MeV/c
- Charge ~ 250 pC
- Imain = 370 A
- Laser: 90%-truncated Gaussian

- RF5 lifetime was issue
- Charge fluctuation (laser power fluctuation)

20.12.2019 19:57 O. Lishilin, R. Niemczyk **Quadrupole calibration for slice emittance measurements**

Setting	High1.Q09	High1.Q10	R12
1	-4.6A	+4.8A	0.67m
2	-4.3A	+4.5A	1.50m
3	-4.0A	+4.3A	2.75m
4	-3.7A	+4.0A	3.60m
5	-3.4A	+3.7A	4.10m
6	-3.0A	+3.4A	5.50m
7	-3.2A	+3.5A	4.60m
8	-2.7A	+3.1A	5.98m
9	0.00A	0.00A	Drift

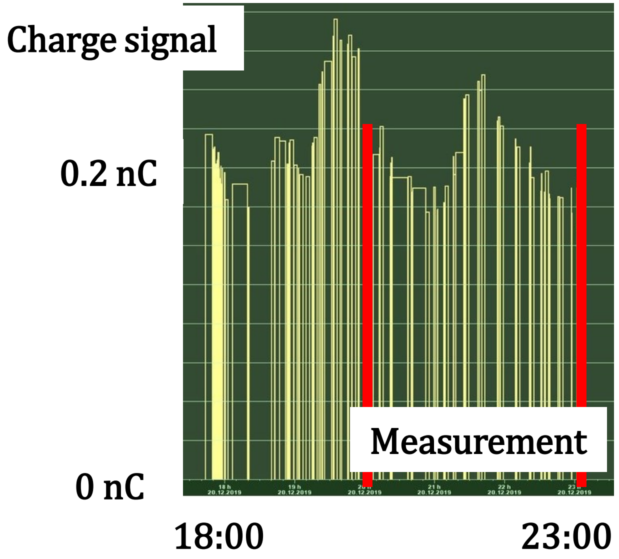
Set the quadrupoles via the following routine: Degauss, go from zero directly to the current value

20.12.2019 20:39 O. Lishilin, R. Niemczyk **TDS Klystron died during slit scan**

Shutter was open, at slit position 36/41
TDS Klystron lifetime: ~3 min 30 sec

20.12.2019 23:13 O. Lishilin, R. Niemczyk **Charge after slice emittance measurement**

The charge dropped from 250 pC to 220 pC, i.e. by 30 pC, more than 10%



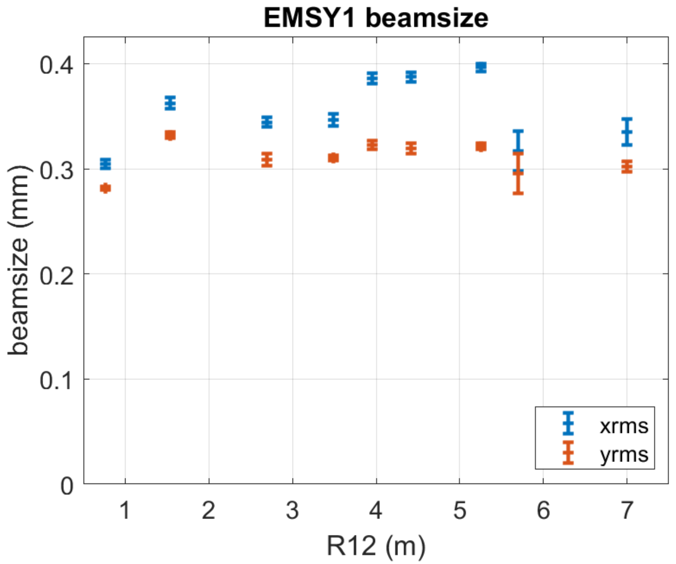
Signal = Low.ICT1/ONE_CH: Absolute values off – relative change interesting

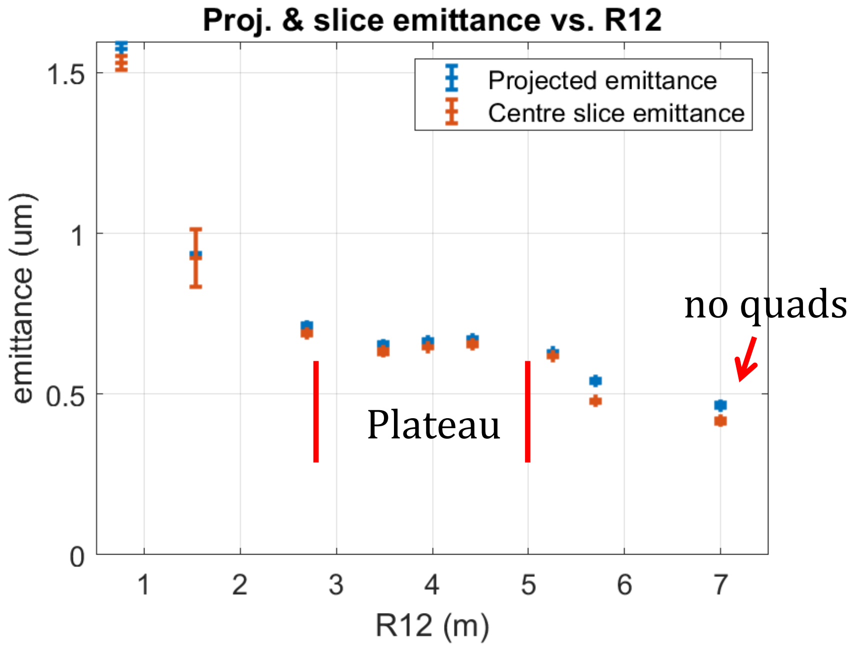
Scan of quadrupoles strength (R12 scan)

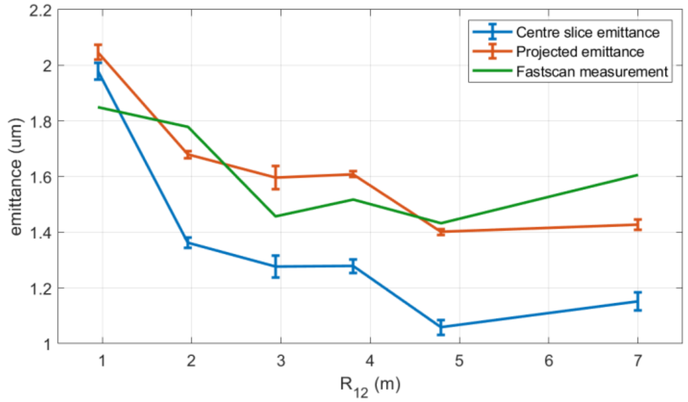
Different focusing strength (should) yield different SNR's

- EMSY1 beamsize fluctuation
  - Settings before EMSY1 constant (no change expected)
  - Charge drifts likely case

- Projected & slice emittance
  - Earlier measurement confirmed (experiment repeatable)
  - R12 [2.8m to 5m]: Increase of measured emit due higher SNR
  - Emittance independent of R12 on plateau → Proper setting for slice emittance measurement
    - R'12 around 3.5m were used so far





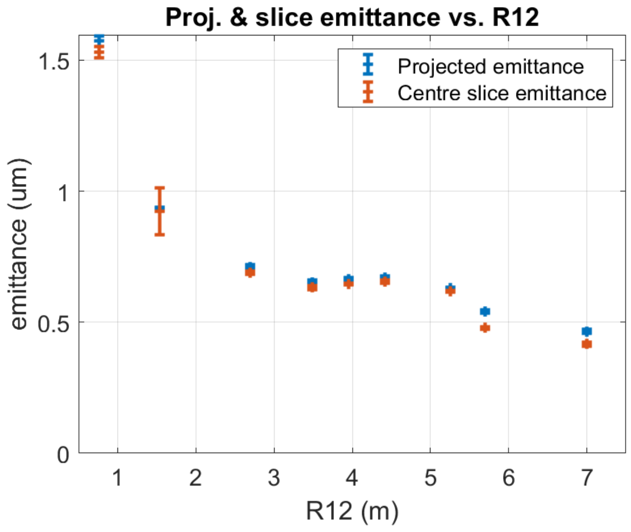


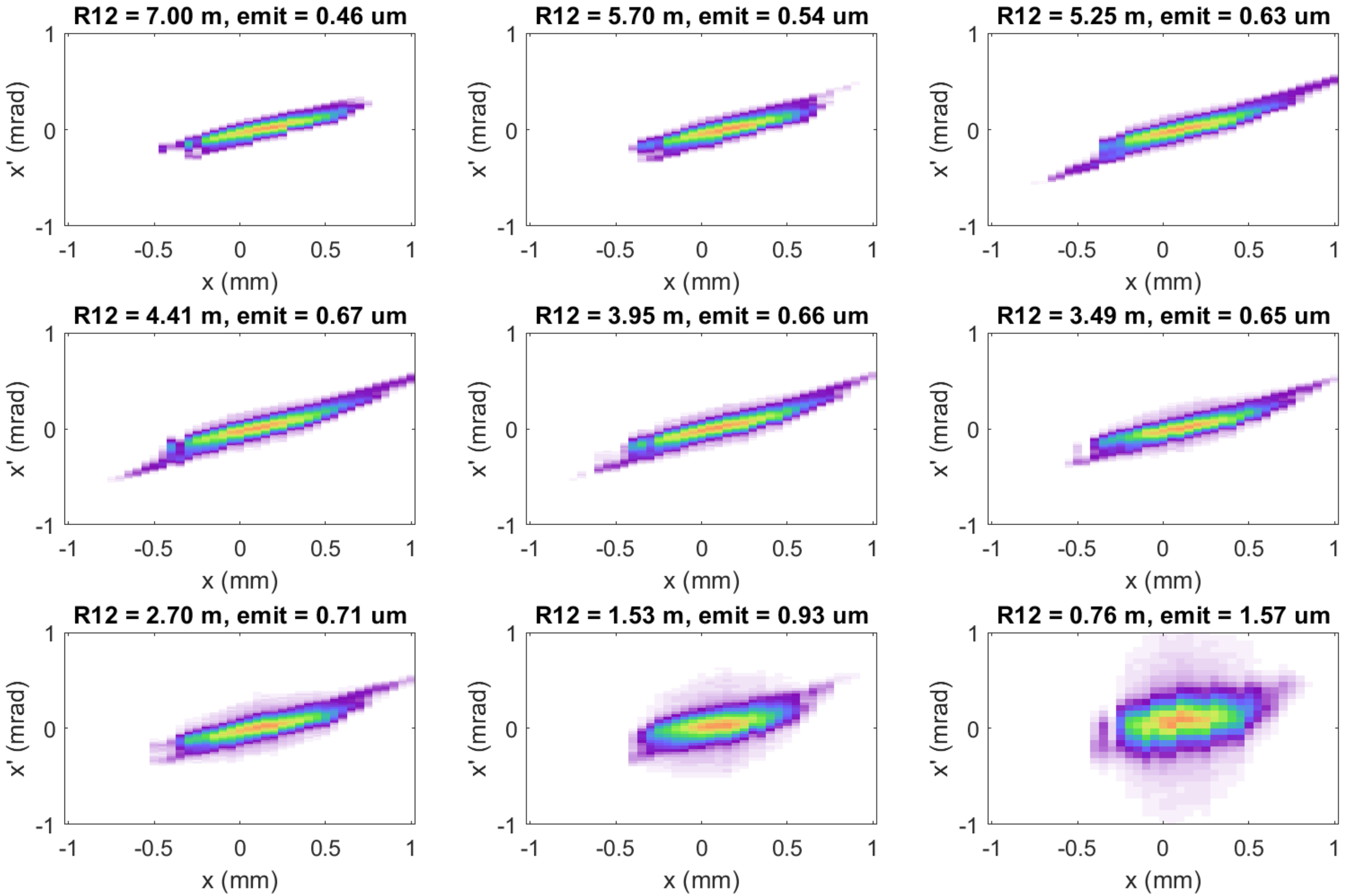
Measurement from 2019-08-16
→ Reproducible result

Scan of quadrupoles strength (R12 scan)

Centre slice phase space for different focusing

- For R12 < 2.7m tails (in x) vanish → contradicts higher SNR interpretation
- For decreasing R12 tails visible → explains emittance increase
- For R12 < 2.7m angular halo (in x') visible → Emittance increase
- Stronger focus (smaller R12) → bigger halo



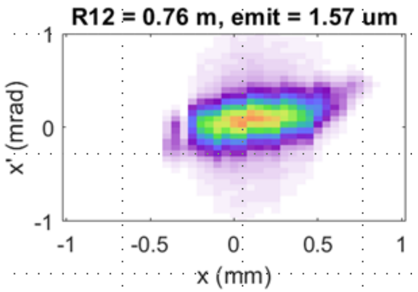


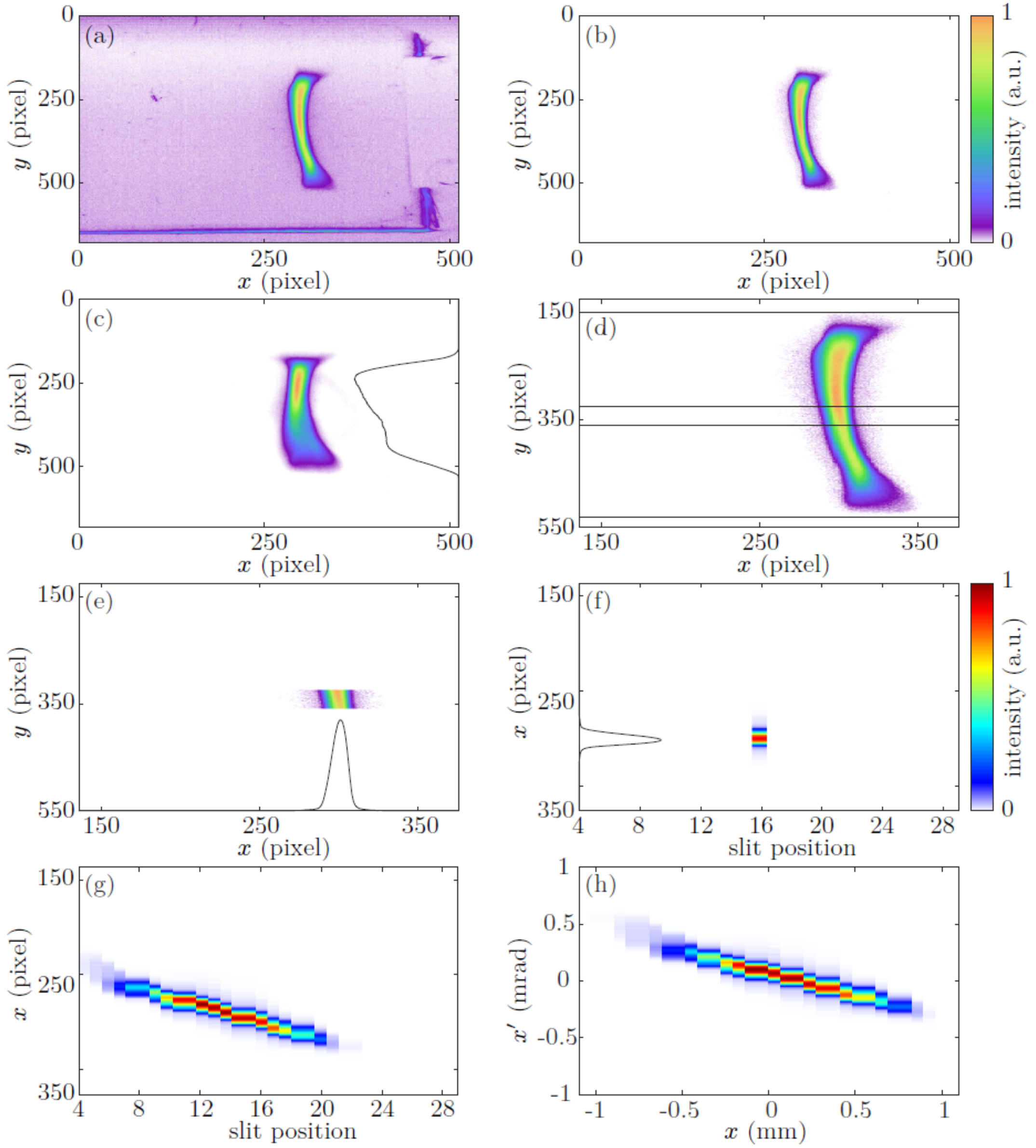
Phase space reconstruction

Assembly of (slice) phase space from raw beamlet images

- Filter of raw images
- Determine where to slice beamlets
- Do projection of sliced beamlets
- Reconstruct phase space from all (sliced) beamlets
  - Consider R11 and R12
- Calculate angle from pixel and size from slit position
- Calculate area → (Slice) emittance

- Angular phase space halo from spatial beamlet halo





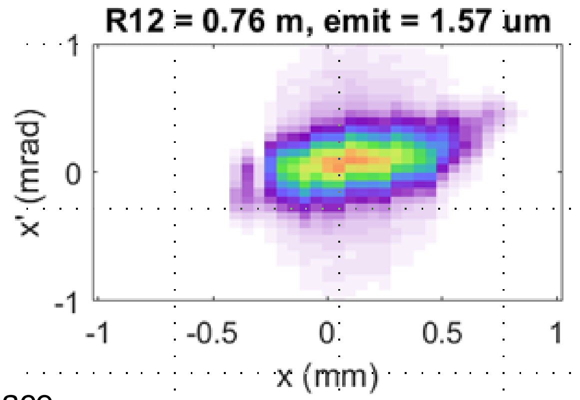
Angular phase space halo

Fastscan measurement on PST.Scr1 btm

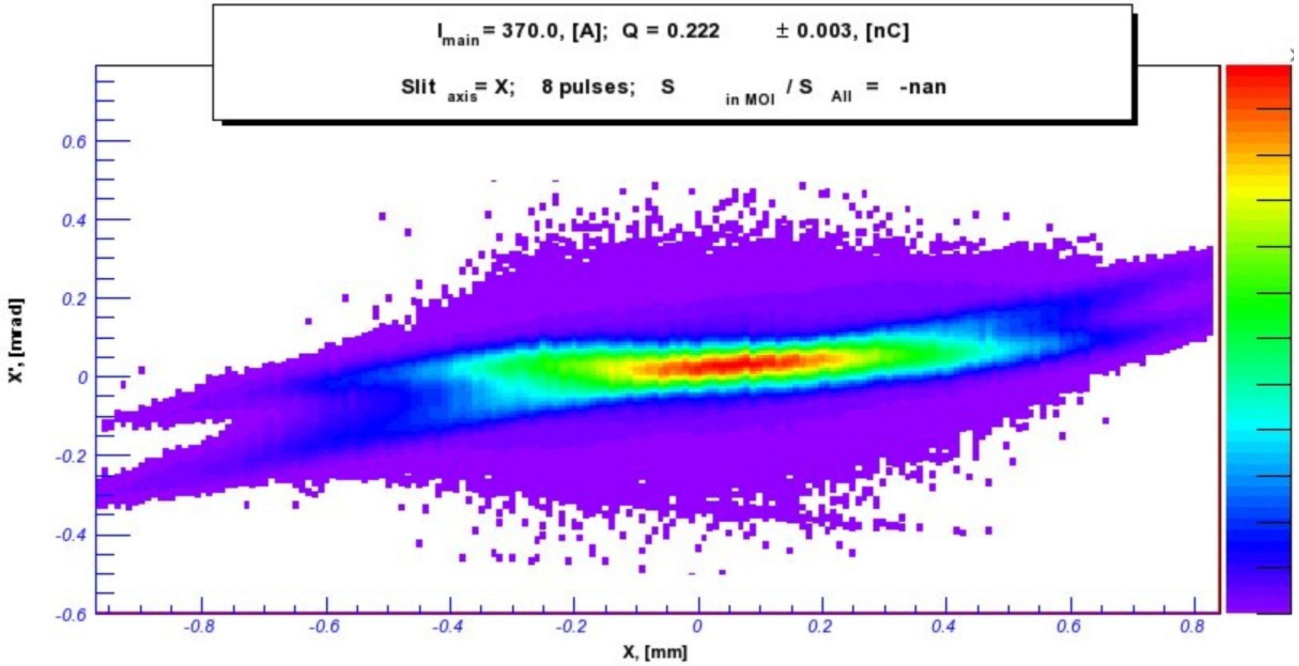
- Earlier observation in May 2019
- Very pronounced in fastscan on PST.Scr1 btm
  - Despite lack of focusing
  - But also: no TDS → Higher charge density

- Fastscans with different number of pulses on both YAG and LYSO might help understand issue

Centre slice phase space, strongest focusing, 2019-12-20



Fastscan measurement, projected phase space, EMSY1 -> PST.Scr1 LYSO, no TDS, no quads



Scan of quadrupoles strength (R12 scan)

Signal-to-Noise ratio for different focusing strength

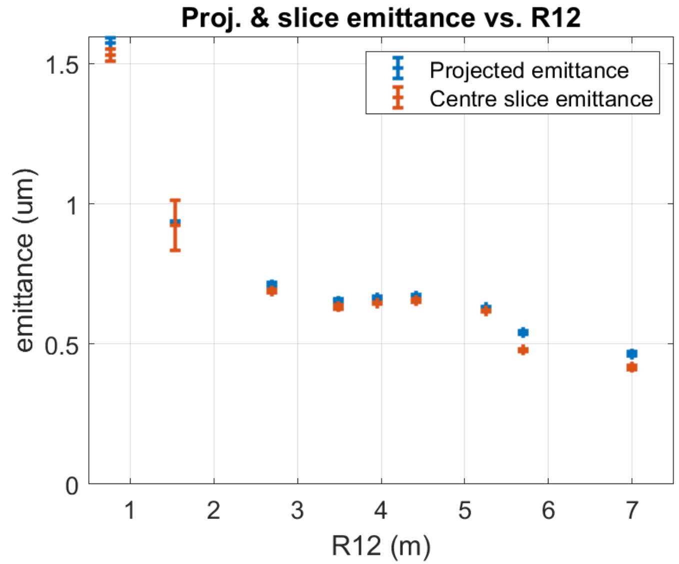
- Noise level = rms of pixel value of all pixel in MOI in all background images (typically ~6.8)
- Signal level
  - Take filtered images
  - Smooth with Gaussian (sig = 0.5 pixel) → Remove hot spots
  - Divide signal (for each focusing strength (R12), each slit position, each of ten images at each slit position) by noise level
  - Average SNR ‘along’ statistics for each slit position
  - Take max SNR ‘along’ slit position (-> centre beamlet)
- SNR higher with stronger focusing

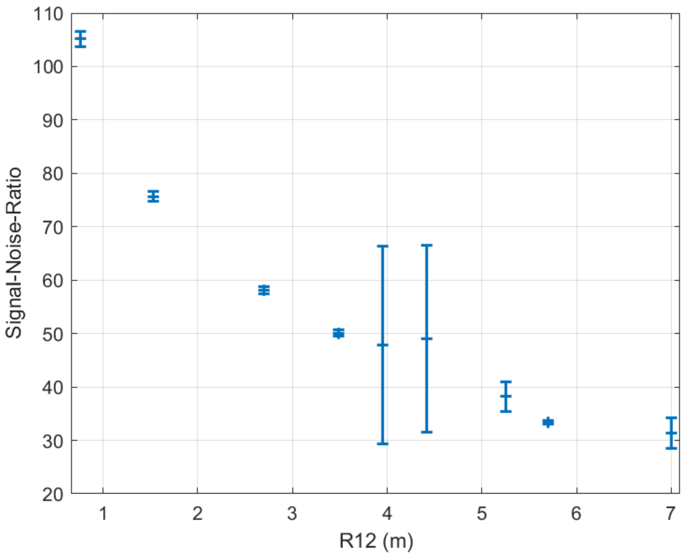
Max. pixel filling observed*: 770

Bkg pixel filling: ~77 -> 10% of max

→ Effectively 700-criterion (also important for fastscan)

* ten-times averaged raw images, strongest focusing

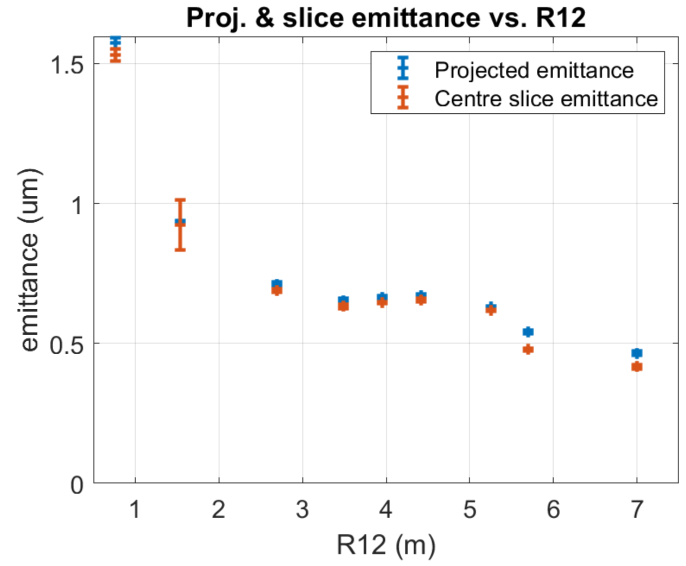


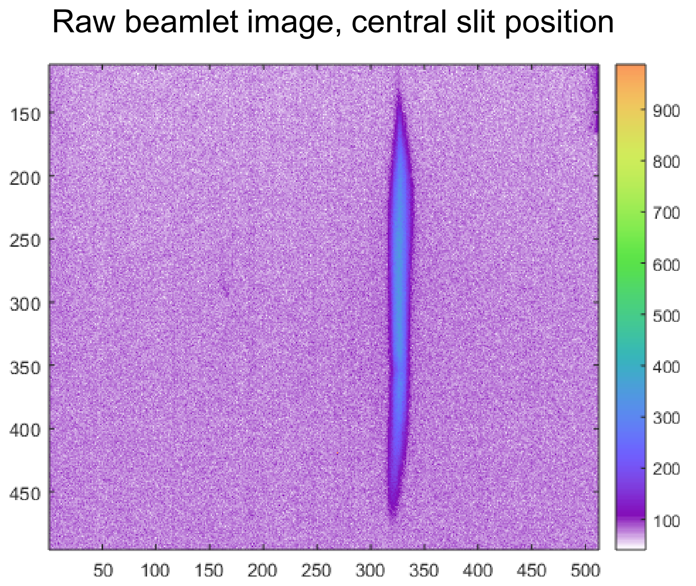


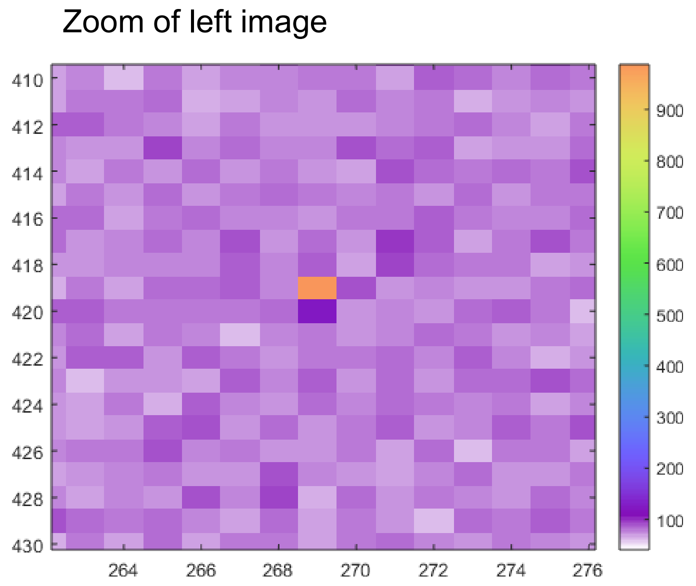
Scan of quadrupoles strength (R12 scan)

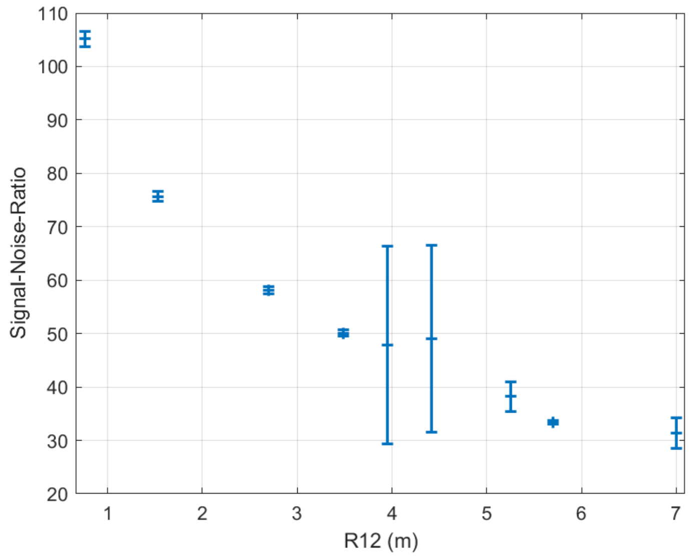
High uncertainty for two settings

- Few times salt'n'pepper noise observed
  - Single pixel with very high filling -> not real, from camera
- Example below
- Might make smoothing necessary
- Gives high uncertainty bars









Outlook

Summary

- Focusing scan (R12 scan) result reproducible
- Plateau for intermediate focusing (R12 = 2.8m to 5m) → Proper measurement setting
- Higher SNR for stronger focus explains higher measured emittance
- For strongest focusing angular halo observed → Strong slice emittance increase
  - Angular halo from spatial beamlet halo
  - Issue of screen/screen station?
  - Beam halo also observed in thermal emittance measurement
    - Also LYSO, also telescope, same screen orientation
    - There: Scattering in screen material blamed (observed earlier at REGAE) [1]
- Analysis of slice emittance/SNR for different TDS voltages pending
- Verification of correct calculation of R11 and R12 in process

[1] M. Hachmann, PhD thesis, Uni. Hamburg (2017)