Impact of Intensity Cuts to Slice Emittance Calculations

Slice Emittance Calculations of Phase Spaces Measurements which Suffered from poor Signal Strength

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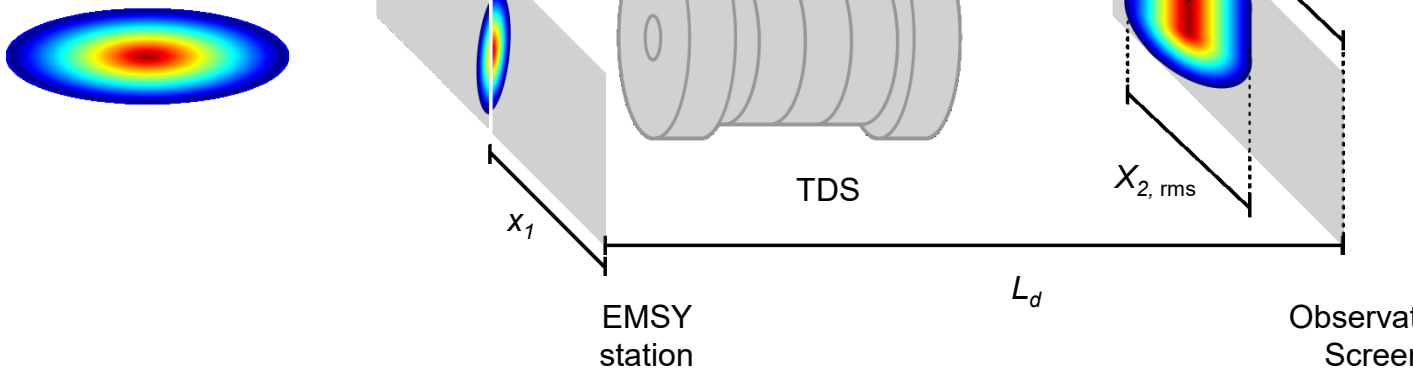
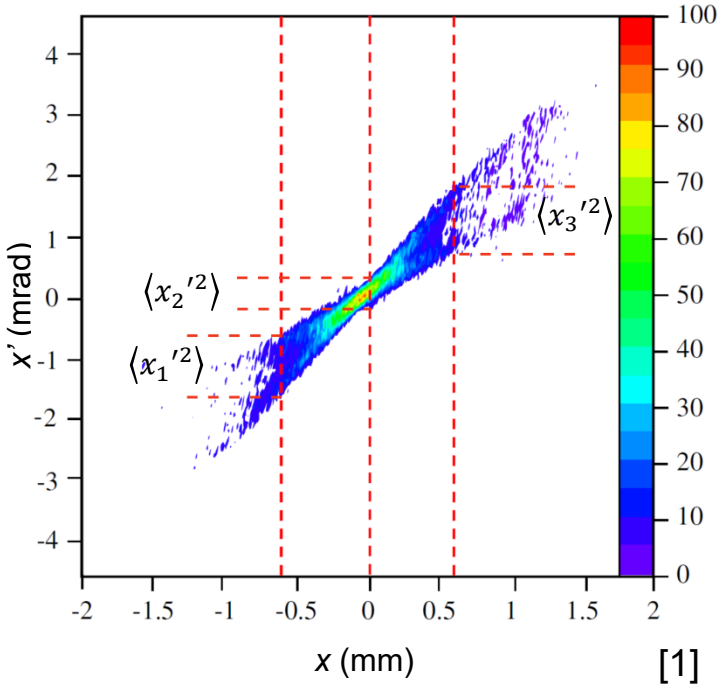
Recap: Slit Scan Method

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).

Analysis of Intensity Cuts

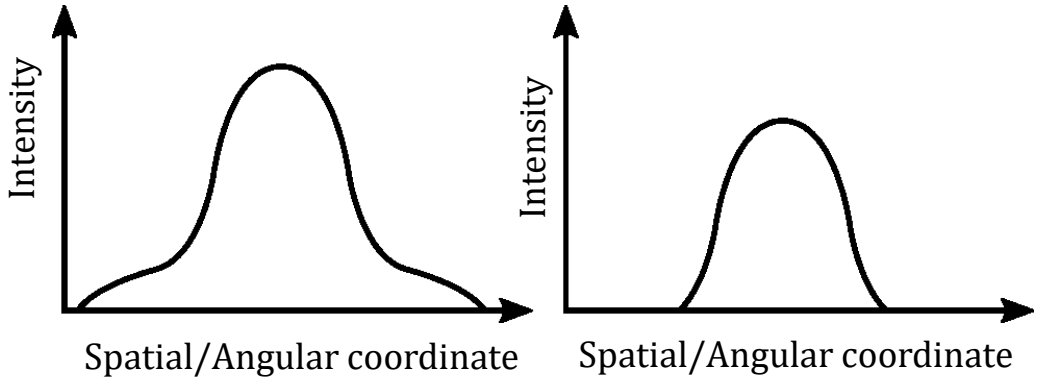
Why is it important to compare the slice emittance at different intensity cuts

- In experiment, phase space areas with low intensity might be undetected
  - Happens when signal strength approaches noise level
  - Or as a result of image noise cut
- As not whole phase space is detected, emittance should reduce
  - By how much for which intensity cut?
    - Systematic Measurement Error
  - Can I fix it with EMSY scaling?

Emittance Reduction due to intensity cut

Definition, Example and Terminology

- Low-intensity areas sensitive to noise
- Emittance underestimation due intensity-cut
- Intensity cut
  - Cut done for whole 3D (x-x'-t) phase space
  - Remove particles with less than x% of maximum intensity
  - Maximum intensity = maximal phase space density in 3D
  - Lower whole phase space, so it aligns with zero intensity



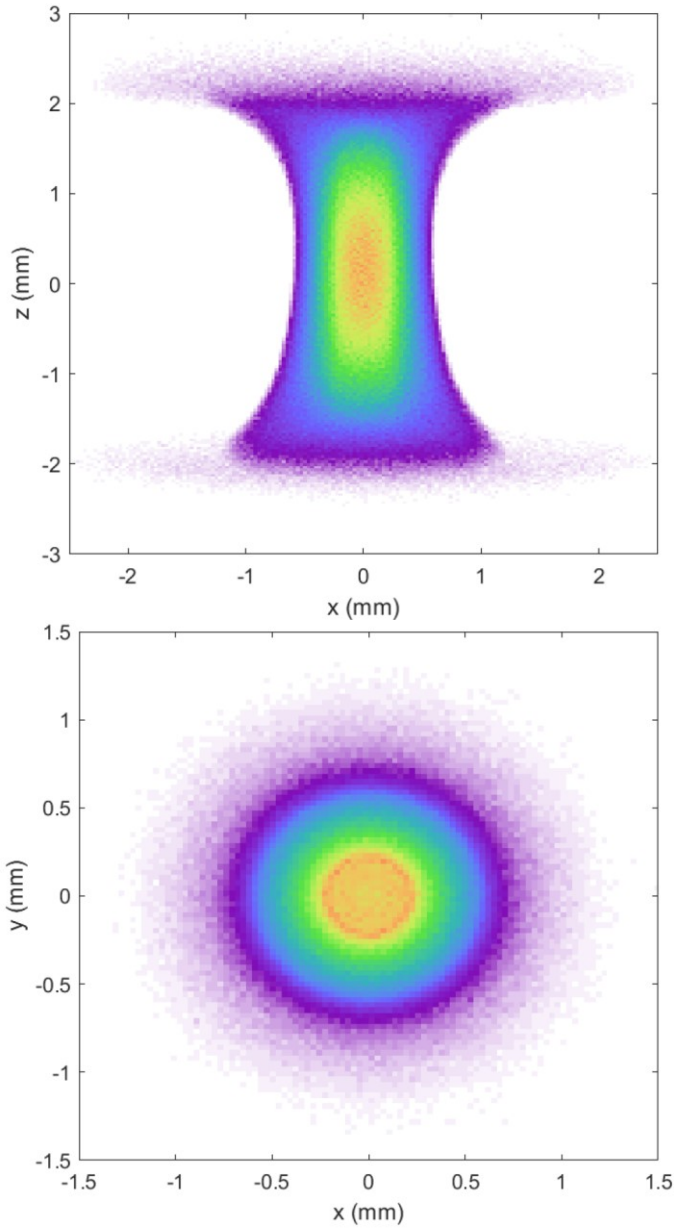
Noise Cut: Filtering (process) of beam images

Intensity Cut: Removal/Reduction of phase space density

Simulation of an Eu-XFEL-type beam

Standard settings, simulated to EMSY1

- Bunch charge = 250 pC
- Laser: temporal Gaussian, 6 ps (FWHM), transverse flattop
- I_{main} = 366 A, BSA = 1.3 mm (emittance minimum)
- p = 6.3 MeV/c, p = 19.29 MeV/c
- EMSY1:
  - σ_x = 0.37 mm
  - ε_x = 0.61 µm

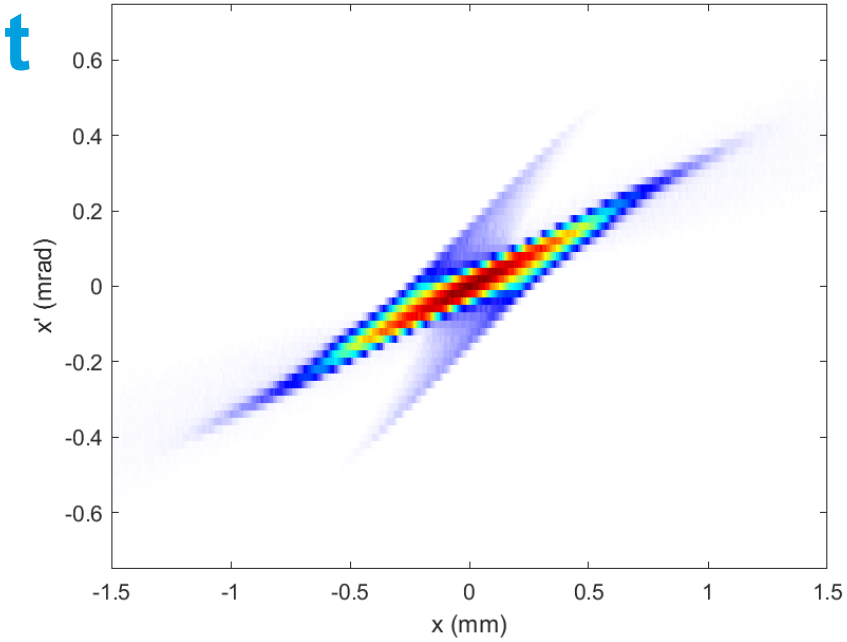


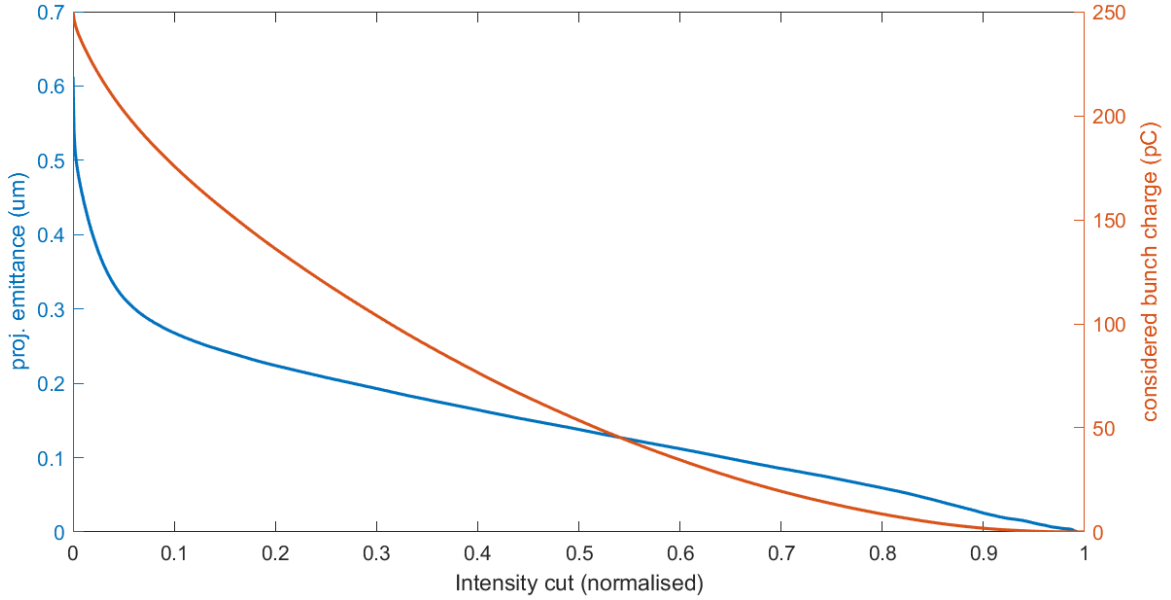
Beam at EMSY1

Emittance Reduction due to Intensity Cut

Projected Emittance

- Transverse emittance vs intensity cut
  - Transverse phase space (top-right)
    - Normalised emittance: ε_x = 0.61 µm
  - Emittance decrease (bottom-right)
    - Rapid emittance decrease for cuts < 5%
    - Further decrease for larger cuts
    - Considered bunch charge decreases correspondingly



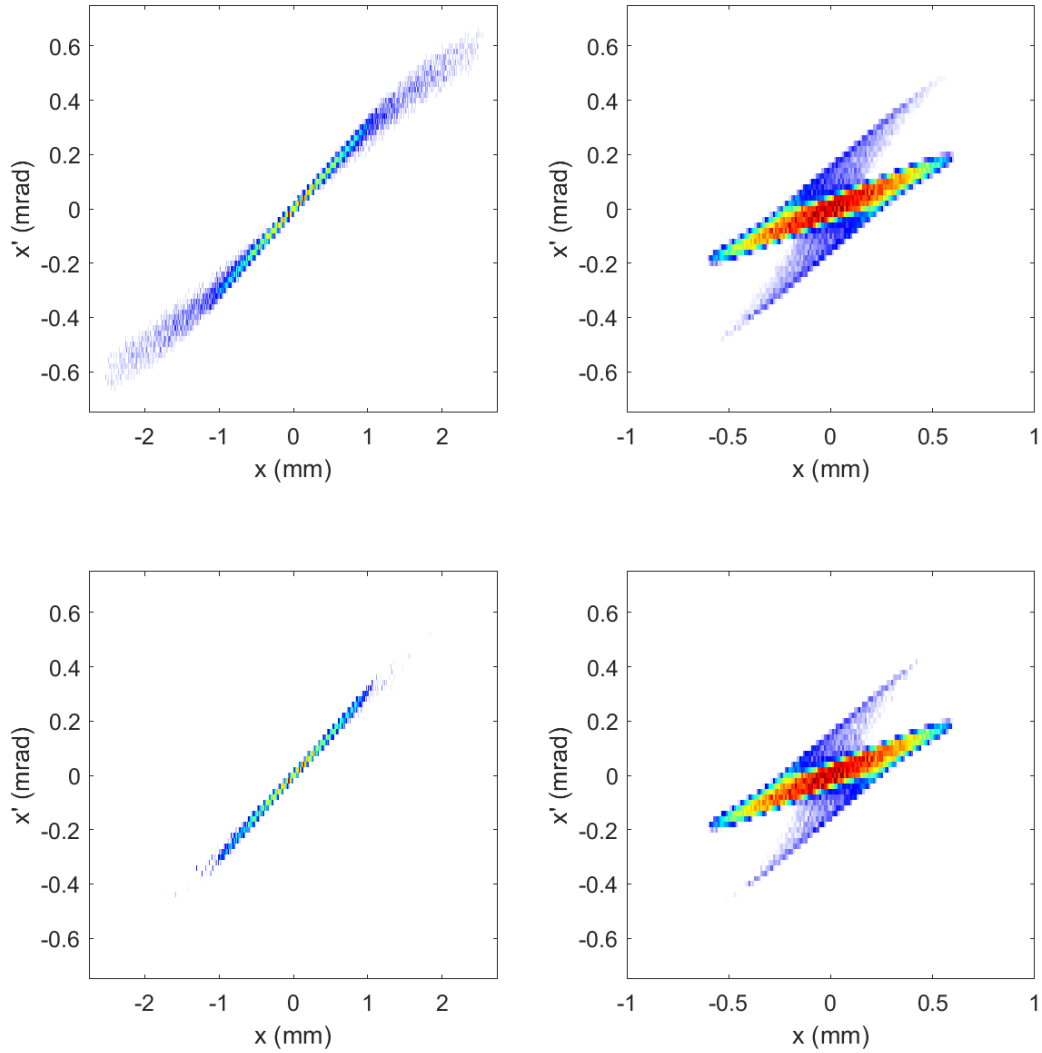


Slice phase spaces after intensity cuts

How does a 2% intensity cut affect the size and shape of a slice phase space

- Plotting slice phase space
  - Top row: No intensity cut
  - Bottom row: 2% intensity cut
  - Left column: Tail (-2.2 mm) phase space
  - Right column: Centre slice phase space

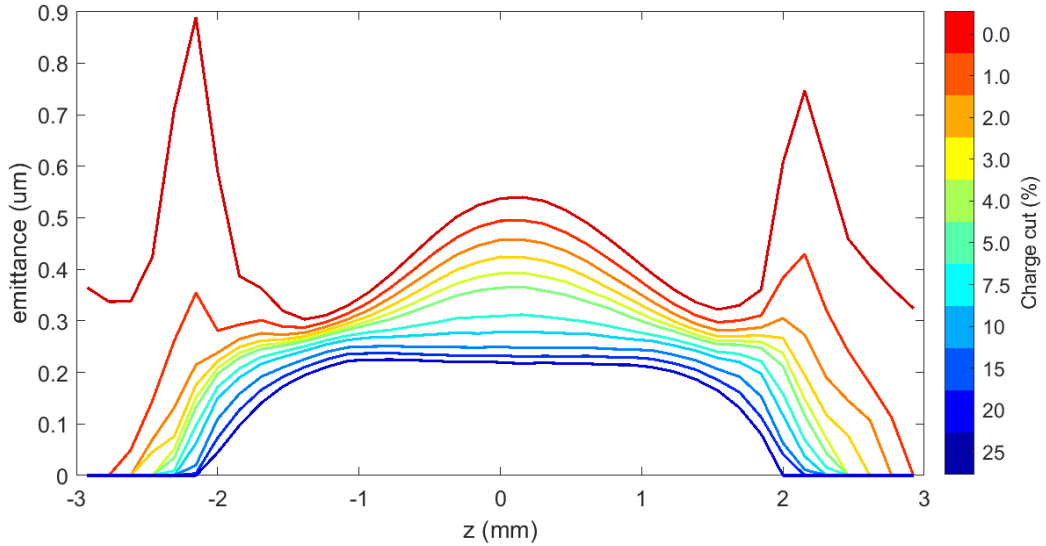
- Strong signal reduction in head/tail visible
- Centre slice phase space changes only slightly



Slice emittance vs. intensity cut

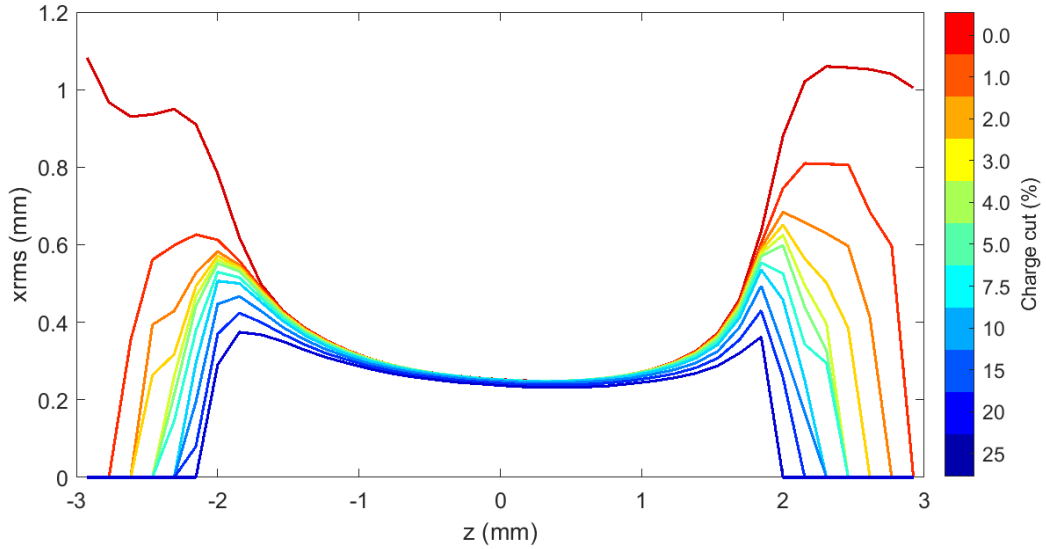
How do intensity cuts affect slice emittance and slice beam size

- Slice emittance
  - Strong reduction in head and tail (for 2% cut)
  - Moderate reduction for more central slices observed



- Slice rms size
  - Strong reduction of head and tail size
  - Almost no reduction for central slices
  - Centre slices insensitive to reduction of signal strength

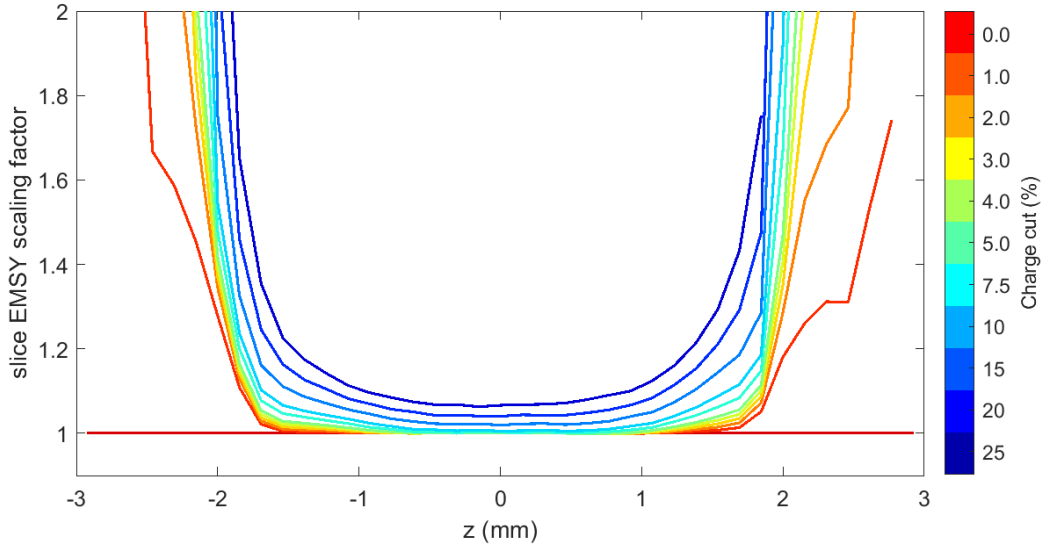
→ EMSY scaling possible in head and tail



Slice emittance vs. intensity cut

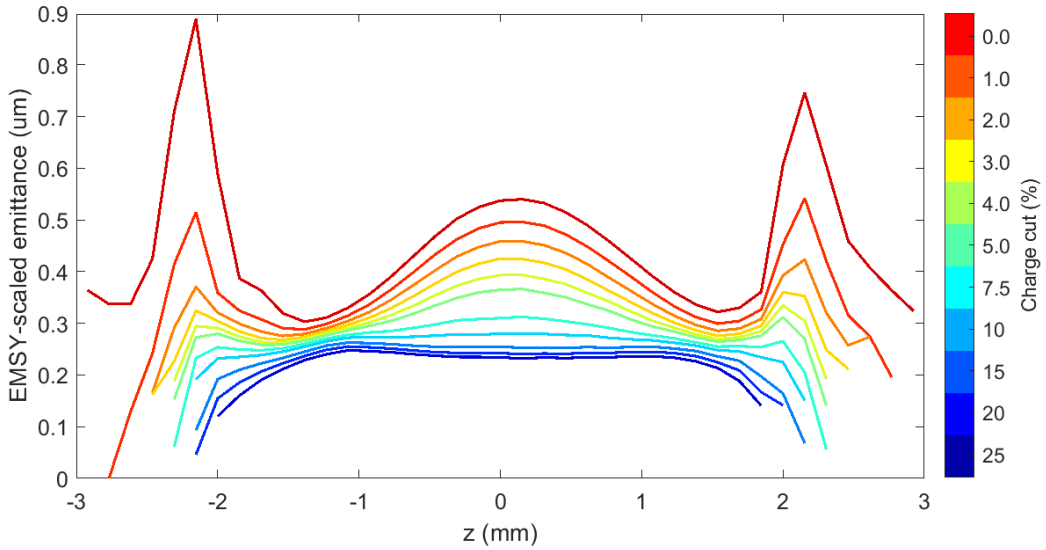
How do intensity cuts affect slice emittance and slice beam size

- Slice-wise EMSY scaling factor
  - Very large EMSY scaling factor for head and tail
  - Reasonable small (< 1.1) EMSY scaling for centre slices



- EMSY scaled slice emittance
  - Improvement in head and tail
  - Almost no reduction for central slices
  - Centre slices insensitive to reduction of signal strength

→ Consideration to EMSY scaling well possible



Comparison with Measurements

Comparison of Intensity-Cut Simulation Result with Measurement Data

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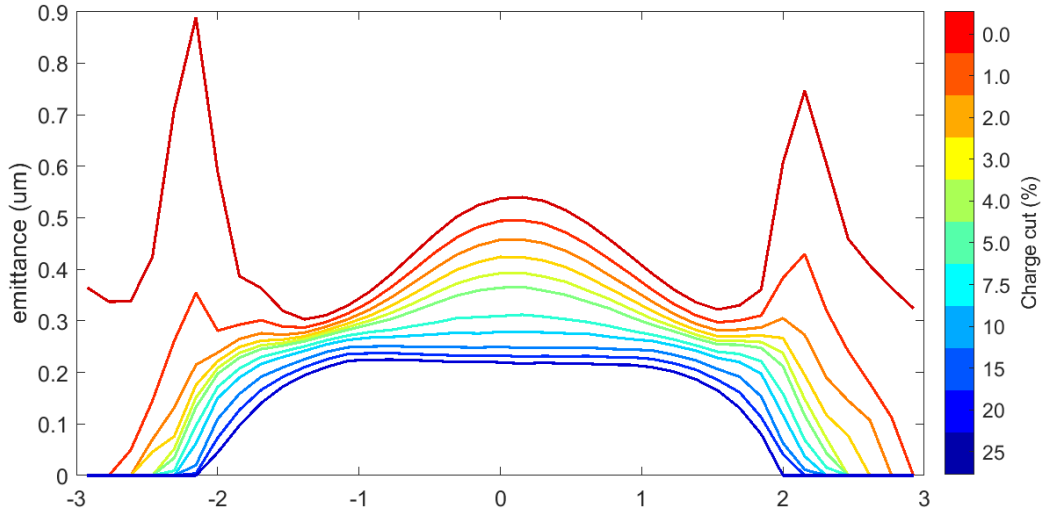

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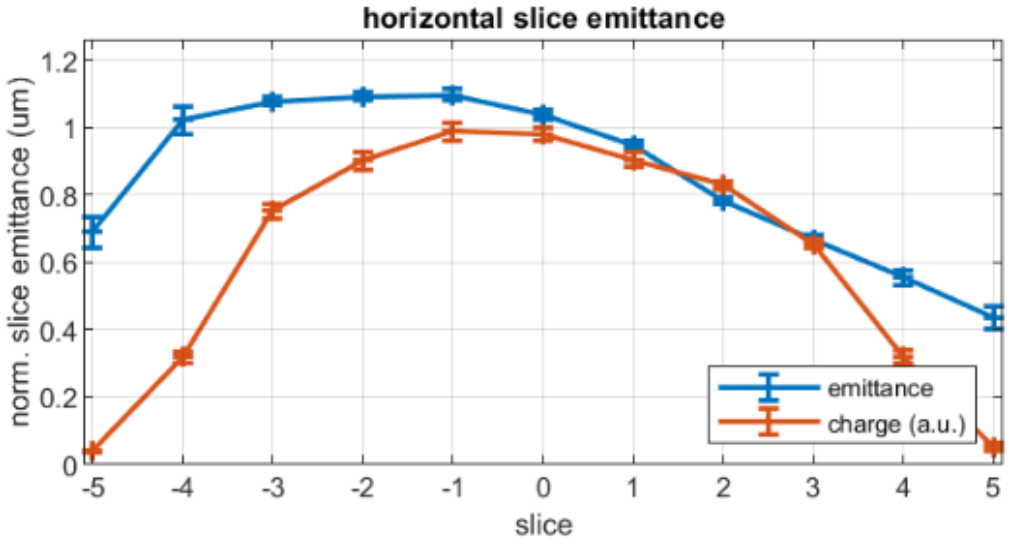

Summary & Outlook

Future prospect of scaling factor for slice emittance

- Simple way to estimate effects from intensity cuts developed
  - Calculation help interpreting slice emittance data
  - Simulation results: similarity with measurement data
- Results show decrease in slice emittance, but not in slice size
  - Strong reduction already for small cuts
  - Correction with EMSY scaling only partially helpful
- Analysis to be continued
  - Temporal flattop profile
  - Ellipsoidal laser shape
  - Fewer low-intensity areas in phase space should increase robustness
- Also: Intensity cut also to be applied on beamlet images directly

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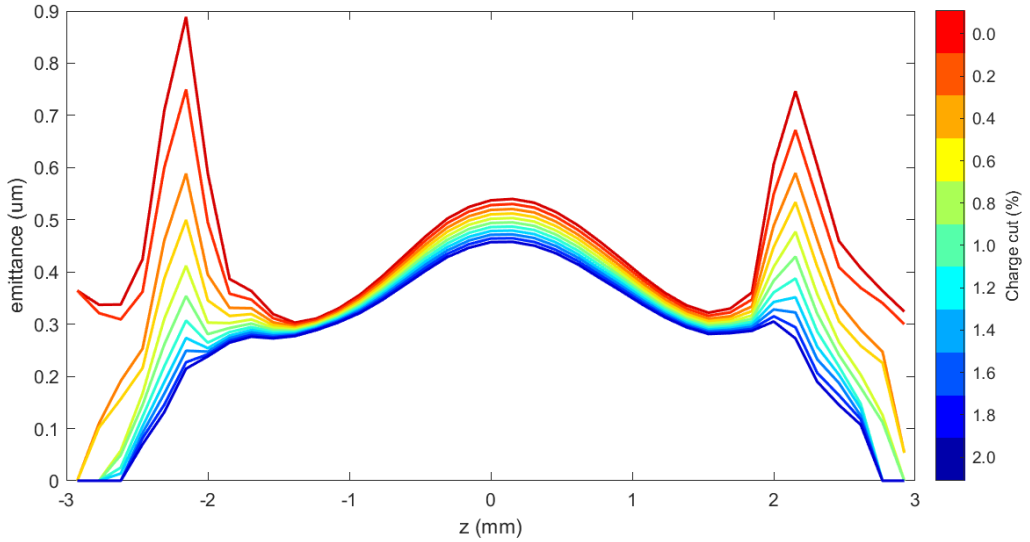

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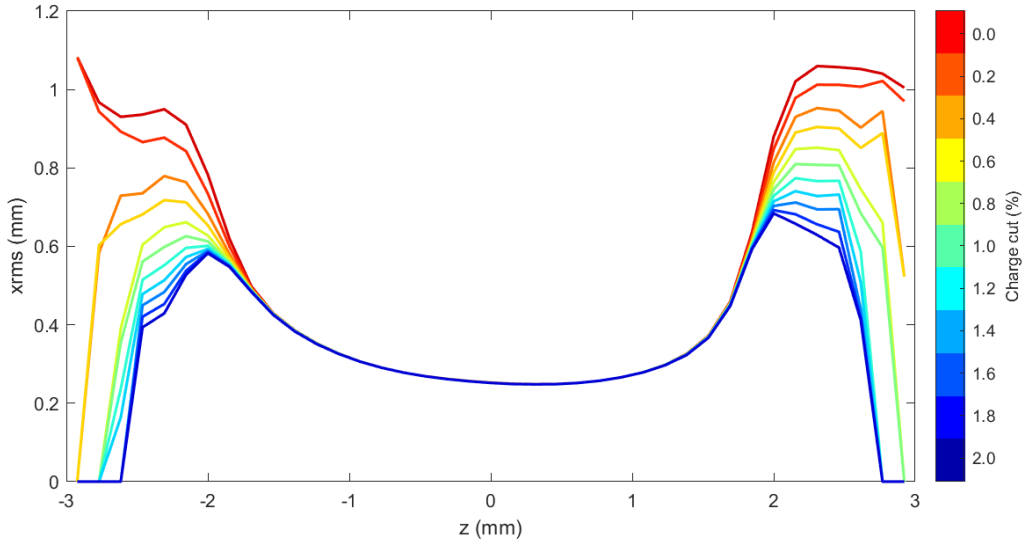

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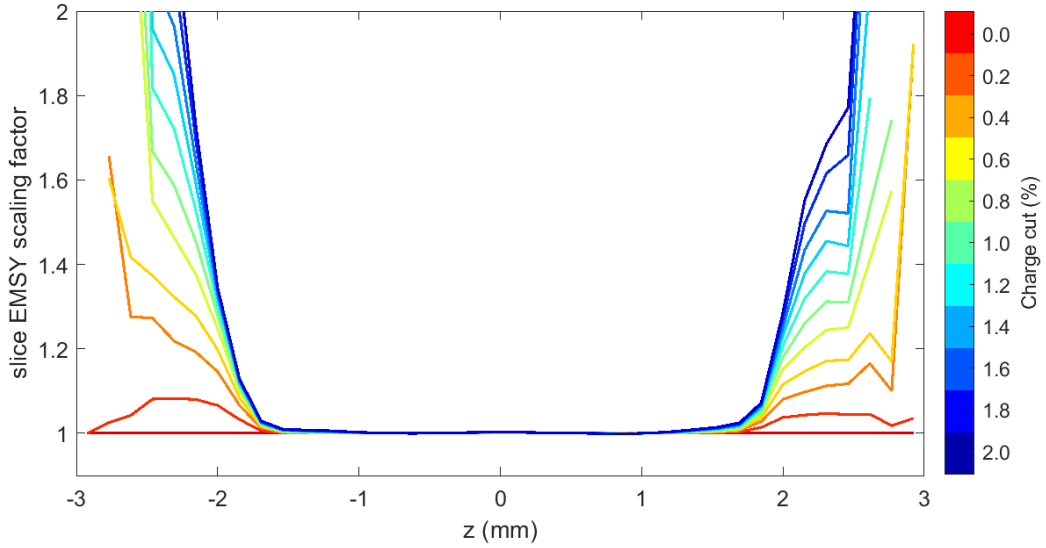

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