Simulation Analysis: Emittance vs. spacial and angular resolution

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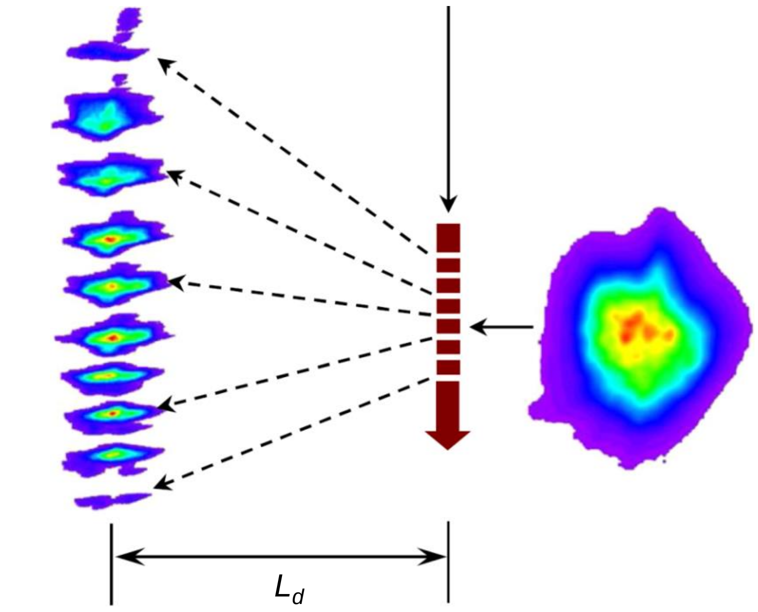
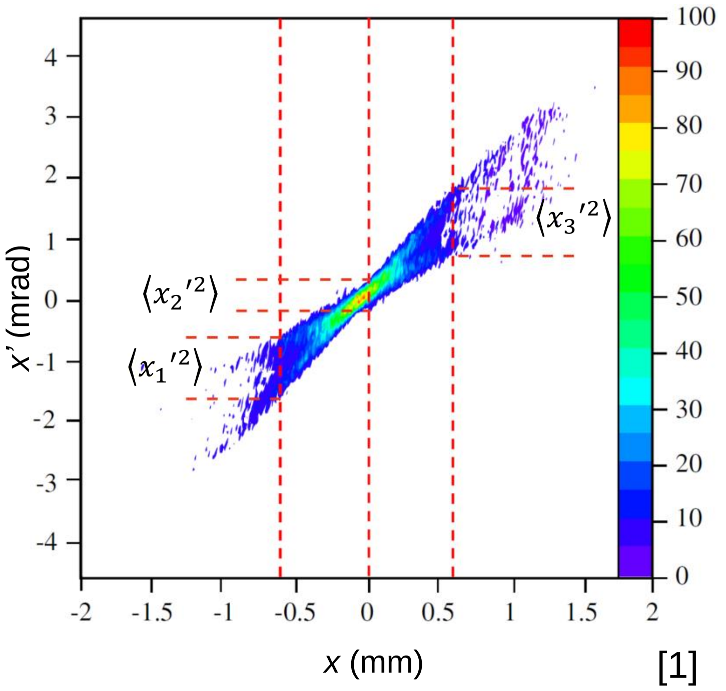
Recap: Emittance measurement

Slit--based emittance measurement



[1]



[1]

> Cut out **emittance-dominated beamlets** from **space charge-dominated beam** with a slit

- Measure the **size**, **position** and **intensity** of each beamlet on screen

> Reconstruct the 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).

Calculating emittance

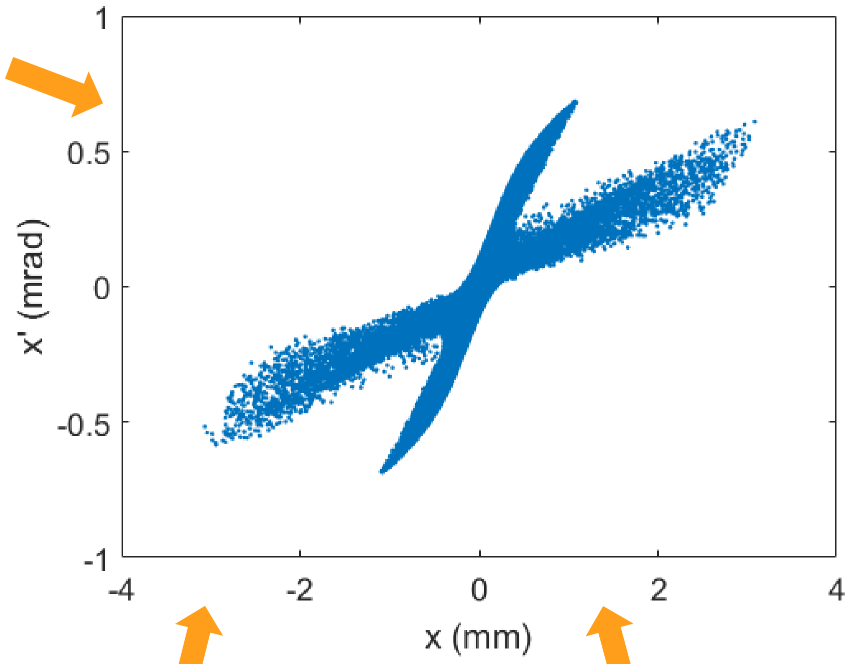
From particle distribution file, from ASTRA

- Calculate the emittance from

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

- Here: We're averaging over every particle (position and angle)
  - Hence: Resolution is much higher than in an experiment
- In a real experiment: Resolution determined by
  1. spacing between slit positions
  2. Screen resolution (camera, camera binning, lens magnification*)
- What happens to the emittance values when I decrease the spacial and angular resolution to our experimental values?

Horizontal phase space @ EMSY2



No density, just all 200k particles plotted

In this example: $\epsilon_{\text{norm},x} = 1.55$ um

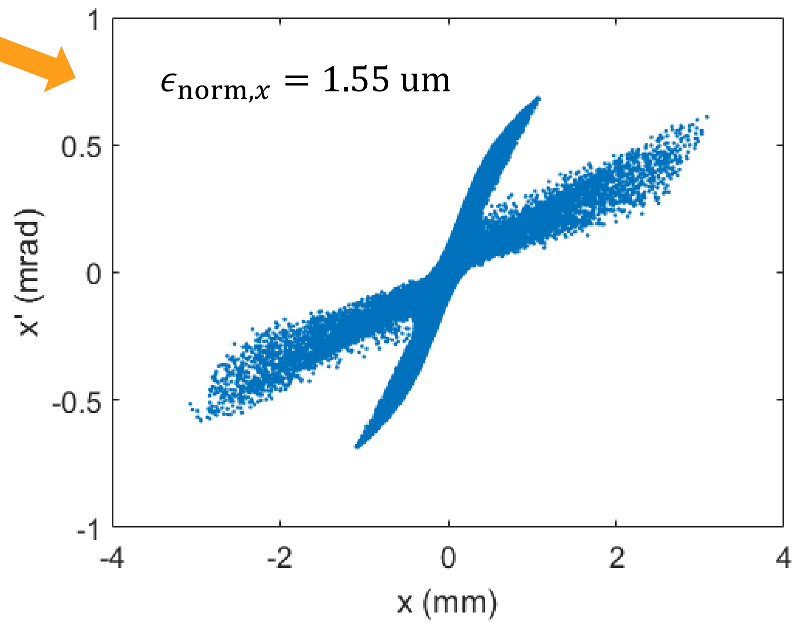
*magnification of the screen image to the camera chip by the lenses of the screen station

Calculating emittance

From particle from measurement

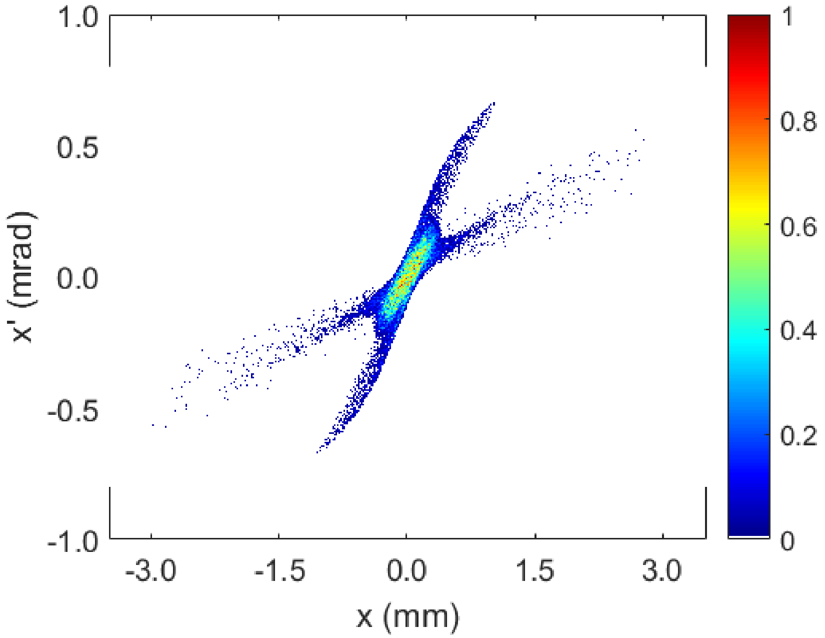
- What happens to the emittance values when I decrease the spacial and angular resolution to our experimental values?
- Histogram the particle positions in space and angle!

Horizontal phase space @ EMSY2

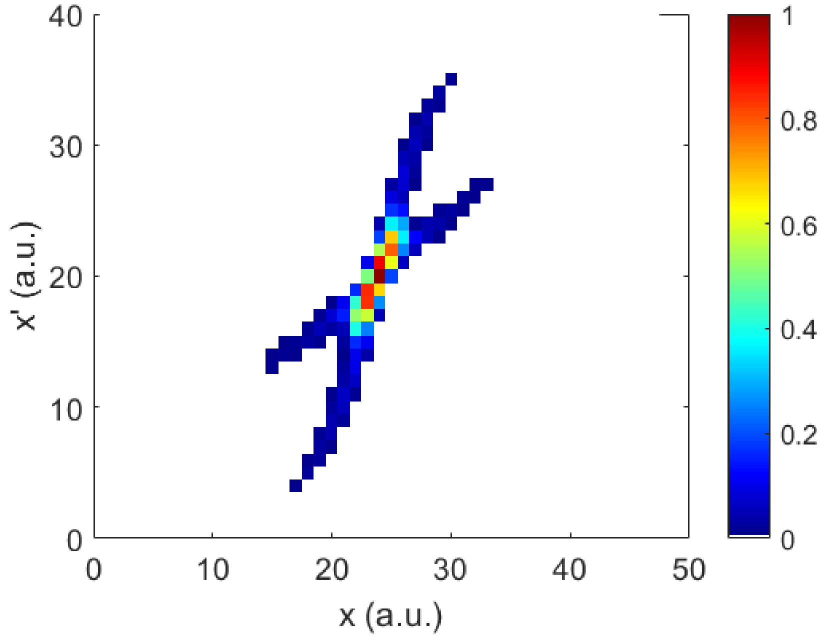


$\Delta x = 0.01$ mm
$\Delta x' = 0.001$ mrad
$\varepsilon_{\mathrm{n},x,\mathrm{rec}} = 1.55$ um

Normalized, reconstructed, horizontal emittance

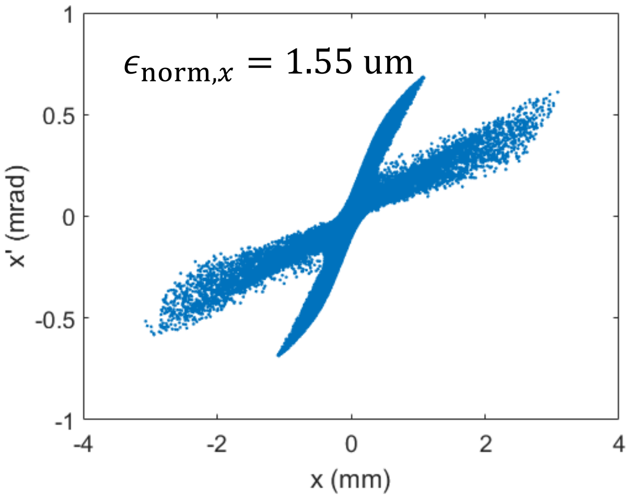


$\Delta x = 0.15$ mm
$\Delta x' = 0.041$ mrad
$\varepsilon_{\mathrm{n},x,\mathrm{rec}} = 1.58$ um

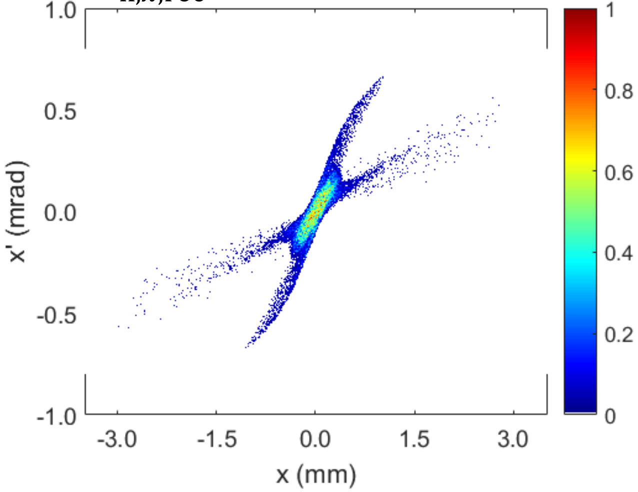


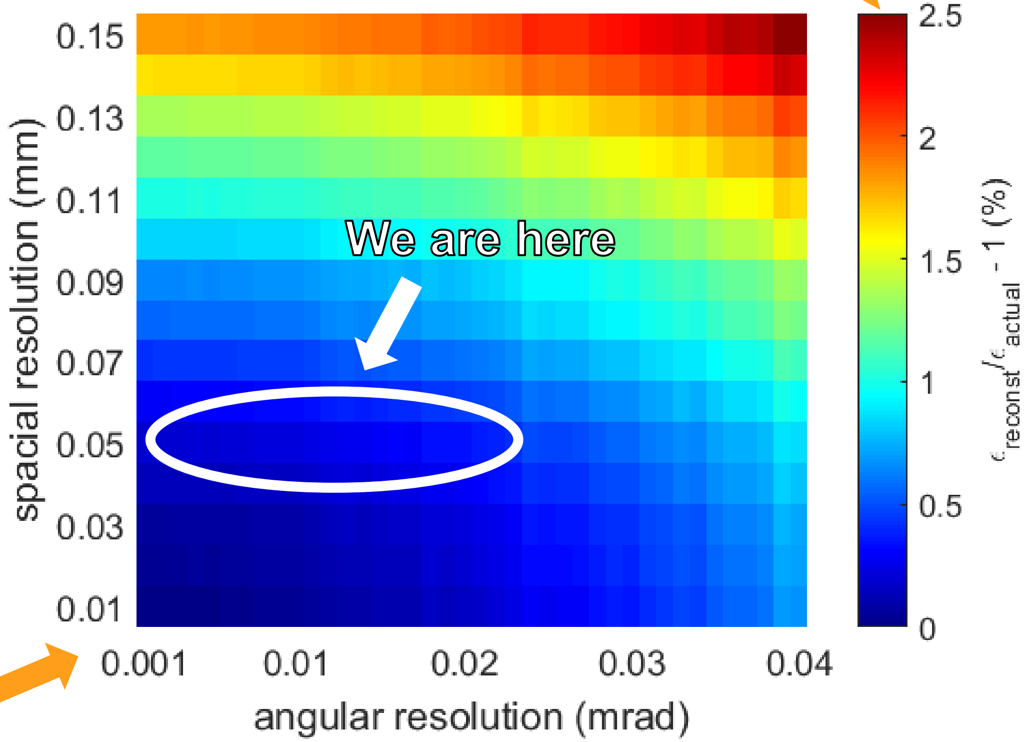
Deviation of reconstructed emittance

For different sets of resolutions

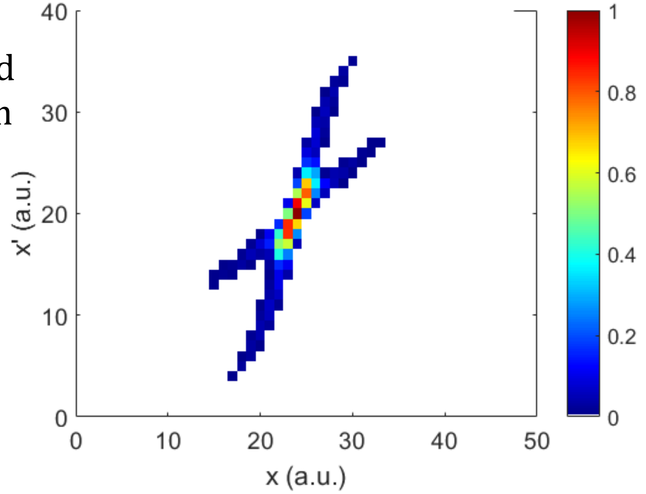


$\Delta x = 0.01$ mm
$\Delta x' = 0.001$ mrad
$\varepsilon_{n,x,rec} = 1.55$ um





$\Delta x = 0.15$ mm
$\Delta x' = 0.041$ mrad
$\varepsilon_{n,x,rec} = 1.58$ um

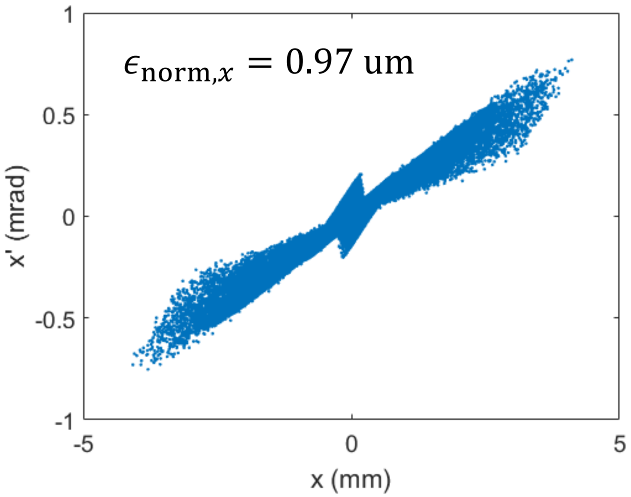


$$\frac{\varepsilon_{rec}}{\varepsilon_{act}} - 1 = 0.22\ \%\ \text{for}\ \Delta x' = 0{,}01\ \text{mrad}$$

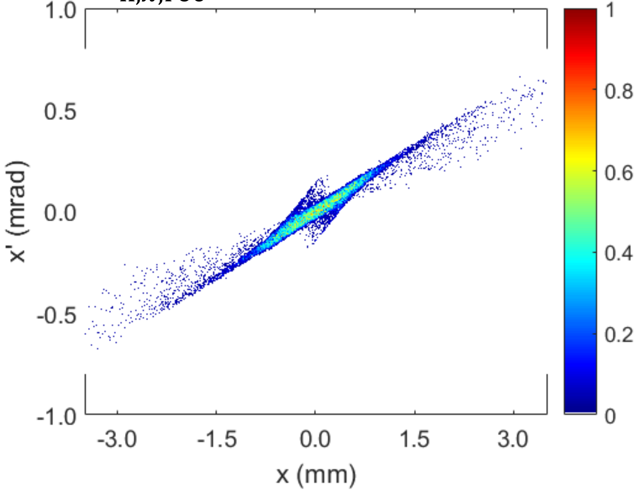
$$\frac{\varepsilon_{rec}}{\varepsilon_{act}} - 1 = 0.35\ \%\ \text{for}\ \Delta x' = 0{,}02\ \text{mrad}$$

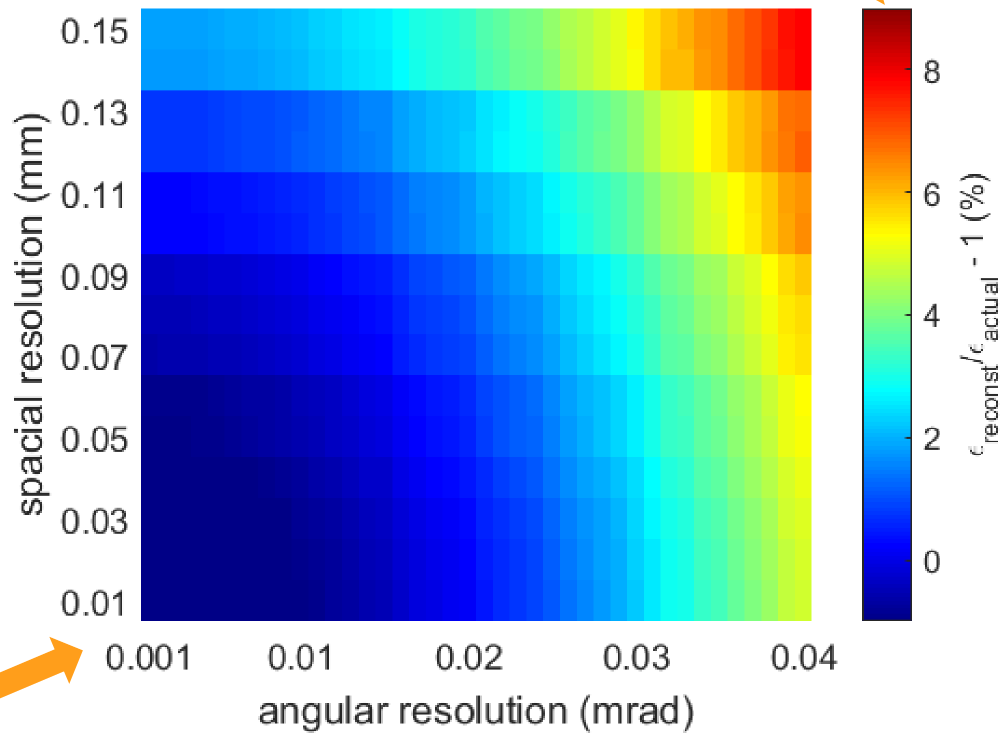
Same for different distribution

Deviation of reconstructed emittance

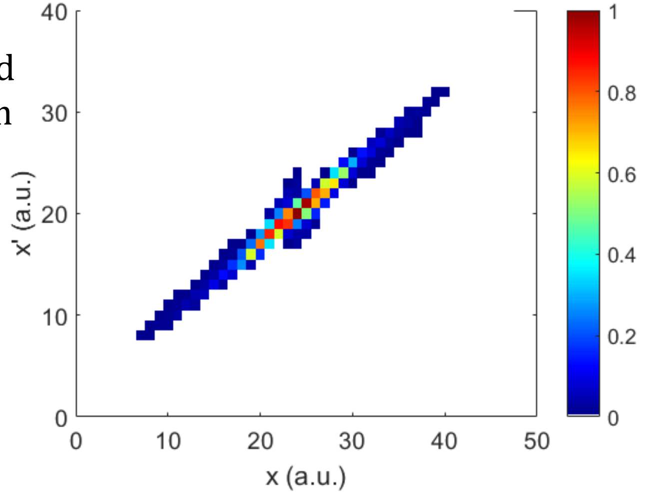


$\Delta x = 0.01$ mm
$\Delta x' = 0.001$ mrad
$\varepsilon_{\mathrm{n},x,\mathrm{rec}} = 0.96$ um





$\Delta x = 0.15$ mm
$\Delta x' = 0.041$ mrad
$\varepsilon_{\mathrm{n},x,\mathrm{rec}} = 1.50$ um



$$\frac{\varepsilon_{\mathrm{rec}}}{\varepsilon_{\mathrm{act}}} - 1 = -0.58\ \%\ \text{for}\ \Delta x' = 0{,}01\ \text{mrad}$$

$$\frac{\varepsilon_{\mathrm{rec}}}{\varepsilon_{\mathrm{act}}} - 1 = 0.57\ \%\ \text{for}\ \Delta x' = 0{,}02\ \text{mrad}$$

Outlook

Reconstructed emittance vs phase space resolution

- Different resolutions change the value of the reconstructed emittance, but
- Deviation from the actual emittance is small, for our resolution < 1%
- Small deviations can sum up to a deviation of 10 %* or more, from
  - Finite slit width
  - Space charge effects

Bottom line: Screen resolution is sufficient for correct reconstructions

*desired maximal systematic uncertainty in emittance measurements