Phase space measurements with tomographic reconstruction at PITZ.

- PITZ – Photo-Injector Test facility @ DESY in Zeuthen
- Emittance measurements at PITZ
- Tomographic reconstruction with 2 quadrupoles
- Summary

G. Asova for the PITZ team

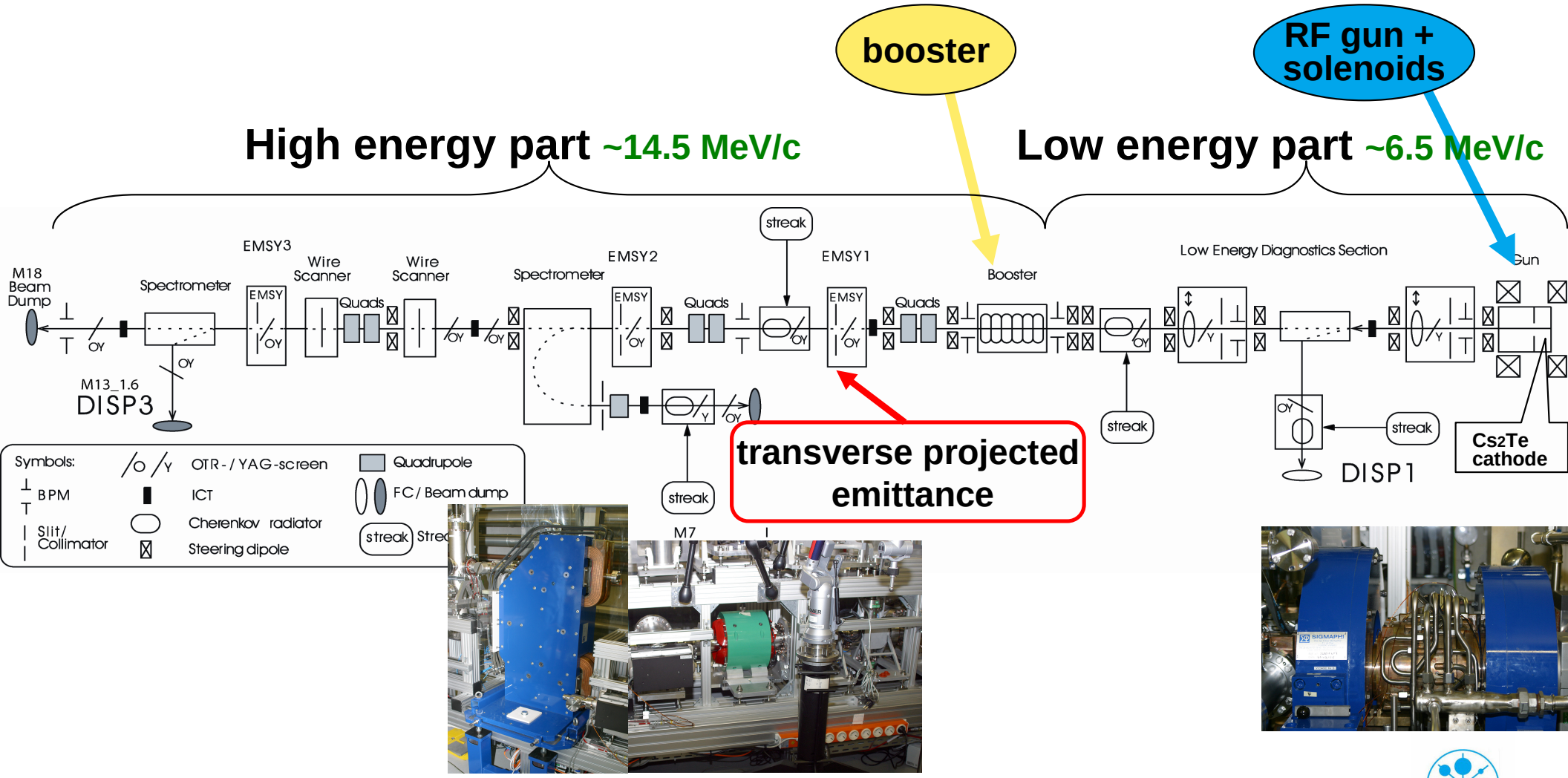
FEL 2010, Malmö

HELMHOLTZ | ASSOCIATION

DESY

PITZ setup: 2008/09

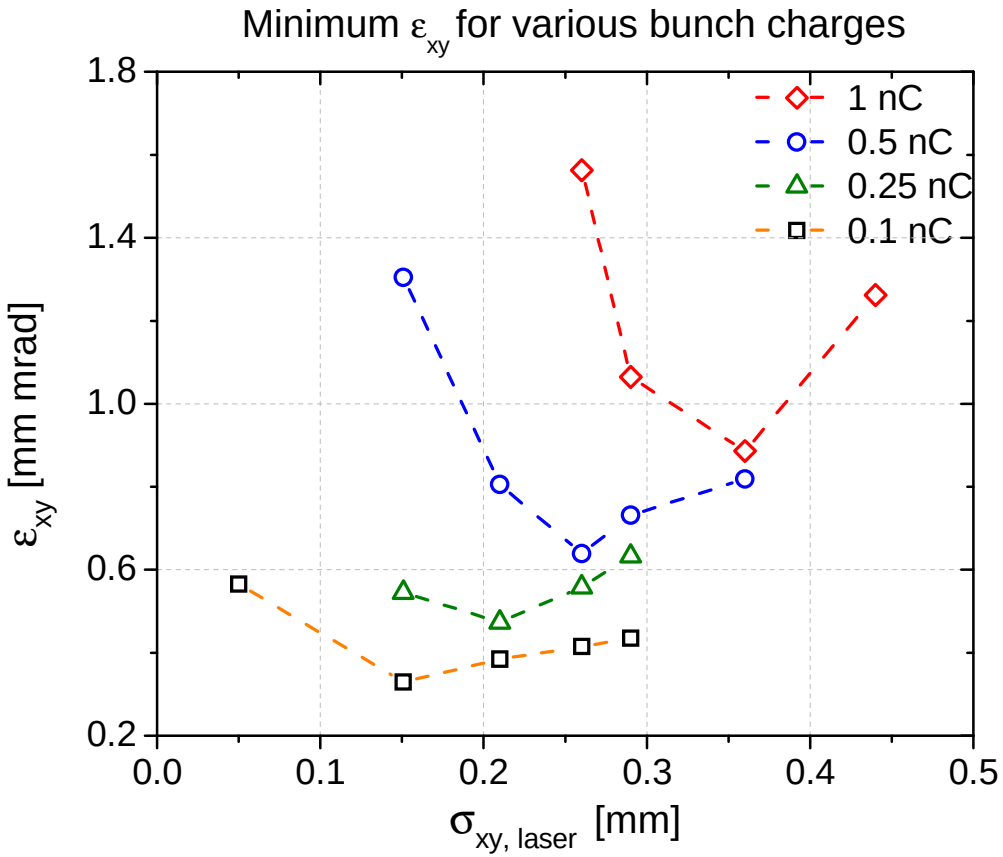
Produce electron beams with minimized transverse projected emittance as required for the European XFEL



Transverse phase space measurements

Single slit scan – standard measurement procedure

S. Rimjaem **WEPB09**



$$\varepsilon_{xy} = \sqrt{\varepsilon_x \varepsilon_y}$$

Q [nc]	ε_{xy} [mm mrad] *	
	100 %	95 %
1	**0.89 ± 0.01**	**0.77**
0.5	0.64	0.6
0.25	0.47	0.41
0.1	0.33	0.3

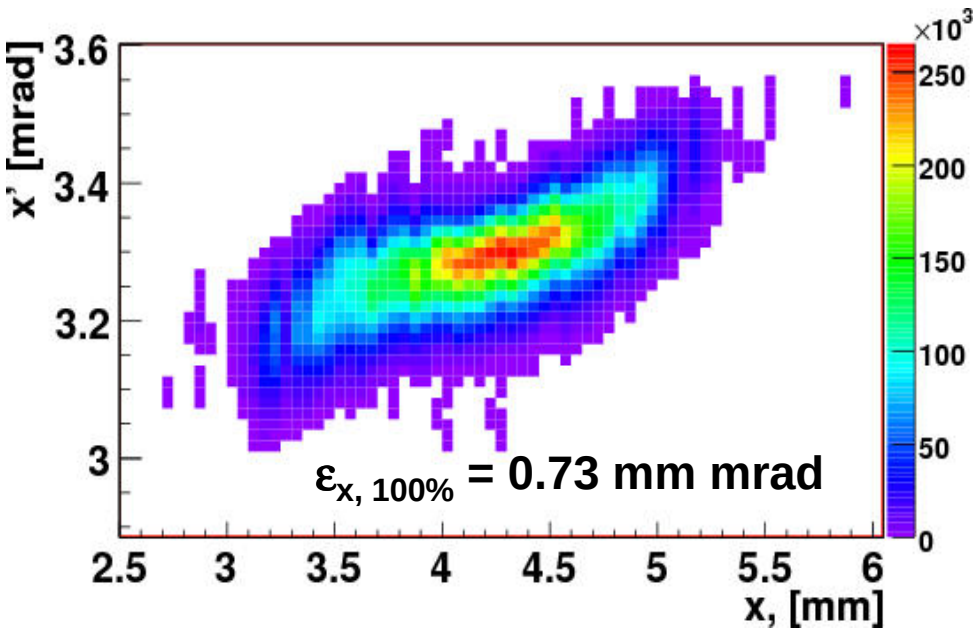
* Values obtained from solenoid scans for various laser spot sizes.

- Beamlet image grabbing while **continuously moving** the slit, duration down to **~ 30 sec**
- Gain time for statistics and more **details of the phase space**
- Image quality criteria - use the full dynamic range of the cameras → **100% ε_{xy}**

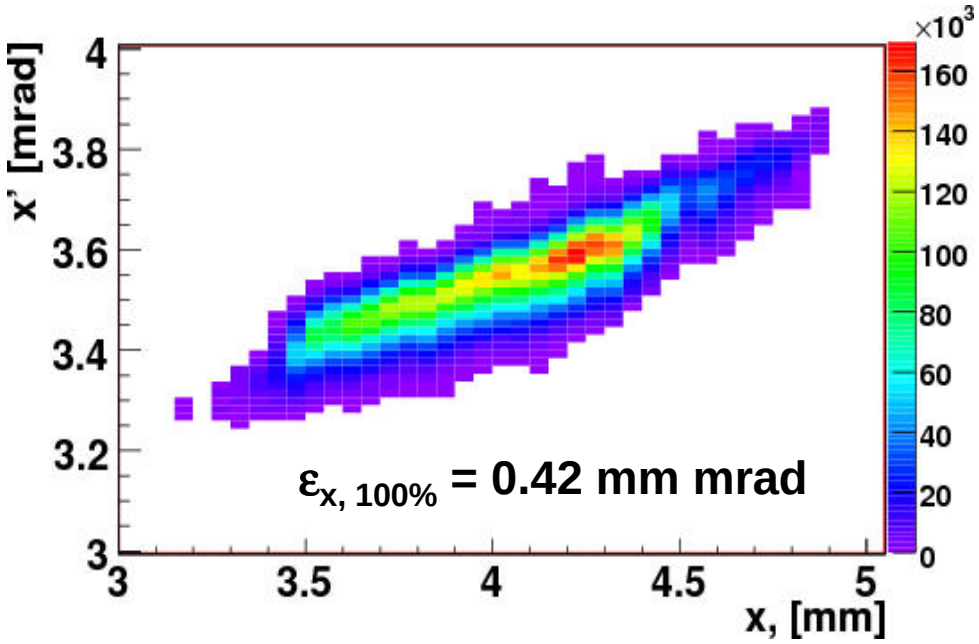
Phase-space portraits from slit scans

- Separately scan the two transverse planes
- Sensitive to S2N ratio → multi-shot measurements to collect as full as possible signal → smearing of the phase space due to possible machine fluctuations, e.g. gun phase

1 nC, 28 laser pulses



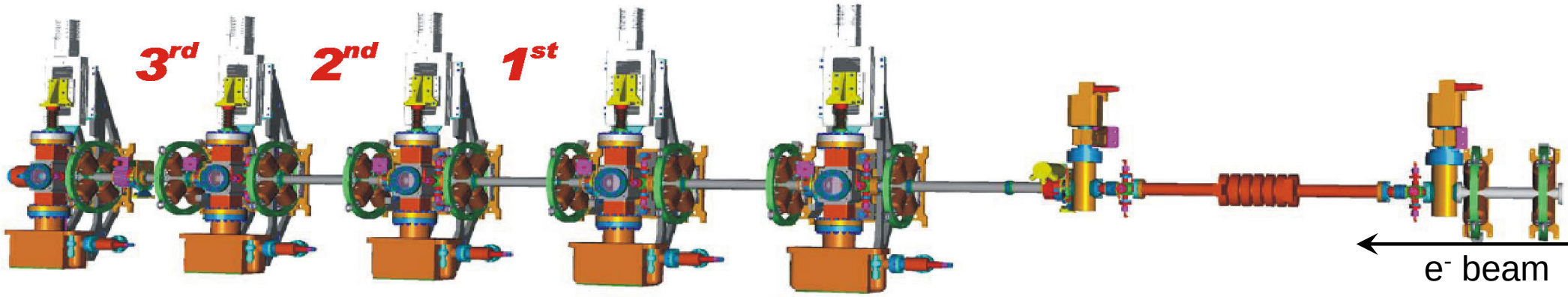
0.25 nC, 41 laser pulses



Tomography module

- Facilitates low charge measurements with short bunch trains

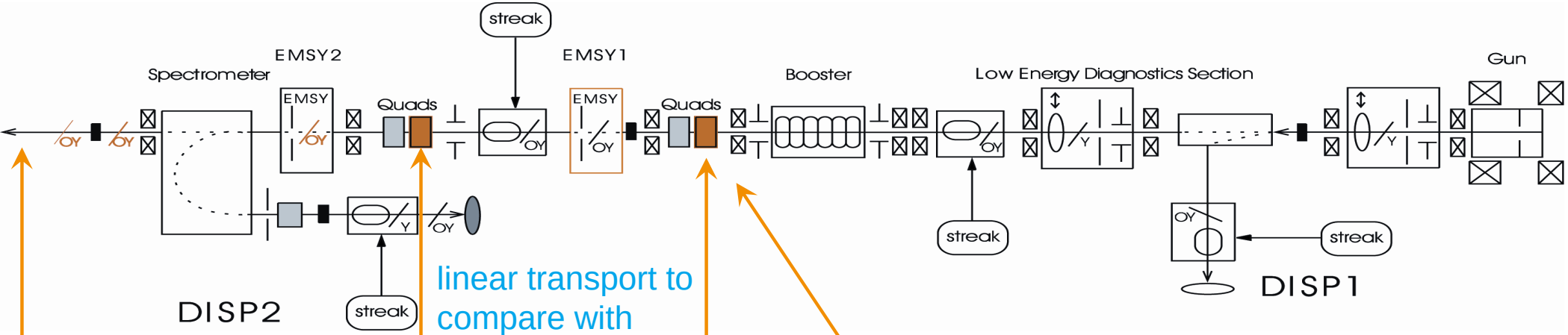
J. Saisut **WEPB10**



- Resolve both transverse planes simultaneously
- Design for 15-30 MeV/c, 1 nC
- Challenging matching due to space charge impact
- Stringent alignment tolerances
  - 20 mrad quadrupole angular misalignment, 100 um longitudinal misplacement
- Slow and complicated analysis
- Currently under commissioning @ PITZ

Reconstruction with quadrupole scan setup in 2008/09

Tests of the Maximum ENTropy – MENT - reconstruction algorithm and the image processing.



linear transport to compare with standard EMSY measurements

position of reconstruction

2 quadrupole magnets needed:

> scanning → single plane can be measured

> second one fixed to counteract rotation of the non-scanned plane and possible space charge effects, avoid small beam sizes

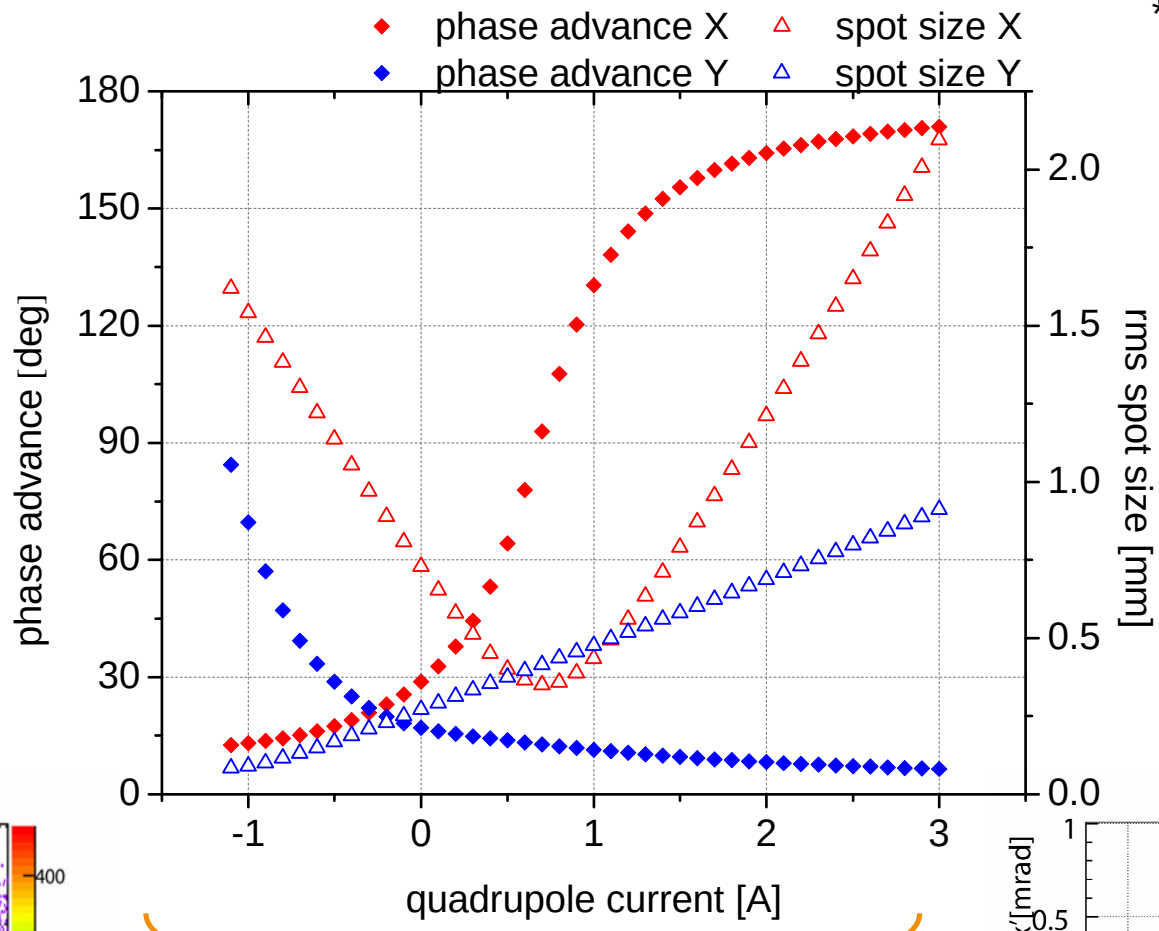
Observation screen position determined by the energy and charge

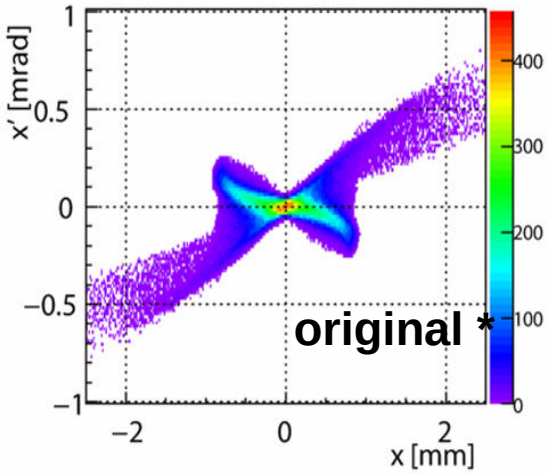
Methodics of a quadrupole scan for tomography – (x, x') reconstruction

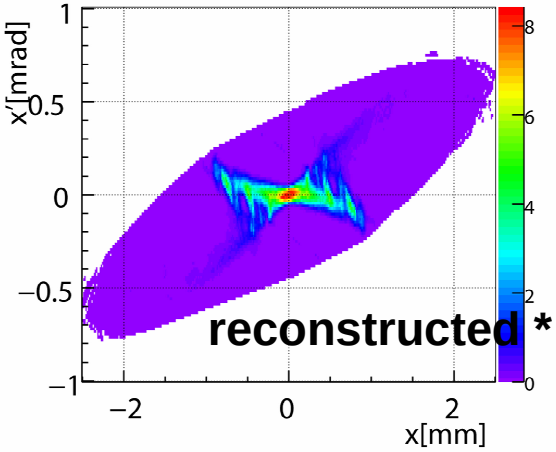
* ASTRA simulations

scanning quadrupole

fixed quadrupole







Full range, including ϕ_y not constant

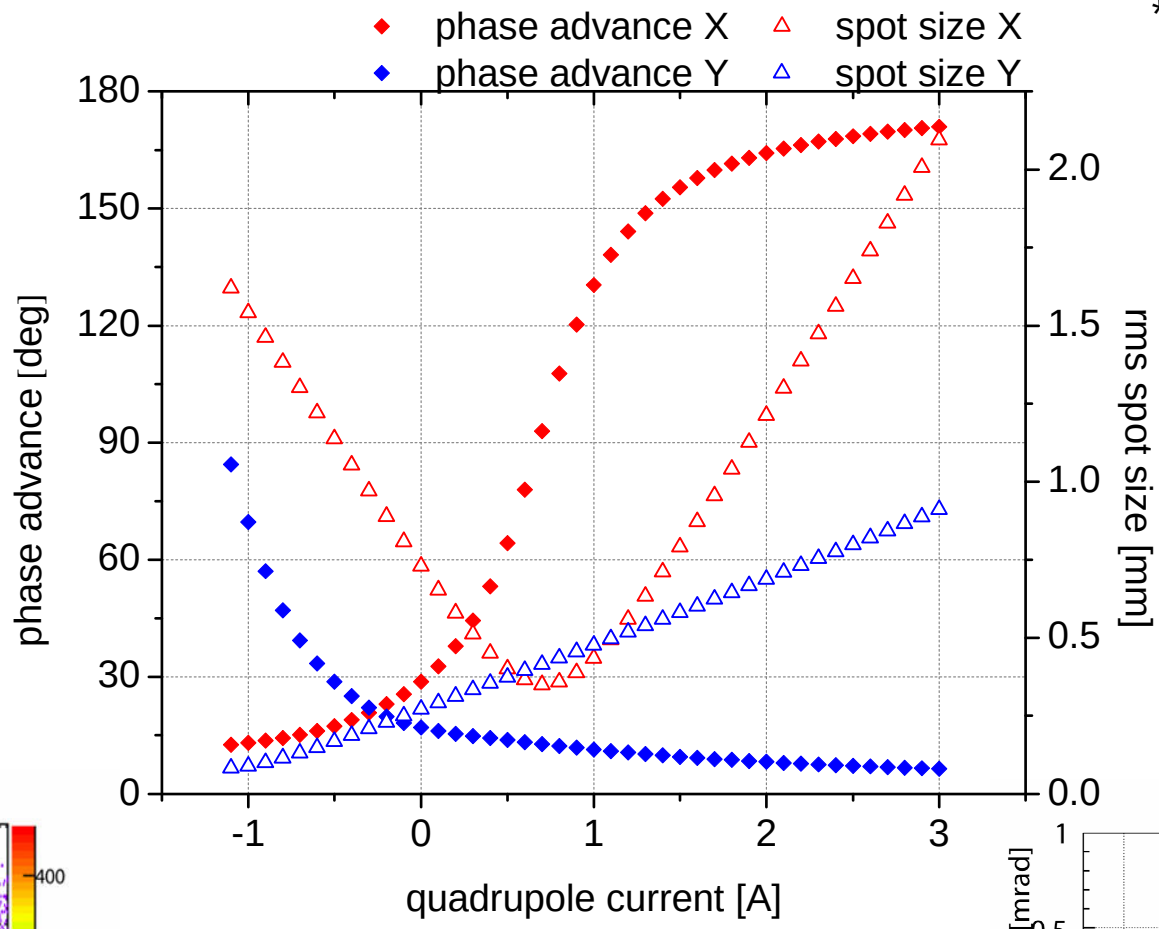
Artefacts in the reconstructed phase space

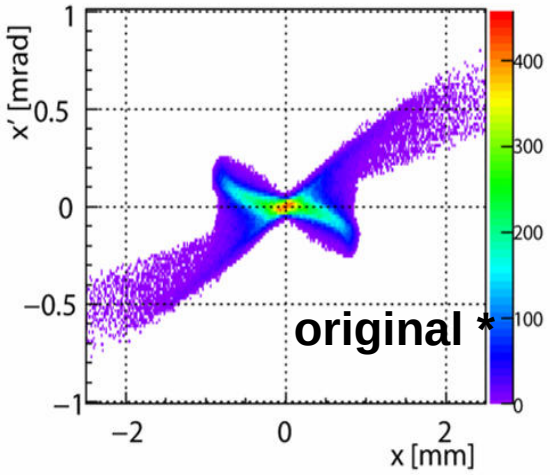
Methodics of a quadrupole scan for tomography – (x, x') reconstruction

* ASTRA simulations

scanning quadrupole

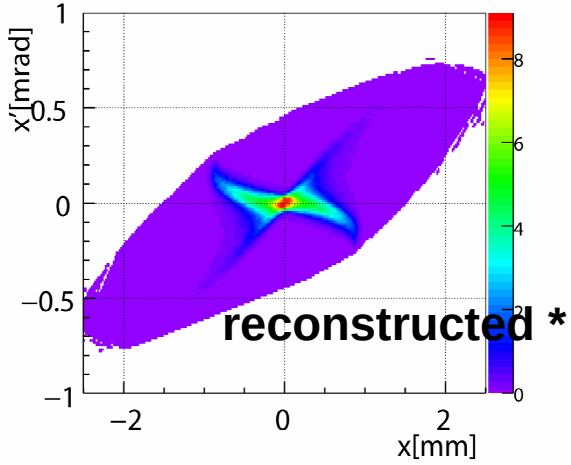
fixed quadrupole





Small variations in ϕ_y

Improved reconstruction quality

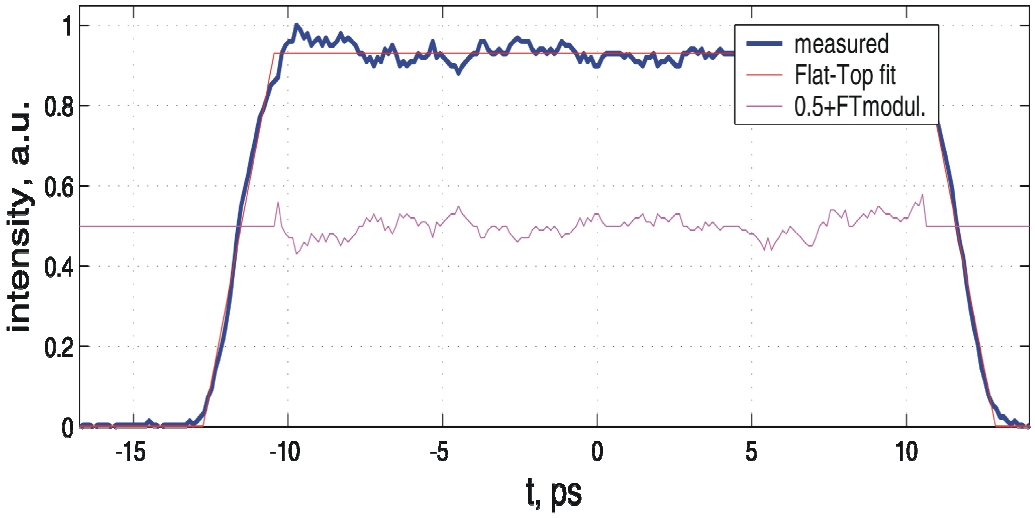


Experimental reconstruction: measurement conditions

- Cathode laser

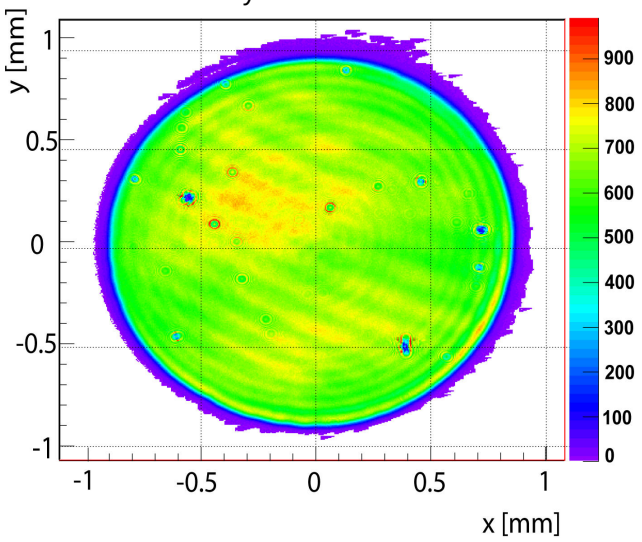
Temporal profile

23 ps FWHM, RT = 2.3 ps, FT = 2.3 ps



Transverse distribution

σ_{xy} = 0.44 mm



Quadrupole and slit scan for each point from a solenoid scan

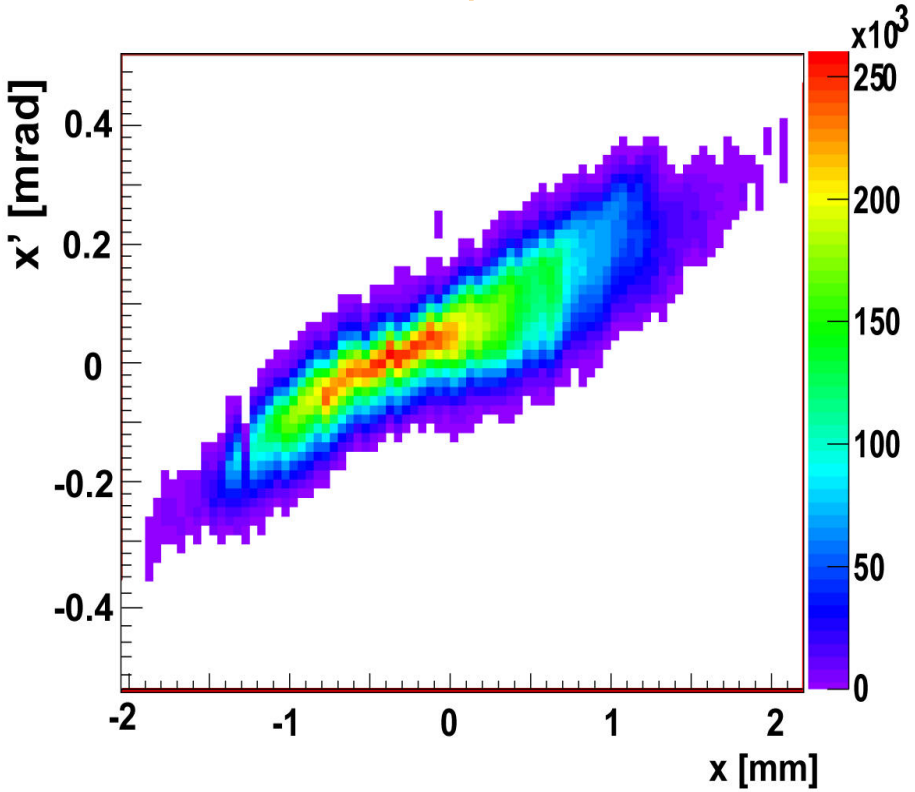
$\varepsilon_{xy} = \varepsilon_{xy}$ (solenoid current)

Q	1	nC
$E_{cathode}$	58	MV/m
ϕ_{gun}	+6	deg
$\phi_{booster}$	0	deg
p_z	14.7	MeV/c

Experimental reconstruction: results

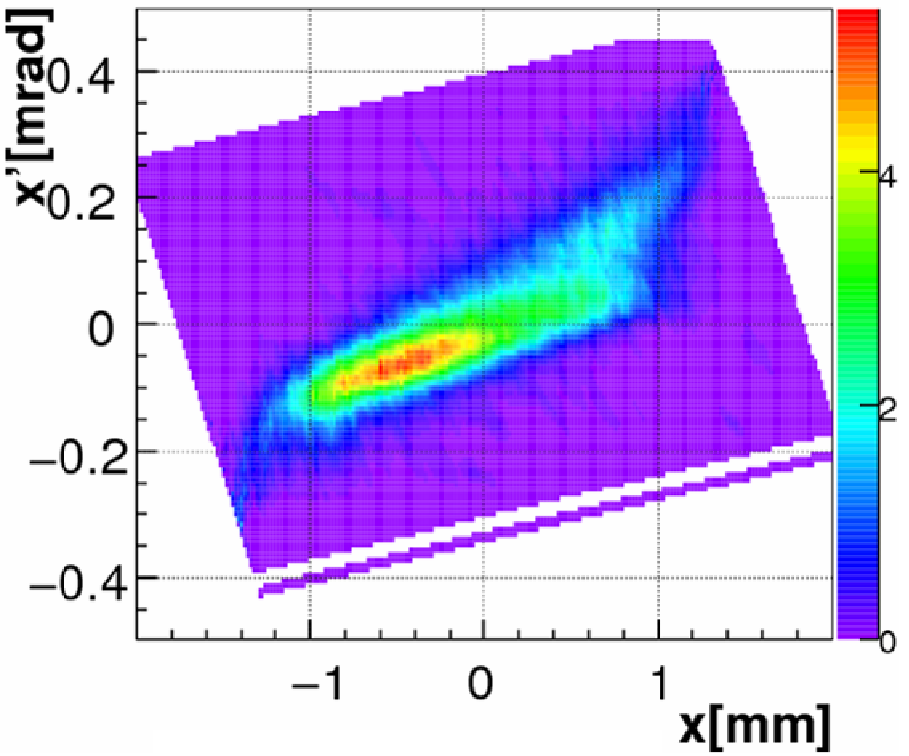
Minimum emittance from the slit scan

Slit scan, 35 pulses



$\varepsilon_{x,N}$ = 1.07 mm mrad

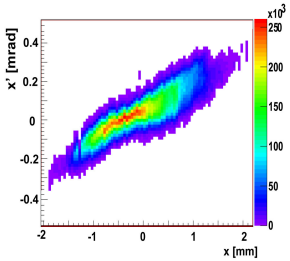
Tomography, 1 pulse, 15 projections

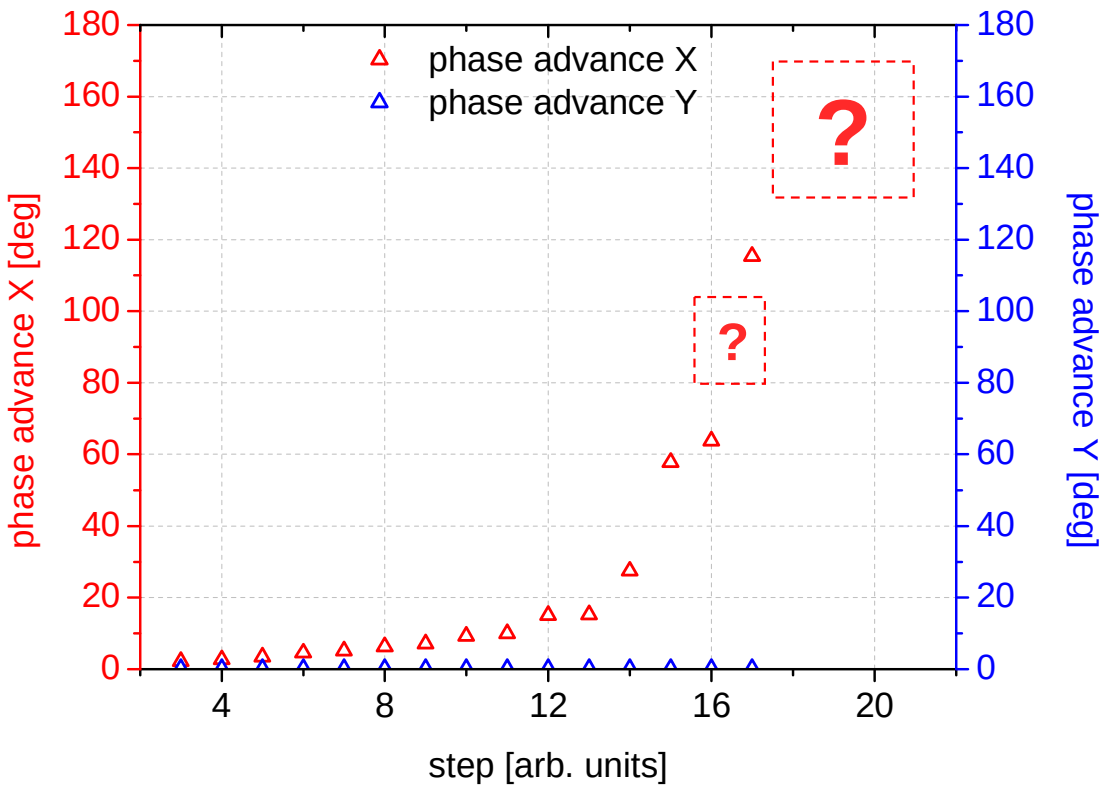


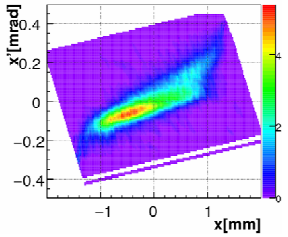
$\varepsilon_{x,N}$ = 1.33 mm mrad

The reconstruction shows bigger area where charge can be distributed.

Experimental reconstruction: phase advance range







ϕ_y ~ const

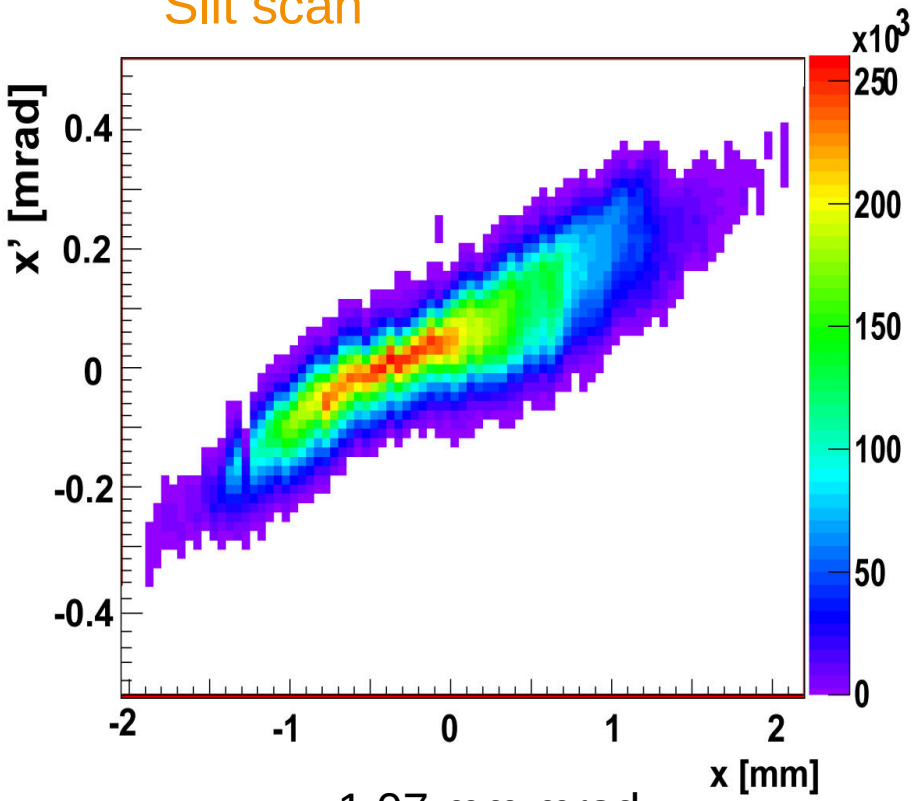
Poor sampling of the range of the horizontal phase advance

→ the phase-space area can decrease further.

Experimental reconstruction: intensity cut

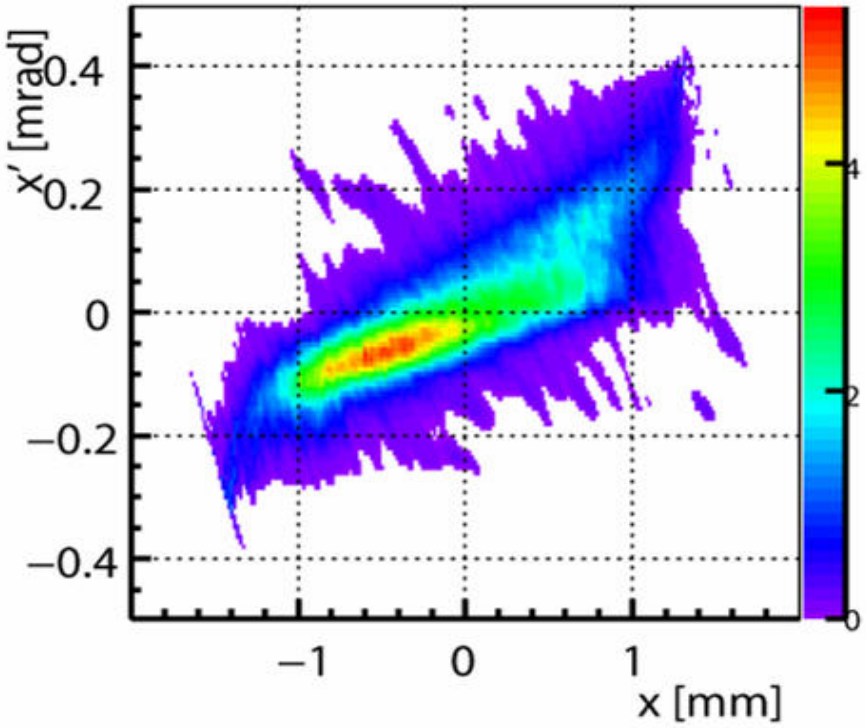
0.5 % intensity cut

Slit scan



$\varepsilon_{x,N}$ = 1.07 mm mrad

Tomography



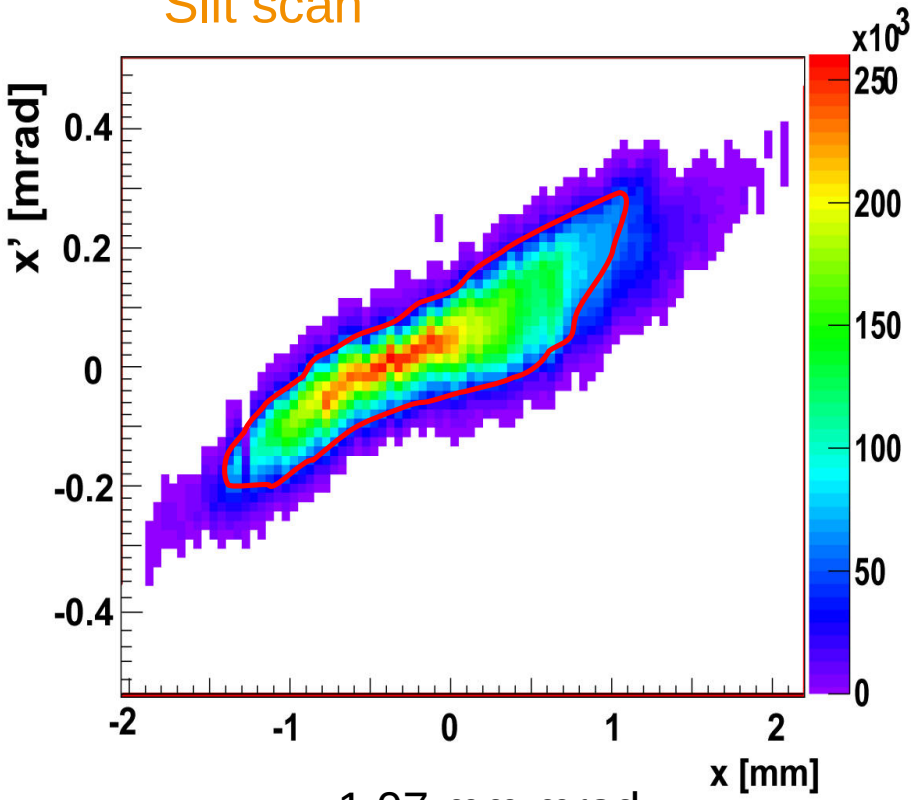
$\varepsilon_{x,N}$ = 1.3 mm mrad

The contribution of the low-intensity bins is negligible.

Experimental reconstruction: intensity cut

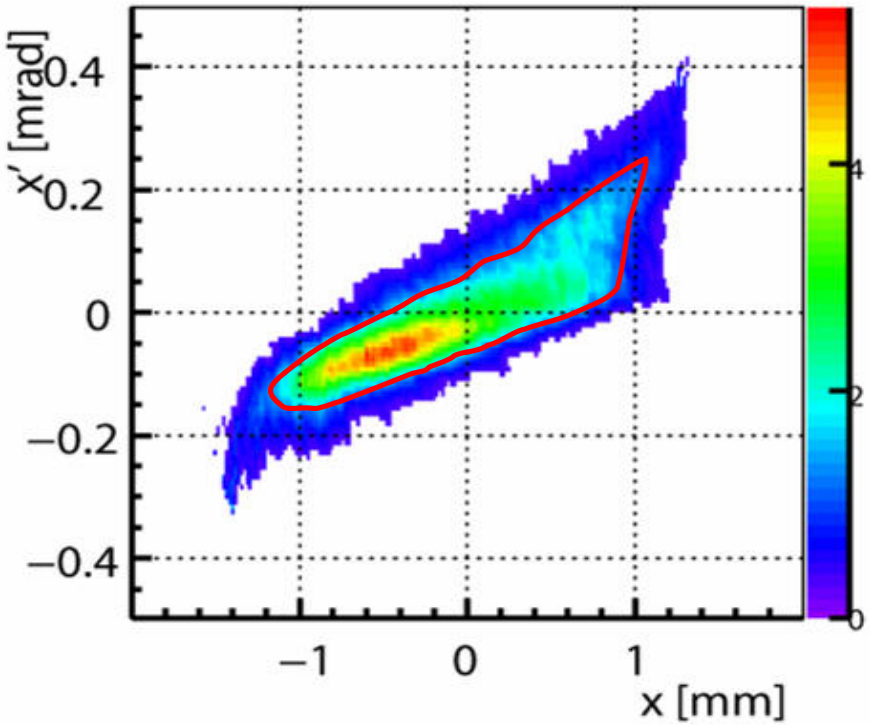
5 % intensity cut

Slit scan



$\varepsilon_{x,N}$ = 1.07 mm mrad

Tomography



$\varepsilon_{x,N}$ = 1.06 mm mrad

- **Common features** in both distributions
  - elongated non-symmetric tails
  - non-symmetric density of the core

Machine stability!

Conclusions

- PITZ has demonstrated XFEL beam quality - low emittance for nominal 1 nC bunch charge

$$\varepsilon_{xy,\ 100\%} = 0.89 \pm 0.01 \text{ mm mrad}$$

- The nominal reconstruction algorithm – MENT, tested
- The slit and quadrupole scans agree well within 5% cut of the max intensity
- Reconstruction with quadrupole scan is more sophisticated measurement but delivers more details in the phase-space portraits for proper scan range
- Phase space tomography module currently under commissioning @ PITZ

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The PITZ collaboration

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