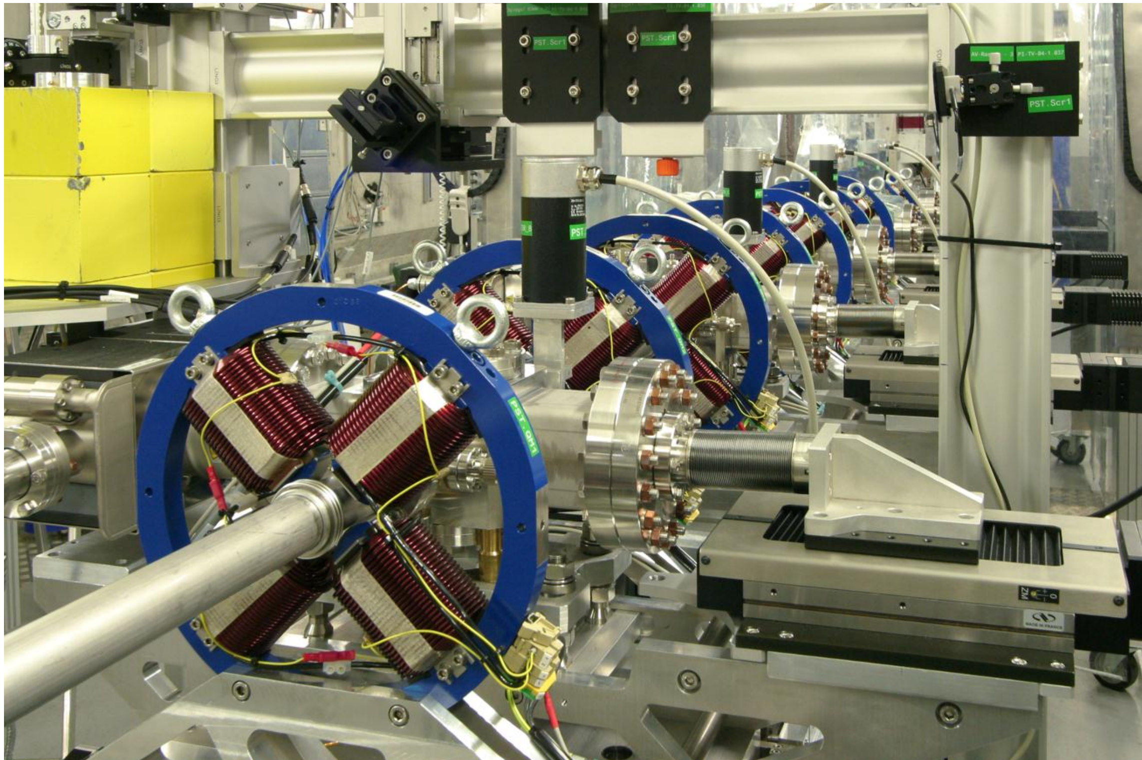
Tomography module for transverse phase-space measurements at PITZ

> **Photo-Injector Test facility @ DESY in Zeuthen - PITZ**
> **Tomography module**
> **Measurement results**
> **Conclusions and outlook**



G. Asova for the PITZ team

DITANET 2011, Seville

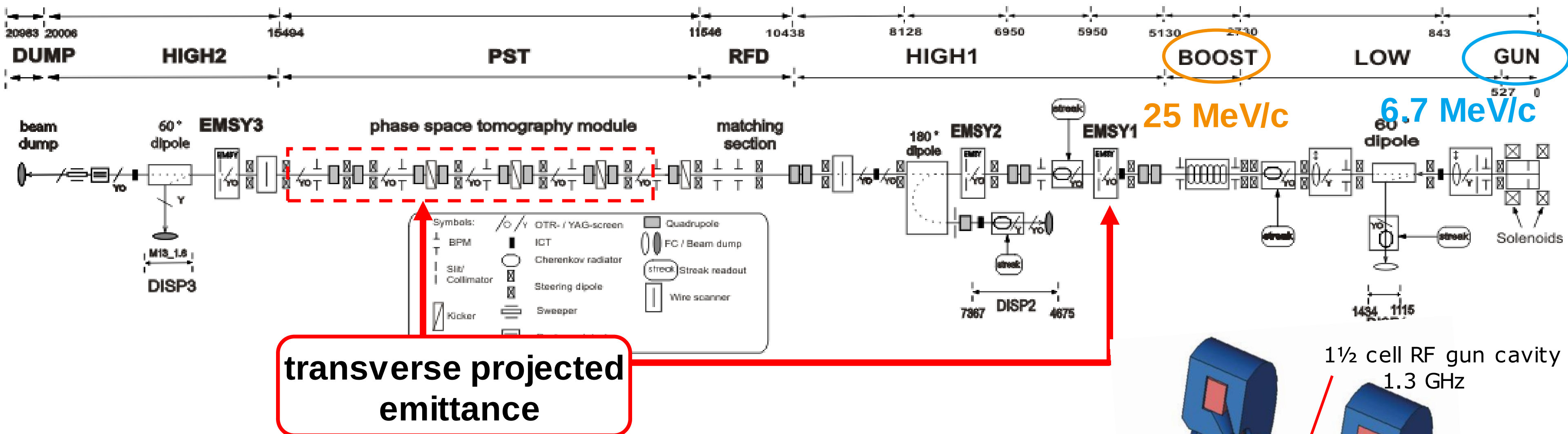
HELMHOLTZ | ASSOCIATION

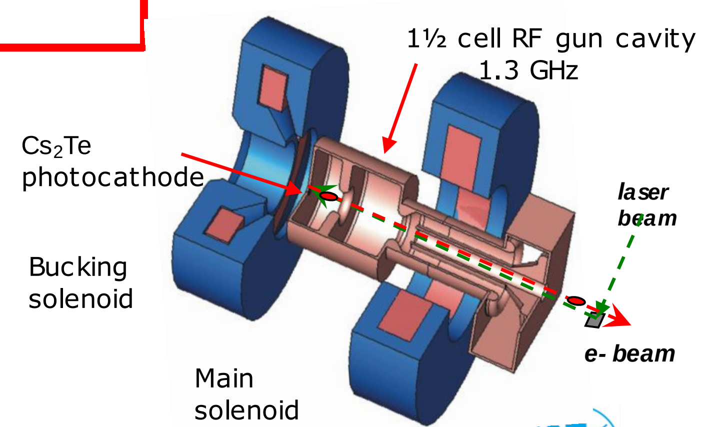
DESY

Photo-Injector Test facility

Produce electron beams with minimized transverse emittance as required for the European XFEL photo-injector:

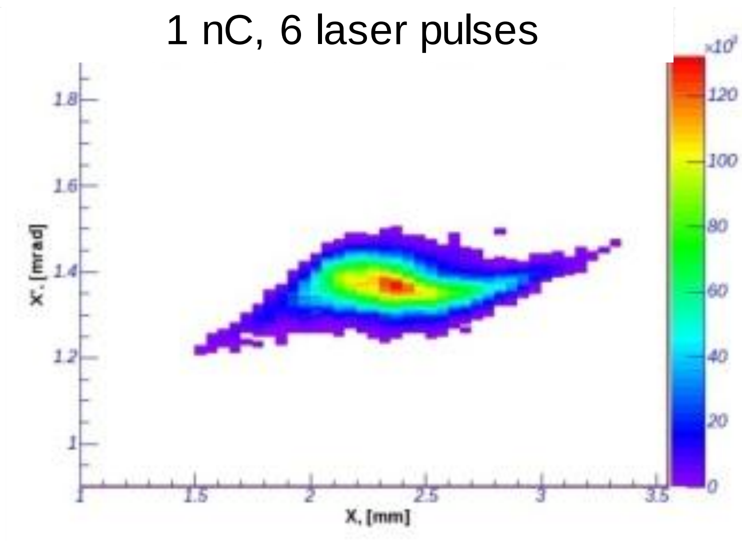
< 1 mm mrad for 1 nC

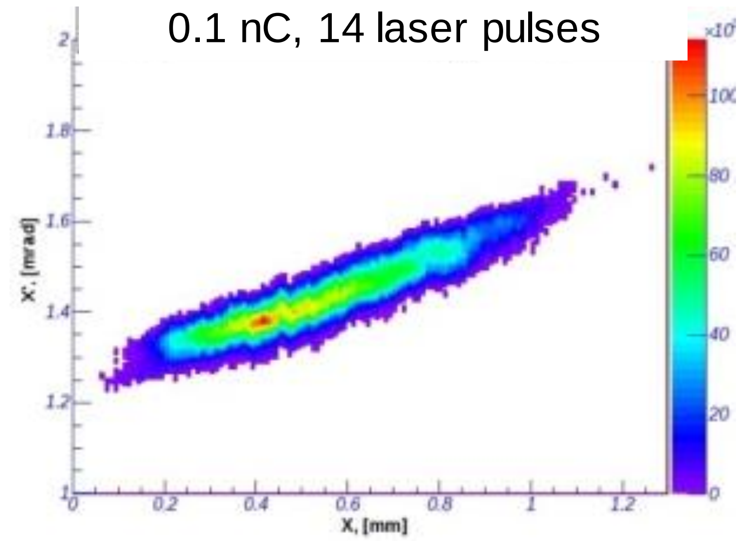




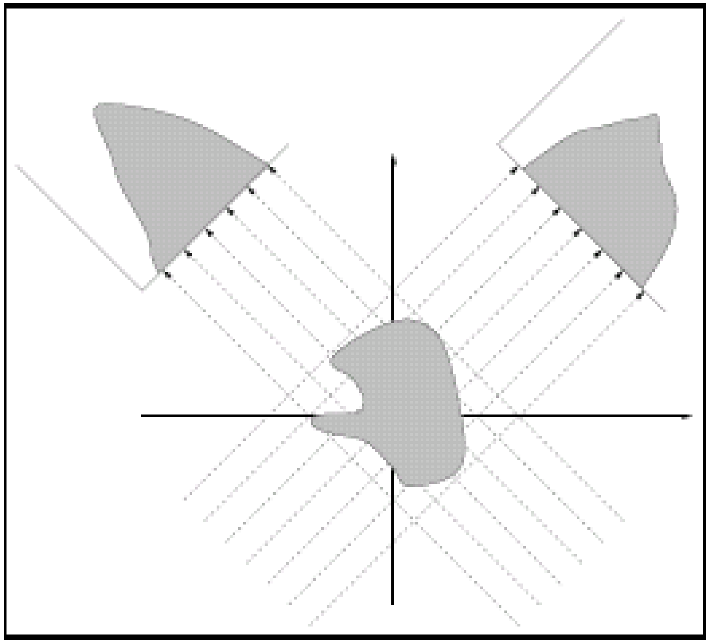
Phase-space portraits

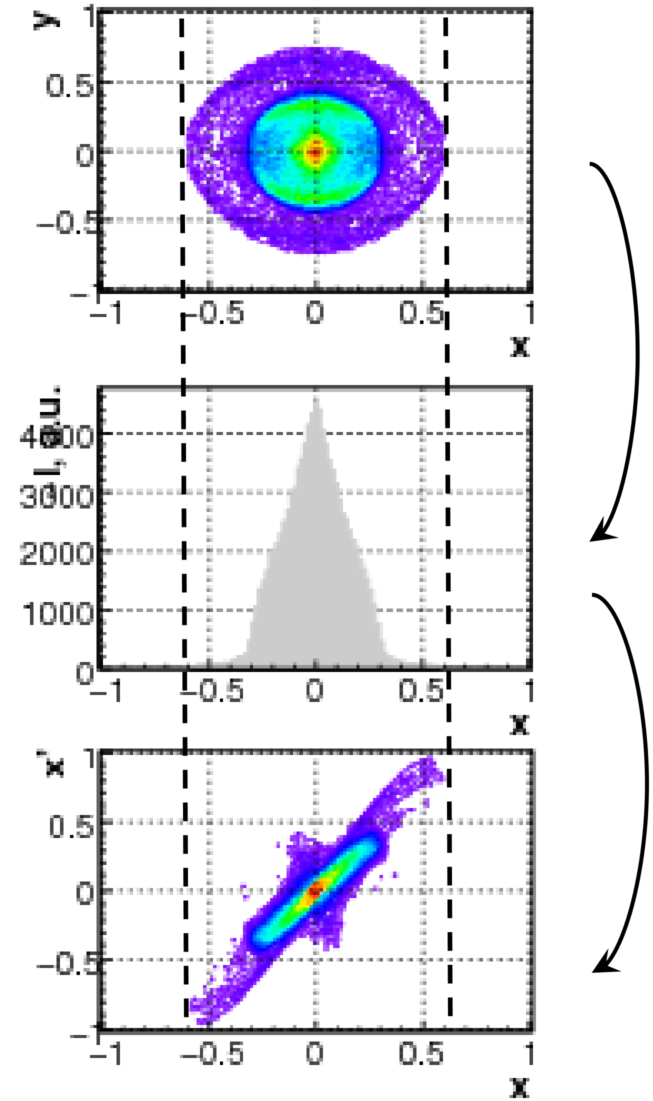
- Standard measurement method – slit scan
- Separately scan the two transverse planes
- Sensitive to signal-to-noise ratio → multi-shot measurements to collect as full as possible signal → smearing of the phase space due to possible machine fluctuations





Tomography

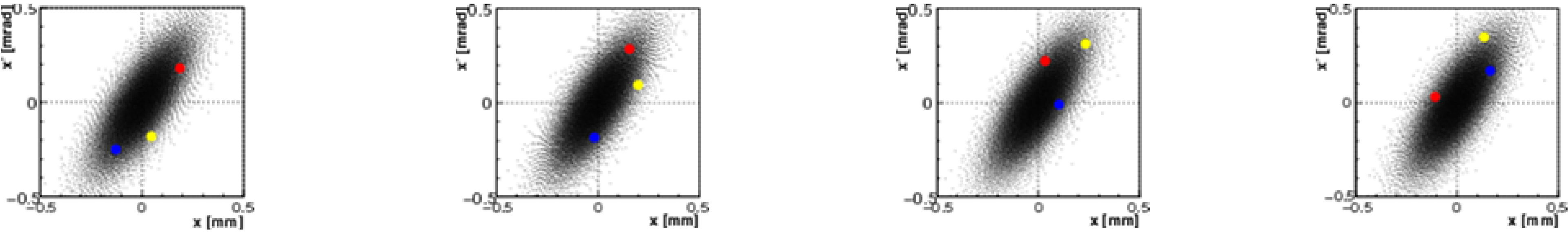


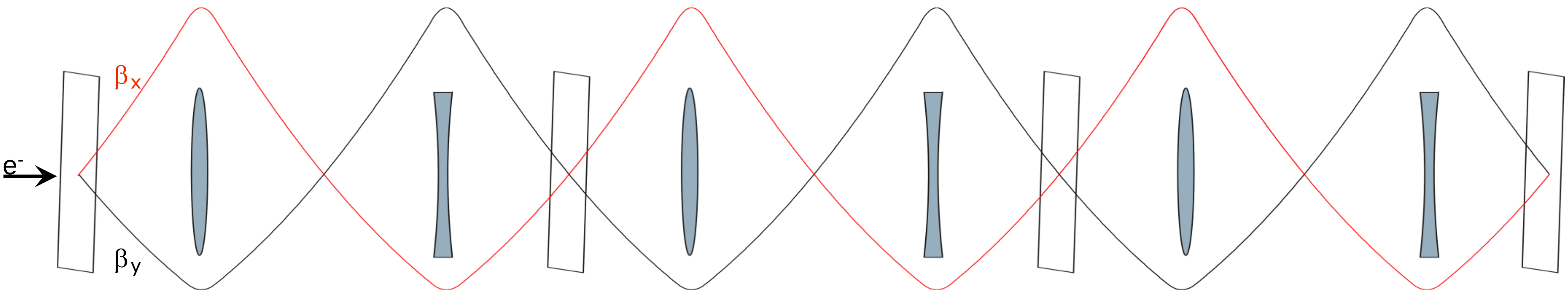


Reconstruction of an object from a number of its projections at different angles -

Radon transform

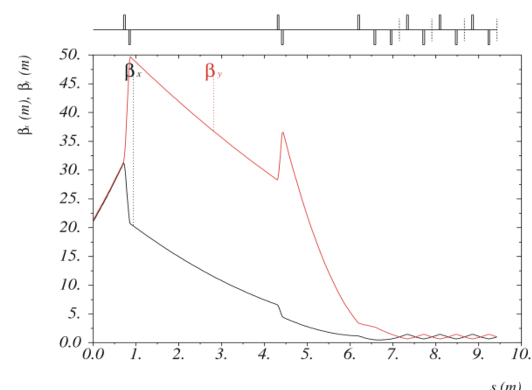
Phase-space tomographic reconstruction





(focusing – drift – defocusing – drift)

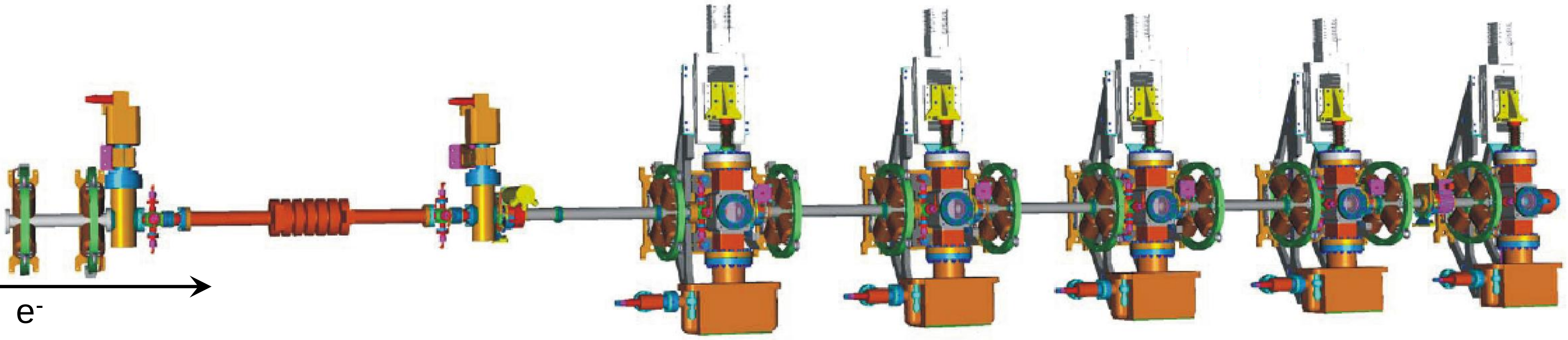
FODO cell



> equidistant angular steps between the screens for both planes (2D)

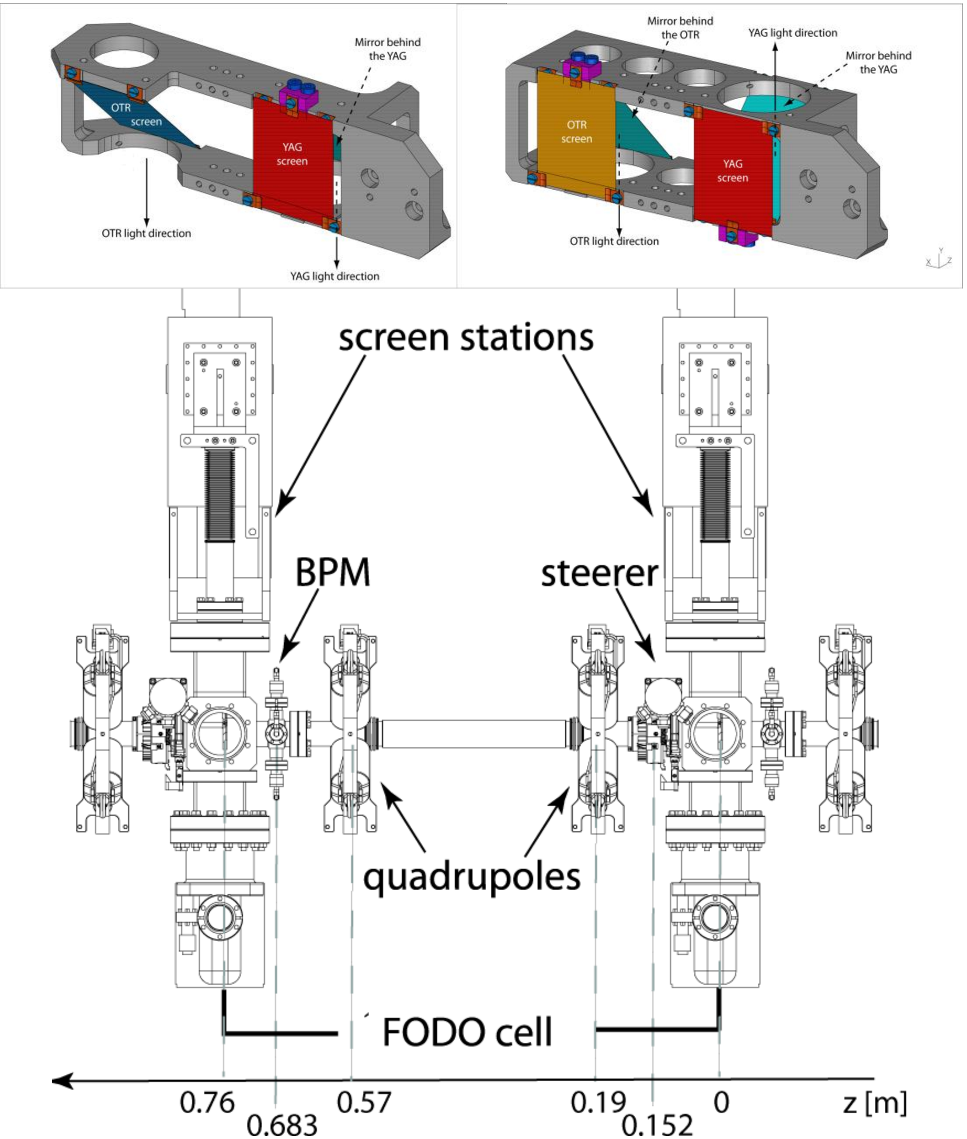
> the beam parameters at the entrance of the lattice are adjusted

Tomography module



- Design for 15-30 MeV/c, 1 nC
- Challenging matching due to space-charge impact
- Slow and complicated analysis

Major components



x 5 FODO cells

Components (details in poster):

- Quadrupole magnets in FODO cells
- Screen stations
- Steering magnets
- BPMs

Short cells:

- Short quadrupoles $L_{eff} = 43$ mm
- Strong focusing
- Precise alignment along the full FODO lattice
  - 20 mrad quadrupole angular misalignment
  - 100 μm longitudinal misplacement

Measurements with the setup

> Nominal charge of 1 nC

- Emittance evolution along the beamline - cross-check the calculated emittance versus results from slit scans
- Different charge densities at the photo-cathode
- Reproducibility of the measurements

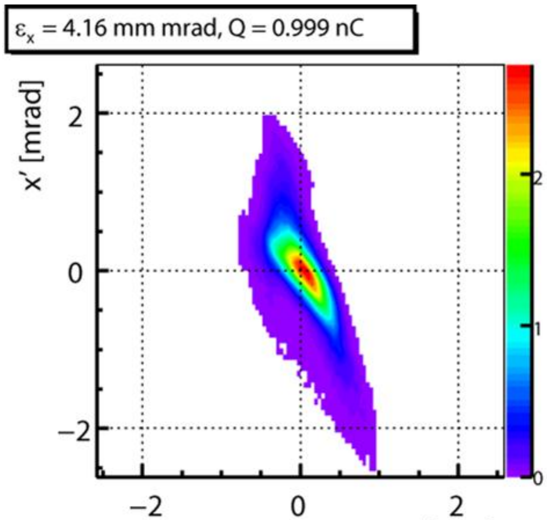
> Lower charges ≥ 100 pC

> Common machine setup:

- Max power from gun and booster, phases for max mean momentum gain, ~ 25 MeV/c
- Laser temporal profile – flat top with 2/22\2 ps

Measured phase spaces, 1 nC

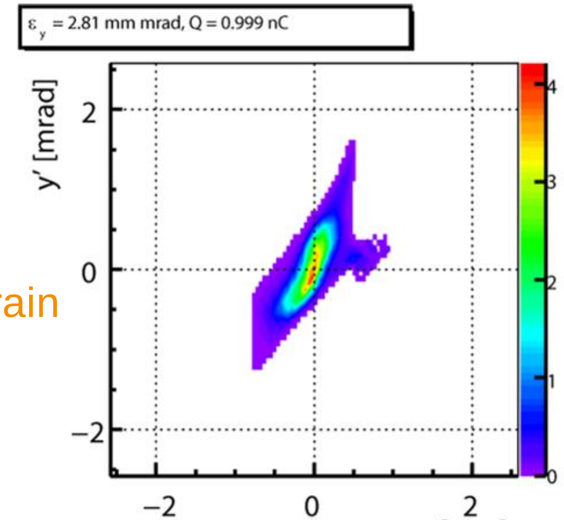
TOMO, z = 13.04 m



Strong tails

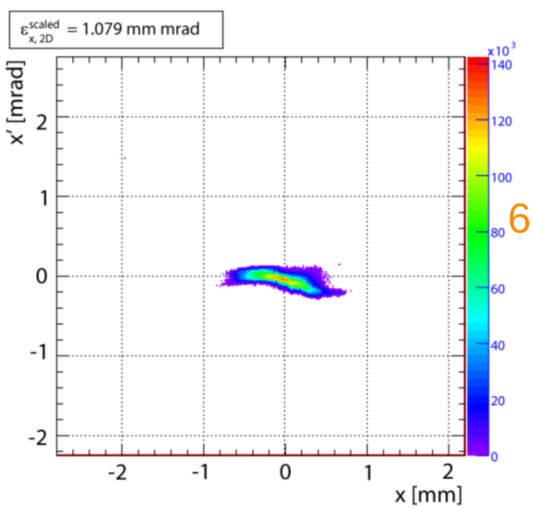
Orthogonal!

1 bunch in the train

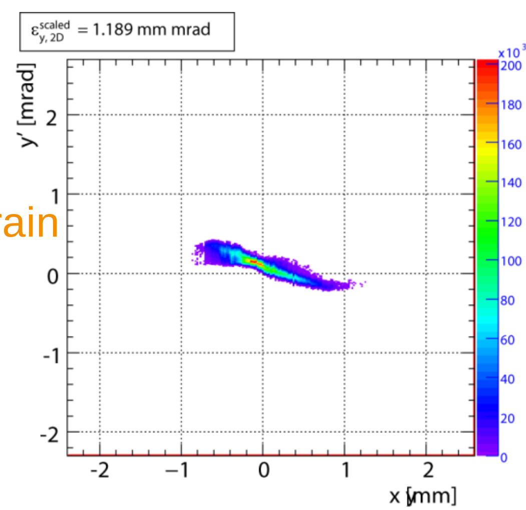


Substructure

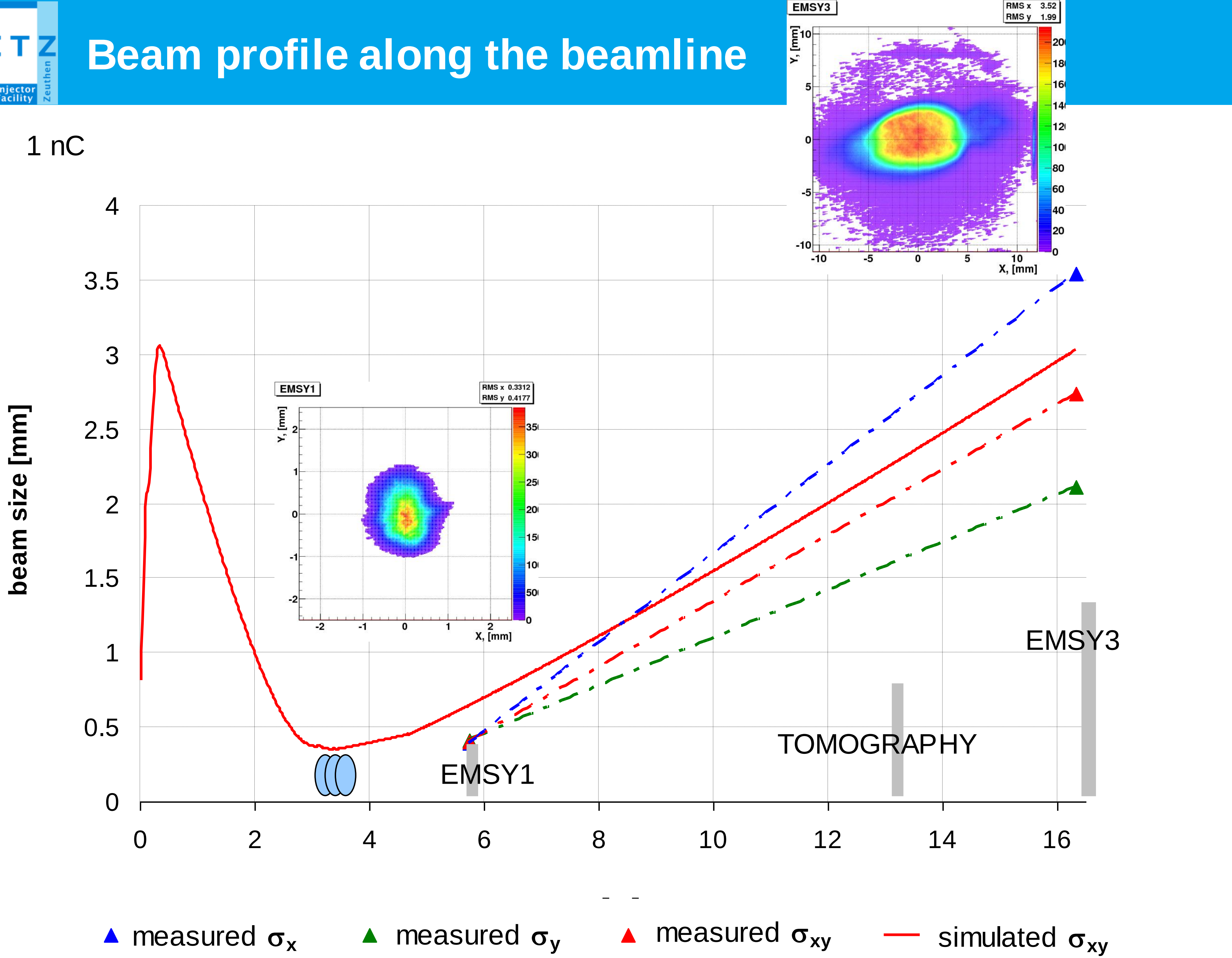
Slit scans, z = 5.74 m



6 bunches in the train

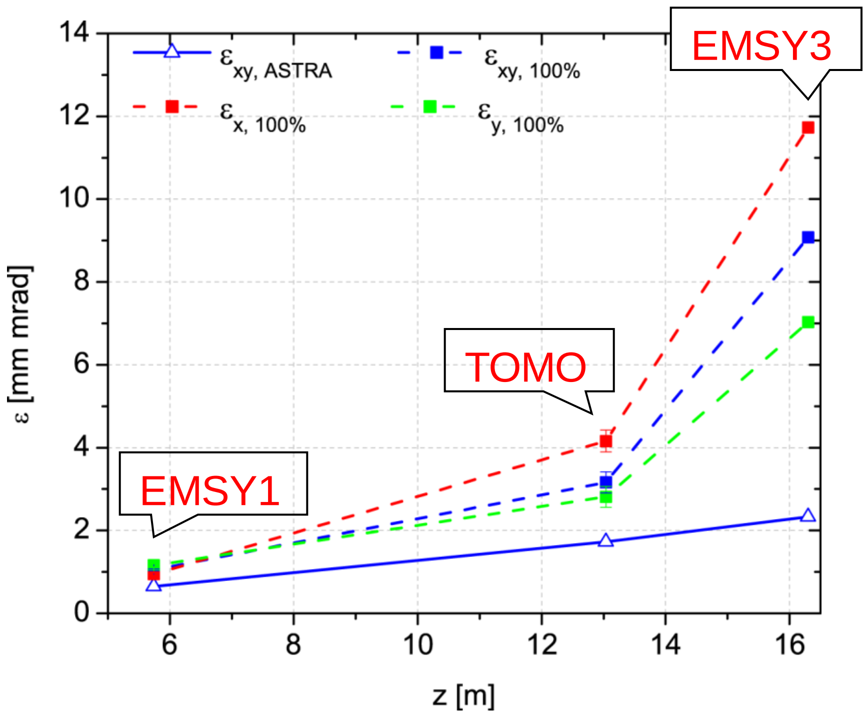


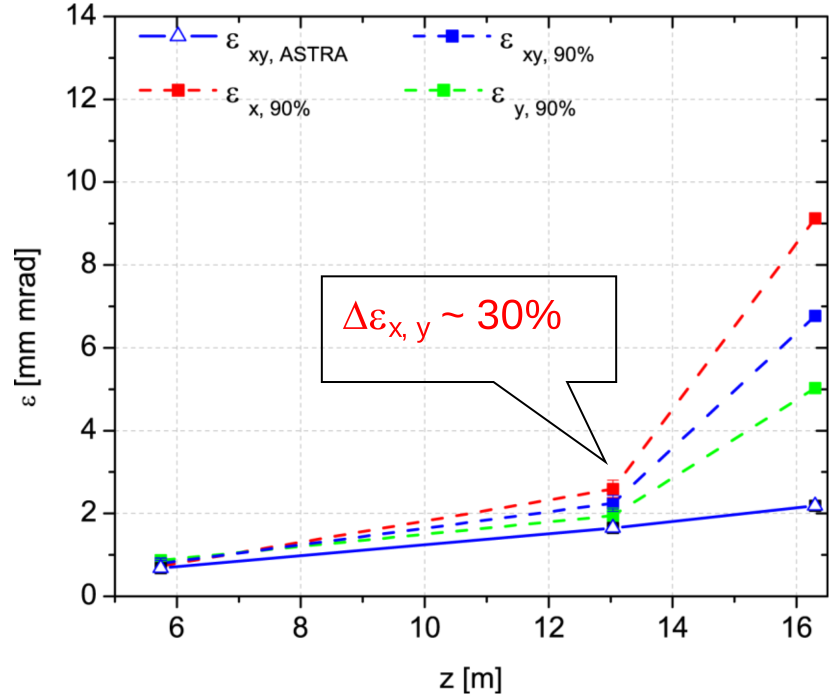
Beam profile along the beamline



Emittance evolution along the beamline

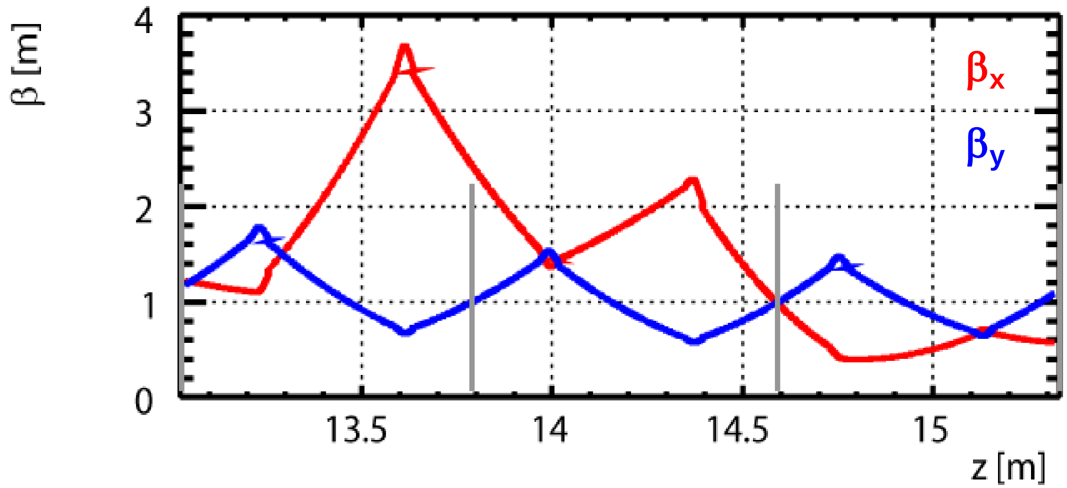
1 nC





Matching for 1 nC, 25 MeV/c

- Hard to keep both planes periodic along the FODO lattice



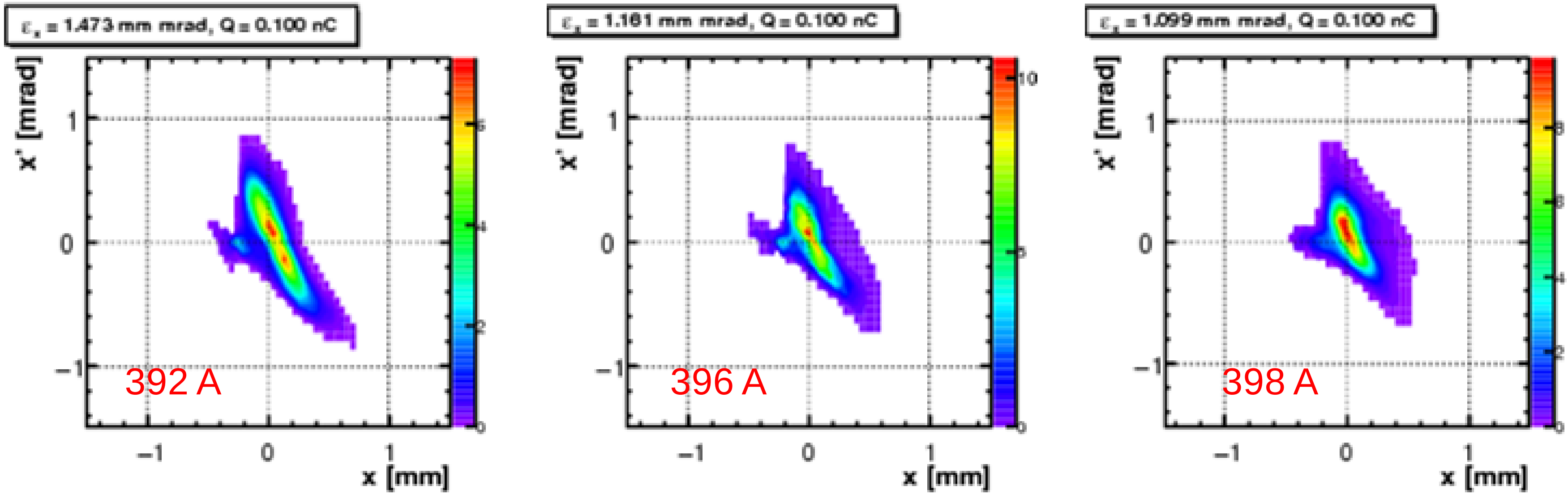
$\Delta\beta_y < 20\%$ - for such mismatches a solution can always be found

$$\Delta\beta = \frac{\beta_d - \beta_m}{\beta_d}[\%]$$

- β_y matched very good, but not β_x
  - consistent for different laser spot sizes, solenoid current, quadrupole settings, bunch charges

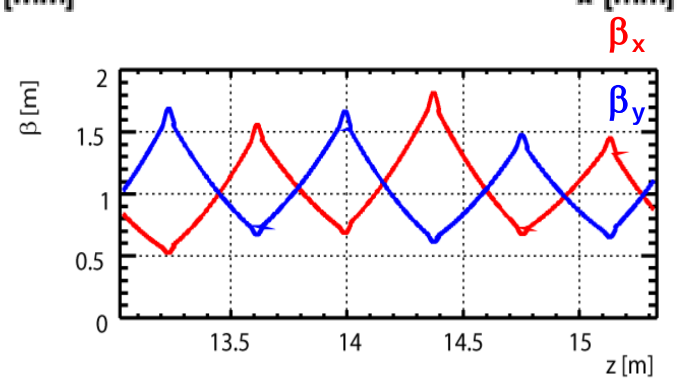
100 pC X-plane

> Emittance decreases with the solenoid focusing



> the orientation of the three distributions

is the same – matching worked in these cases



> As the area of the phase space decreases, the substructure comes closer to the main beam for higher solenoid currents

Conclusions & outlook

- Tomography module successfully commissioned
- Results cross-checked with standard for PITZ slit scans
- Details on the phase spaces downstream the beamline reconstructed in great details for short bunch trains
- The two transverse planes resolved simultaneously

- Kicker magnets to be installed for measurements of selected bunch in the train
- Transverse deflecting cavity for longitudinal phase-space measurements

The PIT Z collaboration

Colleagues participating in measurements / new design:

> **DESY, Zeuthen site:**
J. Bähr, H.J. Grabosch, M. Gross, A, Donat, I. Isaev*, Y. Ivanisenko**, G. Kourkafas***, G. Klemz, D. Malyutin, M. Krasilnikov, M. Mahgoub, J. Meissner, A. Oppelt, M. Otevrel, B. Petrosyan, S. Rimjaem, A. Shapovalov*, F. Stephan, G. Vashchenko

> **DESY, Hamburg site:**
A. Brinkmann, K. Flöttmann, S. Lederer, D. Reschke, S. Schreiber

> **BESSY Berlin:**
R. Ovsyannikov, D. Richter, A. Vollmer

> **ASTeC STFC Daresbury Lab:**
B. Militsyn

> **INRNE Sofia:**
G. Asova, I. Bonev, I. Tsakov

> **INR Troitsk:**
A.N. Naboka, V. Paramonov, A.K. Skassyrskaia, A. Zavadtsev

> **LAL Orsay:**
M. Jore, A. Variola

> **LASA Milano:**
P. Michelato, L. Monaco, D. Sertore

> **MBI Berlin:**
I. Will

> **TU Darmstadt:**
S. Franke, W. Müller

> **Uni Hamburg:**
J. Rönsch-Schulenburg

> **YERPHI Yerevan:**
L. Hakobyan, M. Khojoyan

* on leave from NRNU, Moscow, Russia

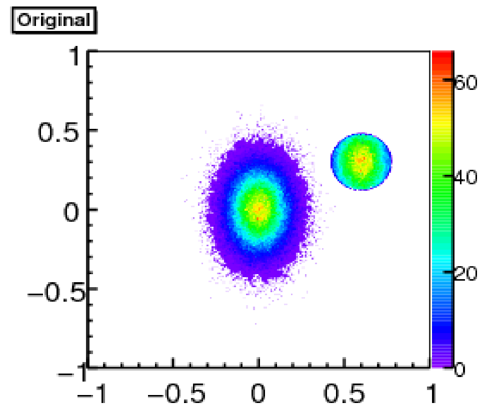
** on leave from IERT, NAS, Kharkiv, Ukraine

*** on leave from Athens, Greece

R. Brinkmann, U. Gensch, J. Knobloch, L. Kravchuk, V. Nikoghosyan, C. Pagani, L. Palumbo, J. Rossbach, W. Sandner, S. Smith, T. Weiland, G. Wormser

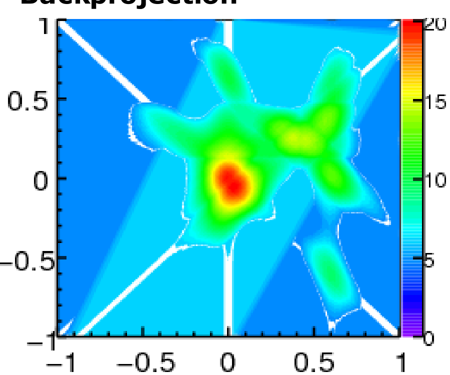
Tomographic reconstruction

- > *N* rotations → *N* projections of the (x, y)
- > Which algorithms are applicable to small *N?* → *N = 4*

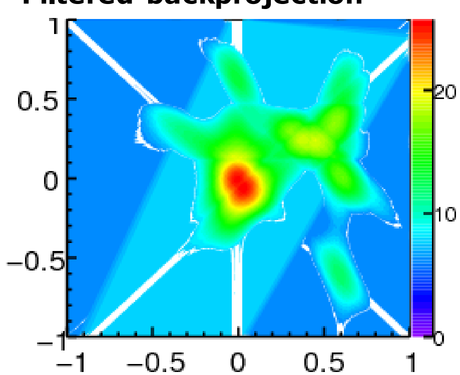


Applicability of different algorithms to limited data sets

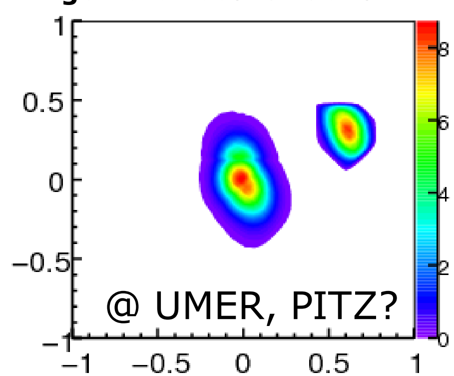
Backprojection



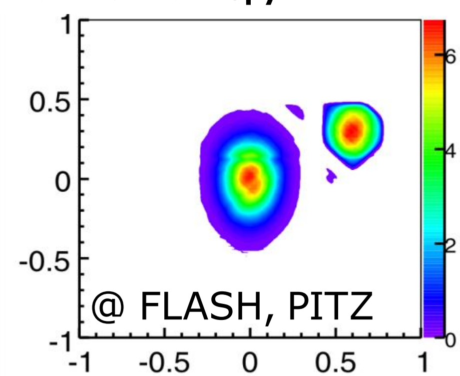
Filtered backprojection



Algebraic reconstruction



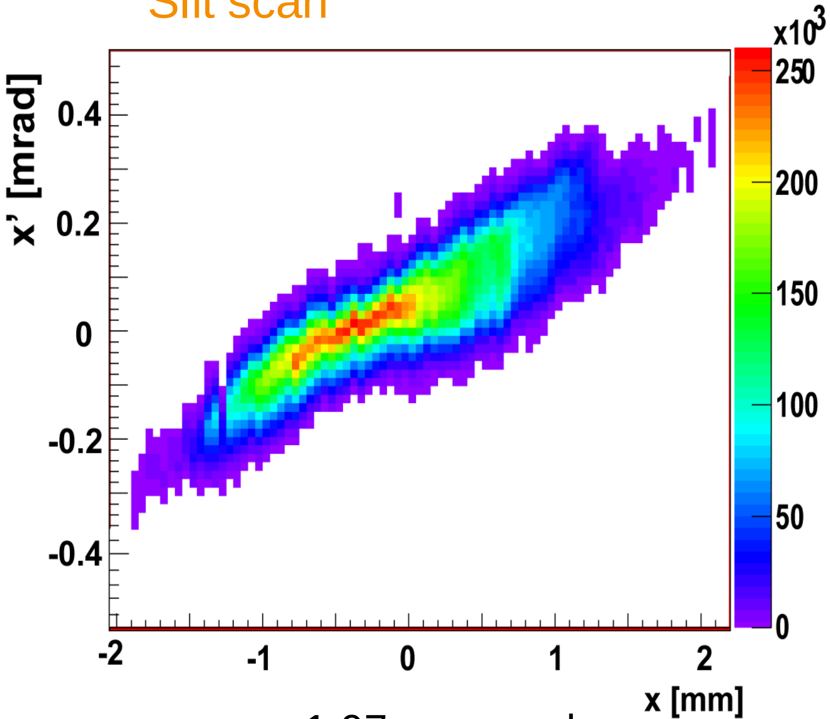
Maximum entropy



Reconstruction of 1 nC, intensity cut

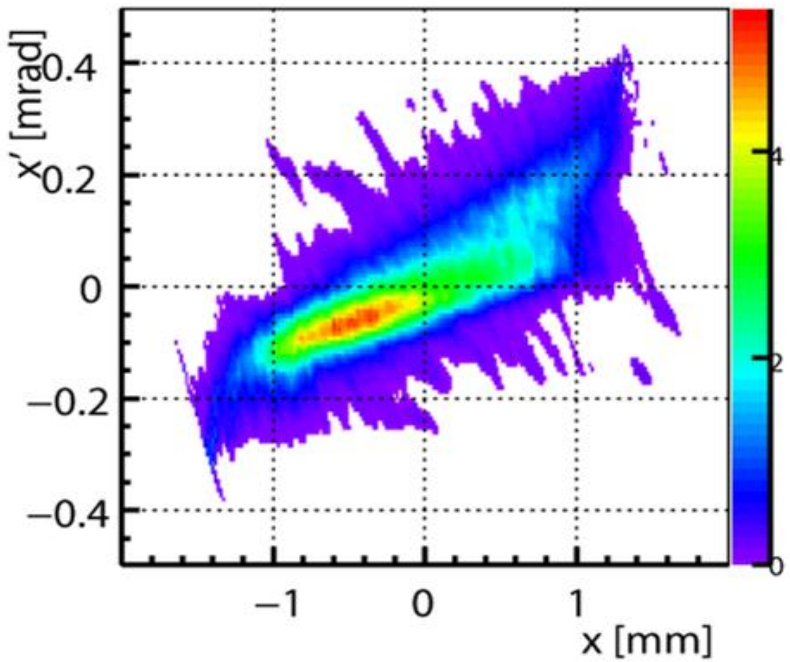
0.5 % intensity cut

Slit scan



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

Tomography



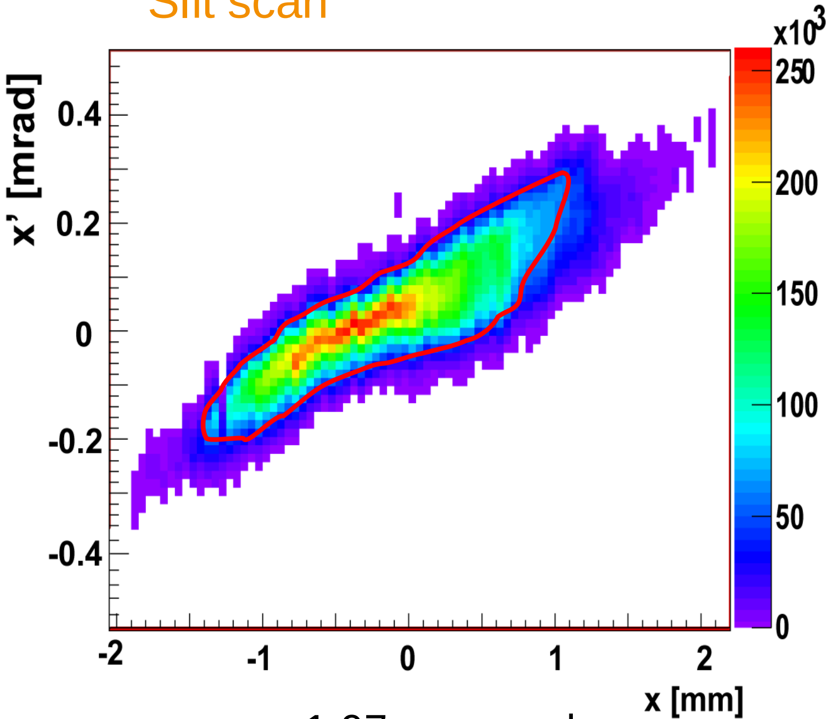
$\varepsilon_{x,N}$ = 1.3 mm mrad

The contribution of the low-intensity bins is negligible.

Reconstruction of 1 nC, intensity cut

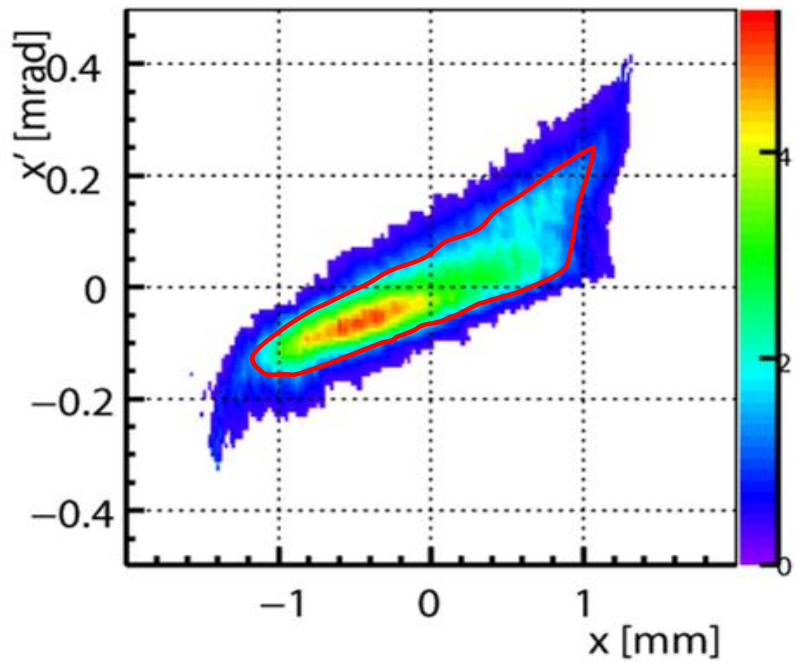
5 % intensity cut

Slit scan



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

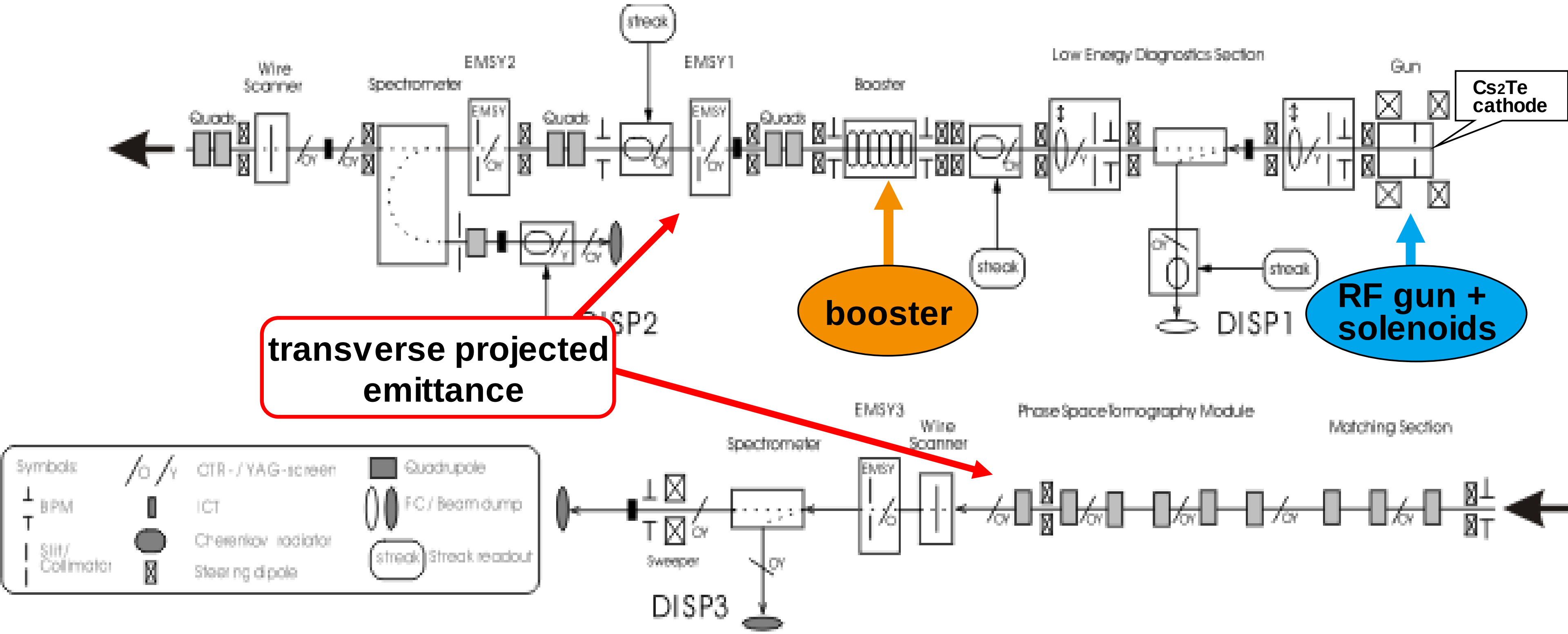
Tomography



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

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

Produce electron beams with minimized transverse projected emittance as required for the European XFEL, < 1 mm mrad

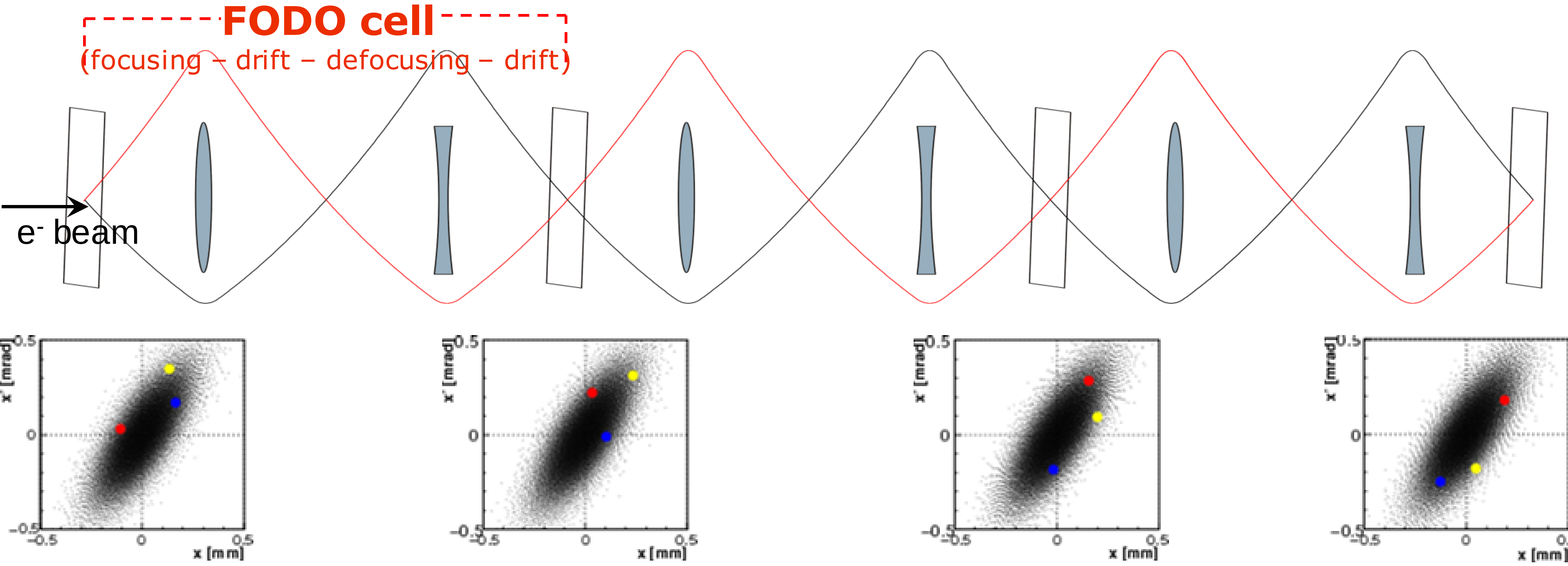


Beam momentum ~ 6.7 MeV/c /25 MeV/c

Nominal bunch charge 1 nC

Emittance measurements at PITZ

Phase-space tomographic reconstruction

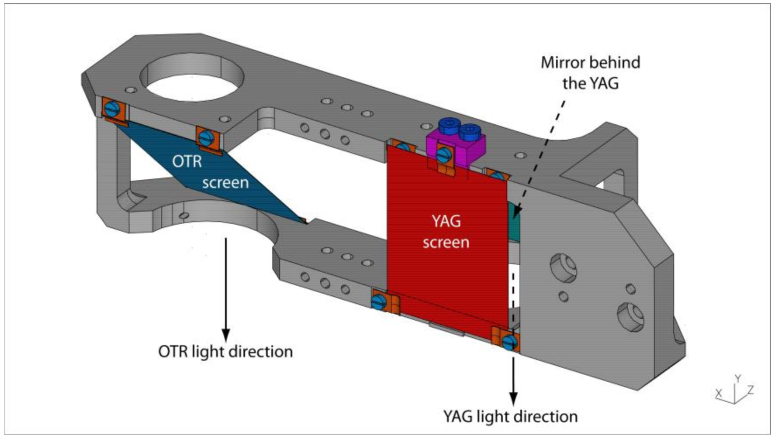


- equidistant angular steps between the screens for both planes (2D)
- rms spot size is uncharged
- the beam parameters at the entrance of the lattice are adjusted
- the data treatment assumes linear transport between the screens

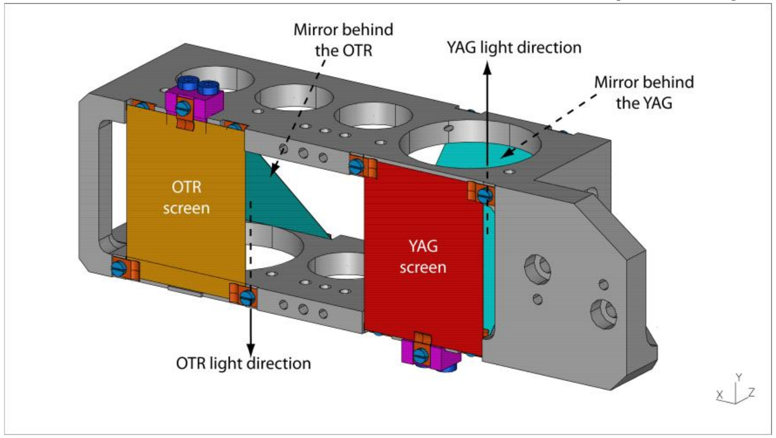
Screen stations

- Actuator holding Ce:YAG-doped and OTR screens
- Precisely movable actuator
- 2 different actuator designs

Nominal

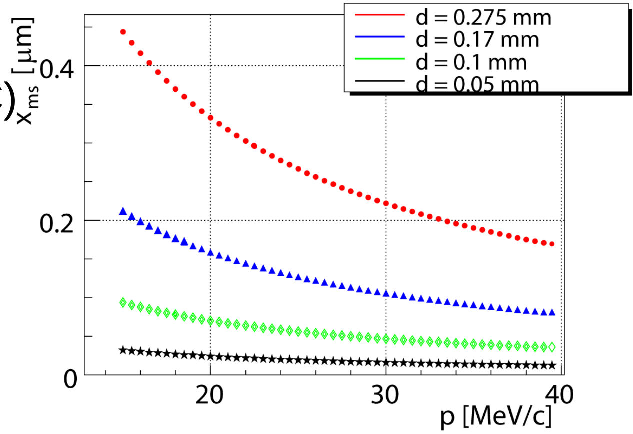


Test, 2 optical systems

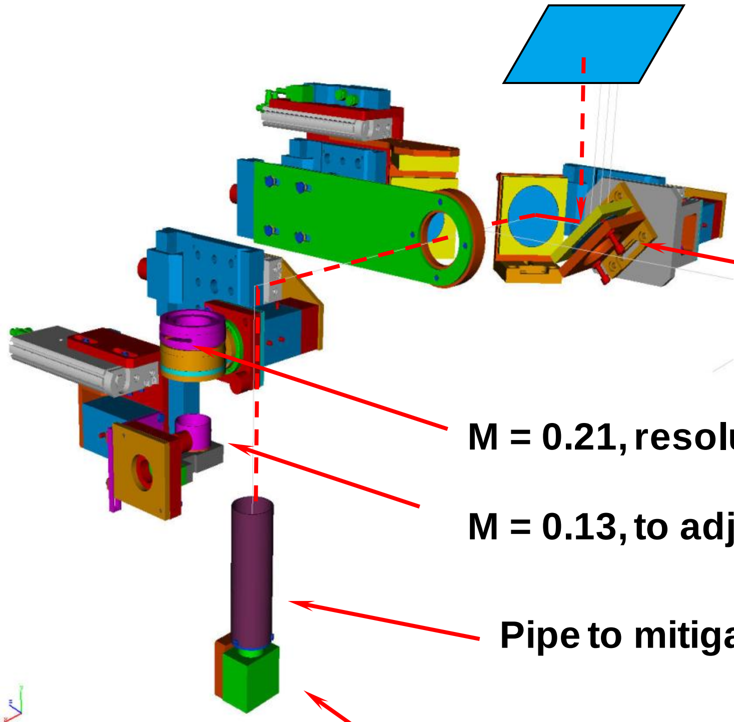


- Design momentum for high charge densities (30 MeV/c, 1 nC)
- Small beam dimensions (0.125 mm for 30 MeV/c)
- Minimize multiple scattering within the Si layer

  100 μm thickness



Optical system



Movable mirror to compensate the different path length for YAG/OTR screen

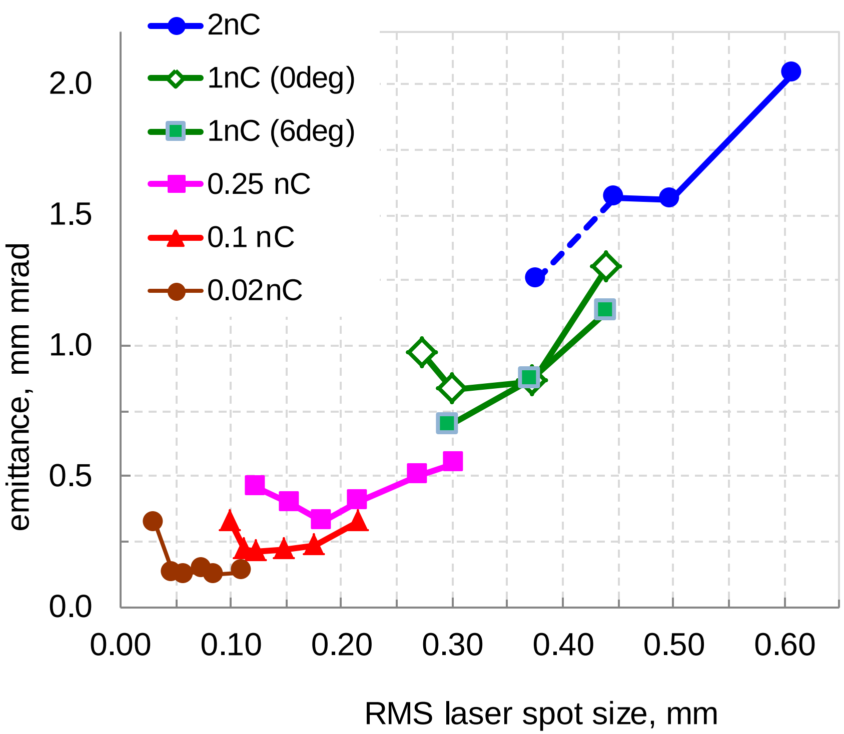
M = 0.21, resolution about 45 um

M = 0.13, to adjust the beam orbit

Pipe to mitigate stray light

16-bit monochromatic CCD camera

Single slit scan – standard measurement procedure



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

Q [nc]	ε_{xy} [mm mrad] *
1	**0.7 ± 0.03**
0.25	0.33
0.1	0.21

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

- Improved RF gun stability
- Improved laser stability and beam transport
- Replaced magnetizable components → critical at low energies