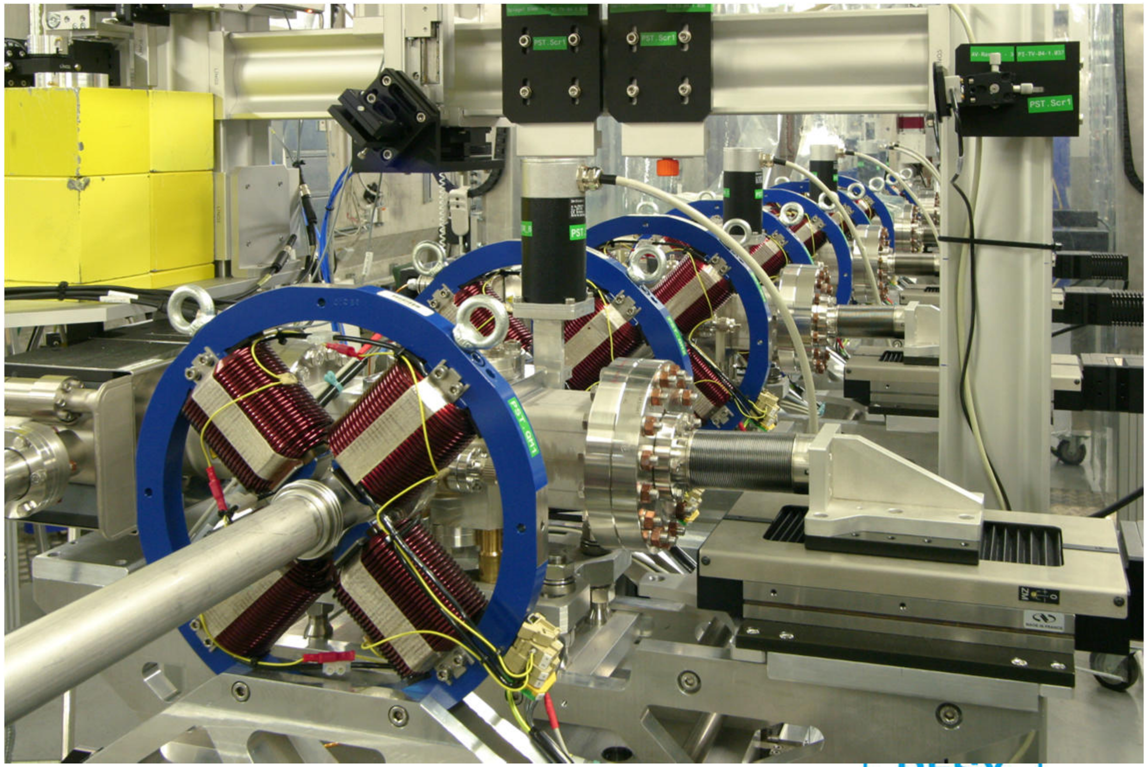
Tomography module for transverse phase-space measurements at PITZ .

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



G. Asova for the PITZ team

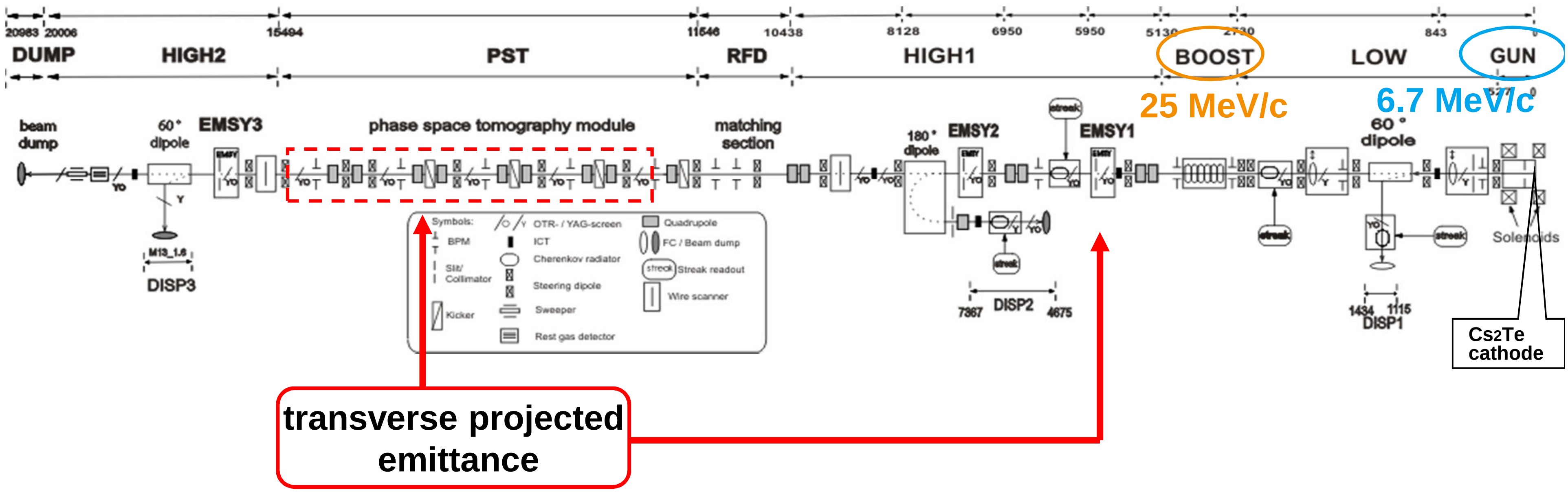
DITANET 2011, Seville

HELMHOLTZ ASSOCIATION

DESY

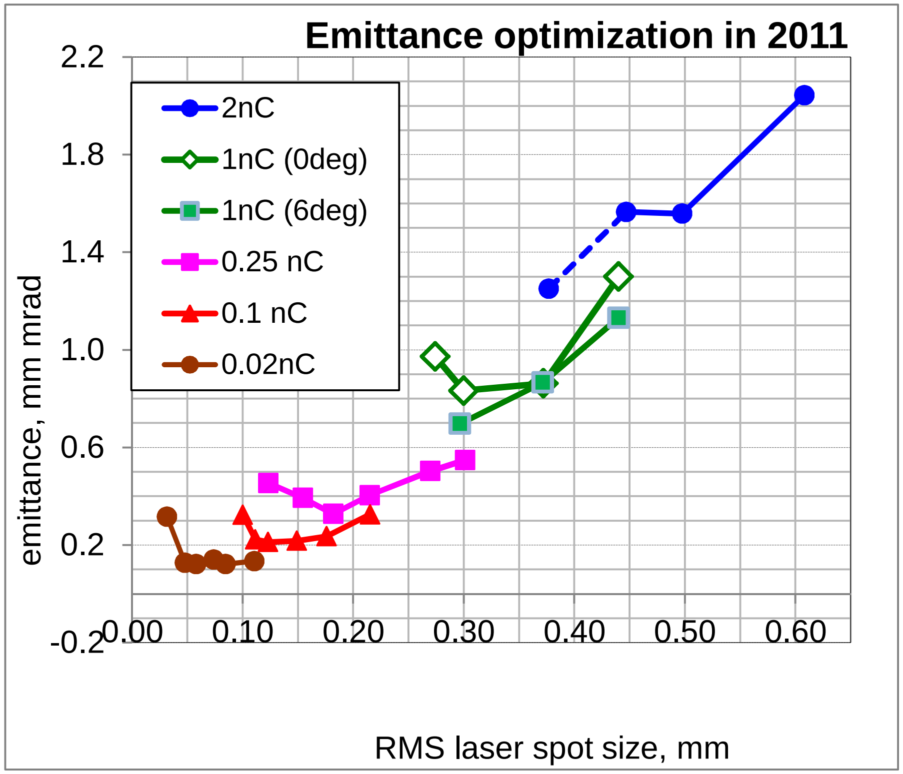
Produce electron beams with minimized transverse projected emittance as required for the European XFEL:

< 1 mm mrad for 1 nC



Transverse phase-space measurements

Single slit scan – standard measurement procedure



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

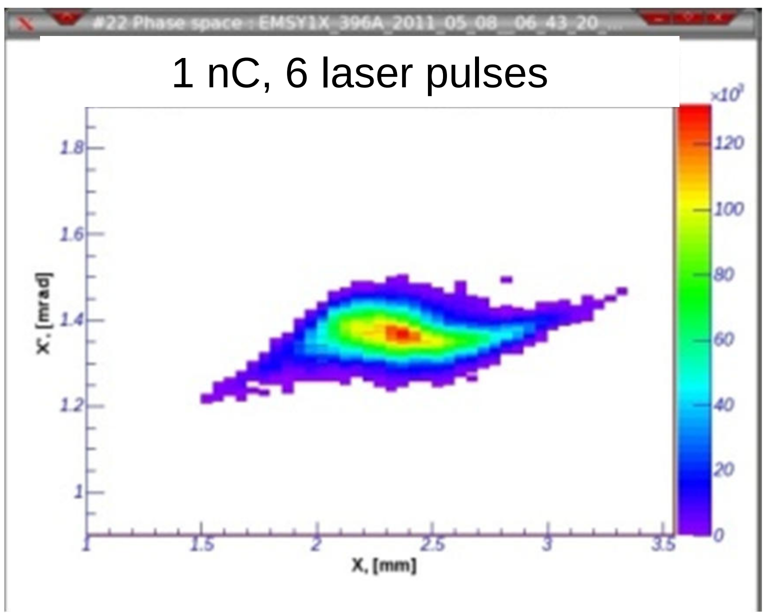
Q [nc]	ε_{xy} [mm mrad] *	
	100 %	$\Delta\varepsilon$ (2009→2011)
1	**0.7 0.03**	**-20%**
0.25	0.33	-30%
0.1	0.21	-35%

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

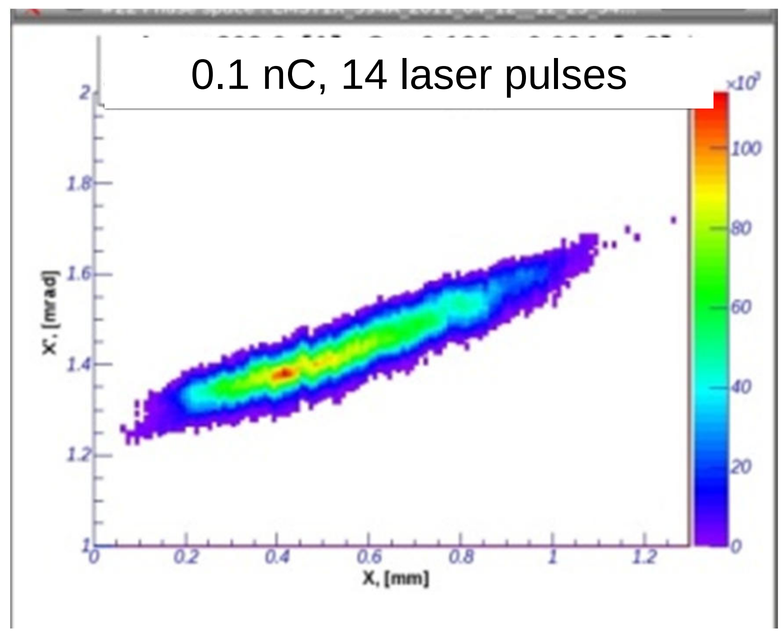
- Improved RF stability
- Improved laser stability and beam transport
- Replaced magnetizable components

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



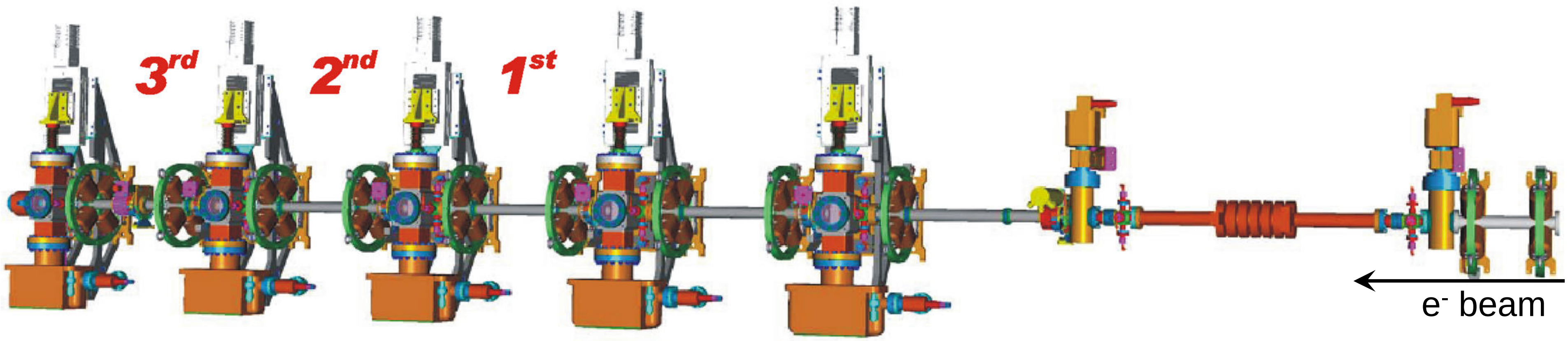
$\varepsilon_{x,\,100\%}$ **= 0.77 mm mrad**



$\varepsilon_{x,\,100\%}$ **= 0.28 mm mrad**

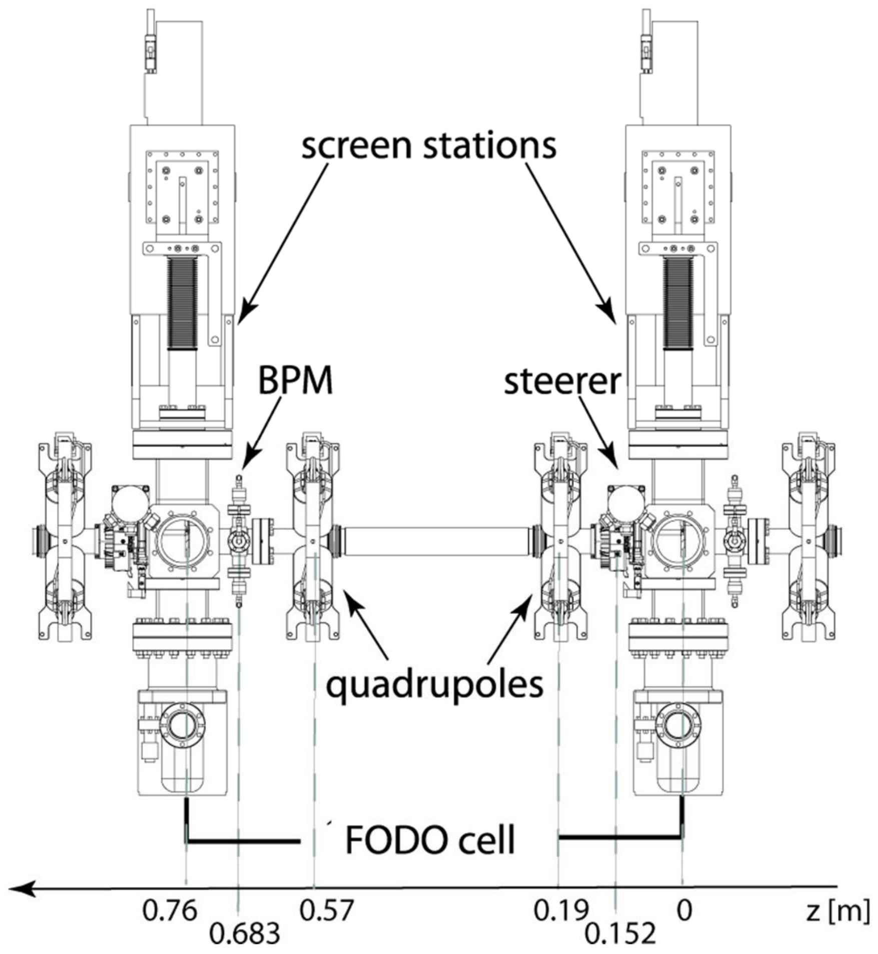
Tomography module

- Facilitates low charge measurements with short bunch trains
- Resolve both transverse planes simultaneously



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

Major components - FODO cells



x 5 cells

Components:

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

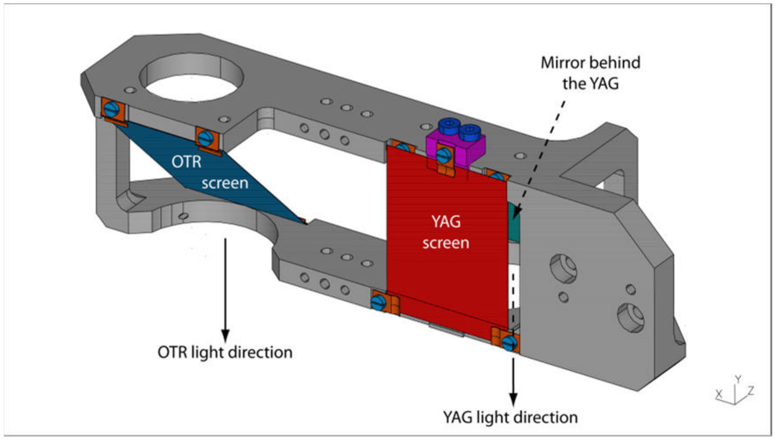
Short cells:

- Short quadrupoles L_{eff} = 43 mm
- Strong focusing, g ~ 5 T/m
- Precise alignment
  - 20 mrad quadrupole angular misalignment
  - 100 µm longitudinal misplacement

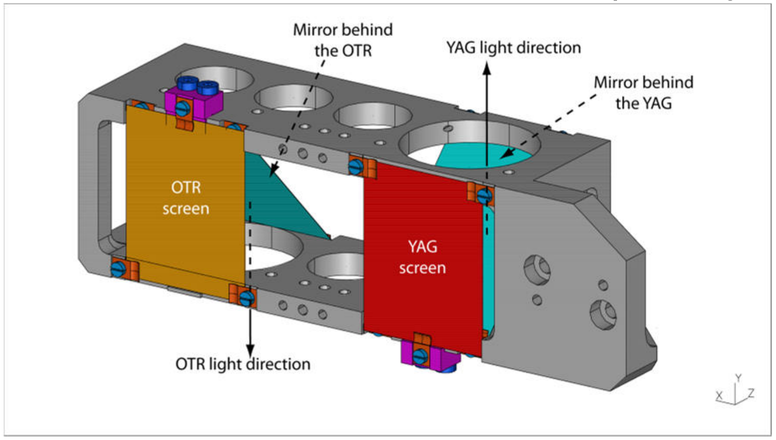
Screen stations

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

Nominal

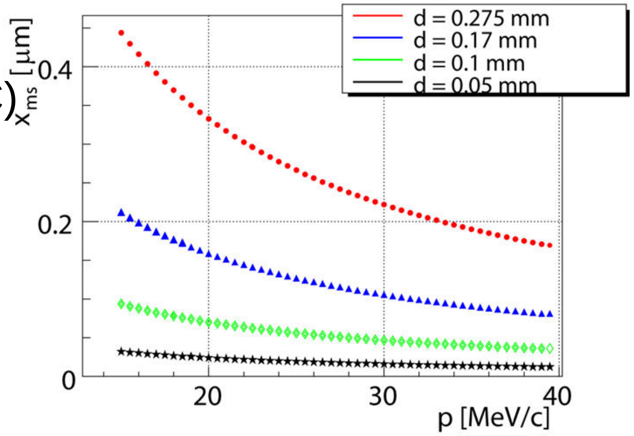


Test, 2 optical systems

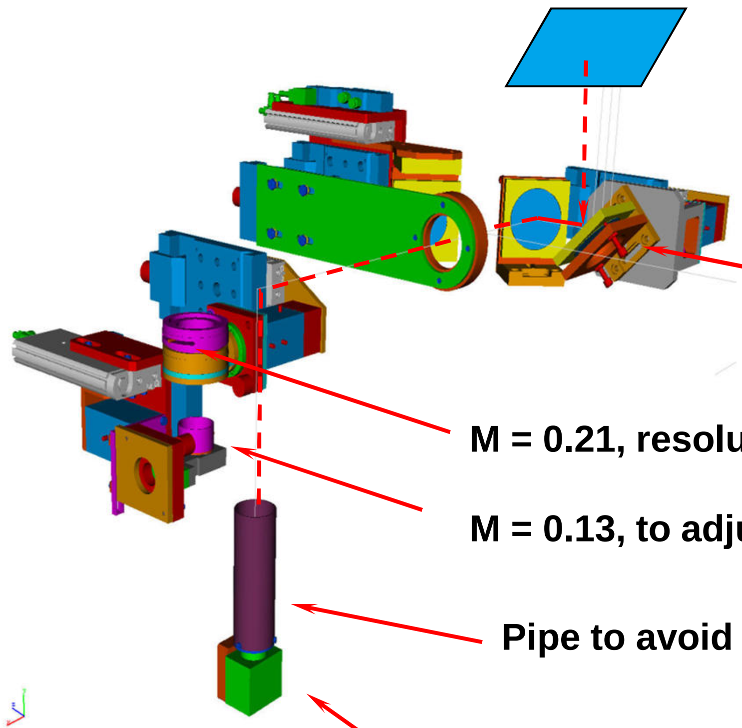


- Design momentum for high charge densities (30 MeV/c, 1 nC)
- Small beam dimensions (0.125 mm for 30 MeV/c)
- Minimize multiple scattering within the Si layer

  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 avoid stray light

16-bit monochromatic CCD camera

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 cathode
- Reproducibility of the measurements

> Lower charges

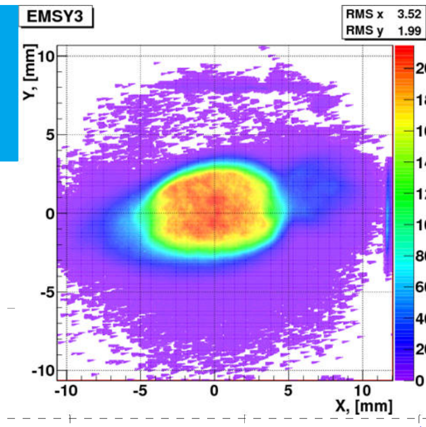
- Consistency

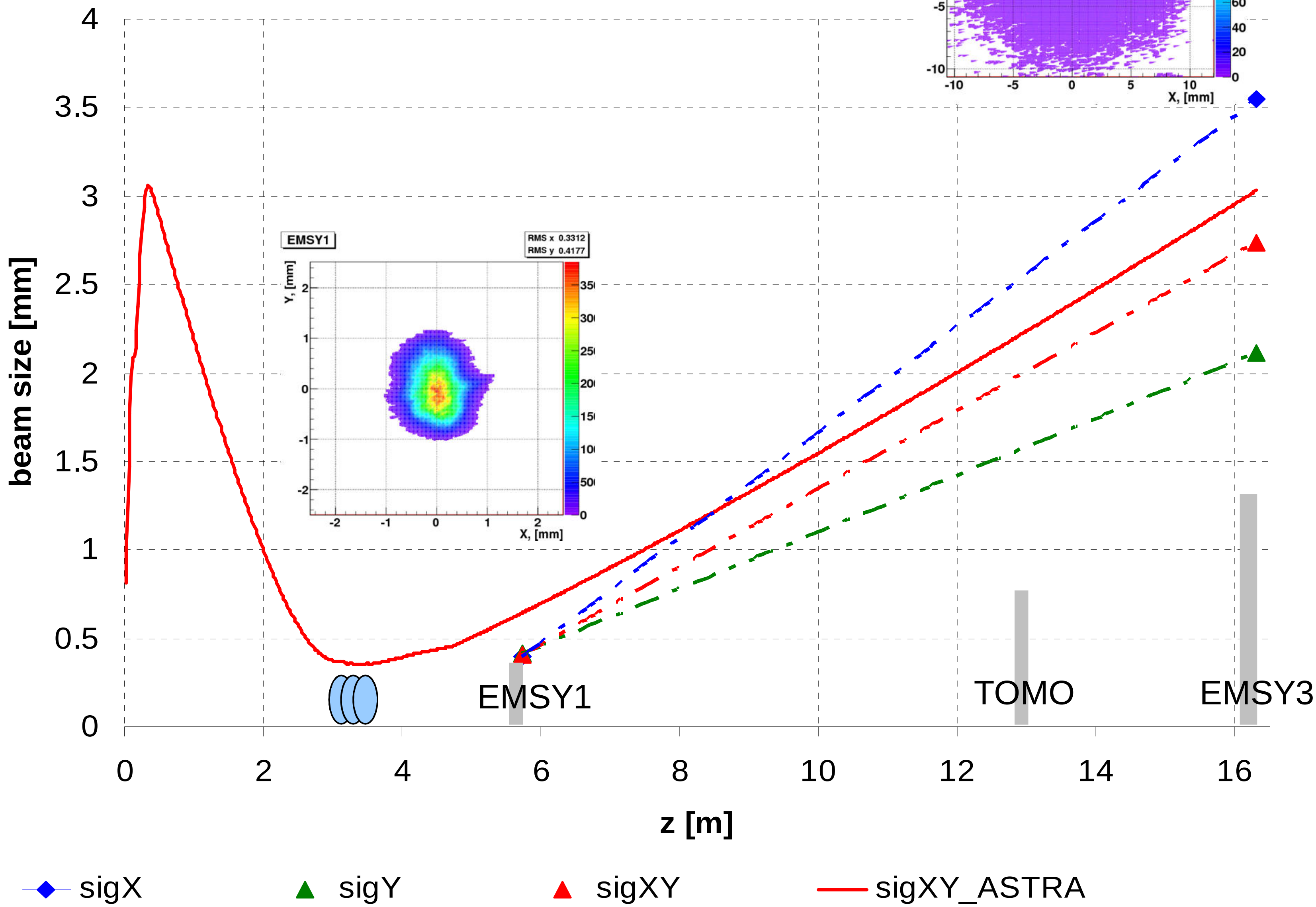
> Common machine setup:

- Max power from gun and booster, both on crest, p ~ 25 MeV/c
- Laser temporal profile – flat top with 2/22\2 ps

Profile along the beamline, 1 nC

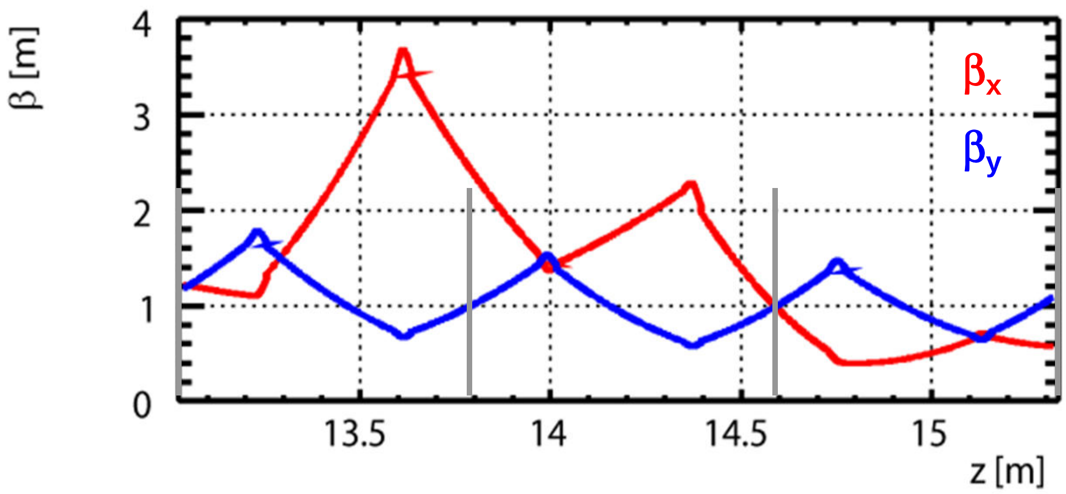
σ_{ini} = 0.4 mm





Matching for 1 nC, 25 MeV/c

- Hard to keep both planes periodic along the FODO lattice



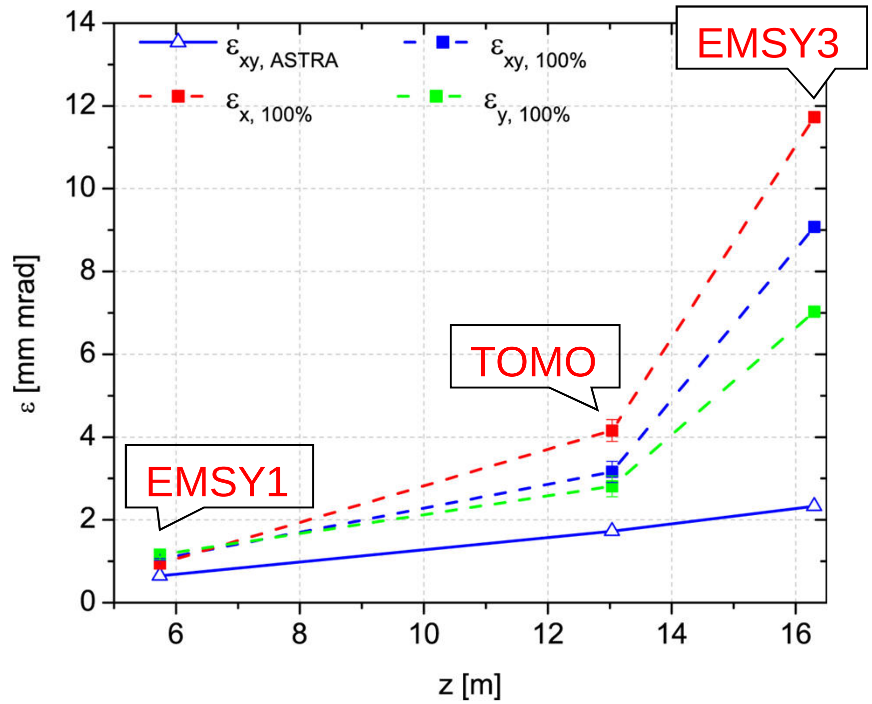
$\Delta\beta_y < 20\%$ - for such mismatches a solution can always be found

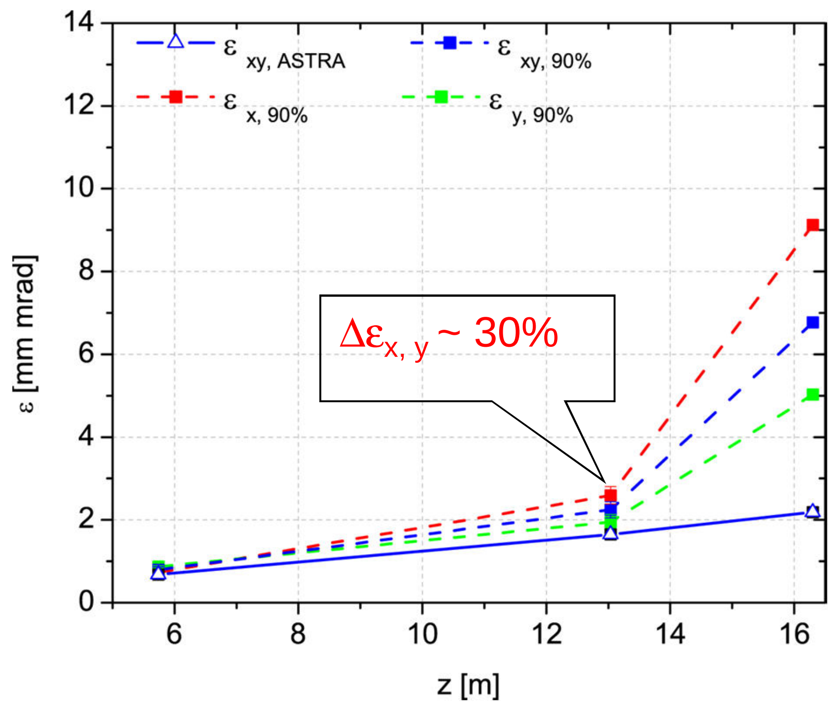
$$\Delta\beta = \frac{\beta_d - \beta_m}{\beta_d}[\%]$$

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

Evolution along the beamline, 1 nC

Solenoid for minimum emittance on EMSY1 $I_{\varepsilon_{min}}$ for this laser spot size





> SC/ε ~ 3.5 on EMSY1, → 0 on the first tomography screen – valid linear transport.

> Emittance for 90% of the integrated intensity much closer to numerical simulation with ASTRA.

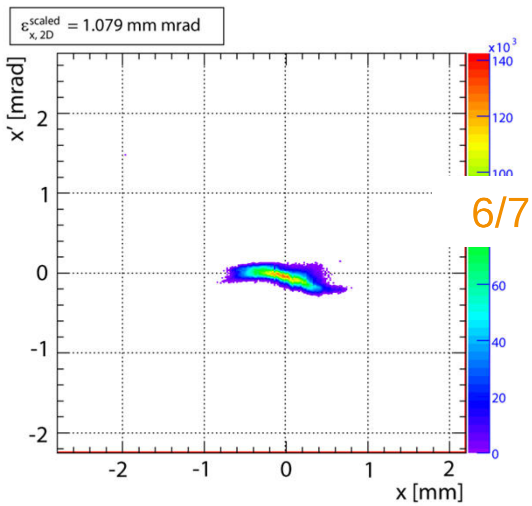
EMSY3 single measurements, Y-plane underestimated due to technical problems

EMSY1 data 10 consecutive measurements for statistics

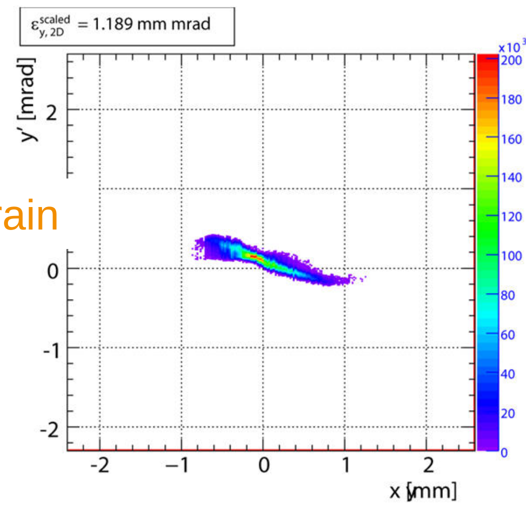
TOMO data 20 images x 4 screen for statistics, each 1x4 analysed separately

The phase spaces, 1 nC

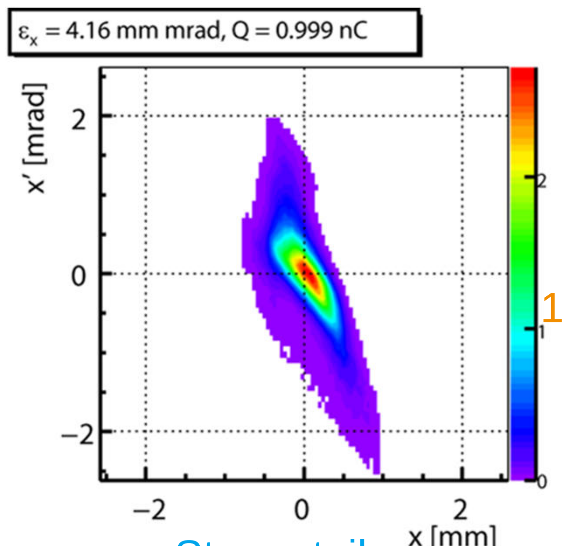
Slit scans, z = 5.74 m



6/7 bunches in the train



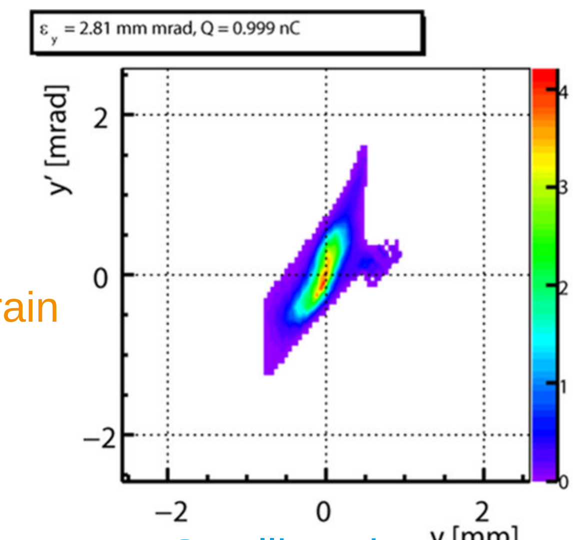
TOMO, z = 13.04 m



Strong tails

Orthogonal!

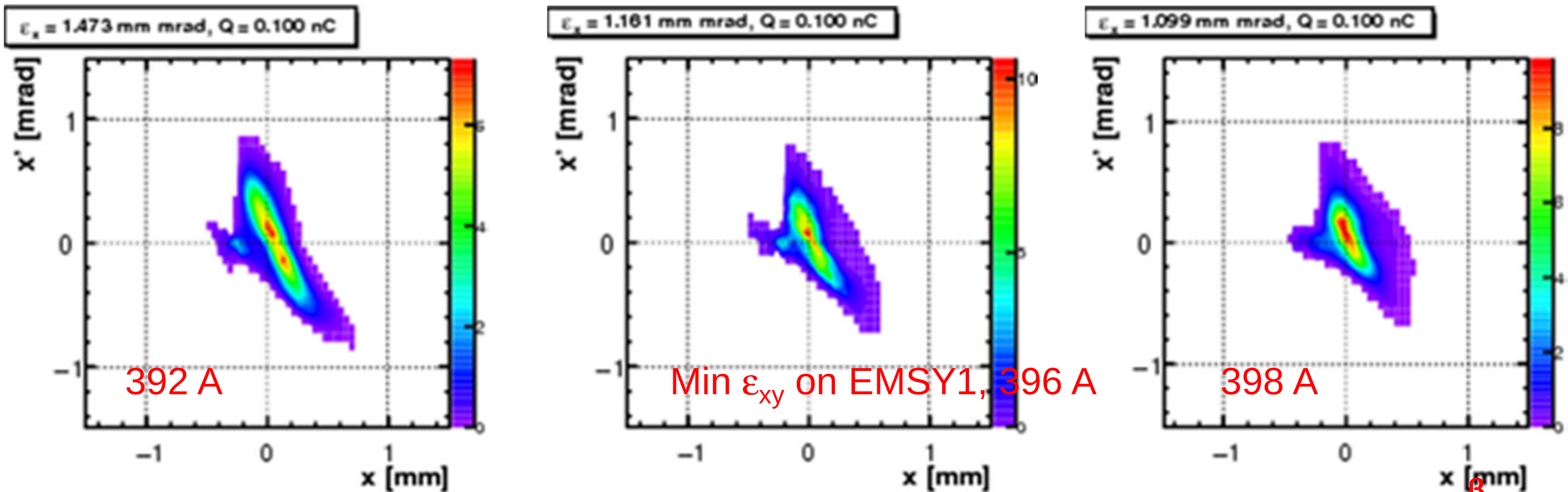
1 bunch in the train

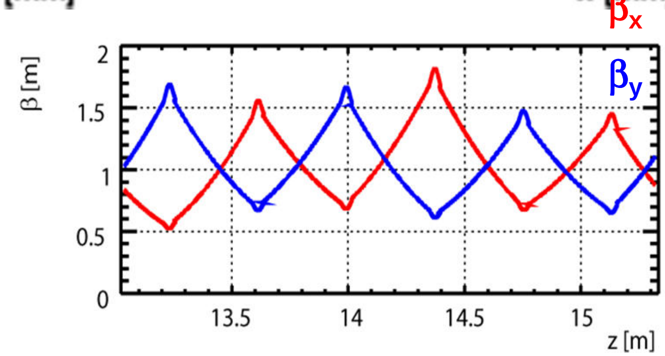


Satellite microstructure

100 pC X-plane

> Emittance decreases with the solenoid current





> the orientation of the three distributions

is the same – matching worked in these cases

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

Conclusions & outlook

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

$$\varepsilon_{xy,\ 100\%} = 0.7 \quad 0.01 \text{ mm mrad}$$

- 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
- For the two transverse planes simultaneously

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

The PITZ collaboration

Colleagues participating in measurements / new design:

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- **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:**
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- **Uni Hamburg:**
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* 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