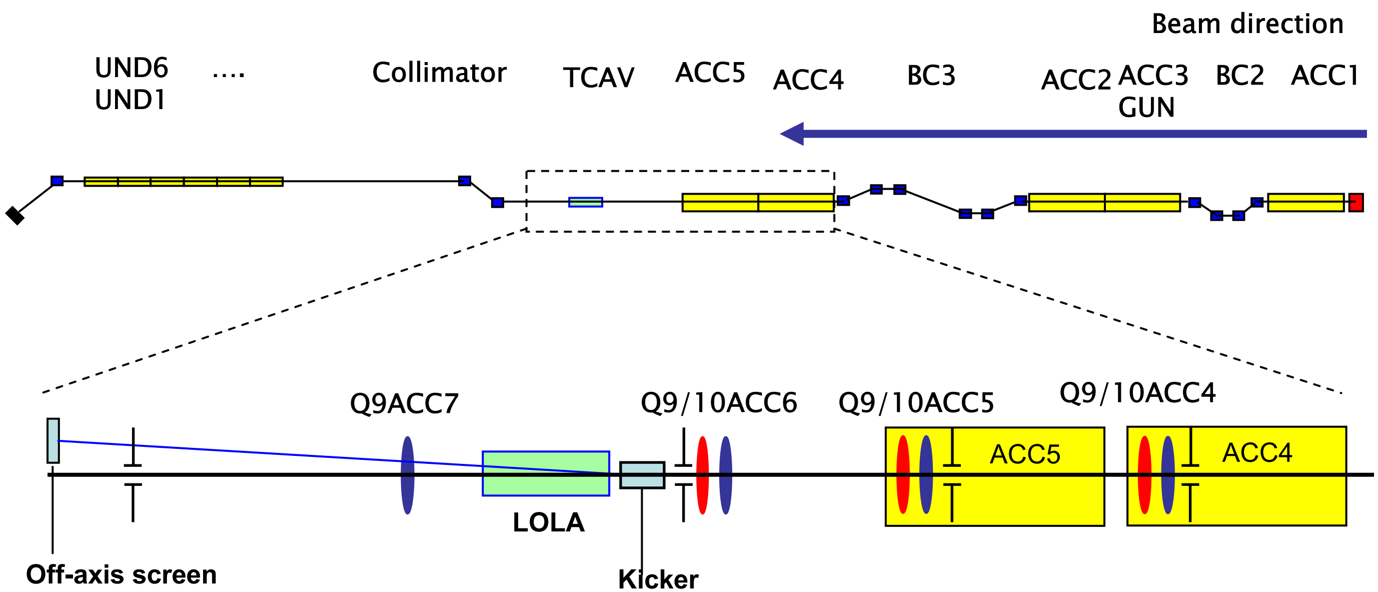
On-crest slice emittance measurements

Michael Röhrs

Outline

- Introduction
- Bunch tilts observed via LOLA
- Simulation of a slice emittance measurement
- Results of slice emittance measurements (on-crest acceleration)
- Accuracy of the results
- conclusions

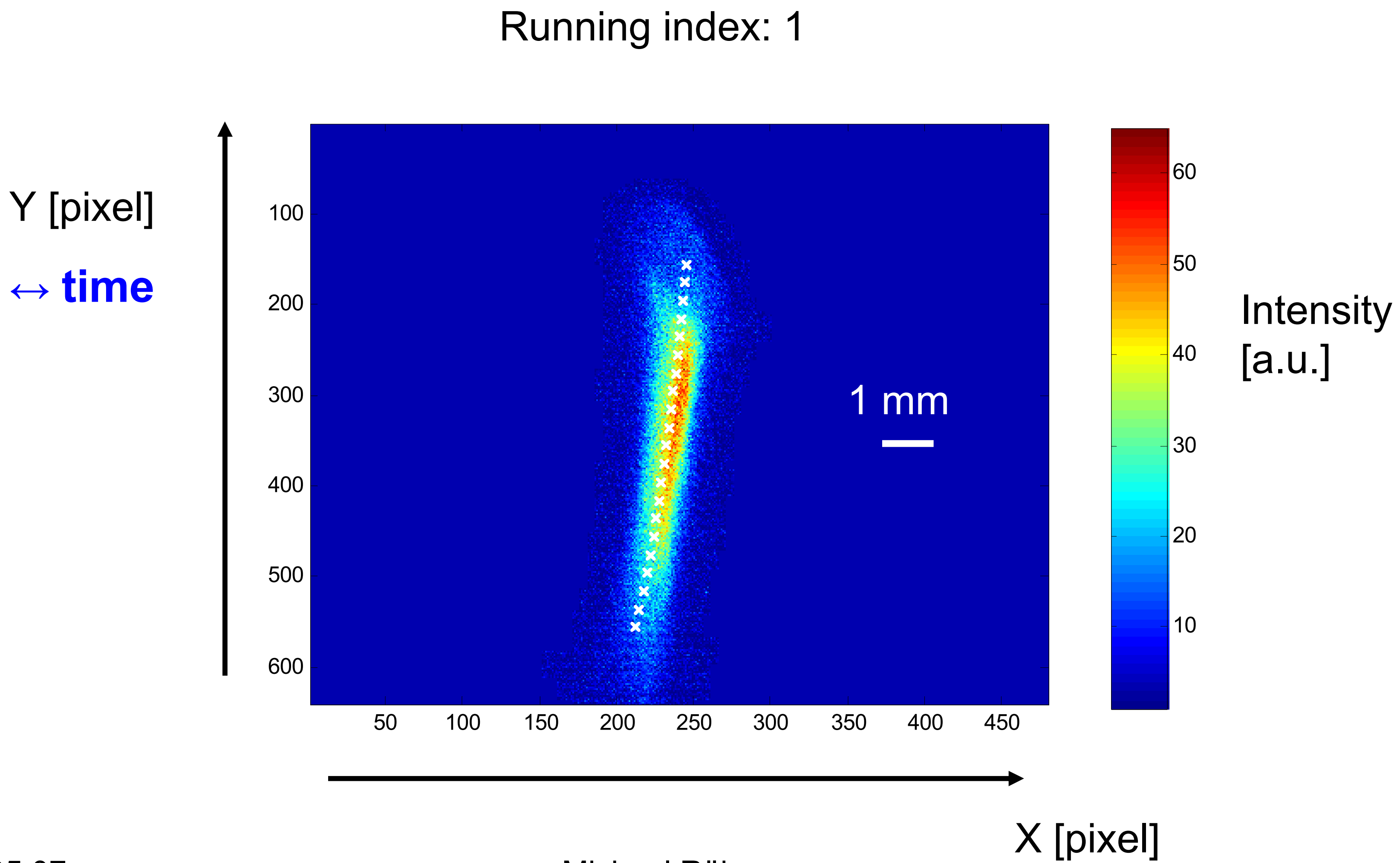
The procedure



Emittance measurements:

- ``Multi-scan”: simultaneous scan of Q9ACC4-Q10ACC6 (optimal longitudinal resolution)
- Scan of Q10ACC6

Example: Images taken during a scan

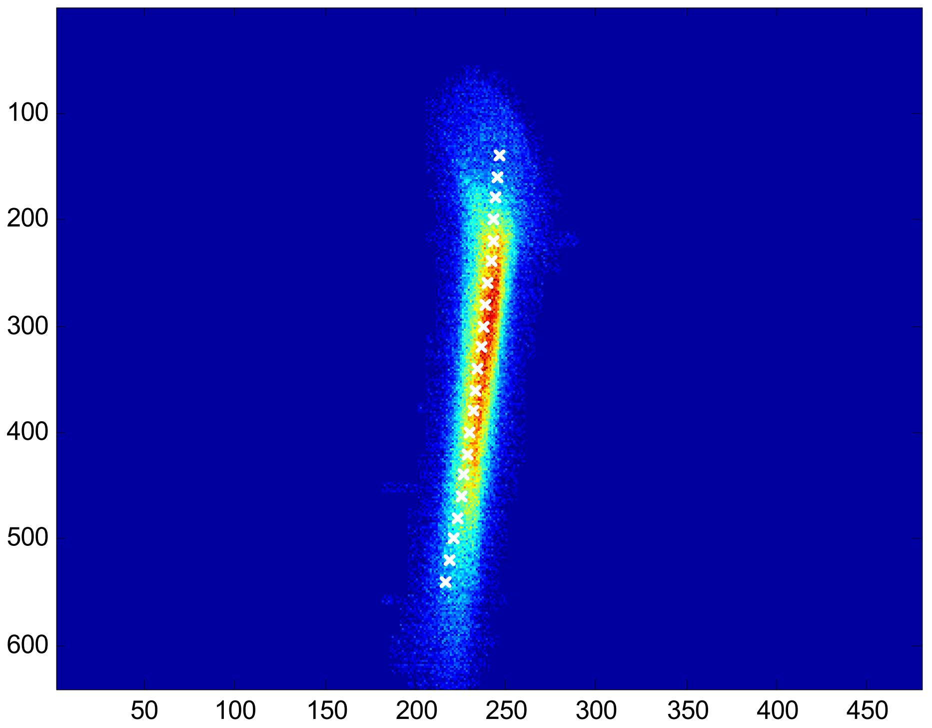


Example: Images taken during a scan

Running index: 2

Y [pixel]

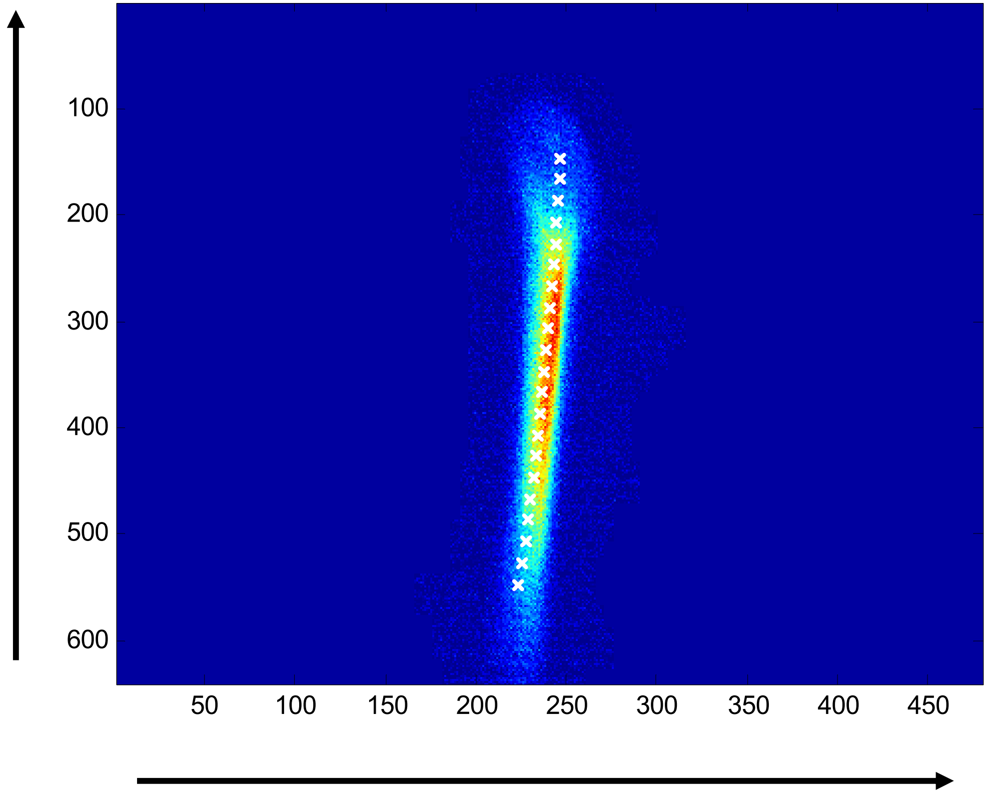
↔ **time**



X [pixel]

Example: Images taken during a scan

Running index: 3



Y [pixel]

↔ **time**

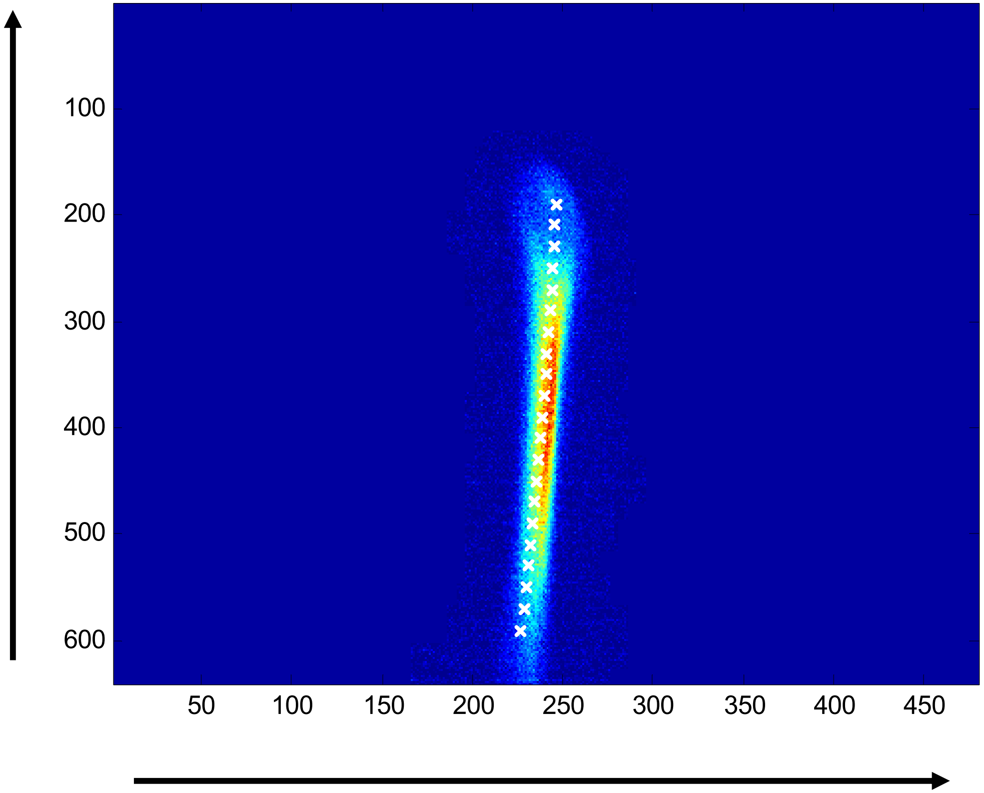
X [pixel]

Example: Images taken during a scan

Running index: 4

Y [pixel]

↔ **time**



X [pixel]

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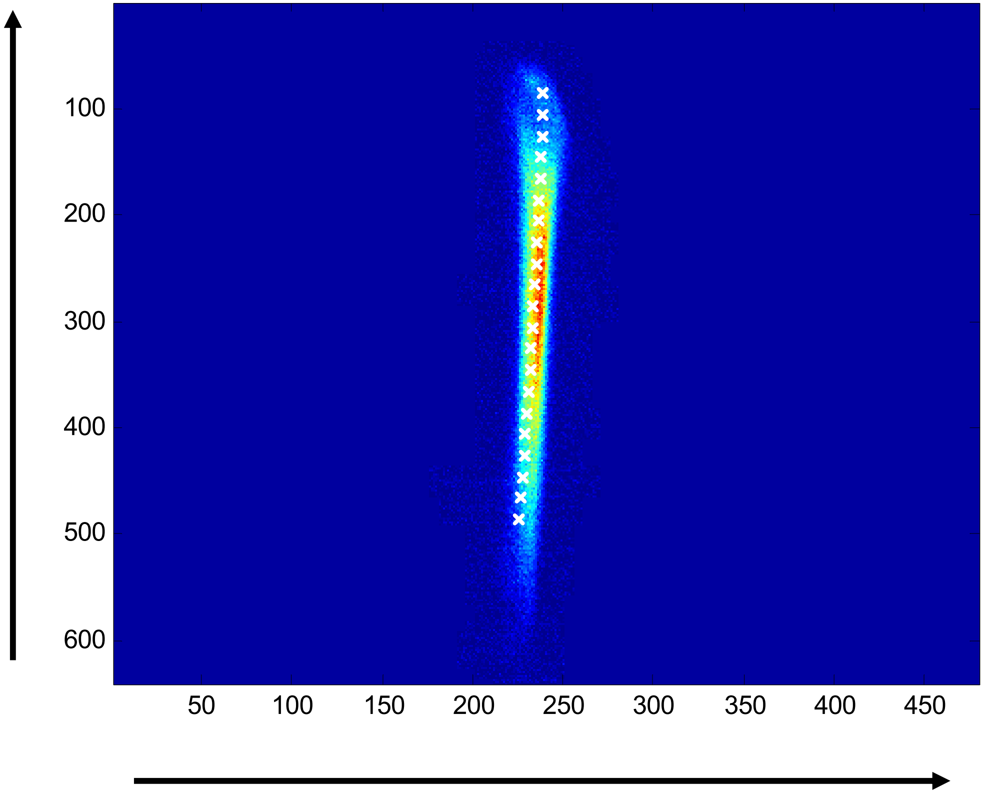
Example: Images taken during a scan

Running index: 5

Y [pixel]

↔ **time**



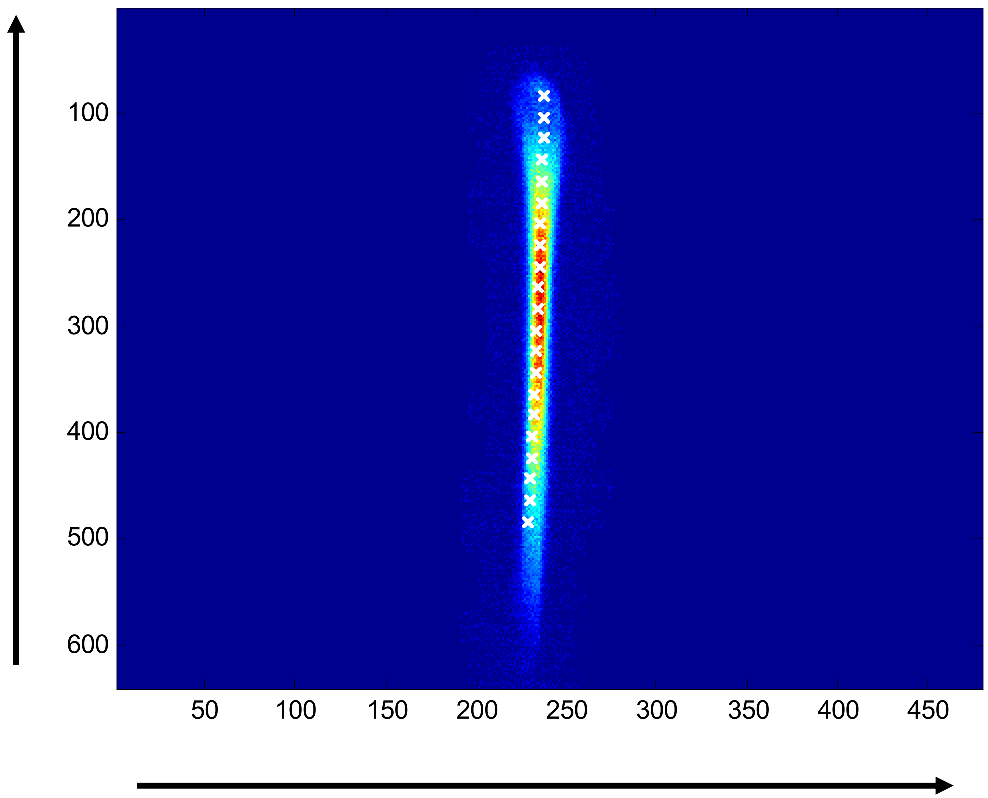
X [pixel]

Example: Images taken during a scan

Running index: 6

Y [pixel]

↔ **time**



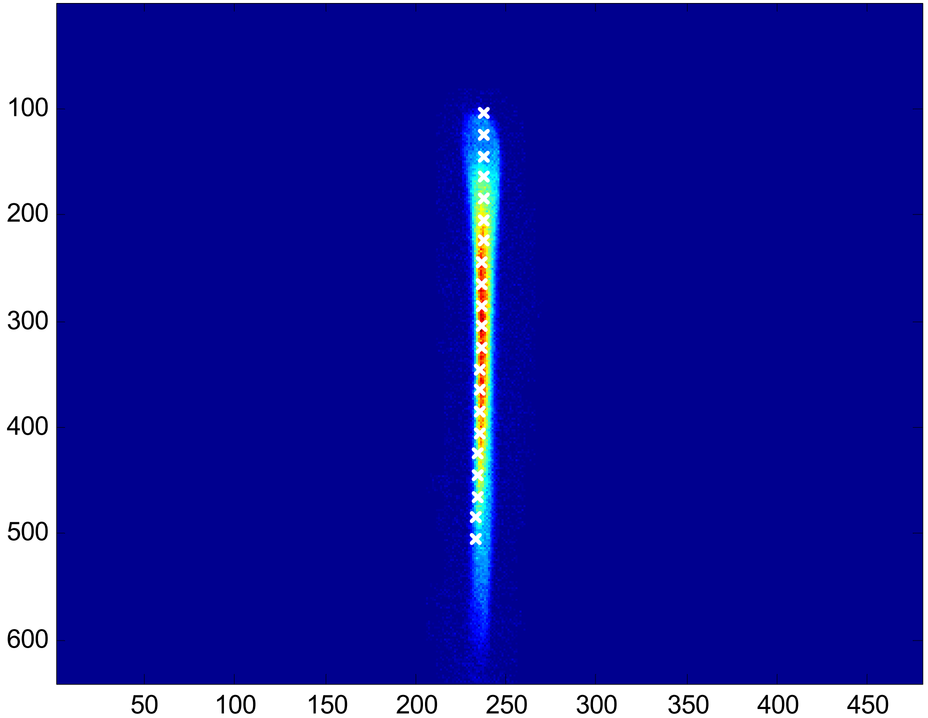
X [pixel]

Example: Images taken during a scan

Running index: 7

Y [pixel]

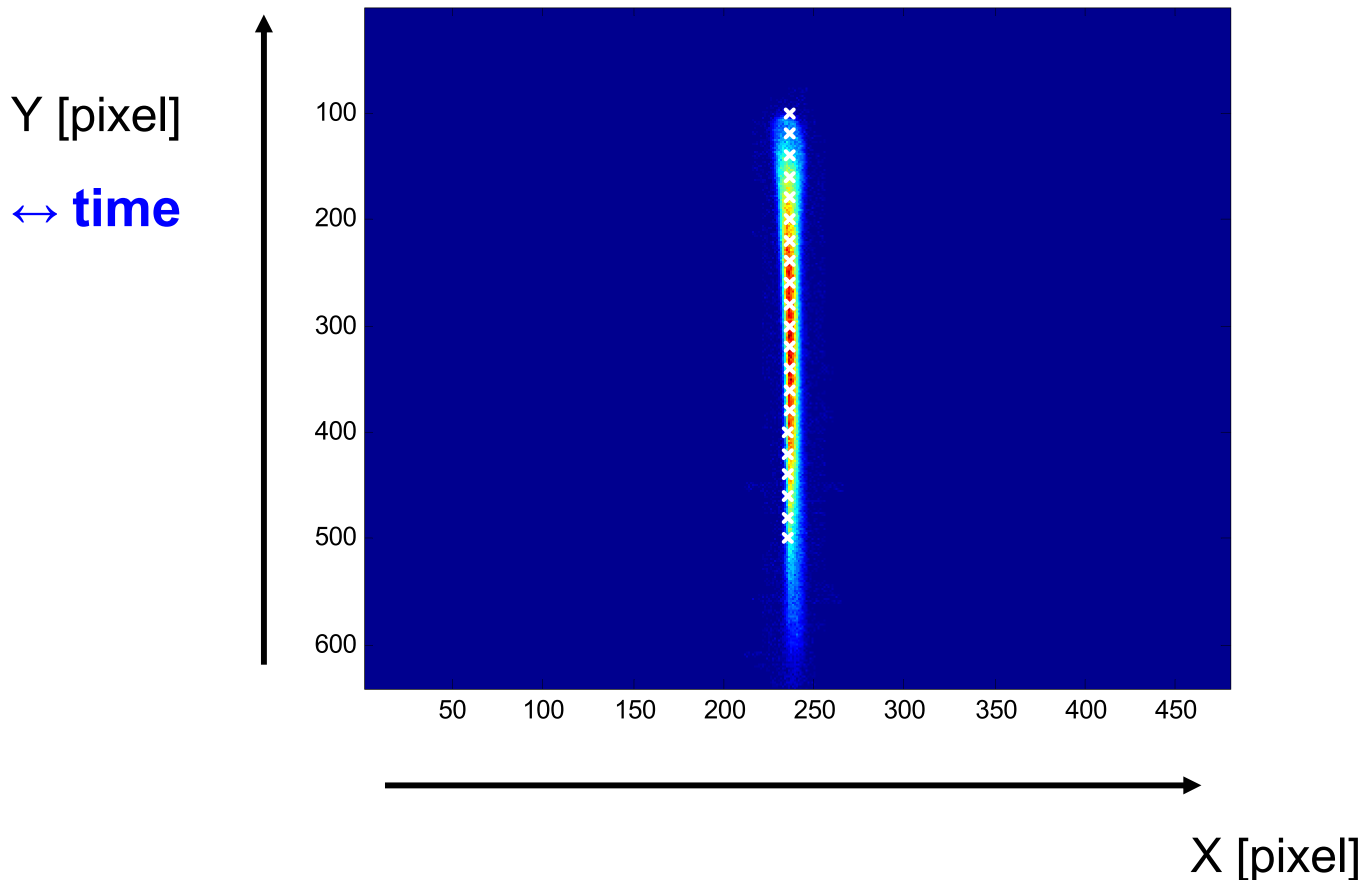
↔ **time**



X [pixel]

Example: Images taken during a scan

Running index: 8

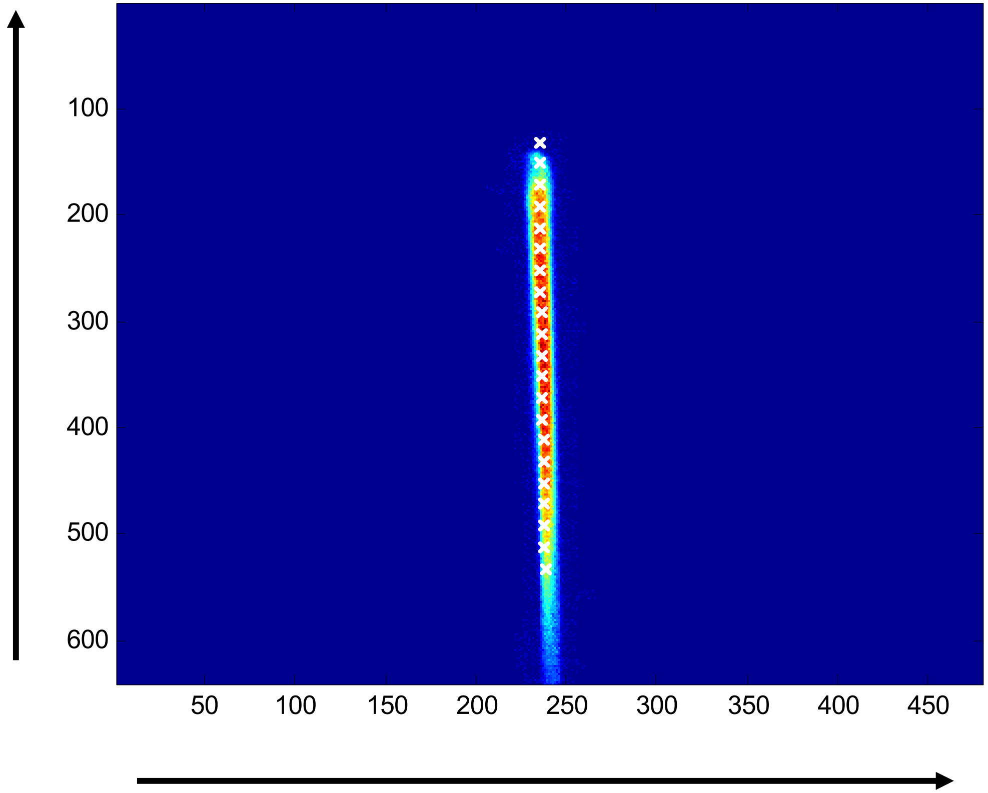


Example: Images taken during a scan

Running index: 9

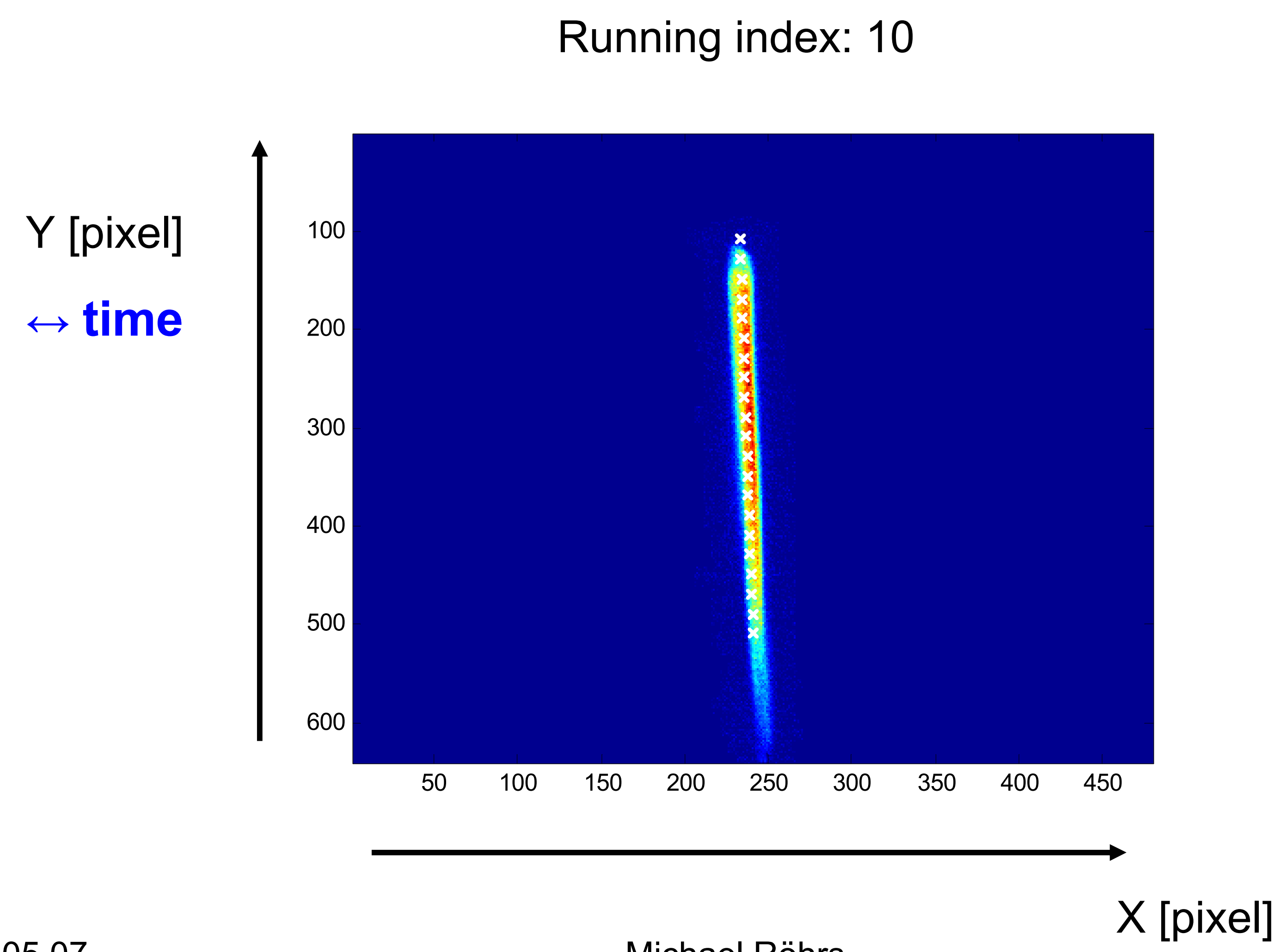
Y [pixel]

↔ **time**



X [pixel]

Example: Images taken during a scan

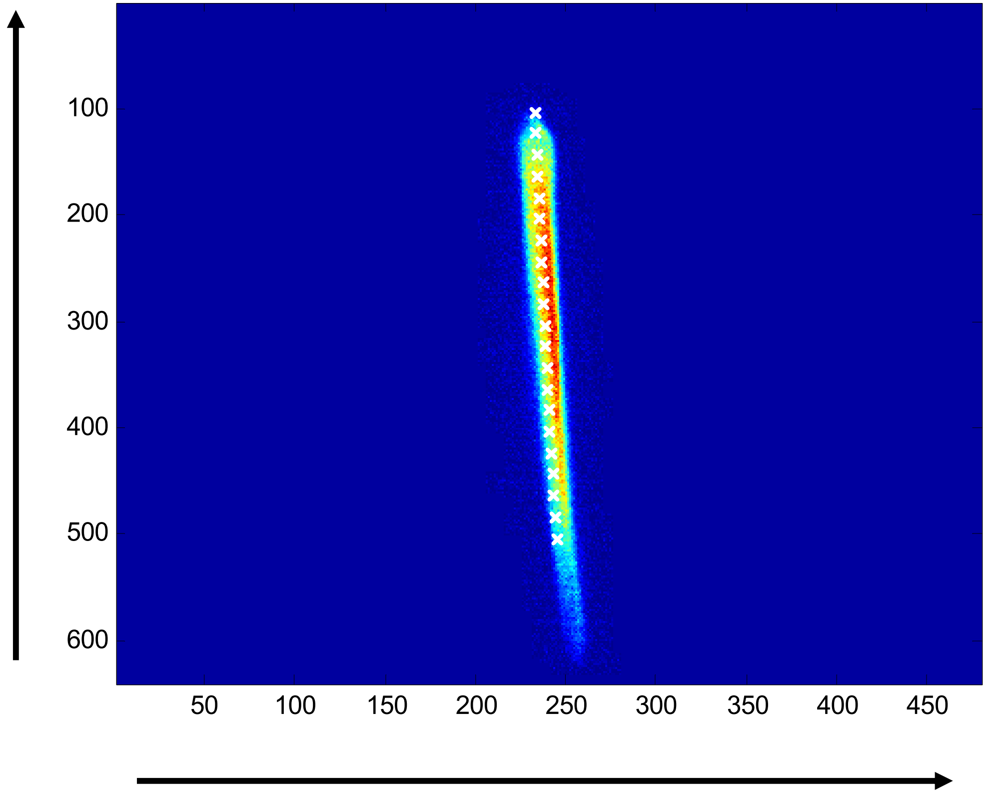


Example: Images taken during a scan

Running index: 11

Y [pixel]

↔ **time**



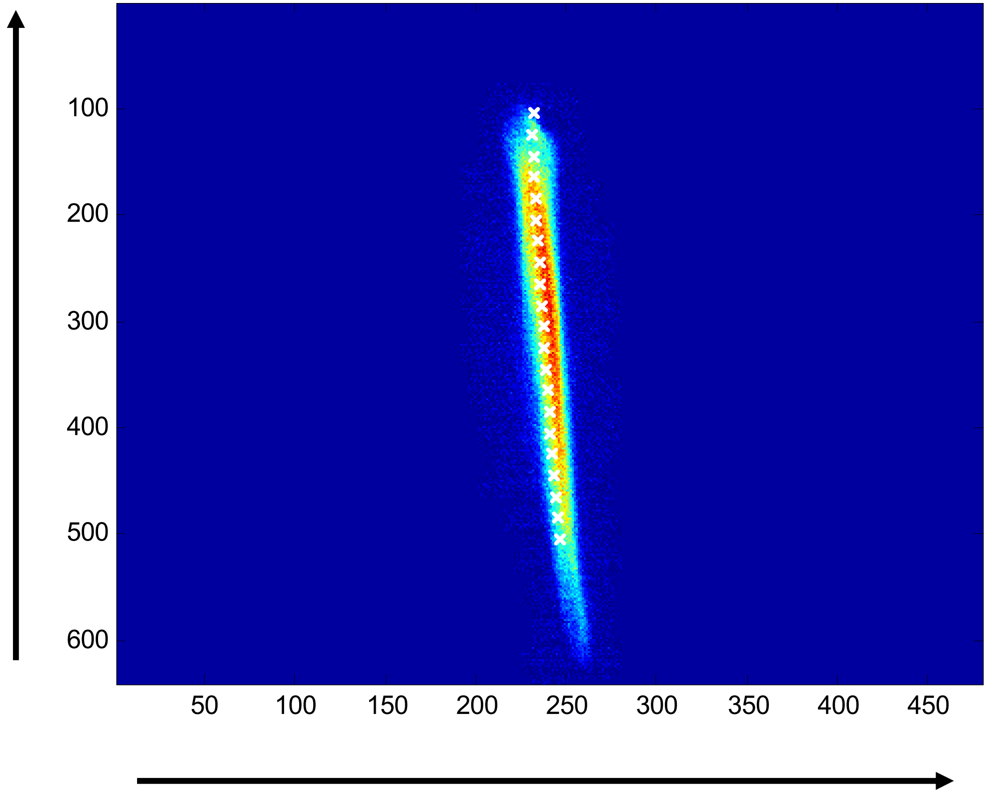
X [pixel]

Example: Images taken during a scan

Running index: 12

Y [pixel]

↔ **time**



X [pixel]

Possible Sources for tilts measured via LOLA (on-crest acceleration)

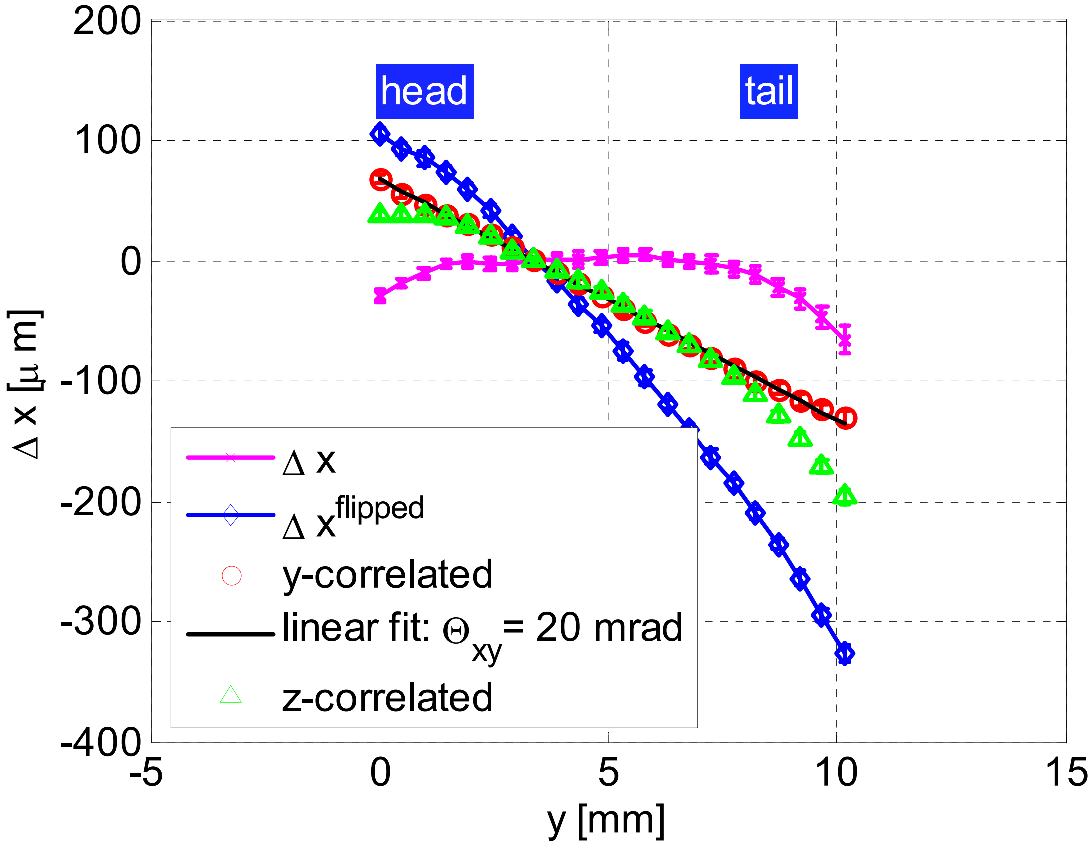
y-correlated sources

- Roll angle of LOLA / the Camera-system
- XY-coupling (bad time resolution)
- Rotation of Q9ACC7 / higher order fields of Q9ACC7
  → rotation < 0.1 mrad according to M. Schlösser
  → similar observations with Q9ACC7 switched off

z-correlated sources

- Transverse wake fields in accelerating modules / in LOLA
- RF-Coupler kicks
- Dispersion
- Causes in the gun-section (Kirsten Hacker)
- Field errors within LOLA
  → excluded by comparison of horizontal profiles with LOLA switched on / off

Measurement of y- and z-correlated contributions by flipping the phase of LOLA



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Y-correlated offsets: Roll angle of the camera and LOLA

- Roll angle of the camera:
  - With respect to the screen holder: ~ 19 mrad
  - With respect to the vertical steerer V10ACC6: ~ 17mrad

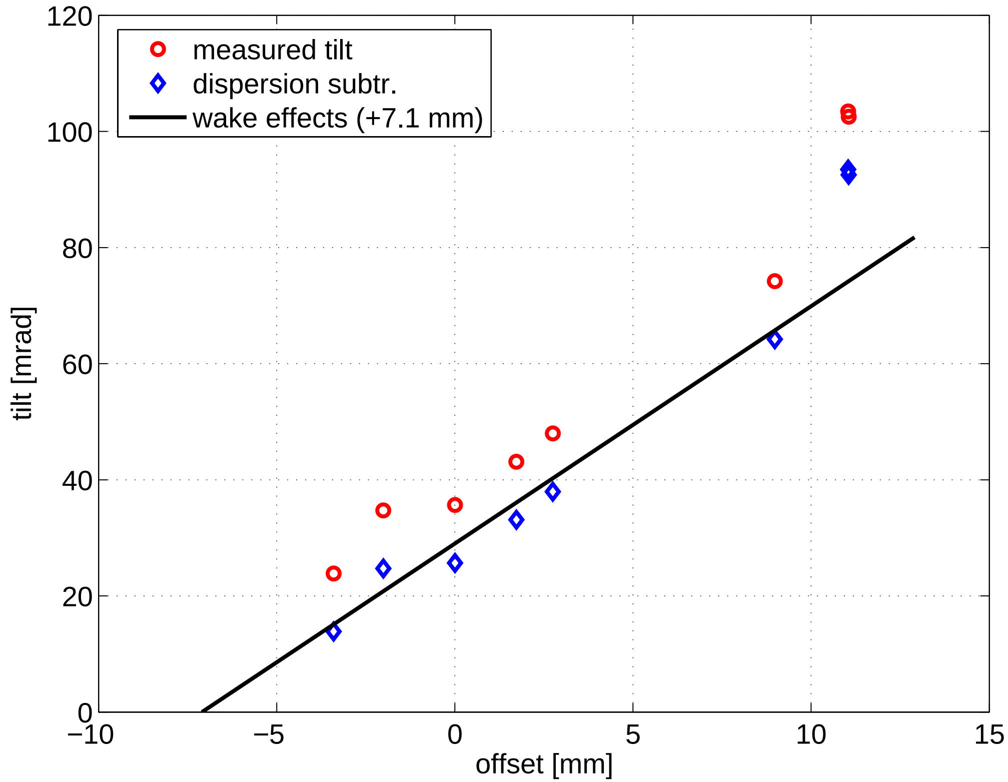
→ **roll angle of the camera: ~1°**

- Roll angle of the camera with respect to LOLA:
  - Phase flip of LOLA: 11 – 21 mrad
  - Phase scan of LOLA: 11 – 17 mrad

→ **roll angle of LOLA < 8 mrad**

Z-correlated offsets : Transverse wake fields in LOLA

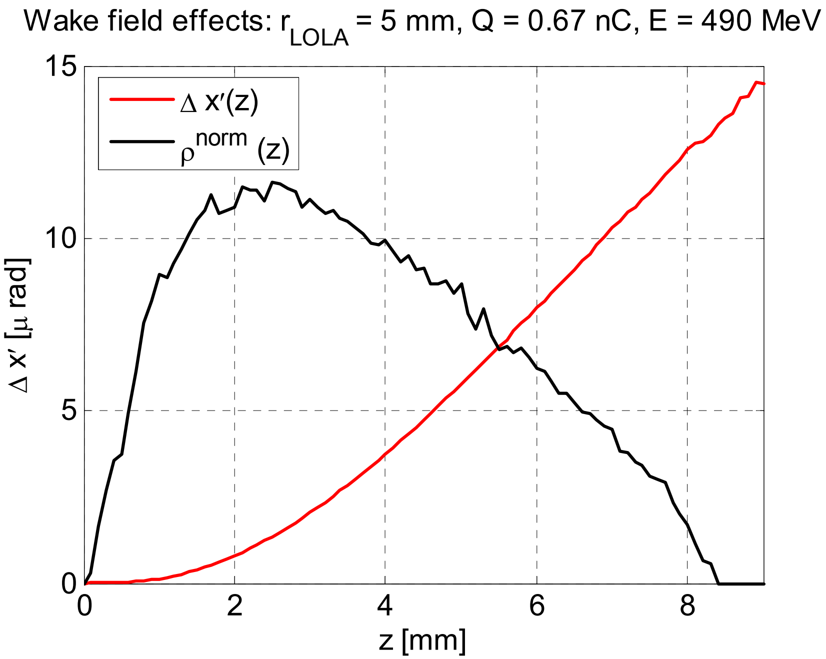
Scan of the mean offset in LOLA:



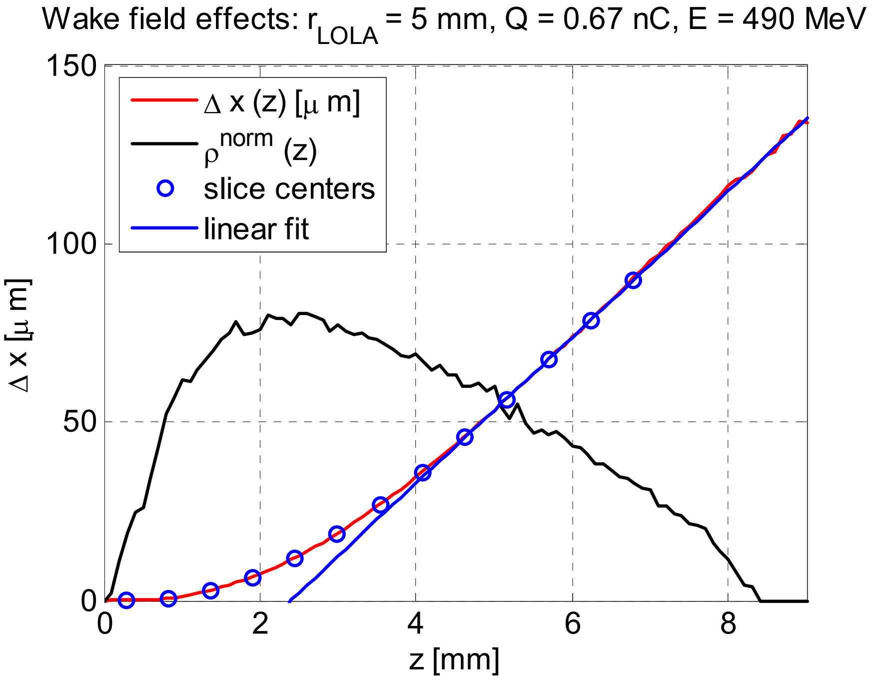
- The aperture of LOLA has been scanned -> structure aligned within 1mm
- There is a significant contribution from wake fields in LOLA in agreement with calculations

Z-correlated offsets : Transverse wake fields in LOLA

Time-dependend kick in LOLA:



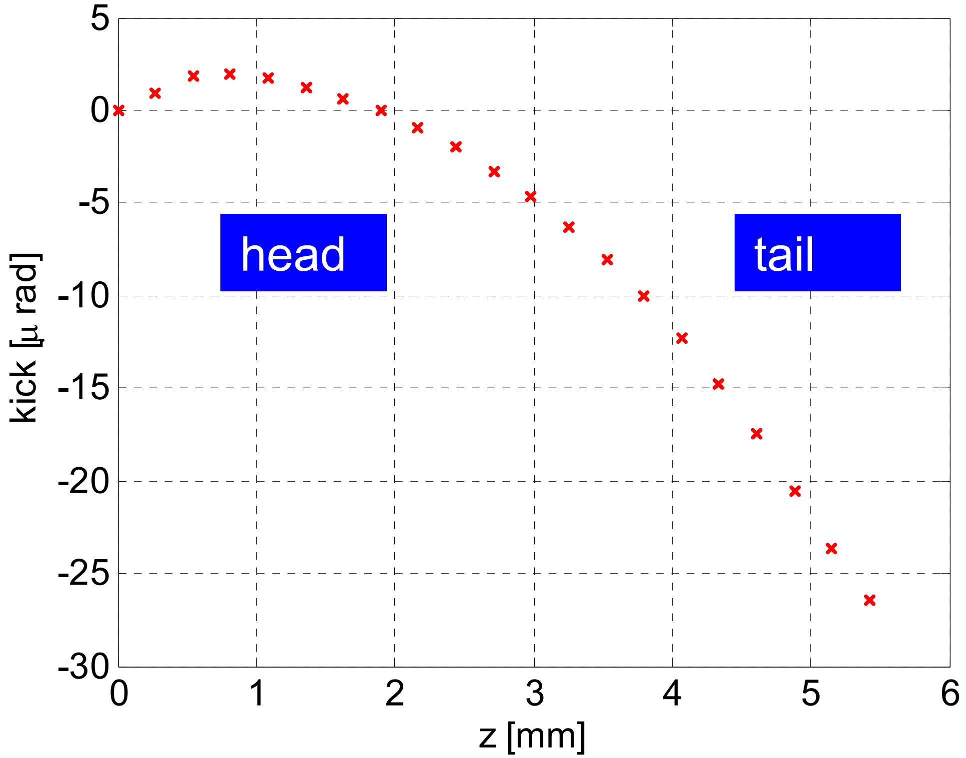
Resulting centroid offset at the screen:



Wake functions : I. Zagorodnov, T.Weiland: TESLA Report 2004-01

Contributions from module ACC5

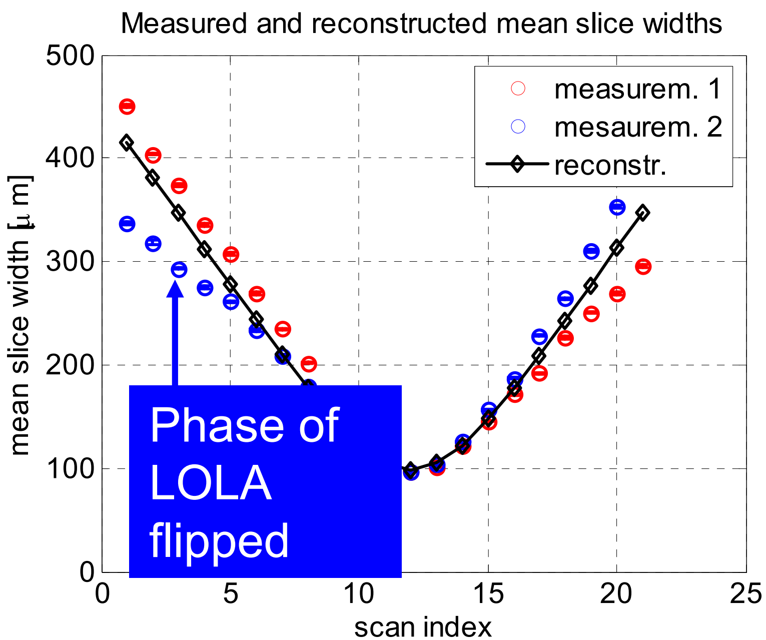
Reconstruction of contributions from ACC5 by quadrupole scans :



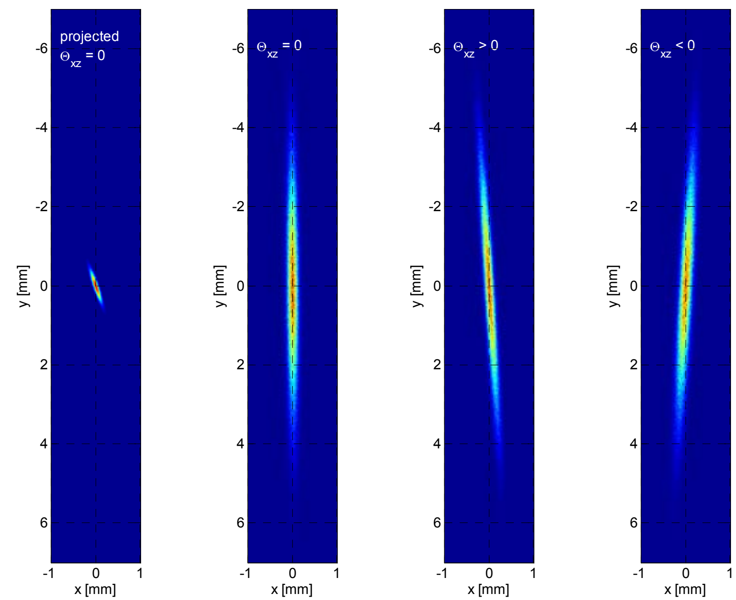
→ Conjecture: Offsets are largely due to transverse wake fields in the accelerating modules and in LOLA

Effects on slice emittance measurements

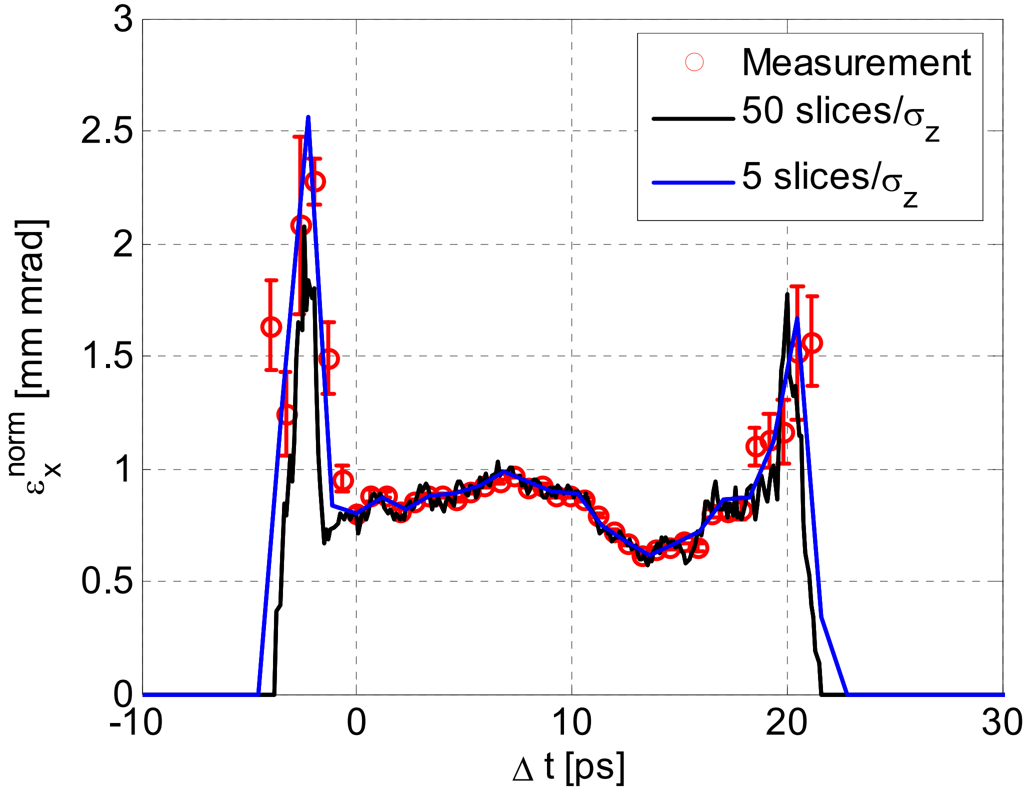
- No significant increase in slice emittance expected from wake fields
- The Projected emittance is strongly effected
- Tilts effect the measured slice widths in case of xy-coupled beams:



Simulation:

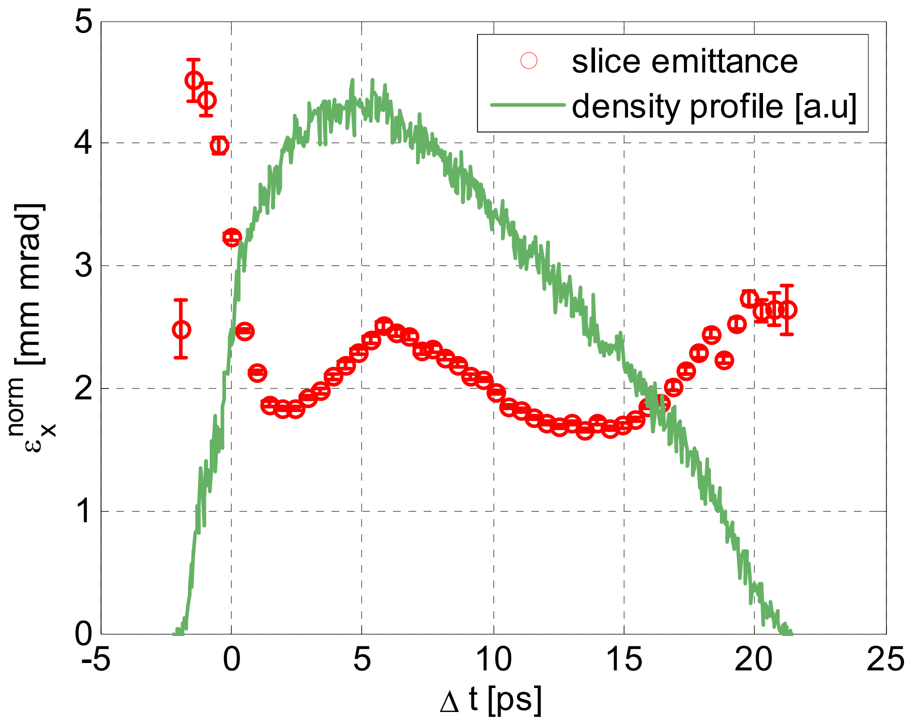


Simulation of a slice emittance measurement



- Bunch from ASTRA-simulation (upstream BC2)
- Simulation: Matching, Beam transport to the screen, Imaging, Addition of noise and centroid offsets, Input into evaluation programs

The ``best” result so far

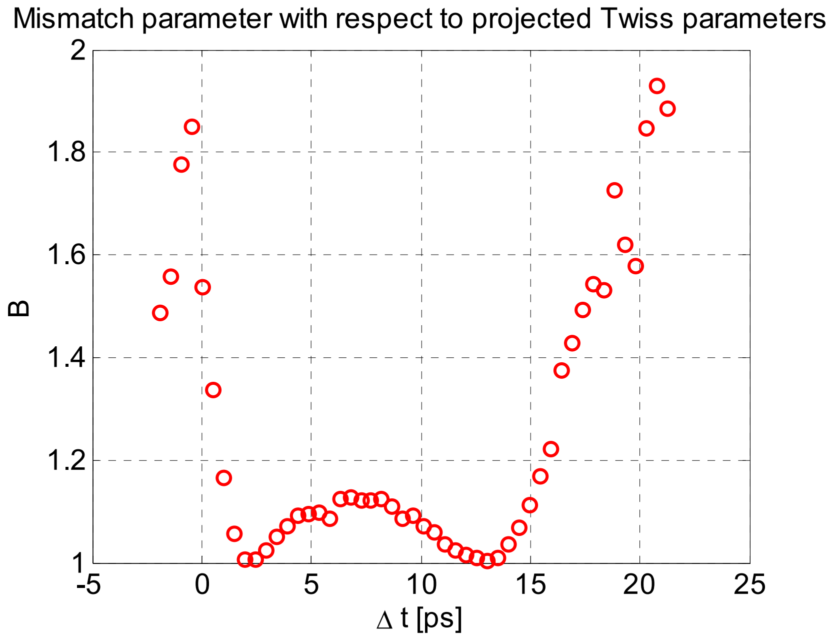


Measurement: 24.01.07, Q = 0.6 nC, E = 494 MeV

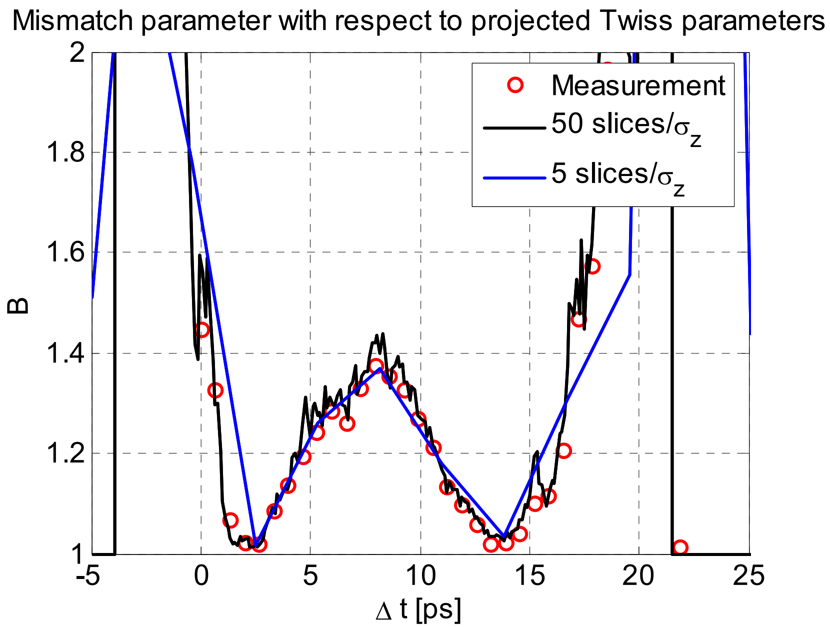
- Basic shape in agreement with simulations
- Core slice emittance between 1.6 and 2.5 mm mrad, no optimization of the machine
- Projected emittance without / with beam inherent / including all measured centroid shifts:
  - 2.4 mm mrad
  - ~3.6 mm mrad
  - 3.8 mm mrad
- Projected emittance measured in the injector: 4.3 +- 0.5 mm mrad

Mismatch parameter

Measurement:

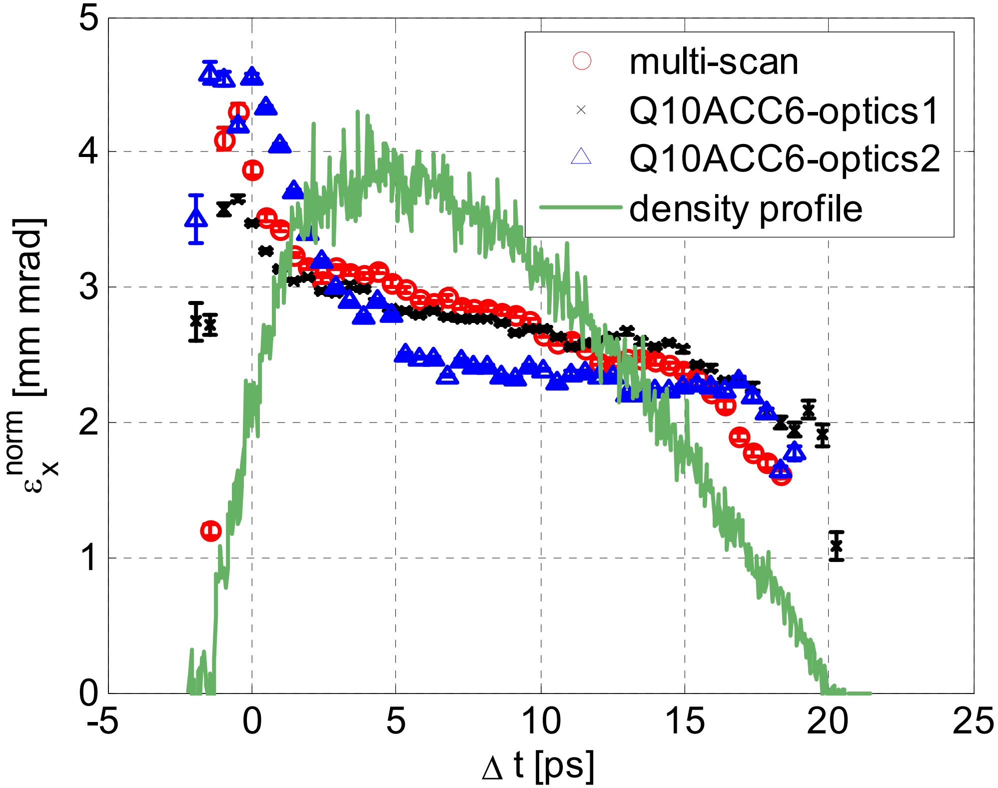


Simulation and simulated measurement (upstream BC2):



Mismatch parameter: $$B = \frac{1}{2}\left(\beta_s\gamma_p - 2\alpha_s\alpha_p + \gamma_s\beta_p\right)$$

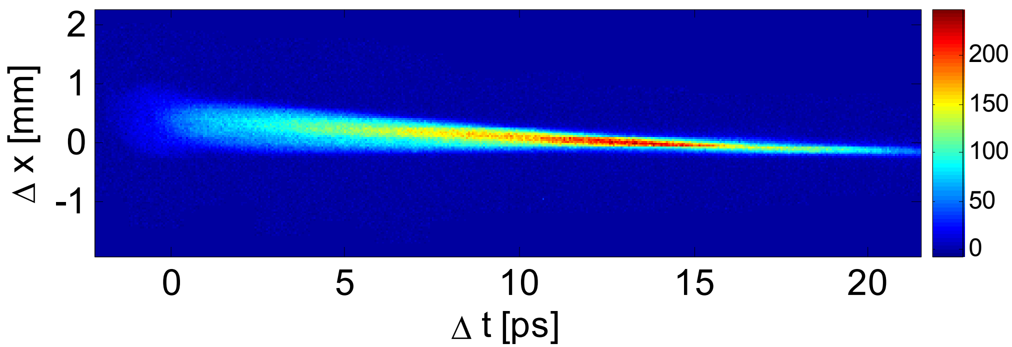
Measurements with three different optics

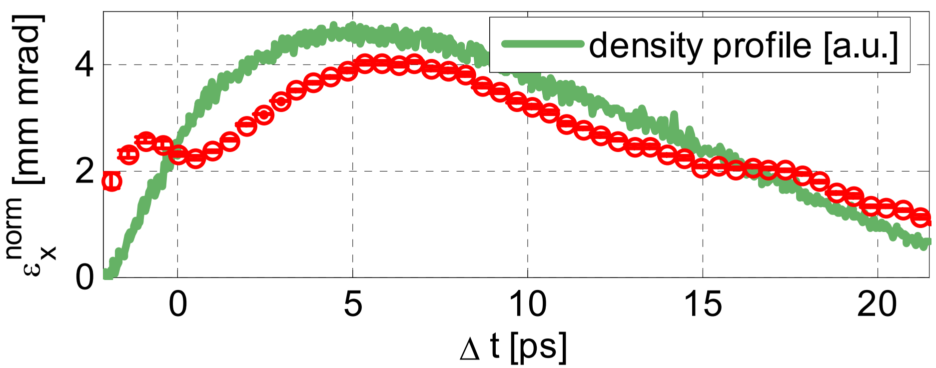


Measurement: 19.02.07, Q = 0.7 nC, E = 500 MeV

- Differences mainly due to different time resolutions
- Projected emittance without / with beam inherent / including all measured centroid shifts:
  - 2.9 mm mrad
  - ~4.0 mm mrad
  - 4.1 mm mrad
- Projected emittance measured in the injector: 3.0 +- 0.2 mm mrad

Some bad results





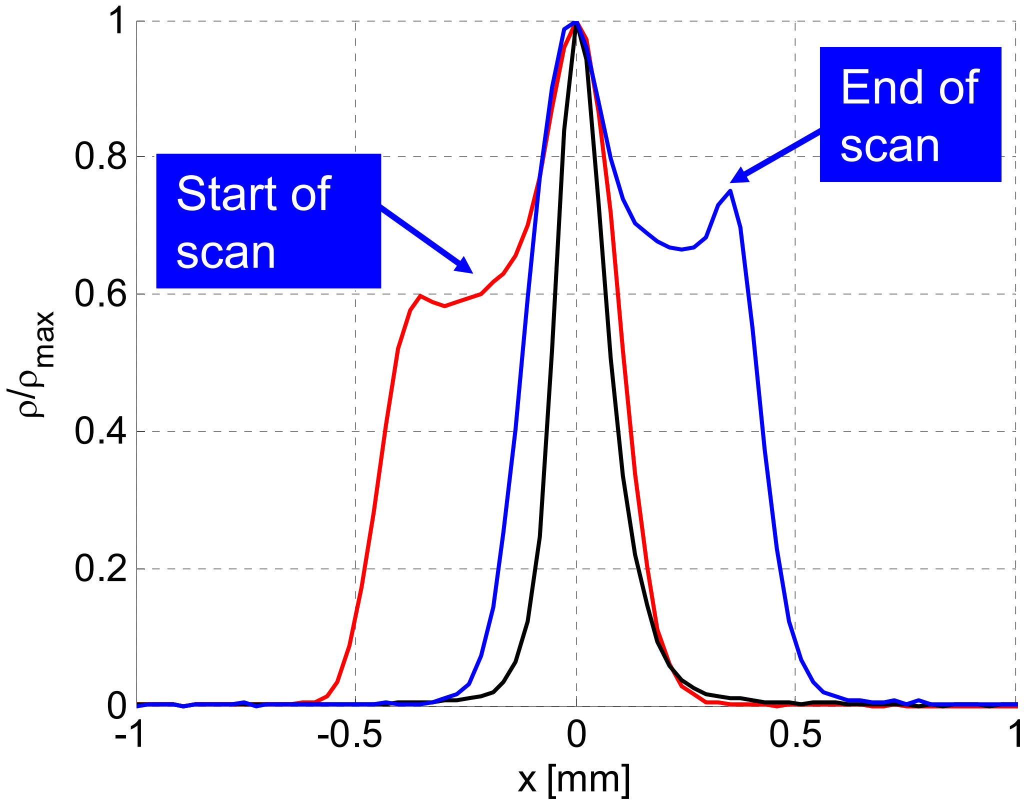
Measurement: 14.12.06, Q = 0.6 nC,
E = 445 MeV

- Projected emittance with / without centroid shifts:
  - 5.5 mm mrad
  - 3.6 mm mrad
- Projected emittance measured in the injector: 3.0 +- 0.1 mm mrad
- Projected emittance measured in the seed section: 4.1 – 5.0 mm mrad (E. Prat, F. Loehl)

→ True increase in slice emittance ?

Degradation of slice emittance

Horizontal slice profile during the quadrupole scan:



- Deformation is not an artefact from centroid offsets
- Degradation caused upstream of the scanned quadrupoles (not by LOLA) and not in the injector
- Gauss-fits not appropriate for determining slice widths

Accuracy of slice emittance measurements

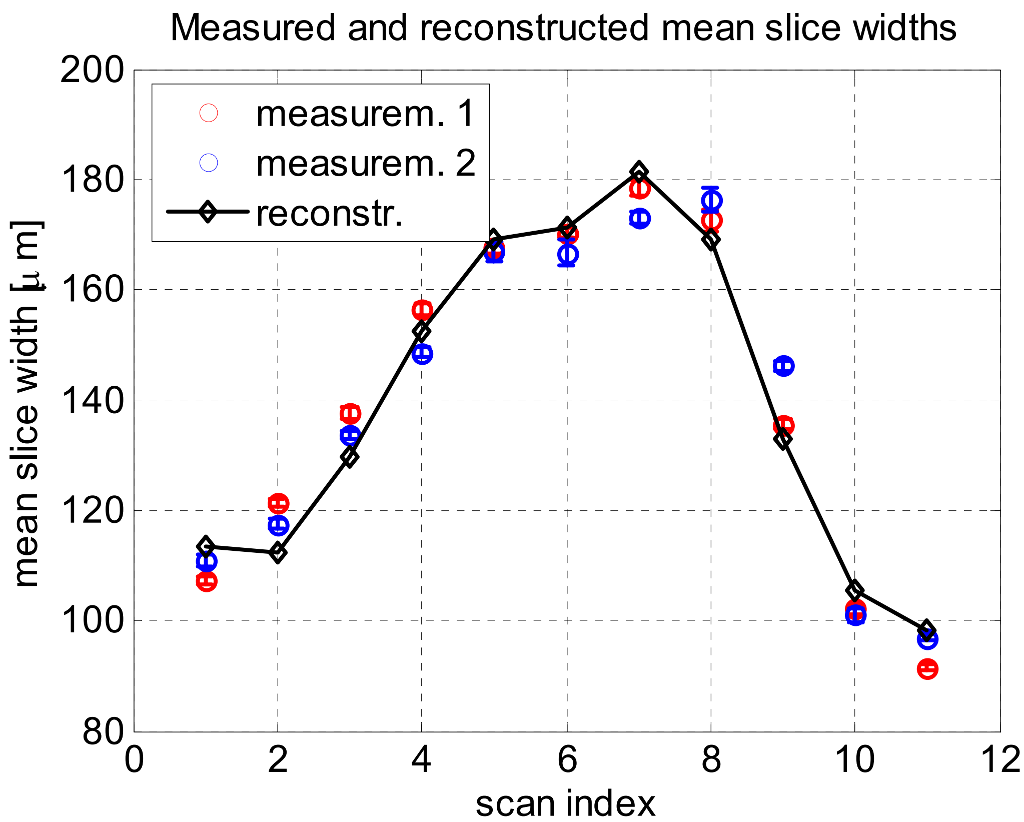
- Statistical errors: ~< 1%
- Systematical errors:
  - Image analysis: checked by simulations
  - Quadrupole gradient errors and energy errors : <10 %
  - Beam imaging : not expected, to be checked in detail
  - Modifications of the beam by LOLA / applying a different optics: not in theory, no indications

Conclusions

- Centroid Offsets observed at the LOLA screen are largely due to wake fields in the accelerating modules and in LOLA
- The observed emittance growth from these offsets is ~30% – 50%
- The smallest slice emittance measured is 1.6 – 2.5 mm mrad in the core of the bunch (no optimization of the machine)
- The measured slice emittance is basically in agreement with measurements of the projected emittance

Thanks to Christopher Gerth, Holger Schlarb, Florian Löhl and Eduard Prat

Measured and reconstructed bunch widths

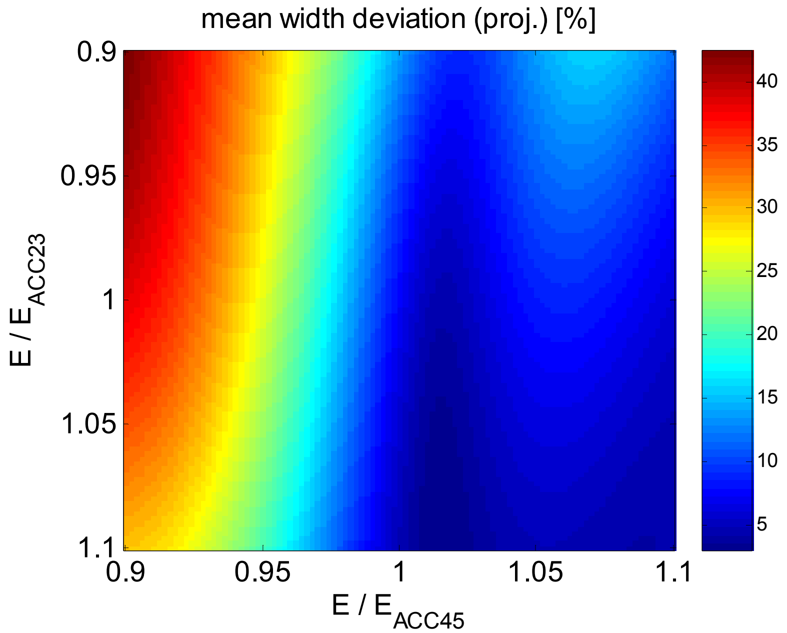


Measure for errors in the used transfer matrices:

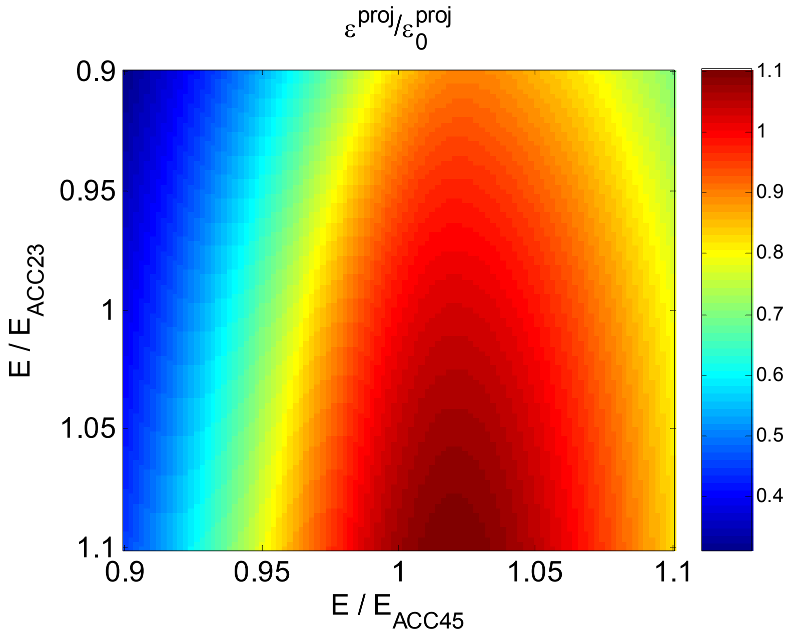
$$S = \sqrt{\frac{1}{N} \sum_{i=1:N} \left(\frac{\Delta \sigma_i}{\sigma_i} \right)^2}$$

Energy Errors

Mean bunch width deviation (S [%]) for different energies (Multi-quadrupole-scan):



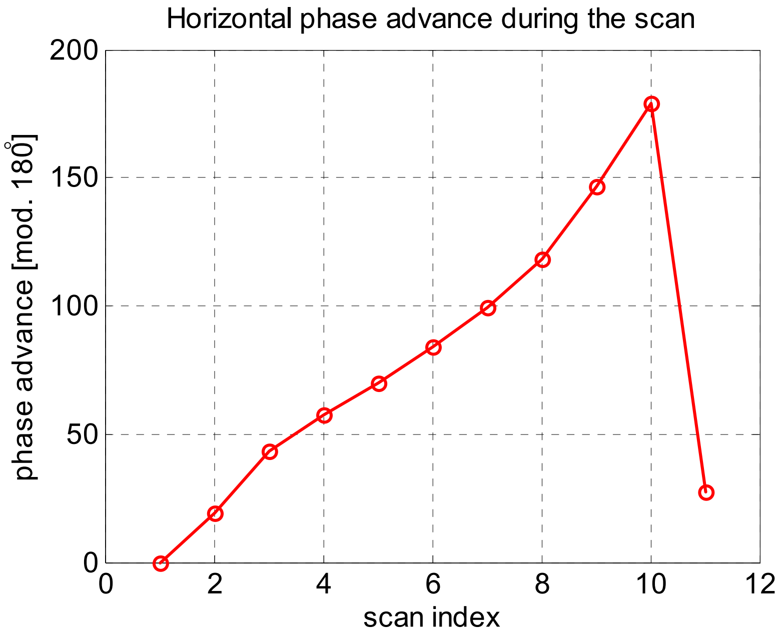
Corresponding changes of the projected emittance:

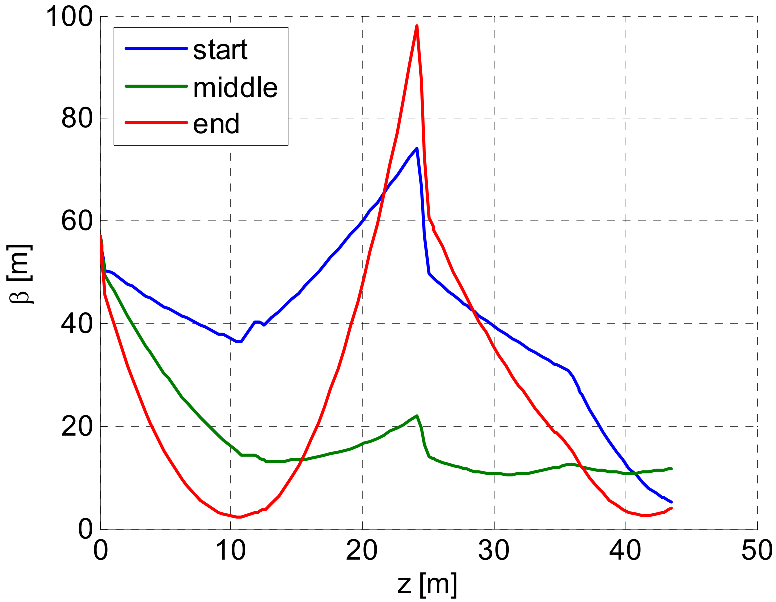


Quadrupole gradient errors

Monte-Carlo Simulation: 2% peak to peak gradient error of all involved quadrupoles (multi-quadrupole-scan):

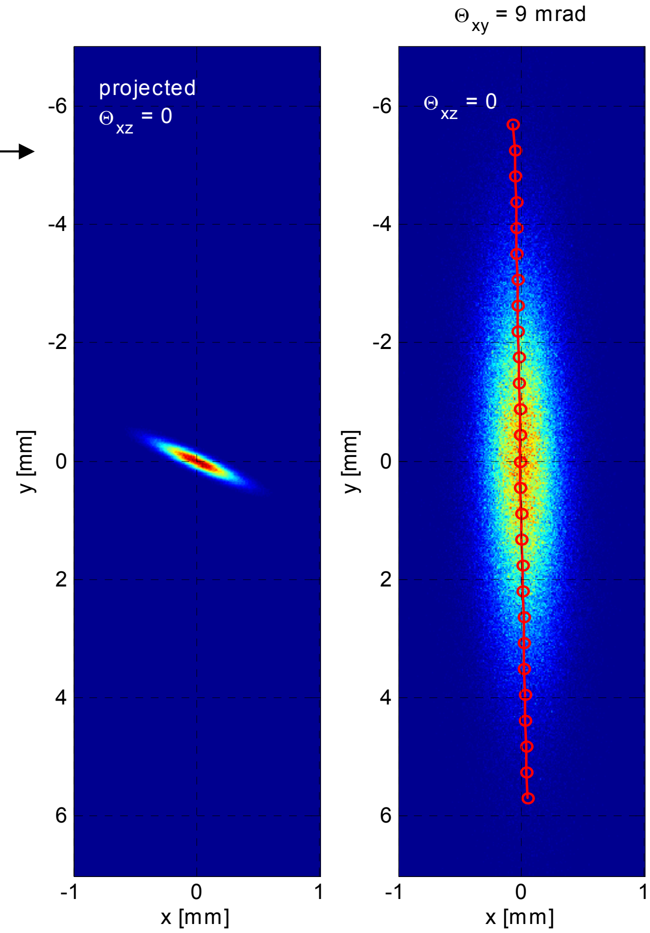
Reconstructed optics





Tilt from xy-coupling: simulation

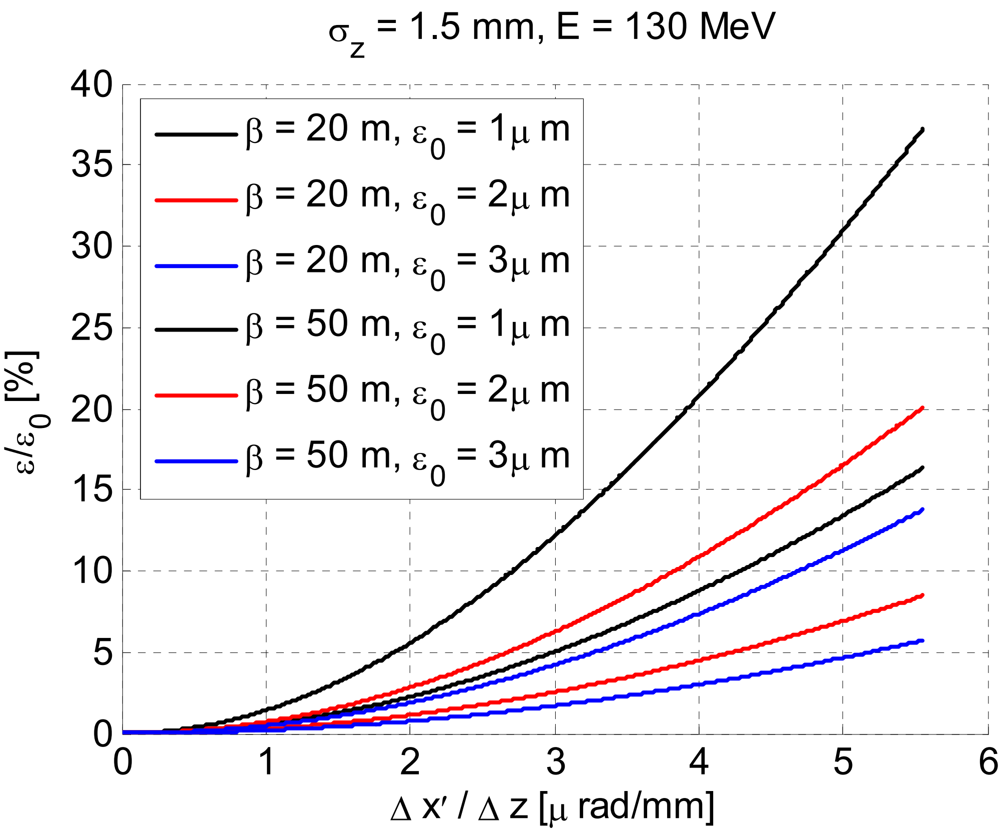
Projected transverse distribution with strong xy-coupling →



→ Tranverse distribution after passing LOLA: A tilt of 9 mrad remains from xy-coupling

Emittance growth due to linear tilts

Gaussian bunch



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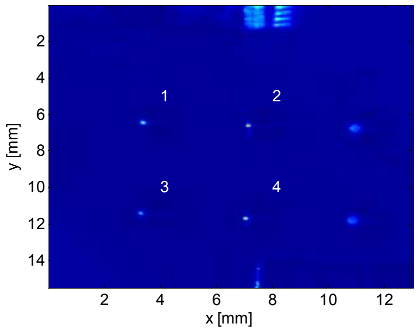
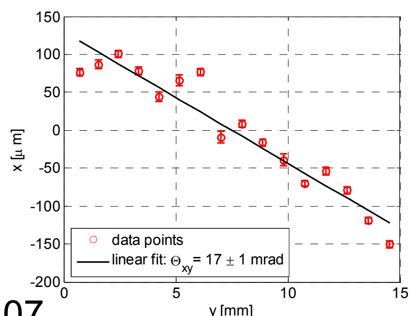
Rotation of the camera / of LOLA

Rotation of the camera:

- With respect to the screen holder: ~19 mrad

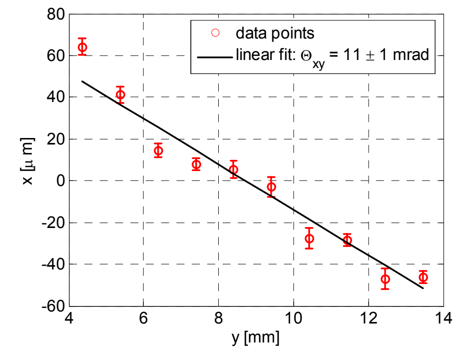


- With respect to V10ACC7 (vertical steerer): ~17 mrad



Rotation of the camera and LOLA:

- LOLA-phase-flip: 11- 21 mrad
- Scan of LOLA-phase: 11- 17 mrad



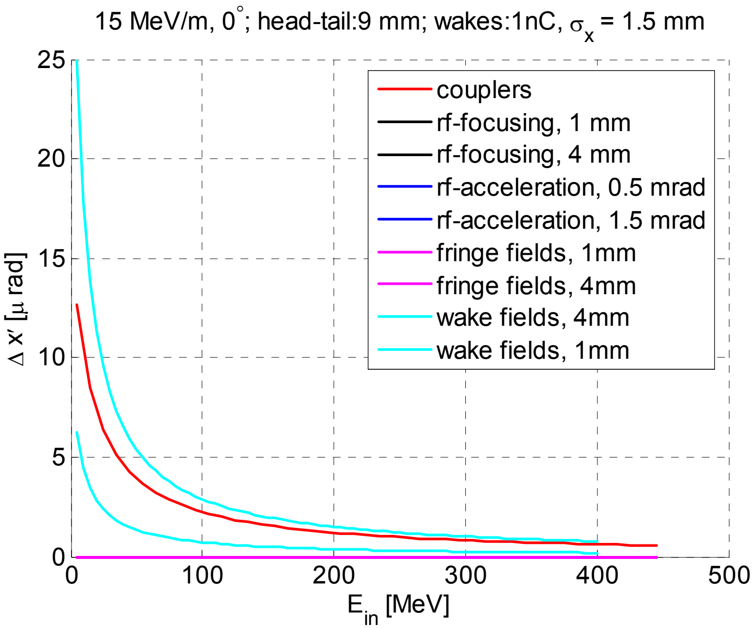
→ Rotation of the camera of ~ 1°

→ Rotation of LOLA < 10 mrad

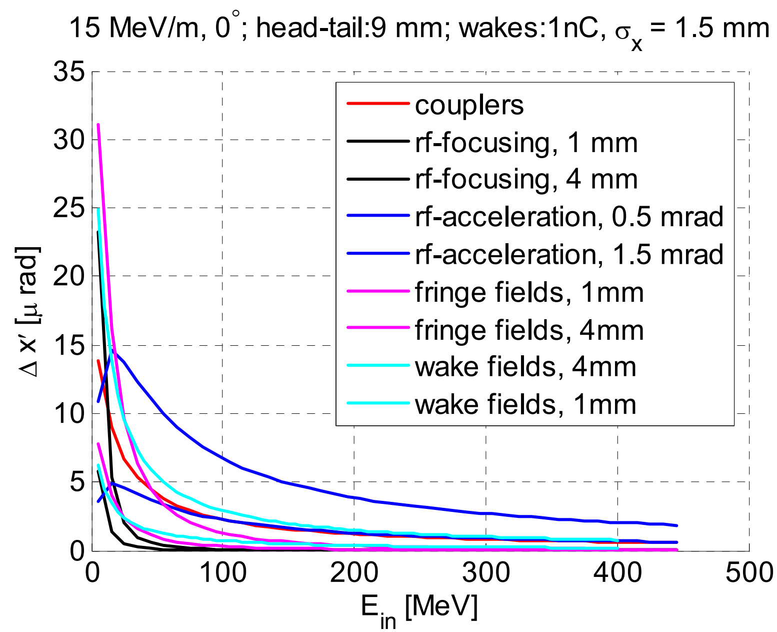
z-correlated tilt sources in cavities

Kick difference Δx’ between head and tail per cavity :

On-crest:



Off-crest:



Emittance growth << 10% !

Wake functions: I. Zagorodnov, T.Weiland: TESLA Report 2003-19;
Coupler Kicks: Presentation of M. Dohlus