Investigation of the Longitudinal Electron Bunch Structure with LOLA

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Outline

- **Description of the measurements**
- **Results:**
  - **Longitudinal profile**
  - **Longitudinal phase space distribution**
  - **Slice emittance**
- **Error considerations for the measured slice emittance values**

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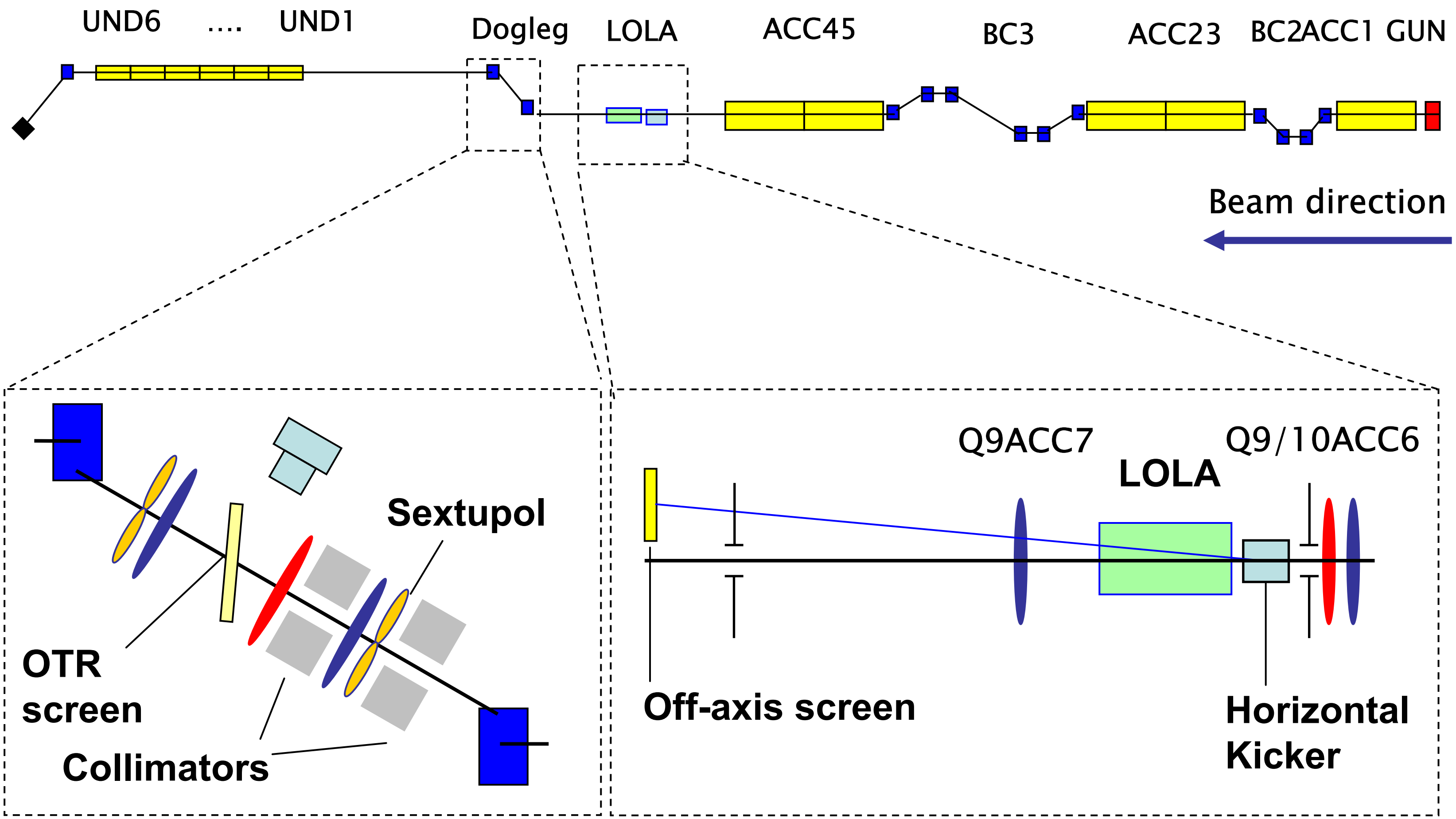
LOLA in the FLASH linac



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Accelerator settings

- **Energy: 677 MeV**
- **Charge: 0.5 nC**
- **SASE signal at 13.7 nm with 5 µJ average radiation energy per bunch**

  → optics downstream of BC3 changed before the measurements!
- **ACC1-phase: -9°**
- **ACC23-phase: -25°**
- **ACC45-phase: 0°**

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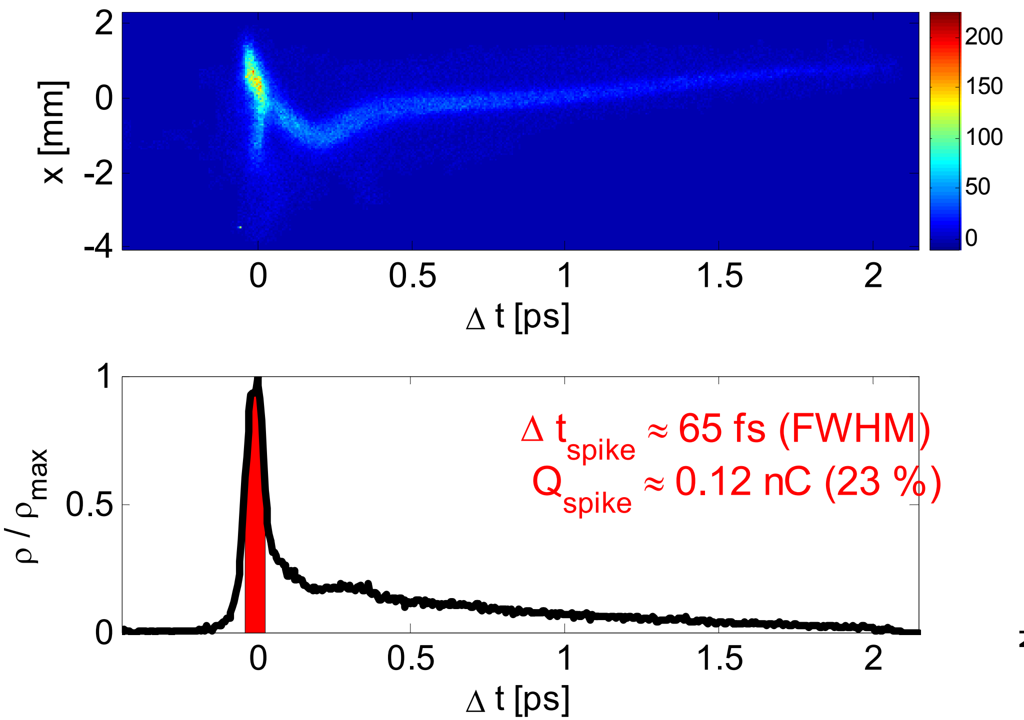
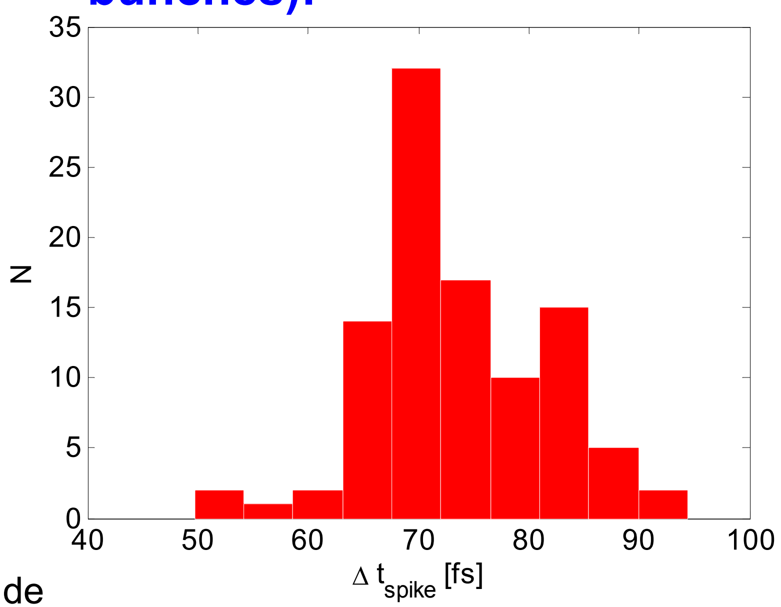
Longitudinal profile



Spike width: ~75 fs (FWHM)
Resolution: ~50 fs (FWHM)
Charge in spike: ~0.12 nC
(23%) spike current: ~1.7 kA

Spike width statistics (100 bunches):



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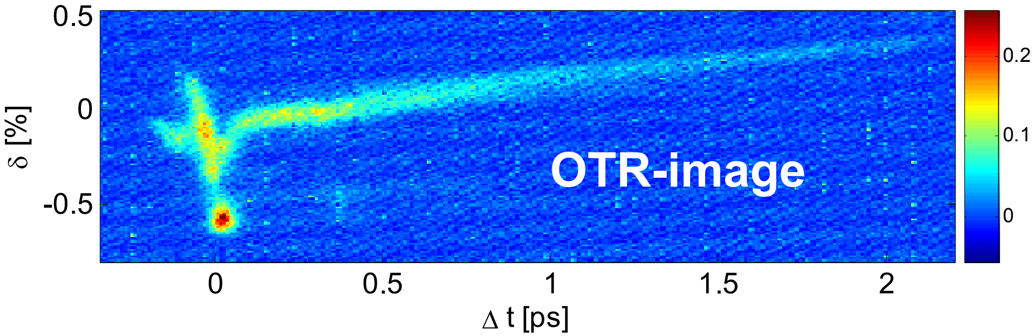
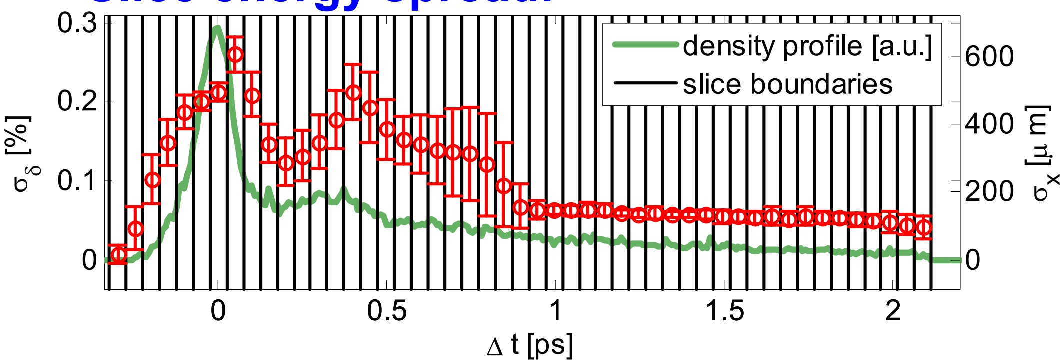
Longitudinal phase space

Head **Tail**

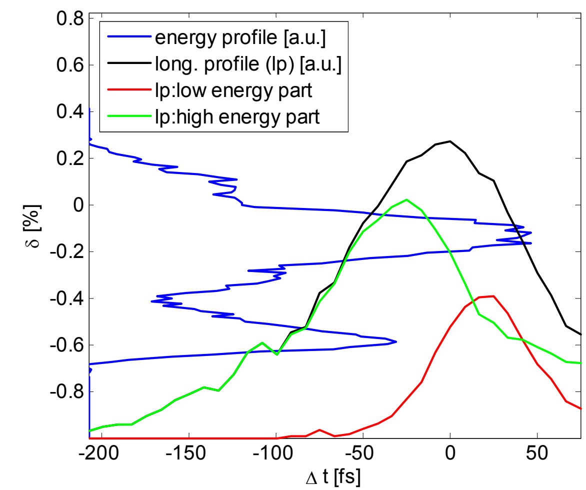


Dispersion: 233 mm;
Time resolution: ~ 50 fs;
Energy spread resolution: ~ 0.06% (380 keV)

Slice energy spread:



Profile of the head



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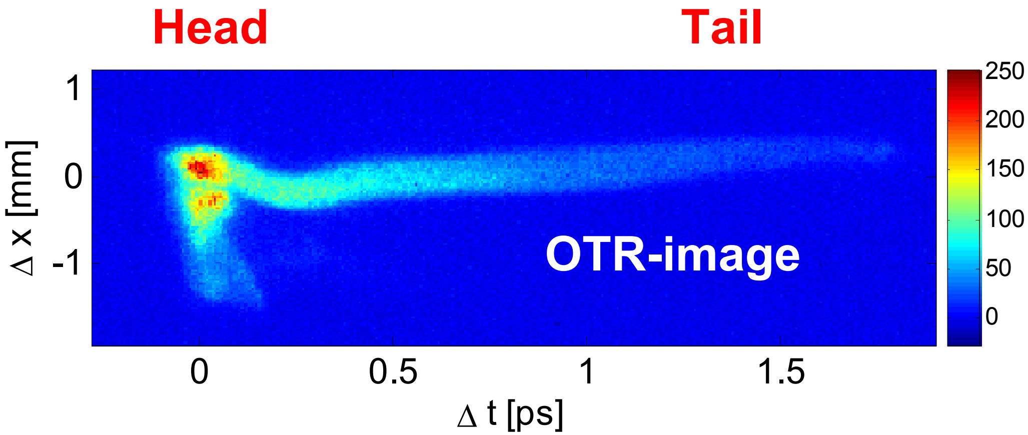
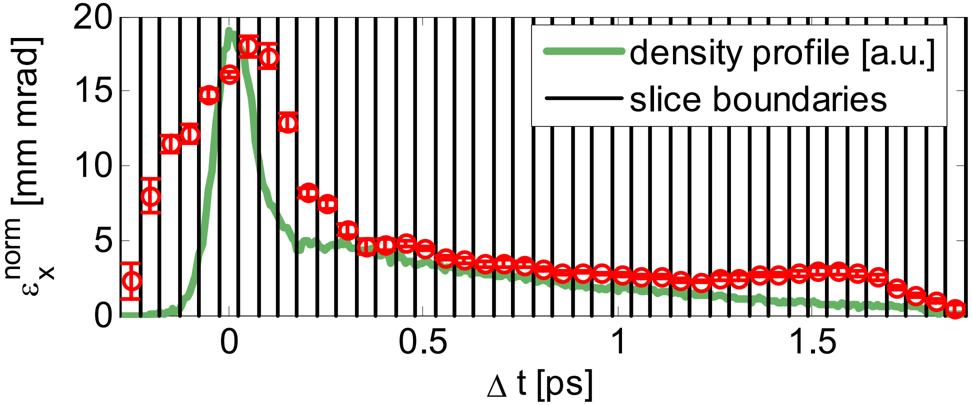
Slice emittance



- **Resolution ~60 fs**
- **Proj. emittance: 13.5 mm mrad**
- **Slice mismatch < 1.5**



↔ SASE signal?

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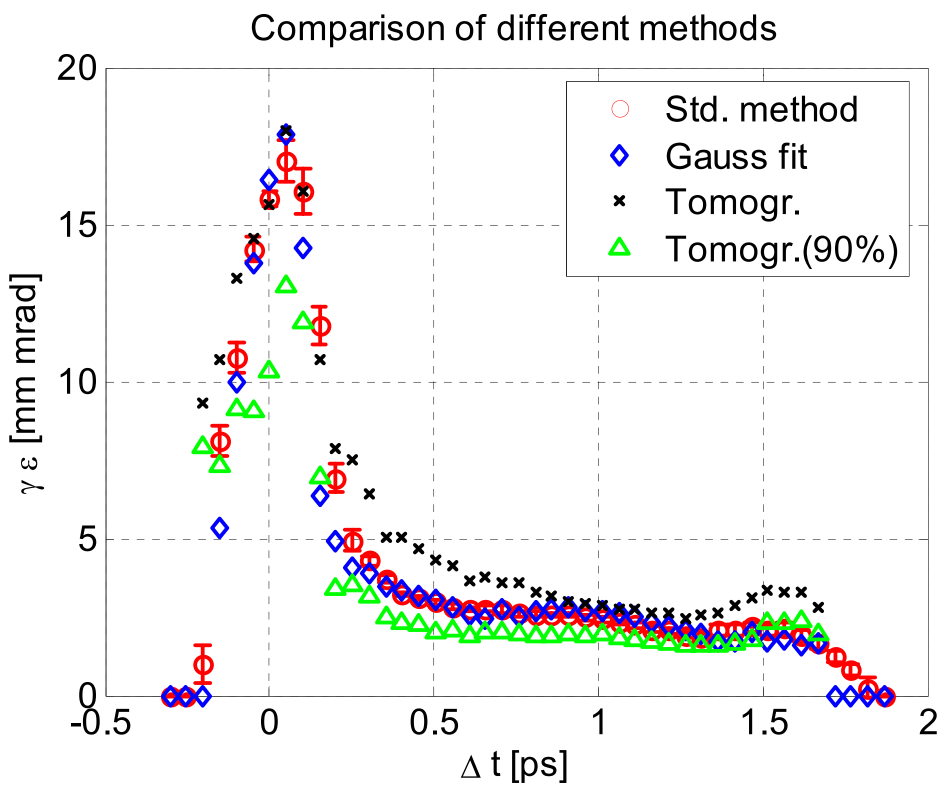
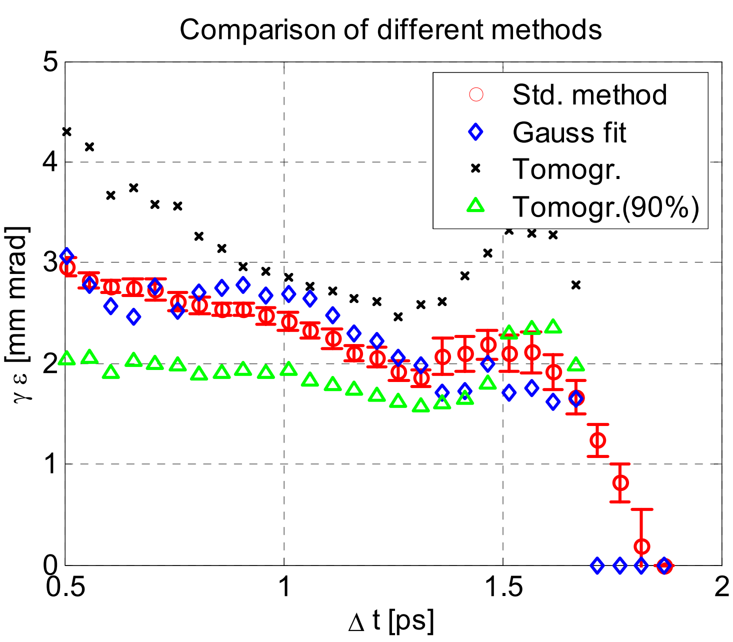
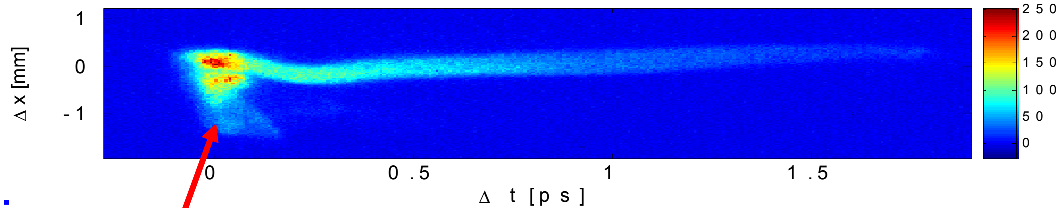
Slice emittance: comparison of different methods



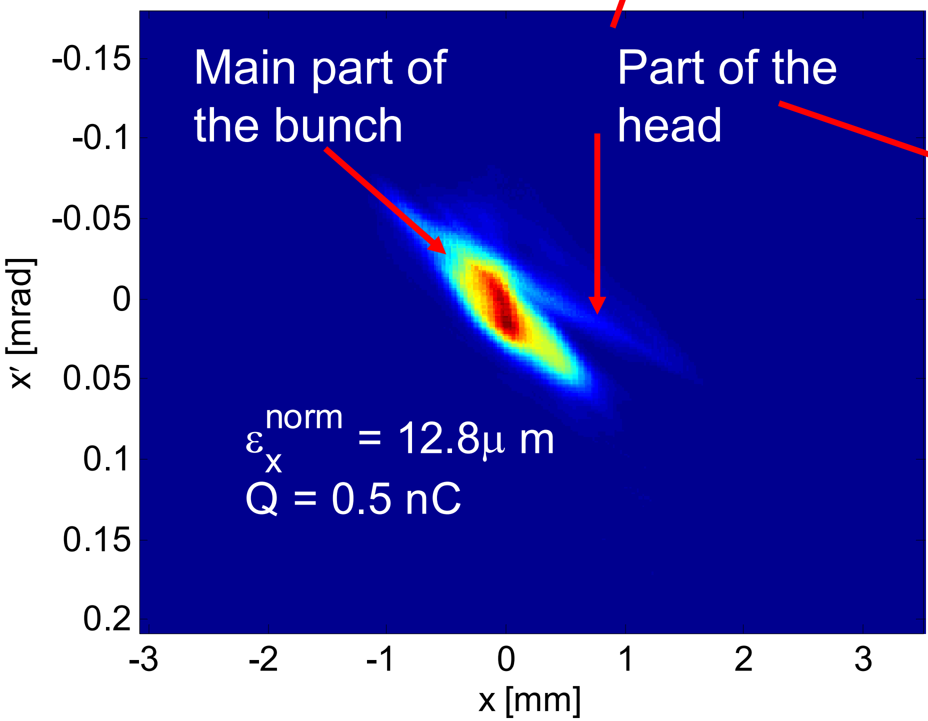
Tail:



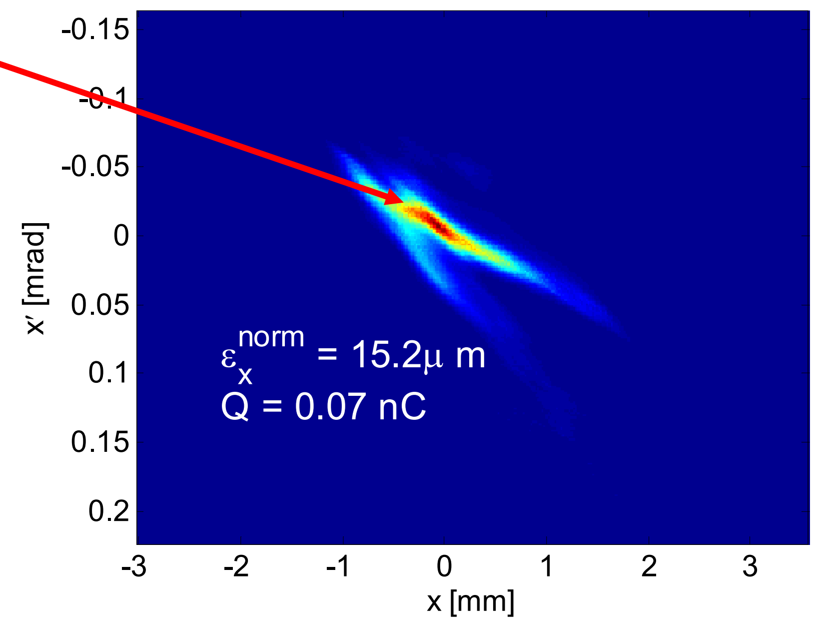
Reconstructed phase space



Entire bunch:



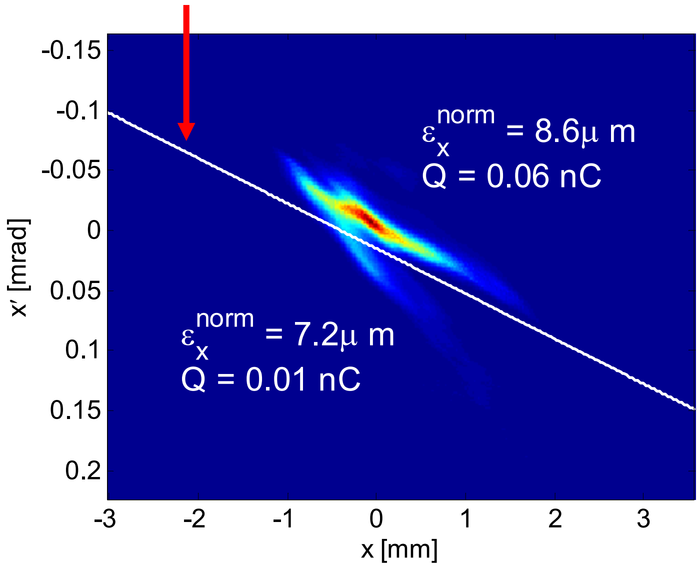
Single slice (~60 fs) within the head:



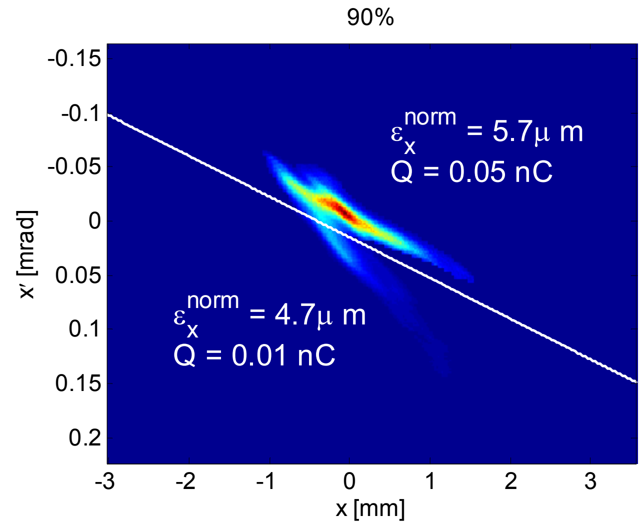
Emittance of substructures in phase space

Single slice (~60 fs) within the head

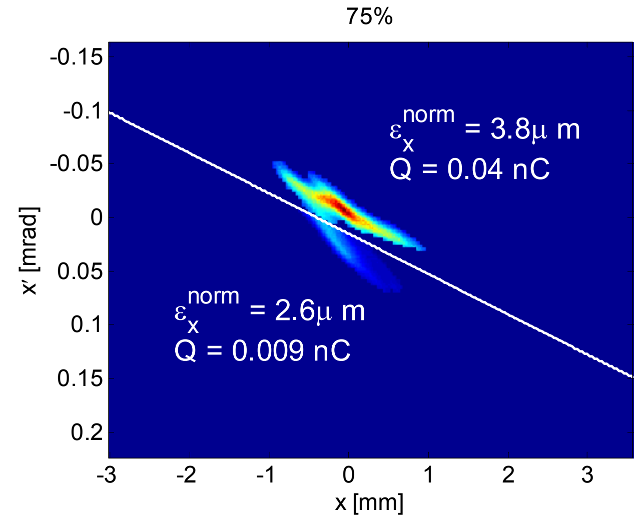
Subdivision of phase space



90% of the total charge (low intesity regions are cut):



75% of the total charge:



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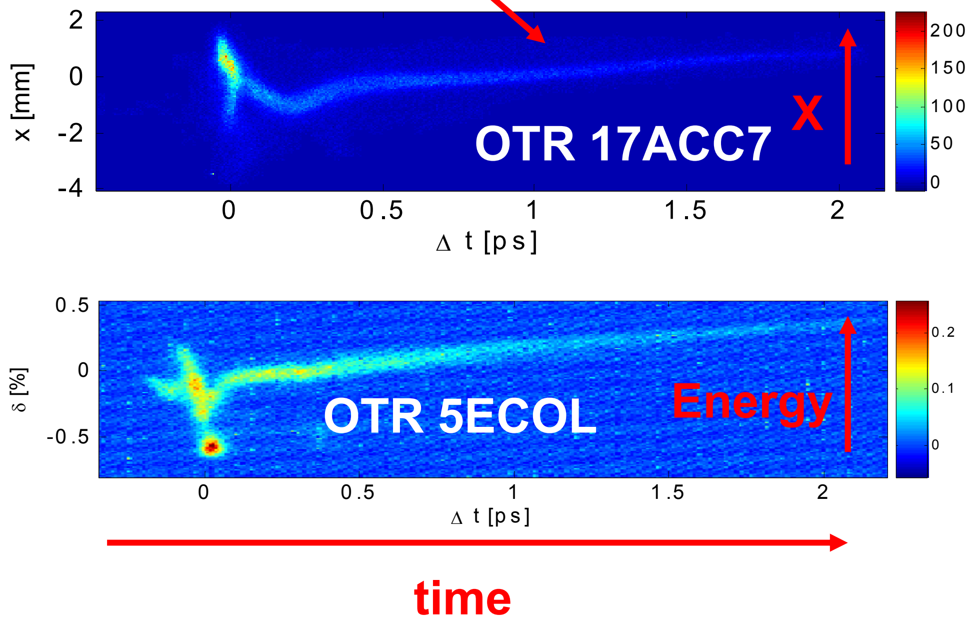
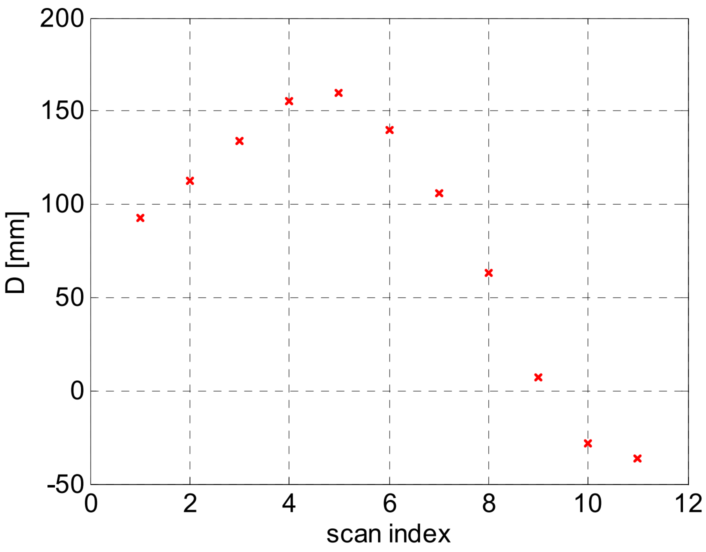
Dispersion

Tilt of the tail due to dispersion(?)



Reconstructed horizontal dispersion during the quadrupole scan:



→ Tilt and long. Phase space distribution can me utilized to estimate dispersion

→ Very large values

→ Tilt not solely due to dispersion?

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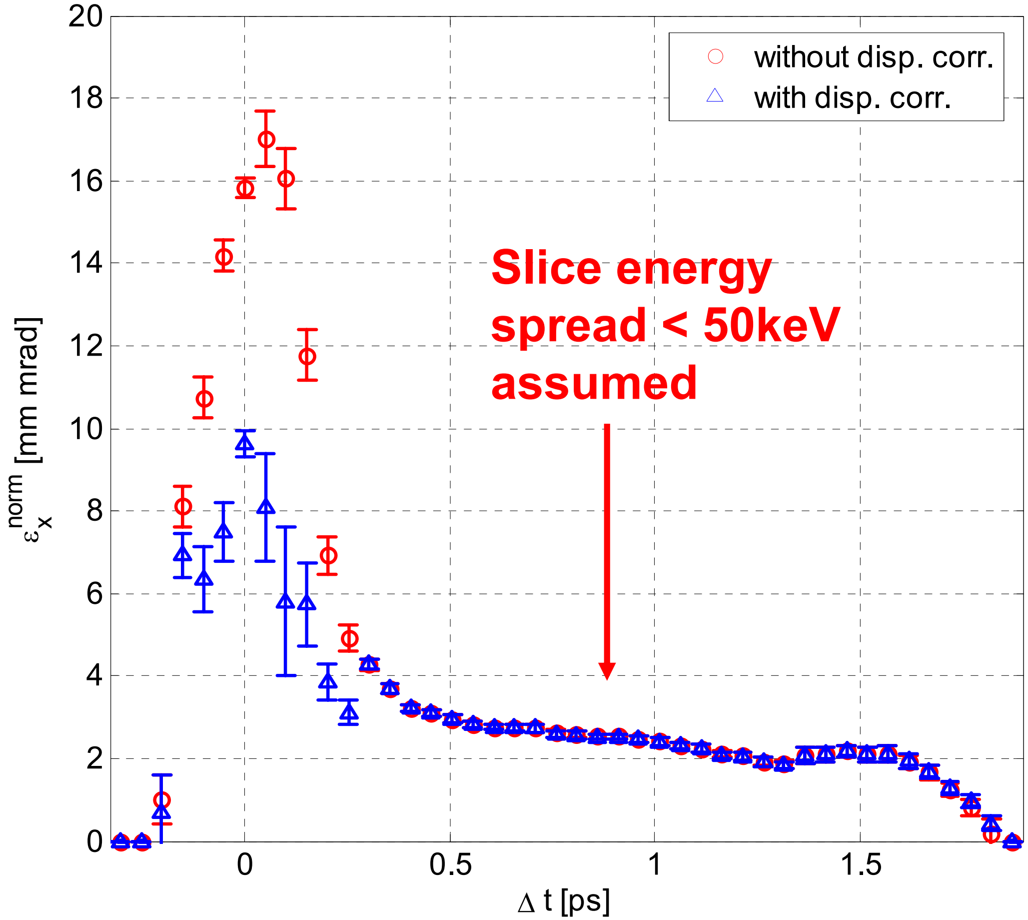
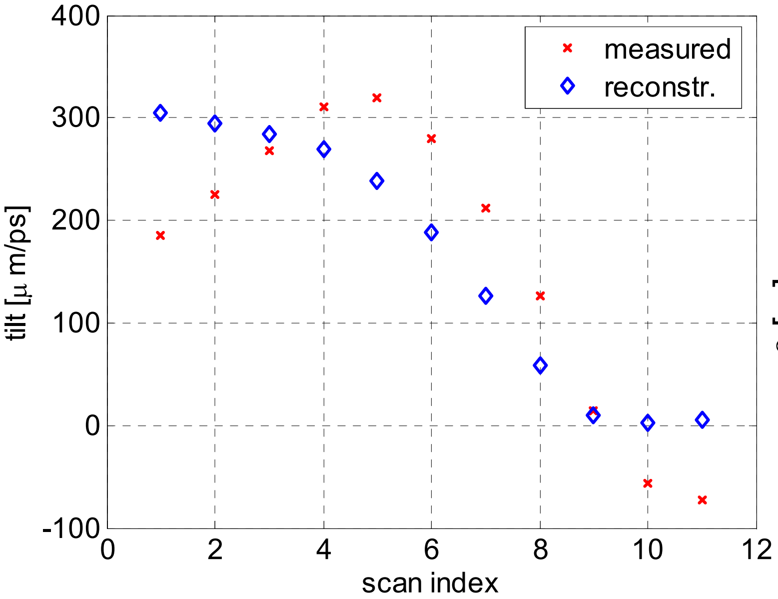
Dispersion-corrected slice emittance

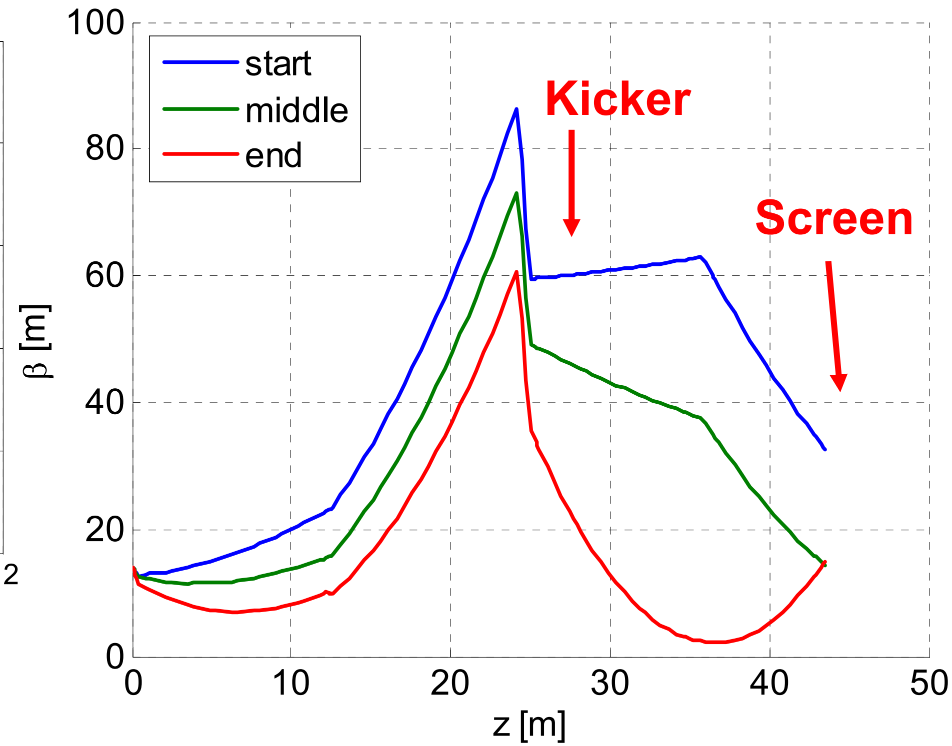


Large Dispersion because of optics?

Measured and reconstructed tilt due to dispersion:

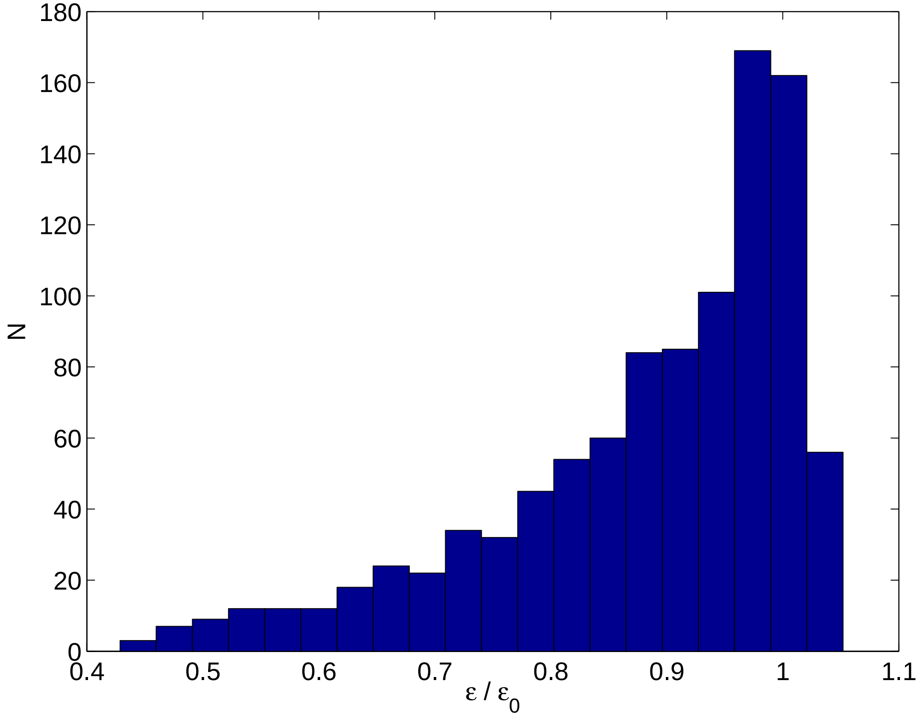


Reconstructed beta-functions during the scan (single slice):



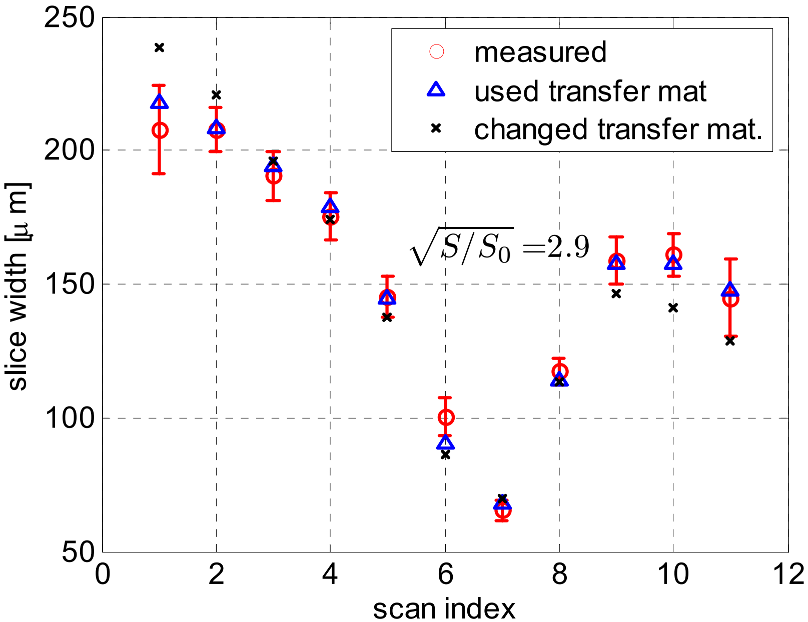
Quadrupole gradient errors

- **Monte Carlo simulation for 3% quadrupole gradient errors (1000 seeds, emittance of one slice):**



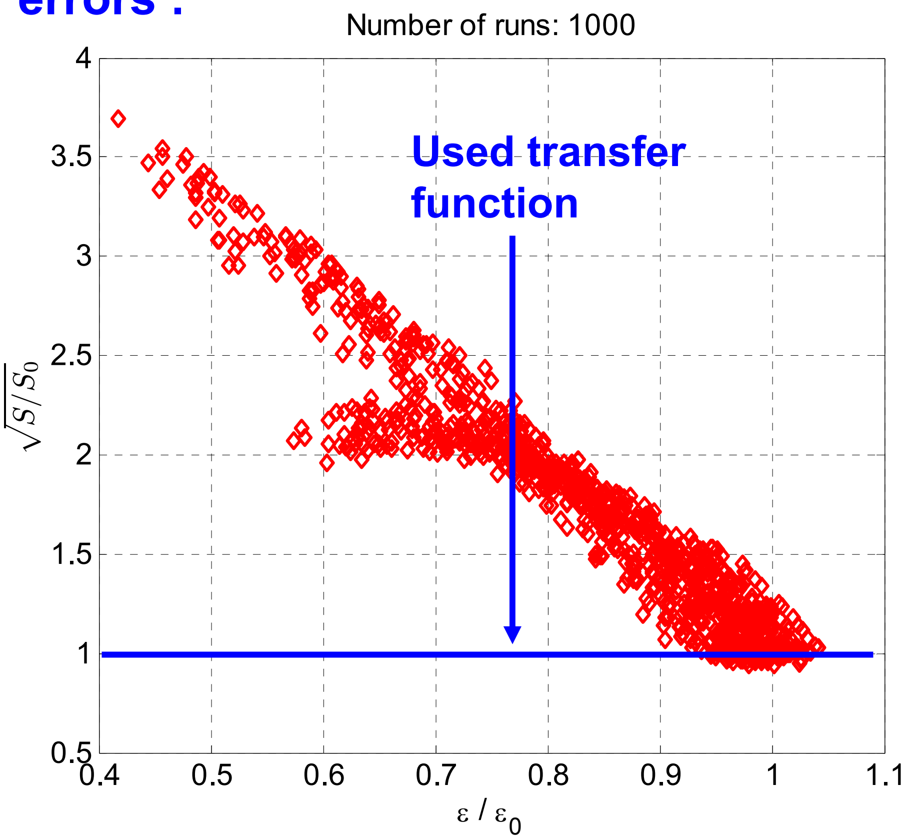
- **Comparison of measured and reconstructed slice widths:**

$$S = \sum_{i=1:N} (\sigma_i^{meas.} - \sigma_i^{reconstr.})^2$$



Quadrupole gradient errors

Comparison of reconstructed and measured slice widths for random gradient errors :



→ **Errors from erroneous transfer matrices much smaller than expected**

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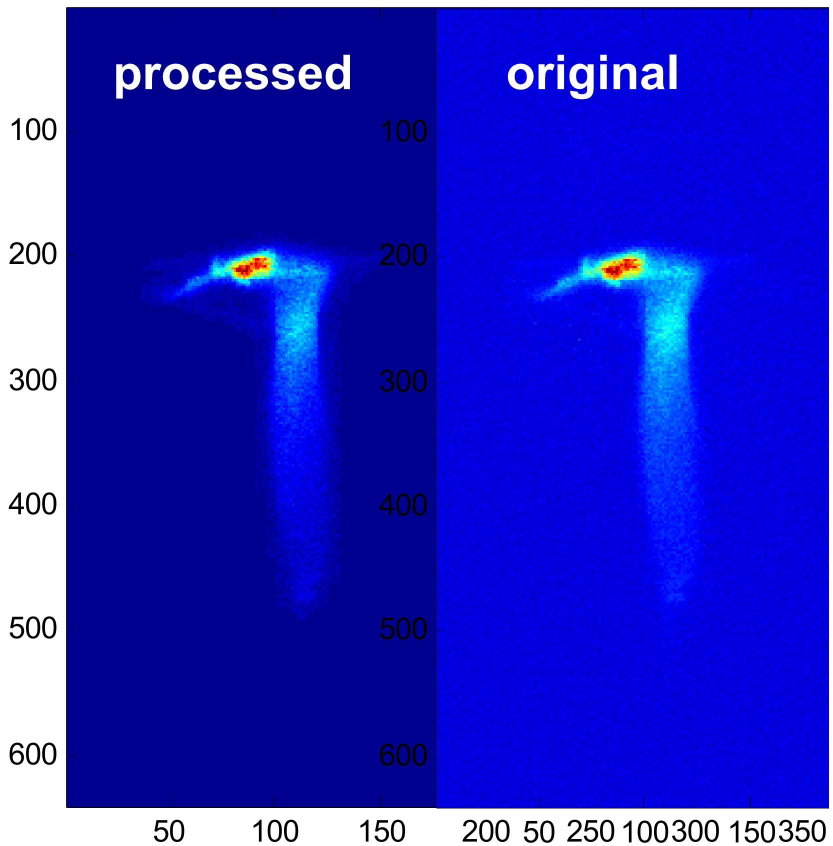
Image analysis



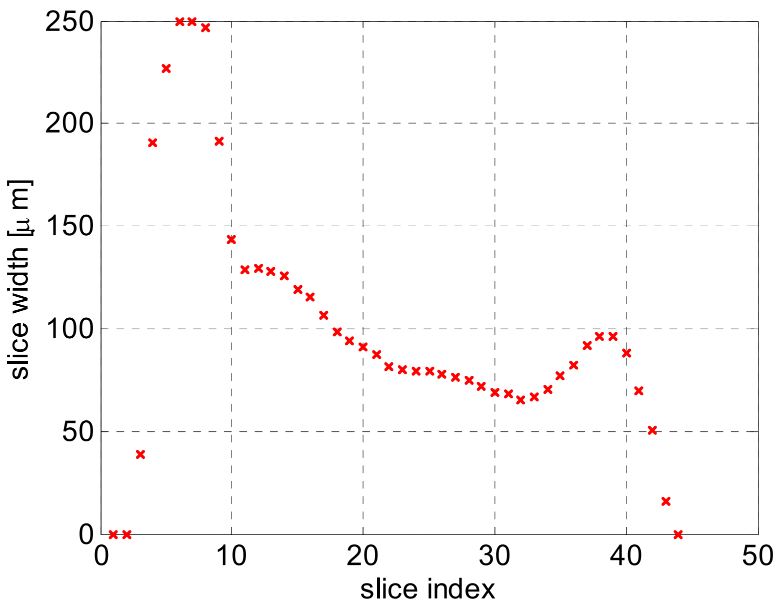
- Algorithm to detect the image region covered by the bunch
- The remainder of the image is set to zero

→ **nearly no influence of noise**

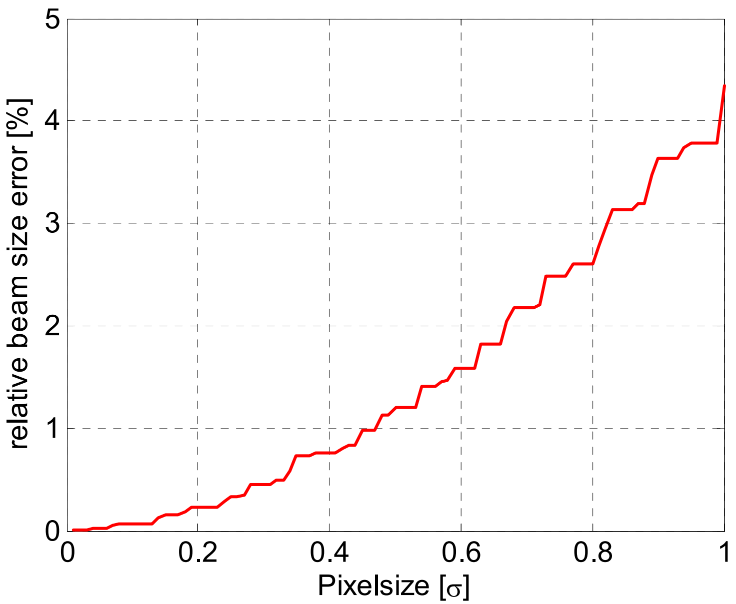
Resolution limitation

- Pixel size: ~25 µm

- Minimum slice widths during the scan:



- Effect of binning on the calculated rms width for a gaussian distribution with standard deviation σ



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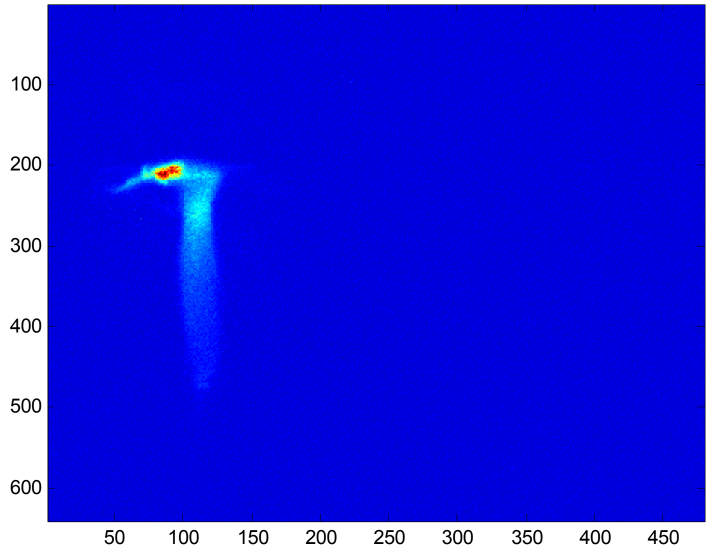
Conclusions

- **Dispersion seems to be a significant error source for slice emittance measurements**
  - **Measure and correct dispersion before slice emittance measurements if possible → smaller emittance values?**
  - **Measurement of dispersion during the scan**
  - **Apply different optics?**

Image analysis 1

Original image with noise (background subtracted):



Bad signal to noise ratio in single slices, noise largely influences calculated rms widths

1. **Local averaging; new pixel size e.g. 5x5 pixels**

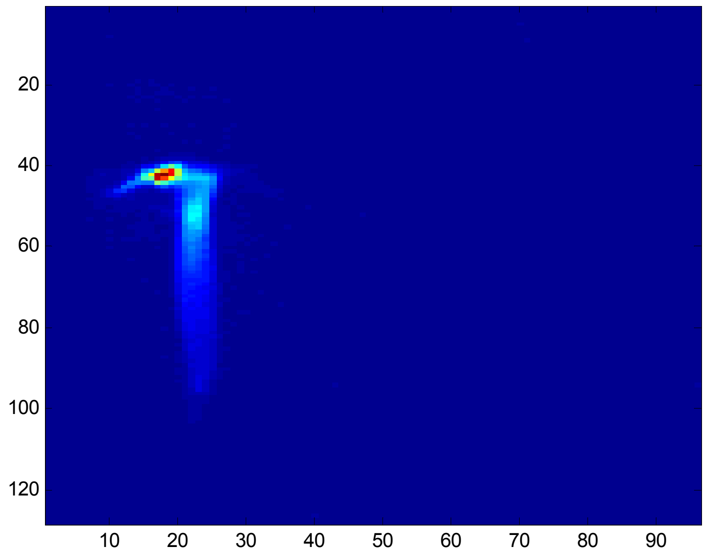


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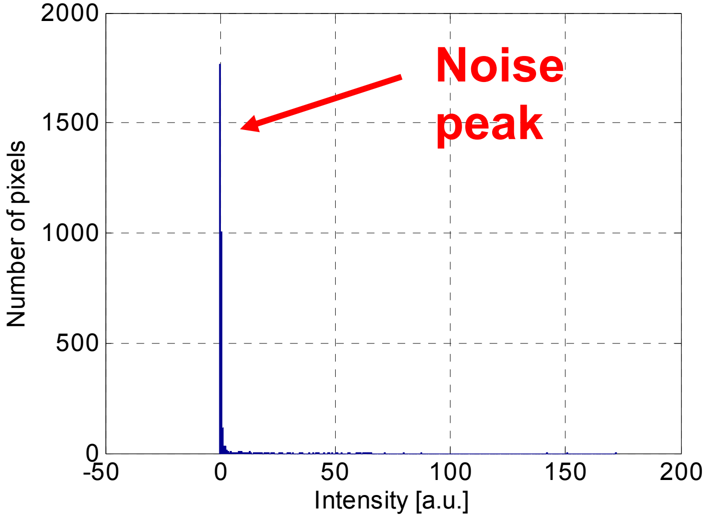
Image analysis 2

2. Determine mean value and variance σ^2 of noise from an intensity histogram



3. Find pixel with maximum intensity

4. Loop: add nearest neighbour pixels, if intensity > n*σ (e.g. n=3)

→ Connected area with intensities above the noise level

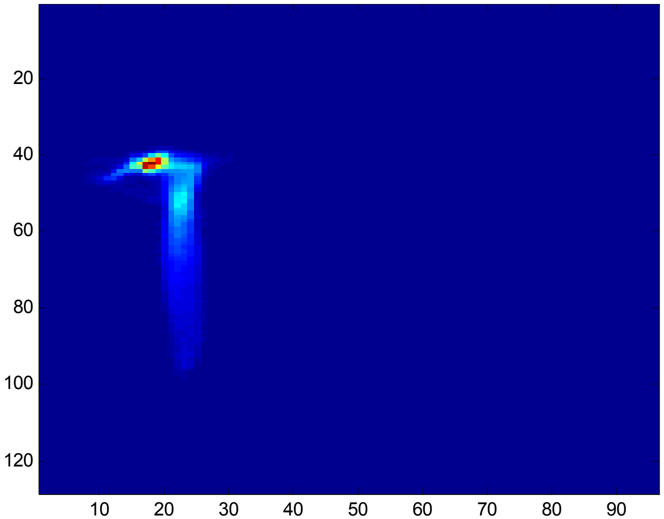
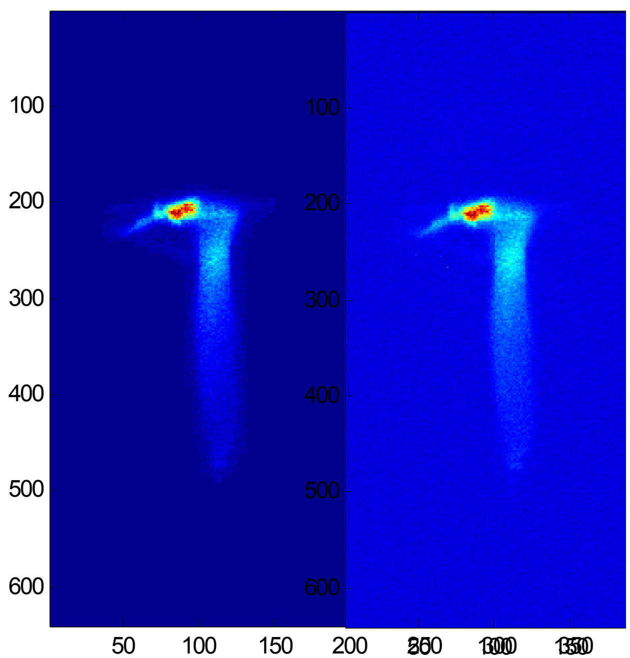


Image analysis 3

5. Transformation back to original pixel size

Comparison: resulting and original image



Optional:

- Boundary layers around the bunch area
- Iterative determination of the noise level, e.g. in case of synchrotron radiation
- Splitting of the image in case of inhomogenous background