Measurement of slice emittance and energy-time correlation with LOLA

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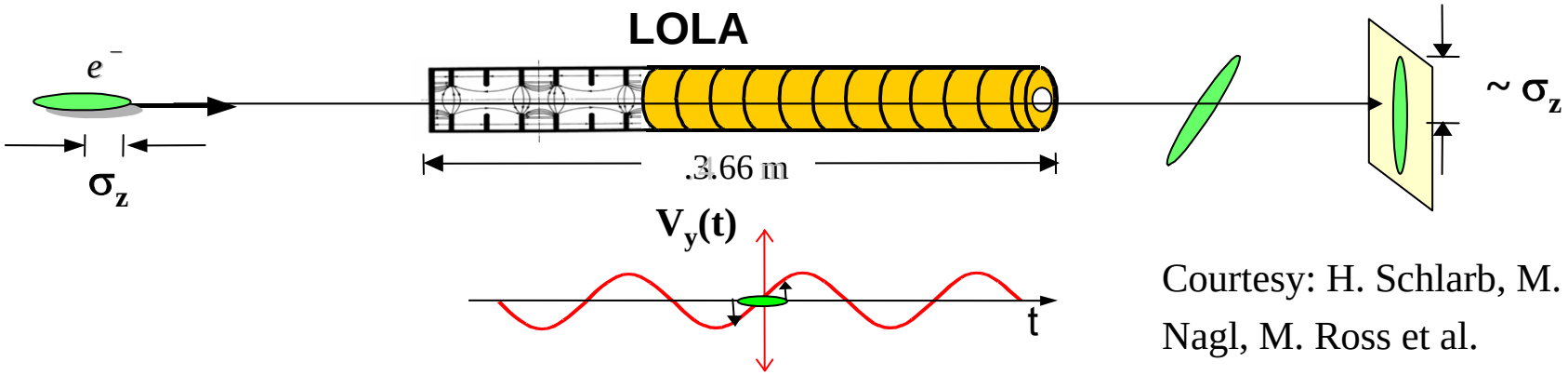
Outline

- Introduction
- Preparation of the measurements
- Some results:
  - Energy-time correlation / slice energy spread
  - Slice emittance
- Outlook

Introduction



Courtesy: H. Schlarb, M. Nagl, M. Ross et al.

Measurements:

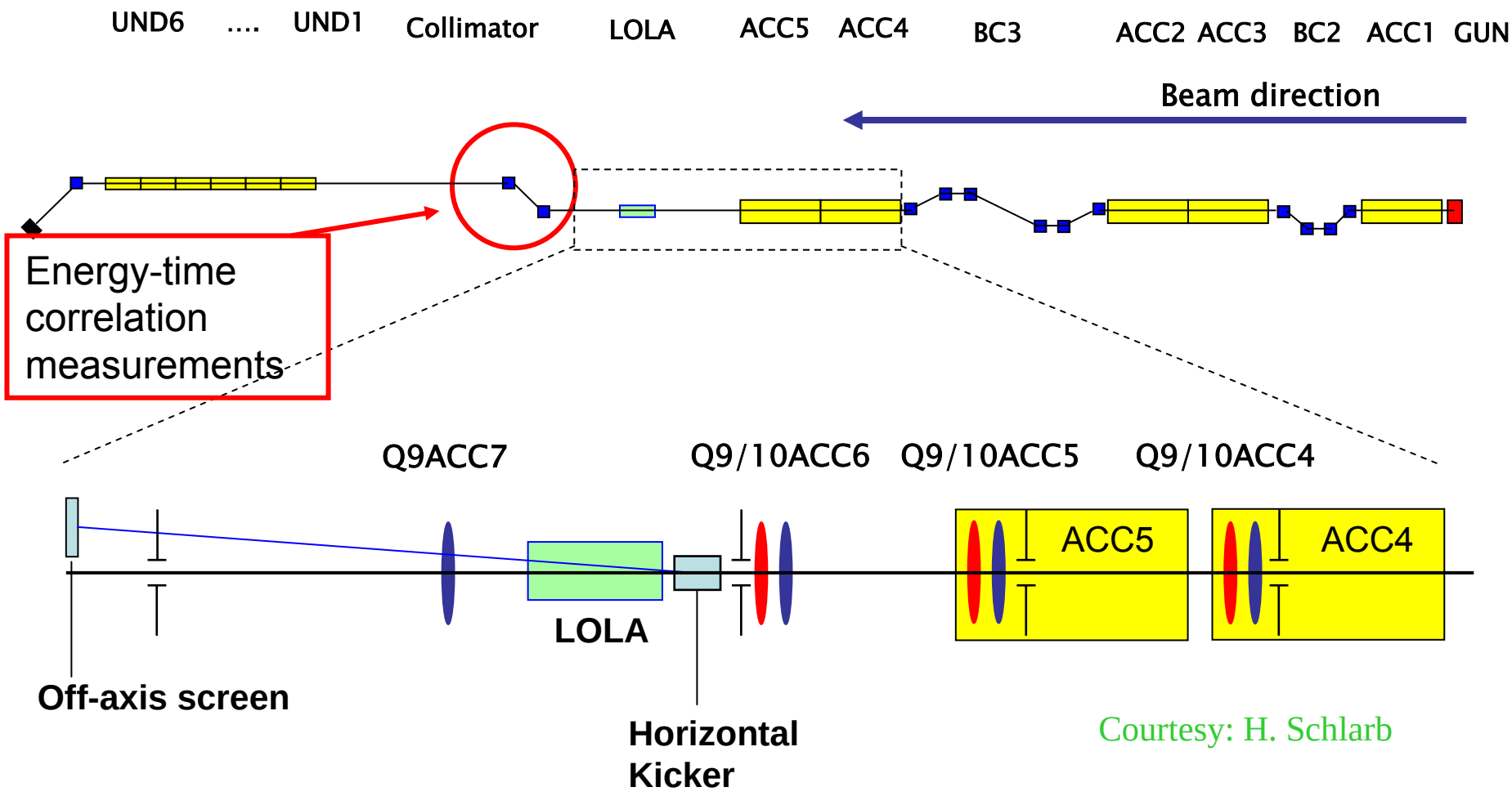
- Longitudinal density profile
- Horizontal slice widths
- Horizontal slice emittance
- Horizontal slice centroid positions
- Dispersive section: energy-time correlation / slice energy spread

Optics-requirements:

- $\sigma_y^{streaked} >> \sigma_y \longrightarrow$ small β_y^{OTR}
- Vertical offset at the screen:

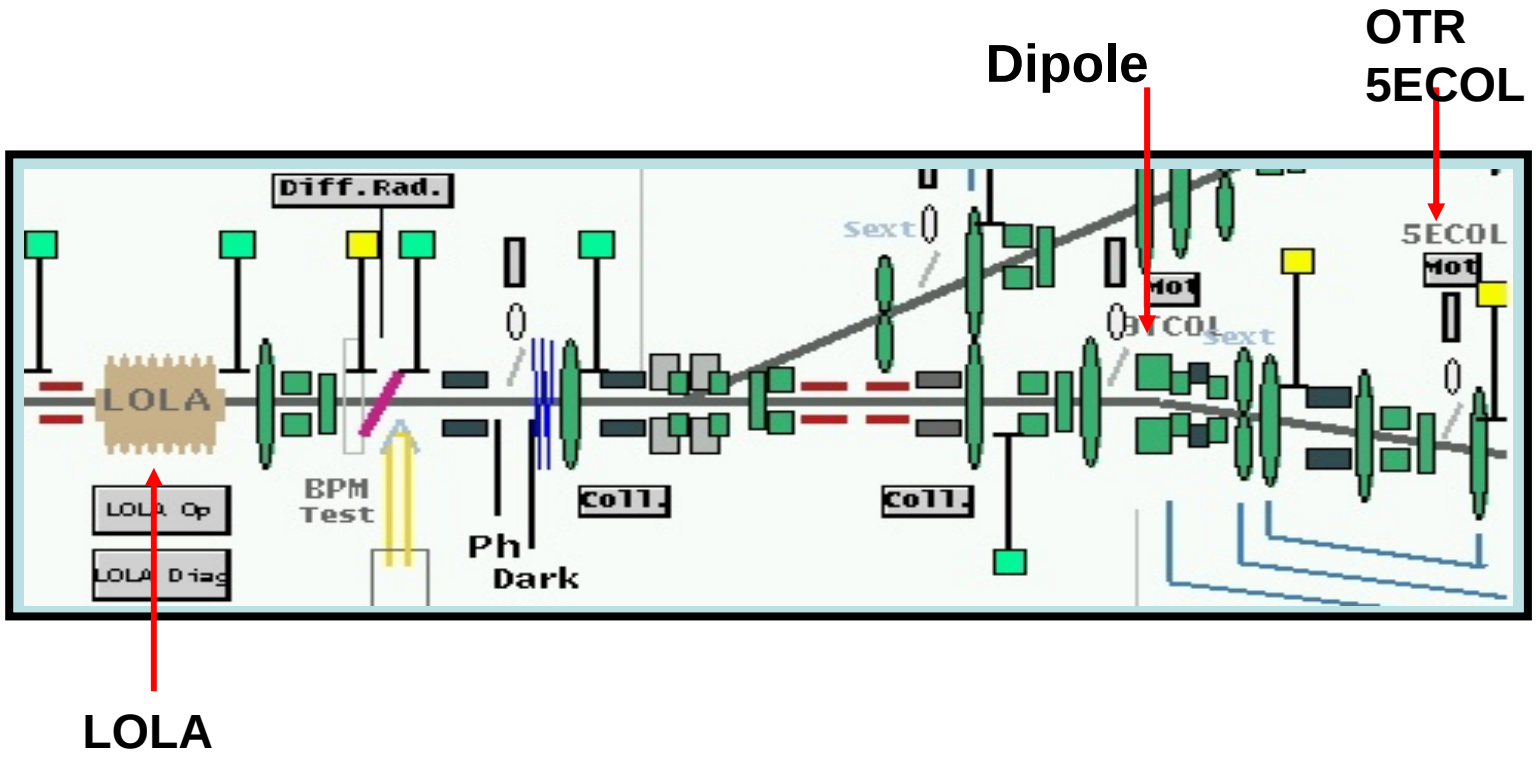
$$\Delta y \approx \sqrt{\beta_{ini}\beta_{end}} \cdot \sin(\phi_y) \cdot y'_{LOLA}$$

LOLA in the FLASH beamline



Courtesy: H. Schlarb

Section used for energy-time correlation measurements

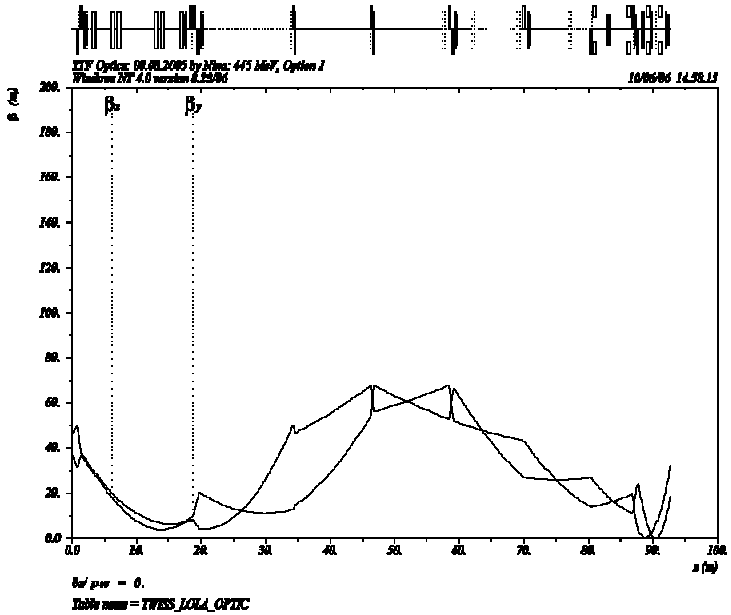


- Collimators were opened
- Sextupole was switched off

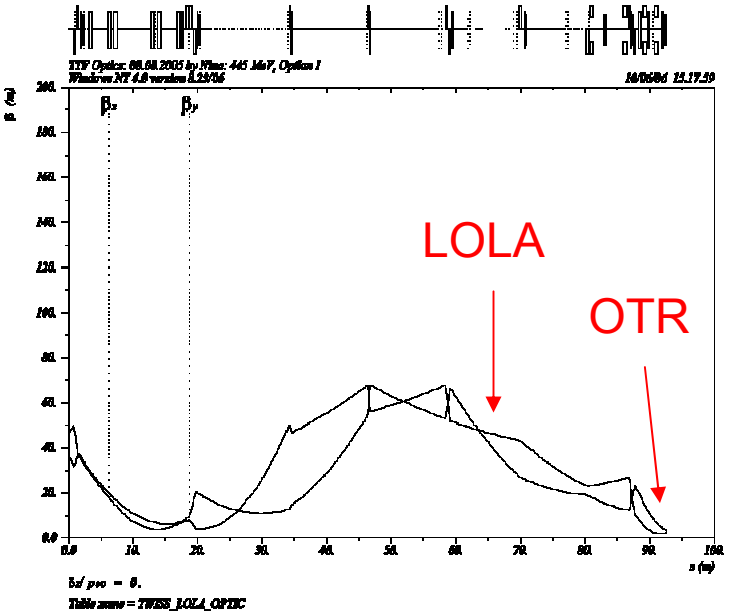
Optics for energy-time correlation measurements

Objectives: small beta function values (~ 3m) , maximum streak, large dispersion at the screen (~290mm),

Standard optics`:

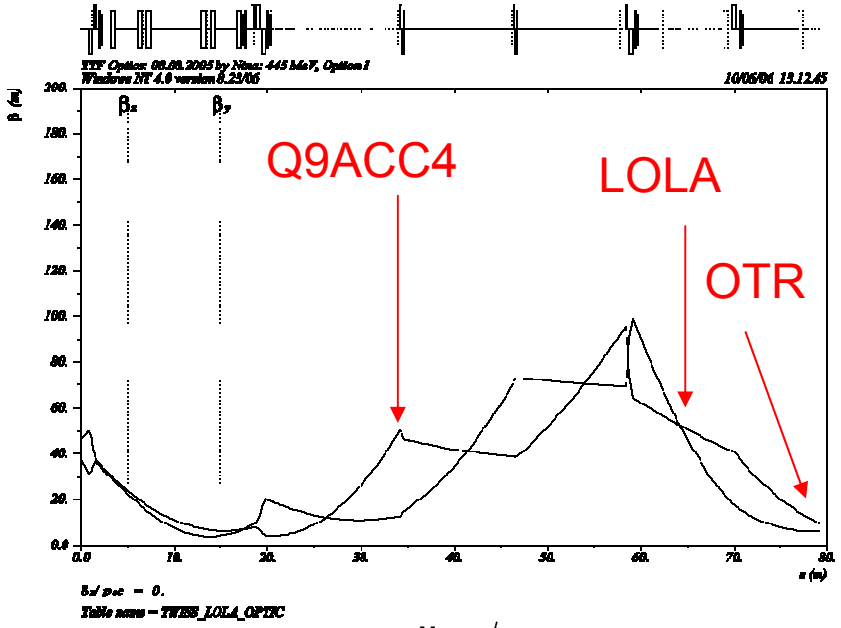


Optics for the measurements:

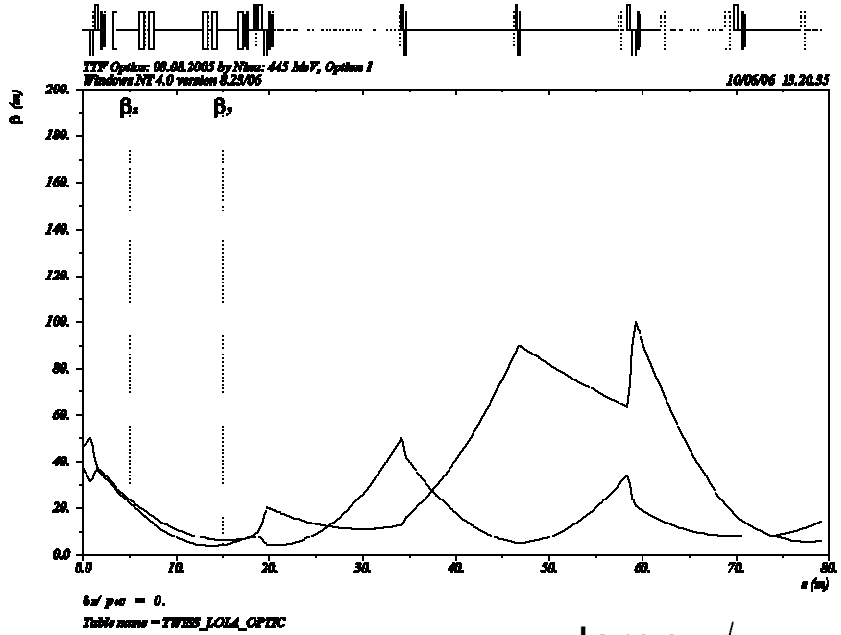


Optics for slice emittance measurements

- Scan of horizontal phase advance (~210 deg range) using the 6 quadrupoles Q9ACC4 – Q10ACC6 upstream of LOLA
- Streak at the screen is held constant
- Values of the beta functions at the screen: ~5m - 10m



small ϕ_x



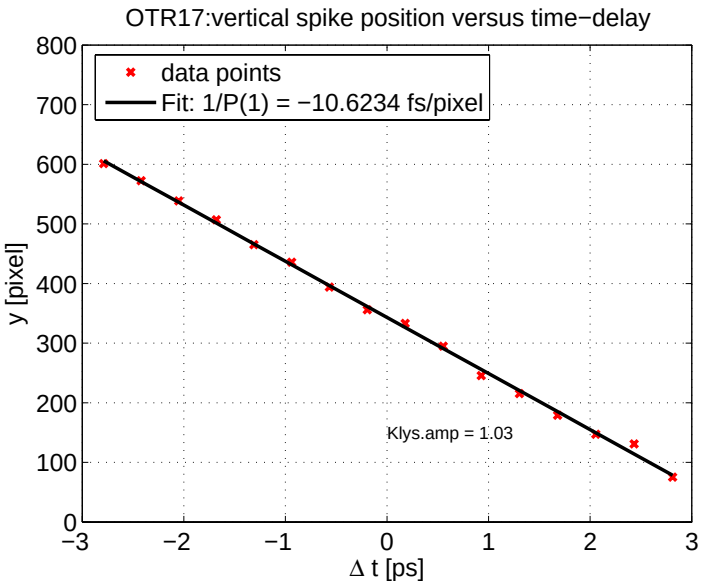
large ϕ_x

Screen Calibration

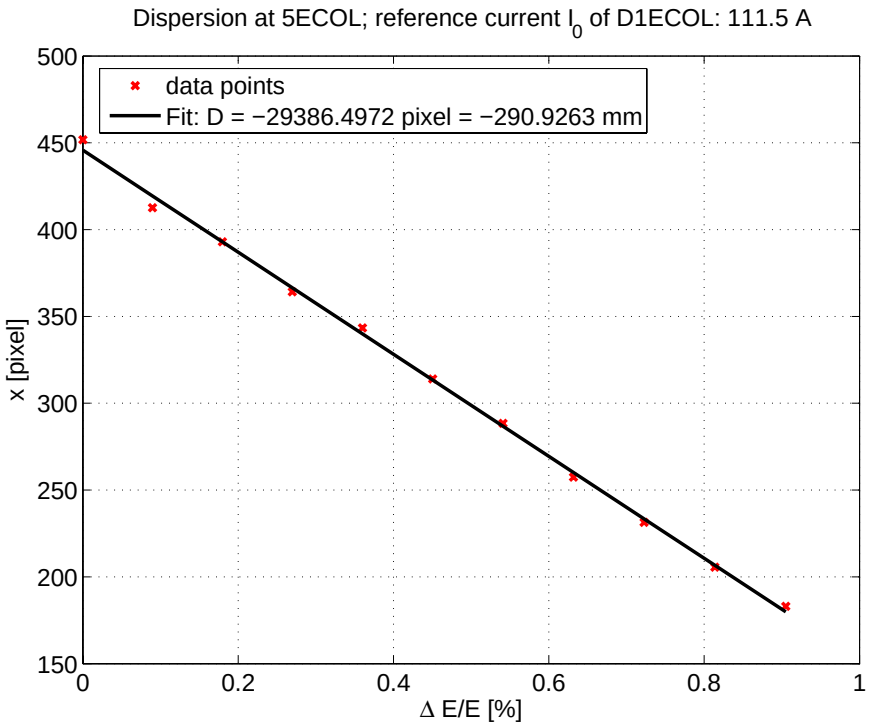
- Time axis (vertical):
  Measurement of the vertical beam position for different phases $\phi = \omega_{LOLA} \cdot \Delta t$

$$\longrightarrow \quad \Delta y \approx y'_{LOLA}$$

$$y'_{LOLA} = \frac{eV_0}{E} \cdot sin(\phi)$$



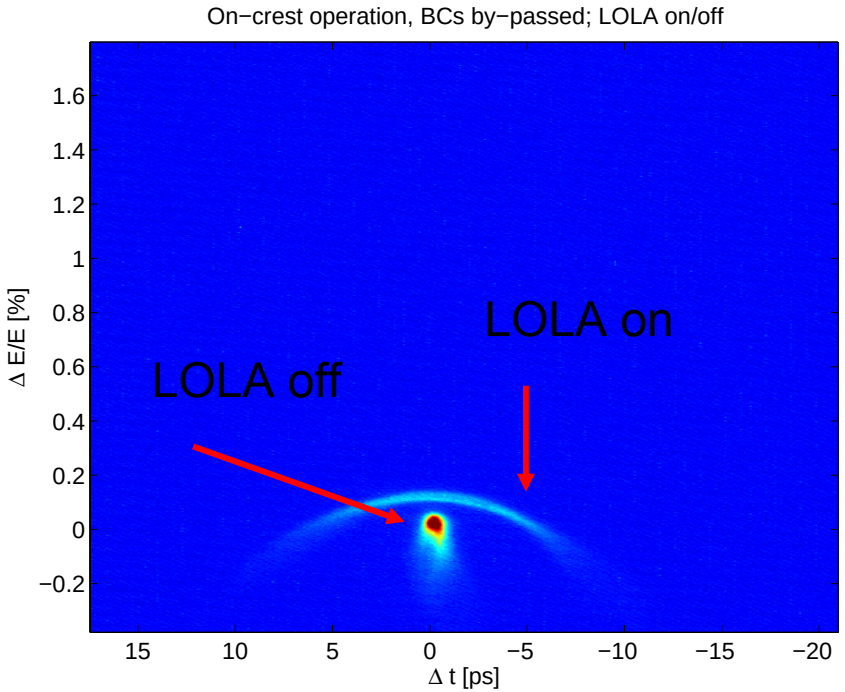
- Energy axis (OTR 5ECOL):
  Measurement of the horizontal dispersion by variation of the current in the dipole

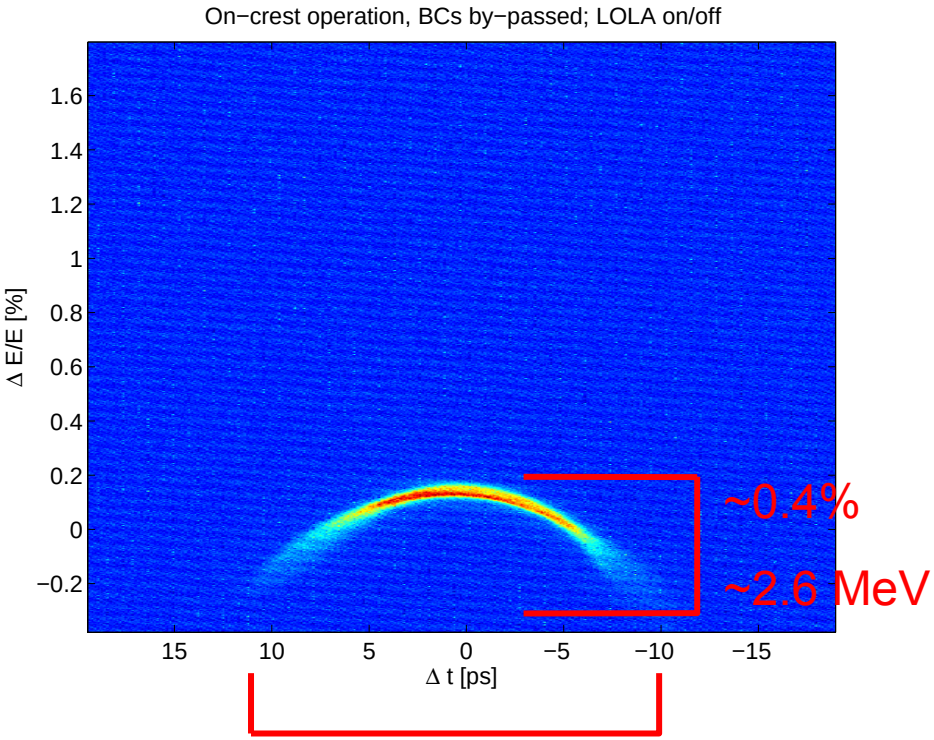


Overview: LOLA measurements

- Slice emittance
  - E = 630 MeV, BC2 on, BC3 on, ACC1: 0 deg, ACC23: 0 deg
  - E = 630 MeV, BC2 on, BC3 on, ACC1: -20 deg, ACC23: 0 deg
  - E = 630 MeV, BC2 on, BC3 off, ACC1: -14.1 deg, ACC23: 0 deg
  - E = 630 MeV, BC2 on, BC3 on, ACC1: 0 deg, ACC23: -26.2 deg
  - E = 650 MeV, BC2 off, BC3 on (5.4 deg), ACC1: 0 deg, ACC23: -26 deg
  - E = 445 MeV, BC2 on, BC3 on, ACC1: -6.5 deg, ACC23: 0 deg (2005)
- Energy-time correlation/ Slice energy spread
  - E = 650 MeV, BC2 off, BC3 on (5.4 deg), ACC1: 0 deg, ACC23: -26..-32
  - E = 630 MeV, BC2 off, BC3 off, ACC1: 0 deg, ACC23: 0 deg (+ scan of gun phase)
- ACC1/23 Phase scans
- Tomography

Energy-time correlation: Both BCs by-passed, ACC1: 0 deg, ACC23: 0 deg





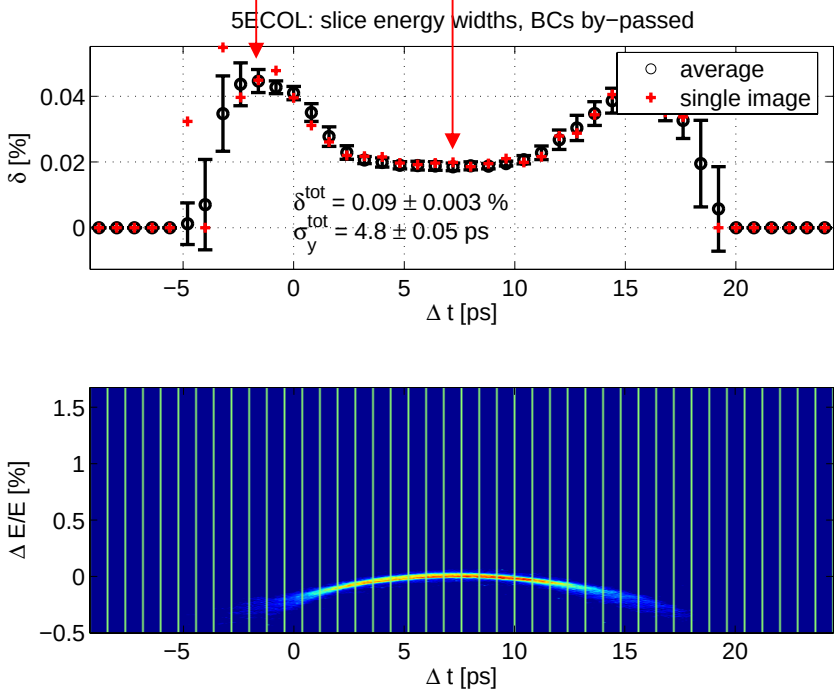
Dispersion: D = 290 mm

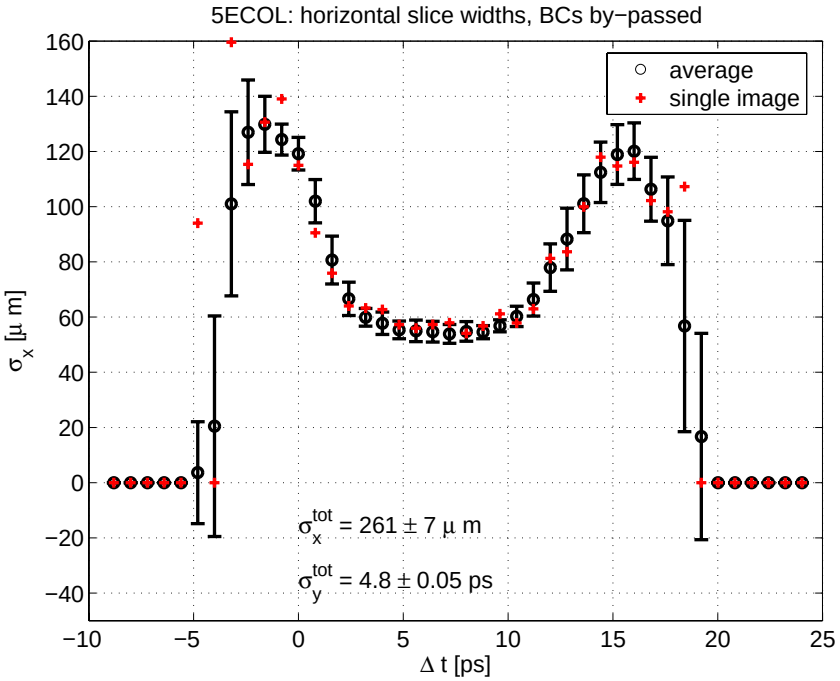
Energy: 650 MeV

$$\sigma_t = 4.8 \pm 0.05\ ps$$
$$\sigma_\delta = 0.09 \pm 0.003\%$$
$$\sigma_E \approx 585\ keV$$

Slice energy spread: BCs by-passed

325 keV 130 keV





→ Measured slice energy width: < 325 keV

E = 650 MeV

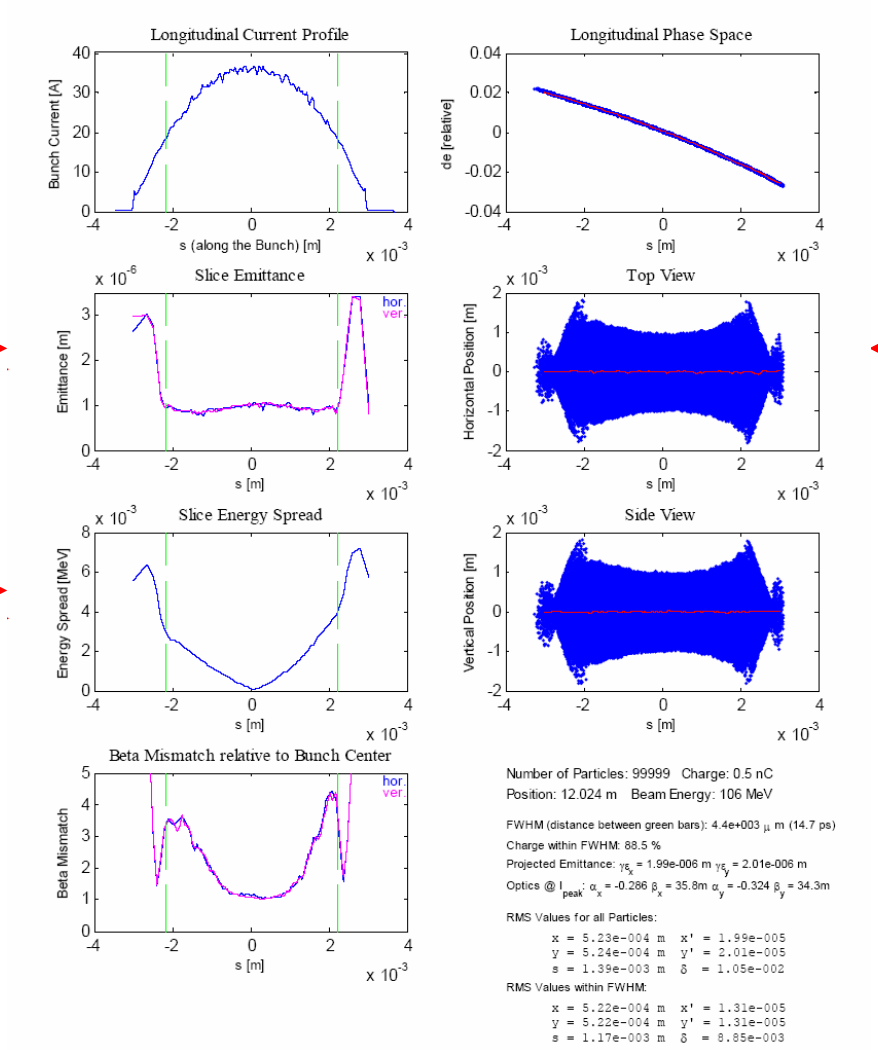
Expected: < 10 keV → slice width not dominated by dispersion

→ Distribution in the (s,x)-plane at the gun

Simulation: Bunch properties at the gun

Slice emittance

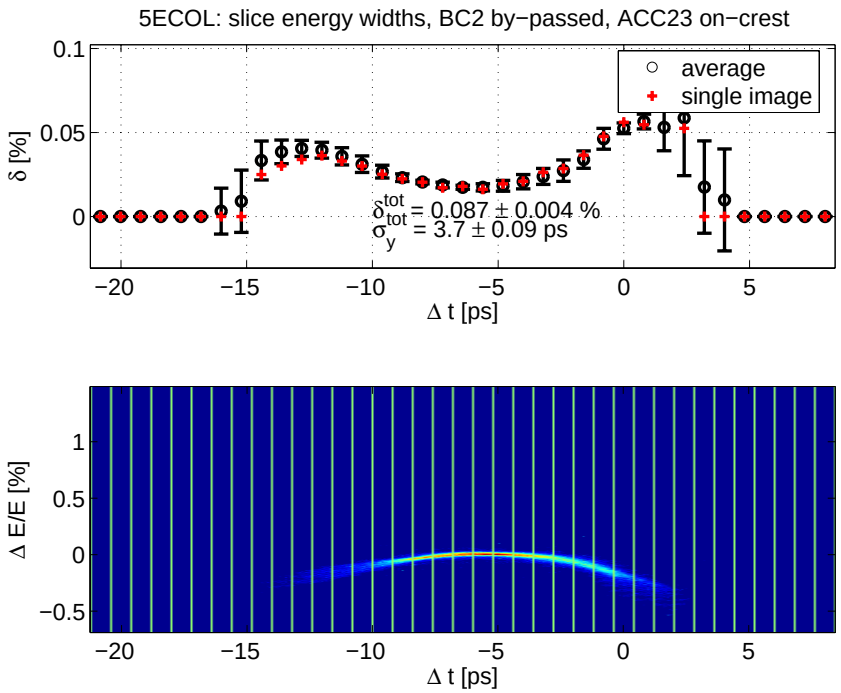
Slice energy spread

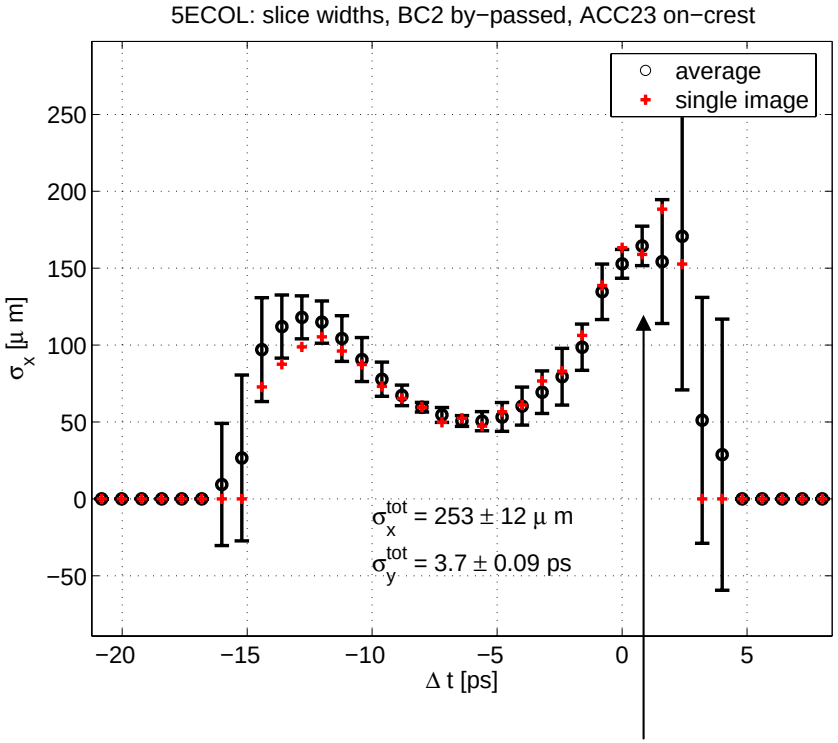


Distribution in the (s,x)-plane

Courtesy: B. Beutner

Slice energy spread: BC2 off, BC3 on, ACC1: 0 deg, ACC23: 0 deg



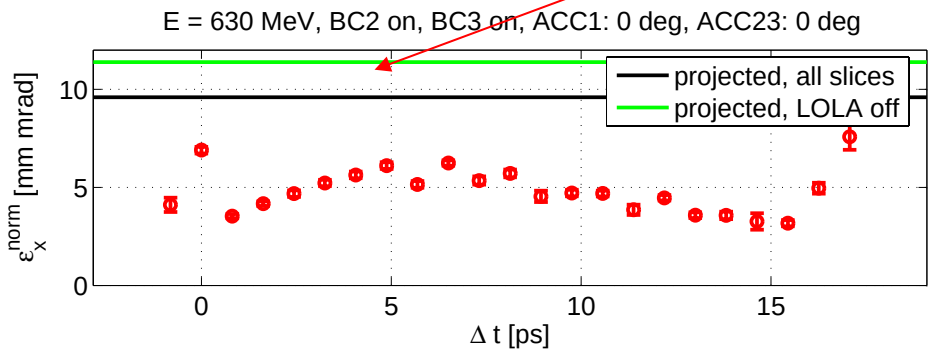


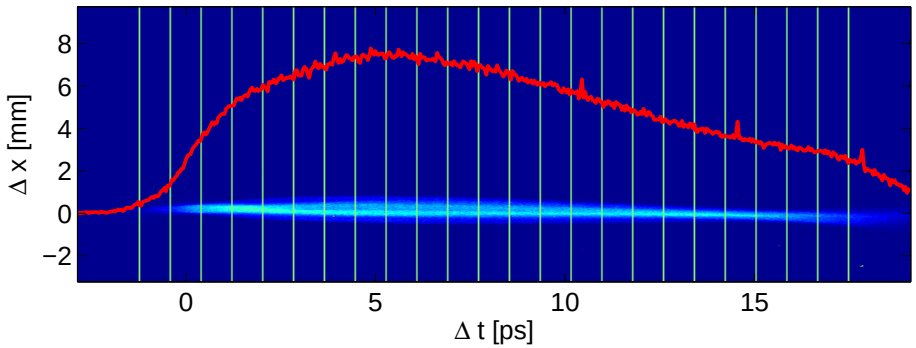
Compression at the front side: 4.8 ps → 3.7 ps

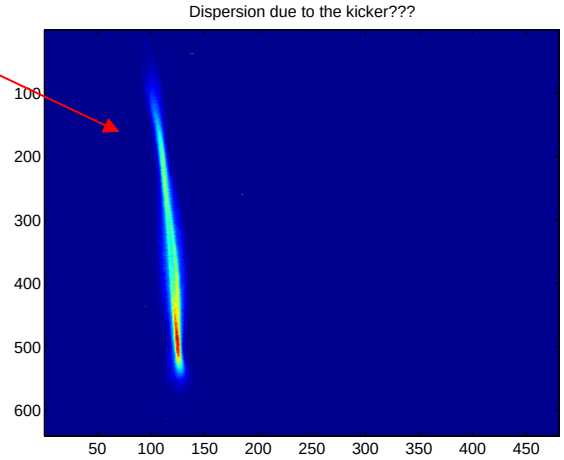
Caused by dispersion ?

Slice emittance: E = 630 MeV, BC2 on, BC3 on, ACC1: 0 deg, ACC23: 0 deg

Caused by tilt

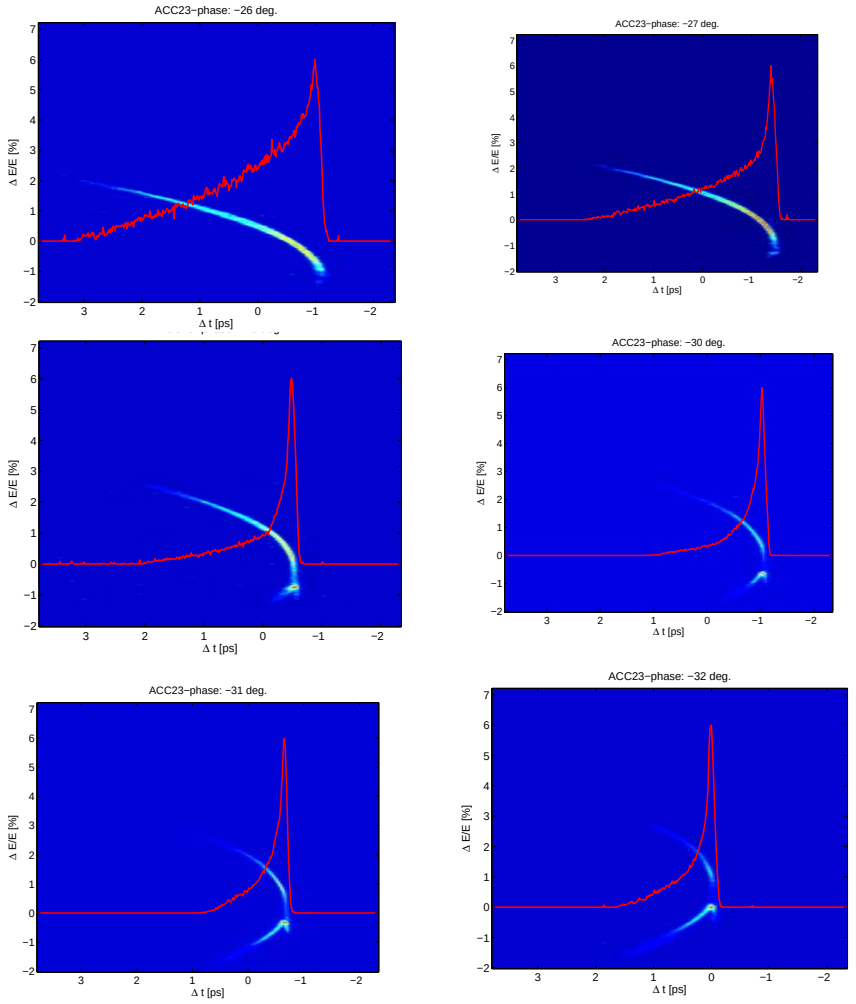


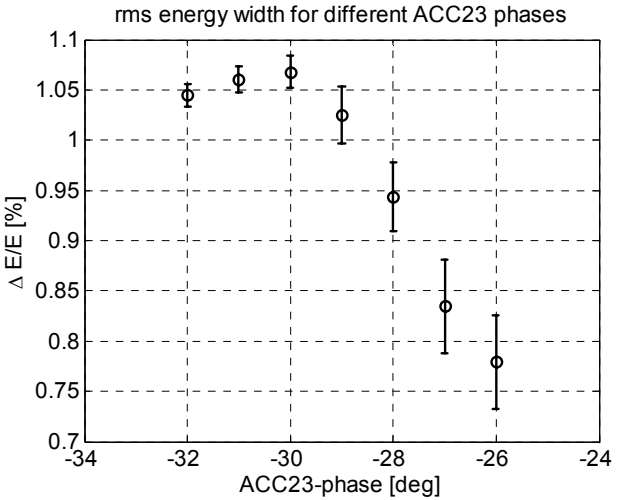


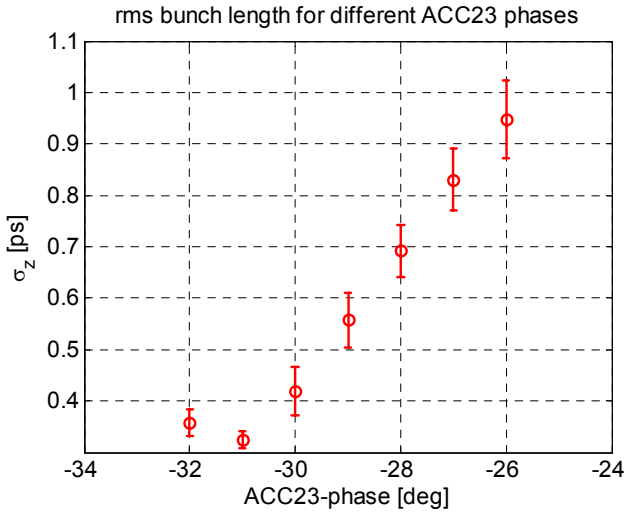


- projected emittance larger by a factor of 2
- tilt caused by Dispersion?
  → D ~ 15 cm
- wake fields?
- BC2-section: 4.3 mm mrad (100%)
- coupler kicks?

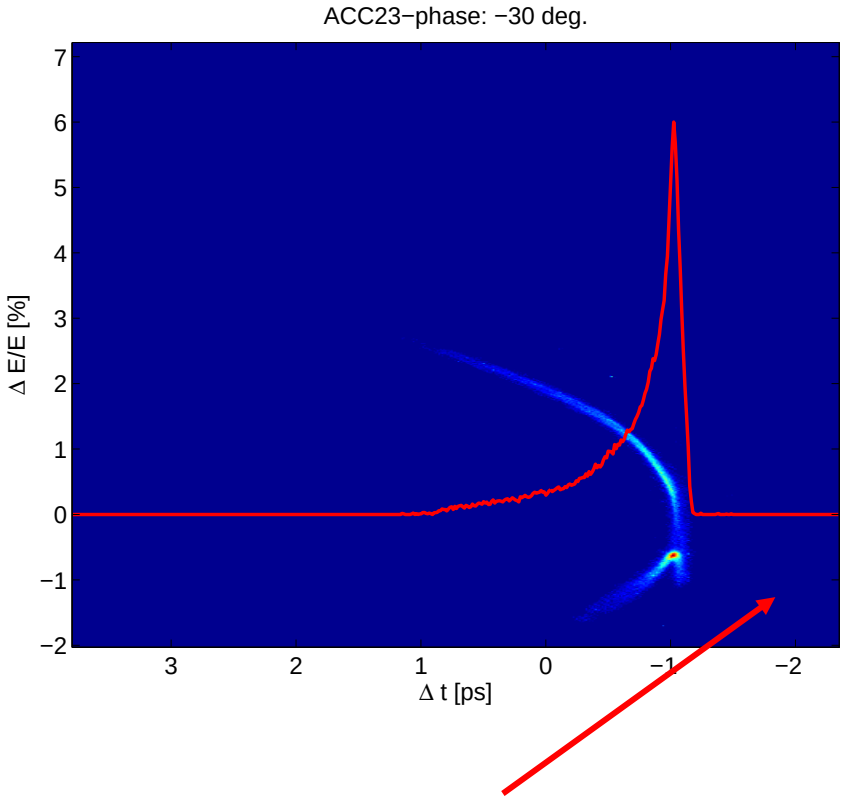
Energy-time correlation: BC2 off, BC3 on, ACC1: 0 deg, ACC23: -26..-32 deg





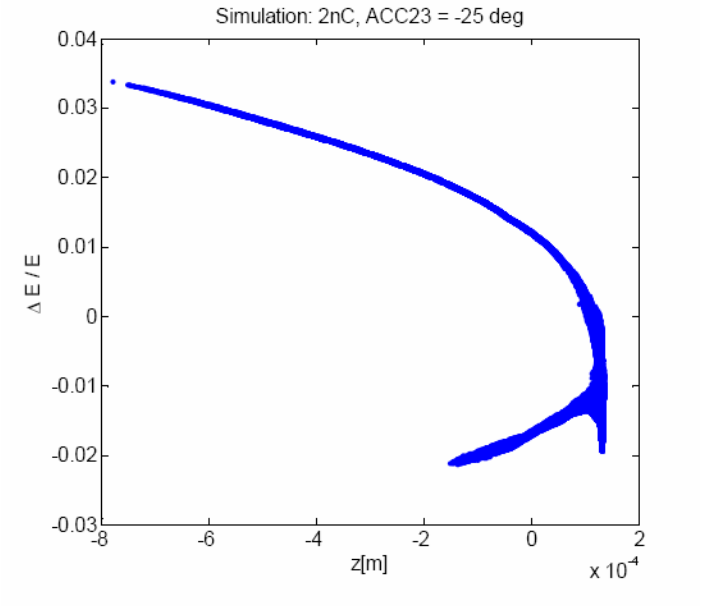


Energy-time correlation: BC2 off, BC3 on, ACC1: 0 deg, ACC23: -29 deg



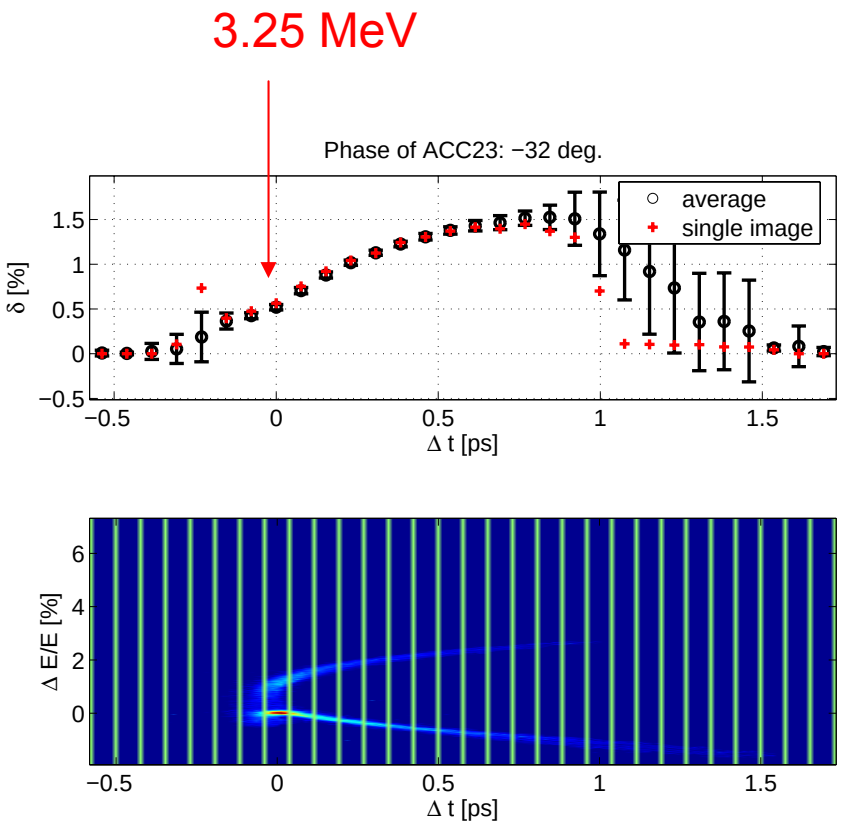
CSR/ longitudinal space charge forces

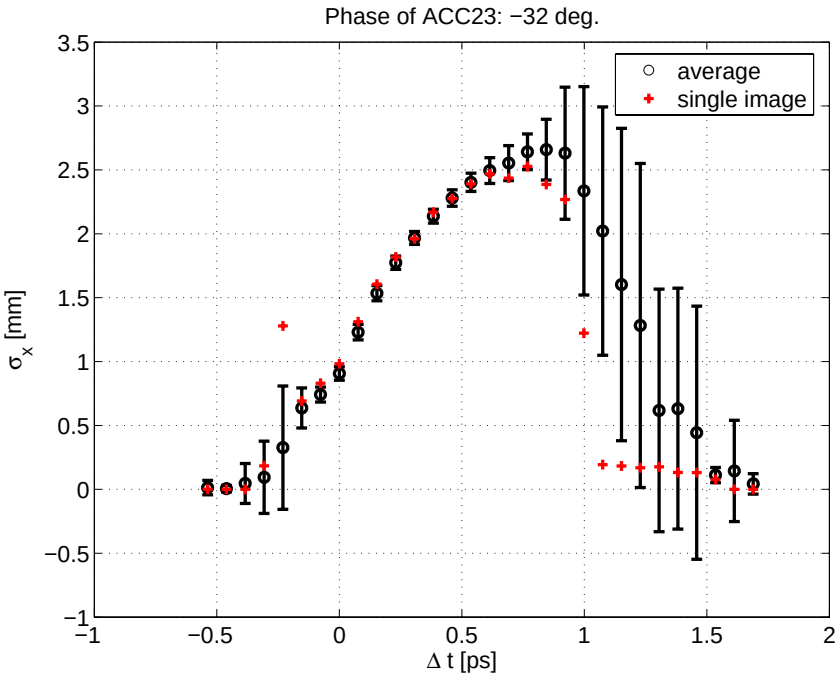
Simulation (slightly different settings):



Courtesy: B. Beutner

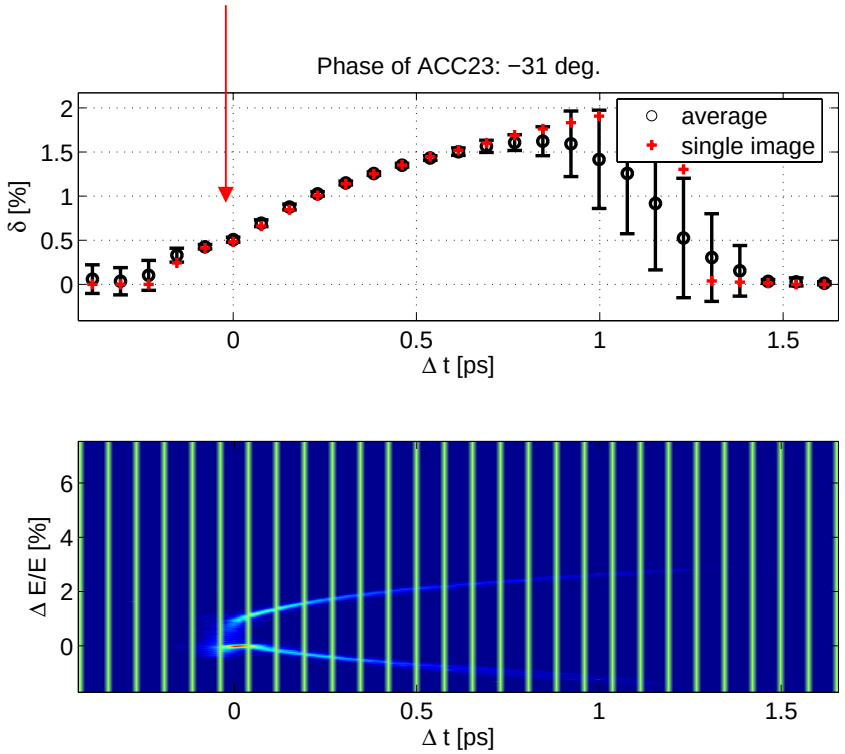
Energy-time correlation/ slice energy spread: scan of ACC23: -32 deg

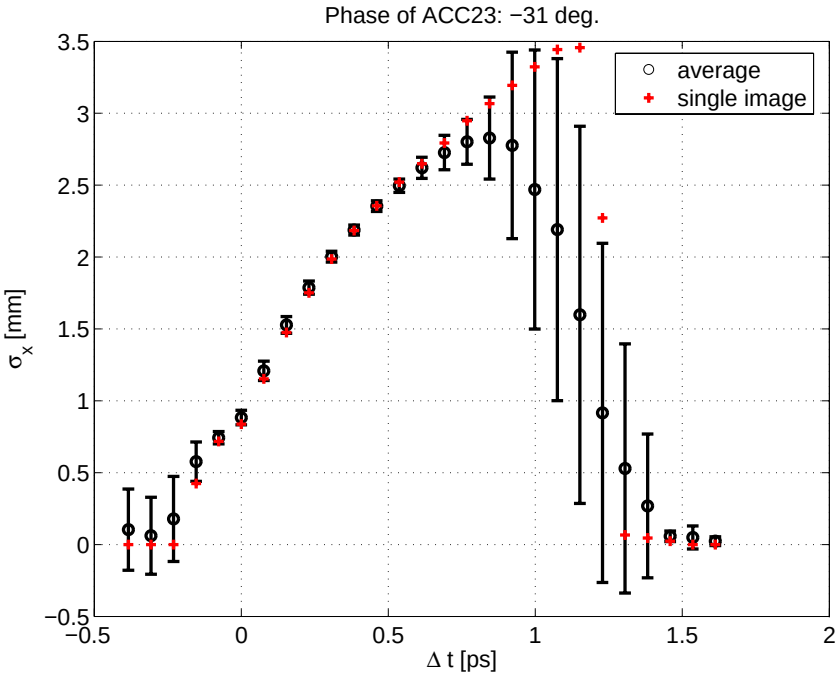




Energy-time correlation/ slice energy spread: scan of ACC23: -31 deg

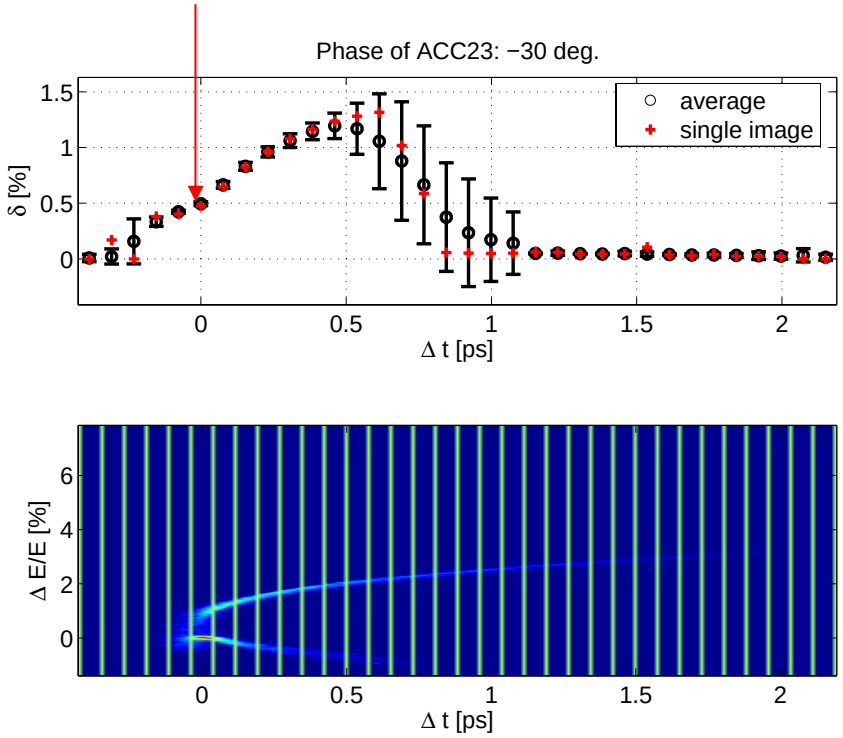
3.25 MeV

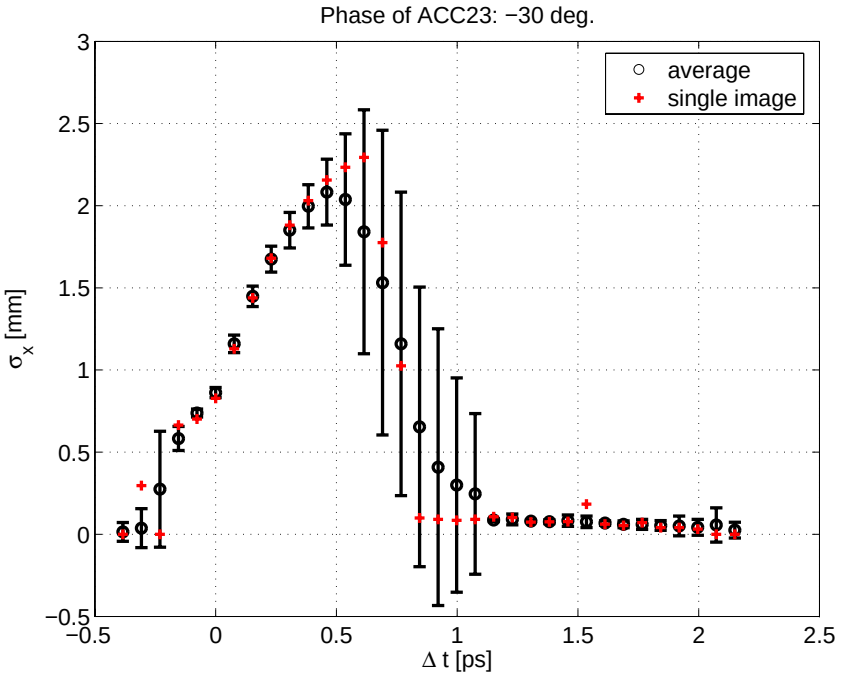




Energy-time correlation/ slice energy spread: scan of ACC23: -30 deg

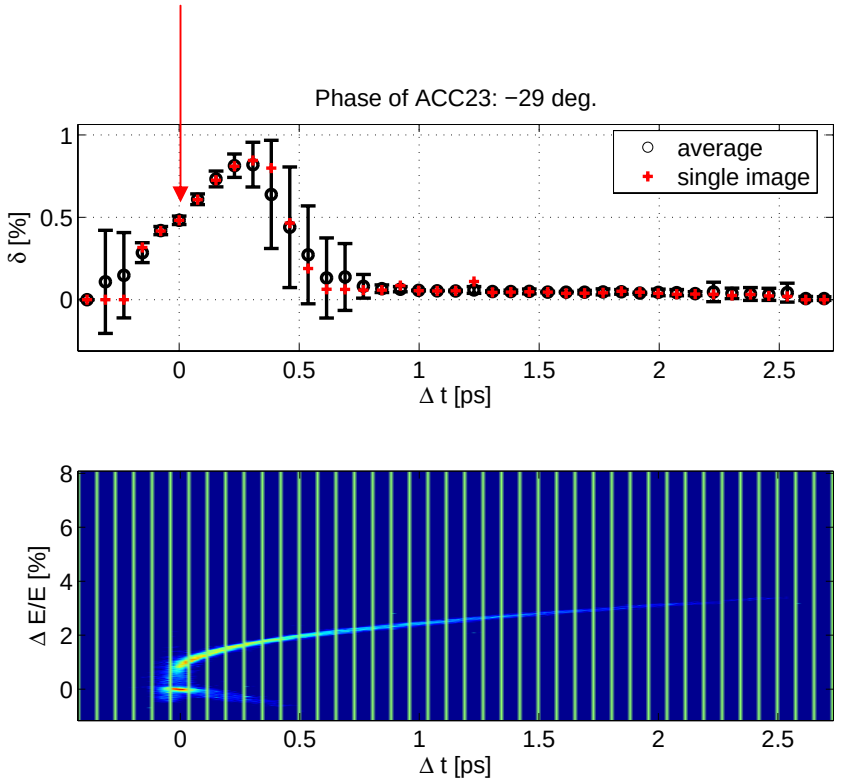
3.25 MeV

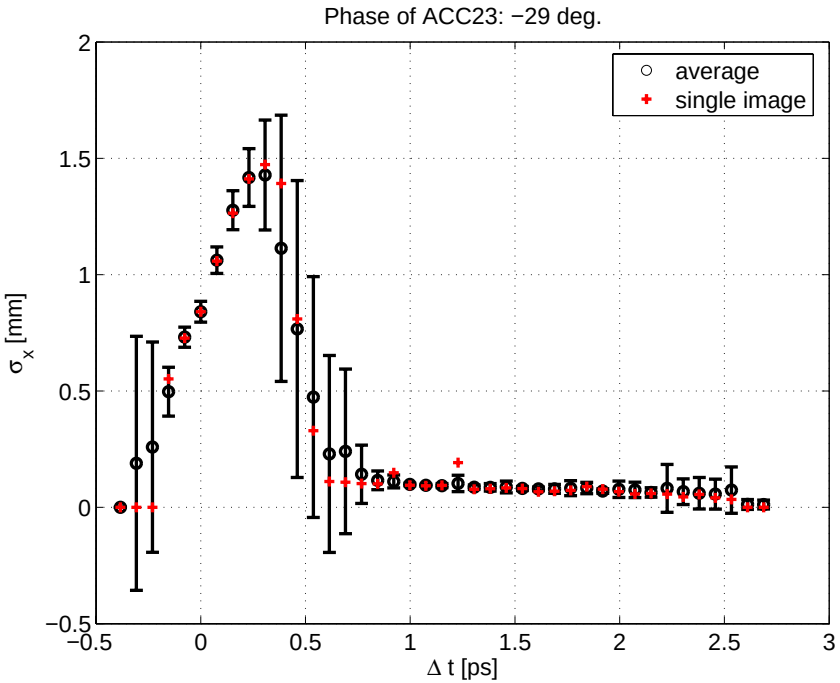




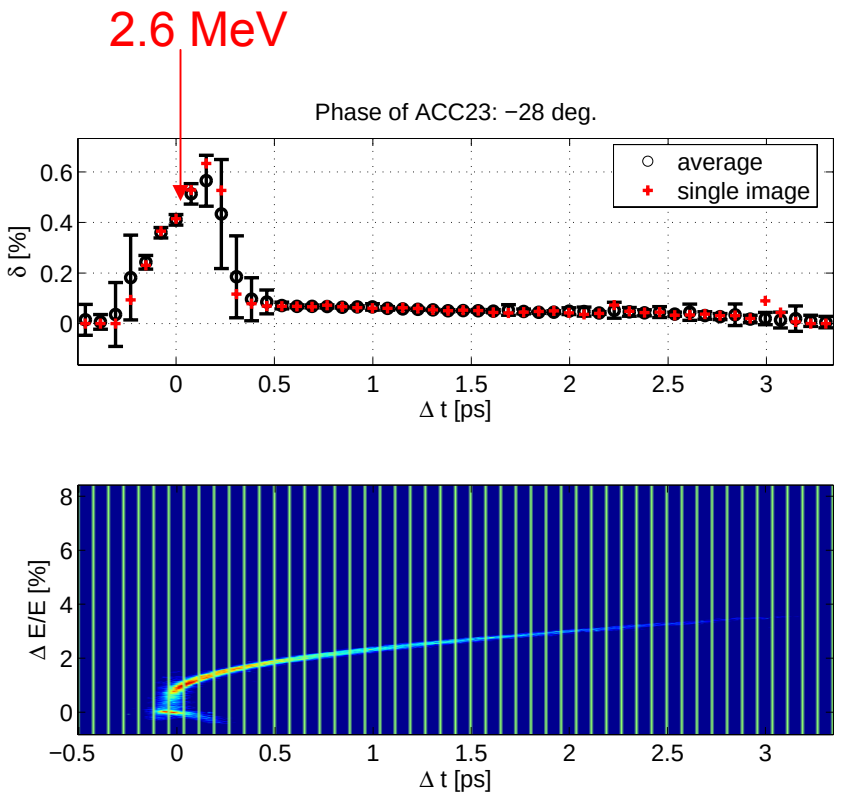
Energy-time correlation/ slice energy spread: scan of ACC23: -29 deg

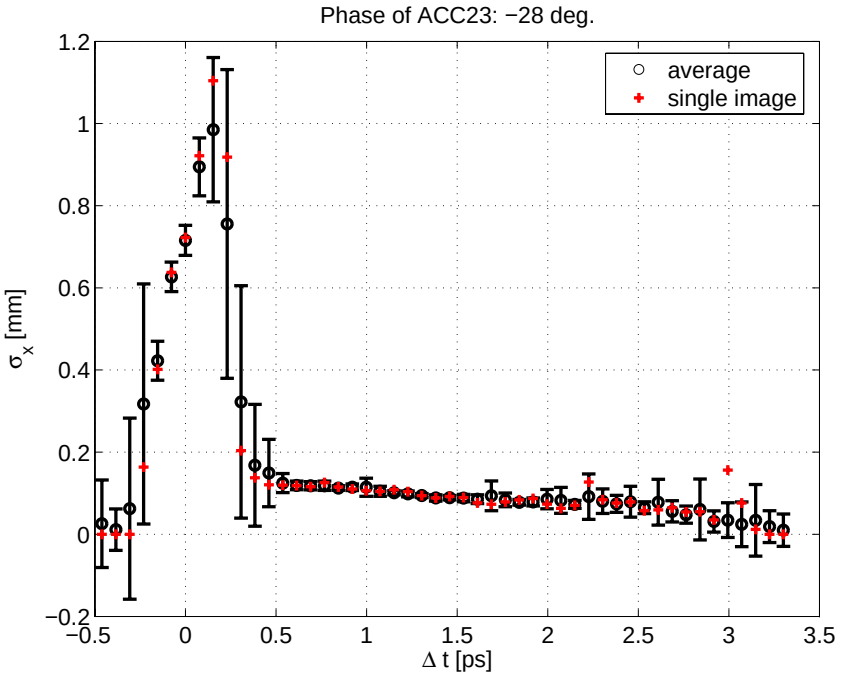
3.25 MeV



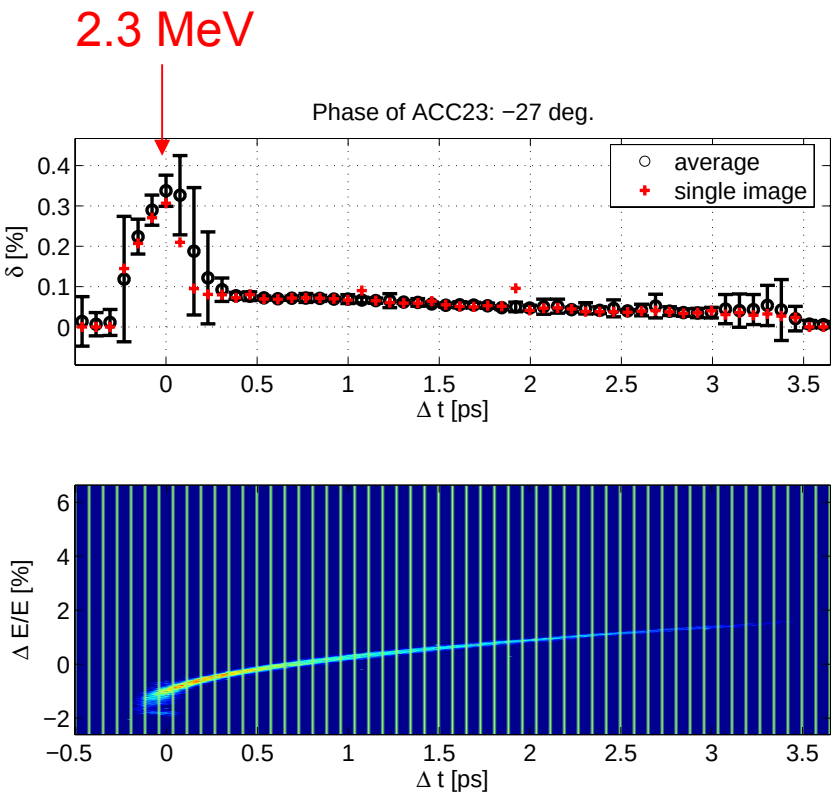


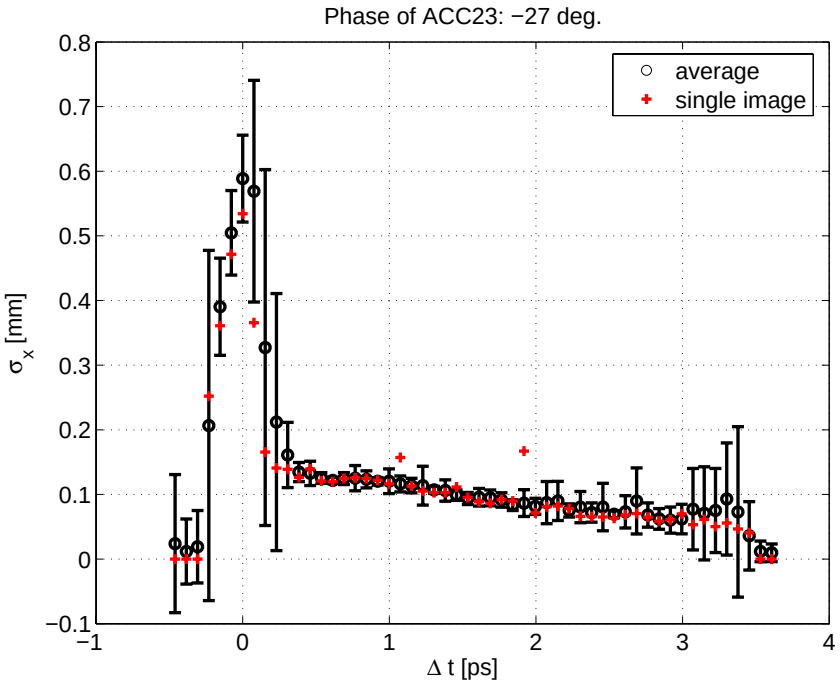
Energy-time correlation/ slice energy spread: scan of ACC23: -28 deg



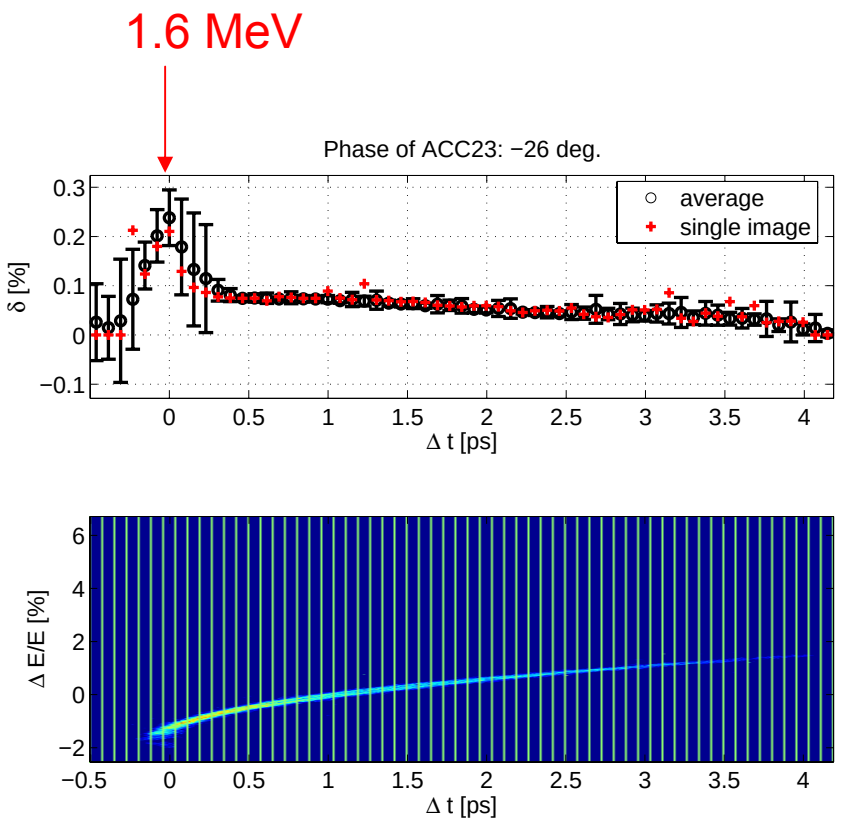


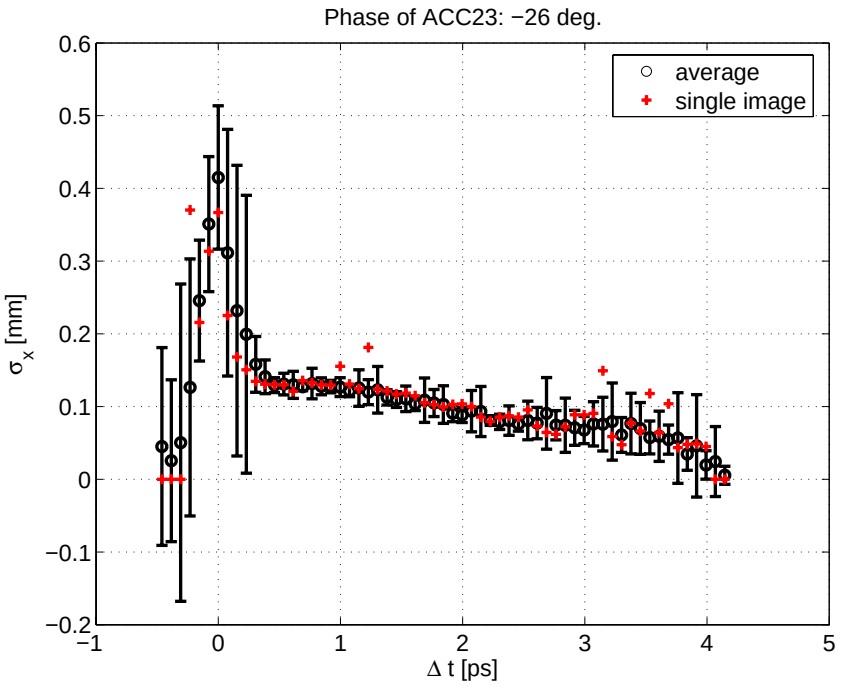
Energy-time correlation/ slice energy spread: scan of ACC23: -27 deg



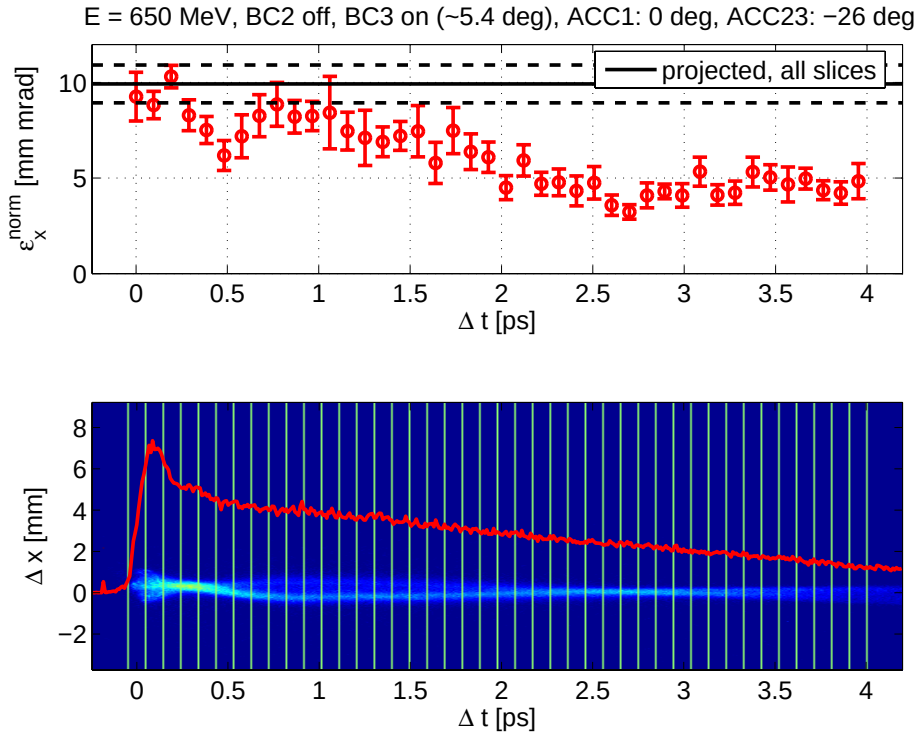


Energy-time correlation/ slice energy spread: scan of ACC23: -26 deg

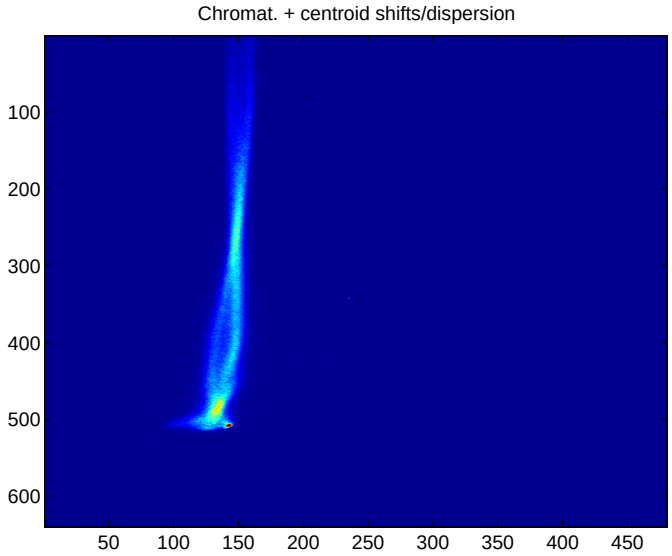




Slice emittance: E = 650 MeV, BC2 off, BC3 on, ACC1: 0 deg, ACC23: -26 deg



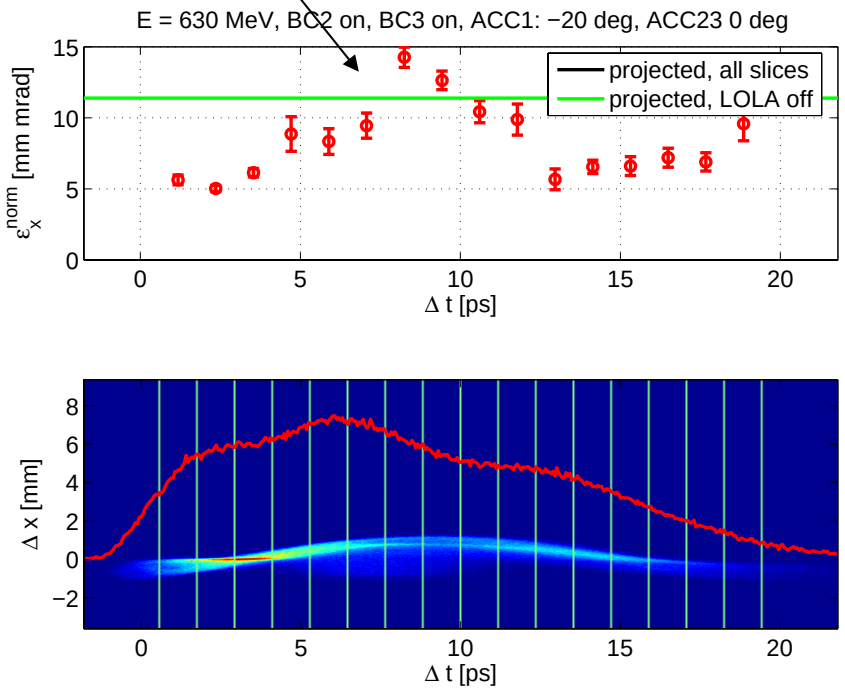
Tilted bunch:



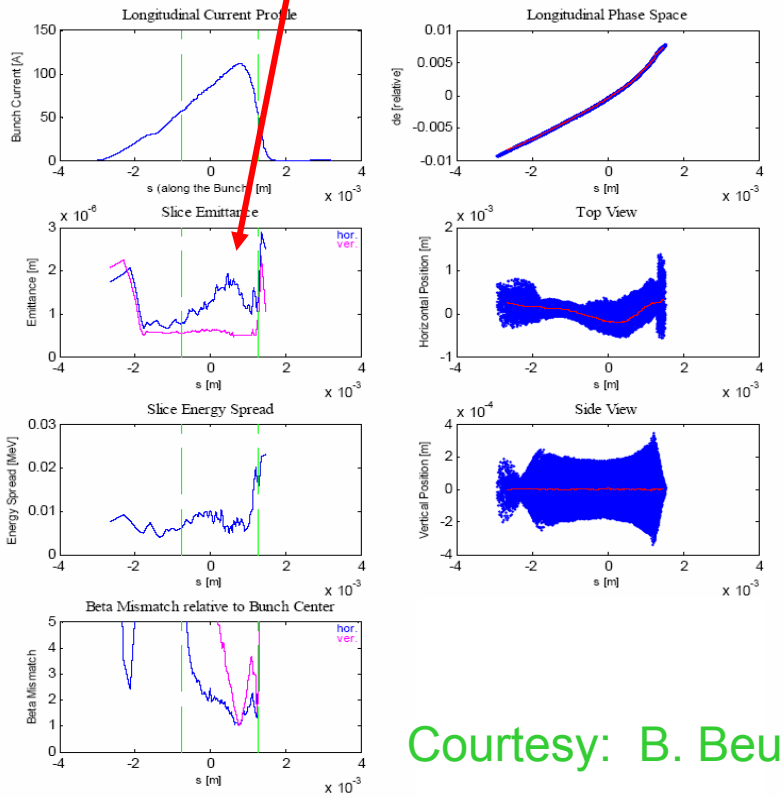
→ increasing slice emittance in the bunch center
with moderate current and no overcompression

Slice emittance / slice mismatch: BC2 on, BC3 on, ACC1: -20 deg, ACC23: 0 deg

Caused by CSR

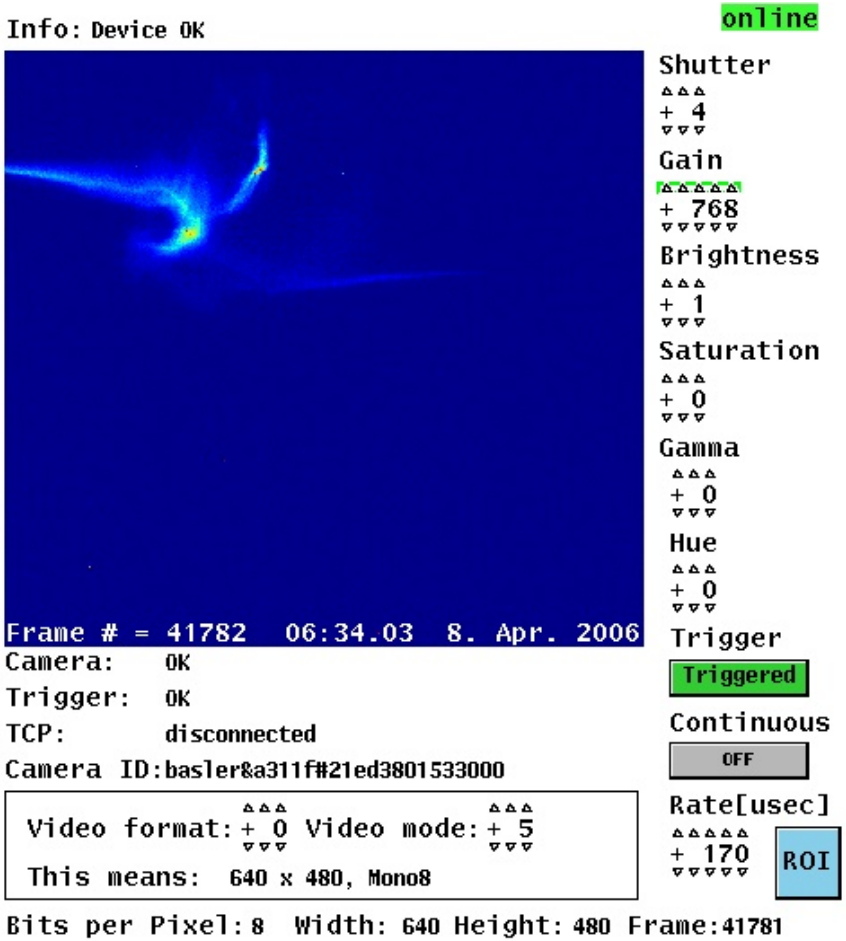


Simulation with similar settings:



Courtesy: B. Beutner

Strongly distorted bunch



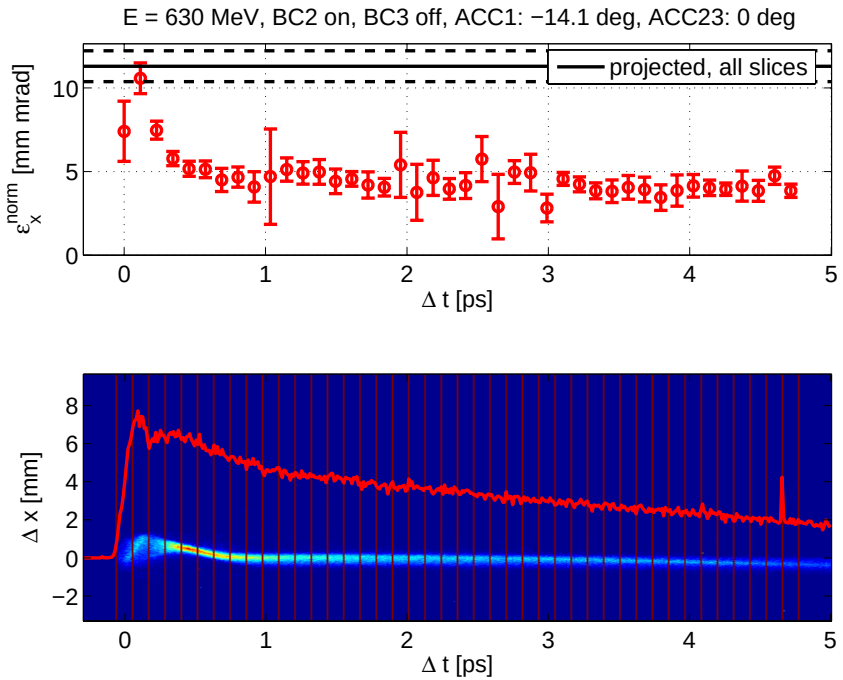
Strong variations from bunch to bunch

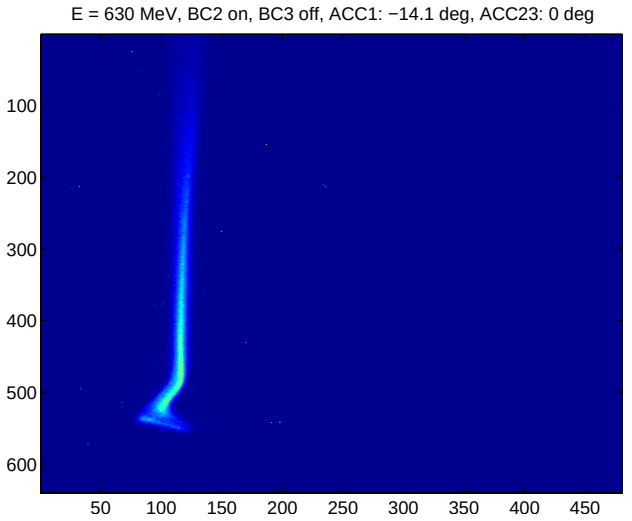
Slice emittance measurements not reasonable

Outlook

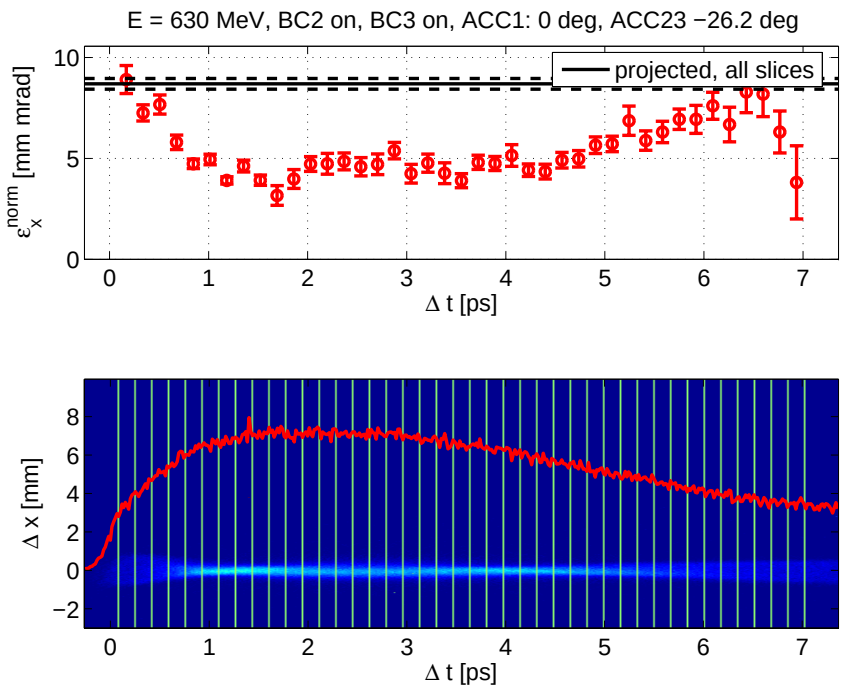
- The results have to be compared more precisely with simulations
- Measurement of slice emittance, energy-time correlation and slice energy spread under SASE-conditions (planned for August)
- Development of a fast tool for slice emittance measurement available for every operator

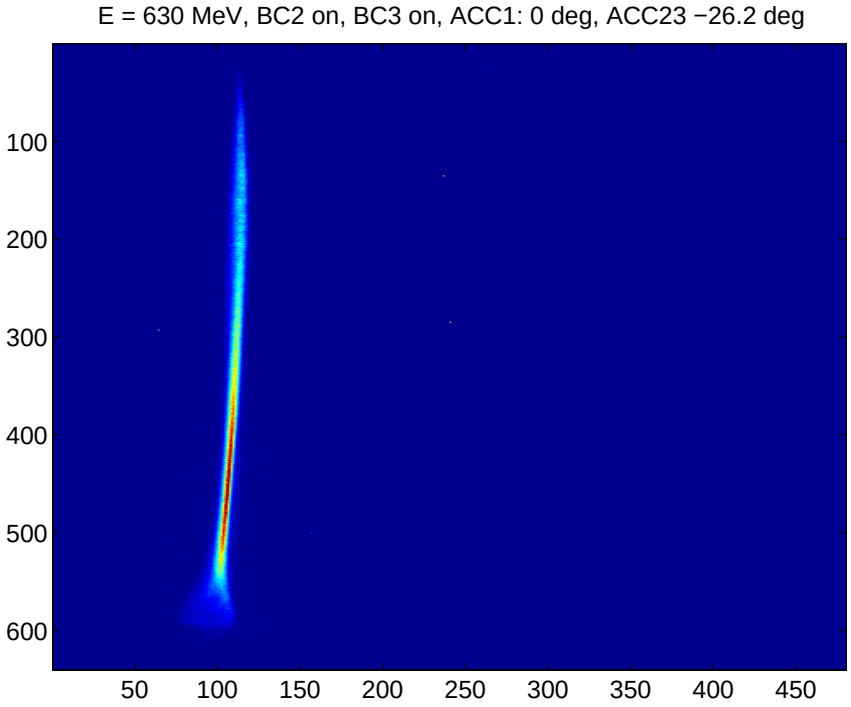
Slice emittance: E = 630 MeV, BC2 on, BC3 off, ACC1: -14.1 deg, ACC23: 0 deg



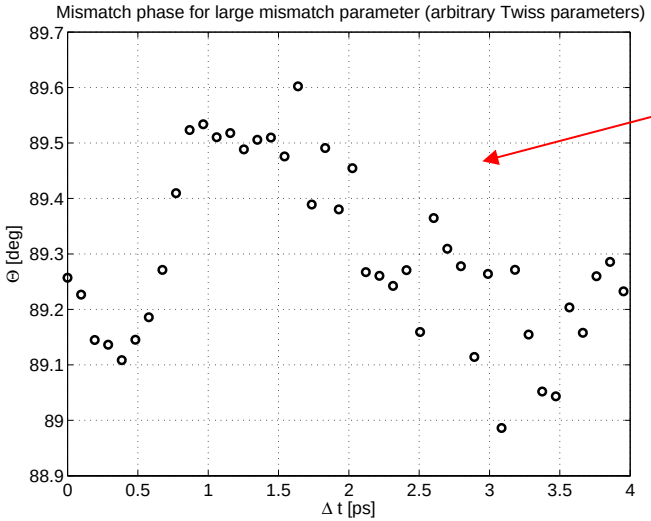


Slice emittance: E = 630 MeV, BC2 on, BC3 on, ACC1: 0 deg, ACC23: -26.2 deg

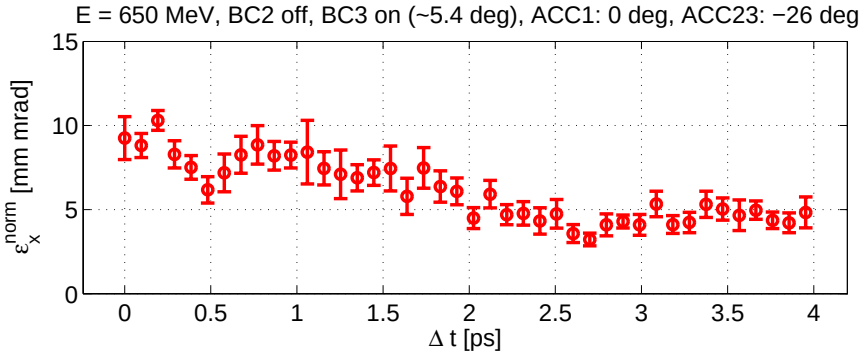


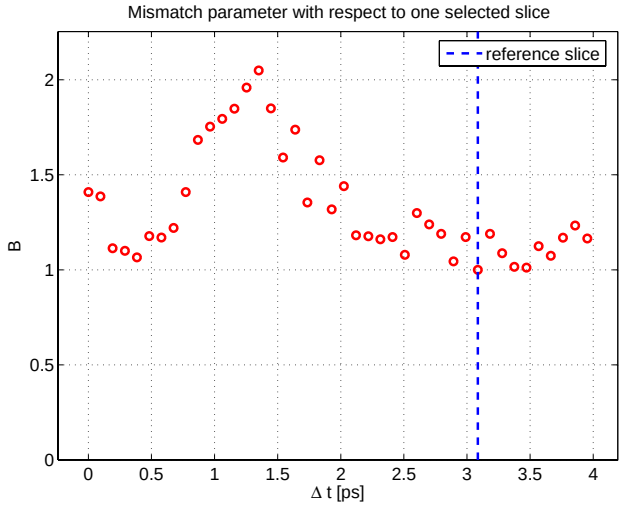


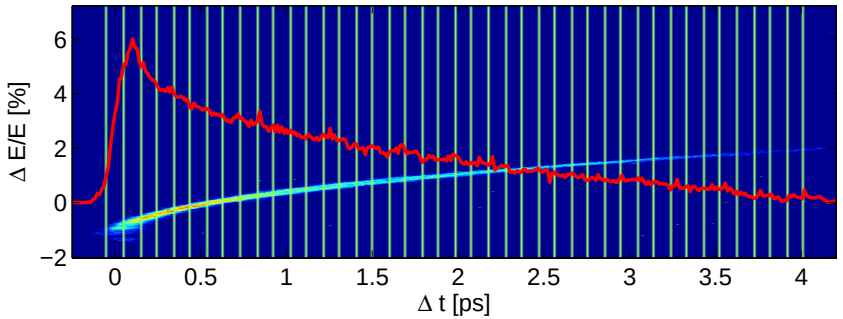
Slice mismatch, Slice emittance and energy-time correlation



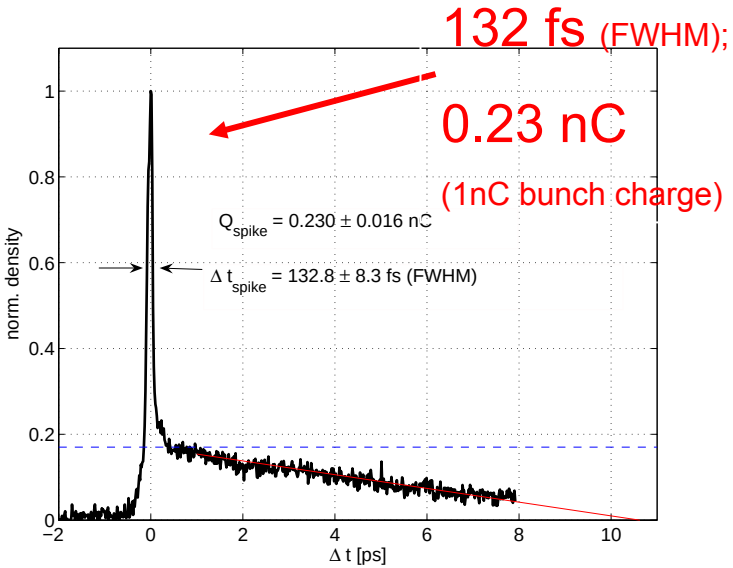
Chromaticity along the machine?

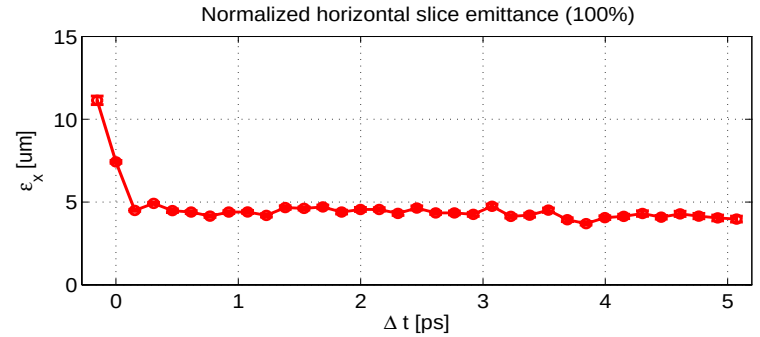


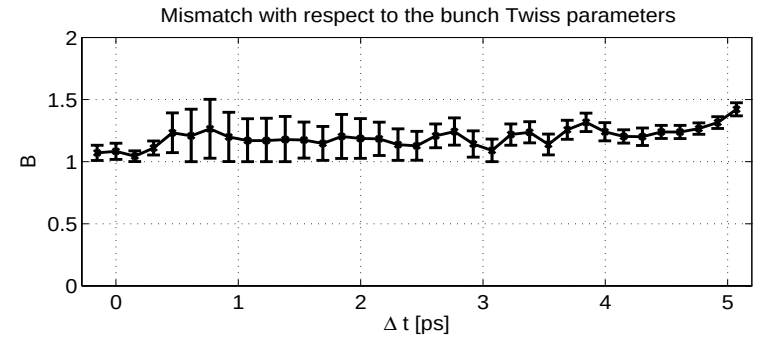


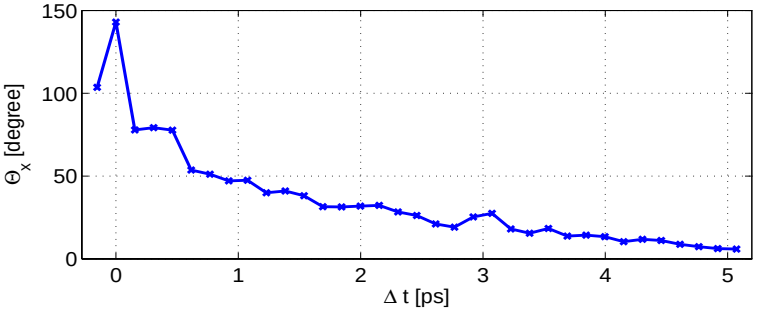


Slice emittance: ACC1: -6.5 deg



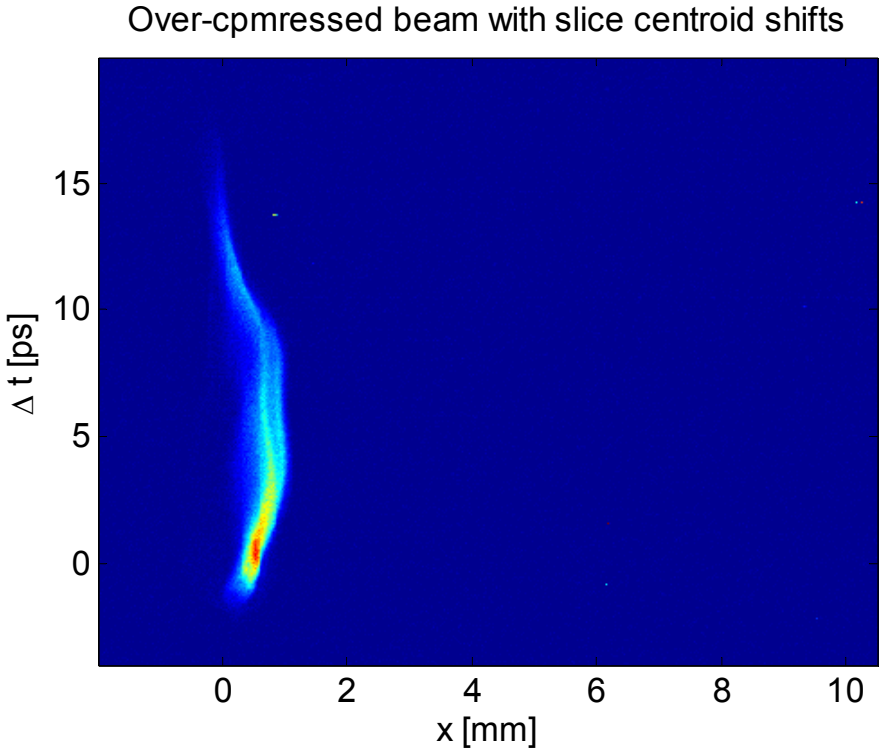






Measurements with LOLA:

Slice centroid shifts



BC2 off, BC3 on,
overcompression

- Energy-loss due to coherent synchrotron radiation in the dipoles of the bunch compressors lead to horizontal slice centroid shifts
- Comparison with simulations (Bolko Beutner)

Measurements with LOLA:

Tomography

- Scanning the LOLA power allows to reconstruct the 3-dimensional spatial particle distribution

  → reconstruction of the vertical slice emittance?

  → combination with phase space tomography?

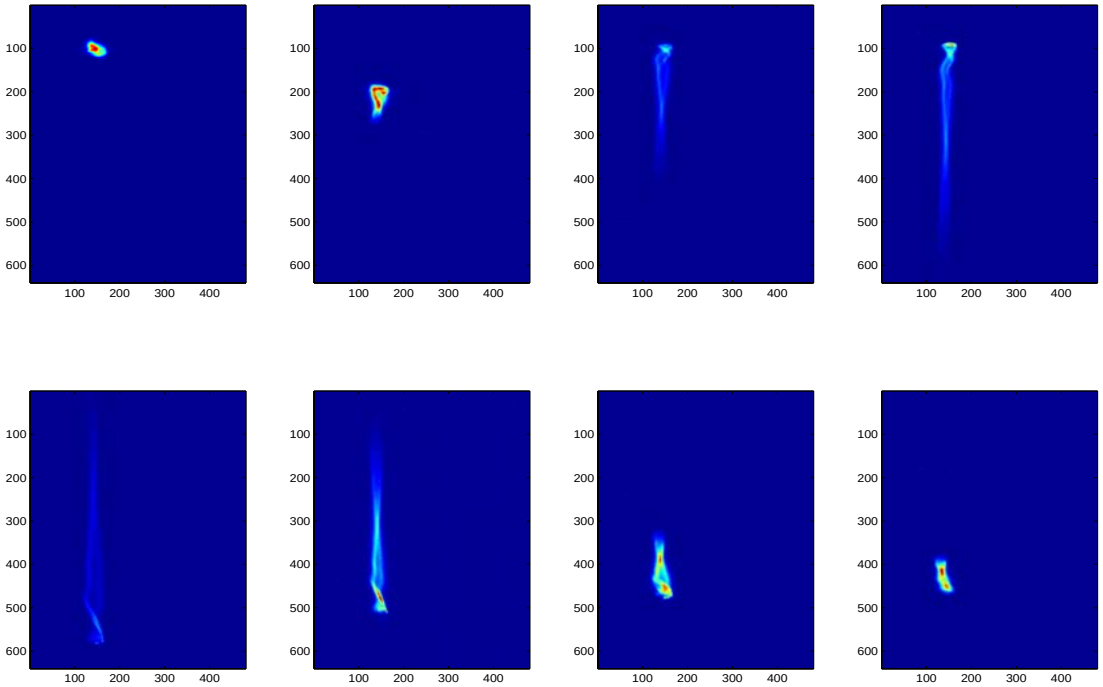
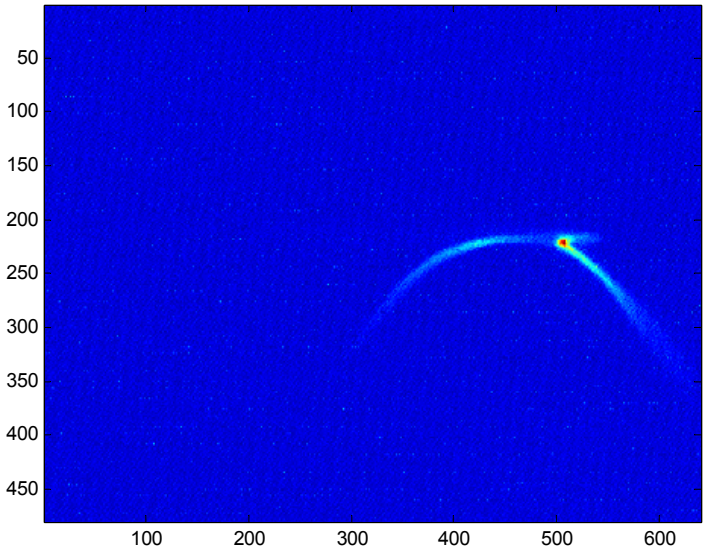
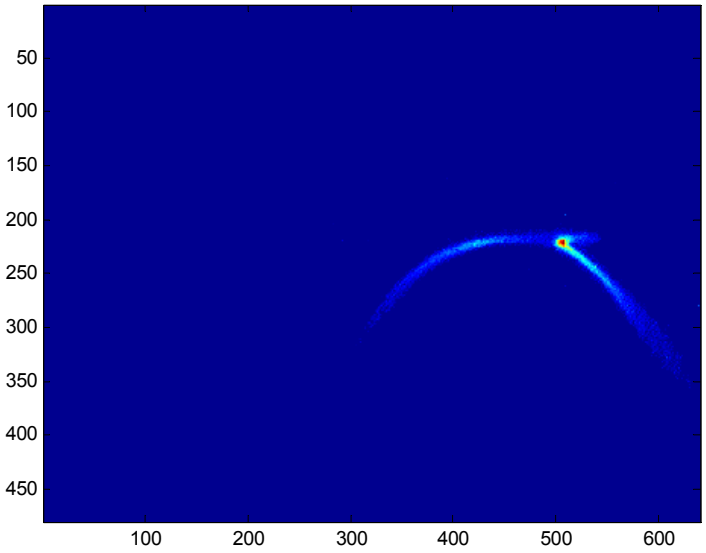
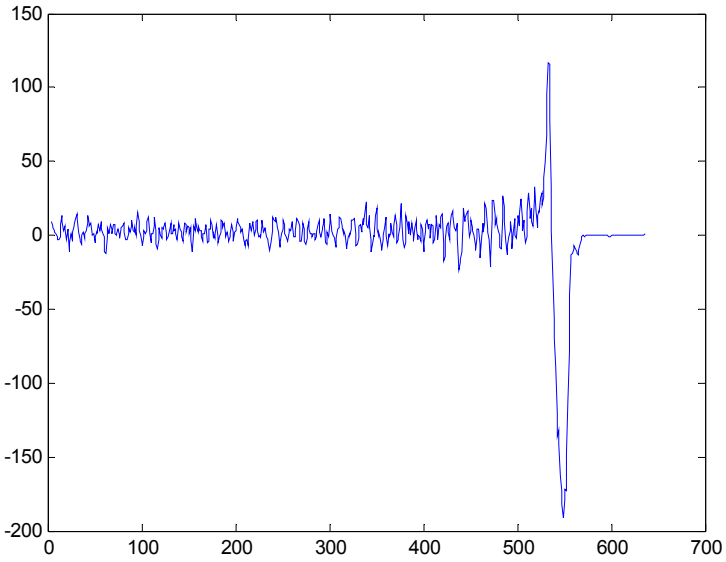


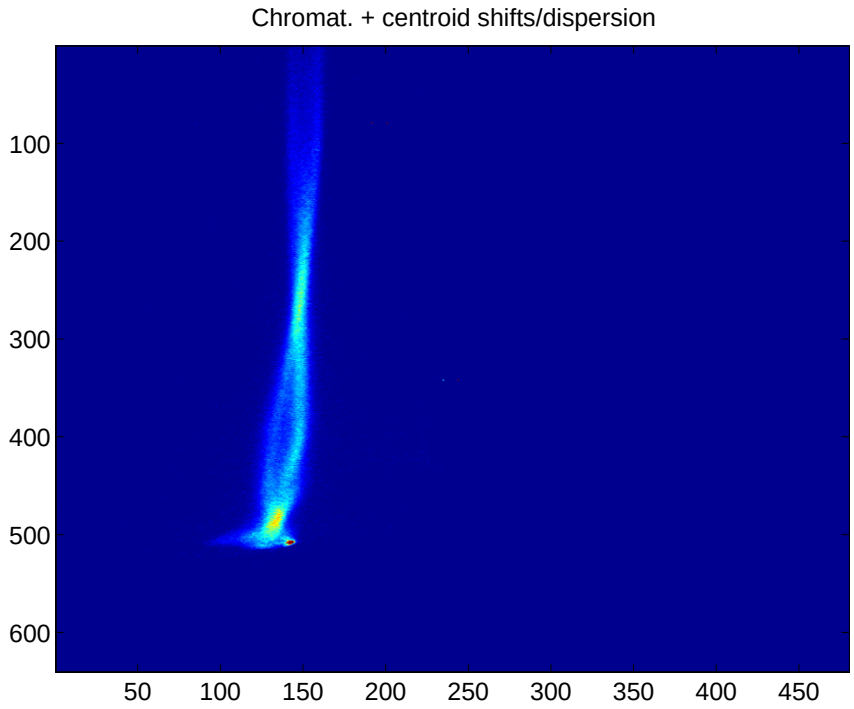
Image analysis





Reference point for slicing





Parameters of LOLA IV

Type of structure	Constant impedance structure
Mode type	TM 11 (Hybrid Mode)
Phase shift / cell	120° (2 Pi / 3)
Cell length	35 mm
Design wavelength	105 mm
Nominal operating frequency	2856 MHz
Nominal operating temperature	45 °C
Quality factor	12100
Relative group velocity	1.89 %
Filling time	0.645 µs
Attenuation	0.477 N = 4.14 dB
Transverse shunt impedance	16 MΩ / m
Deflecting voltage	V_o = 1.6 MV·L/m·$(P_o/MW)^{1/2}$
Nominal deflecting voltage	26 MV at 20 MW
Maximum operating power	25 MW
Length of structure	3640 mm (about 12 feet)
Disk thickness	5.84 mm
Iris aperture	44.88 mm
Cavity inner diameter	116.34 mm
Cavity outer diameter	137.59 mm

Courtesy: M. Nagl