LOLA: Past, present and future operation

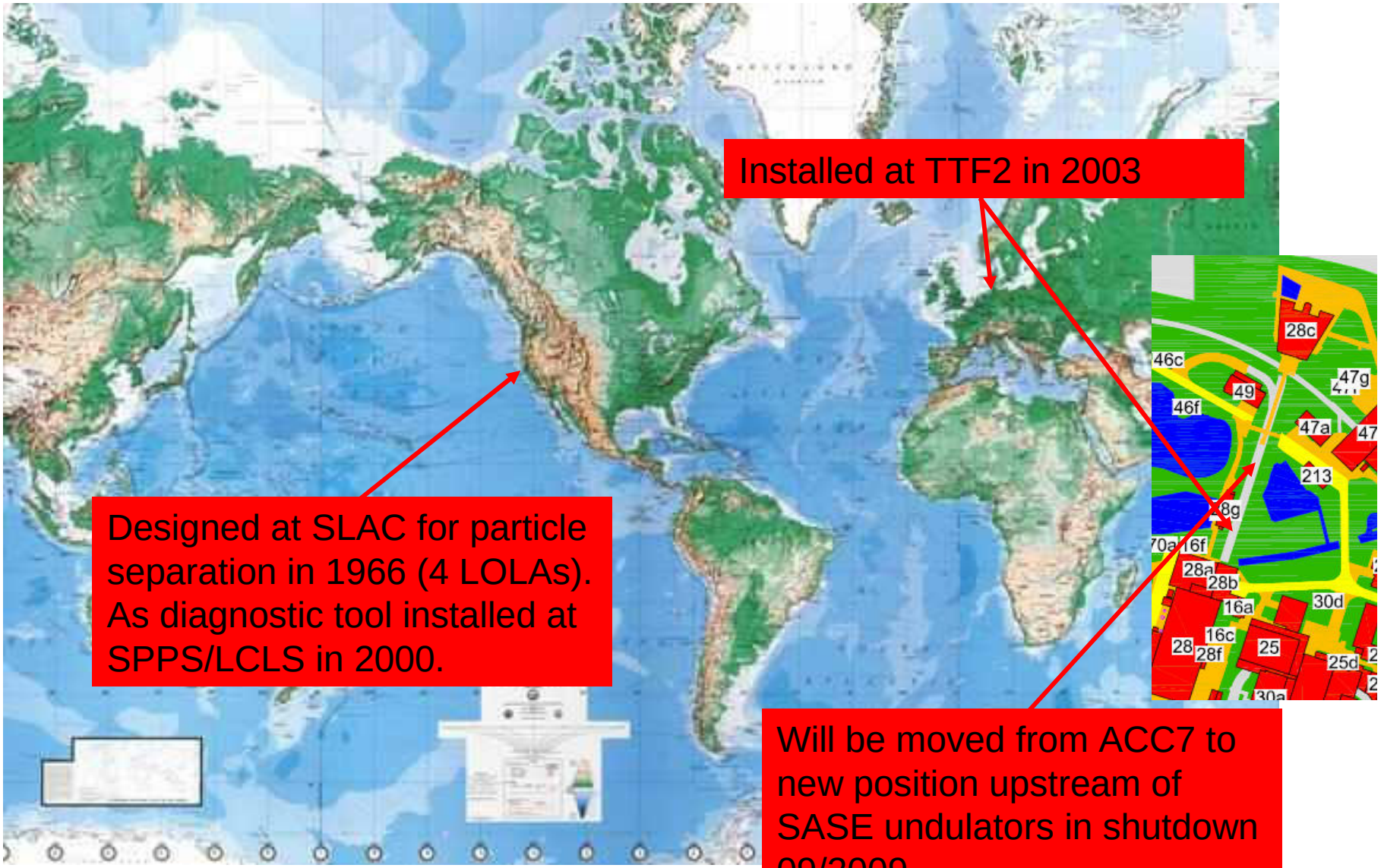
FLASH Seminar 10/02/2009

Christopher Gerth, DESY

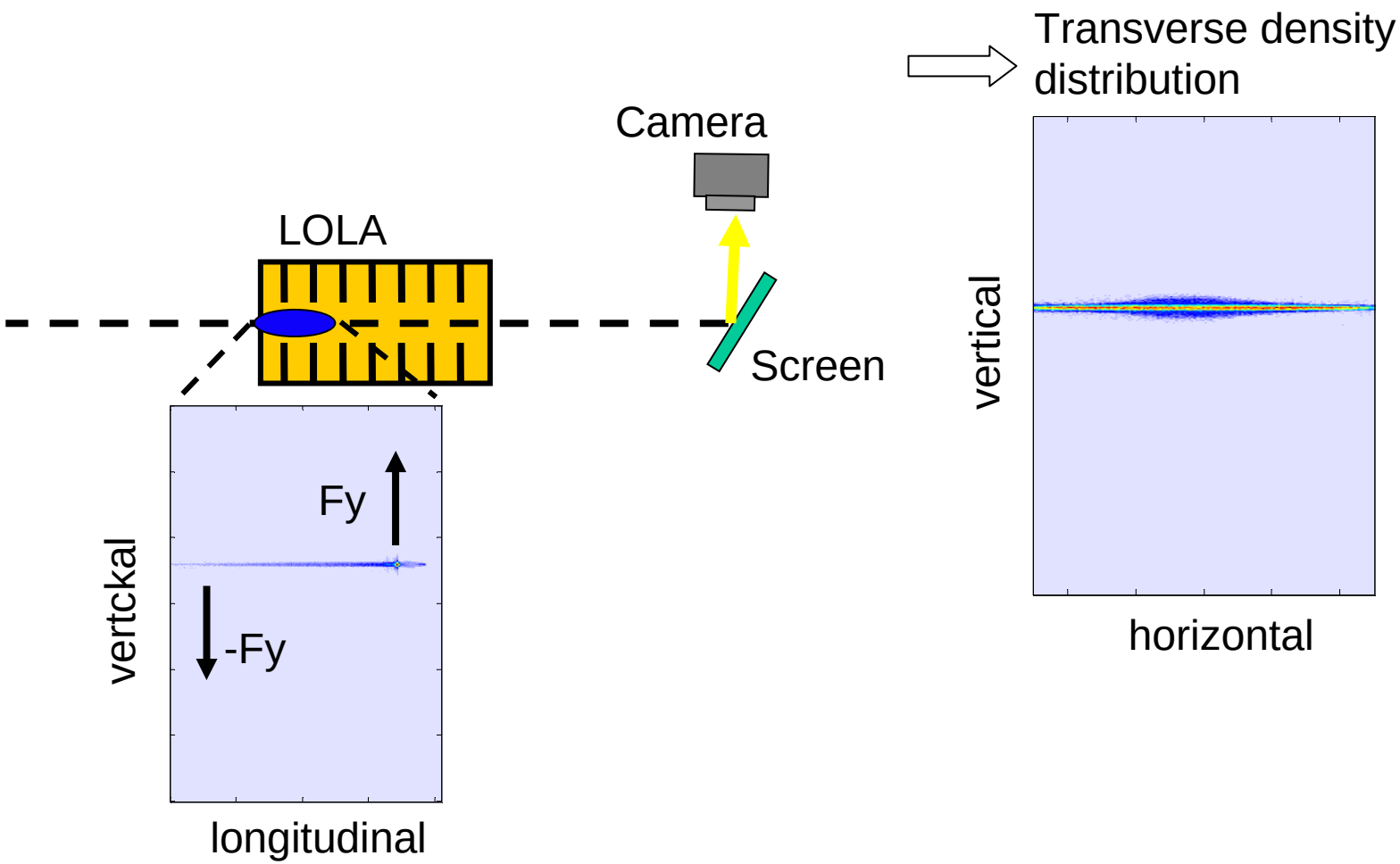
Outline

- Past
- Present
- Future

Past - Present - Future



LOLA operates as 'streak camera'



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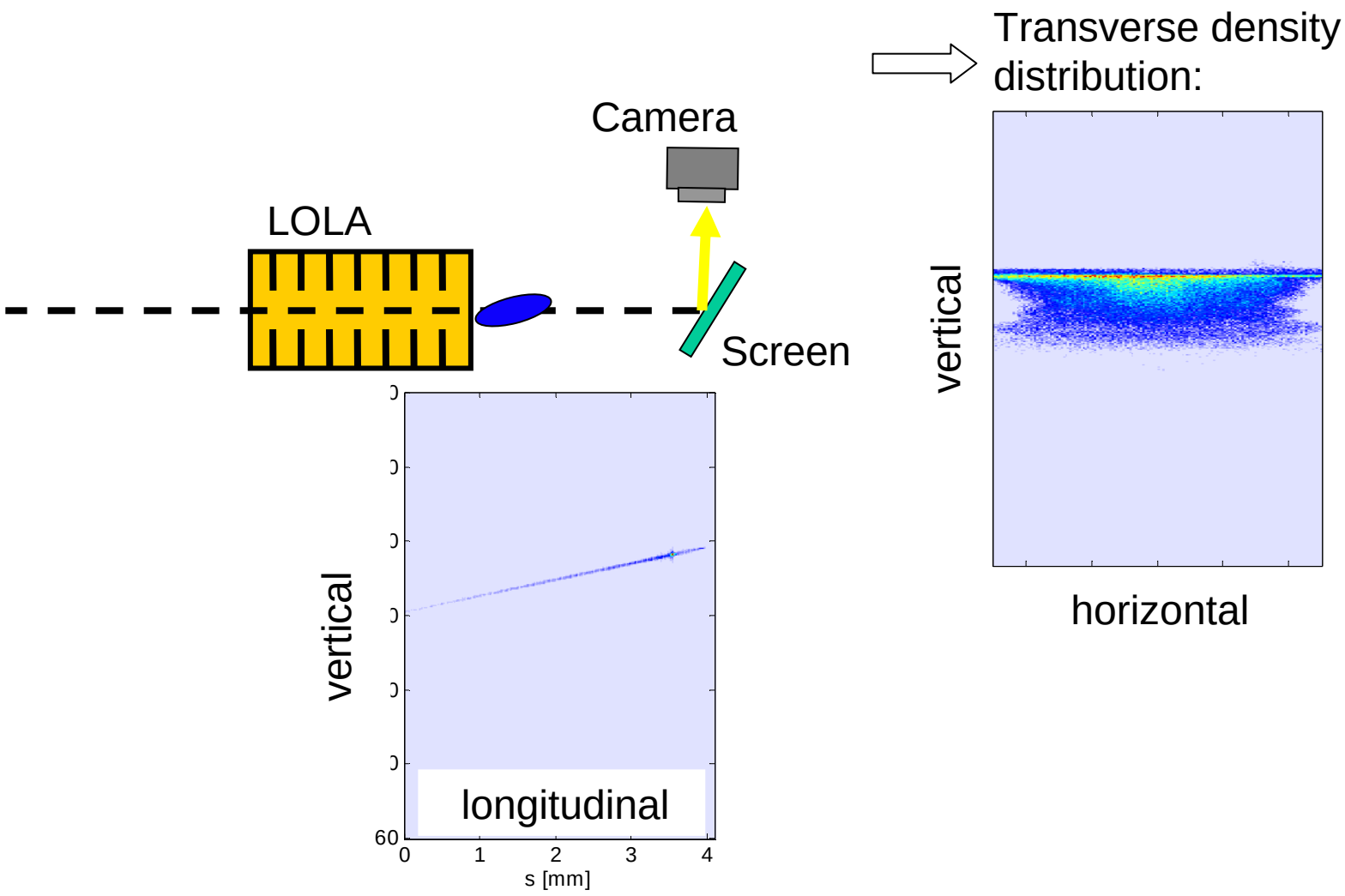
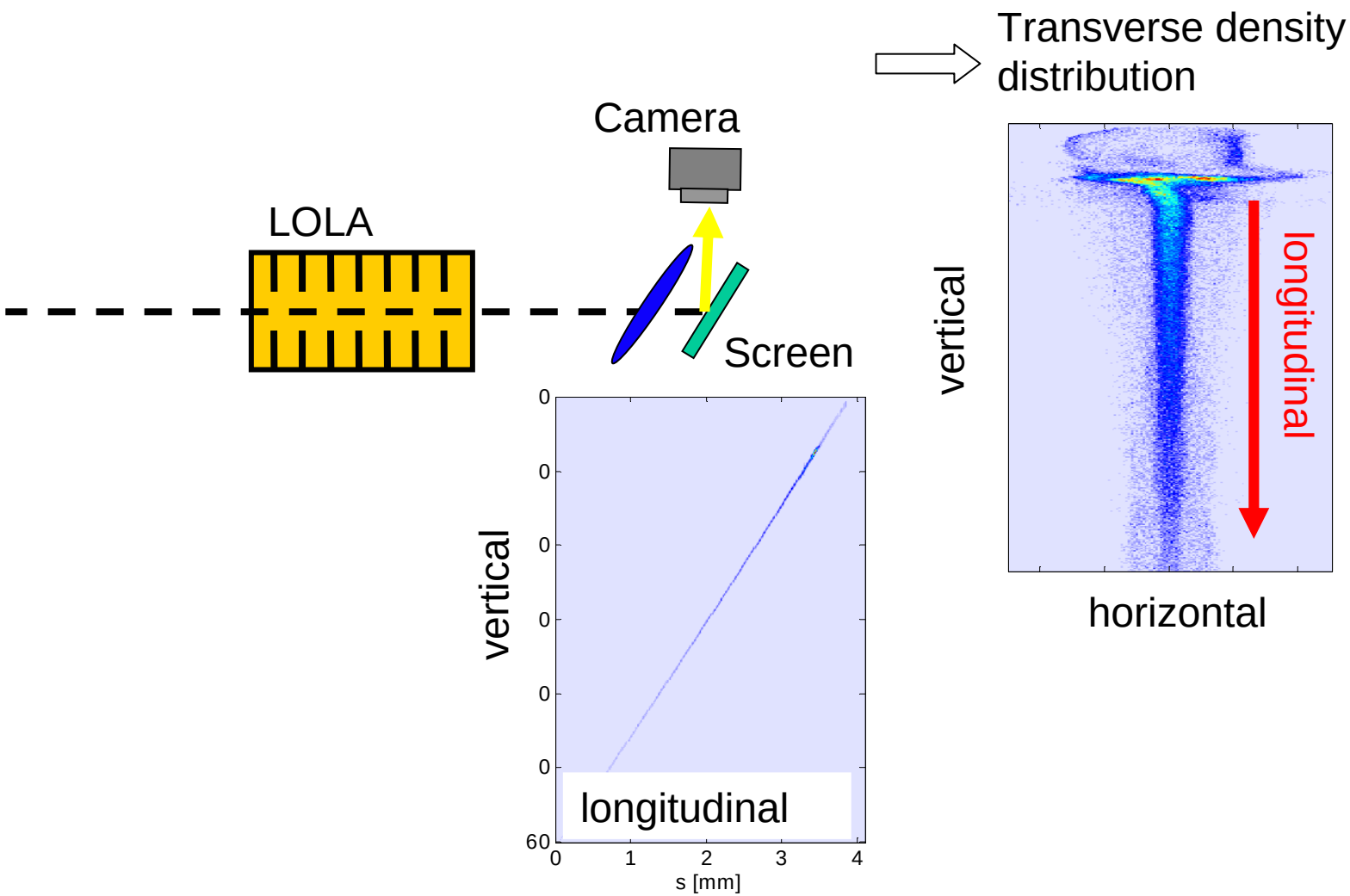
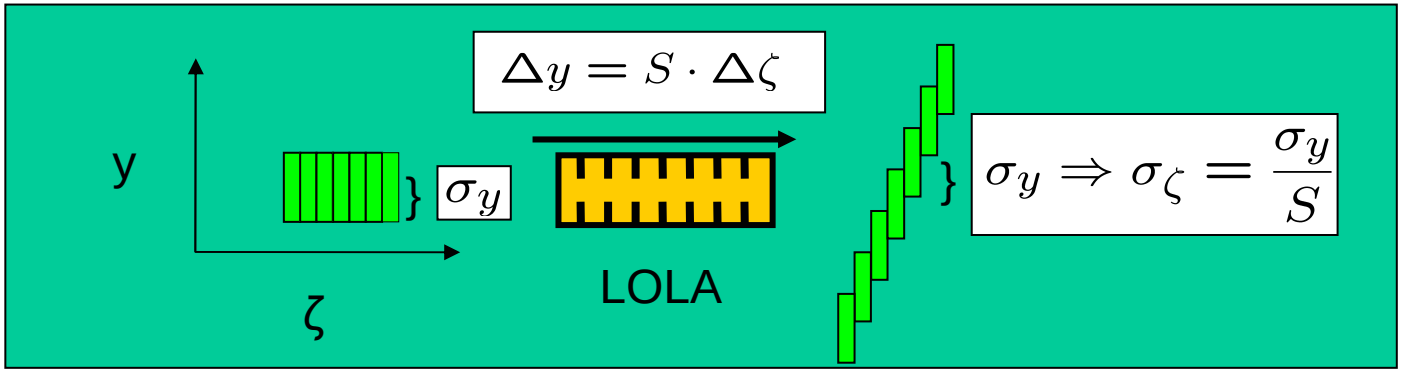


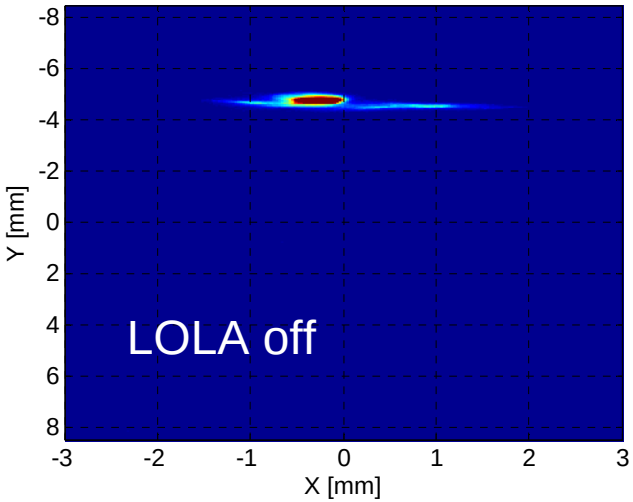
LOLA operates as 'streak camera'



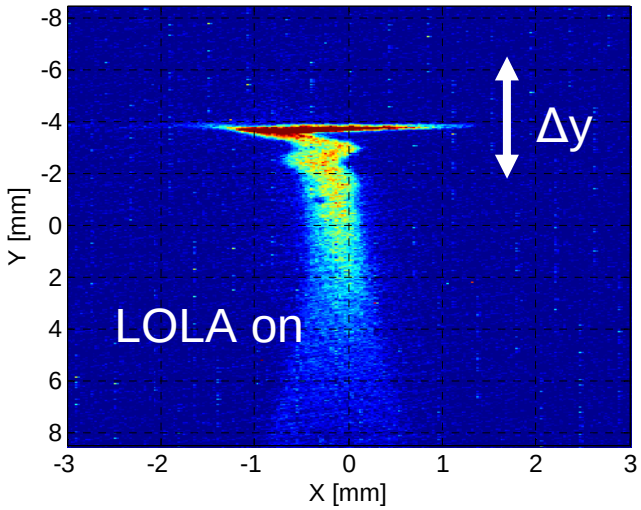
Longitudinal Resolution



Estimation of σ_y



Measurement of Δy as a function of the RF-phase $\Rightarrow S$



Typical values:

$S = 15$

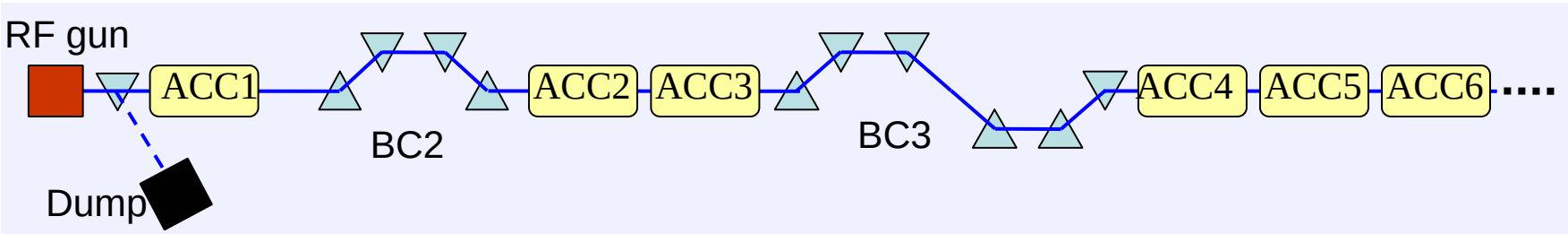
$\sigma_y = 150\ \mu\text{m}$

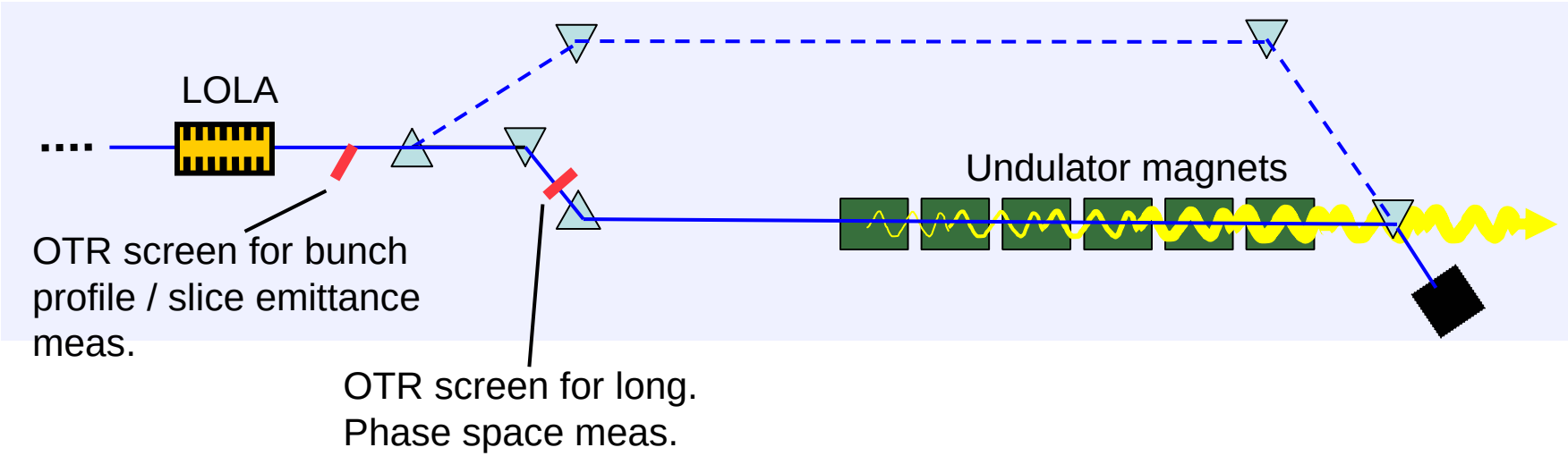
$\Rightarrow \sigma_\zeta = 10\ \mu\text{m}$

(30 fs)

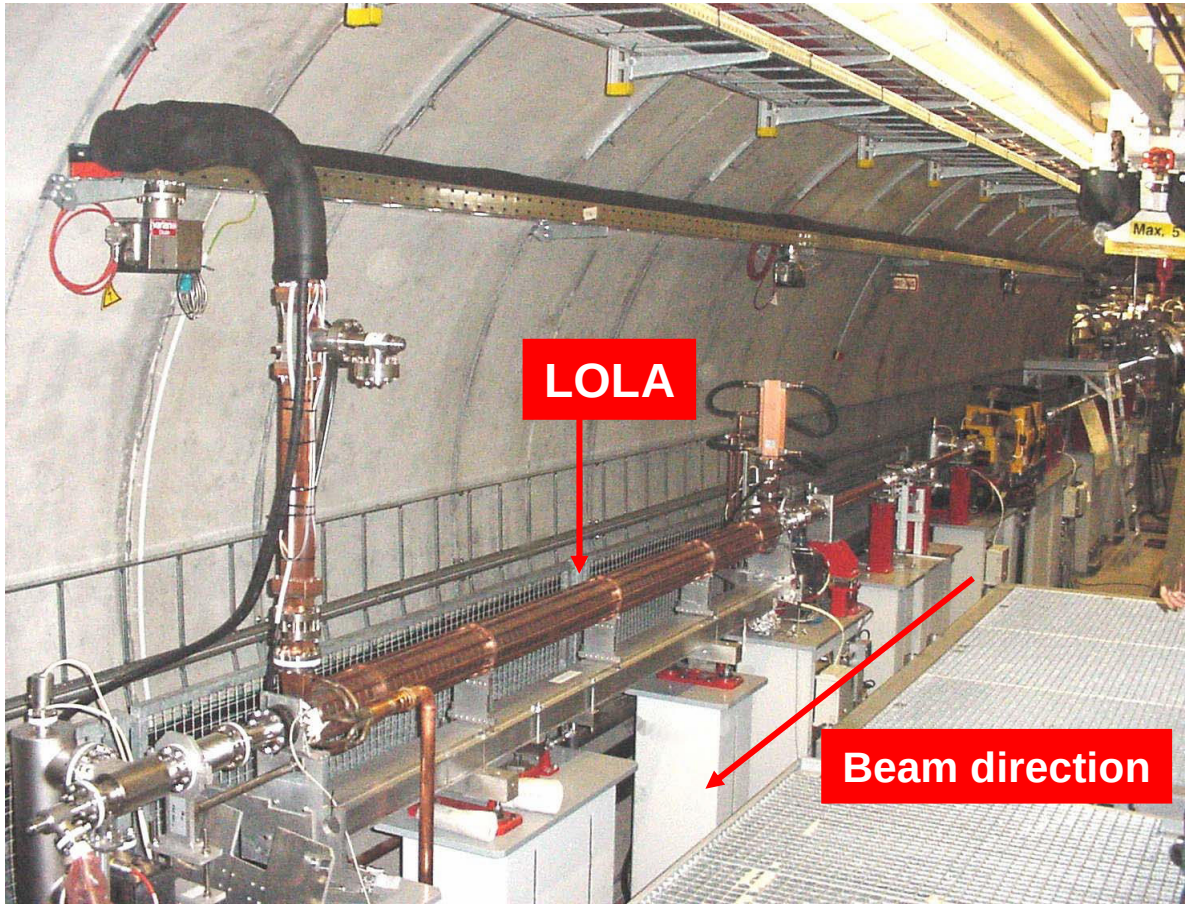
The Present Setup

Current position of LOLA





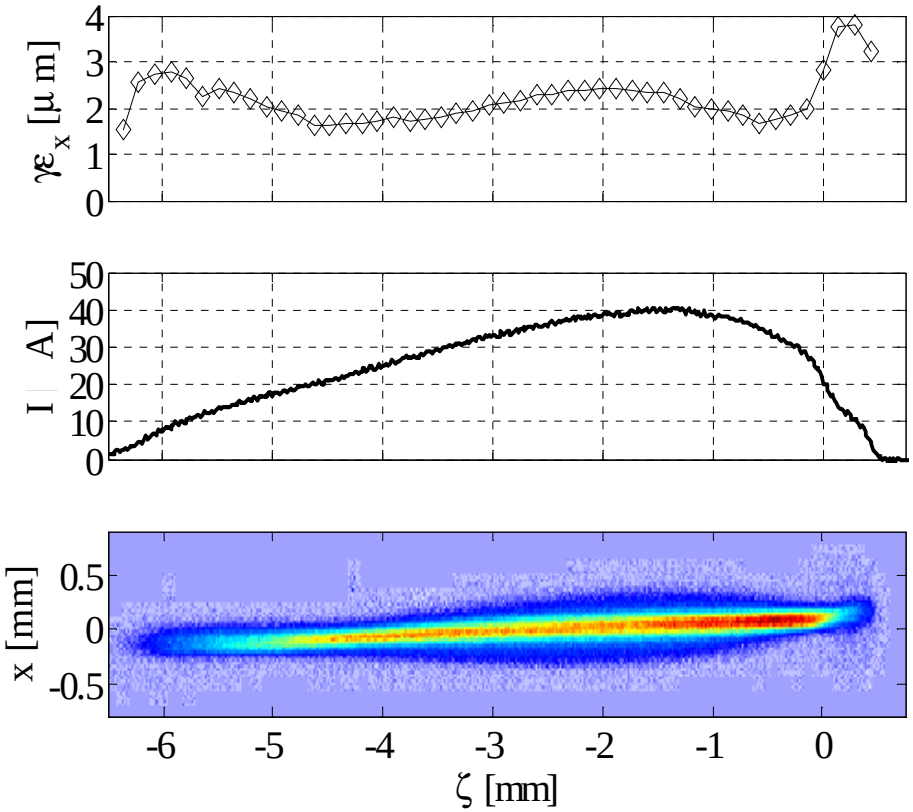
LOLA at position ACC7



- Installed in 2003, Collaboration DESY–SLAC
- Frequency: 2.86 GHz
- Length: 3.6 m
- Maximum deflecting voltage ~ 25 MV @ 20 MW input power

On-crest operation

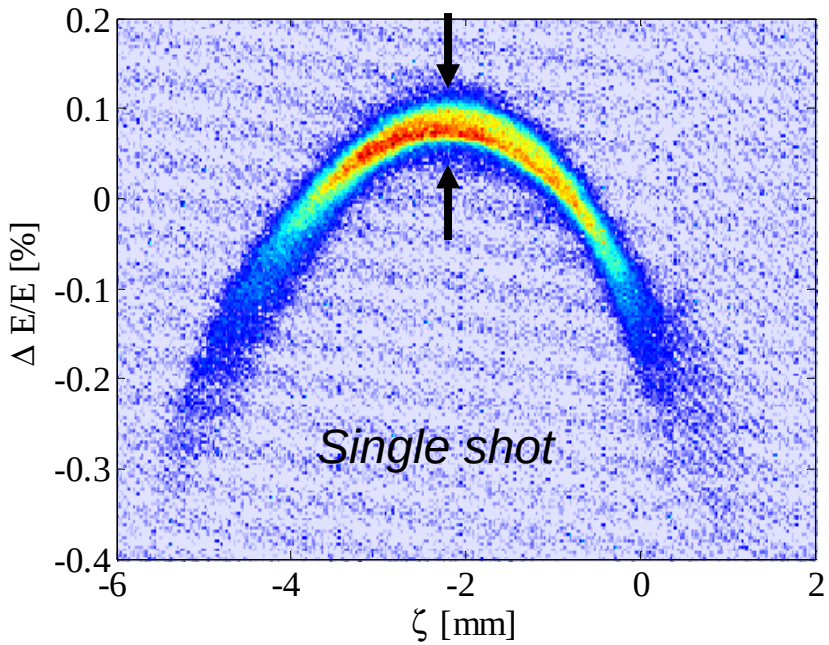
Slice Emittance Measurements:



490 MeV, 0.6 nC

Longitudinal Phase Space:

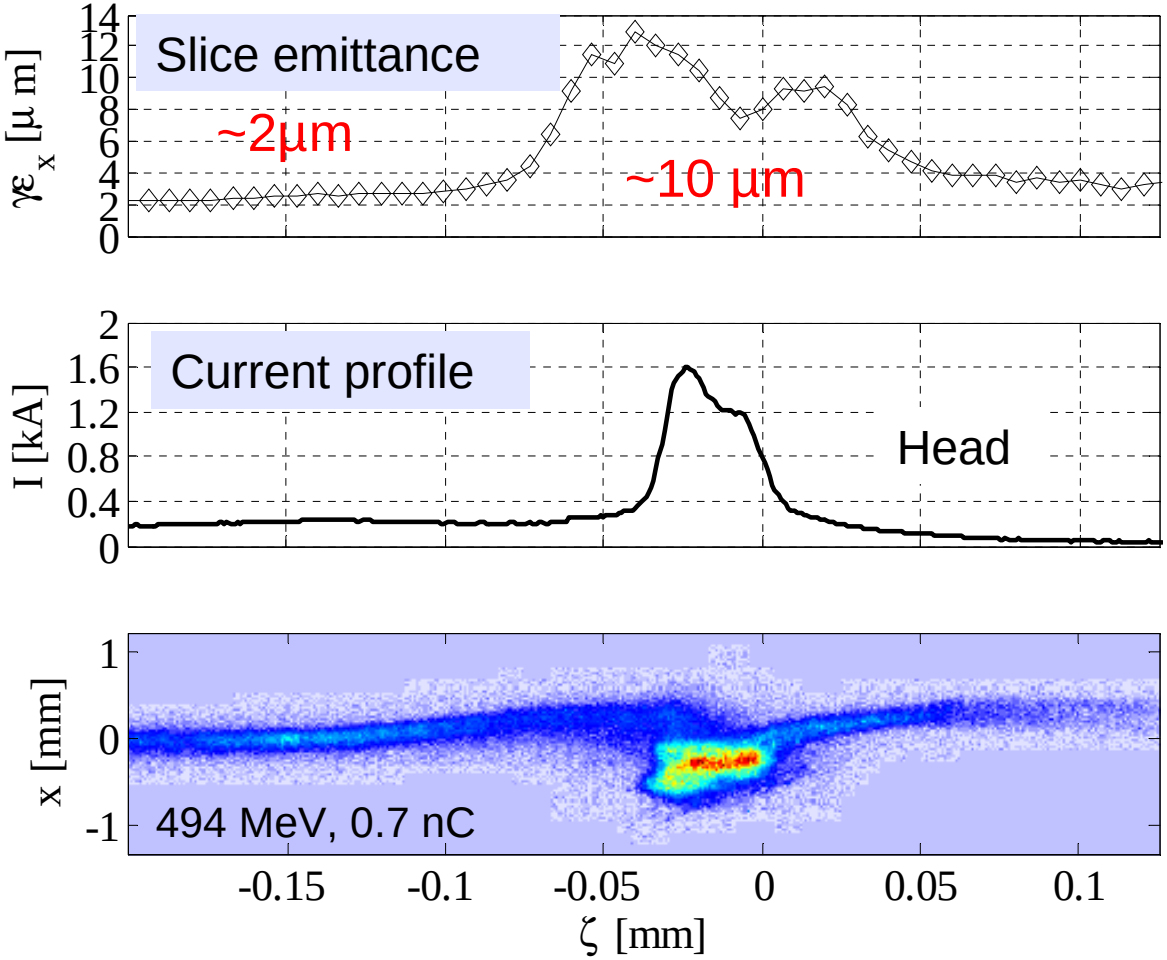
$$\frac{\sigma_E}{E} = 0.025\%(150\ \text{keV})$$



650 MeV, 1nC,
compressor chicanes switched off

Operation @ SASE conditions

Slice Emittance Measurements:



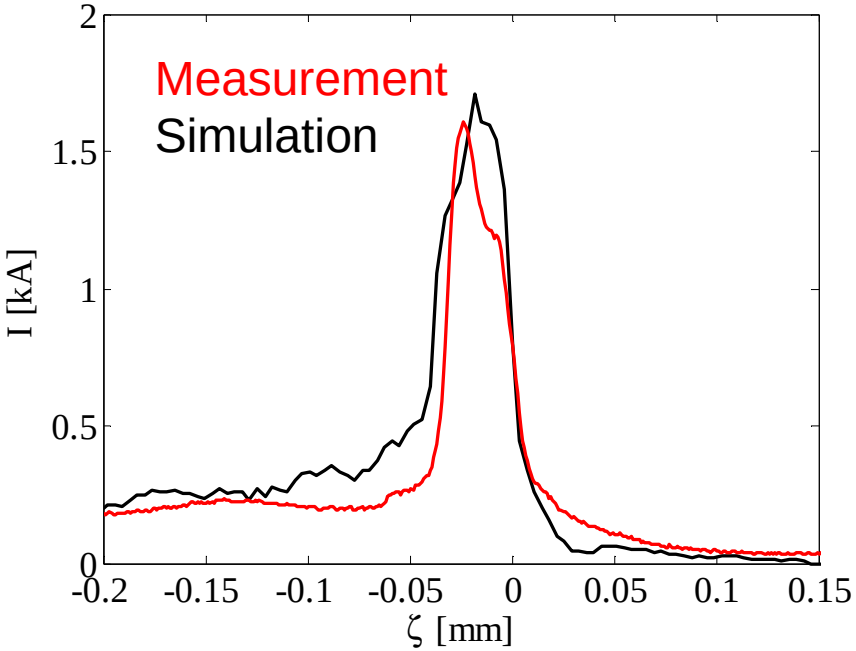
Longitudinal resolution ~ 8 µm (RMS)

Increase in slice emittance in the peak current region:

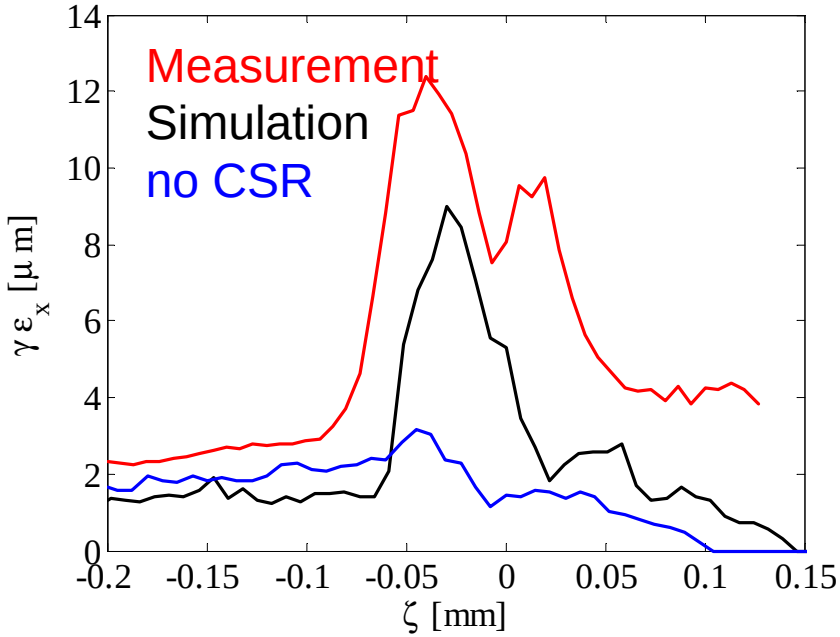
- Cause?
- In contradiction to SASE theory!?

CSR effects

Current profile: RF-phase of module ACC1 adjusted in simulation



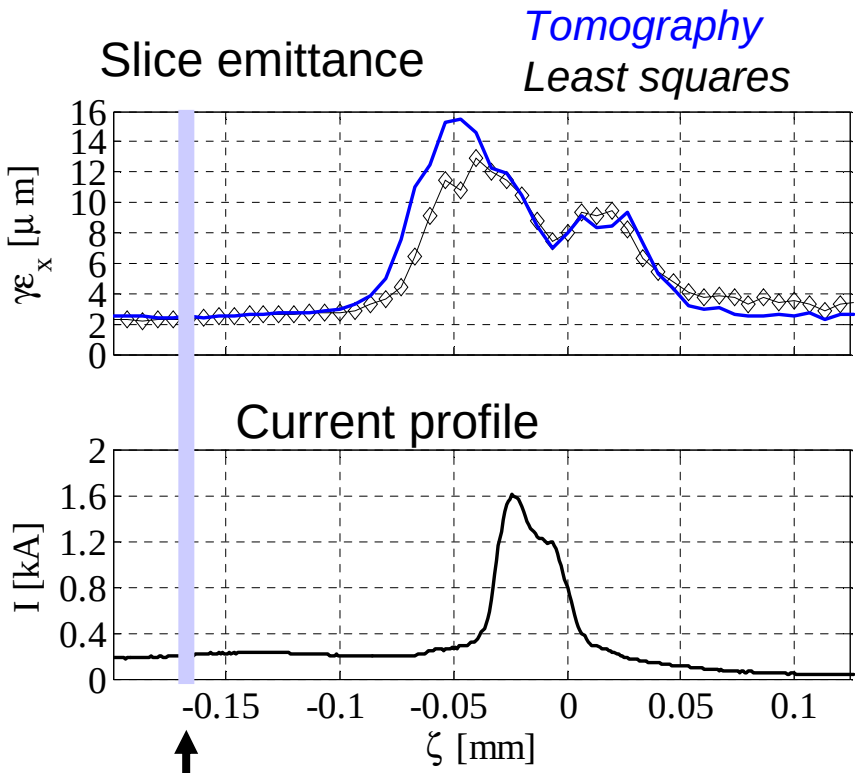
Slice emittance

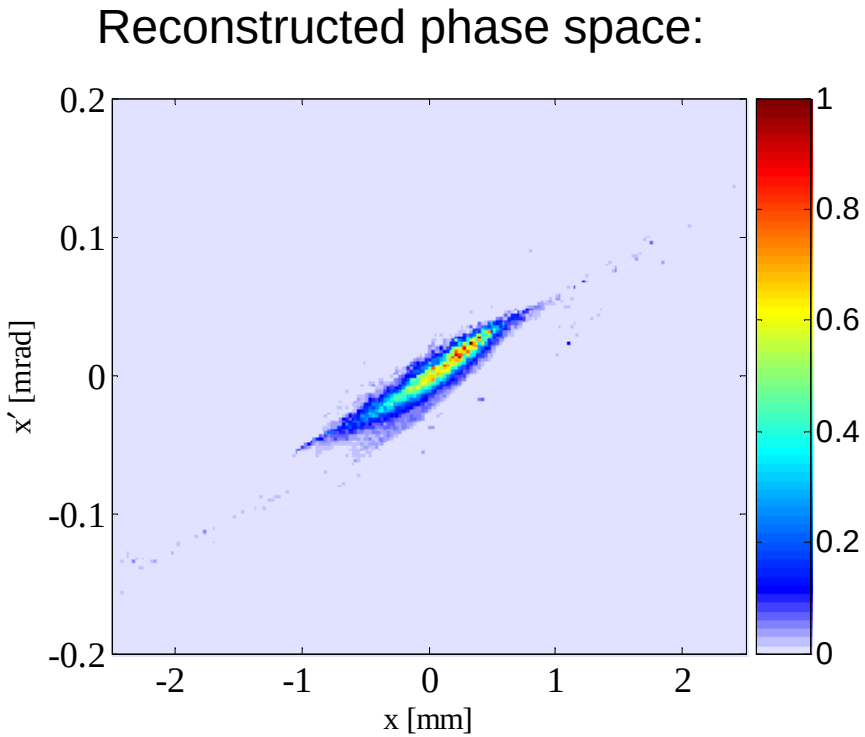


Simulations by M Roehrs with ASTRA (K. Flöttmann) and CSRTrack (M. Dohlus)

Phase-space Tomography

PhD thesis M . Roehrs

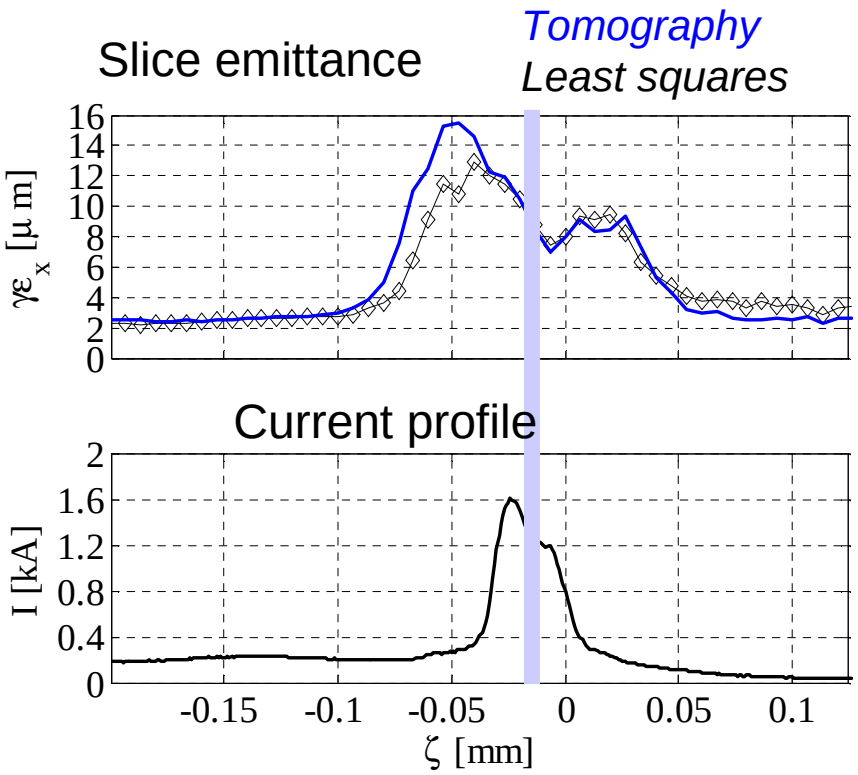


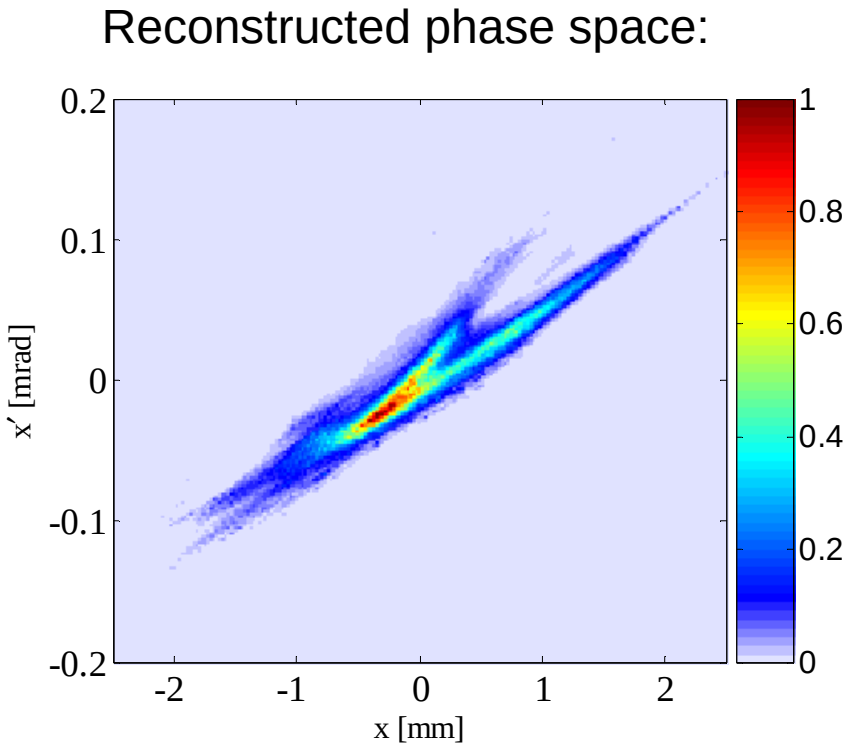


longitudinal slice position,
thickness Δζ = 8 μm

Phase-space Tomography

PhD thesis M . Roehrs



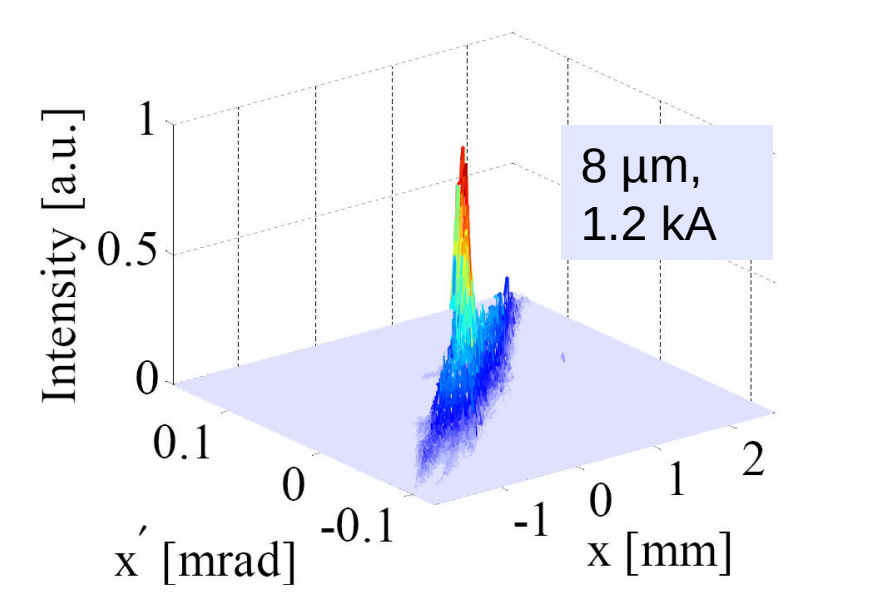


longitudinal slice position,
thickness Δζ = 8 μm

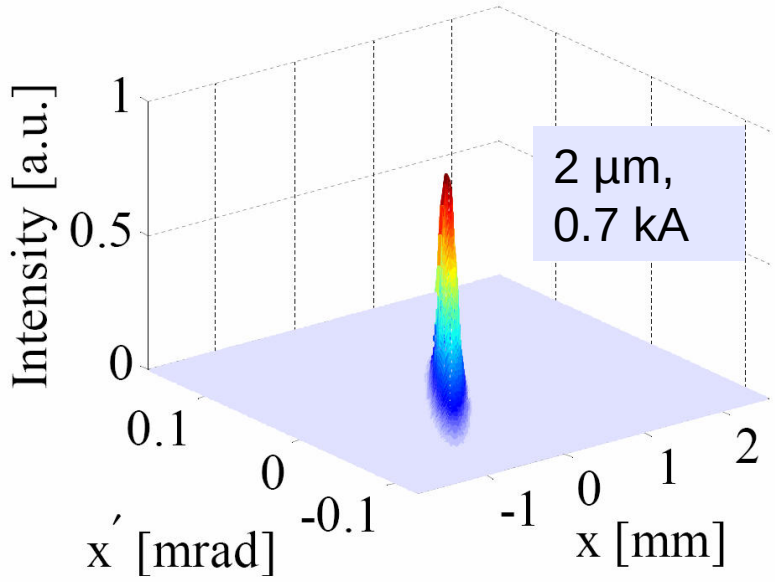
Phase-space Tomography

PhD thesis M . Roehrs

Measured distribution in the peak current region



2-dimensional Gaussian fit to the peak



typical: 2–4 µm normalized emittance, 0.5 – 1.0 kA peak current

→ FEL radiation not saturated (measurements during FEL study shifts)

→ peak current may change downstream of LOLA (e.g. in the dogleg)

Summary: Present

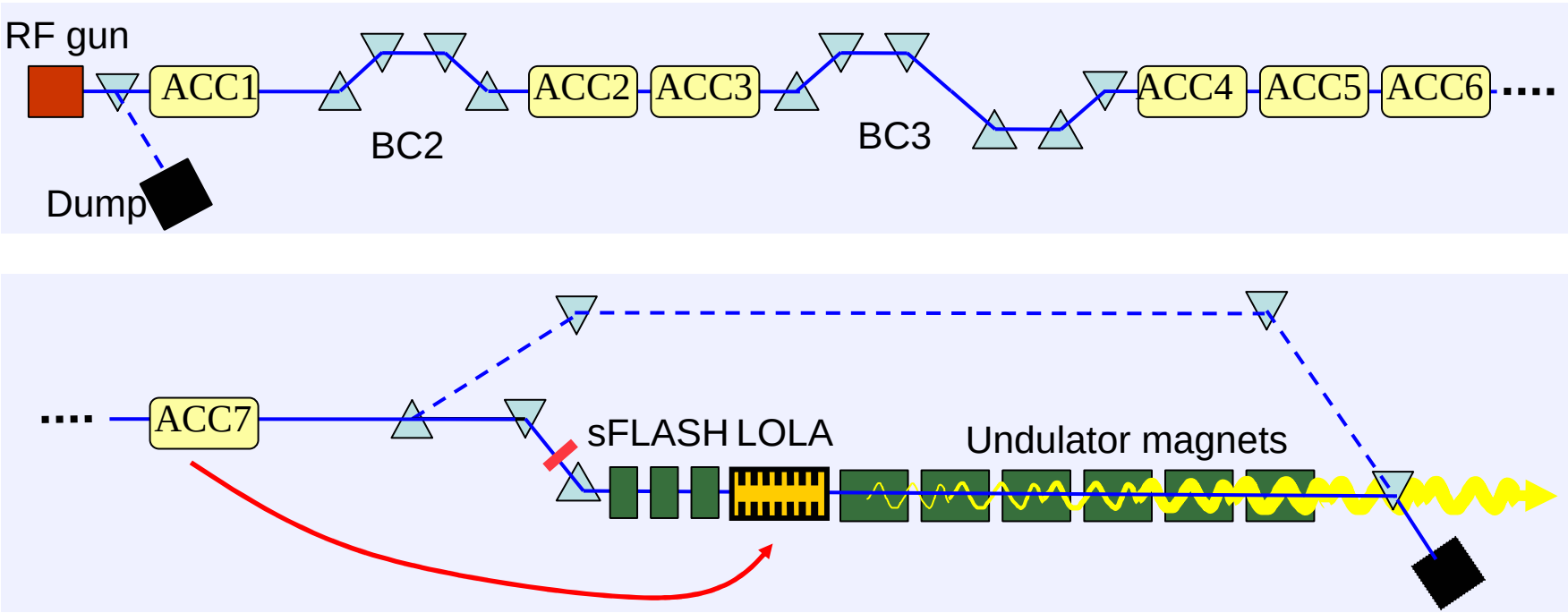
- LOLA does not measure the bunch parameters at the undulator; dogleg contributes to the compression process
- Special optics required for LOLA measurements - online measurements during user operation not possible
- Temporal resolution not sufficient to fully resolve the SASE spike in short-pulse mode (without 3rd harmonic cavities).
- Even slice emittance values are of limited use (at least for comparison with SASE theory).
- Tomographic methods required to ‘access’ the SASE spike
- Transverse space charge effects slightly distort the tomographic method. Inclusion could improve reconstruction.

Good bye Michael …

Dr. Michael Röhrs
Young Scientist Prize at the
Int. FEL Conference 2008.

New location of LOLA

Shutdown Sept 2009:
LOLA will be moved upstream of the SASE undulators



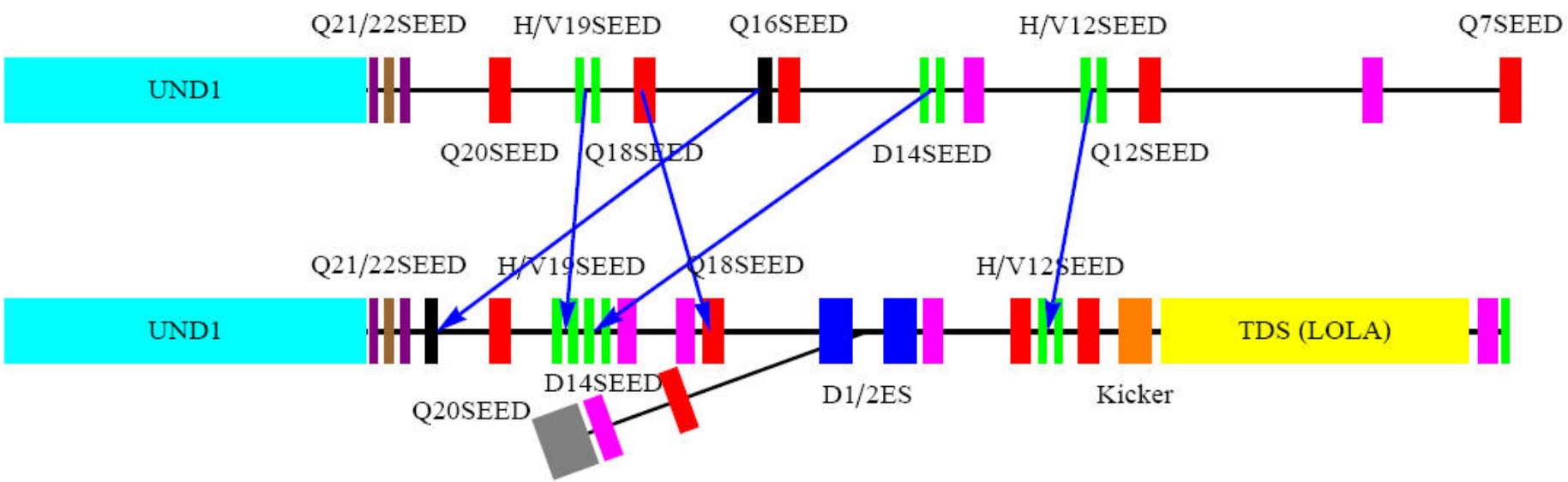
Goals for new setup

- ‘standard optics’ for on-line bunch profile monitor
  - optics layout with ‘optimum’ LOLA performance so that QUAD settings do not have to be changed.
  - matching into SASE undulators (4 options, energy dependent)

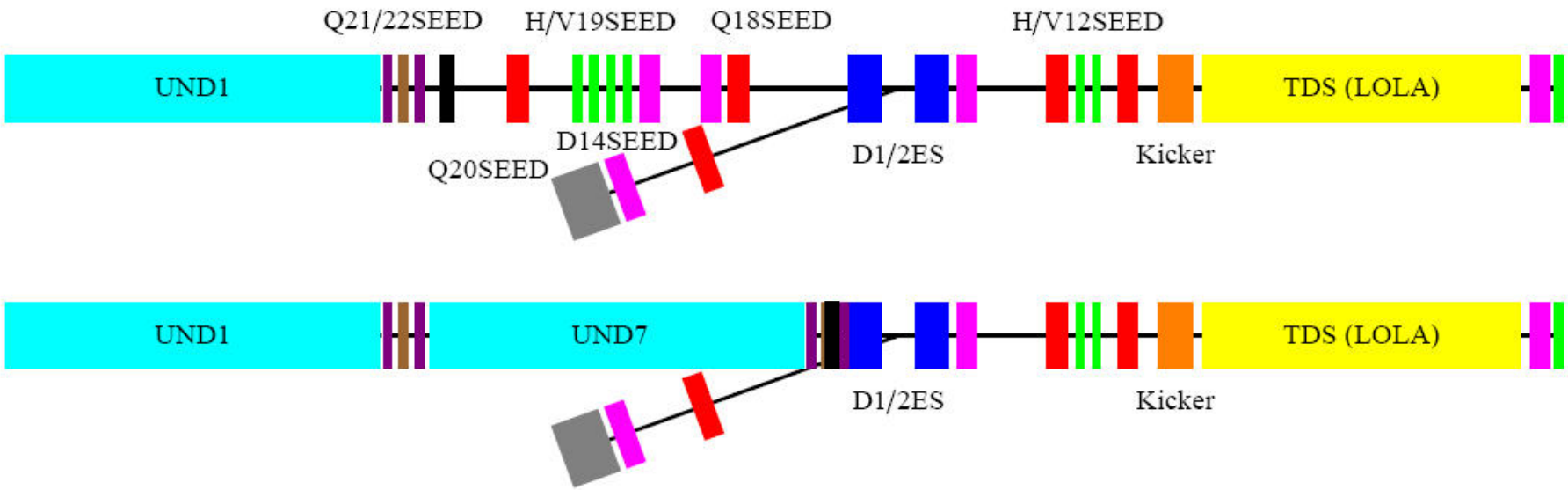
- Design of spectrometer beamline has started
  - longitudinal Phase Space measurements
  - dump for commissioning (1-30 bunches)

- Quad scan for slice emittance measurement
  - special optics needs to be designed: change of phase advance from LOLA to screen by 180 deg in x with upstream QUADs while keeping the beam sizes in x and y constant at the screen.

New Lattice Layout



Later Upgrade with UND7



Installation of undulator UND7 should be possible with minor modifications

LOLA Resolution

Resolution: vertical beam size at OTR / shear parameter $\frac{\sigma_y^0}{S}$

Beam size at OTR: $\sigma_y^0(s) = \sqrt{\epsilon_y \cdot \beta_y(s)}$

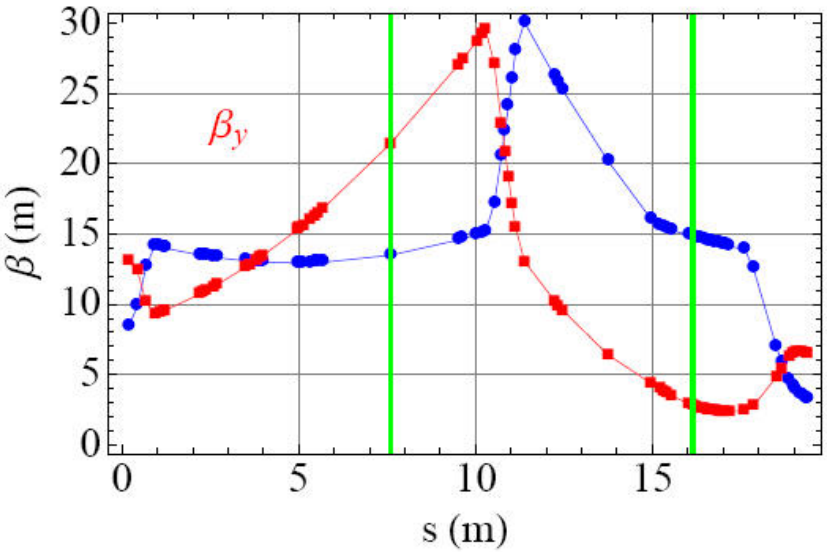
Shear parameter: $S = M_{1,2}^y \cdot \frac{eV_0}{E} \cdot k \qquad M_{1,2}^y(s, s_0) = \sqrt{\beta_y(s)\beta_y(s_0)} \cdot \sin(\Delta\phi_y)$

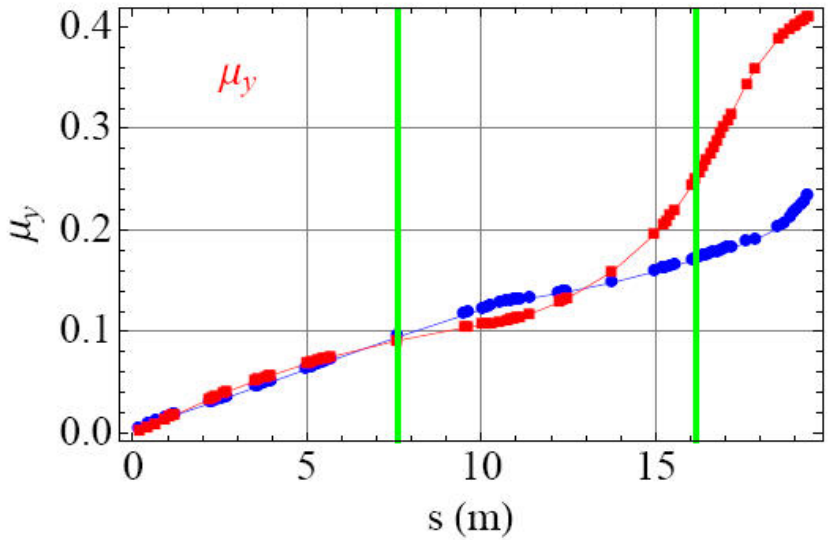
Deflecting voltage: $V_0 \approx 1.6 \frac{MV}{m} \cdot L[m] \cdot \sqrt{P[MW]}$

Maximum input power at LOLA:
18MW => +60m waveguides => 12 MW
Maximum deflecting voltage V_0 : 25 MV => 20.5 MV

Beam size at screen:
Not resolution limited by optical system
Has to fit on the screen (with timing jitter, ~0.2mm*S)

Online Bunch Profile Measurement



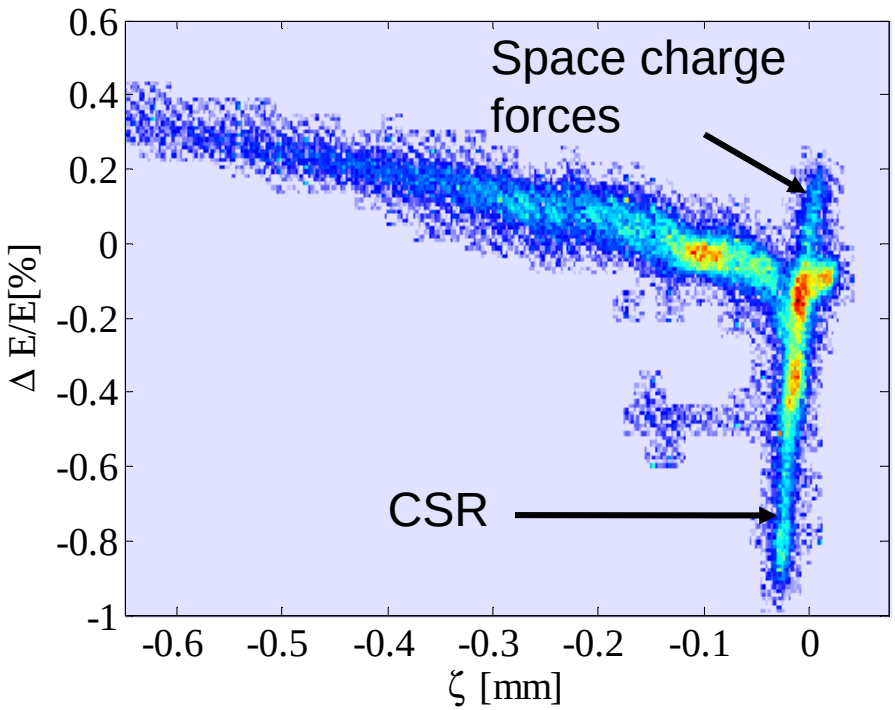


LOLA resolution SASE (fs):	22.6865
Phase advance SASE (deg):	57.2183
Shear parameter SASE:	7.89054

Layout has to be integrated into overall lattice
- check optics for SASE compatibility (matching, focusing, steering, ..)

S2E Simulations Bunch

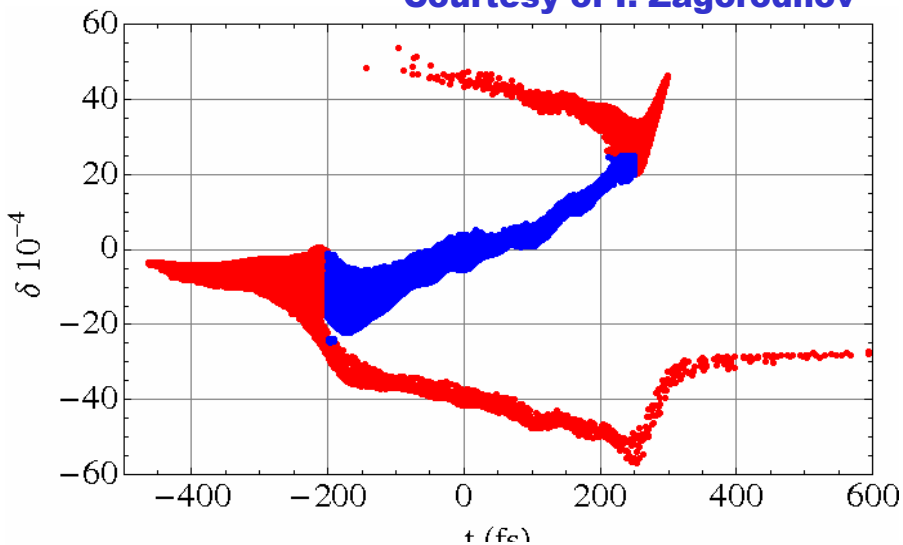
Short bunch mode without 3rd harmonic

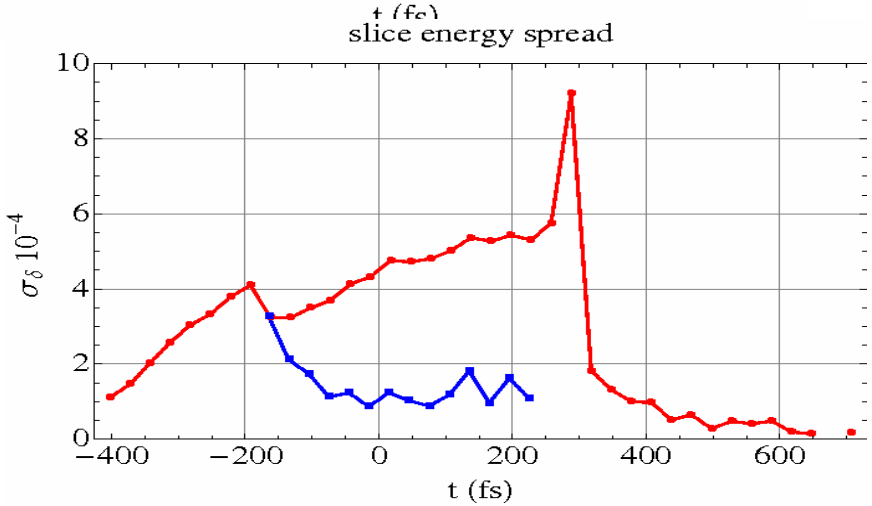


677 MeV, 0.5 nC

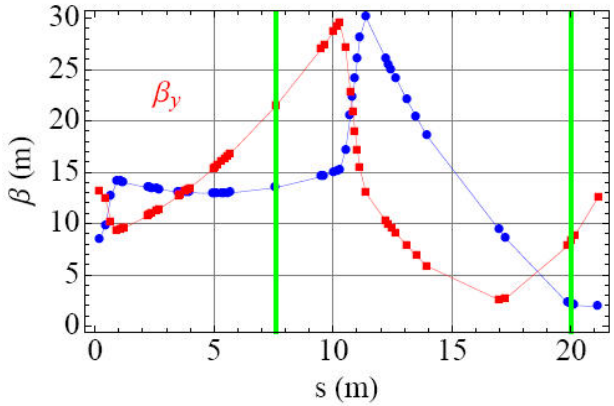
Operation with 3rd harmonic

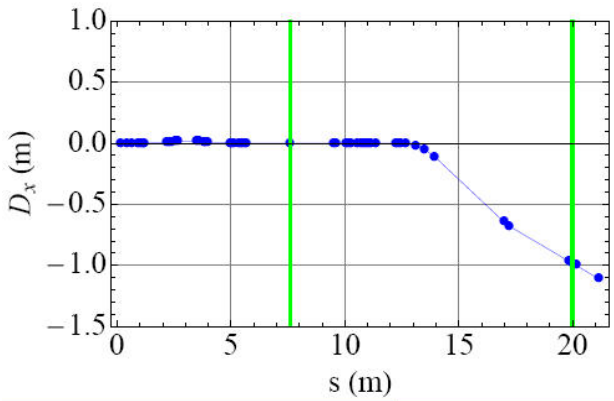
Courtesy of I. Zagorodnov





Energy Spectrometer / Dump





Energy resolution:

Aim: $\sigma_\delta = 50$ keV ($5 \cdot 10^{-5}$ @ 1GeV)

$D_x \cong 1$ m

$\sigma_x = (ß \cdot \varepsilon)^{½} < D_x \cdot \sigma_\delta \rightarrow ß \cong 4$ m

LOLA resolution ES (fs):	21.9694
Phase advance ES (deg):	119.752
Shear parameter ES:	13.9671
Dispersion ES (m):	−0.98436

Degrading effects:

1. Energy spread induced by off-axis longitudinal fields of LOLA
2. CSR effect in dipole magnet
3. Other effects: optics, chromaticity

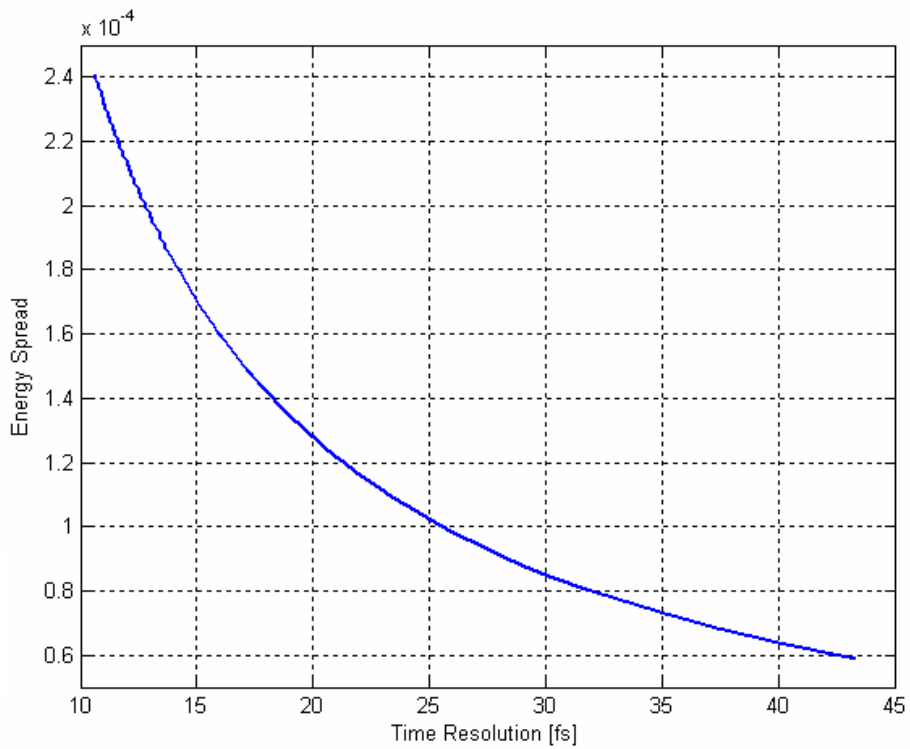
Uncorrelated Energy Spread

Uncorrelated energy spread induced by LOLA due to off-axis longitudinal accelerating fields (for round beams):

$$\delta_E^{LOLA} = \frac{eV_0}{E} \cdot k \cdot \sigma_y$$

$$\delta_E^{LOLA} = S \frac{\sqrt{\epsilon_y}}{\sqrt{\beta_y(s)}\sin(\Delta\Phi_y)} = \frac{\epsilon_y}{\sin(\Delta\Phi_y)} \cdot \frac{1}{\frac{\sigma_y^0}{S}}$$

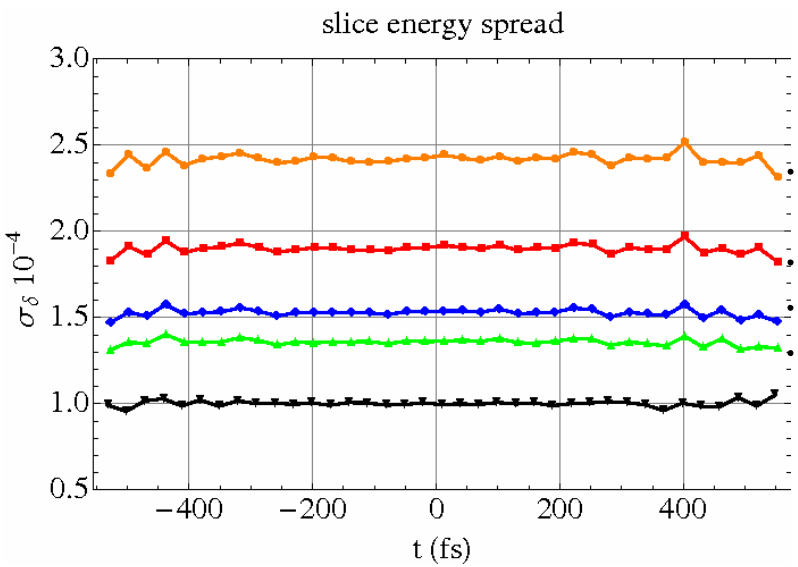
Energy spread induced by LOLA



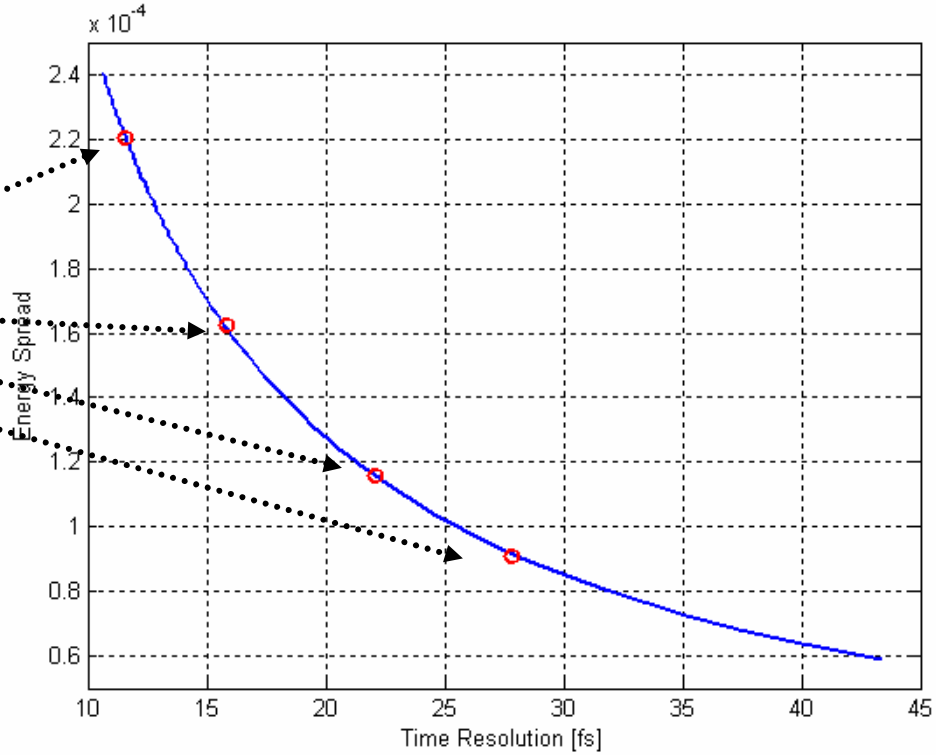
Behrens-Gerth Relation:
=> The energy spread induced by LOLA is anti-proportional to the time resolution.

Uncorrelated Energy Spread

Elegant simulation:



Energy spread induced by LOLA

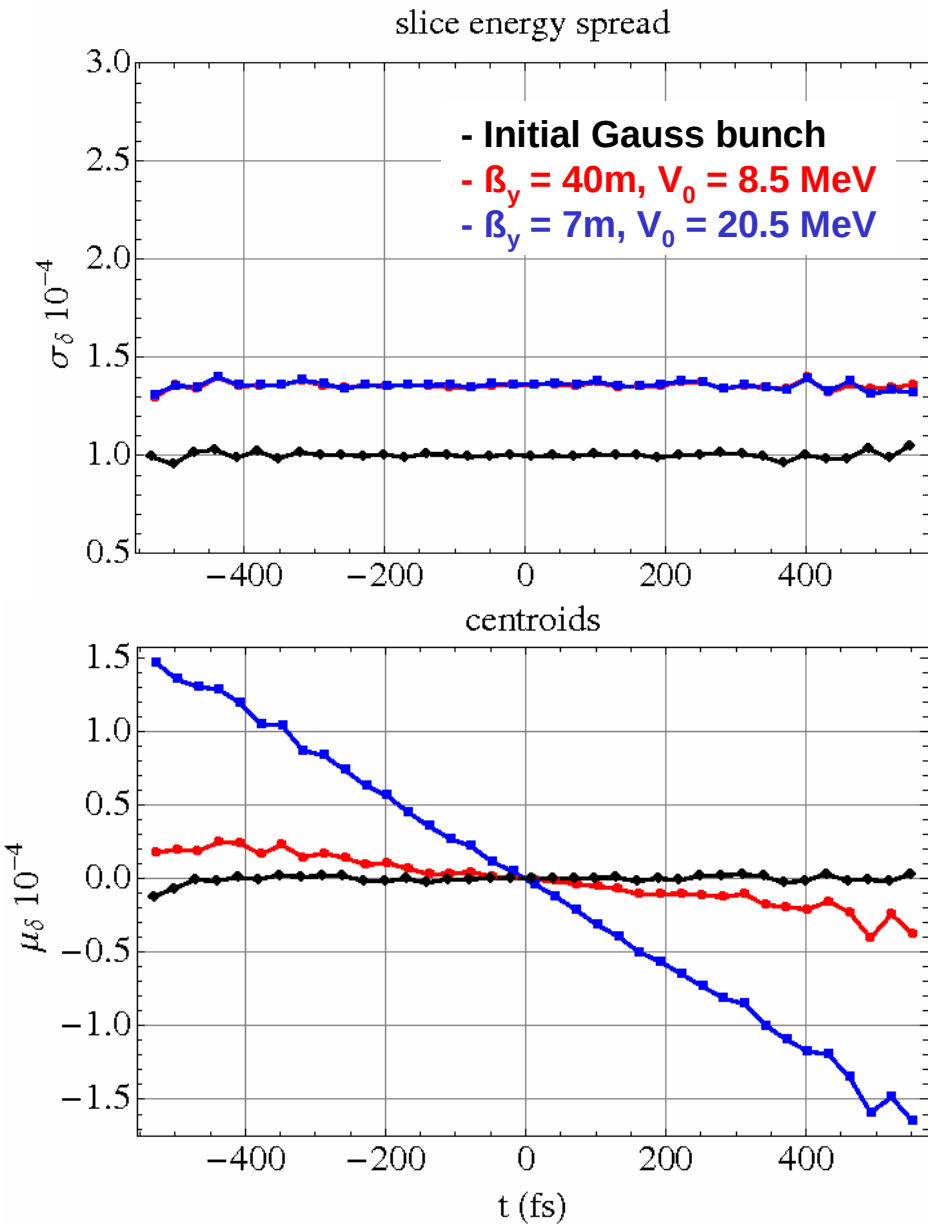


Correlated Energy Spread

Slice energy spread and centroid tilt due to longitudinal accelerating fields of LOLA:

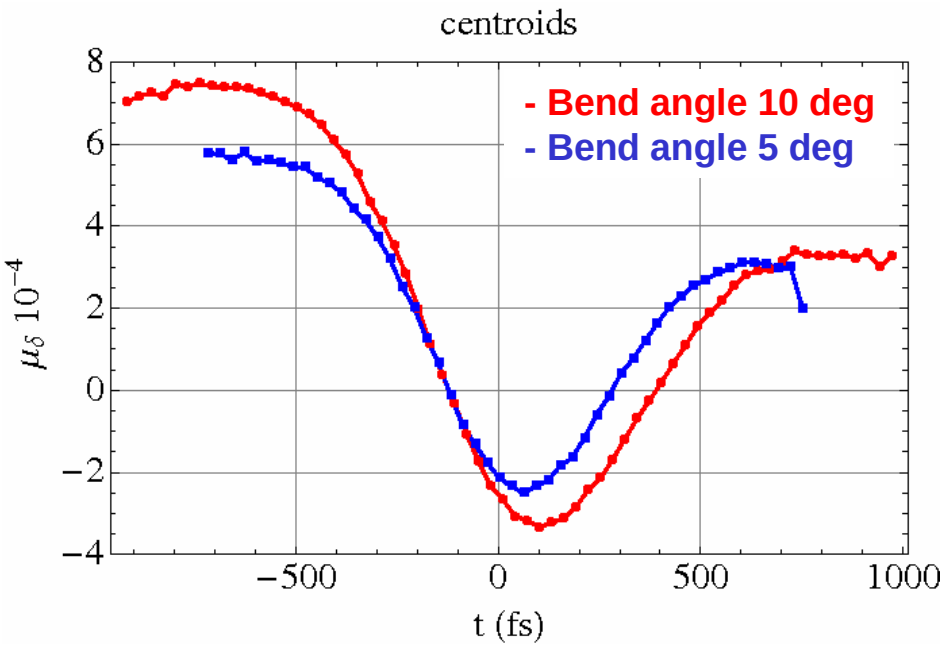
Both cases have the same time and energy resolution but different beta-functions and deflecting voltages V_0.

A smaller beta-functions leads to a larger phase advance within LOLA and stronger shearing and therefore a larger correlated energy spread.

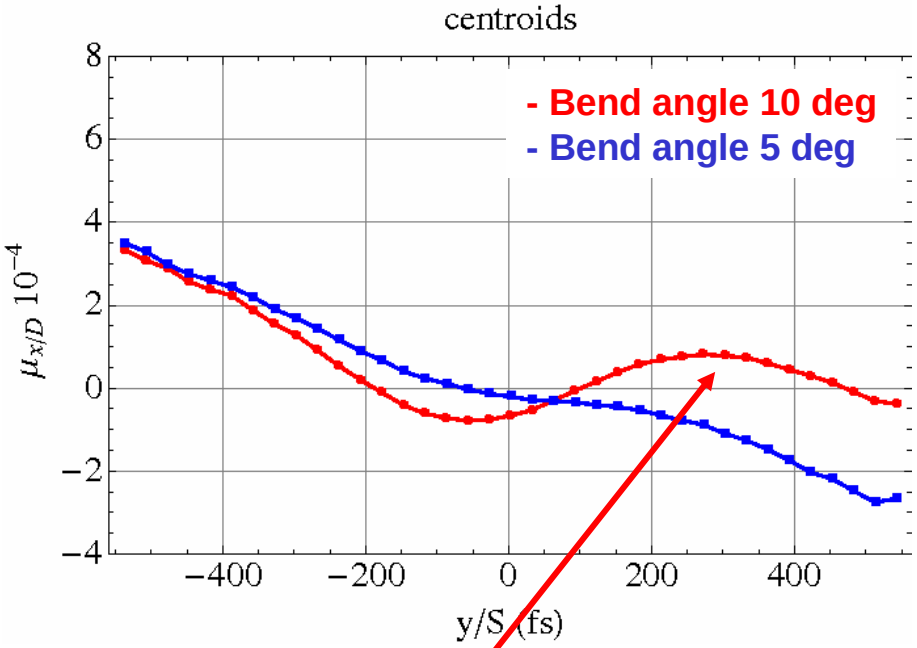


CSR effects

Longitudinal Phase Space at position of OTR screen in energy spectrometer



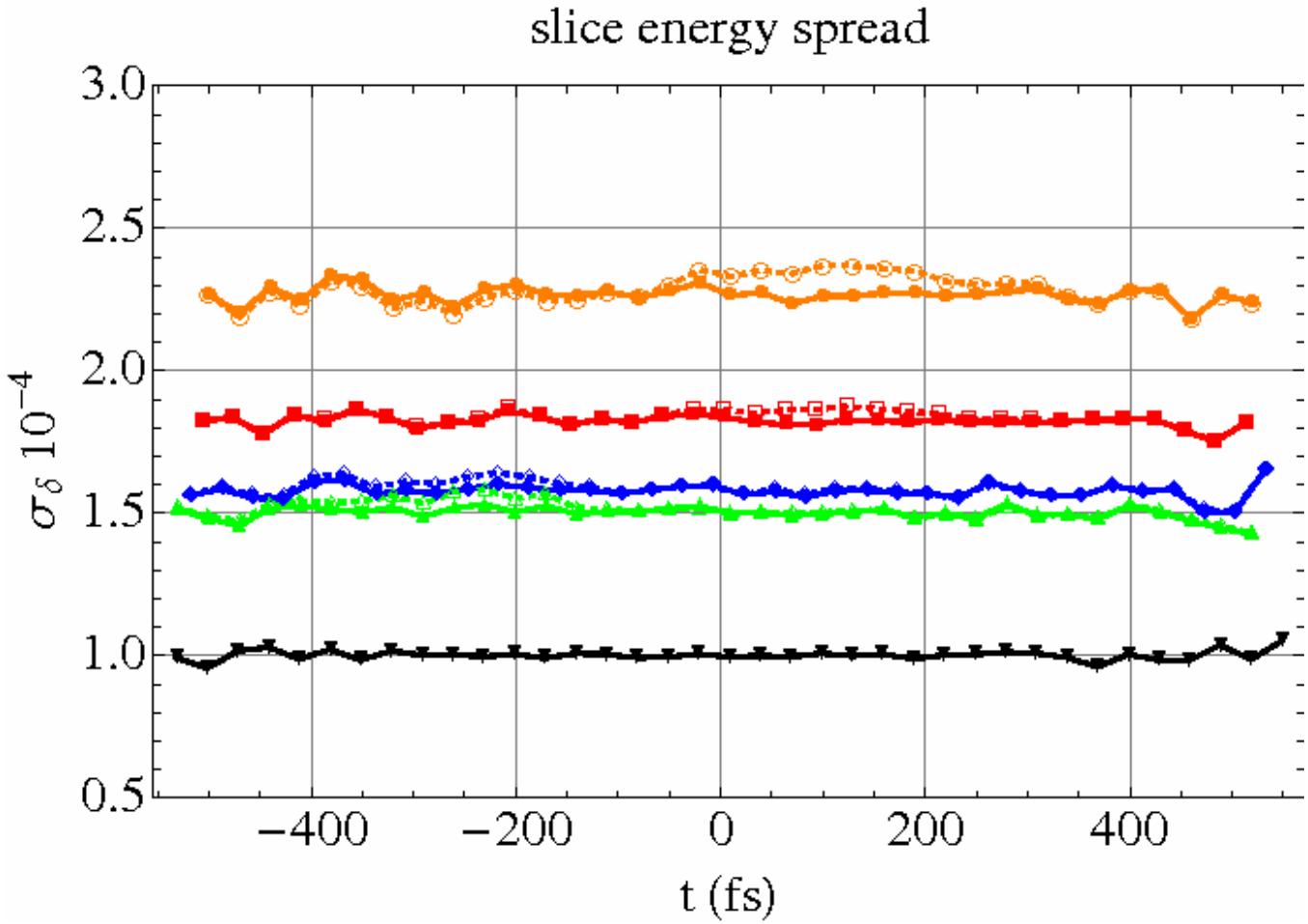
Simulation of measurement at position of OTR screen in energy spectrometer



Correlated energy chirp induced by LOLA partly compensated by CSR

No big difference between 5 and 10 deg bend angle in terms of BD
→ 10 deg option gives technical advantages

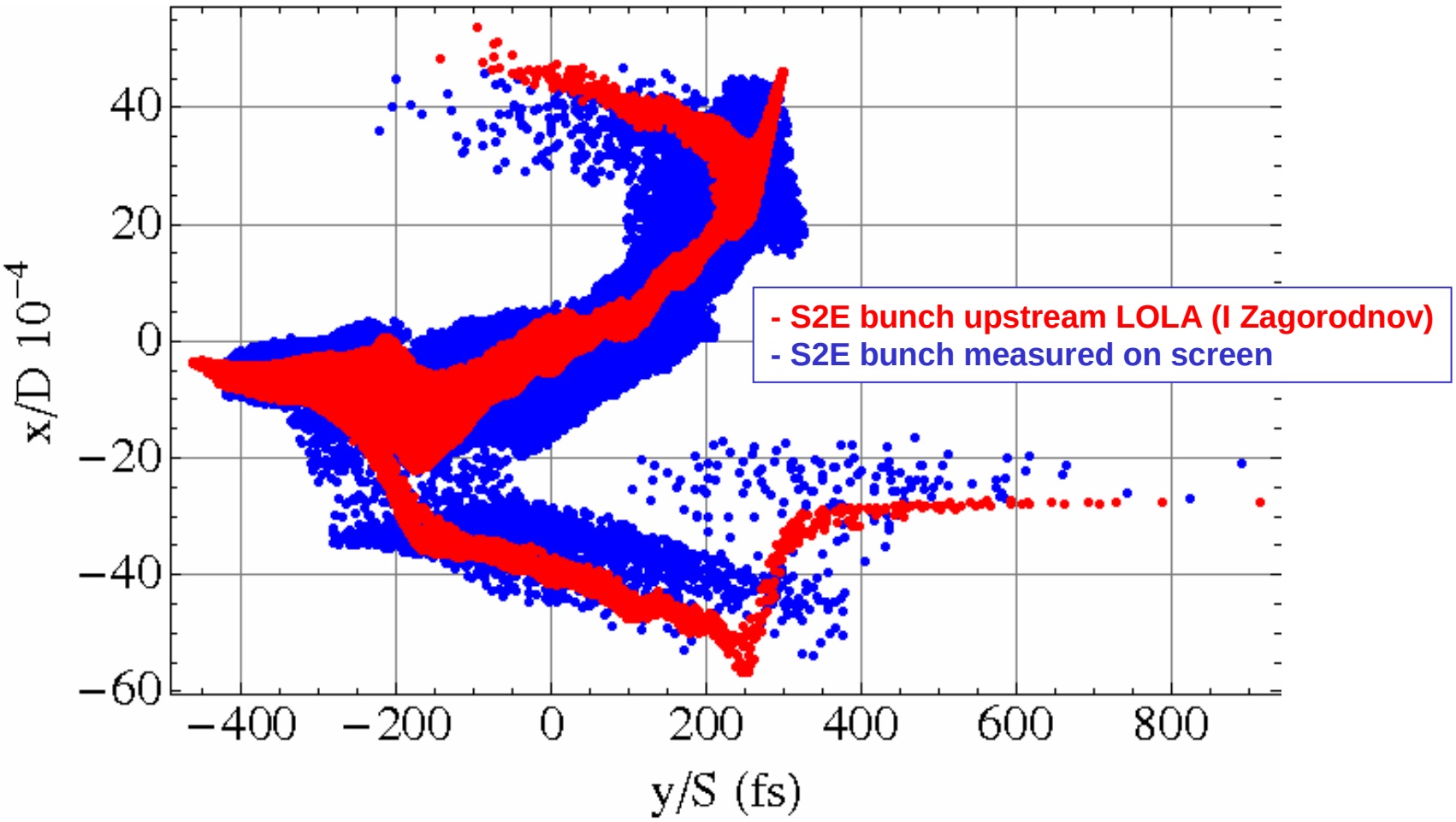
CSR effects



Slice energy spread induced by CSR negligible compared to energy spread induced by LOLA!

S2E Bunch

Simulation of longitudinal phase space measurement



Conclusion: Future

- Current layout of new LOLA section (MATCH) allows for online bunch profile measurements. Layout is being integrated and optics is checked for compatibility with SASE operation.

- Technical design has started (check for collisions, space for pumps and bellows, design of dipole chamber, …)

- Measurements are being simulated with S2E bunches.