

Beam Dynamics Experiments and Analysis in FLASH on CSR and Space Charge Effects

Bolko Beutner, Martin Dohlus, and Michael Röhrs

DESY Hamburg

- Introduction
- FLASH start-to-end simulations (M. Dohlus)
 - Methods
 - Simulation results
- Experiments on CSR effects at FLASH
 - Experimental outline
 - Comparison with simulations
- Conclusion

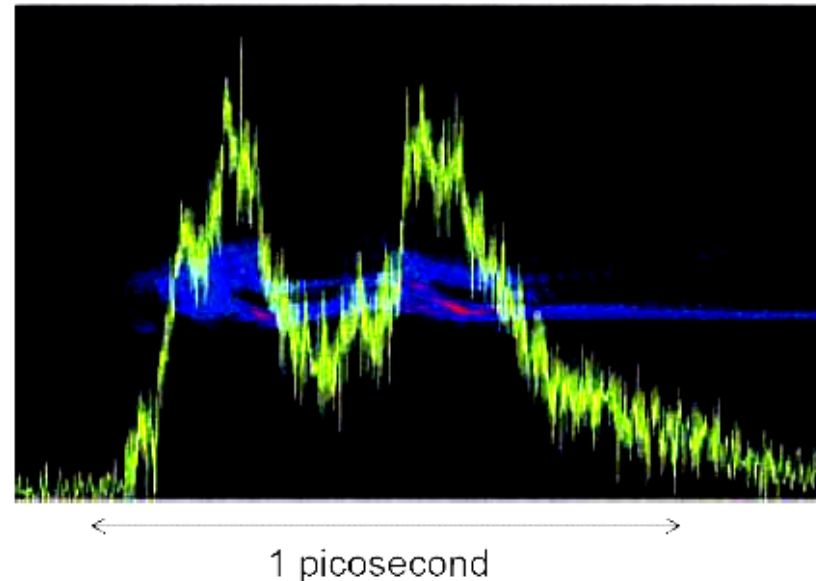
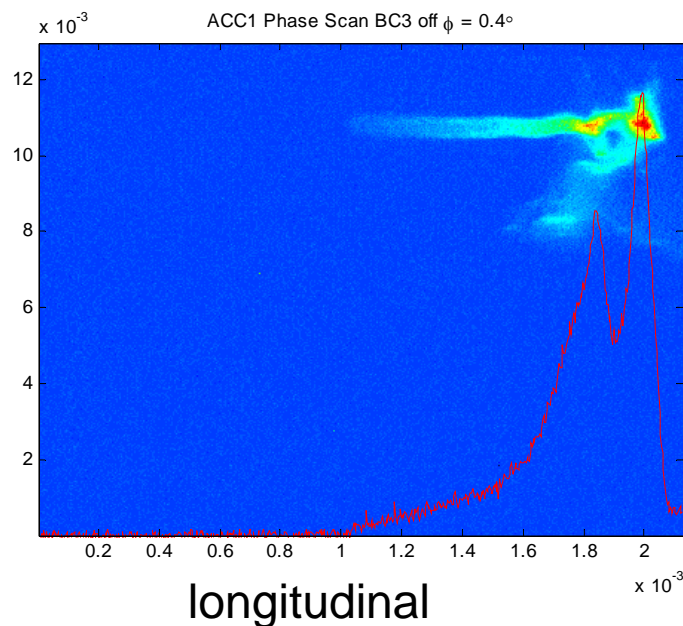
Introduction

Self interactions and collective phenomena like space charge forces and coherent synchrotron radiation are important factors in the beam dynamics of electron linacs.

At FLASH a transverse deflecting RF-structure is used to investigate beam properties in the longitudinal horizontal plane.

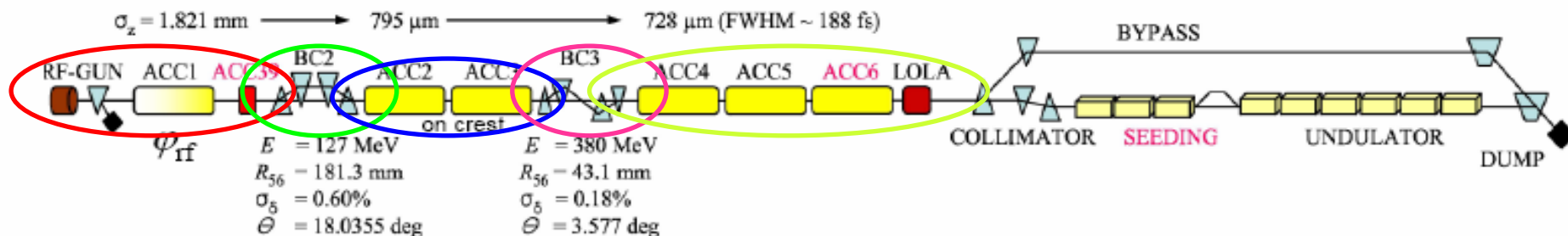
Double spikes and complicated transverse structures are observed.

Tracking calculations are used to understand the data.

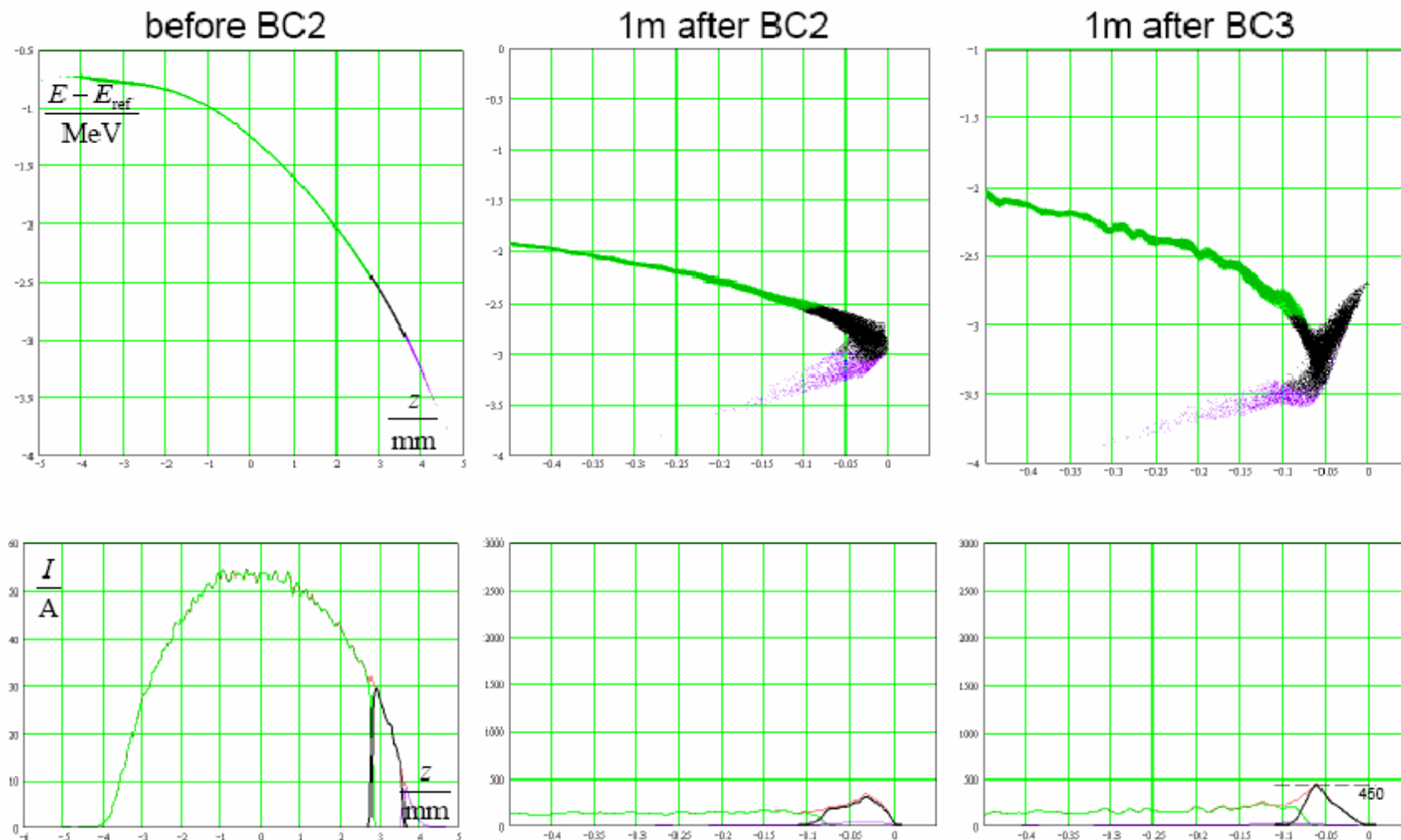


- • RF-gun – **ASTRA**
- • Apply wake field kicks of ACC1 & Optics matching
- • BC2 - **CSRTrack** (projected method)
- • BC2 to BC3 - **ASTRA**
- • Apply wake field kicks of ACC2&3
- • BC3 – **CSRTrack** (projected method)
- • BC3 to LOLA - **ASTRA**

Start-to-end tracking for different phases in ACC1



Simulation Results I - 7deg



ACC1 phase 7deg off crest

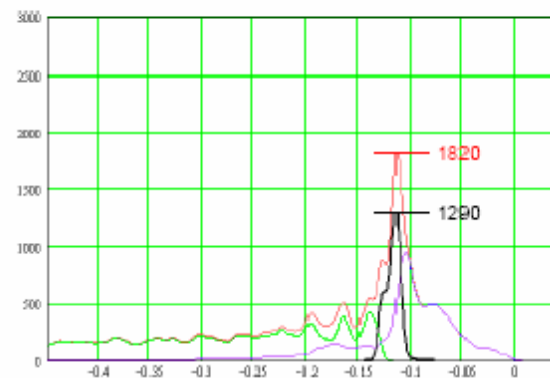
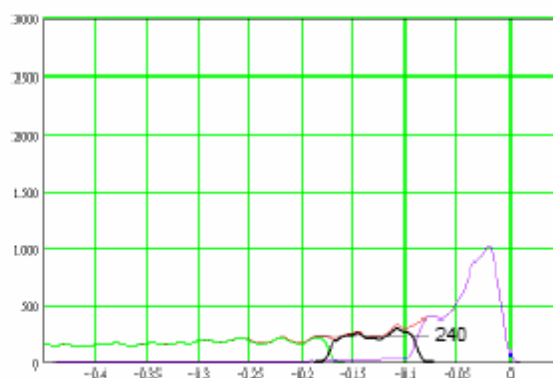
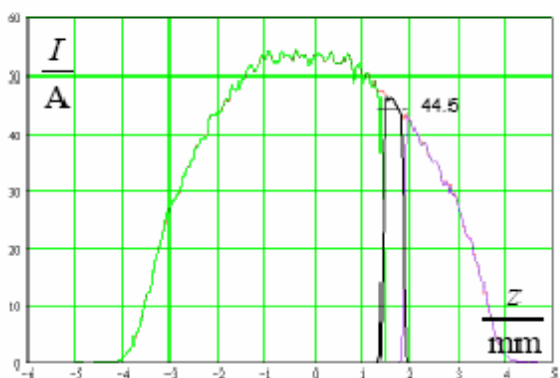
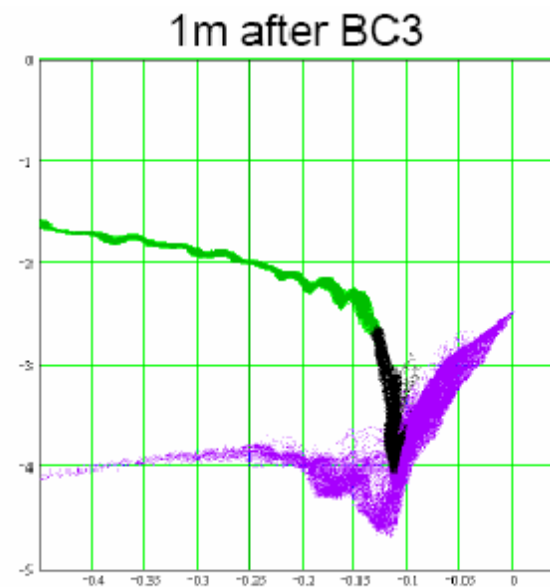
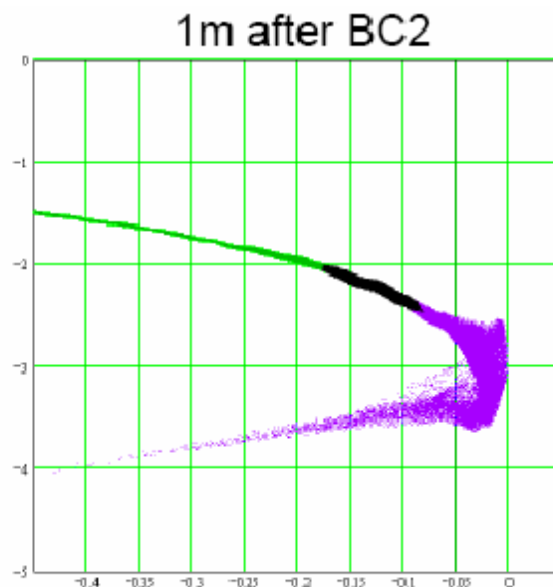
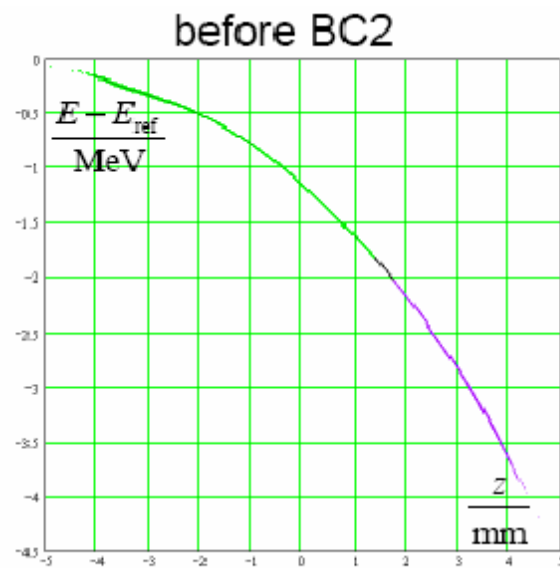
optics version 1

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Simulation Results II - 9deg



ACC1 phase 9deg off crest

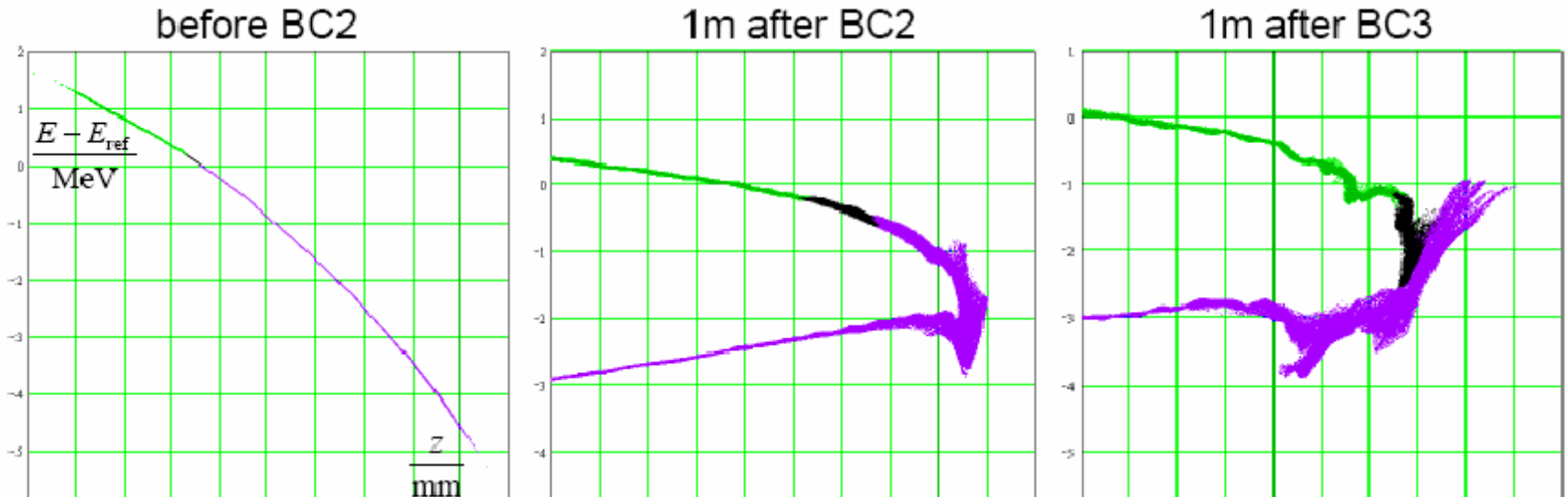
optics version 1

Martin Dohlus

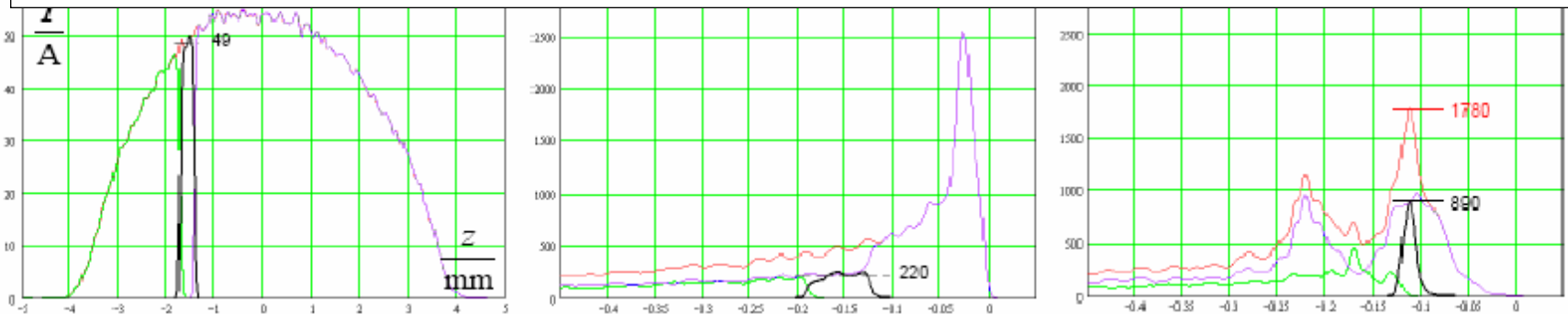
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Simulation Results III - 14deg



Due to CSR forces a second compression slope in the longitudinal phase space is generated in BC2 and then further compressed in BC3.

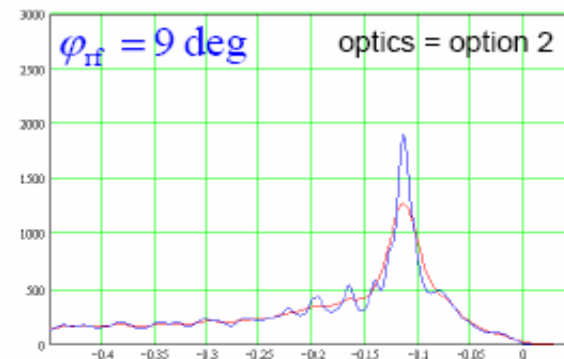
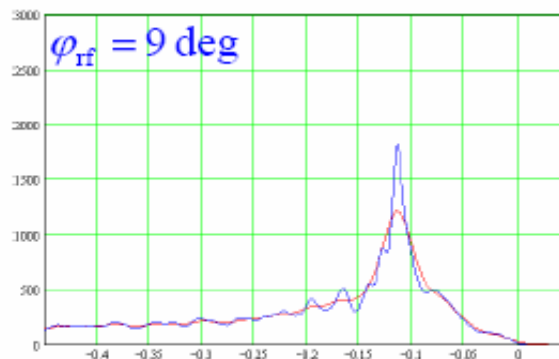


ACC1 phase 14deg off crest

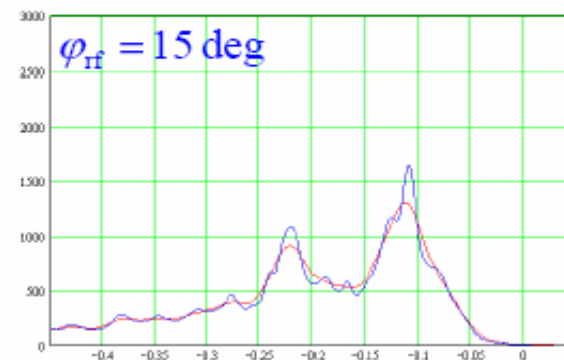
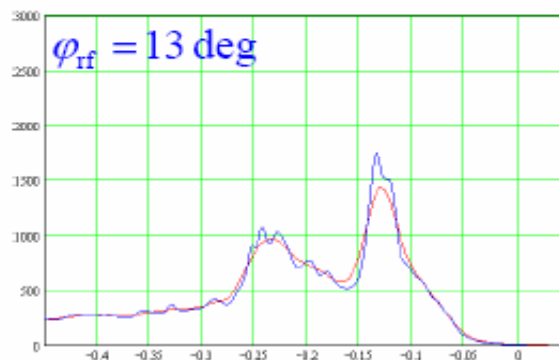
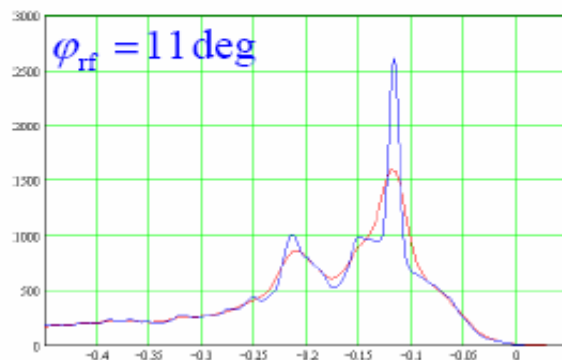
optics version 1

Martin Dohlus

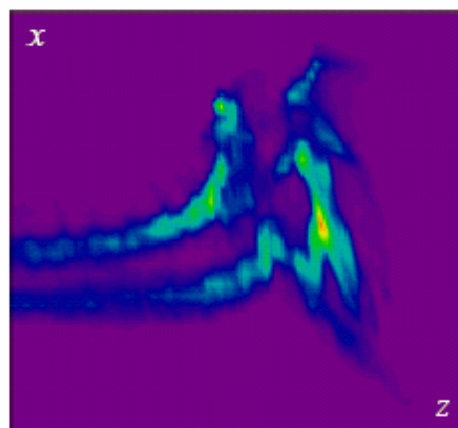
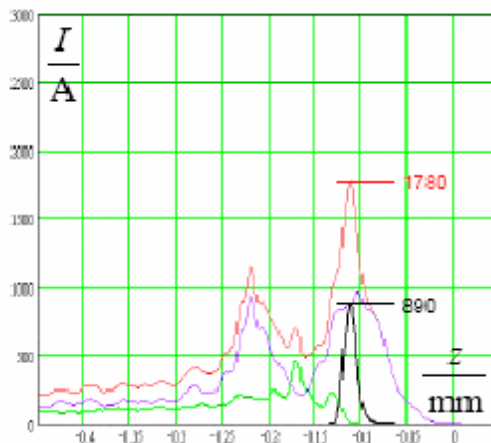
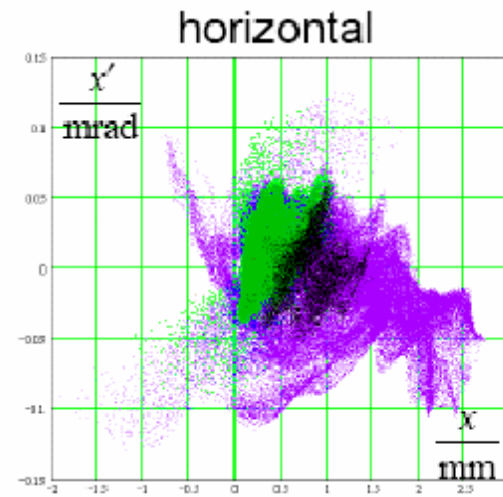
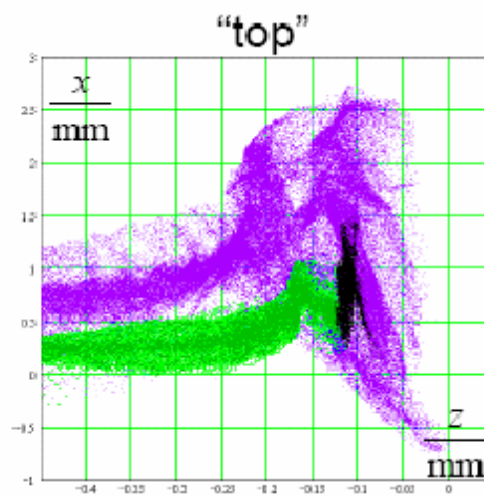
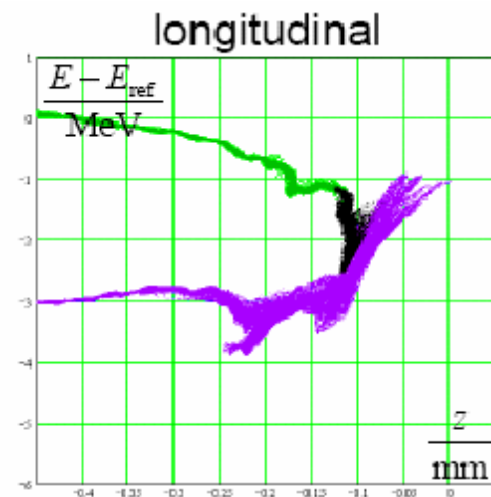
Simulation Results IV



The simulations reproduce the observed double spike structure.



Simulation Results V - 14deg



all particles:
emittance/um = 13.8
rms-length/um = 326
rms-energy spread/keV = 1230

"black" particles:
emittance/um = 3.6
rms-length/um = 6.6
rms-energy spread/keV = 345

ACC1 phase 14deg off crest

optics version 1

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Experiments on CSR effects at FLASH

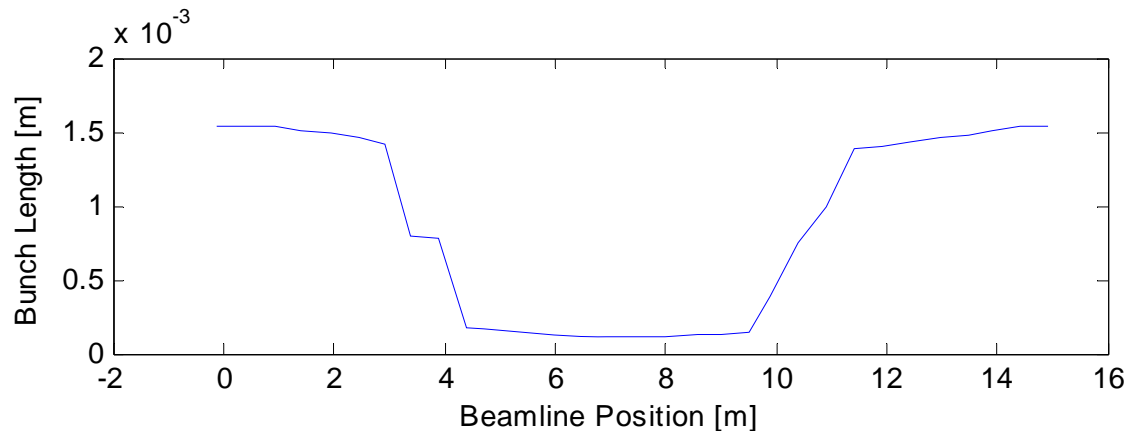


To analyse the effects of CSR on the beam, it is required to disentangle the contributions from CSR and space charge effects.

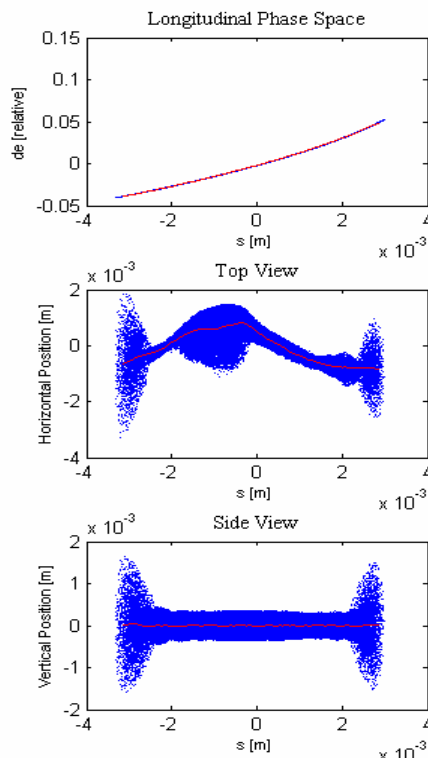
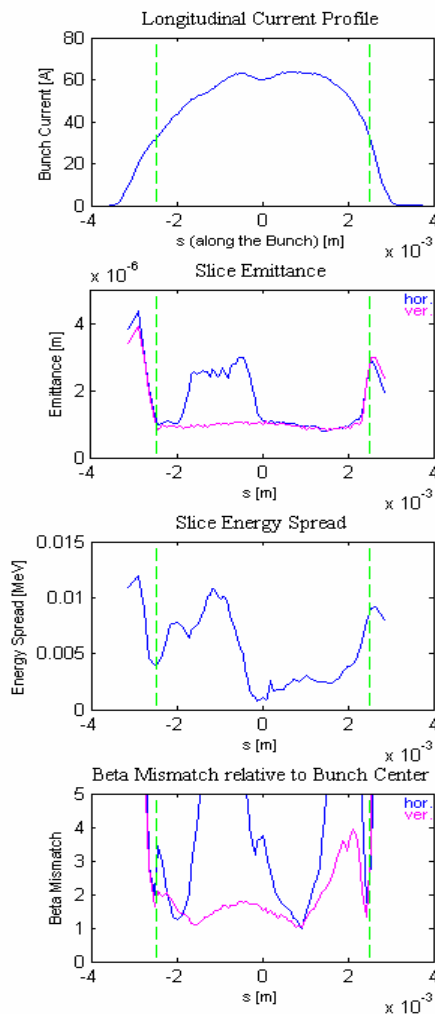
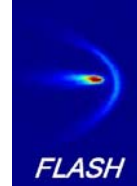
Our approach is to over-compress the beam. In this case we have a long beam downstream of the bunch compressor.

=> low space charge forces in the drifts

Example : BC3 at FLASH ACC1 on crest ACC2&3 40 deg off crest



Experiments on CSR effects at FLASH - Simulations



Number of Particles: 100001 Charge: 1 nC
 Position: 15.09 m Beam Energy: 318.17 MeV

FWHM (distance between green bars): $4.99 \times 10^{-3} \mu\text{m}$ (16.6 ps)
 Charge within FWHM: 92.3 %
 Projected Emittance: $y_x = 7.43 \times 10^{-6} \text{ m}$ $y_y = 2.04 \times 10^{-6} \text{ m}$
 Optics @ l_{peak} : $\alpha_x = -1.1$ $\beta_x = 6.27 \text{ m}$ $\alpha_y = -2.24$ $\beta_y = 18.9 \text{ m}$

RMS Values for all Particles:

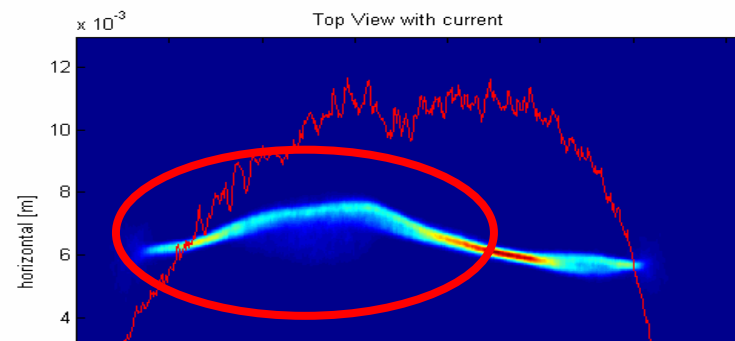
$x = 6.29 \times 10^{-4} \text{ m}$	$x' = 7.49 \times 10^{-5}$
$y = 2.19 \times 10^{-4} \text{ m}$	$y' = 2.39 \times 10^{-5}$
$s = 1.50 \times 10^{-3} \text{ m}$	$\delta = 2.15 \times 10^{-2}$

RMS Values within FWHM:

$x = 6.09 \times 10^{-4} \text{ m}$	$x' = 7.24 \times 10^{-5}$
$y = 1.76 \times 10^{-4} \text{ m}$	$y' = 2.39 \times 10^{-5}$
$s = 1.35 \times 10^{-3} \text{ m}$	$\delta = 1.94 \times 10^{-2}$

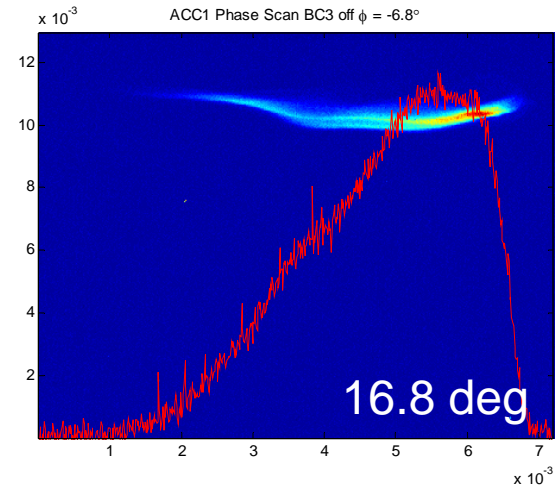
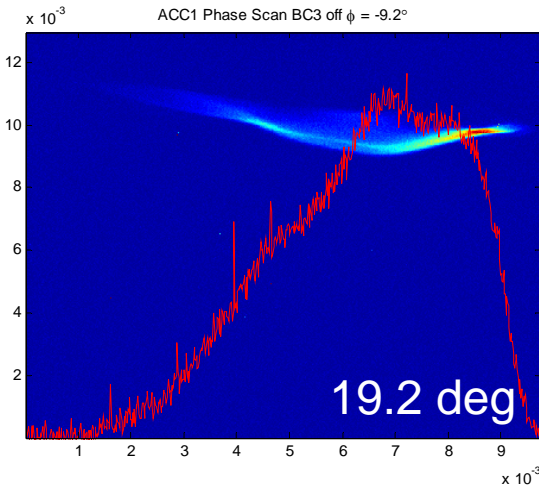
Beam is only compressed in BC3 by keeping ACC1 on crest. The compression chirp is induced by ACC2&3 (40deg off crest).

The bunch length is then the same as before – the beam is longitudinal flipped.

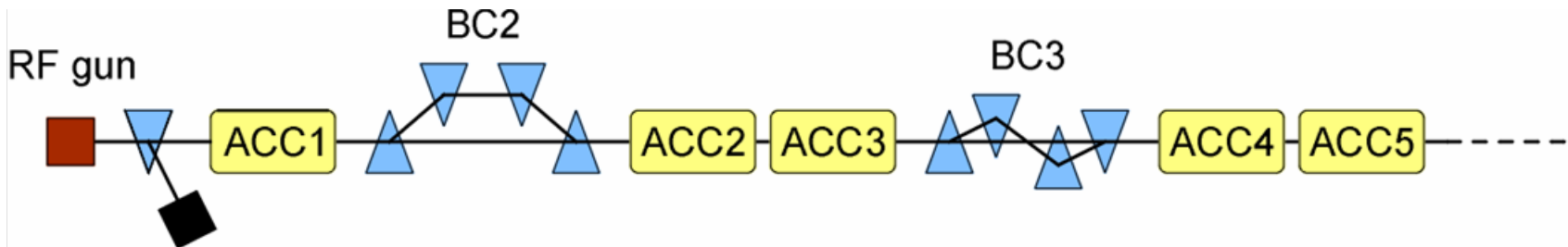


The centroid of the beam is shifted as a result of CSR interaction

Experiments on CSR effects at FLASH - April 2006

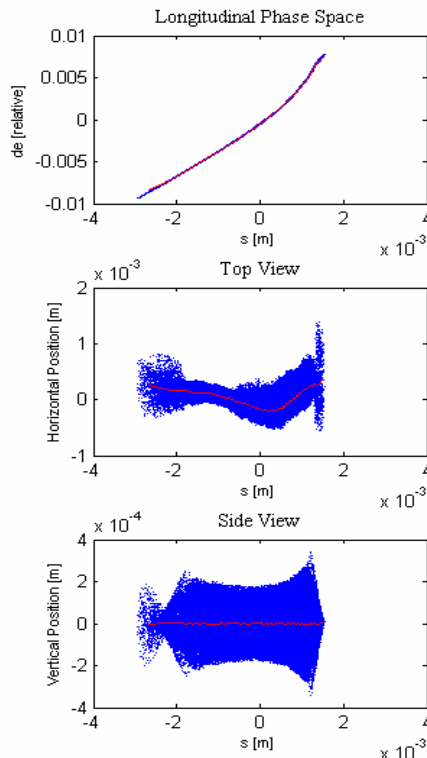
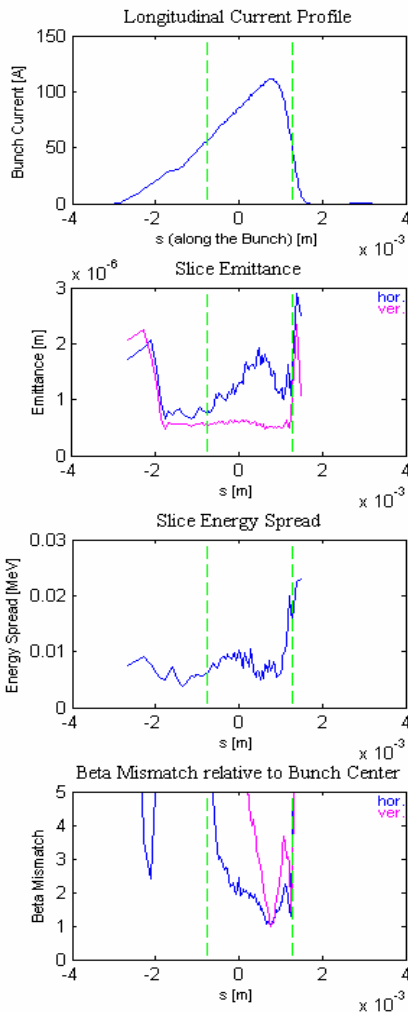


Experiments at FLASH show centroid shifts in over-compression scenarios.



ACC1 Phase is varied while the other modules are kept on crest.
Compression takes place in BC2 and BC3.

Experiments on CSR effects at FLASH - Simulations



Number of Particles: 99999 Charge: 0.8 nC
 Position: 0 m Beam Energy: 374.18 MeV
 FWHM (distance between green bars): $2.02 \times 10^{-3} \mu\text{m}$ (6.74 ps)
 Charge within FWHM: 75.3 %
 Projected Emittance: $\gamma_x = 3.25 \times 10^{-6} \text{ m}$ $\gamma_y = 1.8 \times 10^{-6} \text{ m}$
 Optics @ l_{peak} : $\alpha_x = 15$ $\beta_x = 21.7 \text{ m}$ $\alpha_y = 7.86$ $\beta_y = 16.5 \text{ m}$

RMS Values for all Particles:

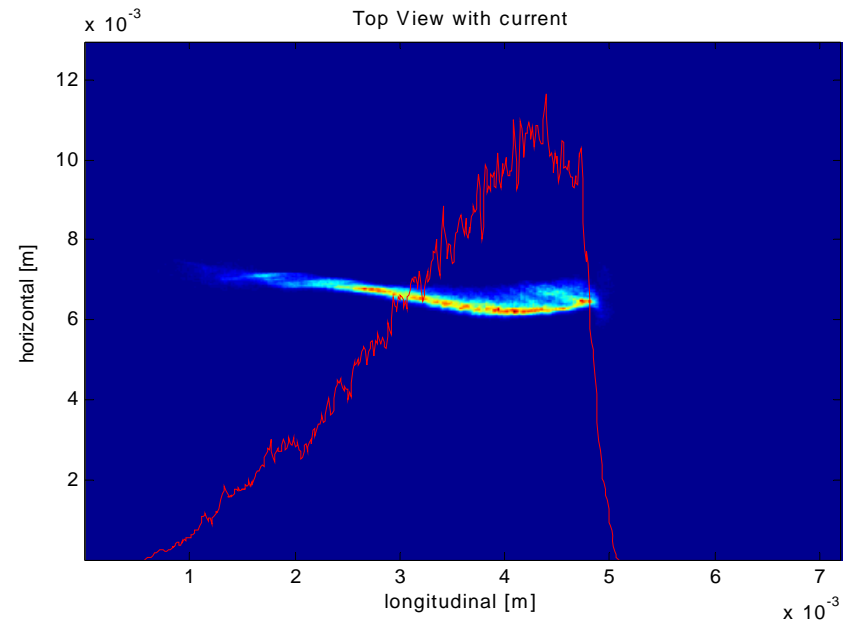
$x = 2.21 \times 10^{-4} \text{ m}$	$x' = 1.47 \times 10^{-4}$
$y = 9.82 \times 10^{-5} \text{ m}$	$y' = 6.41 \times 10^{-5}$
$s = 9.44 \times 10^{-4} \text{ m}$	$\delta = 3.59 \times 10^{-3}$

RMS Values within FWHM:

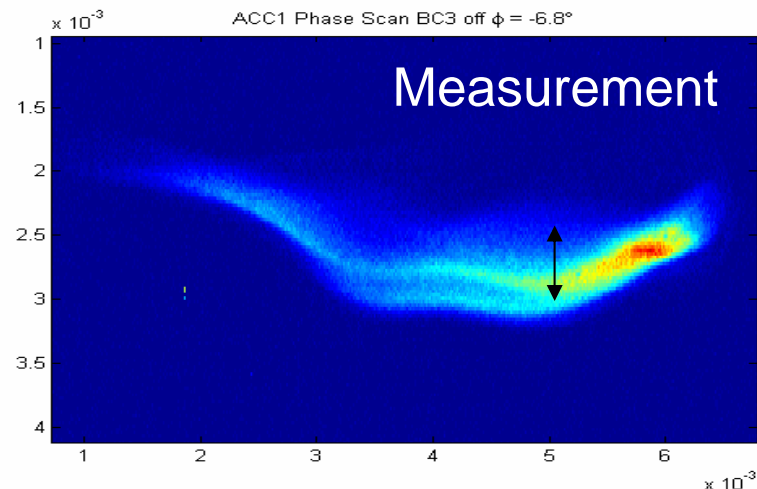
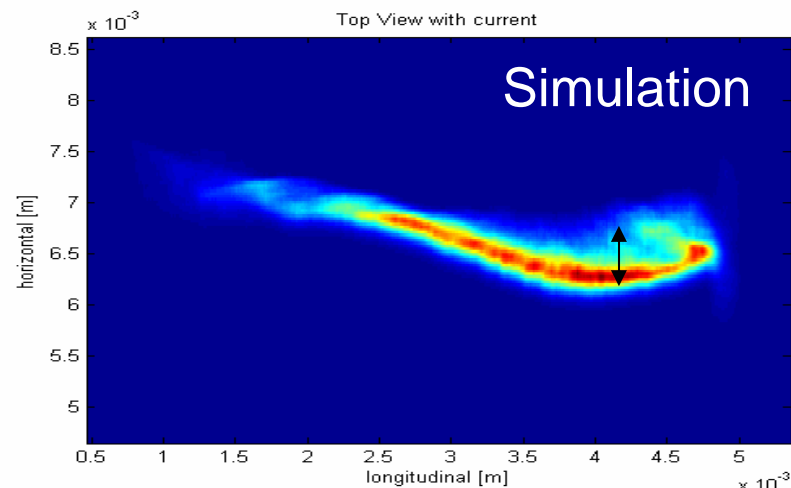
$x = 2.16 \times 10^{-4} \text{ m}$	$x' = 1.42 \times 10^{-4}$
$y = 9.88 \times 10^{-5} \text{ m}$	$y' = 5.42 \times 10^{-5}$
$s = 5.50 \times 10^{-4} \text{ m}$	$\delta = 2.34 \times 10^{-3}$

Simulation with actual machine parameters

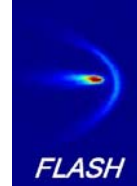
Twiss parameters at 4DBC2 are matched to measured data.



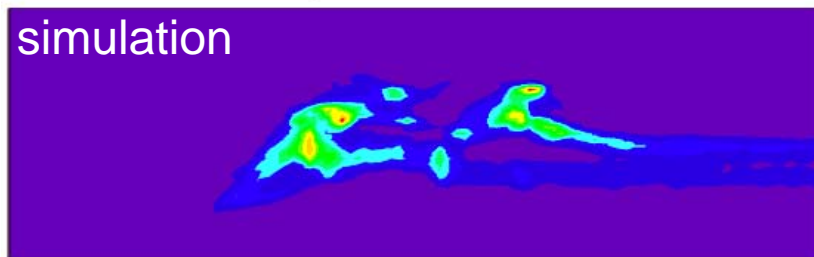
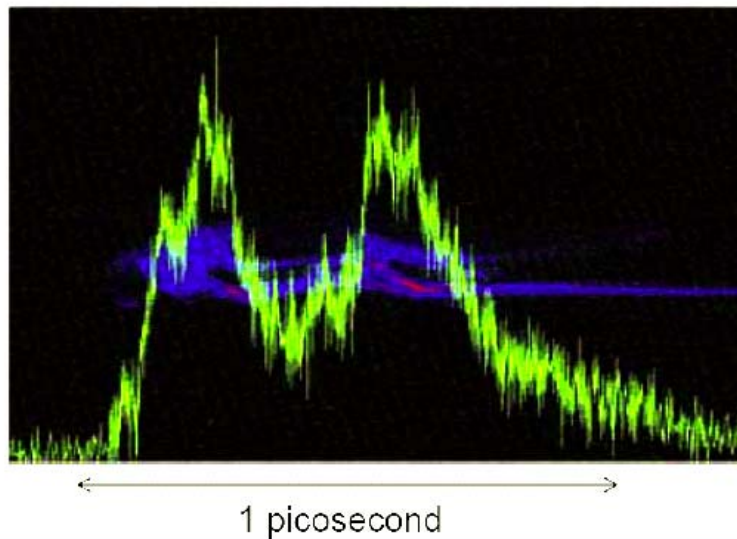
- Qualitative agreement
- Sag near the head is in both cases about 0.5mm
- Optics and dispersion in the machine were not measured
- Disagreements in bunch length



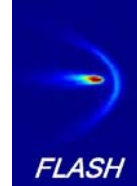
Conclusion I



- The observed double peak structure of the FLASH beam is understood by simulations.
- Qualitative agreement between simulated and measured transverse profiles



Conclusion II



- Experiments on CSR effects were planned and prepared with simulations
- Measurements were done at FLASH
- Qualitative agreement of CSR induced centroid shifts with simulations
- Next steps:
 - Further Analysis of data and simulations
 - Measurements in both bunch compressors individually
 - Impact of optics in the bunch compressors on CSR effects should be studied by experiments and simulations

Thank you!

ACC1 Phase Scan

