Velocity Bunching Studies at FLASH

Bolko Beutner, DESY

XFEL Beam Dynamics Meeting 15.10.2007

Contents

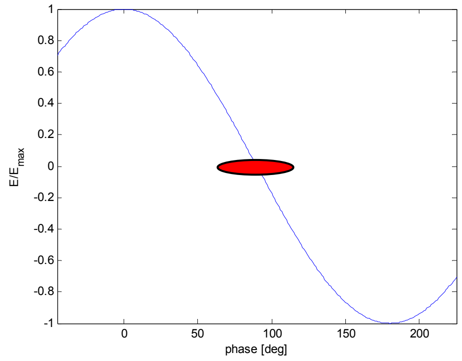
- Introduction
- ASTRA Simualtions
- ACC1 Phase Manipulations
- Experiments at FLASH
  - Indirect Measurements
  - Compression Monitor
  - Streak Camera Measurements
  - Emittance
  - LOLA
- Summary and Outlook

Introduction

At low beam energies ~5 MeV electron velocities are not independent of the particle energy

⇒ correlated energy spread ⇔ velocity spread

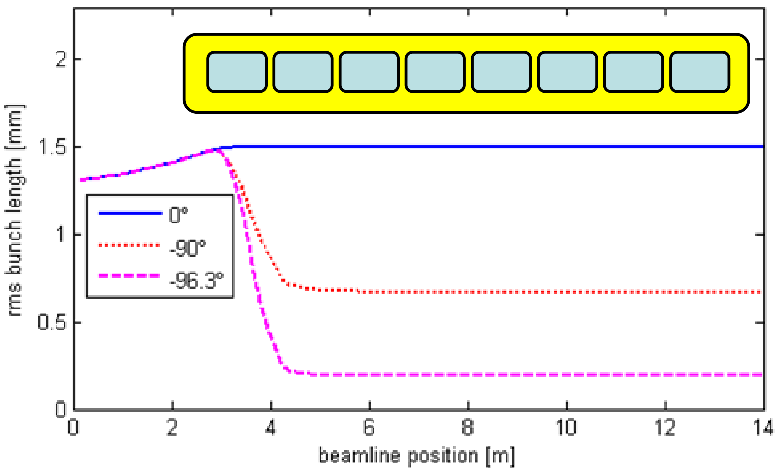
⇒ bunch compression without chicanes



First cavity of ACC1 is operated at the zero crossing (-90deg off-crest)

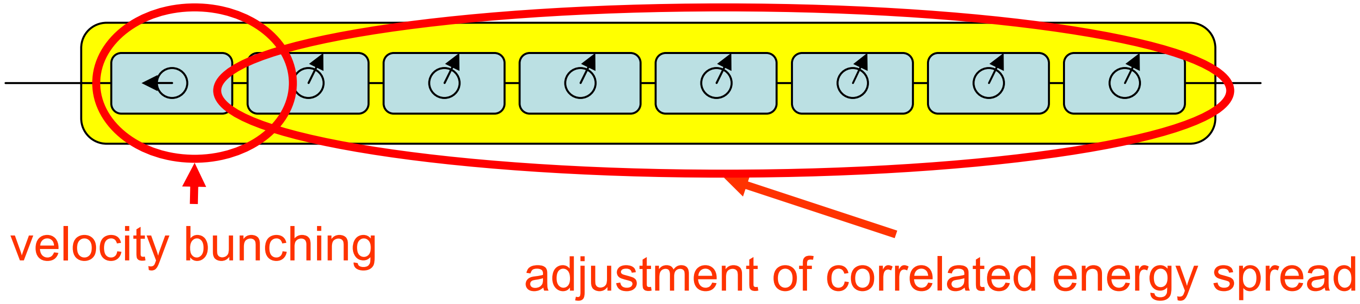
⇒ linear correlated energy spread

Bunching stops in the second cavity since the energy increases and relativistic velocities are reached.



Introduction

The last cavities in the module can be used to adjust the correlated energy spread.

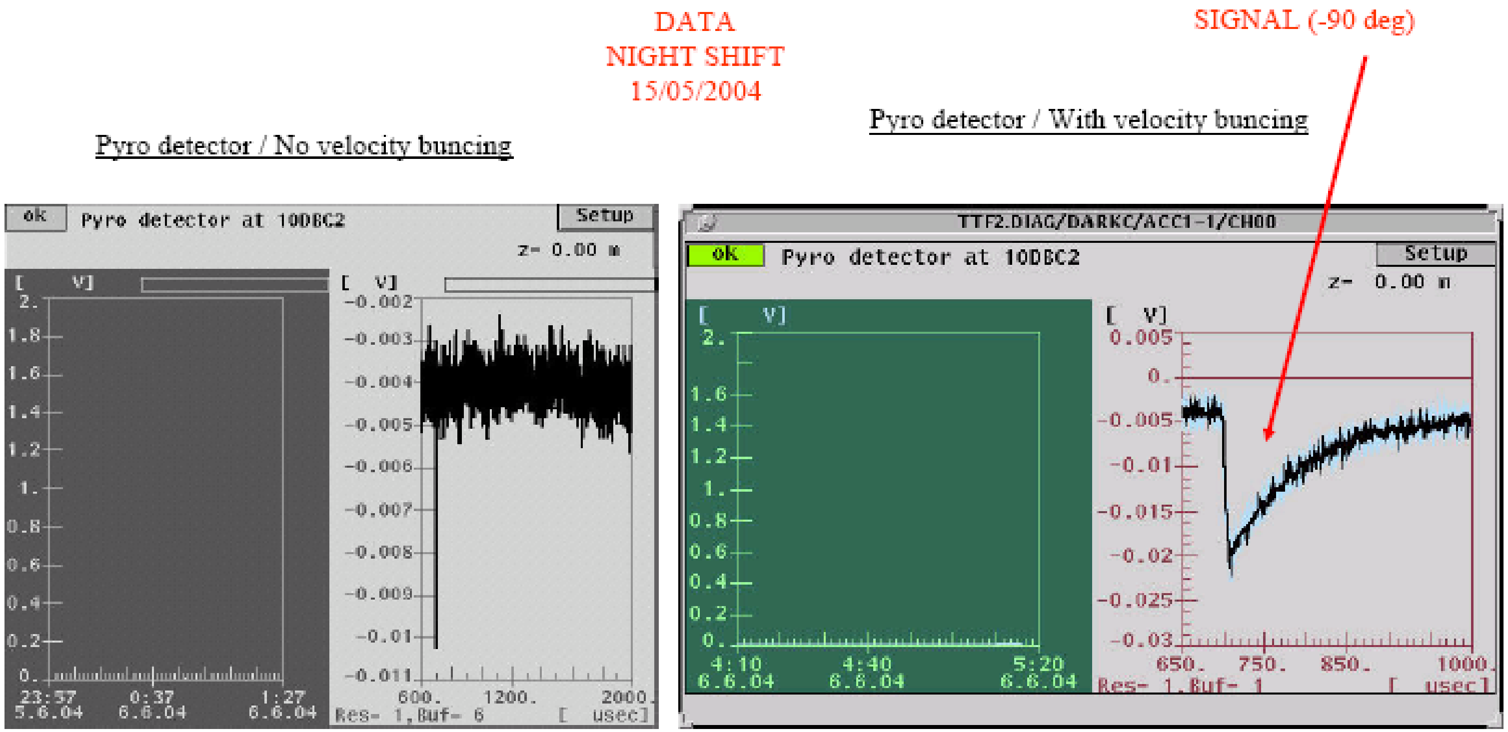


Velocity bunching is an additional “knob” to optimise the bunch compression system.

Studies on microbunch instabilities are possible with additional compression.

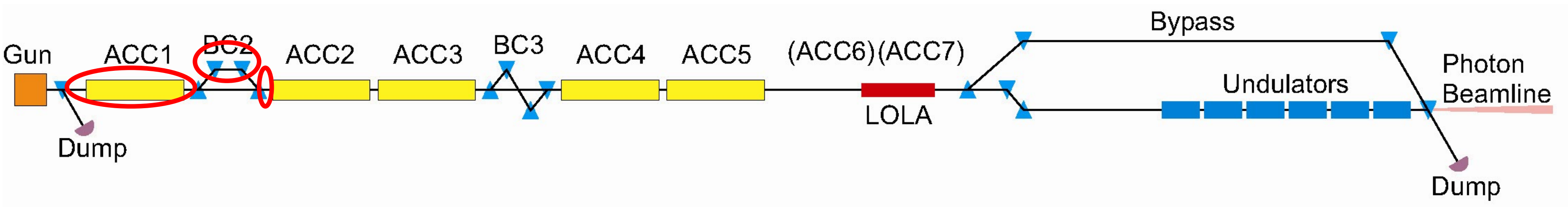
Introduction

J.P. Carniero (2004) : First experiments at FLASH



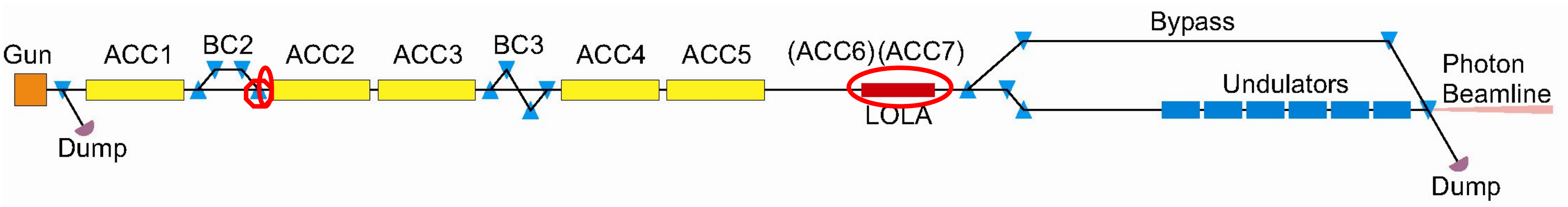
Experiments at FLASH

- Reduction of the energy gain of ACC1
- Modifications of the ACC1.C1 phase offset relative to the phase offset of the whole module ACC1.C1-C8 (up to about 100deg)
- Indirect measurements of compression using the energy spread in BC2 with ACC1.C2-C8 off-crest
- Pyro detector compression measurements ot the DBC2 diffraction radiator or TOSYLAB



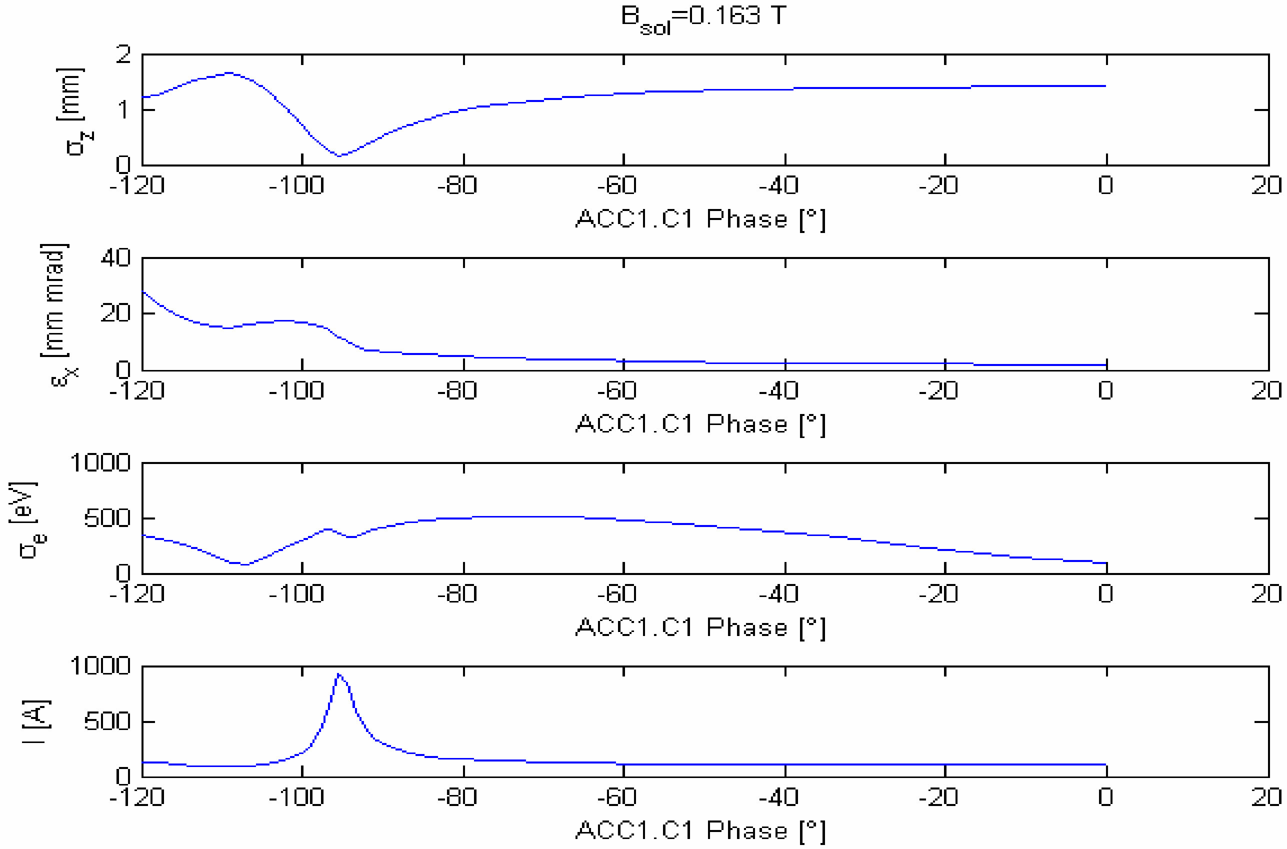
Experiments at FLASH

- Measurements of bunch length vs. ACC1.C1 phase with the streak camera at TOSYLAB using synchrotron radiation from BC2
- Measurements of the emittance in DBC2 FODO section
- Bunch length measurements at LOLA
- CSR microbunch instability studies



ASTRA Simulations

ASTRA simulations based on J.P. Carnieros files (q=0.5nC; 10k particles)



ASTRA Simulations

- New Gun (thanks to Jang-Hui Han)

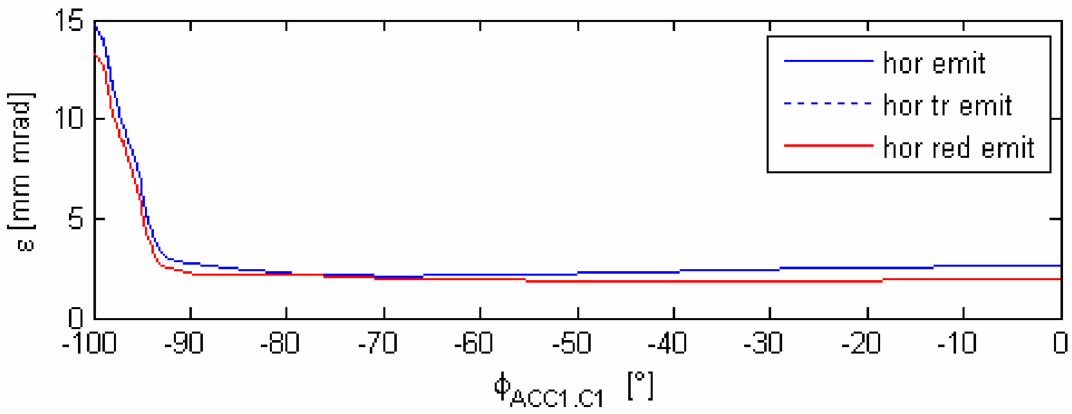
  -10k particles, Nrad=24, Nlong=64

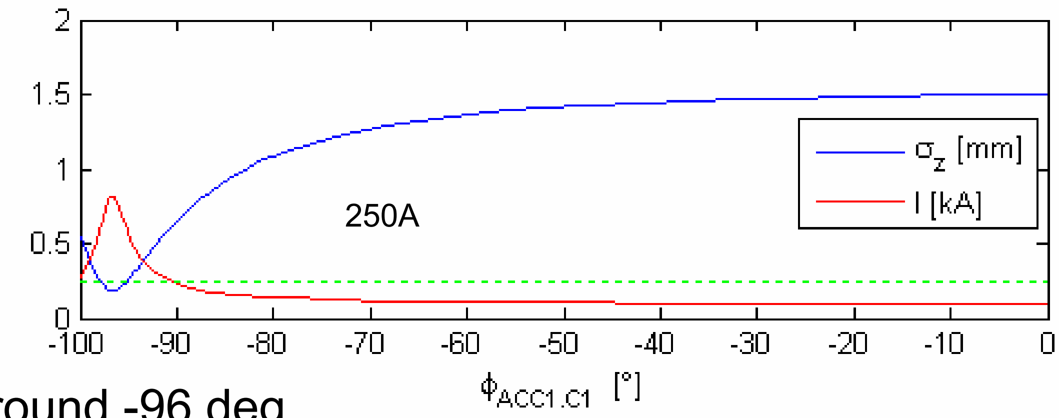
Emittance optimsed with
Solenoid field of B=0.165T

Q=0.5nC

initial bunch length = 1.5mm

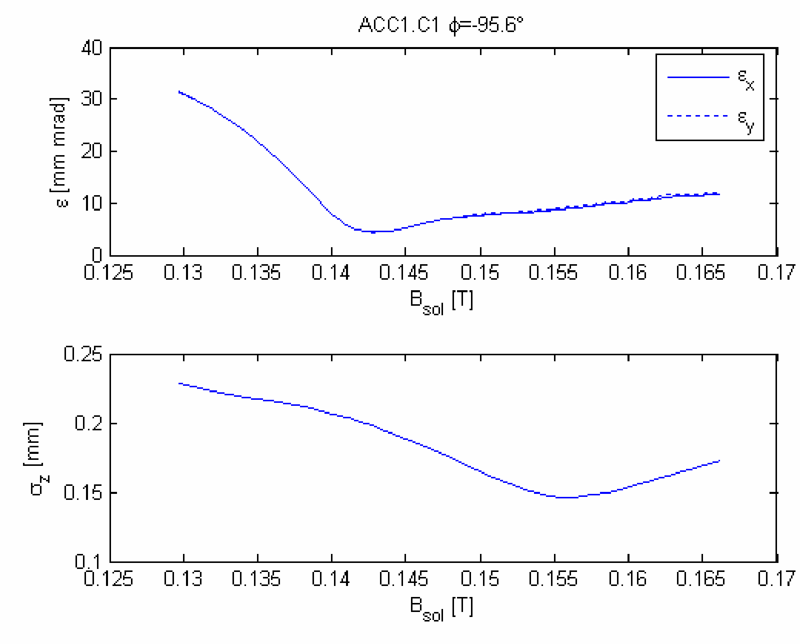
ACC1.C1 Phase [deg]	Bunch length [mm]	emmit. [mm mrad]
-80.0	1.087	2.14
-90.4	0.622	2.29
-96.3	0.183	8.04

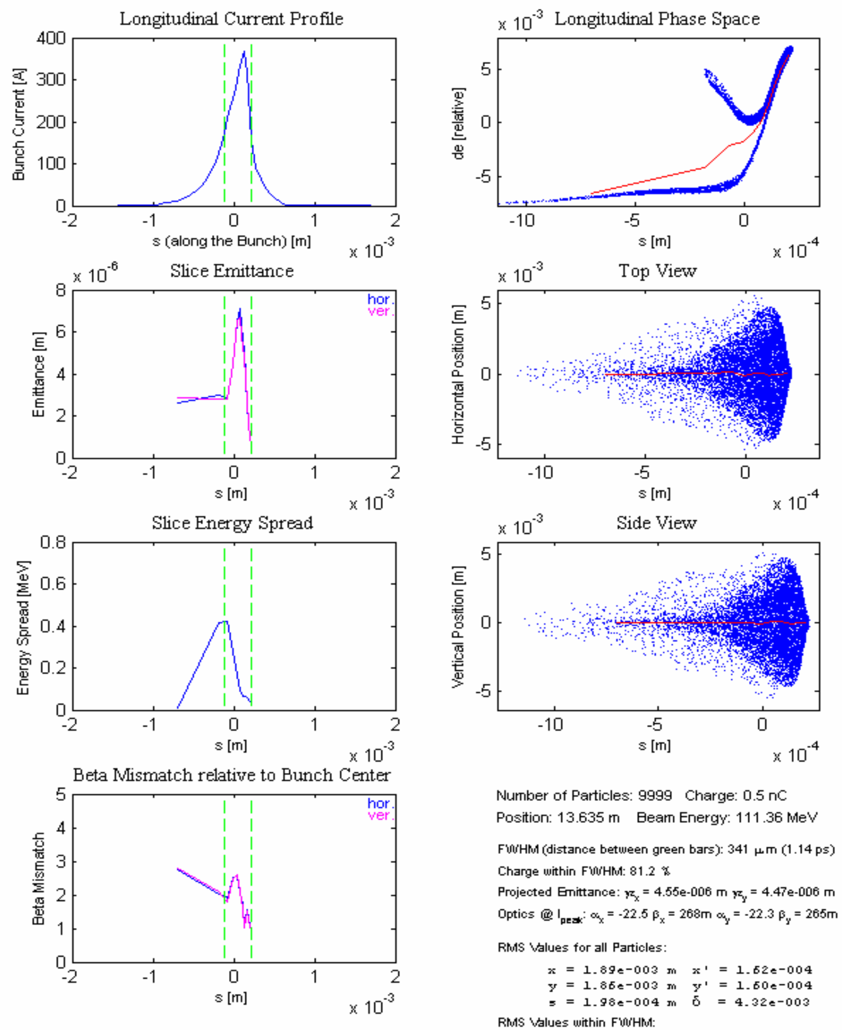




Minimum bunch length expected around -96 deg

ASTRA Simulations





Number of Particles: 9999 Charge: 0.5 nC
Position: 13.635 m Beam Energy: 111.36 MeV

FWHM (distance between green bars): 341 μm (1.14 ps)
Charge within FWHM: 81.2 %
Projected Emittance: $\gamma\varepsilon_x$ = 4.55e-006 m $\gamma\varepsilon_y$ = 4.47e-006 m
Optics @ I_{peak}: α_x = -22.5 β_x = 268m α_y = -22.3 β_y = 265m

RMS Values for all Particles:
x = 1.89e-003 m x' = 1.62e-004
y = 1.86e-003 m y' = 1.60e-004
z = 1.98e-004 m δ = 4.32e-003

RMS Values within FWHM:
x = 2.01e-003 m x' = 1.73e-004
y = 1.98e-003 m y' = 1.71e-004
z = 8.69e-005 m δ = 3.48e-003

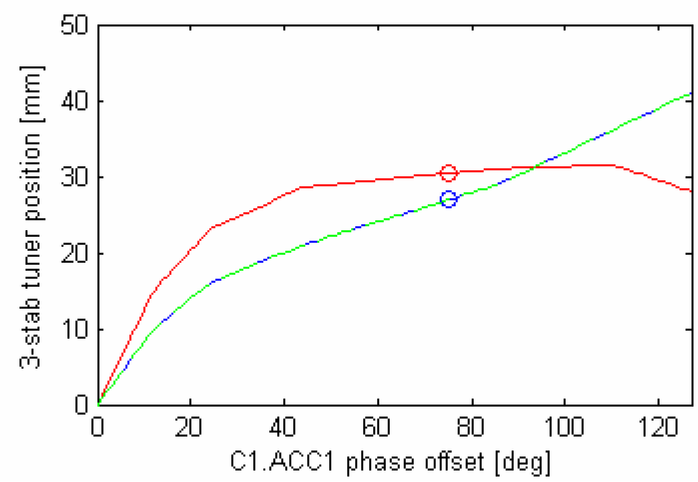
At full compression emittance after solenoid optimisation is 4.5mm mrad after ACC1.

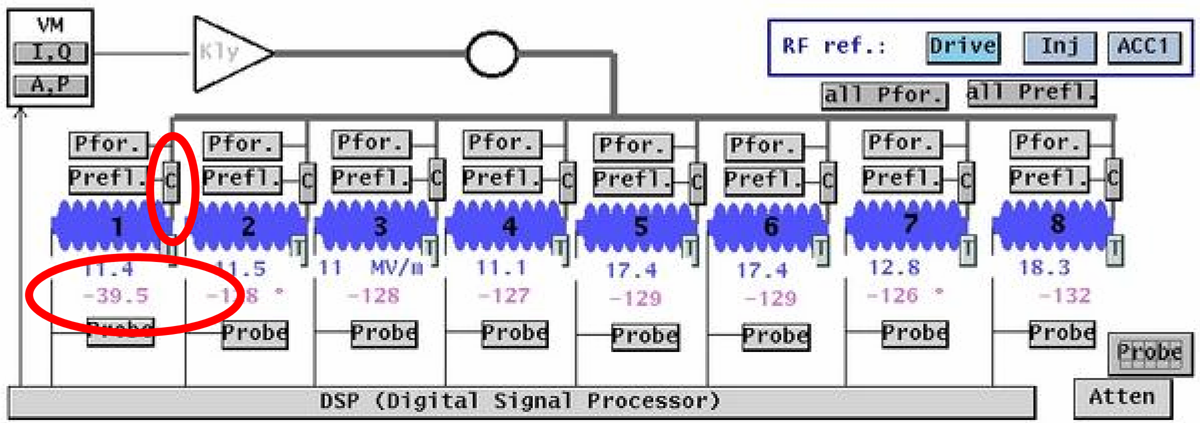
Nonlinear compression

longitudinal Space Charge forces

ACC1 Phase Manipulations

- 3-Stab waveguide tuners are used to shift phase offsets of single cavitites
- Tuner positions are taken from pre-measured curves
- Q of the cavities are kept within reasonable limits by tuning of the middle stab position
- Final phase offsets differ slightly from the intended ones but are measured with the RF probes

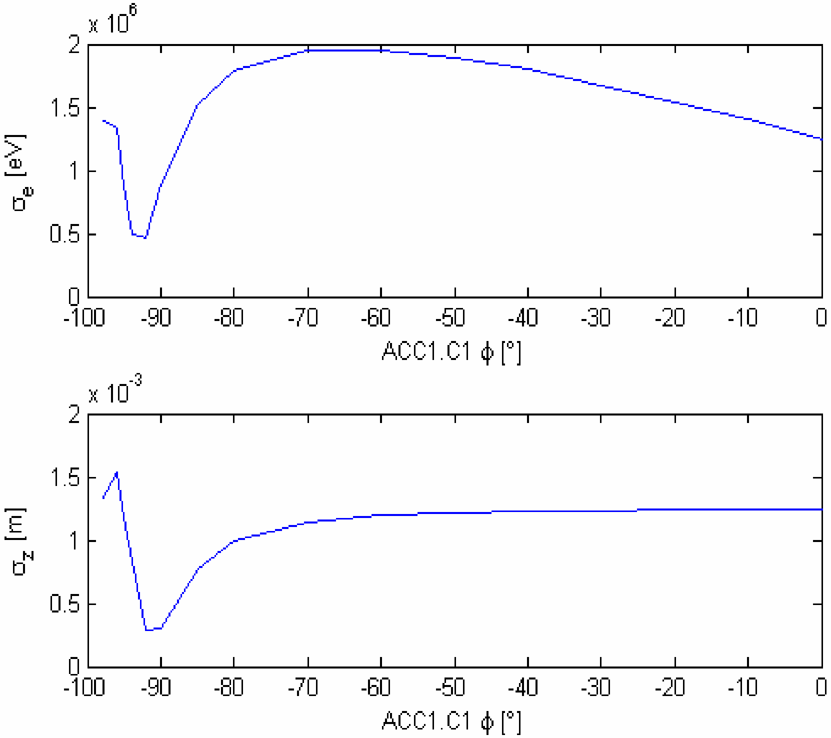




Indirect Measurements of Velocity Bunching

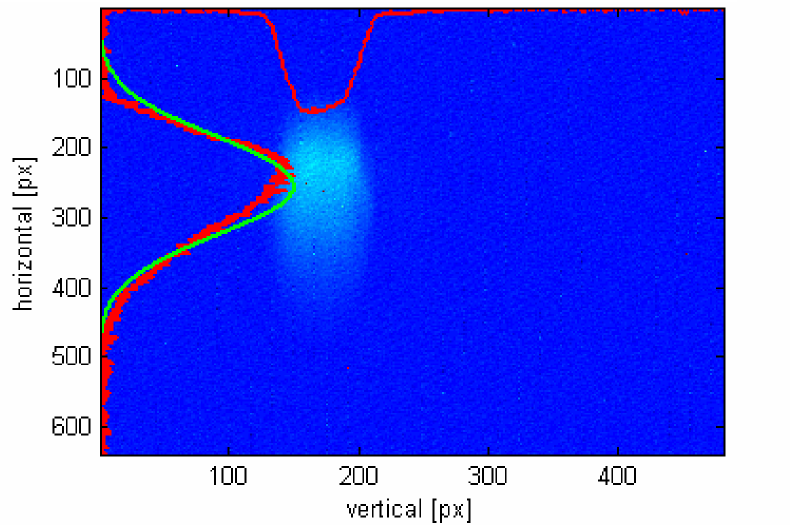
- The cavities C2-C8.ACC1 are set off-crest to map the bunch length to the correlated energy spread.
- Energy spread measurements on the screen (3BC2) in a dispersive section gives indirect data on bunch length.
- A minimum in bunch length corresponds almost to the minimum in energy spread (initial correlated energy spread from the gun shifts the minimum slightly)

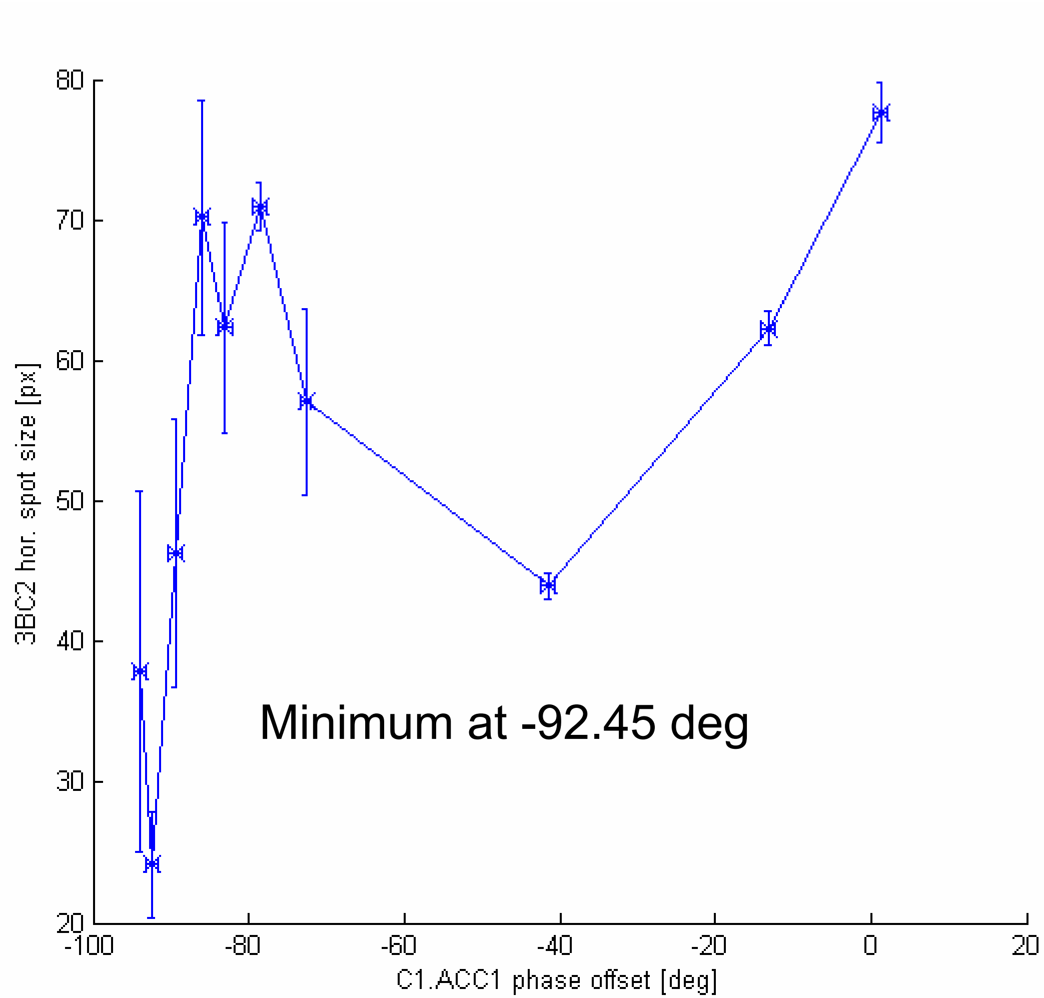
Simulations



Indirect Measurements of Velocity Bunching II

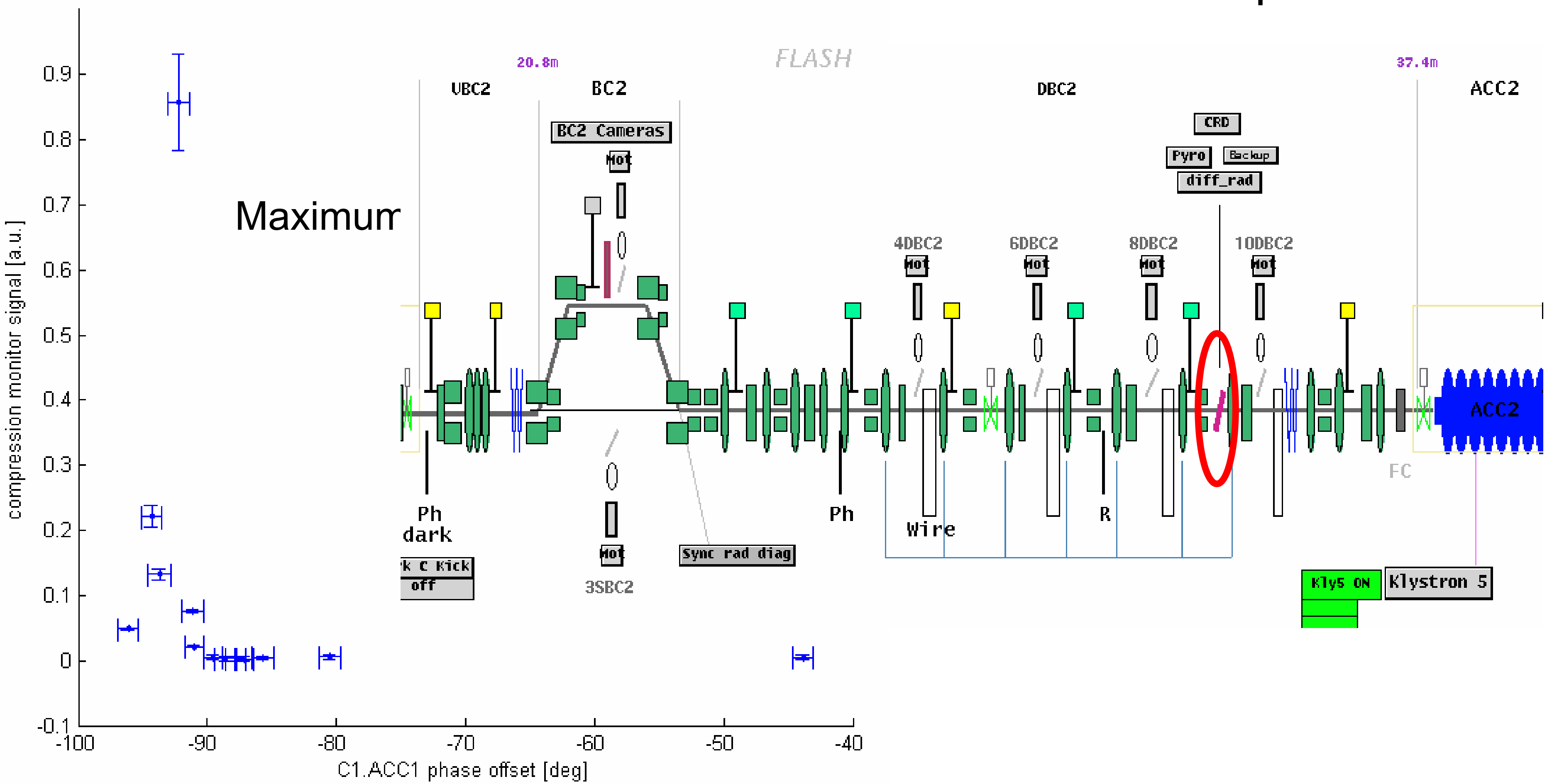
- Scan on C1.ACC1 phase offset while the phase c C2-C8.ACC1 is set +5 deg off crest
- Spot size on the 3BC2 screen is used as a measure for the energy spread





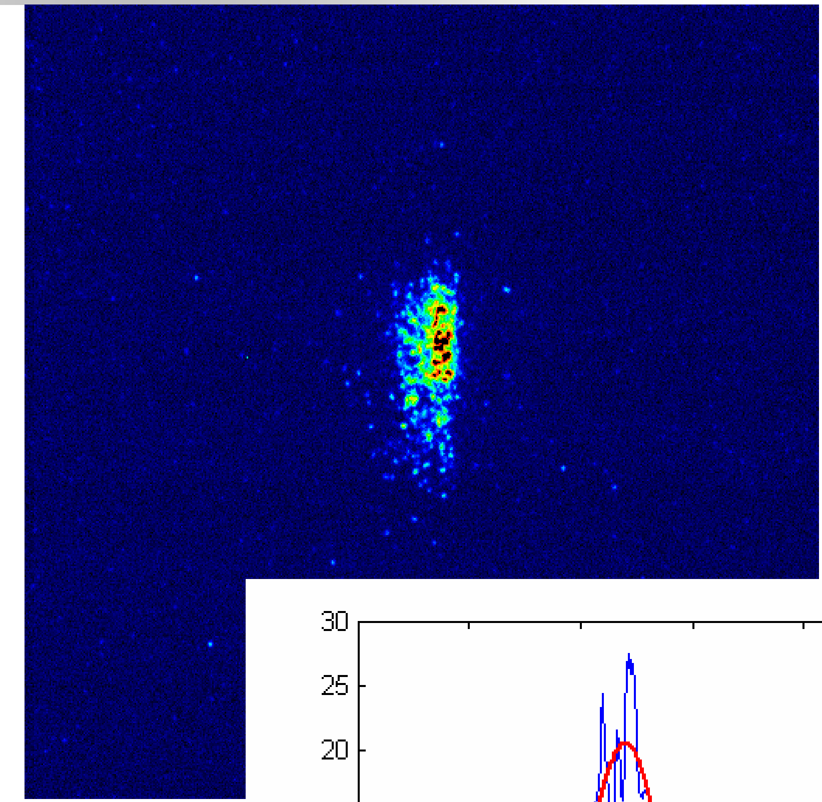
Compression Monitor Measurements

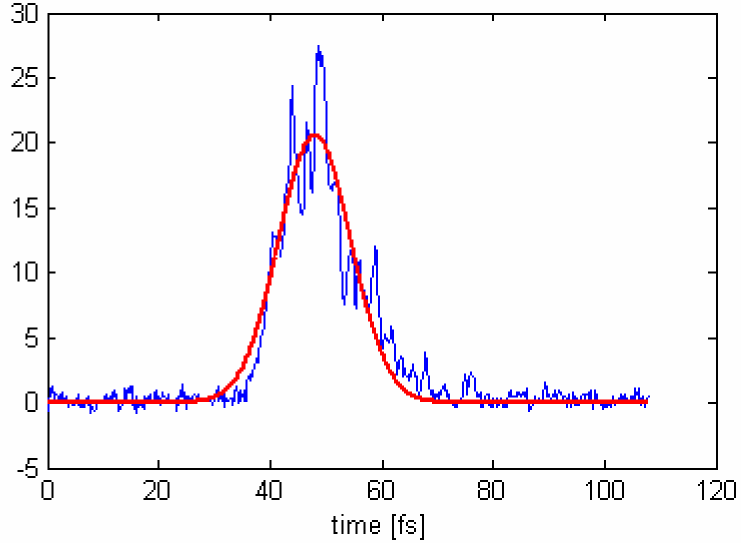
A pyro detector measuring the diffraction radiation at 9DBC2 is used to measure bunch compression



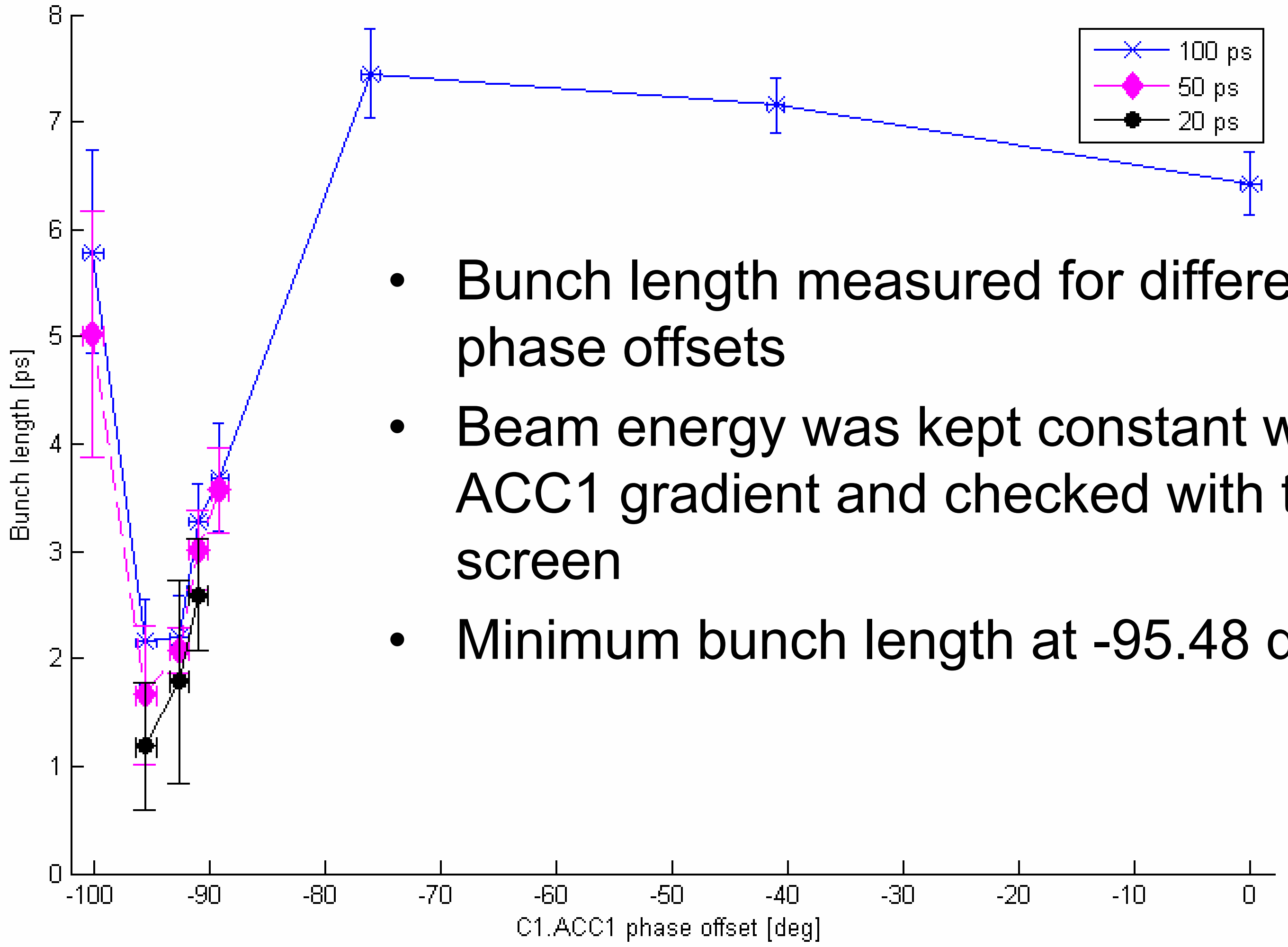
Streak Camera

- Sychrotron radiation from the 4th dipole in BC2 is transported to TOSYLAB via an optical beamline.
- A Hamamatsu streak camera is used to measure synchrotron radiation pulse length and thus the bunch length.
- A 540 nm±40 nm wavelength filter was used suppress resolution limitation by optical dispersion.
- Resolution limit expected around 1 ps.



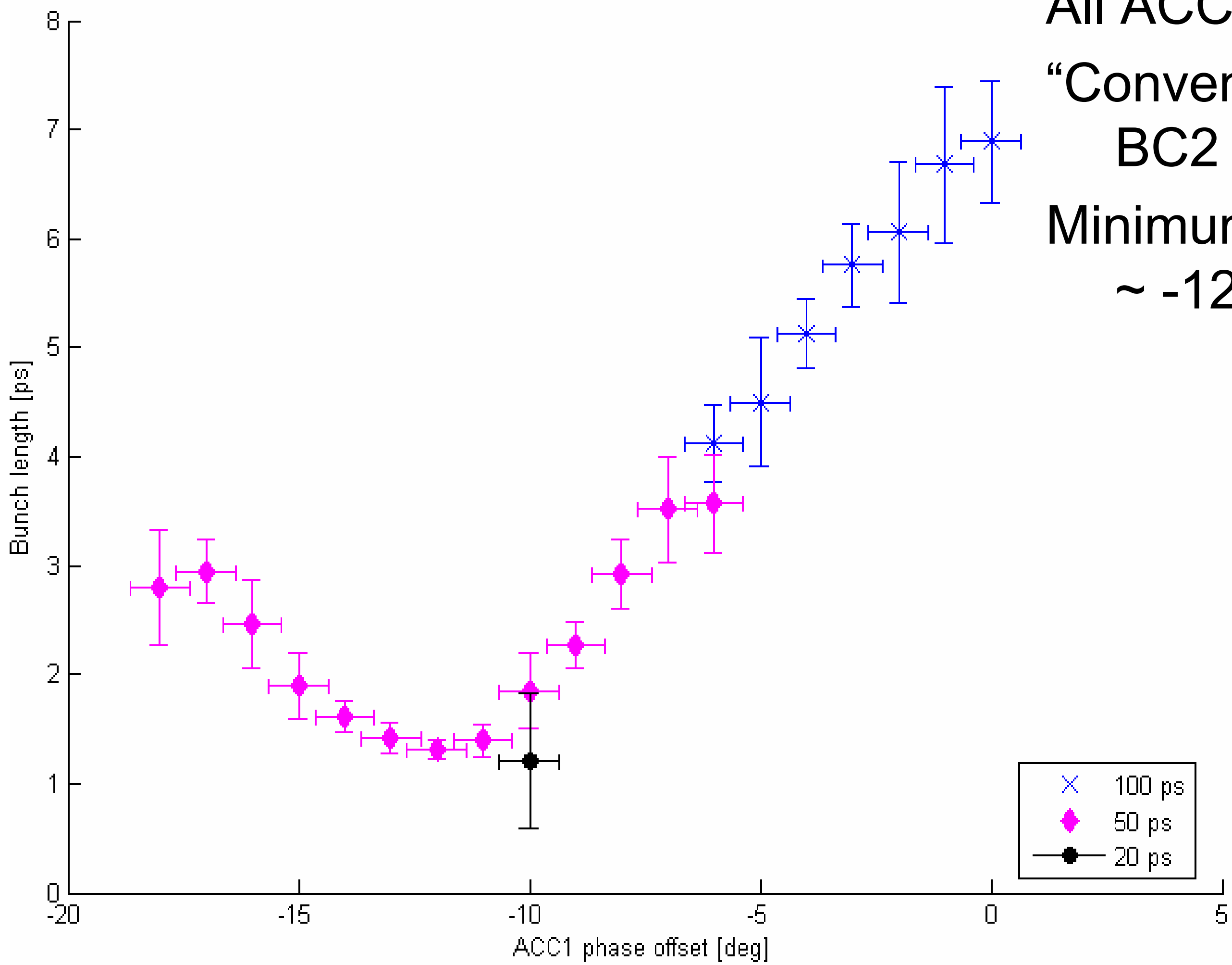


Streak Camera Measurements



- Bunch length measured for different C1.ACC1 phase offsets
- Beam energy was kept constant with the total ACC1 gradient and checked with the 3BC2 screen
- Minimum bunch length at -95.48 deg

Streak Camera Measurements II



Comparison Measurement:

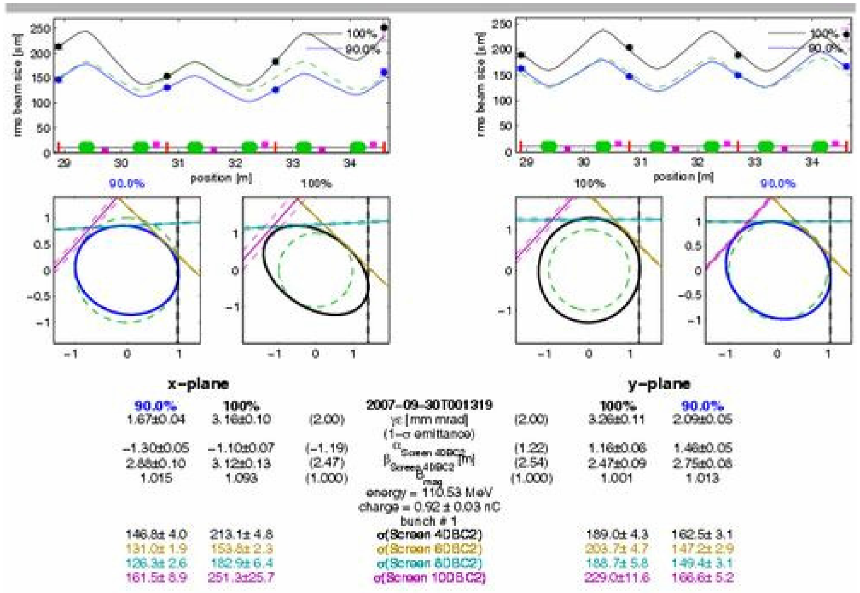
All ACC1 cavities are in phase

"Conventional" compression in BC2

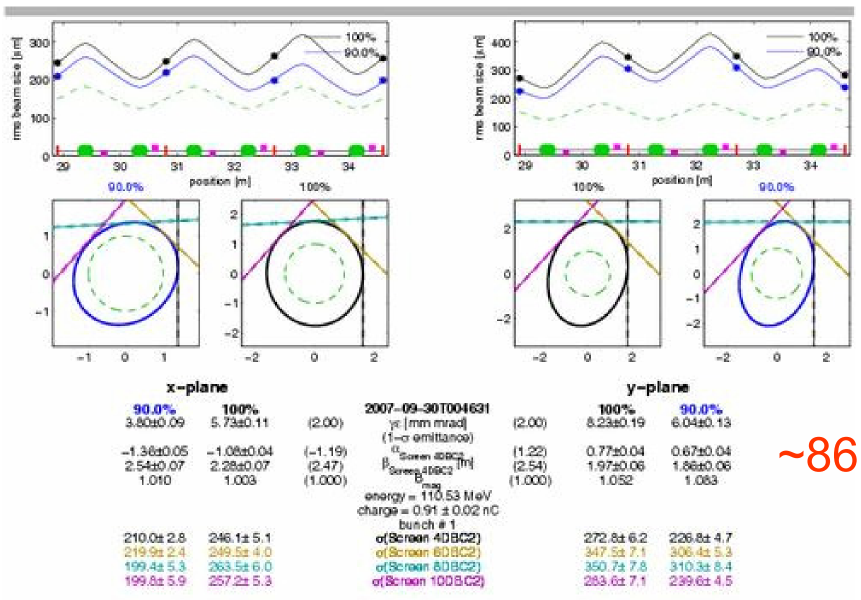
Minimum bunch length at ~ -12 deg

Emittance I

- Emittance is measured in the DBC2 FODO section.
- Four-Screen method was used.
- Optics matching for each emittance measurement



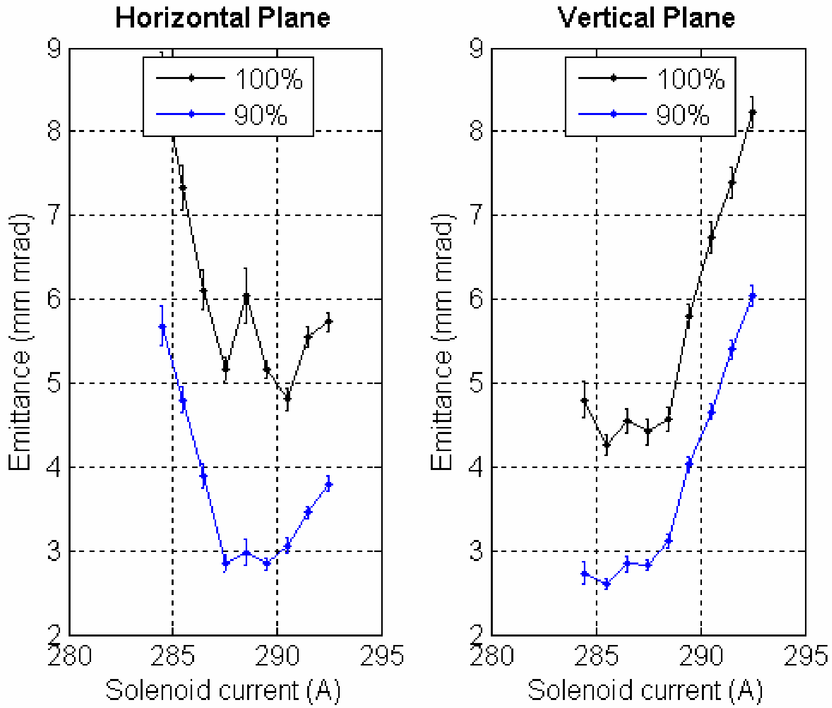
On-crest



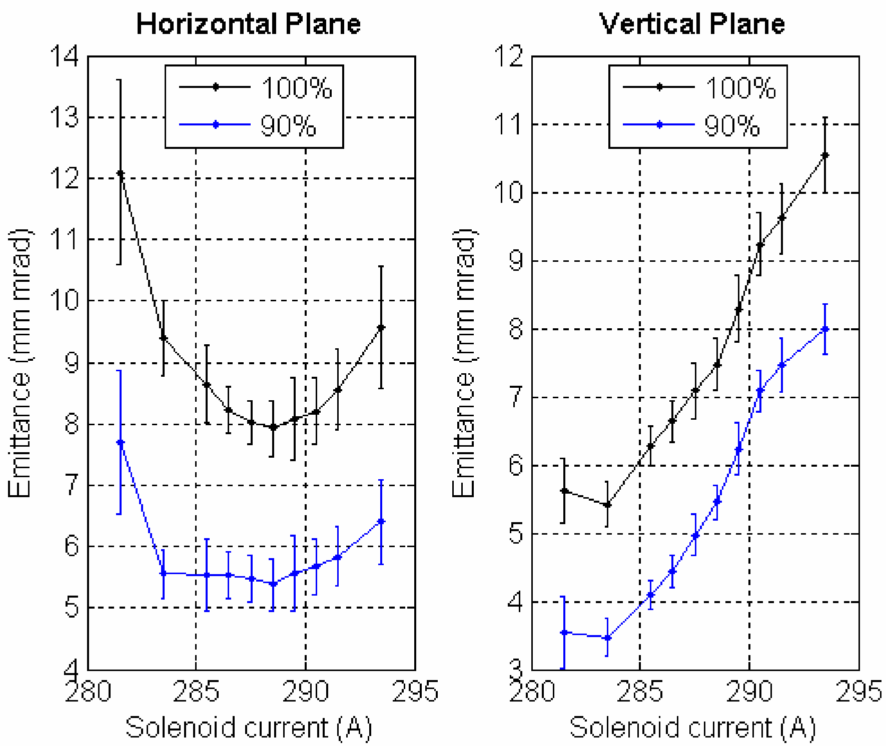
~86.5 deg

Emittance II

- Emittance measured as function of the Main solenoid
- Asymmetry between the horizontal and vertical emittance
- Solenoid current of 288.5 A was chosen as a good working point



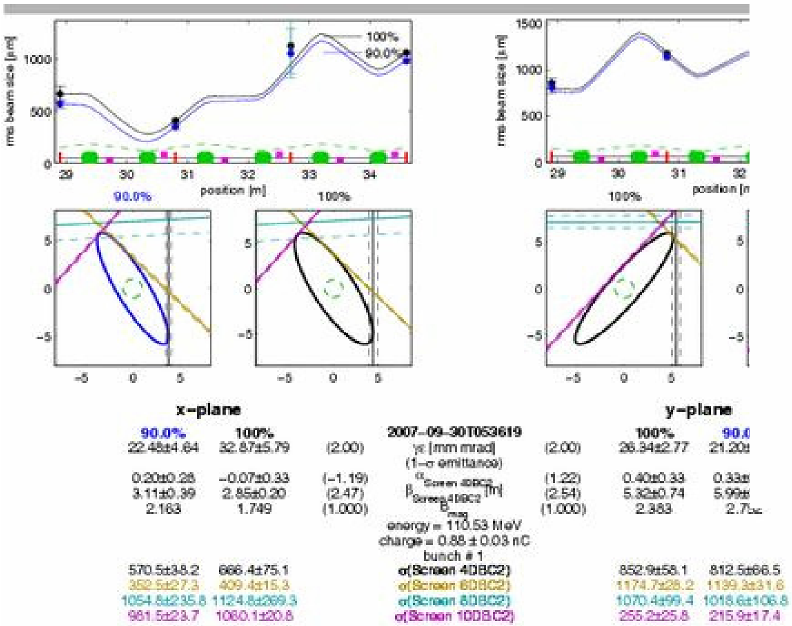
~86.5 deg

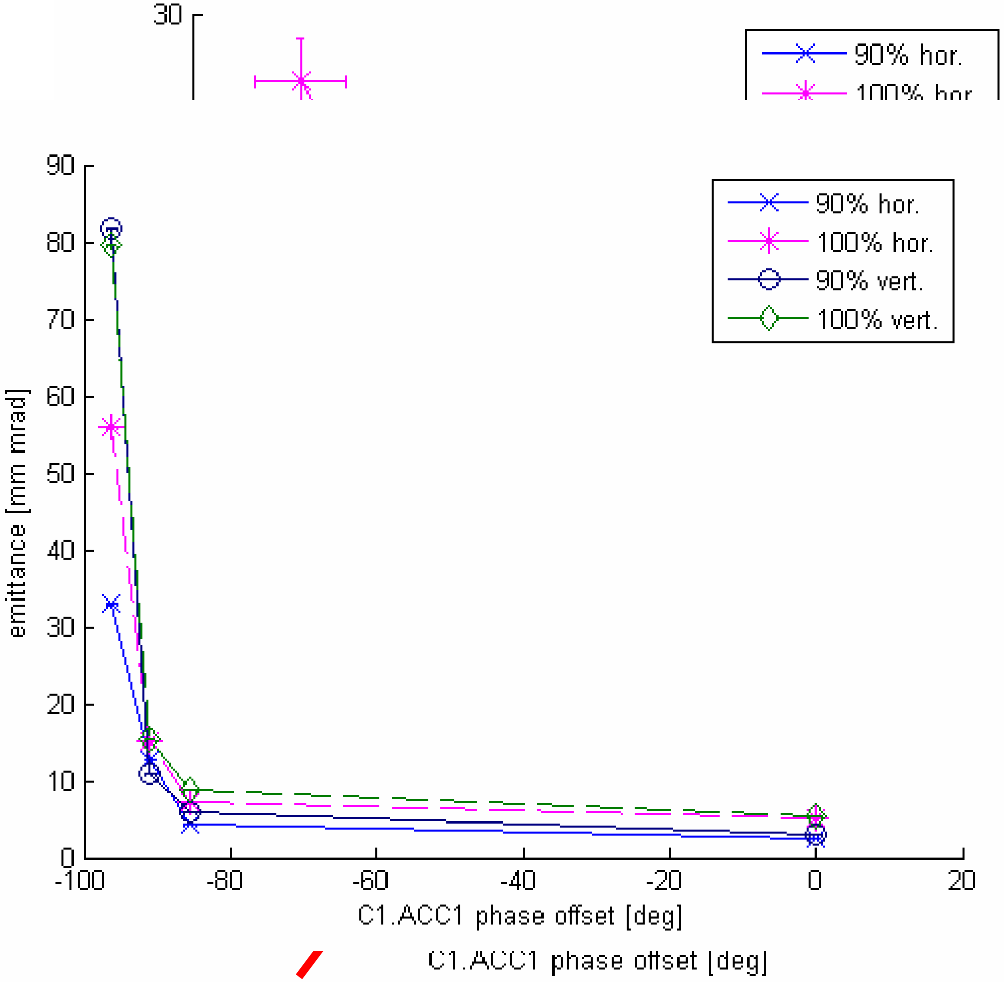


~91.7 deg

Emittance III

- Emittance increase in the phase range of beam compression
- Beam mismatch at phas offset of -96 deg



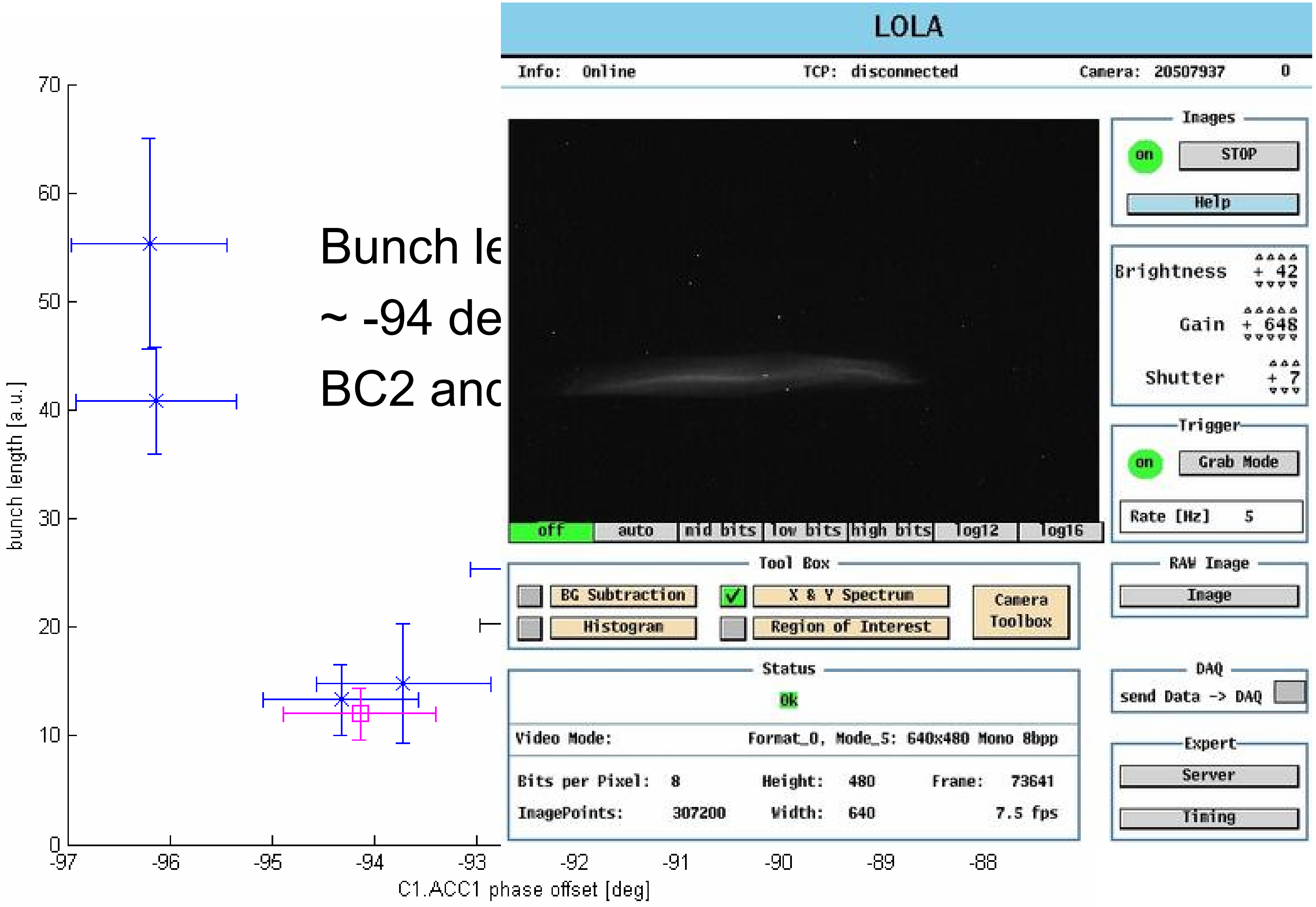


On Crest

Bolko Beutner, DESY

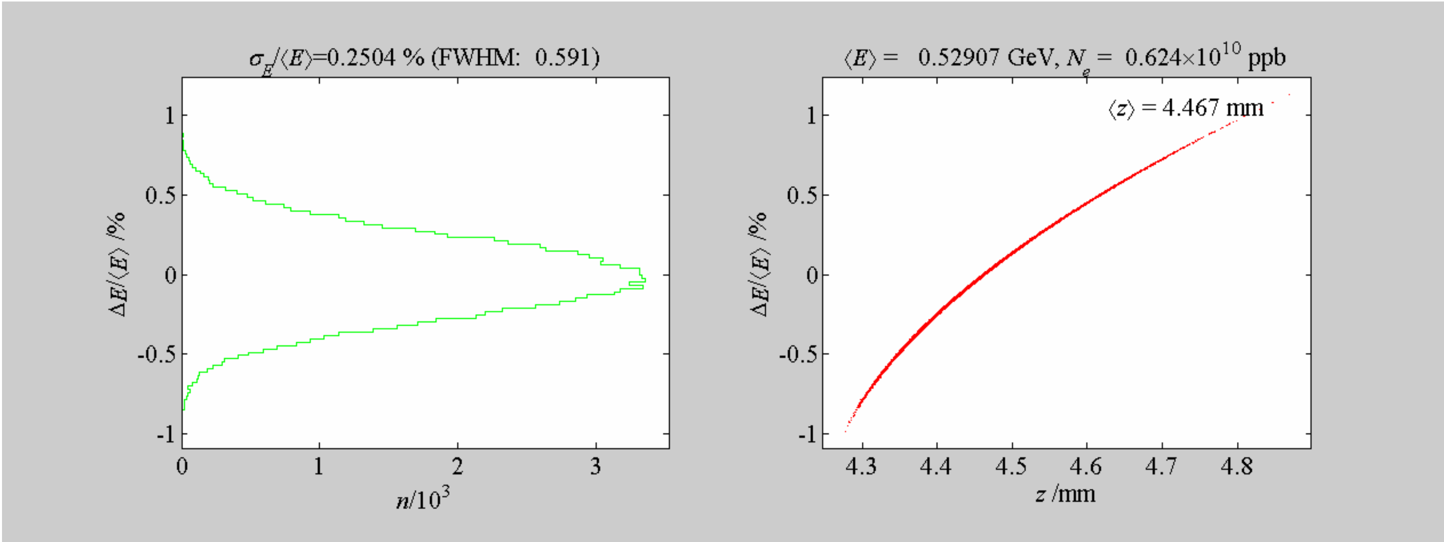
LOLA

Bunch le… imum at
~ -94 de…
BC2 anc…

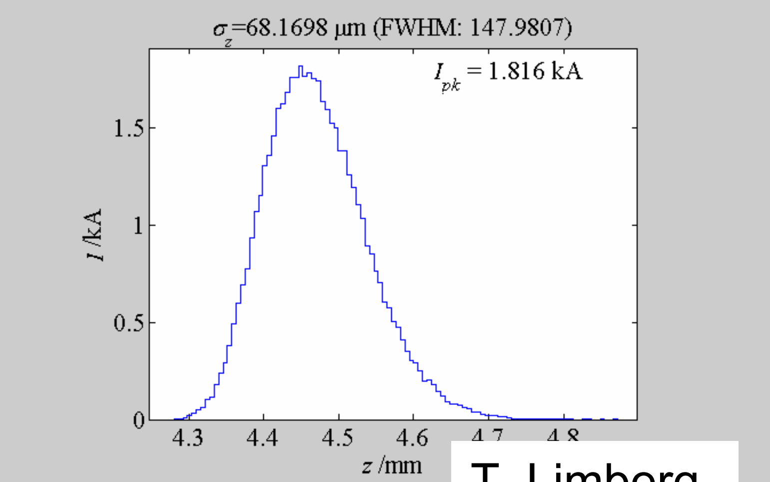


LOLA II

Longitudinal Phase Space @ LOLA



- Velocity bunching at C1.ACC1 ~ -90 deg
- Compression in BC2 and BC3
- 1.8kA in BC3 with a linear energy chirp lead to a strong microbunch instability gain
- Corresponding slice emittance growth should be observable at LOLA



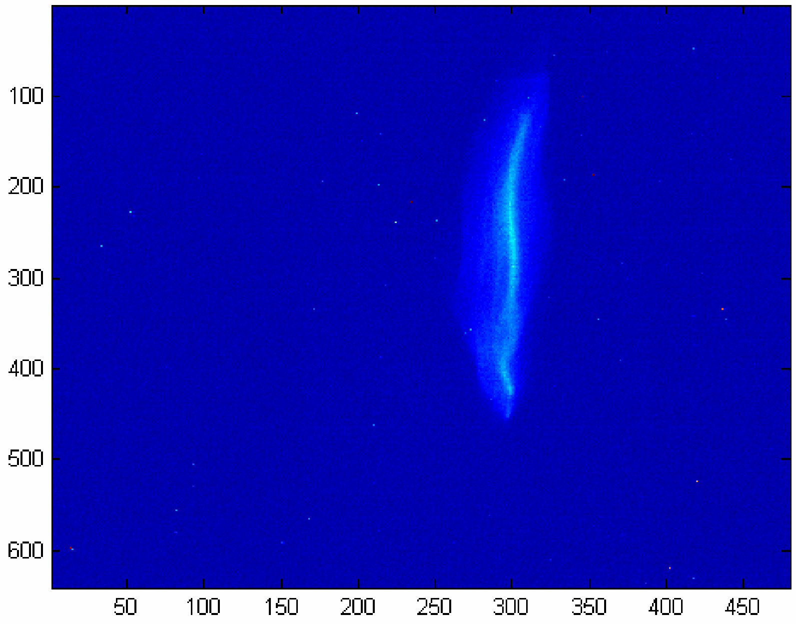
T. Limberg

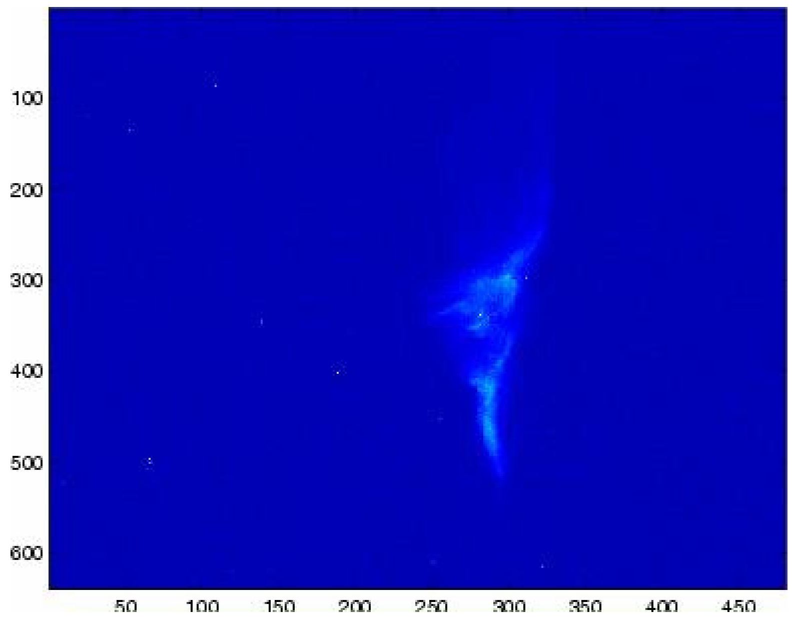
LOLA III

Qualitative observation of microbunch instabilities

Bunch is pre-compressed with velocity bunching(C1.ACC1 ~90deg)

Off-crest acceleration in C2-C8.ACC1 to induce compression in BC2 and BC3





Summary and Outlook

- Velocity bunching demonstrated at FLASH
- Confirmation of J.P. Carnieros results
- Indirect methods as well as compression monitors, streak camera, and transverse deflecting structures were used
- Indications for observation of microbunch instabilities

Next Steps:

- Detailed comparison with ASTRA simulations
- Detailed and dedicated studies studies on microbunch instabilities (=> beamtime request)

Thank you for your Attention

and

Special thanks to V. Ayvazyan, M. Huening, O. Grimm, and K. Klose.