Micro-bunching Instability and COTR Studies at FLASH

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FLASH Seminar 6.05.2008

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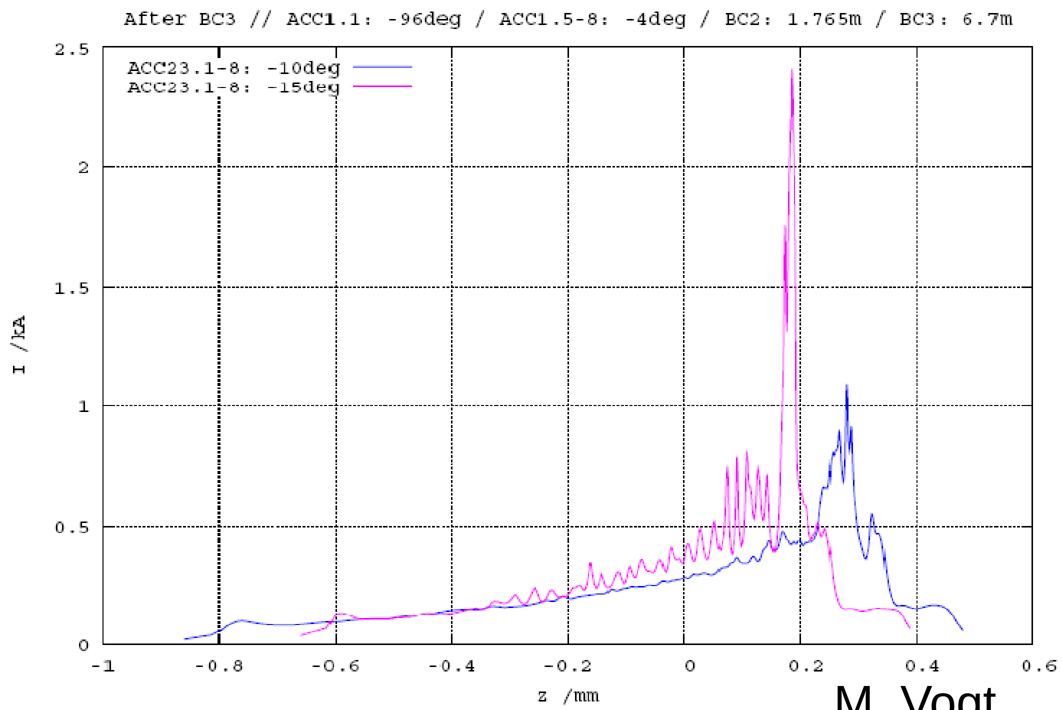
Introduction

- Micobunching instabilities are predicted to have a strong effect on FEL like XFEL or 3rd harm. FLASH – no experiments are done at FLASH so far…
- Velocity bunching can be used to simulate some beam properties of the 3rd harm. System (linear long. Phase space)
- ACC23 as a "knob" to turn microbunching "on and off"
- Microbunch structure can be used for COTR studies



M. Vogt

Goals

Microbuning Instability

- Observation of microbunch (~ 10 um) structure on the bunch with the THz spectrometer
- Observation of instabilities at LOLA
- Studies on possible beam break up

Coherent Optical Transition Radiation

- COTR in “microbunching mode” (OTR screens / LOLA)
- COTR in standard compression (OTR screens)
- Charge dependence

“Microbunching Mode”

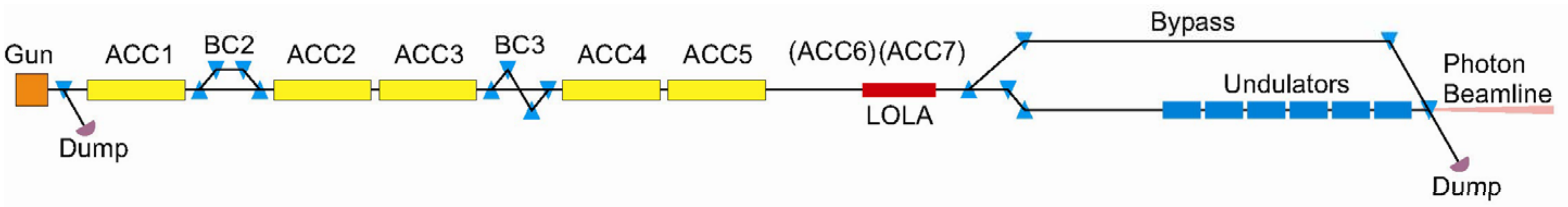
ASTRA/CSRTrack Simulations by M. Vogt

velocity bunching -> (ACC1.C1)

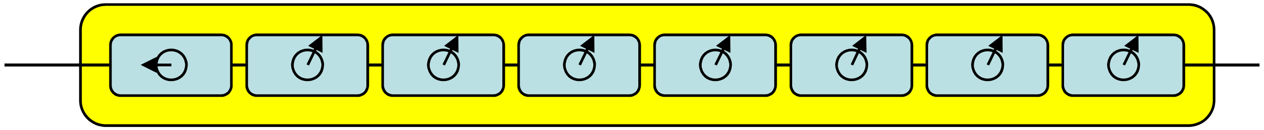
RF Gun	Phi = -0.55 deg	E_max = 44 MeV/m	Q=1nC
ACC1.C1	Phi = -83.00 deg	E_max = 25.35 MeV/m	
ACC1.C2-8	Phi = -2.00 deg	E_max = 37.00 MeV/m	=> <E_out> = 129.3 MeV
BC2	rho = 1.765 m	theta = 16.49 deg	lim: 15-21deg
	=> R56= 0.149	=> I = 57.666 A	
ACC2-3	Phi = -15 deg	E_max = 30.70 MV/m	=> <E_out> = 373.6 MeV
BC3	rho = 6.200 m	theta = 4.64 deg	lim: 1.7-5.4deg
	=> R56= 0.07329	=> I = 47.2674 A	
ACC4-6	Phi = 0 deg	E_max = 26.65 MV/m	=> <E_out> ca. 680 MeV

Experiments at FLASH

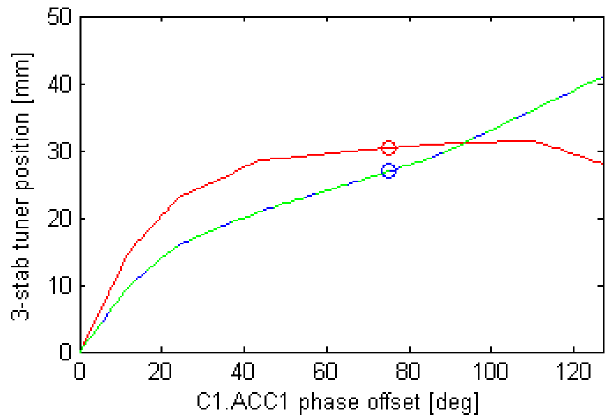
- Setup of velocity bunching (including bunch length measurements)
- ACC23 phase scan in “microbunching mode” (vb on)
  - LOLA
  - THz
  - OTR18ACC7
- Beam Focus on OTR screens in standard comprssion (vb off)
  - ACC1 phase scan BC2 compression / OTR10DBC2

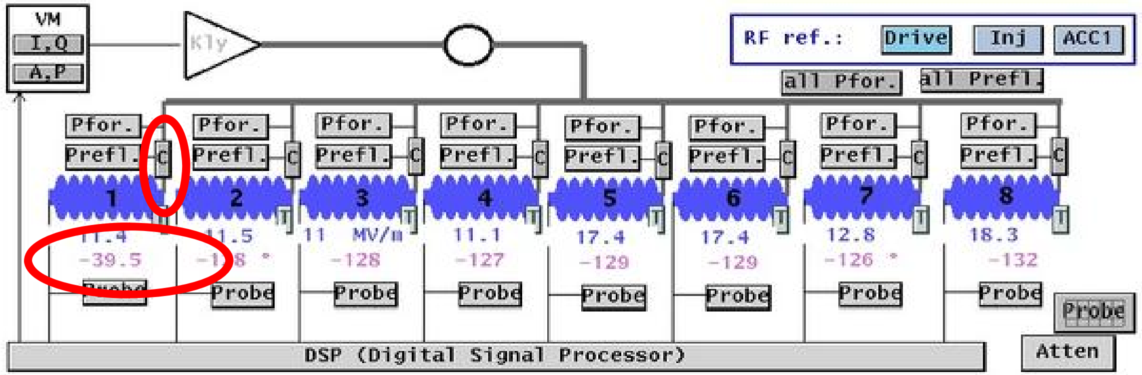


Velocity Bunching



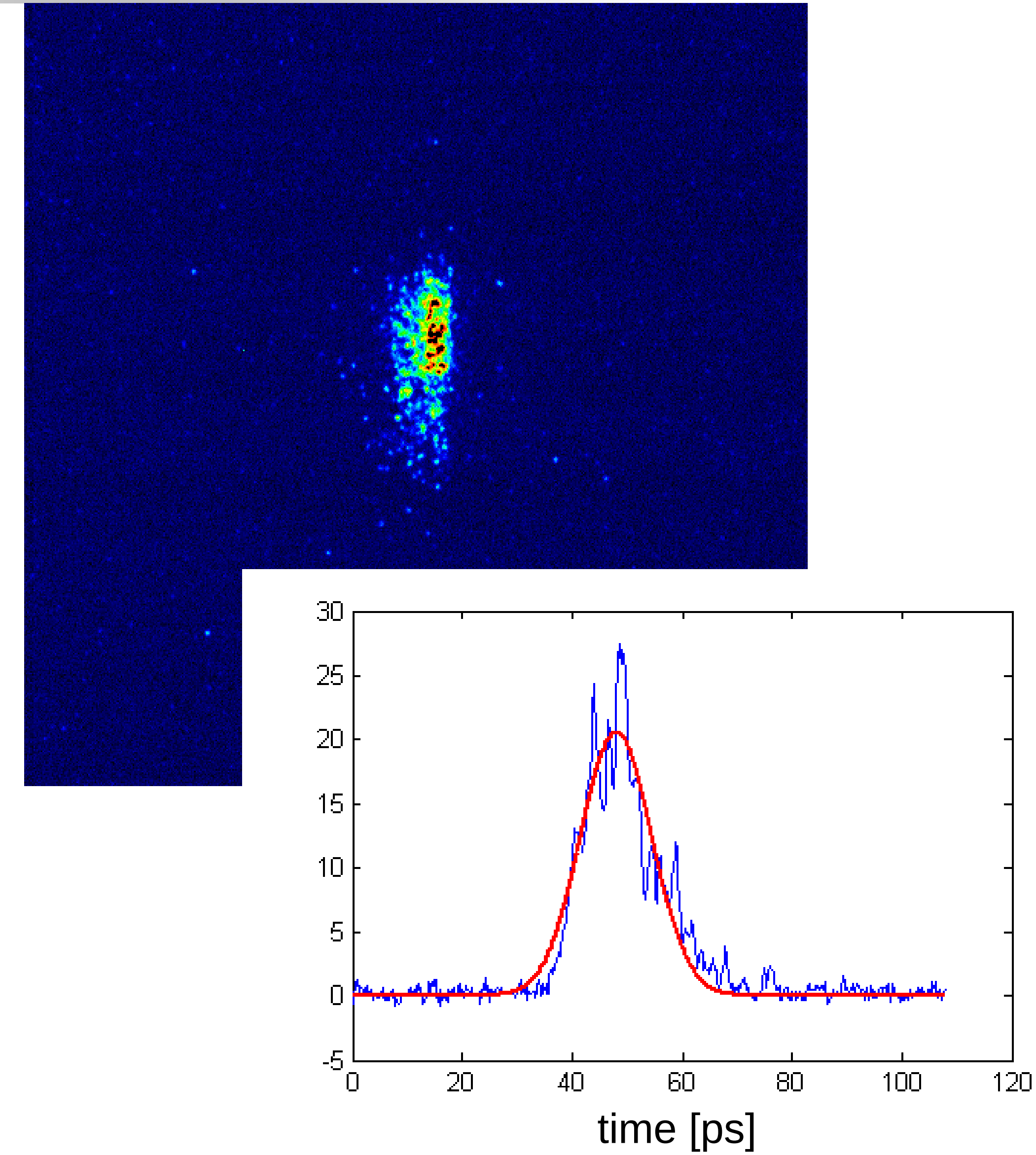
- 3-Stab waveguide tuners are used to shift phase offsets of single cavitites
- Tuner positions are taken from pre-measured curves
- Q of the cavities are kept within reasonable limits by tuning of the middle stab position
- Final phase offsets differ slightly from the intended ones but are measured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





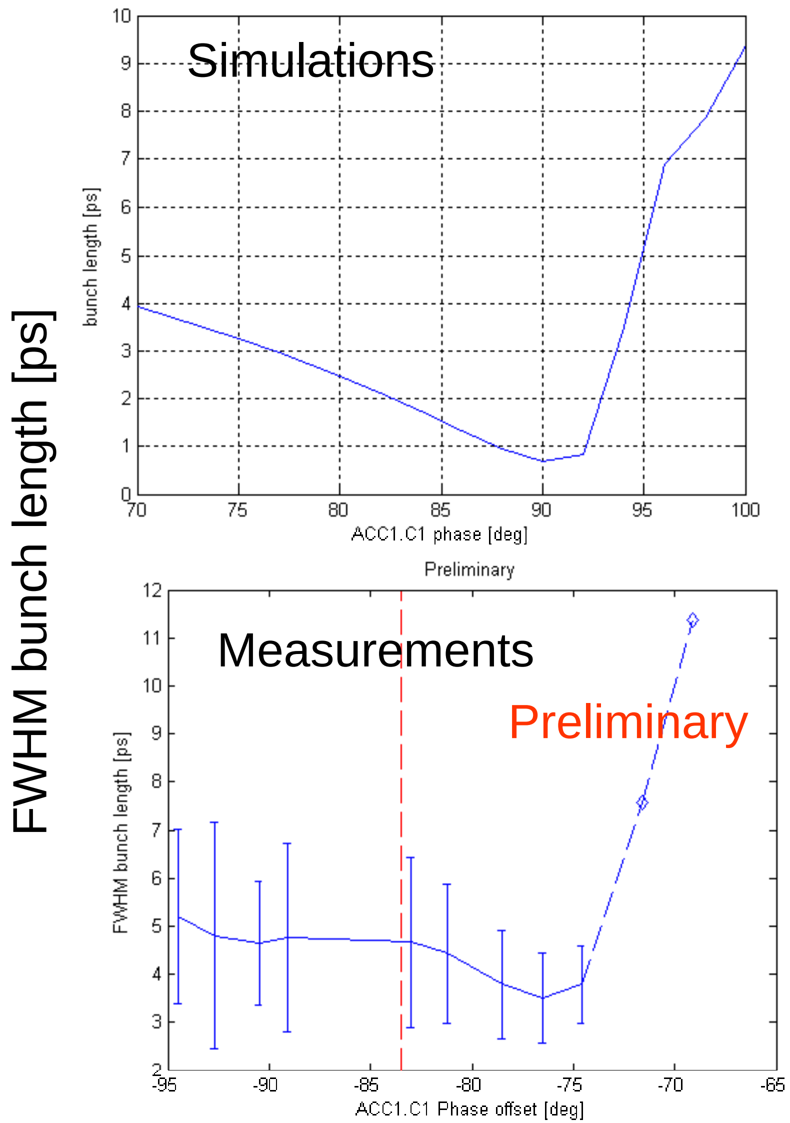
Streak Camera

- 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.



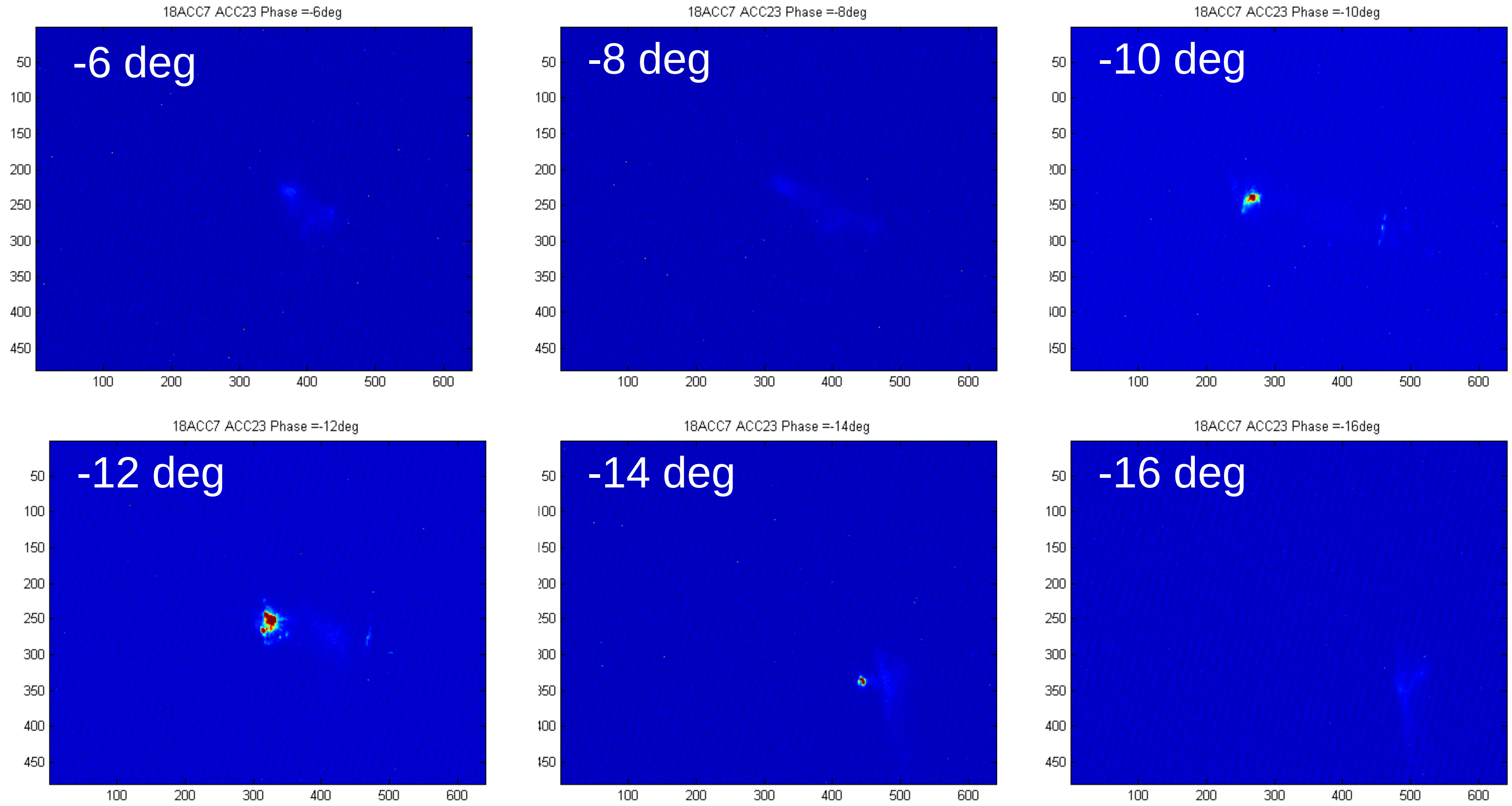
VB Setup

- Bunch length measurements to set up velocity bunching
- Comparison with simulated bunch length data
- Working point set with respect to shortest bunch length



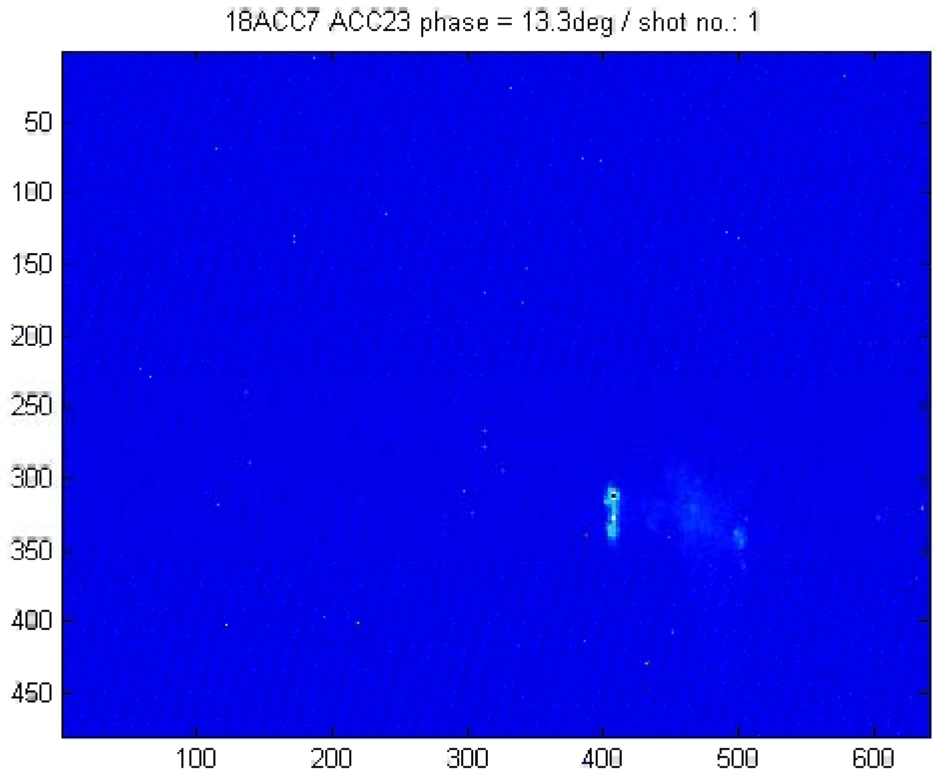
18ACC7

- ACC23 phase scan in “microbunching mode”
- Beam is observed on OTR18ACC7



Beam Breakup

- 13.3 deg in ACC23 – 100 shots



Beam Breakup

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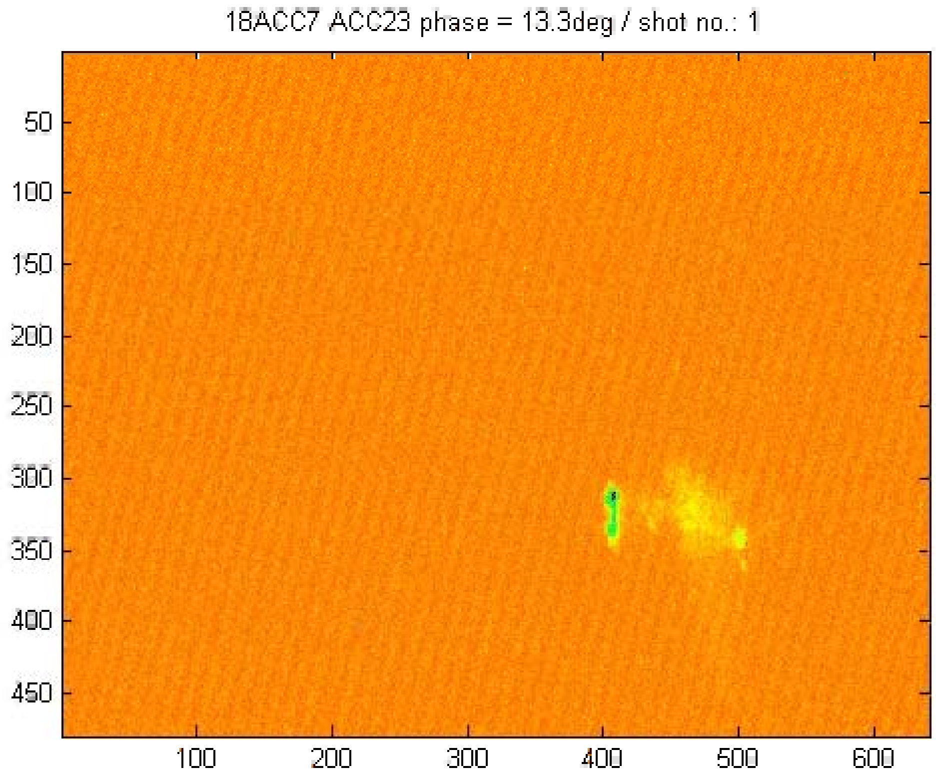
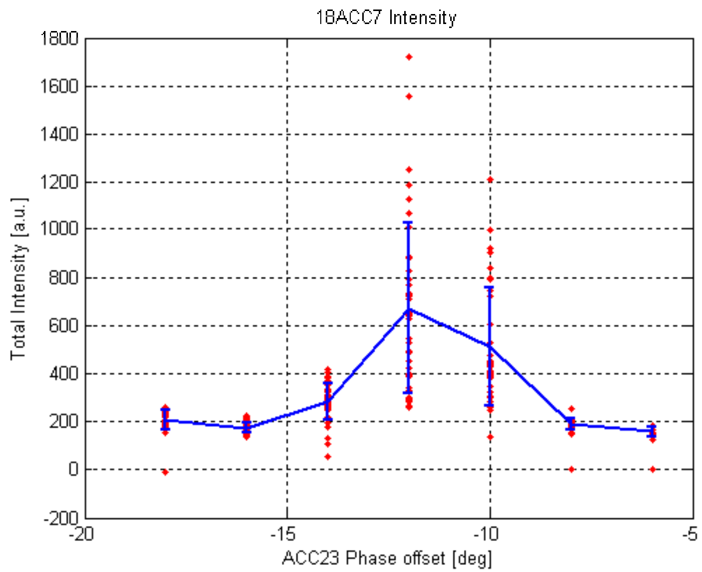
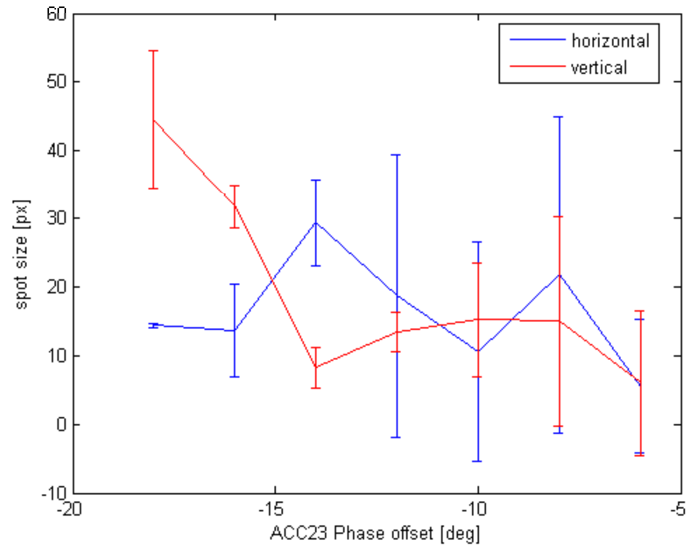


18ACC7

- Strong intensity increase around 13 deg off crest in ACC23
- Strong fluctuations
- Beam size determination is hard due to spiky structure

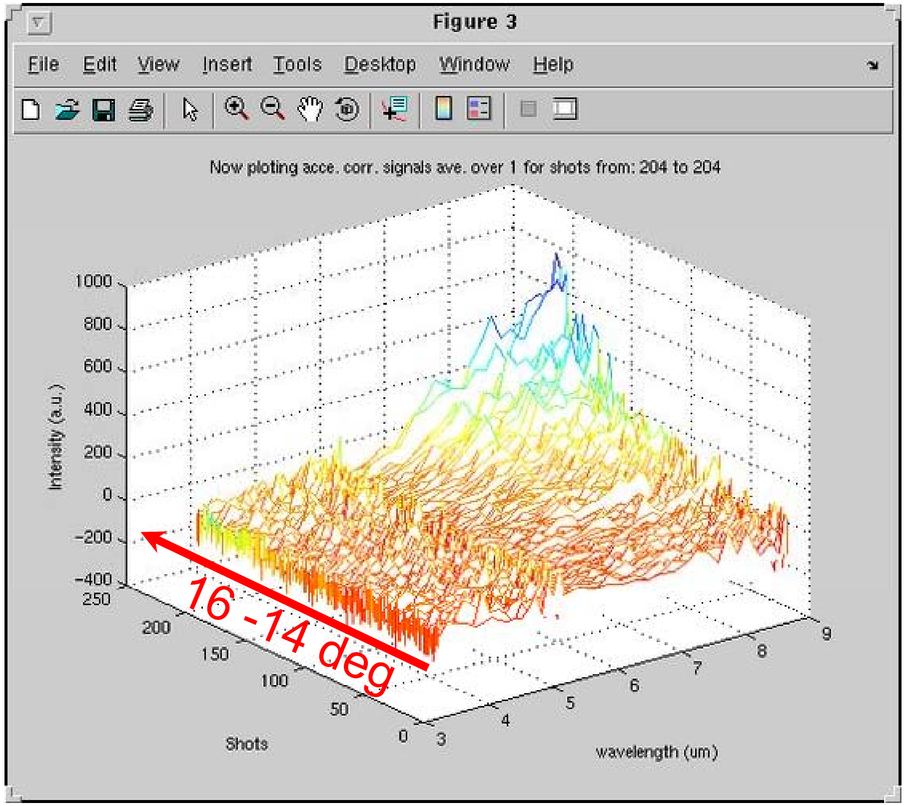
  However there is no significant decrease of spot size which might explain the intensity increase.

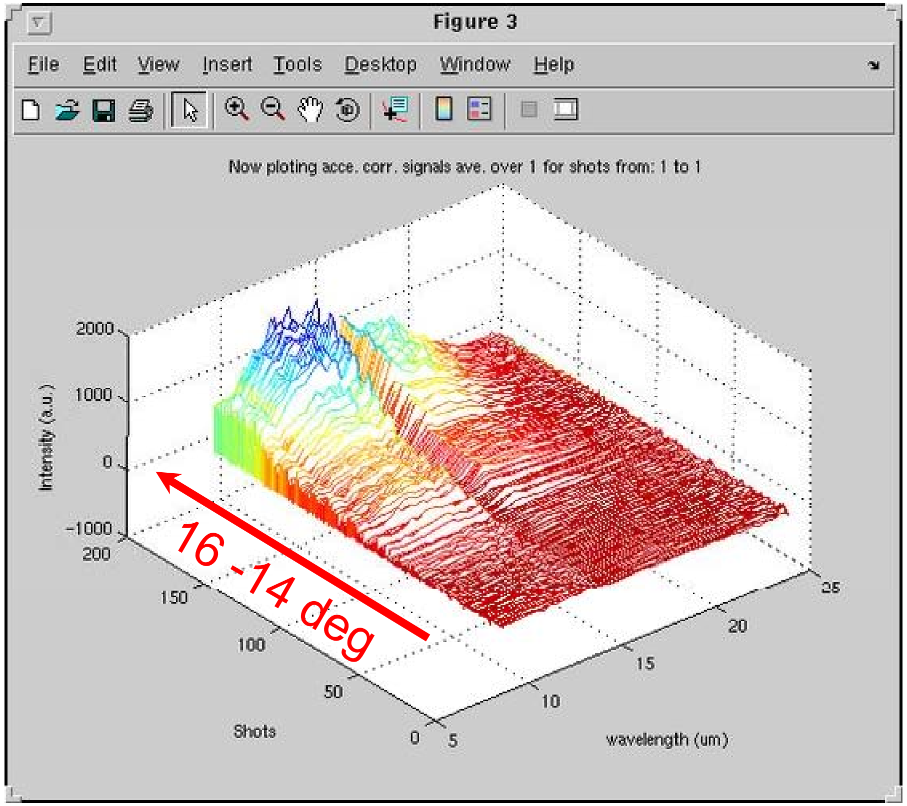




THz Spectra

- Phase scan ACC23 16deg -> 14 deg in ~0.1 deg steps
- Strongest contribution in 8-25um range

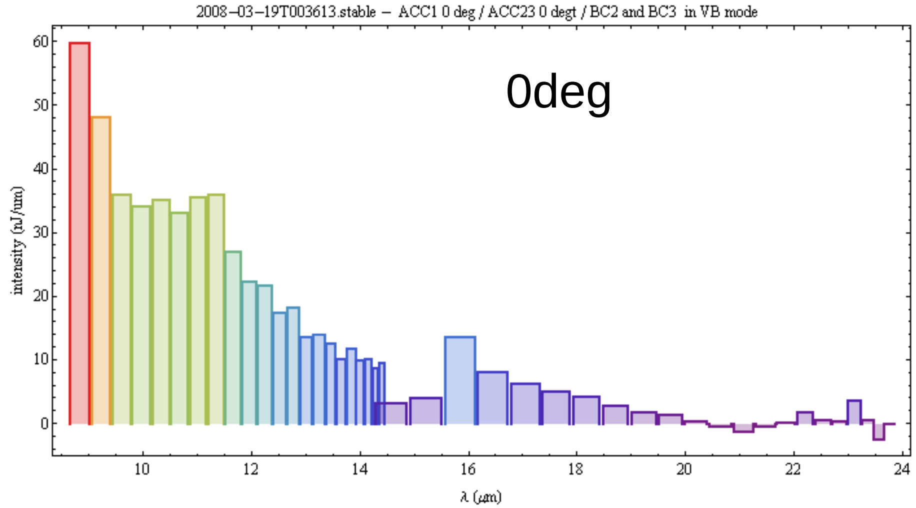


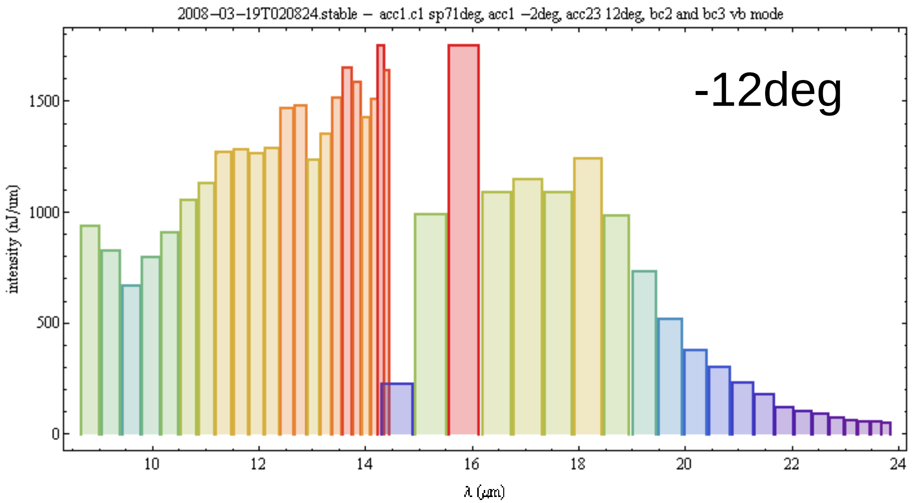


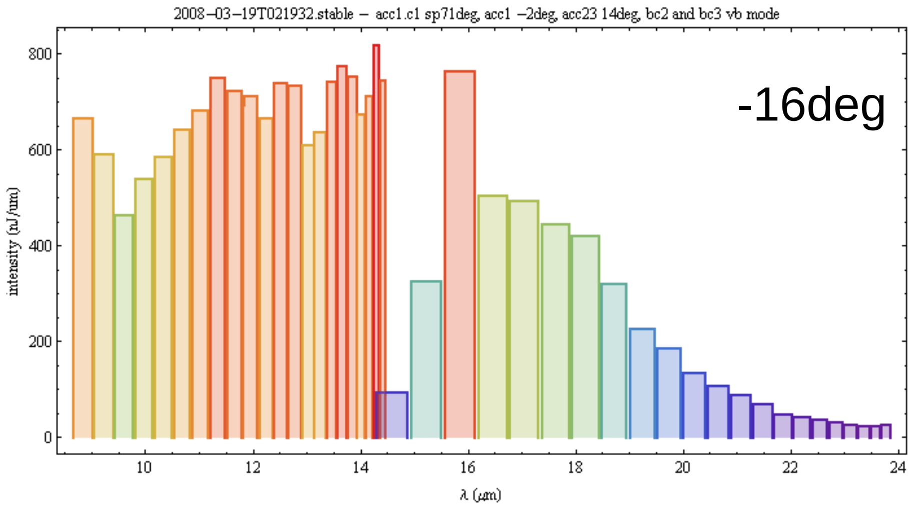
“Microbunching” ?

- ACC1.C1, BC2, and BC3 in “microbunching mode”
- ACC1.C2-C8 -2deg
- ACC23 scan

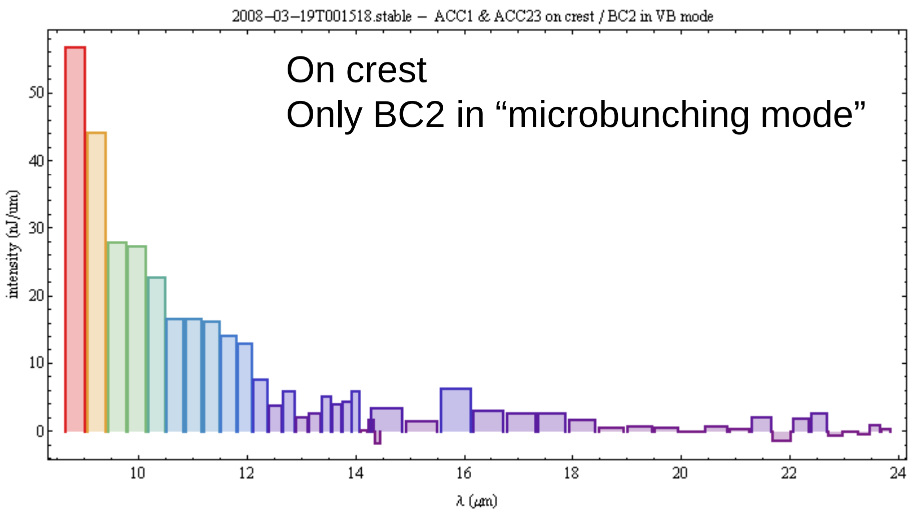
- Strong signals in predicted “microbunchig mode”

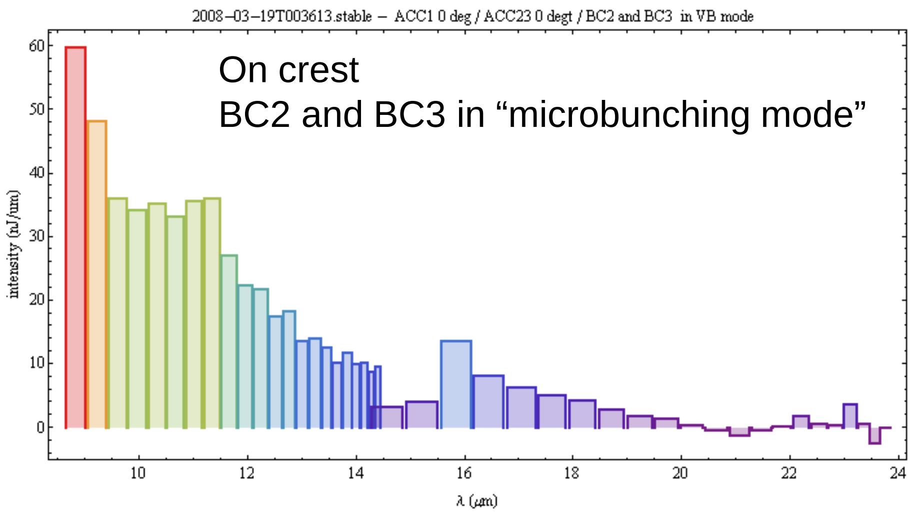


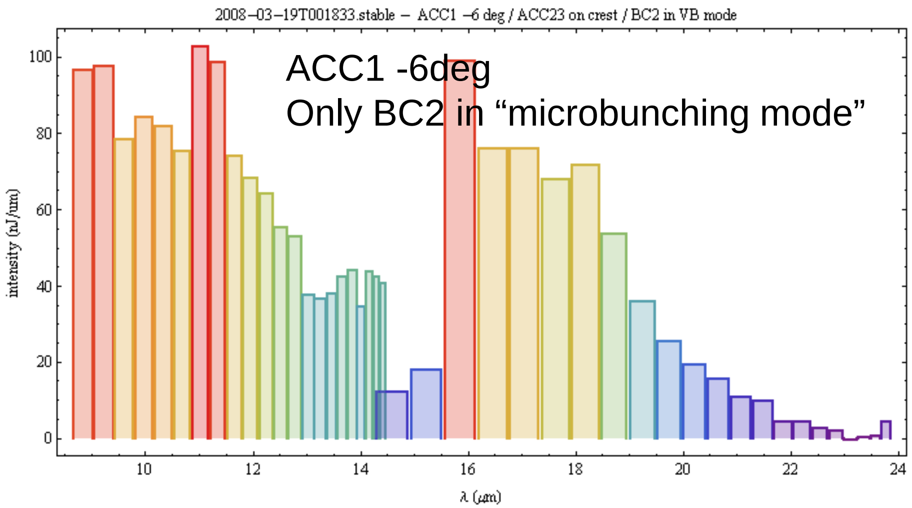




“no microbunching”?



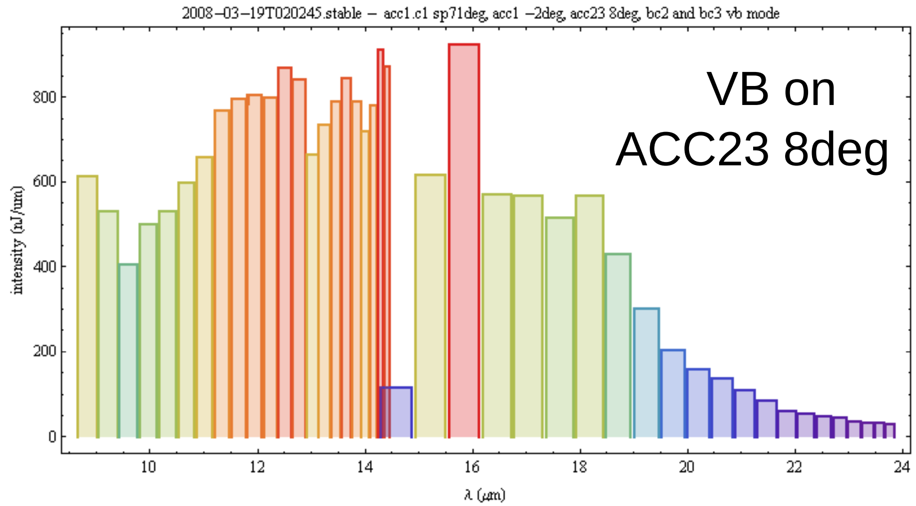


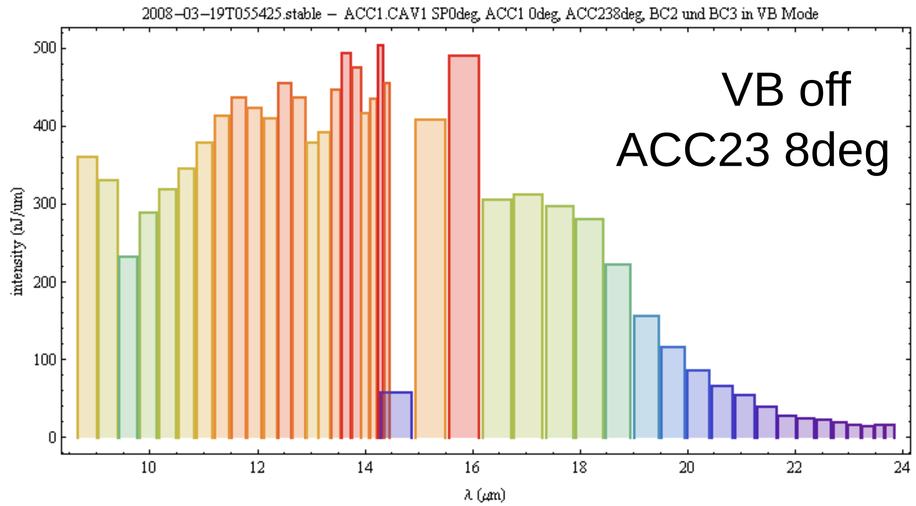


- Structure in the 8-25um range
- Low intensity compared to the “microbunching mode”

VB on and off

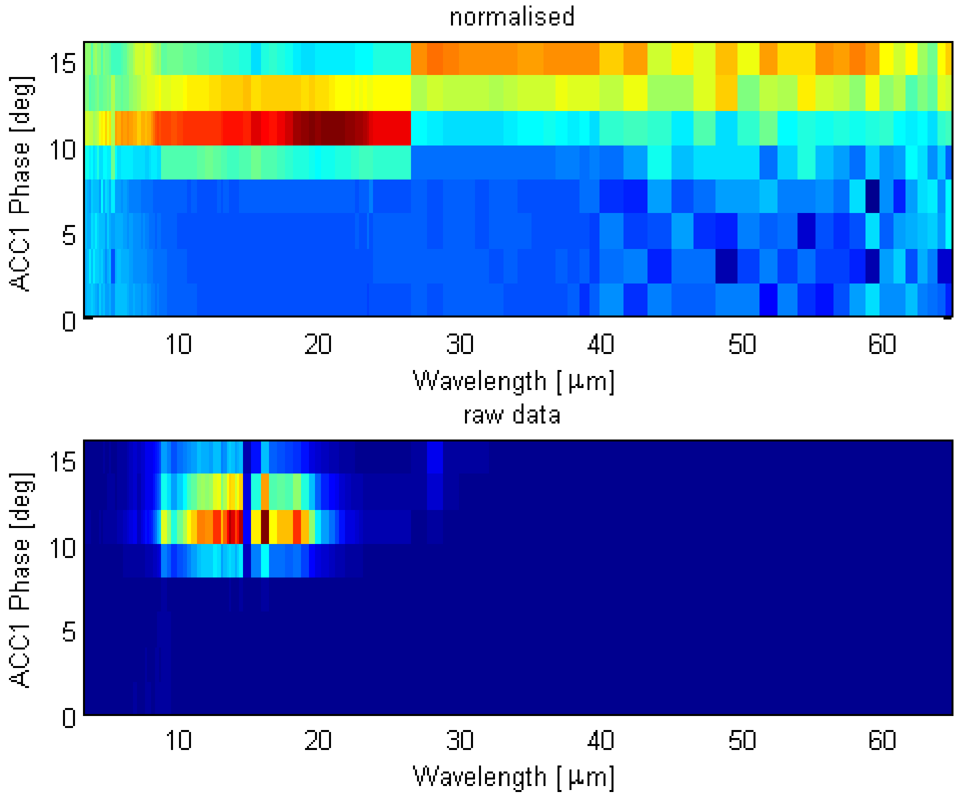
- Similar structure with and without VB
- Strongest THz signal at ACC23 8 deg offcrest in non vb mode
  (~12 deg in vb mode)
- Maximum signal lower than in “microbunching mode” (vb on)





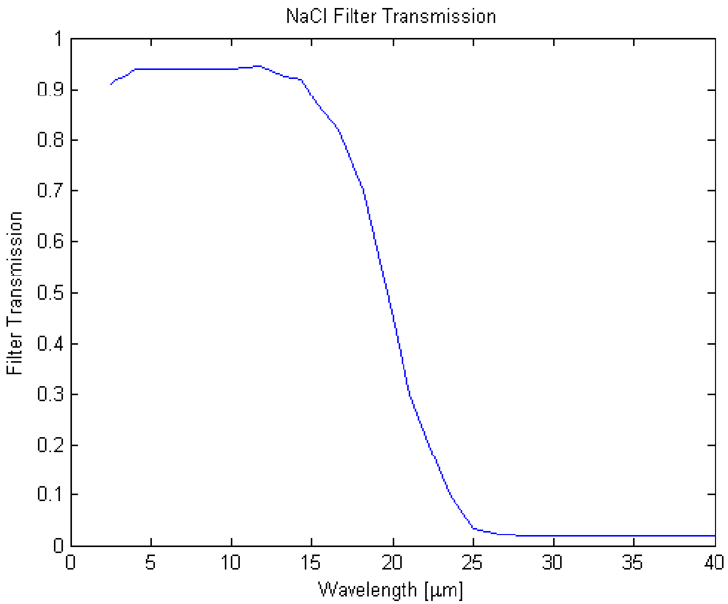
Spectra structure

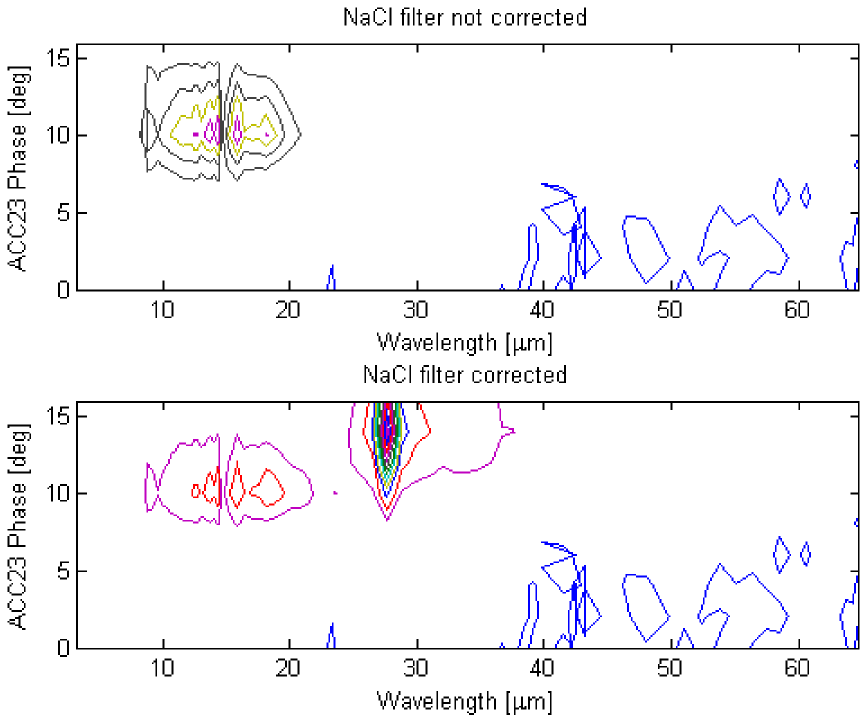
- NaCl filter was in during the measurements
  => wavelength larger than ~20um are suppressed
- Signal contribution between 10 and 20 micron around 10-12deg
- Signal at ~30 micron increasing with phase
- Noise above 30 micron due to NaCl filter



NaCl correction

- NaCl filter transmission curve used for data correction
- Transmission above 30 micron assumed to be constant





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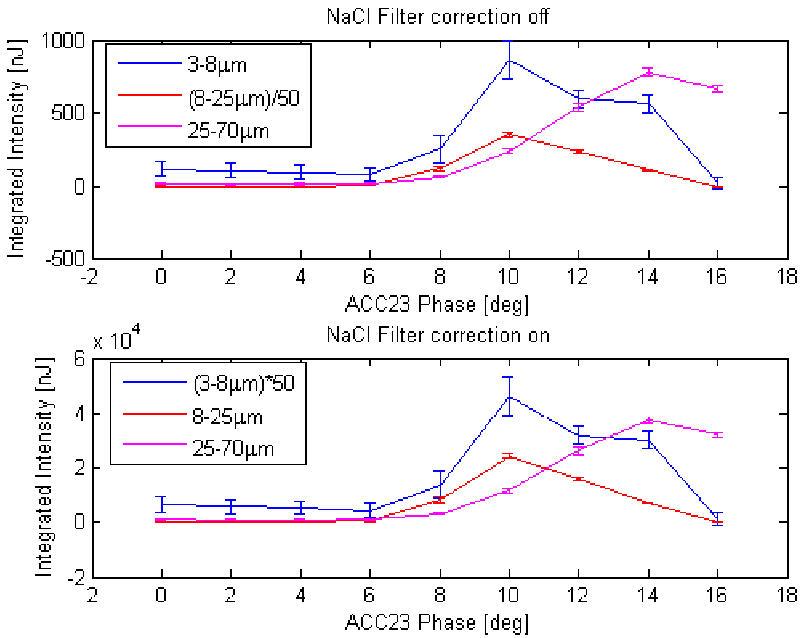
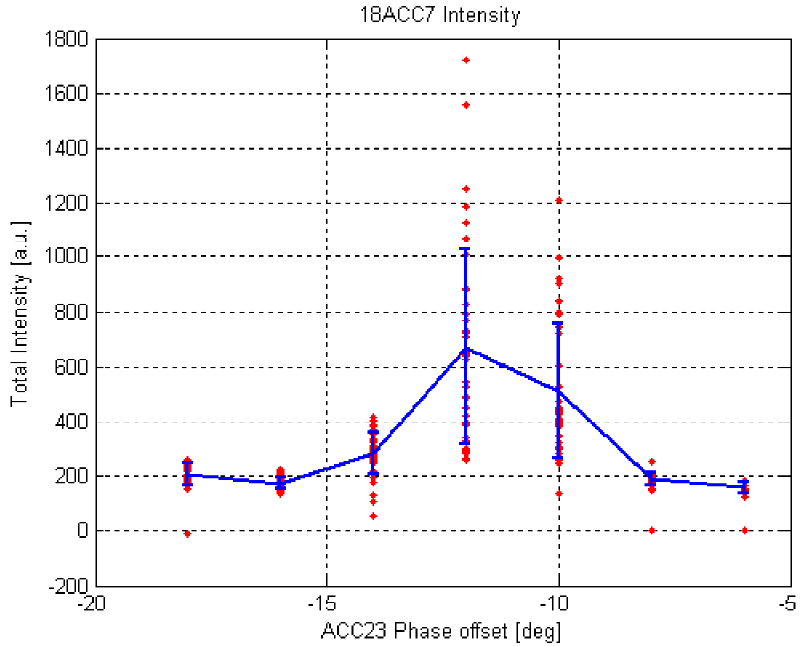
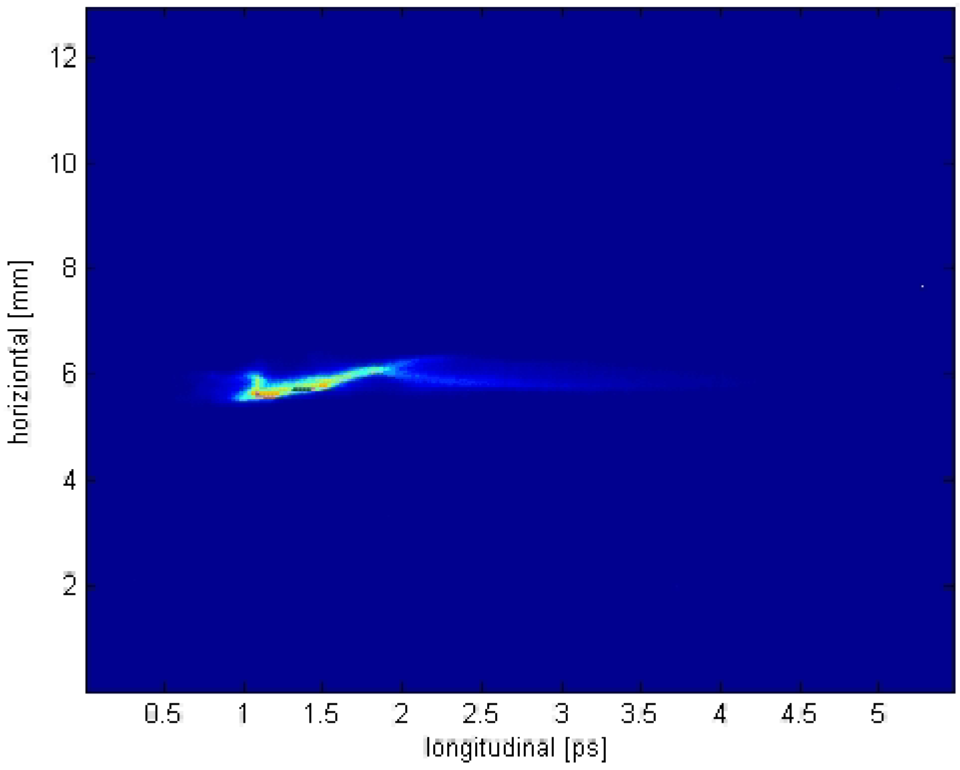
- Wavelength range 25-70um has a maximum at 14deg
- Wavelength range 3-8 and 8-25um with maximum around 10deg
- Short (<25um) wavelength signals correlate more with the 18ACC7 COTR signals



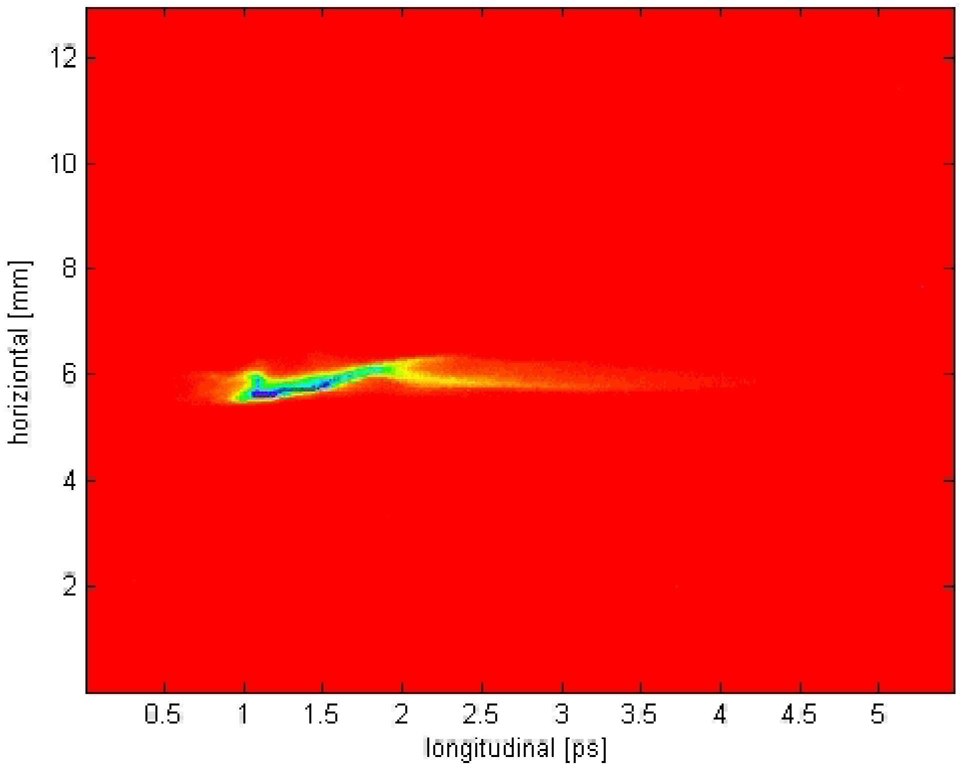


LOLA

- ACC23 13.7deg



- ACC23 13.7deg



LOLA studies

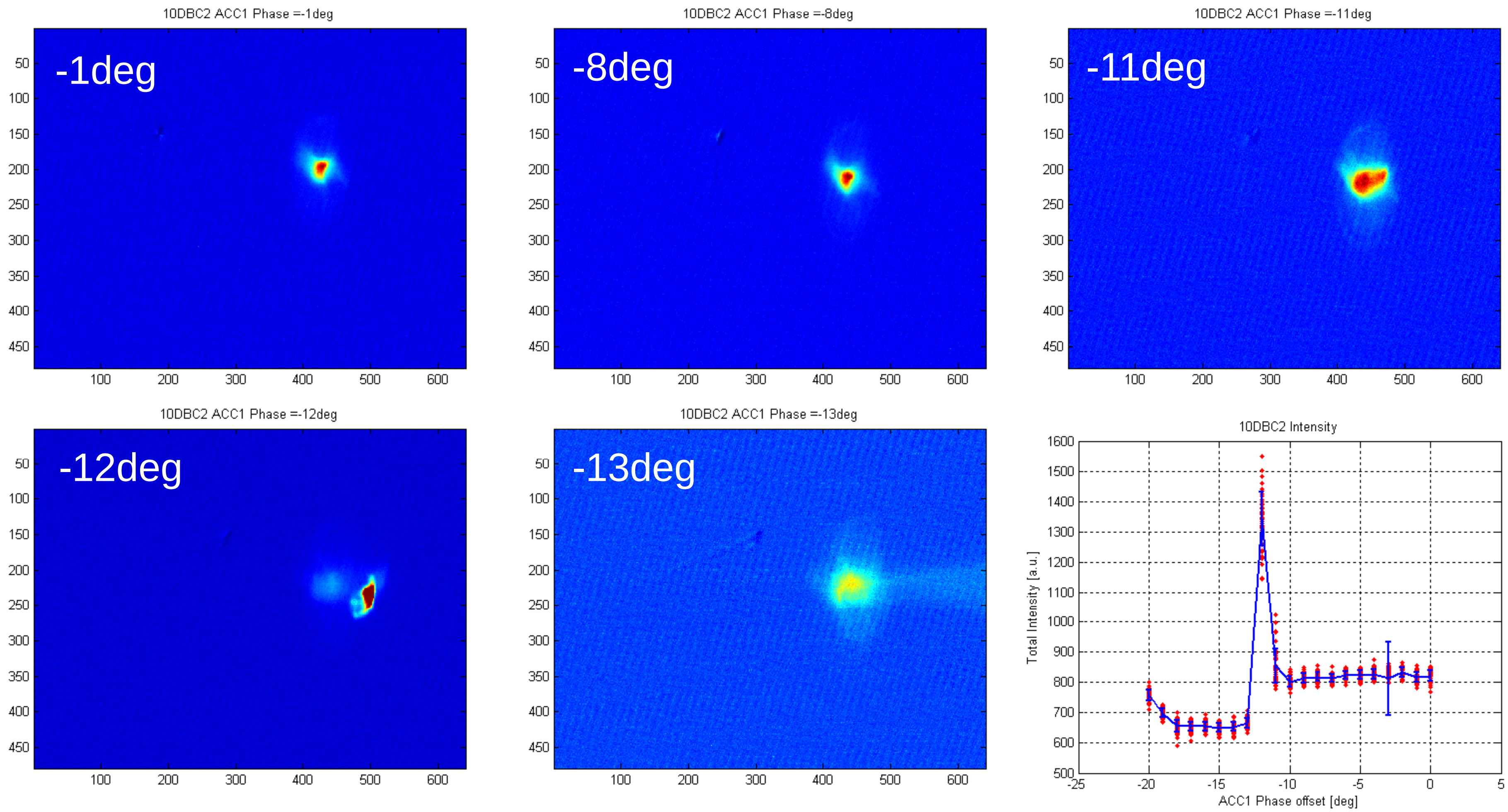
- unstable beam
- longitudinal jitter (rms) 1.1595ps
- Beam profile changes

  => phase jitter

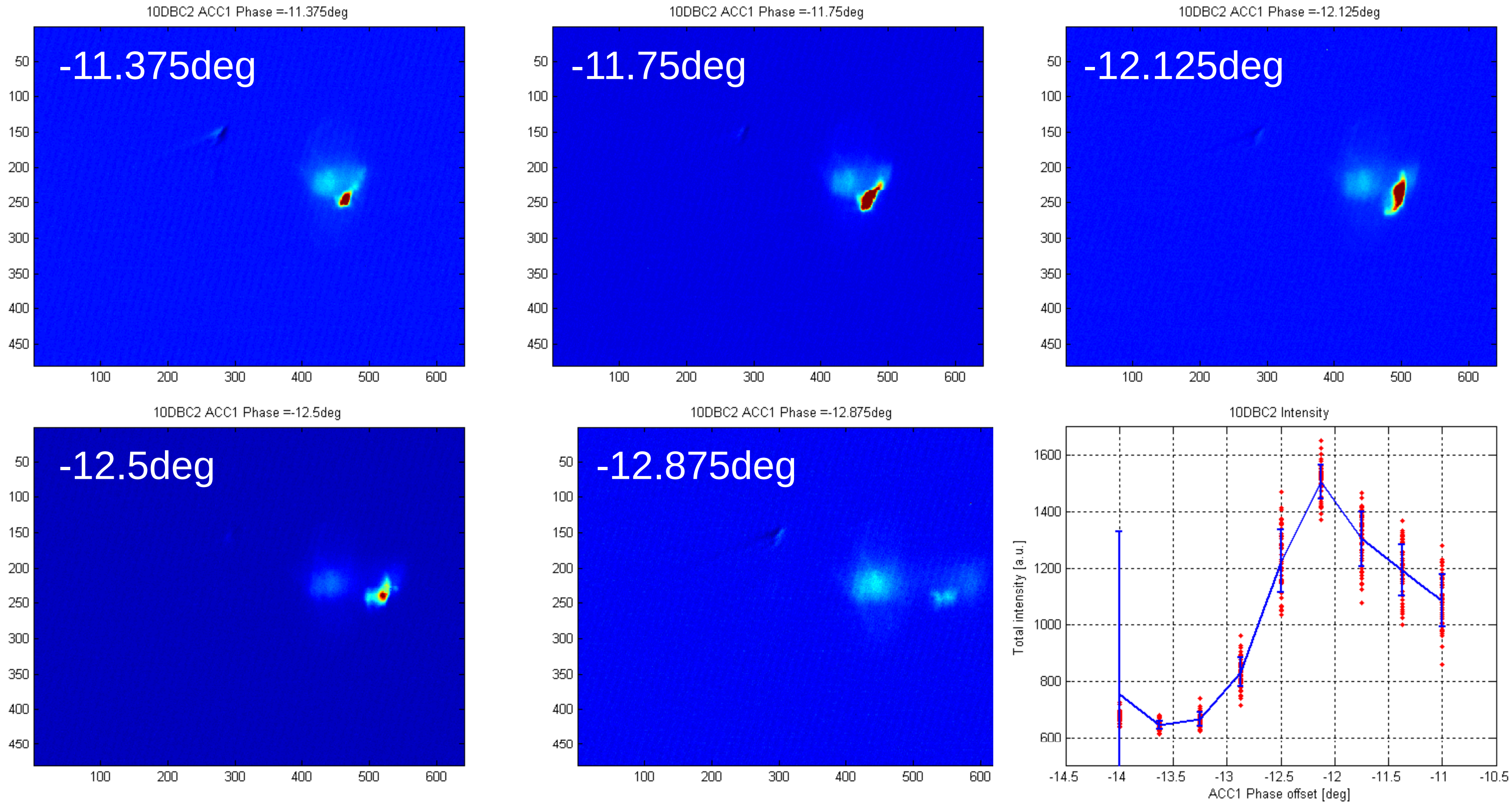
Observed beam distortions are possibly located around the leading spike. To check this COTR studies are done in normal compression mode with BC2.

OTR10DBC2 is observed while the ACC1 phase is scanned and the spot size was minimised using the FODO lattice.

COTR in standard compression?

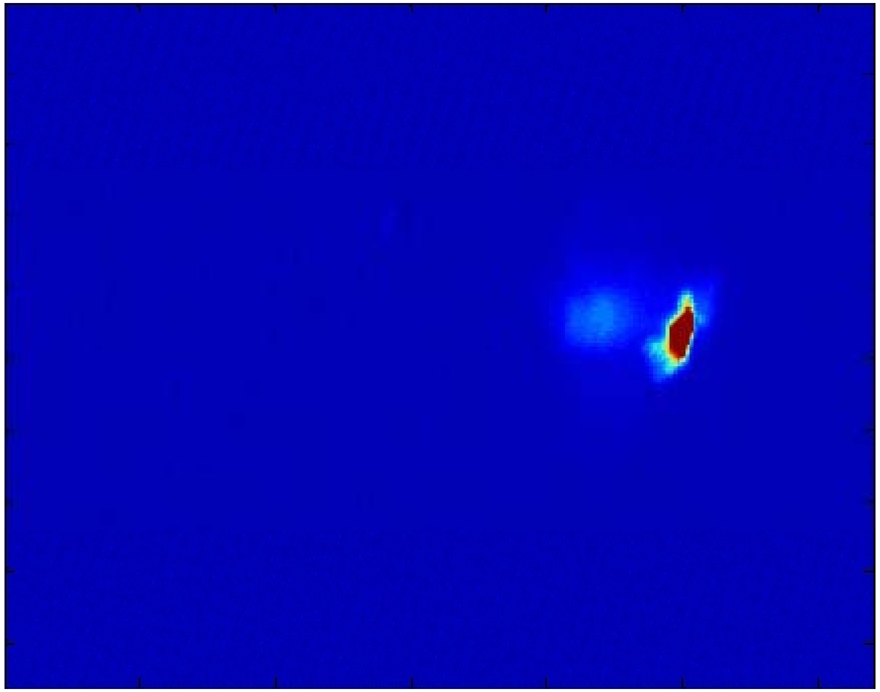


COTR in standard compression?

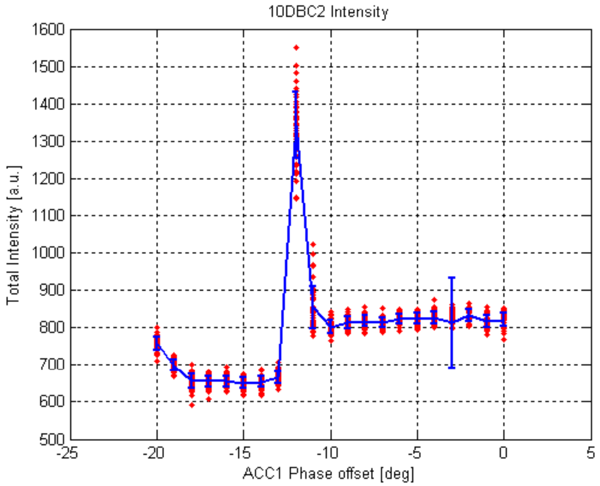


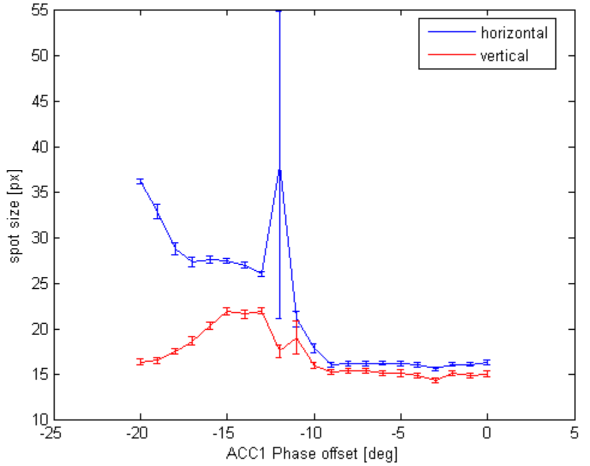
Fluctuations

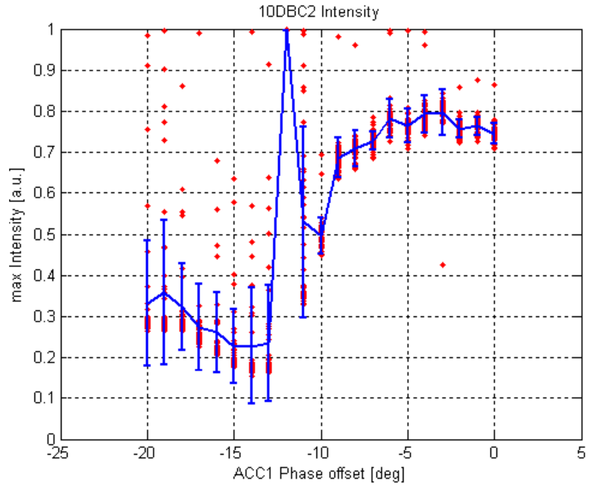
- ACC1 phase 12.125 deg



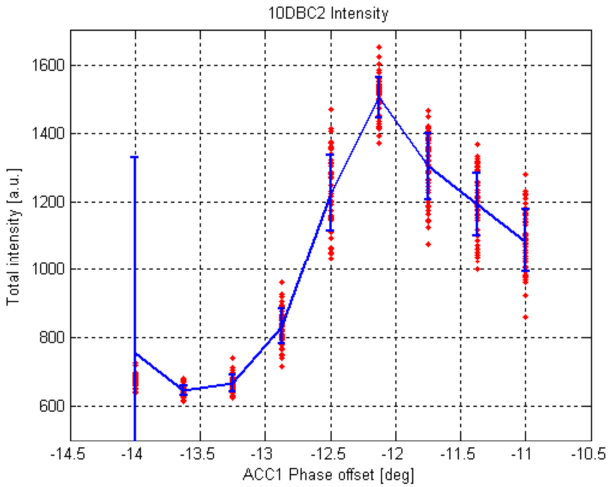
Summary

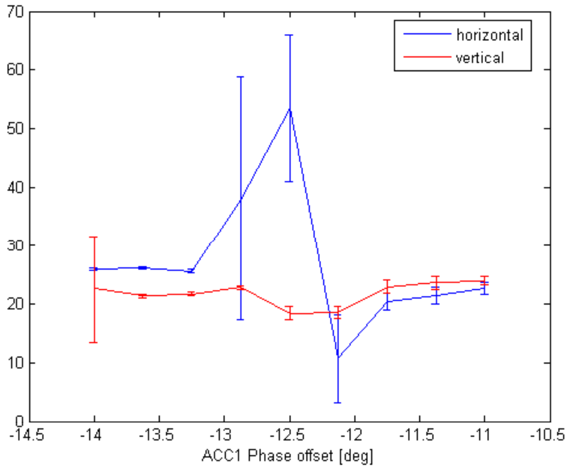


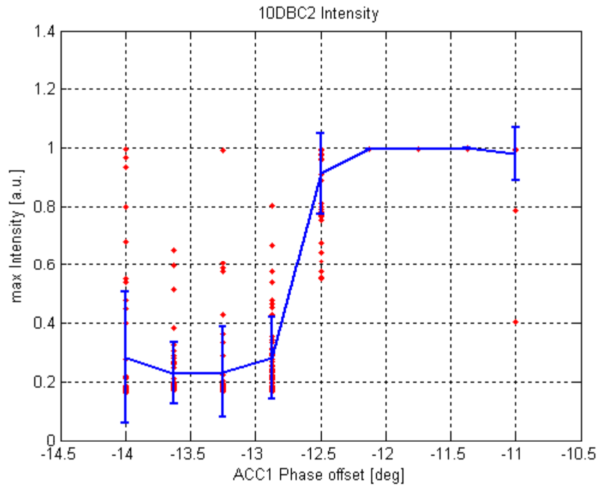




Increased spot size at “full compression” and a peak in maximum intensity

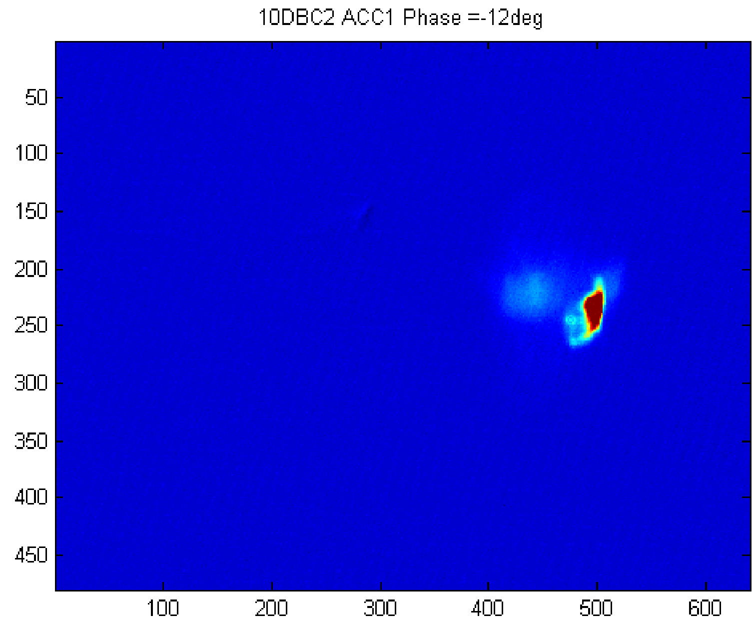


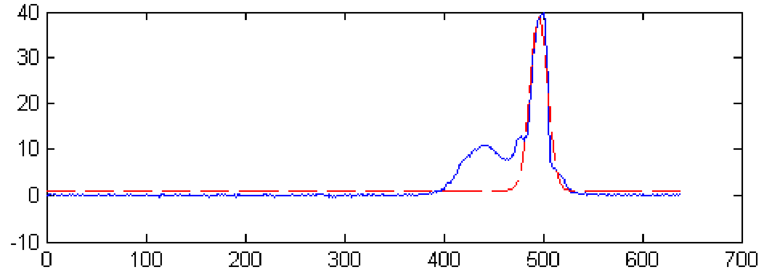


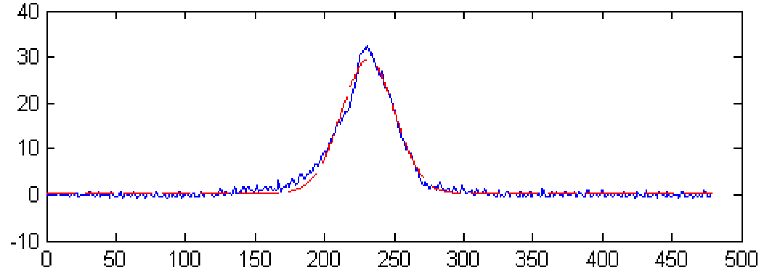


Transverse Structure

- Bright spot horizontally separated from the beam centre
  - $\Rightarrow$ Spot size?
  - $\Rightarrow$ High intensity in narrow region

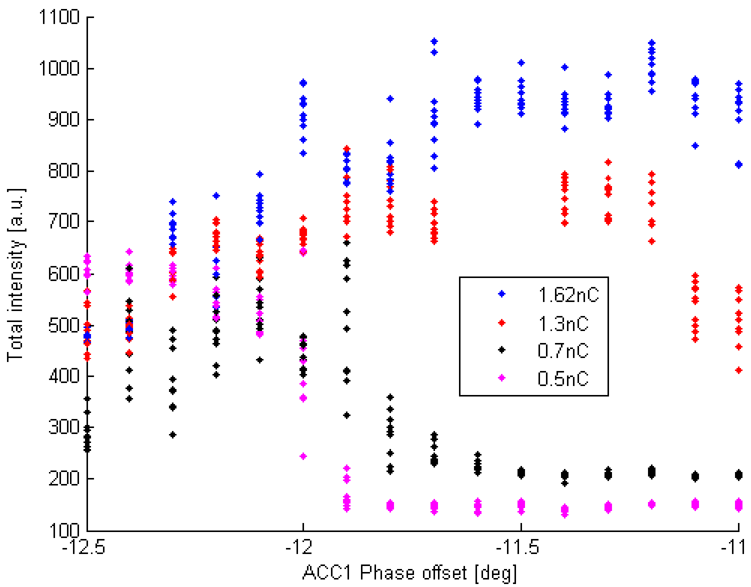


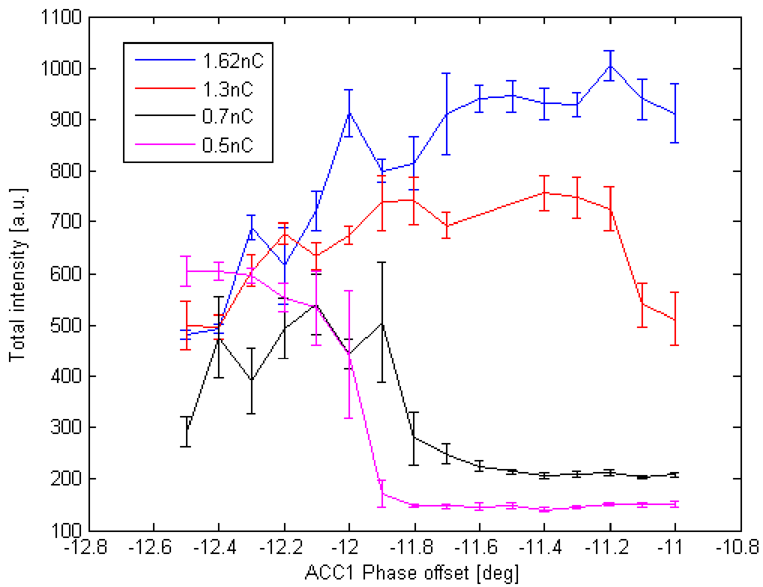




Charge Dependence

- Charge dependence study of OTR/COTR radiation
- Sharp increase of total intensity in low charge regime
- More flat intensity for high bunch charges
  - higher transverse emittance
  - Increased uncorr. energy spread
- Similar Fluctuations in all cases





Summary

- Observation of strong THz signals in predicted “microbunching mode”
- Transverse beam breakup in “microbunching mode”
- COTR radiation in “microbunching mode”
- Strong beam property changes within a few degrees of accelerating phase

- Indications for COTR in standard compression
- Studies on charge dependence of OTR/COTR radiation

Next Steps

- More detailed image analysis
  - Region of Interest
  - Advanced dark current subtraction

- Simulations
  - Start to end simulations with all known machine parameters during the measurements
  - Studies on transverse beam breakup
  - Theoretical studies on OTR/COTR radiation properties at FLASH OTR stations

Further Experiments

- Measurements without spike (BC2 darkcurrent collimator)
- Detailed studies on beam breakup (dispersion, energy spread)
- Further OTR studies after BC2, BC3, and the dogleg to confirm the 10DBC2 COTR interpretation
- Measurements with the FIR undulator

Thank you for your Attention

and

Special thanks to V. Ayvazyan, M. Huening, O. Grimm, B. Schmidt, S. Wesch, C. Behrens, H. Delsim-Hashemi.