Short Bunches at FLASH

T. Limberg

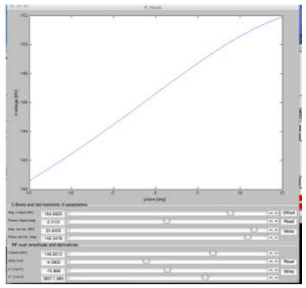
Short Bunches at FLASH

Outline

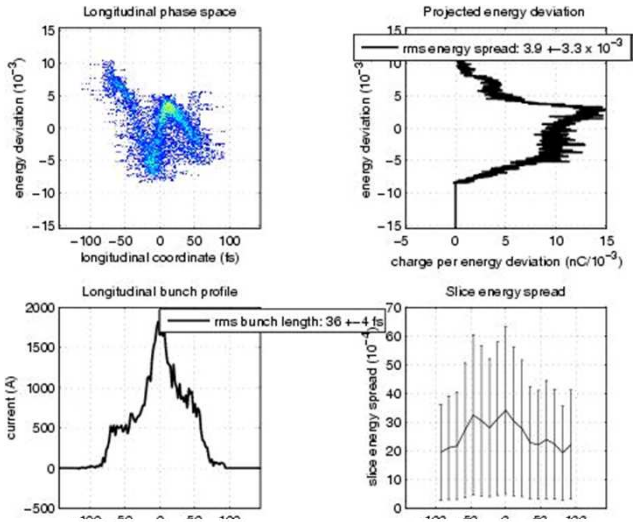
- Start-2-End Simulations and a fast Model for Longitudinal Phase Space Simulations
- Dedicated Benchmark Studies Analysis
- Machine Set Up for Short Bunches with Subsequent Photon Pulse Length Measurements

Short Bunches at FLASH

FLASH Bunch Compression Scheme

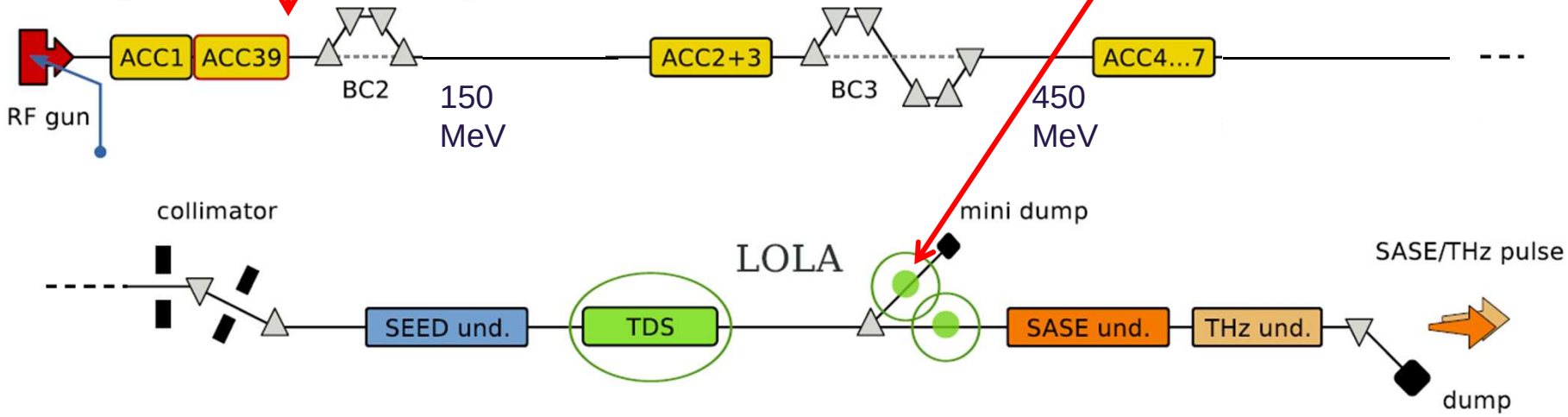


$$\begin{bmatrix} BeamEnergy \\ Chirp\ (V_{sum}{}') \\ V_{sum}{}'' \\ V_{sum}{}''' \end{bmatrix} = F(A_{ACC1}, \varphi_{ACC1}, A_{ACC39}, \varphi_{ACC39})$$



$A_{ACC2/3}$, $\varphi_{ACC2/3}$

35 fs



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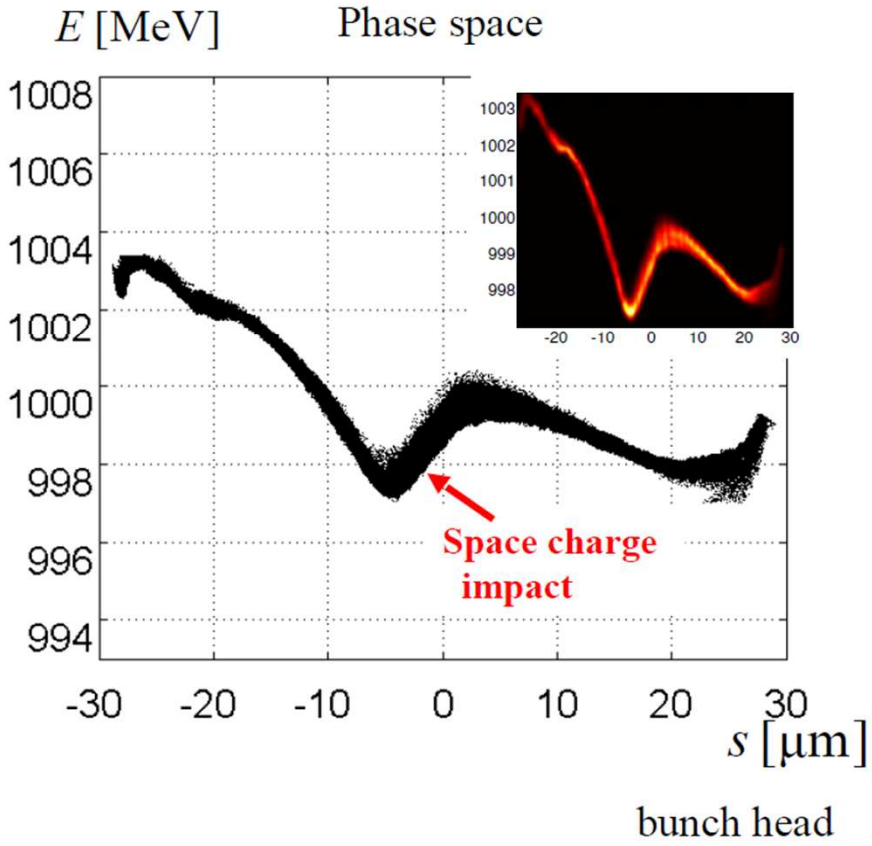
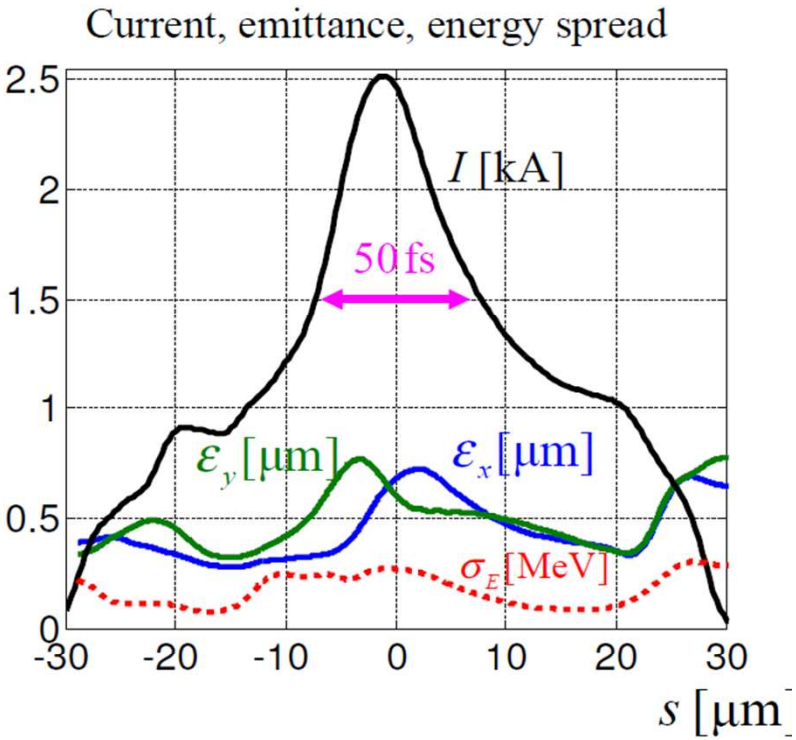
S2E with 250 pC Bunch Charge (I. Zagorodnov)





$$\varepsilon_x^{proj} = 1.14\,[\mu m]$$

$$\varepsilon_y^{proj} = 0.74\,[\mu m]$$

Numerically expensive, optimized parameter set

Photon Pulse Length (FWHM) : 17 fs

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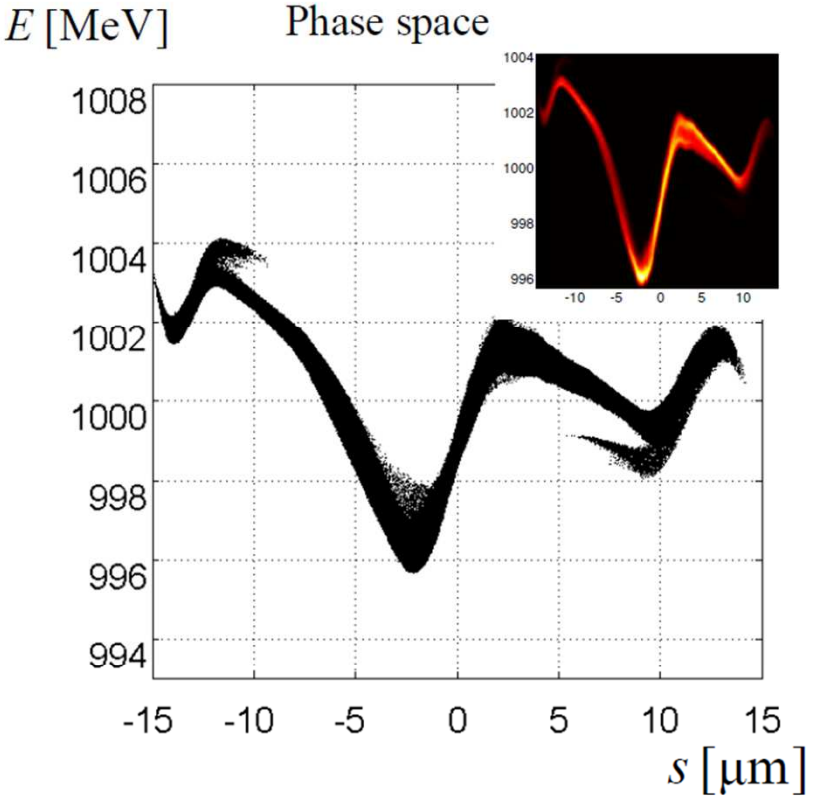
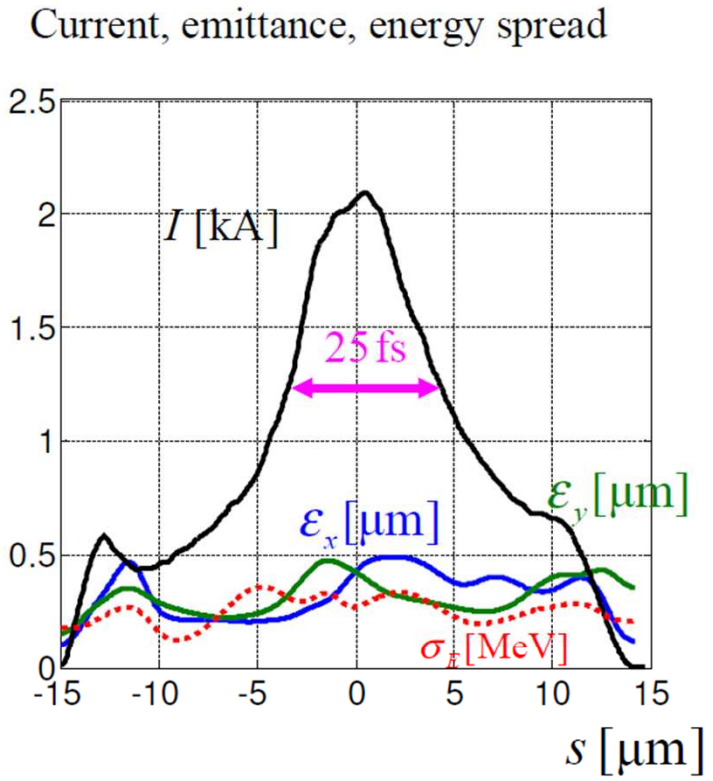
S2E with 100 pC Bunch Charge





$$\varepsilon_x^{proj} = 2\,[\mu\text{m}]$$

$$\varepsilon_y^{proj} = 0.6\,[\mu\text{m}]$$

Photon Pulse Length (FWHM) : 7 fs

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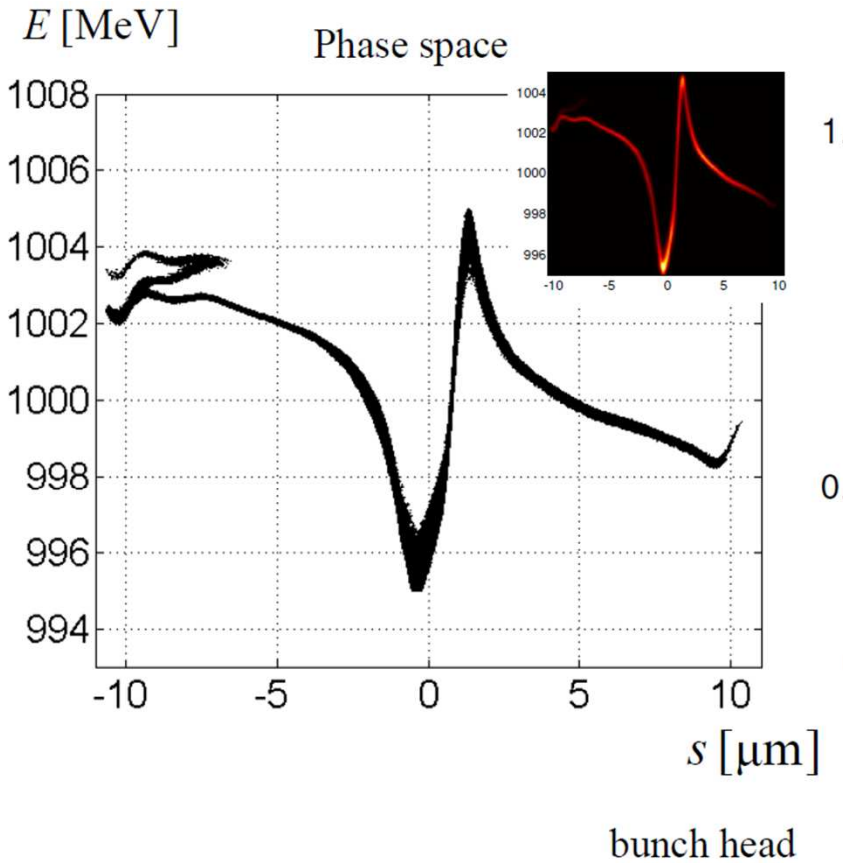
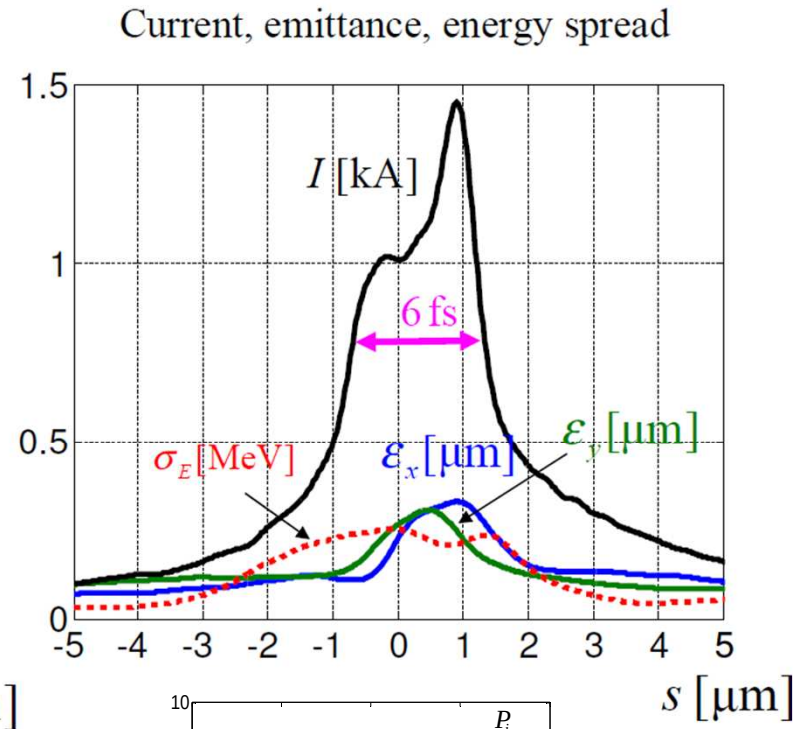
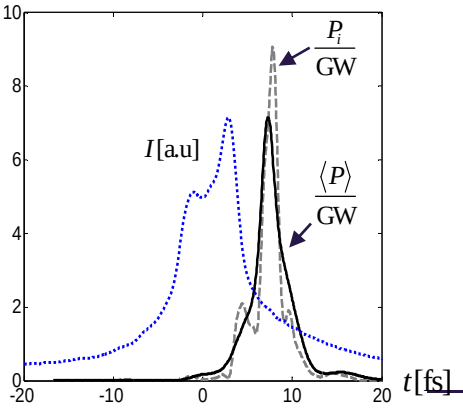
S2E with 20 pC Bunch Charge



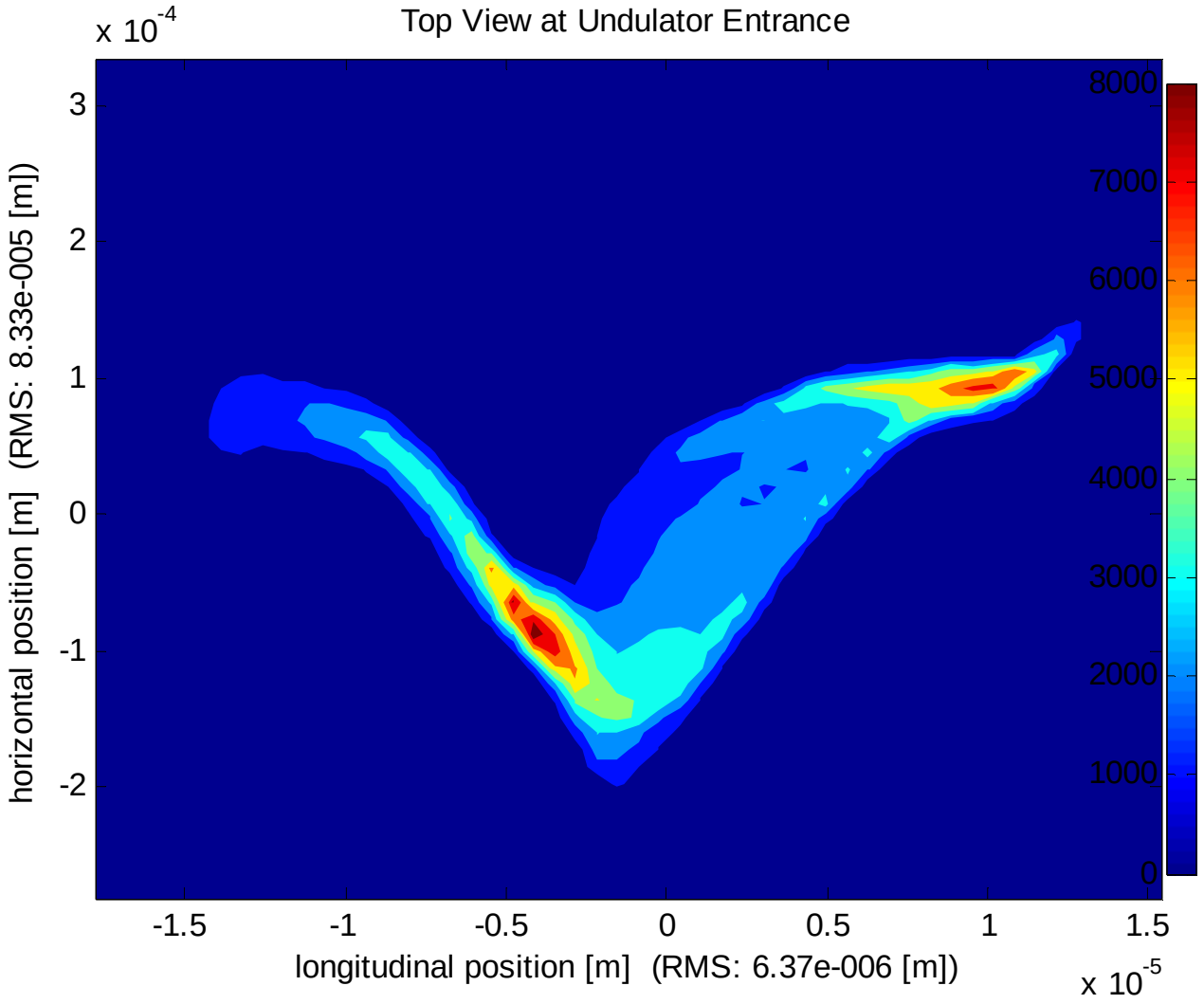




Photon Pulse Length (FWHM) : 2 fs

Short Bunches at FLASH

E-Bunch Length and Photon Pulse Length



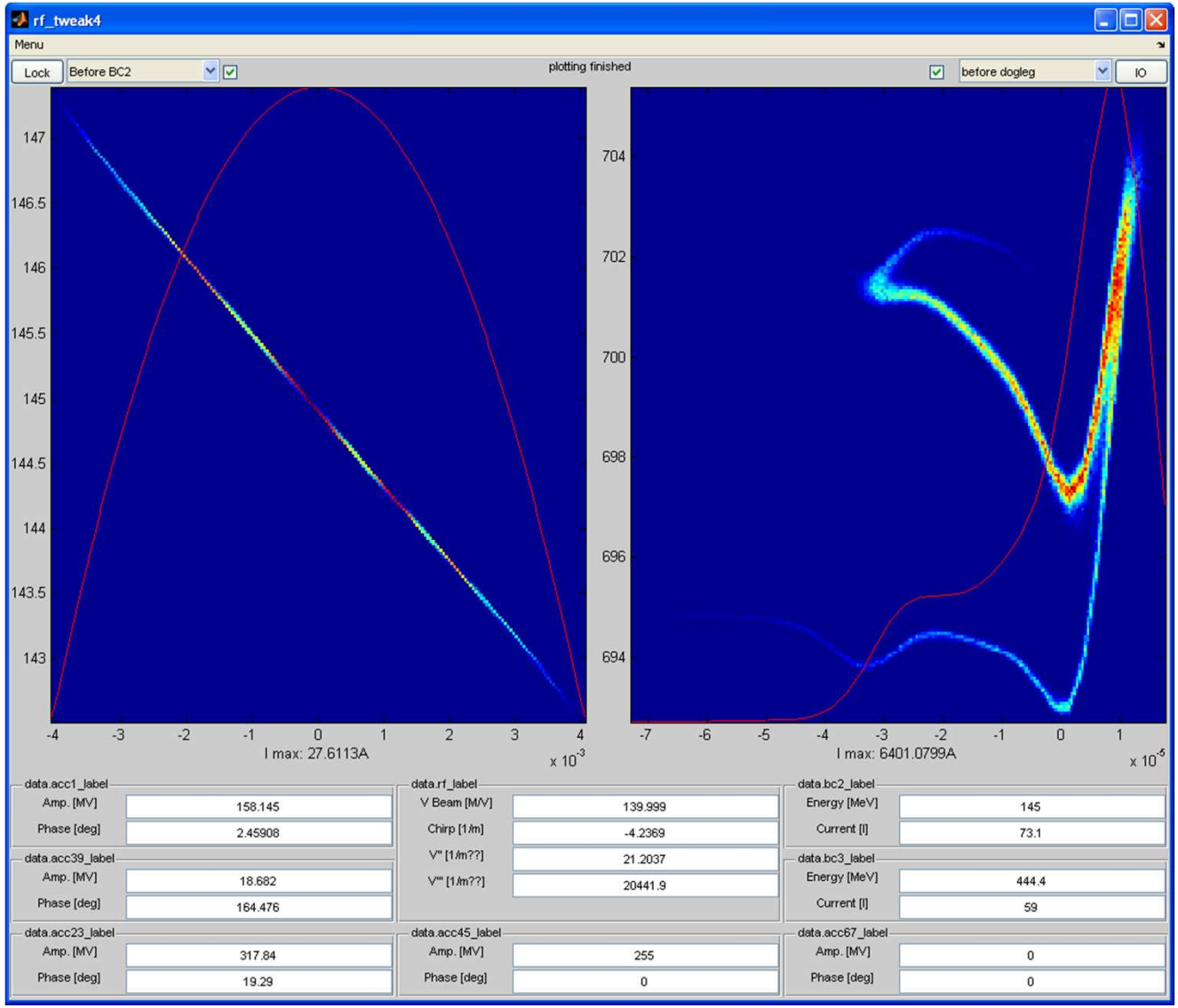
100 pC

Photon pulse length can be reduced by:

- transverse offsets
- energy offsets
- local emittance blow-up
- …

Short Bunches at FLASH

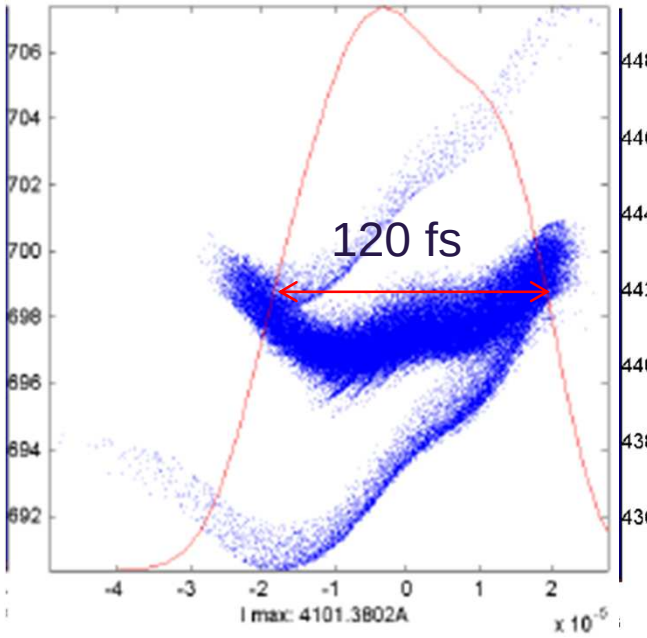
Fast Model for longitudinal Phase Space

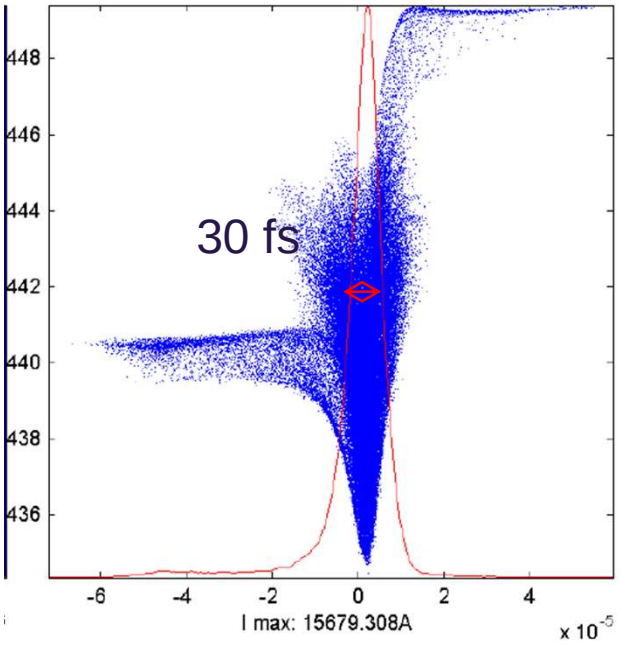


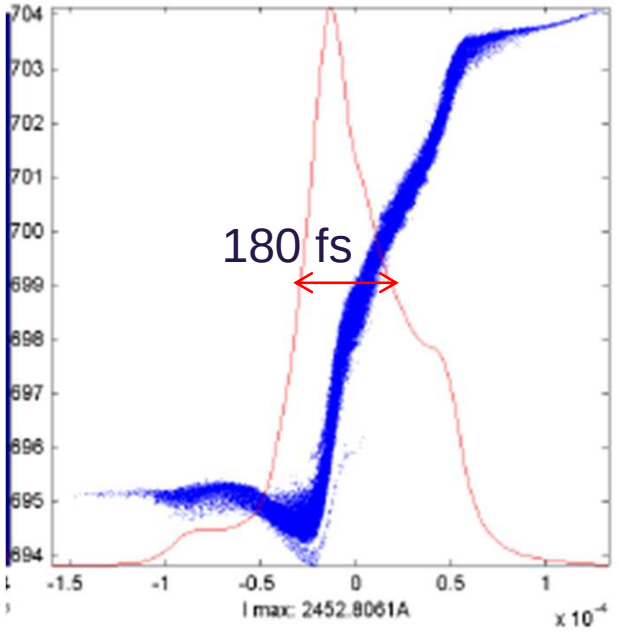
Short Bunches at FLASH

Bunch Shape after Compression vs. First Linac Section Chirp (500 pC)

Minimum bunch length limited
by non-linearities







ACC1-Phase: 2.51 deg

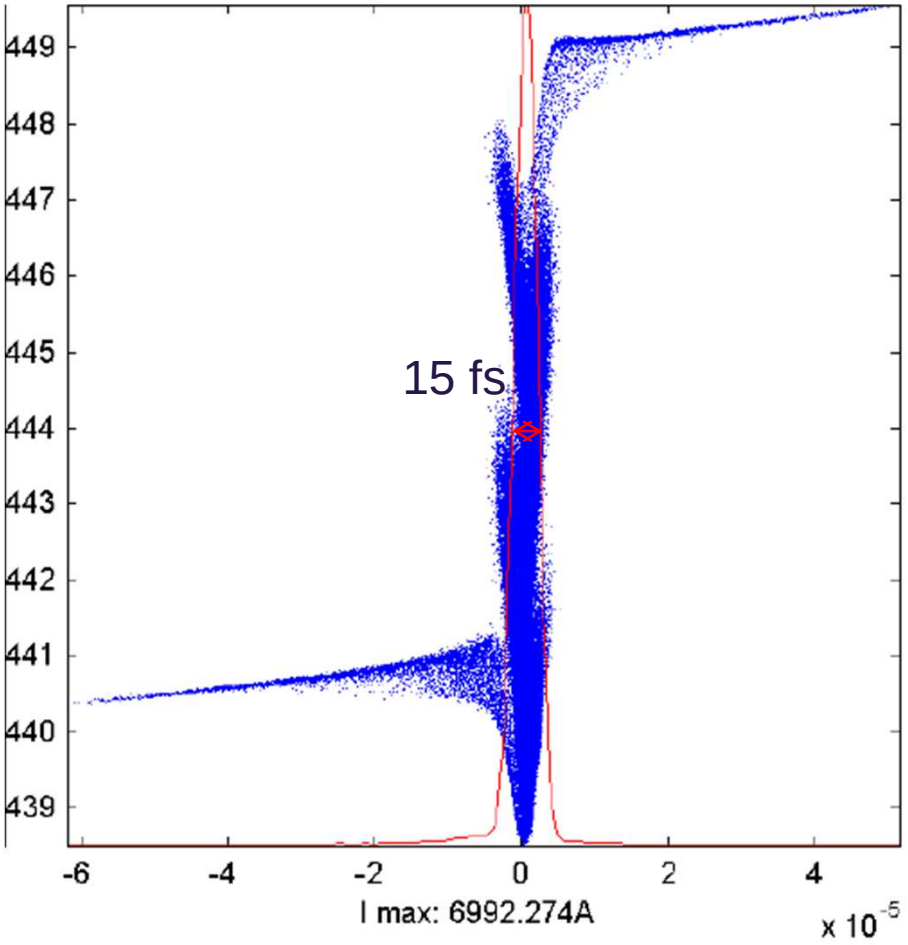
ACC1-Phase: 2.6 deg

ACC1-Phase: 2.8 deg

Stability and Tuning Issue

Short Bunches at FLASH

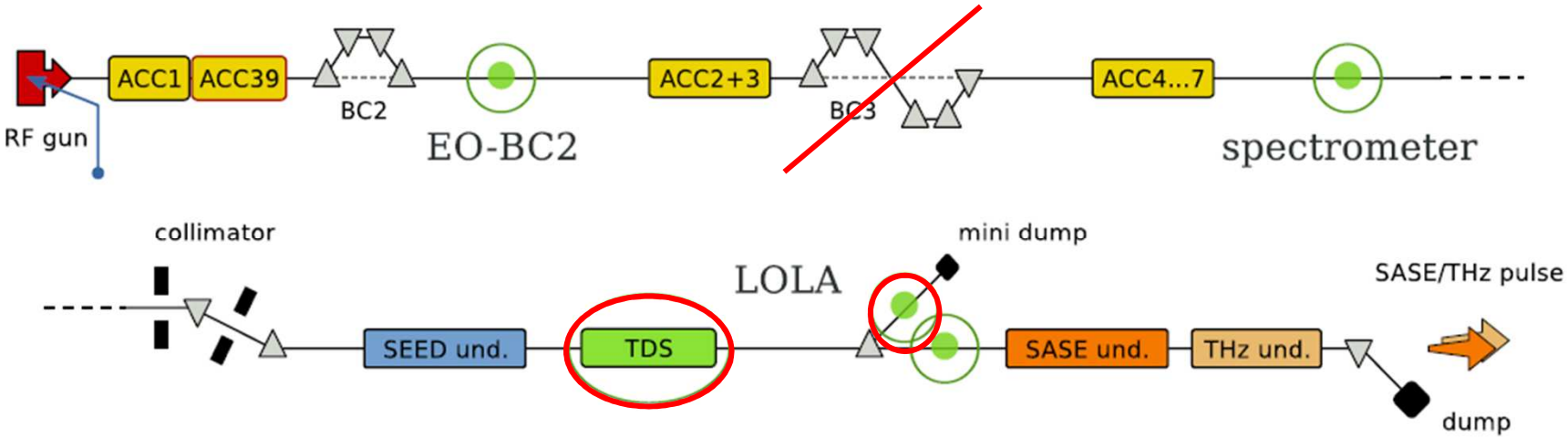
Bunch Shape after Compression (100 pC)



Short Bunches at FLASH

Study by Helen Edwards et al.

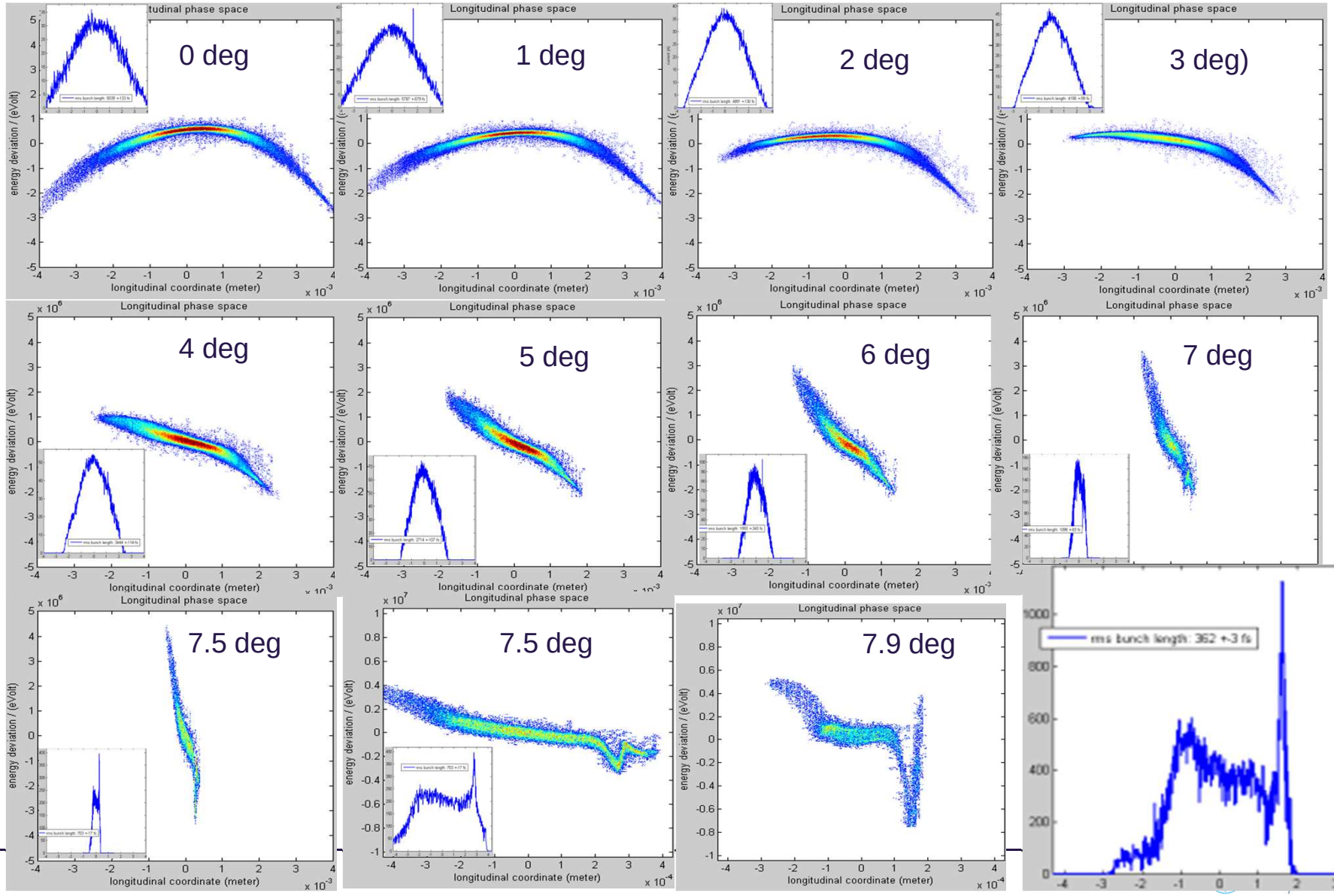
- Only BC-2 is on
- Bunch shape and length as measured with transverse deflecting cavity (LOLA) vs. ACC1/ACC39 phase



FEL Beam Dynamics

Short Bunches at FLASH

Longitudinal Phase Space and Profile vs. Energy Chirp (ACC1 phase monitored)

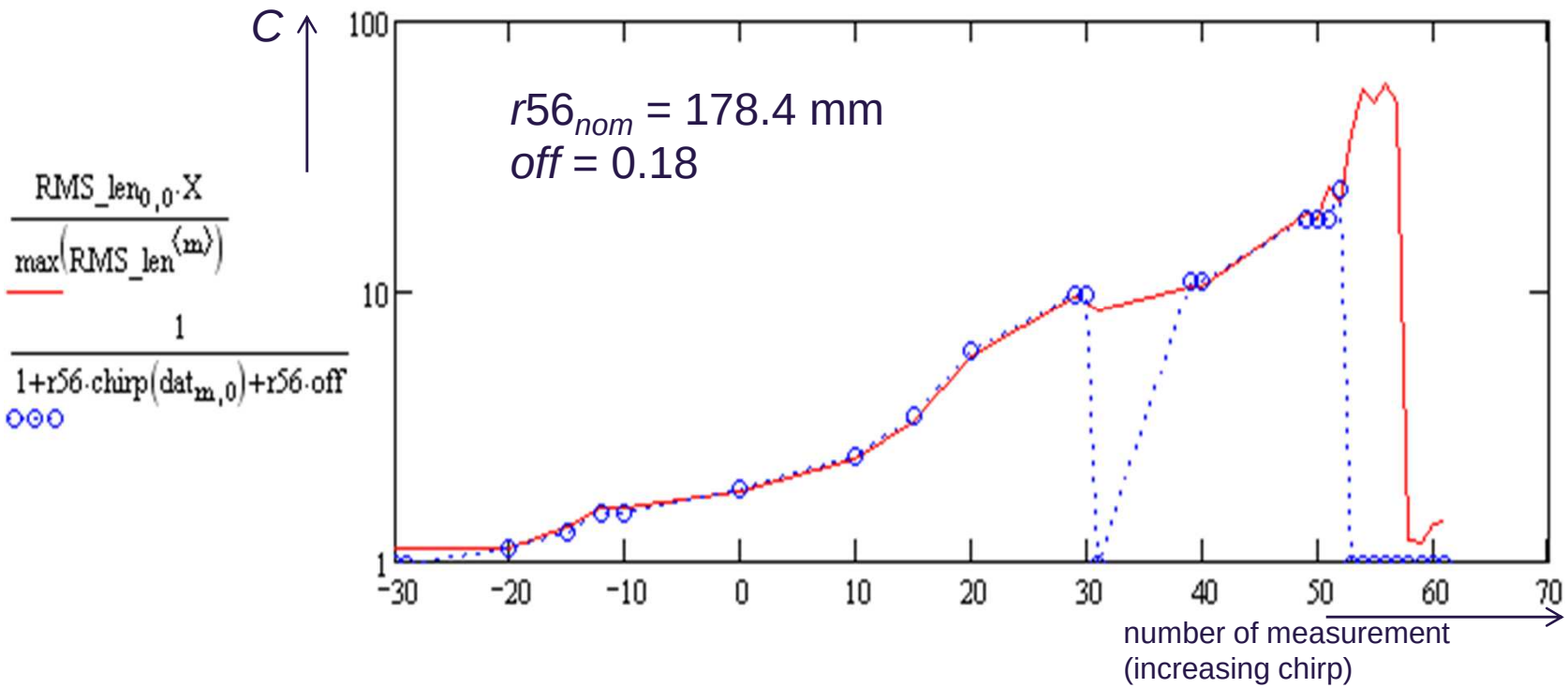


Short Bunches at FLASH

Measured and calculated compression factor (without self-effects)

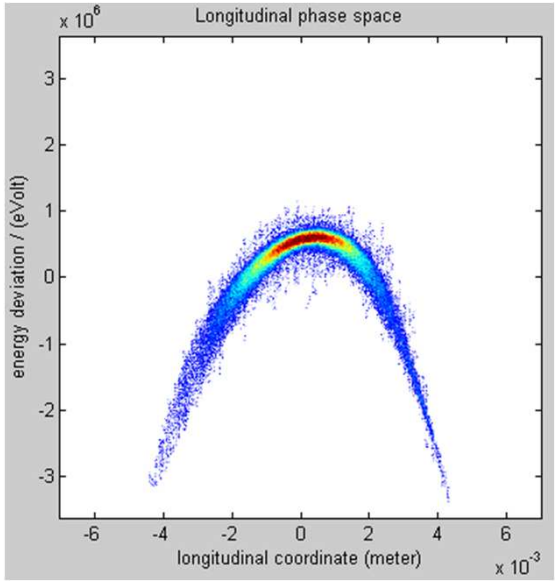
Small additional chirp and 10% correction of LOLA energy calibration:

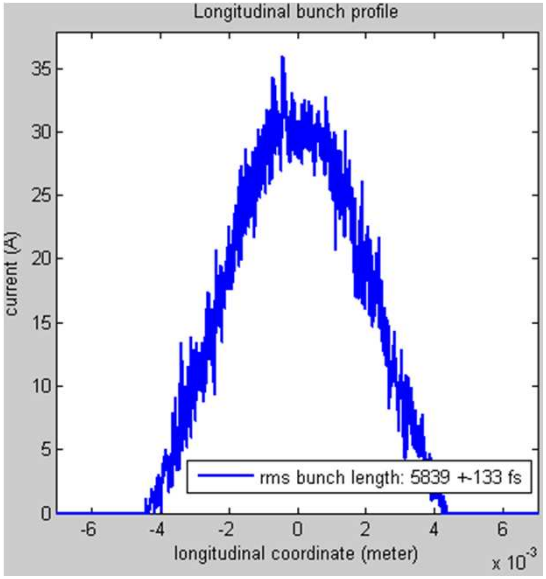
M. Dohlus

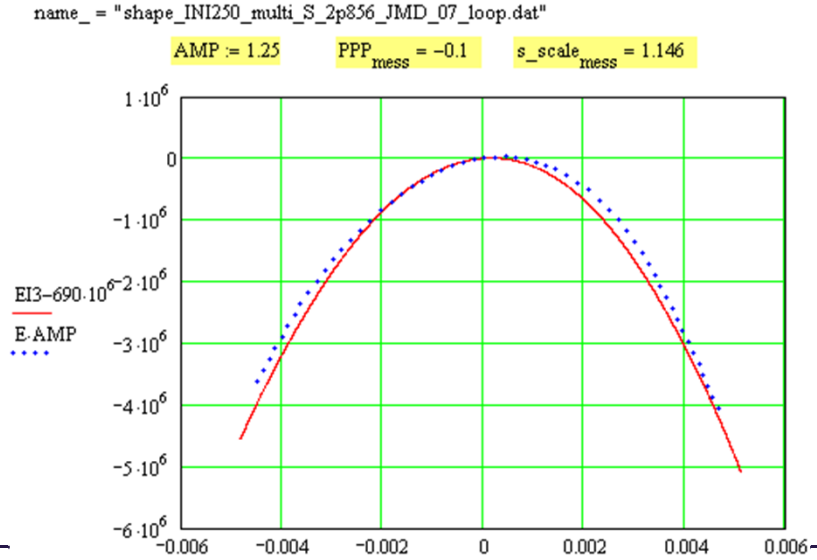


Short Bunches at FLASH

On crest

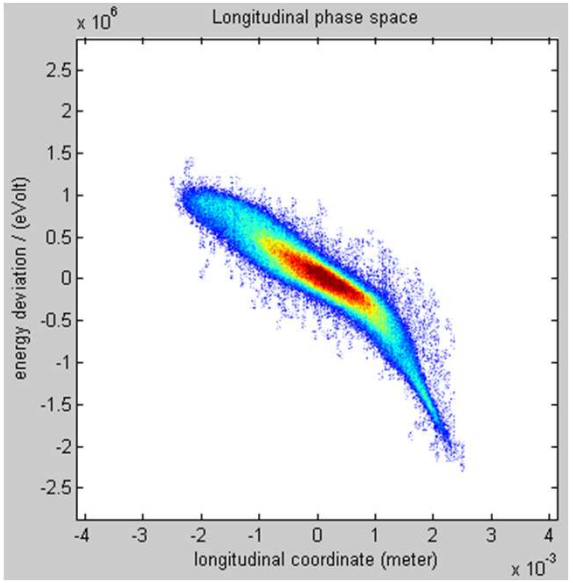


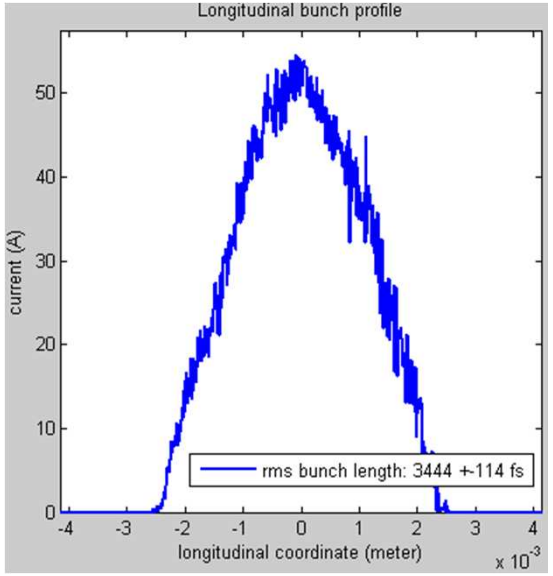


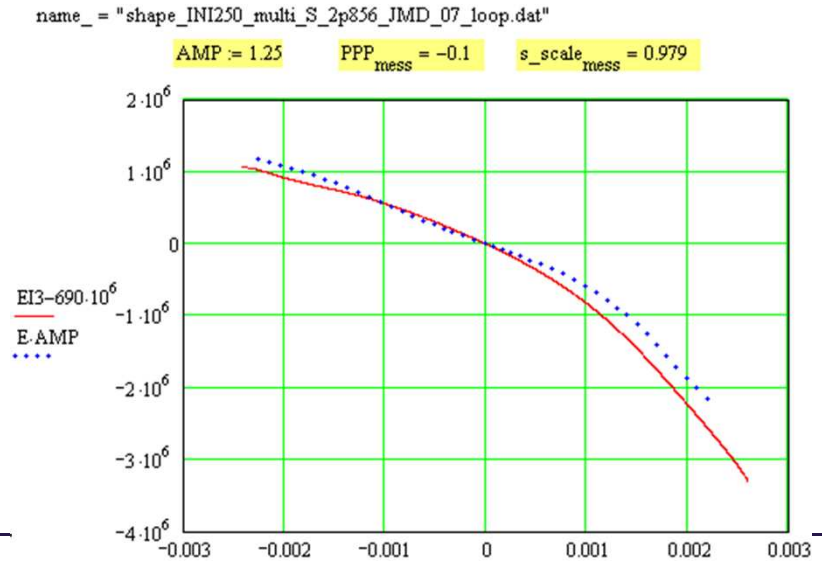


Short Bunches at FLASH

Compressed to ca. 50 A



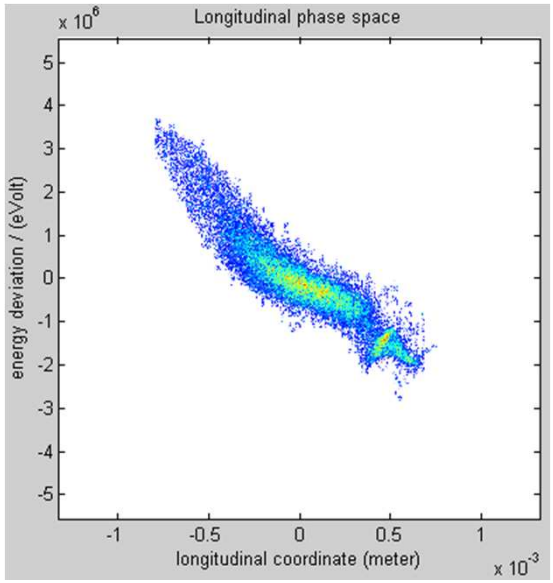


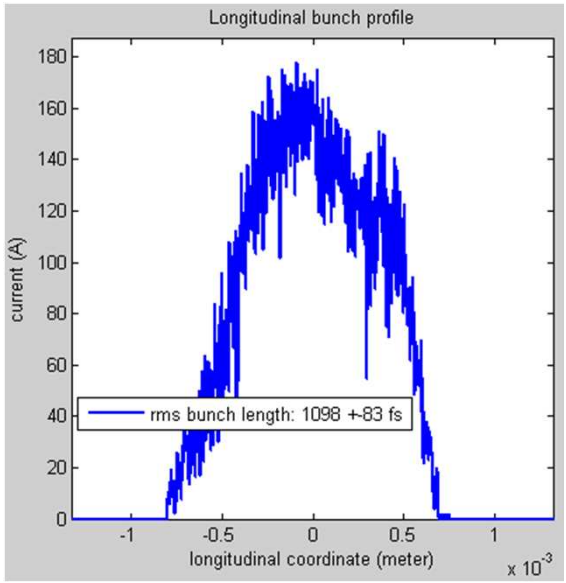


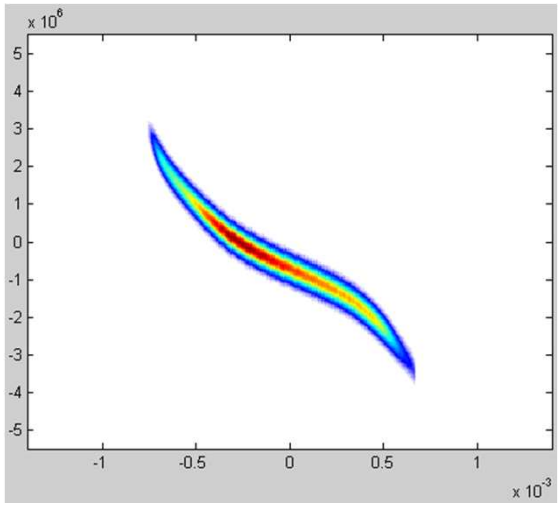
No self-effects

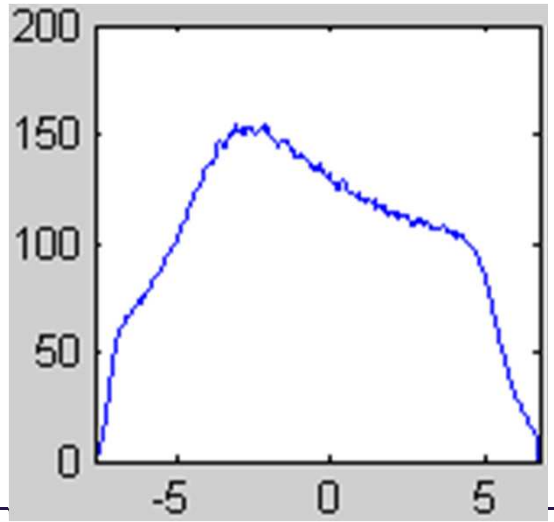
Short Bunches at FLASH

Compressed to ca. 150 A





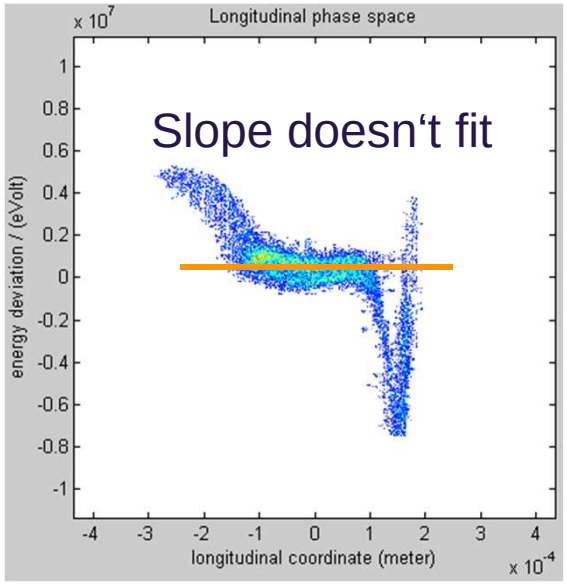


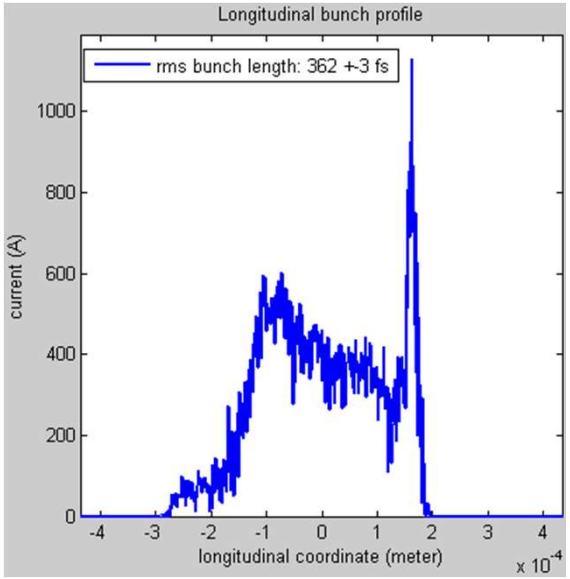


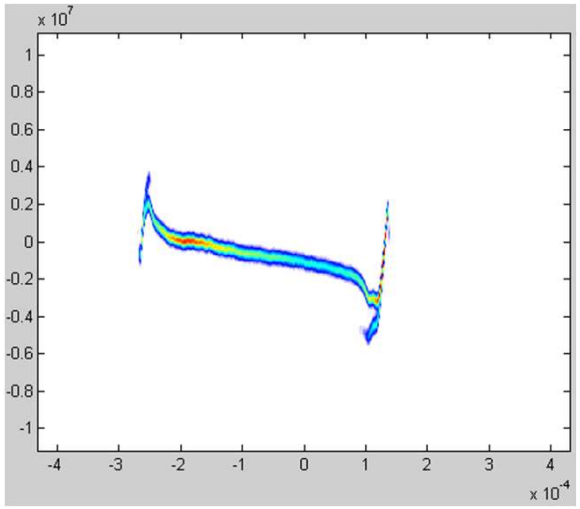
With self-effects

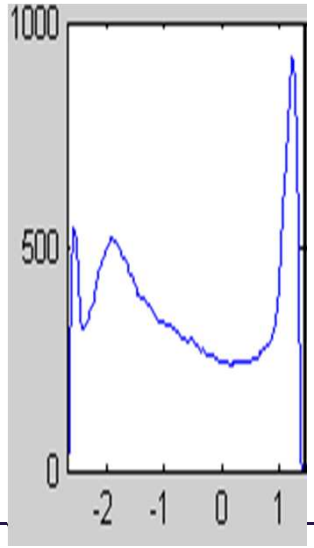
Short Bunches at FLASH

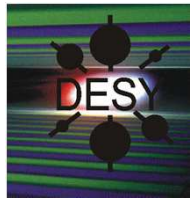
1kA Spike











Tuning and characterization of short electron and FEL radiation pulses at FLASH during shifts 19(a)-21(m).01.2011

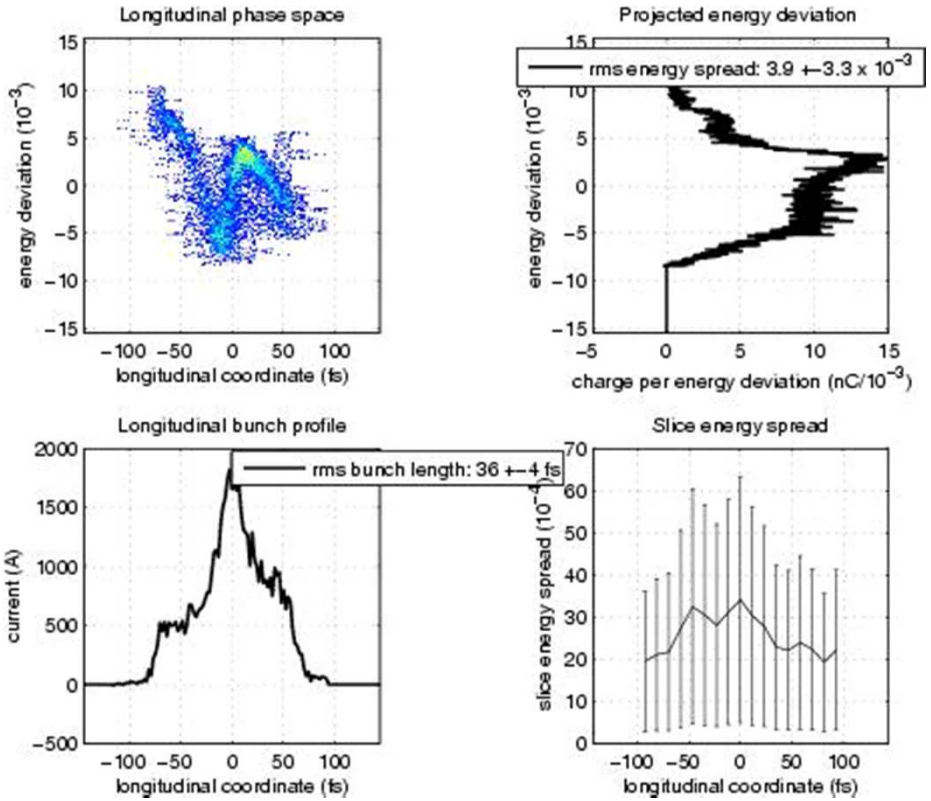
E. Schneidmiller and M. Yurkov (SASE & MCP)

C. Behrens, W. Decking, H. Delsim , T. Limberg, R. Kammering (rf & LOLA)

N. Guerassimova and R. Treusch (PGM & GMD)

Short Bunches at FLASH

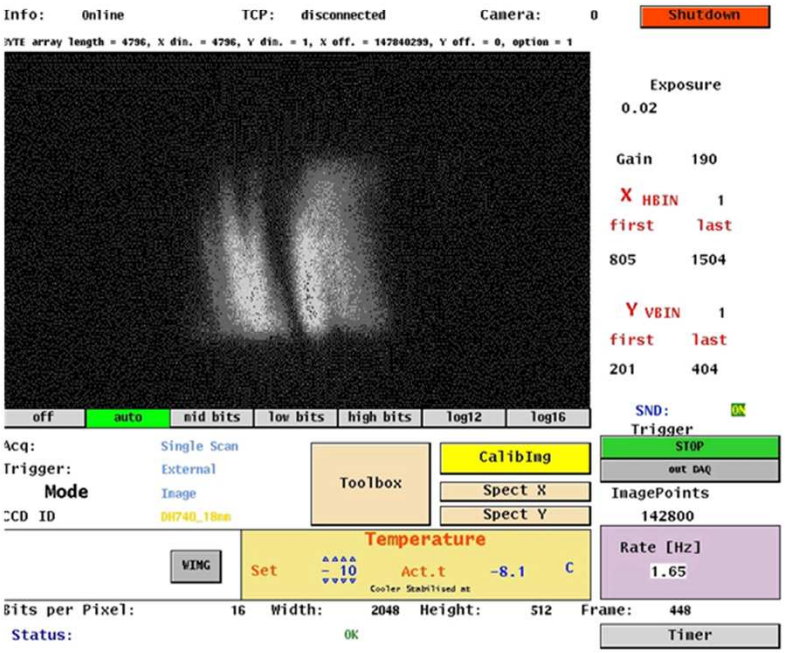
Bunch-Length-Tuning (differential): 150 pC

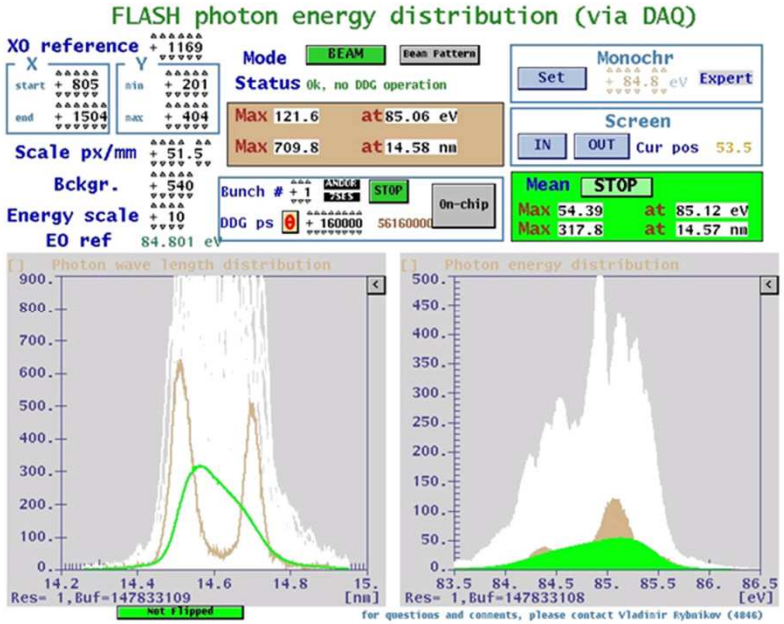


Short Bunches at FLASH

Bunch-Length-Tuning: Spectra and Statistics

- Statistical measurements agree qualitatively with spectral measurements .
- 150 pC sigma = 60% M = 2.8 T_rad ~ 15 fs (+10 fs + 7 fs)





Short Bunches at FLASH
Results from another shift block
(compiled by S. Schreiber (still preliminary))

	FEL Pulse duration in fs (FWHM)			
	0.5 nC	0.25 nC	0.15 nC	
Statistical method	100		35-40	
THz streak		50 – 70		Preliminary estimate
Spectrometer	100		20	20/-/3-4 spikes
Afterburner	170–200		25-70	FROG resolution 25 fs
	Estimate from electron pulse (FWHM, e^- length / 2)			
Coherent radiation			50	
LOLA	150	50 – 70	35	

- In general good agreement for the short pulses - within a factor of 2
- Larger uncertainties for longer pulses

Short Bunches at FLASH

Tuning Issues

- Longitudinal bunch shape changes with pulse train length, but LOLA can take only one bunch
  - Under study/development: UV Pockels cell
- Uncertainty in absolute rf phases
  - Beam Arrival-time Monitors help
- rf drifts
  - LLRF hardware and software upgrades improved situation significantly
- Instrumentation specified and designed for the original design charge of 1 nC

Short Bunches at FLASH

Peak Current for Short Pulses (Gaussian like)

Charge [pC]	Peak Current [kA] E-Bunch <100 fs FWHM	Peak Current [kA] E-Bunch <50 fs FWHM
1000	8.4	16.8
500	4.2	8.4
250	2.1	4.2
100	0.8	1.6

From S2E: At short bunches, peak currents of 2 kA already increase slice emittance.

From SASE Simulations: Peak currents of 1.5 - 2 kA needed for saturation (at least for the shorter wave lengths)

In the charge regime below 250 pC, SASE intensity and very short bunch length should go together

Summary and Remarks

- The tools and methods to tune bunch length exist and have passed first tests
- Extensive feedback from users about photon beam quality is important
- An on-line photon pulse length and pulse shape measurement would be of great help