Studies with Ultra-Short Pulses

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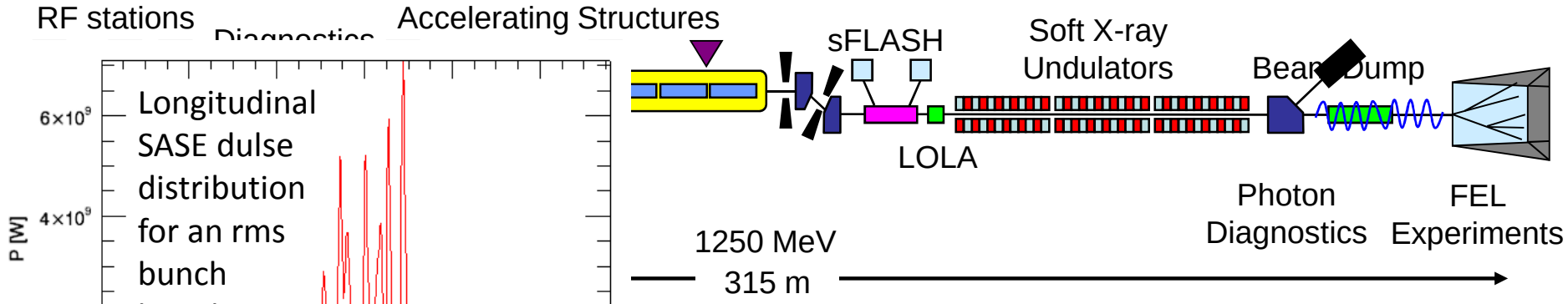
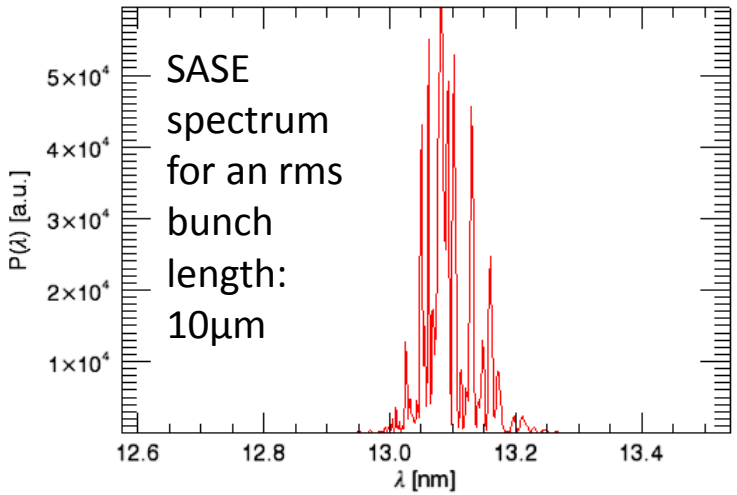
FLASH





FEL Radiation Parameters 2012	
Wavelength range (fundamental)	4.2 – 45 nm
Average single pulse energy	10 – 500 µJ
Pulse duration (FWHM)	30 – 200 fs
Peak power (from av.)	1 – 3 GW
Spectral width (FWHM)	~ 0.7 – 2 %
Photons per pulse	10^{11} – 10^{13}
Average Brilliance	10^{17} – 10^{21} *
Peak Brilliance	10^{29} – 10^{31} *

* photons/s/mrad²/mm²/0.1%bw

Typical bunch charges: 0.08-1 nC

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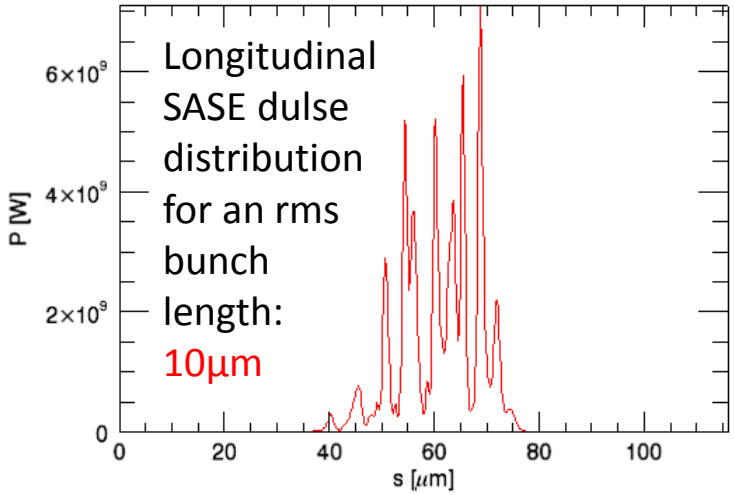
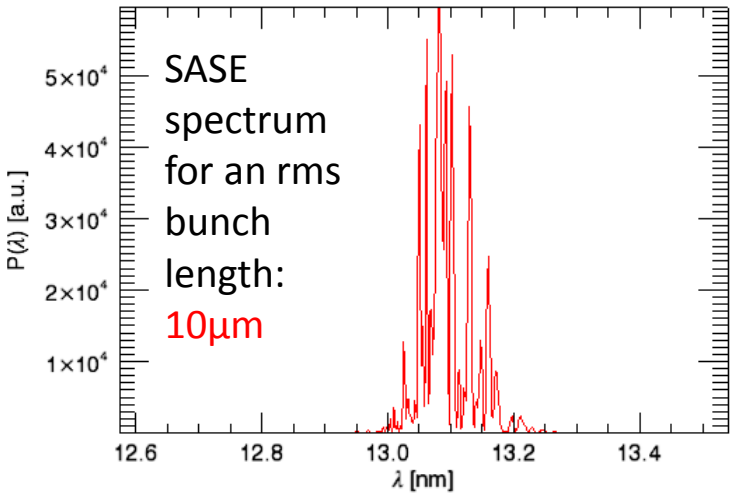
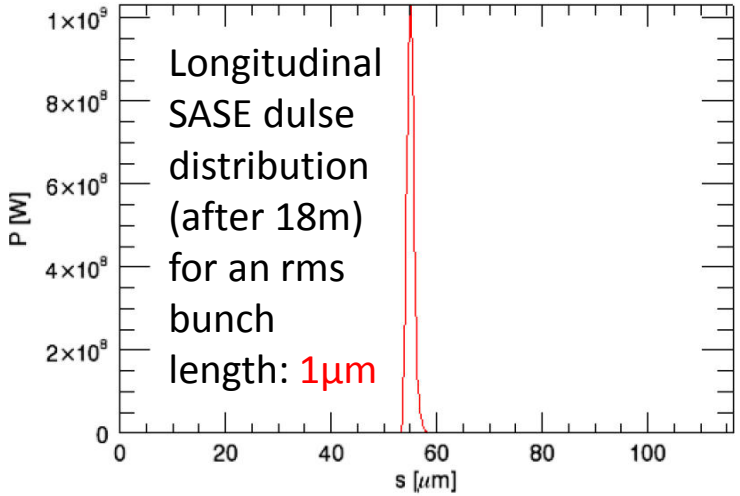
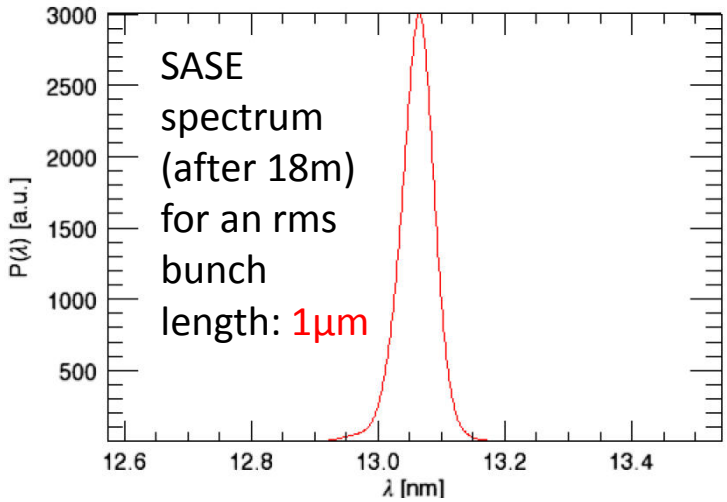
Short pulses at FLASH









Courtesy of M. Rehders

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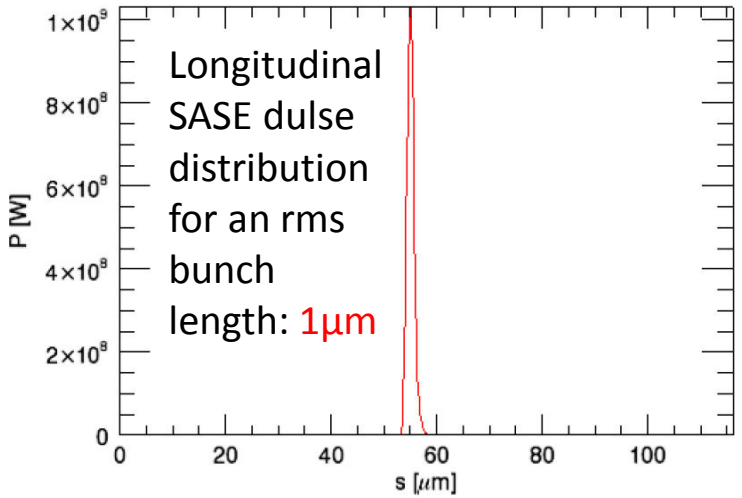
Short pulses at FLASH

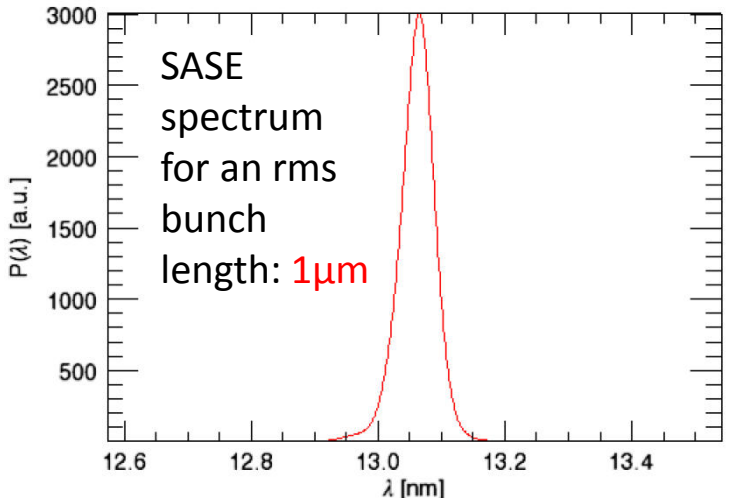
- **Shortest possible SASE pulse duration:**
  - **single-spike operation**: electron bunch length of one longitudinal optical mode

- Condition to be fulfilled: $\sigma_b \leq 2\pi L_c = \frac{\lambda}{2\sqrt{3}\rho}$

➢ generation of single spike, bandwidth limited, longitudinal coherent FEL pulses in SASE mode

➢ short-pulse application mostly do not rely on a high photon count, but some applications are sensitive on the photon flux, requiring **no long background signa**l.





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Short pulses at FLASH

	Typ. FLASH parameters
Injector laser pulse duration (FWHM)	15.3 ps
Bunch charge	0.08 - 1 nC
Bunch duration (rms)	30 - 200 fs
compression	220 - 32.5
FEL pulse duration (FWHM)	30 - 200 fs

For FLASH:
bunch length: ~ 3 fs
→ due space charge forces the bunch charge has to be reduced: ~ 20 pC

➢ **Shorter photo-injector laser pulse is required**
a large compression factor (~1000) cause RF tolerances of 0.0014° phase tolerance (3fs!) and 0.003% amplitude tolerance

New injector laser

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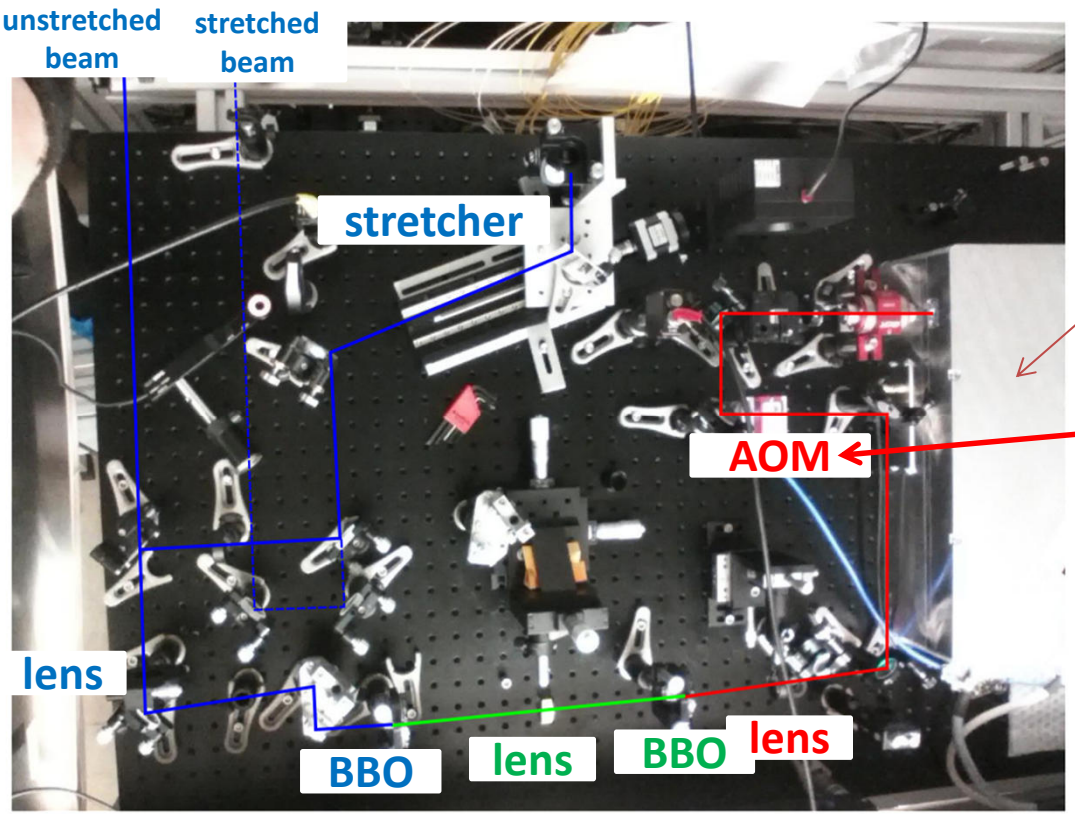
Short pulse injector laser



Goal parameter

Amplified Laser System:

- Seed laser Origami 10 (OneFive)
  - 1030nm, 260mW, 54MHz, 400fs
- 2 stage amplifier (Amphos)
  - 1030nm, 10W, 1MHz, ~600fs (10µJ)

Acousto-optic modulator (AOM) - pulse picker (pulse trains of 10Hz, with 1MHz pulse repetition)

2 BBOs (forth harmonic)
- 1030nm -> 257.5nm
- (10% efficiency @ 10µJ) -> 1µJ

Even the maximum reached efficiency of the fourth harmonic generation was only 1% instead of 10%, enough charge could be produced with a sufficiently adequate transverse distribution.

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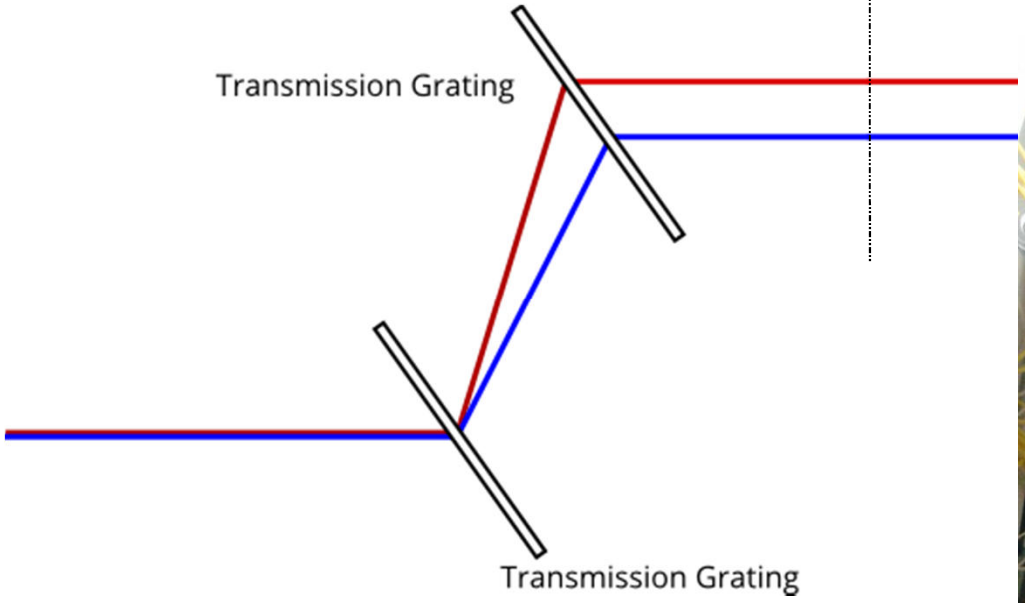
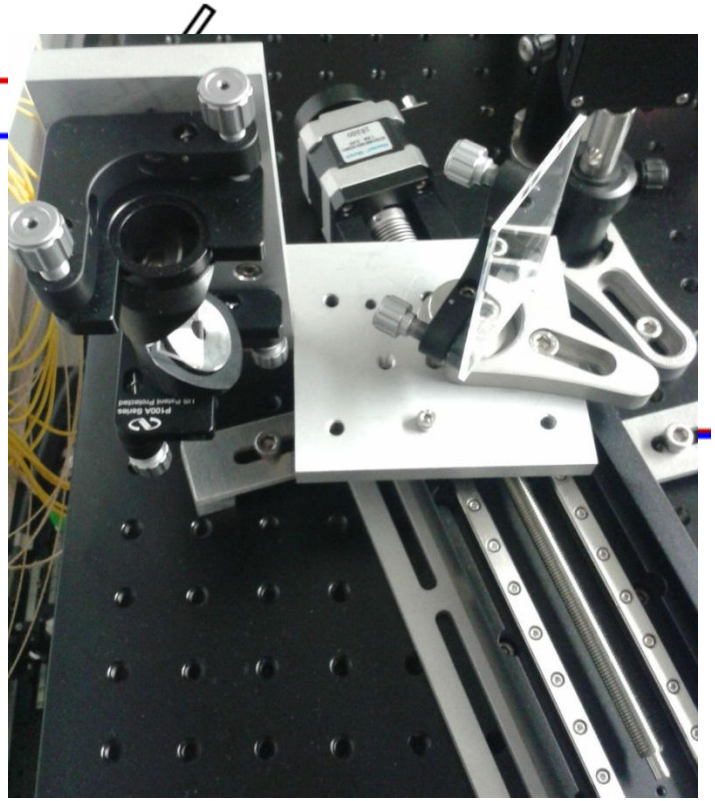
New injector laser





- different wavelength get different diffraction
- part of the pulse has to overcome a bigger distance

→ pulse is stretched

- stretcher is built with two gratings and a periscope
- resulting pulse length is determined by the distance of the gratings
- variable grating distance and thus pulse length come with timing differences that have to be corrected

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New injector laser

- UV-laser pulse with 1µJ power
- Stretcher with 4500 lines/mm transmission gratings
  - expected total transmission: 50%
- Expected losses due to iris / beam line: 75%

➢ the achievable charge depends on the quantum efficiency (typically 0.5<QE<10%)

➢ Theoretically achievable bunch charge: **125pC - 2.5nC**

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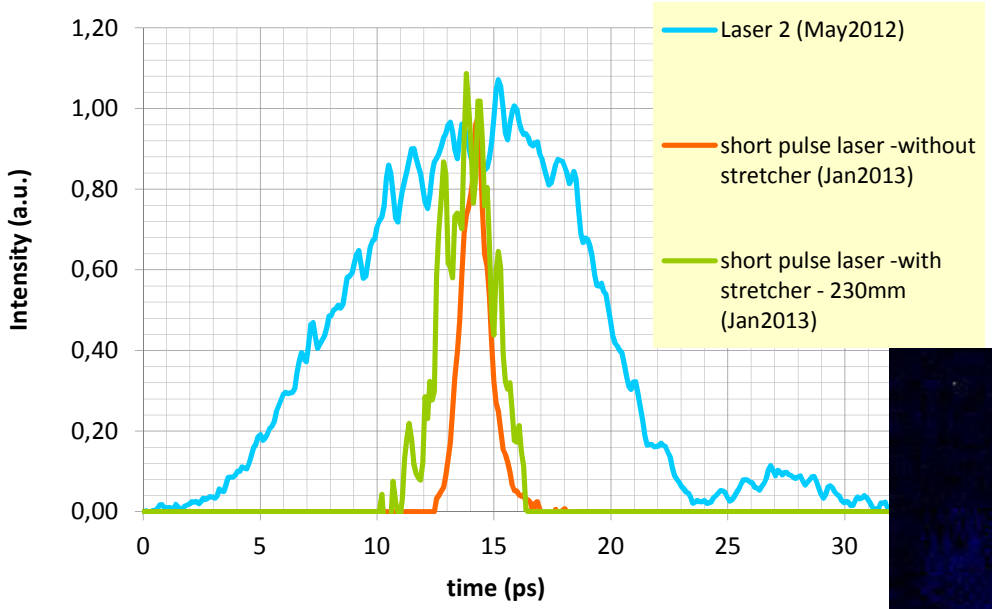
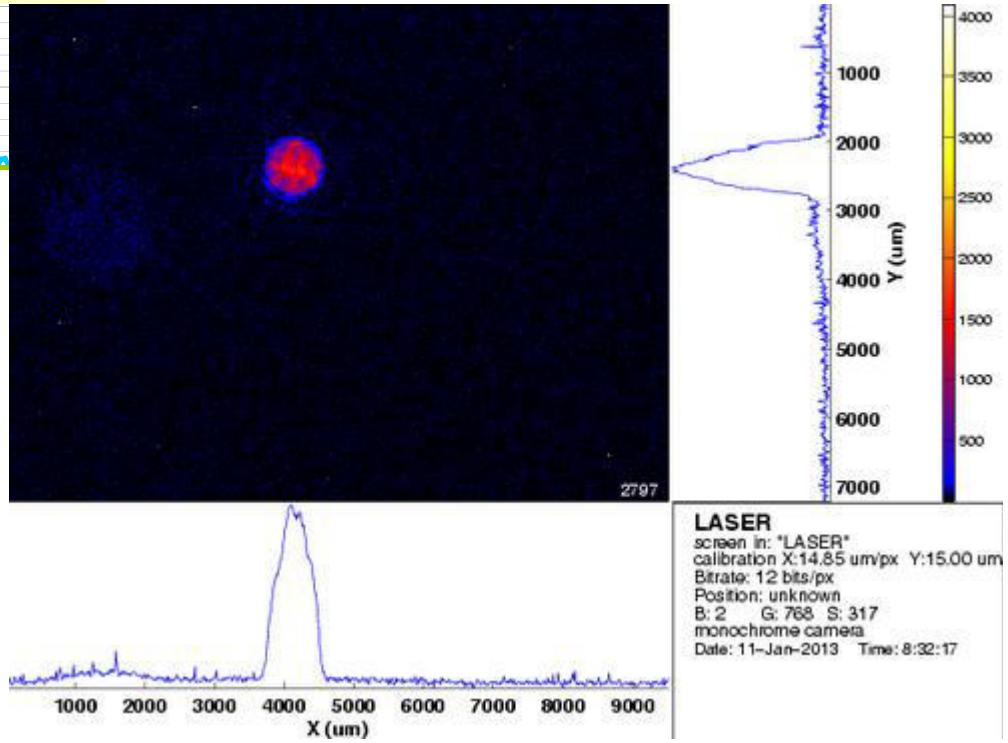
First lasing



Streak camera measurement



Laser properties:

Bunch duration:

without stretcher: 1.3 ps (FWHM)

with stretcher: 2.4 ps (FWHM)

Short Pulse Laser on Virtual cathode with a beam shaping aperture (BSA) of 1 mm (diameter)

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Planed new laser dianostics

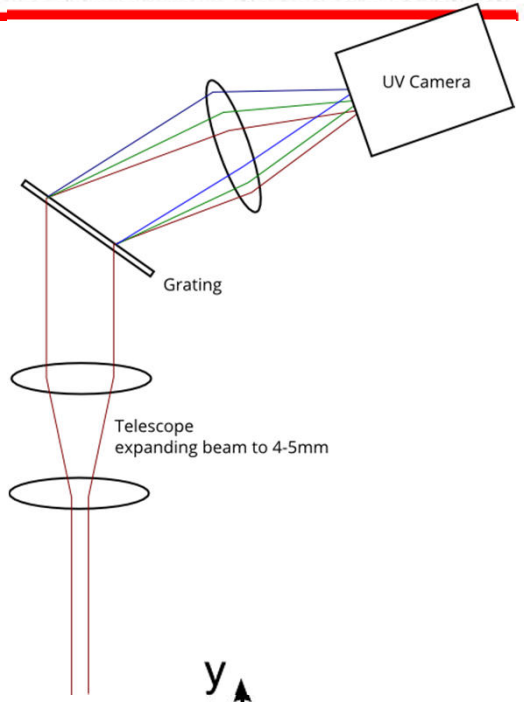
Spectrometer: measure spectral stability of the laser

Requirements:

- Resolution of 1/50 to 1/100 nm
- bandwidth of about 1nm.
- 256-268nm

Components:

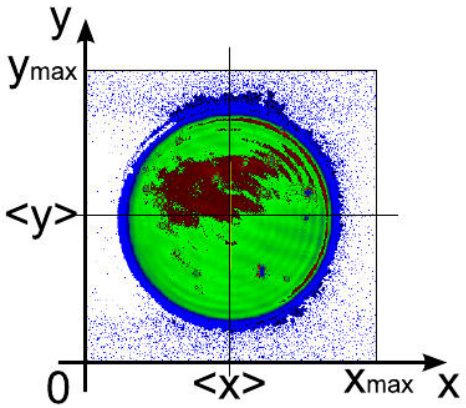
- Grating: 4000 lines/mm
  (222.22nm grating period /
  blazing angle of 35.4°)
- UV camera (4.65 µm pixel size)

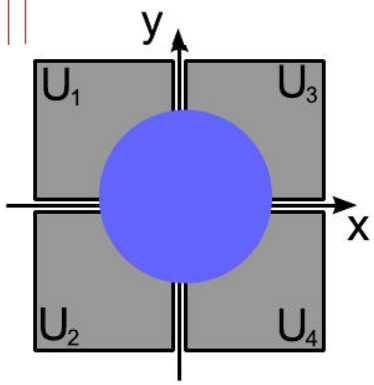


Quadrant Diode

Measurements:

- Position of the intra train laser p
  → stability during pulse train
- Laser pulse energy





[Marc Hänel, Dissertation, 2010]

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Stability measurement
(Sept. 2012)

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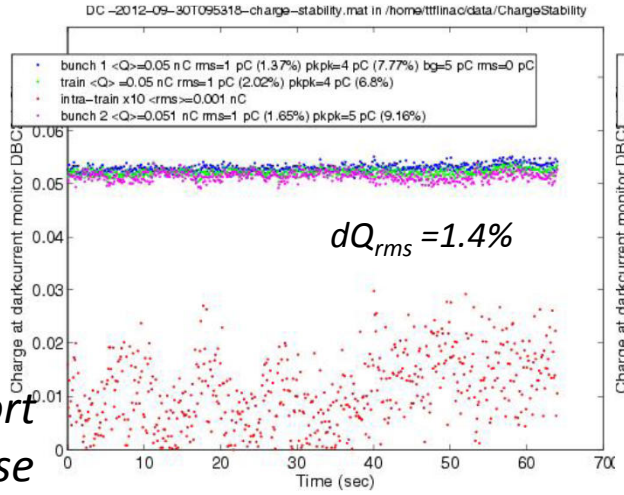
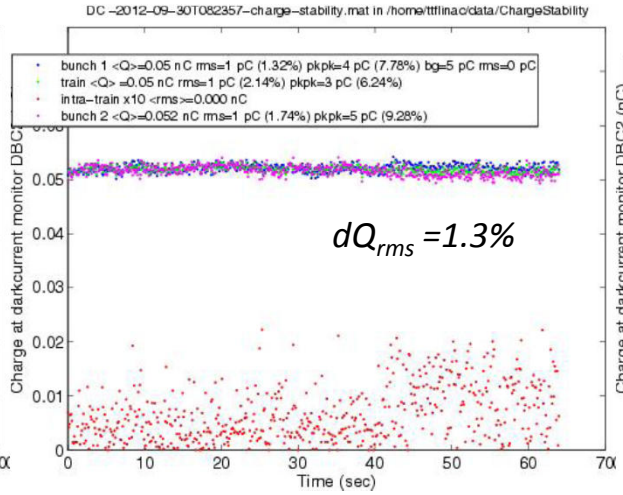
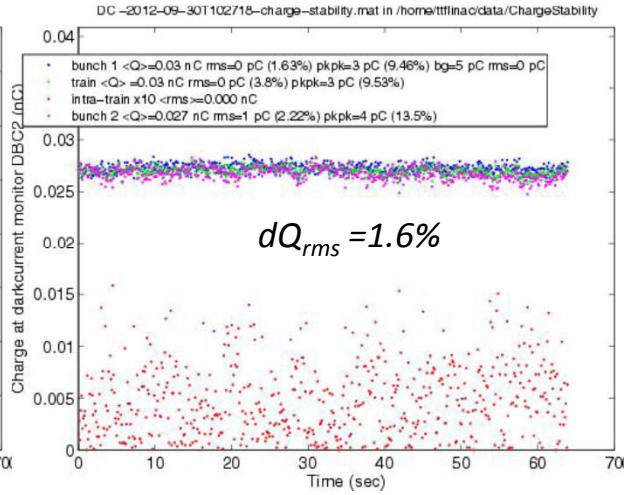
Short Pulse Laser



zero crossing - 78deg

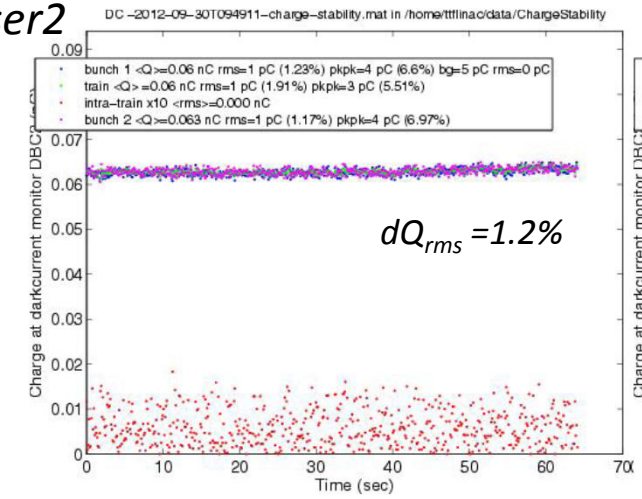


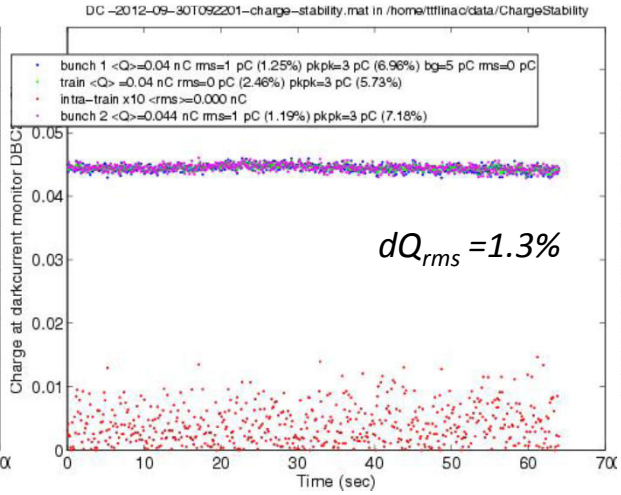
zero crossing - 38deg

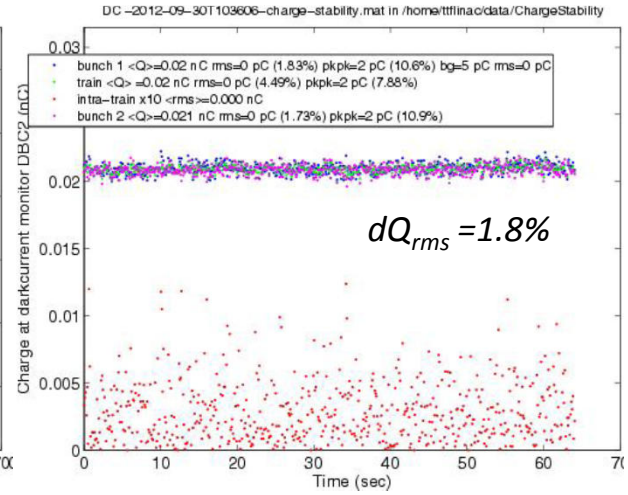


zero crossing - 15deg

Laser2







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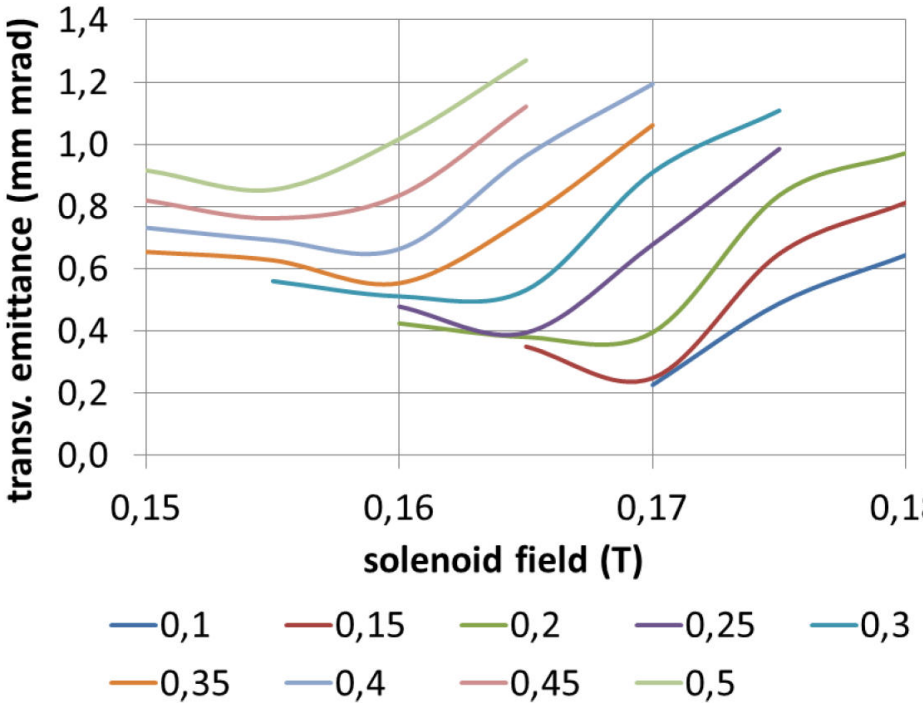
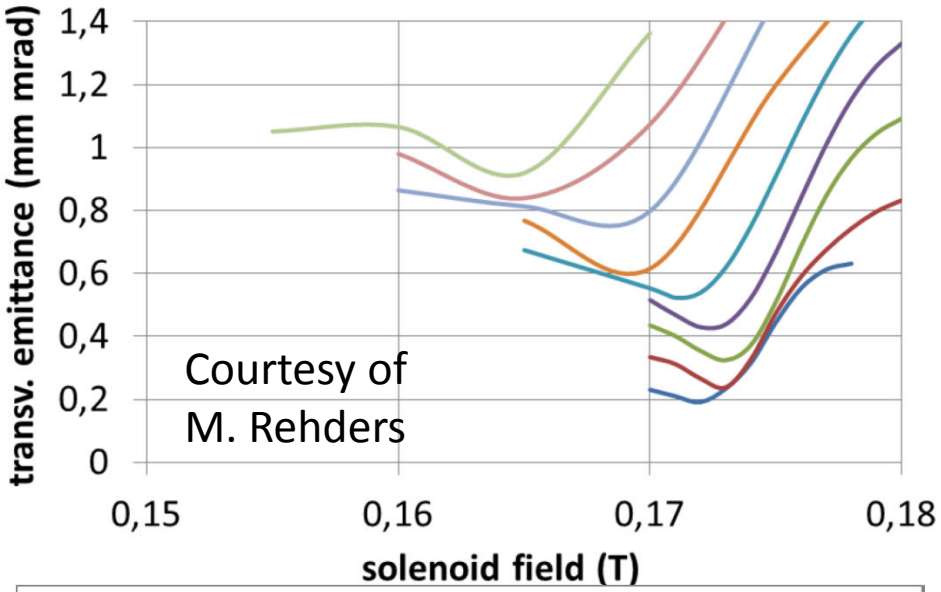
Emittance

Laser pulse duration (rms) = 4.4 ps



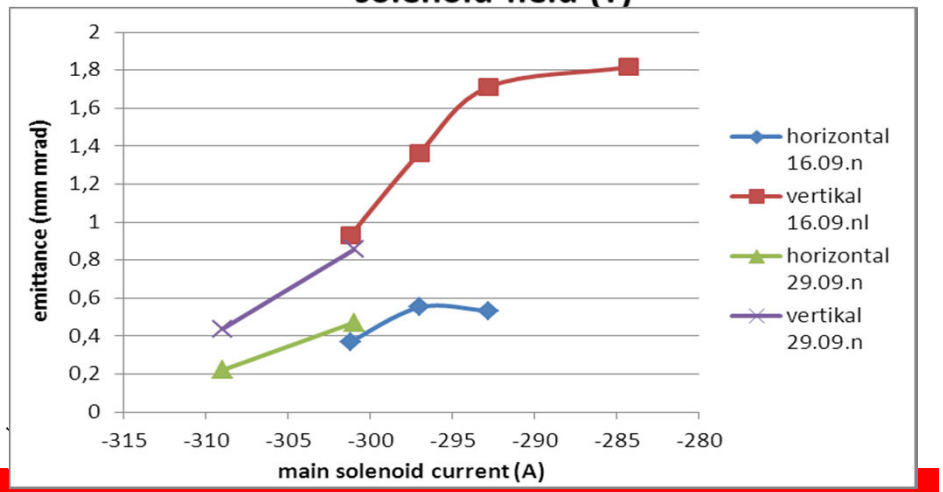
Laser pulse duration (rms) = 1 ps



Courtesy of
M. Rehders

Simulation of the transverse emittance as a function of the solenoid field for different photo-cathode laser spot sizes

Measured transverse emittance as a function of the solenoid field for for 6.5 ps laser pulse duration, 20 pC and an rms laser spot size of 0.23 mm



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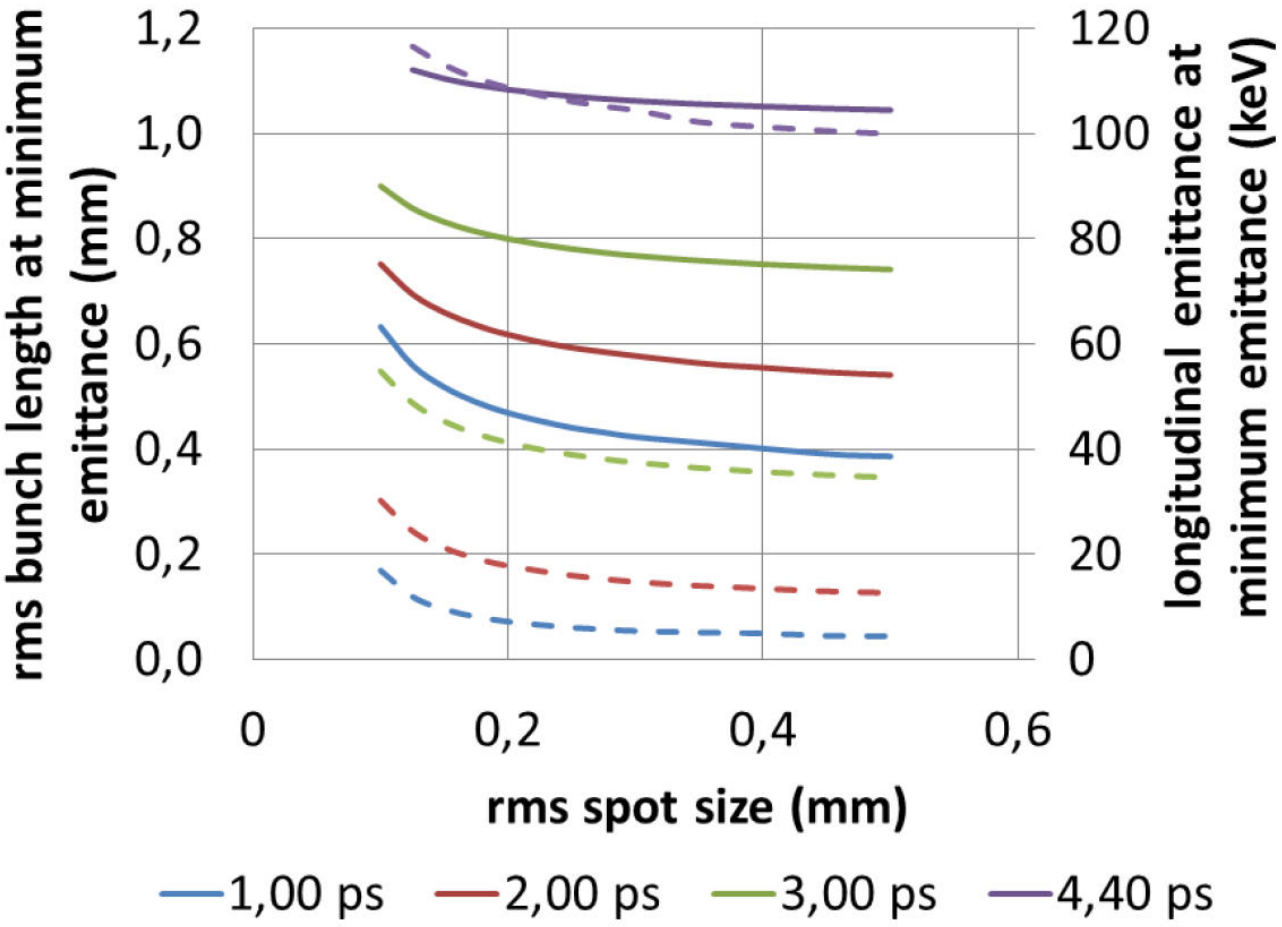
Emittance

Simulation of the rms bunch length and longitudinal emittance as a function of the photo-cathode laser spot size for different bunch durations (for minimum emittance)

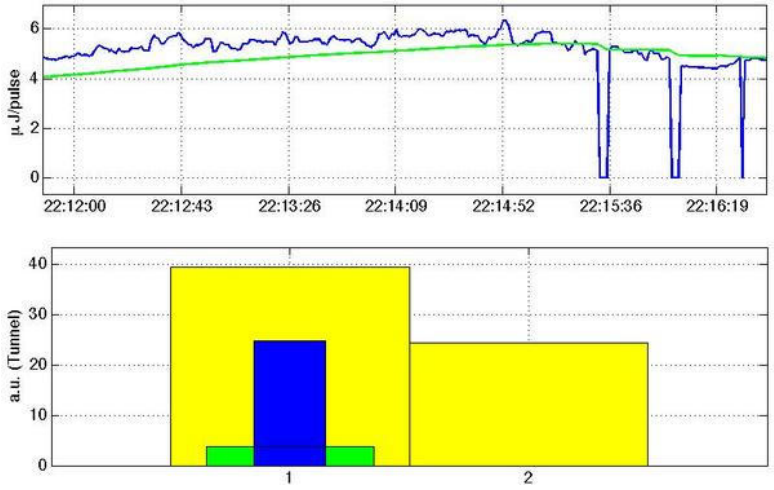


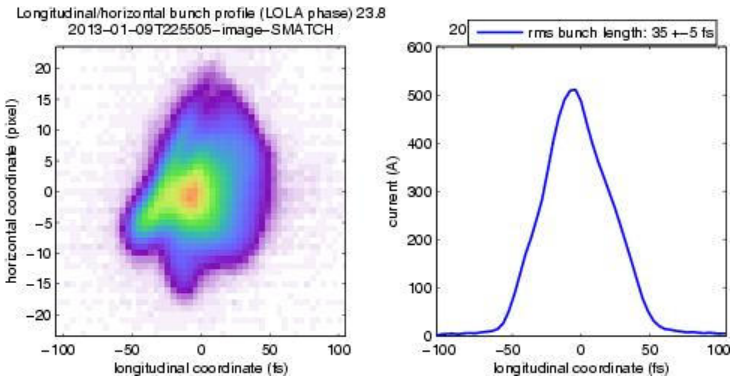
Courtesy of M. Rehders

First SASE with new injector laser

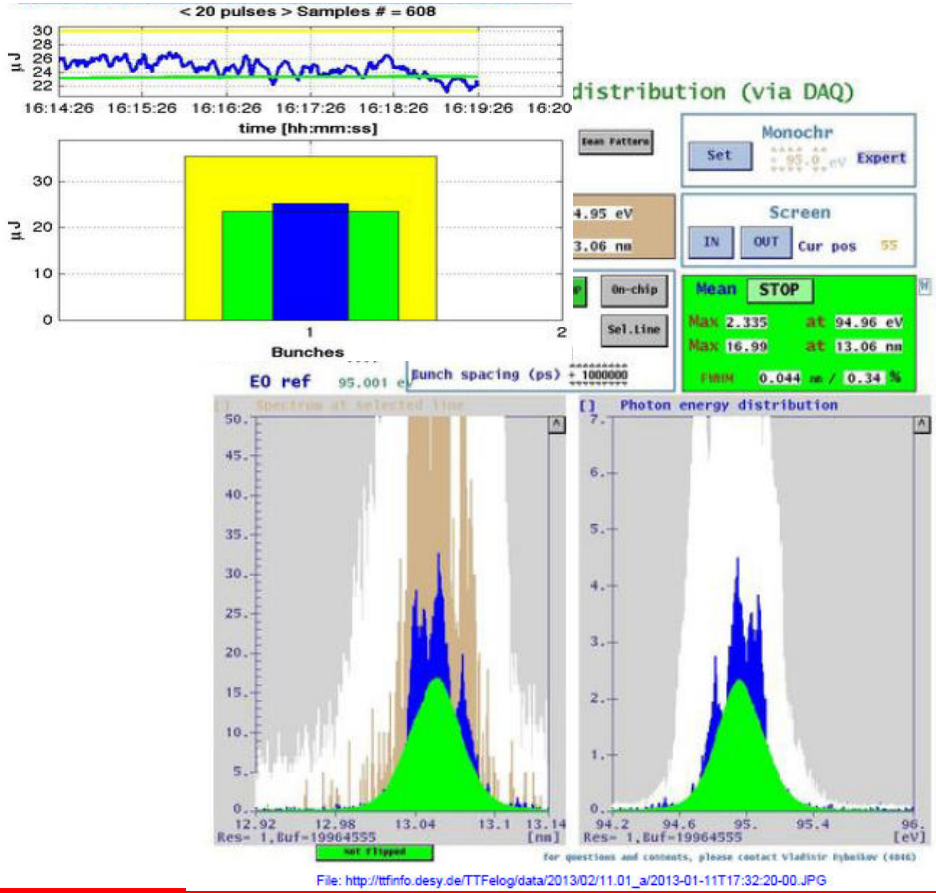
First SASE with short pulse injector laser:

- 9th & 11th of January 2013
- 5 uJ at 13,5 nm, bunch charge 35 pC





- 25 uJ (GMD-T, 10/10 mm) at 13 nm, bunch charge 80 pC
  PG-measurement: Narrow bandwidth
  (0.34 % in linear regime, 0.42% at saturation)



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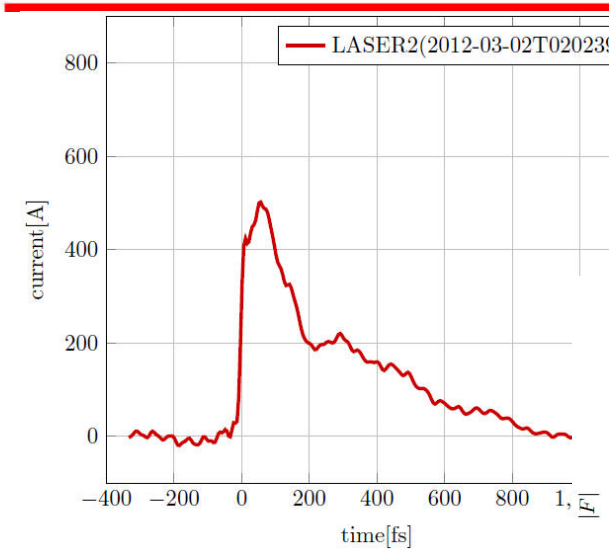
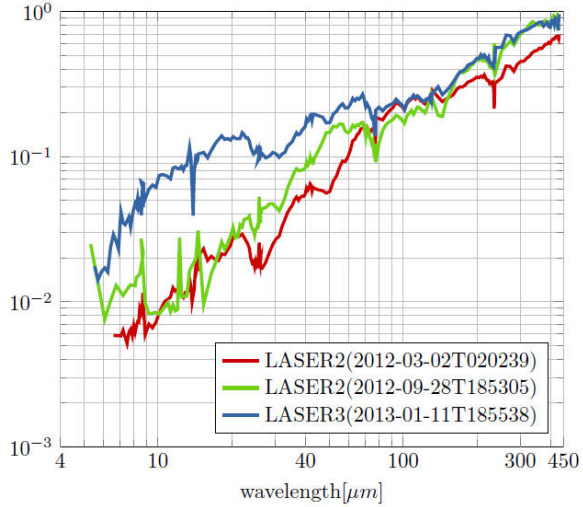
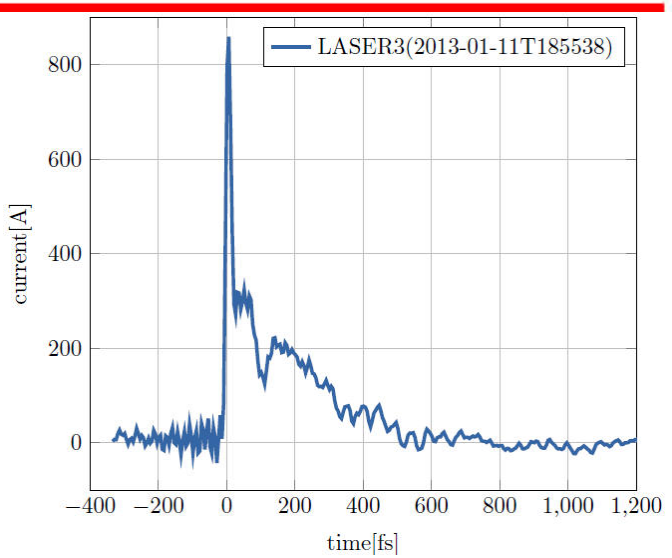
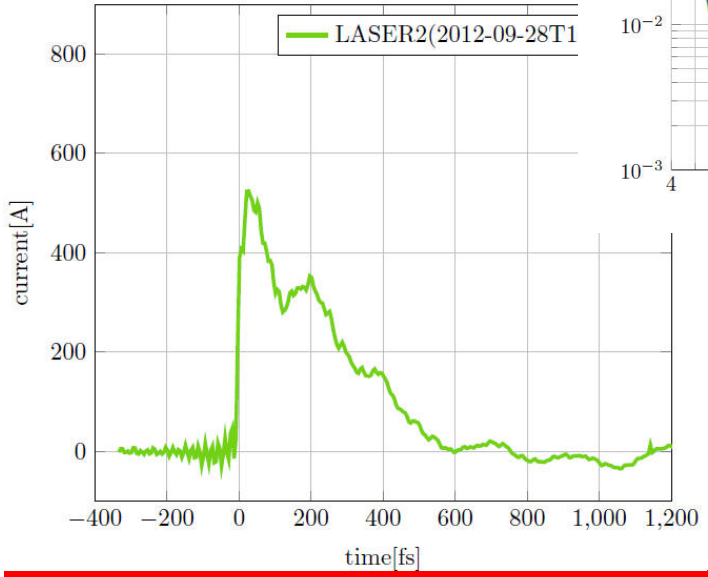
Bunch length measurements

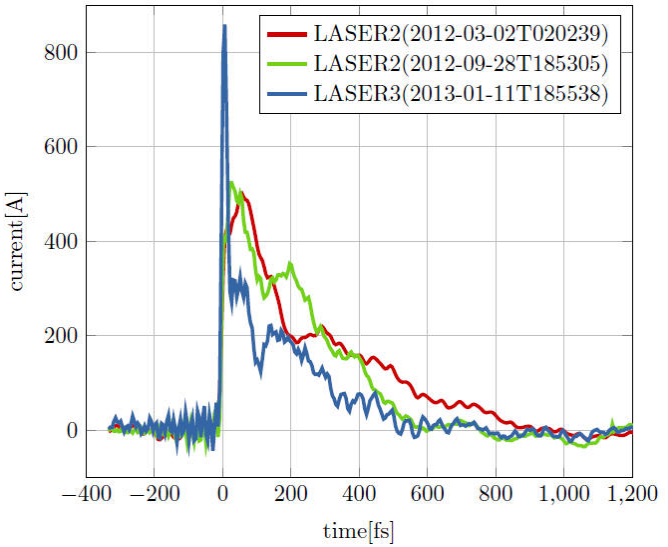








Courtesy of E. Hass



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Stability measurement
(Jan. 2013)

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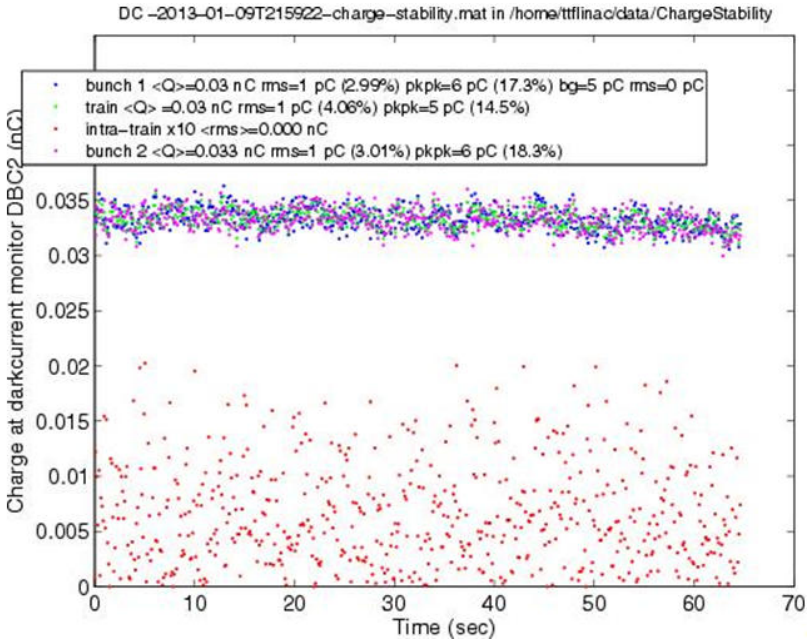
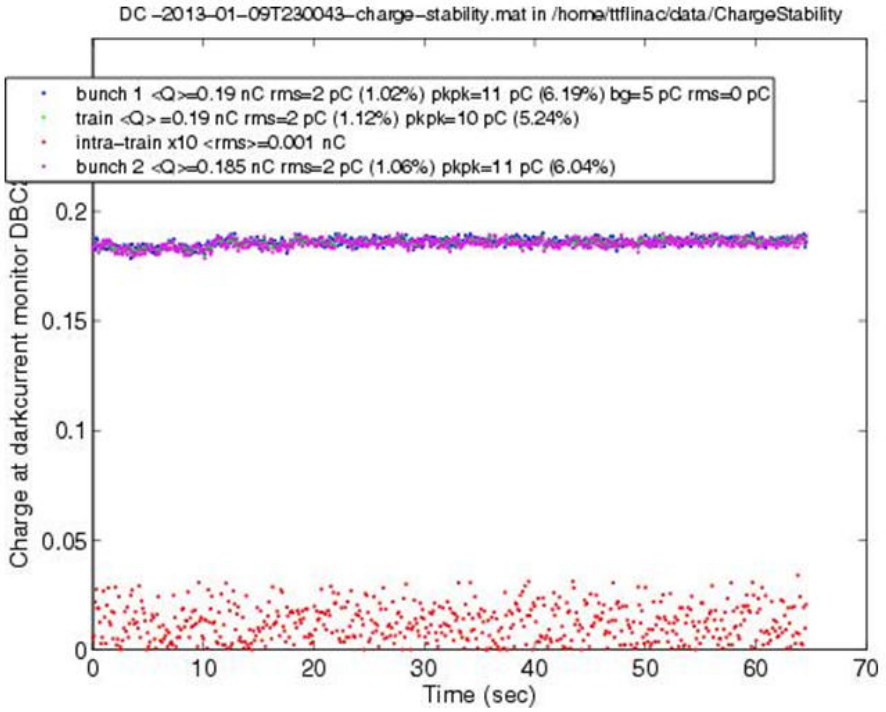
- 35 pC with 3% rms fluctuations





- 190 pC with 1% rms fluctuations

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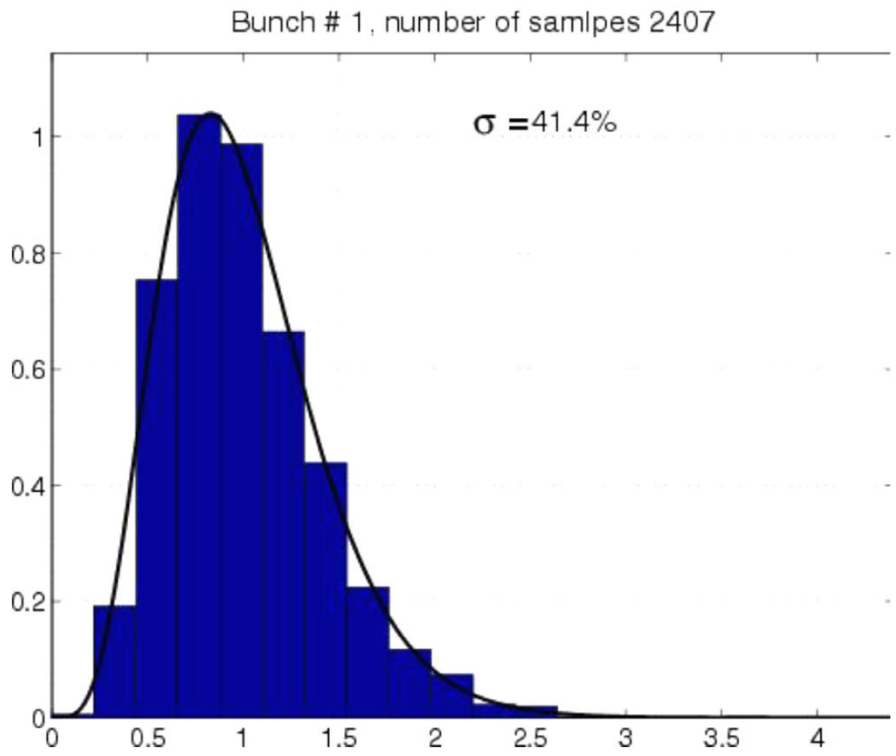
First SASE with new injector laser

- Radiation wavelength: 13.06 nm
- Fluctuations
  - in the linear regime: 42%
    Number of modes: M = 5.7
  - in saturation: 13%
- Saturation length: $L_{sat} \approx 22$ m
- Angular divergence in saturation (FWHM) ≈ 40 µrad.
- **Spectral bandwidth:**
  - **in the linear regime (FWHM): 0.35%**
  - **in the saturation regime (FWHM): 0.42%**
  - close to that generated by monochromatic electron beam (natural SASE bandwidth)
  - lasing part of the beam is not disturbed by chirp
- Radiation pulse length in the linear regime:
- **Radiation pulse duration** at full undulator length is estimated as **50 fs**.



- **rms bunch length** of lasing fraction of the electron beam: **40 fs**.
- Assuming Gaussian shape of the electron bunch: I ≈ 700 A.
- These parameters are consistent with measured properties of the radiation if rms normalized emittance is below 1 mm mrad.

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Bunch length measurements

11th of January 2013

Emittance measurements

Preliminary results

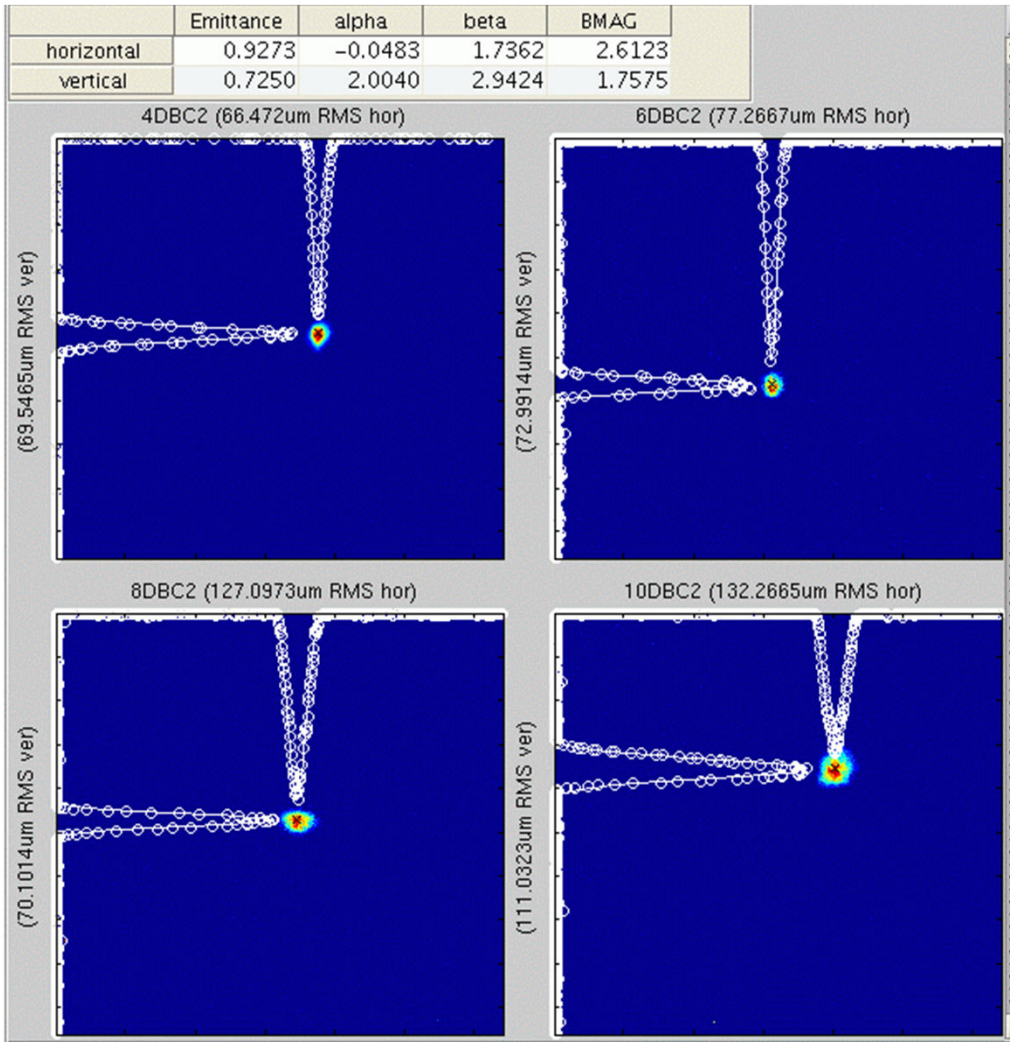
Emittance measurement at DBC2:

εx ≈ 0.9 mm mrad

εy ≈ 0.7 mm mrad

Courtesy of M. Rehders

	Emittance	alpha	beta	BMAG
horizontal	0.9273	-0.0483	1.7362	2.6123
vertical	0.7250	2.0040	2.9424	1.7575



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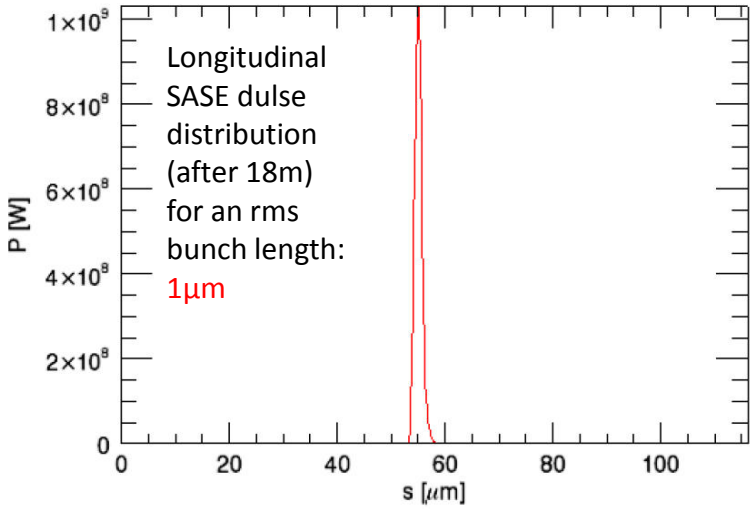
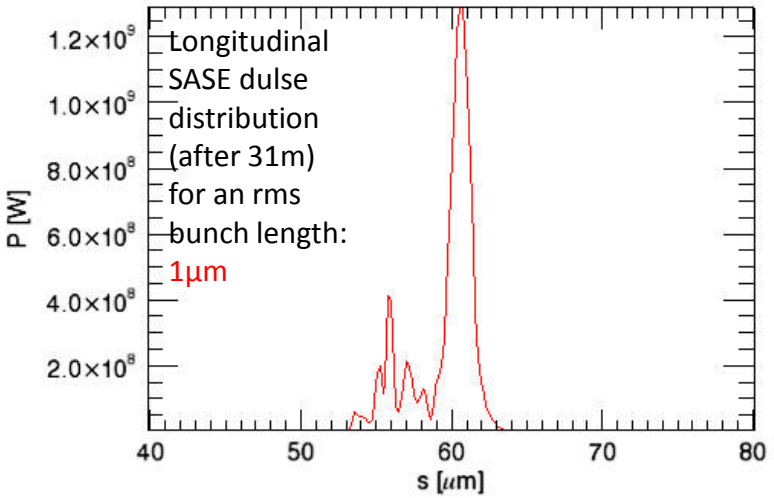
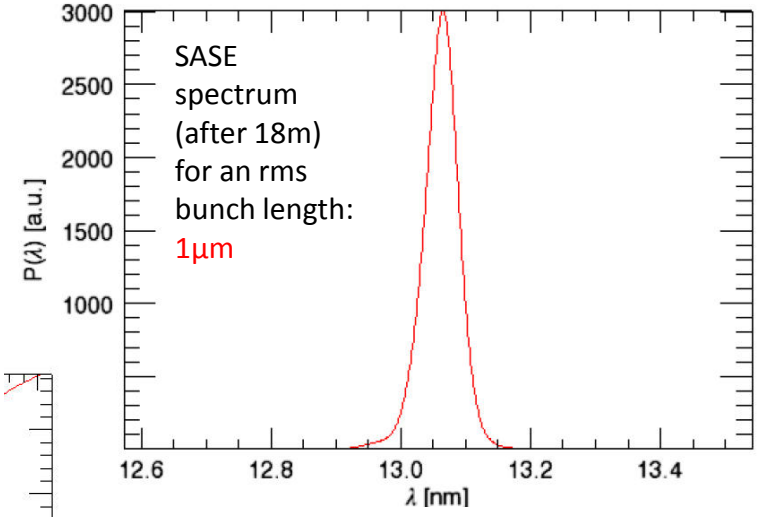
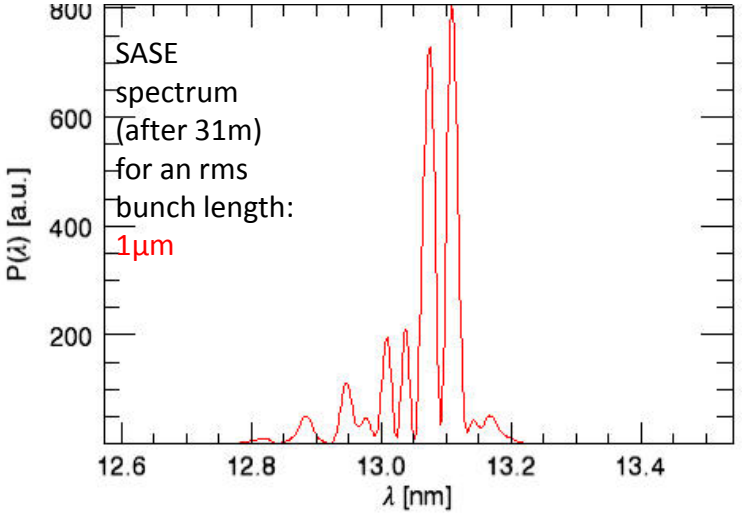
Short pulses at FLASH









Courtesy of
M. Rehders

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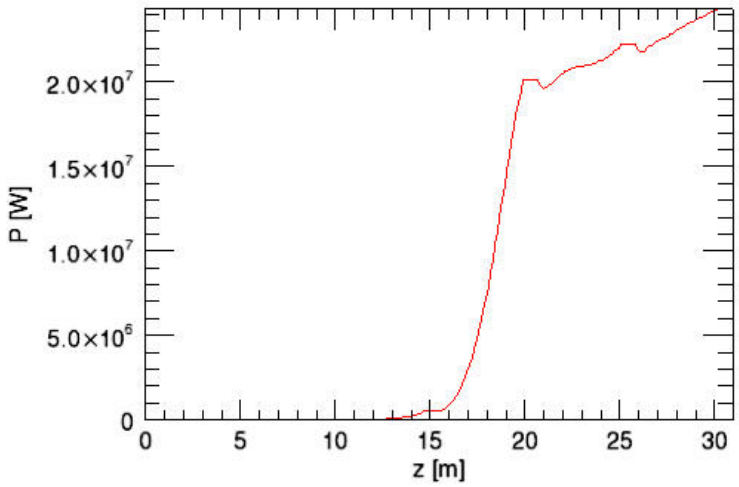
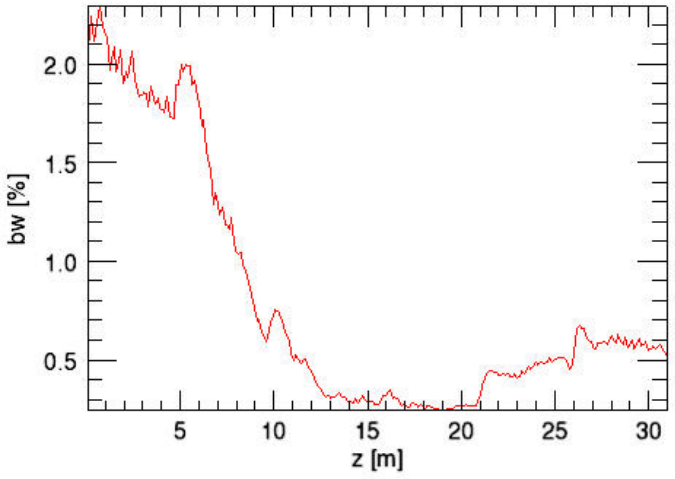
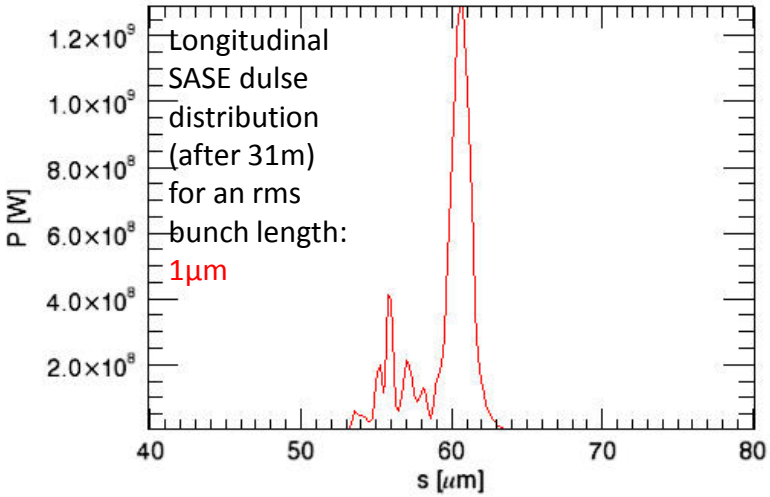
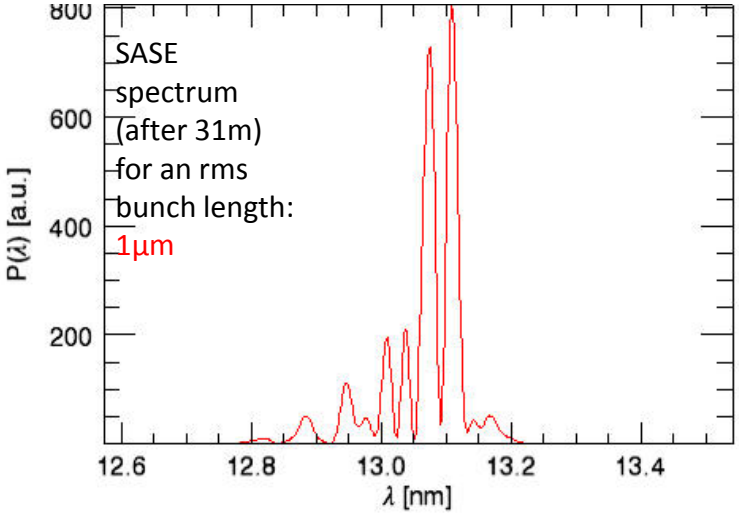
Short pulses at FLASH









Courtesy of
M. Rehders

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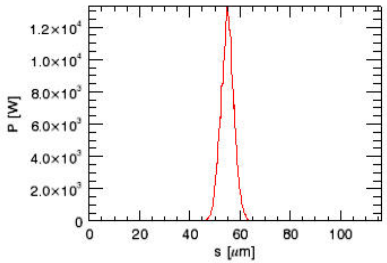
Short pulses at FLASH

Longitudinal SASE distribution at different positions in the undulator
Gaussian bunch shape, Charge: 30pC, Transverse emittance: 2.0mm mrad,
Bunch length (rms): 2.6um, Energie (Gamma): 1369.863, Energy Spread (delgam): 0.3913894

5m



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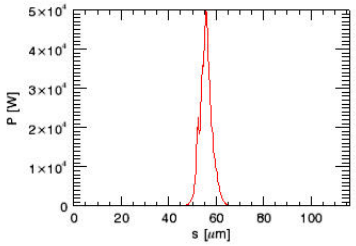

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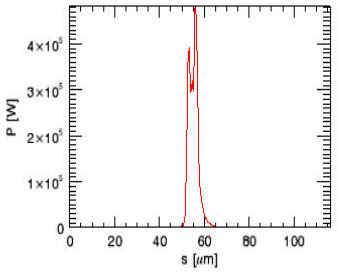

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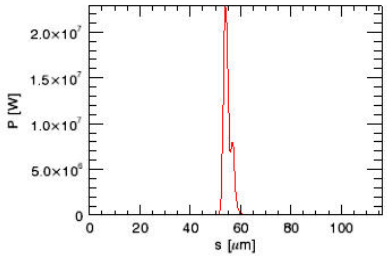

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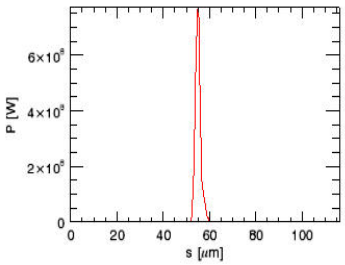
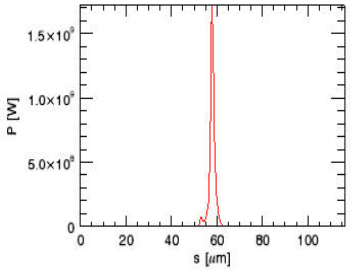


31m



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Short pulses at FLASH

SASE spectrum at different positions in the undulator
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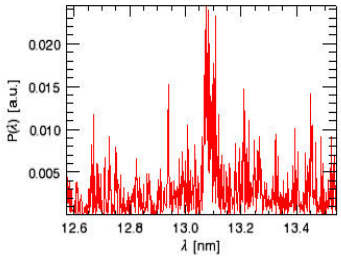
5m



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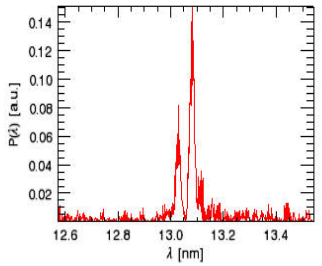

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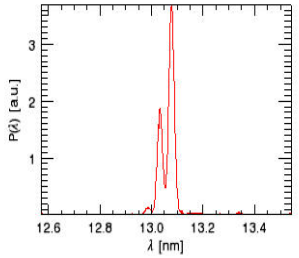

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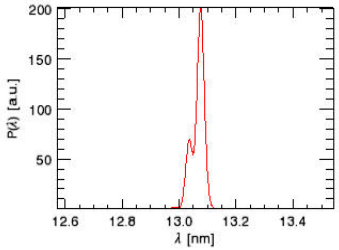

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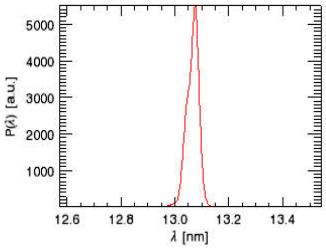

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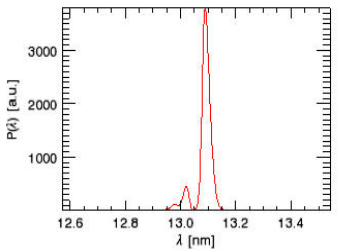

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Short pulses at FLASH

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Longitudinal SASE distribution at different positions in the undulator
Gaussian bunch shape, Charge: 30pC, Transverse emittance: 2.0mm mrad,
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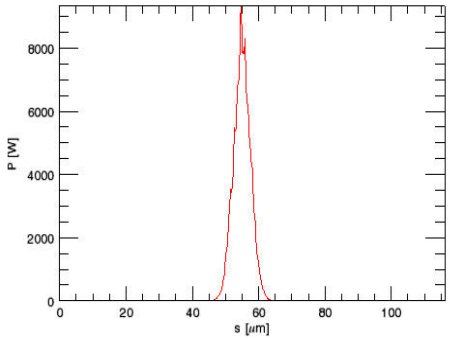
5m



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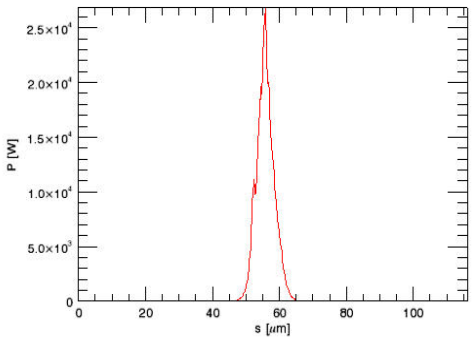

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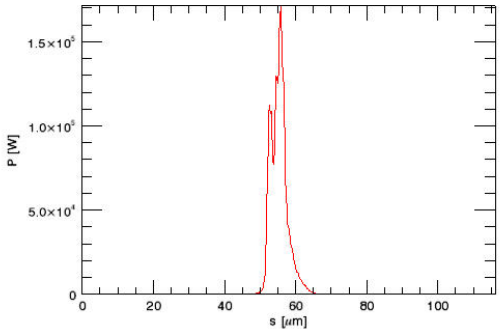

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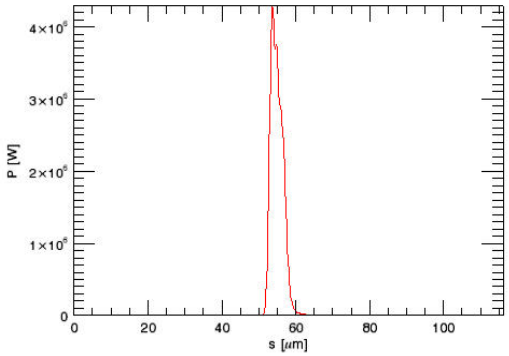

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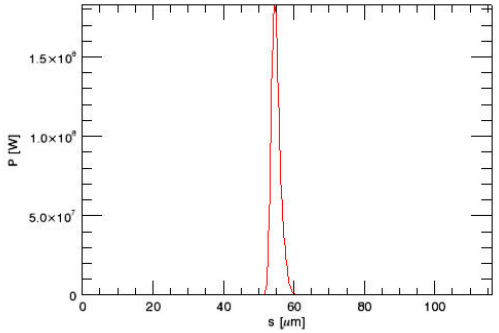

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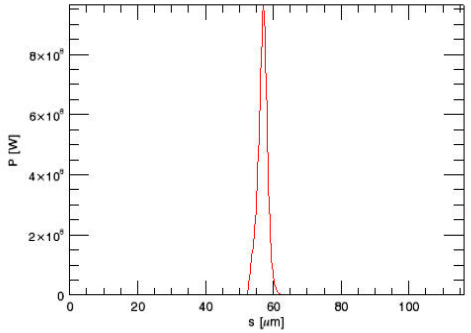

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Short pulses at FLASH

SASE spectrum at different positions in the undulator
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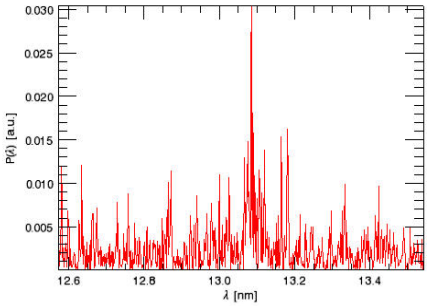
5m



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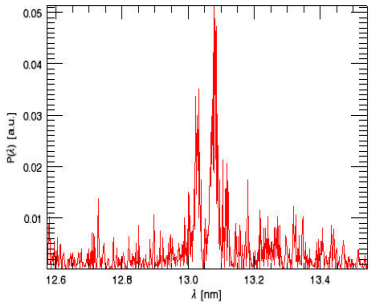

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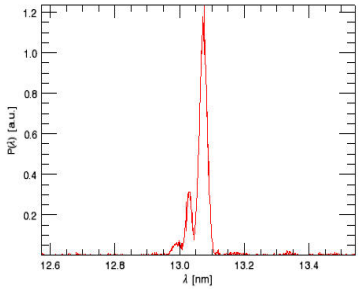

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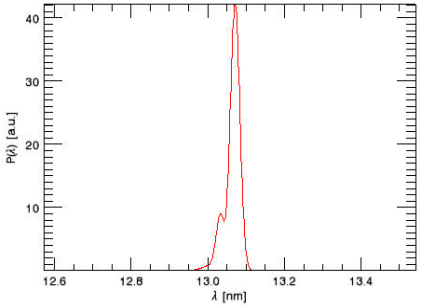

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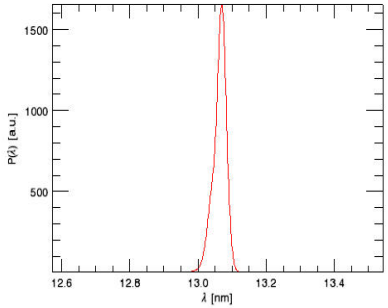

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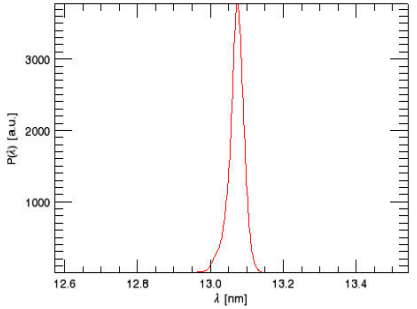

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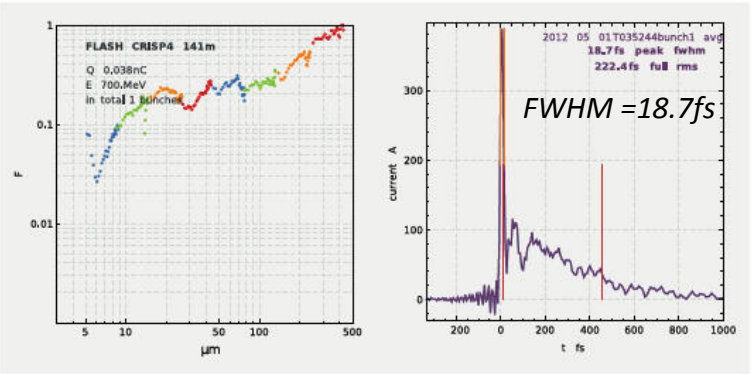
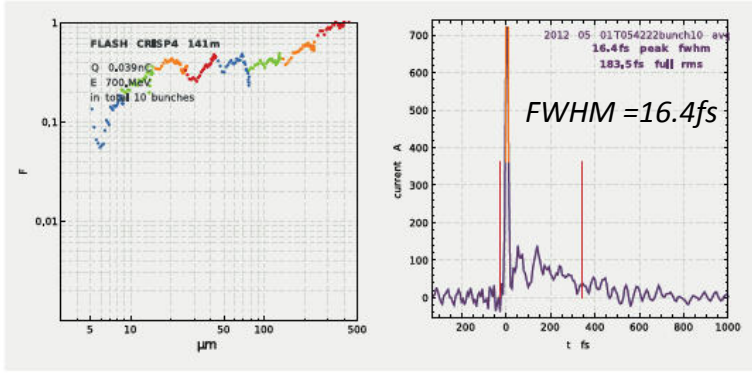
Bunch length measurements

- Measurement of the longitudinal bunch profile of the ultra-short pulses will be performed using a spectrometer, that measures coherent transition radiation.
- A redesigned of the spectrometer is under development for short bunch length and low charges, because the wavelength range changes and the pyro-electric detectors are not **sensitive** enough when small charge is used.
- **MCT** detectors show 10^4 times higher sensitivity

Courtesy of S. Wesch & E. Hass

Electron bunches produced by new short pulse injector laser





short bunches (no lasing) measured with CRISP4

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rms duration

LOLA measurement

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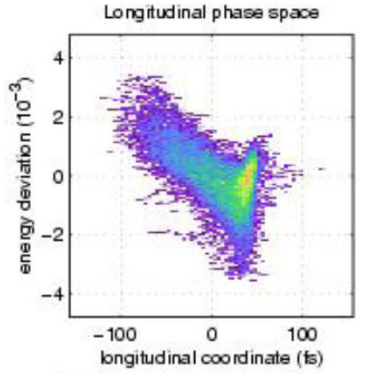
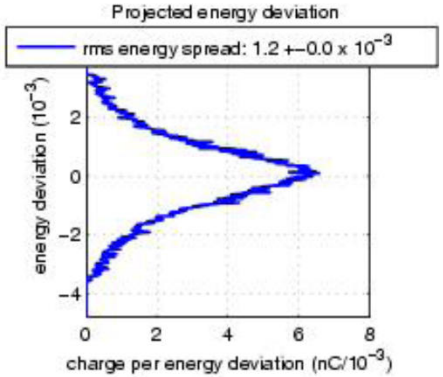
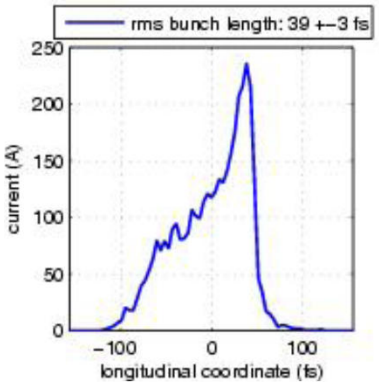
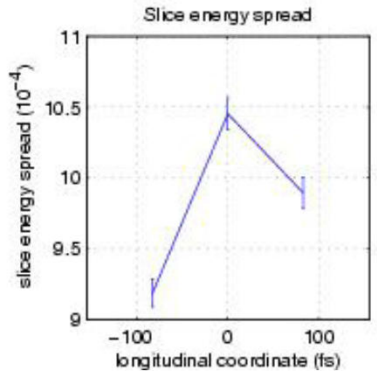
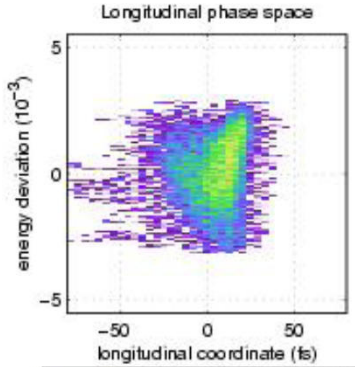


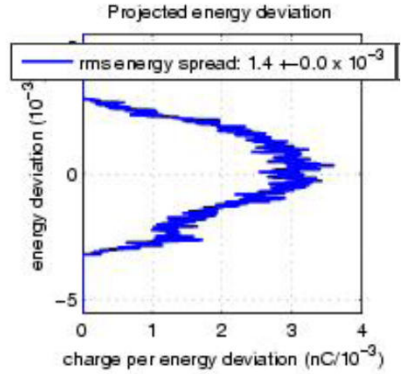


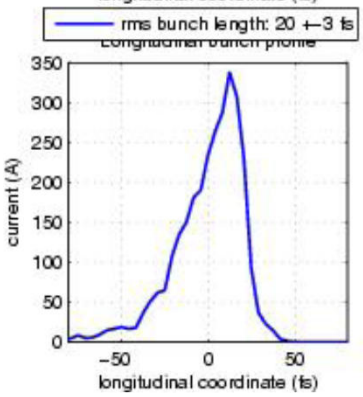


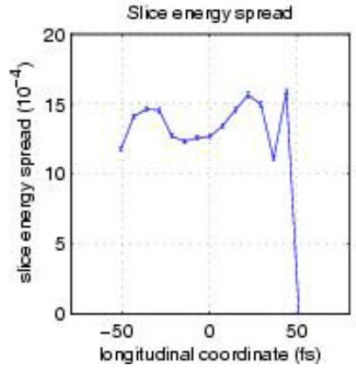


at 20 pC & 39fs - rms









at 15pC with strong compression, 20fs - rms duration

short bunches (no lasing) measured with LOLA

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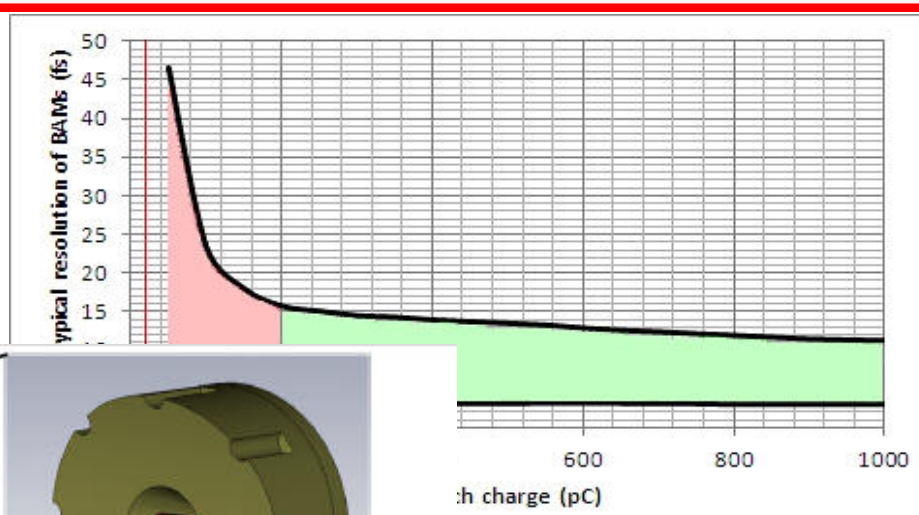
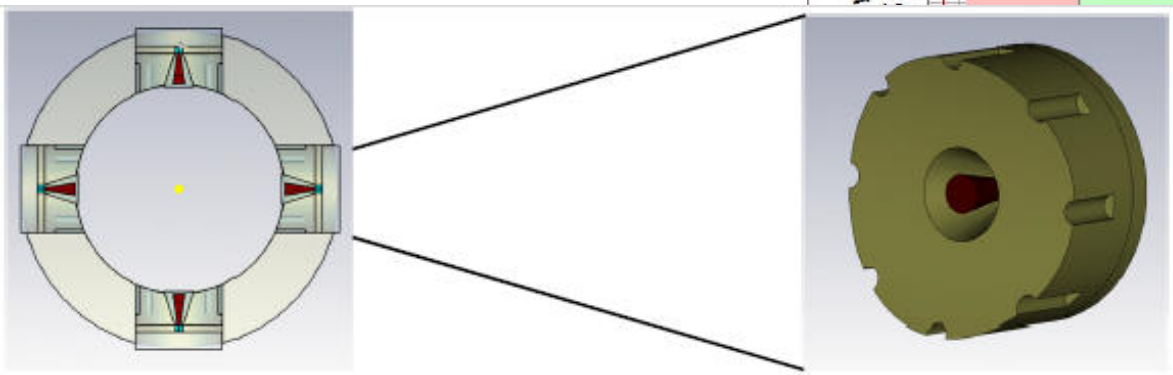
Arrival time

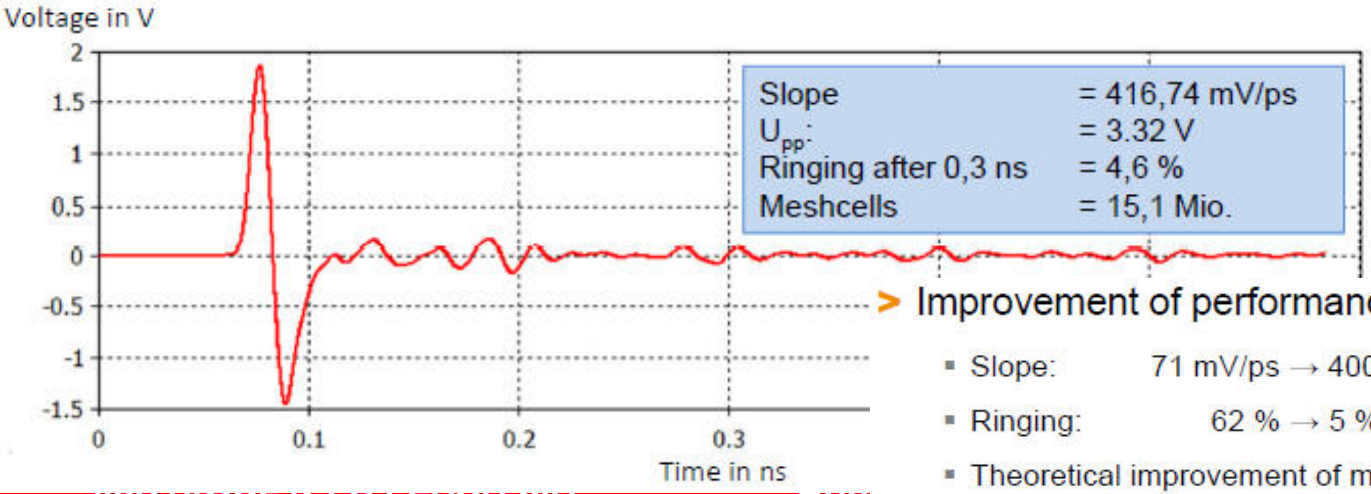
Aim for new BAM design: bandwidth ≥ 40 GHz
expected performance

⇒ expected an arrival time resolution of new BAMs for 20pC is about **12fs**





Courtesy of
M.K. Czwalinna
& A. Kuhl

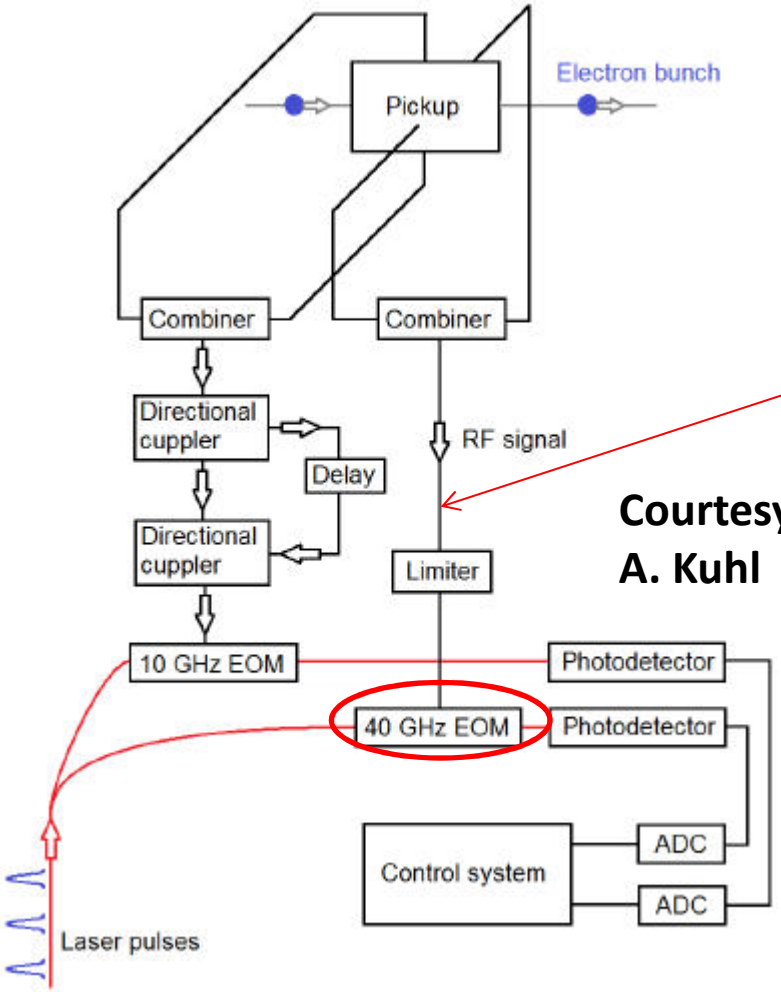


> Improvement of performance (simulated)

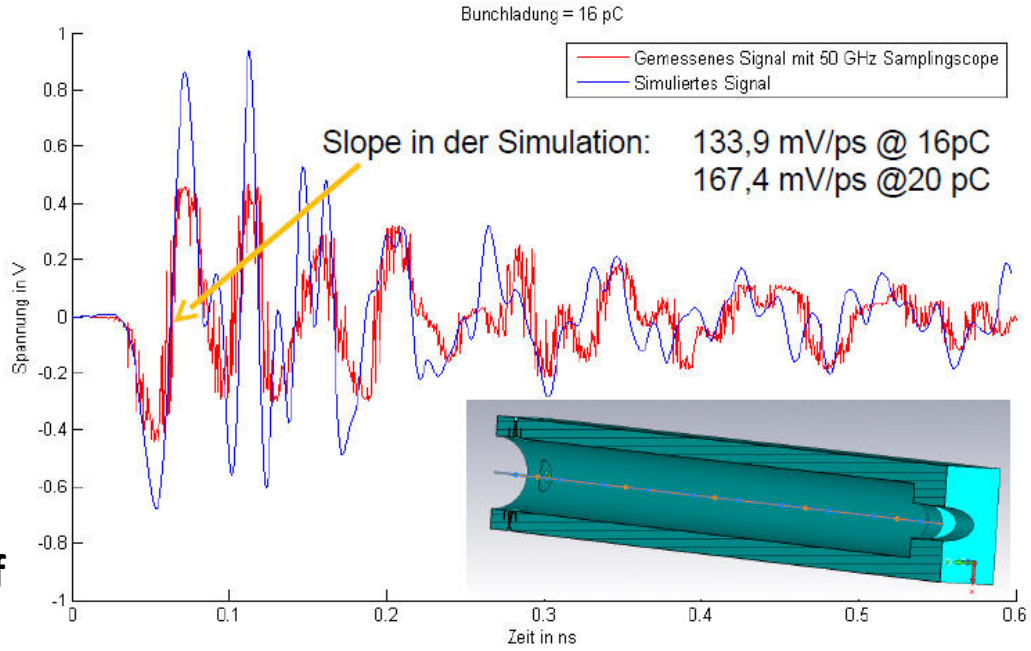
- Slope: 71 mV/ps → 400 mV/ps
- Ringing: 62 % → 5 %
- Theoretical improvement of measurement resolution by factor 5

Arrival time

new BAM installed at FLASH



Courtesy of A. Kuhl



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Thanks for your attention

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Questions ?