# FLASH performance after the upgrade

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HELMHOLTZ GEMEINSCHAFT

**European XFEL / HASYLAB Users' Meeting**
**DESY, January 27, 2011**

DESY

# Upgrade 2009 / 2010

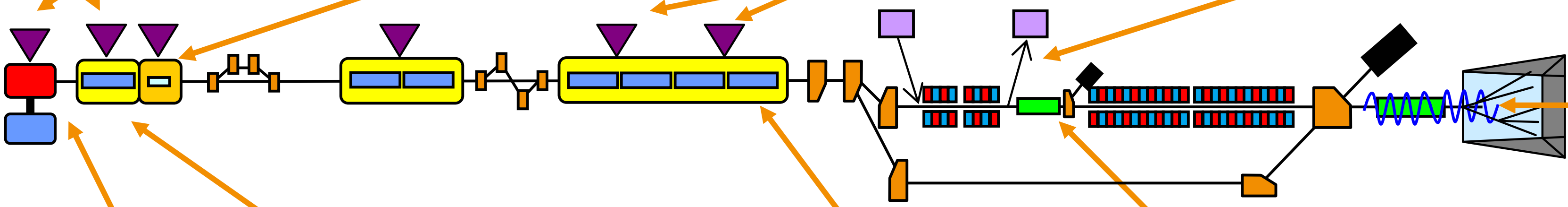
> Upgrade shutdown: September 2009 – February 2010

exchanged RF stations

3rd harmonic module + RF station

additional RF station + exchanged RF station

seeding experiment sFLASH + redesigned electron beamline



upgraded photon diagnostics and beamlines

new RF gun

exchanged 1st accelerating module

7th accelerating module

transverse deflecting cavity + spectrometer arm / tuning dump

new diode pumped photocathode laser; upgraded old laser system

exchanged injector corrector magnets

upgraded magnet controls

maintenance of infrastructure: water supplies, cryogenics

new cabling/layout injector llrf electronics

new synchronization and feedback systems

optimized llrf controls

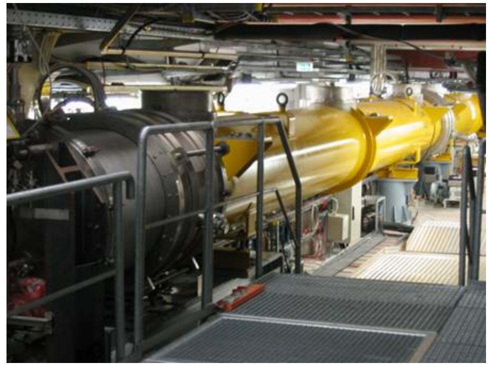
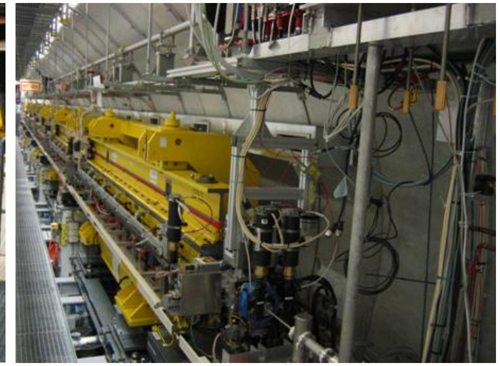
improved survey and alignment of accelerator components (incl. SASE undulators)

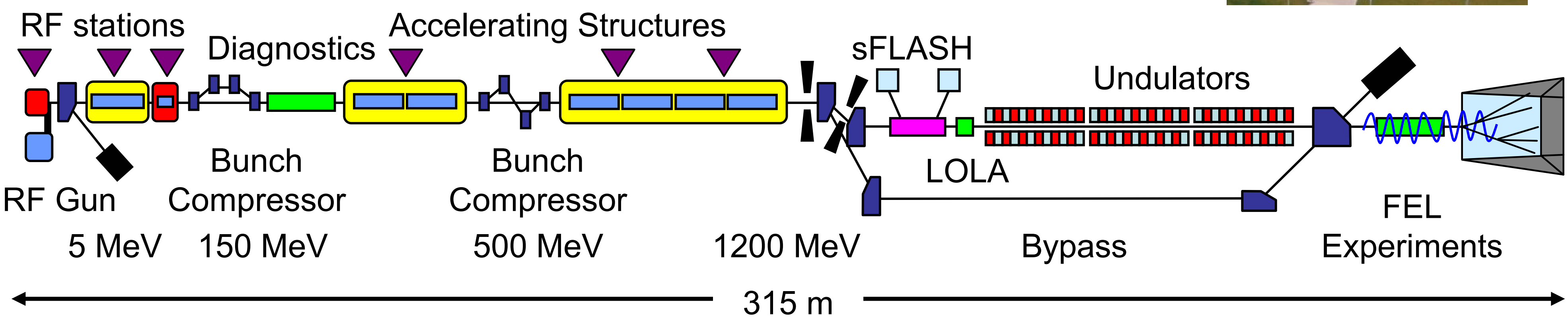
installation of a second master oscillator (as backup)

upgraded and optimized waveguide distribution

upgraded personnel interlock und radiation safety systems

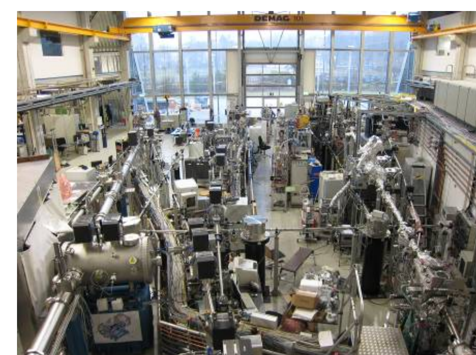
# The new FLASH layout





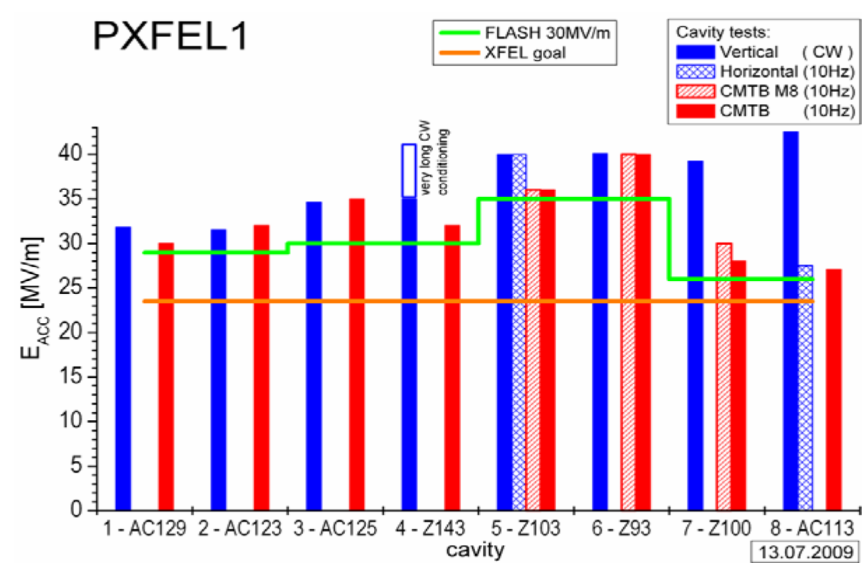


# Energy upgrade

- 7th superconducting TESLA type accelerating module installed
  - Prototype module for the European XFEL
  - Energy reach 240 MeV
- Electron beam energy 1.2 GeV
  => 1.25 GeV


**1.2 GeV demonstrated with beam in May 2010**

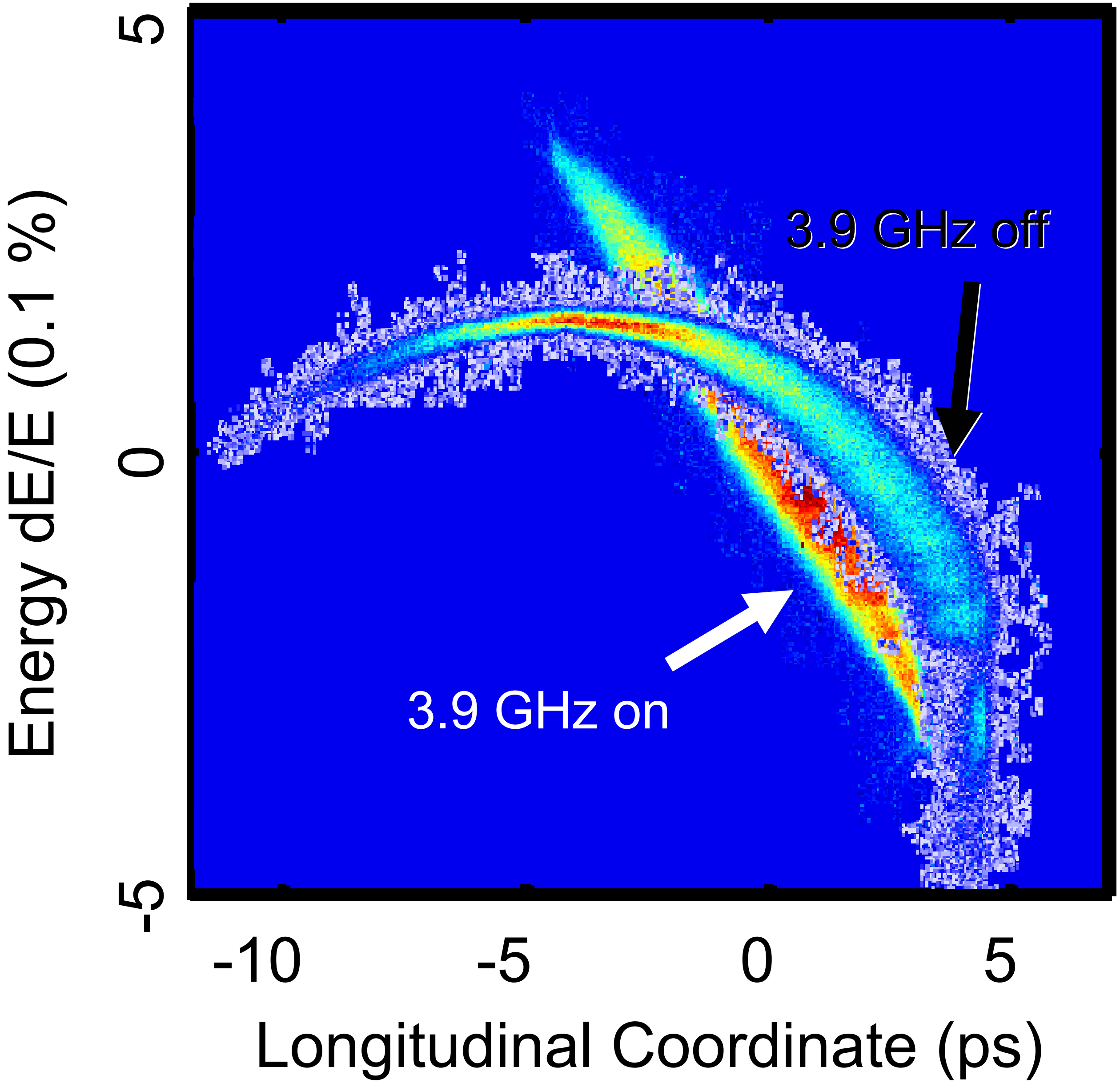

**Results of cavity tests**



# 3.9 GHz (3rd harmonic) Module and Module 1

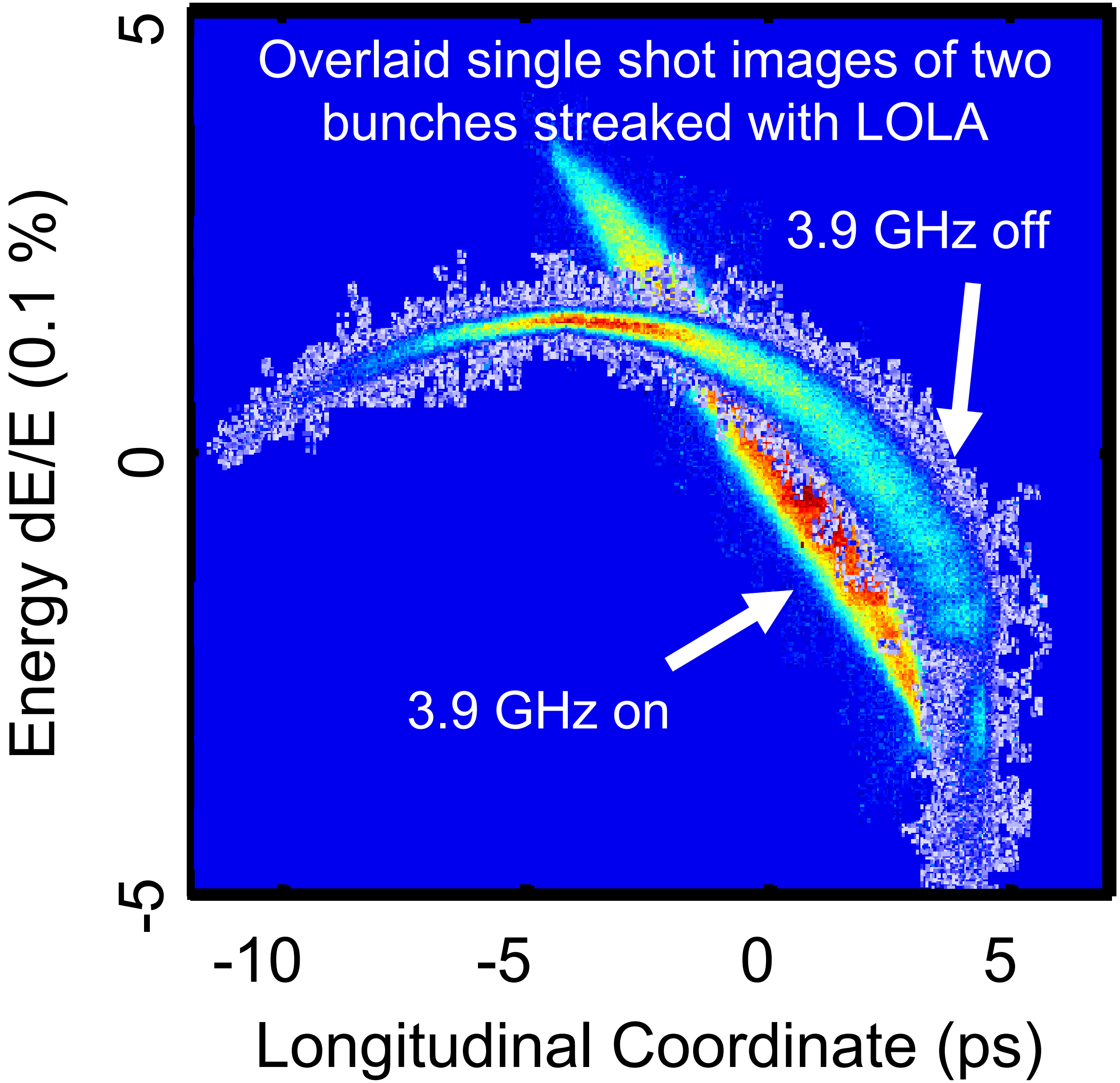
- New 1st accelerating module with improved cavities and Piezo tuners
- 3rd harmonic module with four nine-cell superconducting cavities operated at 3.9 GHz
  - includes RF system and LLRF regulation
  - built at FNAL (Fermilab) in a collaboration with DESY

# Bunch compression using 3rd-harmonic cavities




- measured with LOLA,
- dispersive section
- beam energy 700 MeV
- slight compression with 1st module (ACC1)
- 3.9 GHz cavities on/off

# Bunch compression using 3rd-harmonic cavities




- measured with LOLA,
- dispersive section
- beam energy 700 MeV
- slight compression with 1st module (ACC1)
- 3.9 GHz cavities on/off

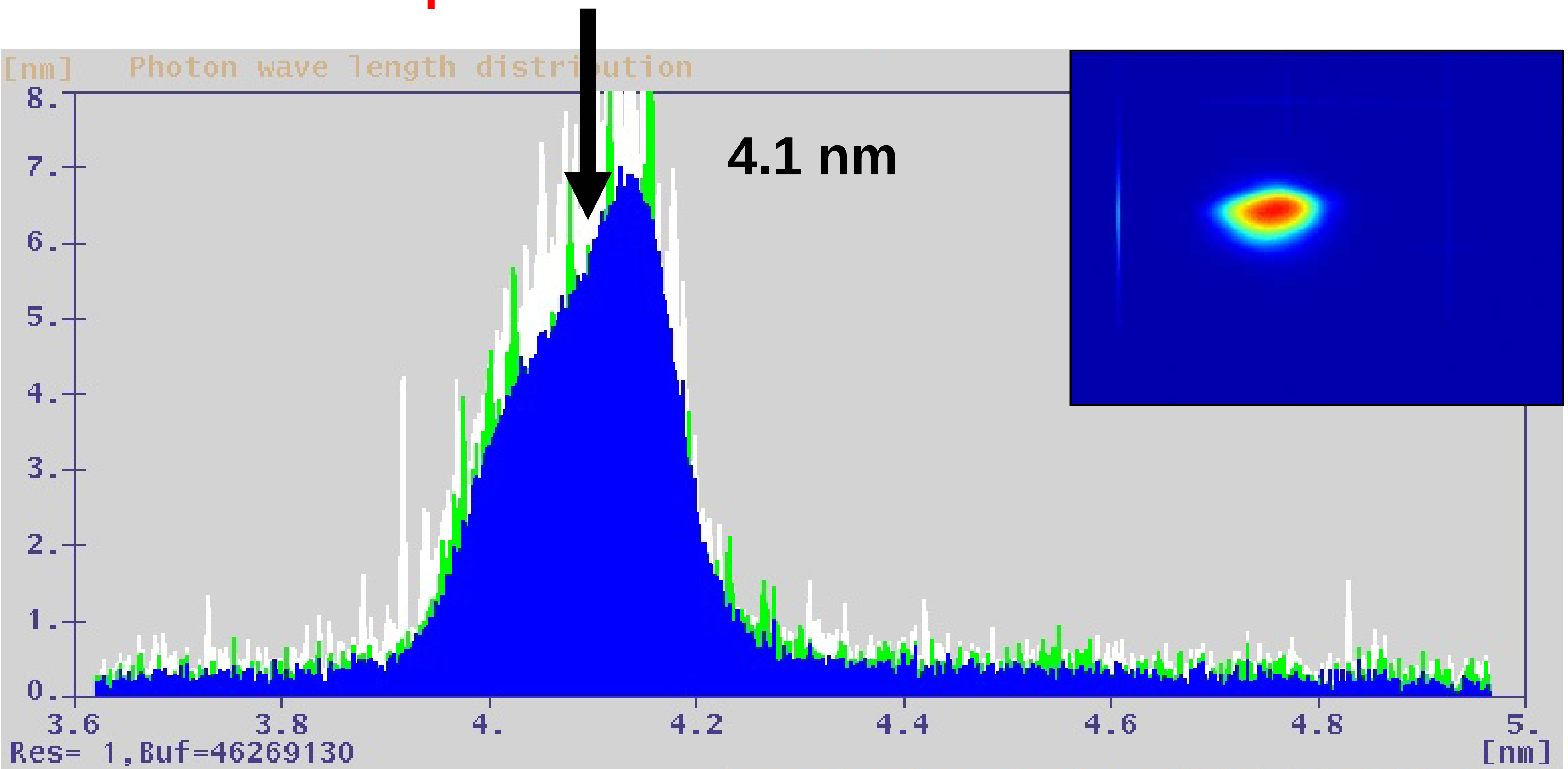
# Lasing in the water window

Photon beam characterisation on 24-25 September, 2010

4.6 nm 120 µJ av. pulse energy

4.2 nm 90 µJ

**4.12 nm ~70 µJ**



# Examples of lasing during commissioning

> 10 Hz, between 1 and 120 bunches (1 MHz), compression using 3.9 GHz cavities

Examples:

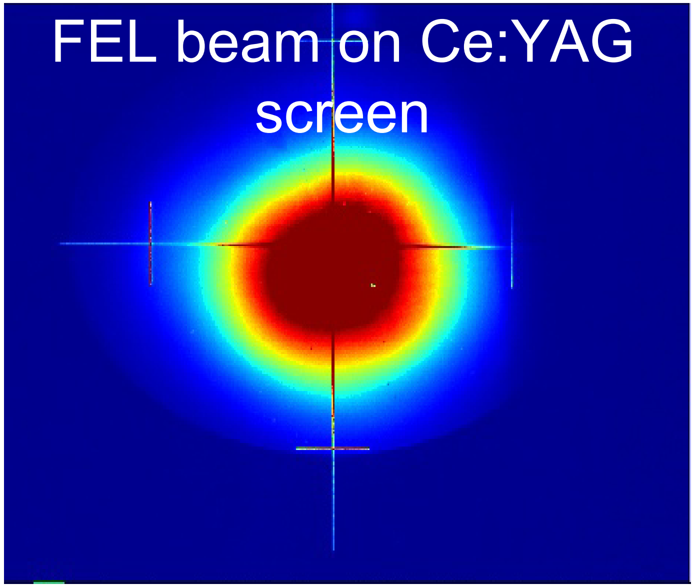
> 4.45 nm, 140 μJ max, average 75 μJ per pulse

> 12.4 nm, 105 μJ max, average 75 μJ per pulse

> 13.4 nm, 300 μJ max, average 250 μJ per pulse

> 19.2 nm, 350 μJ max, average 230 μJ per pulse

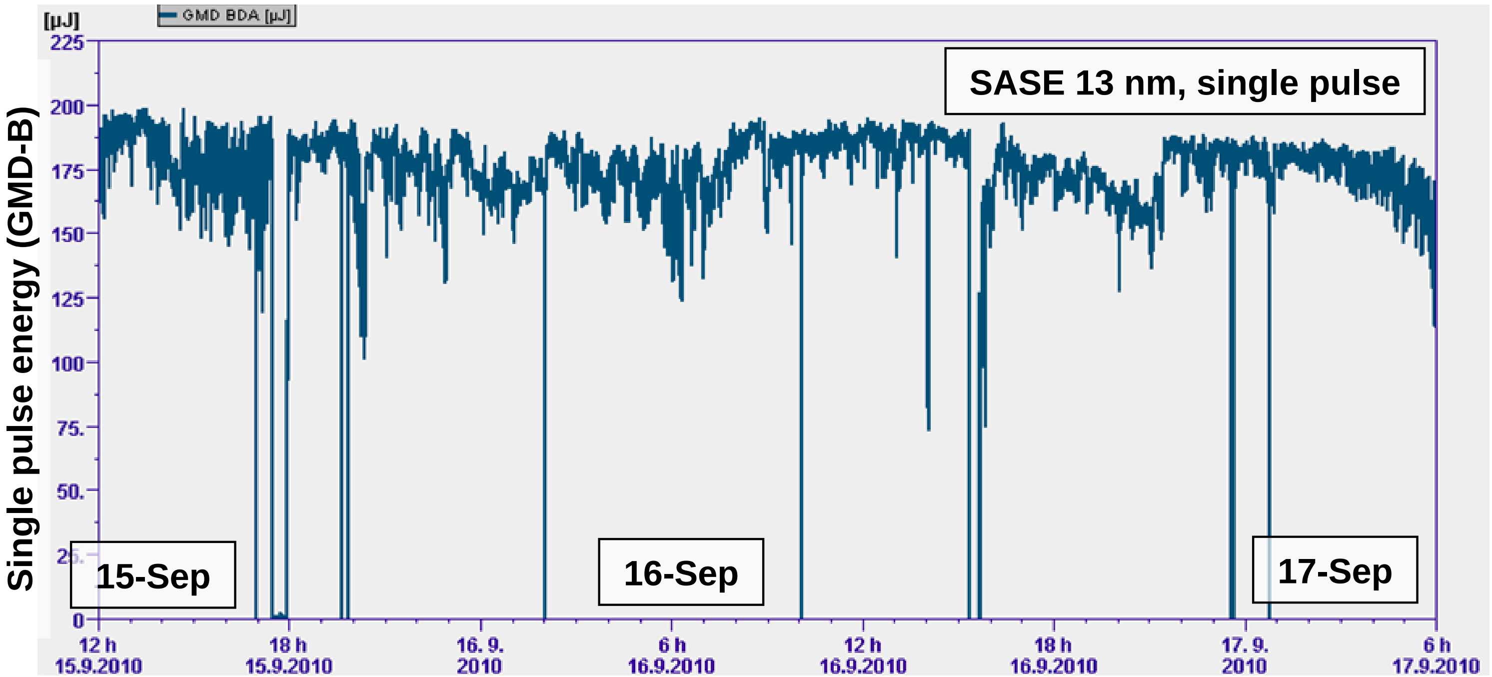
> 26.2 nm, 280 μJ max, average 160 μJ per pulse

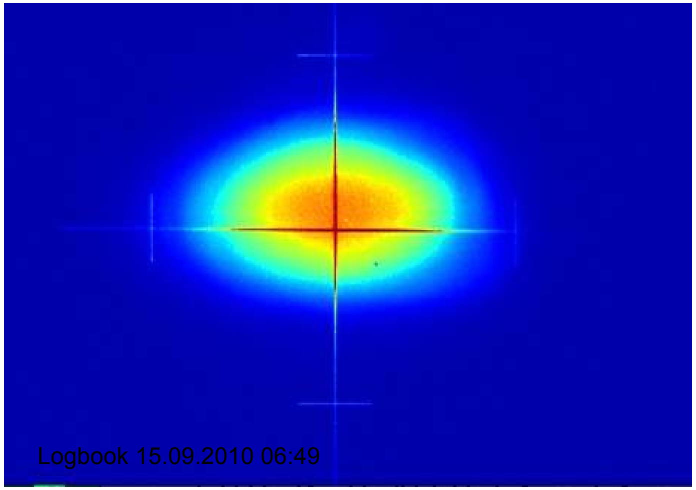


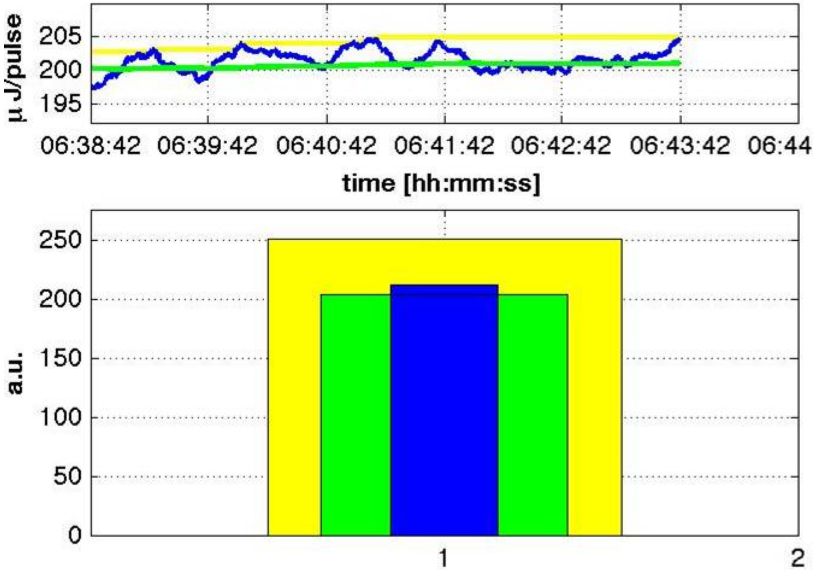

13.4 nm, distance to screen 23.5 m, ticks at 3 mm

Radiation pulse energies are significantly higher and easier to tune compared to roll-over compression

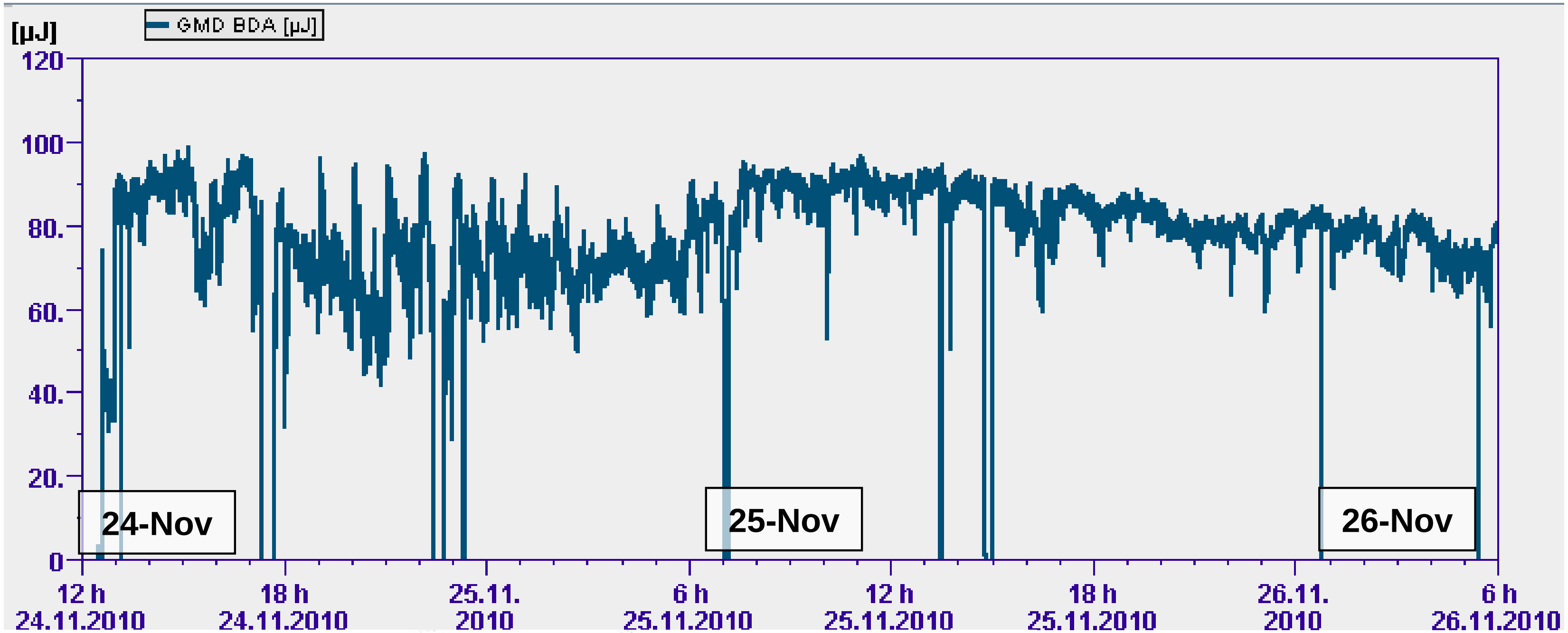
# Examples during user run: 13 nm, single bunch

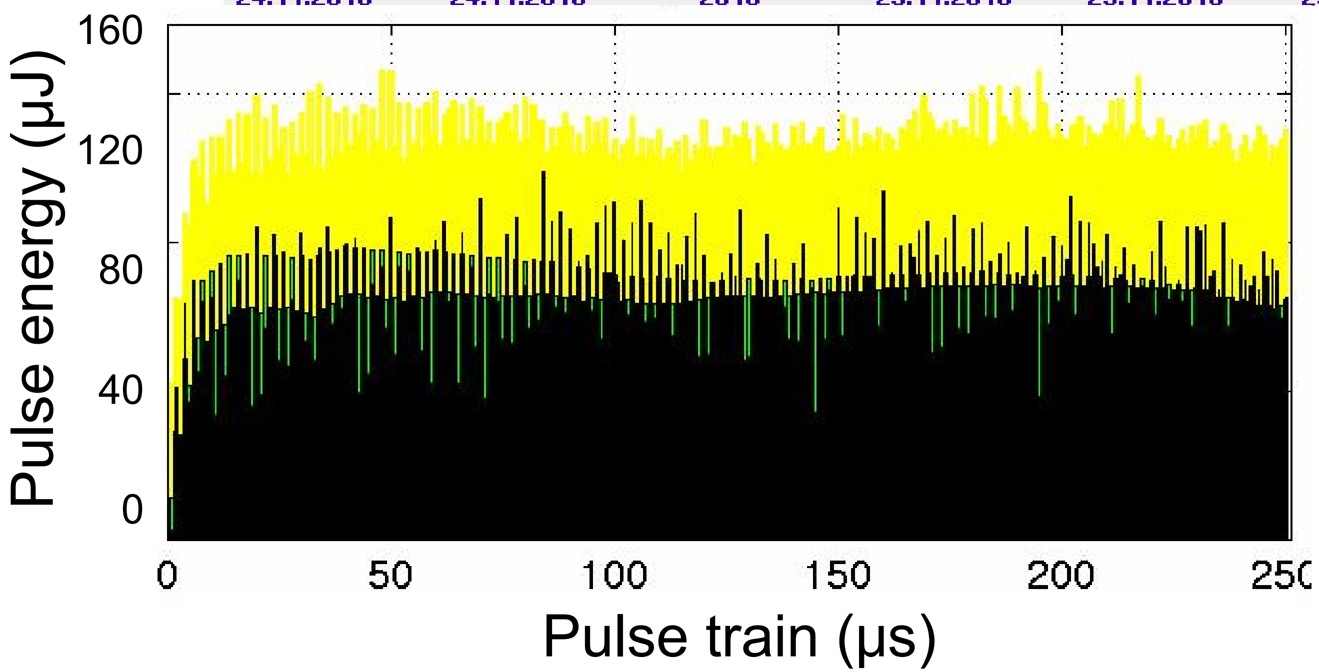


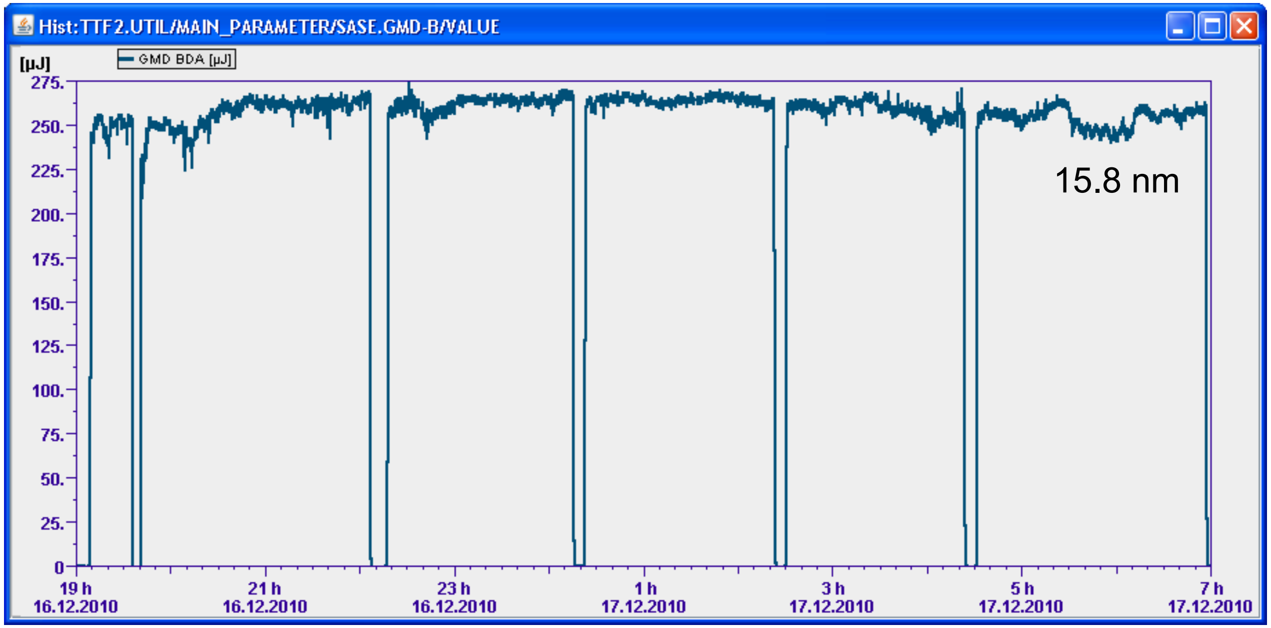
# 4.8 nm, 250 Pulses/Train, 1 MHz

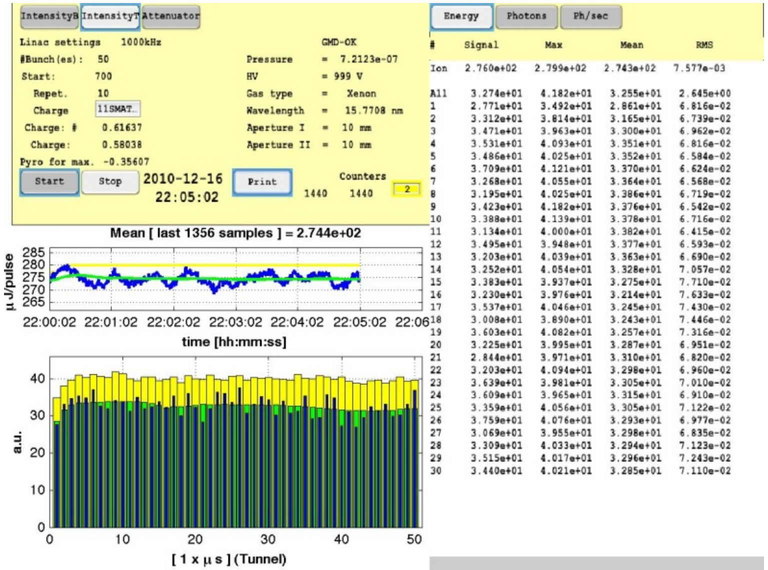


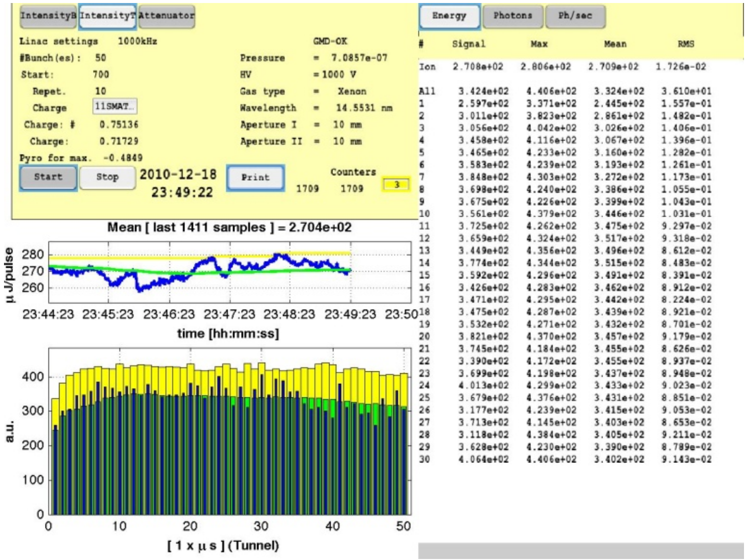



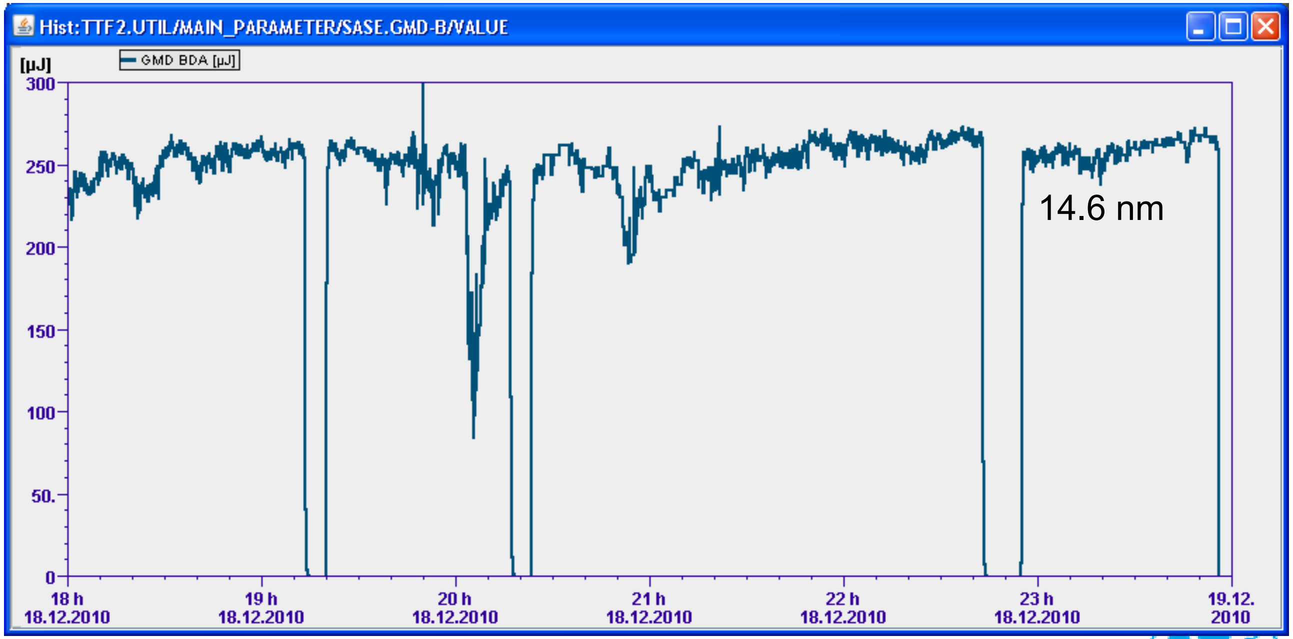

New record for FLASH:
Average power 200 mW
(at 4.8 nm)

# Example 15.8 nm and 14.6 nm, 50 bunches 1 MHz

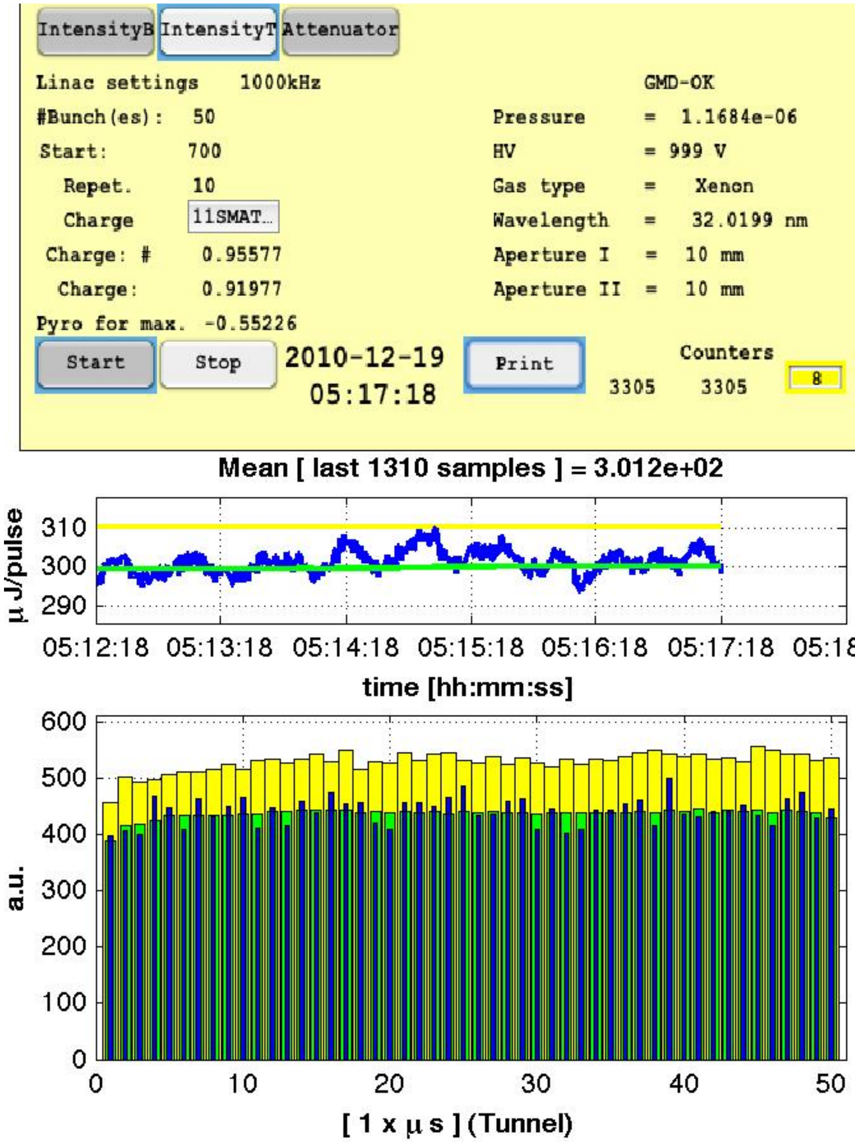


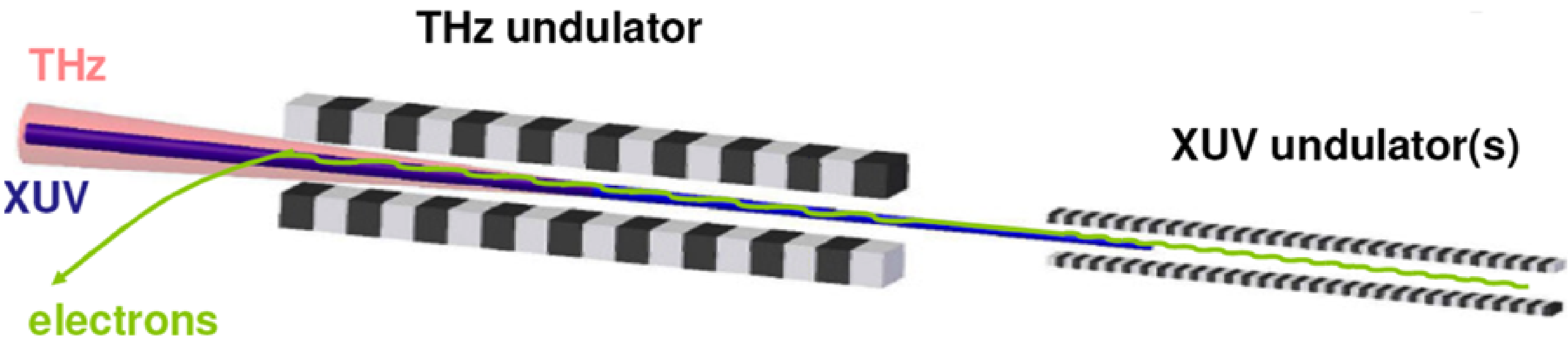
# Example 32 nm, 50 bunches 1 MHz




Energy | Photons | Ph/sec

| # | Signal | Max | Mean | RMS |
|---|---|---|---|---|
| Ion | 2.985e+02 | 3.102e+02 | 3.002e+02 | 1.171e-02 |
| All | 4.415e+02 | 5.561e+02 | 4.369e+02 | 2.393e+01 |
| 1 | 3.971e+02 | 4.564e+02 | 3.888e+02 | 5.412e-02 |
| 2 | 4.058e+02 | 5.009e+02 | 4.162e+02 | 5.363e-02 |
| 3 | 3.999e+02 | 4.923e+02 | 4.185e+02 | 5.230e-02 |
| 4 | 4.676e+02 | 4.981e+02 | 4.246e+02 | 5.435e-02 |
| 5 | 4.471e+02 | 5.063e+02 | 4.338e+02 | 5.310e-02 |
| 6 | 4.089e+02 | 5.108e+02 | 4.340e+02 | 5.634e-02 |
| 7 | 4.645e+02 | 5.112e+02 | 4.332e+02 | 5.444e-02 |
| 8 | 4.319e+02 | 5.150e+02 | 4.342e+02 | 5.752e-02 |
| 9 | 4.501e+02 | 5.239e+02 | 4.335e+02 | 5.616e-02 |
| 10 | 4.664e+02 | 5.150e+02 | 4.363e+02 | 5.666e-02 |
| 11 | 4.116e+02 | 5.321e+02 | 4.369e+02 | 5.722e-02 |
| 12 | 4.480e+02 | 5.328e+02 | 4.398e+02 | 5.733e-02 |
| 13 | 4.155e+02 | 5.278e+02 | 4.402e+02 | 5.703e-02 |
| 14 | 4.589e+02 | 5.340e+02 | 4.428e+02 | 6.185e-02 |
| 15 | 4.379e+02 | 5.416e+02 | 4.437e+02 | 5.893e-02 |
| 16 | 4.753e+02 | 5.281e+02 | 4.438e+02 | 6.066e-02 |
| 17 | 4.538e+02 | 5.503e+02 | 4.426e+02 | 5.890e-02 |
| 18 | 4.570e+02 | 5.165e+02 | 4.386e+02 | 6.060e-02 |
| 19 | 4.198e+02 | 5.294e+02 | 4.418e+02 | 5.956e-02 |
| 20 | 4.094e+02 | 5.274e+02 | 4.390e+02 | 6.027e-02 |
| 21 | 4.564e+02 | 5.456e+02 | 4.414e+02 | 5.846e-02 |
| 22 | 4.560e+02 | 5.322e+02 | 4.381e+02 | 6.108e-02 |
| 23 | 4.506e+02 | 5.426e+02 | 4.409e+02 | 5.849e-02 |
| 24 | 4.654e+02 | 5.454e+02 | 4.372e+02 | 6.052e-02 |
| 25 | 4.856e+02 | 5.320e+02 | 4.405e+02 | 5.873e-02 |
| 26 | 4.339e+02 | 5.275e+02 | 4.386e+02 | 5.971e-02 |
| 27 | 4.351e+02 | 5.370e+02 | 4.402e+02 | 5.775e-02 |
| 28 | 4.589e+02 | 5.245e+02 | 4.379e+02 | 5.955e-02 |
| 29 | 4.631e+02 | 5.351e+02 | 4.388e+02 | 5.929e-02 |
| 30 | 4.083e+02 | 5.270e+02 | 4.369e+02 | 5.971e-02 |

# THz at FLASH: more intensity

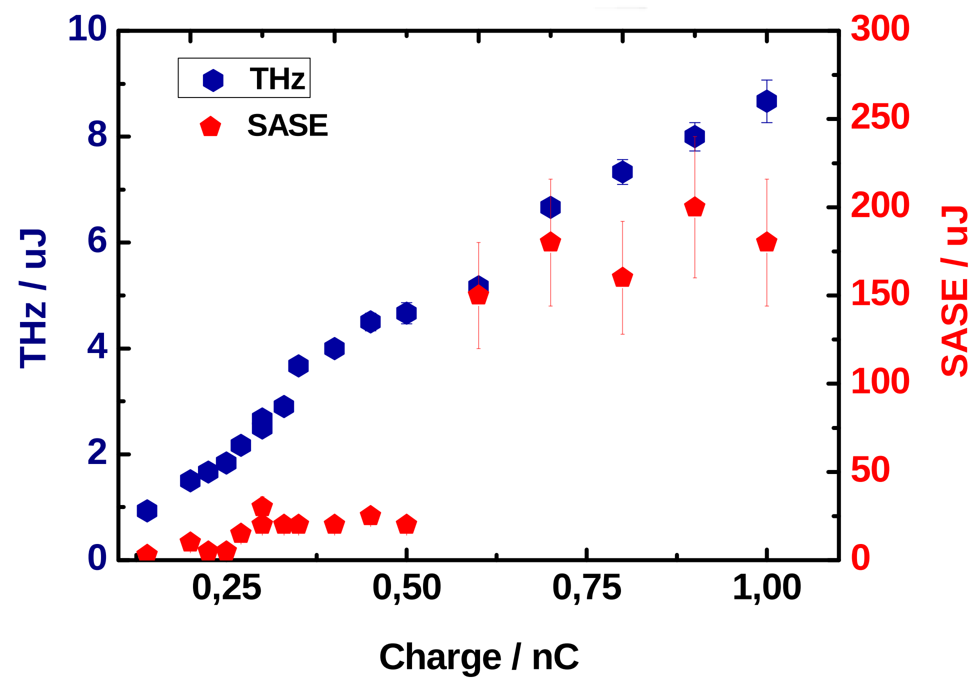



__Cascaded design__:

- Parasitic operation
- Synchronization to XUV pulse

__After Shutdown:__

- Long and short electron bunches
- Up to 10uJ pulse intensities
- Strong SASE

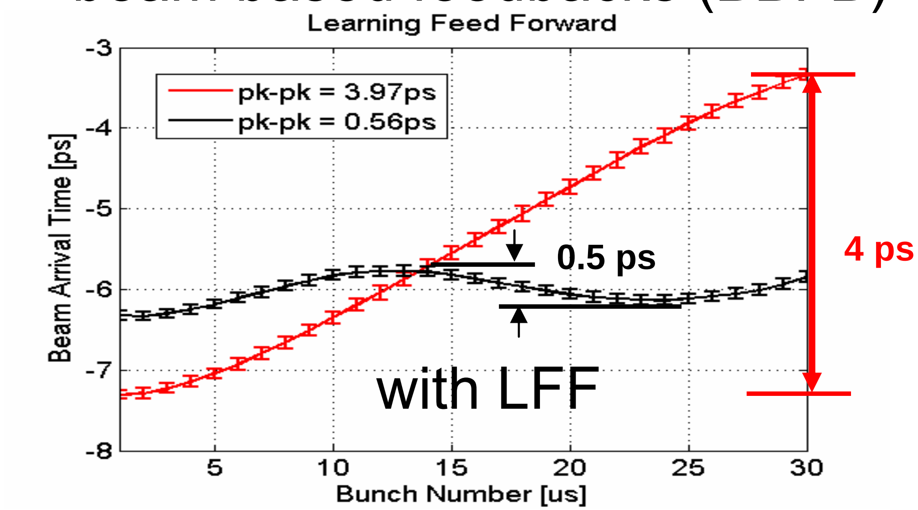


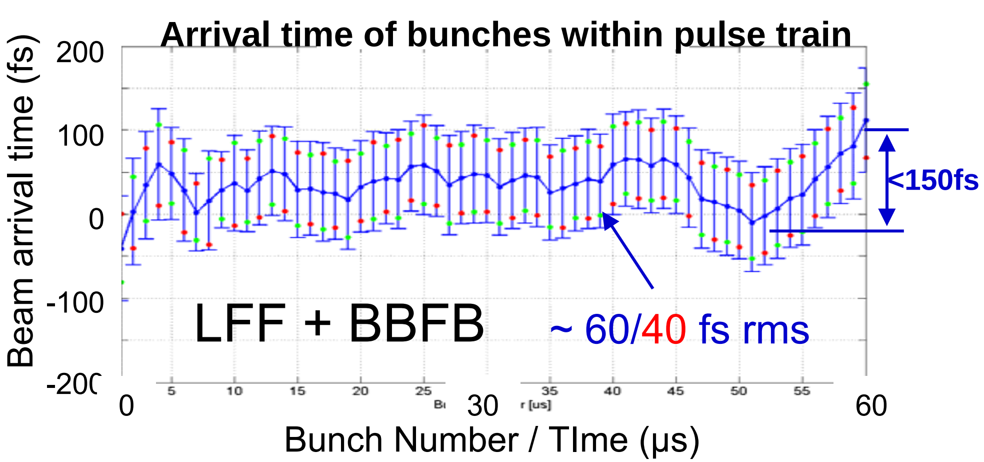


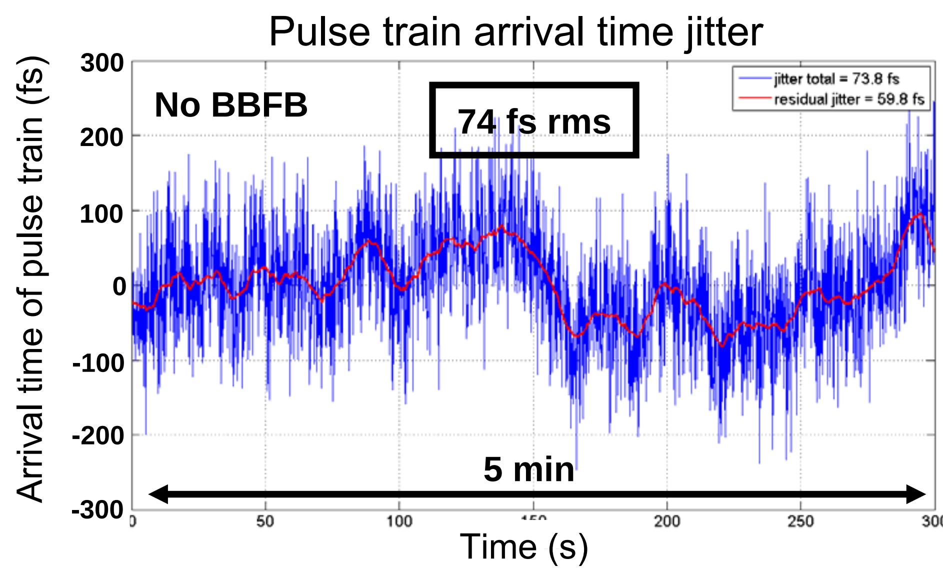
- B. Faatz et al., NIM A 475 (2001) 363.
- G. Geloni, E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov, Nucl. Instr. Method A 528 (2004) 184–188.
- Gensch, M. et al. New infrared undulator beamline at FLASH. Infrared Phys. Technol. 51, 423–425 (2008).

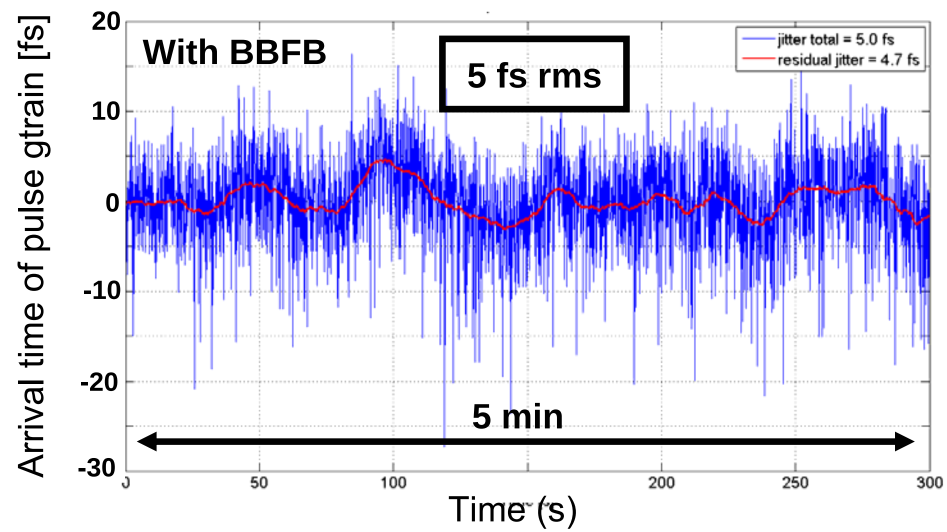
# First results on stability and beam based feedbacks

- Arrival time jitter ds 1st bunch compressor 70 fs rms (5 min) → dE/E (ACC1) < $1 \cdot 10^{-4}$
- Learning feedforward (LFF) and beam based feedbacks (BBFB)



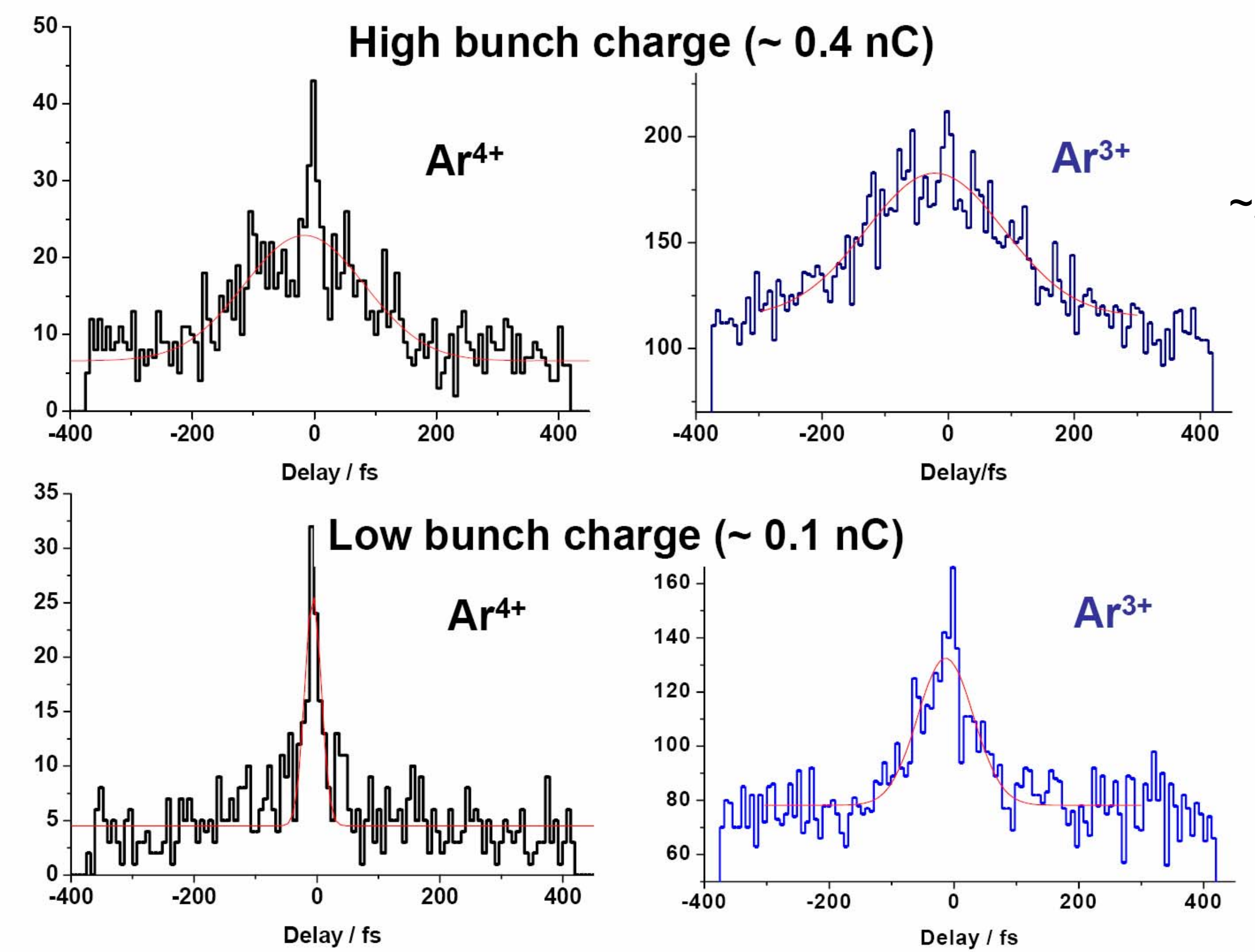




> Still in R&D phase

# Long pulses!




~200 fs

~70 fs

R. Moshammer, A. Rudenko

# Tuning and characterisation of short electron bunches and FEL radiation pulses at 14 nm

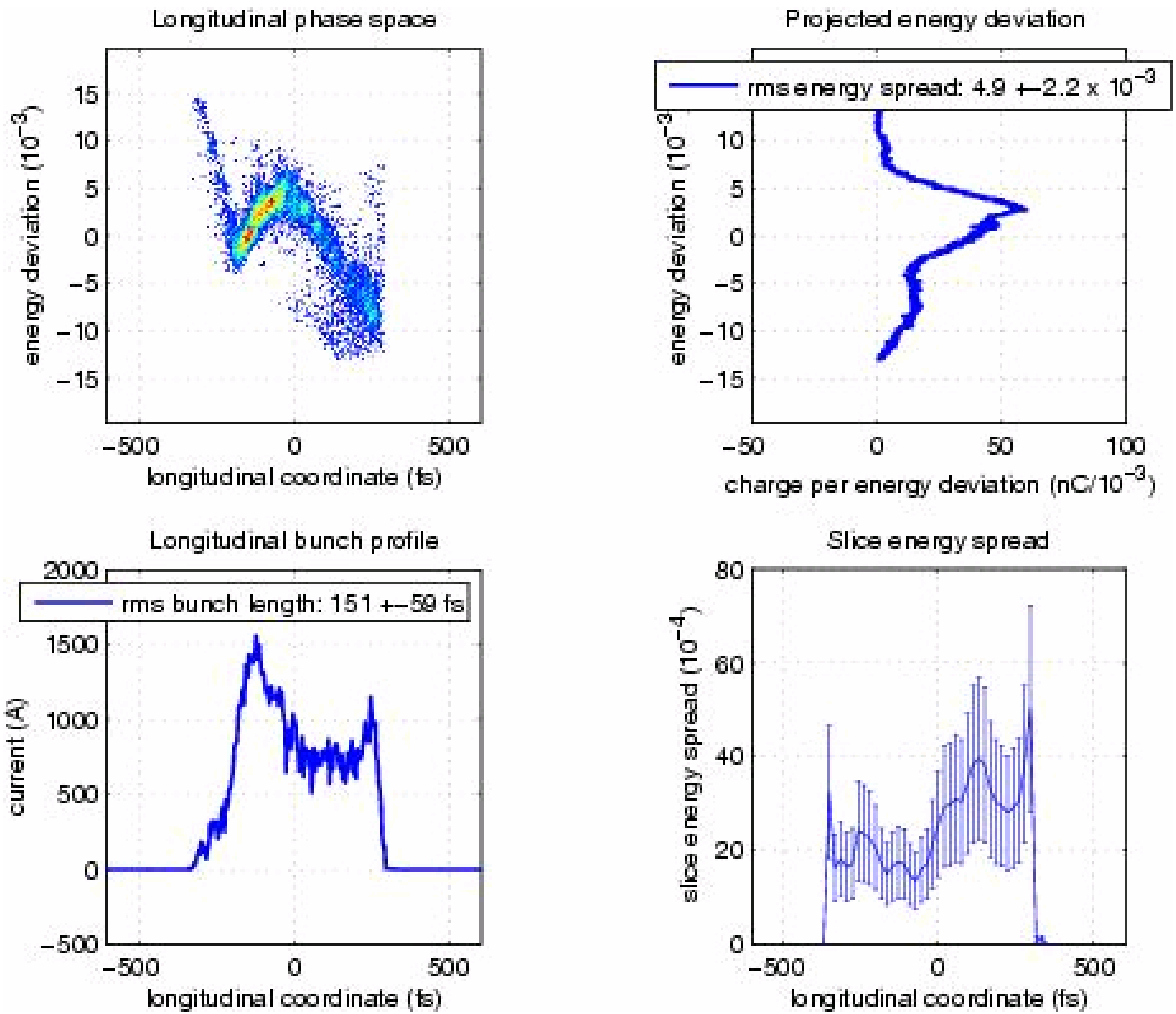
19-21 Jan 2011

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)

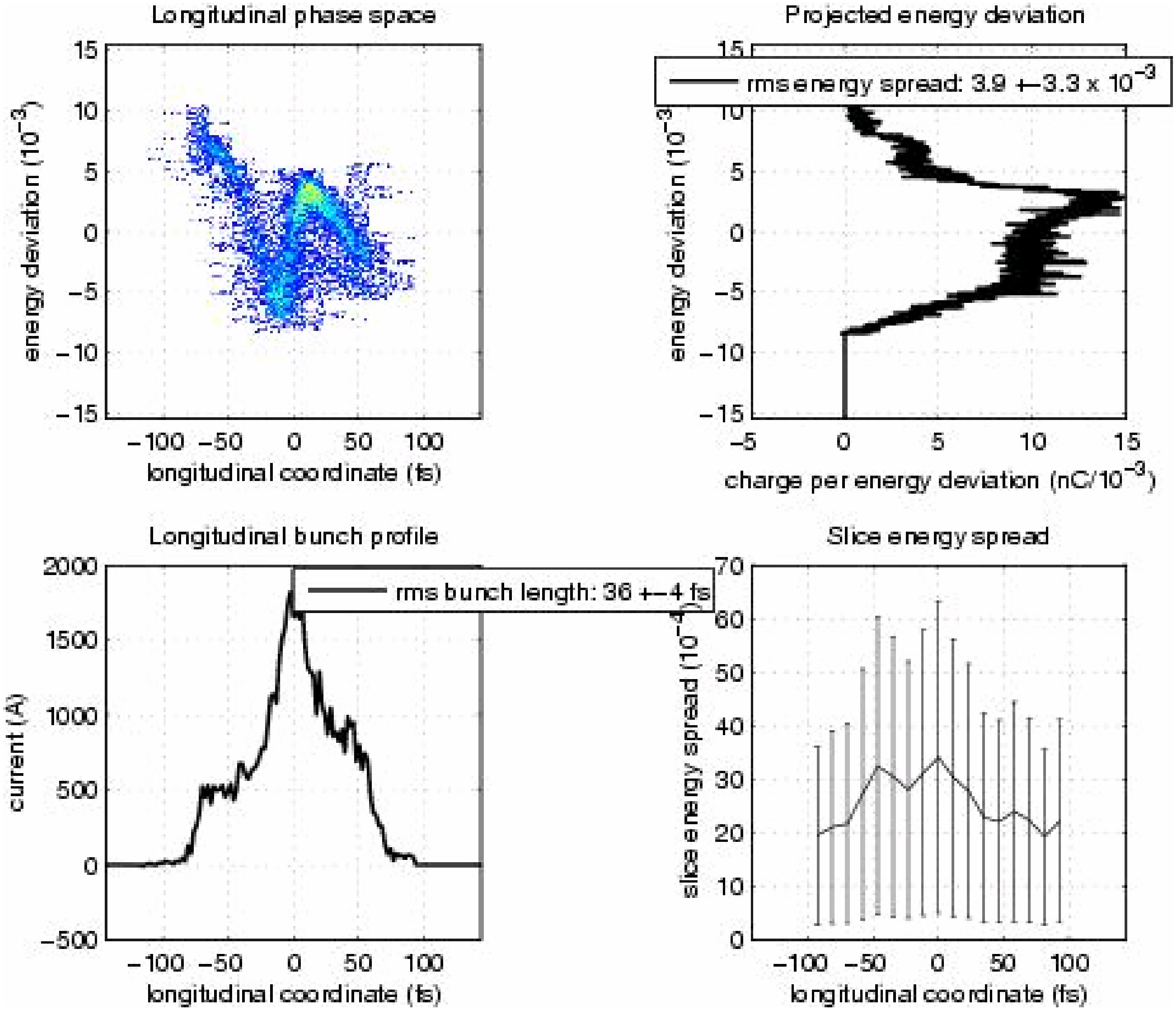
## Characterisation techniques

- Electron pulse:
  - LOLA (pulse shape)
  - toroids (charge)
  - pyro detectors (signal related to bunch shape and charge)
- Photon pulse:
  - pulse energy (GMD and MCP)
  - measurements of statistical fluctuations (MCP)
  - spectral measurements (PGM)

# LOLA images @ 500 pC



# LOLA images @ 150 pC

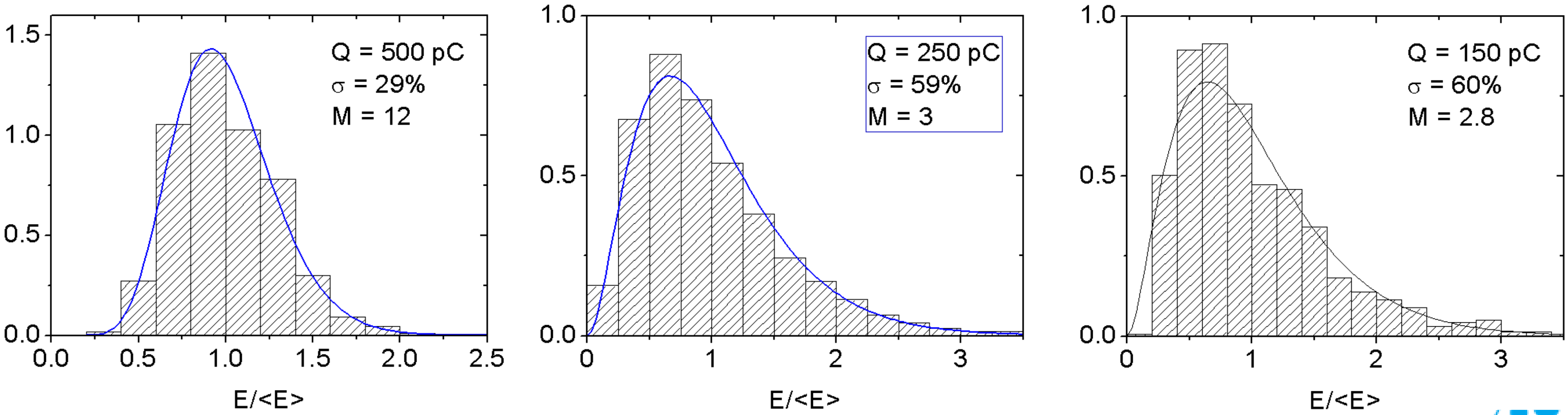


# Results: pulse energy and number of modes

- SASE at 14 nm was tuned to max. pulse energy level for different charges:

| | |
|---|---|
| 150 pC | 25-35 uJ |
| 250 pC | 35 uJ |
| 500 pC | >200 uJ |

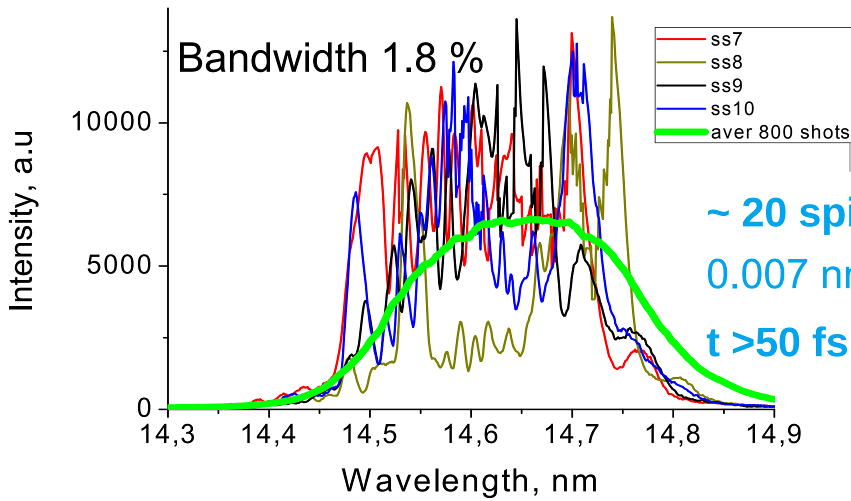
- Then the SASE process was suppressed in the undulator modules 5 and 6 (by orbit kick) in order to operate the FEL in the linear regime.
- The number of modes was determined by statistical measurements using MCP07 detector. Measured number of modes in the linear regime:




DESY, Beam Dynamics Meeting, January 24, 2011
E.A. Schneidmiller, M.V. Yurkov

# Results: spectral measurements

## 500 pC



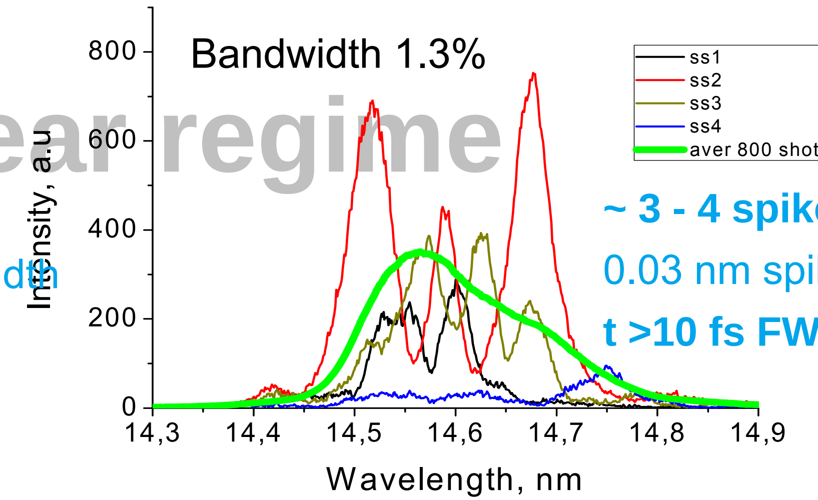

**~ 20 spikes**

0.007 nm spike width

**t >50 fs FWHM**

## 150 pC

**Linear regime**

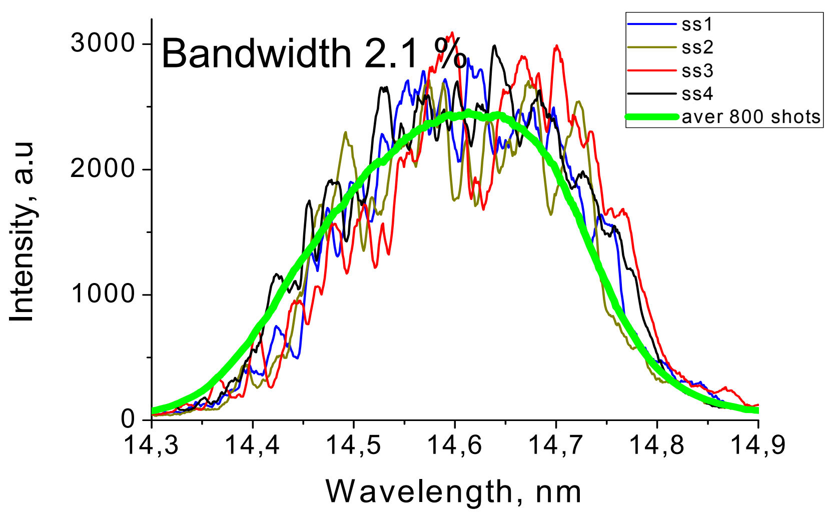


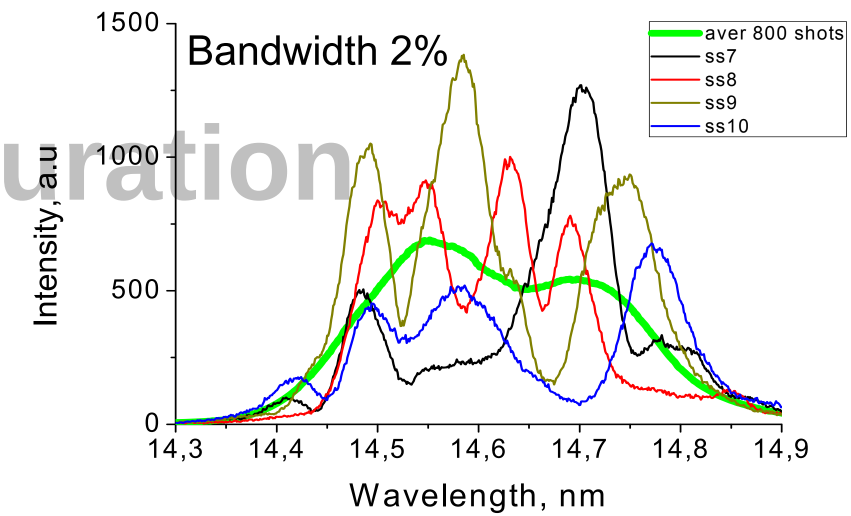

**~ 3 - 4 spikes**

0.03 nm spike width

**t >10 fs FWHM**

**Saturation**



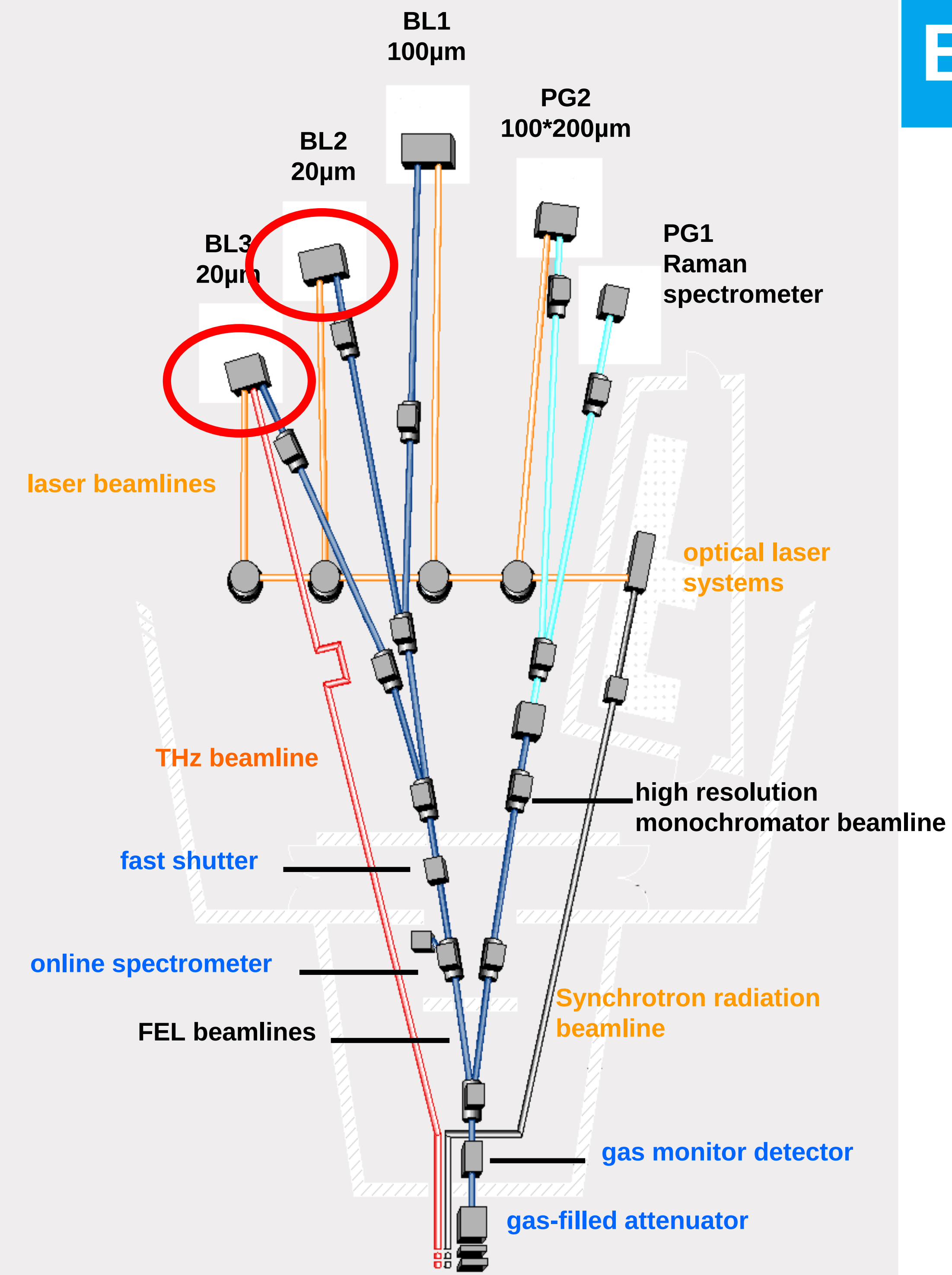




**Statistics** (*Yurkov, Schneidmiller*):

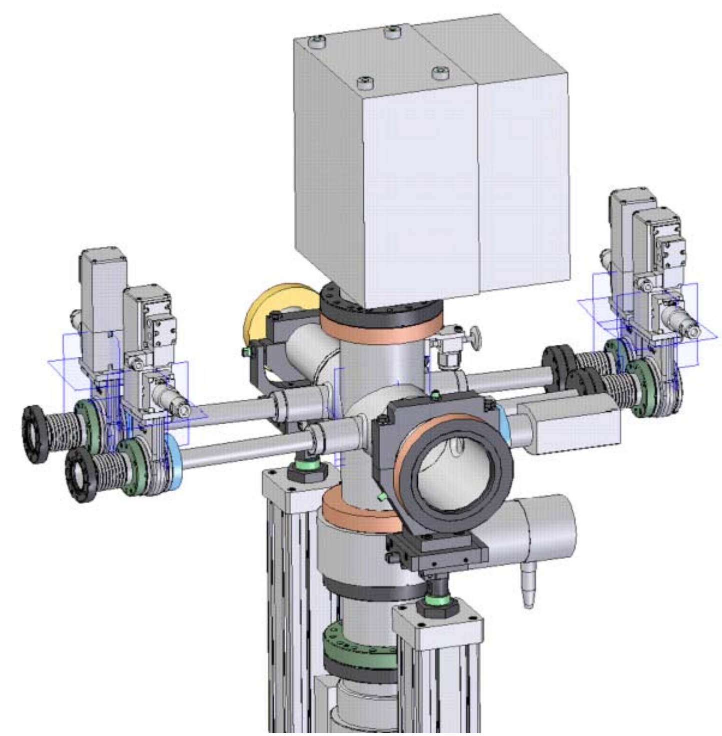
**500 pC**: sigma = 29%, M = 12, T_rad ~ **60 fs** (+10 fs + 30 fs)

**150 pC**: sigma = 60%, M = 2.8, T_rad ~ **15 fs** (+10 fs + 7 fs)

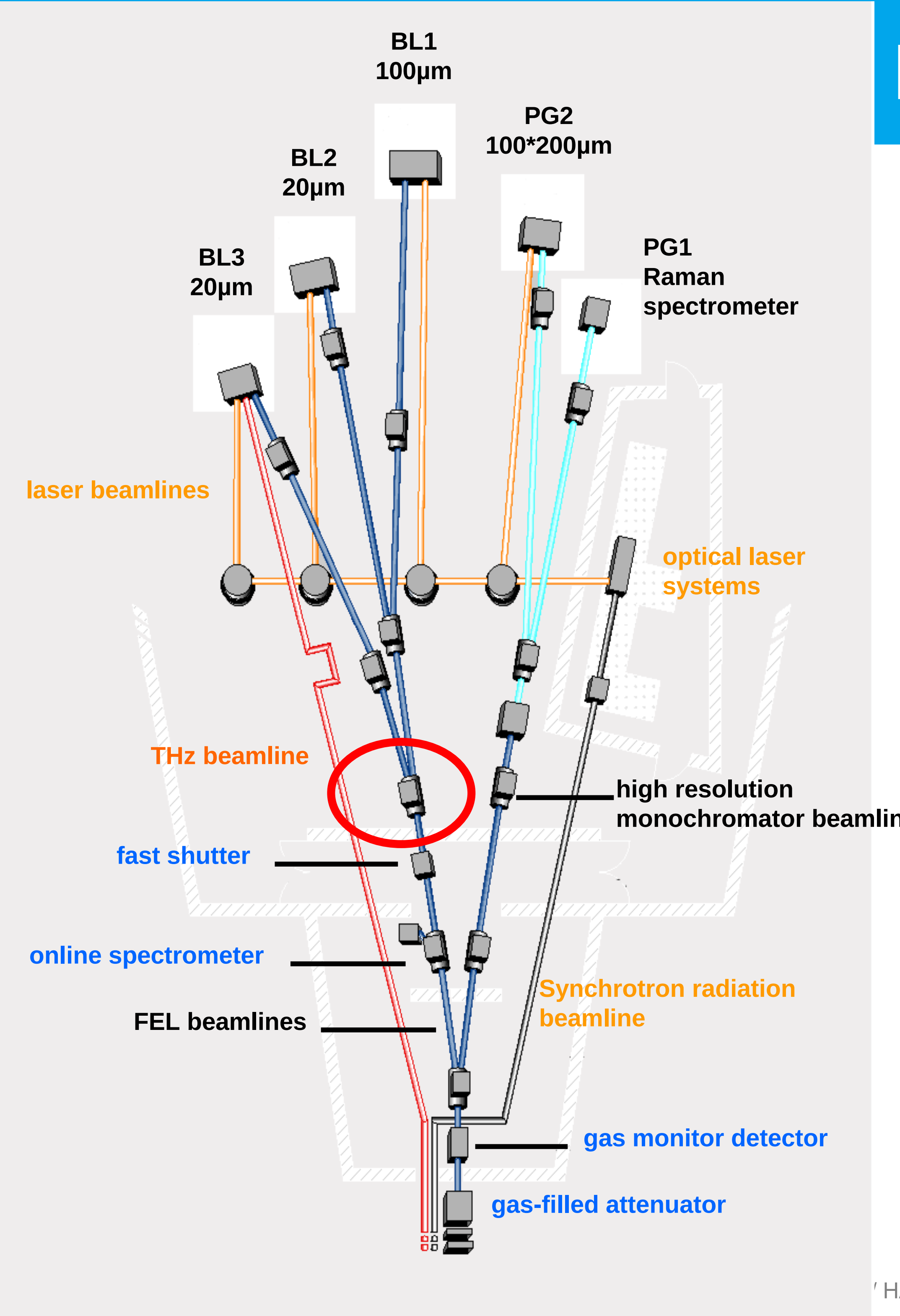
# Beamlines




- ➢ Installation of a focusing mirror at BL3 (same as BL2)
- ➢ Modified differential pumping units on the BL2 and BL3 allow users to choose either the focused or the unfocused beam

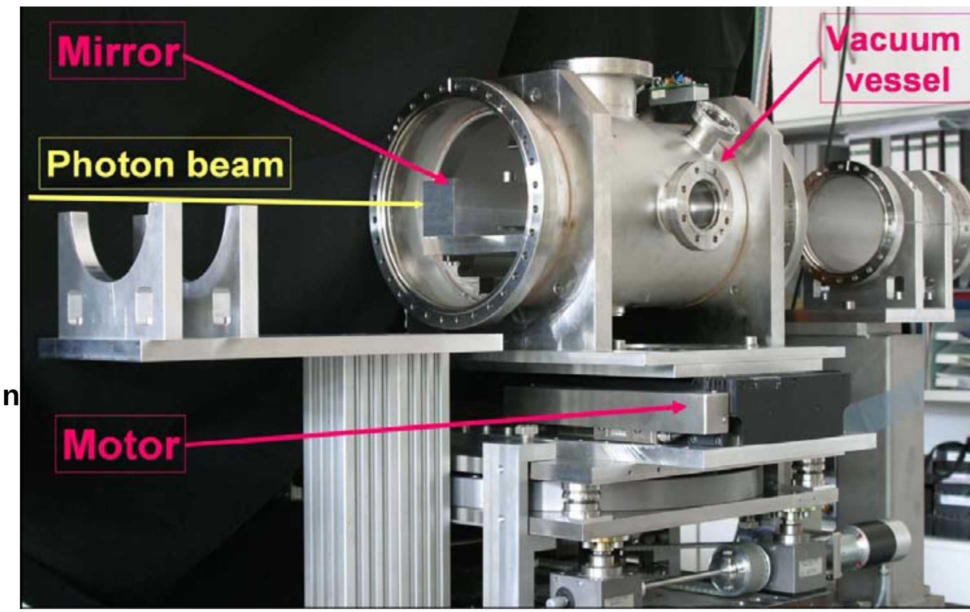


H. Schulte-Schrepping, U. Hahn, M. Hesse,
K. Tiedtke, R. Treusch,

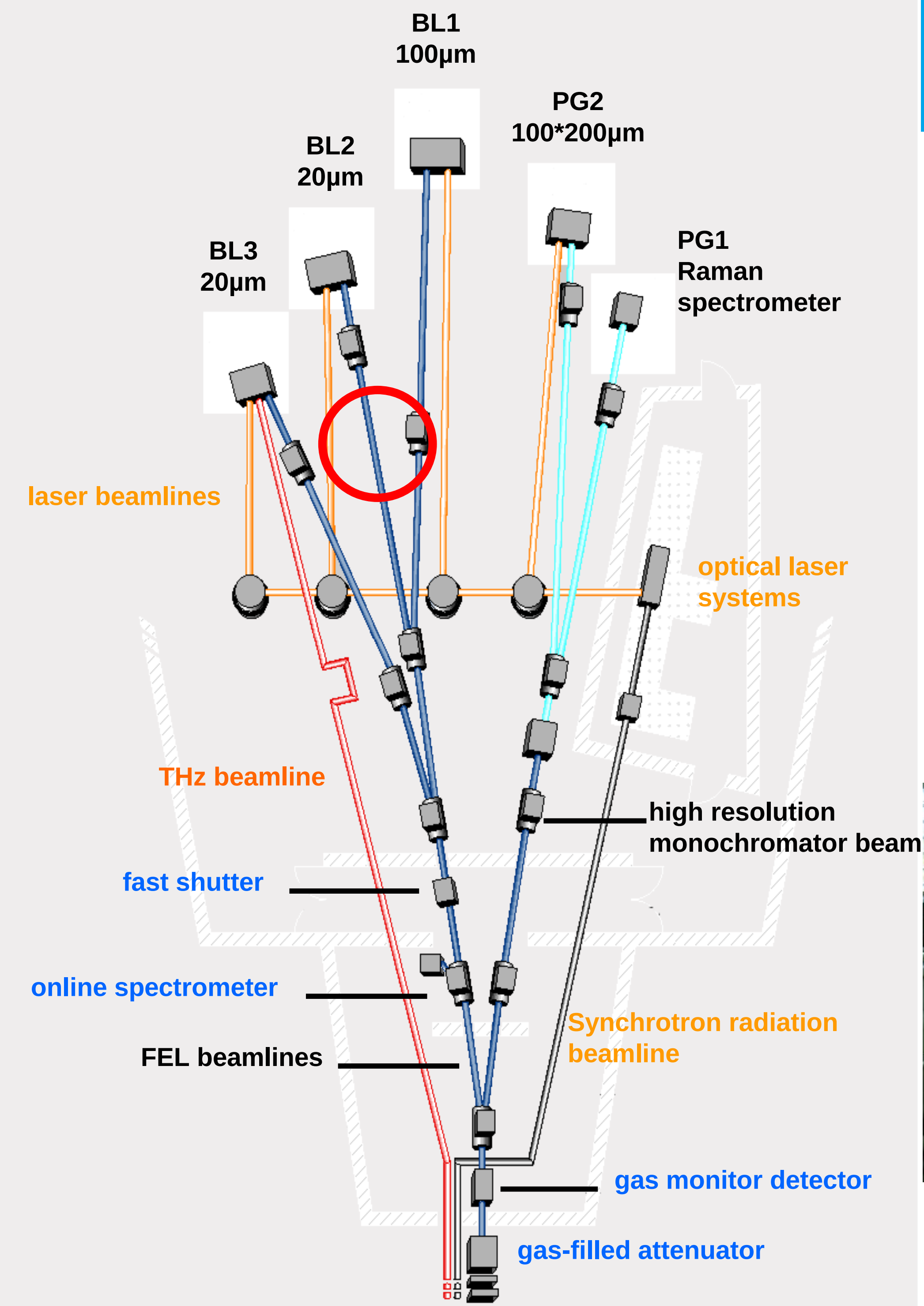



# Fast Switching Mirror

- Installation of a fast switching mirror unit in collaboration with DESY-Zeuthen
- Tested at 2.5 Hz

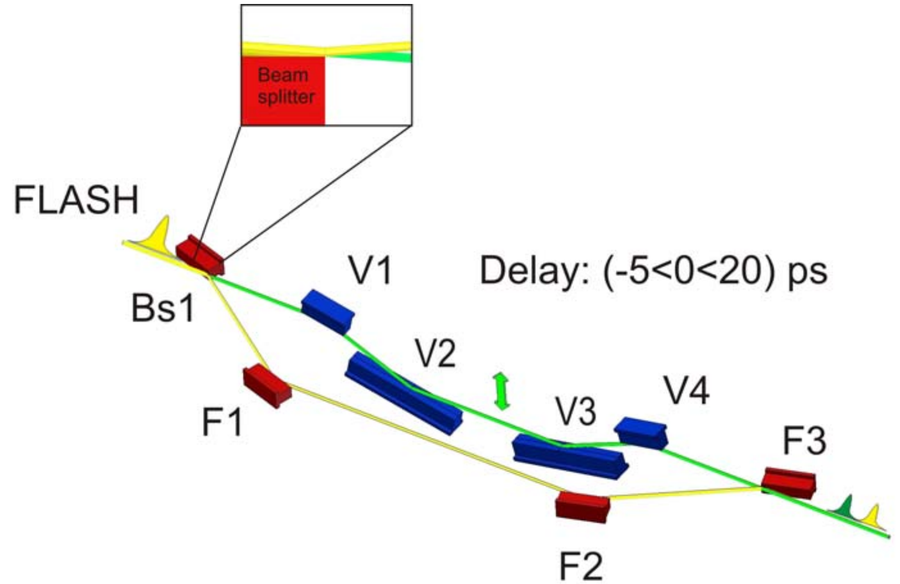


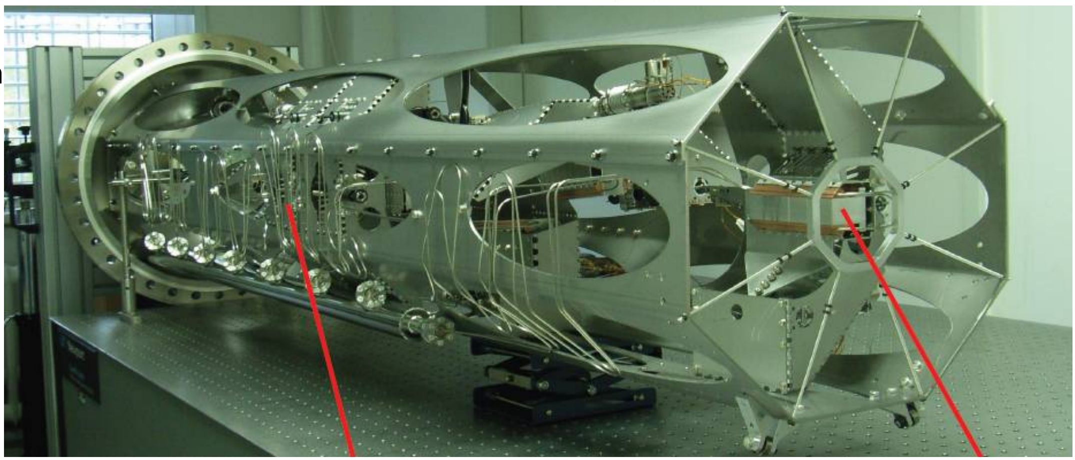

*DESY Zeuthen*: M. Sachwitz, R. Heller, R. Sternberger, D. Thürmann
*DESY Hamburg*: H. Schulte-Schrepping, U. Hahn, and K. Tiedtke




# Beam splitter

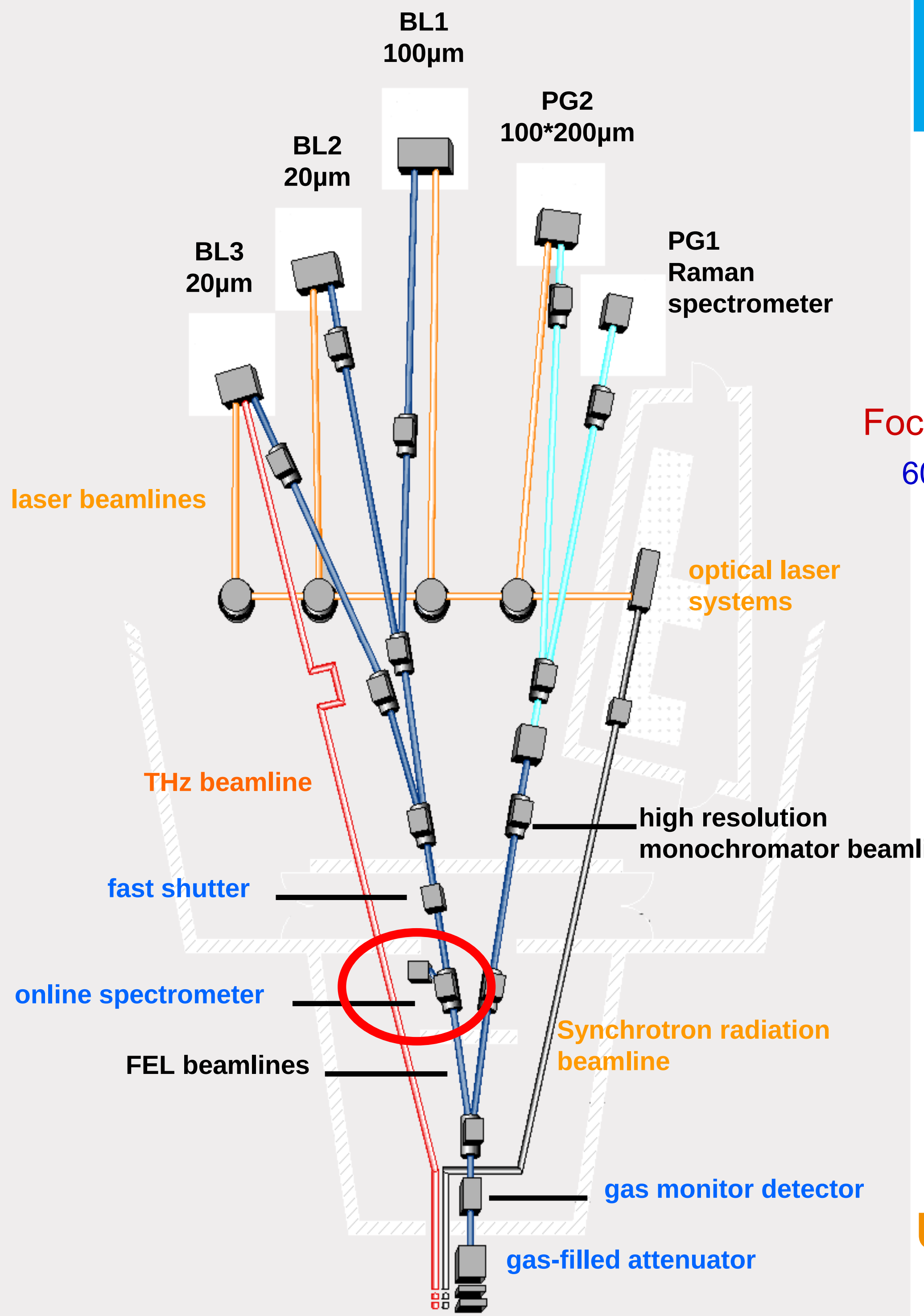
- The beam splitter / autocorrelator has been integrated in the BL2 beamline

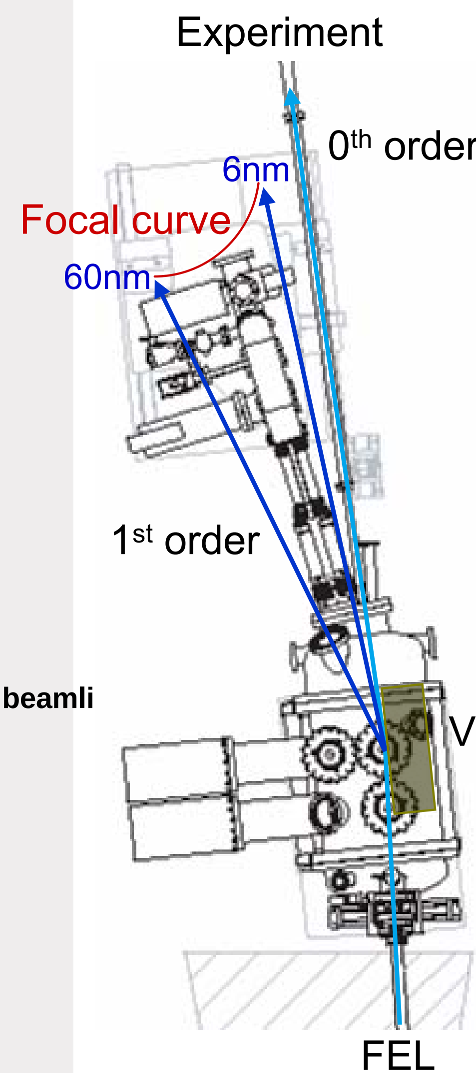


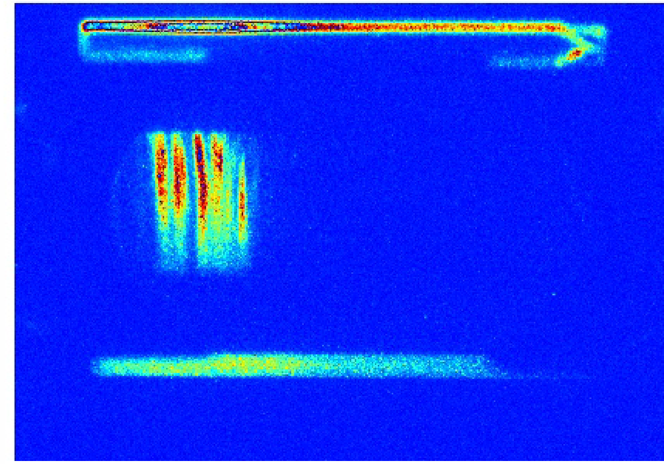



R. Mitzner (HZB), B. Siemer, H. Zacharias (Uni Münster), U. Hahn, M. Hesse, and K. Tiedtke

# VLS Spectrometer



Spectral distribution of a single FEL pulse at 26.5 nm (21 Aug 2010)

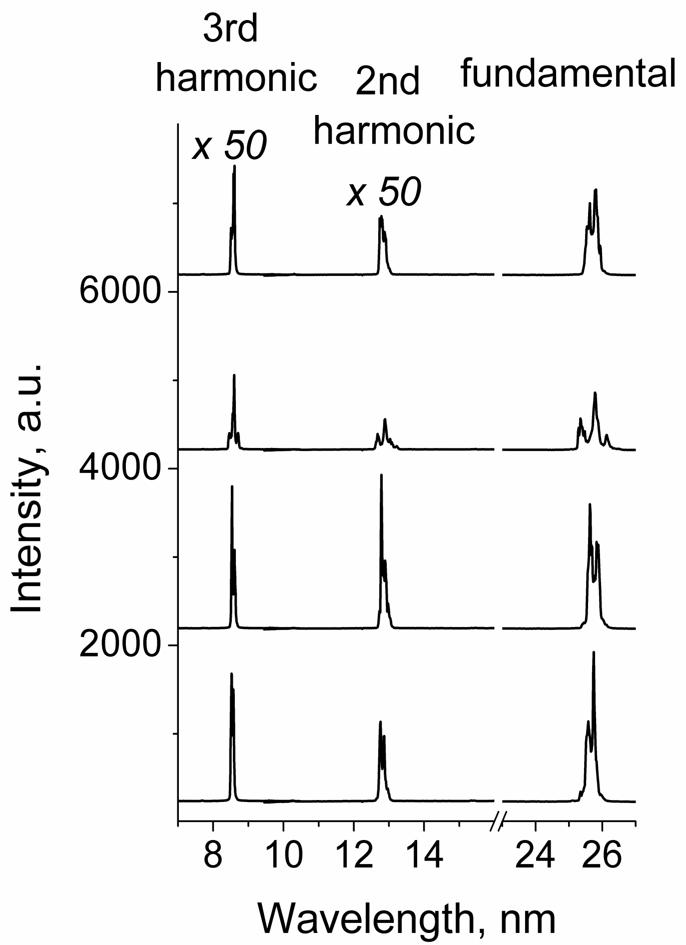
**Under commissioning**

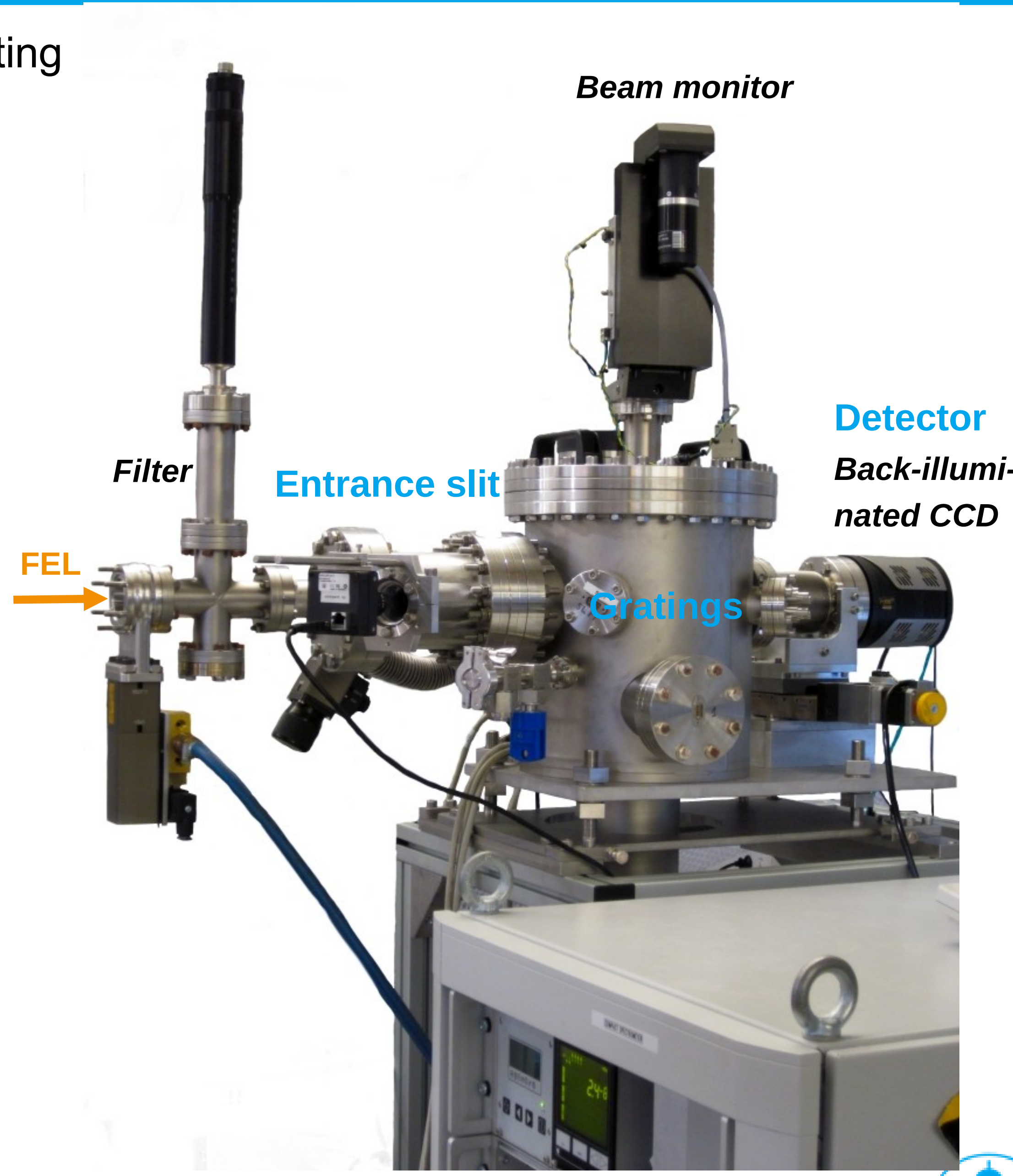
G. Brenner and S. Kapitzki

# Compact spectrometer

- Flat field spectrometer using VLS grating
- Wavelength range: 1 – 40 nm

## High harmonics characterization



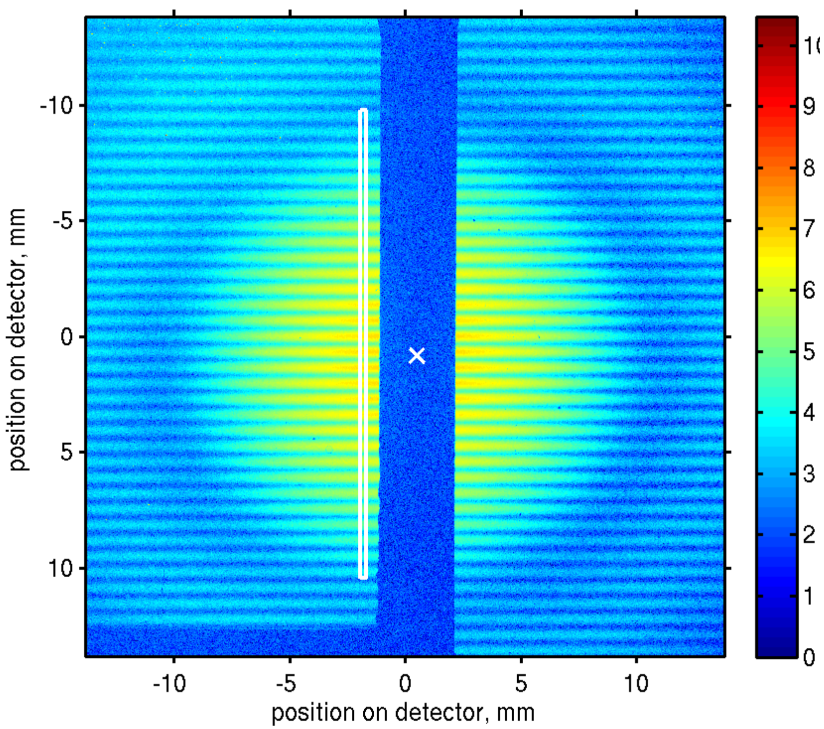




*Collaboration : INFM Padua, DESY*
N. Gerasimova

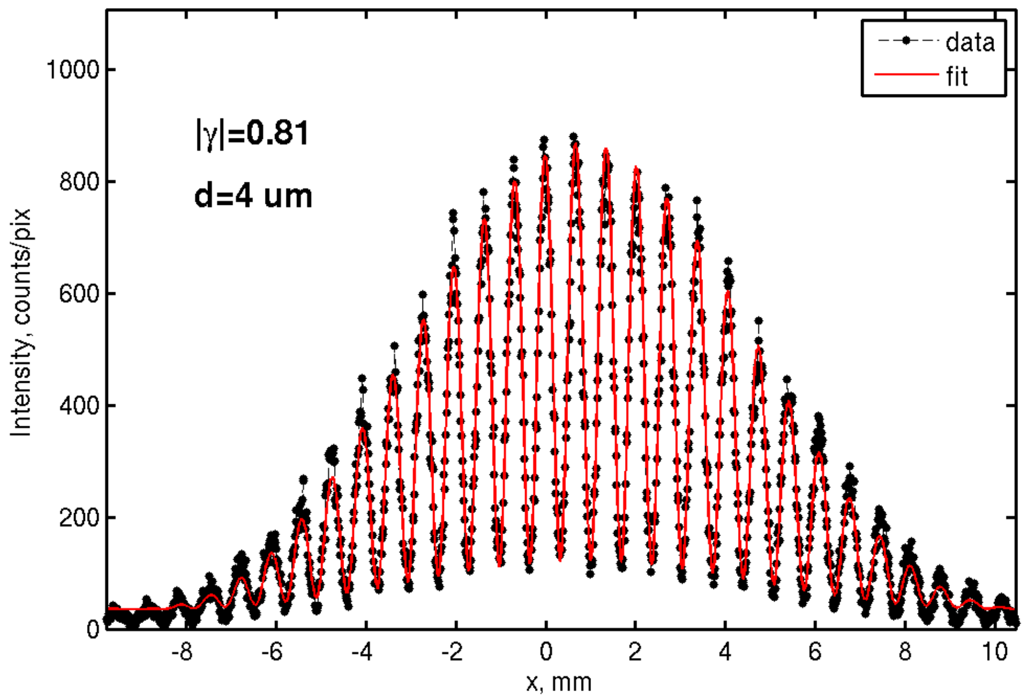
# Transverse coherence measurements in the focused beam at BL2

## Double pinholes 4 $\mu$m separation, vertical direction

**Intensity (log)**




**Theoretical fit**




**Transverse coherence length: 9 $\mu$m**

**Beam size : about 20 $\mu$m FWHM**

**I. Vartaniants *et. al* , October 2010**

**For details see Poster on Friday**

# 3rd User Period

> The 3rd user period started 2-Sep-2010

> Almost 400 12 h-shifts are scheduled until 11-Sep-2011

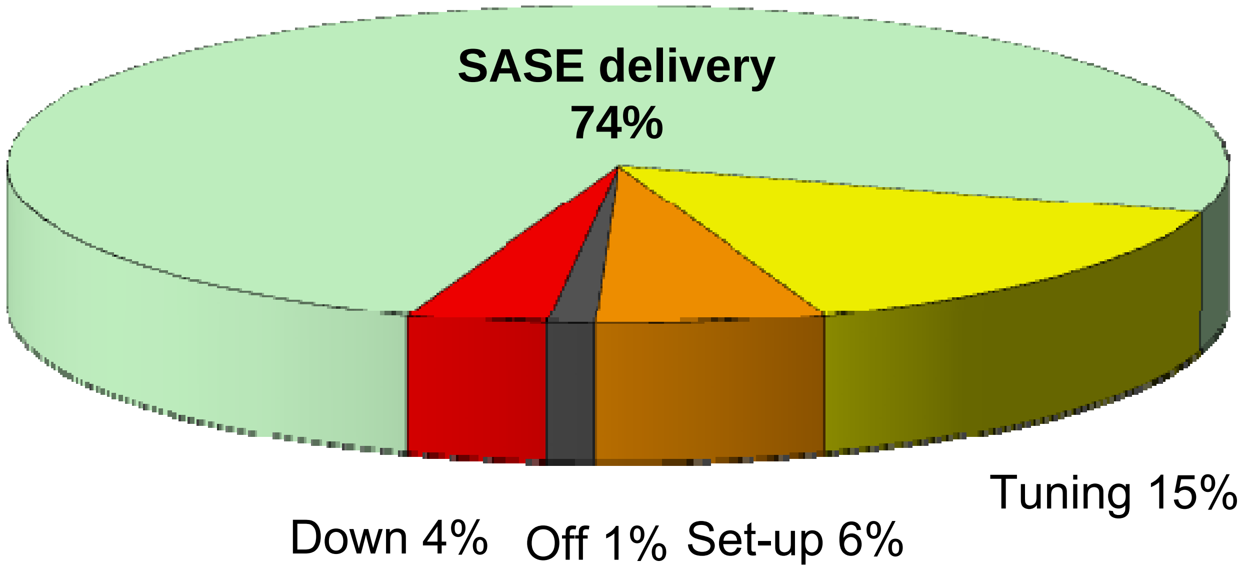
> As usual, blocks of 4 weeks for user experiments are sandwiched by 2-3 weeks for studies and beamline/user run preparation

> Schedule available at flash.desy.de

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 27 | 5.Jul | - | 11.Jul | 7 | | | school holidays HH | lasing with long trains |
| | 28 | 12.Jul | - | 18.Jul | 7 | | | school holidays HH/SH | |
| | 29 | 19.Jul | - | 25.Jul | 2 | FEL studies | | school holidays HH/SH | |
| | 30 | 26.Jul | - | 1.Aug | 2 | | | school holidays HH/SH | |
| | 31 | 2.Aug | - | 8.Aug | 3 | | preparation user run | school holidays HH/SH | |
| | 32 | 9.Aug | - | 15.Aug | 3 | | | school holidays HH/SH | |
| | 33 | 16.Aug | - | 22.Aug | 3 | | | school holidays HH/SH | photon beamlines commissioned |
| | 34 | 23.Aug | - | 29.Aug | 3 | | | **FEL Malmö** | **Start 3rd User Period** |
| | 35 | 30.Aug | - | 5.Sep | 1 | User Run | | **Linac Tsukuba** | |
| | 36 | 6.Sep | - | 12.Sep | 1 | | | | |
| | 37 | 13.Sep | - | 19.Sep | 1 | | | | |
| | 38 | 20.Sep | - | 26.Sep | 2 | FEL studies | | | |
| | 39 | 27.Sep | - | 3.Oct | 3 | | preparation user run | | |
| | 40 | 4.Oct | - | 10.Oct | 1 | User Run | | | |
| | 41 | 11.Oct | - | 17.Oct | 1 | | | | |
| | 42 | 18.Oct | - | 24.Oct | 1 | | | | |
| | 43 | 25.Oct | - | 31.Oct | 1 | | | | |
| | 44 | 1.Nov | - | 7.Nov | 2 | FEL studies | | | |
| | 45 | 8.Nov | - | 14.Nov | 2 | | | | |
| | 46 | 15.Nov | - | 21.Nov | 3 | | preparation user run | | |
| | 47 | 22.Nov | - | 28.Nov | 1 | User Run | | | |
| | 48 | 29.Nov | - | 5.Dec | 1 | | | | |
| | 49 | 6.Dec | - | 12.Dec | 1 | | | | |
| | 50 | 13.Dec | - | 19.Dec | 1 | | | | |
| | 51 | 20.Dec | - | 26.Dec | 5 | Maintenance | | | |
| **January** | 52 | 27.Dec | - | 2.Jan | 5 | | | | |
| **2011** | 1 | 3.Jan | - | 9.Jan | 4 | | preparation accelerator studies | | ***2011*** |
| | 2 | 10.Jan | - | 16.Jan | 4 | Accelerator studies | | | |
| | 3 | 17.Jan | - | 23.Jan | 4 | | | | |
| | 4 | 24.Jan | - | 30.Jan | 2 | FEL studies | | | |
| | 5 | 31.Jan | - | 6.Feb | 2 | | | | |
| | 6 | 7.Feb | - | 13.Feb | 3 | | preparation user run | | |
| | 7 | 14.Feb | - | 20.Feb | 1 | User Run | | | |
| | 8 | 21.Feb | - | 27.Feb | 1 | | | | |
| | 9 | 28.Feb | - | 6.Mar | 1 | | | | |

# User Blocks 1-3 (Sep – Dec 2011)

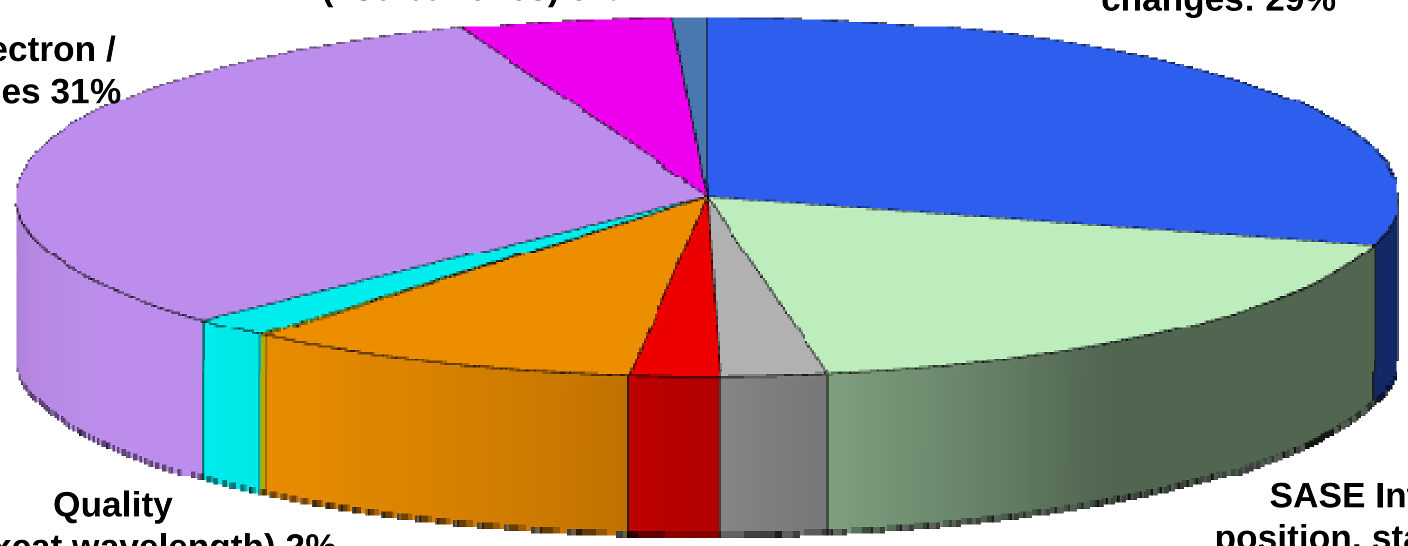
- 19 days + 29 days + 28 days = 76 days
- 21 different wavelengths delivered for users: 44 nm, 35 nm, 32 nm, 28.2 nm, 26.5 nm, 25 nm, 21.5 nm, 21 nm, 20.8 nm, 20.1 nm, 19.8 nm, 15.8 nm, 14.6 nm, 13.5 nm,
  13.3 nm, 13 nm, 12.6 nm, 10.1 nm, 8 nm, 5.7 nm, 4.8 nm




K. Honkavaara

# Block 1+2+3: Tuning + Set-up

Total Tuning + Set-up time 21%




~ 62 % in advance scheduled time slots

K. Honkavaara

# 4th User Period - tentative schedule 2012

| | | | | |
|---|---|---|---|---|
| January | 52 | 26.Dec - 1.Jan | 6 | |
| 2012 | 1 | 2.Jan - 8.Jan | 7 | FLASH I commissioning |
| | 2 | 9.Jan - 15.Jan | 7 | |
| | 3 | 16.Jan - 22.Jan | 4 | Accelerator studies |
| | 4 | 23.Jan - 29.Jan | 4 | |
| | 5 | 30.Jan - 5.Feb | 4 | |
| | 6 | 6.Feb - 12.Feb | 4 | |
| | 7 | 13.Feb - 19.Feb | 4 | |
| | 8 | 20.Feb - 26.Feb | 4 | |
| | 9 | 27.Feb - 4.Mar | 2 | |
| | 10 | 5.Mar - 11.Mar | 2 | |
| | 11 | 12.Mar - 18.Mar | 3 | |
| | 12 | 19.Mar - 25.Mar | 3 | |
| | 13 | 26.Mar - 1.Apr | 1 | |
| | 14 | 2.Apr - 8.Apr | 1 | |
| | 15 | 9.Apr - 15.Apr | 1 | |
| | 16 | 16.Apr - 22.Apr | 1 | |
| | 17 | 23.Apr - 29.Apr | 2 | |
| | 18 | 30.Apr - 6.May | 3 | |
| | 19 | 7.May - 13.May | 1 | |
| | 20 | 14.May - 20.May | 1 | |
| | 21 | 21.May - 27.May | 1 | |
| | 22 | 28.May - 3.Jun | 1 | |
| | 23 | 4.Jun - 10.Jun | 2 | |
| | 24 | 11.Jun - 17.Jun | 2 | |
| | 25 | 18.Jun - 24.Jun | 3 | |
| | 26 | 25.Jun - 1.Jul | 1 | |
| | 27 | 2.Jul - 8.Jul | 1 | |
| | 28 | 9.Jul - 15.Jul | 1 | |
| | 29 | 16.Jul - 22.Jul | 1 | |
| | 30 | 23.Jul - 29.Jul | 2 | |
| | 31 | 30.Jul - 5.Aug | 3 | |
| | 32 | 6.Aug - 12.Aug | 1 | |
| | 33 | 13.Aug - 19.Aug | 1 | |
| | 34 | 20.Aug - 26.Aug | 1 | |
| | 35 | 27.Aug - 2.Sep | 1 | |
| | 36 | 3.Sep - 9.Sep | 2 | |
| | 37 | 10.Sep - 16.Sep | 2 | |
| | 38 | 17.Sep - 23.Sep | 3 | |
| | 39 | 24.Sep - 30.Sep | 1 | |
| | 40 | 1.Oct - 7.Oct | 1 | |
| | 41 | 8.Oct - 14.Oct | 1 | |
| | 42 | 15.Oct - 21.Oct | 1 | |
| | 43 | 22.Oct - 28.Oct | 2 | |
| | 44 | 29.Oct - 4.Nov | 2 | |
| | 45 | 5.Nov - 11.Nov | 3 | |
| | 46 | 12.Nov - 18.Nov | 1 | |
| | 47 | 19.Nov - 25.Nov | 1 | |
| | 48 | 26.Nov - 2.Dec | 1 | |
| | 49 | 3.Dec - 9.Dec | 1 | |
| | 50 | 10.Dec - 16.Dec | 1 | |
| | 51 | 17.Dec - 23.Dec | 4 | |
| | 52 | 24.Dec - 30.Dec | 5 | |
| January | 1 | 31.Dec - 6.Jan | 5 | |
| 2013 | 2 | 7.Jan - 13.Jan | 4 | |
| | 3 | 14.Jan - 20.Jan | 4 | |
| | 4 | 21.Jan - 27.Jan | 4 | |
| | 5 | 28.Jan - 3.Feb | 4 | |
| | 6 | 4.Feb - 10.Feb | 6 | Connection to FLASH II |

- **Between shutdowns for FLASH II, starting March 2012**
- **~25 weeks, i.e. 325 12 h-shifts**
- **Call for proposals upcoming**
- **Deadline for proposals: May/June 2011**
- **Proposal review: September 2011**

# Summary

- Successful re-start of FLASH after the upgrade
- We have reached the carbon K-edge
- FEL beam more intense and stable than ever, tuning easier
- Tuning of short pulses is possible with linearized compression scheme
- Photon beamlines and diagnostics have been significantly improved
- New call for proposals upcoming