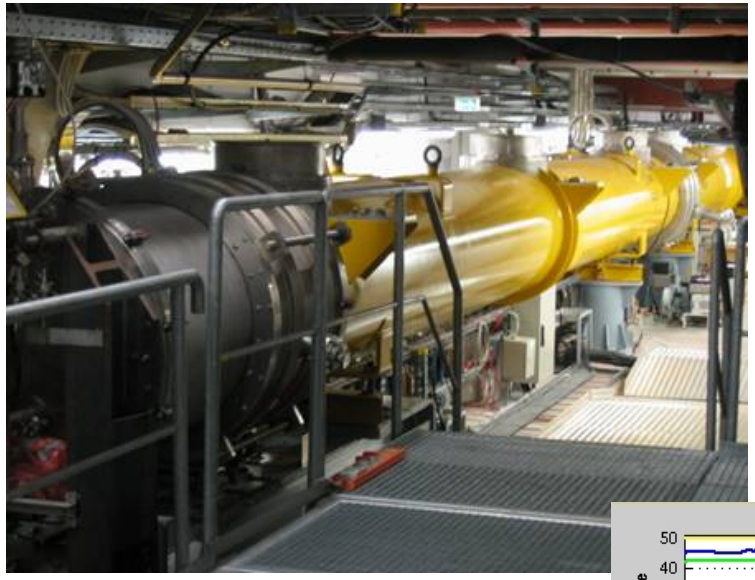
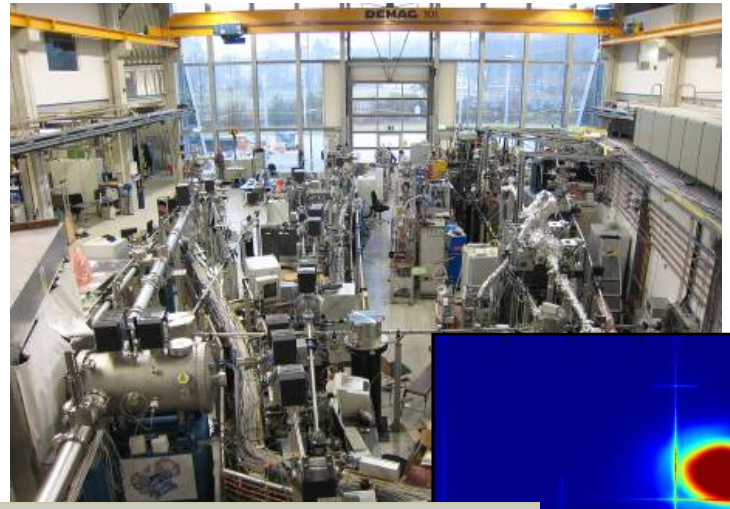
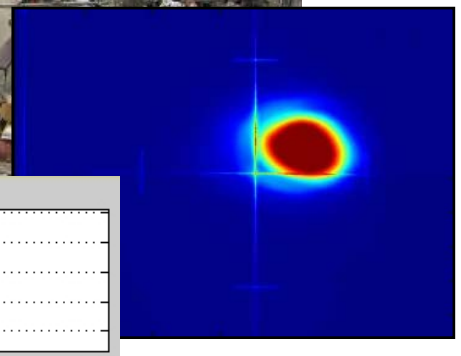
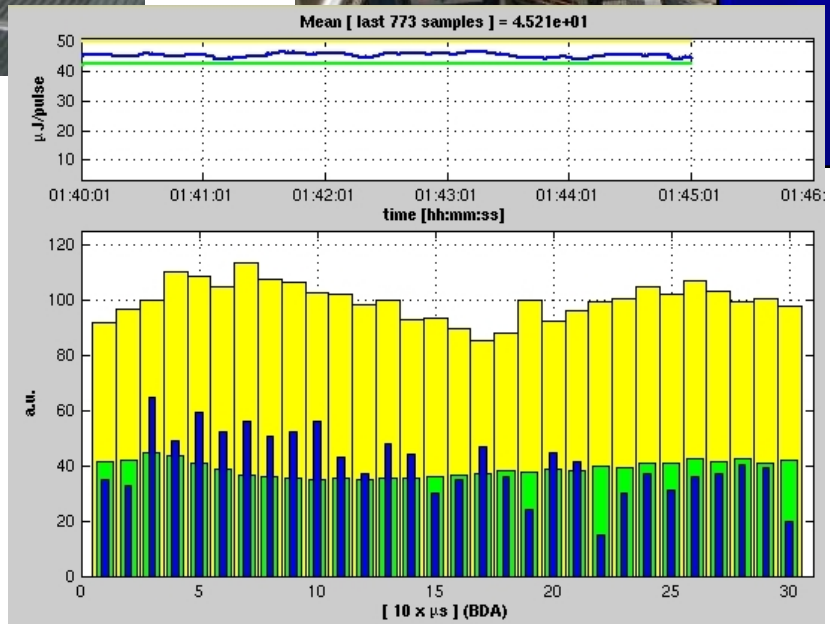
2nd FEL user period at FLASH

FLASH
Free-Electron Laser in Hamburg









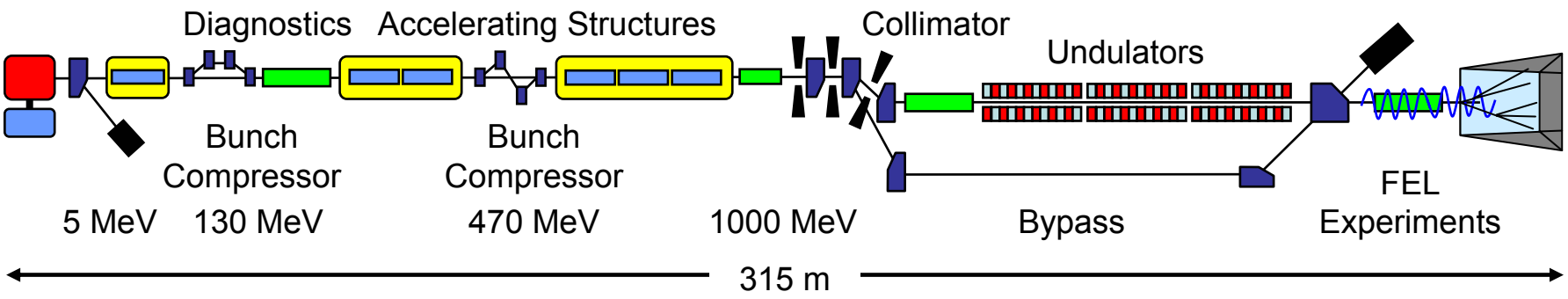
Katja Honkavaara,
Bart Faatz, Siegfried Schreiber
DESY

FLASH Seminar
October-13, 2009

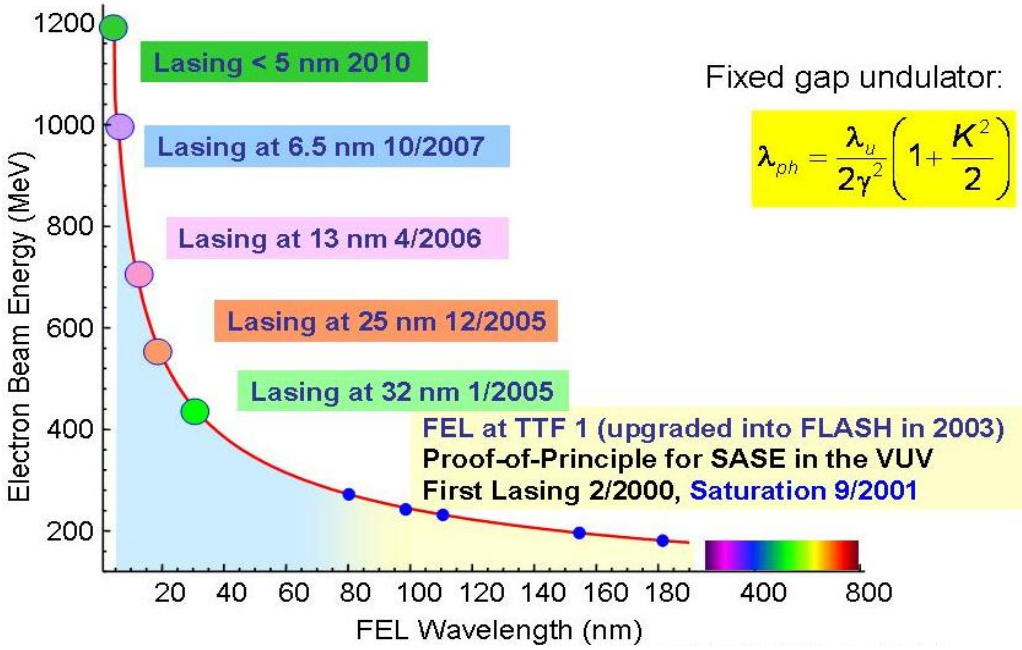
HELMHOLTZ GEMEINSCHAFT

DESY

FLASH at DESY Hamburg



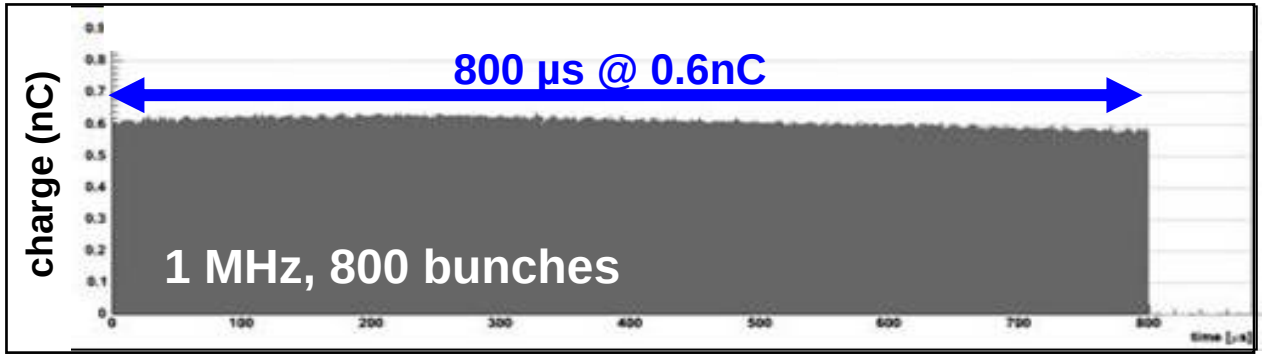
- superconducting linac of six TESLA type accelerating modules (1 GeV)
- single-pass high-gain SASE FEL
- user facility since summer 2005
  - 1st period: Jun 2005 – Mar 2007
  - 2nd period: Nov 2007 – Aug 2009



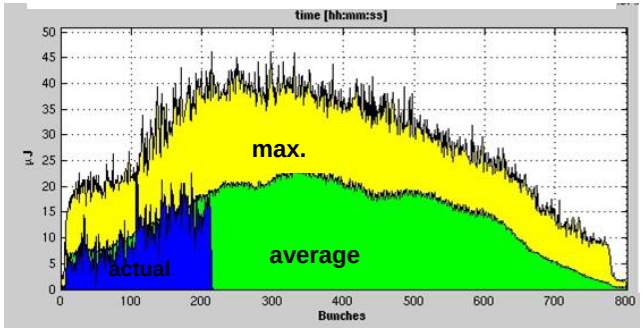
FLASH design goals reached in 2007

FLASH
Free-Electron Laser
In Hamburg

Lasing with a complete bunch train of 800 bunches at 13.4 nm



GMD - gas monitor detector - signal



Electron beam energy of 1 GeV and lasing at 6.5 nm

DESY TELEGRAMM 21. September 2007

Design-Strahlenergie für FLASH erreicht!
Elektronenstrahl mit 6 Modulen erstmals auf 1 GeV beschleunigt

FLASH Reaches Design Beam Energy!
Electron beam accelerated to 1 GeV with 6 modules for the first time

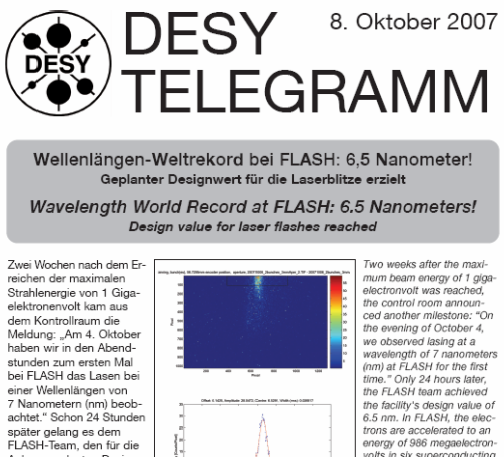
Der Durchbruch passierte wieder in einer Nachtschicht, genauer am 21.9.2007, um 0:57 Uhr. Dieses Mal ging es um das Erreichen der geplanten maximalen Strahlenergie. „Ziel: Betrieb mit höchster Energie – Ergebnis: 1 GeV Energie !! Gemessenes Spektrum der spontanen Emission: ~ 6,3 nm", so der Eintrag im elektronischen Logbuch.

Während der letzten Wartungspause: Einbau des Beschleunigermoduls Nr. 6 in den FLASH-Tunnel. *During the last shutdown: installation of accelerator module no. 6 in the FLASH tunnel.*

Das Team im Kontrollraum beobachtete im Wellen-

As usual, the breakthrough was achieved during a night shift, to be precise: on September 21 at 0:57 a.m. This time, the aim was to reach the planned maximum beam energy. "Goal: Operation to maximum energy—Achievements: 1 GeV!! Spectrum of spontaneous emission measured: ~ 6.3 nm," reads the entry in the electronic logbook.

For the first time, the team in the control room ob-



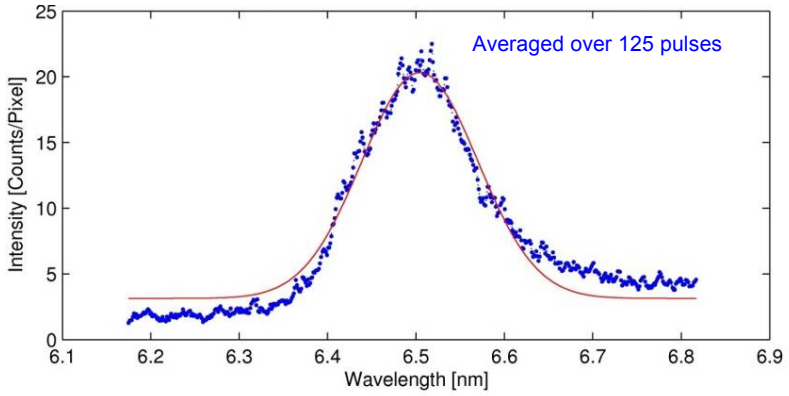
DESY TELEGRAMM 8. Oktober 2007

Wellenlängen-Weltrekord bei FLASH: 6,5 Nanometer!
Geplanter Designwert für die Laserblitze erzielt

Wavelength World Record at FLASH: 6.5 Nanometers!
Design value for laser flashes reached

Zwei Wochen nach dem Erreichen der maximalen Strahlenergie von 1 Gigaelektronenvolt kam aus dem Kontrollraum die Meldung: „Am 4. Oktober haben wir in den Abendstunden zum ersten Mal bei FLASH das Lasen bei einer Wellenlängen von 7 Nanometern (nm) beobachtet." Schon 24 Stunden später gelang es dem FLASH-Team, den für die

Two weeks after the maximum beam energy of 1 gigaelectronvolt was reached, the control room announced another milestone: "On the evening of October 4, we observed lasing at a wavelength of 7 nanometers (nm) at FLASH for the first time." Only 24 hours later, the FLASH team achieved the facility's design value of 6.5 nm. In FLASH, the electrons are accelerated to an energy of 986 megaelectron-



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Organization of beam time

FLASH
Free-Electron Laser
In Hamburg

- FLASH runs 7 days / week, 24 hours / day
- beam time overbooked – by a factor of ~ 3
- 2nd user period: Nov-26, 2007 – Aug-16, 2009
  - ~ 300 days has been scheduled for user operation
  - distributed in 4-week blocks
- between user blocks: study weeks
  - FEL physics studies
  - improvements of the FLASH facility
  - preparation of the next user block
  - general accelerator studies

    2-3 weeks three times per year
    related to e.g. XFEL and ILC

	52	24.Dec - 30.Dec	5	Maintenance
January	1	31.Dec - 6.Jan	5	
2008	2	7.Jan - 13.Jan	4	Accelerator studies
	3	14.Jan - 20.Jan	4	
	4	21.Jan - 27.Jan	2	FEL studies
February	5	28.Jan - 3.Feb	2	
	6	4.Feb - 10.Feb	3	
	7	11.Feb - 17.Feb	1	User Run
	8	18.Feb - 24.Feb	1	
	9	25.Feb - 2.Mar	1	
March	10	3.Mar - 9.Mar	1	
	11	10.Mar - 16.Mar	2	FEL studies
	12	17.Mar - 23.Mar	2	
	13	24.Mar - 3.Jan	3	
April	14	31.Mar - 6.Apr	1	User Run
	15	7.Apr - 13.Apr	1	
	16	14.Apr - 20.Apr	1	
	17	21.Apr - 27.Apr	1	

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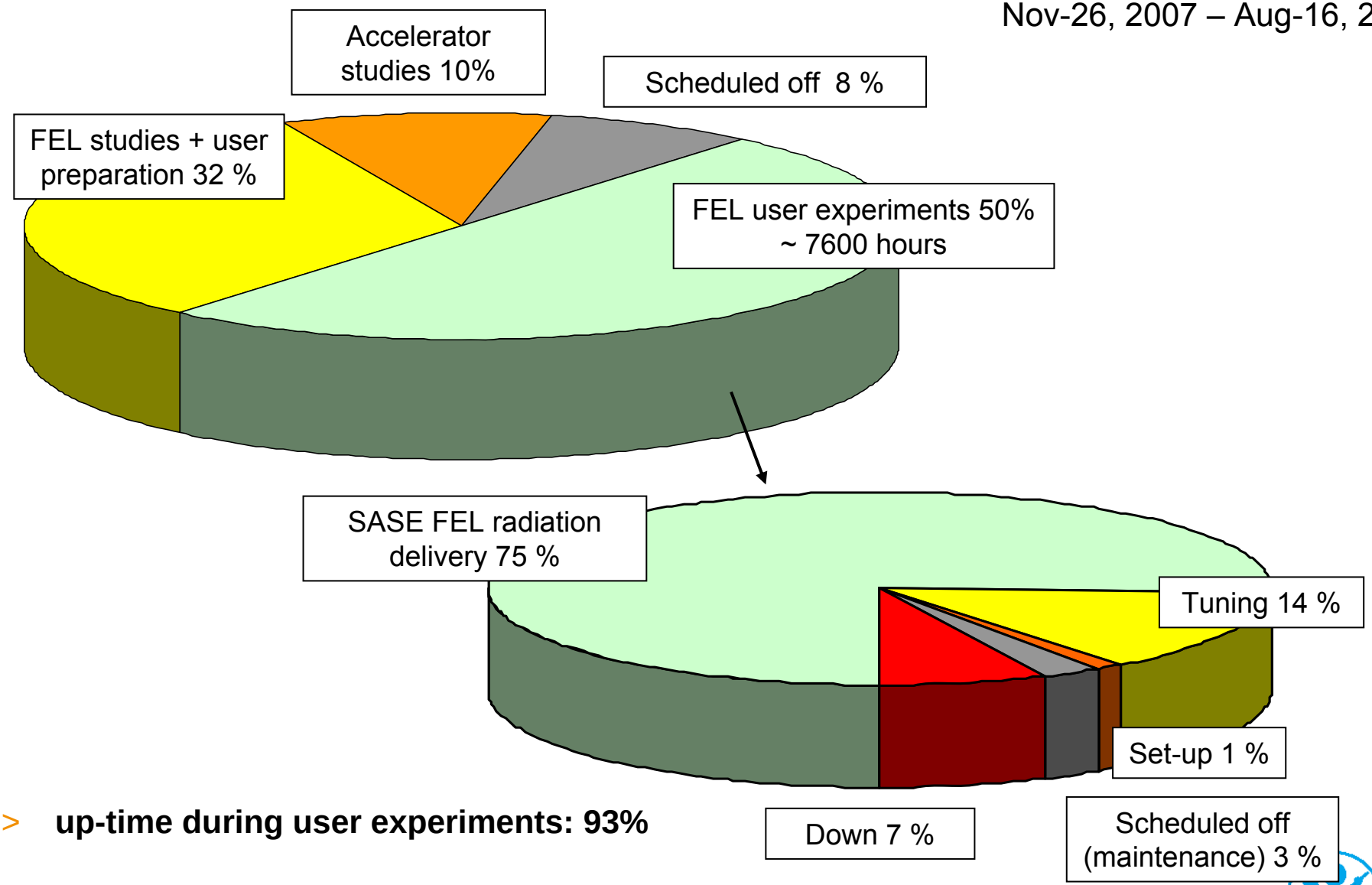
Time distribution during 2nd user period

Nov-26, 2007 – Aug-16, 2009



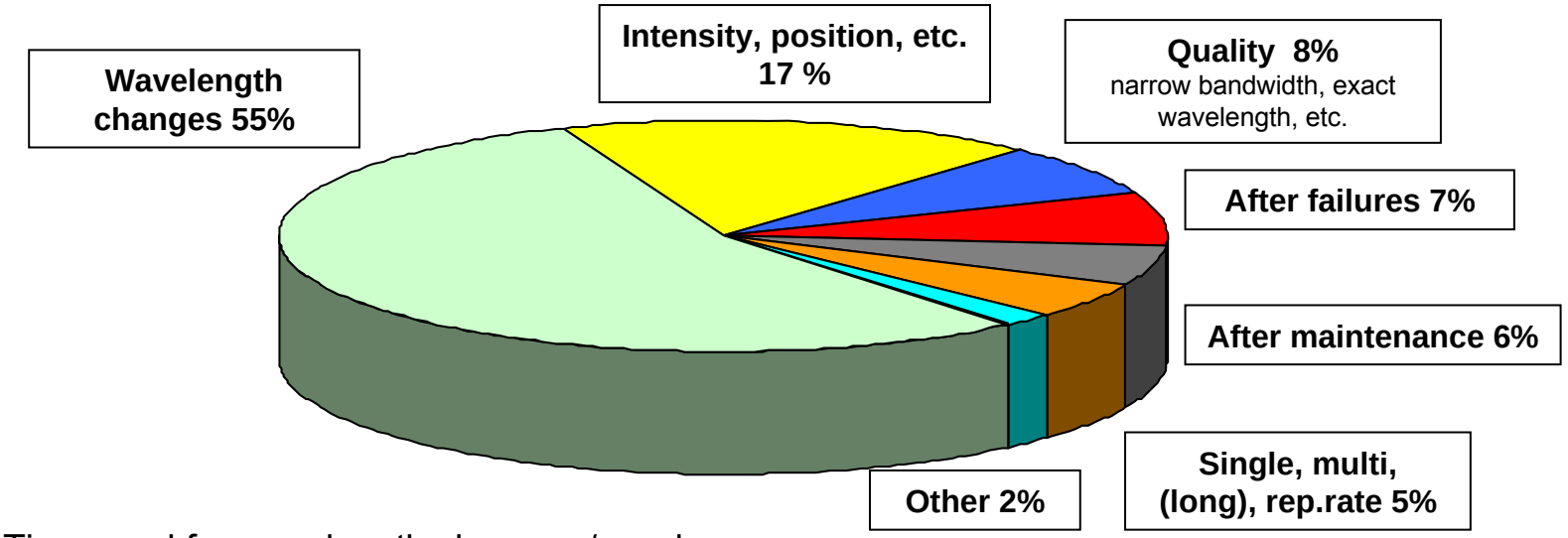
> **up-time during user experiments: 93%**

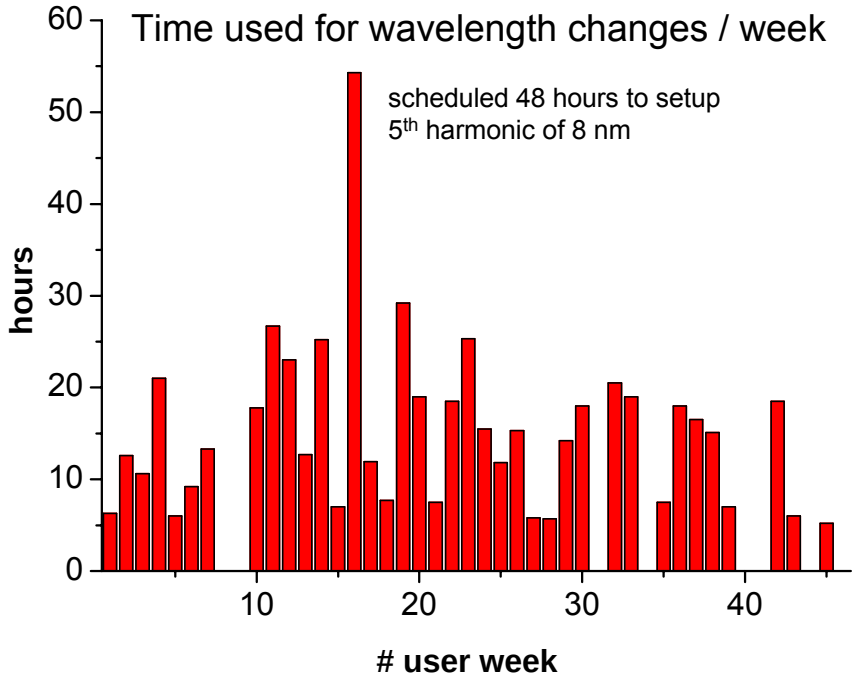
Different user blocks

	2007				2008			2009				
Block	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
SASE	71	79	75	67	69	68	81	78	79	75	75	90
Tuning	14	13	16	24	18	21	12	13	13	12	7	5
Set-up	2	1	1	1	2	1	1	1	1	1	1	0
Maint.	4	4	2	2	1	3	2	3	3	2	2	1
Down	9	3	6	6	10	7	4	5	4	10	15	4

numbers in %

Tuning



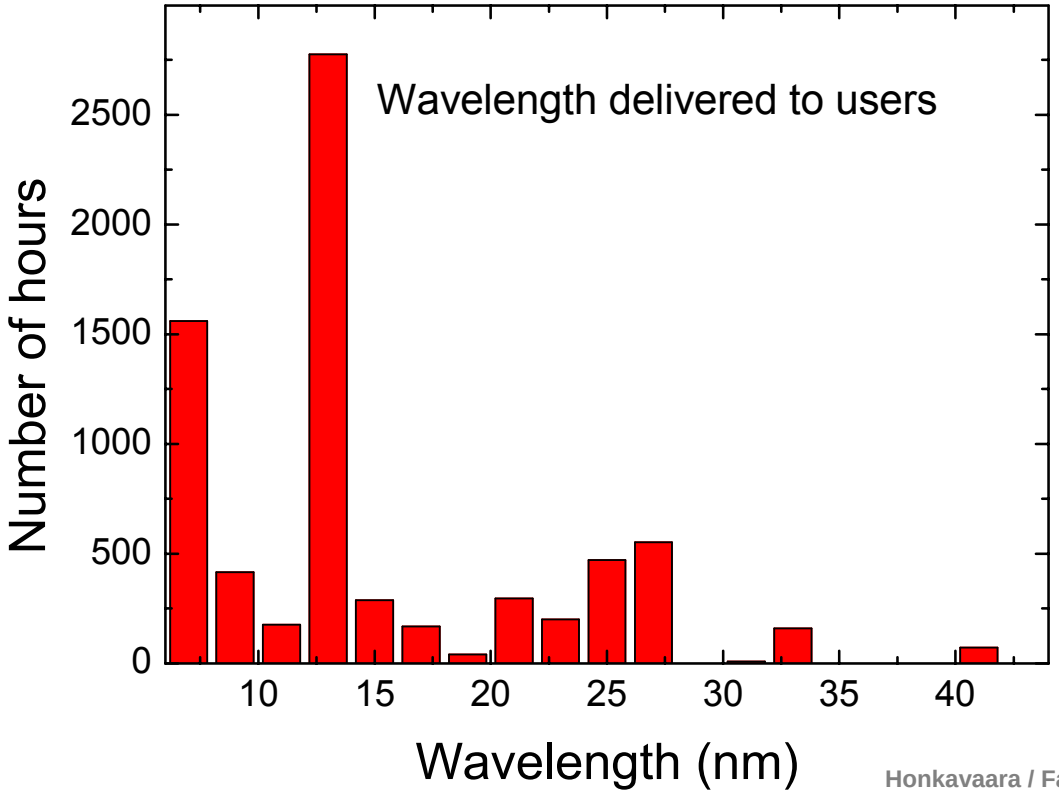


- wavelength has been changed ~ 140 times
- not much improvement in the time required for wavelength change (typically ~ 2 hours), but more wavelength changes done by 'standard' operators / shift crew

Photon wavelengths

FLASH
Free-Electron Laser
in Hamburg

- more than 30 different wavelengths between 6.8 nm and 40.5 nm delivered for users
- most requested wavelengths
  - shortest ones (7-8 nm)
  - around 13 nm (availability of multilayer mirrors)



- experiments using higher harmonics
  - 3rd harmonic of 7 nm
  - 5th harmonic of 8 nm
  - 3rd harmonic of 40.5 nm
- shortest wavelength delivered
  - 1.59 nm (5th harmonic of 7.97 nm)

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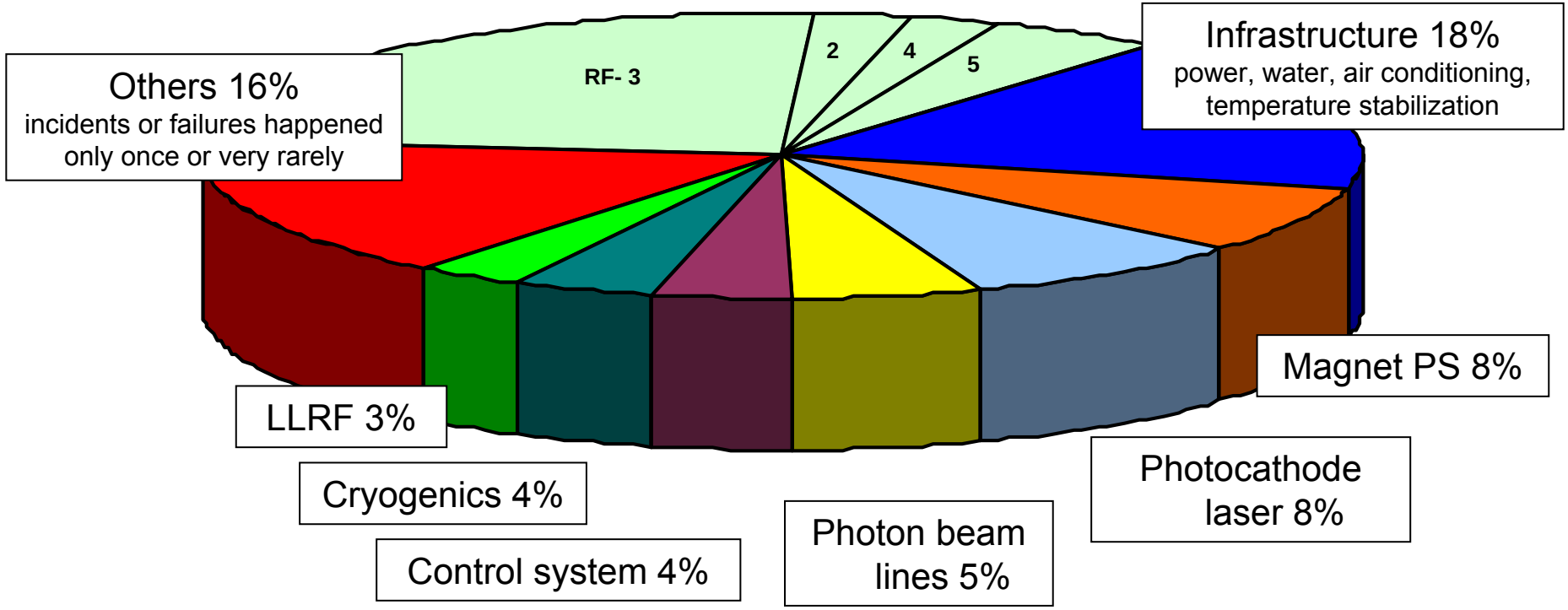
Down time during user experiments

Total downtime 7%

RF stations 34%
klystrons, modulators, transformers, preamplifiers, waveguides
78% due to two old RF-stations



Infrastructure 18%
power, water, air conditioning, temperature stabilization

Others 16%
incidents or failures happened only once or very rarely

Magnet PS 8%

LLRF 3%

Cryogenics 4%

Photocathode laser 8%

Control system 4%

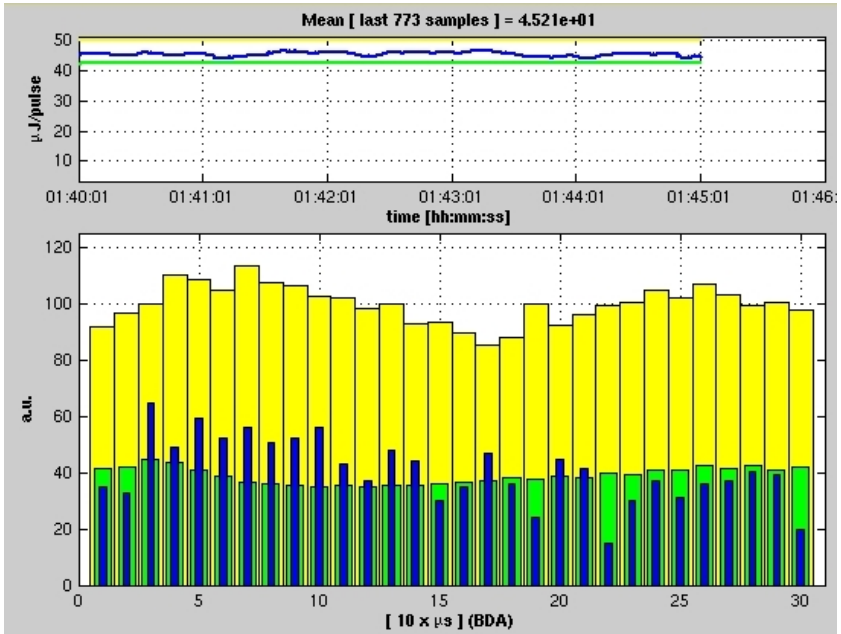
Photon beam lines 5%

SASE performance

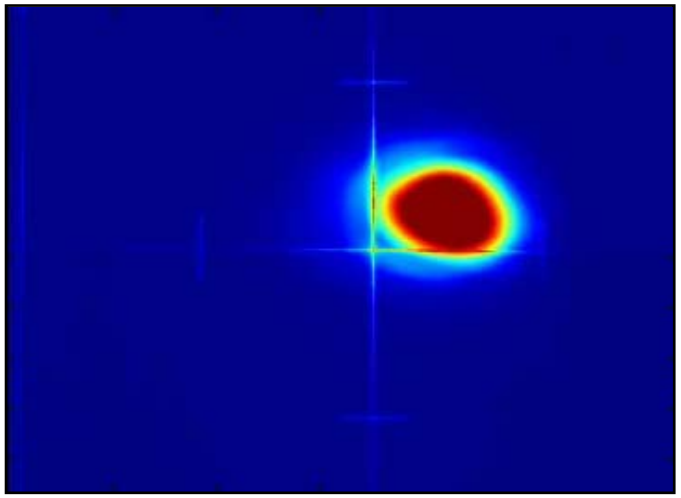
FLASH
Free-Electron Laser
in Hamburg

Typical user operation parameters:

Wavelength range (fundamental)	6.8 – 47 nm
Average single pulse energy	10 – 100 µJ
Pulse duration (FWHM)	10 – 50 fs
Peak power (from av.)	1 – 5 GW
Average power (example for 500 pulses/sec)	~ 15 mW
Spectral width (FWHM)	~ 1 %
Peak Brilliance	10^{29} - 10^{30} B



B = photons/ (s mrad^2 mm^2 0.1%bw)



Multibunch SASE signal (µJ)

max
single
average

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SASE performance

FLASH
Free-Electron Laser
in Hamburg

all wavelengths included

	Week	Average SASE level (μJ)	Fraction long pulse trains	Collimation <= 1mm
2007	48-51	18		2 %
	7-11	28	22 %	
	14-17	22	20 %*	5 %
2008	26-29	13		6 %
	33-36	10		16 %
	43-45	22		
	48-51	34		2 %
	7-10	27	maximum number of bunches limited to 30 / train	
	14-17	23		
2009	20-23	26		3 %
	26-28	26		10 %
	31-33	27		14 %

* reduced to 30 bunches due to energy / charge chirp

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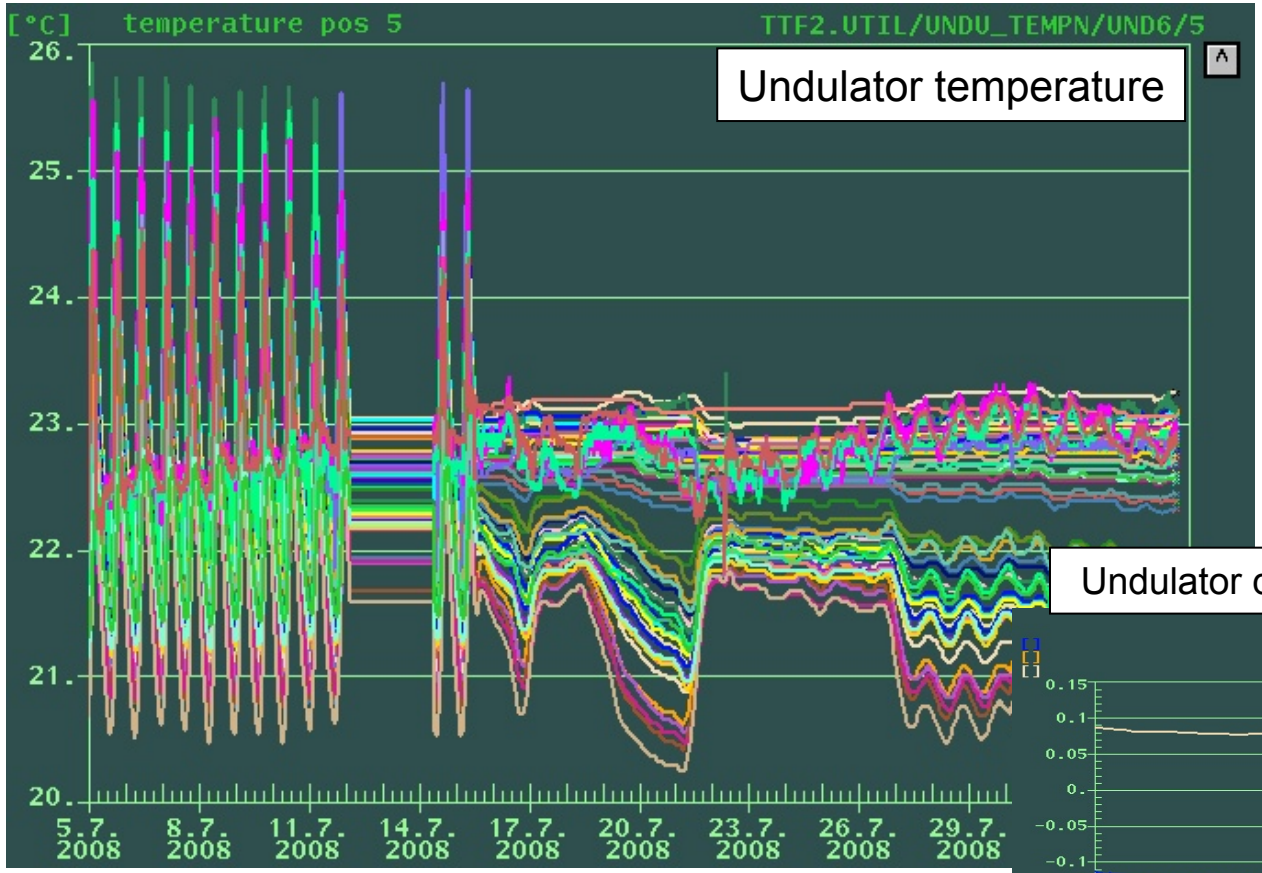
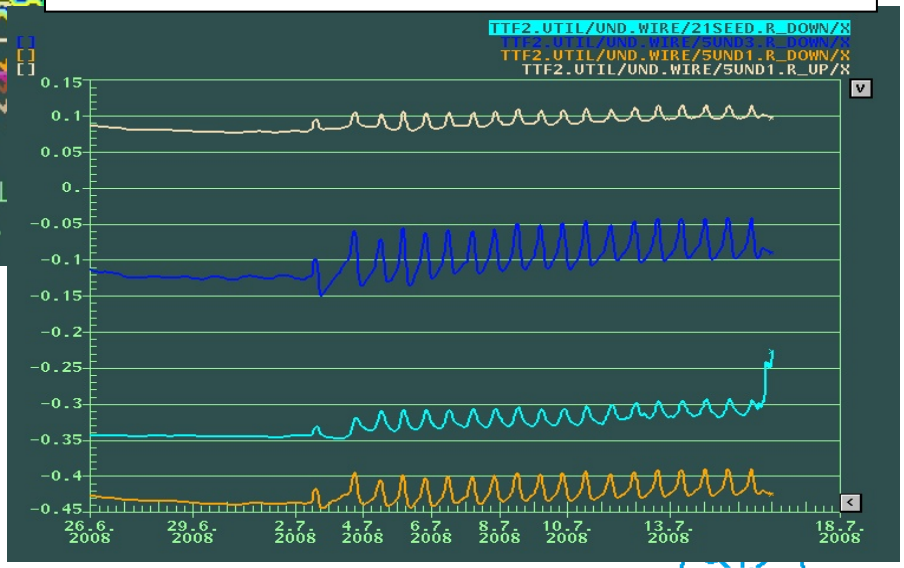
Unstable operation summer 2008

FLASH
Free-Electron Laser
In Hamburg



Undulator temperature

Undulator quadrupole movement up to 100 µm



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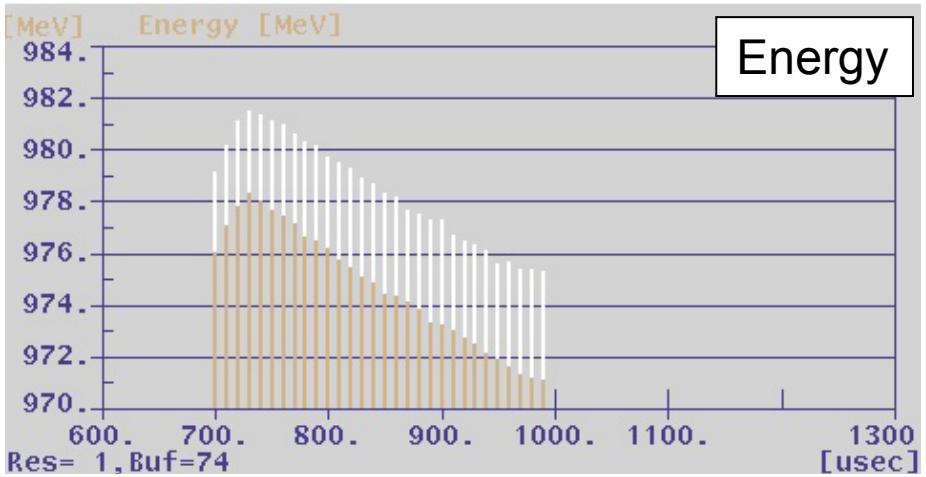
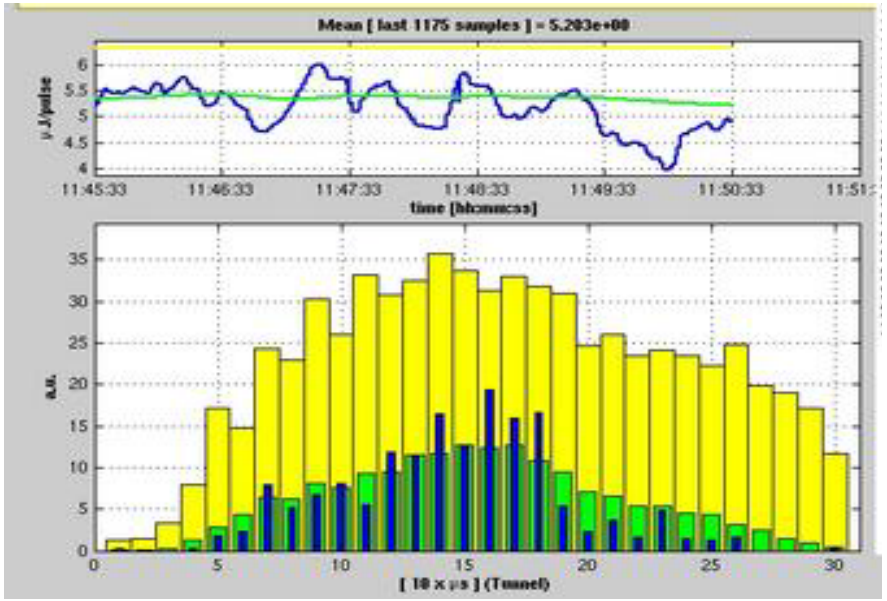
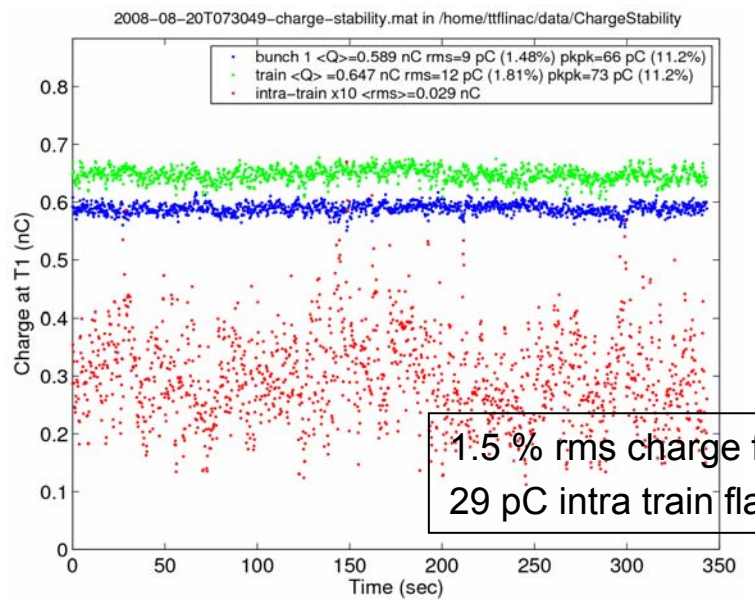
Example from August 2008

FLASH
Free-Electron Laser
In Hamburg



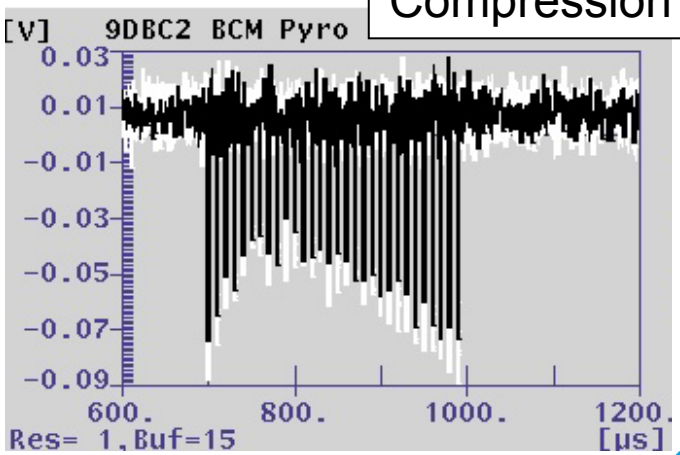
Energy





1.5 % rms charge fluctuation
29 pC intra train flatness

Compression



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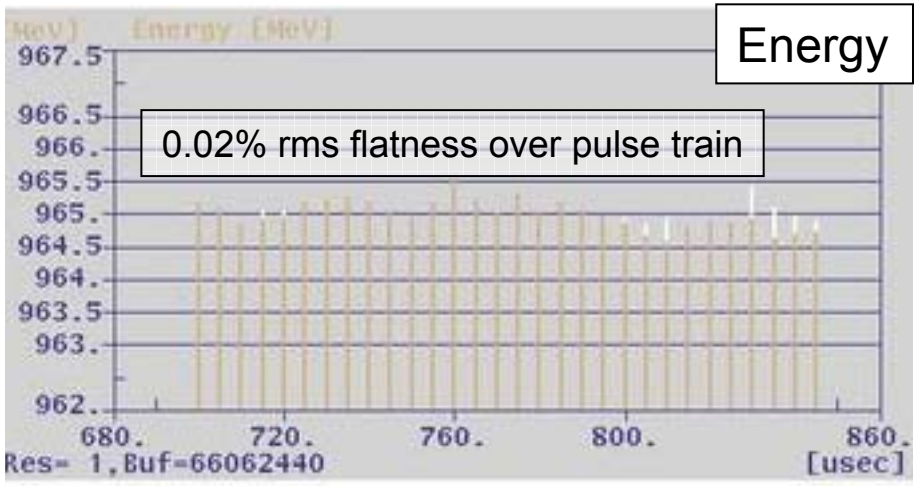
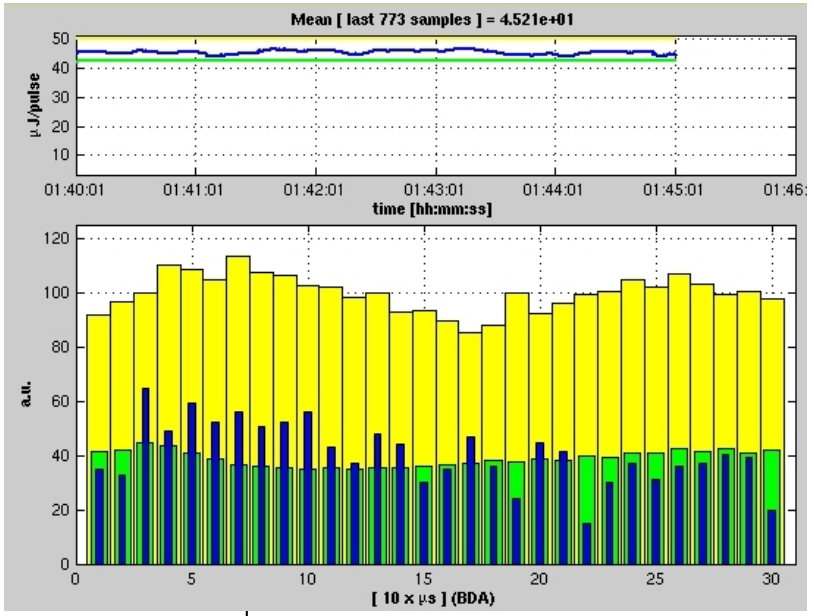
Example from Summer 2009

FLASH
Free-Electron Laser
In Hamburg

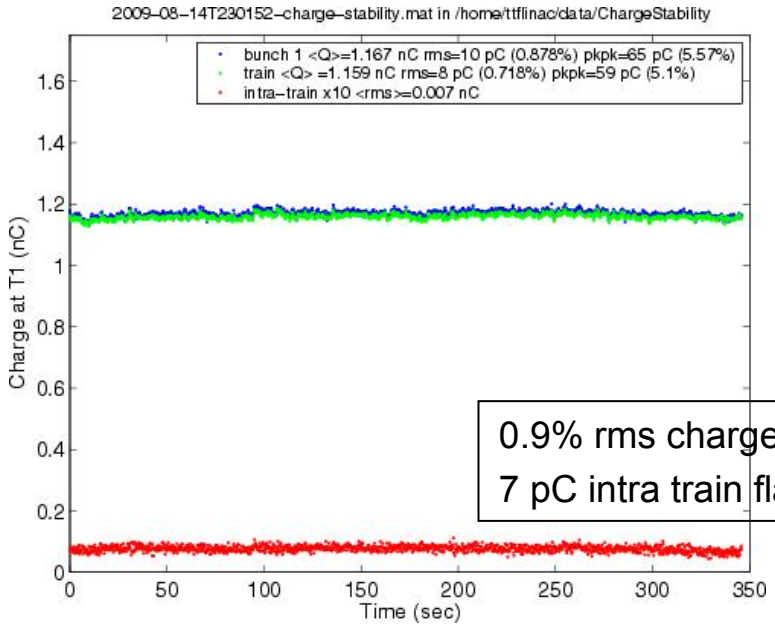
Energy



0.02% rms flatness over pulse train

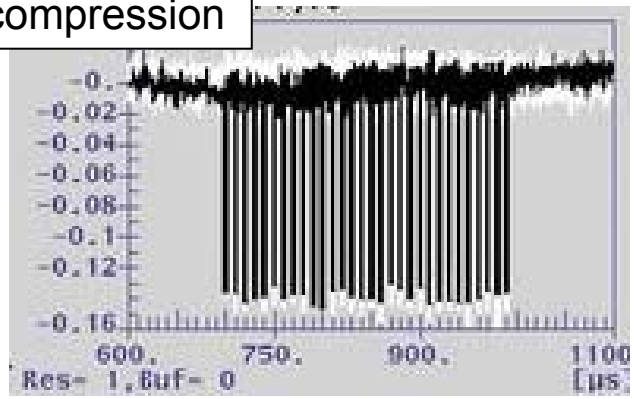


45 µJ, 100 kHz at 7.02 nm



0.9% rms charge fluctuation
7 pC intra train flatness

Flat compression



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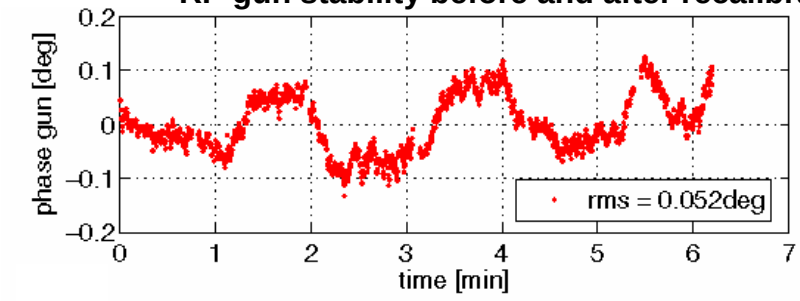
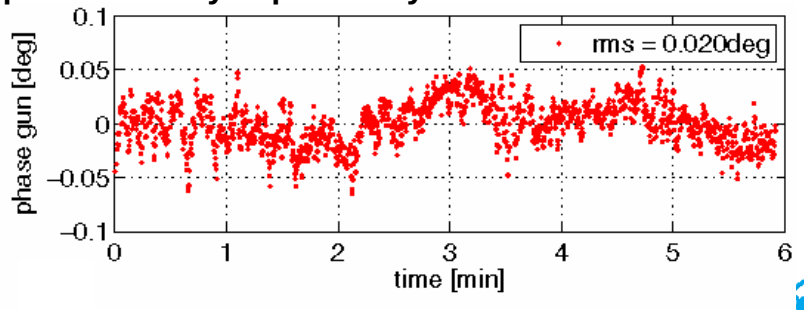
Improvements

FLASH
Free-Electron Laser
In Hamburg

- main improvements
  - LLRF, especially RF-gun: improved vector sum calibration
  - cathode laser stability: improved master rf signals, changed optics + exchanged BBO
  - education of operators, improvements of tools and operation panels
- on-going improvements
  - feedback for pulse train stability: RF and beam based
  - beam based alignment, dispersion & orbit correction
  - BPMs, especially in undulator
  - online spectrometer / photon BPMs

RF-gun stability before and after recalibration: phase stability improved by more than a factor of 2





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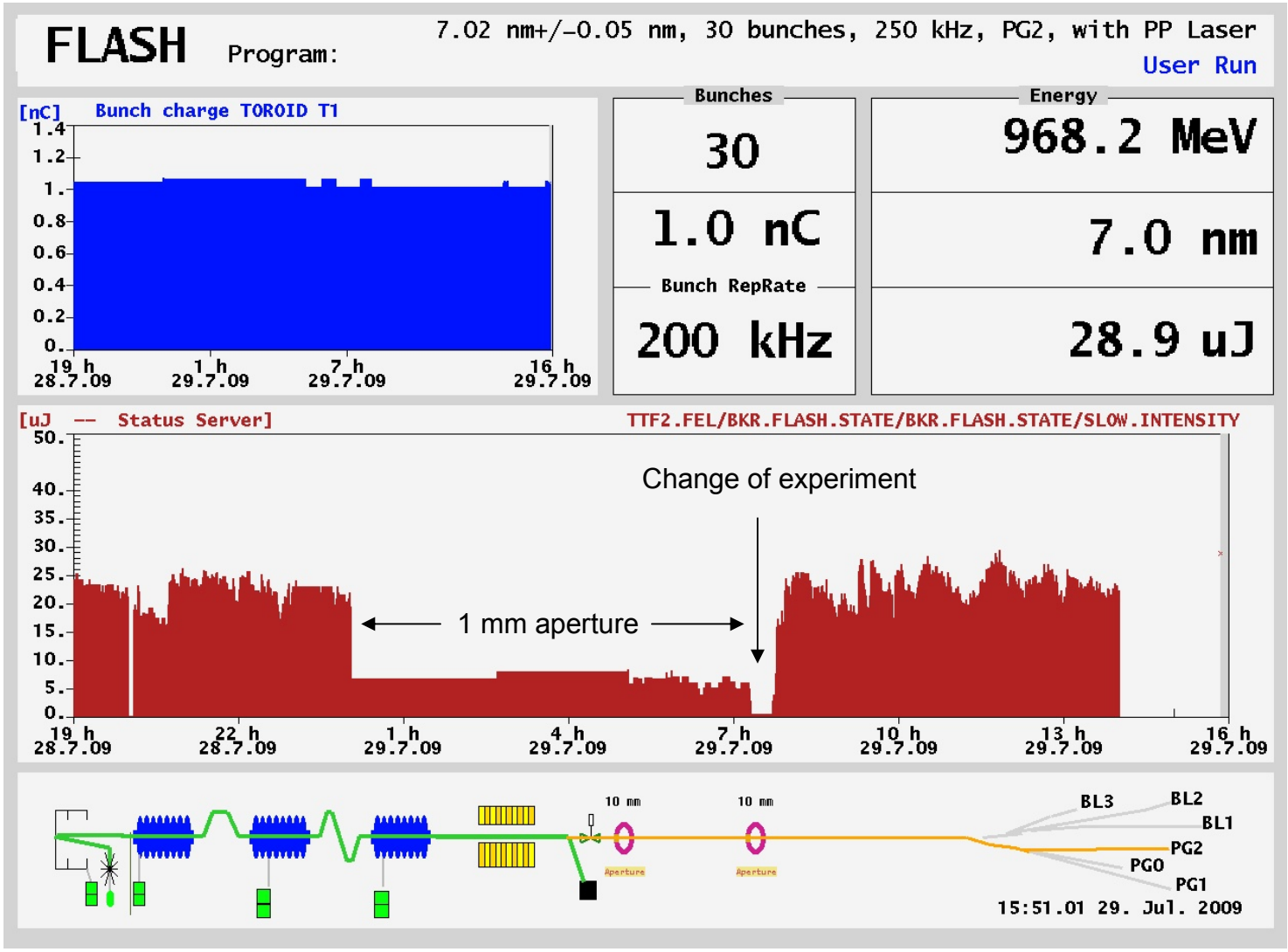
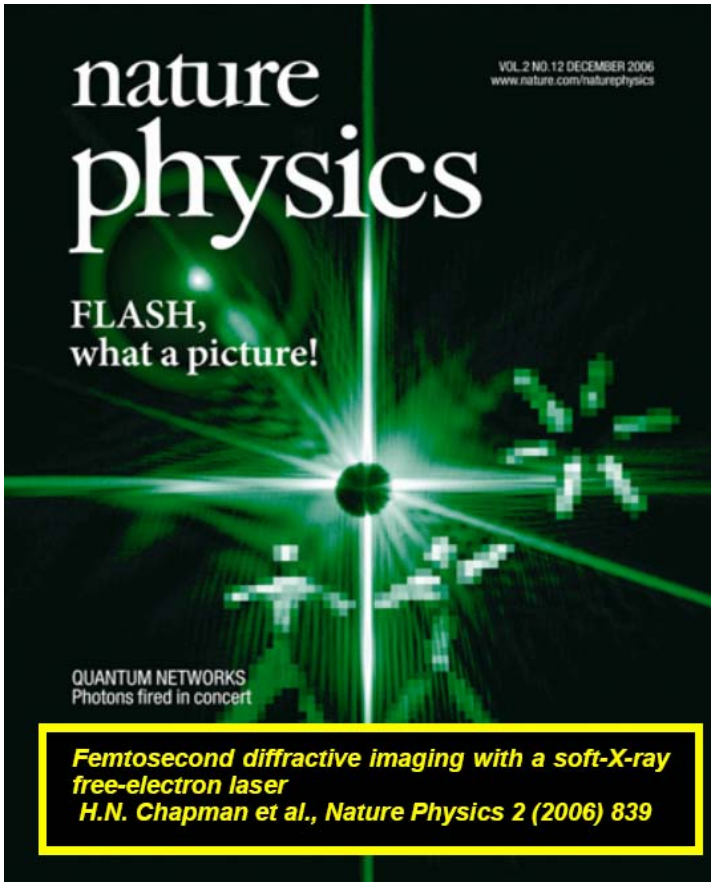
7 nm FEL user run summer 2009



FEL user experiments

FLASH
Free-Electron Laser
In Hamburg

- world-wide unique light source
  - in the wavelength range of 47 nm to 6.8 nm
  - ultra-short FEL pulses (femtosecond range)
  - unprecedented brilliance
- experiments on
  - diffraction imaging
  - solid state-, plasma-, and cluster-physics
  - femtosecond-chemistry, molecular-biology
  - …
- single-shot measurements
- pump-and-probe experiments
- ~ 60 publications + ~10 submitted on photon science experiments performed at FLASH
  - hasylab.desy.de/facilities/flash/publications/selected_publications



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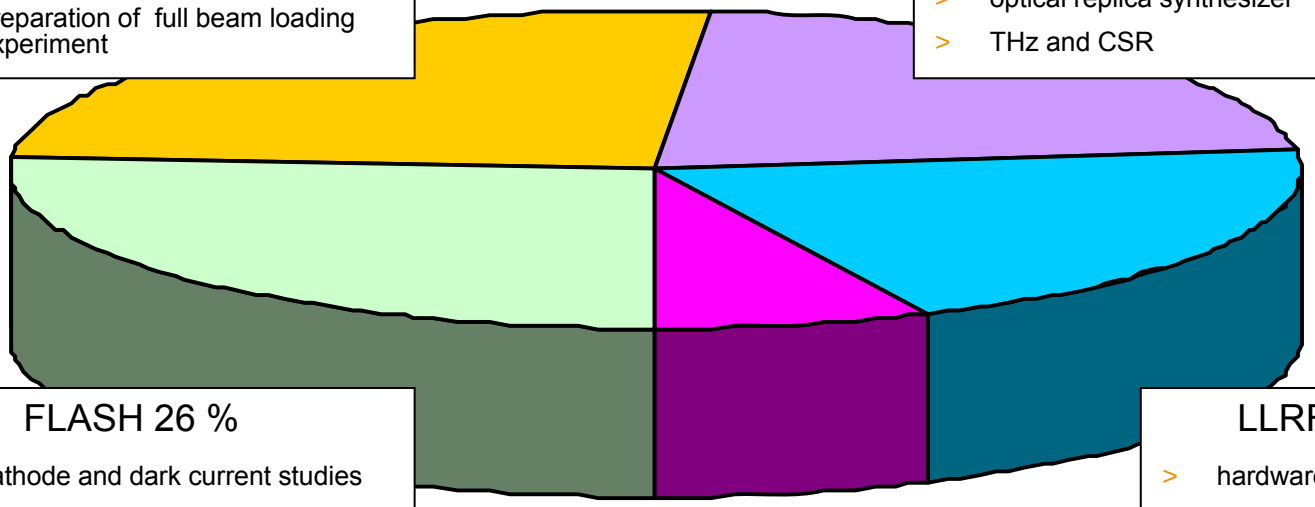
Distribution of study subjects

Developments totally ~ 3600 hours



XFEL + ILC 25 %

- electron beam diagnostics and instrumentation developments
- beam dynamics
- synchronization system
- HOM studies (incl. HOM BPM)
- preparation of full beam loading experiment

New projects 22 %

- infra-red (THz) undulator (incl. beamline and diagnostics)
- optical replica synthesizer
- THz and CSR

FLASH 26 %

- cathode and dark current studies
- beam optics, dynamics, orbit
- stability and feedbacks
- beam diagnostics (esp. BPMs)

Photon diagnostics 7%

LLRF 20 %

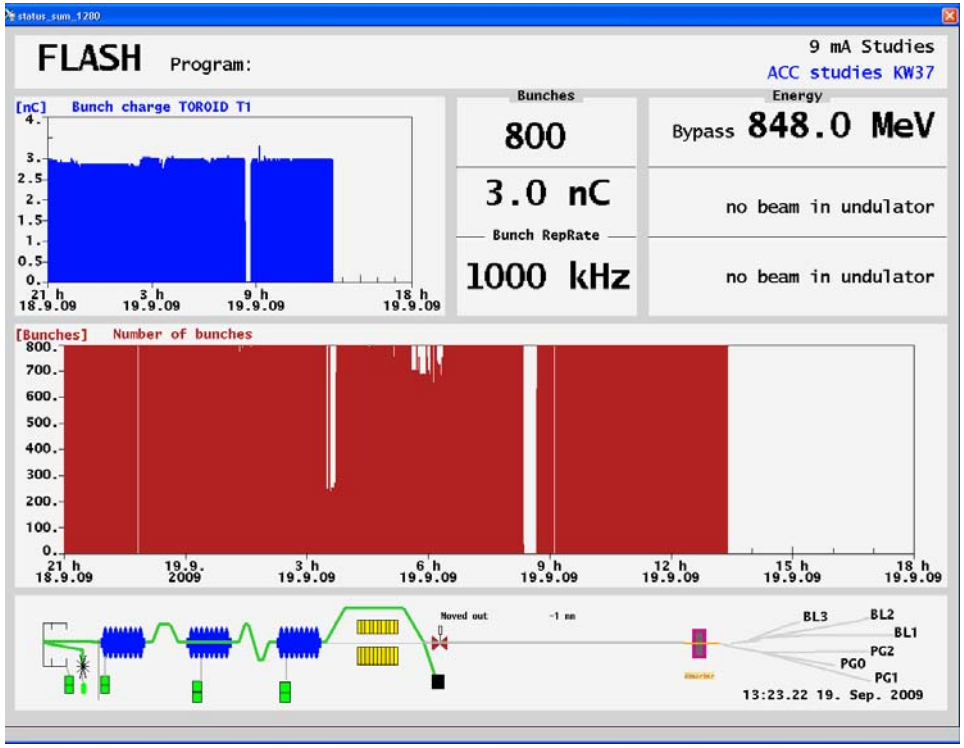
- hardware developments
- control and regulation algorithms and software

Note: 2 weeks dedicated for full beam loading experiment in September 2009 not included

Full beam loading experiment in September 2009

FLASH
Free-Electron Laser
In Hamburg

- demonstration of long-pulse high beam-loading operation
- ILC driven international collaboration
  - important experiment also for FLASH and XFEL
- more details in the coming FLASH seminar



- stable operation with 800 bunches, 3 nC at 1MHz (800 us pulse) over 15 hours
- several hours of ~1600 bunches, ~ 2.5 nC at 3MHz (530 us pulse)
- > 2200 bunches, 3nC (3MHz) for short periods
- beam power to dump up to 22 kW

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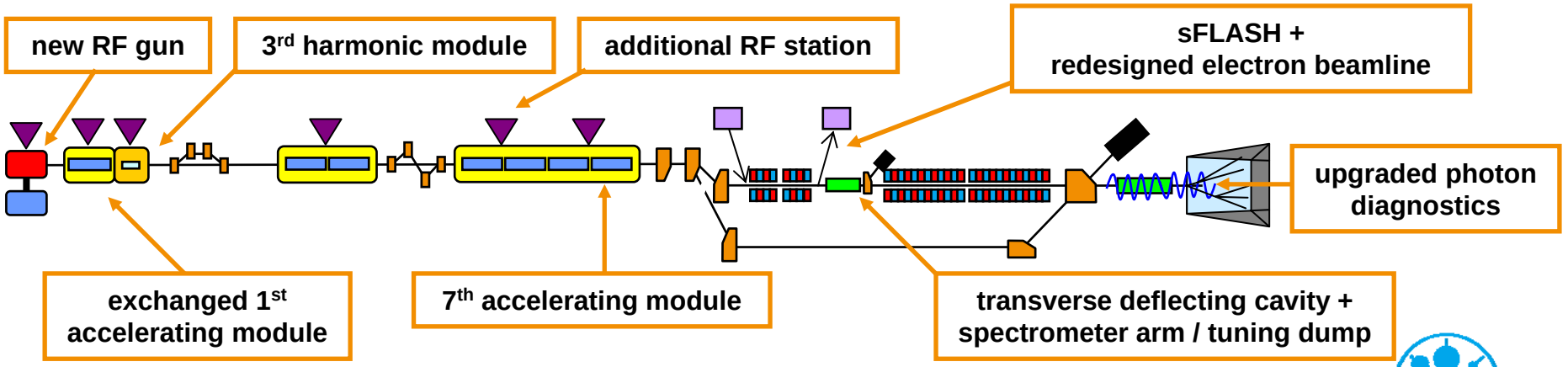
Upgrade 2009/10

FLASH
Free-Electron Laser
in Hamburg

- 5 months upgrade shutdown started September-21, 2009
- major modifications for the FLASH facility
  - exchange of RF gun and ACC1, new steerers BC2 section
  - installation 3rd harmonic (3.9 GHz) module incl. RF system
  - installation of a 7th accelerating module (ACC7) → 1.2 GeV (5 nm)
  - installation of an experiment for seeded VUV radiation "sFLASH"
    → replacement of electron beam line between collimators and SASE undulators (~ 40 meters)
  - upgrades of RF stations (new modulators RF-2 and RF-3) and waveguide distribution
  - upgrades of photon diagnostics



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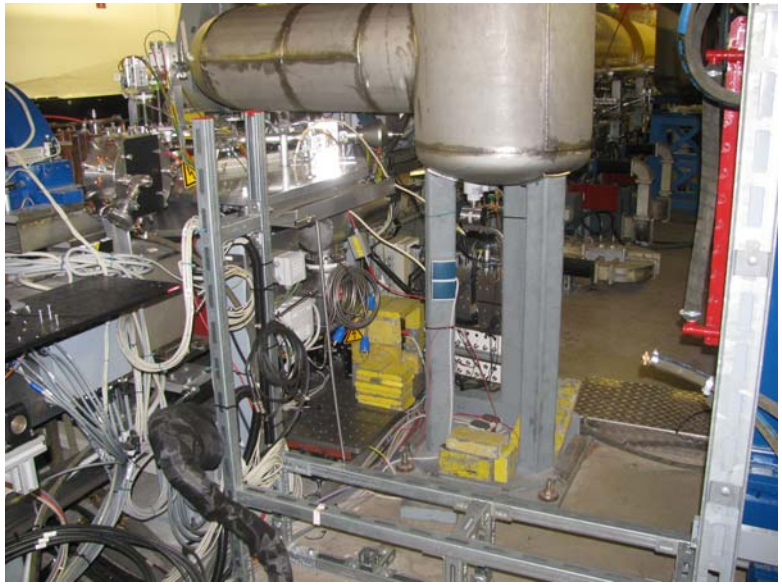
FLASH, October-9, 2009

FLASH
Free-Electron Laser
In Hamburg



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FLASH, October-9, 2009

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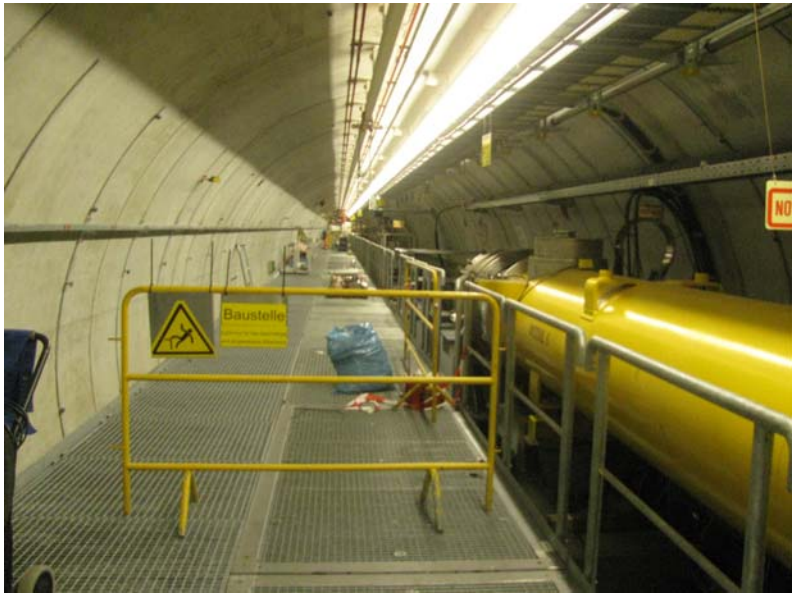
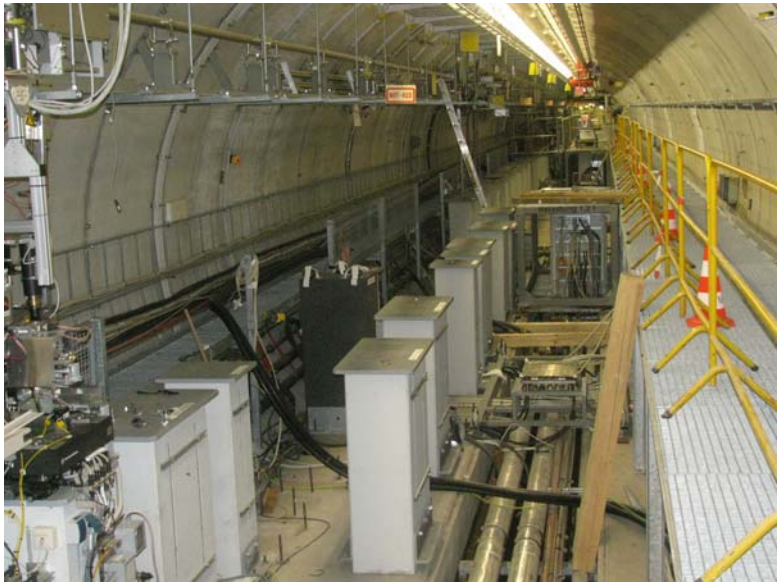
Free-Electron Laser
In Hamburg





DESY

FLASH, October-9, 2009

FLASH
Free-Electron Laser
In Hamburg

DESY

Summary

FLASH
Free-Electron Laser
In Hamburg

- FLASH is a world-wide unique light source
  - in the wavelength range of 47 nm to 6.8 nm
  - ultra-short FEL pulses (10 to 50 fs)
  - unprecedented brilliance
- during the 2nd user period (Nov-26, 2007 – Aug-16, 2009)
  ~ 7600 hours of beam time was scheduled for user FEL experiments
  - up-time 93%, SASE delivery 75%
- several tens of different experiments have been successfully carried out
- many improvements stabilizing SASE performance
- upgrade shutdown started end of September 2009
- commissioning of the upgraded facility in spring 2010
- 3rd FEL user period starting in summer 2010

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