FLASH

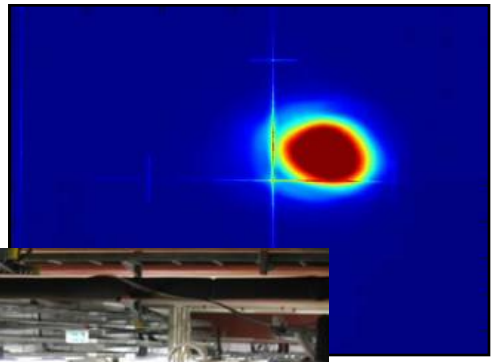
FLASH
Free-Electron Laser
in Hamburg

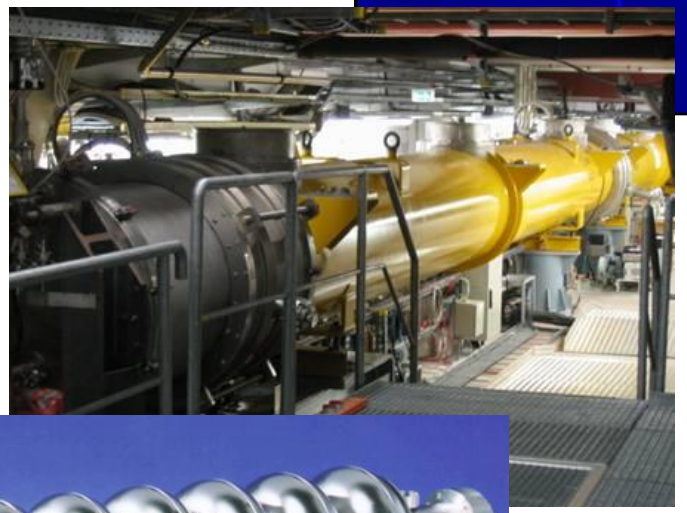
FLASH – The Free-Electron Laser User Facility

Accelerator

Performance and operational issues

Upgrade





Katja Honkavaara **for the FLASH team**
DESY

SRF 2009
Berlin, Germany
20 - 25 September 2009

HELMHOLTZ
GEMEINSCHAFT

DESY

FLASH at DESY in Hamburg

FLASH
Free-Electron Laser in Hamburg

- free-electron laser user facility since summer 2005
  - photon wavelength range from vacuum ultraviolet to soft x-rays
- single-pass high-gain SASE FEL
  - SASE = self-amplified spontaneous emission
- superconducting linac of six TESLA type accelerating modules (1 GeV)
- FLASH is also a test bench for the European XFEL and the ILC

FLASH design goals reached in 2007

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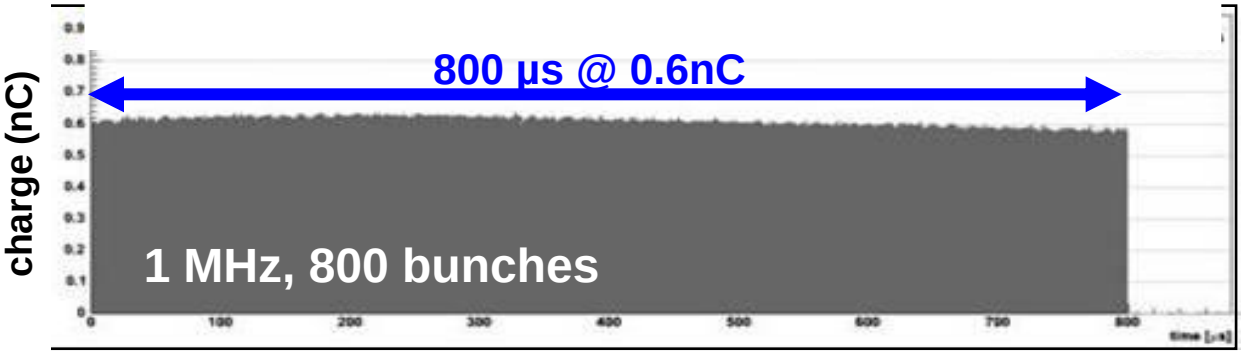
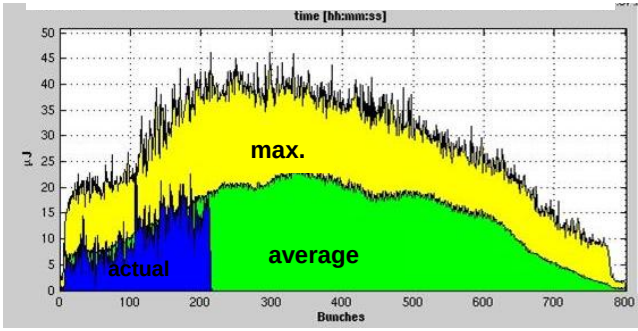
Lasing with a complete bunch train of 800 bunches at 13.4 nm



GMD - gas monitor detector - signal



Electron beam energy of 1 GeV and lasing at 6.5 nm

DESY 21. September 2007
DESY TELEGRAMM

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.

Das Team im Kontrollraum beobachtete im Wellen-

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.*

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.

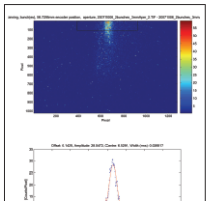
For the first time, the team in the control room ob-

DESY 8. Oktober 2007
DESY TELEGRAMM

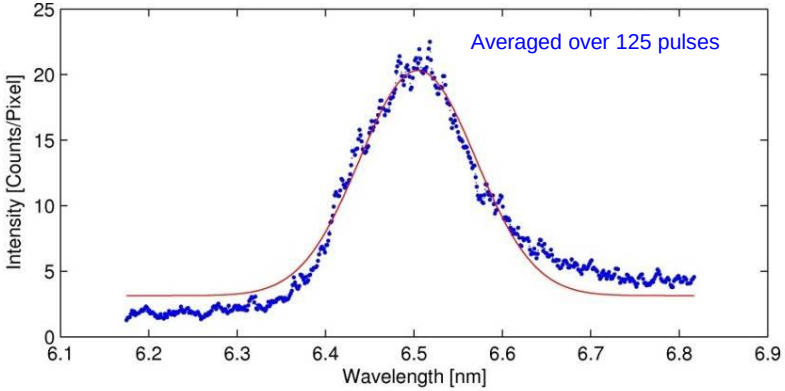
Wellenlängen-Weltrekord bei FLASH: 6,5 Nanometer!
Geplanter Designwert für die Laserblitze erzielt

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

Zwei Wochen nach dem Erreichen der maximalen Strahlenergie von 1 Giga-elektronenvolt 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 giga-electronvolt 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-volts in six superconducting



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Full beam loading experiment in September 2009

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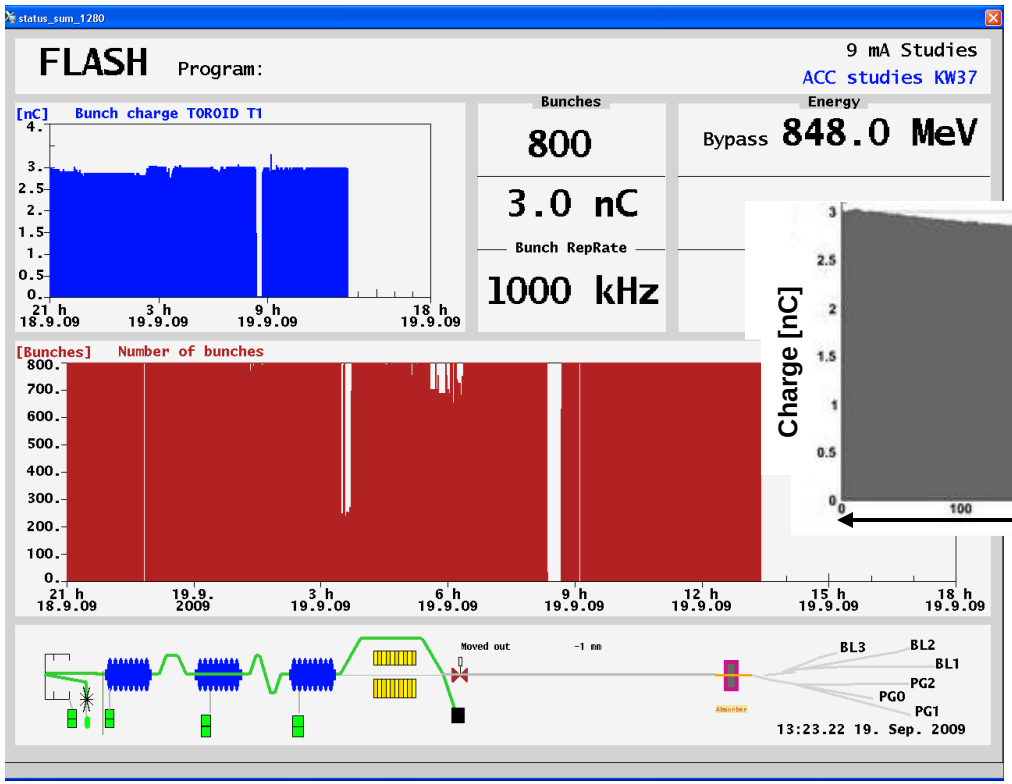
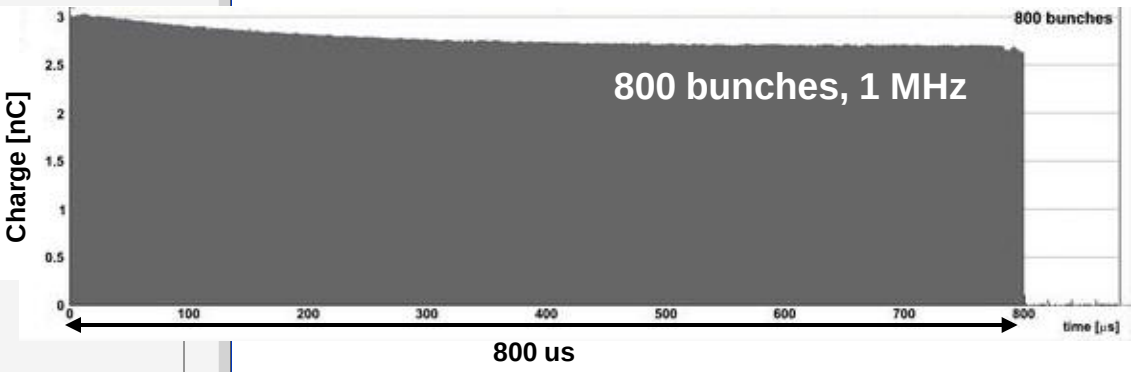
- demonstration of long-pulse high beam-loading operation
- ILC driven international collaboration
  - important experiment also for FLASH and XFEL
- more details: talk by B. Chase (THOBAU06)



- status Sep-19 at 14 h
  - 800 bunches, 3 nC, 1 MHz
  - stable operation over several hours



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FLASH overview

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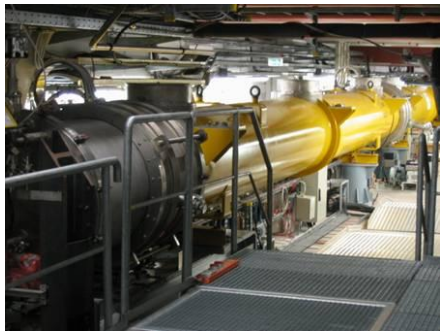
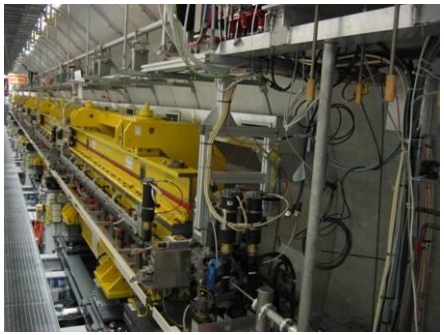


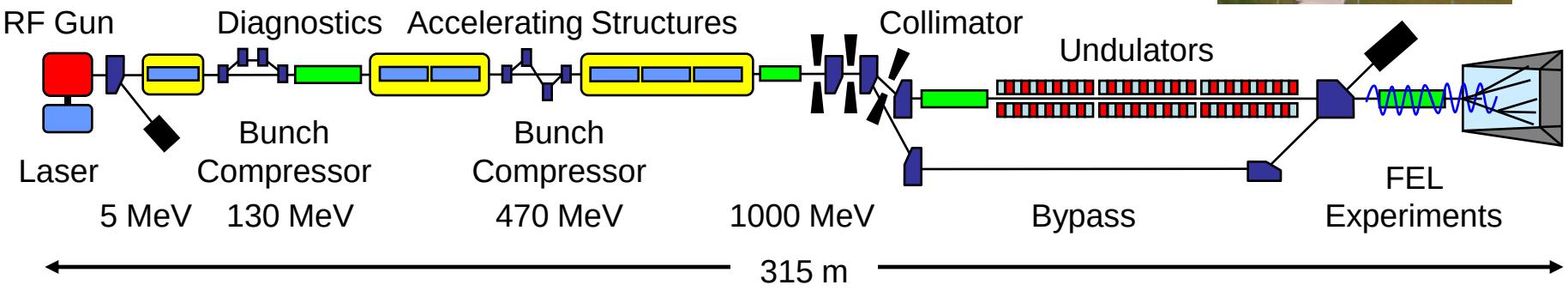




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Electron source

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- Nd:YLF based photocathode laser
- normal conducting RF-gun
  - operated at 1.3 GHz
  - gradient on cathode 46 MV/m (max)
  - RF pulse length 100 to 900 µs
- Cs_2Te cathode
- charge variable to some extend
  - SASE operation: 0.5 nC – 1 nC
  - max charge ~ 3 nC
- macro-pulse repetition rate 5 Hz
  - number of bunches and bunch spacing within the train variable
    e.g. 1 MHz, 500 kHz, 200 kHz, 100 kHz, 40 kHz

Accelerating modules

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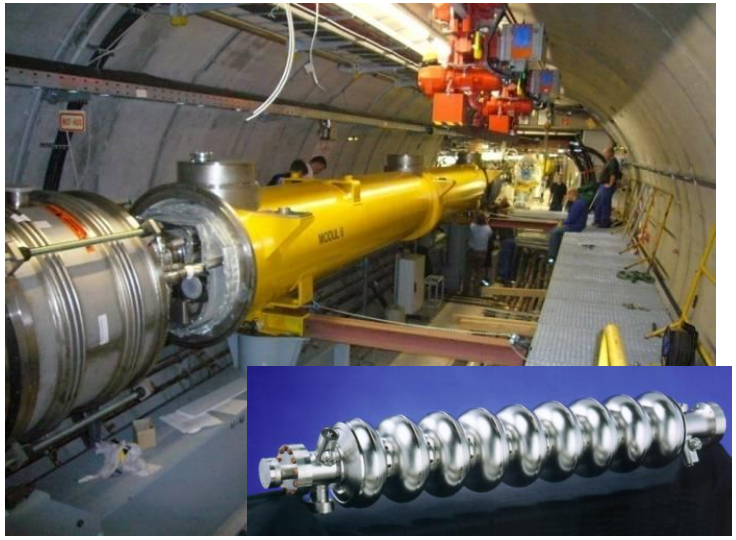
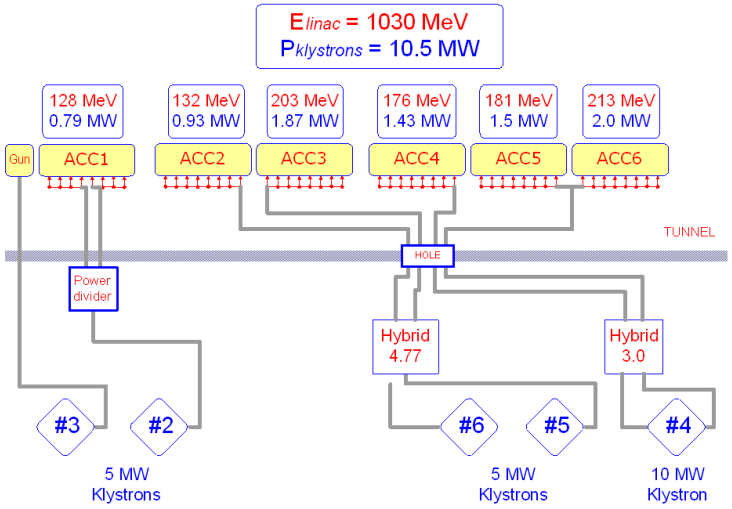
- six TESLA type accelerating modules
  - each having eight 9-cell superconducting niobium cavities operated at 1.3 GHz
- energy upgrade to 1 GeV in 2007
  - 6th module installed, 3rd module replaced
  - both new modules ≥ 25 MV/m in average
  - 4 cavities of 6th module ≥ 30 MV/m
- 4 RF stations
  - three 5 MW and one 10 MW klystrons
- 6th module has XFEL type waveguide system
  - RF power to cavity pairs individually adjusted → optimization of performance





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Example of operating gradients

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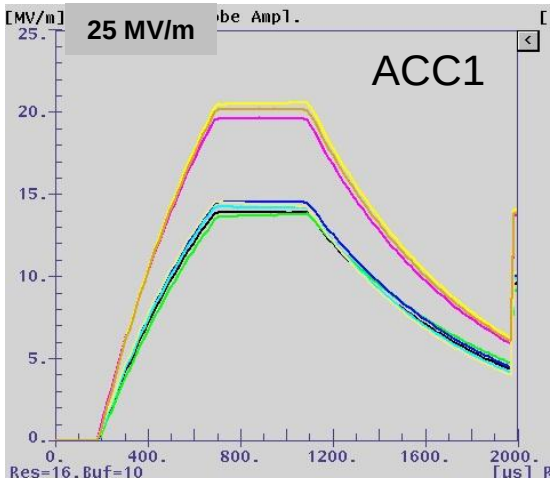
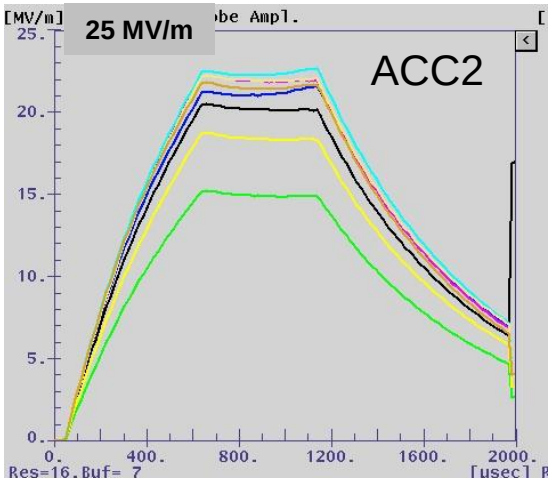
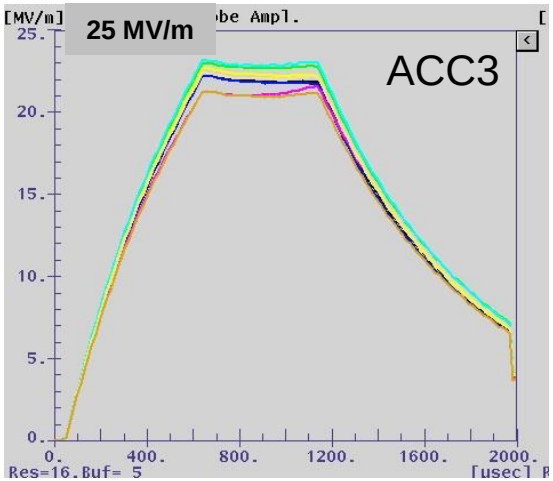
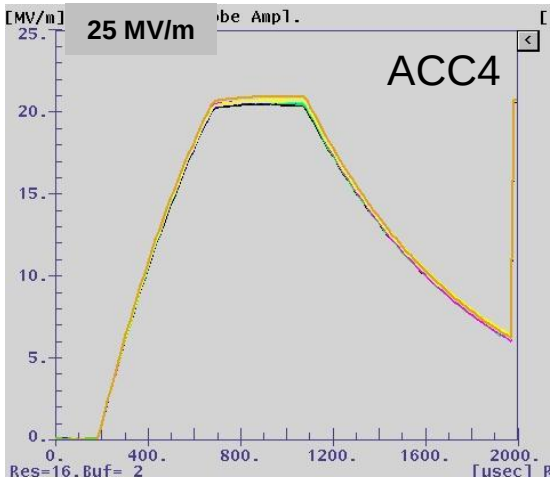
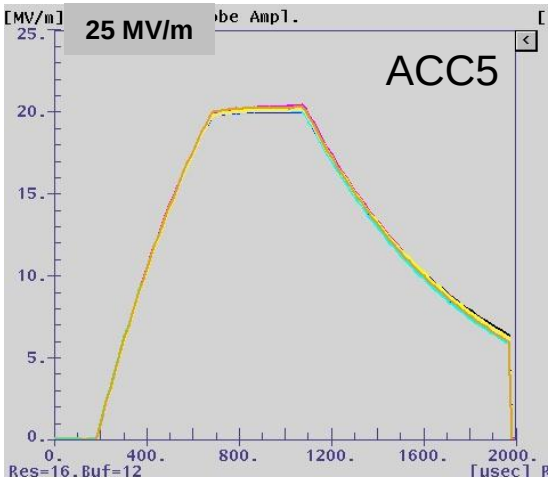
- example of gradients of individual cavities during a 7 nm FEL user run

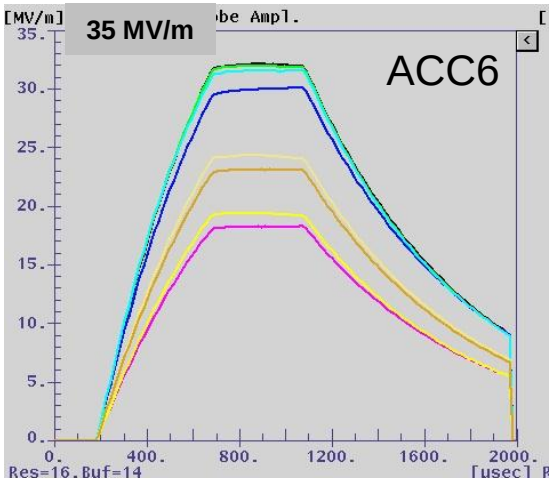












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Undulators

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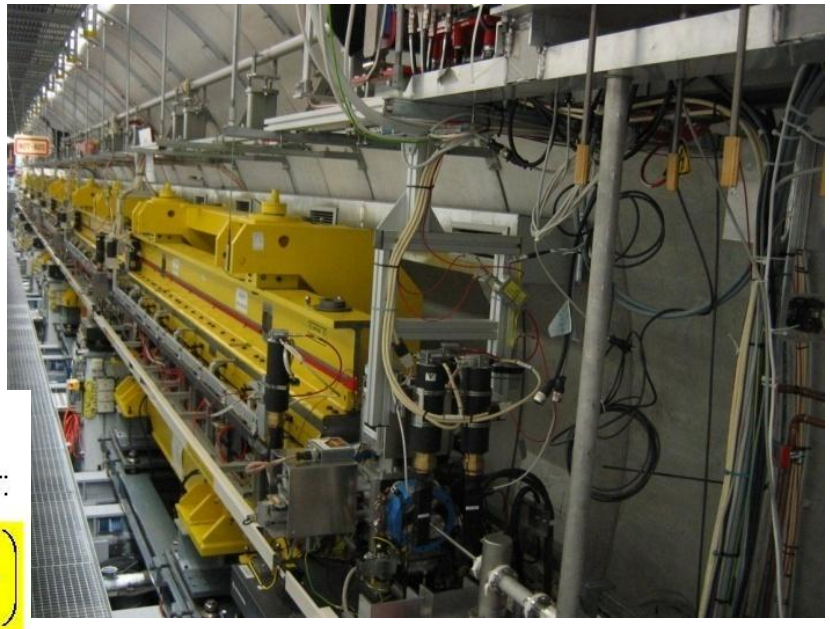
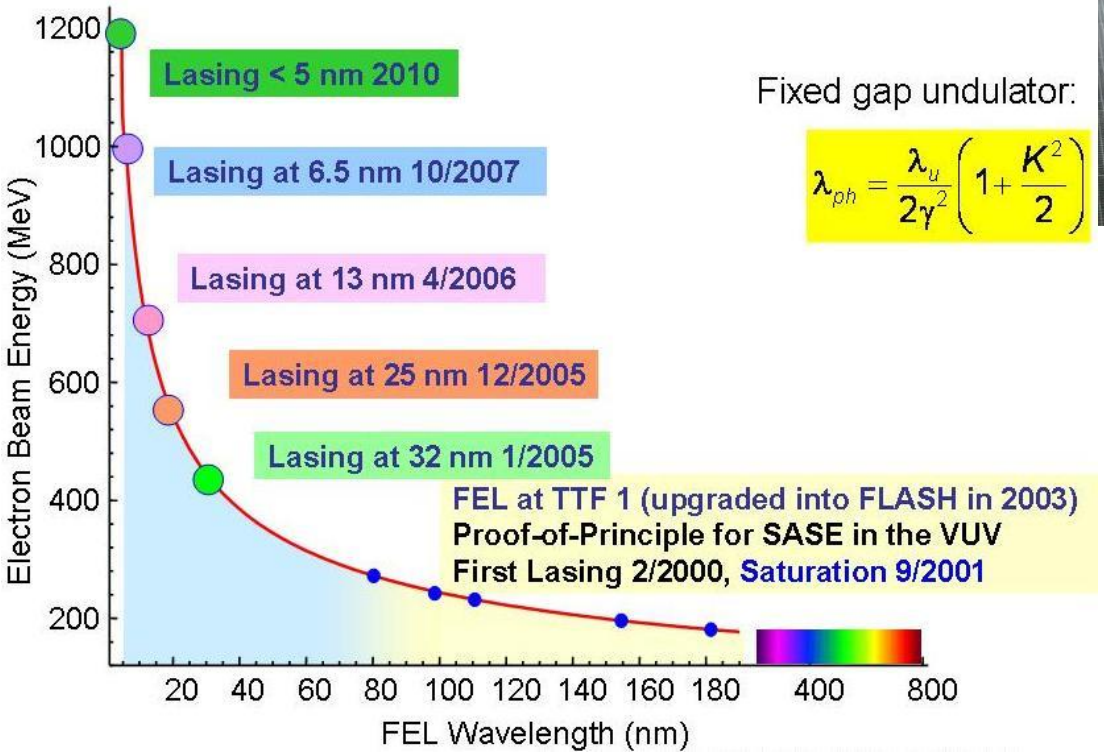
- high-gain single-pass FEL requires a long undulator system
  - 6 modules with a total length 27.3 m
  - permanent NdFeB magnets
  - fixed gap of 12 mm





Fixed gap undulator:

$$\lambda_{ph} = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

- changing photon wavelength requires a change of the electron beam energy

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SASE performance

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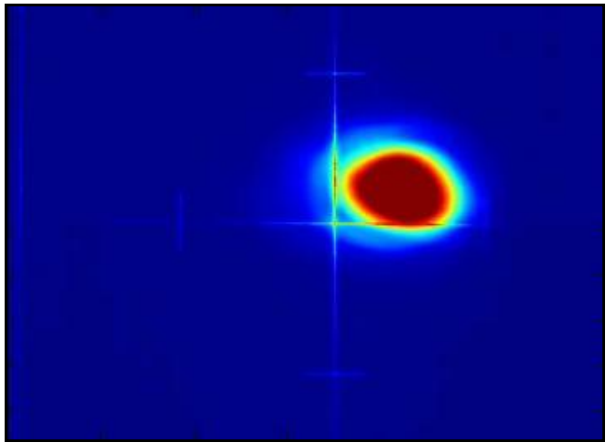
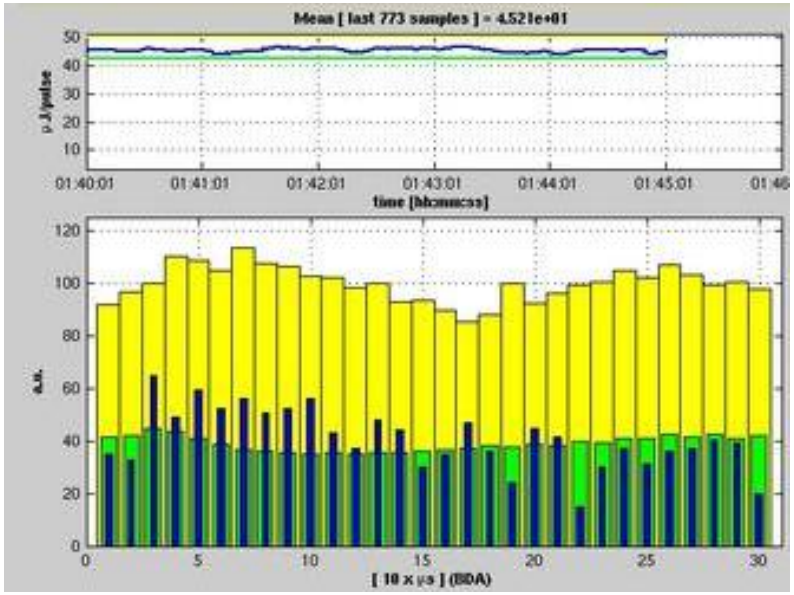
Typical user operation parameters:

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)

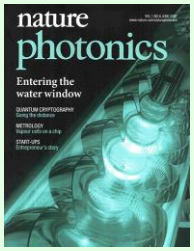


Multibunch SASE signal (µJ)

- max
- single
- average

Top performance at 13.7 nm:

Average energy 70 µJ
Peak energy 170 µJ
Pulse duration 10 fs
Peak power >10 GW
Peak brilliance (6 ± 3) 10^{29} B



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7 nm FEL user run summer 2009

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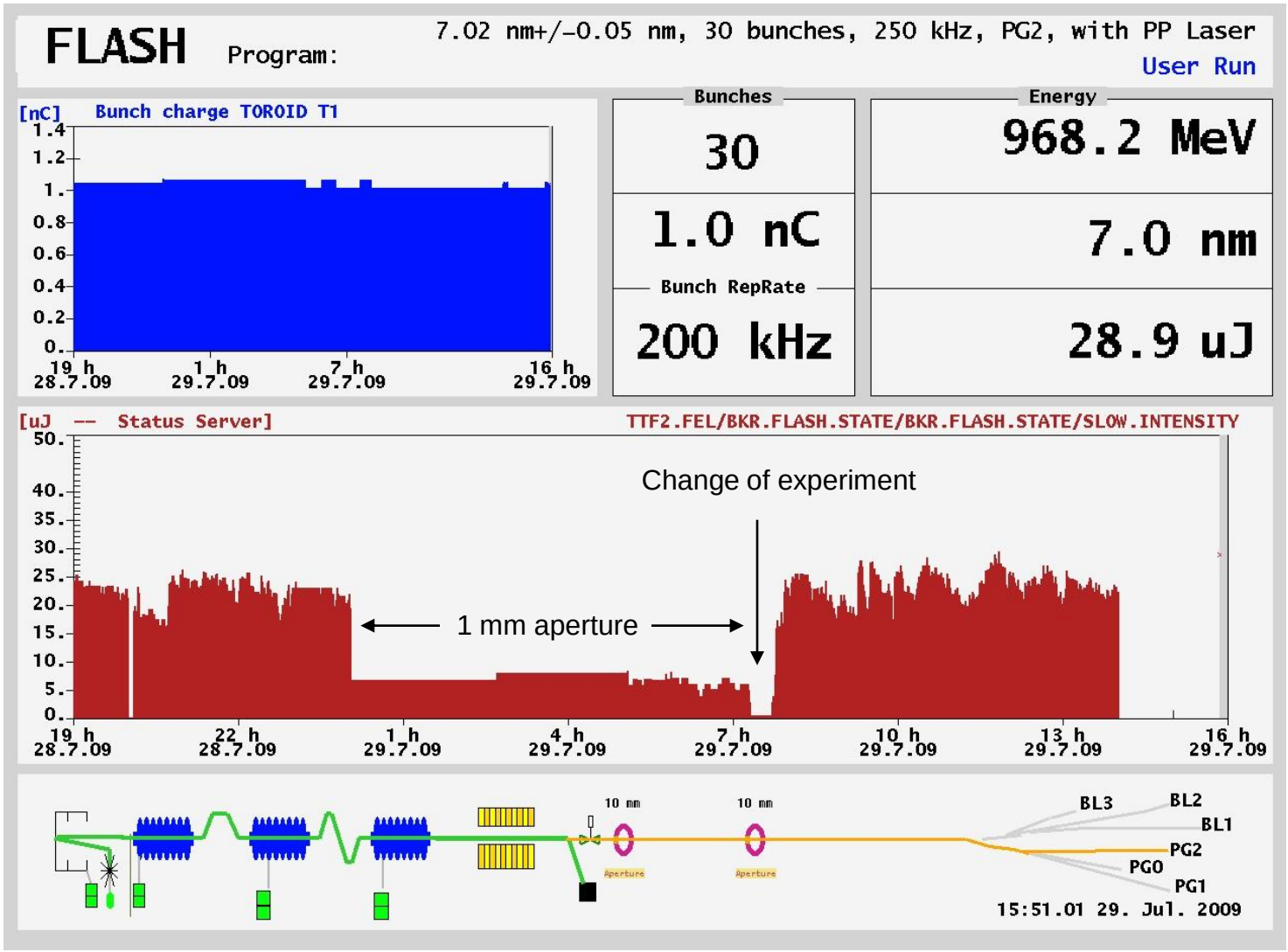

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FEL user experiments

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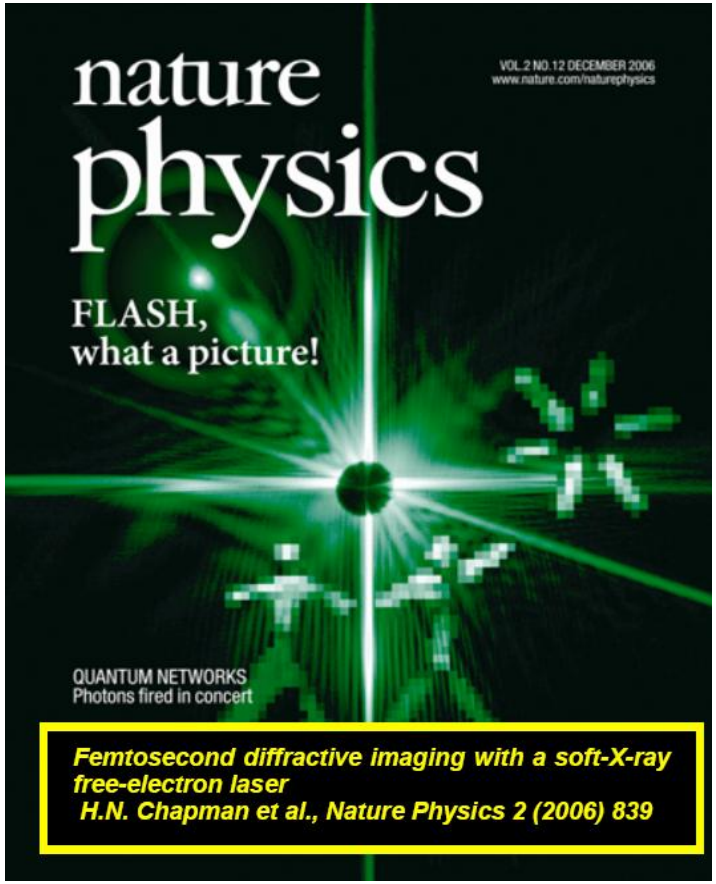
Free-Electron Laser in Hamburg

- 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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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 run

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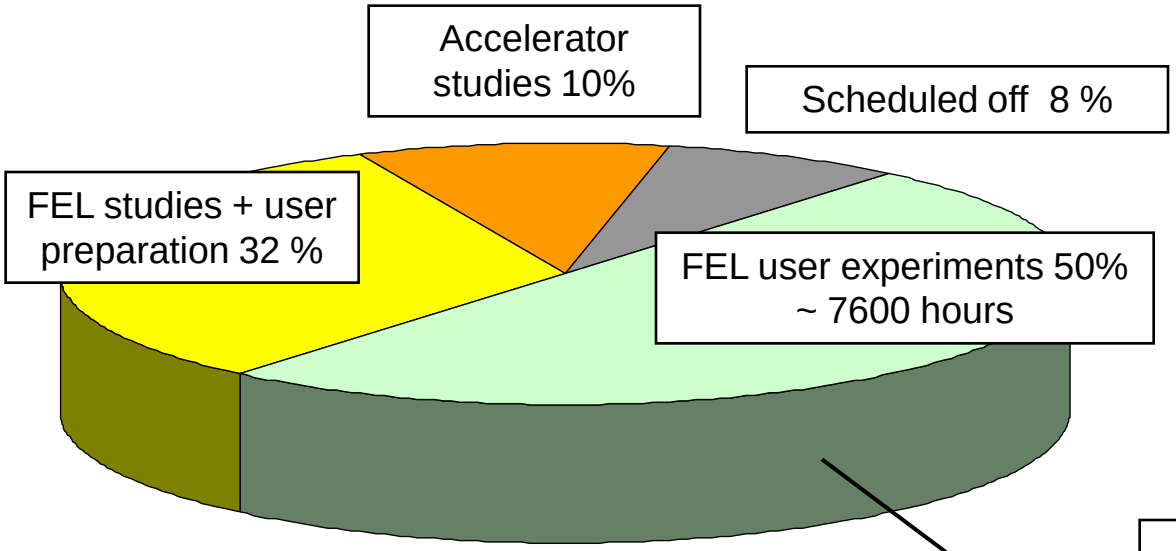

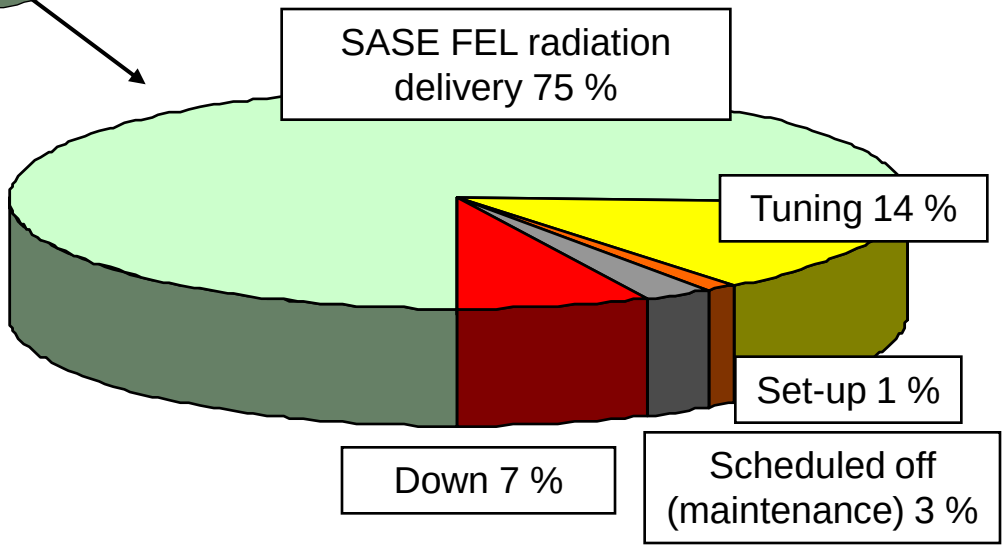

- **up-time during user experiments: 93%**
- tuning: mainly when changing wavelength
  - wavelength has been changed ~ 140 times
  - more than 30 different wavelengths between 6.8 nm and 40.5 nm delivered for users

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Down time during user experiments

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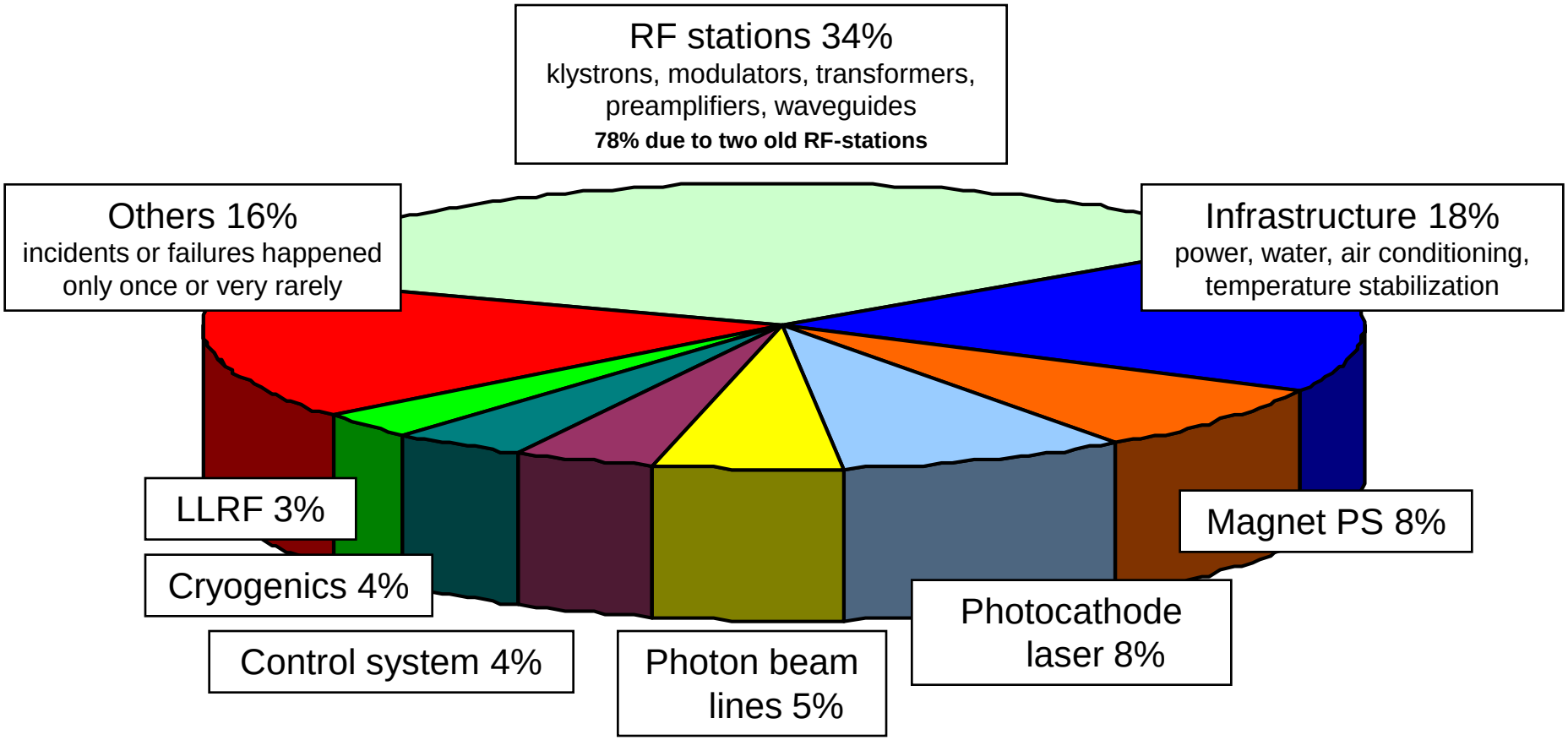
Total downtime 7%



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Distribution of study subjects

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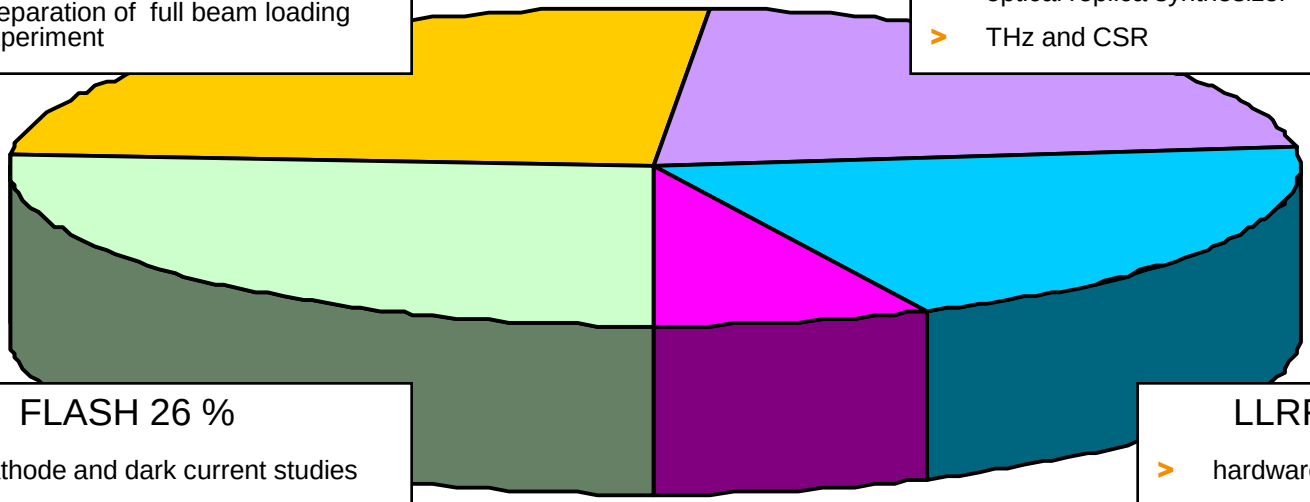
Developments totally ~ 3600 hours



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

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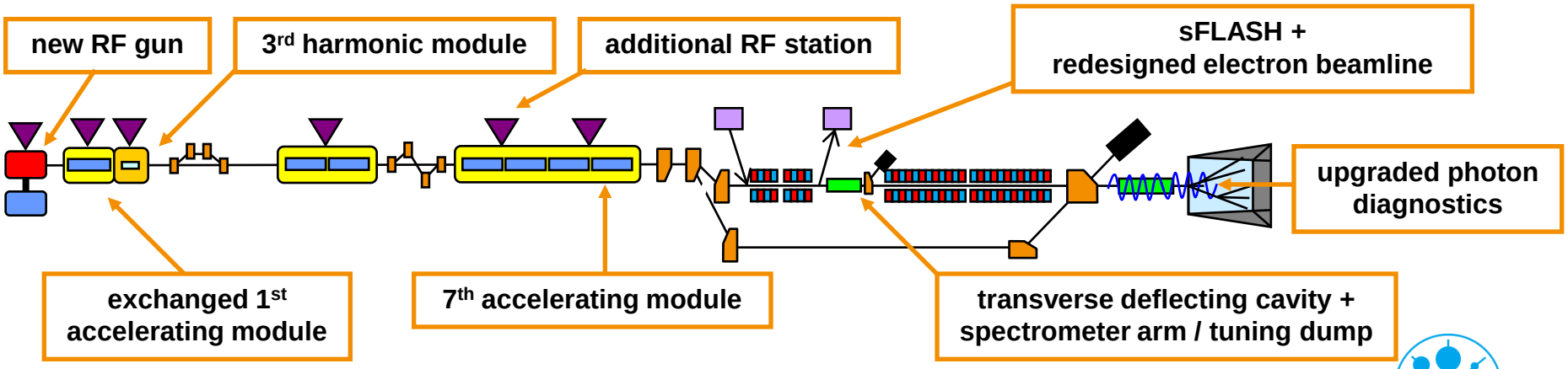
Upgrade 2009/10

FLASH
Free-Electron Laser in Hamburg

- 5 months upgrade shutdown starting September-21, 2009
- major modifications for the FLASH facility
  - exchange of the RF gun and 1st accelerating module
  - installation the 3rd harmonic (3.9 GHz) module
  - installation of the 7th TESLA type accelerating module
  - 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 and waveguide distribution
  - upgrades of photon diagnostics



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3rd harmonic module

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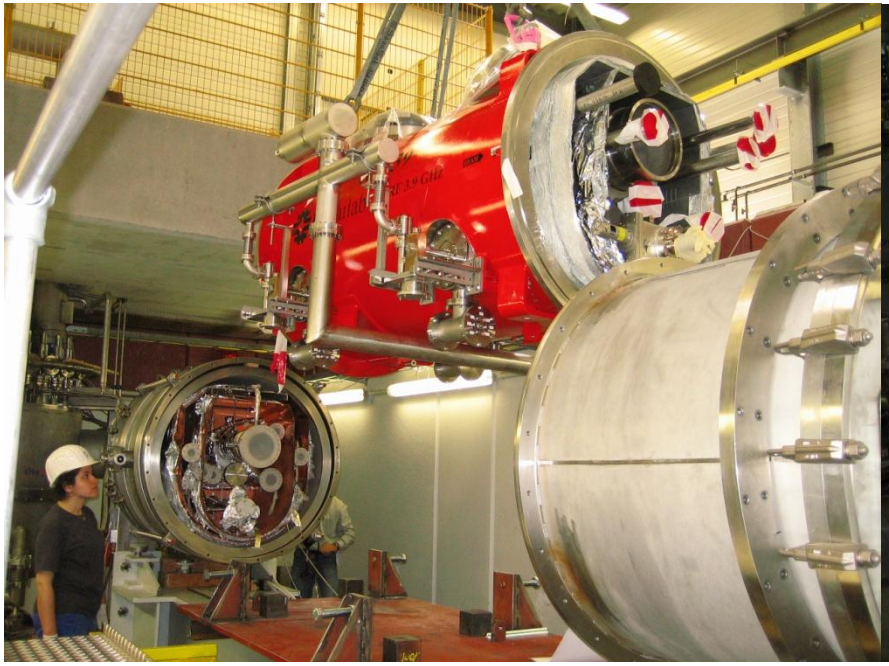
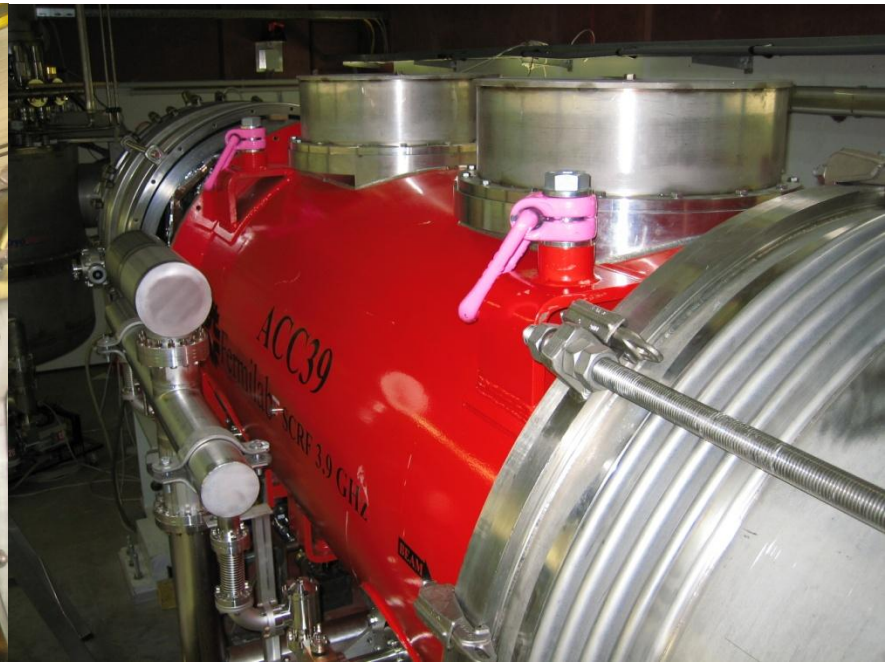
- 3rd harmonic module will be installed after the first accelerating module
  - linearization of the longitudinal phase space
- 4 nine-cell superconducting cavities operated at 3.9 GHz
- more details: talk by E. Harms (MOOBAU01)





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7th accelerating module

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- 7th TESLA type accelerating module (XFEL prototype)
- electron beam energy up to ~ 1.2 GeV ↔ ~ 5 nm photon wavelength
- more details: talk by H. Weise (MOOAAU02) and poster by D. Kostin (TUPPO005)

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Upgrade of RF stations and waveguide system

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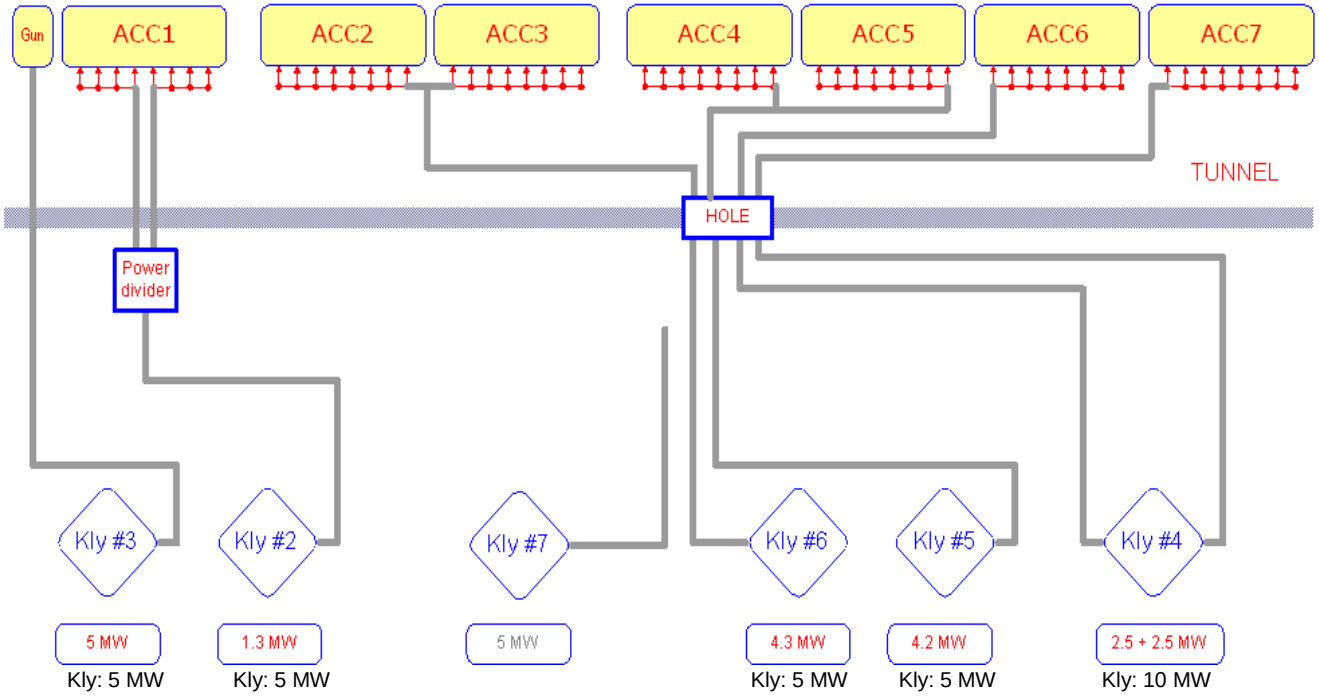
- 2 old RF stations (in operation more than 10 years) will be replaced
- additional RF station to optimize the operation with seven modules
- optimized XFEL type waveguide distribution for the 7th module
  - power for each cavity pair adjusted individually, as already the case for the 6th module



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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
- FLASH is also a world-wide unique test facility for superconducting RF technology
- upgrade shutdown starting end of September 2009
  - 7th accelerating module to increase electron beam energy to 1.2 GeV (5 nm)
  - 3rd harmonic module
  - seeding experiment sFLASH
- commissioning of the upgraded facility in spring 2010
- 3rd FEL user period starting in summer 2010