HELMHOLTZ GEMEINSCHAFT

DESY

FLASH
Free-Electron Laser in Hamburg

Universität Hamburg

First Lasing below 7nm Wavelength at FLASH/DESY, Hamburg

Jörg Rossbach

University of Hamburg & DESY, Germany

- For the FLASH Team -

email: joerg.rossbach@desy.de

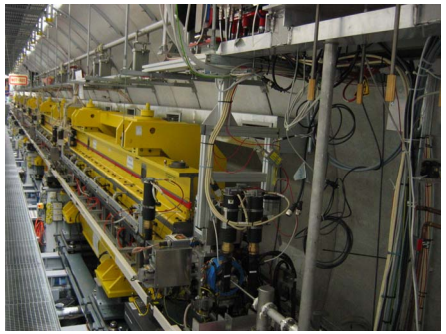
FLASH: The first FEL user facility for the soft X-ray regime

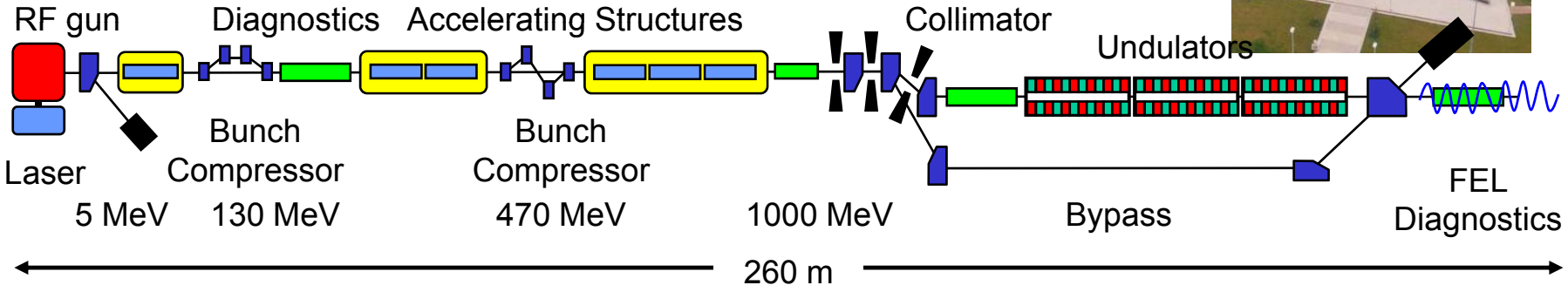
FLASH
Free-Electron Laser in Hamburg

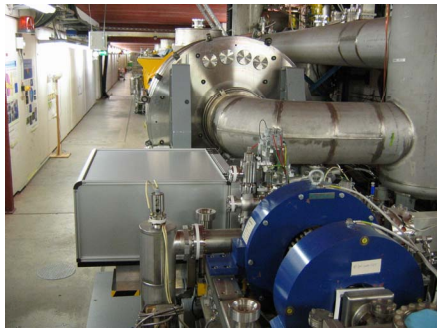
FLASH: over-all layout

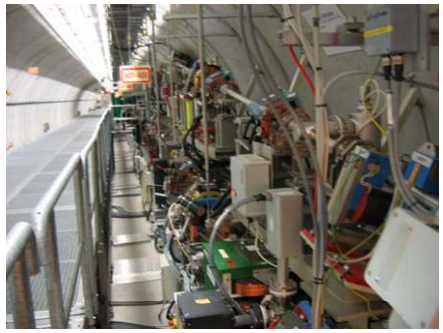
FLASH
Free-Electron Laser in Hamburg





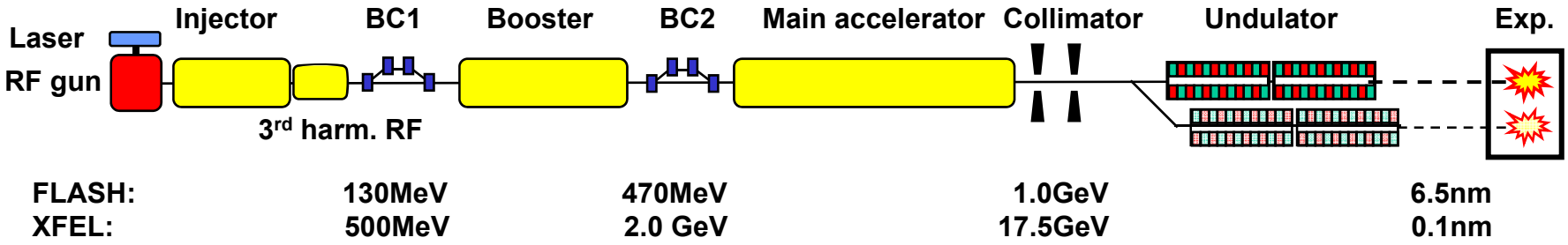





FLASH/European XFEL technology

FLASH
Free-Electron Laser in Hamburg

- FLASH and European XFEL are basically very similar machines:



Based on same SRF technology
Only small differences in beam parameters (except E)
Almost all tests can be carried out at FLASH!

Para.	FLASH	XFEL
$\varepsilon_{x.y}$	2 μm	1.4 μm
I_{peak}	2.5 kA	5 kA
f_{rep}	1 (9)MHz	5 MHz
Q	1 nC	1 nC
E	1 GeV	17.5 GeV
RF	1.3/3.9GHz	1.3/3.9GHz
Δt	800μs	650μs
Δx/Δy	5μm	3μm

Strategy towards 1 Å:

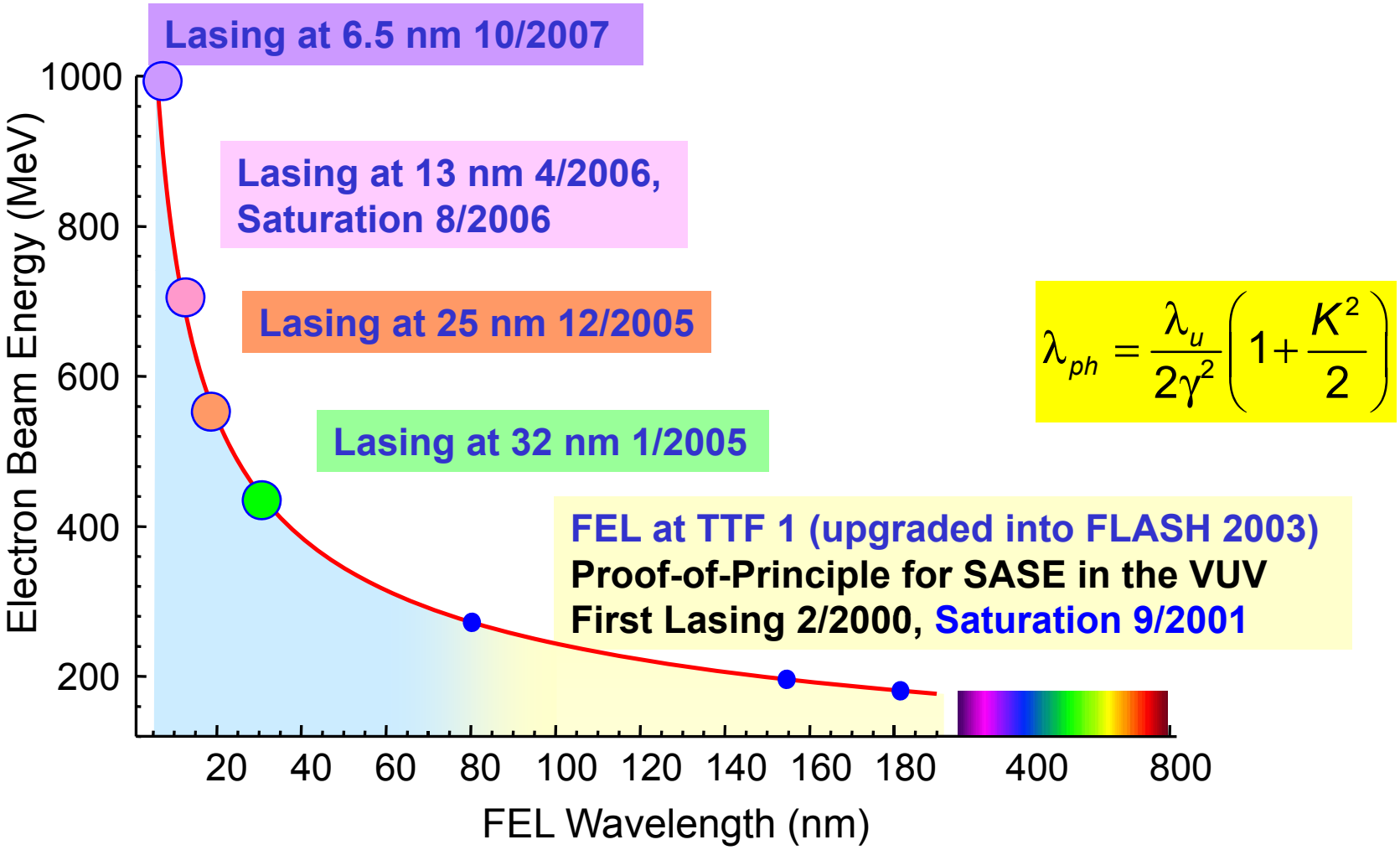
Proceed in stages (starting 1994):
TTF1 (100 nm), FLASH (6.5 nm), XFEL (0.1 nm).
Go for superconducting accelerator:

- excellent stability
- large number of bunches per sec.
- several beamlines
- multi-user facility

Run FLASH as a user facility as soon as possible.

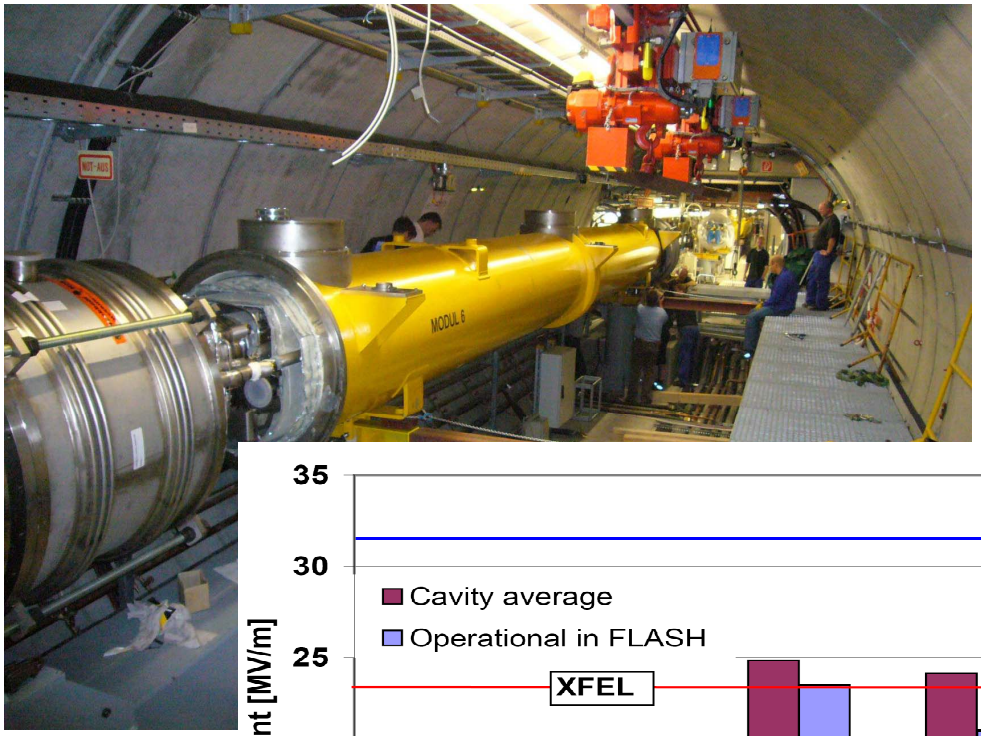
Progress towards short wavelengths

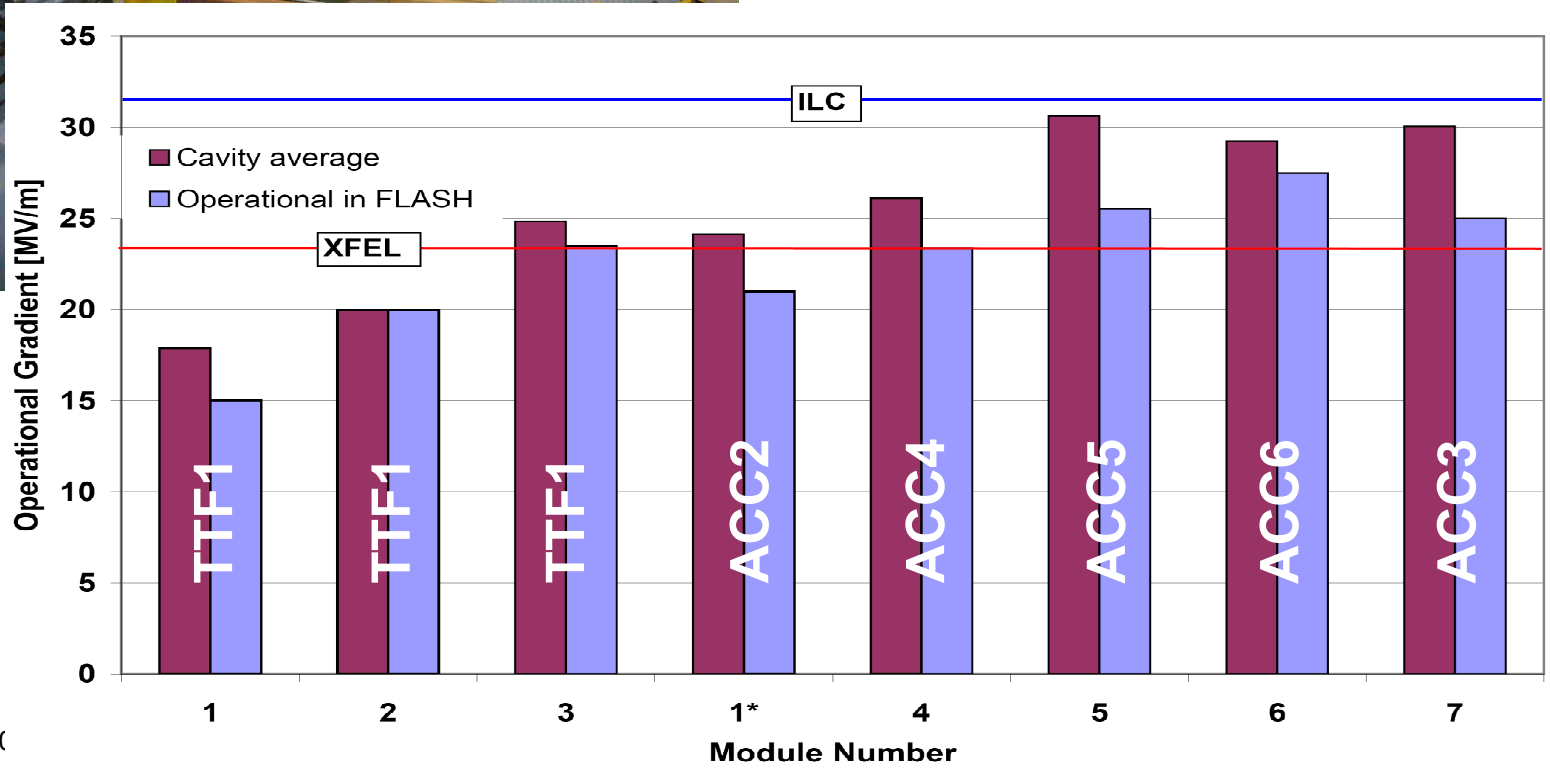
FLASH
Free-Electron Laser in Hamburg



Acc. Module 6 installed → 1 GeV/6.5 nm

FLASH
Free-Electron Laser in Hamburg

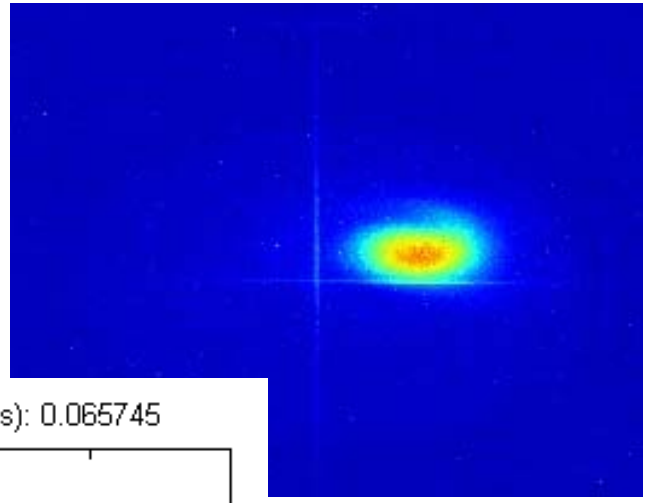


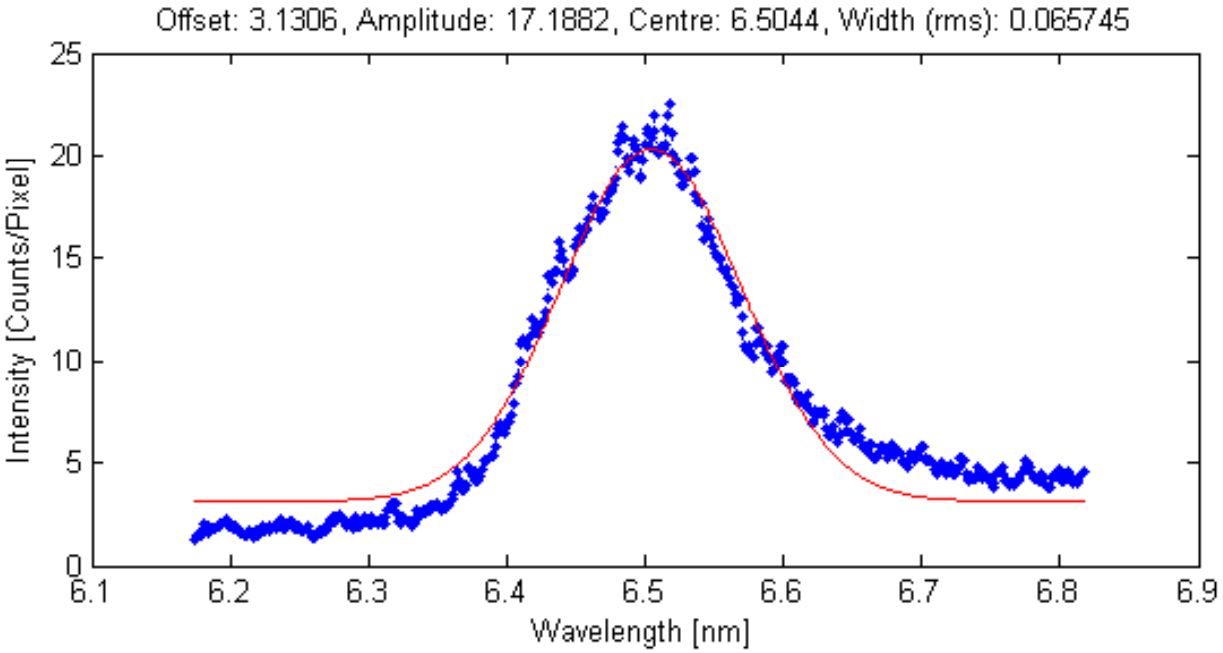


Lasing at 6.5 nm

FLASH
Free-Electron Laser in Hamburg

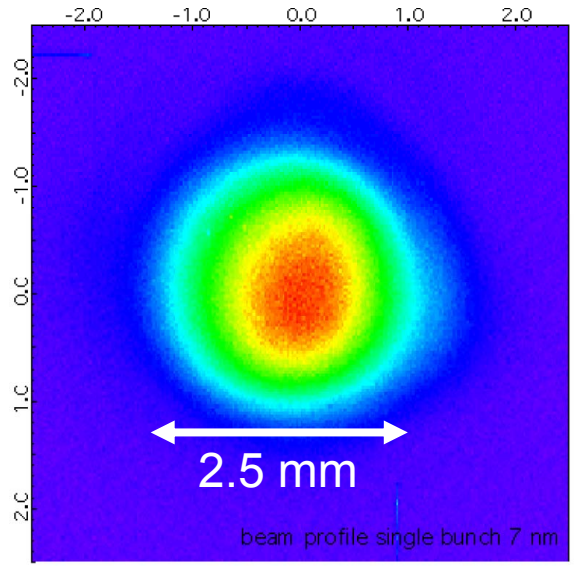
- Lasing at smallest achievable wavelength of 6.5 nm reached in October 5th, 2007
- FLASH design value achieved (defined 1994, presented on FEL95)



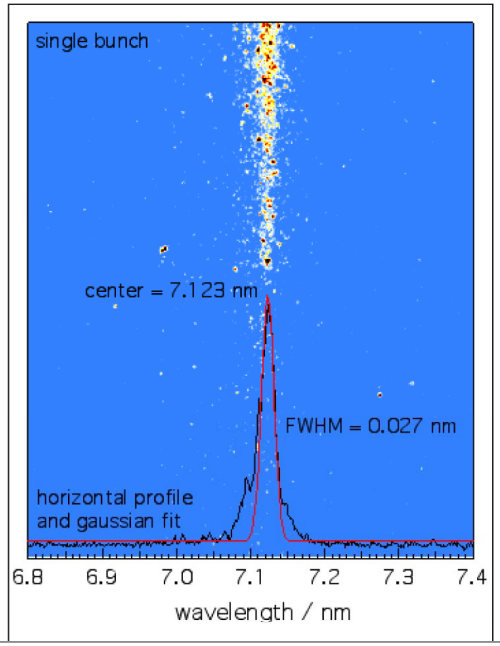


Lasing at 7.1 nm

FLASH
Free-Electron Laser in Hamburg

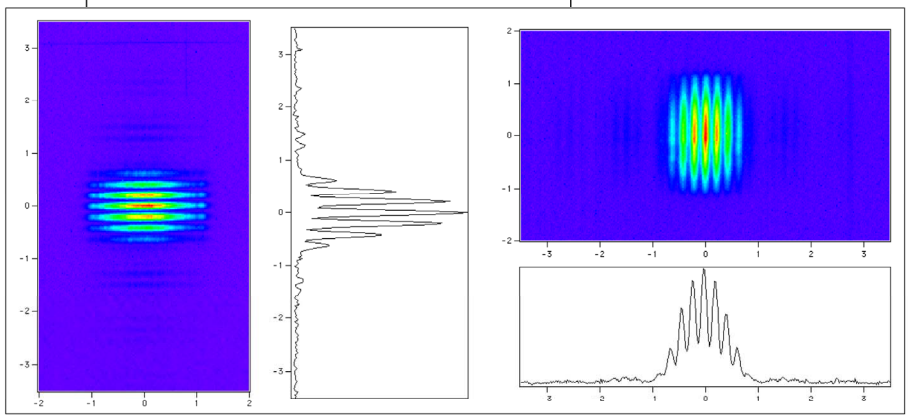


7.1 nm beam on Ce:YAG screen at 20 m distance



Spectral distribution of a single FEL pulse at 7.1 nm

Pulse energy: ~5 µJ
Pulse duration: <10 fs



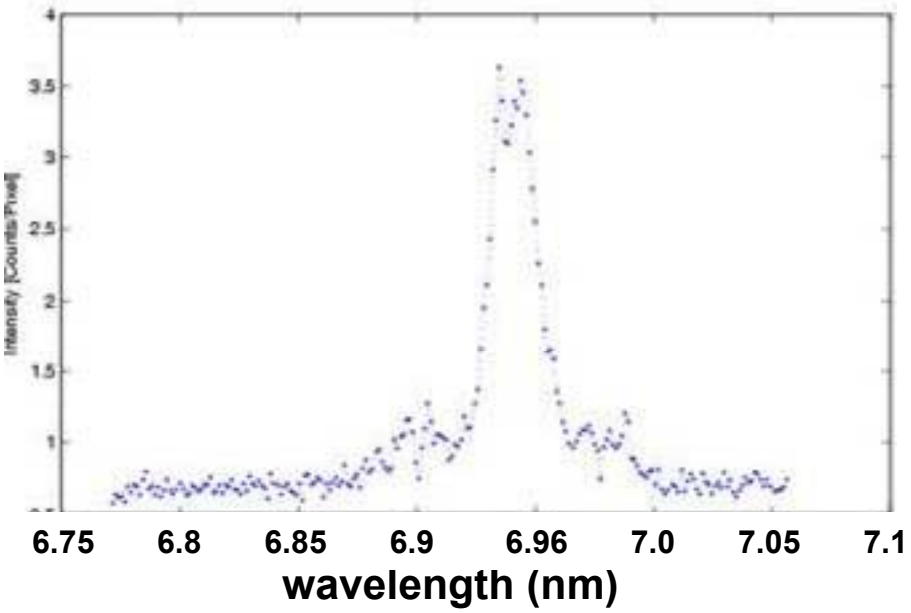
Double slit diffraction patterns at 7.1 nm (0.15mm slit separation)

Wave front:
E. Ploenjes TUBAU03

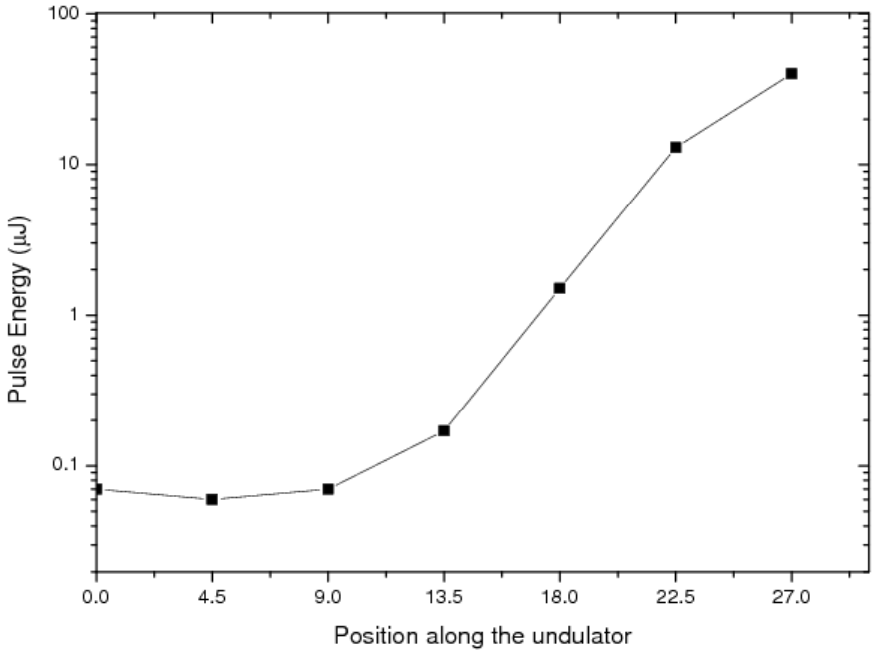
Preliminary Radiation Properties @ 6.9 nm

FLASH
Free-Electron Laser in Hamburg

- Lasing at 6.5 nm and 6.9 nm,
  7 nm delivered to users
- single shot spectra show a small number of modes → preliminary
  estimated pulse length: 5-10 fs
- operation stability acceptable for user, but not yet satisfactory

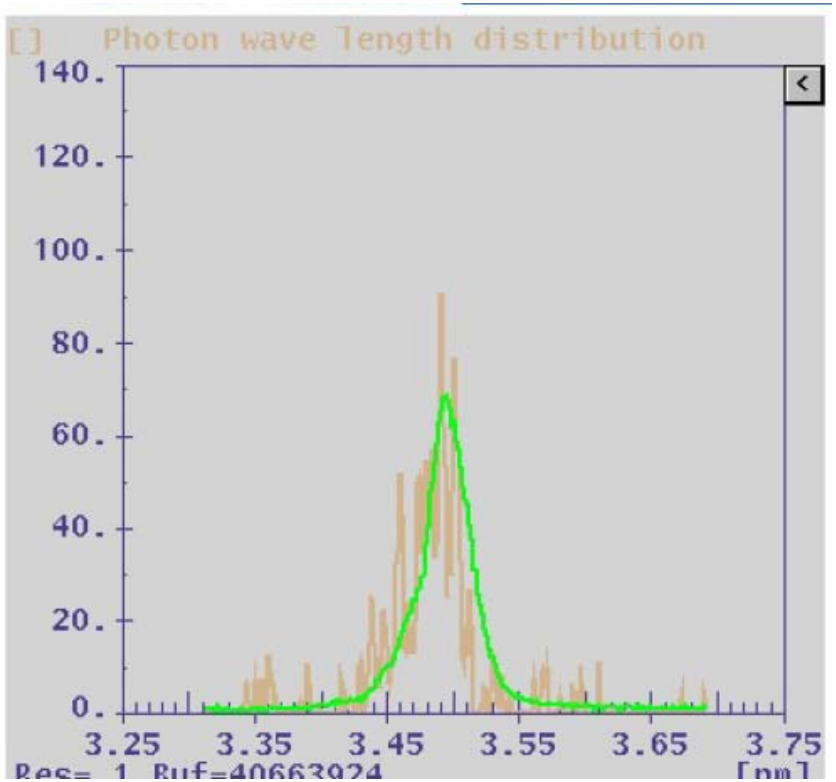


Gain curve @ 6.9 nm (preliminary)

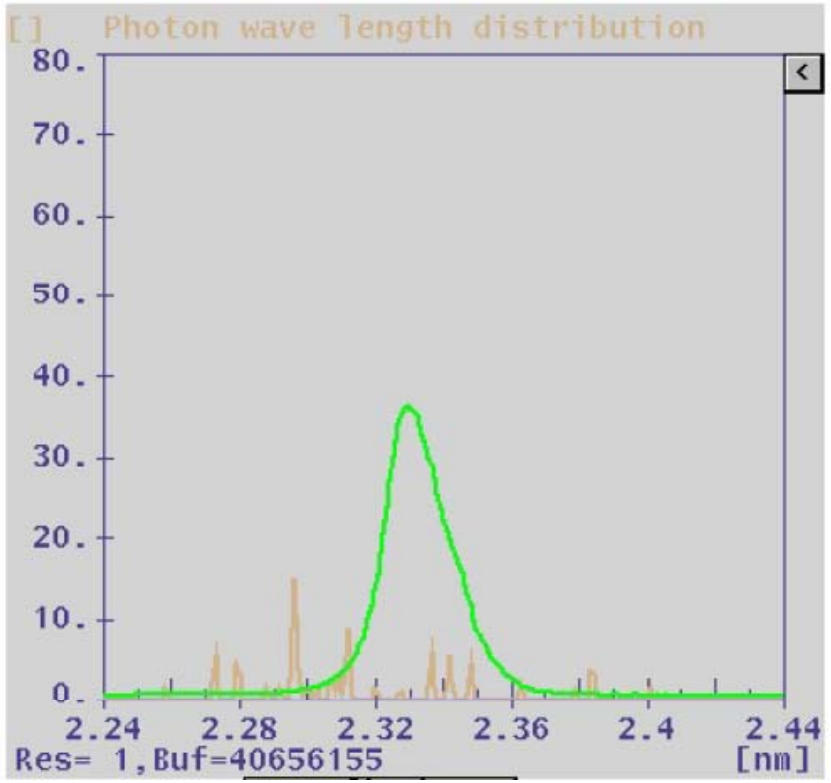


Harmonics

FLASH
Free-Electron Laser in Hamburg



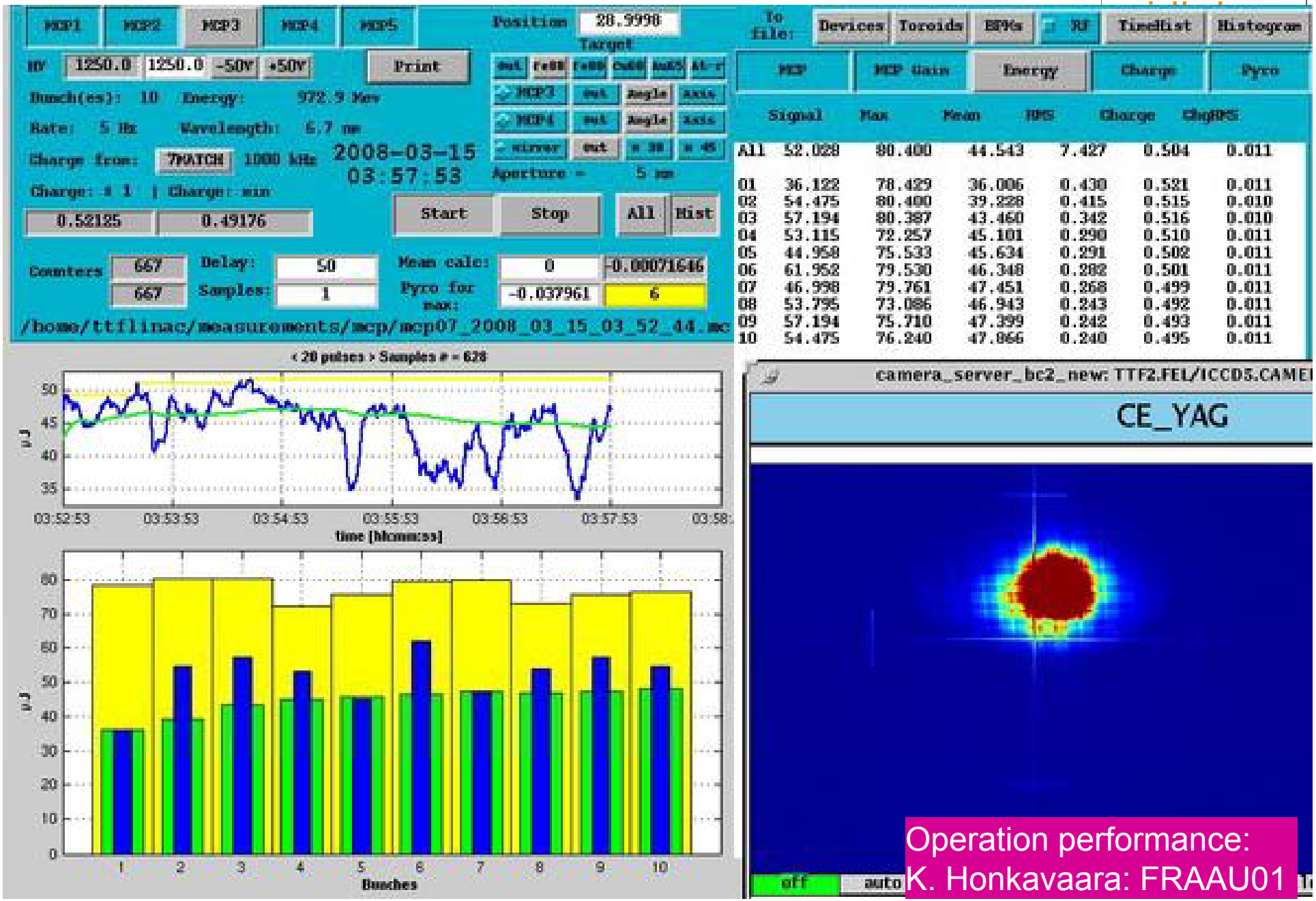
2nd harmonics



3rd harmonics

Performance at 7nm/train of 10 bunches

FLASH
Free-Electron Laser



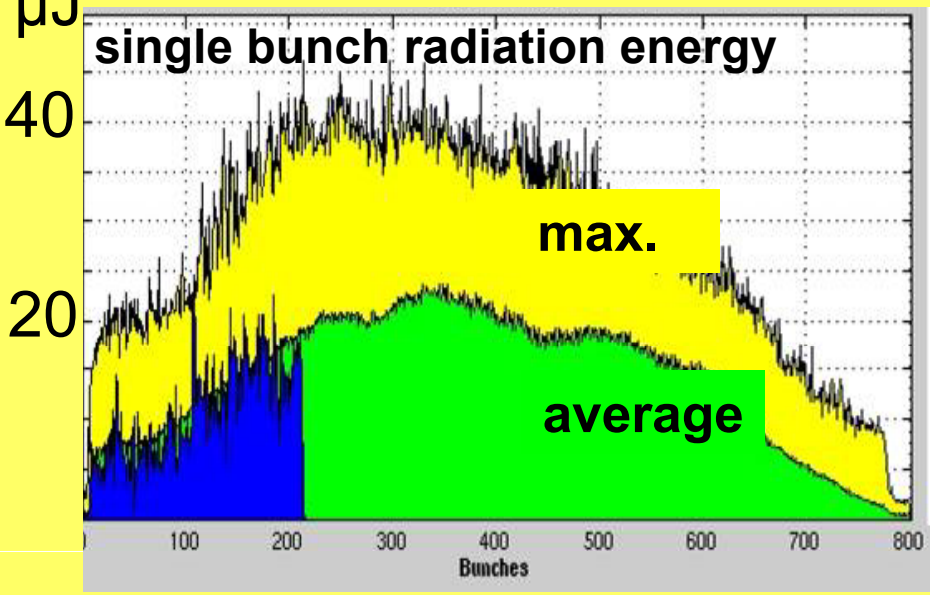
Operation performance:
K. Honkavaara: FRAAU01

Lasing with long bunch trains

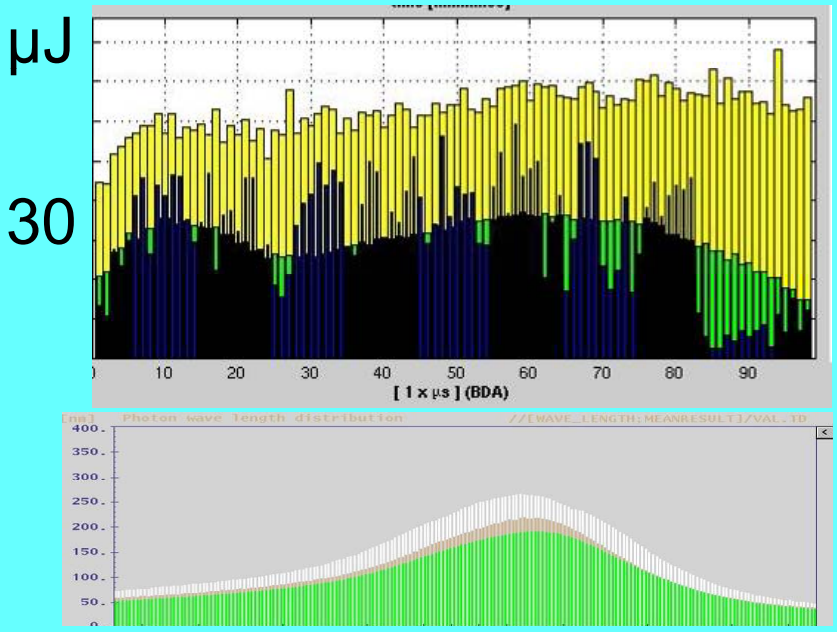
FLASH
Free-Electron Laser in Hamburg

- Lasing with trains of up to 800 bunches, >10 µJ/pulse achieved
- Machine Protection System: fully operational, with minor constraints

800 bunches, 685 MeV, 13.4 nm
<electron beam power> : 2.7 kW
<photon power>: 56 mW



100 bunches, 960 MeV, 7 nm
<photon power>: 14 mW



Peak brilliance

FLASH
Free-Electron Laser in Hamburg

Brilliance: $= \dfrac{\Phi}{4\pi^2 \Sigma_x \Sigma_{\theta x} \Sigma_y \Sigma_{\theta y}}$

with $\Sigma_x = \sqrt{\sigma_{x,ph}^2 + \sigma_{x,e}^2}$ etc.

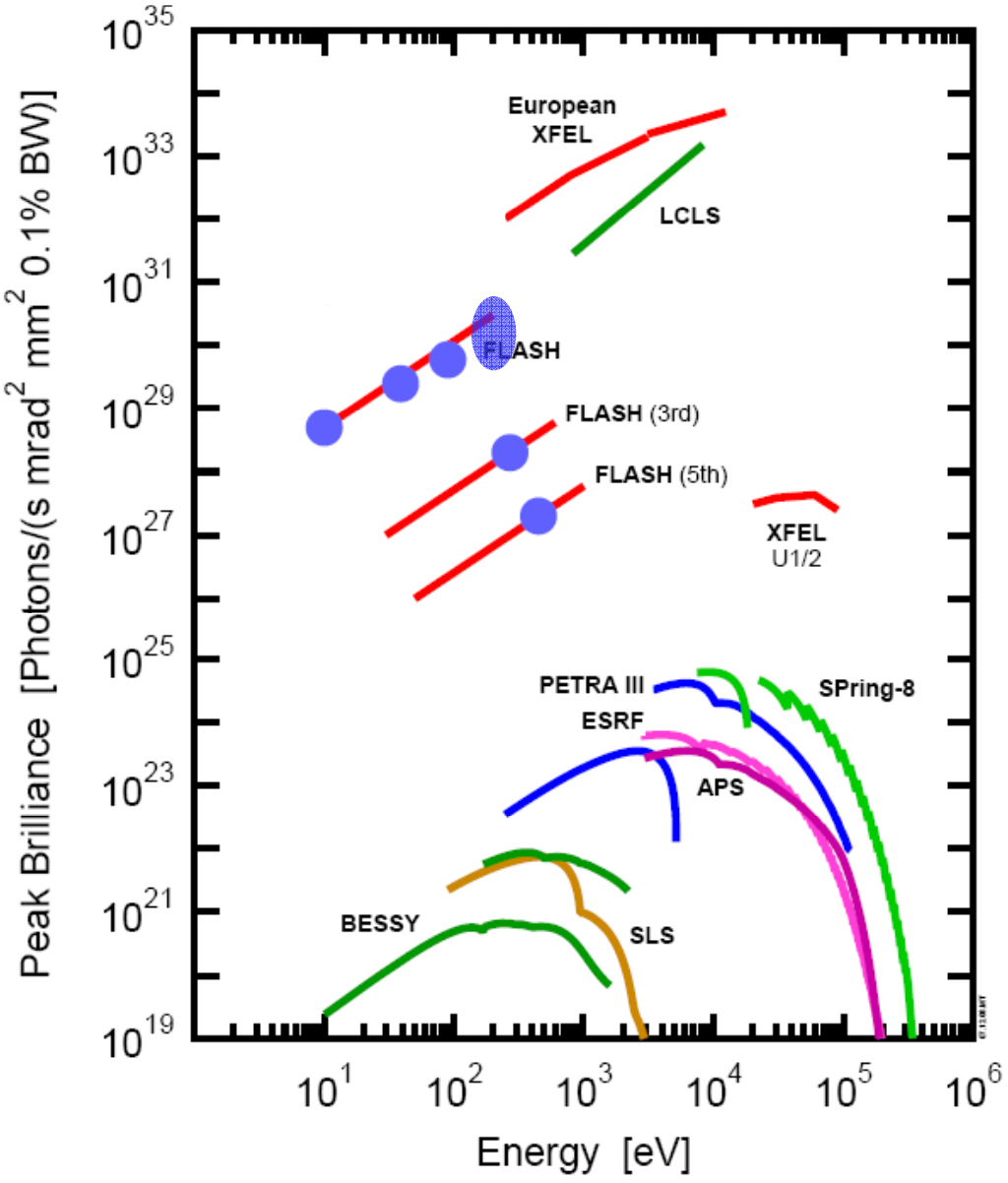
For transv. coherent source:

$$\Sigma_x \Sigma_{\theta x} = \Sigma_y \Sigma_{\theta y} = \frac{\lambda_{rad}}{4\pi}$$

→ $$\boxed{B_{FEL} = \frac{4\Phi}{\lambda_{rad}^2}}$$

Spectral flux:

$$\Phi = \frac{\#\,\text{photons}}{(\text{pulse duration}) \cdot (\text{spectral width})}$$



Peak brilliance

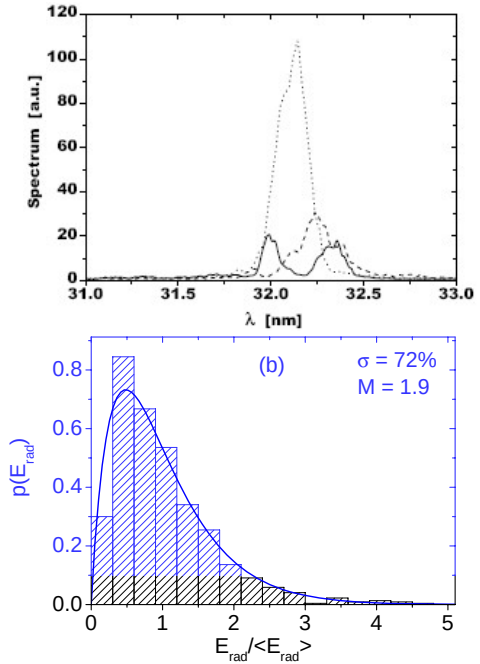
FLASH
Free-Electron Laser in Hamburg

$$\Phi = \frac{\#\,\text{photons}}{(\text{pulse duration}) \cdot (\text{spectral width})}$$

photons: Single pulse radiation energy

spectral width (0.1% units): Avg. spectrum

pulse duration: $T_{rad} \cong 2\pi/(\text{FWHM spectral width of single shot spikes})$



Fluctuation of pulse energy due to start up from noise @ 13.7nm

Cross check:

1. Get coherence length from measured gain length
   - don't use width of avg. spectrum for cross check: spectral widening due to energy chirp within bunch !
2. Count # long. modes *M* from single shot spectra
   - OR extract *M* from fluctuation of pulse energy

   (should be the same !) → $T_{rad} \cong M \cdot \tau_{coh}$
3. Cross check with numerical simulation & measurements of electron bunch profile

M. Roehrs: MOPPH049

U. Frühling: THDAU01

NOTE 1: Time domain measuments under way !

NOTE 2: This all assumes flat top bunch profile !

FLASH @ FEL08

FLASH
Free-Electron Laser in Hamburg

Injector

C.H.Boulware	THAAU05	Electron beam results from PITZ
R. Spesyvtsev	TUPPH037	Slice emittance measuments at PITZ/Zeuthen
J. Roensch	TUPPH038	Long. phase space measurement at PITZ
Y. Ivanisenko	TUPPH079	Slice emittance measurements at PITZ
S. Schreiber	FRAAU05	Cathode issues at the FLASH rf gun

Electrons

K. Honkavaara	FRAAU01	Status of FLASH
B. Faatz	TUPPH063	Radiation damage of undulator
M. Roehrs	MOPPH049	3D electron bunch measurement
B. A. Winter	TUPPH066	Synchronization system
B. Schmidt	TUPPH068	Observation of coherent micro-bunching
F. Loehl	THBAU02	Demonstration of 40 fs synchronization
S. Khan	THBAU04	Optical Replica Experiment
S. Khan	TUPPH072	sFLASH: Seeding FLASH @ 30nm
R.Tarkeshian	TUPPH051	Temporal overlap for seeding
V. Miltchev	TUPPH003	HHG seeding

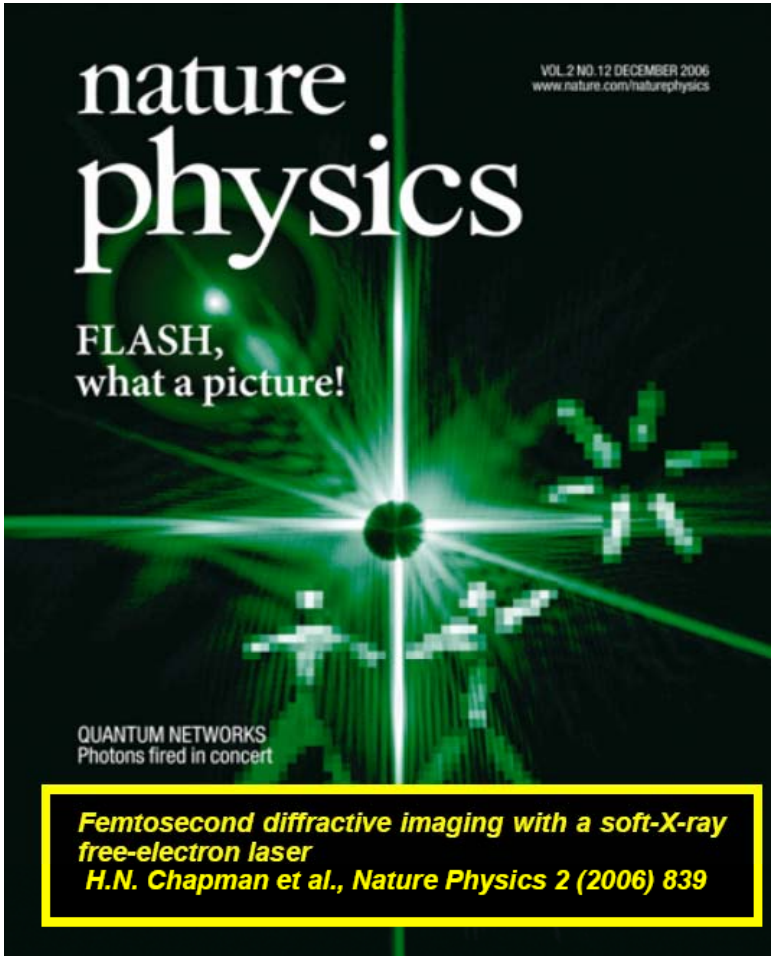
Photons

E. Ploenjes	TUBAU03	Wavefront measurments
B. Faatz	TUPPH004	Polarization from crossed-planar undulator
M. Kuhlmann	TUPPH069	High-resolution online-spectrometer
J. Zemella	TUPPH070	Timing of optical pulse trains
U. Fruehling	THDAU01	Time domain measurement of pulse length
Chr. Gutt	THDAU02	Resonant magnetic scattering

FLASH, what a picture!

FLASH
Free-Electron Laser in Hamburg

1st Round of User Experiments ended 3/2007



18 projects received beamtime
>200 scientists
60 institutes, 11 countries

> 25 publications already,
many more to come

- 4 PRL
- 6 APL
- 1 Nature,
- 1 Nature Physics
- 1 Nature Photonics
- ...

See, e.g.,
http://hasylab.desy.de/facilities/flash/publications

2nd Round of User Experiments

FLASH
Free-Electron Laser in Hamburg

total of 45 proposals, 13 rejected

377 twelve hour user shifts available in 18 months,
316 shifts allocated + ≥10% management contingency ≈ 350 shifts

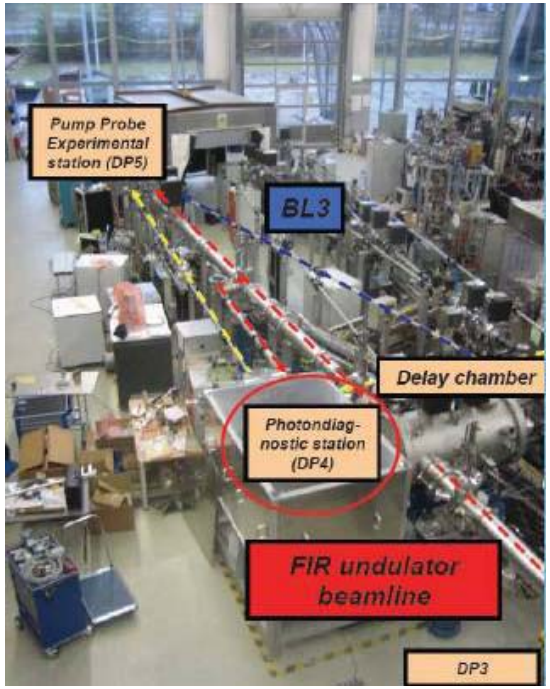
Research fields	Number of 12 hour shifts		Percentage
	Requested (all 45 prop.)	Allocated	
Atoms, Molecules, Ions	247	61	25
Clusters	71	36	50
Imaging, Diffraction	90	53	59
Plasma physics / Warm dense matter	194	56	29
Solids, Surfaces	214	46	21
Methods/ Technology	157	64	41

New infrared undulator

FLASH
Free-Electron Laser in Hamburg

- Located downstream of FEL
- Improved coherent THz diagnostics
- FIR pulse naturally synchronized to FEL pulse
- FIR transported into exp. hall for pump-probe
- Status: - FIR pulse observed,
  -overlap FIR and FEL pulses detected

U. Fruehling
THDAU01



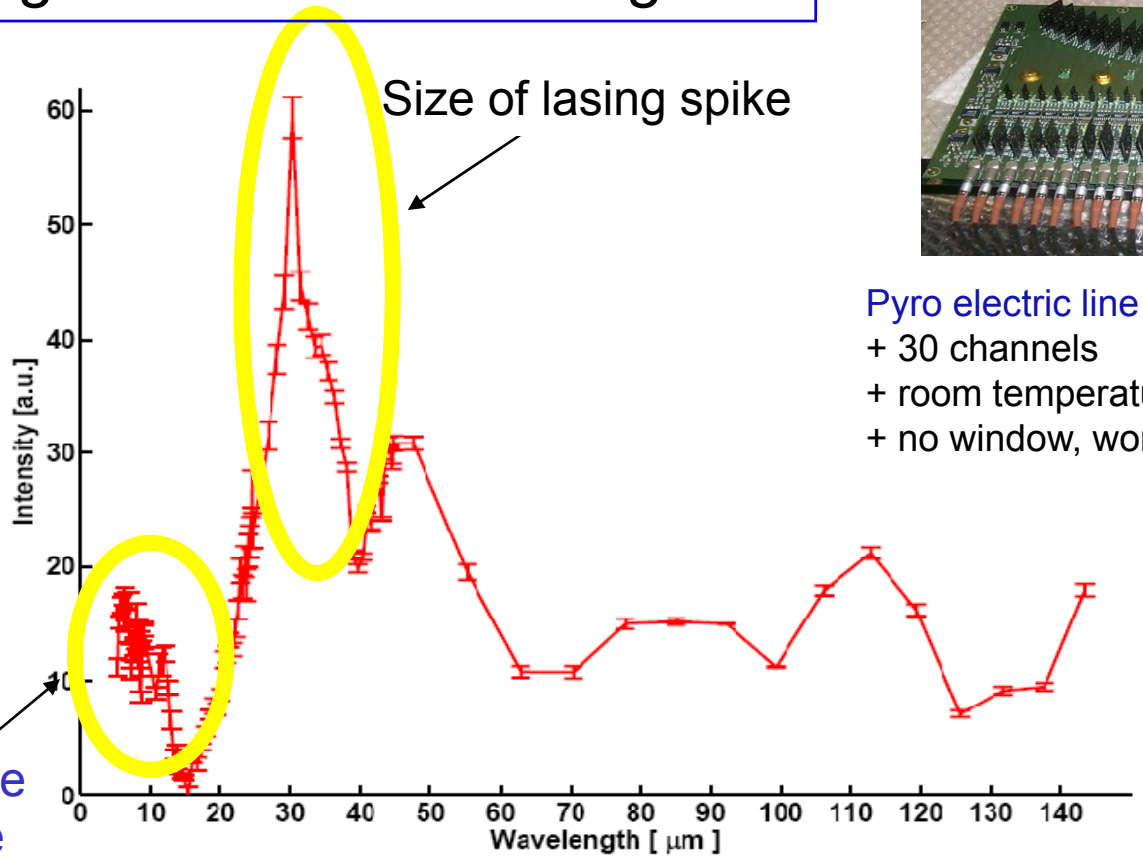
Frequency domain diagnostics with THz rad.

FLASH
Free-Electron Laser in Hamburg

Single shot spectrum of coherent infrared radiation exhibits structure in the longitudinal density modulation < 5 µm !!

Need single shot spectrometer for wide IR bandwidth

THz signal also used for long. FB



Substructure inside spike

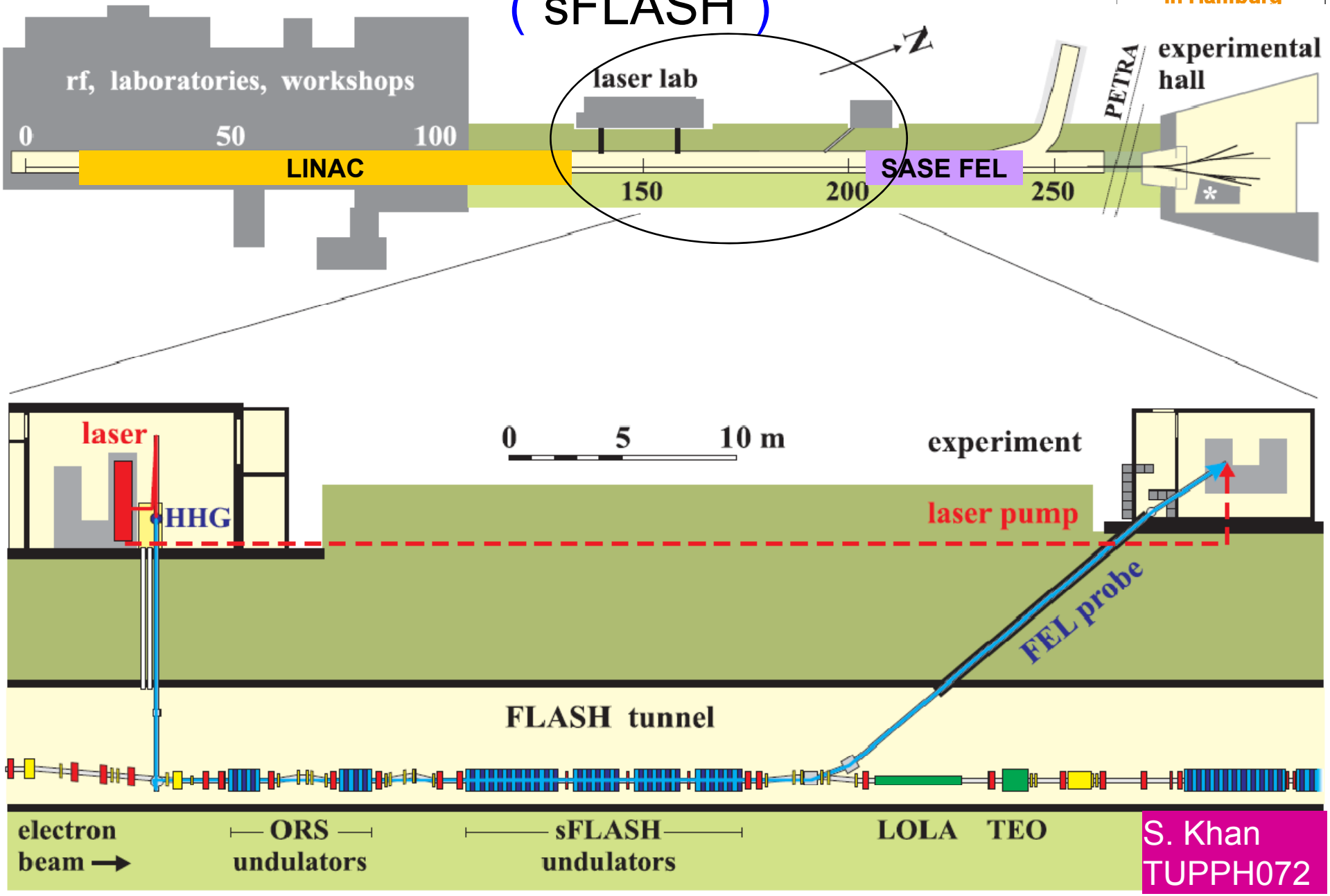
Recent development at DESY/UHH

Pyro electric line detector from individual pyros
+ 30 channels
+ room temperature
+ no window, works in vacuum

B. Schmidt
TUPPH068

High Harmonic Laser Seeding at 30nm ("sFLASH")

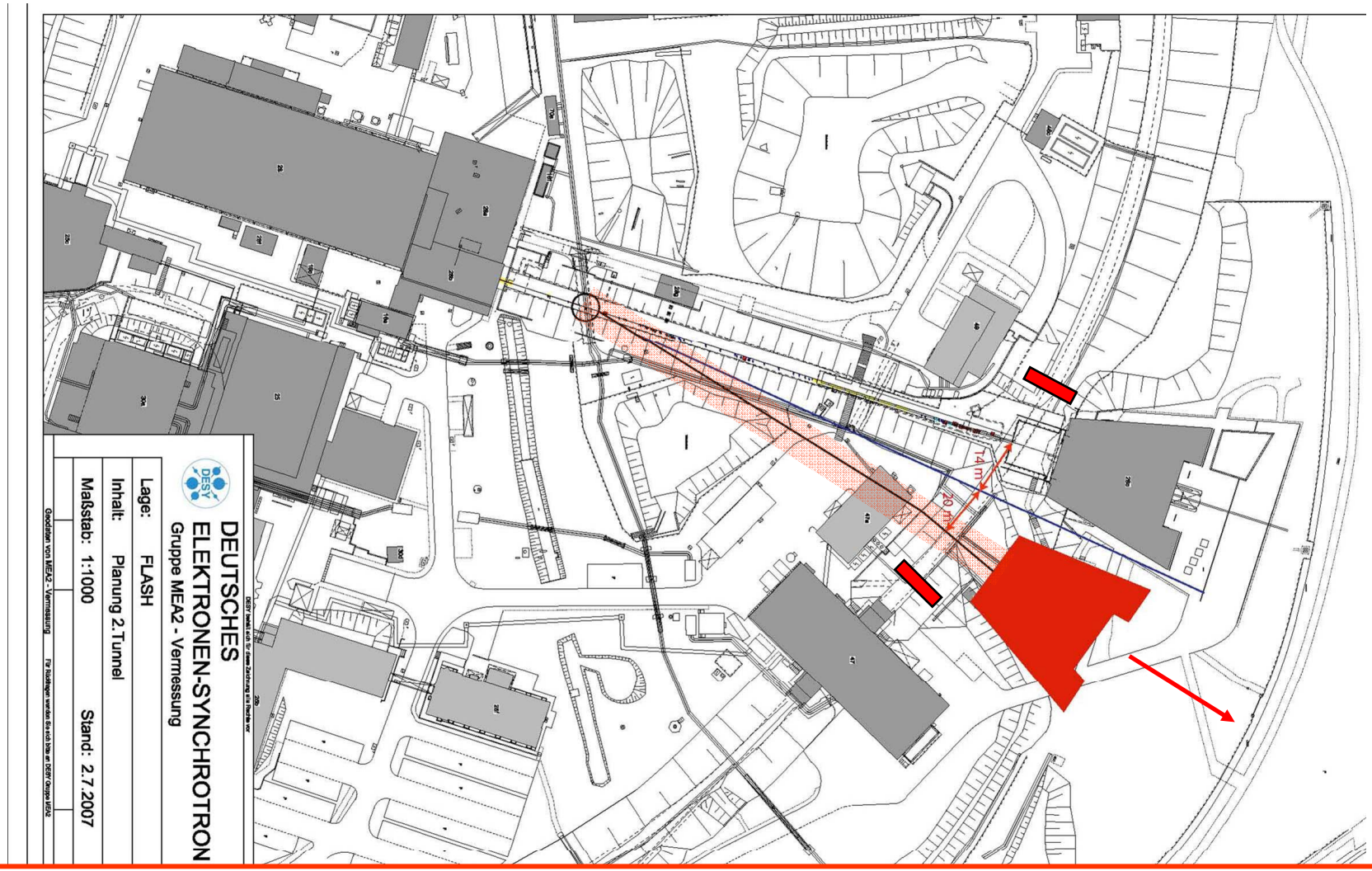
FLASH
Free-Electron Laser in Hamburg



S. Khan
TUPPH072

FLASH II: Proposal for a 2nd FEL beamline

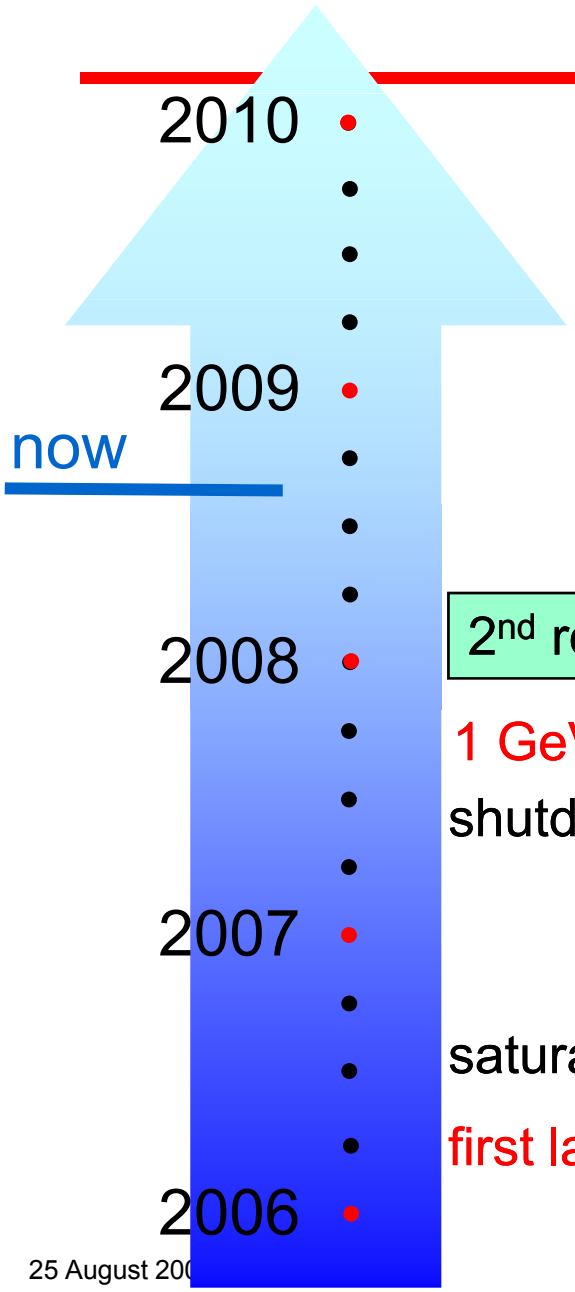
FLASH
Free-Electron Laser in Hamburg



More room for users
Quasi-simultaneous operation with 2 wavelengths

Outlook

FLASH
Free-Electron Laser in Hamburg



- Installation 7th acc. Module → ~1.2 GeV/<5nm
- operation with 3rd harmonic cavity
- long bunch train operation
- variable pulse and energy patterns
- beam stability (LLRF and beam based feedbacks)
- Seeding (sFLASH)
- Proposal for a 2nd FEL beamline

2nd round of user experiments starts

1 GeV beam energy: lasing at 6.5 nm

shutdown: installation 6th module

saturation at 13 nm achieved

first lasing at 13 nm

Summary

FLASH
Free-Electron Laser
in Hamburg

Lasing at 6.5 nm demonstrated.

Considerable user experience gained.

No show stopper visible.

Ambitious upgrade program launched.

Continuous progress towards XFELs.