Development of FELs as user facilities

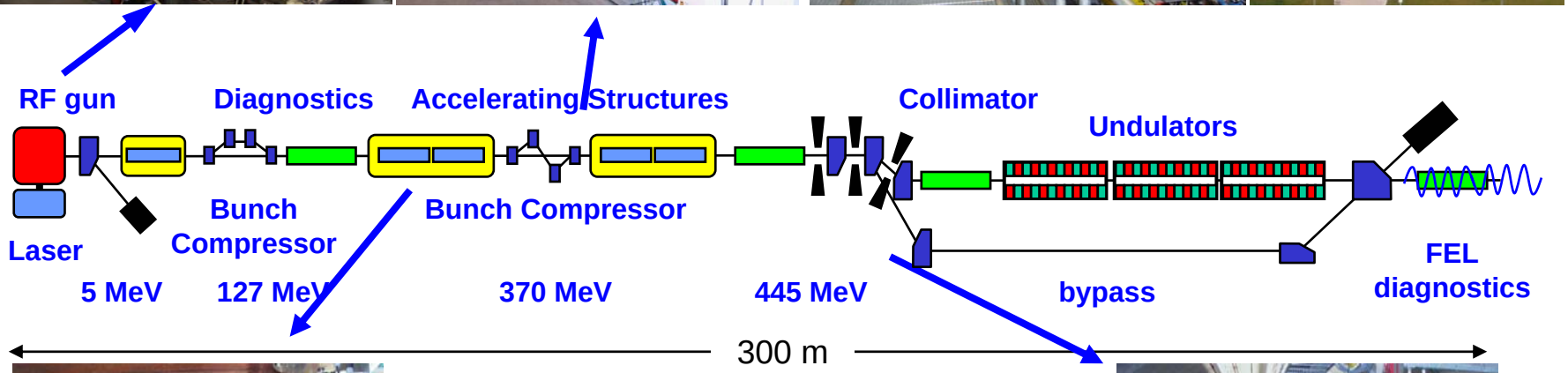
Josef Feldhaus, DESY

Example FLASH:
The Free electron LASer in Hamburg
The first FEL user facility for
VUV/soft X-ray radiation

Introduction

- **Are there other reasons to develop FELs (lasers)?**
  - R&D is fun and challenging
  - it keeps us busy
  - there are always people who can use it
- **FEL user facilities → maximise user access**
  - meet user demands
  - use sources efficiently
  - ideal: superconducting linac in CW mode for many experiments in parallel
- **Many technical challenges**
  - CW operation: gun, bunch compression
  - fast beam distribution
  - …
- **FLASH is the first user facility for soft X-rays**
  - it needs a large portion of time for developments
  - there is a strong interaction between users and operators

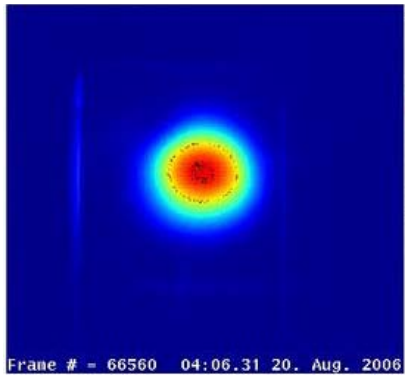
Example: FLASH

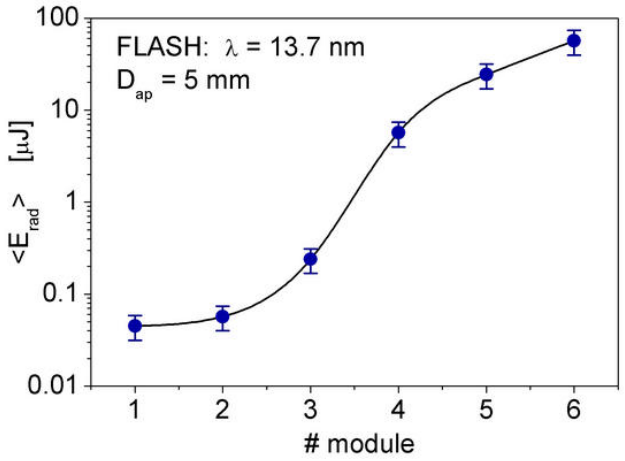


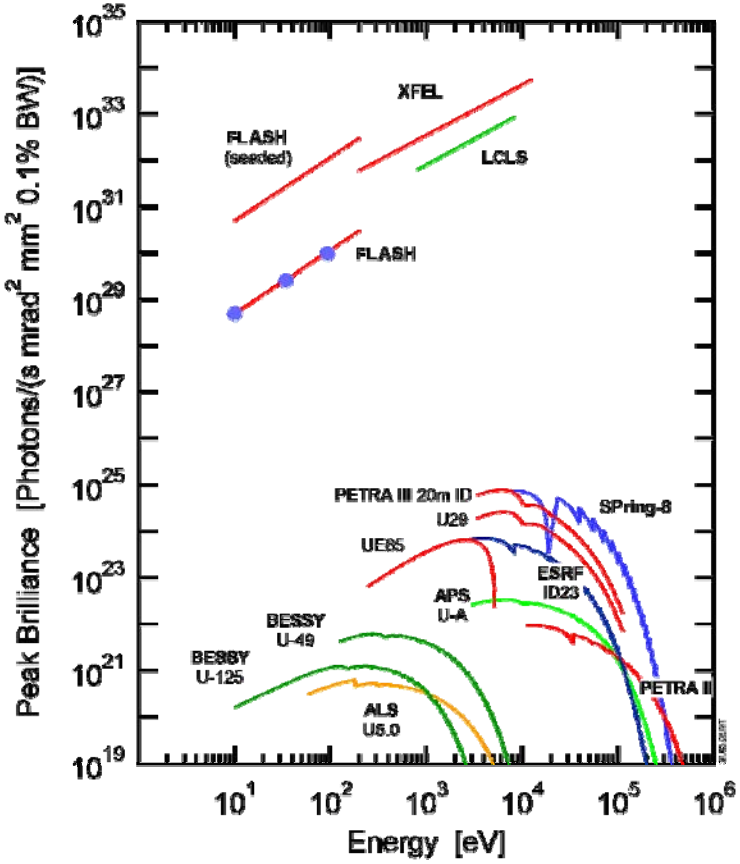
- Jan2005: first lasing at 32 nm
- Aug2005: user operation
- Energy range: ~0.3 - 1GeV
  → ~6.5 - 60 nm
- Reached: 700 MeV → 13 nm

Lasing at 13.7 nm

(August 2006)







average pulse energy ~ 70 μJ

peak pulse energy ~ 170 μJ

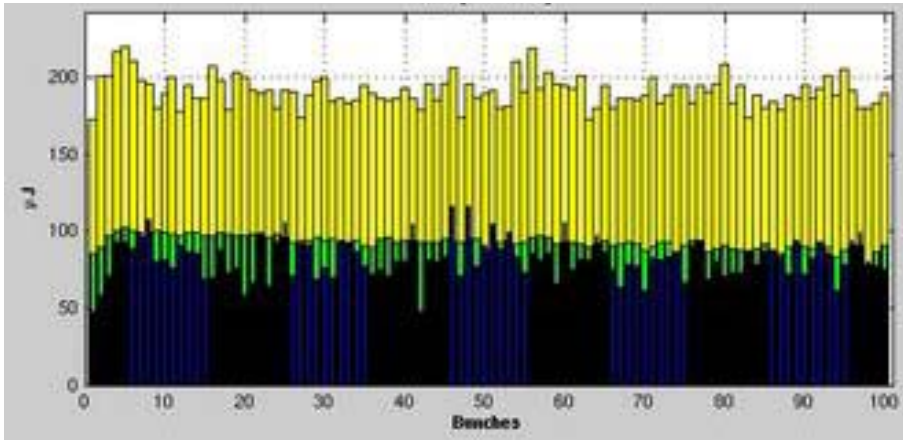
pulse duration ~ 10 fs

divergence ~ diffr. lim. 60 μrad FWHM

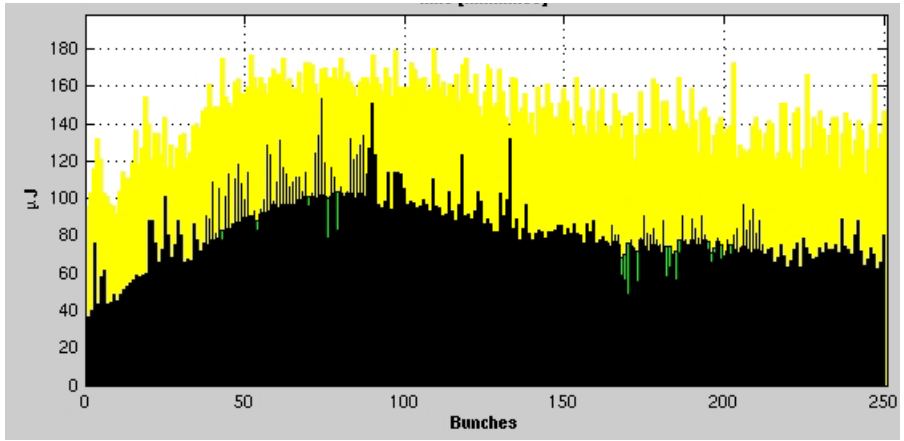
strong odd harmonics (3rd, 5th, 7th)

small even harmonics, ~ circular beam

FLASH performance at 32 nm in Aug06



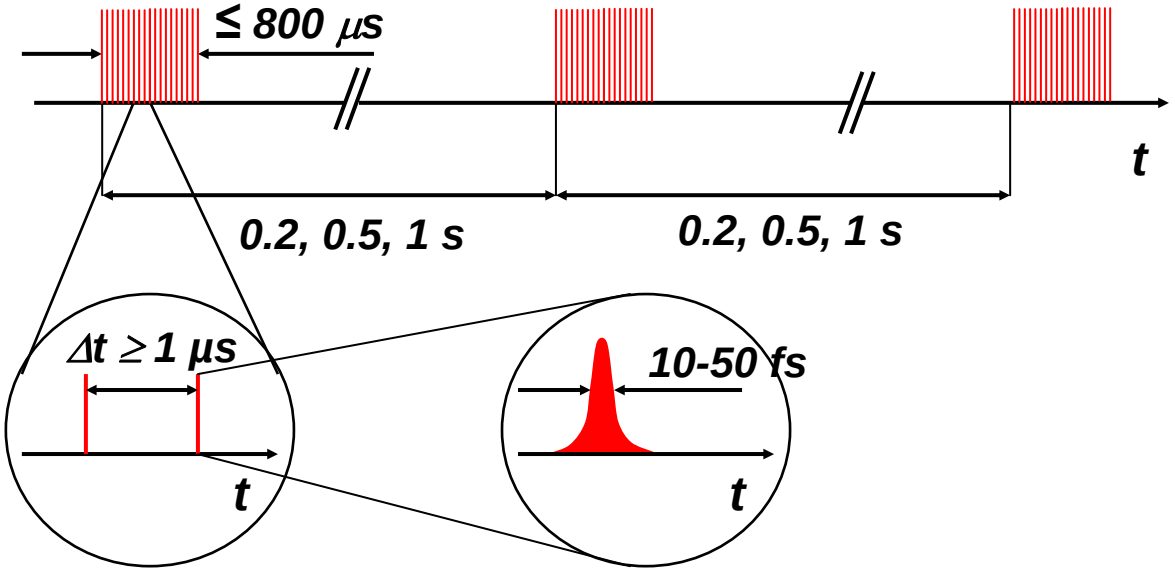
100 pulses lasing with nearly 100 uJ, 5 Hz → 50 mW average power



250 pulses with ~80 uJ average energy, 5 Hz → 100 mW average power

FLASH time structure

FEL bunch trains
up to 800 bunches of 1 nC



- *Pulse train repetition:* *1, 2, 5, (10) Hz*
- *Bunch separation:* *1, 4, 10 μs*
- *Number of bunches:* *1 – N_{max} (≤800 μs)*

1st Round of User Experiments at FLASH

30 proposals submitted in 2002
29 proposals approved in Sept. 2002
200 scientists involved from
60 institutes and
11 countries

Maximise beamtime and efficiency by

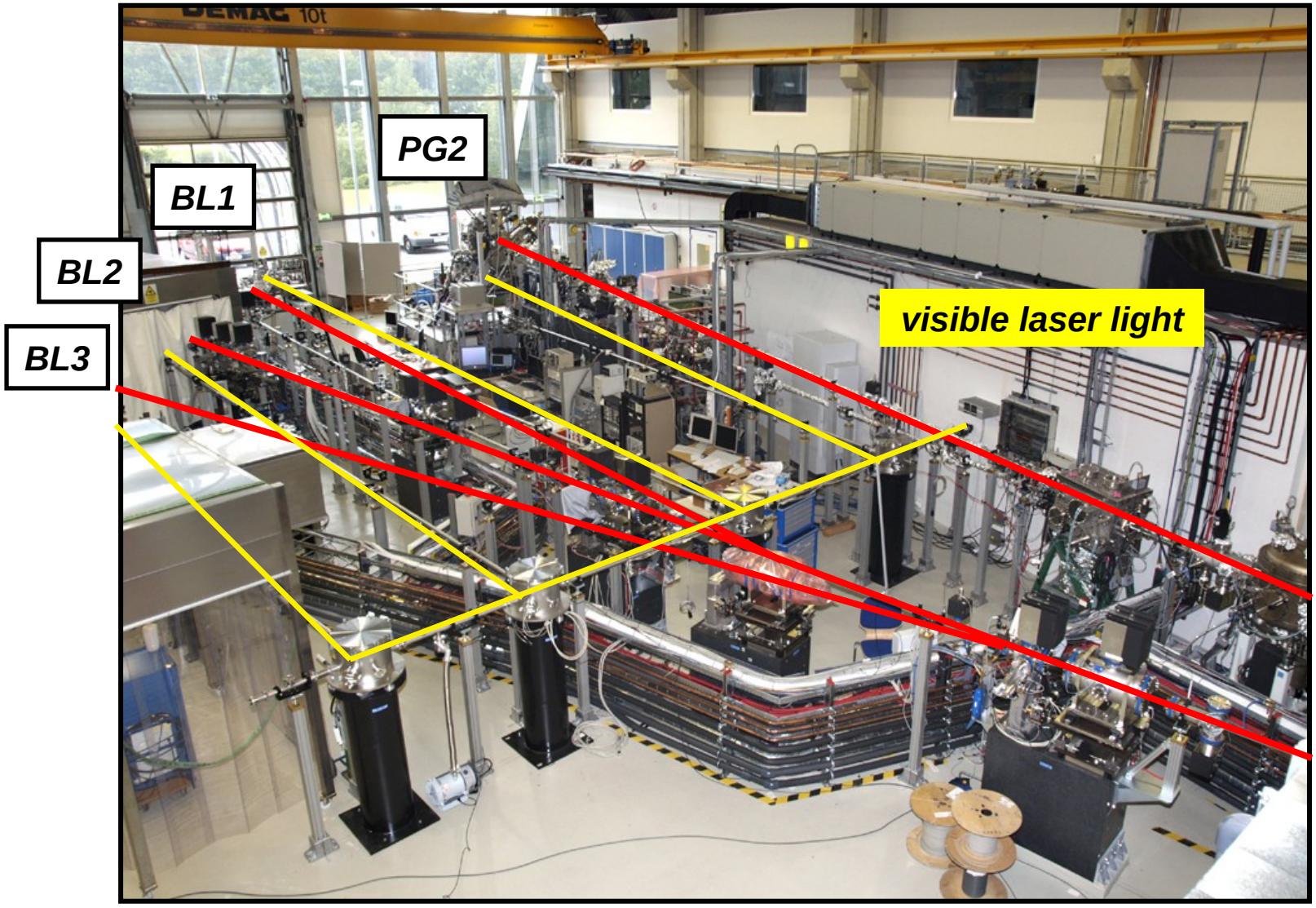
- *Beam switching between different experimental stations*
- *Many groups have formed collaborations*
  (18 projects, 16 are ready and had beam)
- *Some experiments can be combined at one exp. station*
- *Different projects can use the same exp. system*
- *More frequent, short runs; must be well prepared, need support by the facility*

2 beamtime periods from Aug 2005 – Mar 2007

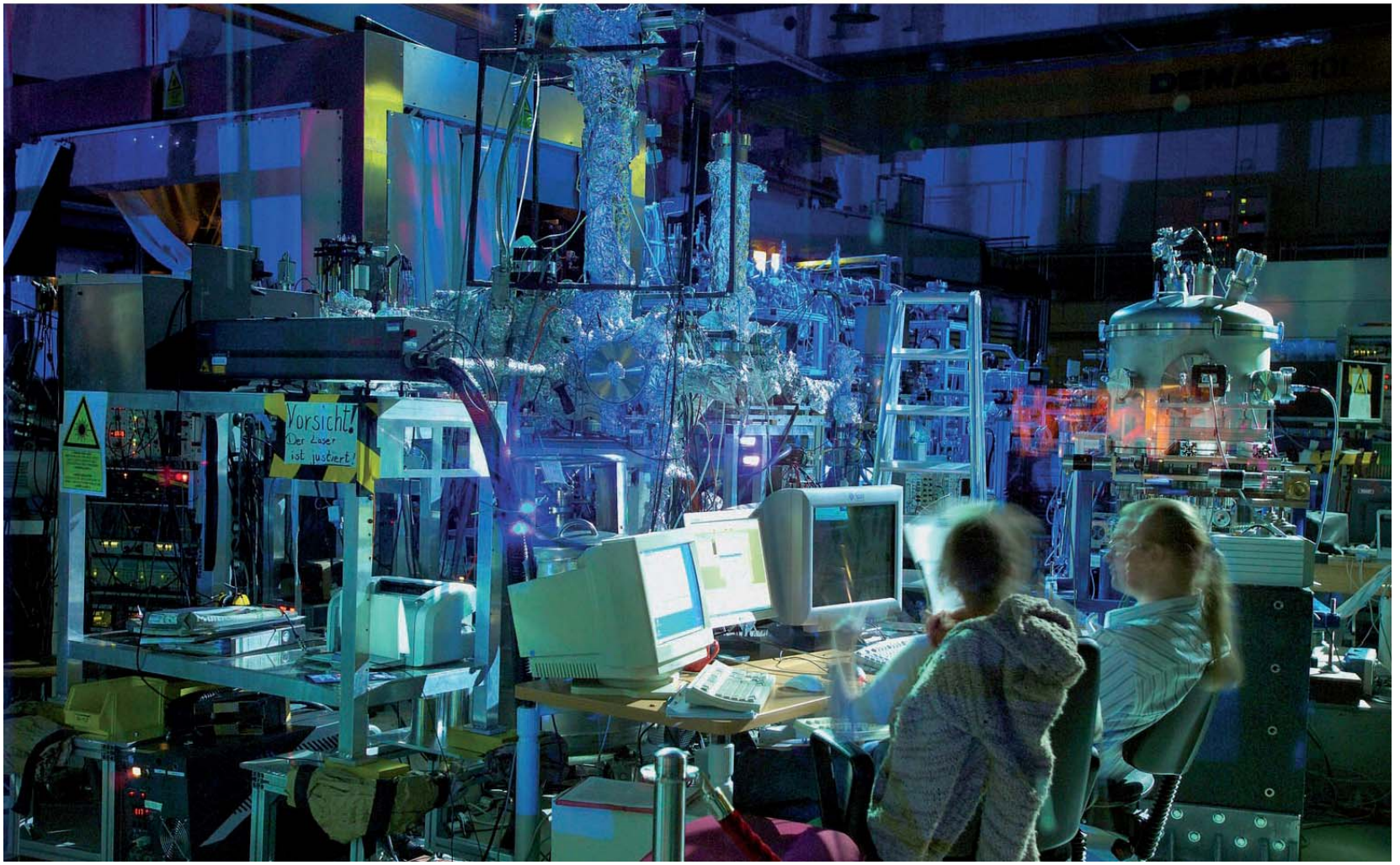
Research Areas

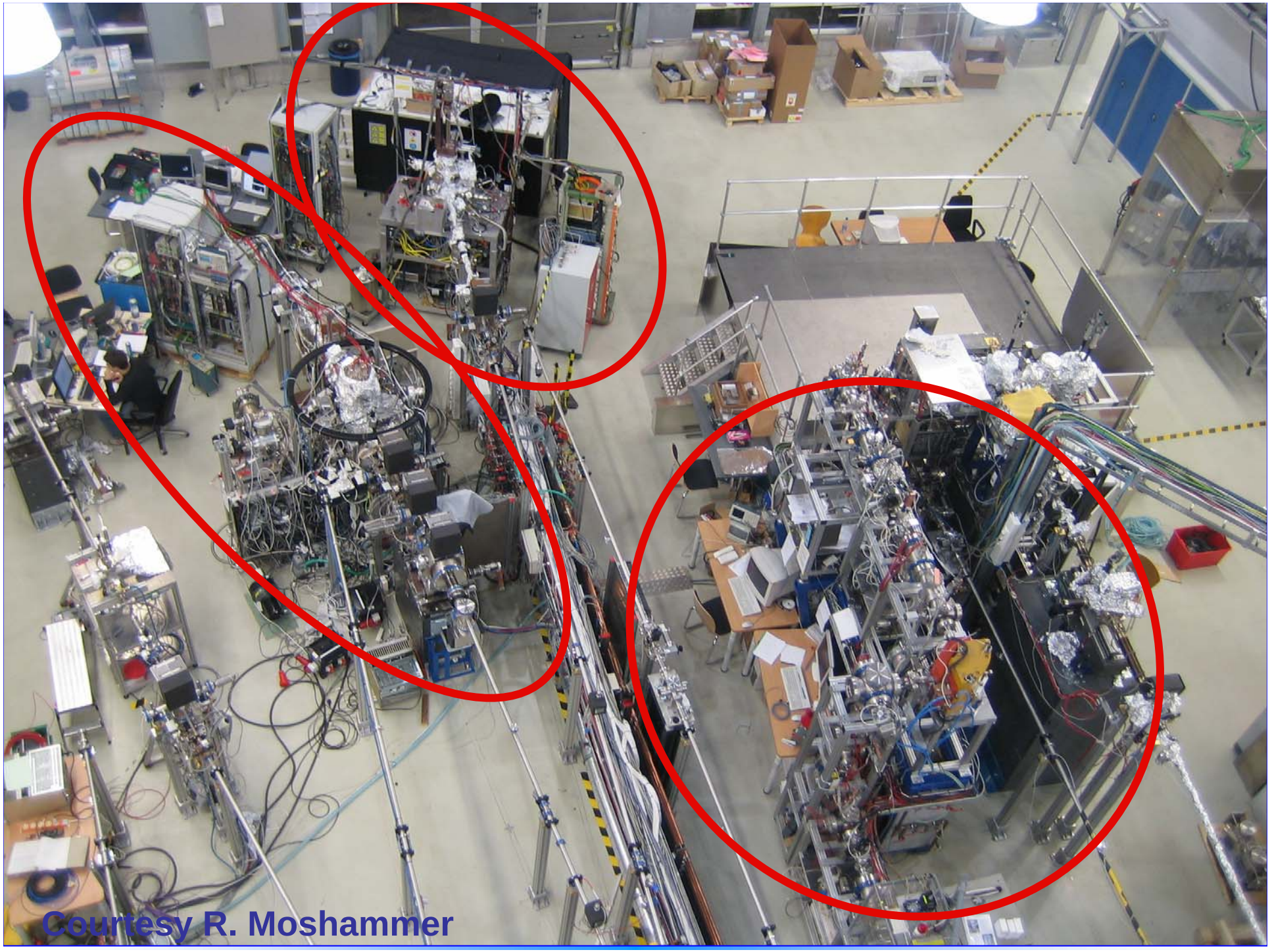
- **Interaction of ultra-intense XUV pulses with matter**
  - multiphoton excitation of atoms, molecules, clusters
  - creation and characterisaton of dense plasmas
  - imaging of biological samples
- **Femtosecond time-resolved experiments**
  - synchronisation FEL - optical laser
  - pump-probe expts. on atoms and molecules
  - sum-frequency generation
- **Investigation of extremely dilute samples**
  - photodissociation of molecular ions
  - highly charged ions
  - mass selected clusters
- **Investigation of surfaces and solids**
  - XUV laser desorption
  - surface dynamics
  - luminescence under FEL radiation
  - meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution

The experimental stations at FLASH

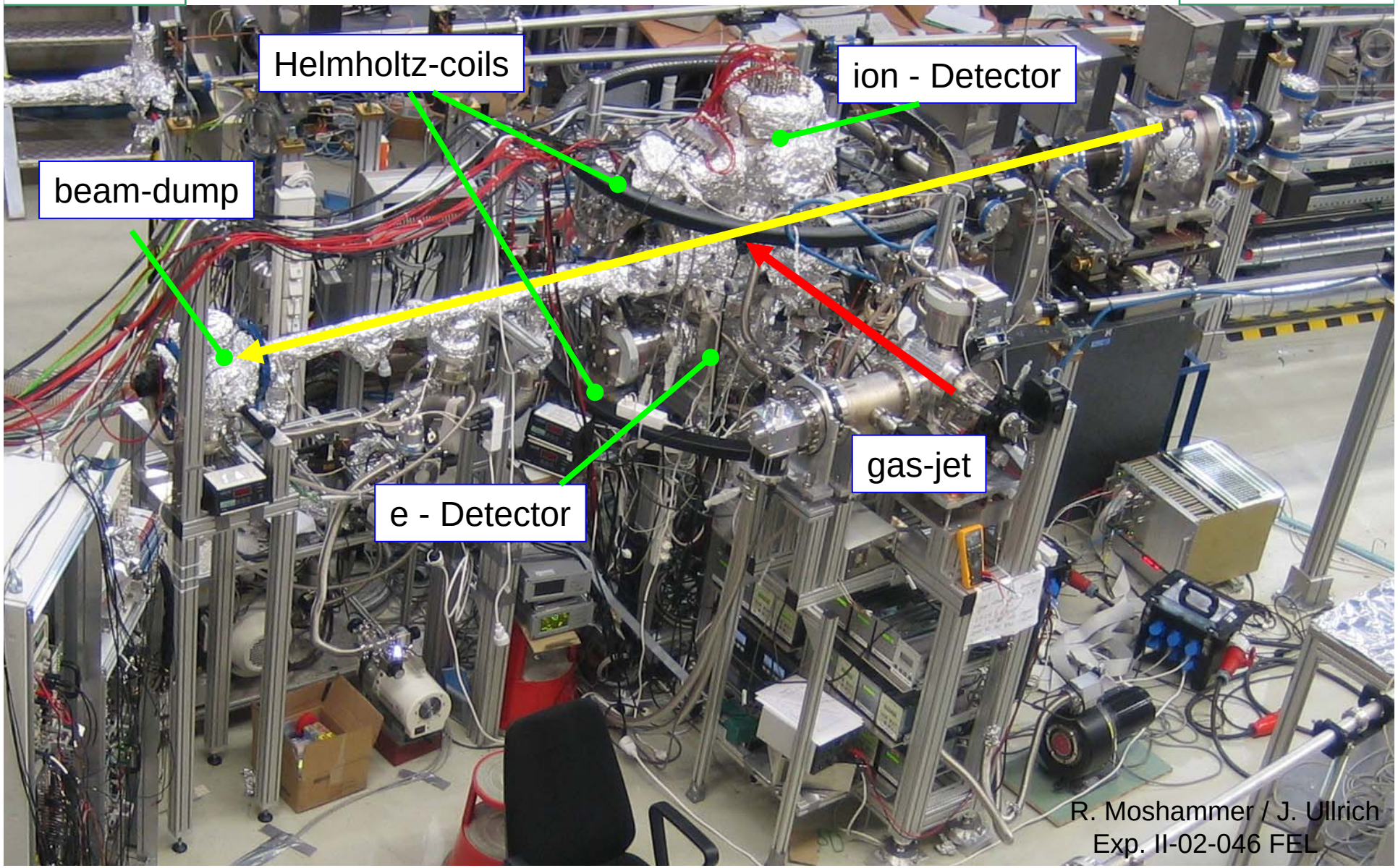


Taking data at night




Courtesy R. Moshammer

The FEL Reaction Microscope



R. Moshammer / J. Ullrich
Exp. II-02-046 FEL

2nd round of user experiments at FLASH

Deutsches Elektronen-Synchrotron
Photon Science

DESY

FLASH, the first free-electron laser built for the vacuum-ultra-violet and soft X-ray region, has started user operation at DESY. Currently the FEL is covering a wavelength range from 13 nm to 50 nm providing typically 150 pulses per second with GW peak power and a pulse duration between 20 and 50 fs.
Within the next two years the facility will provide beams for users with wavelengths from approx. 6.5 to 60 nm with several thousand pulses per second.

Call for Proposals for Experiments at FLASH

Interested researchers and groups are invited to submit proposals for experiments at FLASH starting in summer 2007. They must reach us before October 1, 2006. The evaluation will be based on scientific merit and feasibility at the FLASH user facility. Access is provided free of charge for all non-proprietary research. Detailed information can be found at www-hasylab.desy.de/facility/fel/main.htm.
New users may contact Dr. Josef Feldhaus (phone: +49 40 8998-3901, josef.feldhaus@desy.de) for additional information before preparing a proposal.

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Review on December 4-5, 2006 :

*45 proposals from 9 countries**

- *atoms, ions, molecules and clusters*
- *plasma states, warm dense matter*
- *imaging, diffraction*
- *strong field processes*
- *spectroscopy of bulk solids and surfaces*
- *surface reactions*
- *spin dynamics*
- *diagnostics*
- *methods development*

D	DK	Est	F	NL	P	S	UK	USA
31	1	1	1	1	1	3	3	3

*: Counted are project leader affiliations

2nd Round of User Experiments at FLASH

45 proposals submitted in 2006, 32 proposals approved in Dec. 2006

Beamtime: Jul.(Nov.) 2007 - Dec. 2008, 377 shifts total (38%)

Proposal no	Proposer, Project Leader	Title
II-20060122	Jose Ramon Crespo Lopez-Urrutia	Resonant single- and multi-photon excitation and photoionization of highly charged ions by FEL radiation
II-20060250	Robert Moshammer	Few Photon Multiple Ionization of Atoms and Molecules using a Reaction Microcope
II-20060251	Robert Moshammer	Coulomb-Explosion Imaging of Small Molecules and Pump-Probe Experiments
II-20060259	Reinhard Dörner	Multiple Fragmentation Processes of Molecules and Clusters Probed by Momentum Imaging Spectroscopy
II-20060262	Alexander Dorn	A Lithium Magneto Optical Trap in a Reaction Microscope at FLASH: I. Complete Photo-Fragmentation of Lithium Atoms II. Dynamics of a Strongly Coupled Ultra Cold Plasma
I-20060263	Uwe Hergenhahn	Intermolecular Coulombic decay in doped water clusters
II-20060278 EC	Marc Vrakking	Velocity map imaging of strong field processes
I-20060280 EC	Michael Meyer, John Costello	Two-color photoionization of atoms and molecules
I-20060293	Axel Reinköster, Uwe Becker	Study of multiphoton-ionization processes of free atoms and molecules
II-20060277	Karl-Heinz Meiwes-Broer	Electron Structure and Dynamics in Clusters
II-20060286	Thomas Möller	Ultrafast processes and imaging of clusters
II-20060257	Ivan Vartaniants, Christian Gutt	Characterization and Coherent Scattering Applications of the Femtosecond Pulses at the FLASH Facility
II-20060289	Axel Rosenhahn	Single pulse digital in-line holography with VUV radiation and soft X-rays at FLASH
II-20060264	Stefan Eisebitt	Time Resolved Imaging and Scattering for the Study of Sub-Picosecond Correlations on Nanometer Lengthscales
II-20060270	Henry Chapman	Flash Diffraction Imaging of Biological Samples
II-20060296	Simone Techert	Probing the molecular dynamics of supramolecular assemblies by time-resolved x-ray diffraction in the low q regime
II-20060253	Klaus Sokolowski-Tinten	Transient response of solids to high intensity femtosecond XUV-excitation
II-20060267 EC	David Riley	Probing plasma dynamics using time-resolved spectroscopy
II-20060271	Art Nelson	Creation and characterization of WDM using high intensity XUV radiation
II-20060279 EC	Arne Höll, Gianluca Gregori	Thomson scattering measurements of plasma dynamics
II-20060283 EC	Janos Hajdu, N. Timneanu	X-ray induced Coulomb explosions and nuclear fusion
I-20060254 EC	Andrea Cavalleri	Resonant Soft X-ray Scattering in Complex Oxides with near-2-nm Free Electron Laser Pulses
II-20060258	Kai Rossnagel	Femtosecond Dynamics of Photoinduced Insulator-to-Metal Transitions in Layered Transition-Metal Compounds Probed by Time- and Momentum-Resolved Photoemission
I-20060269	Marco Rutkowski, Helmut Zacharias	Investigation of highly excited surface reactions
II-20060276	Alexander Föhlisch	Non-equilibrium dynamics and low energy excitations in complex systems
II-20060285	Hermann Dürr	Femtosecond electron and spin dynamics in functional materials
II-20060108	Michael Martins	Multi-photon processes in soft X-ray regime
II-20060292	Mathias Richter	Quantitative gas-phase experiments for FEL photon diagnostics at high photon energies and smal spot size
II-20060261	Lutz Kipp	VUV-FEL Nanospectroscopy
I-20060266	Marco Rutkowski, Helmut Zacharias	Evaluation of FEL pulse duration by non-linear autocorrelation in atoms and molecules
II-20060268	Michael Rübhausen	Light Scattering at the FEL
II-20060272	Markus Drescher	Pump-probe experiments exploiting FLASH's intrinsic temporal resolution

Collaboration

Collaboration

Collaboration

Atoms, Molecules, Ions

Clusters

Imaging, Diffraction

Plasma/Warm dense matter

Solids, Surfaces

Methods/Technology

Prelim. beamtime schedule 2007/8

July	27	2.Jul - 8.Jul	7	Commissioning	rf gun commissioning starts	
	28	9.Jul - 15.Jul	7		coupler warm conditioned	School holidays HH
	29	16.Jul - 22.Jul	7			School holidays HH/SH
	30	23.Jul - 29.Jul	7		cool down starts	School holidays HH/SH
August	31	30.Jul - 5.Aug	7		machine cold	School holidays HH/SH
	32	6.Aug - 12.Aug	7			School holidays HH/SH
	33	13.Aug - 19.Aug	2		beam up to dump	School holidays HH/SH
	34	20.Aug - 26.Aug	2		SASE 6 nm	School holidays HH/SH
Septembe	35	27.Aug - 2.Sep	2		SASE 6 nm	FEL 2007
	36	3.Sep - 9.Sep	4	Accelerator studies		
	37	10.Sep - 16.Sep	4			
	38	17.Sep - 23.Sep	4			
	39	24.Sep - 30.Sep	4			
October	40	1.Oct - 7.Oct	2	FEL studies		Dt Einheit 3-Oct
	41	8.Oct - 14.Oct	2			
	42	15.Oct - 21.Oct	2			School holidays HH/SH
	43	22.Oct - 28.Oct	2		SASE	School holidays HH/SH
November	44	29.Oct - 4.Nov	2		SASE	
	45	5.Nov - 11.Nov	2		SASE	
	46	12.Nov - 18.Nov	3		preparation user run	
	47	19.Nov - 25.Nov	1	User Run		
December	48	26.Nov - 2.Dec	1			
	49	3.Dec - 9.Dec	1			
	50	10.Dec - 16.Dec	1			
	51	17.Dec - 23.Dec	1			School holidays HH
	52	24.Dec - 30.Dec	5	Maintenance		School holidays HH/SH
January	1	31.Dec - 6.Jan	5			School holidays HH/SH

Prelim. beamtime schedule 2007/8 contd.

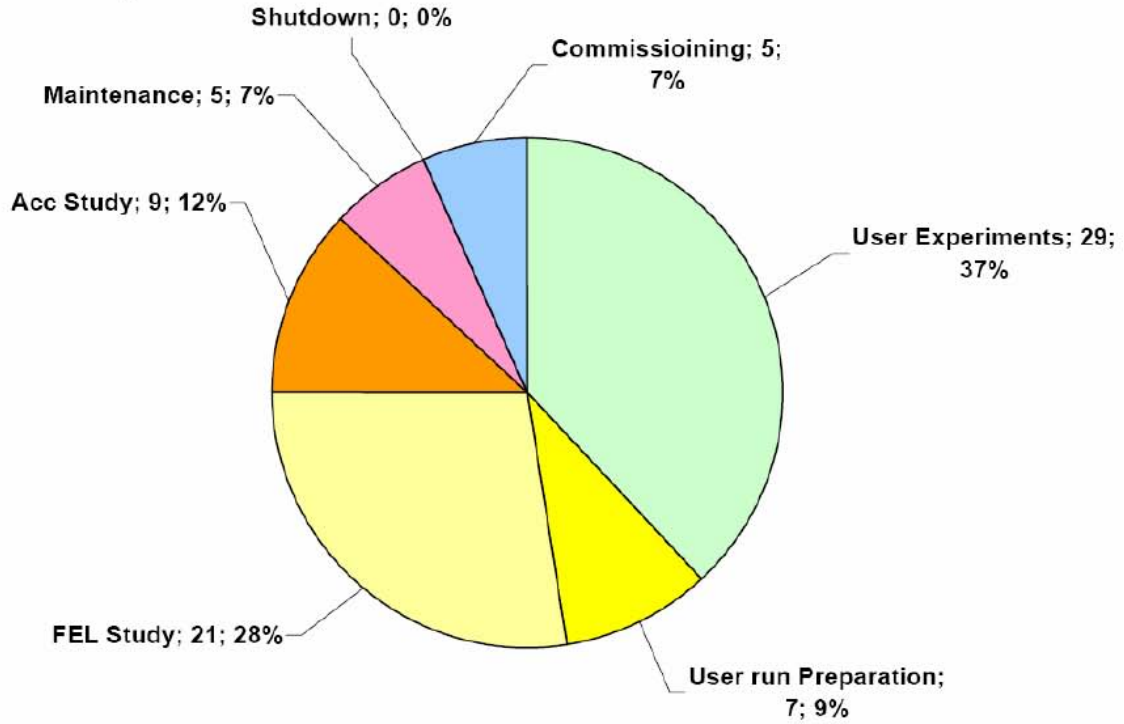
January	1	31.Dec - 6.Jan	5			School holidays HH/SH
2008	2	7.Jan - 13.Jan	4	Accelerator studies		
	3	14.Jan - 20.Jan	4			
	4	21.Jan - 27.Jan	2	FEL studies		
February	5	28.Jan - 3.Feb	2			
	6	4.Feb - 10.Feb	3		preparation user run	
	7	11.Feb - 17.Feb	1	User Run		
	8	18.Feb - 24.Feb	1			
	9	25.Feb - 2.Mar	1			
March	10	3.Mar - 9.Mar	1			
	11	10.Mar - 16.Mar	2	FEL studies		School holidays HH
	12	17.Mar - 23.Mar	2			School holidays HH/SH
	13	24.Mar - 3.Jan	3		preparation user run	astern 23/24-Mar / school holidays S
April	14	31.Mar - 6.Apr	1	User Run		School holidays SH
	15	7.Apr - 13.Apr	1			
	16	14.Apr - 20.Apr	1			
	17	21.Apr - 27.Apr	1			
May	18	28.Apr - 4.May	5	Maintenance	PETRA III installation	Labor Day/Ascension 1-May
	19	5.May - 11.May	5			
	20	12.May - 18.May	5			Pentecost 11/12-May/ School holidays
	21	19.May - 25.May	2	FEL studies		
June	22	26.May - 1.Jun	2			
	23	2.Jun - 8.Jun	3		preparation user run	
	24	9.Jun - 15.Jun	1	User Run		
	25	16.Jun - 22.Jun	1			
	26	23.Jun - 29.Jun	1			
July	27	30.Jun - 6.Jul	1			
	28	7.Jul - 13.Jul	2	Shutdown		
	29	14.Jul - 20.Jul	2			School holidays HH
	30	21.Jul - 27.Jul	3		preparation user run	School holidays HH/SH
August	31	28.Jul - 3.Aug	1	User Run		School holidays HH/SH
	32	4.Aug - 10.Aug	1			School holidays HH/SH
	33	11.Aug - 17.Aug	1			School holidays HH/SH
	34	18.Aug - 24.Aug	1			School holidays HH/SH
	35	25.Aug - 31.Aug	4	Accelerator studies		School holidays HH/SH
Septembe	36	1.Sep - 7.Sep	4			
	37	8.Sep - 14.Sep	4			
	38	15.Sep - 21.Sep	2	User Run		
	39	22.Sep - 28.Sep	2			
October	40	29.Sep - 5.Oct	3		preparation user run	Dt Einheit 3-Oct
	41	6.Oct - 12.Oct	1	User Run		
	42	13.Oct - 19.Oct	1			School holidays HH/SH
	43	20.Oct - 26.Oct	1			School holidays HH/SH
November	44	27.Oct - 2.Nov	1			
	45	3.Nov - 9.Nov	2	User Run		
	46	10.Nov - 16.Nov	2			
	47	17.Nov - 23.Nov	3		preparation user run	
	48	24.Nov - 30.Nov	1	User Run		
December	49	1.Dec - 7.Dec	1			
	50	8.Dec - 14.Dec	1			
	51	15.Dec - 21.Dec	1			
	52	22.Dec - 28.Dec	6	Shutdown	Installation 3rd harmonic etc	School holidays HH/SH
January	1	29.Dec - 4.Jan	6			School holidays HH/SH
2009	2	5.Jan - 11.Jan	6			School holidays SH

Beamtime distribution 2007/8

Distribution 3rd period KW 27 2007 to KW 51 2008

total weeks	76		nb shifts	
User Experiments	29	38%	377	2 shifts/day
User run Preparation	7	9%	140	3 shifts/day
FEL Study	21	28%	420	3 shifts/day
Acc Study	9	12%	180	3 shifts/day
Maintenance	5	7%	176	3 shifts/day·
Shutdown	0	0%	0	3 shifts/day
Commissioining	5	7%	100	3 shifts/day
sum	76	100%		

shutdown excluded



User requirements

- **There are many user groups with a broad range of applications exploiting key FEL features:**
  - **broad, continuous wavelength range**
  - **pulse duration (sub-fs to few 100 fs)**
  - **high repetition rate**
  - **variable polarisation**
  - **combination of different sources etc.**

- **Solutions:**
  - **several FEL undulators per linac**
  - **permanent experimental stations for complex experiments**
  - **some stations for experiments with faster turn around**
  - **fast beam (e^- and phot.) switching for quasi-parallel operation**
  - **SRF linac with high repetition rate or CW operation**
  - **European network of FEL facilities**

Challenges

- **There are many technical challenges**
  - **fast, stable, reproducible beam distribution**
  - **fast wavelength change**
  - **stable combination with optical lasers**
  - **single-shot online photon diagnostics**
  - **CW operation: gun, bunch compression**
  - **…**

FLASH operation costs: ~12 M€ per year
i.e. currently ~3k€ per hour, i.e.
<1€ per 1000 pulses
in the future: < 1 ct per 1000 pulses

The European Research Area

- How many users are there in Europe?
- How many facilities are needed with what features?
- How best organise this in Europe?

Approach:
IRUVX-FEL consortium

IRUVX-FEL

Apr 2006	IRUVX-FEL proposal to ESFRI as: A European Consortium for FELs up to the UV/softXray
Sep 2006	accepted as one of the 35 ESFRI Roadmap 2006 Projects
Consortium:	the five new infrared to soft X-ray accelerator driven FELs in Europe: BESSY FEL, FERMI (ELETTRA), FLASH (DESY), MAX IV (MAX-lab), 4GLS (STFC)
MOU:	signed in Dec 2006, open to others

- to set-up a joint initiative to specify a legal framework for cooperation
- to evolve complementarity in beamlines & experiments of European FELs
- to set-up joint Scientific Advisory Boards
- to develop joint recruitment of human resources

IRUVX-PPreparatoryPPhase

FP7 : **Capacities - Research Infrastrutures Call 22. Dec 2006**
Construction – Support to the Preparatory Phase

submitted: **2. May 2007**

Participants: 5 FEL facilities (MoU signatories), Funding Agencies,…..

Budget: up to 7 M€

Period: 3 years, 2008 - 2011

Coordinator: DESY (J. Feldhaus, U. Krell)

Work packages:

WP1:	Construction of the consortium	(lead. Partner: Elettra)
WP2:	User needs and policies	(BESSY)
WP3:	Coordination and Consolidation of Joint Technical Developments	(STFC)
WP4:	Development of Human Resources	(MAX-Lab)
WP5:	Communication and Dissemination	(DESY)
WP6:	Collaborations with other Research Infrastructures and Industry	(STFC)
WP7:	Technical work on photon beamlines and expts.	(DESY)
WP8:	Technical work on FEL source	(Elettra)

Concluding remarks

- Exciting new developments on sources and applications
- It is difficult to combine R&D with a user facility
- Linac driven FELs must be user facilities
- They must be supported by local user communities and open for other users
- Alternative: small, cheap sources for everybody
  (in the near future only top groups have a chance to work on FELs)
- The user experiments will (must) drive the technical developments
- Various networks develop and use new radiation sources:
  How to organize efficient interaction?
- This is only the beginning …