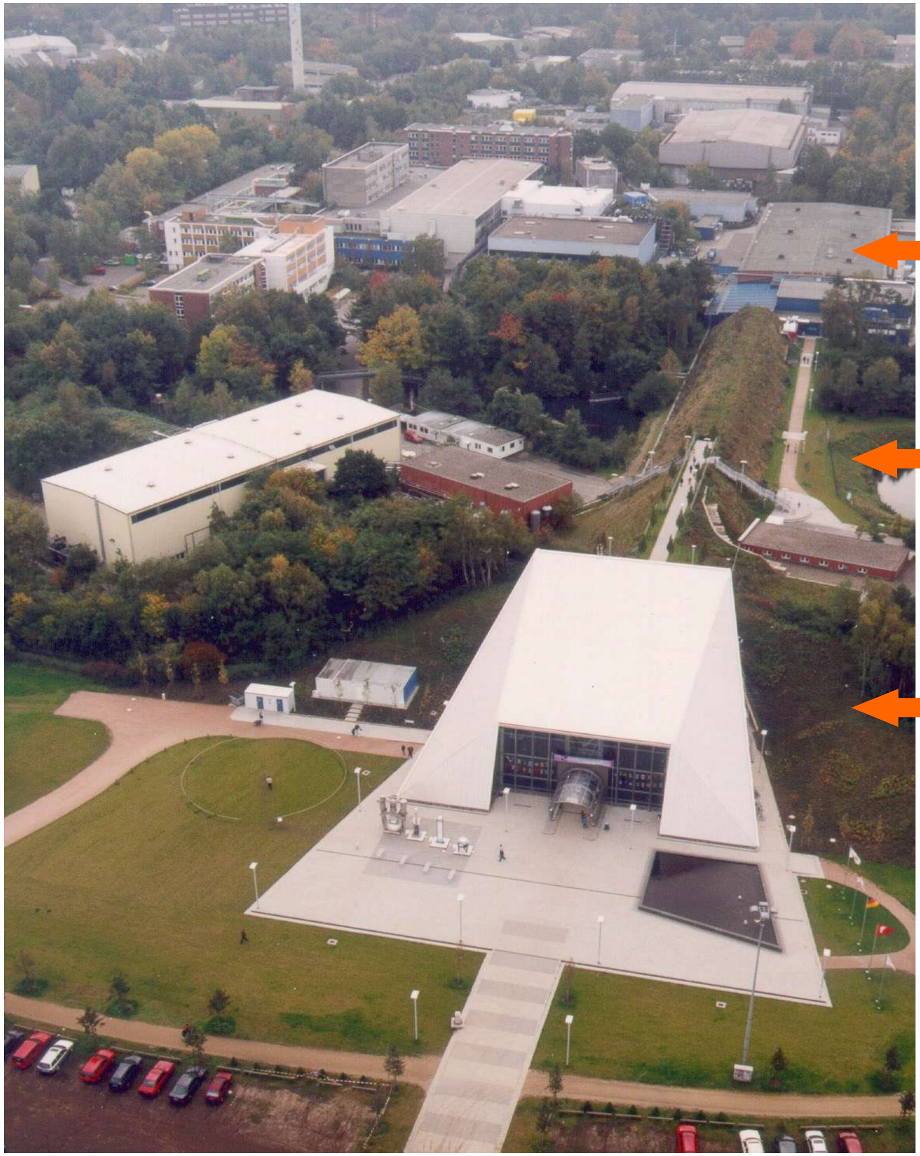
First User Experiments at the VUV-FEL at DESY

Josef Feldhaus

- **Overview of the facility**
- **Status and characteristics of the VUV-FEL**
- **First user experiments: overview and some examples**

The VUV-FEL at DESY

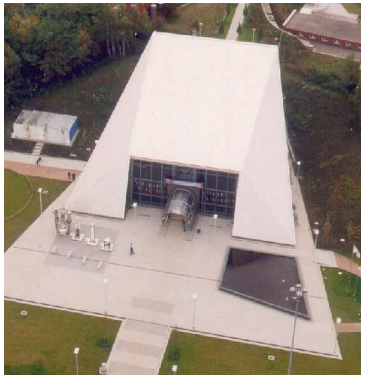


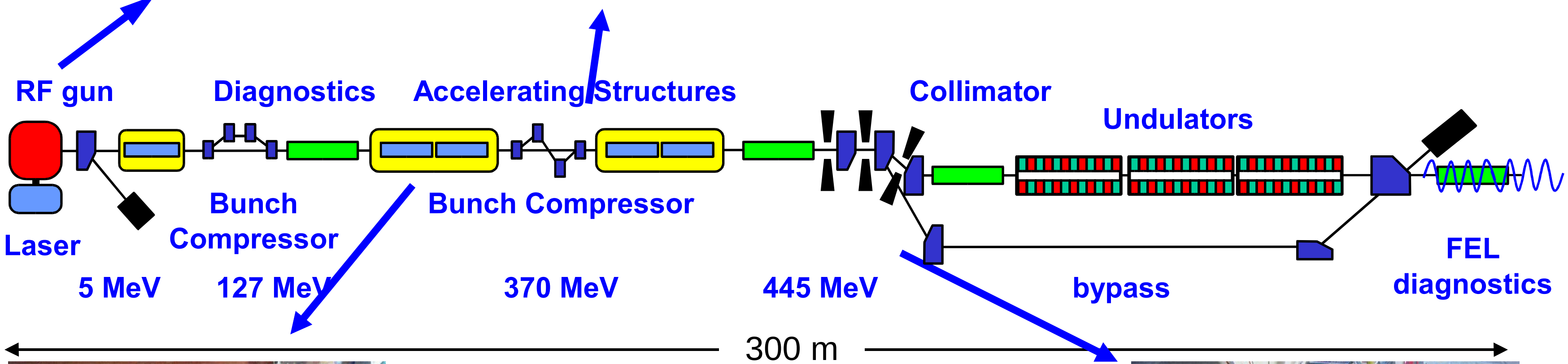
TESLA Test Facility (TTF 1, 1995-2002)

TTF 2

experimental hall

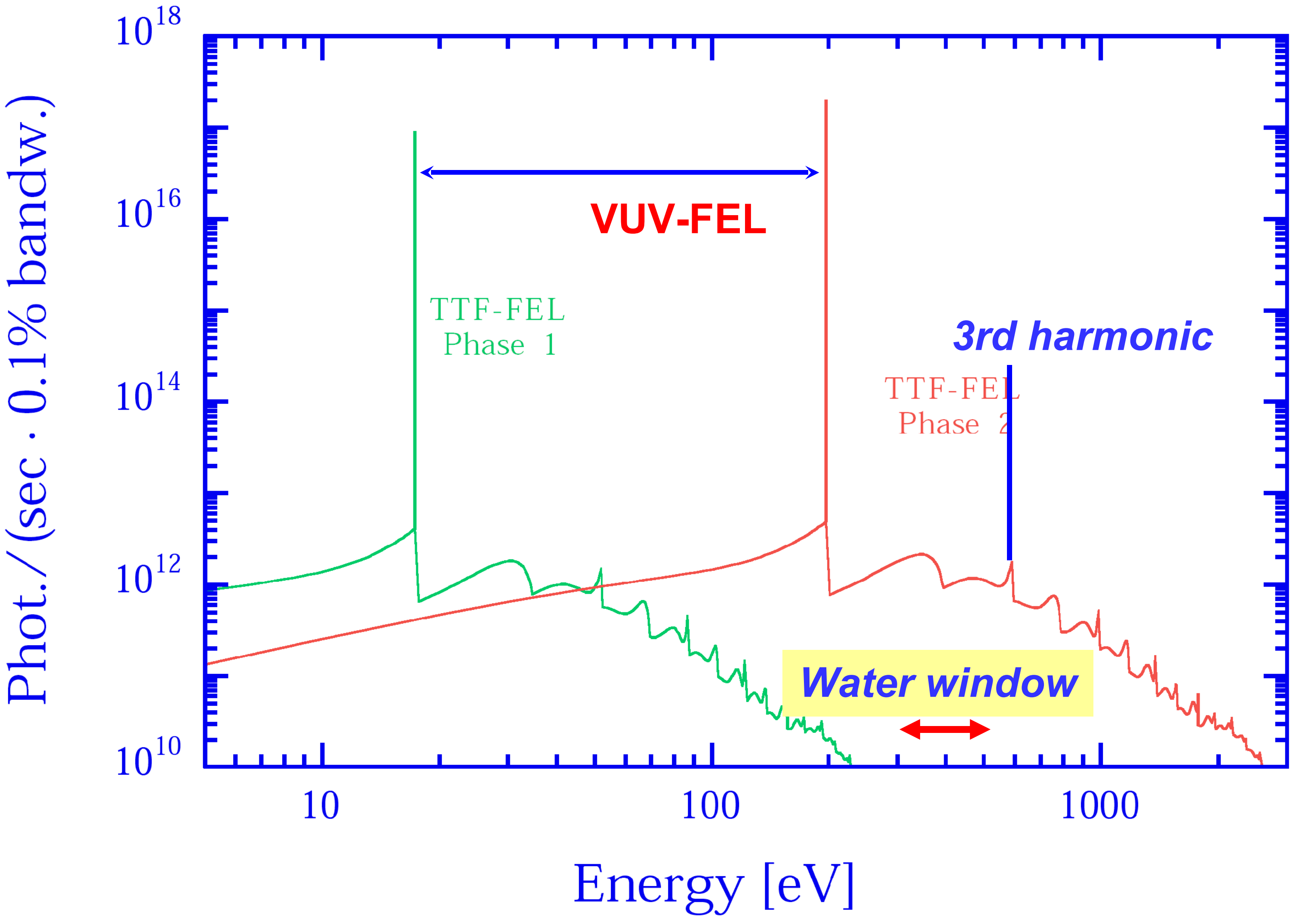
VUV-FEL Overview





- **30.08.2004: tunnel closed for commissioning**
- **Jan 2005: first lasing at 32 nm**
- **Aug 2005: first user exper.**

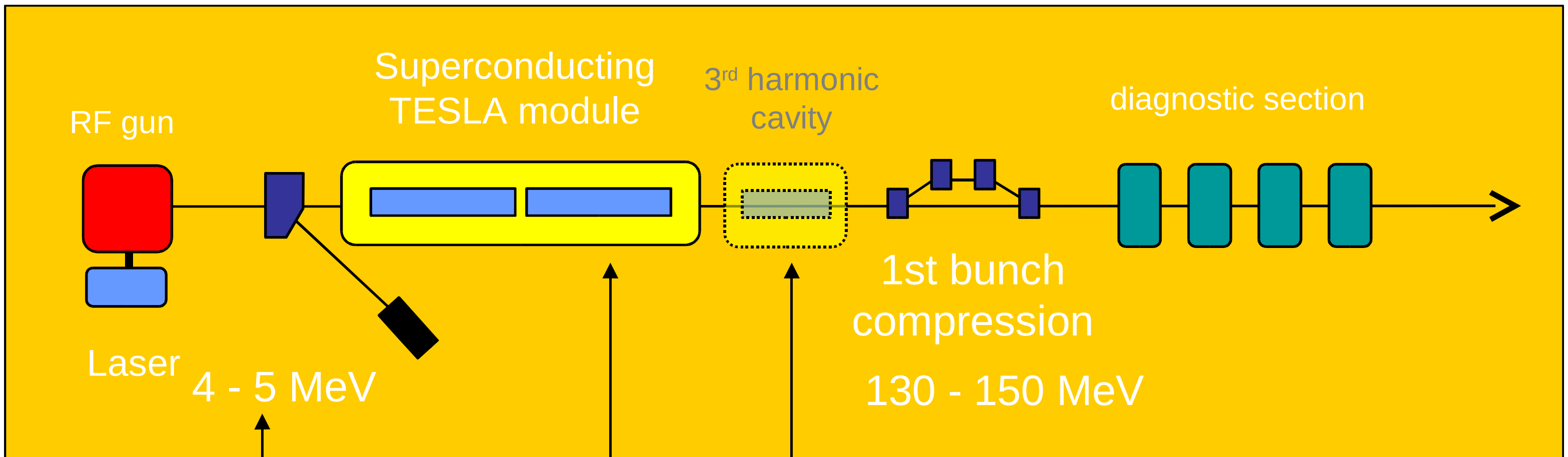
Angle-integrated flux



Start-up 2004/5

2004 March-June	injector commissioning
2004 June-August	final installations in the tunnel
2004 September	start commissioning of entire machine 5 accelerator modules → 800 MeV → ~10 nm
22.12.2004	first electron beam through undulator
14.01.2005	first lasing at 32 nm, single bunches, 2 Hz
30.06.2005	~30 µJ pulse energy at 32 nm, close to sat.
June-Aug. 2005	commissioning of photon beamlines
end of July 2005	first experiments, start of user operation

Producing high peak current

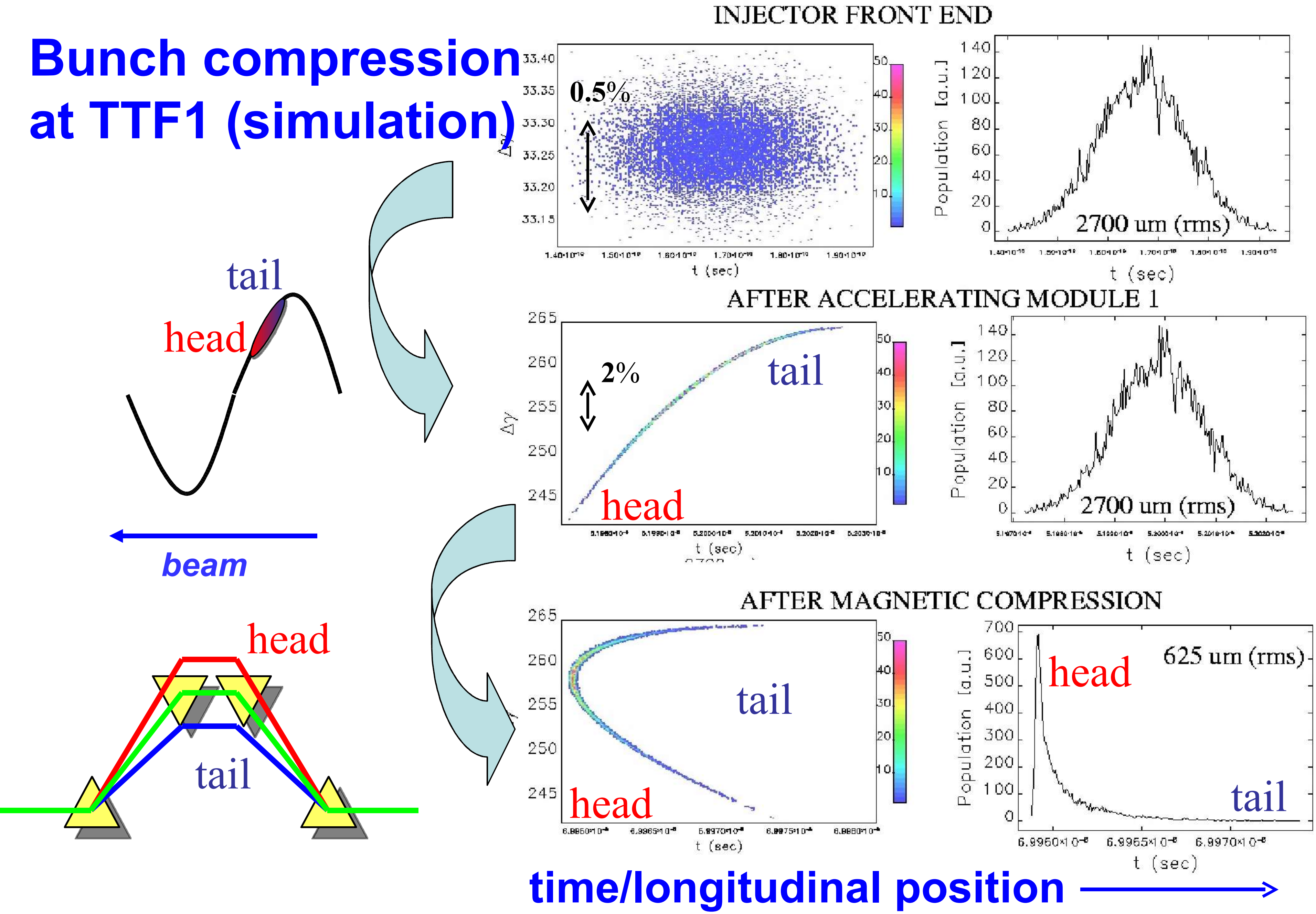


Space charge forces prevent high peak current at low energy

3rd harmonic cavity corrrects non-linear energy chirp

Off-crest operation introduces energy chirp for bunch compression

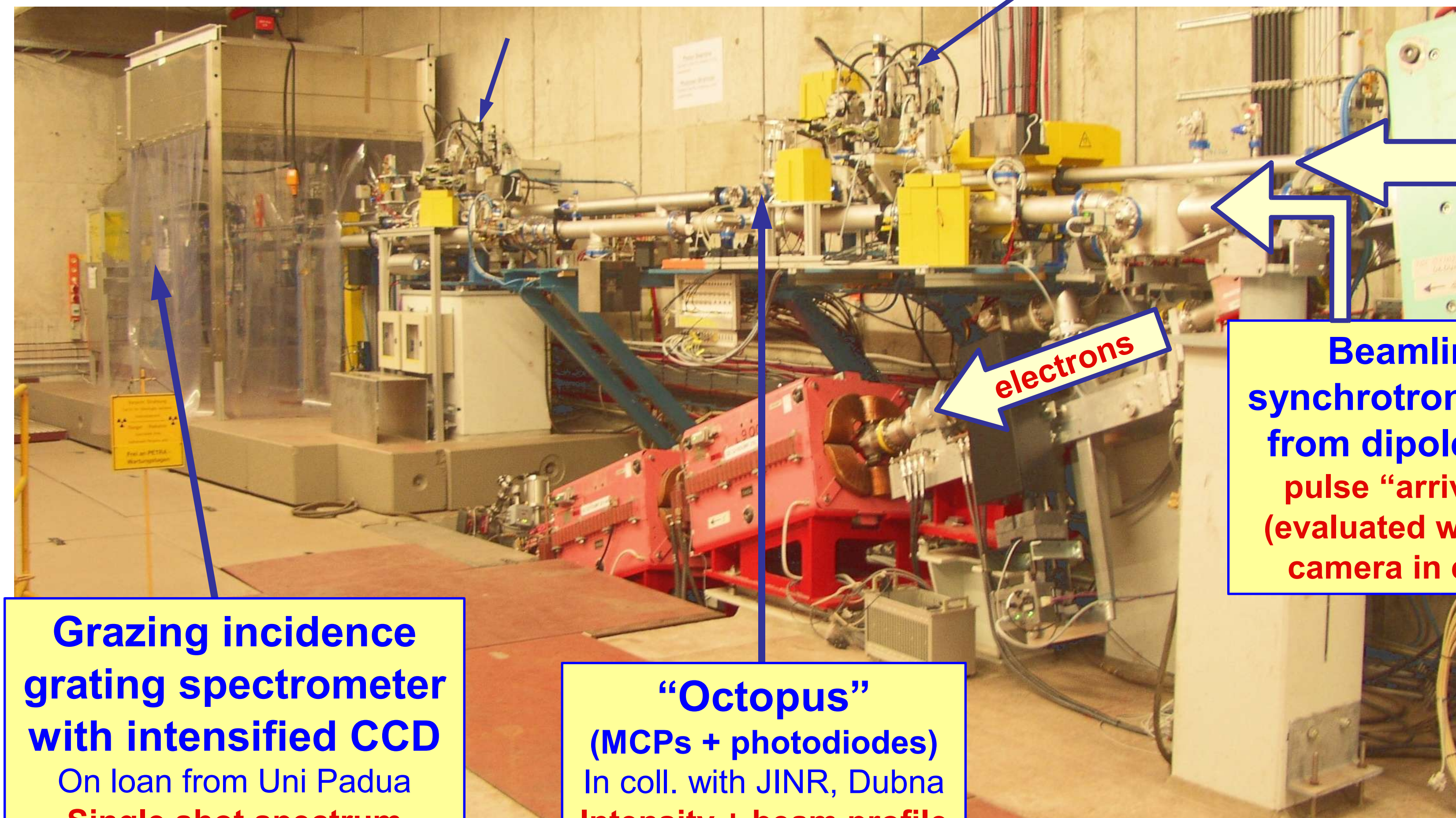
Bunch compression at TTF1 (simulation)



Photon diagnostics for FEL commissioning

Detector Unit F2
(apertures, detectors, mirror)
Intensity + beam profile
+ diffraction (coherence)
+deflection into spectrometer

Detector Unit F1
(apertures + detectors)
Intensity + beam profile
+ double slits (coherence)



Beamline for synchrotron radiation from dipole magnet
pulse “arrival time”
(evaluated with streak camera in exp. hall)

Grazing incidence grating spectrometer with intensified CCD
On loan from Uni Padua
Single shot spectrum

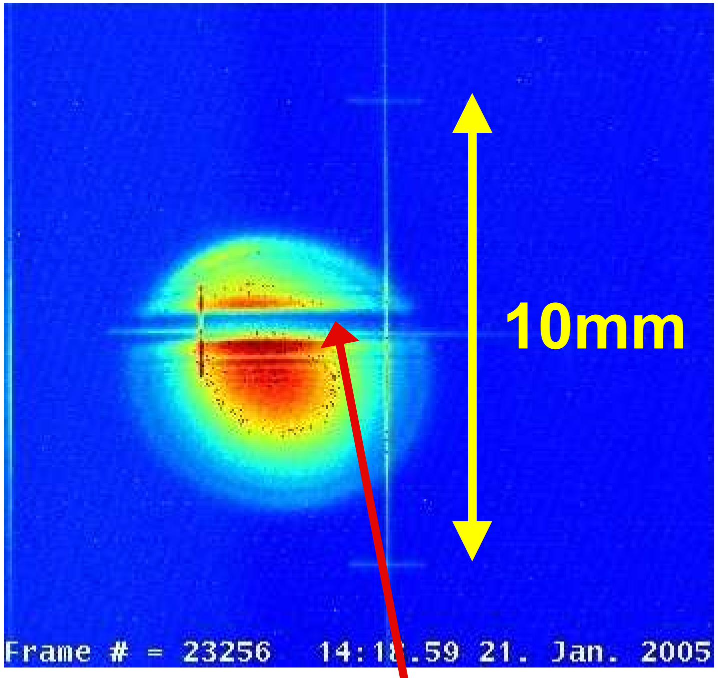
“Octopus”
(MCPs + photodiodes)
In coll. with JINR, Dubna
Intensity + beam profile

First Lasing at 32 nm

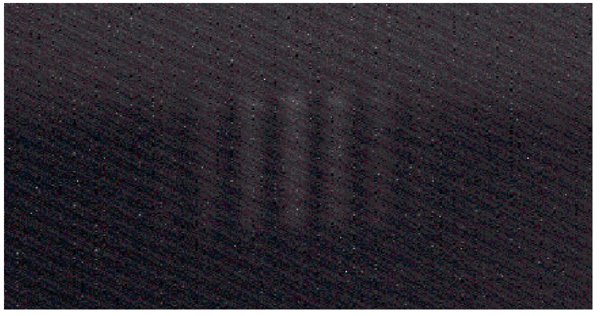
achieved on January 14, 2005

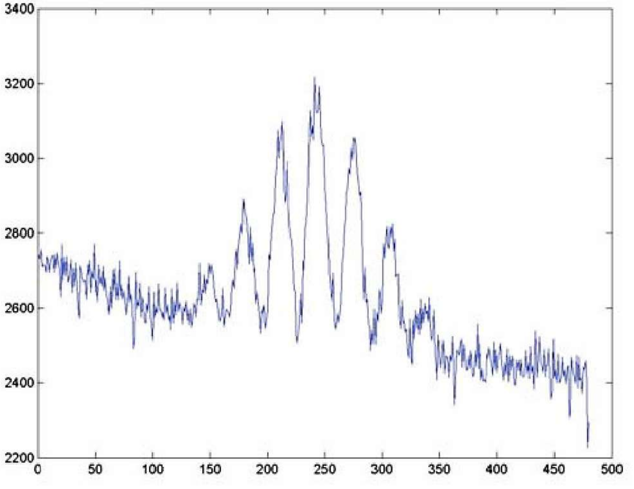
FEL beam on a Ce:YAG crystal 20 m behind the undulator (10 pulses)

Single shot diffraction image of a double slit (30µm wide, 150 µm apart)

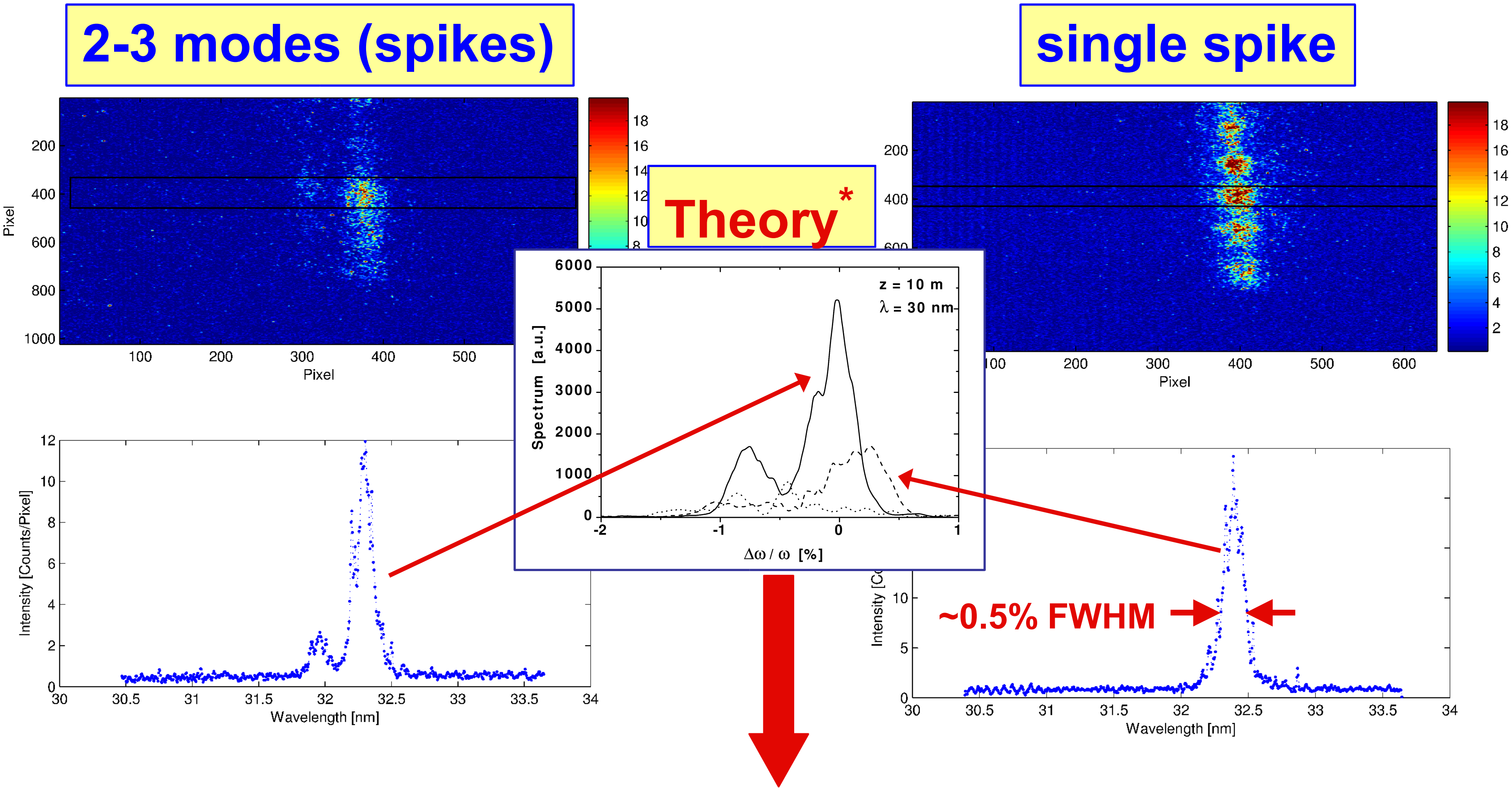


shadow of wire from MCP intensity monitor



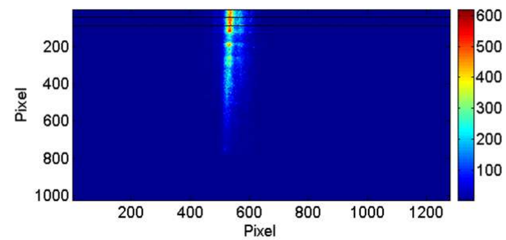


Single-Shot Spectra at 32 nm

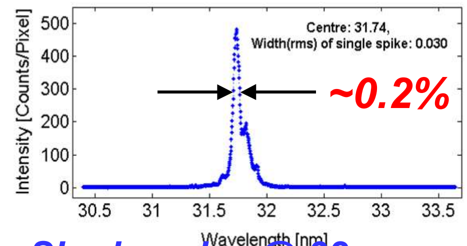


about 20 fs pulse duration

First spectra of FEL harmonics



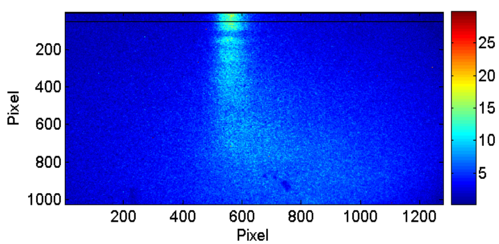
~10 µJ pulse energy

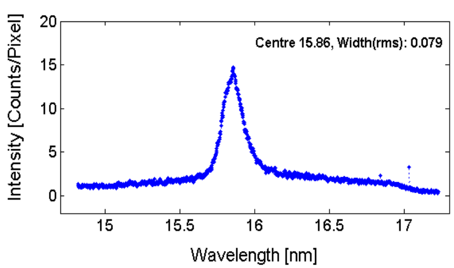


→ ~45 fs pulse duration

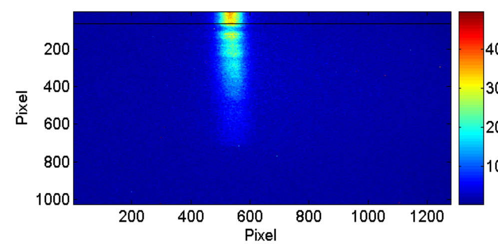
Single pulse @ 32 nm

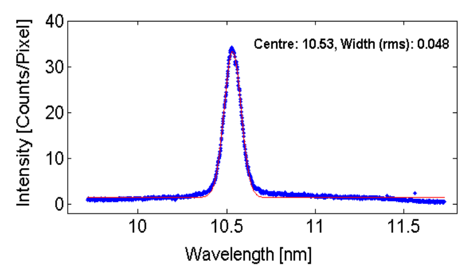
June 2005





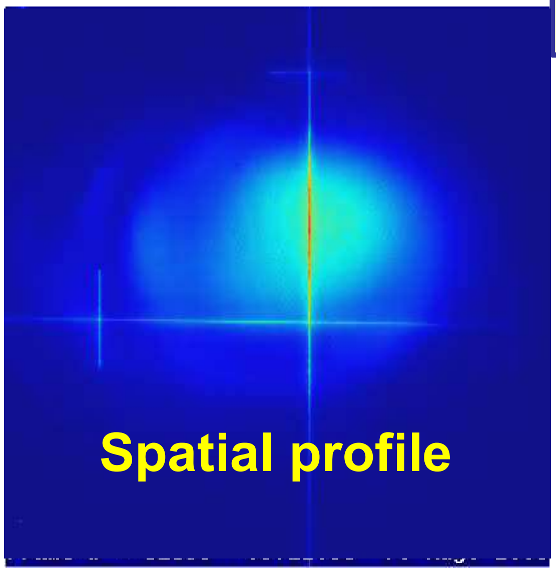
2nd harmonic @ 16 nm
4000 pulses



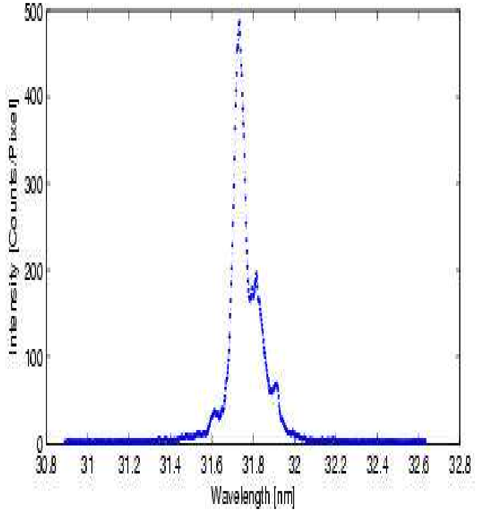


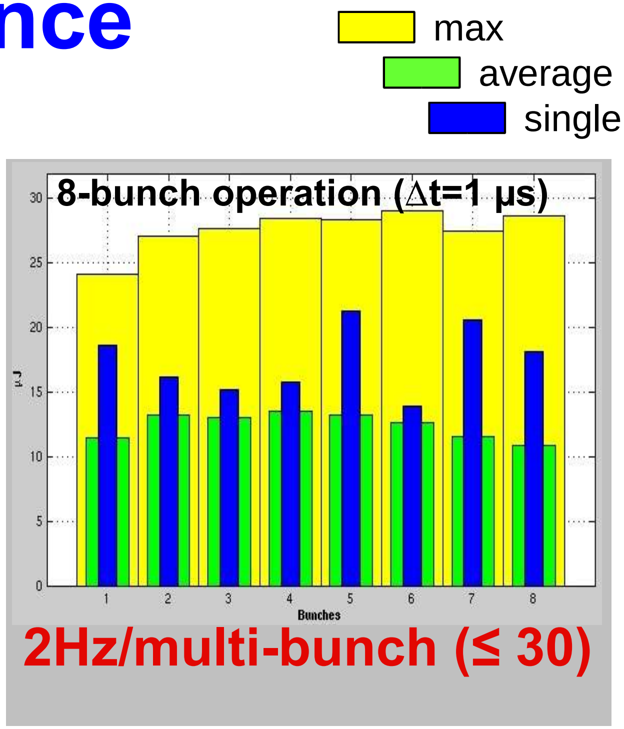
3rd harmonics @ 10.5 nm
4000 pulses

VUV-FEL performance



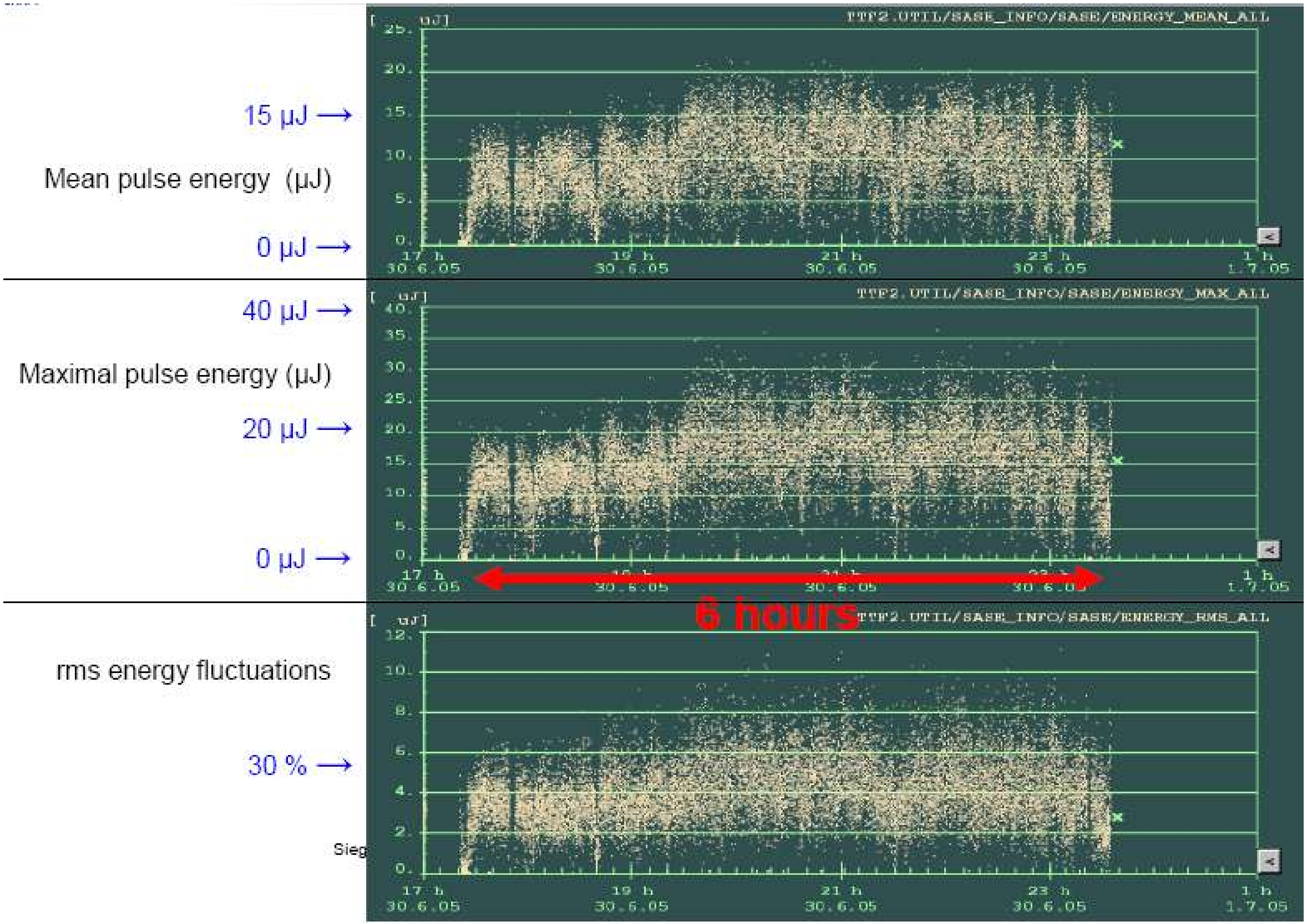
Spectral distribution





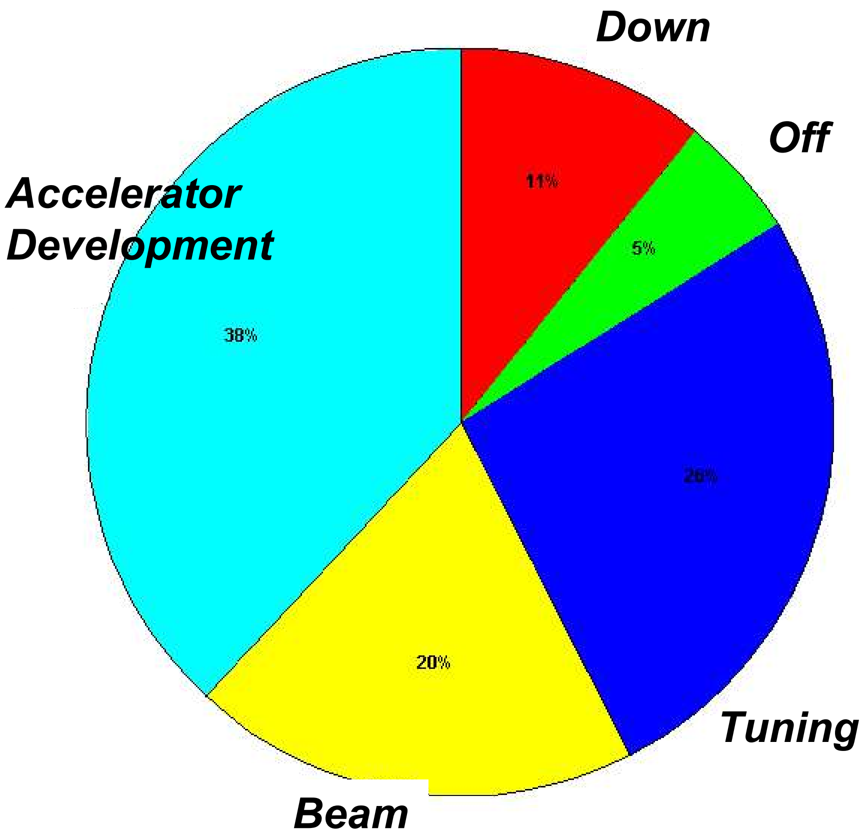
Parameter	Expected (08.04)	Measured
Wavelength	30 nm	**32 nm** (27, 45 nm at lower int.)
Pulse duration	15-50 fs	20-40 fs
Pulse energy	50-150 μJ	up to 130 μJ (mostly 5-10 μJ)
	at saturation	onset of nonlinear regime
Bandwidth	0.8%	0.5-1.0%
Divergence	70-80 μrad	< 150 μrad

Example of a good SASE run

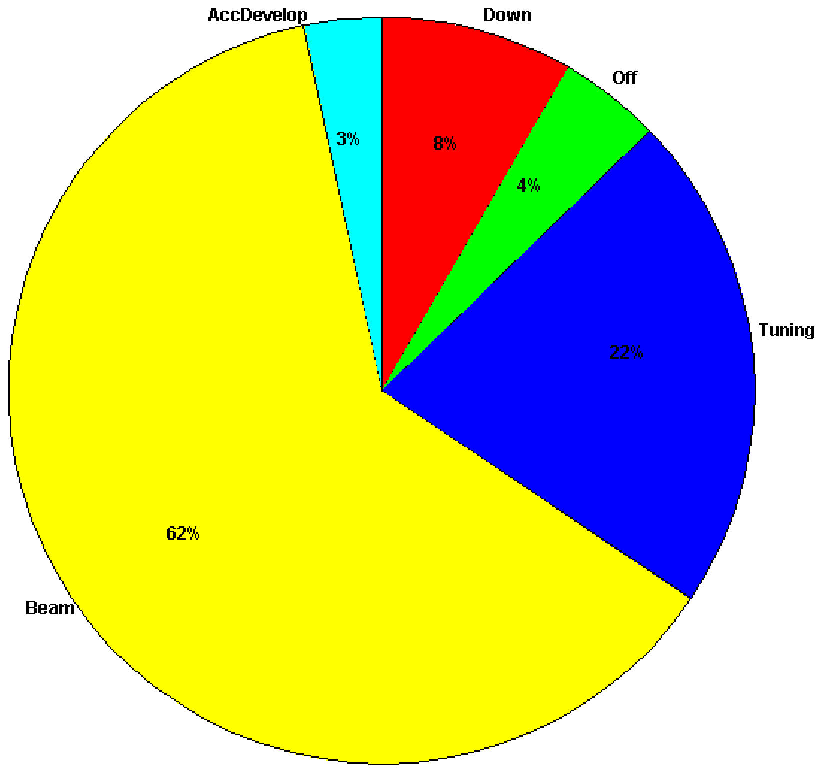


VUV-FEL operation statistics

01.01. – 04.11.2005



User operation
15.08. – 04.09.2005



Main issues and current activities

Quite stable FEL beam possible at ~15-20µJ average, > 50 µJ peak,

but often unstable with < 5µJ average, large fluctuations and low pointing stability

Main issues for FEL tuning:

- Injector and bunch compression (laser, alignment, LLRF)
- Electron beam optics of entire machine
- Electron beam diagnostics (no BPMs until recently)
- Orbit in the undulator (incl. losses, magnets, BBA)

A large amount of FEL oriented machine studies is required to improve the performance of the FEL.

VUV-FEL User Experiments

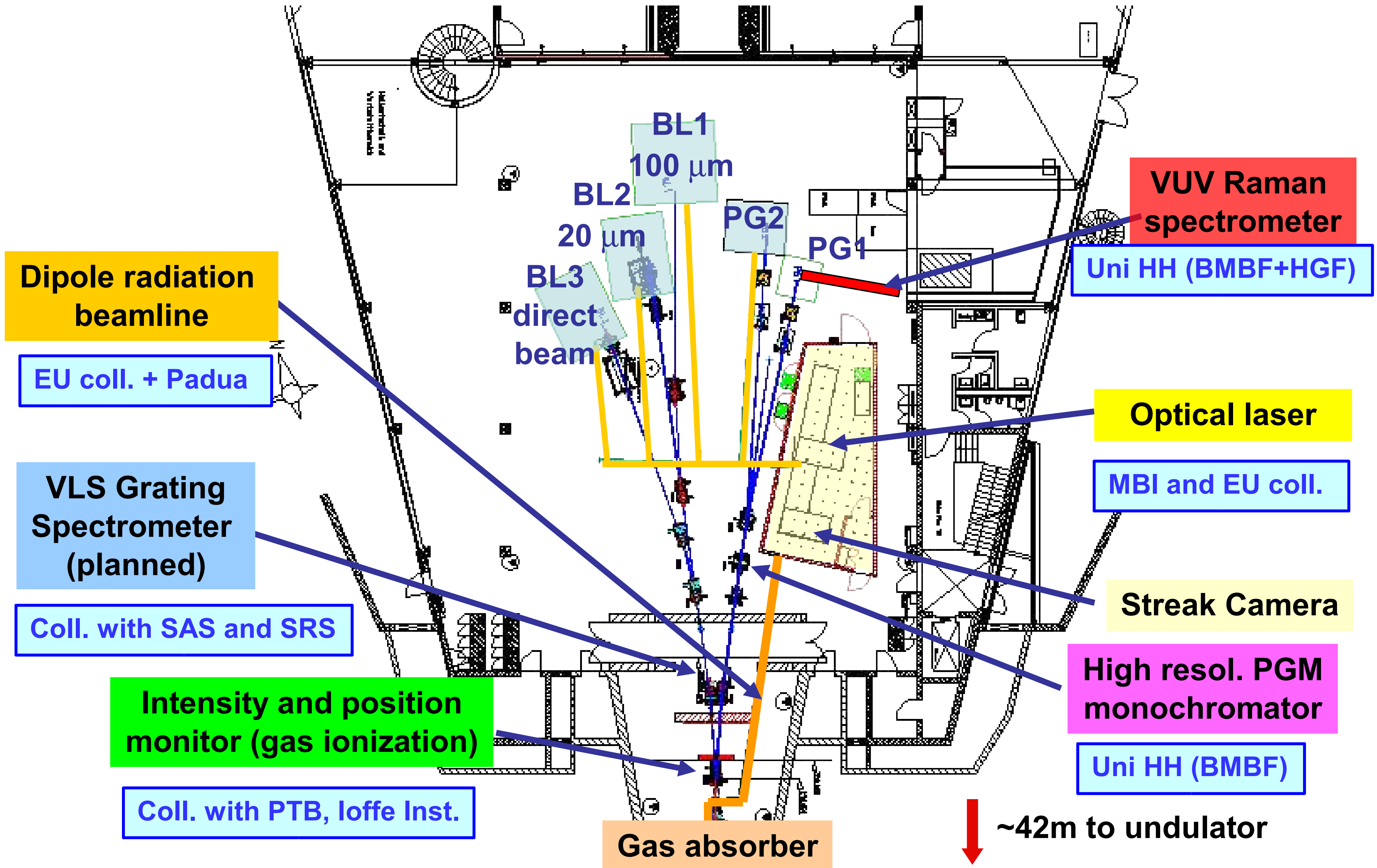
30 proposals submitted in 2002
29 proposals approved in Sept. 2002
200 scientists involved from
60 institutes and
11 countries

Available beam time heavily overbooked

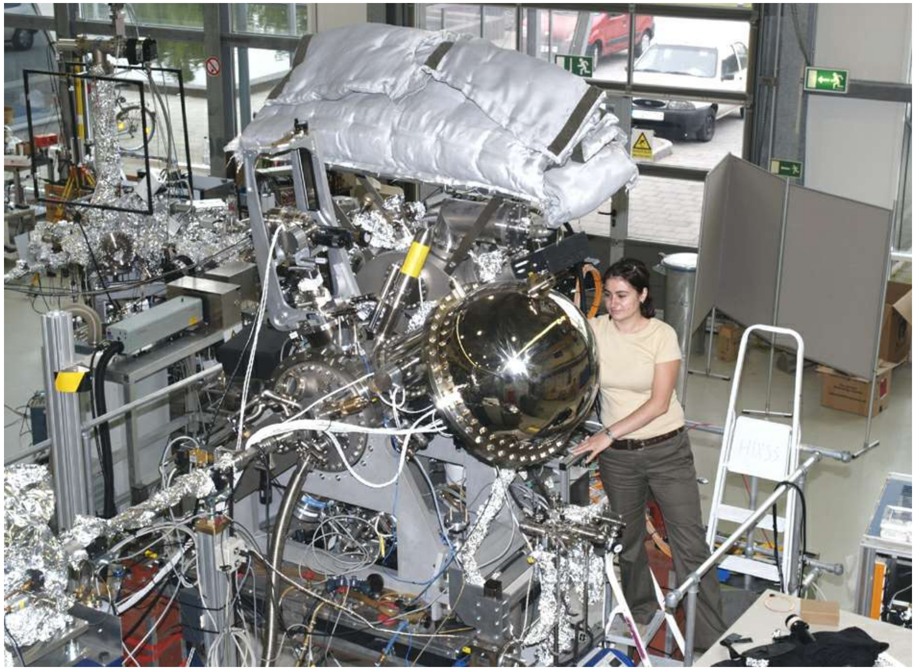
→ **Maximise beamtime and efficiency**

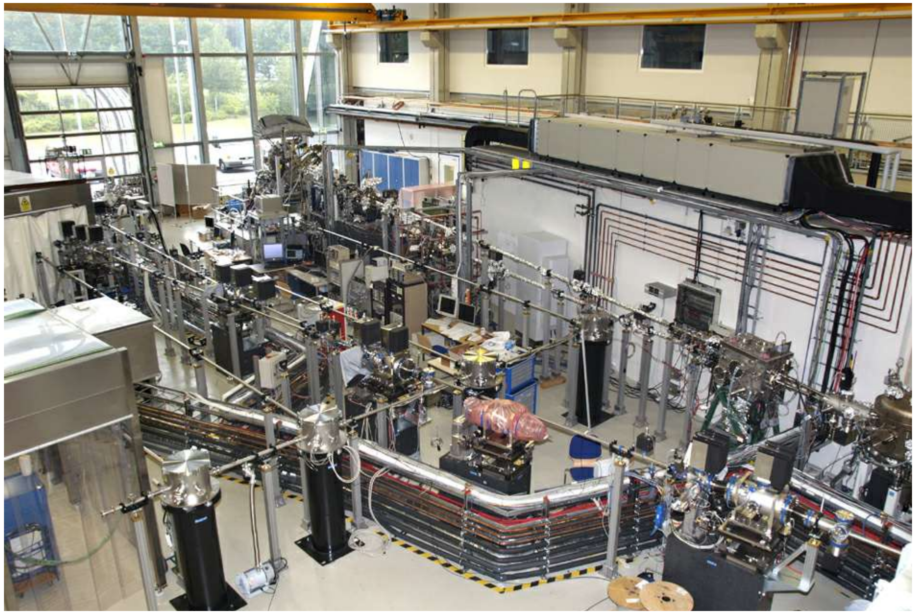
- *Beam switching between as many stations as possible*
- *Many groups have formed collaborations*
  (18 projects, 16 are ready and will have had beam by Feb. 2006)
- *Some experiments can be combined at one exp. station*
- *Different projects can use the same exp. system*
- *More frequent, short runs; must be well prepared*

Experimental area of the VUV-FEL



Pictures of the experimental floor





VUV-FEL schedule, revised 5. August 2005

	week	dates	
January	1	03.01. - 09.01.	VUV FEL commissioning, 30 nm, single bunch
	2	10.01. - 16.01.	
	3	17.01. - 23.01.	
	4	24.01. - 30.01.	
February	5	31.01.- 06.02.	VUV FEL commissioning, 30 nm, single bunch
	6	07.02. - 13.02.	continue and get saturation
	7	14.02. - 20.02.	
	8	21.02. - 27.02.	FEL Studies, evtl. incl. reaching shortest wavelengths
March	9	28.02. - 06.03.	Shutdown for installation of beamline components into the tunnel and interlock tests
	10	07.03. - 13.03.	work on modulators?
	11	14.03. - 20.03.	
	12	21.03. - 27.03.	FEL Studies, evtl. incl. reaching shortest wavelengths
April	13	28.03. - 03.04.	
	14	04.04. - 10.04.	
	15	11.04. - 17.04.	
	16	18.04. - 24.04.	
	17	25.04. - 01.05.	
May	18	02.05. - 08.05.	
	19	09.05. - 15.05.	Commissioning of mono beamline including diagnostics: HASYLAB 2 Shifts per day
	20	16.05. - 22.05.	
	21	23.05. - 29.05.	LLRF studies at moderate gradients,
June	22	30.05. - 05.06.	
	23	06.06. - 12.06.	Maintenance incl. MBK + addl. Klystron/Modulator (Choroba)
	24	13.06. - 19.06.	
	25	20.06. - 26.06.	Commissioning of BL2 and monochromator beamline and photondiagnostics
	26	27.06. - 03.07.	
July	27	04.07. - 10.07.	High gradient studies incl. Cryo and LLRF
	28	11.07. - 17.07.	
	29	18.07. - 24.07.	FEL studies
	30	25.07. - 31.07.	II-02-052 FEL, W. Wurth
August	31	01.08. - 07.08.	II-02-048 FEL, M. Richter and P. Zeitoun: I3-JRA2
	32	08.08. - 14.08.	Accelerator Studies (e.g. HOM studies cav. alignment) or FEL studies
	33	15.08. - 21.08.	Beamline commissioning BL and PG (Martins)
	34	22.08. - 28.08.	II-02-037 FEL, II-02-042 FEL, , II-02-052 FEL
September	35	29.08. - 04.09.	II-02-037 FEL, II-02-042 FEL, II-02-047 FEL or PG commissioning (Martins)
	36	05.09. - 11.09.	Maintenance e.g. modulators
	37	12.09. - 18.09.	
	38	19.09. - 25.09.	LLRF Studies
	39	26.09. - 02.10.	
October	40	03.10. - 09.10.	FEL studies
	41	10.10. - 16.10.	
	42	17.10. - 23.10.	II-02-054 FEL, II-02-050 FEL, II-02-049 FEL R. Lee, P. Zeitoun
	43	24.10. - 30.10.	II-02-047 FEL, II-02-050 FEL, II-02-049 FEL R. Lee, P. Zeitoun
November	44	31.10. - 06.11.	II-02-047 FEL, II-02-050 FEL, II-02-049 FEL R. Lee, K. Sokolowski-Tinten
	45	07.11. - 13.11.	II-02-044 FEL, II-02-050 FEL, II-02-049 FEL R. Lee, K. Sokolowski-Tinten
	46	14.11. - 20.11.	FEL studies
	47	21.11. - 27.11.	
December	48	28.11. - 04.12.	II-02-041 FEL, II-02-046 FEL
	49	05.12. - 11.12.	II-02-041 FEL, II-02-046 FEL
	50	12.12. - 18.12.	II-02-045 FEL, II-02-043 FEL, II-02-052 FEL
	51	19.12. - 25.12.	II-02-045 FEL, II-02-043 FEL, II-02-052 FEL
	52	26.12. - 01.01.	Maintenance
January 06	1	02.01. - 08.01.	FEL studies
	2	09.01. - 15.01.	
	3	16.01. - 22.01.	II-02-052 FEL, II-02-050 FEL, II-02-051 FEL
	4	23.01. - 29.01.	II-02-052 FEL, II-02-042 FEL
February 06	5	30.01. - 05.02.	II-02-049 FEL, R. Lee, R. Fedosejevs, II-02-042 FEL
	6	06.02. - 12.02.	II-02-039 FEL, II-02-047 FEL

User experiments

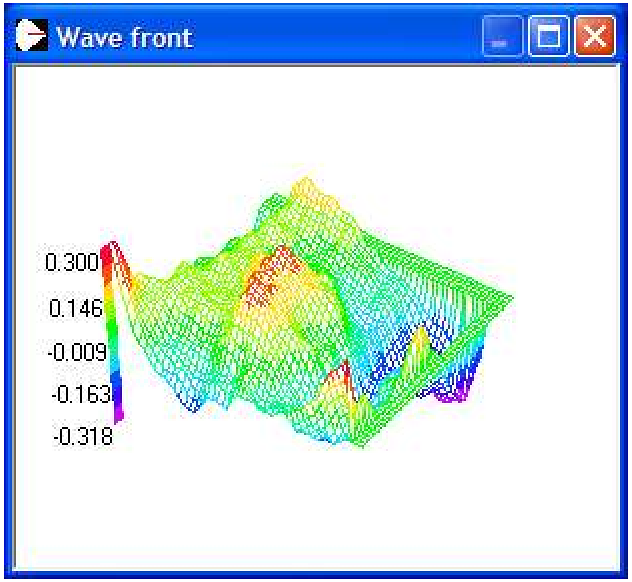
FEL studies

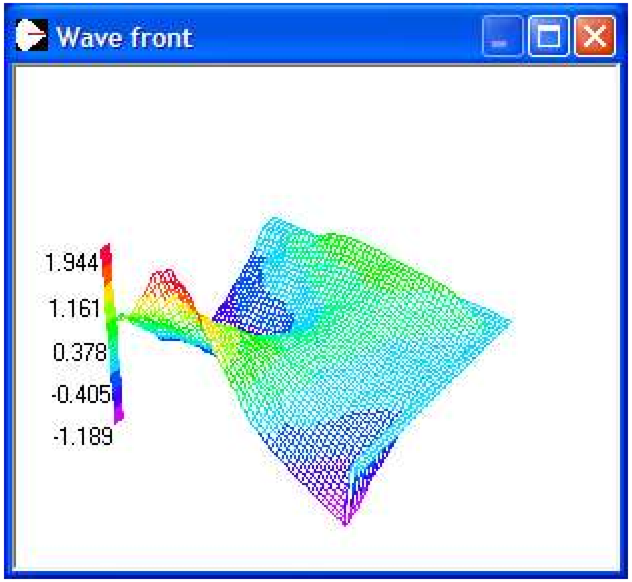
User experiments

Areas of Proposed Research

- **Femtosecond time-resolved experiments**
  - synchronisation FEL - optical laser
  - chemical reactions
  - magnetism dynamics
- **Interaction of ultra-intense XUV pulses with matter**
  - multiphoton excitation of atoms, molecules, clusters…
  - plasma physics
- **Investigation of extremely dilute samples**
  - free radicals
  - mass selected clusters
  - ions
- **High-resolution spectroscopy**
  - nanometer focus
  - meV-resolution photon and photoelectron spectroscopy of surfaces and solids with nm resolution

Wavefront measurements





Wavefront behind the ellipsiodal mirror of BL2: quite well aligned (left) and with significant astigmatism due to misalignment (right) (P. Zeitoun et al.)

Ionization of rare gases

A.A. Sorokin[1,2], S.V. Bobashev[2], K. Tiedtke[3], and M. Richter[1]

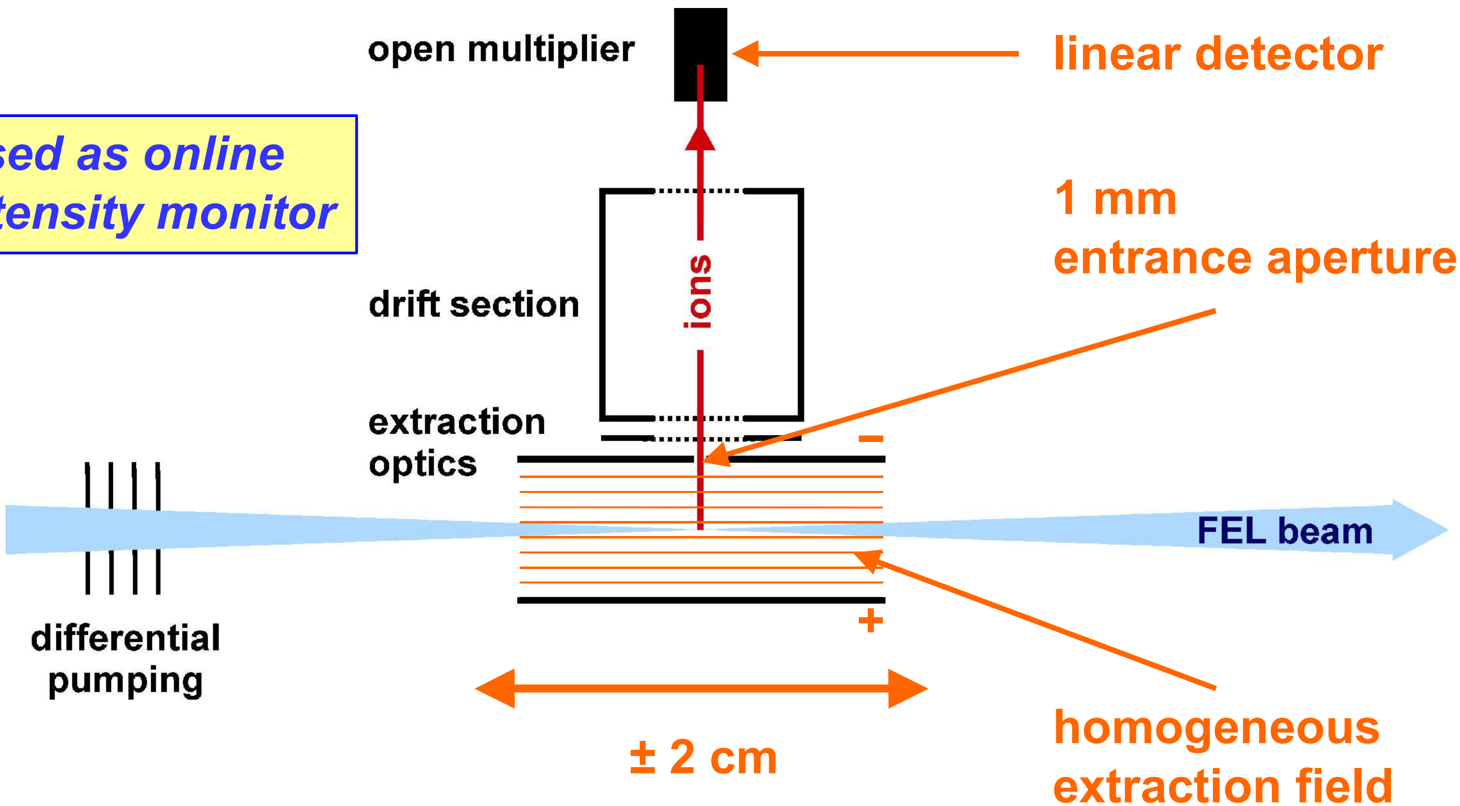
[1]Physikalisch-Technische Bundesanstalt, Berlin
[2]Ioffe-Institute, St. Petersburg
[3]Deutsches Elektronensynchrotron, Hamburg

Photon Radiometry

Ioffe Physico-Technical Institute

DESY

Used as online Intensity monitor

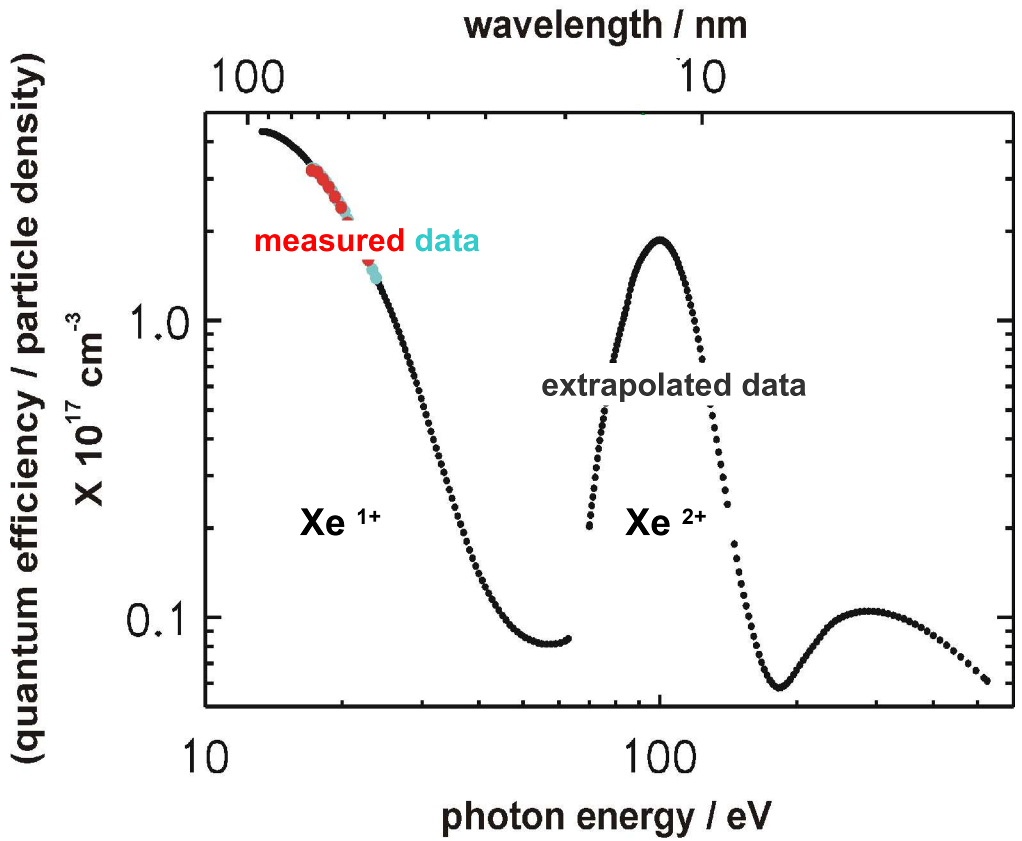


Quantum Efficiency of the TTF 1 Gas-Monitor Detector: Ion-Current Signal of Xenon

Photon Radiometry

Ioffe Physico-Technical Institute

DESY

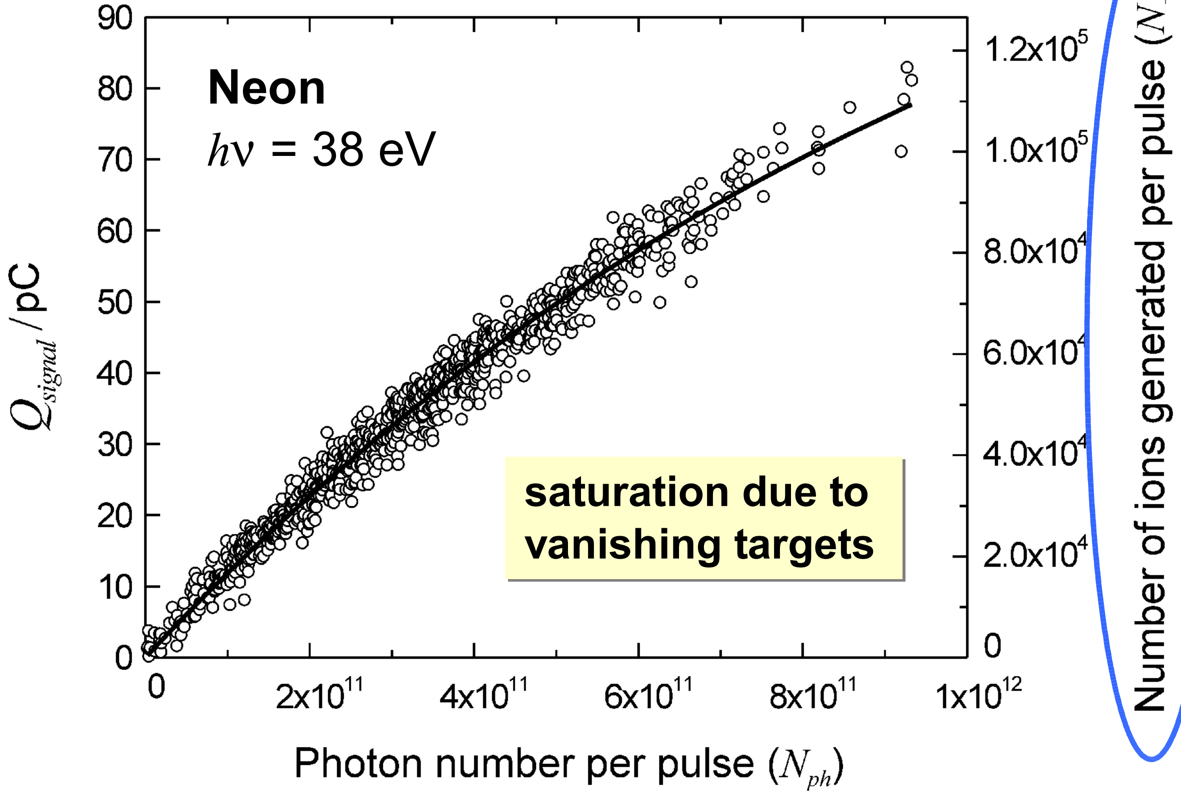


DFG Ri 804/3-1

Relative standard uncertainty: 4 %

M. Richter *et al.*, Appl. Phys. Lett. 83, 2970 (2003)
M. Richter *et al.*, AIP Conference Proceedings 652, 165 (2003)
A. Sorokin, PhD Thesis, Russian Academy of Science (2000)

Photoionization Signal vs. Photon Intensity



saturation effect allows determination of the beam cross section A

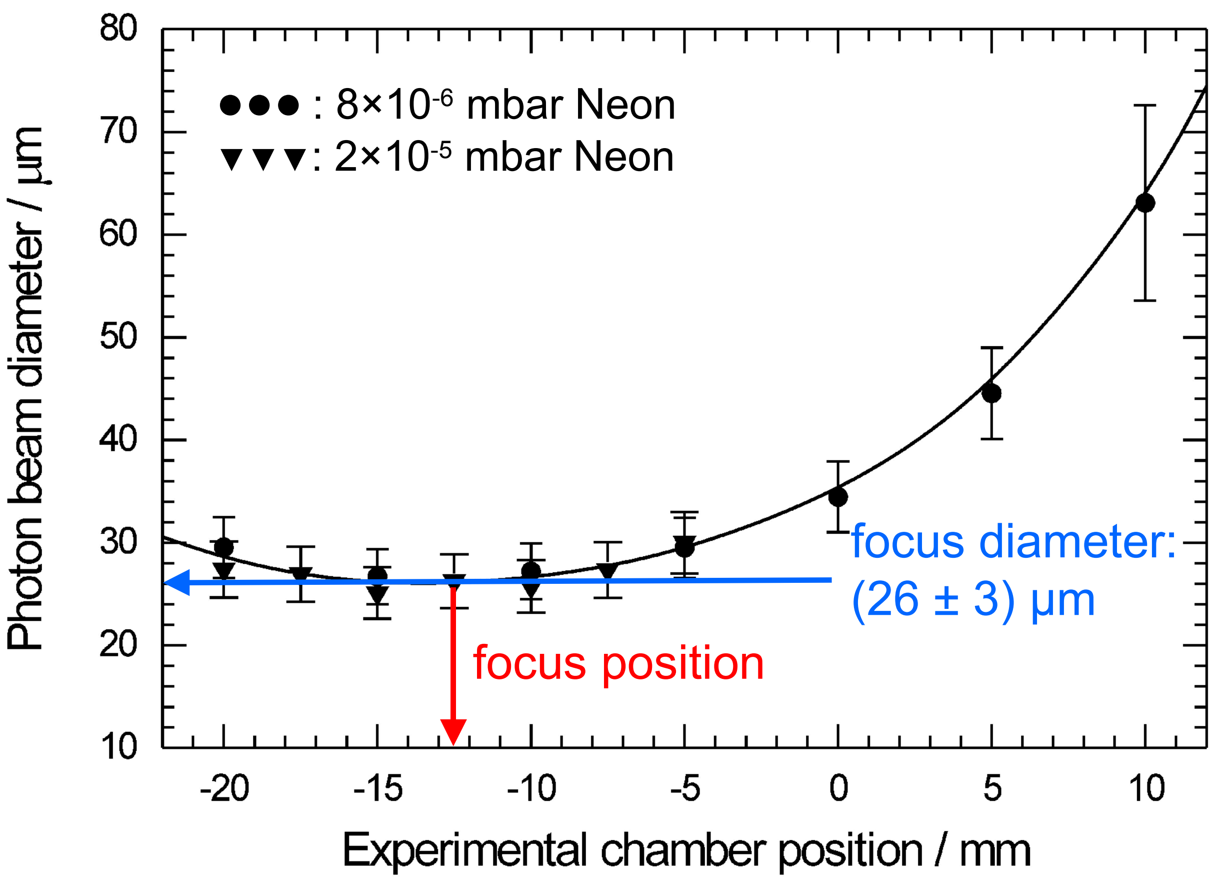
$$\frac{dN_+}{dN_{ph}} = \frac{\sigma}{A}(N - N_+) \quad \Rightarrow \quad N_+(N_{ph}) = N\left(1 - e^{-\sigma \frac{N_{ph}}{A}}\right) \approx n z \sigma N_{ph}\left(1 - \frac{1}{2}\left(\sigma \frac{N_{ph}}{A}\right) + \frac{1}{6}\left(\sigma \frac{N_{ph}}{A}\right)^2\right)$$

Beam Size Measurements at the Microfocus Beamline of the New VUV Free-Electron Laser in Hamburg …

Photon Radiometry

Ioffe Physico-Technical Institute

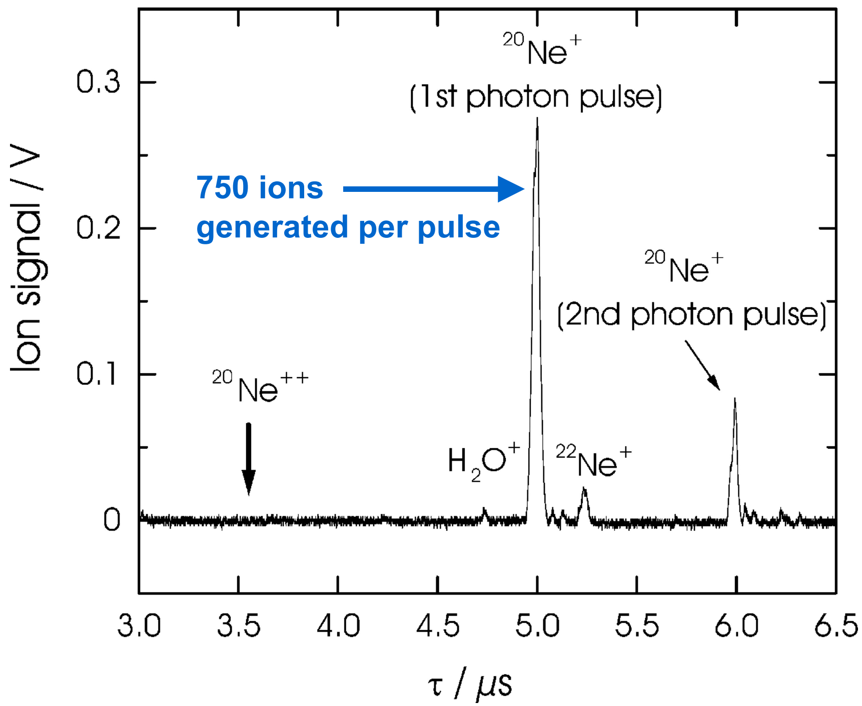
DESY

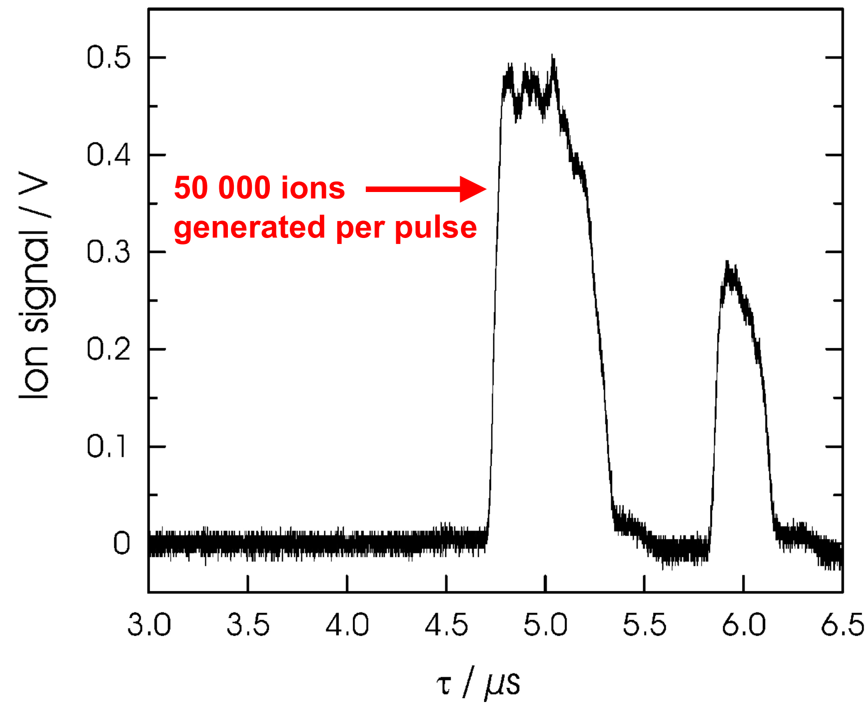


focus position and/or focus size changed during week 31!

… based on a saturation effect in the single photoionization of neon

TOF Spectra of Neon: Space Charge Effects

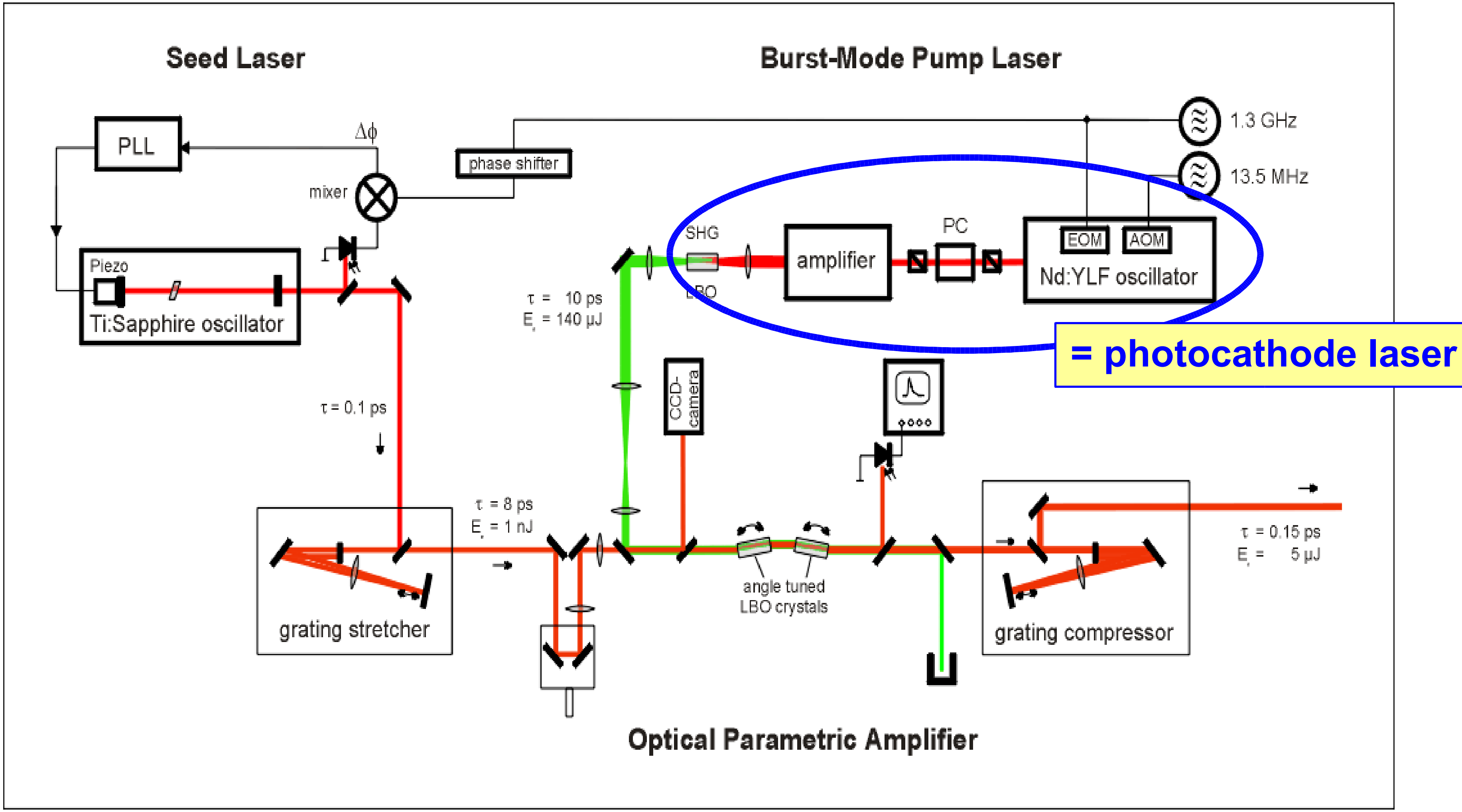




low target gas pressure
low photon intensity

high target gas pressure
high photon intensity

Ti:Sa OPCPA laser for pump-probe experiments



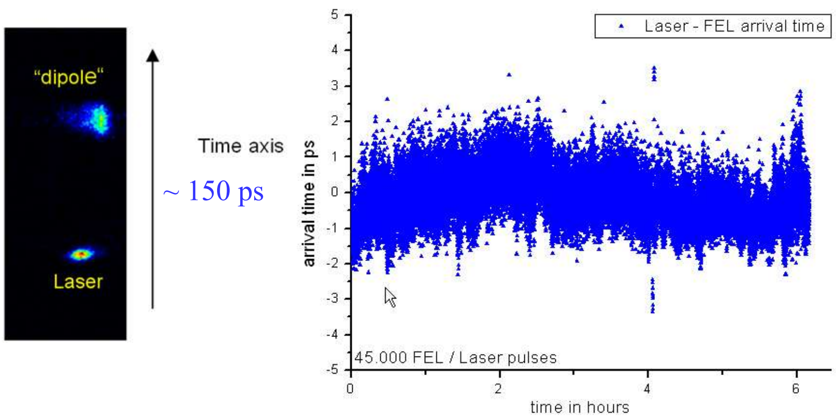
- installed at DESY in 2004
- laser system developed by MBI

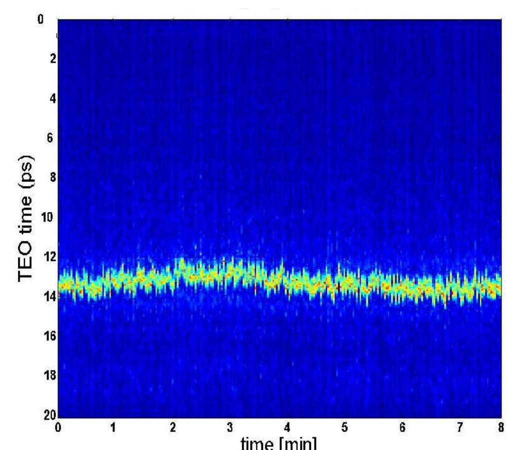
partially funded by EC (XRAY FEL PUMP-PROBE)
Partners: BESSY, DCU, DESY, MAX-lab, MBI, LURE

Synchronisation of optical laser and FEL

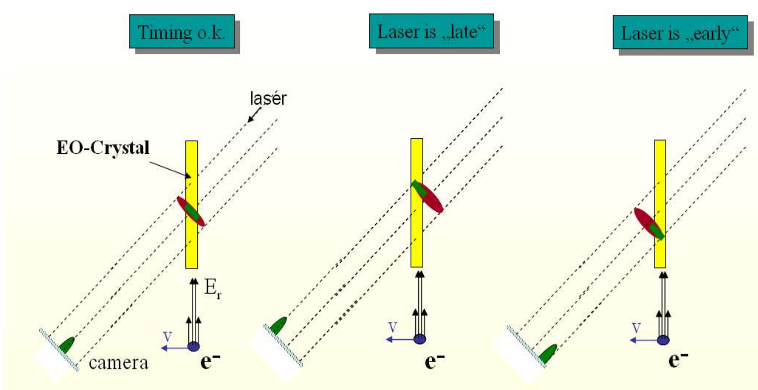
S. Düsterer, H. Redlin et al.

Streak camera measurements





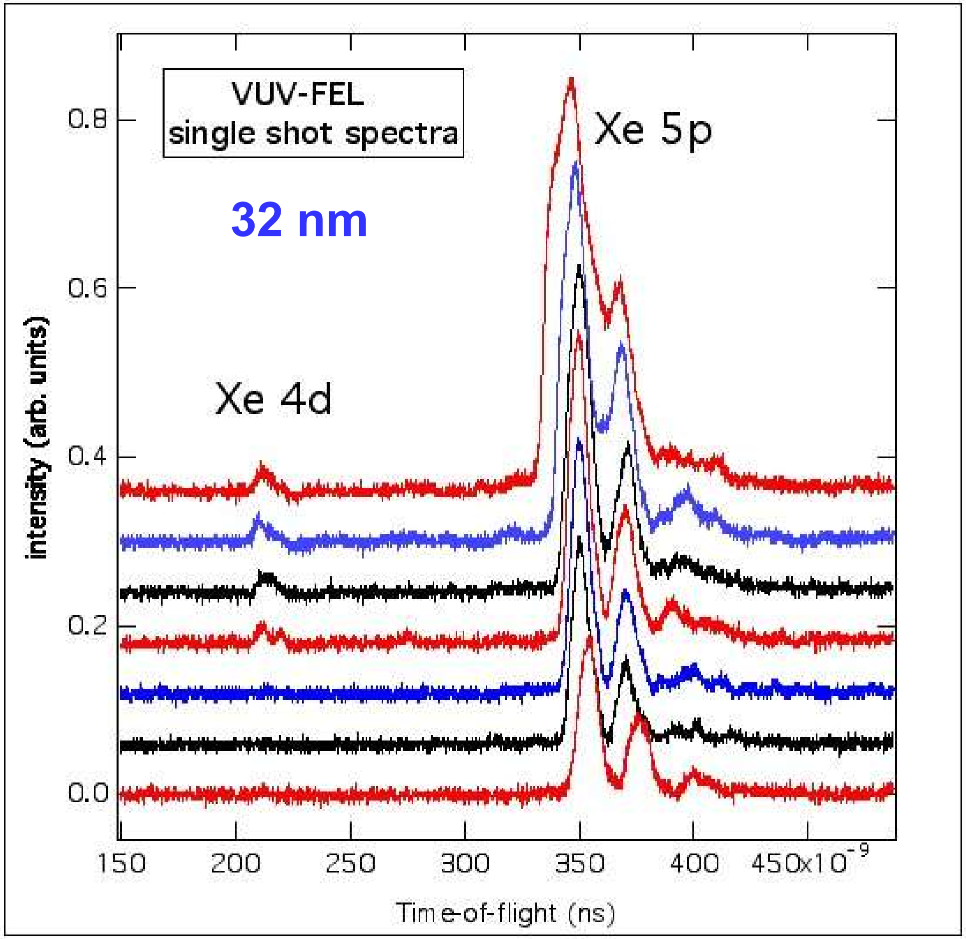
Electro-optical sampling



1000 successive laser / FEL pulses (~8 min)
current time resolution: < 200 fs
timing jitter: 350 fs rms

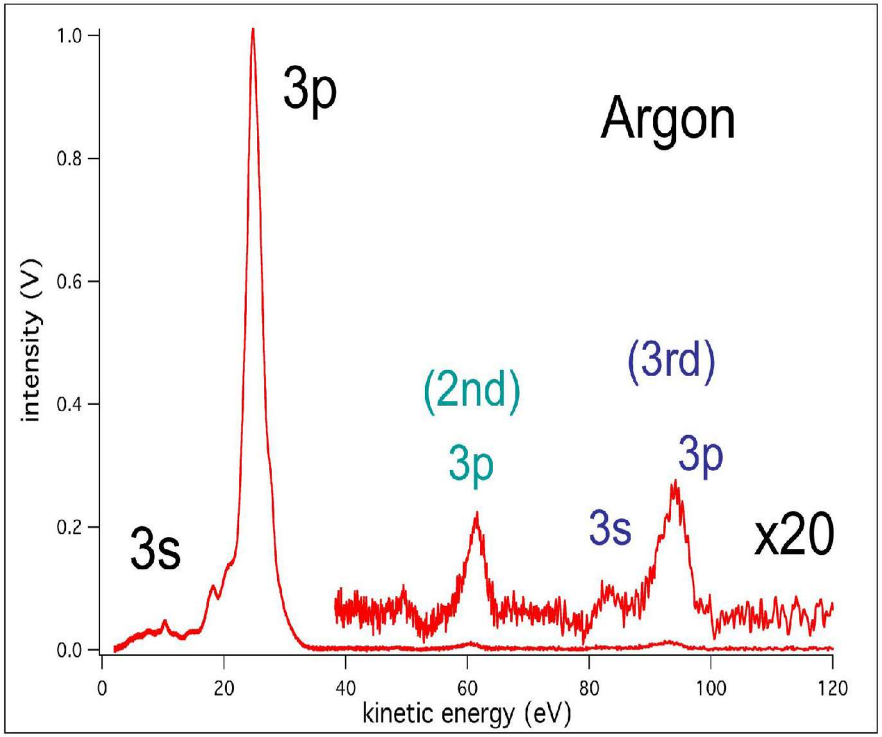
Pump-Probe Experiments in the Gas Phase

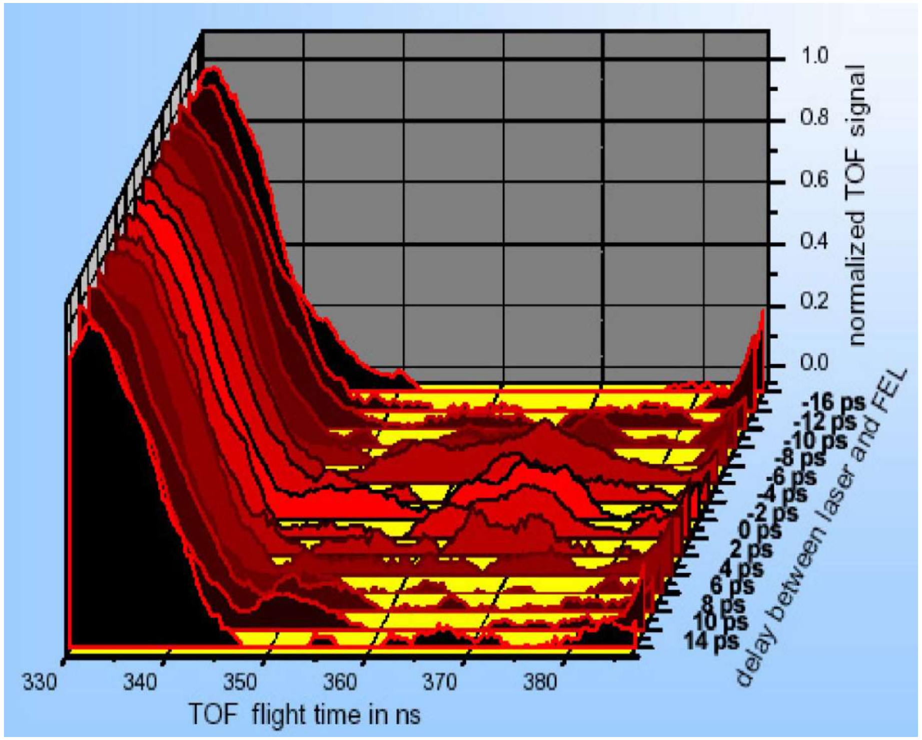
M. Meyer et al.



Pump-Probe Experiments in the Gas Phase

M. Meyer et al.

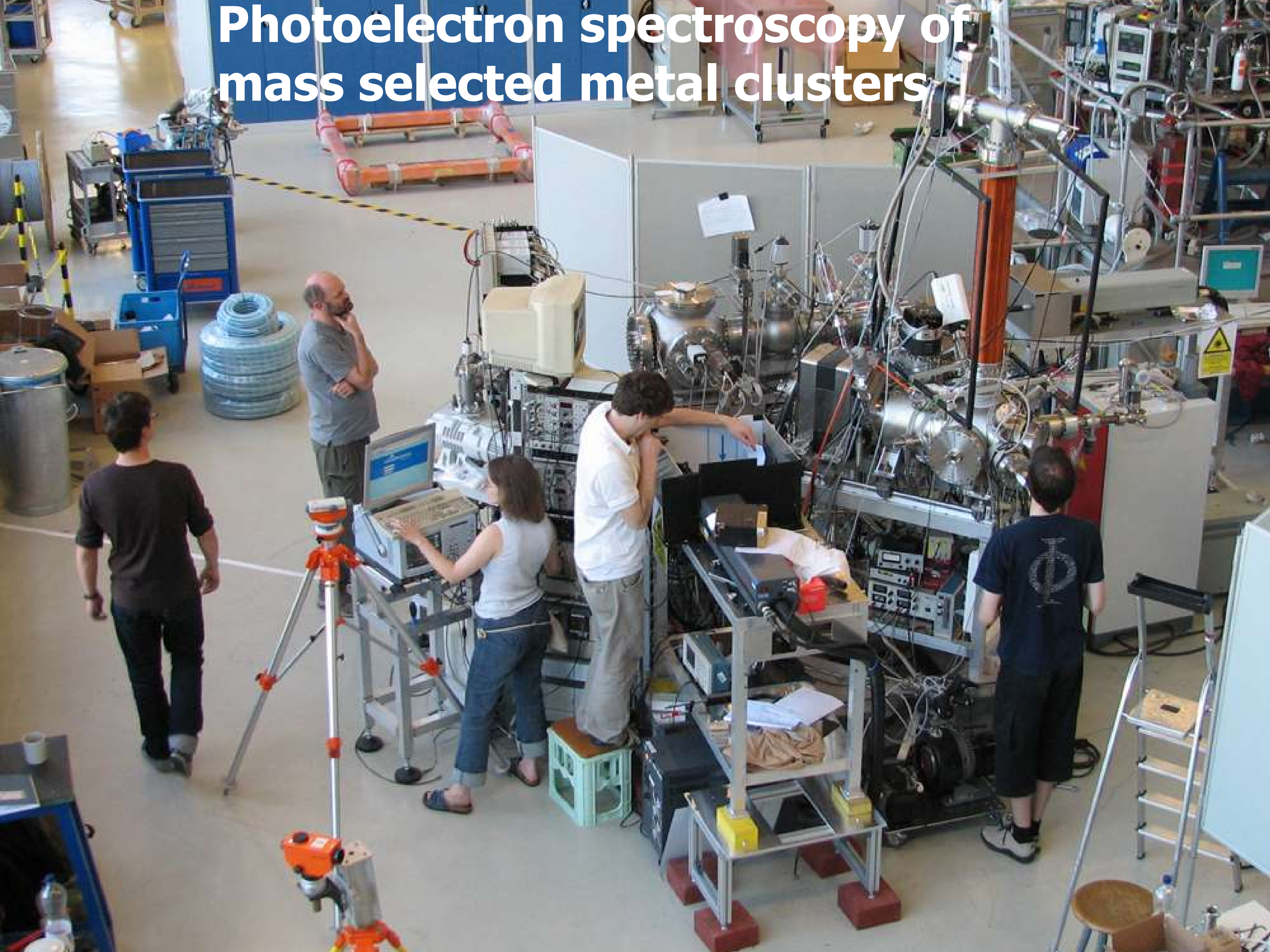




FEL harmonics (~0.5 - 1%)

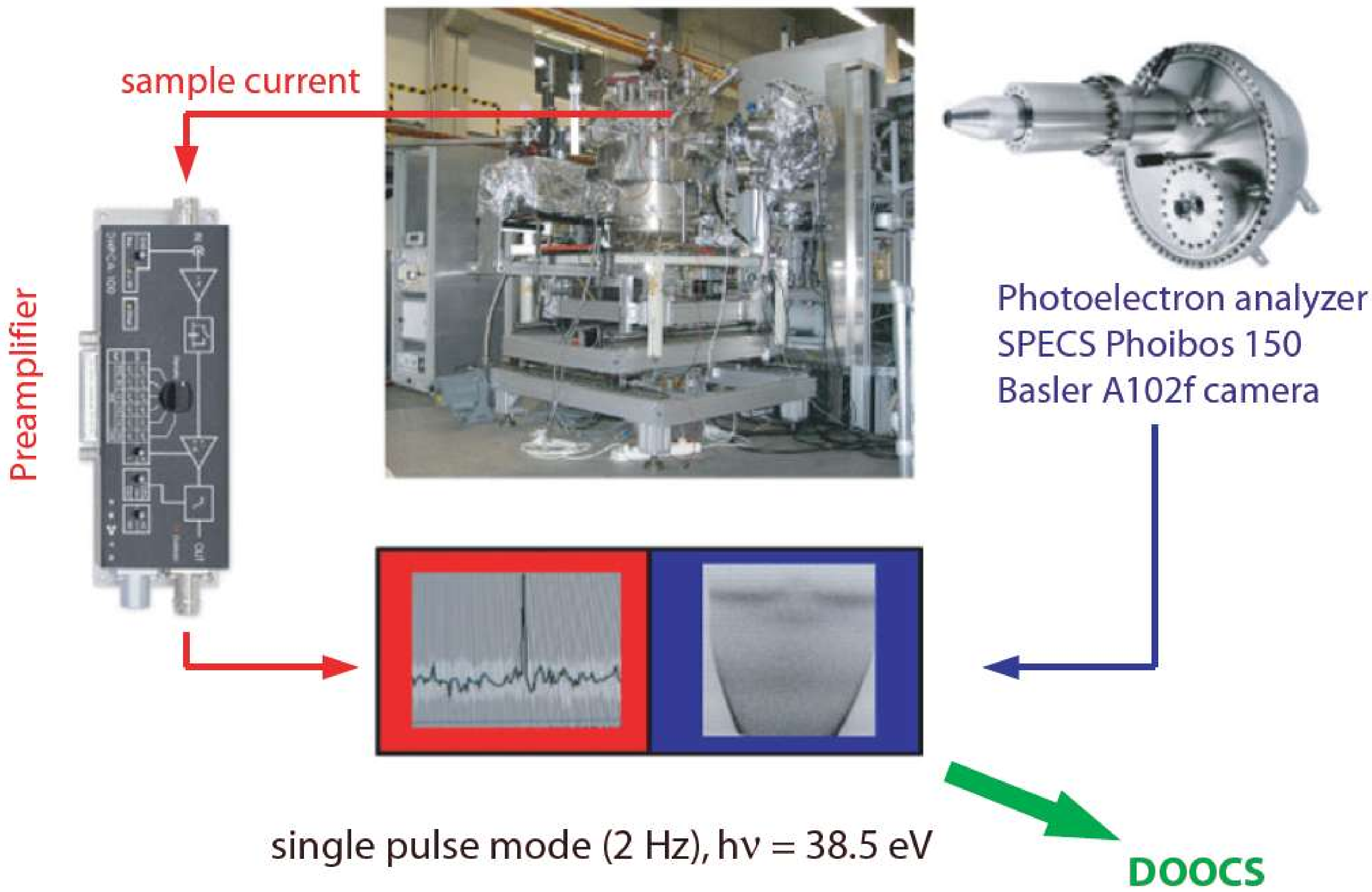
Cross-correlation of FEL and green laser pulse (12ps) in He

Photoelectron spectroscopy of mass selected metal clusters



Angle-resolved photoemission - Nanospectroscopy

L. Kipp et al.



Angle-resolved photoemission

L. Kipp et al.

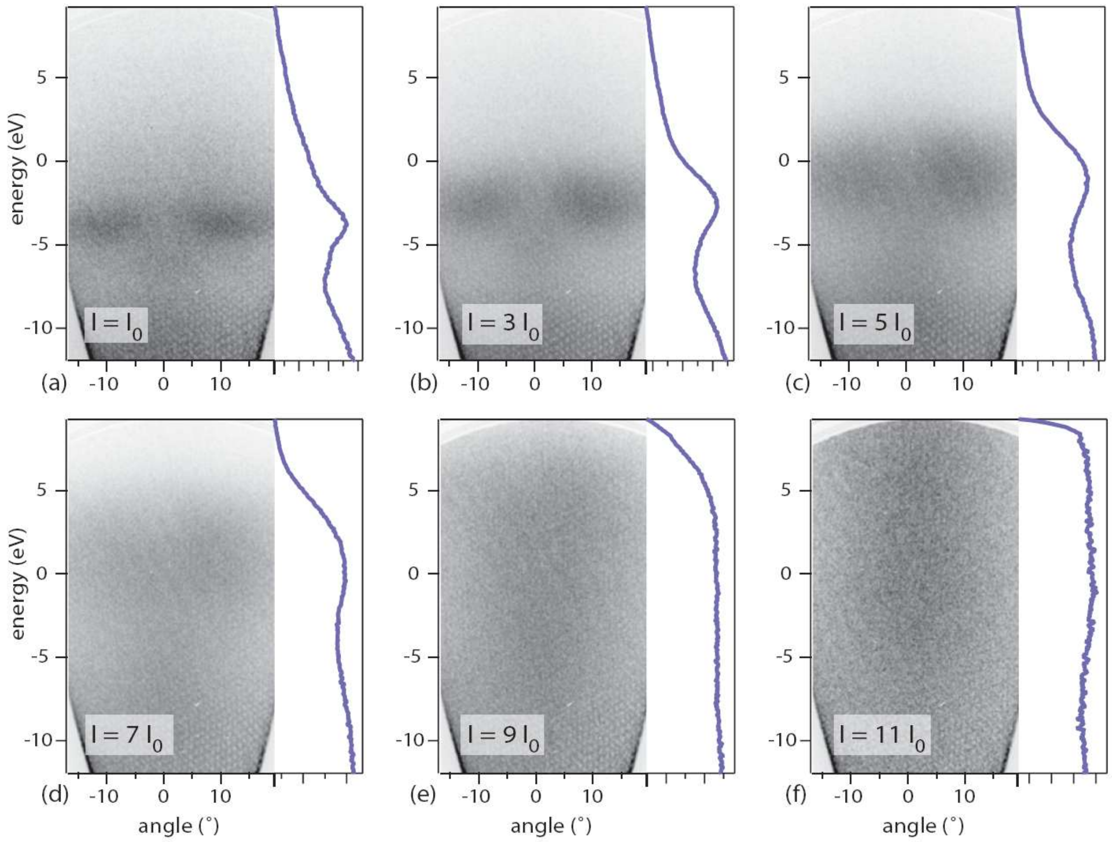
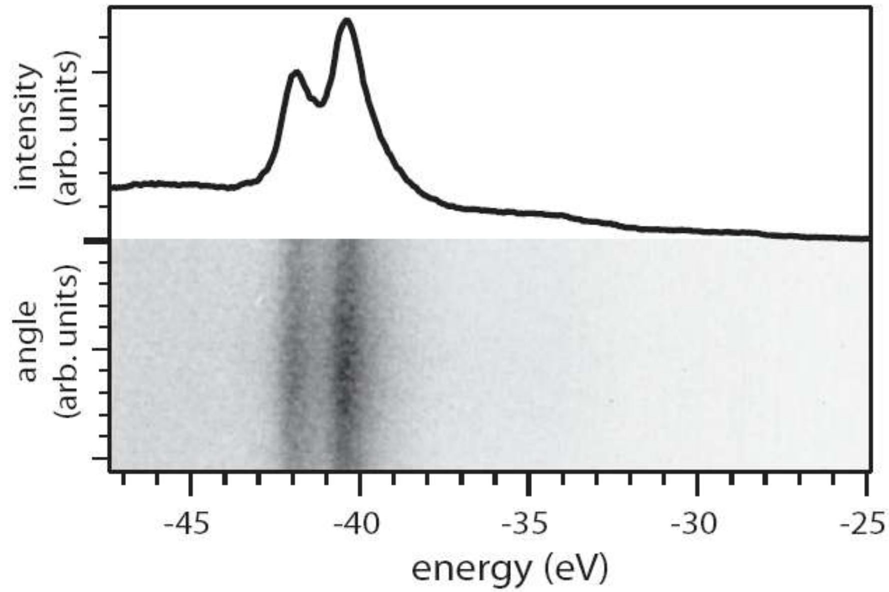


Figure 2: Angle resolved and angle integrated (solid lines) photoelectron spectra of the $TiTe_2$ valence band, taken at $h\nu = 38.5$ eV and sorted according to increasing FEL-intensity from (a) to (f). Photoemission intensity is represented in a linear gray scale with dark corresponding to high intensity.

Photoemission of using $TiTe_2$ 3rd harmonic

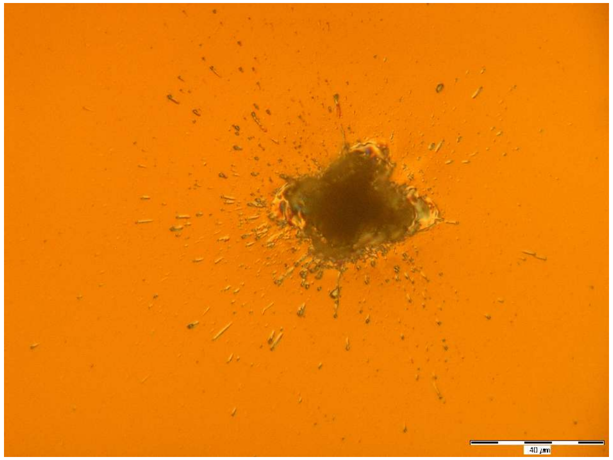
L. Kipp et al.

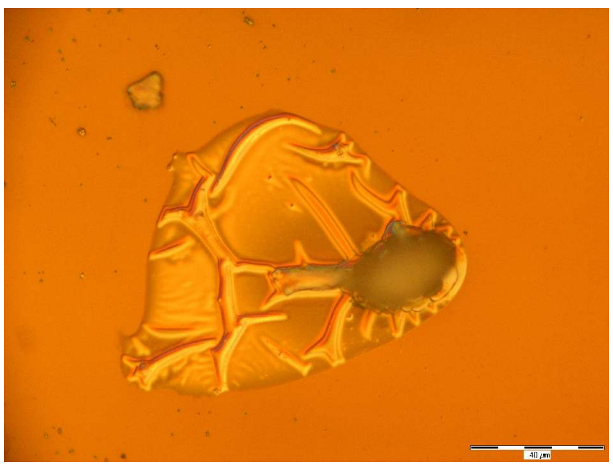


Te 4d electrons emitted by the 3rd FEL harmonic at 116 eV

High energy density experiments

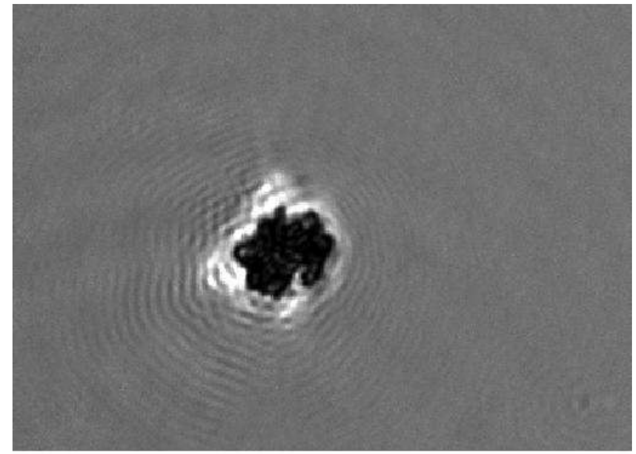
R.W. Lee et al.





Ablation of carbon coating on Si

R. Sobierajski et al.



Ablation of Si,
illuminated by optical laser pulse

K. Sokolowski-Tinten et al.

Summary of user experiments

- ~ 12 user experiments had first beam
- 4 experiments for technical developments were performed
- Most experiments are very complex and include many components ➔
  - groups formed collaborations
  - teams are much larger than at synchrotron radiation facilities
- First reports are very promising:
  - commissioning of most experiments was quite successful although often difficult with present FEL beam conditions
  - most experiments have taken first useful data demonstrating that their concepts work; data are currently evaluated

  Thanks to good preparation and very intense user support
- Continuing implementation of data acquisition and diagnostics

VUV-FEL operation after 2005

The commissioning of the FEL is by far not completed

until end of 2006 *- stable, reproducible operation from ~ 15 - 60 nm*
- operation with long bunch trains (up to 800 μs)

~ end of 2006? - install module ACC6, repair ACC5, replace ACC3

+ 3rd harmonic RF system (FNAL, spring'07 ??)

→ 1 GeV → 6.5 nm → seeding operation

2007? - two-undulator seeding (?)
- further extensions (FIR, exp. stations, …)

alternate periods of FEL commissioning/improvement and user experiments

e.g. 4 weeks commissioning, incl. 1 week photon beamlines and diagnostics,
4 weeks user operation

under discussion