Status VUV-FEL/FLASH

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DESY

- Overview
- Status and achievements
- Outlook

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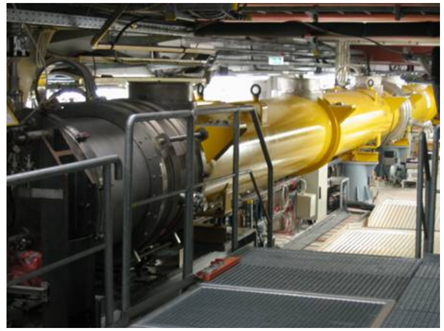
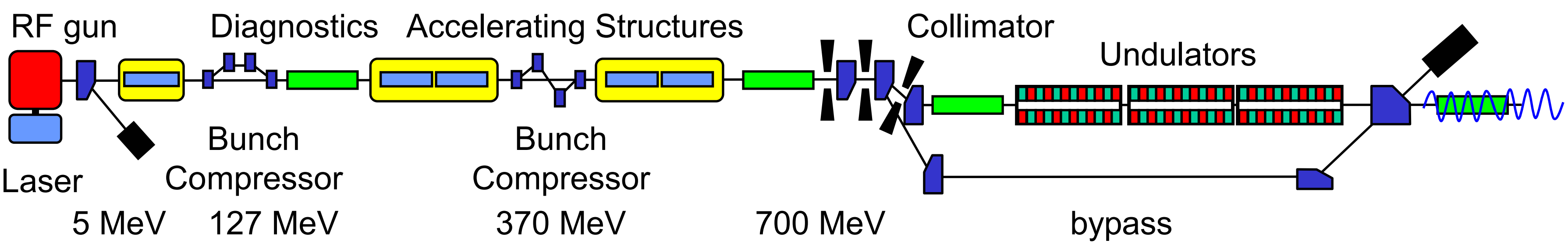
The VUV-FEL has a new name: *FLASH*

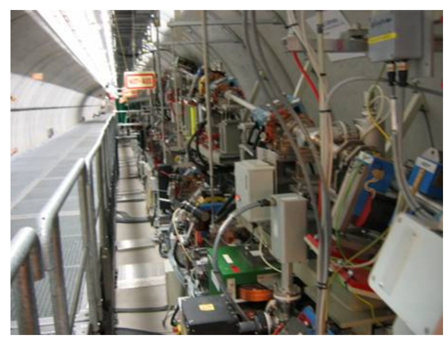
- Stimulated by the users of the VUV-FEL and the first exciting results obtained, the suggestion was made to find a compact name for the facility which is more attractive and easier to pronounce in different languages
- On 6th April 2006 the DESY directorate decided for the new name FLASH instead of VUV-FEL

Present Layout







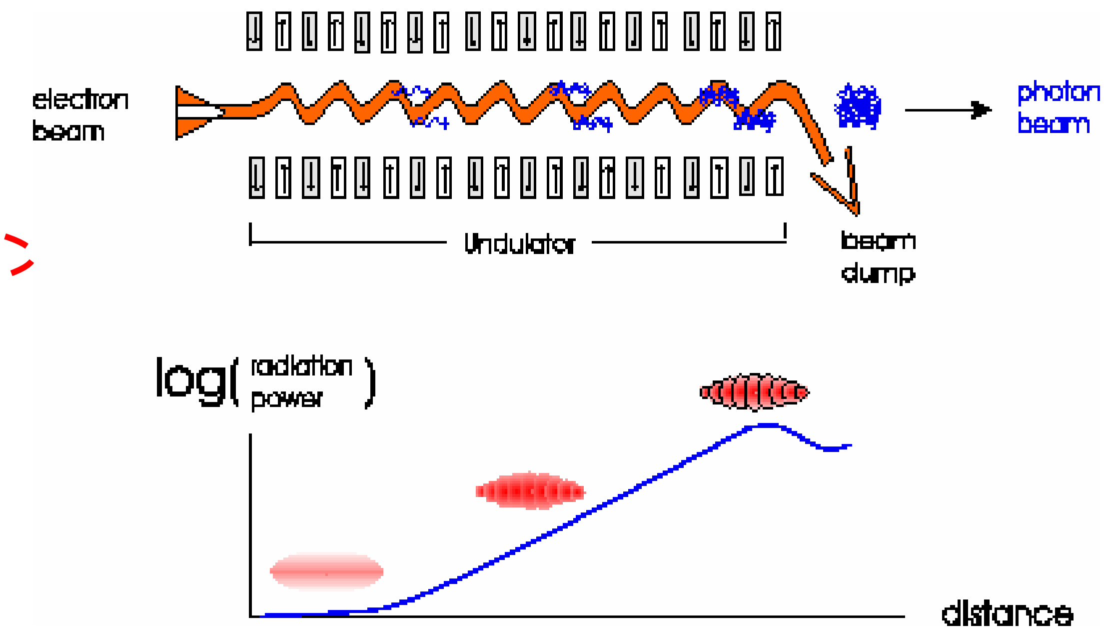

250 m

Radiation power growth exponential …

Radiation power:

$$L_G = \frac{1}{\sqrt{3}}\left(\frac{I_A \gamma^3 \sigma_r^2 \lambda_u}{4\pi \hat{I} K^2}\right)^{1/3}$$

$$P_{rad} = P_0 \, \mathbf{exp}\left(z / L_g\right)$$



I $=$ Peak current ~ 2.5 kA

σ_r $=$ Beam radius

γ $=$ E/m_0 ~ beam energy

λ_u $=$ Undulator period

K $=$ Undulator parameter

⇒ Requires very high level of beam control

⇒ Good understanding of accelerator parameters

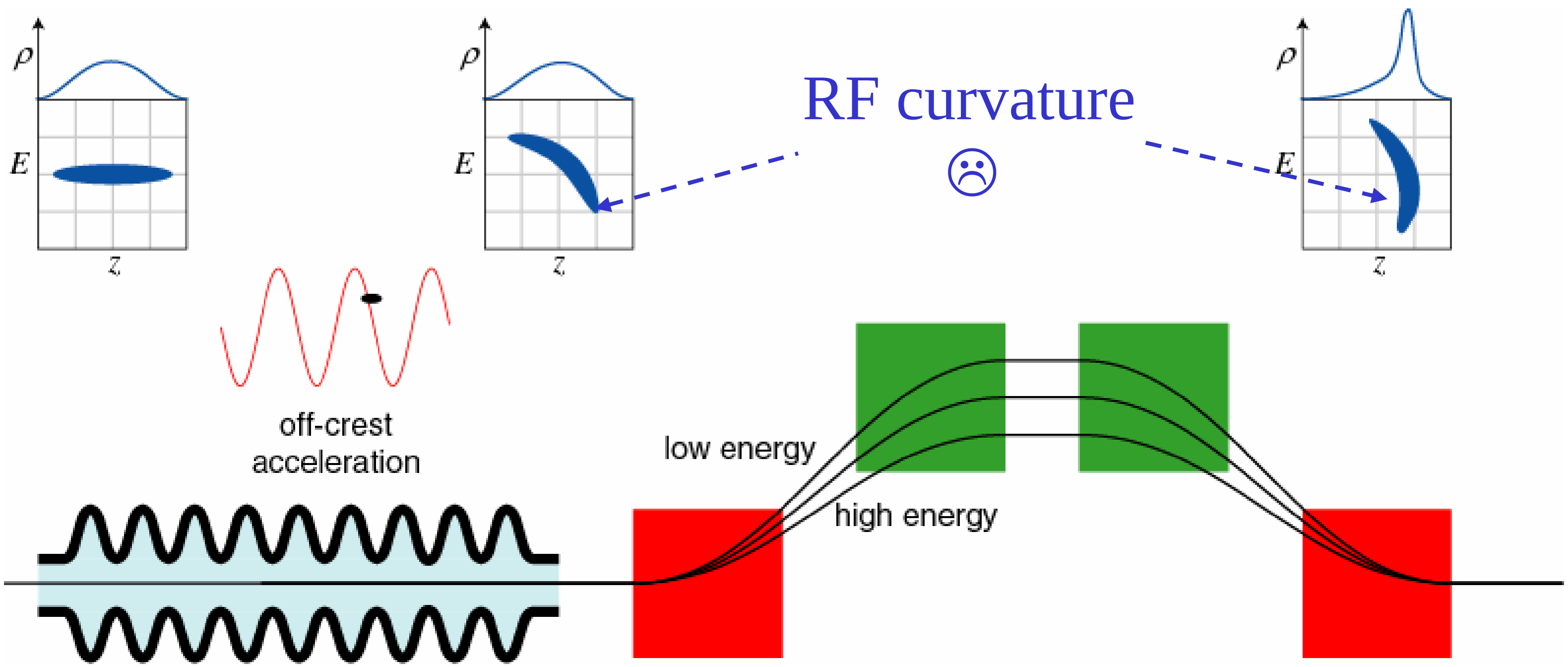
⇒ Small jitter tolerance (orbit, emittance, peak current)

Production of high peak currents …

- at high energy (127 MeV) electrons have 99.9993% c_0

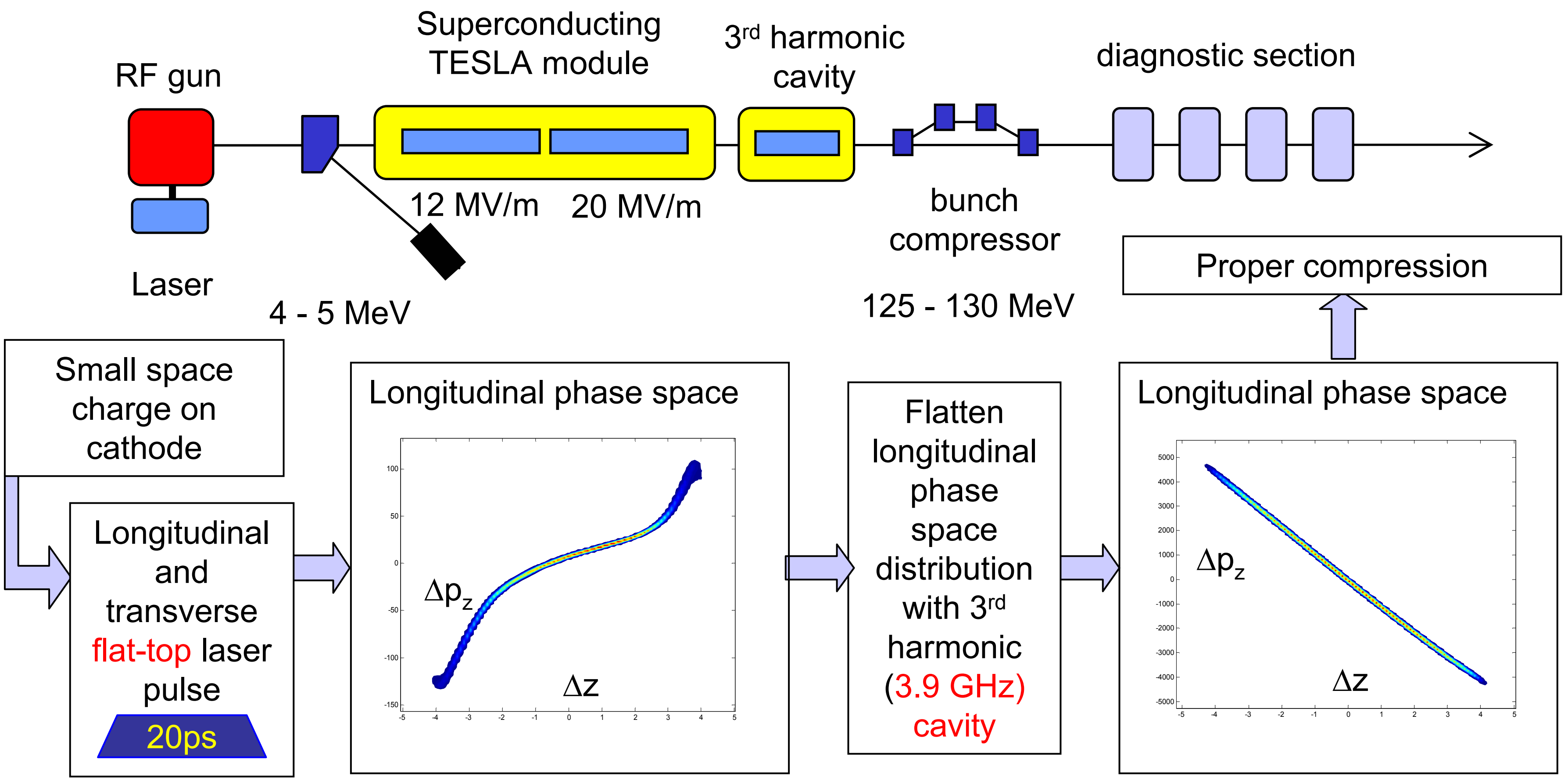
$\Rightarrow$ Introduce energy chirp to e- beam

$\Rightarrow$ section with energy dependent path length using magnetic bunch compressors



Longitudinal phase space injector

- final design (2007) -

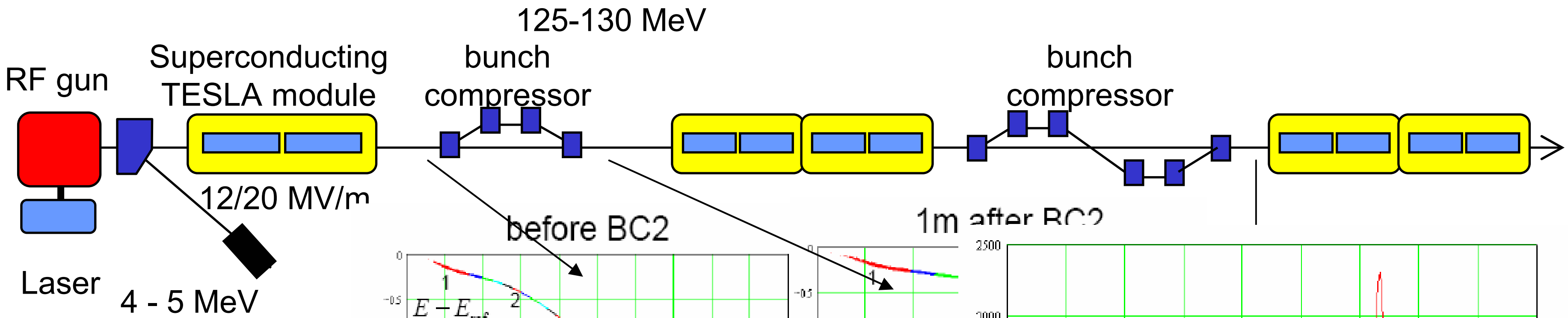


⇒ Uniform longitudinal compression

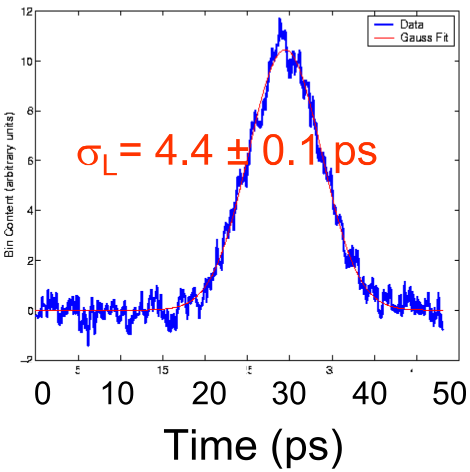
⇒ Small transverse projected emittance

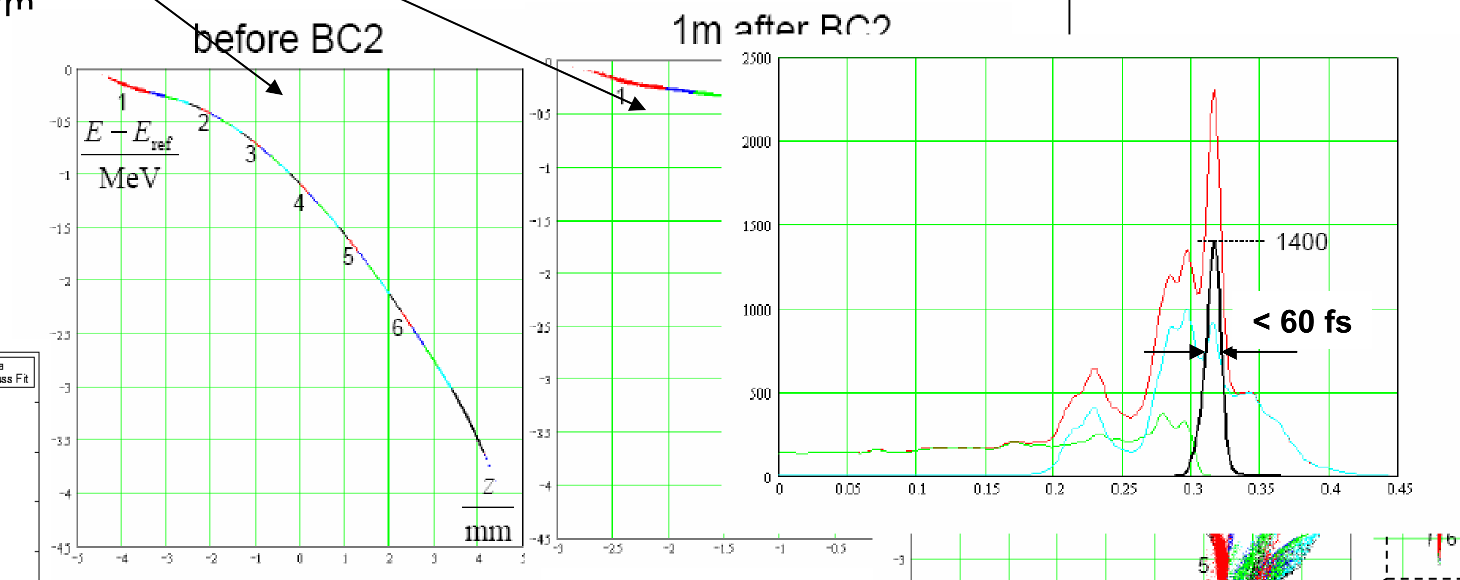
Longitudinal phase space injector

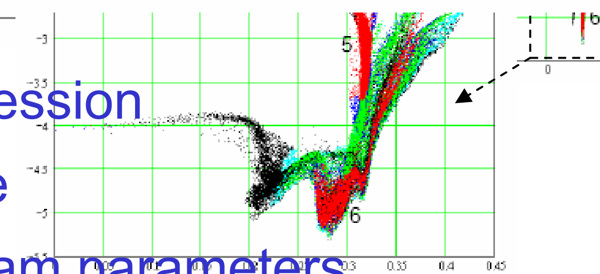
- present design (2005/6) -



Small space charge on cathode







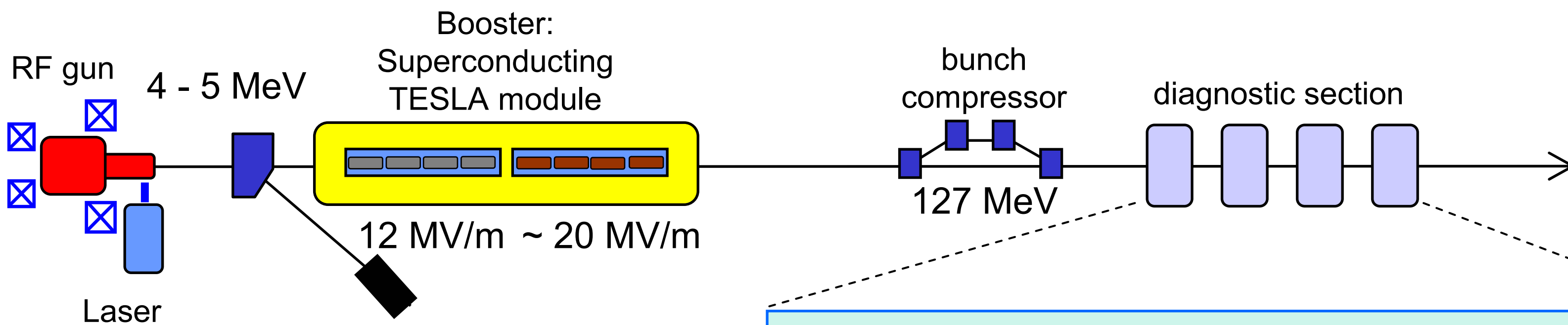
⇒ Non-linear longitudinal compression

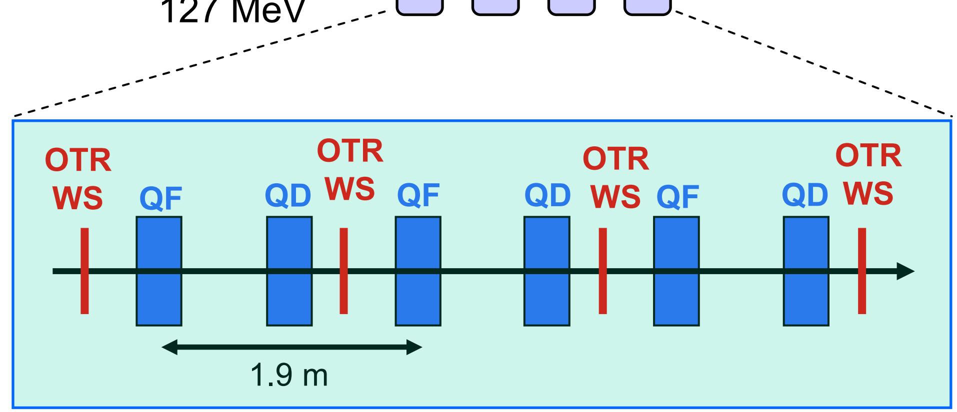
⇒ Blowup of projected emittance

⇒ Difficult access to relevant beam parameters

⇒ Ultra-short photon pulses created ~ 30fs FWHM

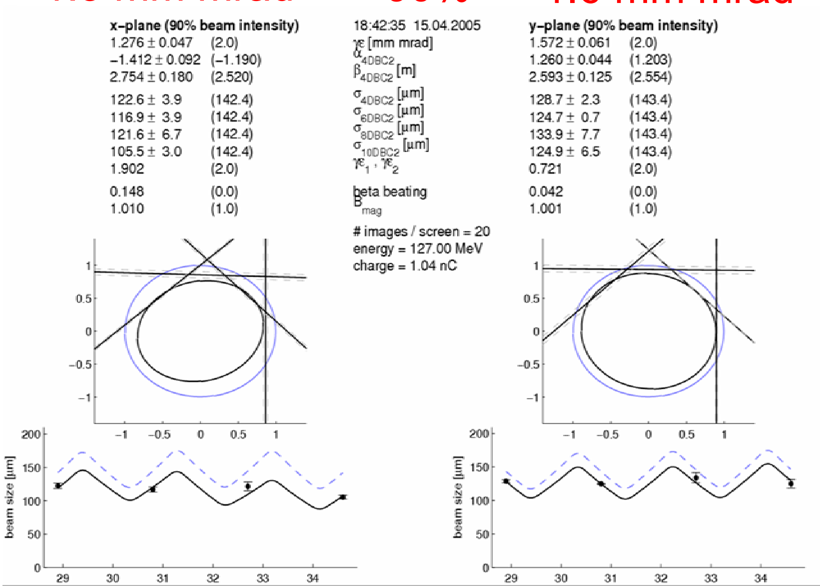
Emittance measurements at the injector



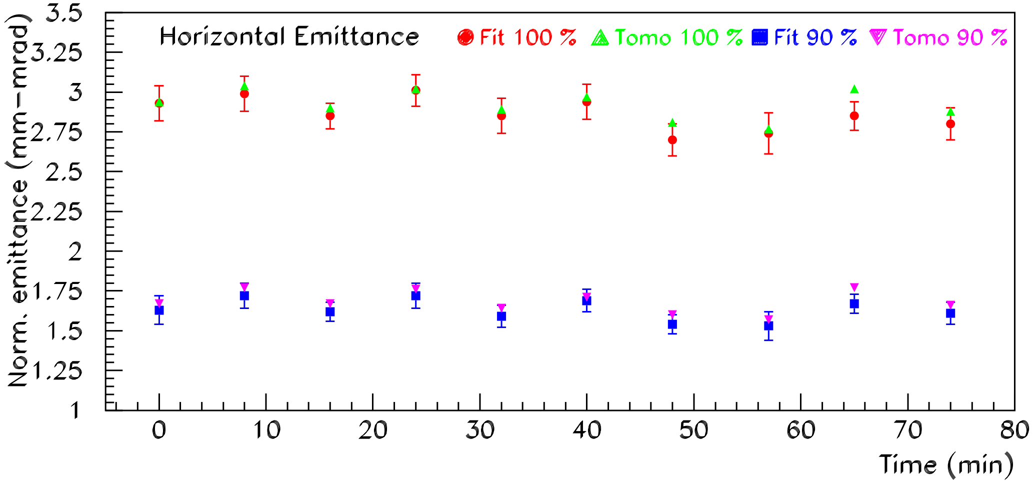


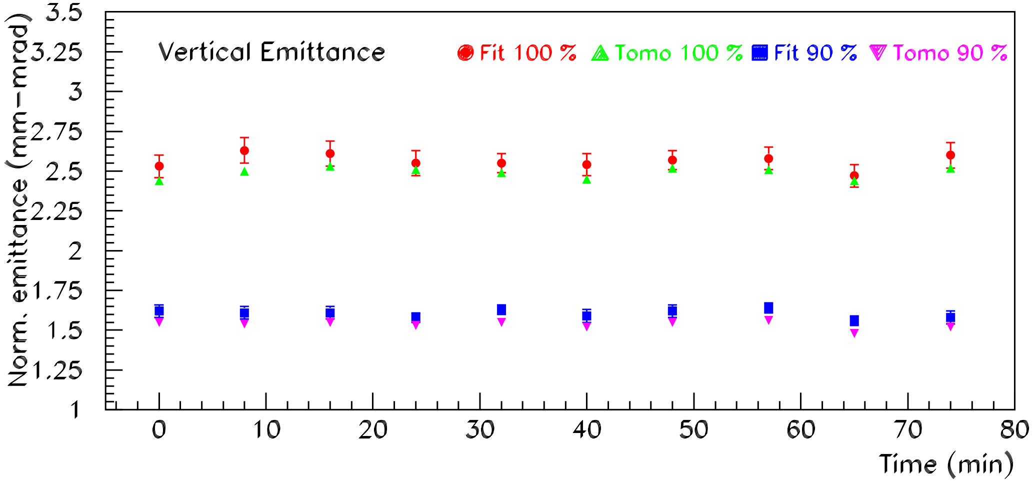
- Four monitor method using OTR monitors or wire scanners

Horizontal	Q =1 nC	Vertical
2.0 mm mrad	100%	2.2 mm mrad
1.3 mm mrad	90%	1.6 mm mrad



Transverse Projected Emittance

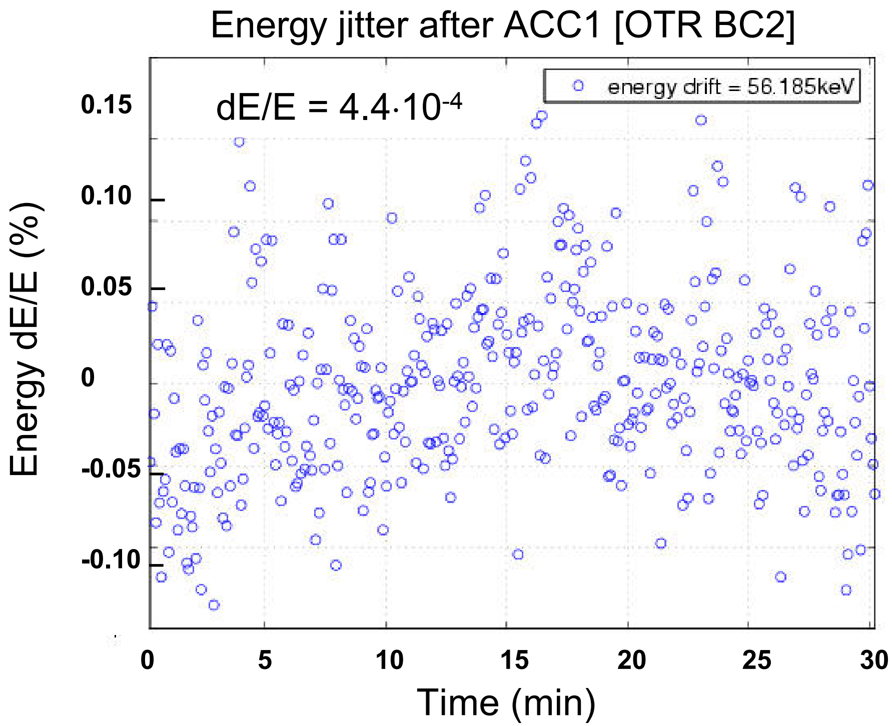


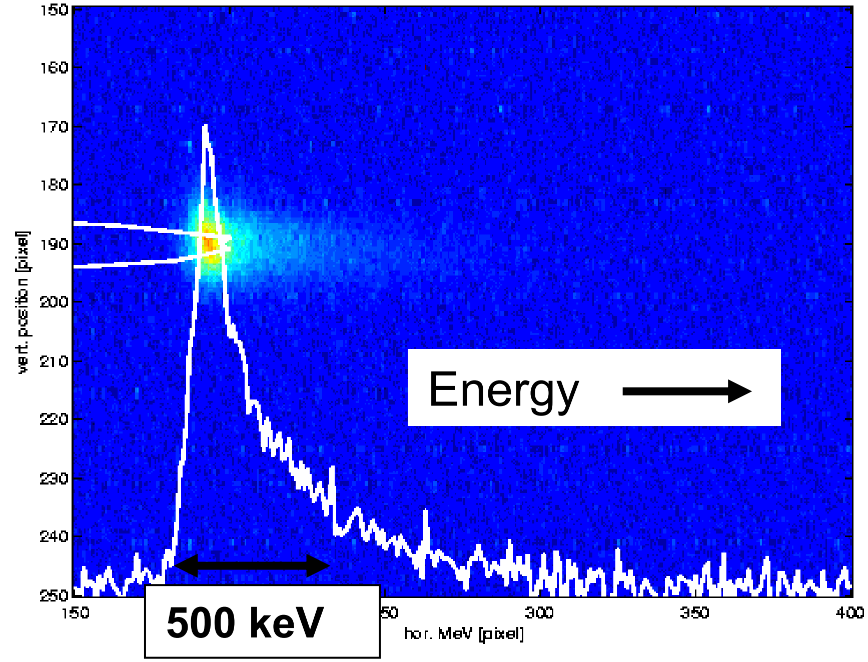


- Continuous measurement of the emittance during a period of ~1.5 hours (1 nC, 127 MeV)
- In this example, the projected normalized 90% rms emittance is ε_n = 1.6 mm mrad
- Jitter 2 - 3 % (rms) → agrees with the statistical error

Fitting method, 100% emittance
Tomography, 100% emittance
Fitting method, 90% emittance
Tomography, 90% emittance

Energy measured after 1st bunch compressor





- Typical energy jitter: dE/E = $5 \cdot 10^{-4}$ (rms) at 127 MeV
- Uncorrelated energy spread < 25 keV (resolution limited)
- Problem: drifts due to temperature effects → temperature stabilization of low level rf electronics etc in work

⇒ Energy jitter translates to timing jitter of electron beam due to chicane!

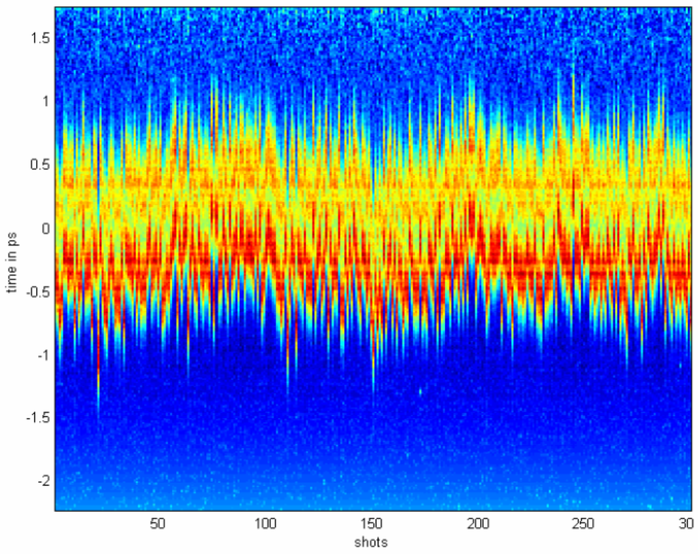
Beam Arrival Time

- Beam arrival time after acceleration measured with electro-optical decoding 200 fs rms

300 consecutive bunches on June 5th,

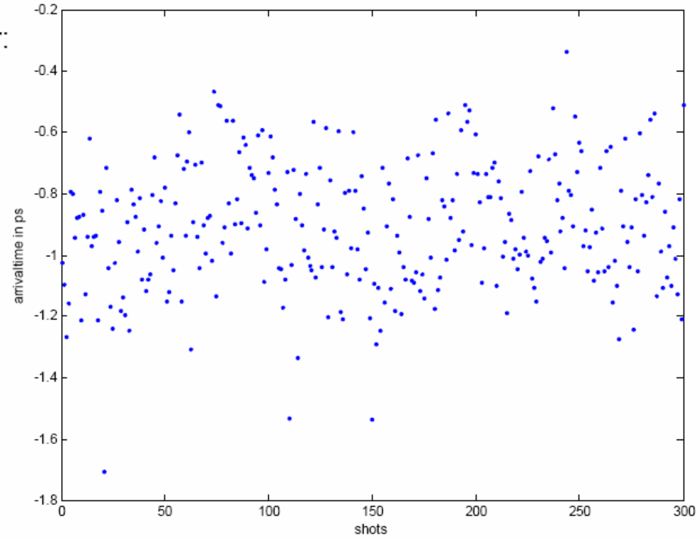
off crest,

1 nC



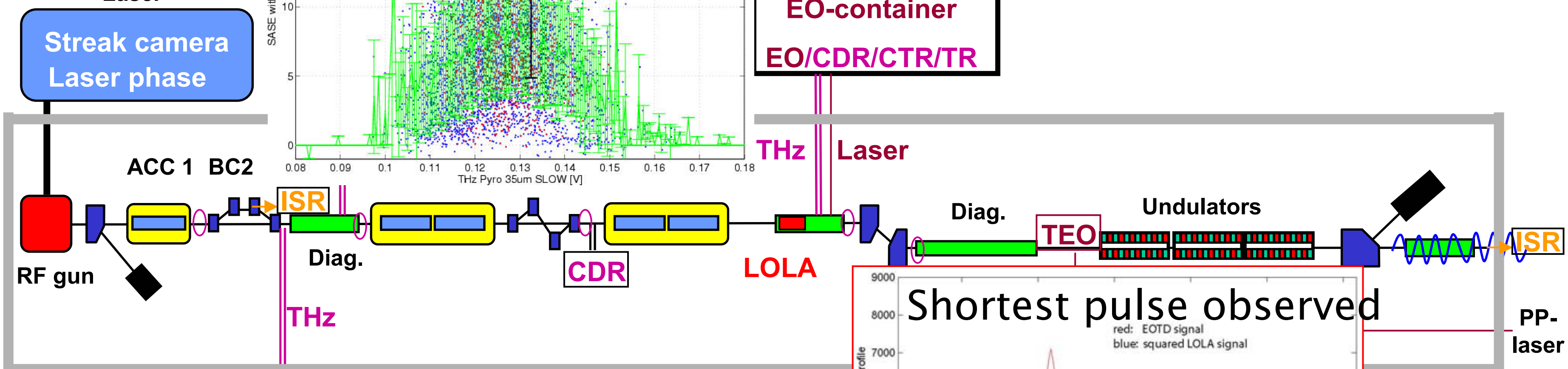
Arrivaltime jitter: 200 fs (rms)

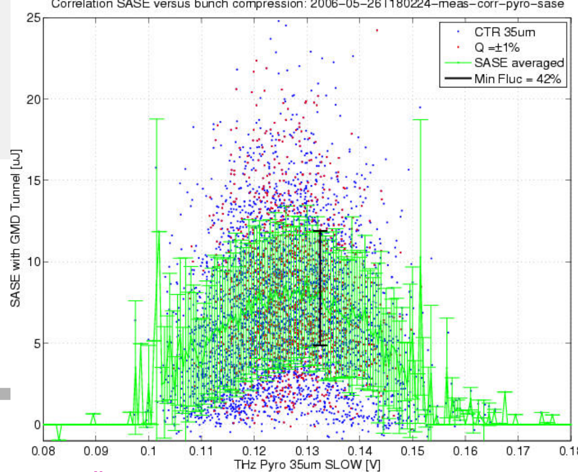
200 fs



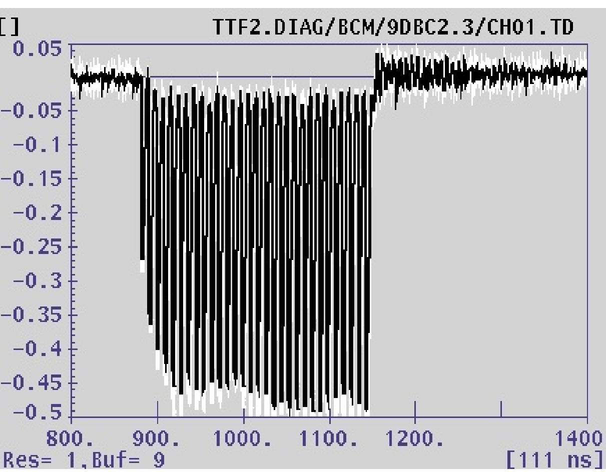
- Important for pump and probe experiments

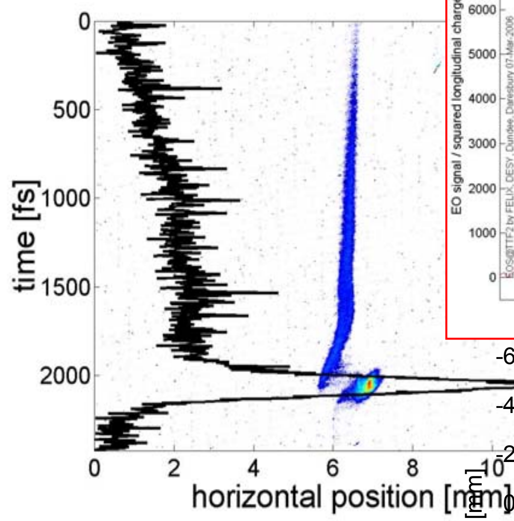
...ong. phase space

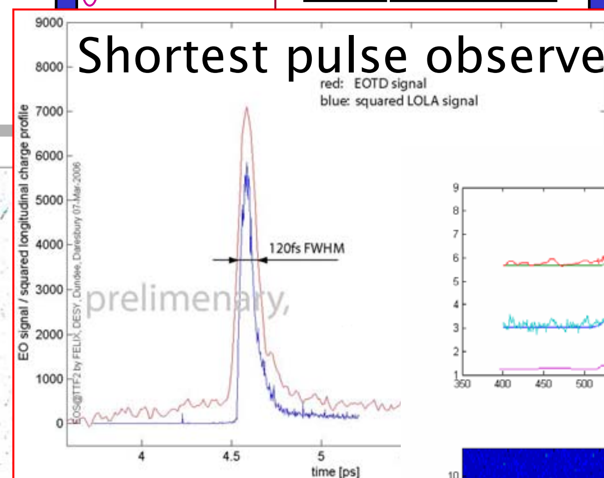


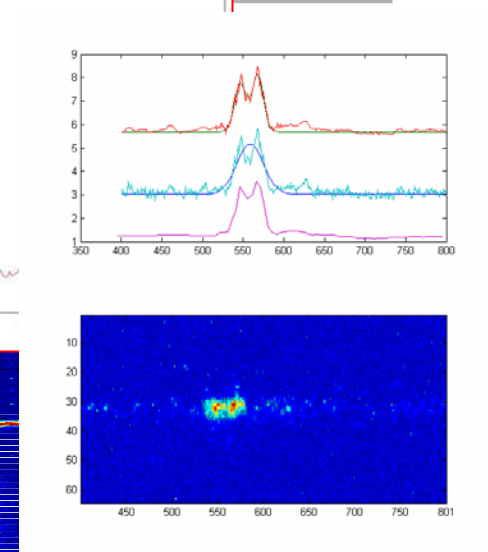


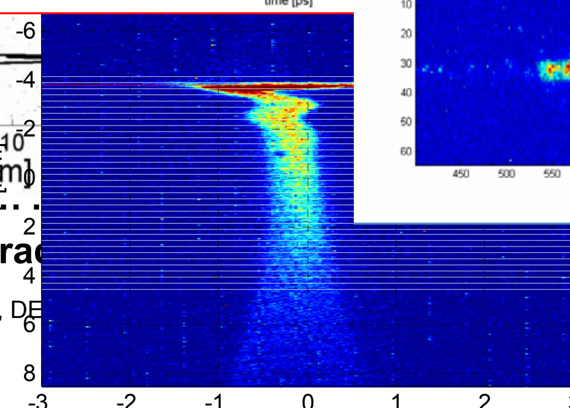
LOLA
⇒ bu
EO:











• CSR: coherent synchrotron ...
• CDR: coherent diffraction ra...

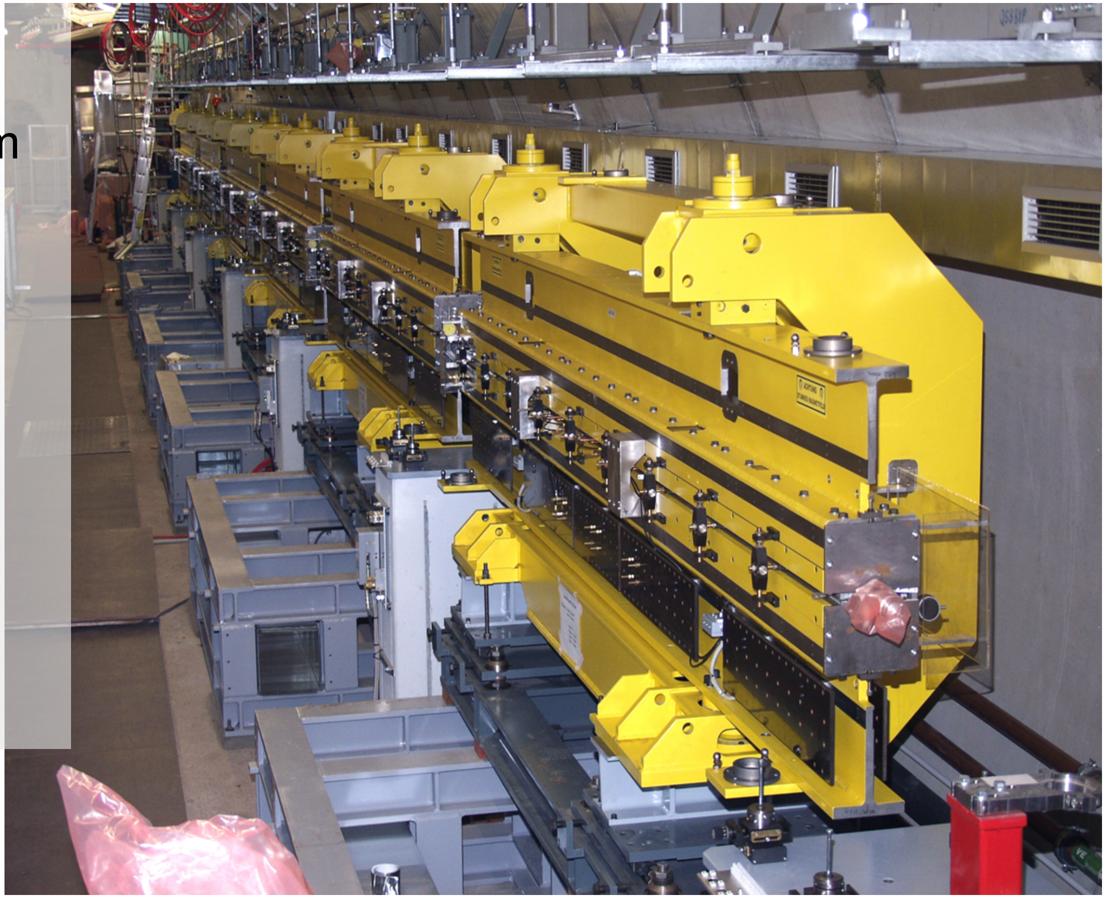
Holger Schlarb, DESY ESC 30-May-2006, DE...

Undulator Section

FLASH is a single pass high gain FEL operating in the SASE mode

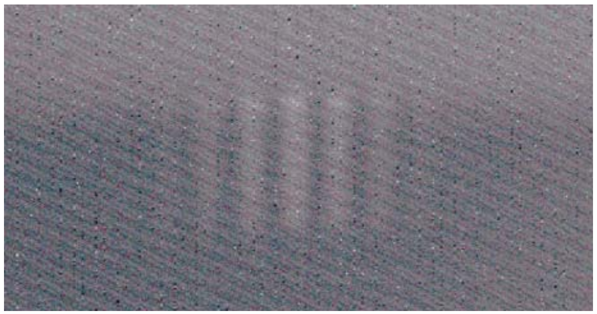
- 6 undulator modules
  - length 4.5 m each
- Permanent NdFeB magnets
  - B=0.48 T, K=1.23, λ_u = 2.73 cm
- Fixed gap of 12 mm

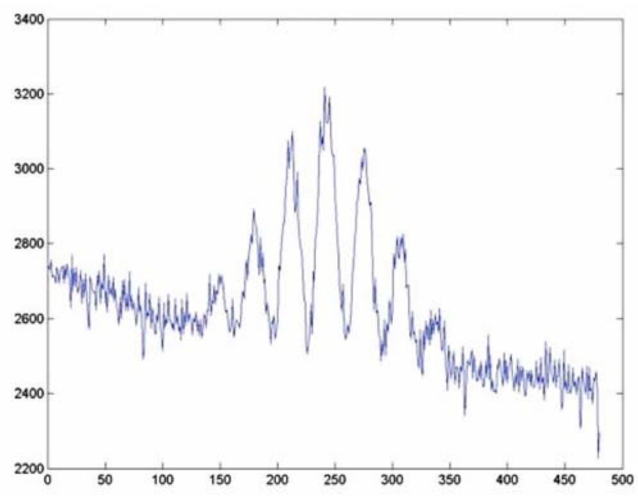
- Electro-magnetic quadrupole doublets between modules
  → provides flexibility to receive different electron energies
- Lasing from 100 nm to 6 nm
  (260 MeV to 1 GeV)



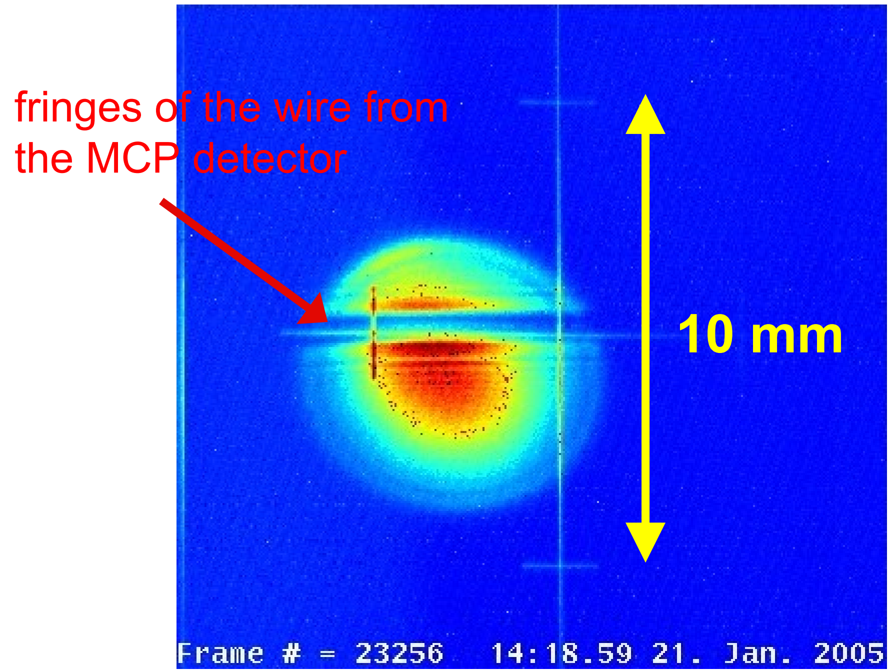
First Lasing at 32 nm

- First lasing at 32 nm achieved 14-Jan-2005



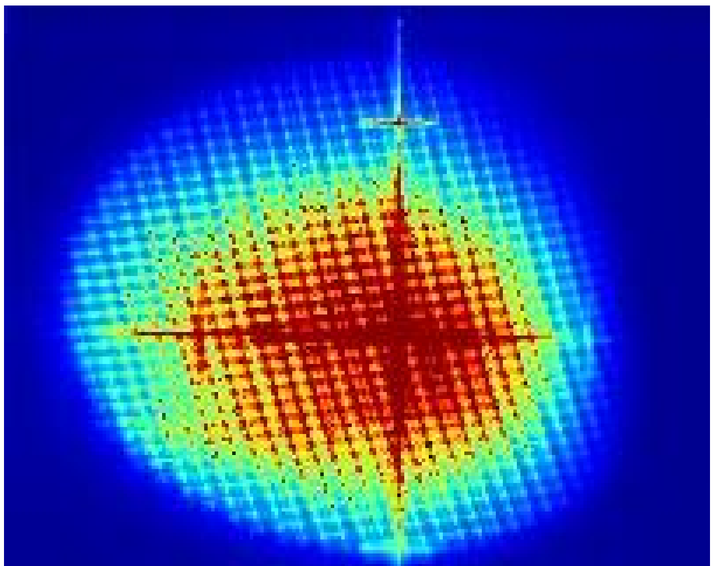


- Single shot diffraction pattern



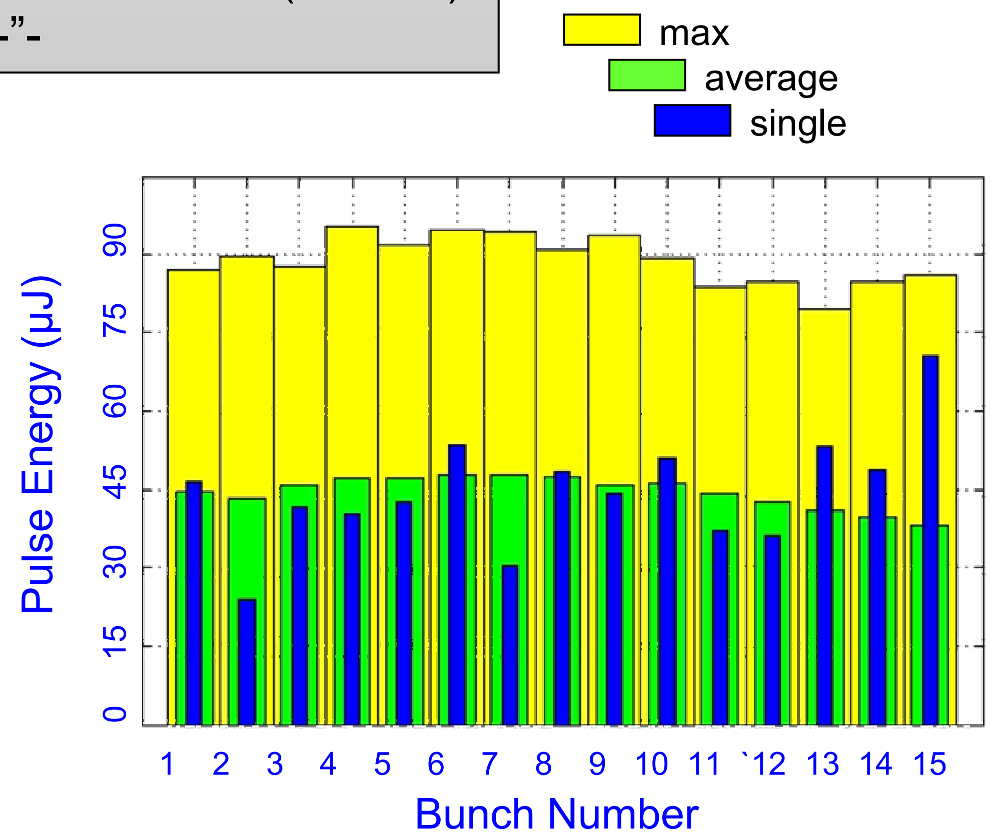
- FEL beam on a Ce:YAG crystal at 20 m from the undulator

Wavelength	32 nm
Average energy per pulse	48 μJ
Maximum energy per pulse	130 μJ
Radiation pulse duration	25 fs
Peak power (from average)	1.8 GW
Spectral width (FWHM)	0.8%
Angular divergence (FWHM)	160 μrad
Peak Brilliance from max	~6 10^{28} ph/s/mrad²/mm²/(0.1%bw)
Peak Brilliance from average	~2 10^{28} -"-

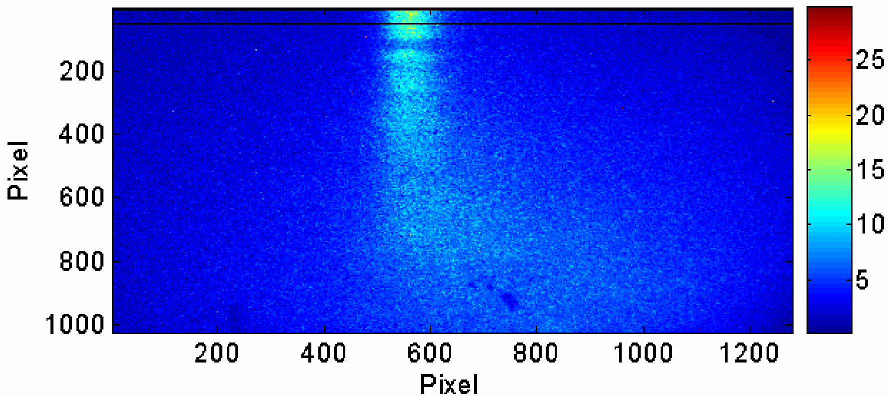


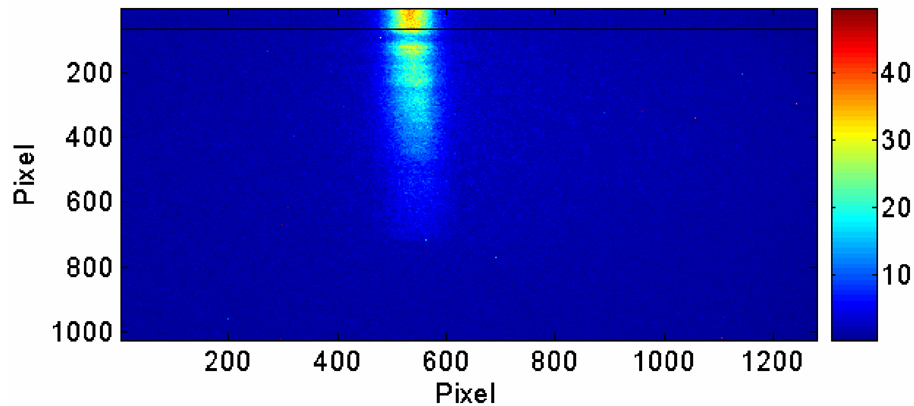
3 mm spot size (FWHM) @ 18.5 m distance
angular divergence 160 μrad
→ high degree of coherence
A gold mesh (0.25 mm pitch) in front of the Ce:YAG screen is used as intensity monitor.

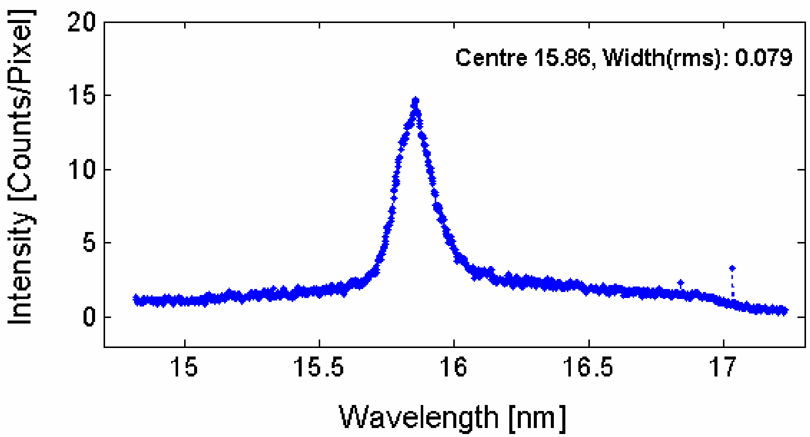
Multibunch SASE signal (μJ) recorded with MCP Detector

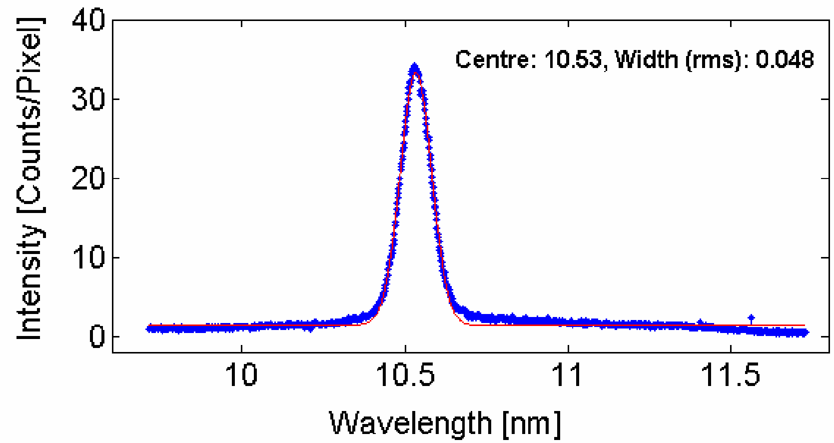


Spectra of 2nd and 3rd harmonics







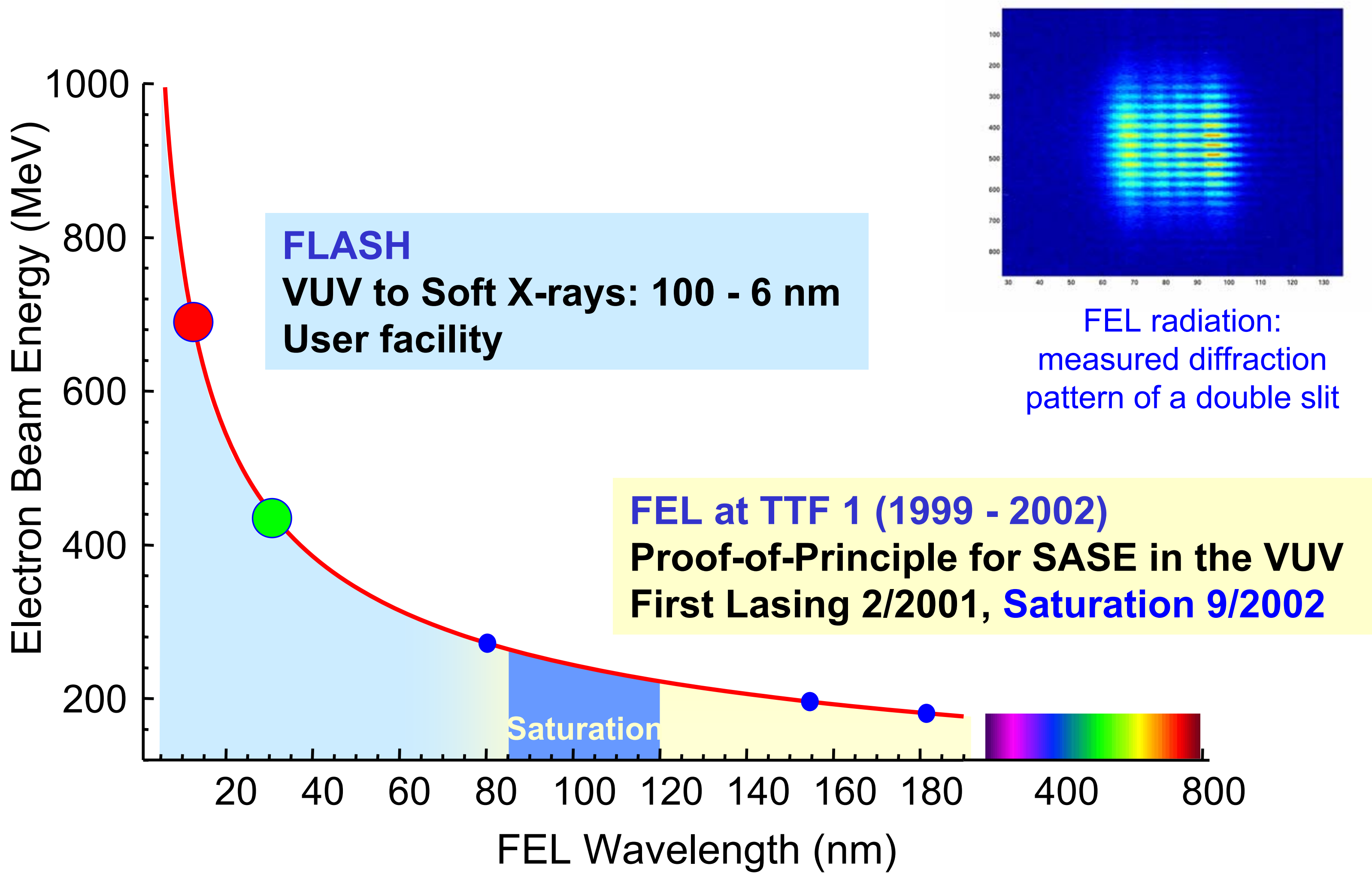


Center λ=15.86 nm

Center λ=10.53 nm

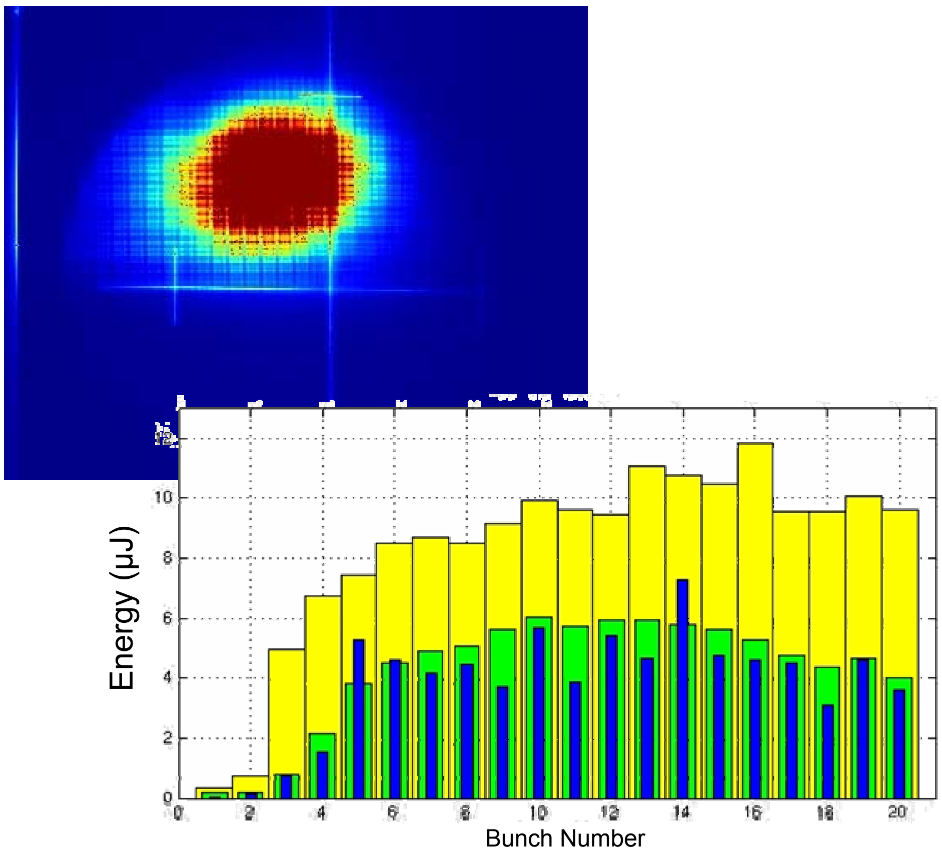
→ Intensities about 0.5 % of fundamental

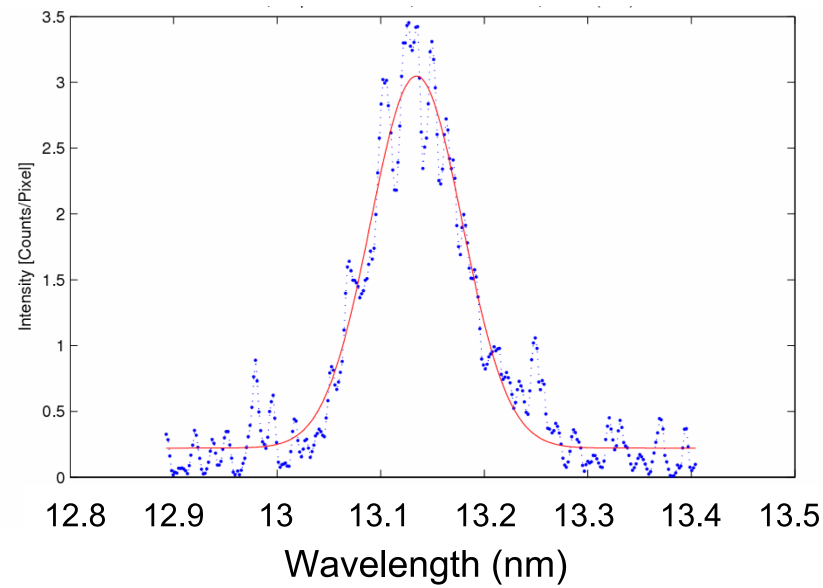
Beam Energy and Wavelength



26-Apr-2006: First SASE at 13 nm achieved

- About 4 hours after starting the SASE search shift
- Beam energy 693 MeV, SASE wavelength 13.1 nm
- Average Energy ~6 µJ/pulse, still in the exponential growth





Accelerator studies to improve machine performance

Major improvements & investigations:

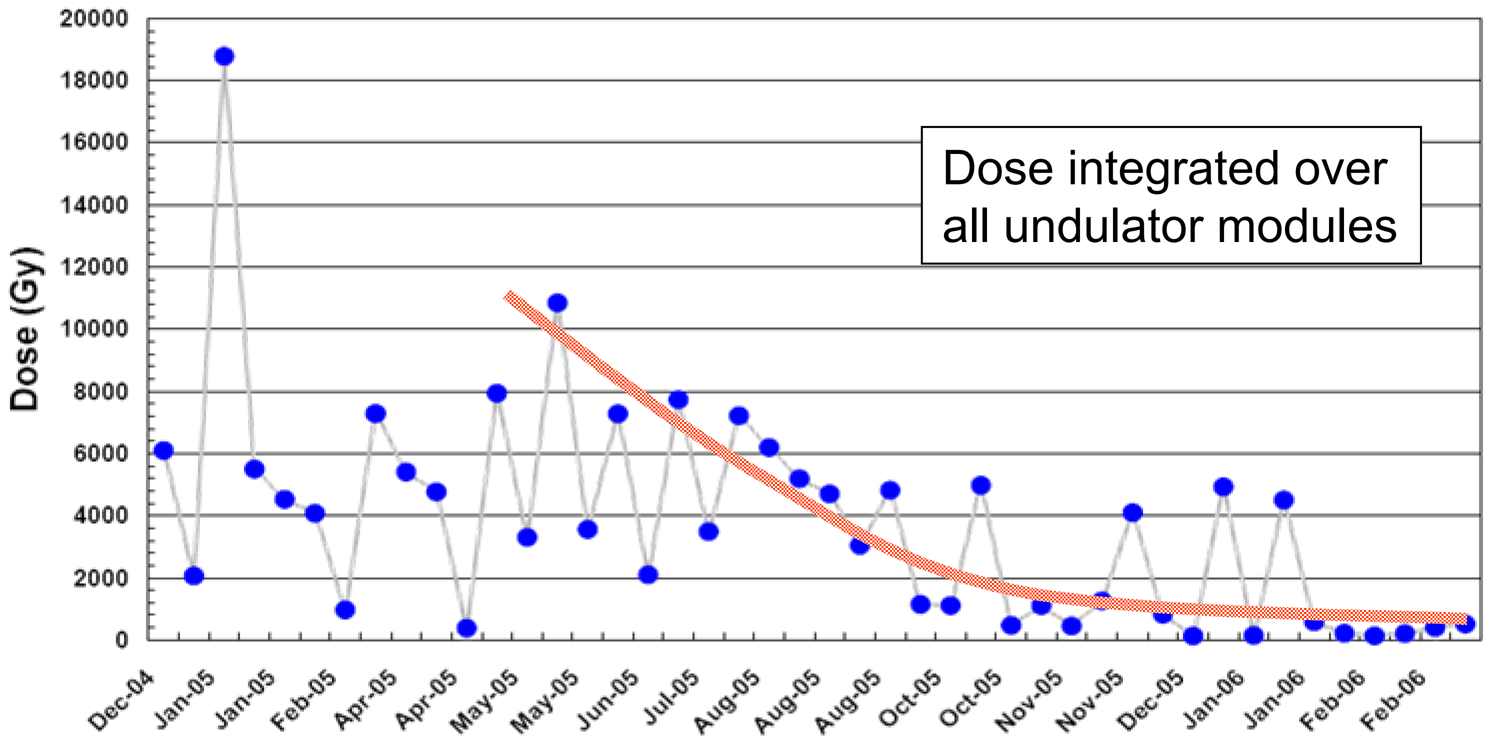
- Improve magnetic & RF reproducibility of machine
- Commissioning and systematic studies of BPM responds
- Systematic transfer measurements in accelerator (short in quad)
- Changed optics to low beta function at BC
- Studies of residual dispersion and compensation in accelerator
- FPG regulation to stabilize RF gun
- Beam based alignment in undulator section
- Long pulse operation at moderate beam loading
- Installation of dark current kicker
- Commission & software upgrades for BLM system

Radiation Level Undulator Section

Darkcurrent from rf gun and beam losses may result in high radiation doses in the undulator modules

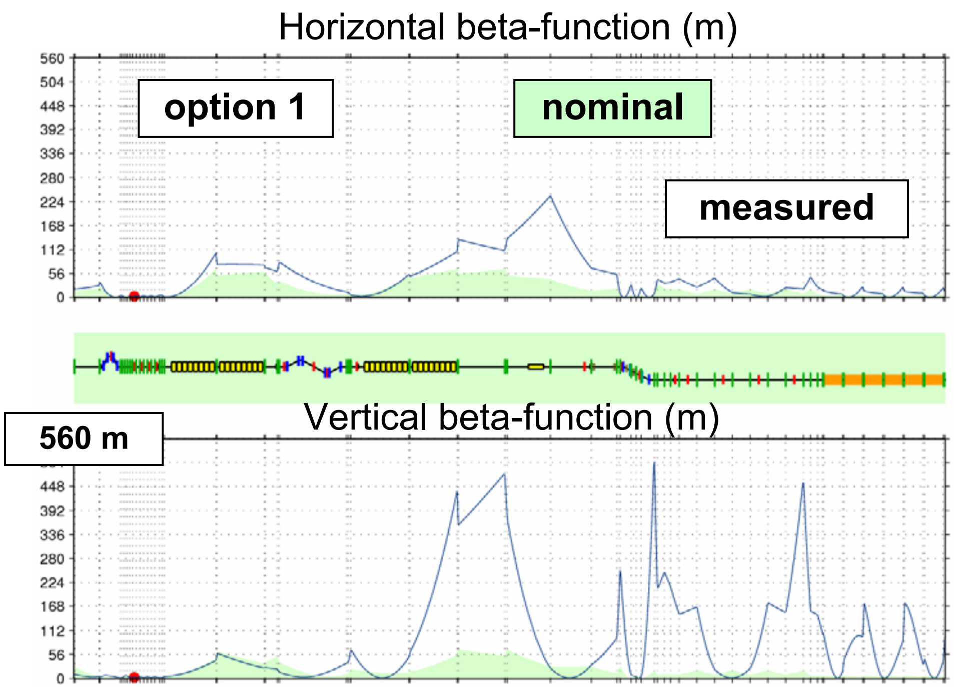
Level of radiation depends on careful set-up of the beam

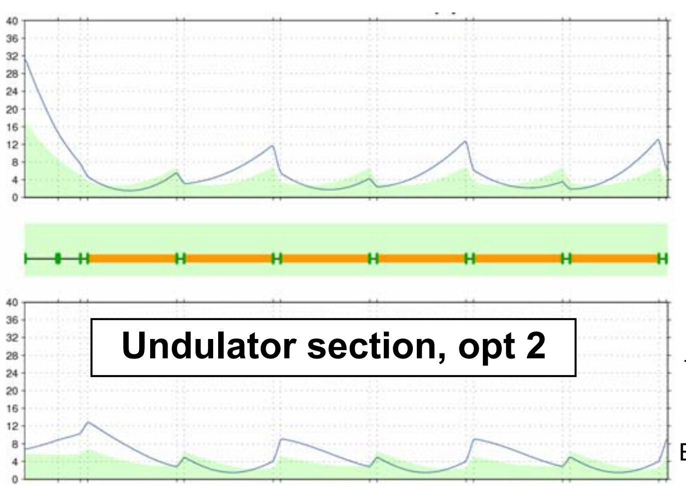
Level is constantly going down together with better tuning of the orbit and the commissioning of the machine safety system



Optics with reduced beta function

- Option 1 with large beta and poor agreement nominal/measured
- Option 2 with small beta and much better agreement

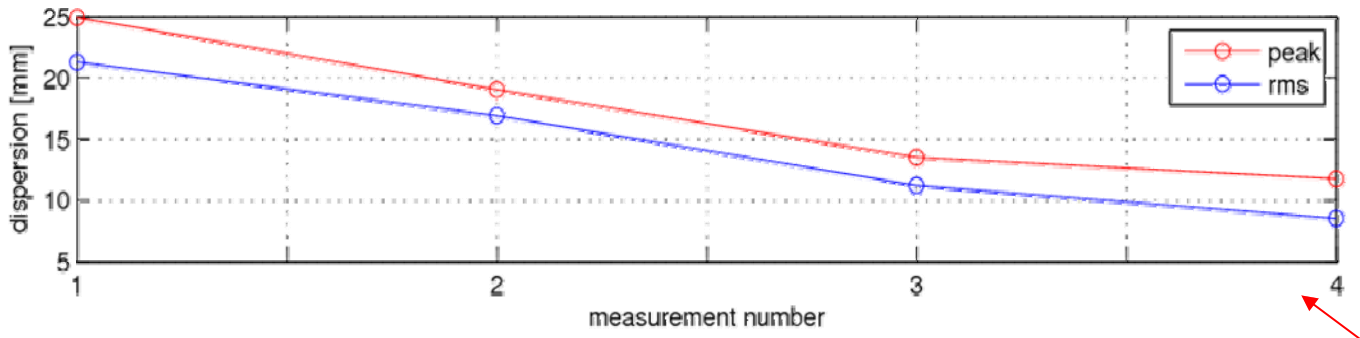




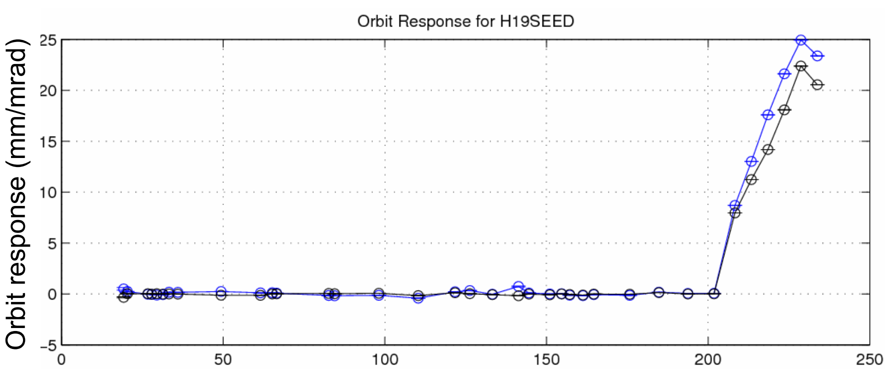
Example of Dispersion Correction

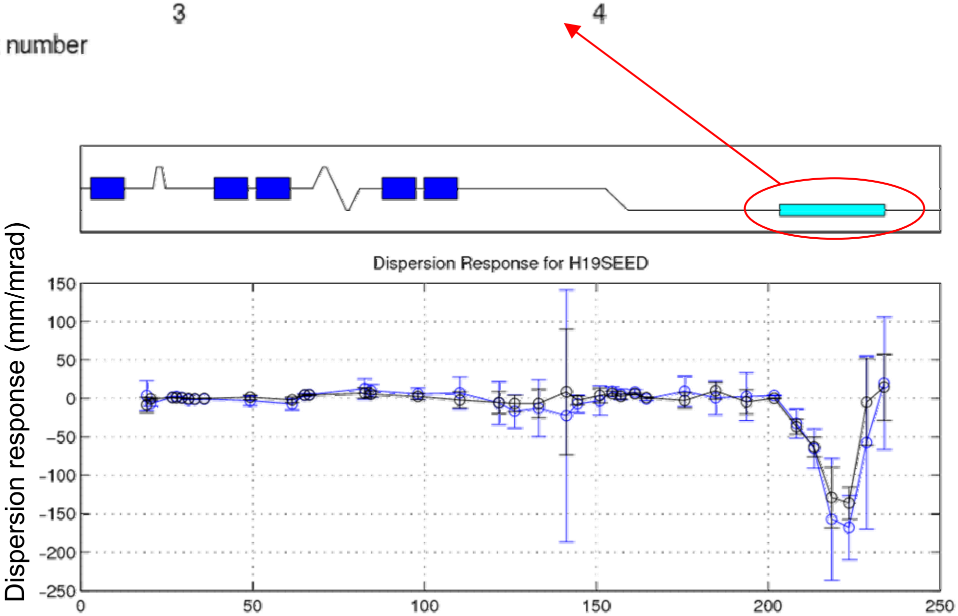
- Dispersion correction in the undulators

→ in this example, the horizontal dispersion has been reduced from 21.7 to 8.4 mm after 4 iterations by correcting the orbit



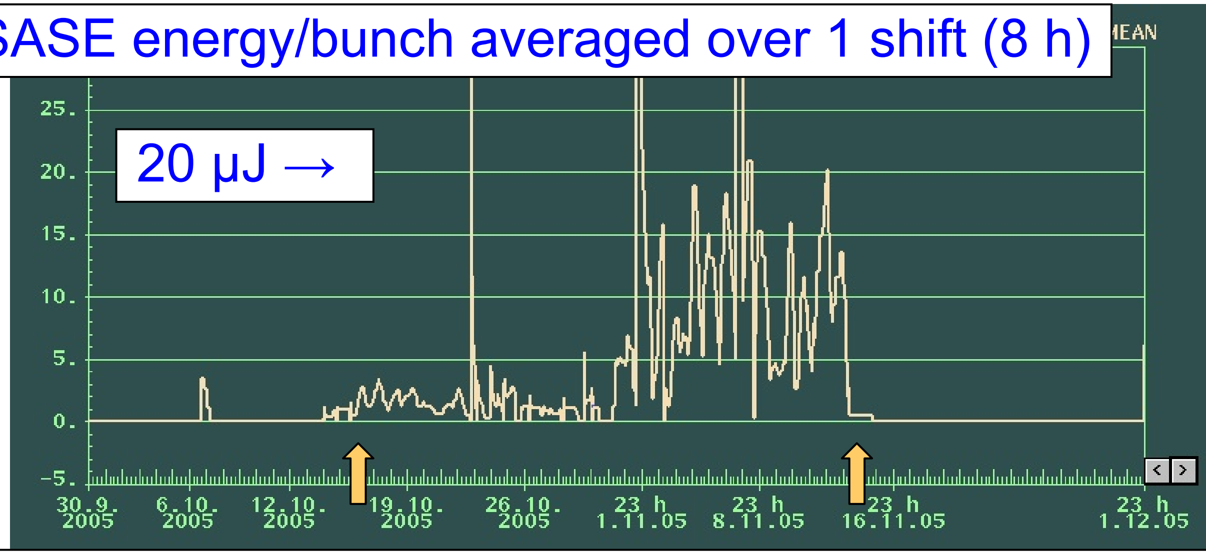
Example of the orbit and dispersion response on a corrector magnet



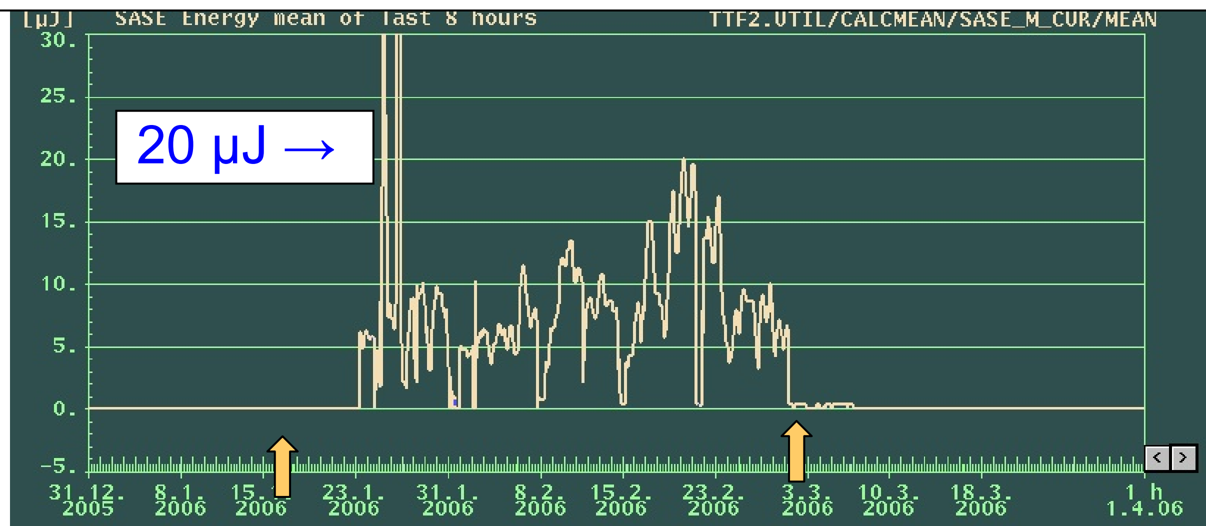


Average SASE energy

History of average SASE energy/bunch averaged over 1 shift (8 h)



User run 17-Oct-2005 – 13-Nov-2005



User run 16-Jan-2006 – 26-Feb-2006

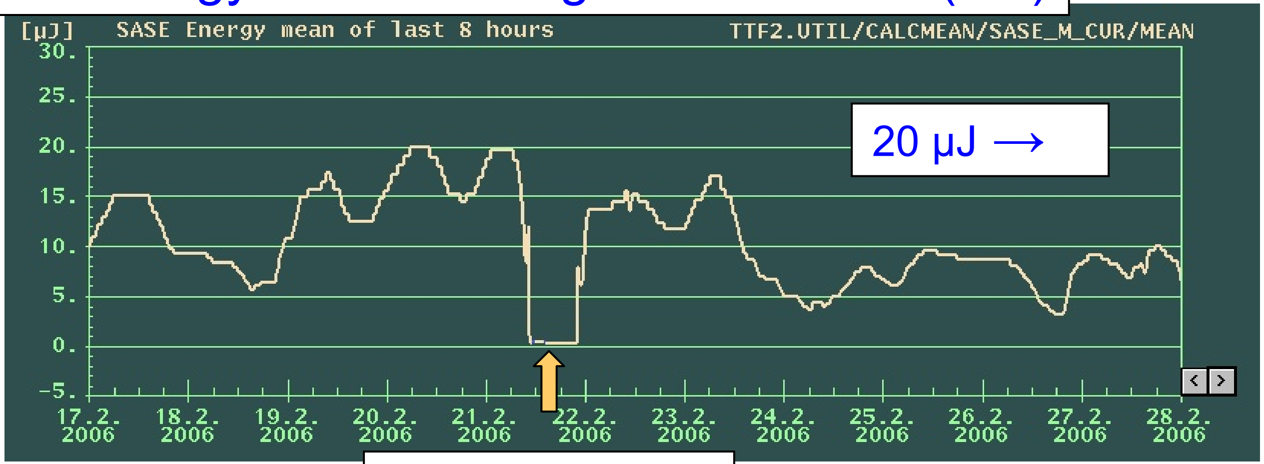
→ quite a big improvement since Nov 2005

due to streamlined organization of tuning shifts and development of procedures to keep good beam

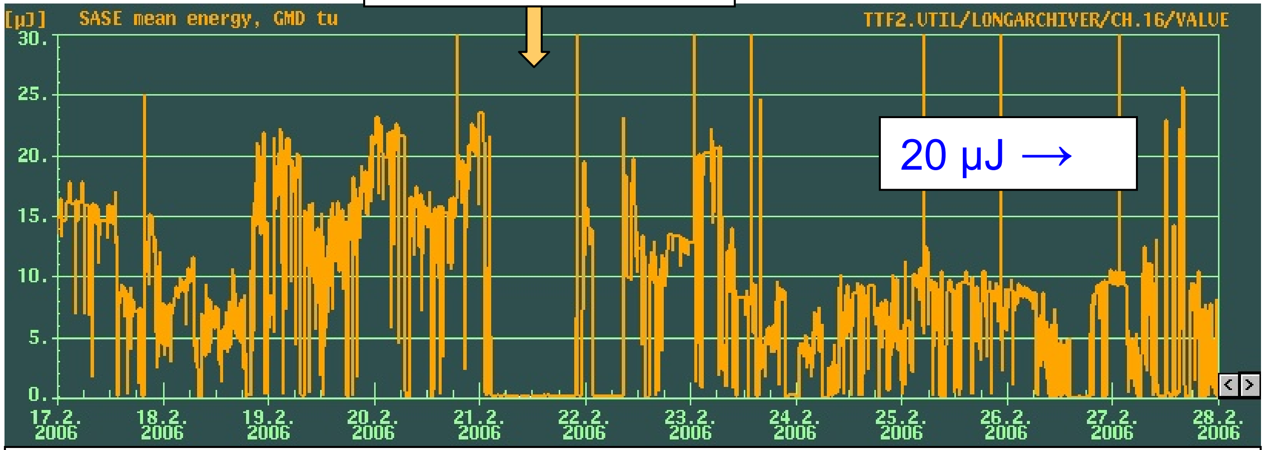
Note:
some users do require high average radiation energy,
some users do even attenuate to 1 µJ level,
may vary from shift to shift

Example of 11 days of operation

Average SASE energy/bunch averaged over 1 shift (8 h)



Maintenance day



17-Feb-2006 – 28-Feb-2006

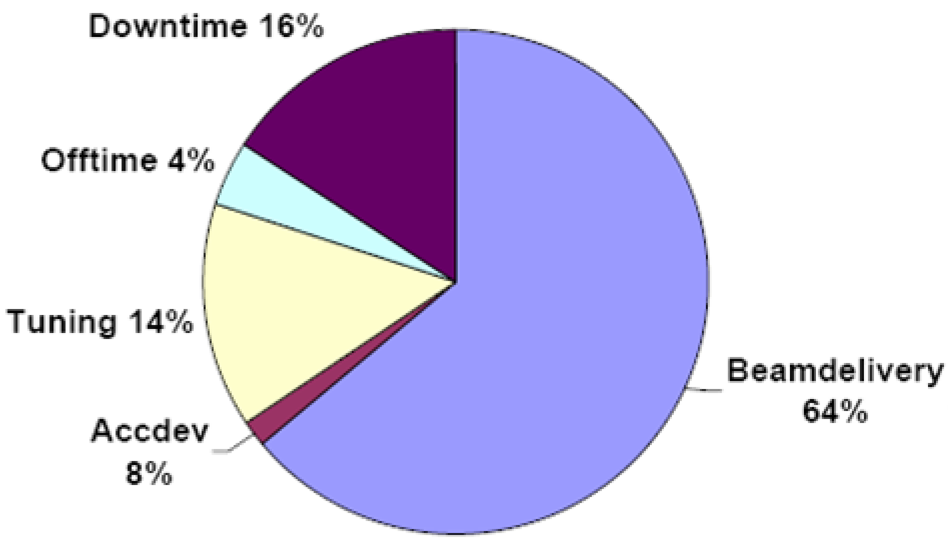
Average SASE energy/bunch averaged over some minutes

- Note: intrinsic fluctuation of SASE in the range of 30 %

VUV-FEL Operation 1st User Period

First User Period 25-Jul-2005 to 26-Feb-2006

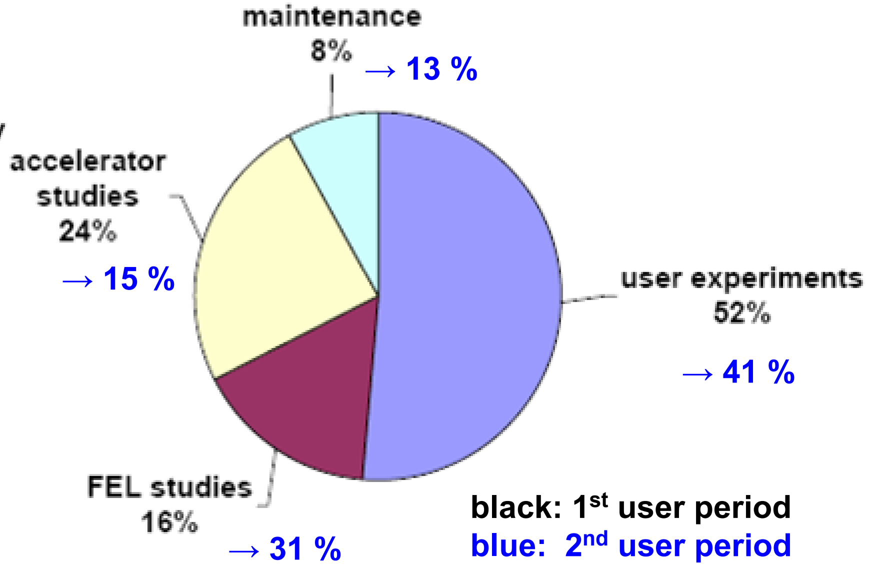
3120 h of operation scheduled for users



Beam time allocation

is divided between

- User FEL experiments
- FEL studies to further develop the FEL
- accelerator studies in a general sense, also for XFEL and ILC related studies



Schedule and Milestones

2008 • Seeding option (mid 08)

• 1 GeV beam energy

• Shutdown: installation 6th module etc

2007 • Lasing with long bunch trains (>30)

• Variation of wavelength on shift-to-shift basis

now

• First lasing at 13 nm

2006 •

• FEL experiments start

• saturation at 32 nm achieved

2005 • first lasing at 32 nm

• first beam to dump

• Commissioning injector started

2004 • Commission RF gun at PITZ finished

User Experiments

FEL and SASE Studies

FEL Studies

Three weeks preparation before each user block

VUV-FEL is a user facility

Improvement of the machine is on-going

- Stability
  - Injection: stability of laser profile, alignment injector section
  - Low level rf: feedbacks and stability
    - new FPGA based hardware with improved precision installed for RF gun
    - stabilize ambient temperatures
  - slow orbit, phase, and bunch length feedback
  - Improved procedures to obtain and maintain good SASE radiation
  - Investigation and fixing external noise sources (EMI)
  - Arrival time stability (LLRF & LbSyn.)
- Orbit and optics
  - Finished measurements of transfer functions: led to a much better understanding of optics and gave a big push in BPM improvements
  - Dispersion measured and partially corrected
  - Low beta function optics tested with success: 13 nm lasing within 4 h
  - Beam based alignment undulator section ongoing, BPM resolution now sufficient
  - Understanding non-linear beam dynamics started

Steps towards design goals

- Lasing at shorter wavelengths and switching between wavelength
  - 44, 32, 27 and 13 nm lasing achieved (limited by the present energy reach)
- Lasing with bunch train pattern and long pulse trains (> 30 bunches)
  - 100 kHz, 250 kHz, 1 MHz and lasing with < 30 bunches achieved
- Lasing with higher repetition rate
  - Currently 5 Hz running, 10 Hz to be tested
- Repair and install modules
  - Old ACC3 to be replaced, ACC5 repair 4 tuners
  - Install new module ACC6 to reach 1 GeV (→ λ=6 nm)
- Install 3rd harmonic cavity
  - downstream ACC1 to improve longitudinal beam profile
- Synchronization of facility to fs-level
  - Installation of laser based synchronization system (2007)
- Seeding option not before mid 2008

Summary

- The new name of the VUV-FEL is FLASH
- During the 1st user period 2005/6, we provided 2000 h of FEL beam for user experiments at 32 nm (64 % of scheduled)
- For the 2nd period 2006/7, 3360 h are scheduled
- The important milestone of lasing at the present energy reach (700 MeV, 13 nm) achieved
- Stability and performance in the last run much improved compared to earlier runs in autumn
- Ongoing improvements in various places: LLRF stability, Diagnostics and new timing system, EMI (power distribution, grounding, magnet power supplies etc)
- Installation of ACC6 and 3rd harmonic, replacement of ACC3 and repair of ACC5 scheduled 12-Mar – 30-Jun-2007