11th Workshop on RF Superconductivity
September 8-12, 2003

Travemünde/Lübeck, Germany

Status of the TTF FEL

Siegfried Schreiber, DESY

- Highlights from the TESLA Test Facility (TTF 1) Linac runs
- Upgrade to a user facility VUV FEL (TTF 2)
- Status and Milestones
- Summary

email: siegfried.schreiber@desy.de

The TESLA Collaboration

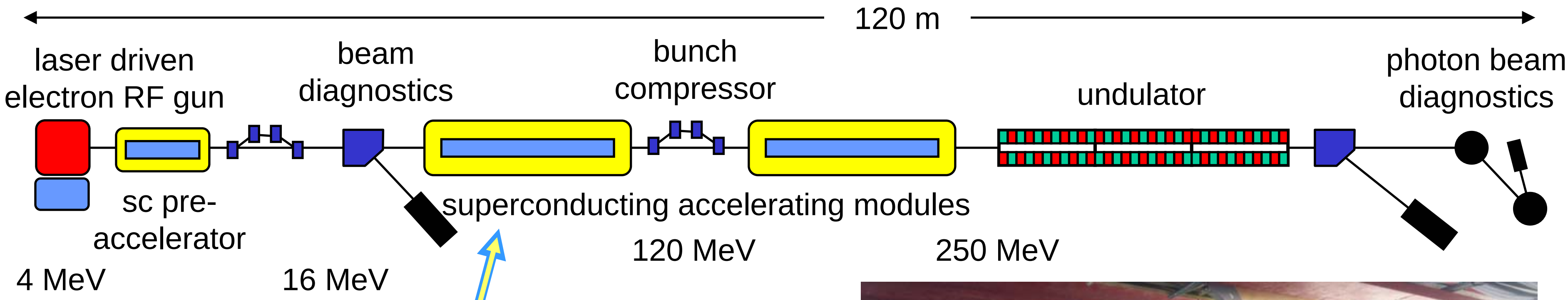
... has at present 3 projects:

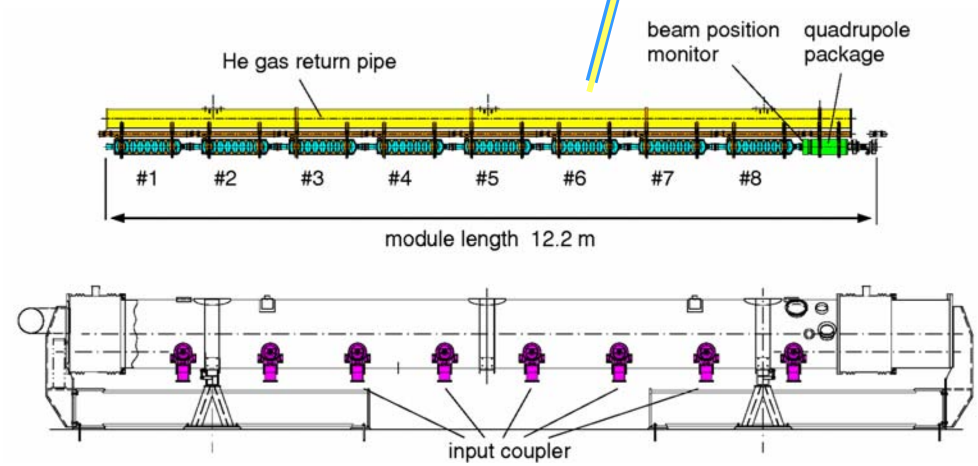
TESLA LC, TESLA X-FEL and VUV FEL (TTF2)

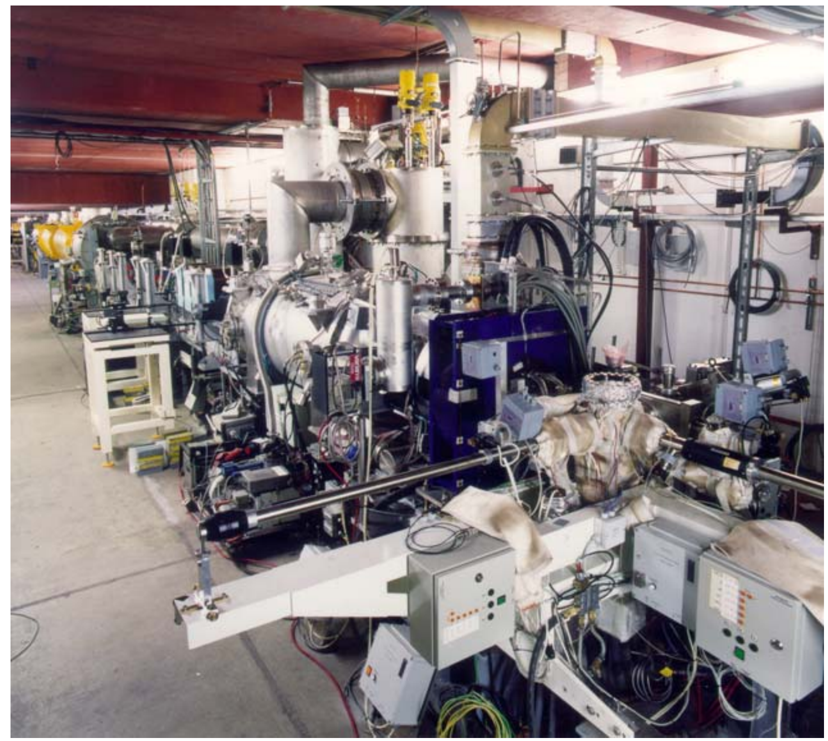
- **TESLA LC** is one of the competitors for the next HEP large accelerator facility.
- **TESLA X-FEL** is the core of a proposal for an European Laboratory of Excellence for fundamental and applied research with ultra-bright and coherent X-ray photons.
- **VUV FEL (TTF2)** will be the first user facility for VUV and soft X-ray coherent light experiments with impressive peak and average brilliance.

It is also a test facility for further TESLA LC related R&D.

TESLA Test Facility Linac (TTF 1)







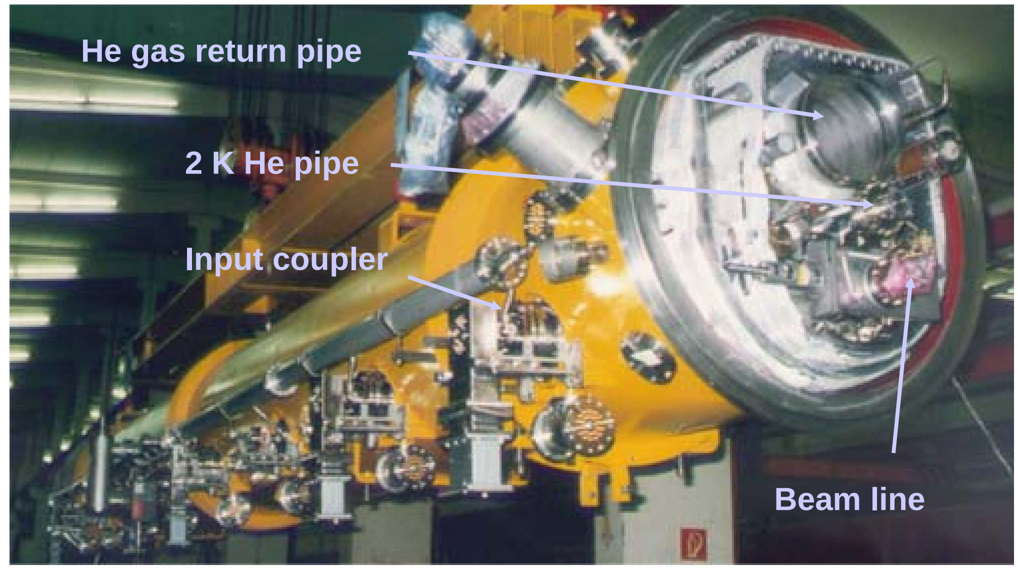
TTF/TESLA Accelerating Modules

C. Pagani et al,
INFN LASA

- **Three "generations" of cryomodule design, with increasing simplicity and decreasing costs**
- **Three 3rd generation modules assembled, 2 installed in TTF**

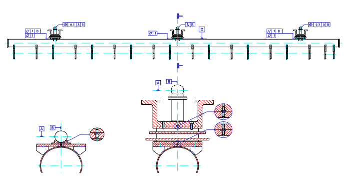
Length	**12 m**	
# cavities	**8**	
# quad doublets	**1**	
Static losses	**@ 2K**	**1.5 W**
	@ 5K	**8 W**
	@ 50 K	**70 W**

- Eight 9-cell TESLA acclerating structures and a quadrupole/steerer package



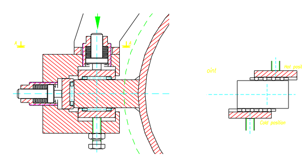
- **Example of improvements**

Simplified alignement Strategy



"Finger Welded" Shields

Sliding Fixtures @ 2 K

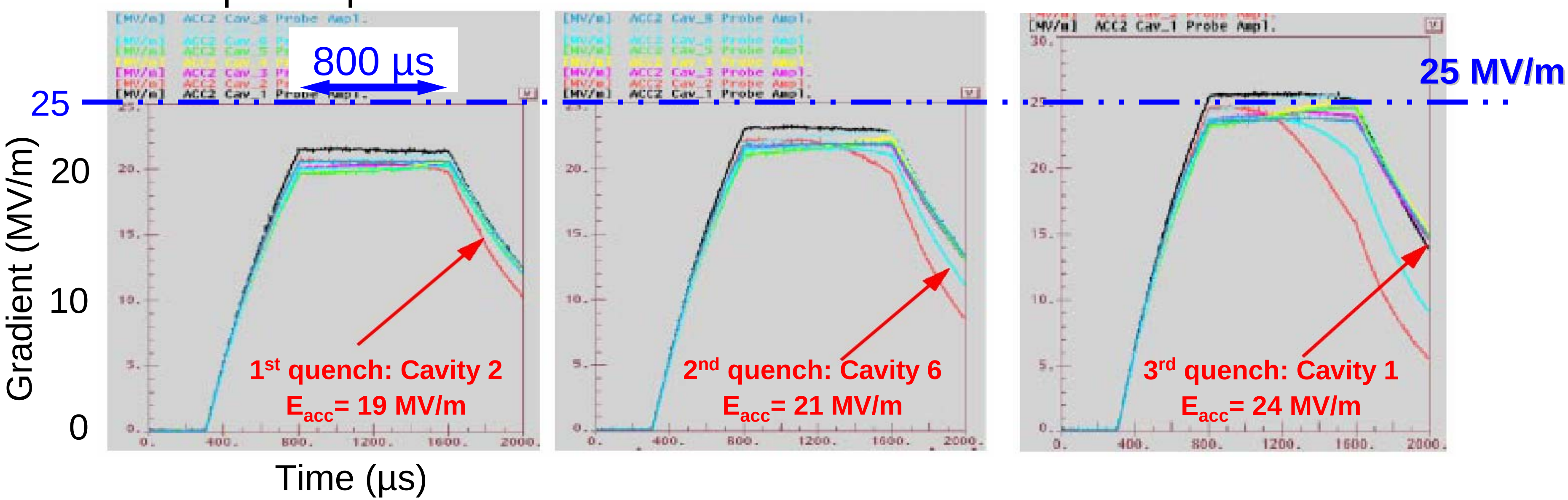


Qualification tests in LASA

Experience from TTF 1 Operation

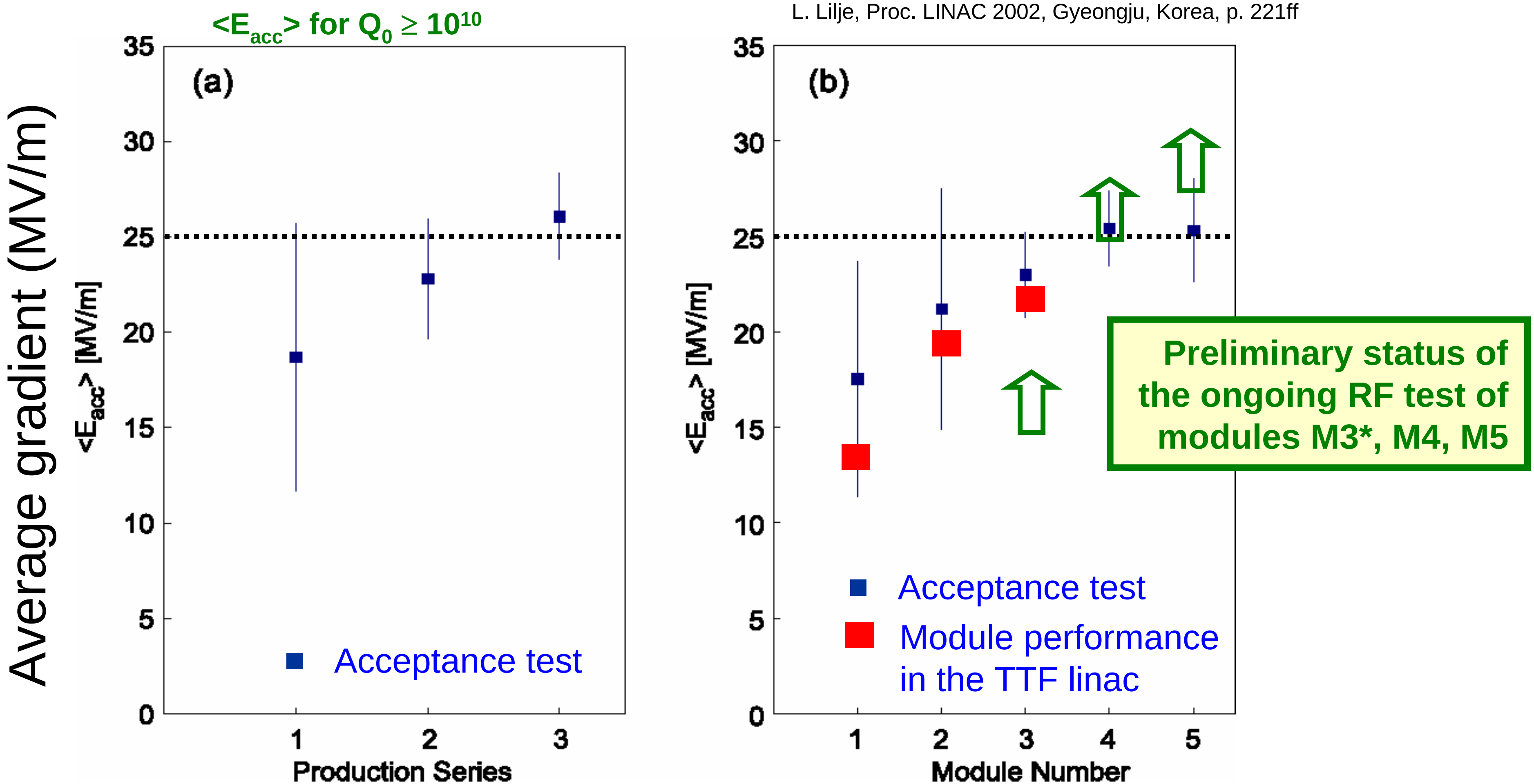
- Maximum obtainable gradient in a cavity
  - is given by low Q, high field emission or quench – but not by structural damage
  - is not a hard limit, it results in higher cryogenic load, radiation, and darkcurrent
- The vector sum low level RF regulation has a “quench detection” to avoid chain quenches

Example of quenches in a module



Cavity performance progress

L. Lilje, Proc. LINAC 2002, Gyeongju, Korea, p. 221ff

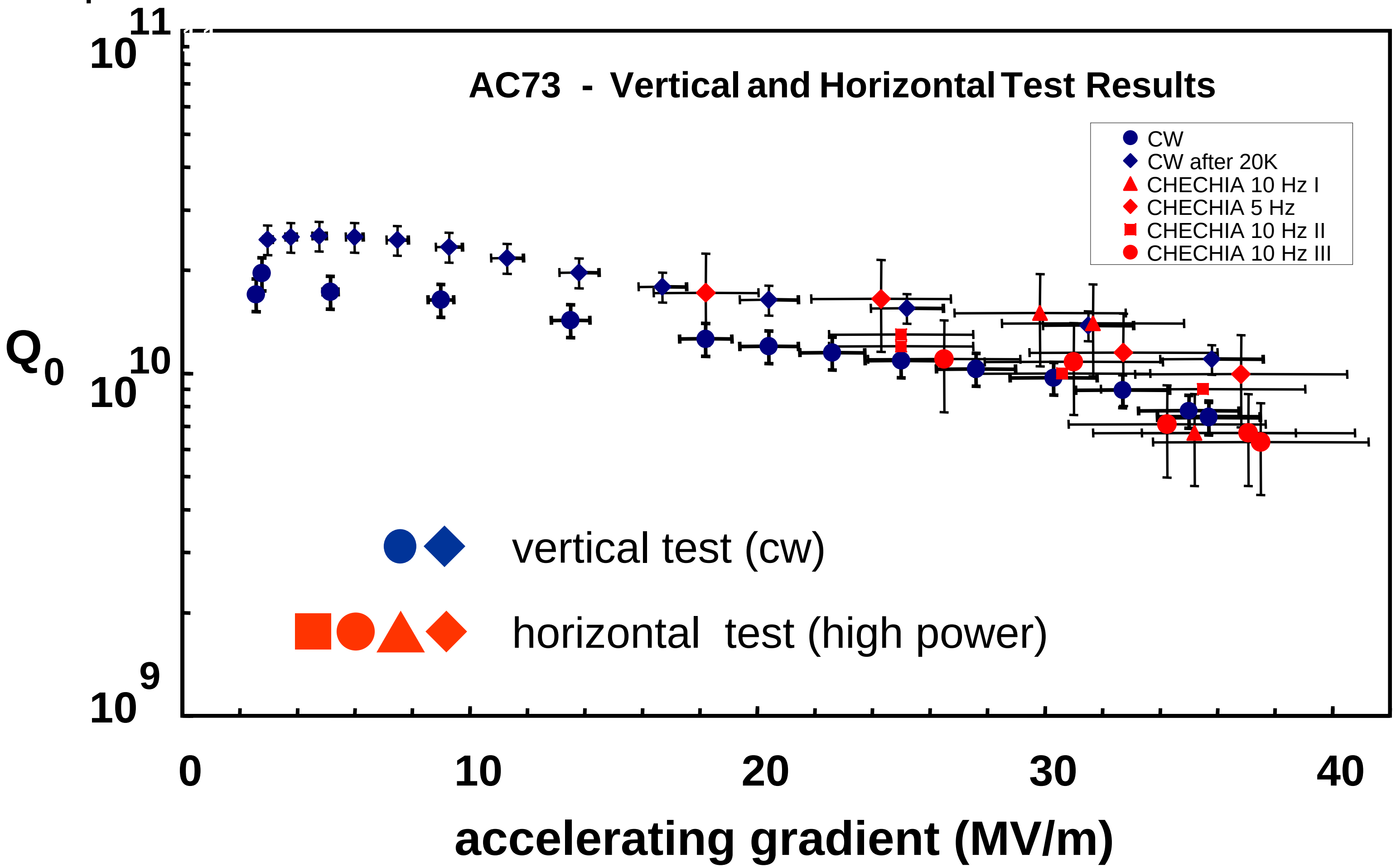


Progress mainly due to: improved welding and stricter Niobium quality control

Electro-polished 9-cell cavity Tests

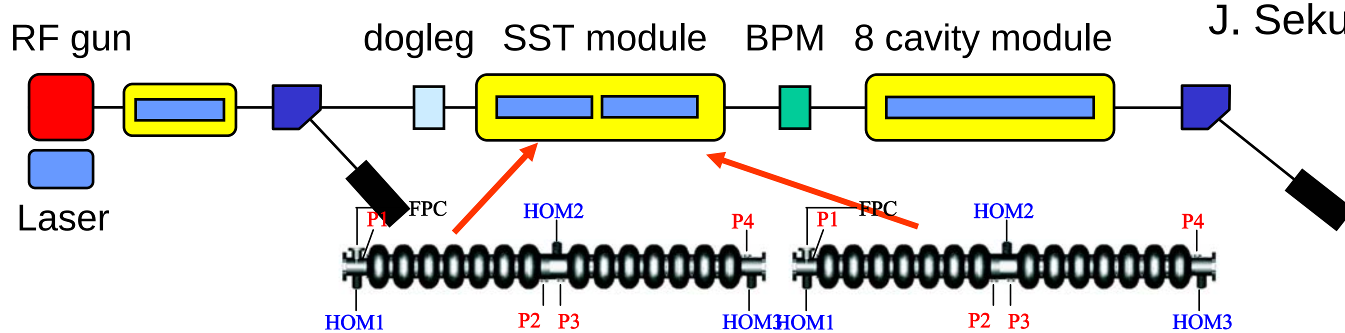
Example:

L. Lilje et al.

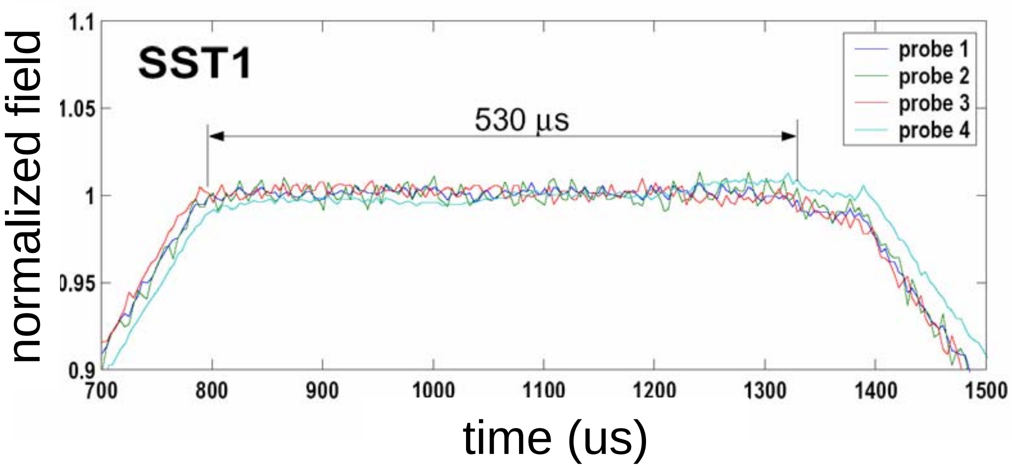


Beam Experiments with Superstructures

J. Sekutowicz et al.



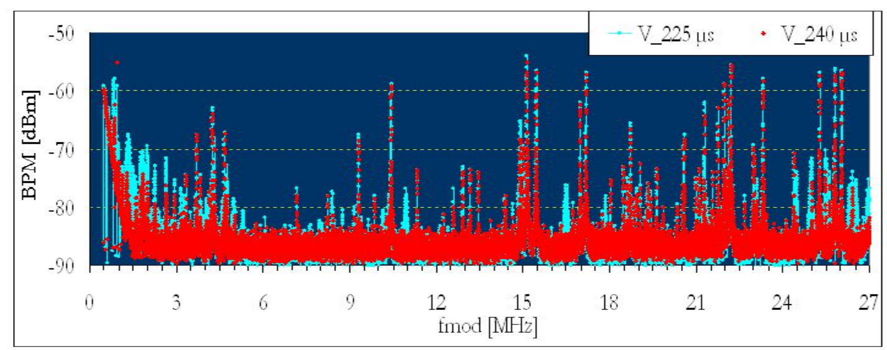
Energy refilling with beam loading (4mA)



- Weakly coupled cavities do accelerate TESLA bunch trains

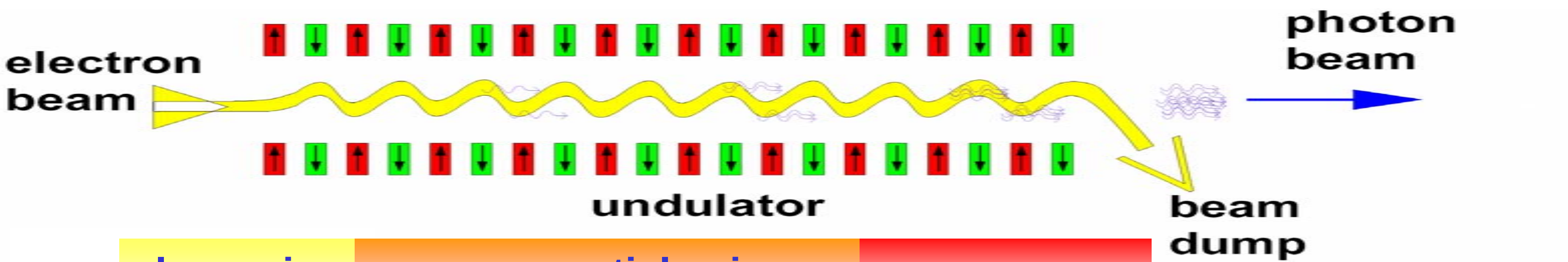
- Dipole modes (<2.6 GHz) are suppressed better than specs

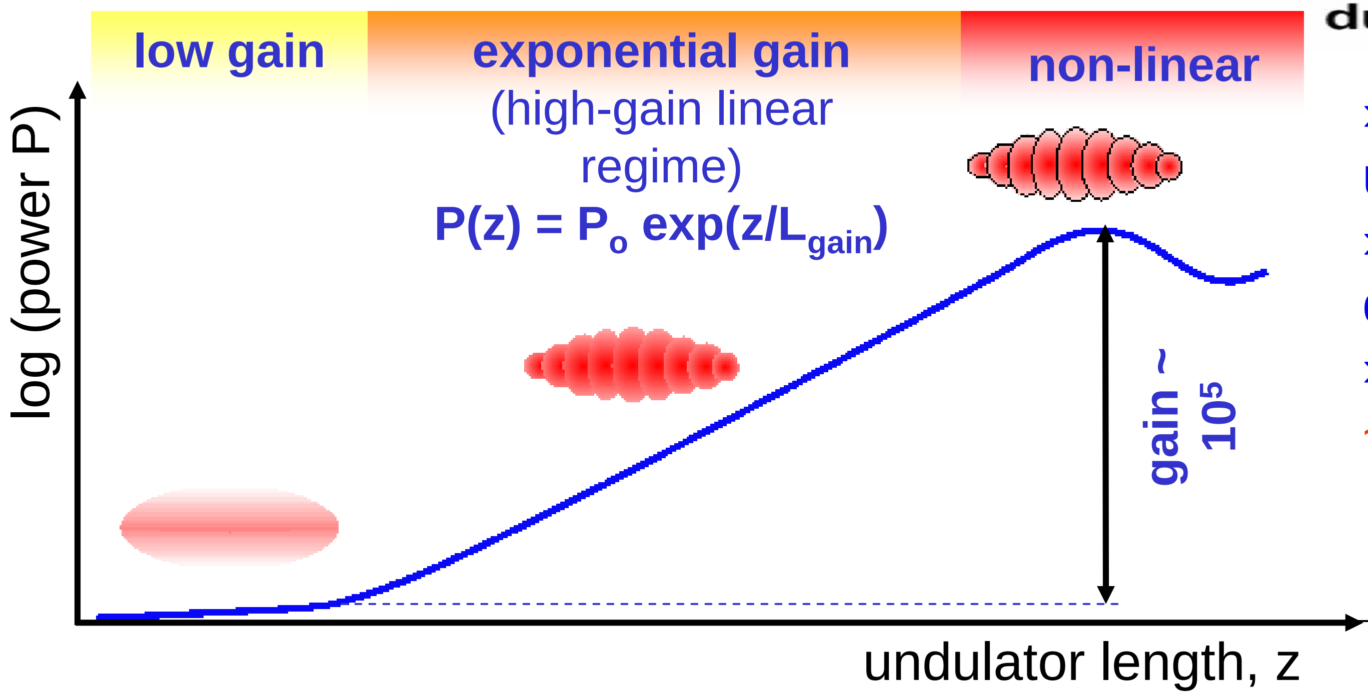
Search for HOM's with modulated bunch trains



Principle of a SASE FEL

SASE Self Amplification of Spontaneous Emission





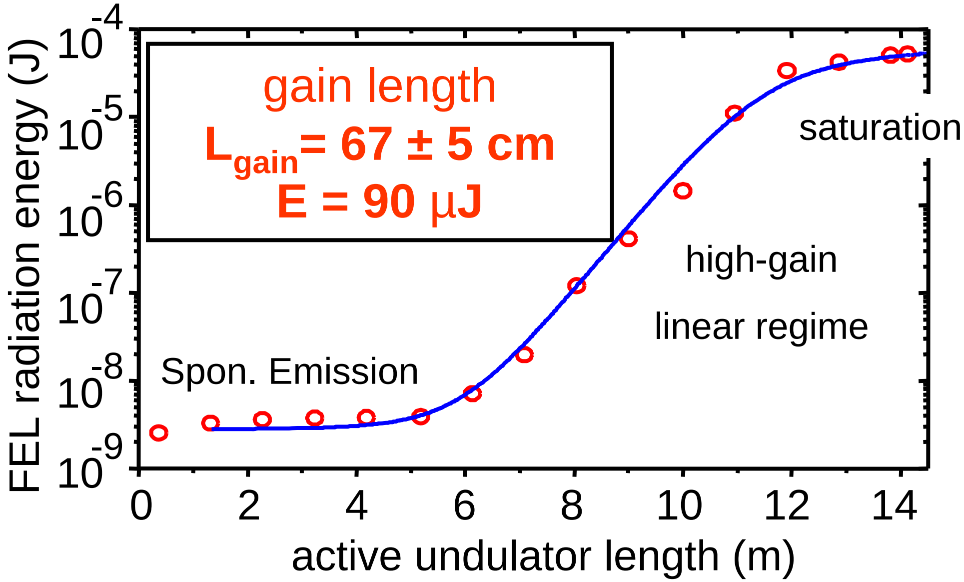
»» bunch interacts with undulator field
»» micro bunches develop
»» which emit coherently ~N^2 with $N \sim 10^6$

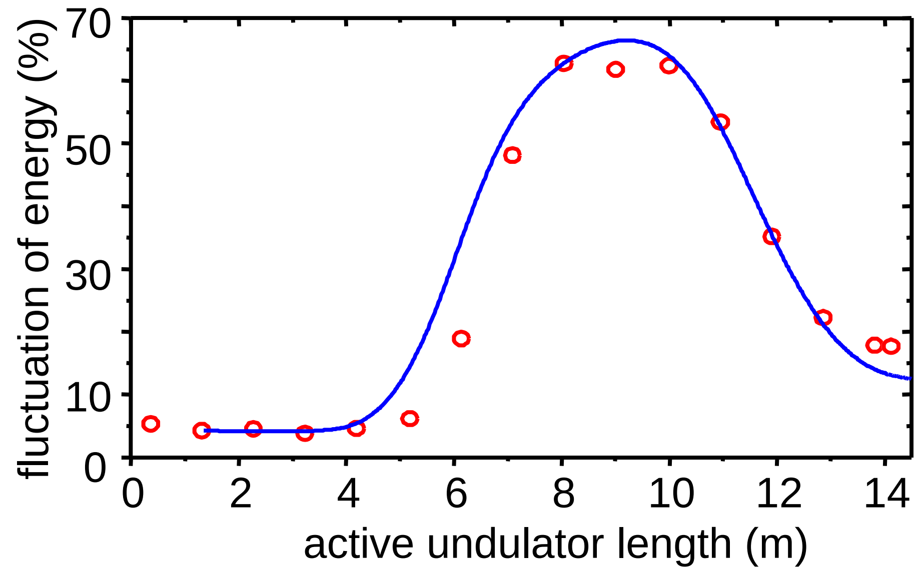
TTF 1: gain length
L_{gain} **= 67 ± 5 cm**

TTF 1 FEL has achieved Saturation

First Lasing: Phys. Rev. Lett. 85(2000)3825

Saturation: Phys. Rev. Lett. 88(2002)10482, The European Physical Journal D 20(2002)149





Saturation achieved Sep 10, 2001 with a wavelength of λ = 98.1 nm

FEL pulse length

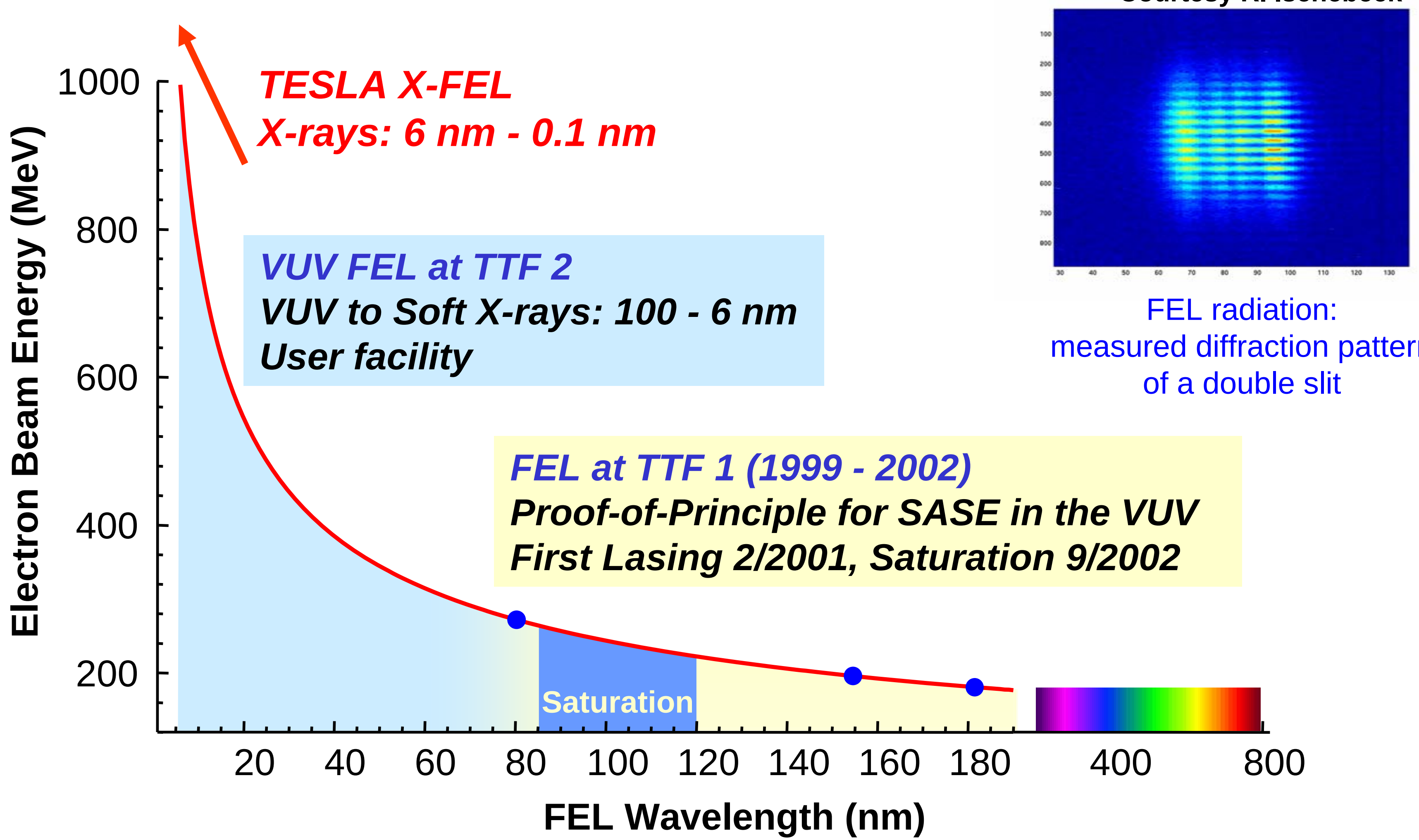
dE^2 = 1 / (nb. of modes M)

= 1 / 2.6

M • coop. length (5 µm) ≈

L_{pulse} = 50 fs

Beam Energy and FEL Wavelength



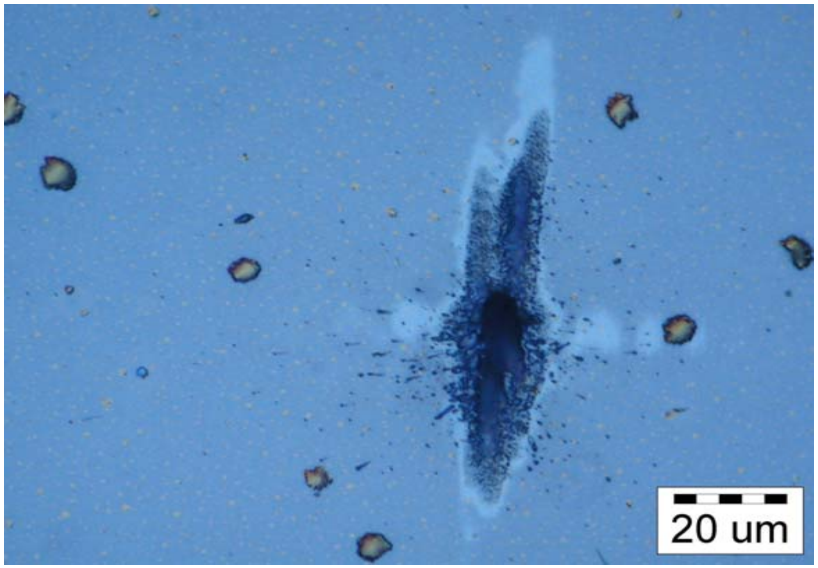
Courtesy R. Ischebeck

FEL radiation:
measured diffraction pattern
of a double slit

First TTF FEL Experiment: Ablation

- Investigation of FEL beam induced damage of optical elements (optical coatings Al or Au, on Si wafers).

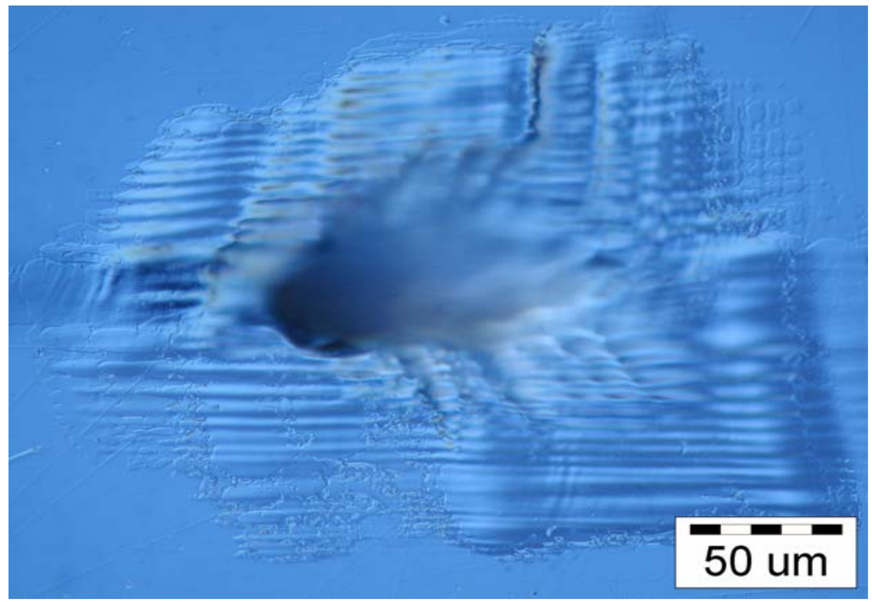
λ = 98 nm, W=100 TW/cm^2



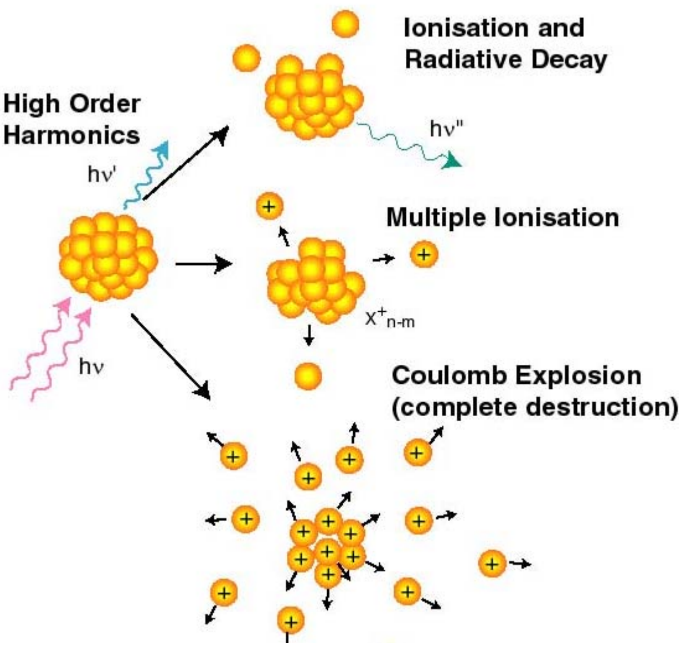
Institute of Physics of the Polish Academy of Sciences (IFPAS), Warszawa
Courtesy J. Krzywinski

Surface of photoresist PMMA (polymethyl methacrylate) after multiple irradiation by SASE FEL pulses

λ = 85 nm

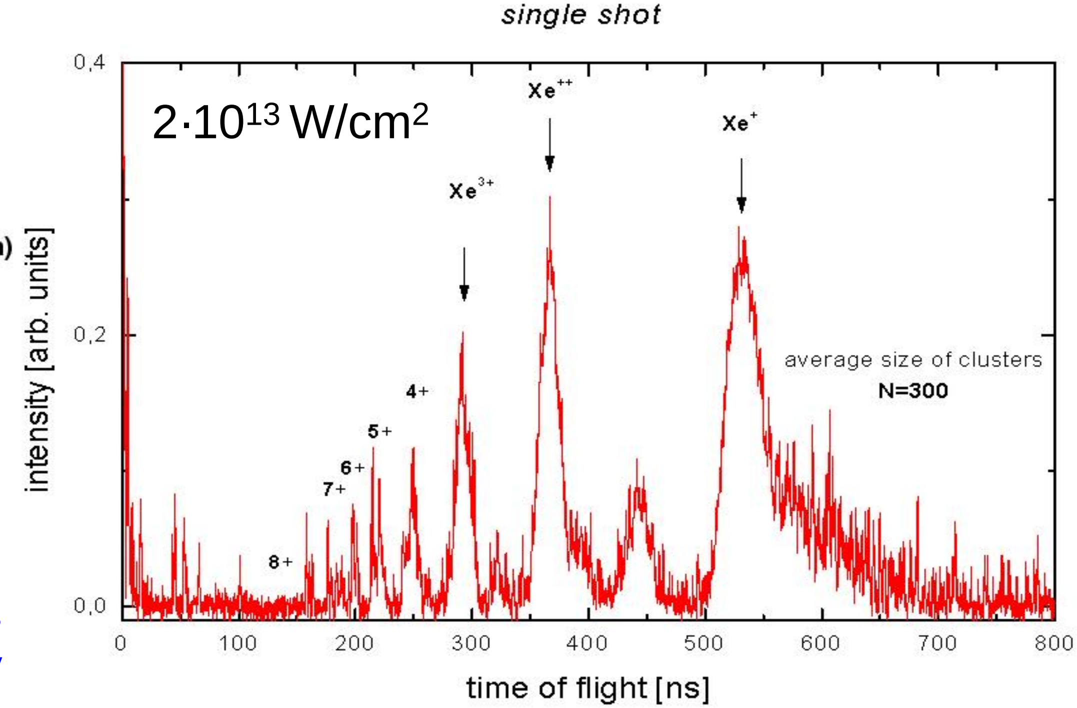


The Cluster Experiment



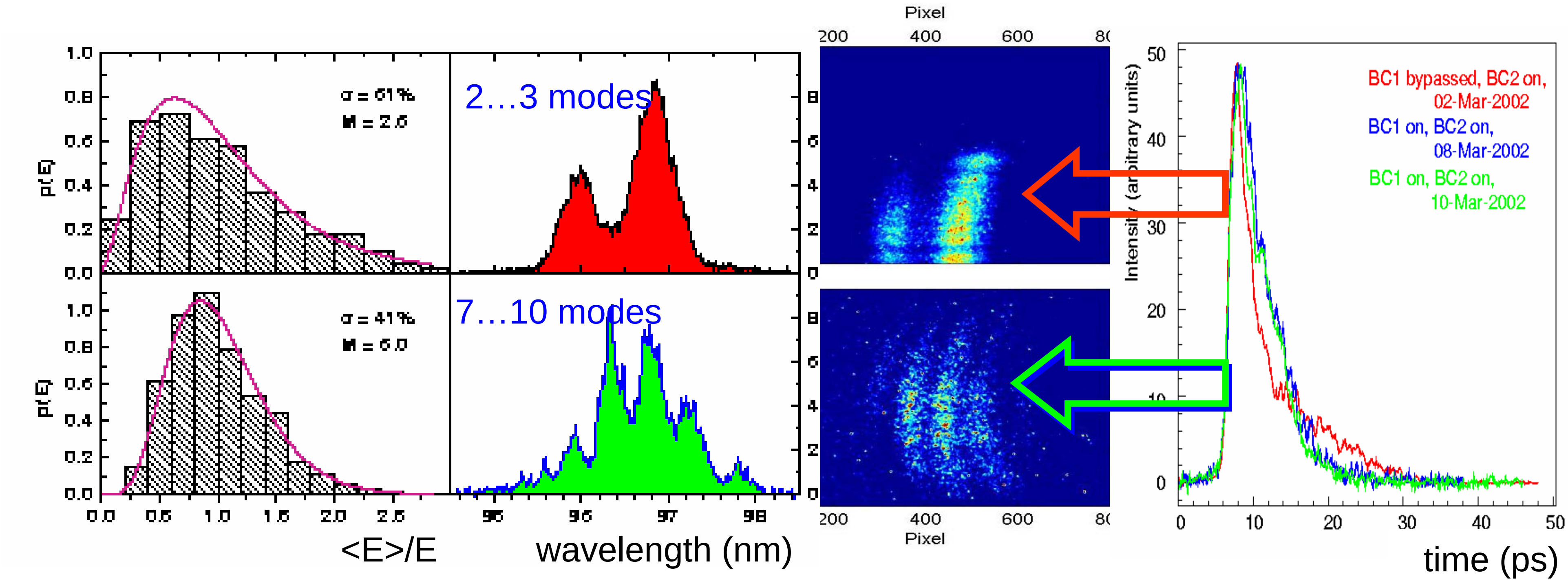
The clusters absorb many photons from the FEL pulse simultaneously and burst by Coulomb explosion

Time of flight mass spectrum of Xe clusters (~300 Xe atoms) produced by multiphoton ionization recorded in a single shot with FEL radiation at 98 nm



H. Wabnitz et al., Nature 420, 482 (2002)

Tuning the FEL Radiation Pulse Duration



probability density distribution of the measured energy in the FEL radiation pulse

single shot spectra profiles

spectrometer image of the FEL radiation pulse

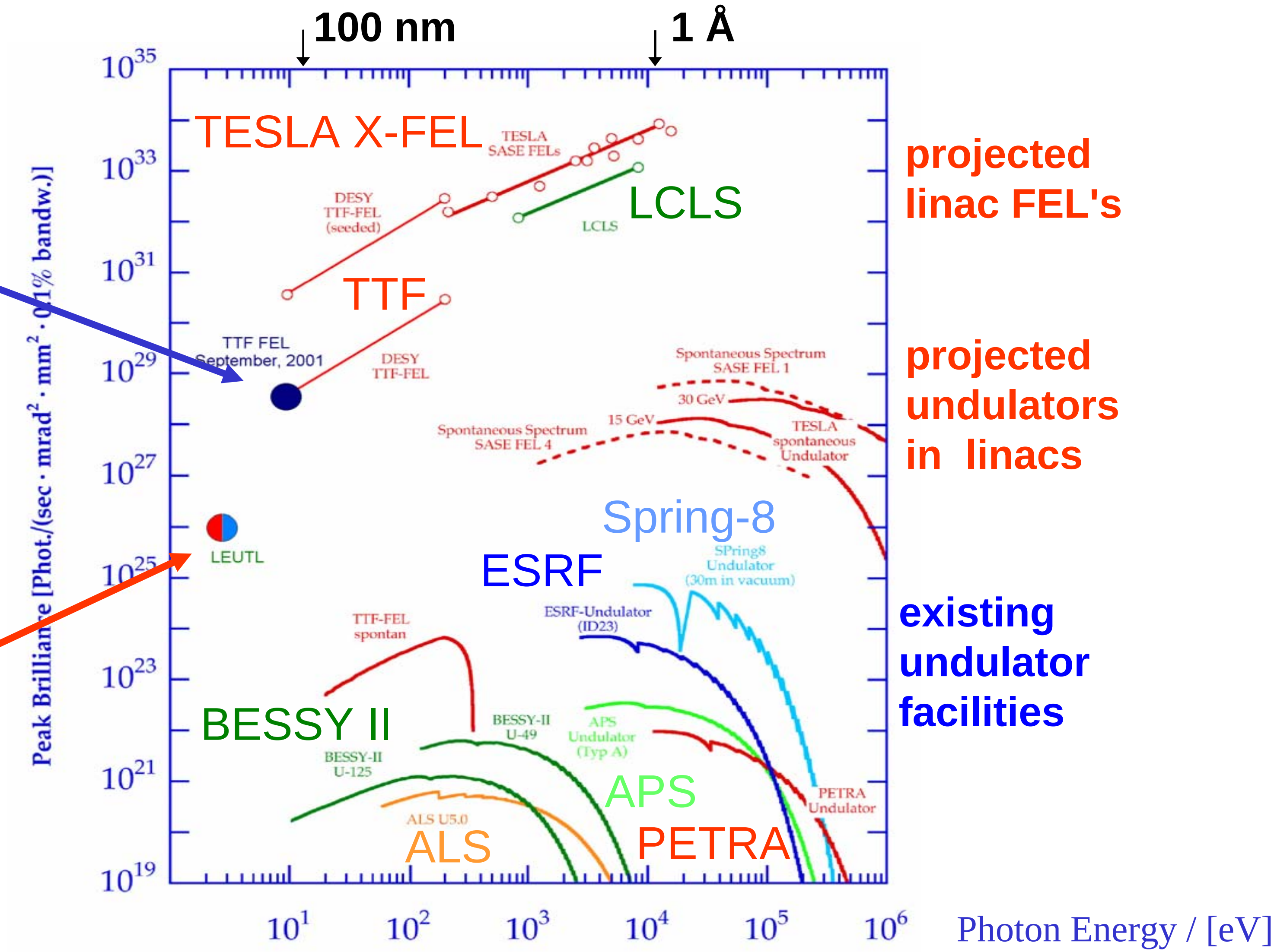
measured longitudinal electron bunch shape

Peak brilliance of the TTF 1 FEL

TTF 1 FEL (Sept. 2001)

peak brilliance 10^{29} ph/(s mrad^2 mm^2 0.1% bw)

Low Energy Undulator Test Line at ANL (Sept. 2000)

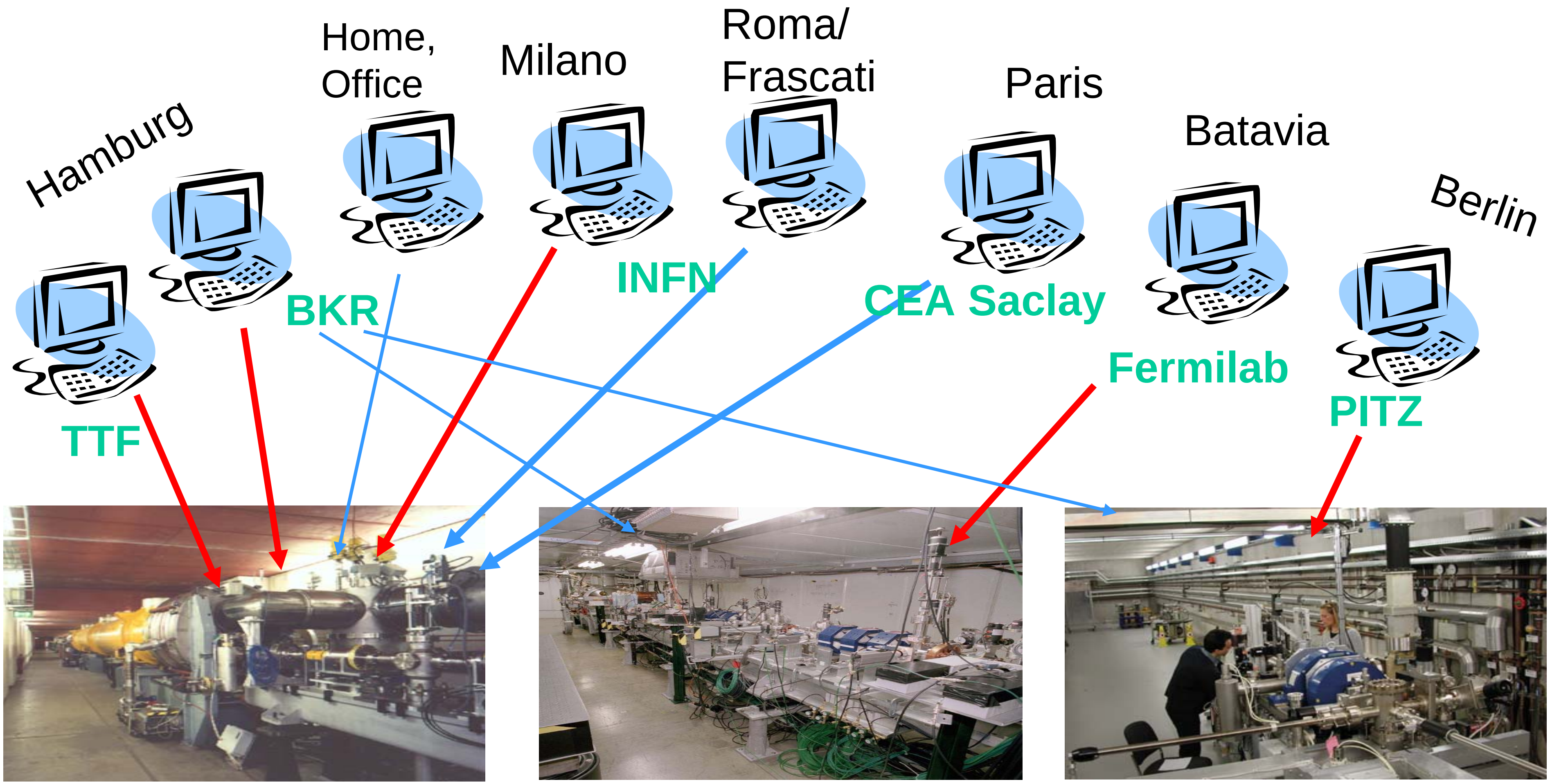


projected linac FEL's

projected undulators in linacs

existing undulator facilities

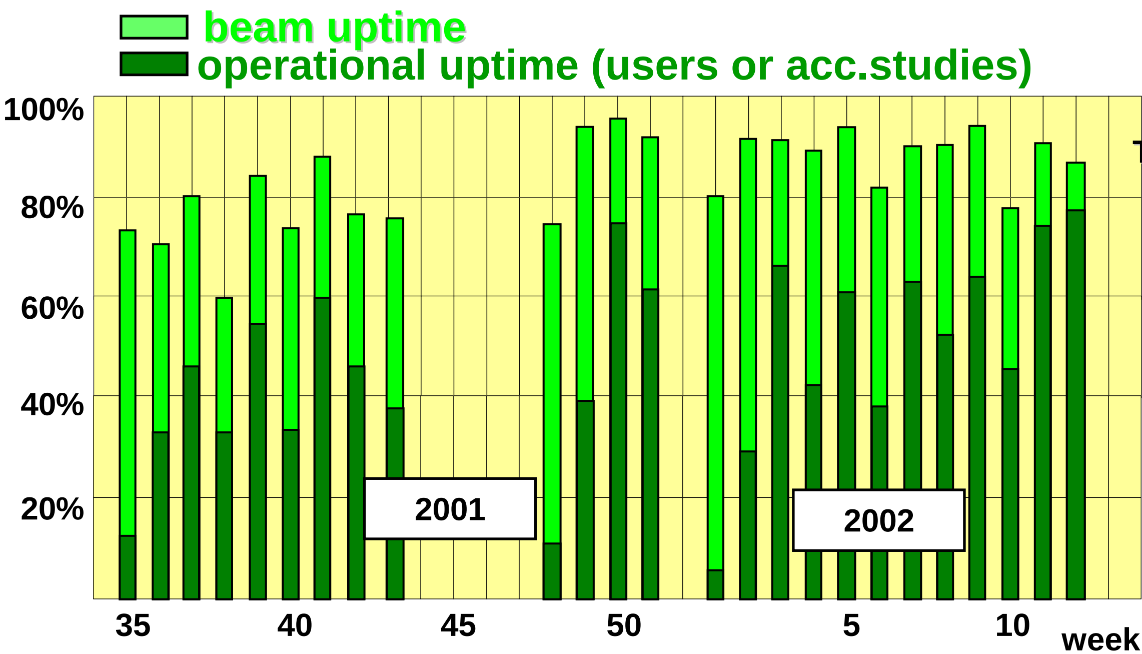
GAN: TTF Practiced Remote Operation

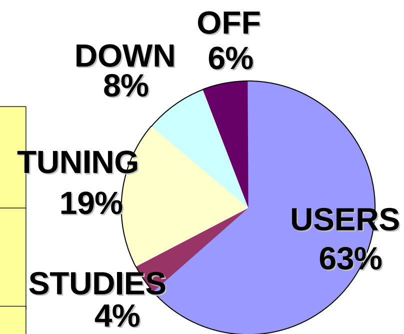


TTF @ DESY   Photoinjector @ Fermilab   PITZ @ Zeuthen

TTF 1 Operational Statistics

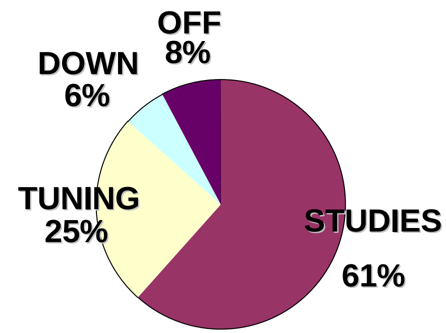
- Operated 7 days per week, 24 hours per day
- 15,000 hours of beam time since 1997
- About 50 % of the time was allocated to FEL operation including a large percentage of user time.





Week 3/2002

FEL Operation



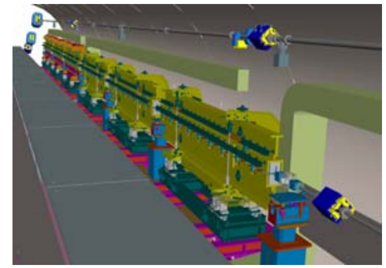
Week 7/2002

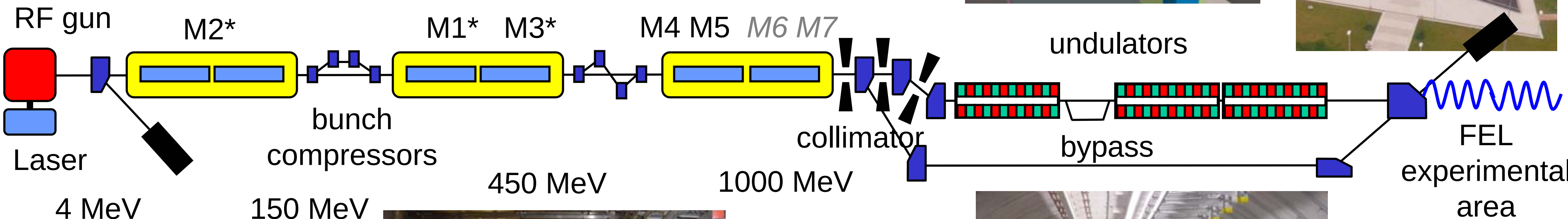
Accelerator Studies

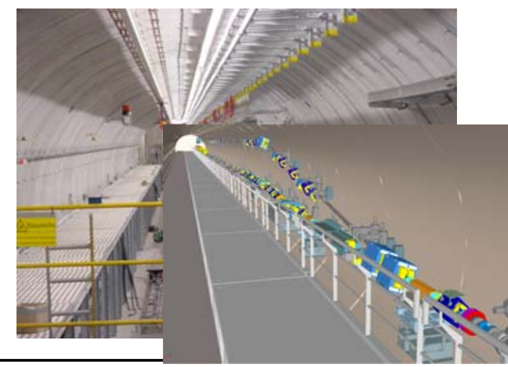
TESLA Test Facility Linac (TTF 2)

Goal: FEL user facility from the VUV to the soft X-ray (6 nm) wavelength range

up to 7 accelerator modules with eight 9-cell superconducting TESLA cavities each



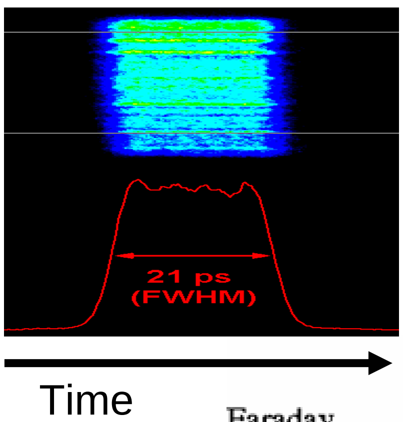


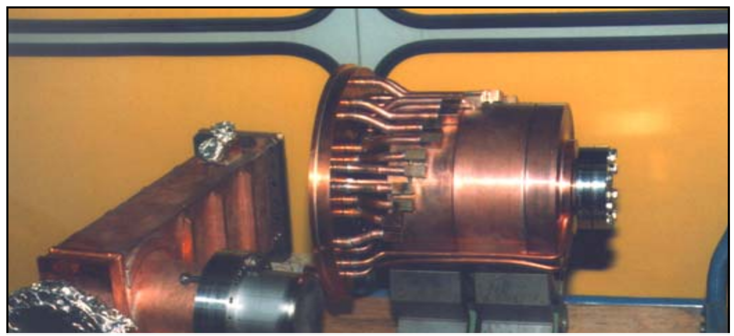


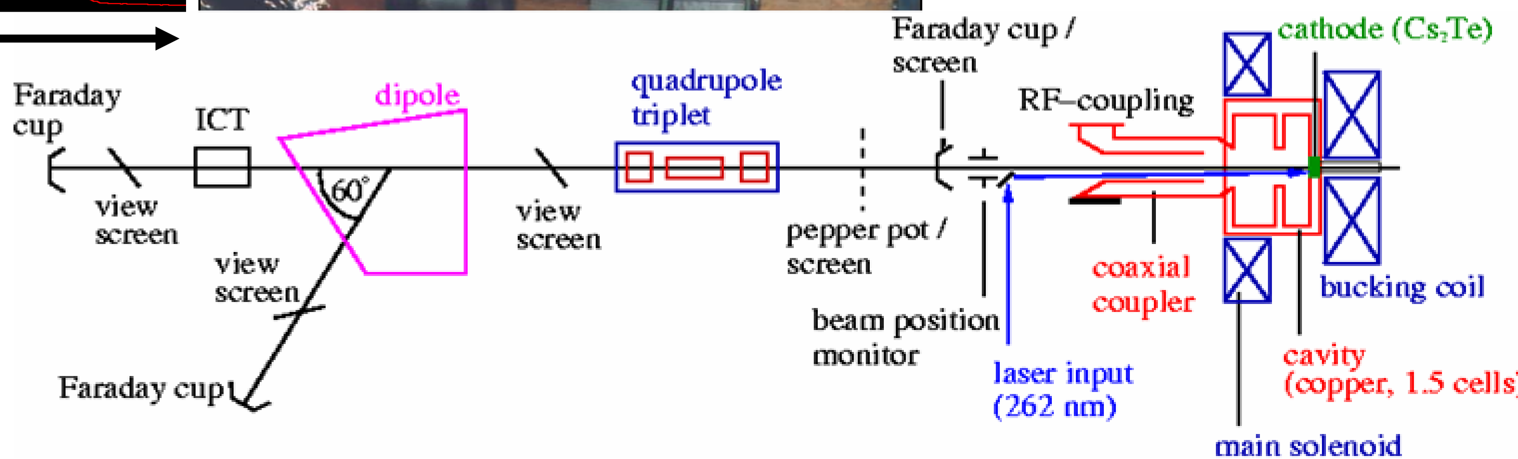
250 m

Photoinjector Test Stand at DESY Zeuthen

- RF gun is commissioned
- flat hat laser system installed
- measurement of beam properties under way



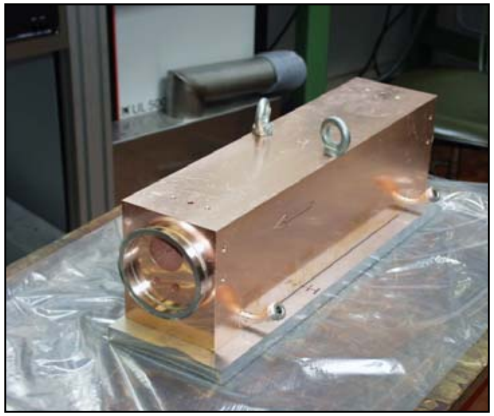




TTF Hardware picture Gallery

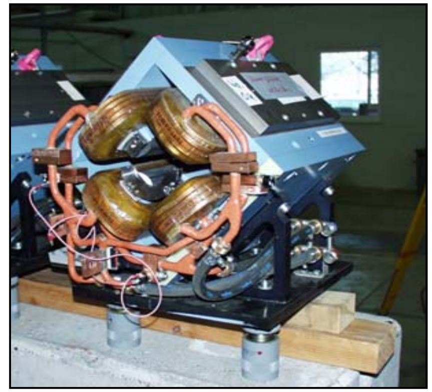
Installation of modules into the TTF linac

TTF 2 Hardware Picture Gallery

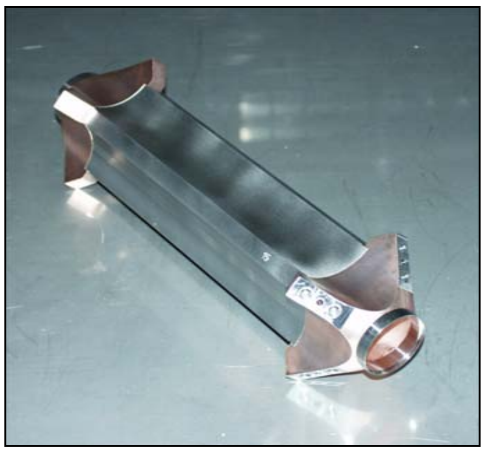


collimator

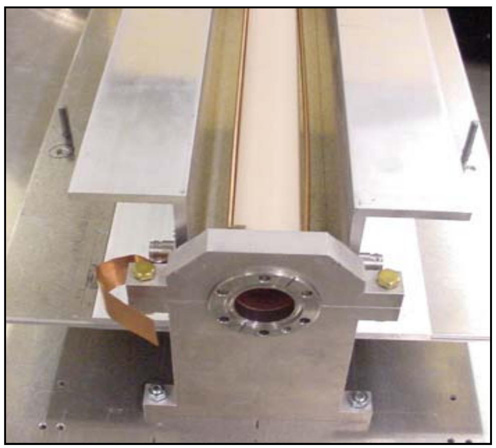
button BPM



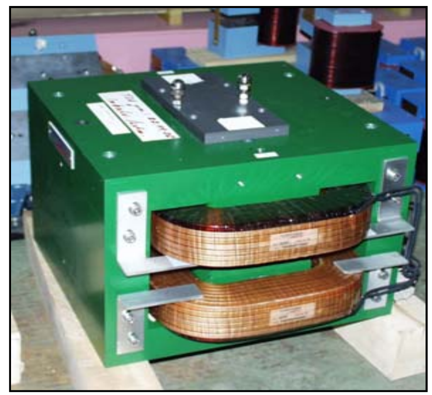
quadrupole, sextupole

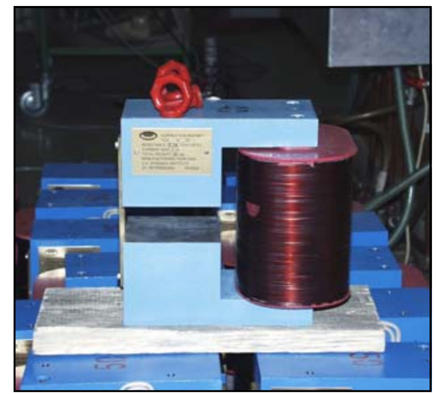


stripline BPM



kicker

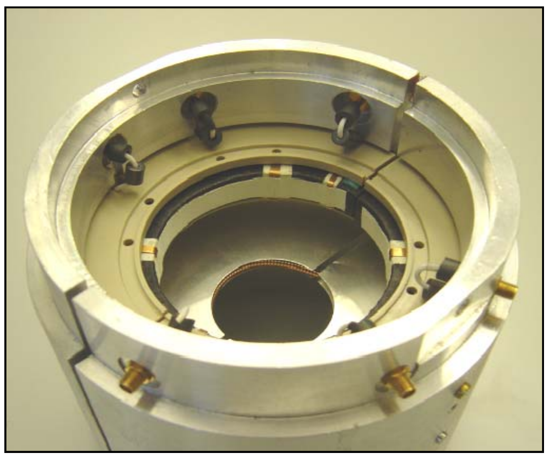




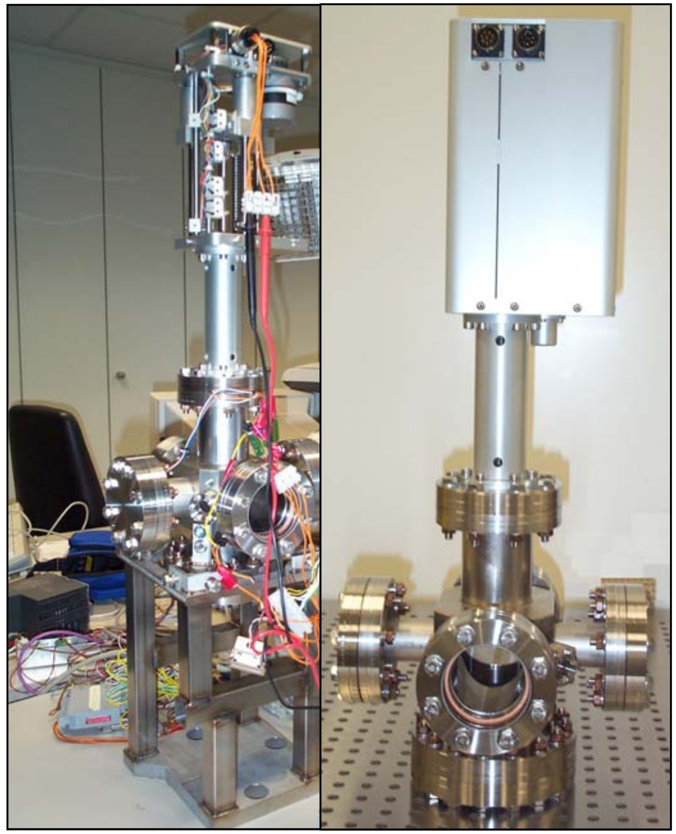
dipole, steerer

TTF 2 Hardware Picture Gallery

wire scanner



toroid



optical transition radiation
(OTR) vacuum chamber
with screen mover

OTR optical system

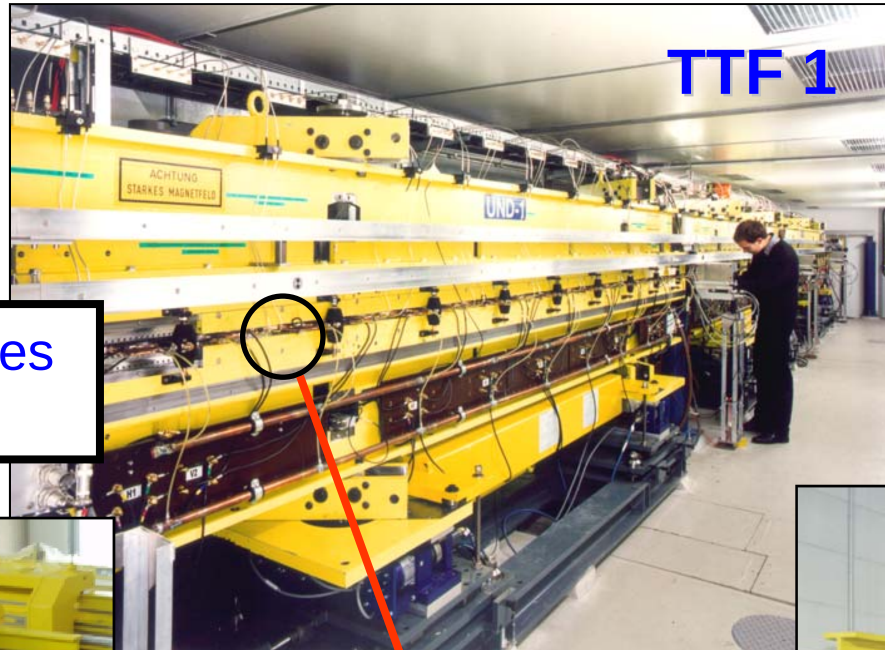
TTF2 Hardware Picture Gallery

L_{und} = 27.3 m

B_{peak}= 0.47 T

Gap = 12 mm

6 undulator modules
à 4.5 m length

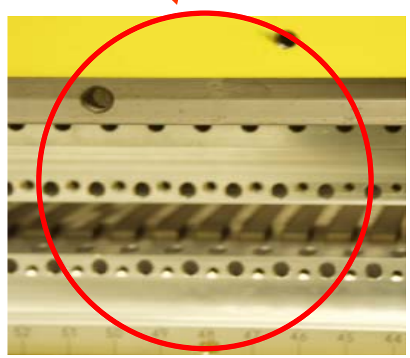


E = 1 GeV

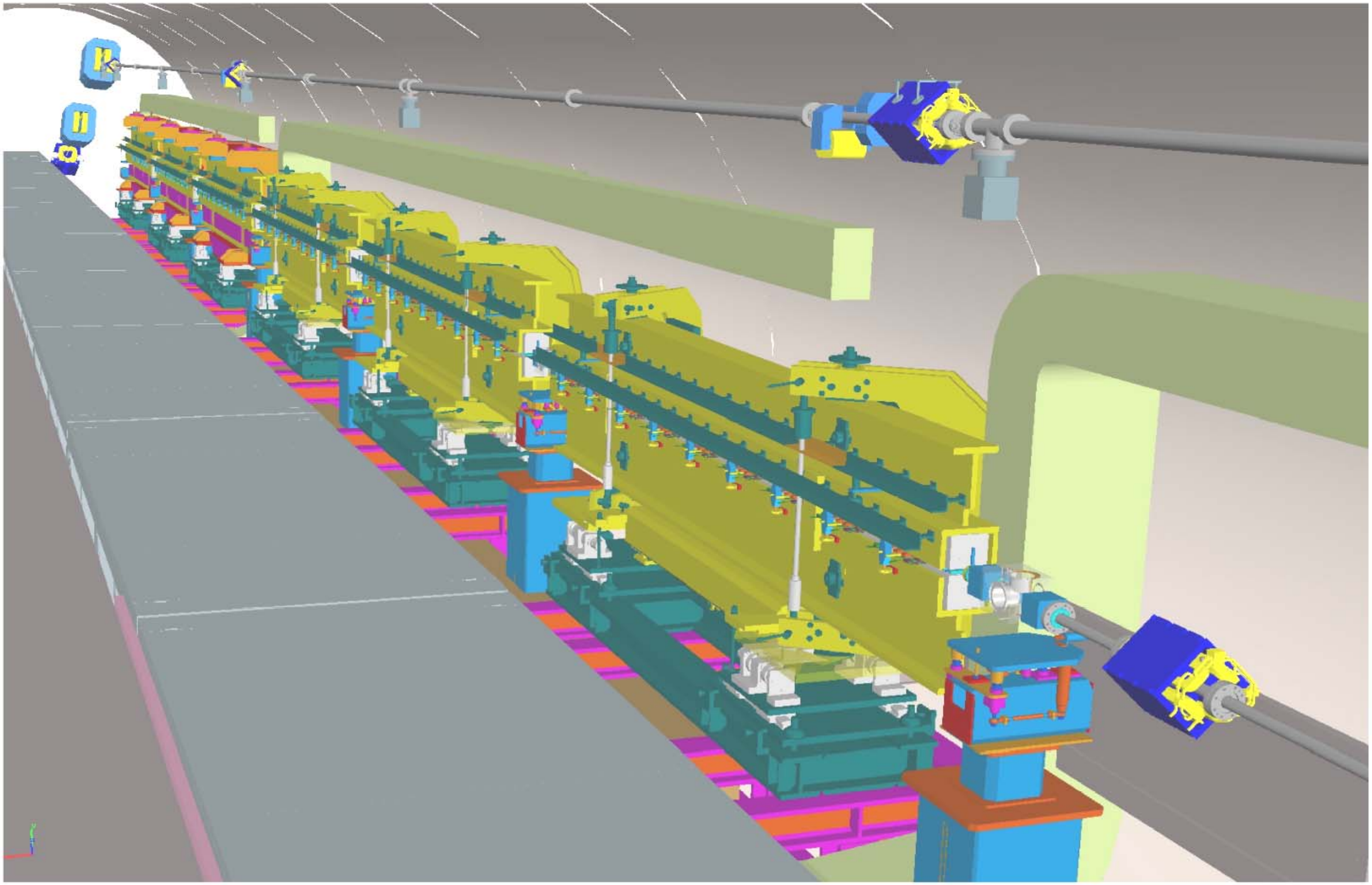
K = 1.17

λ_{rad} = 100 ... 6 nm

J. Pflüger et al.

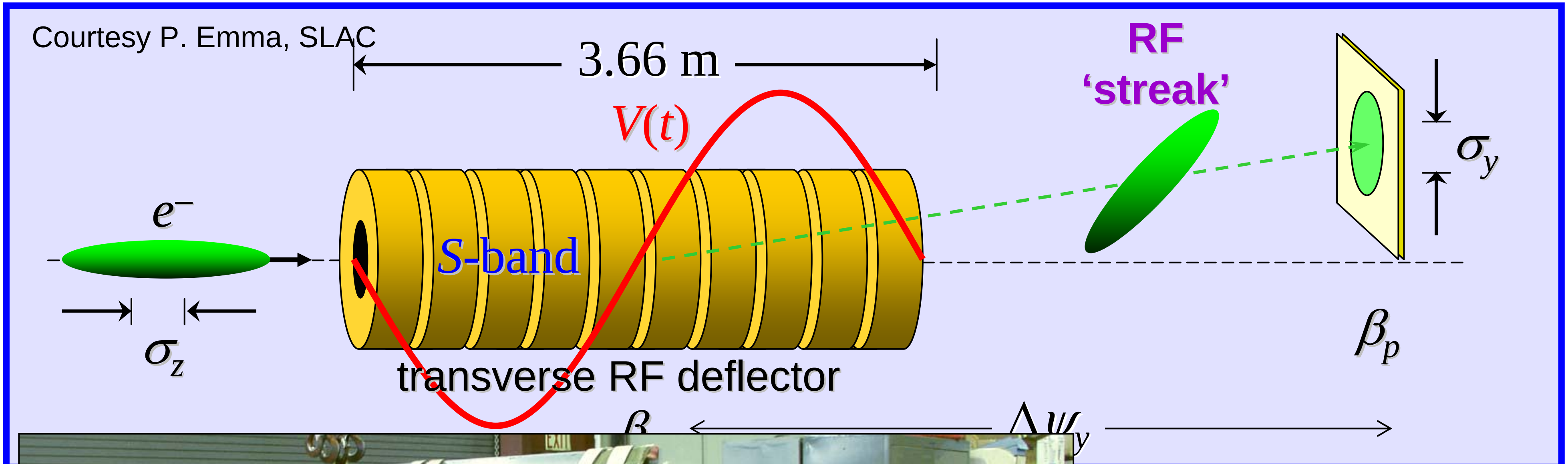


Drawing of the Undulator Section



Bunch Length Measurement Example

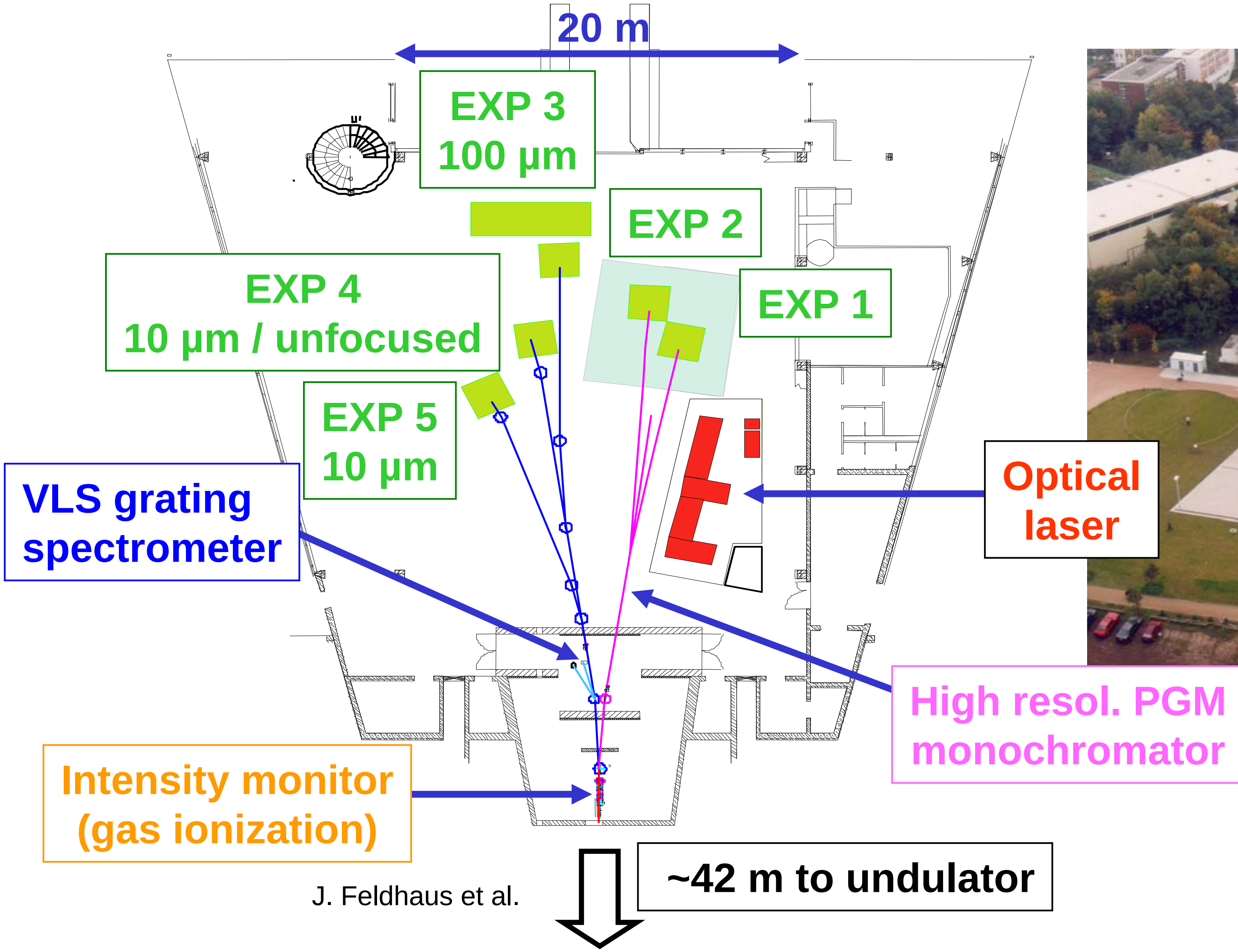
- transverse deflecting cavity: Cooperation SLAC/DESY



Is being installed at DESY now

Expected resolution <10 µm

Layout of the Experimental Hall



J. Feldhaus et al.

TTF 2 Milestones for this and next Year

- pilot FEL experiments
- 2005
- saturation achieved
- first lasing at 30 nm, single bunch
- first beam into dump
- modules 1*, 2* commissioned
- 2004
- now
- modules 3*, 4, and 5 commissioned
- 2003
- TTF 1 operation ends

Tasks:

set-up two FEL experiments

set-up FEL photon diagnostics

beam through undulators

injector run

installation of remaining components

RF test

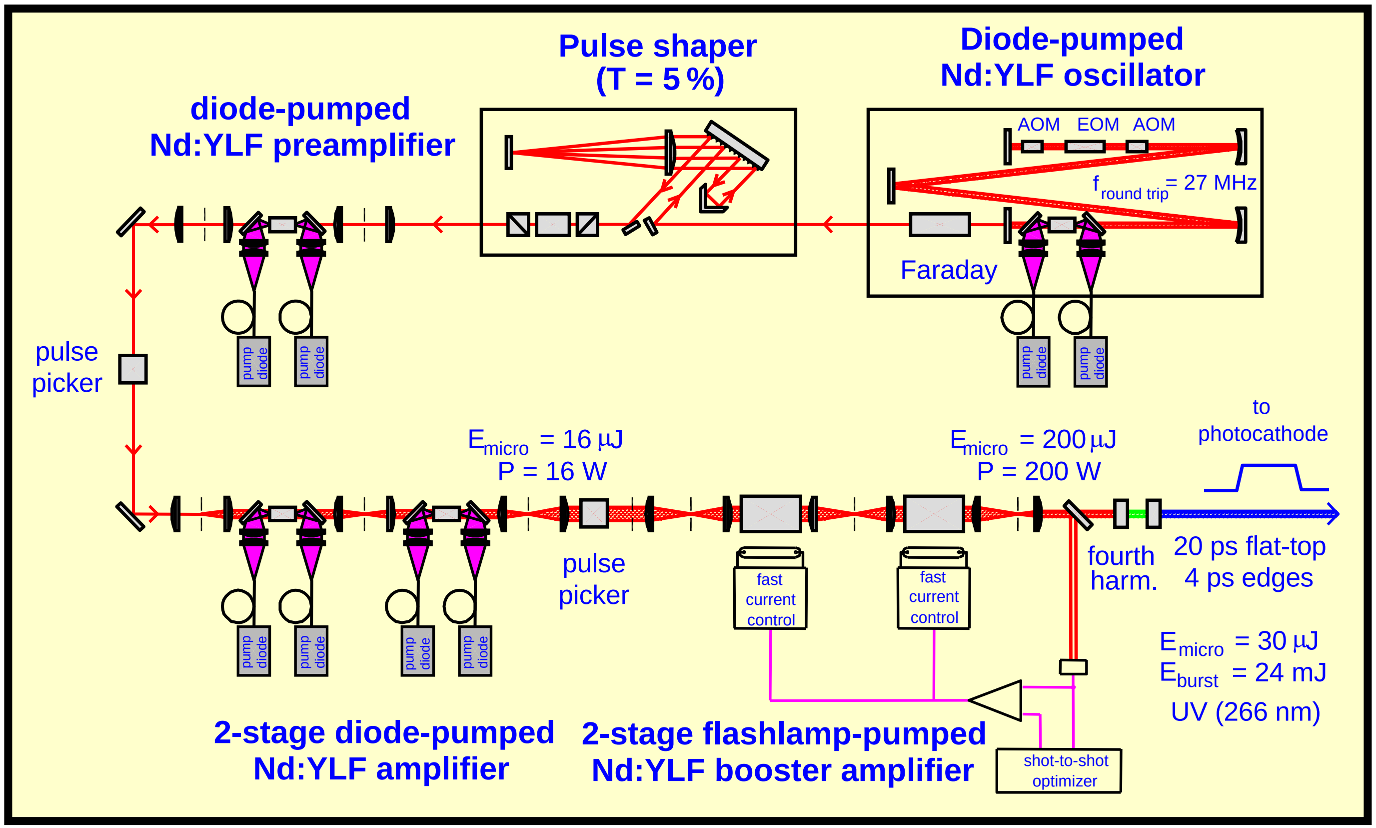
installation of accelerating structures (modules 3*, 4, 5)

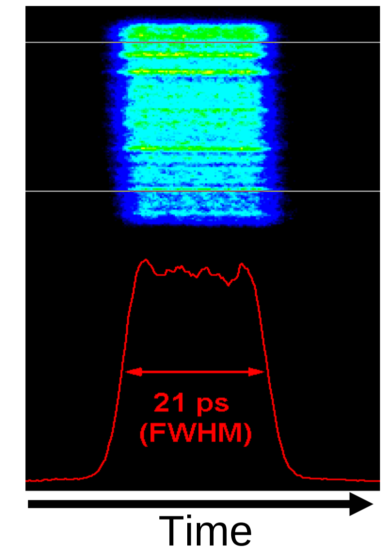
Summary

- TTF 1 run successfully ended Nov 18, 2002 after 15,000 h of beam time
  - several TESLA superconducting accelerating structures tested, with and without full beam loading, incl. higher order modes experiments
  - SASE FEL runs: lasing and saturation in the VUV achieved
  - two successful FEL experiments
- TTF 1 is being extended to 1 GeV with the goal of a user facility from the VUV to the soft X-ray wavelengths
  - RF test of three installed modules ongoing
  - installation of the injector this year
  - remaining installation in parallel to injector runs
  - first beam into the dump expected mid 2004

TTF 2 Laser Upgrade

- Together with Max-Born-Institute, Berlin (I. Will et al.)
- Upgrade is being tested at PITZ (DESY Zeuthen)





NEW:

Longitudinal flat profile

Parameters of the TTF 1 FEL

FEL	Wavelength	80 – 120 nm
	2nd harmonic	48.5 nm at 0.1…1 % intensity of fundamental
	Pulse energy at saturation	30 – 100 µJ
	Pulse duration	30 – 100 fs (fwhh)
	Peak power	1 GW
	Average power	Up to 5 mW
	Spectrum width	1 %
	Spot size	250 µm
	Angular divergence	260 µrad
	Peak brilliance	Up to 10^{29} ph/(s mrad ^{2} mm ^{2} 0.1% bw)
	Average brilliance	Up to 10^{18} ph/(s mrad ^{2} mm ^{2} 0.1% bw)
Beam	Bunch charge	2.7 – 3.3 nC
	Peak beam current	1 – 1.5 kA
	Charge in radiative part of the beam	0.1 – 0.2 nC
	Duration of the radiative part of the beam	50 – 150 fs
	Normalized emittance	4 – 7 mm mrad (rms)