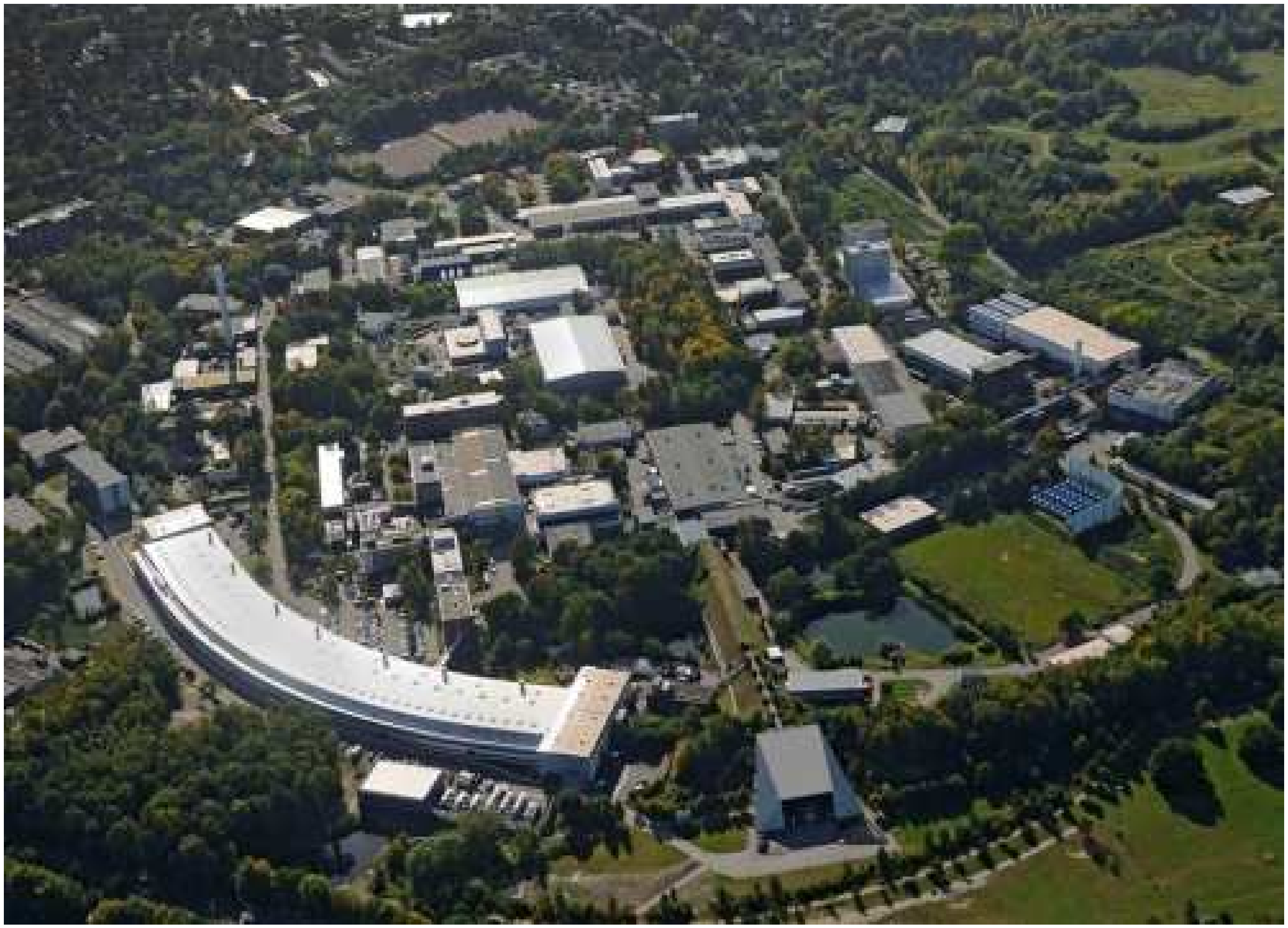
13th ESLS-RF Meeting 2009
DESY, Hamburg



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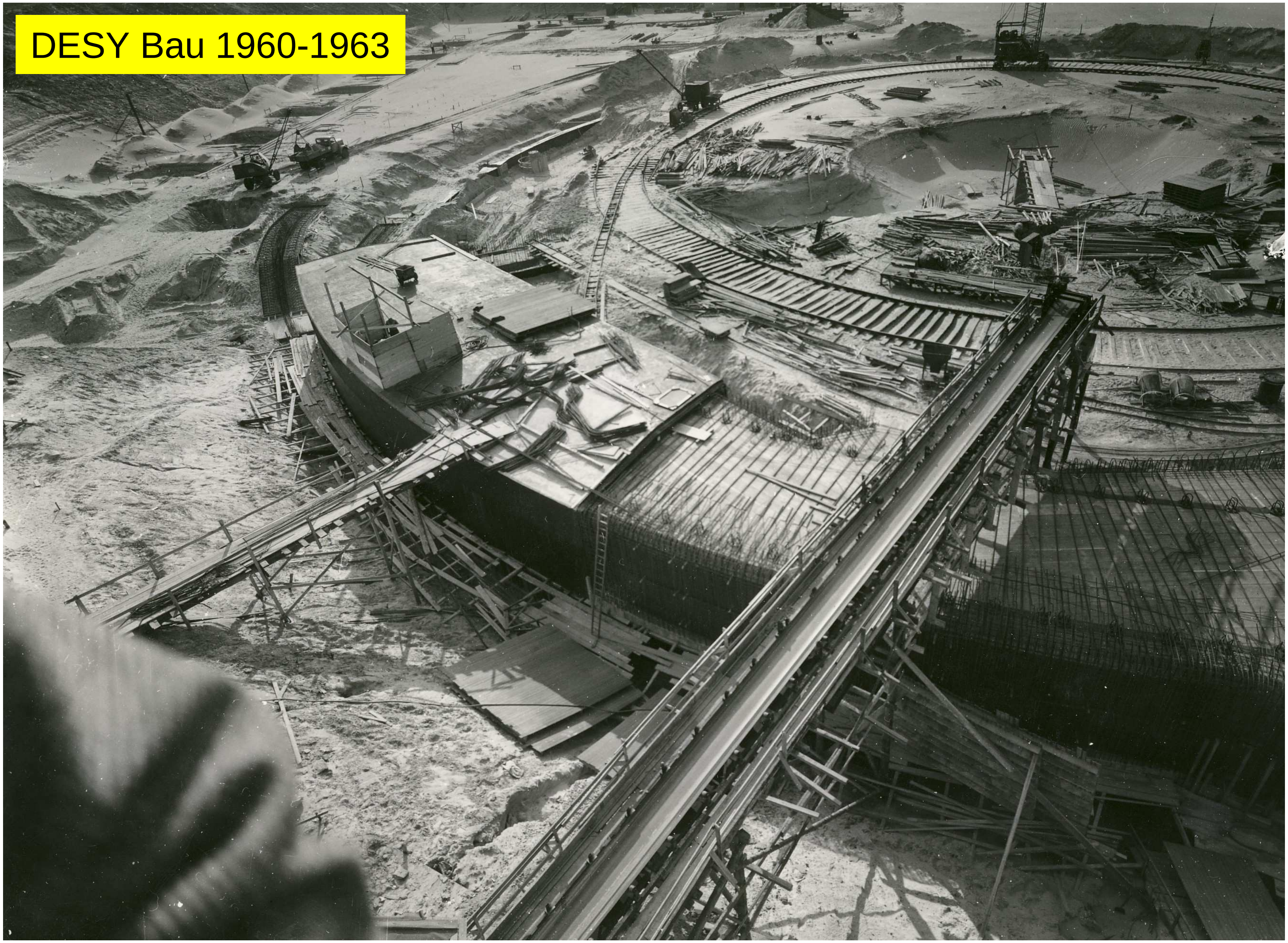
DESY Bau 1960



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The XFEL Injector Site

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DESY

Photon Research SR&FELs
Exp.&Theor. Particle Physics

Accelerators& Development
Including a lot of RF from (3 MHz),
125 MHz - 3 GHZ

• DESY Hamburg Site

- 1056 permanent positions   412 other positions

- HERA   was closed down mid 2007
- DORIS   user facility
- PETRA II   was closed down mid 2007
- PETRA III   construction started mid 2007
  First Beam on Easter Monday 2009
  Machine commissioning is ongoing
- FLASH   user facility and Machine-FEL studies
- XFEL   construction started January 2009

Ongoing Activities at FLASH

- **A very sucessful FLASH user run endet mid August**
- **After a dump repair and maintenance a 9 mA run took place from Sept. 7th – 21st.**
- **Goal: acceleration to 1 GeV of 9 mA in 2400 bunches. Full beamloading test for long pulses.**
- **Since 21st of Sept. Shut down for 5 months.**
- **Goals: Installation of a 3.9 GHz s.c. RF System, a Seeding Option and a seventh Acceleration Module, E_{max} =1.2 GeV hence λ_{min} < 5 nm possible**

FLASH

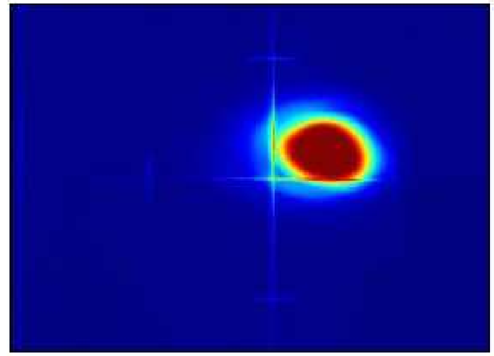
SASE performance

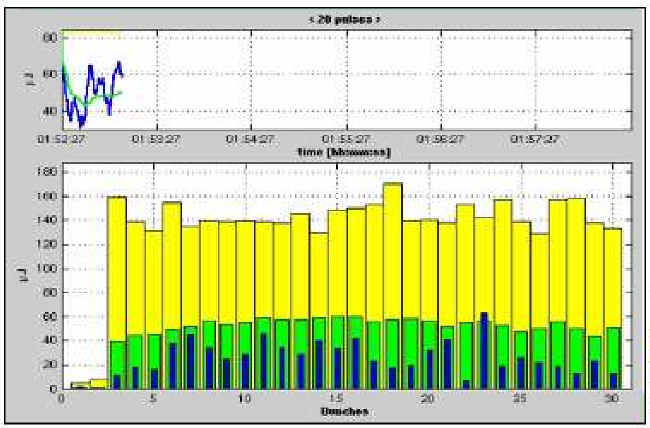
FLASH
Free-Electron Laser in Hamburg

Typical user operation parameters:

Wavelength range (fundamental)	7 – 47 nm
Average single pulse energy	10 – 100 μJ
Pulse duration (FWHM)	10 – 50 fs
Peak power (from av.)	1 – 5 GW
Average power (example for 500 pulses/sec)	~ 15 mW
Spectral width (FWHM)	~ 1 %
Peak Brilliance	10^{29} - 10^{30} B

B = photons/s/mrad^2/mm^2/0.1%bw





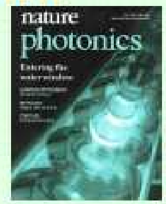
Multibunch SASE signal (μJ) recorded with MCP detector

max

single

average

Top performance at 13.7 nm:



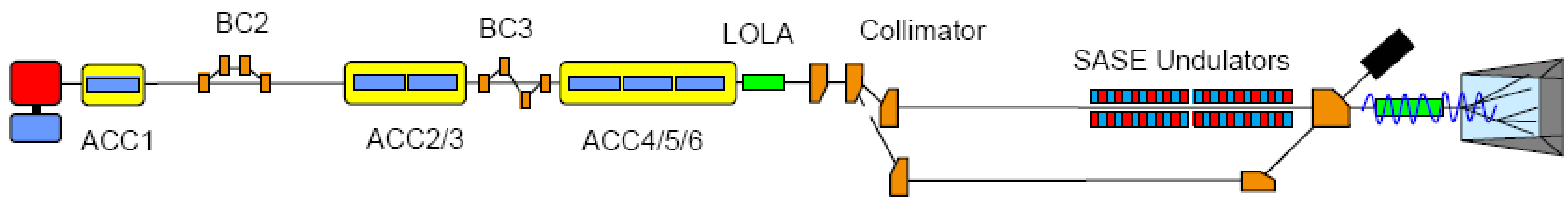
Average energy	70 μJ
Peak energy	170 μJ
Pulse duration	10 fs
Peak power	>10 GW
Peak brilliance	(6 ± 3) 10^{29} B

DESY

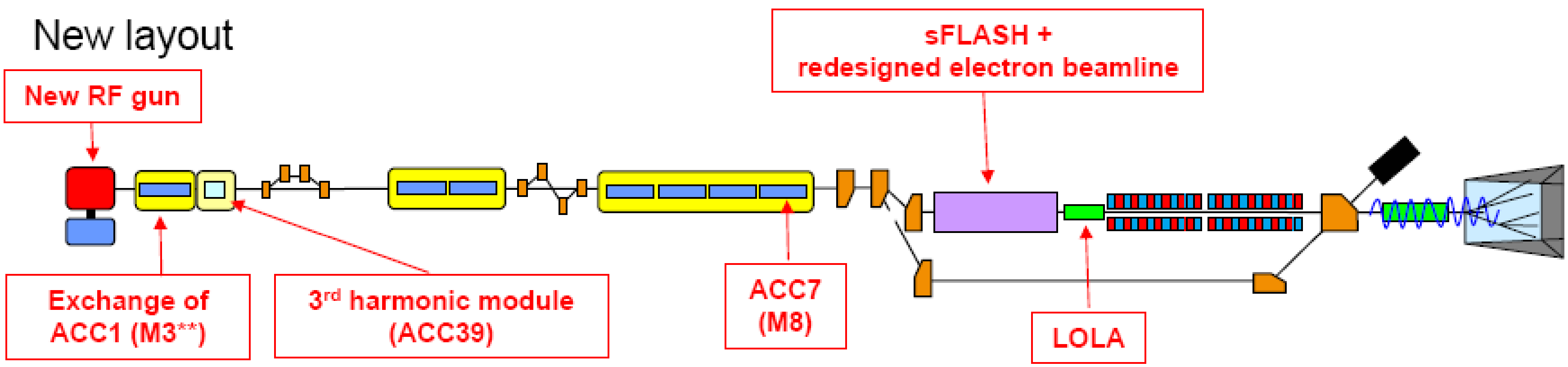
Upgrade: Linac layout

FLASH
Free-Electron Laser
in Hamburg

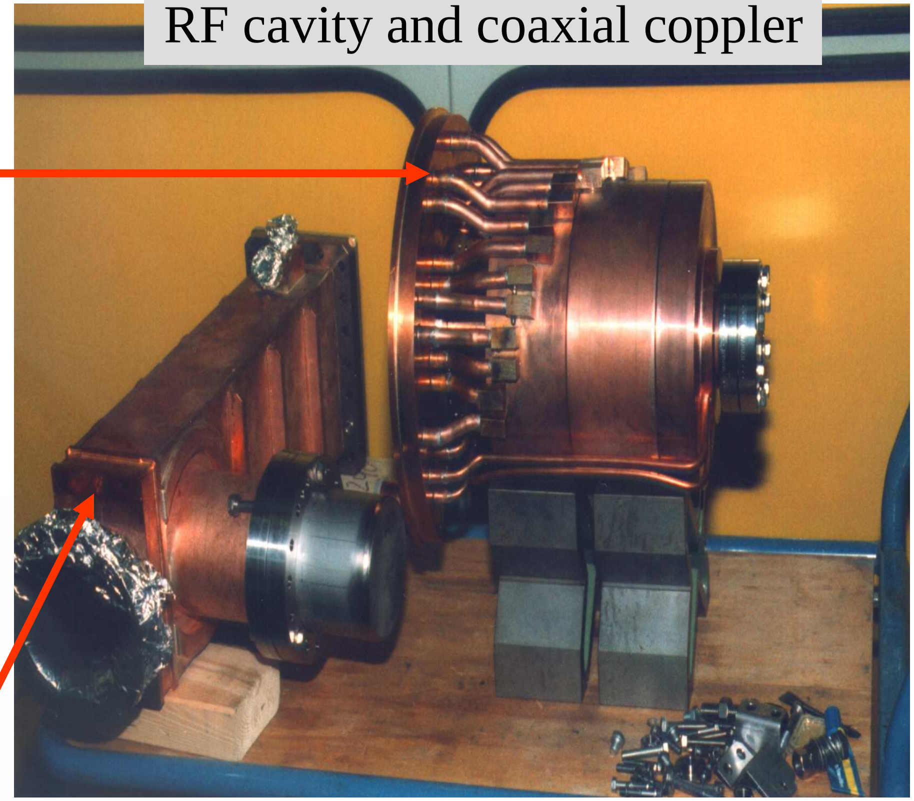
Present layout



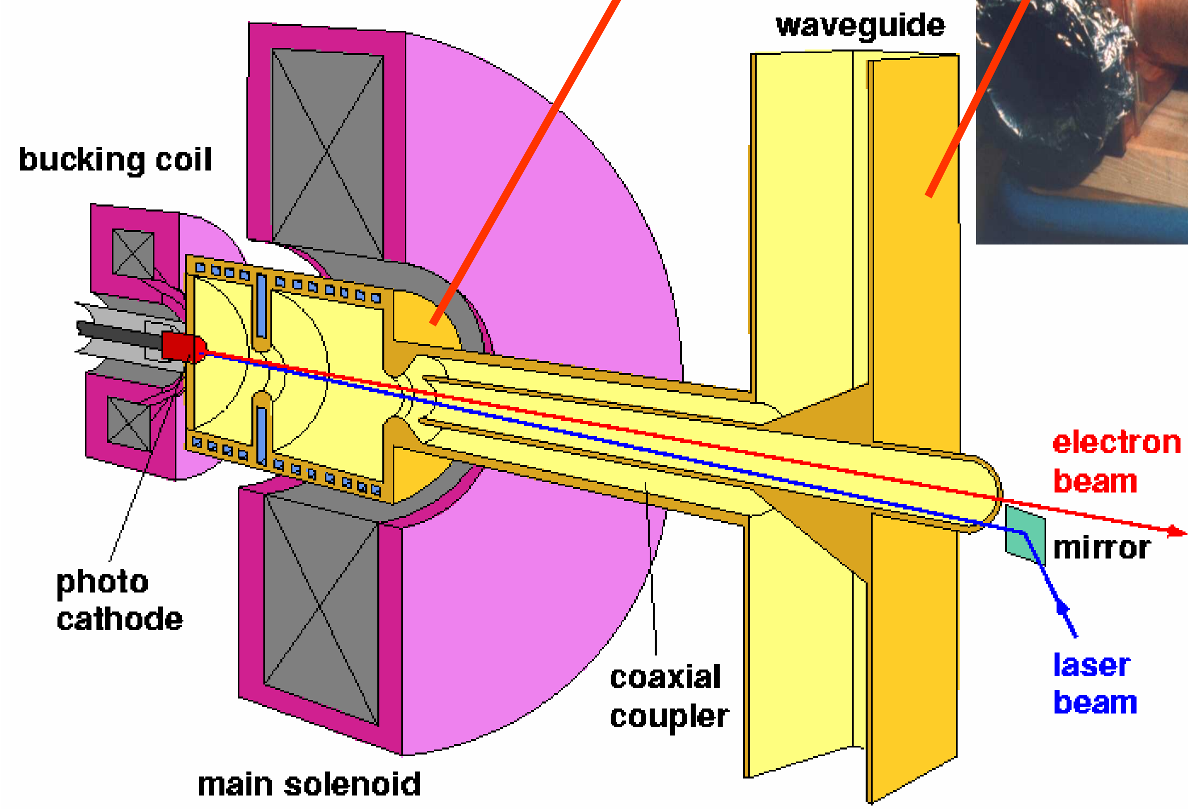
New layout



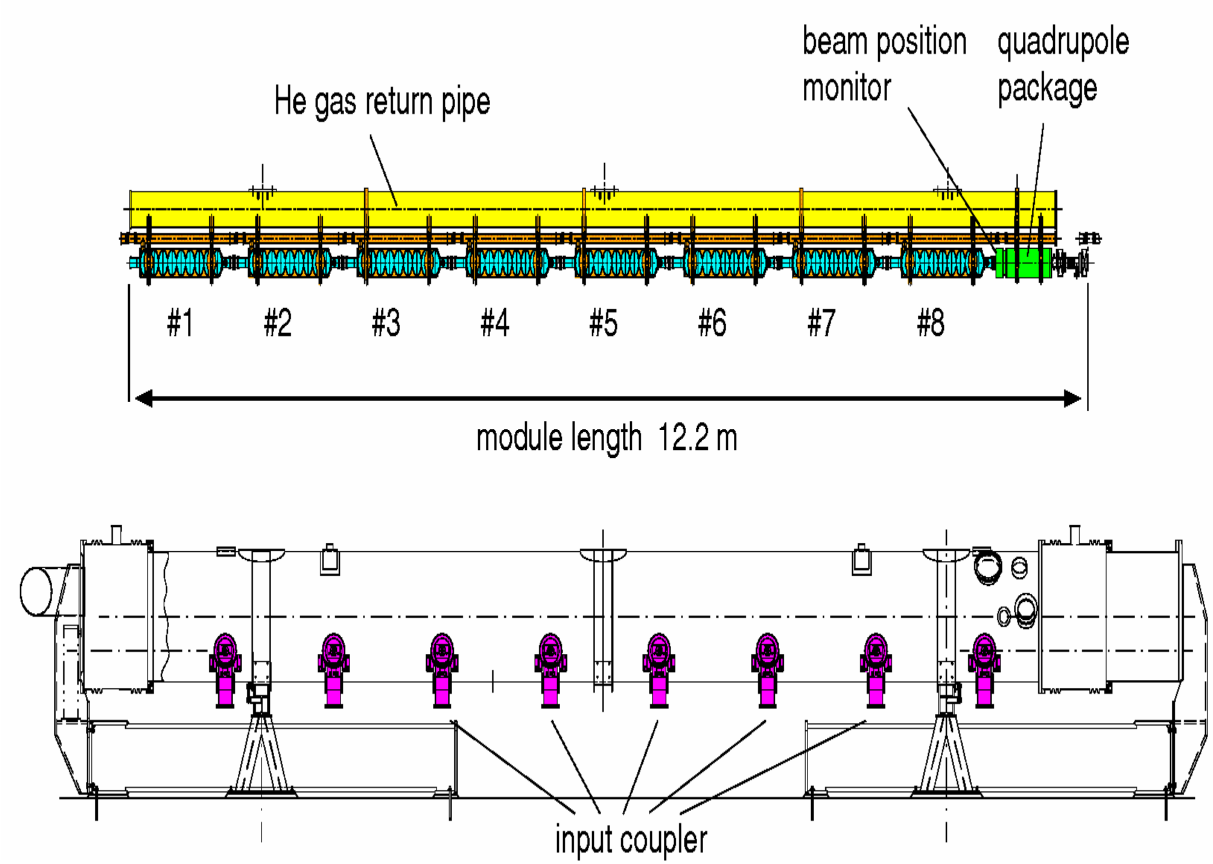
Very dense electron bunches: photo-injector



RF cavity and coaxial coppler



N_e / bunch	$> 10^{10}$
Q / bunch	1- 10 nC
bunches / macro pulse	800 – 7200
macro pulse length	800 μs
bunch distance	1 μs - 111 ns
bunch length	5 ps
RF Power	typ. 3 MW
laser energy / pulse (263 nm)	typ. 10 - 50 μJ



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The User Facilty FLASH

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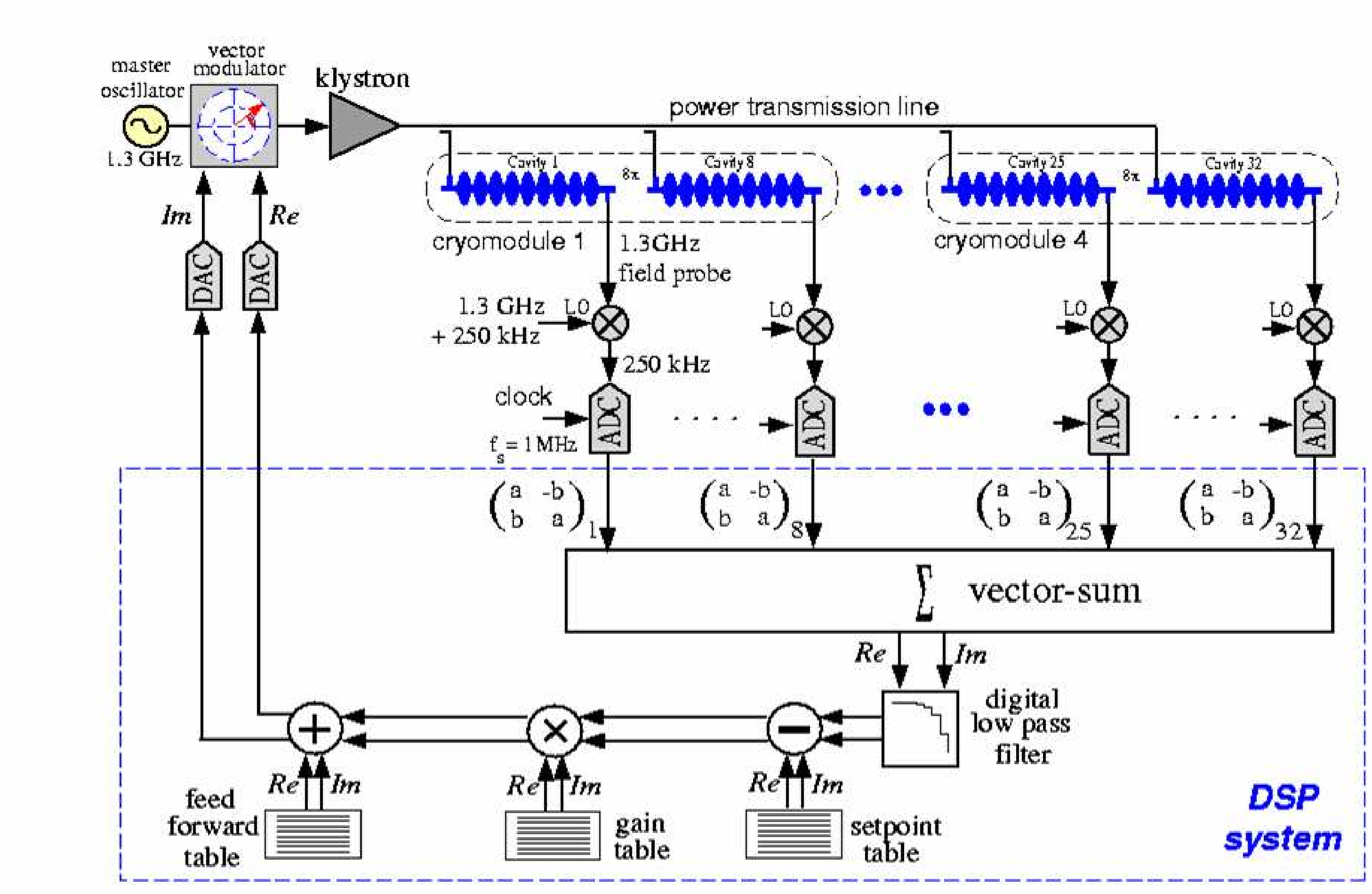
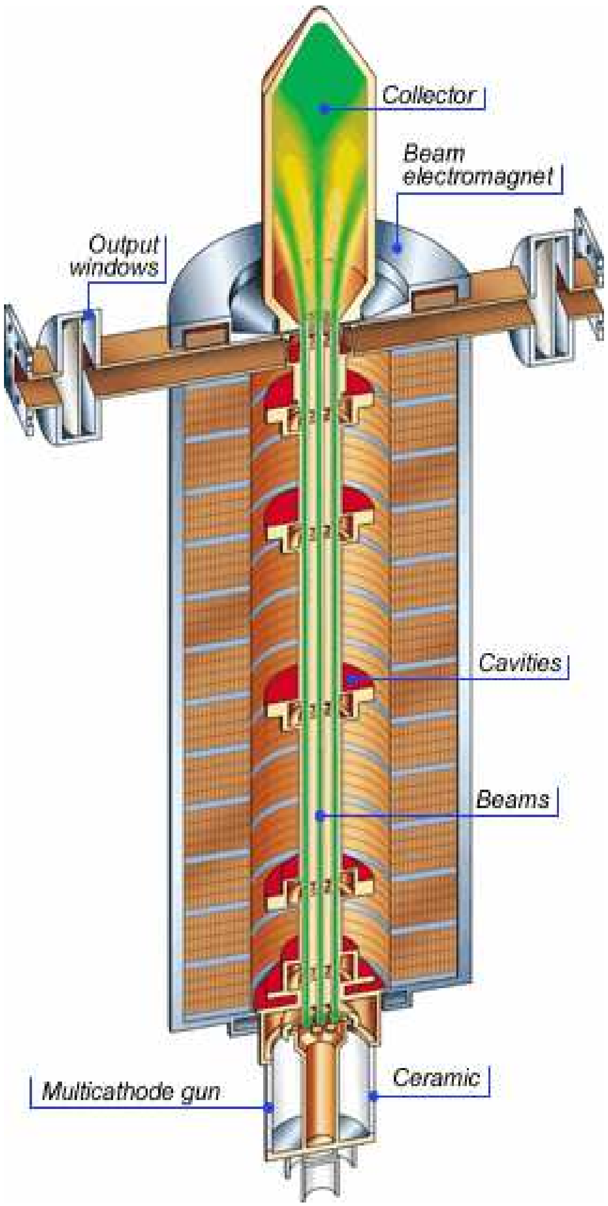
Digital LLRF system
Feedback plus feedforward
Extensive diagnostics and exception handling



Multi Beam Klystrons as Power Sources for the XFEL

Requirements

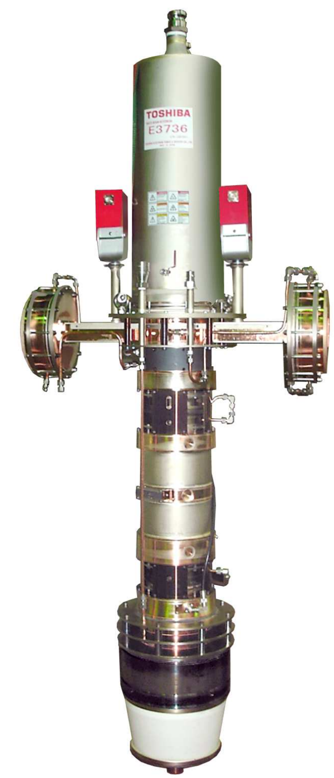
Operation Frequency:	1.3GHz
Cathode Voltage:	< 120 kV
Beam Current:	< 140 A
Max. RF Peak Power:	10MW
RF Pulse Duration: 1.5ms	
Repetition Rate:	10Hz
RF Average Power: 150kW	
Efficiency:	65%
Solenoid Power:	< 5.5kW
Length:	2.5m



3 klystron vendors have developed MBKs during the last years.
Two horizontal MBKs have been delivered to DESY.
CPI has developed a 1.3 GHz 100 kW CW IOT and delivered to DESY in July 2009

THALES TH1801

CPI VKL8301

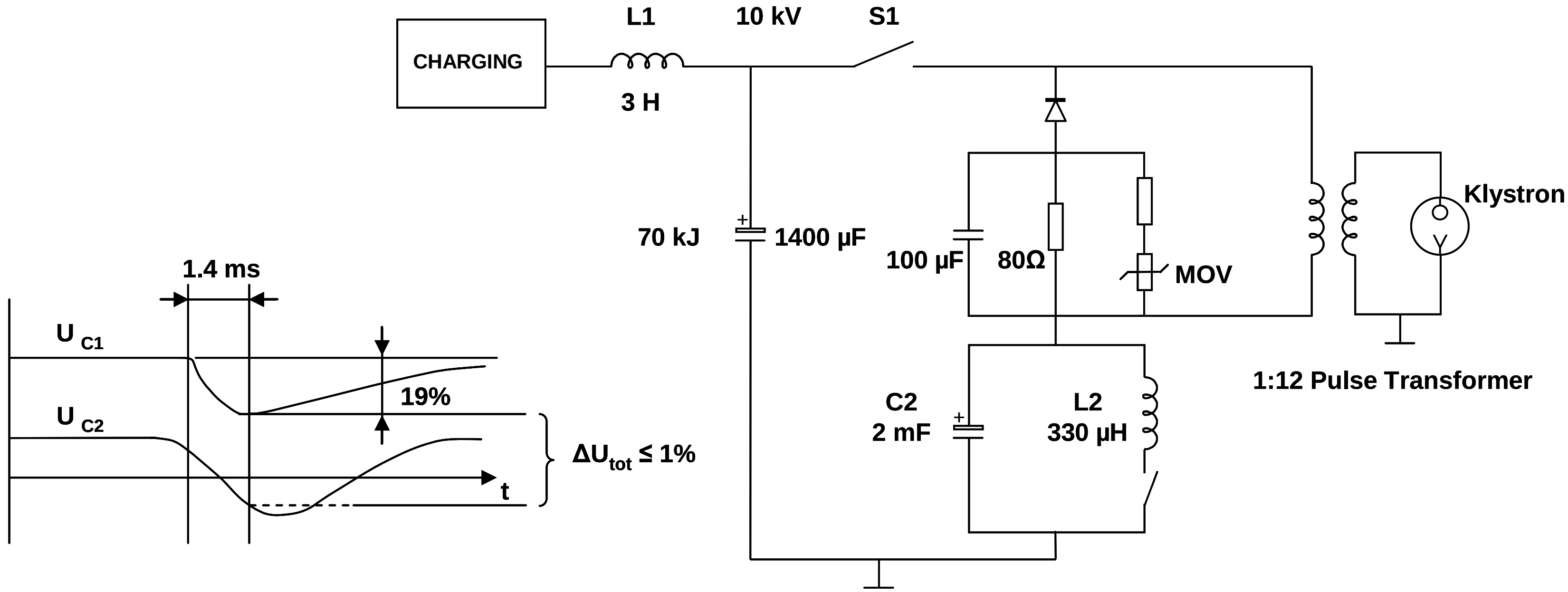


TOSHIBA E3736

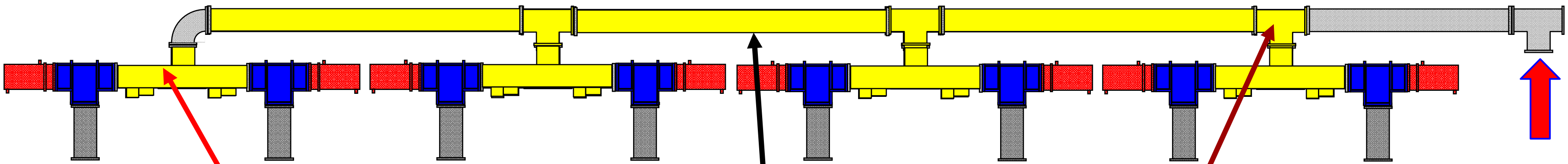
Modulators must generate HV pulses up to 120kV and 140A, 1.57ms pulse length and 10Hz (30Hz) repetition rate

The top of the pulse must be flat within 1%

The bouncer type modulator with its simple circuit diagram was chosen



Optimized Waveguide Distribution for the XFEL



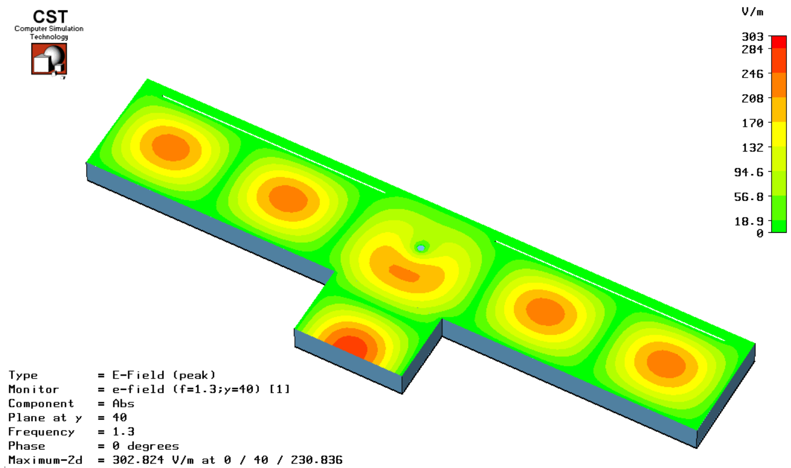
Shunt tee with integrated phaseshifters

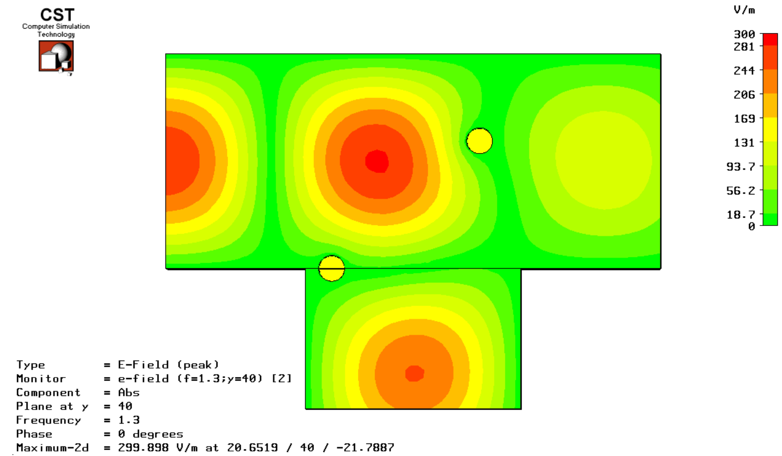
Asymmetric shunt tee 3.0 dB, 4.77 dB, 6.0 dB

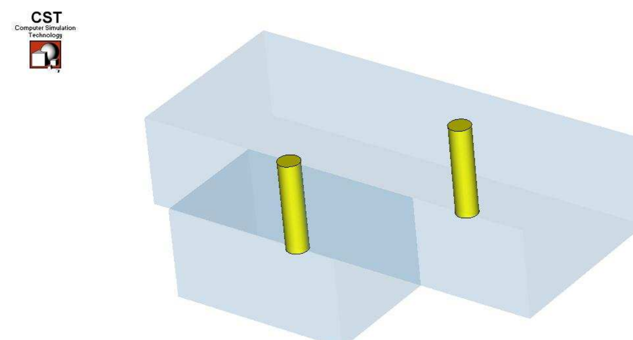
Fixed phase shifters

Many waveguide components have been developed during the last years and have been used for the operation of TTF/FLASH

Symmetric and asymmetric shunt tees





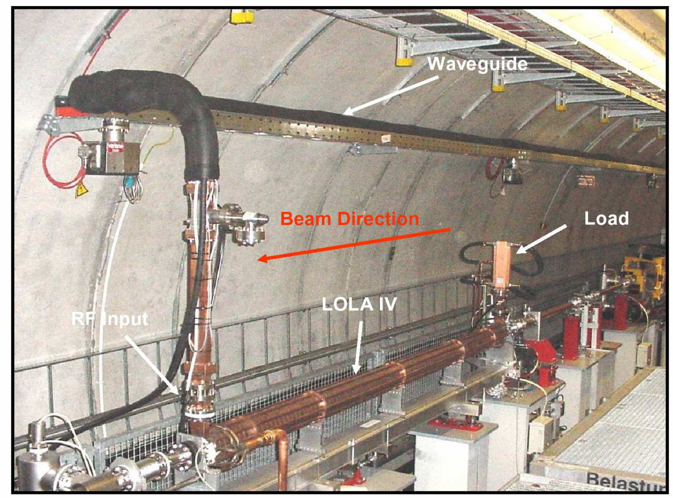


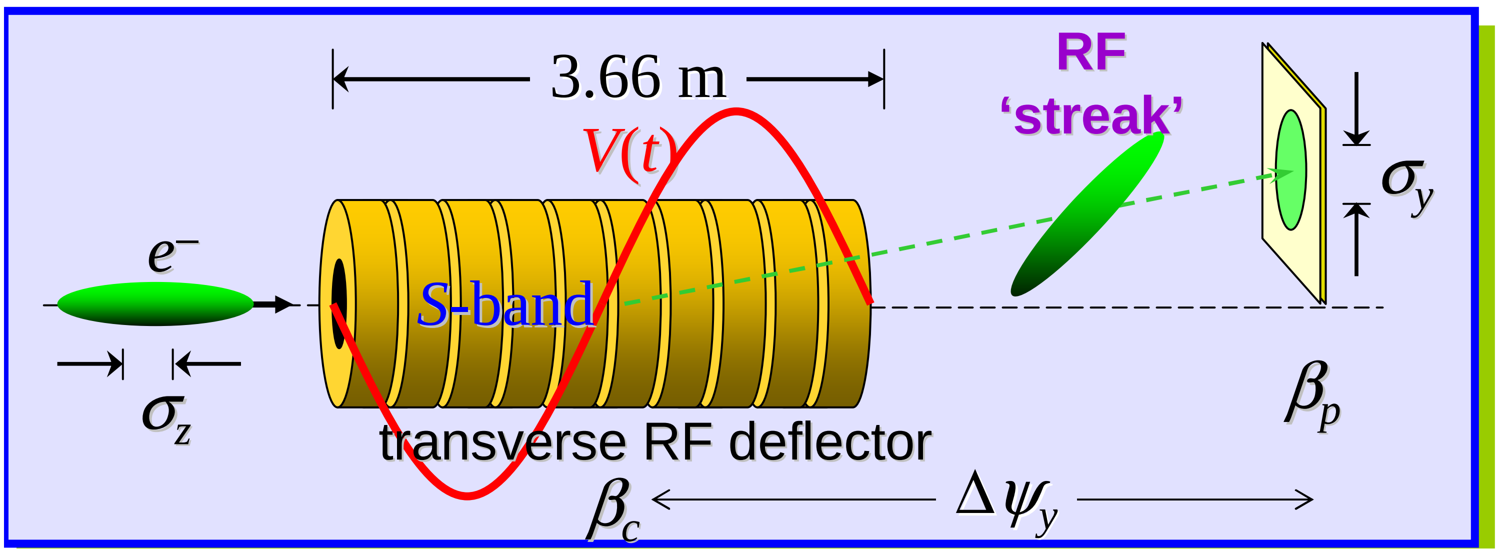
LOLA – Bunchlength measurement

- Vertically deflecting cavity for bunch length measurements at TTF
- Built in the late 60ies by G. Loew et al.
- SLAC contribution to TTF

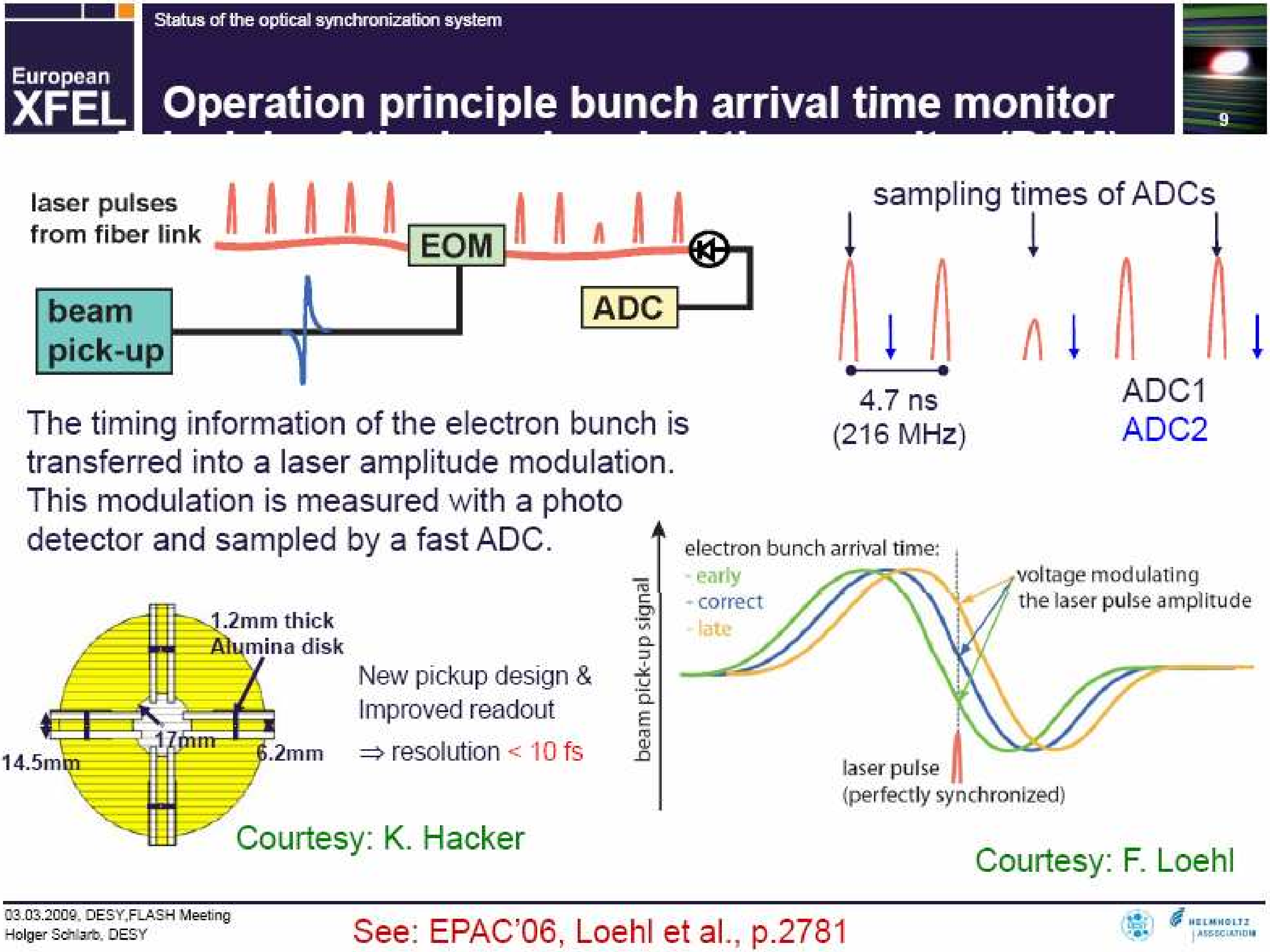
"Intra-Beam Streak Camera"

LOLA IV in the TTF2-Tunnel





Fs timing issues



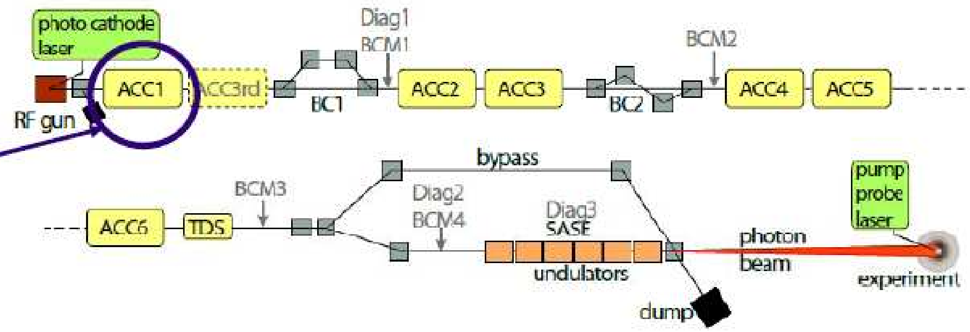
Beam Arrival Time Feedback

- Schematic Layout of FLASH :

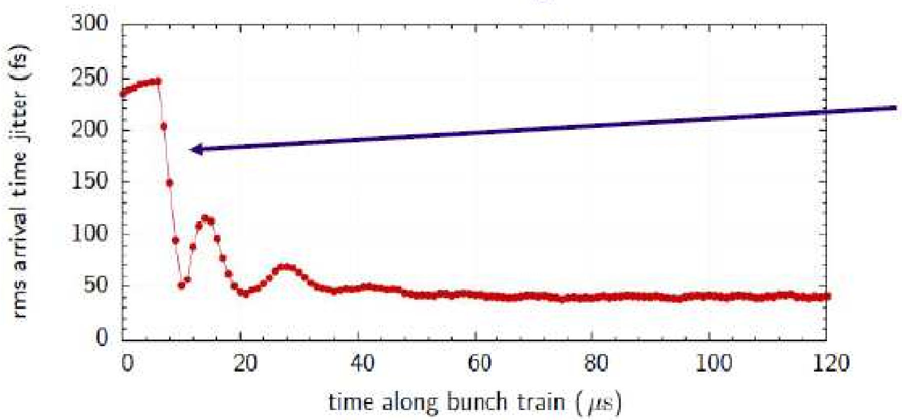
A cavity field fluctuation of 1% causes 6ps bunch arrival time:

0.0016% required for 10fs (without feedbacks)

F.Löhl, „Optical Synchronization of a Free-Electron Laser with Femtosecond Precision ", Hamburg 2009, Section 4.2

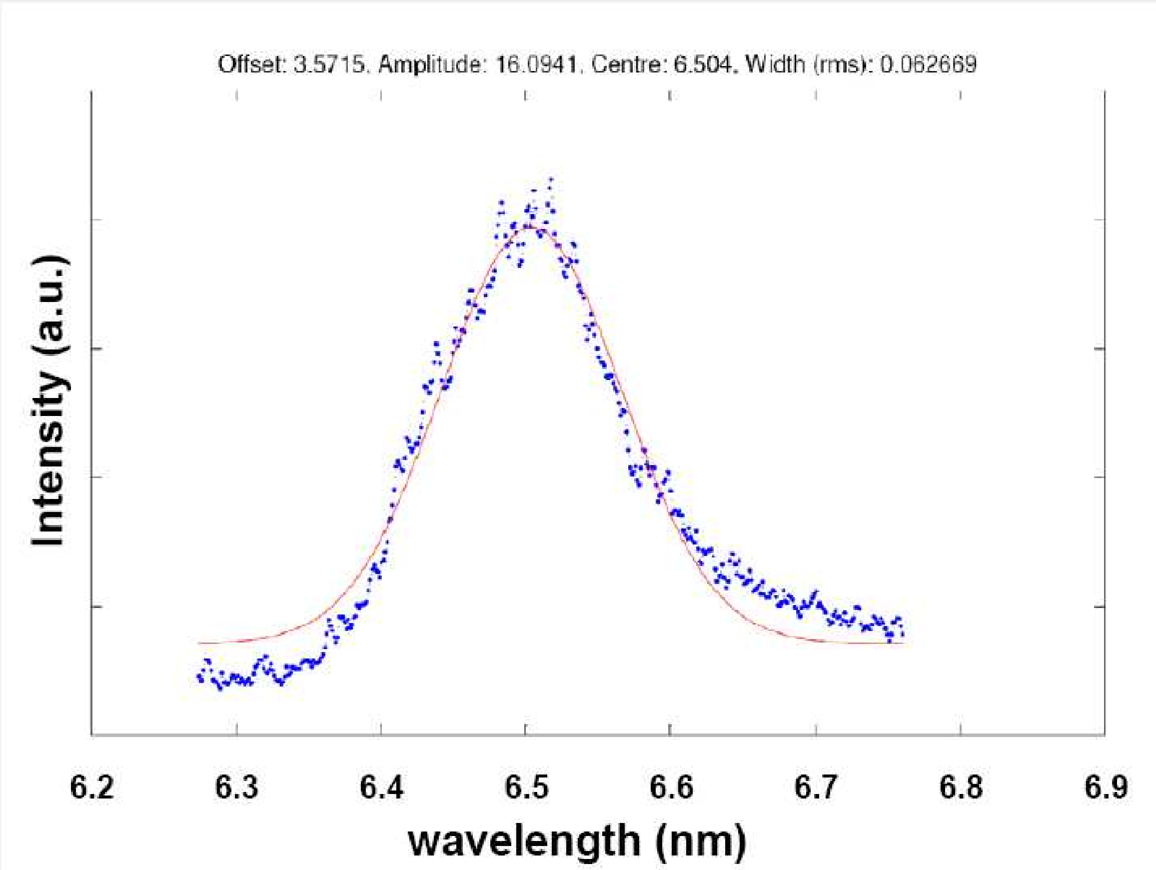


- Bunch arrival time stability with feedback :



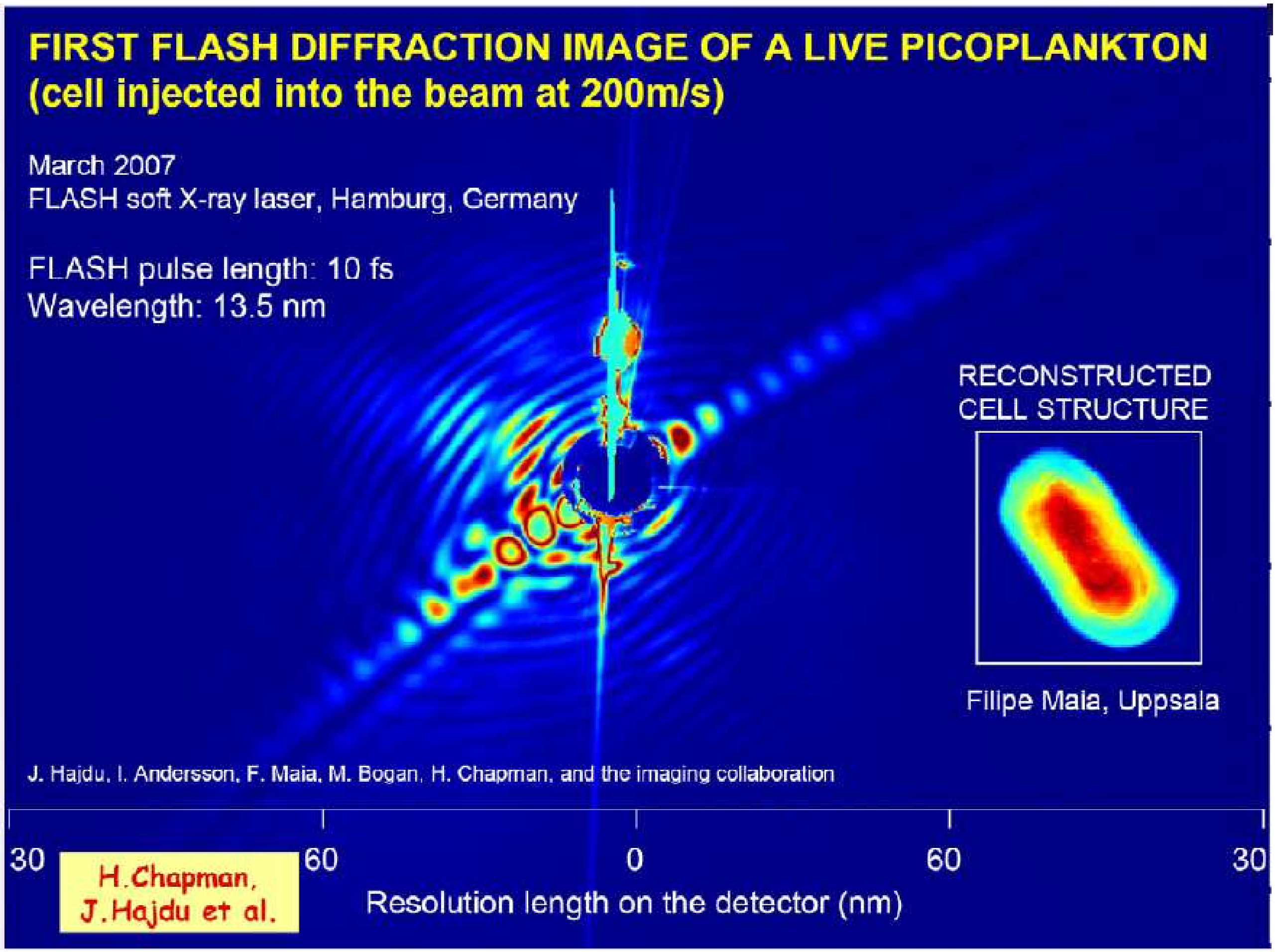
Reduce number of „pilot" bunches:

- Setpoints near to proper values
- Robust machine operation
- Reduce ACC1 cavity fluctuations (short-term and long-term)
- Stable RF-distribution system

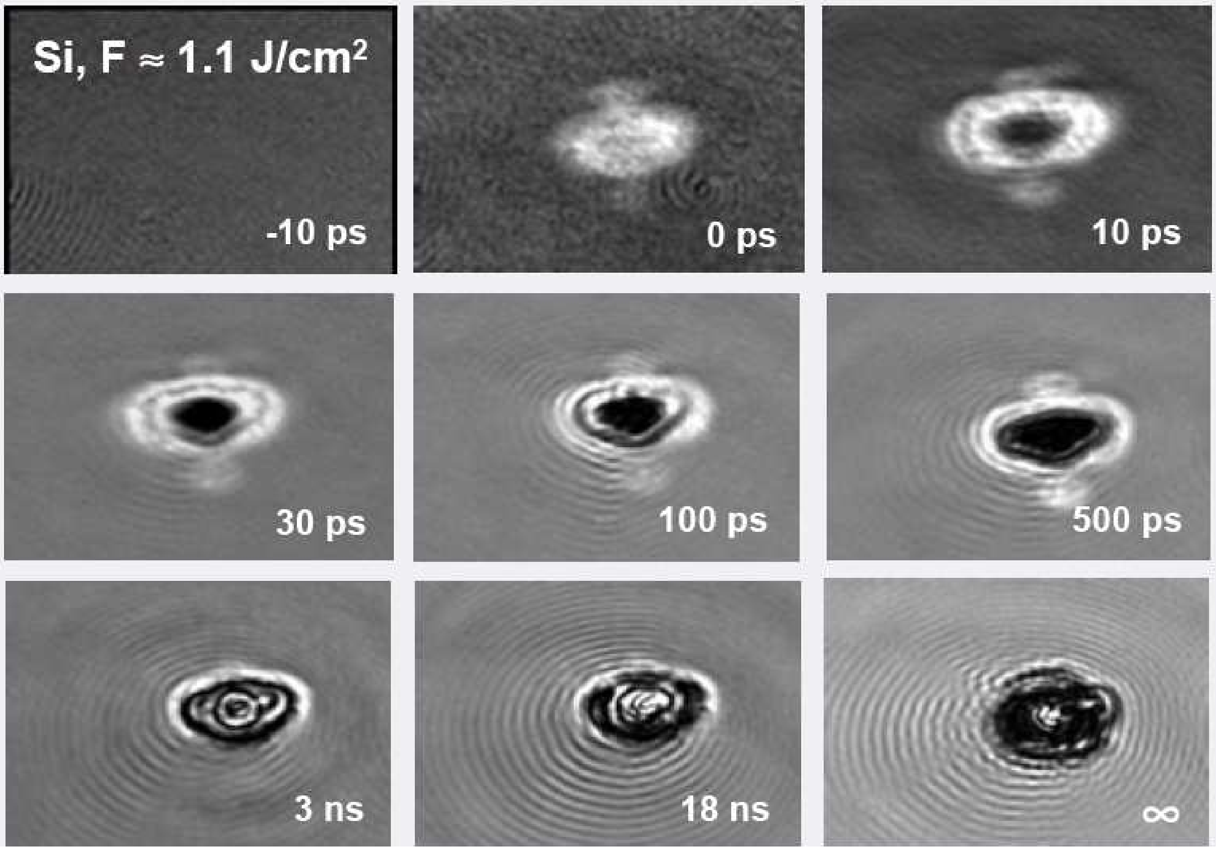


- first lasing at 80 nm (TTF1) took months
- first lasing at 6.9 nm instead of the previously reached 13 nm took hours

This demonstrates the scalability of the concept towards the XFEL.


FIRST FLASH DIFFRACTION IMAGE OF A LIVE PICOPLANKTON
(cell injected into the beam at 200m/s)
March 2007
FLASH soft X-ray laser, Hamburg, Germany
FLASH pulse length: 10 fs
Wavelength: 13.5 nm
RECONSTRUCTED
CELL STRUCTURE
Filipe Maia, Uppsala
J. Hajdu, I. Andersson, F. Maia, M. Bogan, H. Chapman, and the imaging collaboration
30
60
0
60
30
Resolution length on the detector (nm)
H.Chapman,
J.Hajdu et al.

K. Sokolowski-Tinten et al. **Fast melting of silicon**



Time-resolved snapshots of a bulk silicon sample after excitation with a single FEL pulse at a fluence of 1.1 J/cm^2.

Pictures taken with the help of a probe laser.

ACC39 delivered to DESY

FLASH
Free-Electron Laser in Hamburg

- module ACC39 with 3rd harmonic cavities arrived at DESY 28-Apr-2009

XFEL Construction started Jan. 8th 2009

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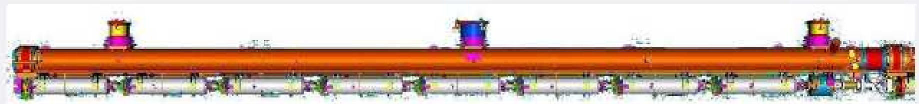
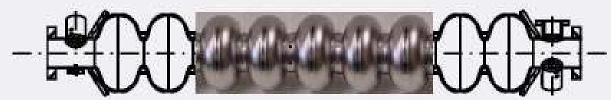
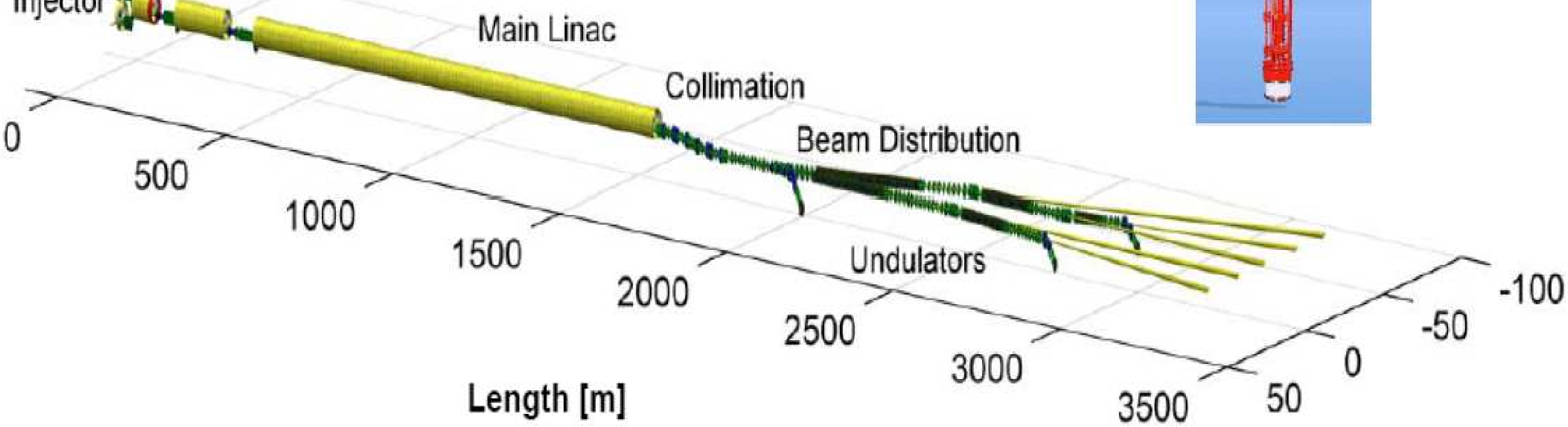
100 accelerator modules



800 accelerating cavities
1.3 GHz / 23.6 MV/m



25 RF stations
5.2 MW each



• DESY Zeuthen Site

- 118 permanent positions 68 other positions

- PITZ
- Modulator Test Facility
- Ice Cube
- Particle Physics

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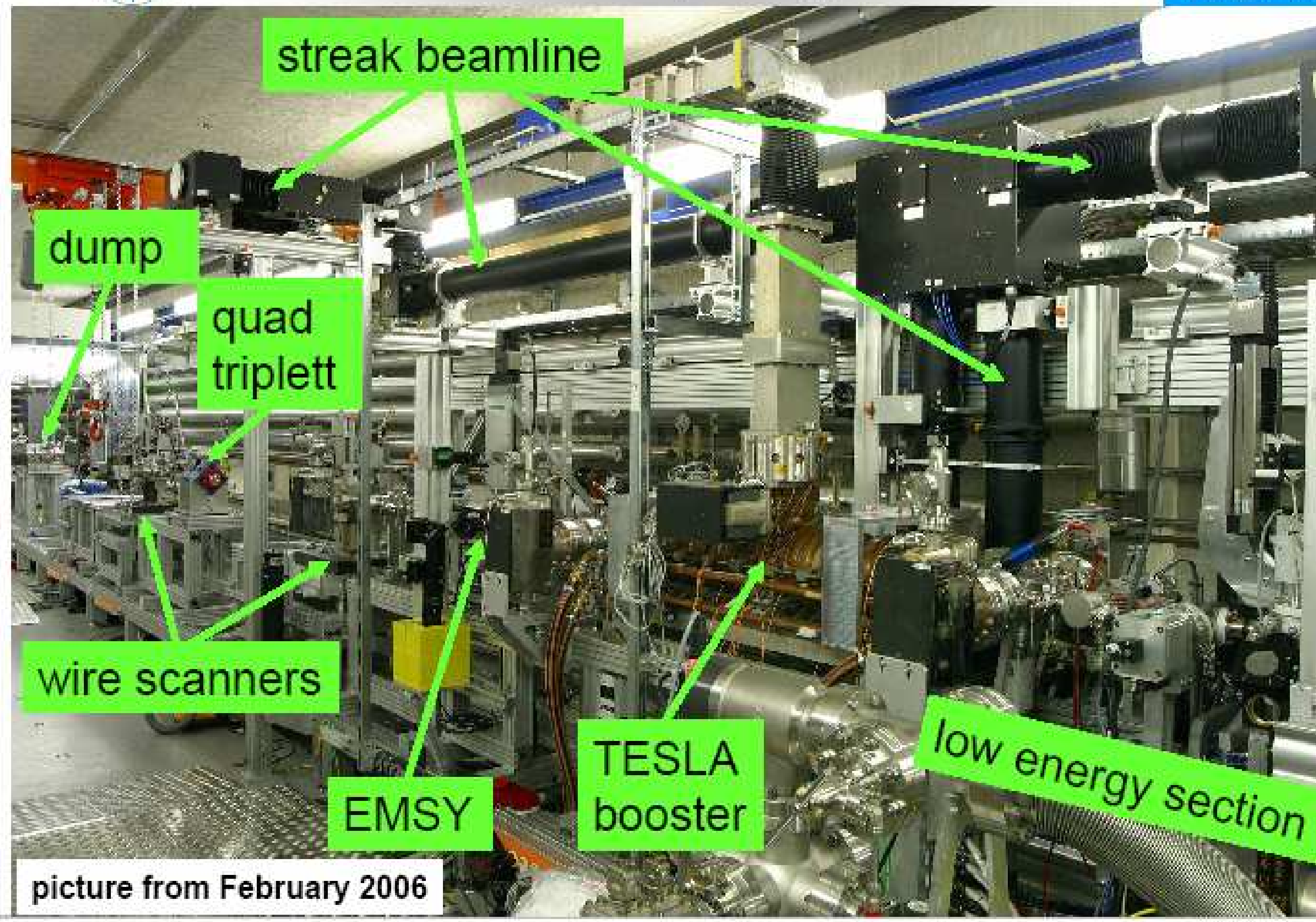
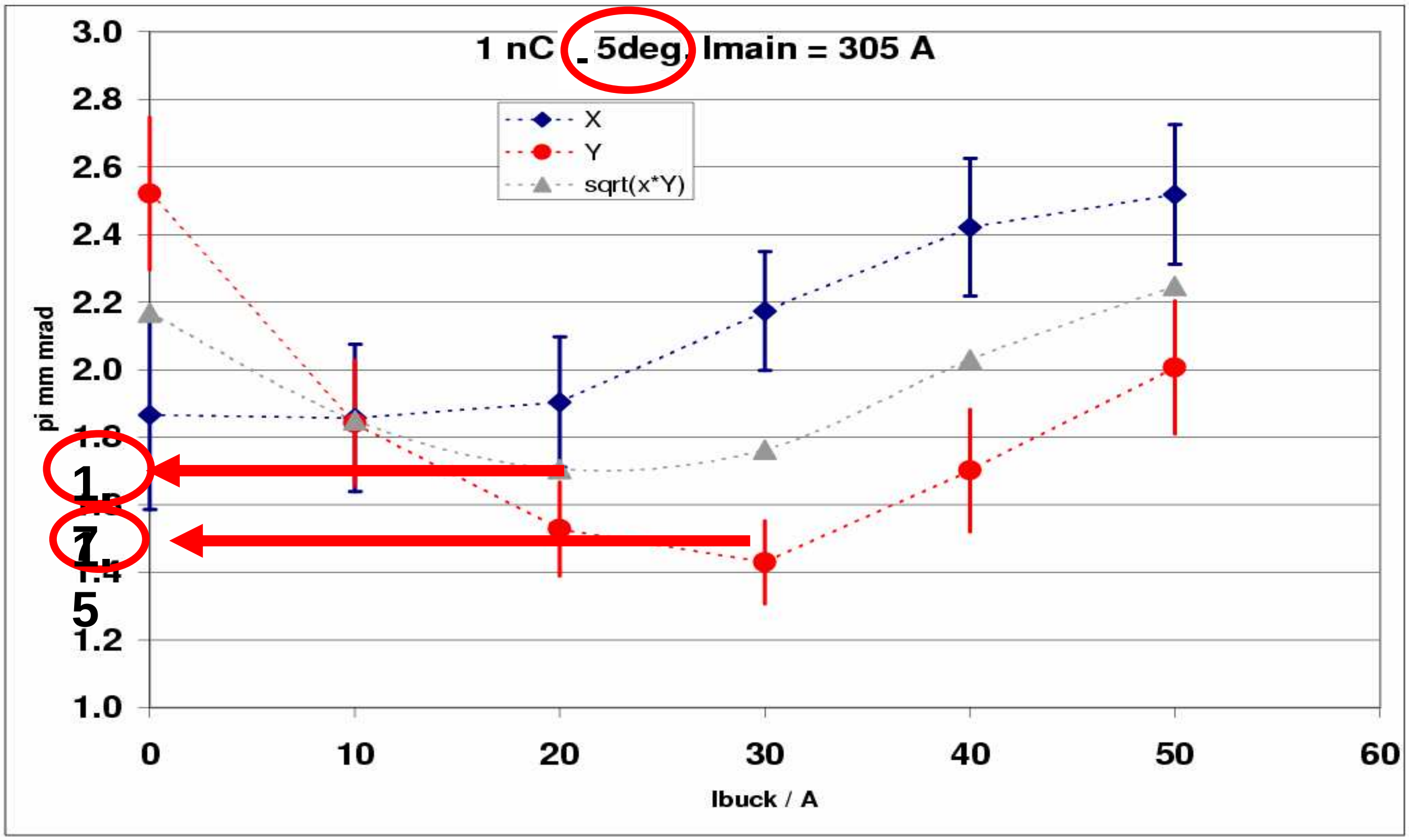
Tunnel in spring 2006

PITZ
Photo Injector Test Facility Zeuthen



Transverse Emittance Measurement @ PITZ



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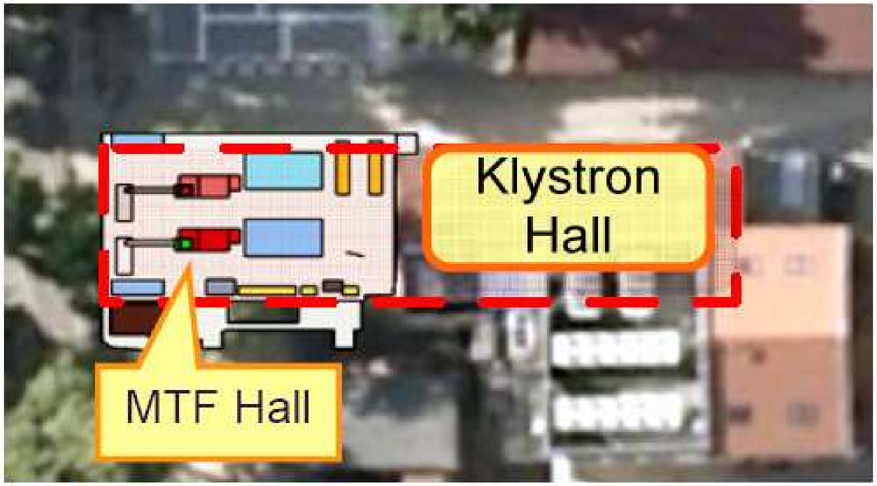
European XFEL

MTF Setup at Zeuthen

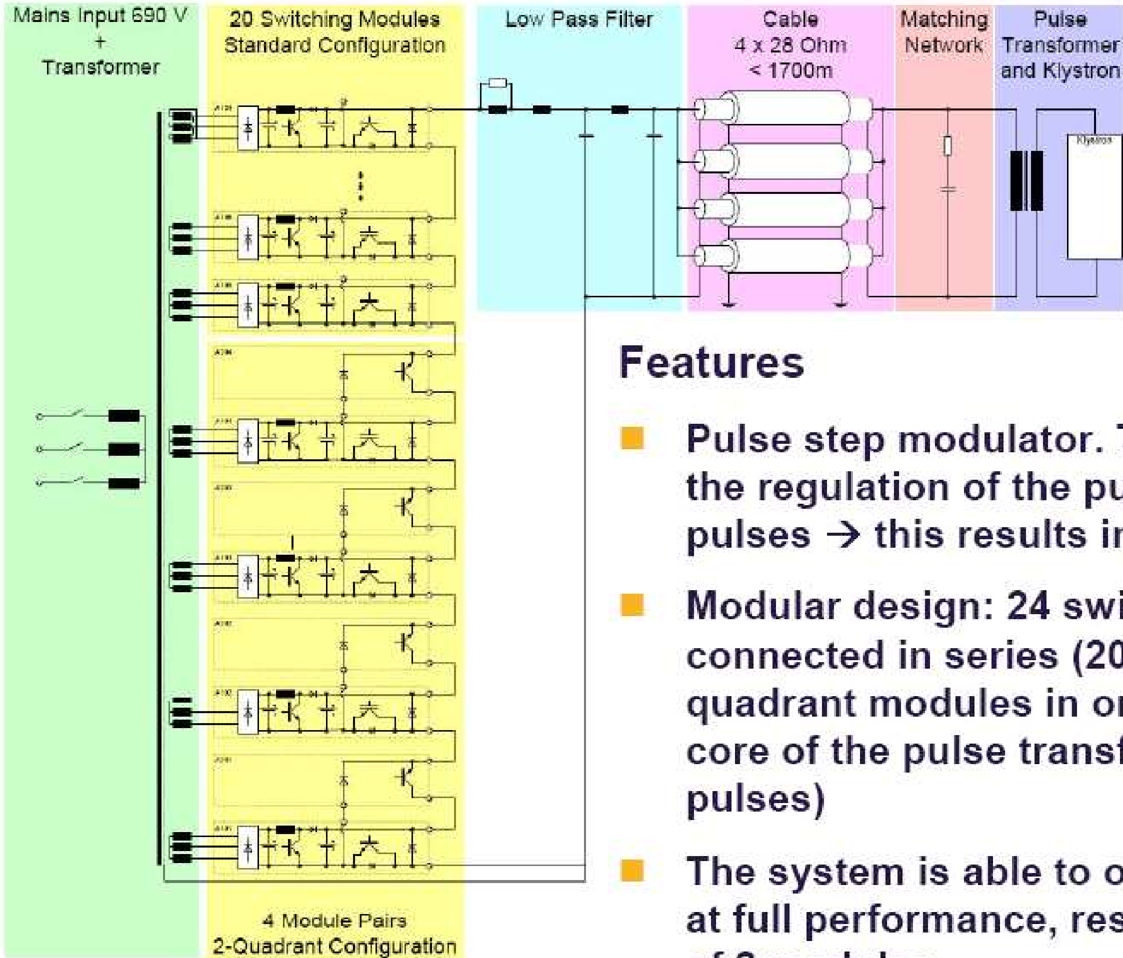
- existing klystron hall has been extended (finished in July 2006)
- Installed: Pulse transformers, klystrons, low level RF, pulse cables, water cooling system, main power transformer, control & interlock hardware, etc.



European XFEL

The Thomson Modulator 2

The Thomson Modulator 1



Features

- Pulse step modulator. This technology allows the regulation of the pulse voltage during the pulses → this results in a good flatness.
- Modular design: 24 switching modules connected in series (20 standard + 4 two-quadrant modules in order to demagnetize the core of the pulse transformer between the pulses)
- The system is able to operate with 22 modules at full performance, resulting in a redundancy of 2 modules

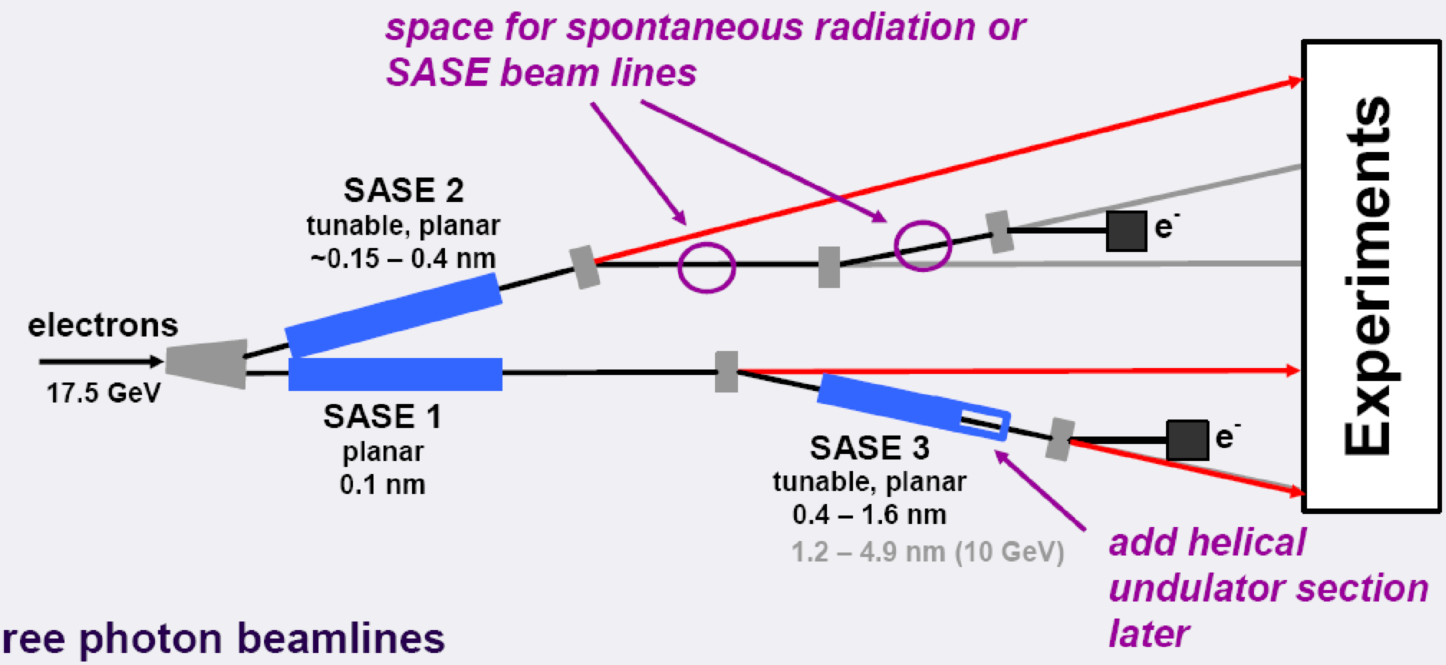
DU1

THANK YOU FOR YOUR ATTENTION

ENJOY THE 13th ESLS MEETING AT DESY

Slide 38

DU1 DESY USER; 07/09/2009

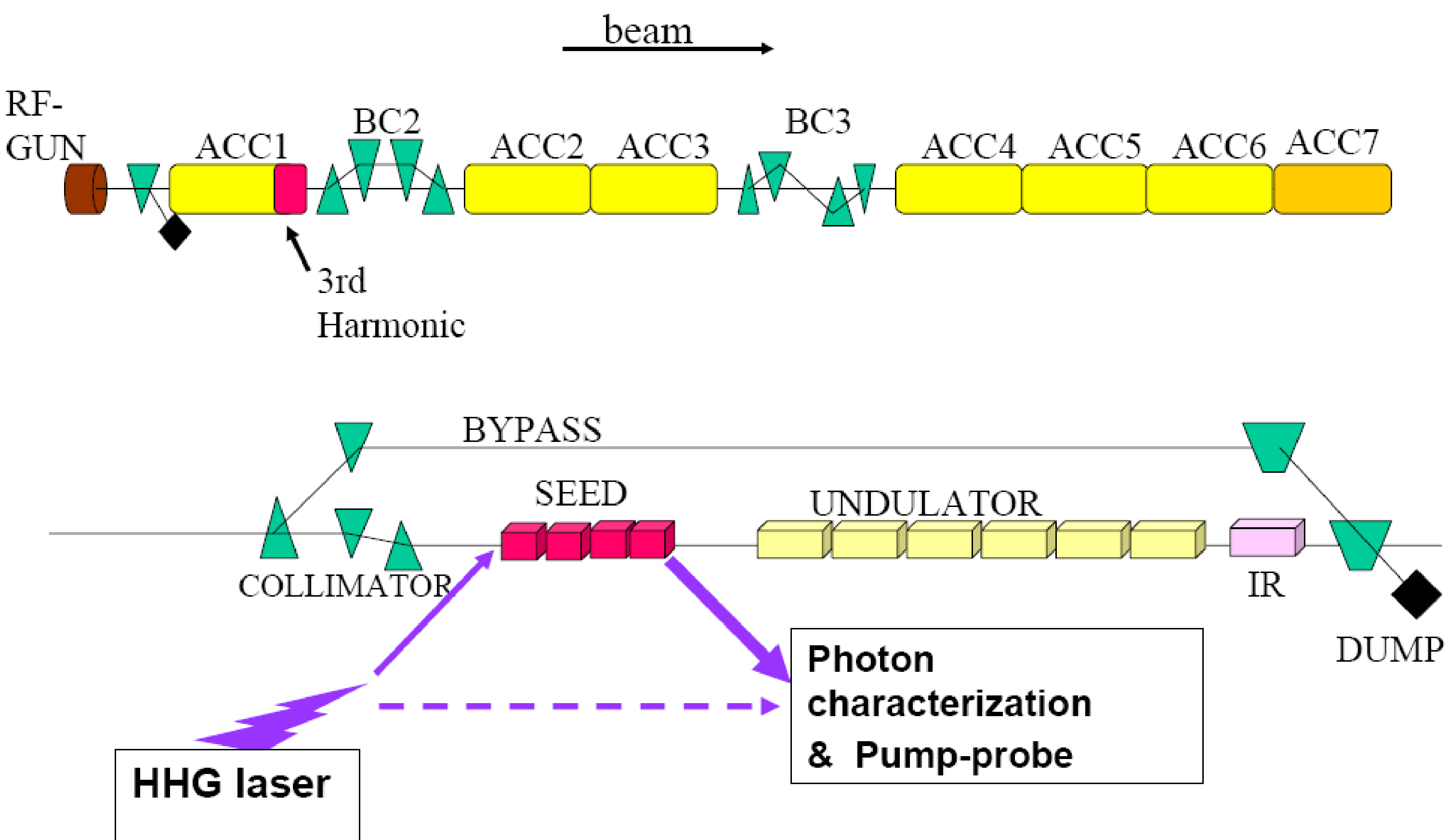


three photon beamlines

superconducting linac: 17.5 GeV

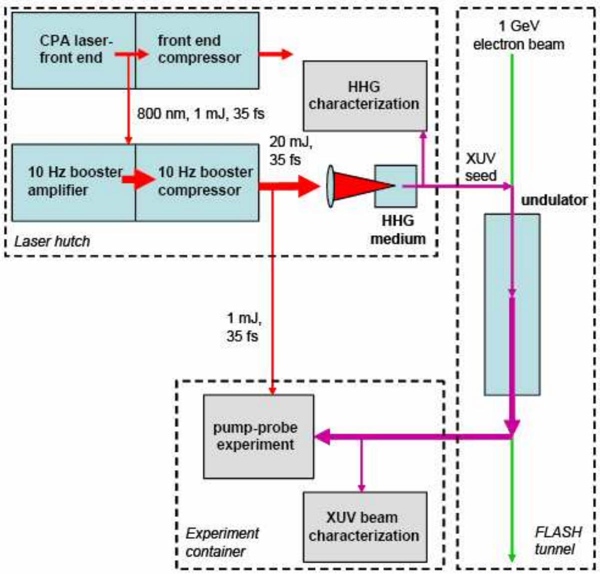
→ Photon wavelengths below 0.1 nm design value require a linac gradient above 23.6 MV/m (design value)

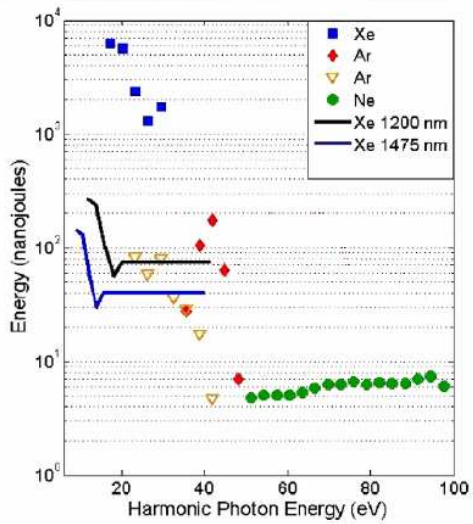
Overview sFLASH



- **Four modules tested** on CMTB → 3 installed at FLASH, 1 in 2009
- **Positive experience** for later series tests:
  - Fast conditioning of RF-power coupler
  - little additional conditioning in FLASH linac necessary
- **Good performance** of the modules → design beam energy reached in FLASH
- **"crash test"** of fault conditions (using old module M3* from FLASH)

Seeding FLASH = sFLASH





Source of high harmonics and photon diagnostics

Experimental data on coherent HHG pulse energies of high harmonics

McNeil et al., New. J. Phys. 9, (2007)

Our assumption: 1nJ

courtesy Markus Drescher

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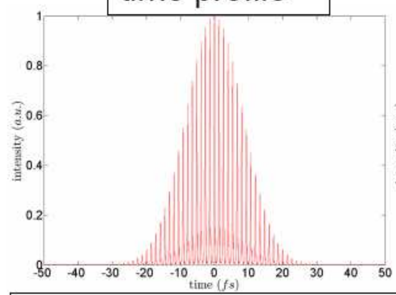
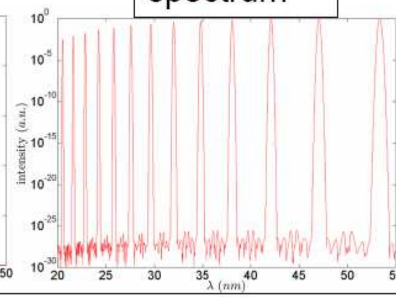
Seeding FLASH = sFLASH

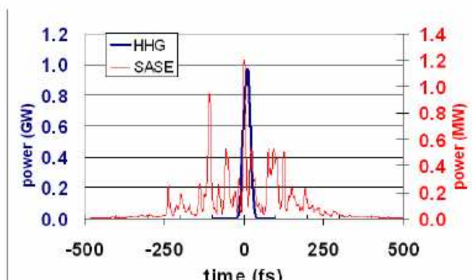
time profile

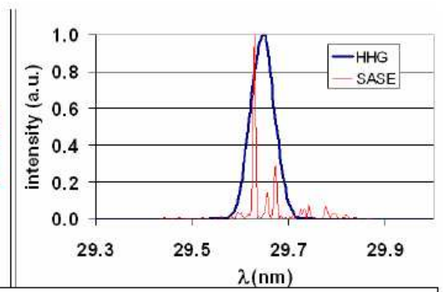
spectrum





Time profile and spectrum of HHG pulse used for numerical simulation of seeding process (GENESIS)

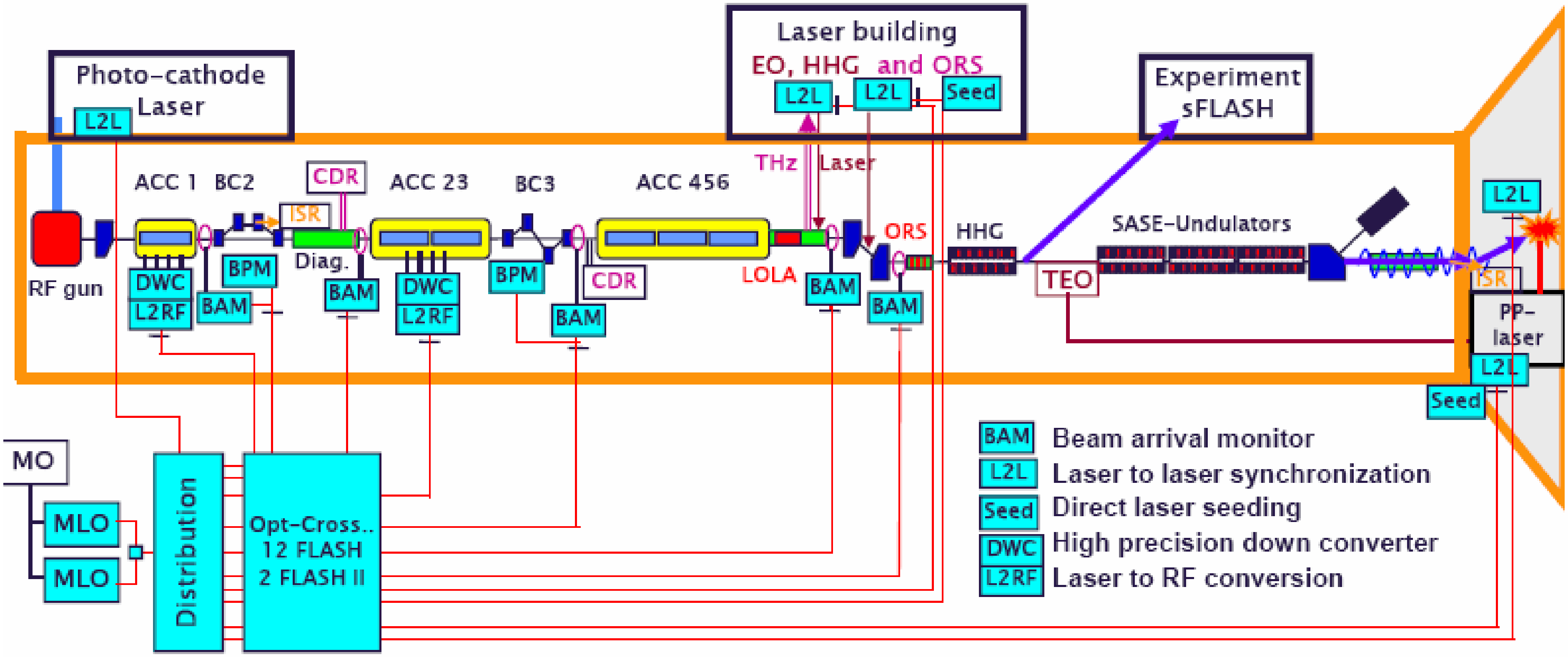




GENSIS result on seeded FEL pulse after 6 m undulator

Layout of synchronization system at FLASH

- Implementation of entire system 06/2008 - 2010

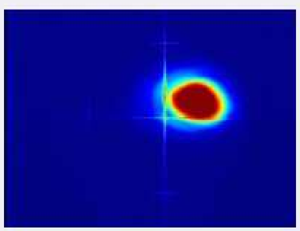


- Backbone: beam based stabilization of arrival time
- Conjunction with high precision synchronization of lasers
- Synchronization of all timing critical devices (~ 14 incl. FLASHII)
- Point-to-point synchronization ~ 10 fs rms (e- < 30 fs rms)
- Permanent operation and long term stability /availability investigation

Parameter	SASE 1 intermediate values	SASE1 final project values	Units
Wavelength	< 0.2	0.1	nm
Peak brilliance	10^{30}	5×10^{33}	Photons/s/mm²/ mrad²/0.1% BW
Dimension at sample (no optics)	< 1.0	~ 0.6	mm², FWHM
Positional stability	50	10	% of beam size, rms
Photon energy stability	~ 0.1	~ 0.1	%
Shot-to-shot intensity fluctuations	Up to a factor 10	0.3 – 0.5	Dimensionless, peak-to-peak

Table 4.1 *Intermediate and final project values for the accelerator and SASE 1 undulator and corresponding photon beamline.*

Wavelength (fundamental)	**47 – 6.5**	**nm**	**(tunable!!!)**
FEL range (harmonics)	**→ 2.7**	**nm**	
Average energy per pulse	up to 100	µJ	
Maximum energy per pulse	200	µJ	
Radiation pulse duration	10 – 50	fs	
Peak power (calc. from average)	~ 3 – 4	GW	
Spectral width (FWHM)	**0.5 – 1**	**%**	
Angular divergence (FWHM)	160	µrad	
Peak brilliance (calc. from max)	**5-10×10^{29}**	ph/s/mrad^2/mm^2/(0.1% bw)	



<E> = 70 µJ