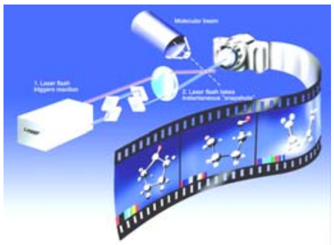
European XFEL Project

overall status & accelerator complex

R. Brinkmann, DESY -M-

For the XFEL Team



Introduction

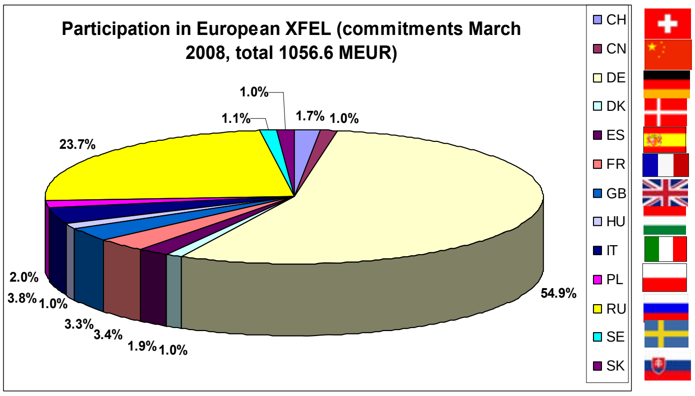
Oct 2002 : XFEL supplement to TESLA TDR → Feb 2003 approval by German government to realize the XFEL as European project with at least 40% funding contributions from partners → ***intense preparation work on technical design, industrialization of components, evaluation of cost/schedule, international project organization***

July 2006: completion of XFEL TDR, submitted to and approved by International Steering Committee → ***986M€/y2005 construction cost (+preparation & commissioning cost), negotiations of funding contributions continuing***

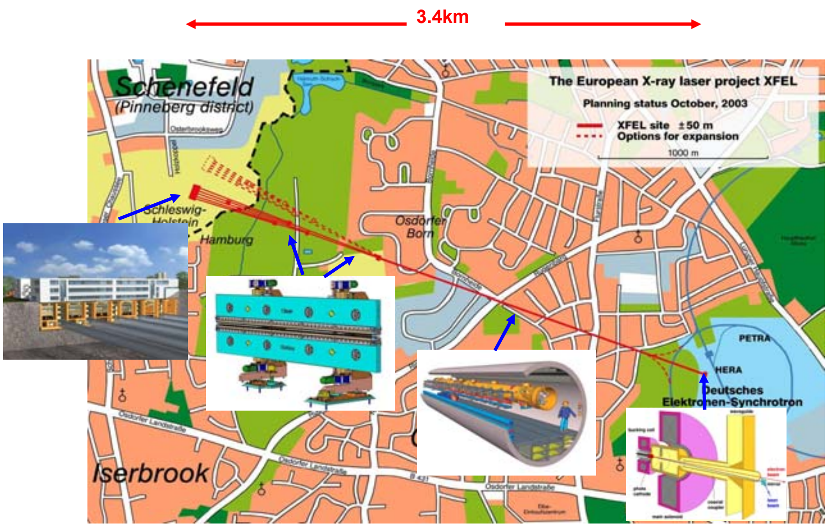
June 5, 2007: Official project start announced on basis of initially de-scoped start version at 850M€/y2005 construction cost → ***launch tender process for civil construction, finalization of legal documents & prep of XFEL GmbH foundation, negotiations of in-kind contributions***

Status of financial commitments to European XFEL project

Includes ~90 M€ project preparation phase & commissioning costs



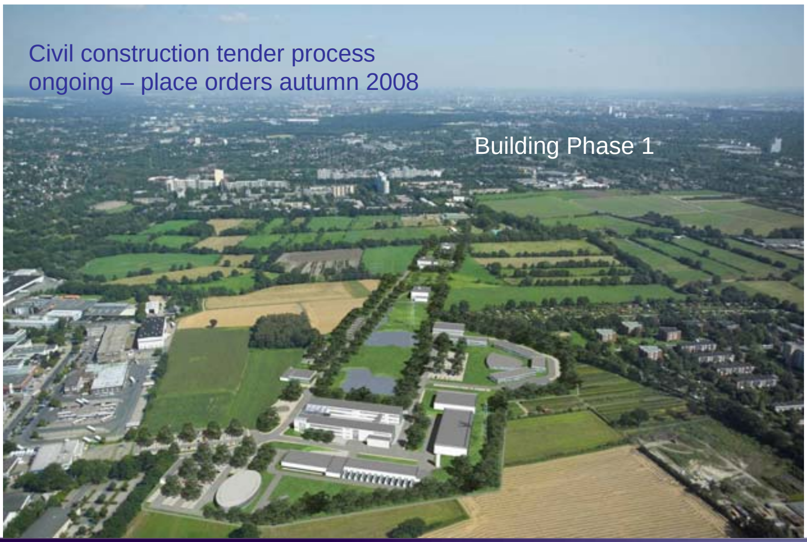
Overall layout of the European XFEL



XFEL site in Hamburg/Schenefeld

The European X-Ray Laser Project XFEL
X-Ray Free-Electron Laser

… after construction *(computer simulation)*



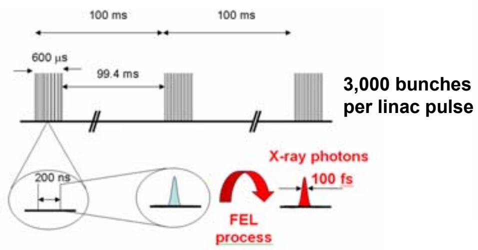
Properties of XFEL radiation

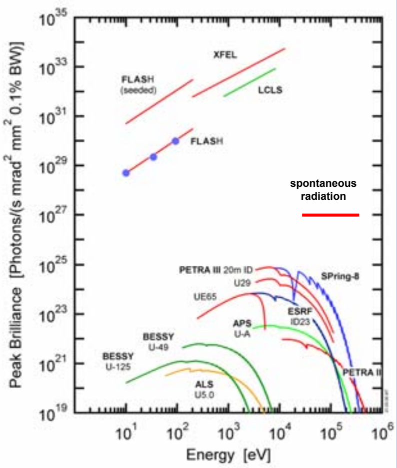
X-ray FEL radiation (0.2 - 12.4 keV)

- ultrashort pulse duration <100 fs (rms)
- extreme pulse intensities 10^{12}-10^{14} ph
- coherent radiation x10^9
- average brilliance x10^4

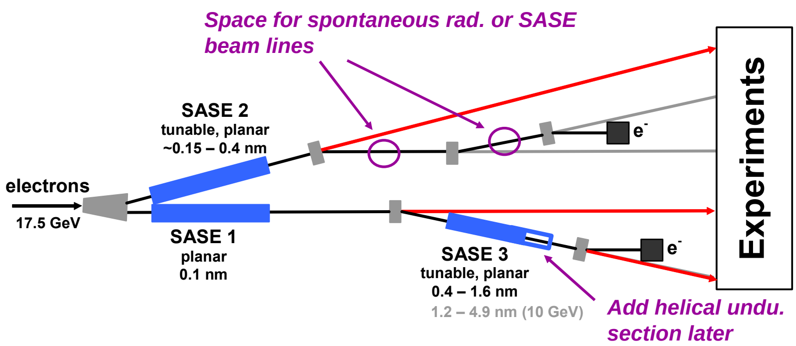
Spontaneous radiation (20-100 keV)

- ultrashort pulse duration <100 fs (rms)
- high brilliance





Beam lines in start version



Additional initial cost saving by shortening s.c. linac 20 → 17.5 GeV

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

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Selection of first instruments

Instrument	Brief description of the instrument
SPB	Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules – **Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.**
MID	Materials Imaging & Dynamics **–Structure determination of nano- devices and dynamics at the nanoscale.**
FDE	Femtosecond Diffraction Experiments – **Time-resolved investigations of the dynamics of solids, liquids, gases**
HED	High Energy Density Matter – **Investigation of matter under extreme conditions using hard x-ray FEL radiation, e.g. probing dense plasmas.**
SQS	Small Quantum Systems – **Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena.**
SCS	Soft x-ray Coherent Scattering **–Structure and dynamics of nano-systems and of non-reproducible biological objects using soft X-rays.**

Hard X-rays: SPB, MID, FDE, HED
Soft X-rays: SQS, SCS

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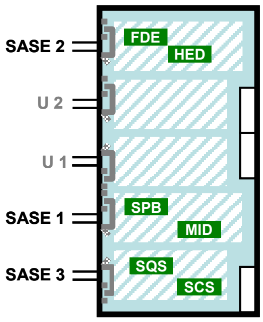
Distribution of first instruments

Source	Photon beam line characeristics
SASE 1	**FEL radiation ~12 keV** **High coherence** **Spontaneous radiation** **(3rd, 5th harmonics)**
SASE 2	**FEL radiation 3-12 keV** **High time-resolution** **Spontaneous radiation** **(3rd, 5th harmonics)**
SASE 3	**FEL radiation 0.25 – 3 keV;** **High flux**
	FEL radiation 0.25 – 3 keV; **High resolution**



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Photon beam systems developments

- Undulators: prototyping ongoing (synergy with PETRA-III), studies of mech. Tolerances, temperature stabilization, …
- Photon diagnostics: conceptual design & tests of beam diagnostics, photon beam based alignment for undulator sections, …
- Investigations of photon beam transport systems
- 2D-Detectors: major challenge e-beam time structure, R&D program launched in two consortia (HPAD, LPD), 3rd under discussion (DEPFET)
- DAQ work package recently established & active

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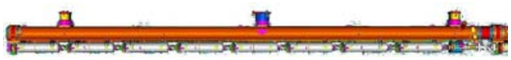
X-Ray Laser Project XFEL
X-Ray Free-Electron Laser

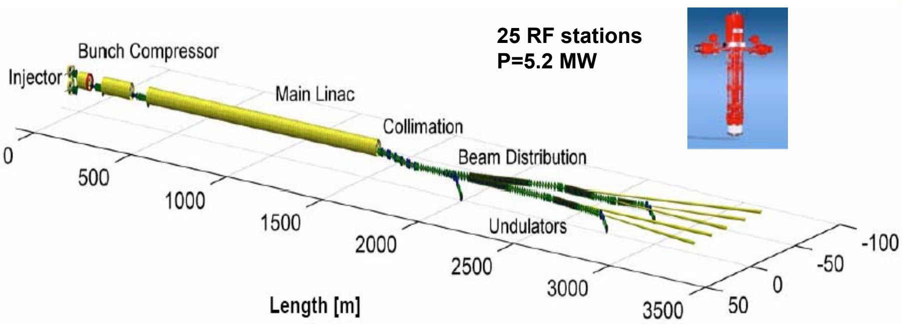
Accelerator complex

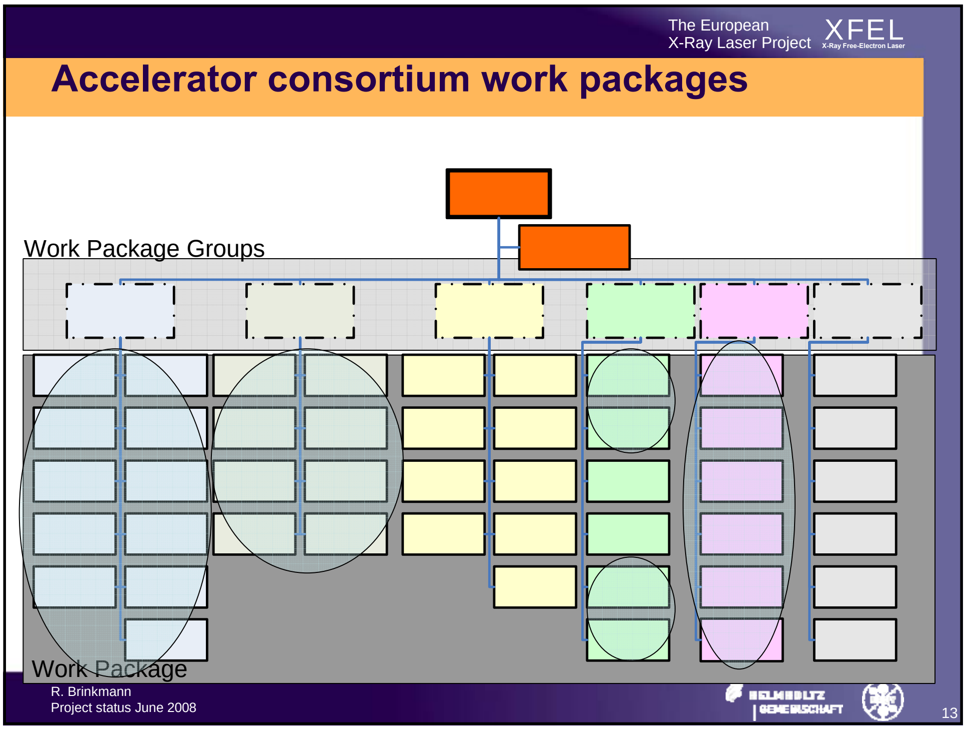
100 accelerator modules

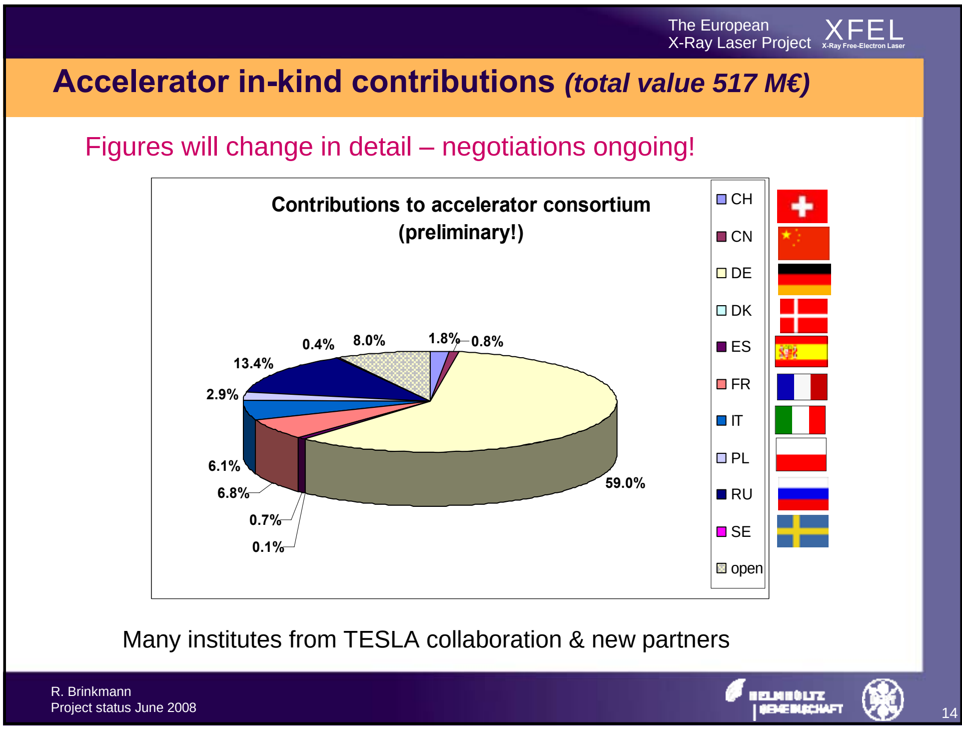


800 1.3 GHZ cavities
g=23.6 MV/m

25 RF stations
P=5.2 MW







PG-1:
NAC

WP-01
RF System

WP-02:
Low Level RF

WP-03:
Accelerator
Module

WP-04:
SC Cavities

XFEL Construction: Overall Organisation & Information Flow

XFEL Council

XFEL GmbH

XFEL Management Board

WPG-3 WPLs & WPCLs

WPG-3 Work Packages

XFEL Project Board

ACB & Consortium Plenary assembles 2 times a year.

Accelerator Consortium

Consortium Coordinator (CC + CT) - DESY -

Accelerator Consortium Board (ACB) (Chaired by the CC)

AC WPLs & WPCLs

AC Work Packages

Assembly of the technical expertise
- Cold Linac Coord. Meeting (monthly)
- Mach. Layout Coord. Meeting (monthly)
- Tech. Coord. Meeting (monthly)

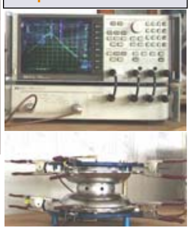
Cavity Fabrication

Half cells are produced by deep drawing.

Annealing is next to achieve complete re-crystalisation.

Dumb bells are formed by electron beam welding.

RF measurements support visual inspection.

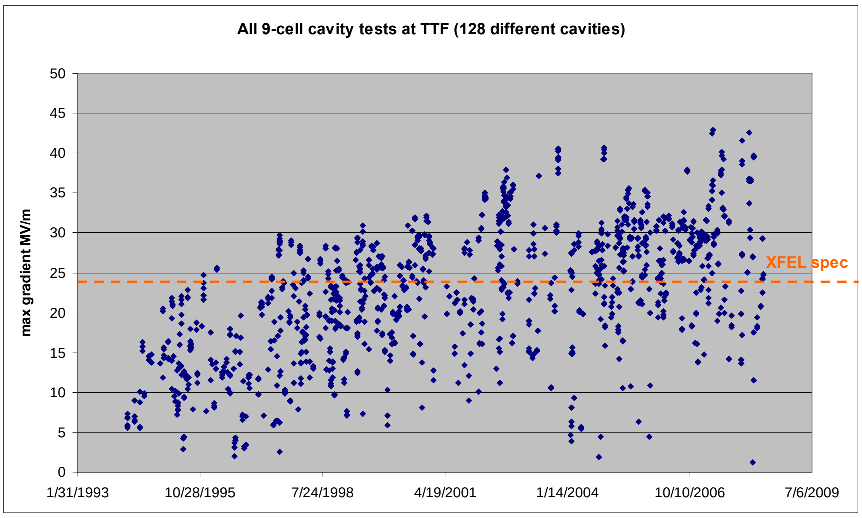


After proper cleaning eight dumb bells and two end group sections are assembled in a precise fixture.

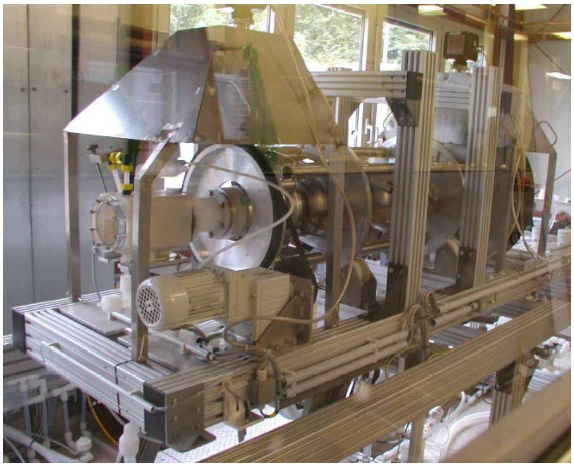
All equator welds can be done in one production step.

Engineering Data Management Systems (EDMS) is used for the documentation of the cavity fabrication process.

s.c. cavities – all measurements @TTF since start of TESLA collaboration



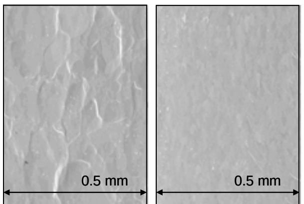
Cavity Preparation (Electrolytical Polishing)



Electro-polishing (EP) instead of the standard chemical polishing (BCP) eliminates grain boundary steps.

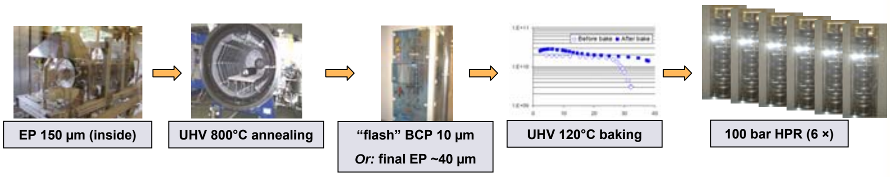
Gradients above 35 MV/m at Q values above 10^{10} were achieved in 9-cells at DESY.

The highest gradient achieved was 42 MV/m (single cell).



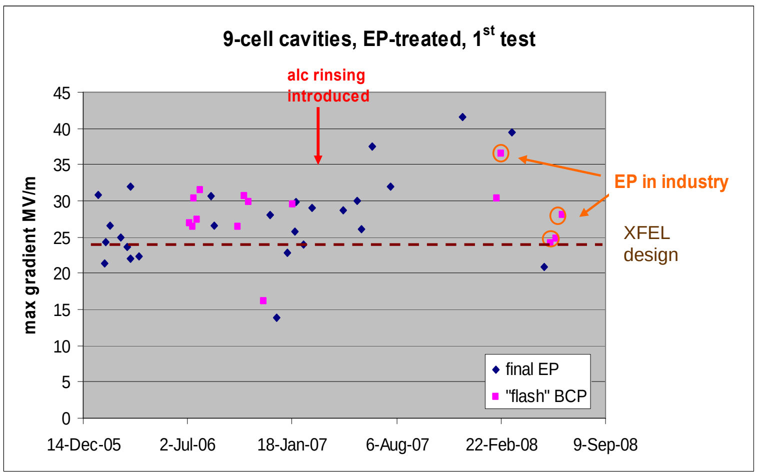
BCP Surface (1µm roughness) | EP Surface (0.1µm roughness)

Cavity preparation cont'd

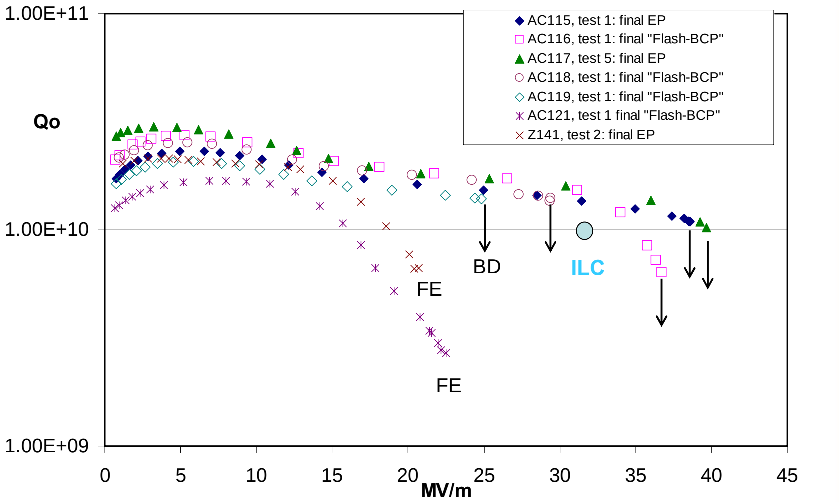


- Industrialization of EP ongoing: several cavities received from each of two companies, 4 cavities tested so far

Cavities since Jan 2006, 1st test



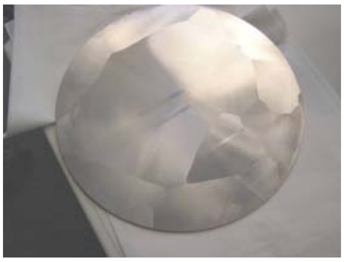
Q_0 vs gradient: best results with final ep



Alternative fabrication – large grain Nb

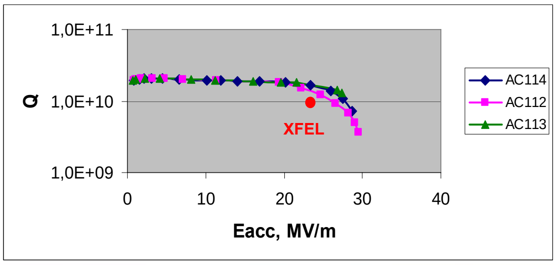
Fabrication from large-grain Niobium – cut sheets directly from ingot (method pioneered at JLAB)

After initial good results with single cells, fabricated and tested three 9-cell cavities – only BCP-treated, no EP!



→building 6 more cavities, possibly alternative fabrication/treatment procedure

→Could later choose the more economic method for industrial production



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X-Ray Free-Electron Laser

Cavity string & module assembly

Using experience gained at DESY and results of industrial studies, the assembly facility for all 100 XFEL modules will be set up at the CEA-Saclay site

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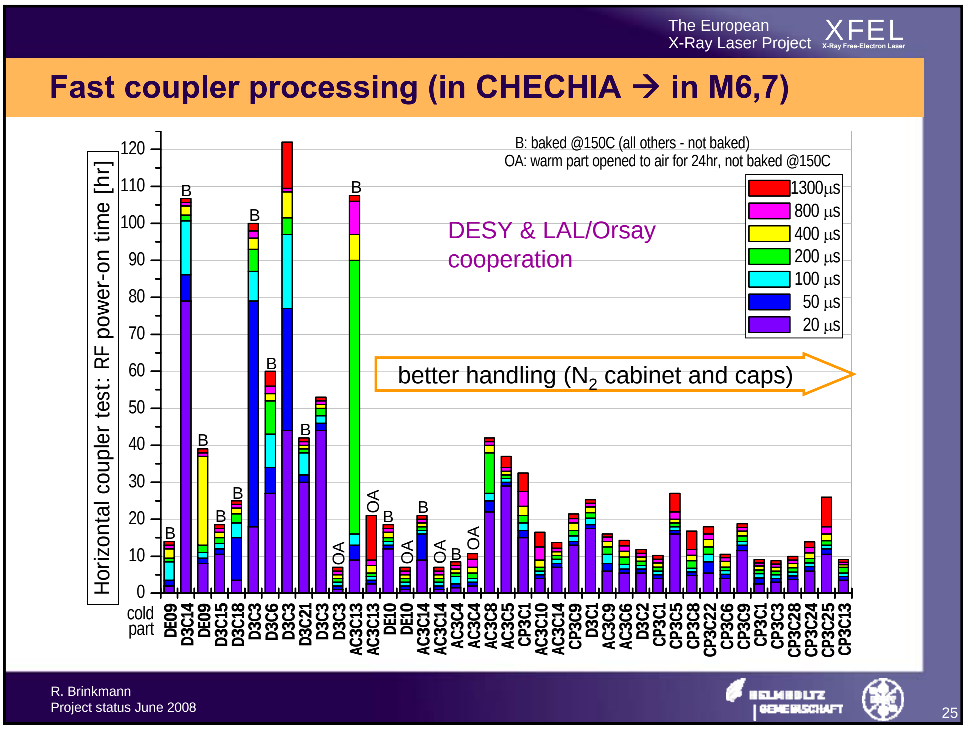
X-Ray Free-Electron Laser

Operation of CMTB *(cryo module test bench)*

- Three modules tested on CMTB → FLASH
- Positive experience for later series tests:
  - Fast conditioning of RF-power coupler
  - Hardly any additional conditioning in FLASH linac necessary
- Good performance of the modules → **design beam energy reached in FLASH**


The European
X-Ray Laser Project
XFEL
Fast coupler processing (in CHECHIA → in M6,7)
B: baked @150C (all others - not baked)
OA: warm part opened to air for 24hr, not baked @150C
DESY & LAL/Orsay cooperation
better handling (N2 cabinet and caps)
1300µs
800 µs
400 µs
200 µs
100 µs
50 µs
20 µs
Horizontal coupler test: RF power-on time [hr]
cold part
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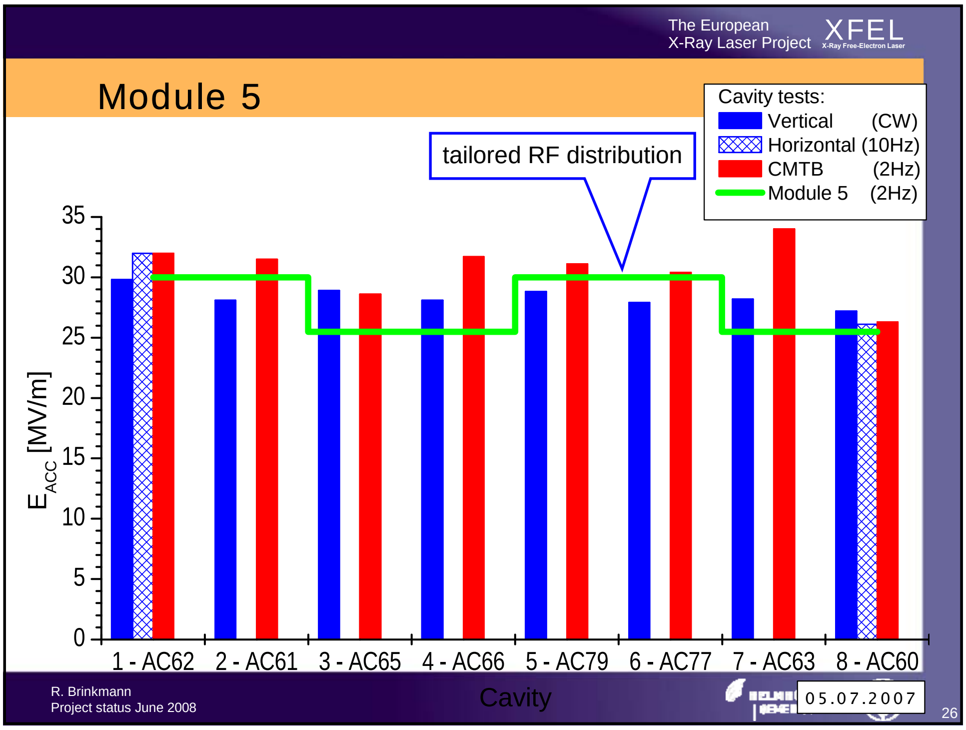
The European
X-Ray Laser Project
XFEL
Module 5
Cavity tests:
Vertical (CW)
Horizontal (10Hz)
CMTB (2Hz)
Module 5 (2Hz)
tailored RF distribution
EACC [MV/m]
1 - AC62
2 - AC61
3 - AC65
4 - AC66
5 - AC79
6 - AC77
7 - AC63
8 - AC60
Cavity
05.07.2007
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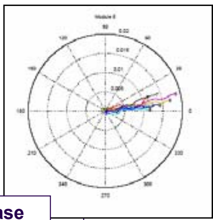
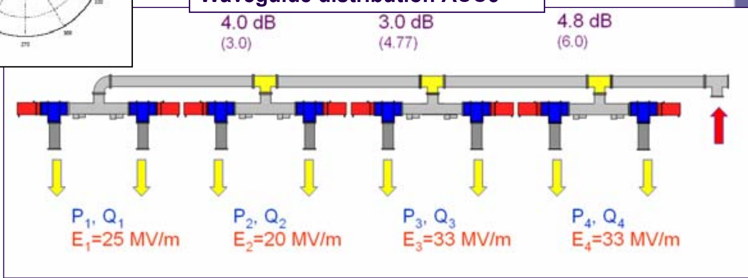
New pre-adjusted waveguide system tested at FLASH/ACC6

Power distribution and phase distribution for the individual cavities almost perfect



Initial phase distribution

Waveguide distribution ACC6



RF system – hor. Klystron

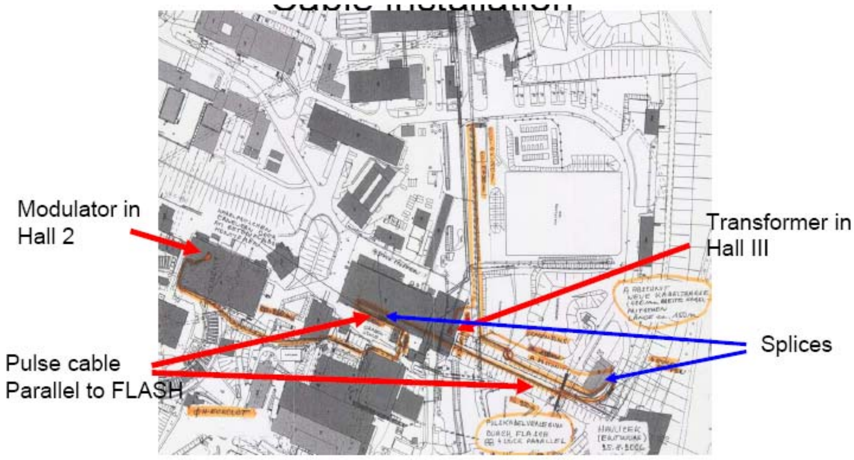
Toshiba E3736H at test stand in August 2007 at Toshiba in Nasu, Japan

Test Results (Toshiba)		*(design)*
Peak Output Power at 117kV (MW)	10.3	*(10)*
Efficiency (%)	~67	*(65)*
Beam Pulse Length (ms)	1.7	
RF Pulse length (ms)	1.5	*(1.5)*
Repetition Rate (pps)	10	*(10)*
Saturation Gain (dB)	50	

- Factory Acceptance Test (FAT) in Nasu successfull on August 22/23, 2007
- Klystron arrived at DESY on 18th Sept.
- Site Acceptance Test (SAT) at DESY ongoing

Modulator prototyping – test stand at Zeuthen

Pulse cable test in FLASH



→ No perturbation of FLASH operation due to EMI from pulse cables

The European X-Ray Laser Project XFEL

Tunnel mock-up completed and installations ongoing

The European X-Ray Laser Project XFEL

Injector R&D - PITZ

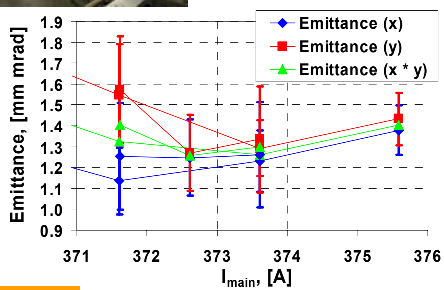
August 2007:

$\varepsilon_{x,n} = 1.25 \pm 0.19$ mm mrad

$\varepsilon_{y,n} = 1.27 \pm 0.18$ mm mrad

@1nC

for 100 % RMS emittance !



Cut of large-amplitude tails:

For 95% RMS ➔ $\varepsilon_{x,y,n} \approx 0.8$ mm mrad

XFEL design values is 0.9 mm mrad from the gun and 1.4 mm mrad in the undulators for FEL saturation at 0.1nm wavelength

Further improvement of projected emittance with laser upgrade

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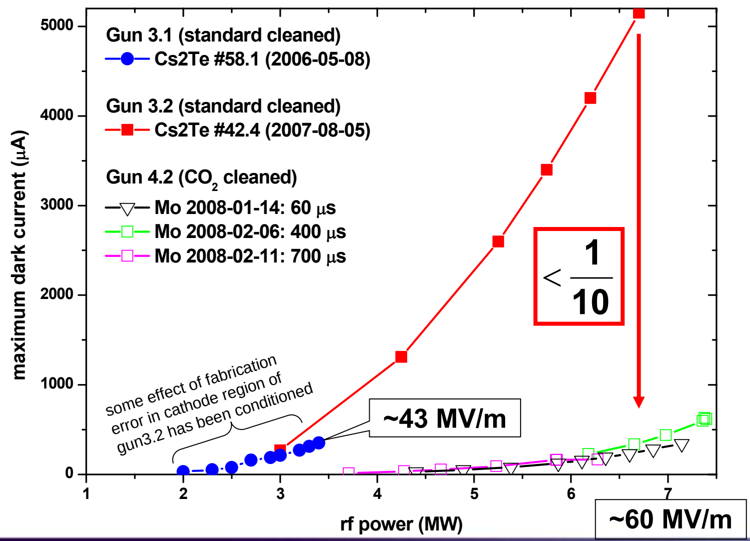
Reduced dark current with new CO_2 cleaned gun 4.2



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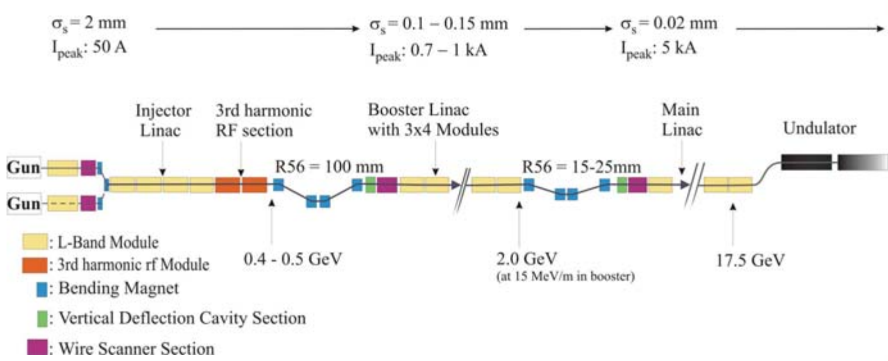
Bunch compressor & diagnostics stations



Extensive S2E studies of beam dynamics

→ Slice emittance at undulators < 1 mm*mrad

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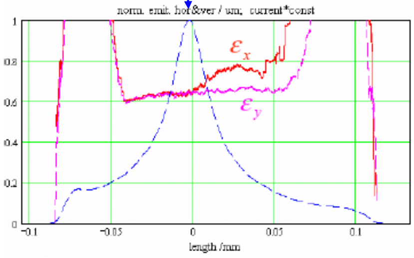
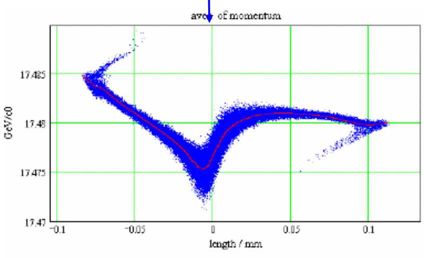
S2E Simulation results

I_{pk} = 5 kA



$\sigma_E \approx$ 1 MeV



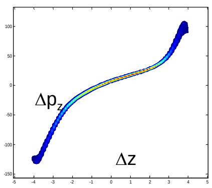
Slice emittance ≈0.7mm*mrad

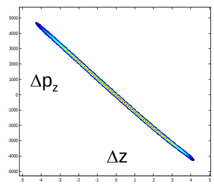
(“x”=BC bend plane)

Longitudinal phase space after linac

3rd harmonic RF-system → FLASH

Entrance ACC1 — 3.9 GHz linearizer → Exit 3rd harmonic cav.

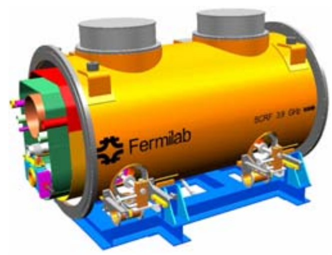




Will gain invaluable experience for XFEL!

Complete cryomodule delivered by FNAL

Installation after ACC1 scheduled for 2009



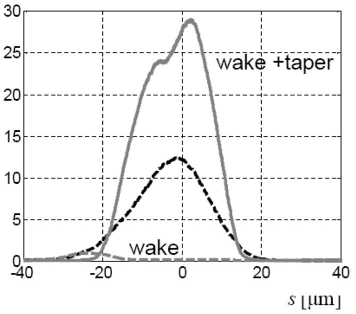
module with four nine cell cavities

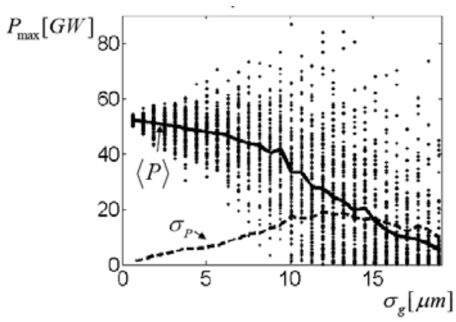
fits type 2 TESLA module

XFEL will use three 6m modules/8 cavities (DESY & INFN coop.)

FEL simulations SASE1 0.1nm with wakefields

*(Slice ε artificially increased to design value 1.4 mm*mrad)*

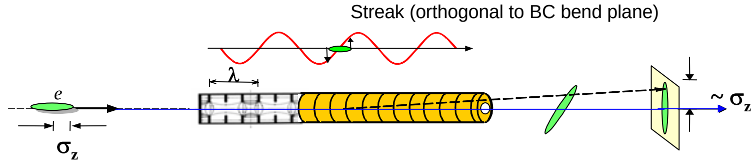


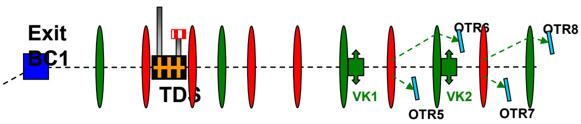


Undulator gap taper by ~1μm per 5m segment (33 segments total) removes power loss due to wakefields

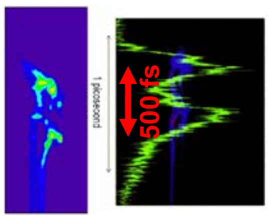
Few μm random gap variation for individual 5m sections are tolerable

Slice emittance diagnostics *(method developed @SLAC)*





XFEL layout: Single bunches can be extracted from bunch train → continuous monitoring of bunch slice parameters



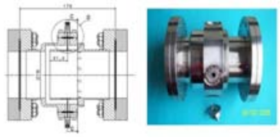
simulation

Example of measurement at FLASH (“LOLA”)

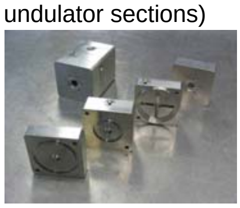
Beam position monitors (DESY-PSI-Saclay coop.)

Button (HERA-e concept)

Re-entrant cav.



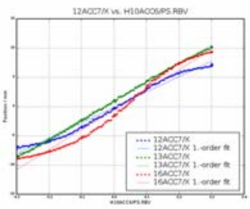
4.4 GHz Cavity (µm resolution for undulator sections)

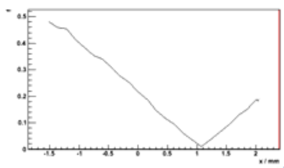


1.3 Resolutionmessung

Alle Resolutions und Noises in RMS.

Charge	Attenuator	Resolution	Resolution	Resolution
-	-	13ACC7	12ACC7	16ACC7
nC	dB	um	um	um
1.1	?	29.2	5.6	48.1
0.5	5	24.6	11.8	73.6
0.4	4	24.6	16.0	81.7
0.3	0	23.0	23.1	88.1
0.2	0	30.7	30.1	109





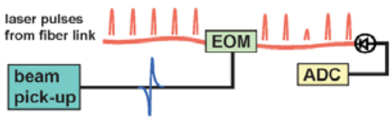
Old TTF stripline

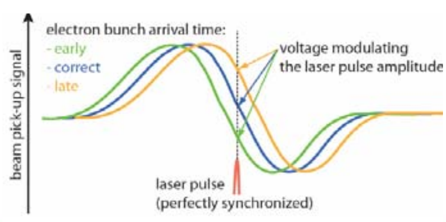
1st test, oscilloscope, no electronics yet

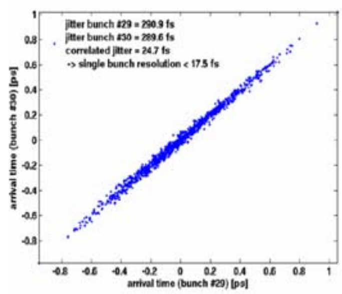
Timing/synchronisation diagnostics in fs-regime

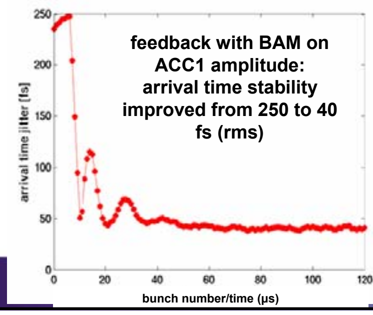
Arrival time monitor installed and tested at FLASH

Timing information of electron bunch is transferred into a laser amplitude modulation.

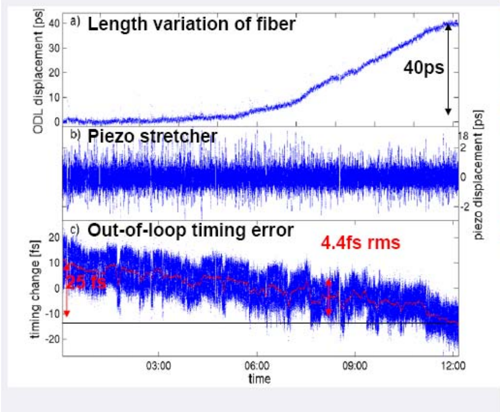




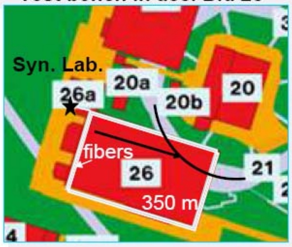




Test of stabilized optical fiber link



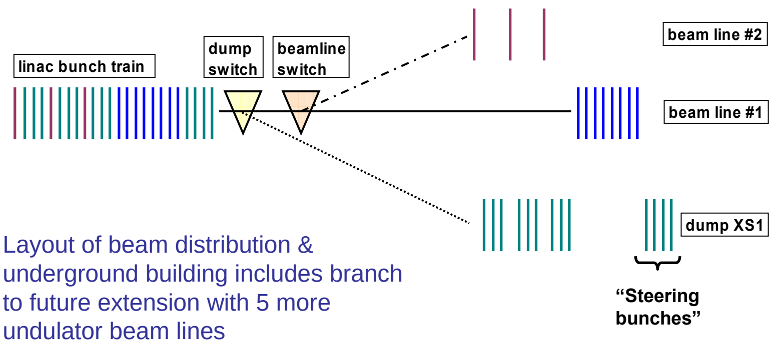
Test bench in acc. Bld 26



- timing jitter over 2 minutes: 4.4 ± 1.1 fs (rms)
- timing drift over 12 hours: 25 fs (total 7.8 fs rms)
- measurement bandwidth: 200 kHz

Beam distribution

Different beam time structure to different experiments – concept using kicker devices permits large flexibility without having to change the (preferably homogenous) bunch train structure in the linac



Layout of beam distribution & underground building includes branch to future extension with 5 more undulator beam lines

Fast intra-train feedback system (DESY & PSI cooperation)

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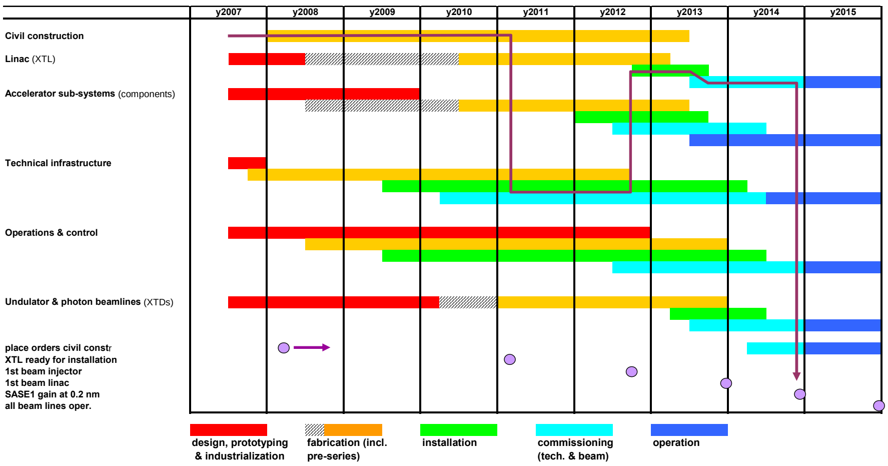
Schedule *(as of July 2007)*



Estimated delay ~ 8…9 months *(tender process underground construction)*

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The end