

John Adams Institute
Oxford



The European XFEL Free Electron Laser at DESY

Hans Weise / DESY

for the TTF/**FLASH** and the XFEL Project Groups

(Free-Electron LASer in Hamburg)

FLASH and XFEL

Time to explore the femtosecond dynamics of nature

- Ever seen the machinery of a living cell at work at atomic resolution?
- Observed how molecules change shape in femtoseconds during chemical or biochemical reactions?
- Watched a drug molecule enter a protein receptor in real time?

Soon X-ray free-electron lasers will enable us to probe ultra fast physical, chemical and biochemical processes at atomic resolution, opening new frontiers for science and technology.

At long last we may see, and not just model, how molecular machines really work.

See more: *FLASH booklet, published in June 2007*

<http://flash.desy.de/>

FLASH.

The Free-Electron Laser
in Hamburg



New technologies for new science: Soon X-ray free-electron lasers will enable us to probe ultrafast physical, chemical and biochemical processes at atomic resolution, opening new frontiers for science and technology. At long last we may see, and not just model, how molecular machines really work.

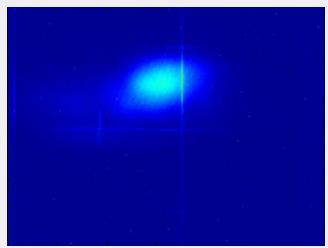
Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
Member of the Helmholtz Association

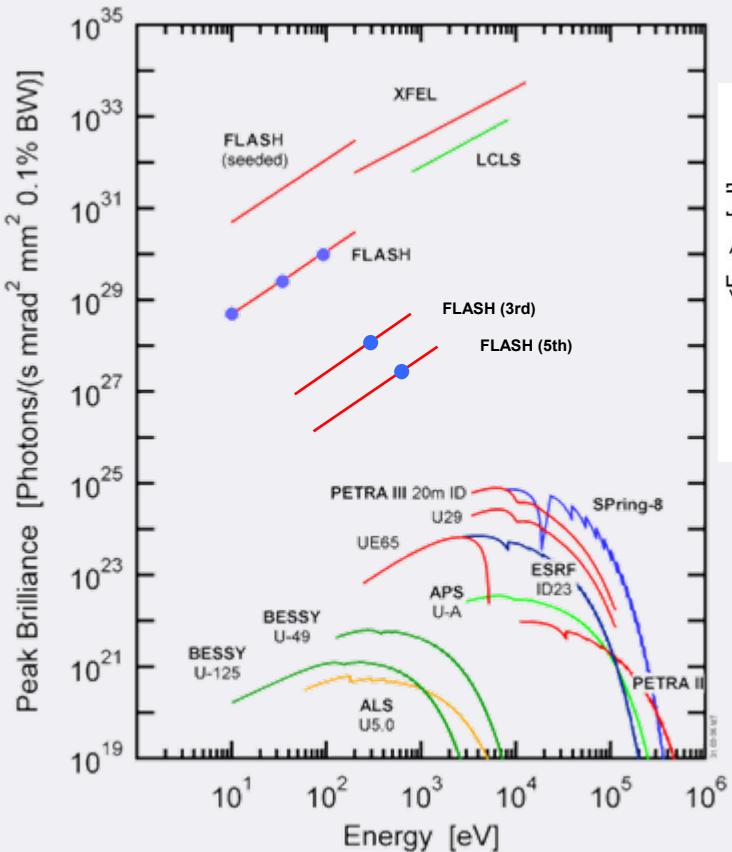


This is, where we are...

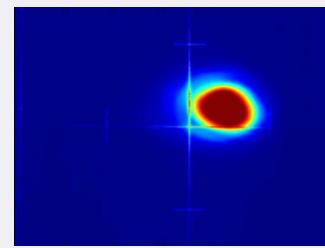
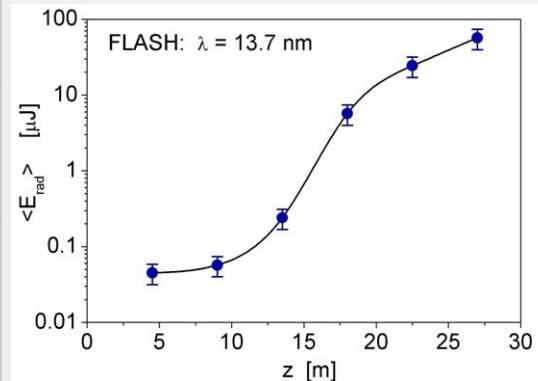
April 26, 2006



$\langle E \rangle = 5 \mu J$



Recent User run
2006 / 2007



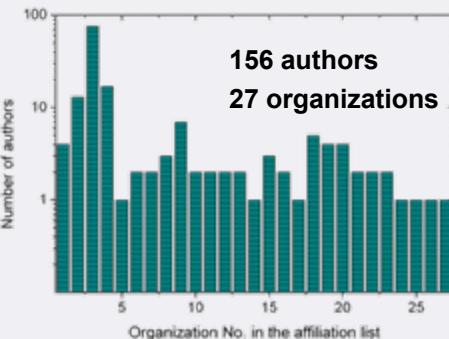
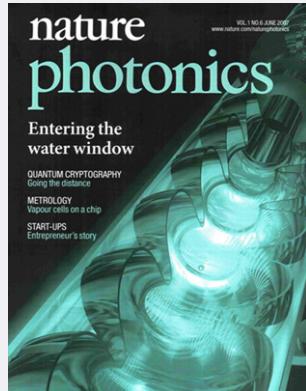
$\langle E \rangle = 70 \mu J$

... the actual reference...

Operation of a free-electron laser from the extreme ultraviolet to the water window

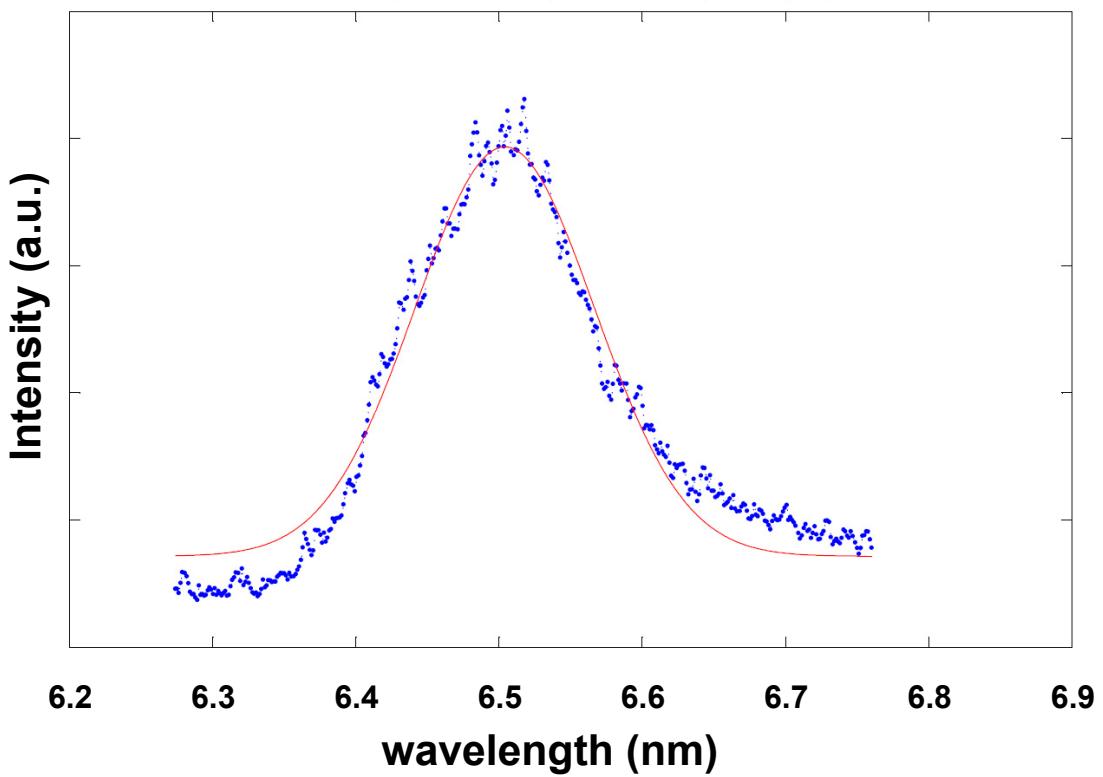
W. ACKERMANN¹, G. ASOVA², V. AVAYAZIAN³, A. AZIMA³, N. BABOI³, J. BÄHR², V. BALANDIN³, B. BEUTNER⁴, A. BRANDT³, A. BOLZMANN⁵, R. BRINKMANN³, O. I. BROVKO⁶, M. CASTELLANO⁷, P. CASTRO³, L. CATANI⁸, E. CHIADRONI⁸, S. CHOROBIA³, A. CIANCHI⁸, J. T. COSTELLO⁹, D. CUBAYNES¹⁰, J. DARDIS⁹, W. DECKING³, H. DELSIM-HASHEMI⁴, A. DELSERIEYS¹¹, G. DI PIRRO⁷, M. DOHLUS³, S. DÜSTERER³, A. ECKHARDT⁴, H. T. EDWARDS¹², B. FAATZ³, J. FELDHAUS³, K. FLÖTTMANN³, J. FRISCH¹³, L. FRÖHLICH³, T. GARVEY¹⁴, U. GEN SCH², CH. GERTH³, M. GÖRLER³, N. GOLUBEVA³, H.-J. GRABOSCH², M. GRECKI¹⁵, O. GRIMM³, K. HACKER^{3,4}, U. HAHN³, J. H. HAN³, K. HONKAVAARA⁴, T. HOTT³, M. HÜNING³, Y. IVANISENKO¹⁶, E. JAESCHKE¹⁷, W. JEZYNSKI¹⁵, R. KAMMERING³, V. KATALEV³, K. KAVANAGH⁹, E. T. KENNEDY⁹, S. KHODYACHYKH², K. KLOSE², V. KOCHARYAN³, M. KÖRFER³, M. KOLLEWE³, W. KOPREK¹⁸, S. KOREPANOV², D. KOSTIN³, M. KRASSILNIKOV², G. KUBE³, M. KUHLMANN³, C. L. S. LEWIS¹¹, L. LILJE³, T. LIMBERG³, D. LIPKA³, F. LÖHL³, H. LUNA⁹, M. LUONG¹⁹, M. MARTINS⁴, M. MEYER¹⁰, P. MICHELATO²⁰, V. MILTCHEV⁴, W. D. MÖLLER³, L. MONACO²⁰, W. F. O. MÜLLER¹, O. NAPIERALSKI¹⁶, O. NAPOLY¹⁹, P. NICOLOSI²¹, D. NÖLLE³, T. NUÑEZ³, A. OPPELT², C. PAGANI²⁰, R. PAPARELLA¹⁹, N. PCHALEK^{3,4}, J. PEDREGOSA-GUTIERREZ⁹, B. PETERSEN³, B. PETROSYAN², G. PETROSYAN³, L. PETROSYAN³, J. PFLÜGER³, E. PLÖNJES³, L. POLETOFF³, K. POZNIAK¹⁸, E. PRAT^{3,4}, D. PROCH³, P. PUCYK¹⁸, P. RADCLIFFE³, H. REDLIN³, K. REHLICH³, M. RICHTER²², M. ROEHR³⁴, J. ROENSCHE⁴, R. ROMANIUK¹⁸, M. ROSS¹³, J. ROSSBACH⁴, V. RYBNIKOV³, M. SACHWITZ², E. L. SALDIN³, W. SANDNER²³, H. SCHLARB³, B. SCHMIDT³, M. SCHMITZ³, P. SCHMÜSER⁴, J. R. SCHNEIDER³, E. A. SCHNEIDMILLER³, S. SCHNEPP¹, S. SCHREIBER³, M. SEIDEL^{3,24}, D. SERTORE²⁰, A. V. SHABUNOV⁶, C. SIMON¹⁹, S. SIMROCK³, E. SOMBROWSKI¹, A. A. SOROKIN^{25,22}, P. SPANKNEBEL²⁶, R. SPESVTSEV¹⁶, L. STAYKOV², B. STEFFEN³, F. STEPHAN³, F. STULLE³, H. THOM³, K. TIEDTKE³, M. TISCHER³, S. TOLEIKIS³, R. TREUSCH³, D. TRINES³, I. TSAKOV²⁷, E. VOGEL³, T. WEILAND¹, H. WEISE³, M. WELLHÖFER⁴, M. WENDT^{3,12}, I. WILL²³, A. WINTER³, K. WITTENBURG³, W. WURTH⁴, P. YEATES⁹, M. V. YURKOV^{3*}, I. ZAGORODNOV³ AND K. ZAPFE³

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... and lasing at 6.5 nm ...

Offset: 3.5715, Amplitude: 16.0941, Centre: 6.504, Width (rms): 0.062669



... and the best:

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

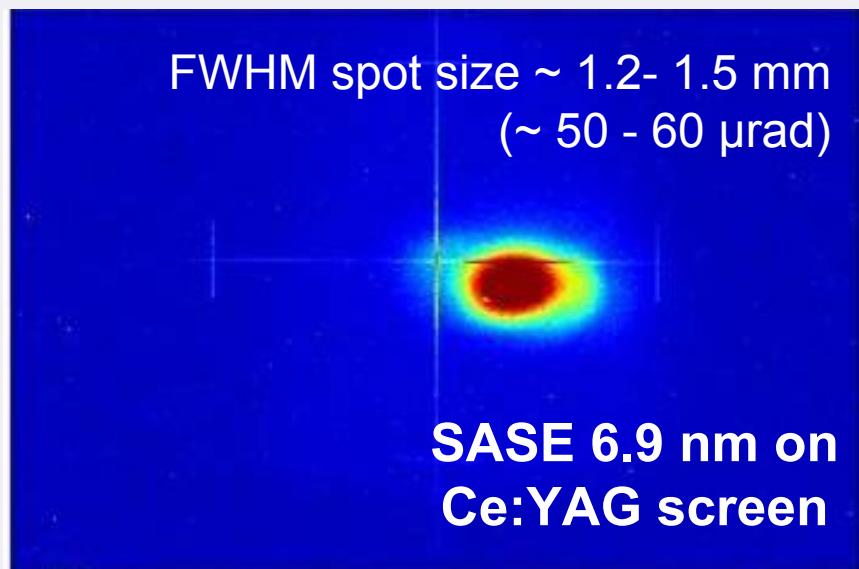
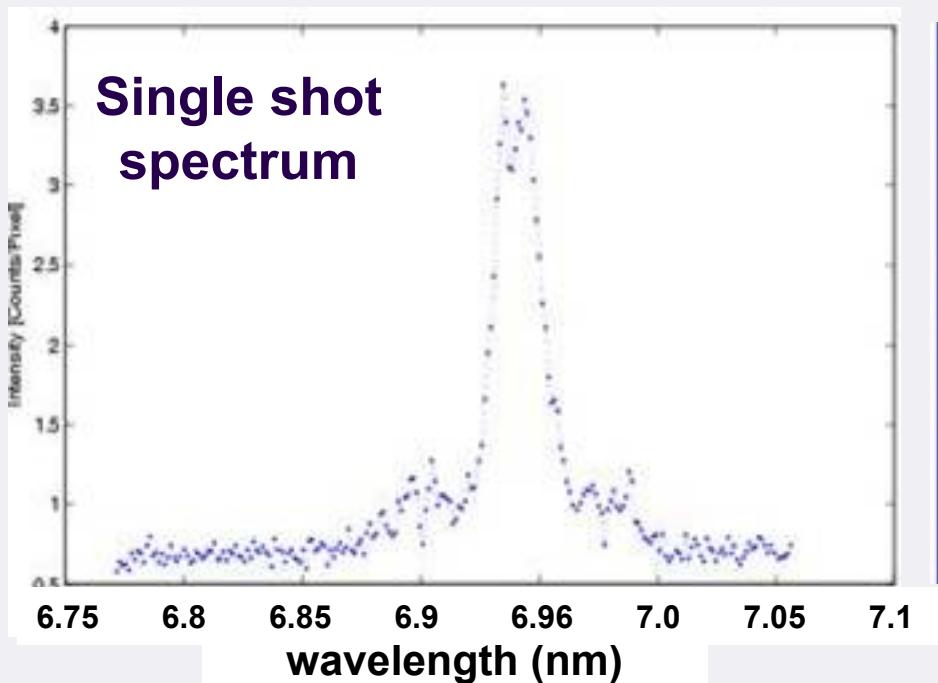
This demonstrates the scalability of the concept towards the XFEL.

... preliminary FLASH radiation properties ...

Lasing could be demonstrated at 6.5 nm and 6.9 nm;
(already now, 7 nm requested by users)

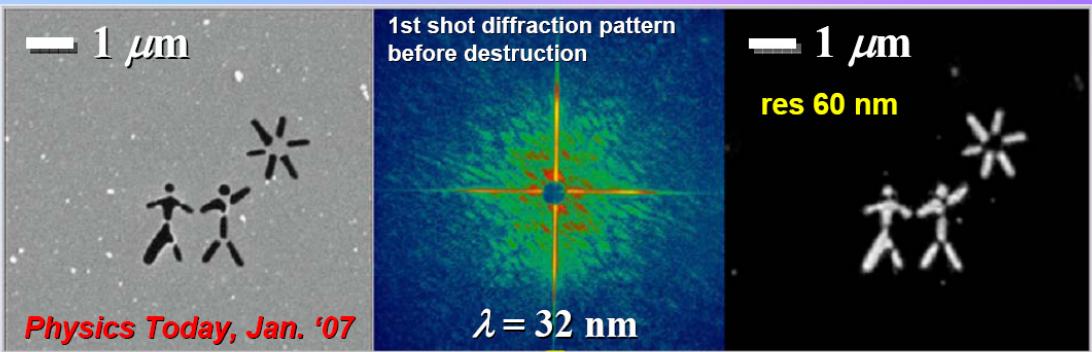
Estimate: 2 μJ level ($\pm 50\%$)

the single shot spectra show a small number of modes \rightarrow preliminary
estim. pulse length: in the 5 fs range (rough extrapolation from the 13 nm)



... this, how others see FLASH ...

Image Reconstructed from an Ultra-Fast (25 fs) FEL Diffraction Pattern at FLASH



The 20- μm -wide square film was destroyed by the laser pulse, but a computer algorithm reconstructed the original image from the diffraction pattern.



H. Chapman, J. Hajdu

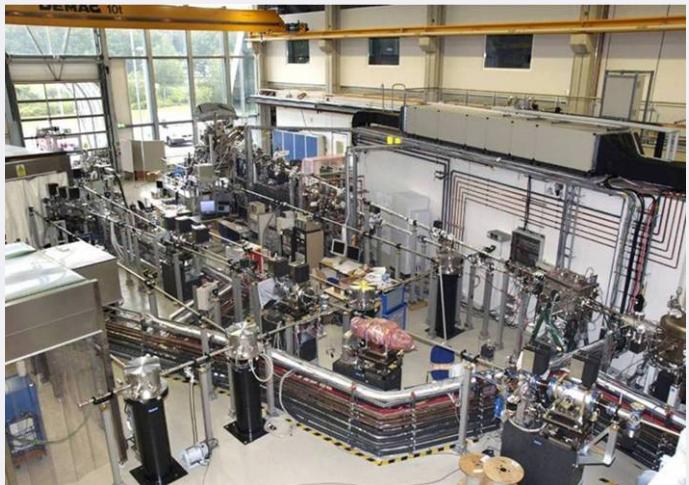
Reconstruction by
A. Barty, Feb. '06



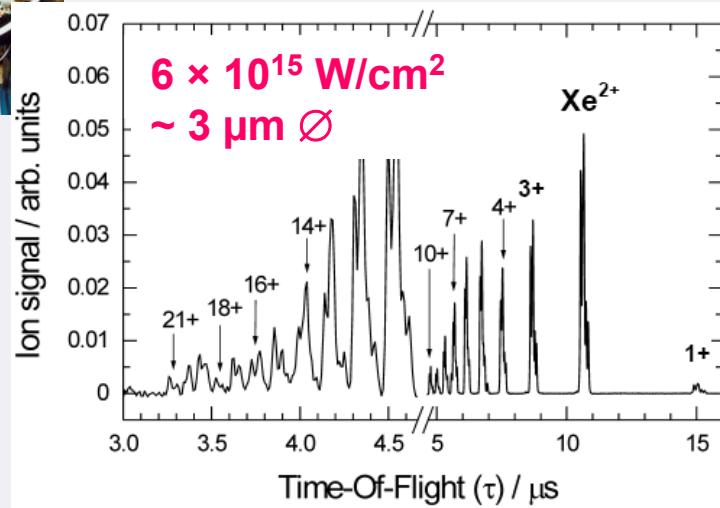
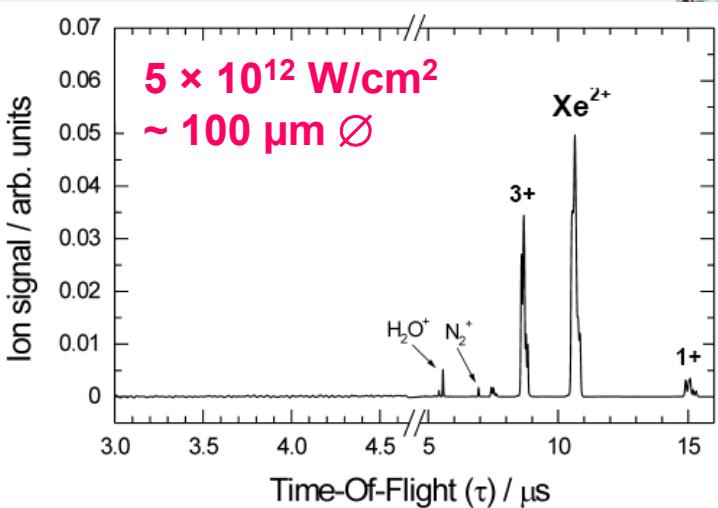
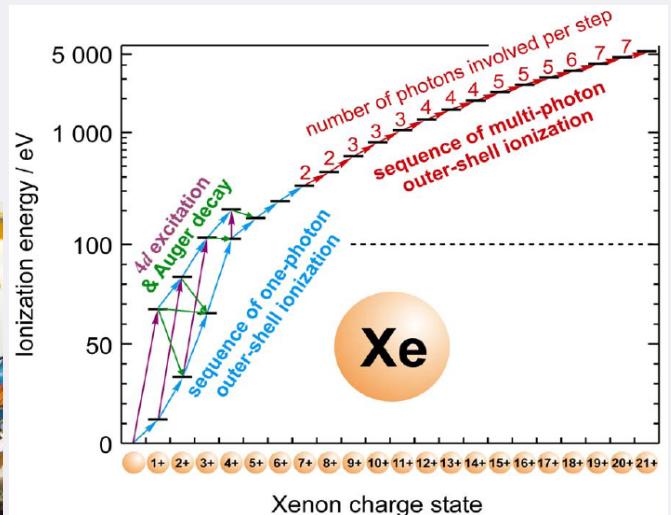
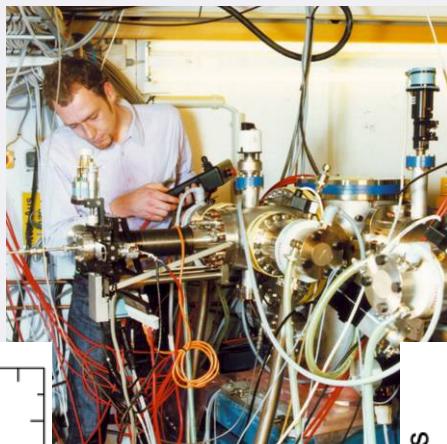
nature physics,
December 2006

Paul Emma: The LCLS Project at SLAC
Fermilab Colloquium, January 31, 2007

... and this, how we experience FLASH ...



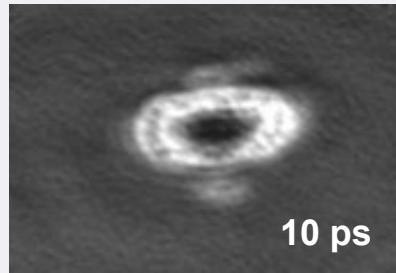
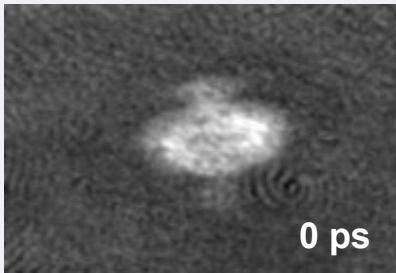
T. Feigl (IOF), M. Richter,
A.A. Sorokin (PTB), K.
Tiedtke, H. Wabnitz (DESY):
FLASH, September 2006



... and this, how we „destroy“ using FLASH

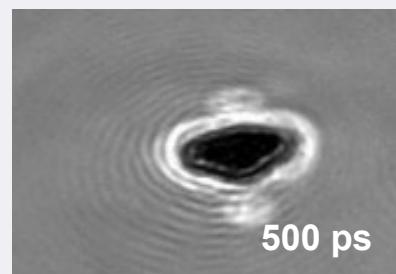
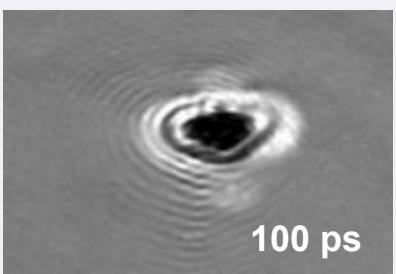
K. Sokolowski-Tinten et al. Fast melting of silicon

Si, $F \approx 1.1 \text{ J/cm}^2$
-10 ps



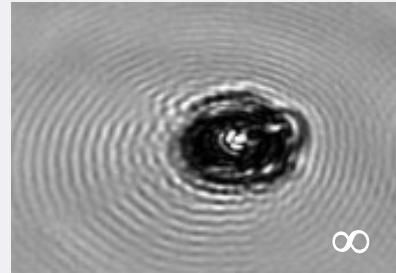
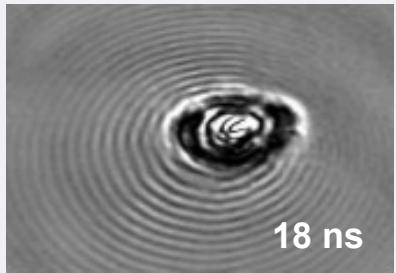
Time-resolved snapshots of a bulk silicon sample after excitation with a single FEL pulse at a fluence of 1.1 J/cm^2 .

30 ps



Pictures taken with the help of a probe laser.

3 ns



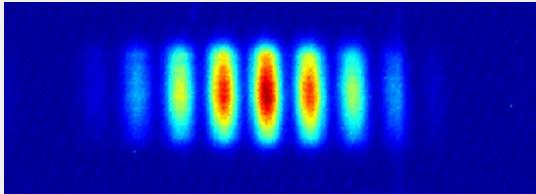
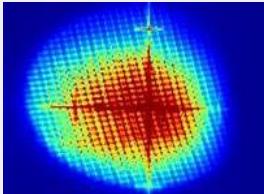
∞

The FLASH Photon Beam

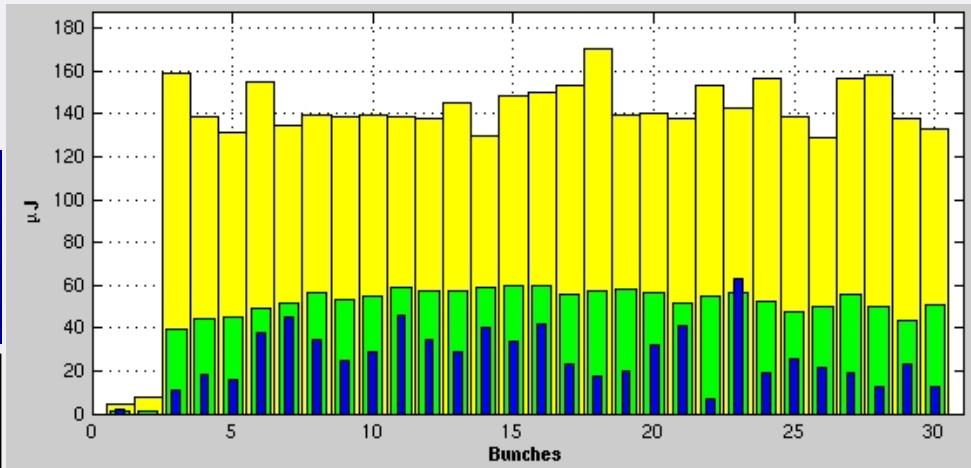
e.g. 25.5 nm wavelength

spot size

double slit diffraction pattern



3 mm spot size (FWHM) @ 18.5 m distance
angular divergence 160 µrad
→ high degree of coherence



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) **5-10×10²⁹** ph/s/mrad²/mm²/(0.1% bw)

Multibunch SASE
signal (µJ) recorded
with MCP Detector

max
average
single

Second Round of User Experiments at FLASH

Collab.

Collab.

Collab.

Proposal no	Proposer, Project Leader	Title
II-20060122	Jose Ramon Crespo Lopez-Urrutia	Resonant single- and multi-photon excitation and photoionization of highly charged ions by FEL radiation
II-20060250	Robert Moshammer	Few Photon Multiple Ionization of Atoms and Molecules using a Reaction Microscope
II-20060251	Robert Moshammer	Coulomb-Explosion Imaging of Small Molecules and Pump-Probe Experiments
II-20060259	Reinhard Dörner	Multiple Fragmentation Processes of Molecules and Clusters Probed by Momentum Imaging Spectroscopy
II-20060262	Alexander Dorn	A Lithium Magneto Optical Trap in a Reaction Microscope at FLASH: I. Complete Photo-Fragmentation of Lithium Atoms II. Dynamics of a Strongly Coupled Ultra Cold Plasma
I-20060263	Uwe Hergenhahn	Intermolecular Coulombic decay in doped water clusters
II-20060278 EC	Marc Vrakking	Velocity map imaging of strong field processes
I-20060280 EC	Michael Meyer, John Costello	Two-color photoionization of atoms and molecules
I-20060293	Axel Reinköster, Uwe Becker	Study of multiphoton-ionization processes of free atoms and molecules
I-20060297	Nora Berrah	High field studies of negative and positive ions at FLASH
II-20060277	Karl-Heinz Meiwes-Broer	Electron Structure and Dynamics in Clusters
II-20060286	Thomas Möller	Ultrafast processes and imaging of clusters
II-20060257	Ivan Vartanian, Christian Gutt	Characterization and Coherent Scattering Applications of the Femtosecond Pulses at the FLASH Facility
II-20060289	Axel Rosenhahn	Single pulse digital in-line holography with VUV radiation and soft X-rays at FLASH
II-20060264	Stefan Eisebitt	Time Resolved Imaging and Scattering for the Study of Sub-Picosecond Correlations on Nanometer Lengthscales
II-20060270	Henry Chapman	Flash Diffraction Imaging of Biological Samples
II-20060296	Simone Techert	Probing the molecular dynamics of supramolecular assemblies by time-resolved x-ray diffraction in the low q regime
II-20060253	Klaus Sokolowski-Tinten	Transient response of solids to high intensity femtosecond XUV-excitation
II-20060267 EC	David Riley	Probing plasma dynamics using time-resolved spectroscopy
II-20060271	Art Nelson	Creation and characterization of WDM using high intensity XUV radiation
II-20060279 EC	Arne Höll, Gianluca Gregori	Thomson scattering measurements of plasma dynamics
II-20060283 EC	Janos Hajdu, N. Timneanu	X-ray induced Coulomb explosions and nuclear fusion
I-20060254 EC	Andrea Cavalleri	Resonant Soft X-ray Scattering in Complex Oxides with near-2-nm Free Electron Laser Pulses
II-20060258	Kai Rossnagel	Femtosecond Dynamics of Photoinduced Insulator-to-Metal Transitions in Layered Transition-Metal Compounds Probed by Time- and Momentum-Resolved Photoemission
I-20060269	Marco Rutkowski, Helmut Zacharias	Investigation of highly excited surface reactions
II-20060276	Alexander Föhlisch	Non-equilibrium dynamics and low energy excitations in complex systems
II-20060285	Hermann Dürr	Femtosecond electron and spin dynamics in functional materials
II-20060108	Michael Martins	Multi-photon processes in soft X-ray regime
II-20060292	Mathias Richter	Quantitative gas-phase experiments for FEL photon diagnostics at high photon energies and small spot size
II-20060261	Lutz Kipp	VUV-FEL Nanospectroscopy
I-20060266	Marco Rutkowski, Helmut Zacharias	Evaluation of FEL pulse duration by non-linear autocorrelation in atoms and molecules
II-20060268	Michael Rübhausen	Light Scattering at the FEL
II-20060272	Markus Drescher	Pump-probe experiments exploiting FLASH's intrinsic temporal resolution

45 proposals submitted in 2006
 32 proposals approved in Dec 2006
 Beamtime: Oct 2006 - ~Dec 2008

Gas phase
(atoms, molecules, ions)

Clusters

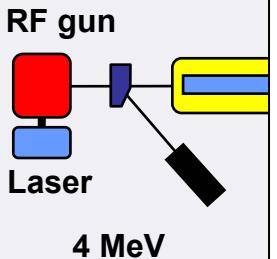
Imaging, diffraction

Warm dense matter

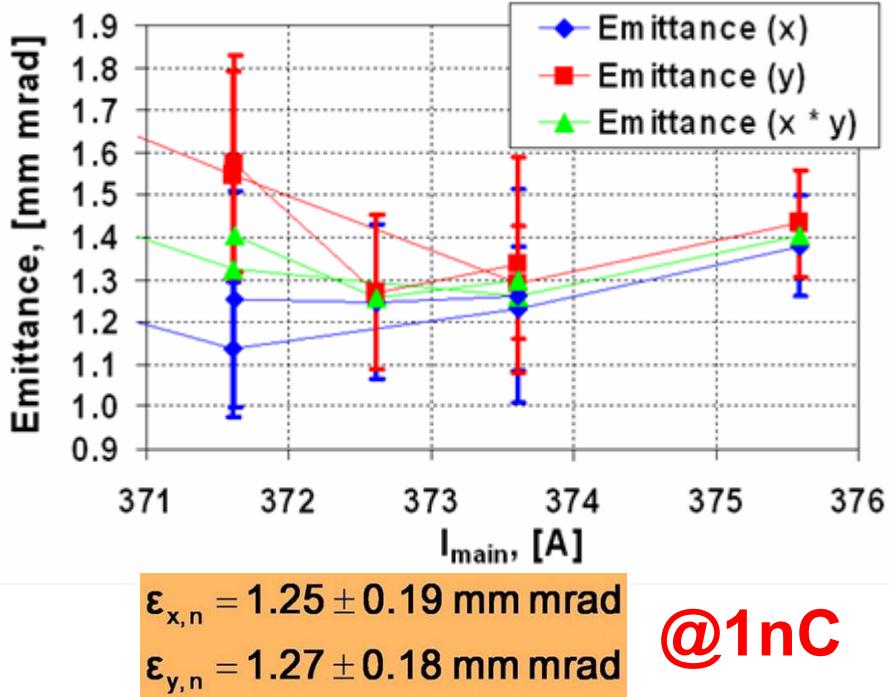
Solids, surfaces

Technical developments

FLASH Facility

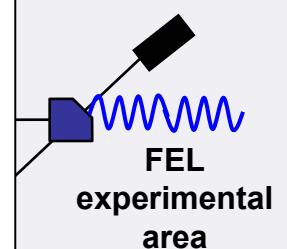


Recently reached at DESY-Zeuthen / PITZ

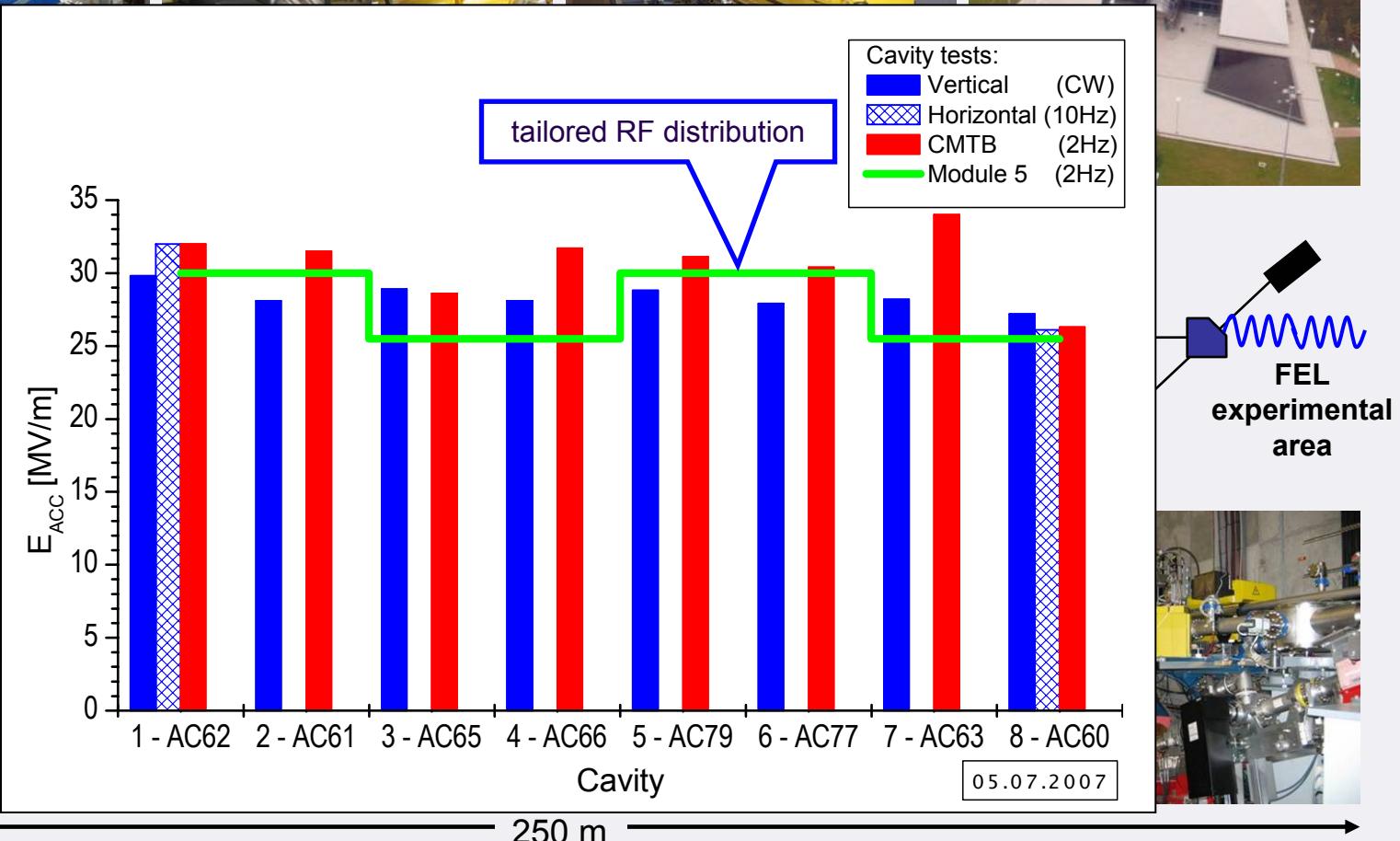
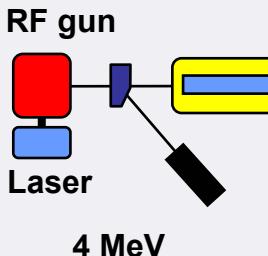


recently reached for 100 % RMS emittance,
i.e. 0.8 mm mrad for 95% RMS w/o tails

250 m



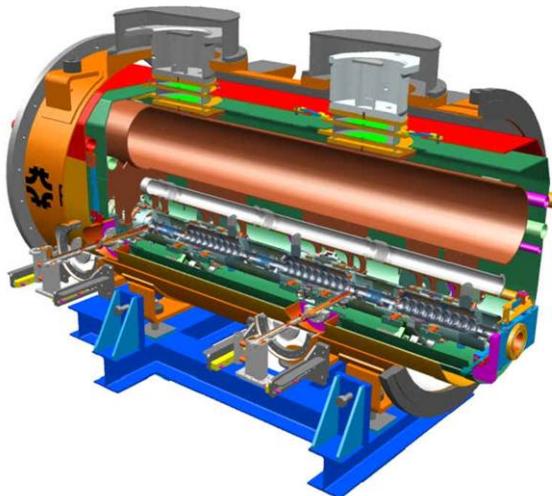
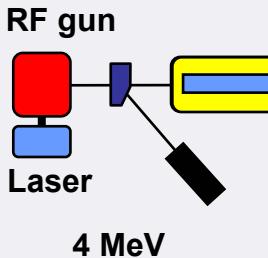
FLASH Facility



FLASH Facility

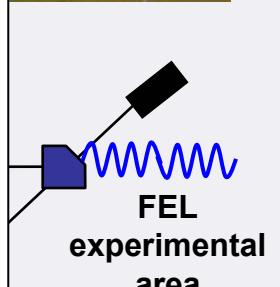


3.9 GHz Module FNAL design FNAL contribution to FLASH



Needed to linearize longitudinal phase space
to reach shorter wavelength
FNAL assembly kit

250 m



3rd Harmonics RF Cavity

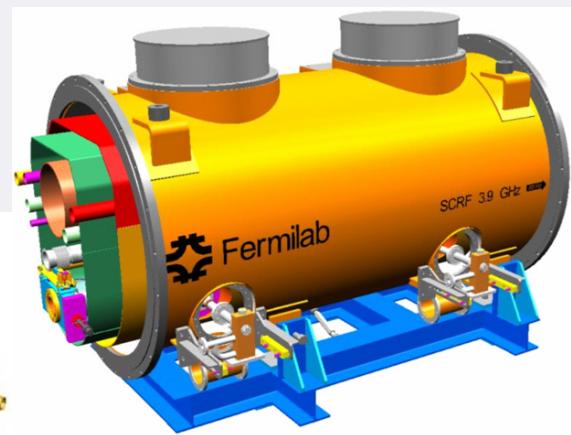
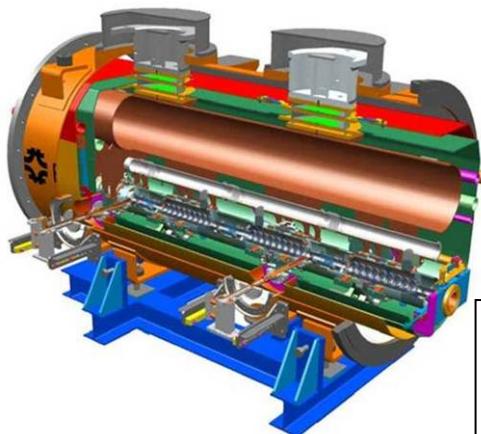
Idea:

Linearization of accelerating voltage in order to linearize phase space distribution



Compress more electrons,
Realize >2kA within >200 fs

- TESLA cavity scaled to 3.9 GHz
- all 'auxiliaries' like coupler, HOM coupler, frequency tuner ... scaled as well
- most of the work done by H. Edwards et al. / FNAL

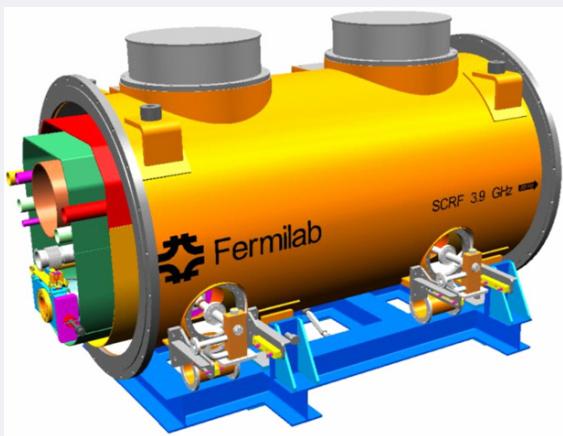
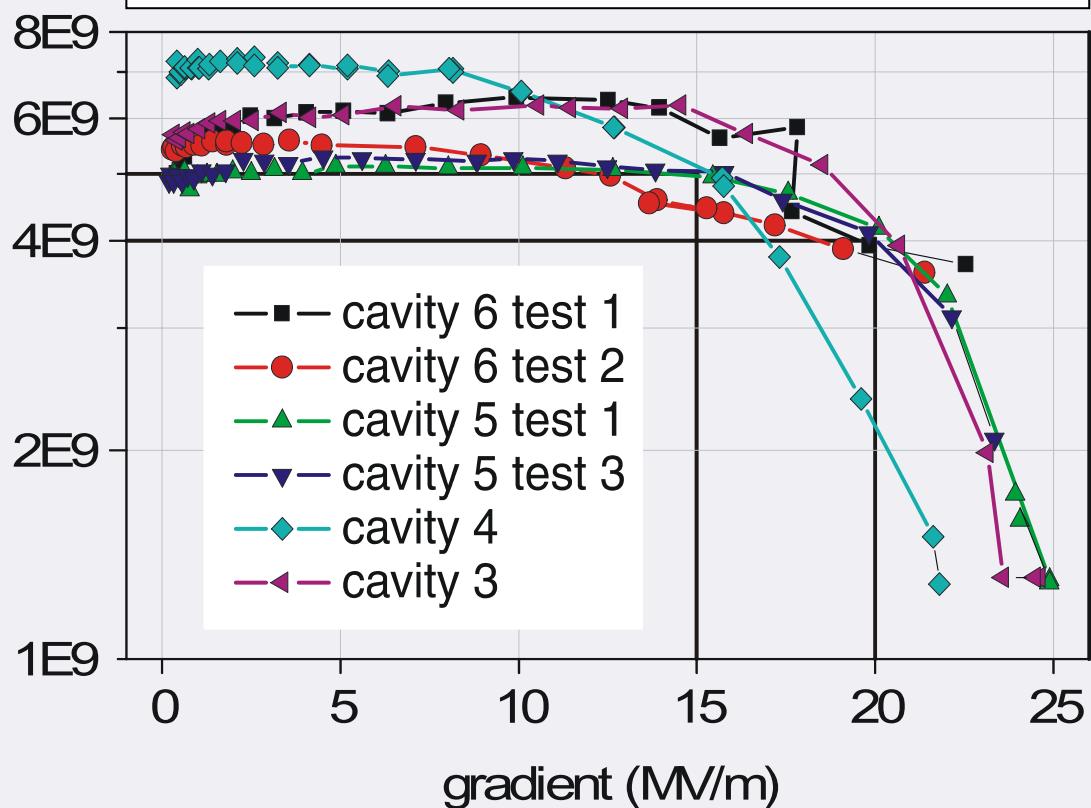


- Produce more photons per pulse, though at longer pulses
- Pre-requisite for all seeding schemes

3rd Harmonics RF Cavity

Cavity performance:

- the design values (15 MV/m) are reached in the vertical test
- the unloaded quality factor matches with BCS

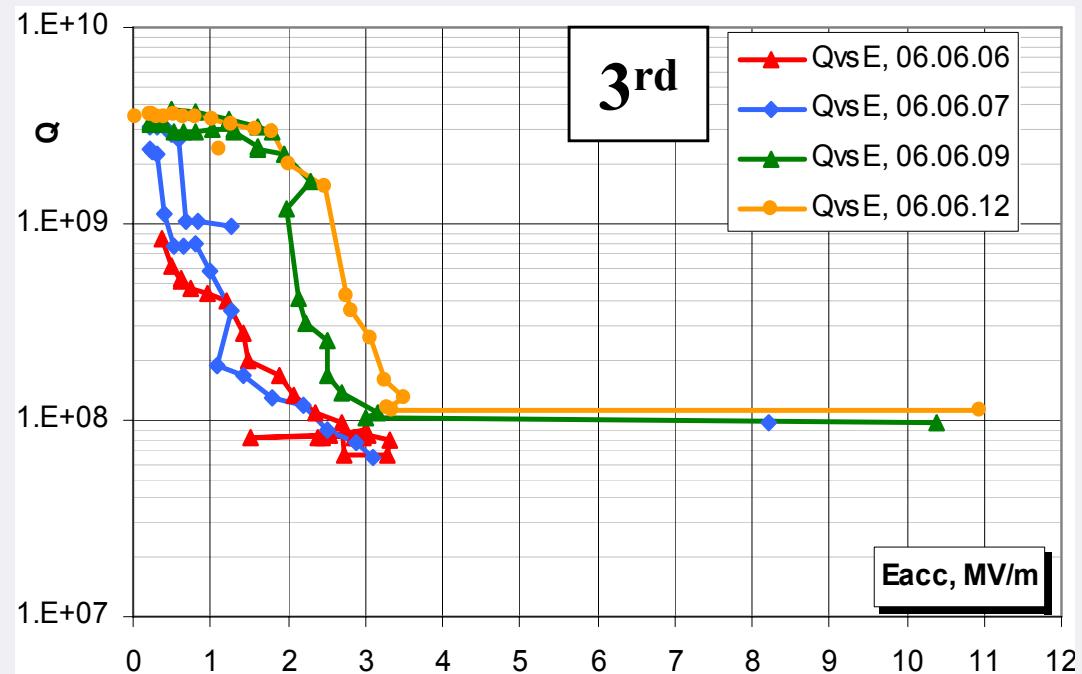
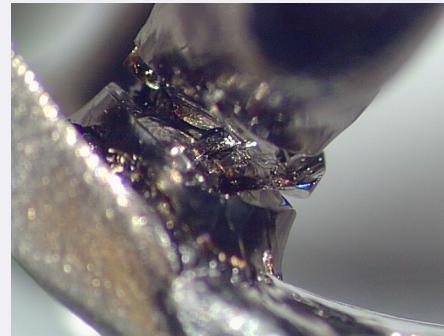
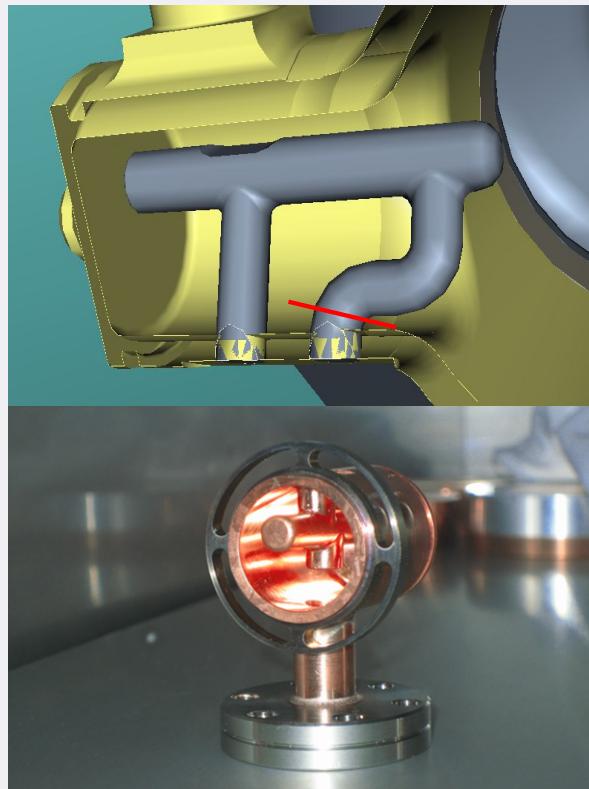


- first helium vessels now at FNAL
- the first horizontal tests are scheduled before the end of 2007

3rd Harmonics RF Cavity

HOM Problem:

- solved by reducing length of double post F-part
- single post F-part should be better concerning multipacting and is attached to latest cavities

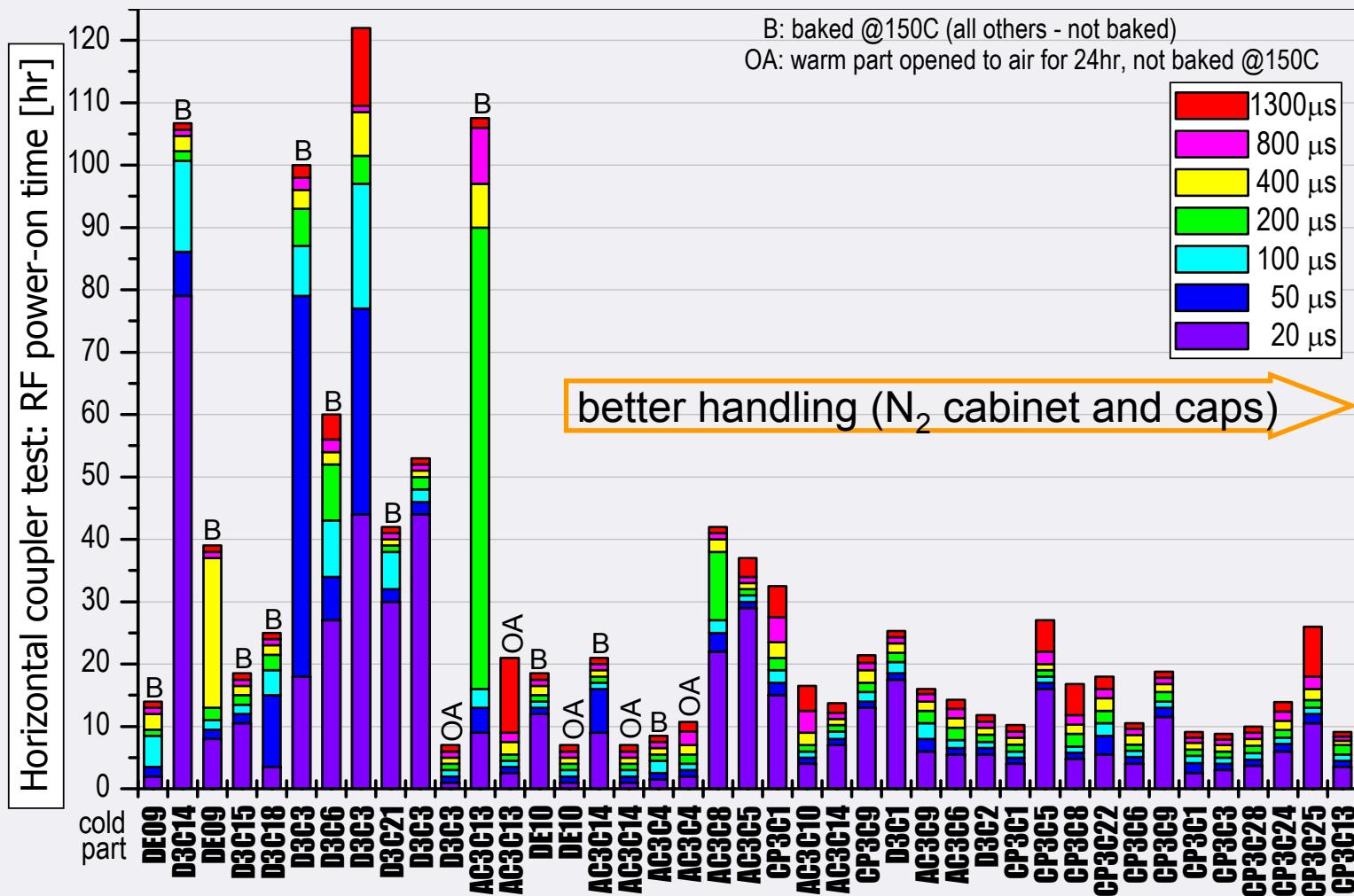


Operation of CMTB (*cryo module test bench*)

- 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**



Fast Coupler Processing Reliably Established



Factory Acceptance Test of the Horizontal Toshiba MBK



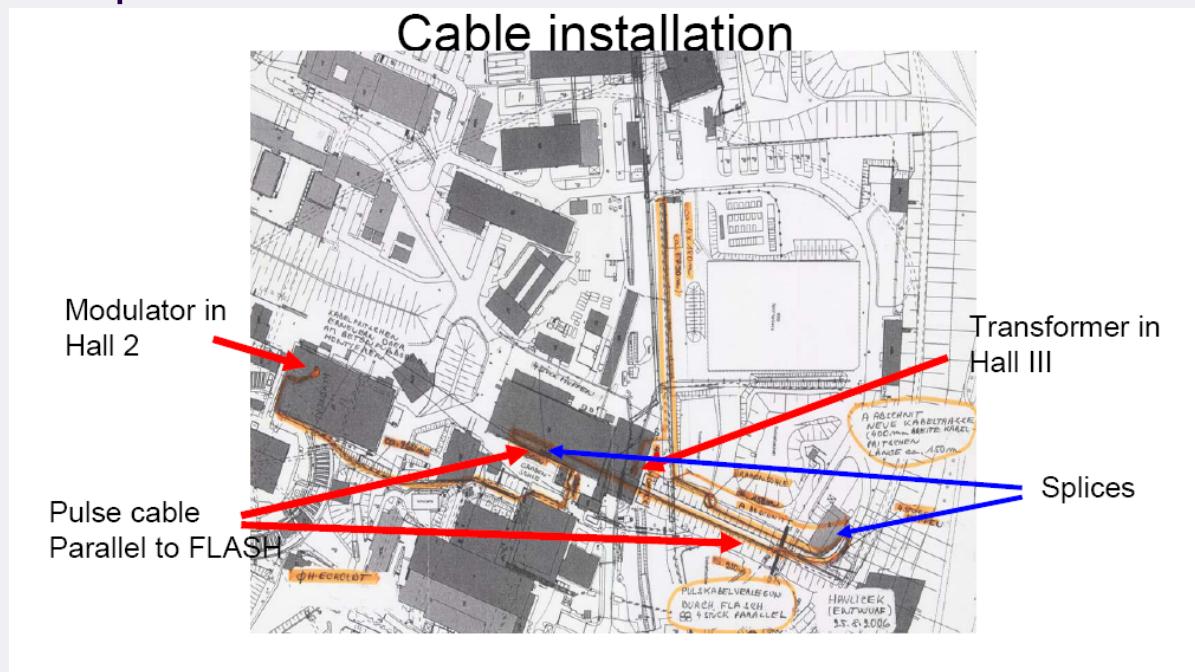
Toshiba E3736H at test stand in August 2007 at Toshiba in Nasu, Japan

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 planned for end of this year

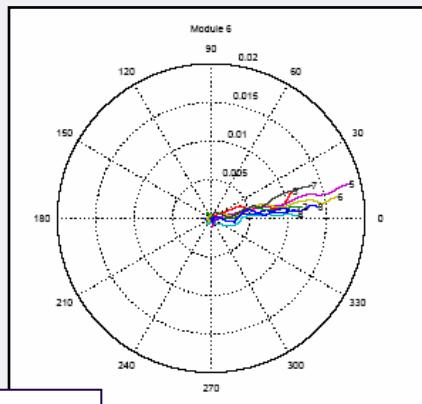
RF System – Modulators, Pulse Cables / EMI

- Modulator prototypes from two manufacturers (CH, NL) under construction → 2008 at DESY, Zeuthen
3rd company (DE) also qualified with FLASH modulators
- FLASH operates routinely with pulse cables in the tunnel – apparently without EMI problems...



New pre-adjusted waveguide distribution system for ACC6

Power distribution and phase distribution
for the individual cavities almost perfect



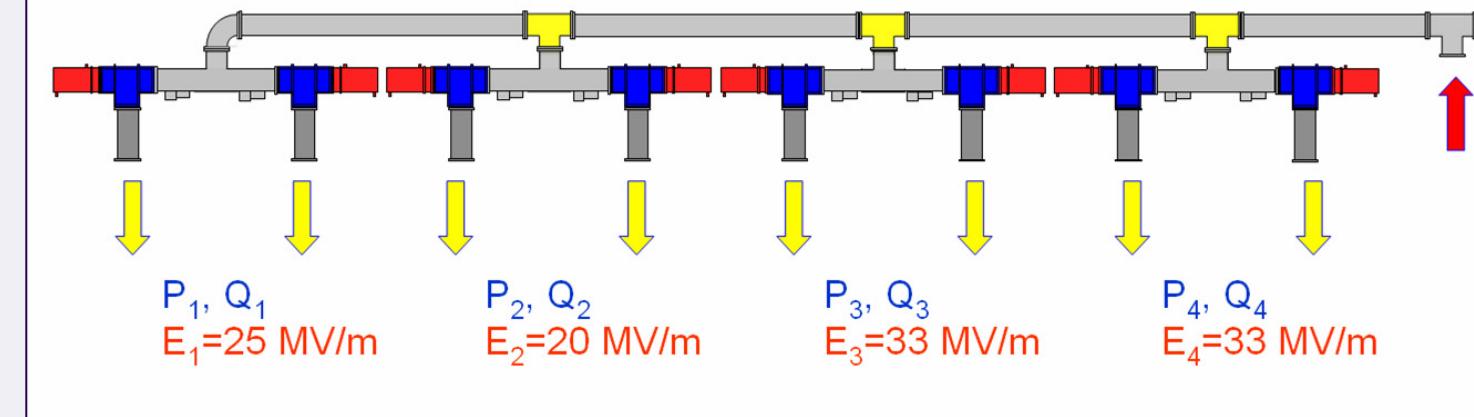
Initial phase distribution

Waveguide distribution ACC6

4.0 dB
(3.0)

3.0 dB
(4.77)

4.8 dB
(6.0)



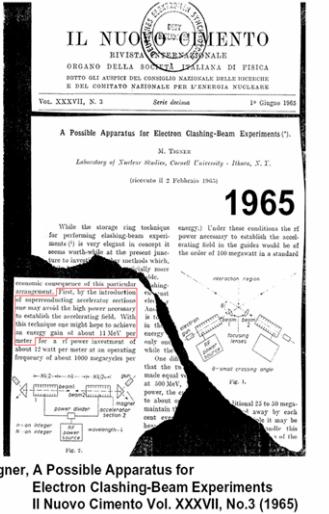
Tunnel Mock-Up Completed and Installations Ongoing



The XFEL is based on the feasibility of a single tunnel design including the support of the cryomodules from the ceiling. Installation procedures to be trained at the mock-up.



The XFEL Technical Design Report (DESY 2006-097)



TESLA

TESLA

The Superconducting Electron-Positron Linear Collider with an Integrated X-Ray Laser Laboratory

Technical Design Report

March 2001

TESLA

TESLA XFEL

First Stage of the X-Ray Laser Laboratory

Technical Design Report Supplement

October 2002

XFEL
The European X-Ray Free-Electron Laser

Technical Design Report

DESY 2006-XXX

JULY 2006

- 03/2001** XFEL as part of the TESLA LC
- 10/2002** Separation of the XFEL
- 2005** Detailed XFEL accelerator layout
- 2006** Final TDR incl. detailed technical layout and experiments
- 2007** project start on June 5th, 2007

International Project Organization

XFEL Steering Committee ISC (Chair: H. Schunck, Germany)

- Representatives of all countries intending to contribute to the XFEL facility
- *13 countries have signed MoU (project preparation phase)*



CH CN DE DK ES FR GB GR HU IT PL RU SE

- *European Project Team (Leader: Massimo Altarelli)*

WG on
Scientific and Technical issues

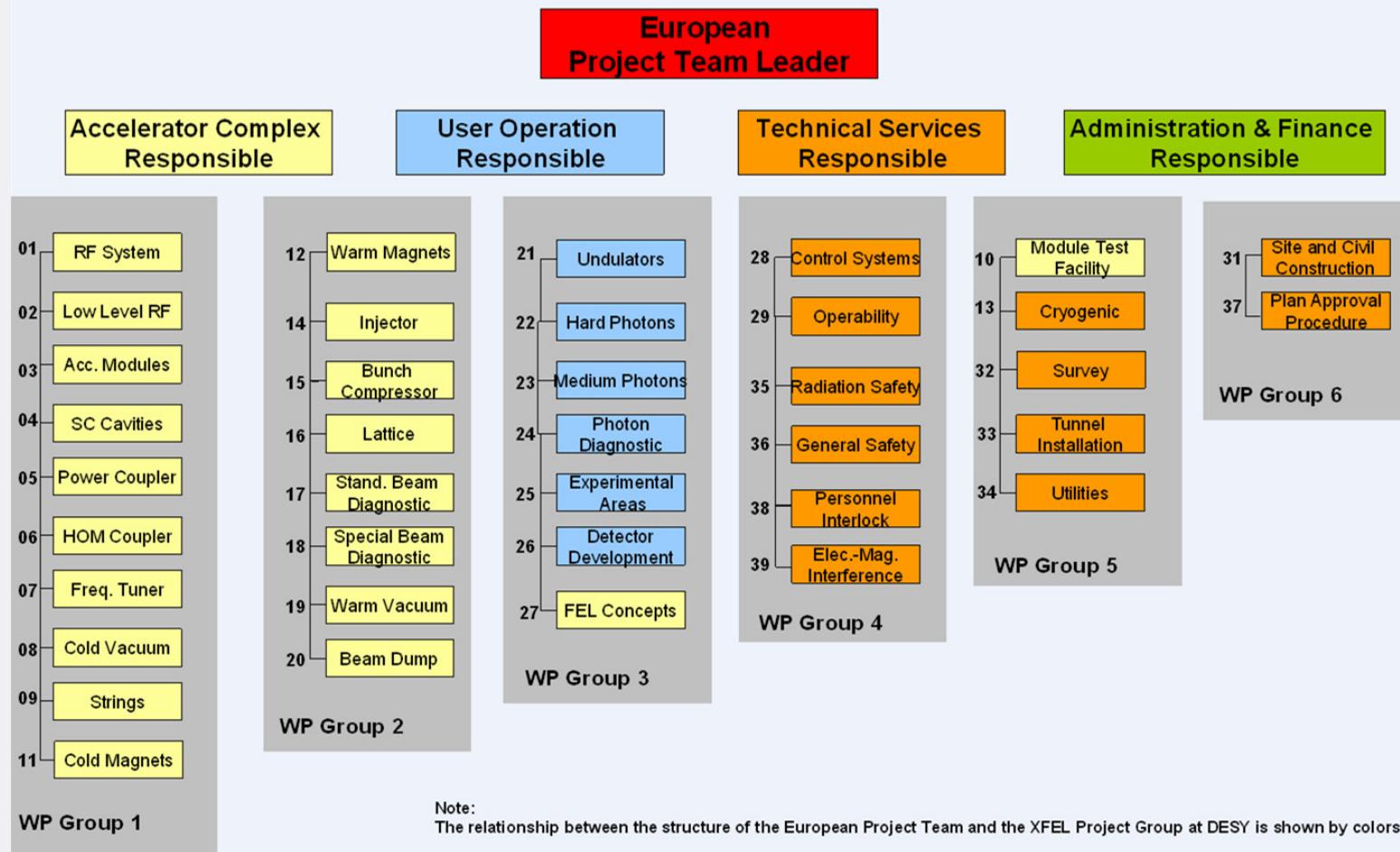
WG on
Administrative and Funding issues

Bi-lateral negotiations between Germany and signature countries on funding contributions are ongoing.

The MoU for the project phase is still to be signed.

XFEL Project Organization

Structure of the European Project Team for the XFEL



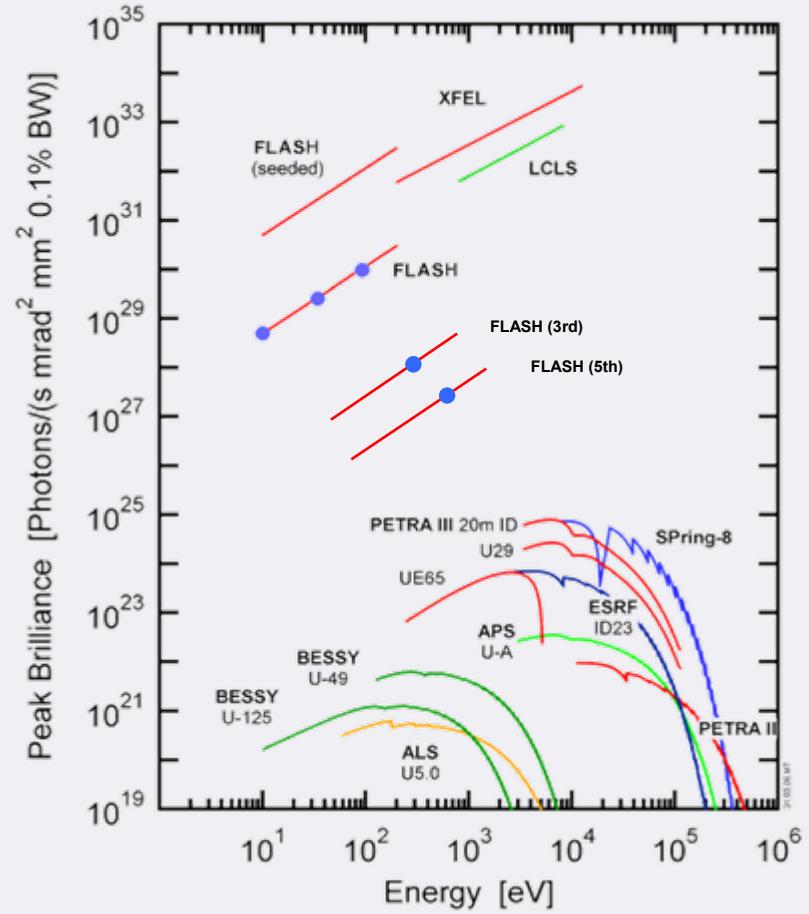
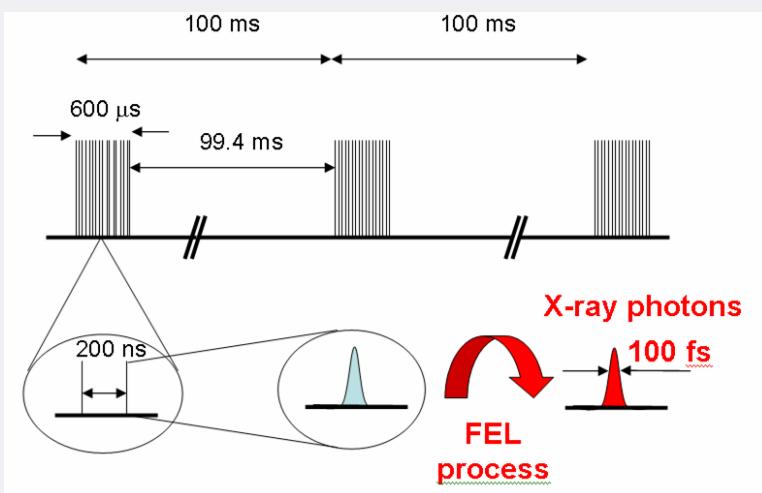
Properties of XFEL radiation

X-ray FEL radiation (0.2 - 14.4 keV)

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

Spontaneous radiation (20-100 keV)

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



~ 260 scientists at 1st XFEL users meeting

First European XFEL Users' Meeting

January 24/25, 2007, Main Auditorium (Bldg 5), DESY, Hamburg

Final Program

Wednesday, January 24, 2007

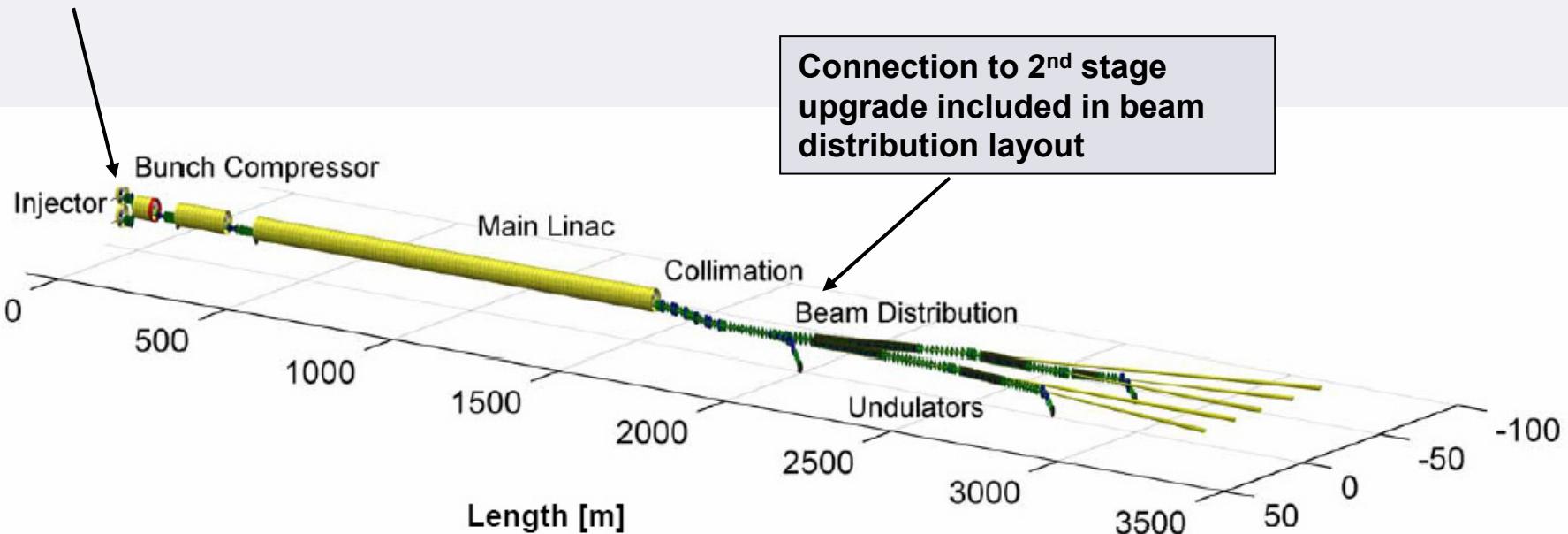
08:15-09:00	Registration		
09:00-10:30	Welcome session	Speakers	
	Welcome remarks	A. Wagner (DESY) R. Koepke (BMBF) J. Wood (CCLRC)	
	Reports from the International Steering Committee (ISC) for the European XFEL and its advisory groups	H. Schunck (ISC) R. Feidenhans'l (Scientific and Techn. Issues) H.-F. Wagner (Admin. and Funding Issues)	
	Coffee break		
10:45-12:45	Project Status Reports	Chair: J. Schneider	DESY Hamburg
10:45	Overview	M. Altarelli	Europ. XFEL Proj. Team
11:15	The superconducting accelerator	R. Brinkmann	Europ. XFEL Proj. Team
11:45	Photon beam systems	Th. Tschentscher	Europ. XFEL Proj. Team
12:15	Detector development for the XFEL	H. Graafsma	DESY Hamburg
	Lunch break		
14:00-16:20	Scientific Perspectives (I)	Chair: I. Lindau	SLAC Stanford
14:00	Ultrafast processes and extreme conditions	J. Wark	Oxford University
14:35	Ultrafast structural changes	R. Feidenhans'l	Copenhagen University
15:10	Time-resolved molecular reactions	M. Chergui	EPFL Lausanne
15:45	Investigation of small quantum systems	J. Ullrich	MPI Heidelberg
	Coffee break		
16:40-18:25	Scientific Perspectives (II)	Chair: I. Robinson	UC London
16:40	Dynamics of nanoscale systems	G. Grübel	DESY Hamburg
17:15	Imaging of single particles	H. Chapman	LLNL Livermore
17:50	Matter in intense x-ray fields	P. Zeitoun	LOA Palaiseau
18:25	End of session		
19:00	Dinner for participants (DESY Canteen, Bldg 9)		

Overall layout of the European XFEL

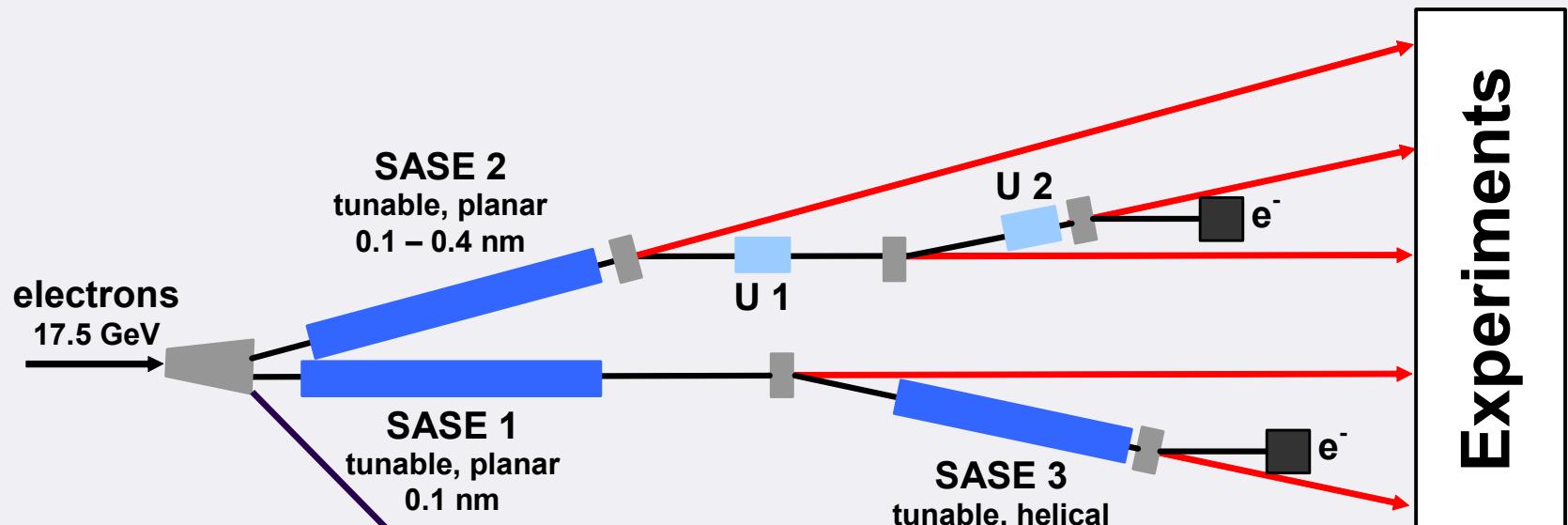


Accelerator layout

One injector initially installed



Photon Beam Lines (TDR Layout)

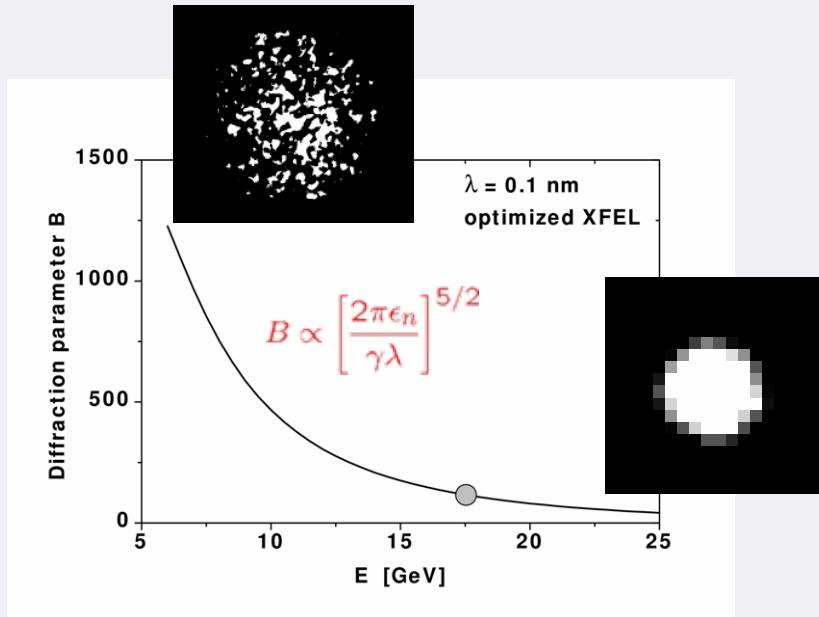
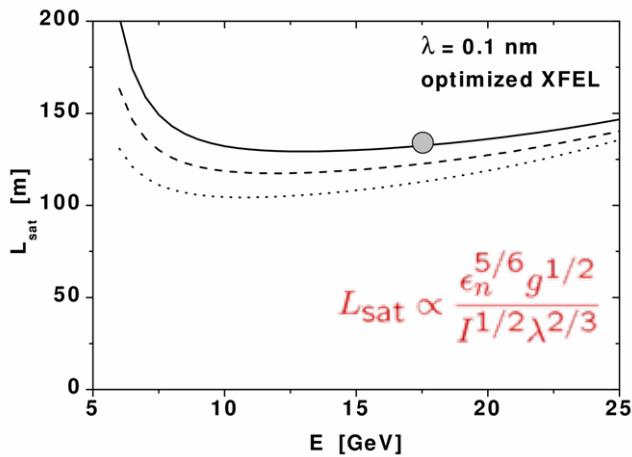


Possible extension by 5 more beam lines
and 10 experimental stations

Start-up scenario has only 3 undulator
beam lines.

Choice of Beam Energy: 17.5 GeV for 0.1nm Wavelength

gap = 6 mm, 8mm, and 10 mm



→ Good photon beam coherence

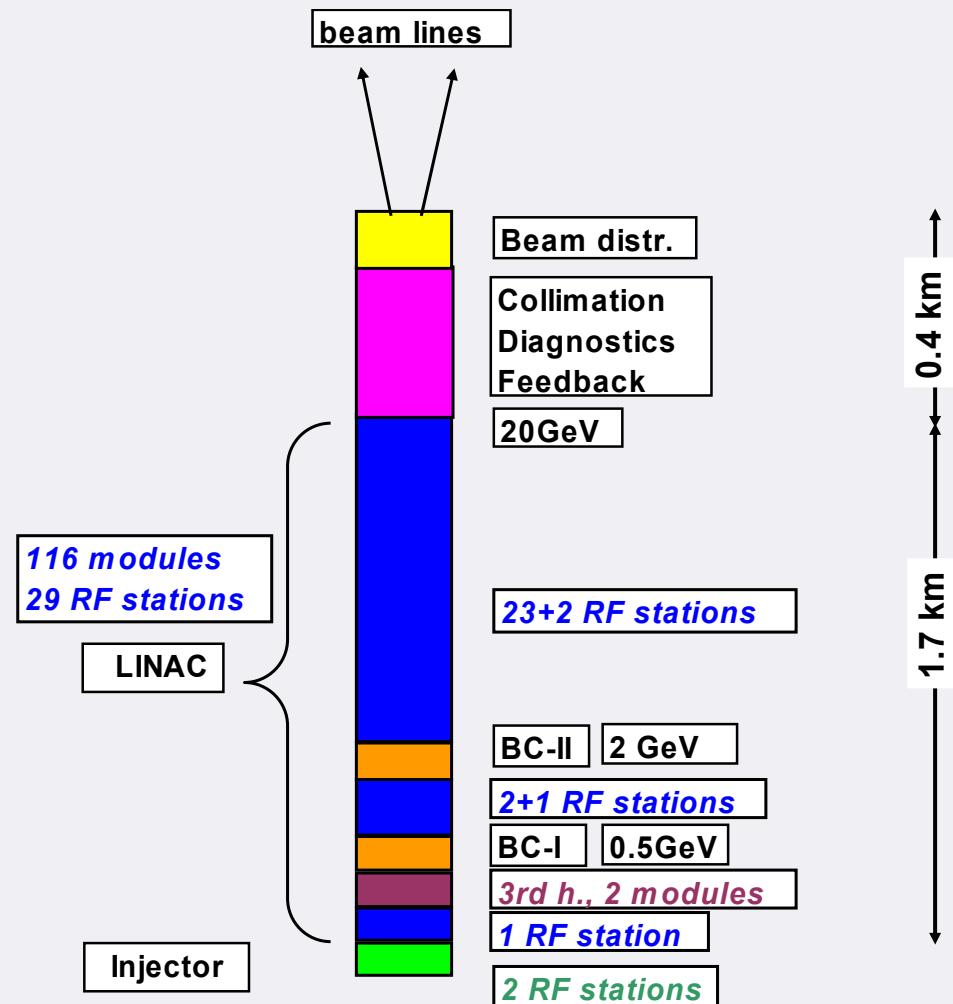
(65 – 85% at 0.1 – 0.15nm, $\epsilon_n = 1.4 \text{ mm}^* \text{ mrad}$)

XFEL Accelerator Layout

XFEL TDR included reserve units to provide high operational availability.

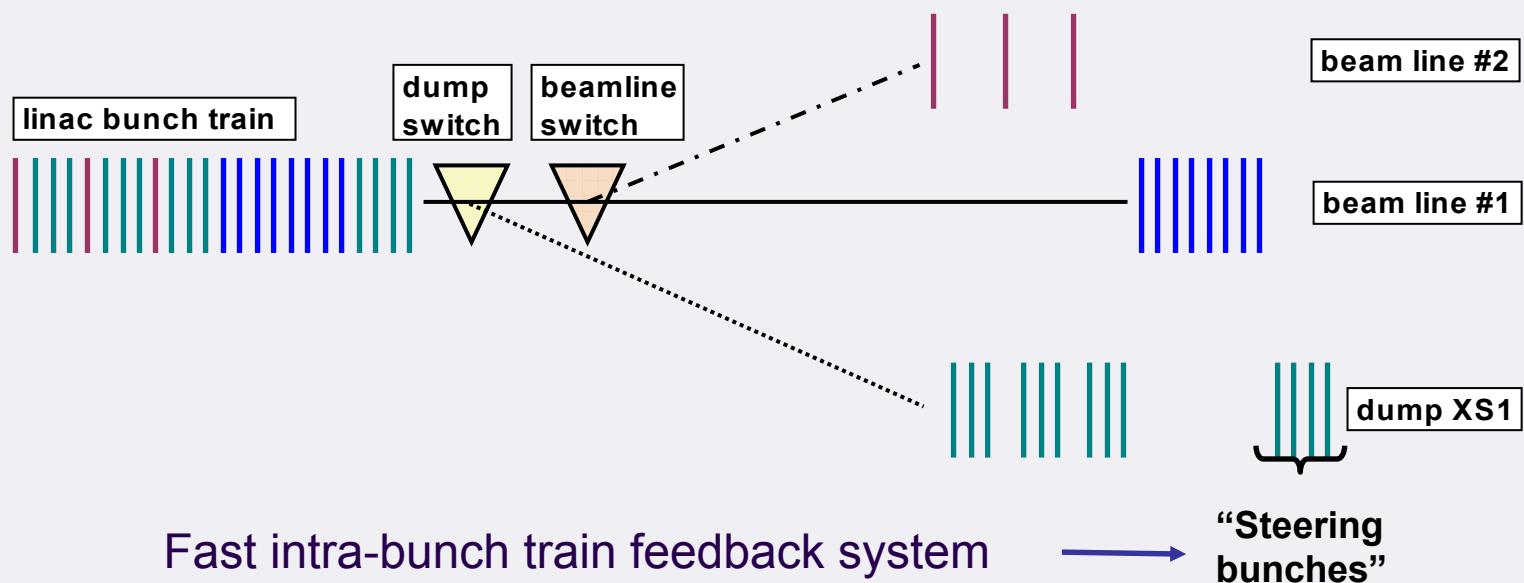
The design accelerating gradient of 23.6 MV/m aimed for 20 GeV – potential for energy upgrade.

The actual funding scenario leads to a reduction in the number of accelerator modules (101 in total). But a safe operation at 17.5 GeV can be assumed.



Operational Flexibility

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

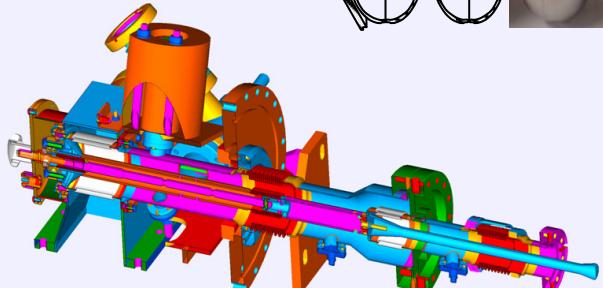


XFEL Accelerator Components

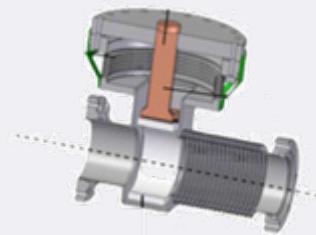
cavities



coupler

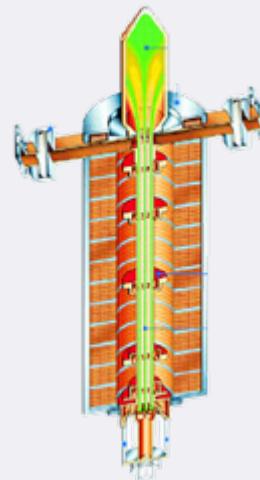
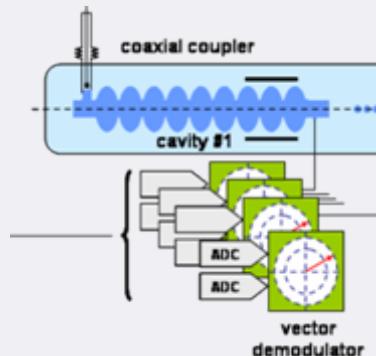


TESLA
Technology



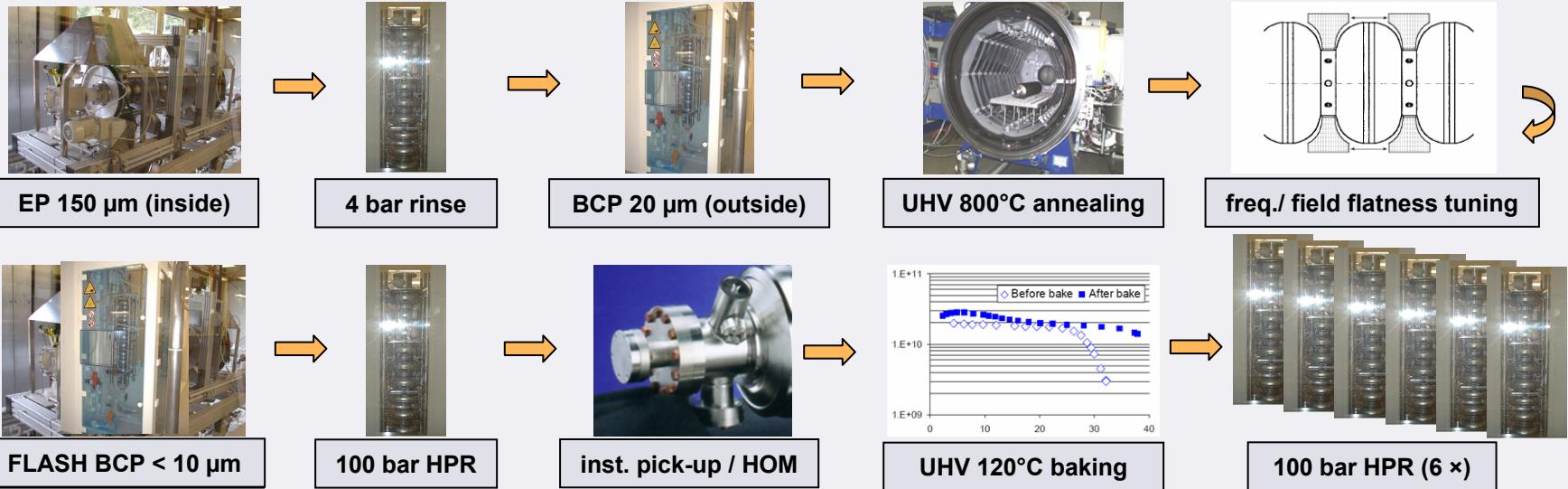
HOMs

LLRF



RF

Cavity Prep. (XFEL Industrial Production)

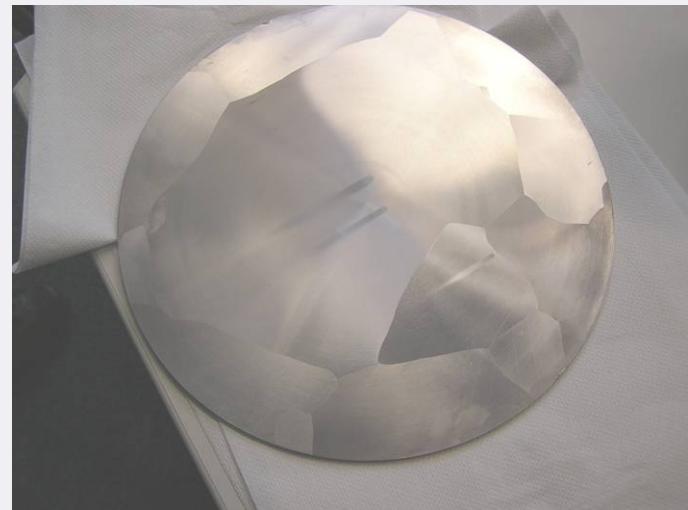


1. electro-chemical removal of a thick niobium layer (so-called damage layer) of about 150 μm from the inner surface
2. a rinse with particle free / ultra-pure water to remove residues form the electro-chemical treatment
3. outside etching of the cavities of about 20 μm
4. ultrahigh vacuum annealing at 800°C
5. tuning of the cavity frequency and field profile
6. removal of a thin and final layer of about 30 μm
7. rinsing with particle free / ultra pure water at high pressure (100 bar) to remove surface contaminants
8. assembly of auxiliaries (pick-up probe and HOM pick-up)
9. baking at 120°C in ultra high vacuum
10. additional six times rinse with high pressure ultra-pure water (100 bar)

Alternative Fabrication – Large Grain Nb

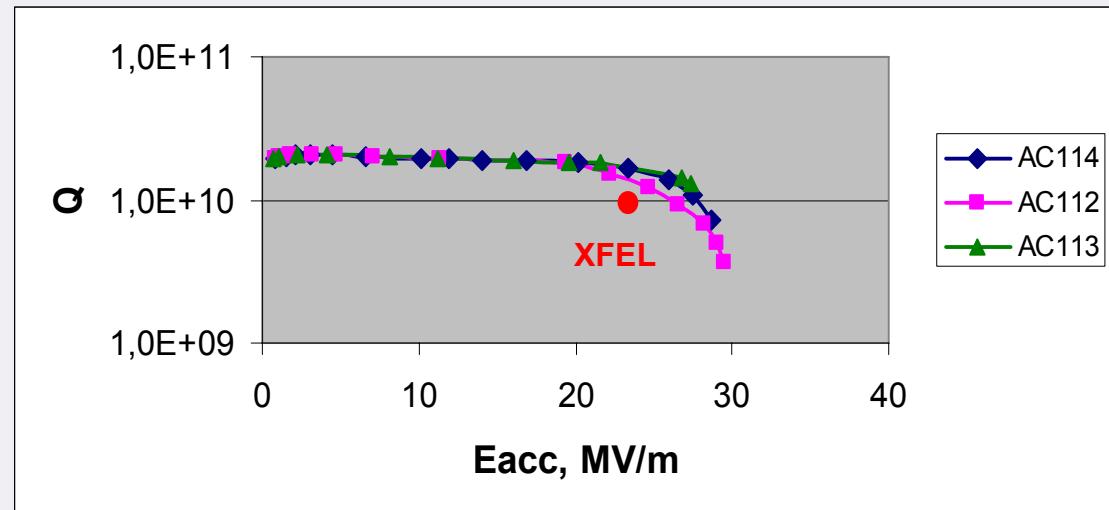
Fabrication from large-grain Niobium – cut sheets directly from ingot (method pioneered by JLAB)

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



→ Will build 6 more cavities, possibly alternative fabrication/treatment procedure

→ Could later choose the more economic method for industrial production



Cavity String Assembly



The assembly of an 8 cavity string

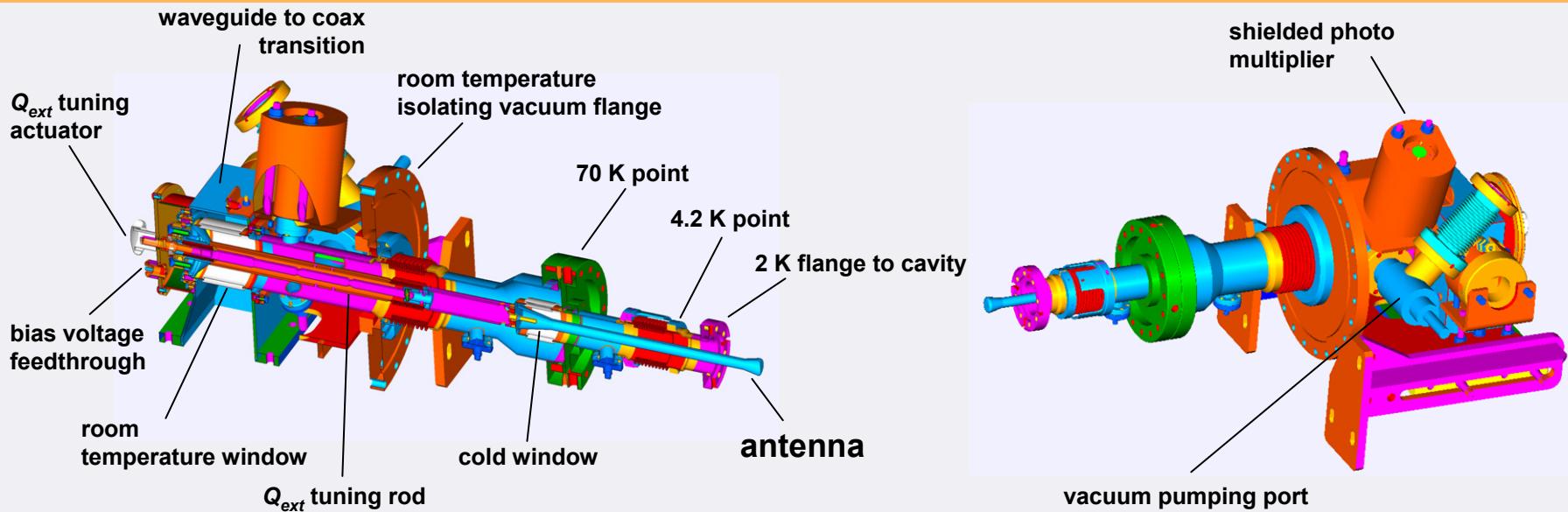
- is a standard procedure at DESY and was also recently done at FNAL.
- was done by technicians from the TESLA Technology Collaboration
- was the basis for two industrial studies.

The transfer of this well known and complete procedure to industry is ongoing.

DESY has provided sub-components for the first string / module built by industry; this allows for an early training.



Auxiliaries – Main RF Power Coupler



At 20 GeV design energy 120 kW are required for the 650 μ s long beam pulse; with 10 Hz rep rate and 720 μ s filling time the average power amounts to 1.6 kW.

Q_{ext} can be varied in the range of 10^6 – 10^7 . At 23.6 MV/m the optimum Q_{ext} is 4.6×10^6 .

Couplers were tested to transmit 1.5 MW of peak RF power in traveling wave mode and 600 kW / 5 Hz in standing wave mode. In a 35 MV/m cavity test, one coupler was operated 2,400 hours at 2.5 kW average RF power.

The two window solution protects the cavity vacuum. Multipacting is suppressed by the coaxial line's design and additional bias voltage (up to 5 kV)

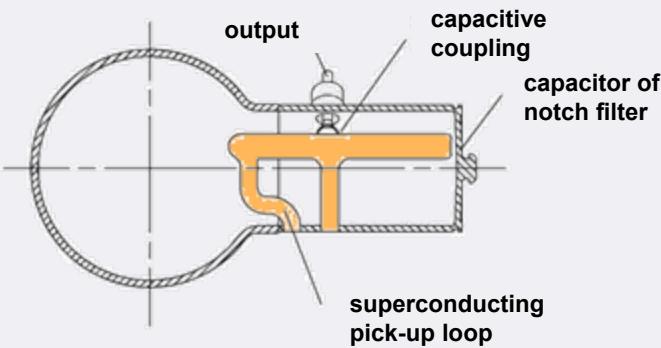
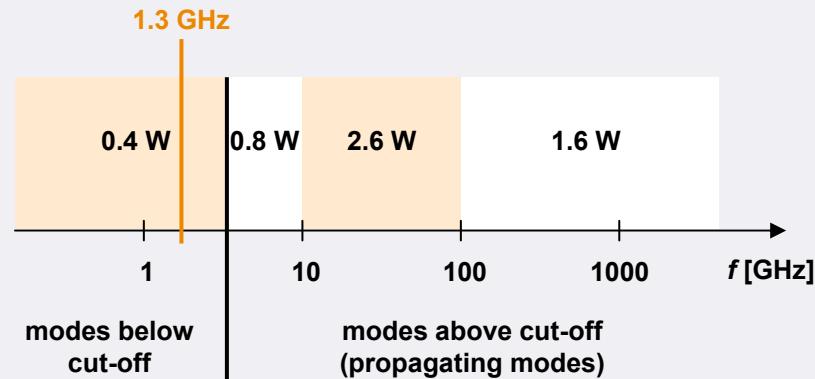
Industrial studies for 1,000 couplers are done at LAL Orsay. The production of 30 couplers was supervised and the conditioning done at Orsay with great success. Another 30 couplers will be produced soon.

Damping of Higher Order Modes (HOMs)

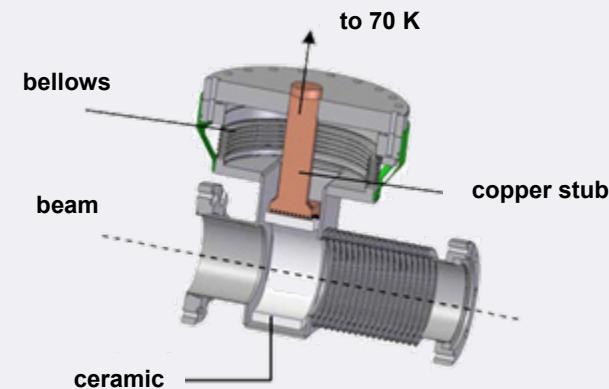
The spectrum of the electron bunch ($\sigma_z = 25 \mu\text{m}$) reaches high frequencies up to 5 THz.

The standard accelerator module has an integrated loss factor of 135 V/pC.

The total power deposited by the nominal beam is 5.4 W per module.

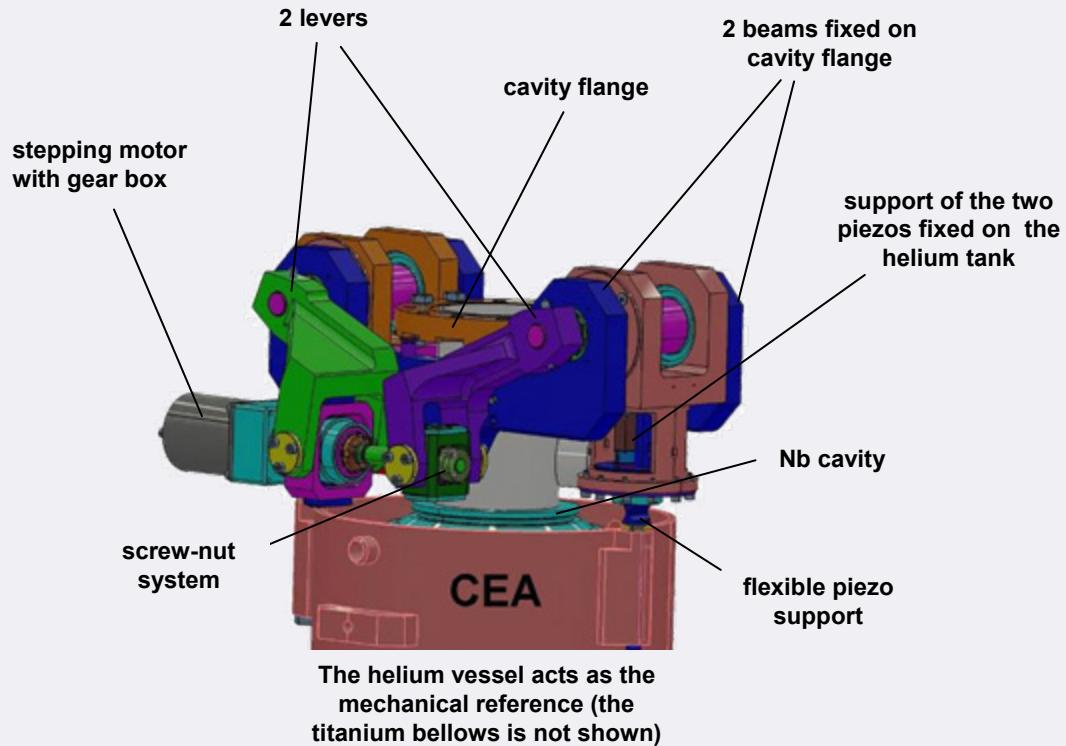


HOM coupler



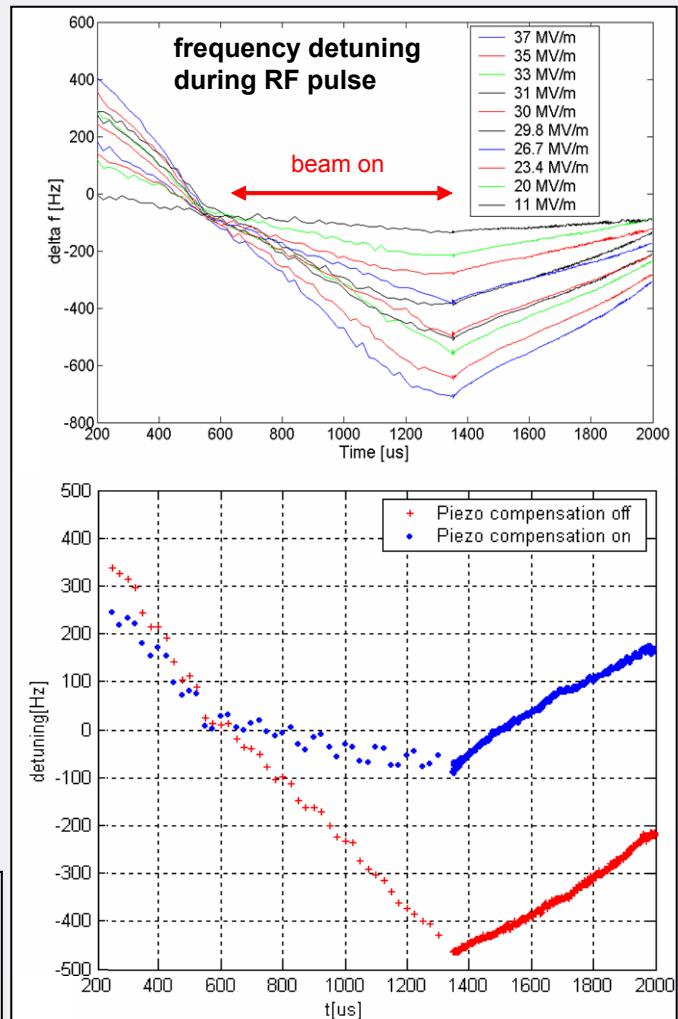
beam pipe absorber

Slow and Fast Frequency Tuner



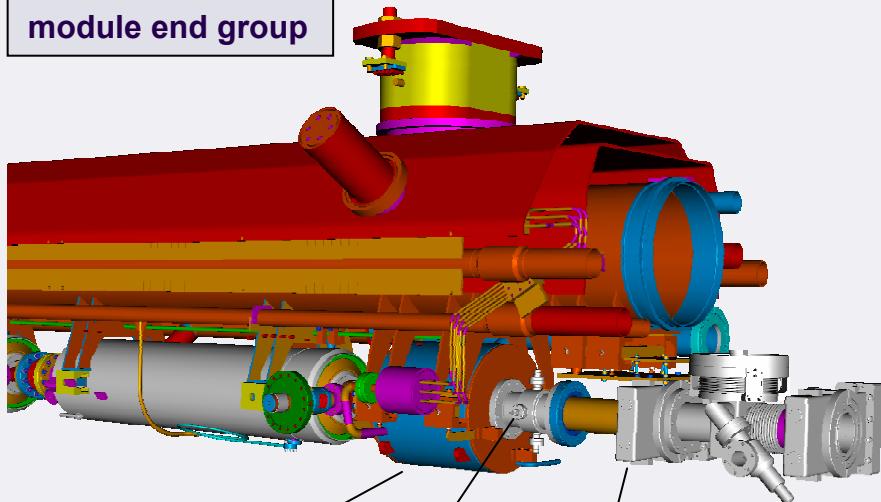
The slow tuner compensates for drifts; 400 kHz range , 1 Hz resolution

The fast tuner compensates the Lorentz-Force detuning during the RF pulse. It is based and piezo crystals.

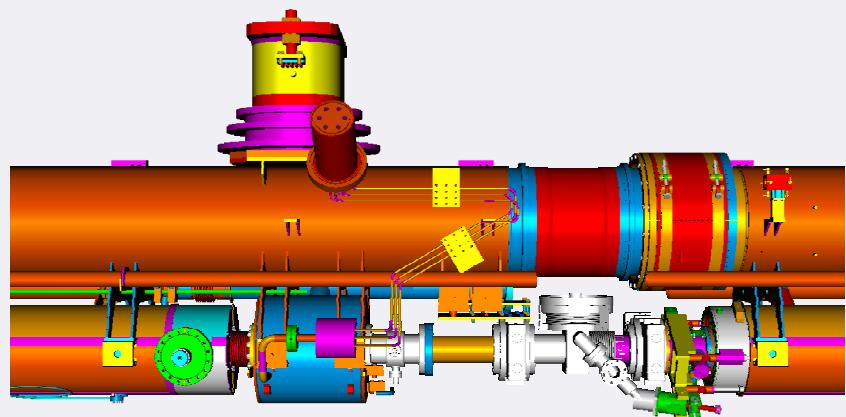


Accelerator Module (Cryomodule)

module end group



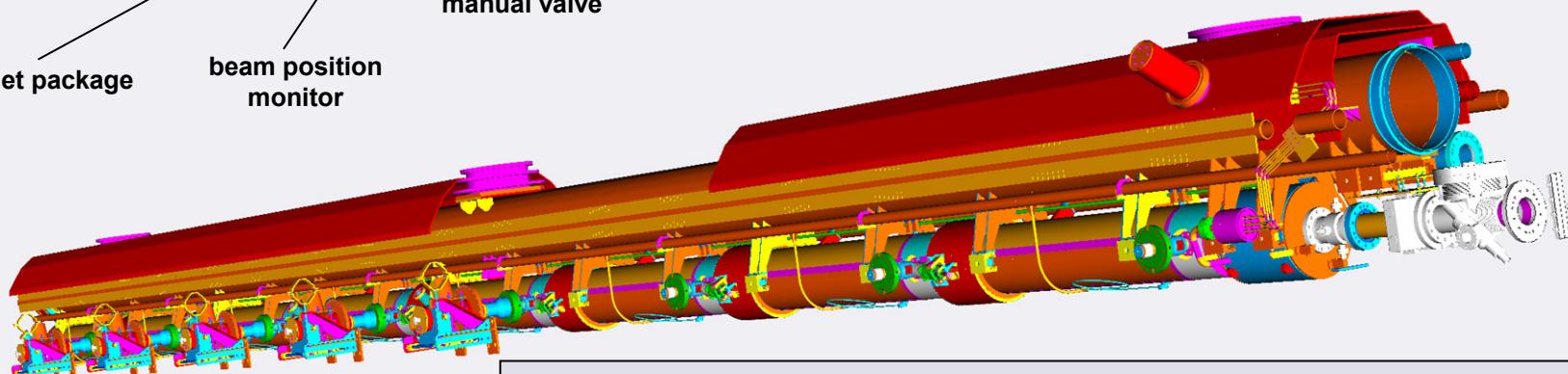
module to module connection



magnet package

beam position monitor

manual valve



Accelerator Module (Cryomodule)

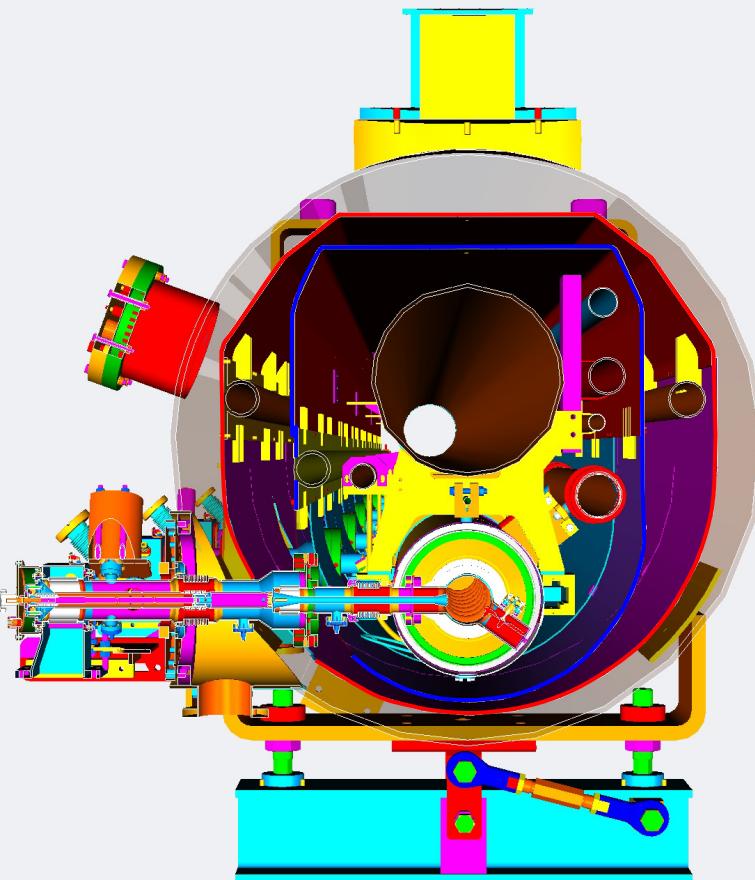
The XFEL accelerator module is based on the 3rd cryomodule generation tested at the TESLA Test Facility and designed by INFN.

Already 10 cryomodules have been built and commissioned for the TTF Linac.

Module 6 and Module 7 (repl. ACC3) were installed last. And allow for the 1 GeV operation.

Up to 4 additional cryostats will be available until end of 2008.

Then series production of 101 modules.



38" carbon steel vessel

300 mm He gas return pipe acting as support structure

8 accelerating cavities

cavity to cavity spacing exactly one RF wavelength

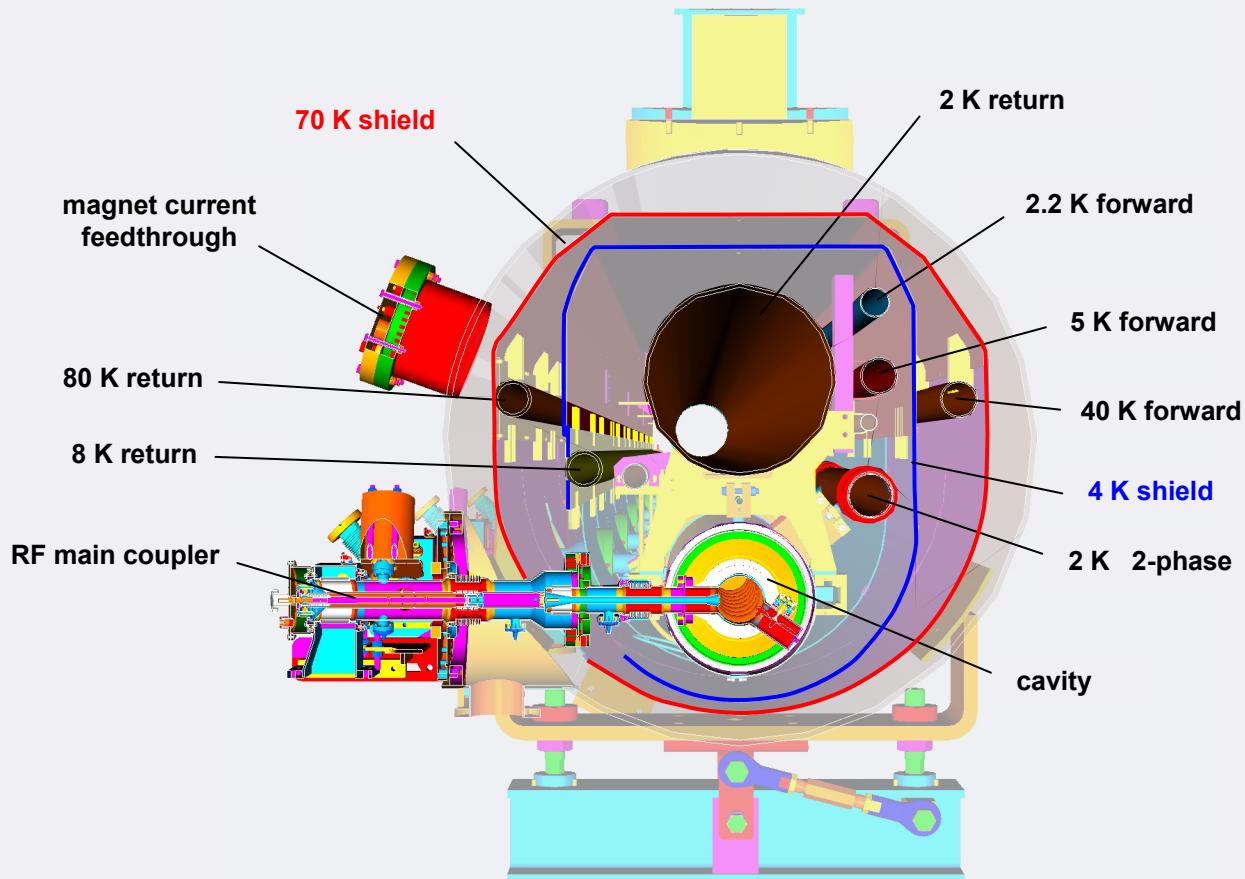
inter-module cavity to cavity spacing a multiple of one RF wavelength

one beam position monitor / magnet unit

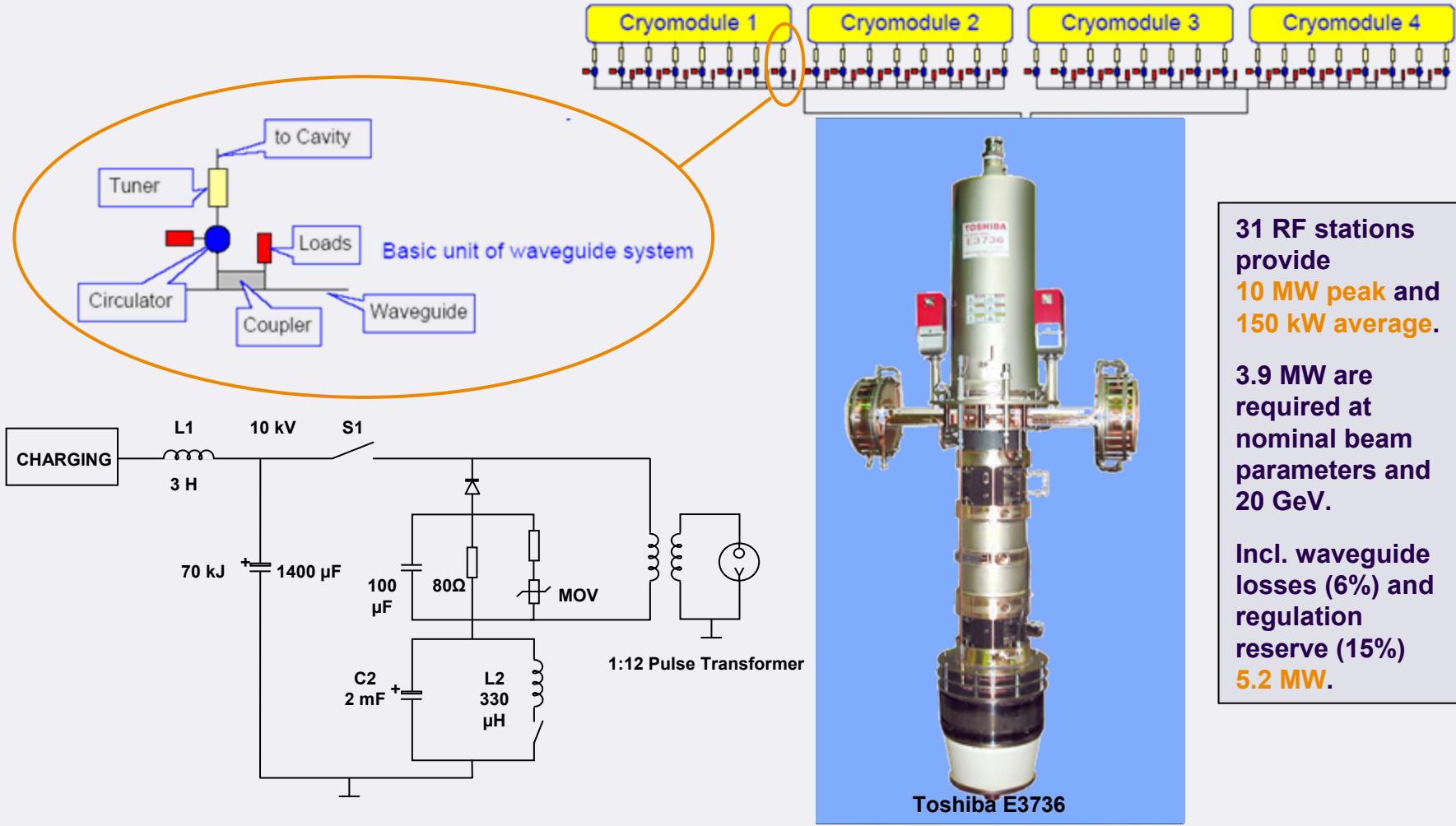
manually operated valves to terminate the beam tube at both ends

longitudinal cavity position independent from the contraction / elongation of the HeGRP during cool-down / warm-up procedure

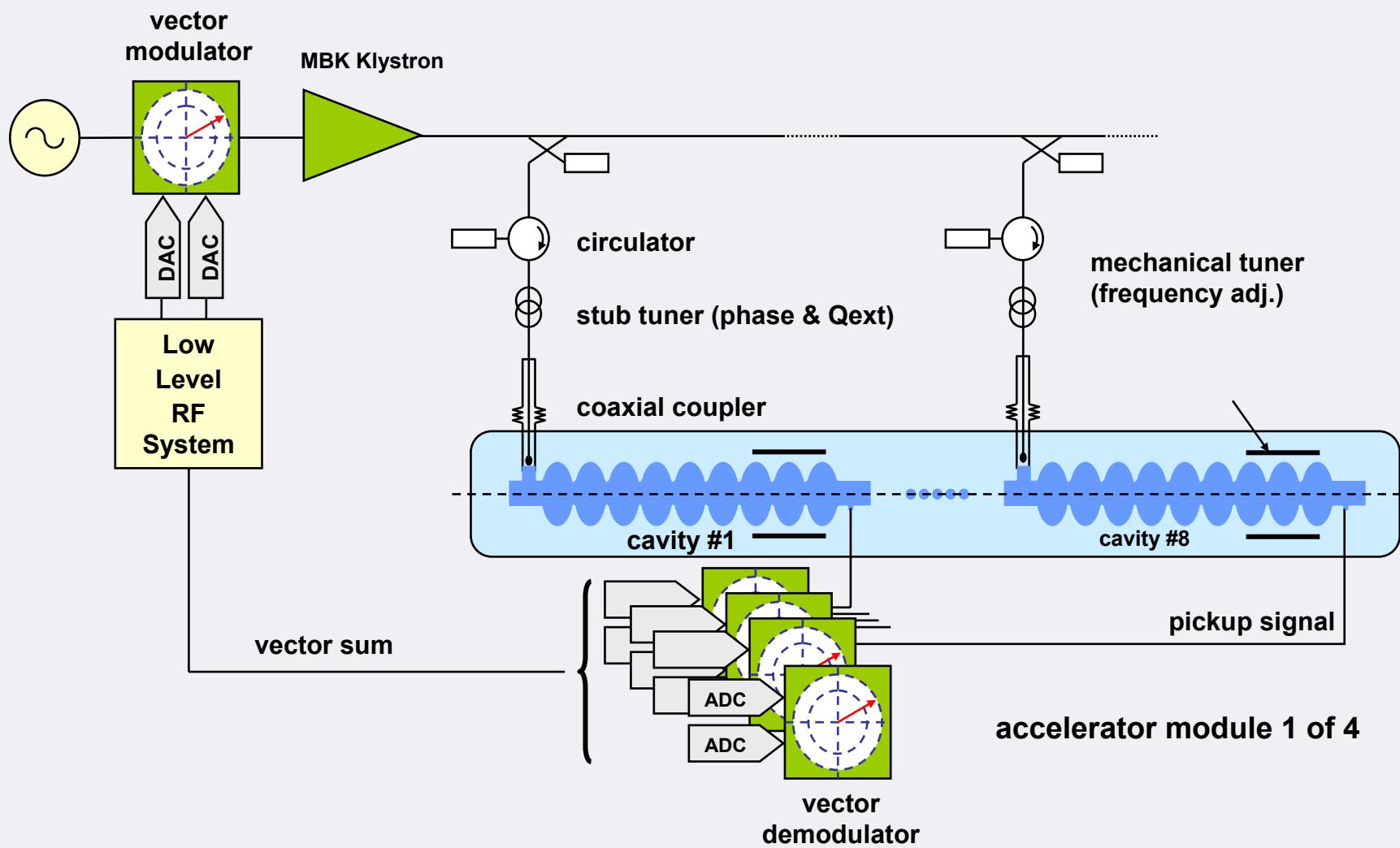
Accelerator Module (Cryomodule)



High Power RF System



Low Level RF Control



Low Level RF Control

Amplitude and Phase Stability

Design parameter are based on

- bunch-to-bunch energy spread
- pulse-to-pulse energy spread
- bunch compression in the injector
- arrival time of the beam at the undulator

The injector RF system needs
0.01% amplitude and 0.01 deg
phase stability!!!

(stability of photon intensity)

TEST at FLASH

Operational Requirements

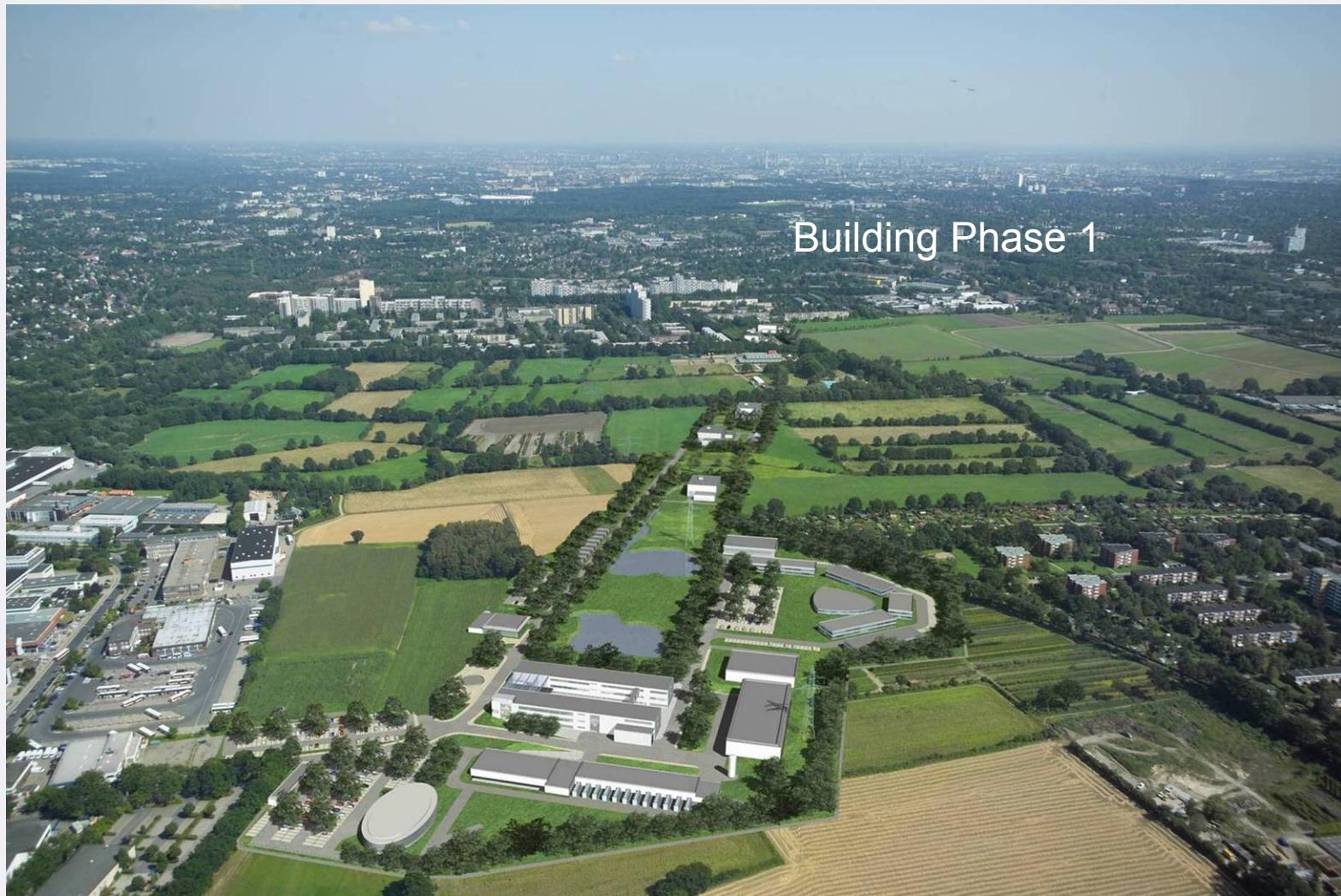
Beside field stabilization, the RF system must provide

- diagnostics for the calibration of gradient and beam phase
- measurement of the loop phase
- measurement of the cavity detuning
- control of the cavity frequency tuners (use fast tuner to correct Lorentz Force detuning)
- exception handling capability to avoid beam loss and to allow for maximum operable gradient
 - e.g. cavity quench detection
 - 'communicate' with spare RF stations
- correct RF system parameters (feed forward tables) according to variable beam loading

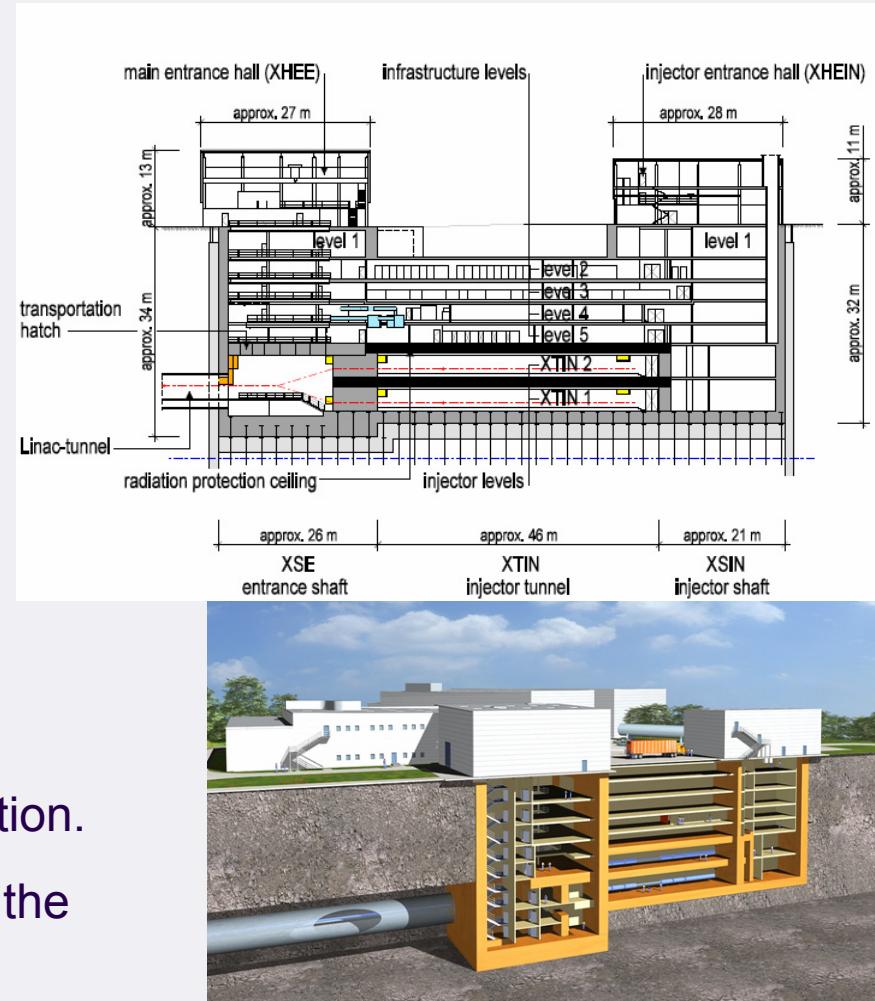
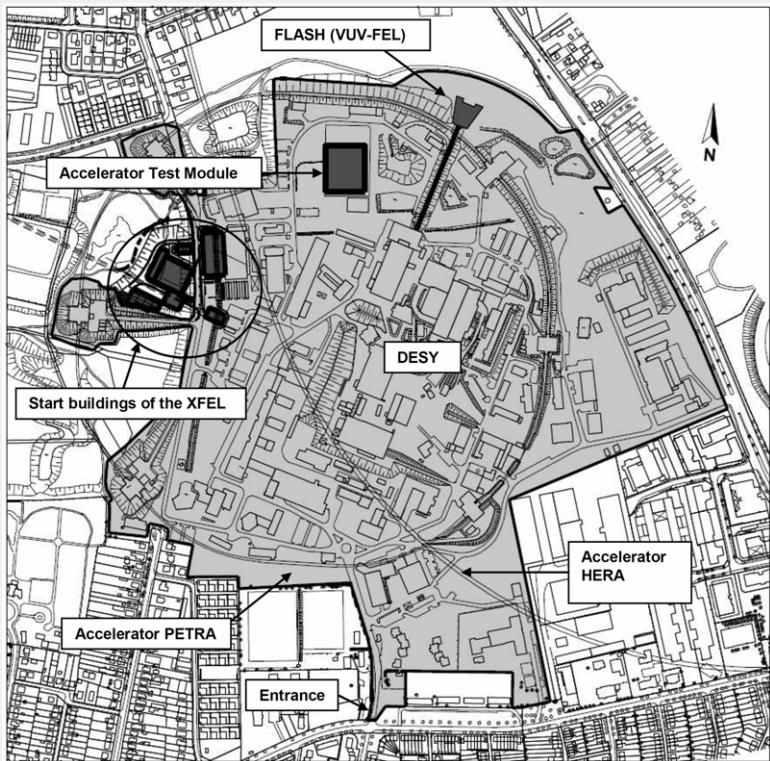
XFEL site in Hamburg/Schenefeld



... after construction (*computer simulation*)



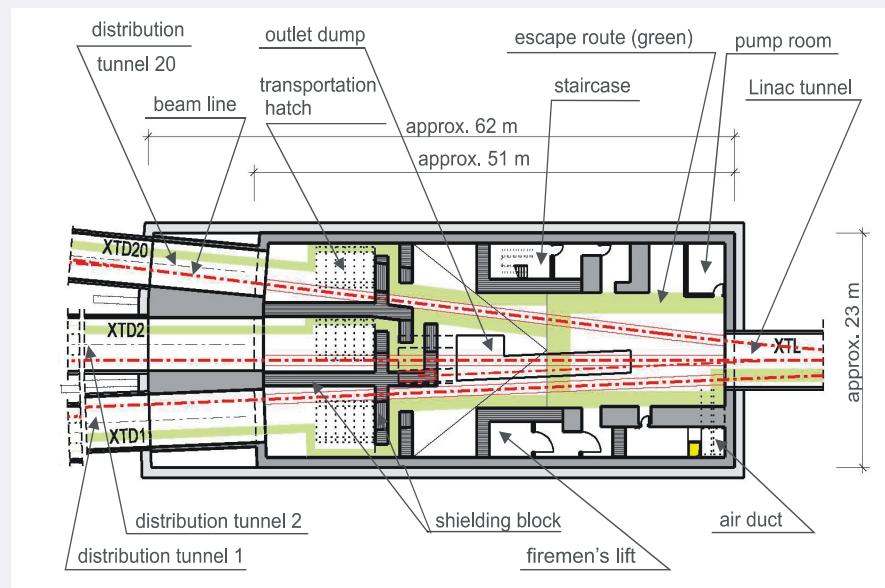
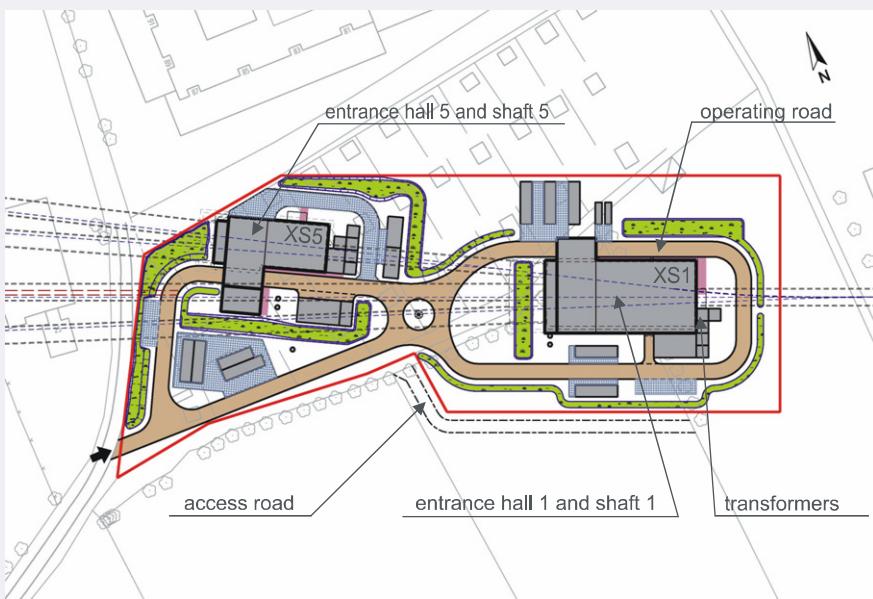
XFEL Buildings on the DESY Site



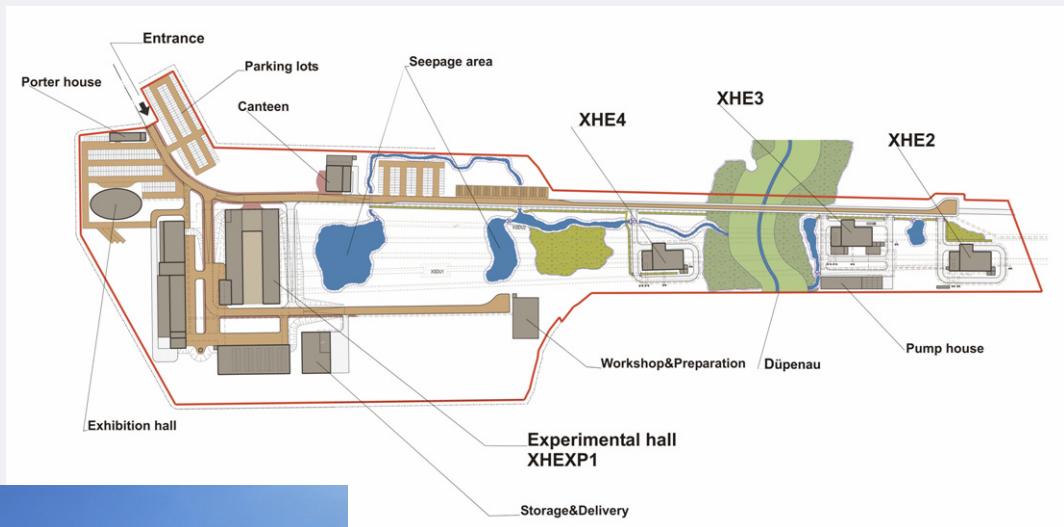
Ongoing call for tender for civil construction.

The XFEL injector is basically a copy of the TTF Linac.

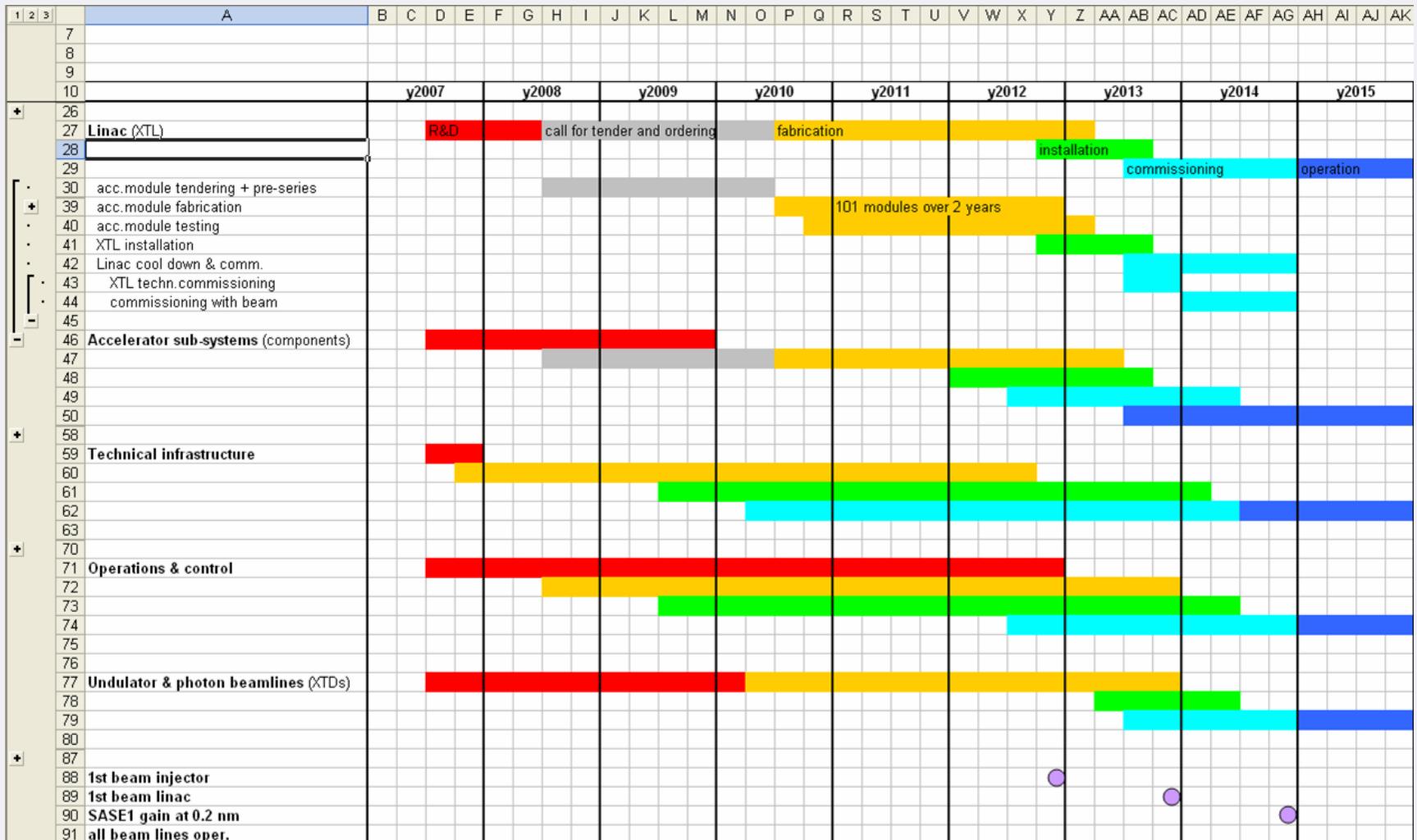
XFEL Distribution Shaft (XSE)



XFEL Experimental Hall



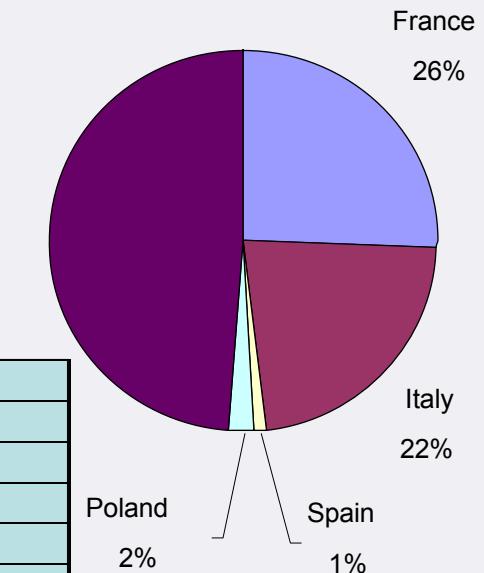
XFEL Schedule – First Beam Through Linac before End of 2013



Contributions to the XFEL Cold Linac

		Laboratory	Country	Invest / M€	FTE	FTE / M€
Accelerator Modules	WP – 3	CEA Saclay	France	60%		43%
		INFN	Italy	19%		29%
		DESY	Germany	21%		29%
	sum			100%		100%
Superconducting Cavities	WP – 4	INFN	Italy	50%		34%
		DESY	Germany	50%		66%
	sum			100%		100%
		Received from WP -9				
Power Couplers	WP – 5	LAL Orsay	France	73%		52%
		DESY	Germany	27%		48%
		or				
		LAL Orsay	France	99%		100%
		DESY	Germany	1%		0%
	sum			100%		100%
HOM Coupler / Pick-up	WP – 6	IPJ Swierk	Poland	100%		100%
	sum			100%		100%
Frequency Tuners	WP – 7	DESY	Germany	100%		100%
	sum			100%		100%
Cold Vacuum	WP – 8	DESY	Germany	100%		100%
	sum			100%		100%
Cavity String Assembly / Clean Room Quality Assurance	WP – 9	CEA Saclay	France	90%		51%
		DESY	Germany	10%		49%
		Transferred to WP -4				
	sum			100%		100%
Cold magnets	WP - 11	CIEMAT	Spain	56%		10%
		DESY	Germany	44%		90%
	sum			100%		100%

XFEL Cold Linac - Proposed Distribution of In-Kind Contributions



Laboratory	Invest / M€	FTE / M€	Sum / M€	
CEA Saclay				
LAL Orsay				
INFN				
CIEMAT				
DESY				
IPJ Swierk				
Sum France				25,4%
Sum Italy				22,7%
Sum Spain				1,1%
Sum Poland				2,1%
Sum Germany				48,7%
Sum WP 3-9 & 11	xxxxx	yyyyy	zzzzz	100%

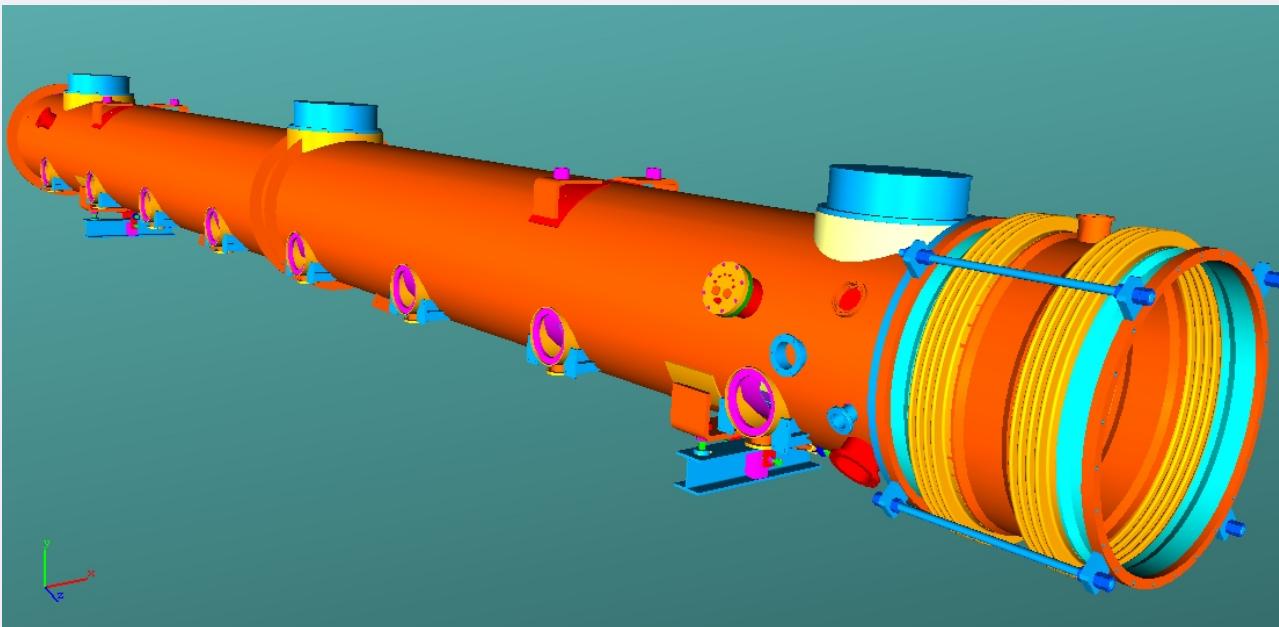
Accelerator Modules

60% CEA
19% INFN
21% DESY

Invest

43% CEA
29% INFN
29% DESY

FTE



- Fabrication of cold masses (incl. outer vessel)
- module assembly w/o frequency tuner & power coupler;
start with assembled string and finish with module installation
- weld connections
- alignment inside modules
- transportation of assembled accelerator modules
- material specifications, safety issues
- define processes for integration / assembly
- magnetic shielding / demagnetization
- sensors inside the accelerator modules
- pre-alignment of cavities and
coupler position

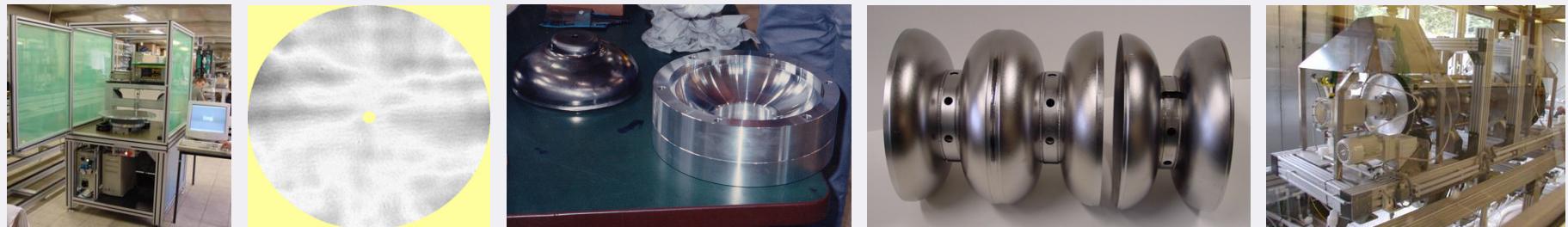
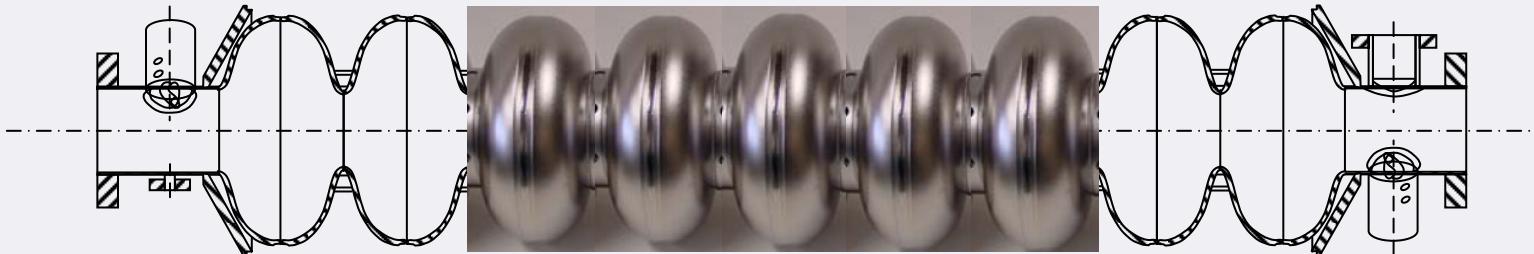
Superconducting Cavities

50% INFN
50% DESY

Invest

FTE

34% INFN
66% DESY



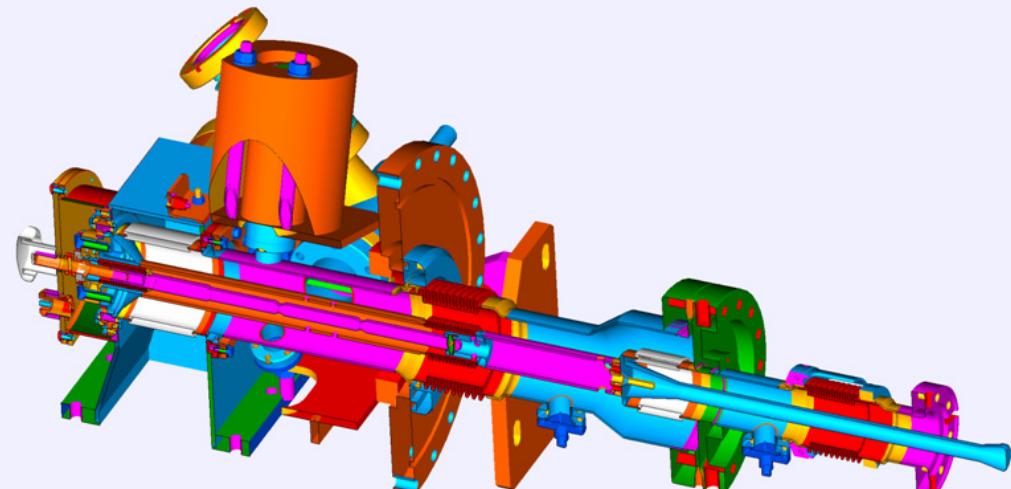
- Procurement of all niobium
- Scanning of NB sheets
- Complete mechanical fabrication of all cavities
- Surface treatment
- Consultant at start up of infrastructure and at full running production
- Data base setup and database running
- EDMS
- Helium vessel incl. Titanium parts (taken over from WP-9)

Power Coupler

73% LAL
27% DESY

Invest

FTE
52% LAL
48% DESY



- Coupler production incl. project and industries follow-up
- Coupler conditioning
- Infrastructure required for coupler assembly and conditioning,
i.e. clean room and modulator / klystron
- Technical interlock
- Tunnel installation / cabling of technical interlock
- Motor electronics

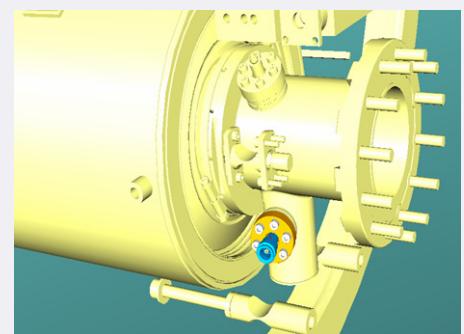
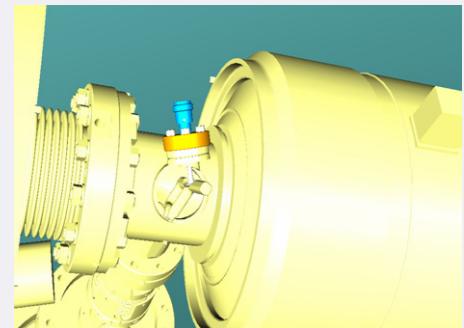
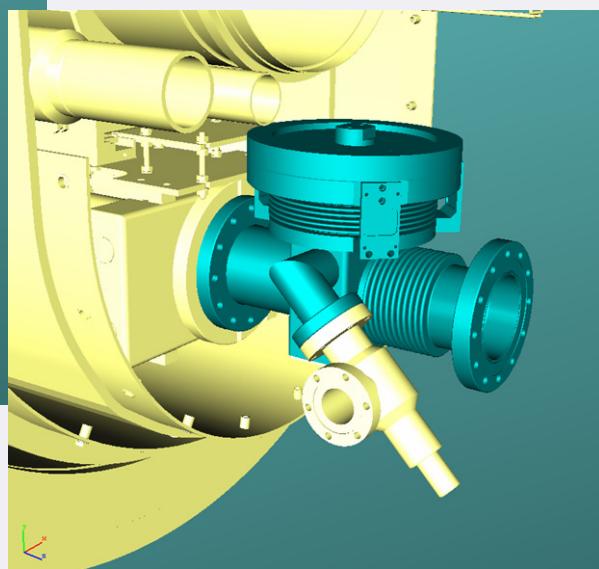
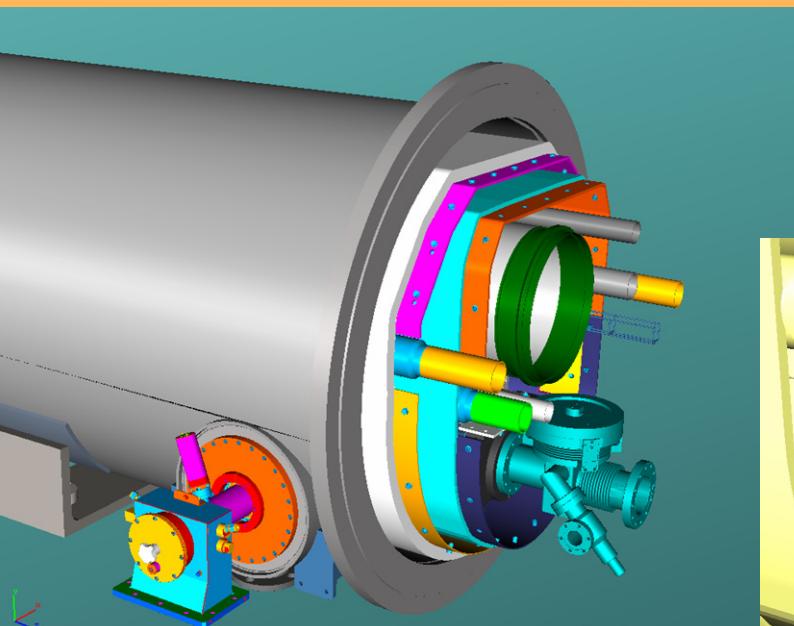
HOM Coupler / Pick-up

100%
Swierk

Invest

100%
Swierk

FTE



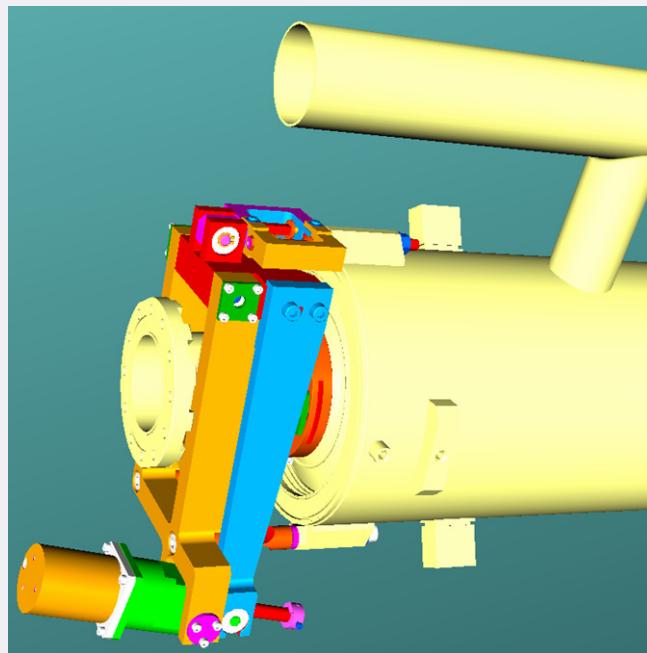
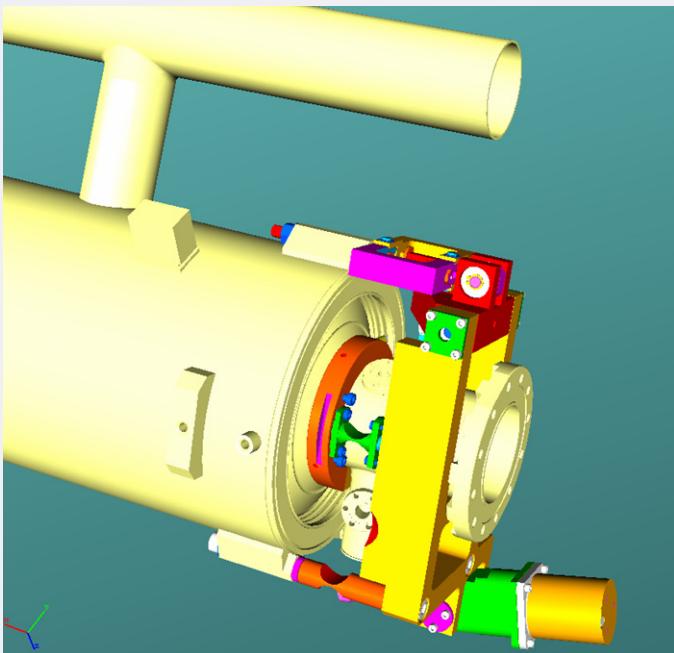
- Fabrication of HOM beam pipe absorbers
- HOM Pick-ups and cables

Frequency Tuners

100%
DESY

Invest

FTE
100%
DESY



- procurement of motors, gear box, piezo actuators
- fabrication of mechanical tuner parts
- fabrication of drive unit (motor and piezo) electronics
- cabling
- survey of production

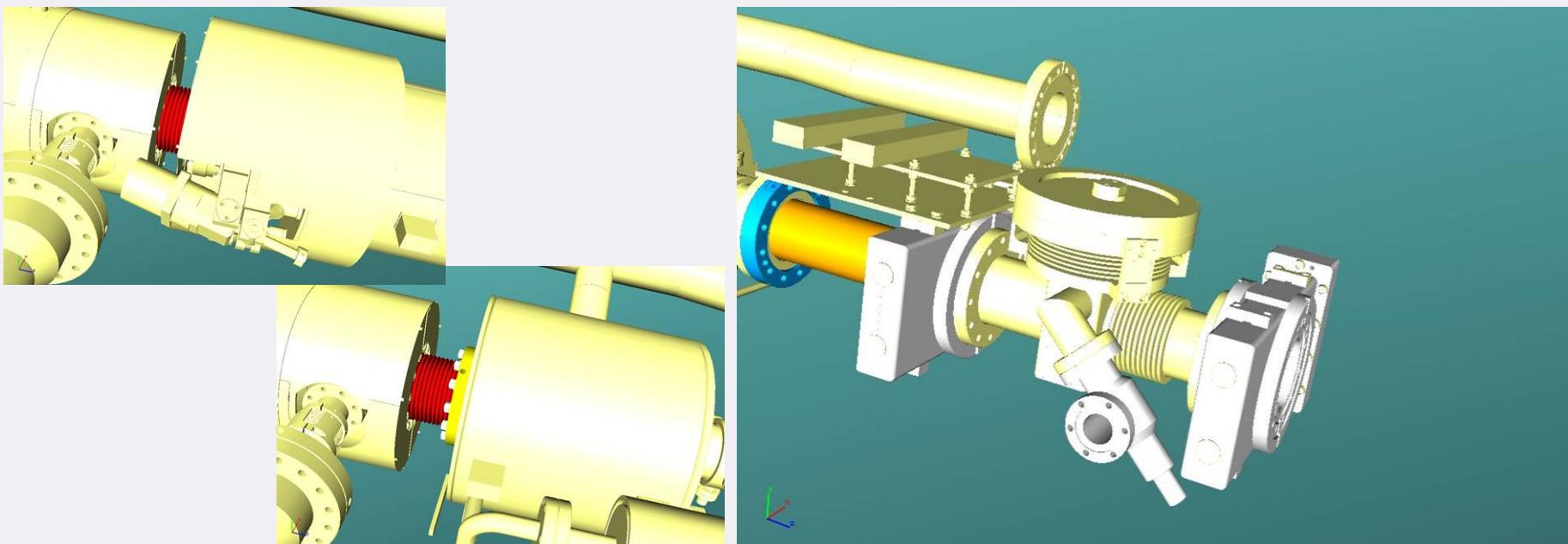
Cold Vacuum

100%
DESY

Invest

100%
DESY

FTE



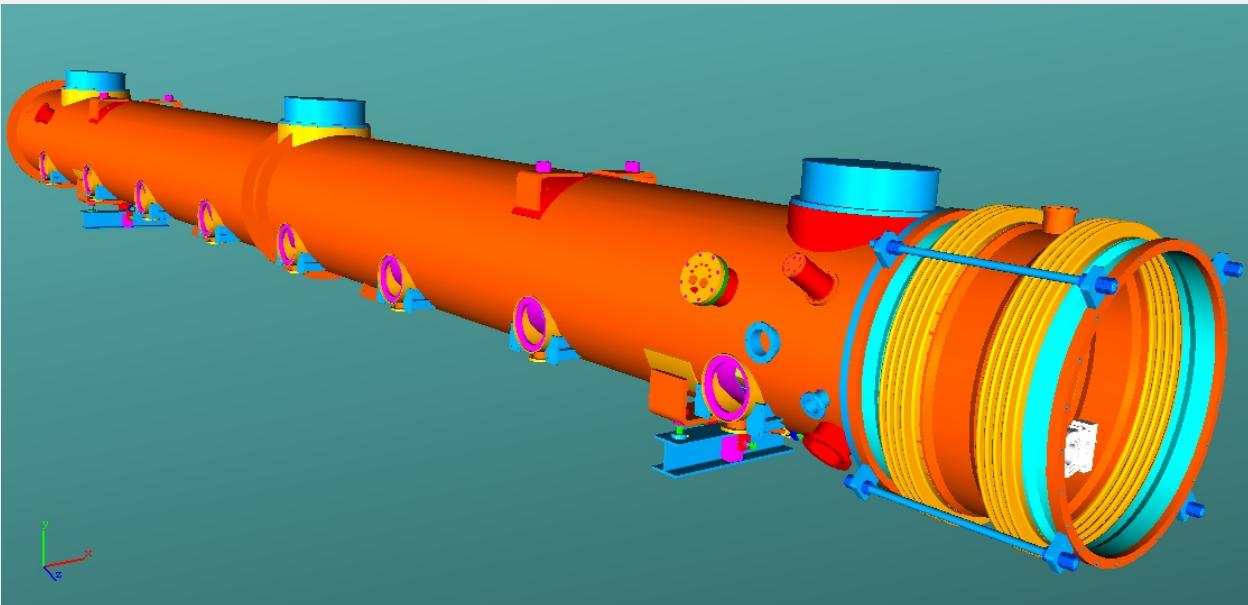
- procurement of all vacuum components within the cold linac, i.e.
 - bellows between cavities
 - cold manual valves at both ends of the cavity strings
 - valves in the module connection
 - isolation vacuum valves
 - ion and TSP pumps incl. power supplies/controllers
 - all vacuum components being part of the cryogenic connection boxes and of the cold-warm transitions
- vacuum components in the injector as well as bunch compressor sections (to be transferred to WP – 19)

Cavity String Assembly / Clean Room Quality Assurance

90% CEA
10% DESY

Invest

FTE
51% CEA
49% DESY



Module assembly see WP-3



- Helium vessel fabrication
- Titanium Tube and 2-phase line
- String assembly
- Knowledge transfer / consultant / training
- Database set-up and running / Quality control of infrastructure
- EDMS

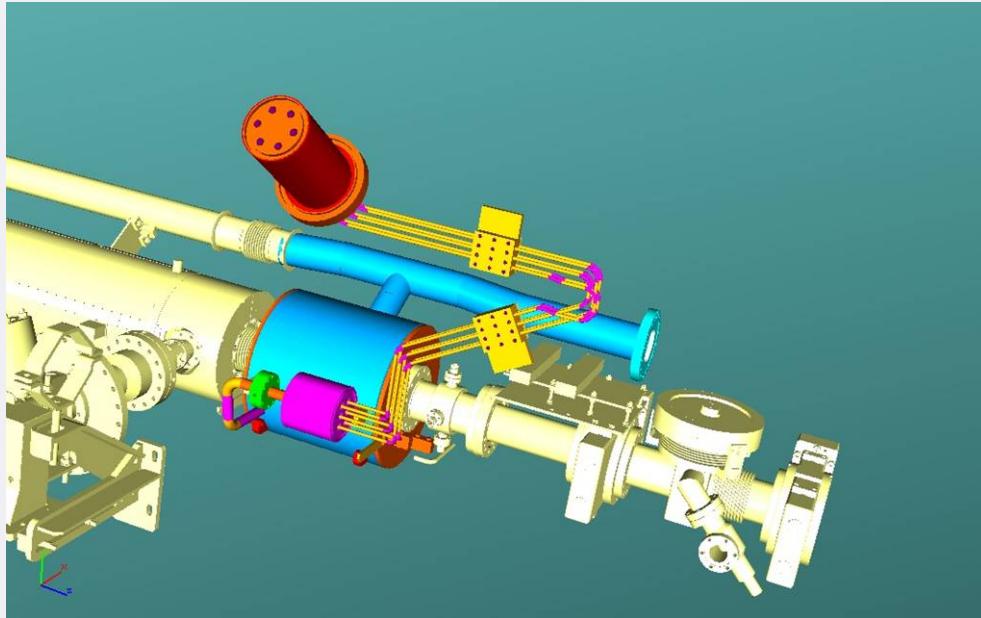
Cold Magnets

56% CIEMAT
44% DESY

Invest

10% CIEMAT
90% DESY

FTE



- fabrication of 2K quadrupole package
- test of quadrupole package

Large Russian Contribution

WP1 RF System	BINP Novosibirsk
WP10 Module Test Facility	IHEP Protvino
WP12 Warm Magnets	NIIIEFA St.Petersburg
WM13 Cryogenics	IHEP Protvino
WP14 Injector	JINR Dubna
WP17 Standard Beam Diagnostics	IHEP Protvino
WP18 Special beam Diagnostics	INR Troitsk
WP19 Warm Vacuum	BINP Novosibirsk
WP20 Beam Dump	IHEP Protvino
WP28 Control Systems	IHEP Protvino
WP33 Tunnel Installation	IHEP Protvino
WP34 Utilities	BINP Novosibirsk

WP21 Undulators
BINP Novosibirsk

WP24 Photon Diagnostics
PhTI St. Petersburg

WP26 Detector Development
JINR Dubna

Some well know
partners
&
a new
management.

Summary

