European XFEL
Status und Ausblick

Winfried Decking (DESY)
für das XFEL Projektteam

M Technisches Semiar
DESY Zeuthen, 11.06.2013

European XFEL at a Glance

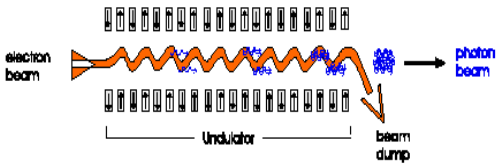
- Multi-Nutzerfacility mit hoher Mittlerer- und Spitzen- Brillianz (= Photonen/(Zeit•Fläche•Raumwinkel•Bandbreite)
- 17.5 GeV supraleitender Linac, 27000 Pulse pro Sekunde
- 3 Undulatoren mit variablem Gap
- Beim Start 6 ausgerüstete Experimente
- Budget 1.150 MEuro inkl. Vorbereitung und Inbetriebnahme

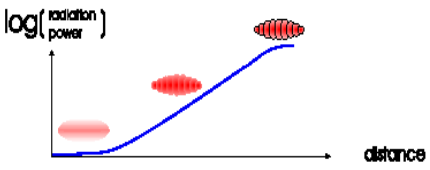
Parameter

Quantity	Value
electron energy	10.5/14/17.5 GeV
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
bunch repetition frequency within pulse	4.5 MHz
bunch charge	0.02 – 1 nC
electron bunch length after compression (FWHM)	2 – 180 fs
Slice emittance	0.4 - 1.0 mm mrad
beam power	500 kW
# of modules (containing eight 9-cell superconducting 1.3 GHz cavities)	101
accelerating gradient for 17.5 GeV	23.6 MV/m
# of 10 MW multi-beam klystrons	27
average klystron power (for 0.03 mA beam current at 17.5 GeV)	5.2 MW

SASE FEL

Self Amplification of Spontaneous Emission (SASE)
Free Electron Lasers (FELs) im Bereich harter Roentgenstrahlung (~0.5 - 60 Å)





Das Prinzip:

Ladungsdichte des Elektronenpaketes wird durch das eigene Strahlungsfeld moduliert

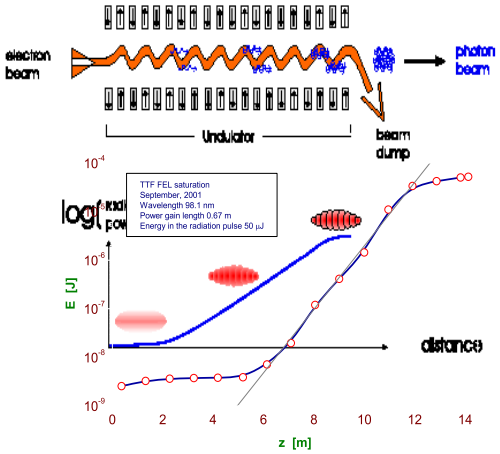
⇒ 'micro-bunching'

⇒ mehr und mehr Elektronen strahlen in Phase: $P \sim N^2$

Außerordentlich gute Strahlqualität
- Kleine Emittanz (Injektor)
- Kleine Energieunschärfe (Injektor)
- Hohe Ladungsdichte (Kompression)

SASE FEL

Self Amplification of Spontaneous Emission (SASE)
Free Electron Lasers (FELs) im Bereich harter Roentgenstrahlung (~0.5 - 60 Å)



Das Prinzip:

Ladungsdichte des Elektronenpaketes wird durch das eigene Strahlungsfeld moduliert

⇒ 'micro-bunching'

⇒ mehr und mehr Elektronen strahlen in Phase: $P \sim N^2$

Außerordentlich gute Strahlqualität

- Kleine Emittanz (Injektor)
- Kleine Energieunschärfe (Injektor)
- Hohe Ladungsdichte (Kompression)

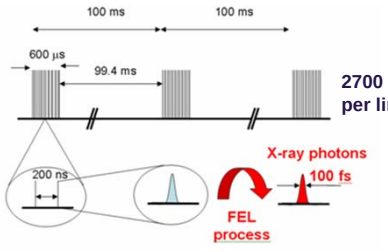
X-Ray FEL Characteristics

- Ultra kurze Pulse <100 fs (rms)
- Extreme Pulsintensitäten 10^{12}-10^{14} ph

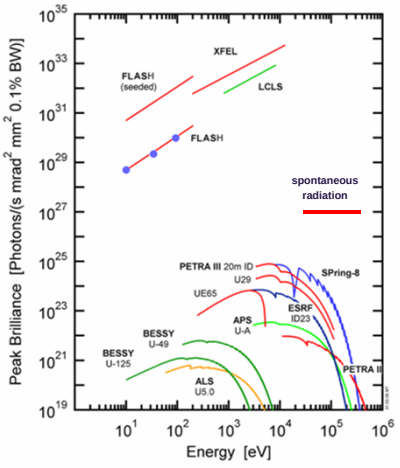
Im Vergleich zu Speicherringen der 3ten Gen.

- Kohärenz x10^9
- Mittlere Brillianz x10^4

Spezielle Zeitstruktur des XFELs

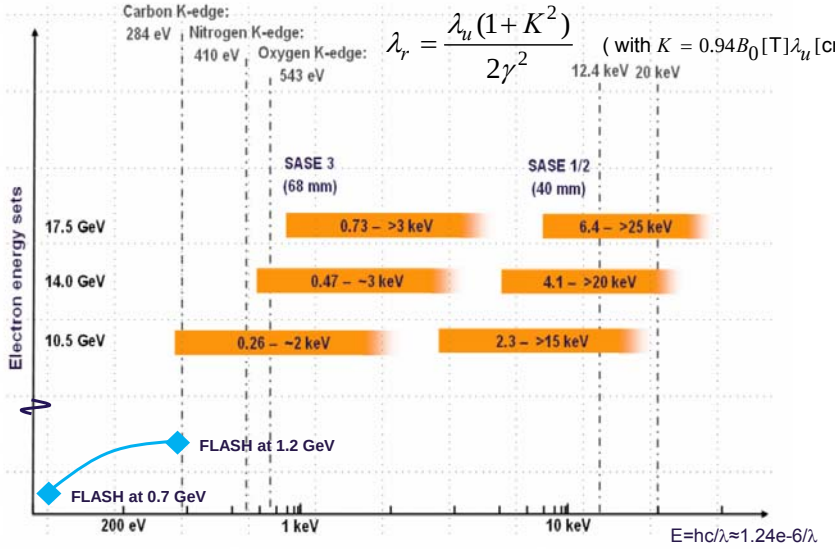


2700 bunches per linac pulse



European XFEL

Wellenlängenbereiche



$$\lambda_r = \frac{\lambda_u(1+K^2)}{2\gamma^2} \quad (\text{with } K = 0.94 B_0[\text{T}]\lambda_u[\text{cm}])$$

European XFEL

X-Ray SASE FEL Theorie

$$\lambda_r = \frac{\lambda_u(1+K^2)}{2\gamma^2}$$

1-4

15-40 mm

1x10^{-10} m

$$\frac{\varepsilon_N}{\gamma} < \frac{\lambda_r}{4\pi} \approx 1\times10^{-5}\ \mu\text{m}$$

$$L_g = \frac{\lambda_u}{4\pi\sqrt{3}\rho} \approx 100\ \text{m}$$

$$\frac{\sigma_E}{E} < \rho \quad <0.1\%$$

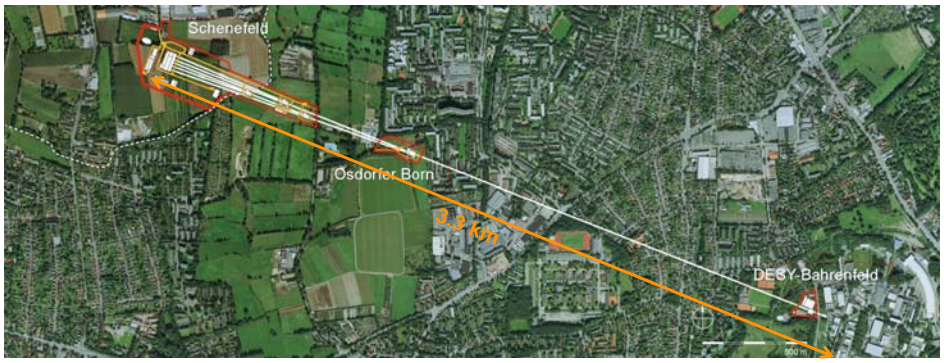
$$\rho \approx \frac{1}{4}\left(\frac{1}{2\pi^2}\frac{I_{PK}}{I_A}\frac{\lambda_u}{\beta\varepsilon_N}\left(\frac{K}{\gamma}\right)^2\right)^{\frac{1}{3}}$$

5 kA

30 m

~10^{-3}

Bau



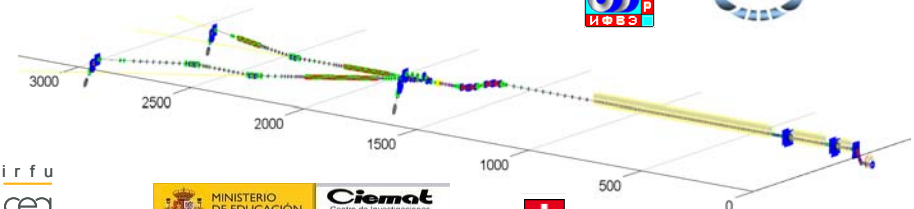
- 3 Baustellen
- 5.8 km Tunnel
- 12000 m^2 Grundfläche der Gebäude
- 150000 m^3 unterirdisches Gebäudevolumen


Osdorfer Born

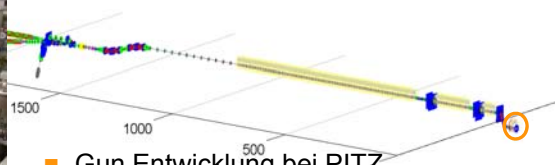

Schenefeld

European XFEL

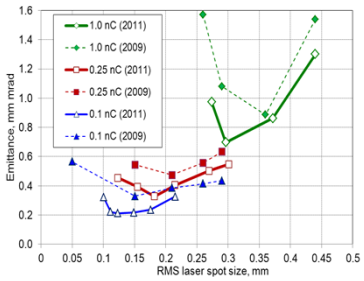
Accelerator Consortium: 16 Institutes bauen den Beschleuniger 'In-Kind'

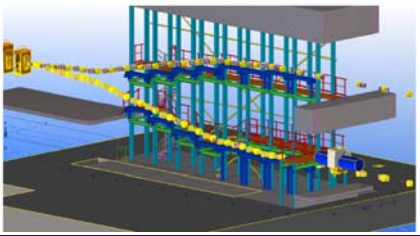


Injektor



- Gun Entwicklung bei PITZ
- Gun Konditionierung durch PITY
- Laser Entwicklung Max Born Institut

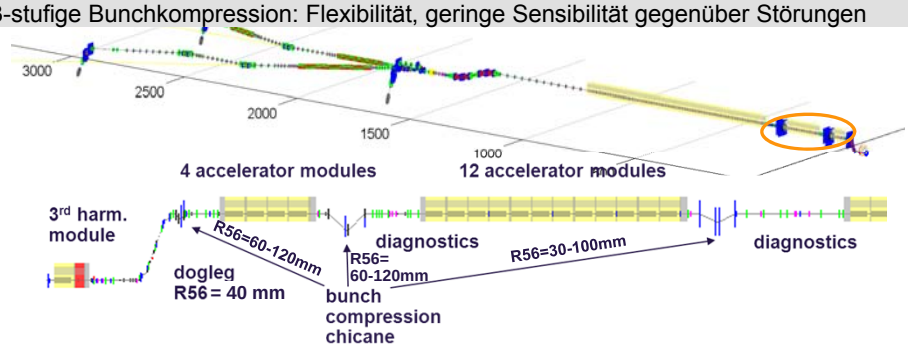




Injector Shaft XSI

Bunch Compression

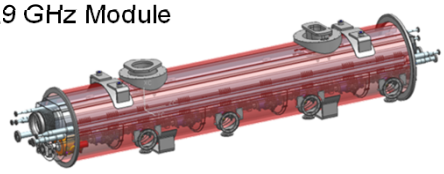
3-stufige Bunchkompression: Flexibilität, geringe Sensibilität gegenüber Störungen



σ_σ = 2 mm	σ_σ = 1 mm	σ_σ = 0.1 mm	σ_σ = 0.02 mm
I_{peak} = 50 A	I_{peak} = 100 A	I_{peak} = 1 kA	I_{peak} = 5 kA
σ_E = 0 %	σ_E = 1.5 %	σ_E = 1 %	σ_E = 0.3 %
E = 130 MeV	E = 130 MeV	E = 600 MeV	E = 2400 MeV

Bunch Compression - Komponenten

- Vakuumkammer und einige Komponenten bis zu 400 mm breit
- Grosse Dipolmagnete mit hohen Anforderungen an die Feldgenauigkeit
- 3.9 GHz Module



Accelerator Complex

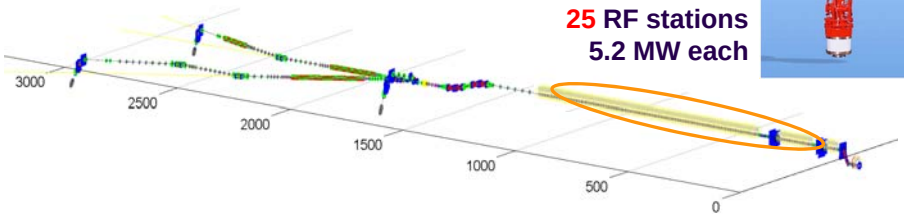
100 accelerator modules

800 accelerating cavities

1.3 GHz / 23.6 MV/m

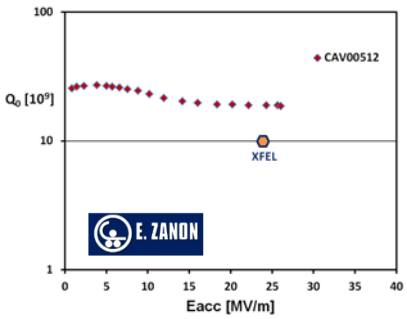
25 RF stations

5.2 MW each



Cavity Produktion

- Produktion, Oberflächenbehandlung und Reinigung der Supraleitenden Cavities in der Industrie (RI und Zanon)
- Aufwändiger aber letztendlich erfolgreicher Technologietransfer
- 50 Cavitäten geliefert, 90% erreichen XFEL Spezifikationen `auf Anhieb`



European XFEL

European XFEL

Cavity Tests in der Accelerator Module Test facility (AMTF)

- Alle 800 Cavitäten werden in der AMTF (DESY Hamburg) getested
- Infrastruktur ist installiert und wird zur Zeit in Betrieb genommen
- Betrieb der AMTF und Testdurchführung durch IFJ-PAN
- Momentan Testbetrieb in CMTB

European XFEL

Module Assembly at CEA Saclay

European XFEL

AMTF Module Tests

- Alle 100 Module werden in der AMTF (DESY Hamburg) getested
- Infrastruktur ist installiert und wird zur Zeit in Betrieb genommen
- Betrieb der AMTF und Testdurchführung durch IFJ-PAN

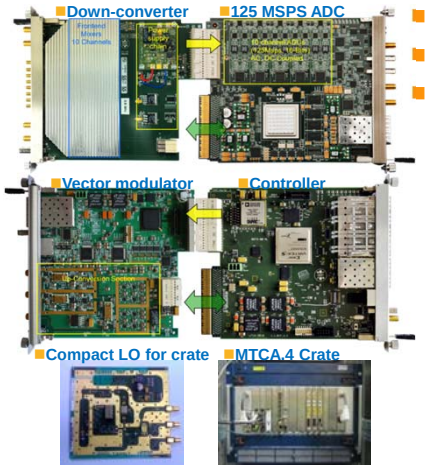
European XFEL

Cold Linac Infrastruktur

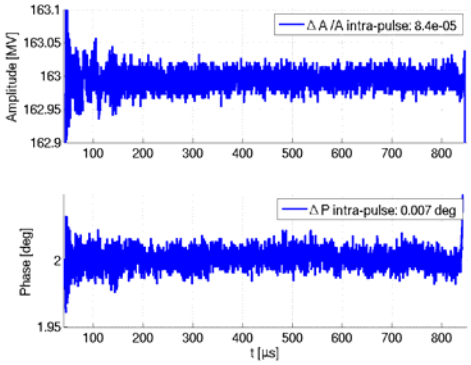
- Erste Klystrons, Modulatoren, Pulstransformer geliefert
- Installation der Infrastruktur in die Modulatorhalle
- Umbau der HERA Cryo-Anlage
- Planung und Beschaffung von Cryo-Komponenten für den Beschleuniger

Low Level RF System

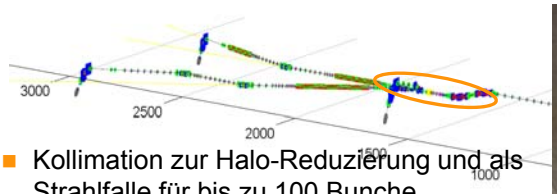
MicroTCA basiertes LLRF system



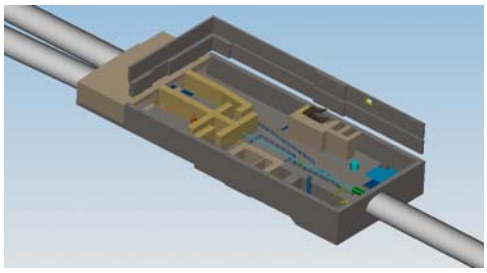
- RMS Amplitude < 9 x 10−5
- Phase < 0.008◦
- Beam Energiestabilität < 0.005%



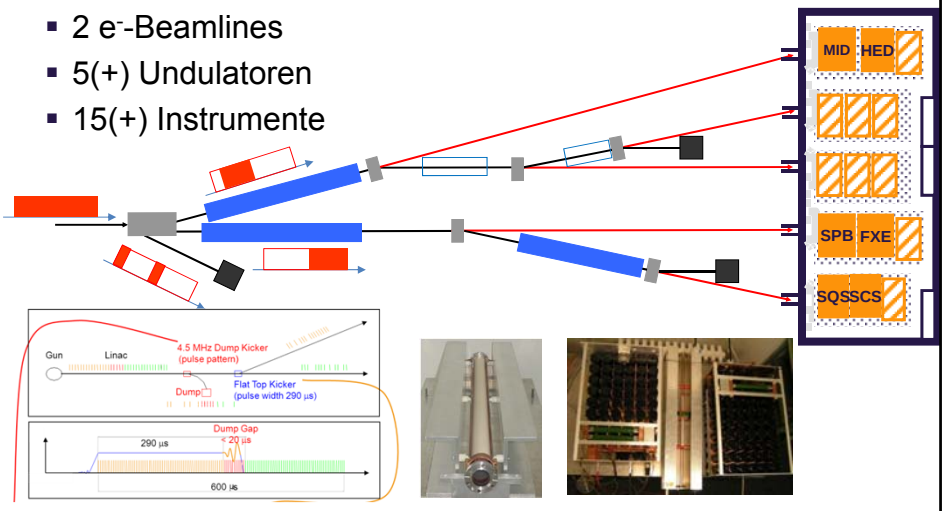
Collimation & Beam Distribution



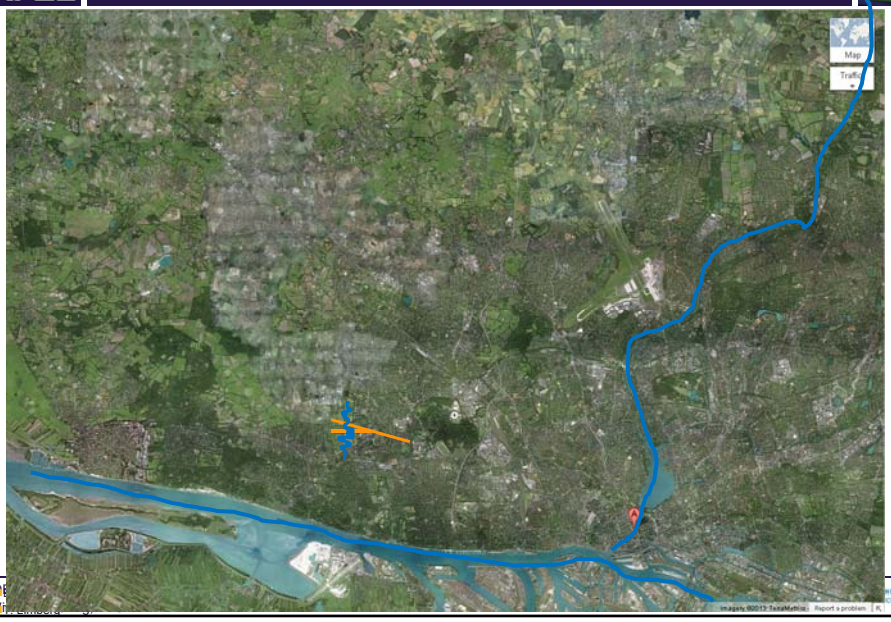
- Kollimation zur Halo-Reduzierung und als Strahlfalle für bis zu 100 Bunche
- Transversales Intra-Bunch Feedback
- Flexibles Strahlverteilungssystem



- Innerhalb eines RF Pulses
  - 2 e^--Beamlines
  - 5(+) Undulatoren
  - 15(+) Instrumente



‘Alster’ and ‘Elbe’ Branch

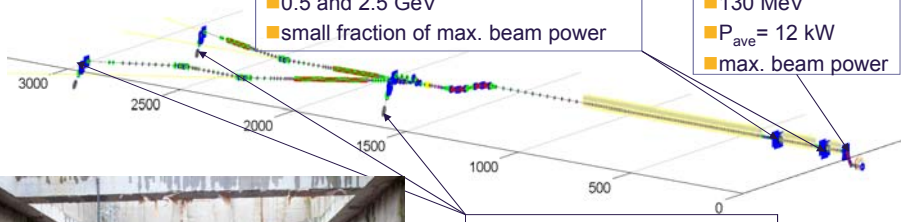


European XFEL

Beam Dumps

- bunch compressor diagnostic dumps
- 0.5 and 2.5 GeV
- small fraction of max. beam power

- injector dumps
- 130 MeV
- P_{ave}= 12 kW
- max. beam power



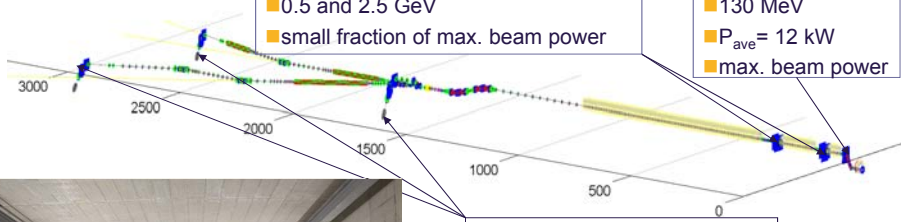
- main beam dumps
- up to 25 GeV
- P_{ave}= 300 kW
- 1/2 max beam power
- beam magnified
- slow sweep to distribute heat

European XFEL

Beam Dumps

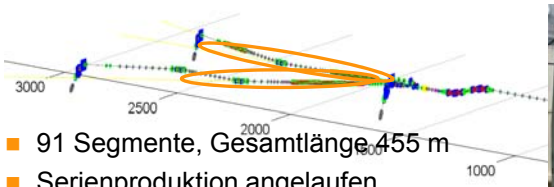
- bunch compressor diagnostic dumps
- 0.5 and 2.5 GeV
- small fraction of max. beam power

- injector dumps
- 130 MeV
- P_{ave}= 12 kW
- max. beam power

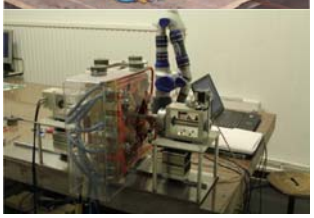


- main beam dumps
- up to 20 GeV
- P_{ave}= 300 kW
- 1/2 max beam power
- beam magnified
- slow sweep to distribute heat

European XFEL – Undulators

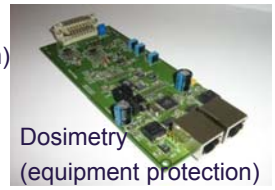


- 91 Segmente, Gesamtlänge 455 m
- Serienproduktion angelaufen
- Messungen in Halle 36
- Quadrupole produziert und vermessen
- Design der Vakuumkammern und Zwischenstücke fertig, Prototypenbau und Serienfertigung

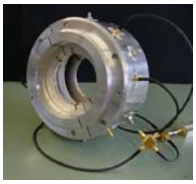


Beam Diagnostics

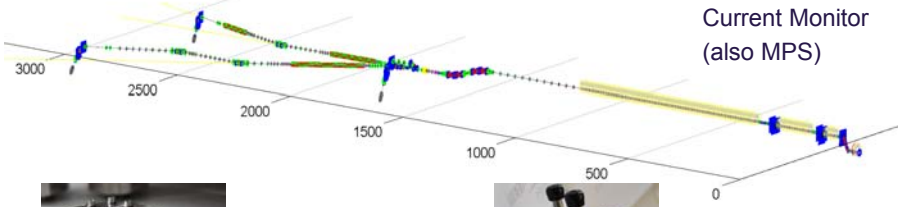
Beam Loss Monitor
(input for Machine Protection System)



Dosimetry
(equipment protection)



Current Monitor
(also MPS)



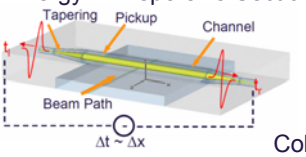
Dark Current Monitor
(also very sensitive charge monitor)

Beam Position Monitor

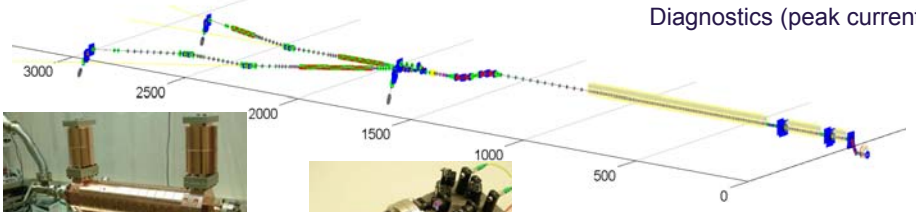
Beam Diagnostics

Beam Size

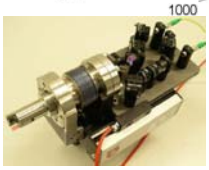
Beam Energy in Dispersive Section



Coherent Radiation Diagnostics (peak current)



Transverse Deflecting Structure (beam size within bunch)



Electro Optical Diagnostics (long. bunch profile)

Synchrotron Radiation Monitors

Beam Arrival Monitors

The XTL Tunnel in Q1/2012 – vor 1 Jahr

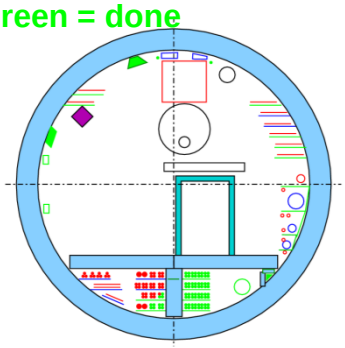
European XFEL

Heute

European XFEL

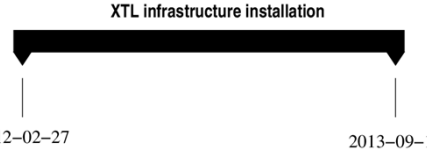
Infrastructure Installation

Green = done



- Cooling water pipes
- electricity+light+telecomm
- cable trays+cables
- pulse cables
- fiber optics tubes
- consoles for modules
- alignment marks
- heating+ventilation
- safety equipment

"Still in time, on schedule."

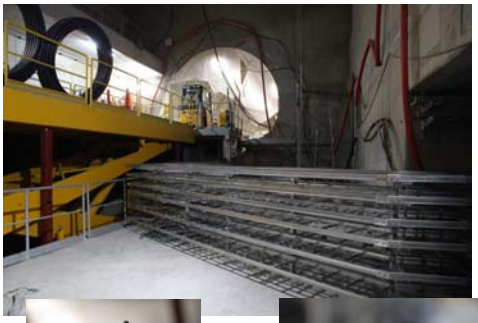


European XFEL

XTL Infrastructure


European XFEL

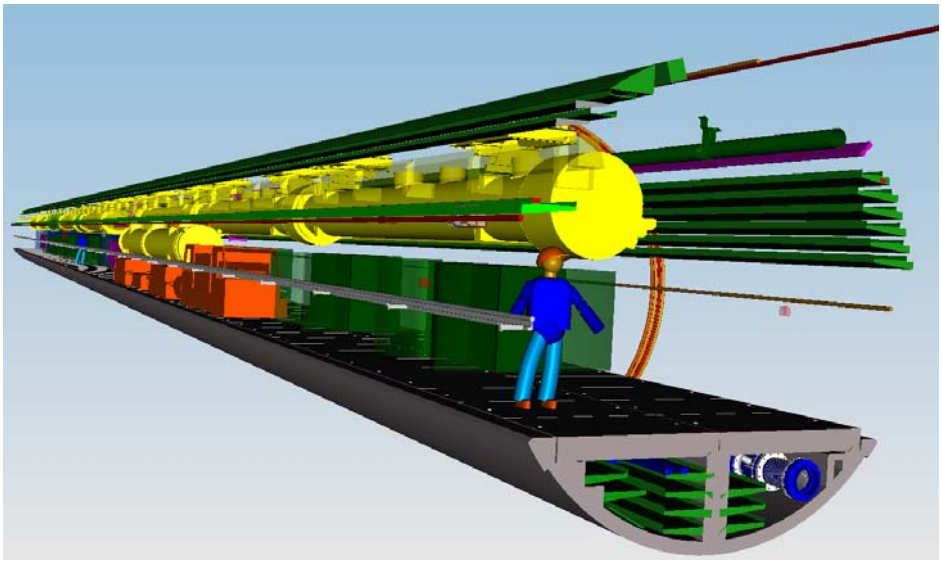
Verlegung der Pulskabel





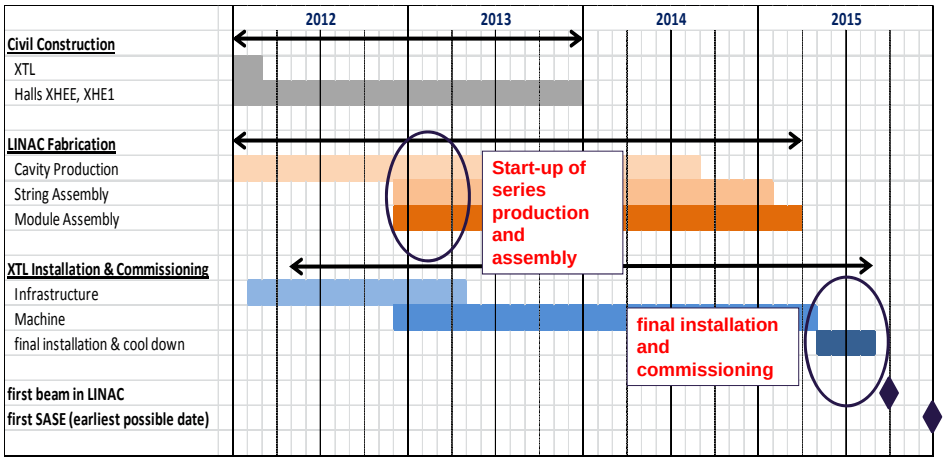
European XFEL

Nächste Herausforderung: Beschleunigerinstallation



European XFEL

Zeitplan & Herausforderungen

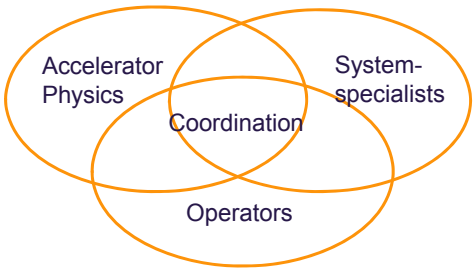


Betrieb: Organisatorisches

- European XFEL GmbH ist für den Betrieb des XFEL verantwortlich
- DESY betreibt im Auftrag und in eigener Verantwortung den Beschleuniger
- De facto ähnlich wie bei allen unseren Anlagen, die ja nie zum Selbstzweck betreiben werden

Betriebsteam

- Coordination (Winni Decking, Injector Frank Brinker, …)
- Accelerator Physicists
- Photon system scientists
- Operators (Electron and Photon systems)
- System Specialists (M- and XFEL-groups)
  - organize on call duty
  - organize full shift participation as needed
  - organize and run development shifts



European XFEL

Accelerator control room crew

24/7 coverage:
- Shift leader (1)
- Operators for PETRA and FLASH (3)
- Operators for power/clima/water on DESY site (2)
- Cryo-plant operator (1)
- Operator and Accelerator Physicist for XFEL (2)

Additional coverage
- Specialists according to program needs

Photon systems staffing to be defined
- Initial commissioning from DESY BKR

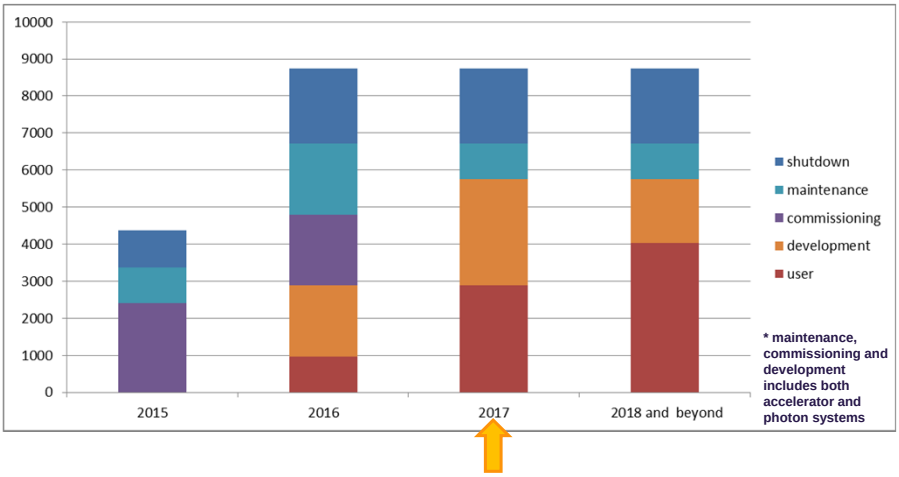
European XFEL

XFEL Commissioning Sequence

- Start of injector cool-down
- Injector commissioning with beam
- Start of linac cool-down
- Overall basic commissioning with beam
- First lasing in SASE1, SASE3, SASE2
- First user experiments
- Further development parallel to ramp up of user operation
- User operation with approx. 4000-5000 user hours and approx. 1000-2000 development hours/year

European XFEL

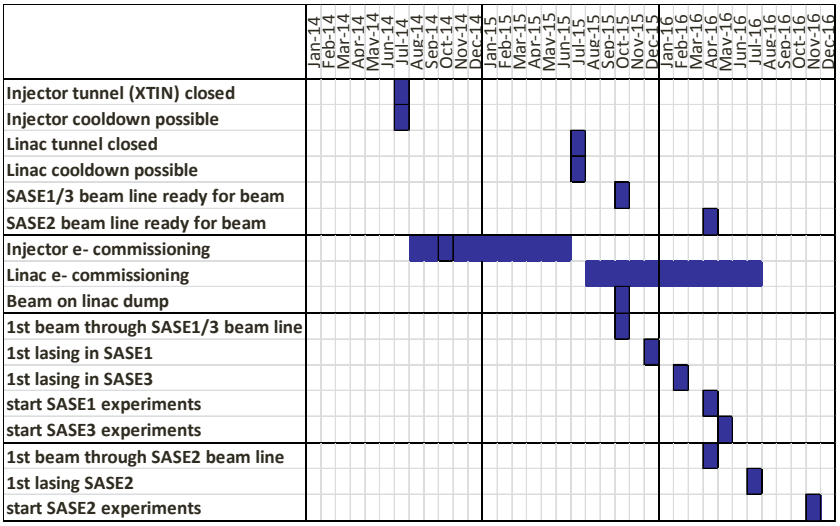
Machine Time Distribution



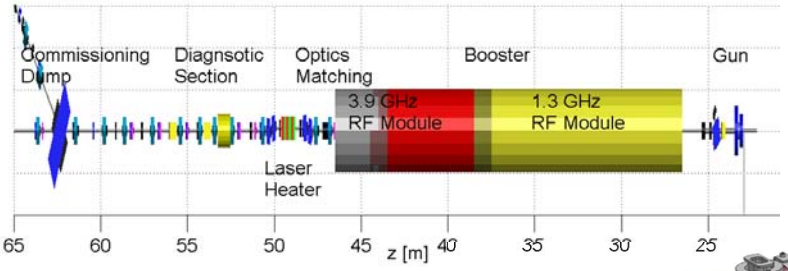
start parallel operation SASE 1,2,3 here, thus total user hours tripled

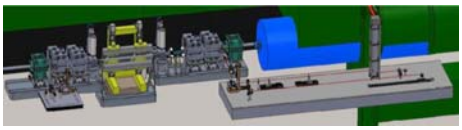
European XFEL

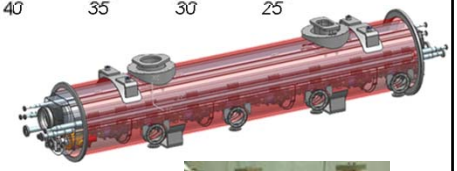
Top-Down Project Schedule

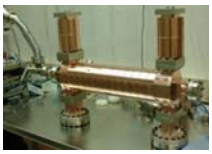


Injector Commissioning





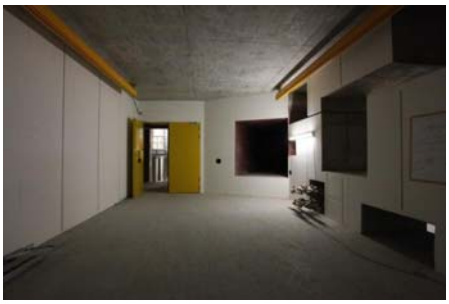




Injector Commissioning

‚Preparatory Work':

- Gun conditioning and characterisation (as possible) at PITZ
- 2 month high-power RF test in XTIN in 09/10 2013
  - Needs infrastructure, media, feedbacks, controls, personnel interlock in the XTIN



European XFEL

Injector Commissioning

- Achieve all XFEL parameters

Quantity	Value
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
bunch repetition frequency within pulse	4.5 MHz
bunch charge	0.02 – 1 nC
Slice emittance	0.4 - 1.0 mm mrad

- Commission sub-components like
- Establish routine operation
- 'Teambuilding'
- Sufficient time foreseen for tests, detours, „trial and error", …
- 1 year overall injector commissioning time planned
- First beam transport to linac possible about 4 month after injector cooldown

European XFEL

XFEL Overall Commissioning

‚Preparatory Work':

- Technical Commissioning of all subsystems as far as possible under installation/open tunnel conditions (i.e. warm coupler conditioning, …)
- Tunnel close
- Personnel interlock check
- Cool-down
- Pre-beam check-out
- LLRF:
  - Cavity tuning and high-power tests without beam
  - Beam to BC1 dump, commission one RF station
  - T0+3 month: beam transport through linac possible

Initial E-beam parameters

Quantity	Value
electron energy	~~10.5/14~~/17.5 GeV
macro pulse repetition rate	10 Hz
RF pulse length (flat top)	600 μs
bunch repetition frequency within pulse	~~4.5 MHz~~ 100 kHz
bunch charge	~~0.02 – 1 nC~~ 0.5 nC
electron bunch length after compression (FWHM)	~~2 – 180 fs~~ 90 fs
Slice emittance	~~0.4 –~~1.0 mm mrad
beam power	~~500 kW~~ 5 kW

XFEL Overall Commissioning – Milestones

1. **First Beam through Linac (T0 + 3 month)**
   - 17.5 GeV, 10 Hz, 0.5 nC, 100 kHz beam is transported through the linac to the TLD dump
   - Control: Charge, peak current, energy and trajectory are controlled by slow feedbacks.
2. **First Beam through 'Alster' Beamline**
   - Electron beam based trajectory alignment in undulator
3. **First Lasing observable in SASE1 (T0 + 6 month)**
   - First lasing is observed at 0.15 nm
   - Commissioning of photon diagnostics & beam line
4. **First Lasing observable in SASE3 (T0 + 7.5 month)**
5. **First Lasing observable in SASE2 (T0 + 12 month)**

European XFEL

First User Operation

- One charge, one electron energy
- Single bunch to 100 kHz (under discussion)
- first SASE-photons as soon as possible to allow commissioning of photon beam lines and experiments
- Approx. 1000 user hours in 2016, serving one undulator a time

"Conditions for 'First User Experiments'

→ experiments can use x-ray beam at TDR performance, but with limited flexibility in terms of pulse pattern, pulse length and photon wavelength"

European XFEL

Further Development

Multi-bunch operation

- **up to 2700 bunches**, 0.5nC, C=100
- slow **and fast** feedbacks

Quasi-simultaneous operation of SASE1 and SASE2 beam line

- up to 2700 bunches, 0.5nC, C=100
- **fast switching** elements

Flexibility in wavelength and bunch length

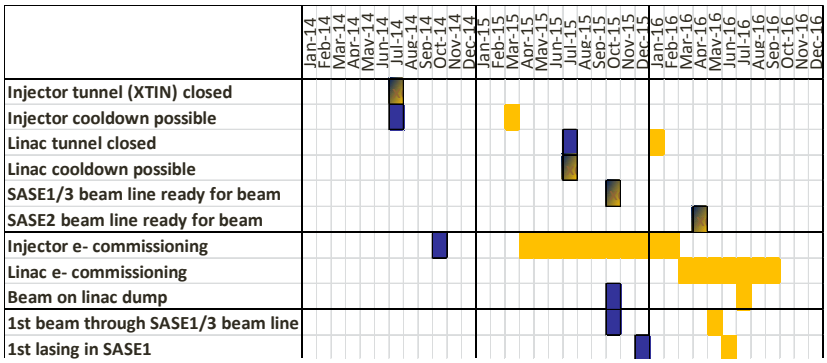
- 2700 bunches, **0.02-1nC, C=2000-50**
- establish procedures to change bunch length/bunch charges
- establish fast procedures to change photon wavelength by changing energy/undulator gap

Seeding

….

European XFEL

Alternate Schedule (late injector cooldown, late linac tunnel closure)



European XFEL

Zusammenfassung