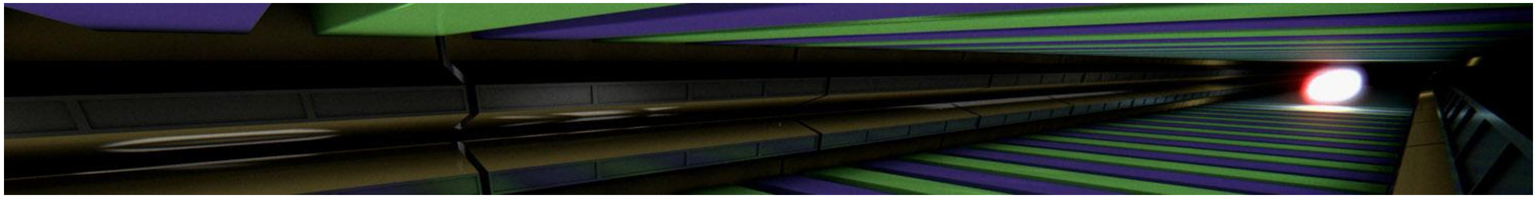


Status & Update European XFEL

Wissenschaftlicher Ausschuss DESY

7. September 2010

Thomas Tschentscher

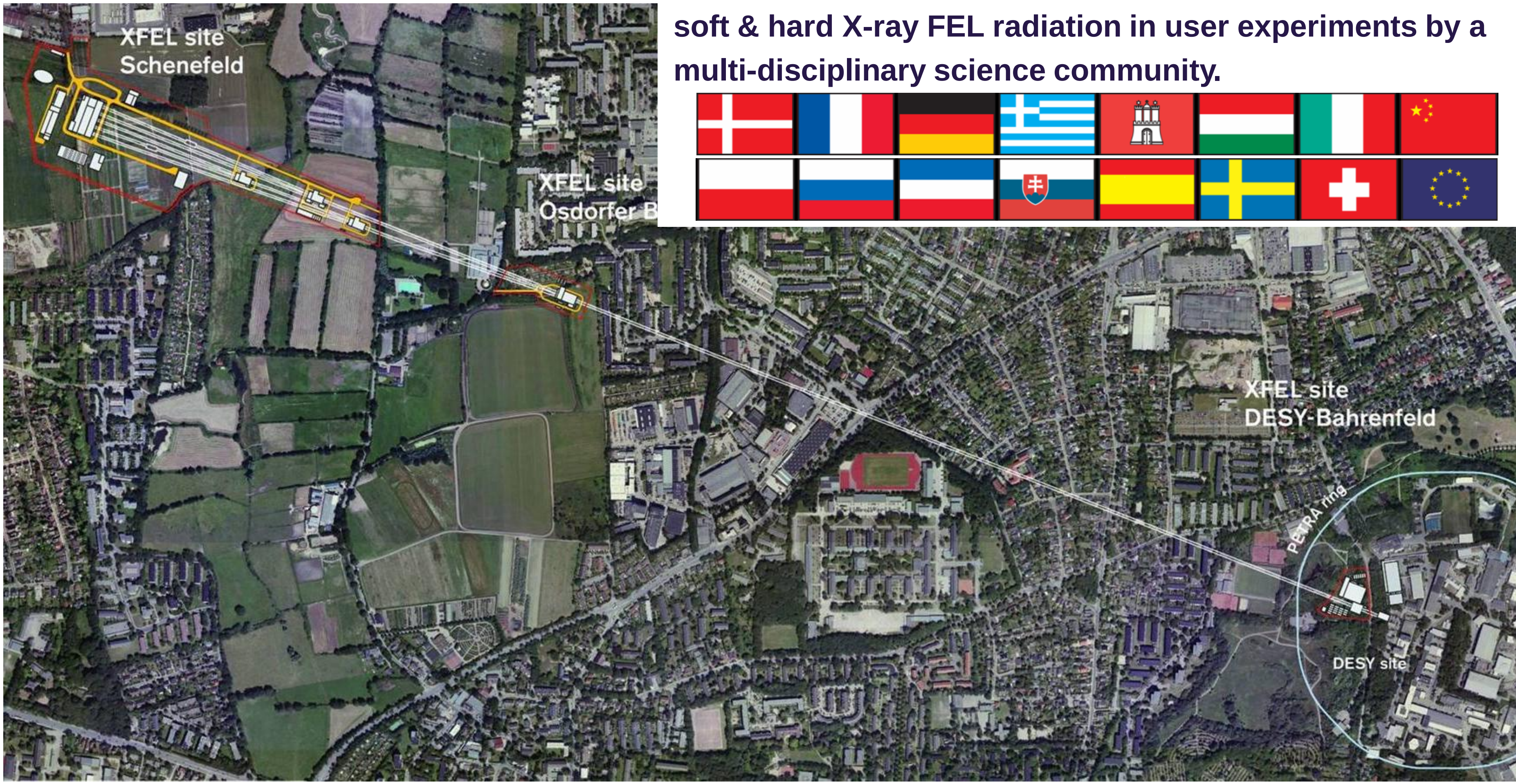
thomas.tschentscher@xfel.eu

Overview

- **Status European XFEL**
  - Overview
  - Accelerator
  - X-ray systems & scientific instruments
  - Civil construction
- **Project update**
  - New developments
  - Adaption of design
  - Project timeline
- **Summary**

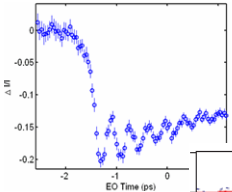
European XFEL

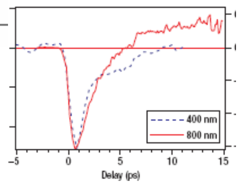
International research infrastructure for the application of soft & hard X-ray FEL radiation in user experiments by a multi-disciplinary science community.



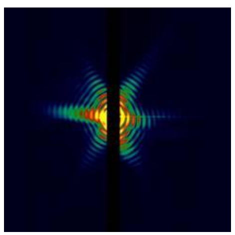
see www.xfel.eu for details

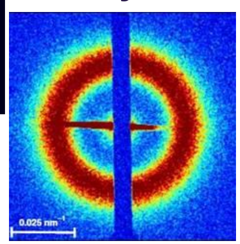
VUV – X-ray Free-electron lasers



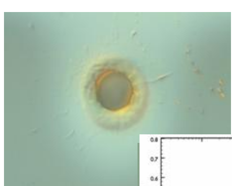


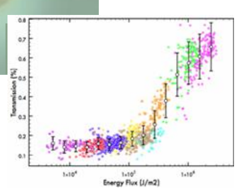
ultrashort x-ray pulses



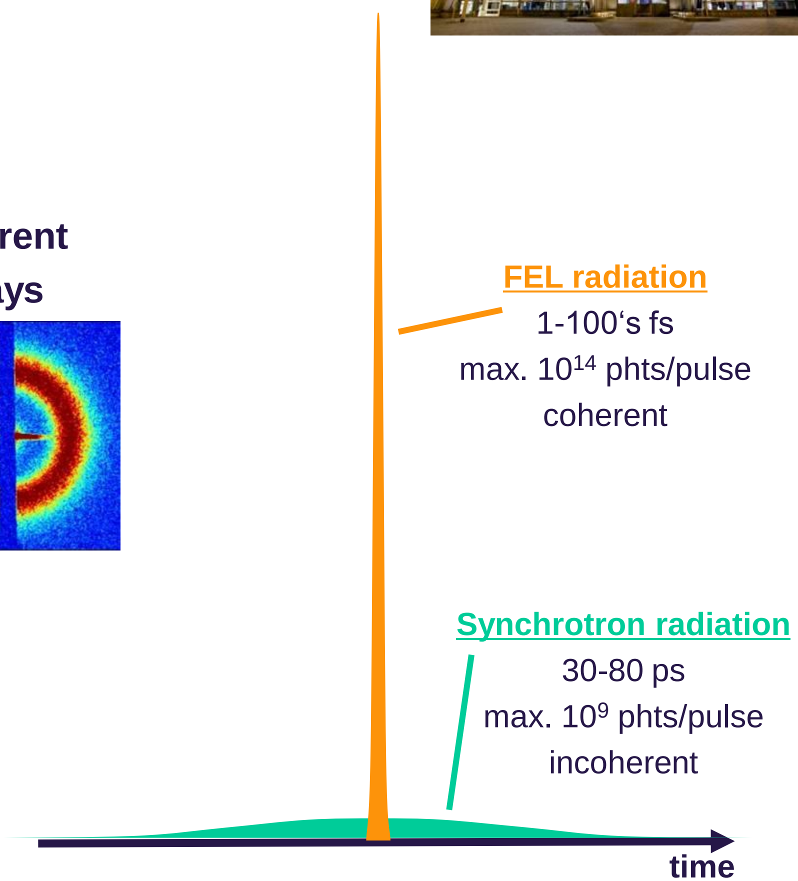


coherent x-rays

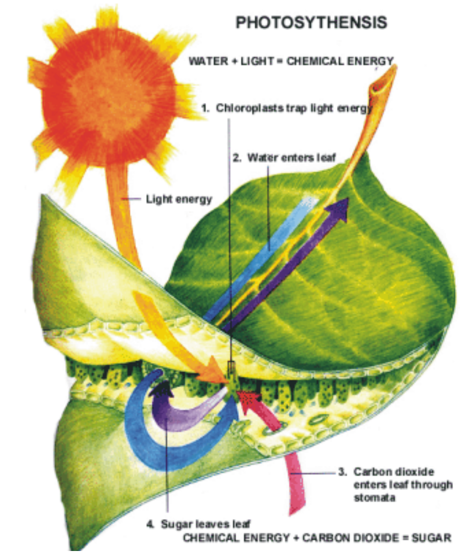




high intensity



Science & application drivers



Reaction chemistry

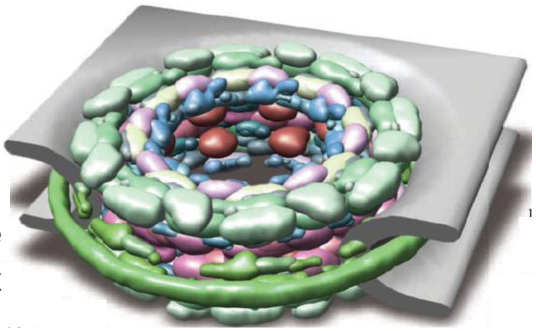
- time-resolved atomic structures
- catalysts, photo-chemistry
- develop new processes & products

Complex materials

- combine atomic & electronic structure
- functional materials, magnetism
- develop new materials

Life sciences

- atomic structure → function
- mol., complexes, cells
- develop new treatments



Nuclear pore complex

… these are only few examples out of a long list of research problems in many scientific disciplines from biology via physics to geo-sciences

European XFEL

European XFEL: An international project

The international process

- Technical design report published 2001/02
- In 2003 first steering committee meetings
- Project start in June 2008
- Signing convention & GmbH creation in Nov 2009
- Currently 11 signatories / 8 shareholders
- France & Italy are expected to join still 2010.
- Spain has confirmed its interest to join, likely in spring 2011. Further countries have indicated interest to join or become associated with the project.

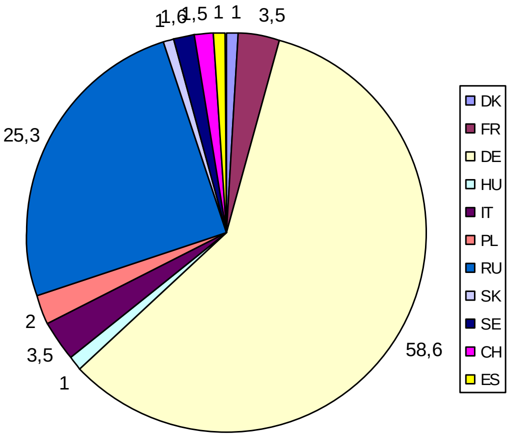
Signing of convention, Nov 2009, Hamburg City hall

Construction project

- Total cost ~1.1 billion EUR
- The German shareholder DESY enabled the preparation, acts as a host laboratory and is largely involved in accelerator construction & operation.

Operation phase

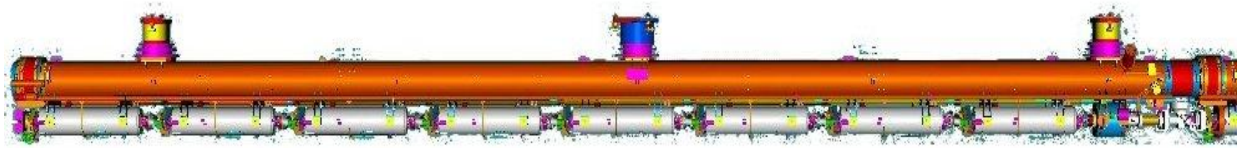
- Initially 15 years with annual budget ~75 M€



% of shares

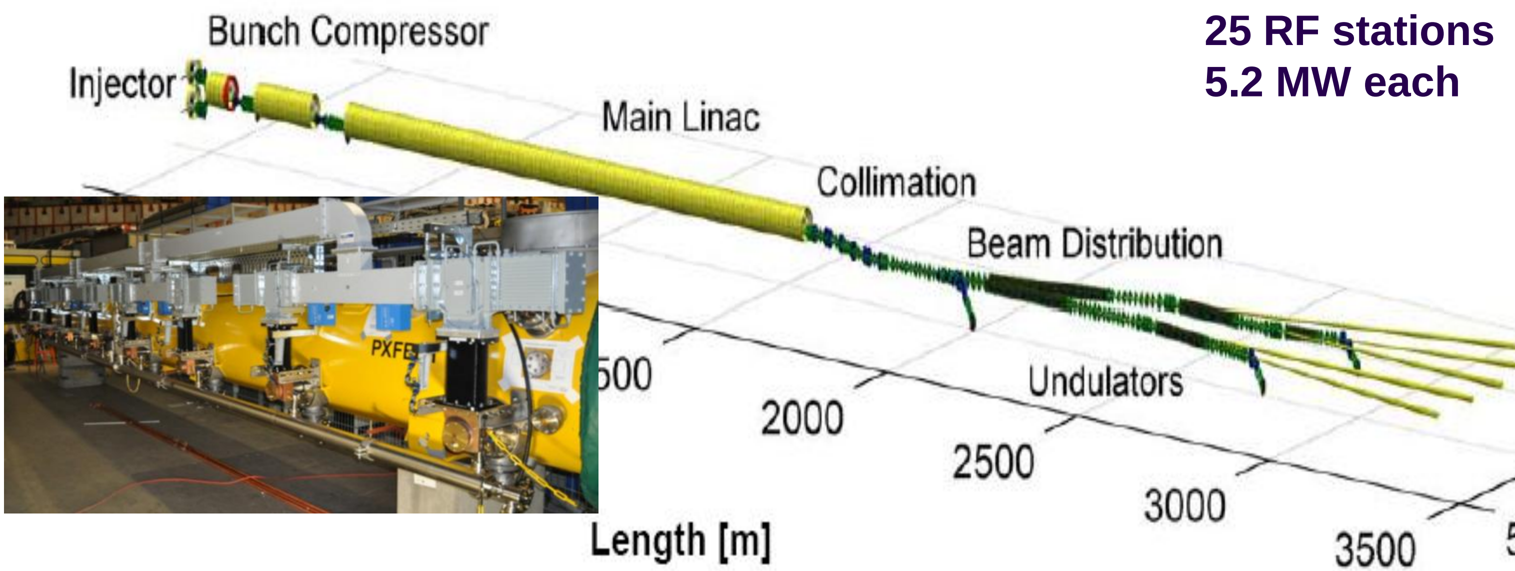
Accelerator Complex

100 accelerator modules

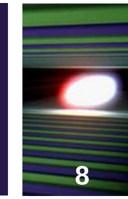


800 accelerating cavities
1.3 GHz / 23.6 MV/m

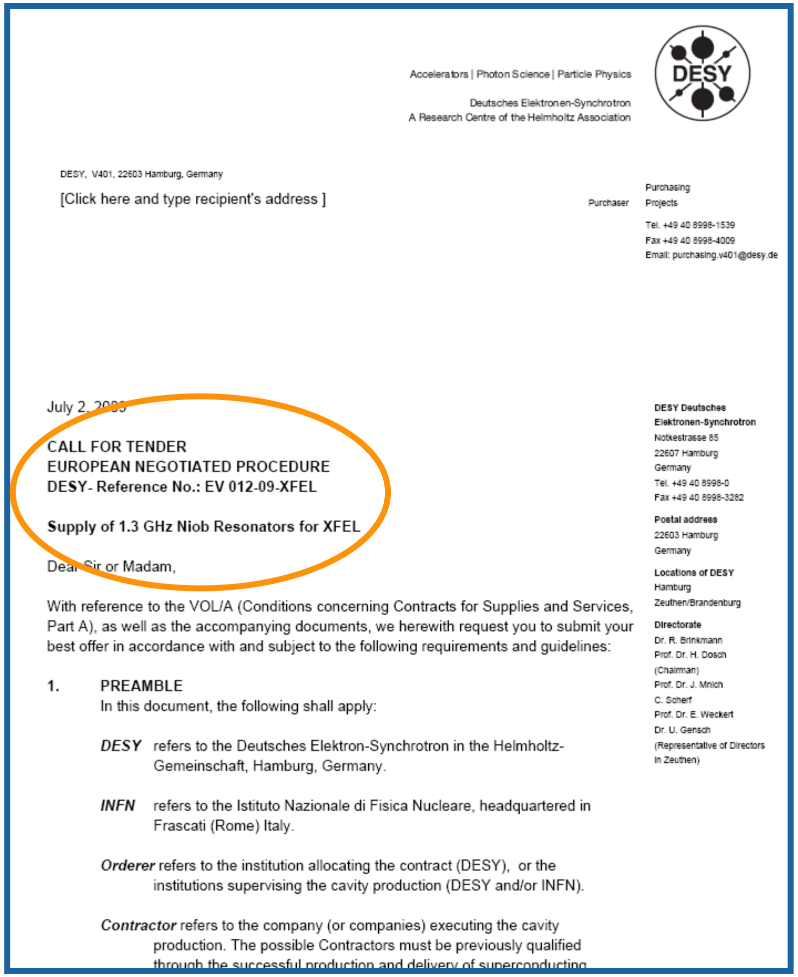
25 RF stations
5.2 MW each



European XFEL



Cavity production



Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

DESY

DESY, V401, 22603 Hamburg, Germany

[Click here and type recipient's address]

Purchaser Purchasing Projects

Tel. +49 40 8998-1539
Fax +49 40 8998-4009
Email: purchasing.v401@desy.de

July 2, 2009

CALL FOR TENDER
EUROPEAN NEGOTIATED PROCEDURE
DESY- Reference No.: EV 012-09-XFEL

Supply of 1.3 GHz Niob Resonators for XFEL

Dear Sir or Madam,

With reference to the VOL/A (Conditions concerning Contracts for Supplies and Services, Part A), as well as the accompanying documents, we herewith request you to submit your best offer in accordance with and subject to the following requirements and guidelines:

1. PREAMBLE
In this document, the following shall apply:

DESY refers to the Deutsches Elektron-Synchrotron in the Helmholtz-Gemeinschaft, Hamburg, Germany.

INFN refers to the Istituto Nazionale di Fisica Nucleare, headquartered in Frascati (Rome) Italy.

Orderer refers to the institution allocating the contract (DESY), or the institutions supervising the cavity production (DESY and/or INFN).

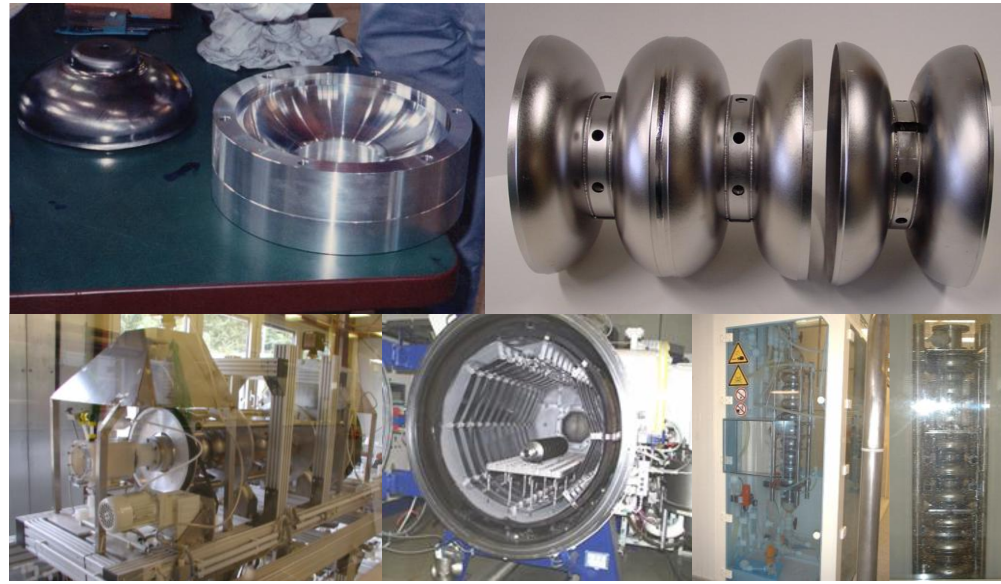
Contractor refers to the company (or companies) executing the cavity production. The possible Contractors must be previously qualified through the successful production and delivery of superconducting

DESY Deutsches Elektronen-Synchrotron
Notkestrasse 85
22607 Hamburg
Germany
Tel. +49 40 8998-0
Fax +49 40 8998-3282

Postal address
22603 Hamburg
Germany

Locations of DESY
Hamburg
Zeuthen/Brandenburg

Directorate
Dr. R. Brinkmann
Prof. Dr. H. Dosch (Chairman)
Prof. Dr. J. Mnich
C. Scherf
Prof. Dr. E. Weckert
Dr. U. Gensch (Representative of Directors in Zeuthen)



- Cavity **Call for Tender was published** on July 2nd, 2009.
- **Production and preparation** in industry.
- Contracts to be allocated by DESY and supervision of cavity production by DESY/INFN.
- Cost much higher than planned
- **Contracts are awarded**

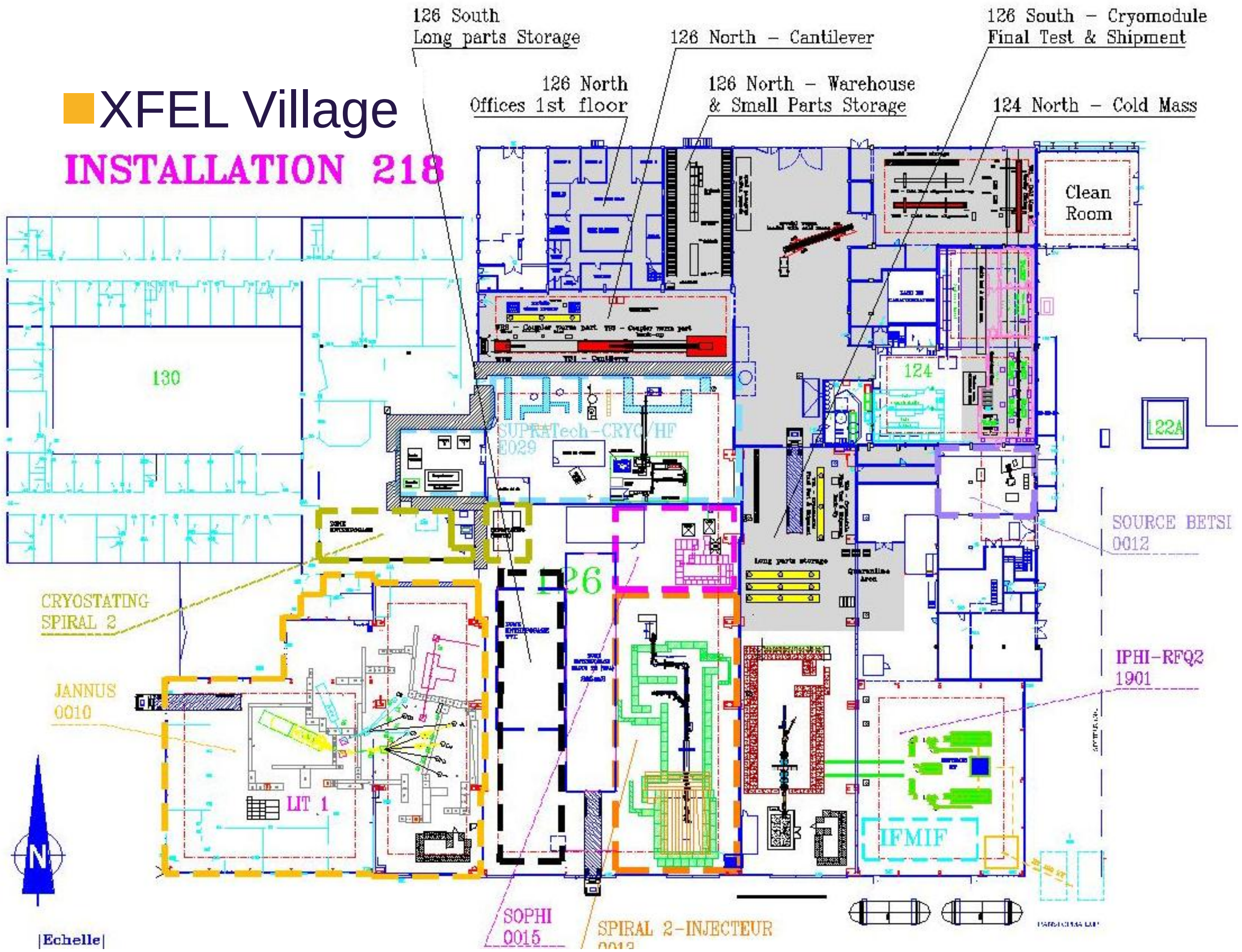
Cavity String & Module Assembly

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.

CEA (IRFU), CIEMAT, DESY, INFN-Milano, LAL Orsay, Swierk take the responsibility for the cold linac.

Infrastructure for Module Assembly

- XFEL Village



- Major part of the civil engineering and general equipments was done; big assembly tools ordered and to be delivered.

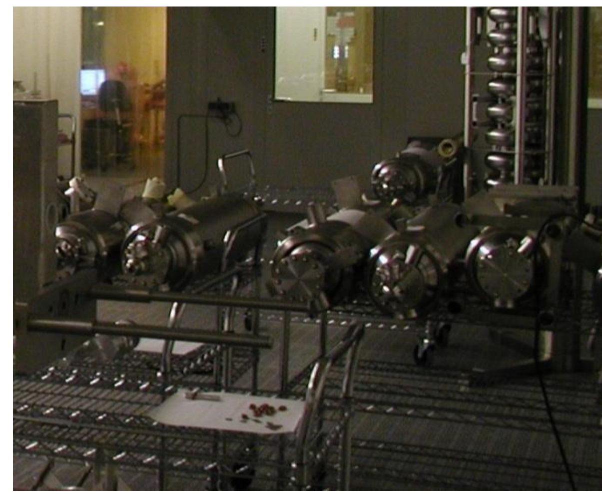
XFEL Accelerator Module Prototypes

Call for tender
European XFEL cold masses
in preparation

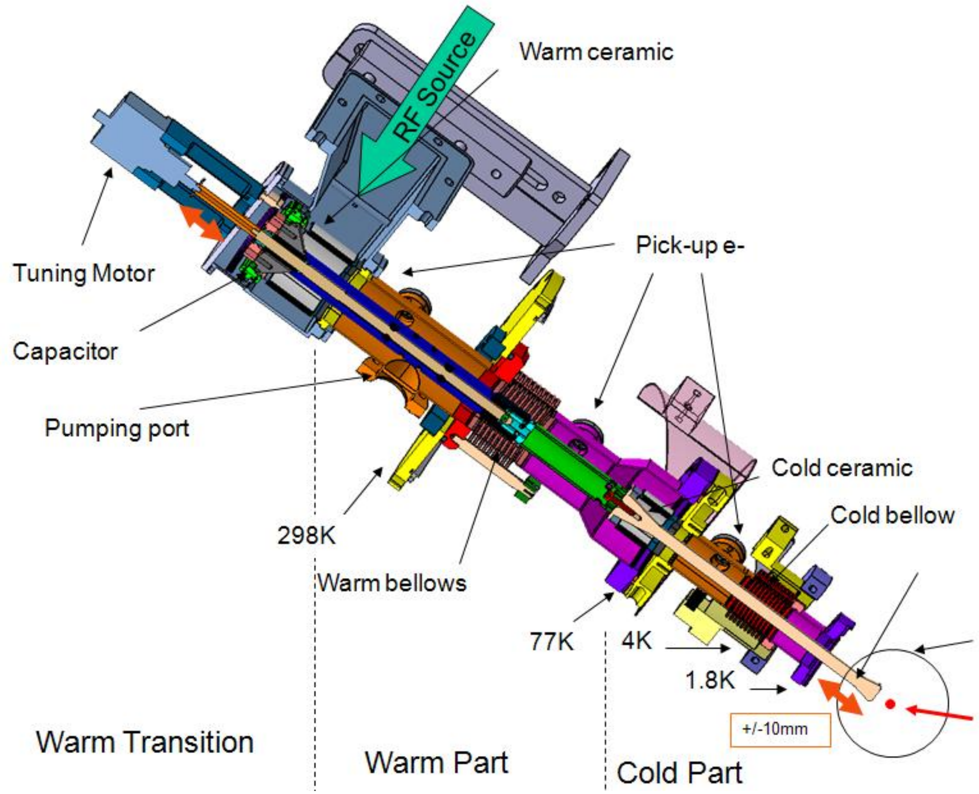
Institute of High Energy Physics
Chinese Academy of Sciences

duro felguera, s.a.

THALES



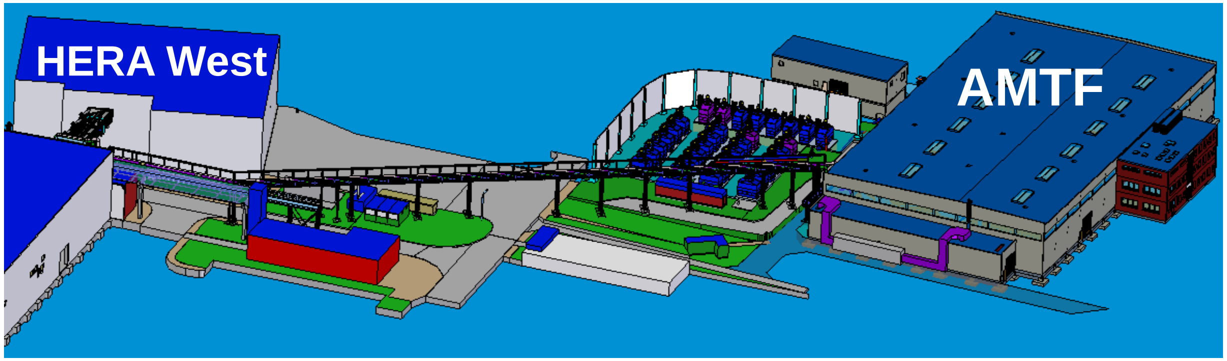
XFEL RF Power Coupler



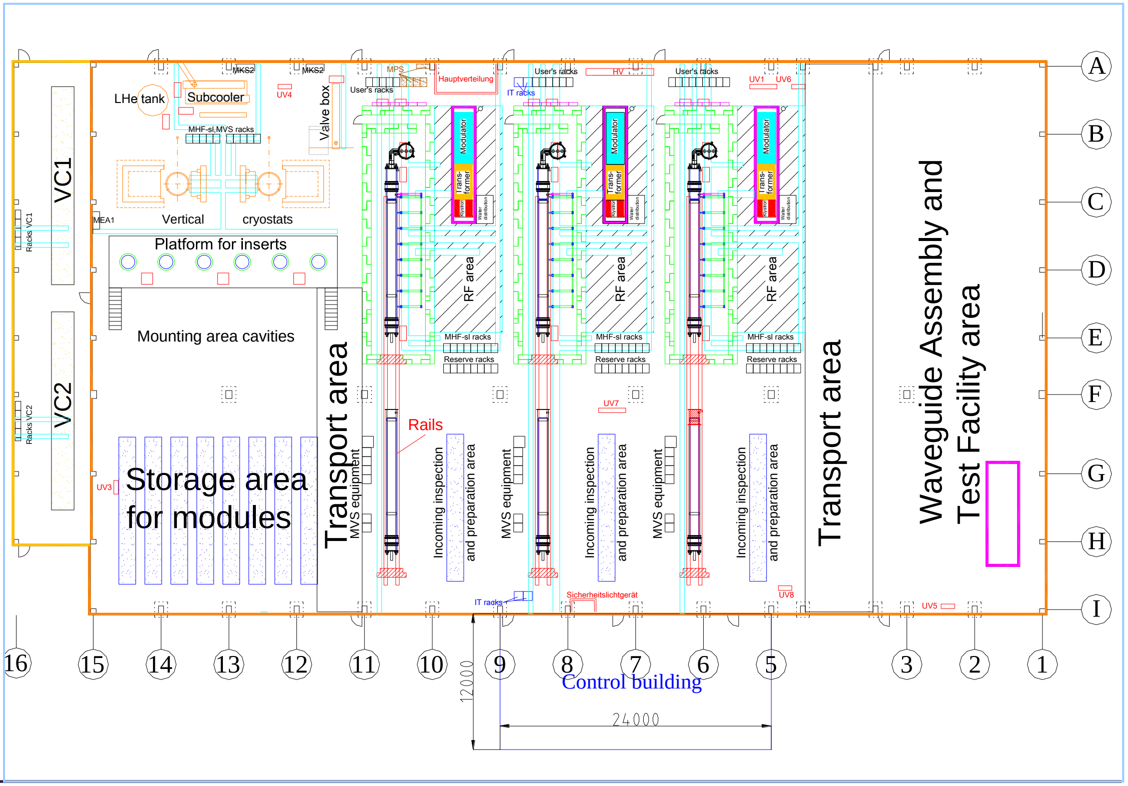
- *TTF3 coupler type*

- **LAL Orsay** has taken over the responsibility for the XFEL RF power **coupler production**.
- **Conditioning** of the couplers will take place at LAL Orsay.
- The **coupler interlock** system was developed and will be **contributed by DESY.**

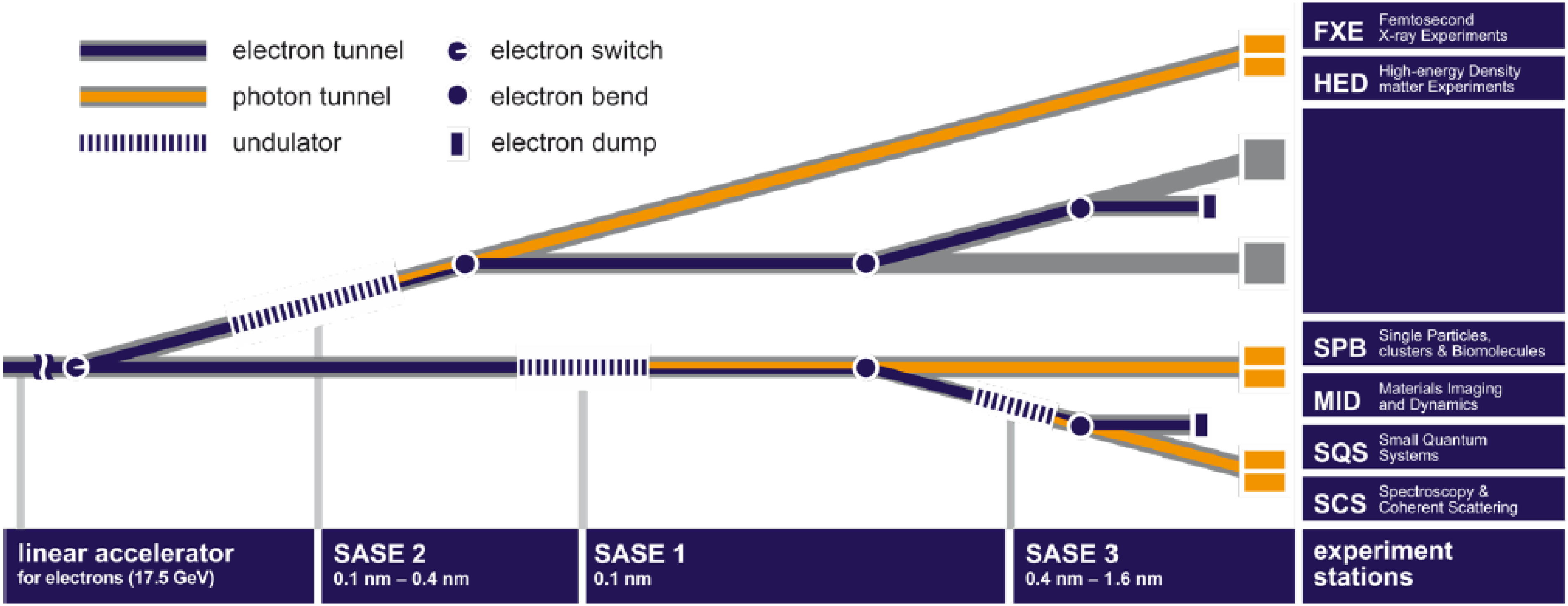
Accelerator Module Test Facility (AMTF) Including Single Cavity Test Facility



- AMTF Civil Construction finished
- Infrastructure installation started
- First **cavity tests** spring 2011
- Commissioning of **module test** facility foreseen for 4/2011
- Major cryogenic contributions from Russia and Poland
- **Waveguide assembly** and test



FEL beamlines & instruments



- civil construction (tunnels/halls) foresees 5 undulator locations
- straight sections for undulators sufficiently long for options
  - ➔ **2-colors and *afterburners***
  - ➔ **self-seeding or laser-seeding or laser-e-beam manipulation**

Ref: TDR 2006/Startup

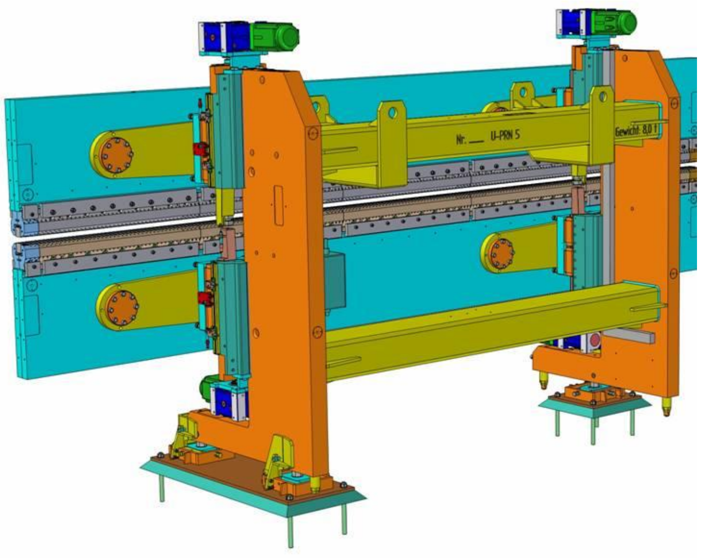
Hard x-ray sources & beam properties

SASE 1

- hybrid magnets; gap tunable (min. 10 mm)
- 165 m magnetic length & 140 m optional
- λ_{und} 35.6 mm ⇒ ~4600 periods
- optimized for 12.4 keV (K=3.3)

SASE 2

- hybrid magnets; gap tunable (min. 10 mm)
- 210 m magnetic length & 100 m optional
- λ_{und} 48 mm ⇒ ~4400 periods
- gap-tunable for 3.1 to 12.4 keV (K=2.8 – 6.1)



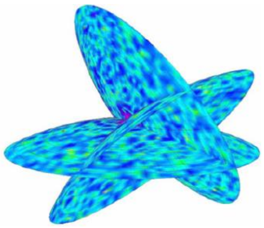
Parameter	Unit	SASE 1	SASE 2	
Photon energy	keV	12.4	12.4	3.1
Pulse energy	mJ	2	2	8
Bandwidth	%	0.08	0.08	0.18
Divergence	µrad	1.0	0.9	3.4
Source size	µm	70	85	55
Polarization		hor. lin.	horizontal linear	

Ref: TDR 2006/Startup

Hard x-ray scientific instruments

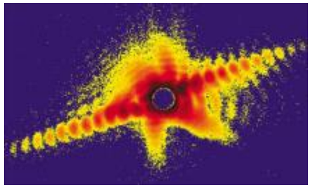
Single Particles, Clusters, and Biomolecules (SPB)

- Structure of atomic clusters, bio-molecules, virus particles, cells
- Time-resolved diffraction from gas molecules
- Techniques: CXI, particle injection; 3-12 keV



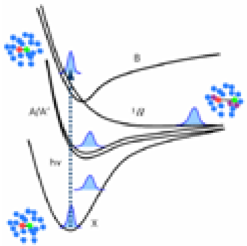
Materials Imaging & Dynamics (MID)

- Structure & dynamics of nanoscale objects
- Techniques: CXI, Bragg-diff., XPCS (SAXS, large Q); 5-25 keV



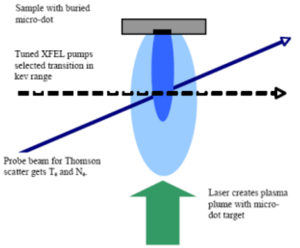
Femtosecond X-ray Experiments (FXE)

- Time-resolved atomic structure of liquid & hard matter
- Techniques: Diffraction, XAS, IXS; solids & liquids; 5-18 keV



High Energy Density Matter (HED)

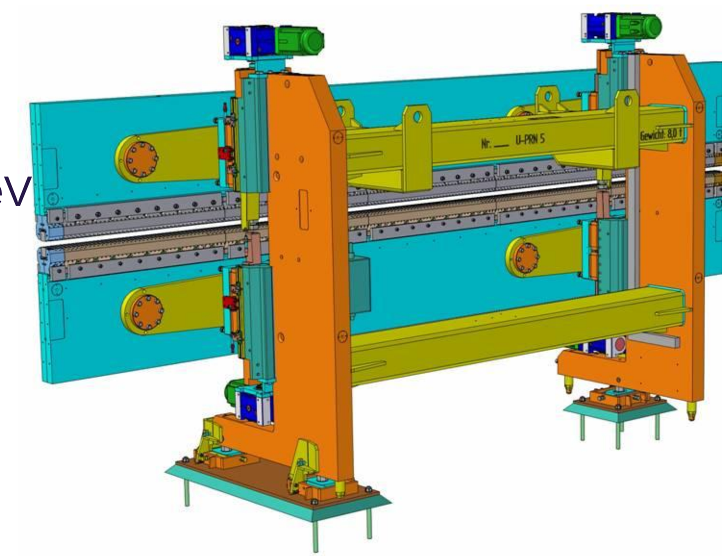
- Structure & dynamics of matter under extr. conditions
- Techniques: Scattering, emission; 3-18 keV



Soft x-ray source & beam properties

SASE 3

- hybrid magnets; gap tunable (min. 10 mm)
- 105 m magnetic length & 60 m optional
- λ_{und} 65 mm $\Rightarrow$ ~1600 periods
- gap-tunable for 0.8 to 3.1 keV and 0.25 to 1.0 keV (K=3.3 – 8.6)



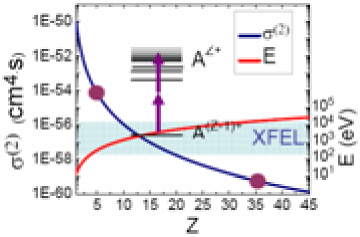
Parameter	Unit	17.5 GeV		10 GeV	
Photon energy	keV	3.1	0.8	1.0	0.25
Pulse energy	mJ	8	13	~10	15
Bandwidth	%	0.2	0.3	~0.3	0.65
Divergence	µrad	3.4	11.4	~10	18
Source size	µm	60	70	~70	90
Polarization		horizontal linear		horizontal linear	

Ref: TDR 2006/Startup

Soft x-ray scientific instruments

Small Quantum Systems (SQS)

- Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena
- Techniques: electron & ion spec., emission; 0.27-3 keV



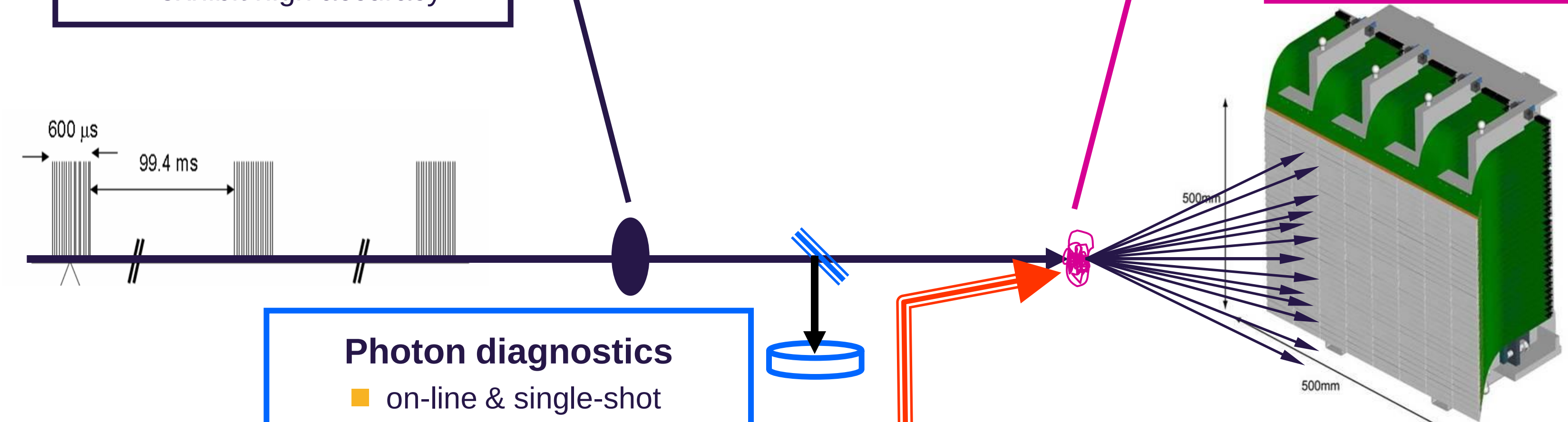
Soft x-ray Spectrocopy & Coherent Scattering (SCS)

- Structure & dynamics of nano-objects and magnetic structures
- Structure of non-reproducible biological objects
- Techniques: electron spec., XAS, IXS, CXI; 0.27-2 keV

High repetition rate challenge

X-ray optics
- withstand repetition rate
- exhibit high accuracy

Sample delivery
- match repetition rate
- positioning

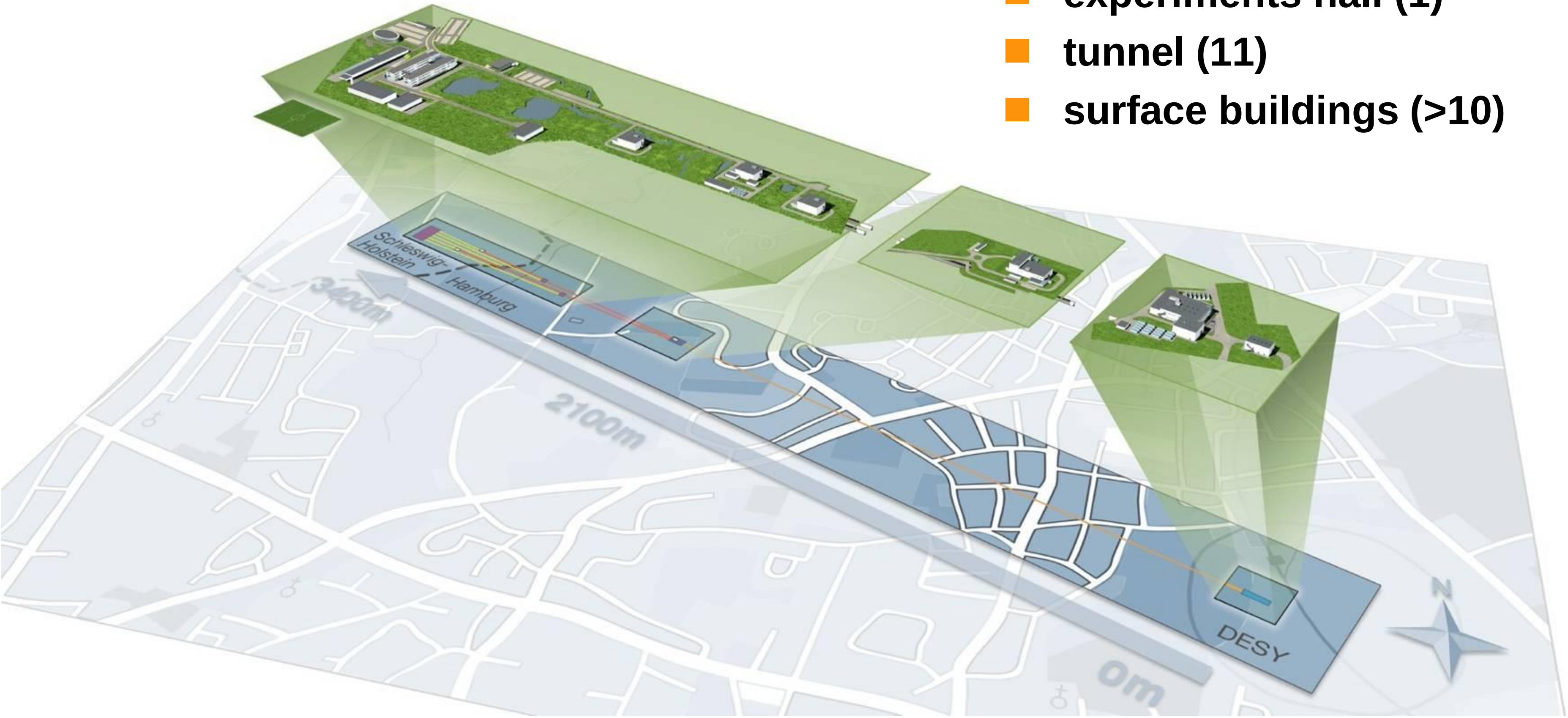


Photon diagnostics
- on-line & single-shot
- match repetition rate

Optical laser
- match repetition rate
- provide ~mJ excitation energy

Detectors
- match frame rate
- large data amounts

Civil construction



- shaft buildings (5)
- experiments hall (1)
- tunnel (11)
- surface buildings (>10)

DESY-Bahrenfeld - Baugrube Injektorkomplex

17. Mai 2009

Construction site webcams 24. August 2010

European XFEL

Tunnelvortrieb – Juli 2010 bis Sommer 2012

Herstellung der Tunnel im Vortriebsverfahren

- Schenefeld ⇛ Osdorfer Born
- Osdorfer Born ⇛ DESY-Bahrenfeld (Juni 2011)
- „Fächer“ aus 5 Tunneln unter Schenefelder Gelände

5777 m Tunnel, Tiefe: 6 m – 38 m

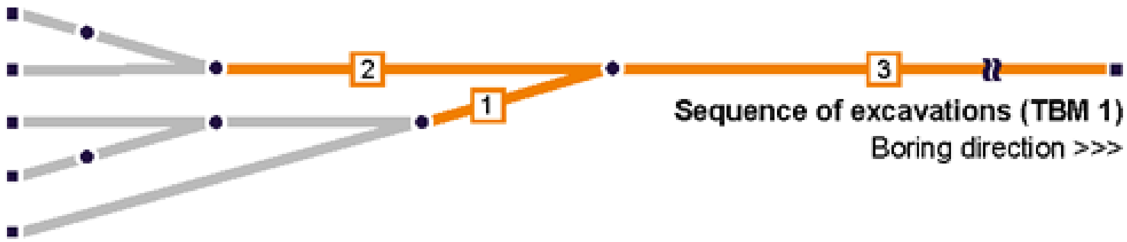
2 Tunnelbohrmaschinen: TBM 1 (5,30 m Ø) und TBM 2 (4,60 m Ø)

- Hydromixschild für heterogene Baugründe
- „TULA“ – TVM(5,30 m): 3 Abschnitte, 1 Umsetzung, 1 Durchfahrt
  Durchmesser: 5,30 m (Tunnel innen), 6,17 m (TBM außen)
- TVM(4,50 m): 8 Abschnitte, 4 Umsetzungen, 3 Durchfahrten
  Durchmesser: 4,60 m (Tunnel innen), 5,48 m (TBM außen)

1 zentrale Separieranlage

European XFEL

Tunnel boring sequence



Sequence of excavations (TBM 1)
Boring direction >>>

1 – XTD1 ... 480 m
2 – XTD2 ... 594 m
3 – XTL .... 2010 m

TBM 1

May 2010
Arrival of TBM 1 at construction site Schenefeld

July 2010
Starting excavation of tunnel sections between Schenefeld and Osdorfer Born (XDT1, XTD2)

Beginning of 2011
Starting excavation of main tunnel between Osdorfer Born and DESY-Bahrenfeld (XTL)

Summer 2011
Arrival at DESY-Bahrenfeld, disassembly

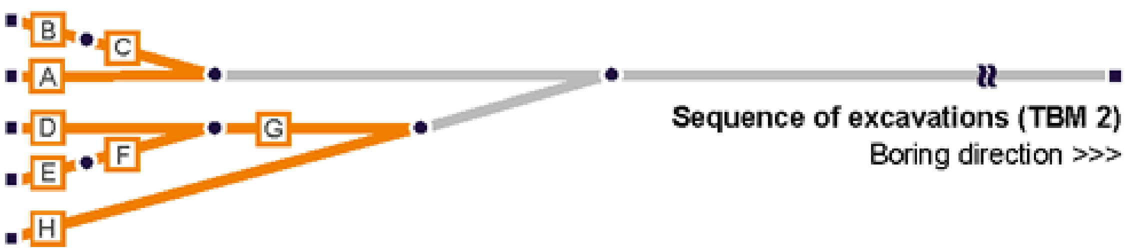
2010 | 2011 | 2012

TBM 2

Fall 2010
Arrival of TBM 2 at site Schenefeld

Beginning of 2011
Starting excavation (XTD9, XTD10, XTD4, ...)

Summer 2012
Arrival at final shaft, disassembly

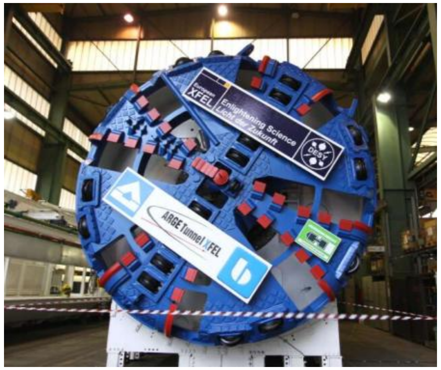


Sequence of excavations (TBM 2)
Boring direction >>>

A – XTD9 ... 544 m
B – XTD10 . 220 m
C – XTD4 ... 300 m
D – XTD8 ... 361 m
E – XTD7 ... 141 m
F – XTD5 ... 200 m
G – XTD3 ... 267 m
H – XTD6 ... 660 m

European XFEL

Tunnelbohrmaschine S-544 – Im Werk



Tunnelbohrmaschine S-544

Transport nach Schenefeld am 19. Mai 2010

„TULA“ – Tunnel- und Bohrertaufe

Tunnelfest am Startschacht am 30. Juni 2010

„TULA” im Einsatz nach ca. 100 m

Blick auf das Ende des Nachläufers und die Tunnelbahn am 27. Juli 2010

TULA arrives at XS1 (first tunnel completed)

Main building Schenefeld – 2014

Architekturbeispiel

Office and Lab building with lecture hall, seminar rooms, library, etc.

from 2014/2015: user operation of beam lines & instruments; research ~300 – 350 Personen

on top of underground experiment hall

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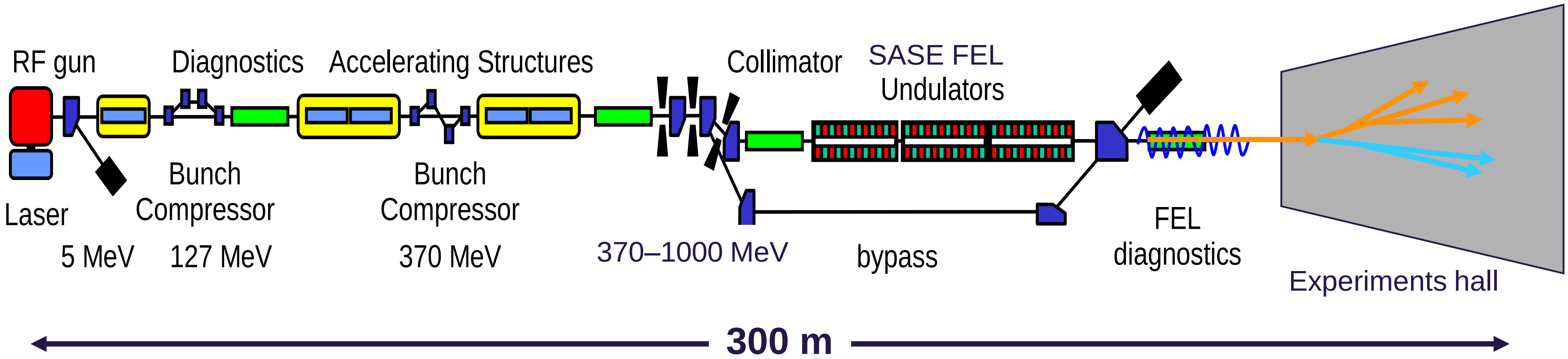
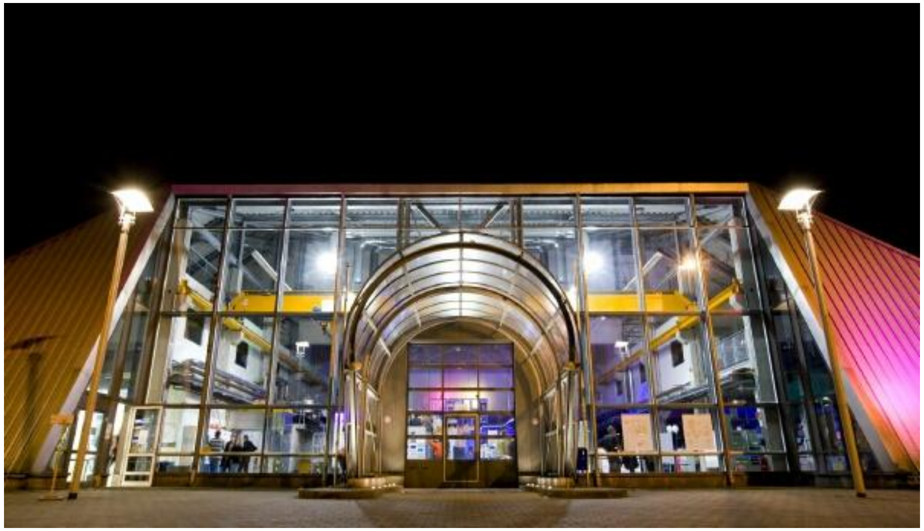
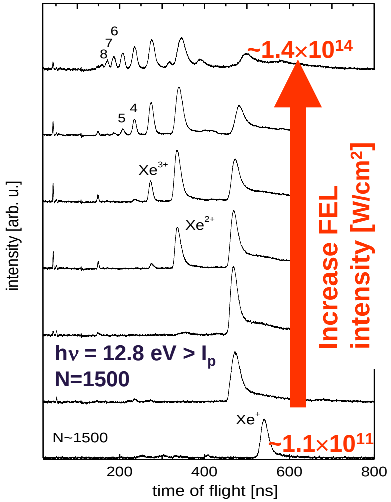
First short-wavelength FEL user facility : FLASH



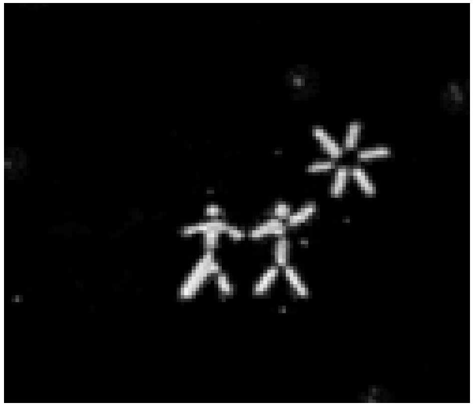


2001



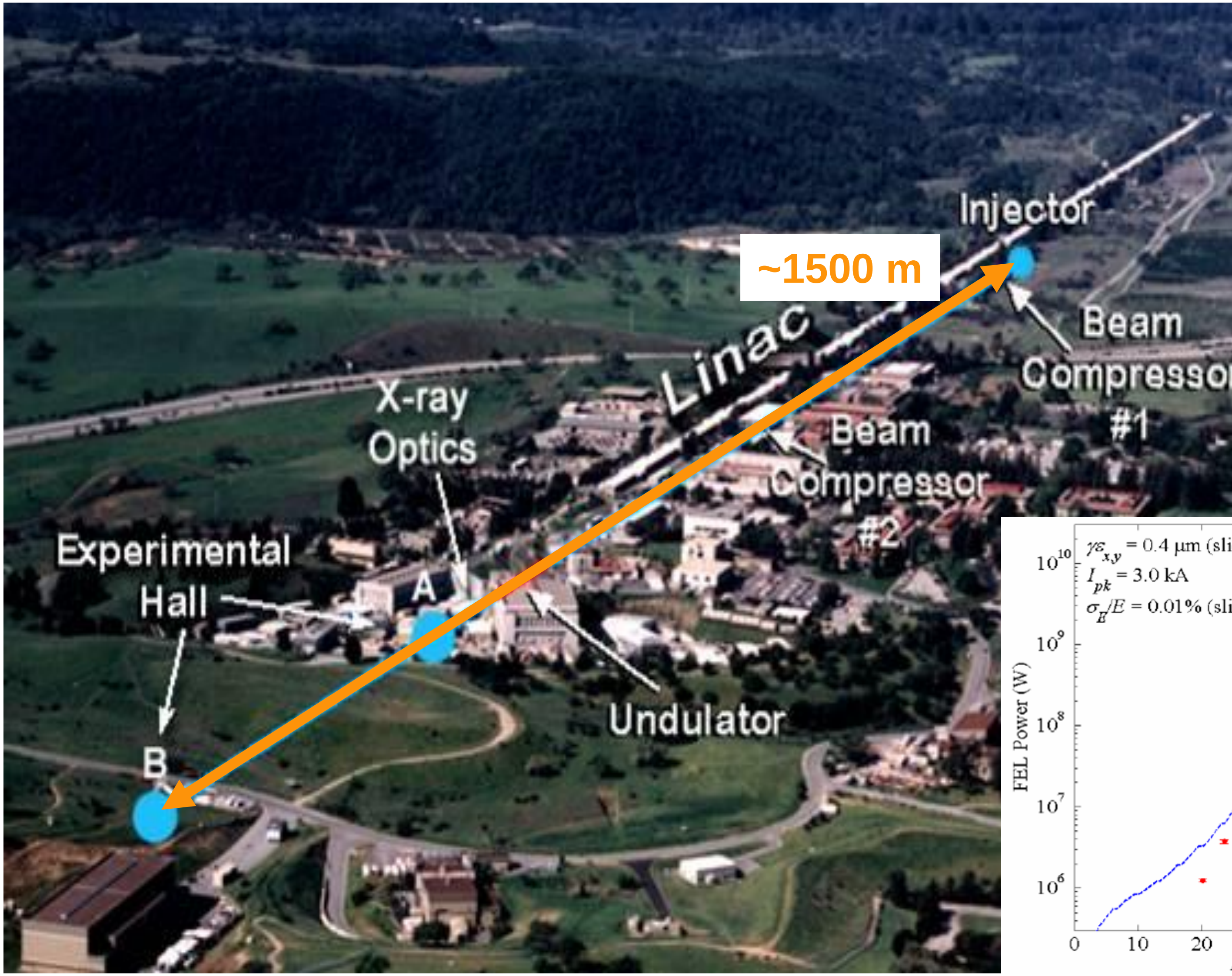
H. Wabnitz et al., Nature 420, 482 (2002)

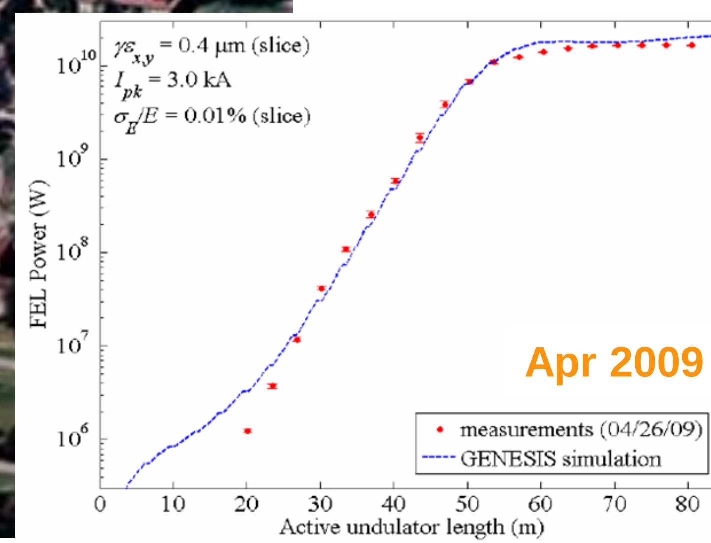
2005



H. Chapman et al., Nature Phys. 2, 839 (2006)

First hard X-ray facility: LCLS



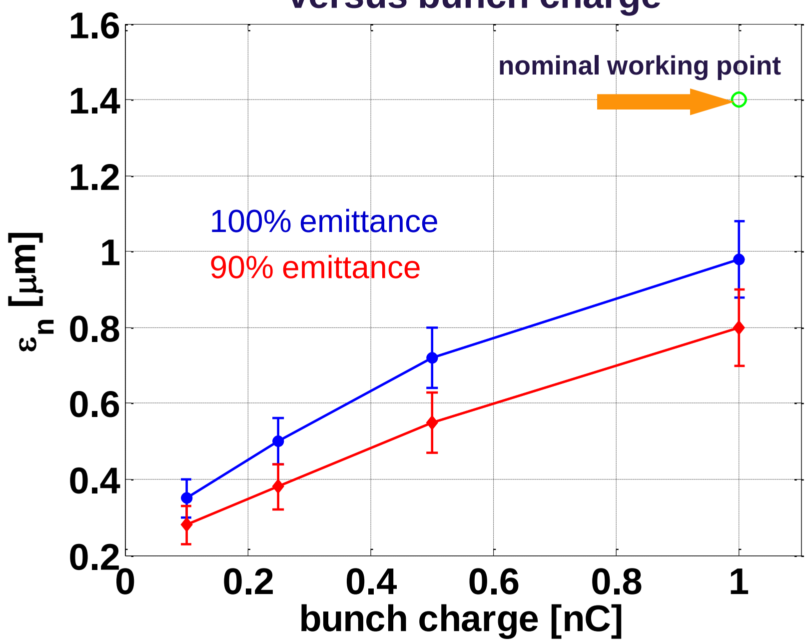


PITZ Results

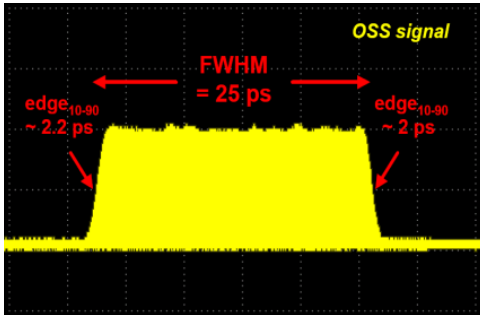
Photo-Injector Test Stand in DESY-Zeuthen

- Photo injector R&D
- Test and pre-conditioning of FLASH and XFEL photo injectors
- Collaborations with MBI (lasers), Rossendorf, HZB & others (cw-gun)

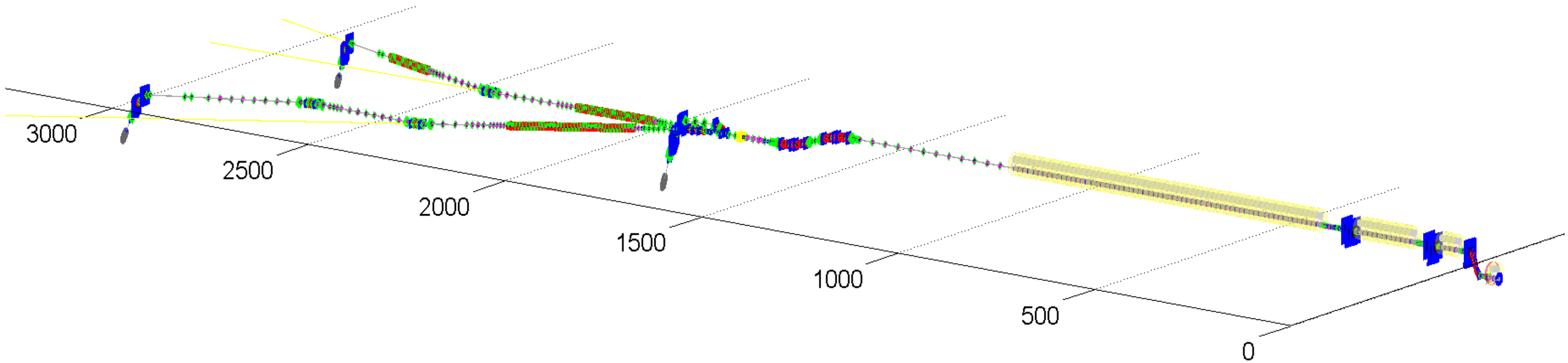
Measured projected emittance versus bunch charge



Flat-Top laser with sharp edges



Under study: New parameter set accelerator



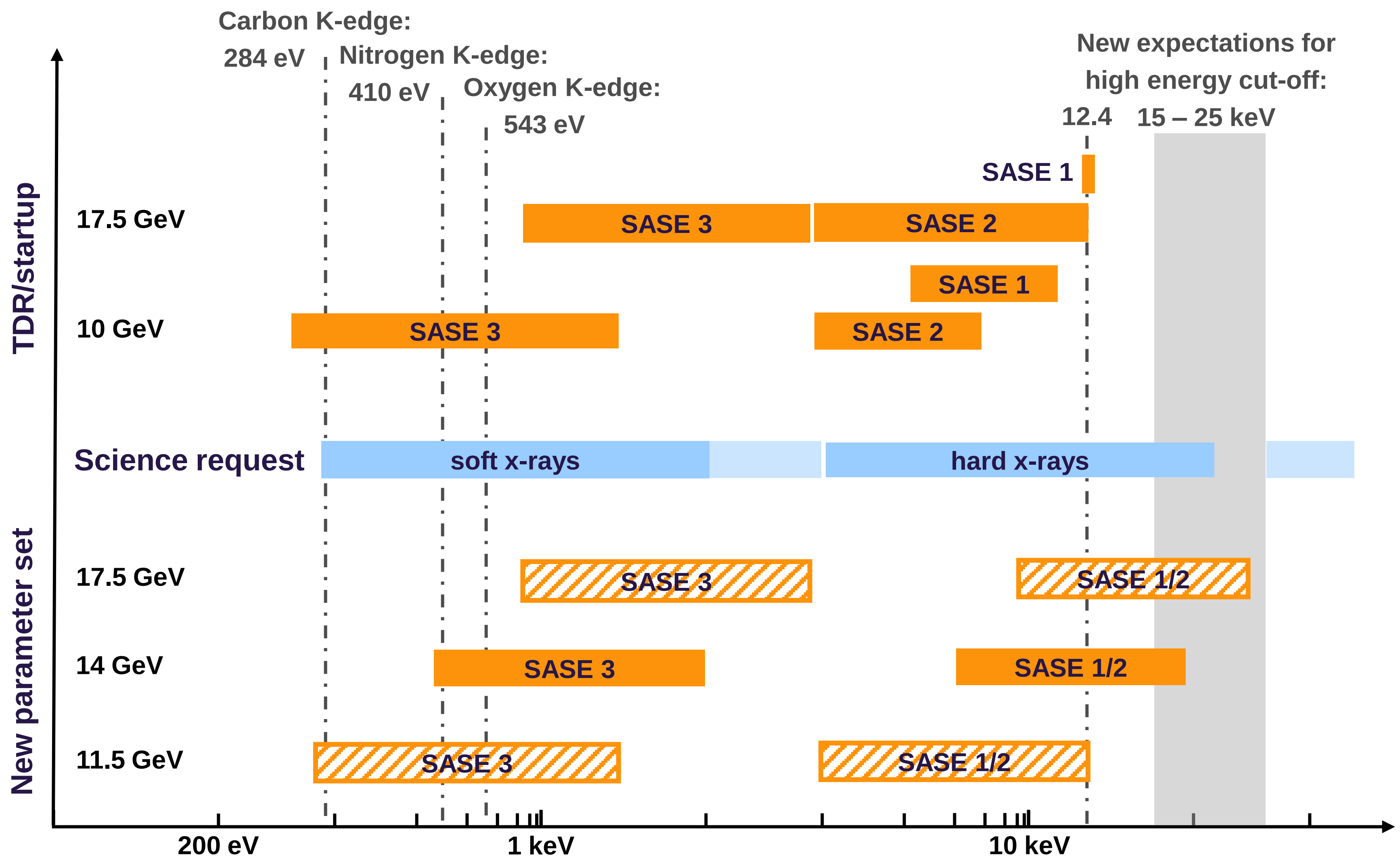
	Unit	TDR/startup	New Set
Electron Energy for 0.1 nm	GeV	17.5	14
Bunch charge	nC	1	0.02 – 1
Peak current	kA	5	2 - 5
Slice emittance	mm mrad	< 1.4	0.4 - 1.0
Slice energy spread	MeV	1.5	4 - 2
Shortest SASE wavelength	Nm	0.1	0.05
Pulse repetition rate	Hz	10	10
Bunch repetition rate	MHz	5	4.5
Bunches per pulse		3000	2700

Accelerator parameter sets

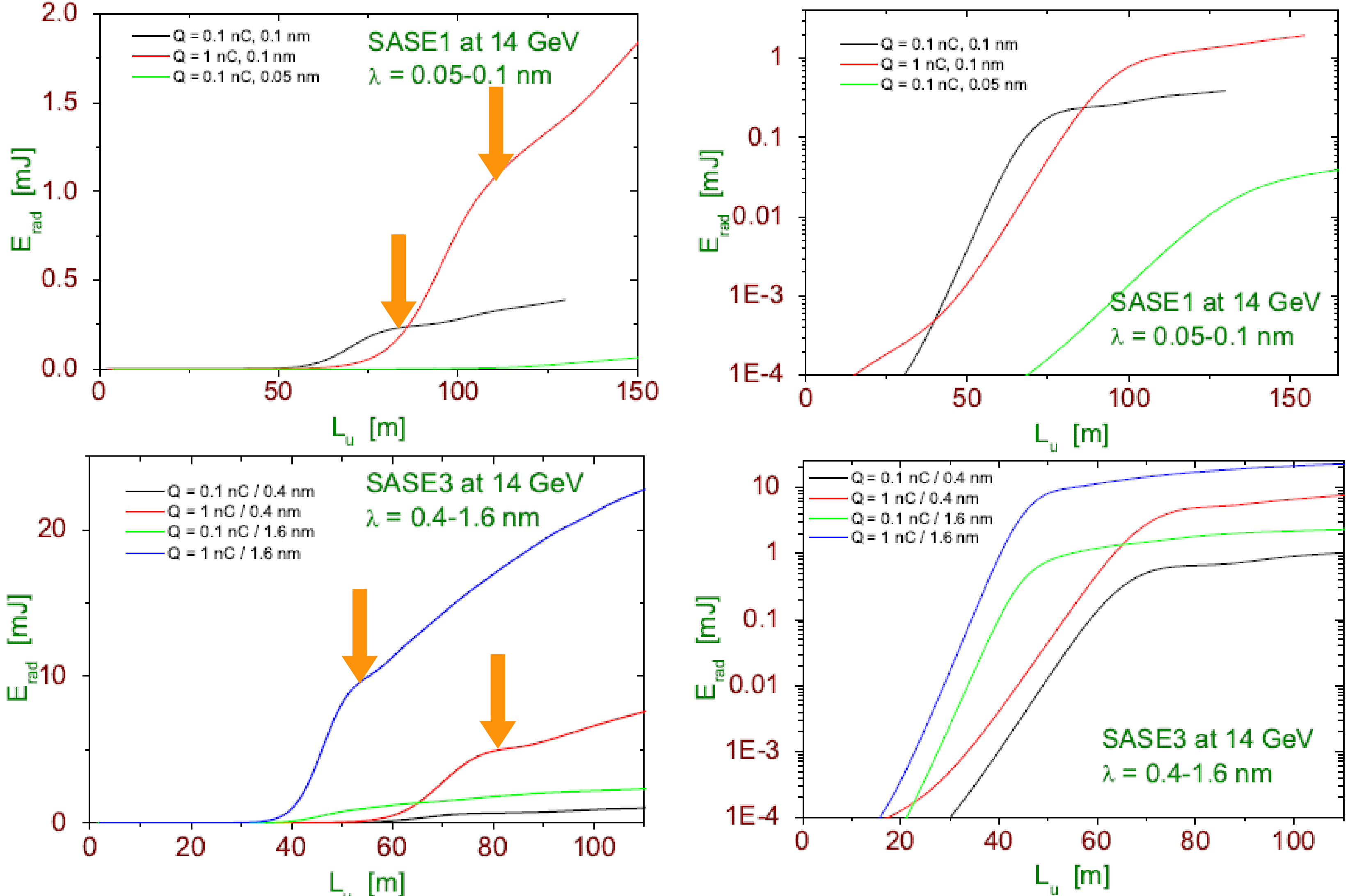
	Charge	nC	1	0.5	0.25	0.1	0.02
Gun	**Peak Current**	**A**	**49.8**	**33.2**	**18.4**	**8.3**	**1.8**
	Slice Emittance	**µm**	**1**	**0.7**	**0.5**	**0.32**	**0.2**
	Slice Energy Spread (LH)	**keV**	**20.0**	**18.2**	**15.3**	**9.8**	**3.6**
Undulator	Peak Current	kA	5.0	4.0	3.0	2.5	2.0
	Slice Emittance	µm	1.05	0.77	0.60	0.42	0.40
	Slice Energy Spread	MeV	2.0	2.2	2.5	2.9	4.1

- Emittance and energy spread numbers based on best present knowledge and leave room for eventual improvement
- Complete accelerator (diagnostics, LLRF, …) has been designed for 1 nC charge, impact of lower charges (signal to noise, stability, …) on accelerator systems under study

Photon energy ranges

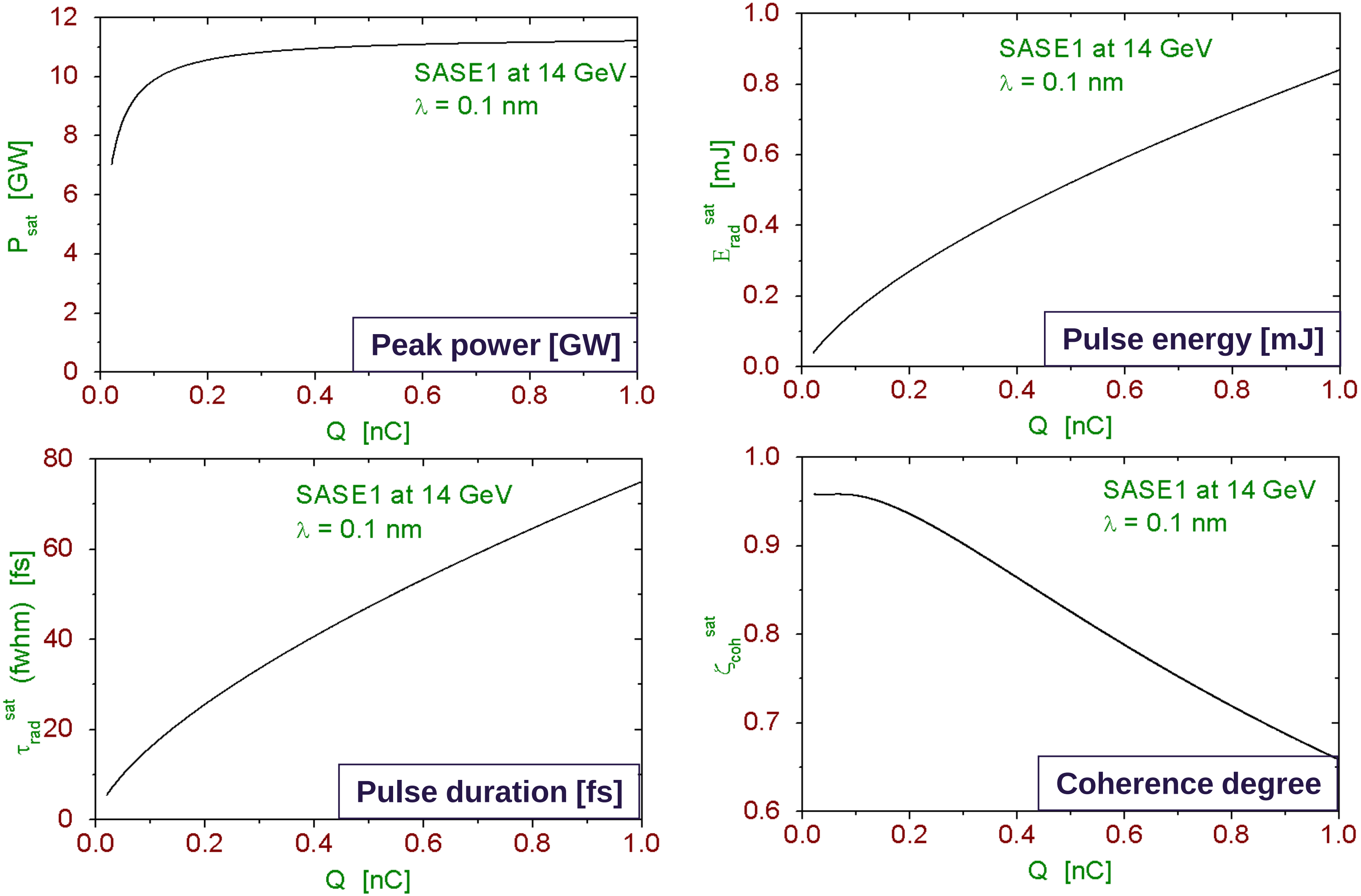


FEL performance (I) – pulse energy



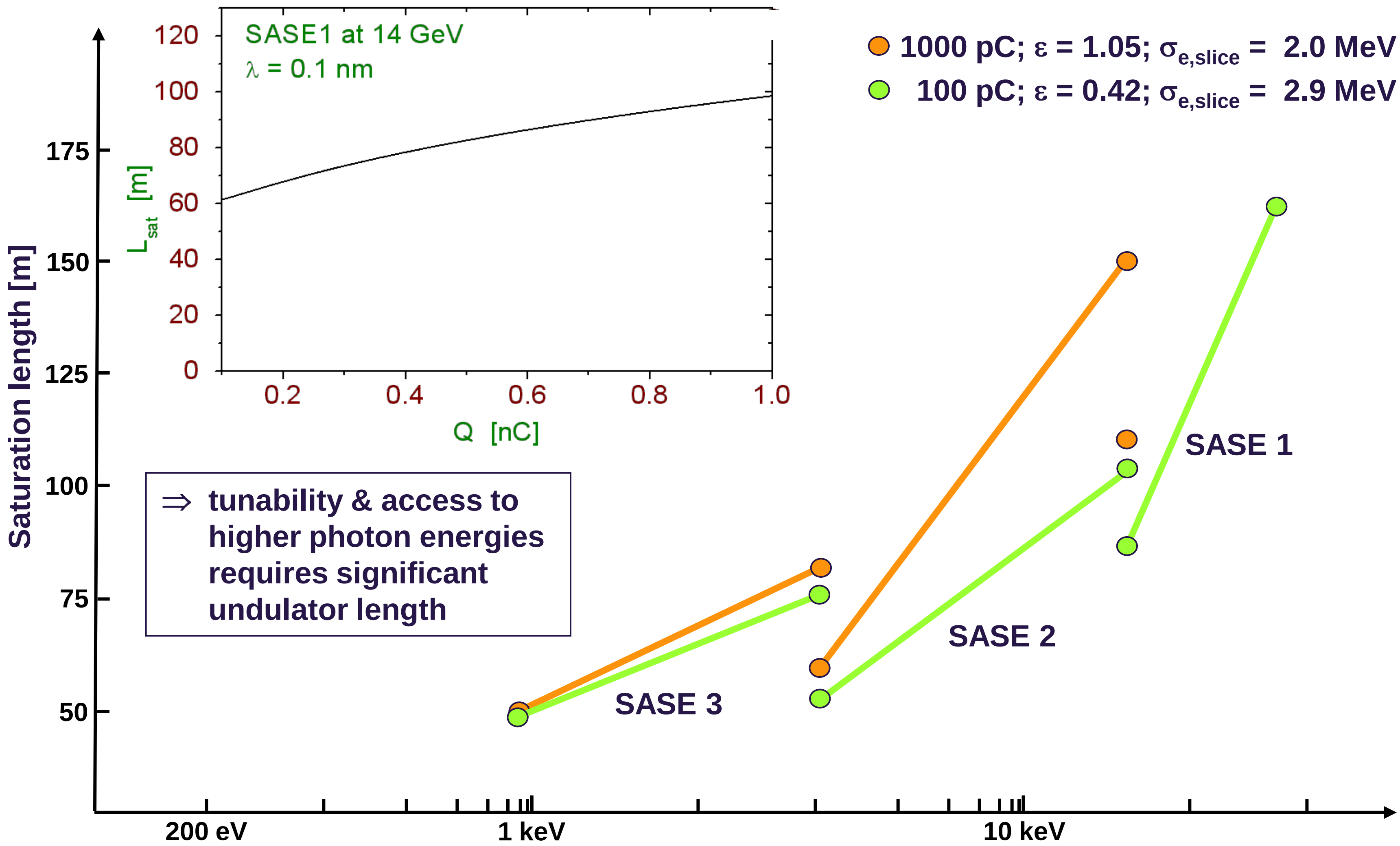
all data E. Schneidmiller, M. Yurkov

FEL performance (II) – bunch charge dependence



all data E. Schneidmiller, M. Yurkov

Saturation lengths



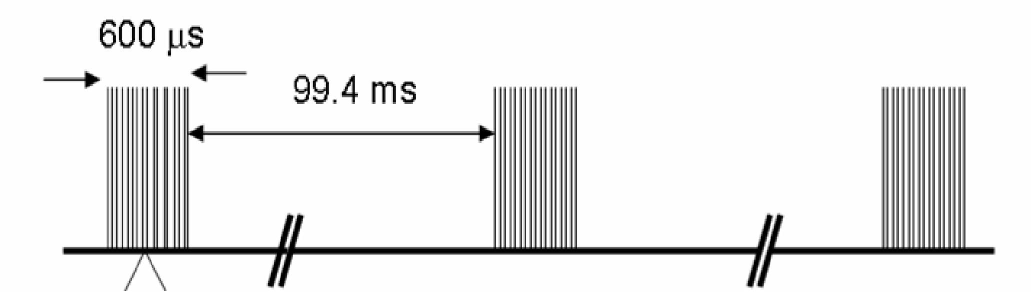
⇒ tunability & access to higher photon energies requires significant undulator length

all data E. Schneidmiller, M. Yurkov

Electron beam bunch pattern

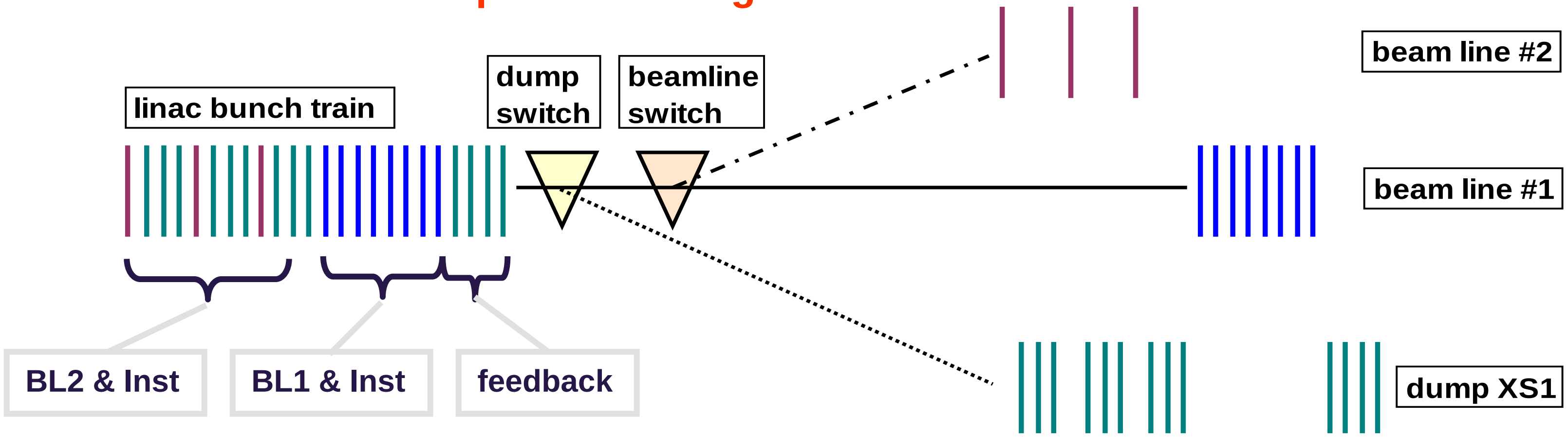
Electron bunch delivery

- due to pulsed RF



Advantages for user operation

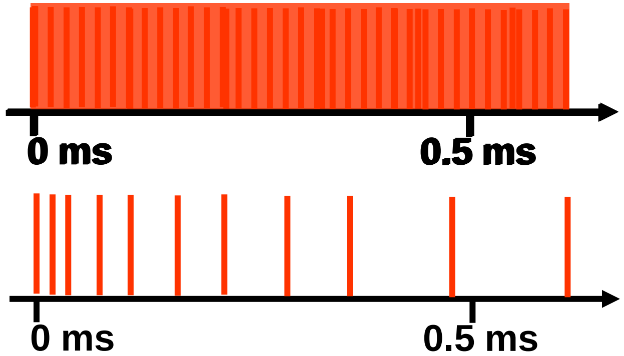
- enables stabilization by intra-bunch feedback
- higher flexibility of operation for simultaneous user experiments
- large number of delivered FEL pulses
  - → **Combination of peak & average brilliance**



User requested bunch delivery

European XFEL accelerator & beam delivery enables flexible patterns

- operate sc-accelerator in (almost) steady-state mode
- select bunch pattern by fast kicking
- bunch delivery pattern determined by user experiment
  - ➔ **single pulses**
  - ➔ **medium repetition rate (10 – 100 kHz)**
  - ➔ **high repetition rates (1 → 4.5 MHz)**
  - ➔ **special fills**
    - logarithmic distribution
    - shorter distances (~700 ps – 220 ns)



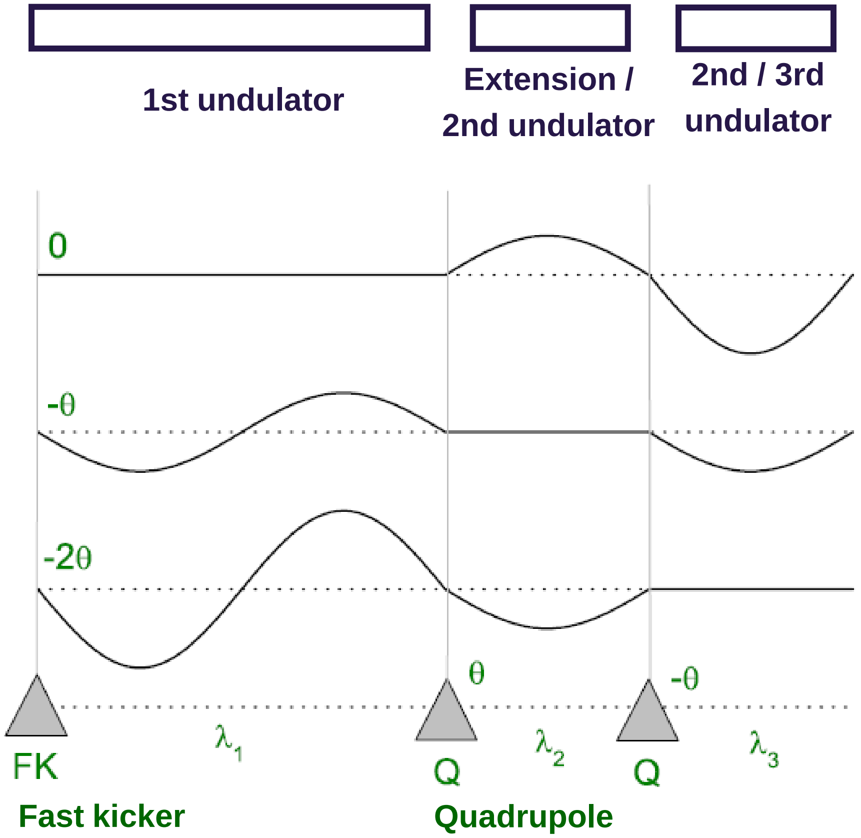
Dedication of bunches to specific FELs

Fresh bunch technique

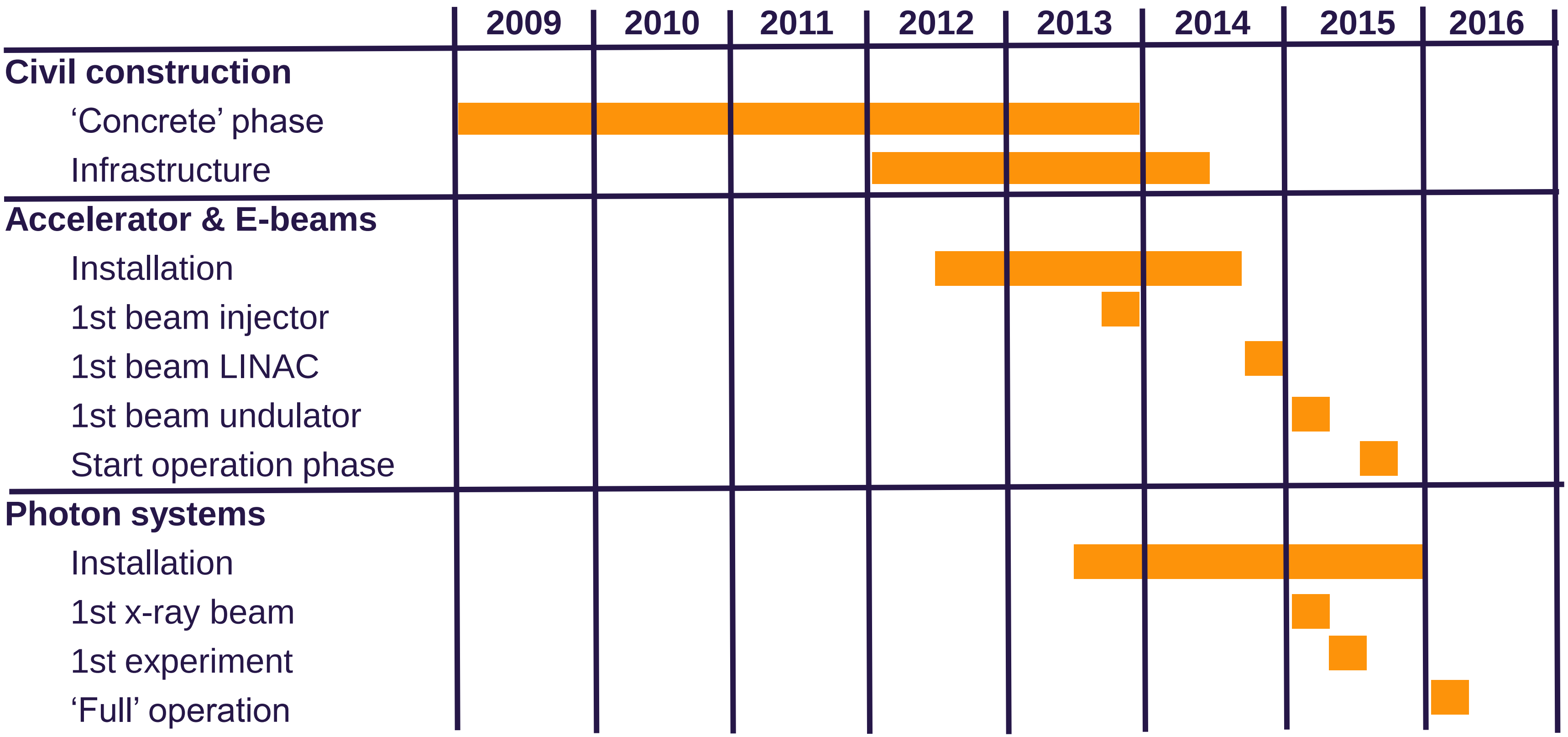
- FEL process spoils energy spread of electron bunch
- surpress FEL process by adding removeable betatron oscillation
- fast kicker for 5 Mhz pattern

- modes for one undulator
  - ➔ **requires L_{und} >> L_{sat}**
  - ➔ **2 photon energies (2-colors)**
  - ➔ **Angular separated beams (*canted*-mode; ~10 µrad)**

- modes for several undulators
  - ➔ **decouple operation**



Timeline European XFEL



Conclusion

European XFEL construction now progresses in all areas. Early experiments are scheduled for 2015.

♦

Civil construction so far goes well and did neither accumulate delays nor large extra-cost. Next step is tendering and awarding of surface buildings.

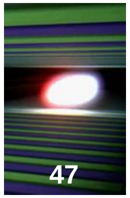
♦

Recent experience LCLS shows great potential for future FEL applications. Bunch charge and variable compression are additional parameters. Users like high stability and fast change of settings. First hard x-ray FEL experiments this September.

♦

Design of European XFEL is currently updated. In contrast to others it will be a multi-user facility from the start. For this purpose several FEL sour-ces and independent x-ray beamlines are built. Bunch delivery system and pulse train operation support specific delivery schemes.

the end



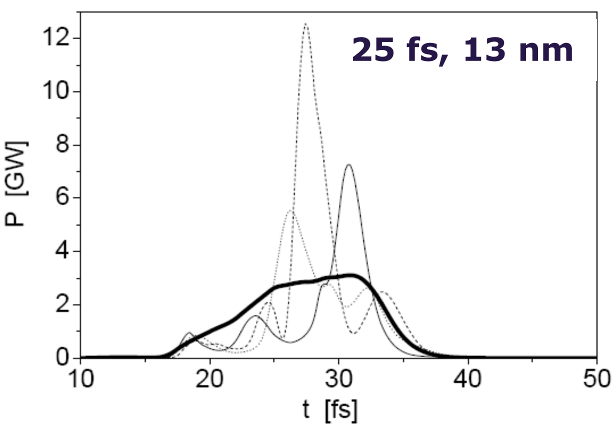
Diffraction limited FEL radiation

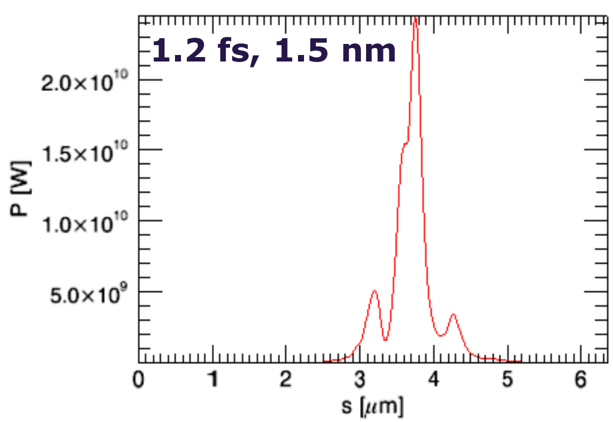
10^{12}(X) – 10^{14}(sX)

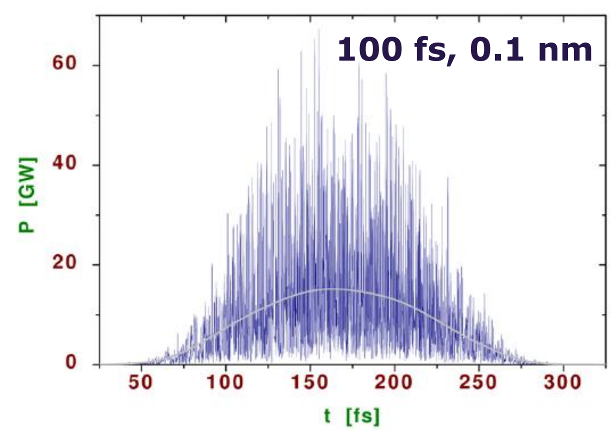
$$\text{Peak brilliance} = \frac{\text{Number of photons}}{\Delta_x \Delta_{x'} \Delta_y \Delta_{y'} \times \text{bandwidth} \times \Delta_t}$$

6×10^{-11}m(X) ~$\lambda/2$

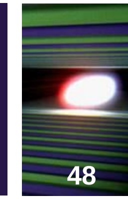
100 fs eV(X) ~25ħ

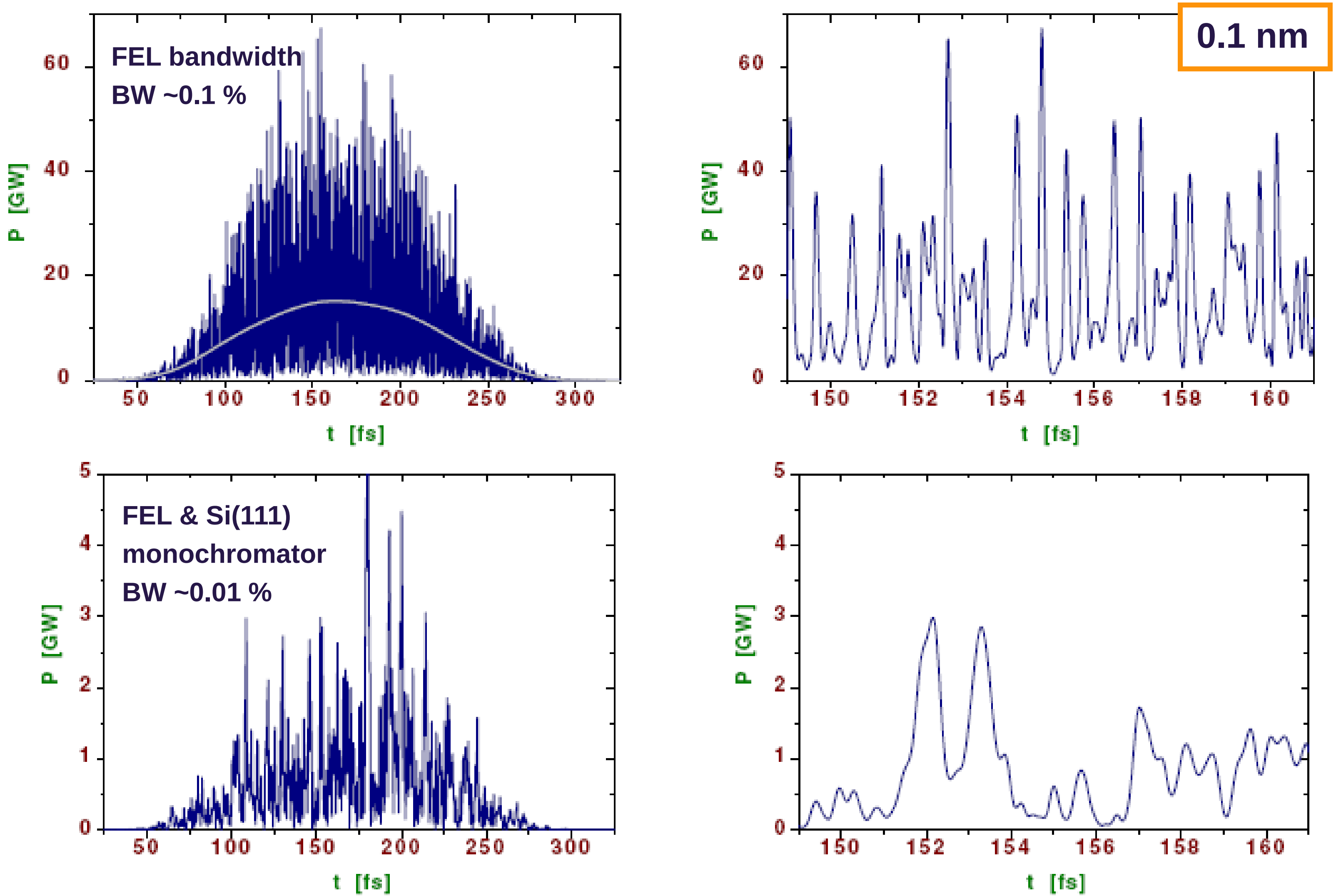






Temporal x-ray beam properties





Simulations performed by E. Saldin, E. Schneidmiller and M. Yurkov

Temporal/longitudinal coherence properties

simplified

$$\tau_c = \frac{1}{2c}\frac{\lambda^2}{\Delta\lambda}$$

more complete

$$g_1(\vec{r},t-t') = \frac{\langle E(\vec{r},t)E^*(\vec{r},t')\rangle}{\left[\langle|E(\vec{r},t)|^2\rangle\langle|E(\vec{r},t')|^2\rangle\right]^{1/2}}$$

quasi-stationary →

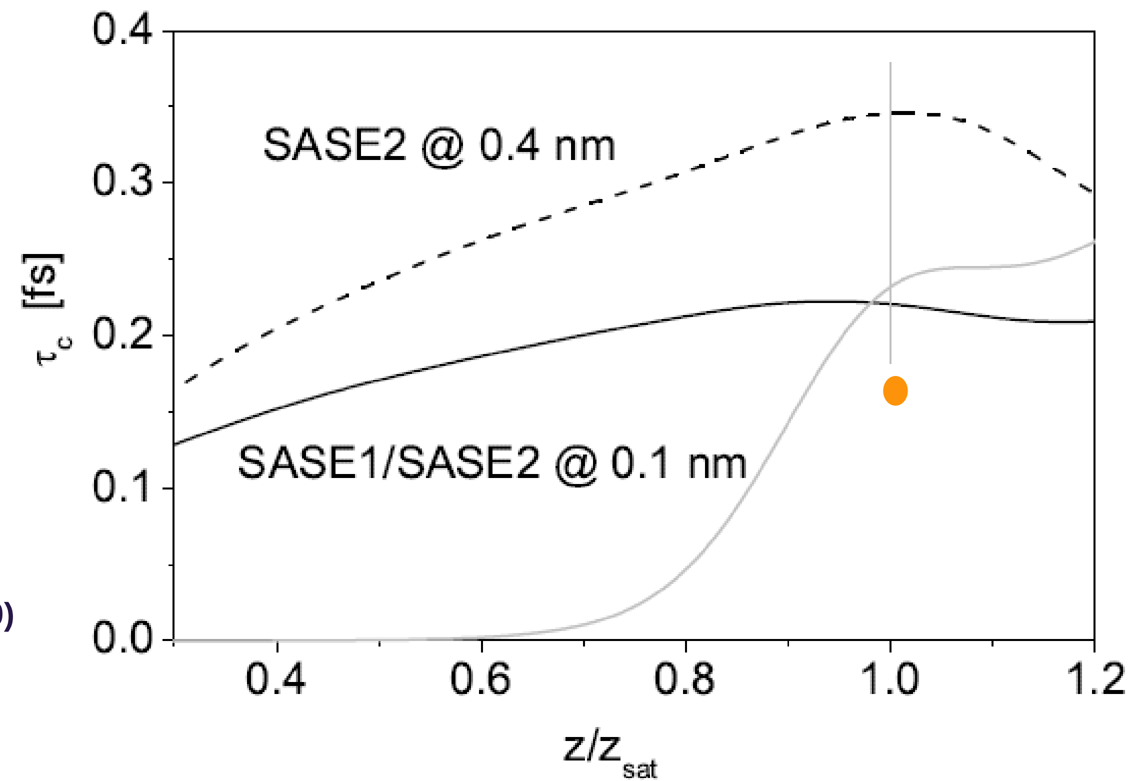
$$\tau_c = \int_{-\infty}^{+\infty} g_1(\tau)\,d\tau$$

European XFEL

SASE1/SASE2 : 12.4 keV
SASE4: 3.1 keV
Saturation curve

Simulations performed by E. Saldin, E. Schneidmiller and M. Yurkov

G. Geloni et al., New J. Phys. 12, 035021 (2010)



Transverse coherence properties

simplified

$$\xi_t = \frac{\lambda L}{2\pi\sigma}$$

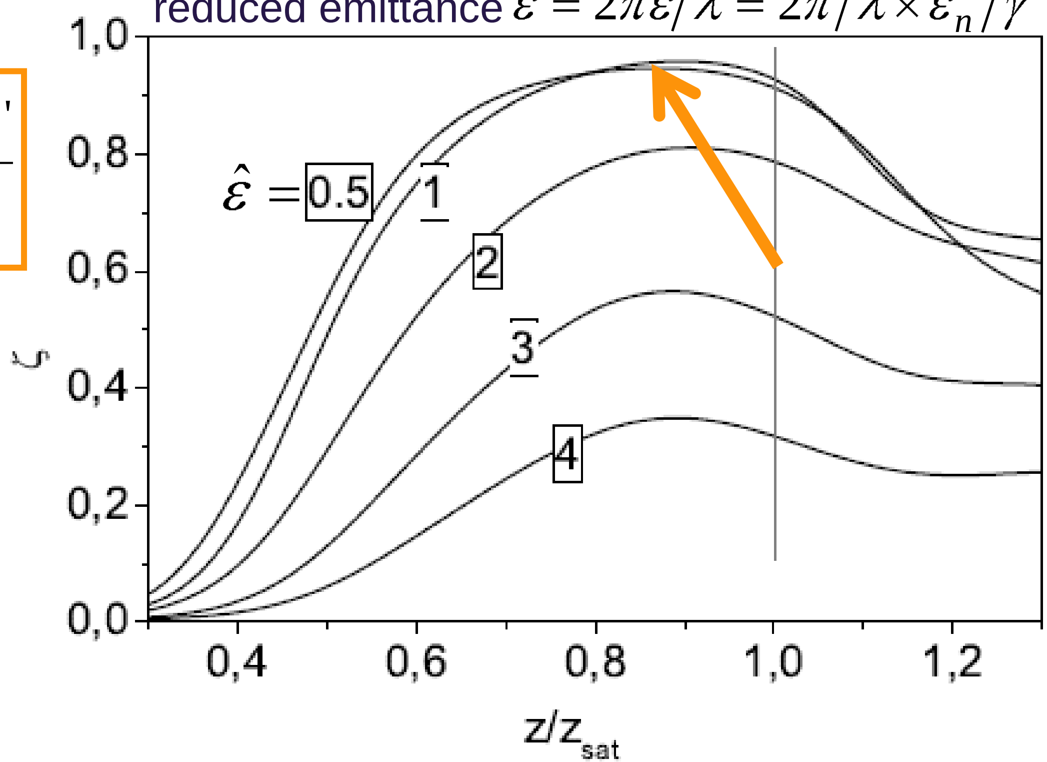
more complete

$$\gamma_1(\vec{r}_\perp, \vec{r}_\perp') = \frac{\langle E(\vec{r}_\perp) E^*(\vec{r}_\perp') \rangle}{\left[\langle |E(\vec{r}_\perp)|^2 \rangle \langle |E(\vec{r}_\perp')|^2 \rangle\right]^{1/2}} \rightarrow \xi_t(\vec{r}_\perp) = \int_{-\infty}^{+\infty} |\gamma_1(\vec{r}_\perp, \Delta r_\perp)|^2 \, d\Delta r_\perp$$

Degree of transverse coherence

$$\zeta = \frac{\iint |\gamma_1(\vec{r}_\perp, \vec{r}_\perp')|^2 \langle I(\vec{r}_\perp)\rangle \langle I(\vec{r}_\perp')\rangle \, d\vec{r}_\perp \, d\vec{r}_\perp'}{\left[\int \langle I(\vec{r}_\perp)\rangle \, d\vec{r}_\perp\right]^2}$$

reduced emittance $\hat{\varepsilon} = 2\pi\varepsilon/\lambda = 2\pi/\lambda \times \varepsilon_n/\gamma$



European XFEL

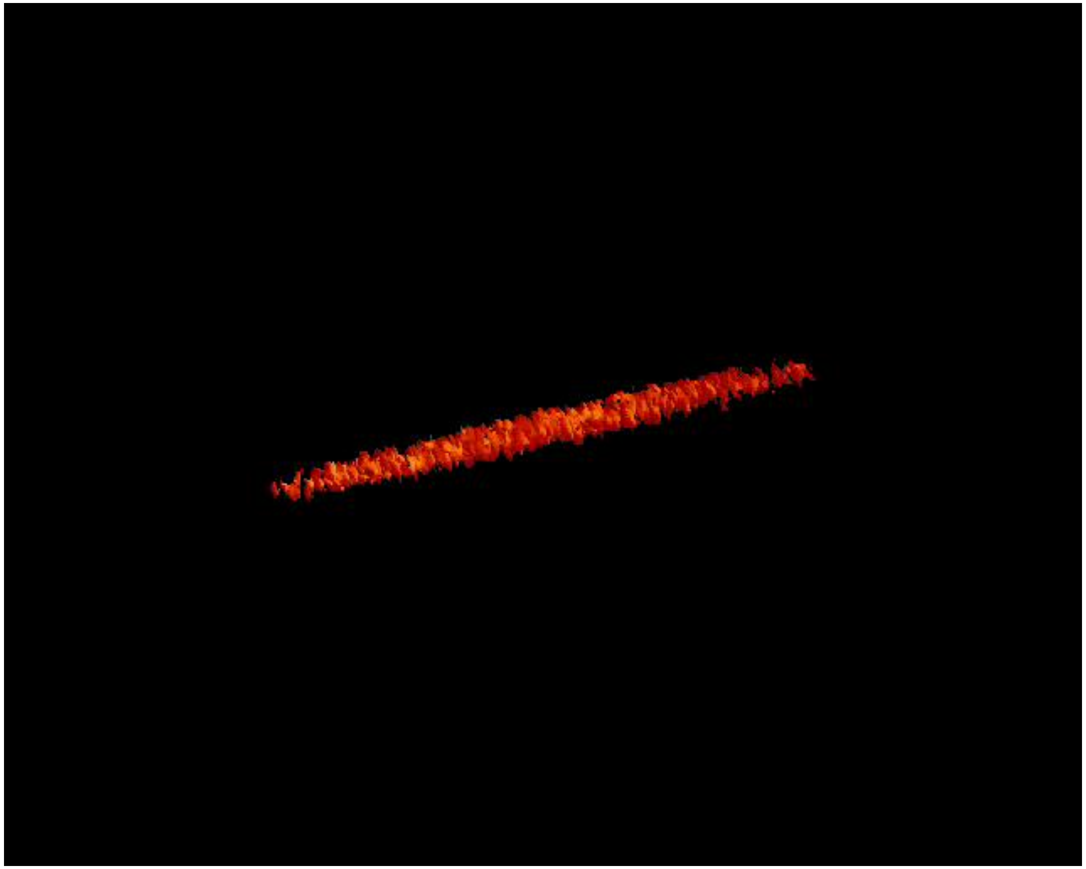
TDR conditions: $\hat{\varepsilon} \cong 2.6$

improved cond.: $\hat{\varepsilon} < 1.0$

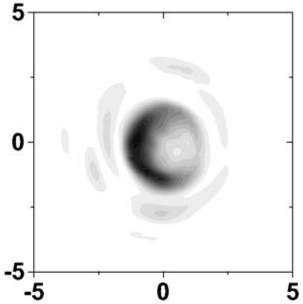
Simulations performed by E. Saldin, E. Schneidmiller and M. Yurkov

G. Geloni et al., New J. Phys. 12, 035021 (2010)

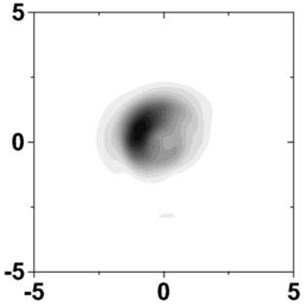
Transverse x-ray beam properties



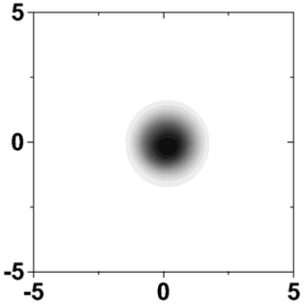
undulator entrance



half-way undulator



full saturation



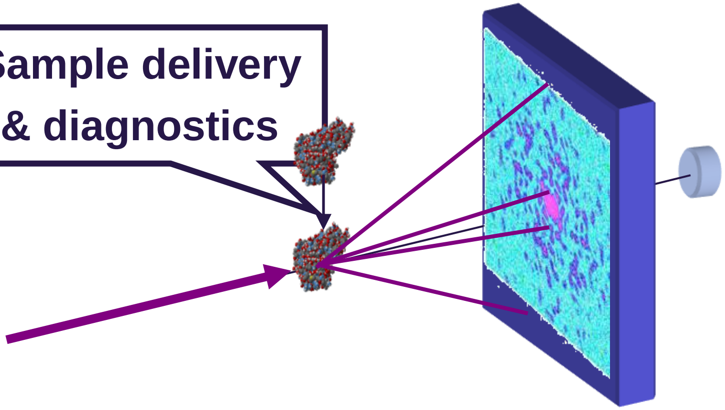
12.4 eV

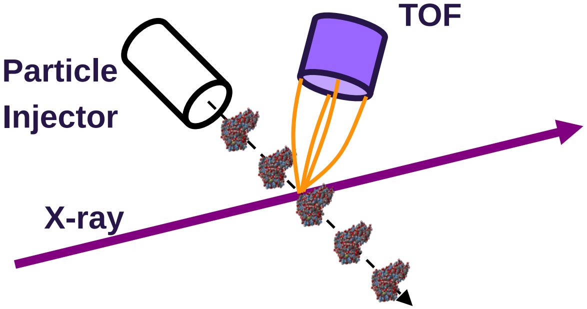
Simulations performed by S. Reiche (UCLA, now SLS)

- **for hard x-rays diffraction limited beams are crucial**

Particle injection

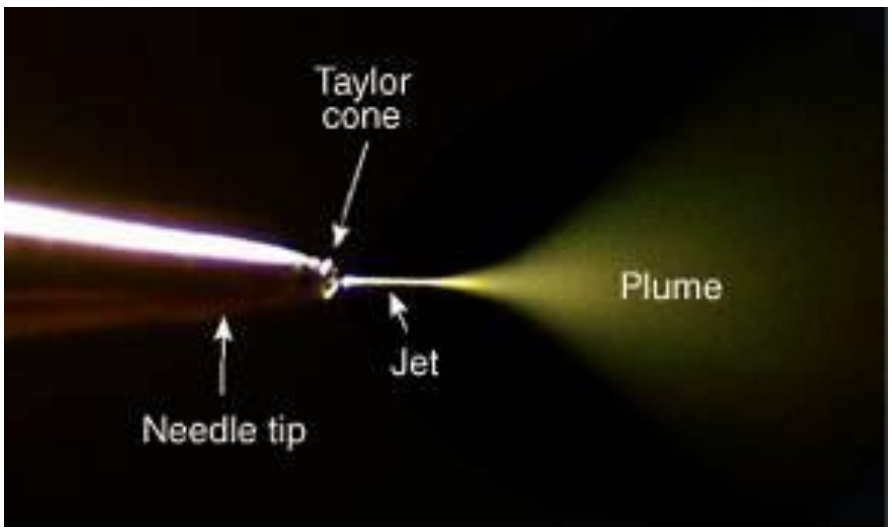
Sample delivery & diagnostics

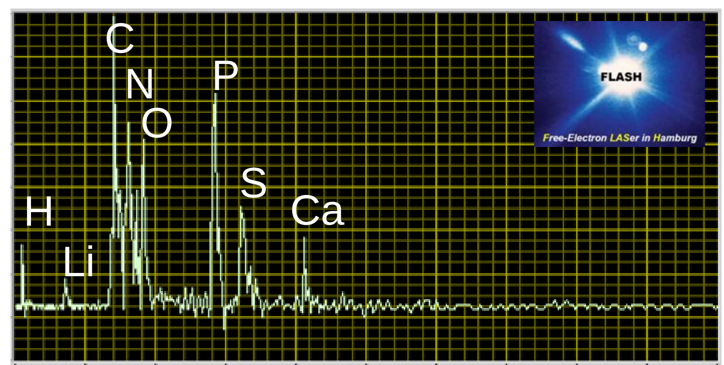




10^5 p/cm^3 = 2.5×10^{-5} p/(250 µm^3)

200 m/s → traverse 1 µm : 5 ns

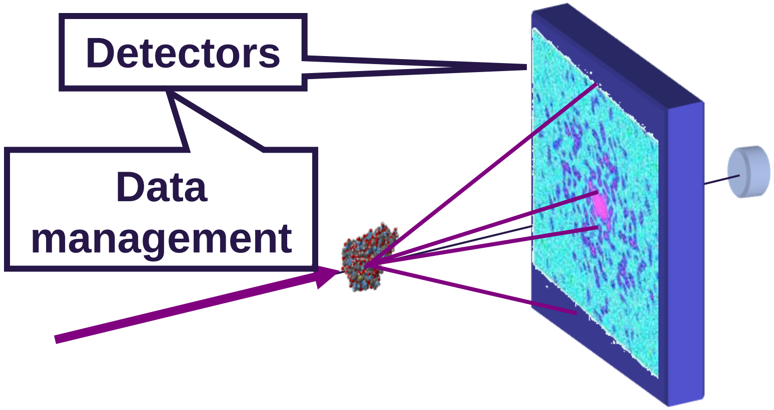


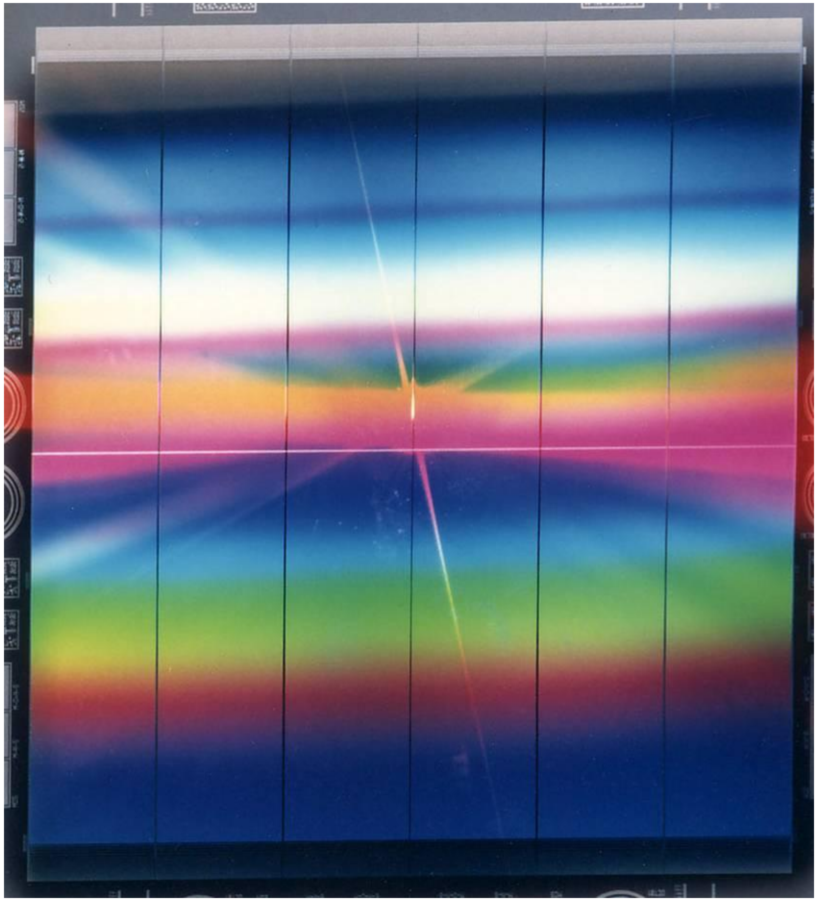


Mass spectrum

data courtesy H. Chapman, J. Hajdu & coworkers

2D pixel detector developments





Challenge

- **4.5 MHz frame rate**
- Efficient detectors
- 2-dimensional pixel detectors
- single photon sensitivity
- integrating large number of counts
- high count rate effects
- **enormous data rates**
- **large data volumes**

European XFEL

2D pixel detector developments

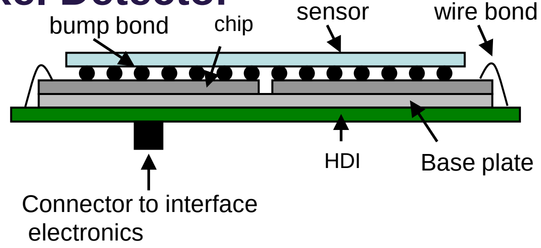
AGIPD **Adaptive Gain Integrating Pixel Detector**

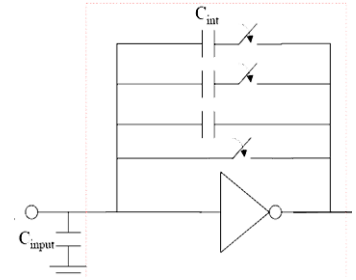
⇒ **dynamic gain switching**

⇒ **1 analog pipeline**

collaboration:

DESY, PSI, U Bonn, U Hamburg





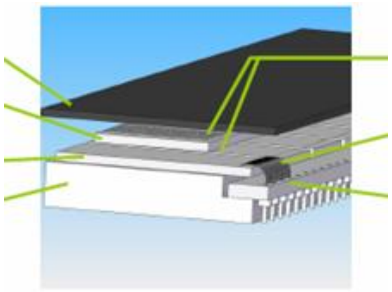
LPD **Large Pixel Detector**

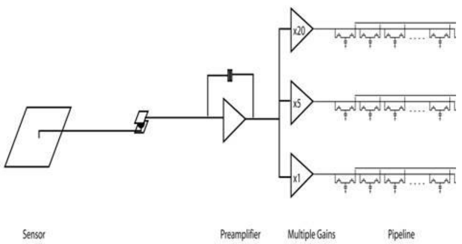
⇒ **large dynamic range**

⇒ **3 analog pipelines**

collaboration:

STFC/RAL, U Glasgow





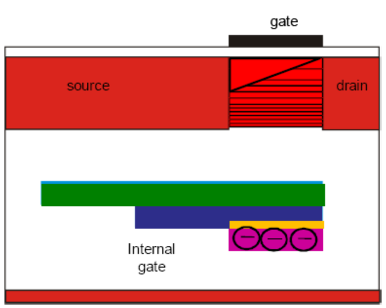
DSSC **DEPFET**

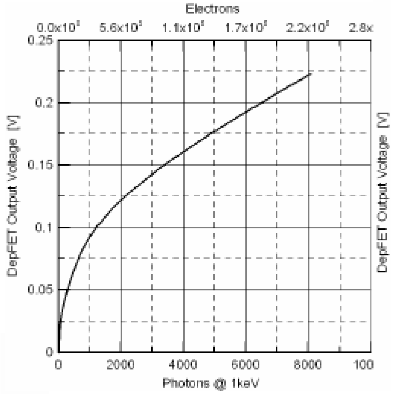
⇒ **non-linear amplification**

⇒ **soft x-ray sensitivity**

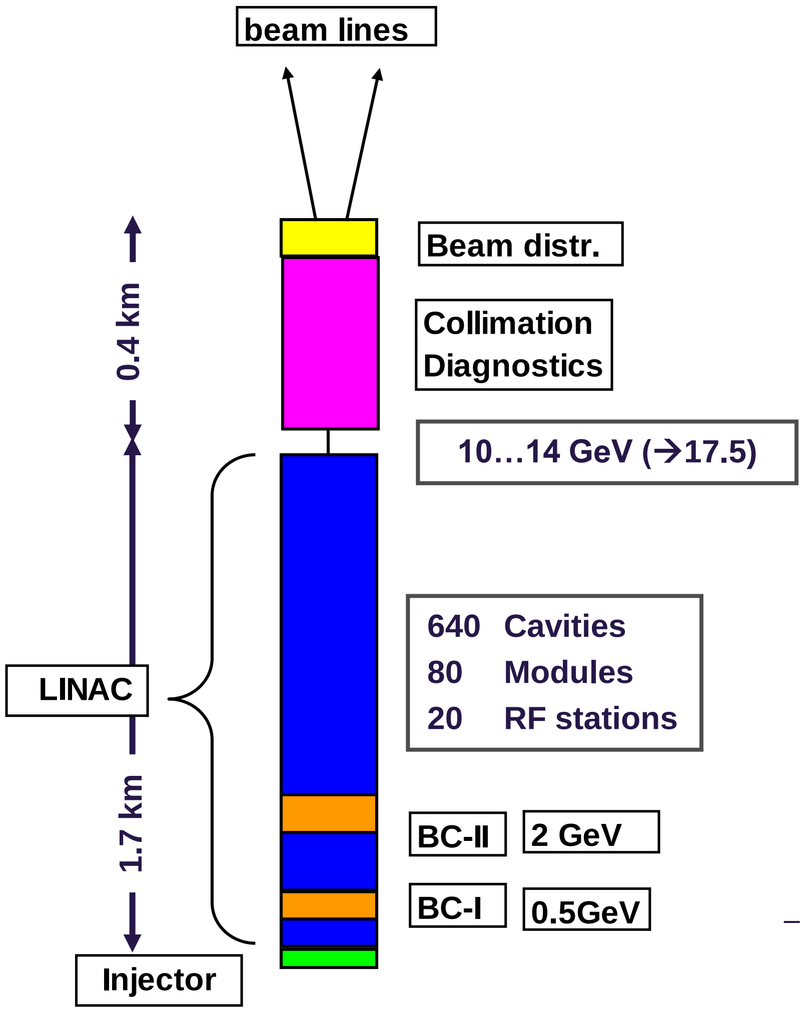
collaboration:

MPI-HLL, U Heidelberg, U Siegen, DESY, Politecnico die Milano, U Bergamo





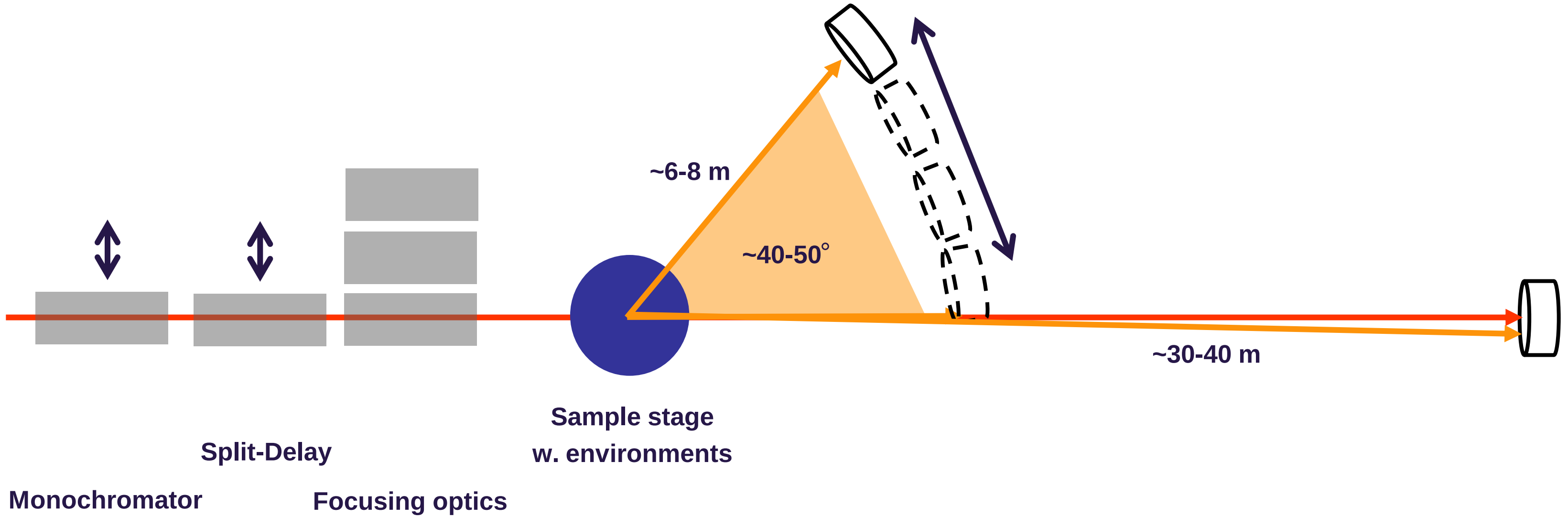
Under study: New parameter set accelerator



Parameter	Unit	Value
Electron energy for 0.1 nm FEL radiation	GeV	14
Accelerating gradient	MeV/m	24.3
Bunch charge	nCb	0.02 –1
Peak current	kA	2 – 5
Normalized slice emittance (rms)	mm mrad	0.4 – 1.0
Electron energy spread (rms)	MeV	4 – 2
RF pulse repetition rate	Hz	10
Repetition rate during RF pulse	MHz	4.5
Max. number of electron bunches per RF pulse		2700
Duration of electron bunchtrain	µs	600

Materials Imaging & Dynamics – MID

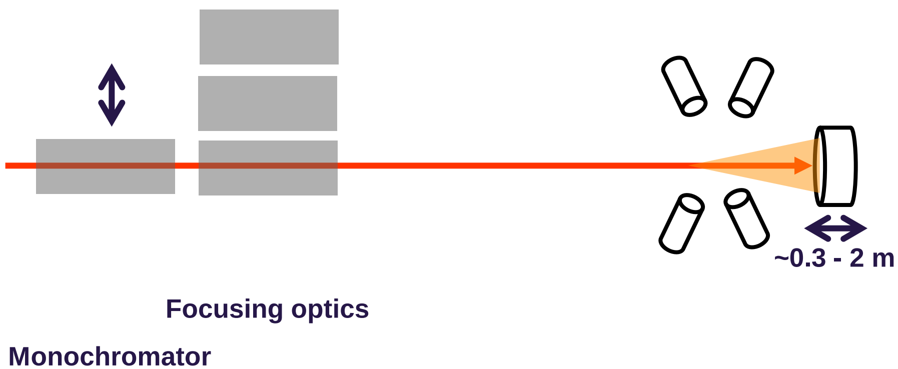
- **Coherent diffraction imaging from nano-structured samples**
- **X-ray photon correlation spectroscopy of nanoscale dynamics**



- use one beam delivery system and sample stage
- possibility to place detector at different distance and up to large angles
- use very hard x-ray radiation (>20 keV) to minimize sample damage

Single Particle & Biomolecules – SPB

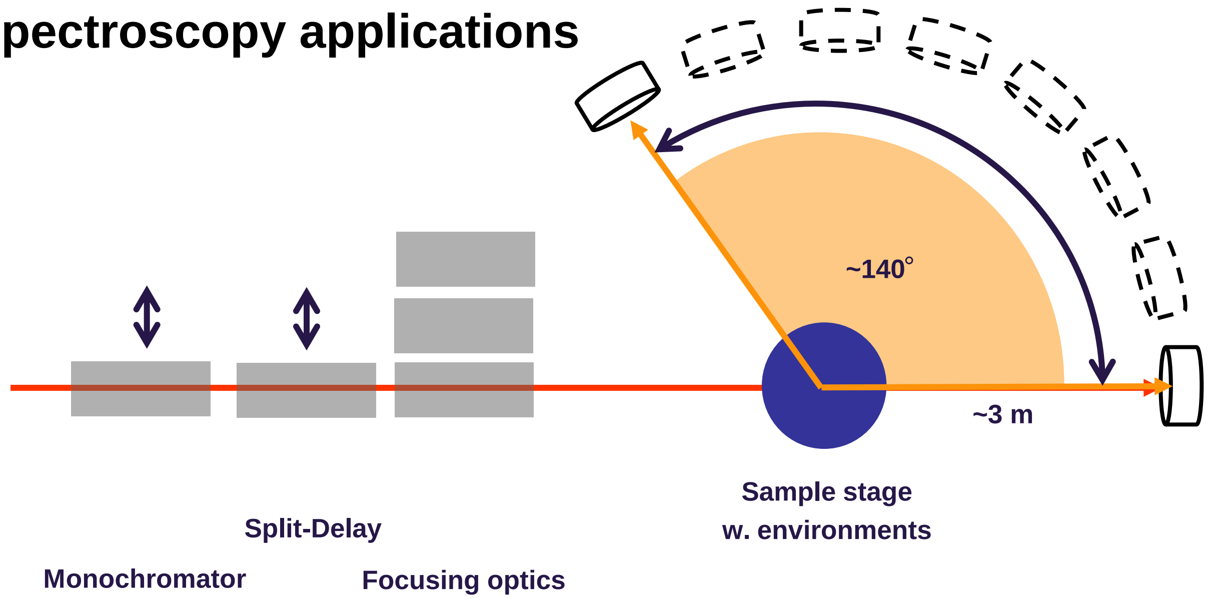
- **Coherent diffraction imaging from injected particles**
- **Time-resolved diffraction from (aligned) gas molecules**



- UHV vacuum system to surpress background scattering on 2D detector
- various sample injectors (liquid jets, droplets, aerosols) & cryo-stage
- sample & beam diagnostics (emission, ion-spec, dedicated samples)

Soft x-ray Coherent Scattering – SCS

- **Coherent diffraction imaging from nano-structured samples**
- **X-ray photon correlation spectroscopy of nanoscale dynamics**
- **Spectroscopy applications**



- use one beam delivery system and sample stage
- use detector at different distance and up to large angles
- sample damage is an issue for resonant absorption (magnetic studies)