XFEL
X-Ray Free-Electron Laser

The European
X-Ray Free Electron Laser Project

Andreas S. Schwarz
DESY
for the XFEL Project Group

1. Basic Design Considerations
2. Technical Layout
3. Parameter Flexibility
4. Present Status of the Project
5. Summary

AUGUST 29 - SEPTEMBER 3
FEL 2004
Trieste, Italy

X-FEL Laboratory - Physics Opportunities

Probe the dynamic state of matter

- with atomic resolution in space and time
- studies of non-equilibrium states
- studies of very fast transitions between different states of matter

Specifically:

- atomic, molecular and cluster phenomena, plasma physics
- non-linear processes and quantum optics
- condensed matter physics and materials science
- ultra-fast chemistry and life-sciences

And:

- this machine will present a quantum jump: prepare for the unexpected!

Basic Design Considerations ff.

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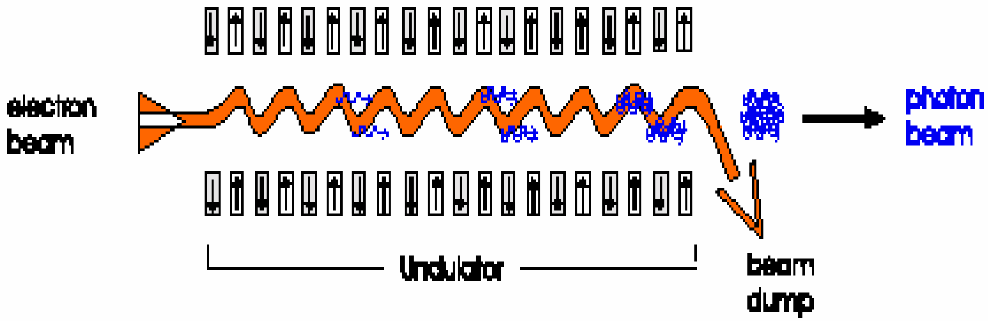
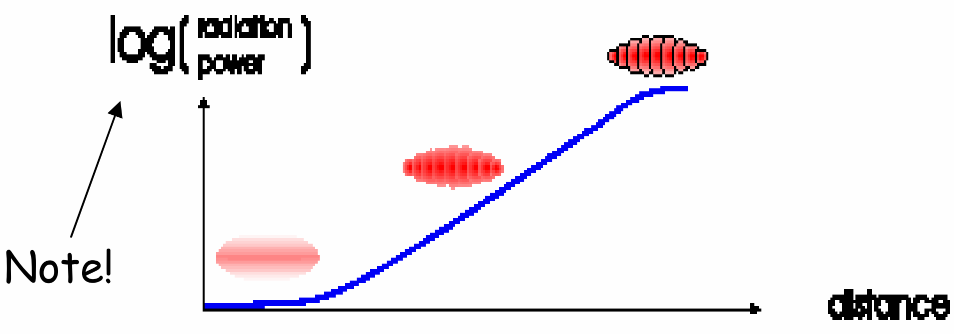
Basic Principle:
Extend the principle of Linear Accelerator based Self Amplification of Spontaneous Emission (SASE) Free Electron Lasers (FELs) into the hard X-Ray regime (~0.85 - 60 Å)





- Modulation of the electron charge density with the (synchrotron radiation) field
  $\Rightarrow$ 'micro-bunching'
- more and more electrons radiate in phase
  $\Rightarrow$ increasingly coherent superposition of the radiation
- saturation: electron beam completely bunched

Need excellent electron beam quality:

- low emittance
- low energy spread
- extremely high charge density

Note: to get down to 1 Å, the undulator has to be VERY long!

Basic Design Considerations ff.

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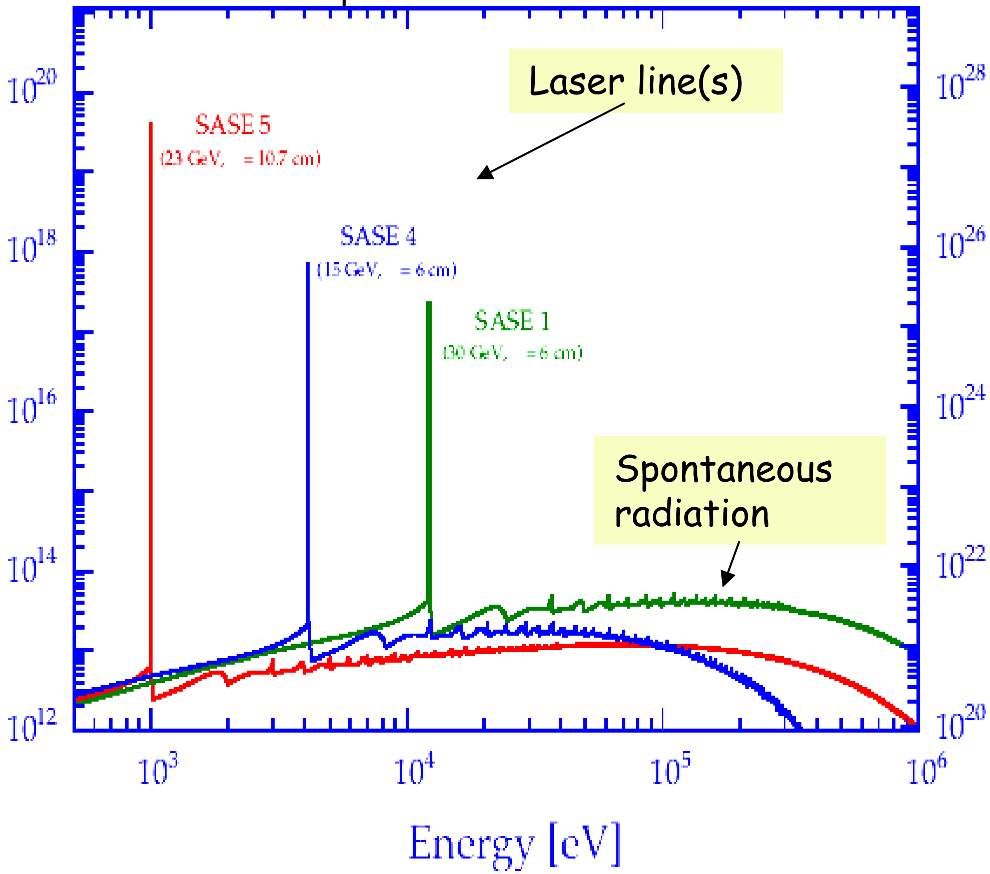
Spectral Characteristics of Radiation

Illustrative example



Spectral distribution of angle integrated radiation

Radiation properties:

- narrow bandwidth
- fully polarized
- transversely coherent

Gain factors:
(compared to 3rd generation sources)

• peak brilliance	10^9 (SASE)
	10^4 spontaneous
• average brilliance	10^4 SASE
• coherence (# photons/mode)	10^9 SASE

Basic Design Considerations ff.

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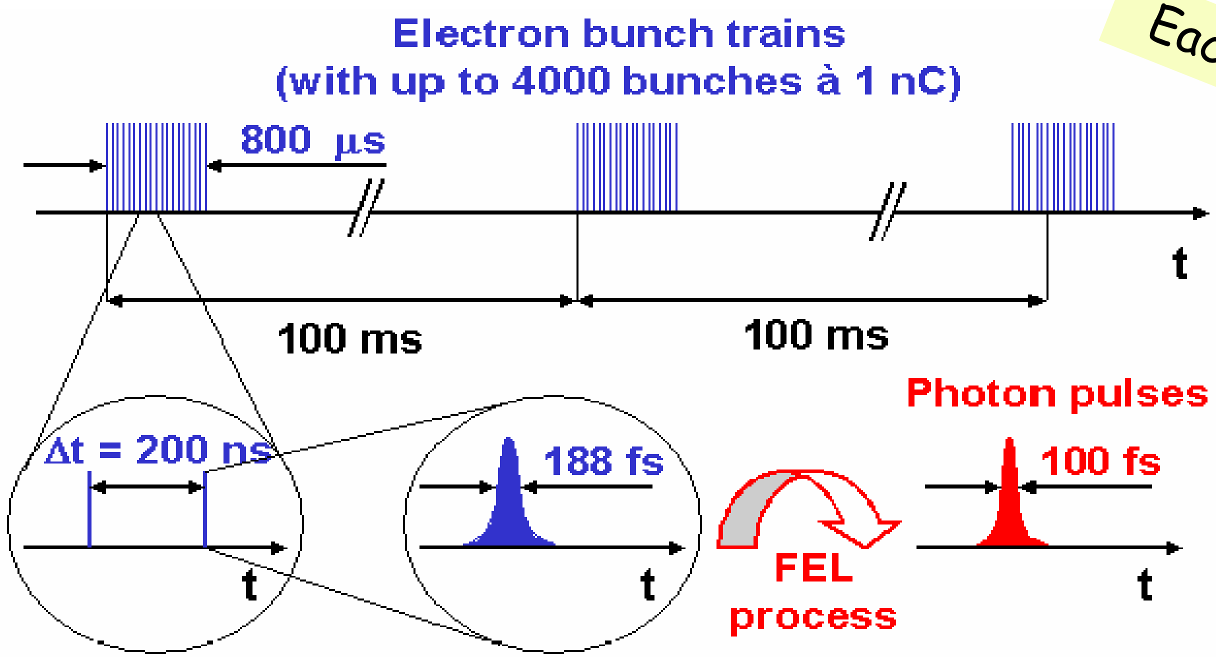
Pulsed electron beam: pulsed photon source!

Each bunch saturates!



Large flexibility
with superconducting
Linac Technology!

- Single bunches, few bunches, long bunch trains
- Bunch trains with variable number of bunches (1 to 3000)
- Bunch trains with varying bunch spacing (200 nsec to ???)

The details will and can be determined to a large degree by the User Community!

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2. Technical Layout

Technical Layout

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Basic Assumptions

- The XFEL is a multi-user facility
- The electron beam is distributed into several e^- beamlines
  - Use electron beam for several FELs and spontaneous radiators
  - Parallel operation of as many experiments as possible
  - Minimize down-time of beam lines/experiments: ideally use every pulse
  - Provide R&D capability parallel to user operation
- The XFEL should continuously cover 200eV → >12.4keV (64Å → <1Å)
- the emphasis is on the hard X-rays
- 1 Å must be reached safely with conservative assumptions on beam parameters
- The XFEL is based on proven technologies (TTF, VUV-FEL, SppS, …)

Technical Layout ff.

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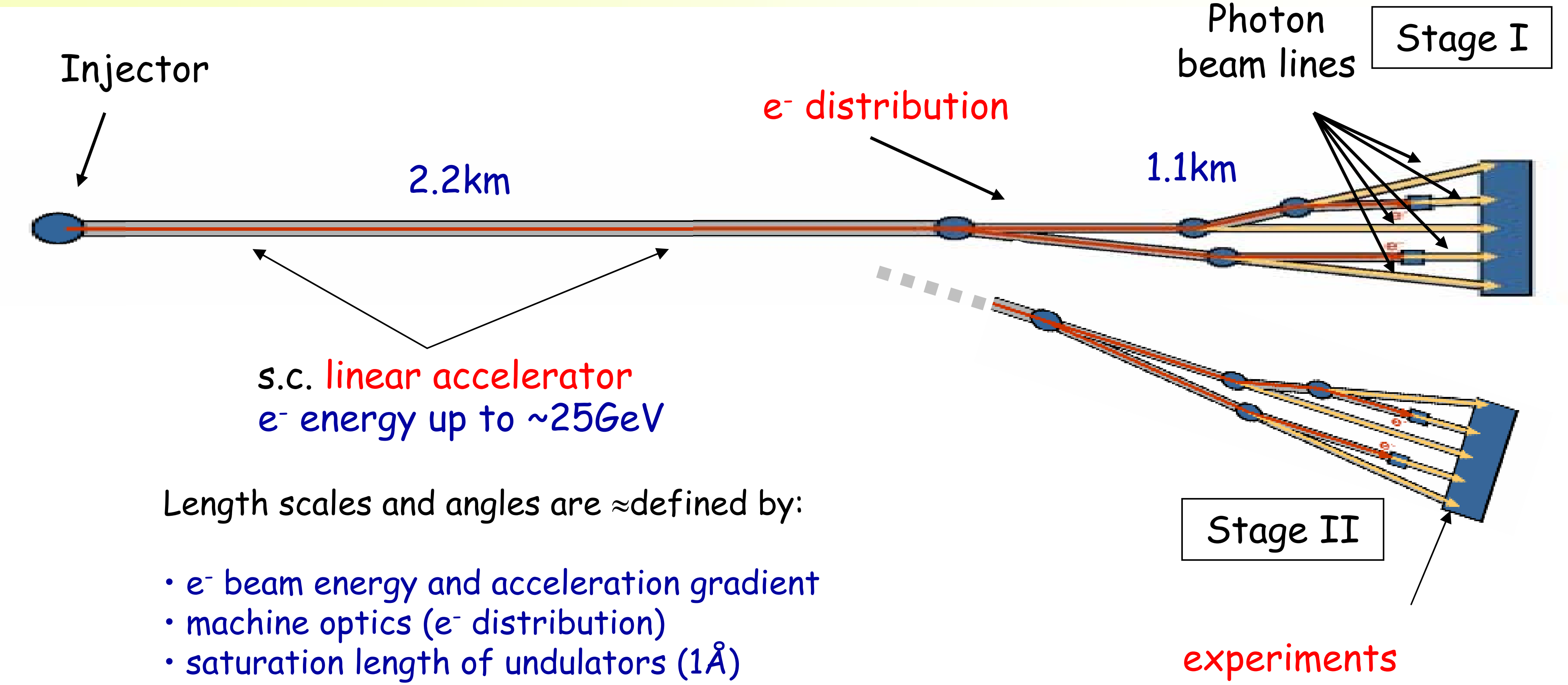
Principle Layout Schematics

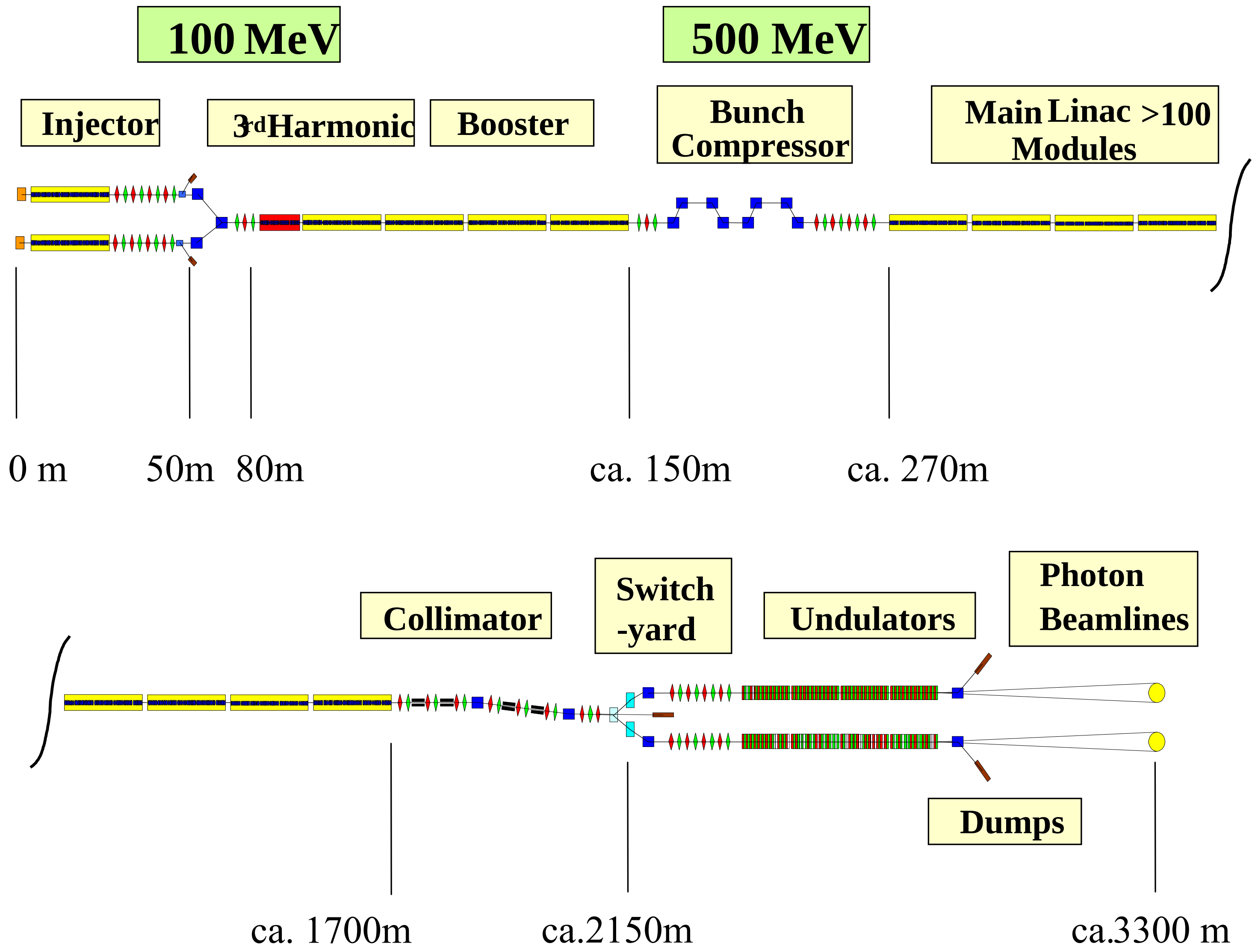


Length scales and angles are ≈defined by:

- e^- beam energy and acceleration gradient
- machine optics (e^- distribution)
- saturation length of undulators (1Å)
- spare space for options (seeding, …)
- divergence of photon beam (spot size)

Linac Layout

XFEL
X-Ray Free-Electron Laser



The XFEL Injector

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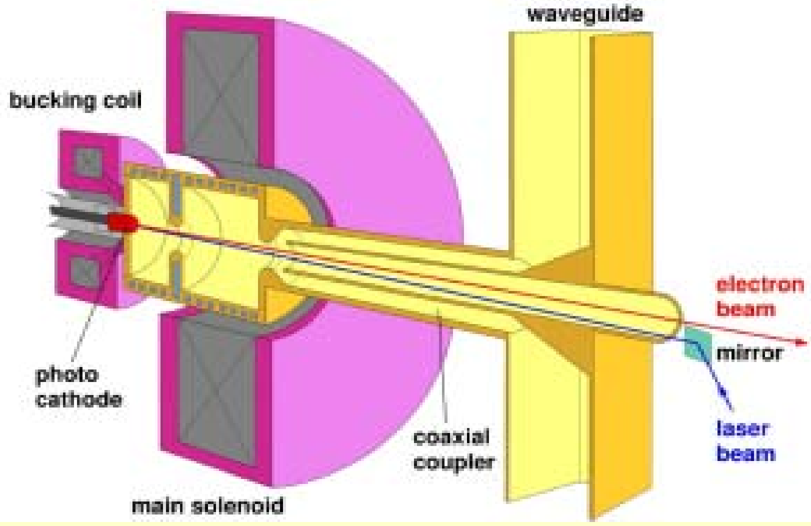

The goal for the XFEL:

charge	1nC
$\varepsilon_{x,y}$	1.4 μm
σ_z	~ 25 μm (80 fs)
$\sigma_{E,\ uncorr}$	< 2.5 MeV

At TTF and PITZ (DESY) these parameters are almost reached

The Accelerating Structures

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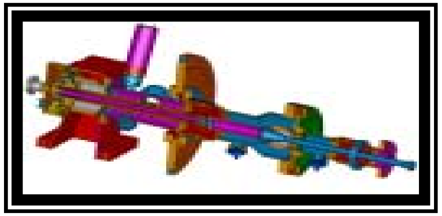
TESLA

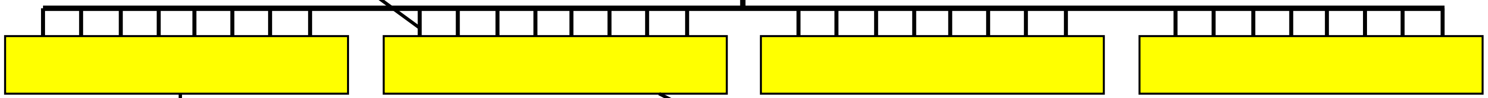


var. Q_ext with adjustable coupler and/or waveguide tuner

5 MW RF source

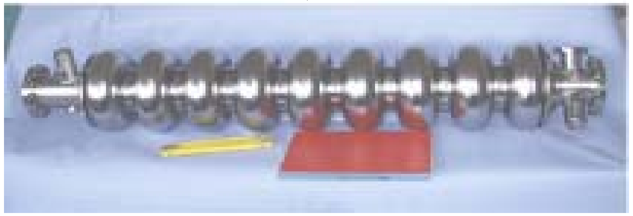
De-rated 10MW MBK

Bouncer-type modulator



eight 9-cell Nb cavities at 2K, $Q_0=10^{10}$

12m TTF-like acc. modules



Linac Reference Parameters

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Main linac	
Energy gain	0.5 → 20 GeV
# installed modules	116
# active modules	104
acc gradient	22.9 MV/m
# installed klystrons	29
Bunch spacing	200 ns
beam current	5 mA
power→beam p. klystron	3.8 MW
incl. 10% + 15% overhead	4.8 MW
matched Q_{ext}	$4.6 \cdot 10^6$
RF pulse	1.37 ms
Beam pulse	0.65 ms
Rep. rate	10 Hz
Av. Beam power *	650 kW
Total AC power	≈ 9 MW

Bunch trains

- Typical rate: 10 Hz
- 1-3000 bunches per train
- each bunch can generate max. brilliance

* Power limitation to ~300kW per beamline → solid beam dump possible

e⁻ Beam Distribution

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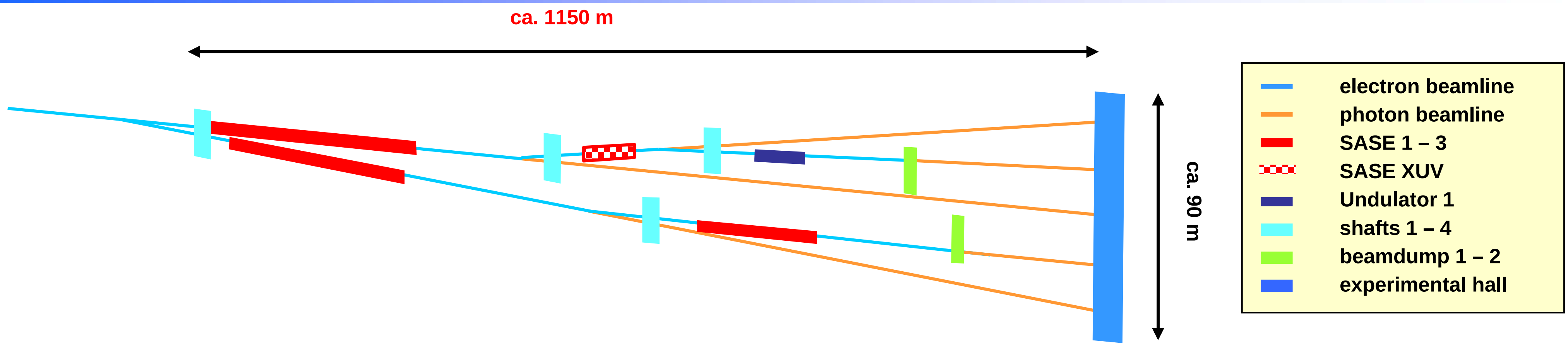

- 10 Hz macro-pulse repetition rate ("bunch trains")
- Distribution of e- bunches on different time scales possible
  - macro pulse to macro pulse
  - bunch to bunch
- Different bunch patterns can be created at source

Macro-pulse:

- 0.65 ms long
- $\approx$ 3000 bunches with $\geq$ 200 ns spacing

DC Magnet	Slow switch train to train	High Q Resonator	Programmable fast kicker for individual bunches
One beamline only	Macro cycle reduced by number of beamlines	Same bunch pattern for every beamline,	Most flexible
Commissioning option	TDR option	full duty cycle	

Alternative approach: photon distribution with phase shifter (Saldin, Schneidmiller, Yurkov)

Generic Beam Line Layout

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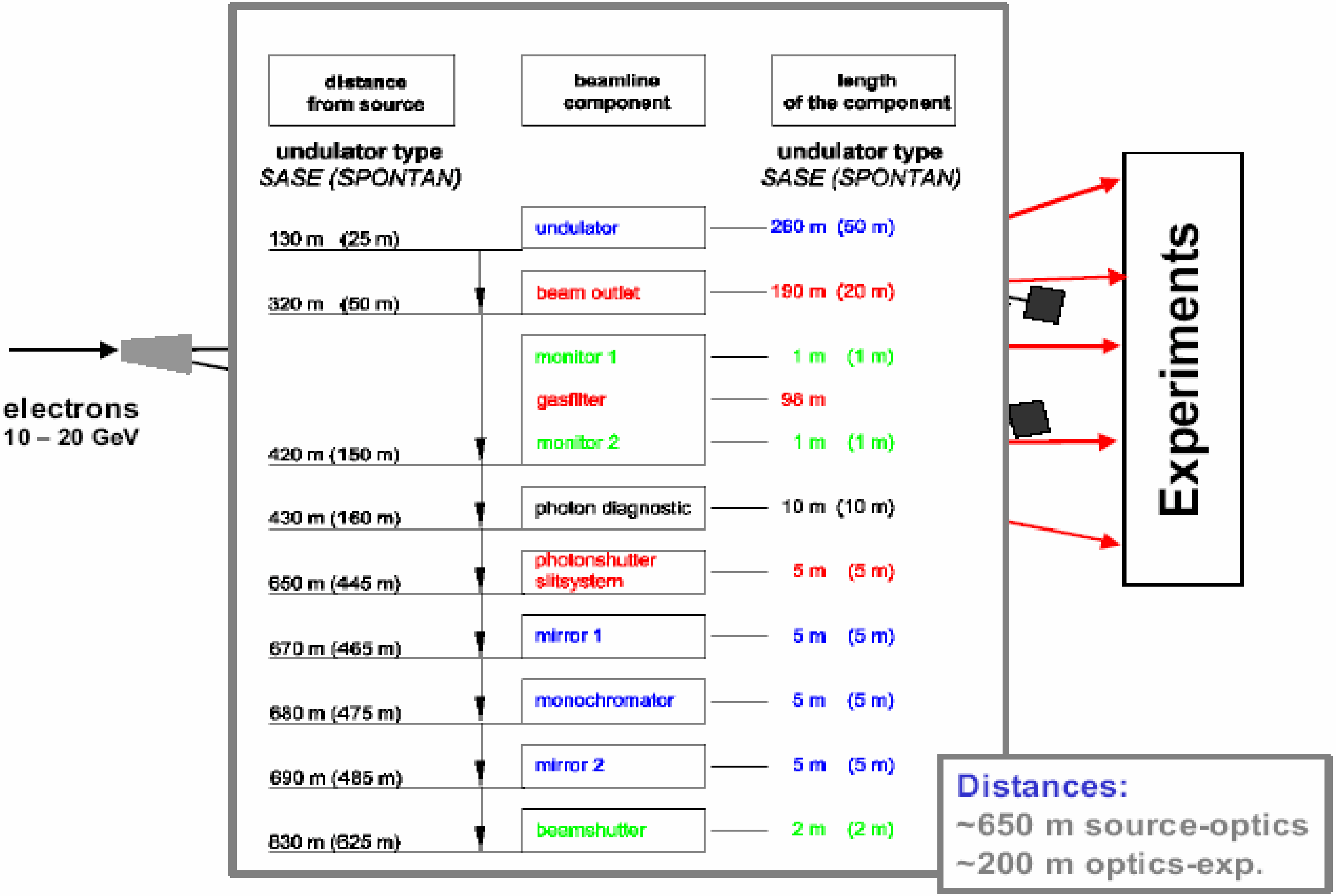

Distances:
~650 m source-optics
~200 m optics-exp.

Undulator concept

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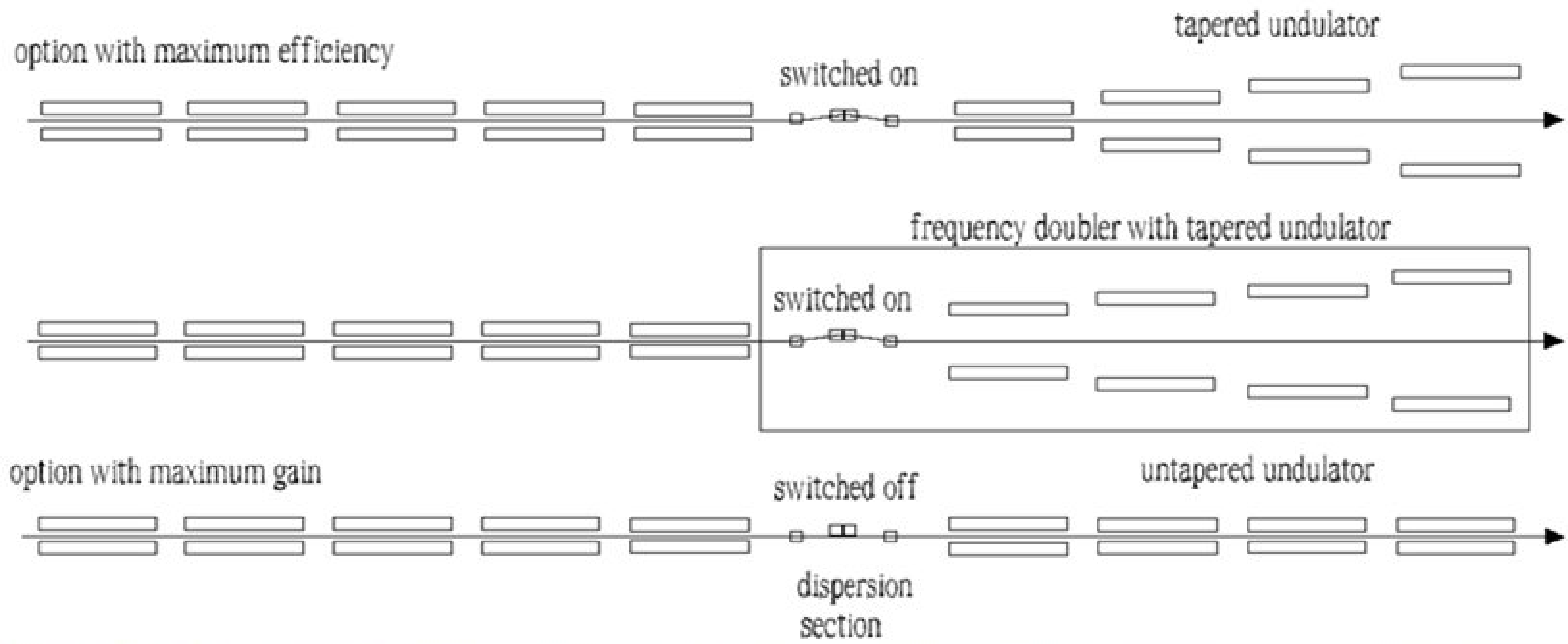
- 3 undulators cover the wavelength range 0.1-1.6 nm continuously at fixed electron energy, XUV covered by 4th undulator.
- All undulators are planar, variable-gap devices with an identical mechanical design.
- Each undulator provides three different modes of operation using the same undulator structure (conventional SASE, high-power, frequency doubling).
- Use of dispersion sections to control amplification process.



FEL parameters for 17.5 GeV

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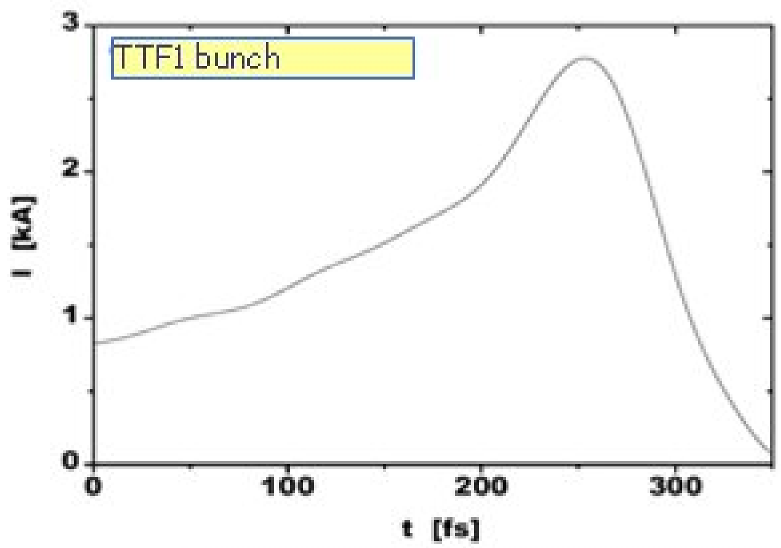
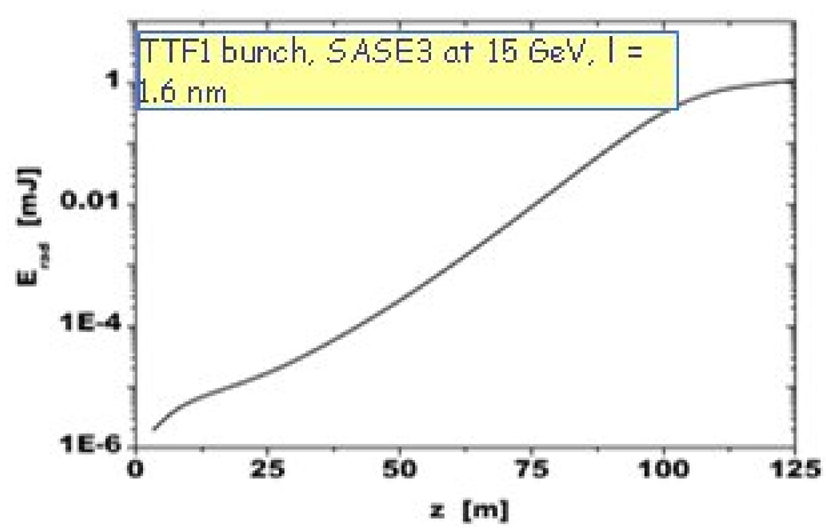
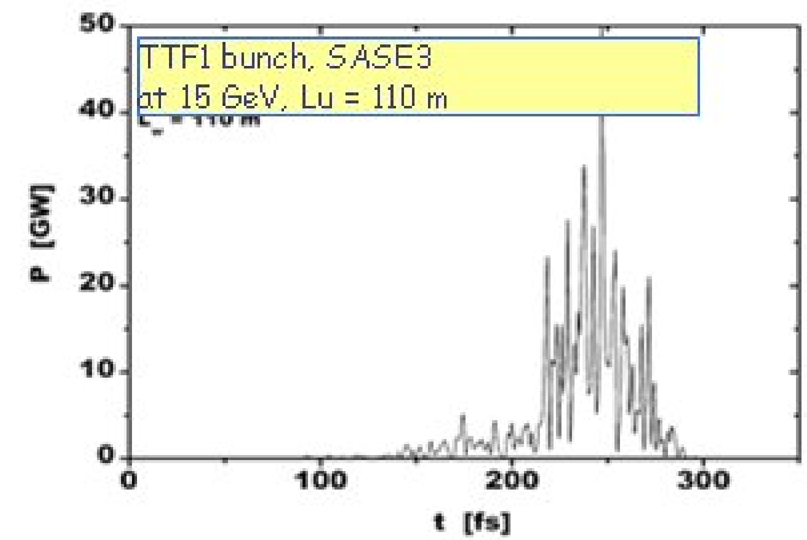
	λ (nm)	λ_u (mm)	L_W (m)	P_{peak} (GW)	Photons/ pulse
SASE1	0.1-0.15	39	150	10	$5\cdot10^{11}$
SASE2	0.1-0.4	47.9	150	20	$2\cdot10^{12}$
SASE3	0.4-1.6	64.8	110	20	$4\cdot10^{12}$
SASE4	1.6-6.4	110	80	100	$2\cdot10^{14}$



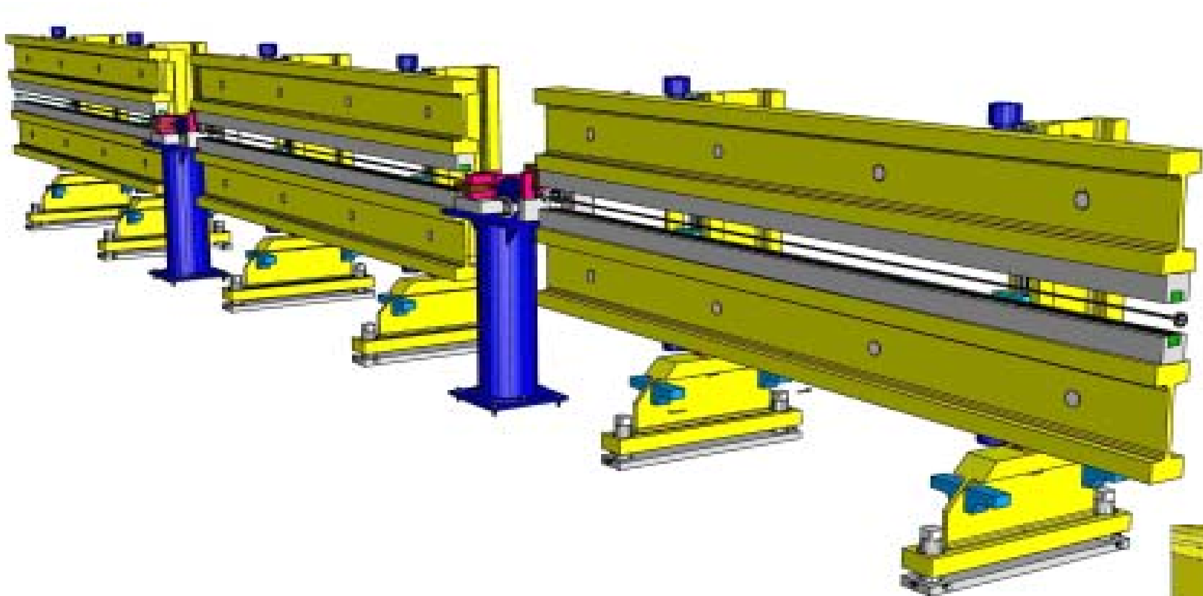




TTF1 bunch at 15 GeV would reach saturation at 1.6 nm !

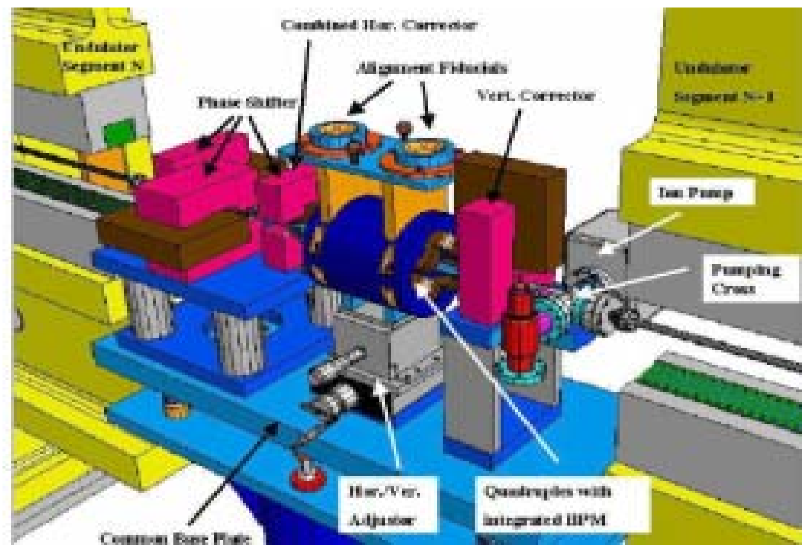
XFEL: Undulator Systems

XFEL X-Ray Free-Electron Laser



Intersection System:

- Phase shifter
- Quadrupole
- BPM
- Correctors
- 1 photon diagnostic station



Undulators:

- Segmentation: 5m Undulator, 1.1m Intersection
- Precision gap tunable (± 1 µm)
- Individual opening possible (tuning, diagnostics)
- High dynamical, high precision 4-axis drive system

Principles tested successfully at TTF1

VUV FEL: Phase 1

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Undulator:

λ_u= 27.3 mm

Gap = 12 mm

B_{peak} = 0.46 T

K = 1.17

L = 3 × 4.5 m

Experimental Area

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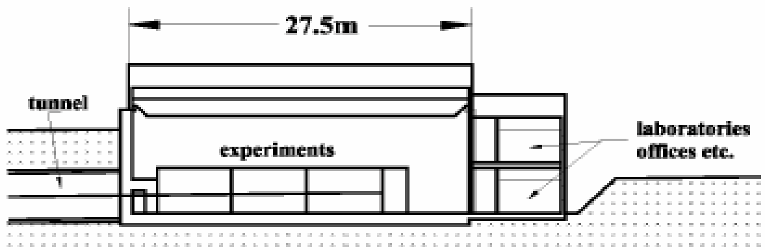
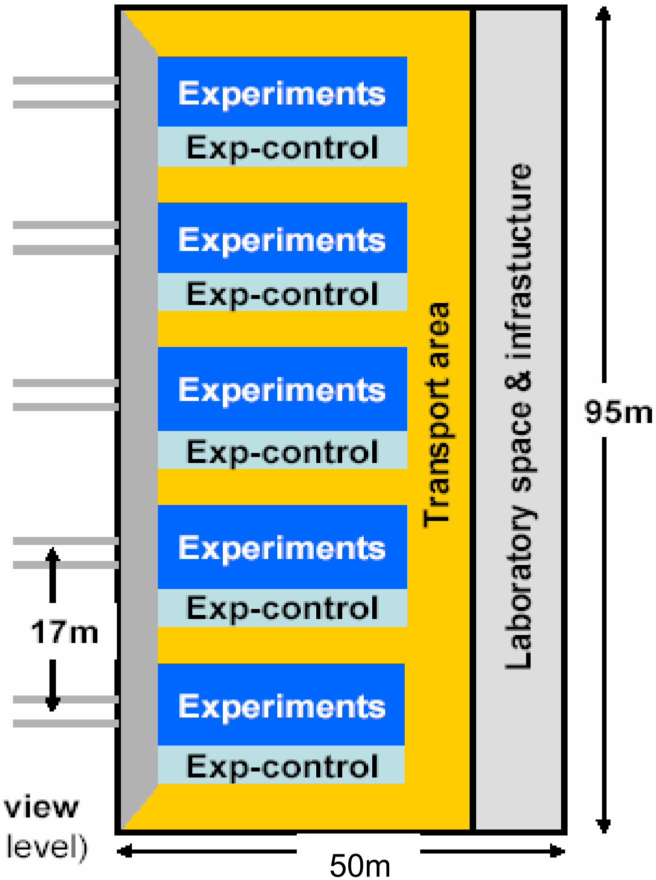
5 beamlines
10 experimental stations
laboratory space
optical laser facility

Side view (from TDR-2002)





Top view
(experiments level)

- Multi-User facility
- Parallel operation of as many experiments as possible

Generic Experiment Layout

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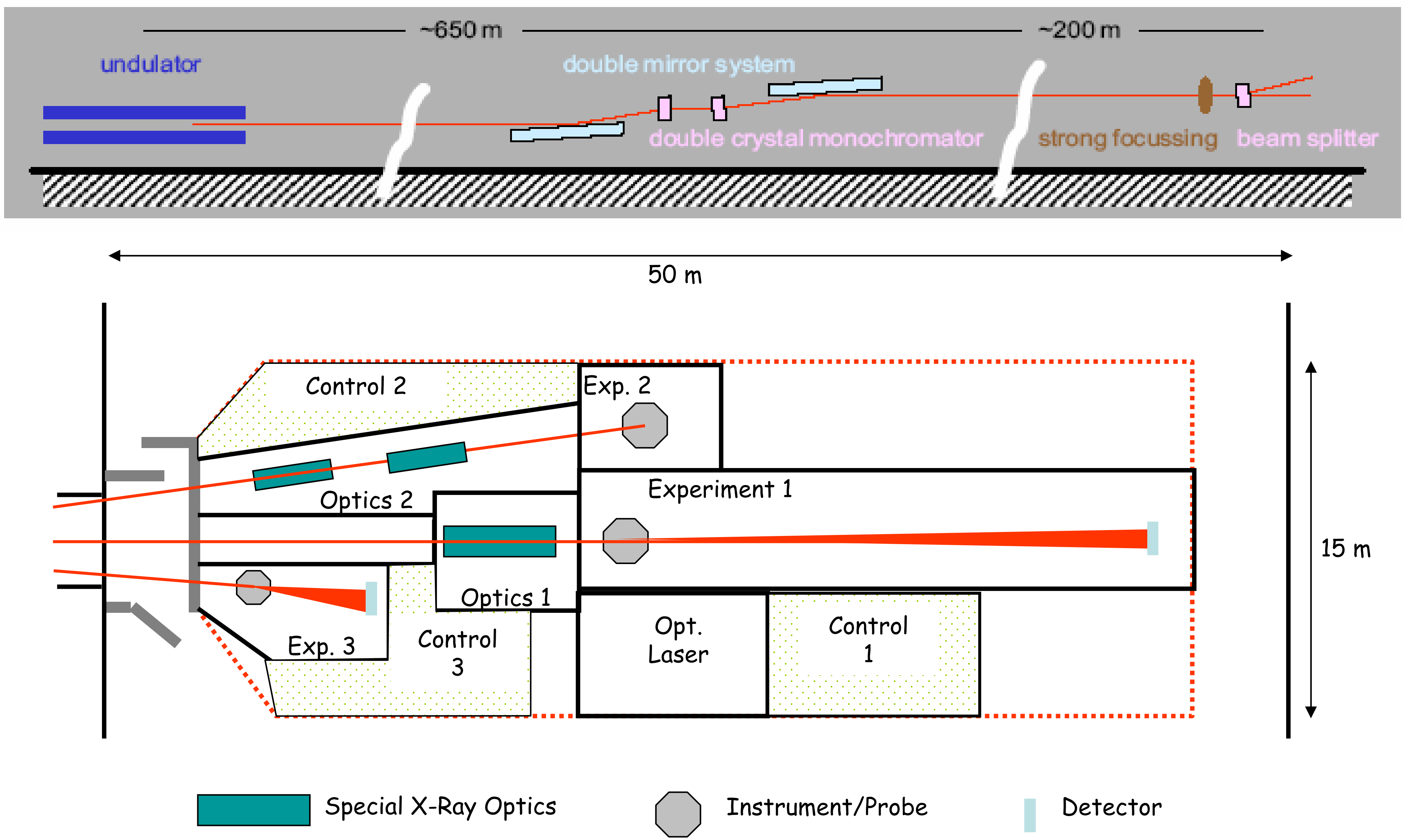

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3. Parameter Flexibility

Parameter Flexibility

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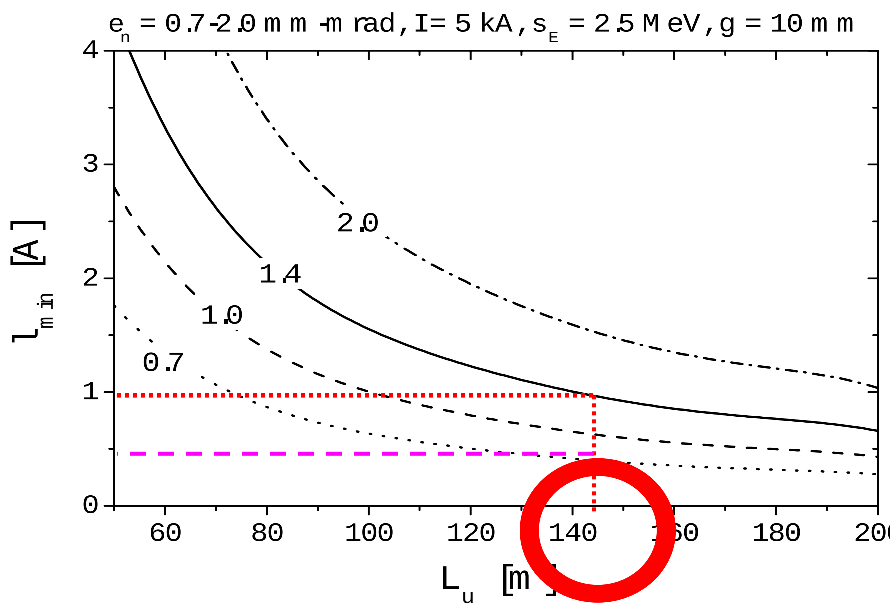
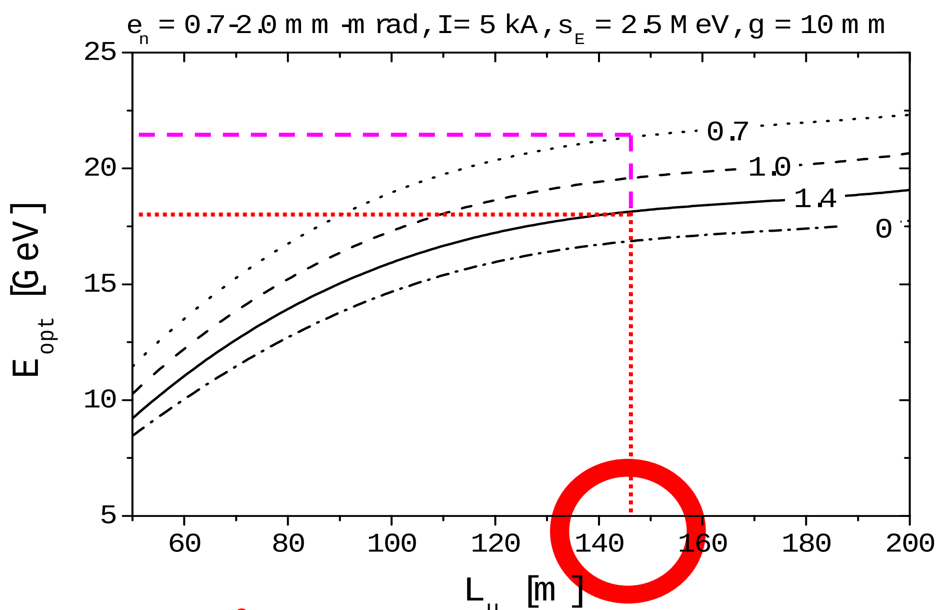
(a) Choice of Beam Energy

Conservative assumptions for

- slice energy spread s_E = 2.5 MeV
- slice emittance e_n = 1.4 mm mrad
- undulator gap g = 10 mm





→ **17.5 GeV for 1Å**

Advantage of High Beam Energy

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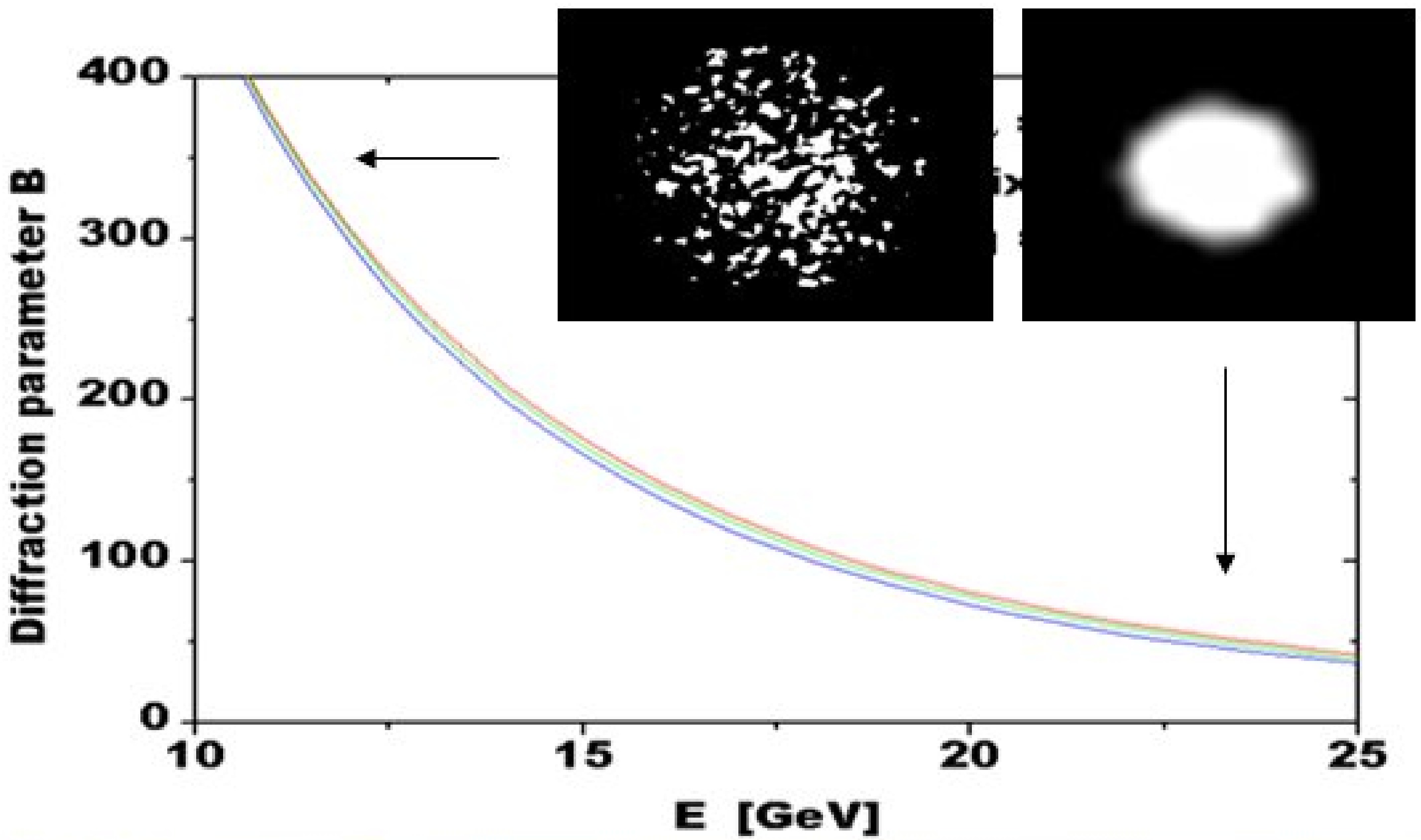
- Safely reach 1 Å to get started with user experiments early
- Allows future upgrades to shorter wavelengths below 0.5 Å
- Advantages compared with lower e-beam energy
  - Higher power (~100 GW vs. ~10 GW)
  - Much better transverse coherence
  - Allows to combine very powerful XUV and X-ray pulses



Parameter Flexibility ff.

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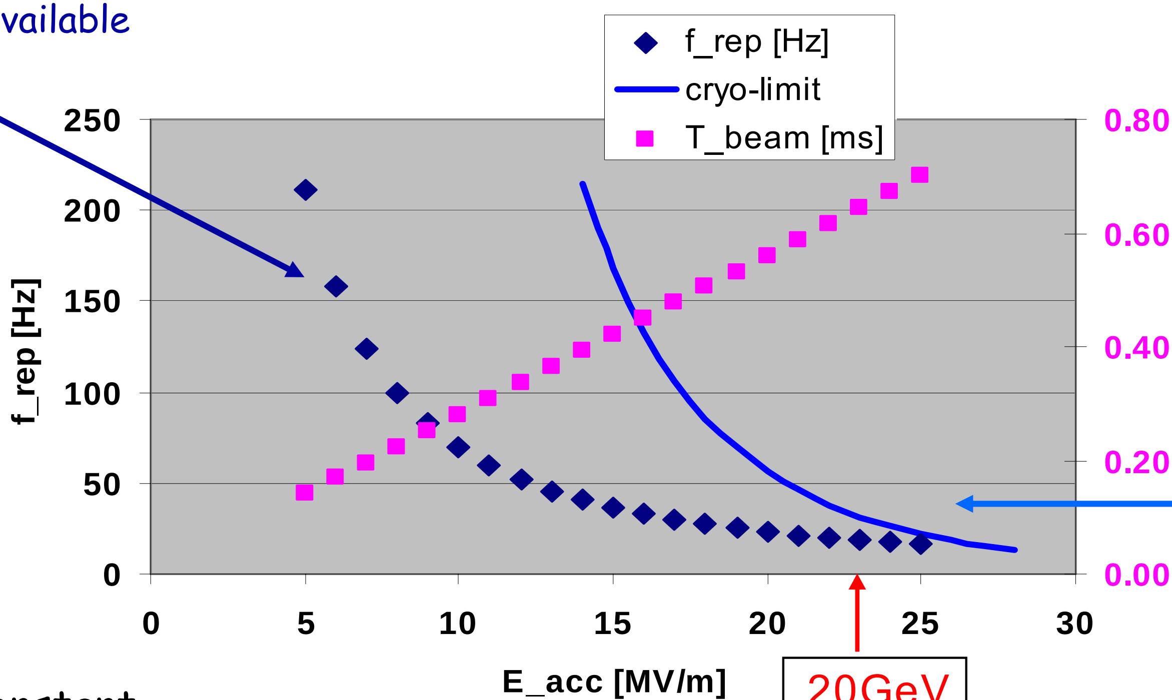
(b) Repetition Rate

Maximum repetition rate and beam pulse length
vs. the accelerating gradient of the s.c. cavities

Limitation from available Rf power



20GeV

Decreasing T_{pulse} at higher f_{rep} helps, but injector is an issue!

Limitation from available cryogenic cooling power

I_{beam} = 5mA constant

Parameter Flexibility ff.

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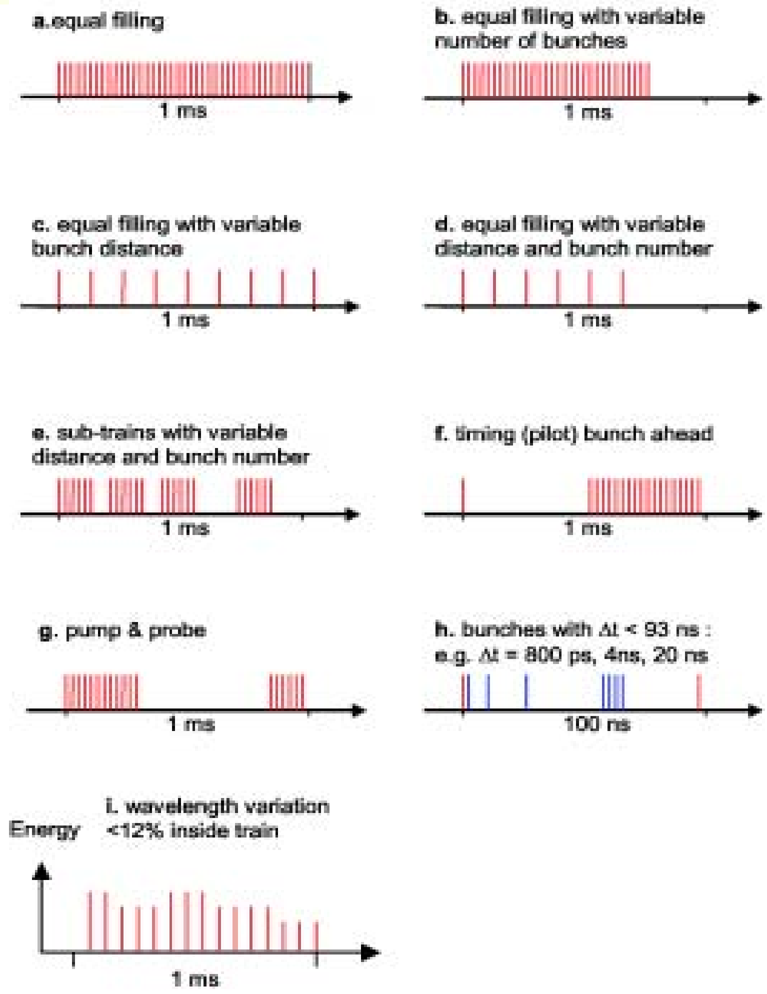
(c) Time Structure

Generation of bunch train patterns:

- At the source → varying transient effects in the entire accelerator (handled e.g. by the LLRF system)
- At the beam delivery/distribution system → more challenging kicker devices

Note: each bunch can lase to saturation!



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4. Present Status of the Project

Present Status of the Project

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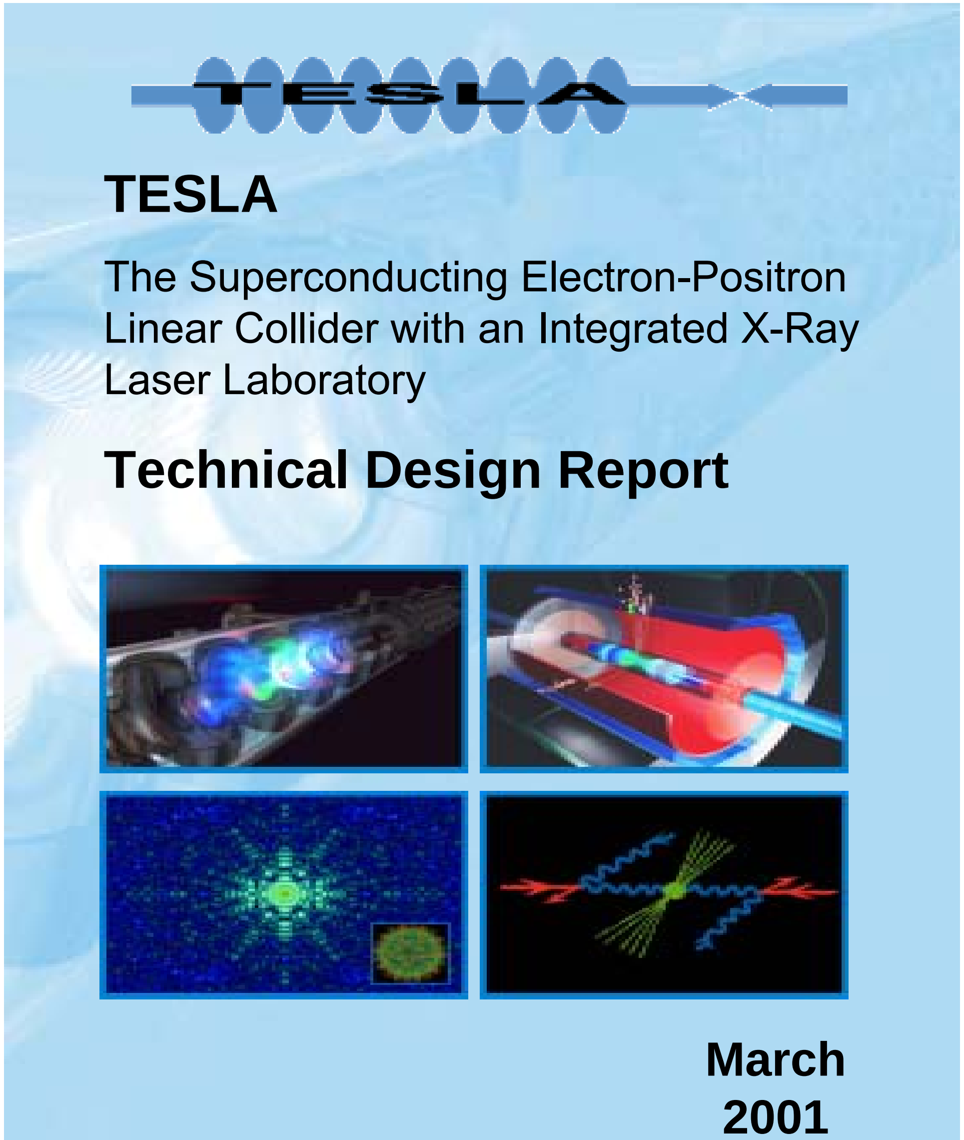


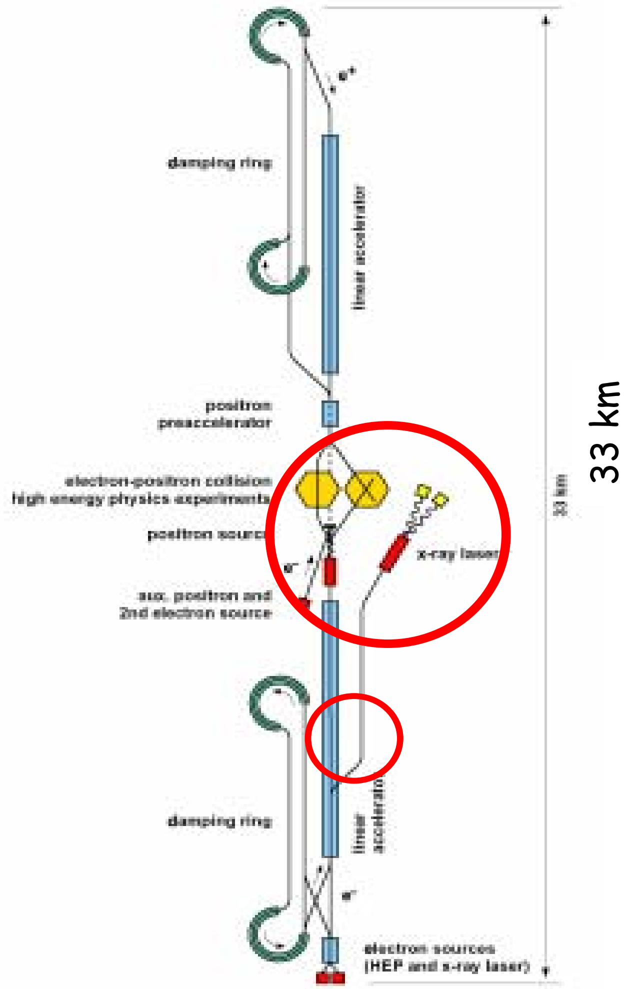
TESLA

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

Technical Design Report

March 2001

History: TDR 3/2001



October 2003

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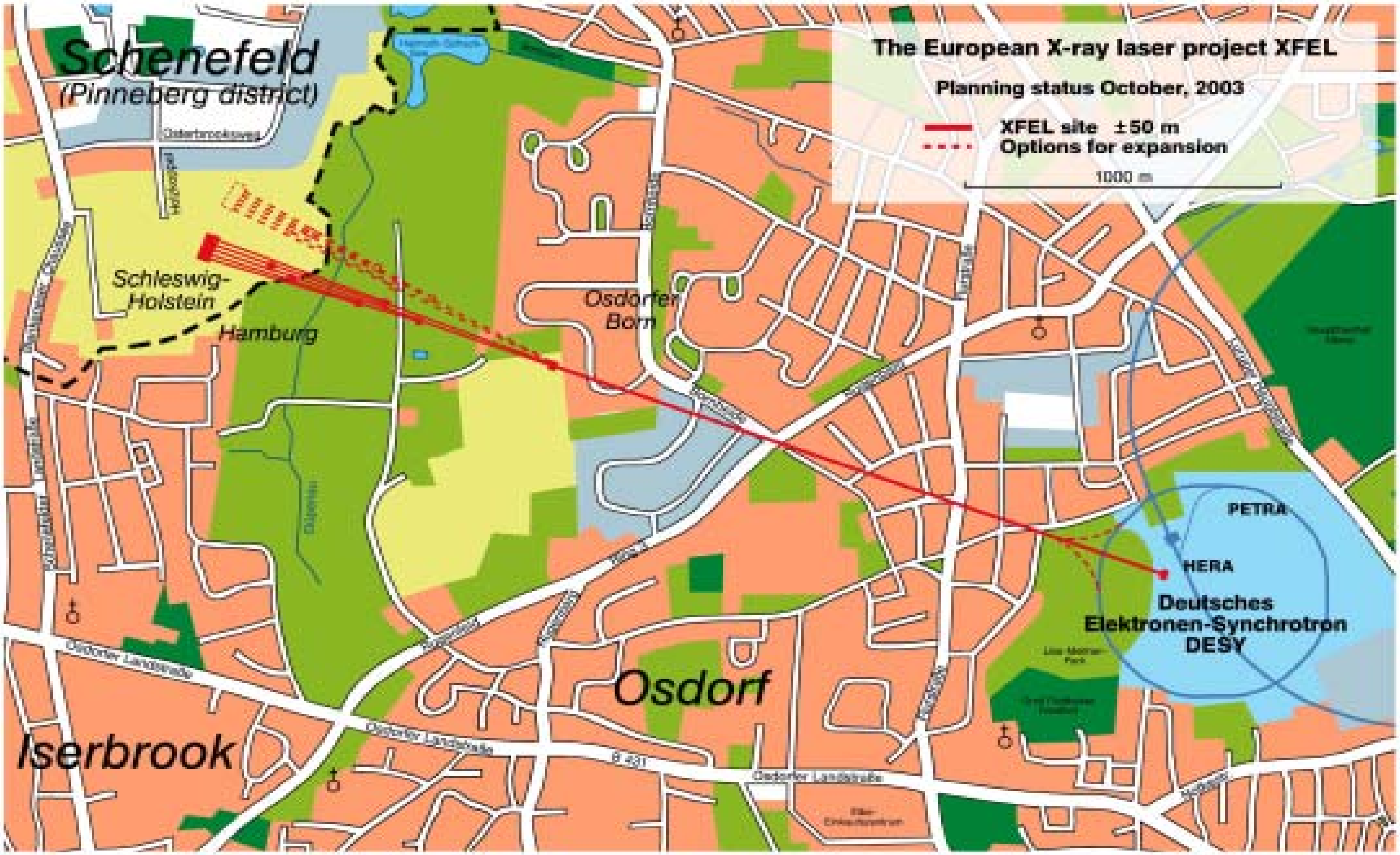
February 2003: Postponement of Linear Collider Decision by German Government
October 2003: New Proposed Site: DESY to Schenefeld



Linac: 2100m Photons: 1100m $E_{beam} \leq 25GeV$ 2 Stages

Proposed Site near DESY - Hamburg

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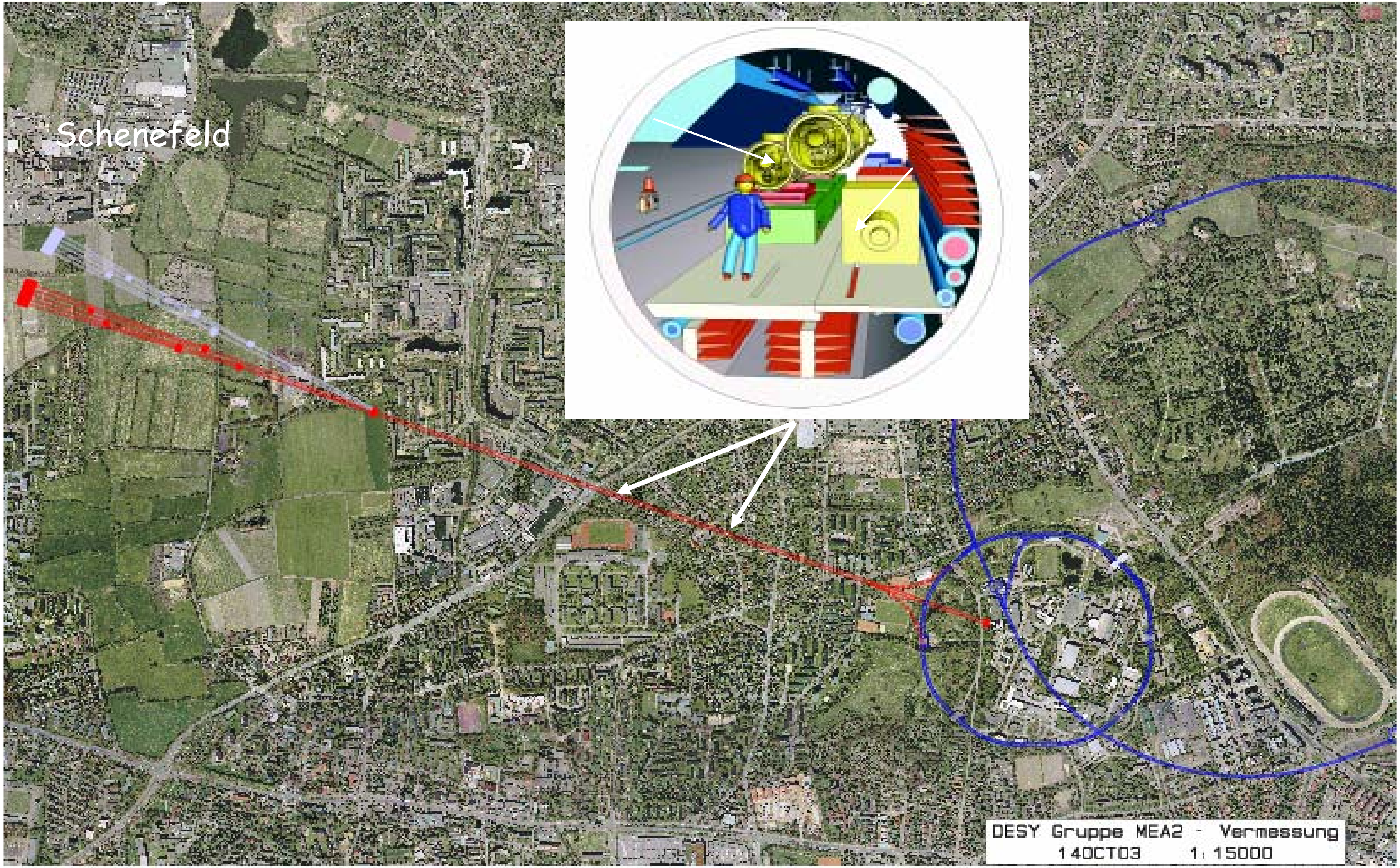

(a) Project Approval Procedure

XFEL
X-Ray Free-Electron Laser

- Background "Project Approval Procedure"
  - It is prescribed by German law for large building projects that affect an appreciable part of the public domain
  - It is mandatory to get approval for construction and operation
  - It is helpful: 'bundling' of many legal approval processes

- Process
  - Need a law that covers the construction and operation of the XFEL
    - "Staatsvertrag" between Hamburg and Schleswig-Holstein to be generated
  - It is mediated by a public authority
  - We have to provide a relatively detailed "macroscopic" layout of the facility (project approval documents)

Project Approval Procedure ff.

XFEL
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Time Table and Status

10/2003	-	Staatsvertrag initiated	✓
02/2004	-	Environmental Impact Study initiated	✓
03/2004	-	"Scoping Date" possibly affected public parties get the chance to request further/special expert reports regarding environmental issues	✓
06/2004	-	Drilling along the planned construction site to study ground properties	✓
07/2004	-	Staatsvertrag signed by governments of Schleswig-Holstein and Hamburg	✓
9/2004	-	28th of September: Staatsvertrag ratified ! (becomes a law)	
11/2004	-	Editorial Deadline for project approval documents	
03/2005	-	Hand in documents plus expert expertises to public authorities	
01/2006	-	Project approved?	
in 2006	-	Start construction?	

Plan of Infrastructure on DESY Site

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(b) Approaching the European XFEL Facility

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August 2003:

Letters of invitation by German Minister of Science and Technology to EU Colleagues:
Establishment of a Steering Committee for the Project at high ministerial level

European Steering Committee "SC"

chairman: H. Schunck
(Federal Ministry of Education and Research)
br. 2nd, 2004

3rd meeting: September 23rd, 2004
4th meeting: January 18th, 2005

"STI"

European XFEL Working Group on Scientific & Technical Issues

chairman: F. Sette
(ESRF, Grenoble, France)
kick-off meeting: April 1st/2nd, 2004

3rd meeting: September 27th/28th, 2004

"AFI"

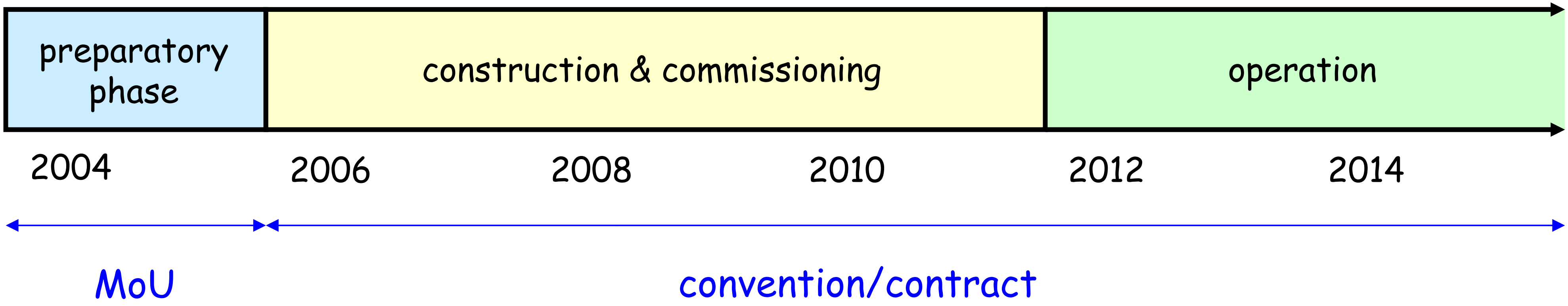
European XFEL Working Group on Administrative & Funding Issues

chairman: H.-F. Wagner
(Federal Ministry of Education and Research)
kick-off meeting: March 19th, 2004

4th meeting: October 11th/12th, 2004
5th meeting: December 20th/21st, 2004

European XFEL Facility

Elements of XFEL organizational scheme



Memorandum of Understanding (MoU)

"Based on these developments (TESLA TDR + Supplement), the signatories of this Memorandum of Understanding want to enter the preparatory phase of a European XFEL Facility ...

... by signing this Memorandum of Understanding the Parties express their interest in participating in the construction and operation of the European XFEL Facility."

...Signing of MoUs by core member countries scheduled for September 28th, 2004...

(c) XFEL – Project Group at DESY

XFEL
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Purpose: Technical Review of the Design; Consolidation; Transfer to new site

⇒ a total of 37 work packages have been created (weekly meetings)

- Overall design & parameters, beam physics
- Major technical components
- Sub-systems
- Other issues (e.g. Plan Approval Procedure)

All work packages have one DESY representative at the moment. This should/will change!

Leadership / participation from other labs/institutions/individuals is highly encouraged!

Work Packages

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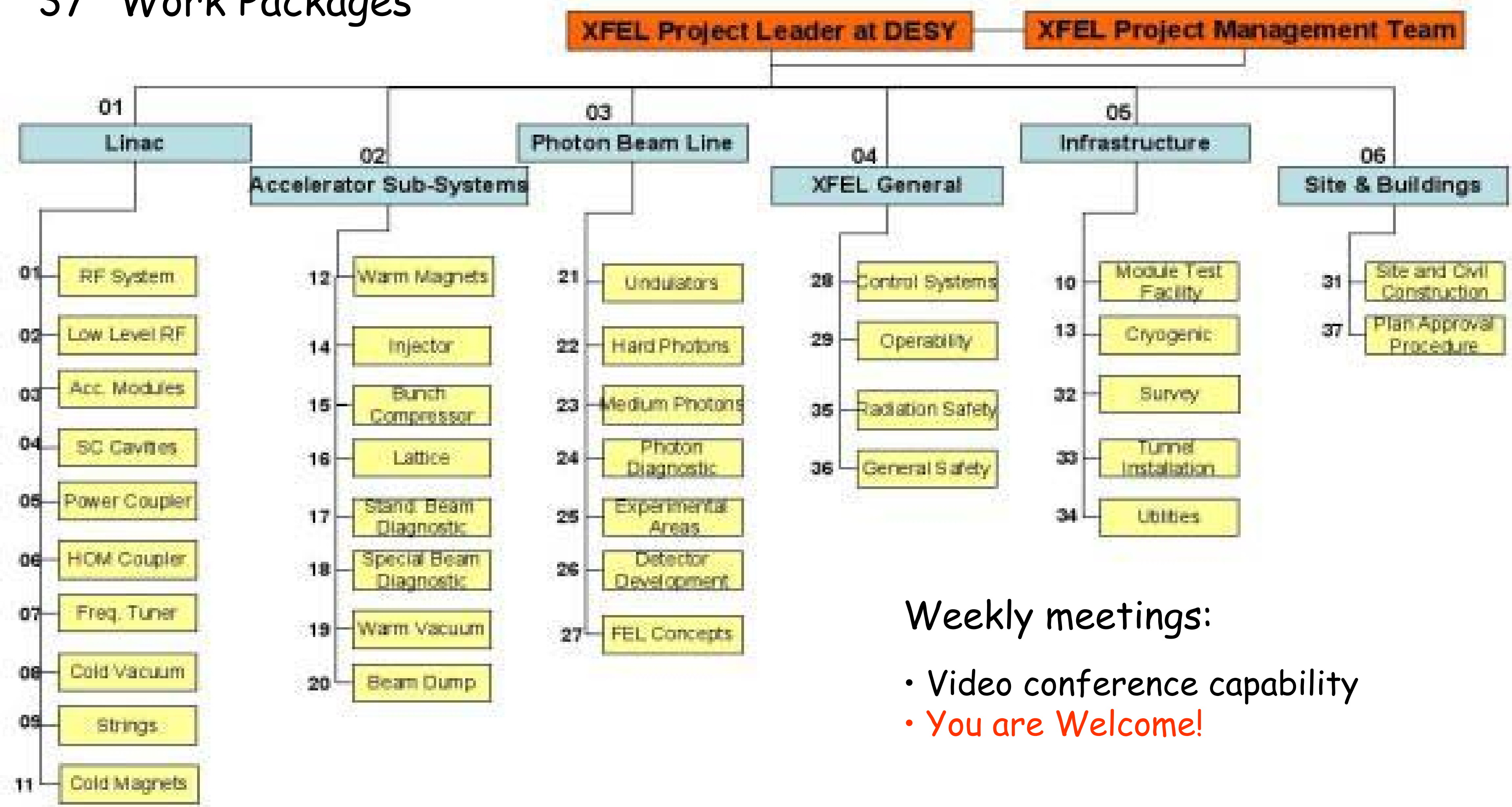
37 "Work Packages"



Weekly meetings:

- Video conference capability
- You are Welcome!

http://xfel.desy.de

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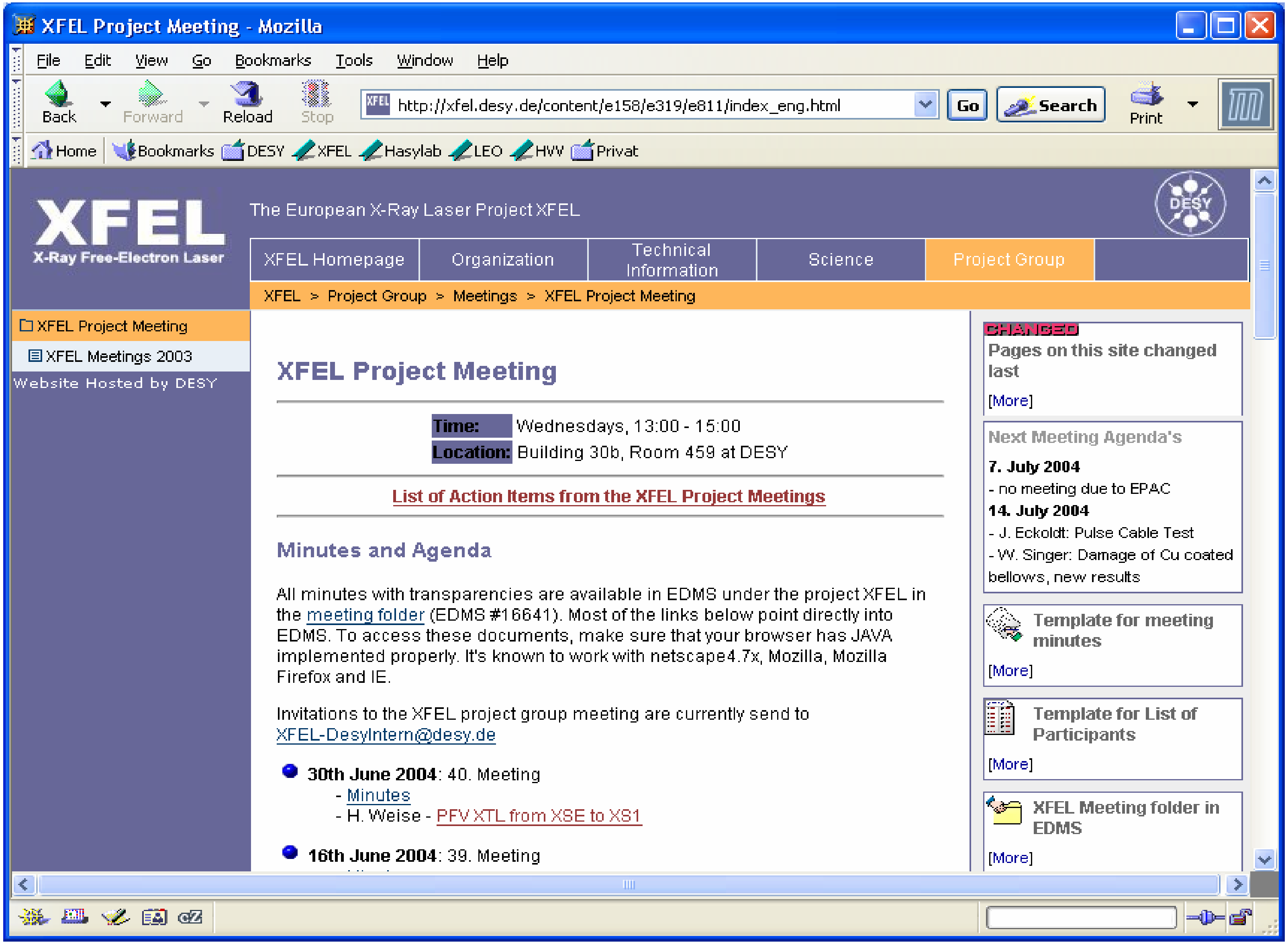

5. Summary

XFEL
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- The European X-Ray Free Electron Laser Laboratory will provide unprecedented opportunities for basic research with photons in the 1Å regime
- The baseline design offers a conservative approach to reach 1Å wavelength
- Much will be learned from current R&D and user operations at the SppS, VUV-FEL and LCLS
- The baseline design is flexible and allows the incorporation of new developments in the photon generation scheme
- The preparatory work for the XFEL is well underway
  - at DESY (XFEL Project Group, Project Approval Procedure)
  - on the European Level (EU Working Groups, Workshops, MoU)
- Timetable:
  - *signing of the Memorandum of Understanding by core members: 2004*
  - *start digging in 2006/2007*
  - *first photons in 2012*

There exists ample opportunities to join in defining the final design of the project!