Workshop on
Technical Challenges of the Proposed European XFEL Laboratory,
DESY, Hamburg, Oct. 30/31, 2003

# XFEL
# laboratory concept

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Topics :
- Undulators for FEL and spontaneous radiation
- Photon beamlines including x-ray optics
- Experiments and experimental facilities

# Overview

## XFEL laboratory concept

- XFEL is intended as a multi-user facility
- Concept of distribution of one electron beam to many beamlines
- Specification of beamlines and their parameters

## Baseline assumptions

- FEL radiation experiments in the x-ray regime (200 eV – 12,4 keV)
- User experiment requirements
- Provide linear and circular polarised radiation

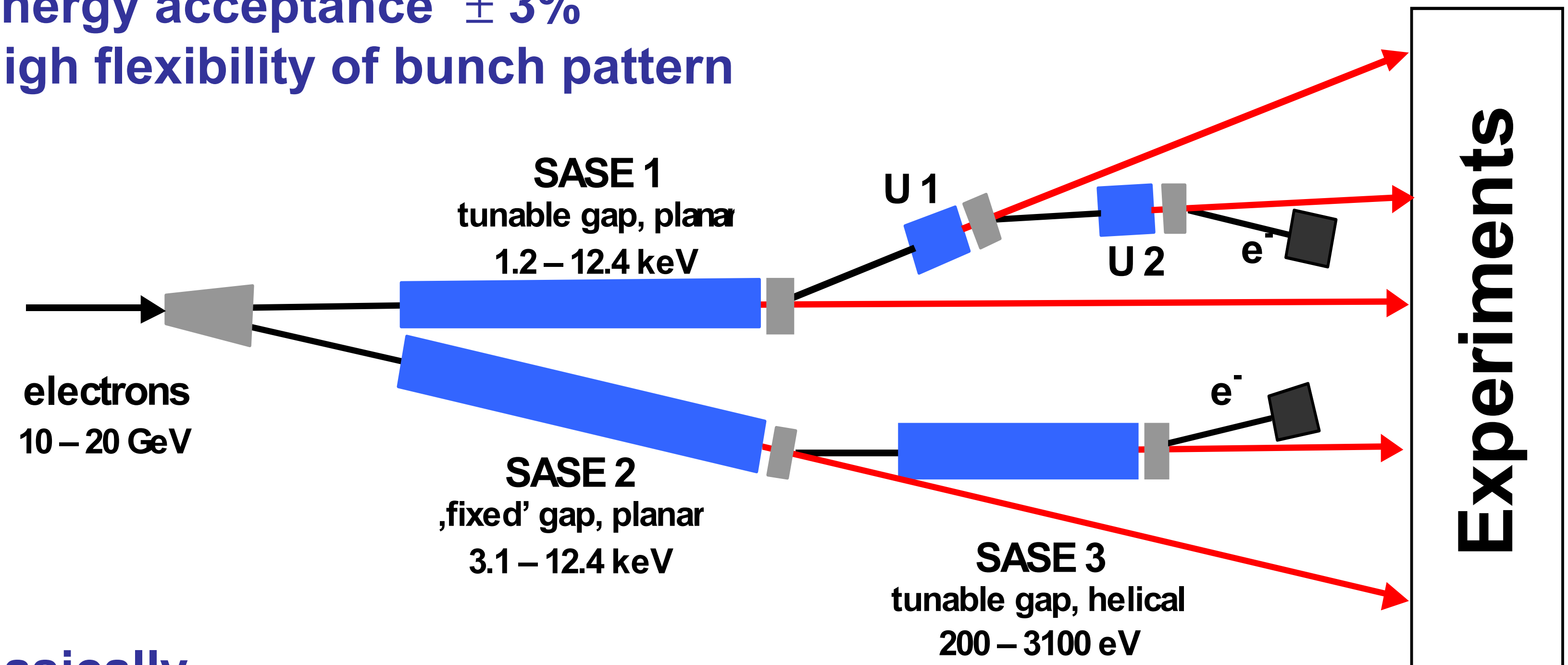
## Efficient usage of electron and photon beams

- Use spent beam for FEL and spontaneous radiation undulators
- Parallel operation of as many experiments as possible
- Minimise down-time of beamlines/experiments

# Electron distribution



**Electron energy 10-20 GeV**
**Energy acceptance ± 3%**
**High flexibility of bunch pattern**




## Basically

- One electron beam into 2 beamlines
- Make use of electrons in either 2 FELs or 1 FEL+2 sp. Undulators

# Photon beam line description

## SASE 1

**Photon energy range 1,0-12,4 keV ($E_e$ and gap tuning)**

**Tunability at 20 GeV : 4,0 keV (gap=10mm) to 12,4 keV (gap=17mm)**

- Spectroscopy and coherence experiments

## SASE 2

**Photon energy range 3,1-12,4 keV ($E_e$ tuning)**

- Diffraction experiments
- Extension to 14,4 keV photon energy
- Full coherence seeding

## SASE 3

**Photon energy range 0,2-3,1 keV ($E_e$ and gap tuning)**

**Tunability at 10 GeV : 200 eV (gap=10mm) to 800 eV (gap=17mm)**

- Soft X-ray spectroscopy and coherence experiments
- Atom, molecule, cluster, and plasma physics

# Beam lines for spontaneous radiation

## Spontaneous synchrotron radiation: U1, U2

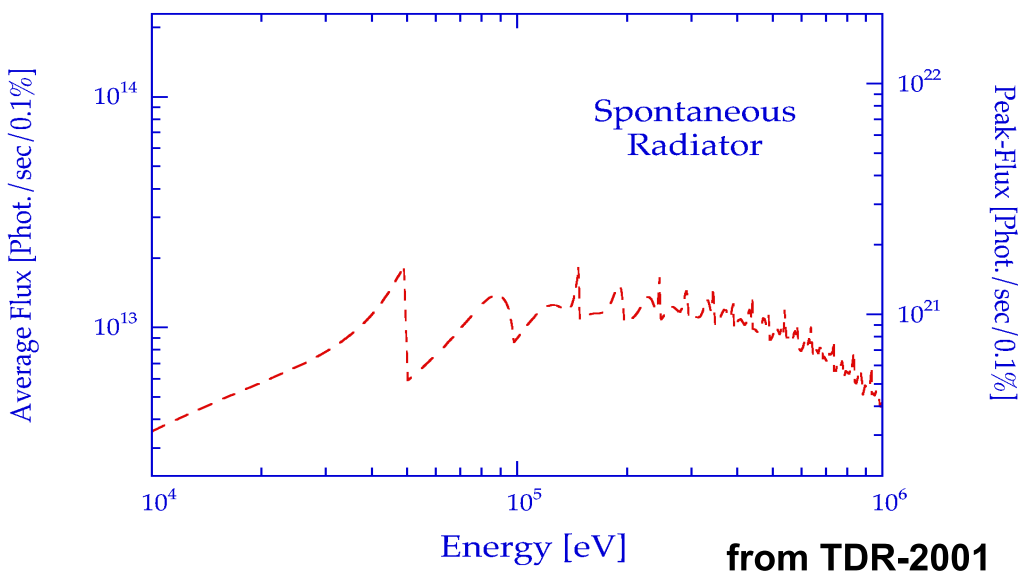
**Photon energy range 12,4 keV to few 100 keV**

**Pulse duration of electron beam: ~188 fs FWHM**

**Photons per pulse ~$10^8$ for 20-300 keV**

**Peak brilliance of the order $10^{28}$ for 20-300 keV**

- Ultrashort, hard x-ray radiation pulses
- Study dynamics in condensed-matter & materials science applications




**from TDR-2001**

# Undulator parameters

## SASE 1

- Planar, gap tunable undulator
- Saturation length 170 m (12,4 keV, 20 GeV)

## SASE 2

- Planar undulator
- Saturation length 145 m (12,4 keV, 20 GeV)

## SASE 3

- Polarisation selectable undulator (Apple design)
- Gap tunable
- Uses spent beam of SASE 2
- Saturation length 95 m (3,1 keV, 20 GeV)

## U1, U2

- Planar, gap tunable (minimum gap 6mm)
- Use spent beam of SASE 1
- Magnet length 50m

**For details of undulator parameters and technology:**

**see posters by E. Schneidmiller and J. Pflüger**

# SASE undulator lengths

## Total length includes

- Saturation length for highest photon energy

+ 22% for intersections (vacuum, quadrupoles, phase unit)

+ 20% contingency (field errors, misalignment, ...)

**SASE 1: 250m SASE 2: 220m SASE 3: 150m U1,U2: 61m**

## Building space allows further options

- Generation of fully coherent radiation by seeding
  - ⇒ **this scheme will be installed and verified at the VUV-FEL**
  - ⇒ **for x-rays: Diamond mono.** **E. Saldin et al., NIM A475, 357(2001)**
- Bunch shortening using a chirped electron beam
  - ⇒ **to be tested for X-rays at LCLS.** **C.B. Schroeder et al., NIM A483, 89(2002)**
- Generation of radiation at photon energies other than 1$^{st}$ harmonic
  - ⇒ **Higher harmonics generation**
  - ⇒ **Visible light generation for pump-probe experiments**

# Undulator realisation

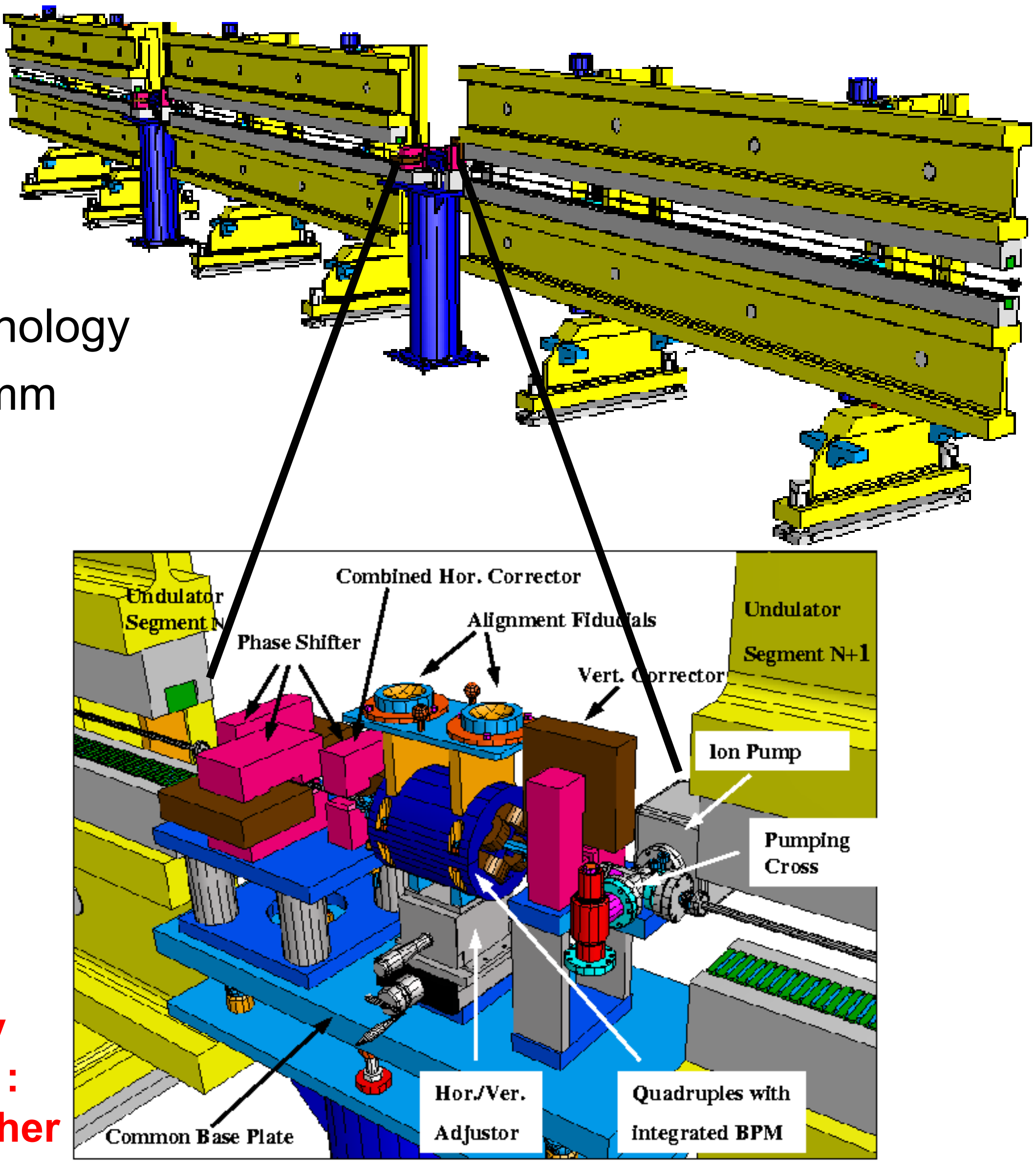
## Design outline

- 5m long magnet structures
- 1,1m intersection
- Hybrid, perm. magnet technology
- Smallest magnetic gap 10mm
- Adjustable gaps

## Challenges remain

- Magnet quality & design
- Mechanics & movements
- Mass production
- Alignment
- Commissioning

**For details of undulator technology and photon beam based alignment : see posters by J. Pflüger & M. Tischer**



# Photon beamlines

## FEL radiation beamlines

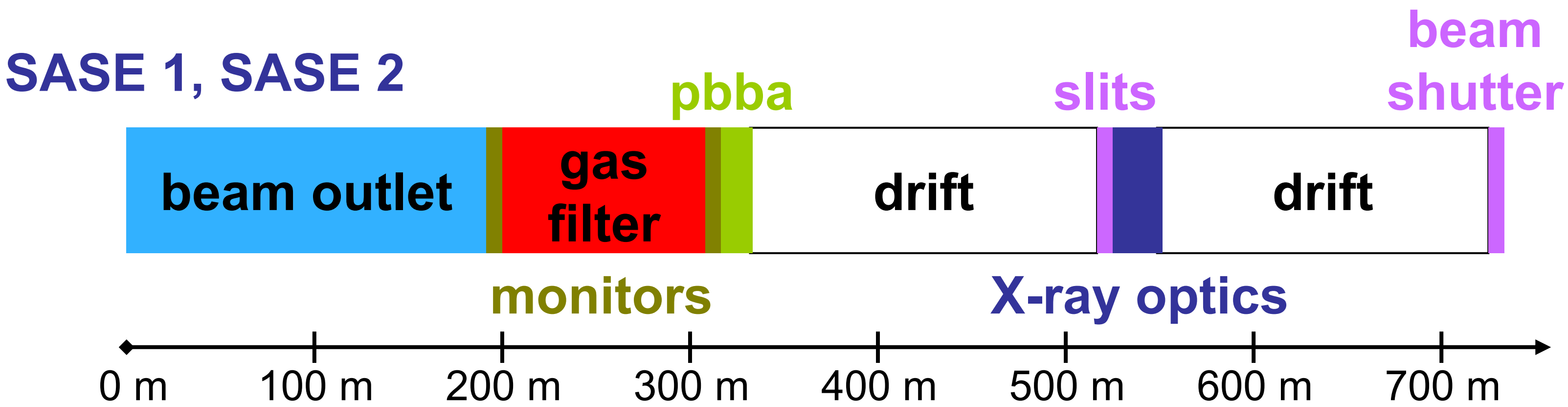
- Preservation of FEL radiation properties : duration, coherence, intensity
- Sufficient length of ~700m (12,4 keV) and ~350m (200 eV)
  - ⇒ **Average power density similar to 3rd gen. SR sorces**
  - ⇒ **Source demagnification > 1000 possible**
  - ⇒ **Requirements due to electron beam & conventional facilities**

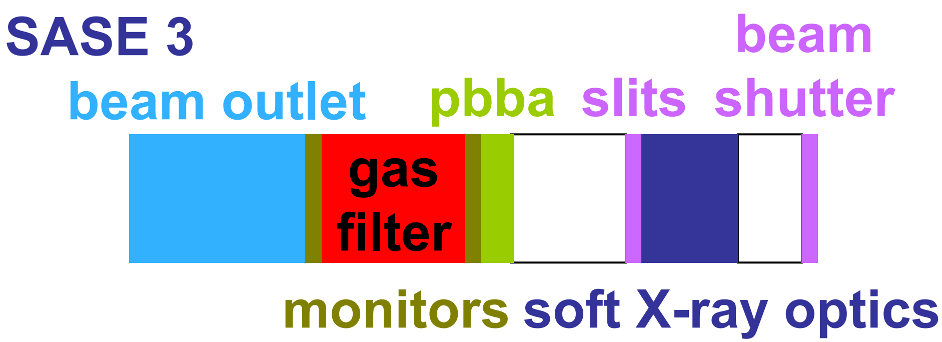
## Generic beamline design

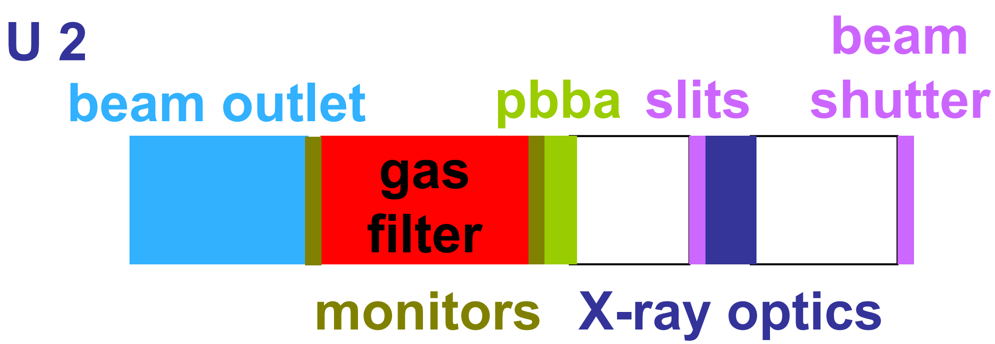
- Long beamlines in tunnels seperated from experimental hall
- Photon diagnostics, absorption cell, beam stop
- Standard x-ray optics here ($10^{-4}$-bw monochromators, mirrors)
- Beam stop for bremsstrahlung
- Photon beam distribution to experiments

**For details of photon beamline design: see poster by U. Hahn**

# Photon beamline layout




**SASE 1 - 770 m**
**SASE 2 - 690 m**
**SASE 3 - 330 m**
**U1 - 600 m**
**U2 - 380 m**

# X-ray optics

## Integrate *standard* x-ray optics into beamline

- $10^{-4}$-bandwidth monochromator
- Mirrors (plane, focussing)
- Fixed-exit geometry
- Block direct beam

## Special optics in experiments area

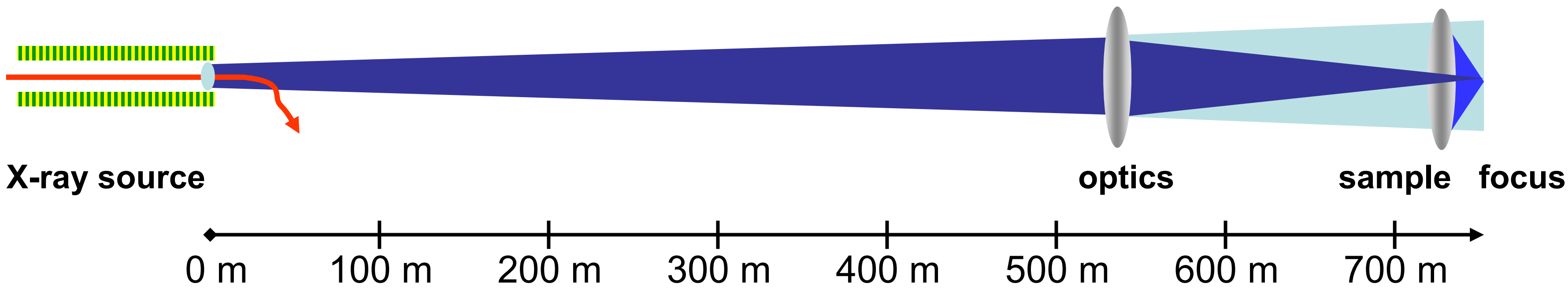
- High resolution monochromators
- Focusing with high demagnification
- Beam splitters and delay units

## Optics requirements

- Propagate coherent radiation
- Withstand power load

**For details of X-ray optics: see poster by H. Schulte-Schrepping**

# FEL radiation power development




| Source | E [keV] | power [W] | source distance [m] | beam size [FWHM-µm] | power density [W/mm²] | remarks |
|---|---|---|---|---|---|---|
| **FEL** | 12,4 | 72 | 0 | 110 | 5.200 | end of undulator |
| | | | 550 | 440 | 330 | x-ray optics |
| | | | 750 | 600 | 180 | experiments |
| | 3,1 | 300 | 0 | 95 | 30.000 | end of undulator |
| | | | 270 | 810 | 400 | soft x-ray optics |
| | | | 370 | 1110 | 210 | experiments |
| | 0,2 | 800 | 0 | 65 | 160.000 | end of undulator |
| | | | 270 | 7290 | 13 | soft x-ray optics |
| | | | 370 | 9990 | 7 | experiments |
| **Sp. rad.** | 50 | 0,08 | 270 | 780 | 0,1 | x-ray optics |
| **3rd SR** | all | >100 | 40 | 1000 | 350 | x-ray optics |

# Diamond as a crystal monochromator

## Characteristics

- Cryogenically cooled (~ 70 K)
- Bandwidth ~$10^{-4}$
- Thickness ~100µm

  ⇒ **Energy absorption per pulse at 12,4 KeV ~100 µJ**

  ⇒ **Temperature jump ~1 K assuming thermal processes**

  ⇒ **No degradation of reflection during pulse is expected**

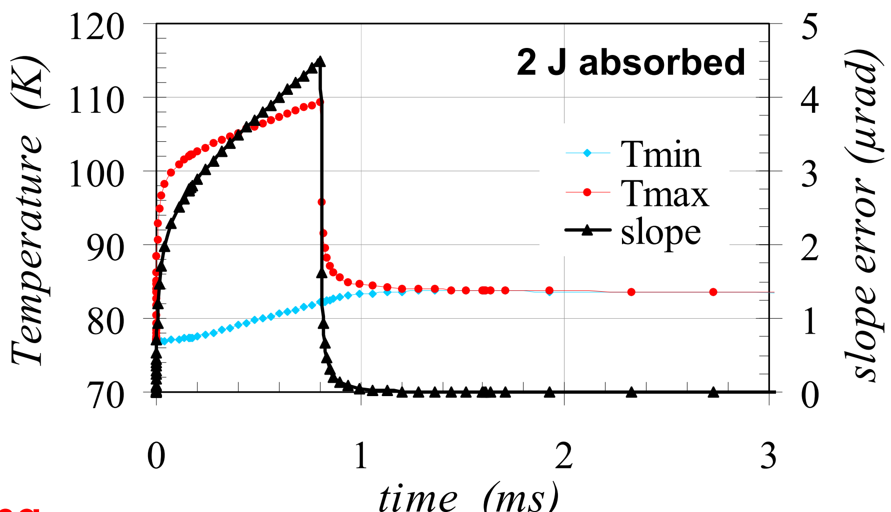
## Response to pulse train

- Thermal relaxation time

  >> bunch spacing

  ⇒ **Temperature rise ~40 K**

  ⇒ **slope error ~3,5 µrad**



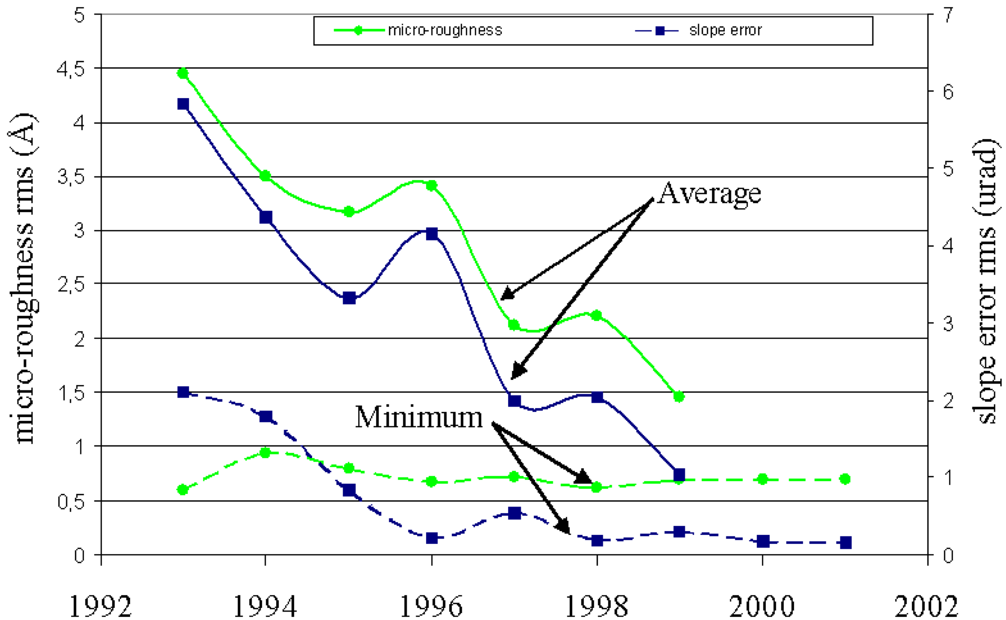

L. Zhang et al, Proc. SRI '03

**For details of X-ray optics: see poster by H. Schulte-Schrepping**

# Mirror considerations

## Performance requirements

- Preservation of brilliance
  - ⇒ **Micro-roughness ~0,1nm**
  - ⇒ **Figure error <~1µrad**
- Diffraction due to coherency
  - ⇒ **at least 5σ acceptance**
- Minimise power absorption
  - ⇒ **Operate below $\theta_c$**
  - ⇒ **Use low Z coatings**




**A. Freund in TDR-2001**

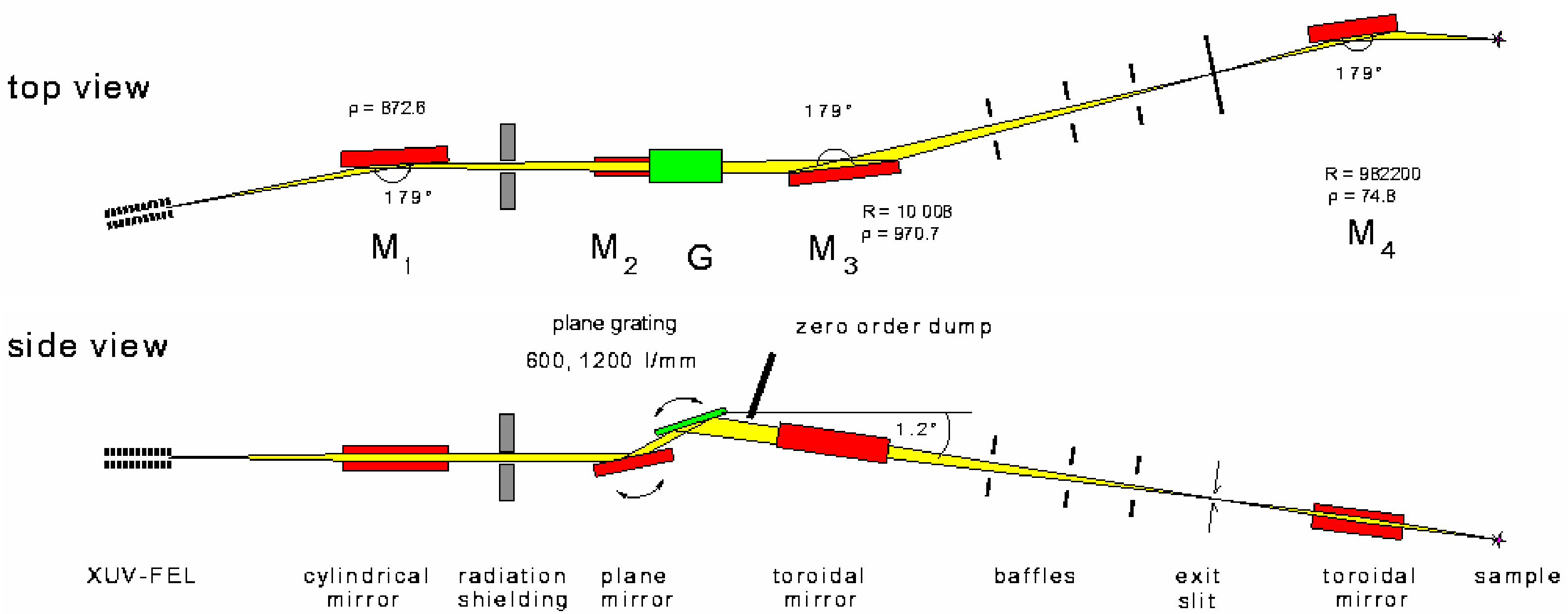
## Proposed realisation

- water-cooled Si mirrors
- dynamic bending
- $\theta$<~1mrad ($\theta_c$~3mrad@12,4 keV)
  - **mirror length ~1m ⇒ ~6σ acceptance** (12,4 keV, 500m)

**For details of photon beamline design: see poster by U. Hahn**

## High-resolution, high-throughput monochromator

- PGM design, energy resolution >10.000
- coverage of full energy range using 600 & 1200 l/mm gratings
- Similar monochromator at VUV-FEL **(M. Martins et al.)**

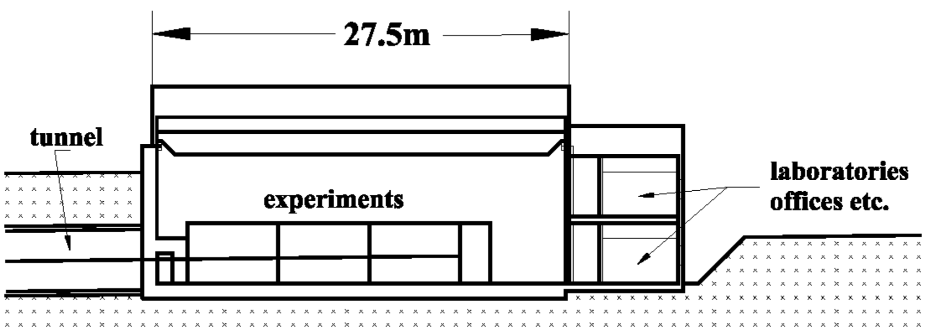


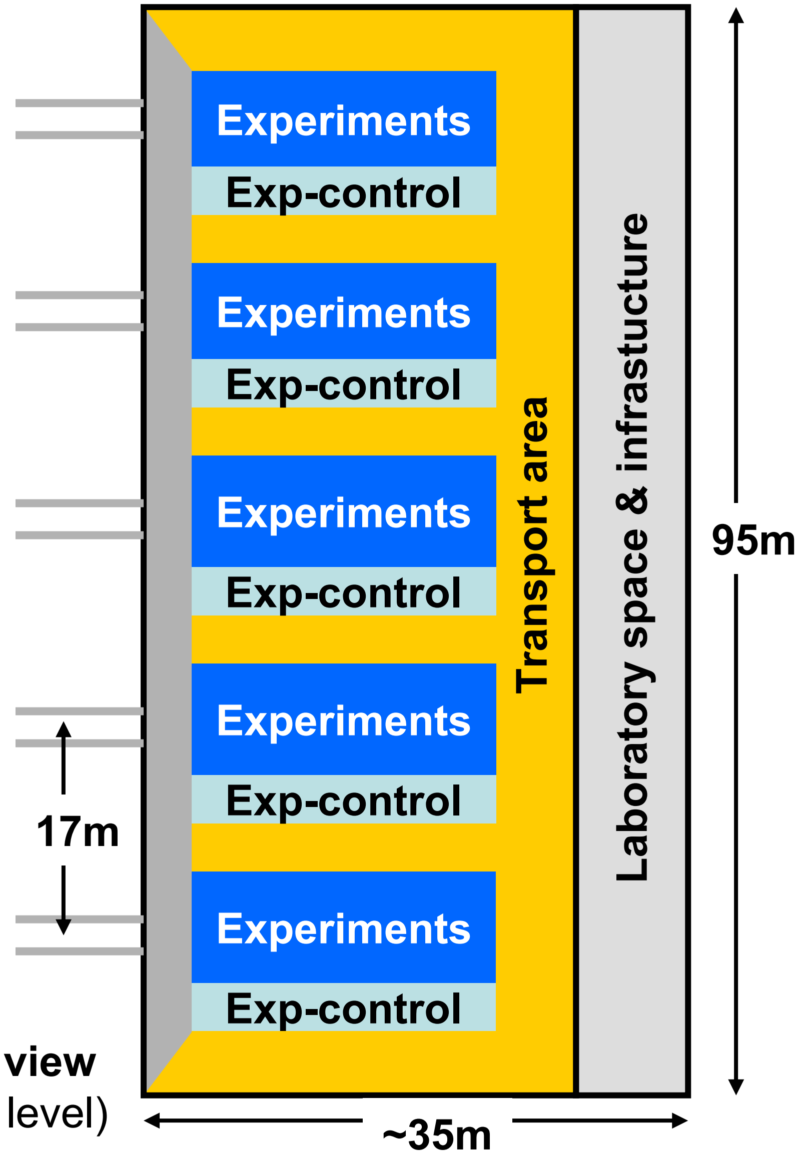

**Layout as described in TDR-2001 based on design by R. Follath, F. Senf (BESSY)**

# Experimental hall

- 5 beamlines
- 10 experimental stations
- laboratory space
- optical laser facility

Side view (from TDR-2002)




Top view
(experiments level)

# Layout of the experiments

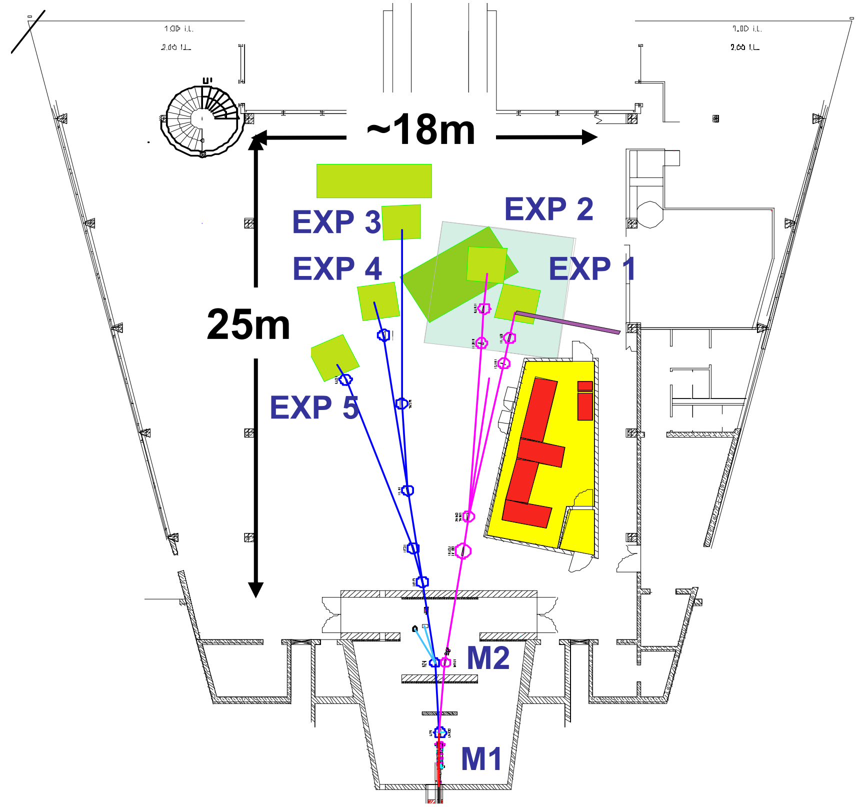
## Beamlines include

- Optics hutch for special optics
  - ⇒ **High-resolution monos**
  - ⇒ **Beam-splitter/delay units**
- Extreme focusing integrated in experimental setup
- Up to 3 experimental stations
- Control area
- 17 m spacing between BL
- 18 m long, 4 m high
- X-ray shielding

## Efficient use of FEL beam

- Fast switching of experiments
- Preperation & pre-alignment

Layout VUV-FEL beamline



# Experiments environment

## Experimental stations include

⇒ Special X-ray optics
⇒ Diagnostics
⇒ Vacuum systems
⇒ Diffractometers and spectrometers
⇒ Detectors

- Mostly integrating detectors
- Store single shot data & sort data by time information
- 2D detectors
- Pixel detectors allow to take data from individual bunches
- R&D needed for
  - fast, low-noise CCDs
  - large Pixel detectors

## Optical femtosecond laser for pump-probe studies

⇒ Central laser or synchronisation of many lasers
⇒ Laser beam distribution

## Preparation laboratories

⇒ Sample preparation and testing
⇒ Off-line tests using optical laser
⇒ Optics and detector labs

# Summary

## Electron beam parameters

⇒ wide range of photon energies

⇒ Flexible operation will be possible

## Undulators

⇒ 3 SASE FEL undulators

⇒ 2 undulators for spontaneous rad.

⇒ Parameter definition according to experiments

⇒ Remaining R&D work has been started

## Photon beamlines & x-ray optics

⇒ Long beamlines with standard x-ray optics

⇒ Main concerns are power and coherence preservation

⇒ Required performance close to today technology

## Experiments

⇒ Dedicated experiments with ancillary laboratories

⇒ Detection will require 2D detectors with very fast read-out

# The end