XFEL, FLASH and E-XFEL STANDARD ELECTRON BEAM DIAGNOSTICS

Dirk Nölle for the XFEL Diagnostics Team

SLAC, May 11th. 2010
DESY has its 50th anniversary
Reception in the City hall of Hamburg
FLASH layout – after the upgrade
E-XFEL/FLASH Time Structure: High Duty Cycle

- Repetition rate
- Macro-pulse
- Bunch
- Slice

- Up to 27000 Bunches/s

FLASH and E-XFEL will have the same time structure
Comparison of machine parameters

<table>
<thead>
<tr>
<th></th>
<th>XFEL</th>
<th>ILC</th>
<th>FLASH design</th>
<th>9mA studies</th>
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<td>Pulse length</td>
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<td>Current</td>
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Nominal experiment setup
- 3nC/bunch
- Bunch rates: 40kHz – 3MHz
- RF systems operating ‘on crest’
- BC magnets on, but no compression
- Beam through Bypass line to dump
- RF gun: 1.5 cell warm PC gun
- ACC1: 8 SC cavities
- ACC23: 2x 8 SC cavities
- ACC456: 3x 8 SC cavities
- LLRF: digital I/Q control of VS
- Piezo tuners: ACC3, ACC5, ACC6
80 bunches, 100kHz, ~3nC/bunch (0.3mA)

Along pulse: 0.035% p-p

2100 bunches, 3MHz, ~2.5nC/bunch (7.5mA)

Along pulse: 0.5% p-p
Pulse-pulse: 0.13% RMS
### SASE performance: 30 Bunches are Standard

**Typical user operation parameters**

- **Wavelength range (fundamental)**: 6.8 – 47 nm
- **Average single pulse energy**: 10 – 100 µJ
- **Pulse duration (FWHM)**: 10 – 70 fs
- **Peak power (from av.)**: 1 – 5 GW
- **Average power (example for 500 pulses/sec)**: ~15 mW
- **Spectral width (FWHM)**: ~1%
- **Peak Brilliance**: $10^{29} - 10^{30}$ B

B = photons/s/mrad²/mm²/0.1%bw

![Multibunch SASE signal (µJ)](image.png)
Long Bunch Train Run at 7 nm in 2008

- 100 bunches 500 kHz for two experiments in March 2008
- Wavelength: 7.05 ± 0.1 nm
- Average SASE level ~30 μJ (14 mW average power)
- We had > 400 bunches lasing @ 1nC
FLASH II

- Main features: Seeding and polarized radiation
- Extend user capacity with SASE and HHG/HGHG seeding
- Tunability of FLASH II by moveable undulator gap
- Using existing infrastructure
- Separation FLASH and FLASH II behind last accelerator module
- Even if the final decision is pending, we can call it a project.
One injector initially installed

Connection to 2nd stage upgrade included in beam distribution layout

- 17.5 GeV superconducting LINAC
- RF photoinjector, two bunch compression stages
- 3 SASE undulators plus 1 spontaneous source, extension possible
- 5 experimental stations to be extended to 10
- Potential extension with a second experimental hall
E-XFEL Time Structure: High Duty Cycle

- Repetition rate
- Macro-pulse
- Bunch
- Slice
- Up to 27000 Bunches/s

Duty cycle ~ XFEL 0.65%

1-5 mA

100ms

1 nC

100-500 fs

2.5kA

XFEL 600μs

Macro-pulse duration

XFEL 222ns

bunch spacing

FLASH and E-XFEL will have the same time structure
Distribution of the electron beam in the beam switchyard

Kicker septum scheme with precision kicker and septum + knock out kicker

- Machine operated with fixed beam loading (only length of the train is varied)
- 3 way switch
  - SASE 1
  - SASE 2
  - Dump
- First bunches send to the dump (used for looking of feedbacks)
- First half train is send to SASE 1
- Second half train is send to SASE 2
- Not needed bunches can be knocked out to the dump
- Civil Construction started 2009
  - Orders of about 250 M€ placed
- Christmas 2009: XFEL Company founded
  - We have a legal entity now!
  - In-kind Contributions:
    - Negotiations and Contracts
- Production Infrastructure under Construction
  - Saclay: Module Assembly Facility
  - Orsay: Coupler Preparation
  - DESY: Advance Module Test Facility
- First big Orders for the Machine
  - Cavity Orders will be placed in May
Accelerator modules – collaborative effort

Vessel & cryostat
- IHEP/Beijing
- DESY
- CEA/Saclay
- INFN/Milano

RF power coupler
- DESY
- LAL/Orsay

Superferric magnet
- DESY
- CIEMAT/Madrid

Freq. tuner
- DESY
- INFN/Milano

BPM
- DESY
- CEA/Saclay
- PSI/Villigen

HOM absorber
- Soltan Inst/Swierk

s.c. cavities
- DESY
- INFN/Milano
Cavity production: Order to be placed soon!
Conditioning rate of 8 couplers per week.
Schedule integrated in overall project schedule.
Direct delivery to assembly site at CE Saclay.
- **Construction work at Saclay** is ongoing;
- cranes, cantilever, all big assembly tools are ordered
- **clean room infrastructure inauguration Nov 2009**
- Vibration/shock-damped transport frame developed in industry
- After truck transport to Saclay, back on CMTB for RF test:
  - No mechanical damage, no vacuum leaks
  - Cool-down and RF-powering without problems
Refurbished DESY Clean Room

- Increased ISO4 assembly area
- Chemistry and ultrasound infrastructure now in ISO6/5 instead of ISO7/6
- New rotational clean room airlock
- Reduced power consumption

- DESY will be able to handle (few exceptional) performance “problem cases” of cavities and modules from series production
XFEL Accelerator Module Prototypes
The accelerator module PXFEL1 was conditioned and tested at the Cryo-Module Test Bench (CMTB).

The average maximum gradient is **32.5 MV/m**.

After string and module installation we have seen a **gradient reduction of only 5%**.

PXFEL1 will be installed at FLASH and **can be operated** there with an average gradient of **30 MV/m**.

The **XFEL waveguide distribution** will be used.
Installation tests in the mock-up tunnel
3rd harmonic accelerator module

Contribute 8-cavity 3.9 GHz module for XFEL

- Smaller version with 4 cavities built at FNAL in collaboration with DESY
- Installed at FLASH after successful test with RF
- Invaluable experience for XFEL
Civil construction started, First **series modules** on teststands mid 2011

- Wroclaw Univ., INP Cracow
- DESY
- BINP/Novosibirsk, IHEP/Protvino
AMTF civil construction

- Laying of foundation stone July 21, 2009
- Start of construction work
- The hall a few weeks ago
E-XFEL Diagnostics

DESY Site

You can already see something!
Pictures taken in April 2010

WEBCAMS: http://www.xfel.eu/project/webcams

Schenefeld (Exp. Hall)

Acceptance of the tunnel boring machine
3.2.2010
tunneling starts in June!

Osdorfer Born (Beam Distr.)
## Accelerator schedule (very coarse!)

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*first experiments*
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<th>Drift (1 week)</th>
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<th>x / y Crosstalk</th>
<th>Charge Dependence (Dx for D/I = 0.1)</th>
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<td>± 1.0</td>
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High Precision Beam Position Measurements
- Resolution of 1 µm @ 1nC
- Cavity BPM with Reference and Dipole Resonator
- 2 Types with "same" RF Properties
- 3.3 GHz, Low Q (~ 70)
- No tuning -> Precision Manufacturing
- Ready for Series Production

BPM Test Facility behind the FLASH Undulator:
- 3 small, 1 big cavity BPM
- Button Array with 3 Button BPMs in a row

Reference Resonator
Dipole Resonator
Coupling Slits
Connector holes
- We need 120 of these sections!
- Contributions from Spain, Sweden, Russia, Germany
Undulator BPMs

17 Undulator Cavity BPMs with 3.3 GHZ resonance frequency produced so far (this includes discs and brazing), 9 with feedthroughs

- Problem: Brazed HF contact between discs caused lower internal quality factor

- Solution:
  - Braze with pure Cu wire higher temperature (T>1050°C)
  - Move brazing joint as close as possible to the resonator

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<tr>
<th></th>
<th>$f_L$ (Dipole) / MHz</th>
<th>$Q_L$ (Dipole)</th>
<th>$f_L$ (Ref) / MHz</th>
<th>$Q_L$ (Ref)</th>
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<td>70±10</td>
<td>3300±50</td>
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<td>All (17)</td>
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<td>72.8±4.2</td>
<td>3290.2±9.4</td>
<td>66±18</td>
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<td>Good HF-contact(13)</td>
<td>3297.3±9.3</td>
<td>73.2±4.1</td>
<td>3291±10</td>
<td>74.4±6.3</td>
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Errors of measurement are standard deviation
Changes of Brazing Geometry

Brazing Joint
old position

Brazing Joint
new position

Cu/Sn -> pure Cu wire
T > 1050 °C
Cavity BPM: 40.5 mm Beampipe Type

- 3.3 GHz, 40.5 mm Beampipe BPM for high precision measurements and Fast Intra-Bunchtrain Feedback System
- Design and first Prototypes ready
- RF Measurements correspond to Expectations
- Prototypes installed in FLASH (and PSI test facility)
- First Beam Measurements, next weeks
2 Types of Cold BPM (Button, Re-entrant Cavity)
- Modest Resolution: 50 µm
- Operation at 2 k Level (-272 °C)
- Close to the Cavities -> Clean room Class 10!
- Installed in XFEL Prototype Accelerator Modules
- Series Production (80 Pieces) will start in 2010
Cold Re-entrant Cavity BPM

- About 1/3 of cold BPMs will be cold re-entrant cavity BPMs
- Operation at 4K
- Monopole mode around 1250 MHz and Q around 24
- Dipole mode around 1725 MHz and Q around 59
- Single bunch measurement
- Signal processing electronics uses a single stage down conversion to obtain $\Delta/\Sigma$
- RF front-end electronics based on a Printed Circuit board
- $\Sigma$ signal uses by a direct detection using a Schottky diode detector
- $\Delta$ signal uses an I/Q demodulator
- Digital electronics designed by PSI

Dirk Nölle, DESY, SLAC, May 2010

Re-entrant BPM mounted in a XFEL prototype cryomodule

Re-entrant RFFE board

Poster by Claire Simon, CEA
Cavity & Button BPM Electronics (PSI Designs)

**Undulator RFFE**
- 3.3GHz (cavity BPM)
- IQ demodulation
- Requirements: Sub-\(\mu\)m resolution & drift

**ADC Mezzanine**
- Six 16-bit ADCs
- 160Msps

**FPGA Carrier Board**
- Virtex-5 FPGAs
- Flexible interfaces: 1-5Gbit Rocket IO, VME, VXS, Ethernet
- Two mezzanines: 500-pin connectors

Low-cost version of IBFB carrier board (no DSPs, …), used for all E-XFEL BPMs

**Modular BPM Unit**
Crate: customized power, backplane & cooling: low noise, high temp. stability

2 cavity BPM or 4 button BPM RFFEs

FPGA/ADC board
BPM Electronics by PSI (and CEA)

- RF Front Ends
  - Cavity: 2nd Prototype iteration
    beam test: Q3/2010
  - Reentrant: PCB Prototype
    beam test: Q3/2010
  - Button: Circuit layout
    beam test: Q3/2010

- ADC Mezzanine for GPAC
  - 16 bit: first prototype works well
  - 12 bit: test with button RFFE in Q3/2010

- GPAC: Prototype production
  test with 16 bit ADC in Q3/2010

- MBU: first components in house
  prototype test in Q3/2010
Intra-Bunchtrain Feedback (PSI Contribution)

Large transverse random perturbations: needs fast intra-train feedback to get \(\sim 3\mu m\) stability in undulators

Ultrafast FPGA-based bunch-by-bunch feedback + adaptive DSP-based train-to-train feed-forward

Existing prototype:
- 4x500Msps 12-bit ADCs
- 2x1Gsps 14-bit DACs
- 4 Virtex4 FPGAs + 2 DSPs

Low-Latency BPM & Signal Processing Electronics

High-BW Stripline Kicker Magnets & Power Amps

Dirk Nölle, DESY, SLAC, May 2010
HOM based monitors for
- beam diagnostics
- cavity/cryo-module diagnostics
- DESY, Manchester Univ. / Cockcroft Inst., Rostock Univ.
- experimental studies at FLASH, ERLP, the wire test facility at CI

HOM-BPMs
- monitor 1 dipole mode and calculate beam position
- proof of principle already made
- resolution expected ~ 1 \( \mu \)m
- advantages:
  - center beam → minimize wakes → critical for 3.9 GHz cav. and at low energies for the 1.3 GHz
  - no new vacuum component
- Go to µTCA Standard with double Size Boards and the RTM Extension
- Try to restrict to few Standard AMC Boards
  - DESY AMC02: Multipurpose Board with VIRTEX5 and 4 optical Links
  - Struck 8300: 10x16 Bit, 125 MHz ADC with VIRTEX5 FPGA
- Customize by application specific RTM
- Establish common “Firmware” Framework for these few boards
Technical Issues: Charge

- DESY Style Toroid:
  - about 40 devices required
  - charge range < 1 nC
  - min. bunch spacing 222 ns
  - arbitrary bunch pattern
  - Prototypes of Ceramics ordered, delivery in July

![Ceramic Gap](image1)

![Beampipe with Gap](image2)

Ferite core (Transformer)
2ndary Coils not visible
- Toroid Readout will base on μTCA DESY AMC02 Board
- Use Powerful FPGA for Charge Processing
  - Connectivity to other Toroids via up to 4 digital links
  - Comparison of charge values for fast transmission interlocks
  - Check of Time Structure possible
  - Provide digital data stream with Charge Information to LLRF
- with custom made Rear Transition Module
  - Analog Signal Conditioning
  - 108 MHz ADC
  - Connection to the Machine Protection System
Dark Current Monitors

- Gun Dark Current: main reason for losses and activation
- Need to control and collimate Dark Current
- DC Monitors: 1.3 GHz Cavities with moderate Q(200)
- Sensitivity ~ 0.5V/mA
- Option for Small Charge Operation
- Prototypes installed at FLASH (and PITZ)
- First Beam Tests during FLASH startup (now
Beam Size Measurements with OTR and Wire Scanners

OTR Main System up to 2 GeV
- Flexible System in Combination with TDS and Kicker System
- Images give more/intuitive Information than just two Profiles
- Risk: Coherent Transition Radiation: Foresee WS Ports for critical Stations

Wire-scanners in the Distribution Line and before SASE1/2
- “Fast” Scanners to allow for Scans within one Bunchtrain
  - 1 m/s; trigger jitter < 10 µs
  - Wire can stand about 800 bunches @ 1 nC
  - Separated Units for X/Y
  - Resolution about 1 µm
Hotspots for Screens/WS
4 stations with known phase advance for optics characterization

X-FEL uses OTR and fast Wire Scanners
- to check and detect beam at critical places
- to match the optics and to measure Emittance at
  - Injector (OTR)
  - Bunch Compressor B1 and B2 (OTR)
  - in the Collimator (OTR/WS)
  - before the Undulator (WS)
- to measure slice parameters in combination
  with a transverse mode structure in
  - Injector
  - Bunch Compressors B1 and B2

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<th>OTR</th>
<th>OTR Off Axis</th>
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Beam Size Measurement: TDS + Kicker

Similar Sections for
- Injector (130 MeV)
- BC1 (500 MeV)
- BC2 (2 GeV)

by Courtesy of C. Gerth, DESY
Requirement: Record On-Axis and Off-Axis (kicked/streaked) Profiles

Resolution 10 µm

Idea: Use “Scheimpflugs” Principle from large format photography

Get a sharp image of an entire plane, if focus, image, and object plane cut in a single line
Design a new scanner based on Linear Motors
Proof of principle Experiment: Success; Trigger Jitter < 10 µs
  ▪ Go for this system!
Electronics (Commercial + µTCA)
  ➔ Commercial Linear Motor with (customized) commercial Controller
  ➔ µTCA based readout of Wire Positions + Interlocks (Board 1)
  ➔ µTCA based Detector (BLM) Readout, independent from Scanner (Board 2)
Wire-Scanner Impressions

- Acceleration/Deceleration 16.5 mm, const. Velocity: 20 mm
- 53 mm Stroke, max speed 1 m/s

Scanner vertical DN50

Titan
TI-Bellow

Scanner horizontal DN50

hor. Fork in / vert. Fork out
Forks cannot hit

OTR-Mover/Screen

Strahl

Viewport DN40

TI Flange
- OTR Wirescanner in on Block
- Space is tight due to emergency road in the tunnel (left side is almost forbidden)
Beam Loss Monitor System for XFEL

Copy of FLASH System with State of the Art Electronics

- Micro-TCA crate
- Readout Electronics
- HV Power supply
- Alarm (to Machine Protection System)

- Two RTM Module/DAMC02 Combinations
  - Comparator, ADC, Alarm Generator
  - Test Pulse Driver
  - HV via slow interfaces to µTCA Crate

- ~300 Beam Loss Monitors (More than half – in undulator area)

- BLMs: IHEP Protvino
  - Readout Electronics, HV: DESY
Beam Loss Monitor Prototype Based on R5900

28 mm Hamamatsu R5900 PMT:
- 30 mm scintillator and light-guide
- 100 uA continuous anode current (maximum)
- $2 \times 10^6$ gain (at 800 V), 900 V maximum
- “old” HV-divider (HERA-B)
- 4 PMT anodes connected together
- differential signal output (with transformer)

Test with signals from losses at FLASH:
- signal shape and amplitudes →
  input for readout electronics development and new HV-base (larger capacitors)

Next tests:
- BLM based on Cherenkov light measurement →
  BLM with lower sensitivity for places with larger expected beam losses (collimation section)

We got 400 PMTs from HERA-B 😊
Fast Alarm with a Comparator, detailed analysis with ADC
Currently the focus is on items produced in bigger numbers

First Activities

- Dosimetry System: Investigation of Detector Types

No work on

- Special OTR Stations for the BC and Dumps
- E-BPM Mechanics and BAM
- Synchrotron Radiation Ports (High Energy)
- Gun Diagnostics (want to clone recent PITZ/FLASH)
Welcome on board
… we are looking forward to seeing you in Hamburg

DIPAC2011
in Hamburg; Germany

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