Detector Calibration Concepts and Status of the Calibration Working Group

Jola Sztuk-Dambietz (XFEL)

on behalf of

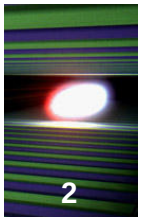
the Calibration Group

November, 19th 2012

13th Meeting of the XFEL Detector Advisory Committee

European XFEL GmbH, Hamburg

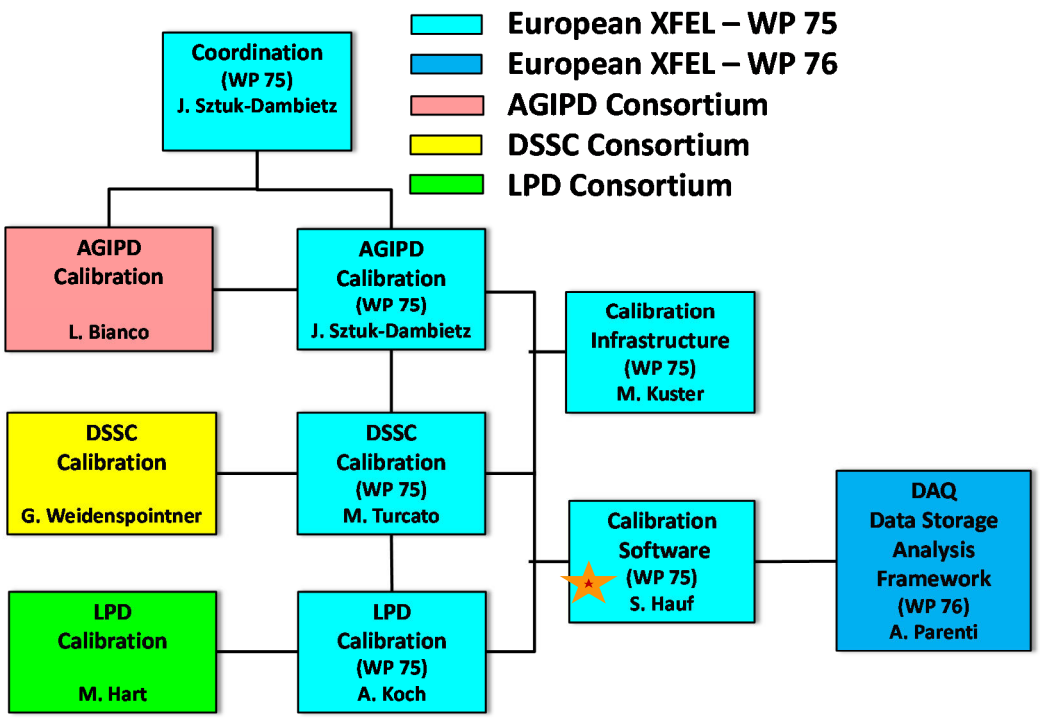
Outline



- Introduction
- Detector calibration group – status update
- Highlights from the last Calibration Meeting
- Infrastructure for detector calibration and tests
- Calibration software – status update
- Summary & plans

Calibration Working Group – Update

Structure of the group:



Physicist for Software Development

★ **S. Hauf started in September:**

- interface to and support of external detector consortia in terms of calibration and data analysis software
- develop and maintain:
  - calibration software & calibration data base for imaging detectors
  - detector-specific data analysis and image processing algorithms
  - detector response & performance simulation software

- **Meetings:** every 6 months

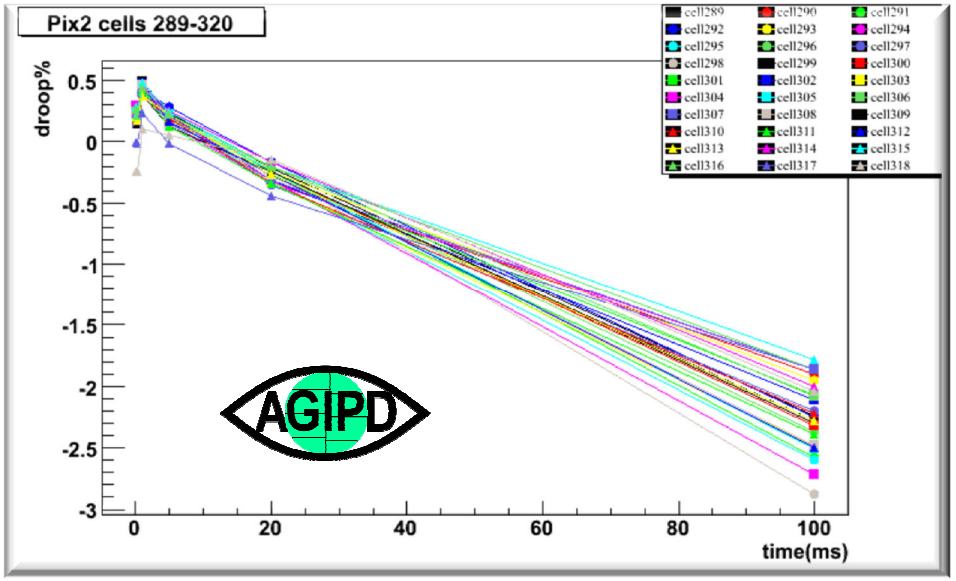
  → next meeting in March

Highlights From the Last Calibration Meeting (I)

- Last calibration meeting took place in September
- Participants: Consortia, XFEL WP-75 and WP76 representatives
- Status of calibration activities in the consortia and XFEL was shown:

AGIPD:

- **Memory droop:**
  - **@ room temperature, a droop effect smaller than 4 % up to 100ms was observed**
  - **Further steps: dependence of droop effects on temperature and irradiation**

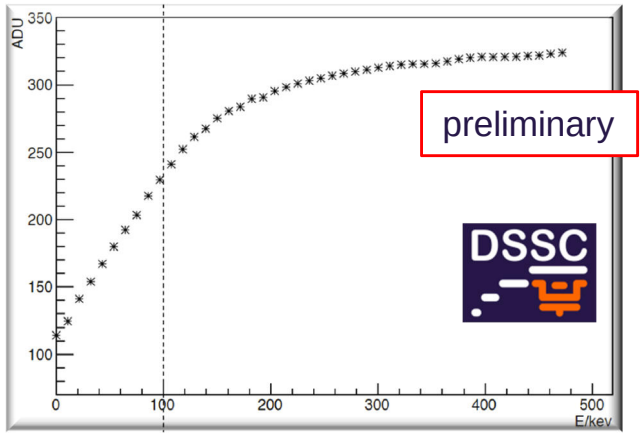


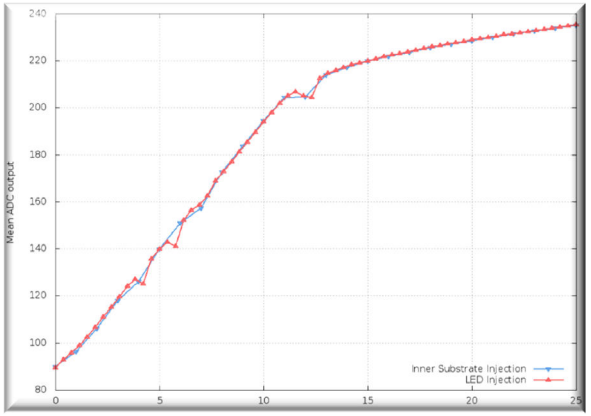
Highlights From the Last Calibration Meeting (II)

DSSC: calibration of DSSC prototype

DSSC prototype = pxd-7 prototype + ASIC prototype

- **Calibration of non-linear system gain (NLSG) for 1 keV photons**
  - **First step:** scan the linear region with ^{55}Fe and fit the 8-bit ^{55}Fe spectrum using a spectral model obtained from the high resolution 14-bits ADC
  - **Second step:** scan the dynamic range of the prototype system, both linear and non-linear region, by pulsed charge injection and calibrate charge injected per pulse by comparison to ^{55}Fe signal





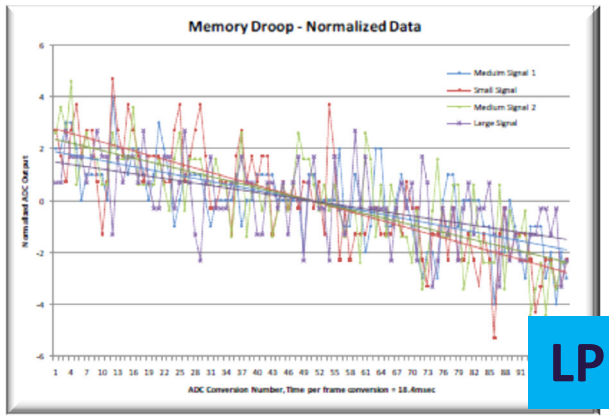
- **Two independent scans of pixel characteristic:**
  - **pulsed internal charge injection via inner substrate contact**
  - **pulsed LED**

- **Software development is ongoing in parallel to experiments and covers all calibration steps.**

Highlights From the Last Calibration Meeting (III)

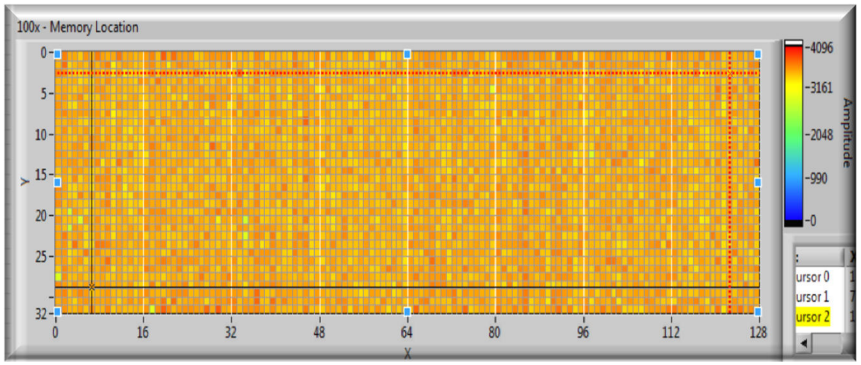
LPD: Characterization of two-tile system (memory droop, gain variation, offset)

Memory droop

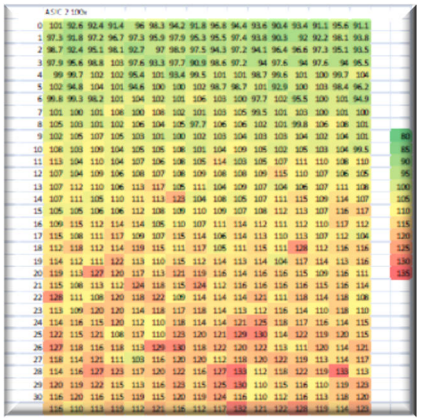


LPD

Offset and dead pixels



Gain variation



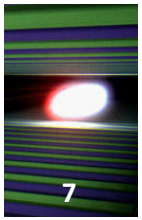
Memory leakage is not an issue

<< Memory and ADC noise

- **Infrastructure requirements** for the calibration and characterization of the LPD systems were defined
- First version of calibration document (calibration concept) is available
- A **two-tile system** will be delivered **to the XFEL** in Q4 2012.

→ More details in the consortia talks at the general and closed sessions

Highlights From the Last Calibration Meeting (IV)



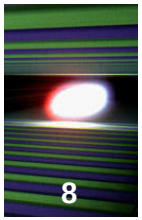
XFEL:

- Status of the test infrastructure at the XFEL → see later in the talk
- Status update of the XFEL scientific framework (Karabo)
  - Work on a software framework for distributed applications is ongoing → serves control framework and data analysis framework.
  - Initial version to be distributed to the consortia in Q2/Q3 2013 (mandatory !!!)
  - Calibration constants and files will be stored in HDF5 files and included in the XFEL database

    → Work on definition of data format, structure and data base is ongoing

    → First stable version needed in mid-2013

Calibration Status – update



Performance characteristic

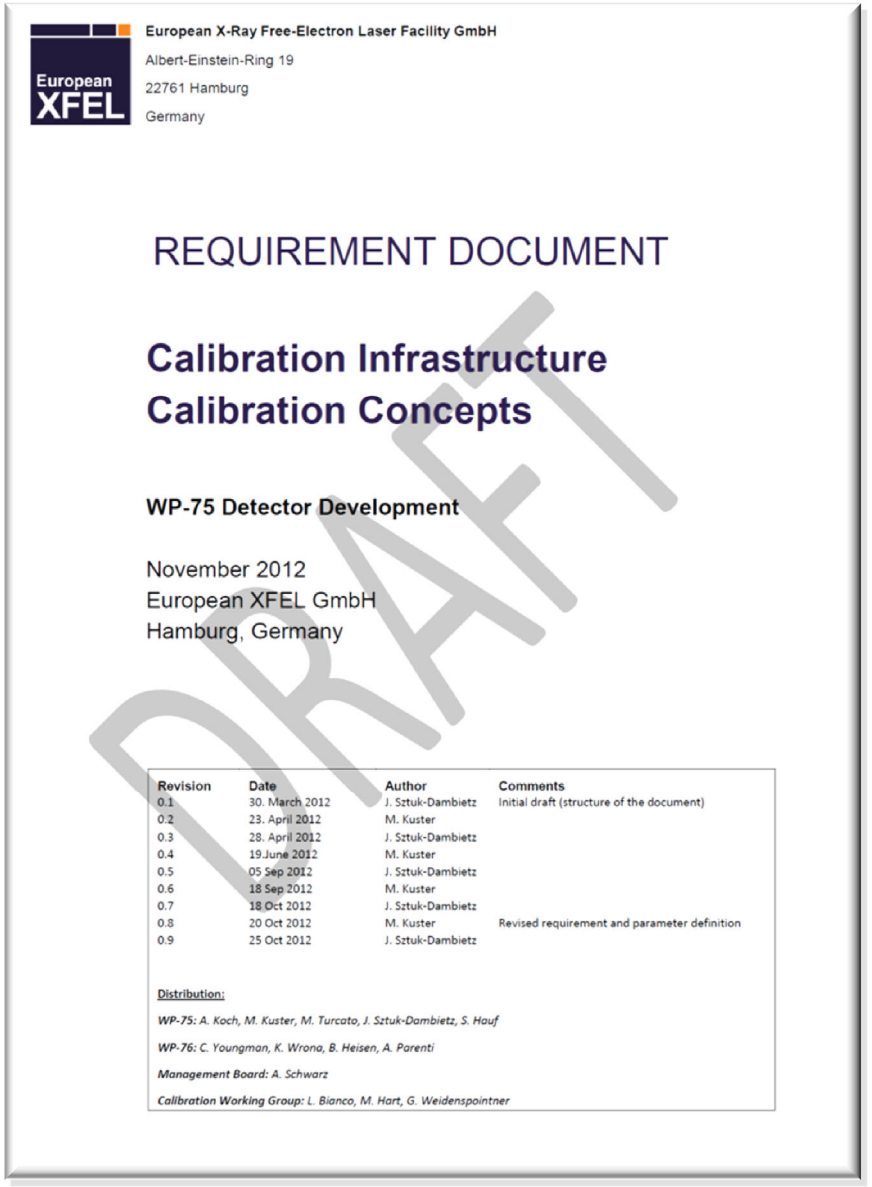
Activity	AGIPD	DSSC	LPD
Noise performance study			
Characterization of memory cell droop after irradiation & at different temperatures		Not applicable	Not an issue
Develop strategy for non-linear gain response	Not applicable		Not applicable
PSF measurement			
QE measurement			
Optimization of calibration strategies with test structures	AGIPD0.1-0.4	pxd-7+ASIC	Two-tile system
Optimization of calibration strategies with simulation			

ready ongoing to be done

Calibration Concept & Infrastructure Requirements

- Requirements for calibration infrastructure were defined
- Proposal for parameters to be calibrated or characterized was prepared
- Requirement document including proposal for responsibilities assignment was distributed to the Consortia

→ feedback from the Consortia by the end of November



European X-Ray Free-Electron Laser Facility GmbH
Albert-Einstein-Ring 19
22761 Hamburg
Germany

REQUIREMENT DOCUMENT

Calibration Infrastructure
Calibration Concepts

WP-75 Detector Development

November 2012
European XFEL GmbH
Hamburg, Germany

DRAFT

Revision	Date	Author	Comments
0.1	30. March 2012	J. Sztuk-Dambietz	Initial draft (structure of the document)
0.2	23. April 2012	M. Kuster	
0.3	28. April 2012	J. Sztuk-Dambietz	
0.4	19.June 2012	M. Kuster	
0.5	05 Sep 2012	J. Sztuk-Dambietz	
0.6	18 Sep 2012	M. Kuster	
0.7	18 Oct 2012	J. Sztuk-Dambietz	
0.8	20 Oct 2012	M. Kuster	Revised requirement and parameter definition
0.9	25 Oct 2012	J. Sztuk-Dambietz	

Distribution:

WP-75: A. Koch, M. Kuster, M. Turcato, J. Sztuk-Dambietz, S. Hauf

WP-76: C. Youngman, K. Wrona, B. Heisen, A. Parenti

Management Board: A. Schwarz

Calibration Working Group: L. Bianco, M. Hart, G. Weidenspointner

Proposal for Responsibilities/Work Assignment

Calibration group is responsible for calibration and characterization of all detectors at XFEL

- For detectors **not** developed by external developers the calibration methodology and tools (software + infrastructure) shall be developed by WP-75
- External developers shall provide calibration procedures and develop the methodology taking into account the following requirements:
  - **The methodology shall be reproducible in the XFEL environment (laboratory or at the XFEL beamlines).**
  - **The calibration and characterization software has to be compatible with the XFEL scientific software framework (Karabo) and developed in close cooperation with the XFEL WP-75 and WP-76 groups.**
- WP-75 shall be responsible for the calibration software integration in the XFEL framework.

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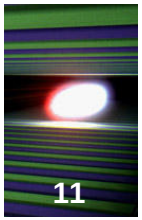
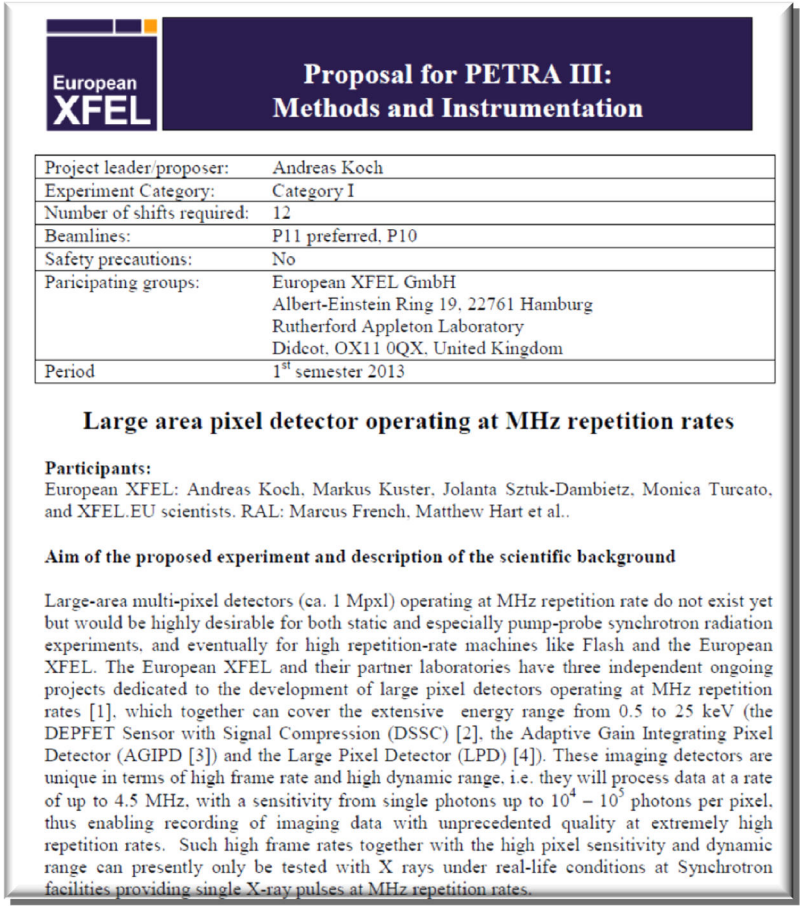
Proposal for Responsibilities/Work Assignment



- WP-75 shall take over the calibration responsibility from the consortia as soon as the detectors are assembled in the XFEL experimental environment. Mandatory for the efficient transfer of information and responsibilities:
  - ➔ **an early involvement of WP-75 in the test (calibration/characterization) activity**
  - ➔ **test devices for each technology at the XFEL to start with integration and test measurements as early as possible**
- WP-75 shall provide the infrastructure needed for detector calibration and characterization at the XFEL including the infrastructure requirements from the detector consortia
- DAQ and control system shall be provided by WP-76
- Definition of the data format and solutions for data management shall be developed by WP-76 in cooperation with WP-75

PETRA III - almost ideal calibration X-ray source

- PETRA III:
  - 40-bunch mode at 5.2 MHz (34, 60-,240-bunch modes possible)
  - High-intensity (10^4-10^6 photons/pulse) monochromatic beam
  - Pink beam (10^8 photons/pulse)
  - Photon energy covers XFEL requirements
- PETRA III access:
  - Standard user procedure→ proposals
    - Proposal for PETRAIII (1st half of 2013) has been accepted → application for beam time has been sent → outcome in November
  - "Unofficial" procedure:
    - PETRA beamline scientists interested in testing new technologies develop for the XFEL has been contacted



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Proposal for PETRA III: Methods and Instrumentation

Project leader/proposer:	Andreas Koch
Experiment Category:	Category I
Number of shifts required:	12
Beamlines:	P11 preferred, P10
Safety precautions:	No
Paricipating groups:	European XFEL GmbH Albert-Einstein Ring 19, 22761 Hamburg Rutherford Appleton Laboratory Didcot, OX11 0QX, United Kingdom
Period	1st semester 2013

Large area pixel detector operating at MHz repetition rates

Participants:
European XFEL: Andreas Koch, Markus Kuster, Jolanta Sztuk-Dambietz, Monica Turcato, and XFEL.EU scientists. RAL: Marcus French, Matthew Hart et al..

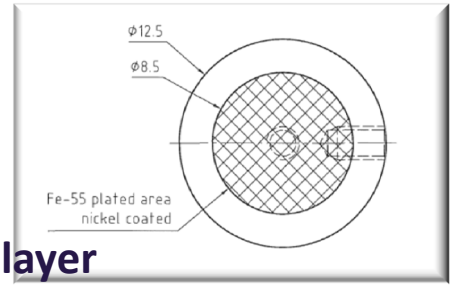
Aim of the proposed experiment and description of the scientific background

Large-area multi-pixel detectors (ca. 1 Mpxl) operating at MHz repetition rate do not exist yet but would be highly desirable for both static and especially pump-probe synchrotron radiation experiments, and eventually for high repetition-rate machines like Flash and the European XFEL. The European XFEL and their partner laboratories have three independent ongoing projects dedicated to the development of large pixel detectors operating at MHz repetition rates [1], which together can cover the extensive energy range from 0.5 to 25 keV (the DEPFET Sensor with Signal Compression (DSSC) [2], the Adaptive Gain Integrating Pixel Detector (AGIPD [3]) and the Large Pixel Detector (LPD) [4]). These imaging detectors are unique in terms of high frame rate and high dynamic range, i.e. they will process data at a rate of up to 4.5 MHz, with a sensitivity from single photons up to 10^4 – 10^5 photons per pixel, thus enabling recording of imaging data with unprecedented quality at extremely high repetition rates. Such high frame rates together with the high pixel sensitivity and dynamic range can presently only be tested with X rays under real-life conditions at Synchrotron facilities providing single X-ray pulses at MHz repetition rates.

Regular access to PETRA should be established → common effort XFEL & consortia

Laboratory Infrastructure for "in situ" Detector Tests

- **Synchrotrons/FELs – almost ideal calibration X-ray source, BUT**
  - Limited access → cannot be used on a daily basis
  - Detector setup has to be transported → risky and time consuming
  - Time structure of the beam not always appropriate
- **First Alternatives:**
  - **Iron-55 setup (radioactive source + housing)**
    - ✓ **electrodeposited as Fe metal on the face of a Cu substrate with protective Ni layer**
    - ✓ **Nominal activity: 1.85 GBq (>36x10^6 photons/s per steradian)**



  - **Amptek Mini-X setup (X-ray tube + detector test chamber)**
    - ✓ **50 kV/80 µA power supply, Ag or Au transmission target, Be end window**
    - ✓ **Filters: Al, Cu, Mo, Ag, W**
    - ✓ **Vacuum feedthrough coupling**

- **First design of source housing (operation in ambient and vacuum) ready**
- **Work on safety regulations finished → application accepted by HH authority**

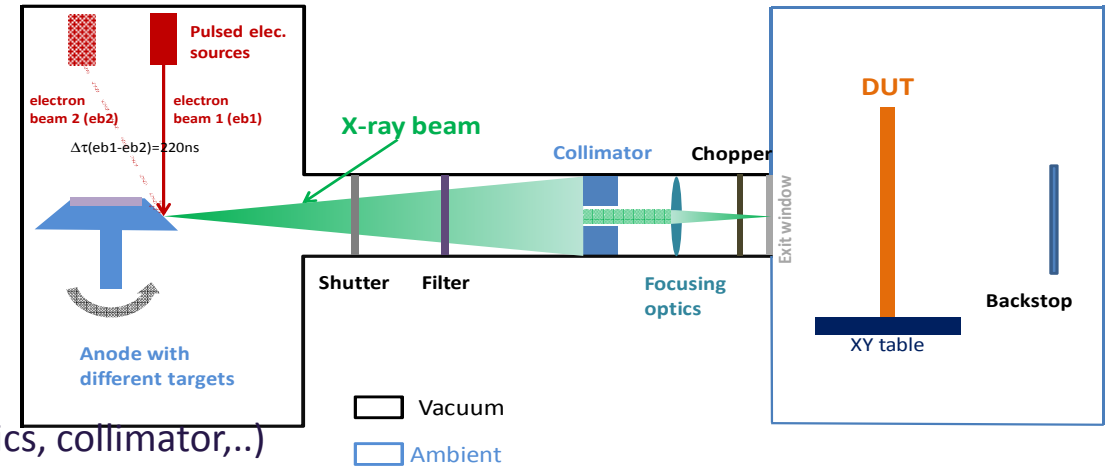
→ First X-ray setups available in Q1/Q2 2013

Multi-Target X-ray Generator Setup

- Laboratory Multi-target X-ray generator setup for detector characterization and calibration
  - complementary to synchrotrons and FELs on daily use
  - electron source for direct electron illumination

Main components:

- Pulsed electron source:
  - **$30 < E_e < 100$ keV**
  - **Current nA < I_{beam} < 20 A**
  - **Pulse width: ~ 20ns - 100 µs**
- Multi-target anode → X-ray energies (0.2-25 keV)
- X-ray optics (filters, monochromator, focusing optics, collimator,..)
  - **monochromatic beam $\frac{\Delta E}{E} \approx 2 - 3 \cdot 10^{-2}$**
  - **beam spot down to 20µm**
  - **collimated beam with size range from a few mm to 10 cm**
- Chopper (optional)
- Detector test chamber
- Reference detector

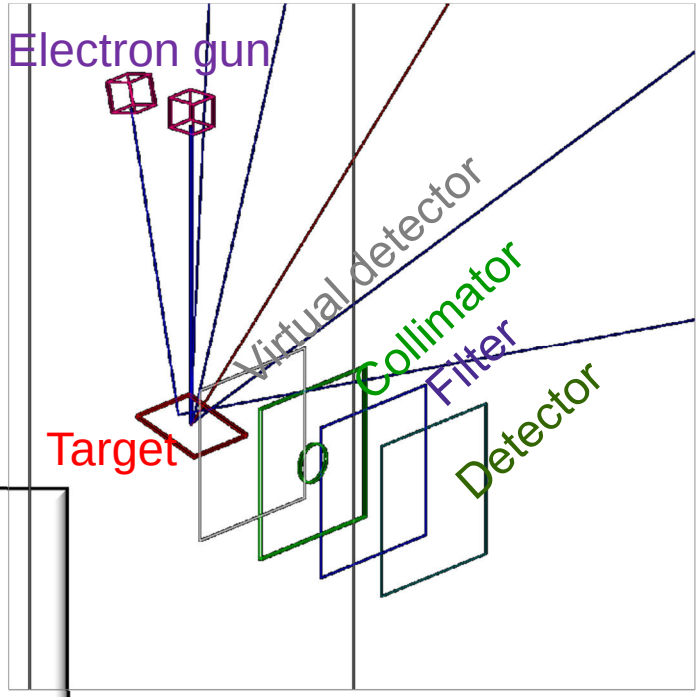


Work on TDR started → X-ray generator setup foreseen Q3 2014

X-ray Generator - GEANT4 Simulation

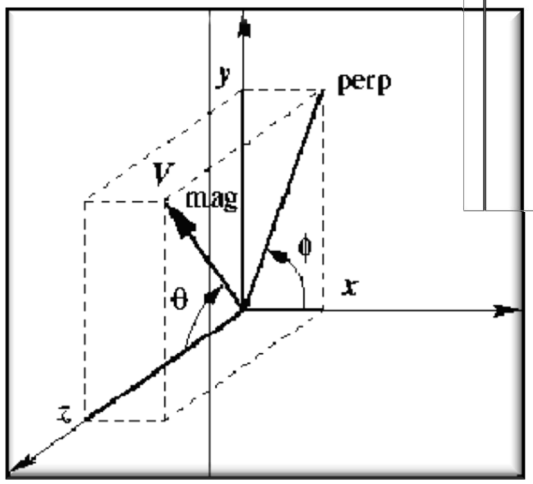
- Optimization of X-ray generator setup parameters using GEANT4 simulation*
  - ✓ target material and angles
  - ✓ filter material and thickness
  - ✓ beam current
  - ✓ geometry
- Estimation of beam intensity
- Shielding definition
- Input to TDR

Geometry definition:



Courtesy S. Hauf

Coordinate definition:

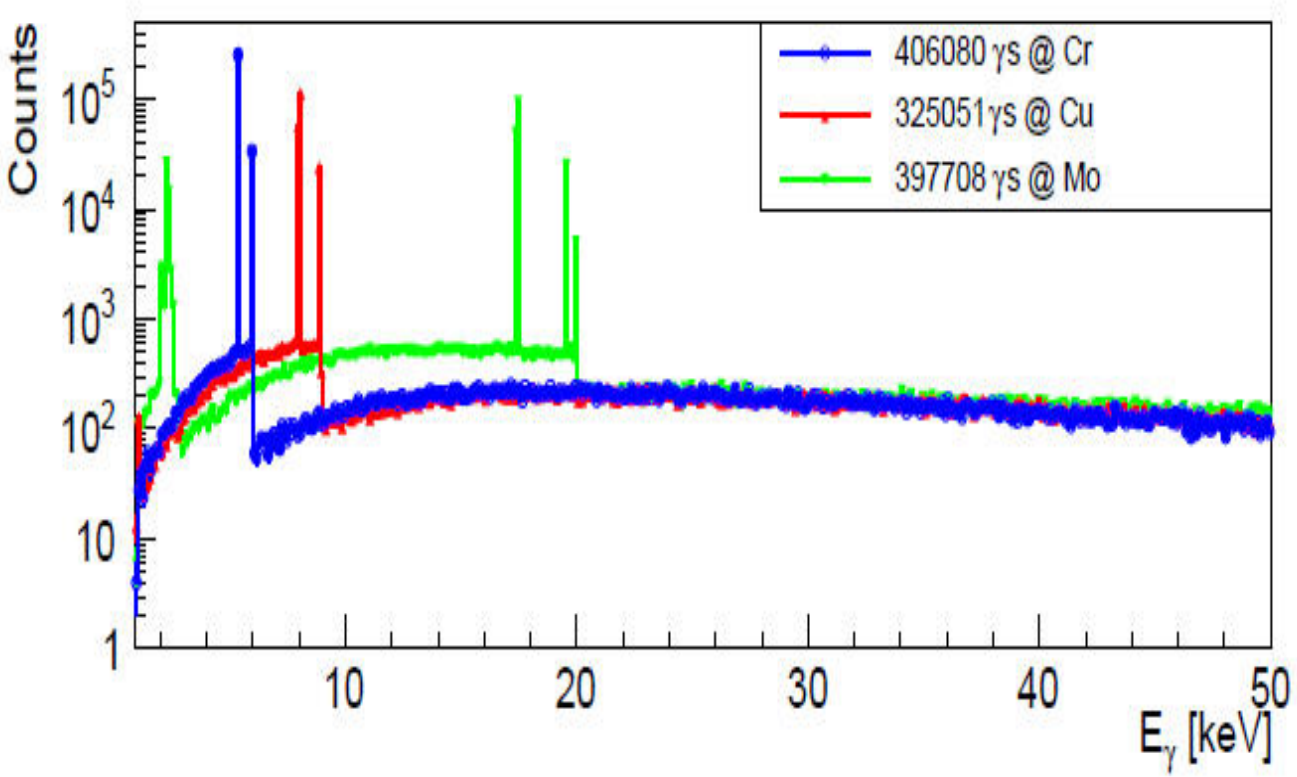


* Code validation based on arXiv:1205.1973

Work on simulation of X-ray source started → first version of the software is ready

Different Targets - Comparison

- Simulation parameters
  - 20 M primary e-
    → 3.2 **x 10^{-12} sec @ 1A***
  - Ee=100 keV
  - Target materials:
    Cr, Cu, Mo…
  - Target angle: $\alpha = 18°$

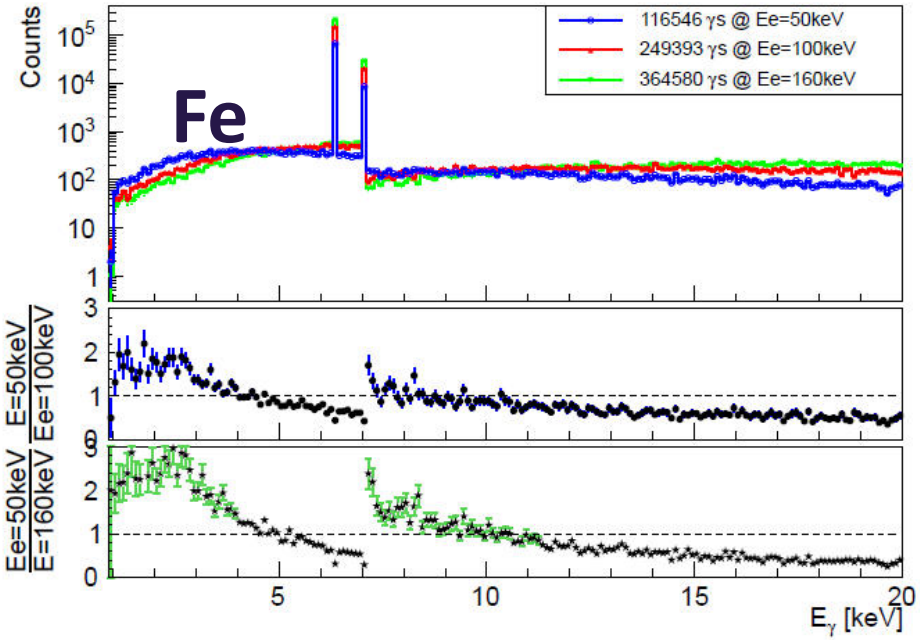


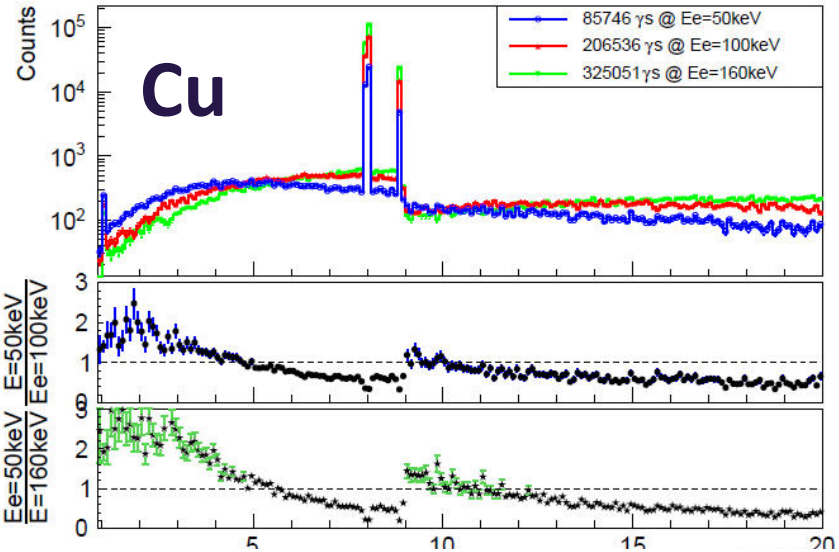
Efficiency of X-ray production ~ 1-2 %

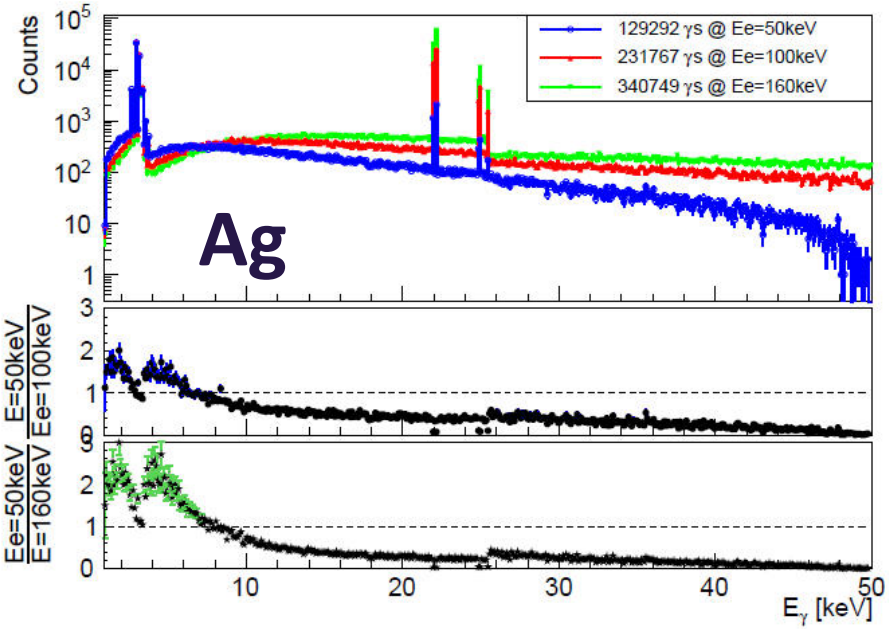
* 1 A = 6.2415 x 10^{18} electrons/sec.

Different Electron Energies - Comparison

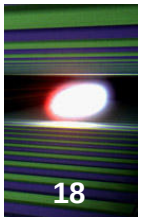
- Simulation parameters
  - 20 M primary e-
  - Ee=50,100,160 keV
  - Target materials: Cu, Fe, Ag…
  - Target angle: $\alpha = 18°$







Calibration Software Development at WP-75 (S. Hauf)



- **Calibration Analysis and Application within the Karabo-Framework**
  - Currently, implementation of calibration pipeline for test detectors is proceeding → First steps for 2D-detector calibration on dark images (status report by S. Hauf in subsequent session)
  - Direct feedback from/ to WP-76 regarding feature requests and improvements
  - **Will lay path for user training and integration of consortia-developed software**

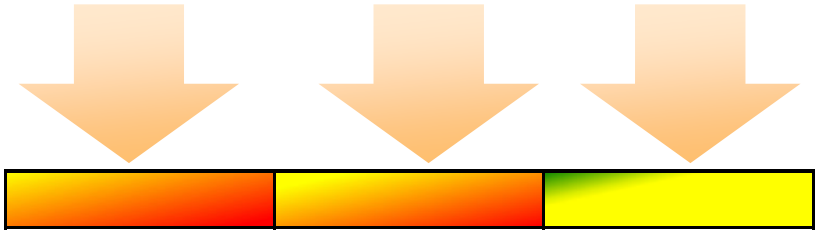
- Feedback from the Consortia on the type and status of the software activities was provided

Karabo Readiness of Consortia Software

- Current assessment based on feedback from consortia
- Note!: Karabo is currently not available outside XFEL → assessment reflects design compatibility with Karabo

- Internal work for pnCCD will be used as example implementation alongside guidelines
- **Computational performance** not assessed yet but **critical (usability for 1M pixel device?)**

	AGIPD	LPD	DSSC
Pipeline	NO	NO	PARTIAL
File format	ROOT, ASCII	BINARY	ROOT, ASCII
Language	C++	PYTHON	C++
Dependencies	ROOT	Numpy Scipy Matplotlib	ROOT (MEGALIB)
Plot production	MANUAL	MANUAL	SEMI-AUTO
Multiprocessing/Threading*	NO	NO	NO
Computing on GPU*	NO	NO	NO



* Not necessary critical but favorable

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Schedule

	2012				2013				2014				2015				2016				2017			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Infrastructure XFEL																								
Laboratory Space	**HERA South**												**Transition**				**Detector Lab. XHQ**							
First Beam																								

Calibration

	2012				2013				2014				2015				2016				2017			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Calibration Infrastructure																								
Requirements Definition																								
Calib. Infrastructure at the XFEL:																								
First Radioactive Sources																								
First X-ray Tube Setup																								
Multi-target X-ray Generator Setup																								
Laser Setup																								
Calibration Concept					**to be discussed**																			
Data Format & Data Base																								
Data Format and Structure																								
Data Base																								
Calibration Software																								
Calibration Software XFEL																								
Calibration Software AGIPD																								
Calibration Software DSSC																								
Calibration Software LPD																								
Calibration Software pn/FastCCD																								
Integ. of External Software in Karabo																								
First lab. Prototype at the XFEL																								

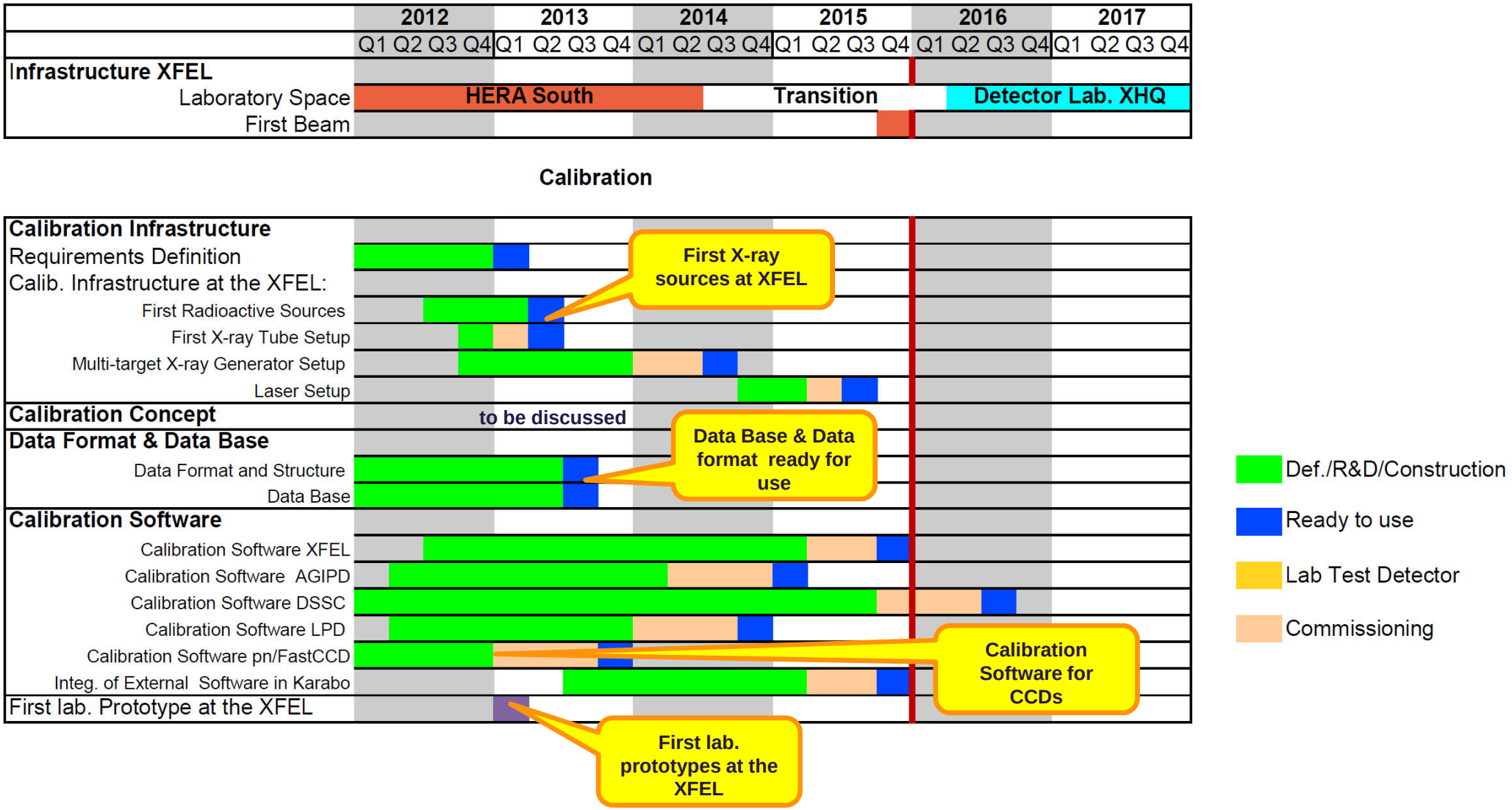
Def./R&D/Construction

Ready to use

Lab Test Detector

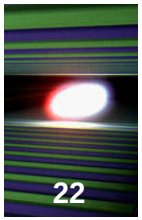
Commissioning

Schedule


2012
2013
2014
2015
2016
2017
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Infrastructure XFEL
Laboratory Space
HERA South
Transition
Detector Lab. XHQ
First Beam
Calibration
Calibration Infrastructure
Requirements Definition
Calib. Infrastructure at the XFEL:
First Radioactive Sources
First X-ray Tube Setup
Multi-target X-ray Generator Setup
Laser Setup
First X-ray sources at XFEL
Calibration Concept
to be discussed
Data Format & Data Base
Data Format and Structure
Data Base
Data Base & Data format ready for use
Calibration Software
Calibration Software XFEL
Calibration Software AGIPD
Calibration Software DSSC
Calibration Software LPD
Calibration Software pn/FastCCD
Integ. of External Software in Karabo
Calibration Software for CCDs
First lab. Prototype at the XFEL
First lab. prototypes at the XFEL
Def./R&D/Construction
Ready to use
Lab Test Detector
Commissioning

European XFEL

Summary



- Work on calibration is ongoing in the Consortia and discussed in regular meetings
- Setup of the calibration infrastructure is ongoing → Fe-55 source and a portable X-ray tube will be available in Q1/Q2 2013
- Work on calibration software and simulation at the XFEL started
- X-ray generator concept being elaborated → first simulation is available
- First attempt to access PETRAIII was done → regular access to PETRAIII requires a combined effort of XFEL and consortia

Answers to the Questions of the XDAC Committee

Comments from the last XDAC report

- *"The XDAC appreciates the start of the activities of the calibration working group and encourages the efforts initiated to define an action plan. In that sense it suggests to look into **methodology in which the responsibilities of the various actors are well defined**"*

Proposal for responsibility/work assignment was included in the technical note "Calibration Concept and Infrastructure Requirements" and distributed to the consortia for comments. Feedback is expected by the end of November.

- *"It would be convenient to have **easy and regular access to a test station at a storage ring facility** that could deliver X-ray photons with a time structure and intensity to the values expected to be seen by the XFEL detectors. Such a station could be used for both testing and calibration for all detectors. An option to be explored could be setting up a long term agreement with a SR facility with the a appropriate modes (few bunch filling with the right timing).''*

First step was done→ slide 12 of this talk

Next step: regular Access to PETRA should be established including common effort XFEL & consortia. In addition we planning detector tests at different light sources (LCLS, ..)

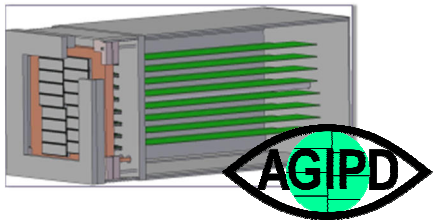
- *"Eventually **calibration and alignment devices** have to be integrated into the beam line, and so an early generic layout seems helpful for further discussion."*

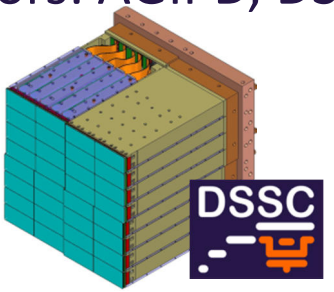
The mentioned devices are planned at the beamlines and will be included in the instrument TDRs.

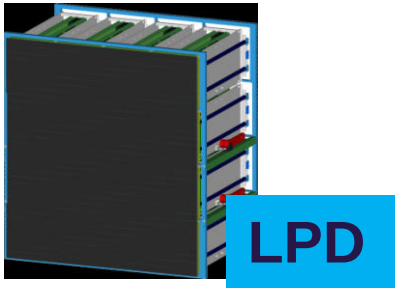
Backup slides

Detectors to be calibrated & characterized - reminder

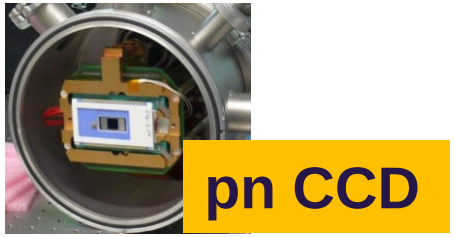
- 2-D Mpixel X-ray imaging detectors
  - High repetition rate detectors: AGIPD, DSSC, LPD

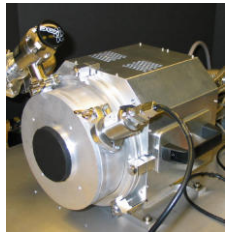




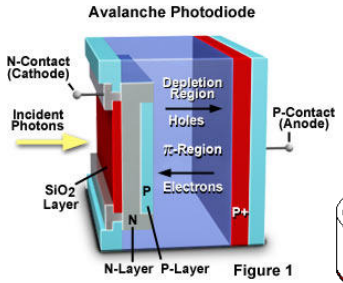


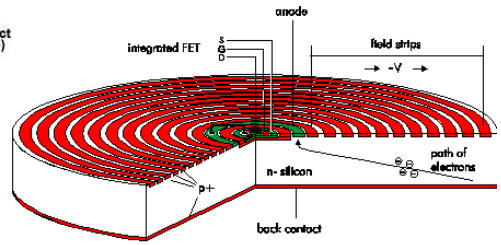
  - Low repetition rate detectors: pn CCD, other CCDs





- ..and more to come
  - 1D detectors
  - Avalanche PhotoDiode (APD)
  - Silicon Drift Detector (SDD)
  - ...



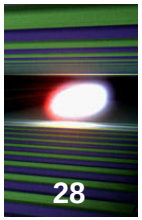


X-ray Generators - Requirements

X-ray source(s) for detector calibration & characterization purpose

- **Photon energy:** Energy range 0.2-25 keV, monochromatic
- **Time structure:**
  - **pulsed source** with repetition rate if possible up to 4.5MHz or at least two pulses delivered with Δt=220 ns
  - **short pulses <1ps**
- **Adjustable and stable intensity** (1ph/pixel/pulse – 10^4ph/pixel/pulse)
- Two types of **illumination**:
  - **point-like illumination** (ideal case: possibility for one pixel illumination)
  - **flat field illumination** with homogeneity of the order of 10% (ideal case: size of the flat field compatible with the size of the full detector module: 20x20cm, or as large as possible)
- Well calibrated **reference detector**
- Vacuum/ambient compatibility

X-ray Generator Setup



- X-ray generator setup with different targets and filters for detector characterization

Targets

Target material		Emission Line Energy [keV]					
Z	Symbol	K_{a1}	K_{a2}	K_{b1}	L_{a1}	L_{a2}	L_{b1}
6	C	0.277					
12	Mg	1.25	1.25	1.30			
13	Al	1.49	1.49	1.56			
8 14	O Si	0.525 1.74	1.74	1.84			
22	Ti	4.51	4.50	4.93	0.452	0.452	0.458
24	Cr	5.41	5.41	5.95	0.573	0.573	0.583
26	Fe	6.40	6.39	7.06	0.705	0.705	0.719
27	Co	6.93	6.92	7.65	0.776	0.776	0.791
28	Ni	7.48	7.46	8.26	0.852	0.852	0.868
29	Cu	8.045	8.027	8.905	0.929	0.929	0.950
42	Mo	17.48	17.38	19.61	2.29	2.29	2.39
47	Ag	22.16	21.99	24.94	2.98	2.98	3.15
74	W	59.32	57.98	67.24	8.40	8.36	9.67
79	Au	68.80	66.99	77.98	9.71	9.63	11.44
	Makrolon (ceramics)	0.52	0.68	0.93	1.25	1.49	1.74
		2.62	3.31	3.59	6.40	7.06	8.04

Filters

Description	Material	Thickness
Multilayer Thin	Al Polyimide	40 nm 160nm
Multilayer Medium	Al Polyimide	80 nm 160 nm
Multilayer Thick	Sn Al Polypropylen Al	45 nm 55 nm 330 nm 55 nm
Al Thin	Al	XX nm
Al Think	Al	XX nm
Cu Thin	Cu	XX nm
Cu Thick	Cu	XX nm
Ni Thin	Ni	XX nm
Ni Thick	Ni	XX nm