Calibration Working Group and Calibration Infrastructure

Jola Sztuk-Dambietz (XFEL)
on behalf of
the Calibration Group

May, 27th 2013
14th Meeting of the XFEL Detector Advisory Committee
European XFEL GmbH, Hamburg

Outline

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

Calibration Group – Organization

Calibration Working Group site @ Alfresco

- Alfresco (content management system) use for:
  - Document management & storing
    - documents
    - engineer drawings,
    - reports
    - contracts, etc..
  - Repository-level versioning
  - Activities workflow

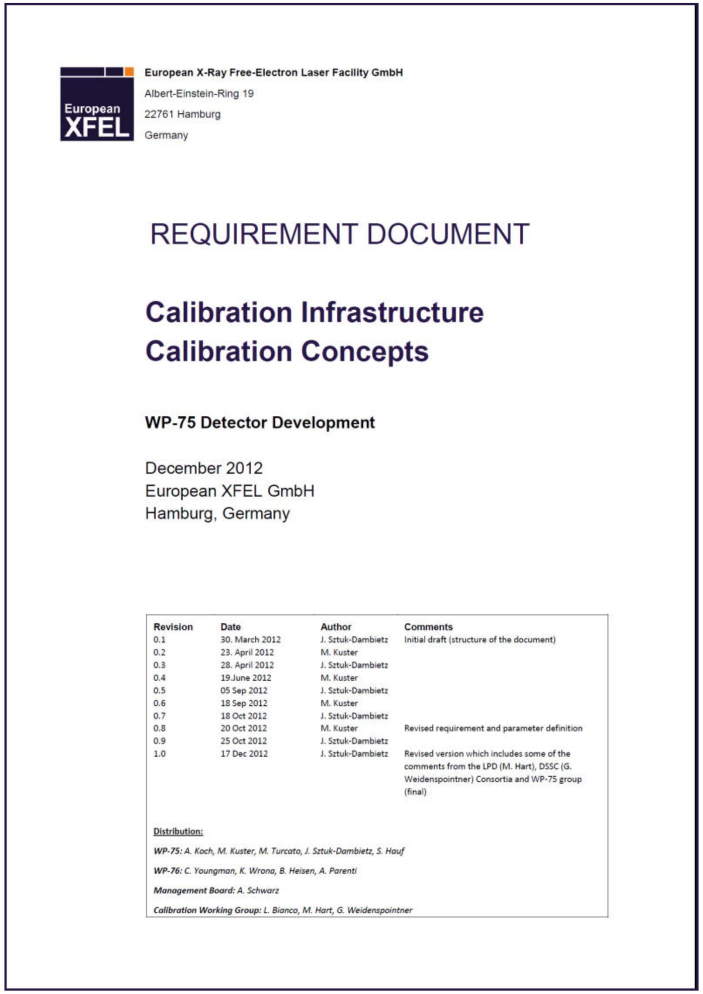
- Calibration site was created and access provided to calibration group members

  https://docs.xfel.eu/share/page/site/calibration/dashboard

Calibration Concept & Infrastructure Requirements

- Requirements for calibration infrastructure were defined (X-ray sources, energies, intensities, etc..) → see later in the talk
- Definition of common language (gain, QE, etc..)
- Proposal for parameters to be calibrated or characterized
- Definition of responsibilities

Final document reviewed by the detector Consortia available on Alfresco



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

December 2012
European XFEL GmbH
Hamburg, Germany

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	
1.0	17 Dec 2012	J. Sztuk-Dambietz	Revised version which includes some of the comments from the LPD (M. Hart), DSSC (G. Weidenspointner) Consortia and WP-75 group (final)

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

Calibration Working Group meeting – April 2013

- **Goal:** Exchange information, discuss progress, next steps and open issues related to calibration
- **Participants:** Consortia, XFEL WP-75 and WP76 representatives
- **Status of calibration activities in the consortia and XFEL:**
  - Status of the calibration activity (memory droop, non-linear gain conversion, etc..) from the detector consortia
  - Potential use of proton beamline for high intensity/charge Si detector calibration
  - Performance estimation for calibration processing software, Karabo release date, coding recommendations and policies
  - Status of detector calibration infrastructure at the XFEL

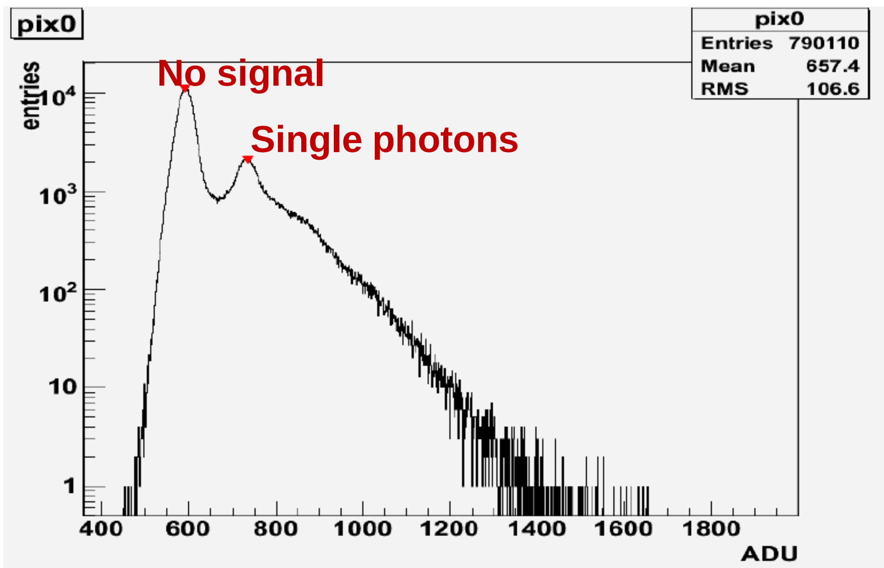
Next meeting September/October 2013

Highlights From the Last Calibration Meeting (I)

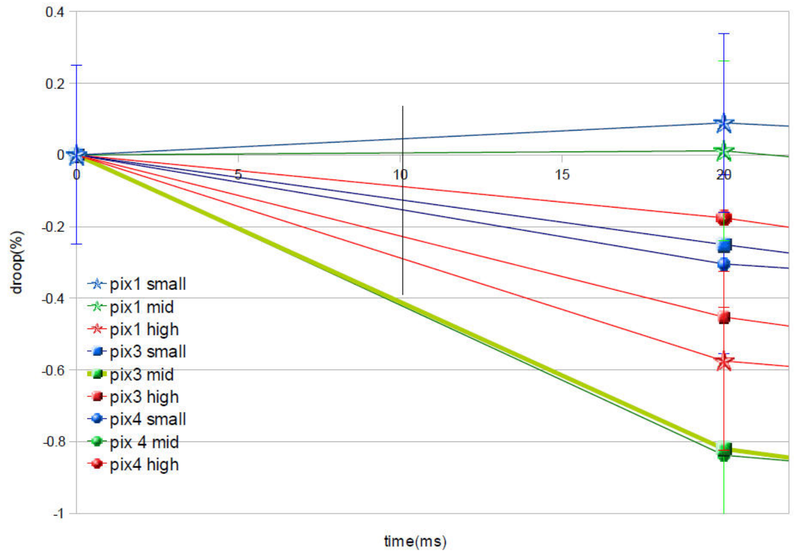
AGIPD (L. Bianco):

- Gain conversion using X-ray tube (Mo)
- Calibration using ASIC internal electrical sources - proof of principle
- Work on software development for calibration is ongoing

Calibration of AGIPD0.4 with Mo X-ray source



More investigation on droop → charge dependence



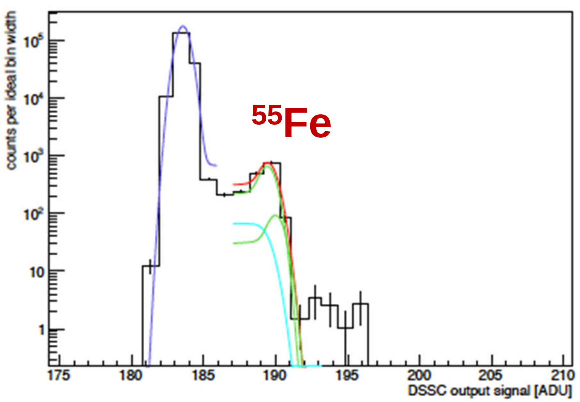
droop below 1%

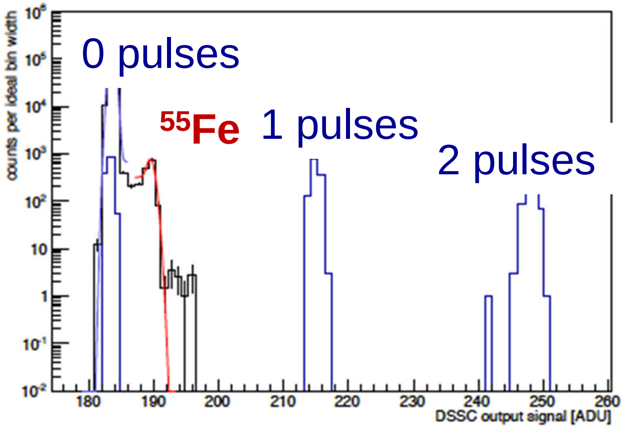
Highlights From the Last Calibration Meeting (II)

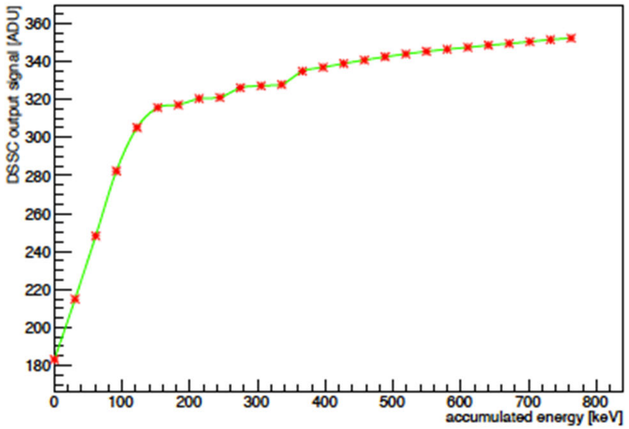
DSSC (G. Weidenspointner):

DSSC prototype = pxd-7 prototype + ASIC prototype

- Calibration of non-linear system gain (NLSG) for 1 keV photons





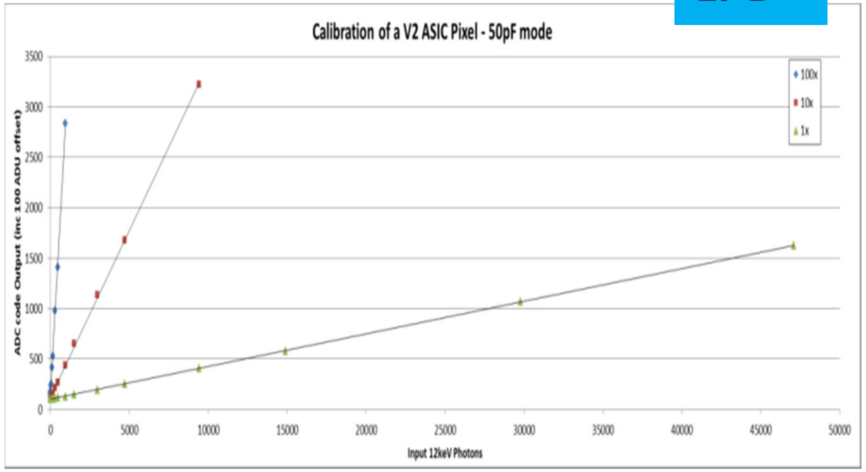


- Tests of calibration functionalities of MM3 ASIC prototype in progress
- Software development (Karabo-compatible) is ongoing in parallel to experiments and covers all calibration steps

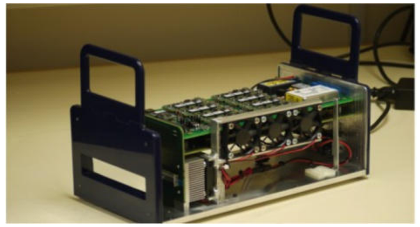
Highlights From the Last Calibration Meeting (III)

LPD

LPD (M. Hart): Characterization of two-tile



- Two-tile system available → delivered to XFEL in March
  - Fully independent standalone air cooled system
  - Firmware development
  - Test bed for tile evaluation
  - Test calibration methodology
  - Analysis and control software development
- Focus on beam test preparation (LCLS and PETRAIII) for May 2013 → work in progress on the data evaluation & analysis
- New firmware and software under development



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

Highlights From the Last Calibration Meeting (IV)

XFEL:

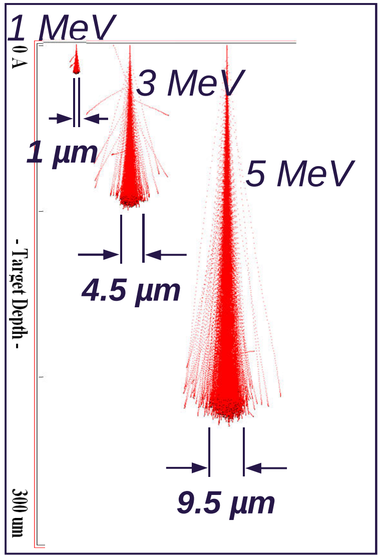
- **Status of the test infrastructure at the XFEL → see later in the talk**
- **Status of the XFEL software development for detector calibration (S. Hauf)**
  - Work on the Karabo-framework which bundles distributed applications is ongoing → serves control framework and data analysis framework.
  - The first public Karabo release will be in summer 2013. → Karabo will be introduced within a workshop which will include user and developer training.
  - Work on pipeline is ongoing:
    - ✓ Evaluation of different pipeline concepts (image-based, event-based, container types, concurrency models) in a minimized, controlled environment
    - ✓ The pipeline core, a mixed data-container (image + event-based), plotting and simplified I/O interface have been implemented. Dark image data can currently be processed
  - Result of the analysis tools (C/C++, Python-based, CERN ROOT) evaluation was presented → C/C++ with boost lib, Python preferable solution, Karabo will provide a data end-point for ROOT (a policy document is being prepared)

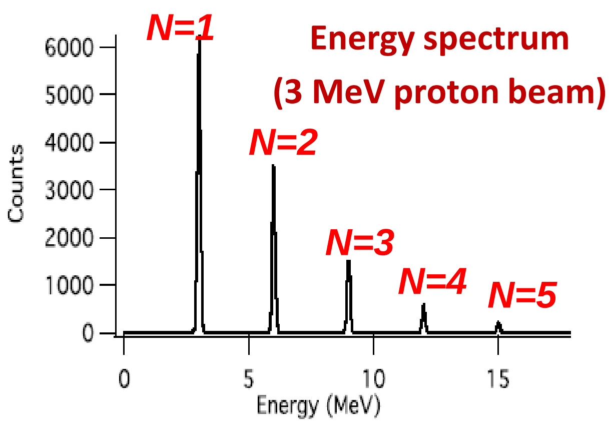
Highlights From the Last Calibration Meeting (V)

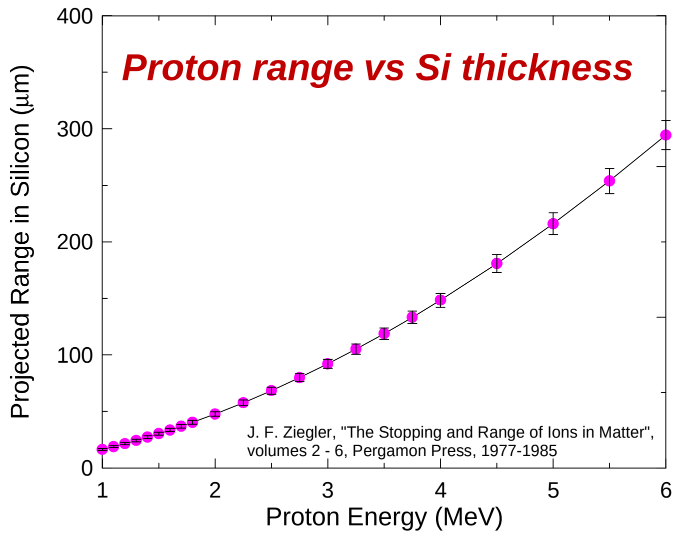
DEFEL (LABeC) proton beam line for silicon detector characterization (A.Castoldi)

- Motivation: calibration for high intensity regime (low gain)
- Solution: mono-energetic MeV protons → energy → absolute gain calibration !
- Main parameters of the facility
  - Energy 1-6 MeV
  - Position resolution of 10-100µm
  - Time resolution <1ns
  - Ionization profile: from shallow (1 MeV p) to deep (6 MeV p)
  - Single shot up to 10 kHz rep rate

Lateral range of protons in Si



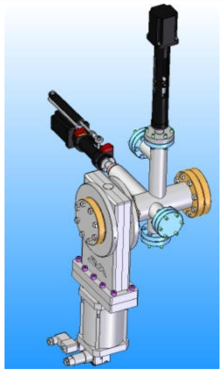




Lab X-ray Sources for Detector Calibration

Laboratory X-ray sources at the XFEL

Radioactive isotopes



Conventional "DC" X-ray tubes

Low power
P < 10W

High power
P > 2kW
micro-focusing

Pulsed multi-target X-ray generator

- Electron source from Kimball
- Multi target anode
- Optics (e.g. polycapillary)

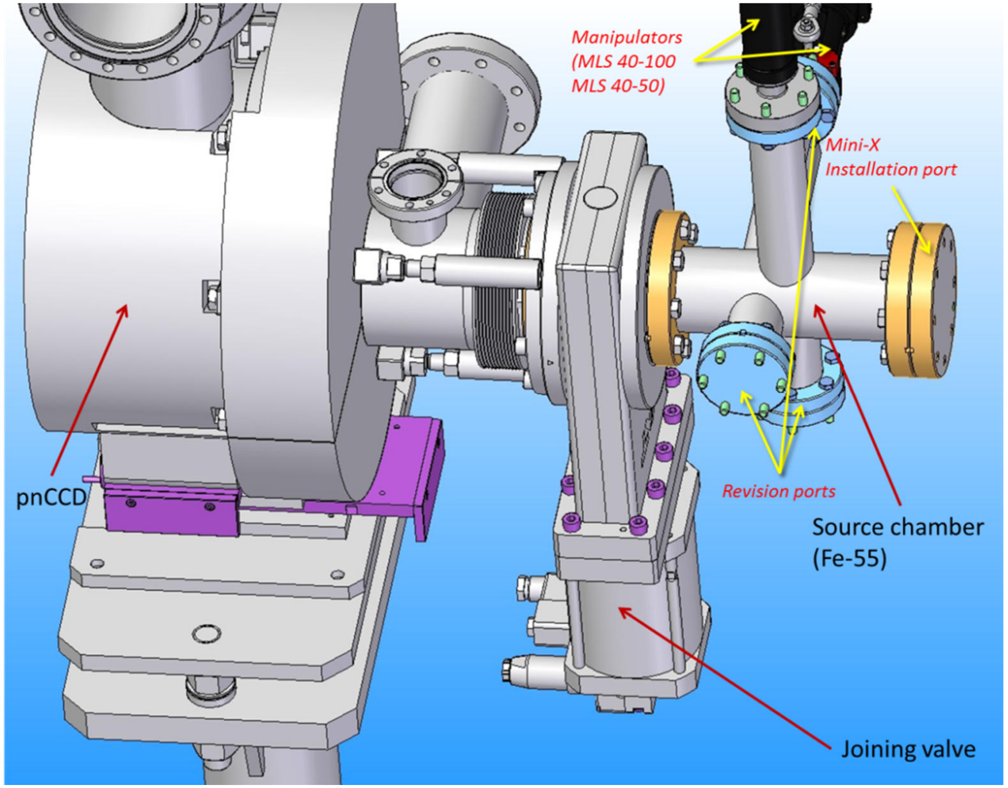
Lab X-ray Sources vs. Requirements

Requirements	Radioactivie isotopes	X-ray source in DC mode	Pulsed multi-target X-ray source
Energy range 0.26 – 25 keV	Different isotopes/filters	Exchangeable X-ray tubes/filters	Anode with different target materials
Pulsed X-rays - Pulse length < 50 ns - Δt = 220 ns or (4.5 MHz rep rate)			Pulsed electron source
Intensity - Adjustable 1- $10^{3\text{-}4}$ photons/ pixel - Instability < 1 %		High-power micro-focusing X-ray tube	
Illumination - point-like d<= 20-50µm - Line-like - Flat –field (homogeinity > 10%)	Optics, pinholes, collimators	Optics, pinholes, collimators	Optics, pinholes, collimators

Modular Calibration Setup for vacuum operation

- Modular flexible device for multipurpose usage (filters, pin-holes, collimator, etc..)
- Interlock and PLC system

Housing was designed to be compliant to different types of sources and test stands



Status:

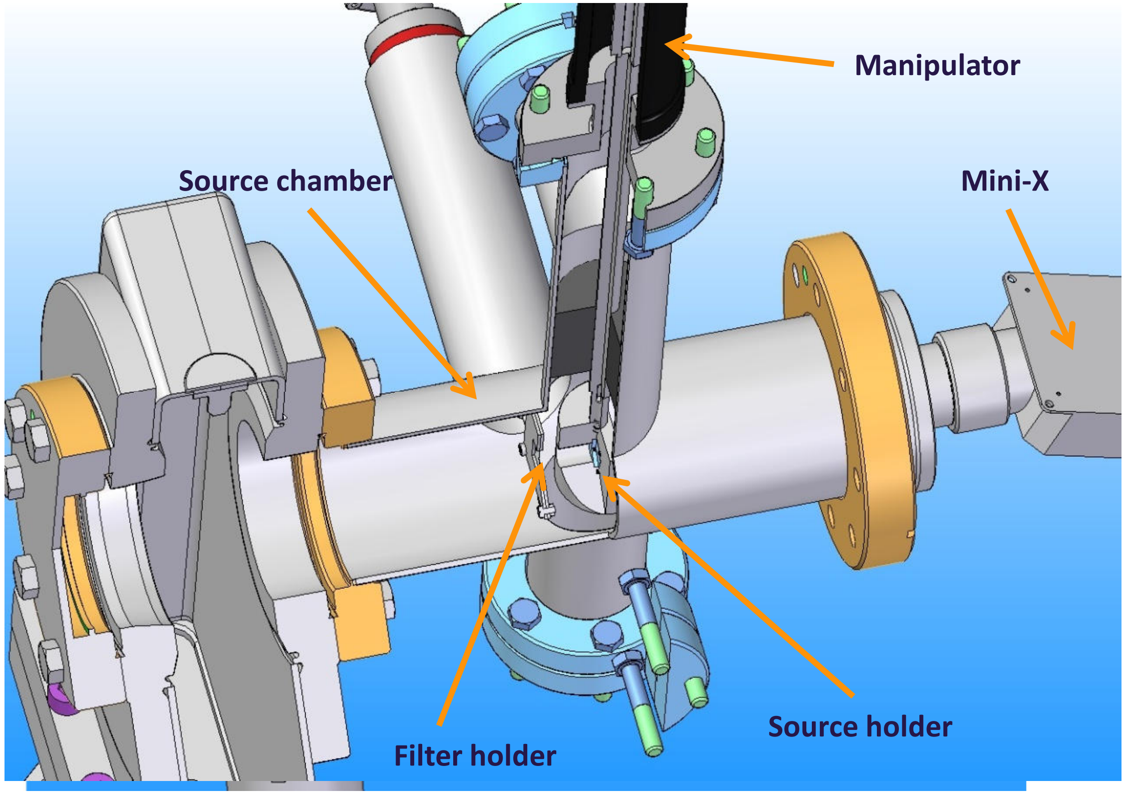
- Design of source housing ready → production in progress
- First X-ray sources delivered to the XFEL: **Fe-55 and Mini-X**

→ Setup available in Summer 2013

Modular Calibration Setup for vacuum operation

- Modular flexible device for multipurpose usage (filters, pin-holes, collimator, etc..)
- Interlock and PLC system

Housing was designed to be compliant to different types of sources and test stands



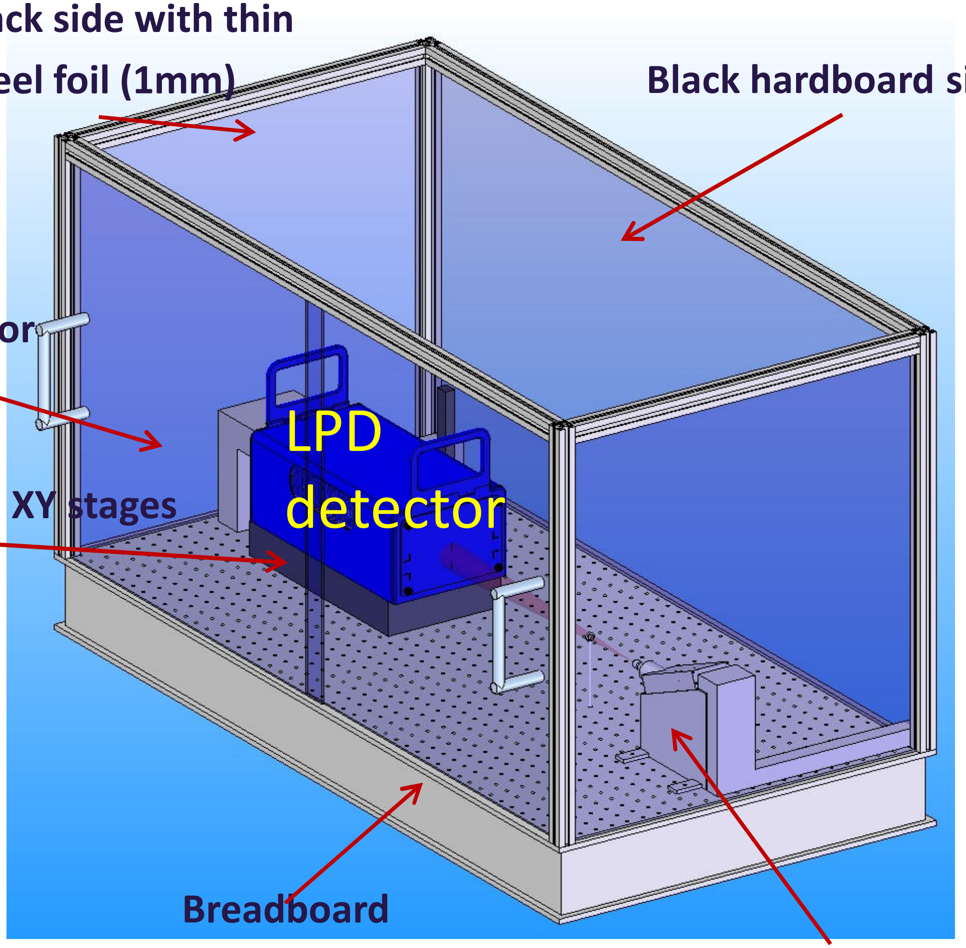
Status:

- Design of source housing ready → production in progress
- First X-ray sources delivered to the XFEL: **Fe-55 and Mini-X**

→ Setup available in Summer 2013

Test bench for small detector prototypes – ambient operation

- Design of test box ready
  → production in progress



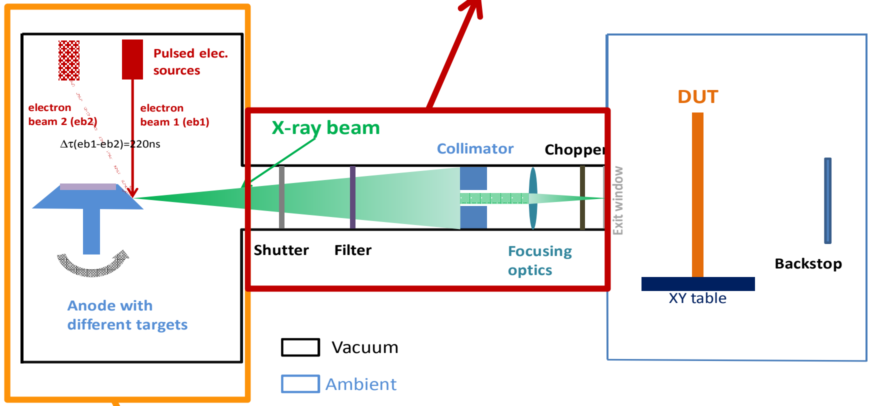
- Planning/requirements definition for the bigger setup for detector quadrant(s) started

→ Available in August 2013

Multi-purpose X-ray/electron Setup

- Laboratory multi-purpose X-ray setup for detector characterization and calibration
  - on daily use
  - use as electron source for direct electron illumination

Modular



Main components:

- **Calibration source (electron or X-ray):**
- **X-ray optics (filters, focusing & collimating optics)**
  - **monochromatic beam** $\frac{\Delta E}{E} \approx 2-3 \cdot 10^{-2}$
  - **beam spot down to 20-30µm**
  - **collimated beam with size range from a few mm to a few cm**
- Detector test chamber
- Chopper (optional)
- Reference detector → pin diodes, SDD

Exchangeable

- ✓ Pulsed X-ray/electron source
- ✓ DC X-ray/electron source
- ✓ Radioactive isotopes

Pulsed multi-target X-ray generator approach

- Multi-target X-ray source
  - DC operation → commercially available high/low power X-ray generators
  - Pulse operation → development is needed
- Design of the vacuum setup (source vessel)
- Design of the detector test chamber
- Optics, filters, chopper → potential suppliers identified

Electron Gun for pulsed multi-target X-ray source

Discussion with Kimball Physics is ongoing → Development is needed → customized EGH 6210/ EGPS-6210 → decision will be taken within next 6-8 weeks

Expected electron gun parameters (based on feasibility study from the company)

- Can be operated in pulsed and DC mode

Parameter	Pulsed mode	DC mode
Electron energy **Ee**	1 - 50 keV (adjustable)	1- 50/60 keV (adjustable)
Electron beam current **Ie**	10µA - 20 mA (adjustable), Stability better than 1 %	10µA – 2(6)mA (adjustable), Stability better than 1 %
Beam diameter d_{beam}	0.15 – 10 mm (adjustable)	0.1-10 mm (adjustable)
Pulsed beam parameters	▪ Length: τ = 10-100 ns (adjustable) rise: 2 ns / fall: 3-4 ns ▪ Burst mode: rep. rate 4-5 MHz (2-10µs ON with high frequency bursts, followed by 200µs OFF gap)	n.a.

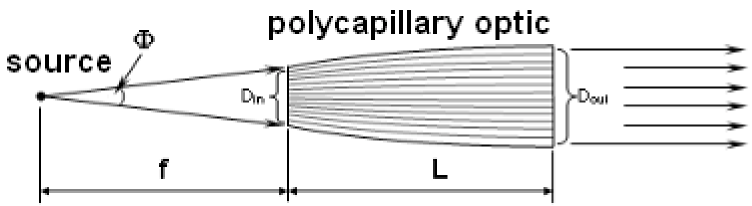
Critical points/issues for the development

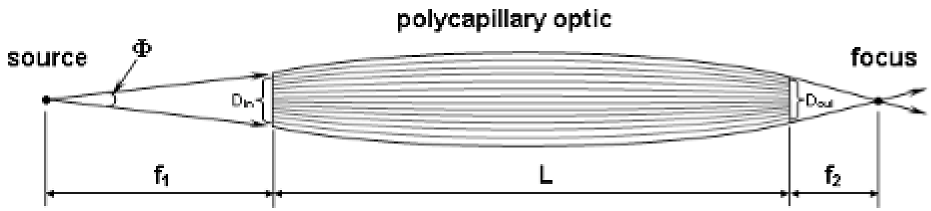
- Pulse generator which is able to produce short pulses with < 5 % jitter time
- Heat dissipation generated from 1kW beam power that will be dumped into the gun vacuum

Pulsed multi-target X-ray generator – Optics

Polycapillary optics for wide energy range

- Potential suppliers were identified
- Delivery time 4-6 weeks
- Could be a full system with support
- Energy range 1(3)- 30 keV and capture angle up to 0.2 rad





IFG Institute for Scientific Instruments

Technical Parameters Collimating Polycapillary

	collimating large semi lens	collimating mini semi lens	collimating micro semi lens
Source - entrance distance f, mm	> 40	> 10	> 5
Length L, mm	75 - 150	25 - 150	20 - 30
Entrance size D_{in}, mm	> 5	> 2	> 1
Exit size D_{out}, mm	8 - 16	5 - 8	3 - 5
Capture angle Φ, rad	0.05 - 0.2	0.04 - 0.15	0.05 - 0.1
Exit divergence Δθ, ° (CuKα)	0.2 - 0.3	0.2 - 0.3	0.2 - 0.3
Transmission coefficient K_{Tr}, % (CuKα)	10 - 60	10 - 60	10 - 60

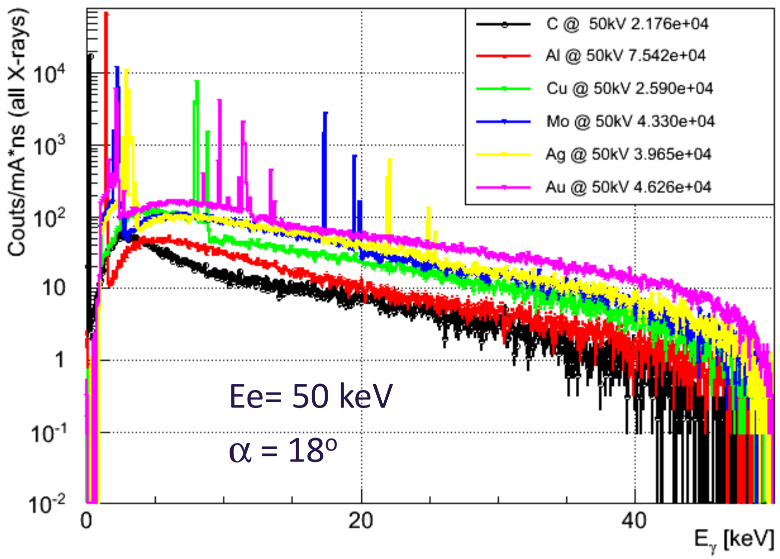
Technical Parameters Focussing Polycapillary

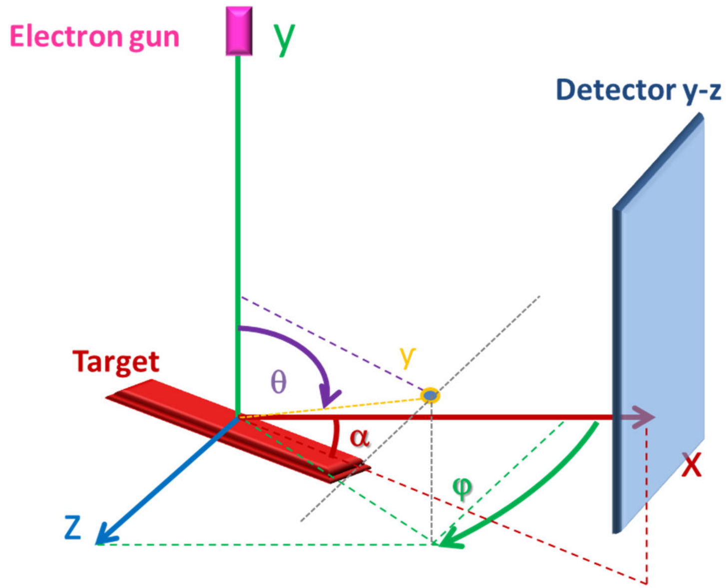
	polycapillary large lens	polycapillary mini lens	polycapillary micro lens
Source - entrance distance f_1, mm	> 40	> 40	> 30
Length L, mm	150 – 300	50 - 300	40 - 60
Exit - focus distance f_2, mm	> 40	> 10	5 - 25
Entrance size D_{in}, mm	> 5	> 4	> 2
Maximal size D_{max}, mm	< 16	7 - 9	4 - 5
Exit size D_{out}, mm	> 5	> 2	> 1
Capture angle Φ, rad	0.05 - 0.2	0.04 - 0.15	0.05 - 0.1
Energy range, keV	1 - 30	3 - 30	3 - 30
Optimal source size, µm	> 50	30 - 1000	30 - 50
Focal spot size, µm	> 200	30 - 600	20 - 100
Intensity gain	500 - 4000	1500 - 20000	1000 - 7000

X-ray Generator - GEANT4 Simulation

Intensity estimation using GEANT4 simulation toolkit

- Model for low energy – EM-physics: Penelope (based on validation in an independent paper*)
- Simulation was done for:
  - different target materials,
  - different electron energies,
  - different electron beam size,





$\tan\theta = y/x$

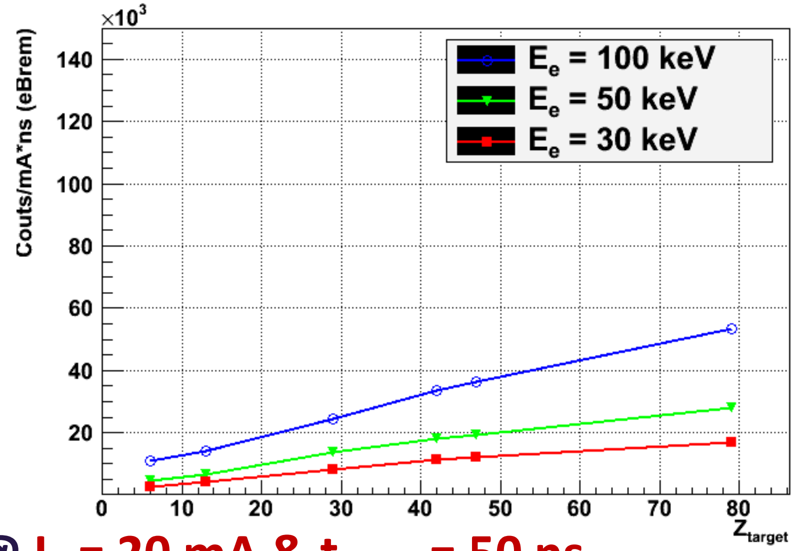
$\tan\varphi = z/x$

* Code validation based on arXiv:1205.1973

Target material & e- energy dependences – X-ray Intensity – Bremsstrahlung

Simulation parameters:

- 40 M primary e-
- Ee = 30,50,100 keV
- Target size: 5mmx100mm
- Target materials: C, Al, Cu, Mo, Ag, Au
- Target angle: $\alpha = 18°$
- **Spherical virtual detector → full angular range**



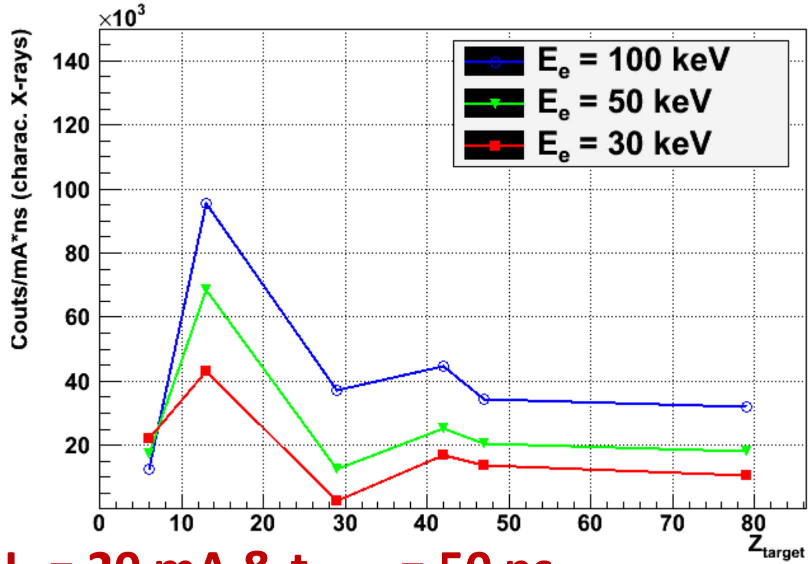
Simulated number of Bremsstrahlung @ I_e = 20 mA & t_{pulse} = 50 ns

Target / e- energy	C Z=6	Al Z=13	Cu Z= 29	Mo Z=42	Ag Z=47	Au Z=79
30 keV	2.6×10^6	4.2×10^6	8.3×10^6	1.1×10^7	1.2×10^7	1.7×10^7
50 keV	4.7×10^6	6.7×10^6	1.4×10^7	1.8×10^7	1.9×10^7	2.8×10^7
100 keV	1.1×10^7	1.4×10^7	2.4×10^7	3.3×10^7	3.6×10^7	5.4×10^7

Target material & e- energy dependences – X-ray Intensity – Fluorescence

Simulation parameters:

- 40 M primary e-
- Ee = 30,50,100 keV
- Target size: 5mmx100mm
- Target materials: C, Al, Cu, Mo, Ag, Au
- Target angle: α =18°
- **Spherical virtual detector → full angular range**



Simulated number of fluorescence @ I_e = 20 mA & t_{pulse} = 50 ns

Target / e- energy	C Z=6	Al Z=13	Cu Z= 29	Mo Z=42	Ag Z=47	Au Z=79
30 keV	2.2×10^7	4.3×10^7	2.8×10^6	1.7×10^7	1.4×10^7	1.0×10^7
50 keV	1.7×10^7	6.9×10^7	1.2×10^7	2.5×10^7	2.0×10^7	1.8×10^7
100 keV	1.3×10^7	9.5×10^7	3.7×10^7	4.5×10^7	3.5×10^7	3.2×10^7

X-ray yield estimation for detector plane

Intensity **estimation** based on simulation:

Simulation parameters

- Ee= 50 keV
- Target: Cu 5mmx100mm
- Target angle: α = 18°
- **Plane virtual detector**

20 cm x 20 cm x 0.5 cm

IP - detector - 20 cm

Expected number of X-rays @

Ee=50keV, I_e = 20 mA & t_{pulse} = 50 ns

2 x 10^6 → 2 hits per pulse/pixel (200 μm x 200 μm)

+ Optics

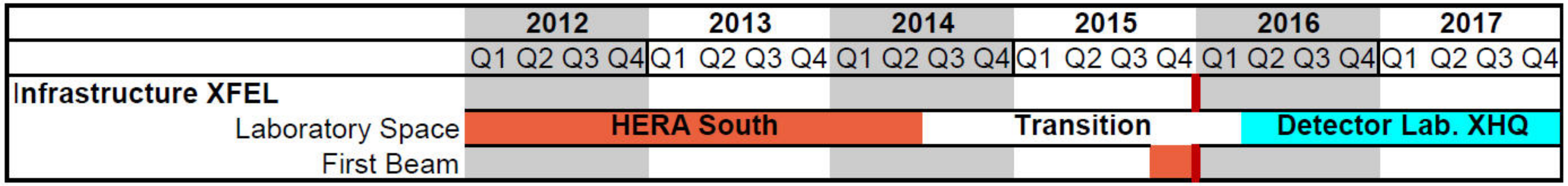
Point-like illumination

- Focusing optics (gain factor = 500 – 20000) → **> 1000 hits per pulse/pixel (200 μm x 200 μm)**

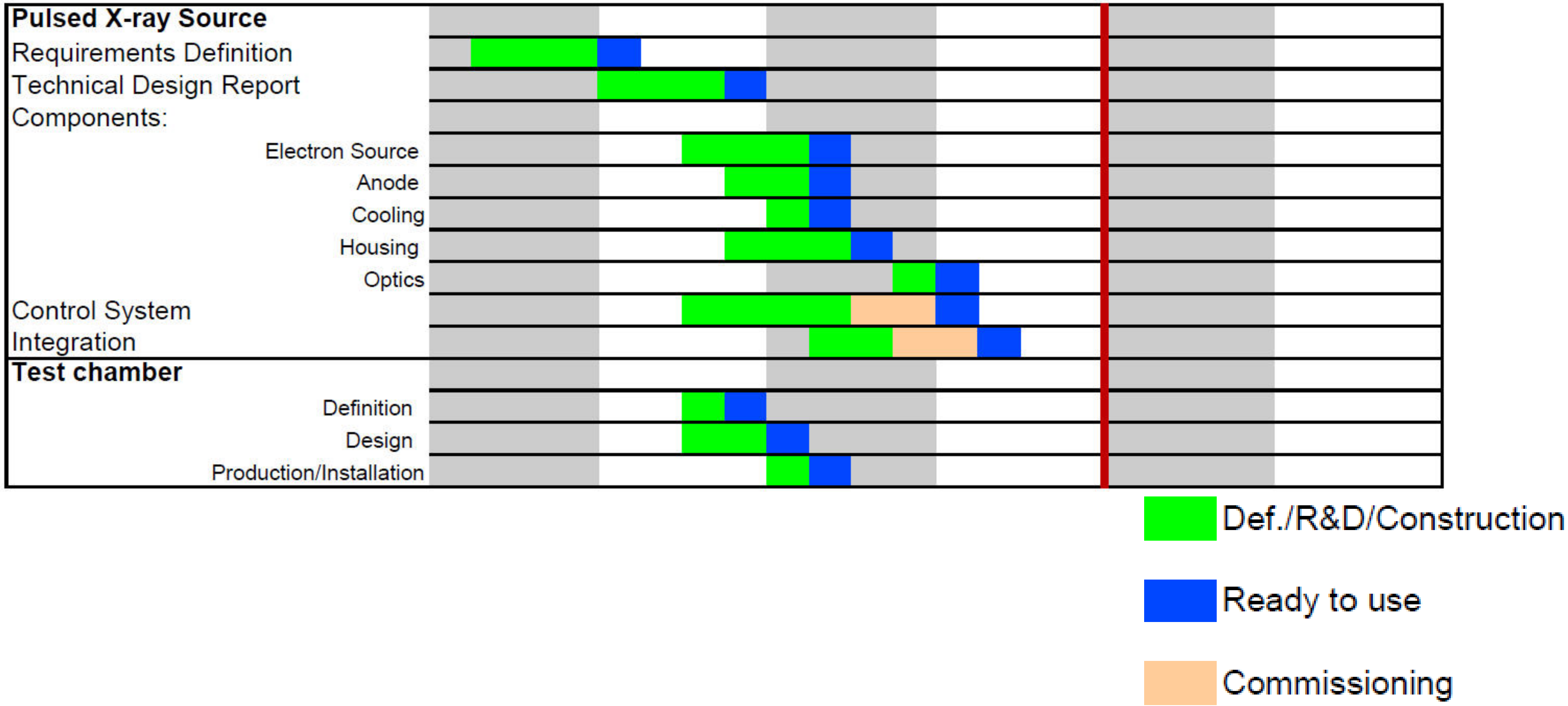
Cluster illumination (~a few mm^2)

- Collimating optics (gain factor > 10) → **> 20 hits per pulse/pixel (200 μm x 200 μm)**

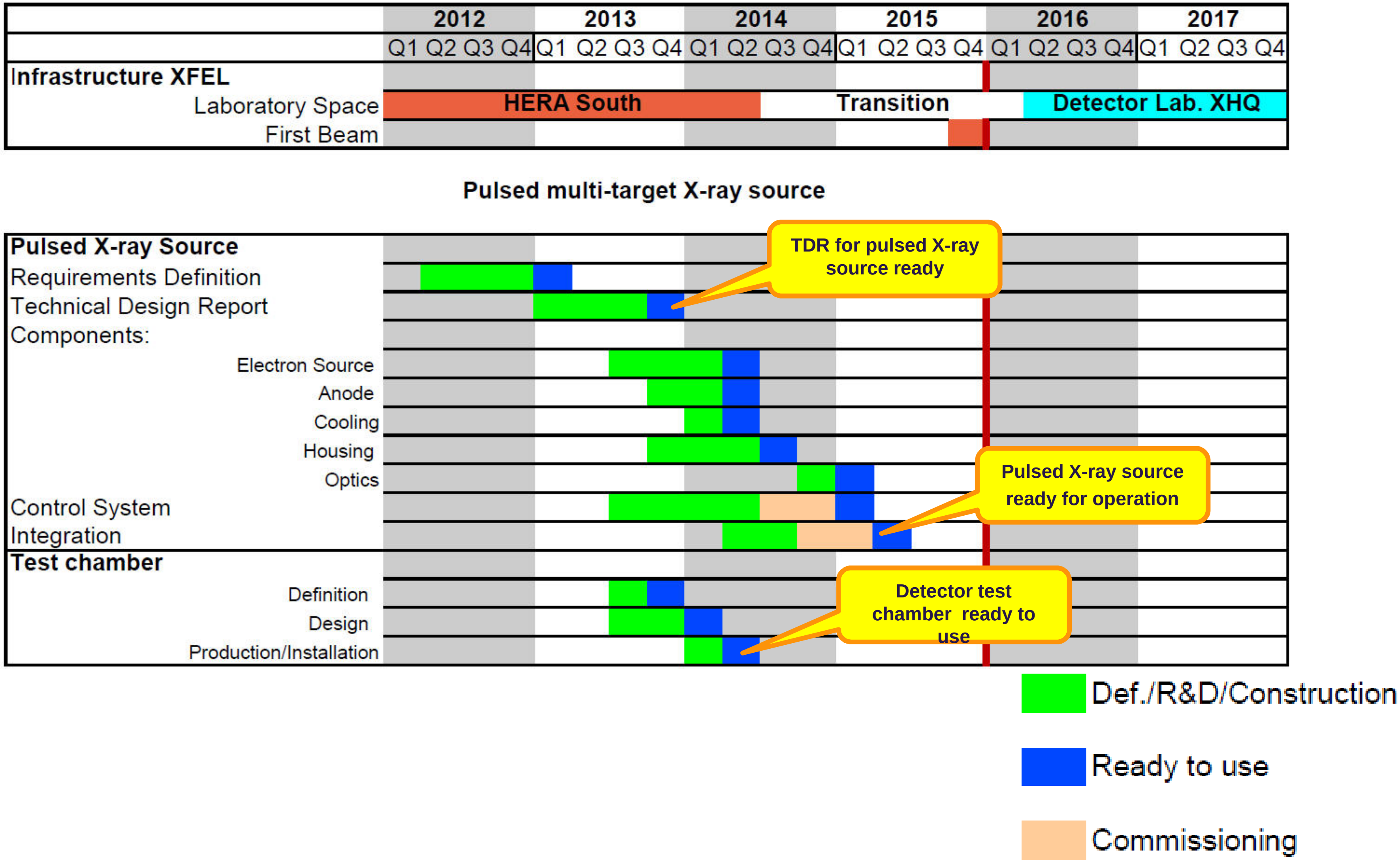
Pulsed multi-target X-ray generator - schedule



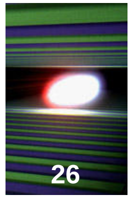
Pulsed multi-target X-ray source



Pulsed multi-target X-ray generator - schedule



Summary



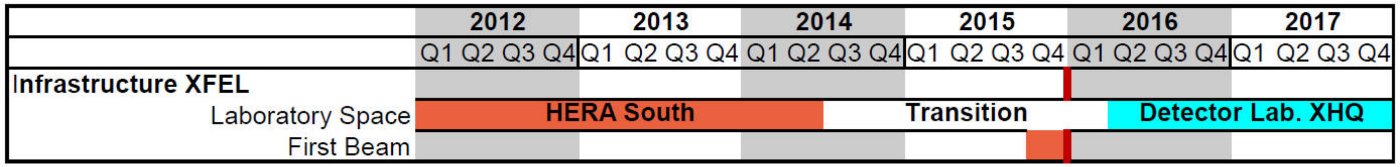
- Work on calibration is ongoing in the Consortia and XFEL → discussed during regular meetings
- Setup of the calibration infrastructure is ongoing → Fe-55 source and a portable X-ray tube setups will be available in Summer 2013
- Work on calibration software and simulation at the XFEL is ongoing
- X-ray generator concept being elaborated

  → simulation is available

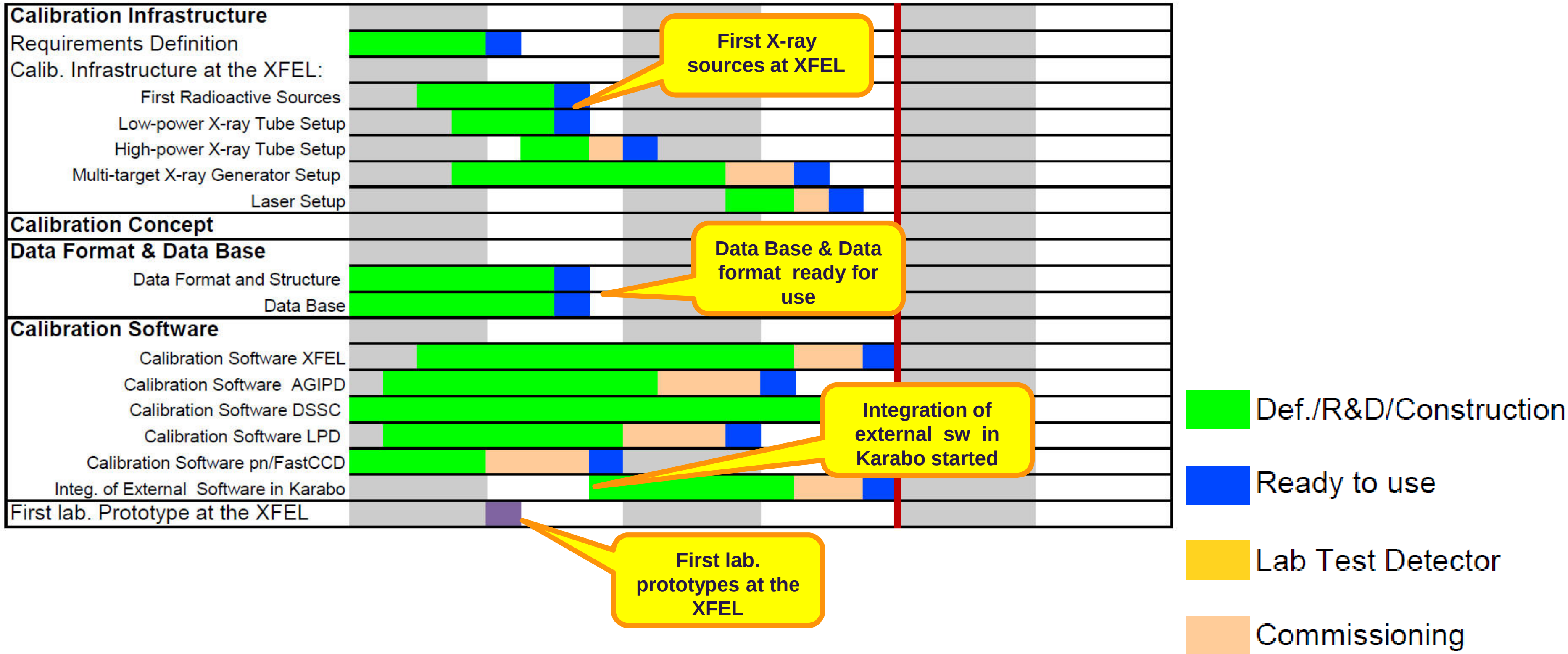
  → the potential components developers identified

  → TDR in preparation
- First 2D detector prototype @ XFEL
- First beam time at LCLS and PETRA

Schedule



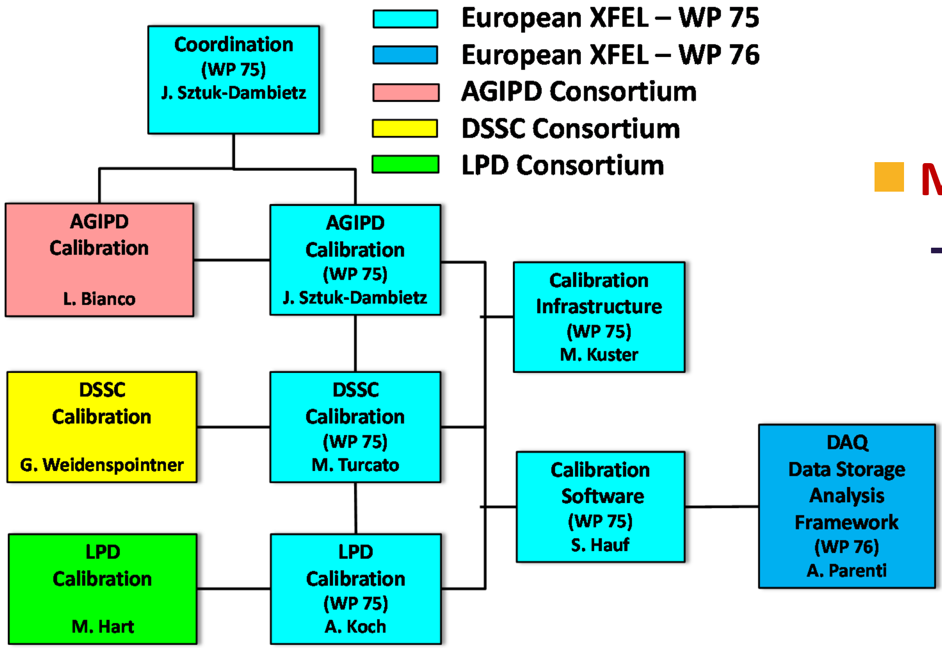
Calibration



Backup slides

Calibration Working Group – Update

Structure of the group:

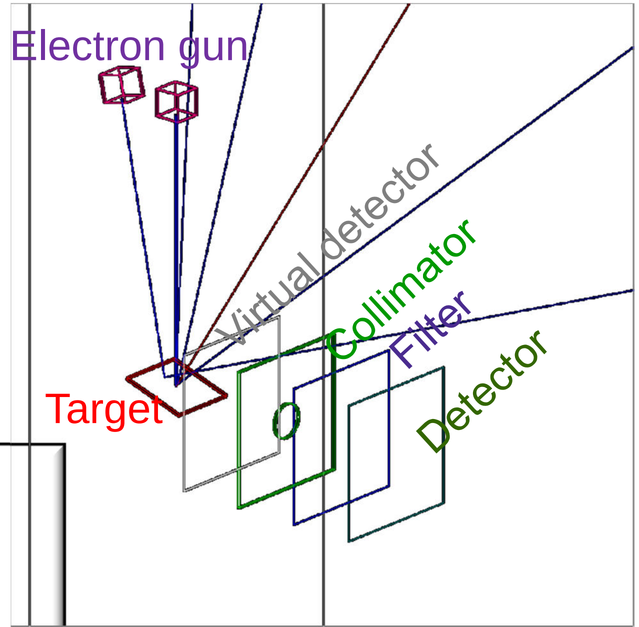


- **Meetings:** every 6 months
  → next meeting in September

X-ray Generator - GEANT4 Simulation

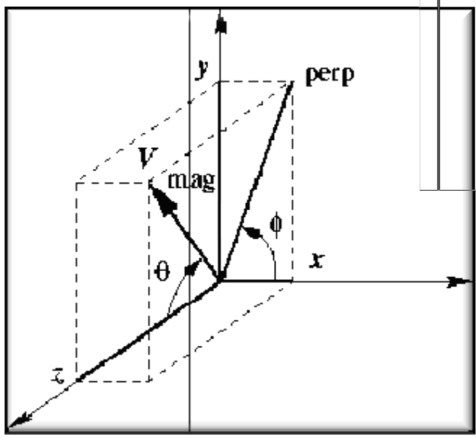
- Optimization of X-ray generator setup parameters using GEANT4 simulation*
  - ✓ target material and angles
  - ✓ filter material and thickness
  - ✓ beam current
  - ✓ geometry
- Estimation of beam intensity
- Shielding definition
- Input to TDR

Geometry definition:



Courtesy S. Hauf

Coordinate definition:



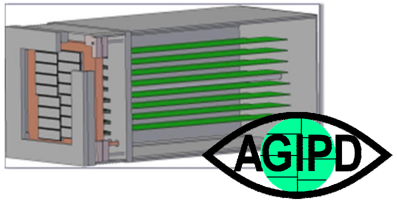
* Code validation based on arXiv:1205.1973

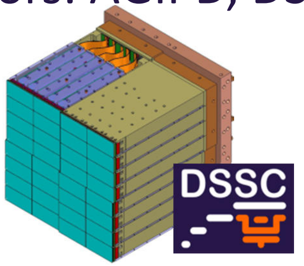
Work on simulation of X-ray source started → first version of the software is ready

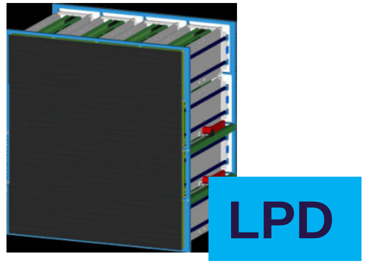
Detectors to be calibrated & characterized - reminder

2-D Mpixel X-ray imaging detectors

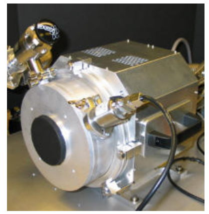
- High repetition rate detectors: AGIPD, DSSC, LPD





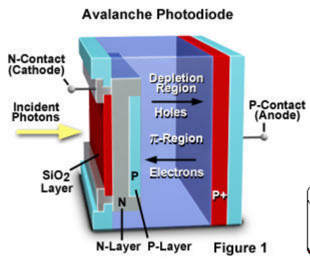


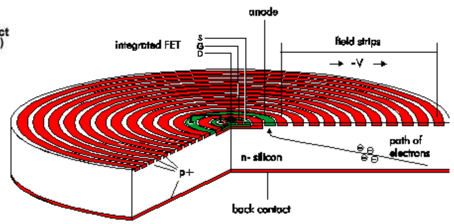
- Low repetition rate detectors:
  pn CCD, other CCDs



..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 < 50 ns**
- **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

Pulsed multi-target X-ray generator – anode

- Anode with different materials coated/deposited on it

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

- Potential company which could design and deliver such kind of anode with most of the materials from the list was identified
  - Open points
    - → Heat load → Input from Kimball is needed
- Self-made anode

Kimball Electron guns – Pulsing

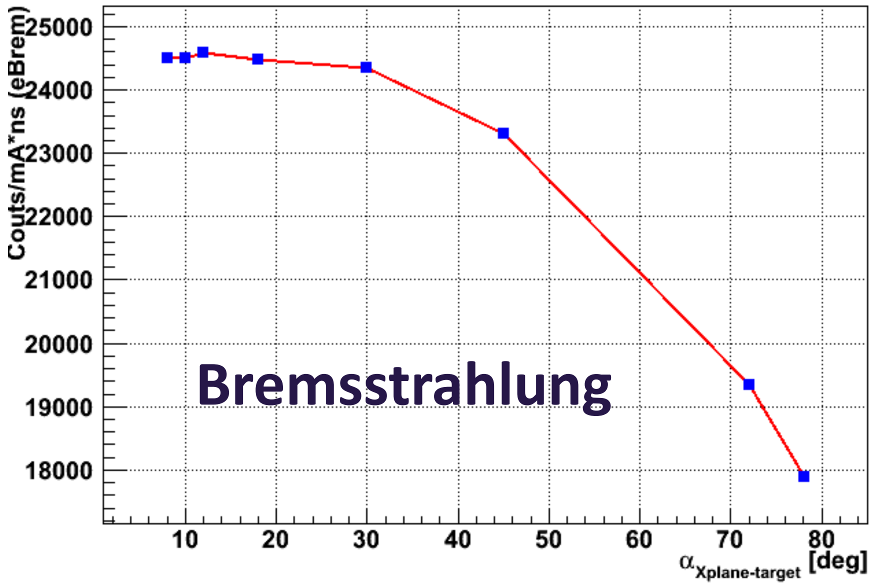
- **Dual grid pulsing** option, there are two grid power supplies built into the main power supply. A pulsing TTL (transistor-transistor-logic) signal switches rapidly between the two supplies, pulsing the beam on and off.

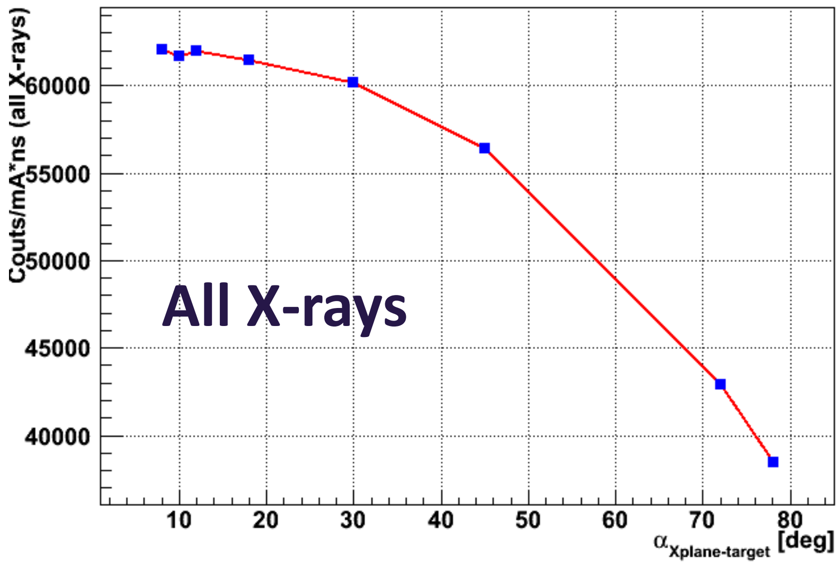
- **Beam blanking** is a different type of pulsing that does not rely on grid cut-off and is used in some high current guns. Blanking deflects the electron beam to one side of the gun tube to interrupt the flow of electrons to the target without actually turning off the beam.

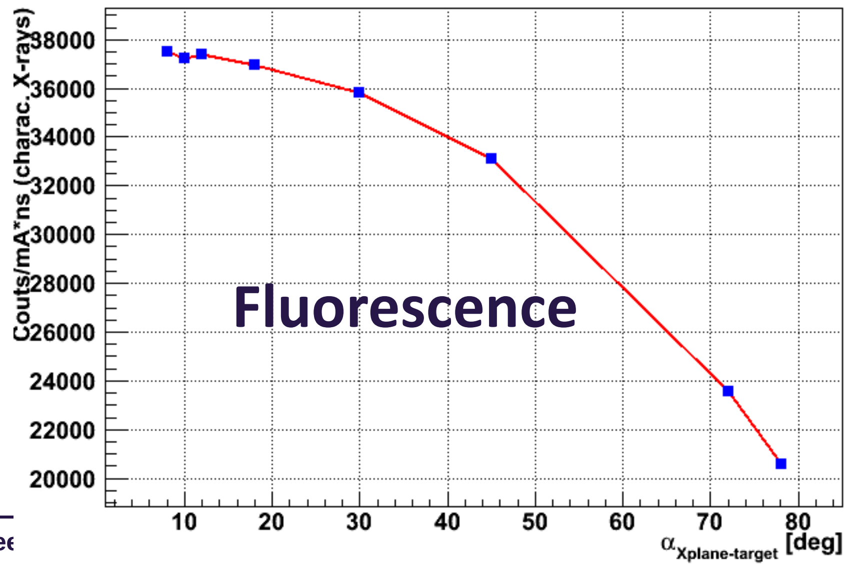
Angle between Target & X plane - α_{target} X-ray production

Simulation parameters

- Ee= **100 keV**
- Target: Cu 5mm x 100mm
- Target angle: α = 8°, 10°, 12°, 18°, 30°. 45°. 72°. 78°



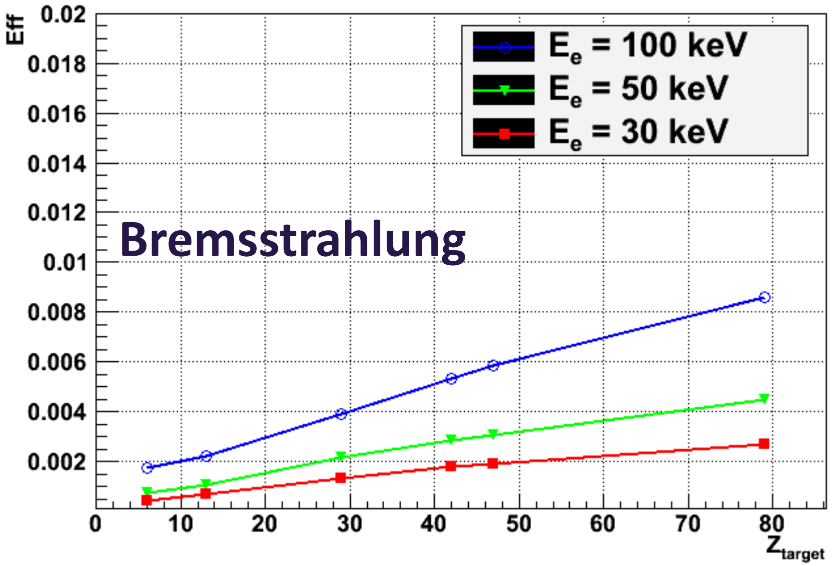


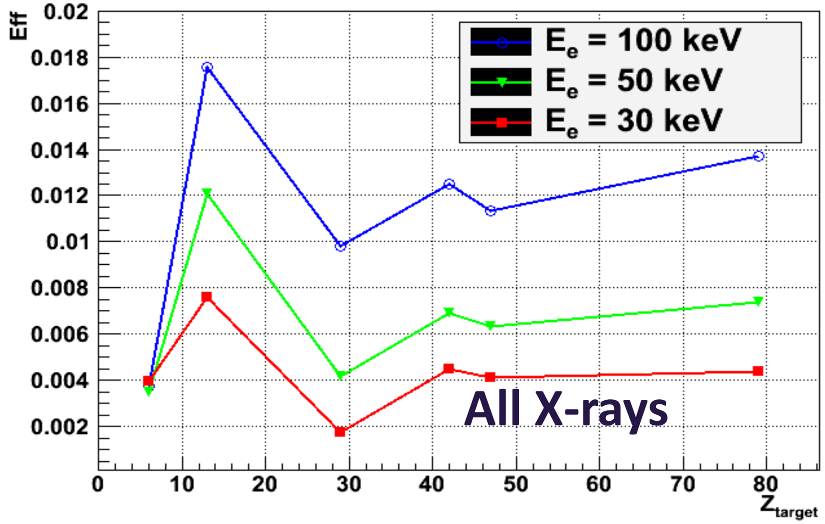


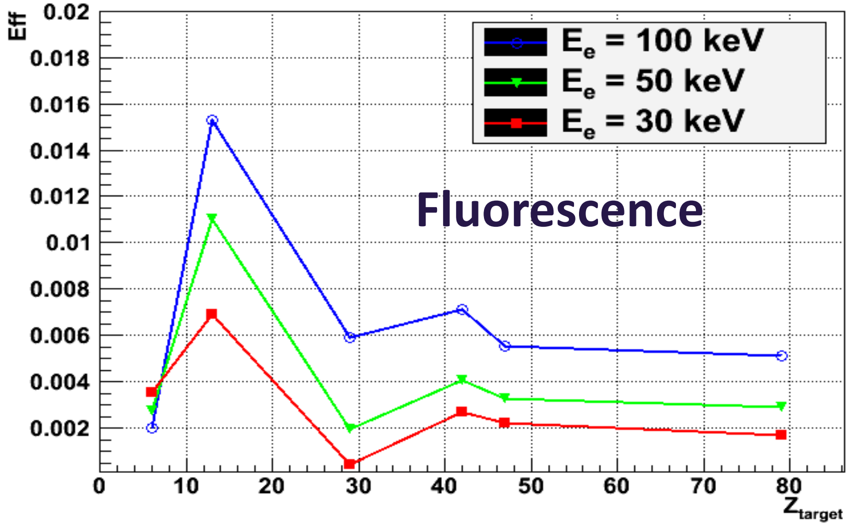
Target angle < 30° → max. intensity

Target material & e- energy dependences – X-ray production efficiency

$$\text{Eff} = \frac{N_{\gamma}}{N_{prim\ electrons}}$$







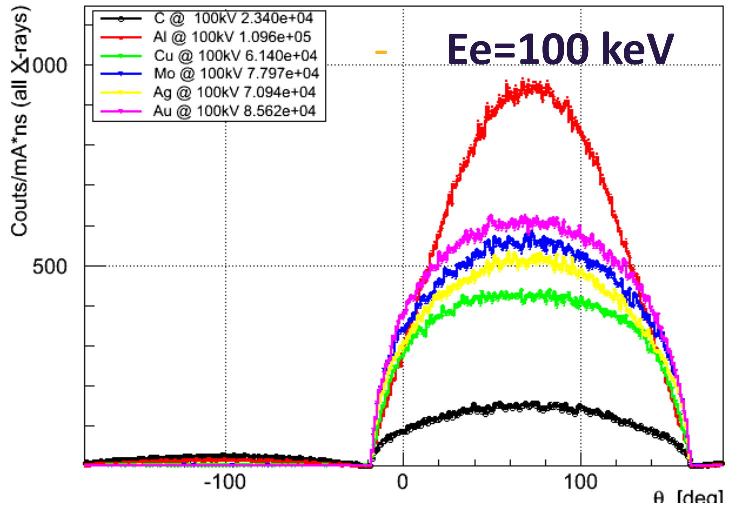
Efficiency of X-ray production

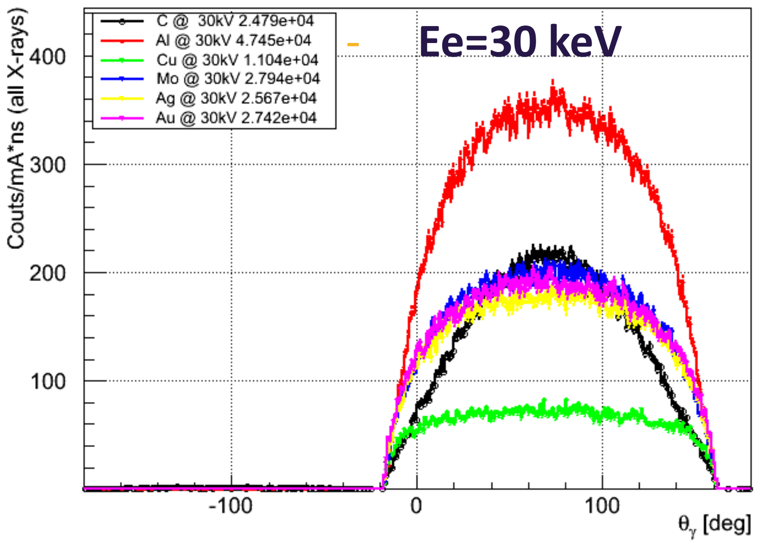
~ 0.2- 1.8 %

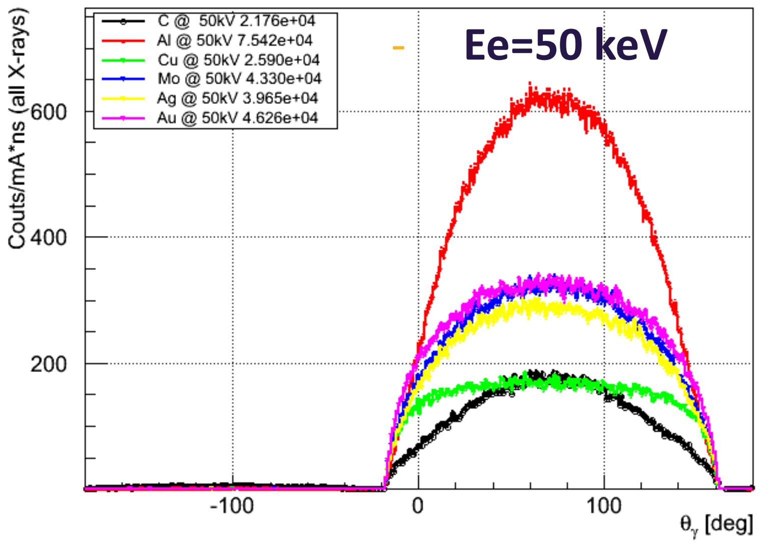
Target material & e- energy dependences – X-ray angles - θ

Simulation parameters

- 40 M primary e-
- Ee = 30,50,100 keV
- Target size: 5mmx100mm
- Target materials: C, Al, Cu, Mo, Ag, Au
- Target angle: α =18°
- **Spherical virtual detector → full angular range**







Target material & e- energy dependences – X-ray angles - φ

Simulation parameters

- 40 M primary e-
- Ee = 30,50,100 keV
- Target size: 5mmx100mm
- Target materials: C, Al, Cu, Mo, Ag, Au
- Target angle: α =18°
- **Spherical virtual detector → full angular range**