First test of a diamond detector at European XFEL

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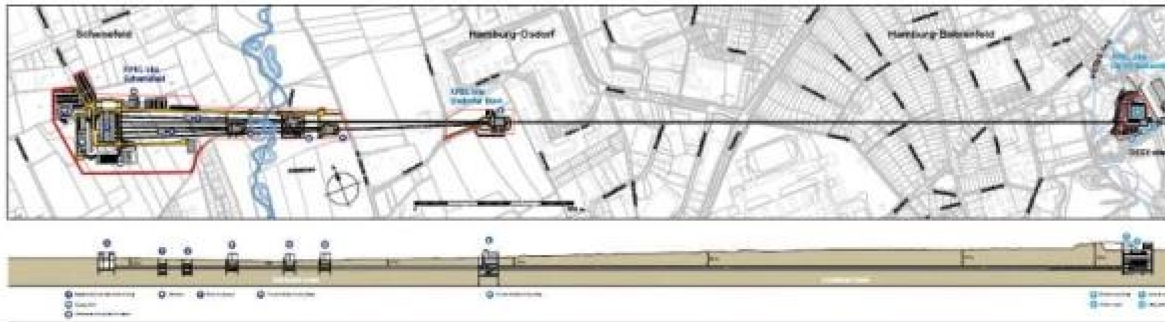
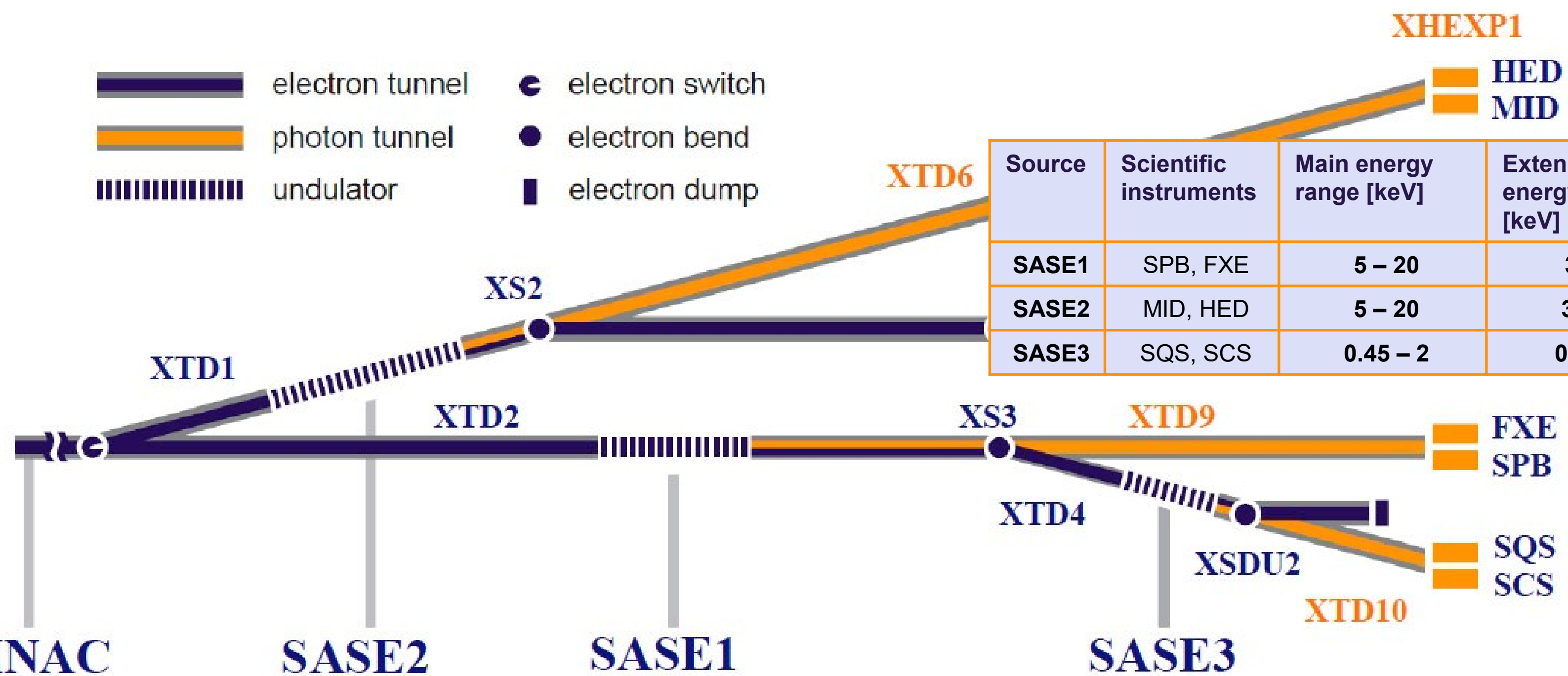
Facility Layout (photon part)

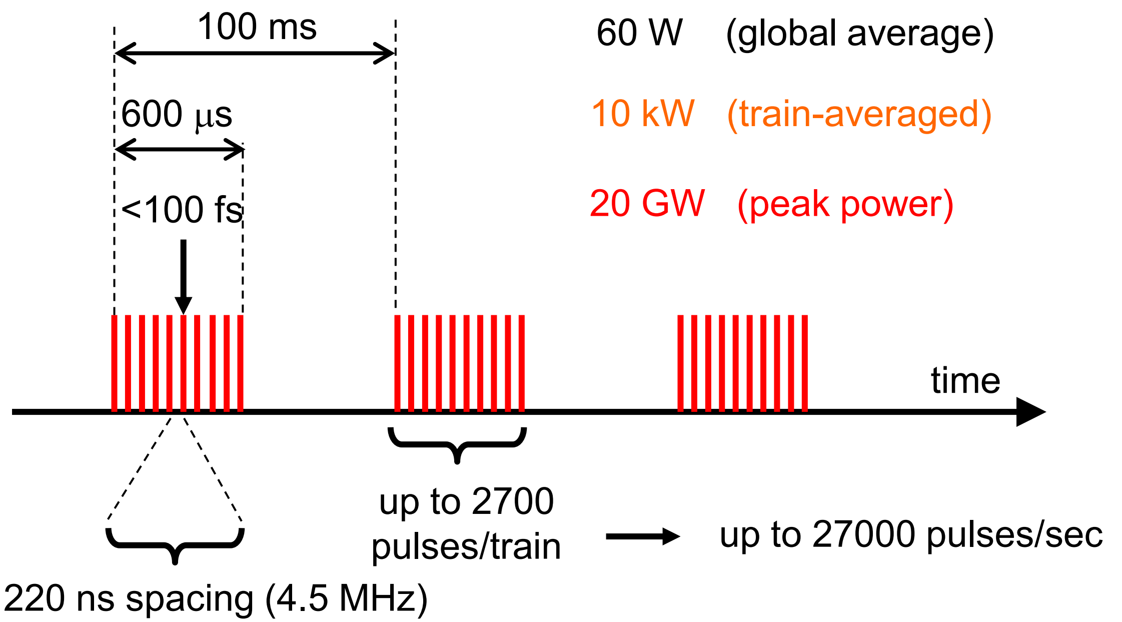


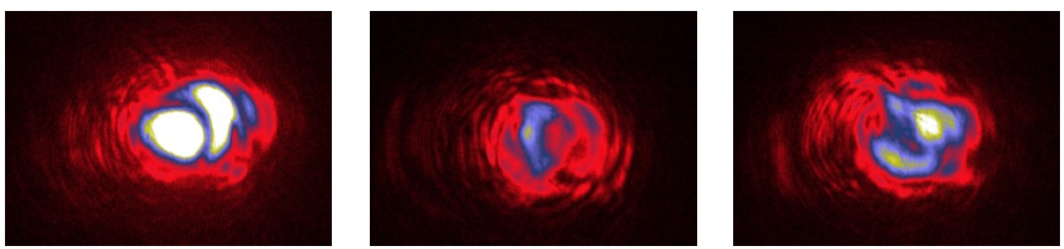


Source	Scientific instruments	Main energy range [keV]	Extended energy range [keV]
SASE1	SPB, FXE	5 – 20	3 – 20
SASE2	MID, HED	5 – 20	3 – 36
SASE3	SQS, SCS	0.45 – 2	0.26 – 3

FEL beam properties (SASE1 and SASE2 undulators)

- Transversal highly coherent beam
- Photon energy 5-20 keV
- Pulse energy from a few μJ to ~ 2 mJ (~ 10^{12} photons)
- Pulse length ~ 50 fs
- Due to SASE process: strong fluctuations from shot to shot





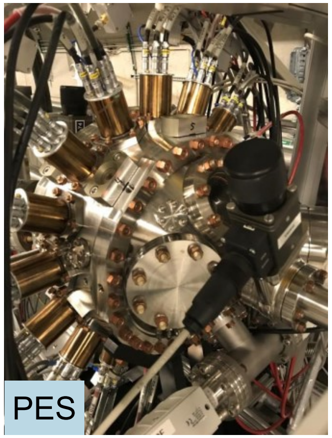
Example of three adjacent FEL pulses – each pulse can have different LASER modes (after monochromator)

X-ray photon diagnostics at European XFEL

Measurement of beam properties

- Invasive diagnostics (Imagers, MCP detector, K-mono, …)
- Gas based online diagnostics
  - XGM (X-ray Gas Monitor), main instrument for pulse energy and avg. beam position
  - PES (Photoelectron spectrometer, 16 TOF)
- Solid-state online diagnostics (minimally invasive)
  - Single-shot spectrometer (HIREX)
  - Backscatter monitors
  - Diamond screens
  - **Diamond detectors**


HIREX
single shot spectrometer


PES

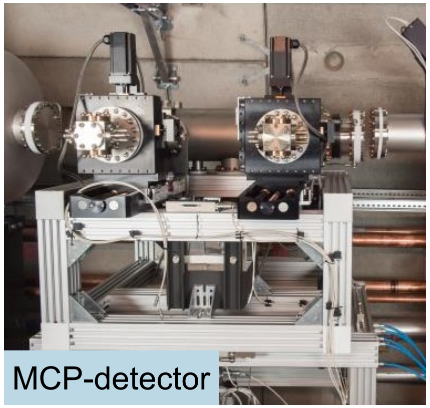

X-ray Gas Monitor (XGM)


Filter Ch. & IMGTR


Pop-in Monitor


K-mono


SR-imager


MCP-detector

Diamond detectors for X-ray photon diagnostics

First diamond detector projects started already in 2012 with tests at Elettra and LCLS (*).
We are now relaunching the detector project. The goal is to build a detector setup for single-shot intensity and position detection in the hard-X-ray beamlines.

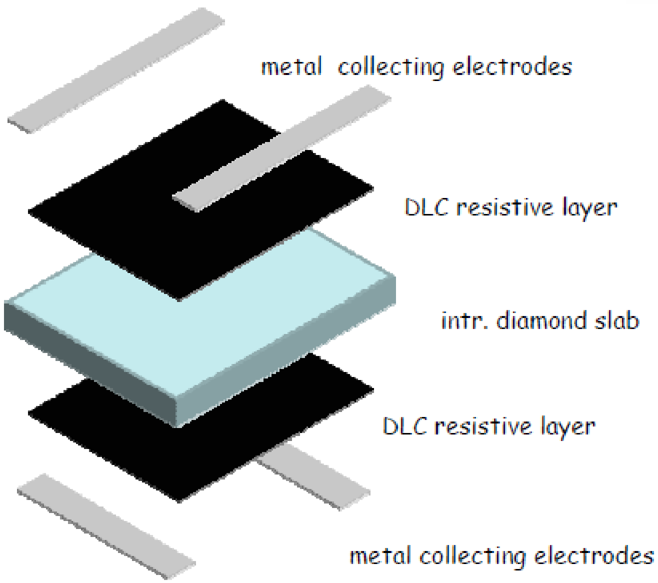
Requirements:

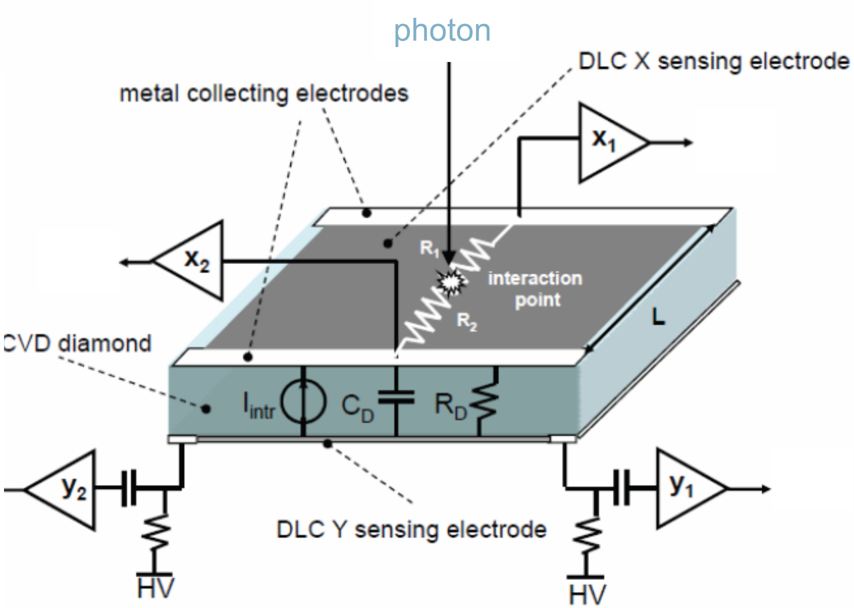
- High pulse energy → radiation hard and robust against single shot damage
- High repetition rate (4.5MHz) → detector speed
- Beam position jitter → measurement accuracy between 10 and 100 µm (depending on position)
- Intensity jitter → relative accuracy better 1% and high dynamic range
- Continually in beam path → minimal interference with beam
- e.g. use ins split and delay units for adjustment of beam path → small detector
- Fast feedback to accelerator → pulse resolved detector

(*) Roth, T., Freund, W., Boesenberg, U., Carini, G., Song, S., Lefeuvre, G., Goikhman, A., Fischer, M., Schreck, M., Grünert, J. & Madsen, A. (2018). J. Synchrotron Rad. 25, 177-188.

Duolateral diamond detector

- Detector fabricated at CEA Saclay (M. Pomorski)





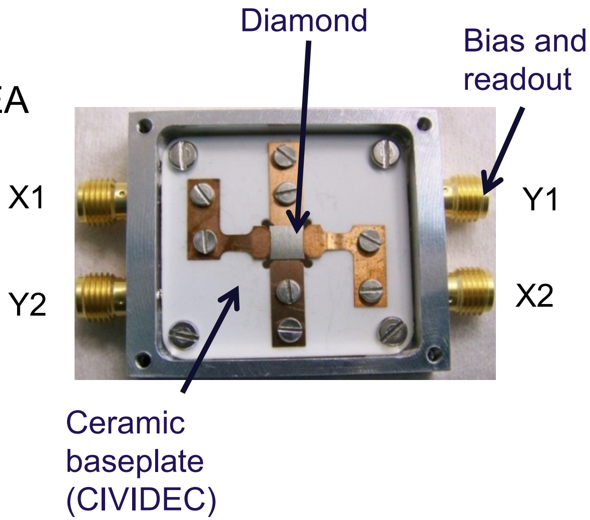
$$X = \frac{A(x_1) - A(x_2)}{A(x_1) + A(x_2)} \cdot \frac{L}{2} \qquad Y = \frac{A(y_1) - A(y_2)}{A(y_1) + A(y_2)} \cdot \frac{L}{2}$$

Images courtesy M. Pomorski

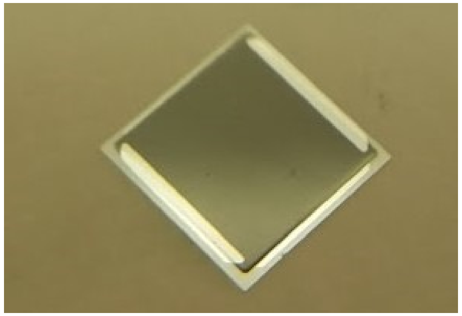
Ref: M.Pomorski et al., Phys. Status Solidi A **206**, No. 9, 2109–2114 (2009) / **DOI** 10.1002/pssa.200982229

Detector assembly

- Tested diamond sample EG-6 processed by Michal Pomorski, CEA (40 µm single crystal CVD, electronic grade)
- DLC layer: surface resistance of 350 Ω and 750 Ω
- Al contacts at the edges

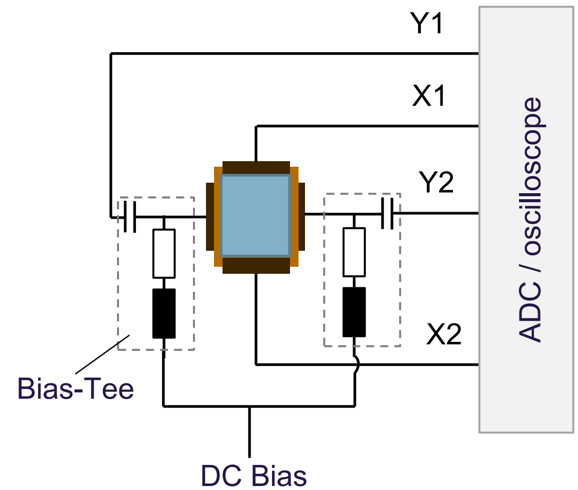


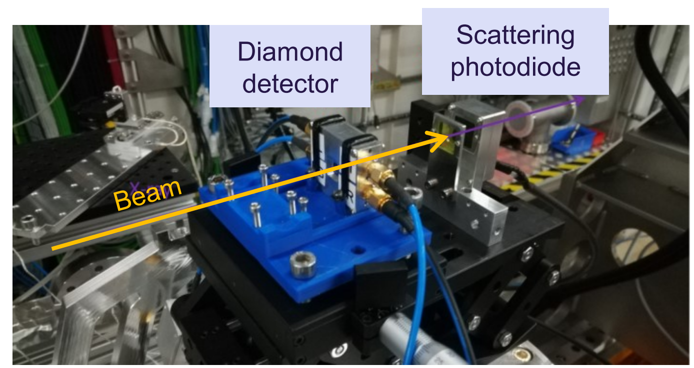
- Why using a duo-lateral and not a four-quadrant detector ?
  - SASE-FEL strongly jitters in energy, position, shape: non-gaussian beam with large deviation from the center → no reliable measurement (4-quadrant)
  - FEL is highly coherent: non-homogenous contacts introduce wavefront distortion (probably pure carbon contacts could be used)

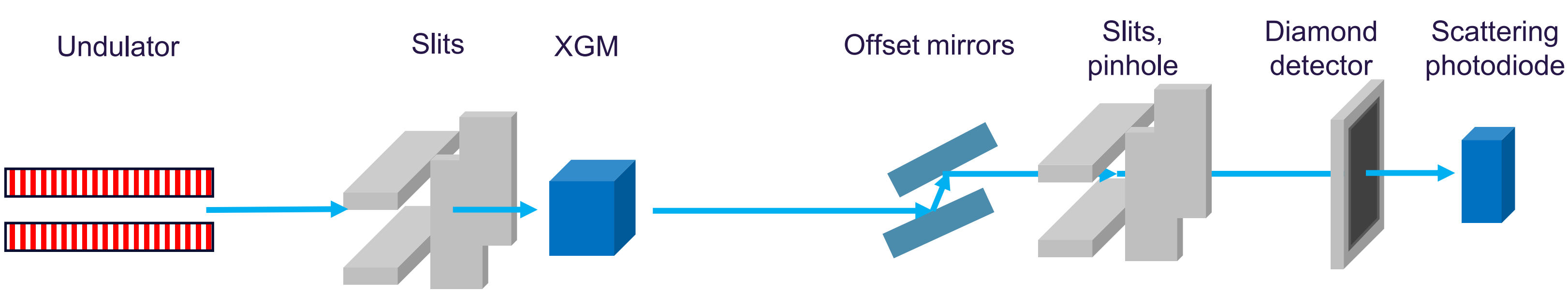


Measurement setup

- Beam parameters:
  - 9.3 keV x-rays
  - max. 1.1 mJ per pulse (~ $7 \cdot 10^{11}$ photons)
  - Pulse length ~ 50 fs
  - 4.5 MHz repetition rate
  - Beam diameter approx. 1- 2 mm (not focused)
- Setup:
  - Fast oscilloscope (50 GS/s) or ADC board (108 MS/s) with pulse stretcher
  - Up to 30 dB attenuators at the 50 Ohm inputs no amplifiers





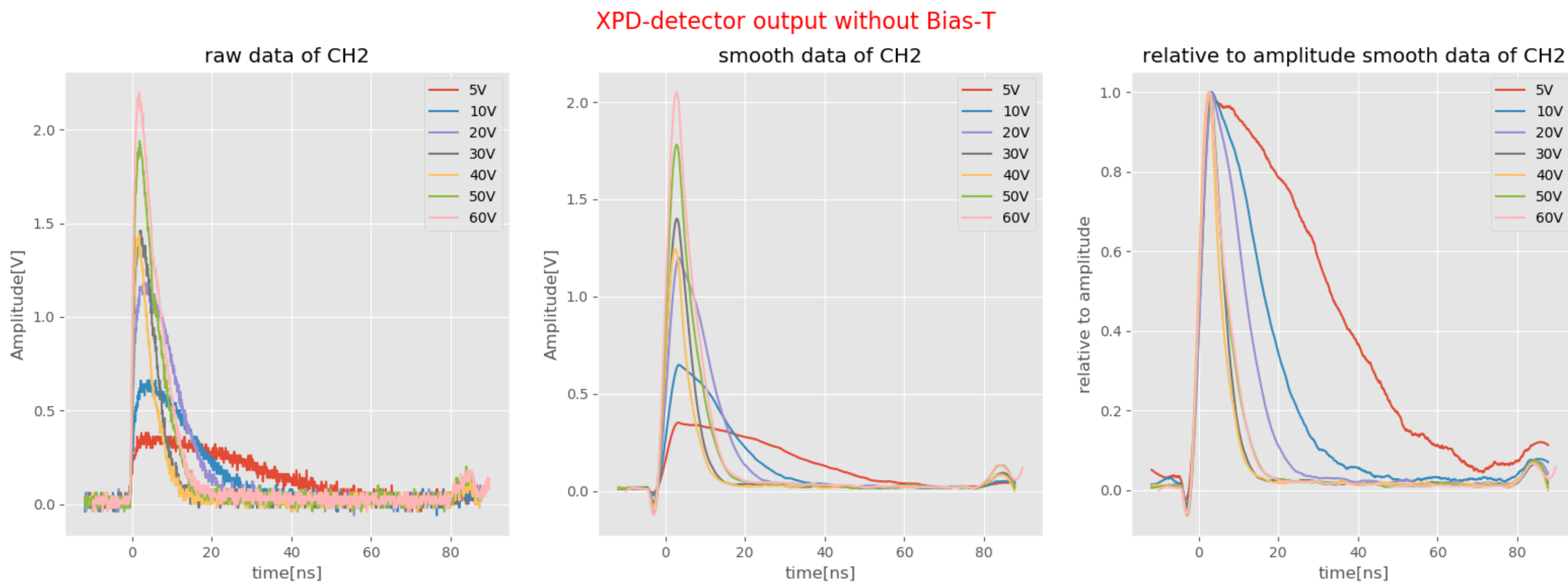


Measurements

- MID instrument in SASE2 (Materials Imaging & Dynamics)
- Commissioning beamtimes:
  - February 2019 with 7.5 keV / 30 µJ beam
    before first user run, beam was not stable, test of instrumentation
  - July 2019 with 9.3 keV / 1.2 mJ beam
    good beam conditions, DAQ problems
- Difficult to get fully supported user beamtimes for our detector development

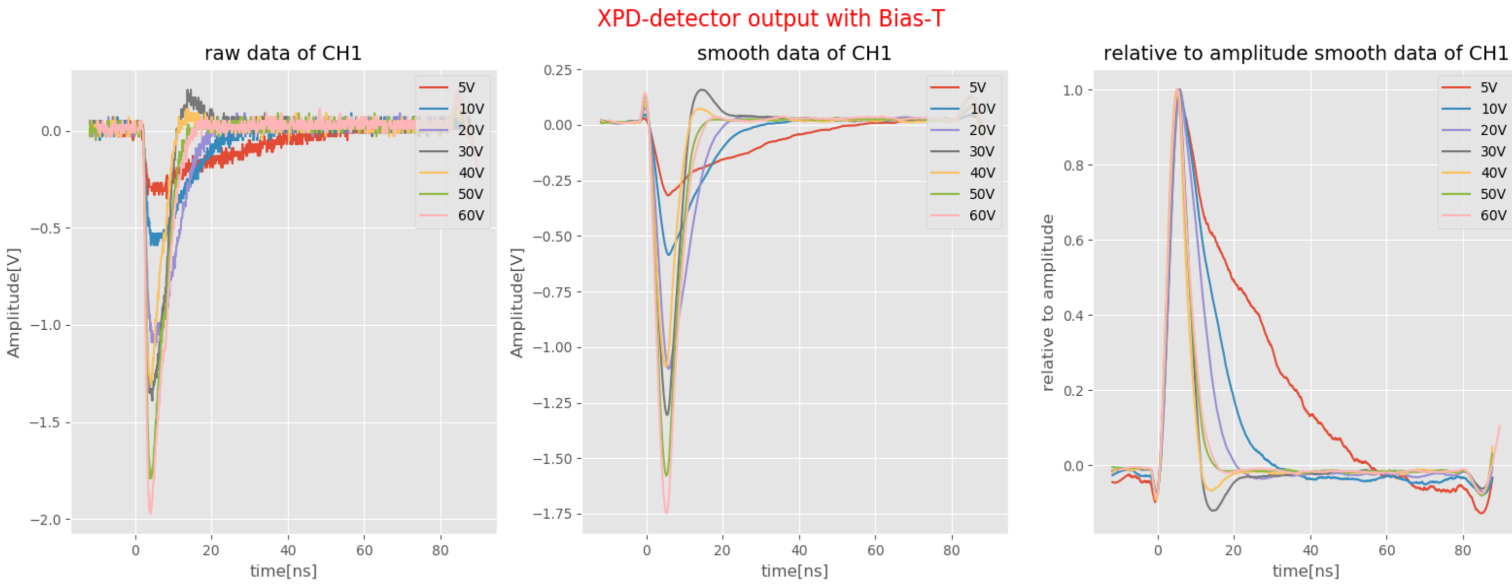
Pulse shape at low intensity

- Beam condition: 7.5 keV, 30 µJ, repetition rate 1.1 MHz
- Detector directly connected to oscilloscope, signal from front side
- Best timing with 30-50 V bias



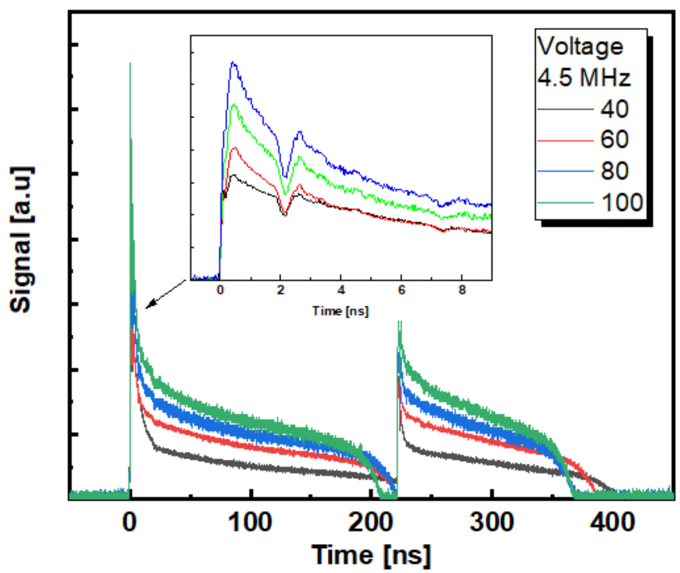
Pulse shape at low intensity

- Beam conditions and setup as before
- Signal readout via bias-Tee from backside
- Similar signal as before, but some overshoot after the main peak → optimization of electronics

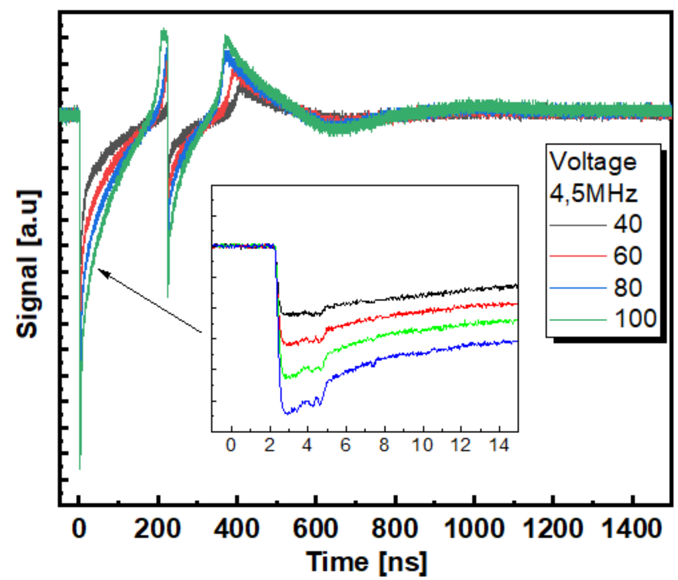


Pulse shape at high intensity / high rep-rate

- Measured signal vs bias voltage
- 9.3 keV, 1.1 mJ, 2 bunches@ 4.5 MHz



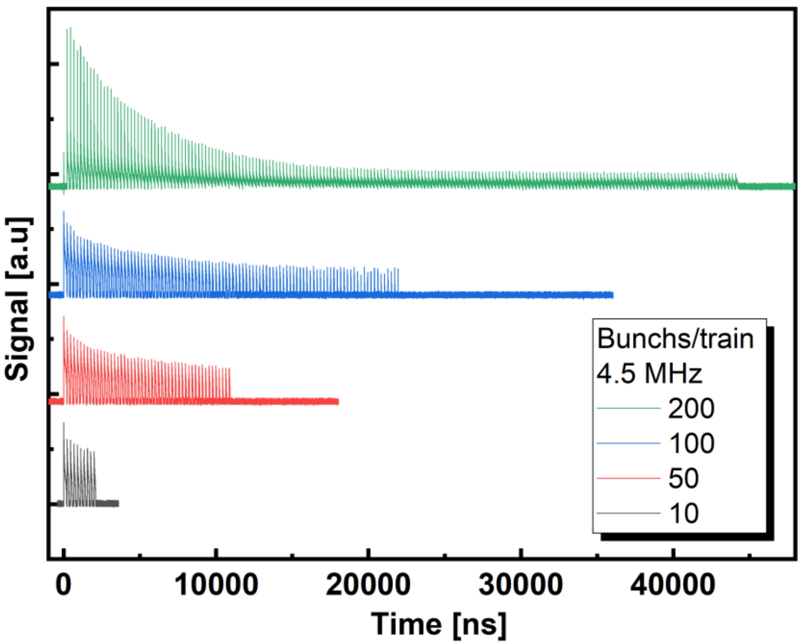
Diamond BPM channel Right



Diamond BPM channel Top with Bias-T

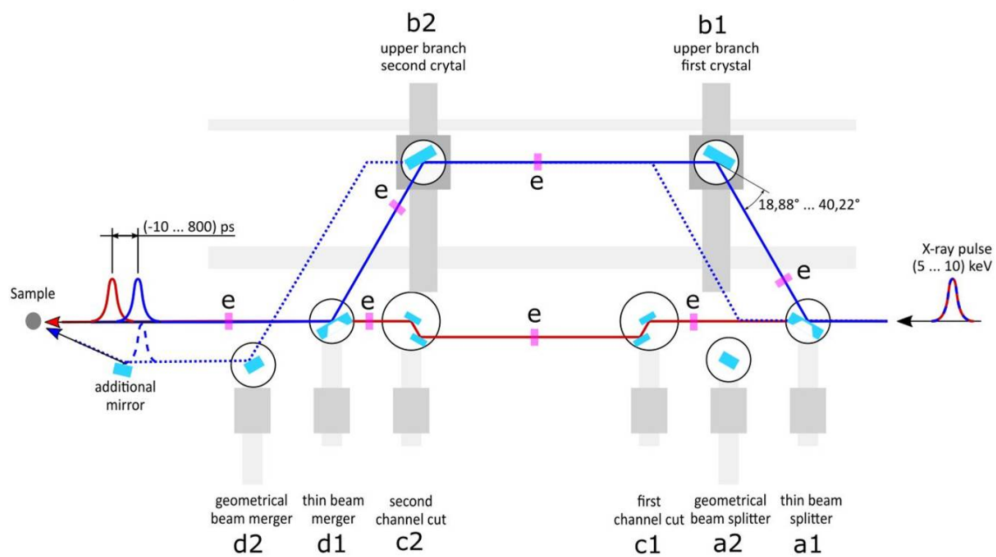
Pulse shape at high intensity / high rep-rate

- Beam: 9.3 keV, 1.1 mJ, 4.5 MHz
- Detector:
  - right channel without Bias-T
  - 100 V bias on back side
- Longer pulse trains: 10 to 200 pulses
- Memory effect at 4.5 MHz:
  detector system doesn‘t recover from last pulse
  → exponential decay
- At 1.1 MHz this effect was negligible



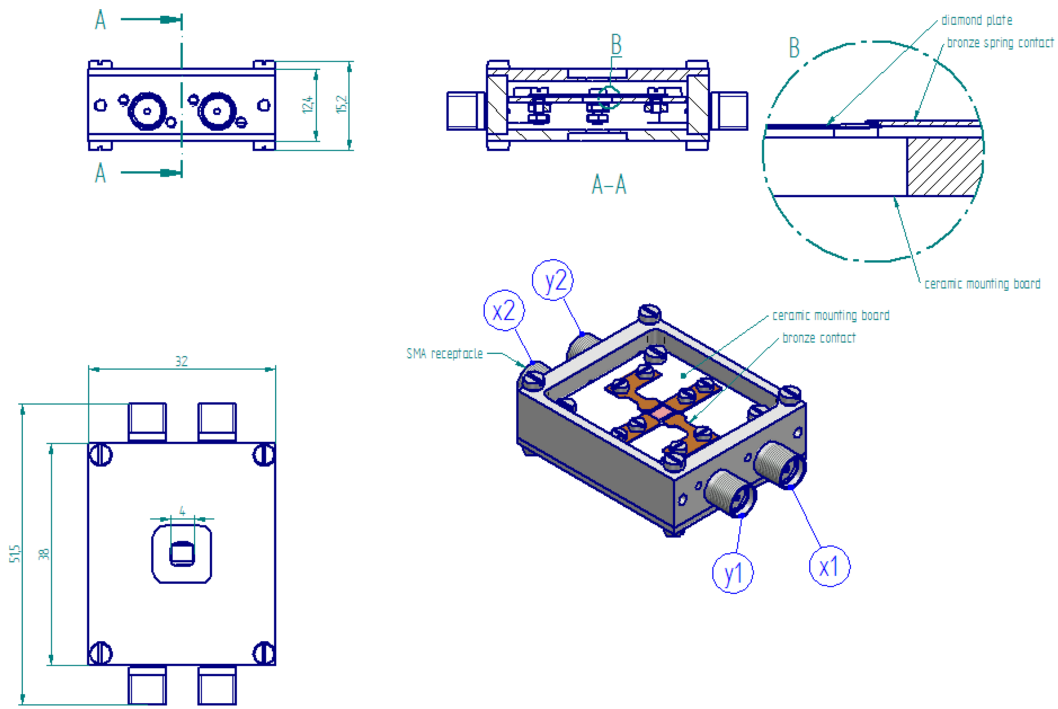
Conclusions and outlook

- Detectors worked well at low pulse energy. Saturation effects at higher intensity (> 100 µJ).
- Need faster detectors:
  - Lower surface resistance of electrodes (may compromise position accuracy)
  - Test of four-quadrant detector with carbon electrodes
  - Thin detectors ~ 10 µm
- Diamond detectors could be used for beam stability high speed feedback systems
- Need a small series of detectors for MID split-and-delay-unit, which must be compact and UHV compatible (e)



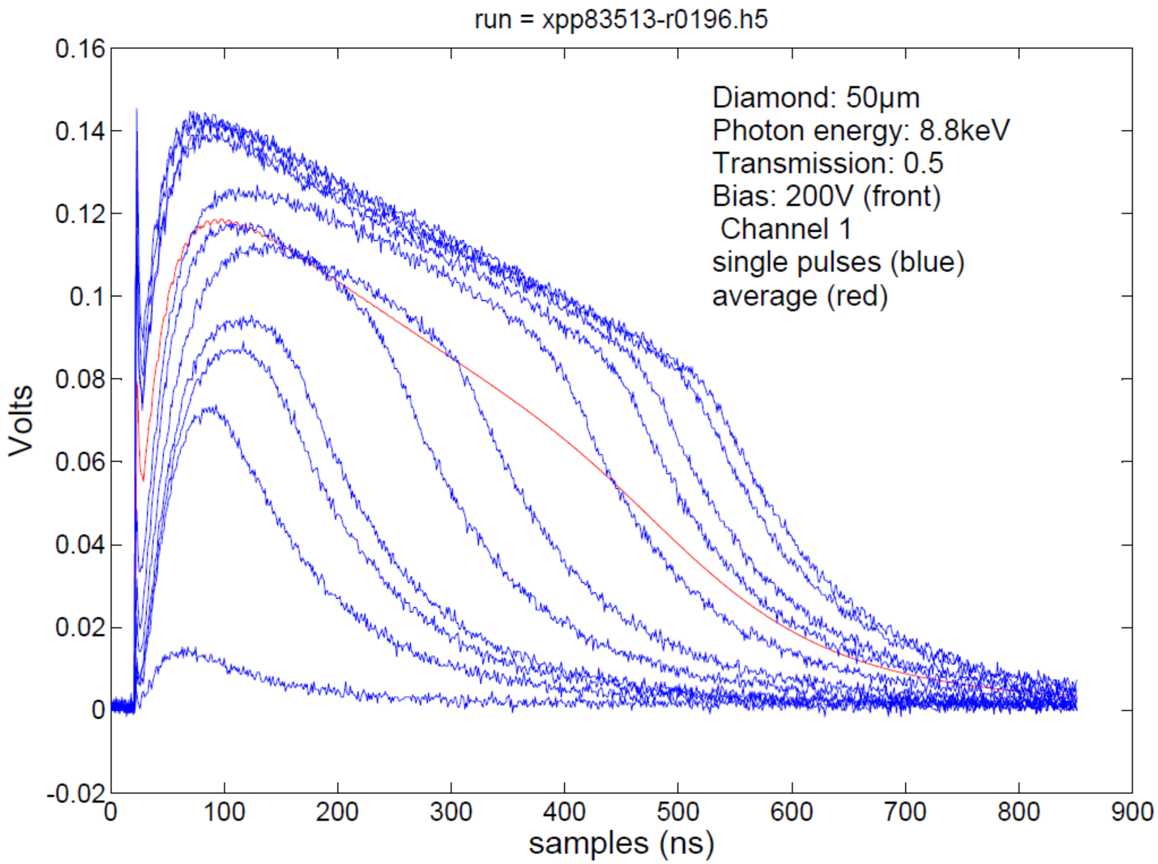
Thank you for your attention

SPARE SLIDES



Measurements at LCLS from 2013

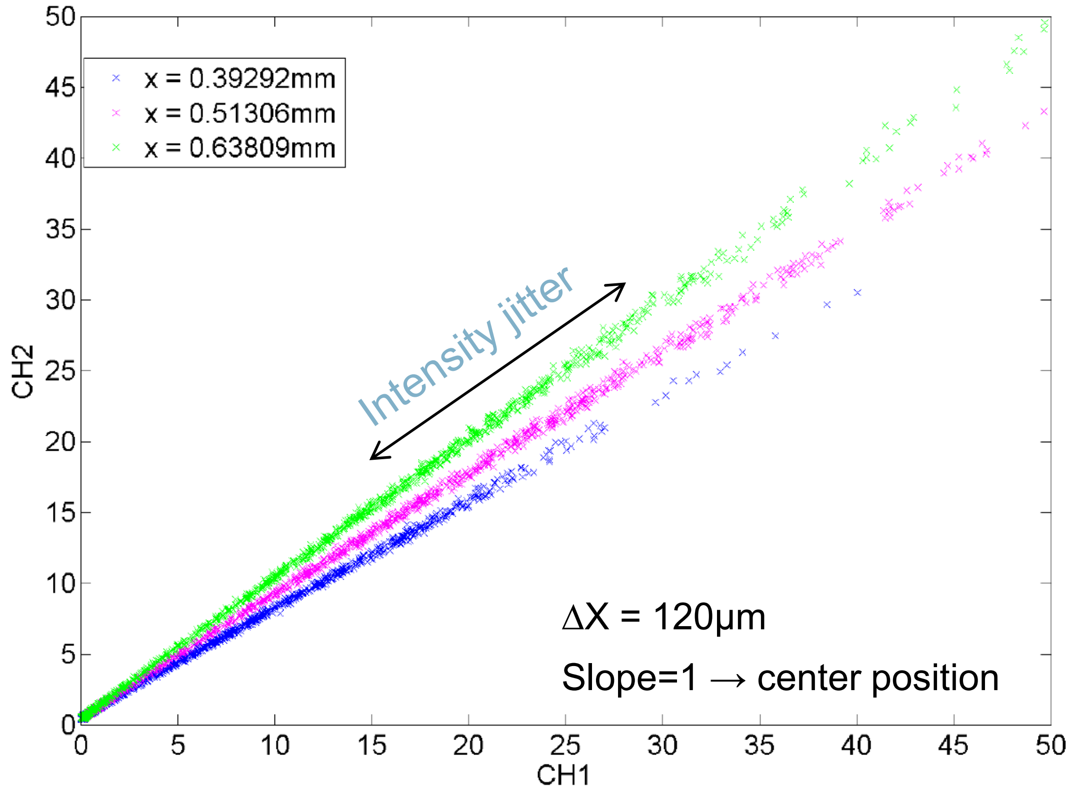
- 50 µm diamond
- Contact resistance 125 kΩ and 2.6 kΩ
- Beam:
  - 8.8 keV
  - Max. 10 µJ



Measurements at LCLS from 2013

1D-position scans / moved DD on x-y-stage in x-direction

- 300 µm diamond
  3.4 kΩ/8.2 kΩ
- 3 different x-positions
- Slits: 100 x 100 µm
- Attenuation: 10^{-2} (transm.)
- Bias: +200 V at front
- Single shot data
- Averaged position accuracy better 5 µm



Measurements at LCLS from 2013

1D-position scans / moved DD on x-y-stage in x-direction

- 300 µm diamond
- 5 µm stepwidth / 1mm range
- Slits: 100 x 100 µm
- Attenuation: 10^{-2} (transm.)
- Bias: +200 V at front
- Average of 1000 shots/step