Large area position-sensitive CVD diamond detectors for X-ray beam monitoring with extreme position resolution

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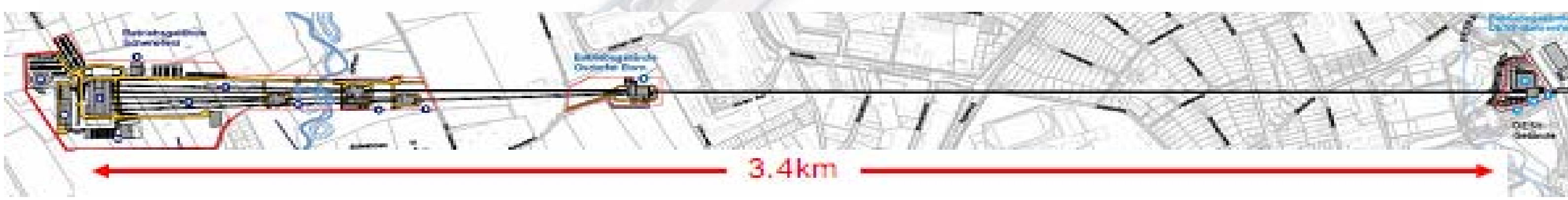
Talk Outline

- Motivation/Goal
- Why Diamond?
- Detector Fabrication and Read-out
- Measurements and Results
    - in-beam duo-lateral scCVD-PSD
    - pulse-mode XBPM @ MHz regime
    - four-corner PSD - lab tests
- Summary and Outlook

Development of novel solid-state PSDs for x-ray beam monitoring

including:

a hodoscope for EU XFEL commissioning (and normal operation?)
beam tracking within ~700m (pulse-mode, 4mm^2, σ≤7μm)

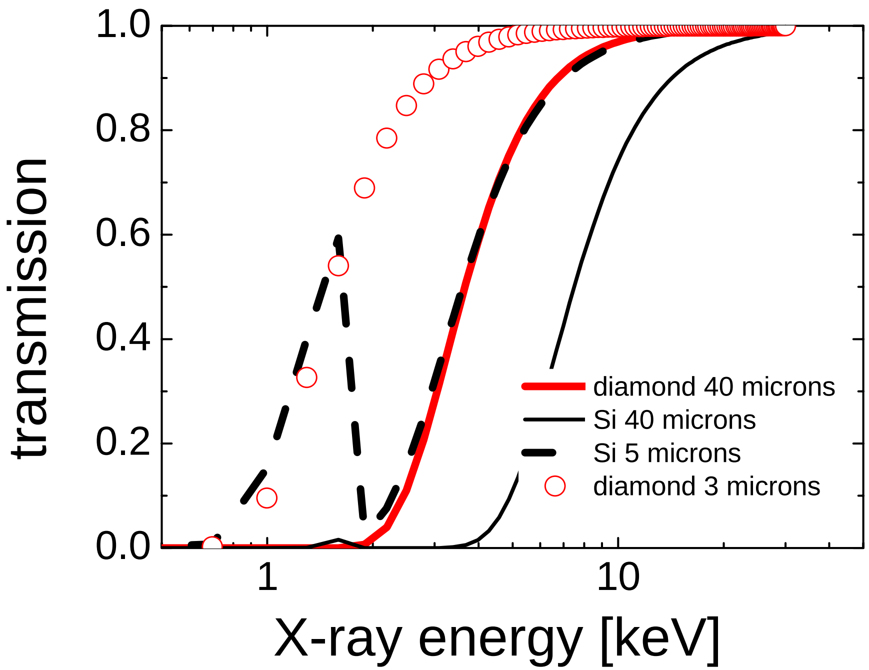


EU XFEL (Jan Gruenert talk 1st CARAT workshop)

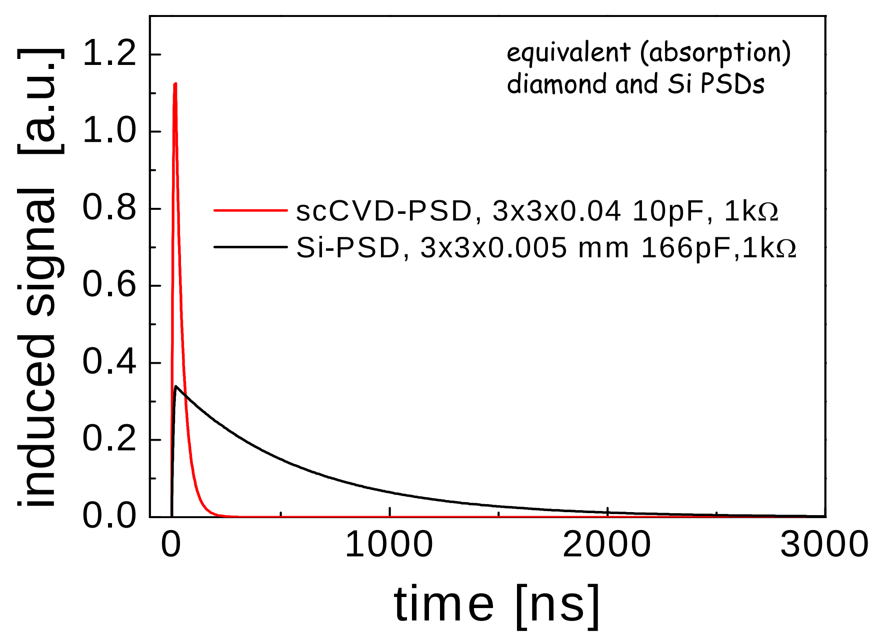
Why Diamond ?

Physical Properties

transparency



fast response



40 μm Diam ~ 5 μm Si

heat conductivity, radiation hardness, solar-blind, no dark-current, compact device

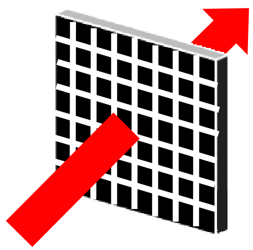
CVD Diamond Radiation (Particles) Detectors

Basics

diamond position sensitive detectors for X-ray beam monitoring

pixel, strip

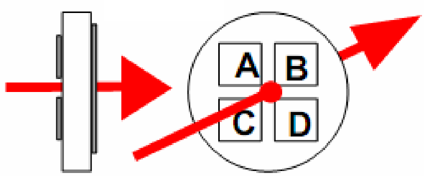
☺ large sensitive area
☺ beam position and profile



☹ sophisticated electronic
☹ pixel size limits position resolution

quadrant

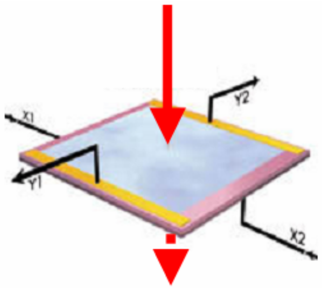
☺ fast
☺ only 4 channels



☹ small 'active' area
☹ beam size dependence

resistive electrode

☺ large sensitive area
☺ only 4 channels

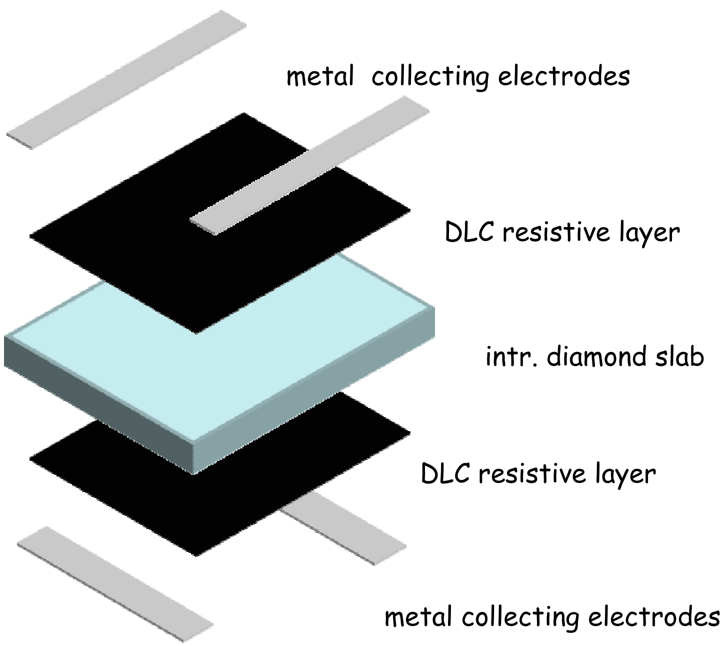


☹ speed limited by RC

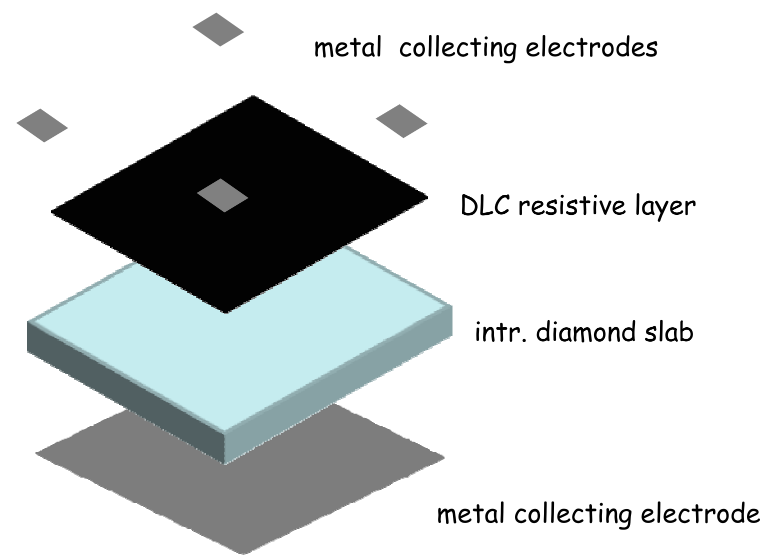
Diamond Position Sensitive Detectors

Detector Fabrication

duo-lateral PSD



four-corner PSD



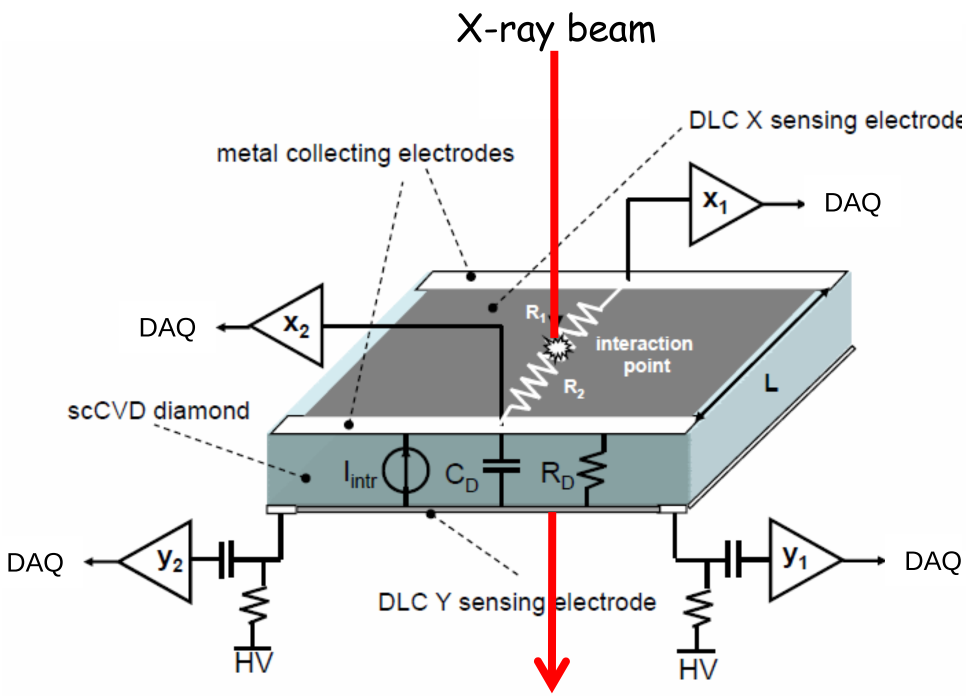
diamond material: electronic grade scCVD

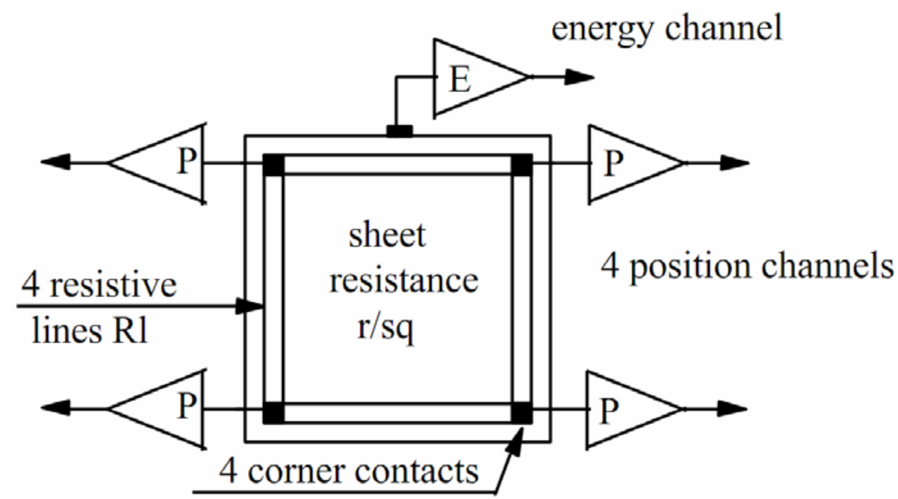
DLC resistive layer: PVD, R from 1kOhm□ to few MOHms□

metal collecting electrodes: PVD, Al or CrAu, photolithogr.

Diamond Position Sensitive Detectors

Duo-lateral PSD: Read-out Electronics





$$X = \frac{L}{2}\frac{(I_2 + I_3) - (I_1 + I_4)}{I_1 + I_2 + I_3 + I_4}$$

$$Y = \frac{L}{2}\frac{(I_3 + I_4) - (I_1 + I_2)}{I_1 + I_2 + I_3 + I_4}$$

position coordinates from signal division
(reconstucted position)

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

$\sigma_{pos} \sim L^*\sigma_{ele}/I0$

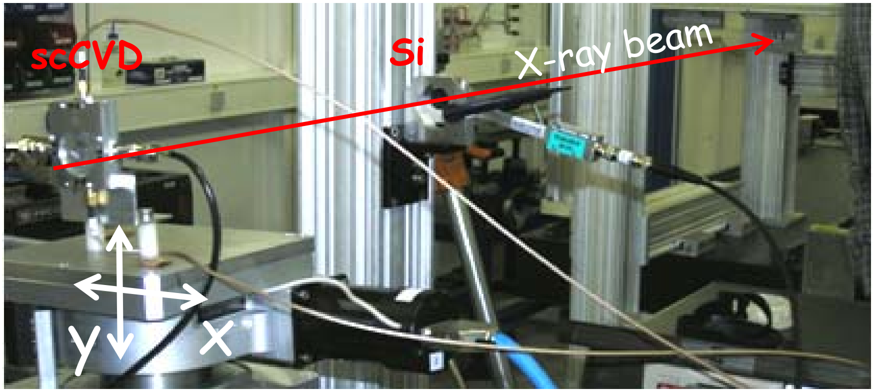
(…slope .. similar to timing)

DC mode (10Hz) – Keithley electrometers ; pulse mode – FEMTO ampl. (200MHz)

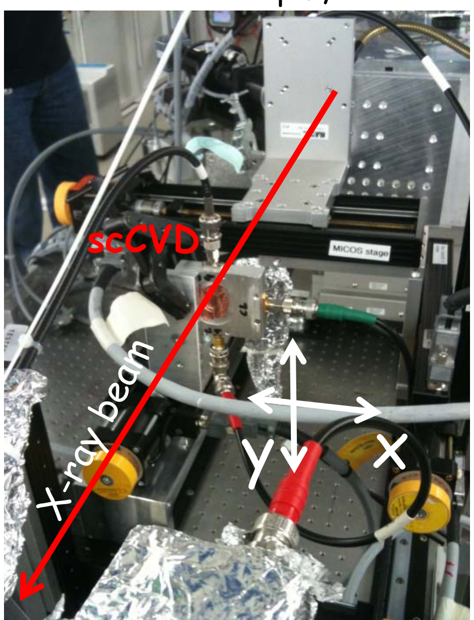
Diamond Position Sensitive Detectors

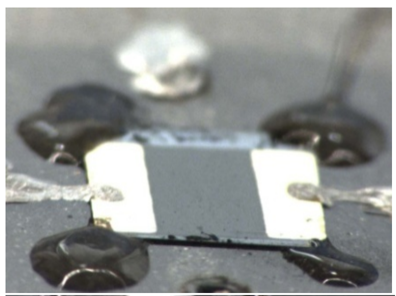
Duo-lateral PSD: Experimental Environment

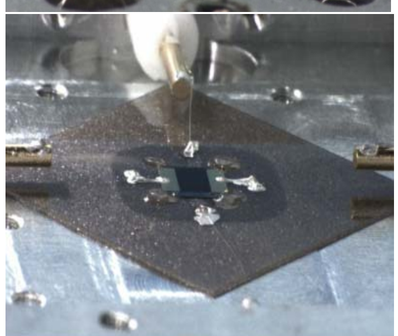
masurement setup @ ID06 ESRF



measurement setup@μXAS SLS







ESRF, Grenoble FR, ID06

Beam energy: 10.5 keV

Beam size: 100 x 100 μm (slits limited)

Beam flux: 1.6 x 10^{11} ph/sec

Flux absorbed = 1.56 x 10^{8} ph/sec/μm

scCVD XBIC ~ 0.5 μA DC

DC

Soleil, Gif-sur-Yvette FR, Proxima1 & SIXS

Beam energy: 12.6 keV & 5.6 keV

Beam size: 300 x 300 μm (slits limited)

Beam flux: 2.3 x 10^{12} ph/sec

Flux absorbed = 4.6 x 10^{8} ph/sec/μm

scCVD XBIC ~ 10 μA DC

DC

Swiss Light Source, Villigen CH, μXAS

Beam energy: 7.05 keV

Beam size: 50 μm FWHM

Beam flux: 4.8 x 10^{12} ph/sec

Flux absorbed = 10^{3} ph/pulse

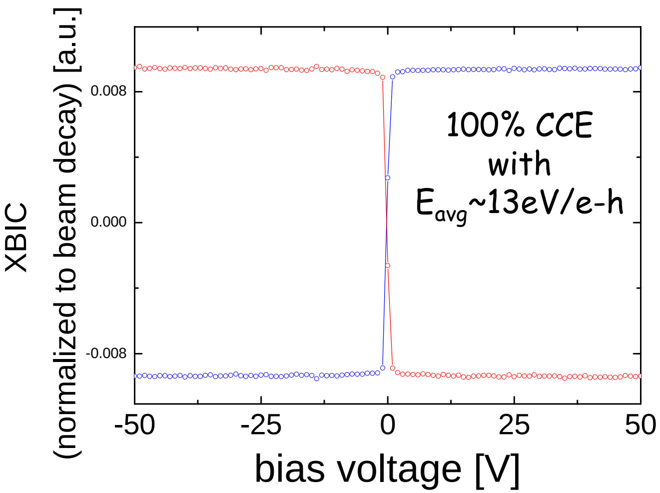
scCVD XBIC ~ 19 μA DC

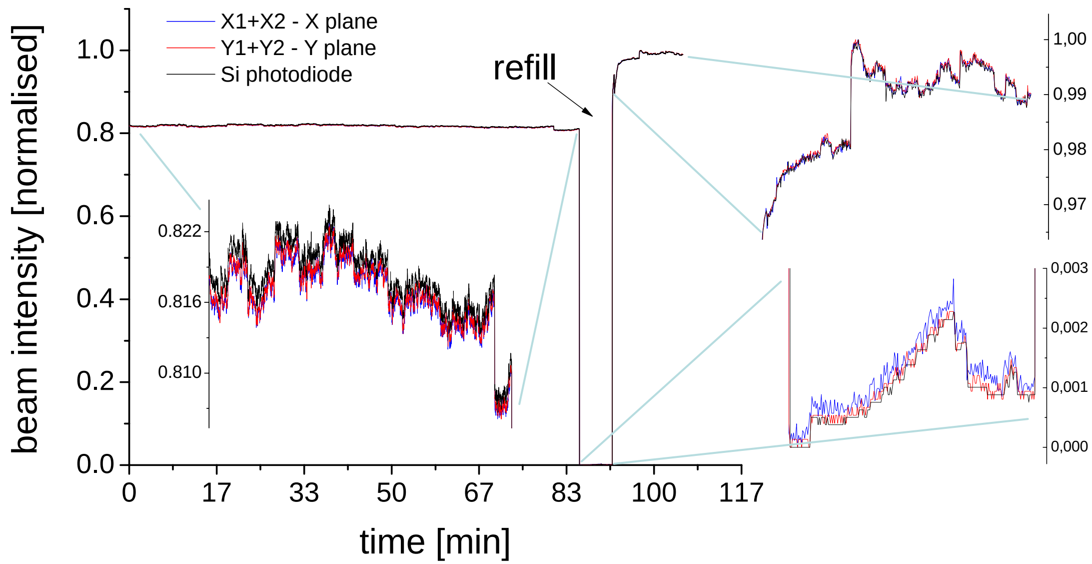
pulse

Diamond Position Sensitive Detectors

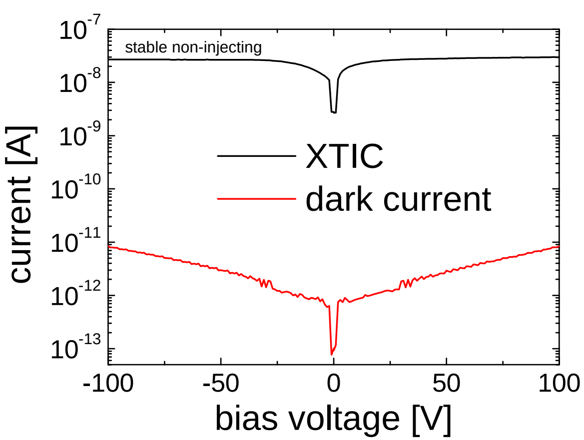
In-beam Performance: Beam Intensity Monitoring (DC mode)

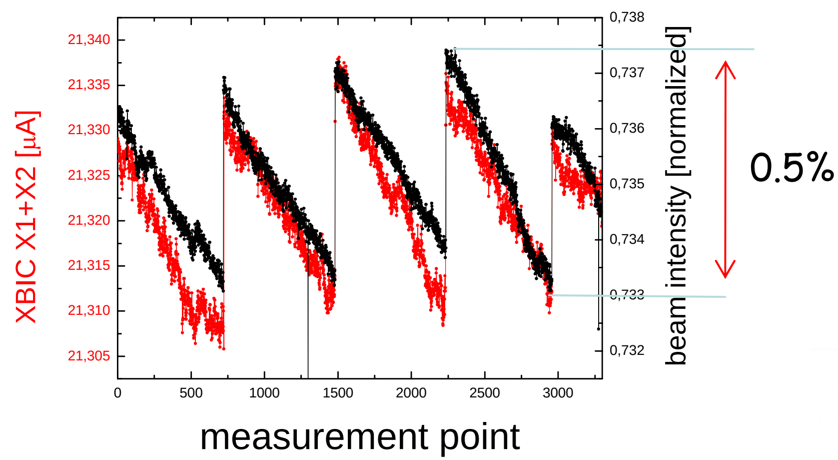
Beam intensity monitoring @ ID06 ESRF (X1+X2 and Y1+Y2) scCVD-PSD 40 μm





Beam intensity monitoring @ Proxima 1 Soleil (X1+X2) scCVD-PSD 300 μm



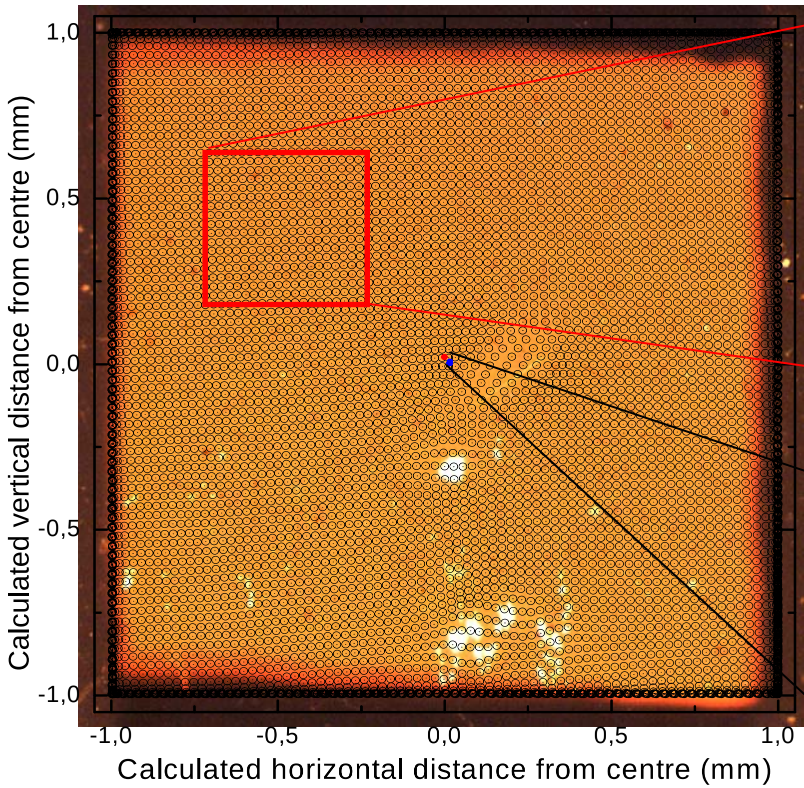


Diamond Position Sensitive Detectors

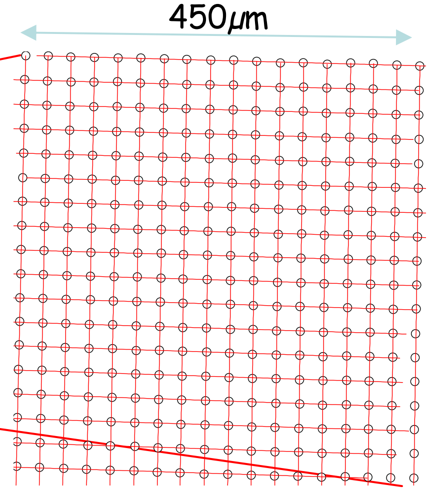
In-beam Performance: Reconstructed Position Pattern and Linearity

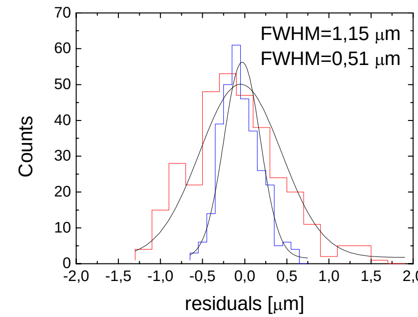
40 μm scCVD-PSD cartography (ESRF ID06)

fine raster scan with 25 μm step (80x80 points)



local linearity



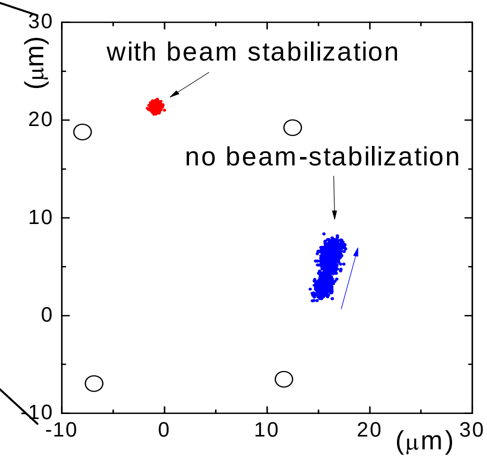


deviation from linear fits in the probed region

plane X $\sigma_L \leq 0.1\%$

plane Y $\sigma_L \leq 0.25\%$

2D beam tracking



step motors crash (during the second scan):

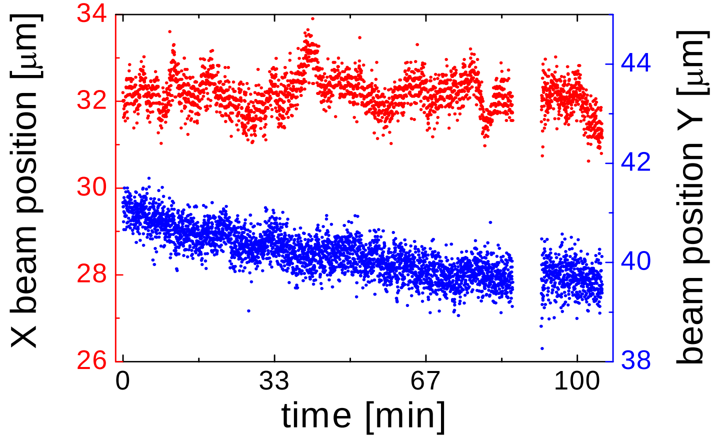
integral absorbed dose ~0.3 Giga Gy

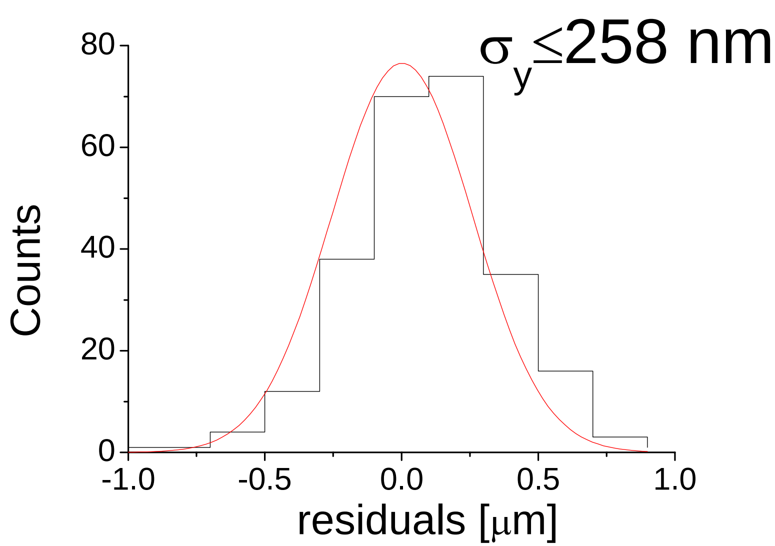
no radiation damage signs

Diamond Position Sensitive Detectors

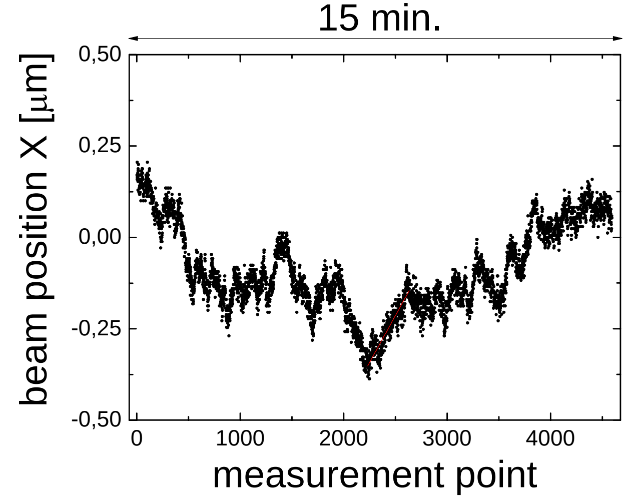
In-beam Performance: Position resolution (DC mode)

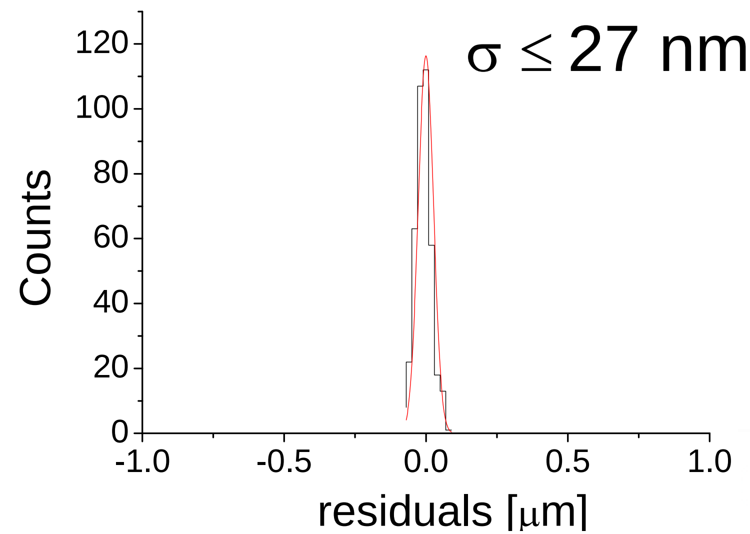
20 kΩsq. scCVD-PSD 40 μm, S/N ~10^4, active area 2 x 2 mm^2, ESRF ID06





1 MΩsq. scCVD-PSD 300 μm, S/N ~10^5, active area 2.5 x 2.5 mm^2, Soleil Proxima1



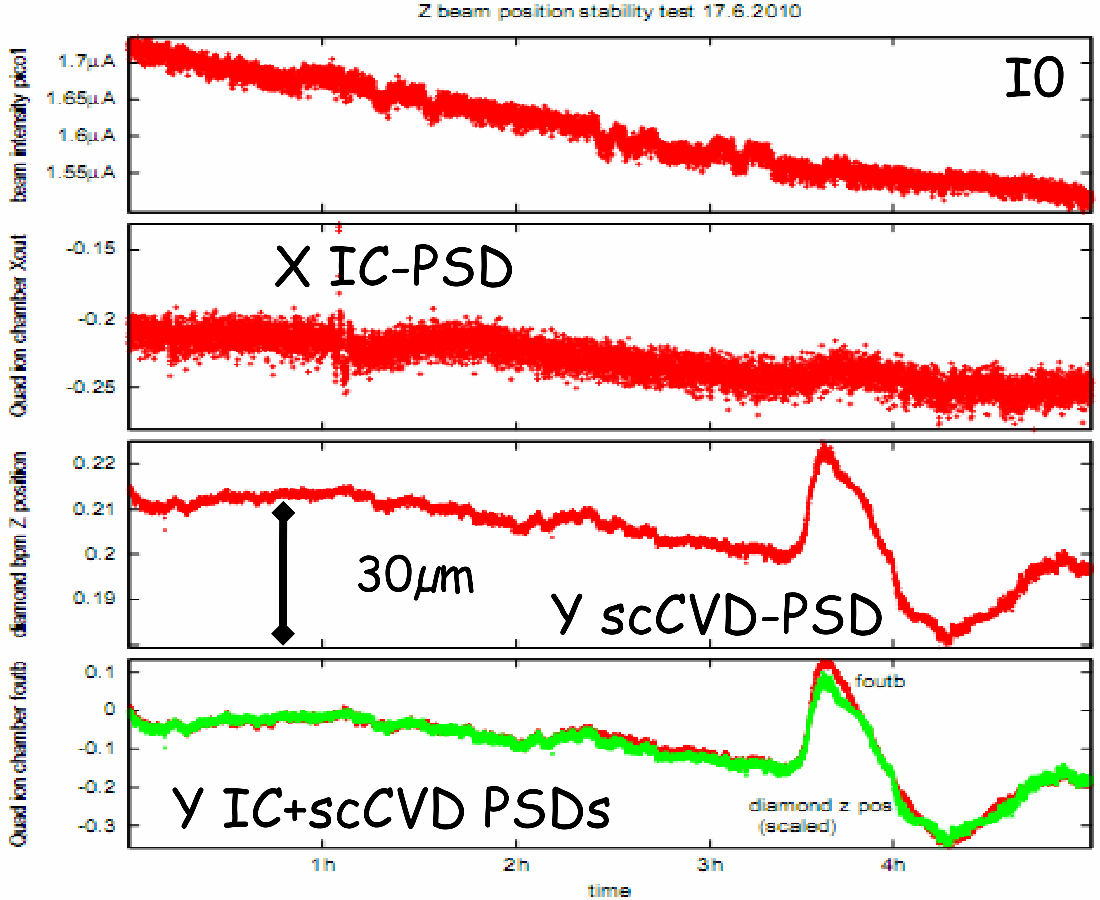


Diamond Position Sensitive Detectors

In-beam Performance: Long Term Stability @ ESRF ID06

40 μm scCVD-PSD permanently mounted at the ID06, vacuum 10^{-7} mbar

beam drift measurement with scCVD-PSD and IC-PSD after few months in the X-ray beam



no feed-back

data here courtesy: Thomas Roth and Carsten Detlefs ID06, ESRF

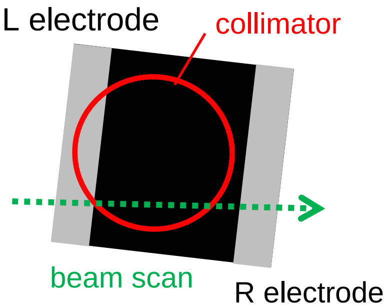
Diamond Position Sensitive Detectors

In-beam Performance: Pulse-mode XBPM @ MHz Regime PRELIMINARY

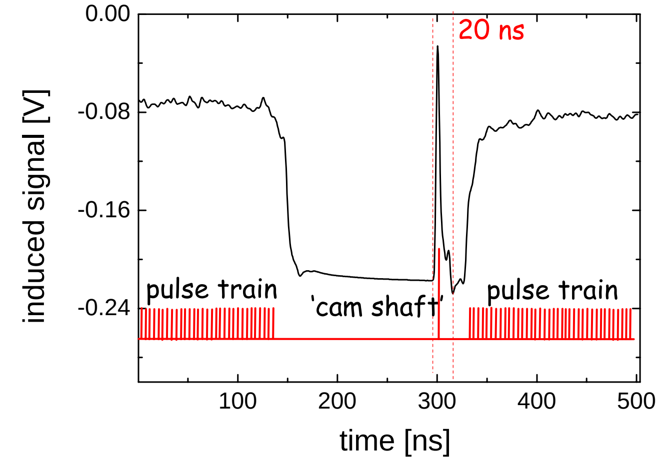
1 kΩsq. lateral 1D **scCVD**-PSD 400μm, active area 1.4 x 2 mm^2

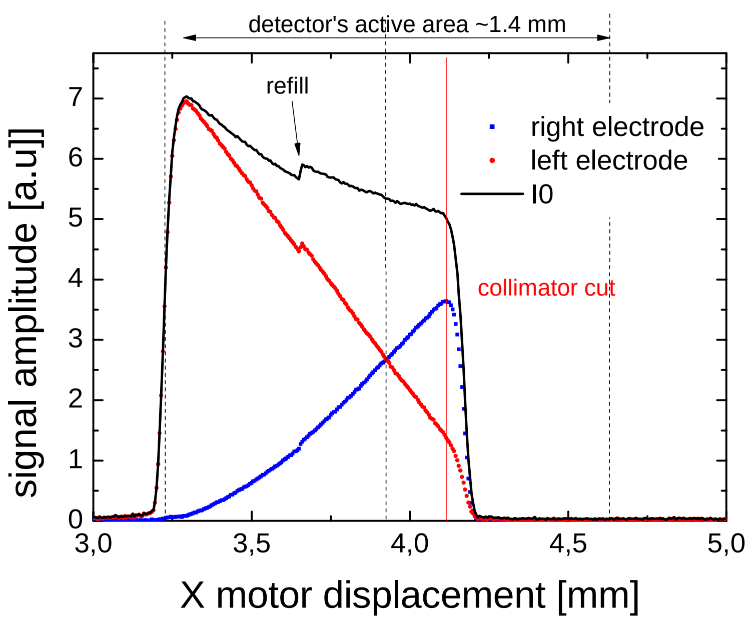
test @ SLS to understand applicability
range of diamond detectors for XBPM @ EU XFEL

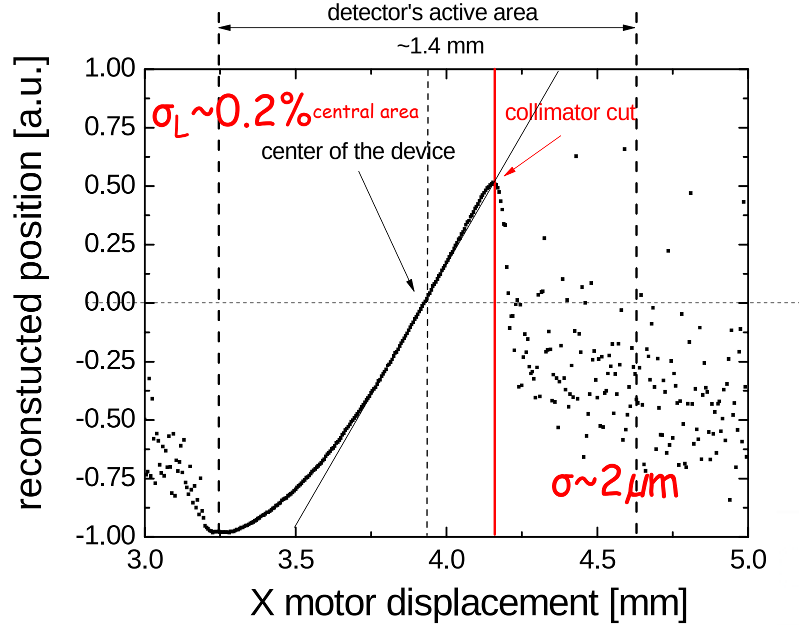
irradiation
geometry



beam time structure with scCVD-PSD



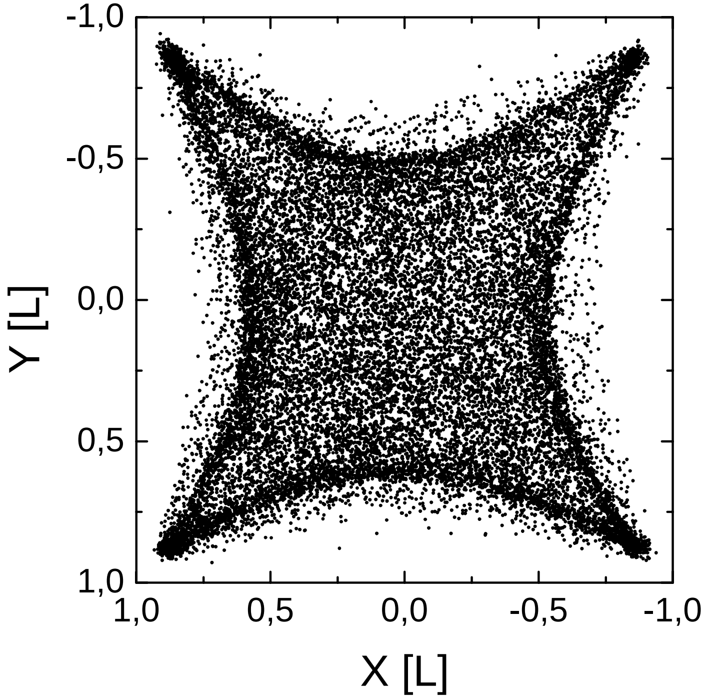




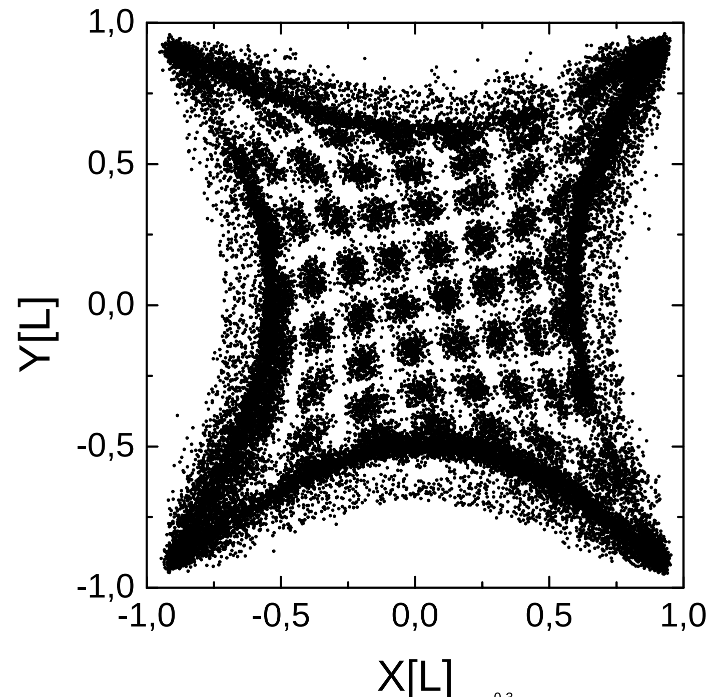
Diamond Position Sensitive Detectors

Four-corner PSD: preliminary lab tests

full area irradiation

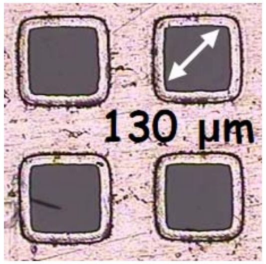


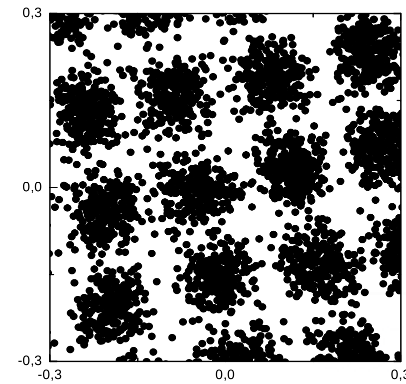
irradiation throught a metal mesh



^{241}Am α-particles injection ~ 4MeV (50 fC)
(measurement in air)

Pulse mode with, fast CSA (Mircea Ciobanu),
200ns integration time





Summary

A novel type of PSD based on scCVD diamond and DLC resistive electrodes has been built and tested for XBPM at synchrotrons:

- semitransparent in-beam detector, stable and reliable operation
- absolute beam intensity monitoring with a precision of ~0.1%
- sub-micron position resolution (reaching 27 nm σ)
- very good (<<1%) linearity up to 4x4 mm^2 active area
- pulse-mode operation within 20ns integration time demonstrated (can be used also as a single particle PSD)

Future Work

- to build and test more prototypes
  - long term stability tests
  - detector performance evaluation in function of the bandwidth
  - tests in extreme conditions: white beams, XFEL

- ultra-thin scCVD-PSD for low energy (<3keV) lines

- tetra-lateral approach
  - + resistive lateral lines
    - boron doped CVD diamond layer (PIM structure)

- dedicated electronics missing

Thank you for your attention !