Single Crystal CVD Diamond Position-Sensitive Detectors using DLC resistive electrodes

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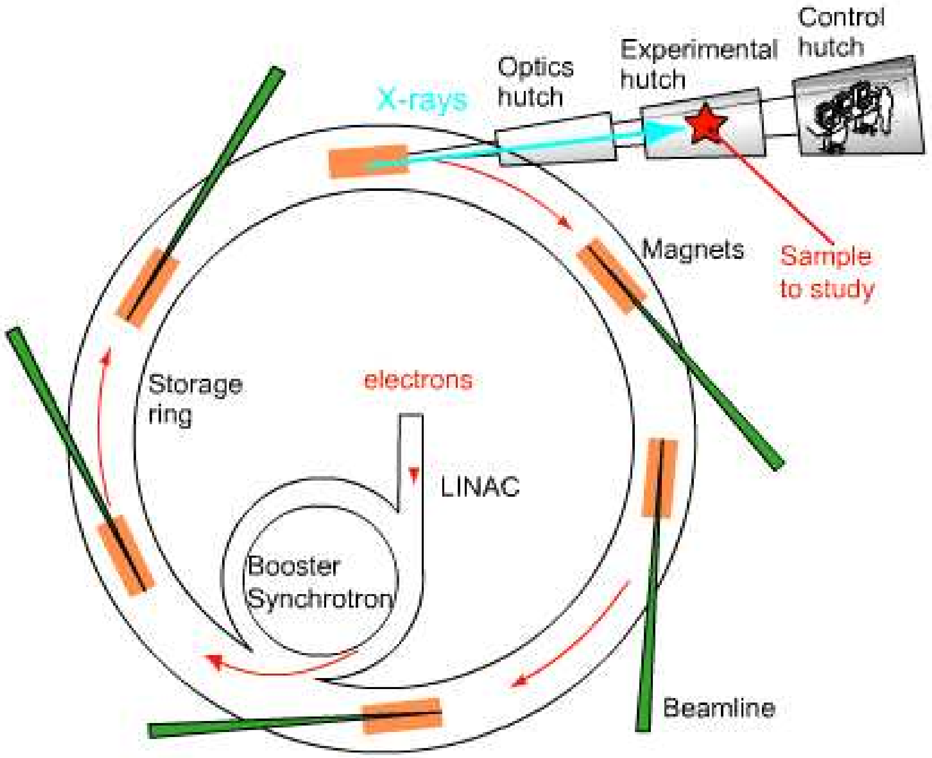
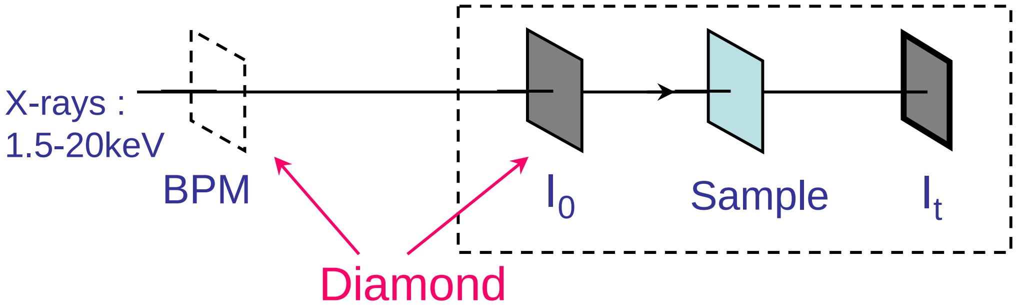
Motivations

Probing the beam characterisitics (position, intensity, profile) at low energies and with a semitransparent material

- in front end (white light, high fluences – 10^{17} ph./s)
- in beam lines (monochromatic light, 10^{8} – 10^{13} ph/s)





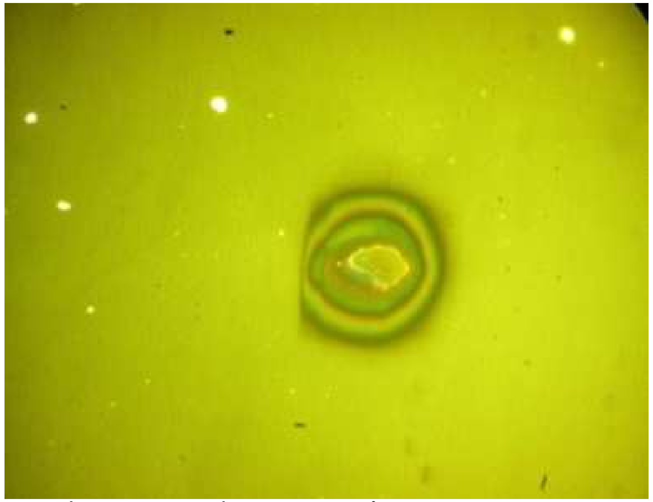
Motivations

- Synchrotron beam monitoring

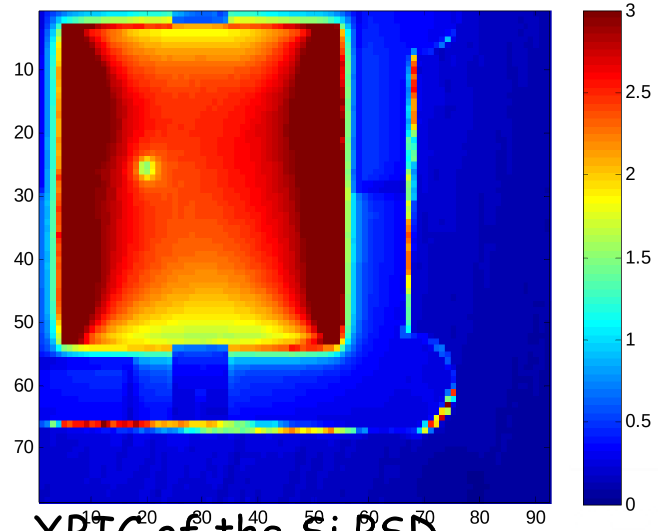
Z=6 → low specific X-ray absorption / beam scattering

Wide bandgap energy (~5.5 eV), excellent thermal/mechanical properties

Si PSD permamently damaged after 1 month in the beam



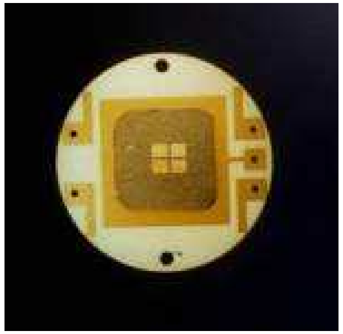
damaged area photo

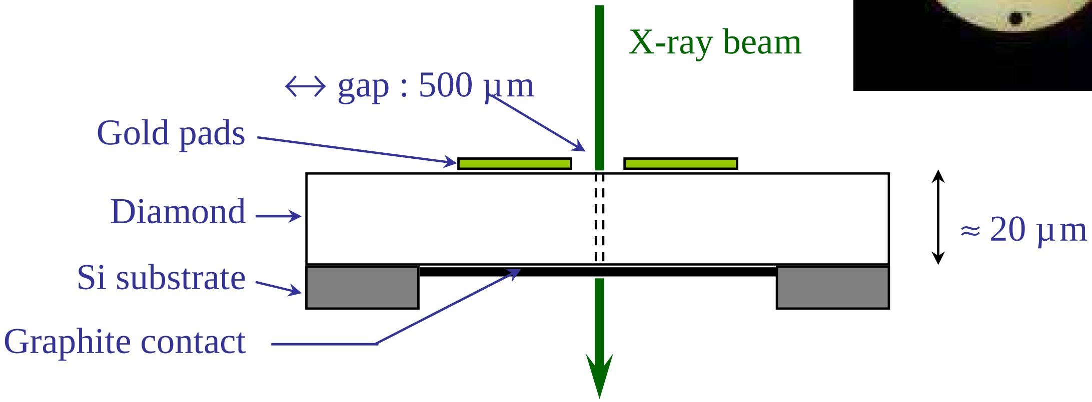


XBIC of the Si PSD

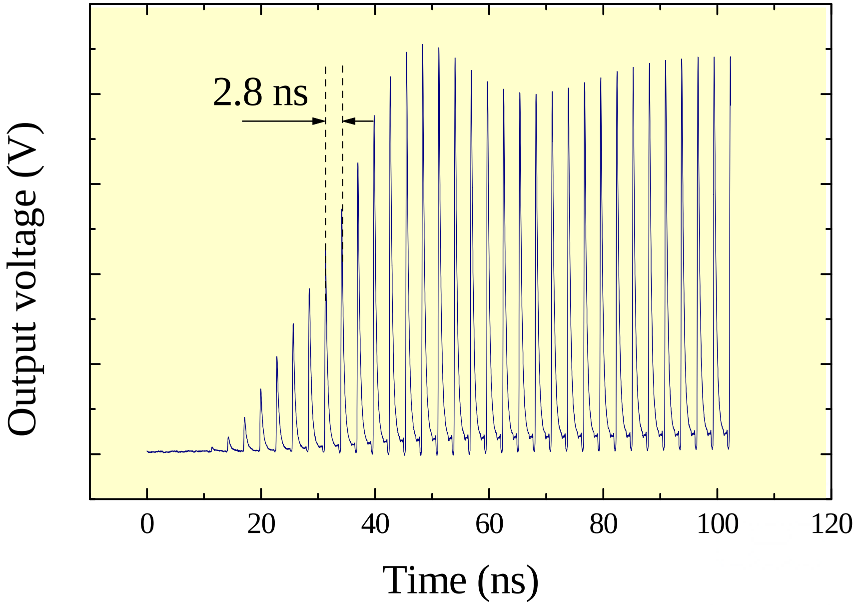
History

- Semitransparent BPMs
  - high transparency (low Z)
  - fluence hardness
  - temperature hardness
  - mechanically resilient





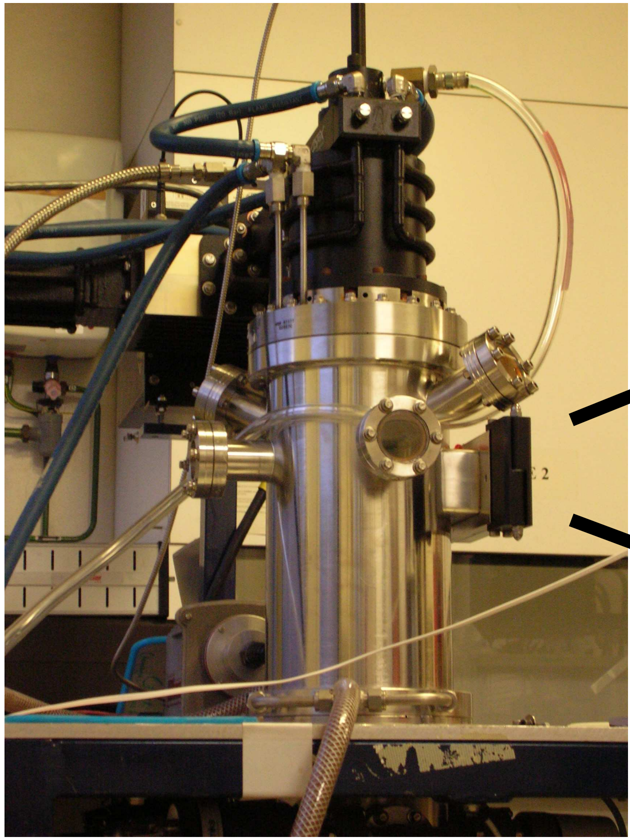
- Realisations have included
  - Intensity monitors
  - Beam position monitors →2µm
  - Beam Profile monitors



Diamond and Related Materials 9, 960-4 (2000).
Journal of Synchrotron Radiation 6(1), 1-5 (1999).
Applied Surface Science. Feb. 155, 179-85 (2000).

Detector Fabrication

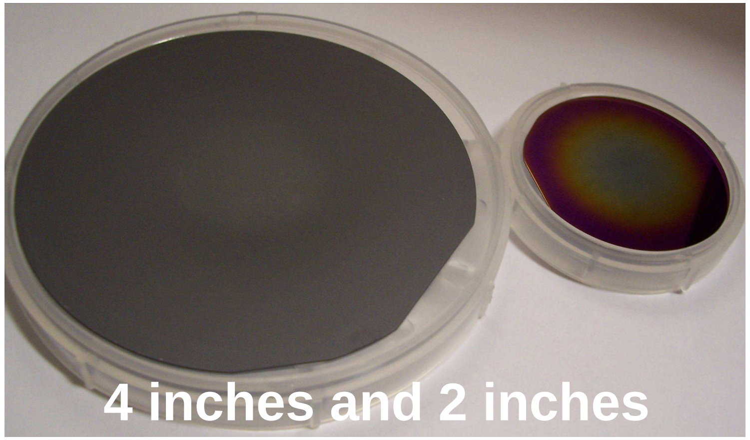
- Diamond growth



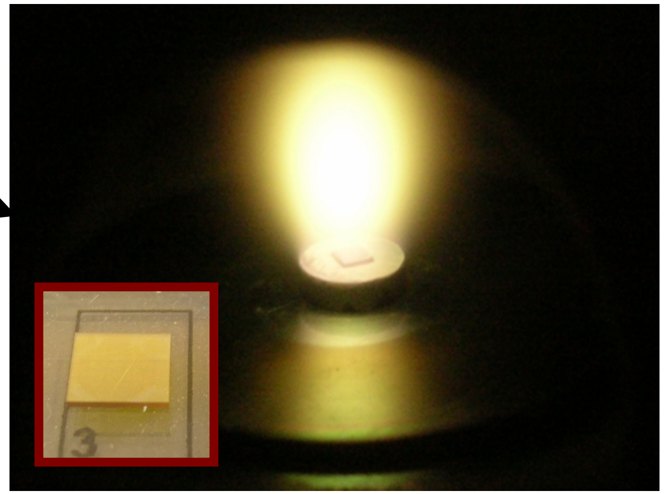
ASTEX 5400

p-CVD diamond

Si, Ir, quartz, SiC



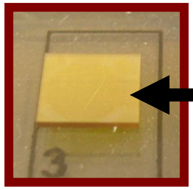
Flame type deposition plasma

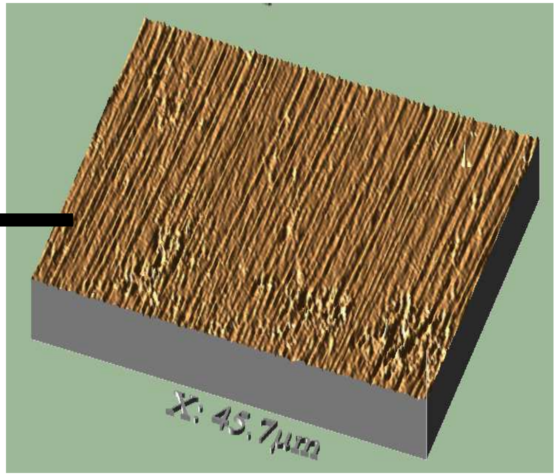


sc-CVD diamond

Detector Fabrication

Diamond growth





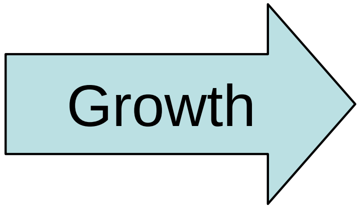
AFM measurements

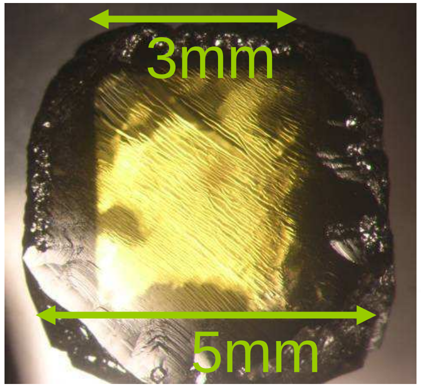
As introduced substrates →

- Reproducible polishing
- Analysis on 50 x 50 µm^2
- Space between lines: 20 nm
- RMS: 3 nm
- Maximum peak to Valley: 8 nm

Plasma pre-treatment →

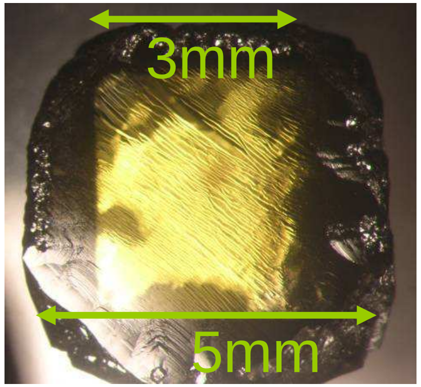
- remove polishing traces (stress + stripes)
- reduce surface defects
- **be up to make reproducible growth**





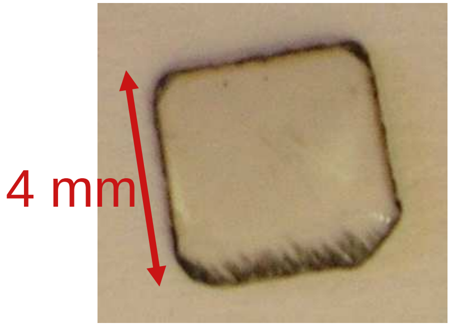
Detector Fabrication

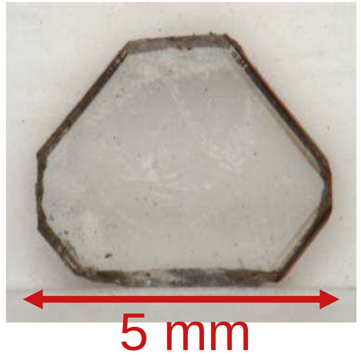
- Diamond bulk



Laser cut
+
polishing

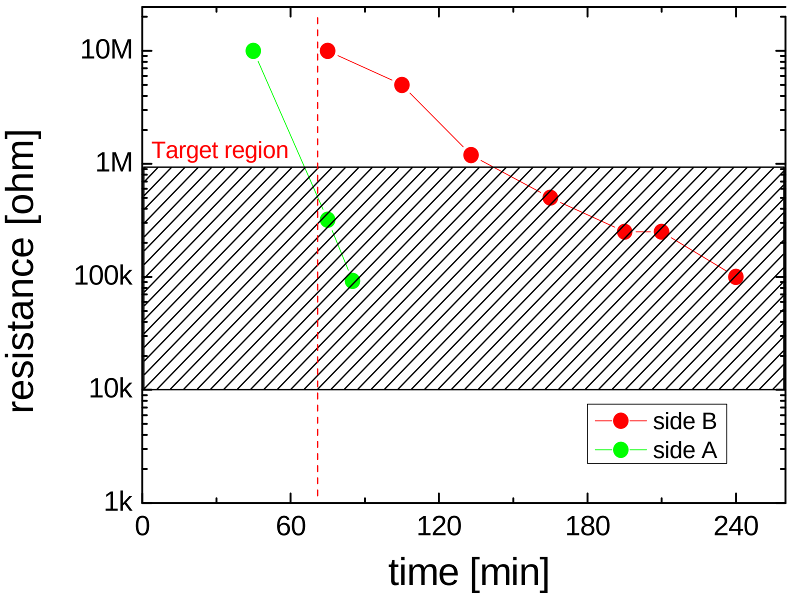
Free standing plates

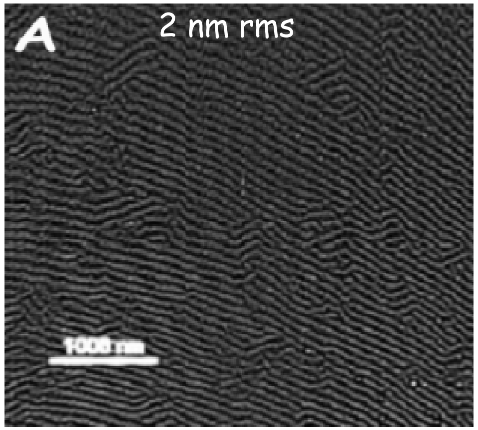


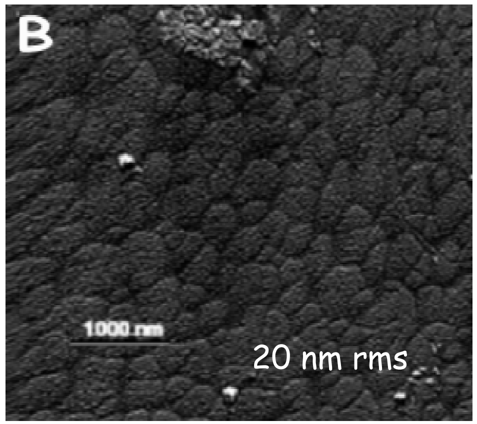


- DLC deposition on diamond surfaces

DLC Surface morphologie influence



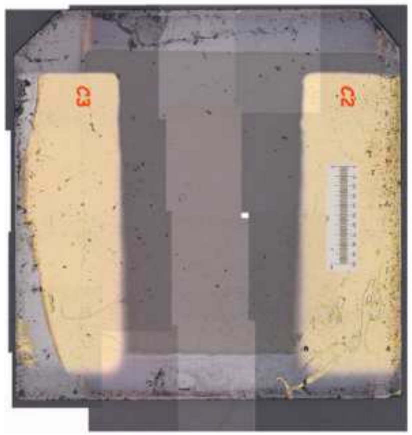




Detector Fabrication

- Metal collecting electrodes (Cr/Au)

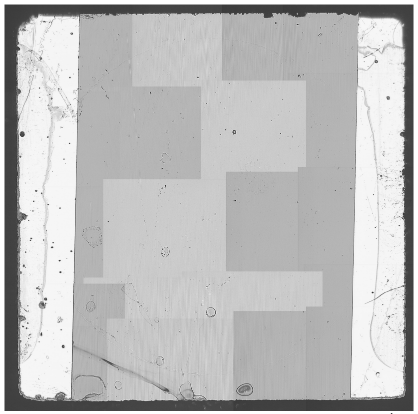
shadow masks



+ easy
+ clean surfaces
+ any metal

- fuzzy edges
- relatively large motives
- problems with positioning

negative photo-lithography

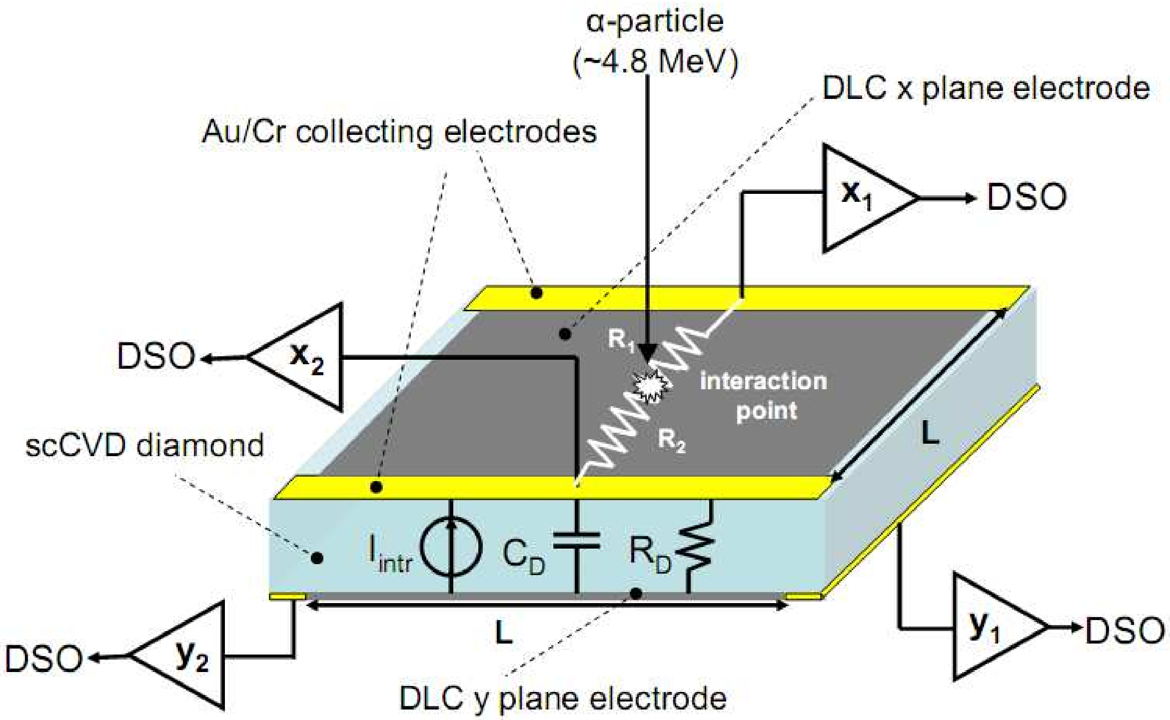


4 mm

+ sharp edges
+ clean surfaces (no resin processing prior metal dep.)
+ small motives

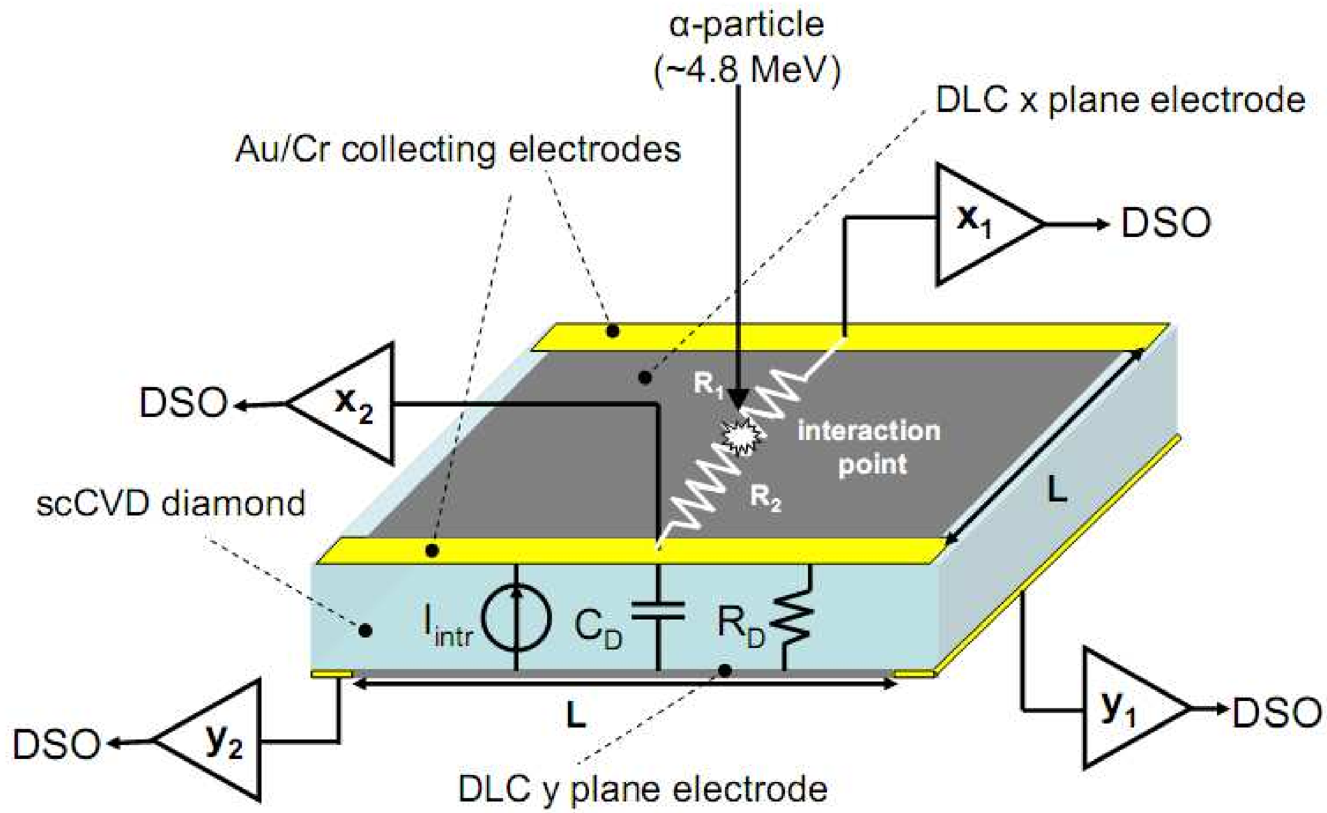
- quite tricky for double side processing

Principles of the Duo-lateral scCVD-PSD



- detector bulk consists of scCVD electronic grade diamond
- prototypes active area up to **4 x 4 mm** possible – thickness 40-500 μm
- resistive electrodes made of robust thin DLC layer (entire active area made of C)
- charge sensitive readout … but current readout possible (pulsed and continuous)
- position sensitive single particle detection and energy spectroscopy possible

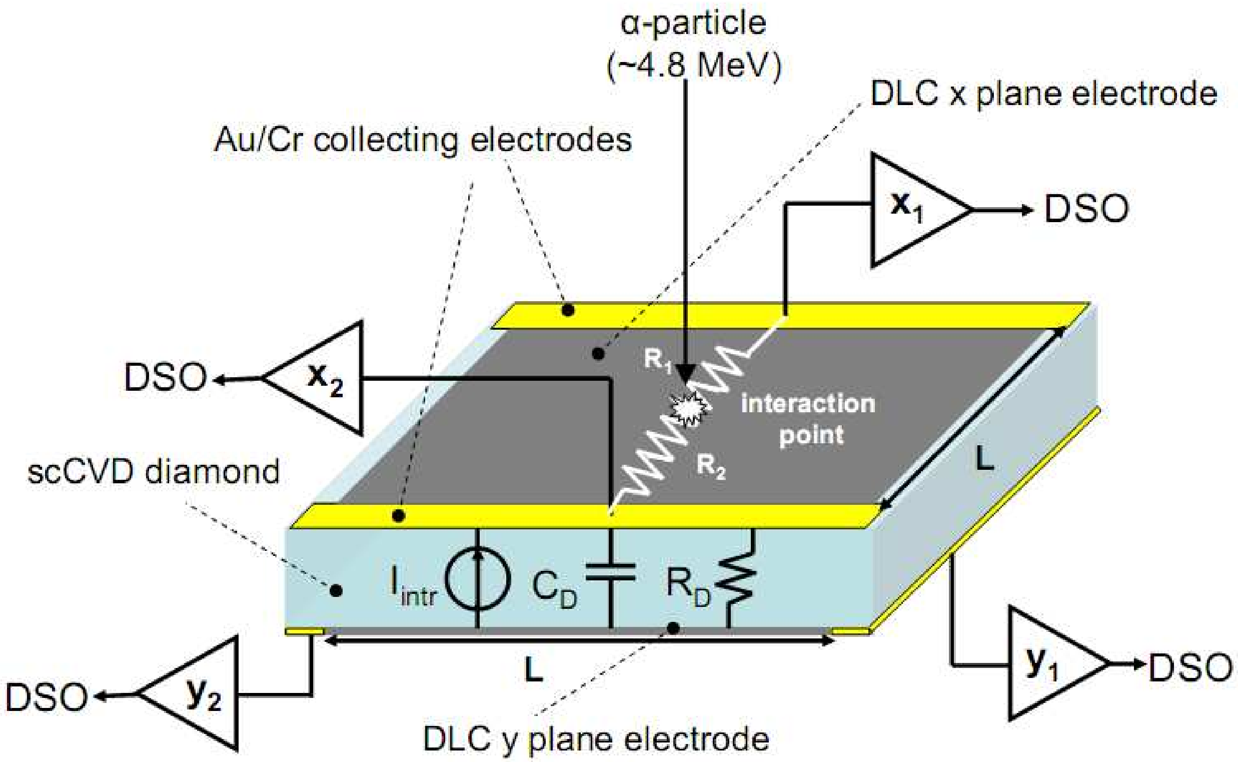
Principles of the Duo-lateral scCVD-PSD



Position coordinates from signal division:

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

Detector characterization: pulsed mode



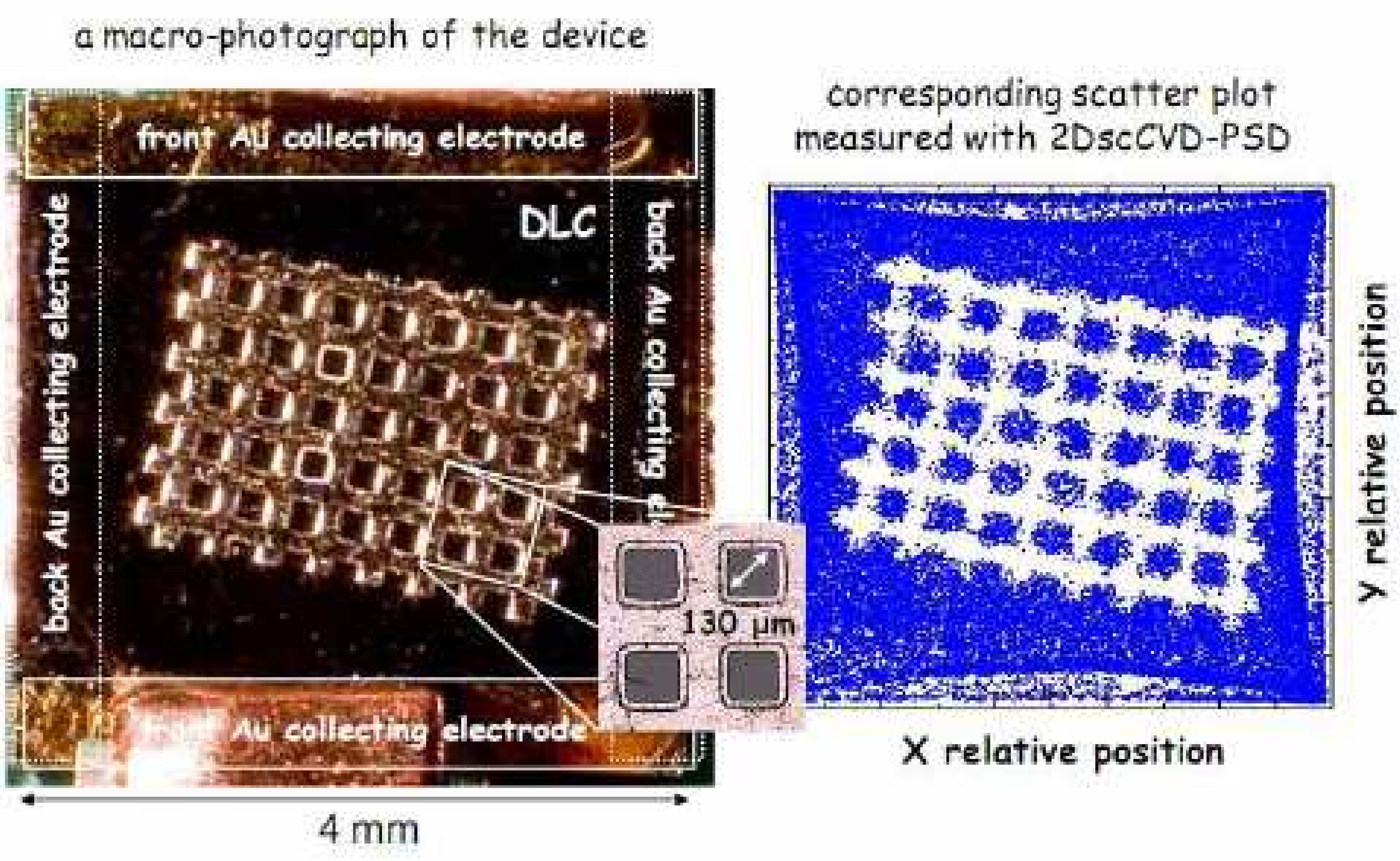
20kBq ^{241}Am source
4.8 MeV α-particles
measurement in air

- Electronics:

4 fast TCSA (M. Ciobanu of GSI, Darmstadt) with ~100ns rise time
3GHz DSO LeCroy (limited BW) for signal processing and 'histogramming'

not the best set-up possible regarding the s/n ratio (current s/n ~100)

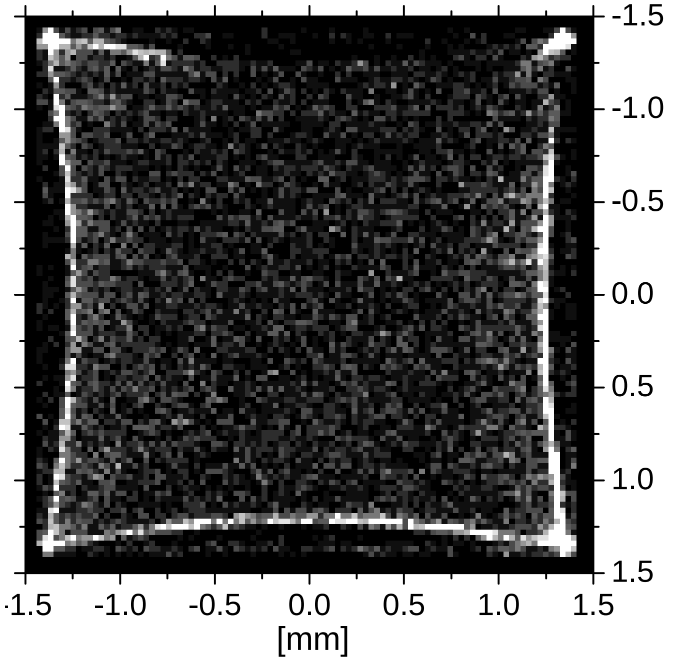
Irradiation through Calibration Masks

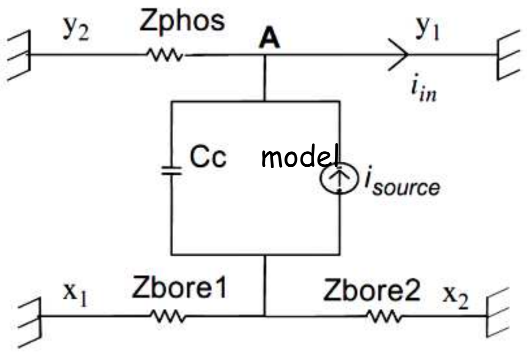


M. Pomorski et al., Phys.StatusSolidiA,1-6(2009)

Full Area Irradiation and the Cushion Distortion Correction (Pulsed Mode)

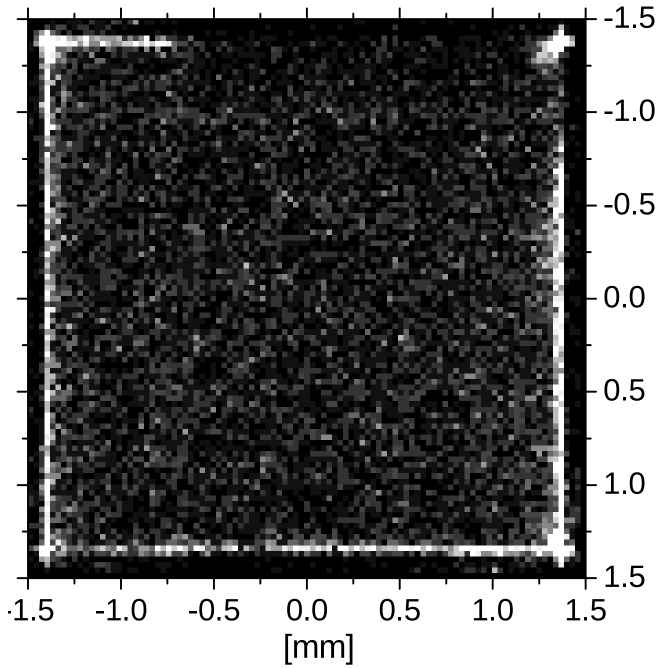
before correction



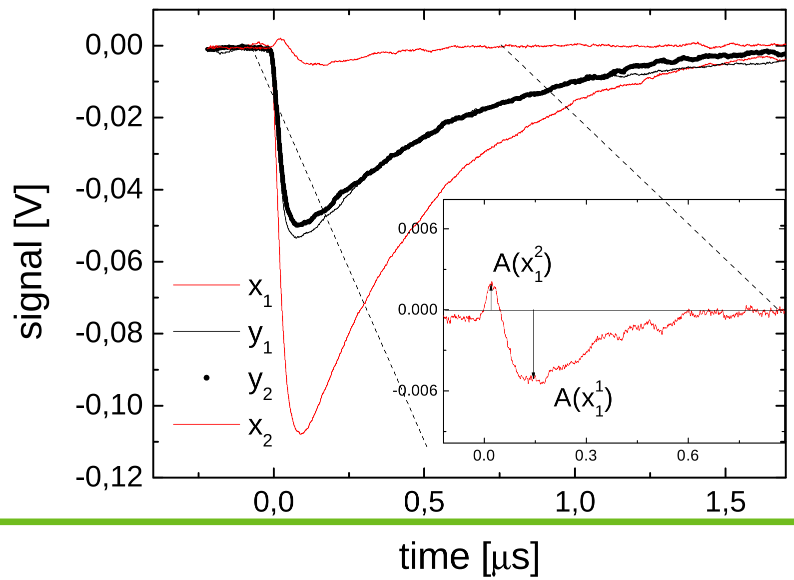


M.Solal,Nucl.Instrum.Methods,A 572,1047-1055(2007)

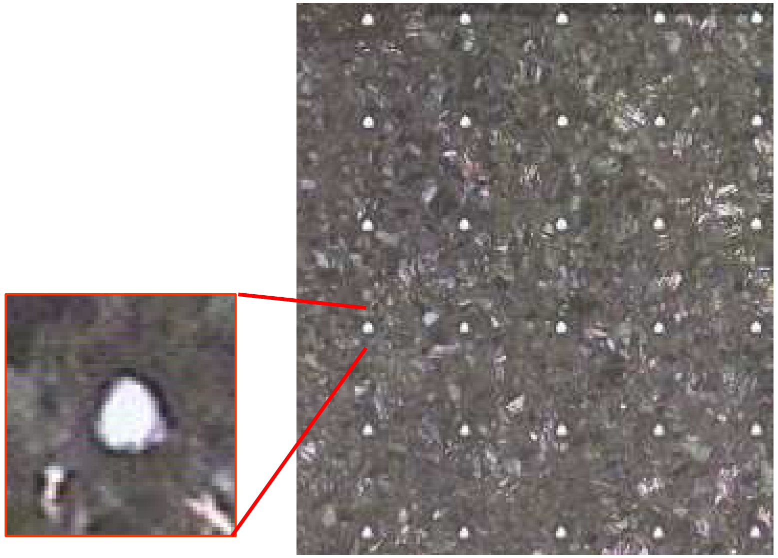
after correction



on-line signal processing



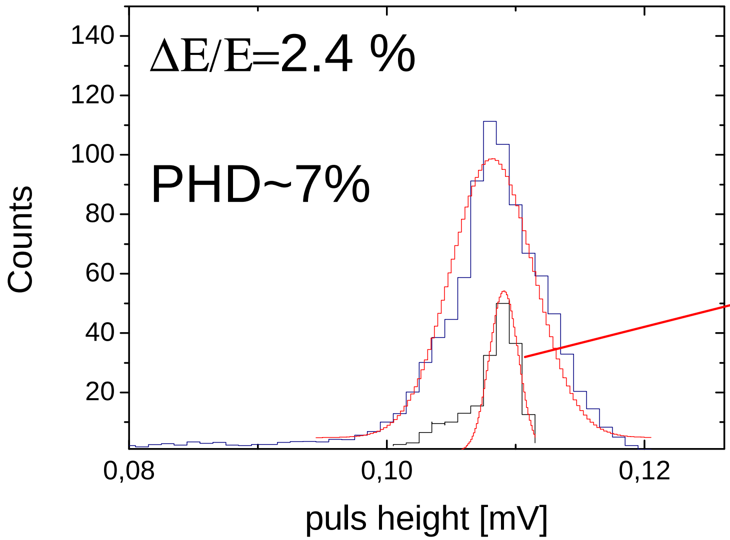
Irradiation through Calibration Masks

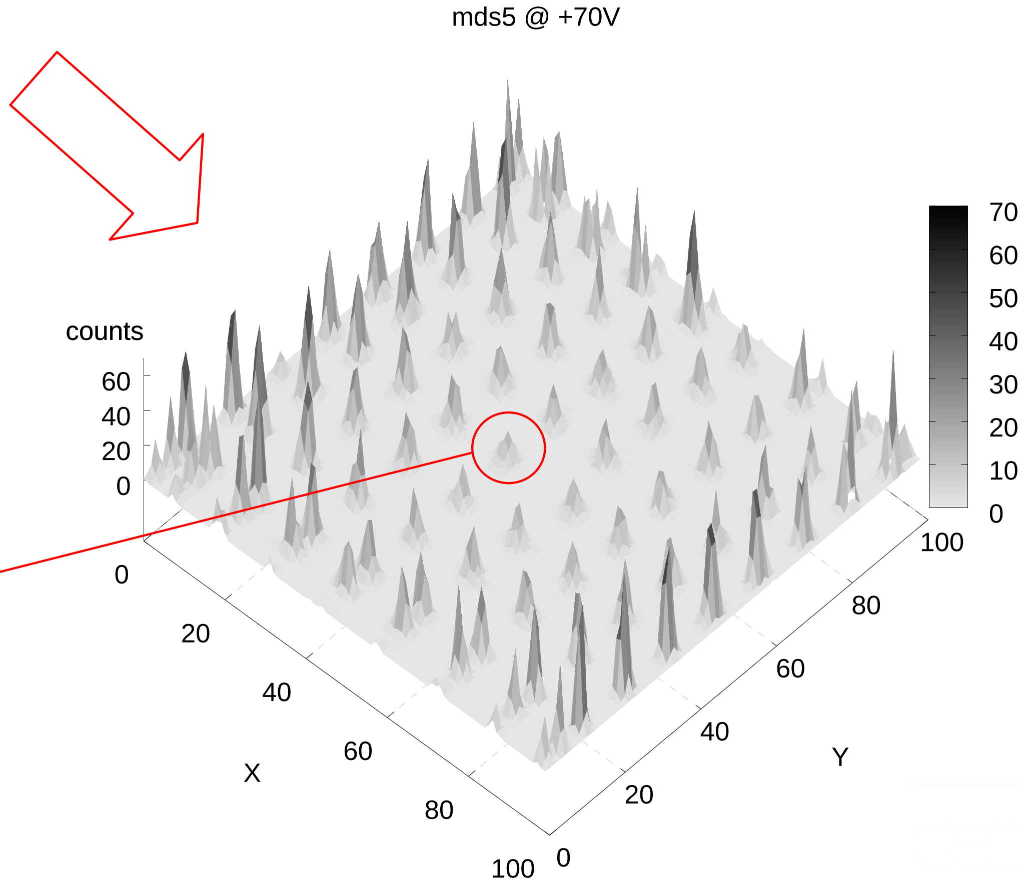


Calibration mask - squared pcCVD diamond with laser drilled micro-holes

diam. ~30 μm, dist. ~200 μm

energy resolution for ~4.8 MeV α-particles

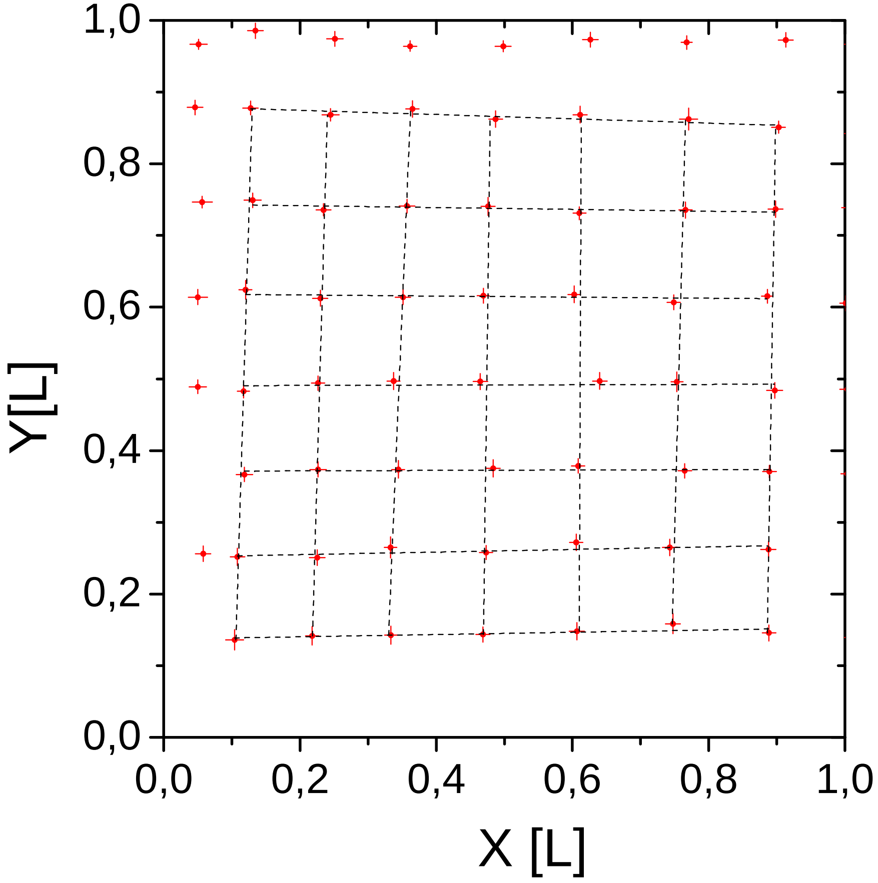




energy res. limited by electronics used

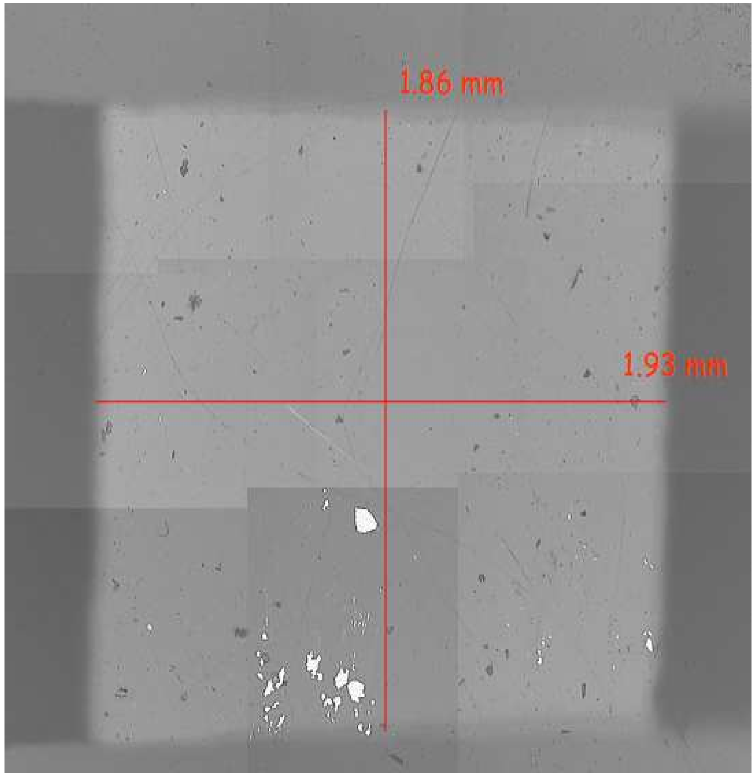
Linearity and Position Resolution

detector cartography
3D Gaussian fits



position resolution (FWHM) ≤ 1% of L
'global' linearity ≤ 2%

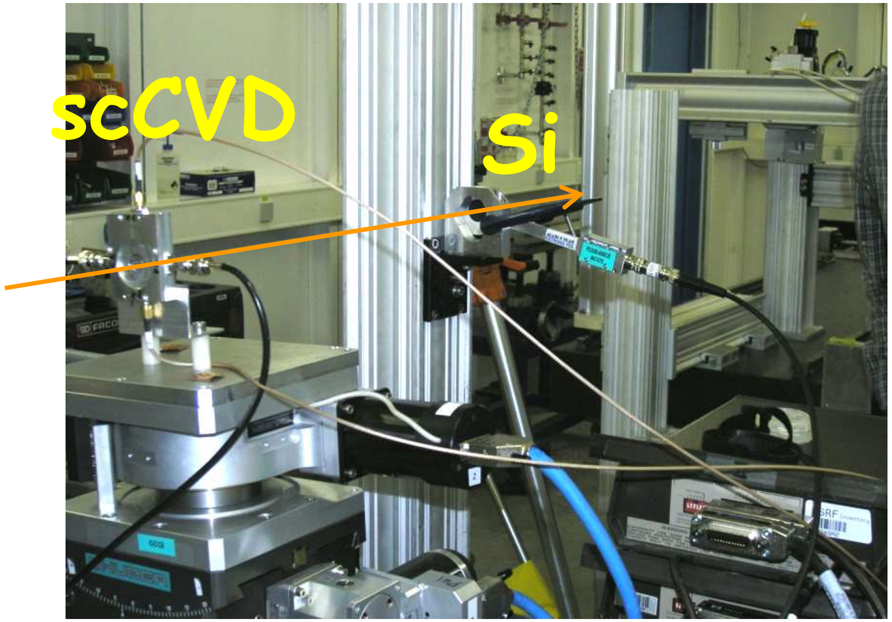
detector active area as seen with OM

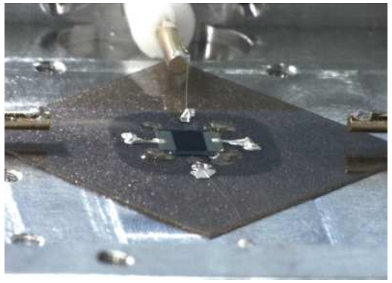


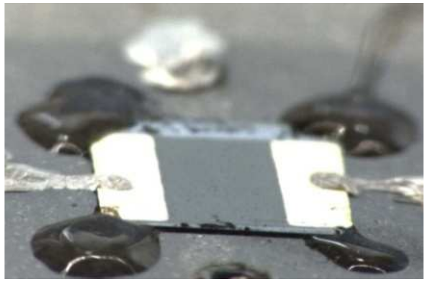
- diffused edges of metal electrodes
- some defects in the DLC layer

‼ Easy to improve in future devices ‼

In-beam Performance: DC mode



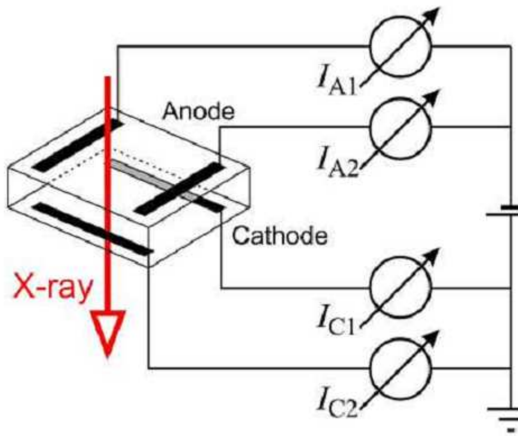




ESRF, Grenoble, ID06

Beam energy: 10.5 keV
Beam size: 100 x 100 μm (slits)
Beam flux: 1.6 x 10^{11} ph/sec
Flux absorbed = 1.56 x 10^{8} ph/sec/μm

Soleil, Gif-sur-Yvette, Proxima1



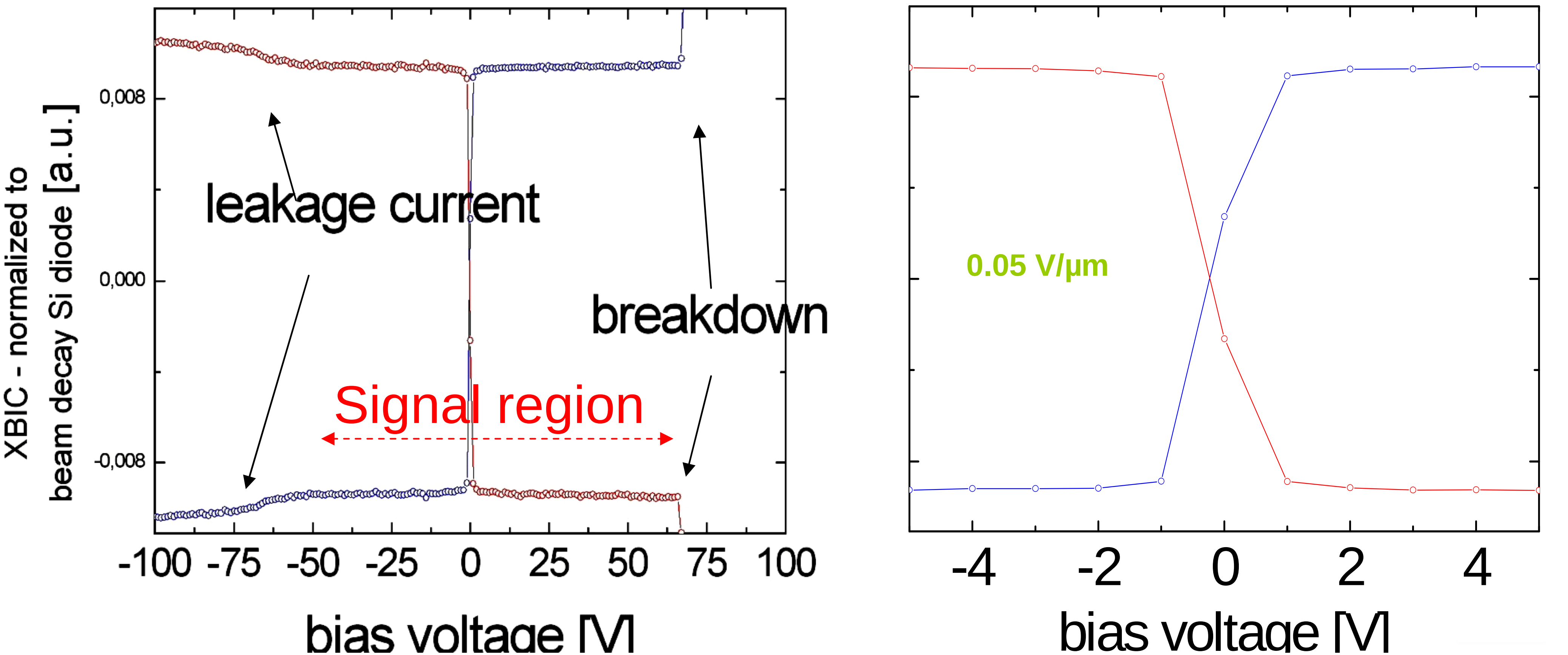
4 x Keithley 485's electrometers

10Hz bandwidth – a 'DC' mode

Integral absorbed dose ~0.3 Giga Gy
no radiation damage signs

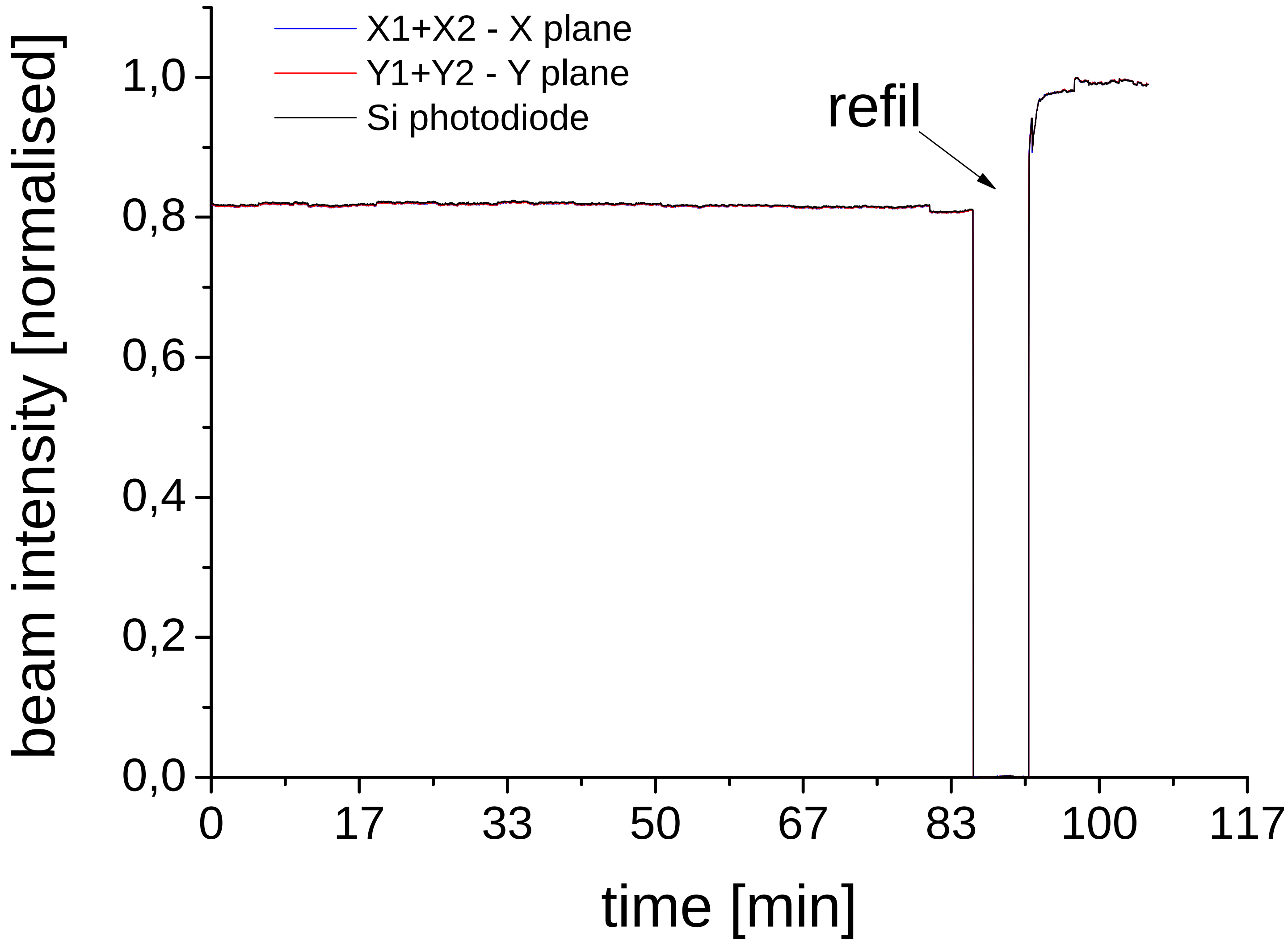
In-beam Performance: I-V, XBIC, intensity monitoring

- X-ray beam induced current



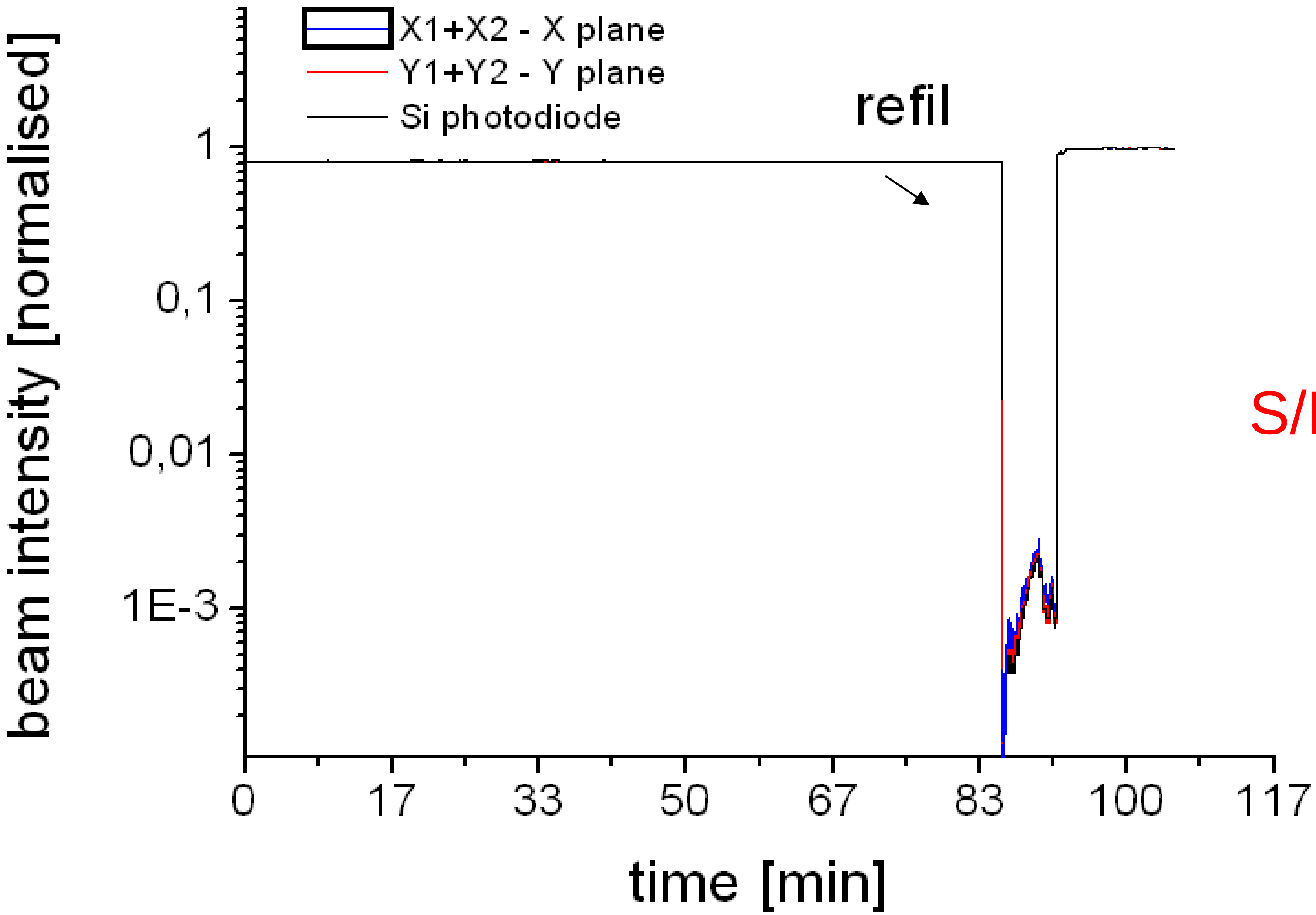
In-beam Performance: I-V, XBIC, intensity monitoring

- Beam intensity monitoring X_1+X_2 or/and Y_1+Y_2



In-beam Performance: I-V, XBIC, intensity monitoring

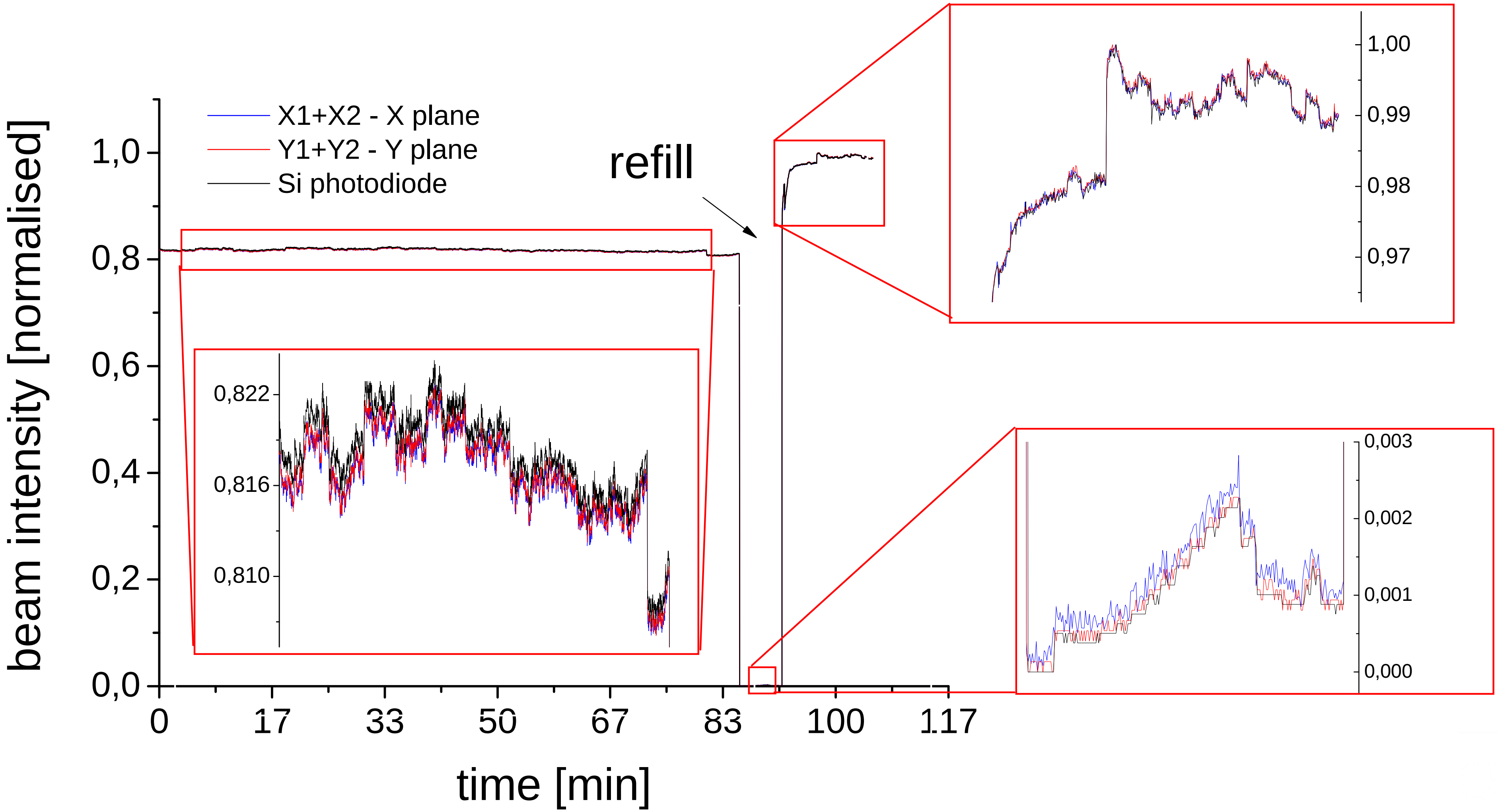
- Beam intensity monitoring X_1+X_2 or/and Y_1+Y_2



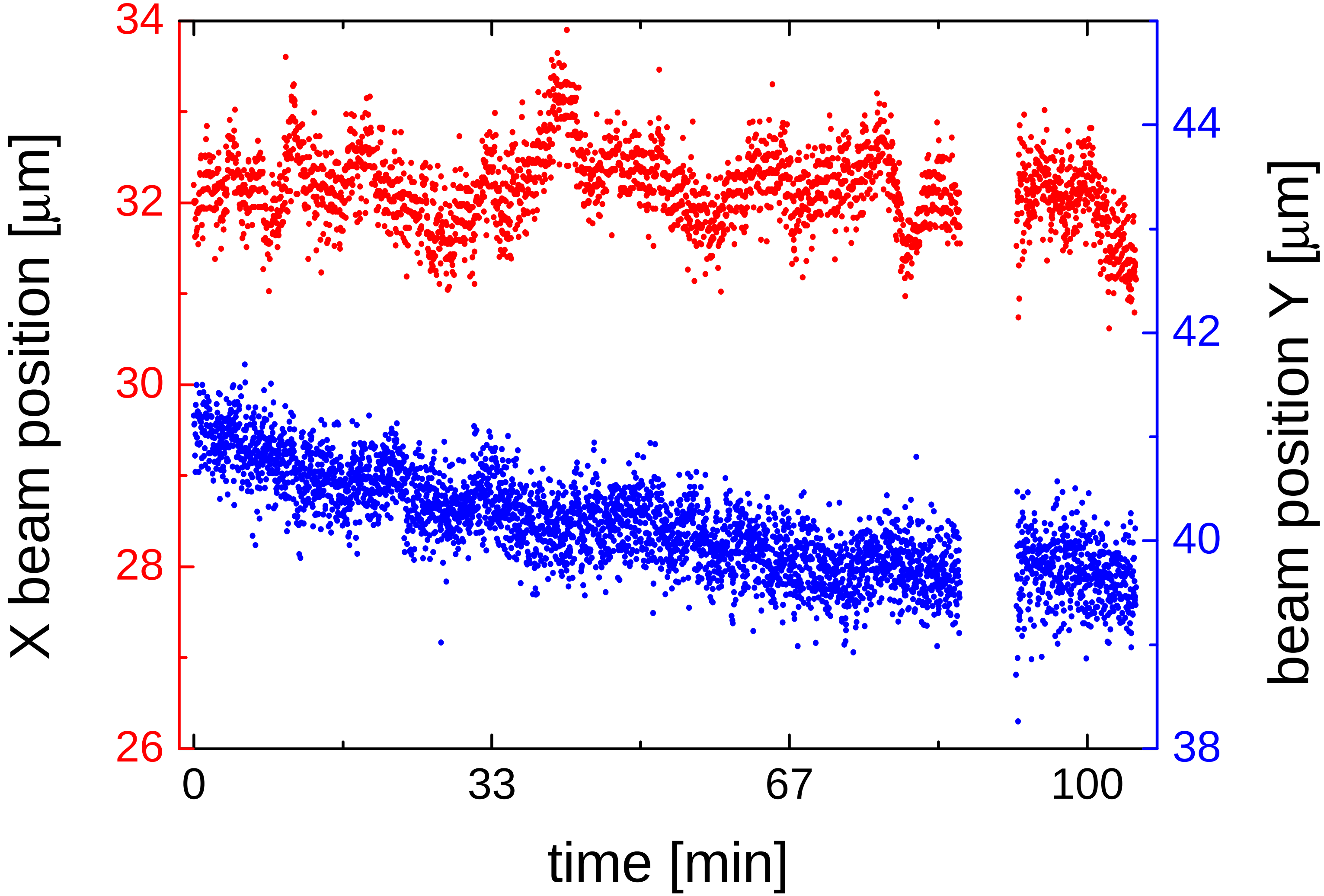
S/N > 3 decades

In-beam Performance: I-V, XBIC, intensity monitoring

- Beam intensity monitoring X_1+X_2 or/and Y_1+Y_2



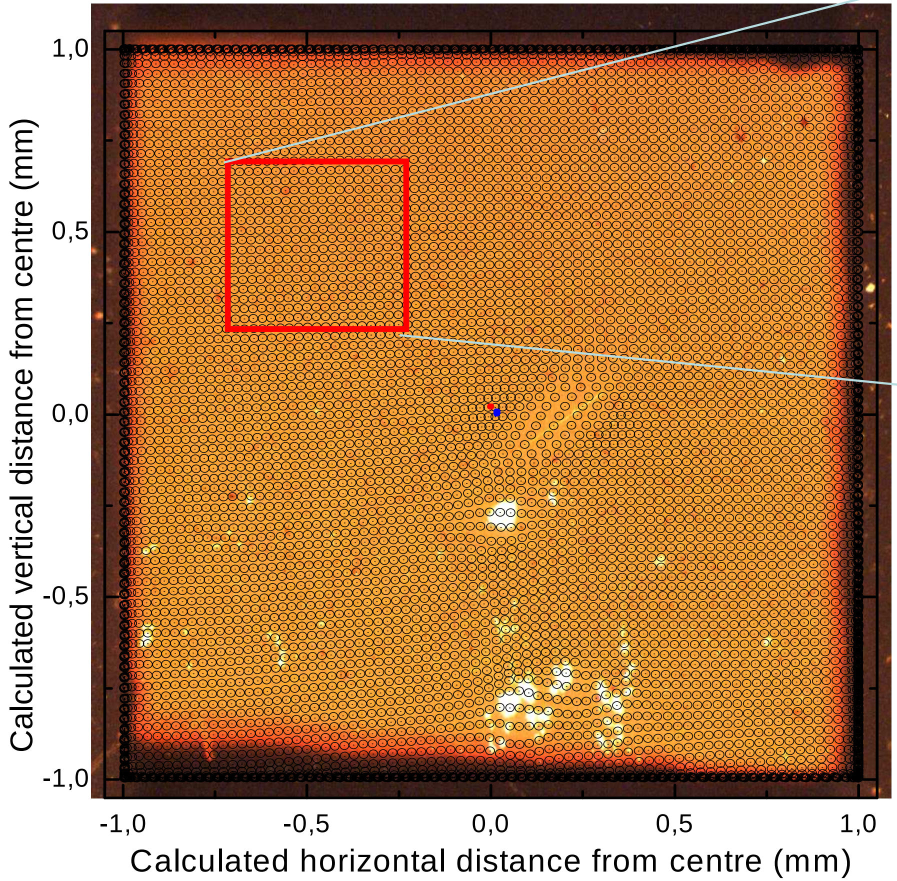
- Beam drift

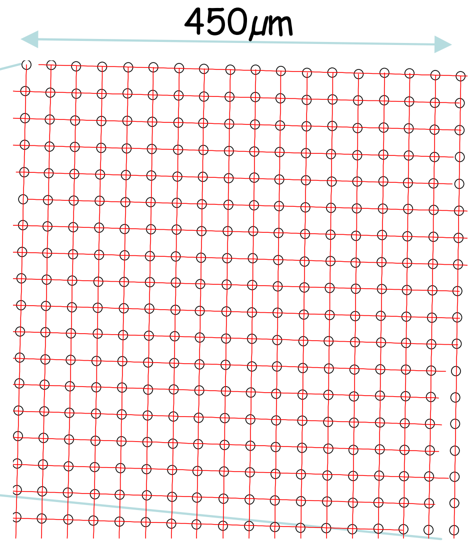

34
32
30
28
26
44
42
40
38
0
33
67
100
time [min]
X beam position [μm]
beam position Y [μm]

In-beam Performance: linearity, position resolution

Detector cartography

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





No pincushion, barrel distortion for 10 Hz

Step motors crash

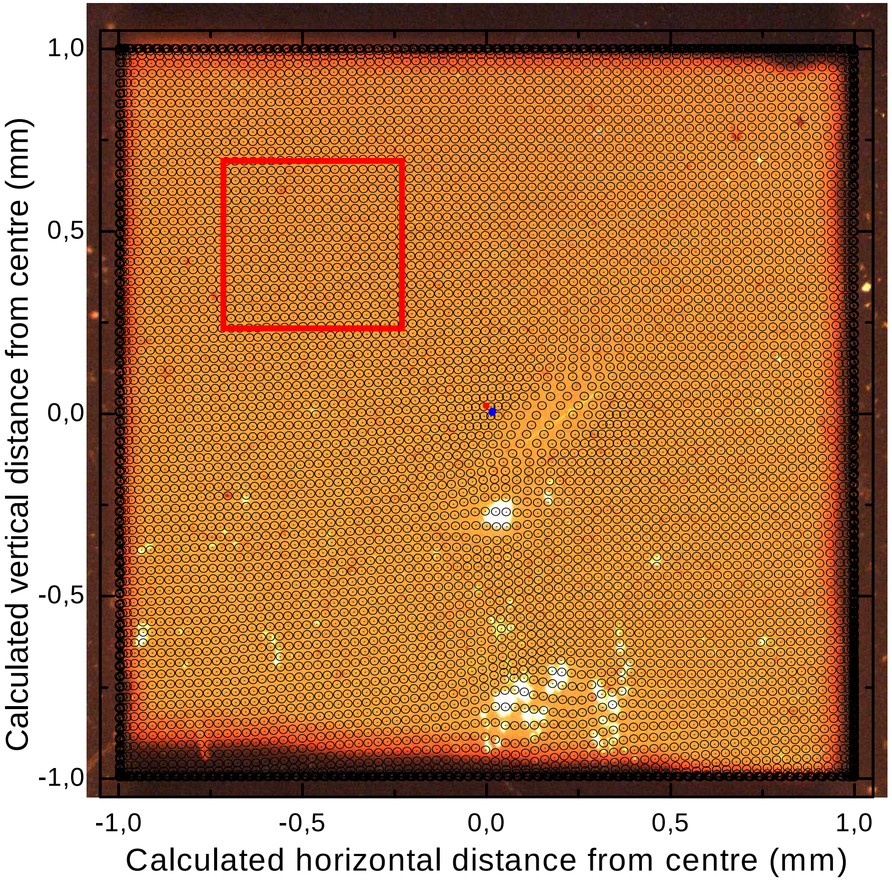
Integral absorbed dose ~0.3 Giga Gy

No radiation damage signs

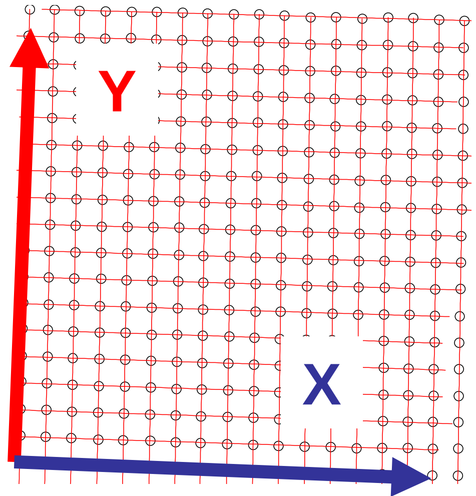
In-beam Performance: linearity, position resolution

Detector cartography

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

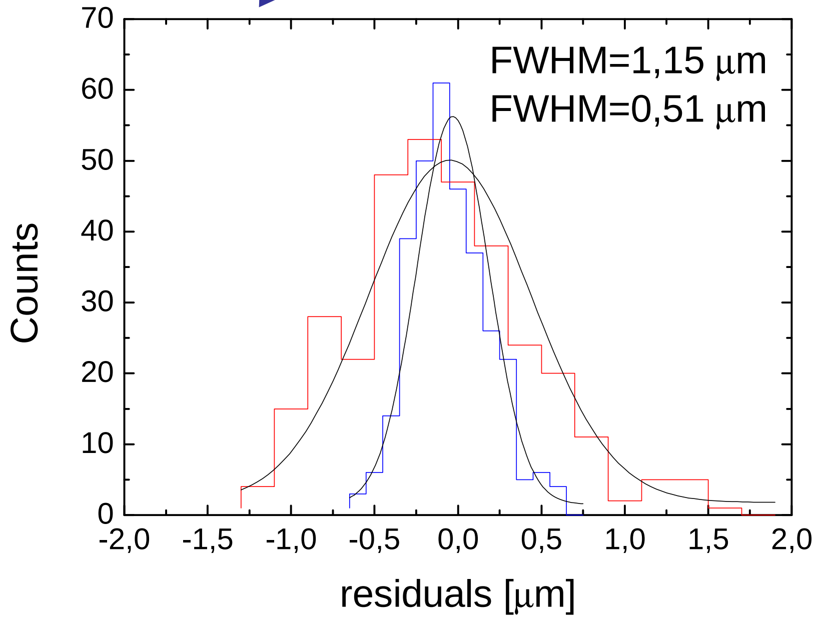


Local linearity



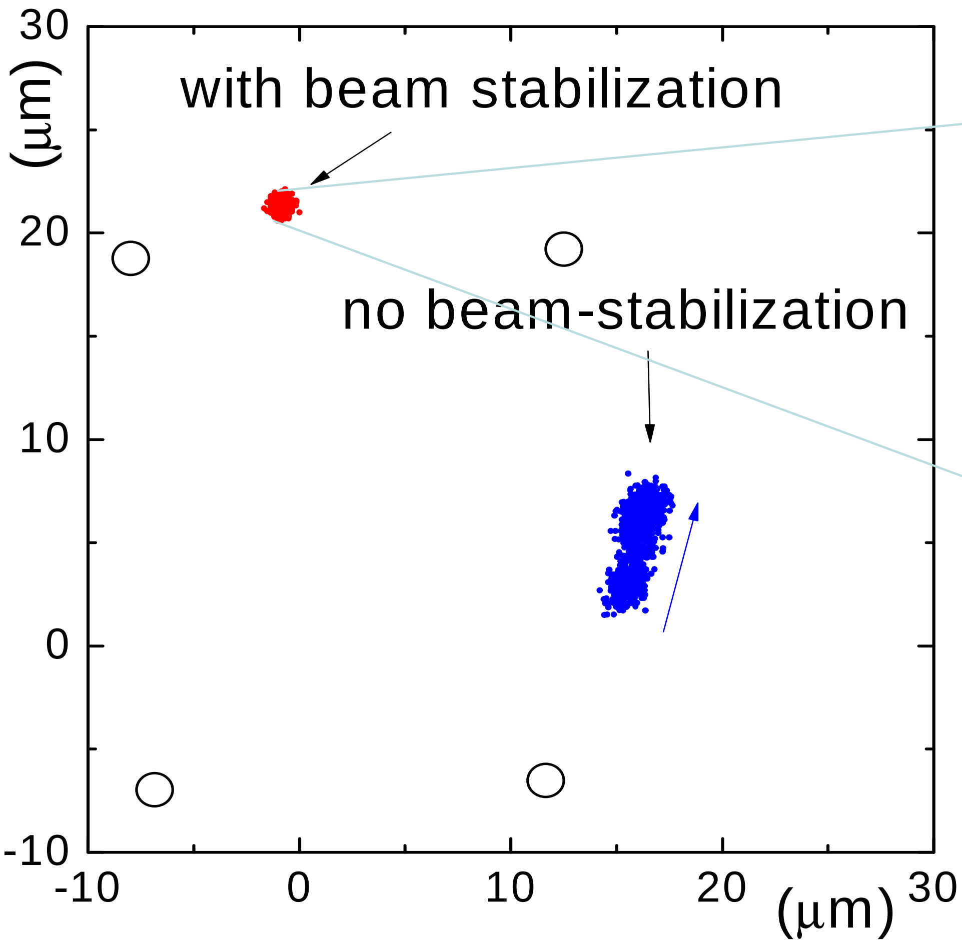
FWHM 0.51 µm 0.10%

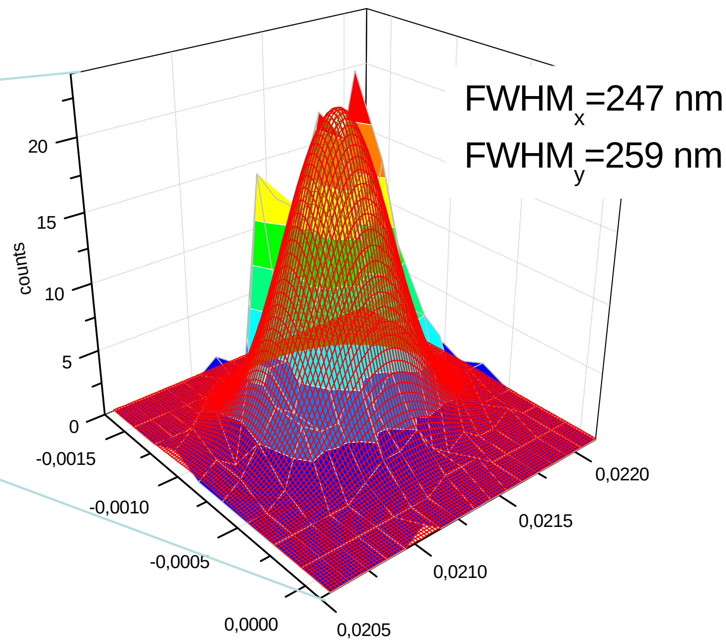
FWHM 1.15 µm 0.25%



In-beam Performance: linearity, position resolution

- Position resolution capability





$FWHM_X$ = 247 nm
$FWHM_Y$ = 259 nm

Summary

- Today scCVD-PSD prototypes

  Duo-lateral configuration & Pulse mode
  Cushion distorsion compensation
  Stable and reliable
  Position : resolution in the 250 nm range
  Intensity : S/N > 3 decades

- Future developments

  Radiation hardness tests
  Performance with high thermal load – 'white beam' applications

Acknowledgments

Dr. Mircea Ciobanu, GSI, Darmstadt, for development and providing of FCSAs used for the PSDs characterization

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Thank you for your attention