Tests of a diamond quadrant detector at Hasylab (DESY) using the Libera Brilliance

J Morse European Synchrotron Radiation Facility, France

H Graafsma Hasylab, DESY, Germany

B Solar Instrumentation Technologies, Slovenia

Acknowledgements

Eleni Berdermann	GSI Darmstadt
Michal Pomorski	CEA-Saclay
Harris Kagan	Ohio State Unversity
Muriel Salomé	ESRF Grenoble
Liam Gannon	University of Bath

Objectives:

- evaluate the feasibility of using RF readout with diamond beam position monitors;

- compare performance, practical issues… with the (usual) electrometer read-out approach.

1. X-ray Synchrotron beam monitoring requirement
   why diamond?

2. some background: tests at ESRF

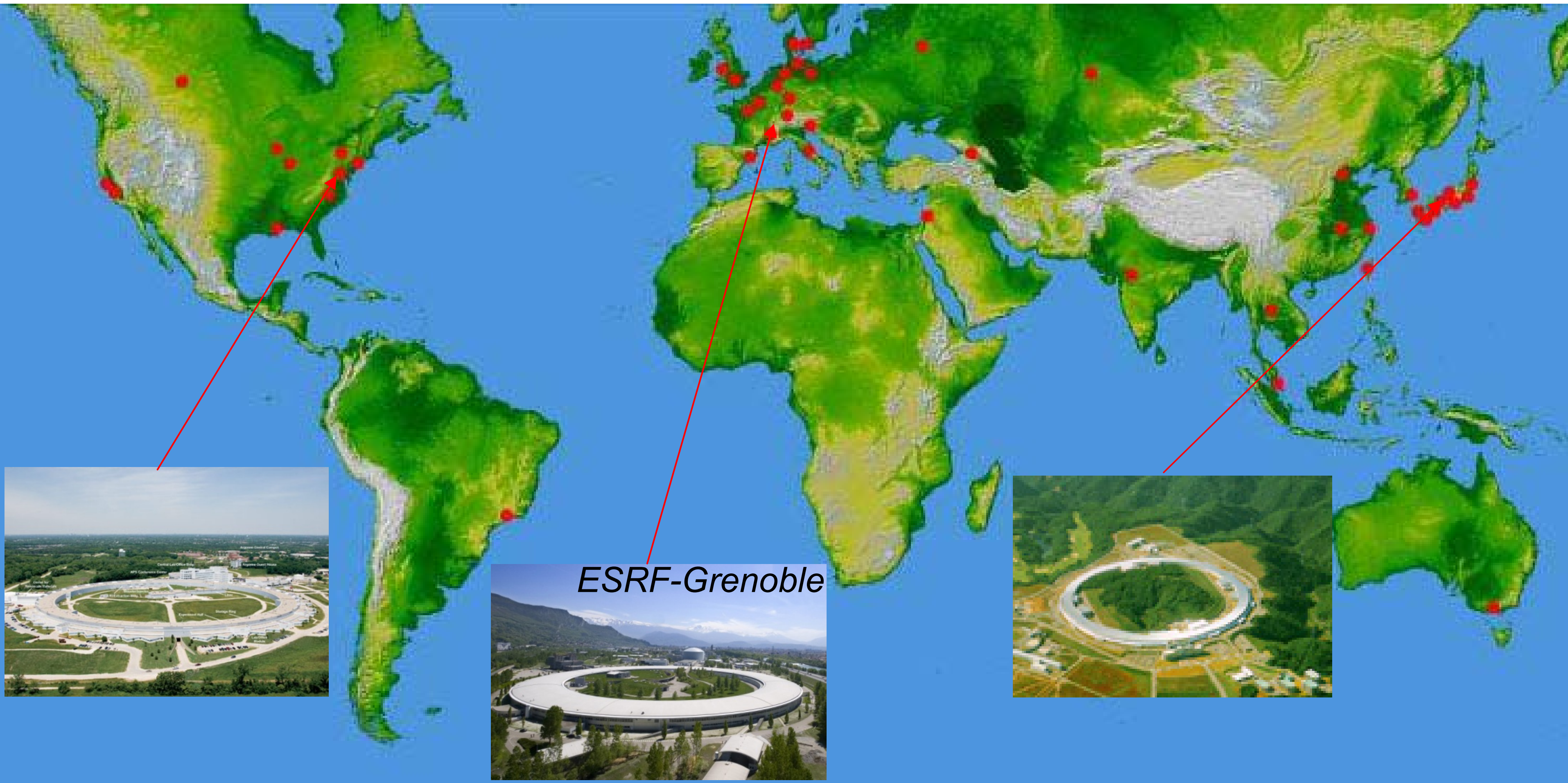
3. the Libera Brilliance system

4. DESY F4 beamline measurements/results

global application scale

2009: about 50 synchrotrons in the world…

infra-red to MeV photon beams, but main interest 5 ~ 50keV



European Synchrotron Radiation Facility

ESRF

~5000 external user experiments / year

with high intensity, coherent

X-ray beam probes 0.5 ~ 500keV

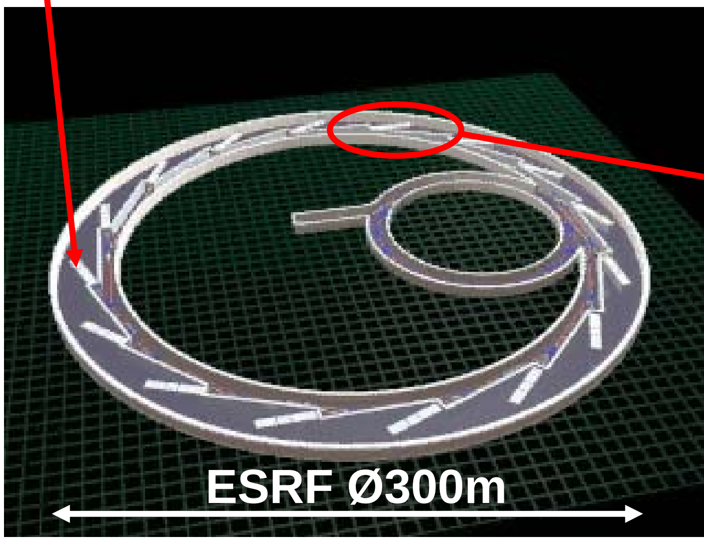
→ basic and applied research in

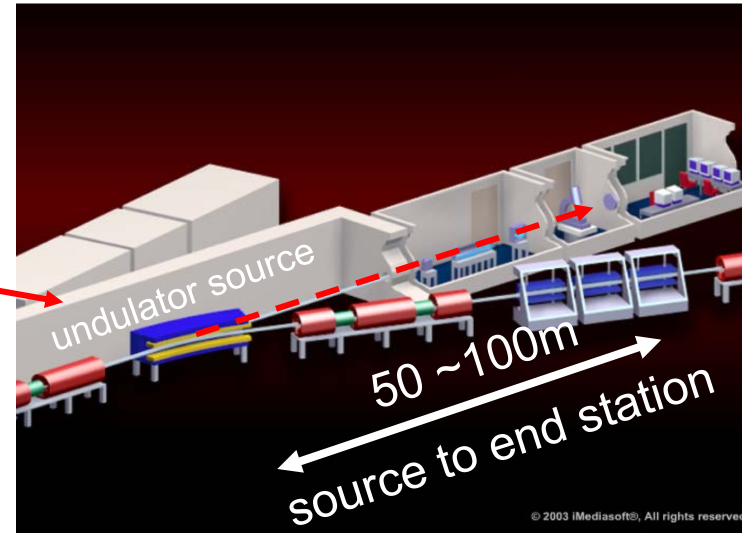
- biology (protein structures…)
- materials science
- chemistry, catalyisis…
- (coherent) imaging

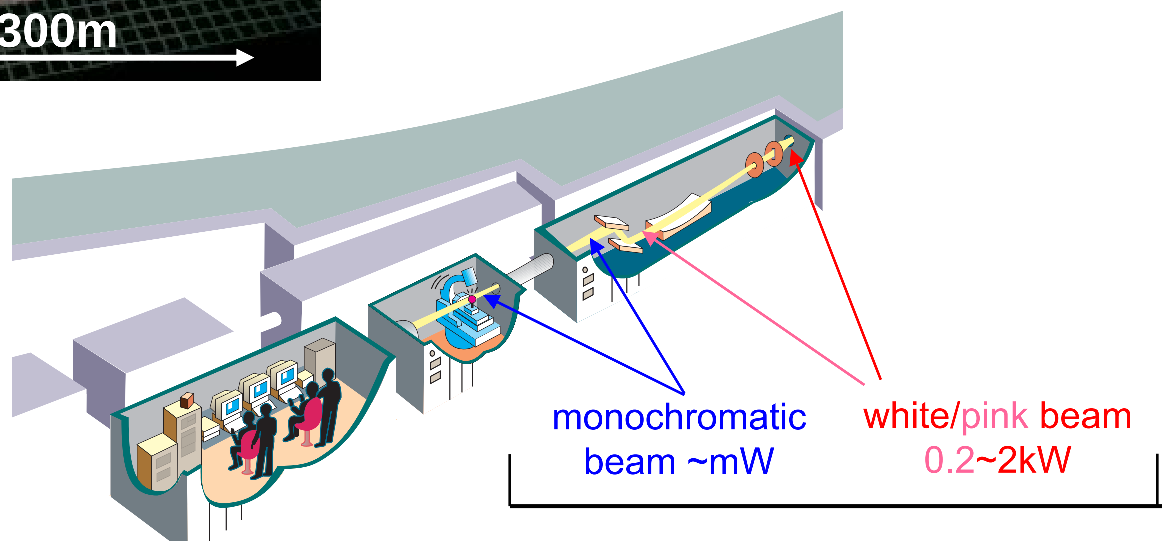
-- at micro, nano, molecular & atomic scales …

3rd generation synchrotrons

~ 50 beamlines

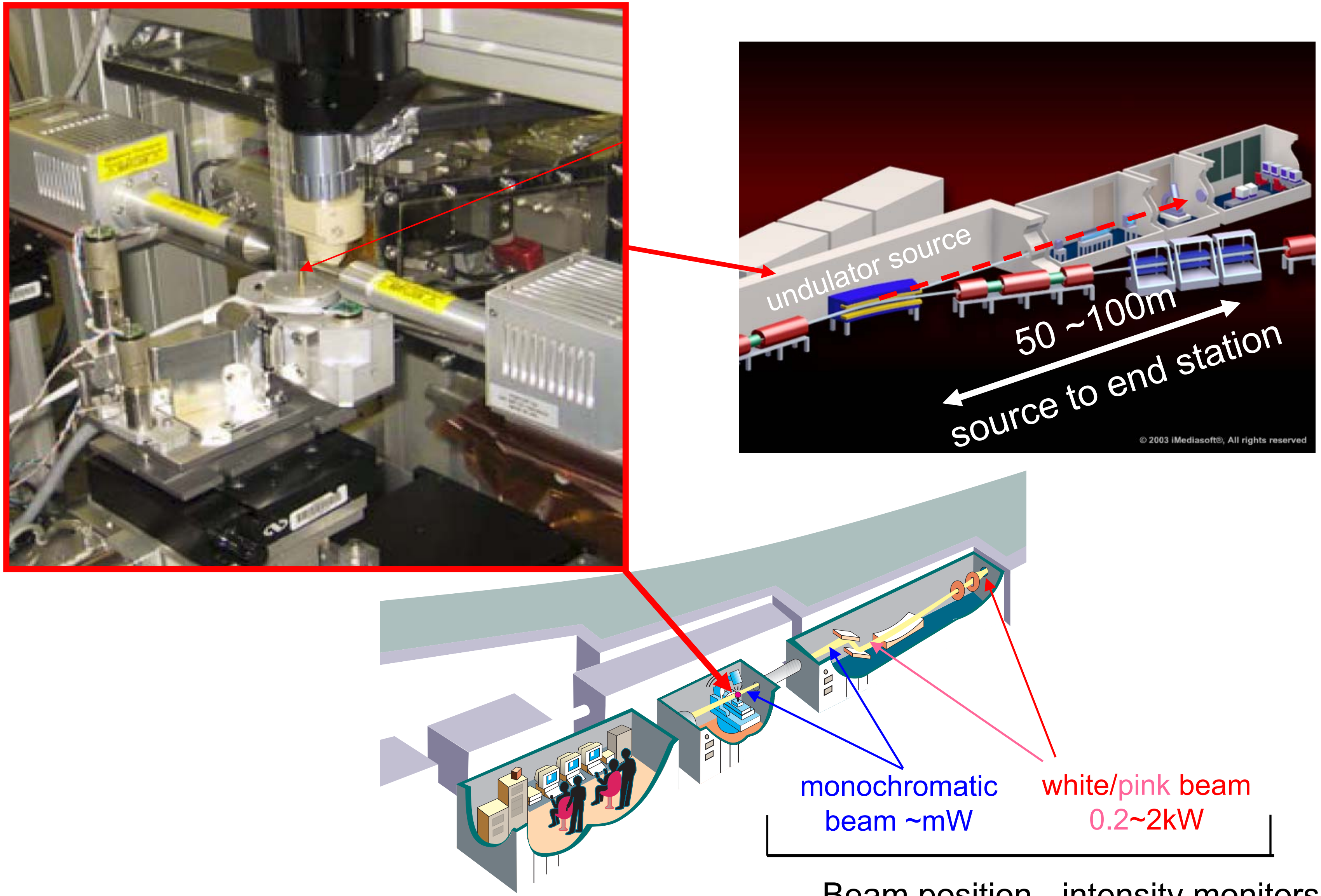






Beam position - intensity monitors

3rd generation synchrotrons



Beam position - intensity monitors

X-ray beamline monitoring requirements

Position — required beam stability ~10% of beam size 0.1 ~ 50µm,
nanofocusing goals → 10nm
measurement rates required ***dc*** *~ 1kHz* (acoustic vibrations !)

Intensity: — accuracy & linearity requirement ≤ 0.1%

Timing: — synchronization with optical lasers in ~psec pump probe experiments (X-ray photon bunches ~50psec at 10^5~10^8 pulses/sec

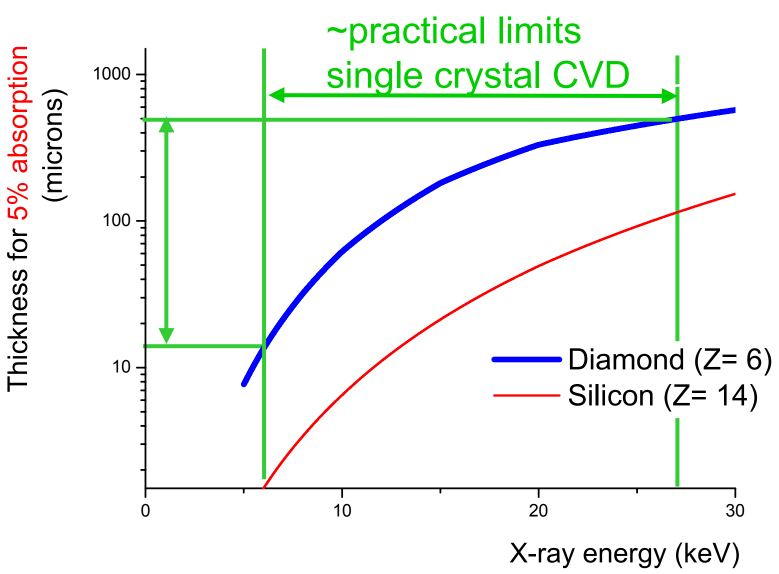
device… — *minimal beam interference*: absorption, scattering, coherence loss
beamline compatibility:
package size, operation in air, dirty-vacuum, clean-UHV
ionizing radiation load >10^4 Gray/sec

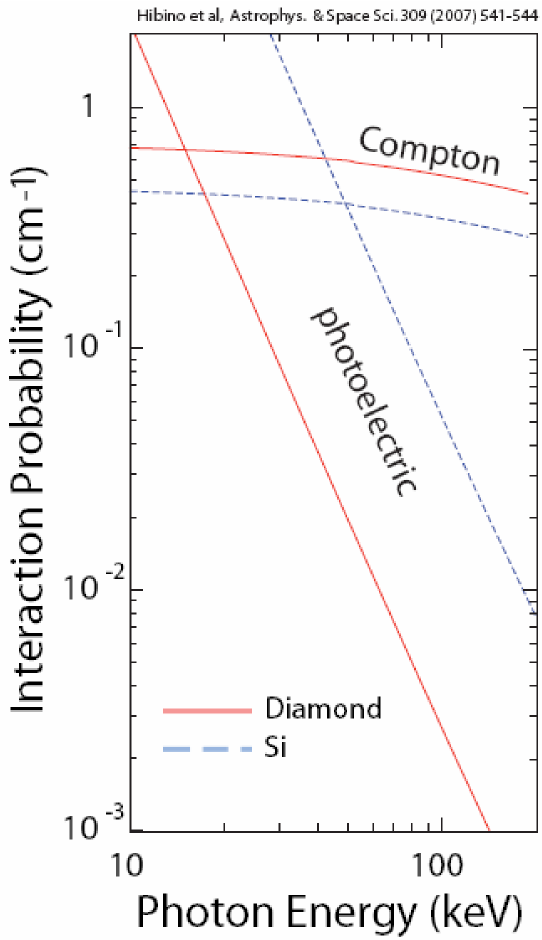
→ max. *absorbed* X-ray power: ≤ few mW monochromatic beams
but ≥100W in ~mm² 'white' beam applications: ONLY possible with diamond

why diamond ?

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

…and short range of photoelectric- or Compton electron

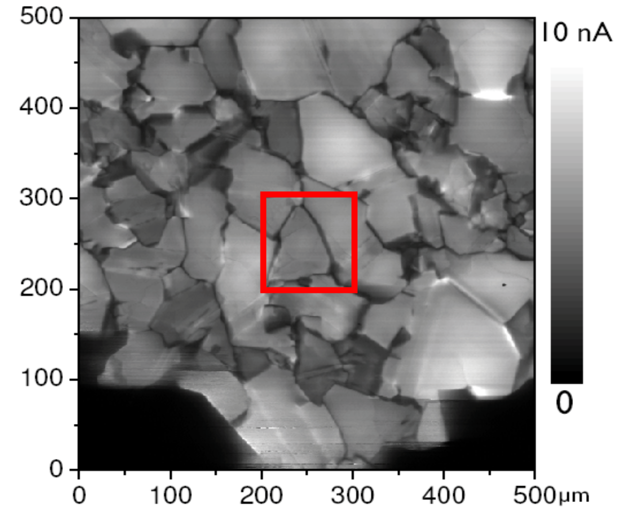




- *'zero' leakage current*
  → *can use high E-field* → *nsec response*
- *simple devices can be radiation hard*
- *outstanding thermal conductivity*
  diamond 2000, cf. Si 150 ($Wm^{-1}{}^{o}K^{-1}$)

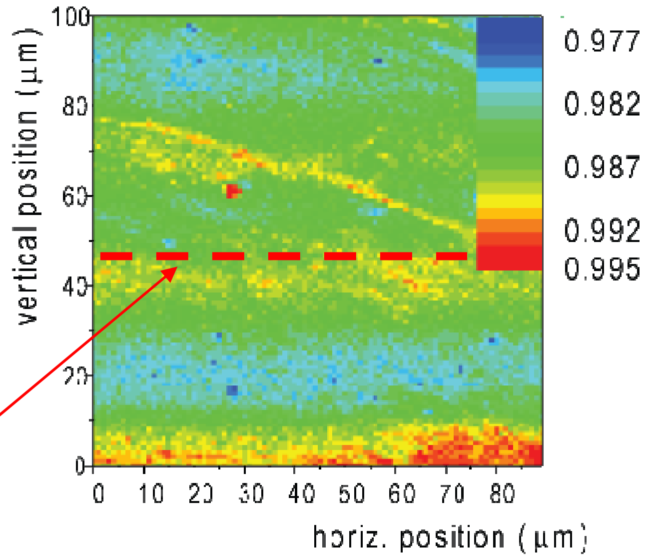
XBIC: signal current maps made from x, y raster scan of micron X-ray beam

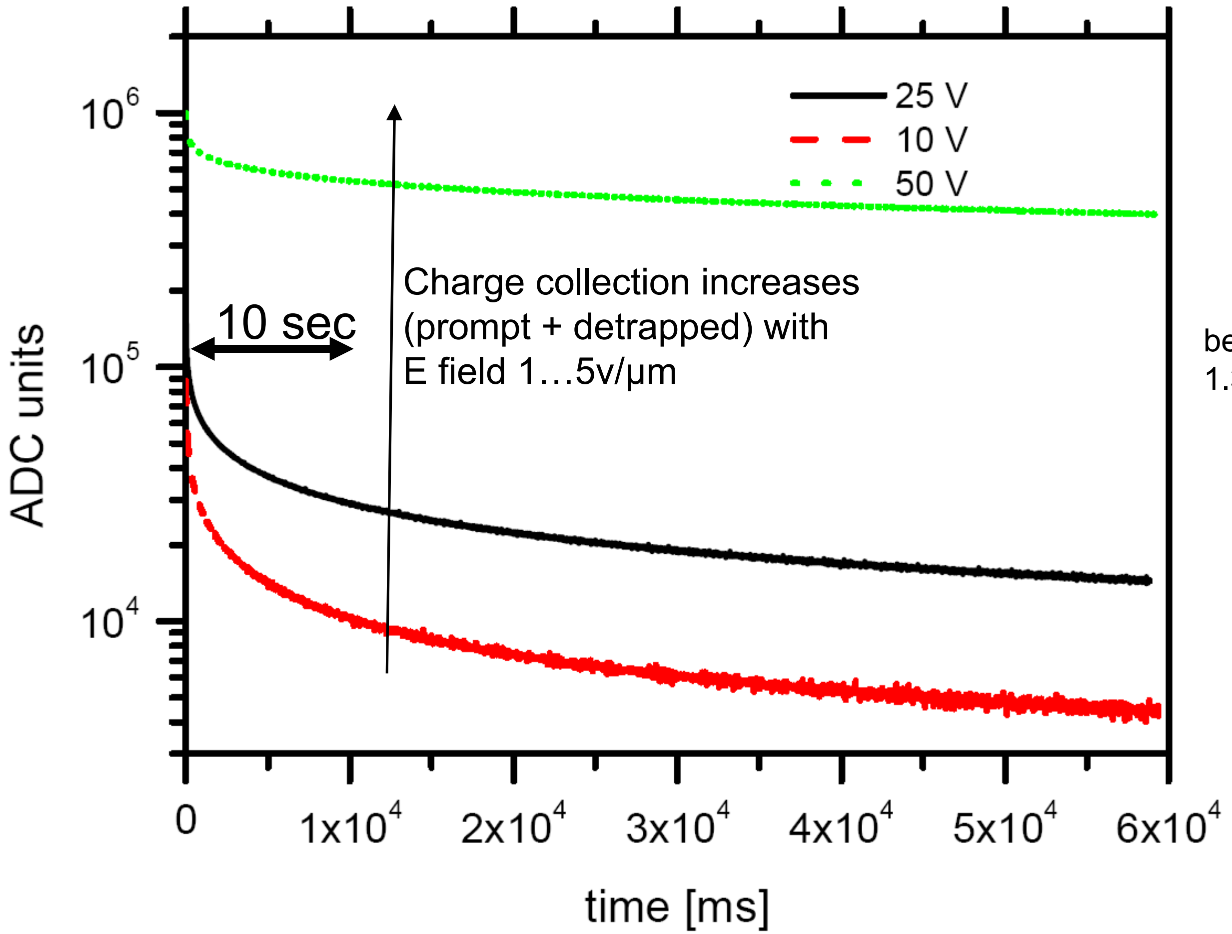
Polycrystalline:
grain-boundaries
→trapping and local field distortions,
signal response lag
→X-ray scattering…



Single Crystal:
excellent spatial uniformity…
'unity gain' charge collection with
blocking contacts

1σ signal variation **0.103%**
over 100 point row



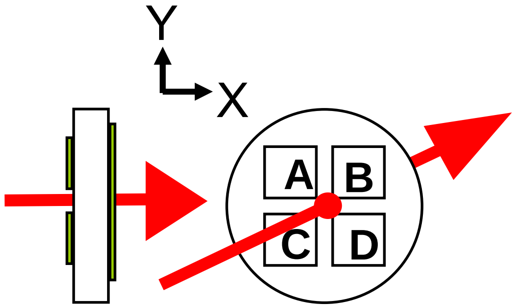


beam 15 x 100µm^2 ,
1.3 x 10^{12} ph/sec at 12keV

Ralf Menk, 2006 SLS data on polycrystalline ~10µm thick (sourced by Diamond Materials??)

operation of diamond XBPM devices

- diamond plate, thin (30…100µm) diamond with 'X-ray transparent' <100nm surface contacts Cr, Ti, … Ni, Al (Au, Pt, W))
- in beam, diamond bulk acts as solid state 'ionization chamber'
  electron thermalization range ~few microns
- current signal readout 'DC' up to synchrotron RF clock frequencies possible



position (and intensity) found with…

multiple electrodes:

exploits *diffusion splitting (~10µm)* of charge

e.g. simple quadrant motif

→ difference/sum of electrode currents A, B, C, D givesbeam 'centre of gravity'

→ sum of currents gives beam intensity

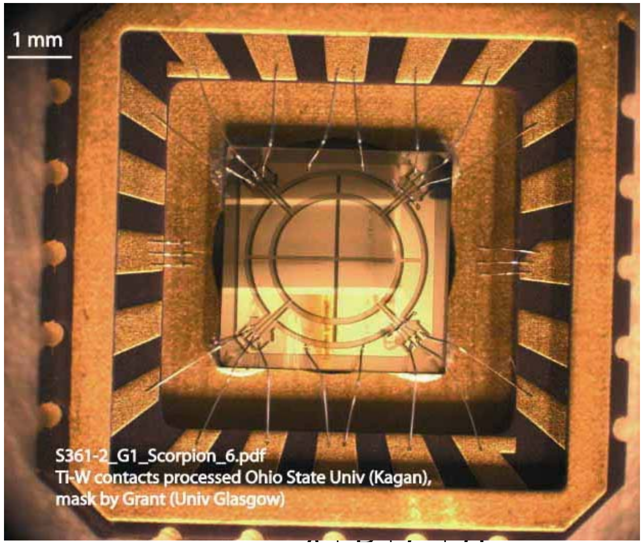
$$X = \frac{(A+C)-(B+D)}{A+B+C+D}$$

$$Y = \frac{(A+B)-(C+D)}{A+B+C+D}$$

operation of diamond XBPM devices

- diamond plate, thin (30…100µm) diamond with ‘X-ray transparent’ <100nm surface contacts Cr, Ti, … Ni, Al (Au, Pt, W))
- in beam, diamond bulk acts as solid state ‘ionization chamber’

  electron thermalization range ~few microns
- current signal readout ‘DC’ up to synchrotron RF clock frequencies possible



Packaged device,
ID09B, ID11, Desy F4 tests

position (and intensity) found with…

multiple electrodes:

exploits *diffusion splitting (~10µm)* of charge

e.g. simple quadrant motif

→ difference/sum of electrode currents A, B, C, D givesbeam 'centre of gravity’

→ sum of currents gives beam intensity

- diamond plate, thin (30…100µm) diamond with 'X-ray transparent' <100nm surface contacts Cr, Ti, … Ni, Al (Au, Pt, W))

- in beam, diamond bulk acts as solid state 'ionization chamber'
  electron thermalization range ~few microns

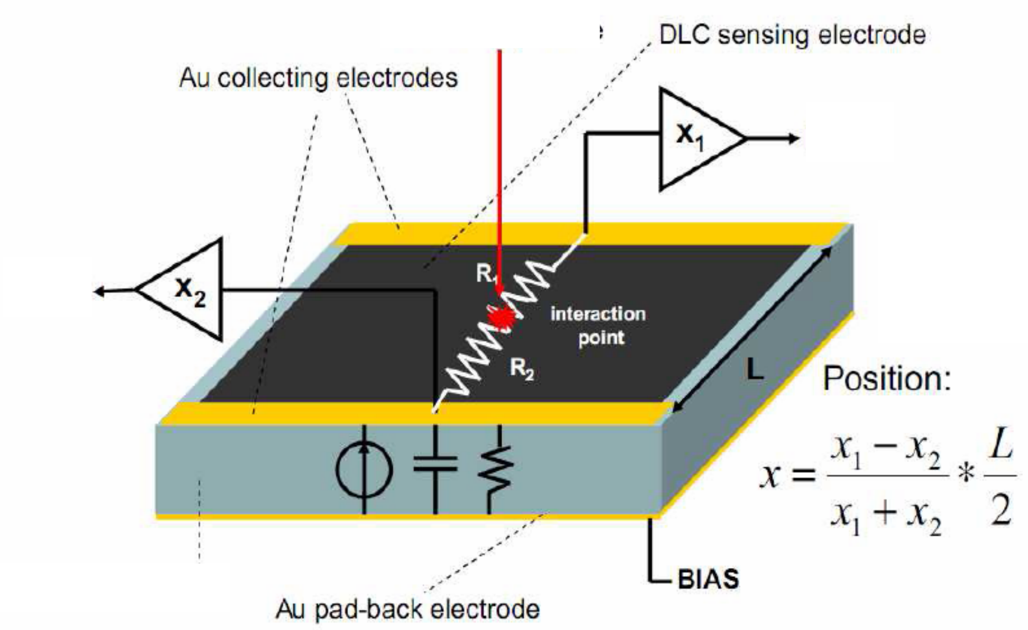
- current signal readout 'DC' up to synchrotron RF clock frequencies possible

position (and intensity) found with…

duo- and tetra-lateral devices

→ linear position response
over several mm

(*but less precise*)



operation of diamond XBPM devices

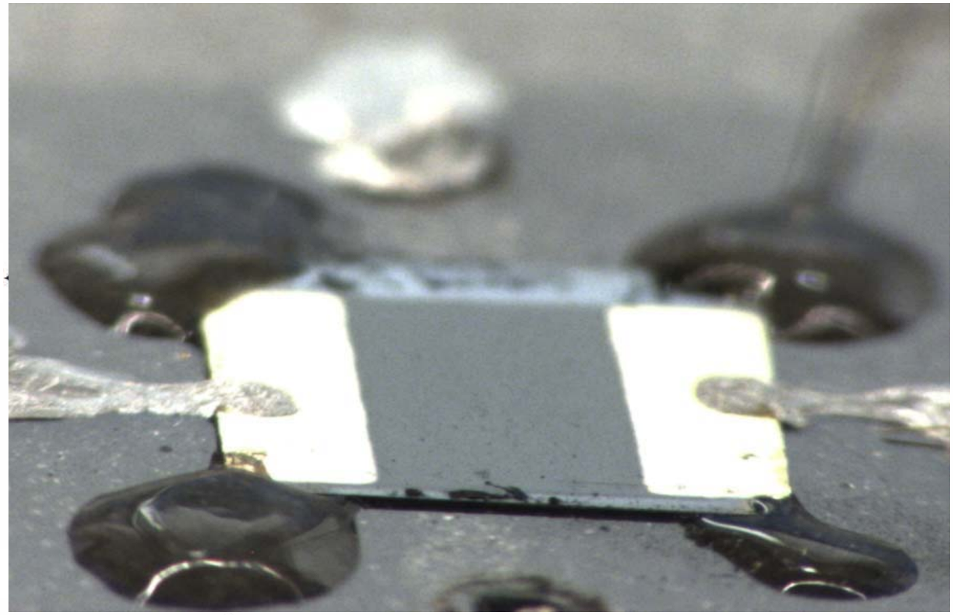
- diamond plate, thin (30…100µm) diamond with ‘X-ray transparent’ <100nm surface contacts Cr, Ti, … Ni, Al (Au, Pt, W))
- in beam, diamond bulk acts as solid state ‘ionization chamber’
  electron thermalization range ~few microns
- current signal readout ‘DC’ up to synchrotron RF clock frequencies possible

position (and intensity) found with…

duo- and tetra-lateral devices

→ linear position response
over several mm

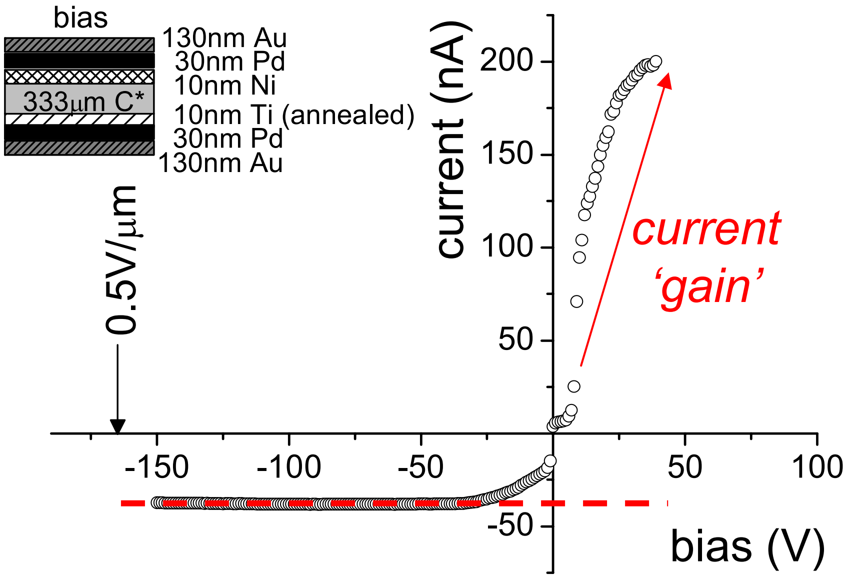
(*but less precise*)



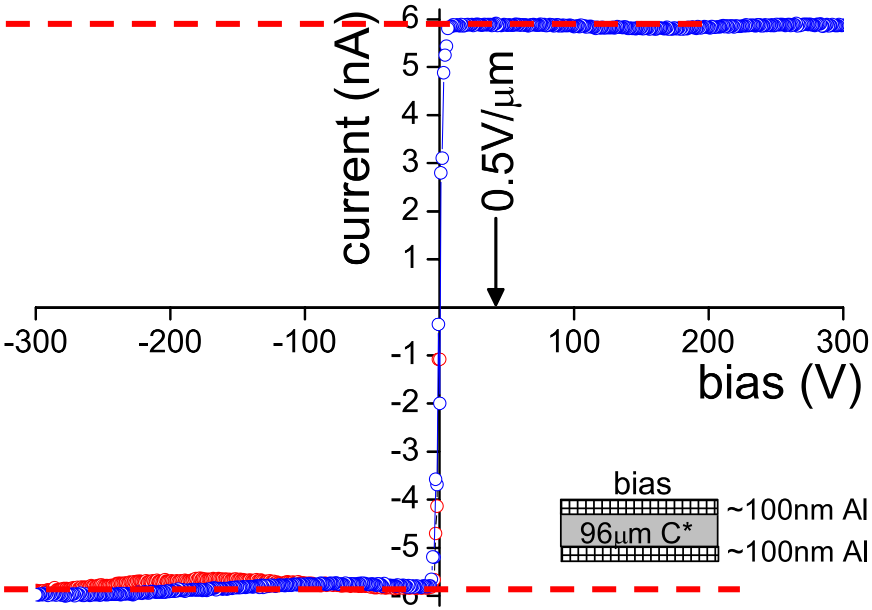
ID06 tests– *see Pomorski talk !*

I-V curves under steady-state X-ray beam illumination (7.2 and 6.0 keV)

Lift-off litho' evaporated contacts
(Glasgow University)



Shadow mask, sputtered contacts
(GSI Darmstadt)



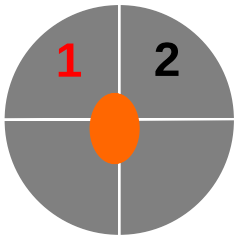
Blocking contact(s) give saturated current response for $>0.3 V\mu m^{-1}$ applied E field:

'overbias' → *excellent area response uniformity*

Si beam flux calibration
→ $\varepsilon_{Diamond}$ = 13.05 +/-0.2 eV/e-h pair
(ESRF, MI-885)

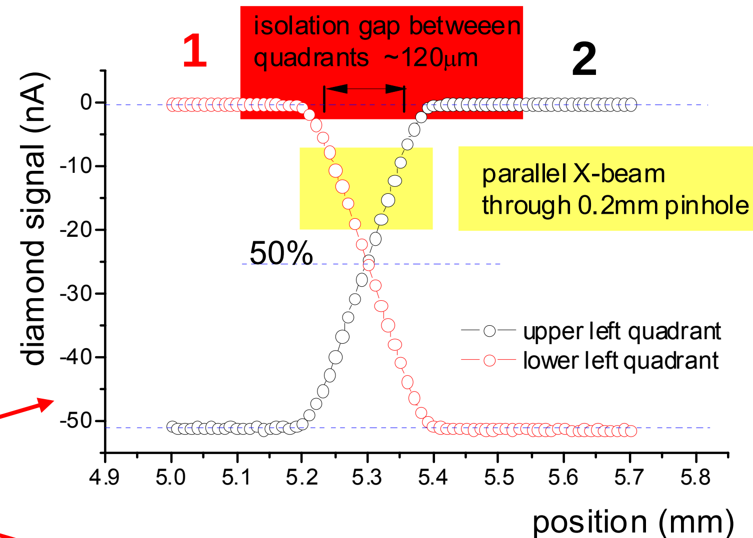
quadrant devices: position response

For large beamsize (> 50µm), device ‘crossover response’ is simply the line integral across the beam intensity profile



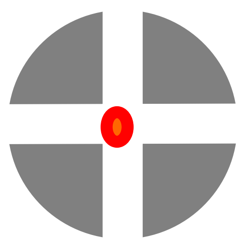
!! This data from 0 - 10Hz bandwidth electrometer measurements, i.e. charge integral measurements… what about the time domain??

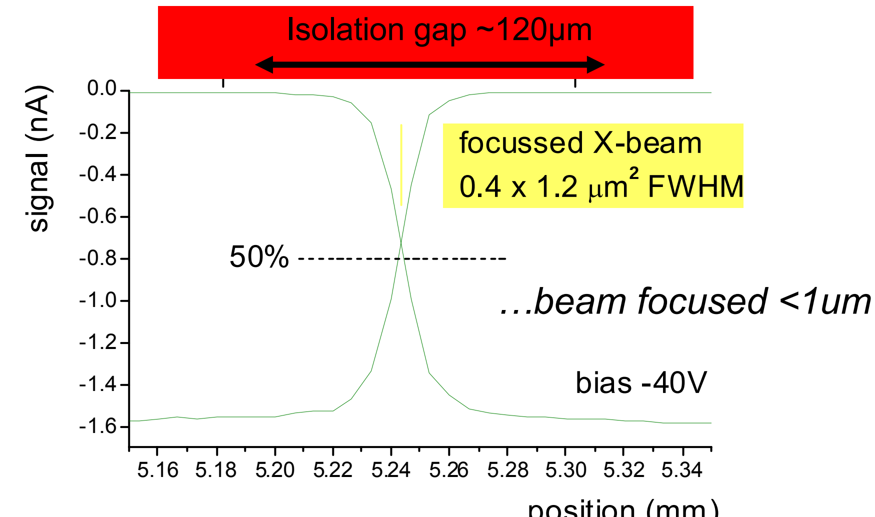
ID21 data, beam collimated 200µm



signal slope ~0.5% /micron

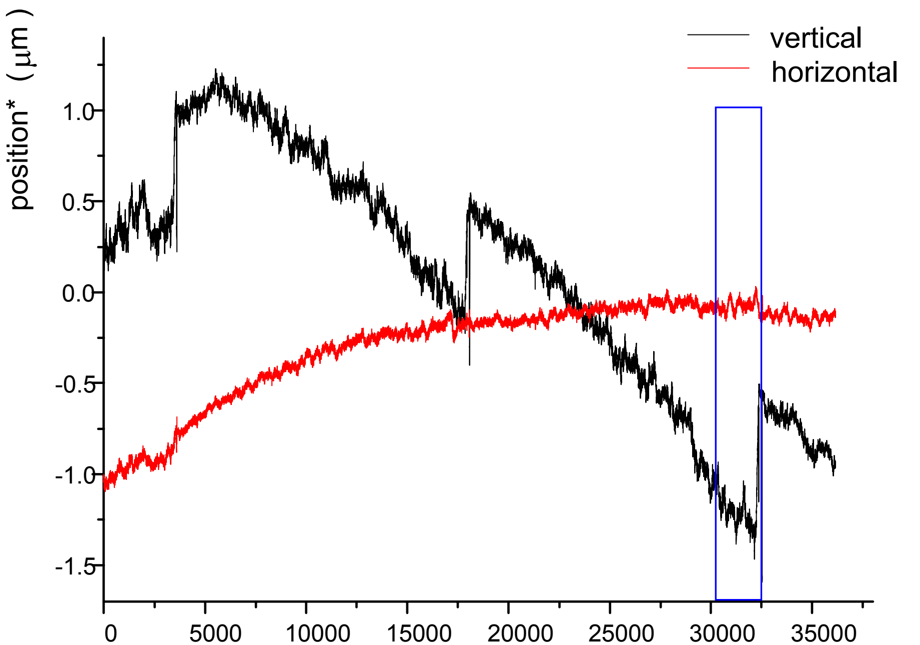
For a small beam (< 10µm), crossover response is convolution of *photoelectron thermalization range* and *lateral charge diffusion ocurring during drift*





signal slope ~5% /micron

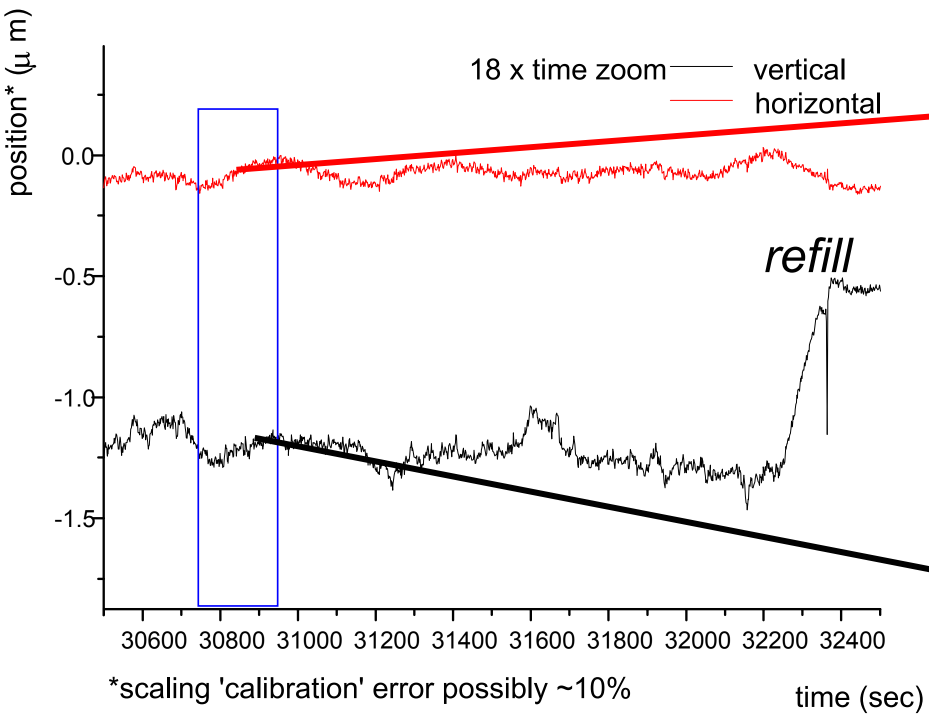
ESRFMI-885, ID21 microfocus beamline
1sec/point: beam shifts

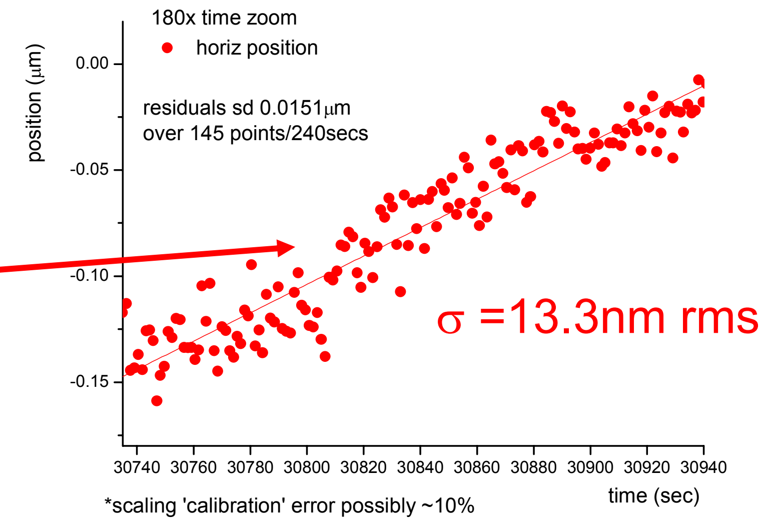


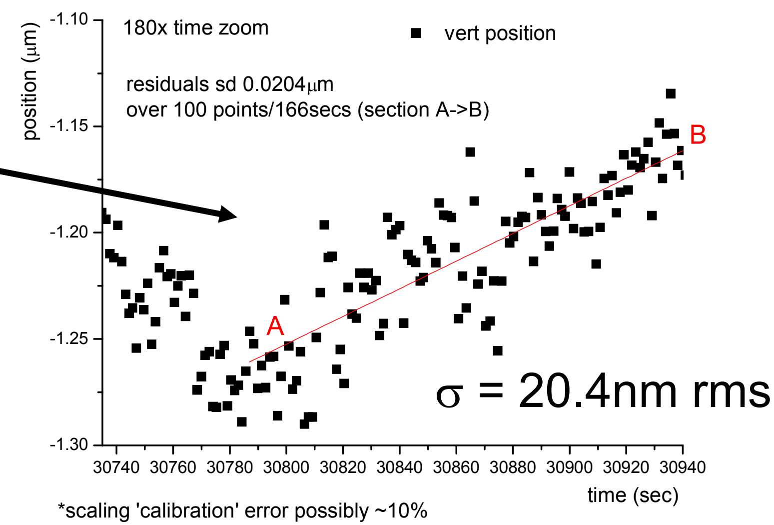
*scaling 'calibration' error possibly ~10%

X-ray flux ~10^8 s^{-1} at 7keV →
~ 20fC in diamond per X ray bunch
~ 10nA ‘dc equivalent’ signal current)

ESRFMI-885, ID21 microfocus beamline
1sec/point: beam shifts





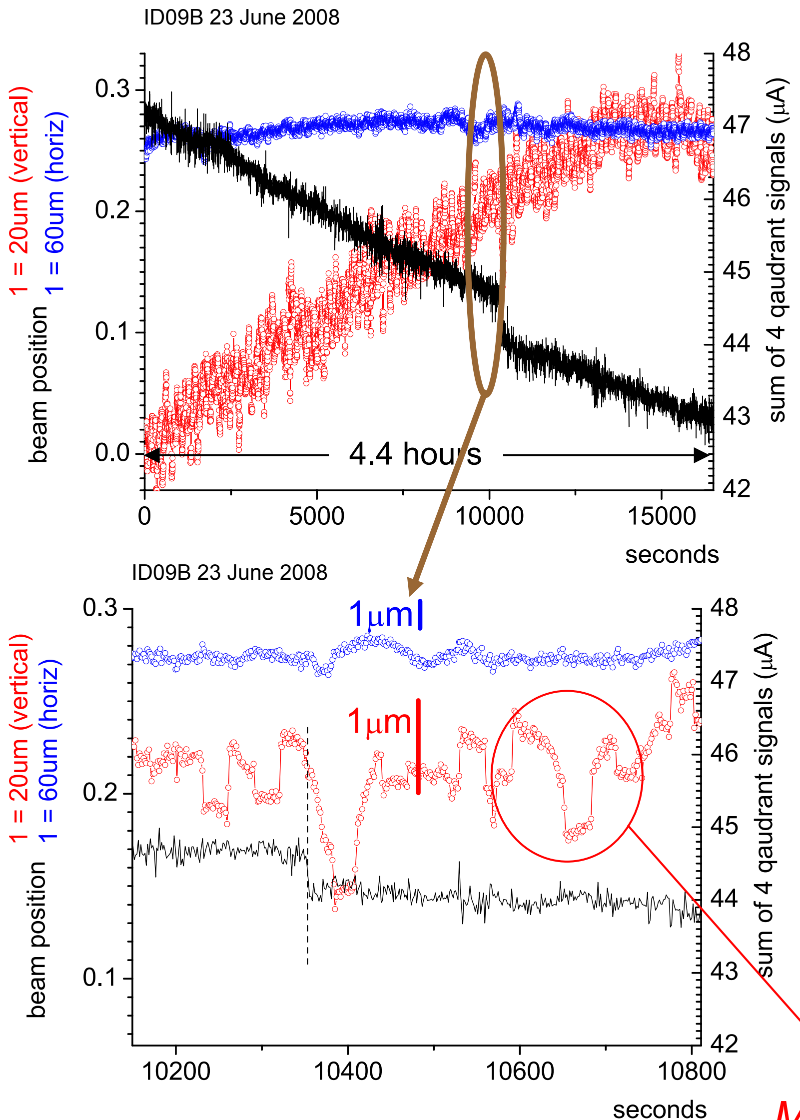


X-ray flux ~10^8 s^{-1} at 7keV →

~ 20fC in diamond per X ray bunch

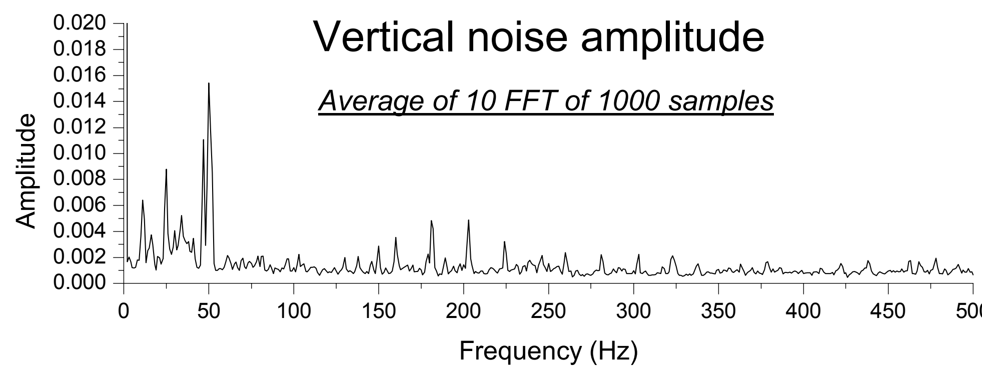
~ 10nA 'dc equivalent' signal current)

position timescan and ‘vibrations’, ID09B:



~ 14 keV beam

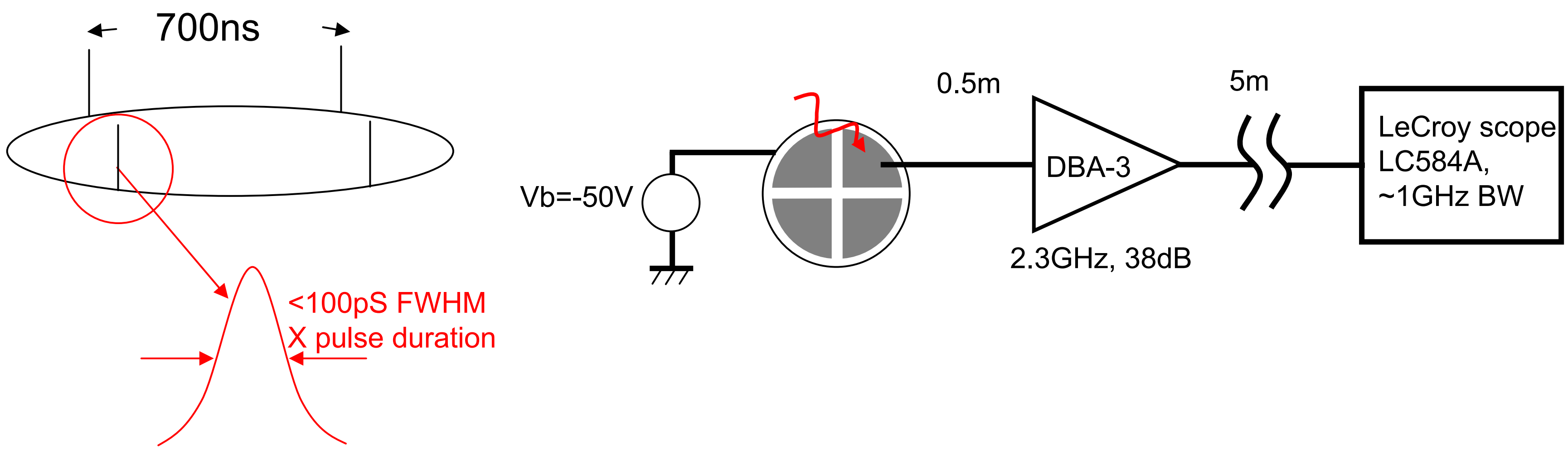
currents measured with Keithley 485 electrometers, (10Hz BW, mean current/electrode ~10μA
→ charge generated in diamond ~ 100 fC /pulse



FFTs using Femto DLPCA-200 current preamps (simultaneous sampling ADCs at 1ksample/sec)

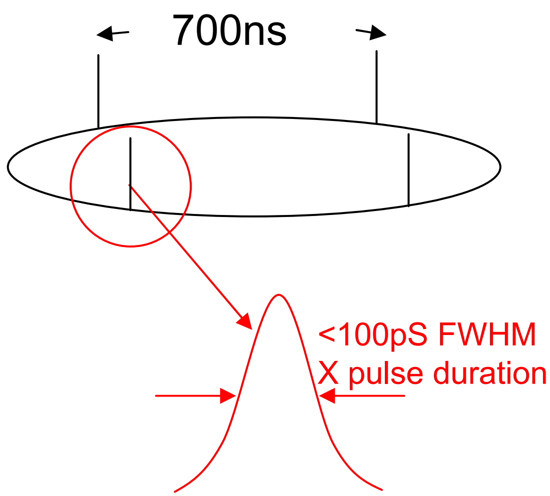
Machine artifacts or something upstream on beamline…

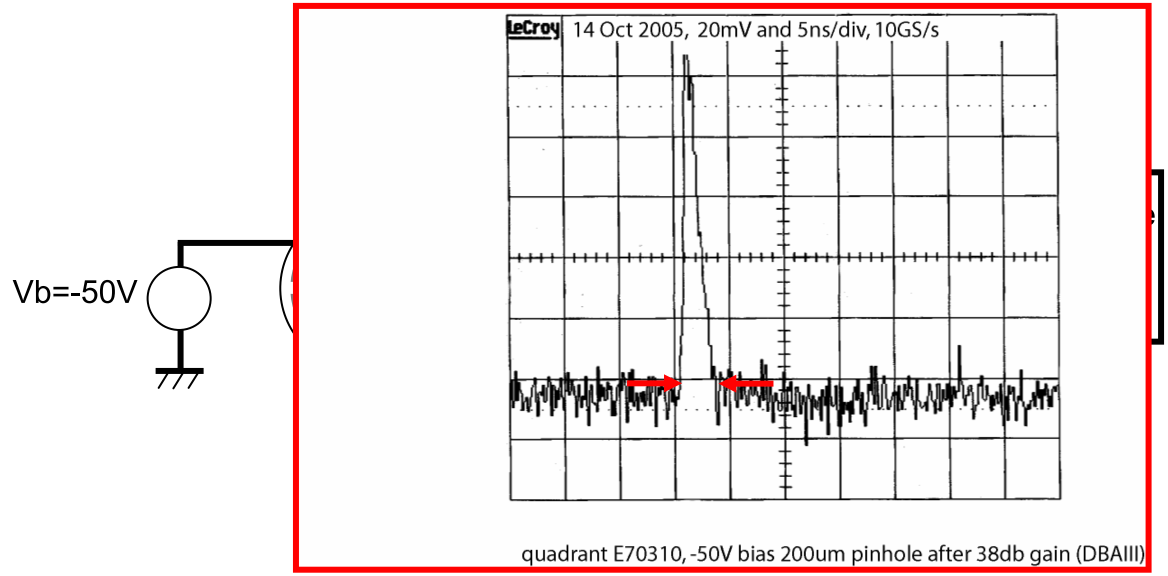
ESRF 4 bunch mode,
ID21 beam ~10^8ph/sec mean flux (very weak beam intensity…)



diamond temporal response

ESRF 4 bunch mode,
ID21 beam ~10^8ph/sec mean flux (very weak beam intensity…)





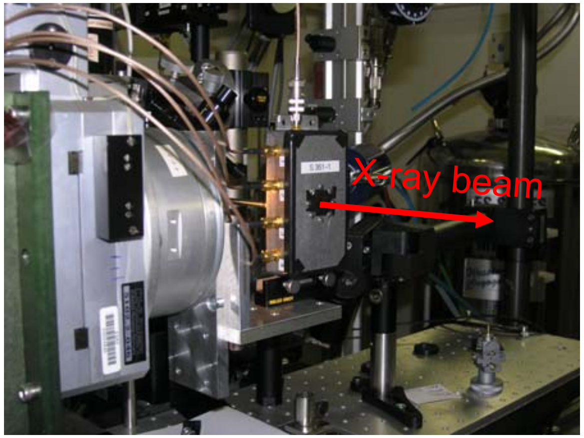
Signal response to crossing of *one* X-ray bunch

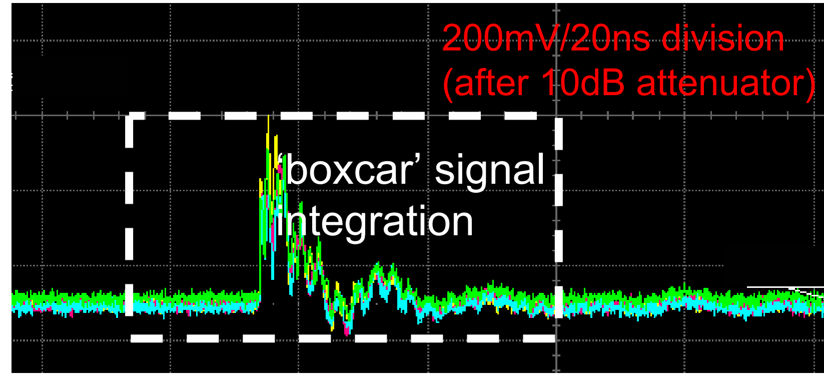
→ absorption of ~160 photons at 7.2keV (total ~1MeV = 12fC /pulse)

Linear fit to slope gives signal full base width ~2.5ns, → e- drift velocity ~40 μm ns^{-1} at ~1.1 V $μm^{-1}$

S361-1, sample

TiW contacts processed by Kagan-OSU.



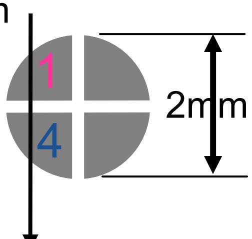


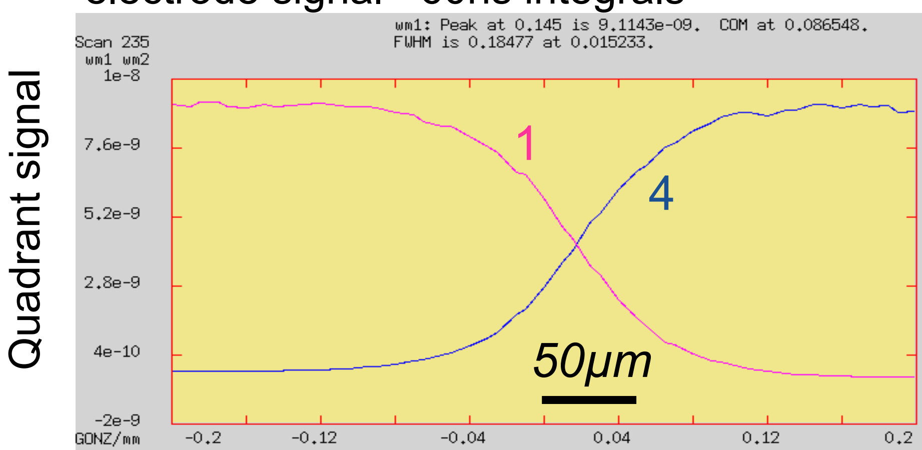
signal direct to DSO: poor decoupling and 50Ω matching → signal 'bounce'

20keV beam, incident flux ~1 x 10^7ph per pulse (1kHz mechanically chopped *white* beam)
~ 5% X-ray absorption in diamond 385µm thick, ~50% photoelectric/50% Compton
→ **~50pC**/pulse in diamond (diamond electrode capacity ~ 0.5pF, bias at 500V → 'CV' charge limit ~200pC)

electrode signal ~60ns integrals

Vertical beam scan





Spatial position (motor scan of diamond)

'crossover' response of electrodes, beam size fwhm 40µm (V), 90µm (H)

Signals in: 1, 2, 3, 4 →

→ X, Y, Σ out over network

!! developed for stabilization of *electron* beams

High performance if adequate 'tuned' RF signal power…

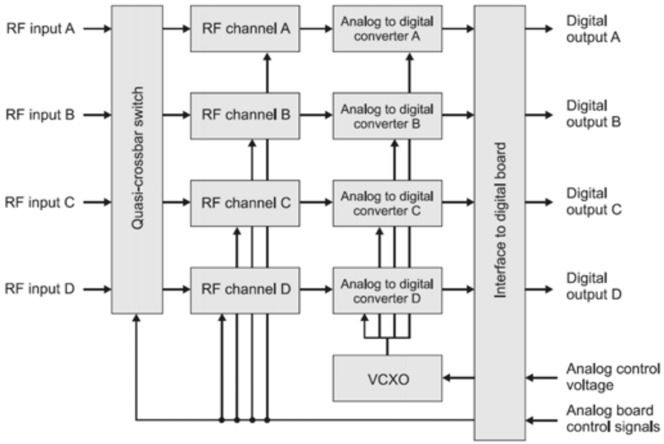
but can it work with diamond signals?

Parameter	Range	Guaranteed performance, k=10mm			
		Libera Brilliance (TBT=131kHz)		Libera Brilliance (TBT=1.15MHz)	
		non switched	switched	non switched	switched
Resolution (turn-by-turn)	→-28 dBm	1 μm	1 μm	3 μm	3 μm
	→-44 dBm	5 μm	5 μm	15 μm	15 μm
Beam Current Dependence	0→-24 dBm	1 μm		1 μm	
	0→-32 dBm	1,5 μm		1,5 μm	
	0→-50 dBm	2 μm		2 μm	
Fill Pattern Dependence	100%-20% duty cycle	1 μm		1 μm	
FA Resolution	0→-20 dBm	0,25 μm		0,25 μm	
Crosstalk		-45 dB to -70 dB			

~10kHz — (FA Resolution)

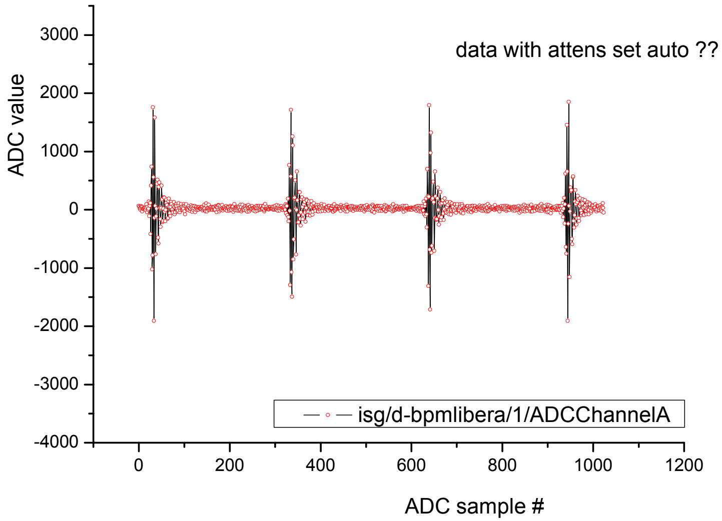
25 ppM

analog stage: tuned filter (352 or 500MHz)

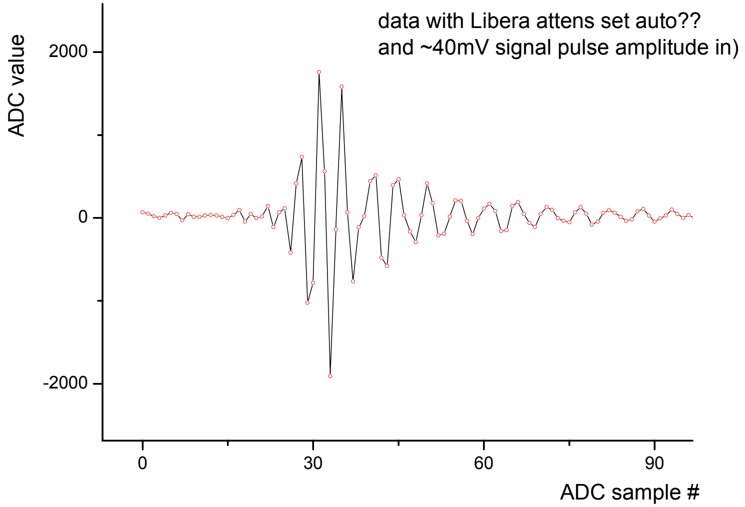


what's inside? performance?

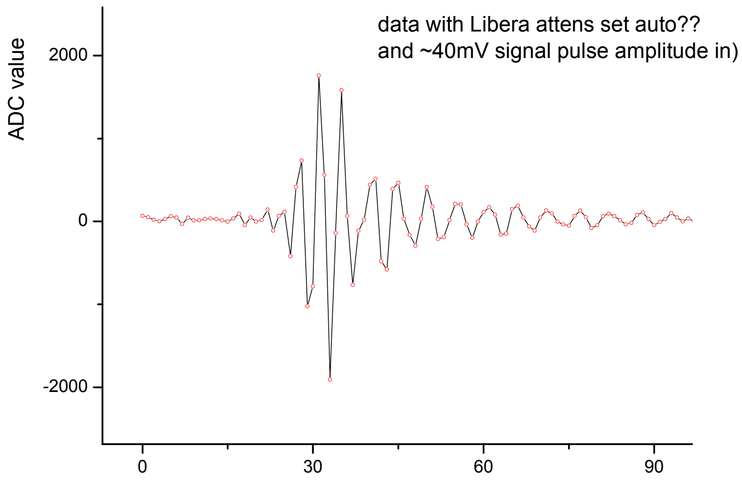
analog stage: tuned filter (352 or 500MHz)

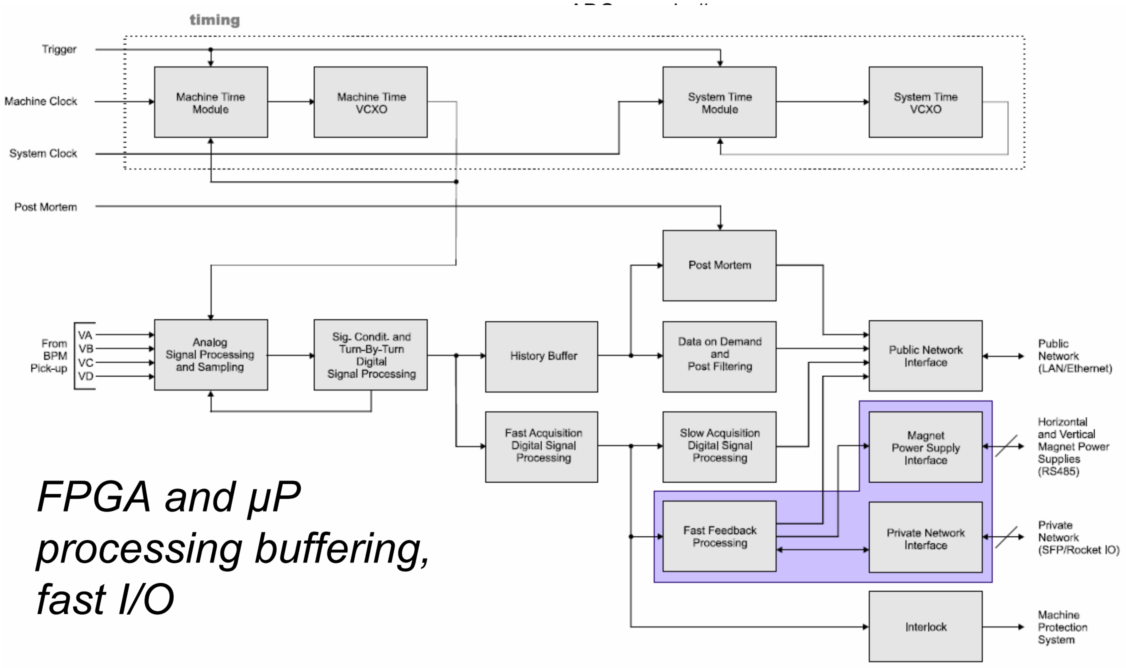


analog stage: tuned filter (352 or 500MHz)



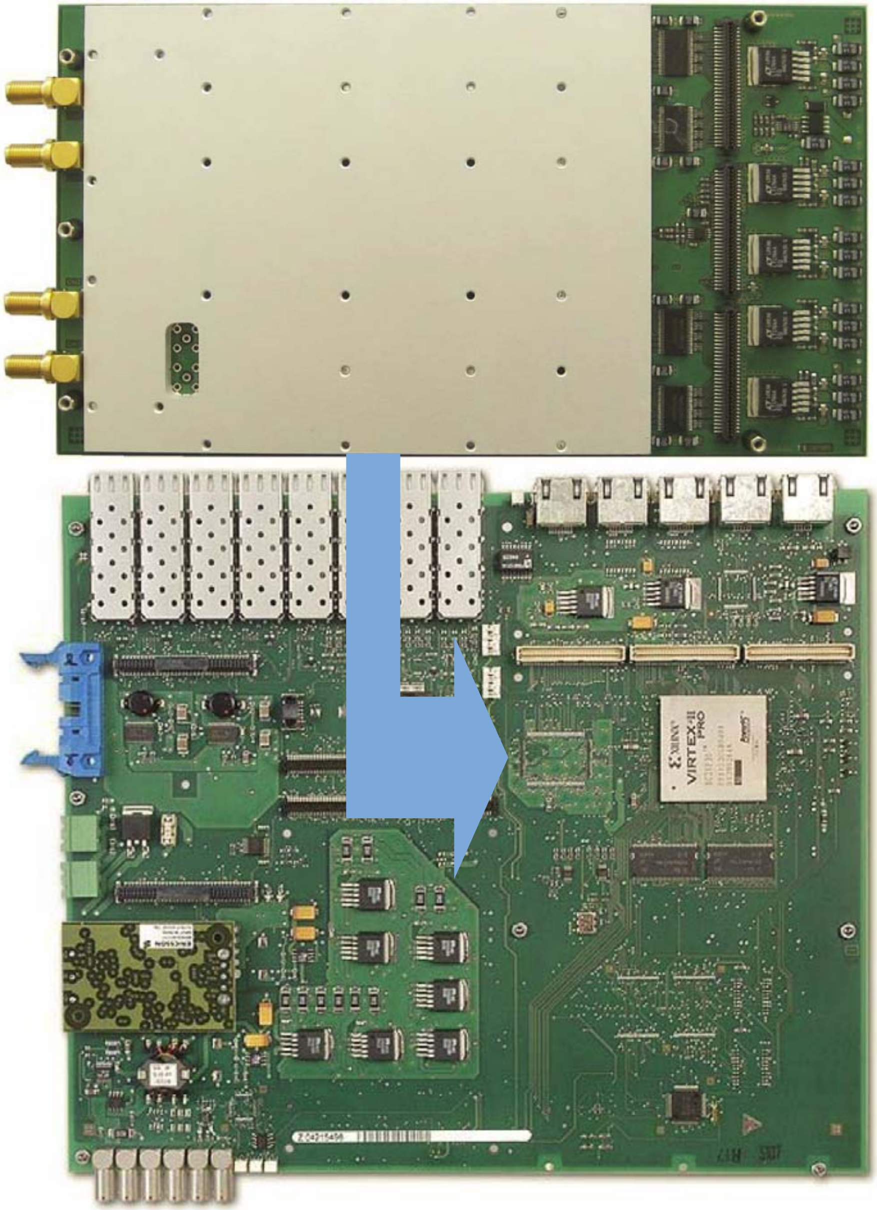
analog stage: tuned filter (352 or 500MHz)



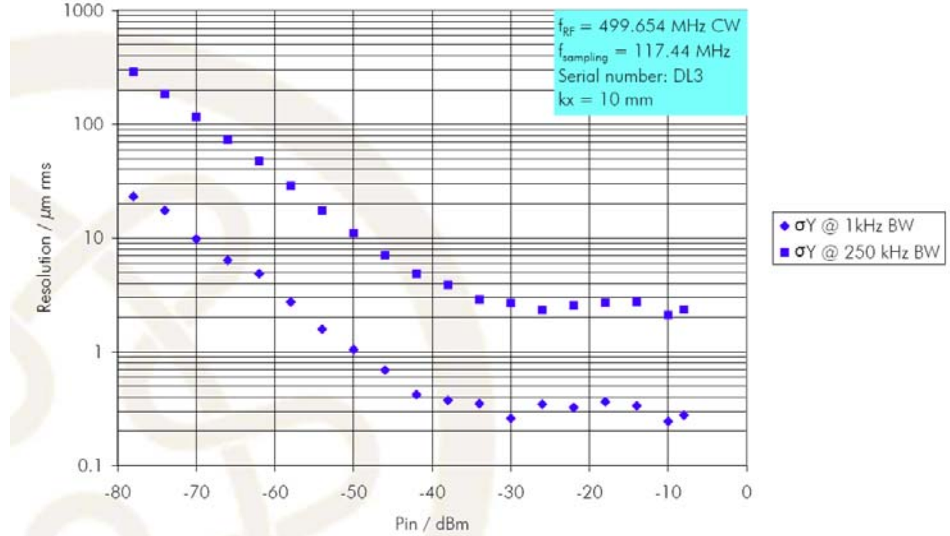


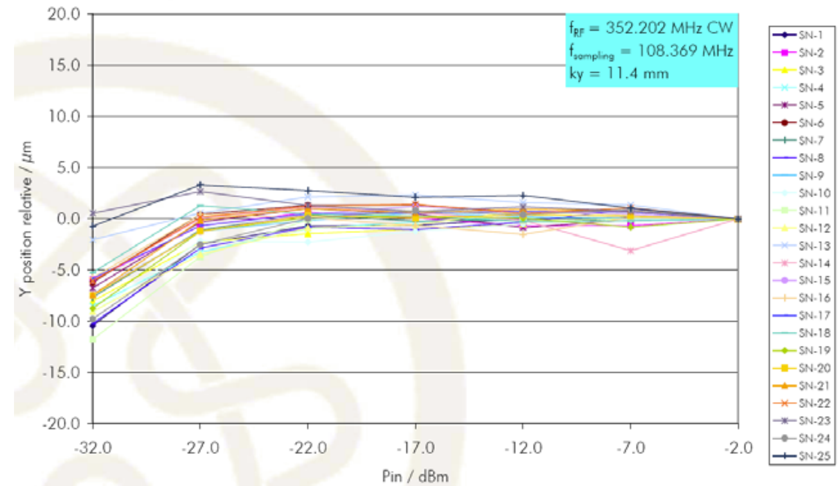
FPGA and µP processing buffering, fast I/O

what's inside? performance?

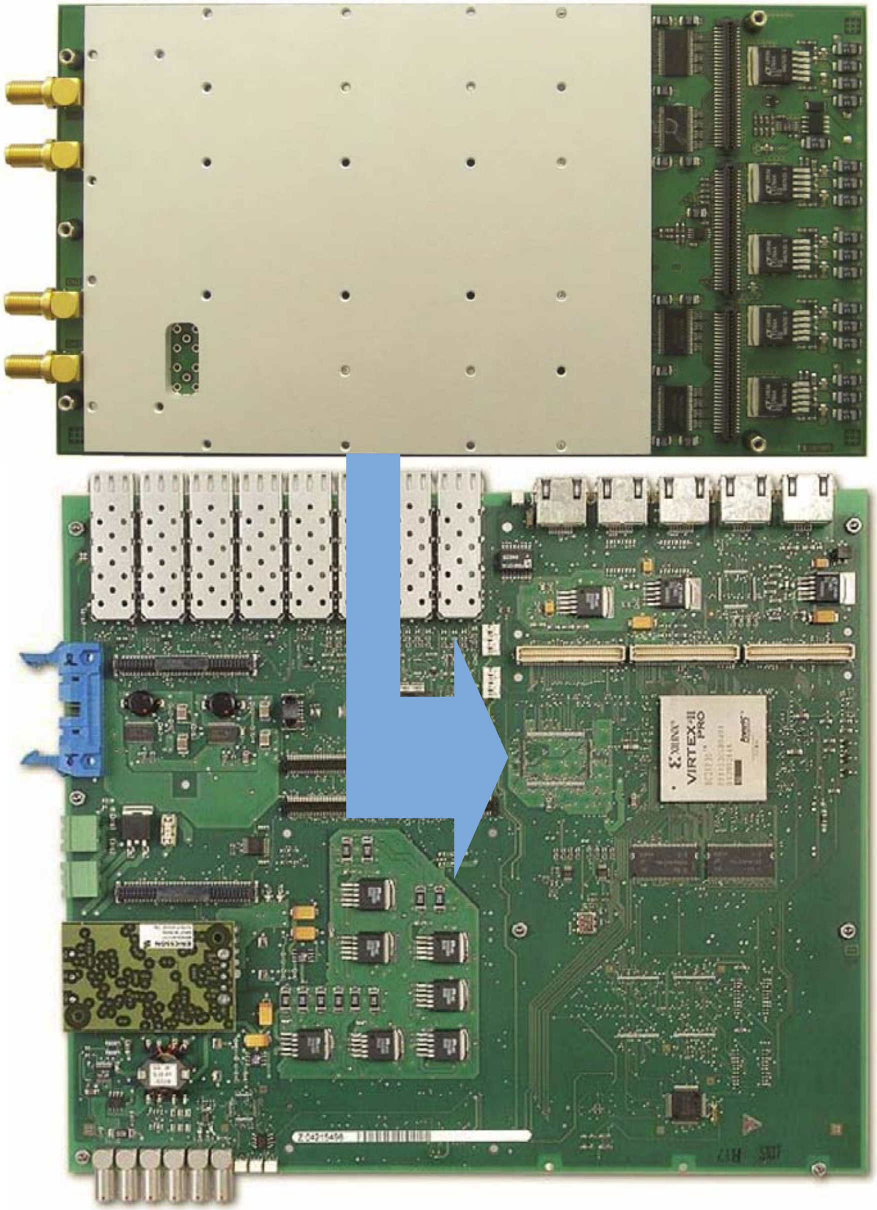


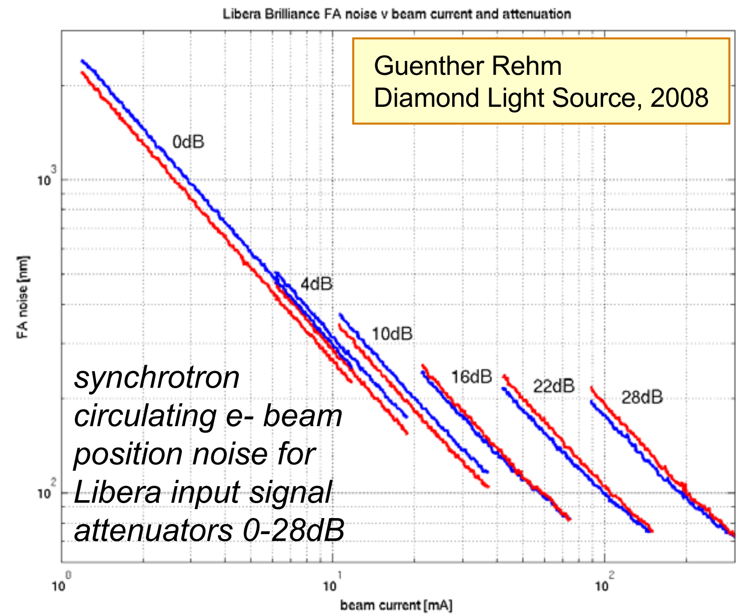
Rok Uršič, I-Tech Dec 2004 for Libera *Electron*

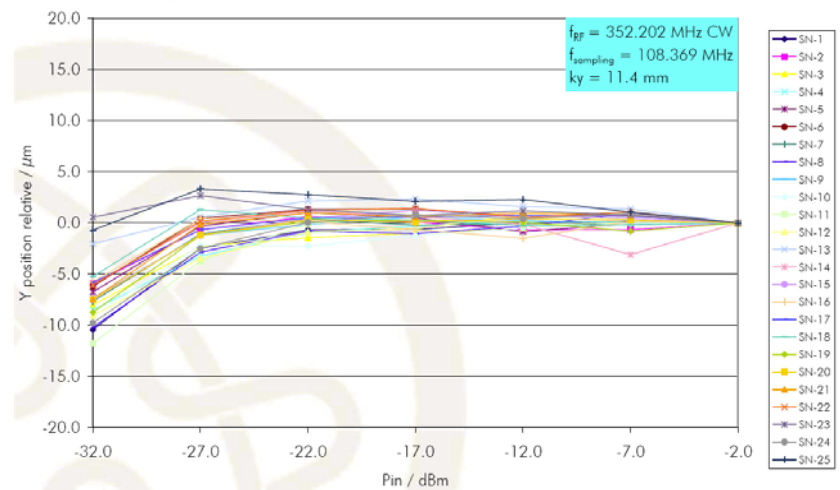




what's inside? performance?

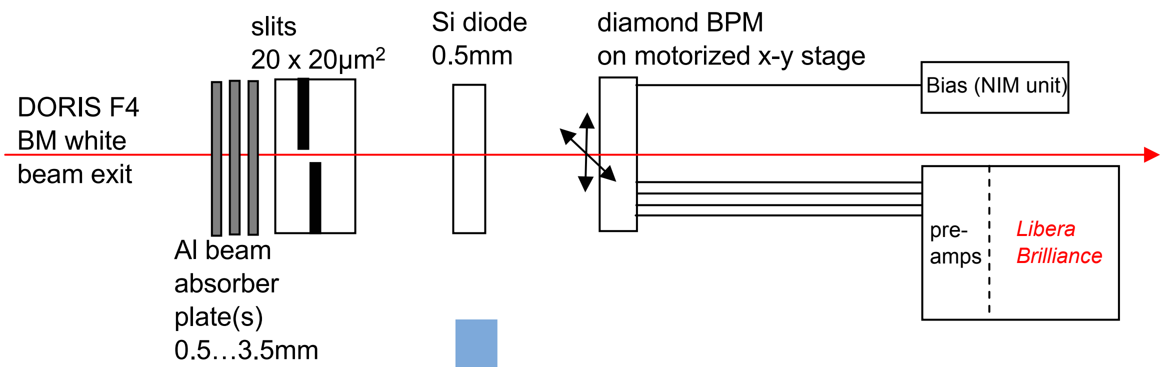


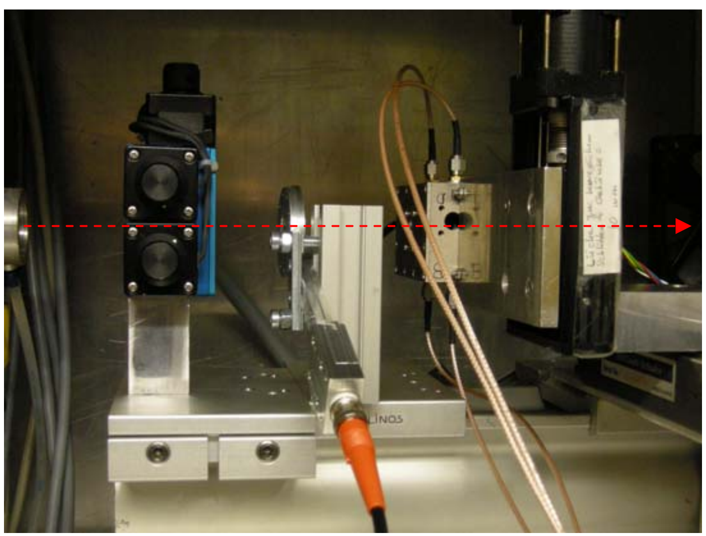


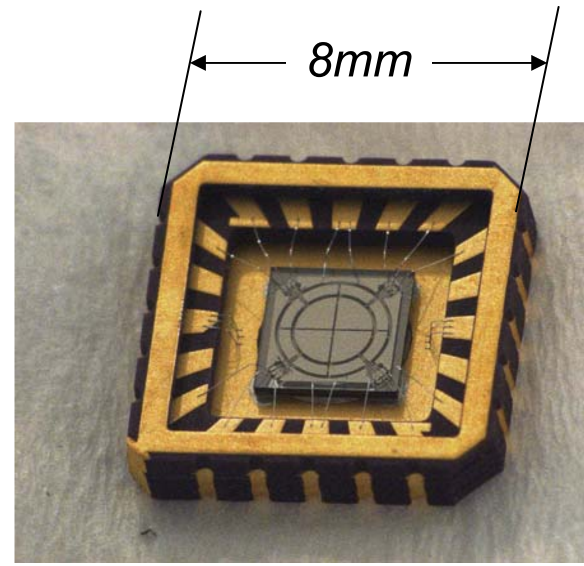


RF readout: Doris F4 tests May 2009

ESRF-Desy ‘DIMOX’ collaboration (readout of diamond BPMs using *Libera* electronics)

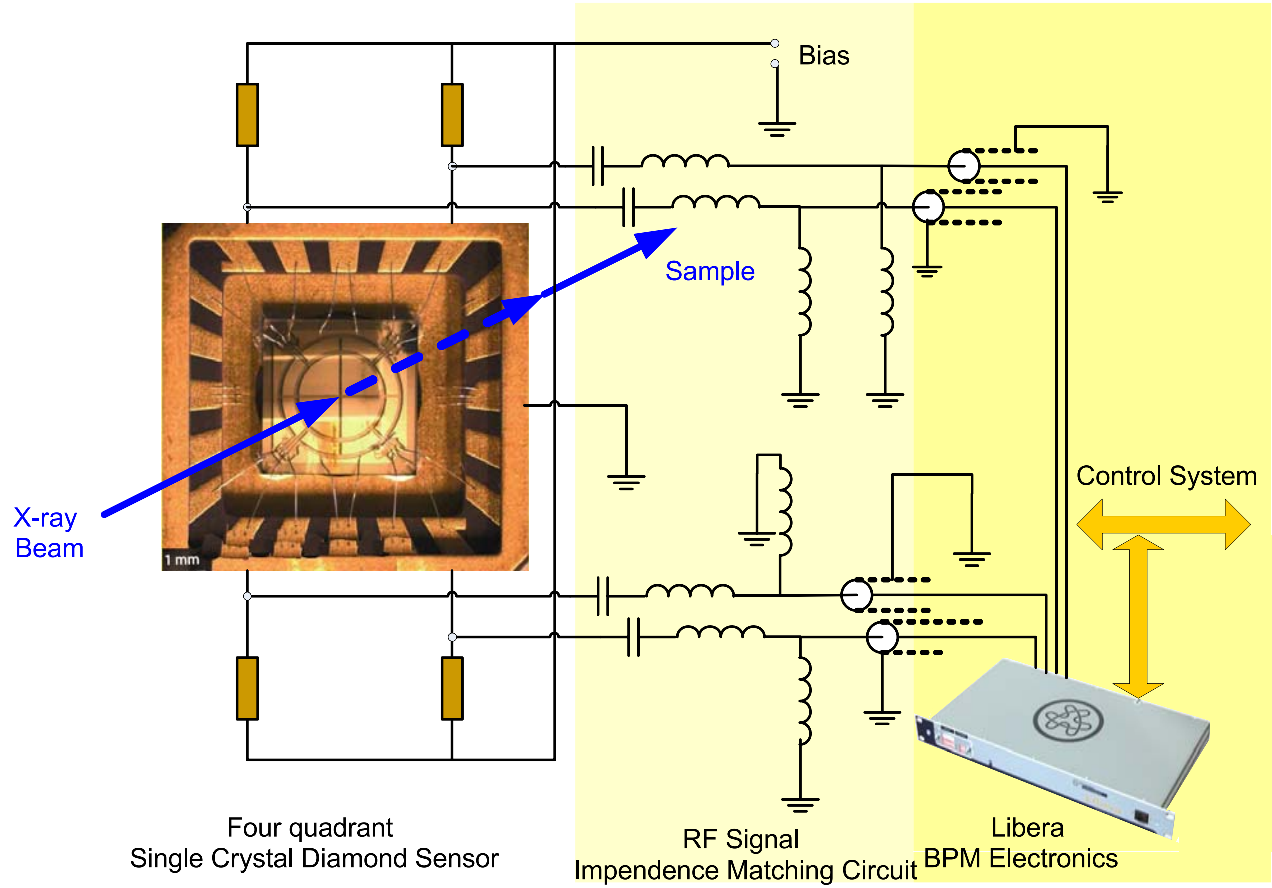






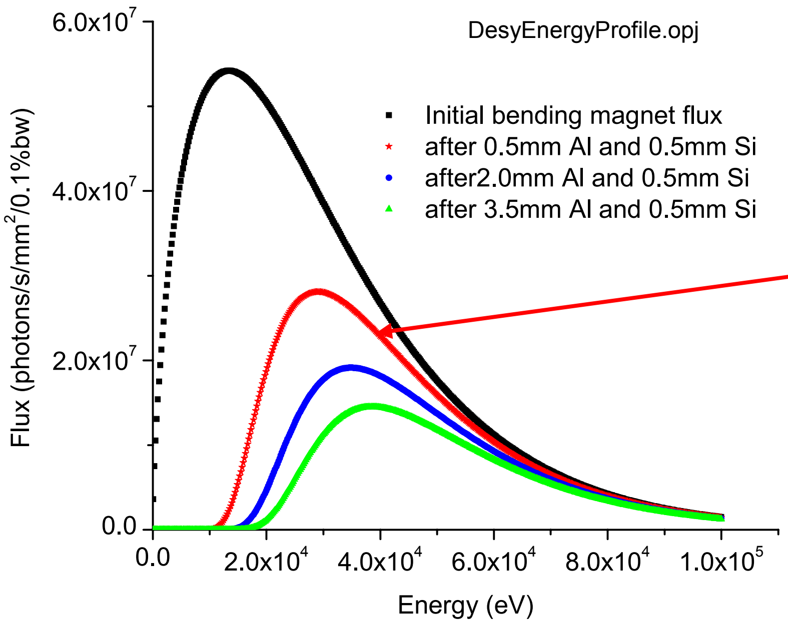
E6 SC diamond in ceramic mount before PCB assembly. 389µm thick, 50µm isolation cross, 3mm hole under the diamond for beam passage.
~100nm TiW contact processing: Harris Kagan, OSU

diamond mounting and RF signal cabling

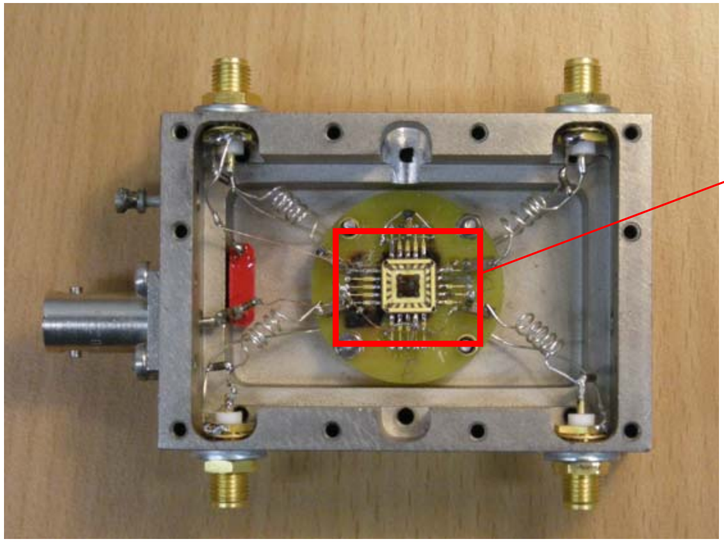


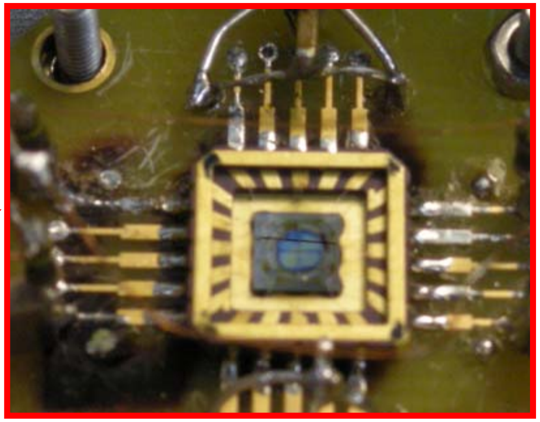
Modified Brilliance: new +12dB
input preamps after crossbar switch

Doris F4 bending magnet X-ray beam



Flux incident on diamond *after 0.5mm Al absorber* ~1.1 x 10^{12} ph/sec
2.9% of incident beam absorbed (photoelectric and Compton)
→ 'dc' equivalent current generated in diamond ~15µA (3pC/ pulse at 5Mpps)





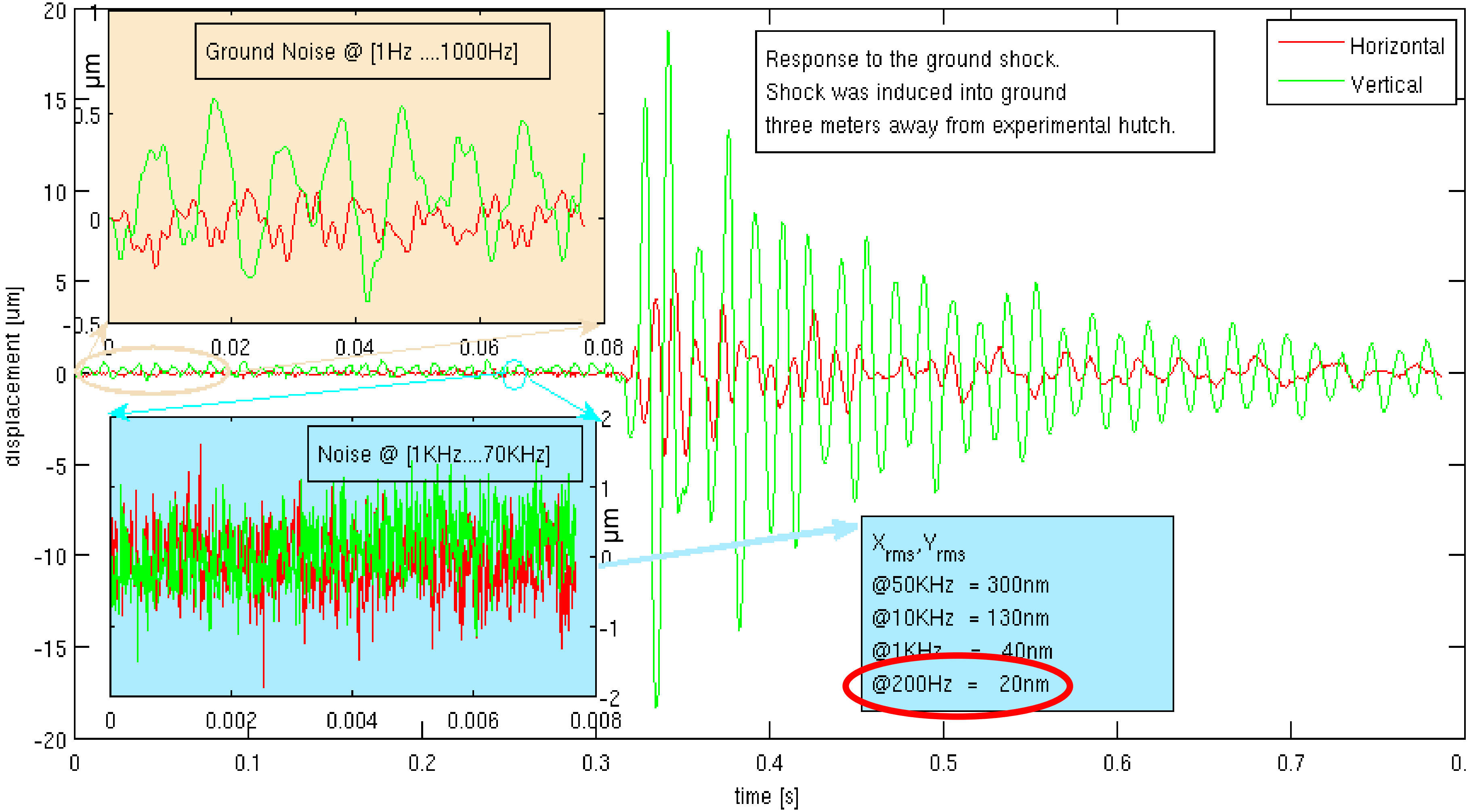
effect of full 'white' beam on PCB and diamond…
Following measurements shown were made after these "accidents"

Three slides of results removed from this presentation (these show data that will be included in a publication in preparation)

Please contact speaker directly for these missing slides
(morse@esrf.fr)

dynamic position response: jump test

Libera ADC buffer data at 130KHz sampling-average



nb. noise includes real beam-sensor movements etc.

High level modeling software for semiconductor devices: 2 & 3D graphics and script input to describe simple to complex devices.

Program solves Poisson and charge continuity (finite element methods) equations.
Simulates drift, diffusion, recombination etc. of charge carriers, and signals induced on electrodes for various external load models

Accurate/well tested for silicon devices: input parameter and model files can easily be configured for other semiconductor materials.

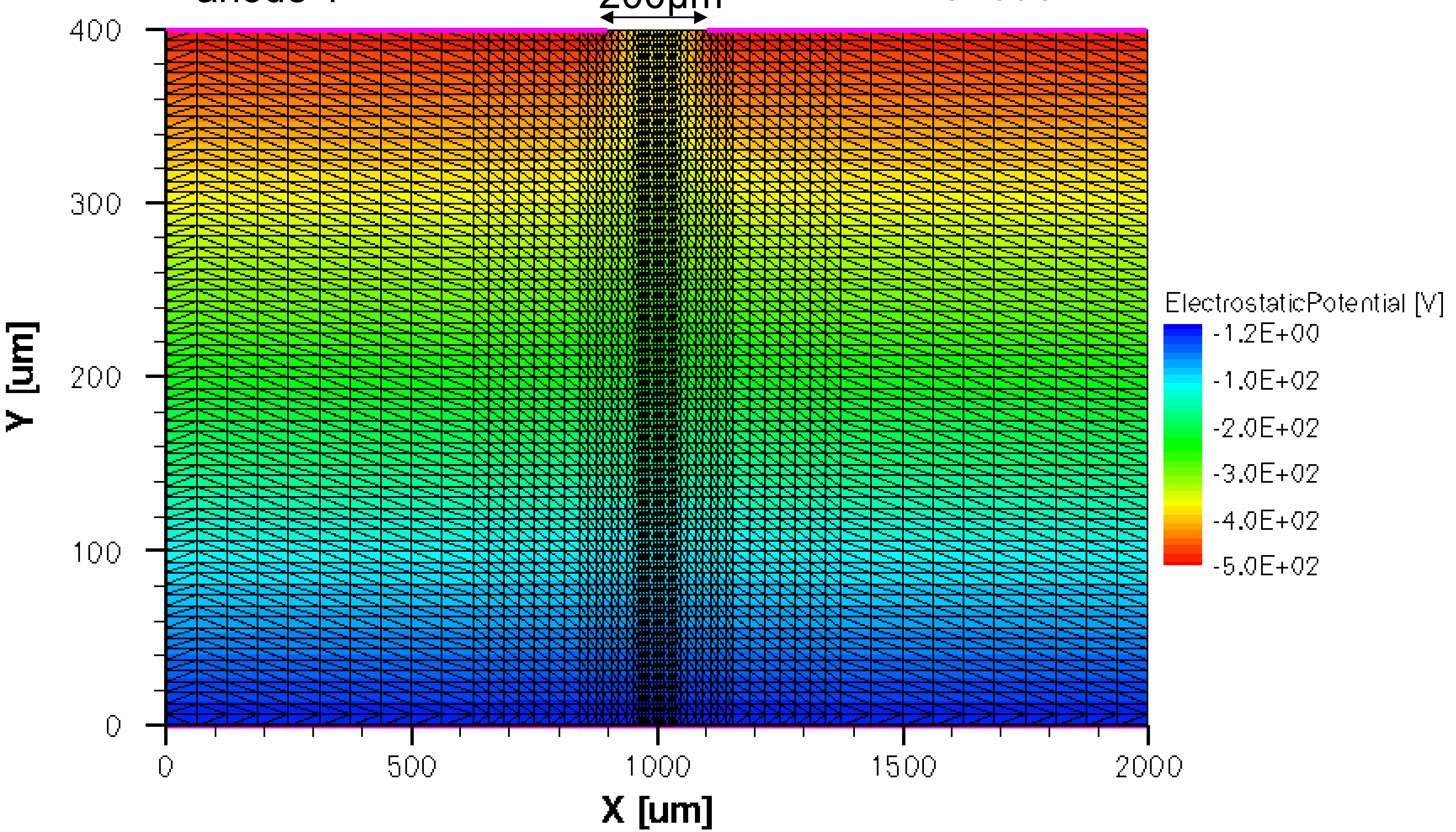
Following slides show FIRST ATTEMPTS at 2D simulations for diamond using
permittivity = 5.7   band gap = 5.47 eV   electron/hole mobility = 2300/1800 (cm^2/ Vs)

carrier velocity saturation model??

anode 1

200μm

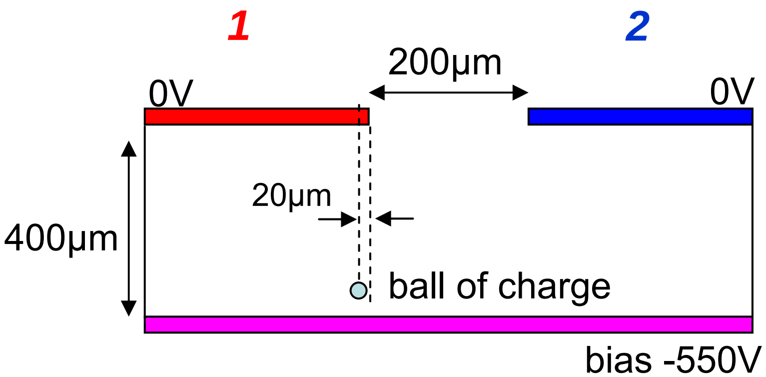
anode 2



cathode

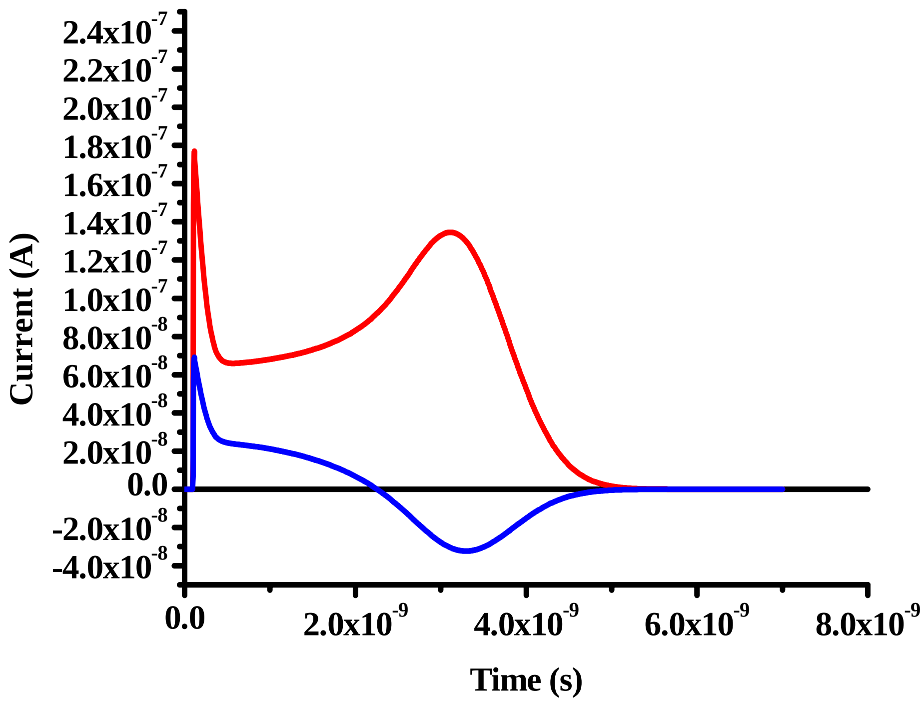
L Gannon, Sentaurus Device Editor

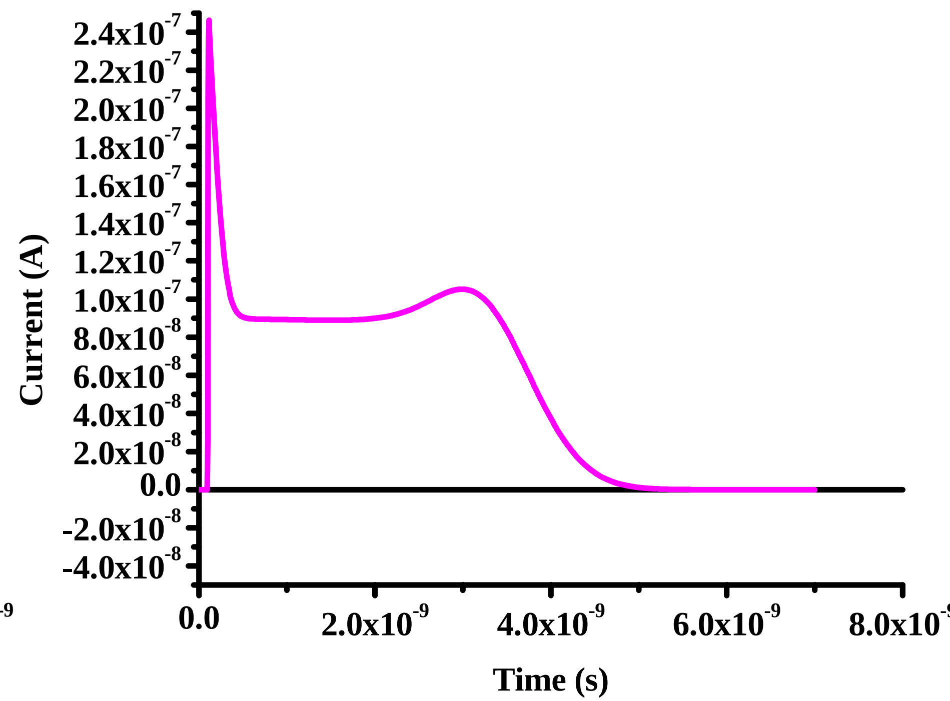
Signal development during charge transit



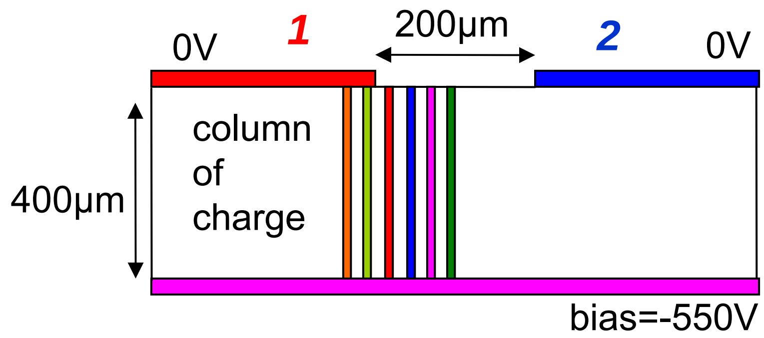
Sentaurus Device Simulator

1. charge created near the cathode
2. holes reach the cathode and are collected, so signal current is ~halved
3. electrons drift and diffuse across a region of homogenous electric field.
4. as electrons approach anode 1, electric field gradient increases so a rise in current is observed on this anode.
5. As electrons are collected at anode 1 the current decreases to zero (tailing caused by transit diffusion)

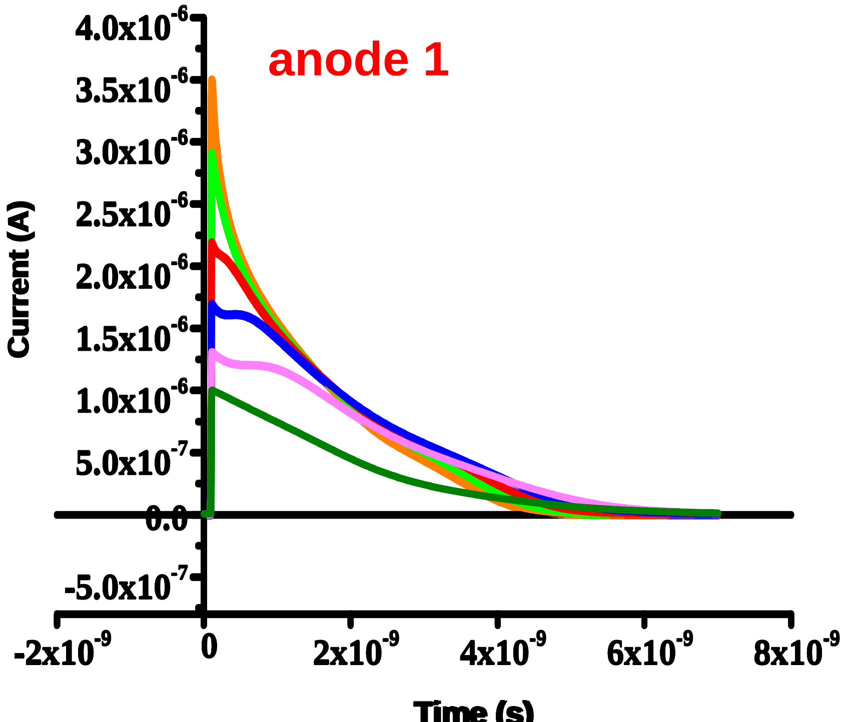


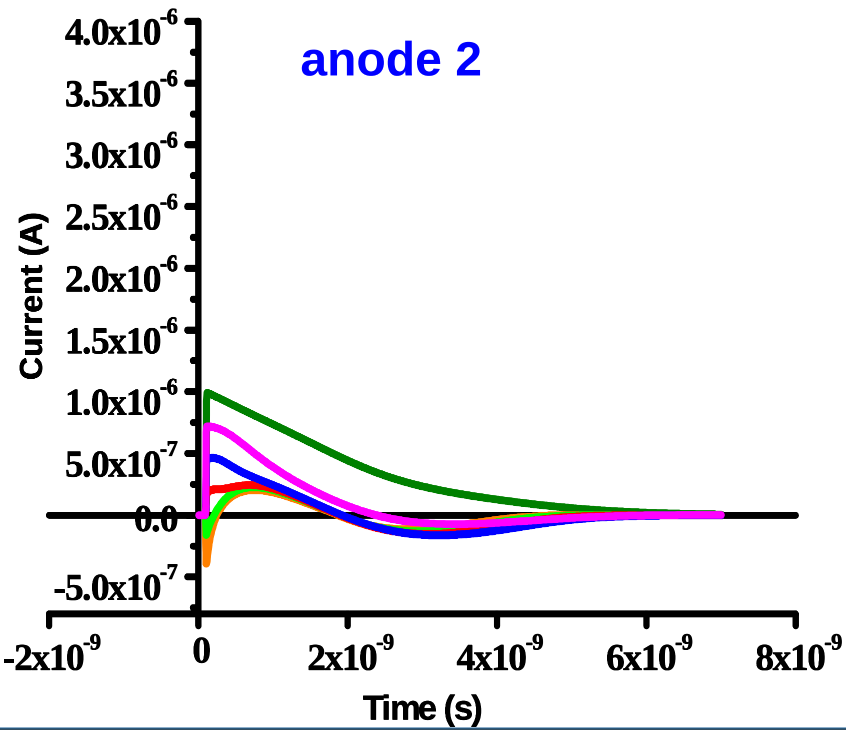


Signal variation with position of incident beam



Sentaurus Device Simulator





‘Proof of principle’ established for position readout using Libera Brilliance system
resolution < 0.1μm demonstrated, but initial DESY tests limited by (white) beam size and beam position noise

Further *quantitative* tests needed to directly compare narrowband RF *vs.* electrometer readout, especially signal/noise performance *vs.* absorbed beam energy
(new test in planning, will use ~10keV monochromatic X-ray beam at ESRF)

Better understanding needed of signal development in multi-electrode device coupled with response of signal processor, e.g. Libera: system ~2MHz passband at 352MHz
(modelling just started with TCAD-Sentaurus)