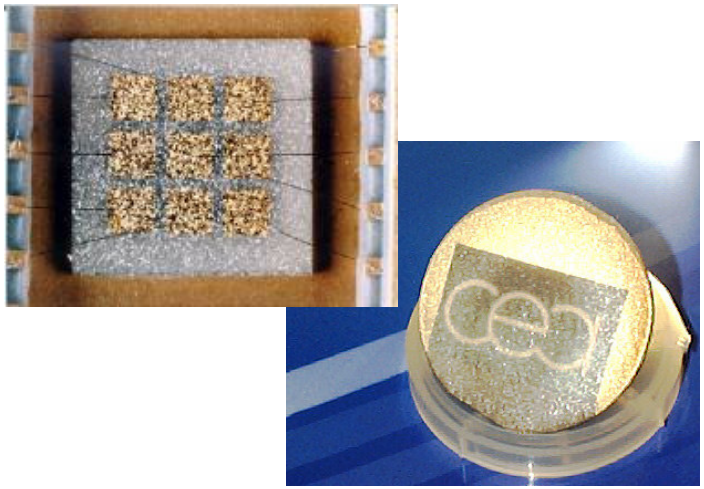
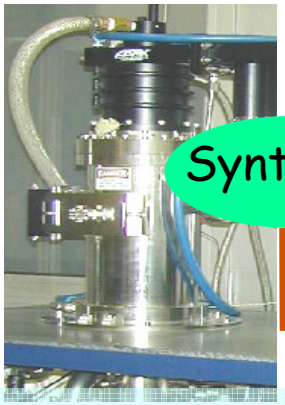
Diamond Detector Applications at CEA-Saclay



Le diamant à Saclay: de la synthèse aux dispositifs

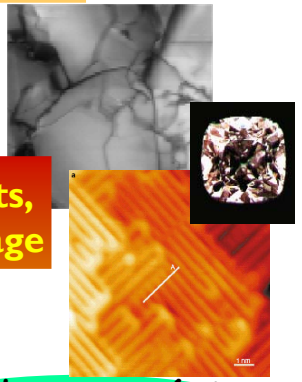


Synthèse

dépôt chimique par plasma

Substrats

Analyse optique, électrique, sous ray[t], traitements plasma, Contacts, litho, défauts



Défauts, monoX, dopage

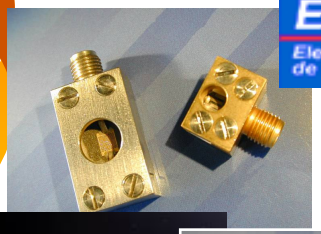
Etudes matériau
bâtis UHV + caract.

PECVD microonde:
Non-dopé : 3 bâtis, Ø5cm
Dopage : 2 bâtis - 2003

Développement de dispositifs pour applications spécifiques

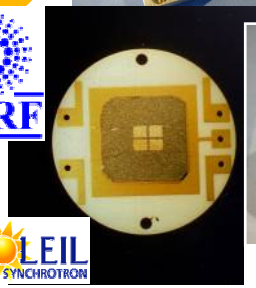
Nouveaux marchés

Capteurs



EDF Electricité de France

ESRF



SOLEIL SYNCHROTRON

COGEMA

industrie
(semiconducteur grand gap)

santé/dosimétrie
(Z=6 : équivalence tissus)

Bio-capteurs
(biocompatibilité)

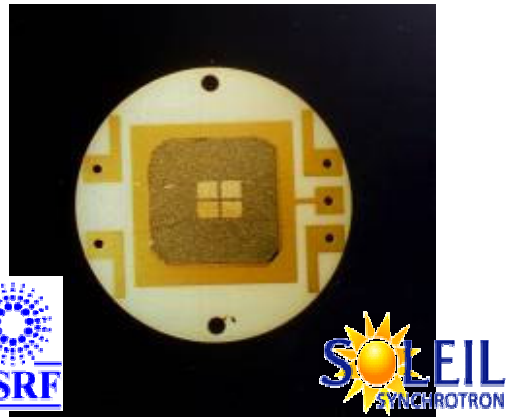
détecteurs de rayonnements
(inertes chimiquement, compatibles milieux hostiles)

Diamond device fabrication at CEA

- Growth (3 reactors)
- Laser cut
- Device processing
- Defect 'passivating'
- Contacts
- Packaging

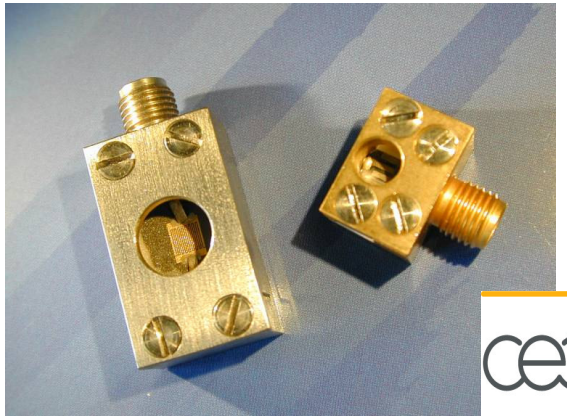
Growth

Films



Beam monitors (ESRF)

Corrosion hard alpha detectors (COGEMA)

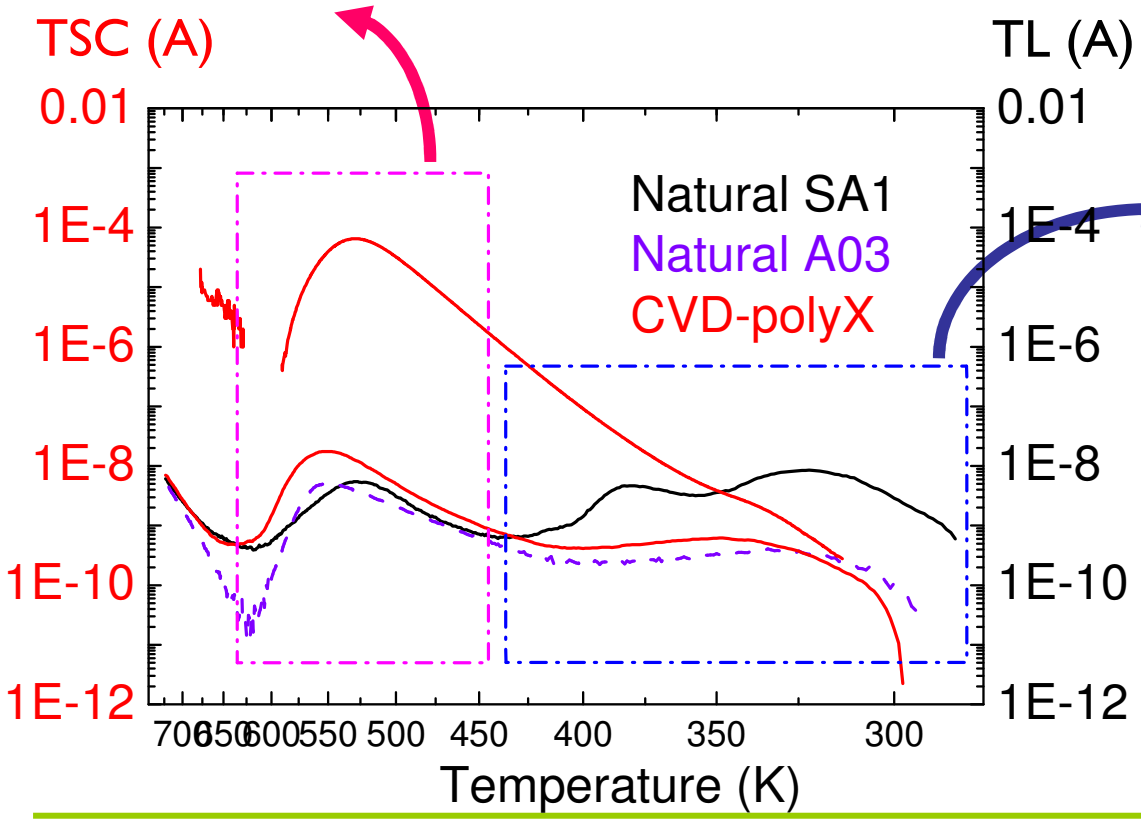


Fast pulse metrology (Defence)

The role of defects

☞ CVD materials, as well as high quality IIa type diamonds inherently exhibit defect levels

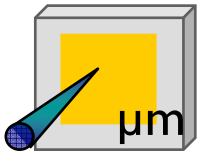
- of interest for TL dosimetry
- stable at RT

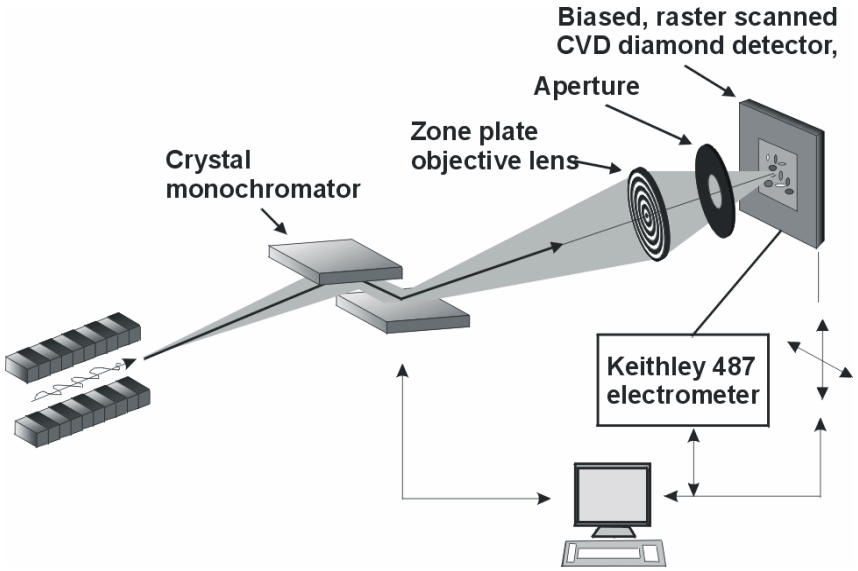


- highly detrimental for IC
- → unstability

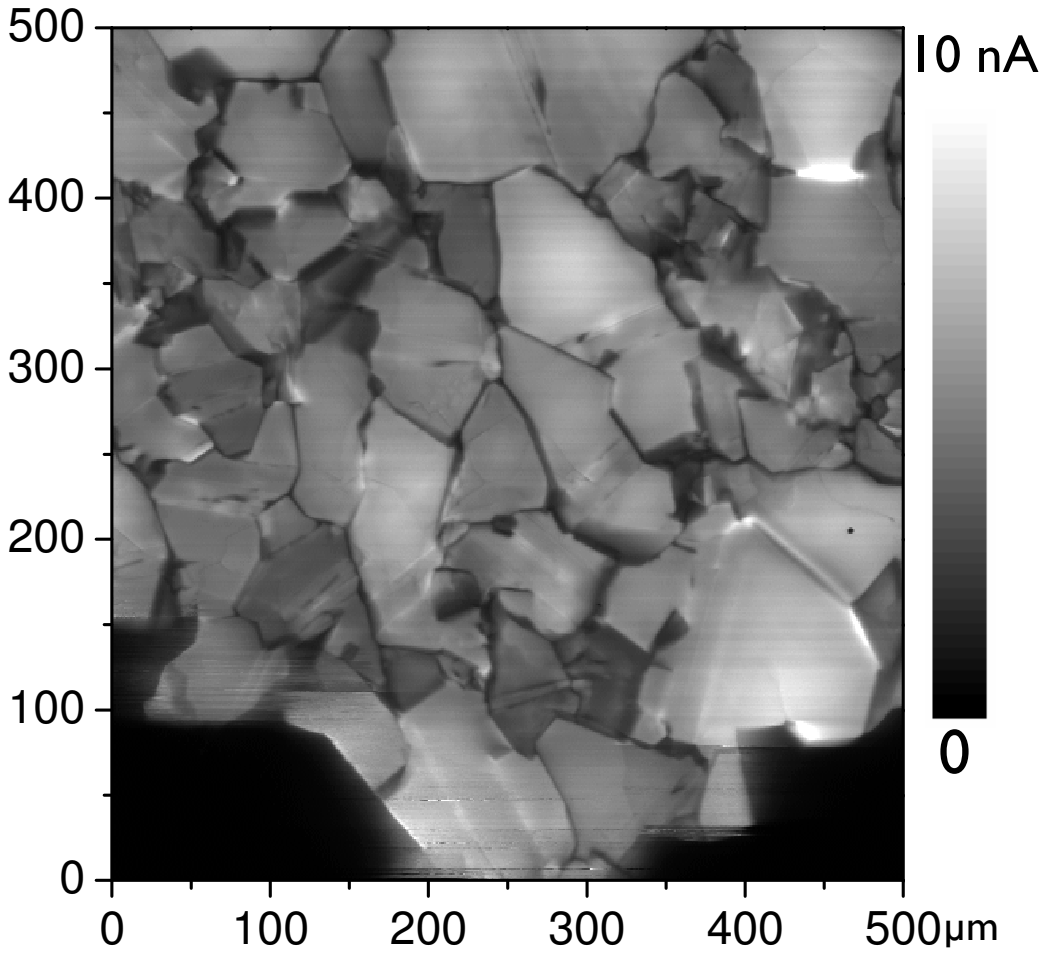
Non-uniformity of the sensitivity

X-ray microbeam :
5 keV (Volume)
att. length : 150 µm (1/e)
≈1.4 10^9 ph/s
beam spot <1 µm
resolution : 1 µm



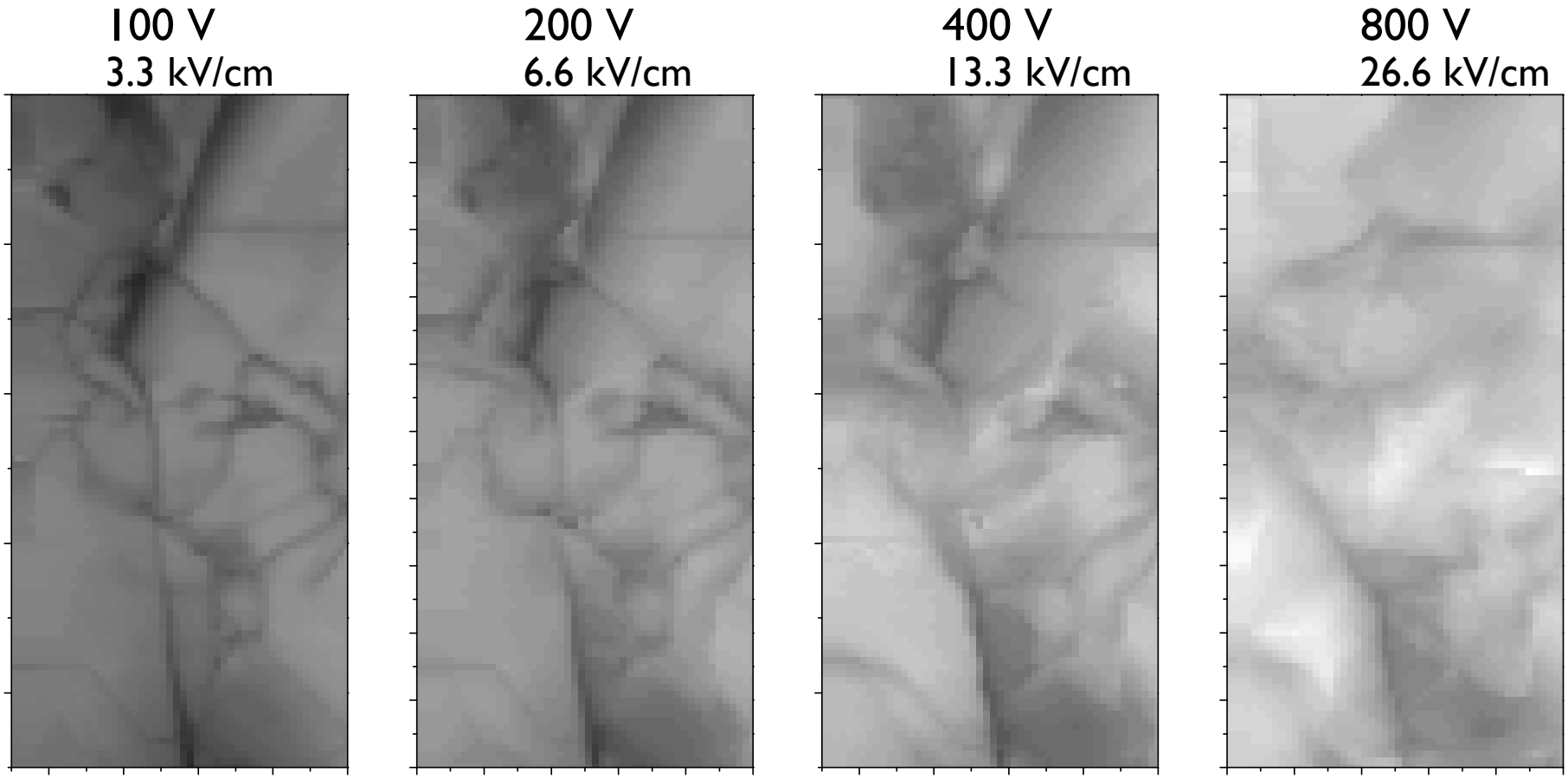


➔ **Comm. Avail. 300µm Det. Grade**



Strong Non-uniformities observed
➔Detrimental for beam metrology

Electric Field Influence

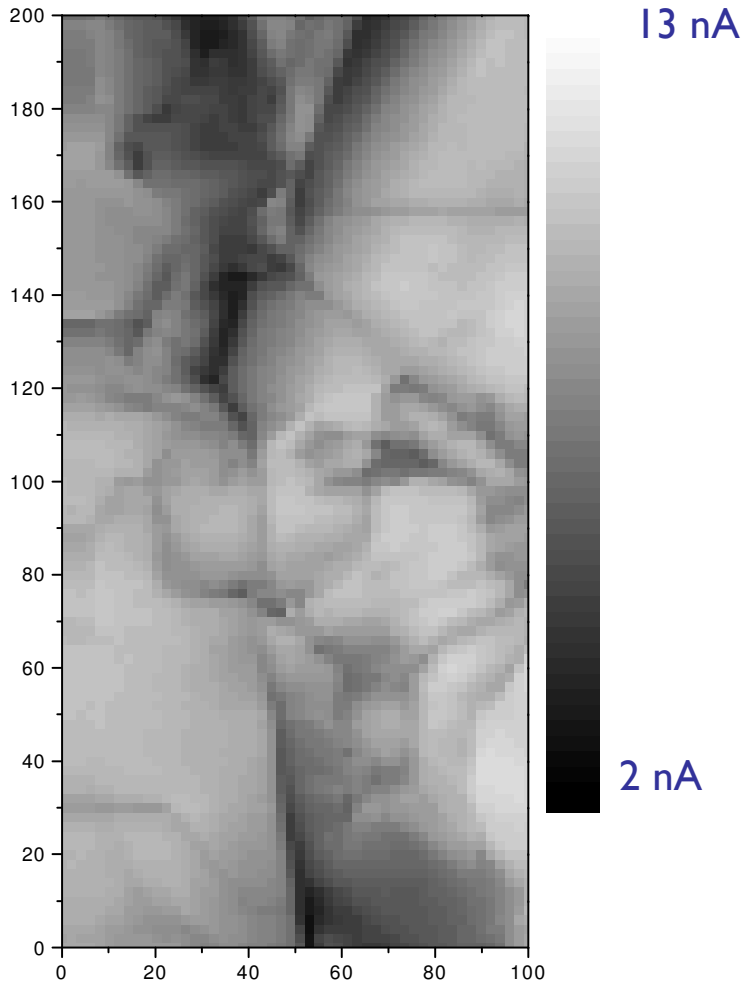


(Identical grey scale : 1 to 28 nA – log)

➔Velocity of saturation can be reached locally (likely from 10 kV/cm)

Evidence of charge build-up

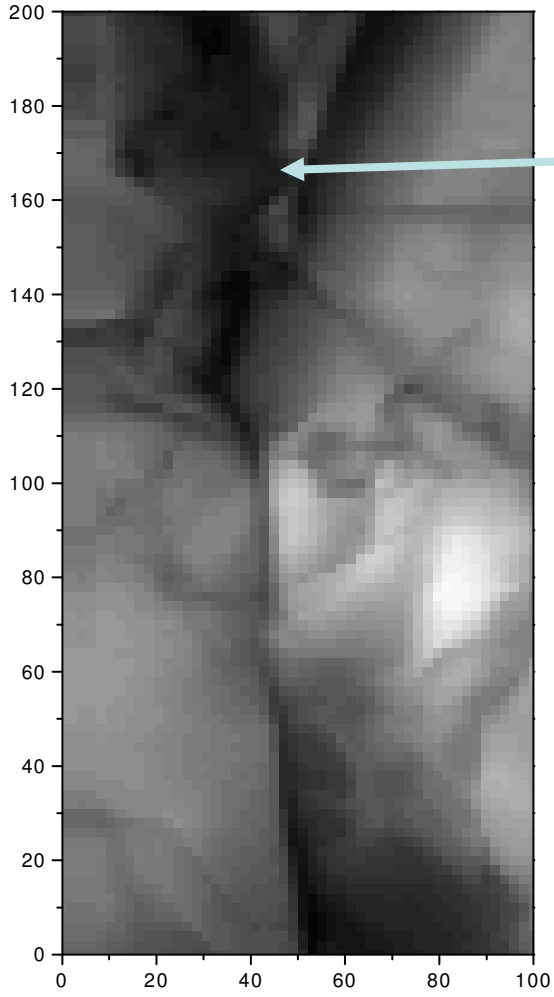
At 200V



13 nA

2 nA

At 200V, after one scan at 800V

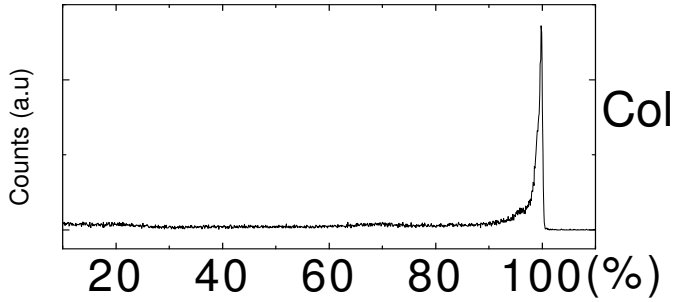


Darker area :
Sensitivity is lower

Defects in natural SC diamonds

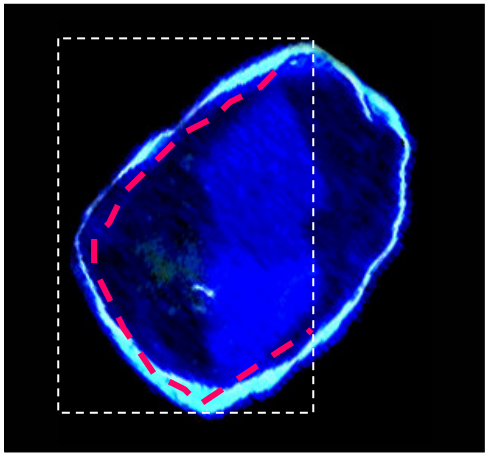
Similar measurement performed on high quality detector grade IIa type

under ^{241}Am alpha particles :
100% cool. efficiency,
ideal response

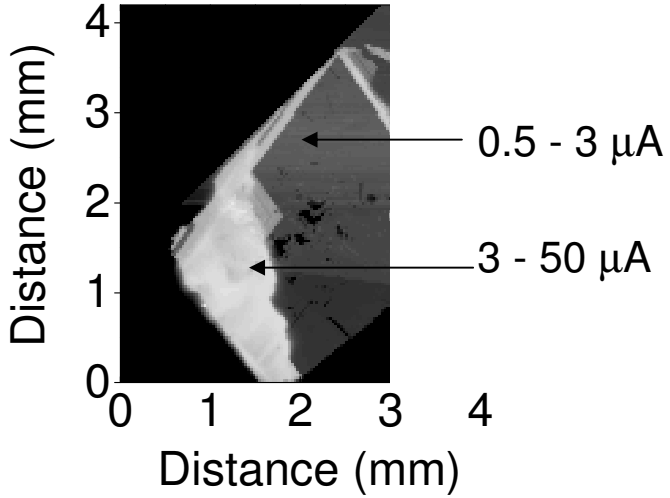


Collab. Triniti, Moscow

Luminescence response



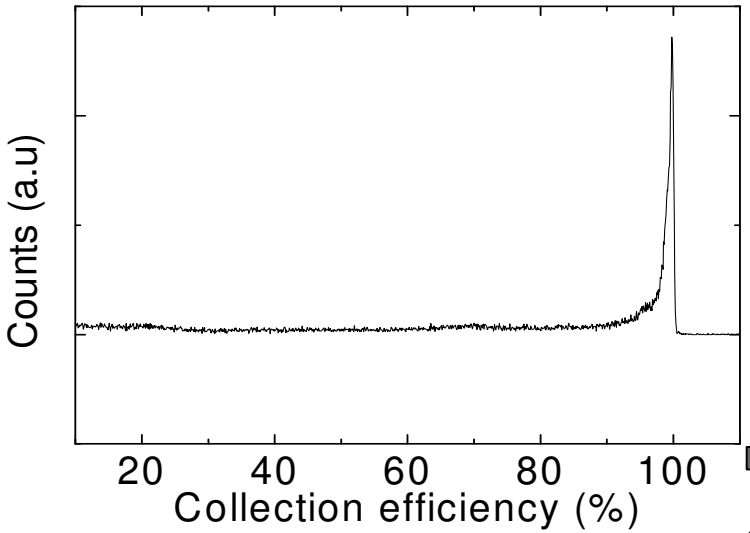
X-ray sensitivity : micro beam analysis

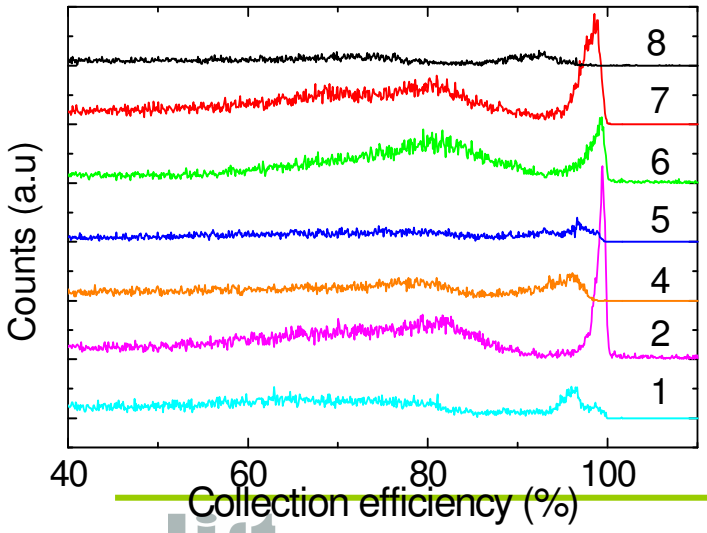


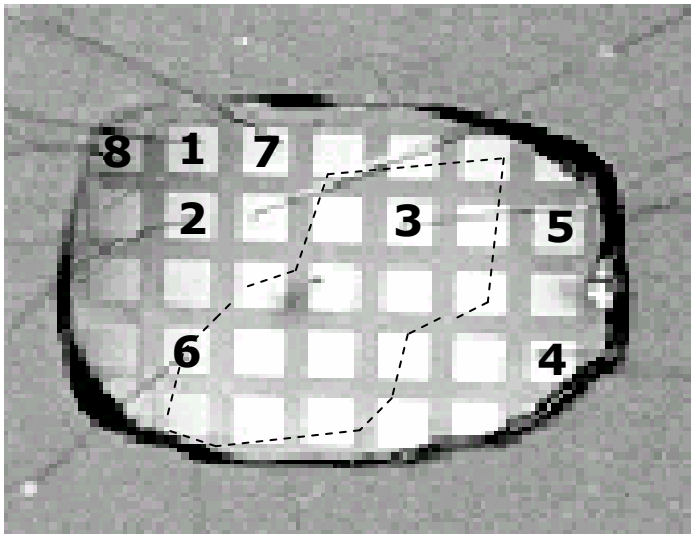
Defects here mostly associated with N

High quality natural diamond detectors

Alpha detection spectra







BUT

- global detection :
collection efficiency reaches 100 %

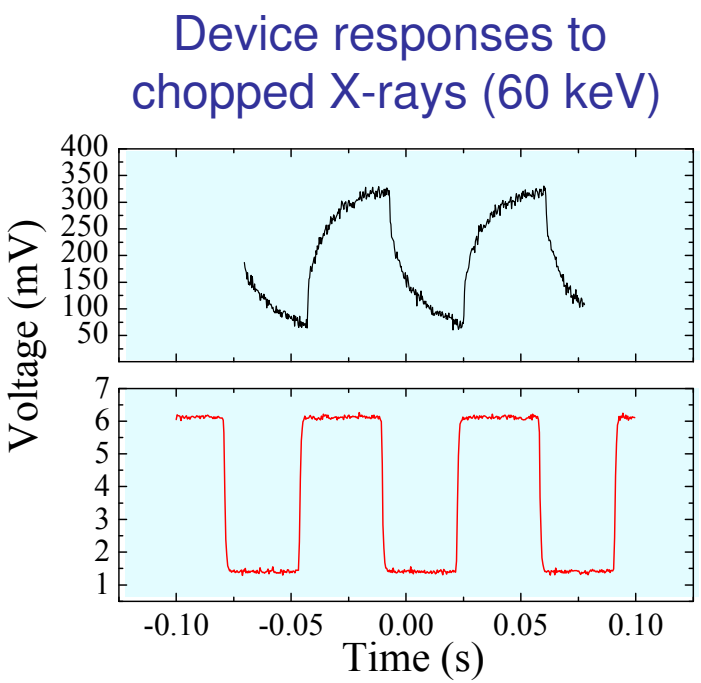
- localised variation of the detection properties : blind zones vs high collection efficiency zones

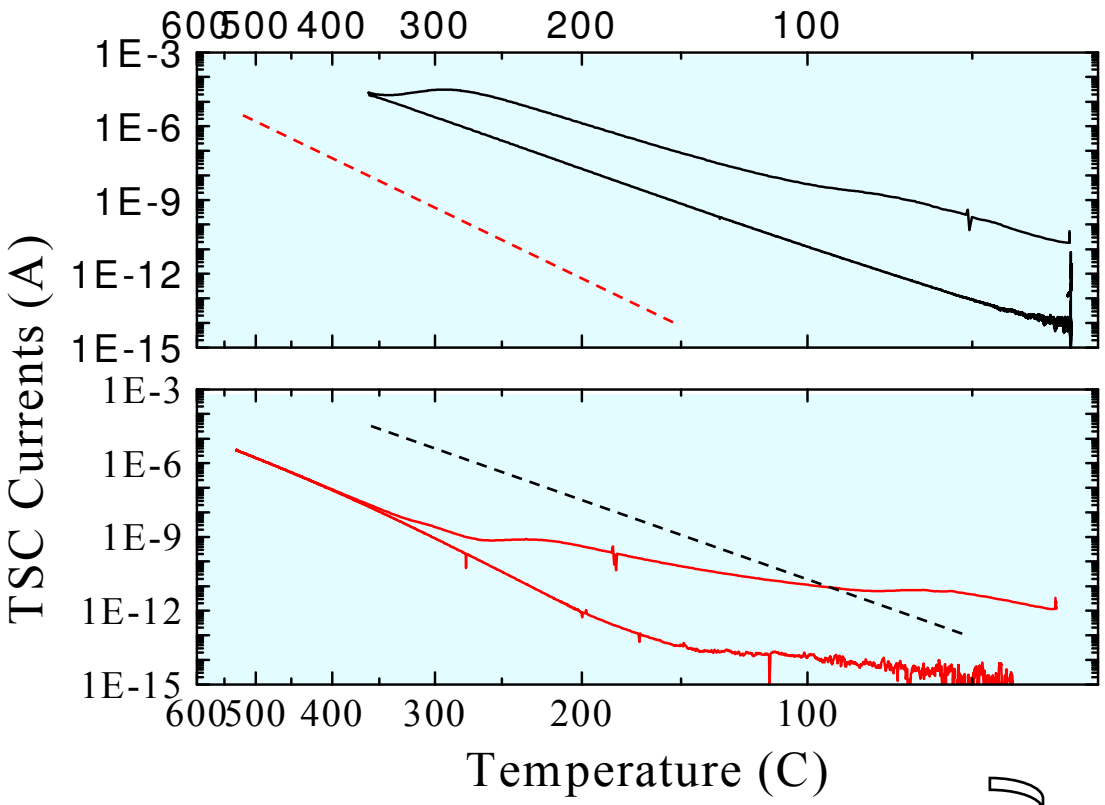
Material optimisation from growth

Impurities : effect on the response time

TSC Signatures (10^4V/cm)

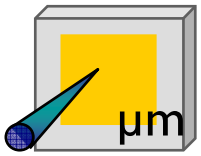
Device responses to chopped X-rays (60 keV)



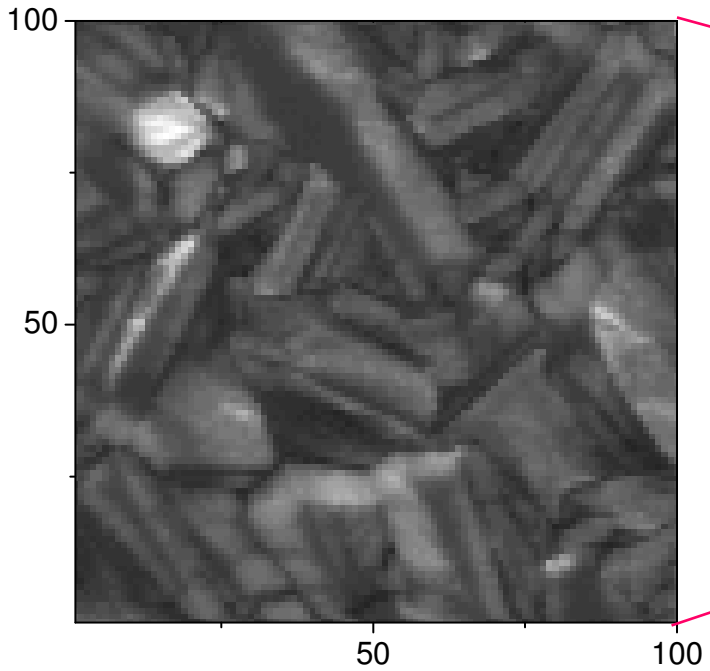


Observed non-uniformity of the sensitivity

X-ray microbeam :
6 keV (Volume)
att. length : 150 µm (1/e)
≈5 10^8 ph/s
beam spot <1 µm
resolution : 1 µm



➔ **150 µm thick + smaller grains (CEA)**



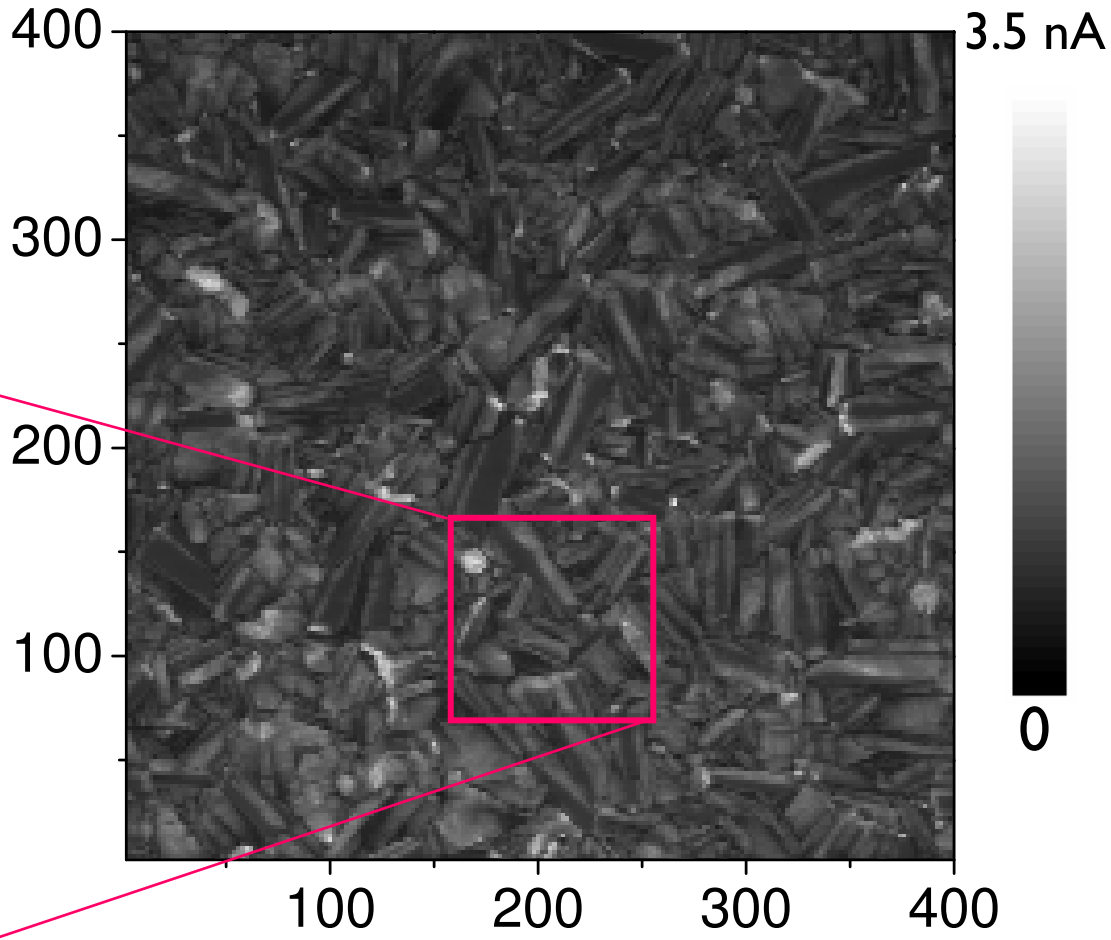
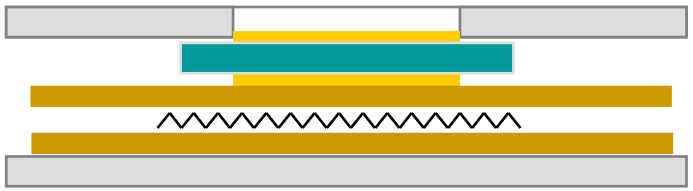
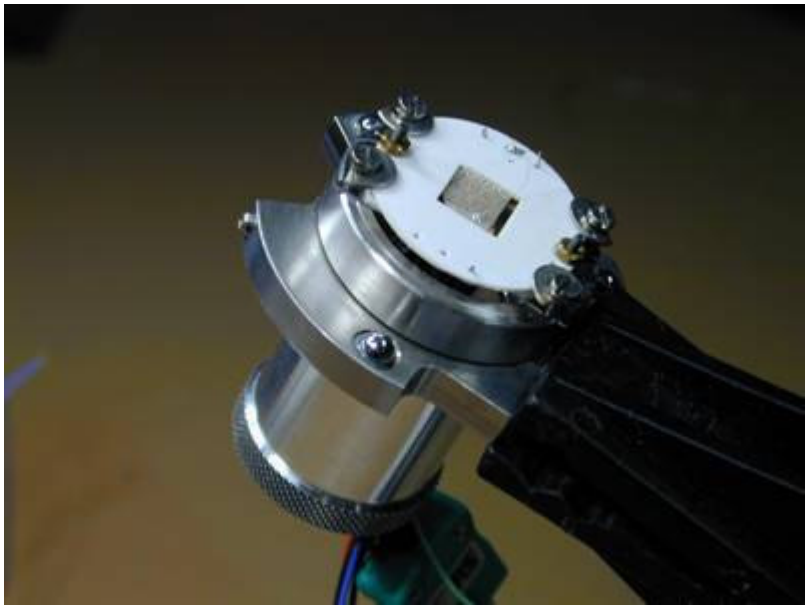


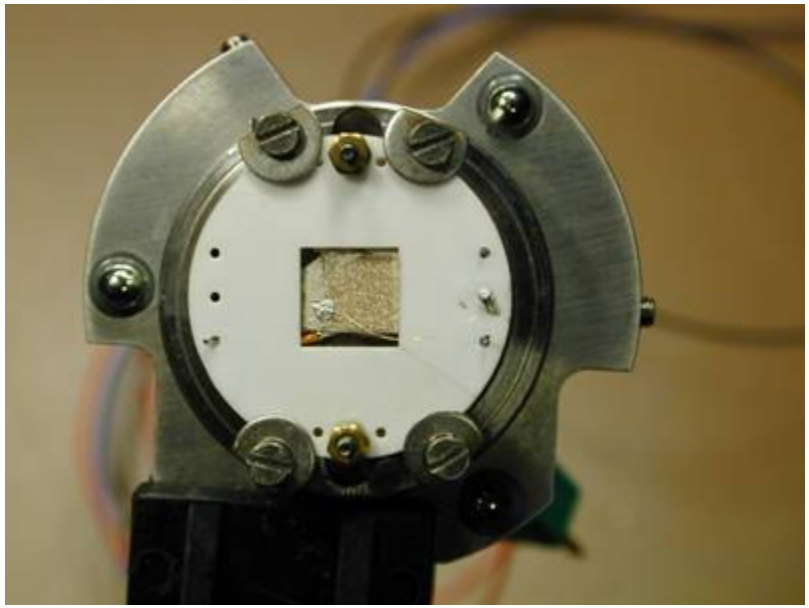
Image may appear more uniform
➔But what about charging-up effects ?

Temperature effects on the sensitivity maps

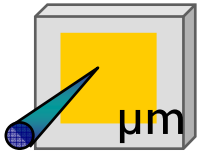
Sample mount equipped with resistive heater



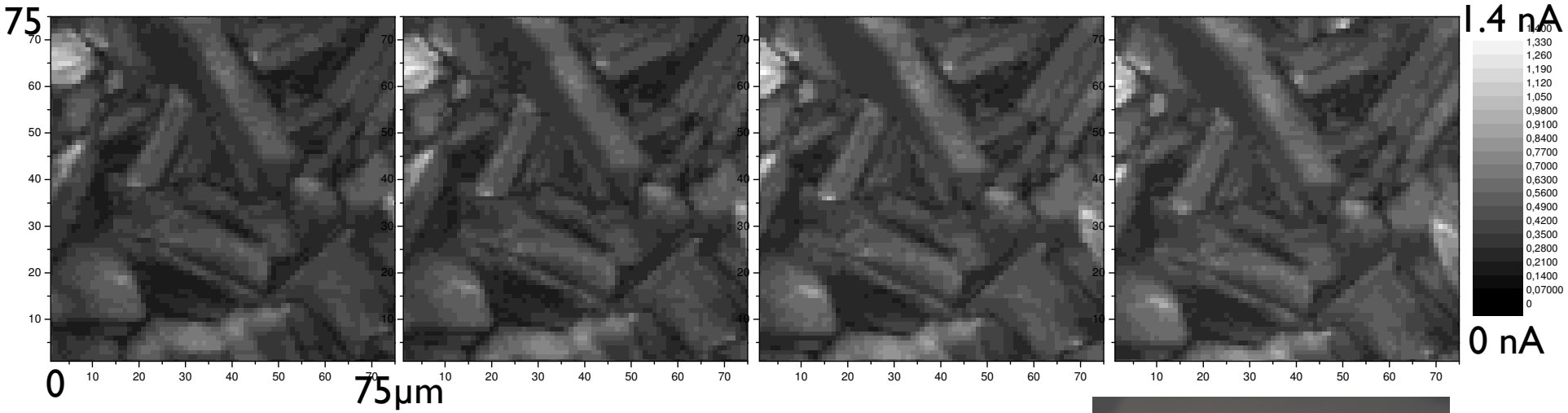




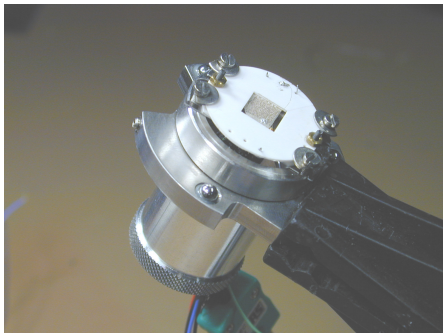
Effect of the temperature



RT 50°C 80°C 100°C



sample on heating stage



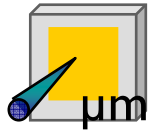
Bias is 0.4 V/µm

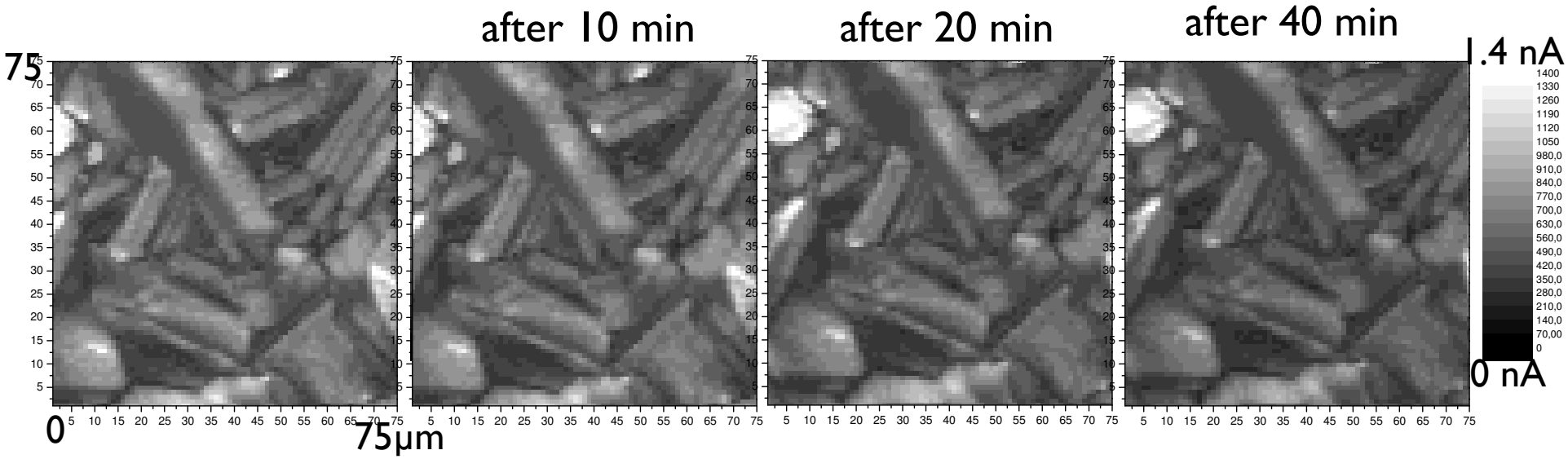
5 10^8 photons/s, @ 6keV

➔ Hardly any influence of the temperature is observed

Effect of the thermal detrapping

After each scan, the sample is kept under heat before mearsurement

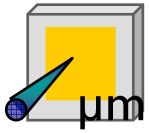




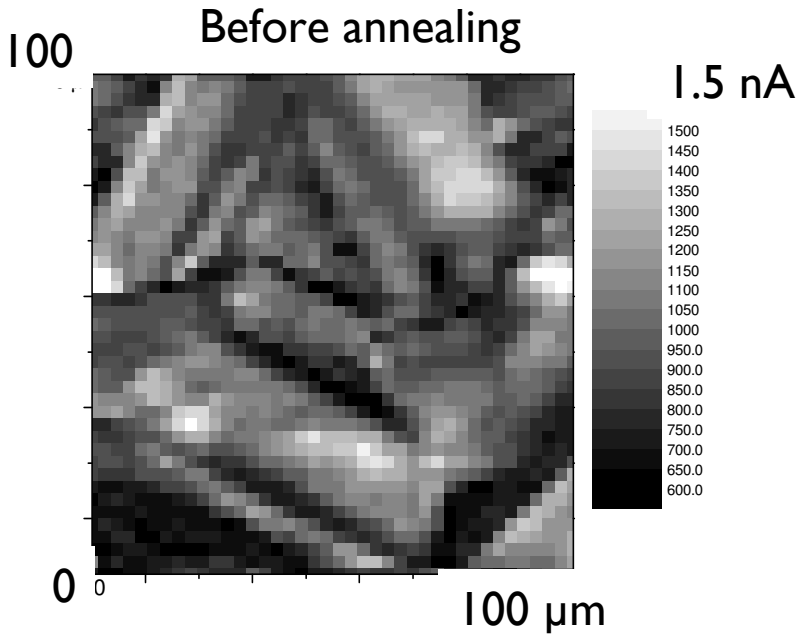
Temperature is kept at 100°C
Bias is 0.4 V/µm
5 10^8 photons/s, @ 6keV

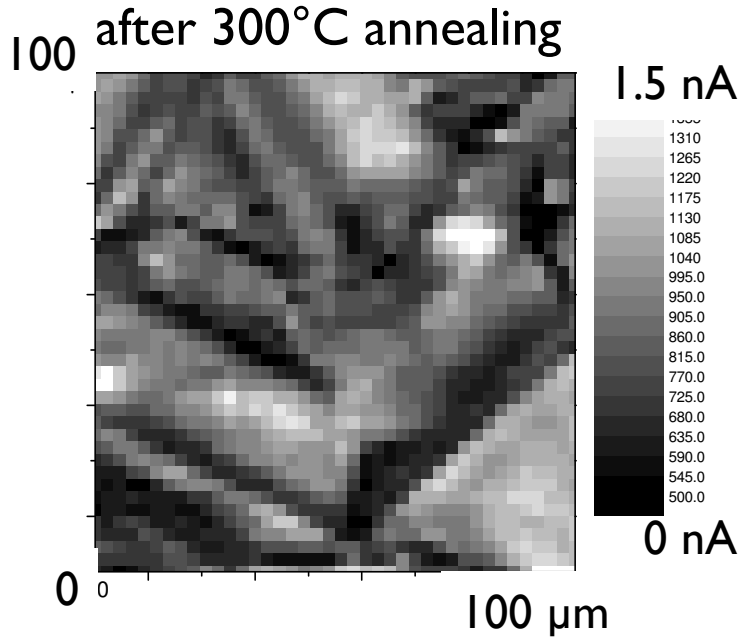
➔ Hardly any effect observed
➔ Thermal detrapping not significant ? Or immediate « re-pumping ? »

Effect of high temperature annealings (300°C)



Bias is 1 V/µm
5 10^8 photons/s, @ 6keV

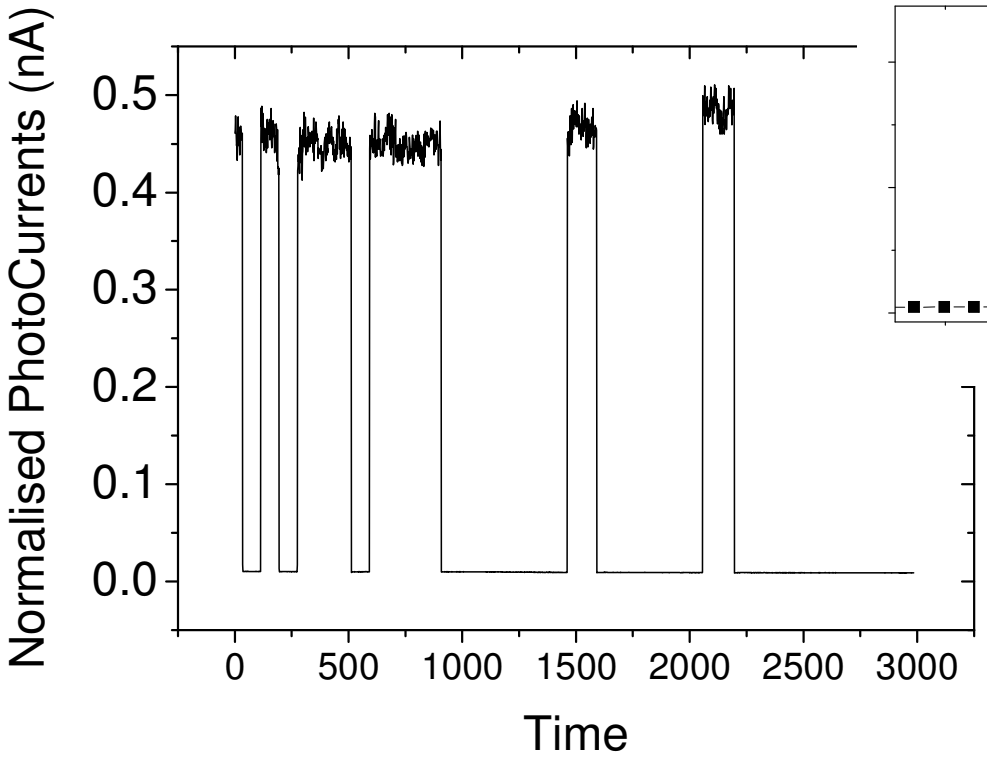


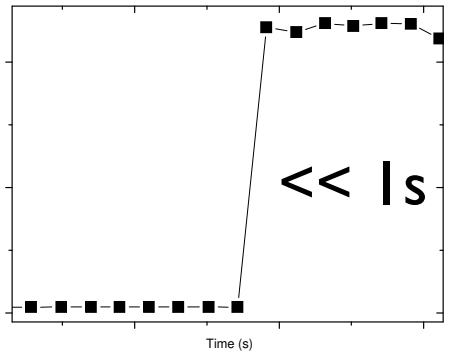


Hardly any effect of the temperature is visible :
In fact, dose calculations ⇒ typ. 10^5 Gy/s at the focal point
➔Pumping is instantaneous during measurement…
whatever the temperature…
➔ Trapping / Detrapping : not a real problem for synchrotron applications ?

Dynamics of the photoresponse

Back to RT,
The response is probed dynamically (Beam On/Off) under µ-beam





Hardly no pumping nor trapping/ detrapping effects observed

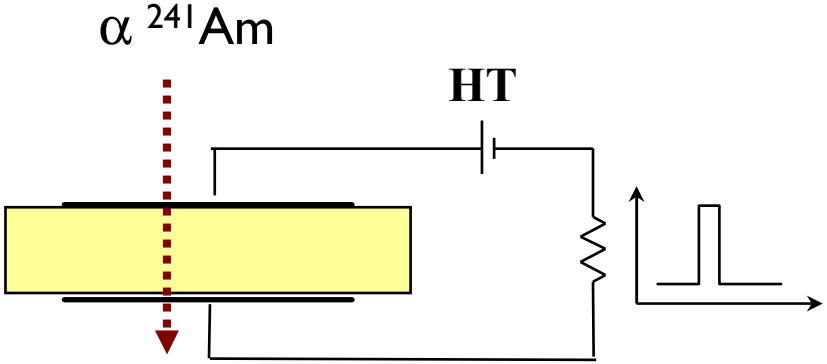
Specific detectors for very hostile environments

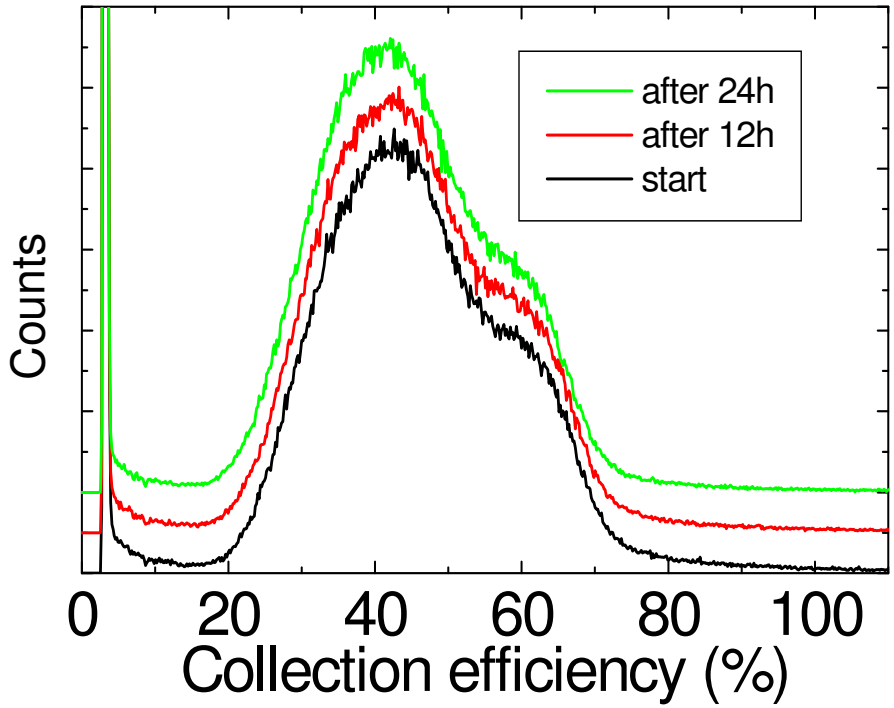
- *In-core nuclear reactors (EDF) :*
  α, n, and intense γ fluxes monitoring
- *Nuclear waste processing (COGEMA):*
  corrosion hard α counters
- *Synchrotrons (ESRF):*
  High transparency to low energy X rays
  Heat and flux resilient
- *Medical dosimetry :*
  tissue equivalence
- *Fast pulse metrology* (defence)
  lasers (UV, VUV), synchrotrons, X-ray flash pulses

Alpha particle detection

Device optimisation :

- stable α detection
  (no polarisation)
- thin (20 to 30 µm) is best
- pumped (typ. 10Gy)





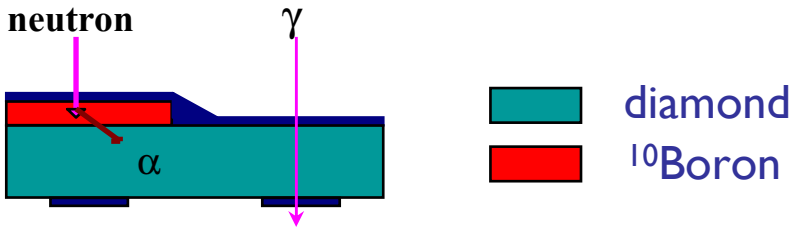
Neutron Detection (EDF) (^{10}B)

Aiming at probing neutron fluences in core of nuclear reactors :

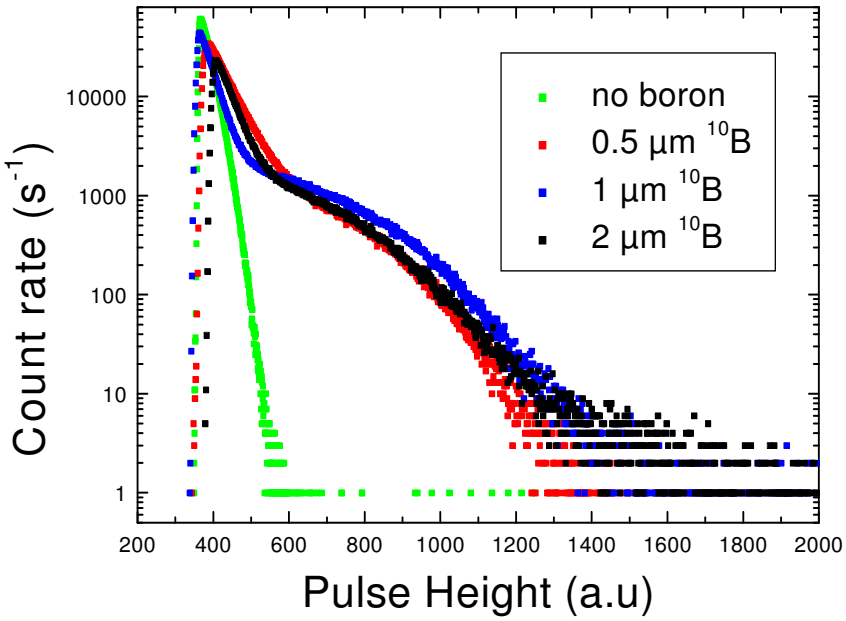
Pros : naturally exhibiting high neutron to gamma selectivity + radiation hard

Neutrons are probed via α detection

e.g. : $n + {}^{10}B \rightarrow {}^{7}Li^{*}$ (0.84 MeV) + ^{4}He (1.47 MeV)



The neutron flux appears :
- as a 'continuum'
  (angular distribution of the energy)
- the integral of the area above the no-boron
  gives the neutron counts
  (with high neutron to γ selectivity)



Neutron Detection (EDF) (^{10}B)

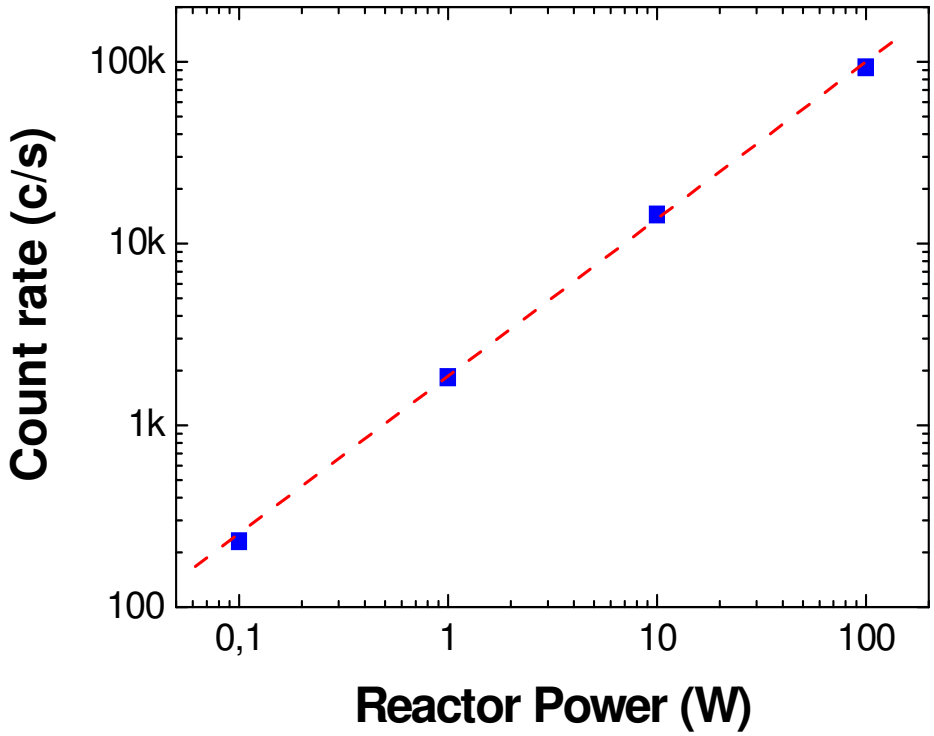
Mapping the neutron flux profile (Ulysse facility -exp. nuclear reactor, Saclay)

- Here device in-core (few 10 cm) :

- Linearity with the flux

- The overall efficiency is low
(typ. 3% due to ^{10}B conversion)

- Higher efficiencies have been
obtained using ^{235}U converter
but... Uranium
... turns into Plutonium...

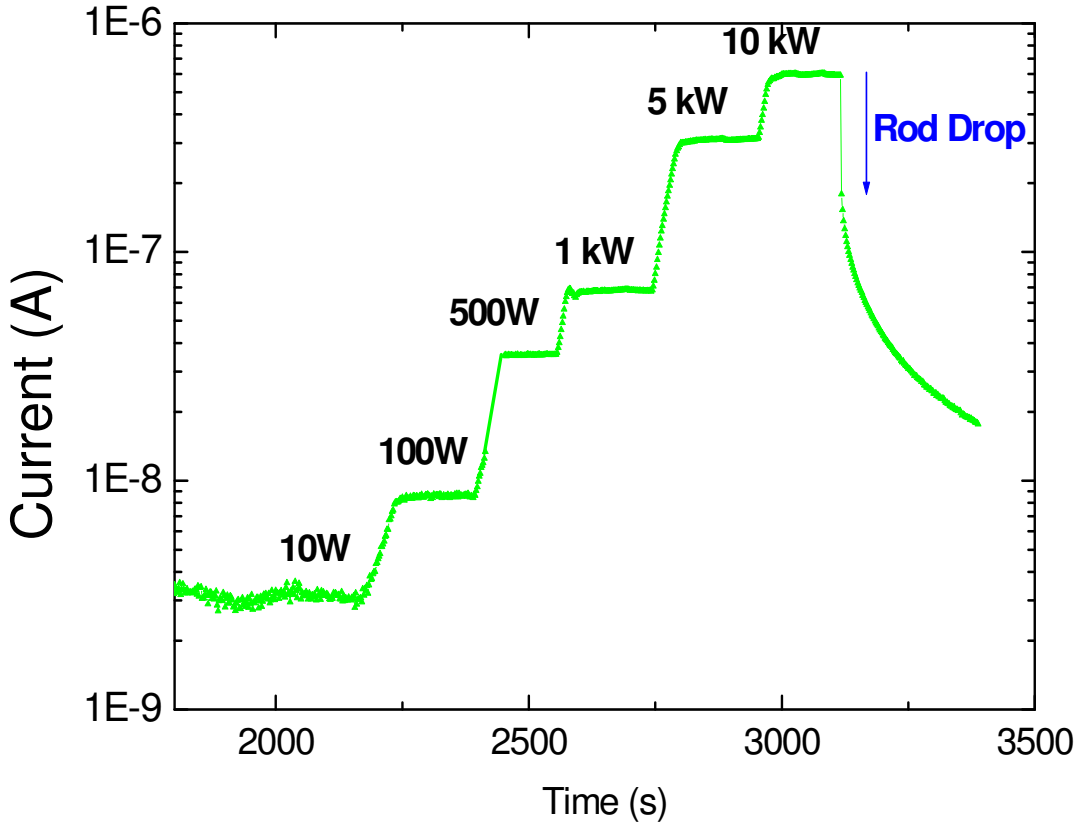


Neutron Detection (EDF) (amps)

At higher neutron energies, the fluence can be measured from the induced current caused by the carbon recoil

No convertion layer needed

- Each ^{12}C atoms 'receives' $1/12^{th}$ of the neutron energy
- Only possible at high flux and neutron energies (fission neutrons)

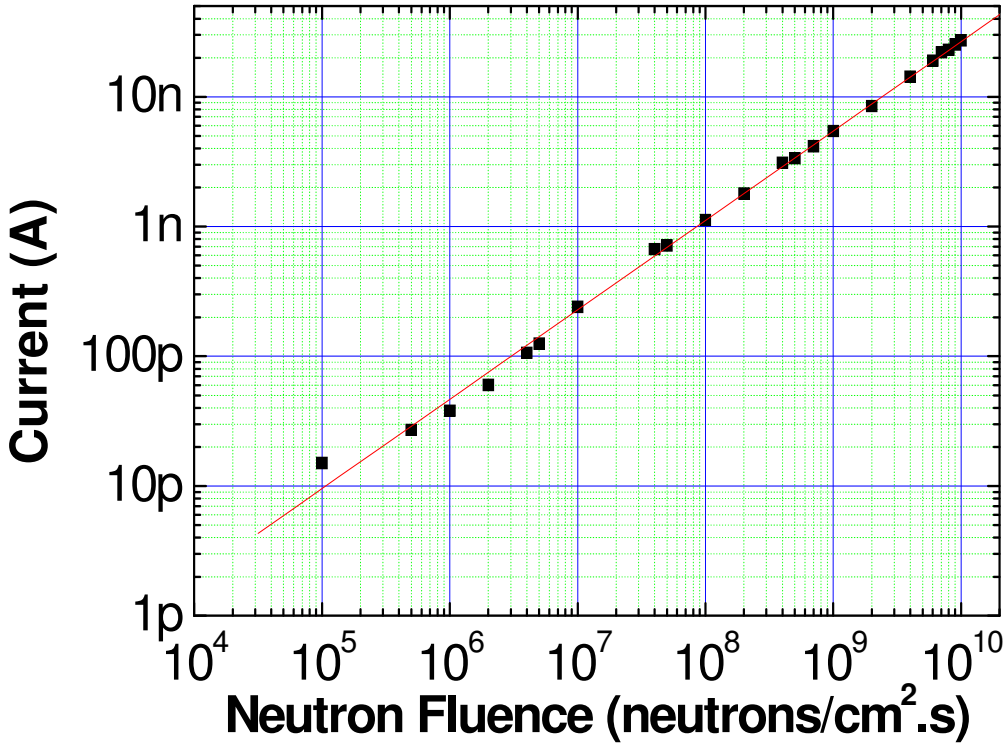


Neutron Detection (EDF) (amps)

At higher neutron energies, the fluence can be measured from the induced current caused by the carbon recoil

No convertion layer needed

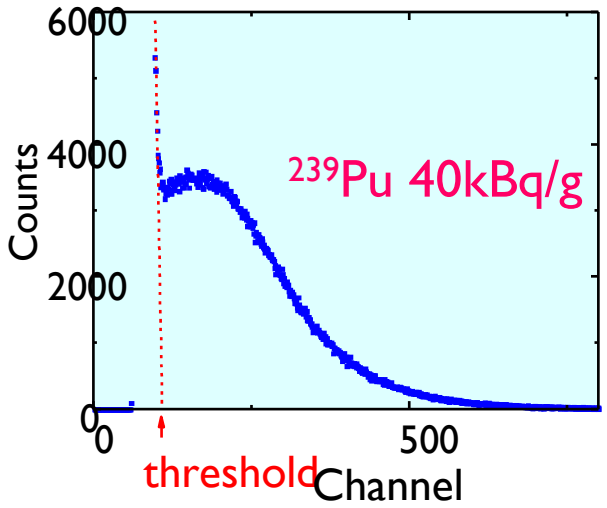
- Each ^{12}C atoms 'receives' 1/12th of the neutron energy
- Only possible at high flux and neutron energies (fission neutrons)



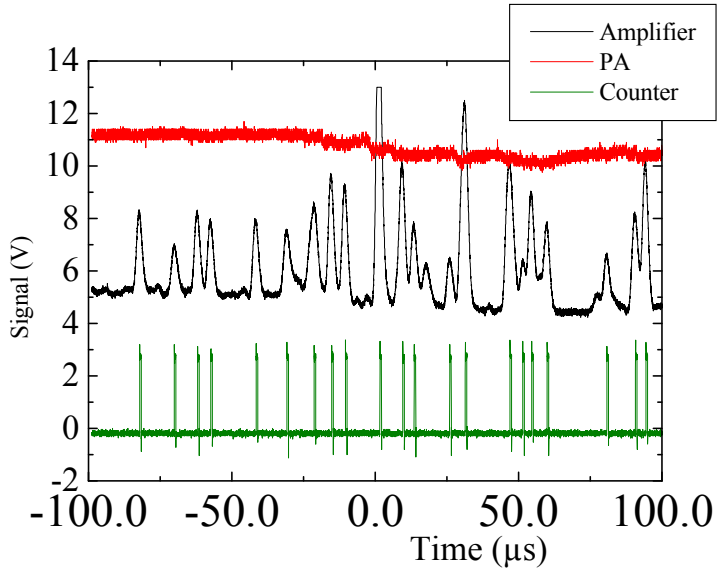
Nuclear Detection Applications : Nuclear wastes

α detection in corrosive liquid sources
Nuclear reprocessing plants (France + Japan)
Devices used in Rokkasho-Mura plant

No alternative from CVD :
Requires large area and thin material



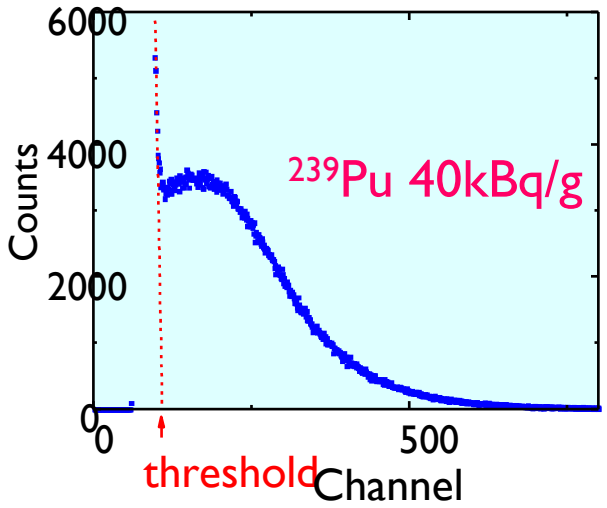
COGEMA



70.000 cts/s ; 2h ⇔ 1 week real conditions

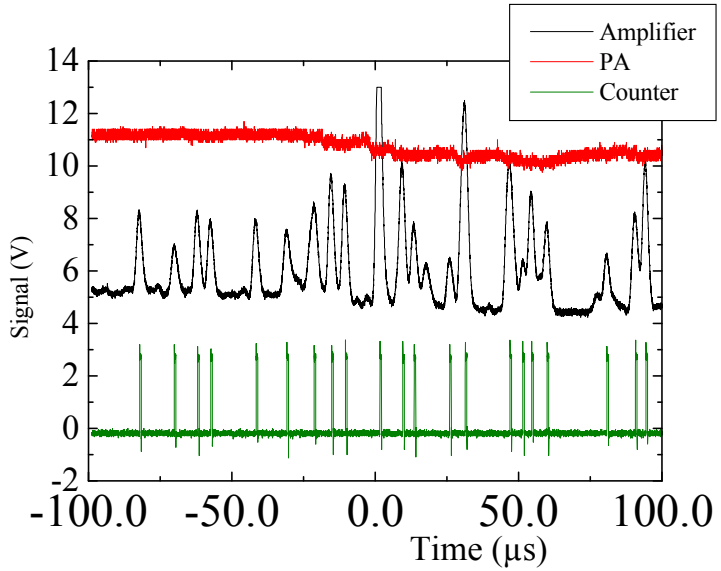
Nuclear Detection Applications : Nuclear wastes

α detection in corrosive liquid sources
Nuclear reprocessing plants (France + Japan)
Devices used in Rokkasho-Mura plant



No alternative from CVD :
Requires large area and thin material

COGEMA

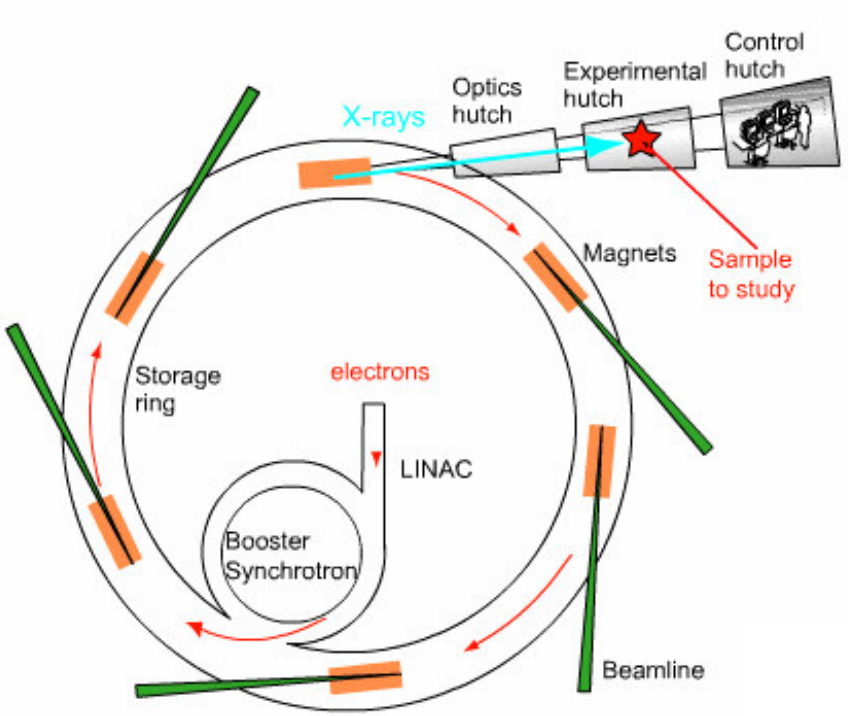


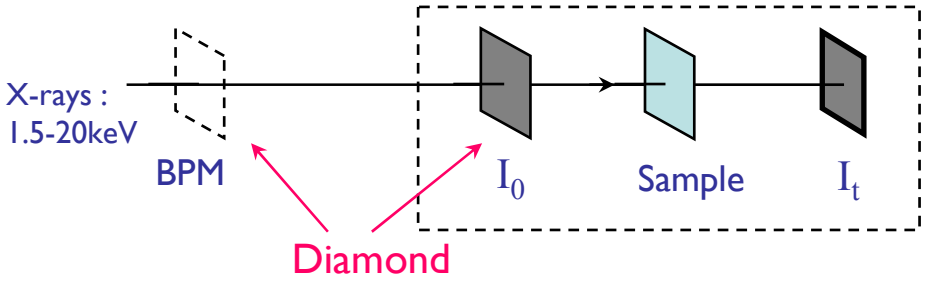
70.000 cts/s ; 2h ⇔ 1 week real conditions

Diamond for synchrotron beam monitoring

Aiming at 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)





Monitoring devices must exhibit :

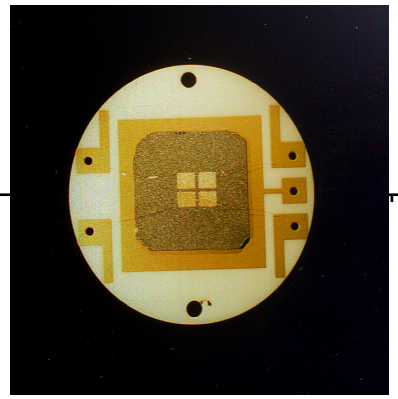
- high transparency (low Z)
- fluence hardness
- temperature hardness
- mechanically resilient,

Realisations have included

- Intensity monitors
- Beam position monitors (2 µm resol.)
- Beam Profile monitors

Probing the beam instabilities

4 quadrant semitransparent BPM



- Square beam
- 200µm x 200µm
- 4 keV

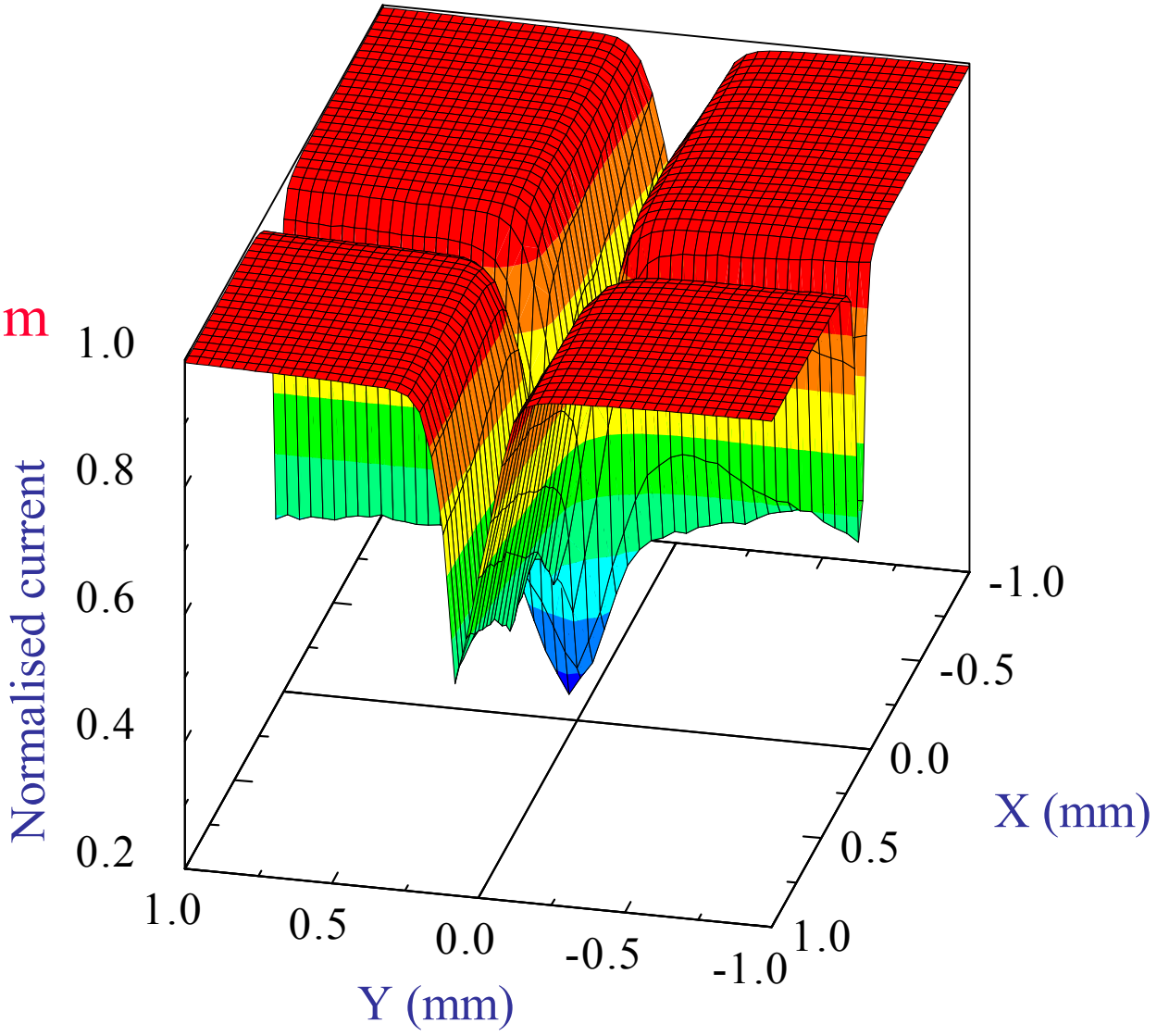
ID12A : 17/01/98
T_0 : 22h : 42 : 51

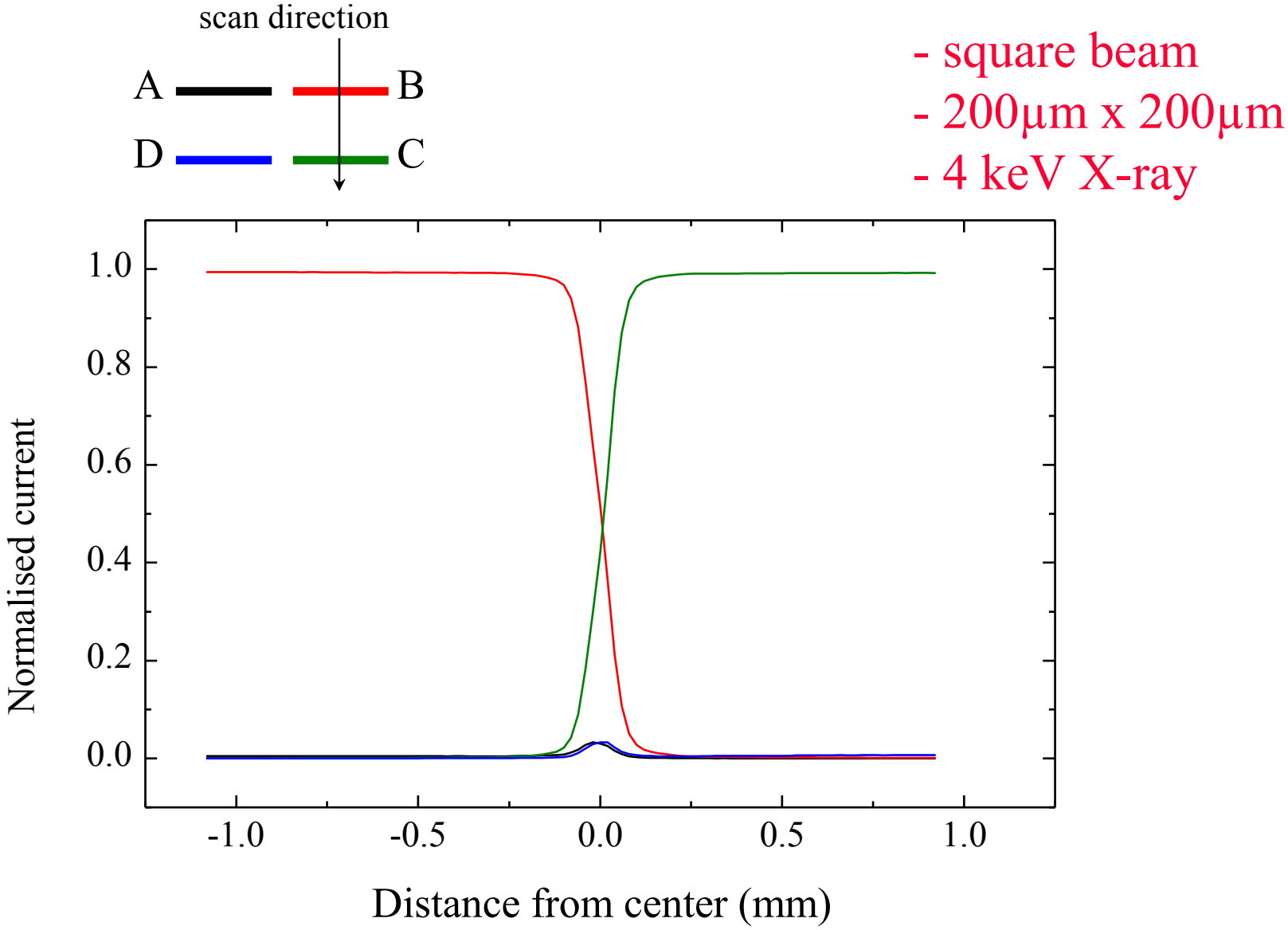
Beam gmobal feedback
causes the observed instabilities

Resolution well beyond 2µm

Measured 3D scan response

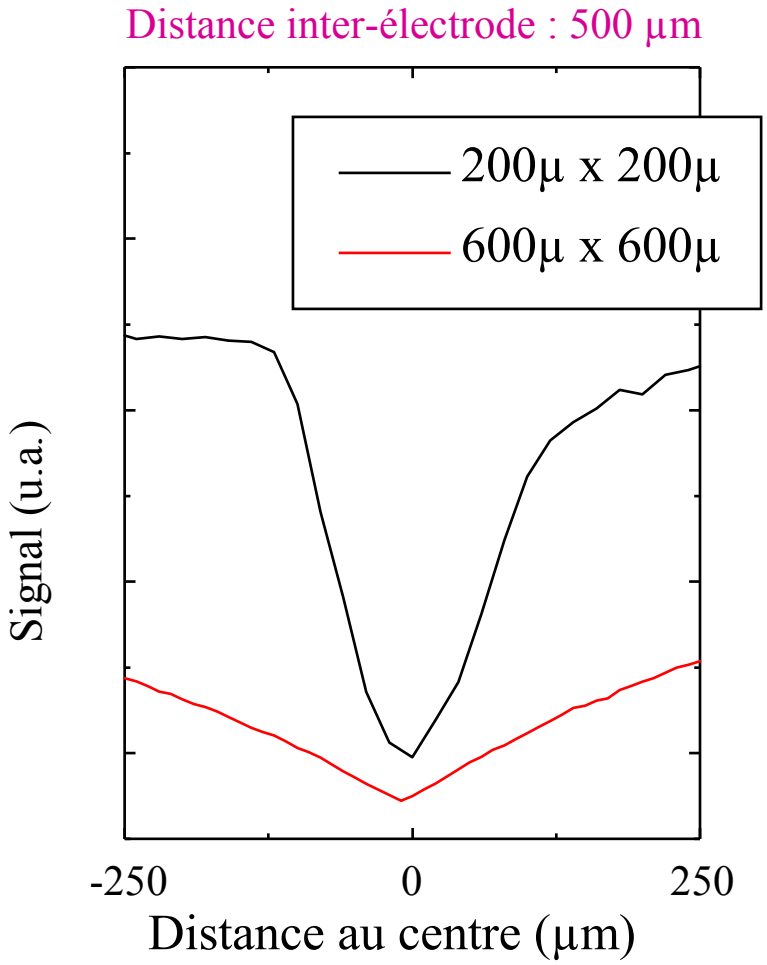
- square beam
- 200µm x 200µm
- 4 keV X-ray

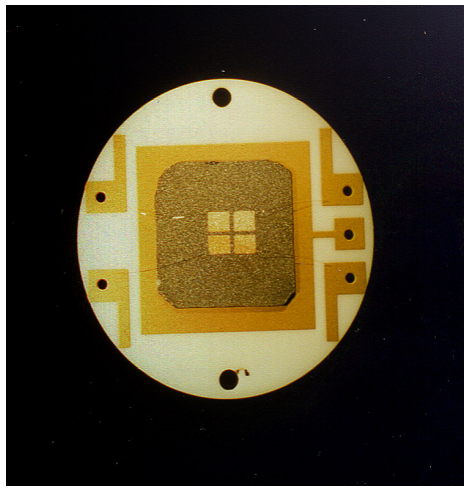



scan direction
A
B
D
C
- square beam
- 200µm x 200µm
- 4 keV X-ray
Normalised current
1.0
0.8
0.6
0.4
0.2
0.0
-1.0
-0.5
0.0
0.5
1.0
Distance from center (mm)

Dispositif 4 quadrants :

Position du faisceau X : résolution < 2 µm , semi transparence





⇒ **Mais** la résolution
dépend de la taille du faisceau

⇒ nouveau concept : dispositif résistif

Capteurs à couche résistive:

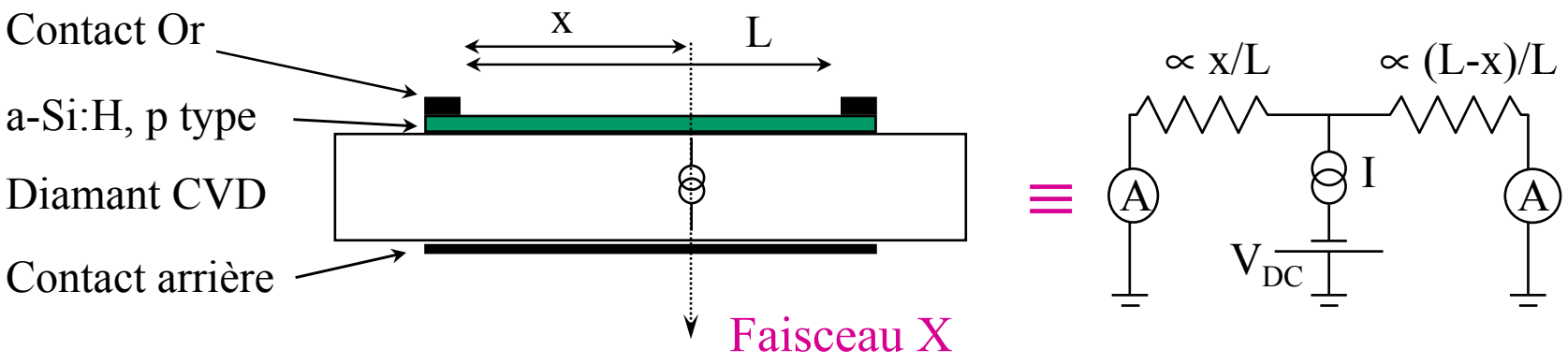
Principe :

une couche résistive d'épaisseur et de résistivité ajustée est déposée sur le diamant

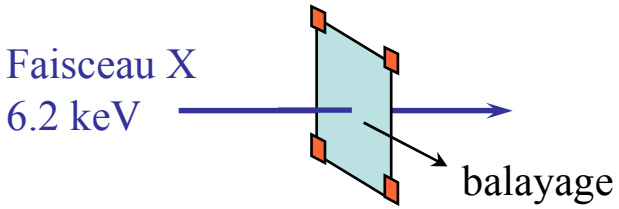
⇒ division des courants entre les quatre contacts

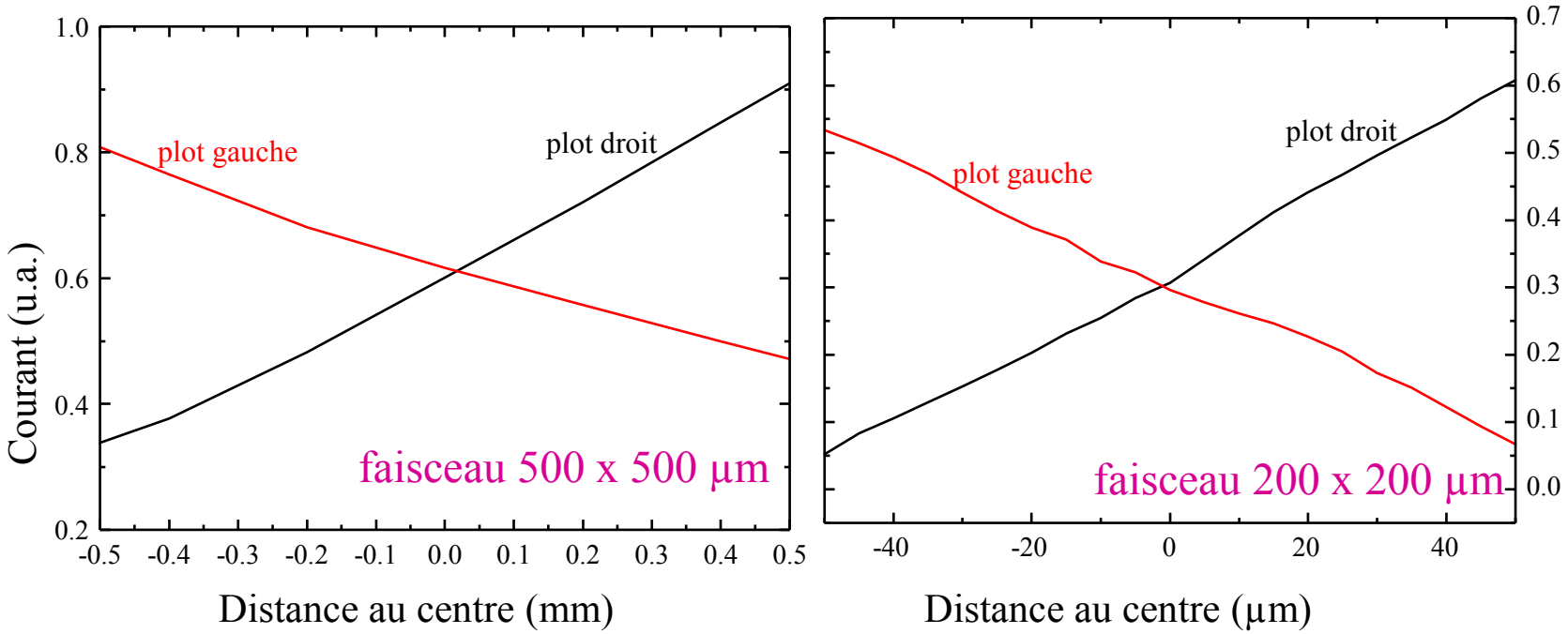
⇒ Le courant total reste constant

couche de a-Si:H , type p, $\rho \approx 10^5\ \Omega.cm$



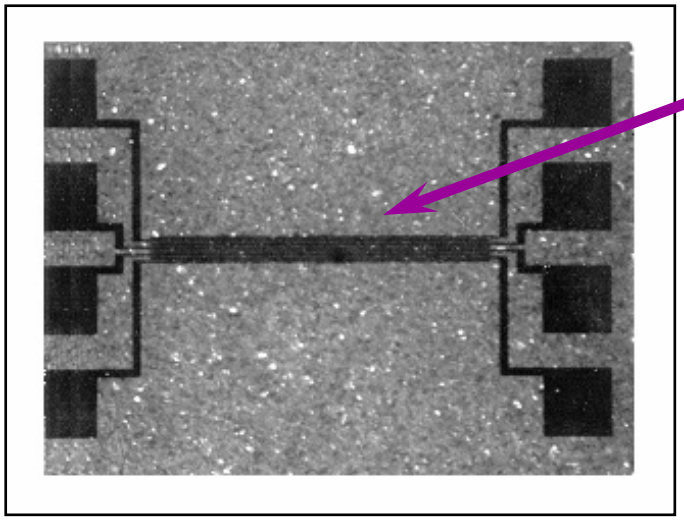
Capteur à couche résistive : parfaite linéarité du détecteur

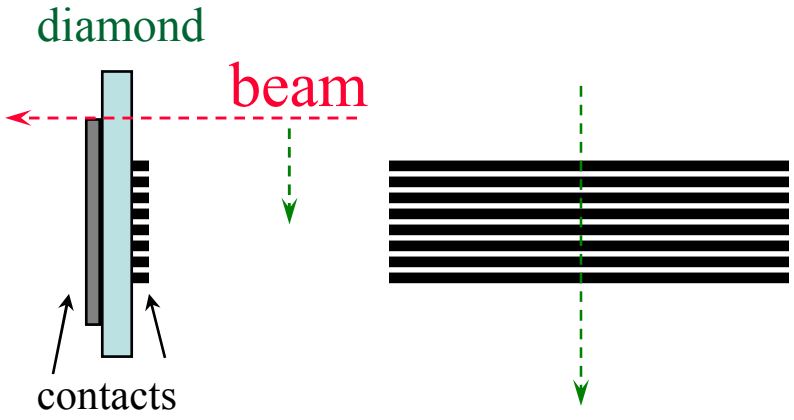


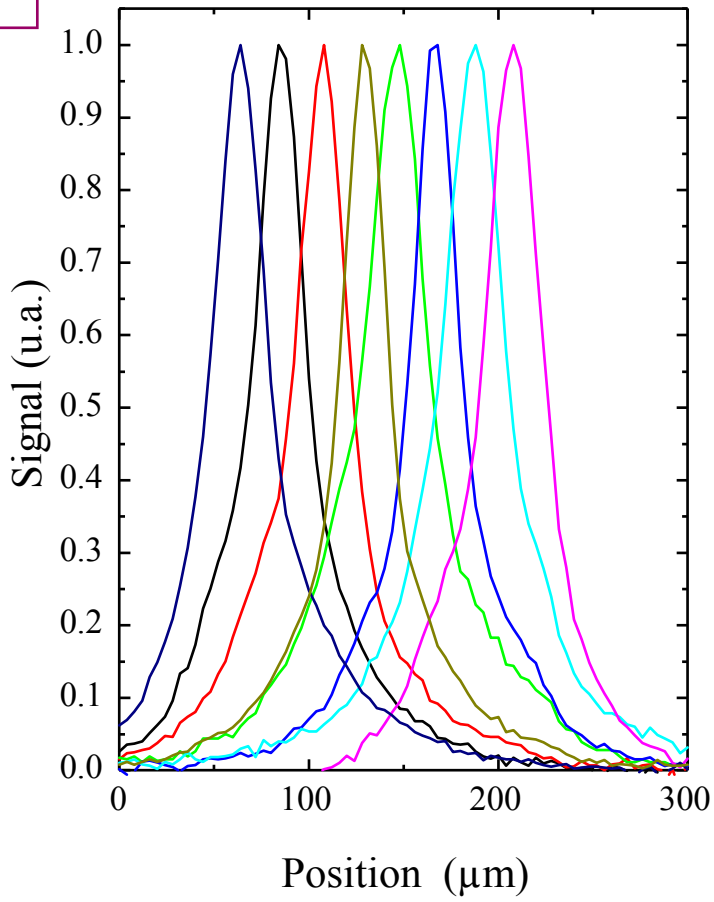


Beam Profile Monitors

May efficiently be coupled with BPM

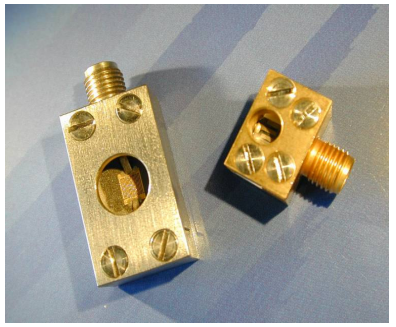






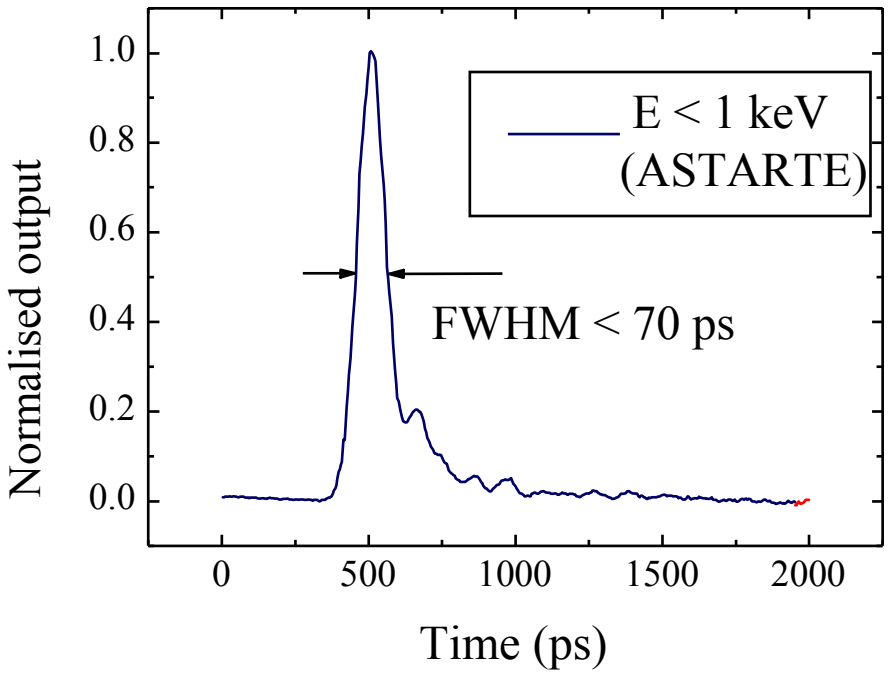
Ultra-fast pulse metrology

Diamant = matériau rapide pour détection d'impulsions



☺ :
- Faible durée de vie des porteurs
- Forte mobilité des porteurs

☹ :
- Faible sensibilité

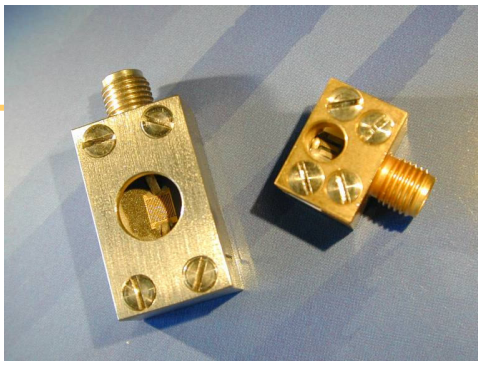


☞ < 70 ps

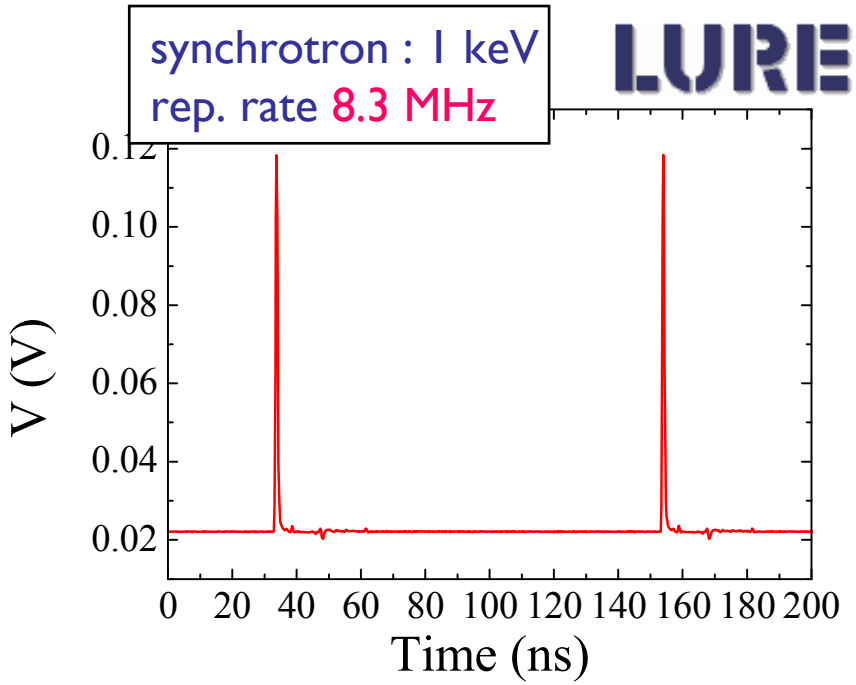
Intérêts : mesure distribution temporelle faisceau synchrotron (ESRF)

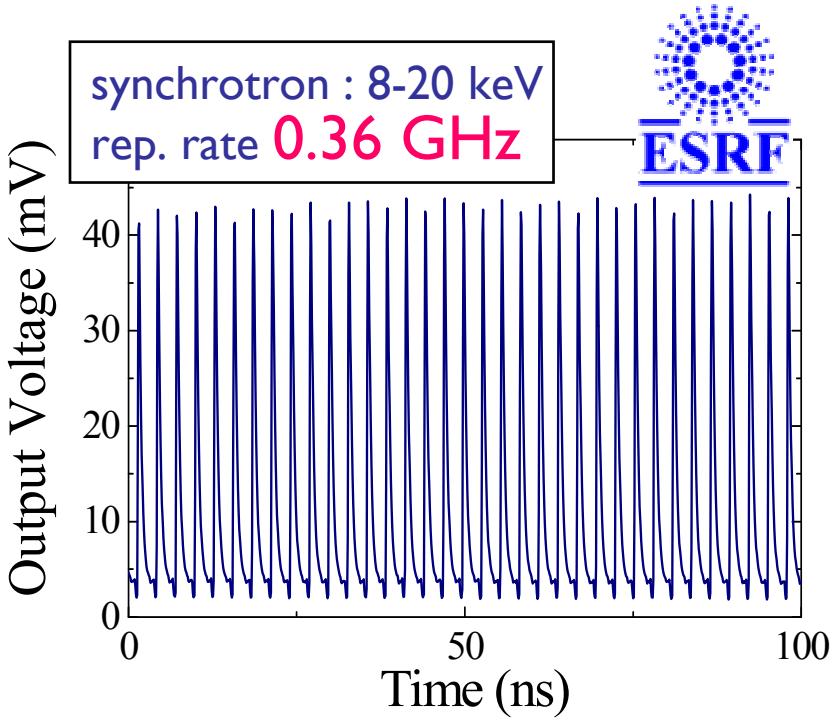
Seule électronique :
un détecteur + 1 oscillo

Ultra-fast pulse metrology

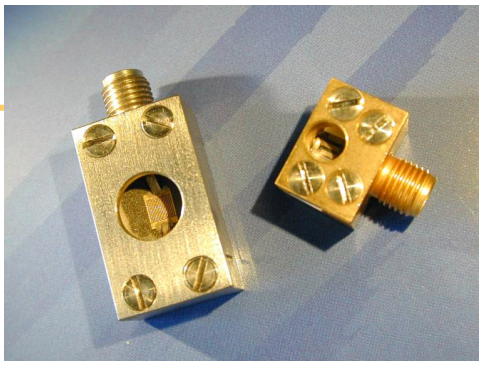


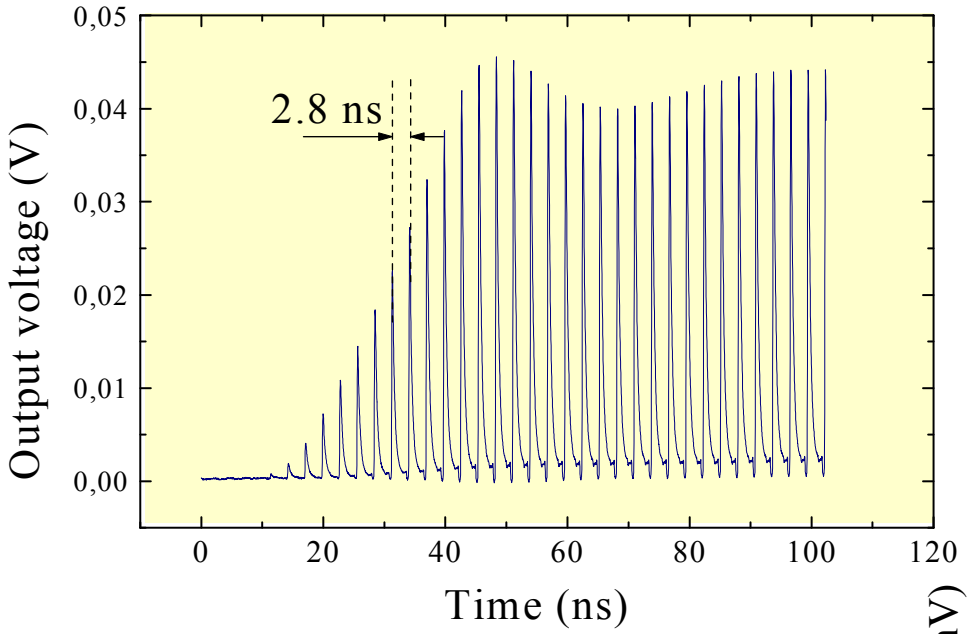
Application to synchrotron machine diagnostics (e.g., LURE, ESRF)





Bunch temporal distribution



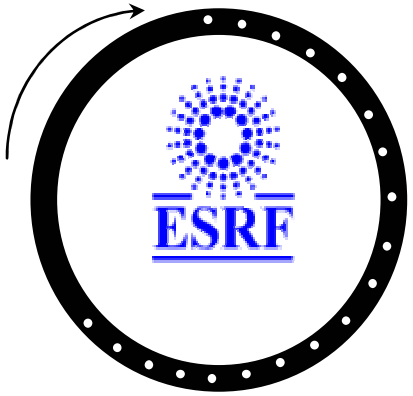


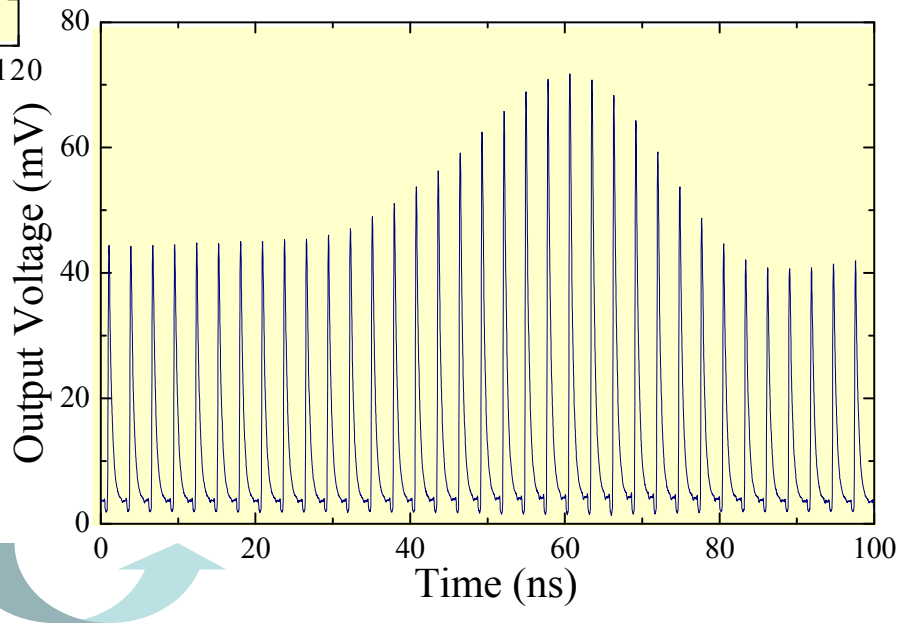
ESRF (2/3rd filling)

BM5

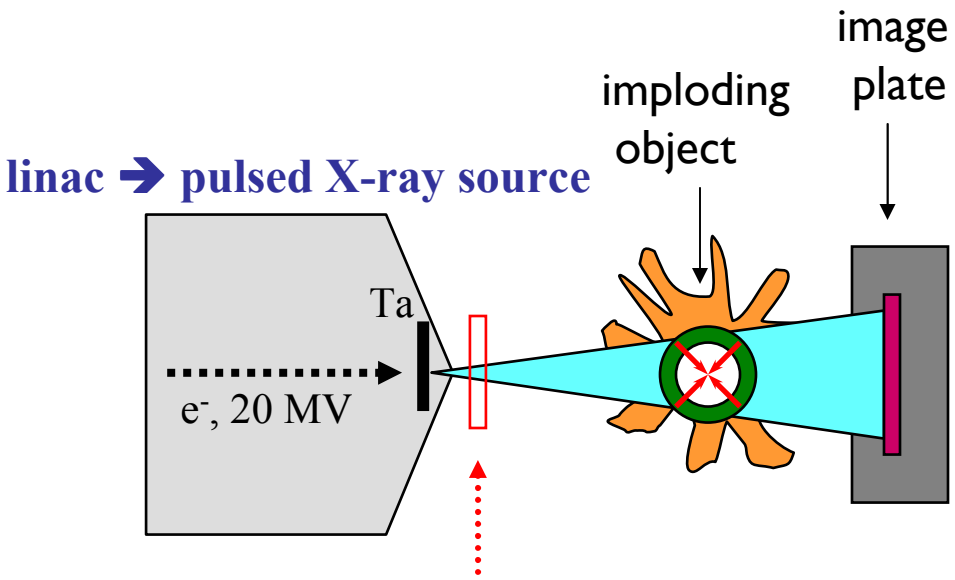
White light

Device Temperature > 170°C





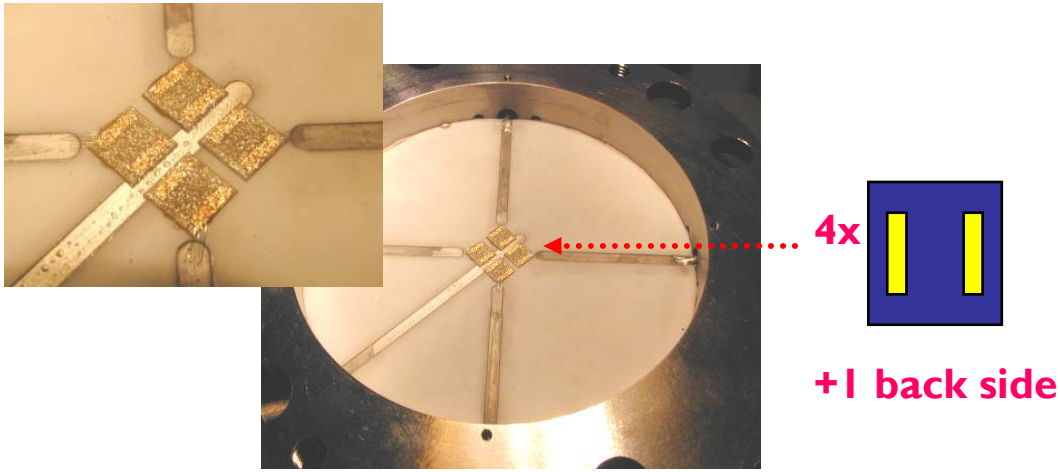
Flash X-Ray radiography diagnosis tool (defence)

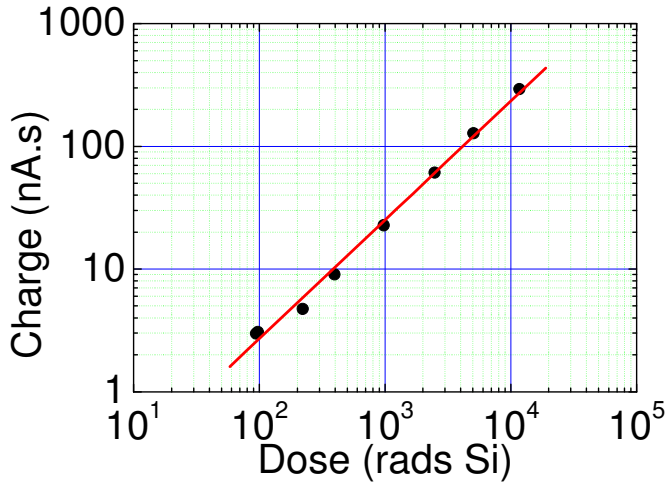


AIRIX (Accélérateur à Induction de Radiographie pour l'Imagerie X)

Demanding specifications

- typ. ≈ 1 MeV
- Dose (< 5 krad (Si)/flash)
- Duration : typ. 50ns FWHM
- 500 shots / yr / 15 yrs (> 15Mrad)
- Resilient (EMC and schock 10g)
- High transmission (< 0.1 g/cm^2 (W))





Conclusions

- Detectors :
  - Controlling the electronic characteristics with respect to the growth conditions is necessary for radiation detector fabrication

  - Pre-optimisation of the devices is necessary
    (defects priming etc)

- Devices :
  - for neutron detection in the core of nuclear reactors
  - for alpha activity monitoring in acids
  - ultra-fast pulse monitoring

- BUT : to date diamond detection :
  mostly addressing small markets ...

Collaborators

CEA/Saclay
D. Tromson, M-J. Guerrero, C.Mer, S. Delclos,
E. Snidero*, M. Pomorski*, M. Rebisz*

ESRF (microprobe analysis)
J. Morse, R. Barrett, W. Ludwig

IFN
P. Olko, B. Marcewska

IMO-IMEC
M. Nesladek, Ken Haenen

UCL London + WSI Munich
R-B. Jackman, O. Williams (now Argonne Nat. Labs) et al.
C.E. Nebel, J.A. Garrido

*Acknowledgements : EU funding from HPRN-CT-1999-00139