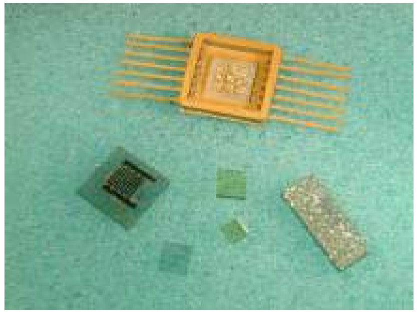
Diamond activities at CEA-LIST



Philippe.bergonzo@cea.fr, *Diamond Sensor Laboratory, CEA-LIST, Saclay*

Who are we ?

Where ?

CEA/Saclay, near Paris

LIST (Research and Technology Direction)

Team members :

M. Nesladek,
D. Tromson,
C. Mer,
N. Tranchant,
J.C. Arnault,
S. Saada,
H. Hamrita,
S. Allard,
C. Gesset

Collaborations

CEA/DRECAM (Saclay)
UCL (London)
WSI (Munich)
AIST (Tsukuba)
CNRS-NEEL (Grenoble)
Technion
TRINITI (Moscow)
GEMaC-CNRS (Meudon)
ESRF & SOLEIL

Industriel partners

COGEMA
SGN (AREVA)
ALSTOM
EDF

Diamond synthesis

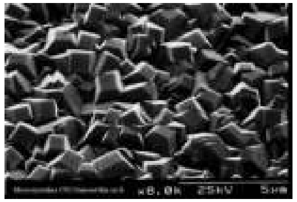
*Plasma CVD → **GROWTH***

- Precursors : CH_4 + H_2 (+ O_2, Ar, CO_2; etc…)
- Grain growth
- Temperatures : **600- 900°C**

→ **Various material types :**

- **Homoepitaxy → Single crystals**

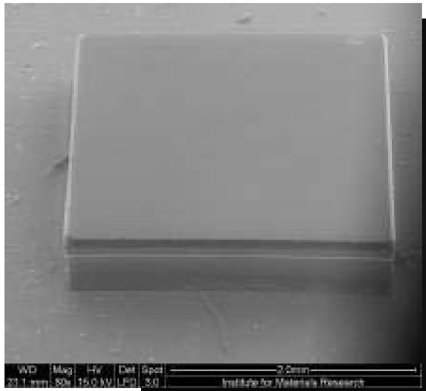
  µ : 4000$cm^2V^{-1}s^{-1}$
  but substrates 3x3mm typ 300€



- **Heteroépitaxy → polycrystalline**
  - substrates Si, Verre, Quartz, W, Ti etc.
  - Highly resistive ***10^{12} - 10^{14} Ω.cm***

- **Nanocrystalline materialas:** NCD, UNCD
  coatings, bio interfaces etc

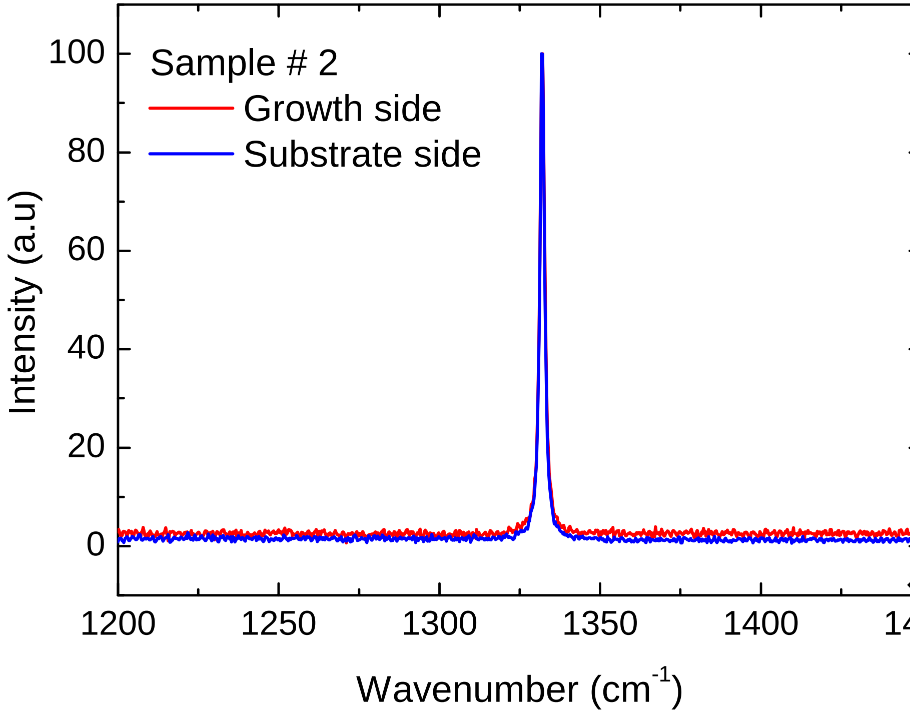
Diamond growth



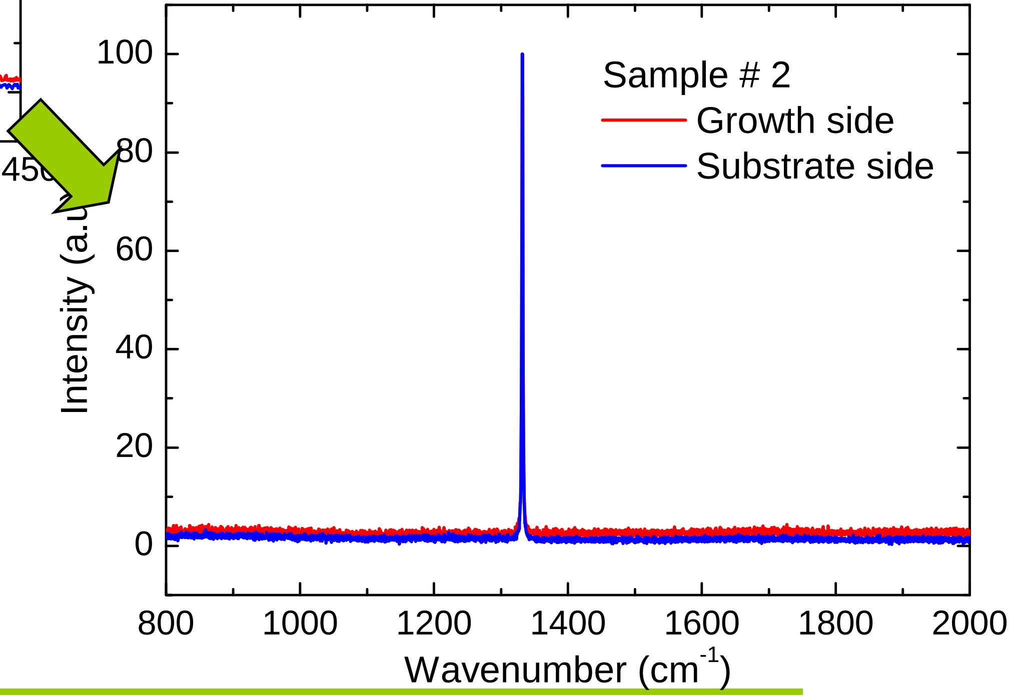
Carbon from methane : CH_4

→ 7 growth kits at Saclay: from 2 to 4 inches
→ Microwave plasma CVD

Raman characterization

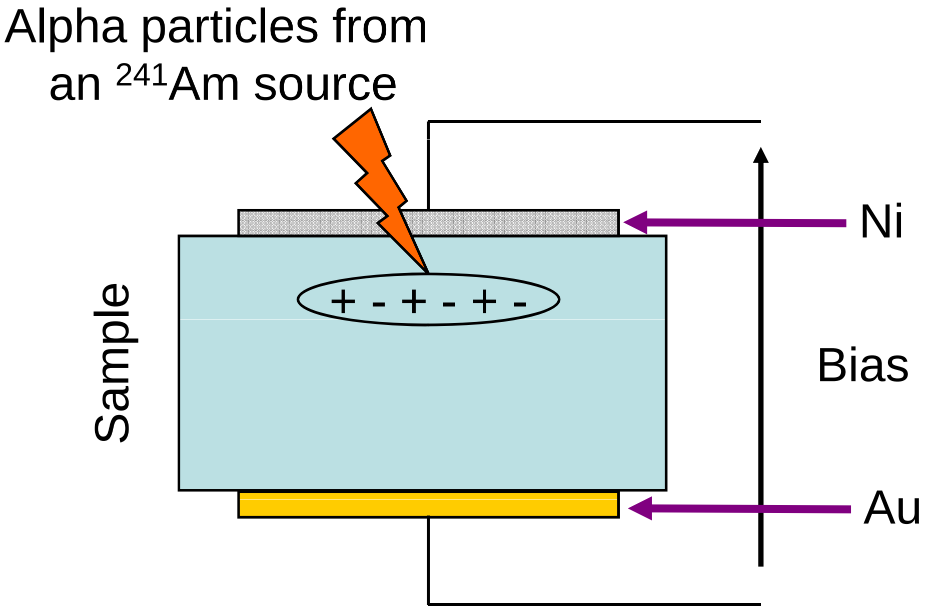


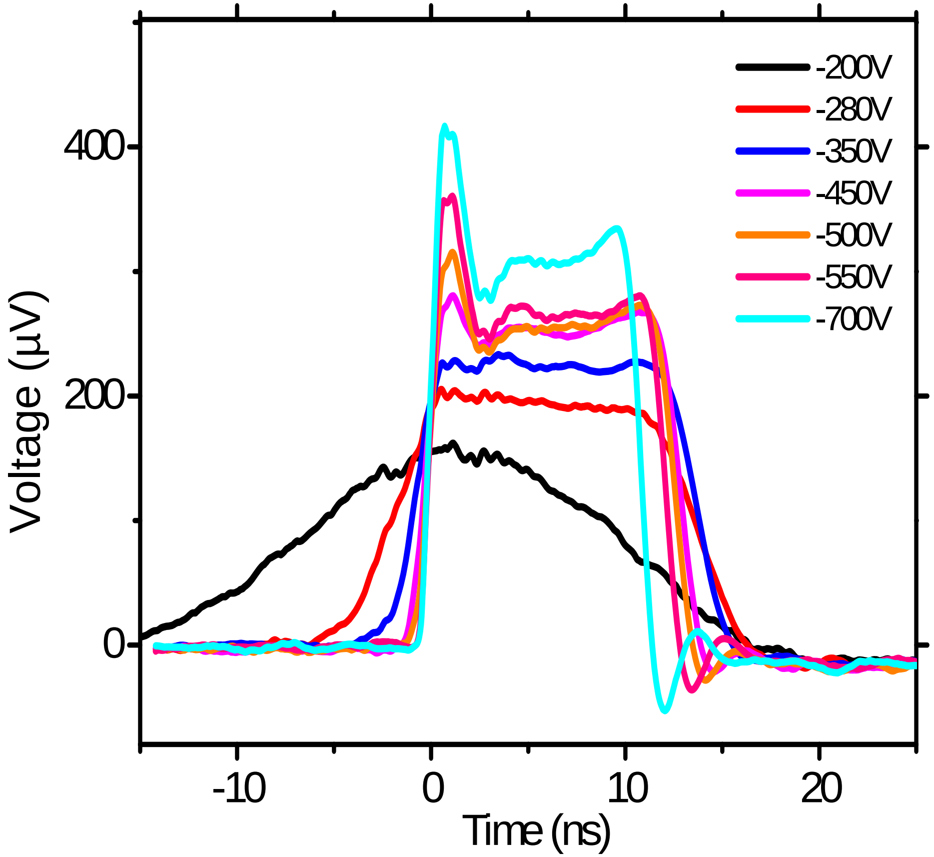
Side	Position	FWHM
Growth	1331.98	1.47
Substrate	1332.03	1.70



- Good crystalline quality
- No graphitic inclusion

Time Of Flight (TOF) measurements





$$\mu_{(\vec{E})} = \frac{\mu_0}{1+\frac{\mu_0 E}{v_s}}$$

Least squared fit

μ_0, mobility at 0 field

V_s, saturation velocity

Time Of Flight (TOF) measurements

	Sample # 1	Sample # 2
μ_0^{h+} (cm^2.V^{-1}.s^{-1})	**2450**	**3200**
v_s^{h+} (V.cm^{-1})	$2{,}1.10^6$	$3{,}5.10^6$
μ_0^{e-} (cm^2.V^{-1}.s^{-1})	**1850**	**2500**
V_s^{e-} (V.cm^{-1})	$2{,}7.10^6$	$1{,}9.10^6$

Hole mobility is higher than electron mobility for both

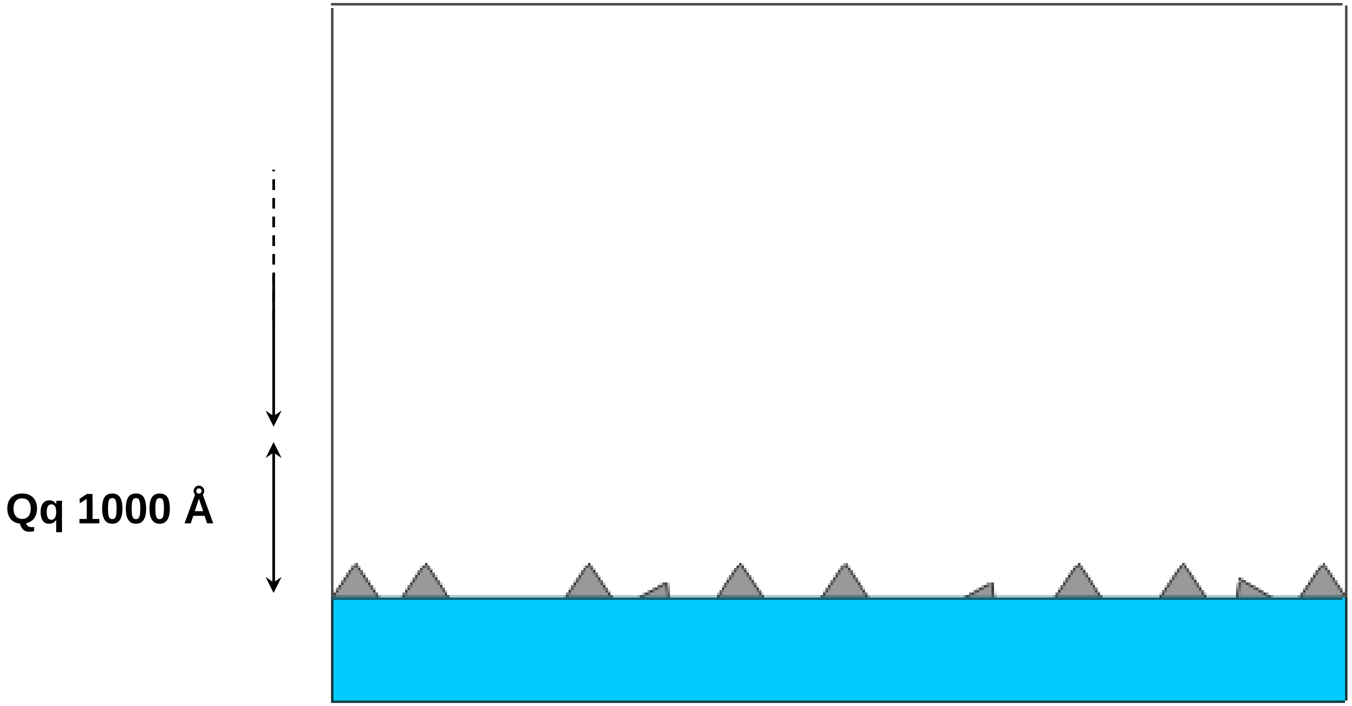
High mobilities values performed → low defect concentration

Growth facilities

Growth kits
Exclusively microwave CVD

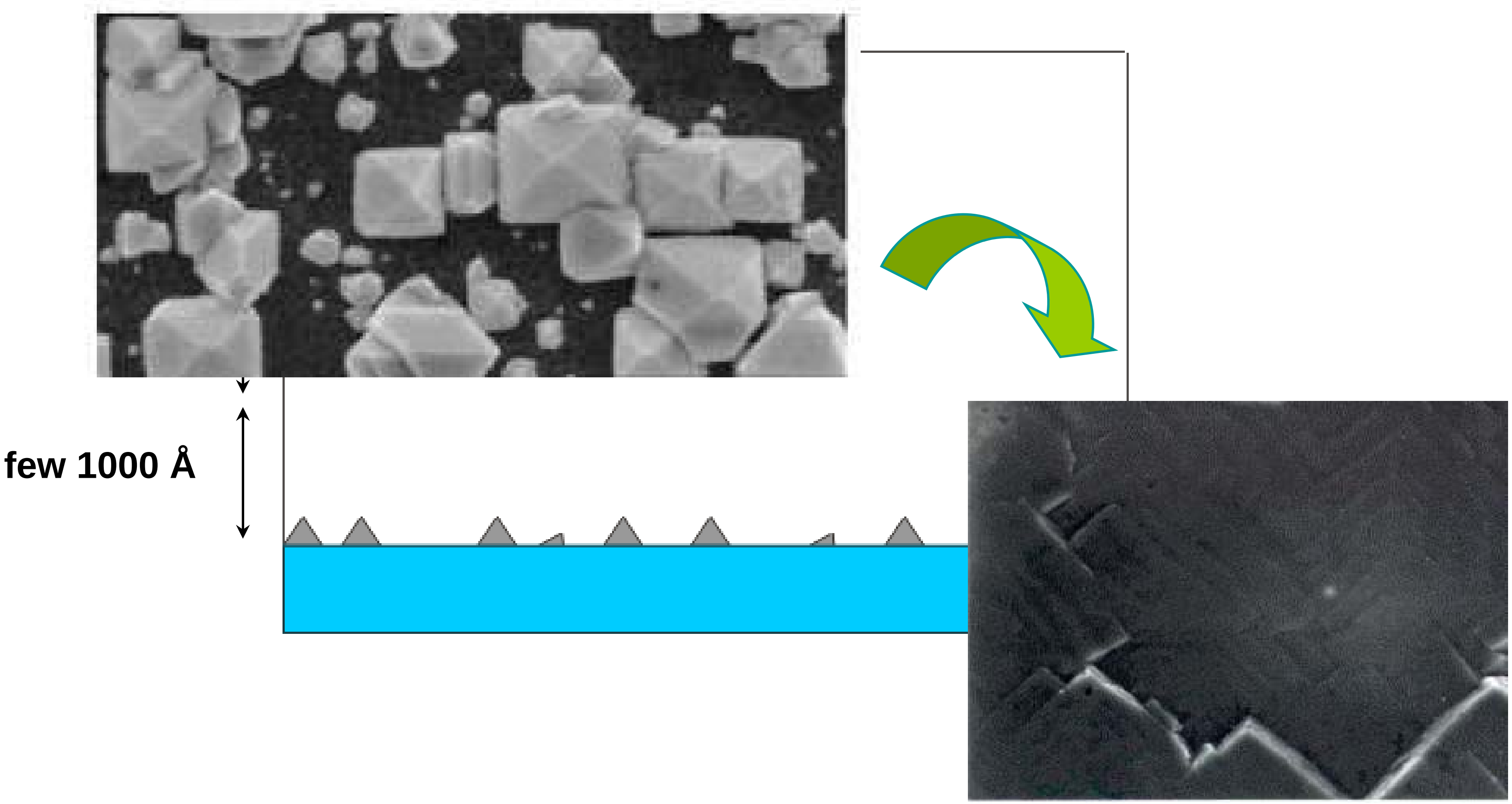
- 3 for intrinsic diamond growth,
  (inc one SEKI AX5400)
- 1 dedicated to boron doping,
- 1 dedicated to phosphorous doping,
- 1 large area SEKI 6500 (..→ 3 to 4 inch)
- 1 dedicated to heteroepitaxy (Ir, etc)

Polycrystalline growth

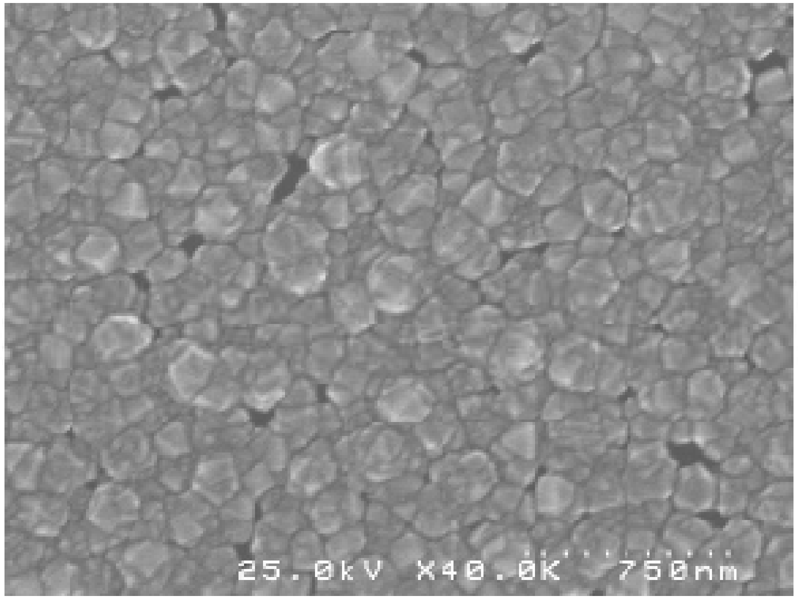


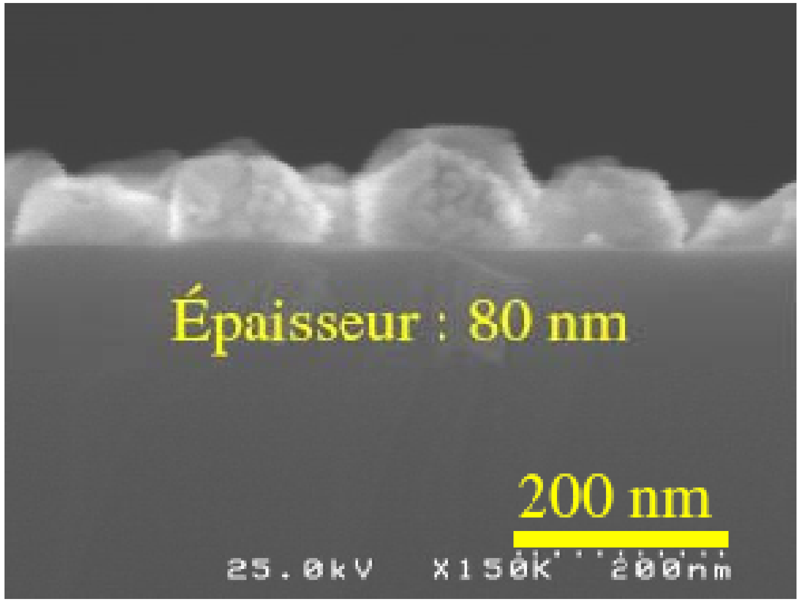
Le diamant synthétique

Polycrystalline growth

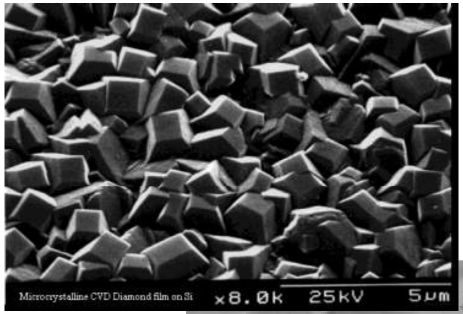


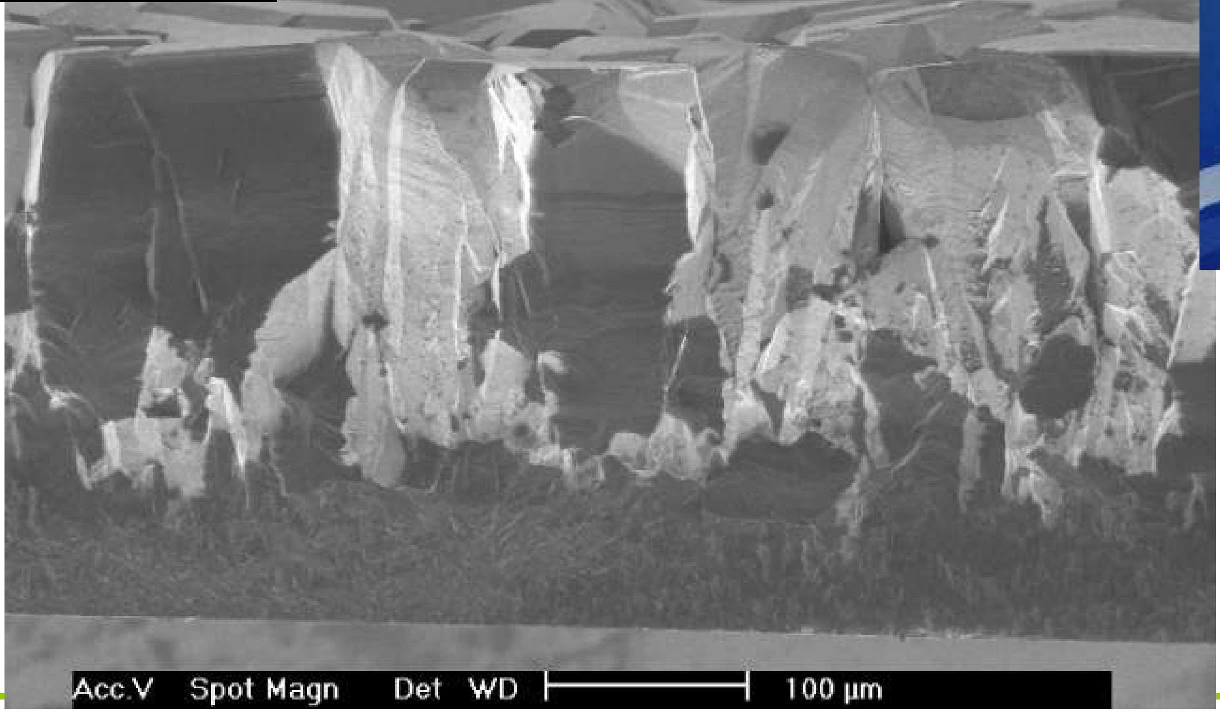
From very thin layers





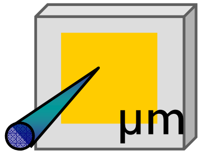
To thick films…

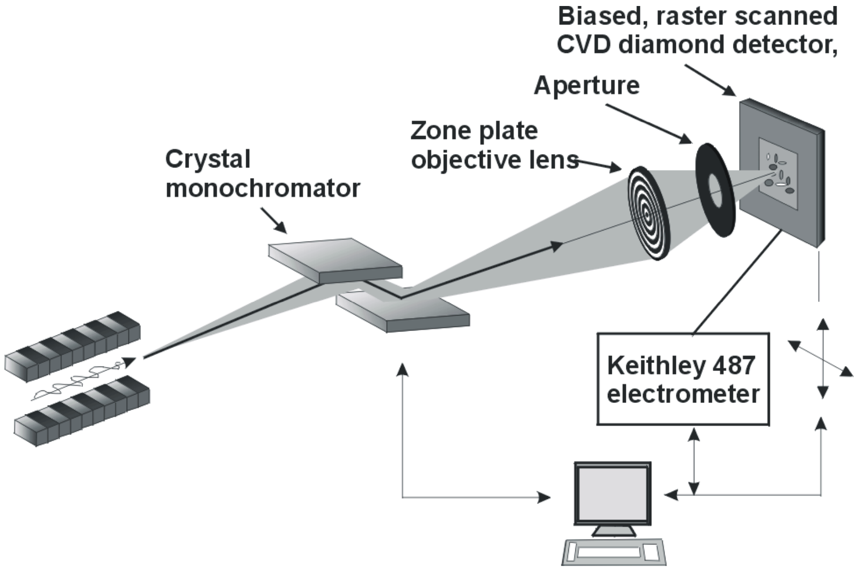




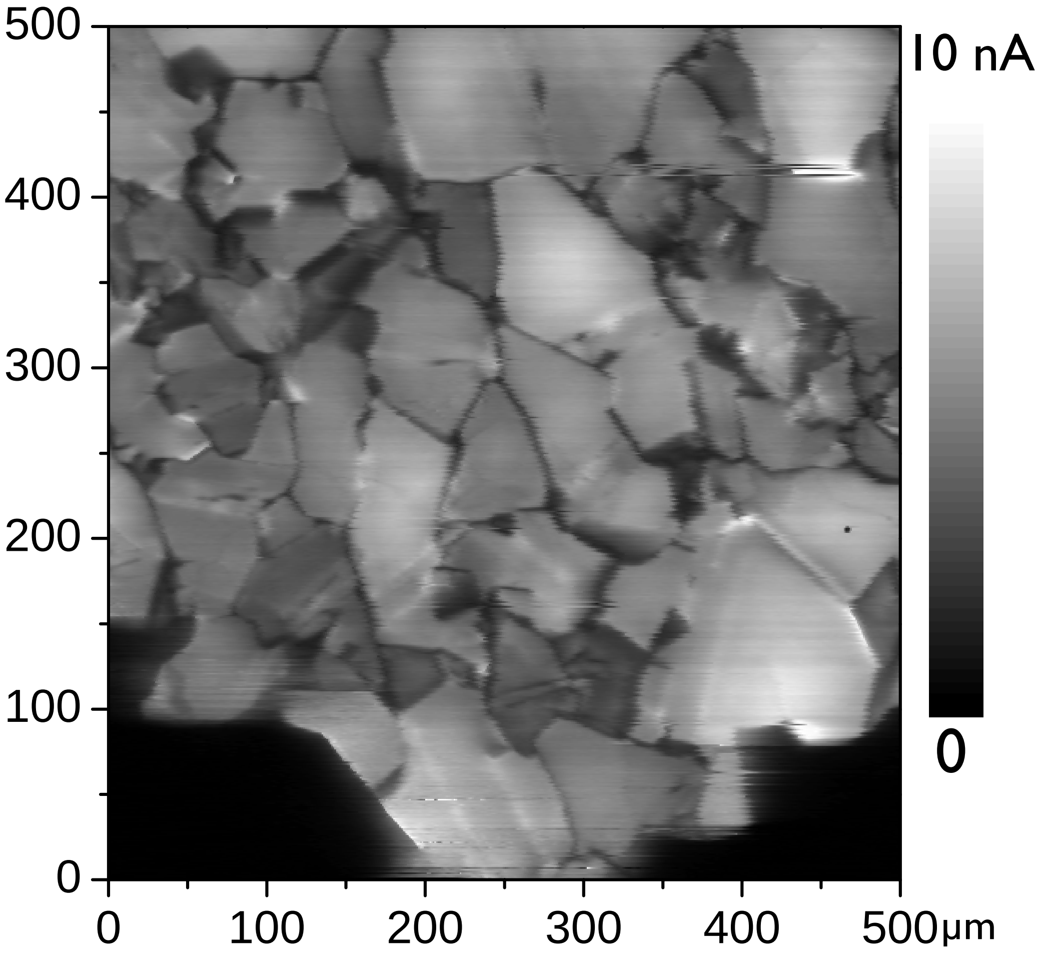
Non-uniformity of the sensitivity

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



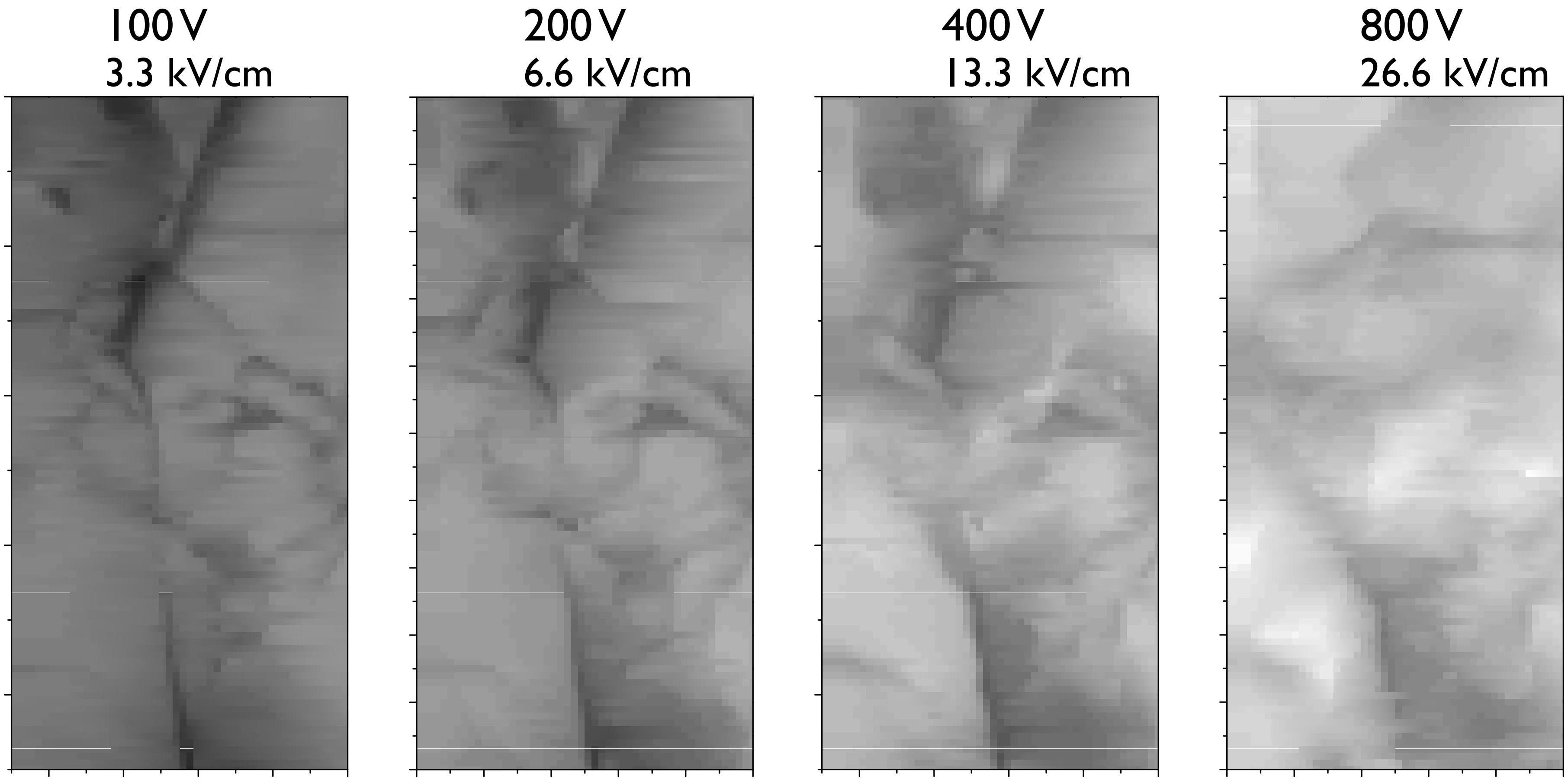


➔ Comm. Avail. 300µm Det. Grade



Strong Non-uniformities observed
➔Detrimental for beam metrology

Electric Field Influence

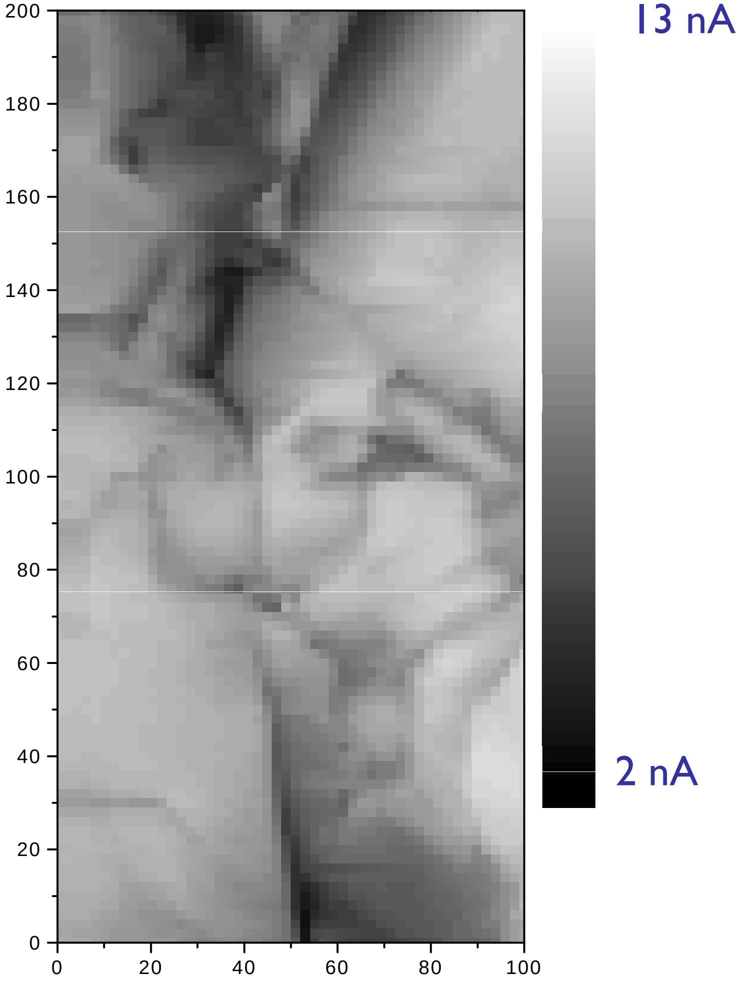


(Identical grey scale : 1 to 28 nA – log)

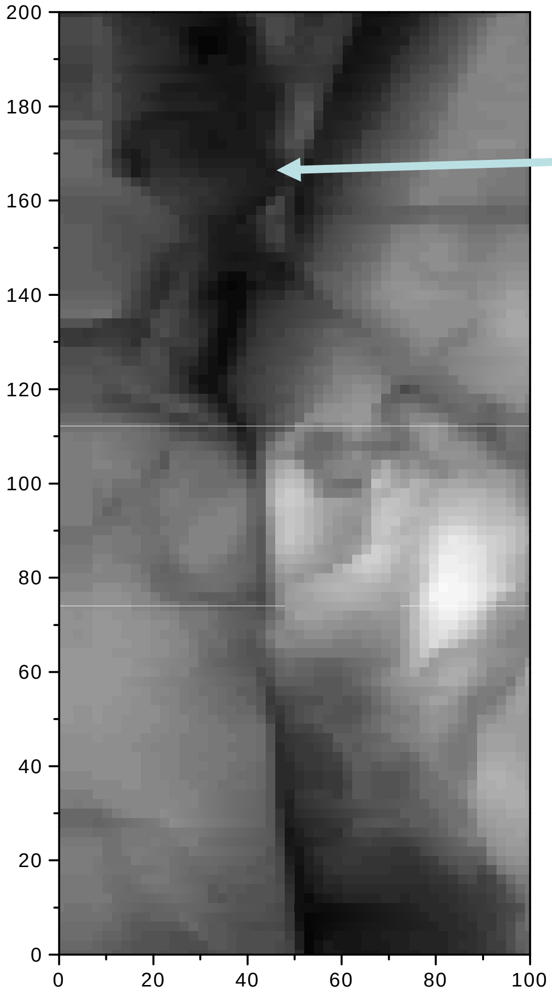
➔Velocity of saturation can be reached locally (likely from 10 kV/cm)

Evidence of charge build-up

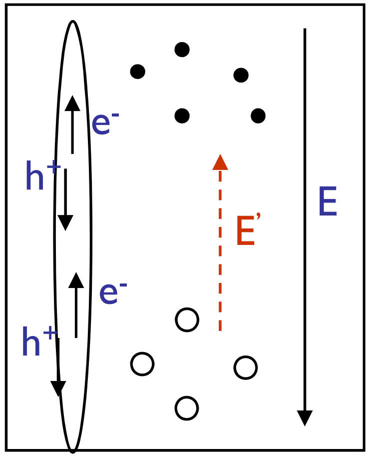
At 200V



At 200V, after one scan at 800V

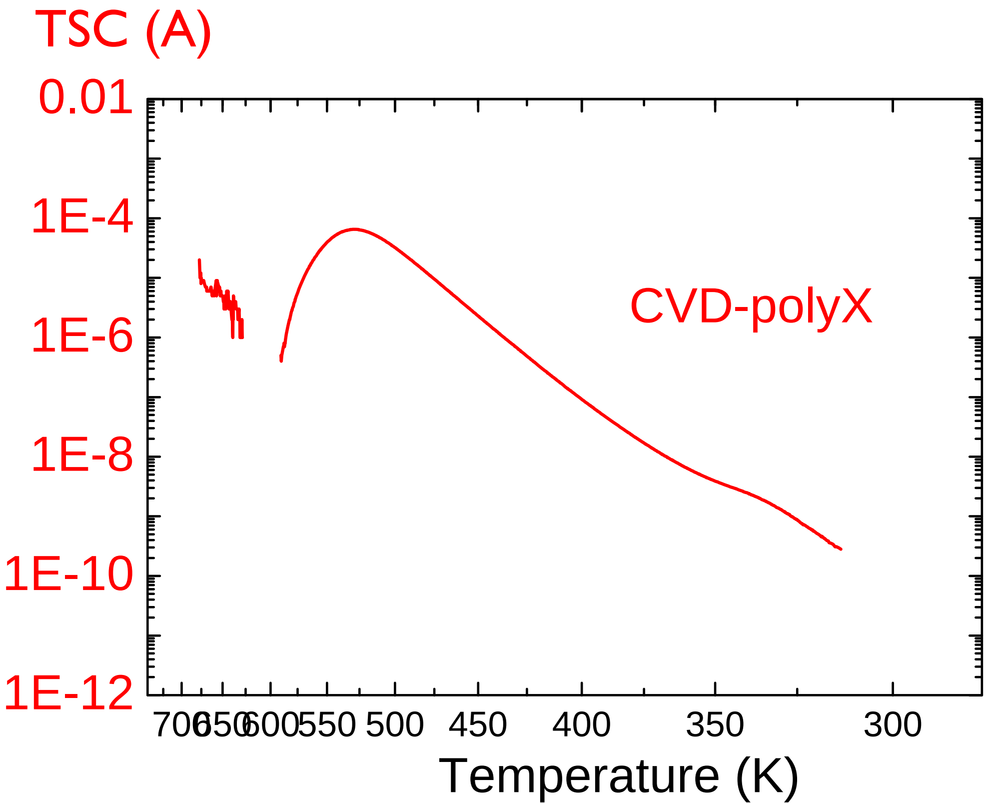


Darker area :
Sensitivity is lower



The role of defects

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



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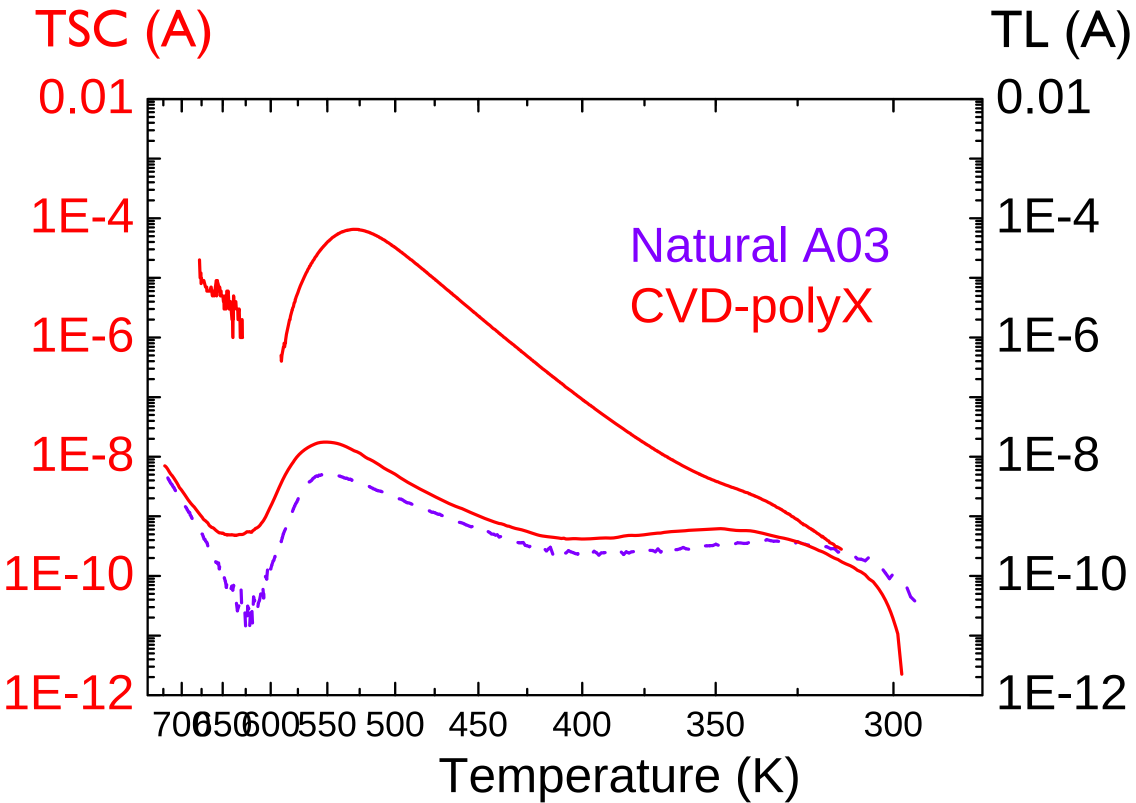

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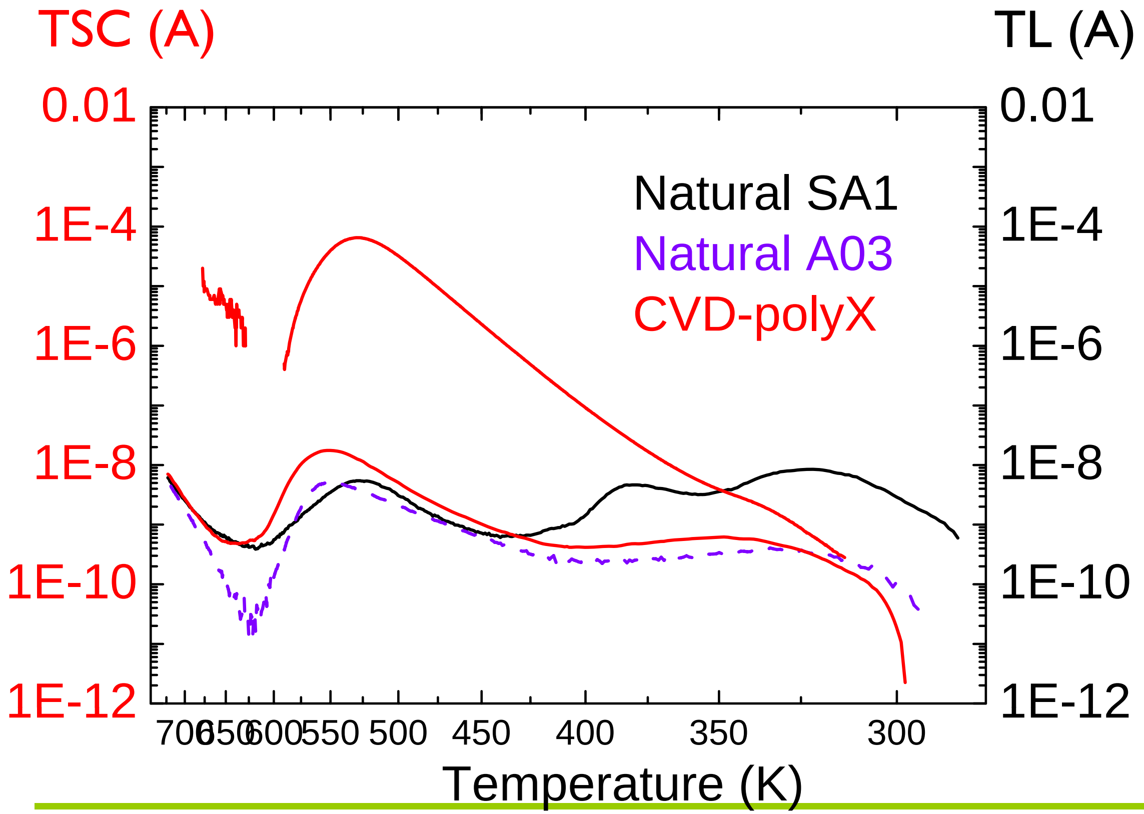
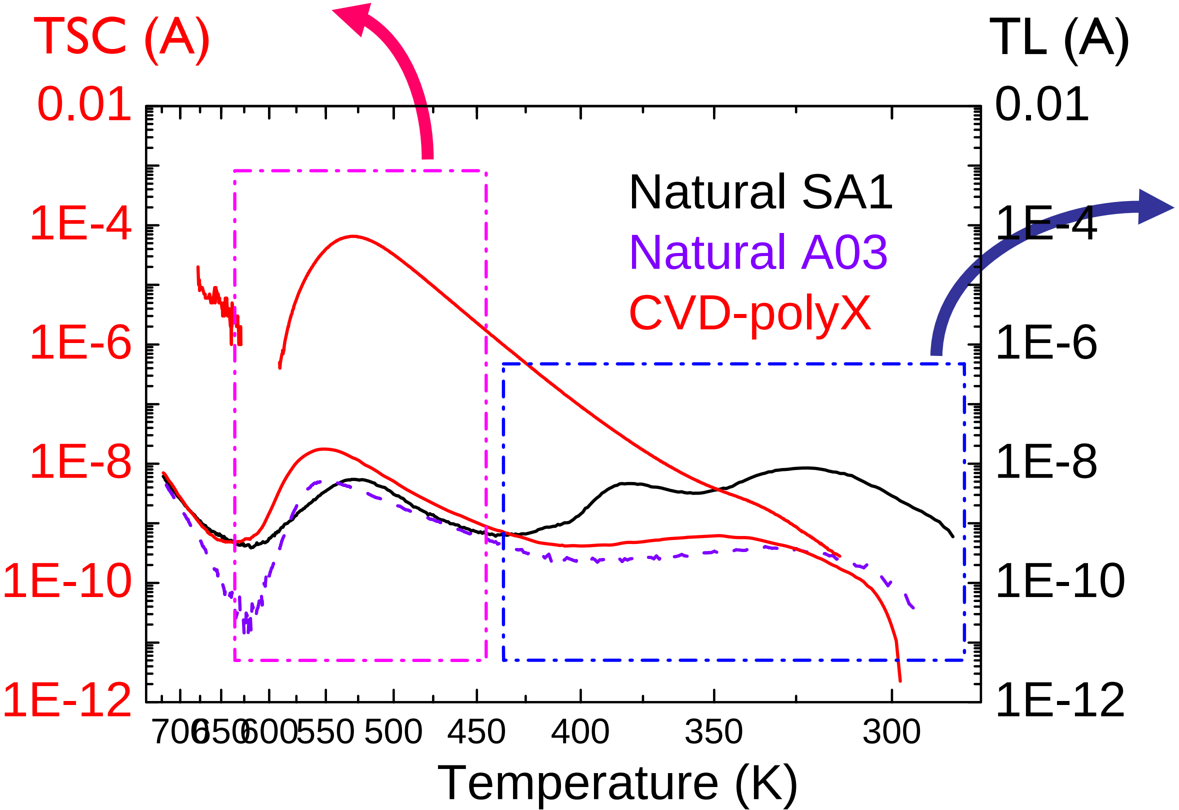


The role of defects

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

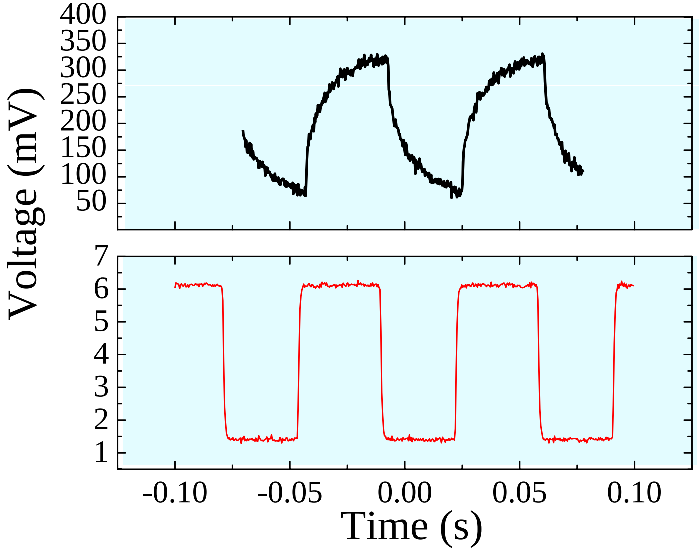
- of interest for TL dosimetry
- stable at RT



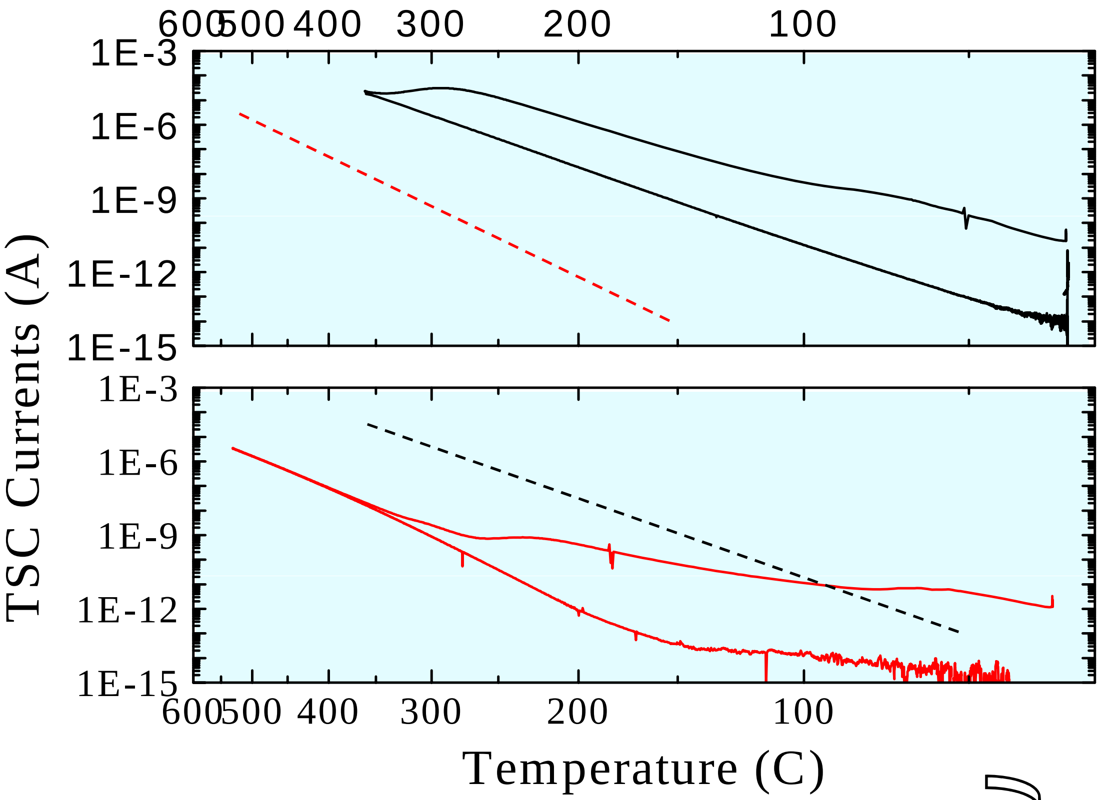
- highly detrimental for IC
- ➔ unstability

Impurities : effect on the response time

Device responses to chopped X-rays (60 keV)



TSC Signatures (10^{4}V/cm)

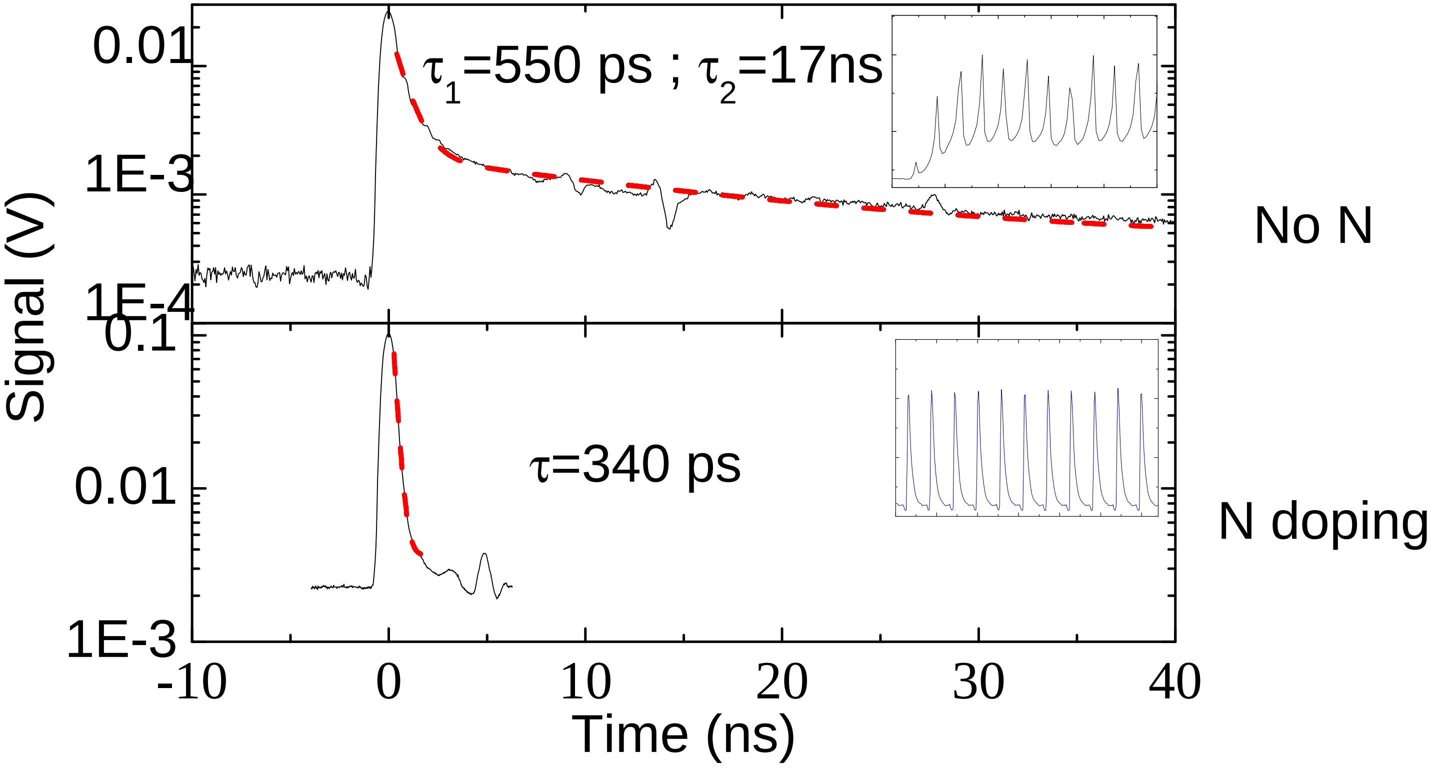


Defects and response time

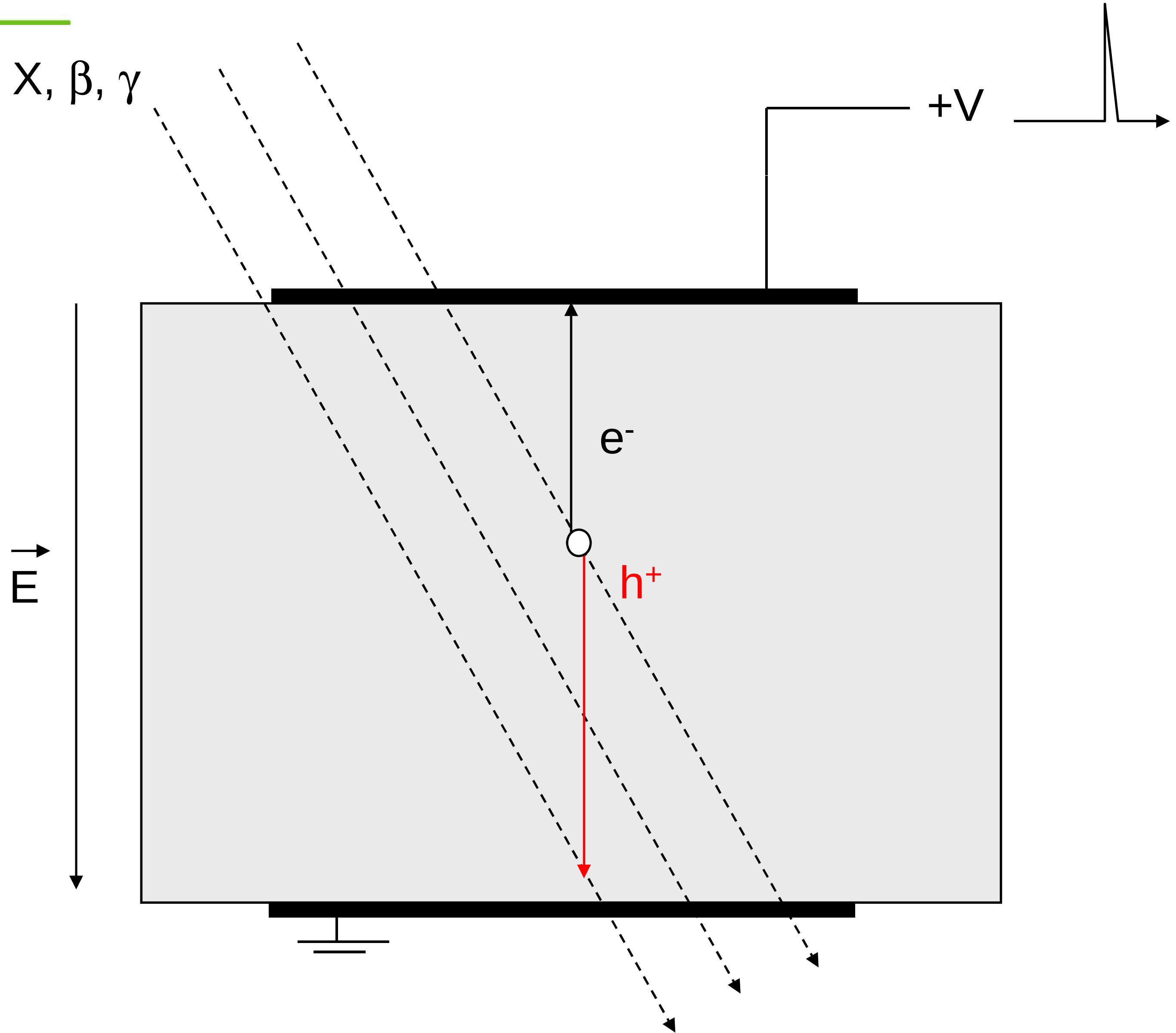
Defects strongly influence the signal temporal decay :

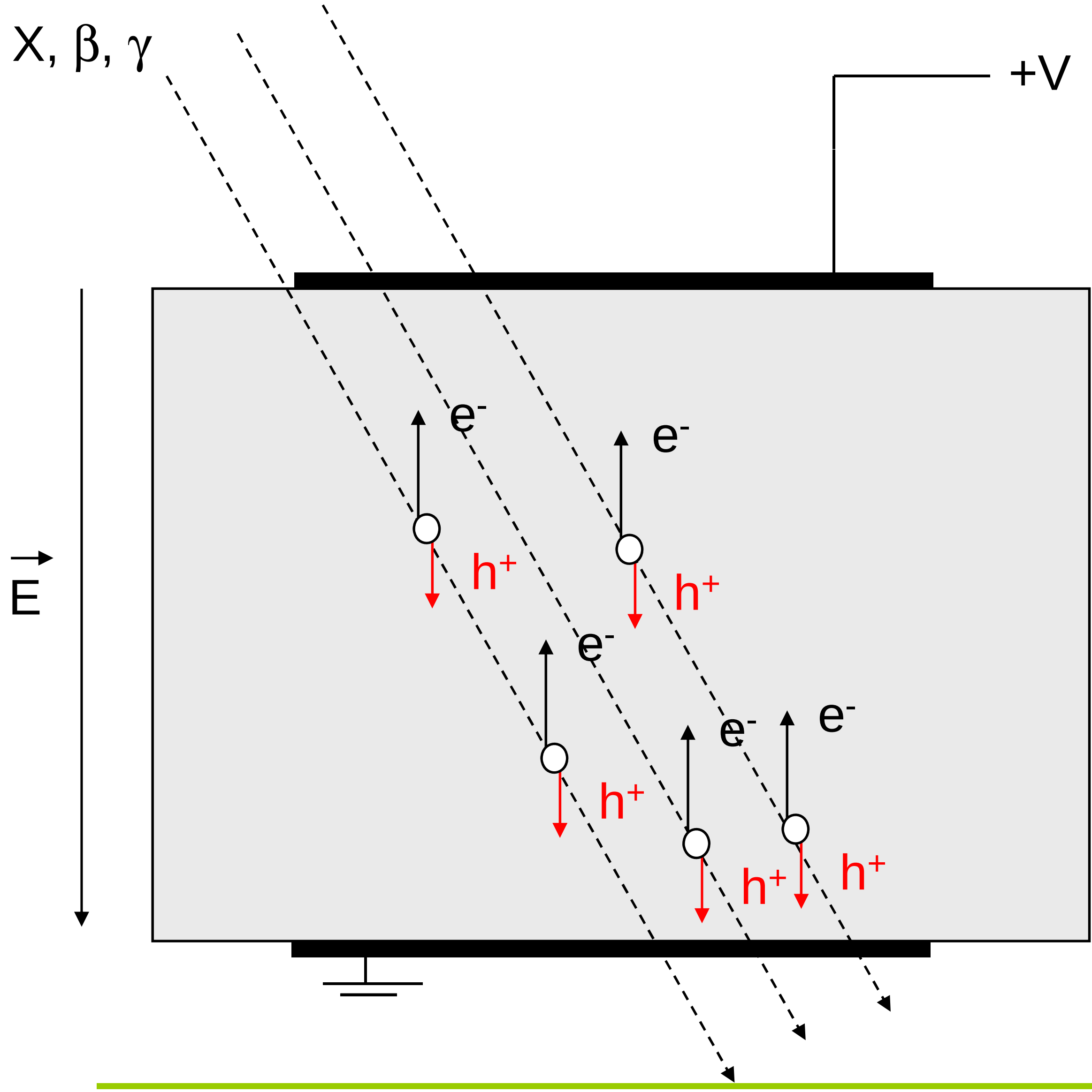
If Nitrogen is added to the gas phase during growth

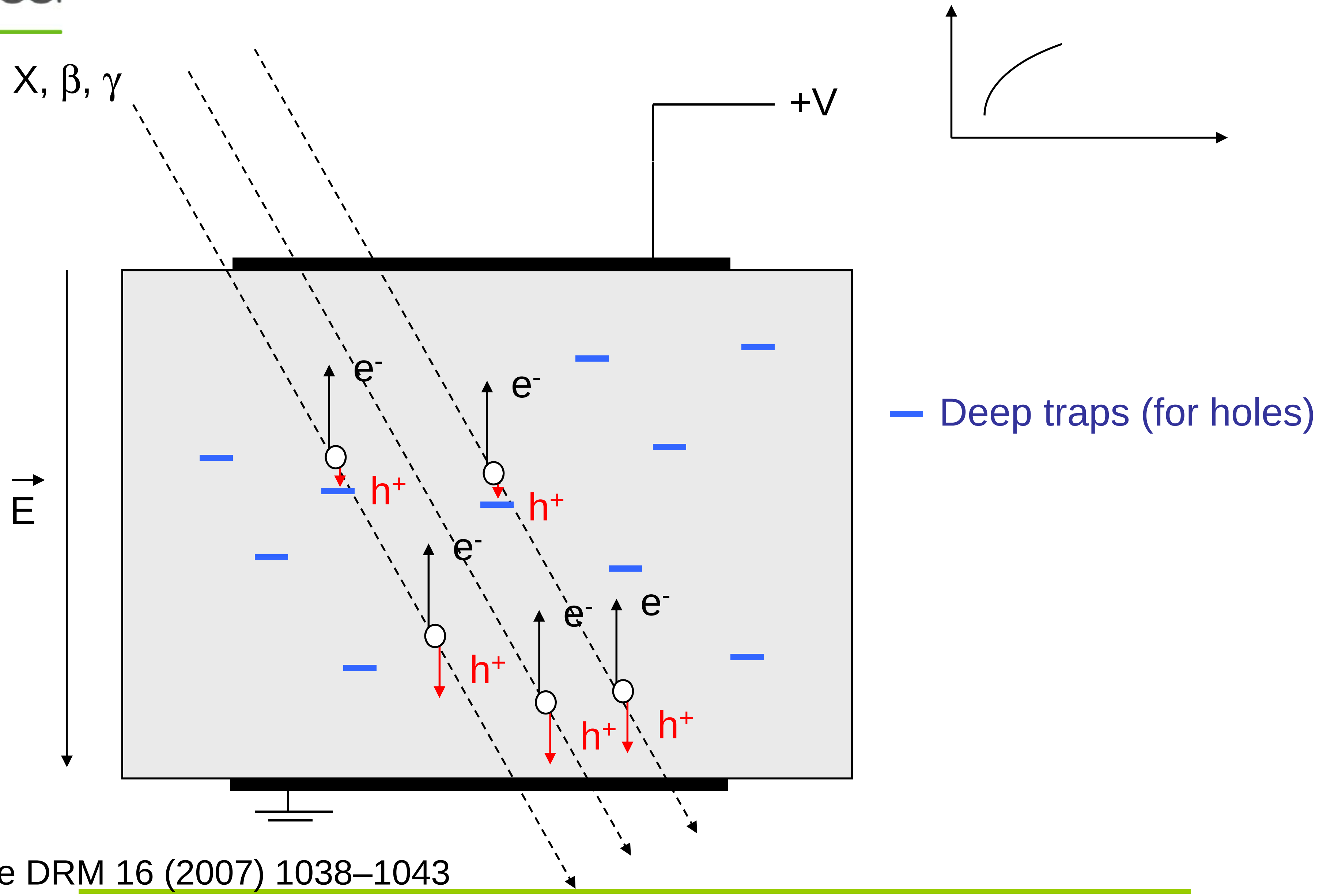
2 CVD polycrystalline diamonds,
Synchrotron pulses at LURE (≈1 keV),



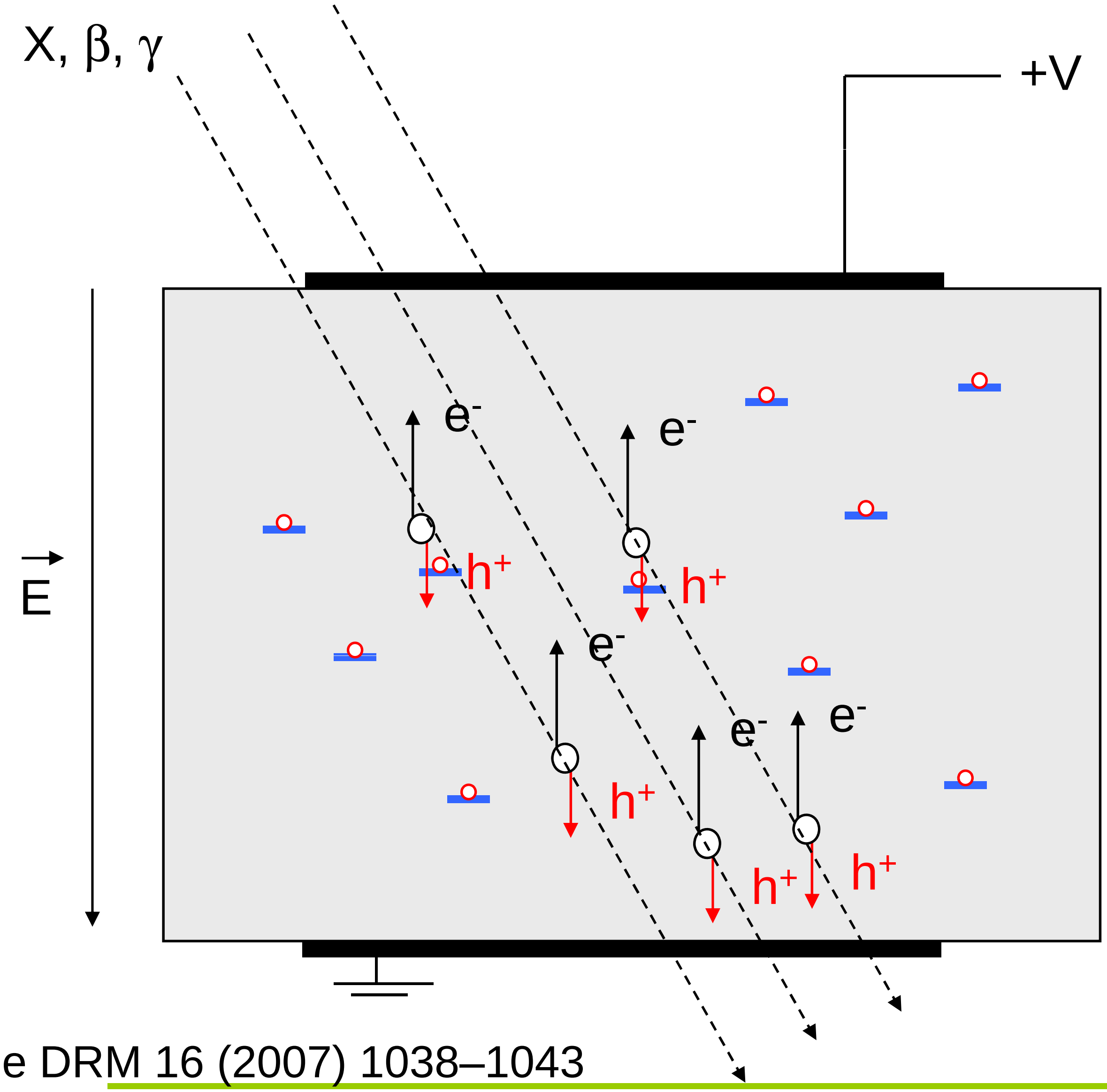
Basics of signal formation

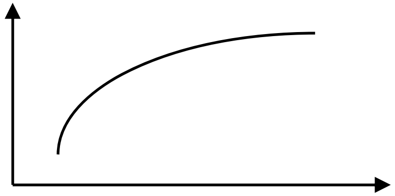



X, β, γ
+V
$\vec{E}$
e-
e-
e-
e-
e-
h+
h+
h+
h+
h+



See DRM 16 (2007) 1038–1043

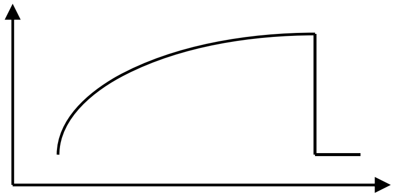


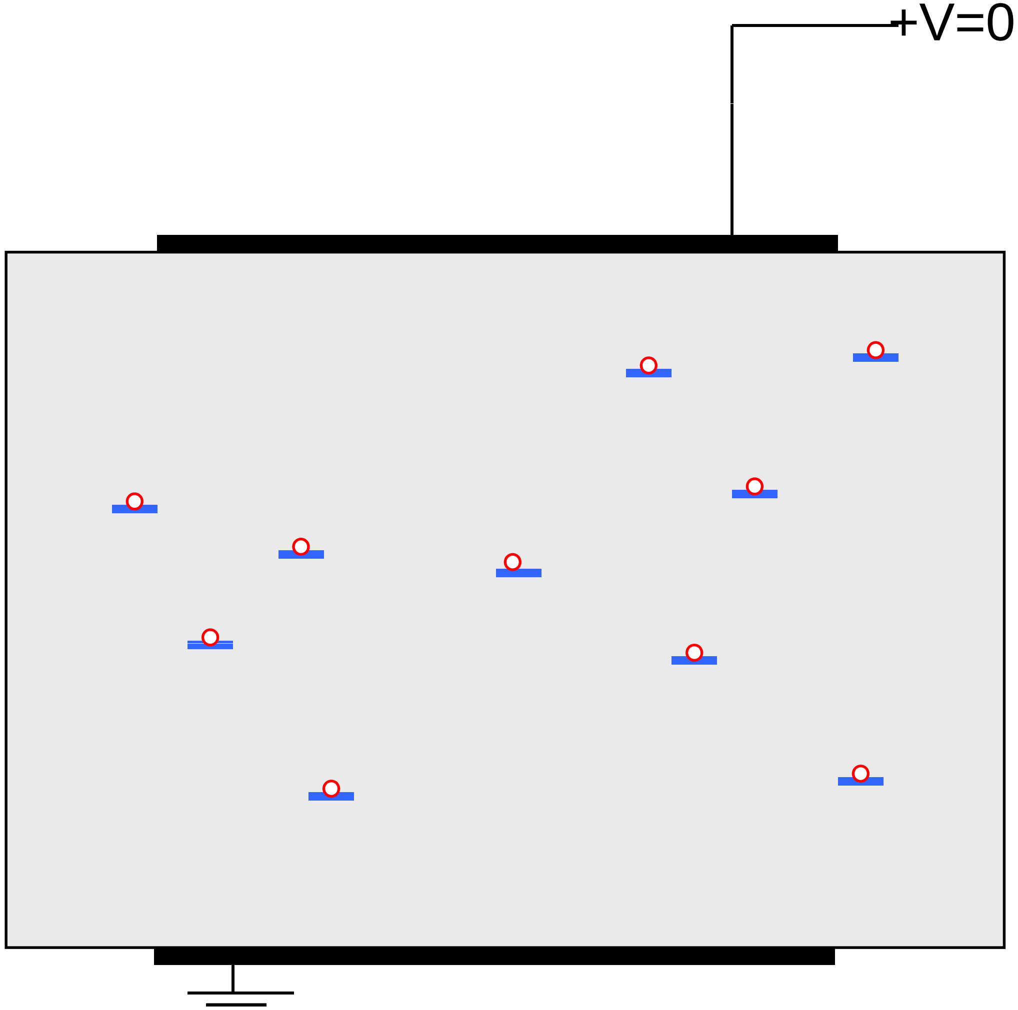


— Deep traps (for holes)

→ Pumping

See DRM 16 (2007) 1038–1043





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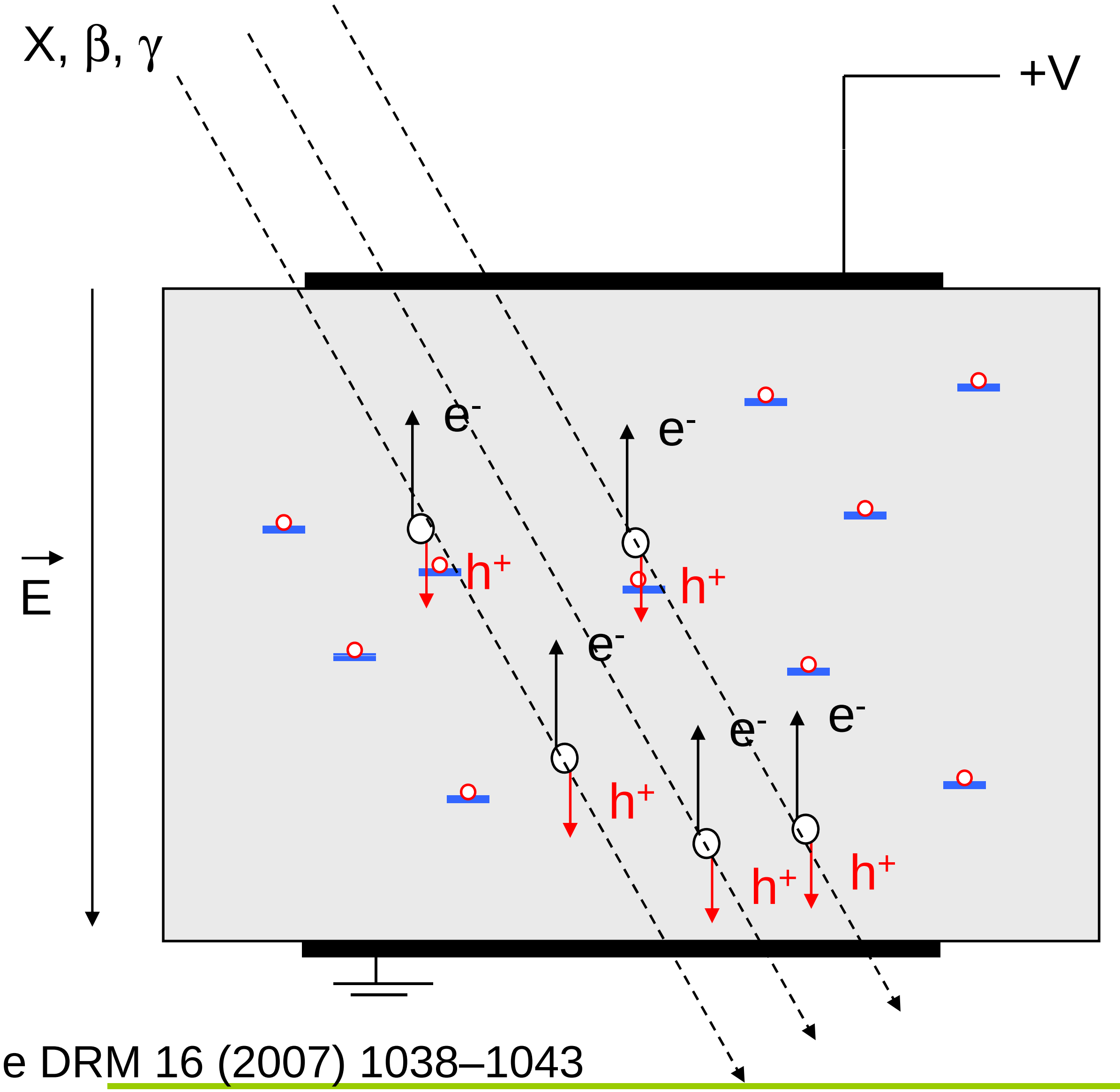

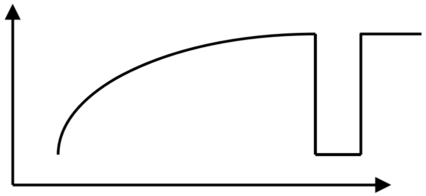

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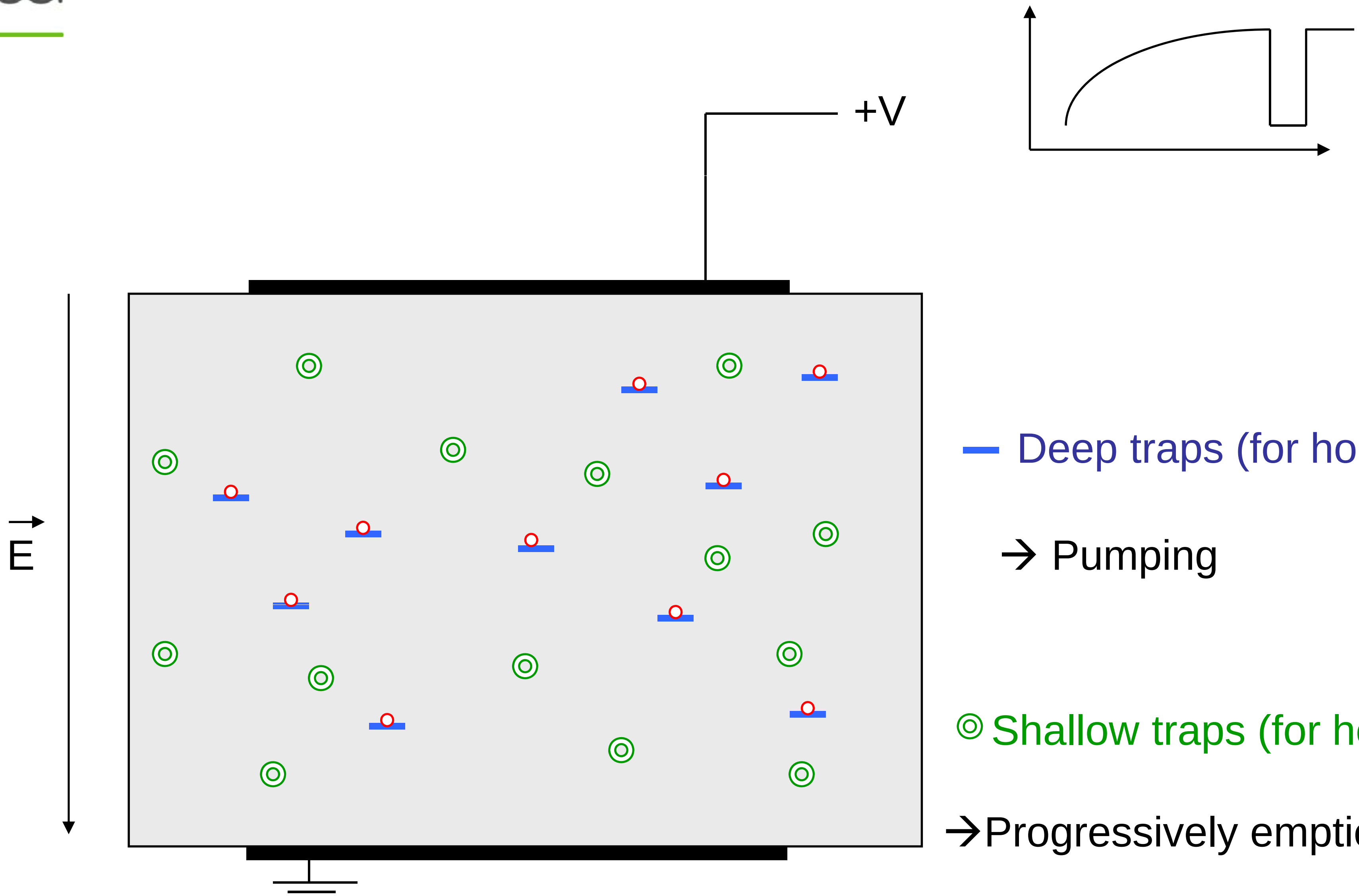

— Deep traps (for holes)

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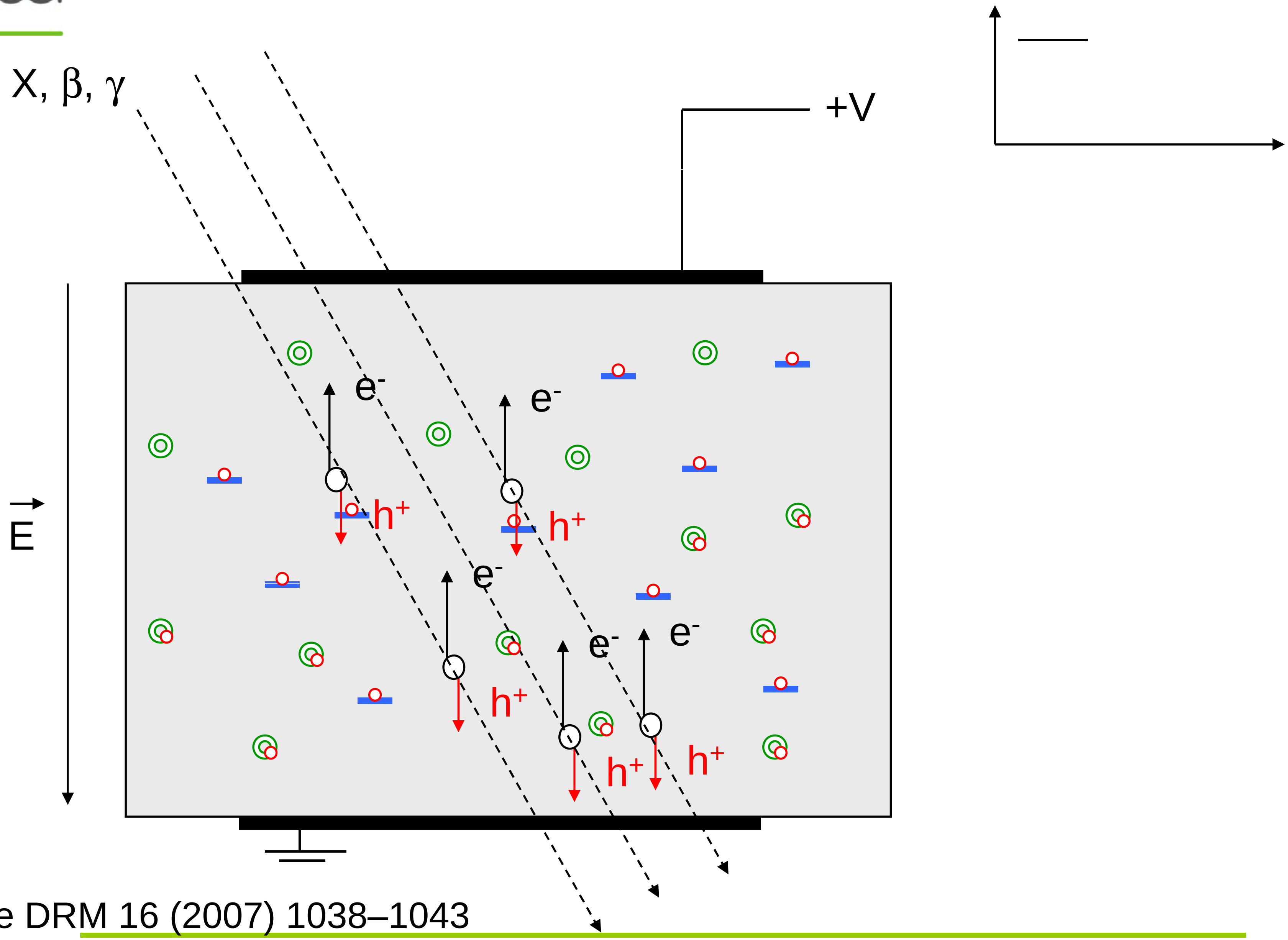
◎ Shallow traps (for holes)

→Progressively emptied

See DRM 16 (2007) 1038–1043



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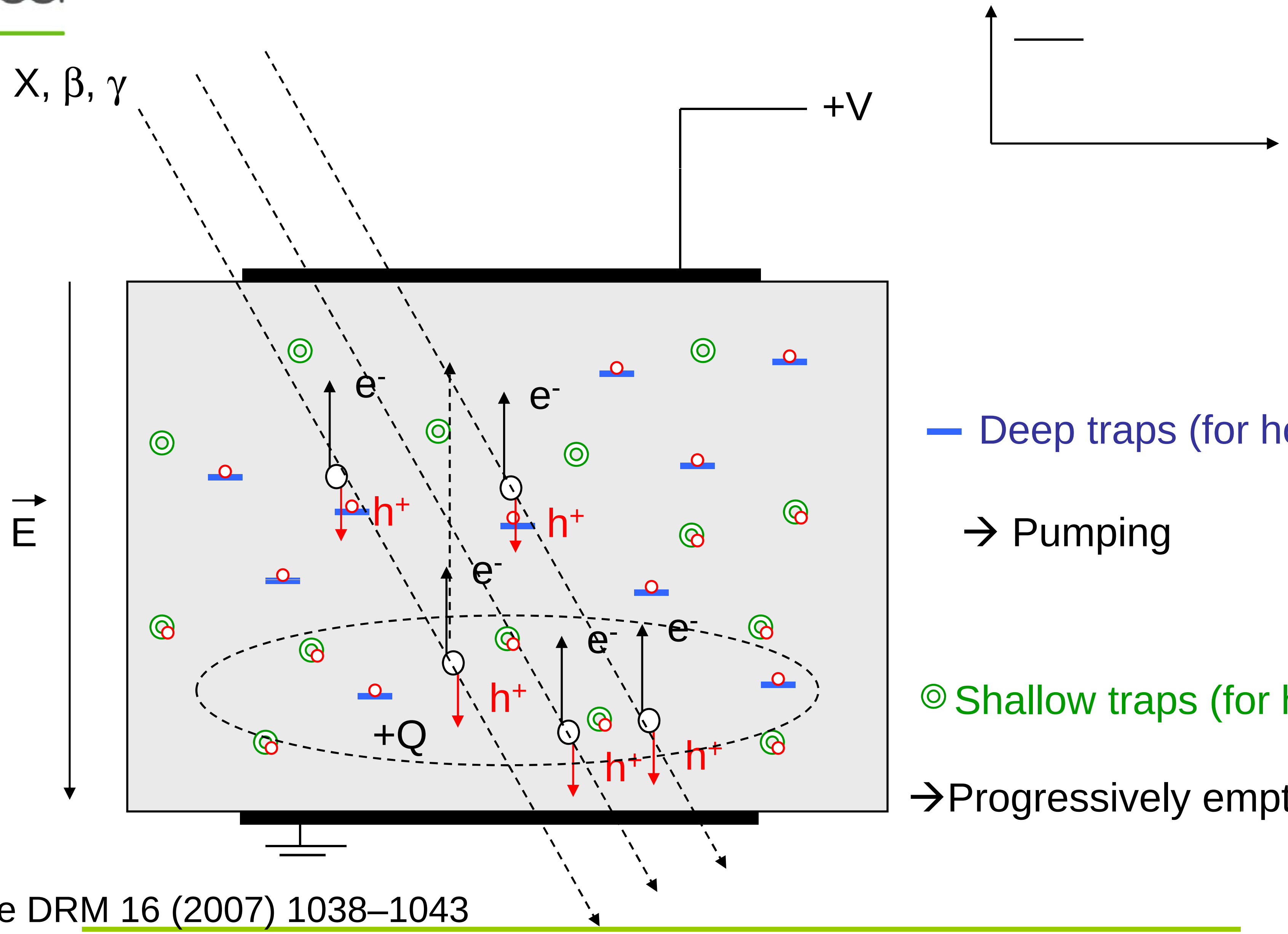

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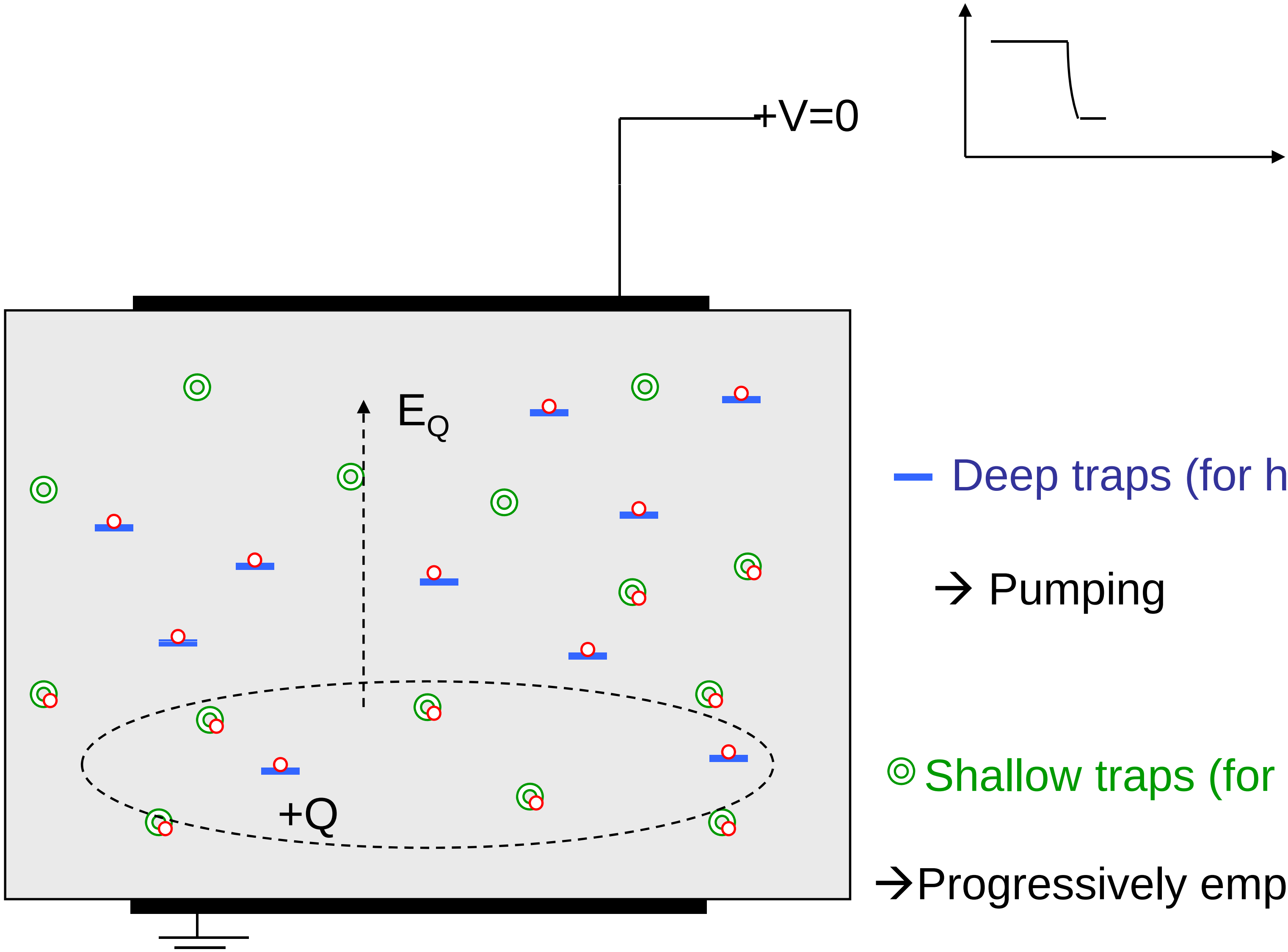

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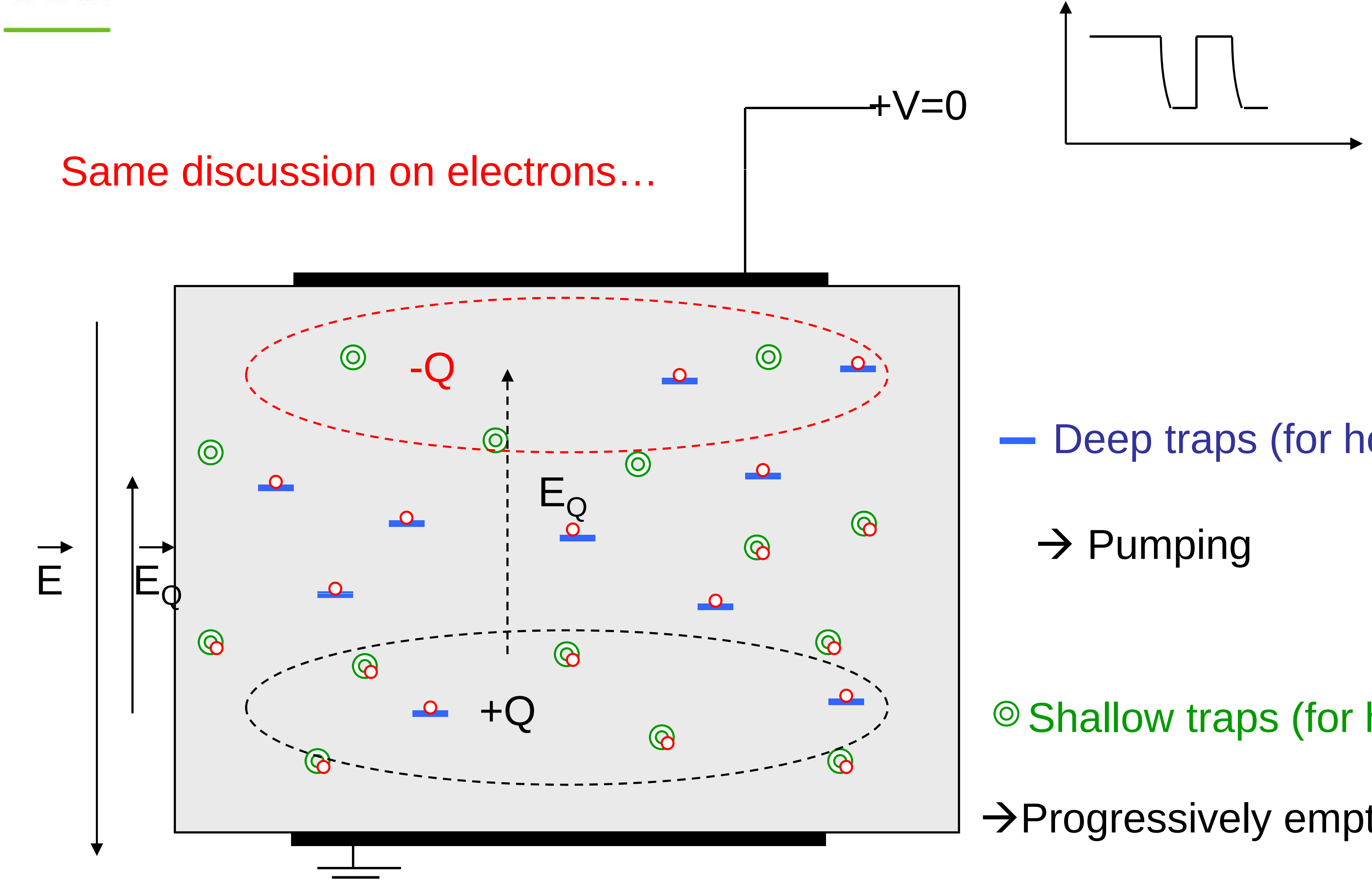
See DRM 16 (2007) 1038–1043

Same discussion on electrons…



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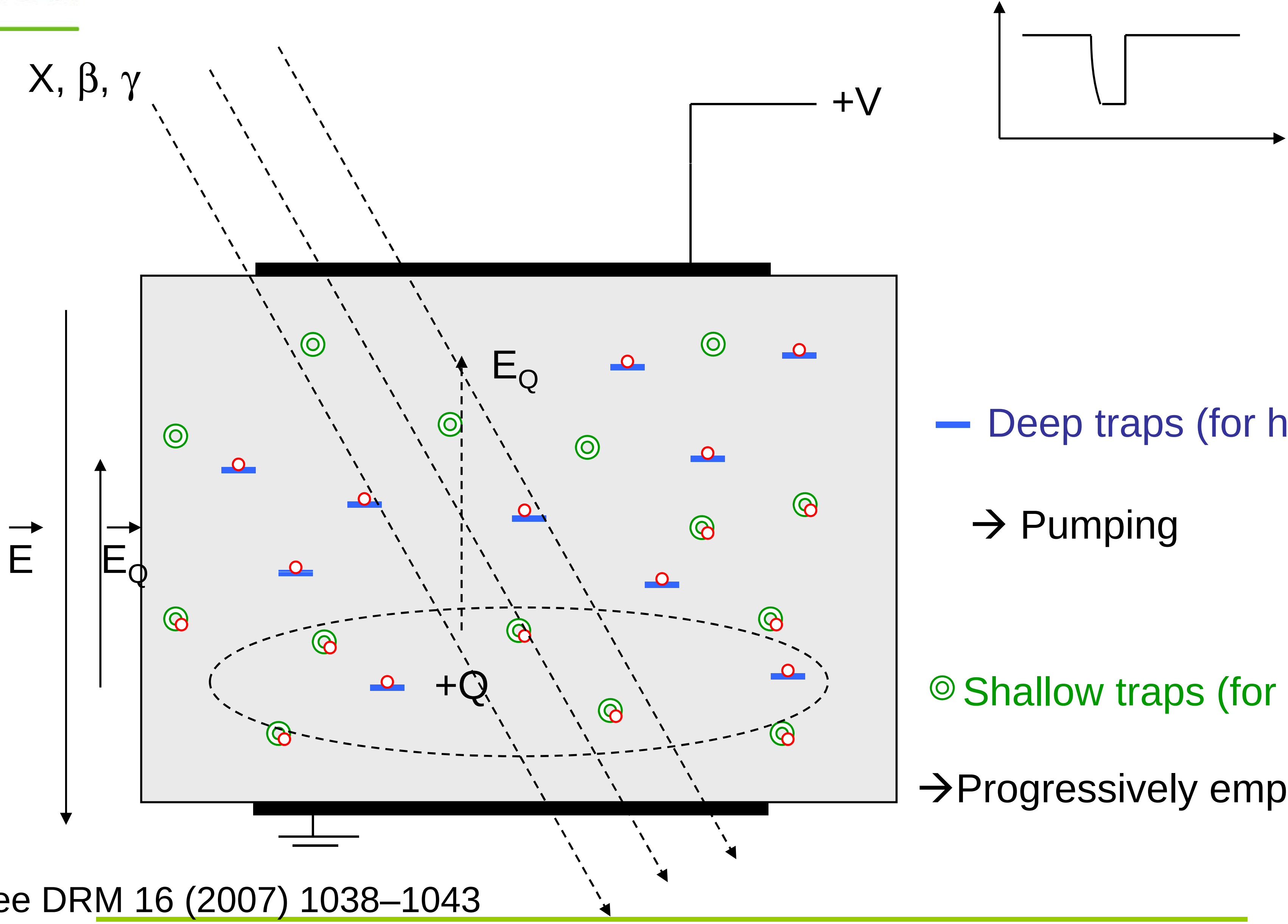

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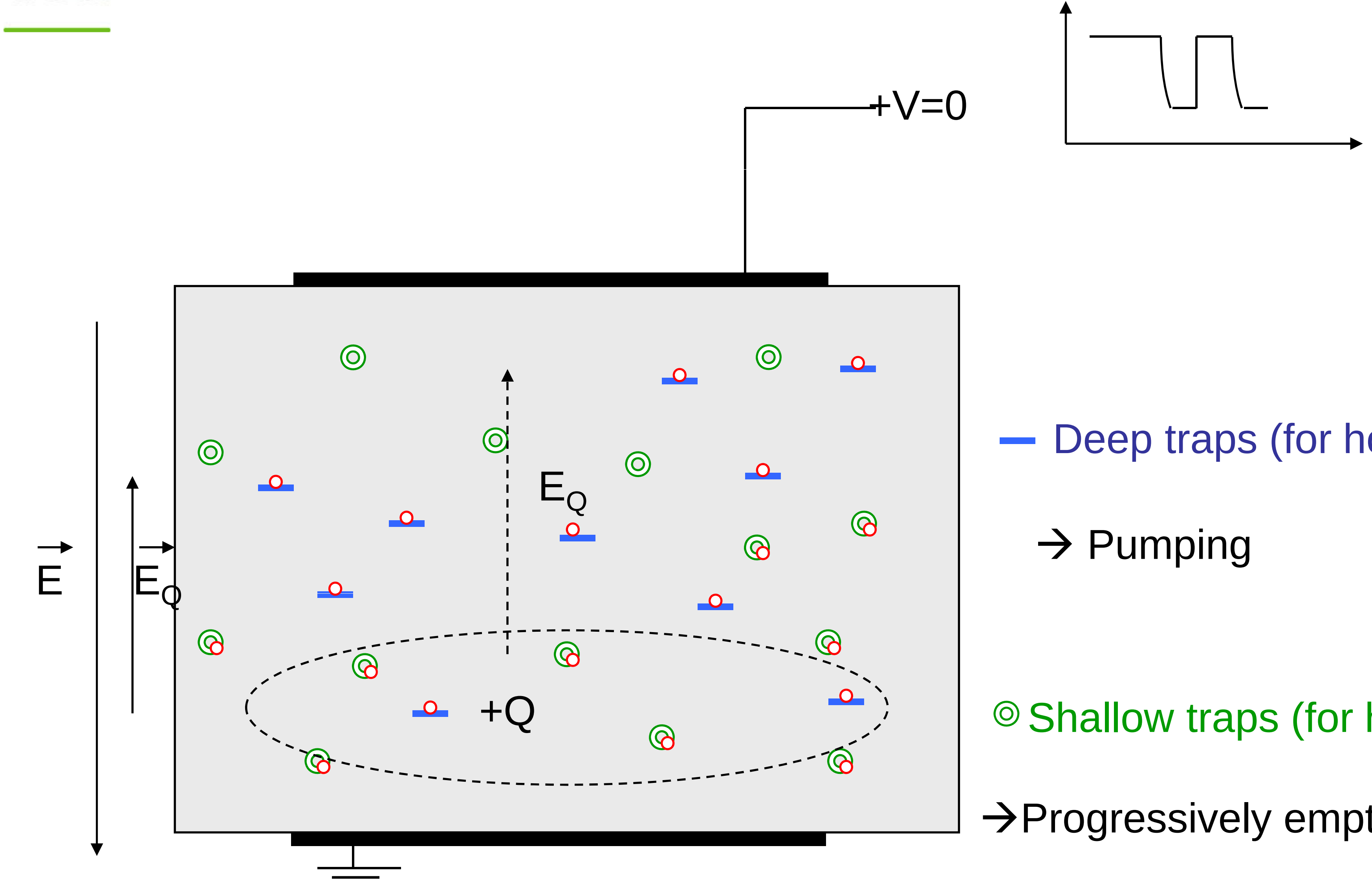

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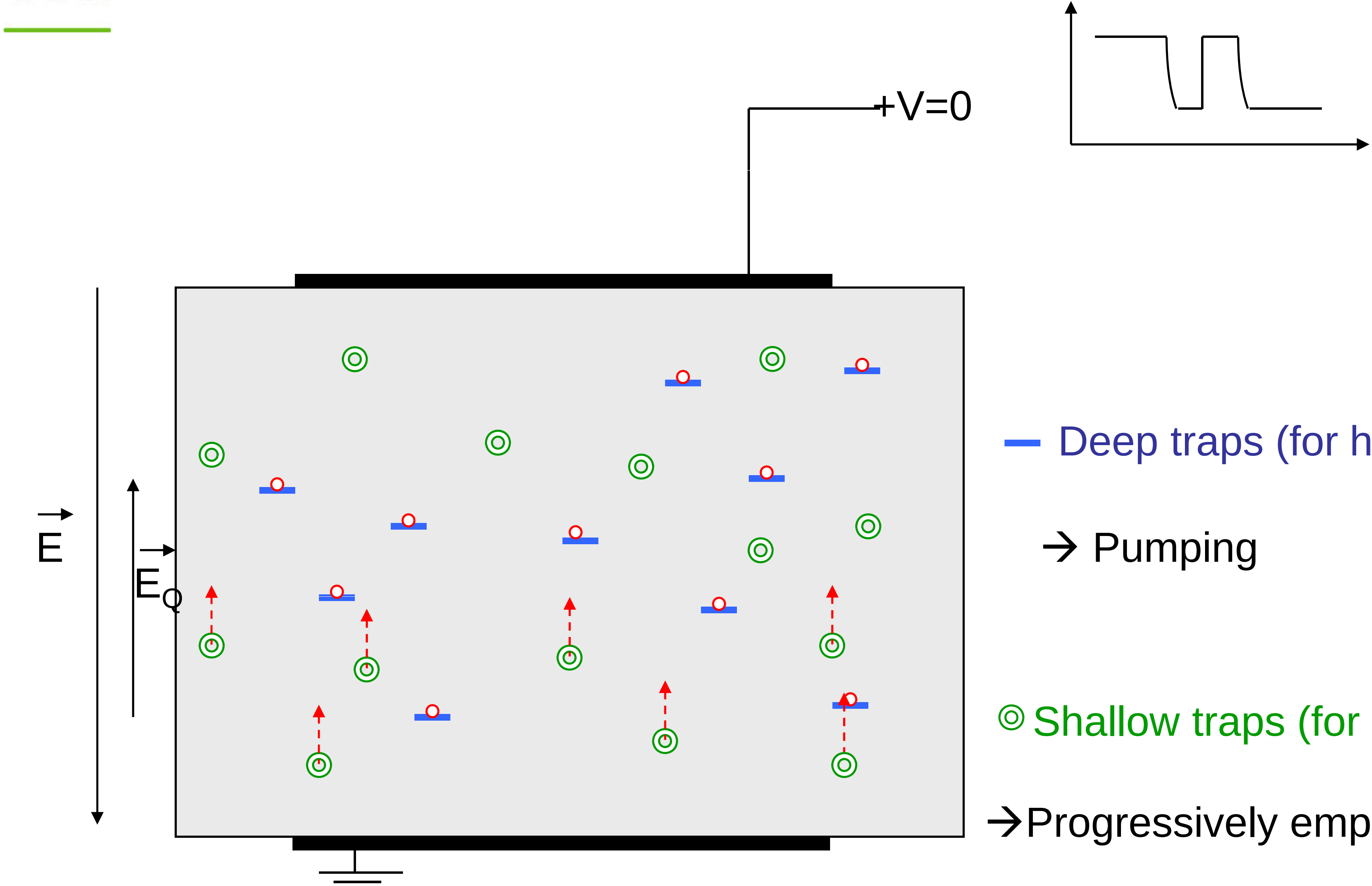

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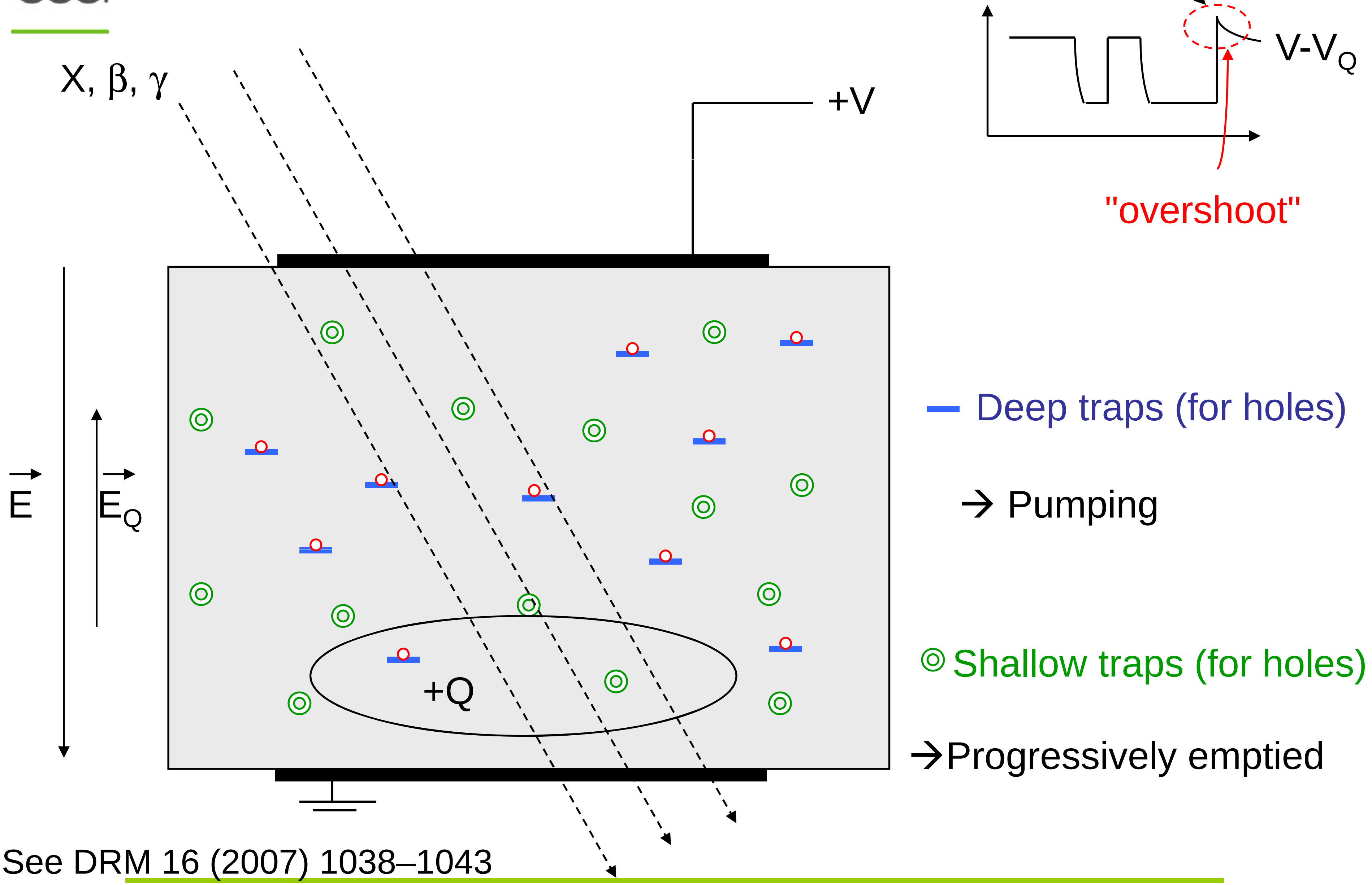

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See DRM 16 (2007) 1038–1043

It comes :

- The ON state is related to an equilibrium between carrier trapping and de-trapping :

- Sensitivity is strongly affected by transiting charges

- Equilibrium also varies with dose levels
  → Non linearities

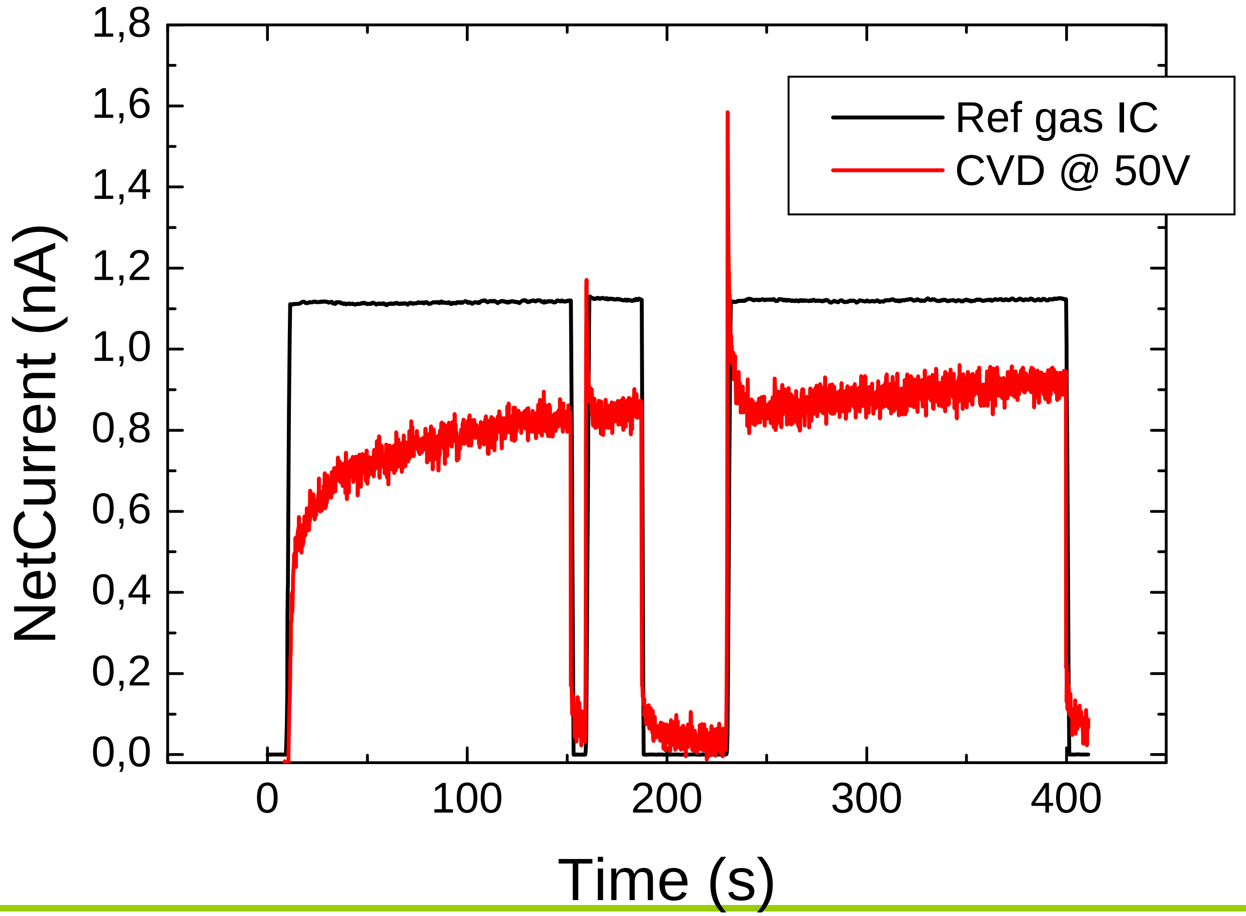
- Stability is strongly varying with the device temperature :

→ This is one way to improve the signal stability : work at Temperatures at which shallow levels are emptied.
→ OK but not always applicable

See DRM 16 (2007) 1038–1043

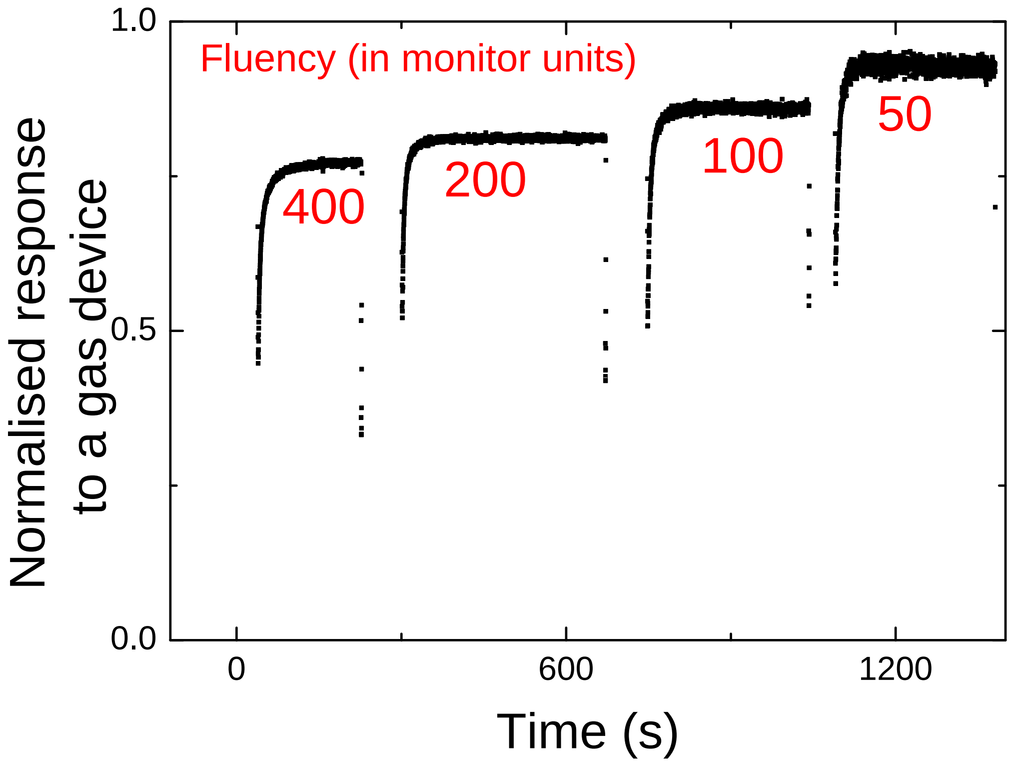
Steady state measurements

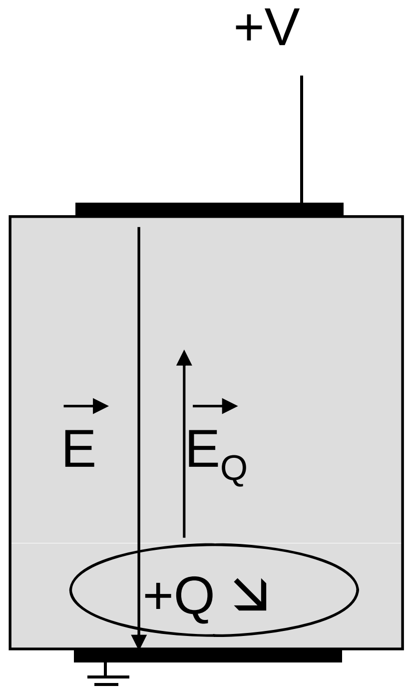
Experiments performed under 6 MeV photon beams.
Comparing a diamond device to a reference gas ionisation chamber
Typ. dose rate is = 3Gy/min



Effect of the dose rate

E_Q is only created by the carriers transiting through the device
→ Therefore the greater the signal the greater E_Q

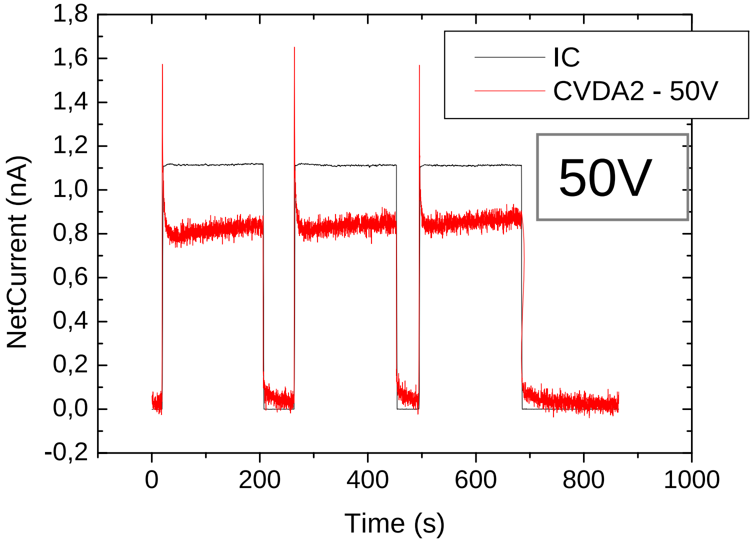


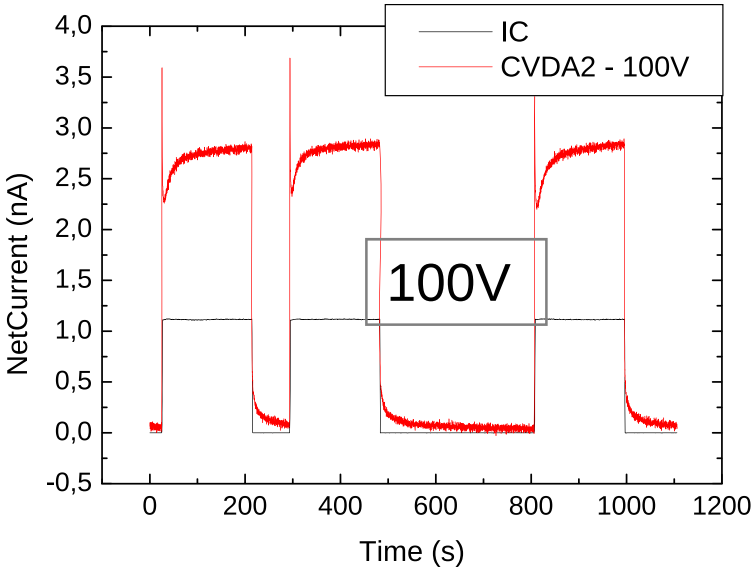


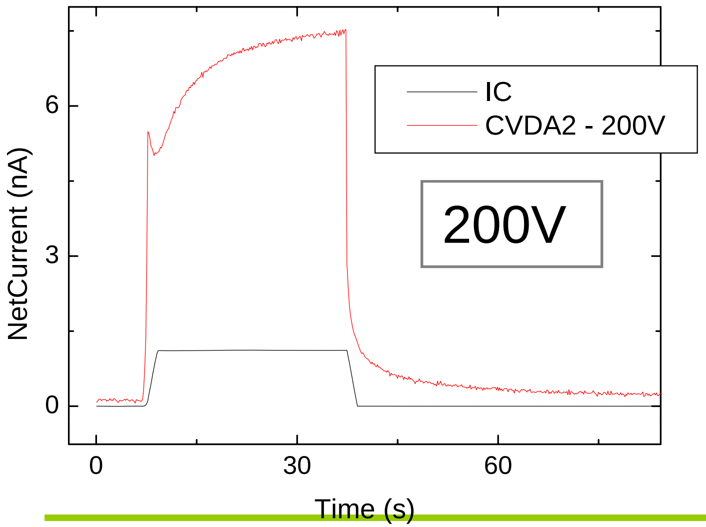
→The lower the fluency, the lower the signal :
→ the lower the trapped charge,
→ higher signals after stabilisation (E$_Q$ vanishes)

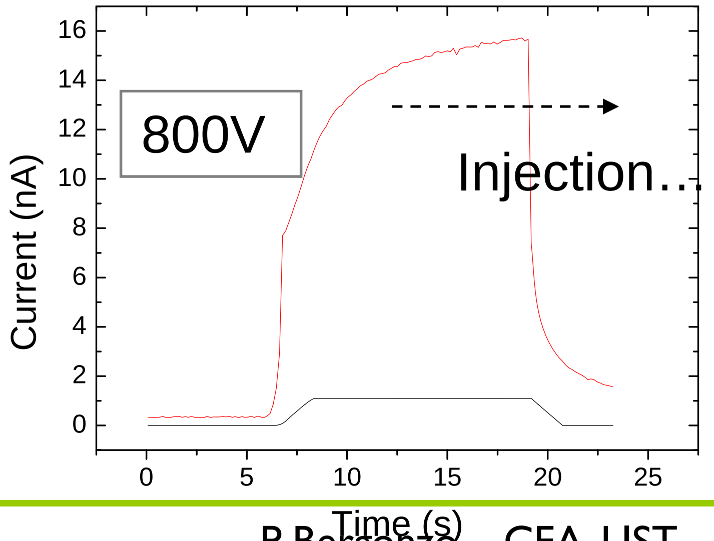
Effect of the E field

At low E fields, the overshoot is predominant, and vanishes at high E fields









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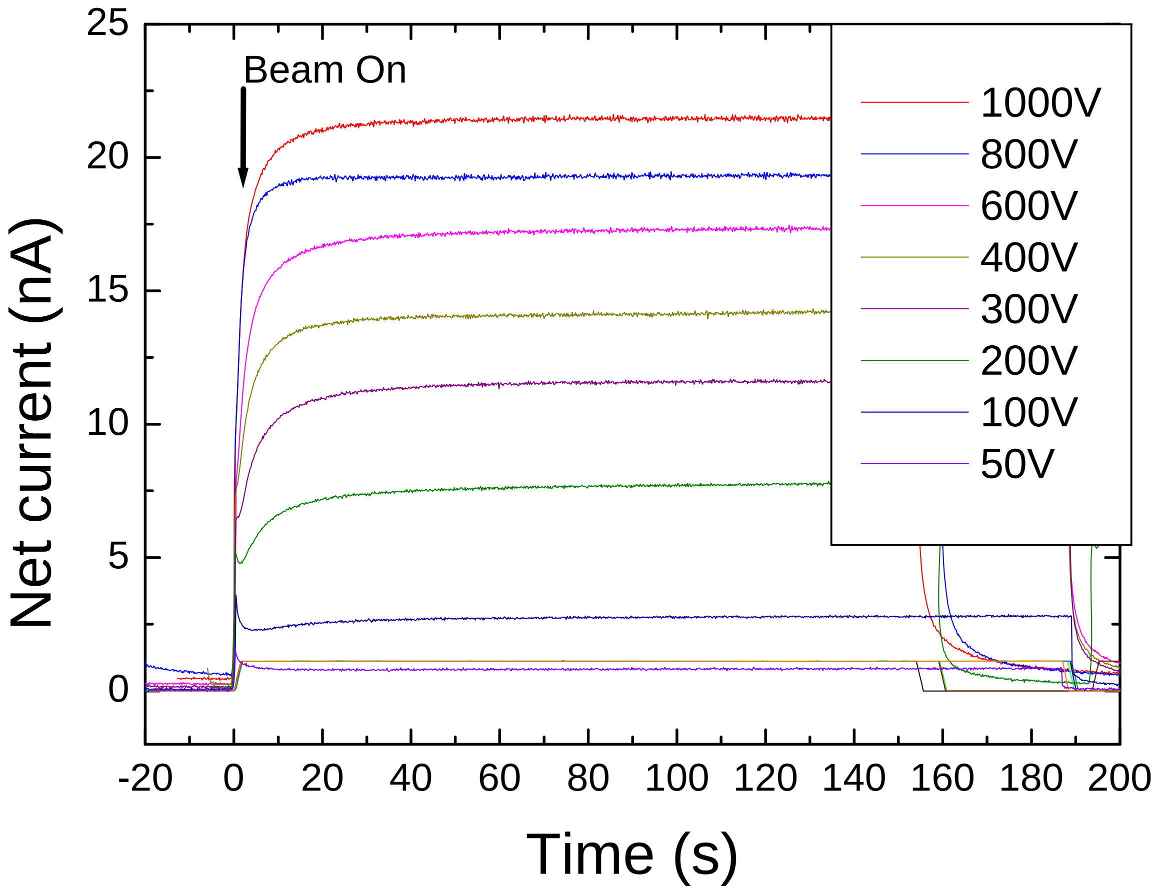

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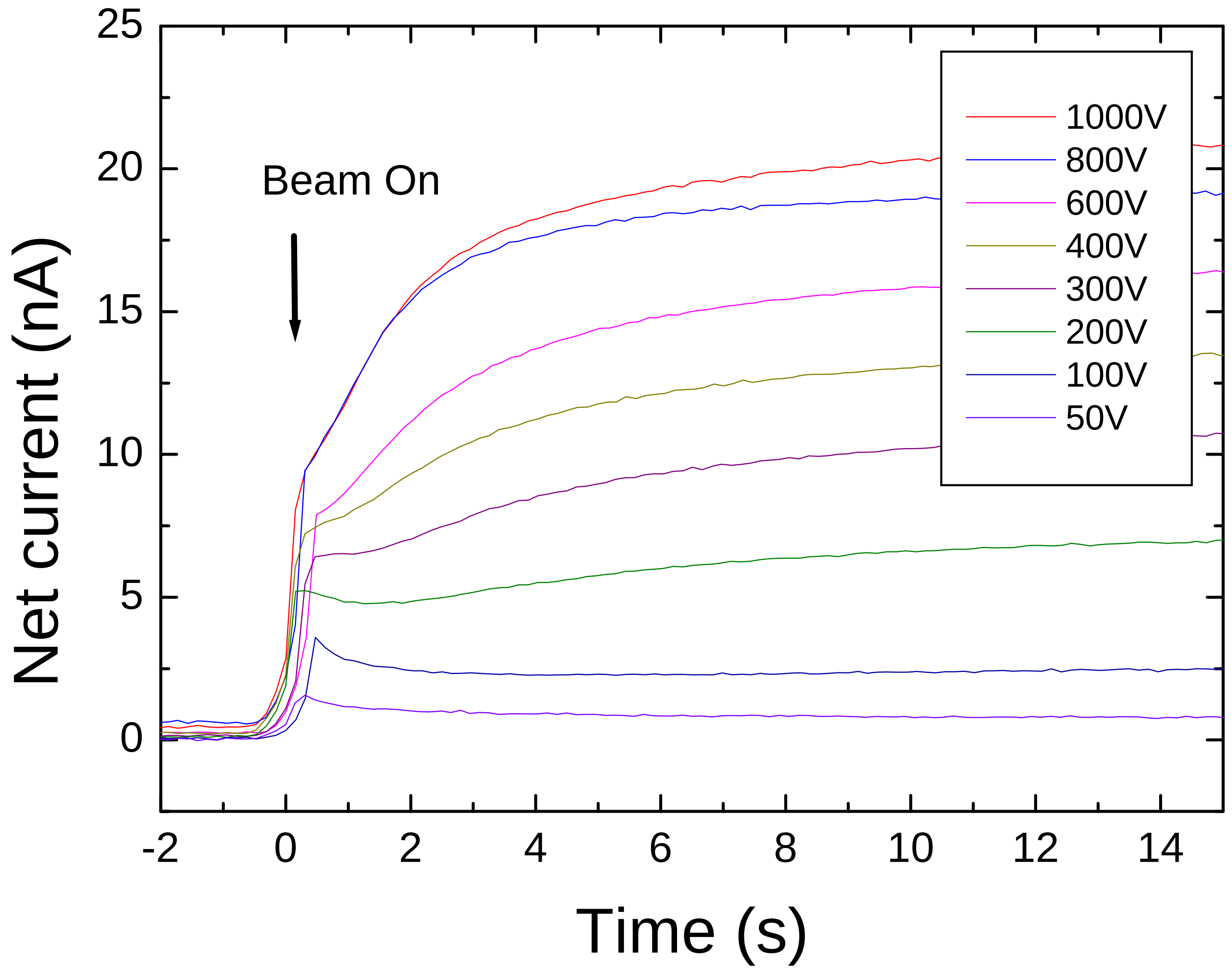
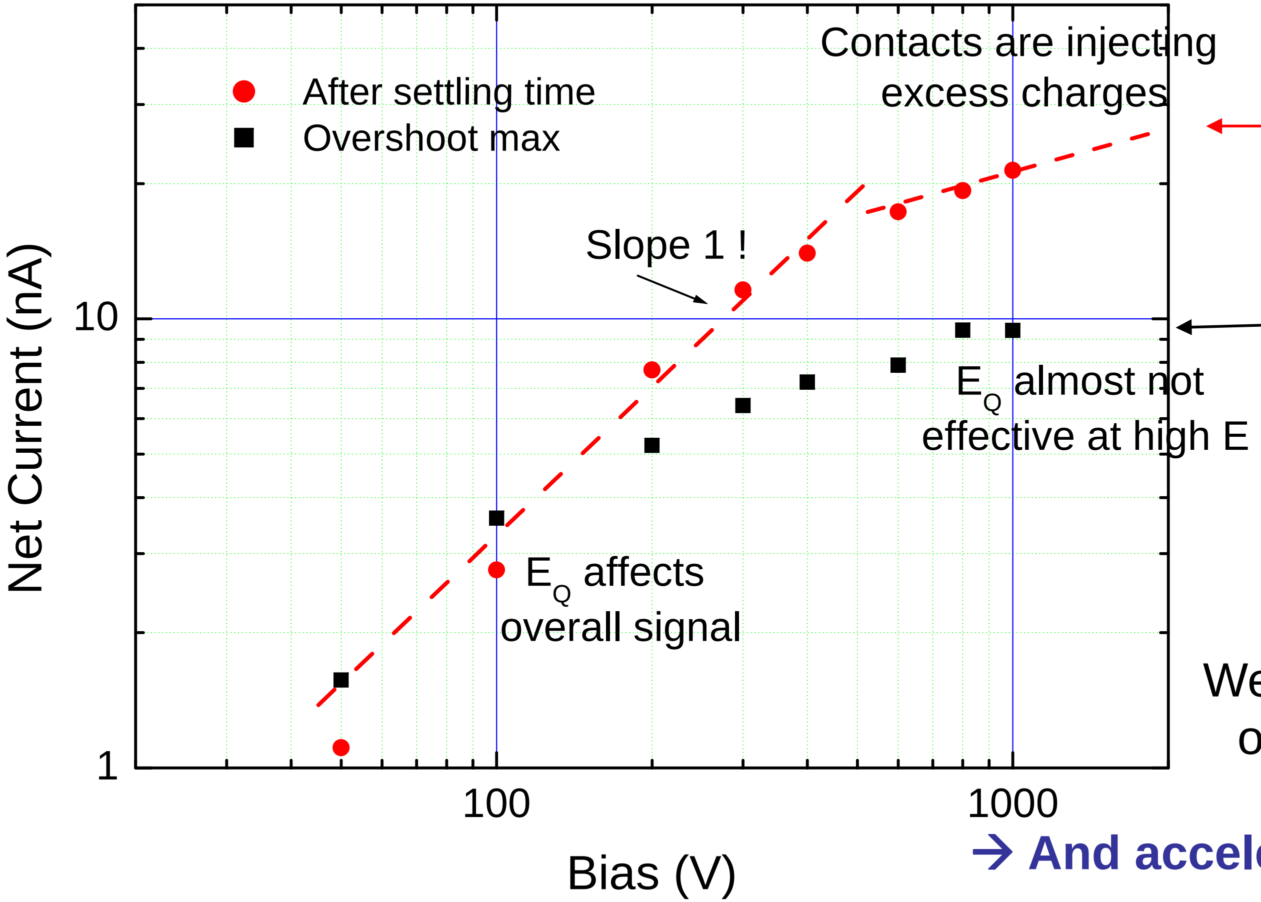


Effect of the E field

The overshoot is caused by the absence of E_Q, and drops during E_Q build-up.
However E_Q is only created by the carriers transiting through the device
→ Therefore the greater the signal the faster the overshoot drops



Over estimation ?

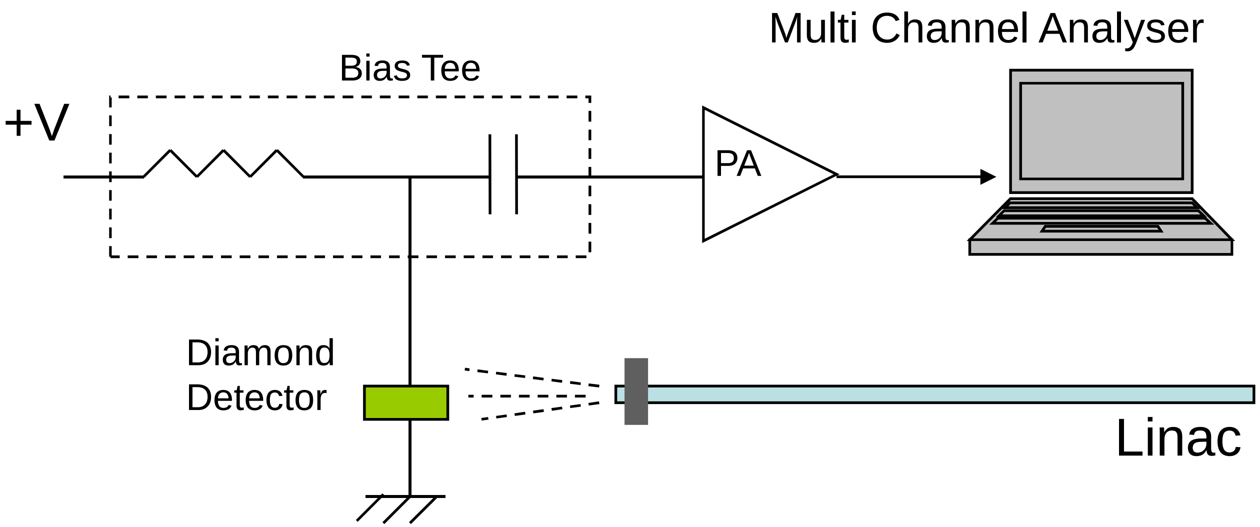
Saturation :
here is the real signal

We have a precise response
on short pulses !

→ And accelerators are often pulsed !

Response to a pulsed excitation

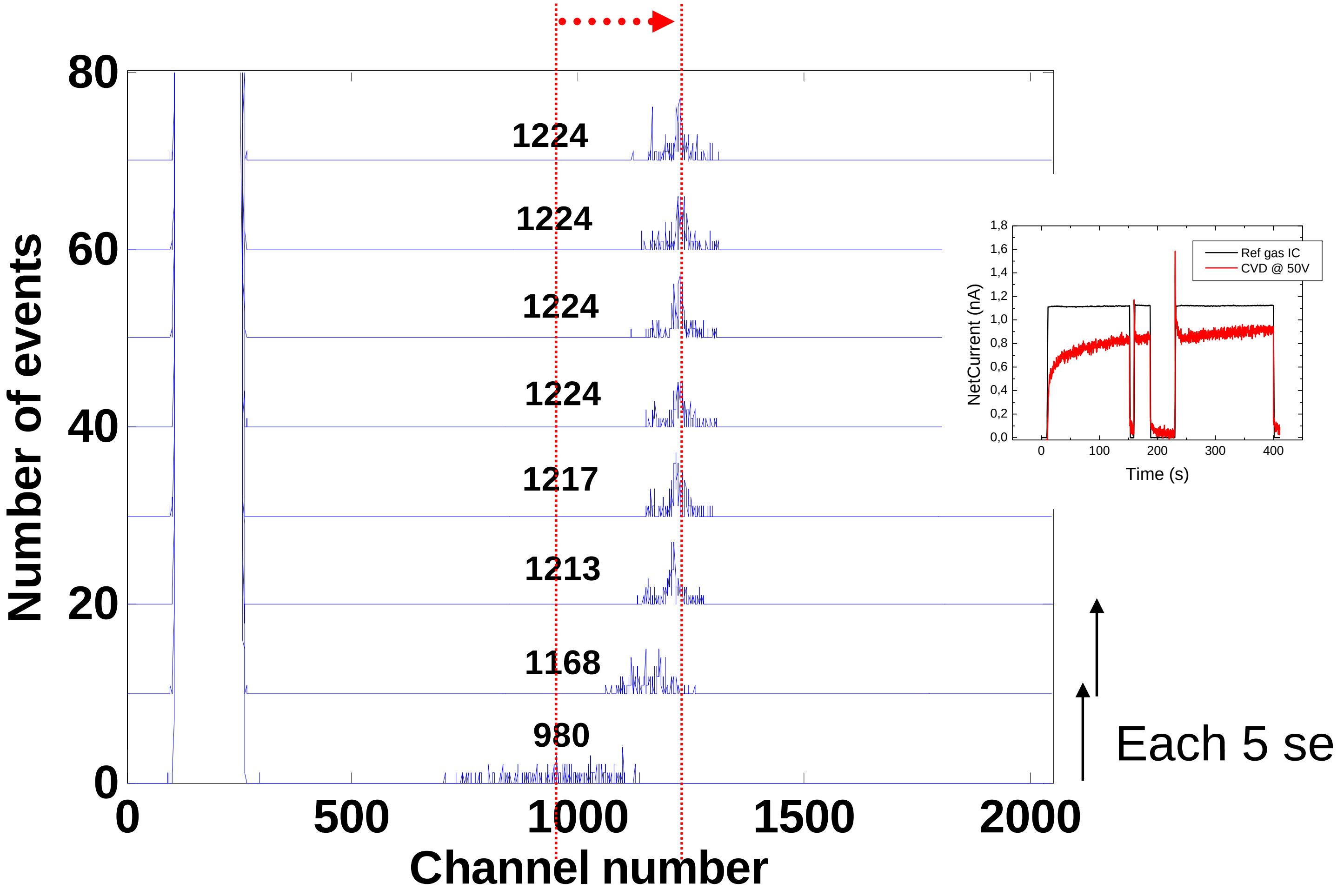
Tests on the SAPHIR accelerator (Saclay)
Pulsed X-rays, 17MV accelerator
Pulses are 2µs long, at 25 Hz



Pulsed height spectra under DC bias

Bias is 0.5 V/µm

priming

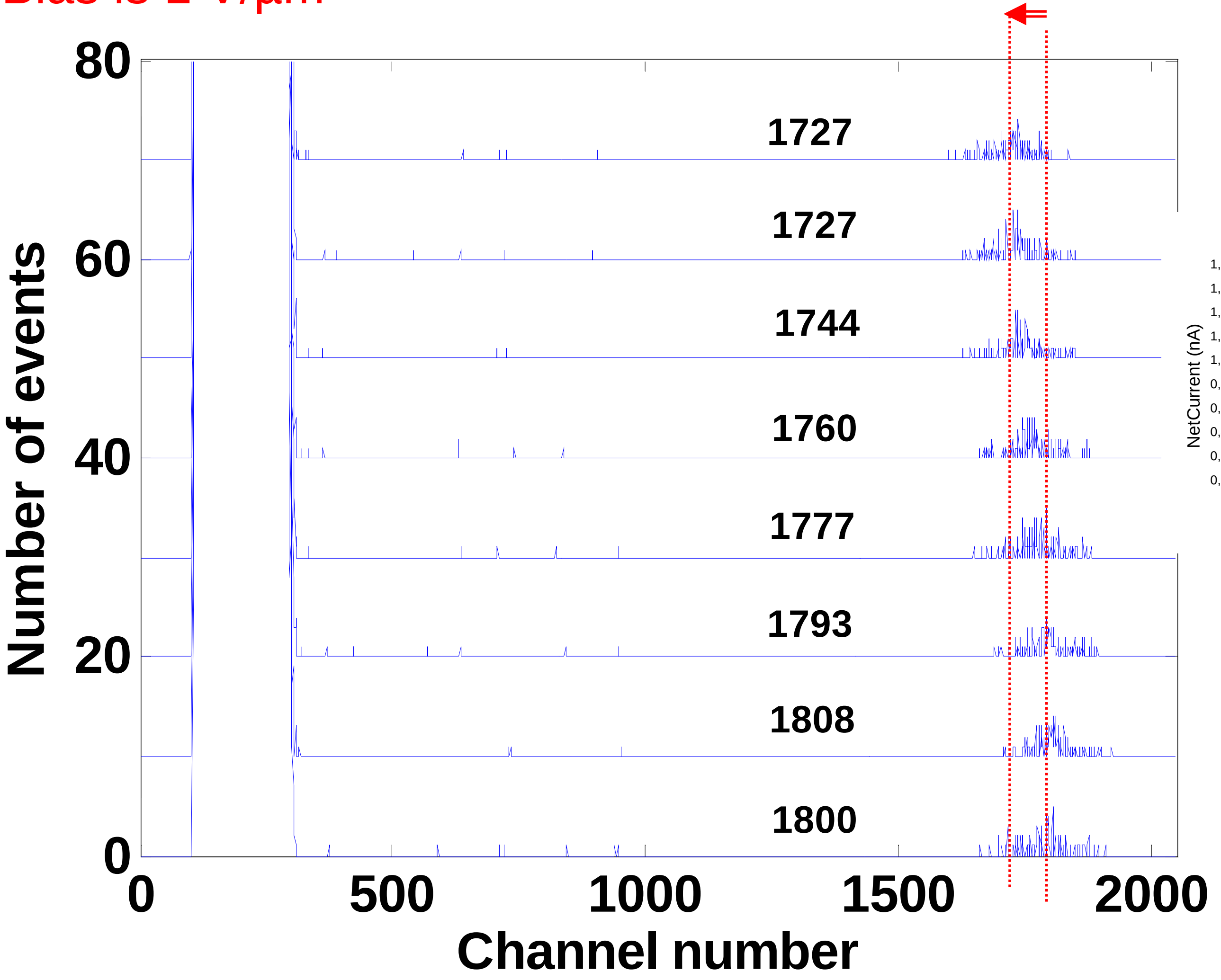


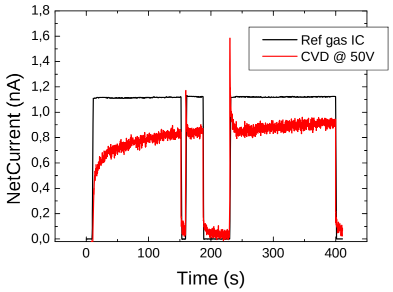
Each 5 sec

Pulsed height spectra under DC bias

Bias is 1 V/µm

Overshoot

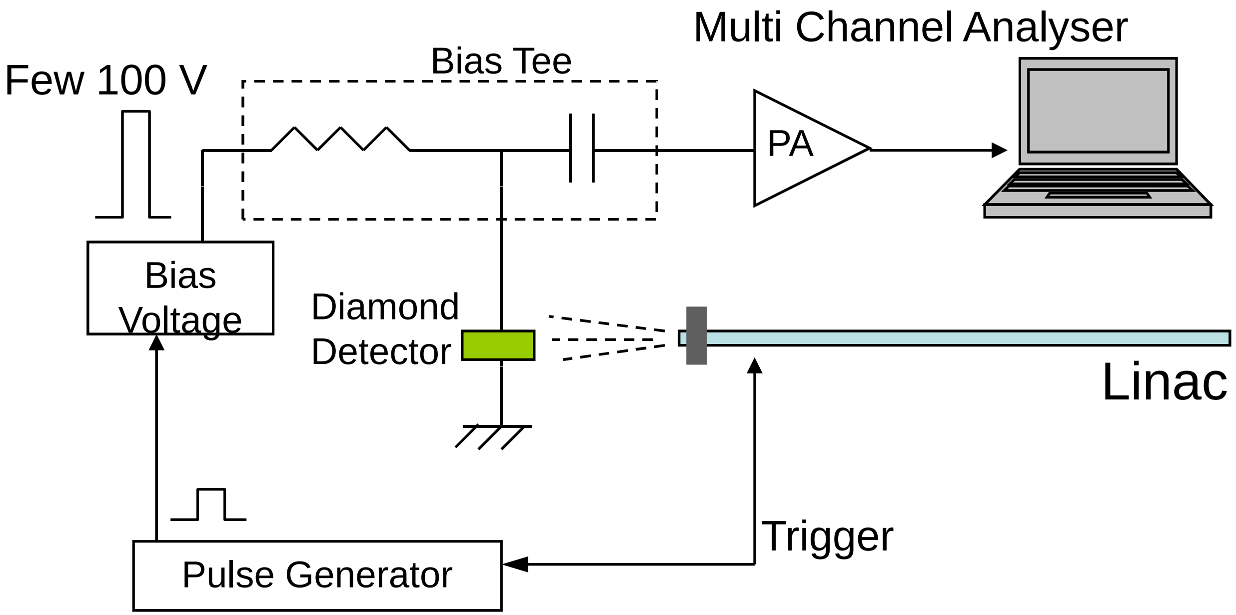


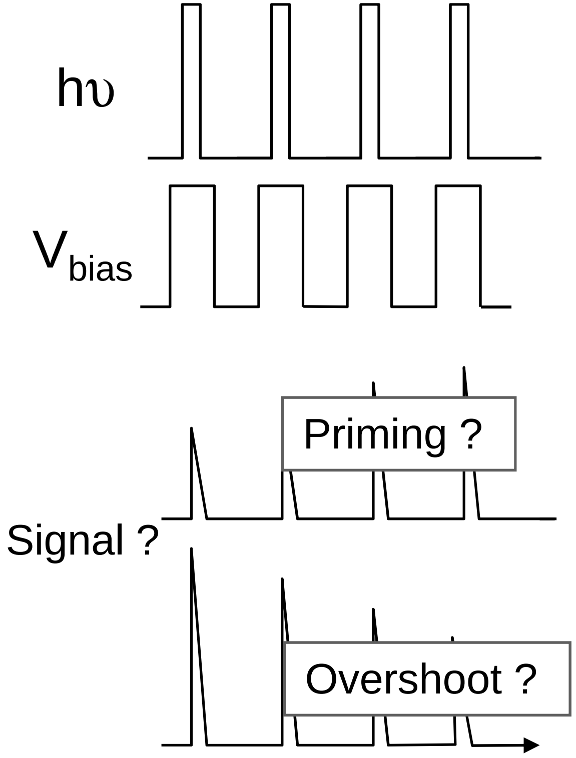


Each 5 sec

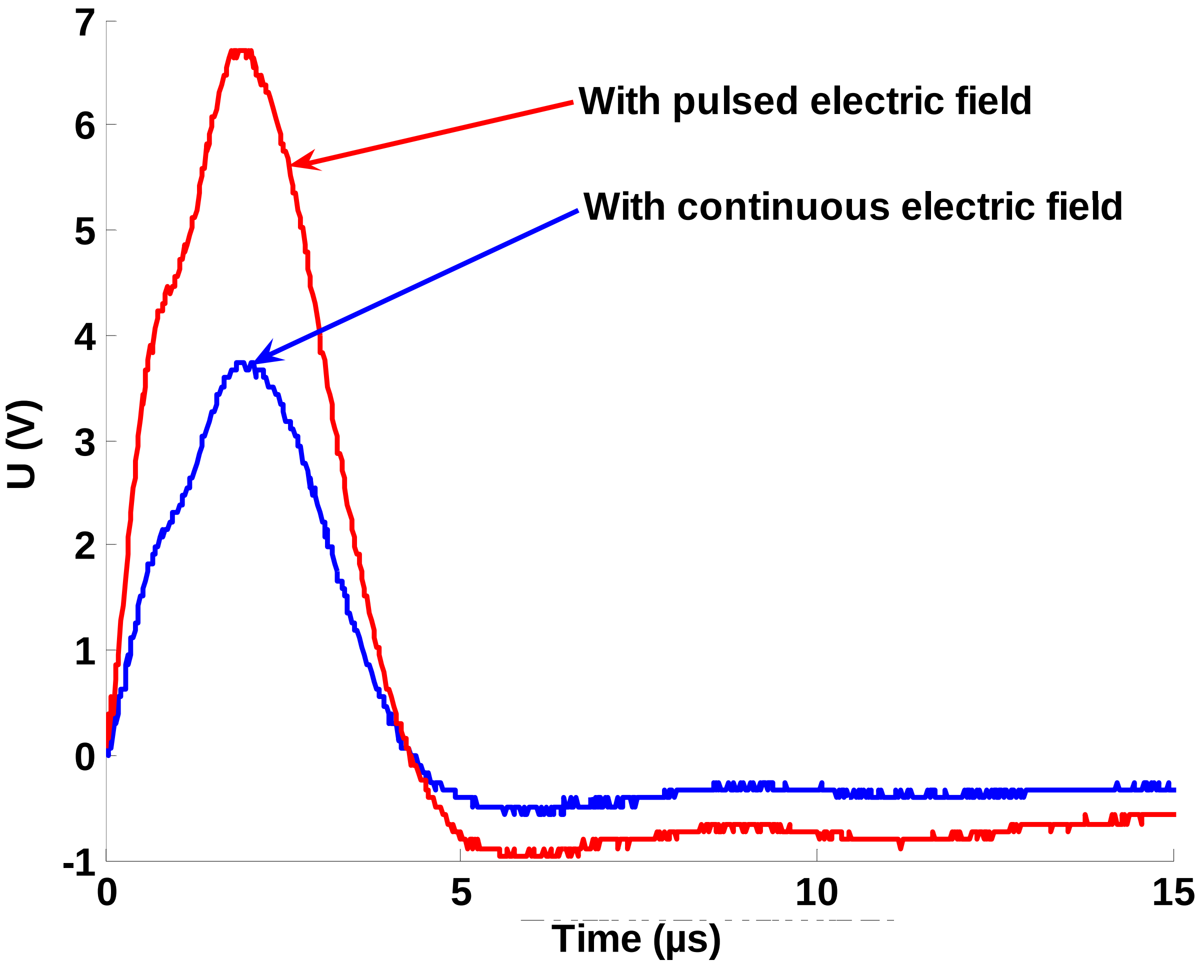
Response to pulsed excitation

Tests on the SAPHIR accelerator (Saclay)
Pulsed X-rays, 17MV accelerator
Pulses are 2µs long, at 25 Hz

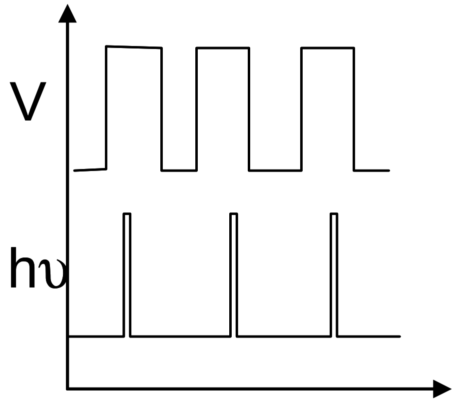




Pulsed height spectra under pulsed bias

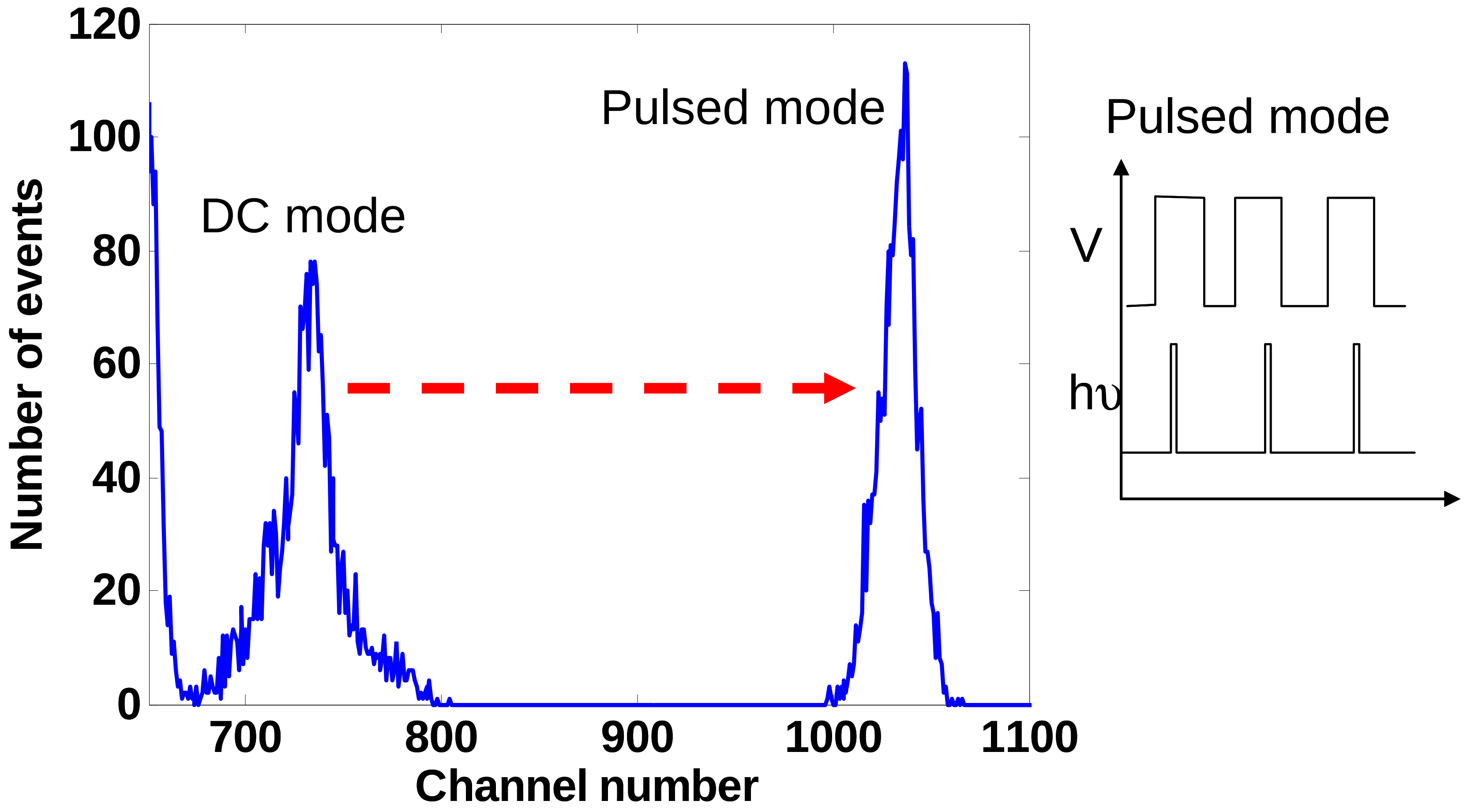


Pulsed mode



➔ Strong improvement of the photosensitivity

Pulsed height spectra under pulsed bias



➔ Strong improvement of the photosensitivity

It comes :

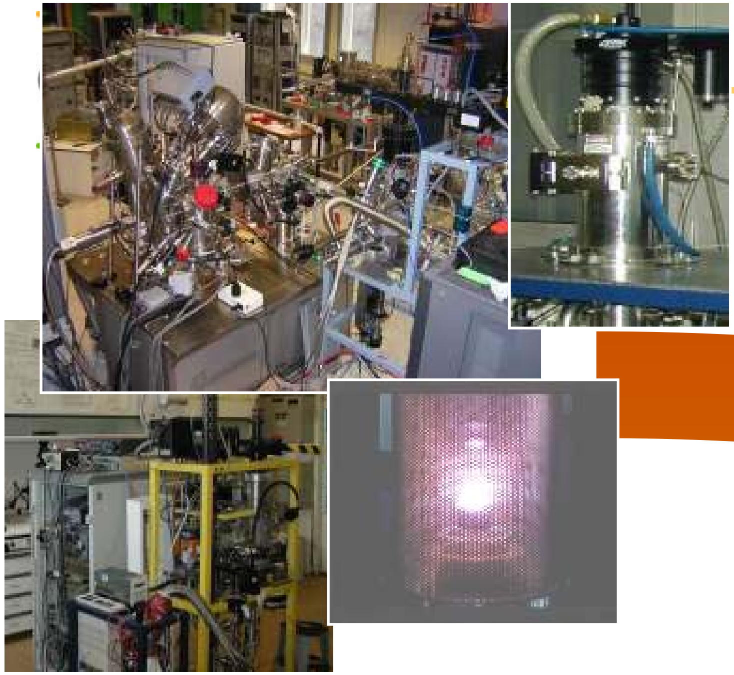
- Shallow levels are effectively altering the photoresponse

- But simply pulsed biases improve the response stability

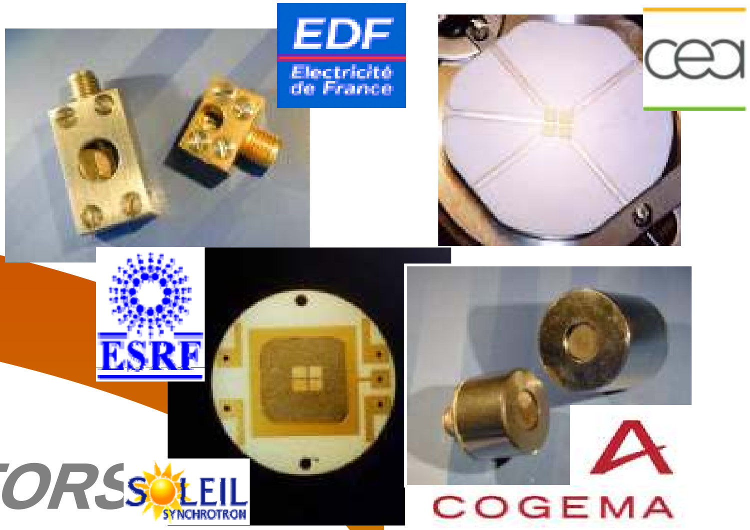
→ Unstable effects are observed in polyX devices

→ they are not constituting a problem when pulsed excitations are used !!

Diamond at LIST in Saclay



PROCESS



DETECTORS and SENSORS

APPLICATIONS

Electronique

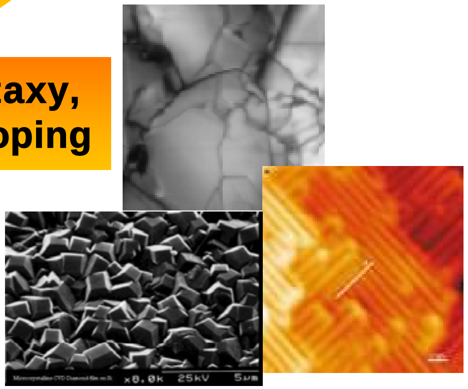
Extreme environments

Interfaces

Bio fonctionnalisation

Sensors and transducers

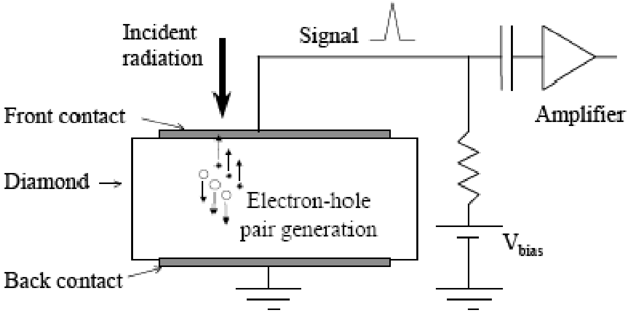
R&D on épitaxy,
Single crystal growth, doping



Radiation detection applications devices at CEA

Detectors for Alpha monitoring in corrosive media

Devices for confinment plasma monitoring



Micro -dosimeters

Ultrafast pulse monitors

eavy ion physics

Semi transparent devices For beam monitoring

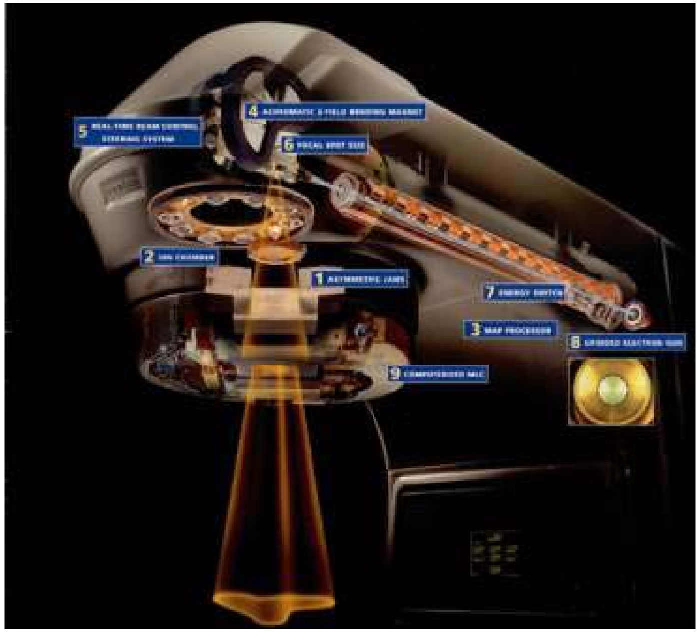
Alpha measurements in corrosive media

- 2004 : delivering devices to the Rokkasho Mura reprocessing plant

- Application : On-line alpha measurement

- pros of diamond :
  withstand extreme conditions
  (HNO_3, 5N, 5bars, 80°C)

Radiotherapy : Maestro

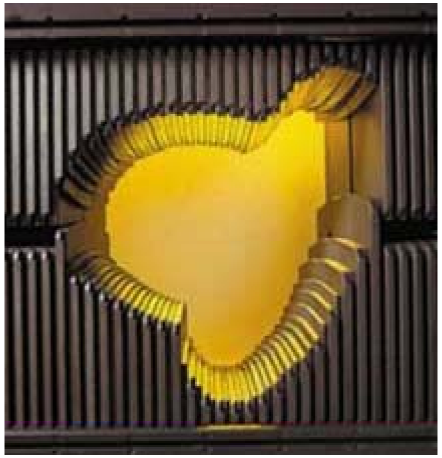


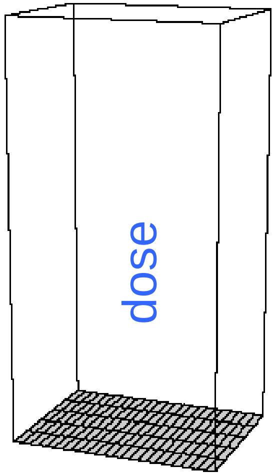
Maestro : EU IP VIth Framework

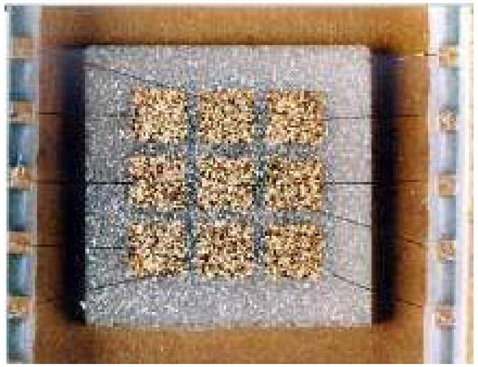
Methods and Advanced Equipment for Simulation and Treatment in Radio Oncology

- Dose resilient
- Tissue equivalent
- Chemically inert
- Compatible with in-vivo
- Arrays

→ **Accurate & real time dose monitoring**

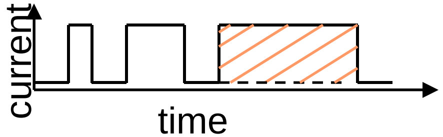




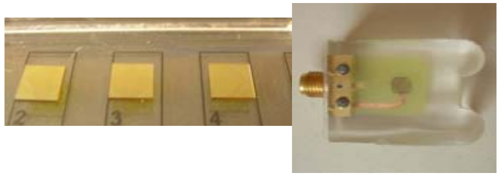


Evaluation of dosimetric parameters for SCDD

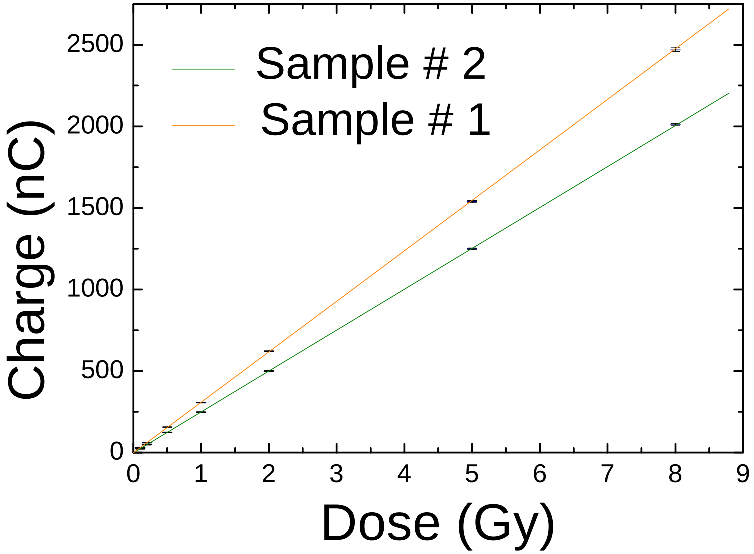
→ Dose dependence

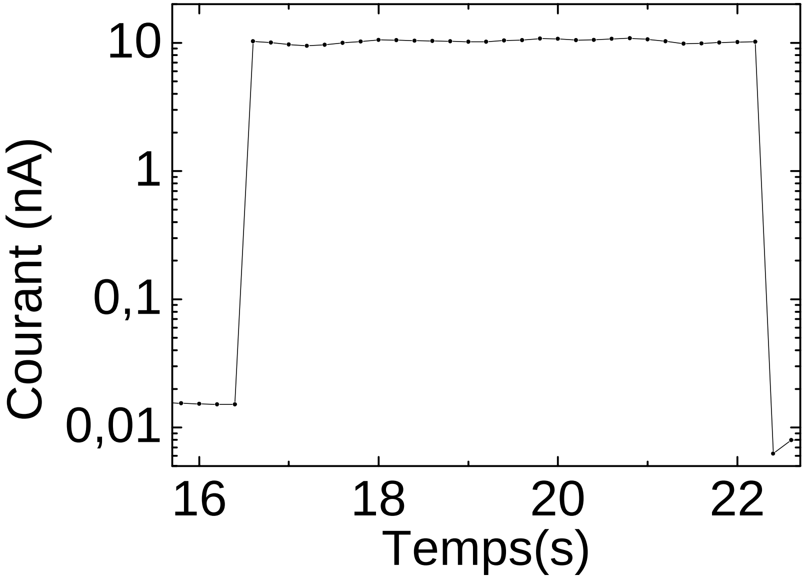


Dose calculated from area
under curve at fixed dose rate



Exp conditions :
2Gy/min - 6MV photons beam
Doses from 0.1 to 8 Gy

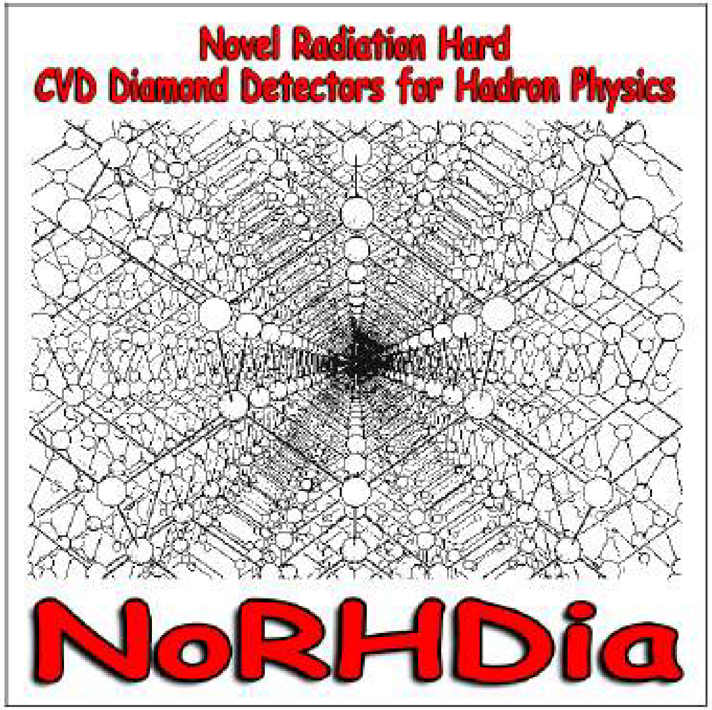




Linear behaviour : R = 0.99999

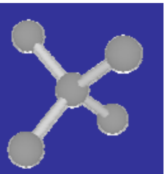
Signal to noise > 1000
Response time < 200ms

Similarly : for heavy ion beams



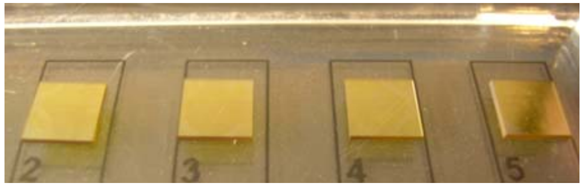
NORHDIA : one of the 29 activity of the I3HP project "Integrated Infrastructure Initiative on Hadron Physics"

- Dose resilient
- Tissue equivalent
- Chemically inert
- Compatible with in-vivo
- Arrays



Real time and accurate monitoring of heavy ion beams (position, fluency, etc)

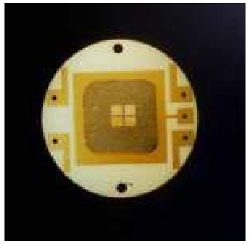
+ EU Network :
INFN, GSI, CERN,
ESRF, DESY, TUM,
Karlsruhe Univ, etc

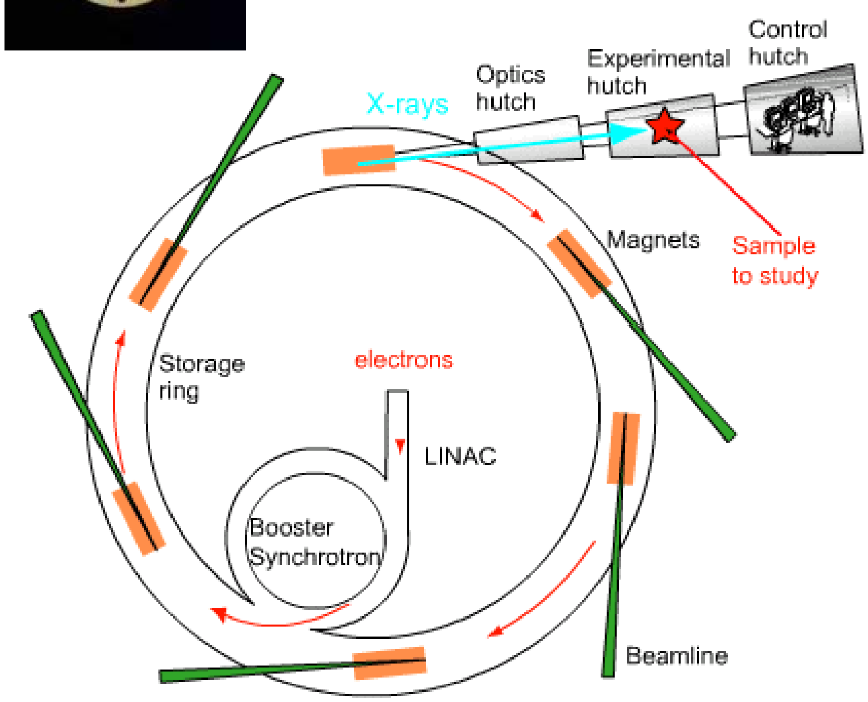


Diamond for synchrotron beam monitoring

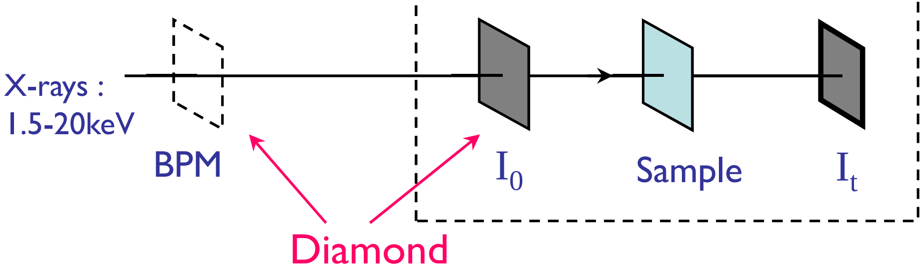
Aiming at probing the beam characterisitics (position, intensity, profile) at low energies and with a semitransparent material

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





J. Synchrotron Radiation, Vol. 13 (2) 151-158 (2006)



Monitoring devices must exhibit :

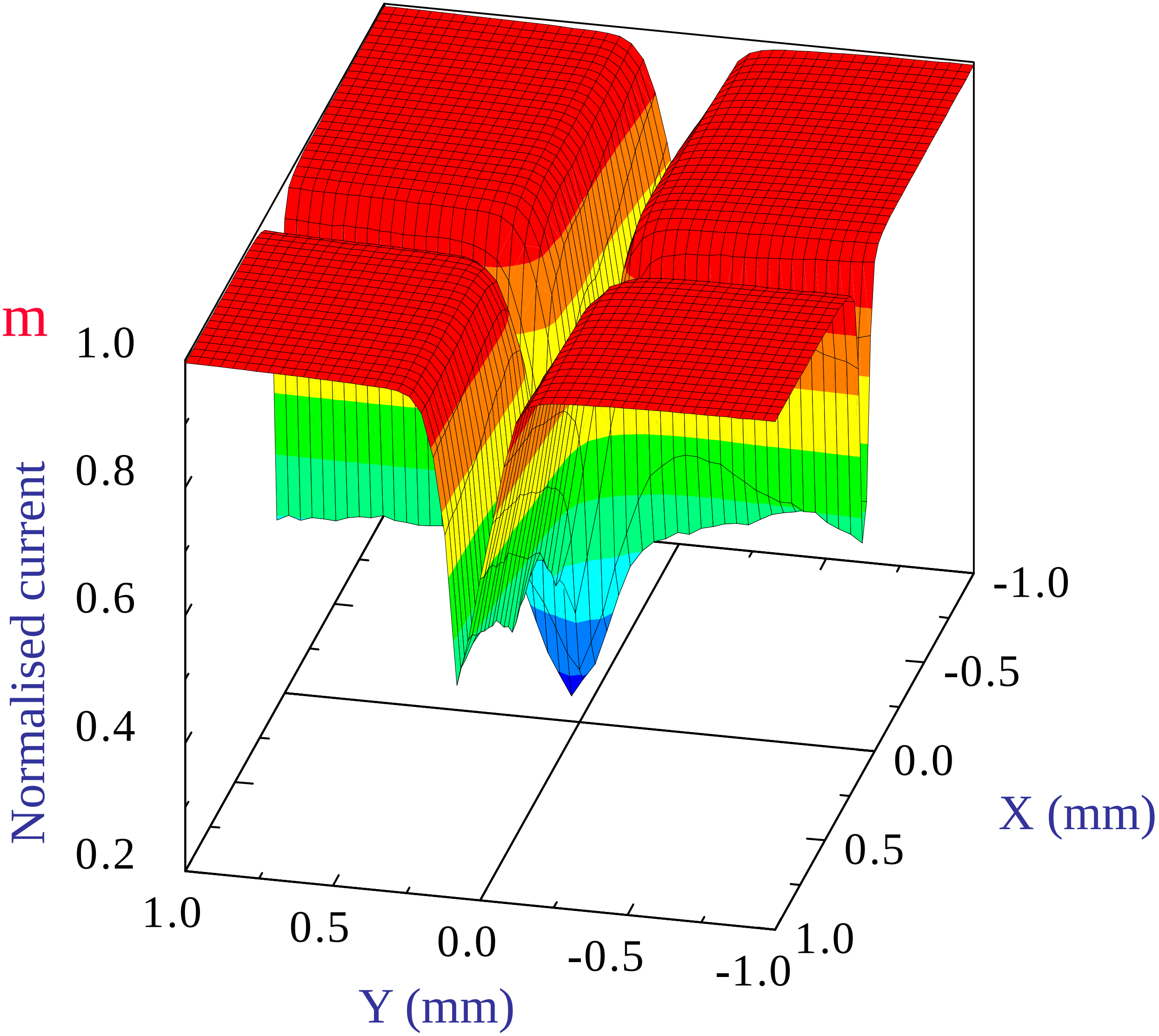
- high transparency (low Z)
- fluence hardness
- temperature hardness
- mechanically resilient,

Realisations have included

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

Measured 3D scan response

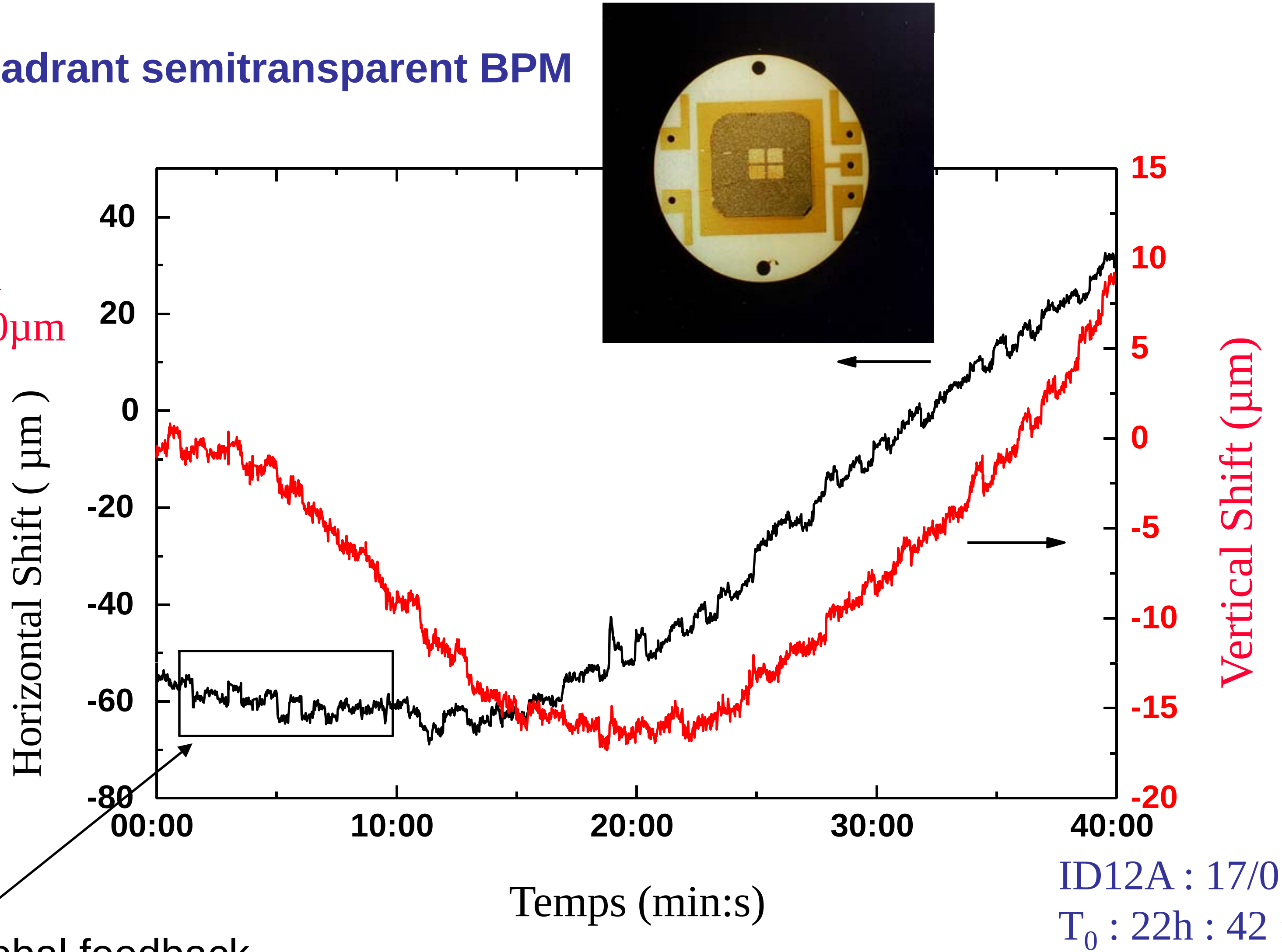
- square beam
- 200µm x 200µm
- 4 keV X-ray



Probing the beam instabilities

4 quadrant semitransparent BPM

- Square beam
- 200µm x 200µm
- 4 keV



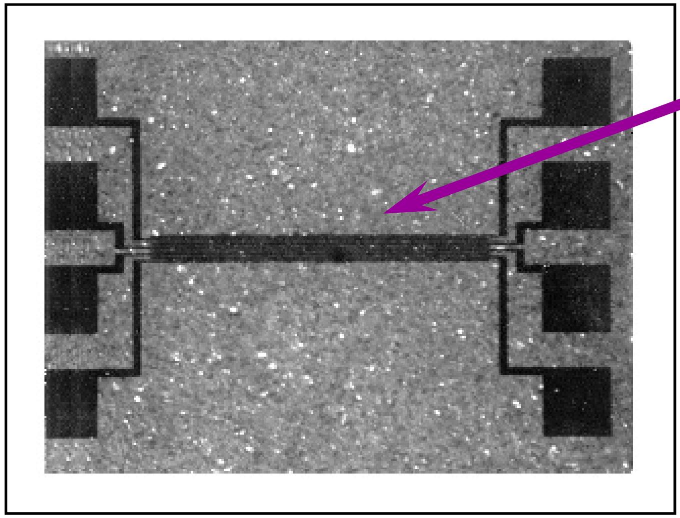
Beam gmobal feedback
causes the observed instabilities

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

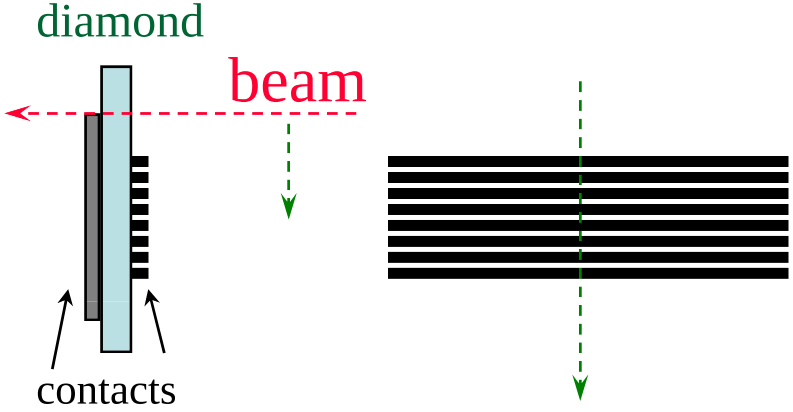
Resolution well beyond 2µm

Beam Profile Monitors

May efficiently be coupled with BPM



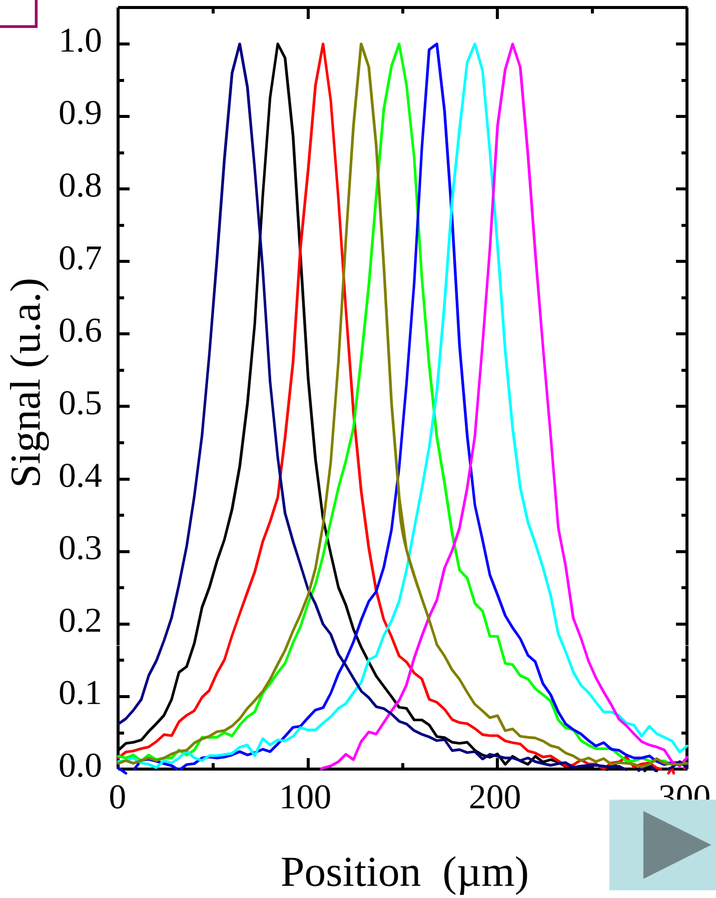
8 lines,
width : 15µm
pitch : 20 µm



diamond

beam

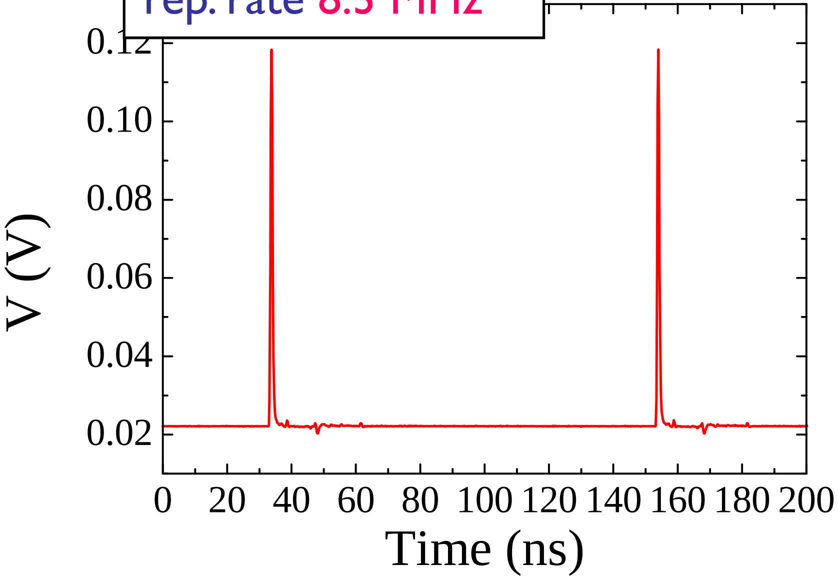
contacts



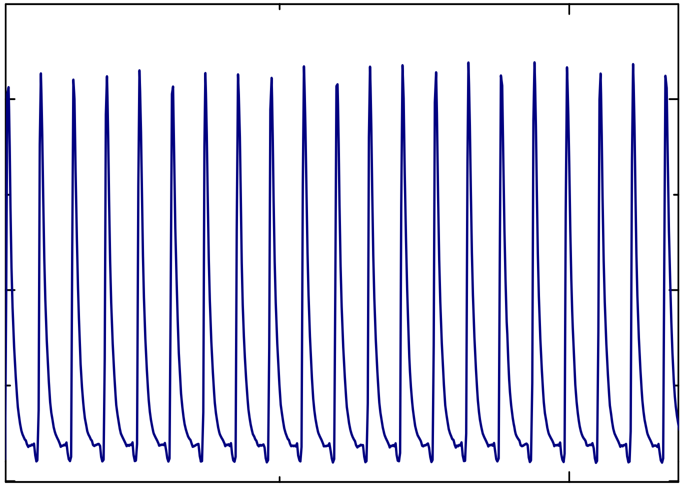
Ultra-fast pulse metrology

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

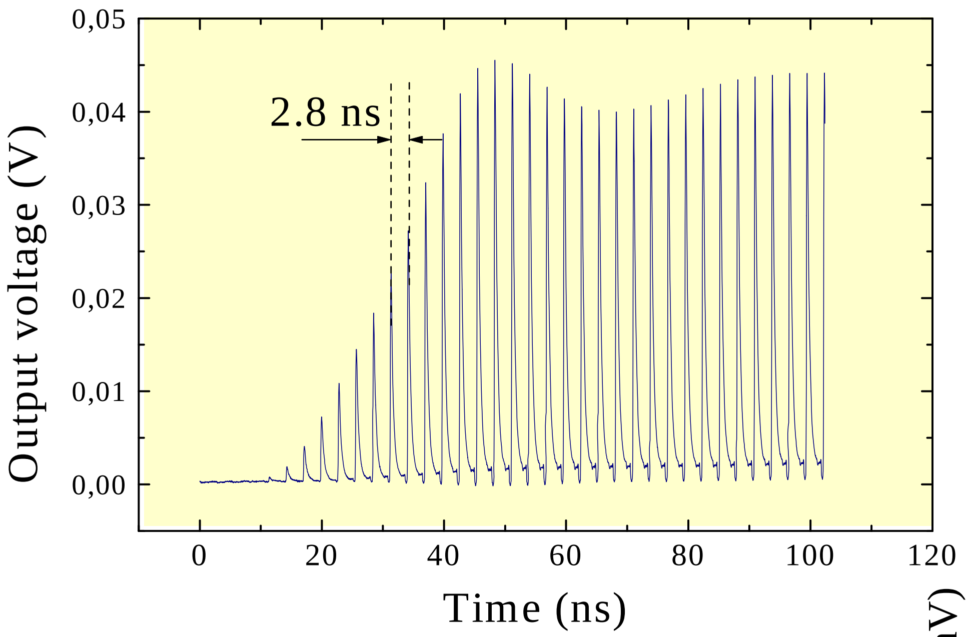
synchrotron : 1 keV
rep. rate 8.3 MHz



synchrotron : 8-20 keV
rep. rate 0.36 GHz



Bunch temporal distribution

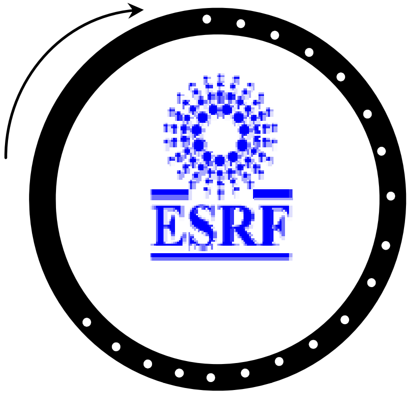


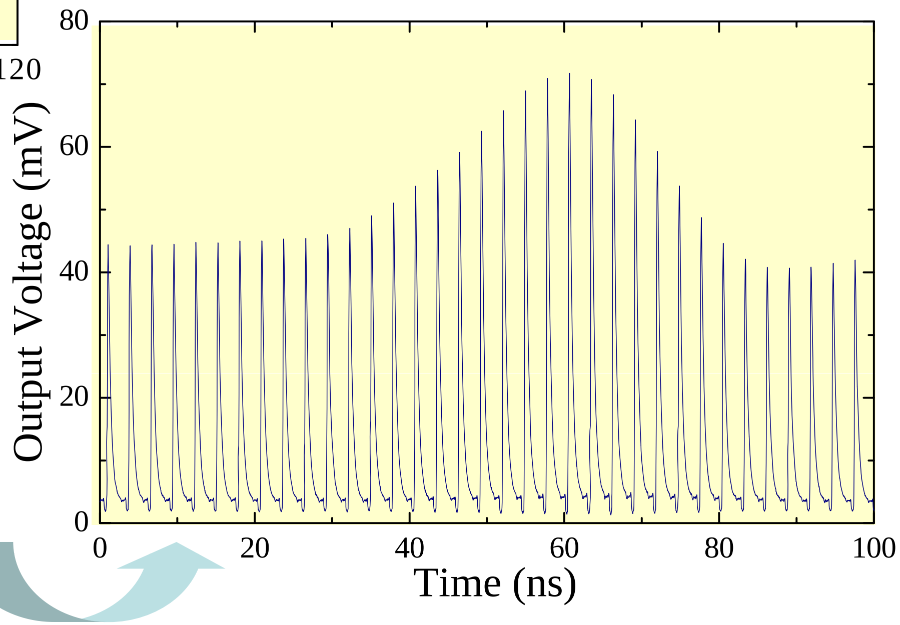
ESRF (2/3rd filling)

BM5

White light

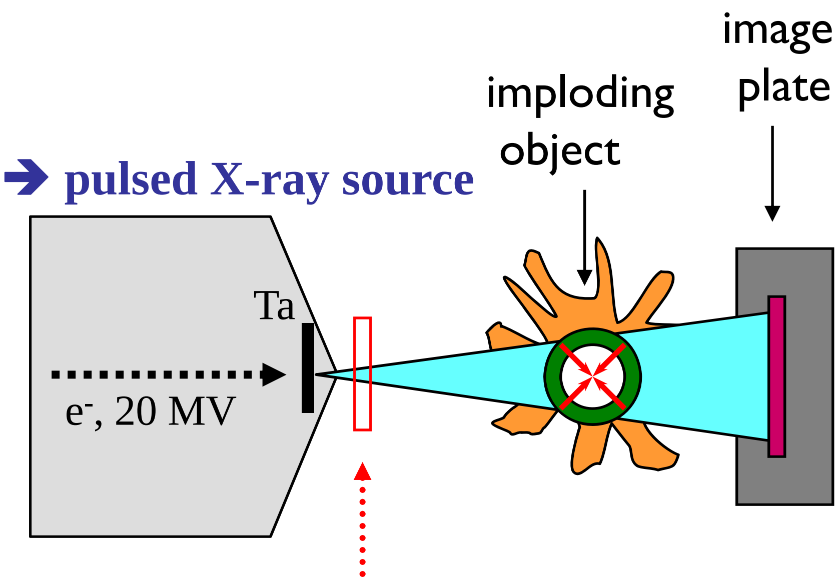
Device Temperature > 170°C





Flash X-Ray radiography diagnosis tool (defence)

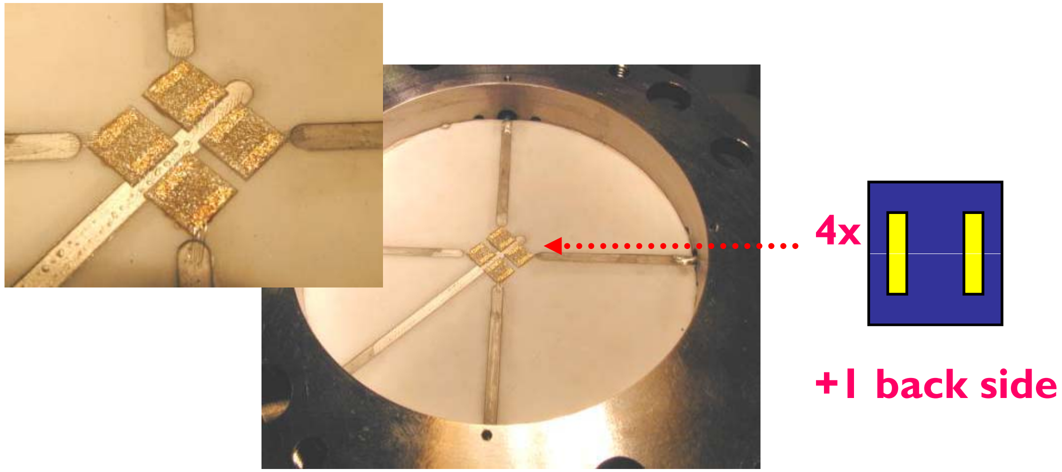
linac → pulsed X-ray source

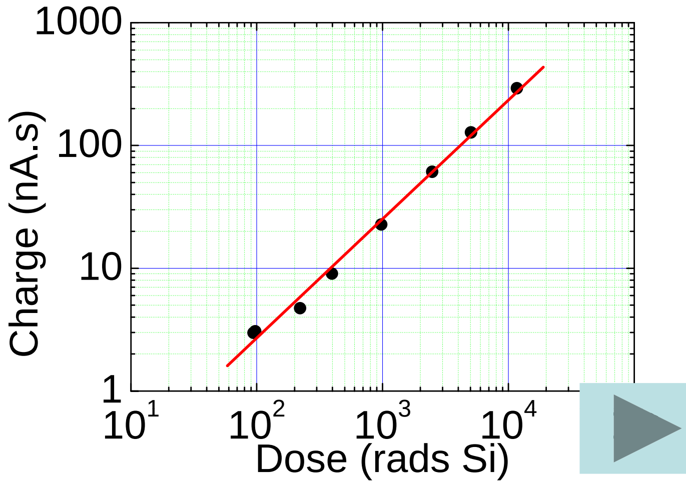


AIRIX (Accélérateur à Induction de Radiographie pour l'Imagerie X)

Demanding specifications

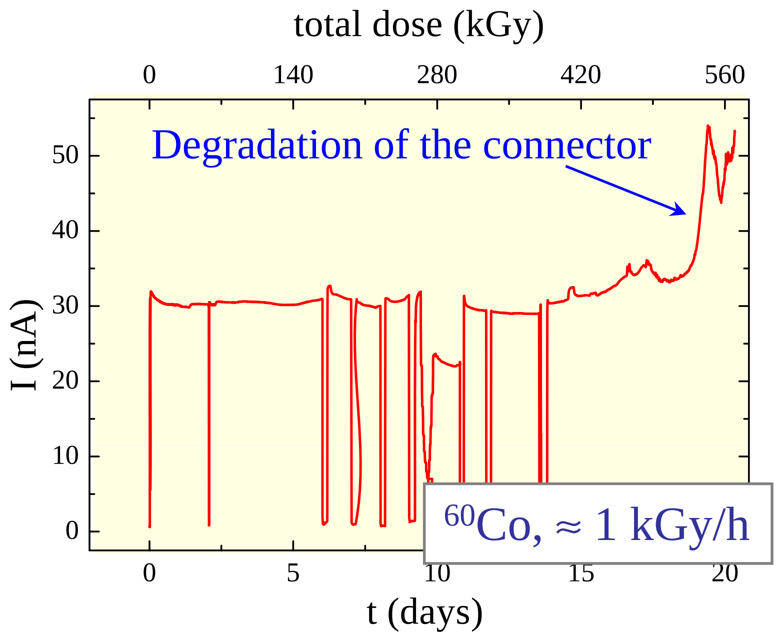
- typ. ≈ 1 MeV
- Dose (< 5 krad (Si)/flash)
- Duration : typ. 50ns FWHM
- 500 shots / yr / 15 yrs (> 15Mrad)
- Resilient (EMC and schock 10g)
- High transmission (< 0.1 g/cm² (W))

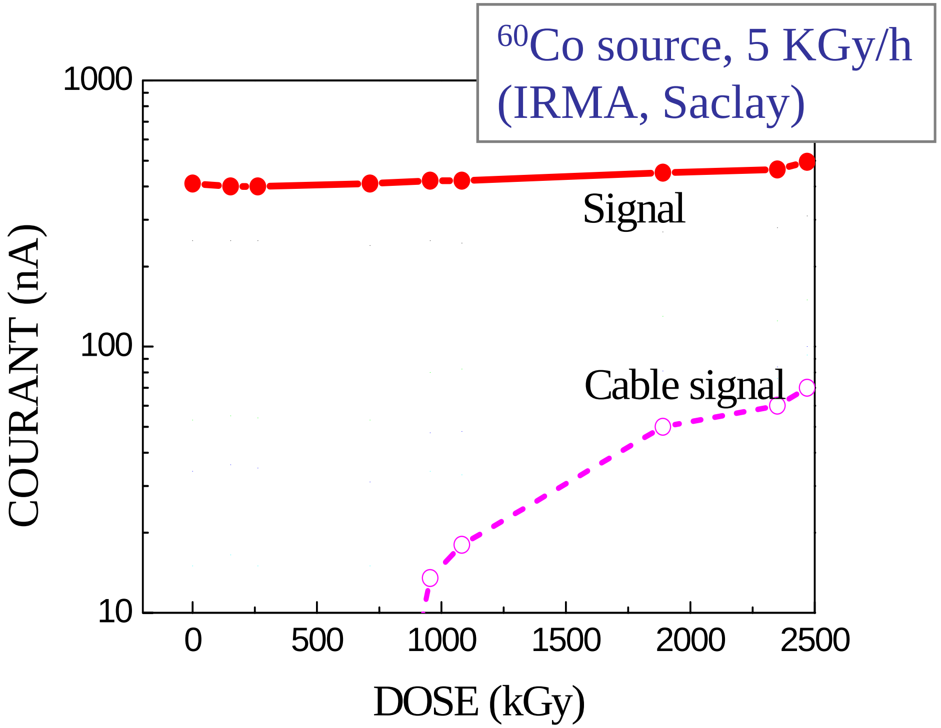




Radiation Hardness

Dose measurements under γ photons



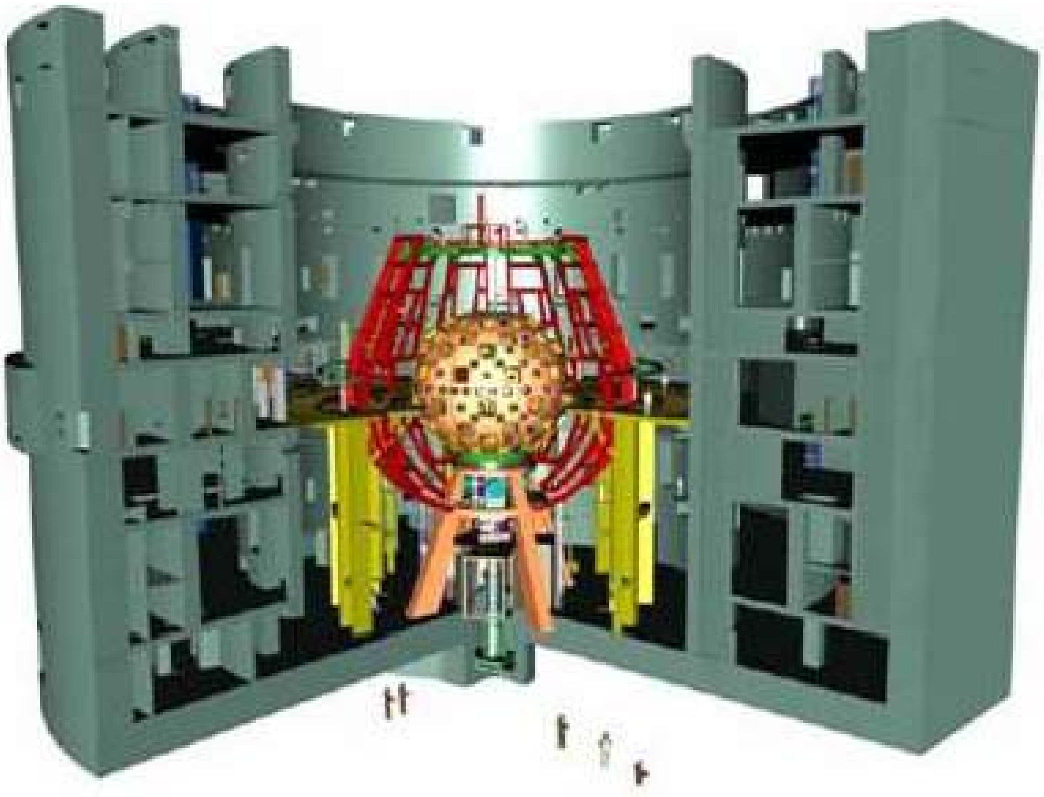


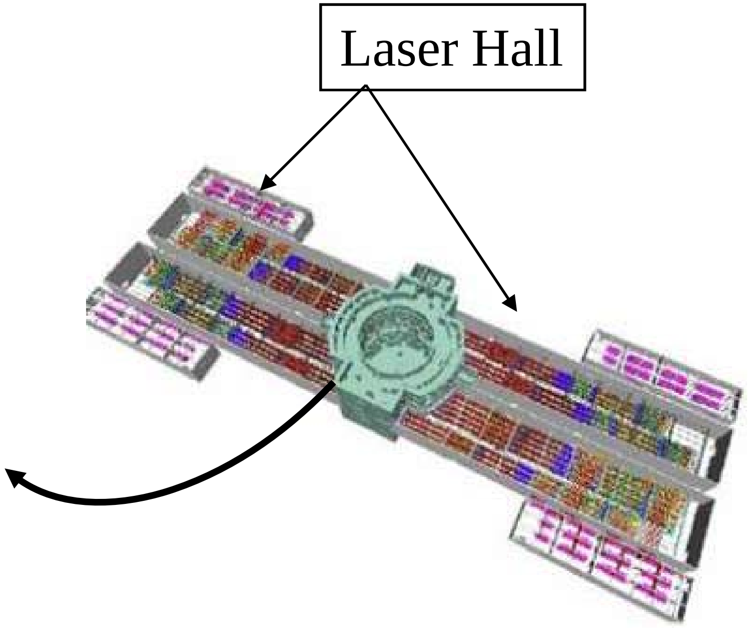
- Stable device response
- altered by cable degradation

No degradation of the detector signal after
a 2,5 MGy integrated dose

The Laser MégaJoule Facility.

- **First experiment in 2011**



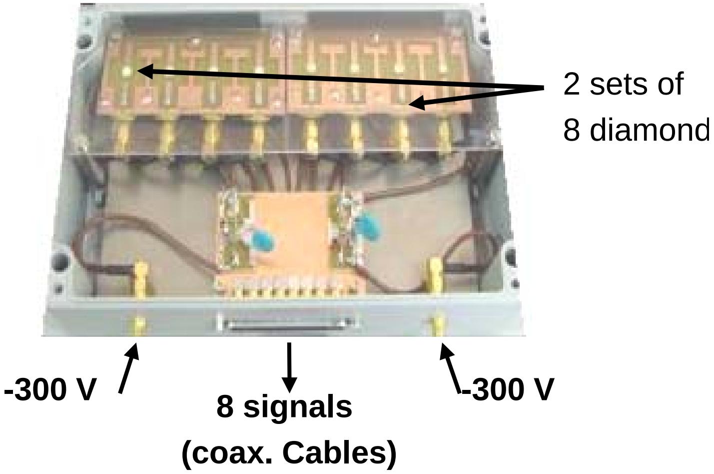


Plasma de fusion par confinement
e.g. (D,T) → n (14MeV)

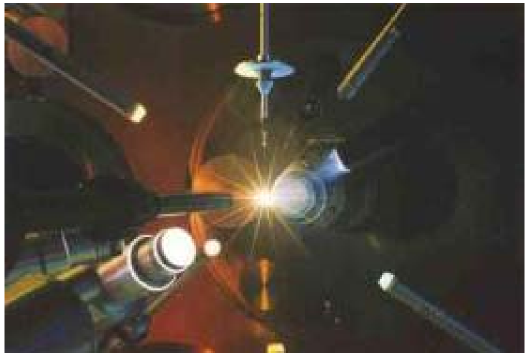
Fast Neutrons

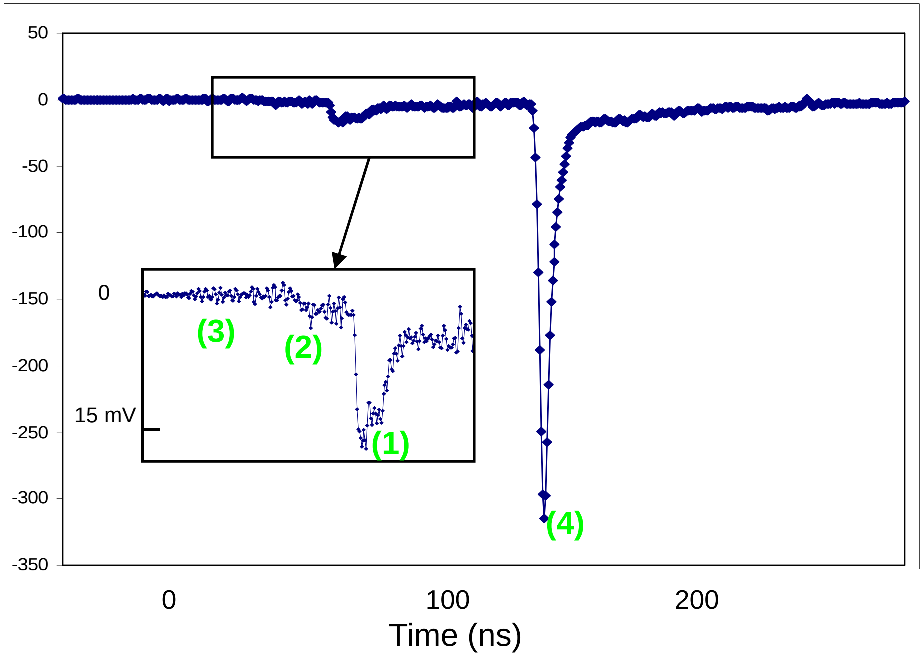
Based on the ^{12}C (n, α) → high n/γ selectivity

For n time of flight measurement



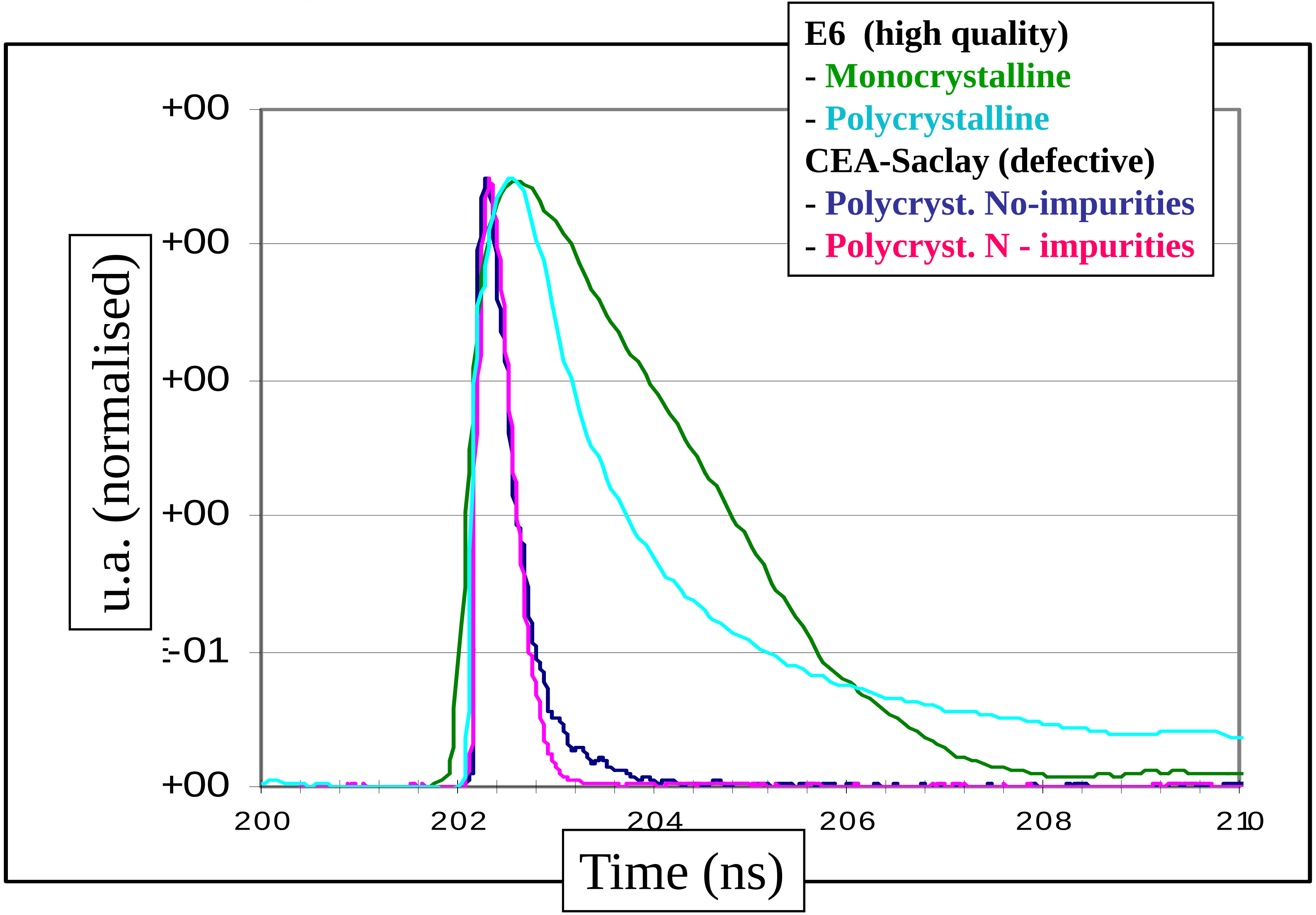
*Rochester (30kJ<1ns)





Response to fast 16 MeV electron pulses

(FWHM=40ps)



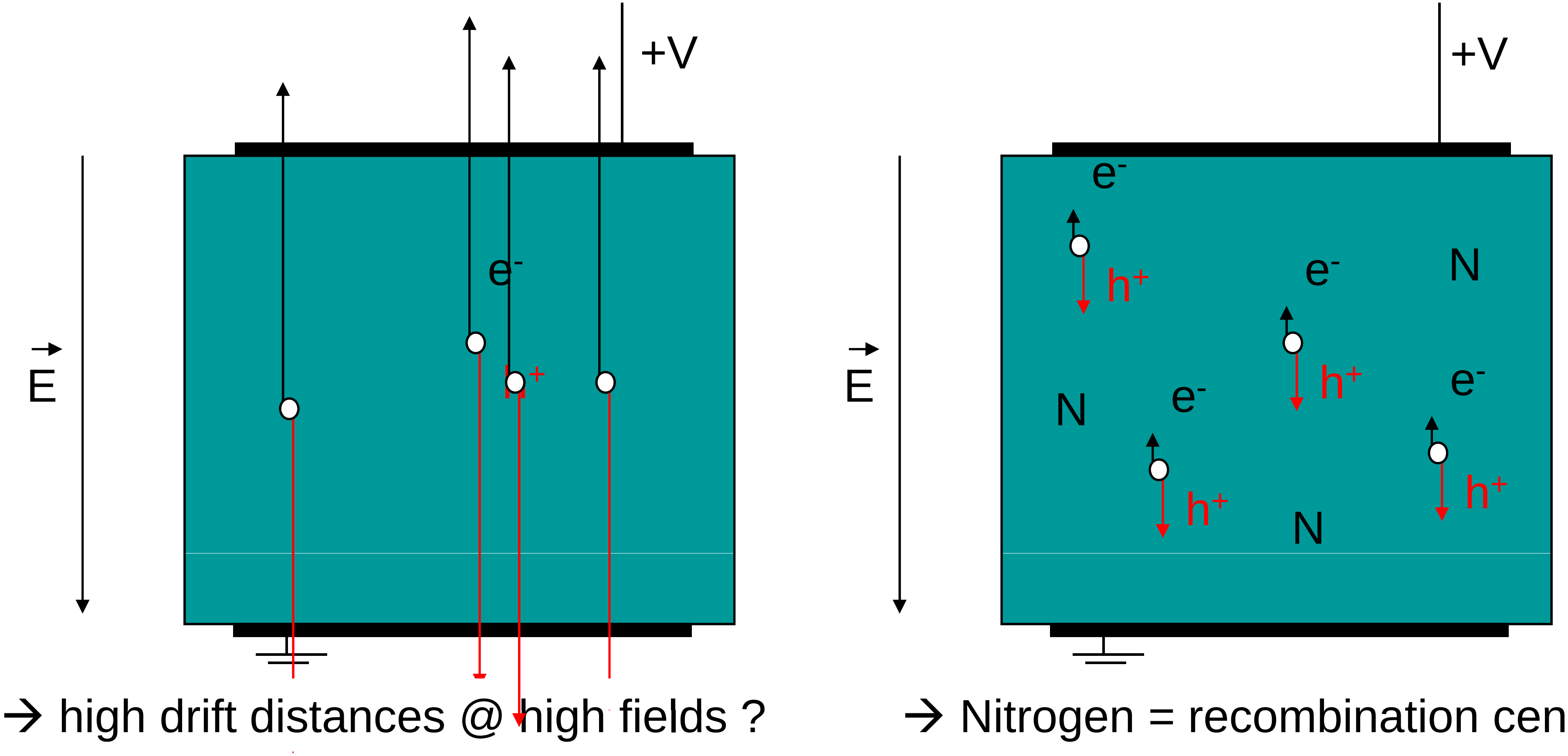
Fast ?

"Carriers transiting through the device must do it quickly ! "

2 ways :

Get the carriers out !

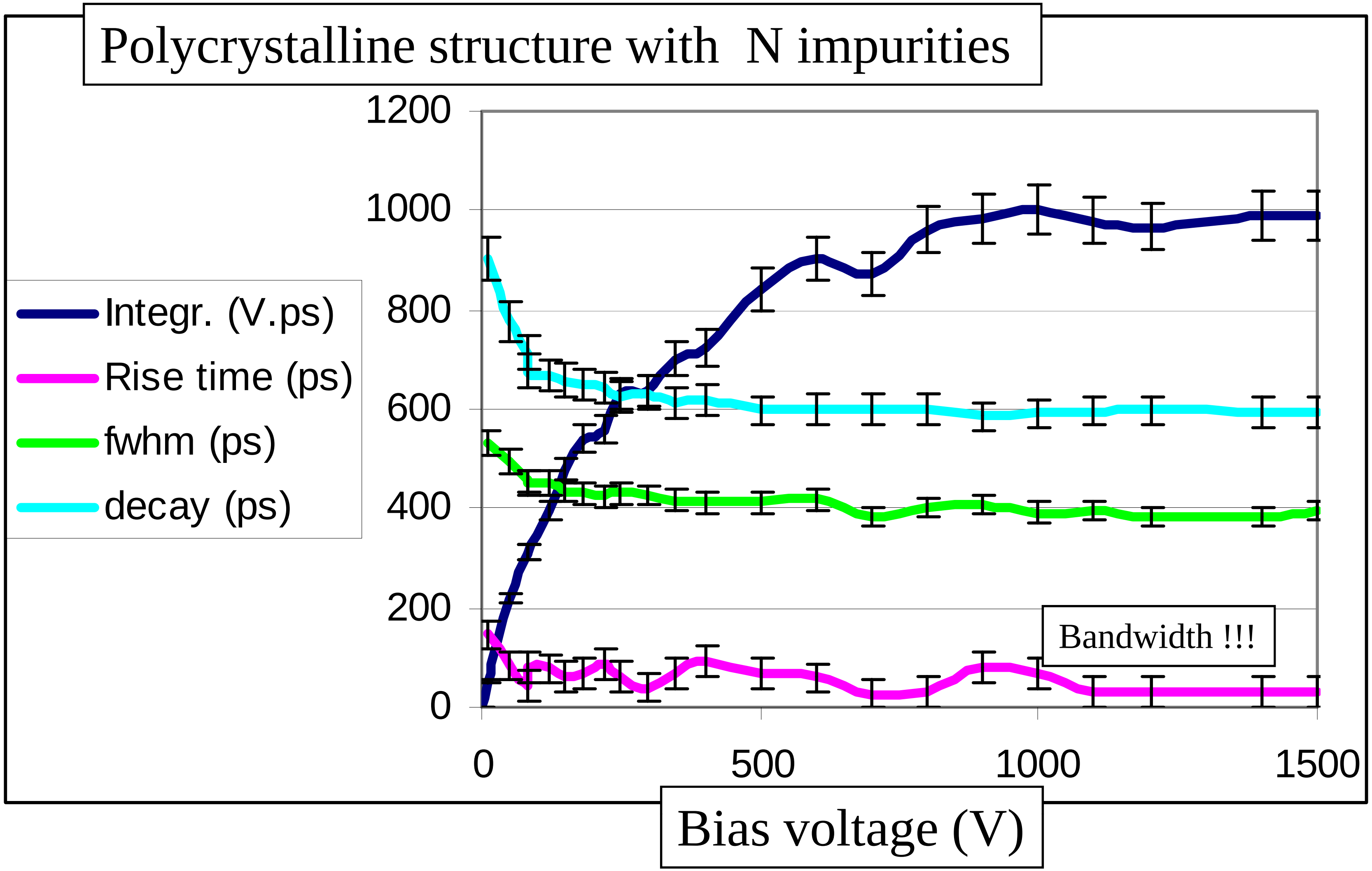
Kill the carriers !



→ high drift distances @ high fields ?

→ Nitrogen = recombination centre

Pulse shape analysis under fast electron beam



Conclusions

☞ Detectors :

- Controlling the material characteristics with respect to the growth conditions is necessary for radiation detector fabrication

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

☞ Devices readily available for extreme hostile environments and few specific applications :

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

☞ Indeed : performances of SC unmatched by polyX materials
But still size and availability remains challenging

Acknowledgements

Partners and collaborators…

Applications

Growth and material characterisation

LEPES + LPSC + LPICM

Project partners ... etc