LASER MICRO-MACHINING FOR 3D DIAMOND DETECTORS APPLICATIONS

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1st ADAMAS WORKSHOP | 17 DEC 2012

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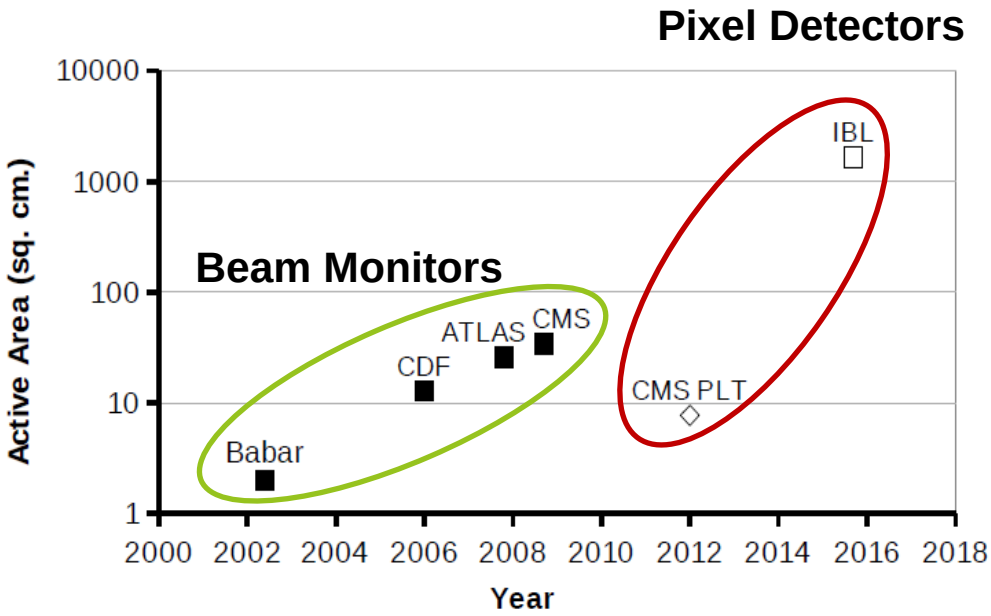
Diamond detectors in High Energy Physics

All LHC experiments already use diamonds for beam monitoring or as pixel detectors

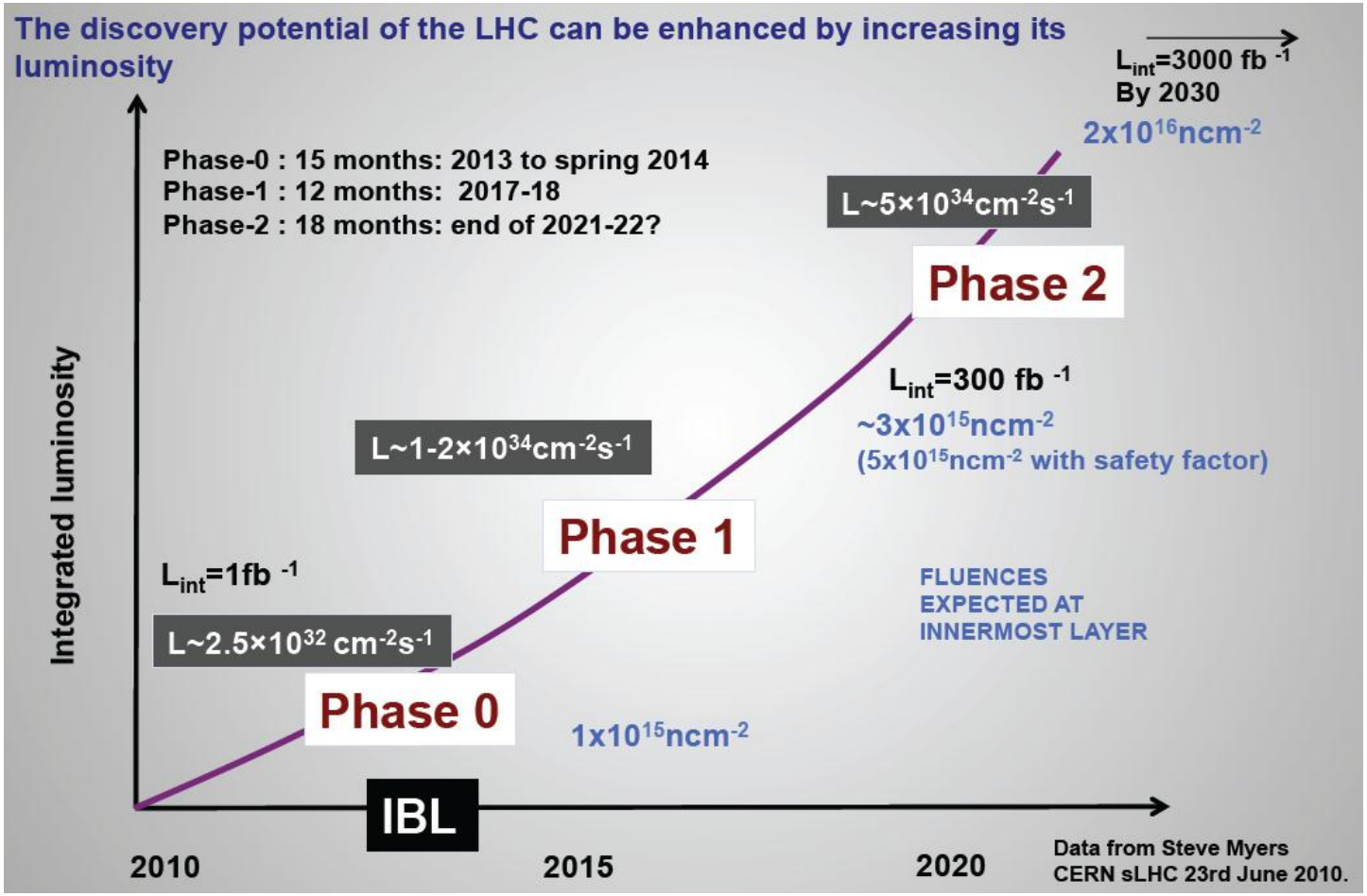
- **CMS is building Pixel Luminosity Telescope**
  - » 48 scCVD pixel modules (5 mm x 5 mm)
- **ATLAS is building Diamond Beam Monitor**
  - » 24 pCVD pixel modules (21 mm x 18 mm)
- **Upgrade plans include diamond as candidate for innermost pixel tracker layer(s)**



Marko Mikuž “Diamond Sensors”, ICHEP (2012)

Luminosity previsions

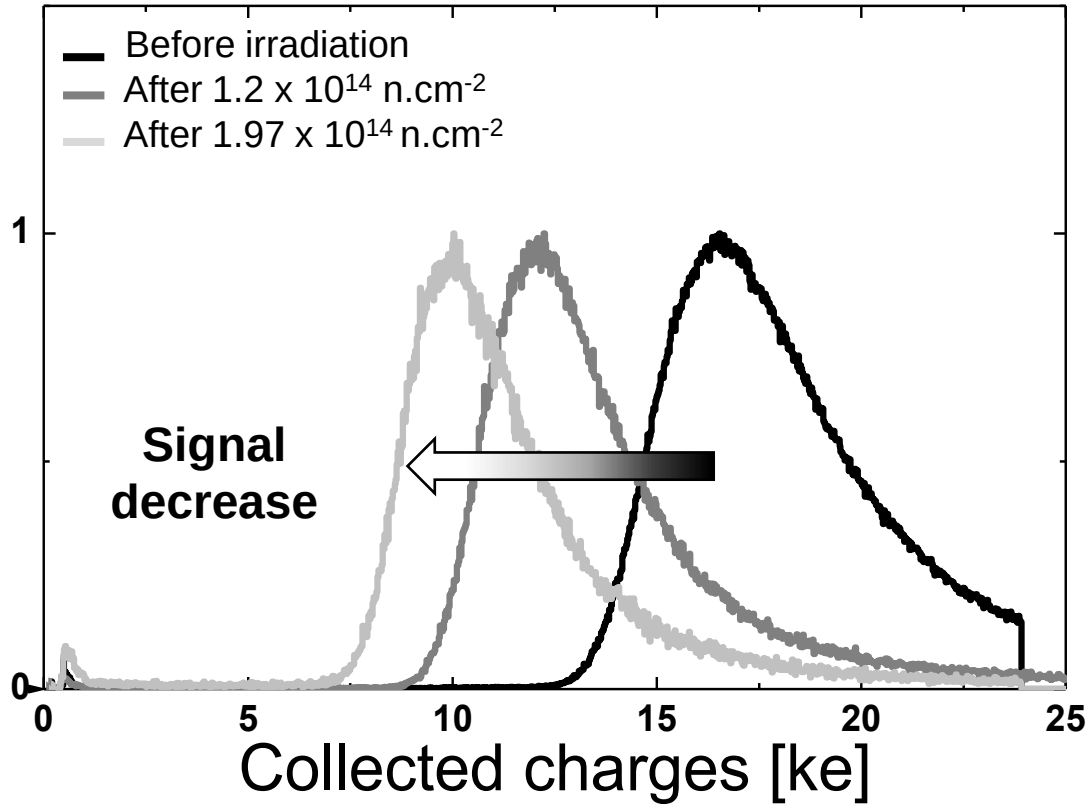
At LHC, luminosity will increase more and more in the following years



Radiation hardness is still an issue in diamond

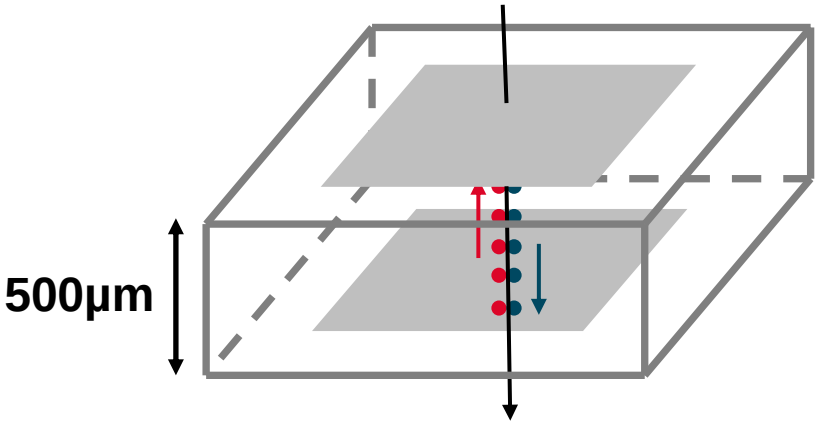
NIEL induces bulk defects…

- **Higher luminosity**
  - » **Faster signal decrease**
- **Development of advanced detectors**
  - » **Diamond detectors**
  - » **Silicon 3D detectors**
- **Why won't we try to build the radiation hardest detector ever ?** **A 3D Diamond Detector…**

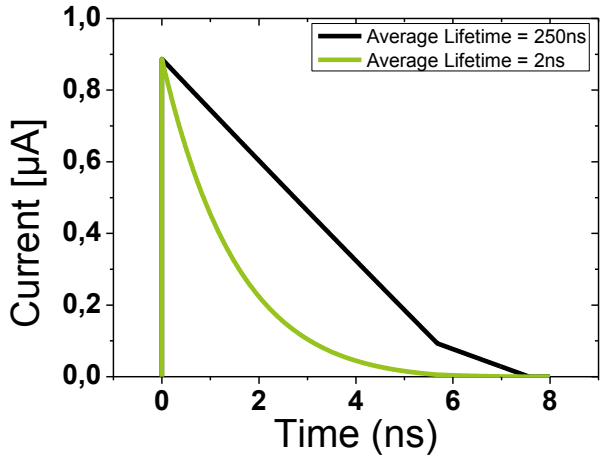


What is a 3D detector ?

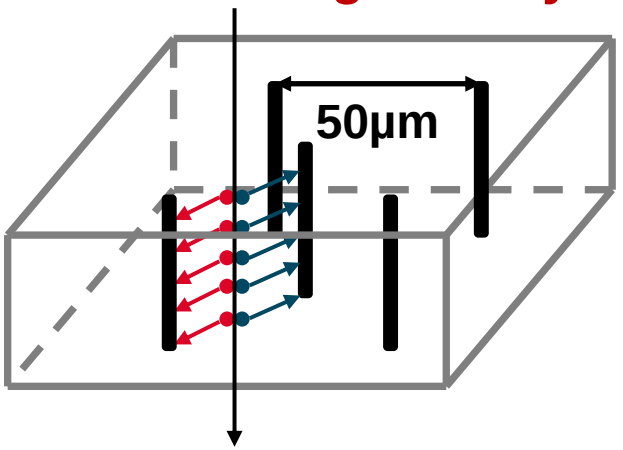
Planar geometry



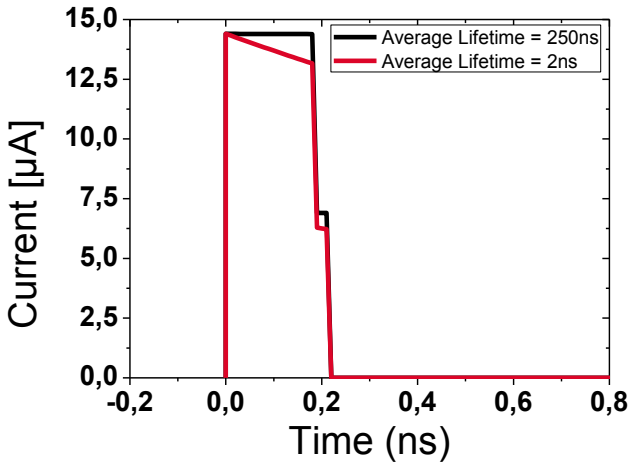
- Q_{MIP} = 18000 e-h pairs



3D geometry



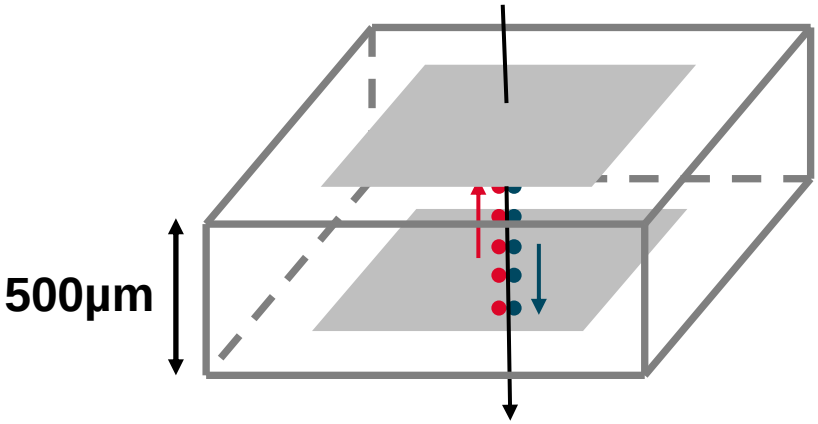
- Q_{MIP} = 18000 e-h pairs



- Analytically calculated currents generated by a MIP

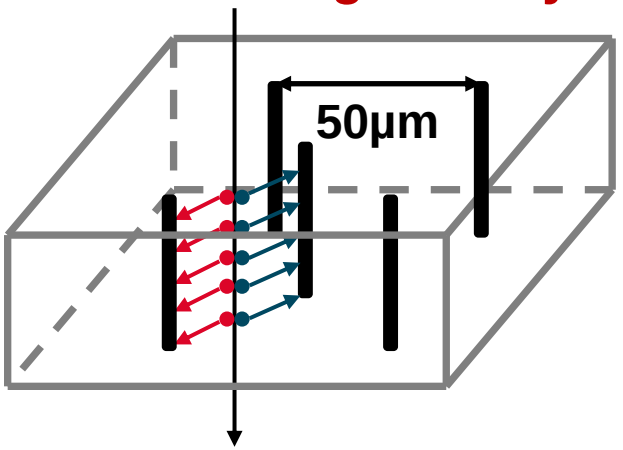
What is a 3D detector ?

Planar geometry



❑ Q_{MIP} = 18000 e-h pairs

3D geometry



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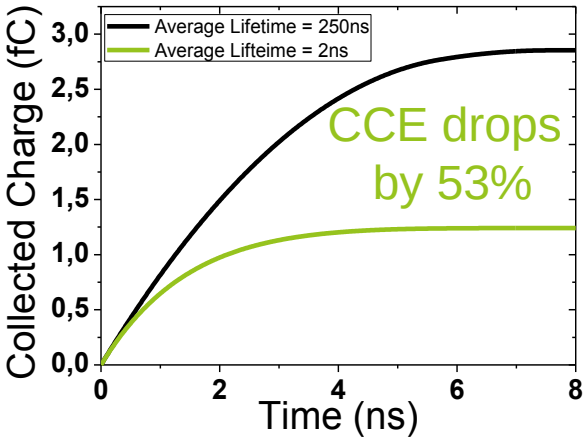
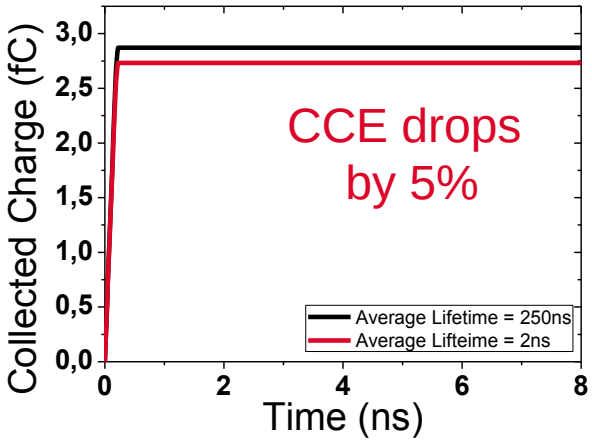


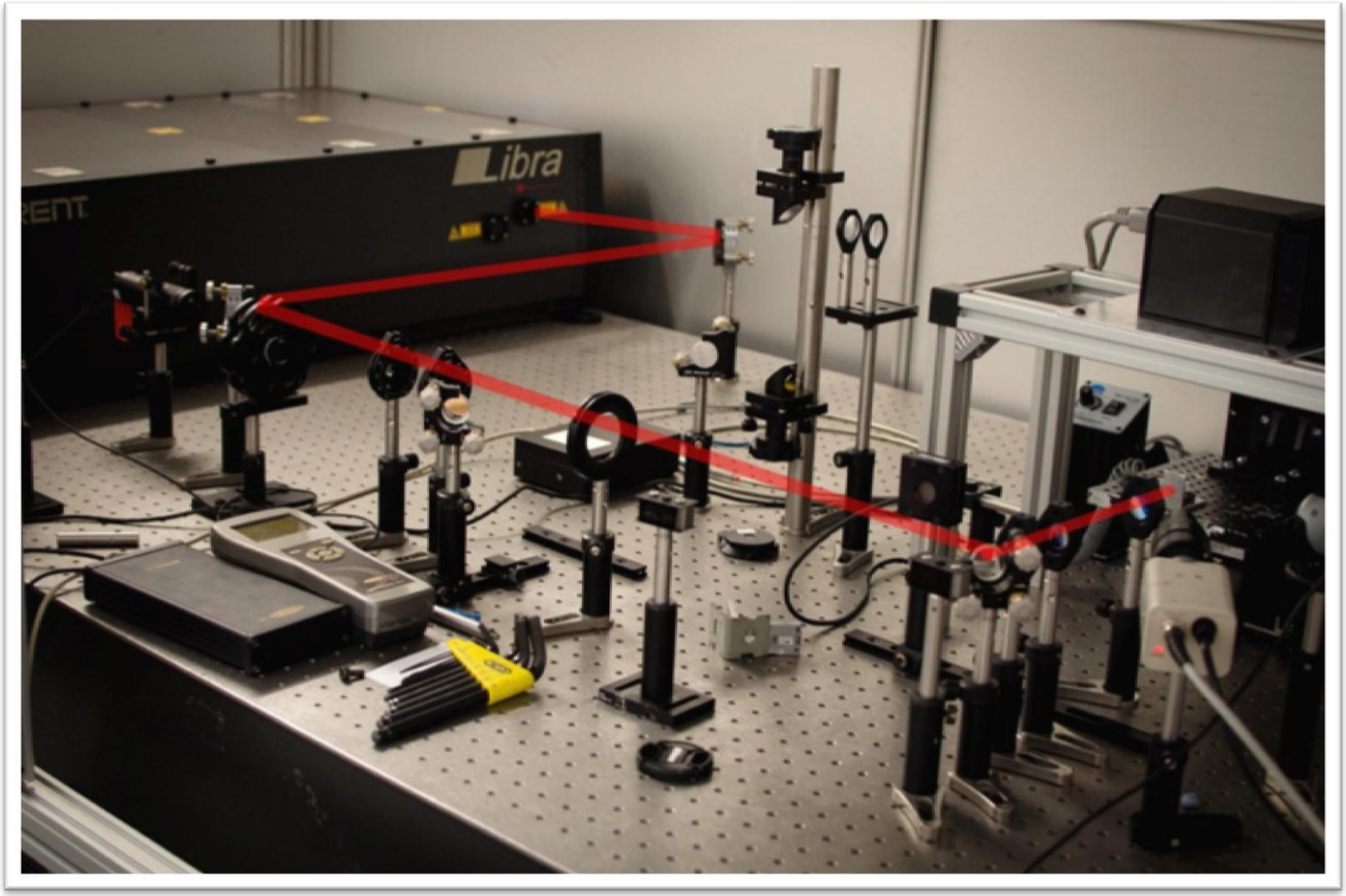


❑ **Analytically calculated charge collection**

Laser setup and fabrication

Electrodes are processed using laser-induced graphitization

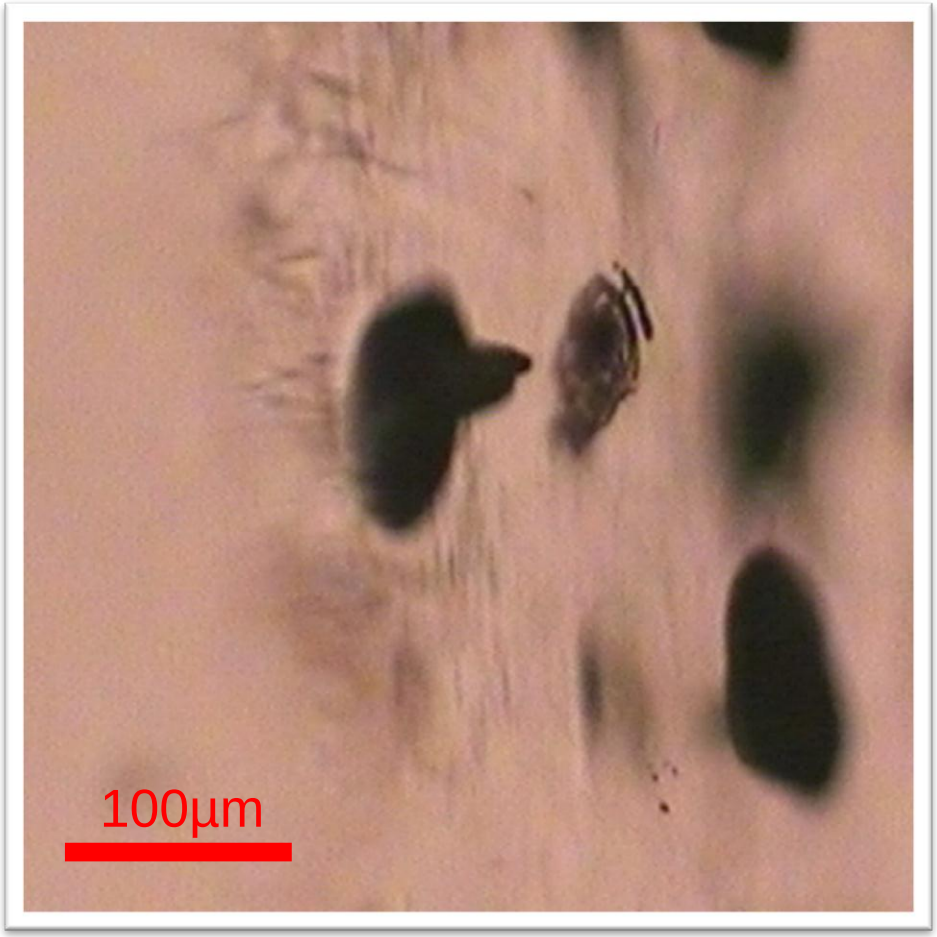
- **Wavelength : 800nm**
- **Repetition rate : 1kHz**
- **Pulse length : 100fs**
- **Spot size : 10µm**



MANCHESTER 1824
The University of Manchester

Process improvement over the past two years

- **YAG Laser**
  - Hollow, conical shape
  - Diameter : 100µm
  - Pitch : 300µm

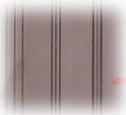


Dec 2010

Feb 2011

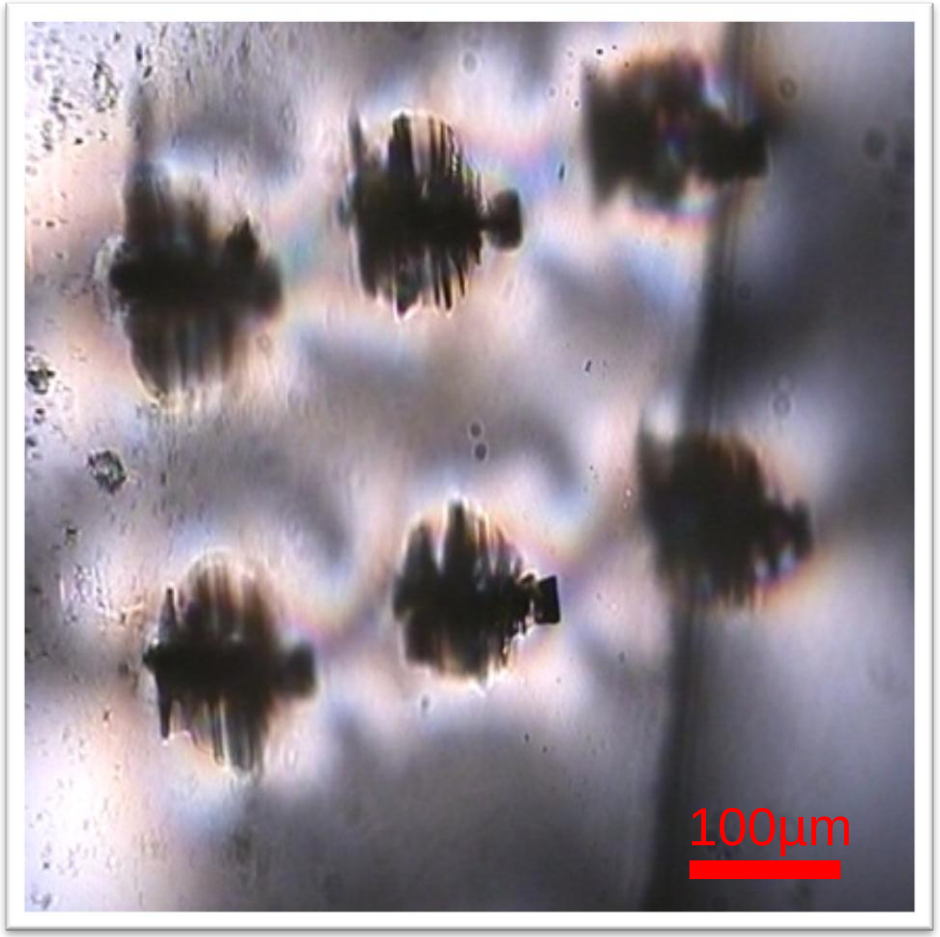
Jun 2011

Apr 2012



Process improvement over the past two years

- **UV Laser + x10 Lens**
  - » **Diameter : 75µm**
  - » **Pitch : 200µm**



Dec 2010 

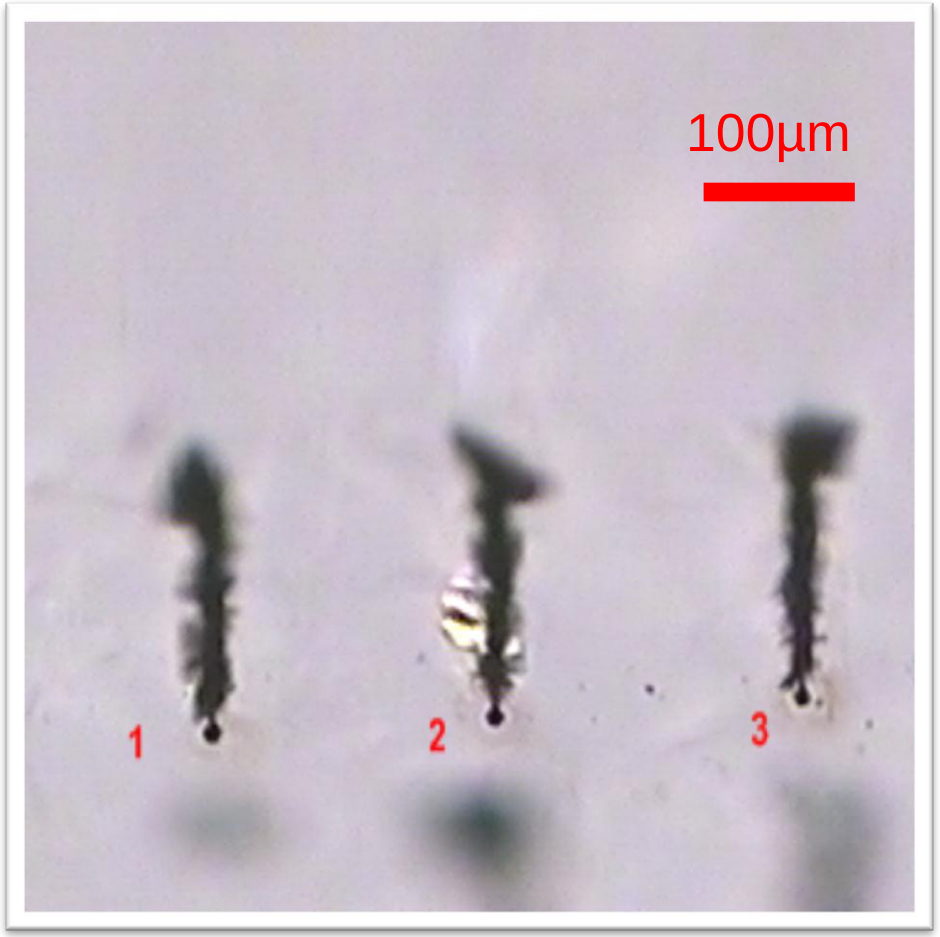
Feb 2011 

Jun 2011 

Apr 2012 

Process improvement over the past two years

- **UV Laser + x20 Lens**
  - » **Diameter : 20µm**
  - » **Pitch : 150µm**



Dec 2010

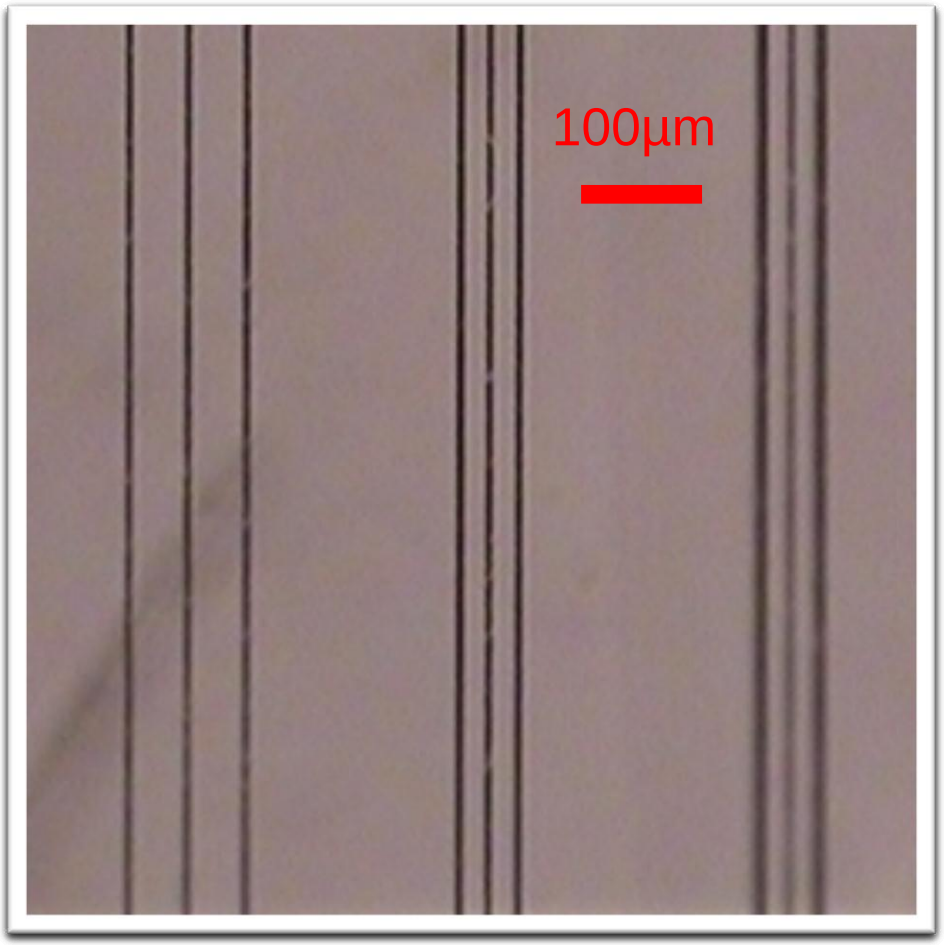
Feb 2011

Jun 2011

Apr 2012

Process improvement over the past two years

- **Femtosecond laser**
  - » Diameter : 5µm
  - » Pitch < 35µm



Dec 2010 

Feb 2011 

Jun 2011 

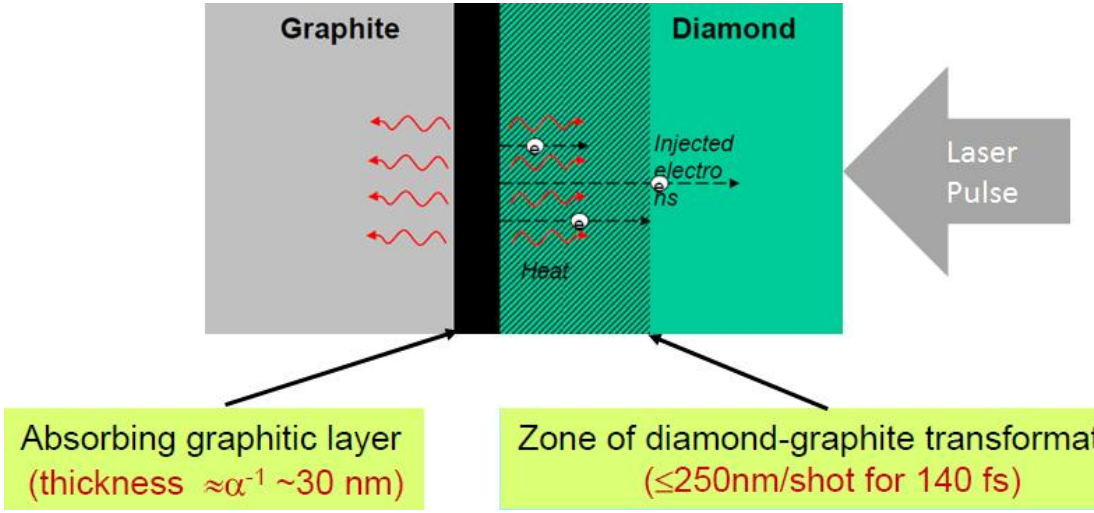
Apr 2012 

Why is femtosecond laser so much better ?

A two-step process

- **Producing a graphitic seed at the surface**
  - » Excitation of a large number of valence electrons via multi-photon absorption
  - » Energy barrier decreases
  - » Phase transition Diamond- Graphite

- **Propagation of laser supported graphitic wave**

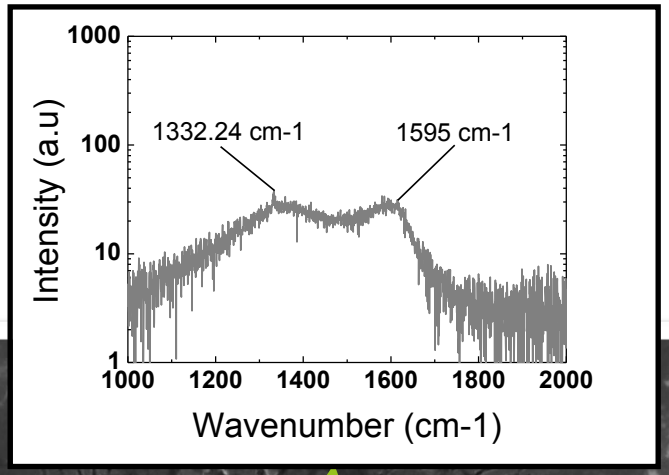


No heat accumulation

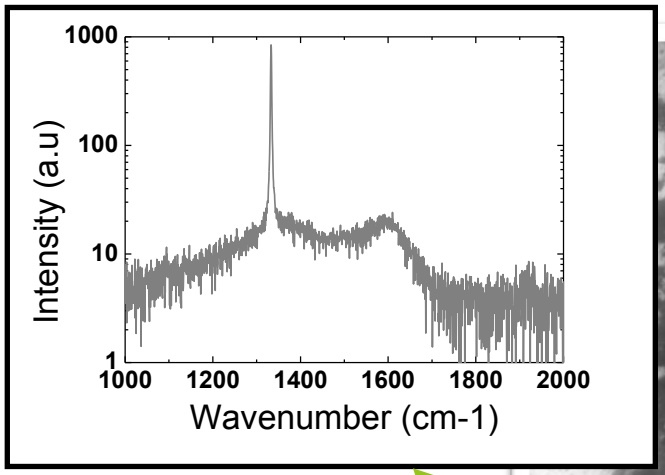
T.V. Kononenko et Al – Rus'nanotech (2010)

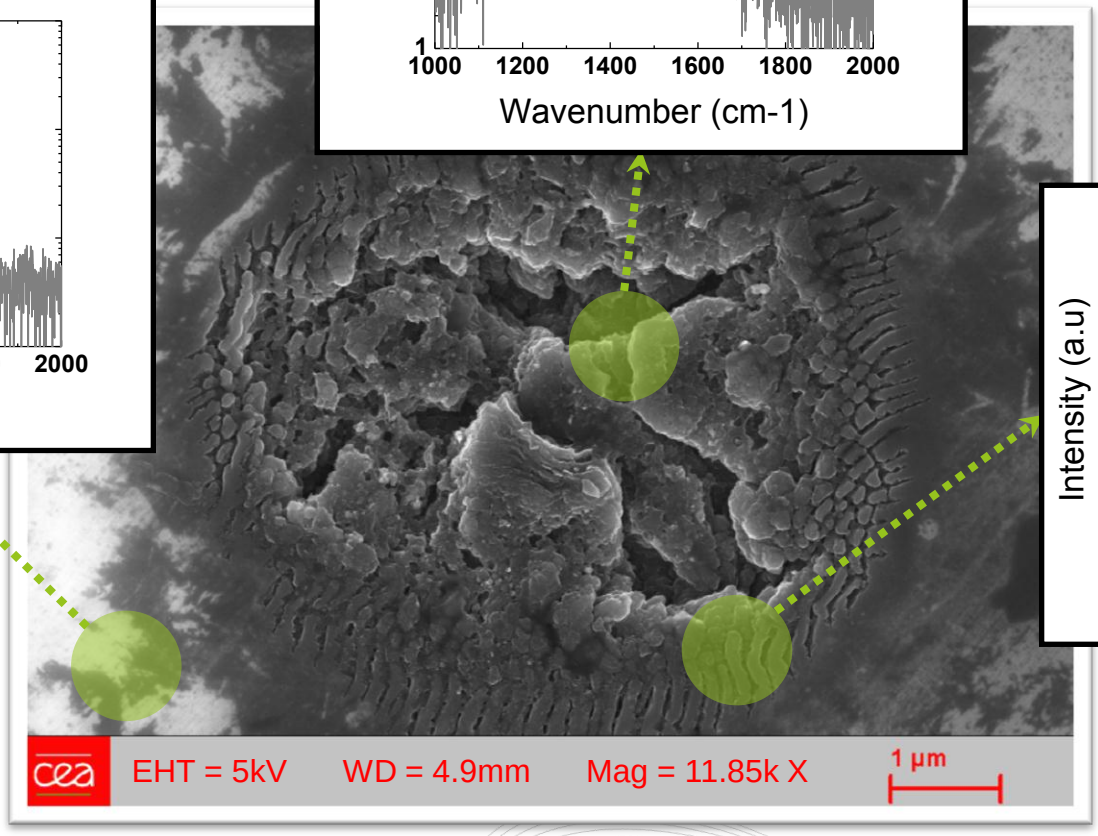
Raman Analysis

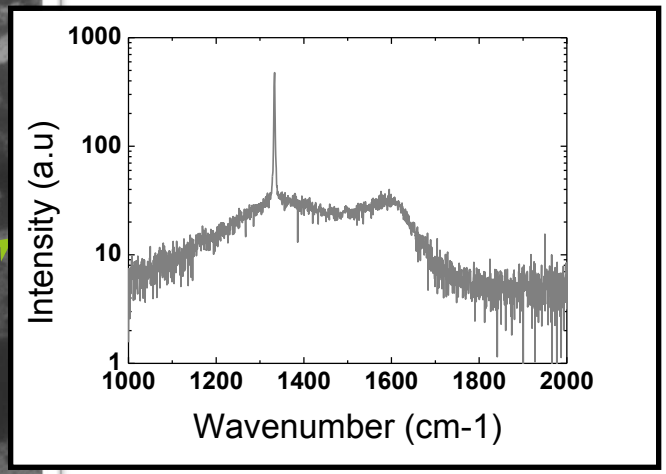
❑ **Electrode**



❑ **Diamond**

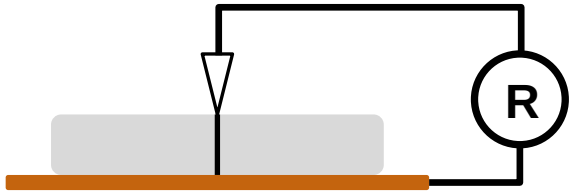


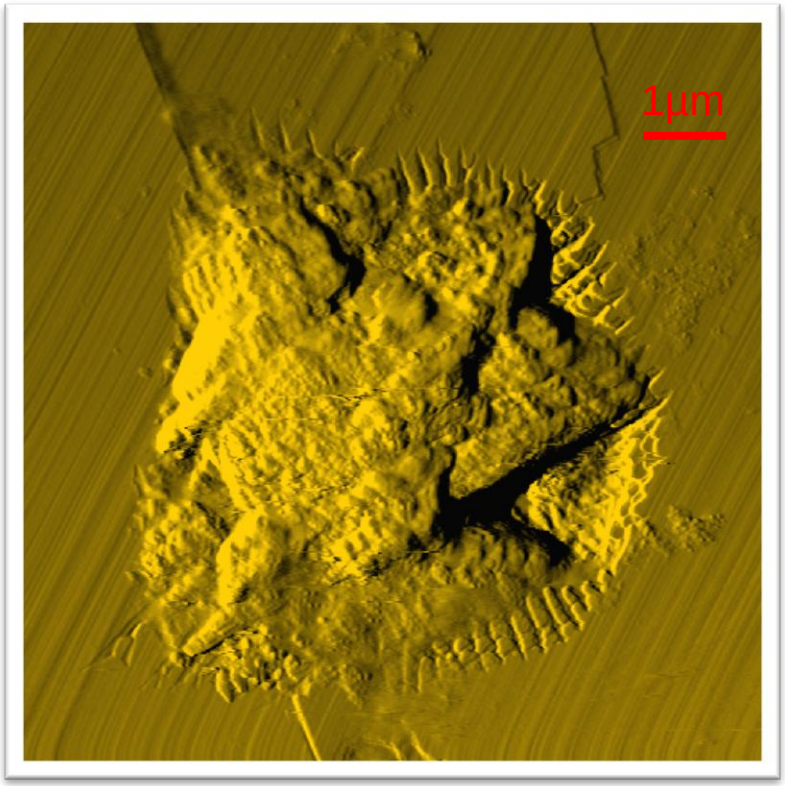


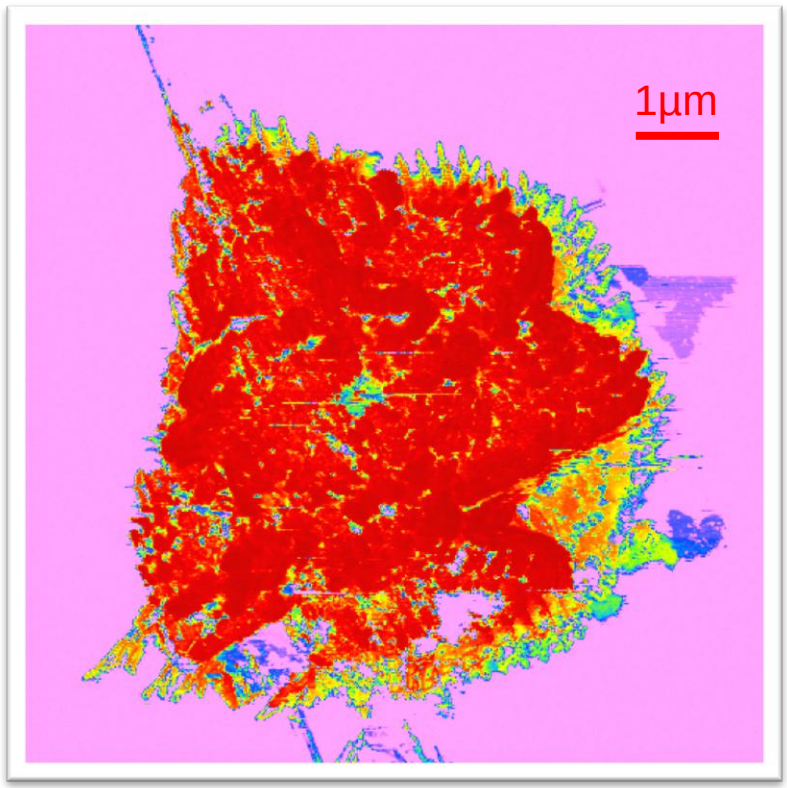


❑ **Border**

Electrode mapping using Conductive probe AFM

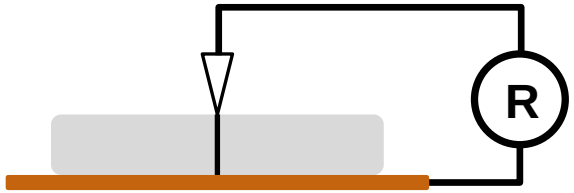


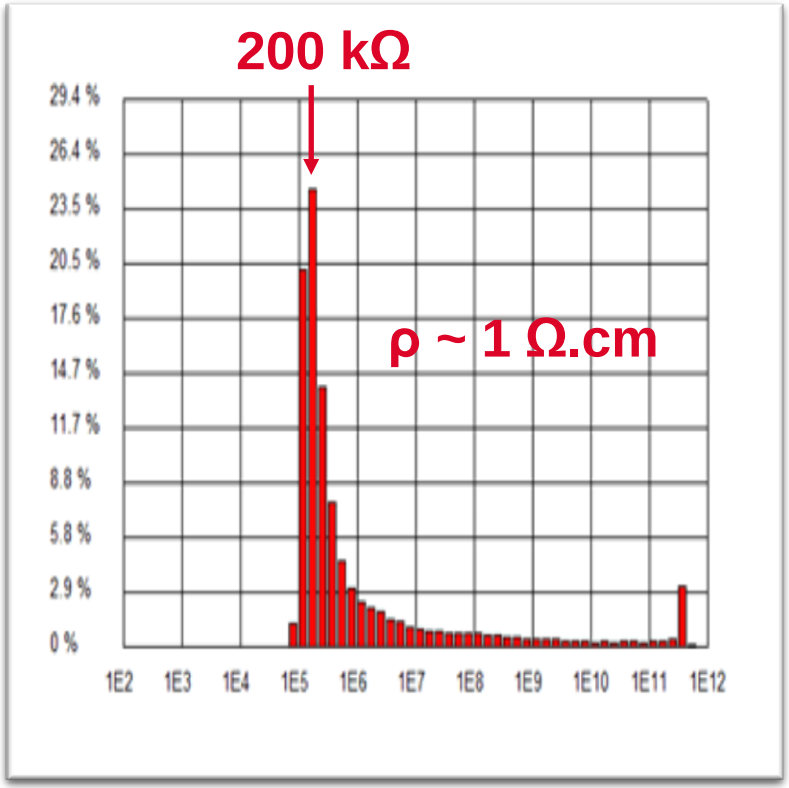


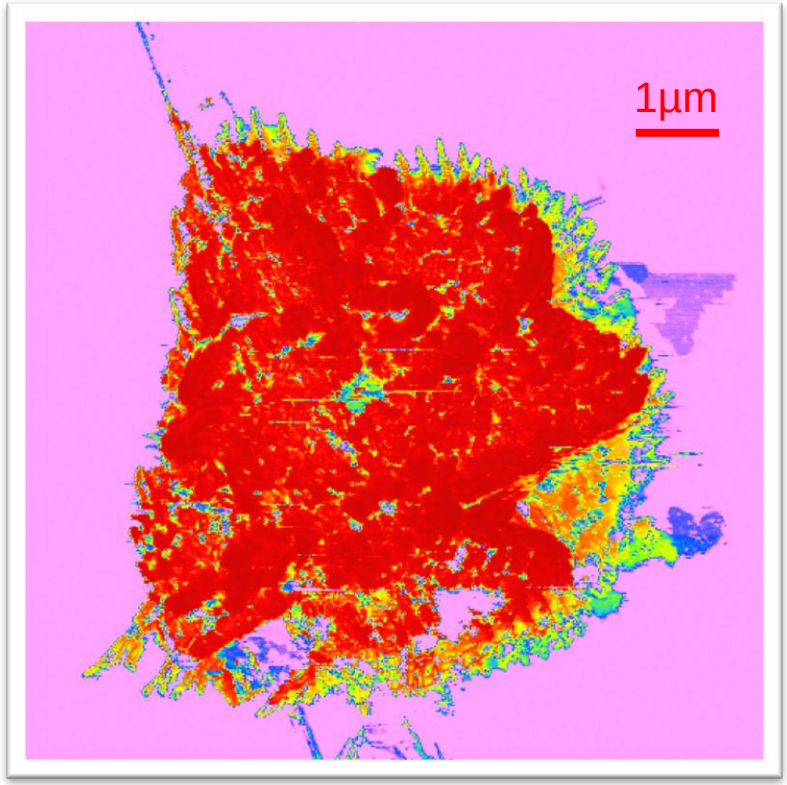


- AFM mapping
- Resistance mapping

Electrode mapping using Conductive probe AFM



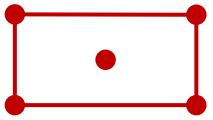




- Resistance distribution in the mapping area
- Resistance mapping

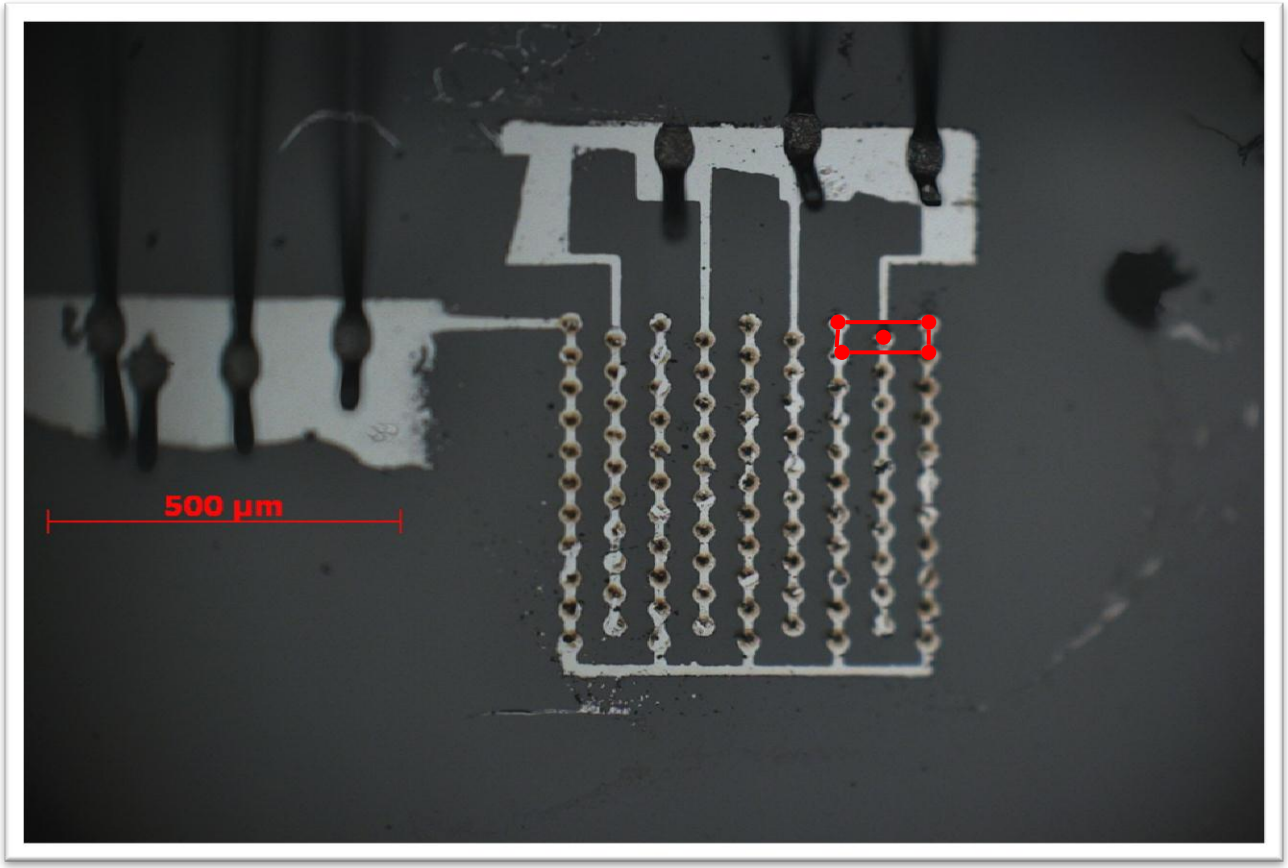
Optical microscopy

125µm



50µm

Rectangular unit cell

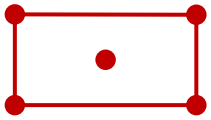


- scCVD sample

Courtesy of CERN

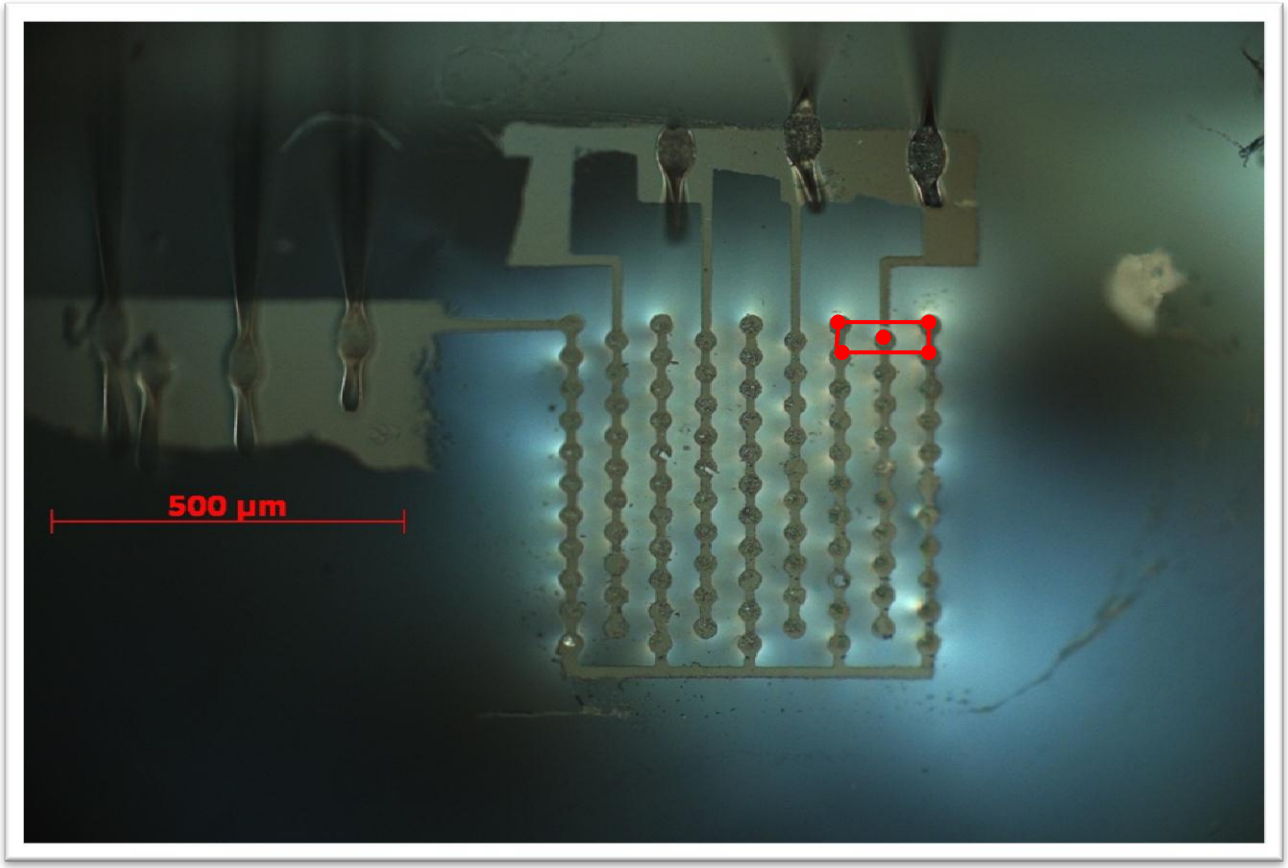
Optical microscopy – Crossed polarizers (Surface)

125µm



50µm

Rectangular unit cell



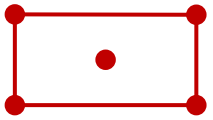
- scCVD sample

Courtesy of CERN

» Graphitization process wasn't optimized – 70% success rate

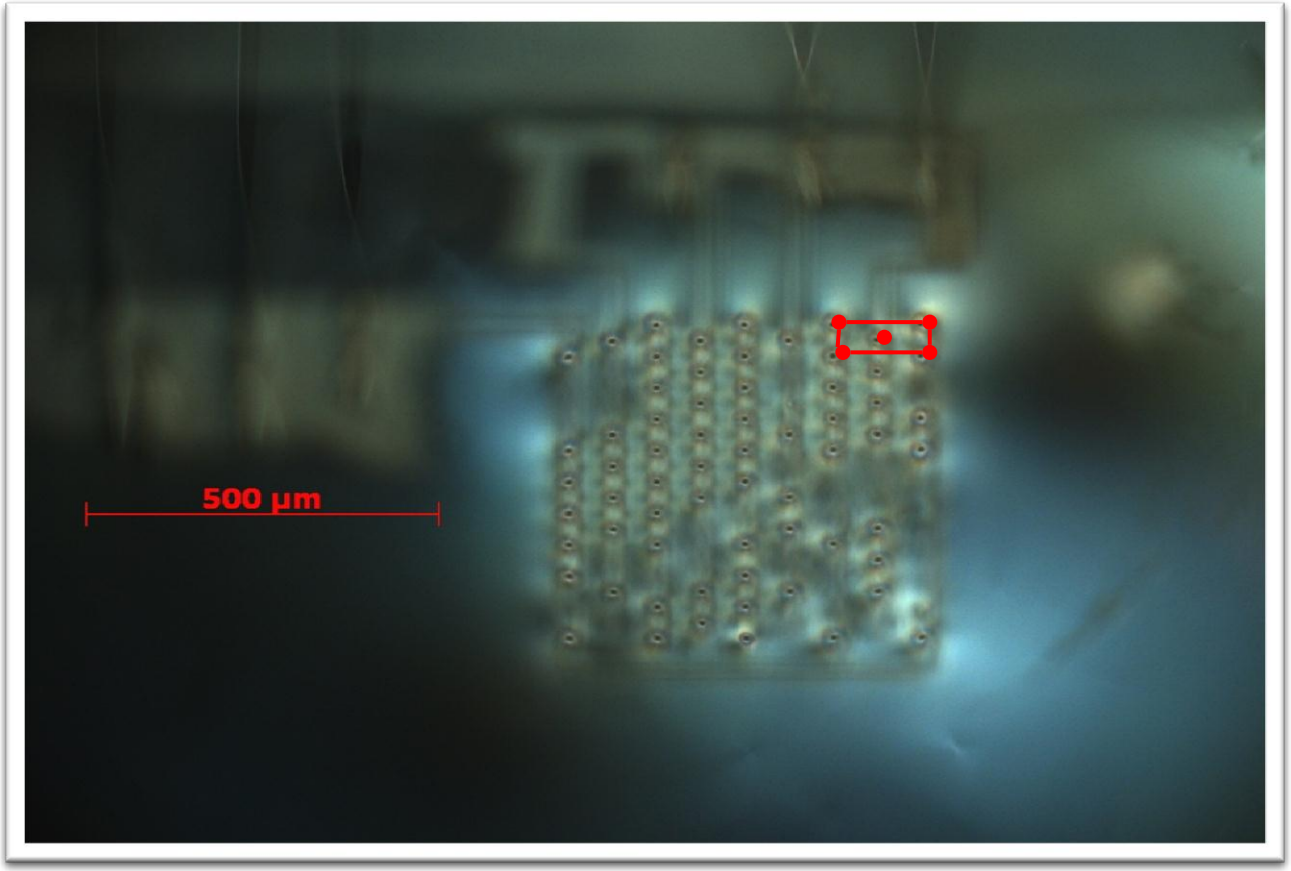
Optical microscopy – Crossed polarizers (In Bulk)

125µm



50µm

Rectangular unit cell



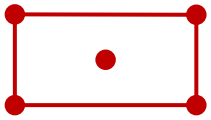
- scCVD sample

Courtesy of CERN

» Graphitization process wasn't optimized – 70% success rate

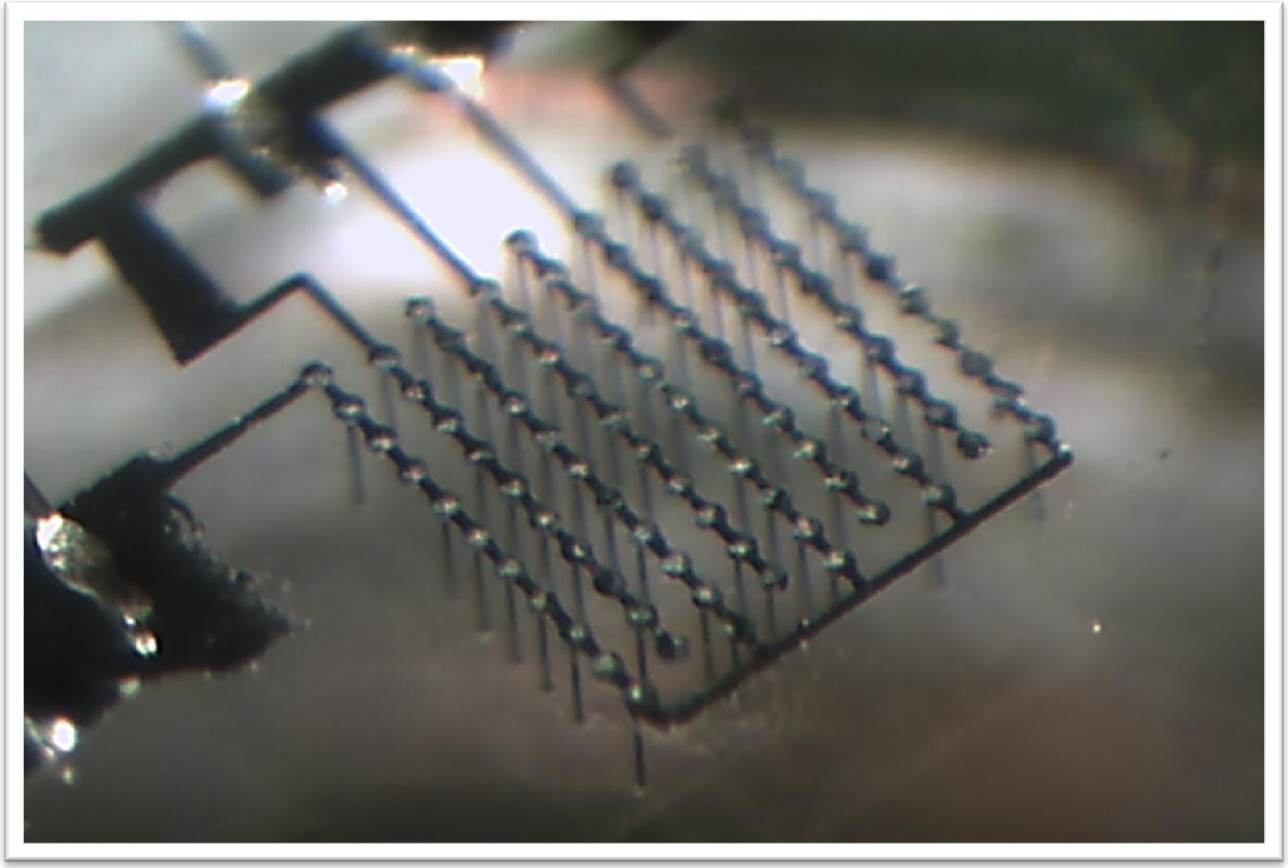
Optical microscopy – 45° Tilt

125µm



50µm

Rectangular unit cell

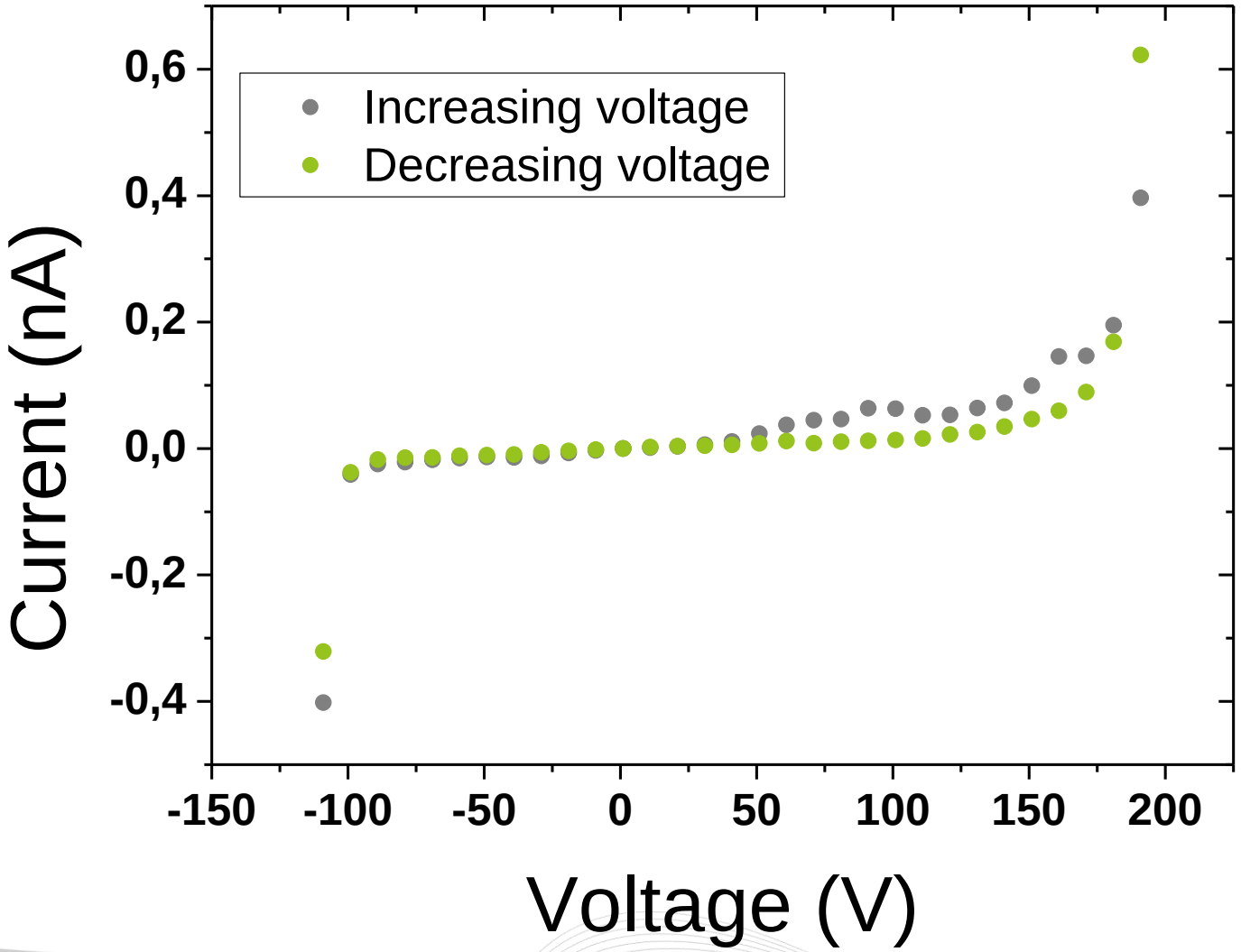


- scCVD sample

Courtesy of CERN

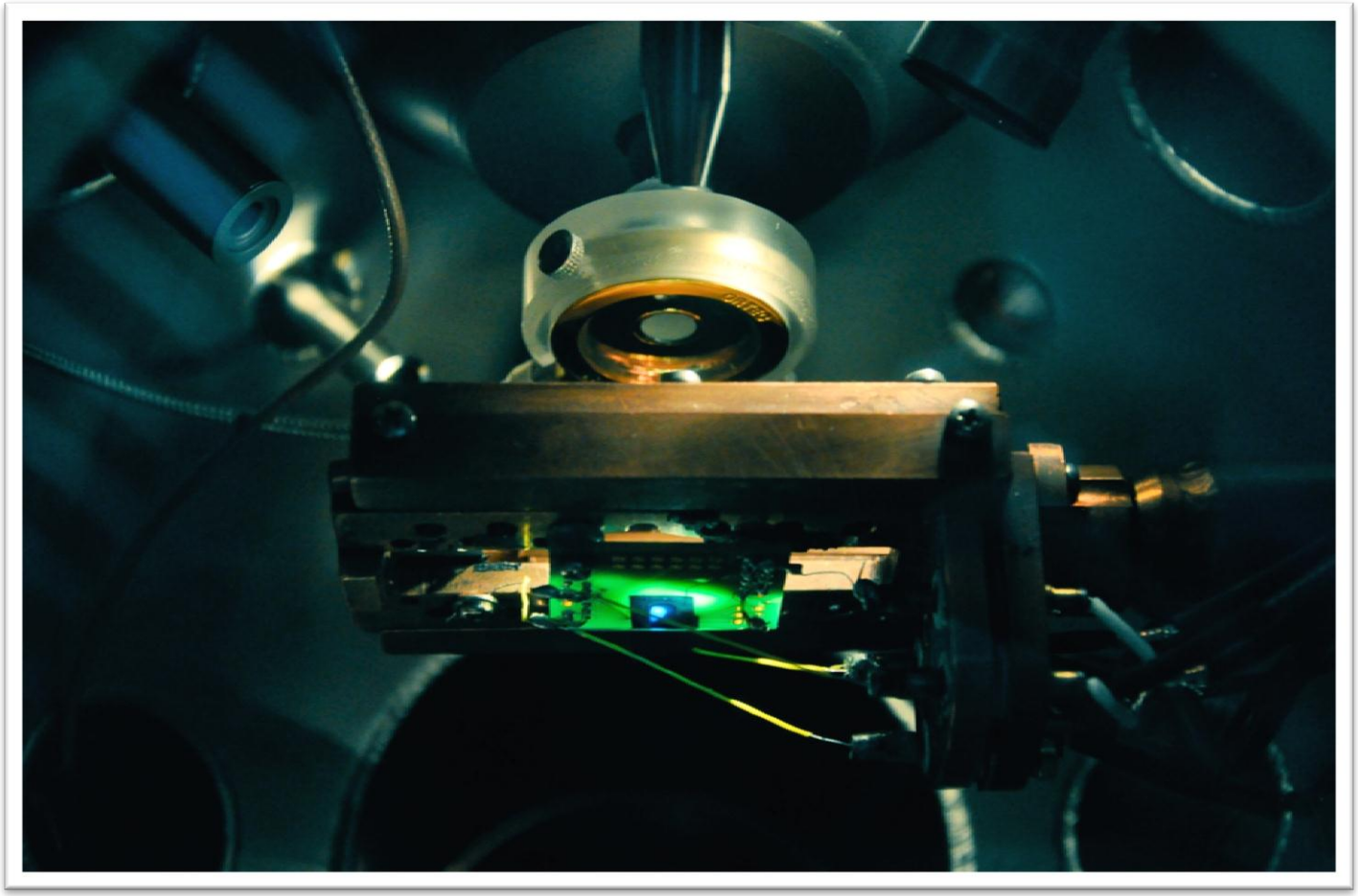
» Graphitization process wasn't optimized – 70% success rate

I(V) measurement



Characterization using protons micro-beam

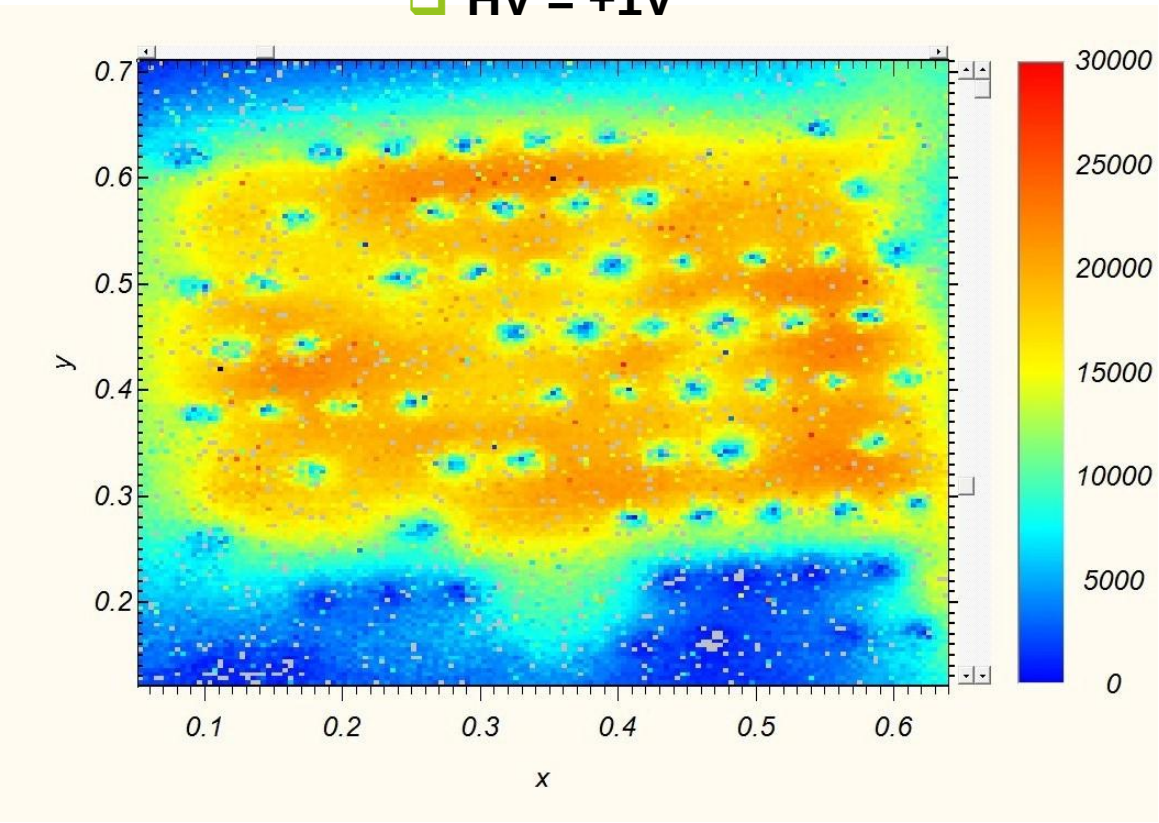
Experimental setup @IRB, Zagreb – 4,5 MeV protons µ-beam (1µm resolution)

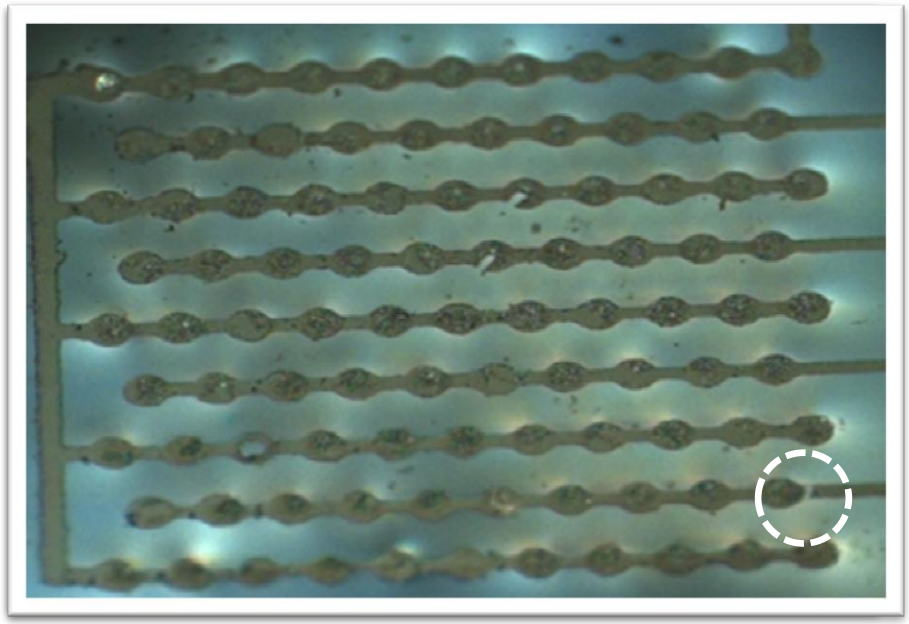


Characterization using protons micro-beam

IBIC mapping

- **HV = +1V**



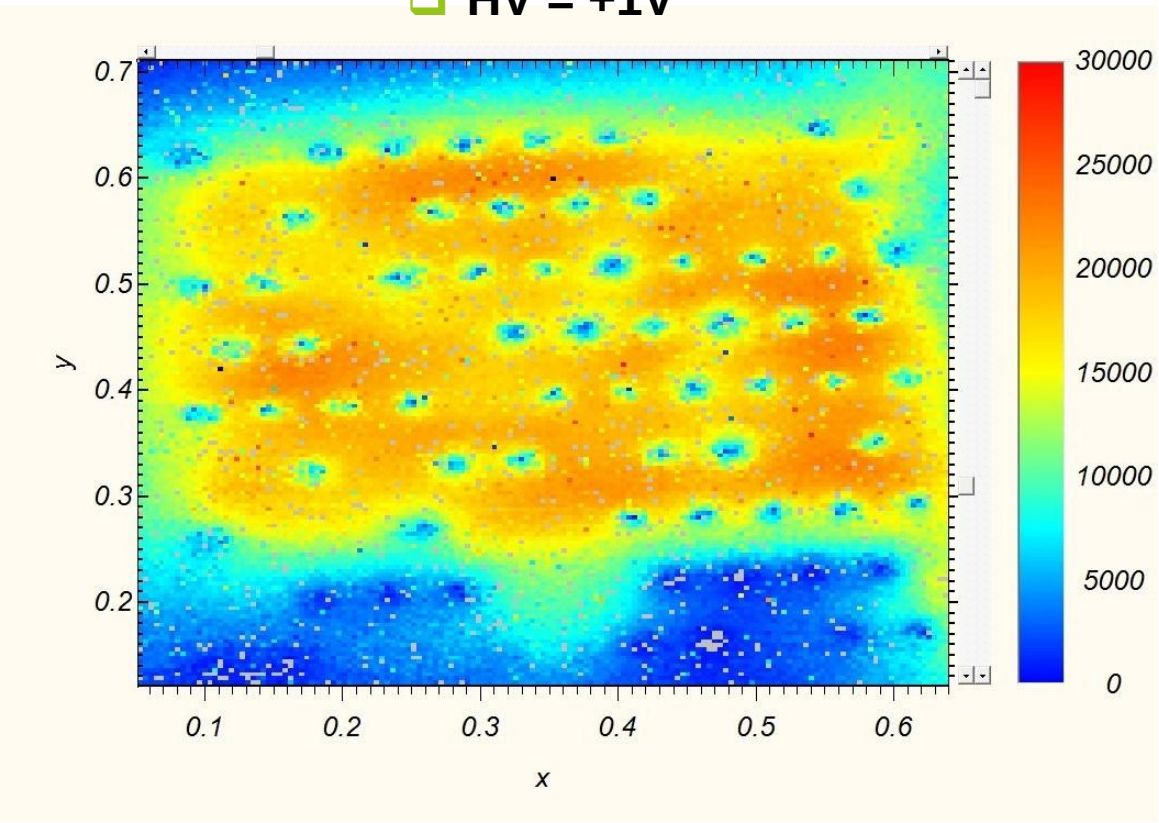


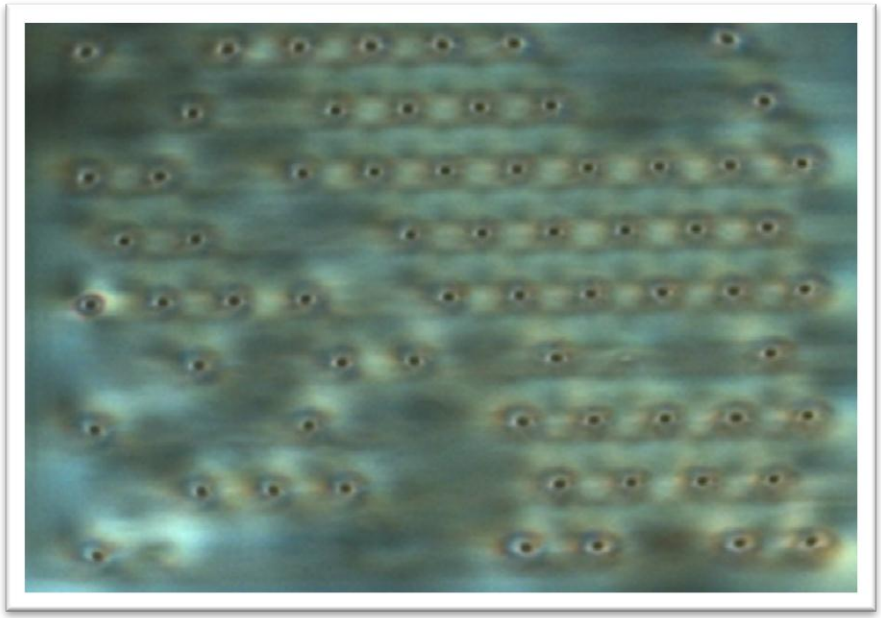
» **The dead area is due to a broken strip**

Characterization using protons micro-beam

IBIC mapping

- **HV = +1V**



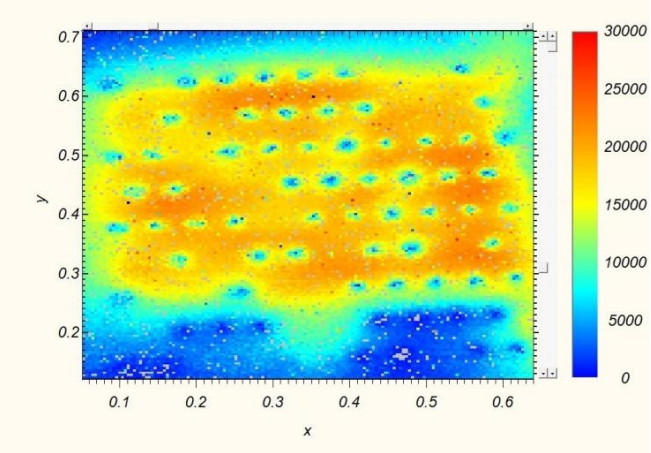


» **All connected colums are active**

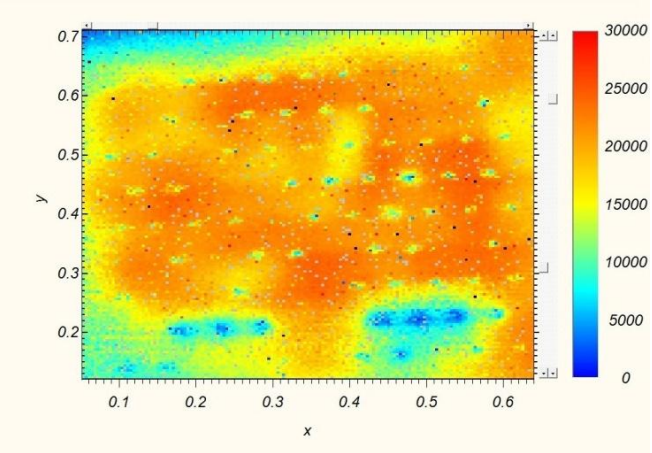
Characterization using protons micro-beam

IBIC mapping – Increasing positive bias

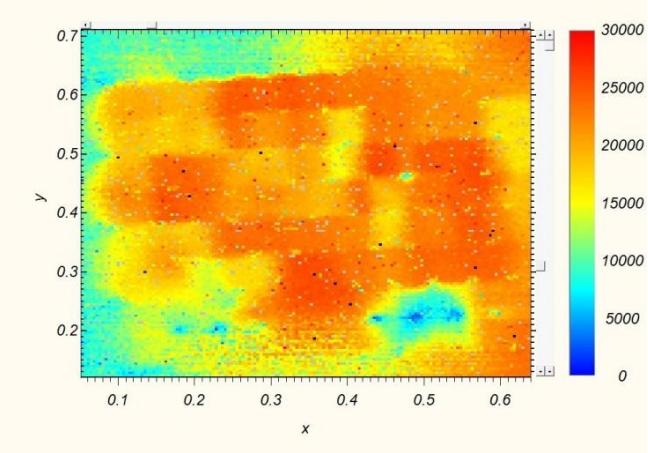
- +1V



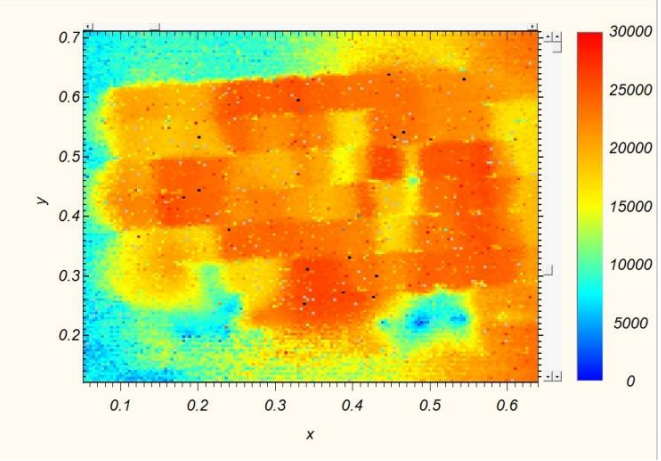
- +5V



- +40V



- +100V

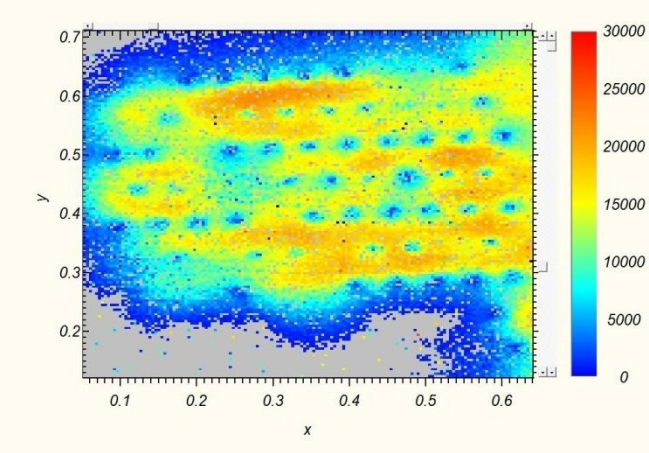


» **CCE is strongly non uniform**

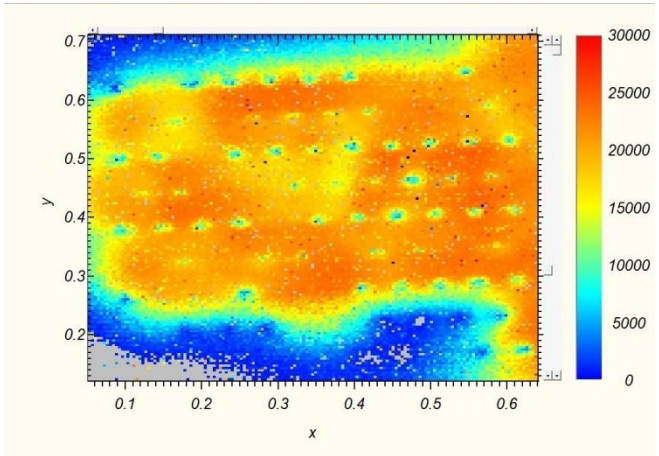
Characterization using protons micro-beam

IBIC mapping – Increasing negative bias

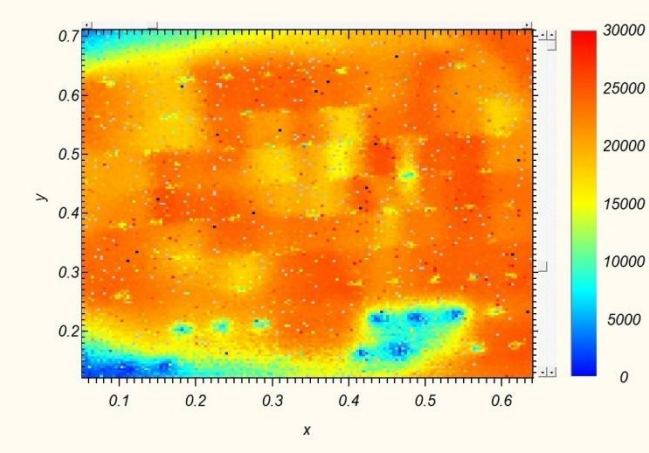
- -1V



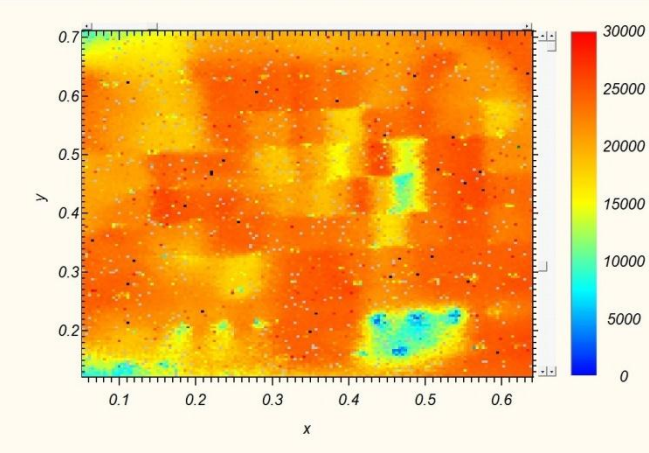
- -5V



- -40V



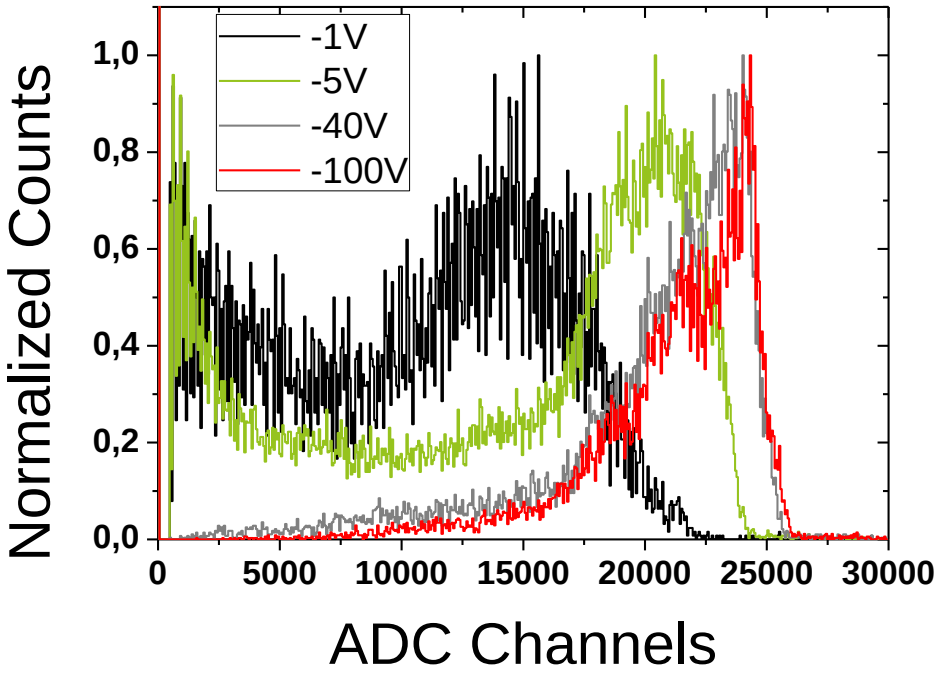
- -100V

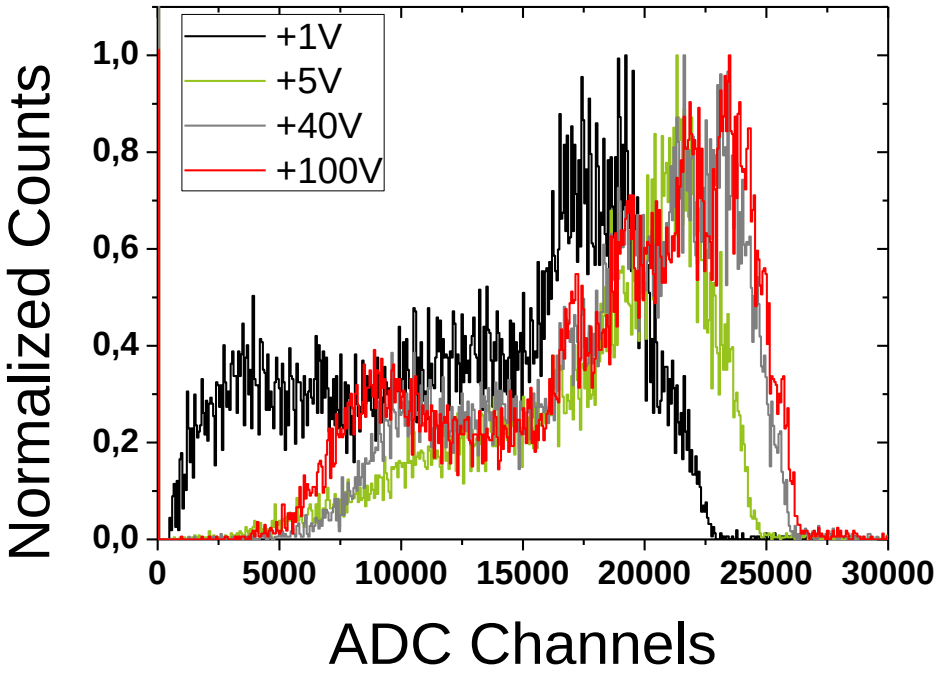


» Similar behaviour with negative polarity

» Probably due to bad contact (Al) quality

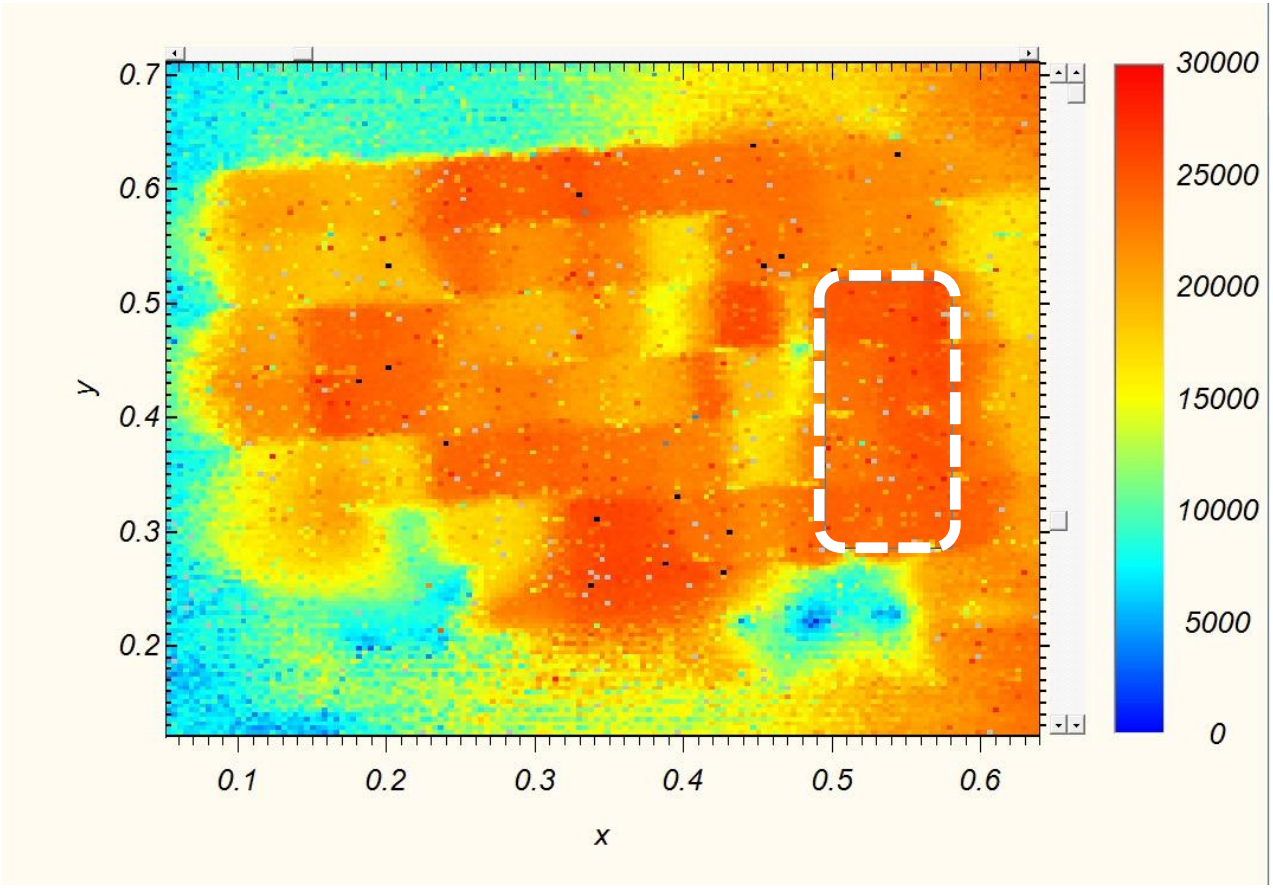
IBIC mapping – Charge Collection efficiency spectra





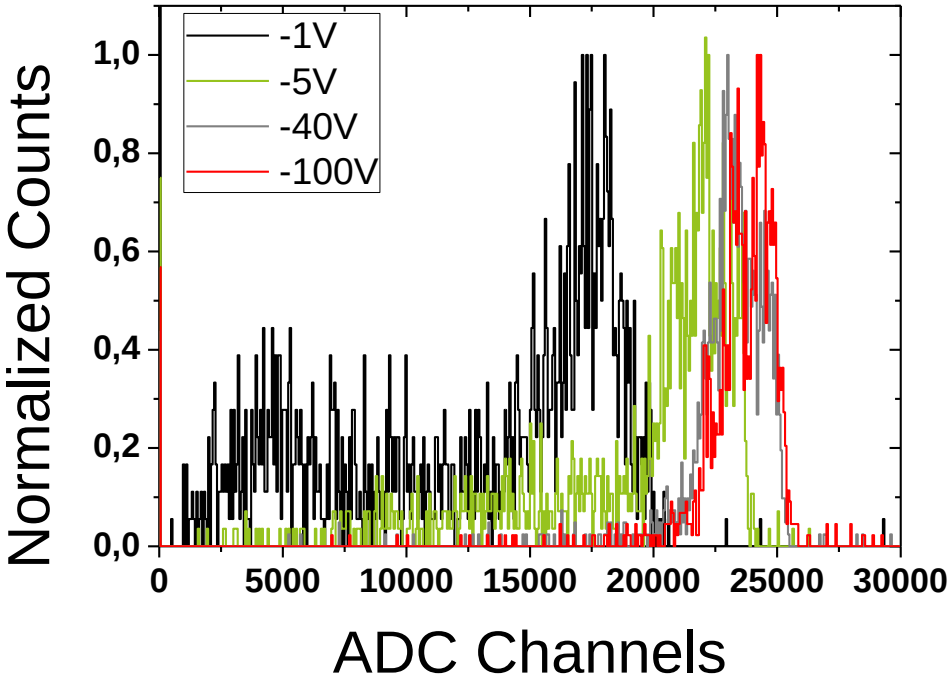
- **Negative biases**
- **Positive biases**

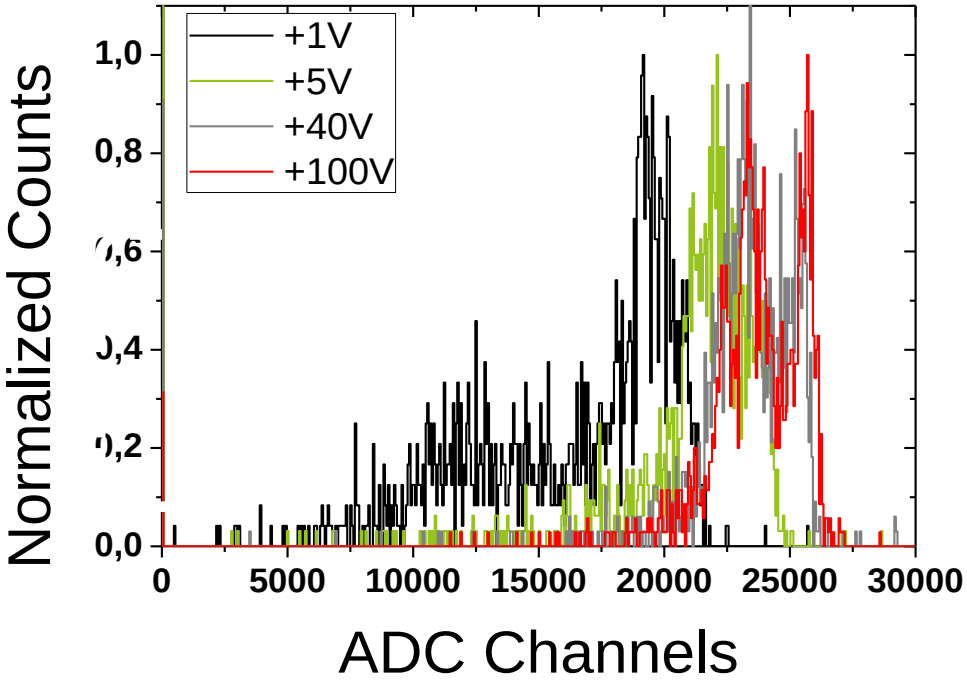
IBIC mapping – Focusing on a high CCE area



Characterization using protons micro-beam

IBIC mapping – Focusing on a high CCE area

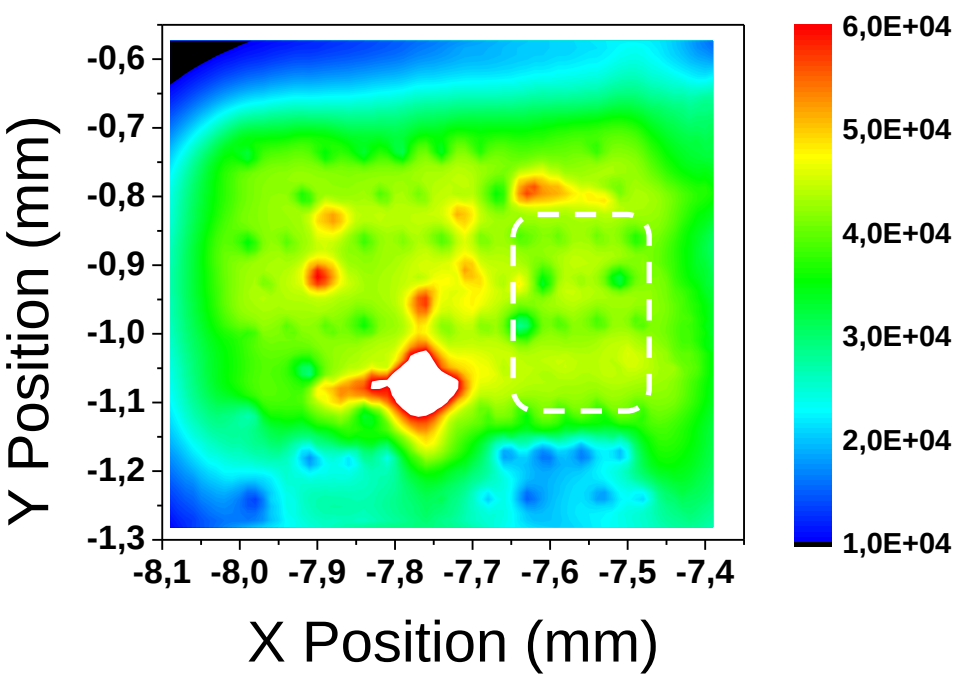


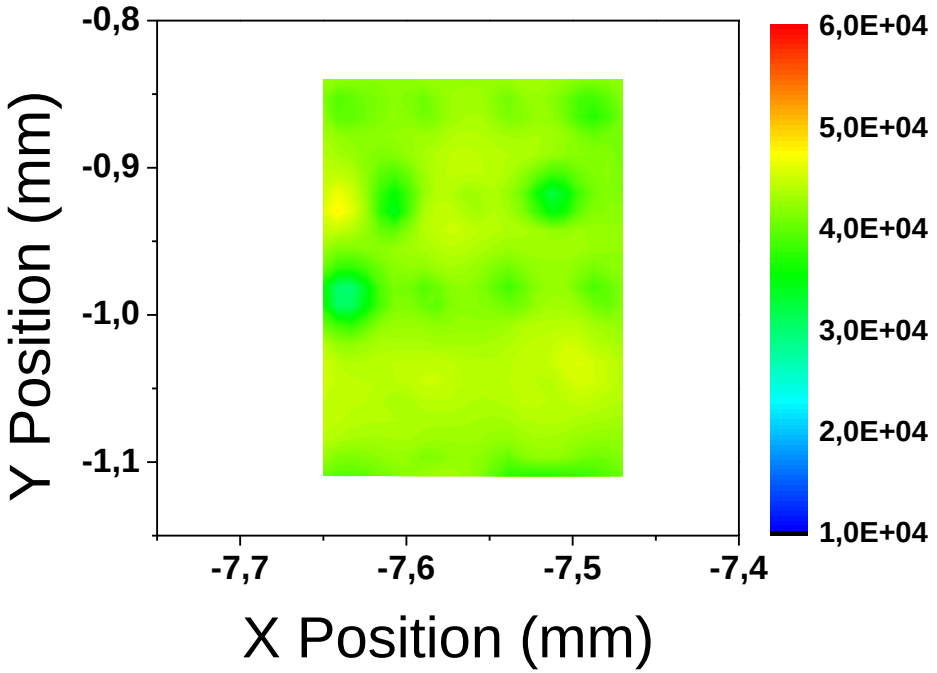


- **Negative biases**
- **Positive biases**

Mapping using 11.5keV photons (10µm resolution)

- HV = +10V





» Response homogeneity is OK

» There are hot spots that need to be investigated (material related)

Summary

We managed to…

- Produce graphitic electrodes with suitable dimensions for detectors applications
- Check that electrodes conductive enough and allow 100% CCE
- Check that device can be used in both single particle and DC measurements

Now we need to…

- Optimize contacts (see Alex talk)
- Understand these hot spots
- Irradiate samples and measure their radiation hardness

Thanks for your attention !

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