Production & characterization of large-size diamond detectors for particle tracking and medical applications

Detector R&D and Data Handling - 1010

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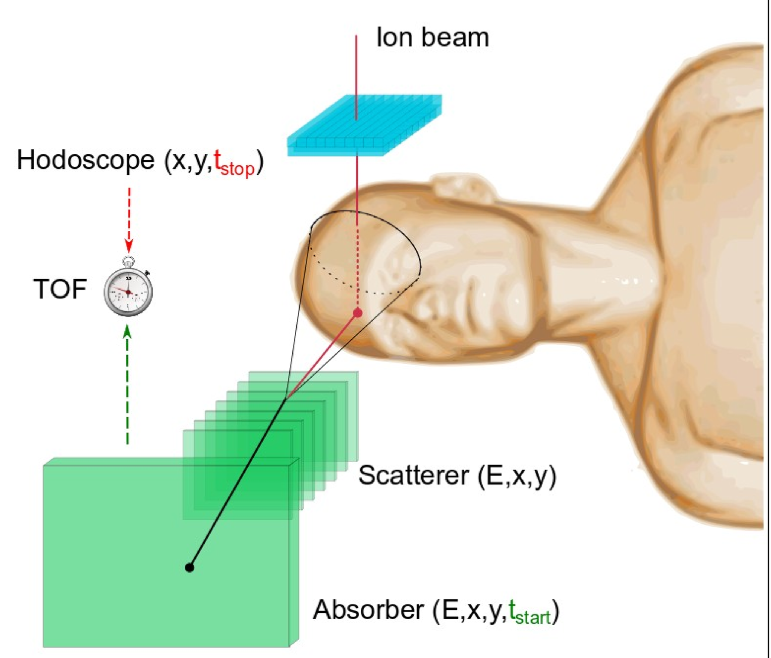
Context

Poly- and single-crystal CVD diamond samples were tested under various ionizing particles. Their metallization was performed by using Distributed MicroWave Plasmas, a fully original technology developed by LPSC. Their applicability as particle detector was investigated using α and β radioactive sources, 95 MeV/u carbon beams from GANIL (Caen) and short-bunched 8.5 keV photons from ESRF. This last facility offers unique capability of highly focused beams, together with an energy deposition which is almost uniform in the irradiated volume, as it would be for minimum-ionizing particles or single protons and carbon ions used for hadrontherapy.

The MoniDiam project is part of the French national collaboration CLaRyS for the on-line dose monitoring of hadrontherapy. It relies on the imaging of nuclear reaction products that are related to the ion interaction in the human tissue. The goal here is to provide large-area detectors with a high detection efficiency for carbon or proton beams, yielding time and position measurement at count rates greater than 100 MHz (beam tagging hodoscope). A time resolution ranging from 20 ps up to 40 ps and an energy resolution varying from 7 % up to 10% were measured. It allowed us to conclude that pCVD diamond detectors are good candidates for our beam tagging hodoscope development. The final detector will be a ~15x15 cm2 mosaic made of stripped-diamond sensors read by a dedicated integrated fast read-out electronics (~1800 channels).



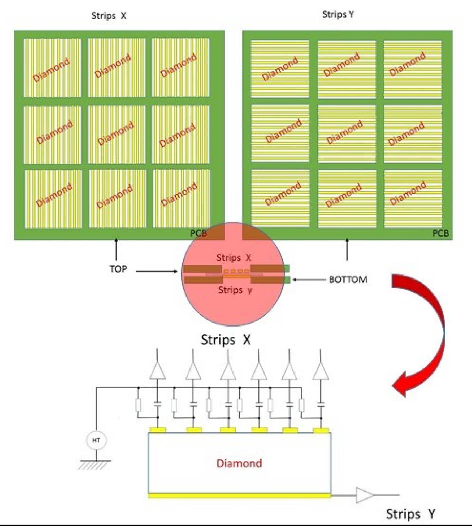
The Compton camera project of the CLaRyS collaboration

Goal : Development of a beam hodoscope

Existing development :
Array of scintillating fibres coupled to multichannel photomultiplier tubes (PMT).

Limitations :
- radiation hardness
- PMT admissible counting rate (10^7 Hz/channel)

Foreseen development :
MoniDiam project aims to develop a diamond-based hodoscope and its dedicated integrated fast read-out electronics

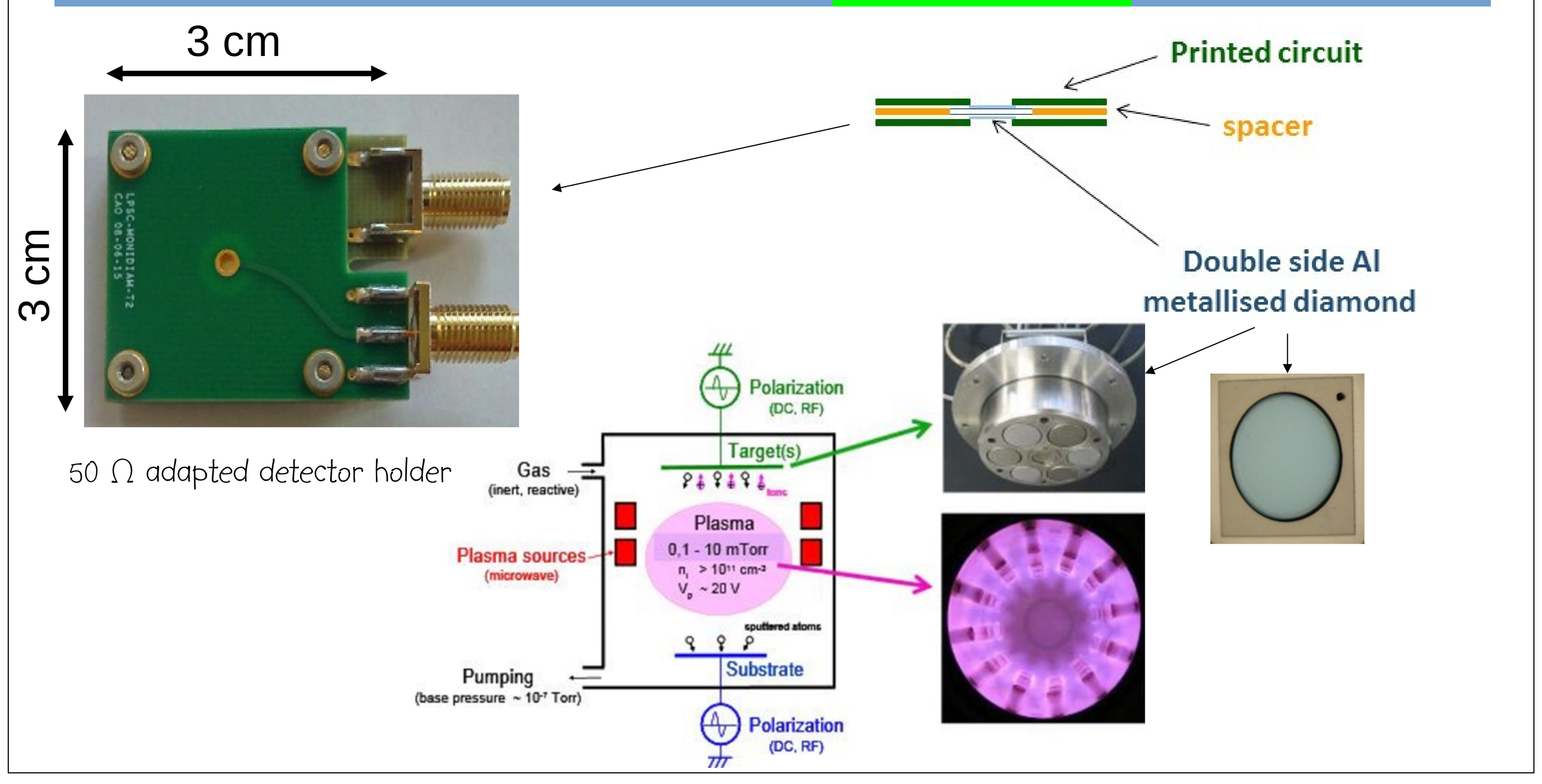


Diamond advantages :
- Intrinsic radiation hardness
- Fast signal risetime enables timing precision of a few tens of ps
- Low noise

Diamond sensors

Synthetic pCVD diamond detectors are foreseen to equip the detector

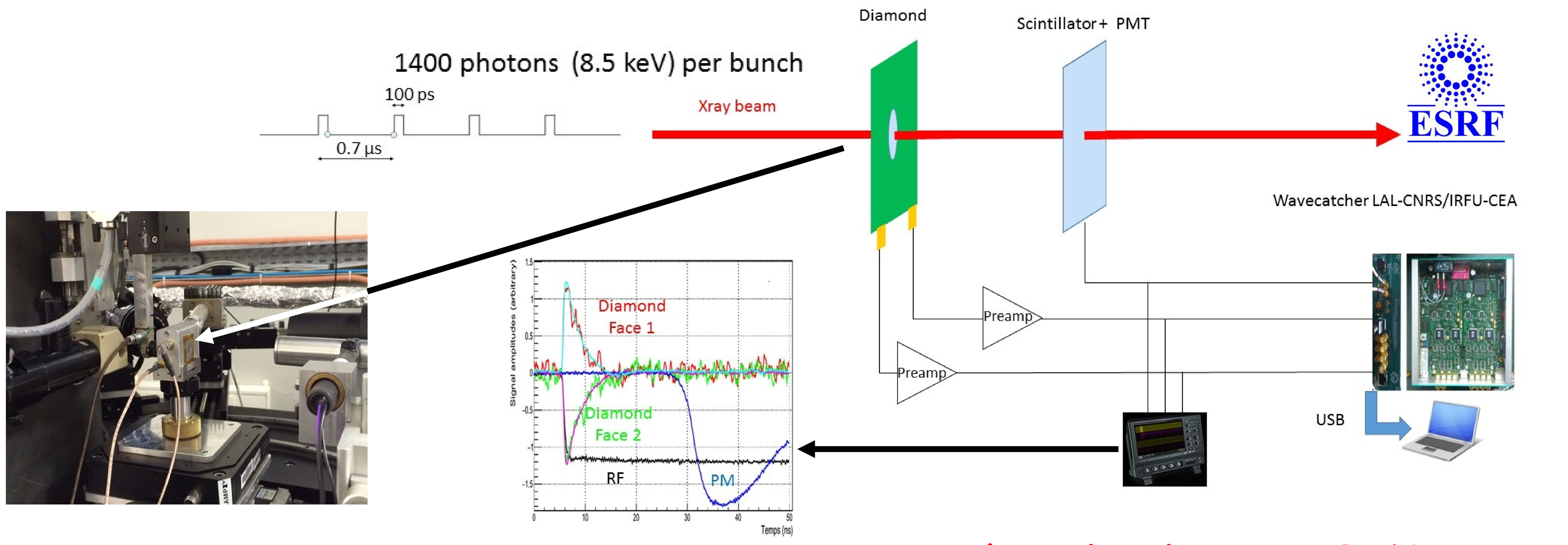
Properties	Diamond	Silicon
Density [g.cm^3]	3.52	2.33
Gap [eV]	5.48	1.12
Energy required to produce e-h [eV]	13.1	3.62
Mean signal MIP [e-/µm]	36	89
Resistivity [Ω.cm]	10^{13} – 10^{16}	10^5 – 10^6
Thermal conductivity [W.cm^{-1}.K^{-1}]	>1800	1.48
Displacement energy [eV]	43	25
Electron mobility [cm^2.V^{-1}.s^{-1}]	1900	1450
Hole mobility [cm^2.V^{-1}.s^{-1}]	2300	505



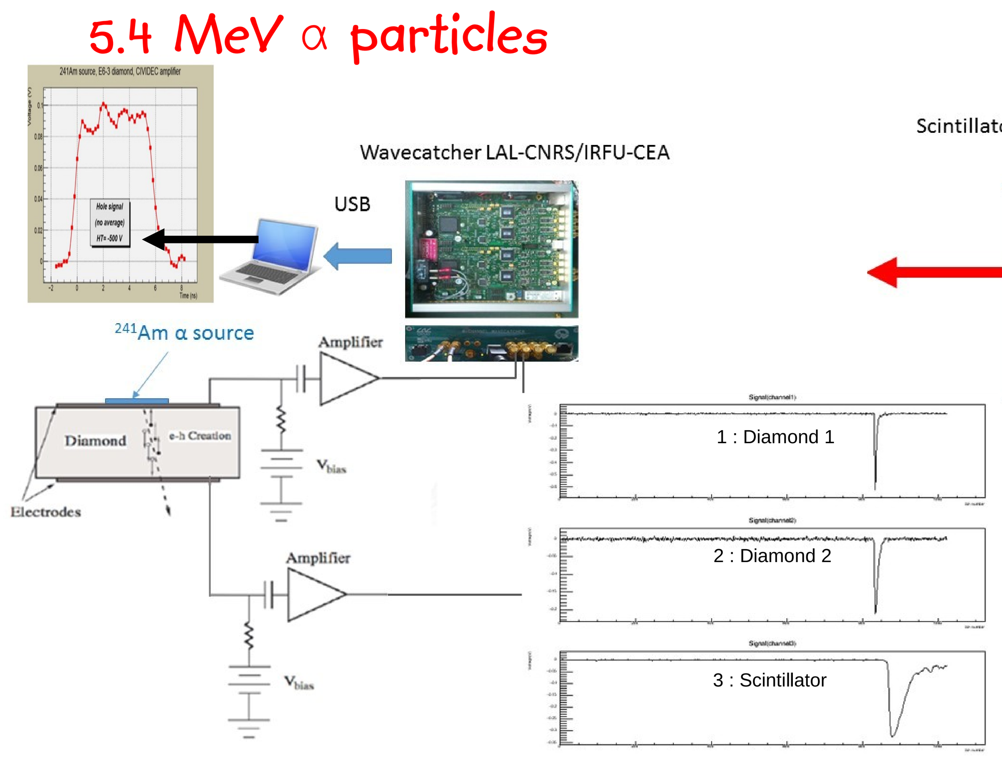
50 Ω adapted detector holder

Characterization of diamond detectors

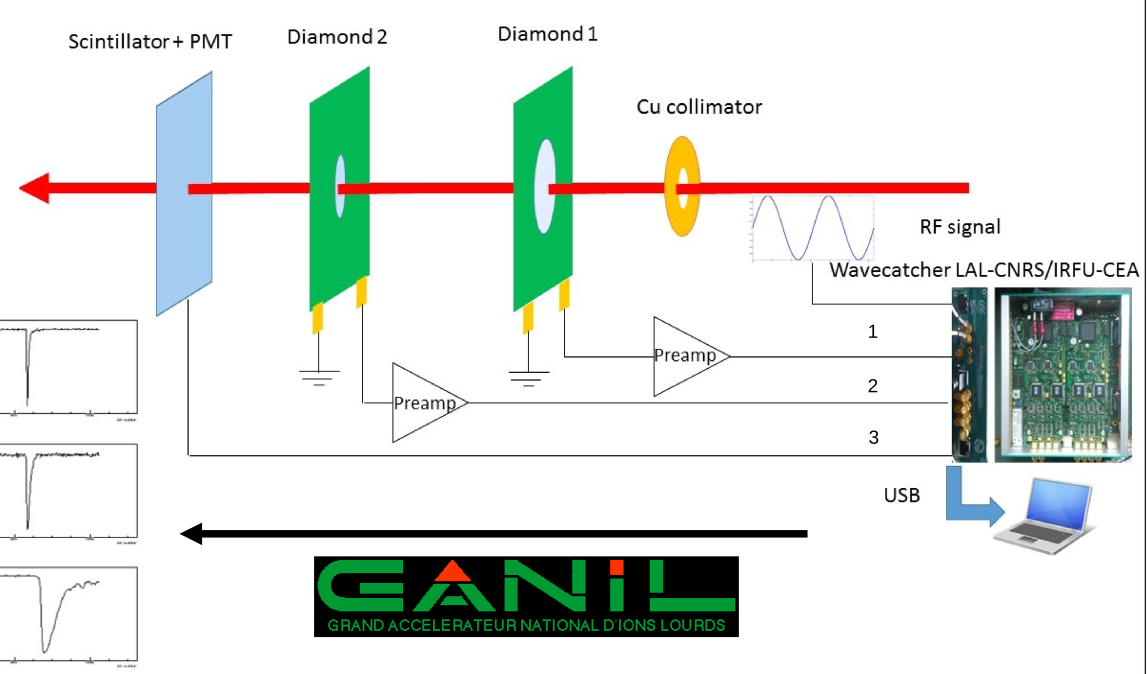
Pulsed beam (8.5keV, ~100ps) at ESRF ID21 X-ray Microscopy beamline



5.4 MeV α particles



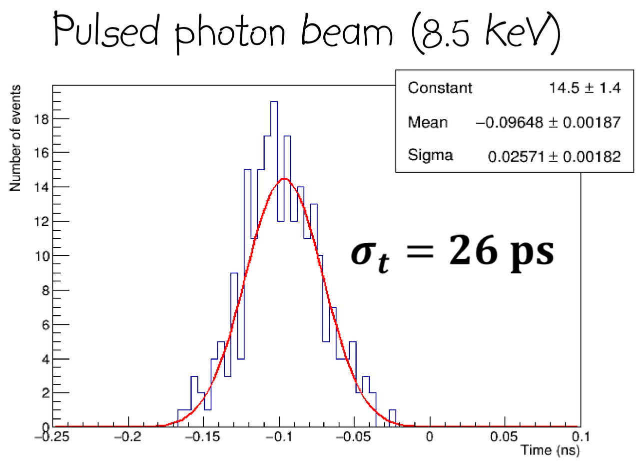
95 MeV/u carbon beam at GANIL



Results

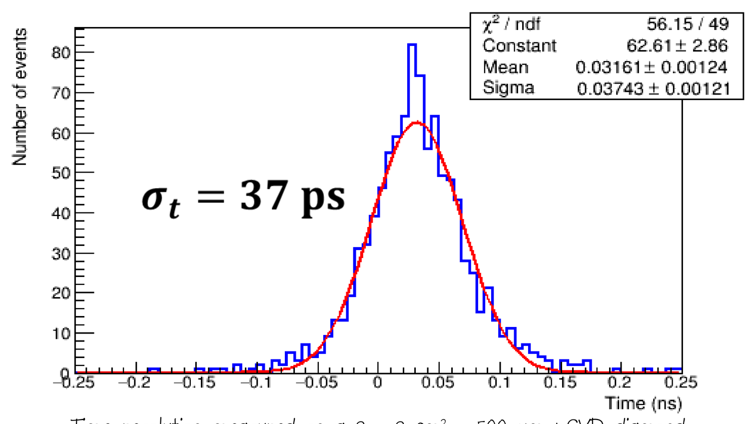
Time resolution

Pulsed photon beam (8.5 keV)



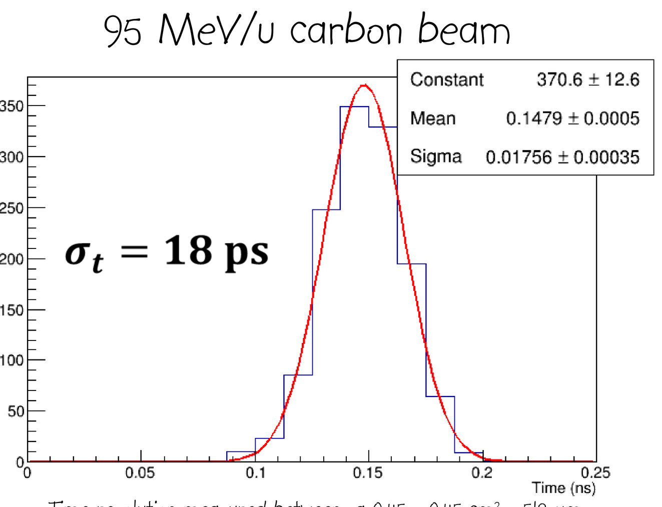
Time resolution measured on a 0.45 × 0.45 cm² × 518 µm sCVD diamond (difference of the timing of both surface signals)

5.4 MeV α particle



Time resolution measured on a 2 × 2 cm² × 500 µm pCVD diamond (difference of the timing of both surface signals)

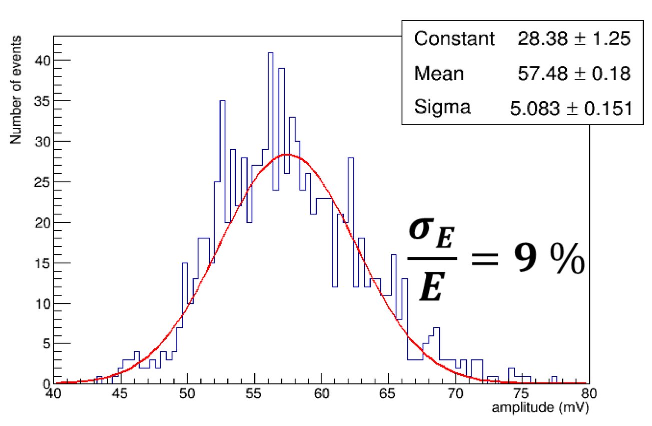
95 MeV/u carbon beam



Time resolution measured between a 0.45 × 0.45 cm² × 518 µm sCVD diamond and a 0.5 × 0.5 cm² × 300 µm pc-CVD diamond

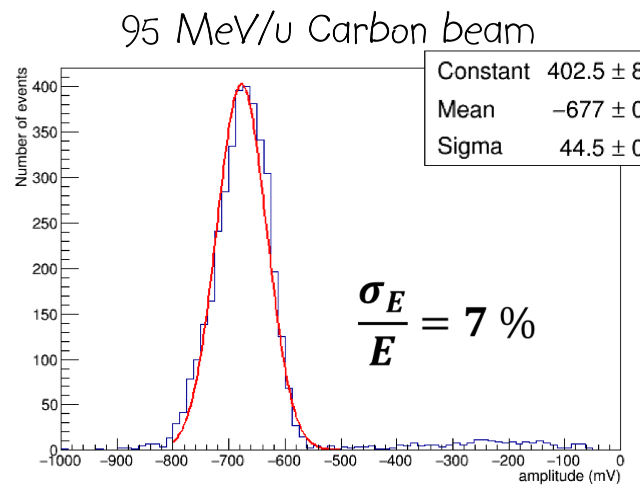
Energy resolution

Pulsed photon beam (8.5 keV)



Energy resolution measured on a 0.5 × 0.5 cm² × 300 µm pCVD diamond

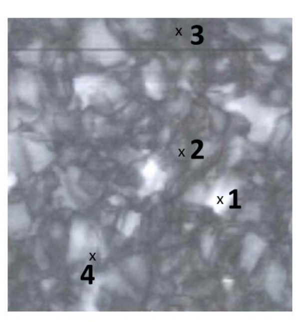
95 MeV/u Carbon beam



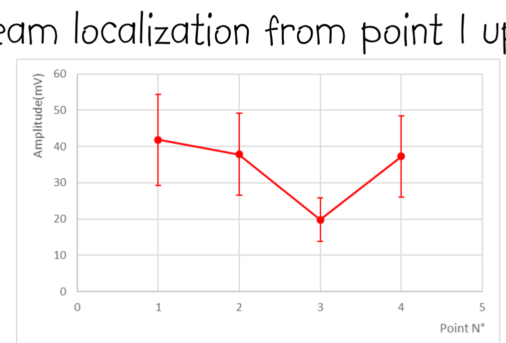
Energy resolution measured on the same 0.5 × 0.5 cm² × 300 µm pCVD diamond

Structure of pCVD diamond

Xray analysis of a 1 x 1 cm² x 500 µm pCVD diamond over a surface of 1 mm²



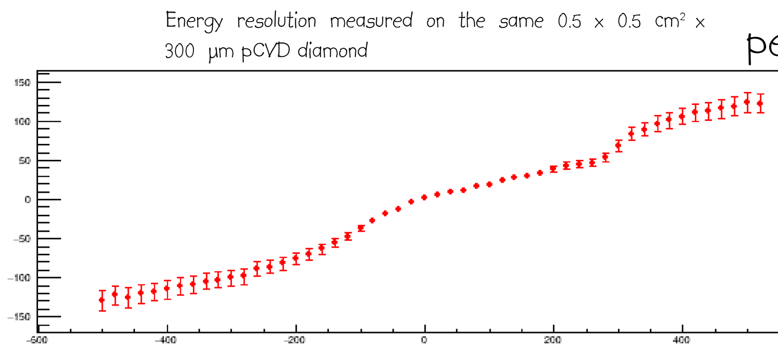
Amplitude of the signal versus the pencil beam localization from point 1 up to 4



Diamond signal response versus bias voltage

Pulsed photon beam (8.5 keV) at ESRF

0.45 x 0.45 cm² x 518 mc-CVD diamond



Conclusion and Perspectives

Synthetic pCVD diamond detectors are foreseen for on-line hadrontherapy beam tagging applications.

They will be used as a hodoscope to tag particles using time-of-flight both in a gamma camera & Compton camera projects put forward by the CLaRyS French collaboration. Other applications such as proton radiography and secondary proton vertex imaging are also foreseen.

Their radiation hardness, fast response and good signal-to-noise ratio make diamonds good candidates :

- a time resolution better than 40 ps
- an energy resolution better than 10 %
- a signal amplitude variation quasi linear with bias voltage

They were measured by irradiating their whole surface with various ionizing particles, despite the obvious non uniformity of the crystalline structure.

The final detector will consist of a ~15x15 cm² mosaic arrangement of stripped sensors read by a dedicated integrated electronics (~1800 channels) with the following characteristics :

- counting rate per channel :10 MHz,
- time resolution at the level of few tens of ps,
- spatial resolution at the level of 1 mm.

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