Diamond detectors for biophysics applications

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Synthetic diamond as radiation detector

Crystal structures

Single-crystal CVD diamond (sc-CVD) ← **Crystal quality – Charge collection** | **Size – Price -Availability** → **Polycrystalline CVD Diamond (pc-CVD)**

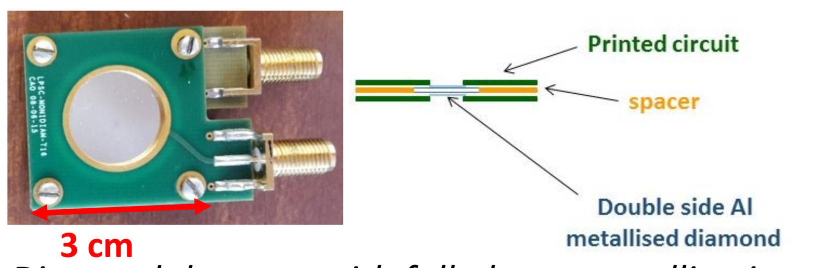
Alternative : **Diamond heteroepixtaxy on Iridium substrate (DOI)**

➡ Large samples (> 1cm²) with high charge collection properties **BUT** still R&D

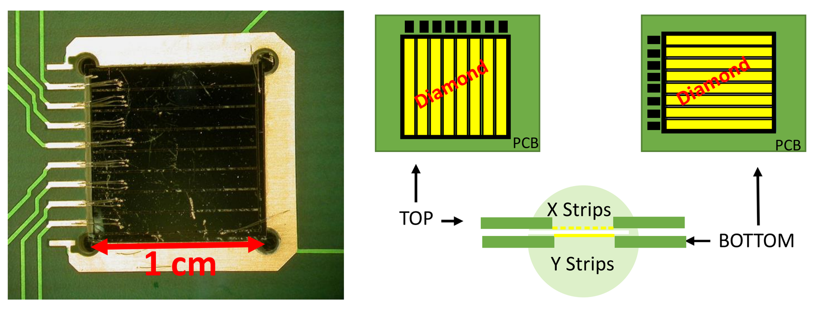
Intrinsic properties

Resistivity	> 10^{13} Ω.m	→ Low leakage currents
e/h pair creation energy	13.1 eV	→ Good Signal-to-Noise Ratio (SNR)
Displacement Energy	43 eV	→ Radiation hardness
Charge carrier mobilities	≥ 2000 cm²/V/s	→ Fast time response
Atomic number	6	→ Tissue-equivalent

Development in instrumentation at LPSC



Diamond detector with full planar metallization

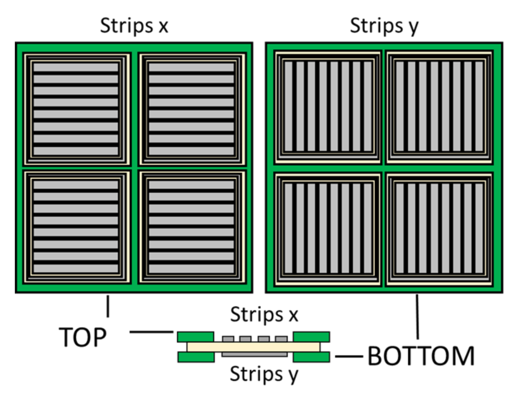


Double-side stripped diamond demonstrator for the development of a beam tagging hodoscope

Diamond applications in biophysics at LPSC

- **Beam tagging hodoscope for online ion range verification in hadrontherapy**

Hadrontherapy is external radiotherapy by means of light ion beams. The technique enables a ballistic targeting of tumors but is sensitive to uncertainties on the effective ions range. In-vivo online ion range assessment could reduce security margins currently set during treatment planning.
A diamond based beam hodoscope is currently developed at LPSC Grenoble. It aims to provide time- and 2D position-tagging of ion beams in the context of Prompt-Gamma Imaging (CLaRyS collaboration). It is an online in vivo ion range verification technique.



Design principle of the diamond based hodoscope, made with 4 large area diamonds

- **New project : In-vivo dosimetry for synchrotron radiation therapy**

The European Synchrotron Radiation Facility (ESRF) is one of the few accelerators in the world that has already carried out clinical tests of radiation therapy by means of intense synchrotron radiation. The feasibility and safety of the method has been proven.
Due to ultra-high dose rates, the question of in vivo dosimetry is particularly challenging for synchrotron radiotherapy and has not been addressed so far. In this context, a diamond-based portal dosimeter is currently developed at LPSC Grenoble. It aims to provide a real-time information on the dose delivered to the patient.

Rat irradiation during first tests with a portal diamond dosimeter at ESRF

Requirements **: radiation hard, fast, low leakage currents, tissue-equivalent, very large area (ideally 20 x 20 cm²)**

Characterization of developped detectors

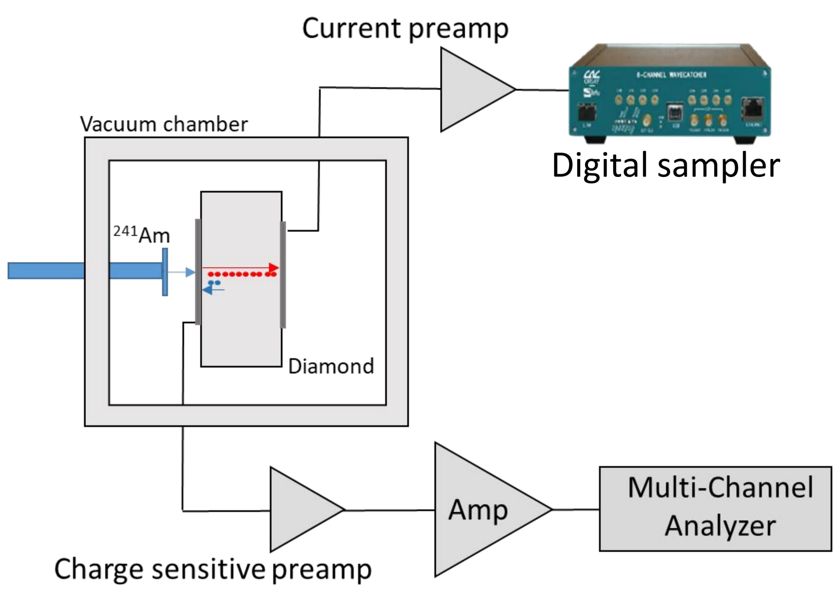
^{241}Am alpha source

^{241}Am source: E ≈ 5.5 MeV (67 fC in diamond)

⇒ Range in diamond ≈ 14 µm << thickness (300µm)

⇒ Bias polarity enables to select charge carriers

⇒ Study of charge carriers properties



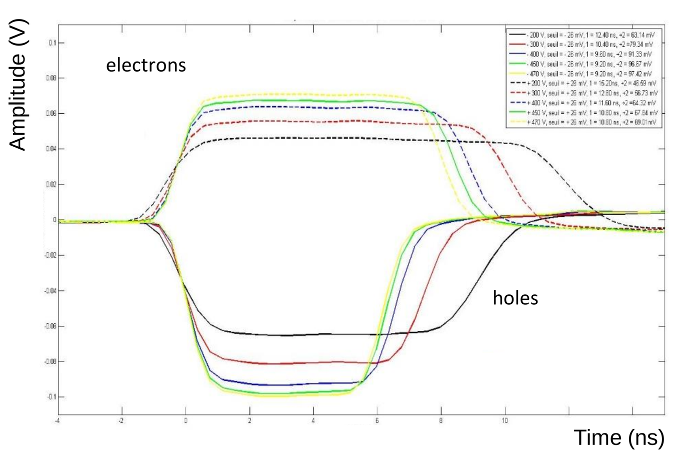
Wide-band current electronics

Preserves the original shape of the current pulse at the sample output

Pulse shape analysis ⇔ Intrinsic crystal quality

Measurement of charge carriers electronic properties:

- Drift velocitiy
- Charge carrier lifetime
- Low-field mobility



Typical electron and hole pulse shapes measured on a sc-CVD diamond under short-range alpha irradiation at various bias voltages

Charge-sensitive electronics

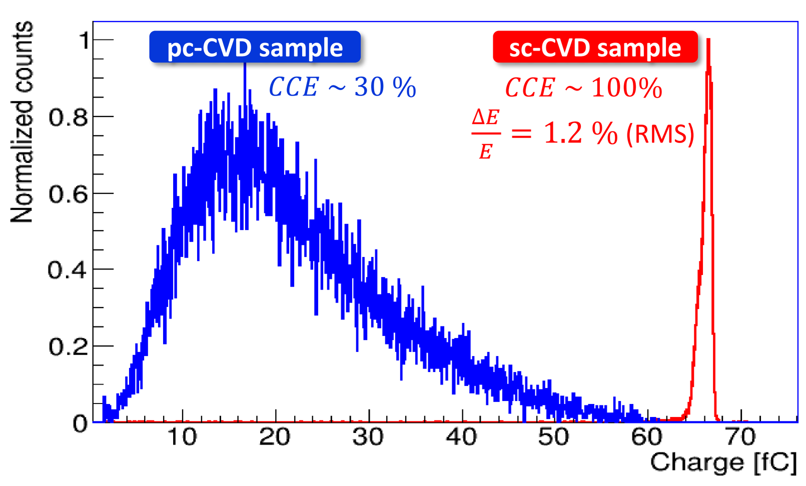
Integrates/filters the incoming charge

⇒ Enhances Signal-To-Noise Ratio

Assesses the spectroscopic capabilities of the sample:

- Energy resolution
- Charge Collection Efficiency (CCE)

$$CCE = Q_{collected}/Q_{generated}$$

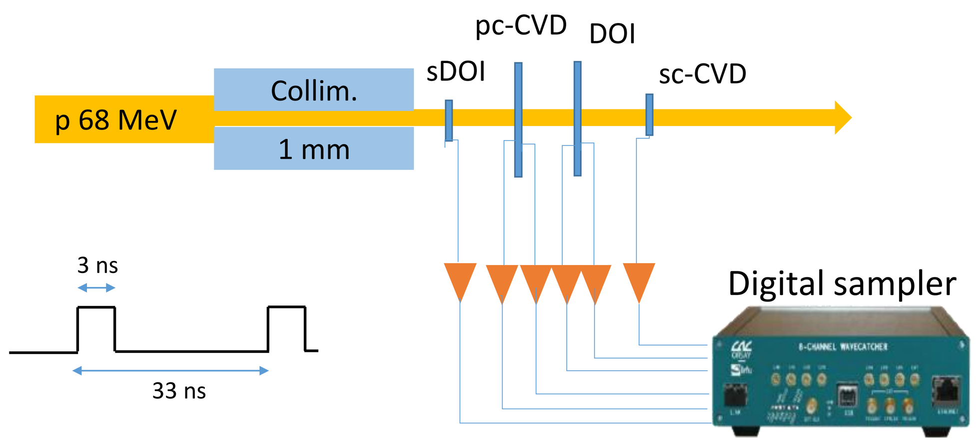


Spectroscopic response of sc-CVD and pc-CVD diamond detectors to short-range alpha irradiation

68 MeV proton beam @ ARRONAX

Diamonds: sDOI : 5.0 x 5.0 mm² x 300 µm
pc-CVD : 10 x 10 mm² x 300 µm
DOI : 10 x 10 mm² x 300 µm
sc-CVD : 4.5 x 4.5 mm² x 515 µm

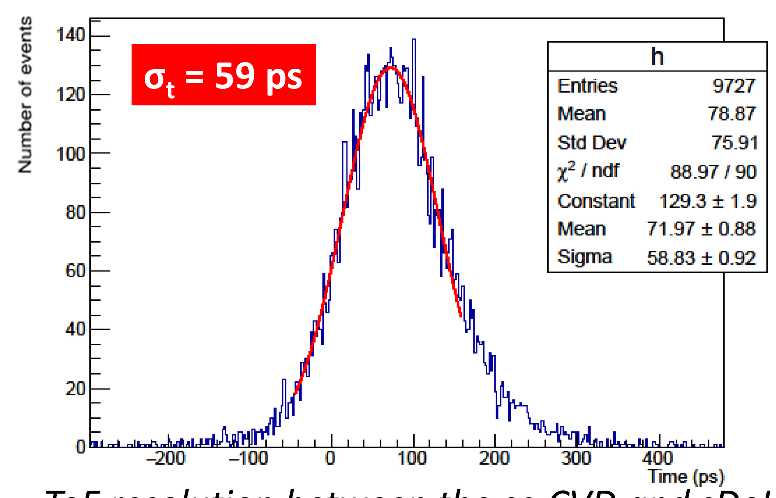
Electronics : CIVIDEC current preamplifiers (2GHz, 40dB)



Time resolution

Energy deposition/ion (SRIM) :

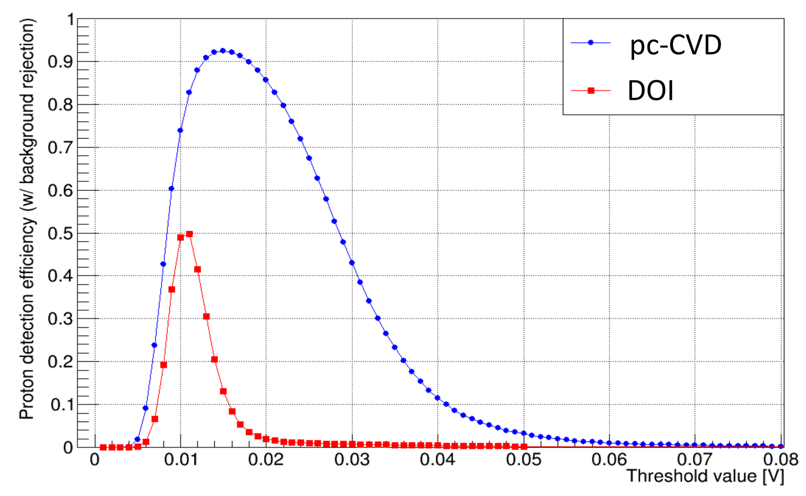
Thickness	300 µm	515 µm
Energy deposit	0.93 ± 0.10 MeV	1.6 ± 0.13 MeV



ToF resolution between the sc-CVD and sDoI samples

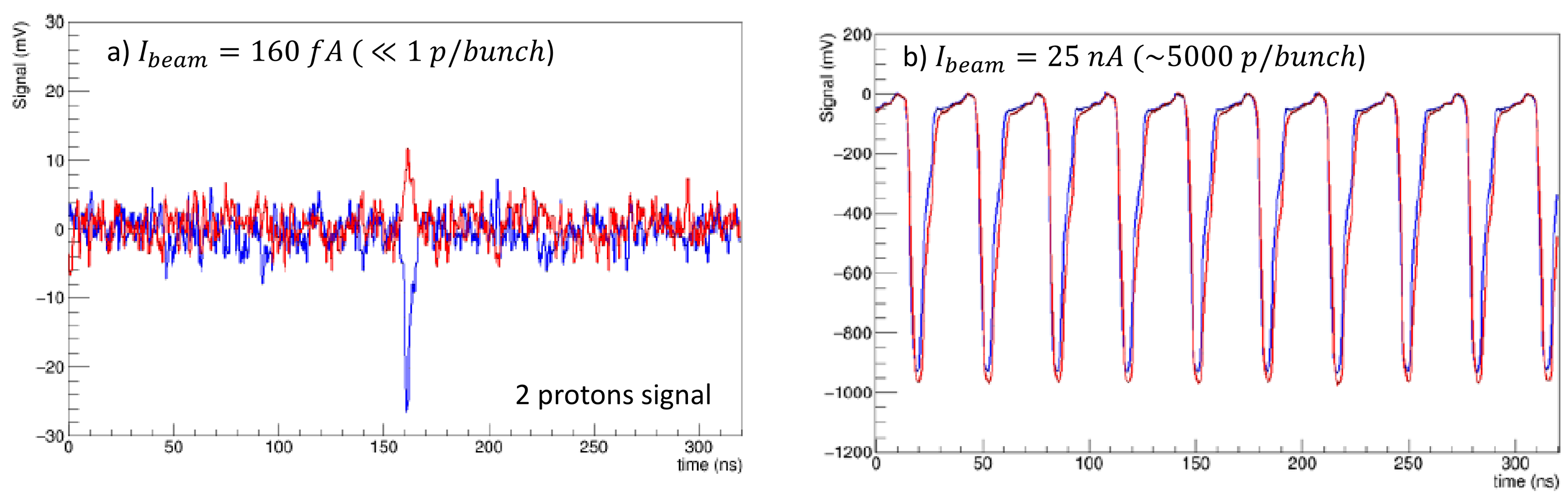
Single proton detection efficiency

$$\varepsilon = \frac{N_{triple}}{N_{double}}\left(1 - \frac{N_{random}}{N_{double}}\right)$$



Single 68 MeV proton detection efficiency obtained with the pc-CVD and DOI samples

Stability at high intensity



Recorded waveforms obtained at a) low and b) high intensity with the pc-CVD (blue) and the DOI (red) samples

Conclusions and perspectives

Diamond detectors exhibit very interesting properties for particle tracking. Their low noise high time resolution and radiation hardness make them good candidates to trigger Time-of-Flight measurements while being exposed to high radiation fields. Various types of crystal qualitiy have been characterized and tested so far. Even if they can provide a good charge response, sc-CVD diamonds are not available in large area, that is going to limit their use in the development of a ion beam diamond hodoscope. From the results presented here, pc-CVD samples have enlightened very good single proton efficiency and stability to beam intensities up to 25 nA. The DOI samples response is worse even if they also showed good stability at high intensity.
As they fulfil size and efficiency requirements, pc-CVD samples are foreseen to be used to develop a ion beam tagging hodoscope. The instrumental development of the 4-diamond demonstrator is ongoing. In parallel to this, the electronics group at LPSC is developing a dedicated electronics that will provide timing and spatial information of incoming ions. It will be assembled with the detector to be tested under light ion irradiations.

References : ML Gallin-Martel et al, ANIMMA 2017, EPJ Web of Conferences **170**, 09005 (2018) https://doi.org/10.1051/epjconf/201817009005
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