Diamond-based thin detectors for radiobiological applications of charged-particle microbeams

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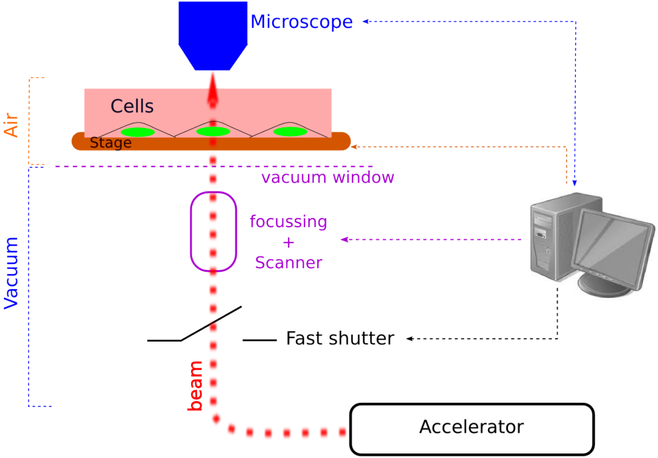
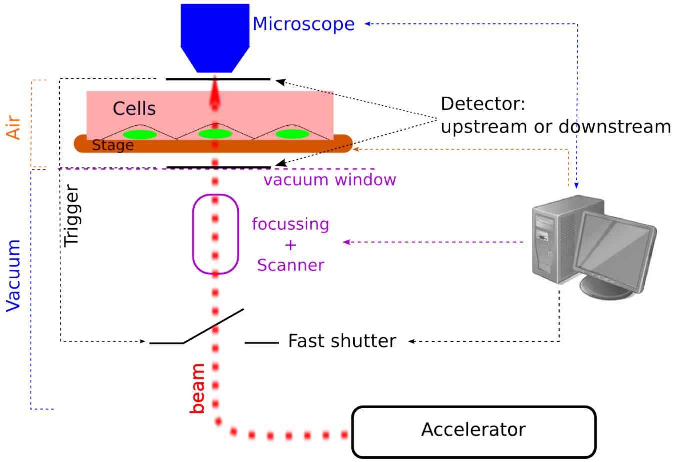
AIFIRA facility

- 3.5 MV Singletron accelerator (HVEE)
- Ions: p, d and helium
- 2 microbeam lines → 1 dedicated to targeted irradiation of cells

Micro-irradiation and dose control



Micro-irradiation and dose control



For MeV light ions (p, He), medium too thick ⇒ detector upstream the sample

Detecting (efficiently) MeV light ions

We have to use **thin transmission detectors**
Several approaches:

- Thin plastic scintillators (e.g. Gray Lab, PTB ...)
- Gas detectors
- Secondary electrons from vacuum window
- Thin semi-conductors (Si or diamond)

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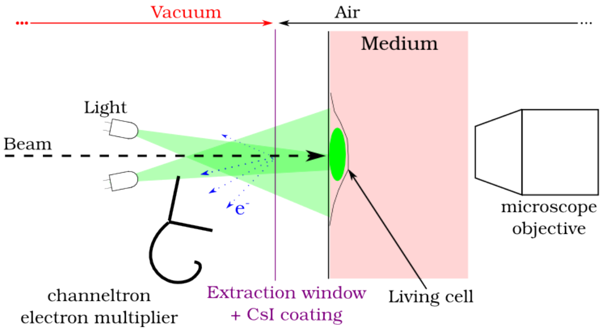
3 MeV Helium ions :
140 keV$\cdot\mu$m^{-1} in water, range $\approx$ 15 μm
$\Rightarrow$ secondary electrons
3 MeV protons :
12 keV$\cdot\mu$m^{-1} in water, range $\approx$ 150 μm
$\Rightarrow$ thin active scCVD membrane

Secondary electrons detectors

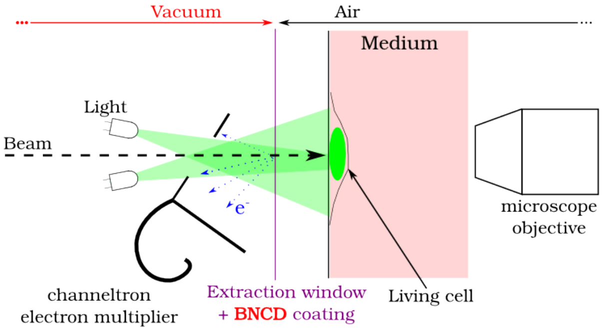
Up to now, mainly used for detecting heavy ions (GSI Darmstadt)
B. Fischer et al. (2003), NIMB 210, 285–291

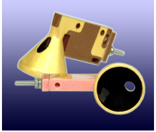


Secondary electrons detectors

We revisited the idea of using Boron-doped NanoCrystalline Diamond (BNCD) coatings

⇒ coating of commercial Si_3N_4 vacuum windows with nm thick BNCD

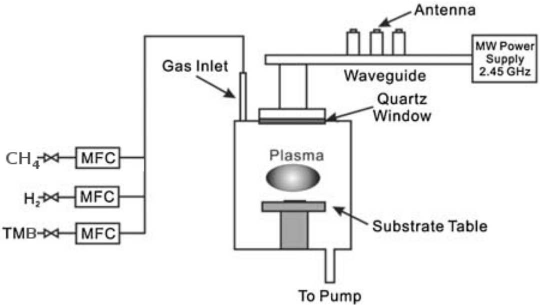




Dr. Sjuts Optotechnik GmbH

BNCD membranes fabrication

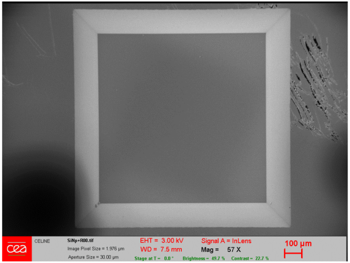
1. Substrate seeding with 5 nm diamond nano-particles on Si_3N_4 windows
2. MWCVD p+ diamond growth (MicroWave assisted Chemical Vapour Deposition)

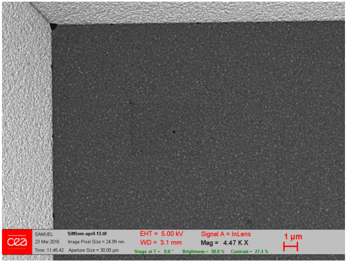


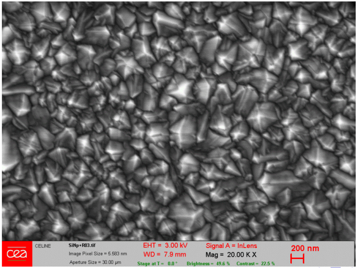
Fabrication: Diamond materials and sensors lab, CEA (Michal Pomorski)

BNCD membranes fabrication

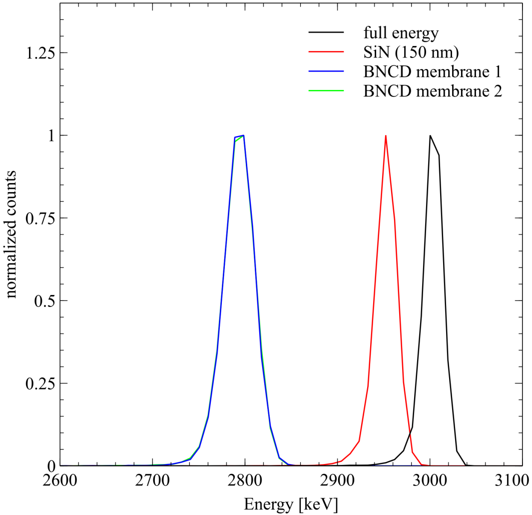
BNCD growth on 150 nm thick Si_3N_4 windows

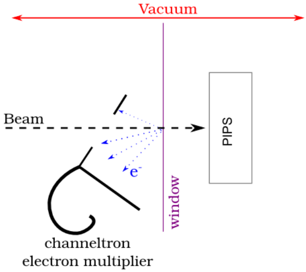






Thickness measurements



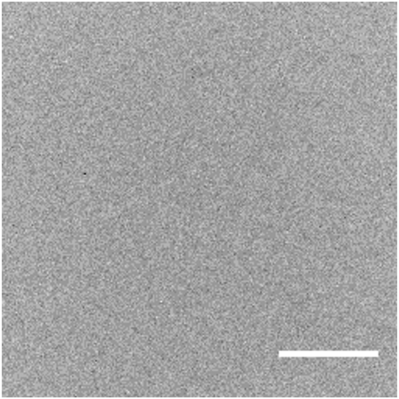


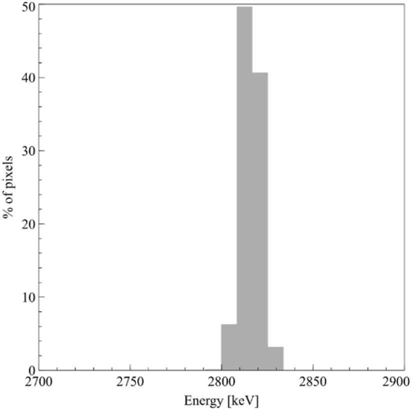
STIM measurements:

- 3 MeV He
- Energy loss ≈ 200 keV

⇒ BNCD thickness ≈ 500 nm (SRIM)

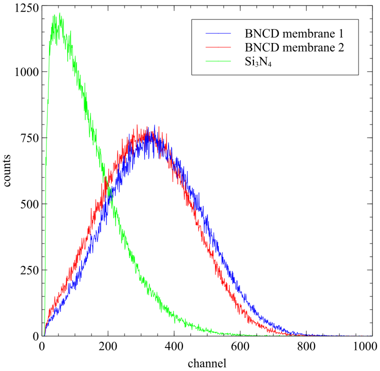
Thickness homogeneity

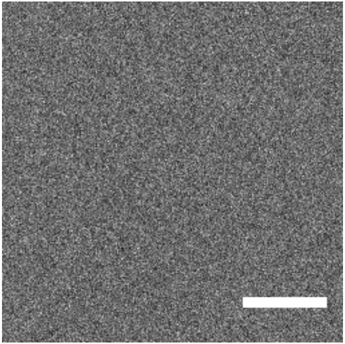




Median map of the energy transferred through the BNCD membrane
⇒ very good homogeneity on mm scale (scale bar = 100 μm)

Channeltron pulse height analysis



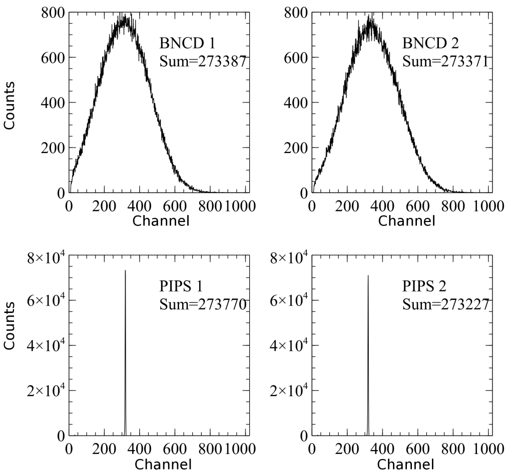


SE map (Scale bar: 100μm)

- Pulse height well separated from the background
- Very low dark counts ($< 10\ s^{-1}$)
- Good reproducibility and homogeneity over the membrane surface

Efficiency measurements

Counting the transmitted particles with a silicon detector



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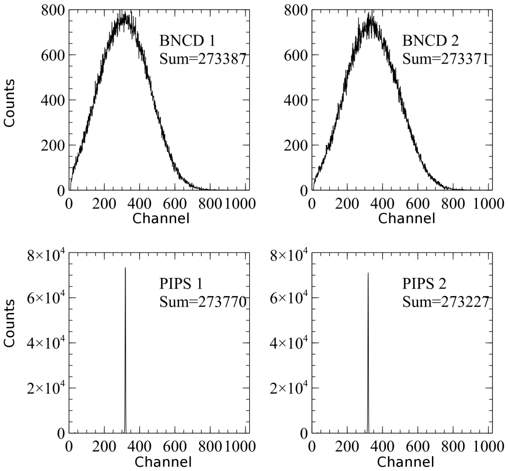
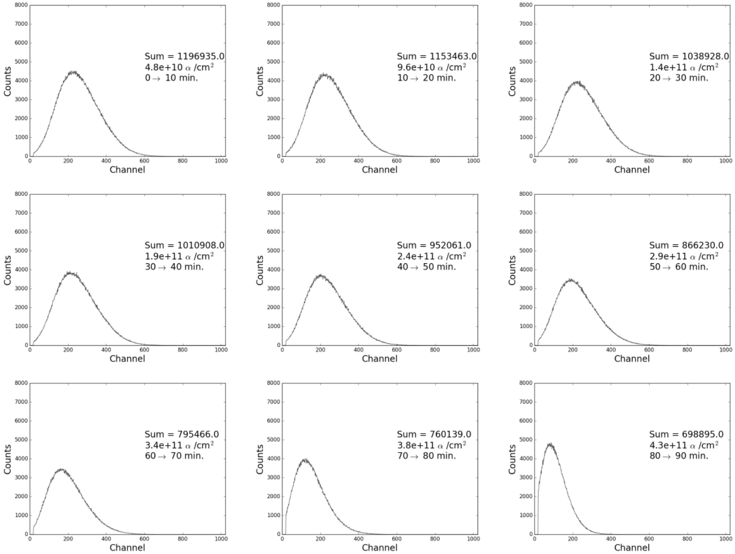
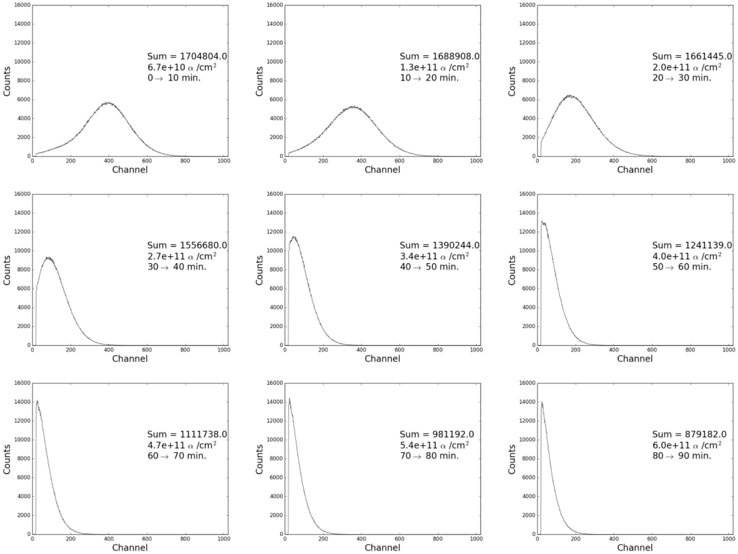


$\Rightarrow$ 100% efficiency

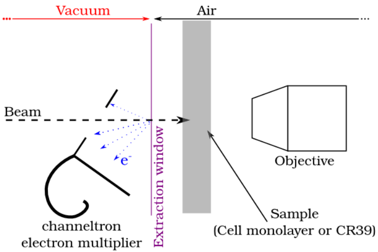
Radiation hardness: BNCD

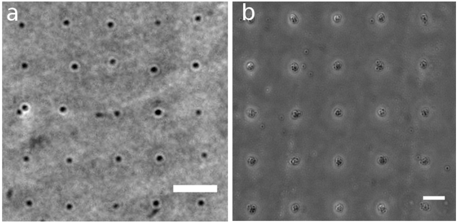


Radiation hardness: CsI



Validation using track detectors





Use of BNCD membrane as a vacuum window.

CR39 Track detectors irradiated in air through the BNCD membrane
a. Single He ions delivered in air (Scale bar = 10 μm)
b. 10 He per spot (Scale bar = 10 μm)

Validation for cell irradiation

Irradiation of U2OS cells expressing RNF8-GFP
RNF8 Ubiquitylates Histones at DNA Double-Strand Breaks

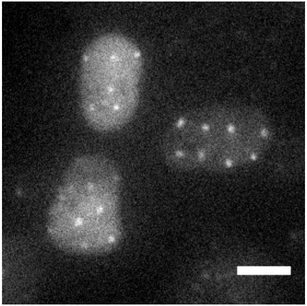


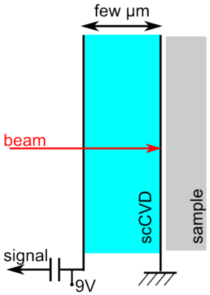
Figure : 1 He ion delivered every 5 μm. Online image acquisition 30 min. after irradiation (Scale bar = 10 μm)

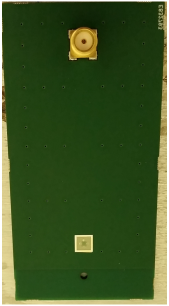
scCVD active membrane

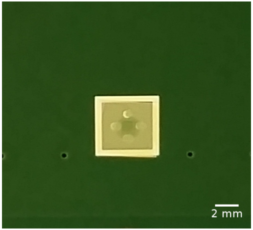
Secondary electron yield is not sufficient for proton detection

$\Rightarrow$ active membrane

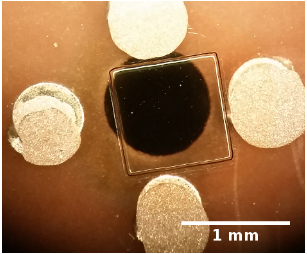
Grilj *et al.* App. Phys. Lett. 103, 243106 (2013)



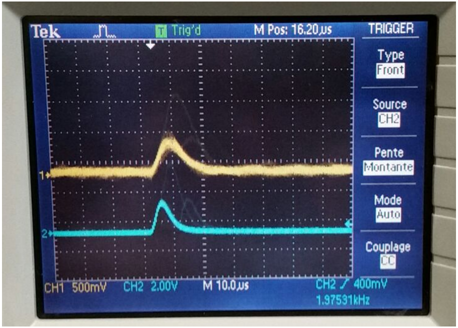




Preliminary measurements (1)

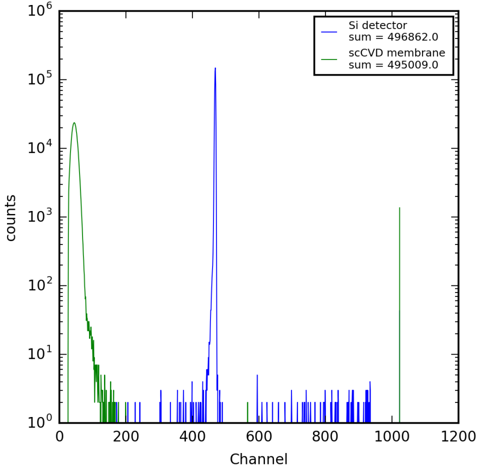


Microscope view of the membrane



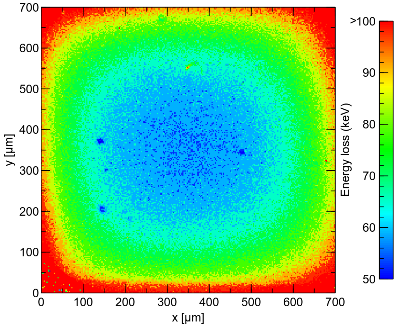
Pulses :
blue = Si detector
yellow = membrane

Preliminary measurements (2)

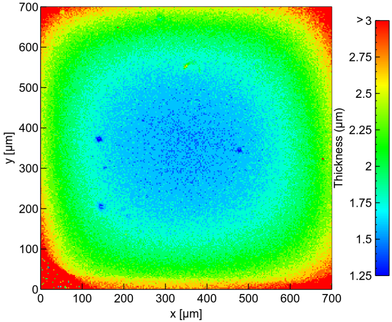


S/N ration not very high but enough to achieve 99.6 % efficiency

Preliminary measurements (3)



Energy loss measurements under vacuum with a 3 MeV proton microbeam



Thickness assuming 37 $keV \cdot \mu m^{-1}$ for 3 MeV protons in diamond

Conclusion

BNCD based thin detector:

- Thin enough for MeV Helium ions
- 100% efficient
- Compared to CsI :
  - Radiation hard ($2 \times$ CsI)
  - Can be stored in air

This detector is now installed on the AIFIRA facility in Bordeaux for routine irradiations
Work submitted to *Scientific Reports*, under review ...

scCVD active membranes for proton detection :

- 100 % efficiency is achievable with thicknesses $\leq 3\ \mu$m
- Further testing in progress ...

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