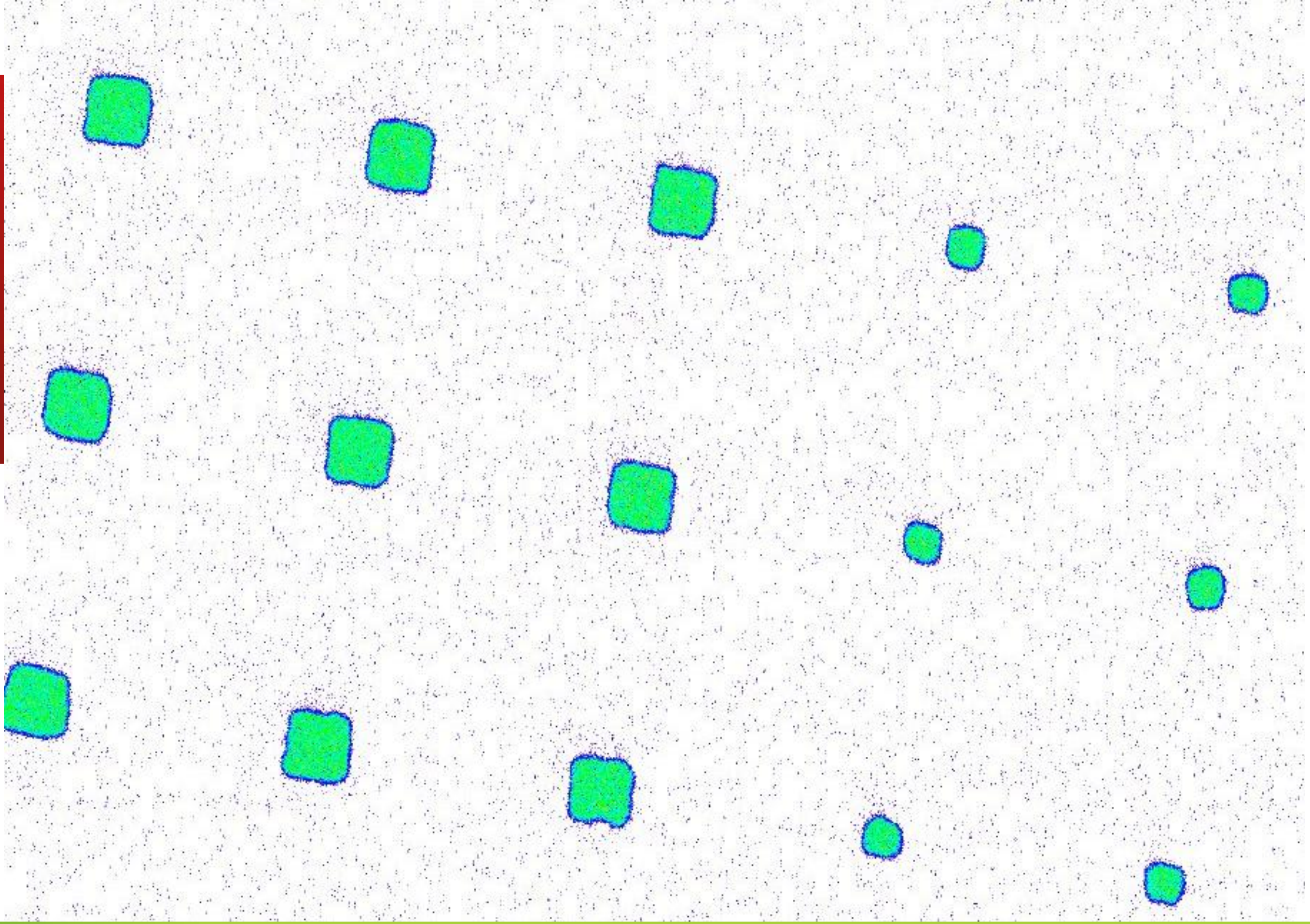


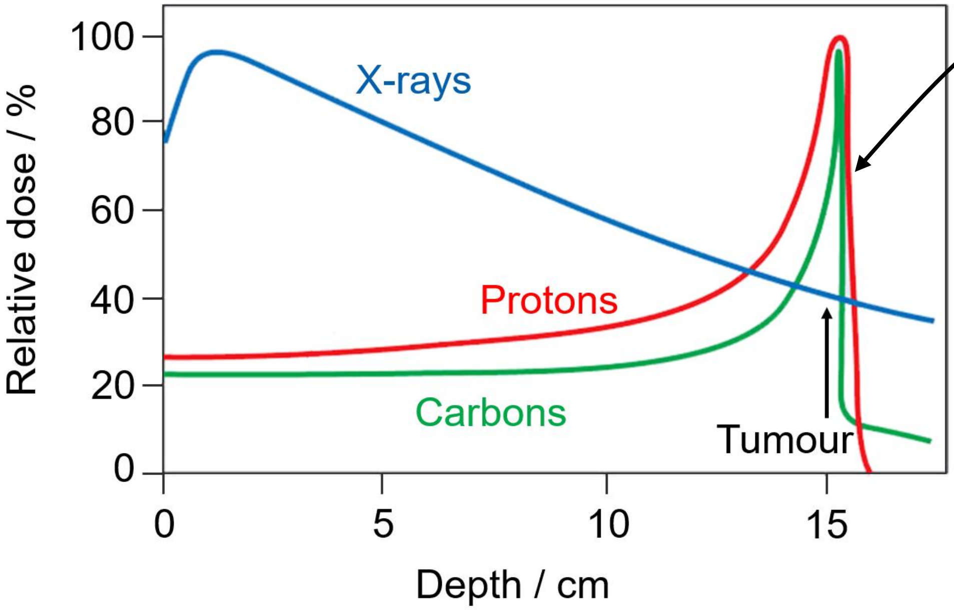
ADVANCES IN DIAMOND BASED MICRODOSIMETRY FOR HADRONTHERAPY

Michal Pomorski, ADAMAS2018, 13-14 December 2018, Wien

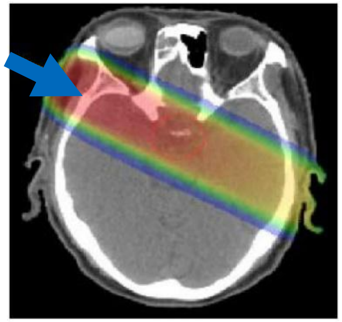
OUTLINE

- Context
- Fabrication of the diamond microdosimeters
- Sensors' characterization under nuclear microbeam probe
- Sensors' performance in clinical beam
- Summary and what's next

HADRON THERAPY

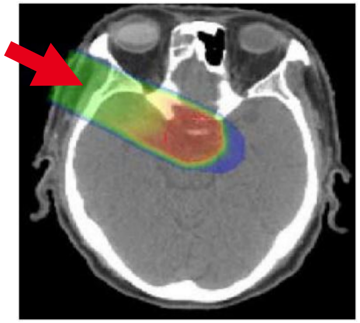


Most of the energy is lost in the **Bragg Peak**



[A. Rosenfeld]

Photons



[A. Rosenfeld]

Ions

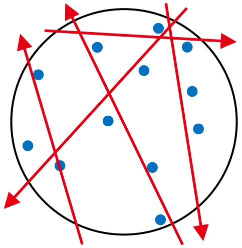
- **120 hadron therapy centres** worldwide (increasing);
- 3 operating clinical **proton therapy** centres in France: Orsay, Nice, Caen;
- **an intense field of research activity** including new methods of treatment (^{16}O, ^{14}N, micro,minibeams, FLASH).

LINEAR ENERGY TRANSFER

SPARSELY ionizing radiation:

e.g.: X-rays, Gammas

[M. Scholz]

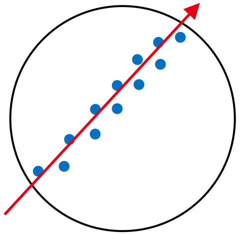


Low LET

DENSELY ionizing radiation:

e.g.: Carbon ions

[M. Scholz]



High LET

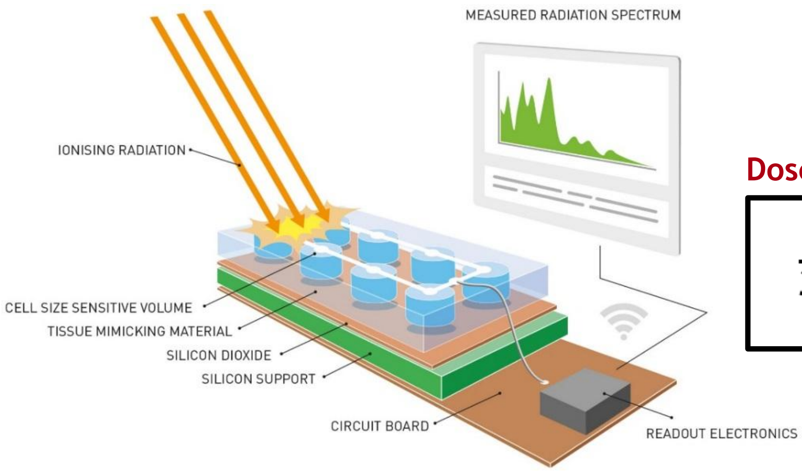
same dose but **different LET**

thus various biological effectiveness (**RBE**)

RADIATION QUALITY - MICRODOSIMETRY

'MICRODOSIMETRY is a methodology that involves the measurement or calculation of stochastic energy deposition distributions in a micron size sensitive volume (SV) within any arbitrary mixed radiation field.'

A concept of solid-state microdosimeter



picture from Si-3DMiMic collaboration

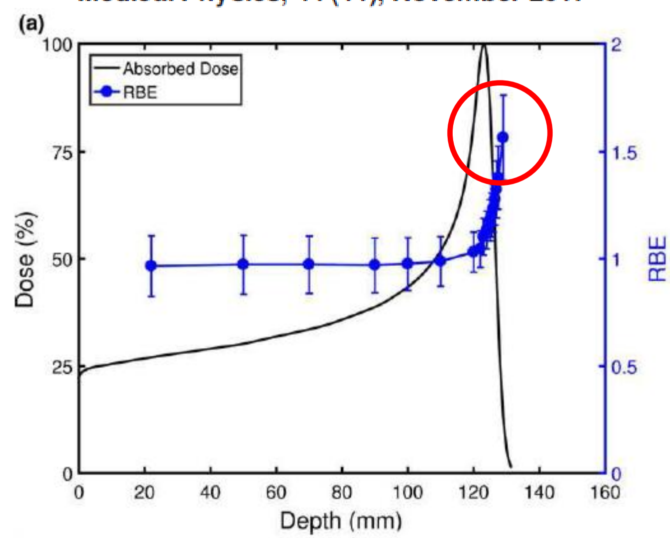
Lineal Energy

$$y = \frac{\varepsilon}{\bar{\ell}}$$

Dose Mean Lineal Energy

$$\bar{y}D = \int_0^\infty y d(y) dy$$

Medical Physics, 44 (11), November 2017



microdosimetry ≠ dosimetry at micron scale

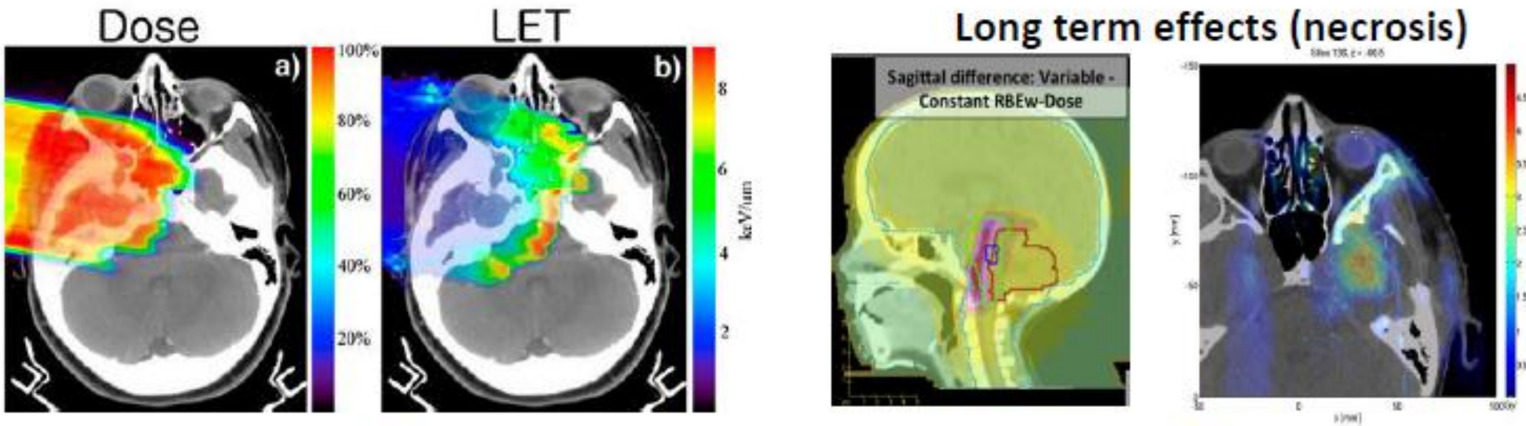
- single-particles (low charge),
- ns to µs integration time (10^9 p/cm2),
- **pulse-height spectra**,
- **SV** from micro to nano size (30 µm cell, 10 µm cell nucleus, > 1 µm DNA size)

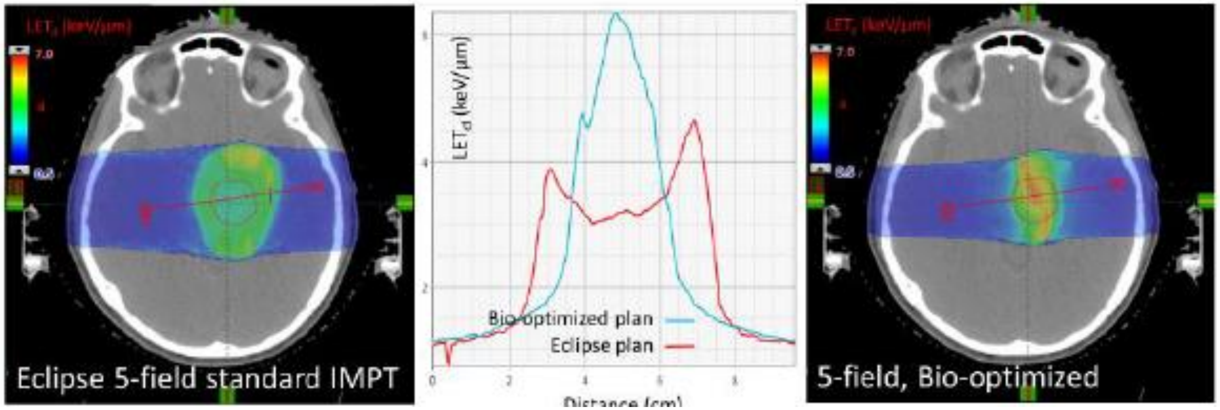
- ms integration time
- DC current or charge
- macroscopic (mm) SV size

Relative biological efficiency (RBE)

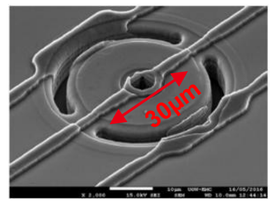
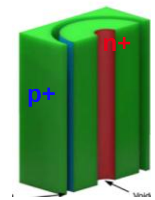
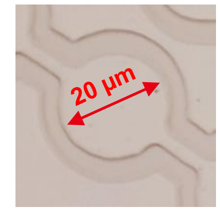
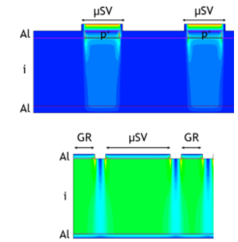
- Biological basis : clinical impact

❖ Dose/RBE inhomogeneities→ LET painting, late effect epidemiology





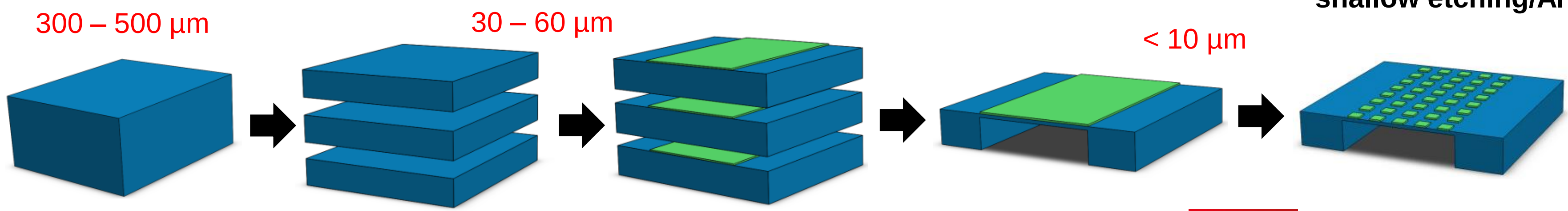
MICRODOSIMETERS STATE OF THE ART

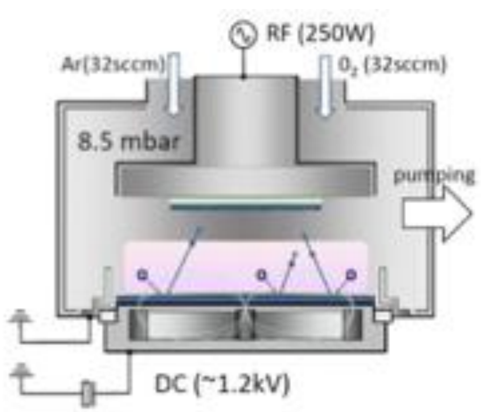
Tissue Equivalent Proportional Counter (TEPC):	Silicon Solid-State Microdosimeters (Mushroom):	**Diamond** Solid-State Microdosimeters:
	 	 
The 'Gold Standard' Tissue-Equivalence & Radiation Hardness Sensitive (Internal Amplification)	Compact Device Multiple Micro-SVs Si – Easy for Microfabrication	**More Tissue-Equivalent (Z = 6)** **Radiation Hardness** No Leakage Current, Fast Drift Velocity for e-h, Low Capacitance
Maintenance (Gas Flow & High Voltage) Low Spatial Resolution Large size	Radiation Hardness ? Tissue-Equivalence ? (Correction Factor)	High ~13 eV/e-h – Lower Signal Diamond - 6' Wafers rather Difficult

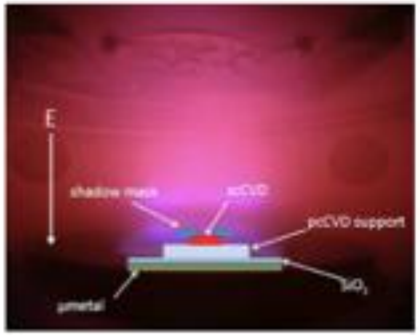
DIAMOND MEMBRANE MICRODOSIMETER PROTOTYPES

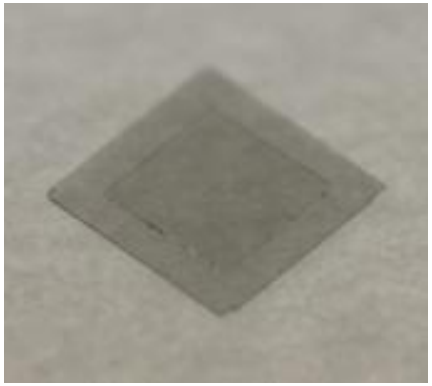
Freestanding single crystal diamond membranes (<10 µm) of up to several mms later size

1. Slicing and polishing **2. p+ CVD growth** **3. Ar/O deep etching** **4. Patterning Ar/O shallow etching/Al**



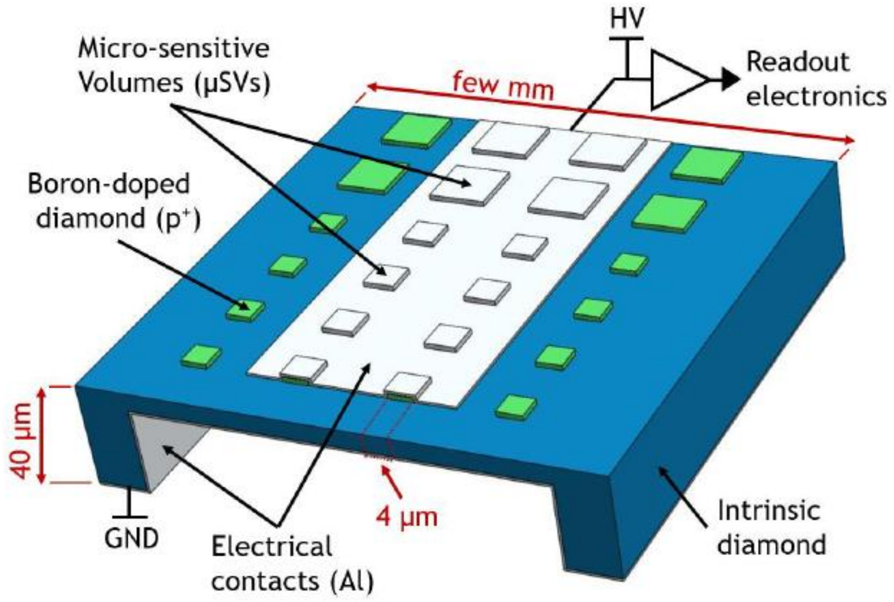




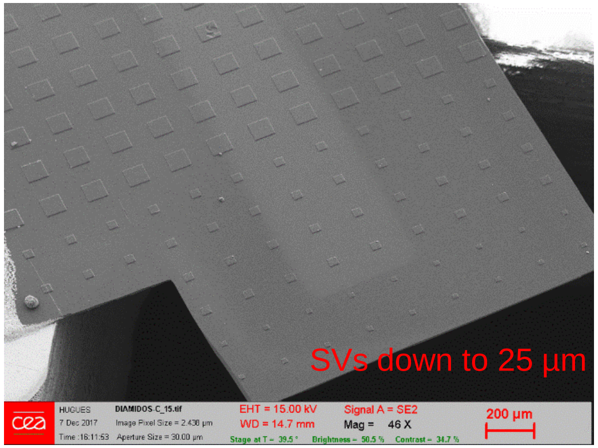


DIAMOND MEMBRANE MICRODOSIMETER PROTOTYPES

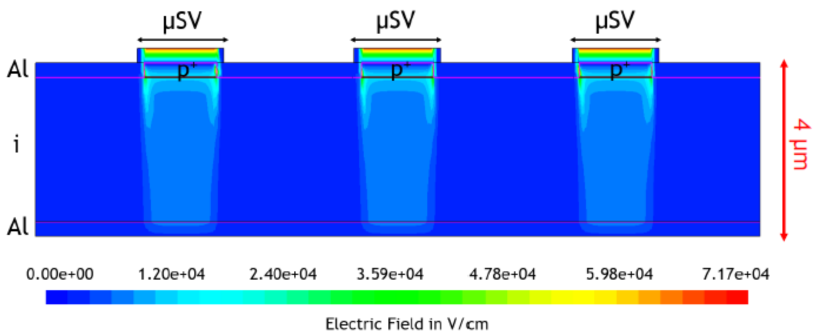
scCVD diamond membrane DIAμDOS p+ microdosimeter



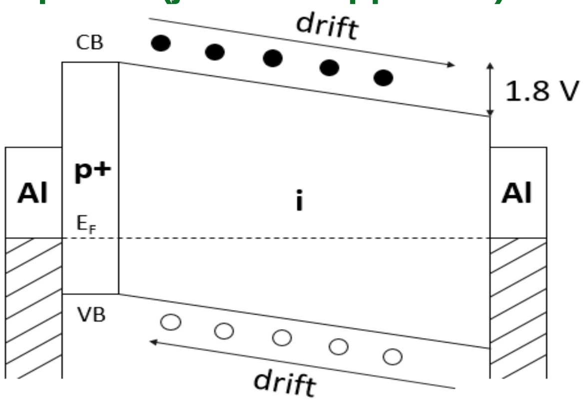
SEM Image



TCAD simulation



p+-i-m (junction approach)

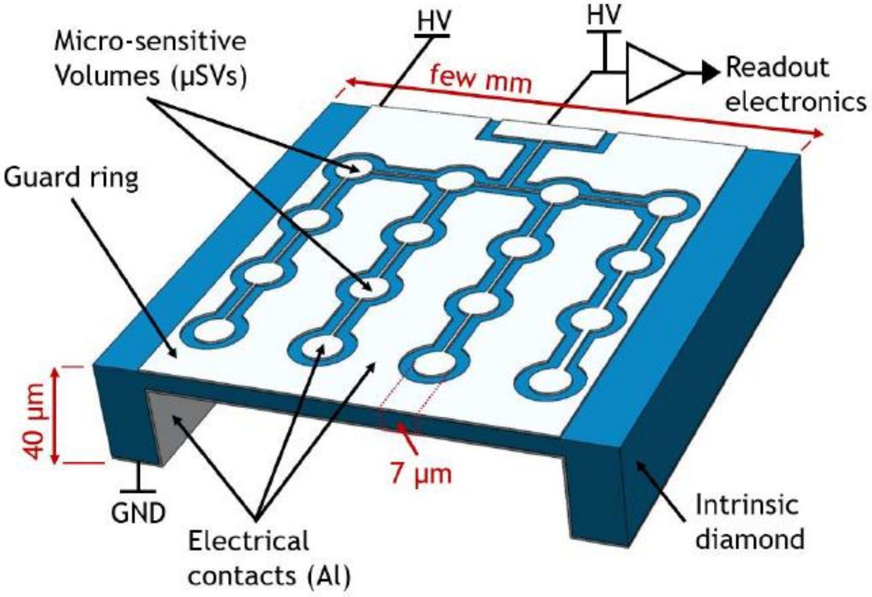


0V extr. bias, fully depleted

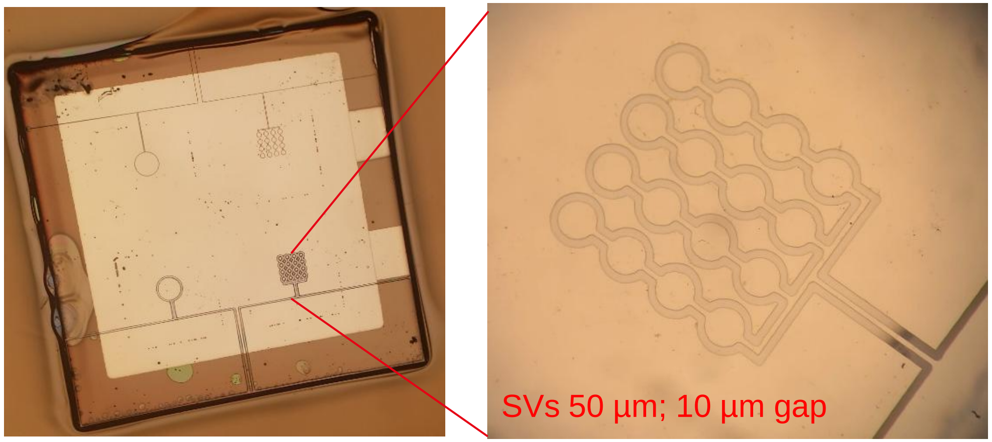
TCAD charge transport simulations ongoing

DIAMOND MEMBRANE MICRODOSIMETER PROTOTYPES

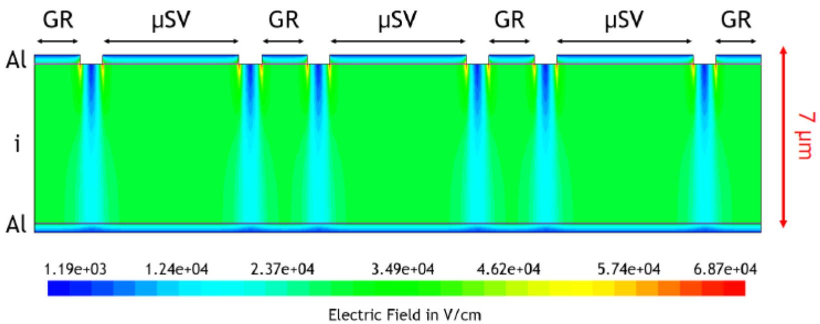
scCVD diamond membrane DIAμDOS guard- ring microdosimeter:



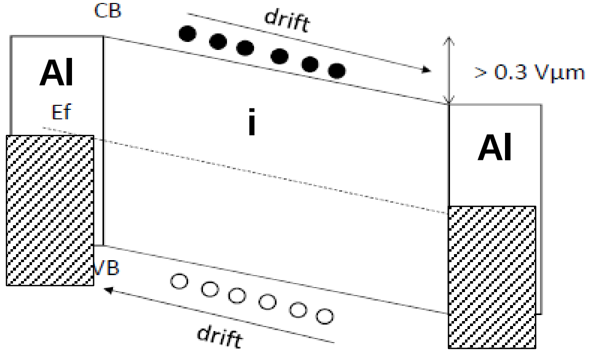
Microscopic Image



TCAD simulation



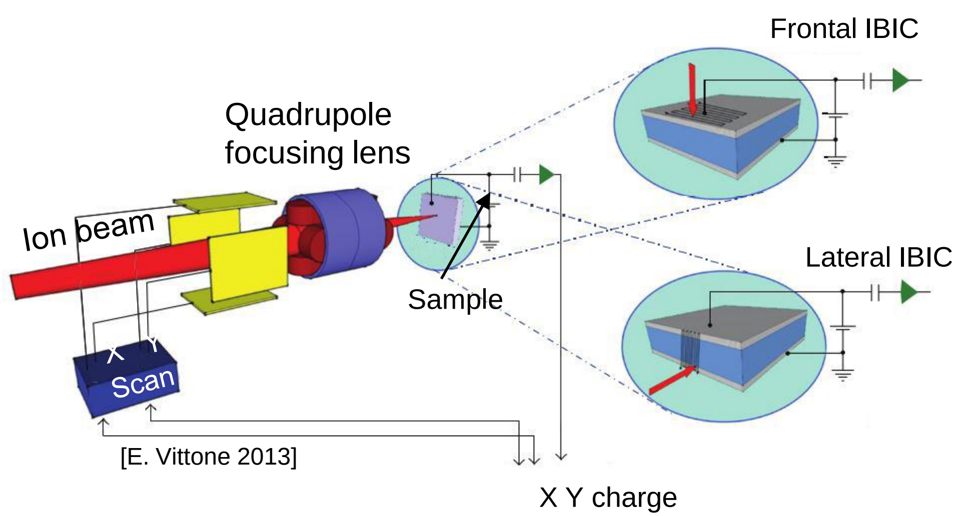
m-i-m (ionization chamber approach)



TCAD charge transport simulations ongoing

PROBING CHARGE TRANSPORT WITH IBIC

IBIC (Ion Beams Induced Current):



- Single ion irradiation (precision: 1 micron)
- Raster scanning + pulse height spectra
- Charge transport maps (µSV definition)
- Well controlled projectile Energy and LET

Perfect tool to test new types of microdosimeters before implementing in clinical conditions (less control)

Several beamtimes @ microbeam facilities:

CENBG

H 2.0 MeV
He 3.0 MeV

RB

^{12}C 16.6 MeV

ansto

H 2.0 MeV

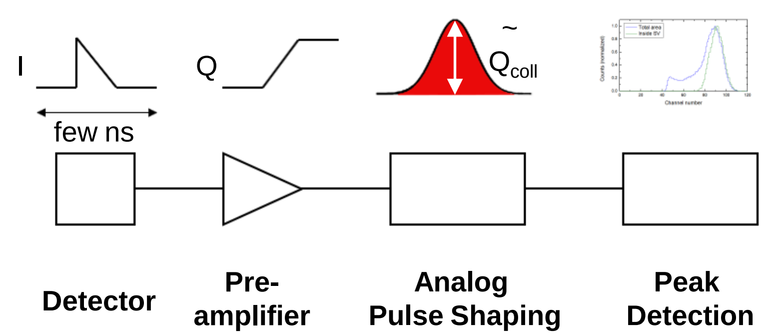
He 1.5 MeV/3MeV/5.5 MeV

^{16}O=8MeV/17.5MeV/25MeV

^{12}C 6 MeV/16.6 MeV/24 MeV

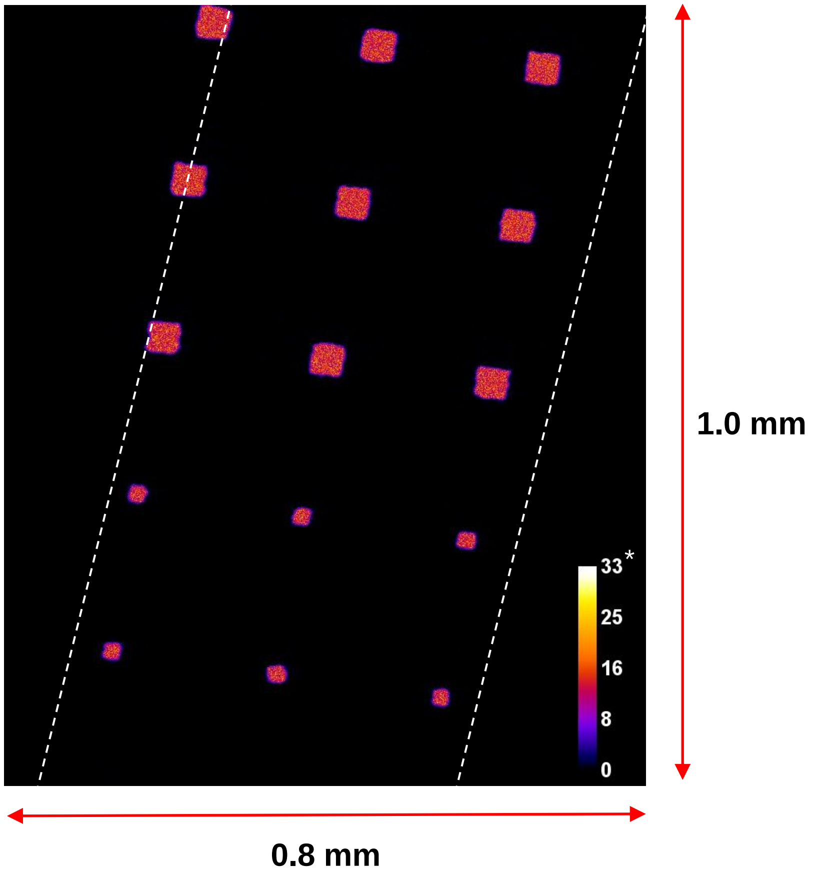
covers wide span of LET present in clinics

Analog read-out electronics:

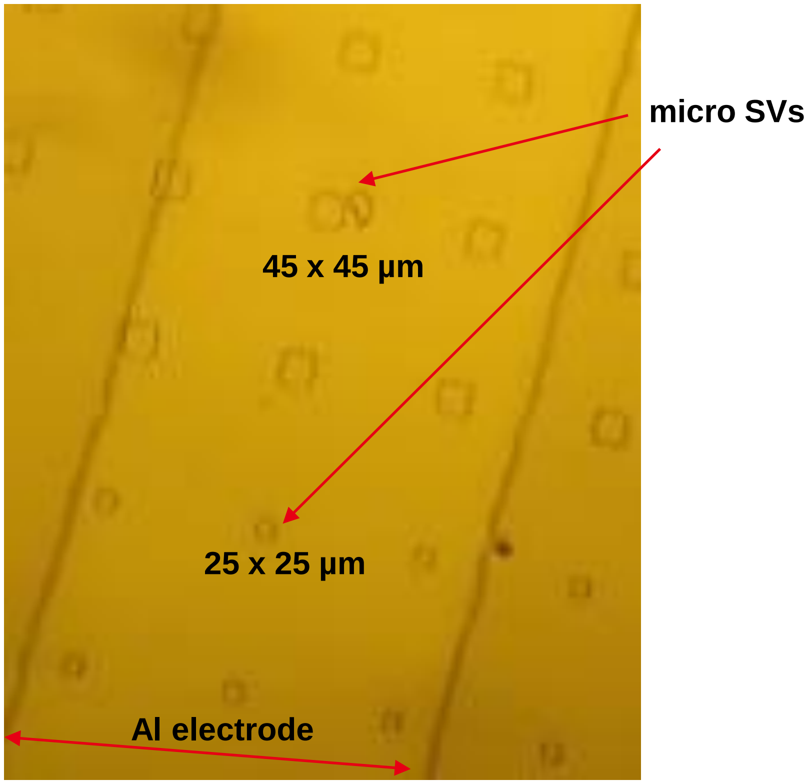


IBIC – GLOBAL RESPONSE P+ @ 0V - 2 MEV P

Raster scan of device @ 0 V



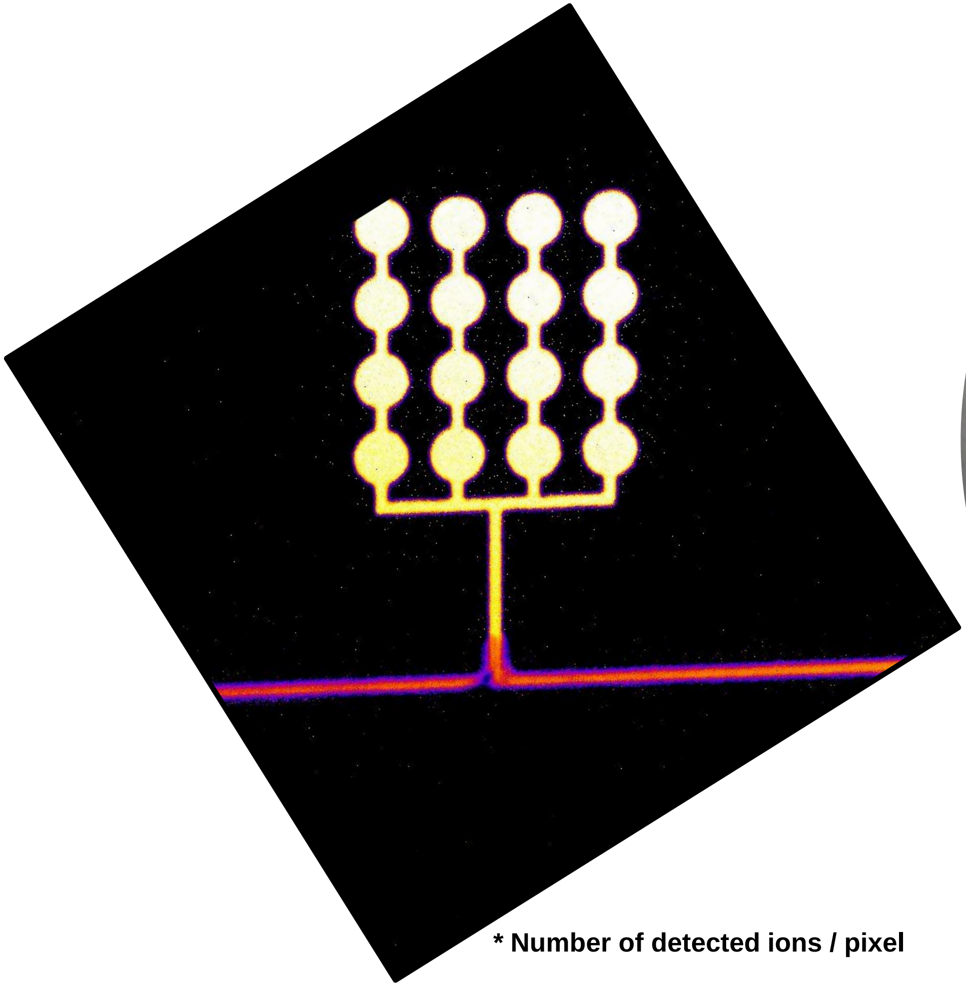
Microscopic Image



* Number of detected ions / pixel

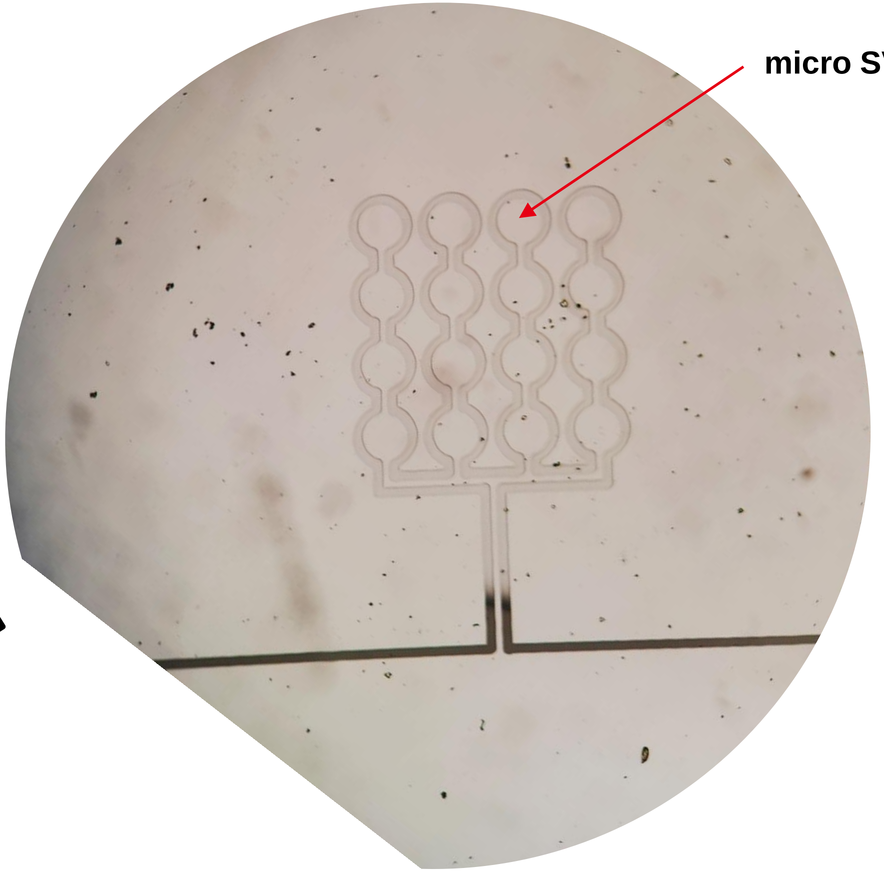
IBIC – GLOBAL RESPONSE GUARD RING @ 20V

Raster scan of device @ +20 V



* Number of detected ions / pixel

Microscopic Image

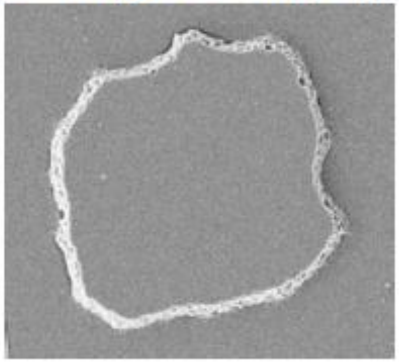


IBIC – DETAIL P+ @ 0 V

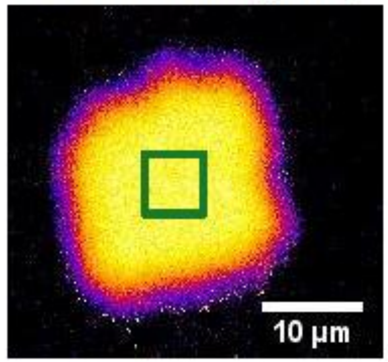
This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

Response of DIAμDOS p⁺ to 2 MeV single proton ion beam

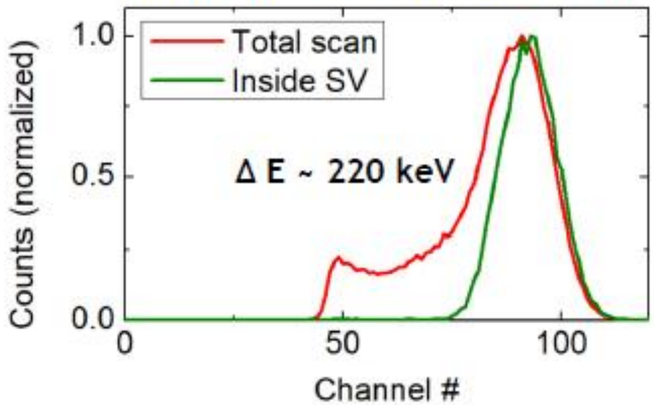
SEM image of a single μSV



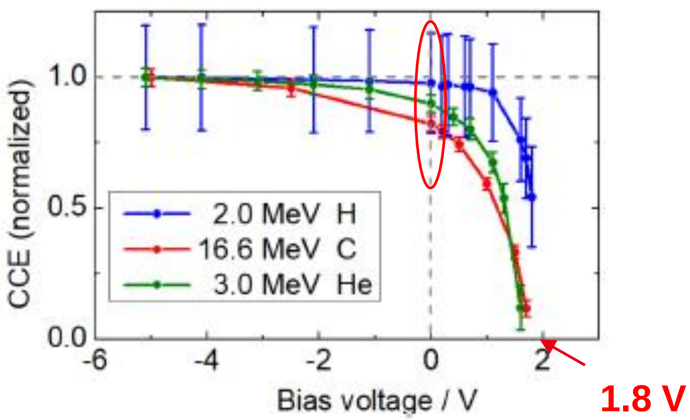
Median Energy Map



Normalized energy spectrum



Charge Collection Efficiency (CCE)



E ~ 0,4 V/μm

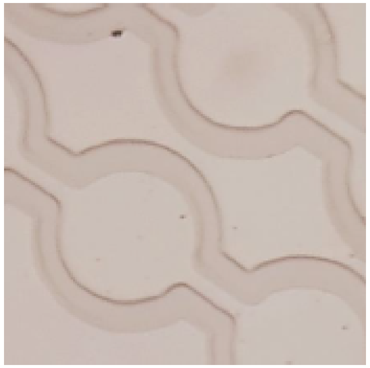
Ion	CCE @ 0V	**Radiation Hardness** CCE drop after ions / cm²
Proton	100%	1% after 2.5 x 10^{13}
Carbon	80%	12% after 0.6 x 10^{12}
Helium	90%	5% after 1.5 x 10^{10}

Performance approaching SoA silicon based microdosimeters

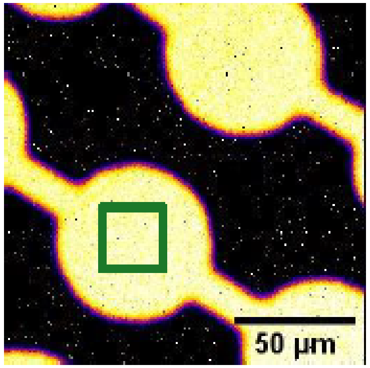
IBIC – DETAIL GUARD RING @ 20V

Response of DIAµDOS guard ring to 2 MeV single proton ion beam

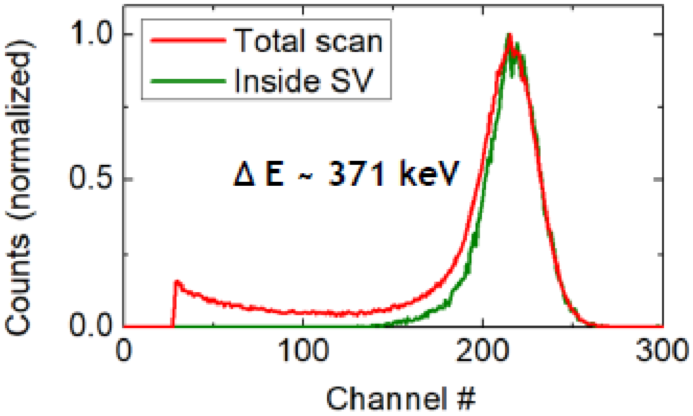
Opt. microscope image



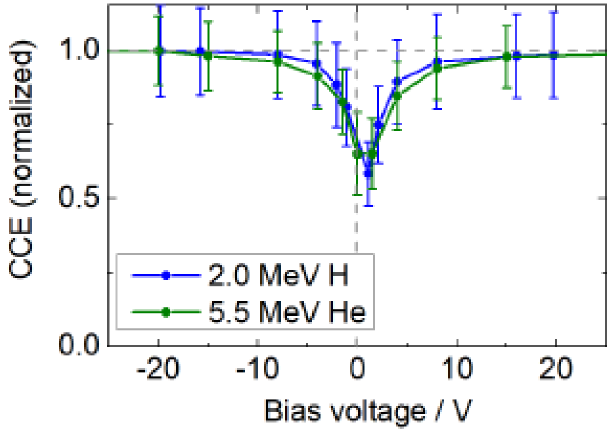
Median Energy Map



Normalized energy spectrum



Charge Collection Efficiency (CCE)



E > 3 V/µm

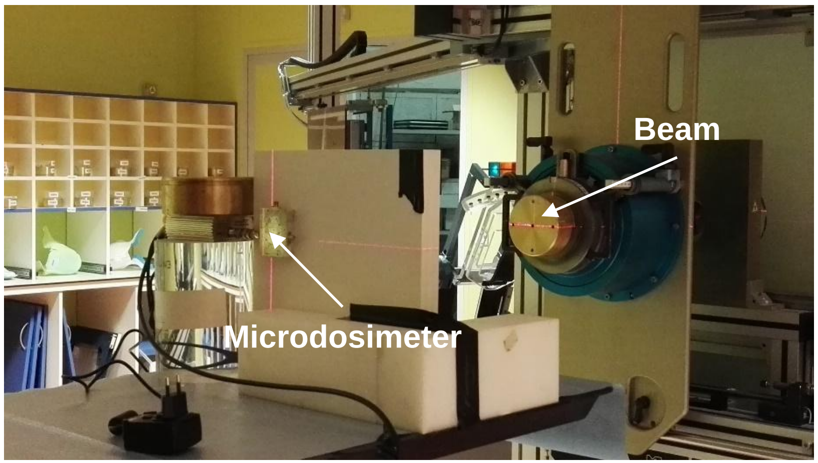
Ion	CCE @ 0V	Radiation Hardness CCE drop after ions / cm^2
Proton	100%	3% after 9.4 x 10^{12}
Helium	100%	-

Applying $^{+/-}$ 20 V to the device resets the radiation damage

Performance approaching SoA silicon based microdosimeters

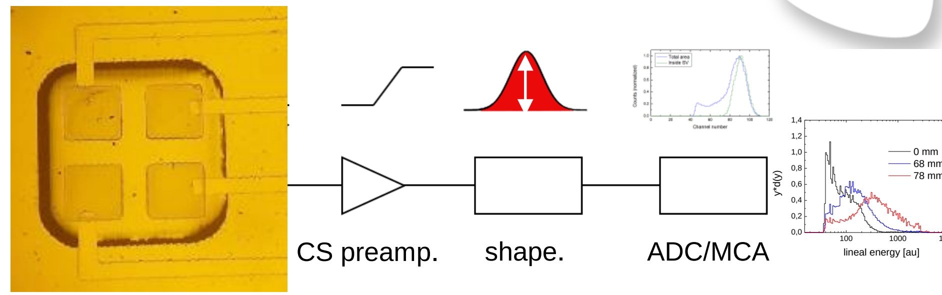
P+ SENSORS PERFORMANCE IN CLINICAL PROTON BEAM

Institute Curie, Proton Therapy Center (Orsay, France)



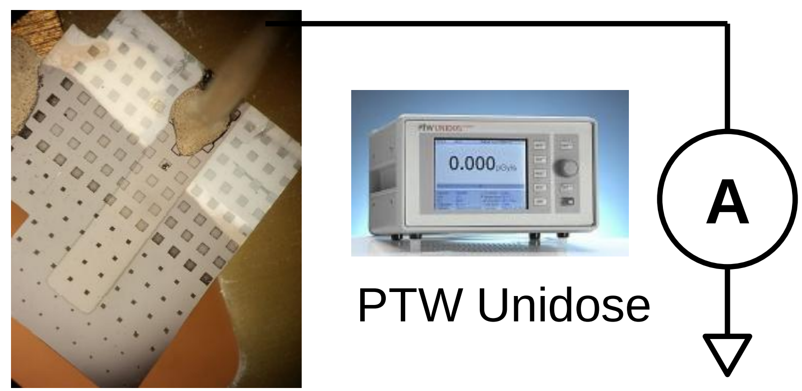
- Proton beamline for intracranial treatments
- **100 MeV p**
- 80 mm variable thickness solid-water phantom
- diamond p+ microdosimeter prototypes

Microdosimetry



Single proton pulse-height measurement in clinical conditions

Dosimetry

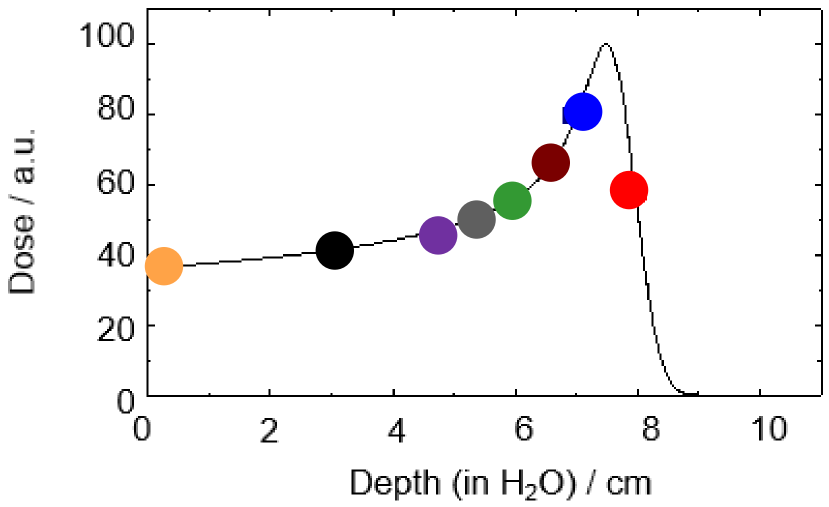


'DC' induced charge/current (ms) monitoring, with commercial high precision electrometer used in clinics for dosimetry

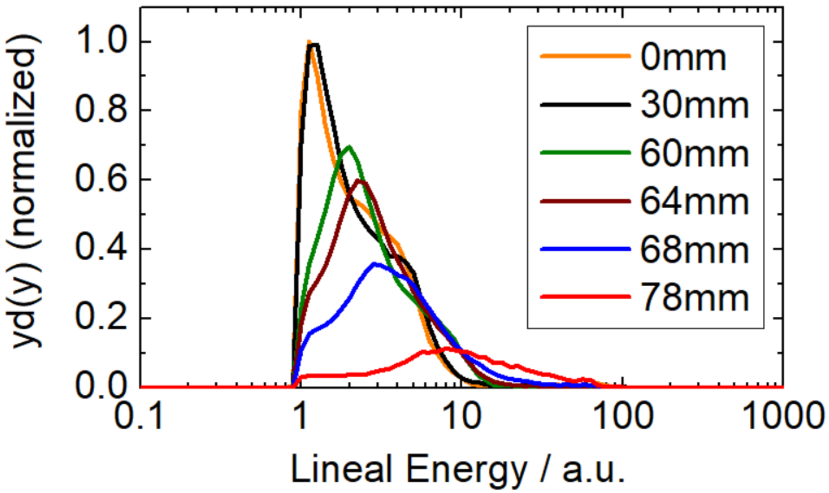
SENSORS PERFORMANCE IN CLINICAL PROTON BEAM

Preliminary diamond p+ microdosimeter prototype performance

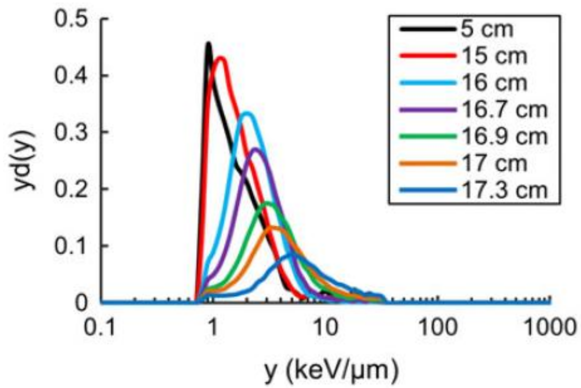
Bragg peak (IBA PP05)



Diamond membrane microdosimeter



Si ‘bridge’ microdosimeter (160 MeV p)

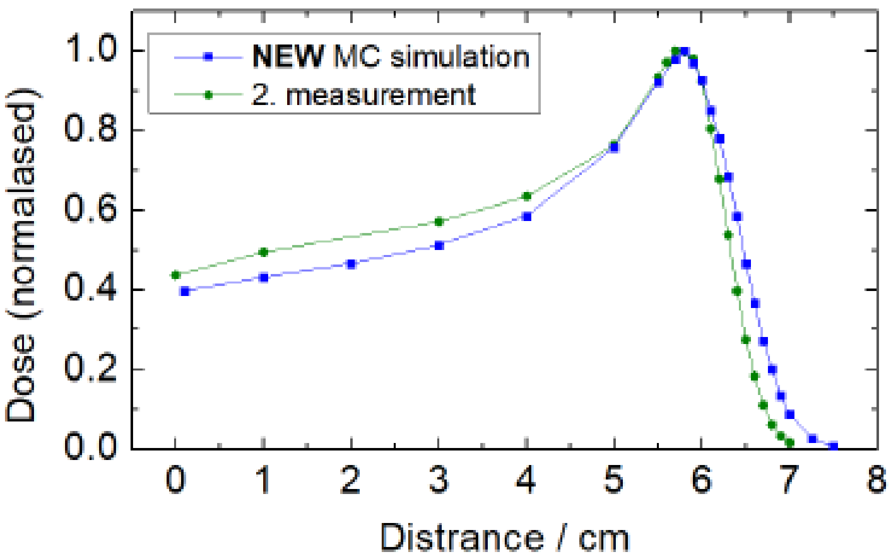


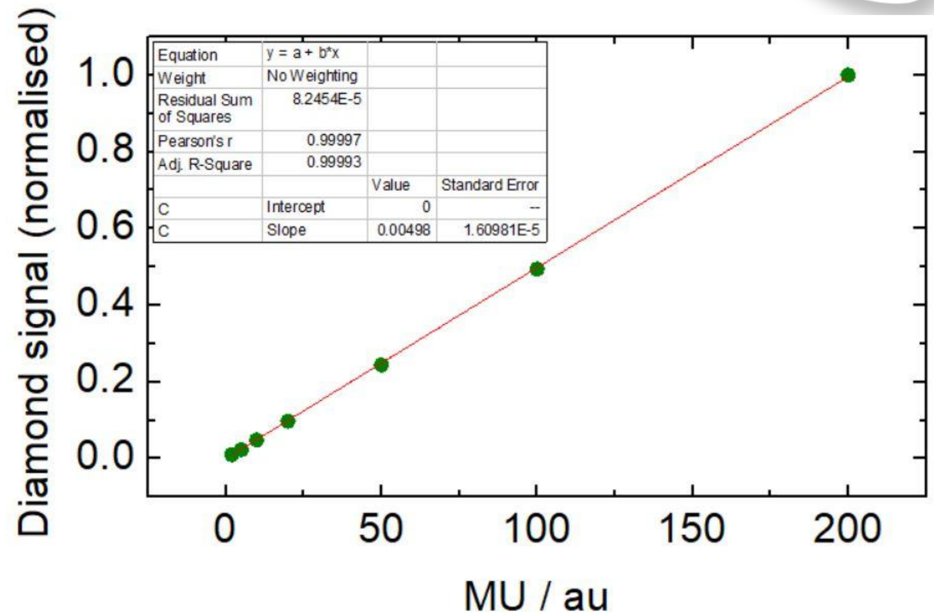
Anderson *et al.*: Med. Phys. 44 (11), November 2017

- works in clinical environment (!)
- no tissue-equivalent packaging…
- no calibration (rather qualitative meas.)
- but trend identical to Si micro. (very promising)

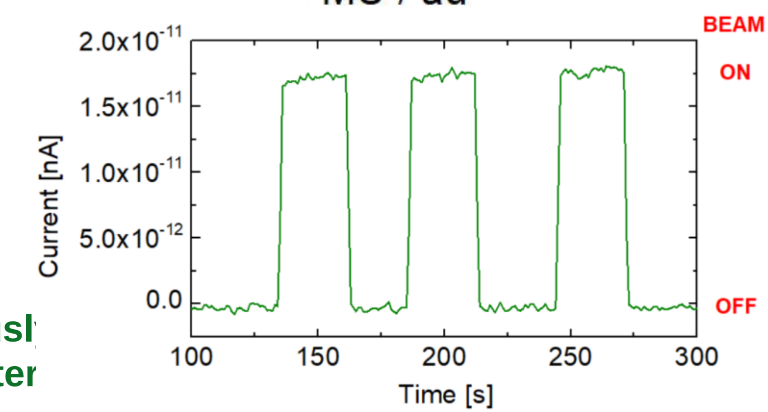
P+ SENSORS PERFORMANCE IN CLINICAL PROTON BEAM

Use of diamond p+ microdosimeter as a low noise dosimeter





- good agreement with MC GEANT4 simulations
- perfect linearity with dose
- no leakage current (very low noise)

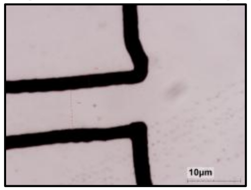


Diamidos microdosimeter can be possibly use simultaneousl (monitoring of DC beam induced current with an electrometer

SUMMARY AND WHAT'S NEXT

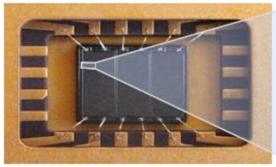
- Prototyping and microfabrication
- Ion microprobe characterization
- Encapsulation and integration
- Clinical evaluation + LET
- LET simulation

2µm isolation gap



More prototypes based on p+ and guard ring approach
(3D etching, isolation gap)
+ TCAD simulations and IBIC

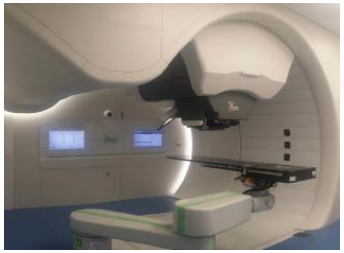
Dedicated pcb's + universal chip carrier mounting of the sensors + encapsulation



with possible electronics integration (ASIC)

Clinical evaluation of encapsulated devices @TIRO/Lacassagne p Center + LET simulations

Antoine Lacassagne
CENTRE DE LUTTE CONTRE LE CANCER DE NICE



TIRO
UMR E4320

AUTHORS AND CO-AUTHORS

ORIGINAL PAPER

Microdosimeter

physica status solidi pss a
www.pss-a.com

scCVD Diamond Membrane based Microdosimeter for Hadron Therapy

Izabella A. Zahradnik, Michal T. Pomorski,* Ludovic De Marzi, Dominique Tromson, Philippe Barberet, Natko Skukan, Philippe Bergonzo, Guillaume Devès, Joël Herault, Wataru Kada, Thierry Pourcher, and Samuel Saada*

DIAμDOS
Diamond-Membrane-Microdosimeter-Collaboration

NATIONAL AND INTERNATIONAL COLLABORATIONS

DIADEM : Diamond membrane based microdosimetric system for radiation quality assurance in hadron therapy
2 years **national project**; *kick-off 26/11/2018*

Postdoctoral Scientist

1 year contract asap

The position:

- MC simulations of clinical proton/carbon beams interactions with matter, to benchmark experimental response of the microdosimeter prototypes
- participation in beamtimes for devices testing with clinical beams and particle microbeams at accelerator facilities
- possible participation in fabrication process of the devices (surfaces preparation, thin layer deposition, photolithography, dry plasma etching)

Requirements:

- PhD in physics/medical physics or equivalent
- knowledge of relevant Monte Carlo simulation programs
- knowledge of solid-state particle detectors, associated electronics and signal processing, possibly including some experience at accelerator facilities
- communication verbally and written in English (French would be additional asset)
- knowledge of simple printed circuit boards design and semiconductors simulation software would be an asset

!!! Thank you very much for your kind attention !!!

Commissariat à l'énergie atomique et aux énergies alternatives
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