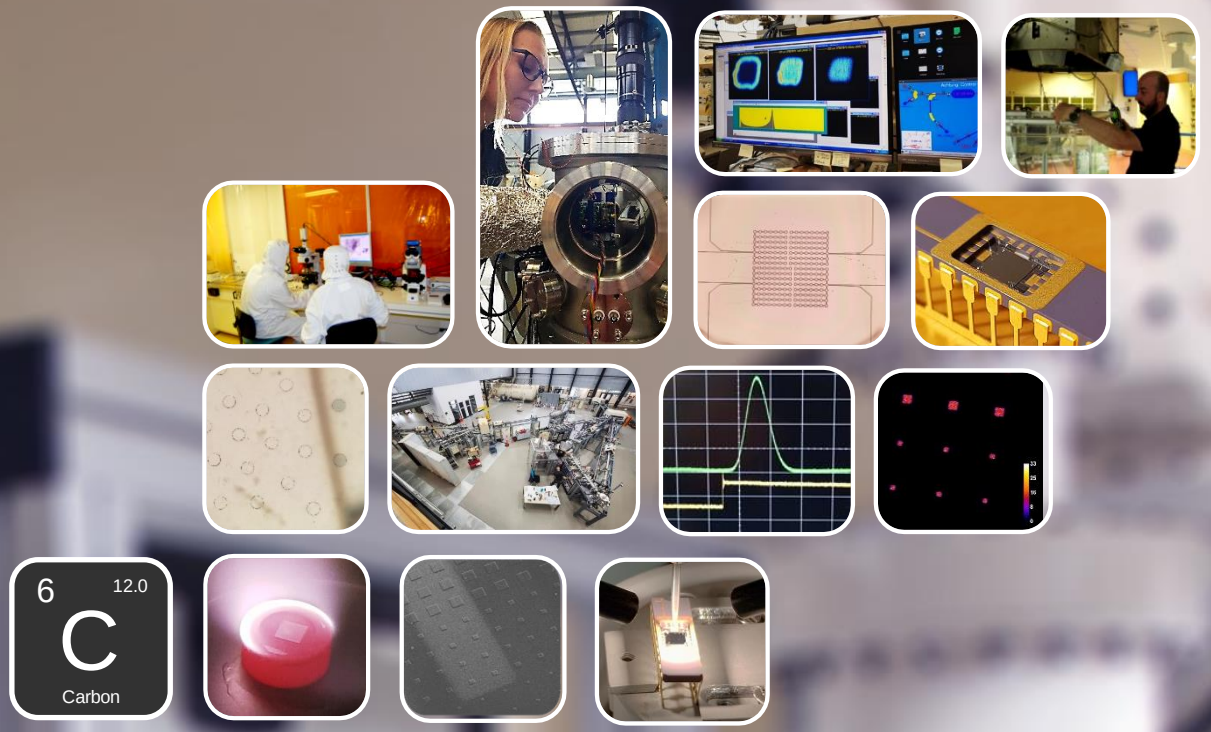
list
cea tech



6 12.0
C
Carbon

DIAMOND MICRODOSIMETRY FOR HADRON THERAPY

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28th - 29th May 2019
LAL Orsay

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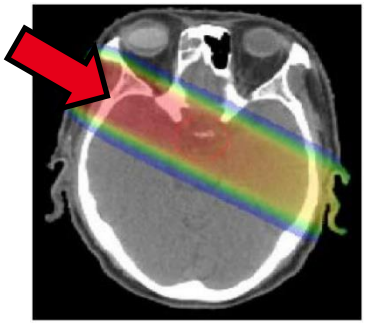
École Doctorale PHENIICS Doctoral School

Pheniics Fest 2019

CONTEXT
HADRON THERAPY

Photons *(SPARSELY ionizing radiation)*



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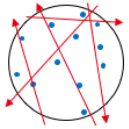
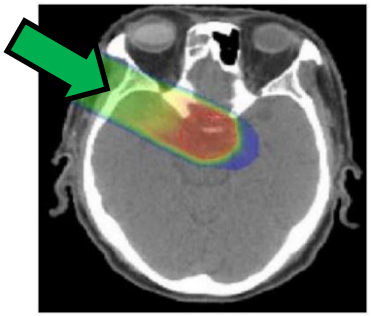
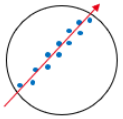


Low LET

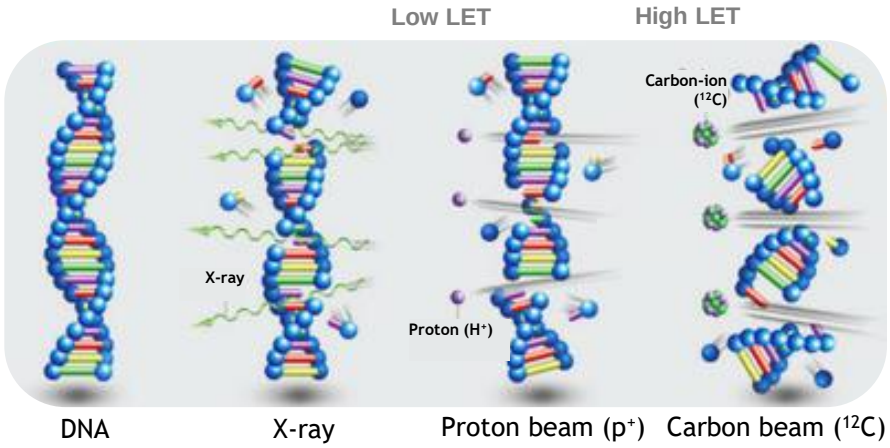
Ions *(Ddensely ionizing radiation)*



[GSI]



High LET



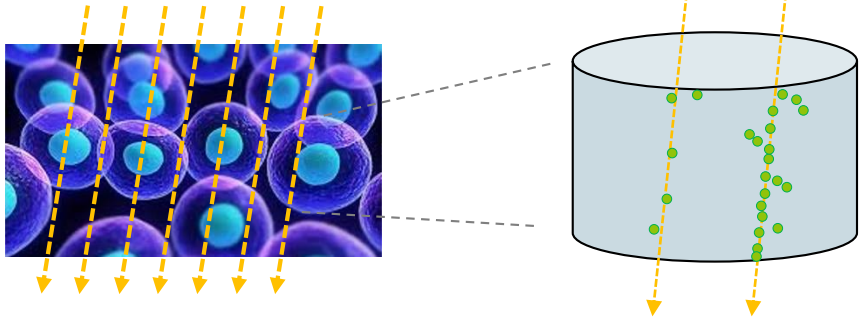
Same dose but **different LET**
=
Various relative biological effectiveness (**RBE**)

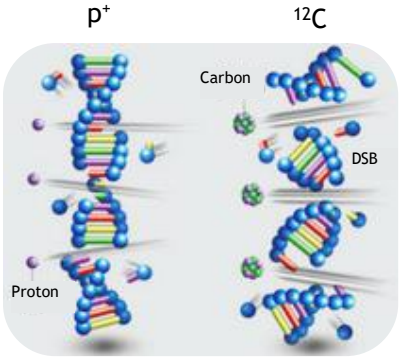
OBJECTIVES AND CHALLENGES

MICRODOSIMETRY FOR RADIATION QUALITY IN HADRON THERAPY

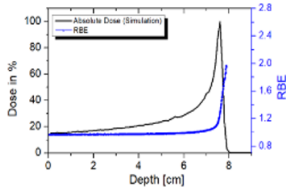
Concept of Microdosimetry

Biological cell
(µm)

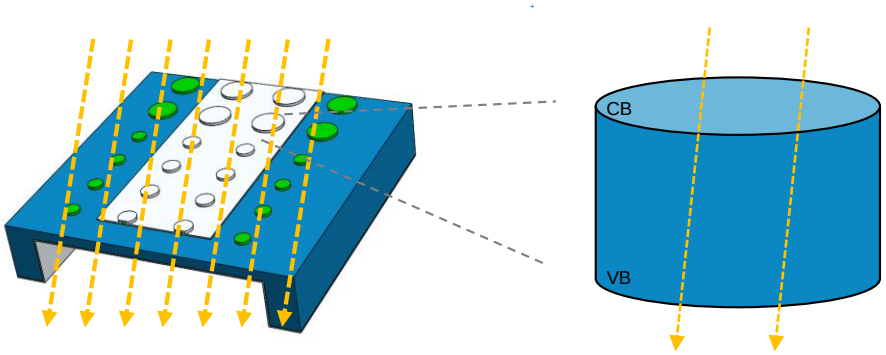


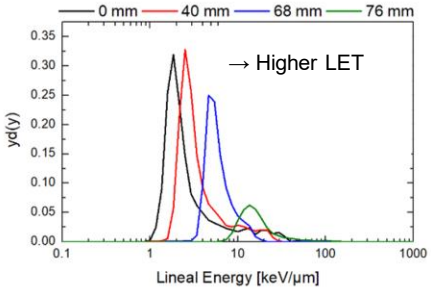


RBE



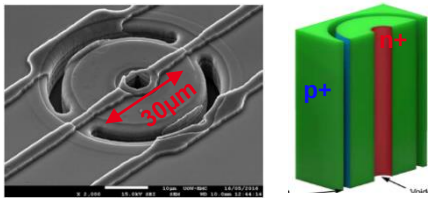
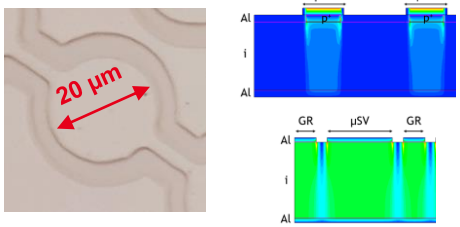
Micro-Sensitive-Volumes
in Detector *(µm)*





STATE OF THE ART

WHY DIAMOND?

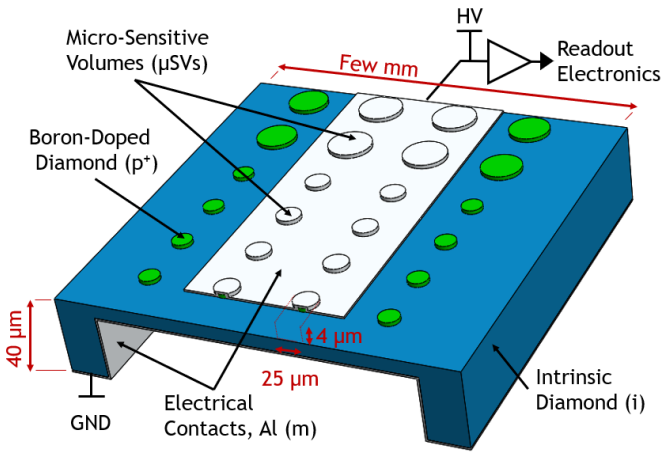
	Tissue Equivalent Proportional Counter (TEPC):	Silicon Solid-State Microdosimeters (Mushroom):	Diamond Solid-State Microdosimeters:
			
+	The 'Gold Standard' Tissue-Equivalence & Radiation Hardness Sensitive (Internal Amplification)	Compact Device Multiple Micro-SVs Si – Easy for Microfabrication	**More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

CONCEPT DIAMOND MICRODOSIMETER

P+ – PROTOTYPE

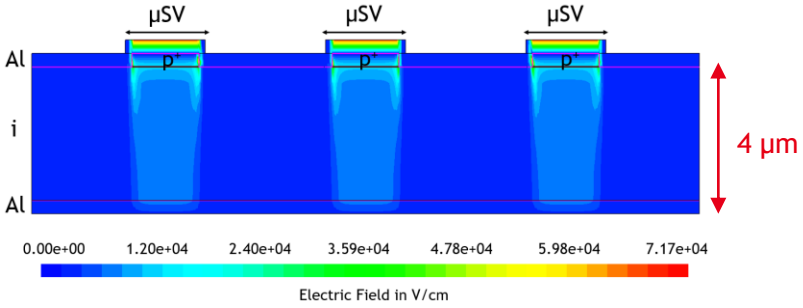
DIAμDOS p$^+$

5. Metallisation (electrical contacts)

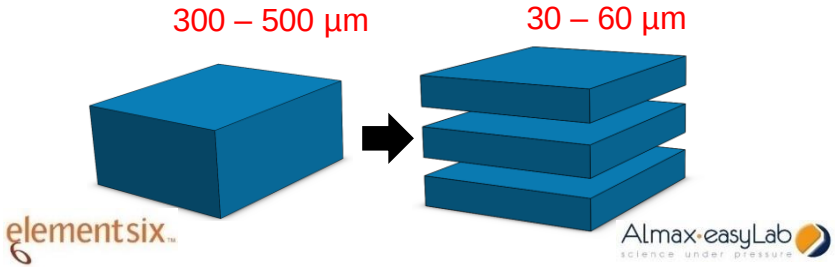


I. A. Zahradnik et al., Phys. Status Solidi A, July 2018

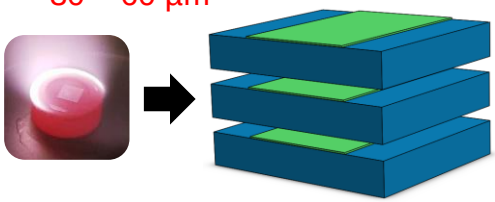
Electric field @ 0V



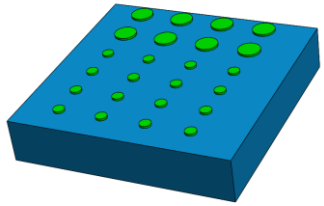
1. Slicing and polishing



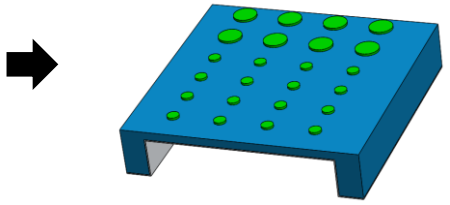
2. p$^+$ CVD growth



3. Patterning & Ar/O$_2$ shallow etching



4. Ar/O$_2$ deep etching



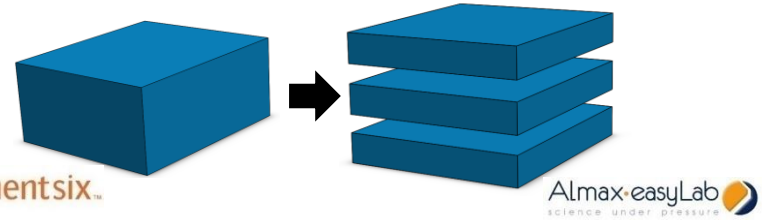
CONCEPT DIAMOND MICRODOSIMETER

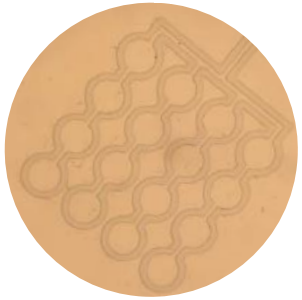
GUARD RING – PROTOTYPE

DIAµDOS guard ring

1. Slicing and polishing

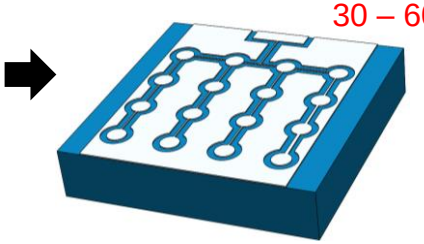
300 – 500 µm → 30 – 60 µm



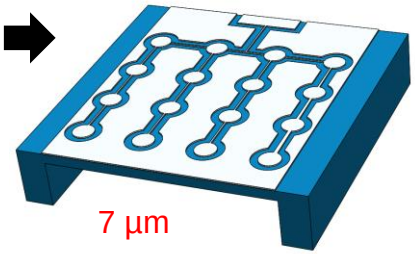


2. Metallisation (front), patterning & chemical etching

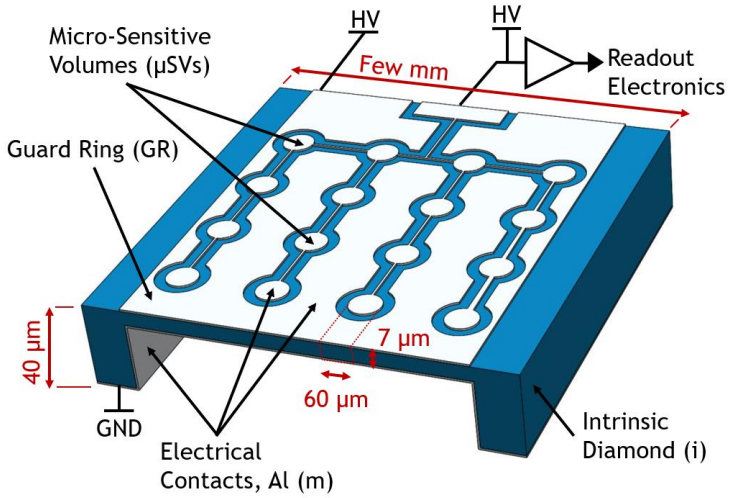
30 – 60 µm



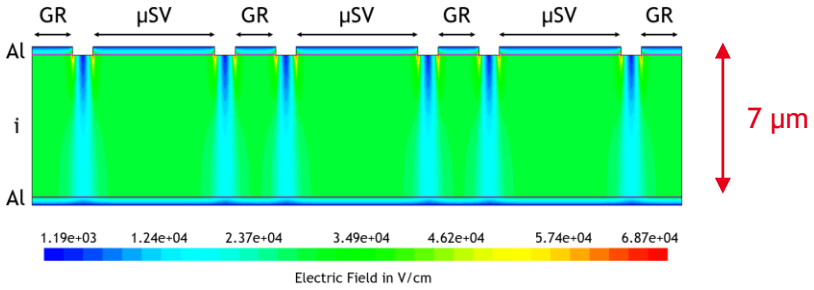
3. Ar/O_2 deep etching



4. Metallisation (back)



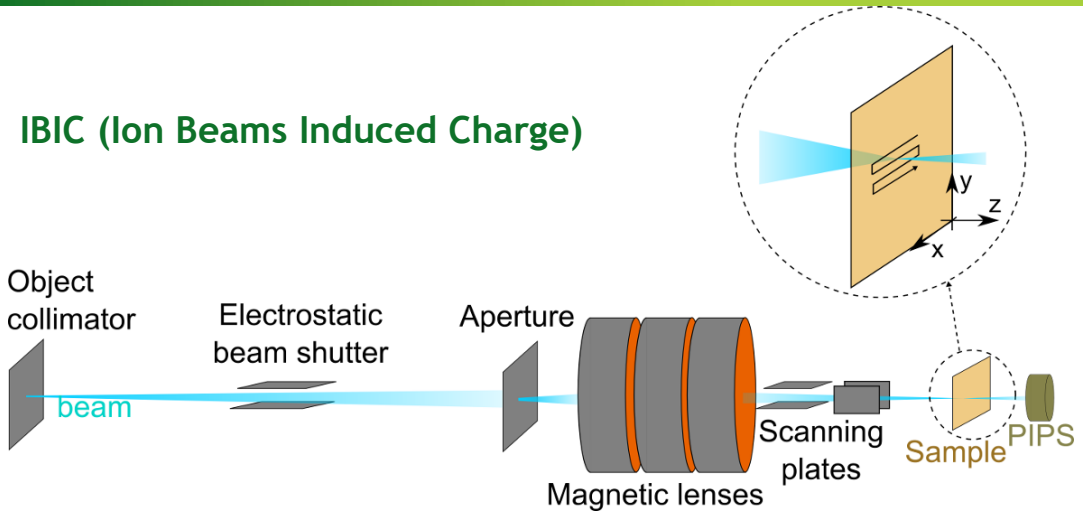
Electric field @ +20V



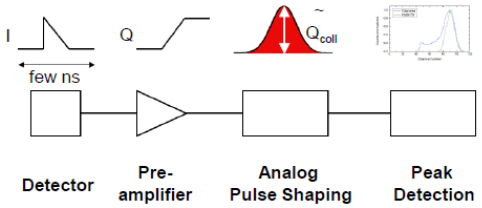
CHARACTERIZATION METHOD

PROBING CHARGE TRANSPORT WITH IBIC

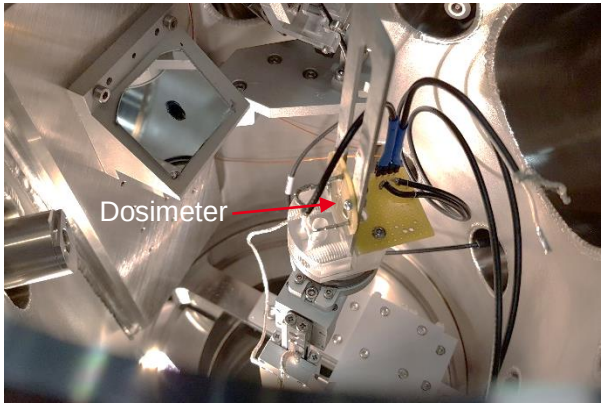
IBIC (Ion Beams Induced Charge)



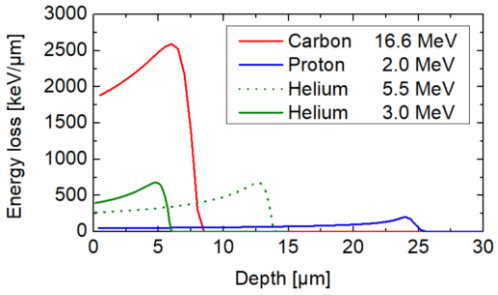
- Single Ion Irradiation (Precision: 1 µm)
- Raster Scanning + Pulse-Height Spectra
- Charge Transport Maps (µSV Definition)
- Well Controlled Projectile Energy and LET



PERFECT TOOL TO TEST NEW TYPES OF MICRODOSIMETERS BEFORE IMPLEMENTING IN CLINICAL CONDITIONS



TRIM Calculation for Energy Loss in Diamond

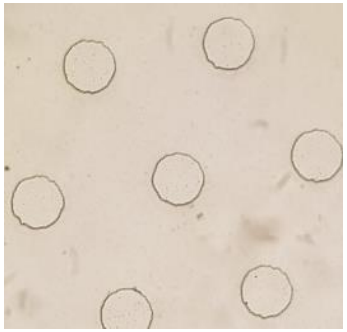


RESULTS

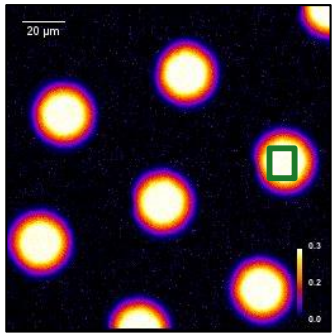
RESPONSE OF DIAMIDOS P+ TO SINGLE ION BEAMS

DIAμDOS p$^+$ & 0V to 2 MeV p

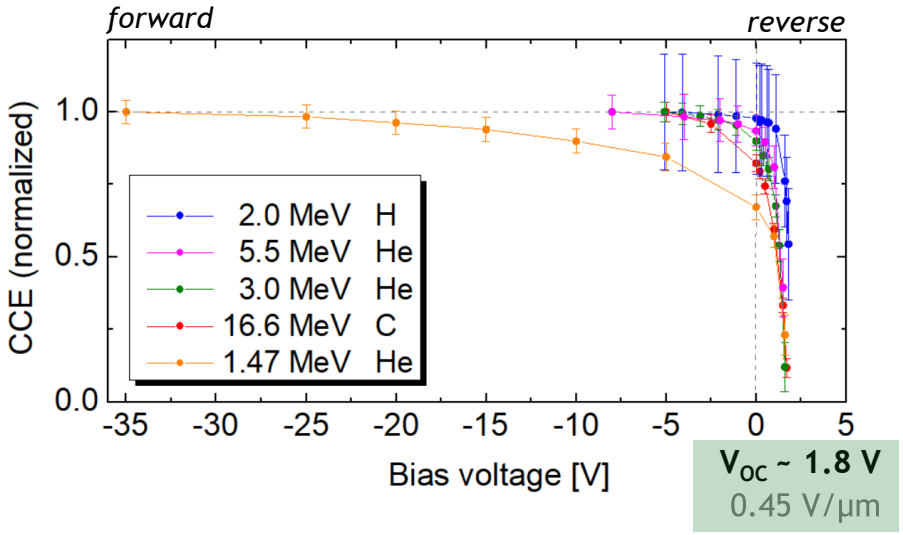
Opt. Microscope Image



Median Energy Map

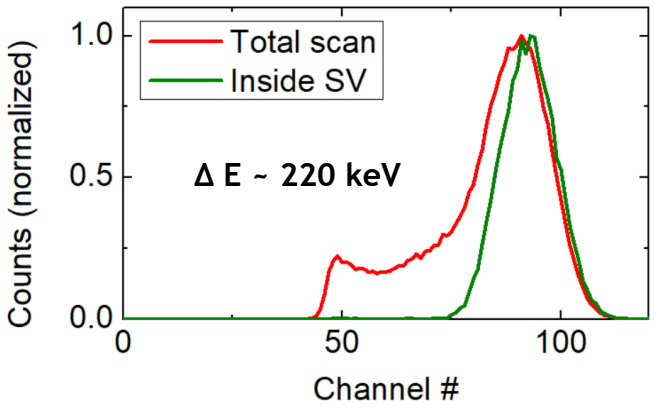


CCE vs. Bias



V_{OC} ~ 1.8 V
0.45 V/µm

Normalized Energy Spectrum



Ion / Energy	CCE @ 0V	Radiation Hardness CCE drop after ions/ cm^2
Proton 2.0 MeV	100%	1% after 2.5 x 10^{13}
Helium 5.5 MeV	93%	12% after 0.6 x 10^{12}
Helium 3.0 MeV	90%	5% after 1.5 x 10^{12}
Carbon 16.6 MeV	80%	-
Helium 1.47 MeV	67%	-

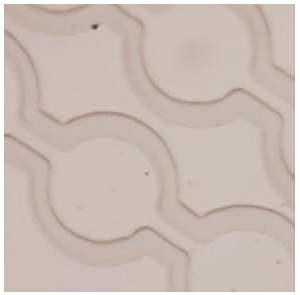
Performance approaching Si-based microdosimeters

RESULTS

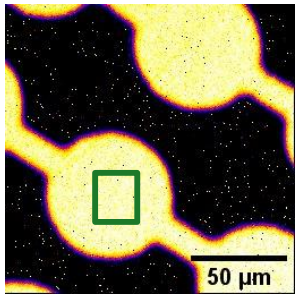
RESPONSE OF DIAMIDOS GR TO SINGLE ION BEAMS I

DIAμDOS GR & +20V to 2 MeV p

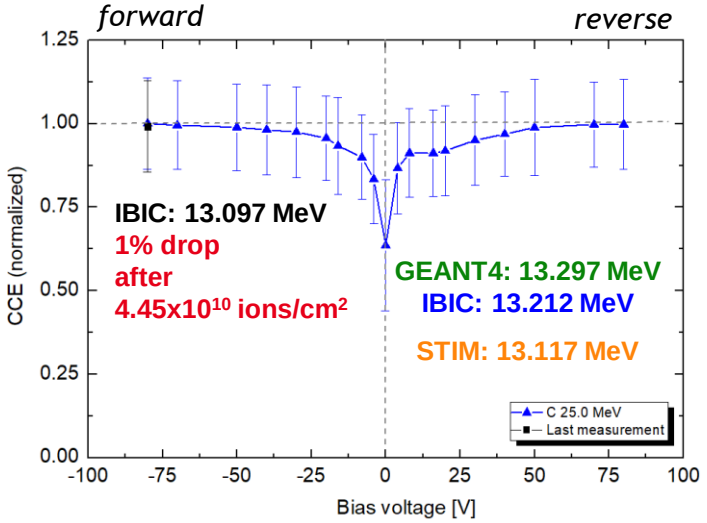
Opt. Microscope Image



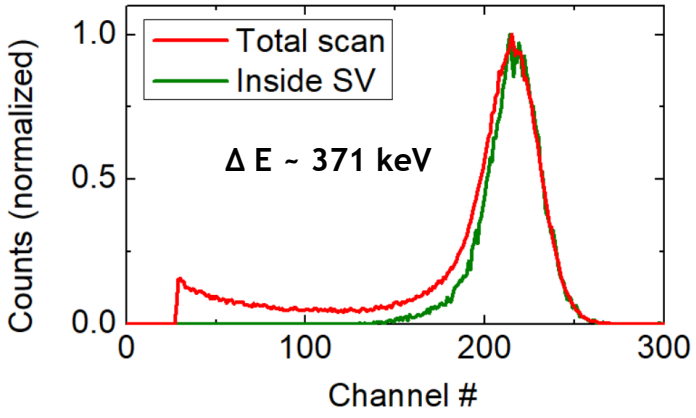
Median Energy Map



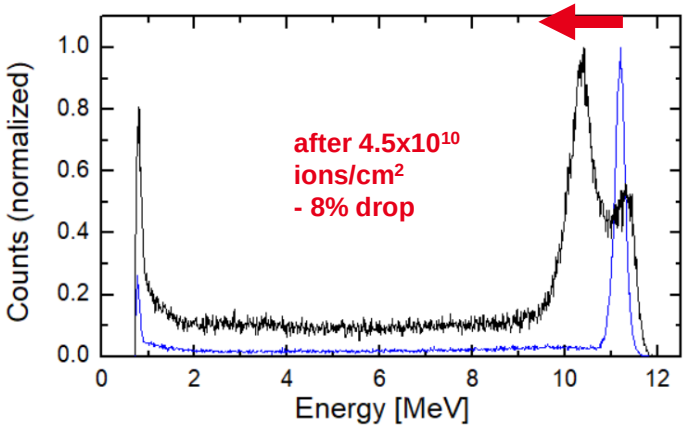
CCE vs. Bias for 25 MeV carbon



Normalized Energy Spectrum



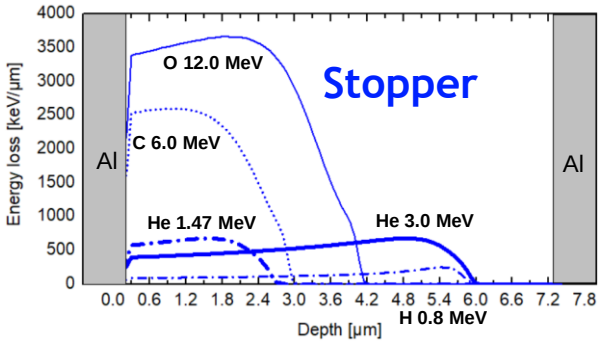
Radiation Damage Effects for 12 MeV oxygen

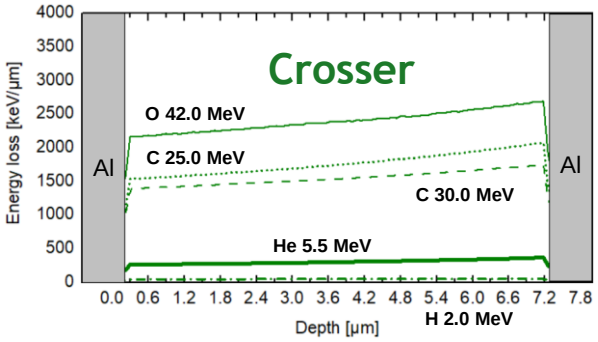


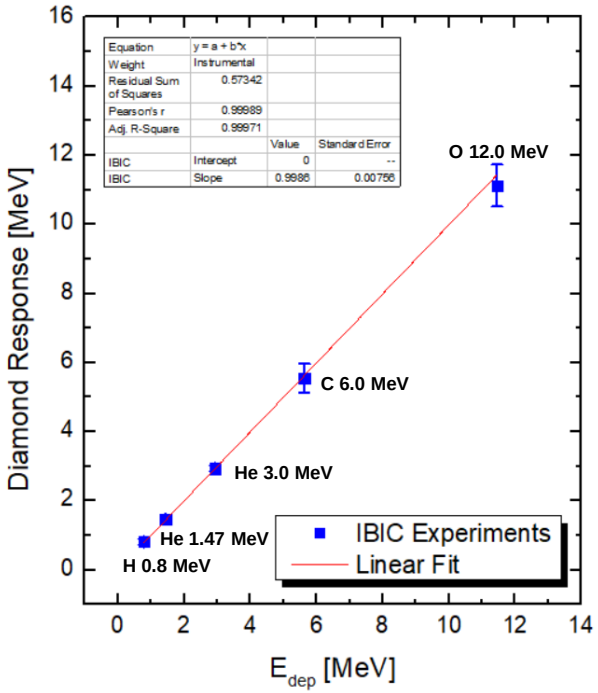
RESULTS

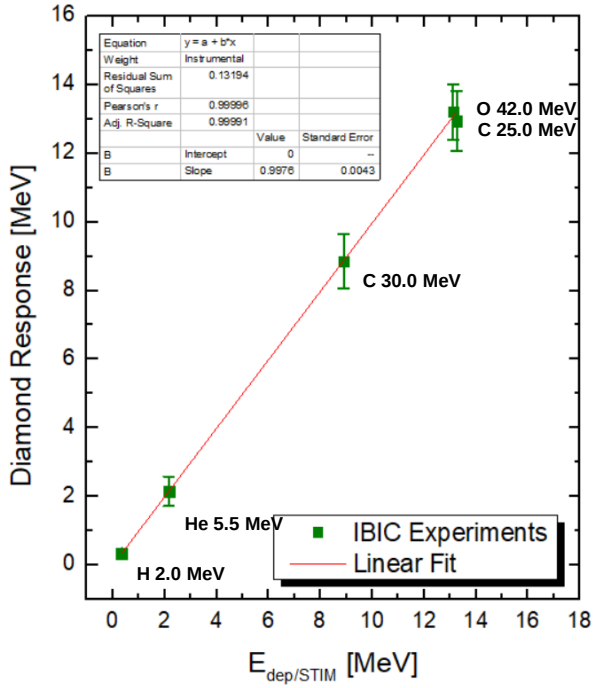
RESPONSE OF DIAMIDOS GR TO SINGLE ION BEAMS II

Linearity of DIAμDOS guard ring

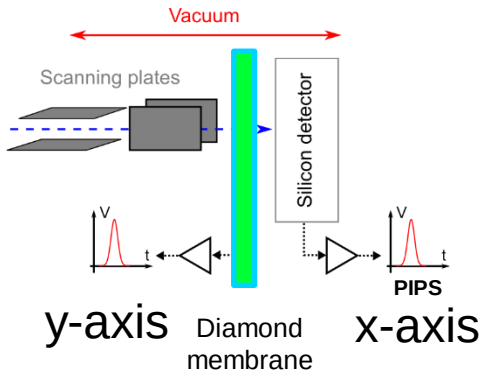








Calibration with STIM (Scanning transmission ion microscopy)

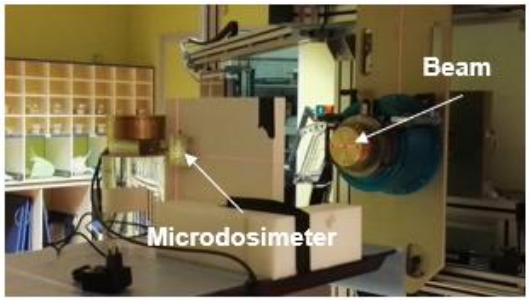


ΔE + E configuration

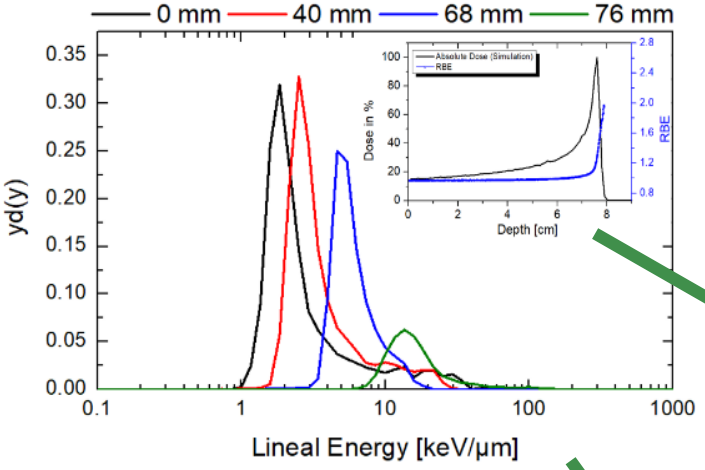
RESULTS

SIMULATIONS OF DIAMIDOS MICRODOSIMETERS IN CLINICAL BEAMS

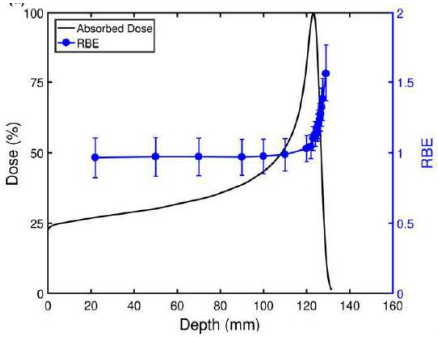
Clinical setup at CPO



Simulated Microdosimetric Spectra with GR Diamond-Detector

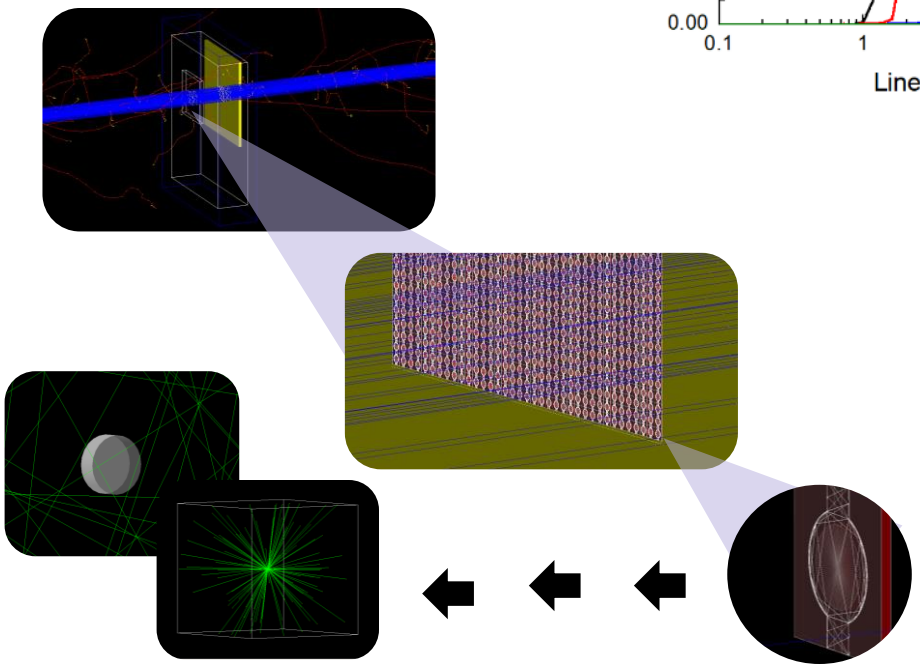


Measured with Si-Detector



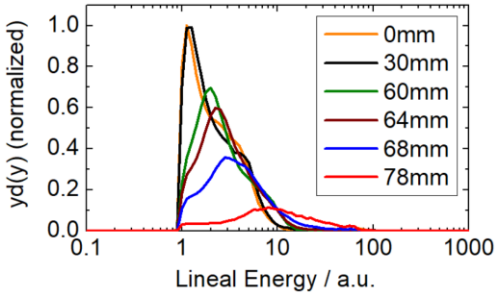
L. Tran et al., Med. Phys., 44 (11), November 2017

GEANT4 Simulation of DIAµDOS p+



Mean chord length

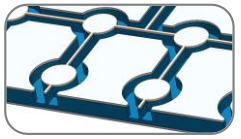
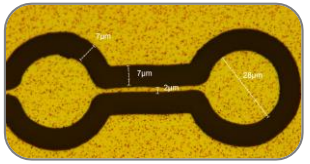
Measured Microdosimetric Spectra with DIAµDOS p+



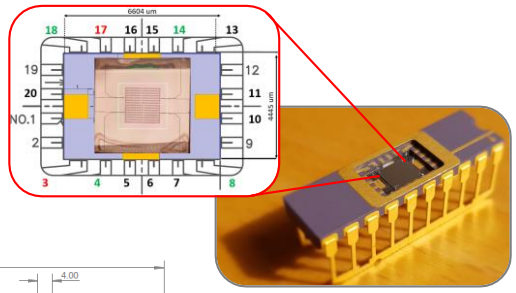
SUMMARY AND NEXT STEPS

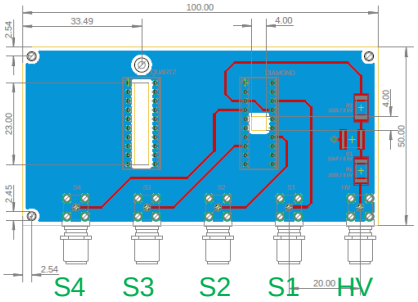
- **Prototyping and microfabrication**
- **Single ion beam characterisation**
- **Monte Carlo Linear Energy and TCAD Electric Field Simulations**
- **Encapsulation and integration**
- **Clinical evaluation**



New prototypes based on guard ring approach (etching of isolation gap, sub-micron membranes)





Dedicated **PCB** + universal diamond **sensor carrier** + **encapsulation**

IBIC characterisation and **calibration**

Coming up! 11. – 14. June 2019

CENBG

Clinical evaluations

Coming up! July 2019: CPO Orsay, France (p)

September 2019: Gunma and HIMAC, Japan (C, O, Fe/Si)

2019/2020: TIRO/Centre Antoine Lacassagne, Nice, France (p)

INVOLVED PROJECTS AND COLLABORATIONS

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UNIVERSITY OF WOLLONGONG AUSTRALIA

imagerie et modelisation en neurobiologie et cancerologie

Australian Government

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laboratoire de physique corpusculaire

DIAμDOS

Diamond-Membrane-Microdosimeter-Collaboration

CENBG

université PARIS-SACLAY

DIADEM

Diamond membrane based microdosimetric system for radiation quality assurance in hadron therapy

INSTITUT CARNOT TN@UPSaclay

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Antoine Lacassagne

CENTRE DE LUTTE CONTRE LE CANCER DE NICE

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CONTEXT

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