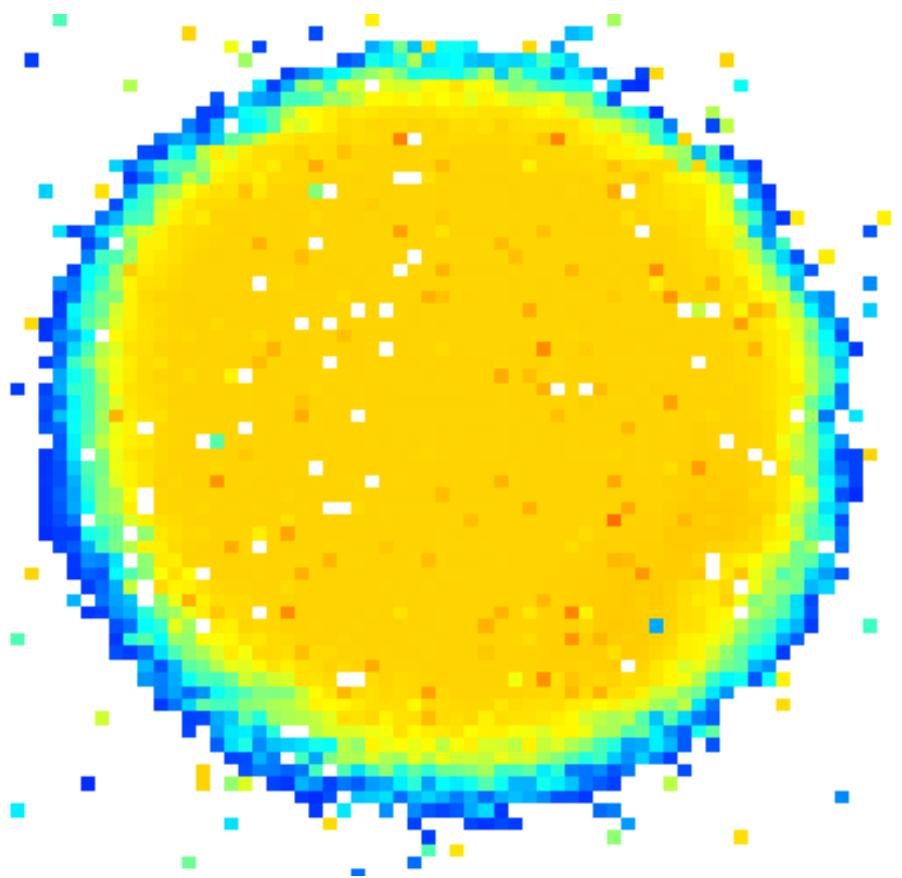




La Doua IP2I, Lyon, 1st September 2020



## A NEW MICRODOSIMETRIC SYSTEM BASED ON SCCVD DIAMOND MEMBRANE SENSOR

Michał Pomorski et al, CEA-LIST Diamond Sensors Laboratory

Journée d'étude GDR MI2B - LabEx PRIMES sur les moniteurs faisceaux  
et contrôle en ligne des irradiations biomédicales

Diamond  
microdosime  
ters  
development

Microbeam  
characterizati  
on

Integration into  
microdosimetric  
system

Clinical beam  
tests

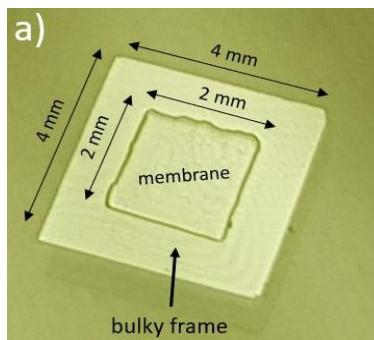
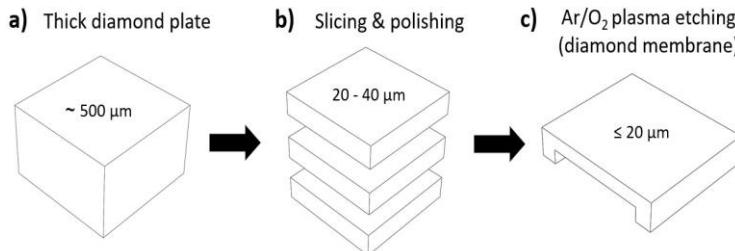
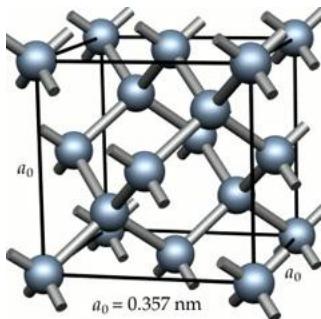
Microdosimetry  
in clinical hadron  
beams

MC/Si  
benchmar  
king

## Founding bodies:

## Other involved institutions:

# Why Diamond ?



Large band-gap (5.5eV) semiconductor

A solid-state ionization chamber

more tissue equivalent ( $Z=6$ ) and radiation hard (43 eV)



- + no leakage current and no need for p-n junction
- + fast drift velocity for e-h
- + low capacitance
- + high electrical breakdown ( $> 1000 \text{ V}/\mu\text{m}$ )
- + VIS light and temp. insensitivity



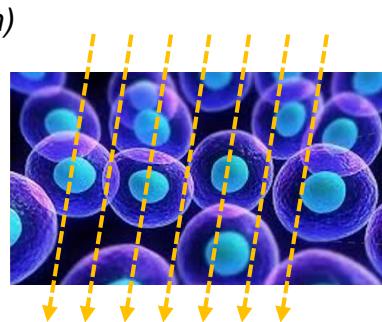
- high  $\sim 13 \text{ e-h/eV}$  - lower signal
- it's diamond (for instance pls. forget 6' wafers)

since 2002 high purity electronic grade CVD diamond available commercially  
Nowadays 'boom' of man made diamond for jewellery

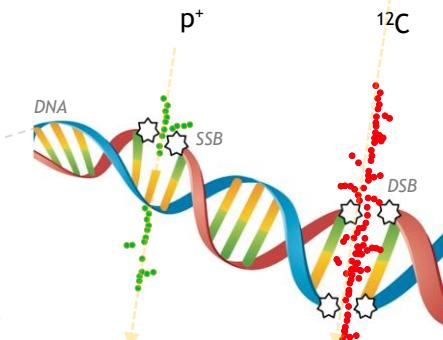
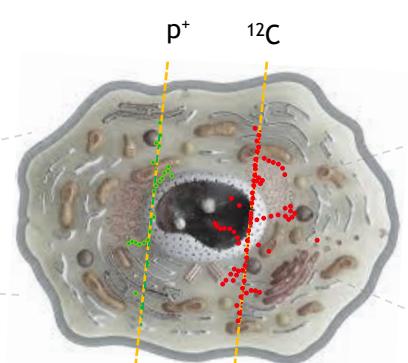
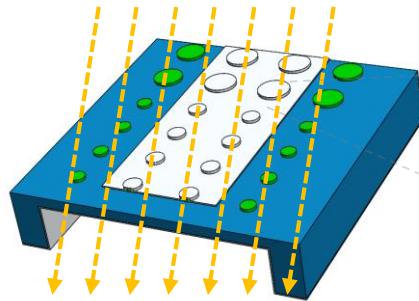
All sensors here are based on thin free standing scCVD diamond membranes

# Solid-state microdosimeters

## Biological Cells ( $\mu\text{m}$ )

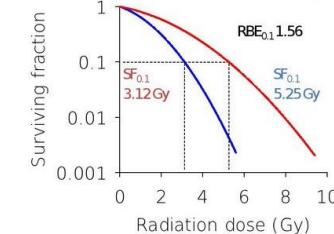


## Micro-Sensitive-Volumes ( $\mu\text{SVs}$ ) in microdosimeter ( $\mu\text{m}$ )

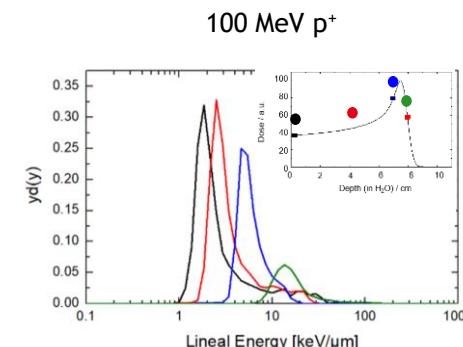
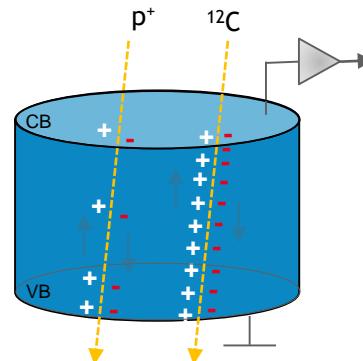


direct

RBE



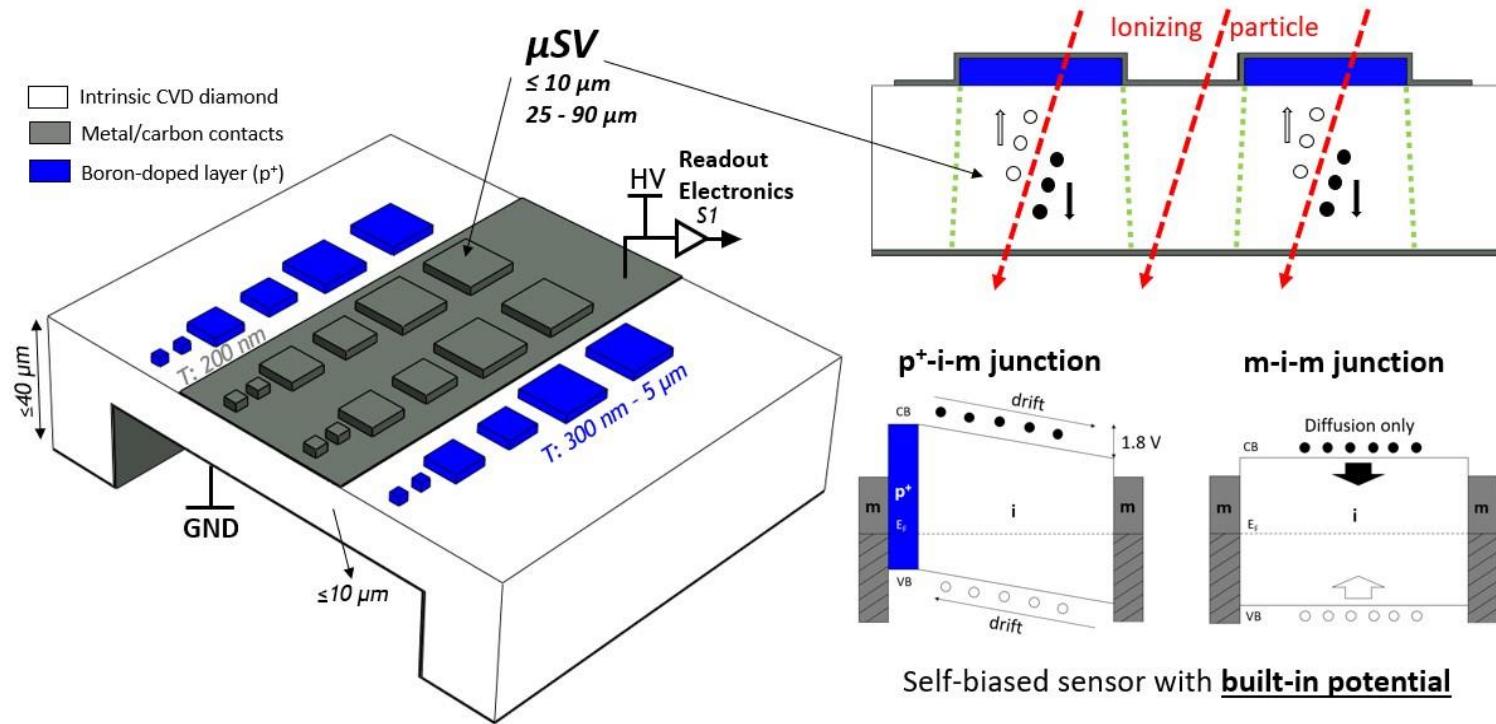
model



**MICRODOSIMETRY** is a method which involves measurements of stochastic energy deposition distribution in a micron size sensitive volume ( $\mu\text{SV}$ ) within any mixed radiation field

Experimentalist point of view: **pulse-height measurements in challenging conditions**

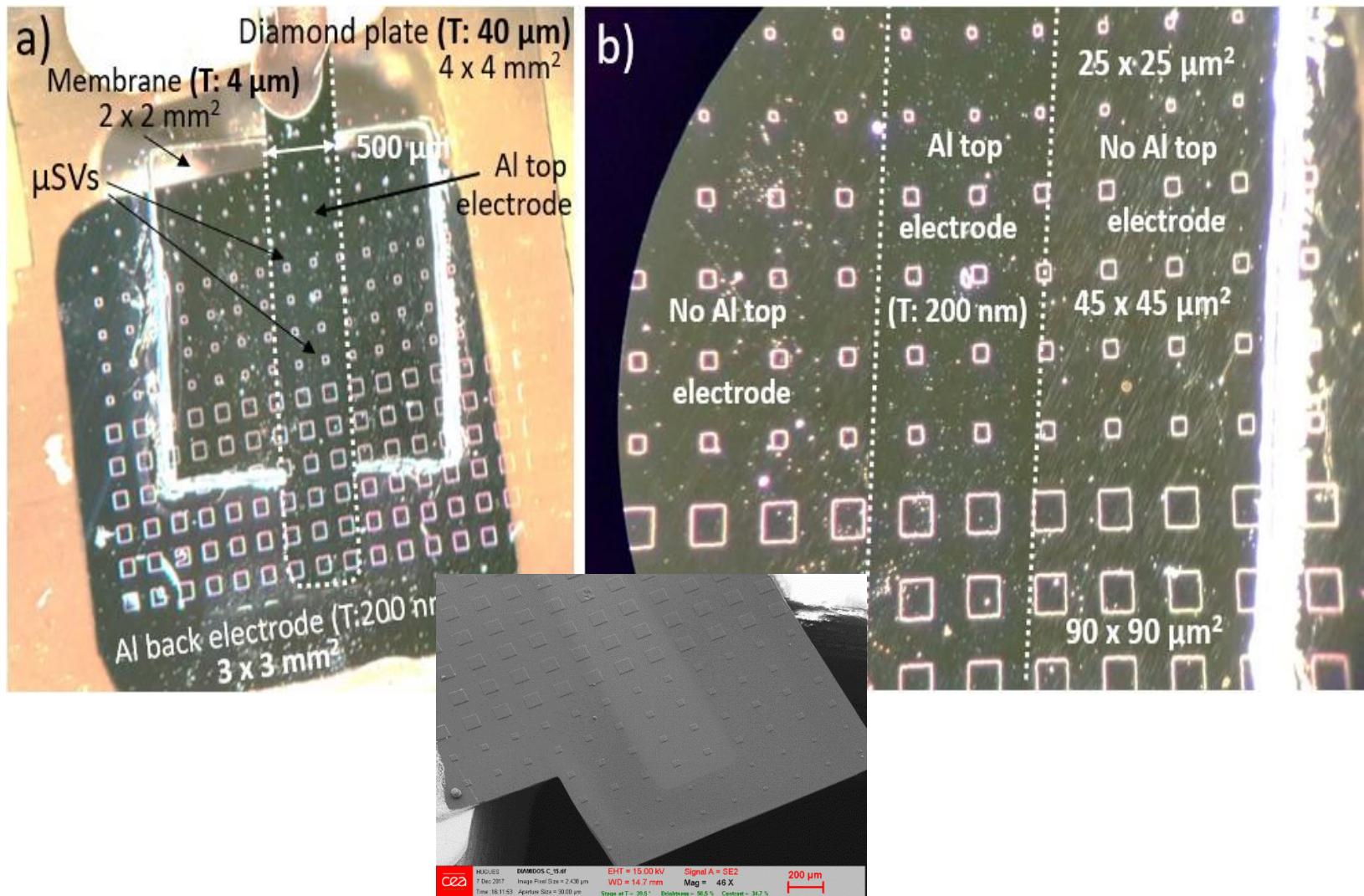
# P+ type sensor → concept



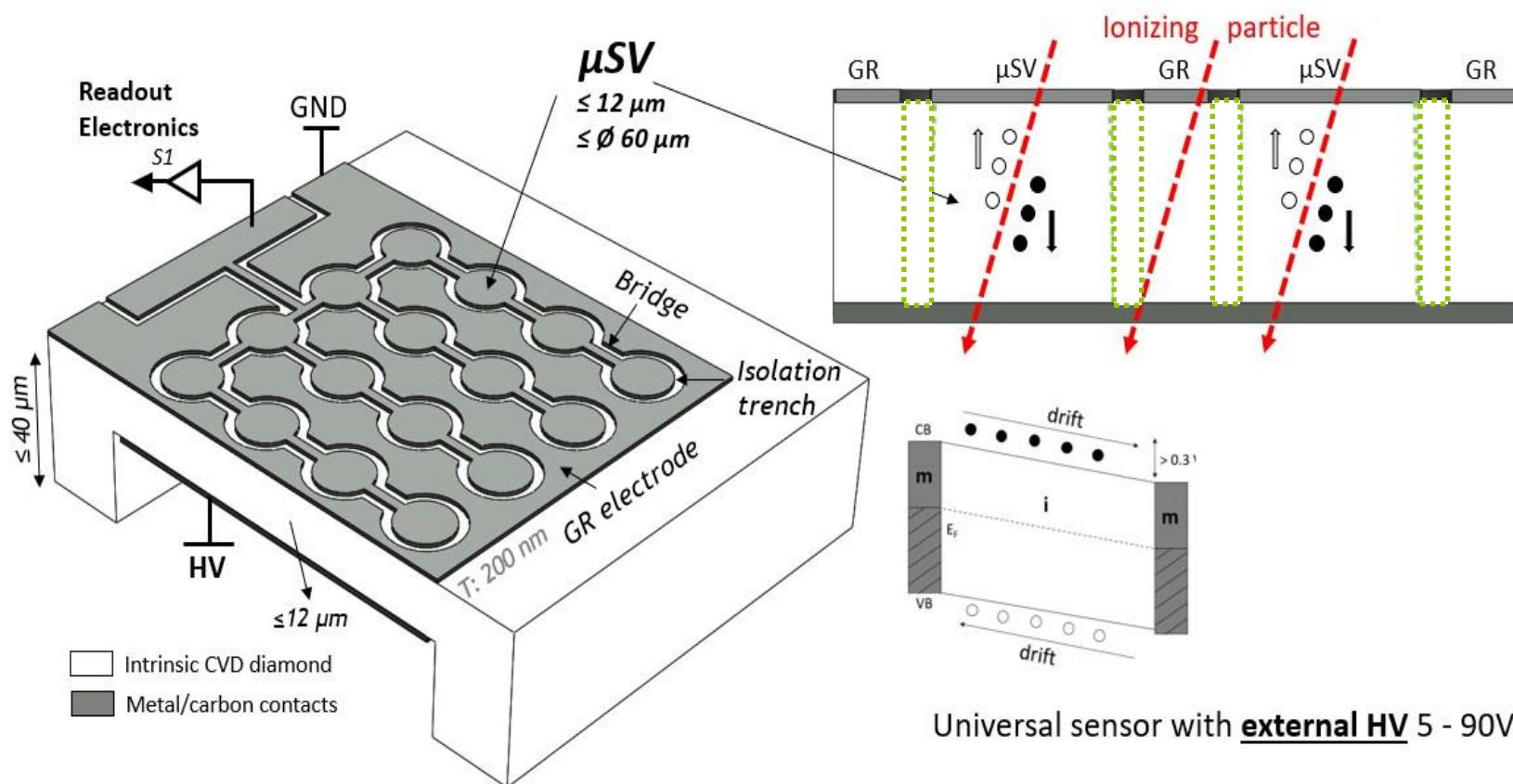
## Processing:

- CVD boron doped diamond growth
- photolithography techniques
- shallow Ar/O plasma etching
- electrodes deposition (here PVD)

# P+ type sensor → fabrication



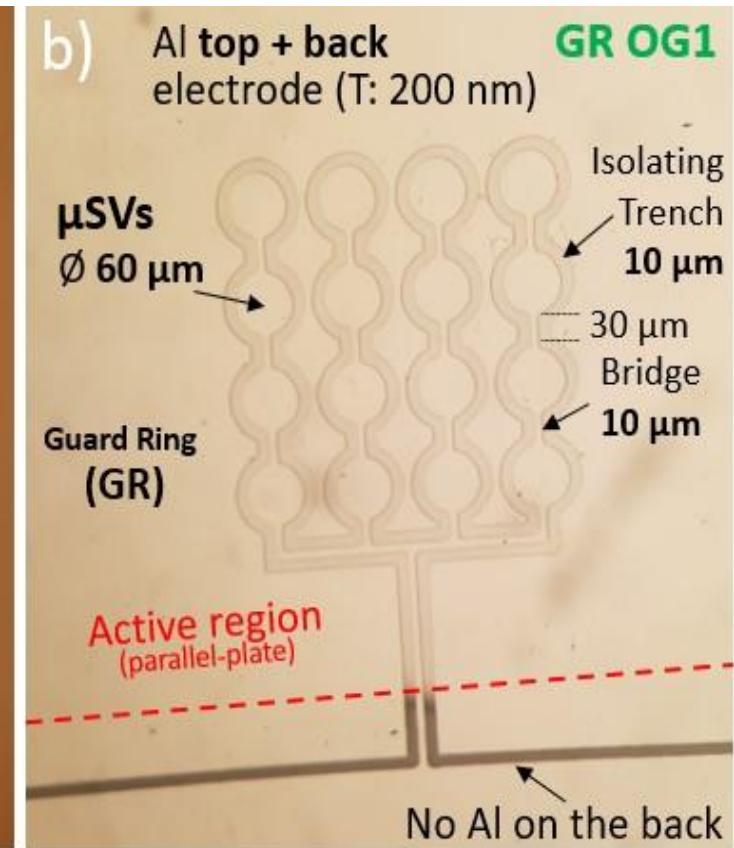
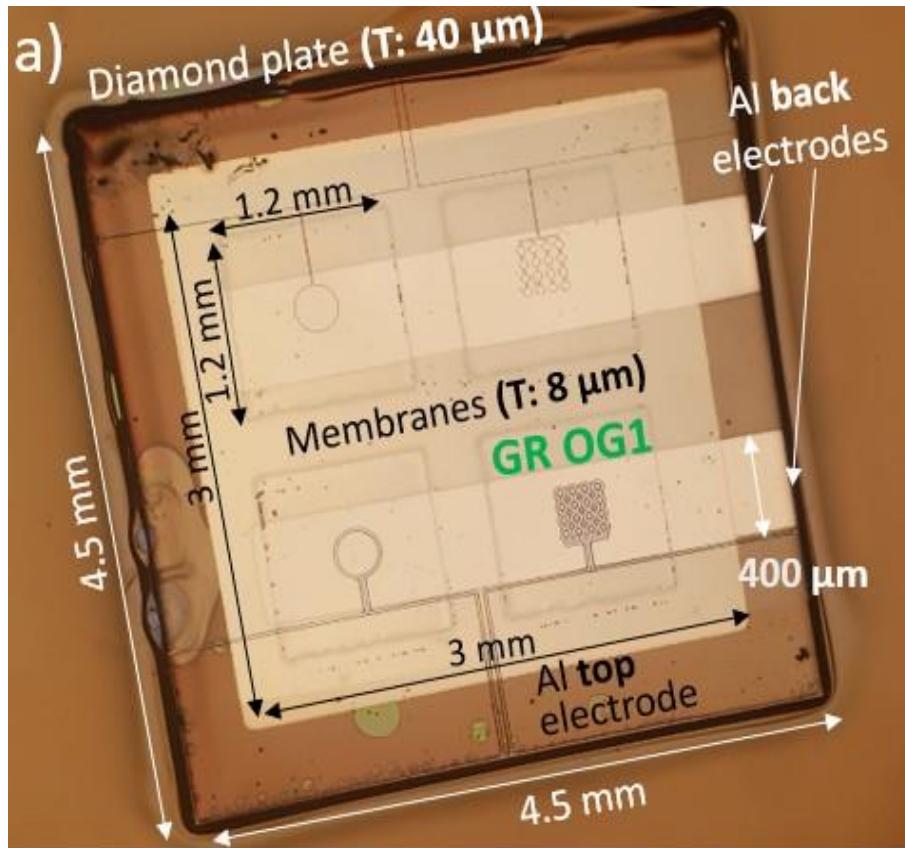
# GR type sensor → concept



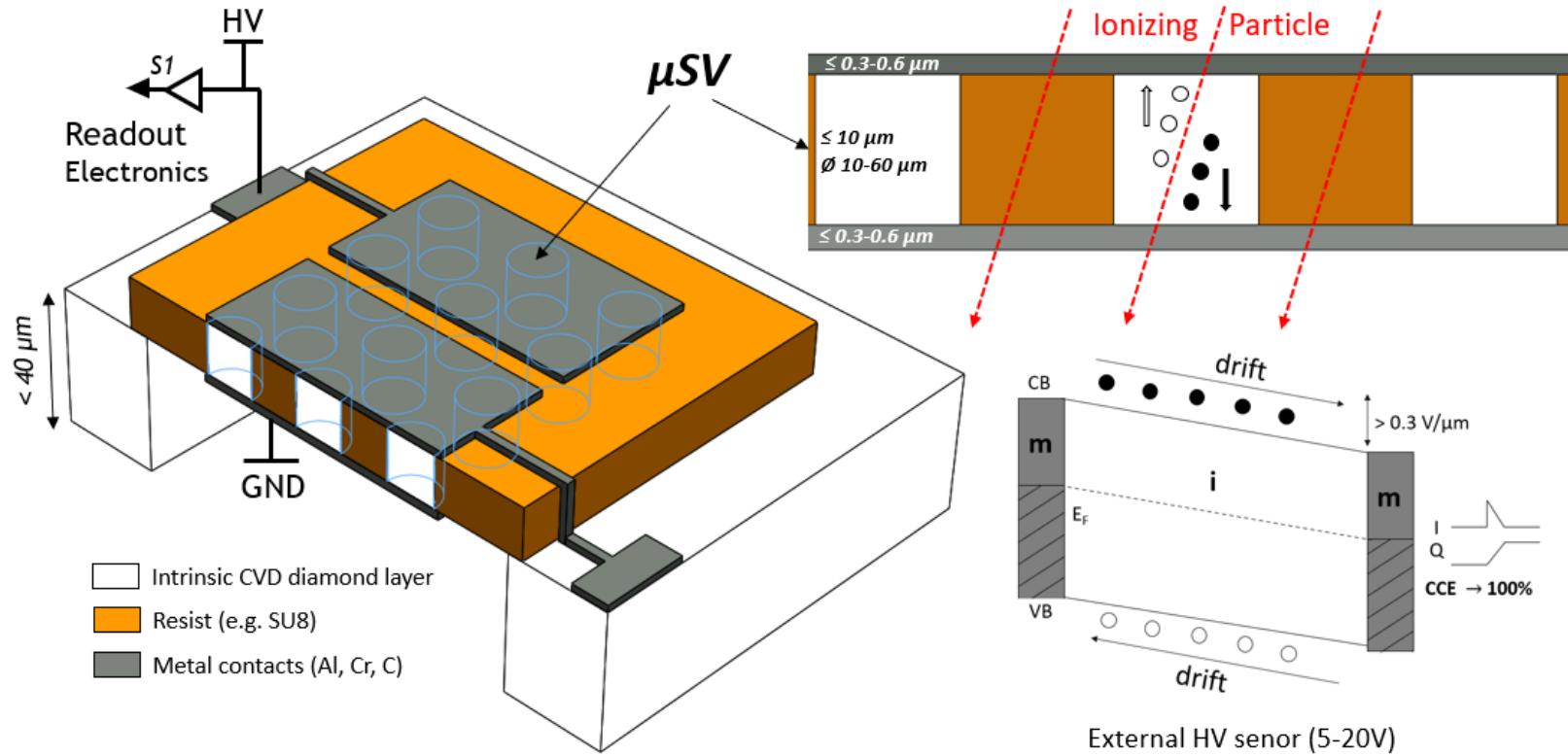
## Processing:

- photolithography techniques
- electrodes deposition (here PVD)

## GR type sensor → fabrication



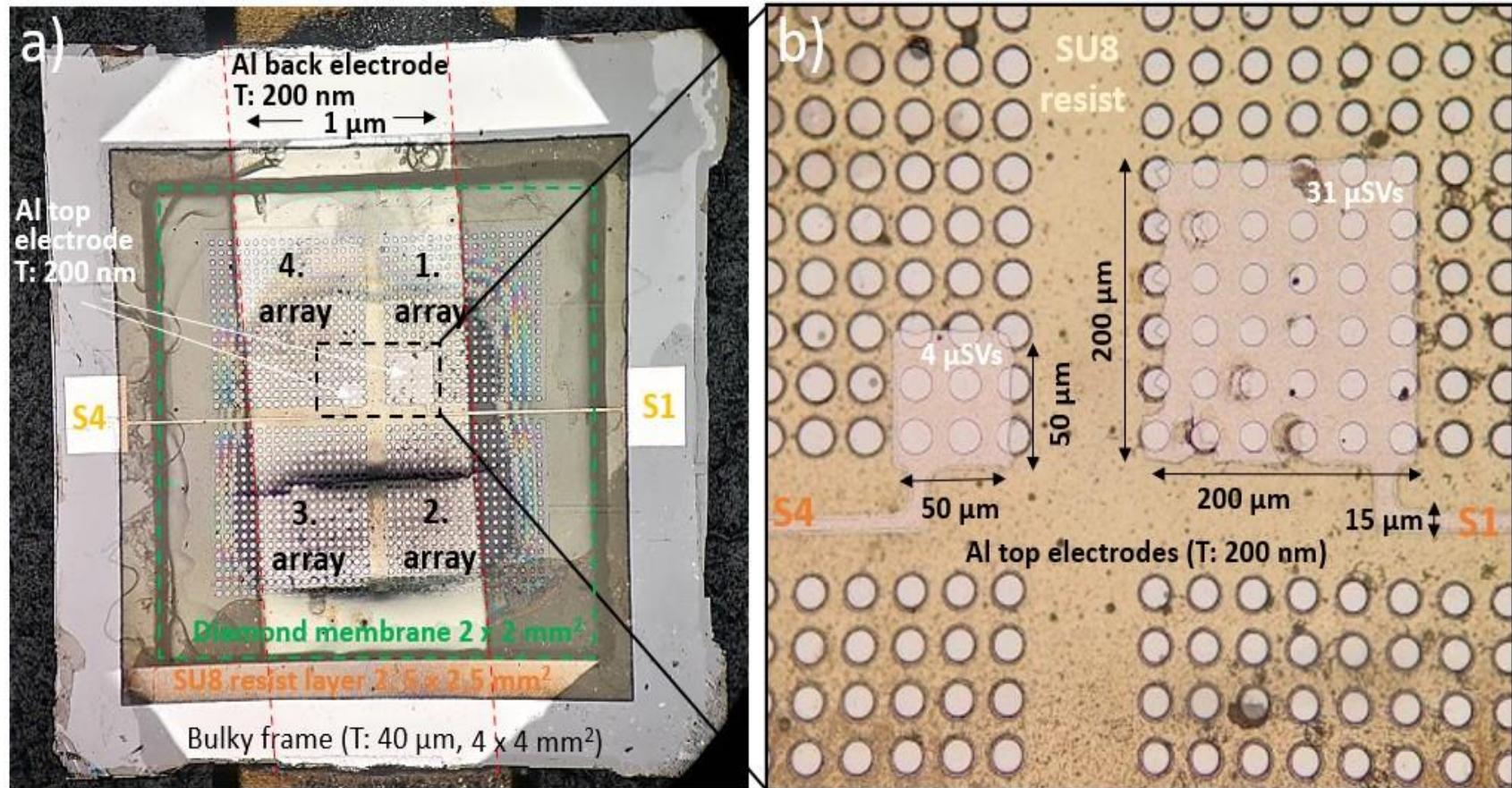
## 3D type sensor → concept



### Processing:

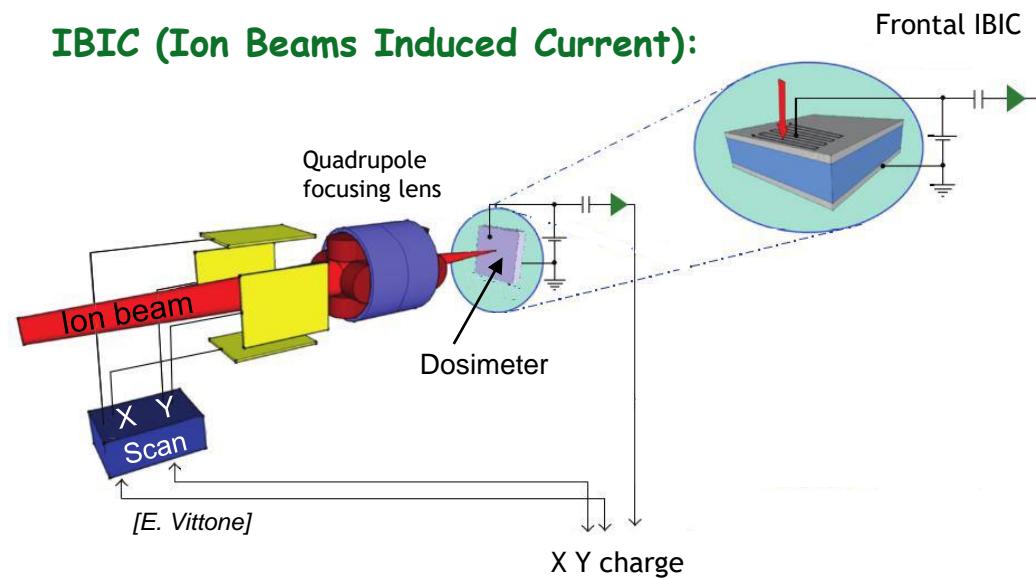
- multistage processing
- photolithography techniques
- shallow/deep Ar/O plasma etching
- electrodes deposition (here PVD)

## 3D type sensor → fabrication



# Probing Charge Transport with IBIC

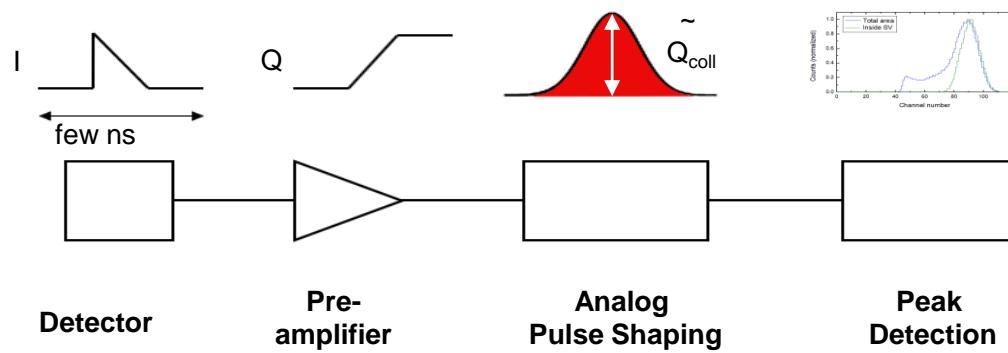
## IBIC (Ion Beams Induced Current):



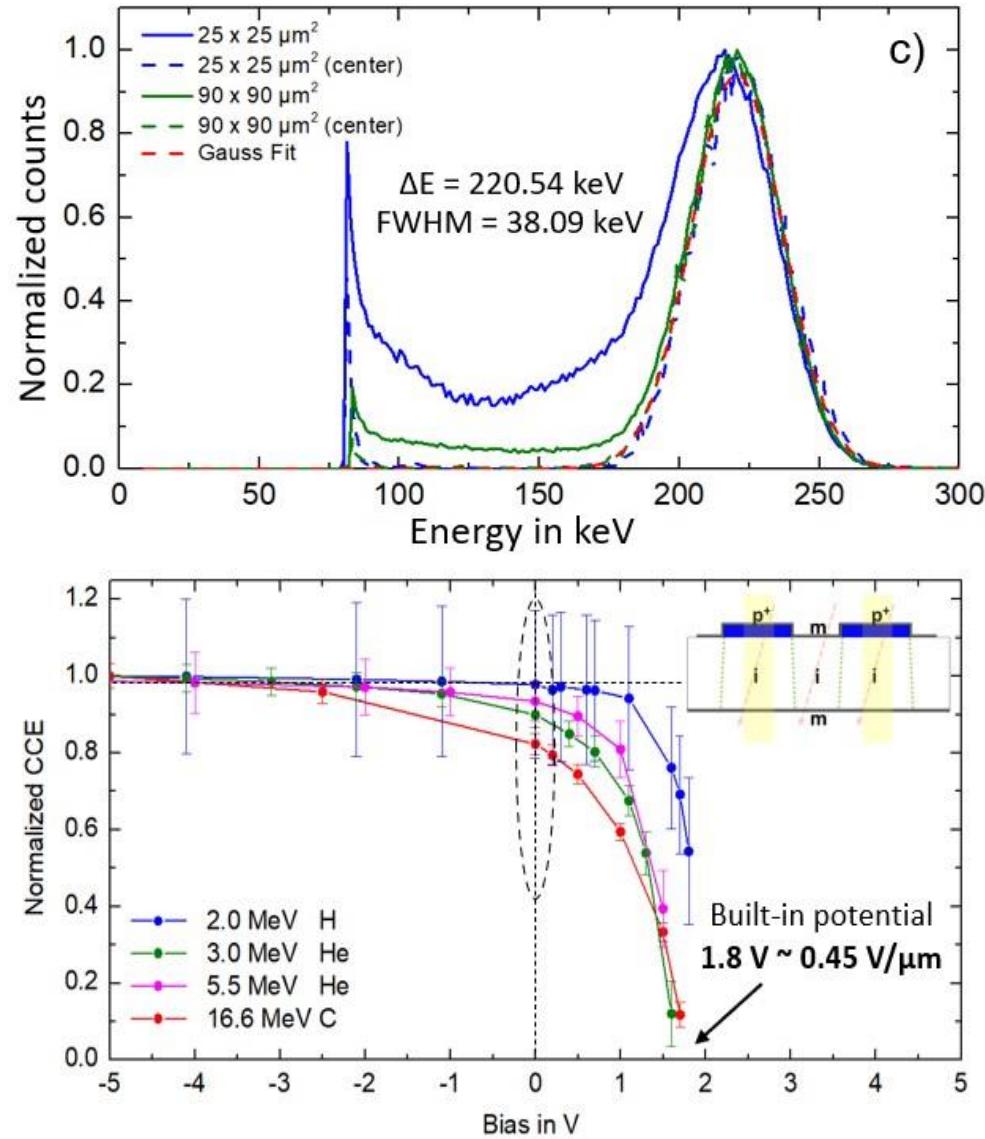
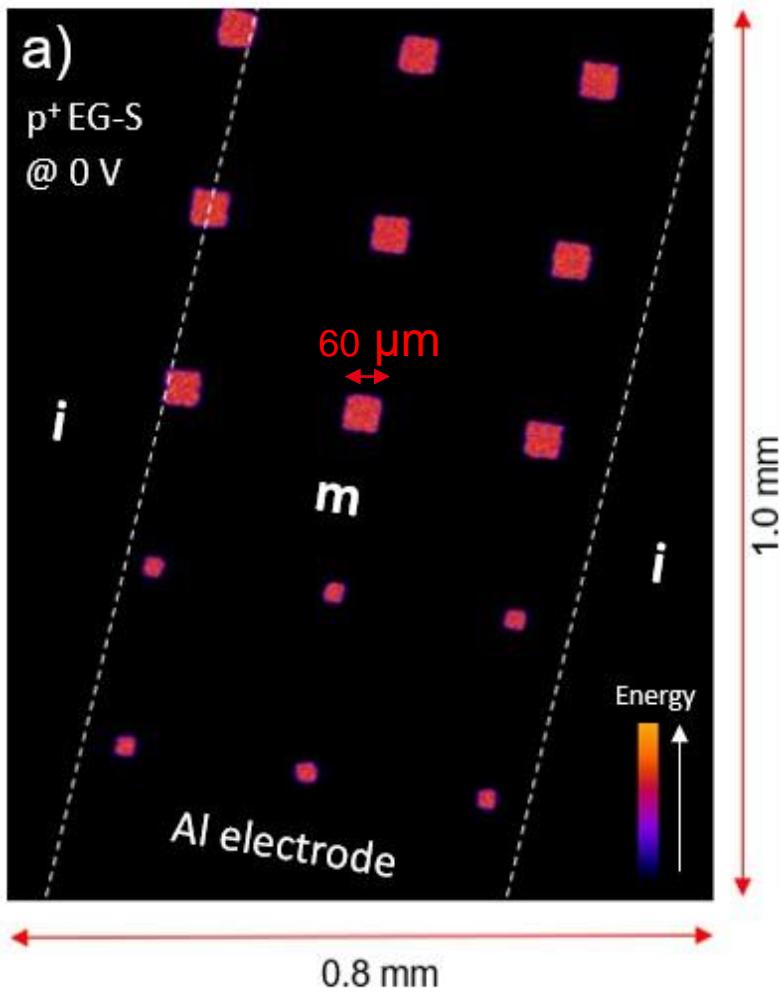
- Single ion irradiation (precision: 1 micron)
- Raster scanning + pulse height spectra
- Charge transport maps ( $\mu\text{SV}$  definition)
- Well controlled projectile Energy and LET

**Perfect tool to test new types of microdosimeters before implementing in clinical conditions**

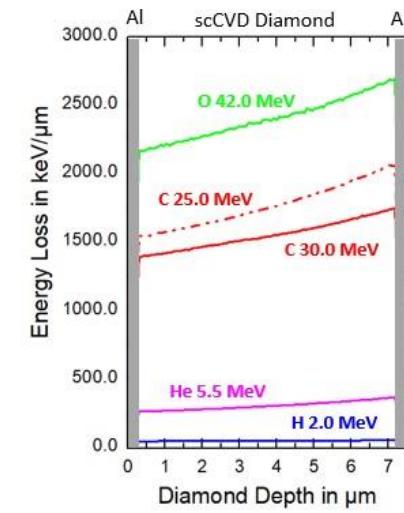
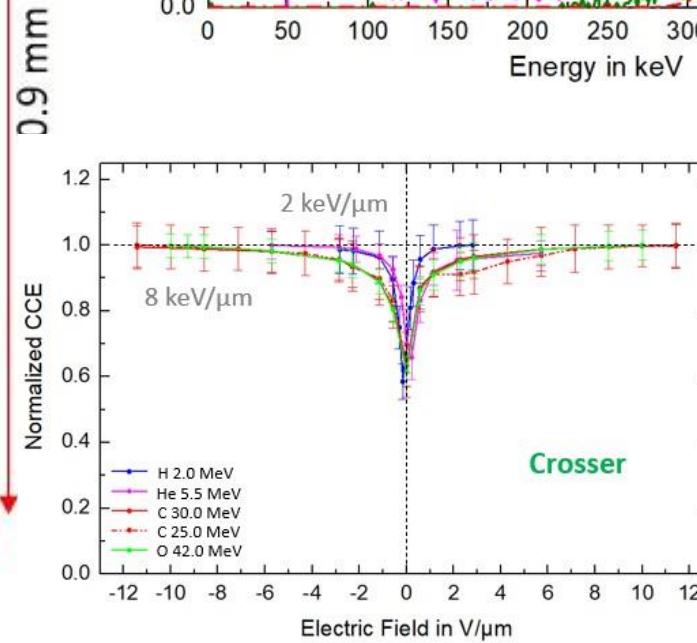
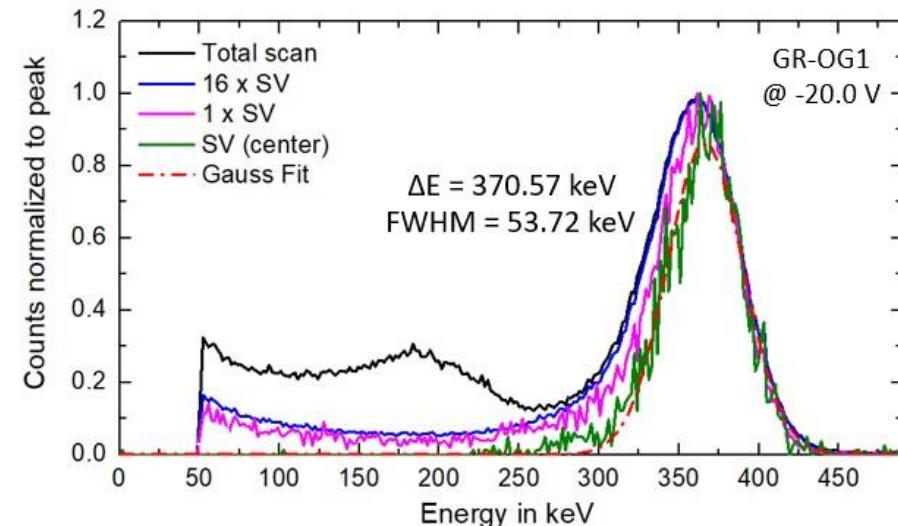
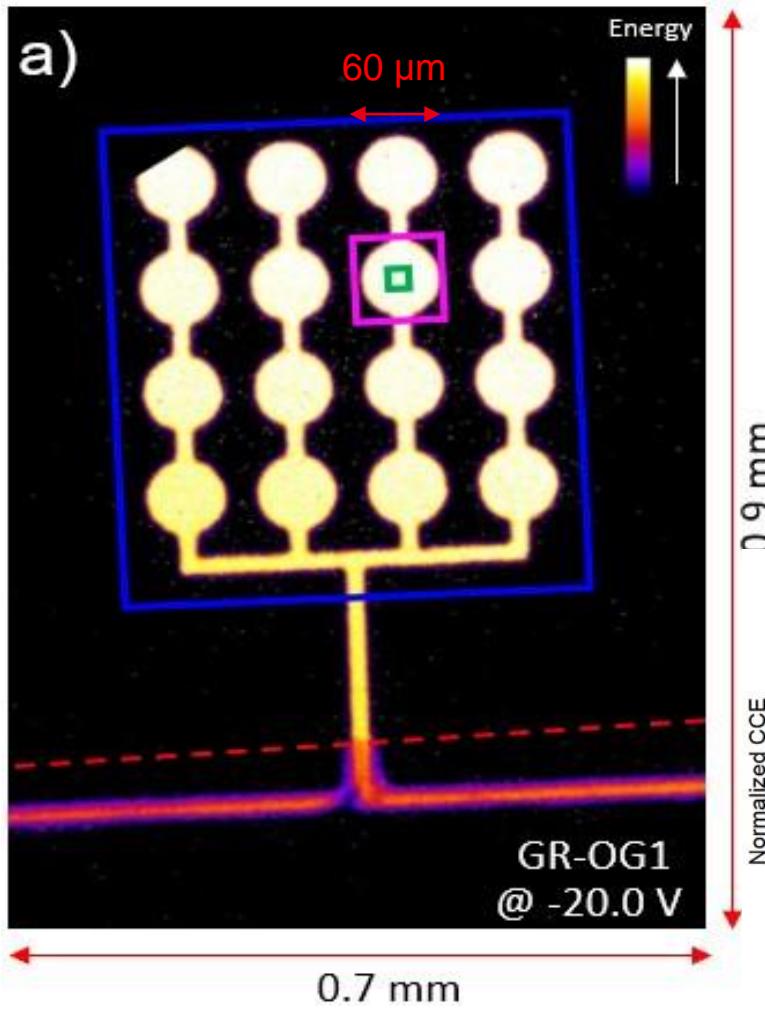
## Analog read-out electronics:



# Charge transport properties → p+ sensor

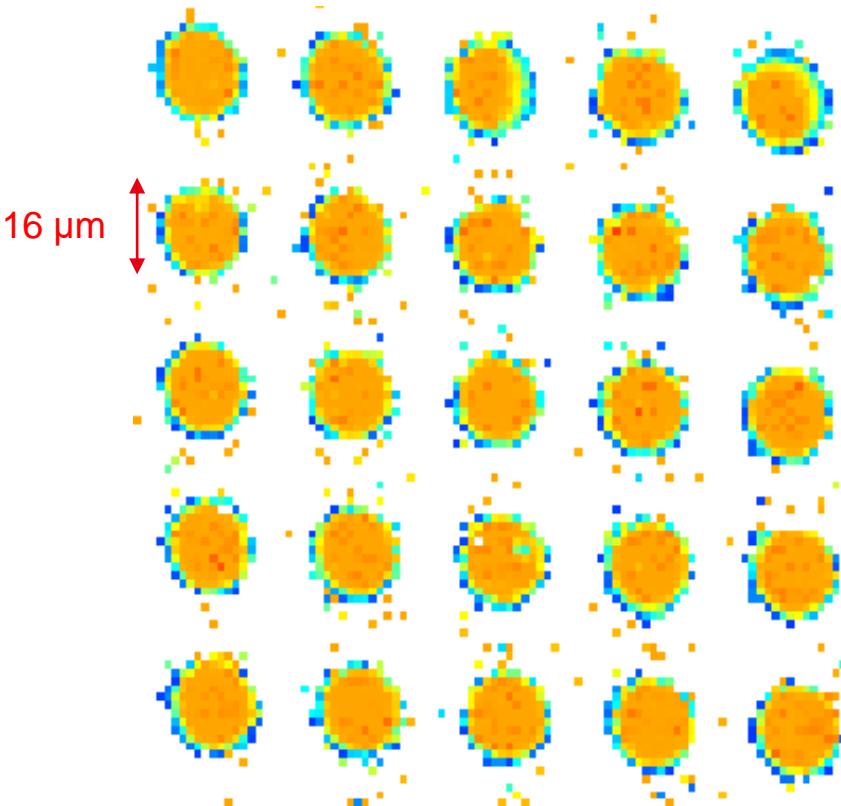


# Charge transport properties → GR sensor

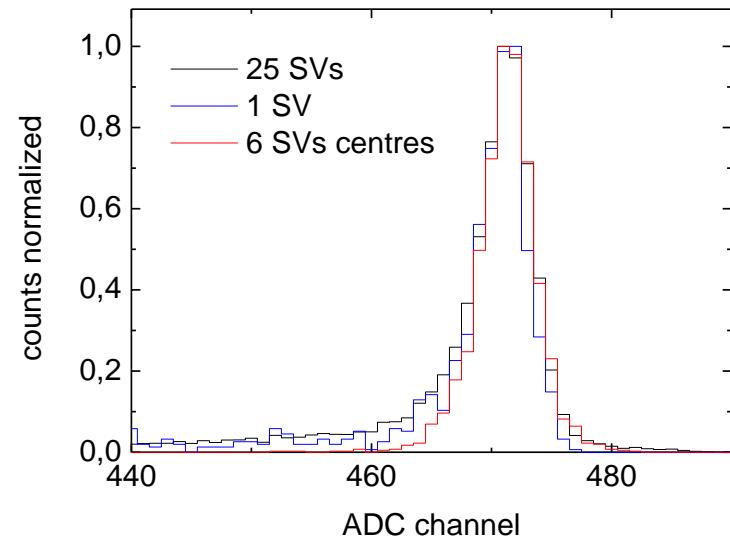
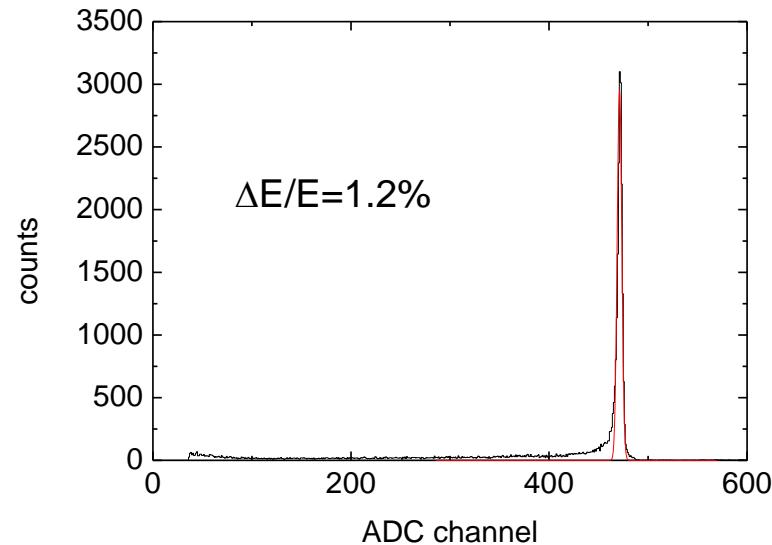


# Charge transport properties → 3D sensor

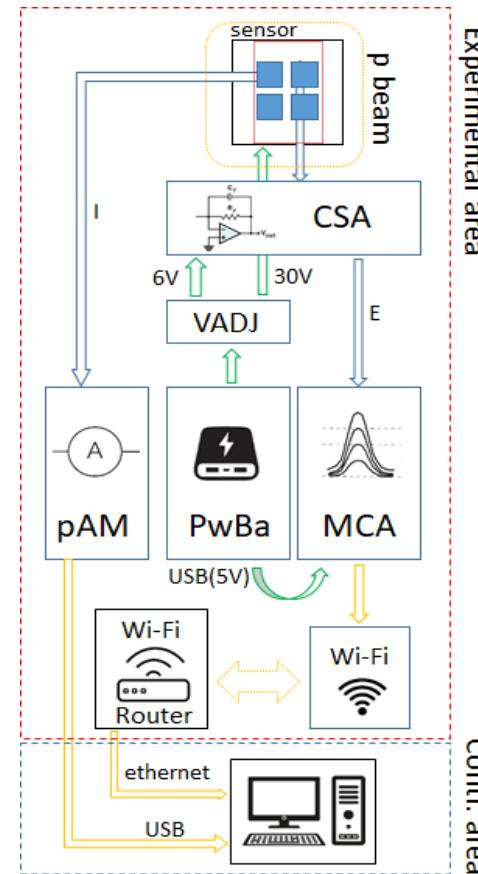
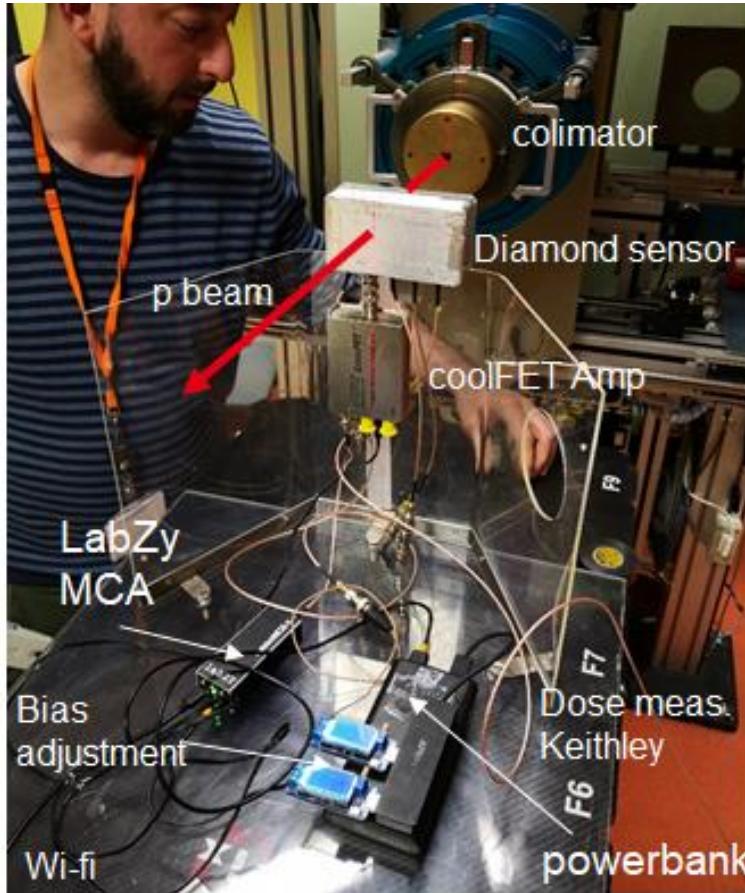
Here: 12MeV C (stopper), sensor @ 3 V/ $\mu$ m



- p, He, C, Si ions studied
- CCE vs. bias, LET linearity
- Heavy irradiations → RH, stability
- TCT signals
- operated @ 30 V/ $\mu$ m



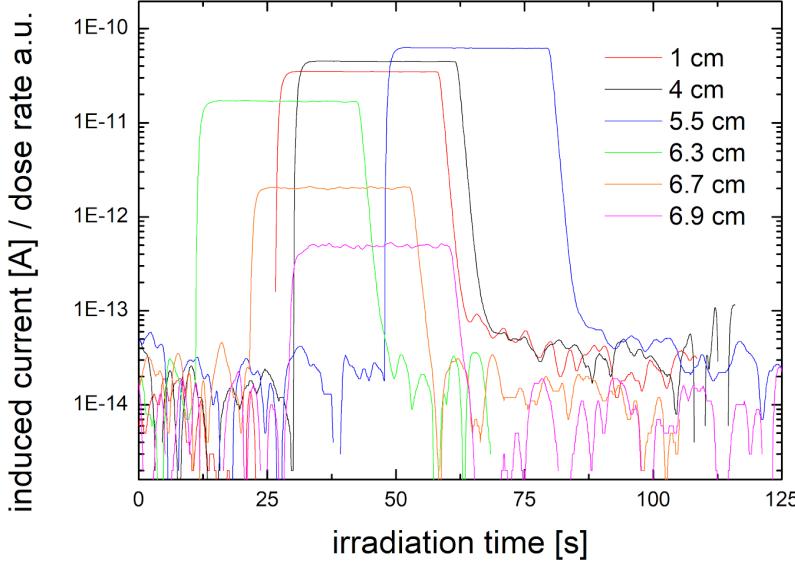
# Recent clinical proton beam measurements @ IC-CPO



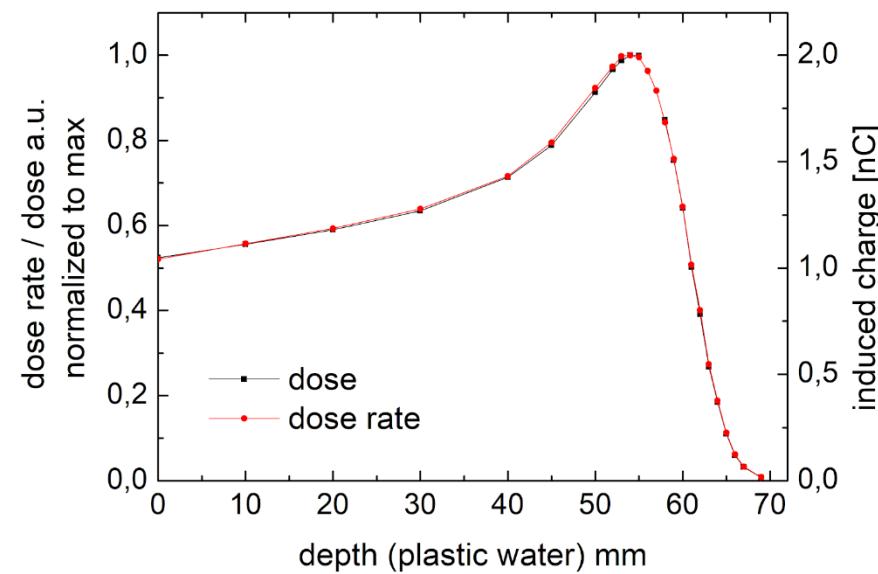
- <100 MeV scatter proton beam Y1 beamline @ IC-CPO
- GR diamond sensor (16 SVs of 60 µm diam.)
- ‘Plastic water’ plates for dose profile
- Simultaneous dose+microdose measurements

# Recent clinical p beam measurements - dosimetry

dose rate (induced current)



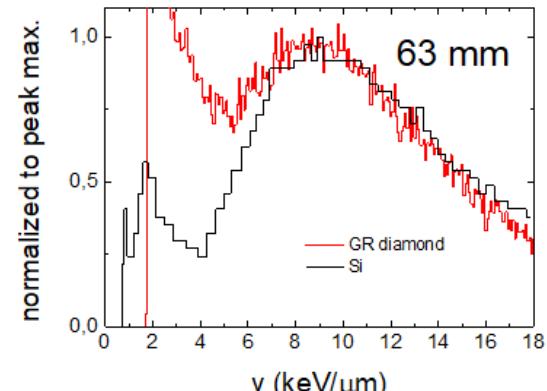
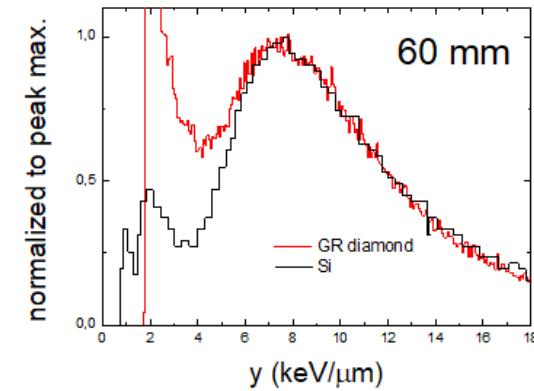
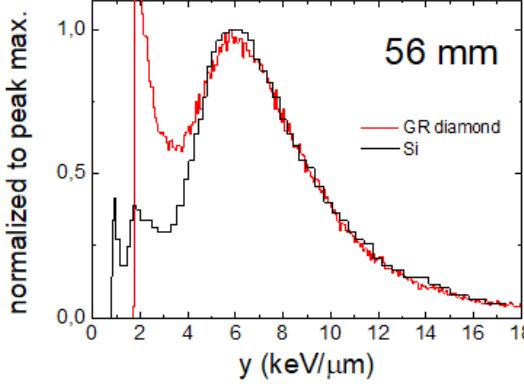
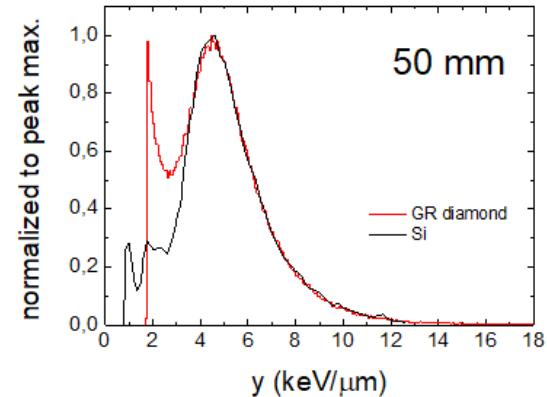
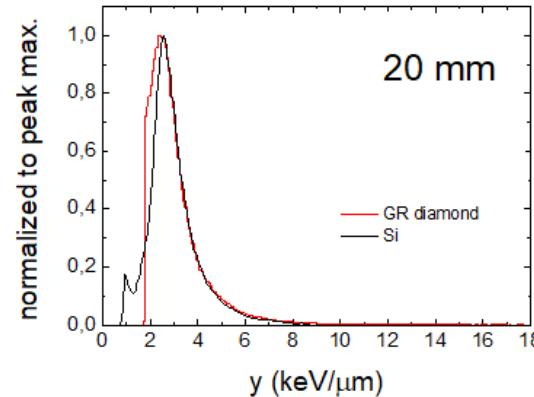
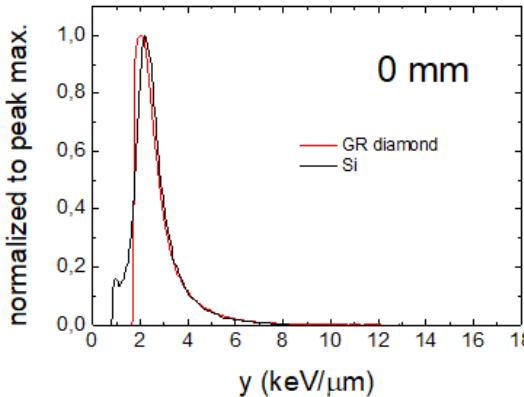
dose (charge) normalized



- extremely low dark current ~dozens of fA
- dose rate  $\Leftrightarrow$  dose  $\rightarrow$  fast scanning possible in water phantoms
- True ‘pin-point’  $\rightarrow$  active volume  $\sim 5.7 \times 10^{-4} \text{ mm}^3$

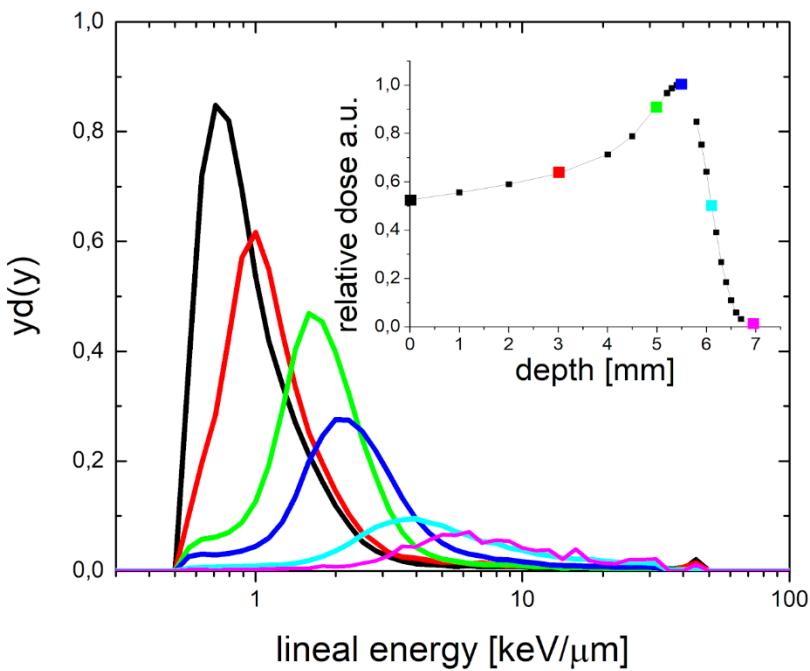
# Recent clinical p beam measurements - microdosimetry

calibrated energy loss (diamond) spectra

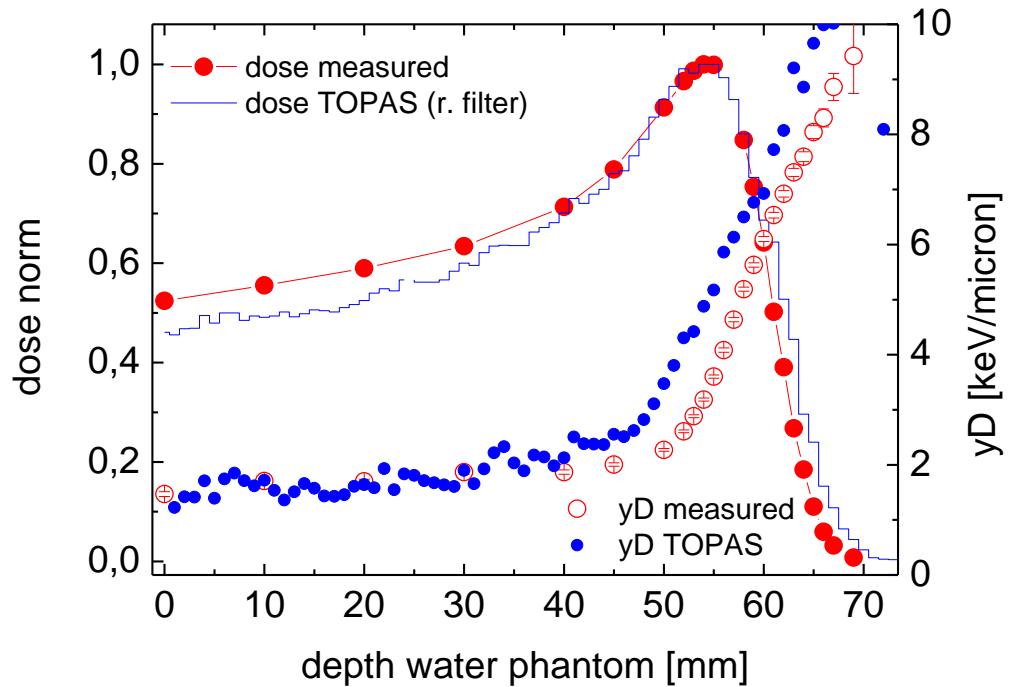


# Recent clinical p beam measurements

microdosimetric spectra (water eq.)

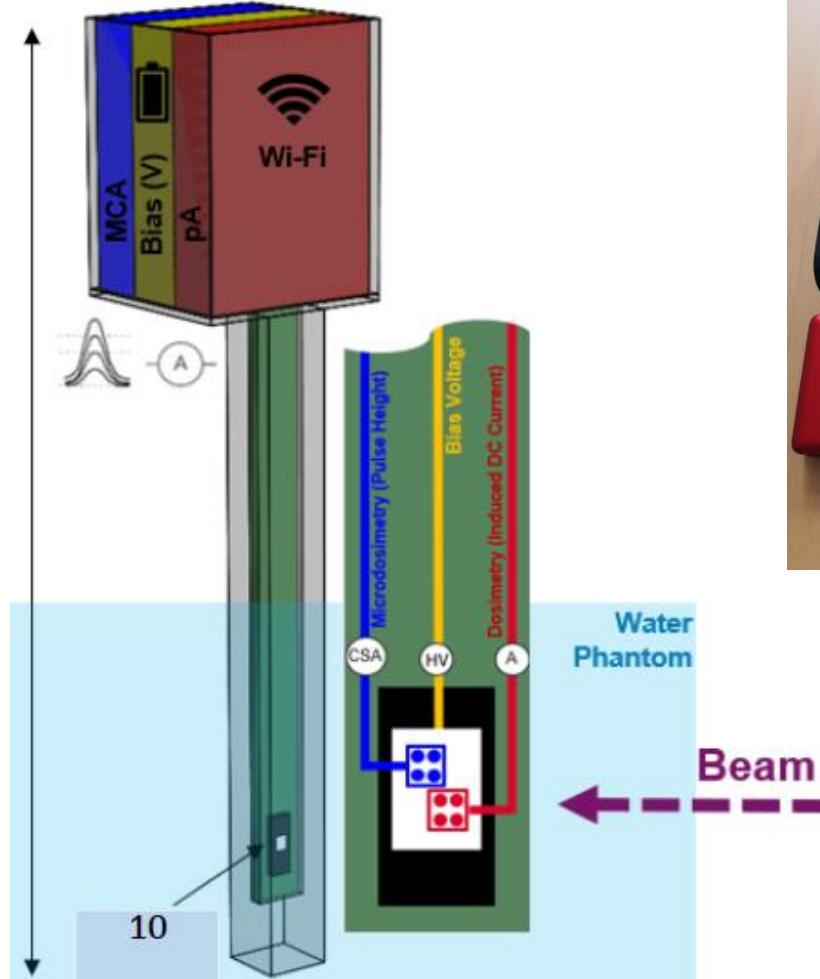


dose+yD vs. TOPAS



- unexpected plateau/peak ratio for the dose
- good agreement with literature data for yD and yd (Si)
- yD follows dose slope

# Outlook - portable microdosimetric/dosimetric system

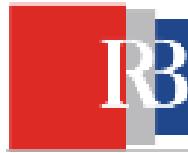


- diamond sensors on universal DIL20 carrier
- dedicated pcb based on Amptek250F chip
- LabZY MCA – microspectra – WiFi readout
- high precision electrometer – dose- WiFi readout
- USB PowerBank powering (voltage converters)
- PMMA waterproof housing
- dedicated software

## Summary

After ~3 years (Diamidos (end 11/2020) / Diadem (end 05/2021)):

- **sensors:** three generations fabricated based on scCVD membranes
  - **next:** few more (GR or/and 3D) optimized for clinical measurements
- **characterization:** all sensors generations characterized in terms of charge transport properties using numerous projectiles (p, He, Li, C, O, Si ..)  
@ microbeam facilities
  - **next:** quick check of new sensors possible
- **clinical beam tests:** p+ and GR sensors operated in clinical beams (p, C in scattered and PBS mode)
  - **next:** check of all microdosimetric system + 3D sensor
- **next: Clinical microdosimetry** using complete system in 2021 (some data actually already acquired with GR sensor)



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Andre Crnjac, Georgios Provatas, Mauricio , Milko Jaksic

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# Thank you for your attention

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