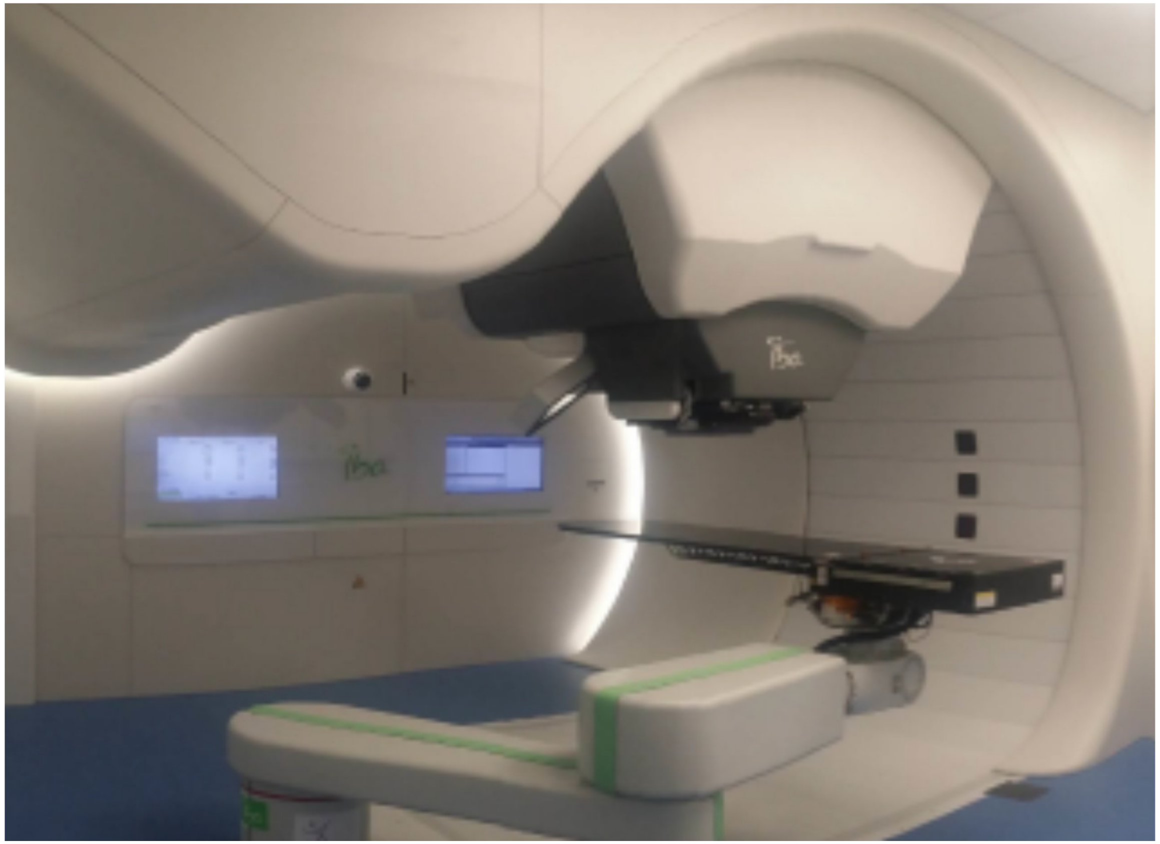
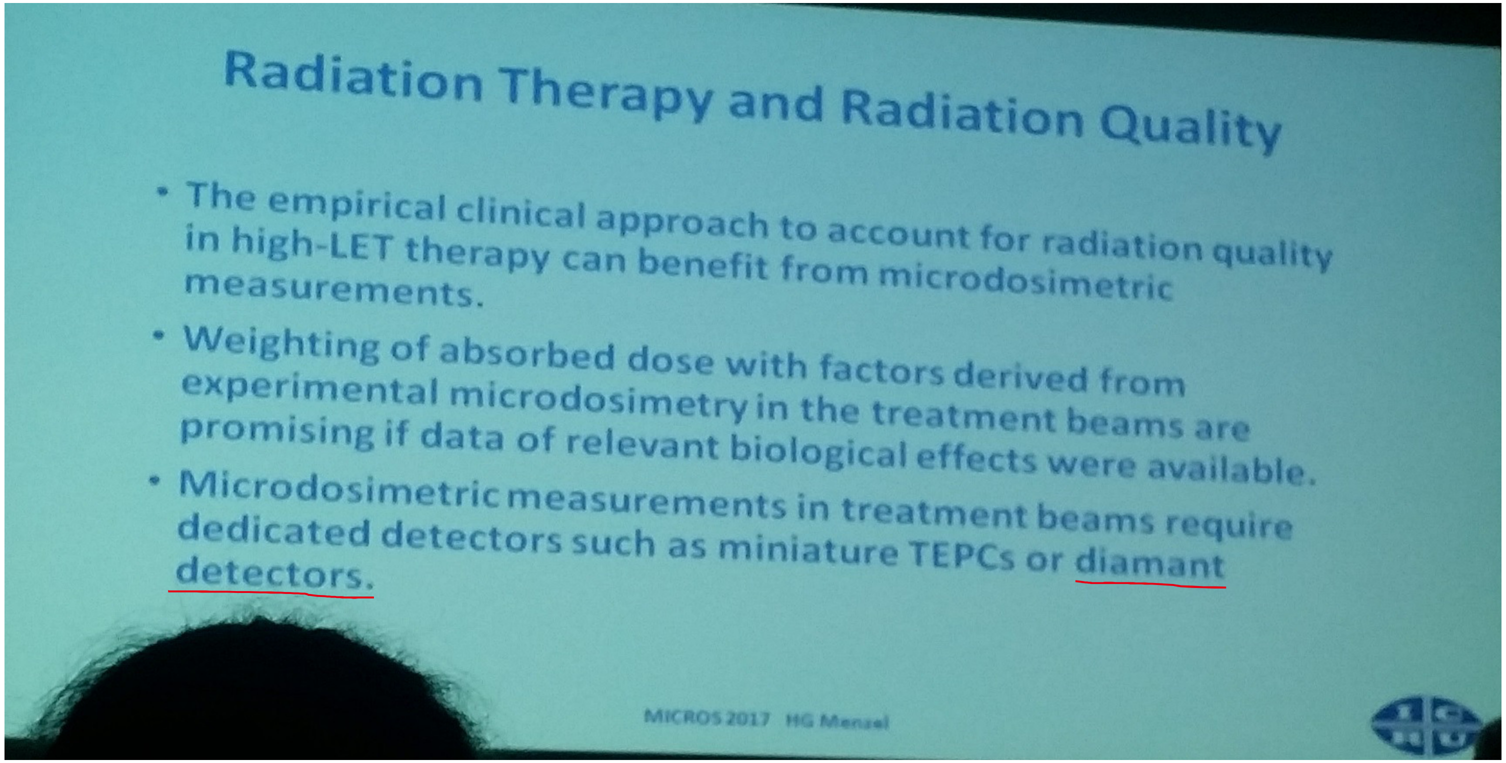


SINGLE CRYSTAL CVD DIAMOND MEMBRANE MICRODOSIMETERS FOR HADRON THERAPY

ADAMAS2017 Zagreb 28/11/2017 | Pomorski Michal
michal.pomorski@cea.fr

INTERESTS FOR MICRODOSIMETRY COMMUNITY

A slide from the opening lecture of MICROS2017 17th International Symposium on Microdosimetry By H.G. Menzel (5th November 2017)



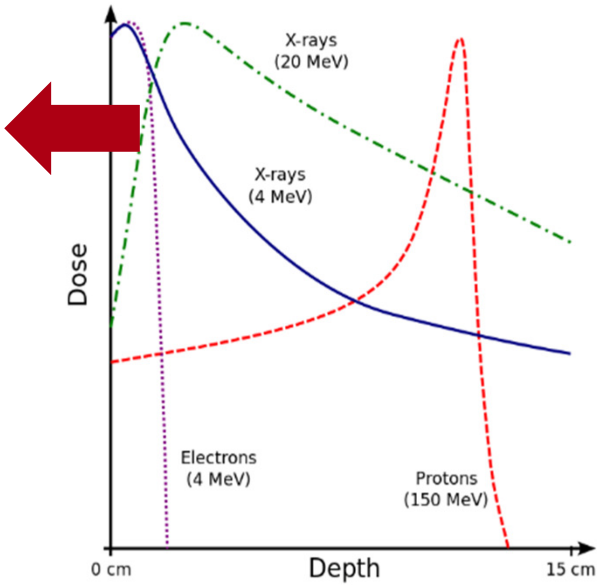
Microdosimetric community seems to be waiting for diamond based sensors !

OUTLINE

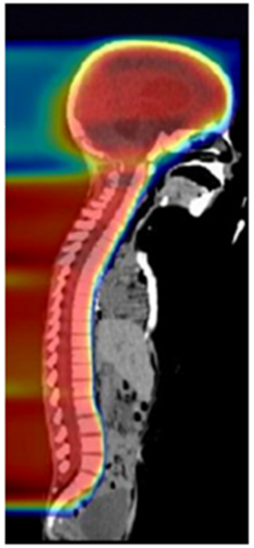
1) Introduction
2) Concept and fabrication
3) Charge transport with p, C microbeams
    a. *micro SV definition*
    b. *charge collection efficiency*
    c. *radiation hardness*
4) Preliminary LET for 100 MeV proton beam

HADRON THERAPY

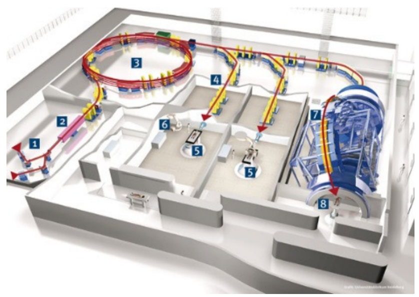
Photons distribution



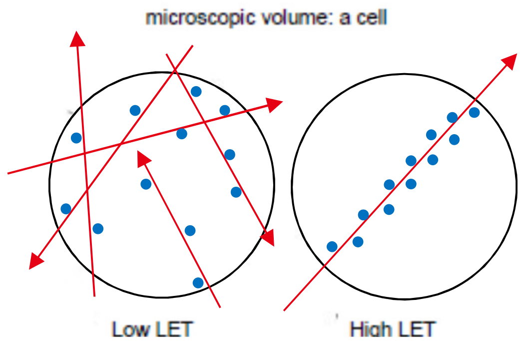
Protons distribution



- **120 hadron therapy centres** worldwide (increasing);
- **100 000 patients treated**;
- operating clinical proton therapy centres in France: Orsay, Nice, Caen;
- ARCHADE : first carbon therapy centre in France;
- **an intense field of research activity** including new methods of treatment (mini and microbeams, FLASH).

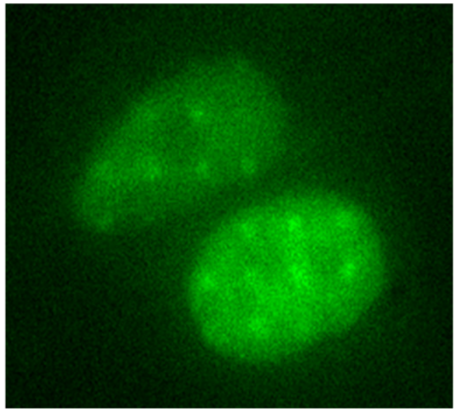


RADIATION QUALITY



same dose but **different LET**
thus various biological effectivness

Double-strand DNA breaks



single α-particle irradiation

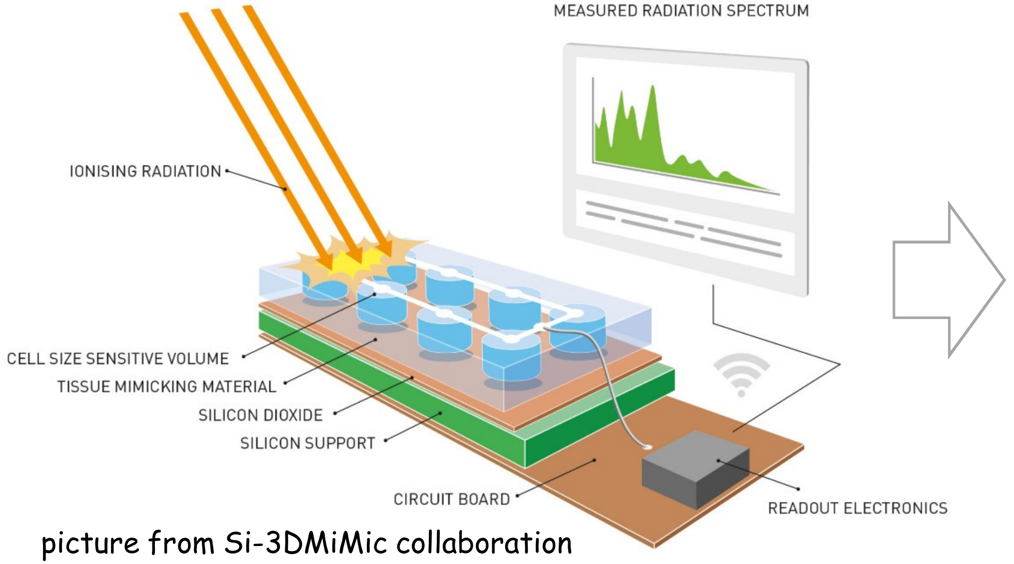
- RBE (**Relative Biological Effectiveness**) of protons is uncertain : limits the efficiency of treatments;
- strong correlation between a microdosimetric quantity (i.e. spatial **distribution of energy deposition by single particle at cellular level**) and RBE : LET (linear energy transfer) and biological effects of charged particles in tissues are related;
- measurement of LET is difficult : today **no detector is available in clinical routine.**

Simple dosimetry is not enough to assure radiation quality in hadron therapy

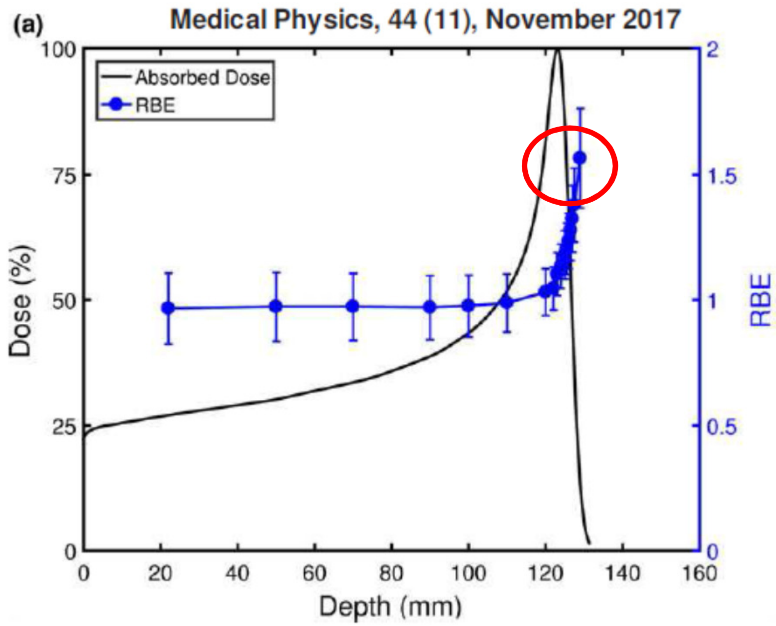
RADIATION QUALITY - MICRODOSIMETRY

'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



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

MICRODOSIMETRY IN HADRON THERAPY

Tissue Equivalent Proportional Counter (TEPC)

+ a 'gold standard'

+ sensitive (internal amplification)

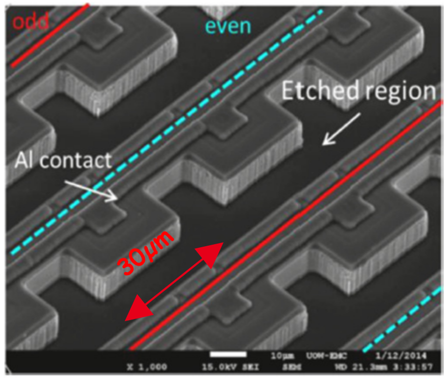
+ tissue-equivalence, radiation hard

- size (not really microscopic SV, wall effect)

- rate issue

- maintenance (gas flow)

Silicon solid-state microdosimeters



A. Rosenfeld, NIM 2015

+ compact device

+ multiple 'real' μSVs

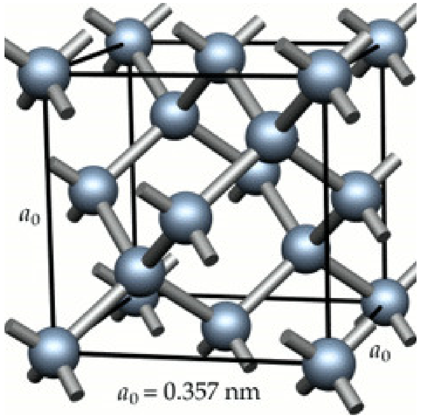
+ it's Si – easy for micro-fabrication

- tissue equivalence (?)

- radiation hardness (?)

? Can diamond join the advantages of both, and get rid of their pitfalls ?

WHY DIAMOND?



Large band-gap (5.5eV) semiconductor

A solid-state ionization chamber
(soon a proportional 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 V/μm)
+ VIS light and temp. insensitivity

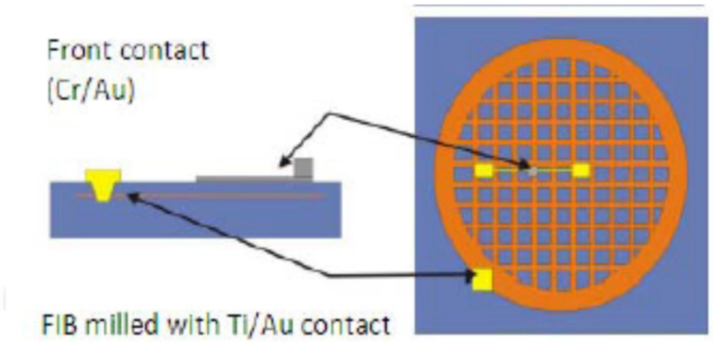
- high ~13 e-h/eV – lower signal
- high density, excitons – pulse height defect
- it's diamond (for instance pls. forget 6' wafers)

since 2002 high purity electronic grade CVD diamond available commercially

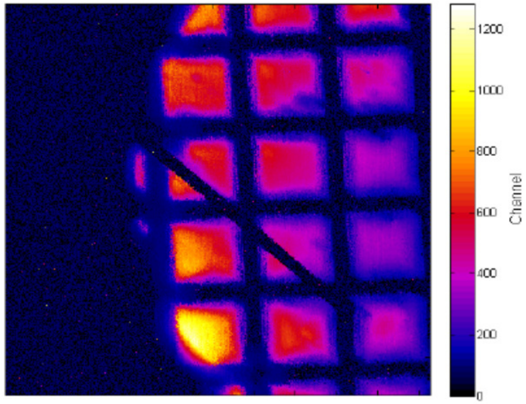
MICRODOSIMETRY IN HADRON THERAPY

existing **diamond microdosimeters** prototypes

The idea



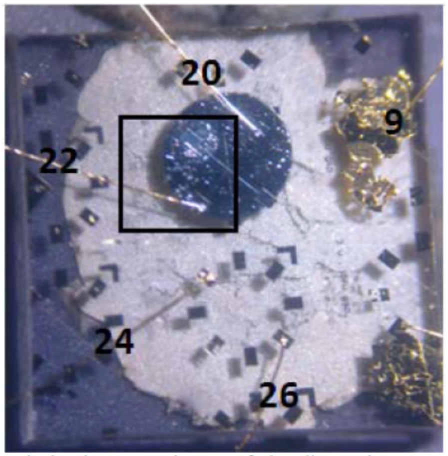
5.9 MeV Be microbeam CCE mapping



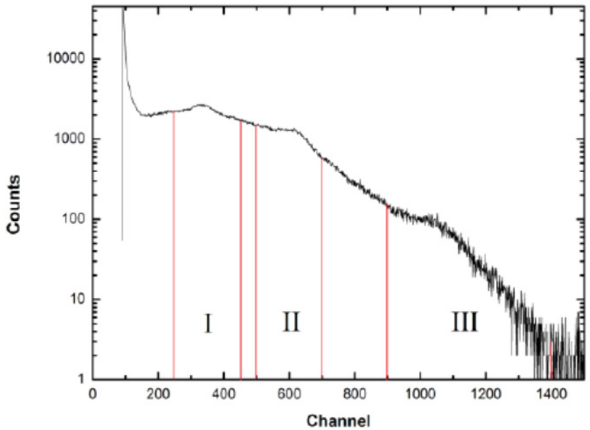
UNIVERSITY OF WOLLONGONG AUSTRALIA

Real device

commercial e6 EG scCVD diamond



Pulse-height spectra



-not uniform CCE

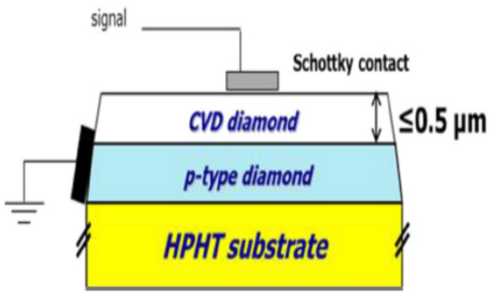
- not resolved spectra

Characterization of a novel diamond-based microdosimeter prototype for radioprotection applications in space environments. IEEE Transactions on Nuclear Science, 59 (6), 3110-3116.

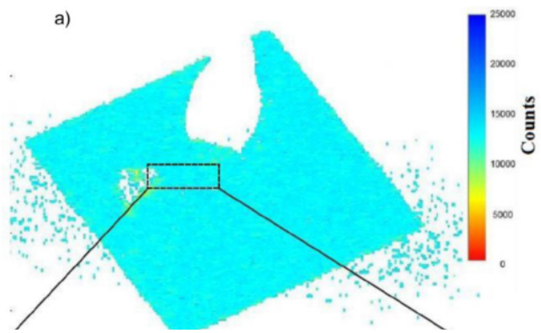
MICRODOSIMETRY IN HADRON THERAPY

existing **diamond microdosimeters** prototypes

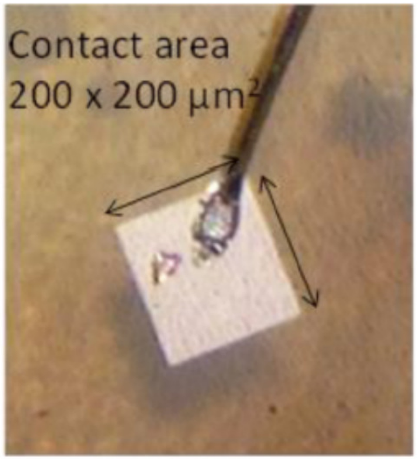
The idea



4 MeV C microbeam CCE mapping

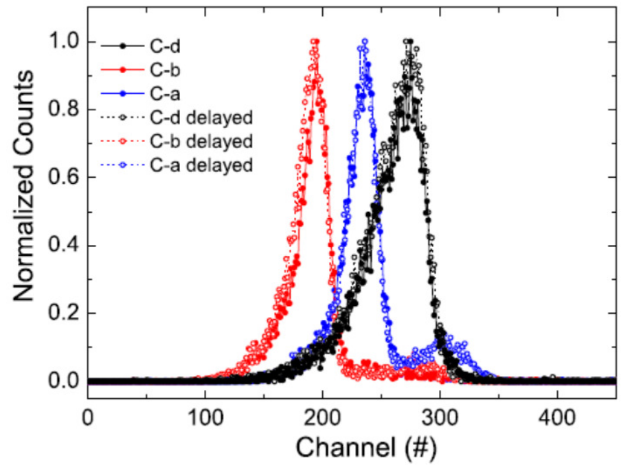


Real device



lab grown
scCVD diamond

Pulse-height spectra @ 0V bias voltage



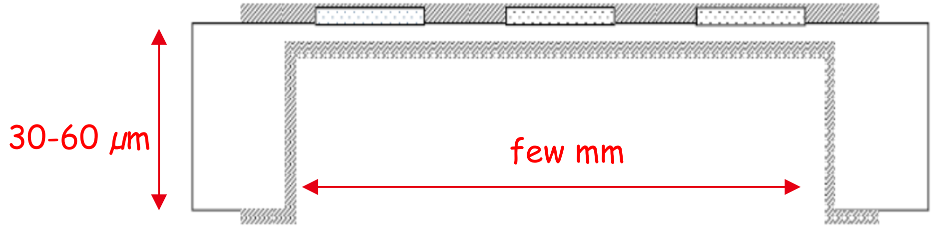
Università di Roma Tor Vergata

J. Appl. Phys. **118**, 184503 (2015); doi: 10.1063/1.4935525

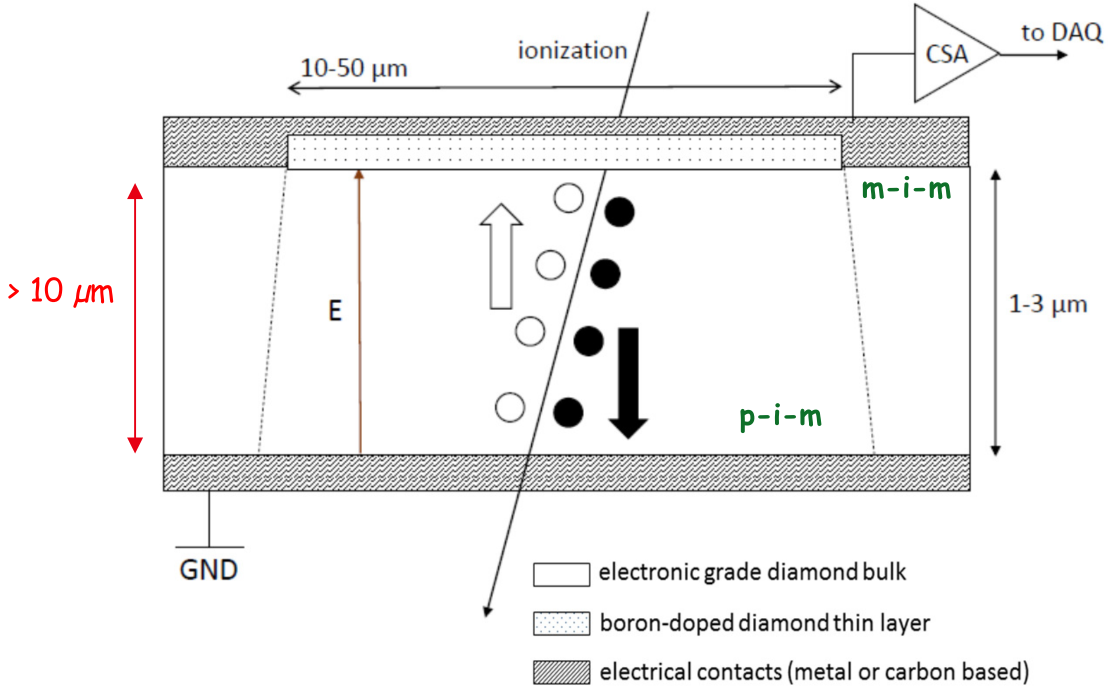
- problematic to create multiple µSVs

DIAMOND MEMBRANE MICRODOSIMETER CONCEPT

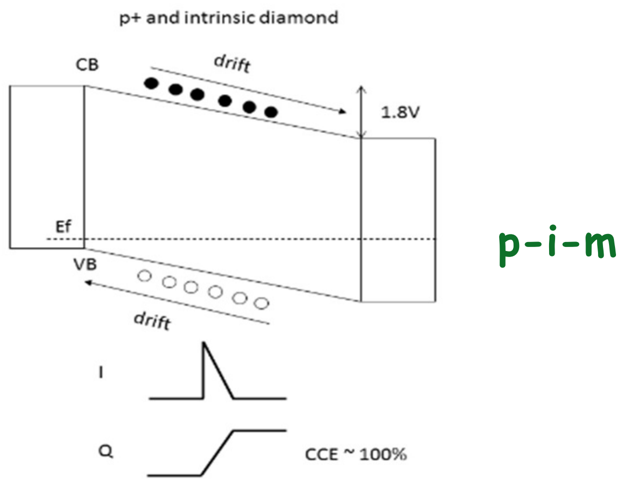
scCVD diamond membrane

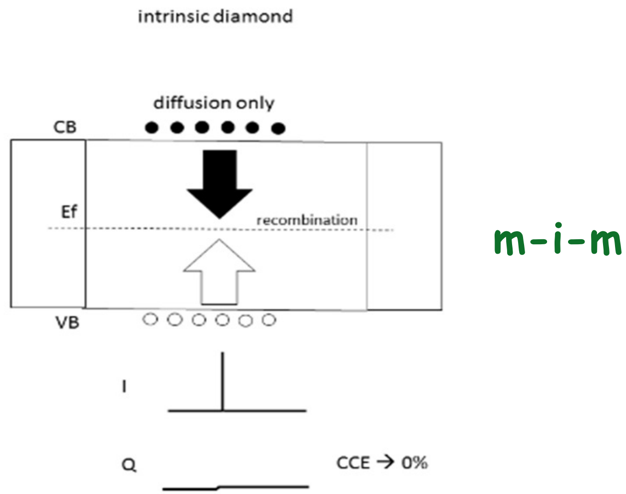


µSV



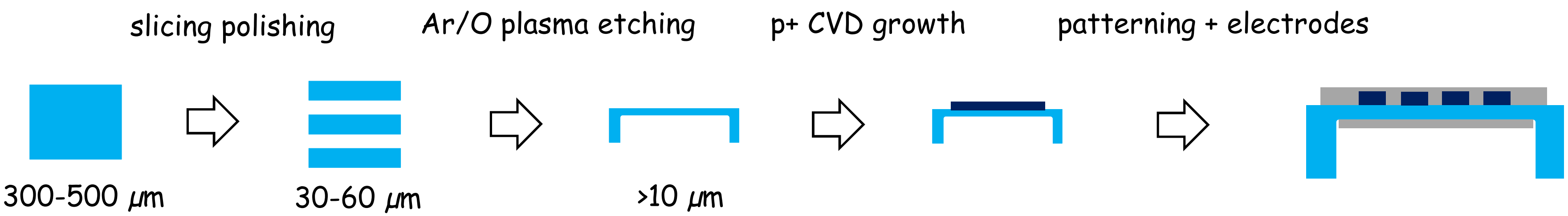
Charge transport @ 0V

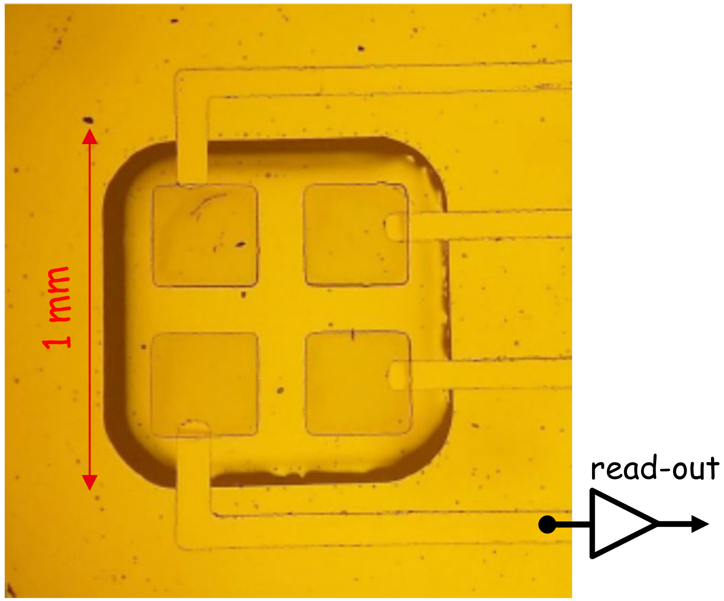




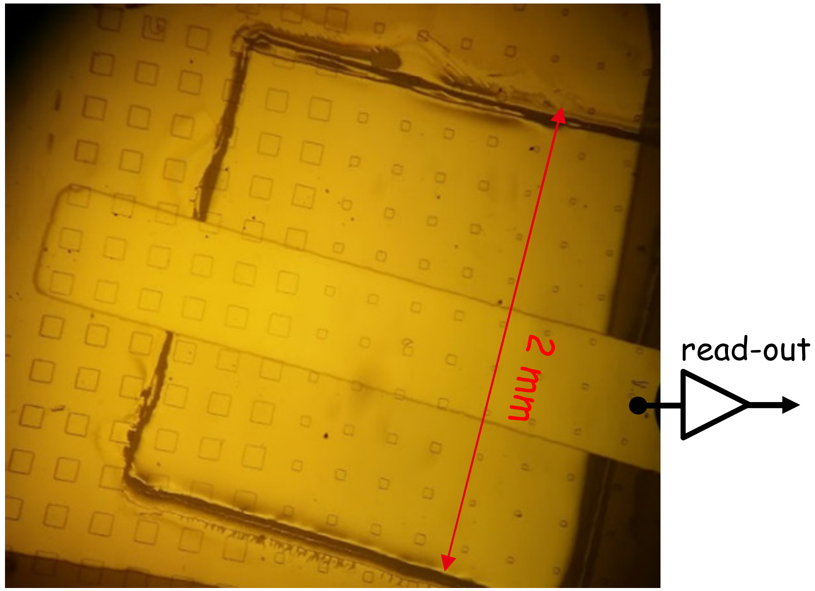
DIAMOND MEMBRANE MICRODOSIMETER PROTOTYPES

ElementSix electronic grade single crystal CVD diamond samples





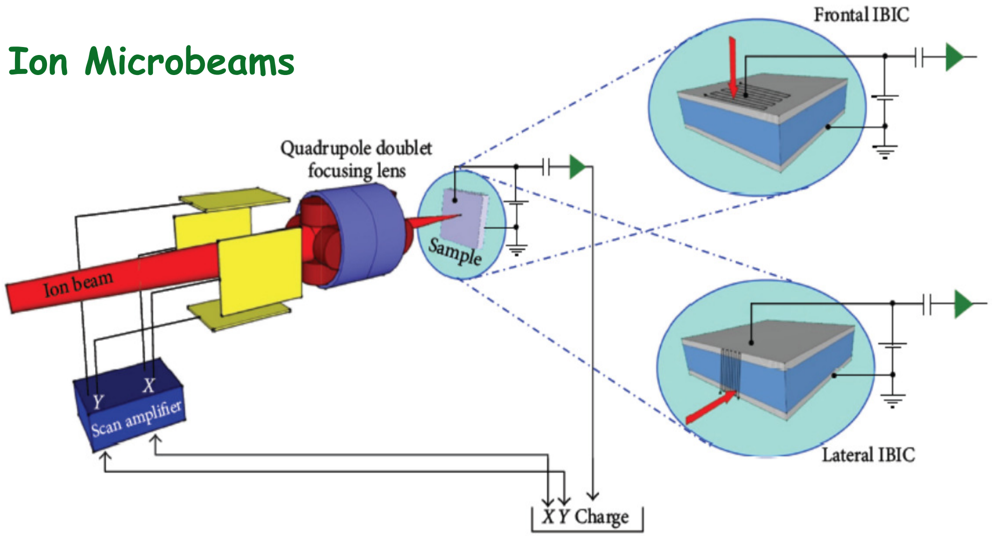
300 µm pixels (SV),
6 µm thick scCVD diamond membrane

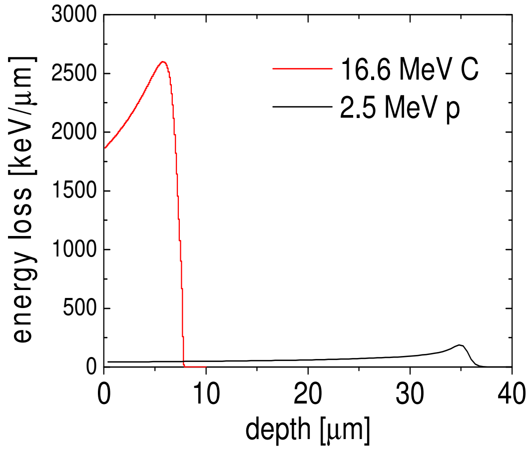


30, 60 and 120 µm pixels (SV),
4 µm thick scCVD diamond membrane

CHARGE TRANSPORT CHARACTERIZATION – IBIC

Ion Microbeams



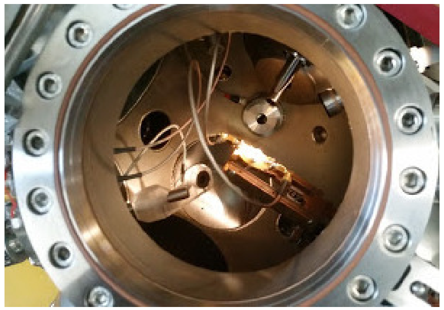


2.5 MeV proton

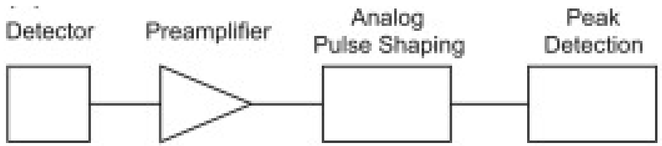
1 µm FWHM

16.6 MeV carbon

~ 1 µm FWHM



CS electronics

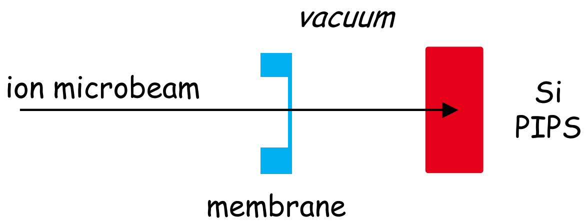


preamp.: Amptek 250 CoolFet

Shaping time.: 500 ns

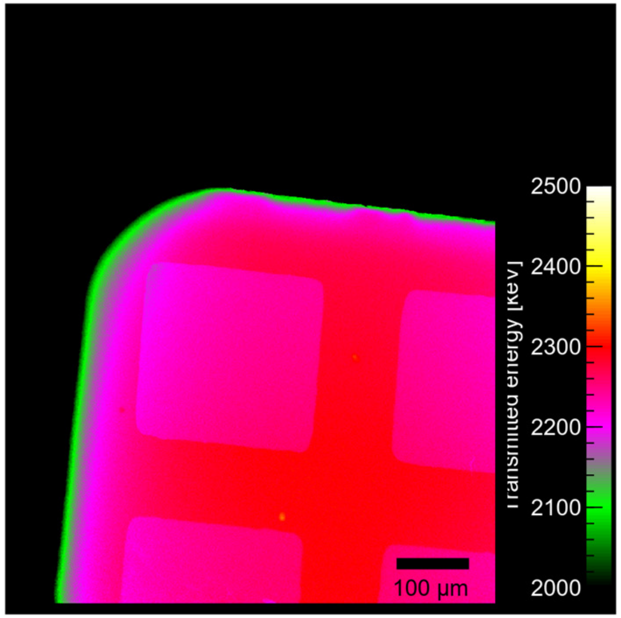
local DAQ

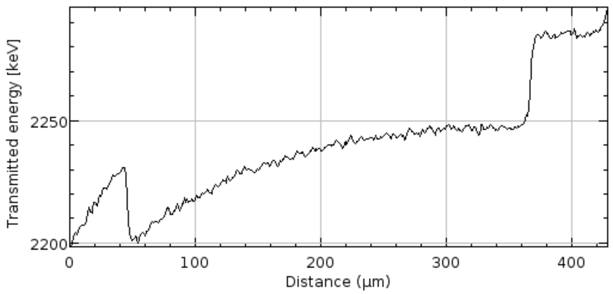
ΔE + E configuration



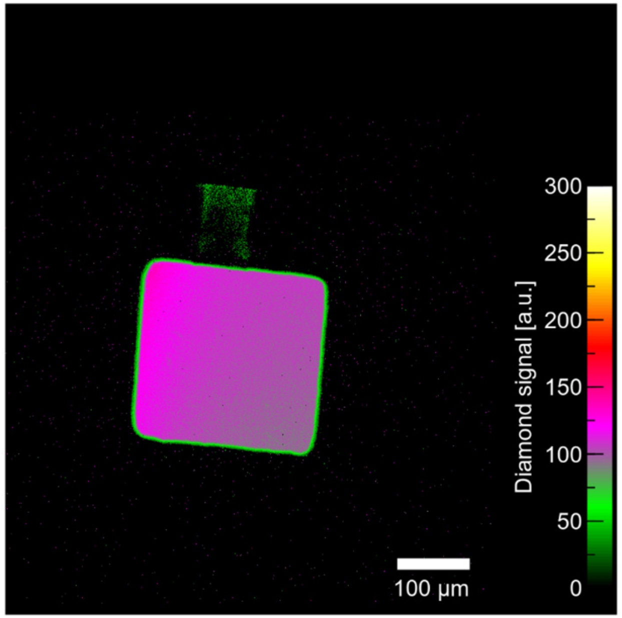
IBIC – 2.5 MEV PROTON MICROBEAM

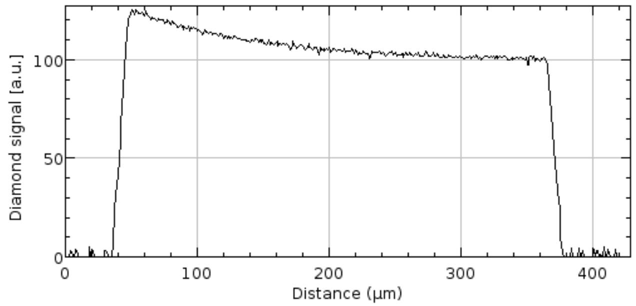
STIM (Si downstream)





diamond signal @ 0V

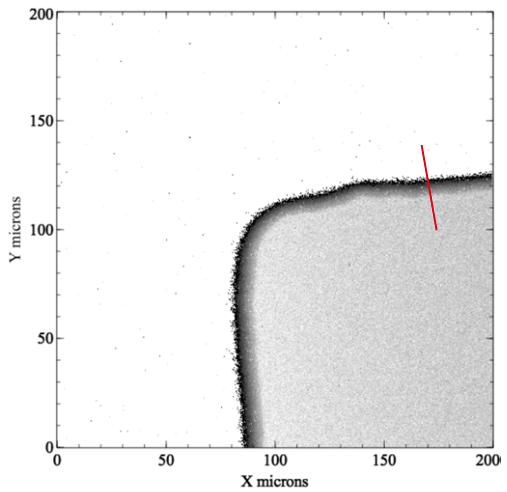


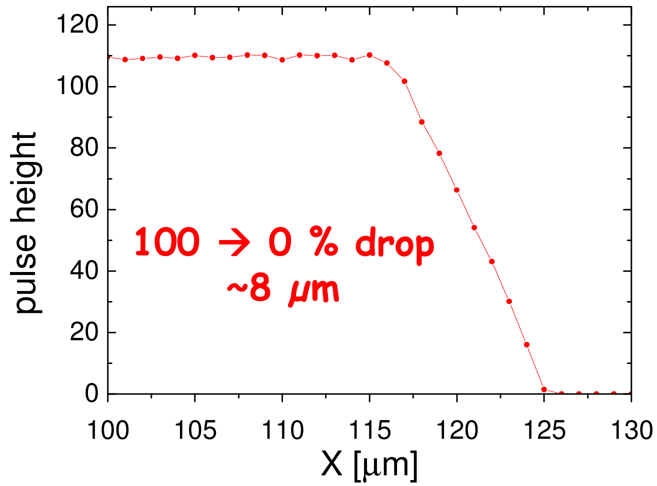


*STIM – scanning transmission ion microscopy

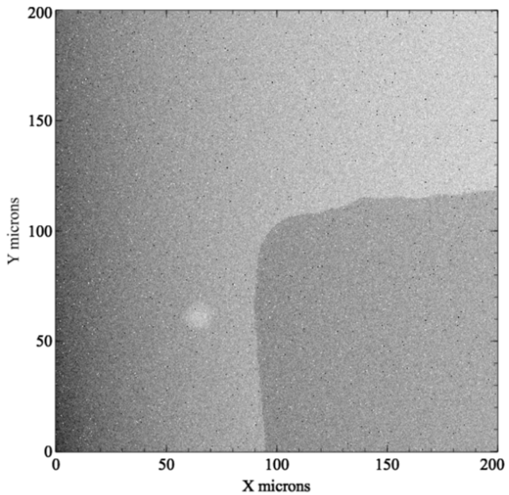
IBIC - 2.5 MEV PROTON MICROBEAM

diamond signal @ 0V

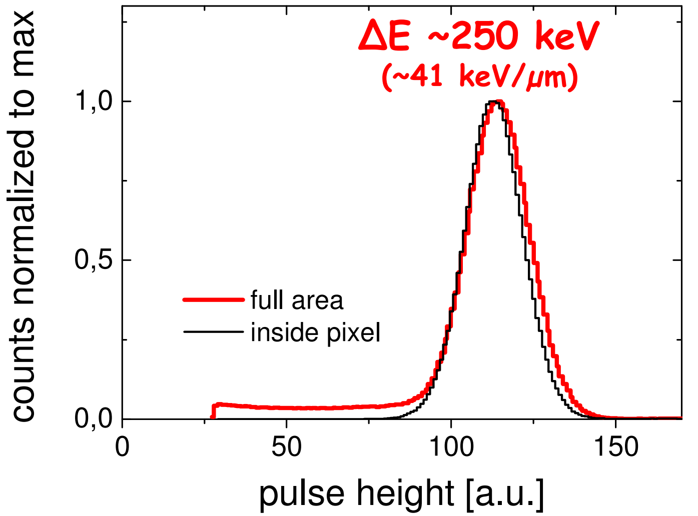




STIM (Si downstream)

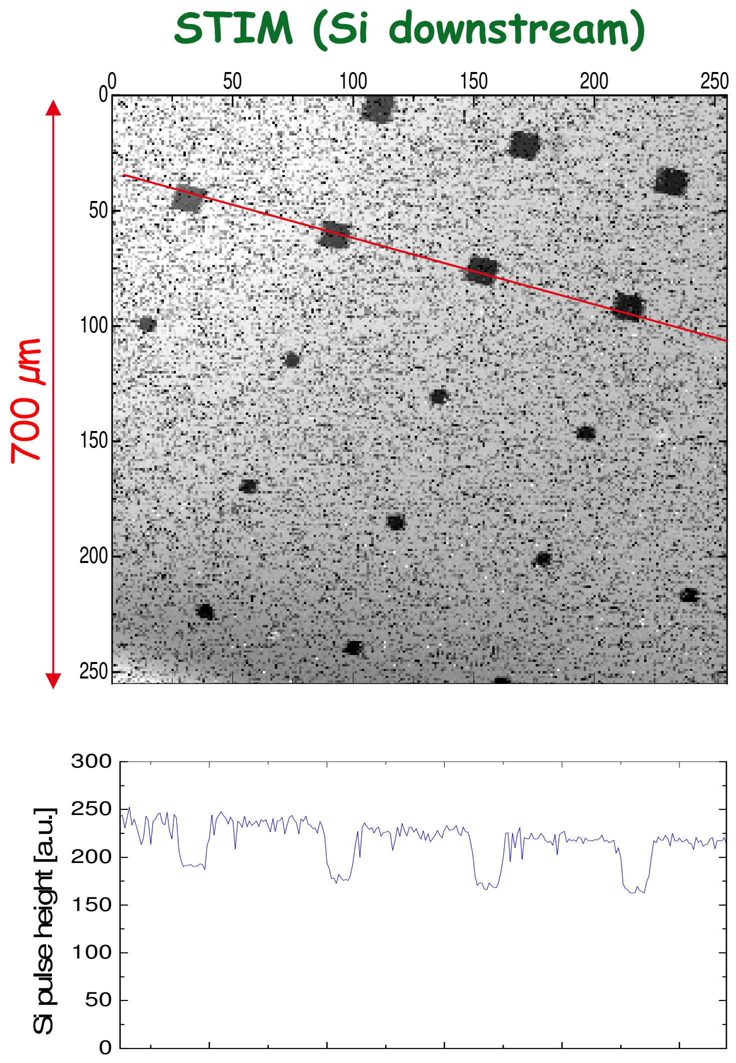


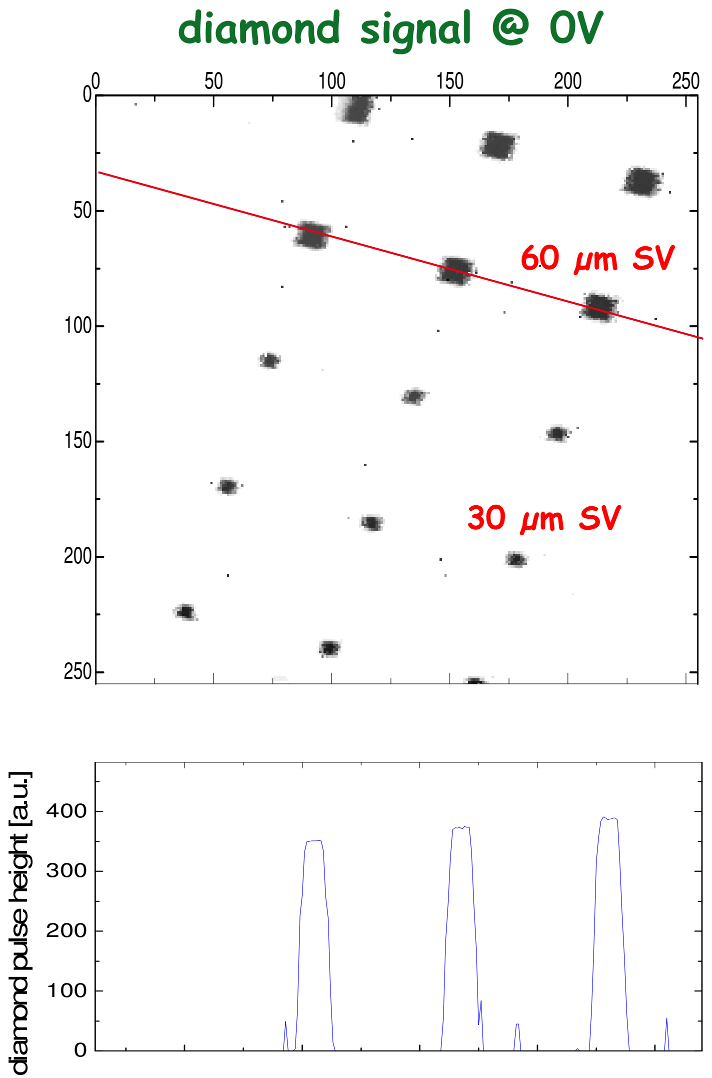
pulse-height spectra



*STIM – scanning transmission ion microscopy

IBIC – 16.6 MEV CARBON MICROBEAM

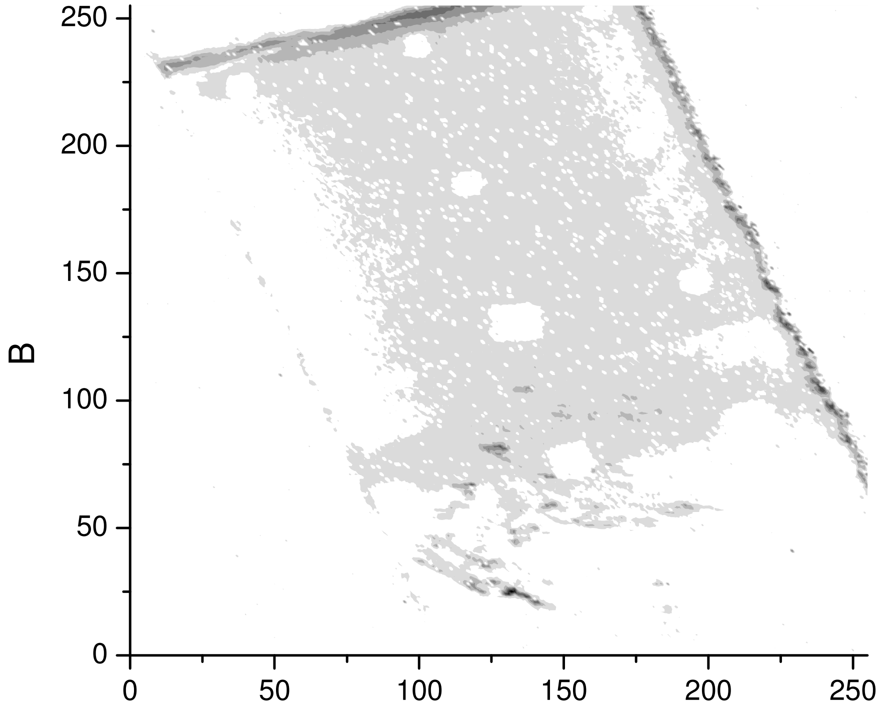


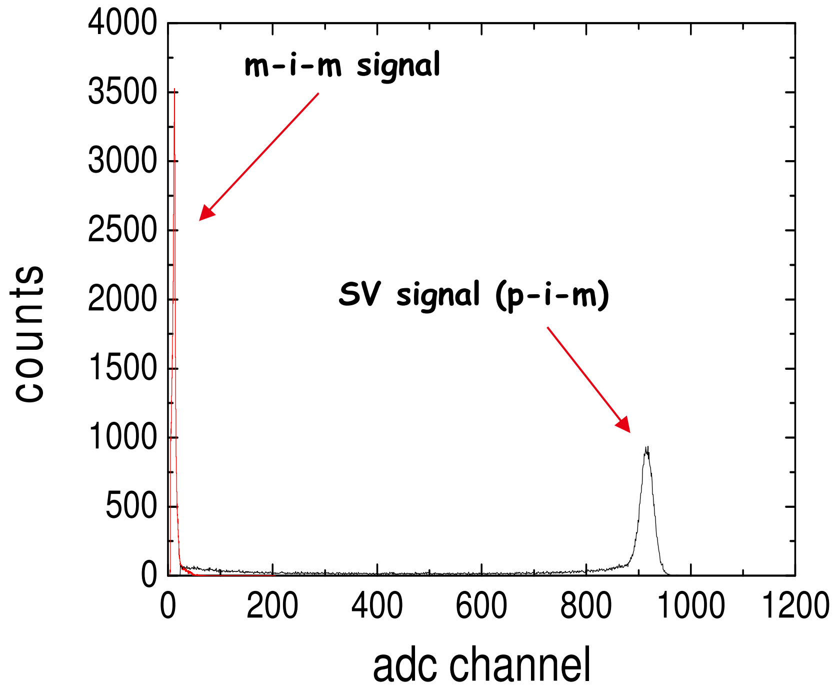


*STIM – scanning transmission ion microscopy

IBIC – 16.6 MEV CARBON MICROBEAM

m-i-m 'parasitic signal' inverted polarity

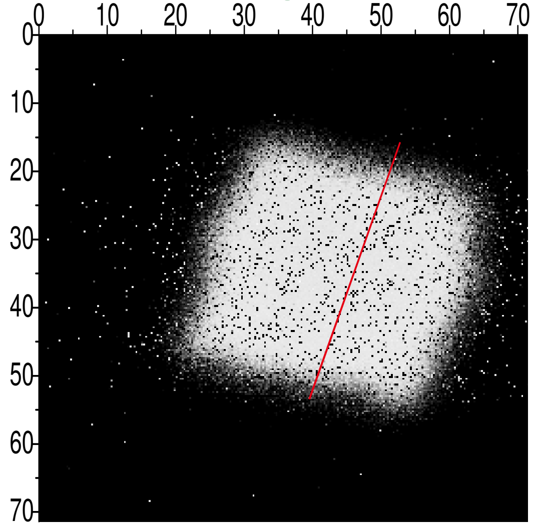


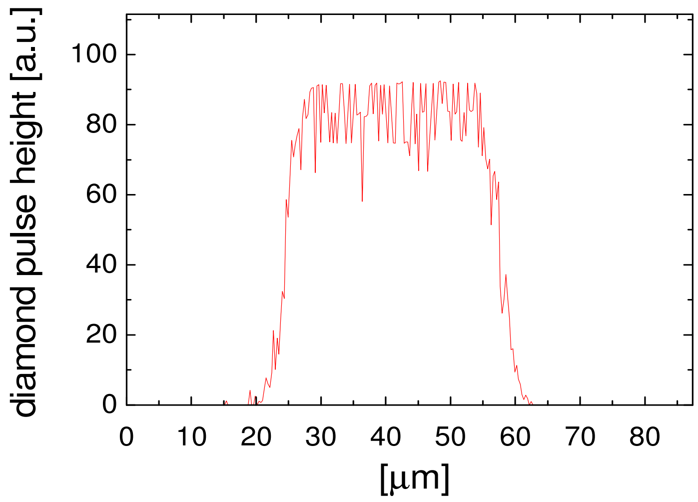


Higher signals at the edges → strain some areas with zero PH

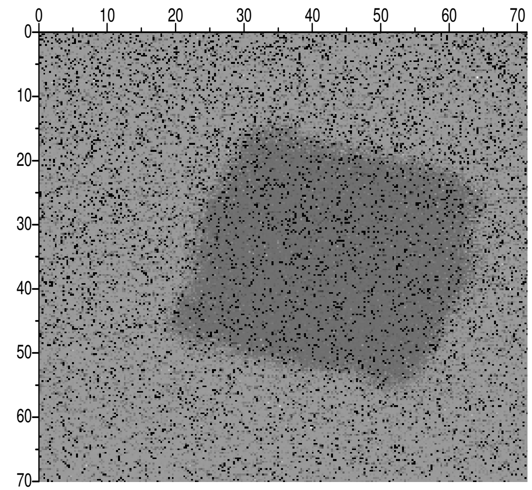
IBIC – 16.6 MEV CARBON MICROBEAM

diamond signal @ 0V

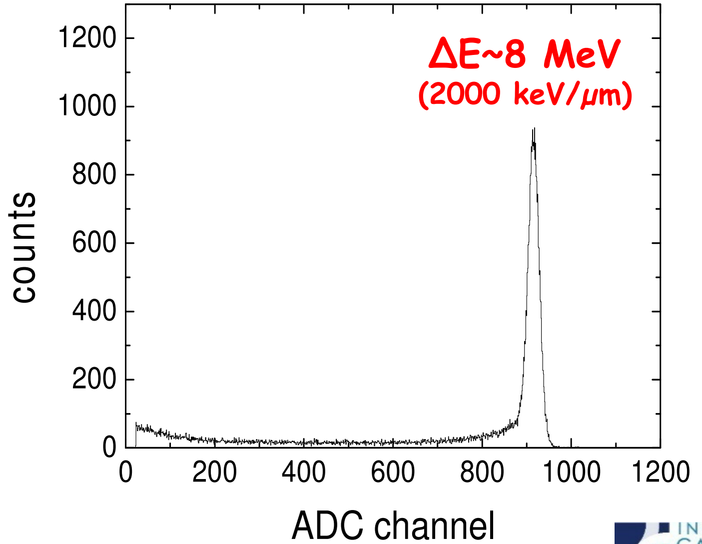




STIM (Si downstream)



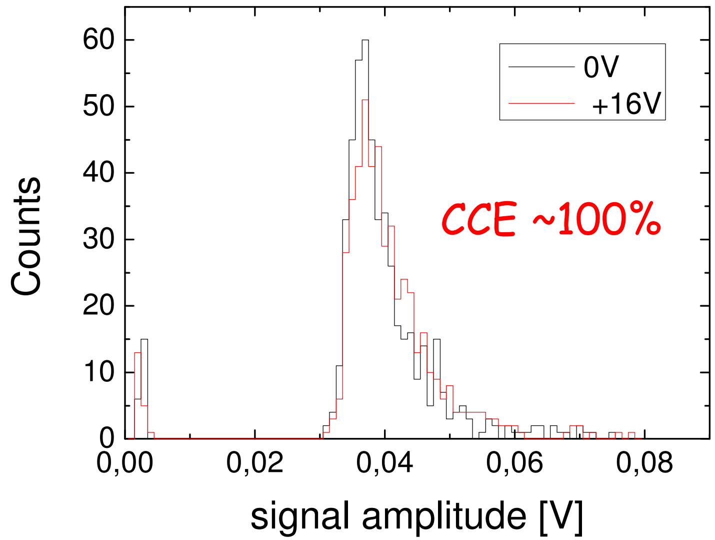
pulse-height spectra



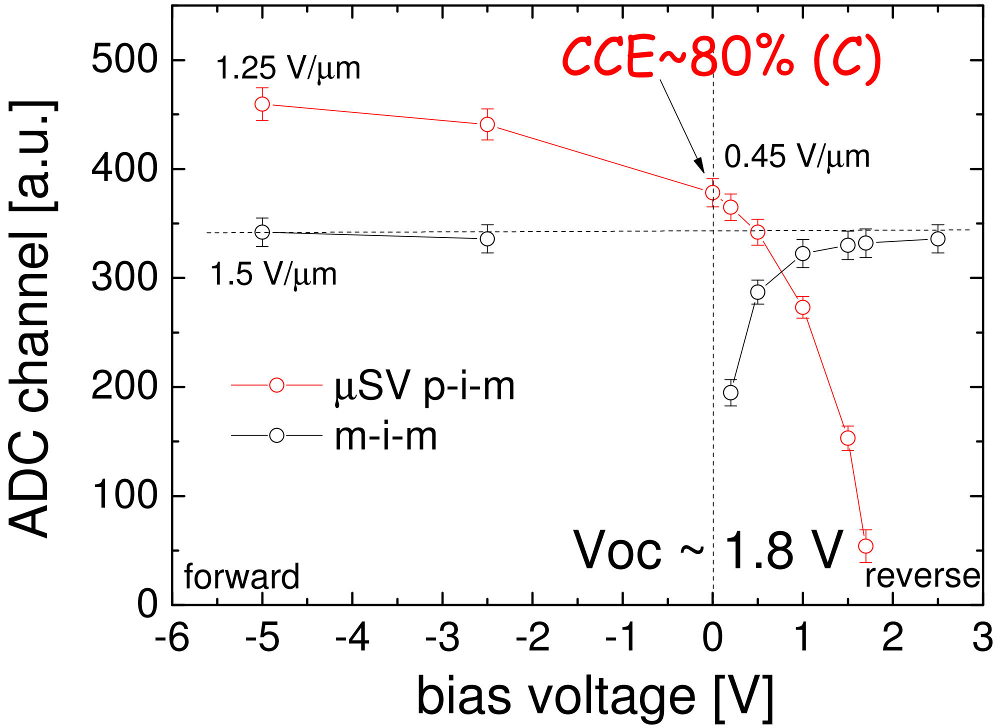
*STIM – scanning transmission ion microscopy

CHARGE COLLECTION EFFICIENCY

~5 MeV α (^{241}Am source)



16.6 MeV C (microbeam)



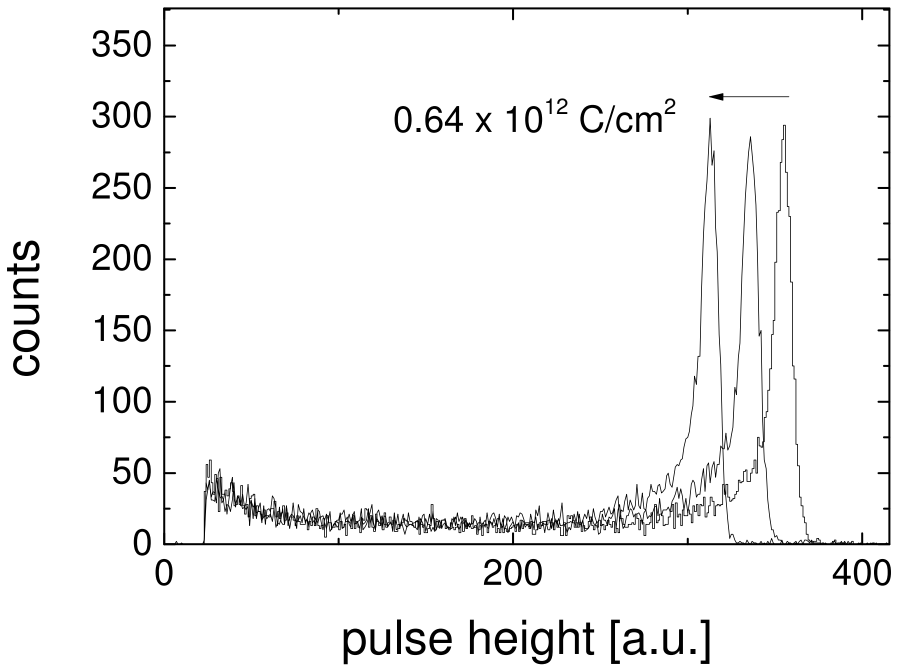
~100% CCE @ 0V (0.3 V/µm built-in) **p, α**

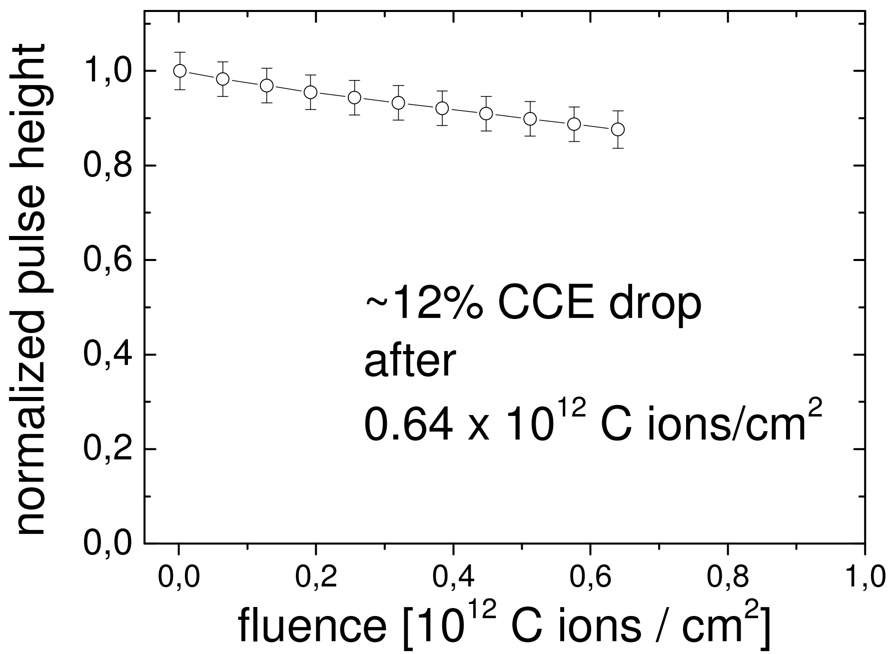
~80% CCE @ 0V (0.45 V/µm built-in) **C**

solution: use of thinner membranes for high LET
i.e. 1.8 V / 1 µm ~100% CCE

RADIATION HARDNESS – CARBON MICROBEAM

High flux C (16.6 MeV) microbeam continuous irradiation of one 30 x 30 µm µSV
(all spectra measured @ 0V)

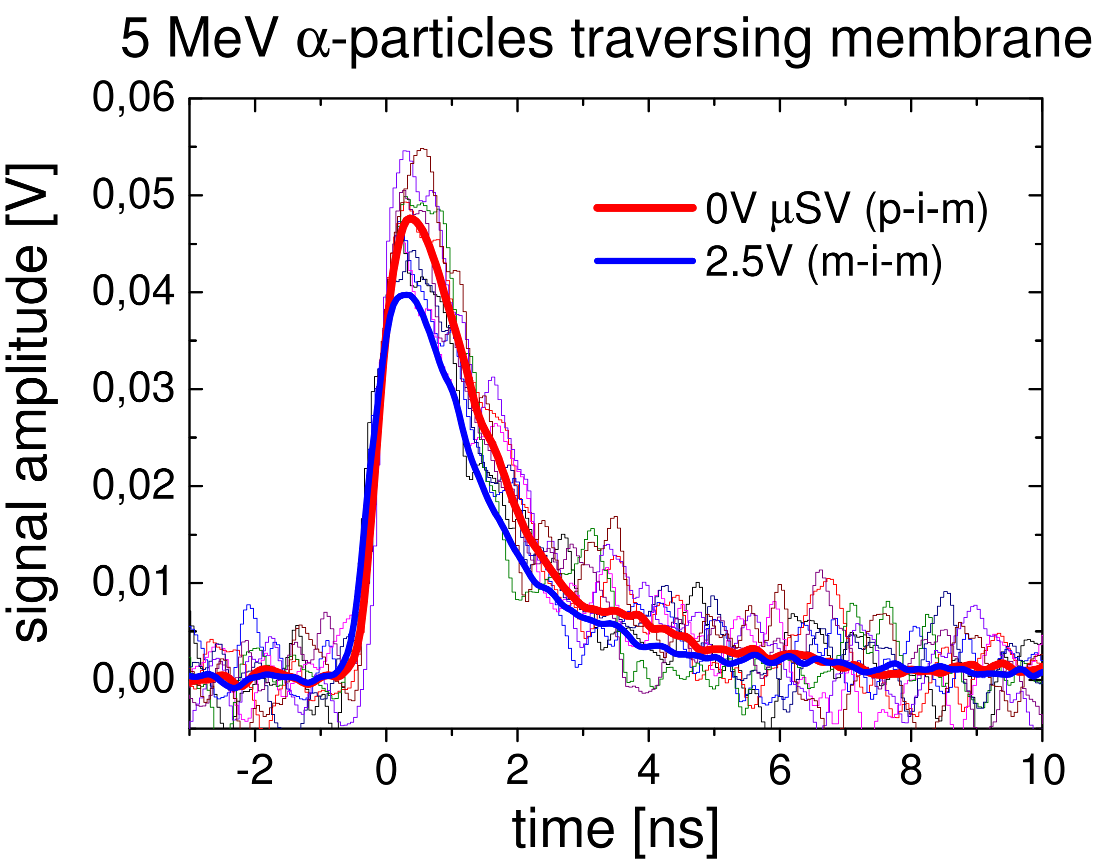




no change: Voc, spectrum shape, peak FWHM, dark current, µSV geometry

even better results expected for thinner membranes (shorter drift path; higher E)

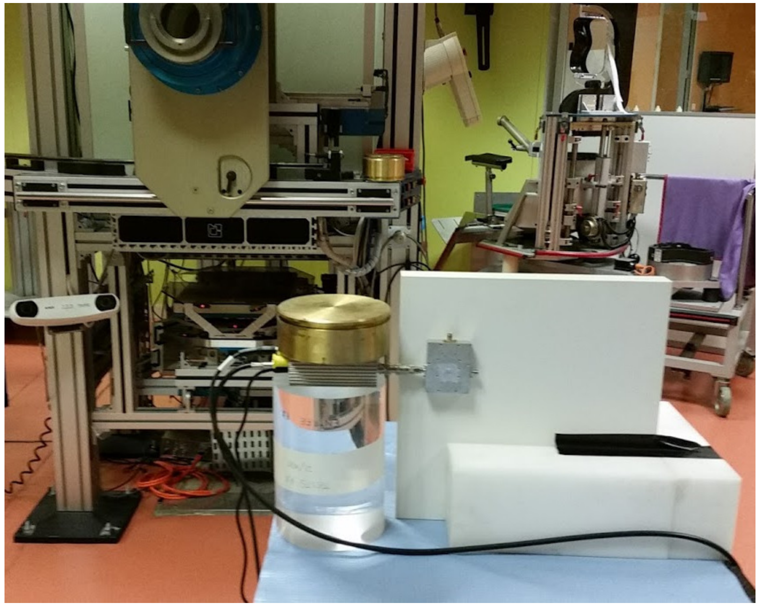
SIGNAL FORMATION – TRANSIENT CURRENTS



fast signals (clearly RC limited, 1mm^2 contacts area)
contact surface optimization → << 1 ns FWHM + high amplitude

LET MEASUREMENT – 100 MEV PROTON BEAM

Institute Curie Proton therapy Center (Orsay, France)

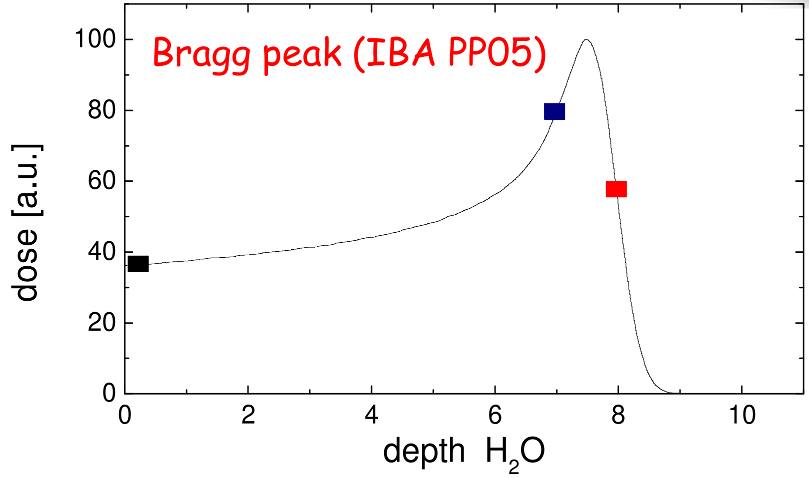


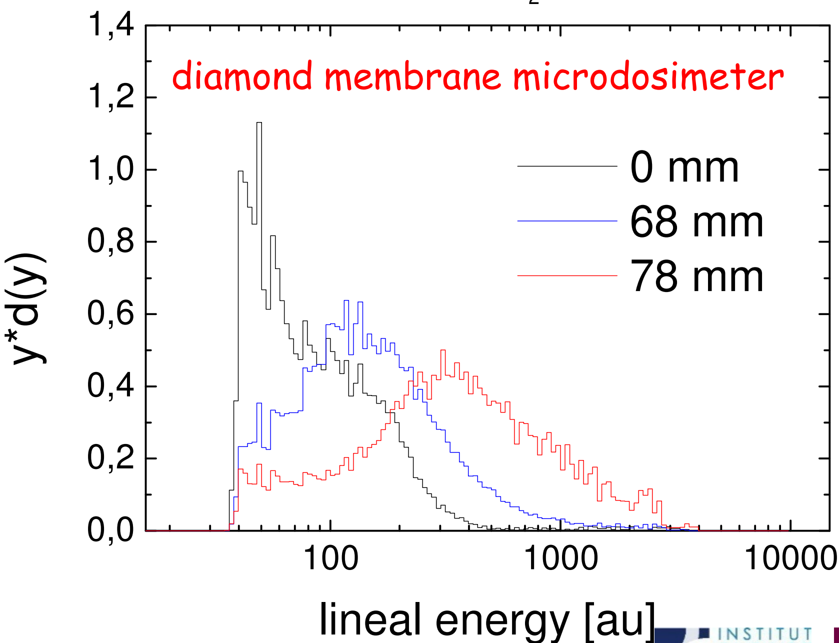
Proton beamline for intracranial treatments

100 MeV p

80 mm variable thickness solid-water phantom

300 µm SV diamond microdosimeter prototype





DIAMOND MEMBRANE MICRODOSIMETER-SUMMARY

scCVD diamond membranes have a great potential for solid-state microdosimetry

- full CCE (p,α) @ 0V, well-defined μSV, ΔE spectra, fast
- radiation hard (preliminary C data)
- First LET measurements in clinical p beam (promising)

Issues to be addressed soon:

- μSV geometry optimization: 3D, implantation, thickness homogeneity
- pulse-height defect for high LET (C)
- dedicated electronics
- 'real' LET measurements (mixed fields)

DIAMIDOS COLLABORATION – CO-AUTHORS

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THANKS TO:

DiamFab for growing excellent quality p+ diamond homoepitaxial layers
www.diamfab.eu

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

Commissariat à l'énergie atomique et aux énergies alternatives
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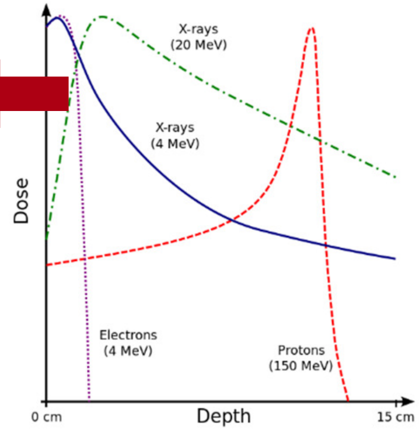
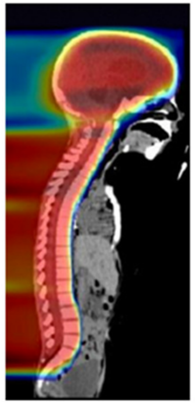
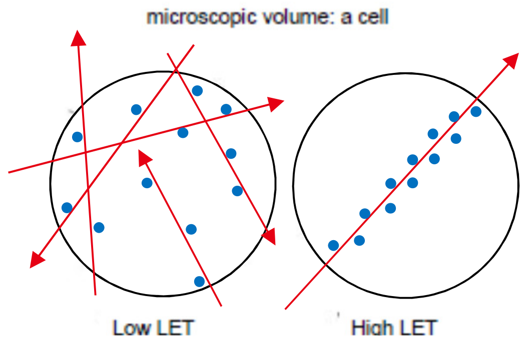
MICRODOSIMETRY IN HADRON THERAPY

Photons distribution



Protons distribution





same dose but **different LET**
thus various biological effectiveness

- RBE (**Relative Biological Effectiveness**) of protons is uncertain : limits the efficiency of treatments;
- strong correlation between a microdosimetric quantity (i.e. spatial **distribution of energy deposition by single particle at cellular level**) and RBE : LET (linear energy transfer) and biological effects of charged particles in tissues are related;
- measurement of LET is difficult : today **no detector is available in clinical routine.**

Challenges: single particles, pulse-height, low-signals, high rates, radiation damage