The lesson learned developing microdosimetry systems at INFN-PoliMI: going from Si design toward SiC-based applications

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and

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Outline

- Microdosimetry
- Silicon microdimetry
- Front-end Electronics
- Si2SiC ?

CLINICAL BEAM QUALITY & TREATMENT PLANNING

Effectiveness of a radio therapeutic treatment

Accurate knowledge of the local distribution of energy

Beam quality assessment

Absorbed dose gives a macroscopic description

MICRODOSIMETRIC APPROACH

Stochastic quantities

Specific energy: $$z = \frac{\varepsilon}{m}$$

Lineal energy: $$y = \frac{\varepsilon}{\bar{l}}$$

Estimate of the absorbed dose:

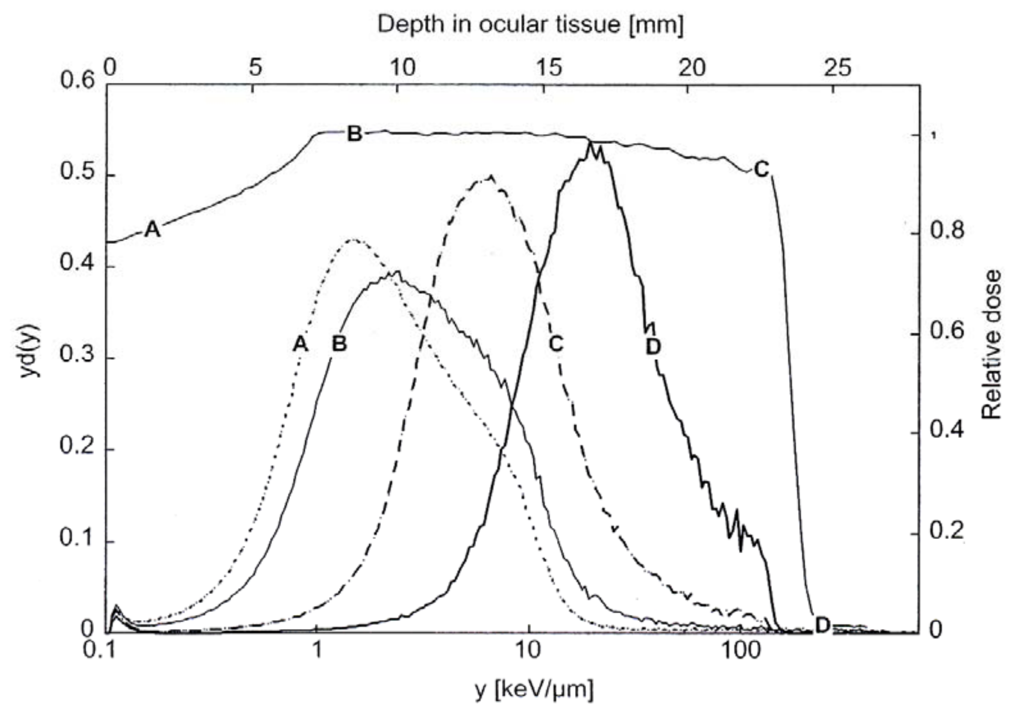
$$\bar{z} = \int z \cdot f(z)dz \cong D$$

… and the associated statistical fluctuations

$$d(z) = \frac{z \cdot f(z)}{\bar{z}}$$

MICRODOSIMETRIC APPROACH:
STUDIES OF CLINICAL PROTON BEAMS

Studies concerning the characterization of the quality of proton beams by exploiting microdosimetric measurements performed with Tissue Equivalent Proportional Counters (TEPC) has been presented.

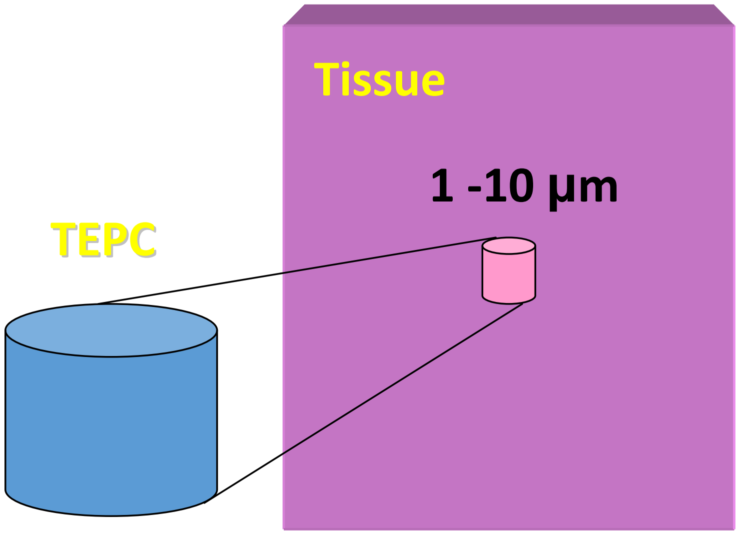


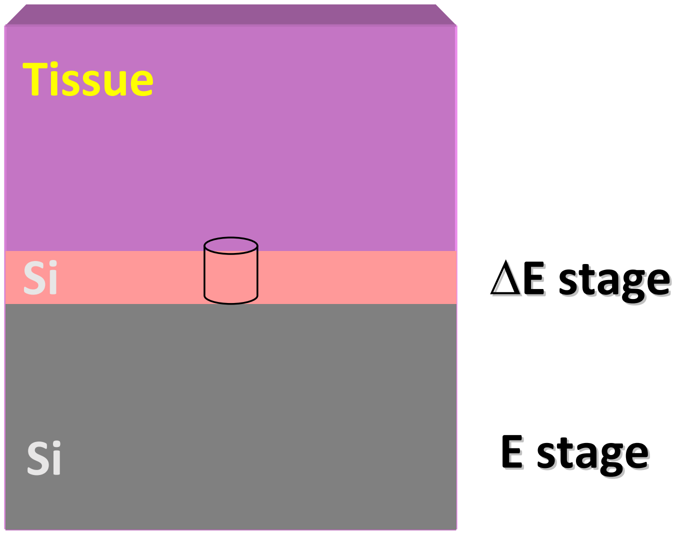
CATANA facility

$$RBE_{\mu} = \int r(y) \cdot yd(y) d(\log y)$$

[1] L. De Nardo, D, Moro, P. Colautti, V. Conte, G. Tornielli and G. Cuttone, “Microdosimetric investigation at the therapeutic proton beam facility of CATANA”, Radiat. Prot. Dosim. 110, 681-686 (2004).

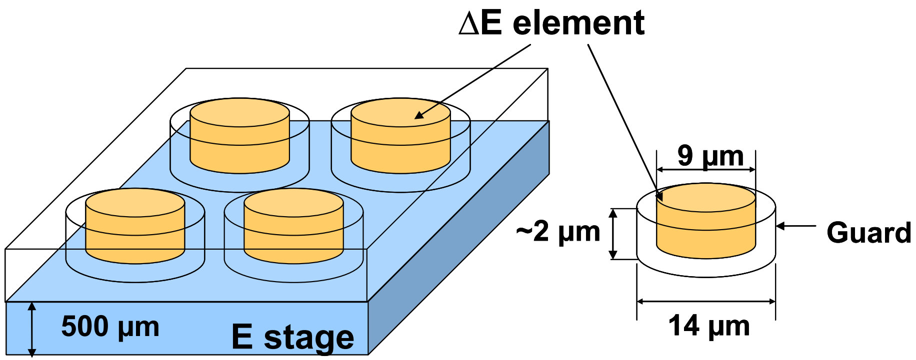
Microdosimetry





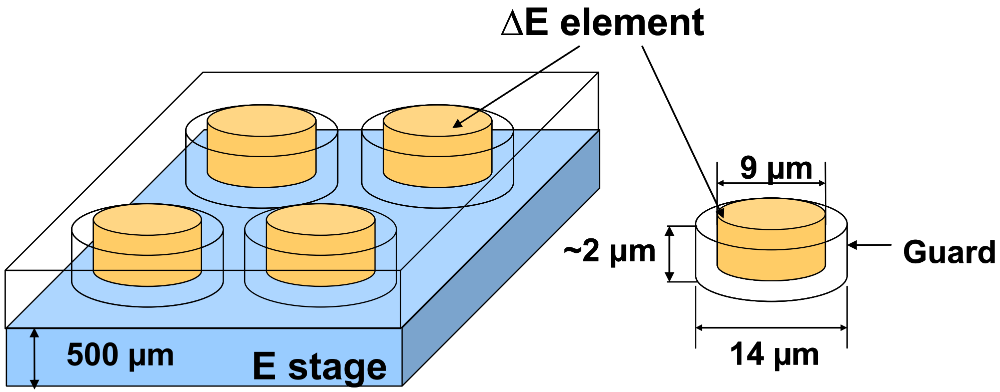
1 – 10 mm

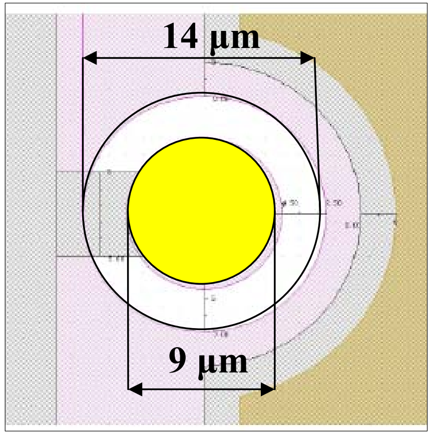
Micrometric sensitive



ΔE/E Silicon Microdosimeter

ΔE stage : matrix of 7400 cylindrical diodes (h= 2 µm , d= 9 µm)





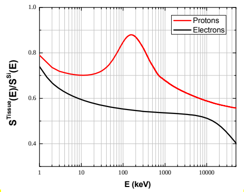
Lineal energy $y = \varepsilon / \bar{l}$

ε = energy imparted

Optimized Tissue Equivalence correction

$$\varepsilon_{\Delta E}^{Tissue}(E) = \varepsilon_{\Delta E}^{Si}(E) \cdot \frac{S^{Tissue}(E)}{S^{Si}(E)}$$

Event-by-event correction (ΔE/E)

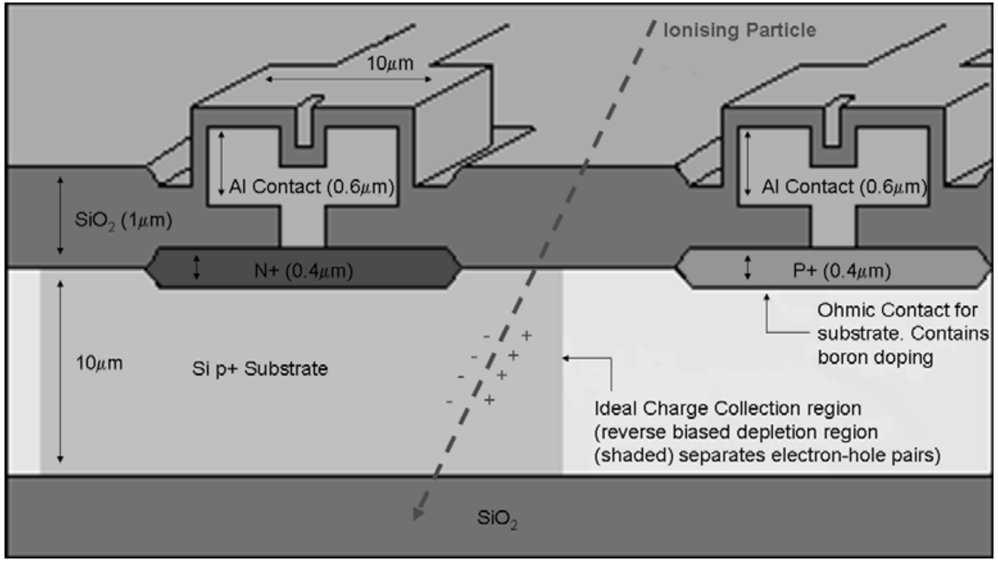


$\bar{l}$ = mean chord length

Shape equivalence correction based on cord length distribution

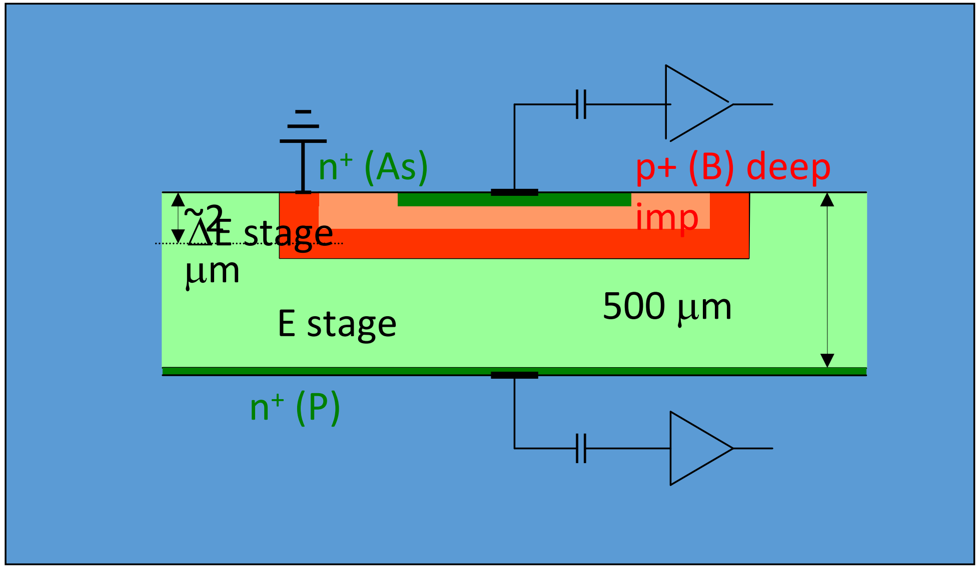
Charge collection in the SV

Lateral drift (and diffusion)



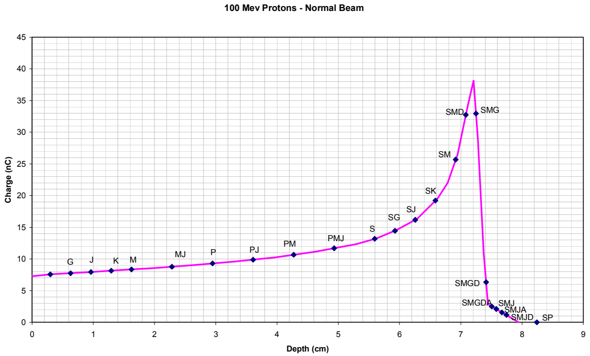
SOI device

Vertical drift

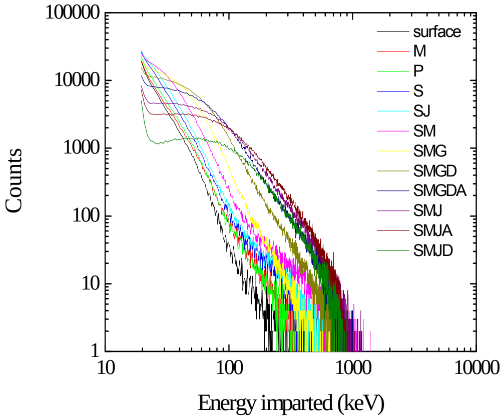


Monolithic Silicon Telescope

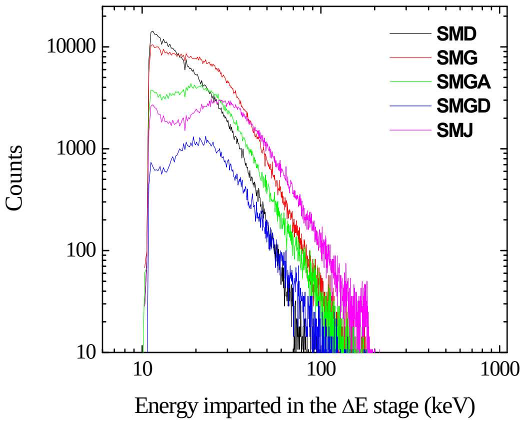
Chage collection comparison

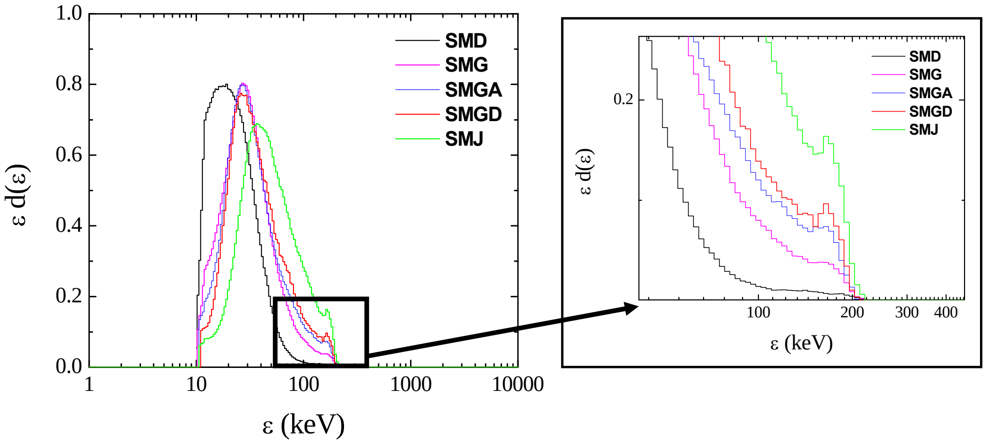


Un-modulated 100 MeV proton beam (LLUMC, CA)



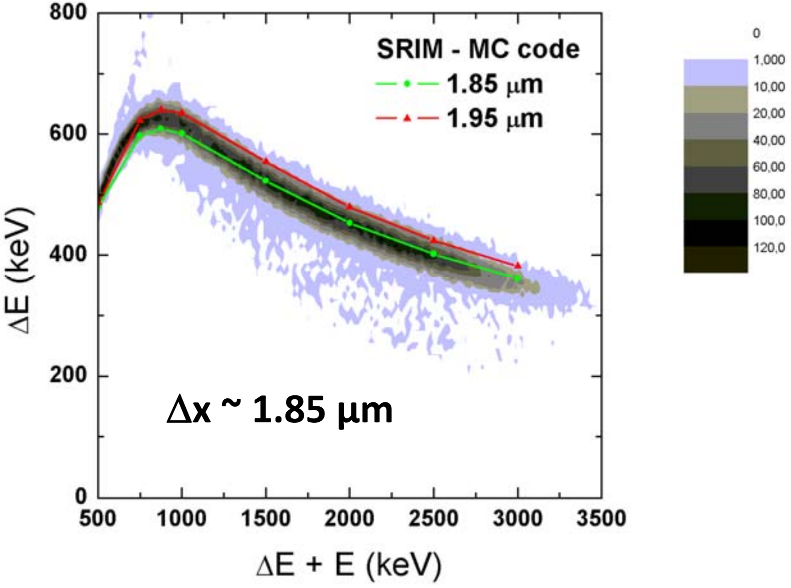
SOI device

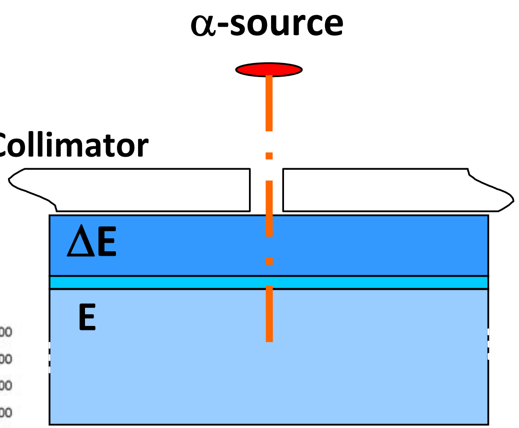


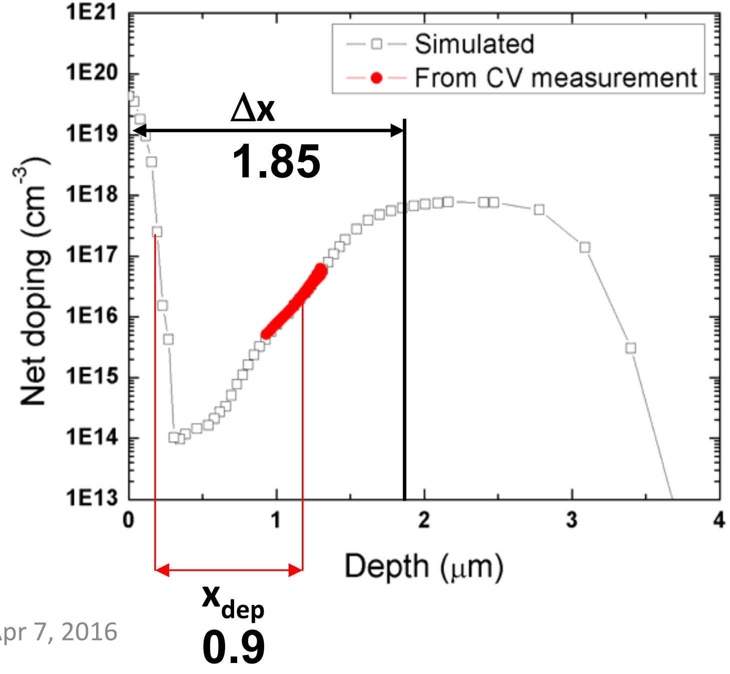


Monolithic Silicon Telescope

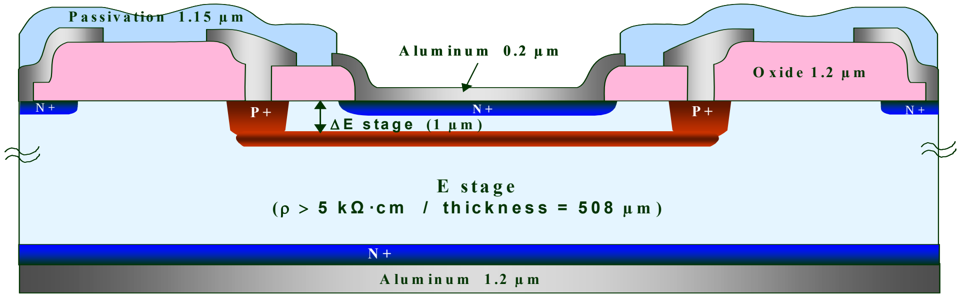
Micrometric thickness of the SV

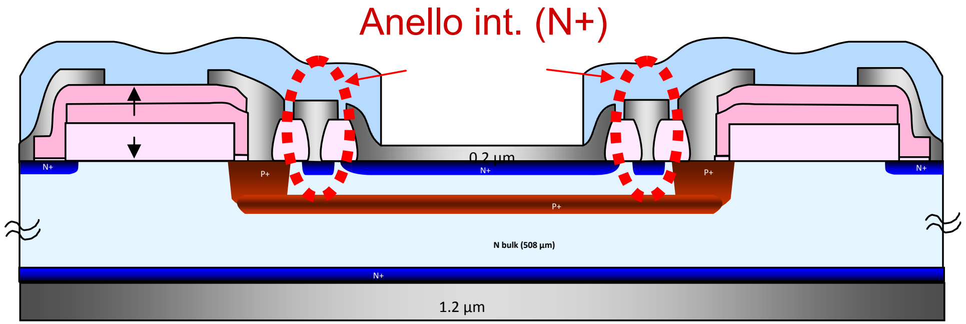


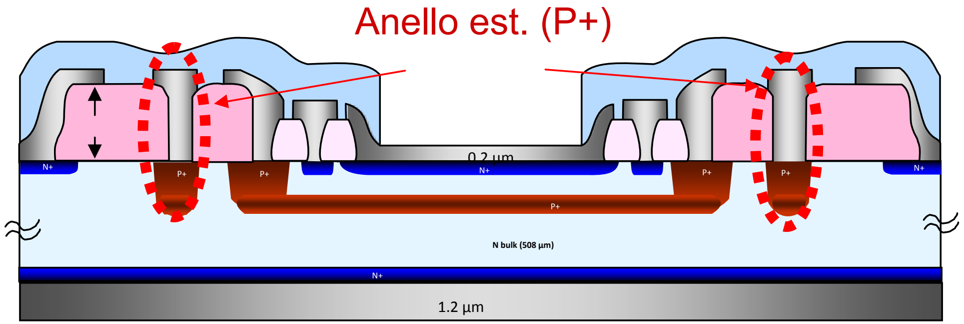




Lateral definition of the SV: Guard rings

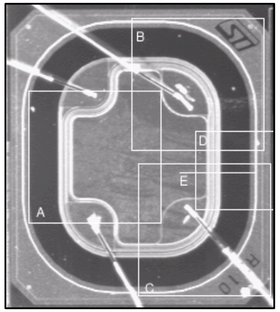






Lateral confinement: ion beam induced charge (IBIC) analysis

IBIC α 3 MeV
@ANSTO



ΔE

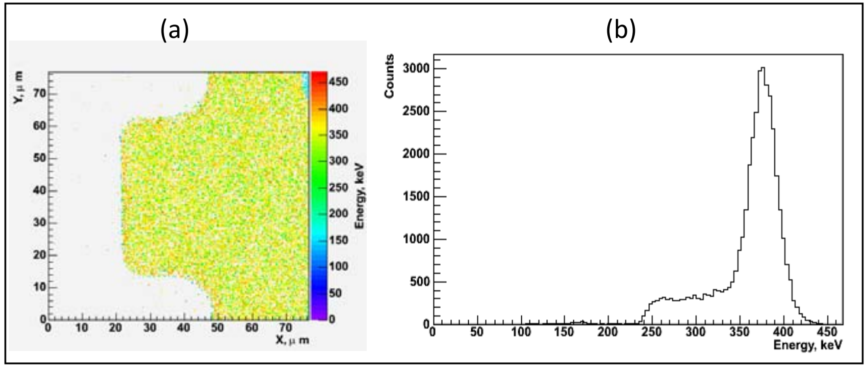


Fig. 14 Results of scan A. X-y mosaic (a) and deposited energy distribution (b) of the events generated in the ΔE stage.

E

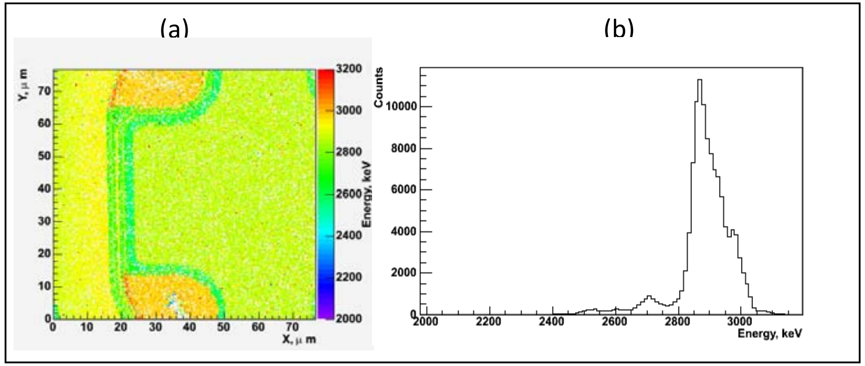
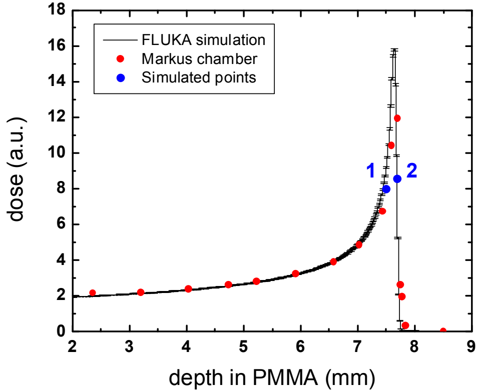
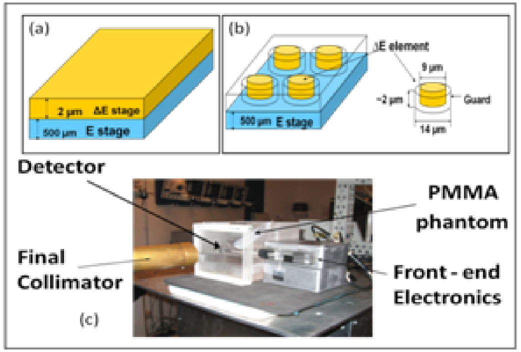


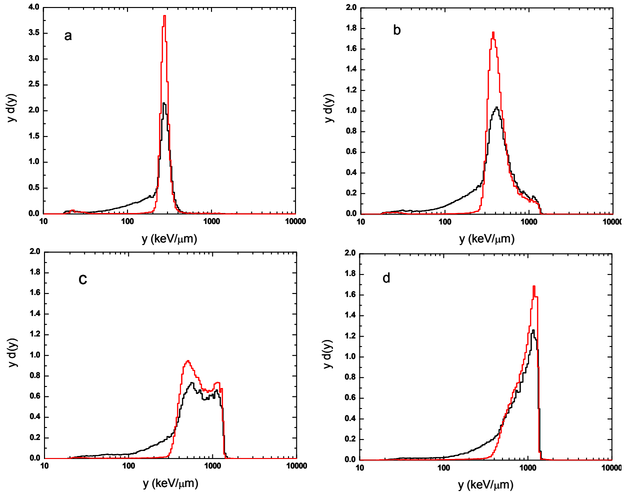
Fig. 15 Results of scan A. X-y mosaic (a) and deposited energy distribution (b) of the events generated in the E stage.

Charge sharing

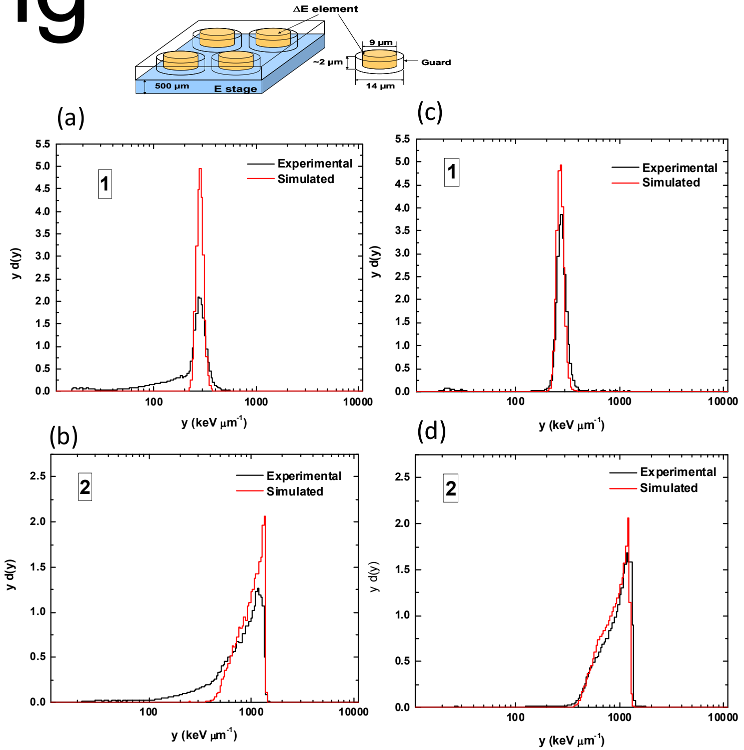
LNS 62 AMeV C-ion





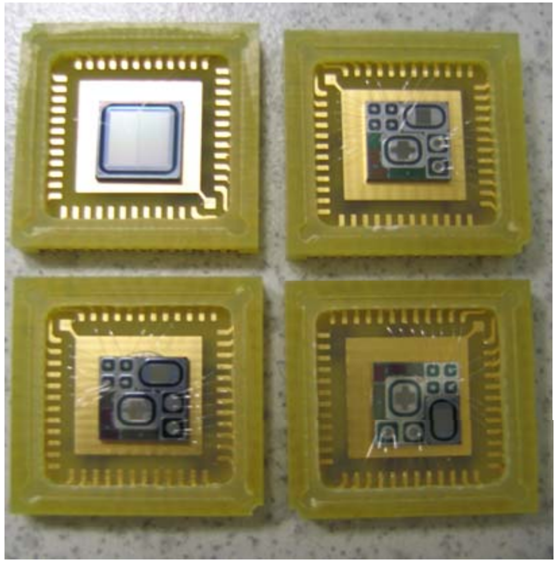


Lineal energy spectra measured with the MST (red line) and SMST (black line) at PMMA depths of 7.5 (a), 7.6 (b), 7.65 (c) and 7.7 mm (d) across the Bragg peak.

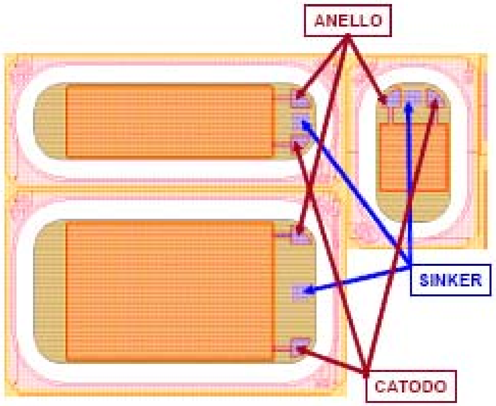


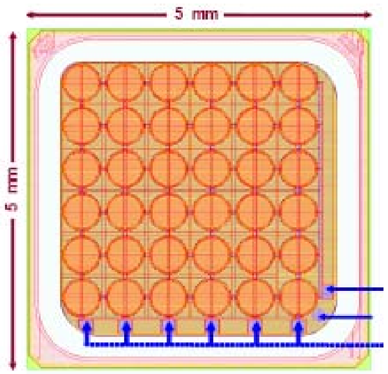
Lineal energy spectra measured (black) and simulated (red) by considering as the detector the SMST (a and b) or the MST (c and d). 1 and 2 are the measurement positions.

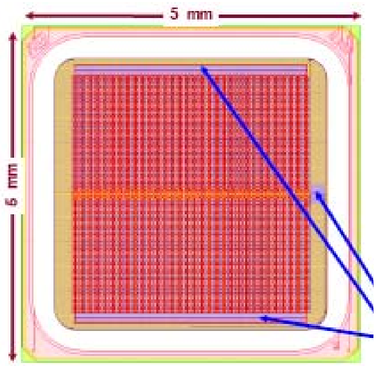
Samples



Monolithic Si - ΔE/E detector
(ST-Microelectronics & PoliMi)







In order to perform a direct comparison with the microdosimetric spectra acquired by a TEPC, the distributions of the energy imparted per event measured by the silicon detector were corrected for:

1) **Tissue-equivalence**

Since protons cross both stages, the simplest correction procedure consists of applying a scaling factor given by:

$$\varepsilon_{\Delta E}^{Tissue}(E) = \varepsilon_{\Delta E}^{Si}(E) \cdot \frac{1}{E_{max}} \int_0^{E_{max}} \frac{S^{Tissue}(E)}{S^{Si}(E)} dE \Rightarrow \varepsilon_{\Delta E}^{Tissue}(E) = \varepsilon_{\Delta E}^{Si}(E) \cdot 0.574$$

2) **Shape equivalence**

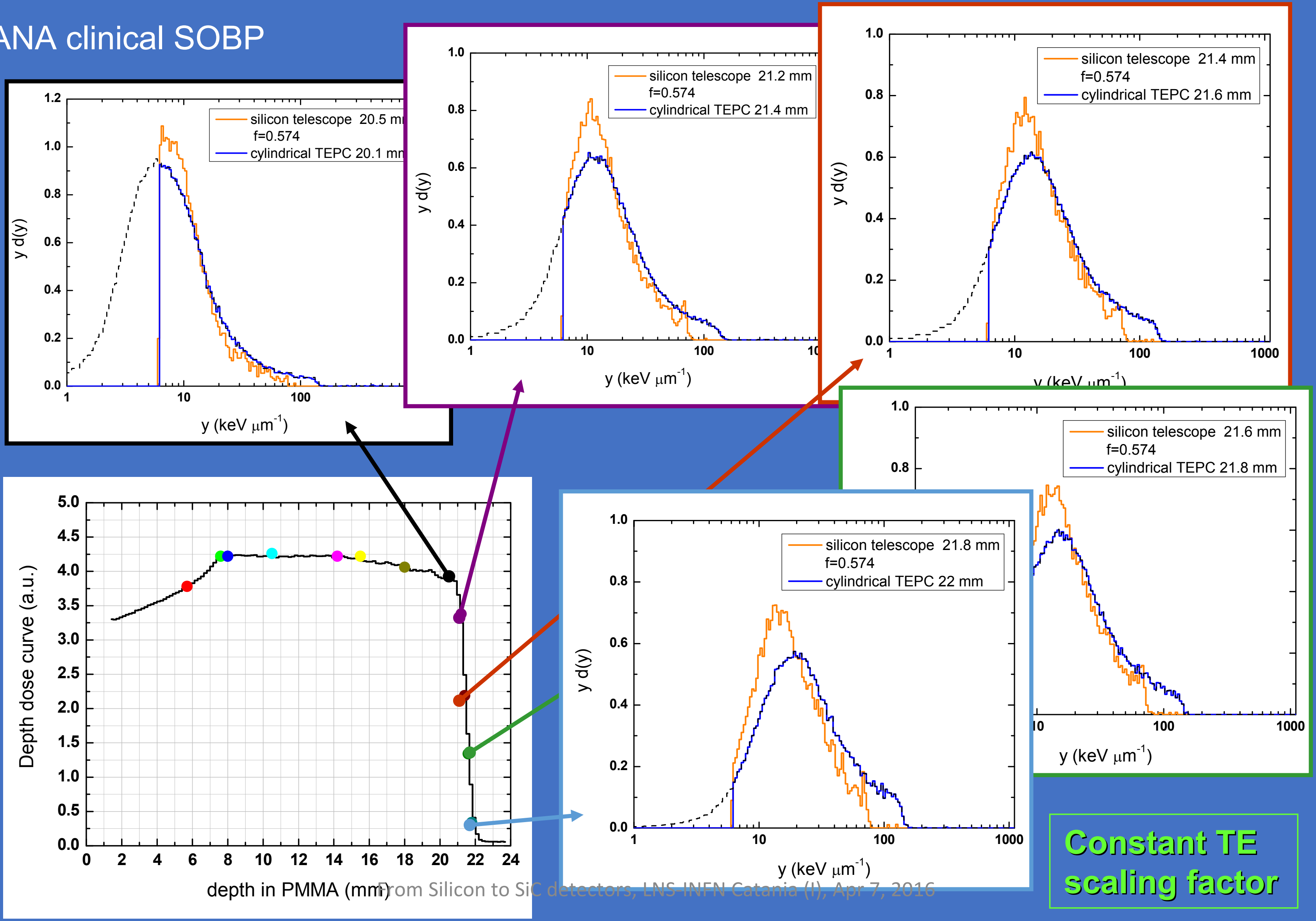
By equating the dose-mean energy imparted per event for the two different shapes considered:

$$\bar{\varepsilon}_D^{\Delta E} = L \cdot \bar{l}_D^{\Delta E} = \bar{\varepsilon}_D^{TEPC} = L \cdot \bar{l}_D^{TEPC} \Rightarrow \eta = \frac{\bar{l}_D^{TEPC}}{\bar{l}_D^{\Delta E}} = 0.533$$

1. S. Agosteo, P. Colautti, A. Fazzi, D. Moro and A. Pola, "**A Solid State Microdosimeter based on a Monolithic Silicon Telescope**", Radiat. Prot. Dosim. 122, 382-386 (2006).
2. S. Agosteo, P.G. Fallica, A. Fazzi, M.V. Introini, A. Pola, G. Valvo, "**A Pixelated Silicon Telescope for Solid State Microdosimeter**", Radiat. Meas., 43 (2-6) (2008), 585-589.

Comparison with cylindrical TEPC: distal part of the SOBP

LNS CATANA clinical SOBP



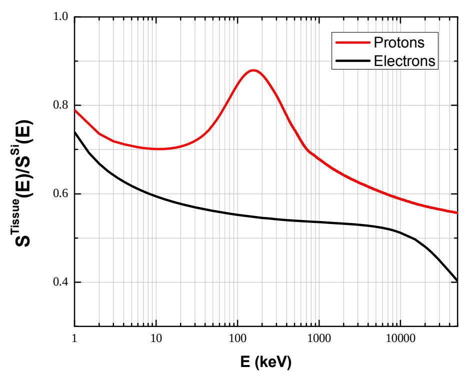
Constant TE scaling factor

But… in the distal part of the SOBP almost all protons stop within the E stage of the silicon detector.

An accurate tissue-equivalence correction can be applied by exploiting <u>event-by-event</u> the information given by the two stages

$$\varepsilon_{\Delta E}^{Tissue}(E) = \varepsilon_{\Delta E}^{Si}(E) \cdot \frac{1}{E_{max}} \int_0^{E_{max}} \frac{S^{Tissue}(E)}{S^{Si}(E)} dE$$

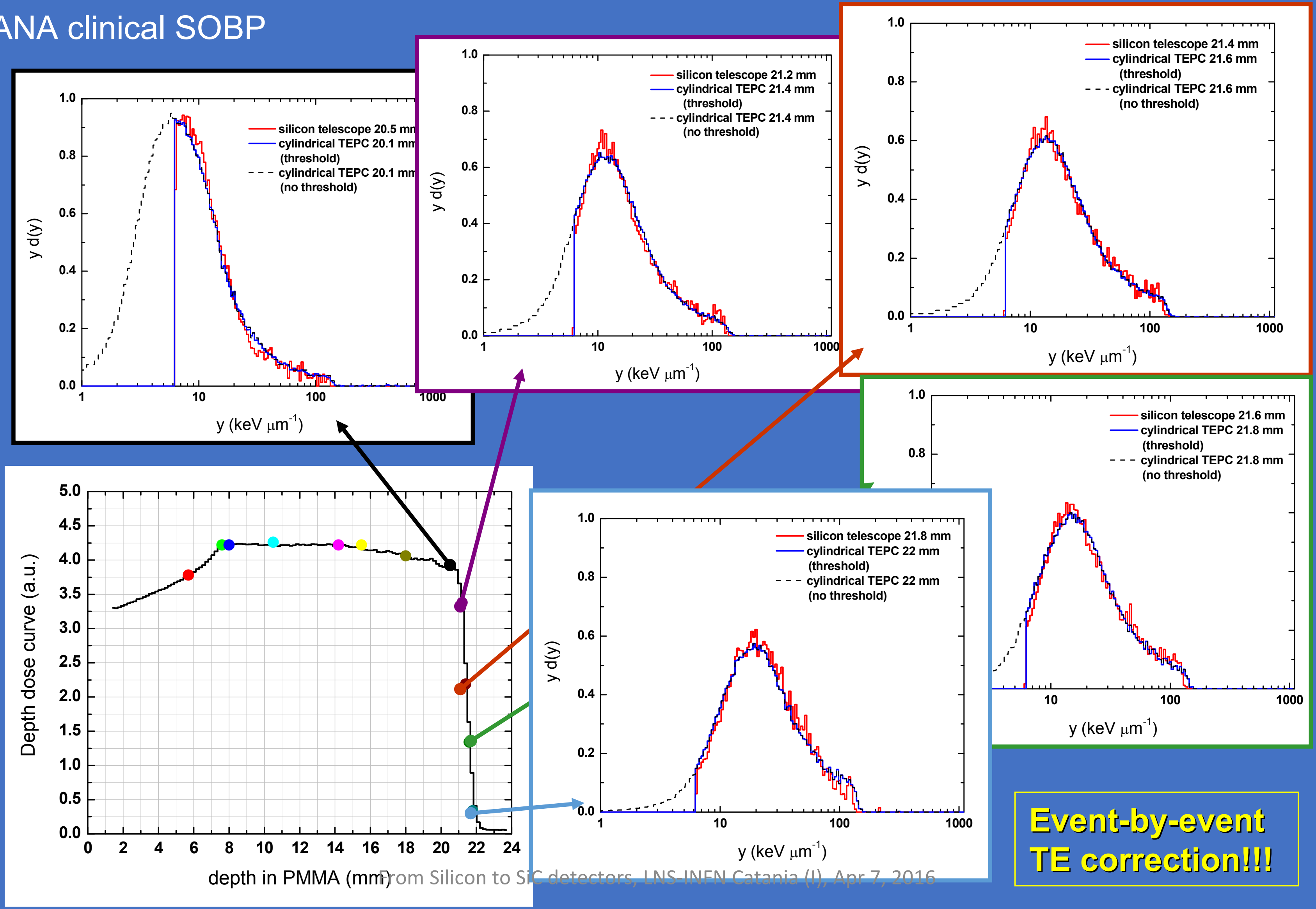
$$\varepsilon_{\Delta E}^{Tissue}(E) = \varepsilon_{\Delta E}^{Si}(E) \cdot \frac{S^{Tissue}(E)}{S^{Si}(E)}$$



where $$E \cong \varepsilon_{\Delta E}^{Si}(E) + \varepsilon_{E}^{Si}(E)$$

Comparison with cylindrical TEPC: distal part of the SOBP

LNS CATANA clinical SOBP

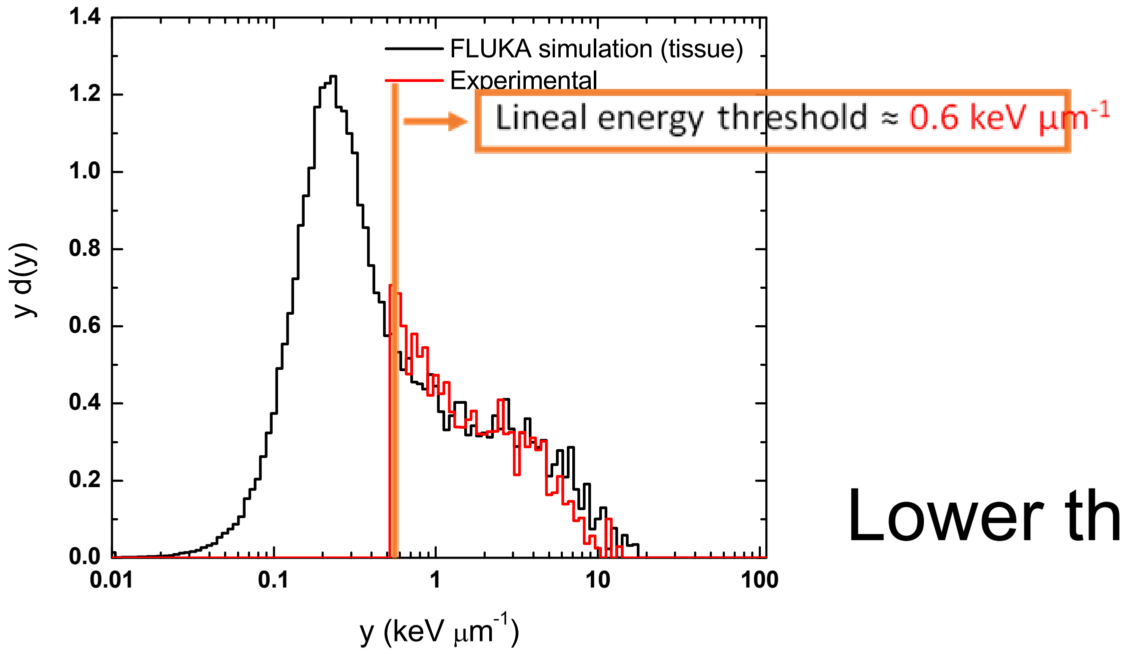


Event-by-event TE correction!!!

Minimum lineal energy y

Irradiations with β particles emitted by a ^{137}Cs source

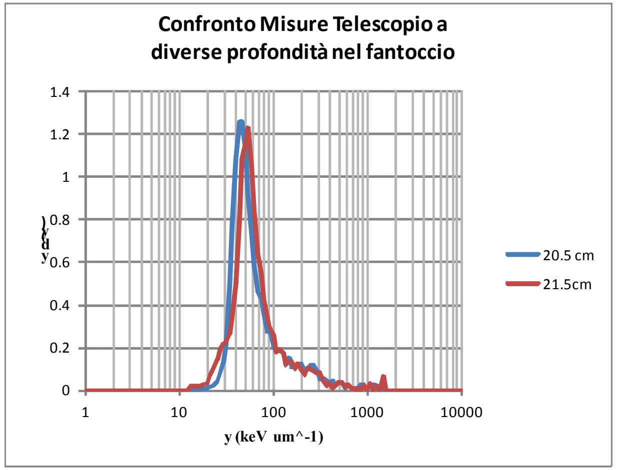
Single pixel 50 um

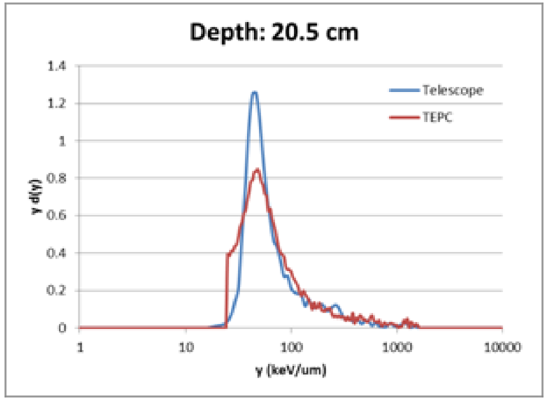


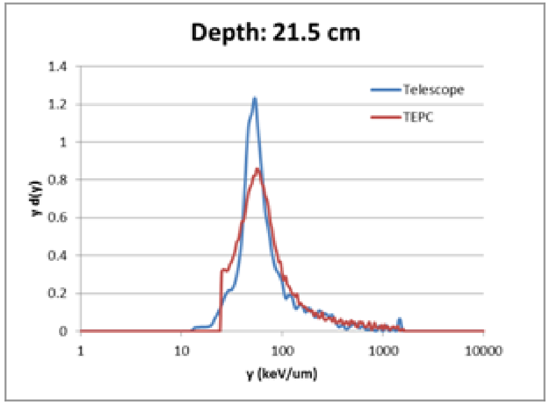
Lower threshold

Test at CNAO (Preliminary)

12C-ion 365 AMeV
Clinical beam 3x3x3cm^3
Water phantom



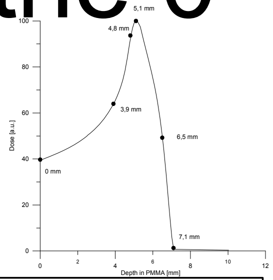


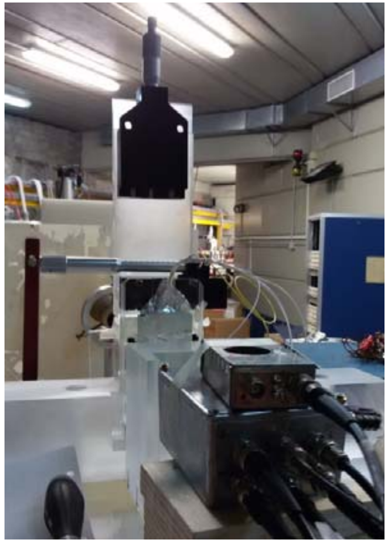


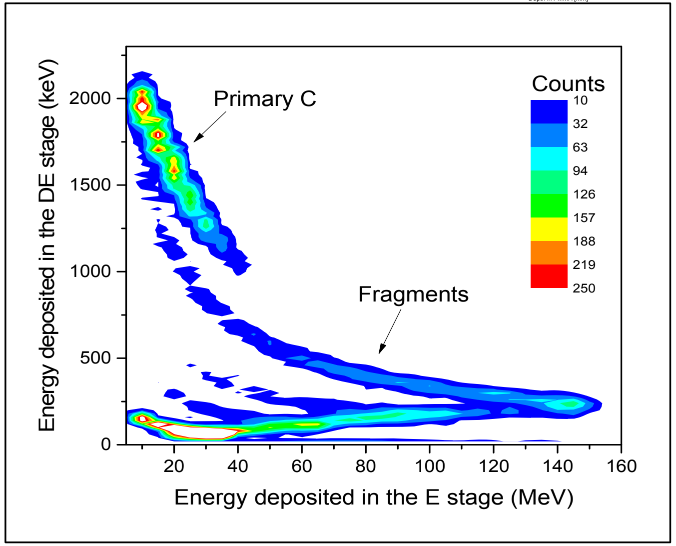
Comparison with a mini-TEPC

Test at LNS on the 0° line (Preliminary)

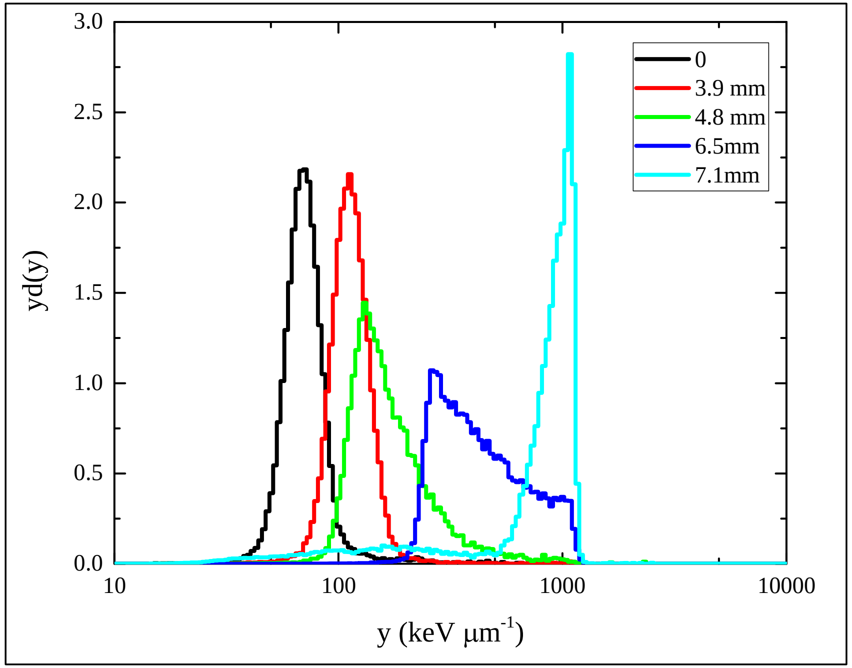
Ridge filter moduleted 62 AMeV 12C-ion beam







ΔE-E scatter plot at 7.1 mm depth in PMMA phantom (distal edge)



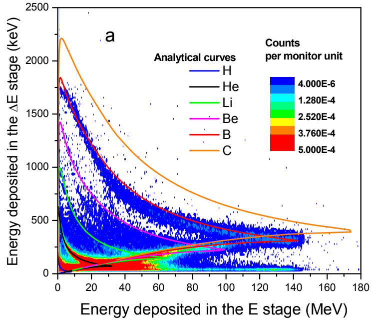
Microdosimetric spectra measured at different depths in PMMA phantom

Test at LNS: Experimental setup

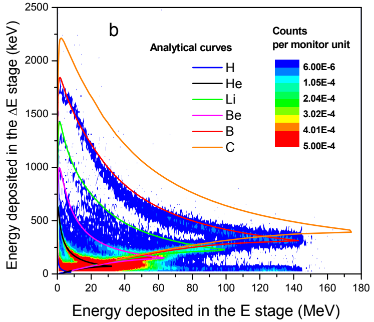
Irradiations with 62 MeV/u un-modulated carbon beam (not clinical)
at the cyclotron facility of the LNS-INFN in Catania (I)

Measurement position beyond the distal edge

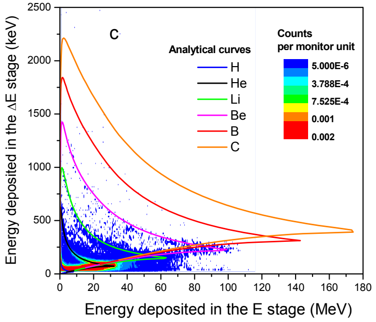
MST



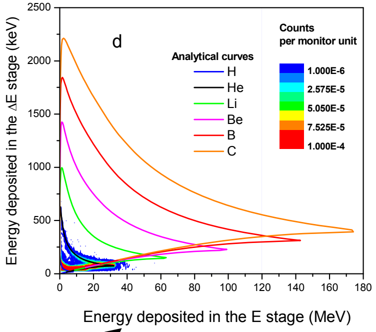
8 mm E)



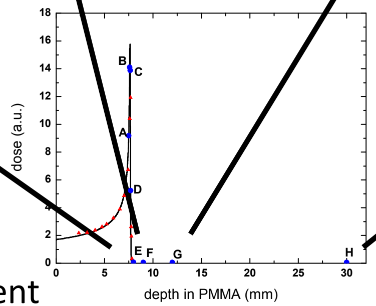
9 mm F)



12 mm G)



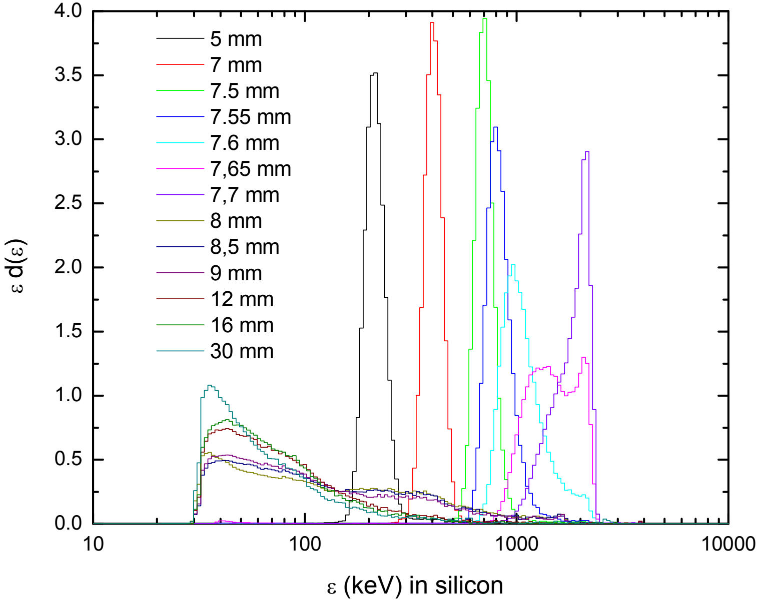
30 mm H)

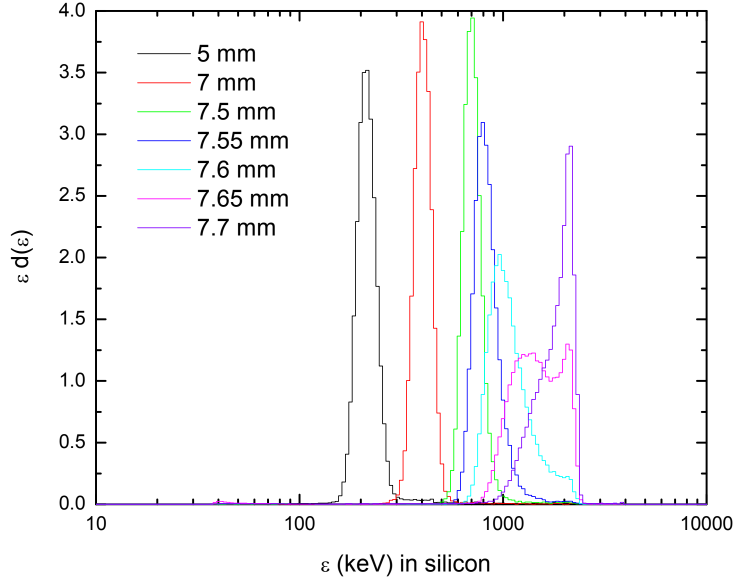


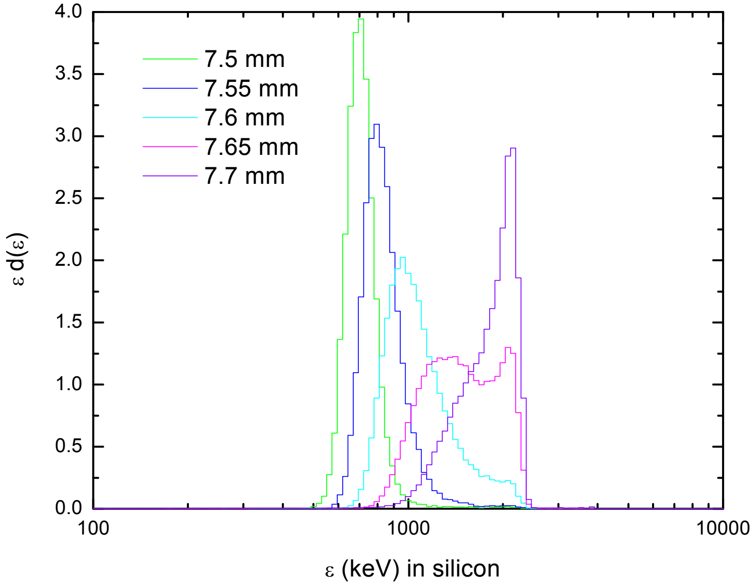
Fragment identification

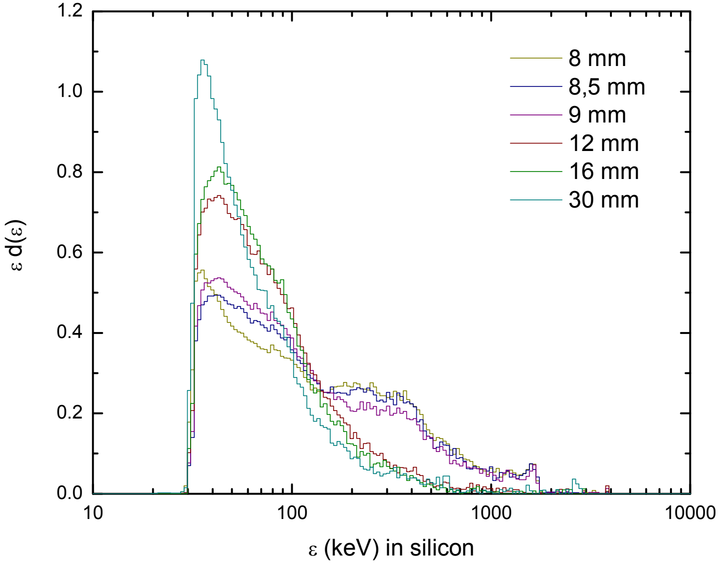
- at 9 mm all kind of fragments are present
- at 12 mm boron ions do not appear
- At 30 mm lighter fragments such as helium ions and protons are still present.

50 µm Increment Spacial resolution

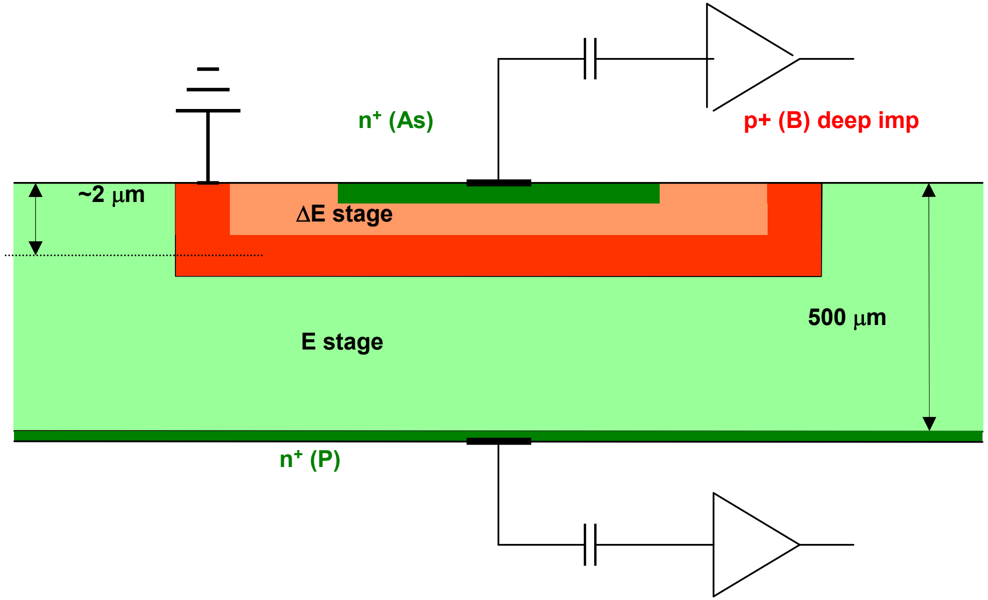








Signal Read-out scheme



FRONT END ELECTRONICS: requirements

Spectroscopy grade requirements

- Low noise (lowest detection limit)
- Wide dynamic range
- Linearity

Detector area

$$ENC^2_{opt} = \left(\frac{k_B T \cdot m}{\omega_T} \right) \cdot C^0_{DET} \cdot A \cdot \frac{1}{\tau_{sh}} + q \cdot I^0_{LEAK} \cdot A \cdot \tau_{sh}$$

$ENC^2{}_{opt}$ $\propto$ Detector area $\propto$ Efficiency

Noise efficiency trade-off $\Rightarrow$ Detector segmentation

Silicon to SiC ?

doping ?

- X_D ~ SQRT(V_R / N_{dop})
- Thick depletion layers need:
- thick, high purity, defect free epi-layer
- Low residual doping ($<10^{13}cm^{-3}$)

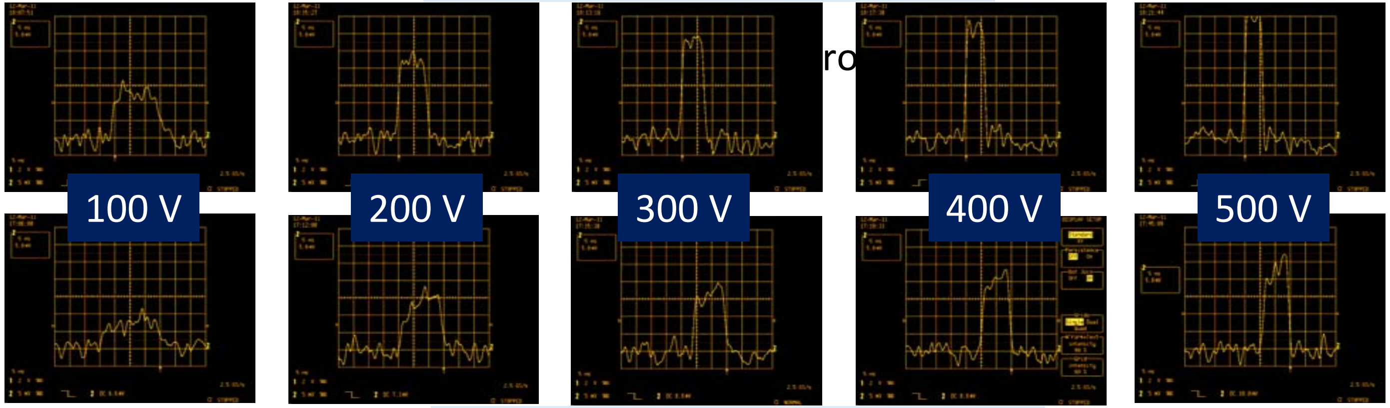
Signal induction ?

High Purity Single Crystal Diamond (DDL)
Thickness: 500 µm
Metallization (3nm DLC/ 16nm Pt / 200 nm Au)
Active area: 4.6x4.6 mm²

Positive Bias Voltage on Front Contact

Alfa source ^{241}Am

FRONT illumination **HOLES** drift



5 mV/div
5 ns/div

BACK illumination **ELECTRON** drift

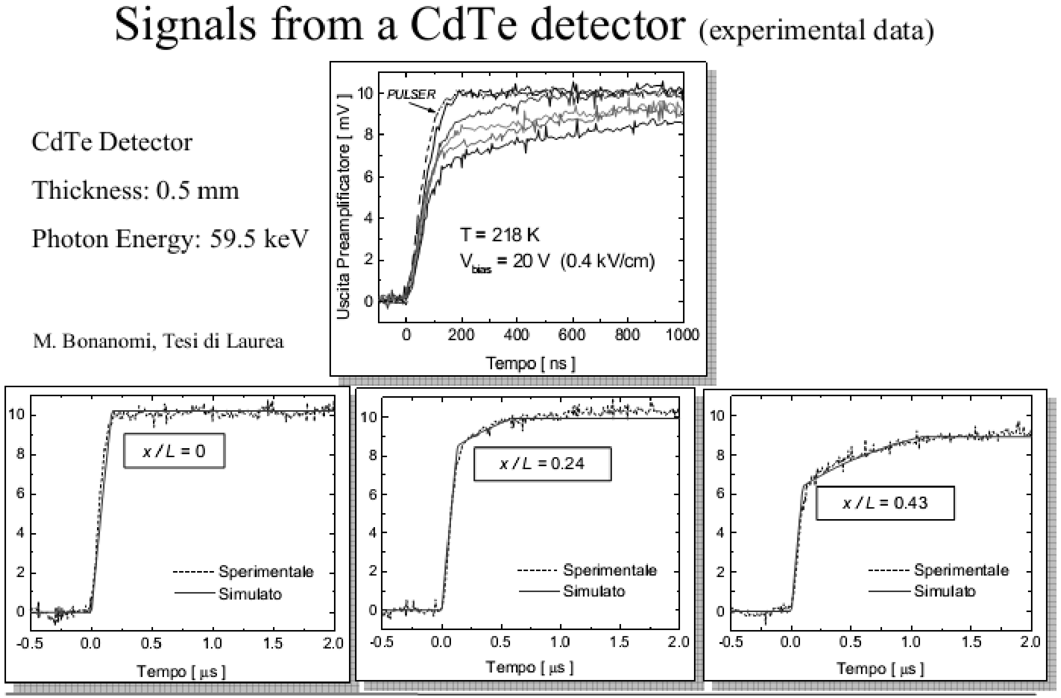
Low mobility ?

SiC/Si hole mobility ratio = 1/ 4-8

Trade off det. thickness vs shaping time
(0.9 mm at 5 us)

Elec/hole mobility ratio = 10-20

Tha same as CdTe.
Position dependent ballistic deficit for thick detectors.
(rise-time discrimination/correction?)

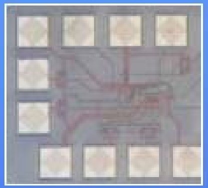


Trapping ? Polarisation ? Rad hardness ?

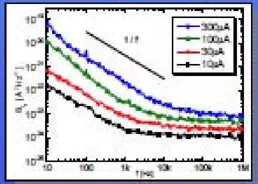
Mean drift length:

$\lambda_h = v_h \tau_h = (\mu_h \tau_h) E$

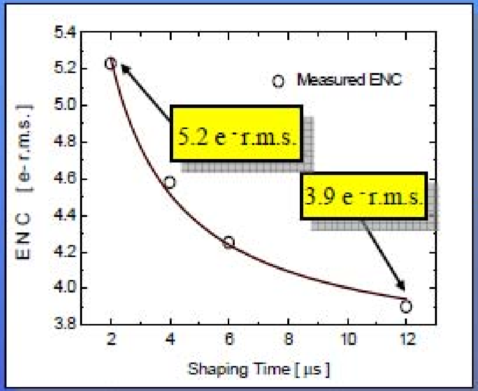
Ultra Low Noise CMOS Charge Amplifier for SiC Detectors

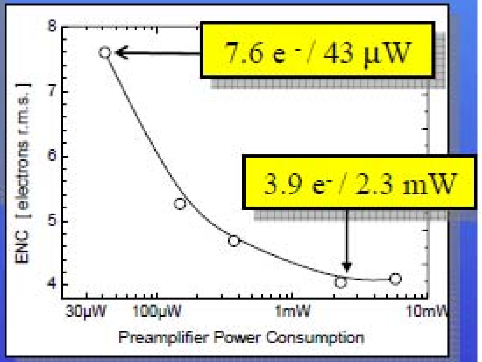


CMOS
Preamplifier chip



LF Noise
modelling

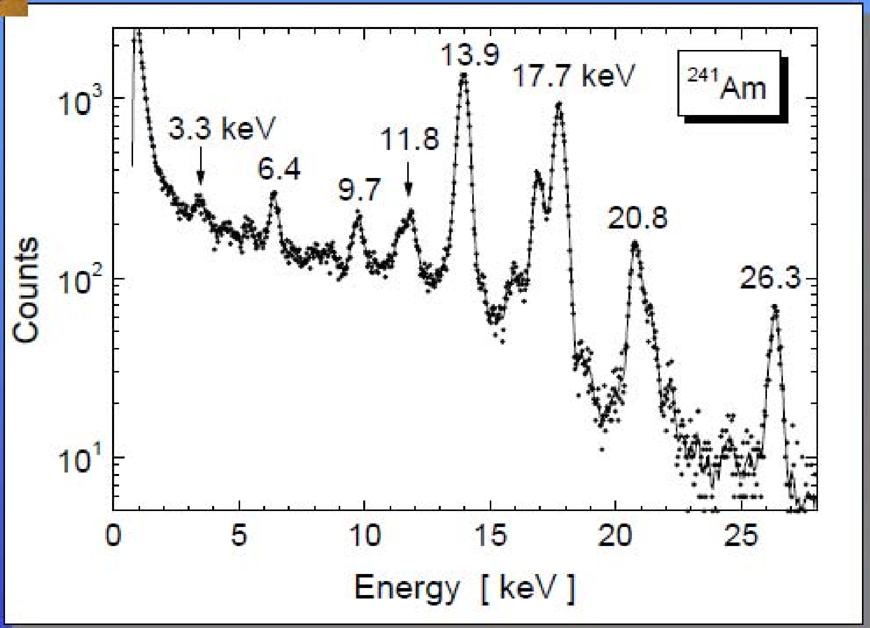




G. Bertuccio and S. Caccia,

11th Symposium on Radiation Measurements and Applications, Ann Arbor, Michigan, USA, May 23-25, 2006 - Submitted to NIM A, May 2006

SiC pixel at 27 °C (300 K)



Energy resolution: 315 eV FWHM (17 e^- r.m.s.)

Electrical characterisation of SiC wafer@MI

- I-V down to fA level (Keythley 6430)
- Triaxial probes for the probe station
- Clean measurement environment