



A silicon microdosimeter for radiation quality assessment

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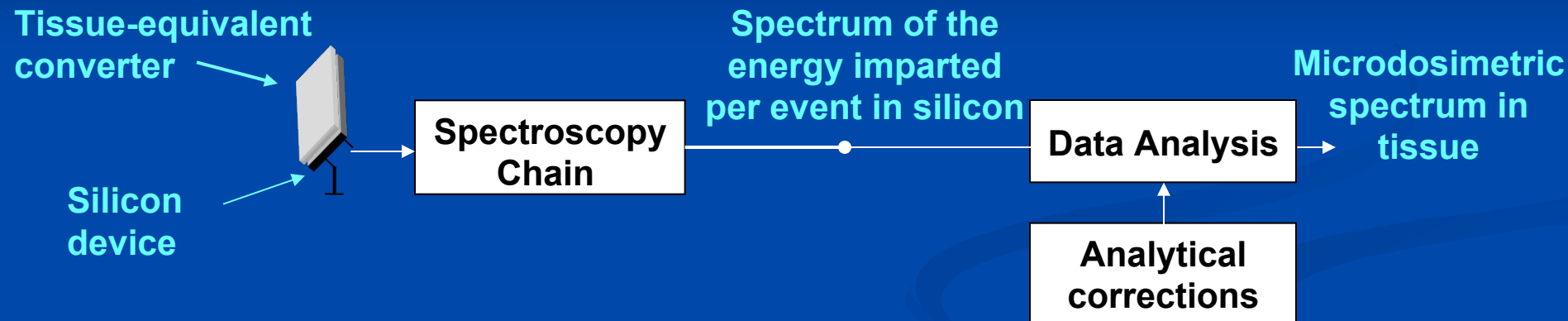
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SOLID STATE MICRODOSIMETERS

Si-devices can provide sensitive zones of the order of a micrometer

CHALLENGING DEVICES FOR MICRODOSIMETRY

HOW a Si-DEVICE BASED MICRODOSIMETER WORKS?...

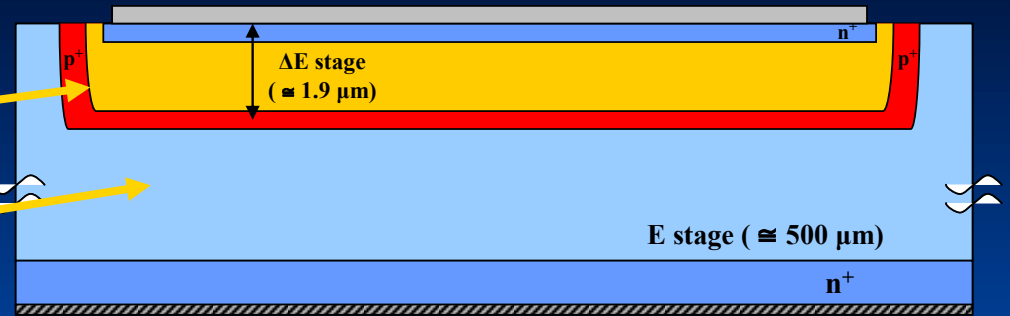


PN diodes in SOI wafer

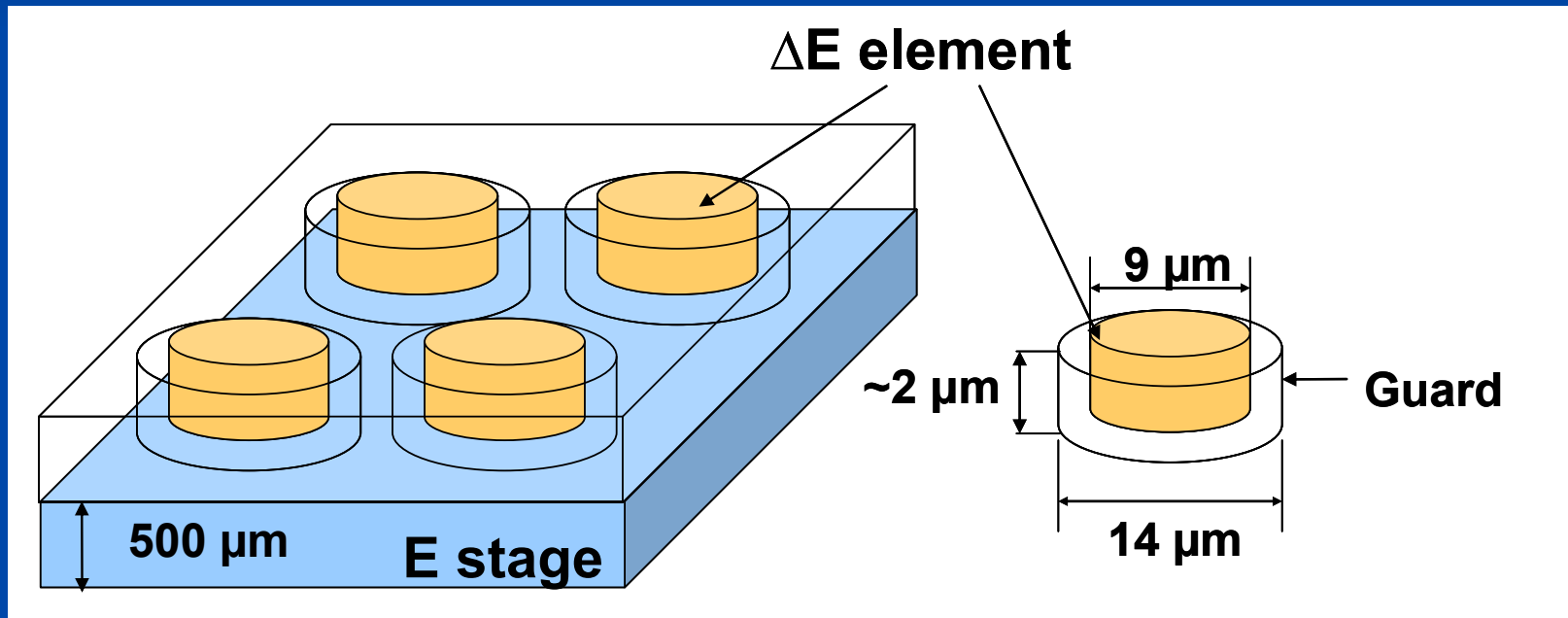
- [1] B. Rosenfeld, P. Bradley, I. Cornelius, G. Kaplan, B. Allen, J. Flanz, M. Goitein, A.V. Meerbeeck, J. Schubert, J. Bailey, Y. Tabkada, A. Maruashi, Y. Hayakawa, *New silicon detector for microdosimetry applications in proton therapy*, IEEE Trans. Nucl. Sci. 47(4) (2000) 1386-1394.
- [2] P. Bradley, A.B. Rosenfeld, B.J. Allen, J. Coderre, and J. Capala, *Performance of silicon microdosimetry detectors in boron neutron capture therapy*, Radiation Research 151 (1999) 235-243.
- [3] P.D. Bradley, *The Development of a Novel Silicon Microdosimeter for High LET Radiation Therapy*, Ph. D. Thesis, Department of Engineering Physics, University of Wollongong, Wollongong, Australia (2000).

SEGMENTED SILICON TELESCOPE

Silicon telescope:
a thin ΔE stage (1.9 μm thick)
coupled to a residual energy
stage E (500 μm thick)
on the same silicon wafer.



ΔE stage: matrix of cylindrical diodes ($h = 2 \mu\text{m}$, $d = 9 \mu\text{m}$)



More than 7000 pixels are connected in parallel to give an effective detection area of the ΔE stage of about 0.5 mm^2

MICRODOSIMETRIC SPECTRA: TISSUE-EQUIVALENCE AND GEOMETRICAL CORRECTIONS

In order to derive microdosimetric spectra similar to those acquired by a TEPC, corrections were studied and discussed in details [1,2]

Tissue equivalence of silicon

The telescope allows to optimize the tissue equivalence correction by measuring event-by-event the energy of the impinging particles and by discriminating them.

Shape equivalence

By following a parametric criteria given in literature, the lineal energy y was calculated by considering an equivalent mean cord length.

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., accepted for publication.

TISSUE EQUIVALENCE CORRECTION

The tissue equivalence of silicon device requires:

A suitable correction to the measured distribution in order to obtain a spectrum equivalent to that acquired with an hypothetical tissue ΔE detector

Analytical procedure for tissue-equivalence correction

$$E_d^{\text{Tissue}}(E_p, l) = E_d^{\text{Si}}(E_p, l) \cdot \frac{S^{\text{Tissue}}(E_p)}{S^{\text{Si}}(E_p)}$$

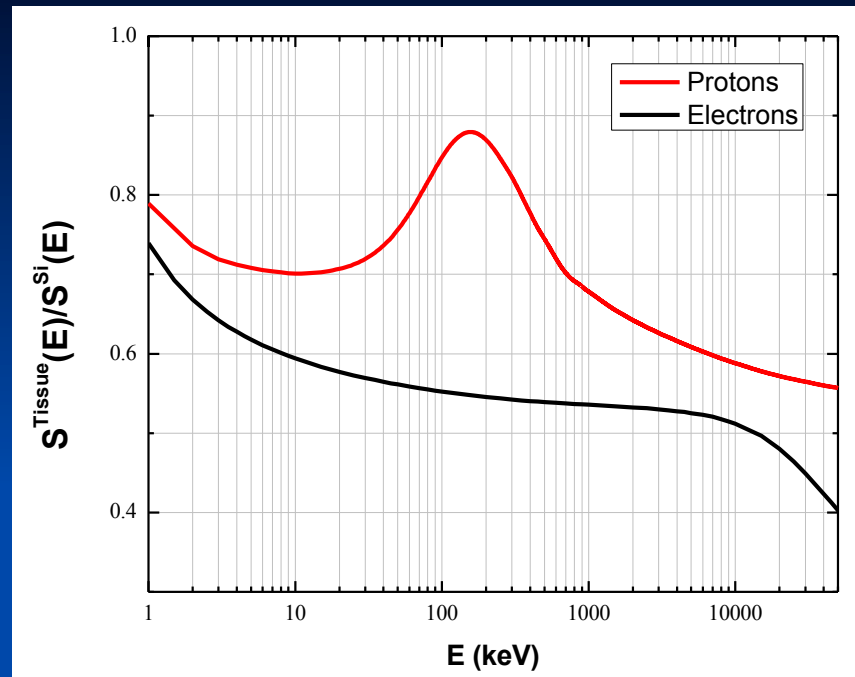
Energy deposited along a track of length l by recoil-protons of energy E_p in a tissue-equivalent ΔE detector

Scaling factor :
stopping powers ratio

TISSUE-EQUIVALENCE CORRECTION

The scaling factor $\frac{S^{\text{Tissue}}(E)}{S^{\text{Si}}(E)}$

depends on the energy and
the type of the impinging
particle



E stage of the telescope
and ΔE -E scatter-plot

Limits:

the thickness of the E stage restricts the TE correction to recoil-protons below 8 MeV (alphas below 32 MeV)

Electrons release only part of their energy in the E stage

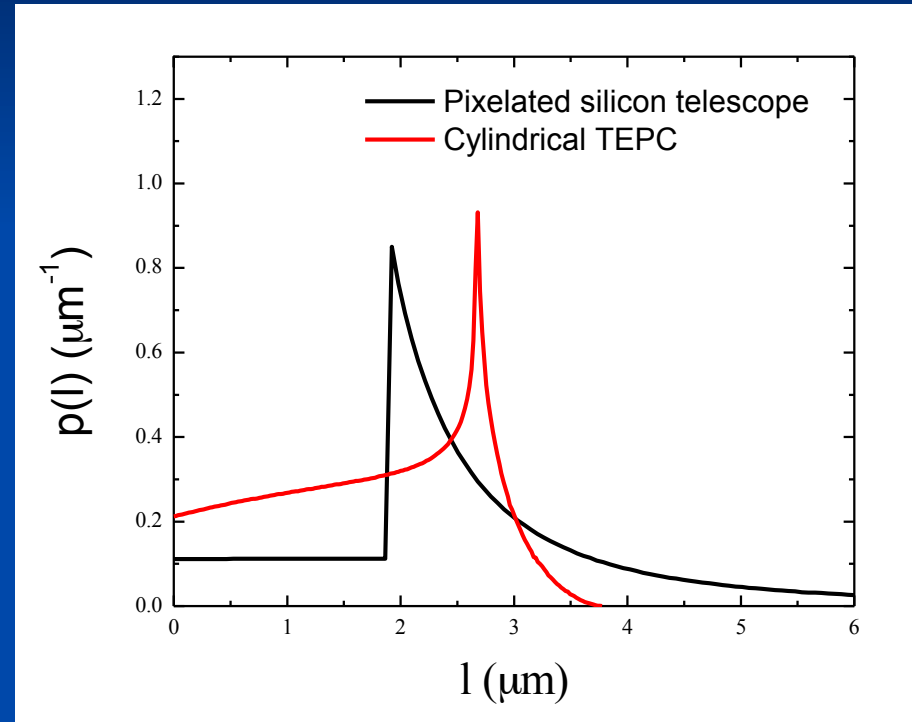
Mean value over a wide energy range (0-10 MeV) = 0.53

SHAPE ANALYSIS

Pixelated silicon telescope ($d \approx 10 \mu\text{m}$)

The correcting procedure can be based on cord length distributions, since ΔE pixels are cylinders of micrometric size in all dimensions (as the TEPCs).

Correction is only geometry-dependent (no energy limit)



SHAPE ANALYSIS

The equivalence of shapes is based on the parametric criteria given in the literature (Kellerer).

By assuming a constant linear energy transfer L:

$$\bar{\varepsilon}_D = L \cdot \frac{\int_0^{\infty} l^2 \cdot p(l) dl}{\bar{l}} = L \cdot \bar{l}_D$$

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

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

Dimensions of ΔE stages were scaled by a factor η ...

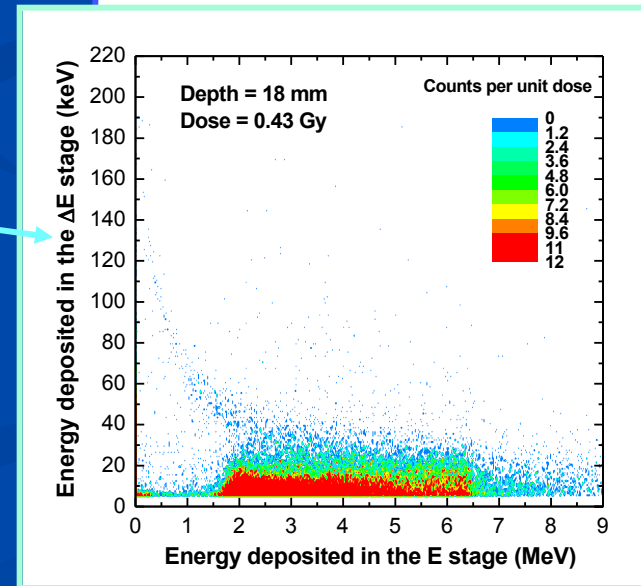
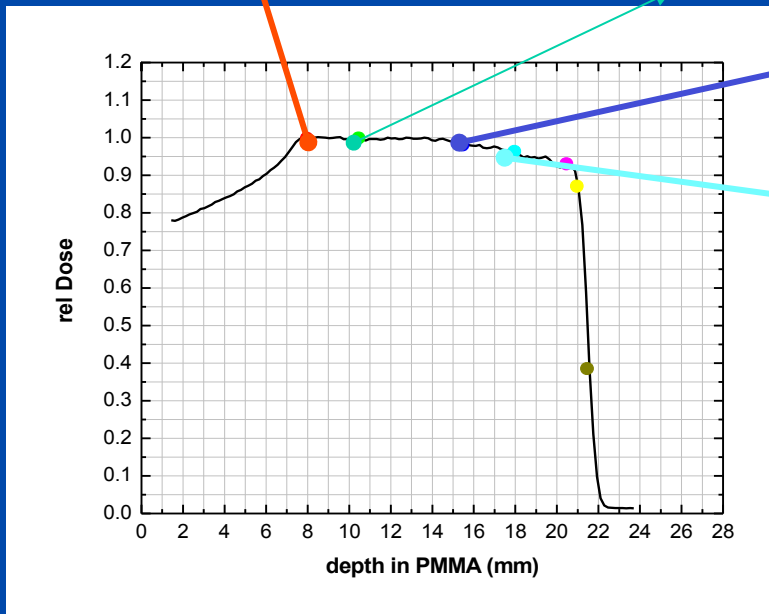
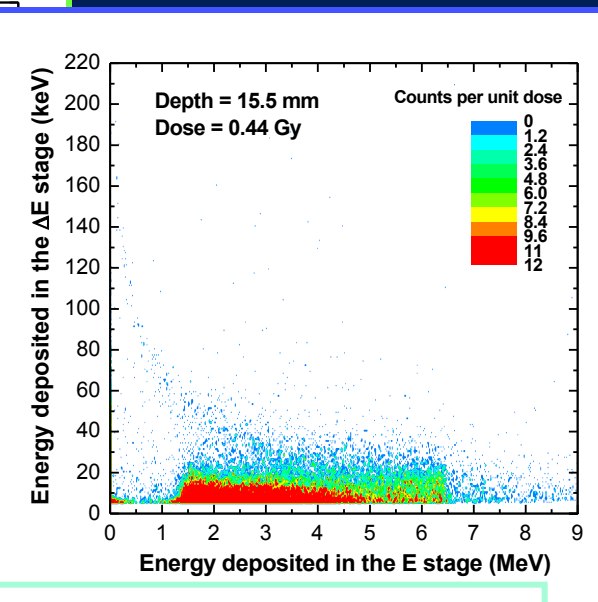
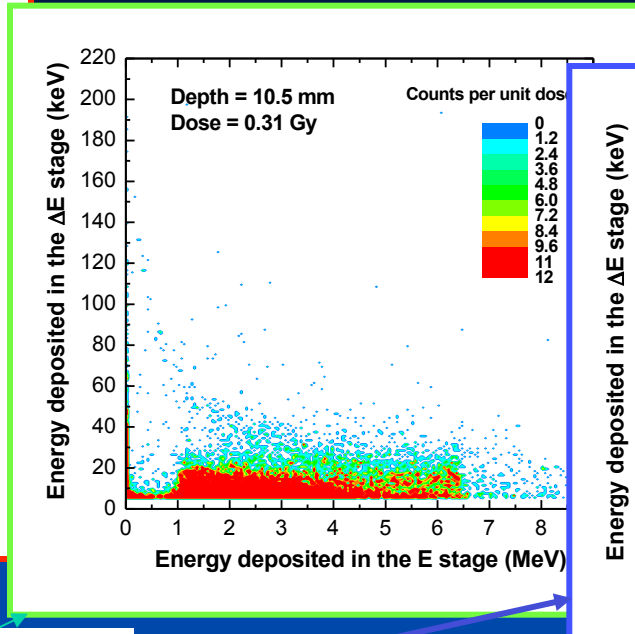
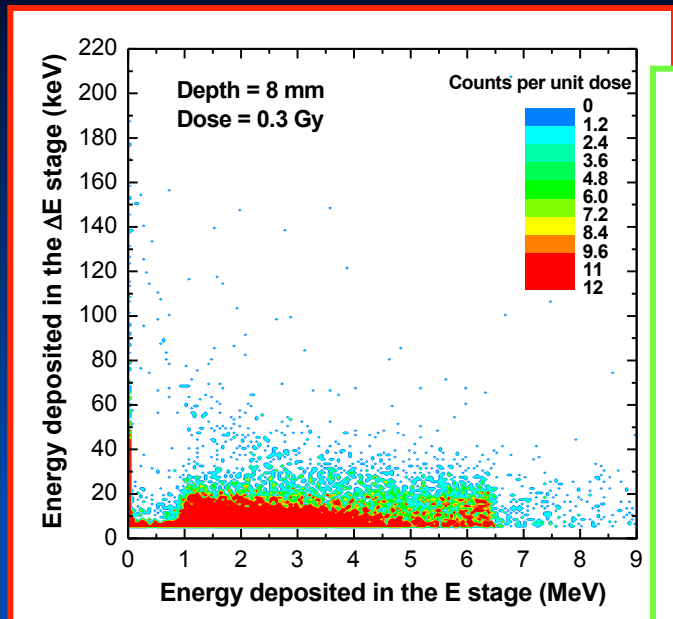
... the lineal energy y was calculated by considering an equivalent mean cord length equal to:

$$\bar{l}_{\Delta E, \text{eq}} = \bar{l}_{\Delta E} \cdot \eta$$

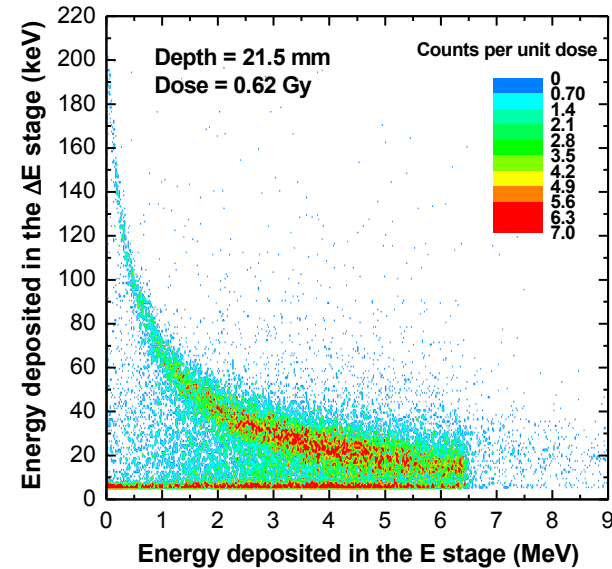
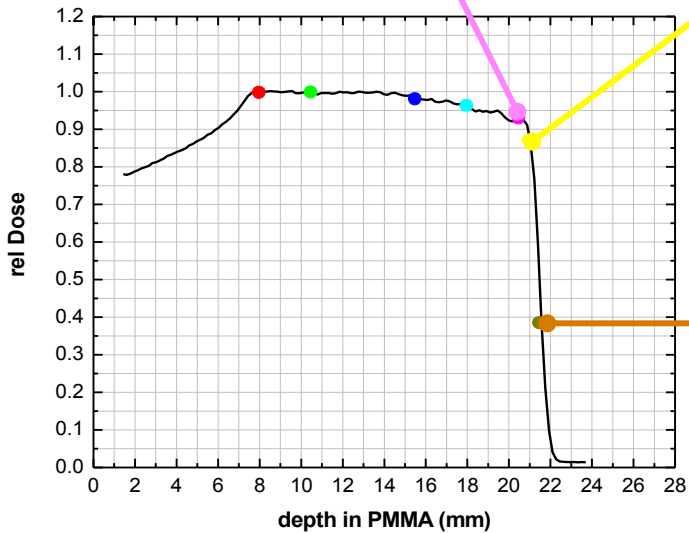
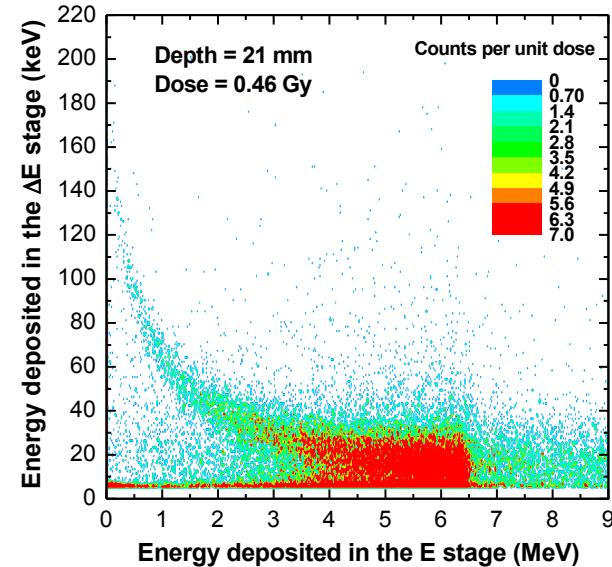
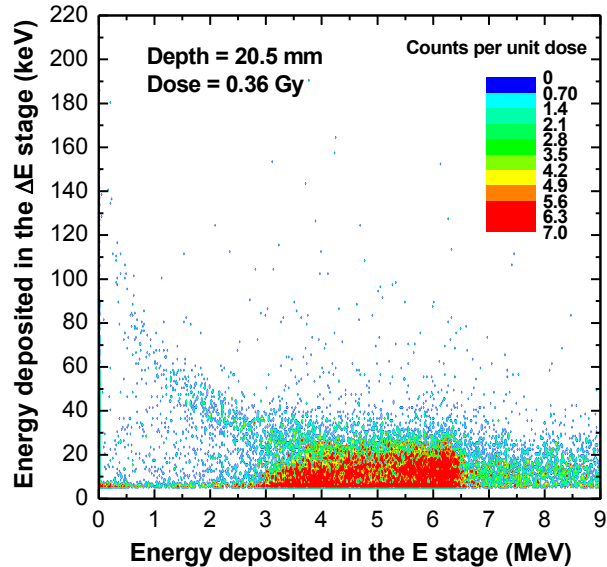
RESPONSE TO PROTONS:

Irradiations with
62 MeV modulated proton beam
at CATANA facility
(LNS-INFN Catania)
and
comparison with cylindrical TEPC
(De Nardo et al., RPD 110, 1-4 (2004))

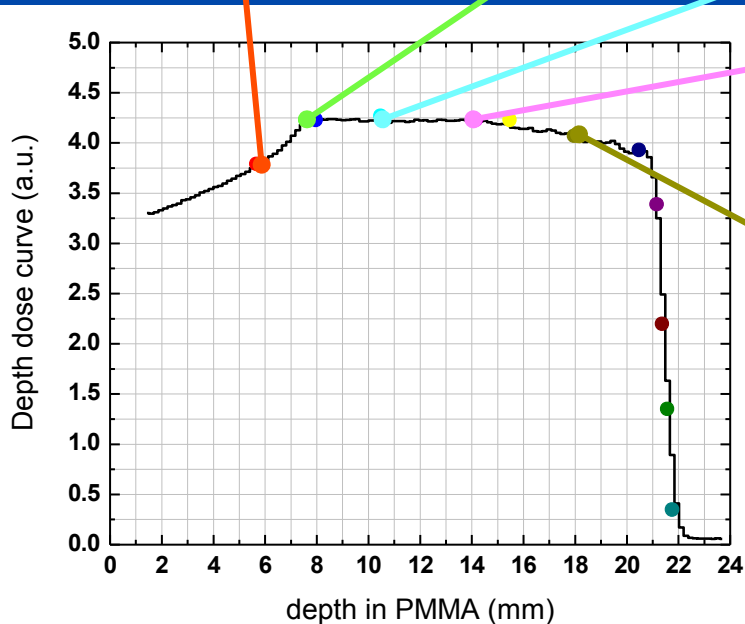
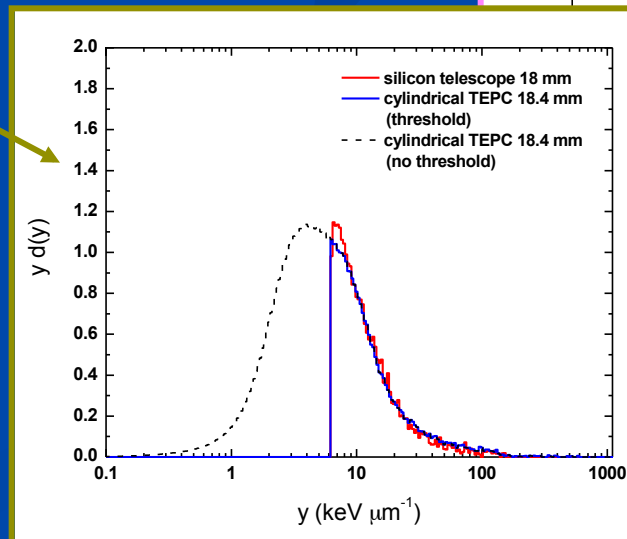
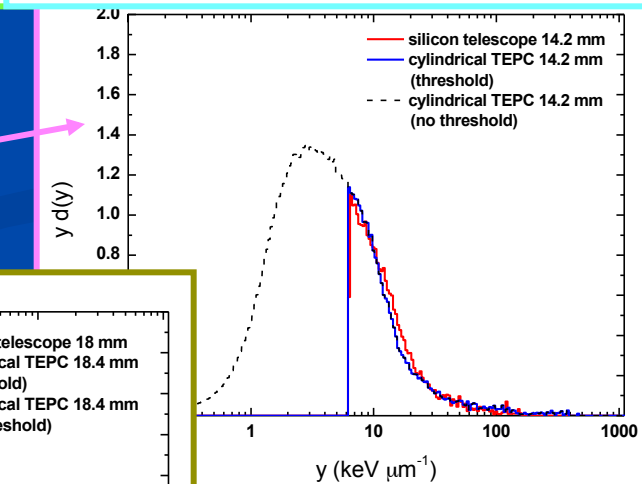
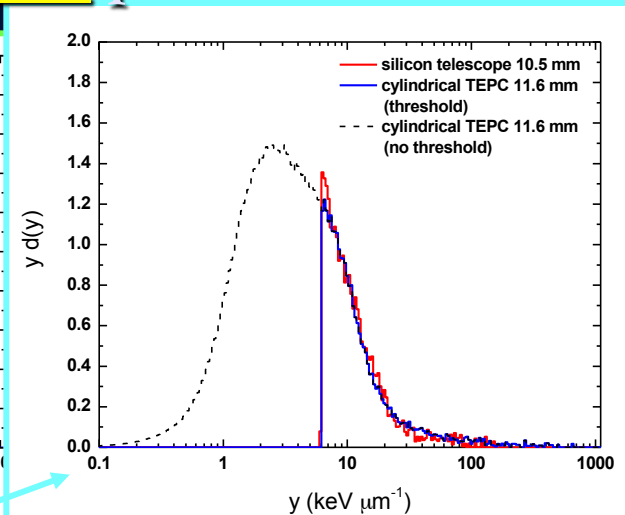
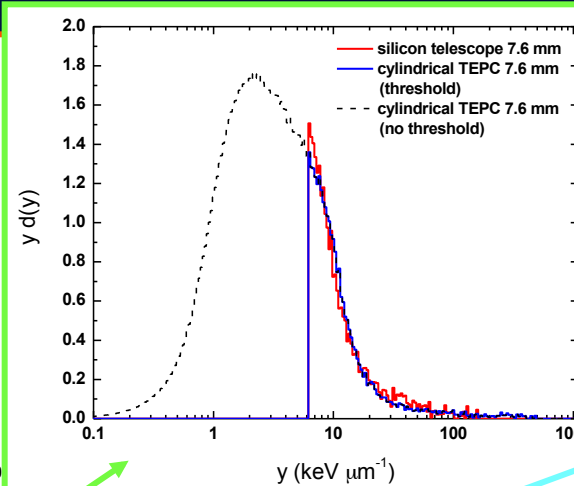
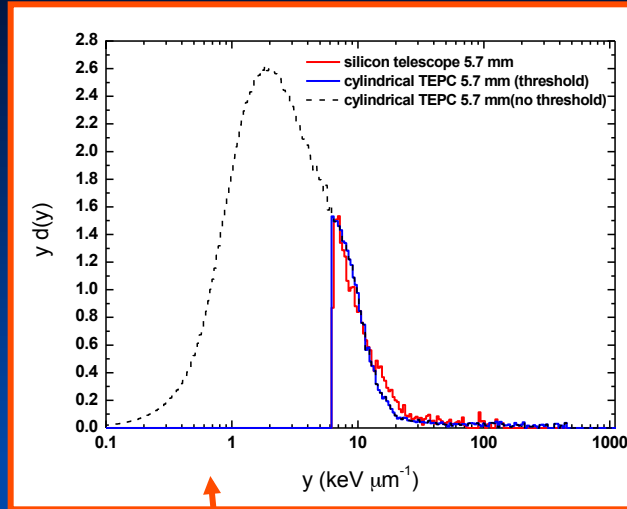
62 MeV modulated proton beam (CATANA)



62 MeV modulated proton beam (CATANA)

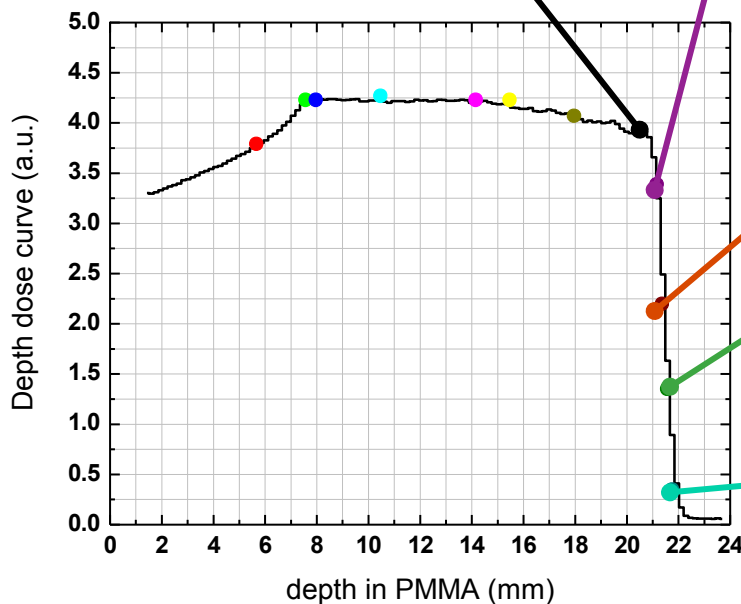
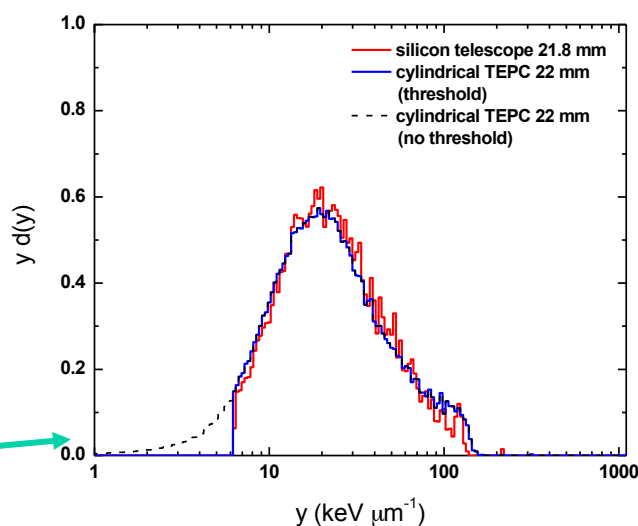
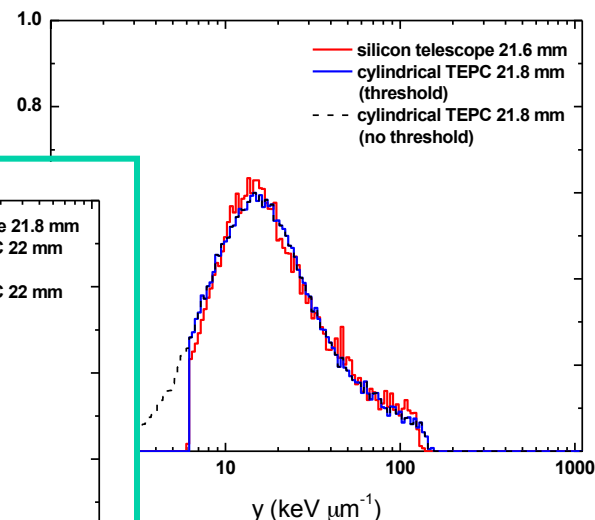
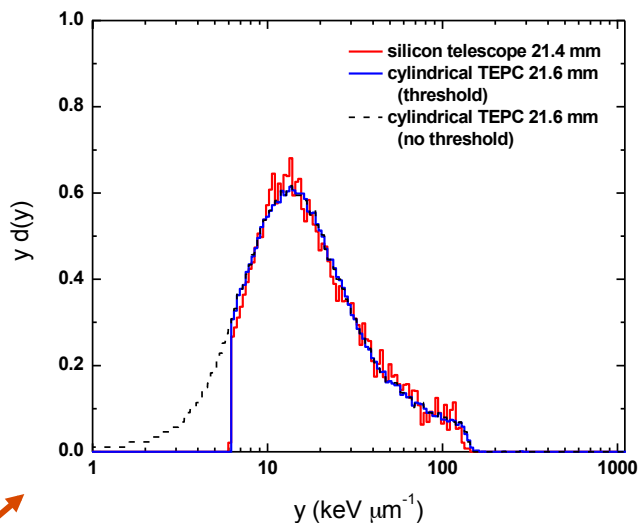
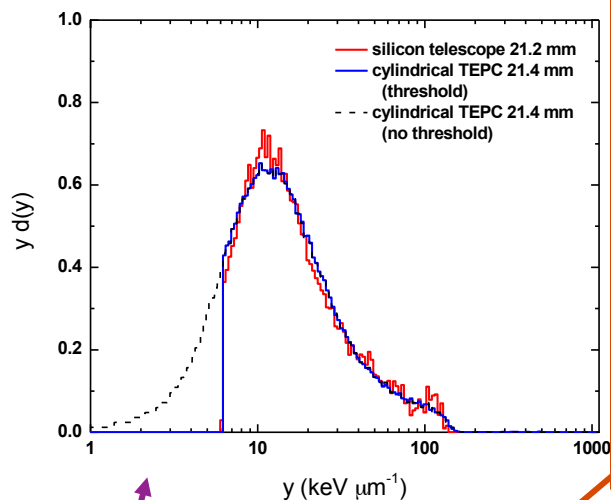
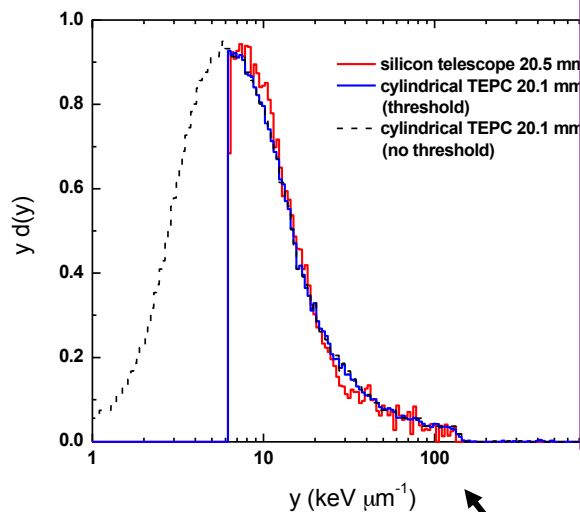


Comparison with cylindrical TEPC: proximal part of the SOBP



**Constant TE
scaling factor**

Comparison with cylindrical TEPC: distal part of the SOBP



**Event-by-event
TE correction**

62 MeV modulated proton beam (CATANA)

Results:

- easy-of-use system;
- rapid data processing;
- good measurement repeatability;
- high spatial resolution;
- good agreement at lineal energies higher than 7-10 keV μm^{-1} up to the proton edge.

Problems to solve or to minimize:

- high electronic noise;
- counting rates, mainly related to the relative dimension between ΔE stage and E stage active areas.

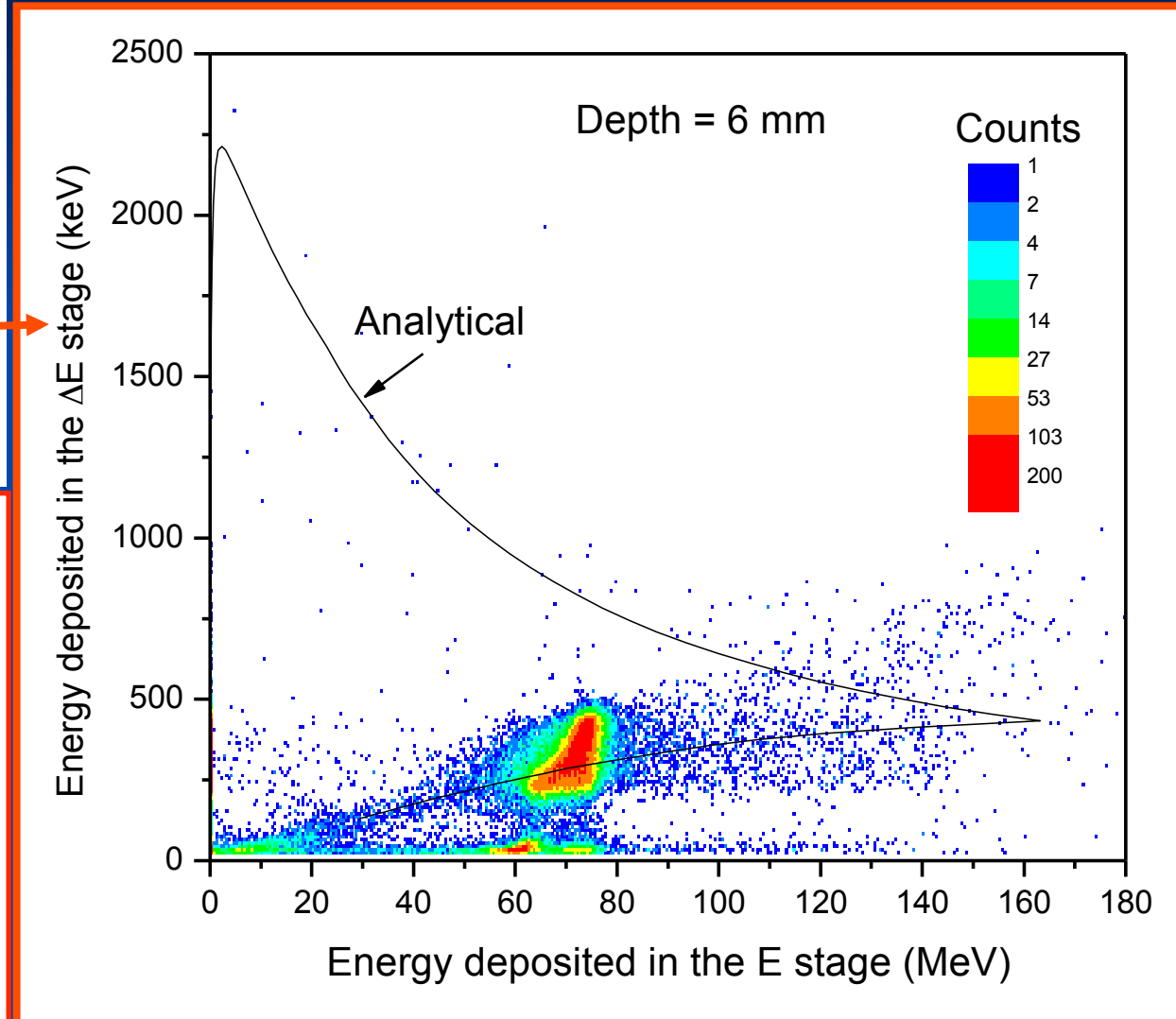
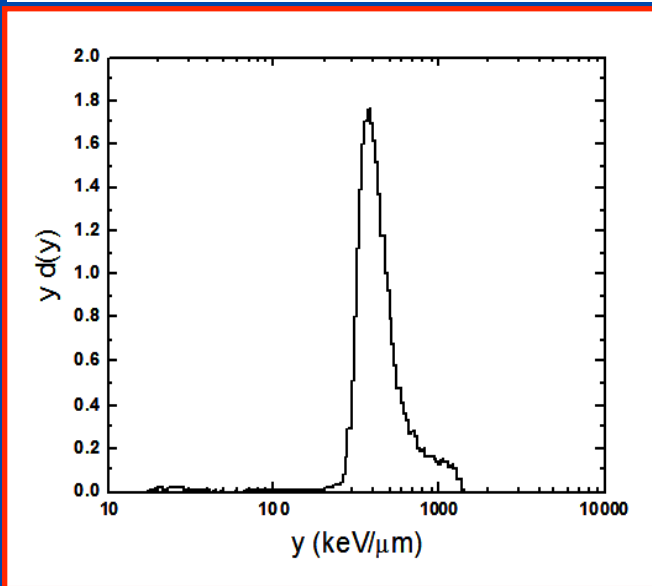
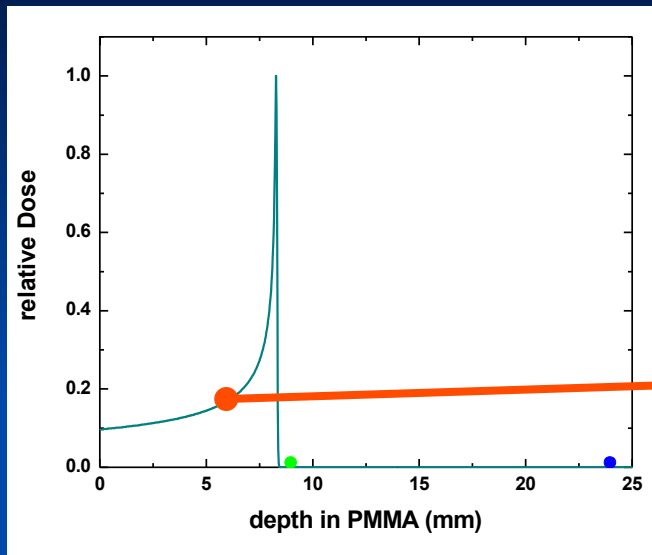
Issues:

- accurate estimate of dose profile;
- radiation damage.

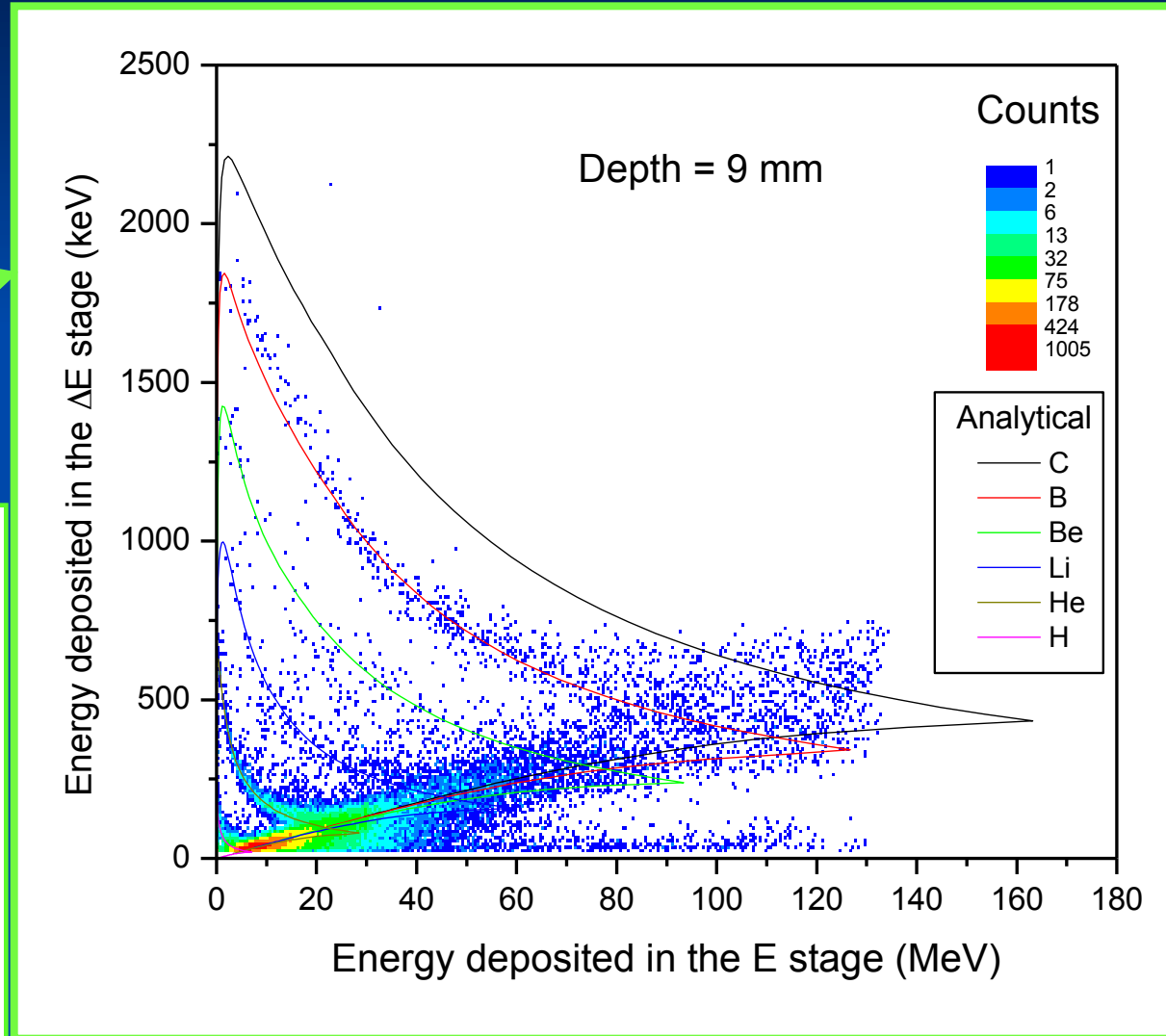
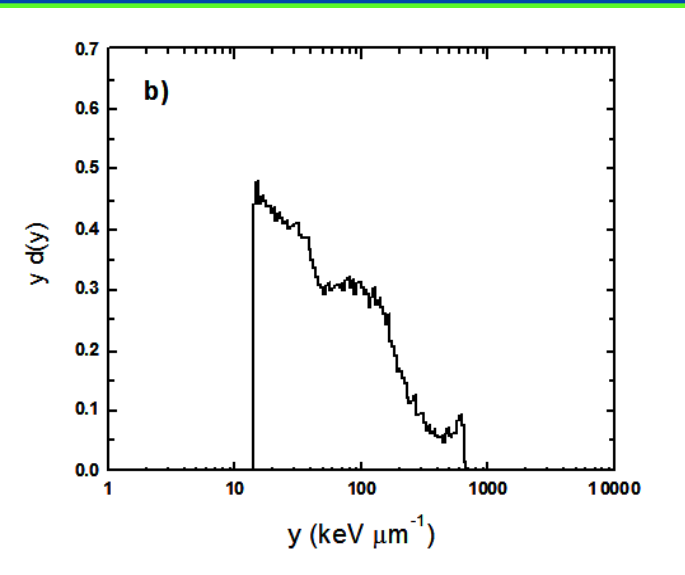
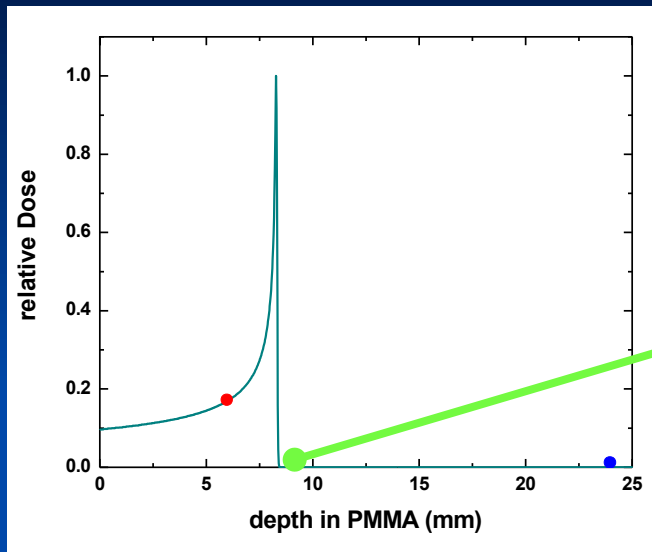
RESPONSE TO CARBON IONS:

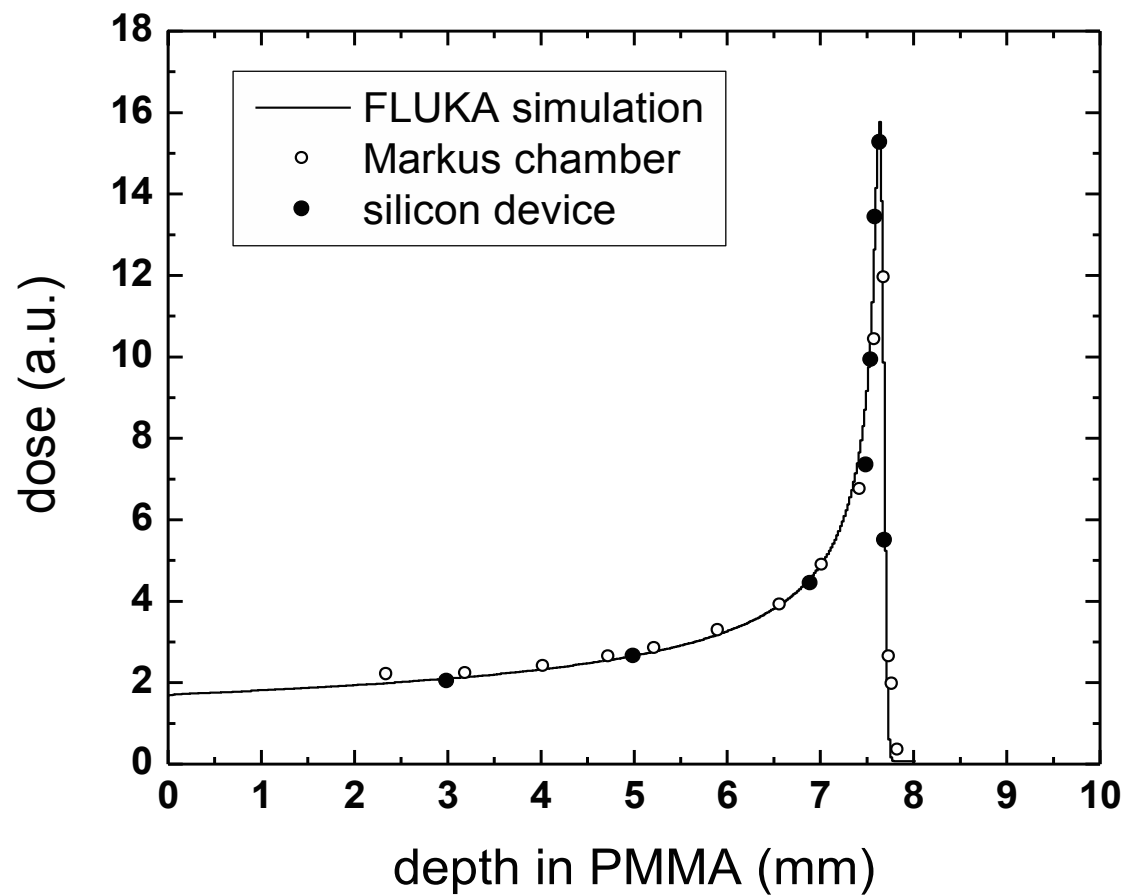
Irradiations with
62 MeV/u un-modulated carbon beam
at CATANA facility
(LNS-INFN Catania)

62 MeV/u un-modulated carbon beam (CATANA)



62 MeV/u un-modulated carbon beam (CATANA)





62 MeV/u un-modulated carbon beam (CATANA)

Results:

- high spatial resolution;
- capability of operating in a complex and intense radiation field;
- discrimination capability and potentialities.

Problems to solve or to minimize:

- relative dimension between ΔE stage and E stage active areas;
- counting rates;
- radiation damage.

CONCLUSIONS

IMPROVEMENT OF THE ENERGY TRESHOLD:

A feasibility study of a low-LET silicon
microdosimeter

Improvement of the energy threshold

The main limitation of the system is the high energy threshold imposed by the electronic noise.

New design of the segmented telescope with a ΔE stage having a lower number of cylinders connected in parallel and an E stage with an optimized sensitive area

1. Decrease the energy threshold below $1 \text{ keV } \mu\text{m}^{-1}$
2. Optimize the counting rate of the two stages