Study of a Silicon Microdosimeter for Radiation Quality Assessment in Hadron Therapy Fields

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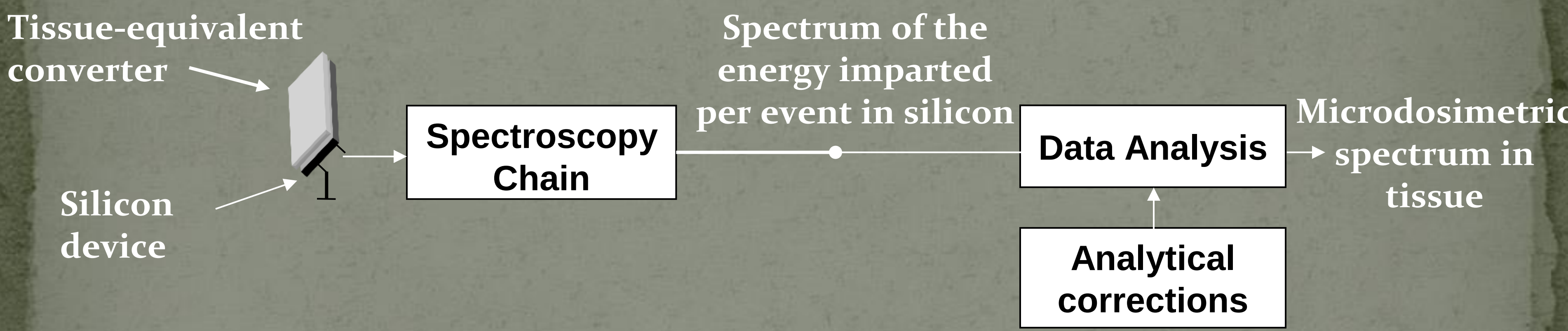
Solid State Microdosimetry

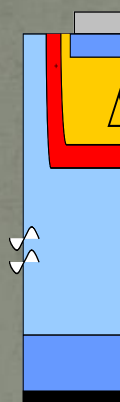
Concept of silicon microdosimetry

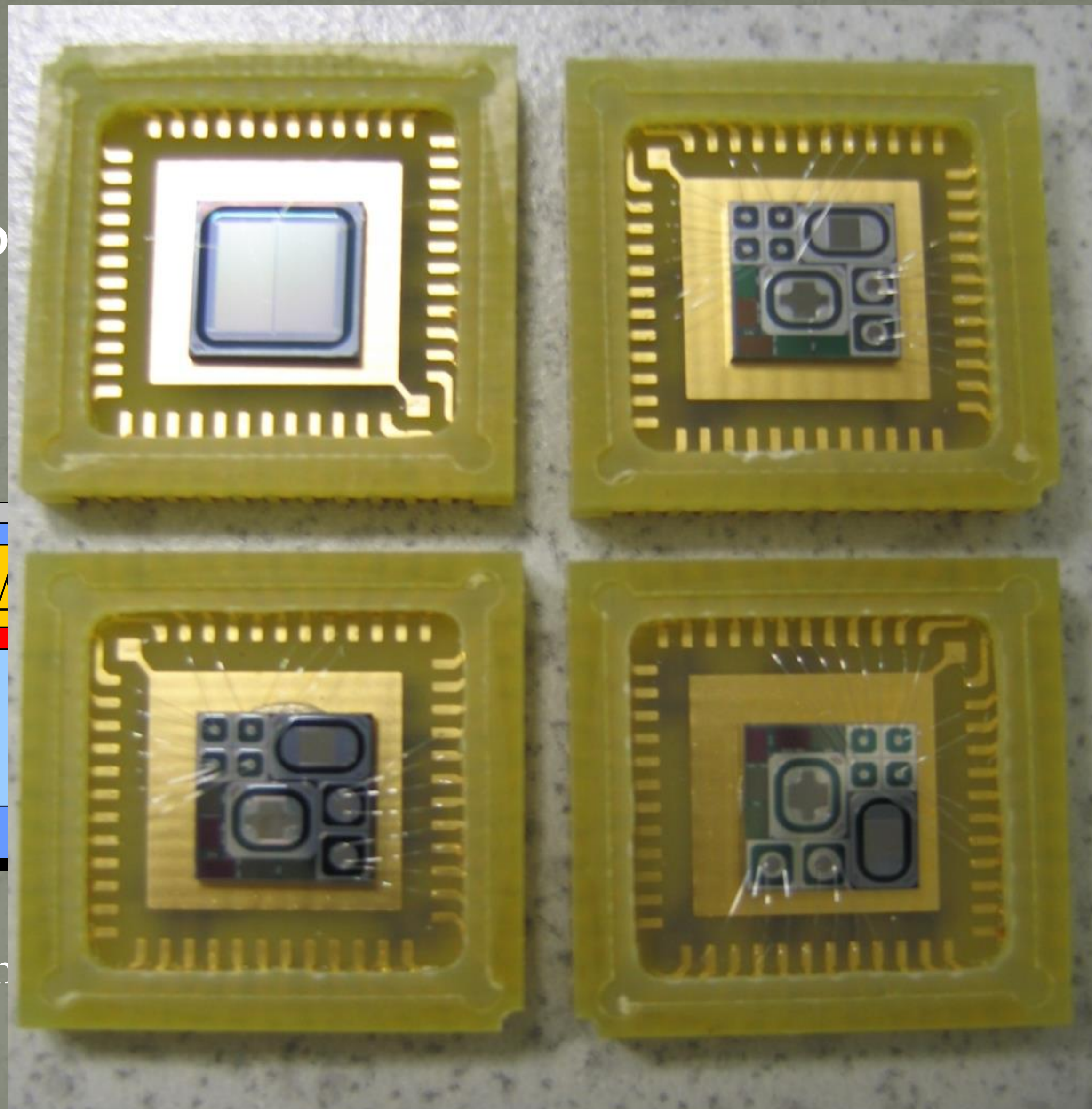
Si-devices can provide sensitive zones of the order of a micrometer



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.

- Mo … E stage





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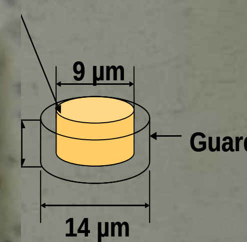


Ser … parallel
… .5 mm²

Tissue equivalence and Geometrical Corrections

- For deriving microdosimetric spectra comparable to those a acquired by a TEPC:

- Tissue equivalence for silicon
  Optimized tissue equivalence correction by measuring event–by–event the energy of the impinging particles.

- Shape equivalence
  The linear energy is calculated by the mean chord 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

Analytical procedure for tissue-equivalence correction

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

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

Energy & type of impinging particle

Geometrical correction

The procedure is based on chord length distributions

⬇

The ΔE elements are cylinders of micrometric dimensions as the TEPCs

By assuming a constant linear energy transfer L:

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

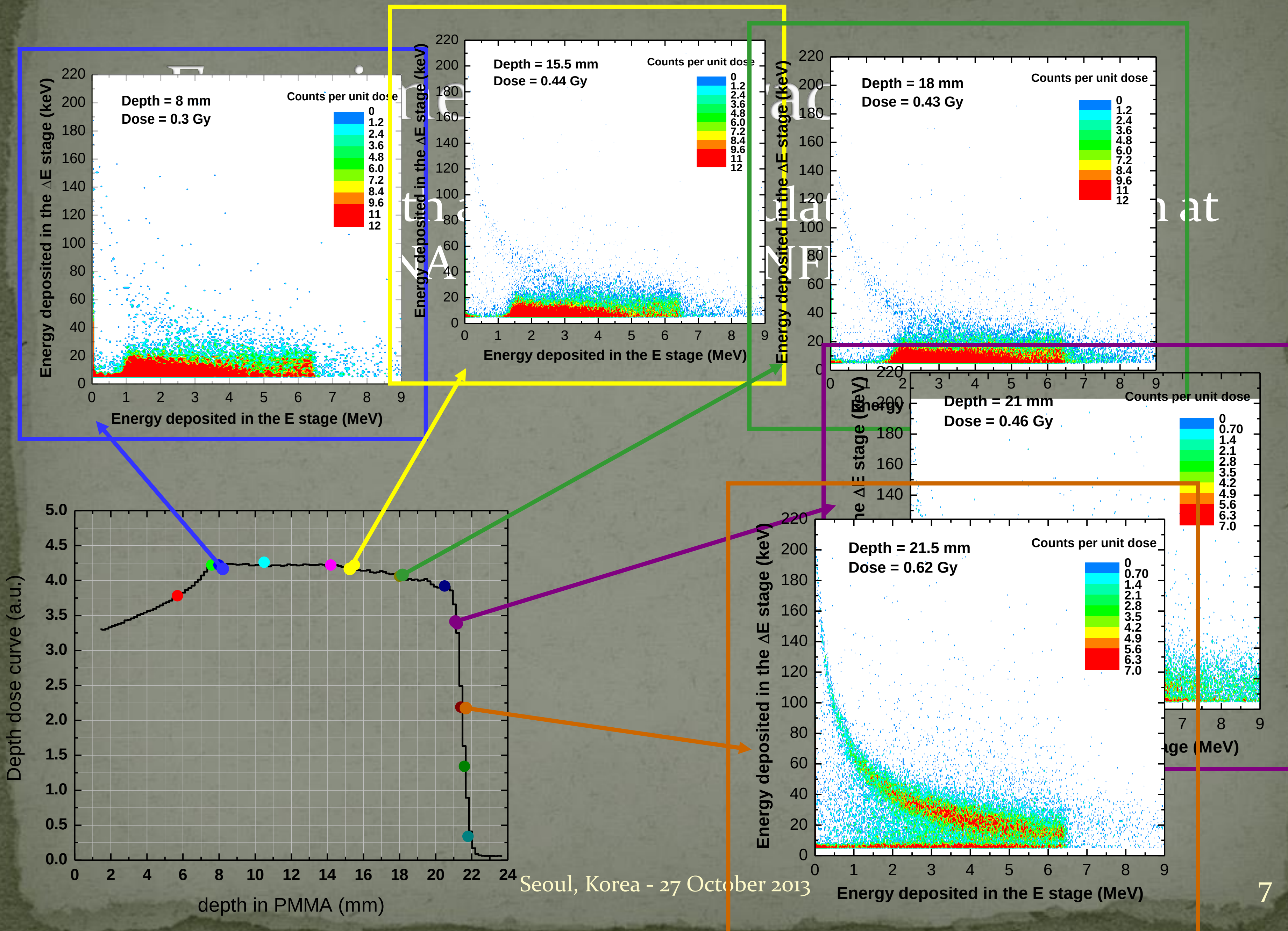
By equating the dose-mean energy imparted per event for the two different shapes considered:

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

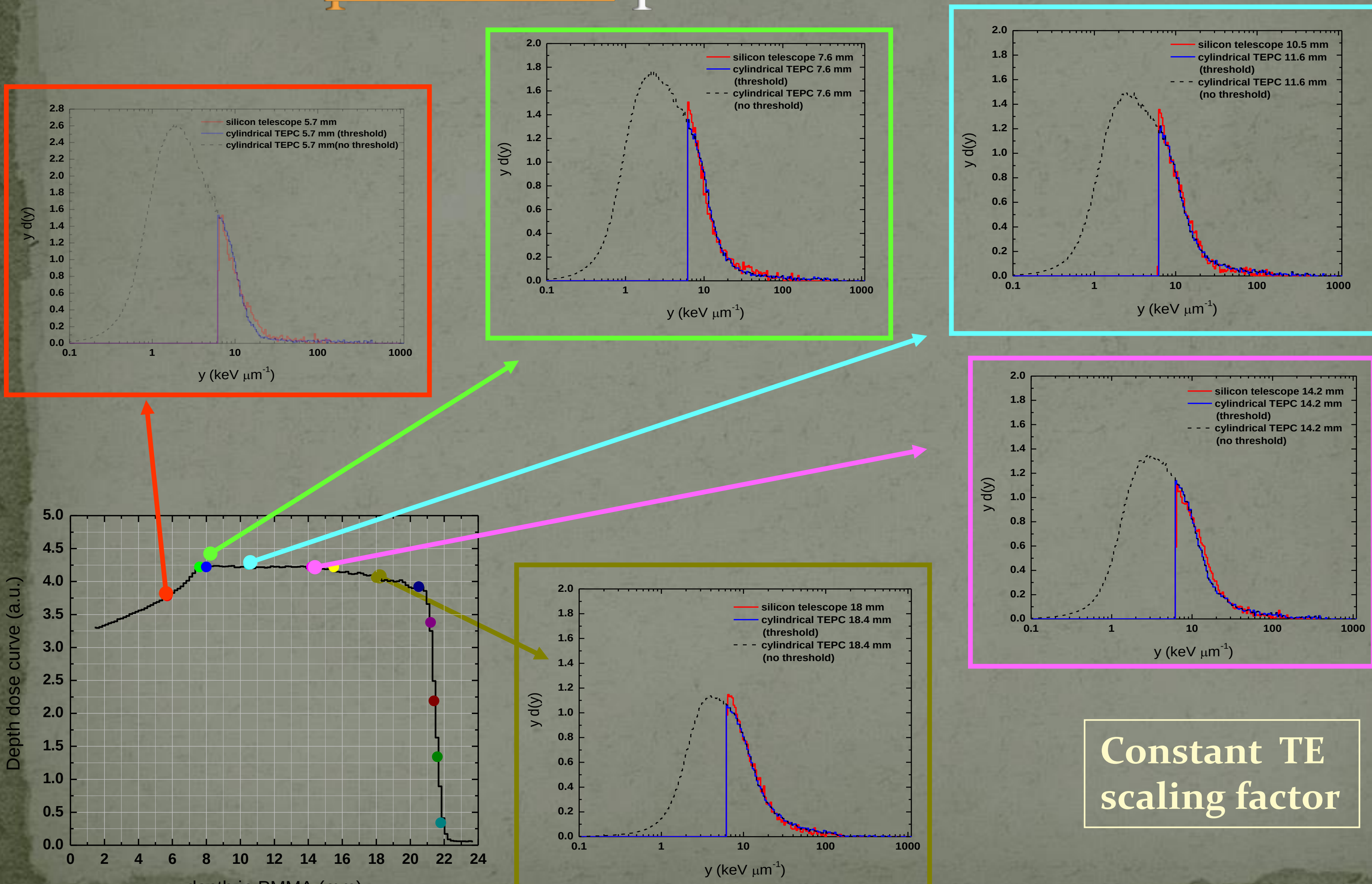
Dimensions of ΔE stages were scaled by a factor η …

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

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

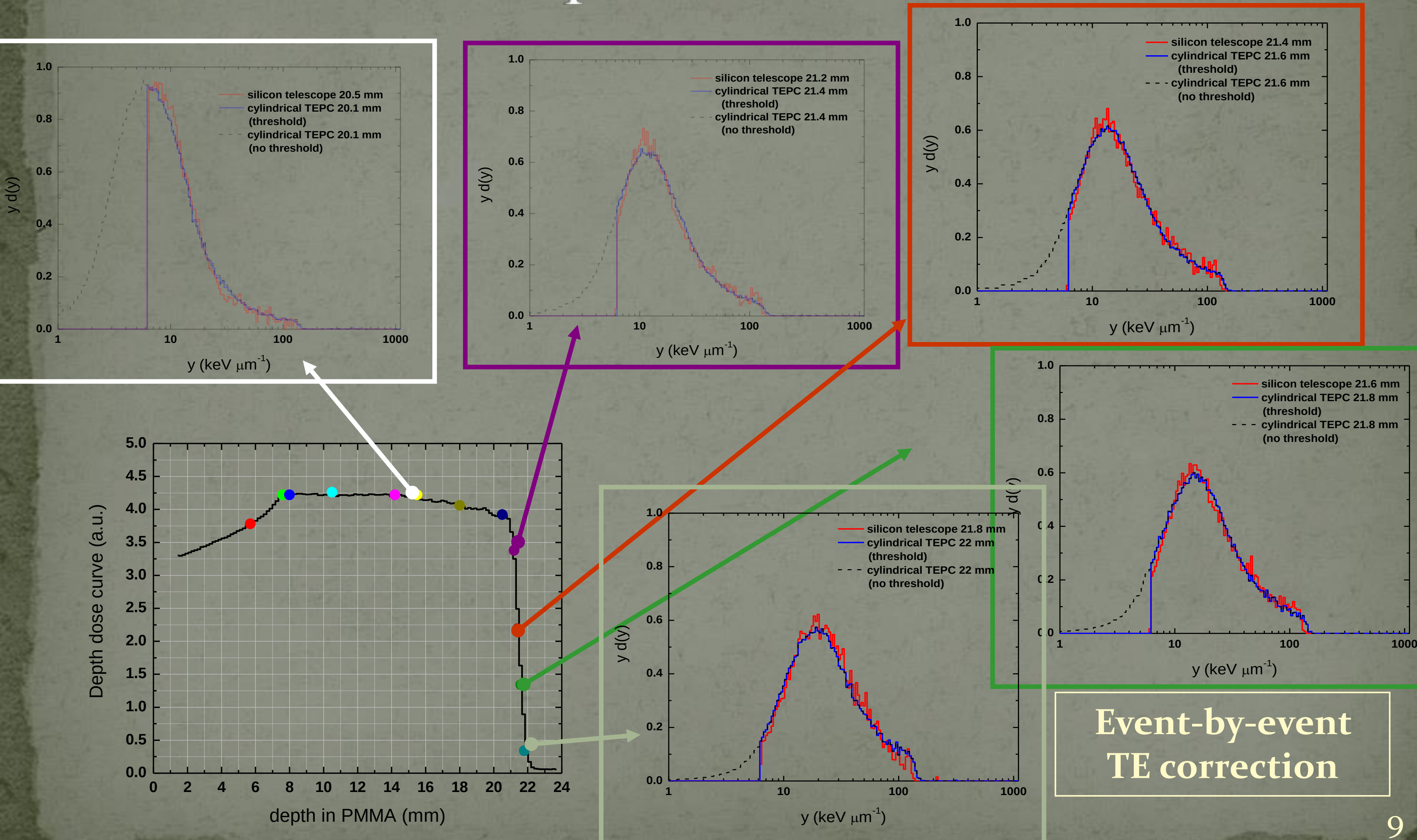

Depth = 8 mm
Dose = 0.3 Gy
Counts per unit dose
Energy deposited in the ΔE stage (keV)
Energy deposited in the E stage (MeV)
Depth = 15.5 mm
Dose = 0.44 Gy
Depth = 18 mm
Dose = 0.43 Gy
Depth = 21 mm
Dose = 0.46 Gy
Depth = 21.5 mm
Dose = 0.62 Gy
Depth dose curve (a.u.)
depth in PMMA (mm)

Comparison with cylindrical TEPC: proximal part of the SOBP



Constant TE scaling factor

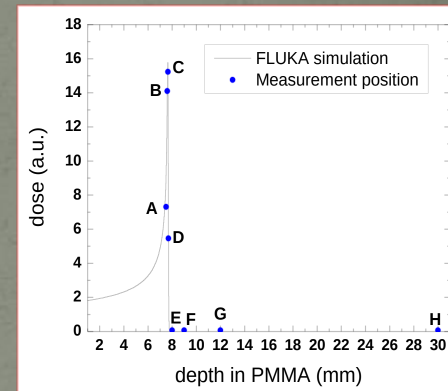
Comparison with cylindrical TEPC: distal part of the SOBP

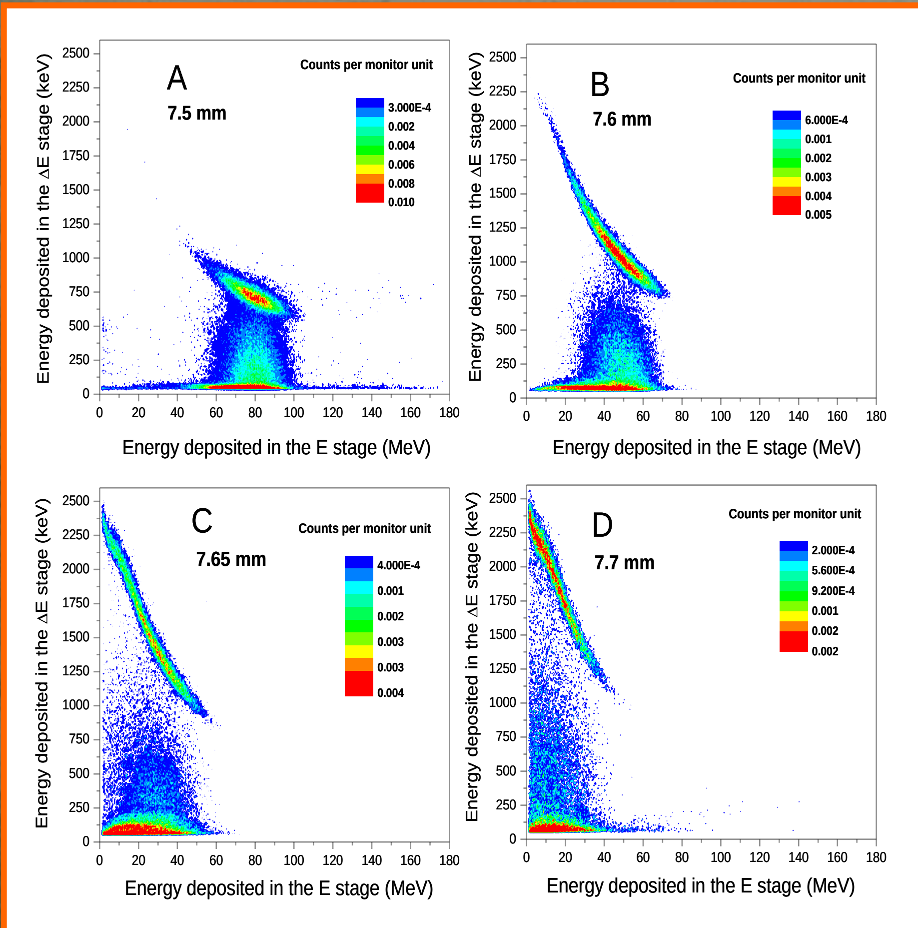


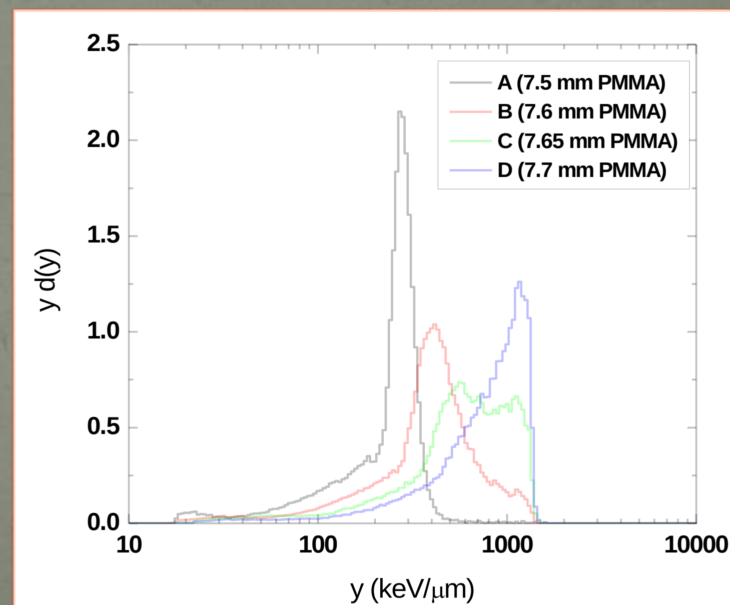
Event-by-event TE correction

Preliminary irradiations with carbon ions 62 AMeV un-modulated carbon beam at the INFN-LNS

ΔE-E scatter plots and lineal energy spectra







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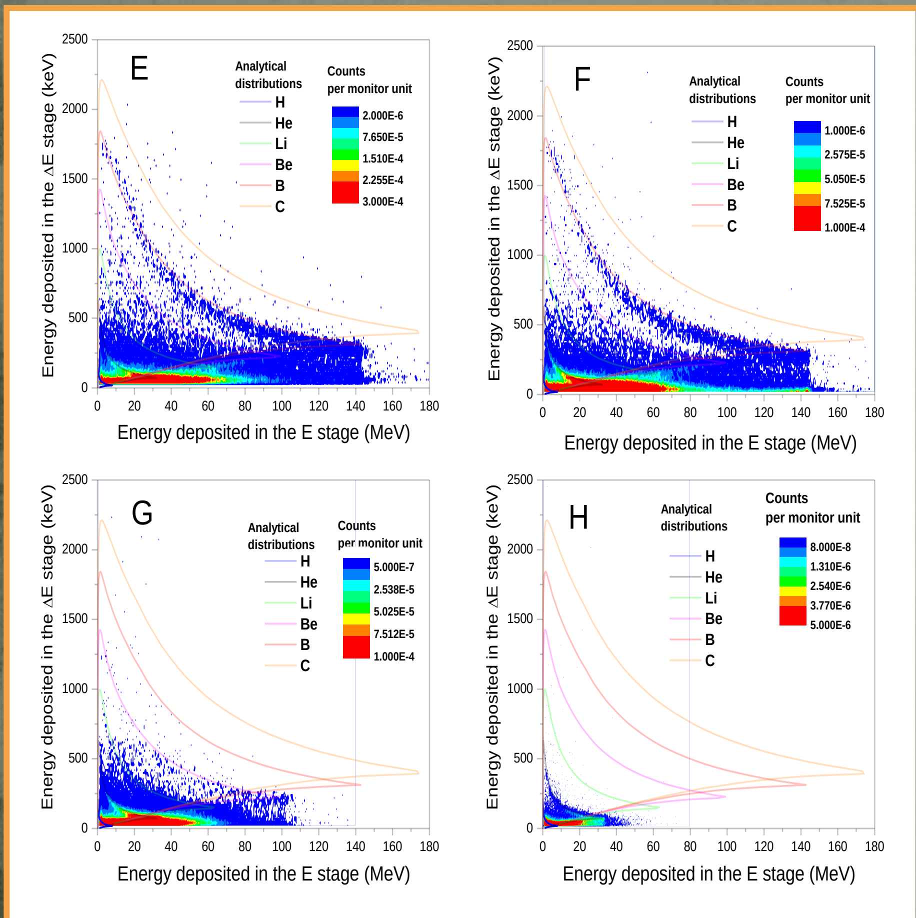
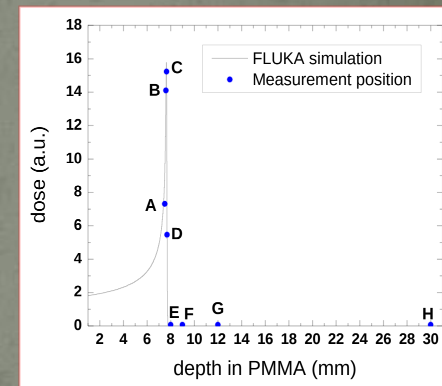
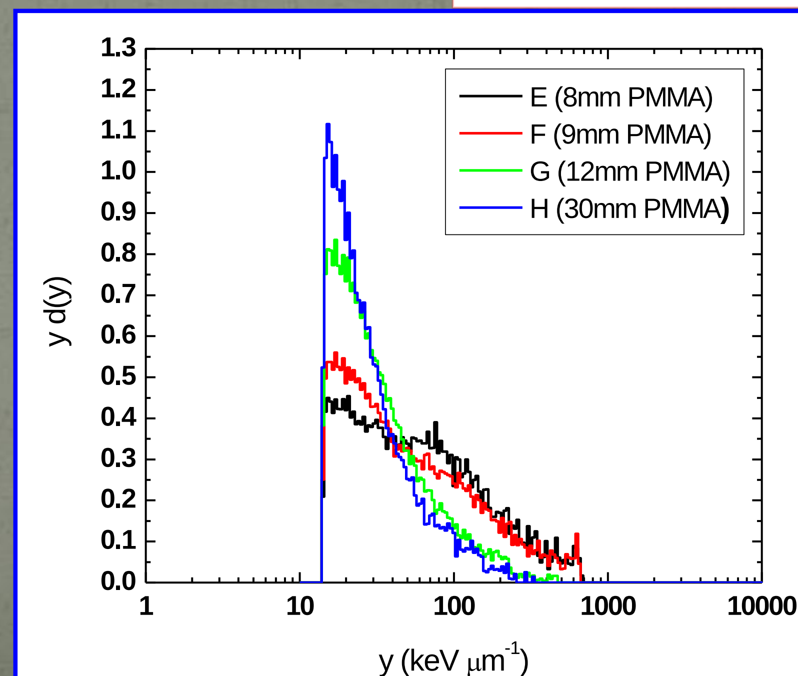


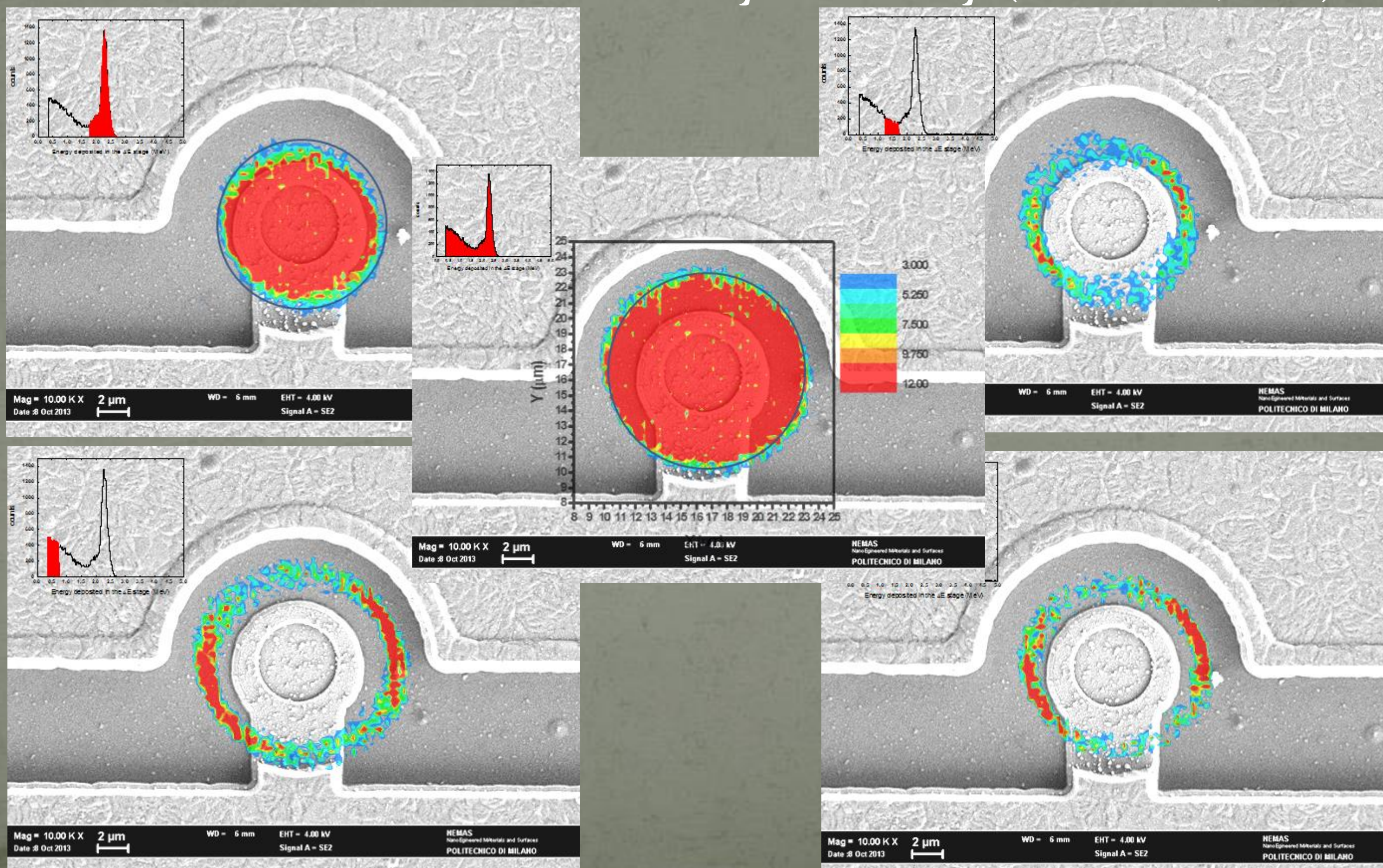




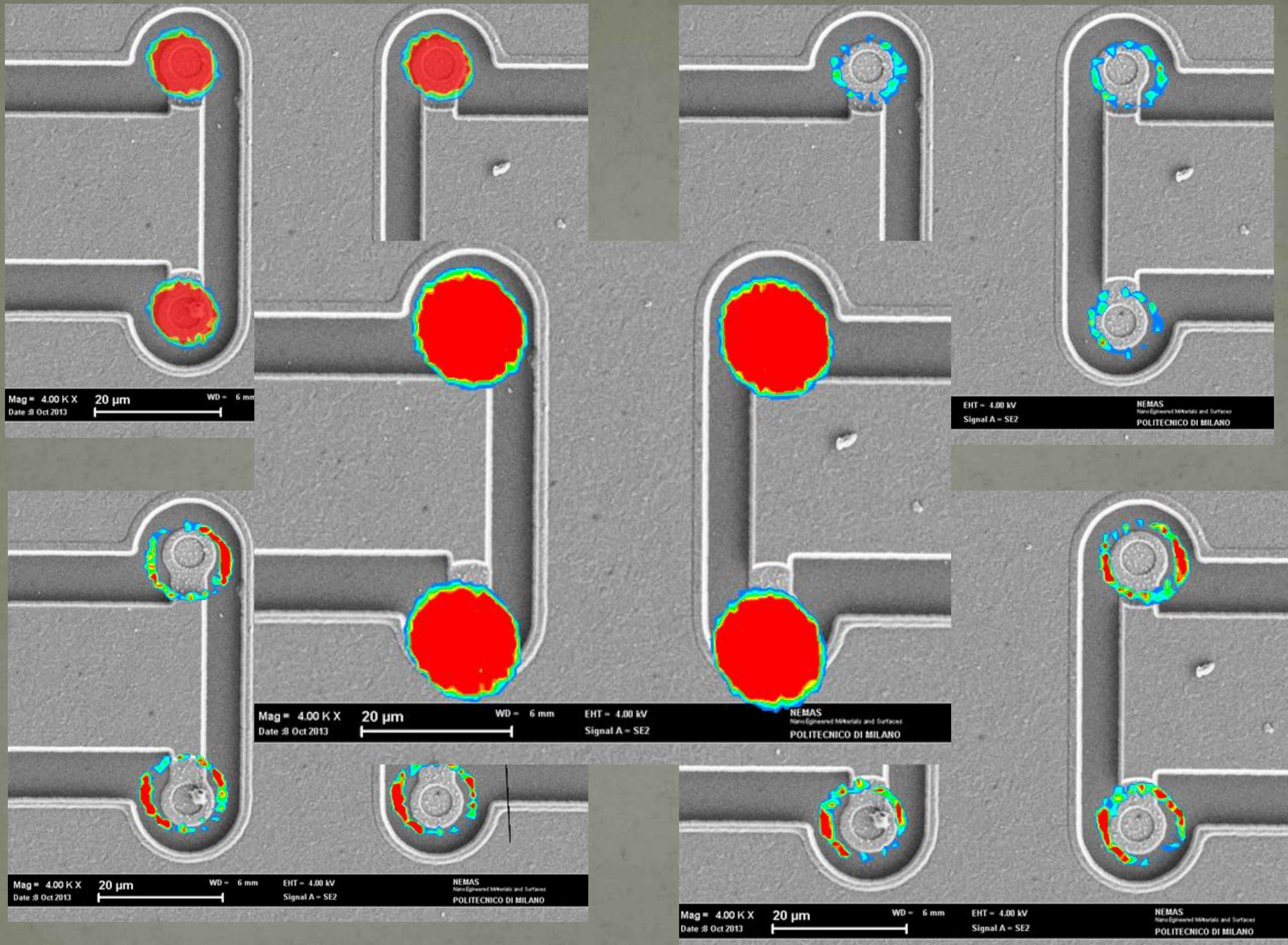
The figures have been kindly provided by A. Pola, P. Teles and S. Galer (BioQuart Project – EURAMET and SPIRIT Project – EU)

Microbeam ~ 1.5µm spot size of 10MeV carbon ions

Ion Beam Centre of University of Surrey (Guilford, UK)

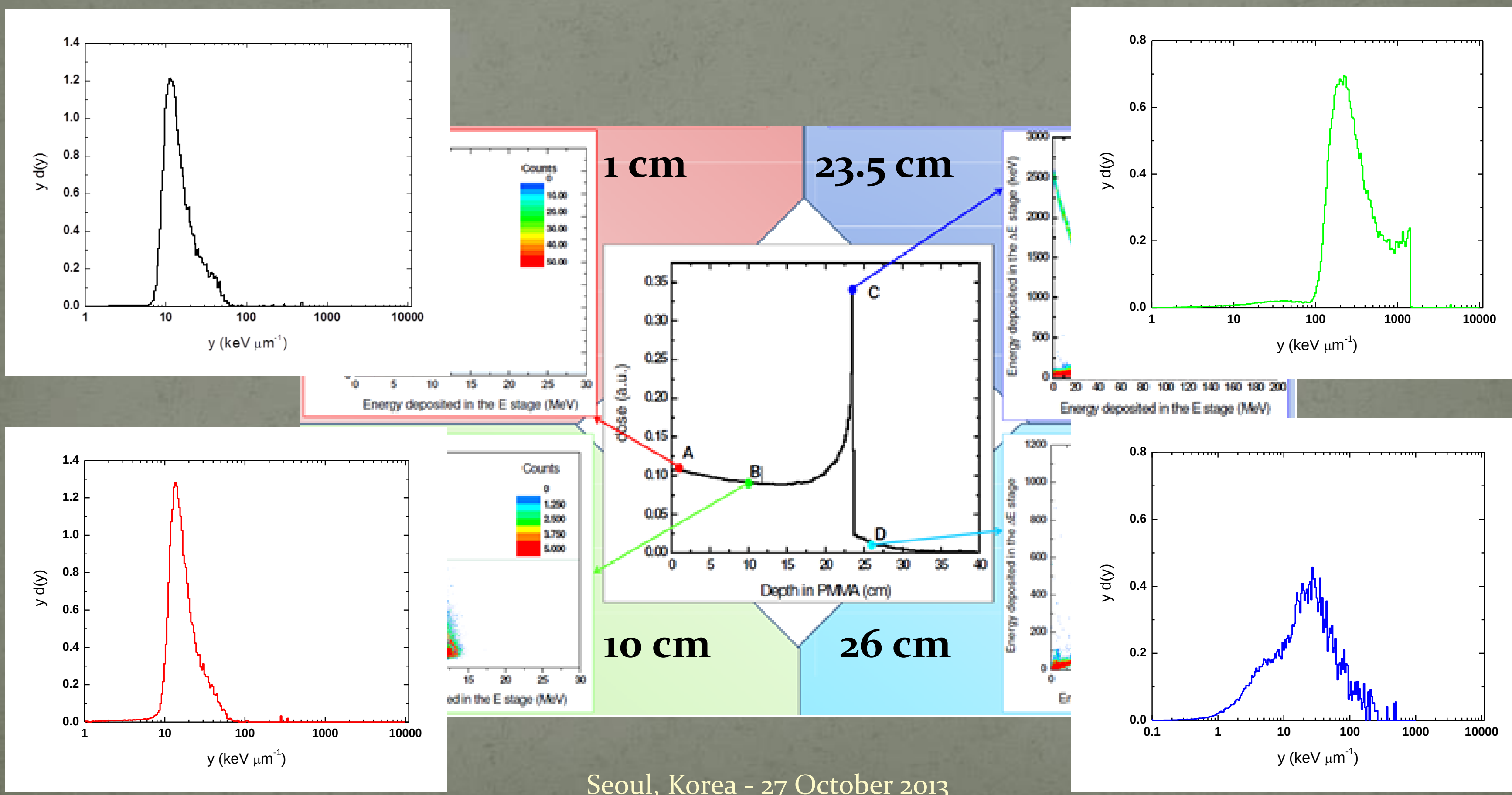


BioQuart Project – EURAMET and SPIRIT Project – EU



Simulation Results

FLUKA simulations → ^{12}C 400MeV/u in PMMA



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Conclusions

- ☺ The silicon microdosimeters show interesting features for microdosimetry, but still there are some issues that should be shorted out:
  - ☹ electronic noise (minimum detectable lineal energy);
  - ☹ radiation hardness when exposed to high-intensity hadron beams.

☞ Further study