# A silicon microdosimeter for radiation quality assessment

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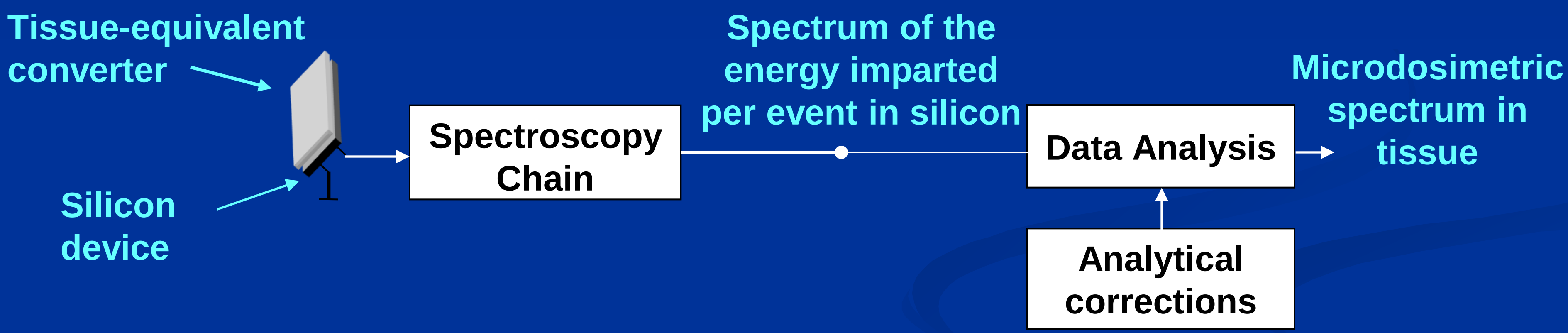
[3] ARDENT project.

# 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?…




## PN diodes in SOI wafer

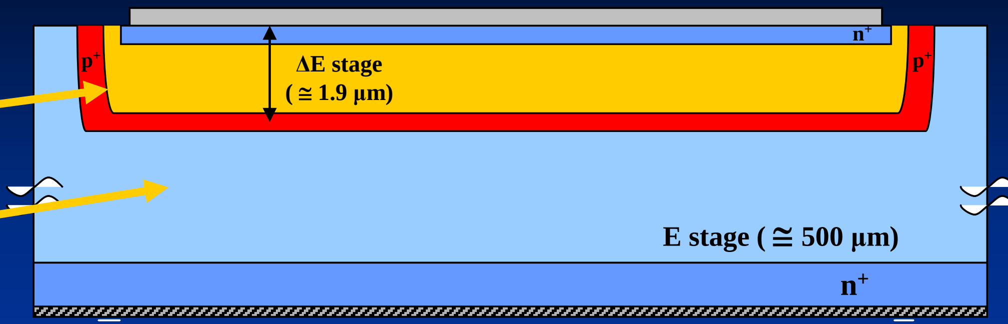

[1] B. Rosenfeld, P. Bradley, I. Cornelius, G. Kaplan, B. Allen, J. Flanz, M. Goitein, A.V. Meerbeeck, J. Schubert, J. Bailey, Y. Tabkada, A. Maruashi, Y. Hayakawa, *New silicon detector for microdosimetry applications in proton therapy*, IEEE Trans. Nucl. Sci. 47(4) (2000) 1386-1394.

[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.

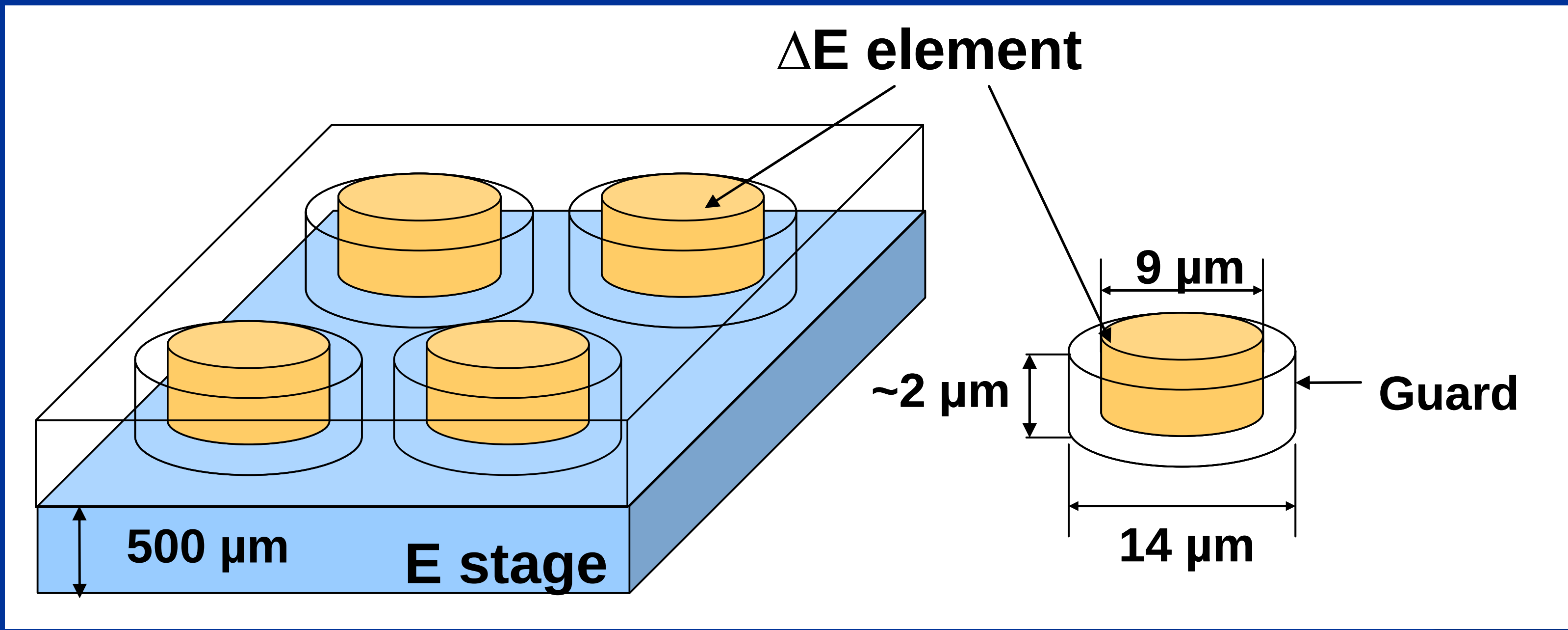
[3] P.D. Bradley, *The Development of a Novel Silicon Microdosimeter for High LET Radiation Therapy*, Ph. D. Thesis, Department of Engineering Physics, University of Wollongong, Wollongong, Australia (2000).

# 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 μm , d= 9 μm)




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**

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

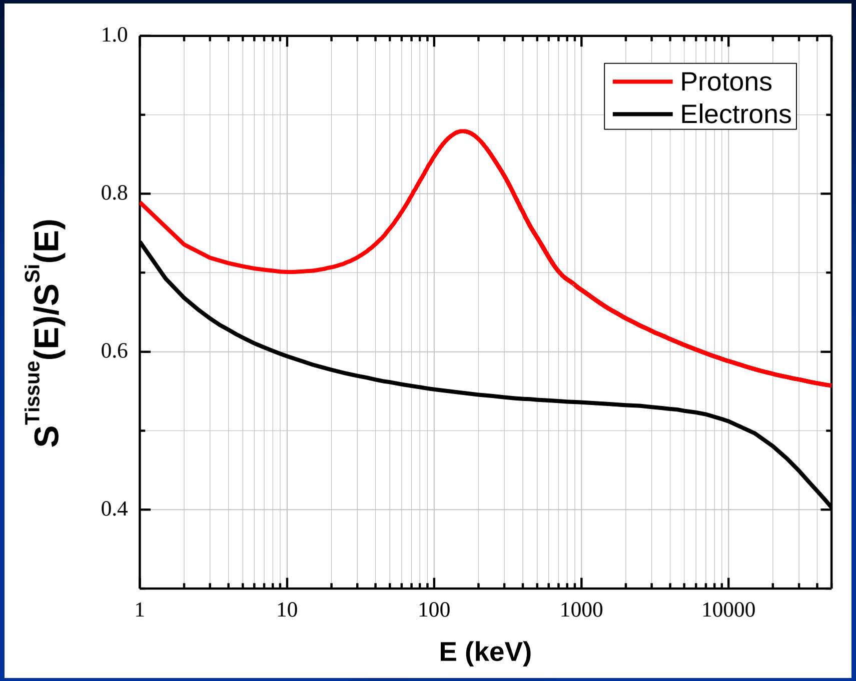
**Energy deposited along a track of length l by recoil-protons of energy $E_p$ in a tissue-equivalent ΔE detector**

**Scaling factor : stopping powers ratio**

# TISSUE-EQUIVALENCE CORRECTION

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

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

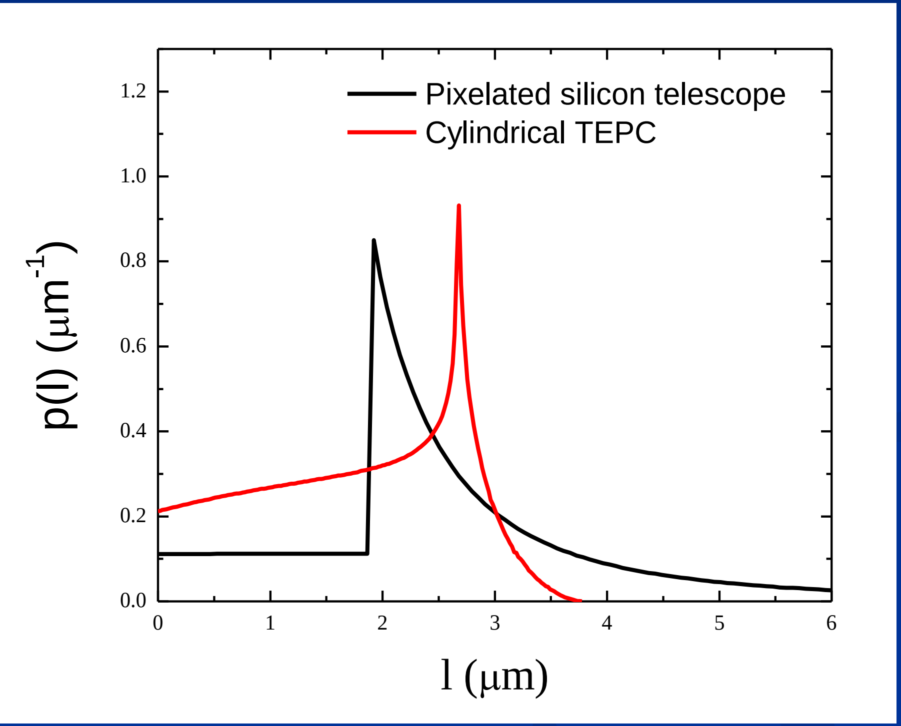
Mean value over a wide energy range (0-10 MeV) = 0.53

# SHAPE ANALYSIS

## Pixelated silicon telescope (d≈10 μm)

**The correcting procedure can be based on <u>cord</u> 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:**

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

**Dimensions of ΔE stages were scaled by a factor η …**

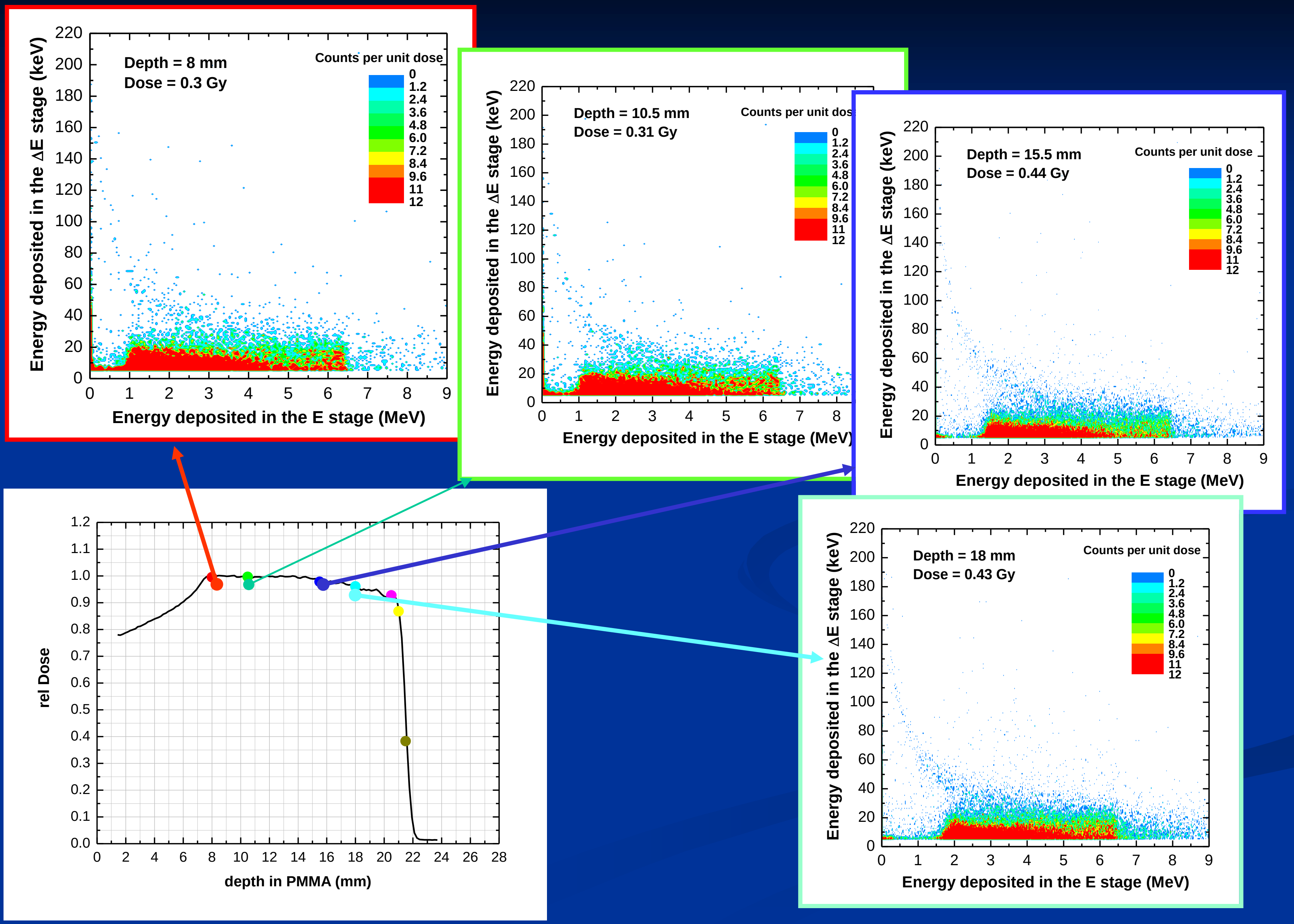
**… the lineal energy y was calculated by considering an equivalent mean cord length equal to:**

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

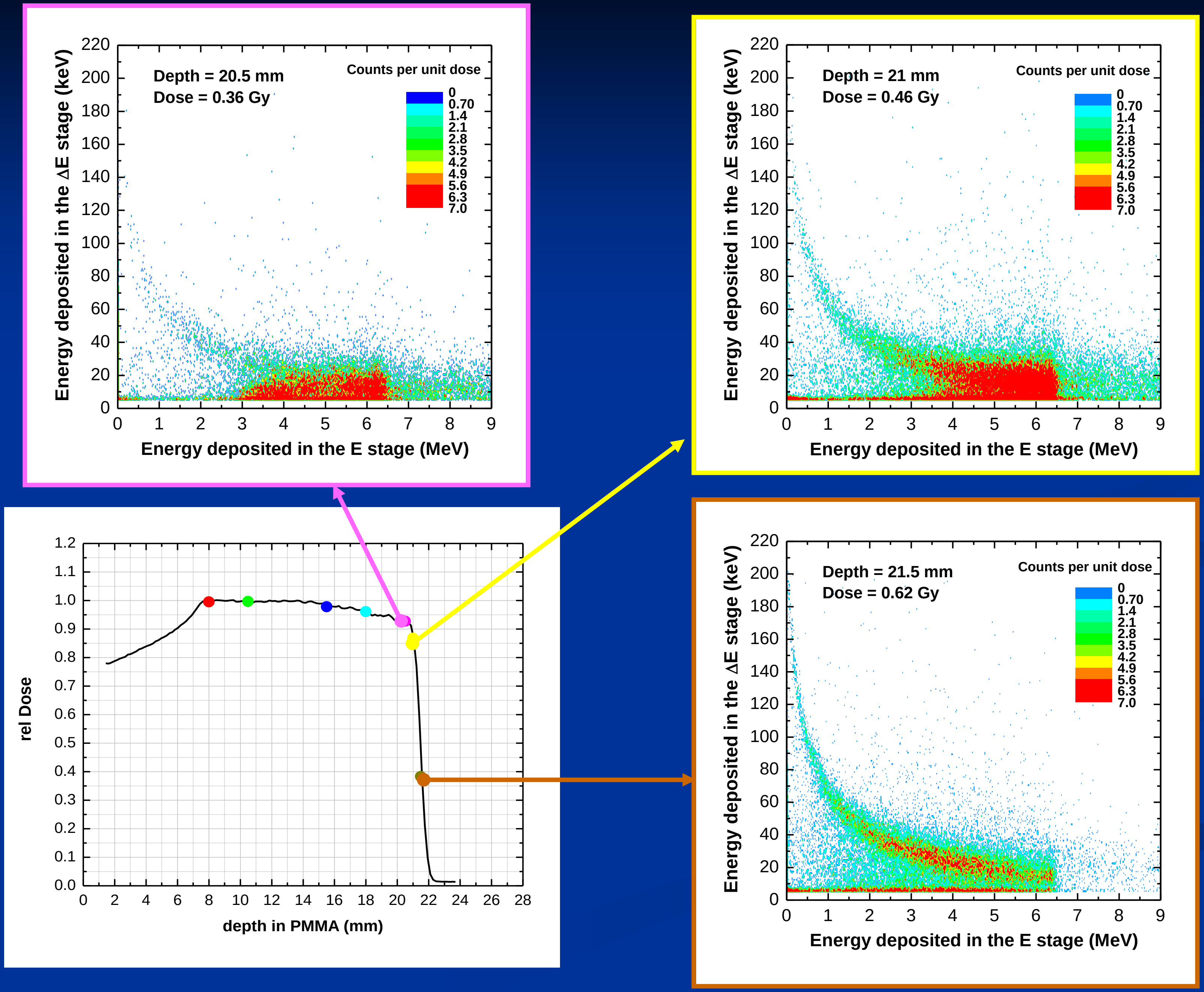
# RESPONSE TO PROTONS:

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))

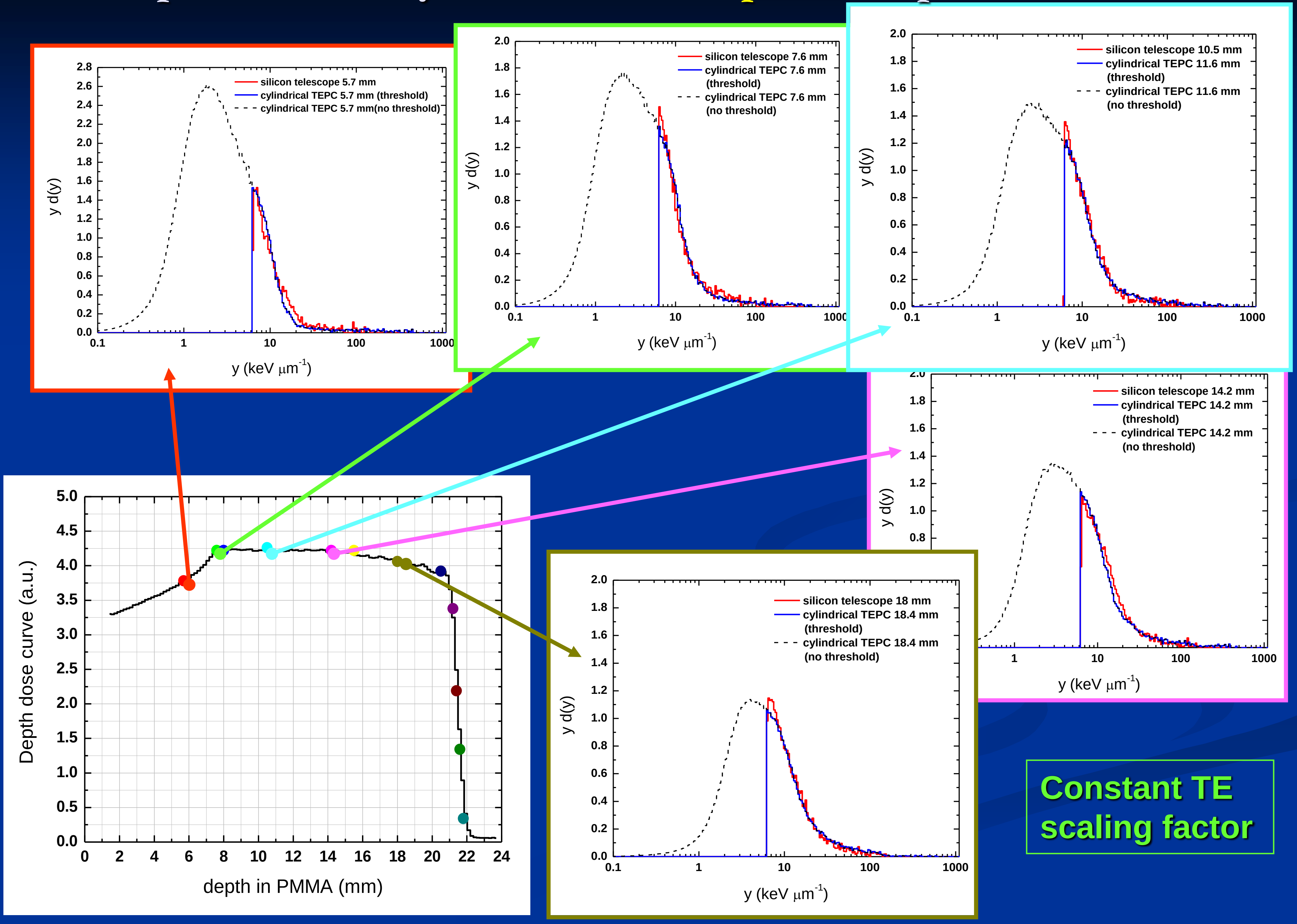
# 62 MeV modulated proton beam (CATANA)



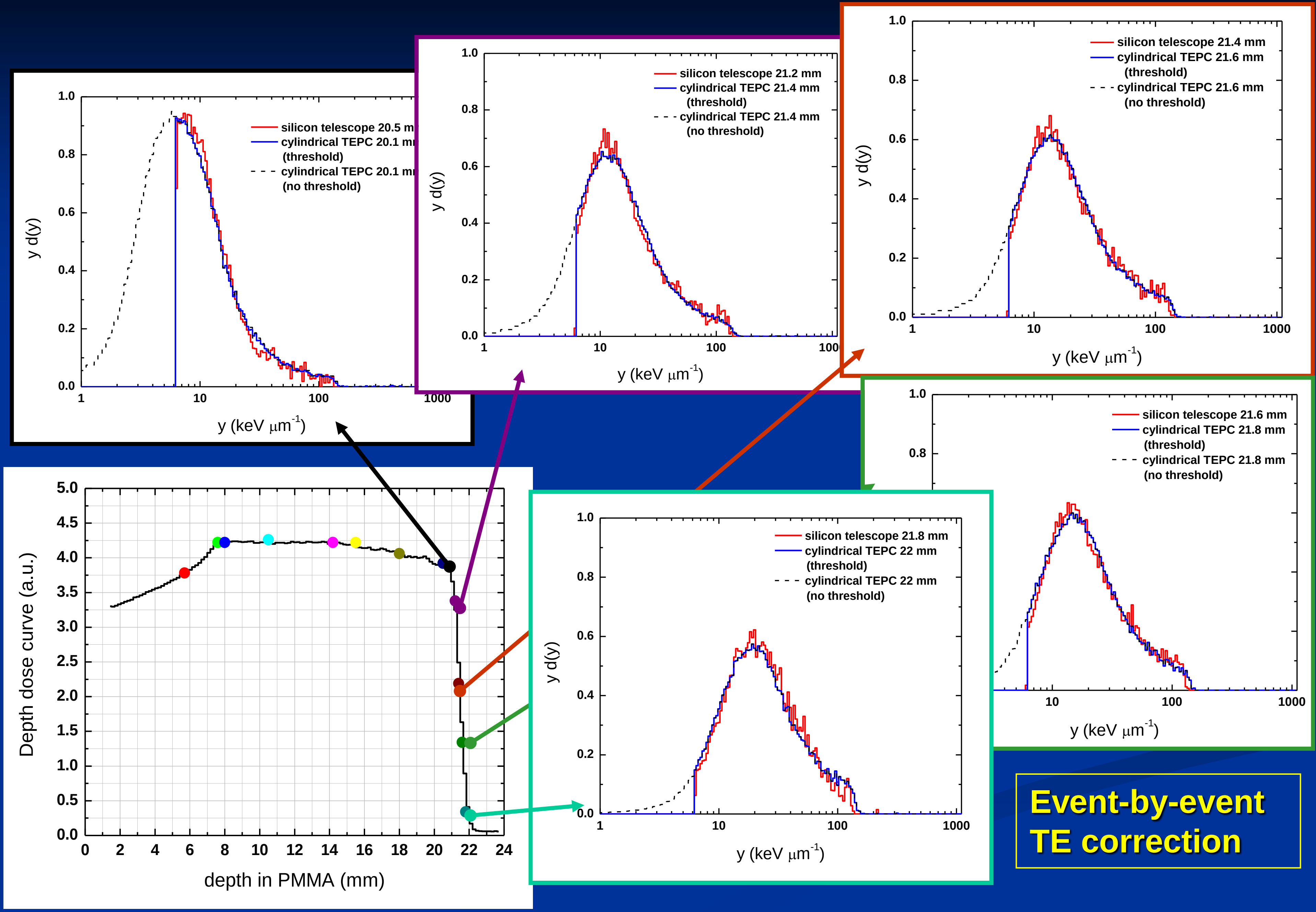
# 62 MeV modulated proton beam (CATANA)



# Comparison with cylindrical TEPC: proximal part of the SOBP



# 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 $\mu m^{-1}$up to the proton edge.

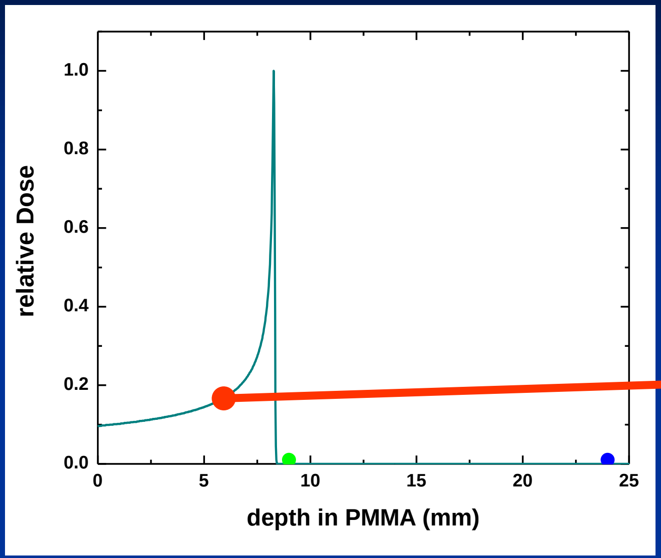
Problems to solve or to minimize:
- high electronic noise;
- counting rates, mainly related to the relative dimension between $\Delta E$ stage and E stage active areas.

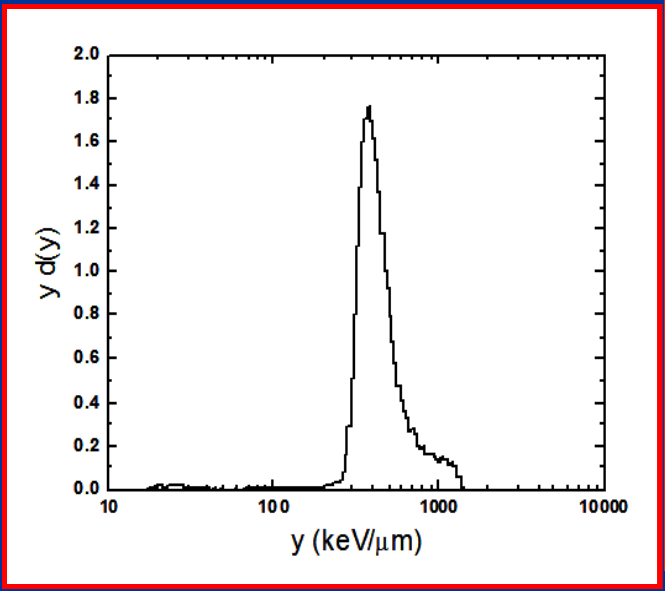
Issues:
- accurate estimate of dose profile;
- radiation damage.

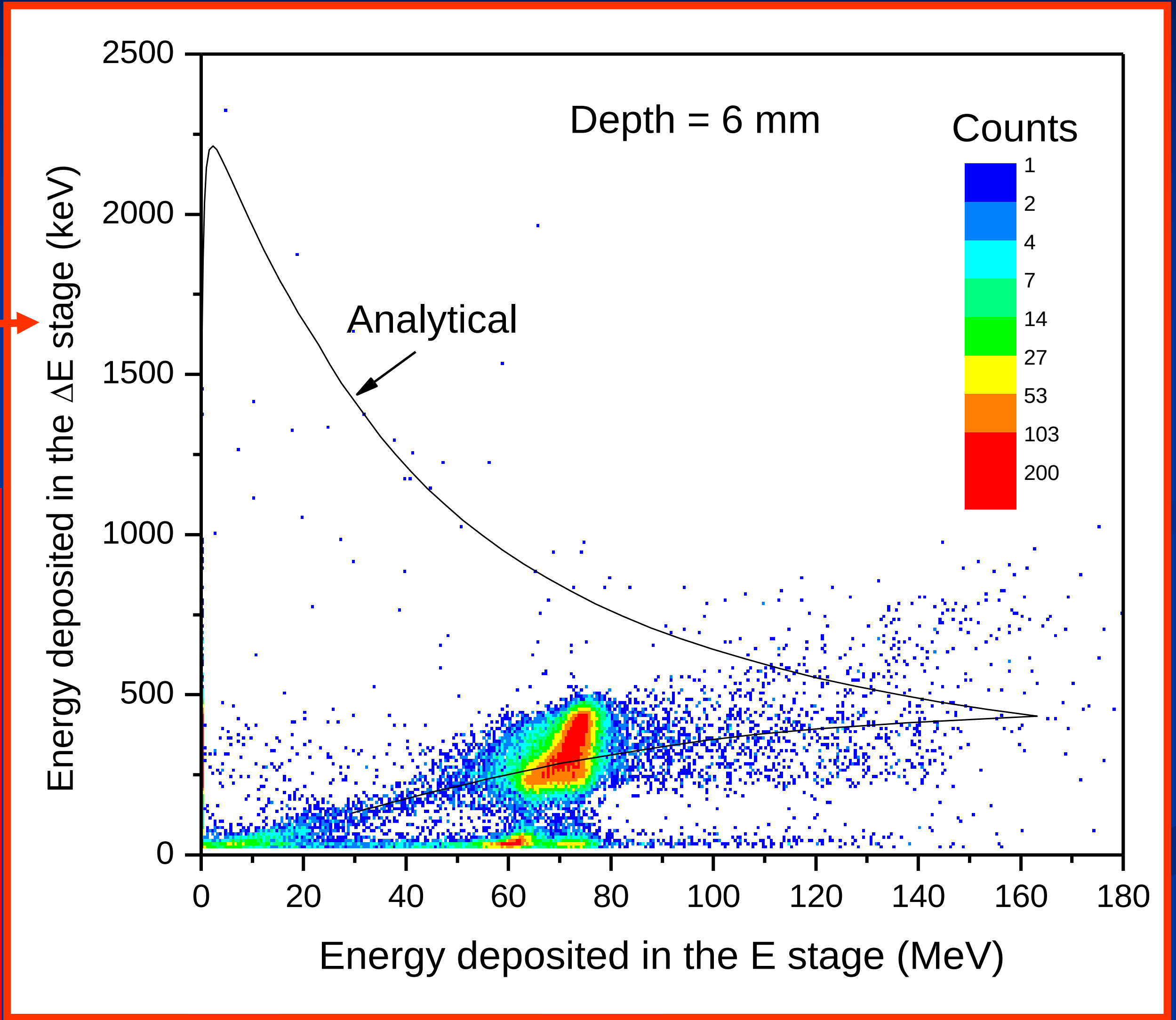
## RESPONSE TO CARBON IONS:

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

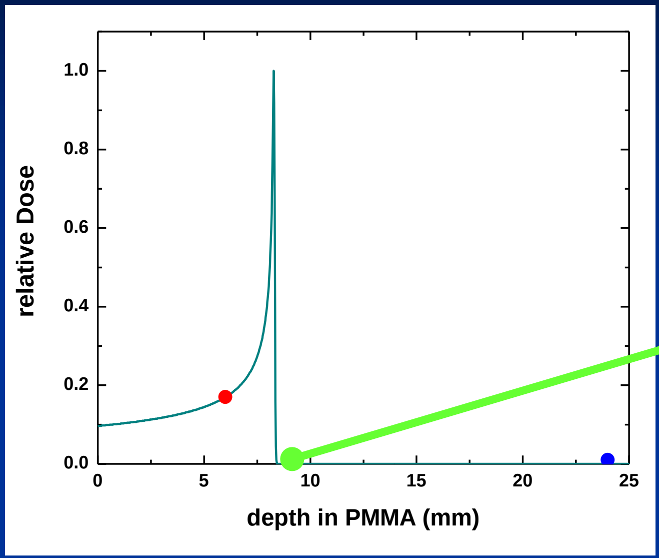
# 62 MeV/u un-modulated carbon beam (CATANA)

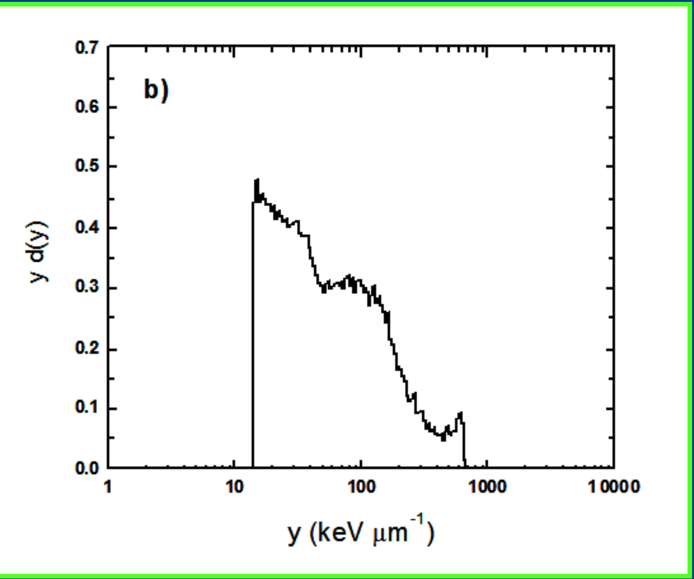


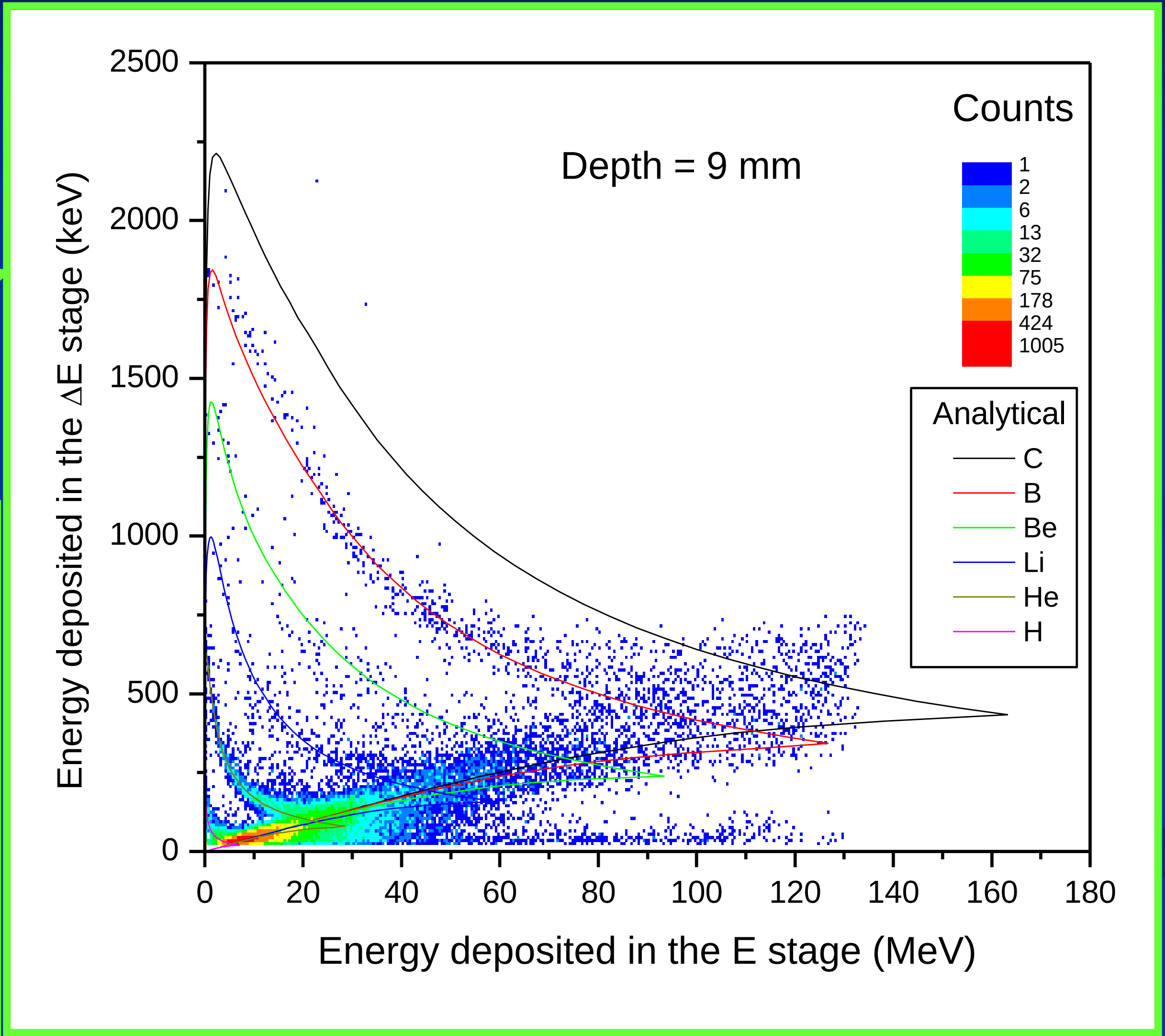



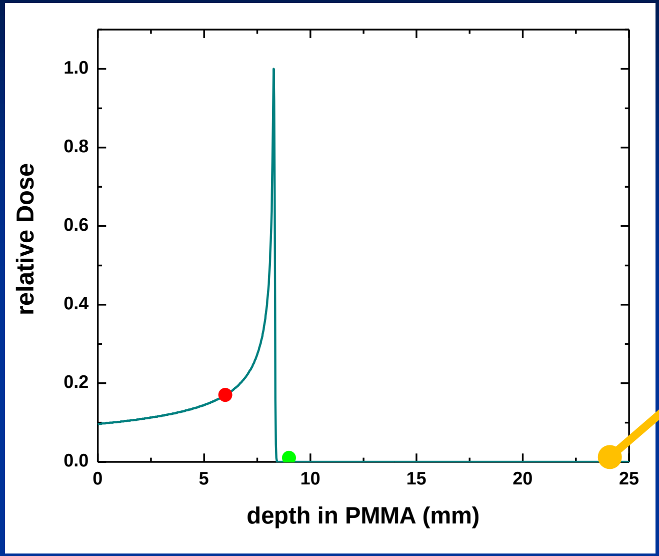
# 62 MeV/u un-modulated carbon beam (CATANA)

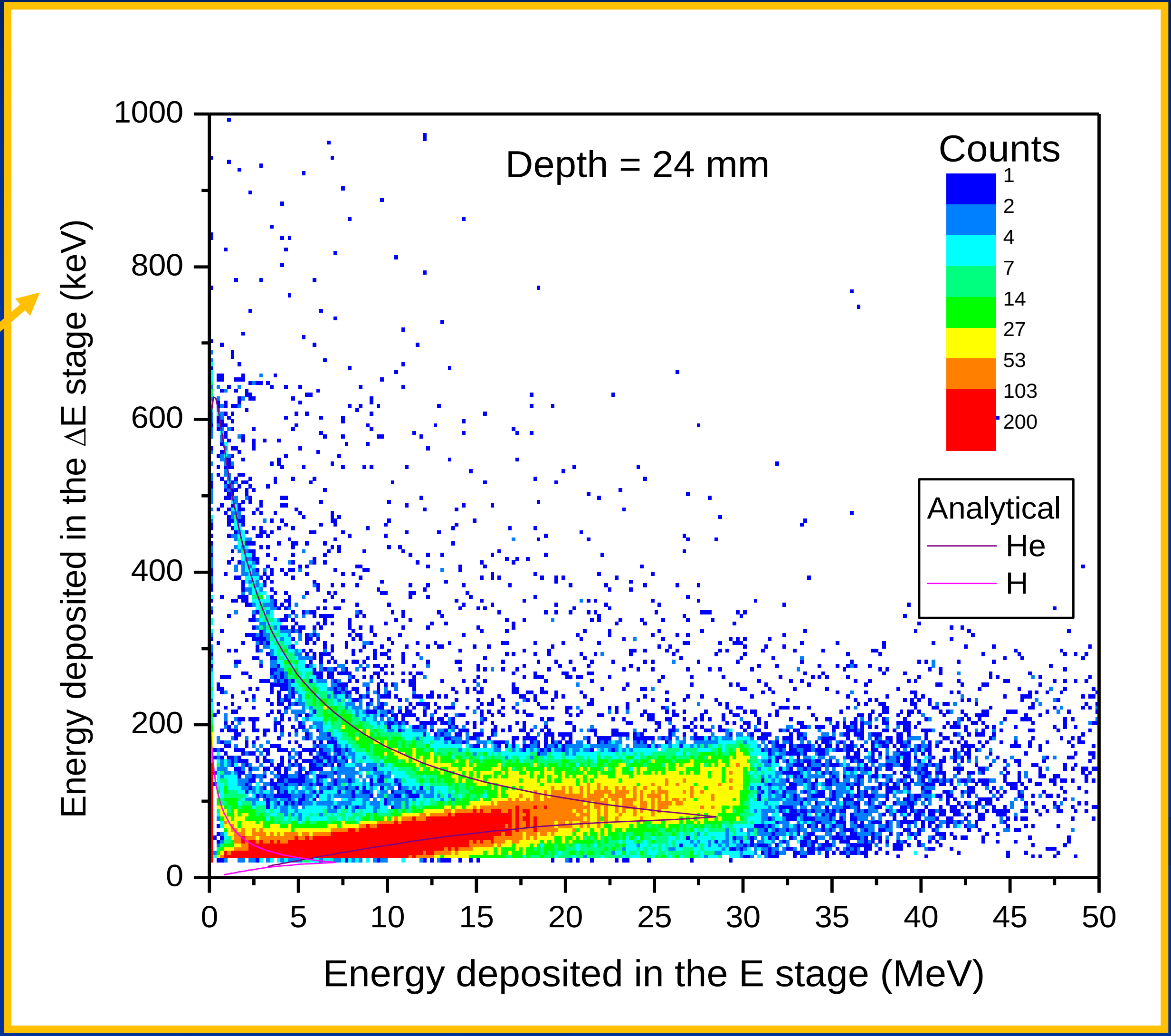


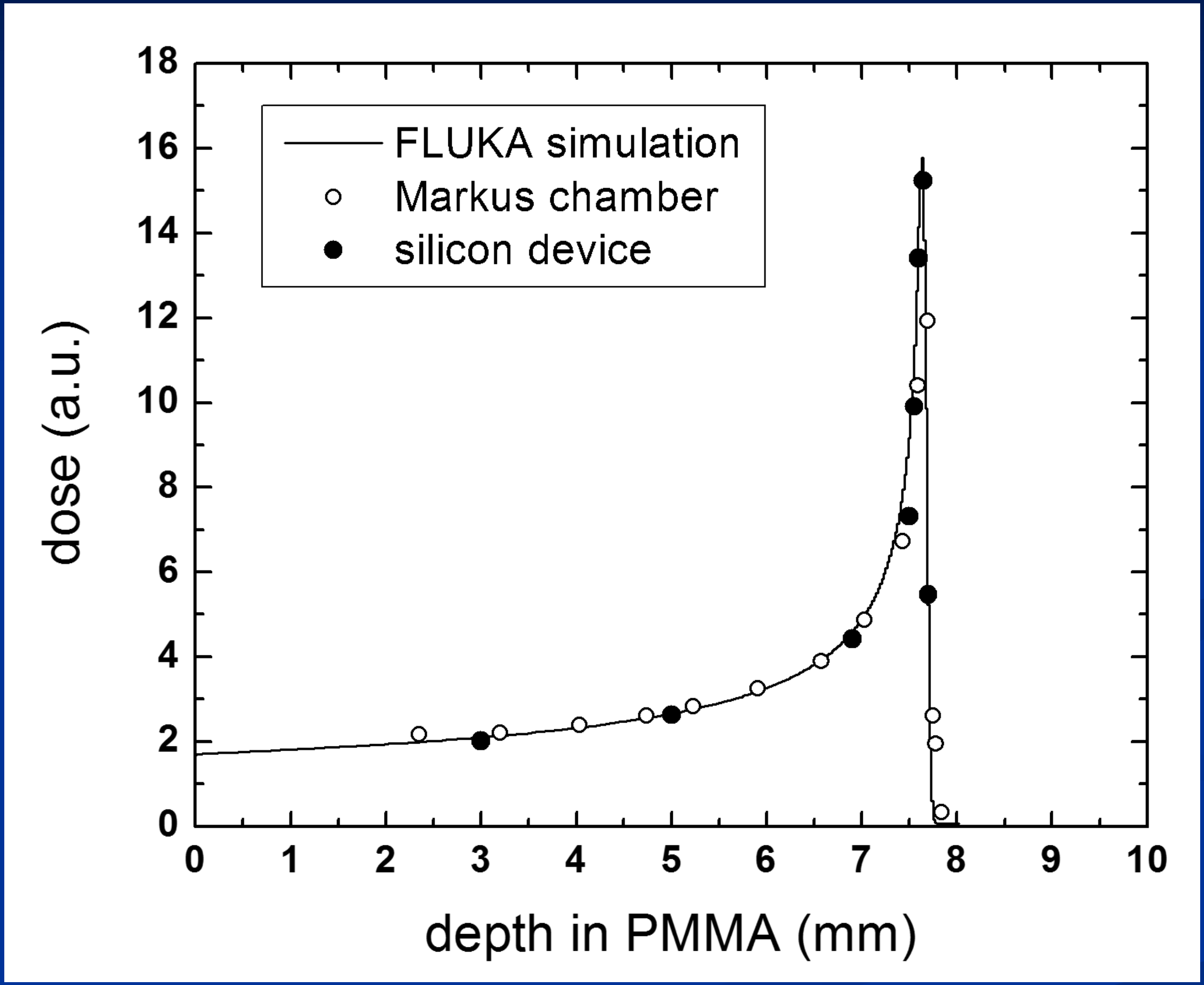



# 62 MeV/u un-modulated carbon beam (CATANA)




FLUKA simulation
Markus chamber
silicon device
dose (a.u.)
depth in PMMA (mm)
0
2
4
6
8
10
12
14
16
18
0
1
2
3
4
5
6
7
8
9
10

# 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.

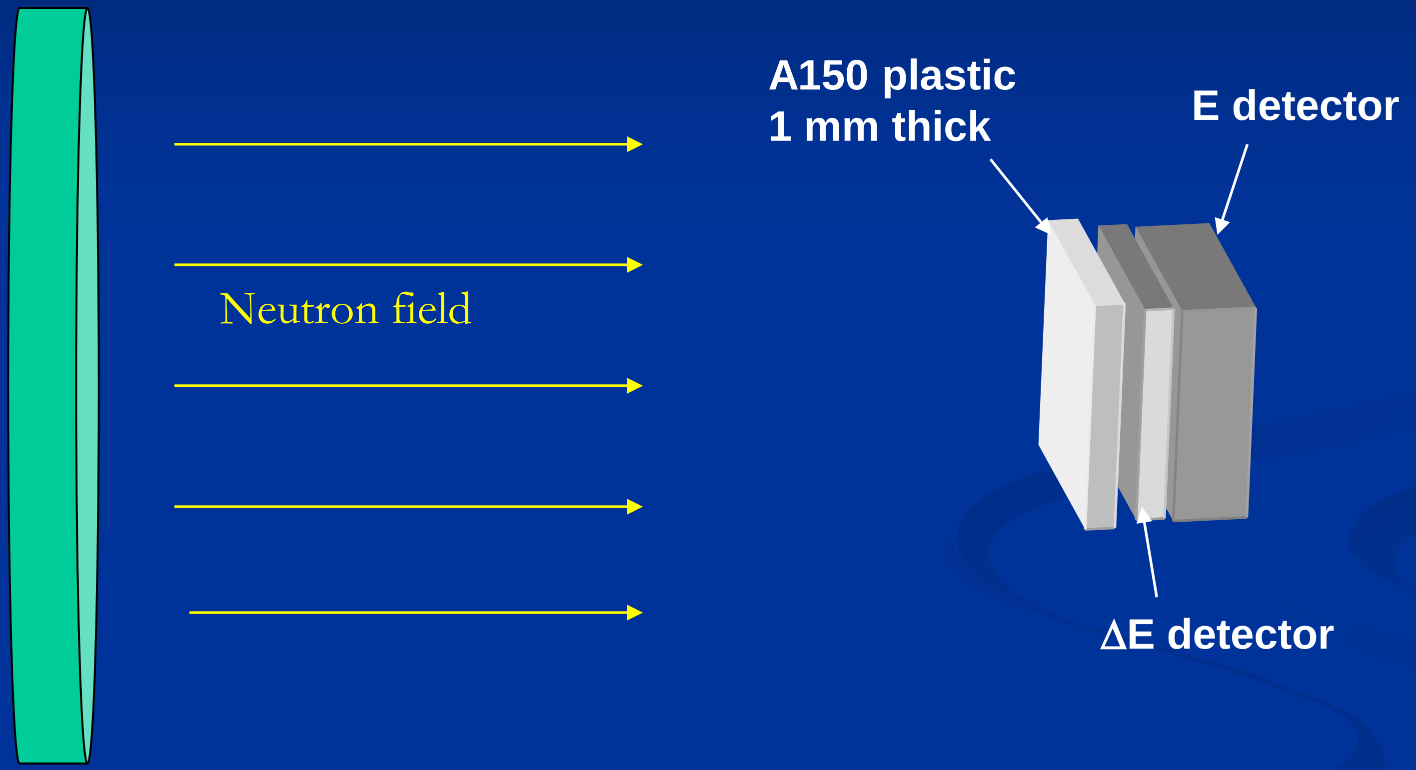
Problems to solve or to minimize:

- relative dimension between $\Delta E$ stage and E stage active areas;
- counting rates;
- radiation damage.

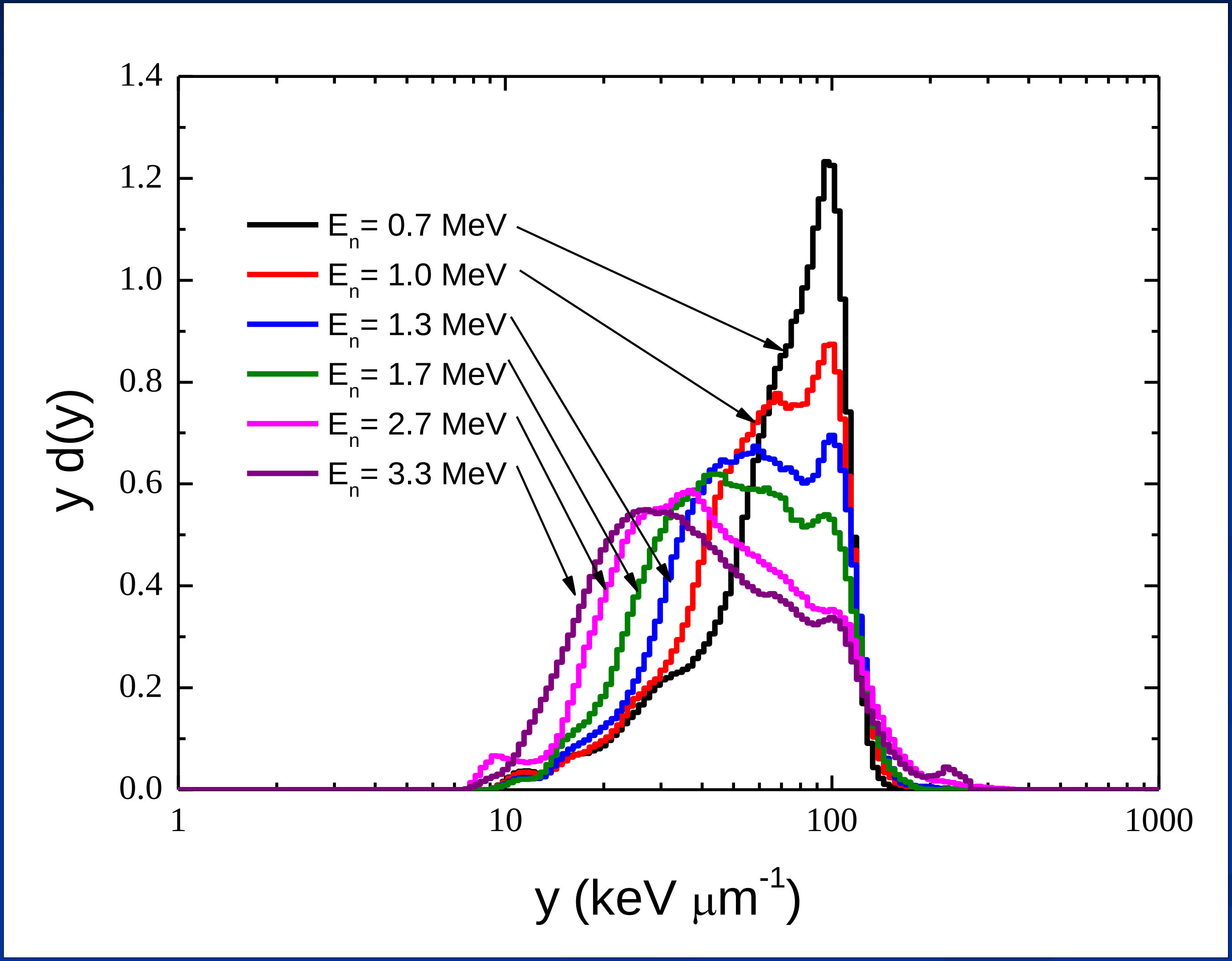
# RESPONSE TO NEUTRONS:

## Irradiations with
## different energy neutron beam
## at CN Van de Graaff facility
## (LNL-INFN Legnaro)

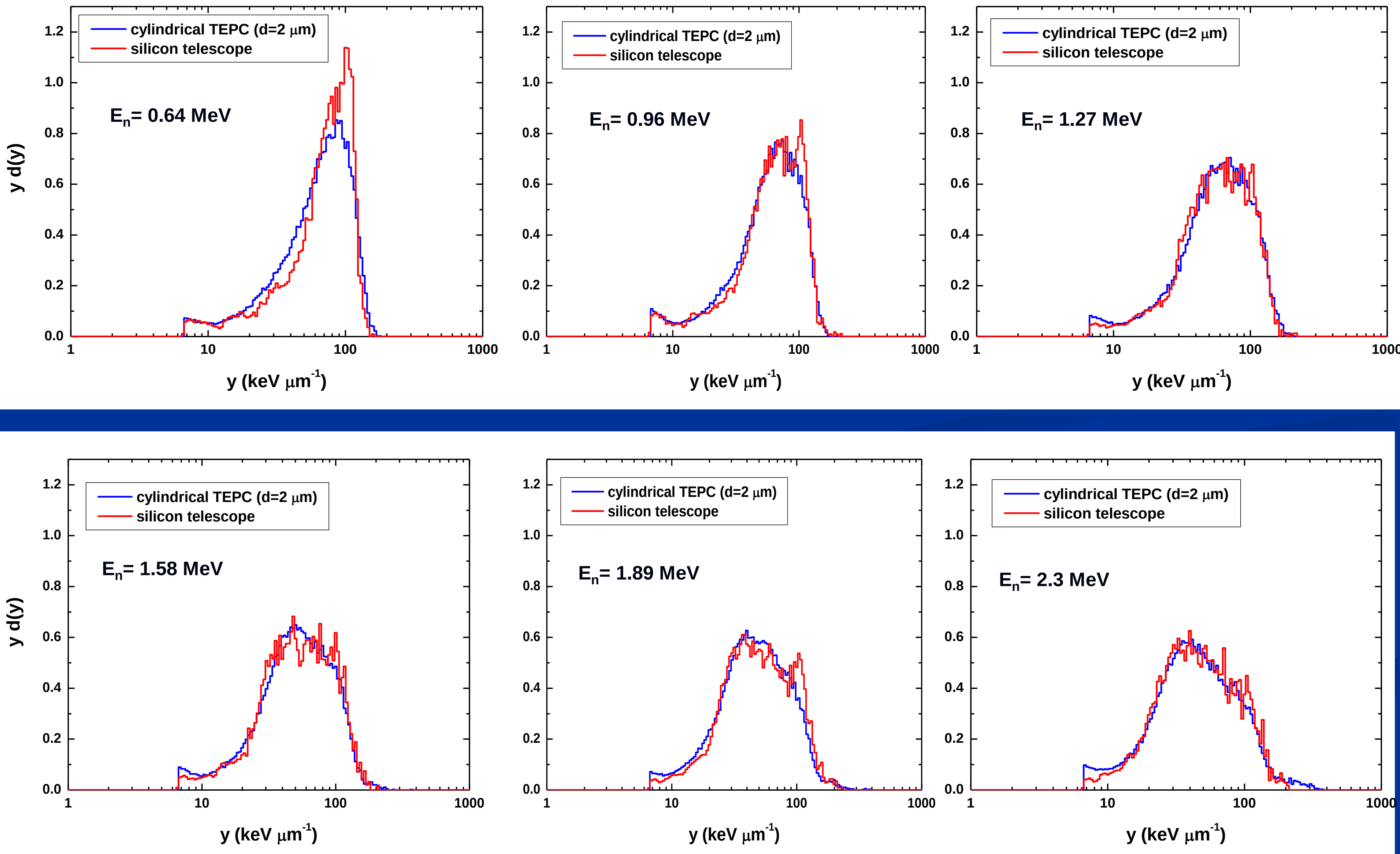
# Device coupled to A150 plastic:
# Irradiation with monoenergetic neutrons



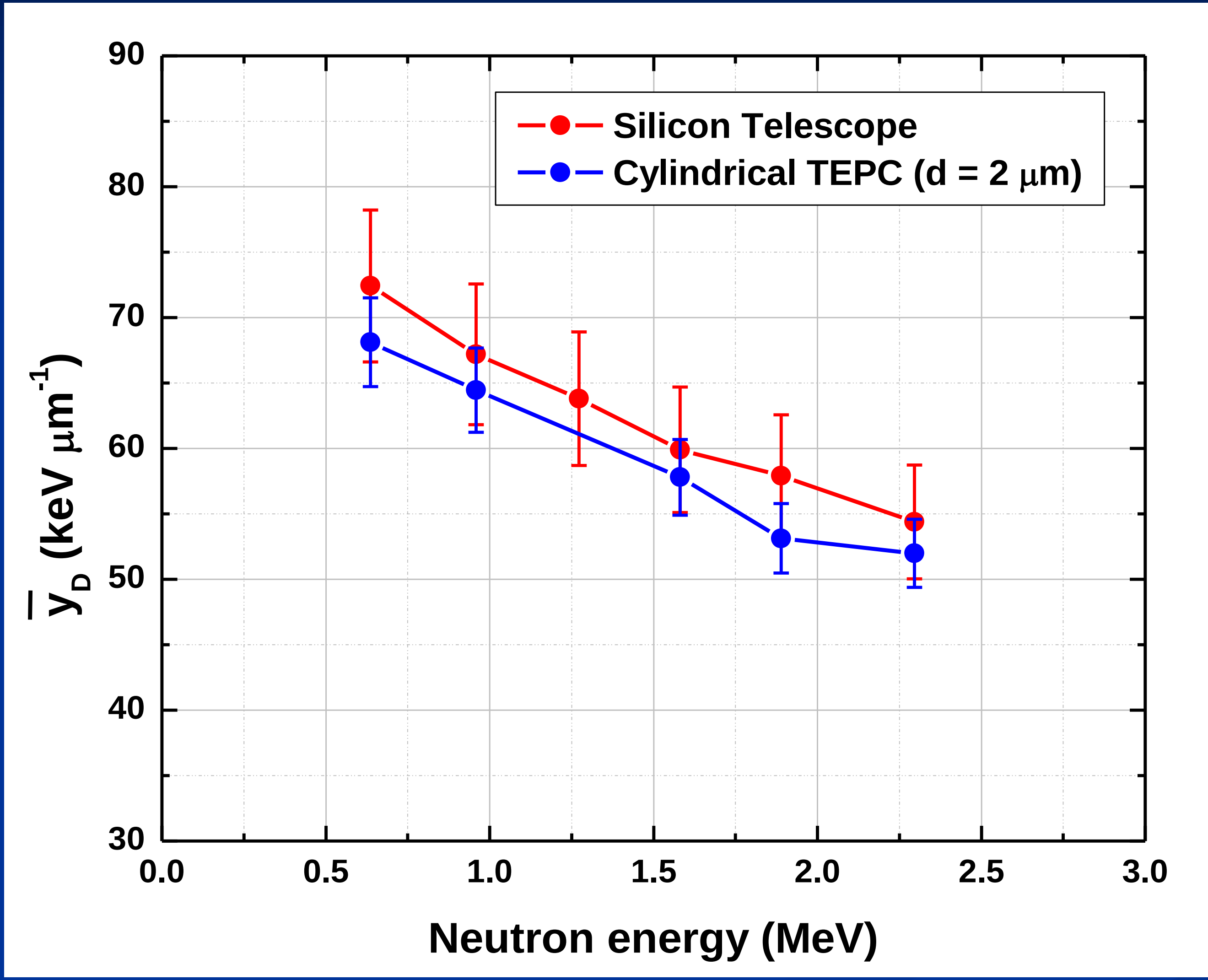
# Irradiation with fast neutrons at different energies



# Direct comparison with a cylindrical TEPC: y- distribution at different neutron energies $E_n$



# Direct comparison with a cylindrical TEPC: y- distribution at different neutron energies $E_n$




**Uncertainties:**
**Si Telescope 8% -11%**
**TEPC: 4% - 7%**

# Irradiation with fast neutrons at different energies

Results:
- easy-of-use system;
- good measurement repeatability;
- good agreement at lineal energies higher than 7-10 keV $\mu m^{-1}$ up to the proton edge.

Problems to solve or to minimize:
- high electronic noise;
- thick detector dead layer.

Issues:
- poly-energetic neutron fields;
- angular response;
- contribution of electrons to microdosimetric spectra (low y- values).

## 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.**

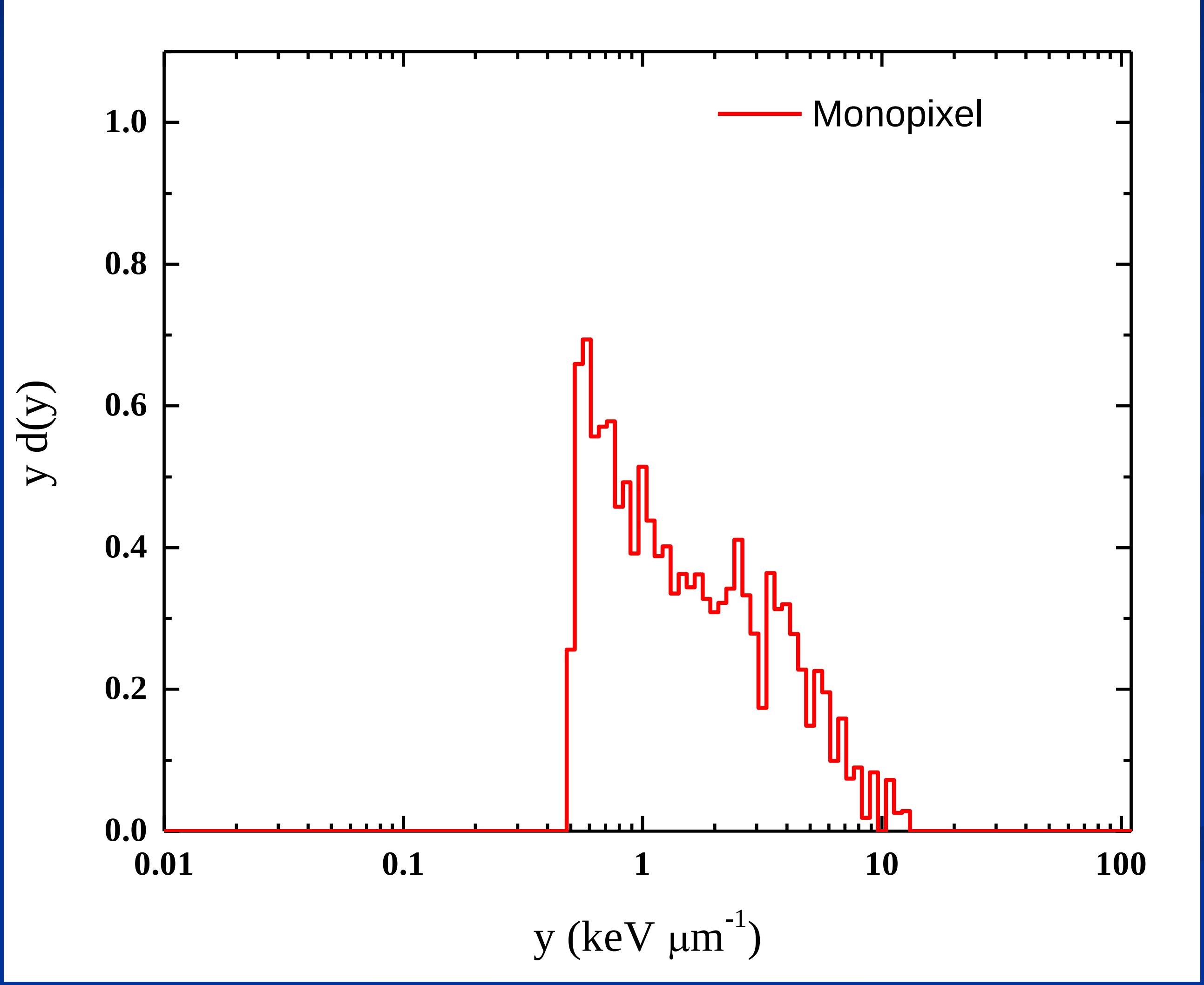
**New design of the segmented telescope with a ΔE stage having a lower number of cylinders connected in parallel and an E stage with an optimized sensitive area**

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

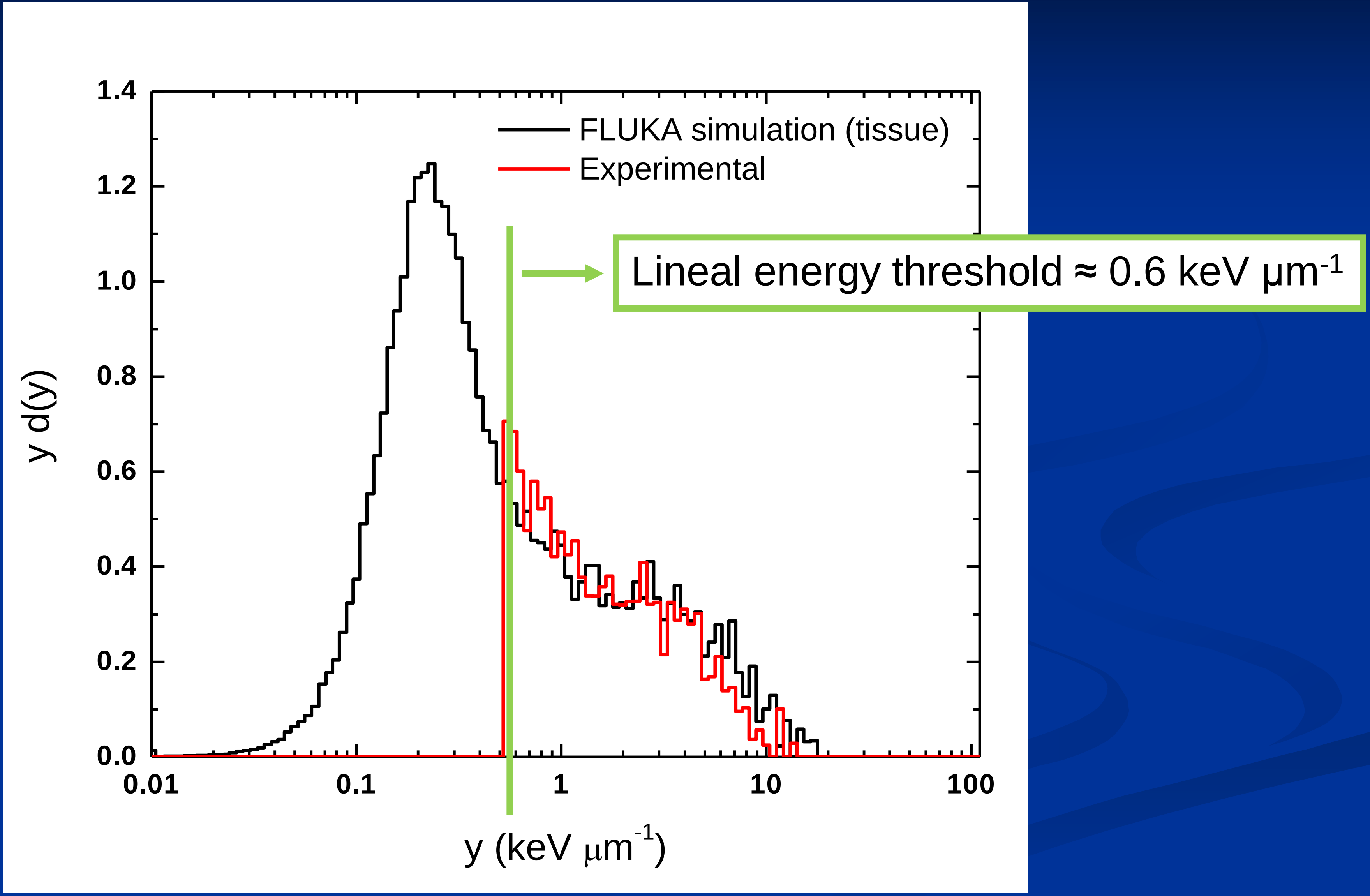
A feasibility study with a low-noise set-up based on discrete components was carried out in order to test this assertion

# Improvement of the energy threshold: Test with a Cesium-137 source

**A telescope constituted by a single ΔE cylinder coupled to an E stage was irradiated with β particles emitted by a $^{137}Cs$ source**



# Improvement of the energy threshold: Test of the tissue-equivalence correction procedure for electrons



# Improvement of the energy threshold: Irradiation with 2.3 MeV neutrons at LNL CN facility