Extremely high-granularity digital tracking calorimeter for the detection of charged and neutral radiation in hadron therapy

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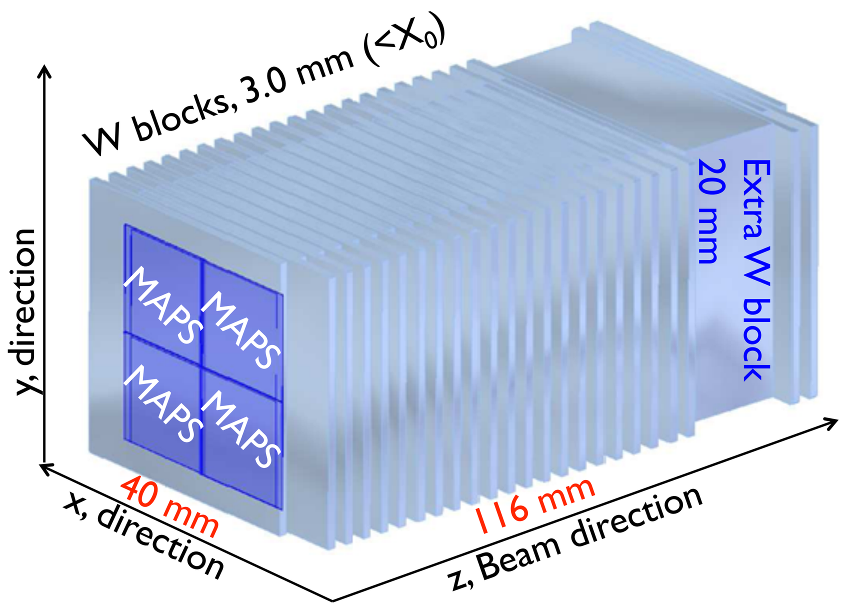
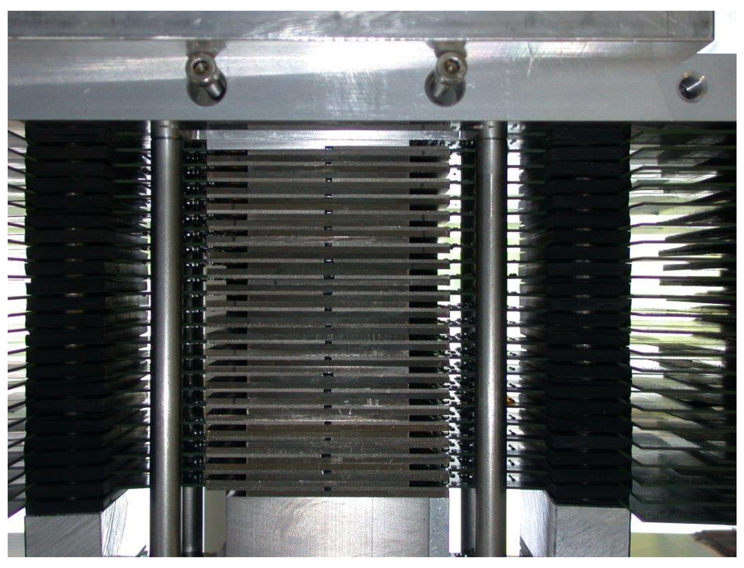
A compact, high-granularity digital calorimeter detector will allow the real-time monitoring of the irradiated volume position by detecting the trajectory of secondary radiation (charged particles and photons) in hadron therapy. Simulations studies and future plans are presented.

The detector:

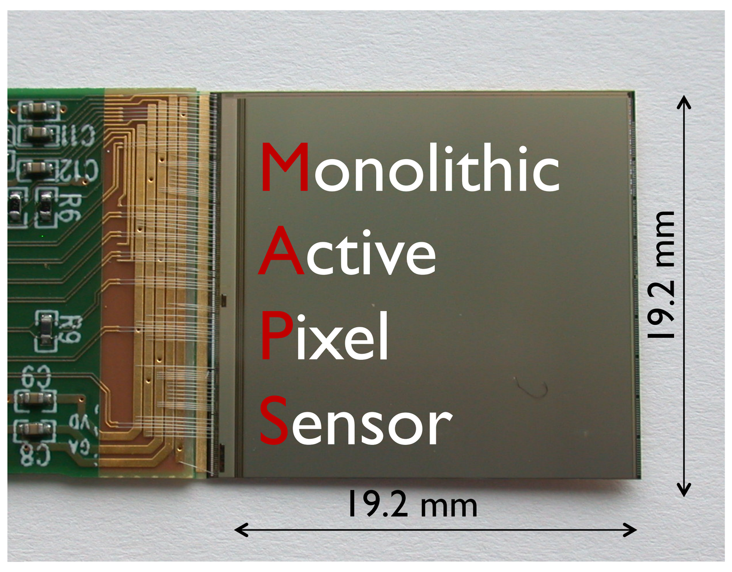




Prototype picture

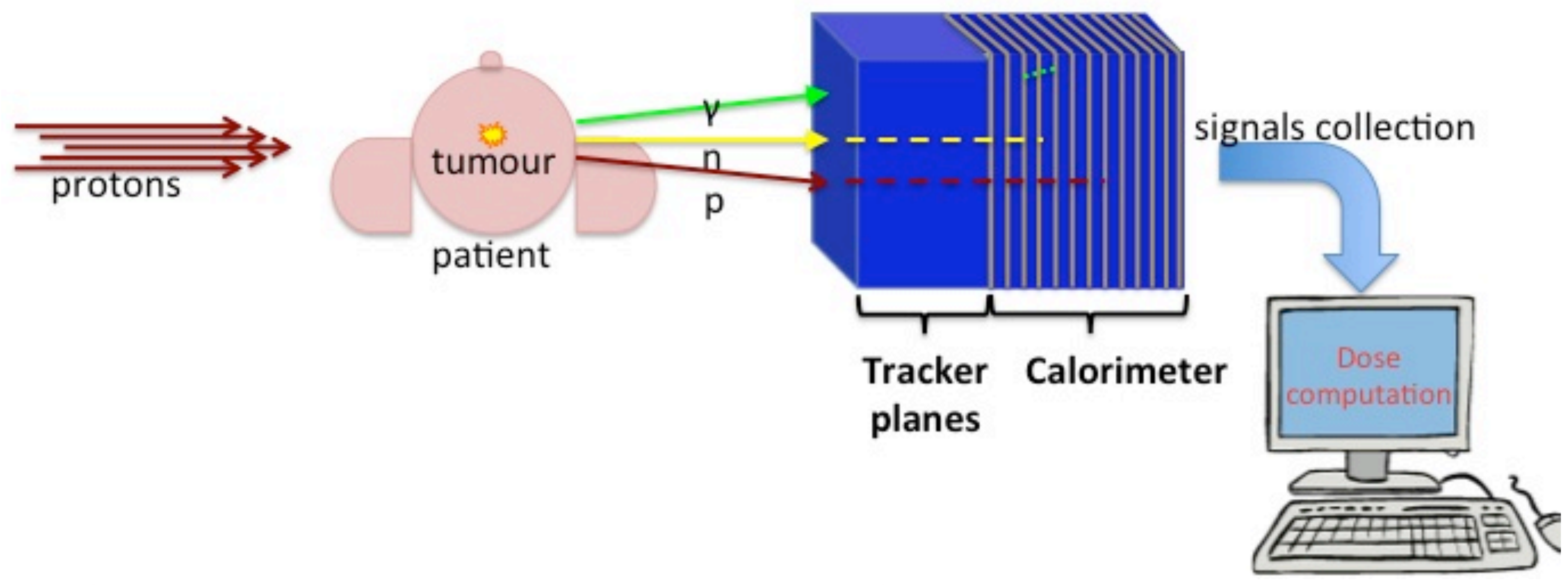
The prototype consists of :

- 24 layers (W+Si sensors)
- 96 chips
- 39 million pixels
- 1 chip= 640 pix*640 pix
- On-chip digitisation: chip level threshold setting, 1 bit per pixel
- Sequential chip readout ("rolling shutter")
- Chip r/o time: 642 μs (to be improved!!)



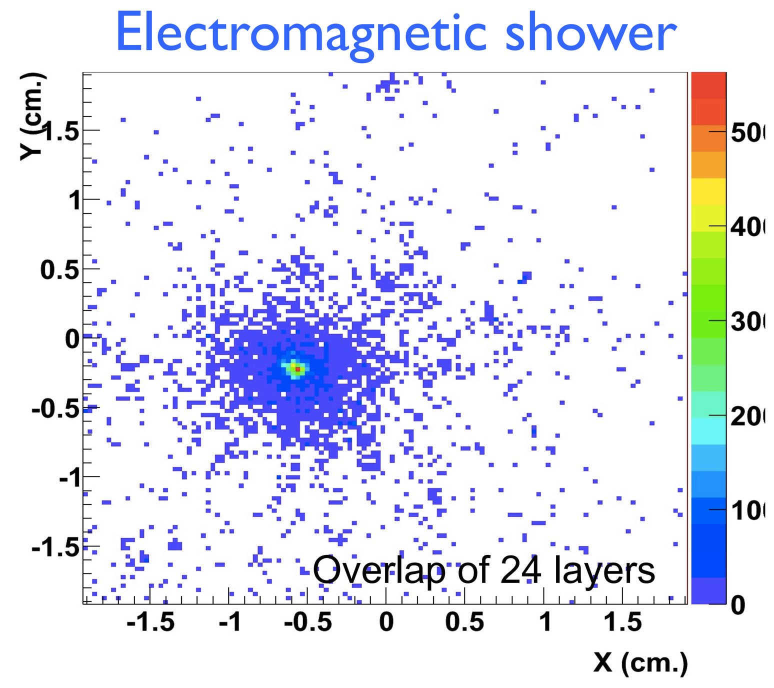
CMOS integrated circuit

A possible setup:

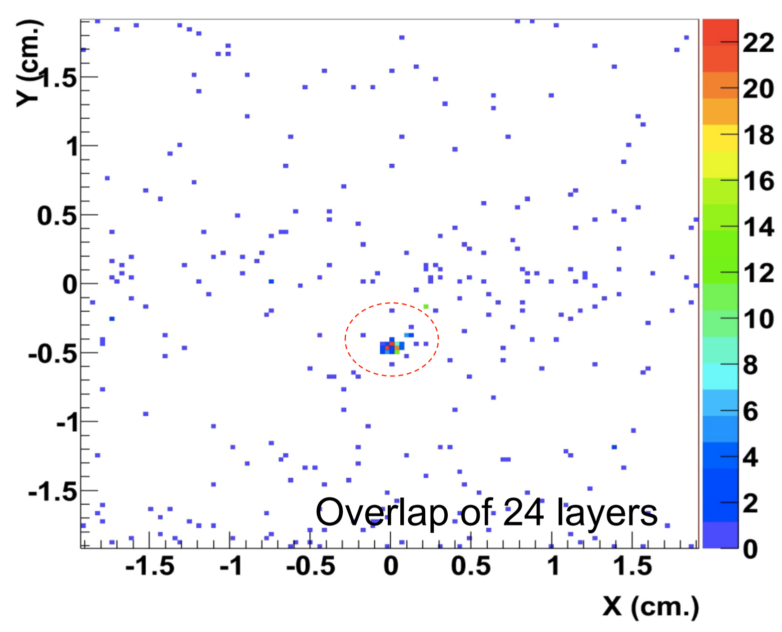


Glance on the detector performance at high energies (200 GeV): particle identification

Electromagnetic shower



Pion track



Low noise level (<5 pixels per frame)

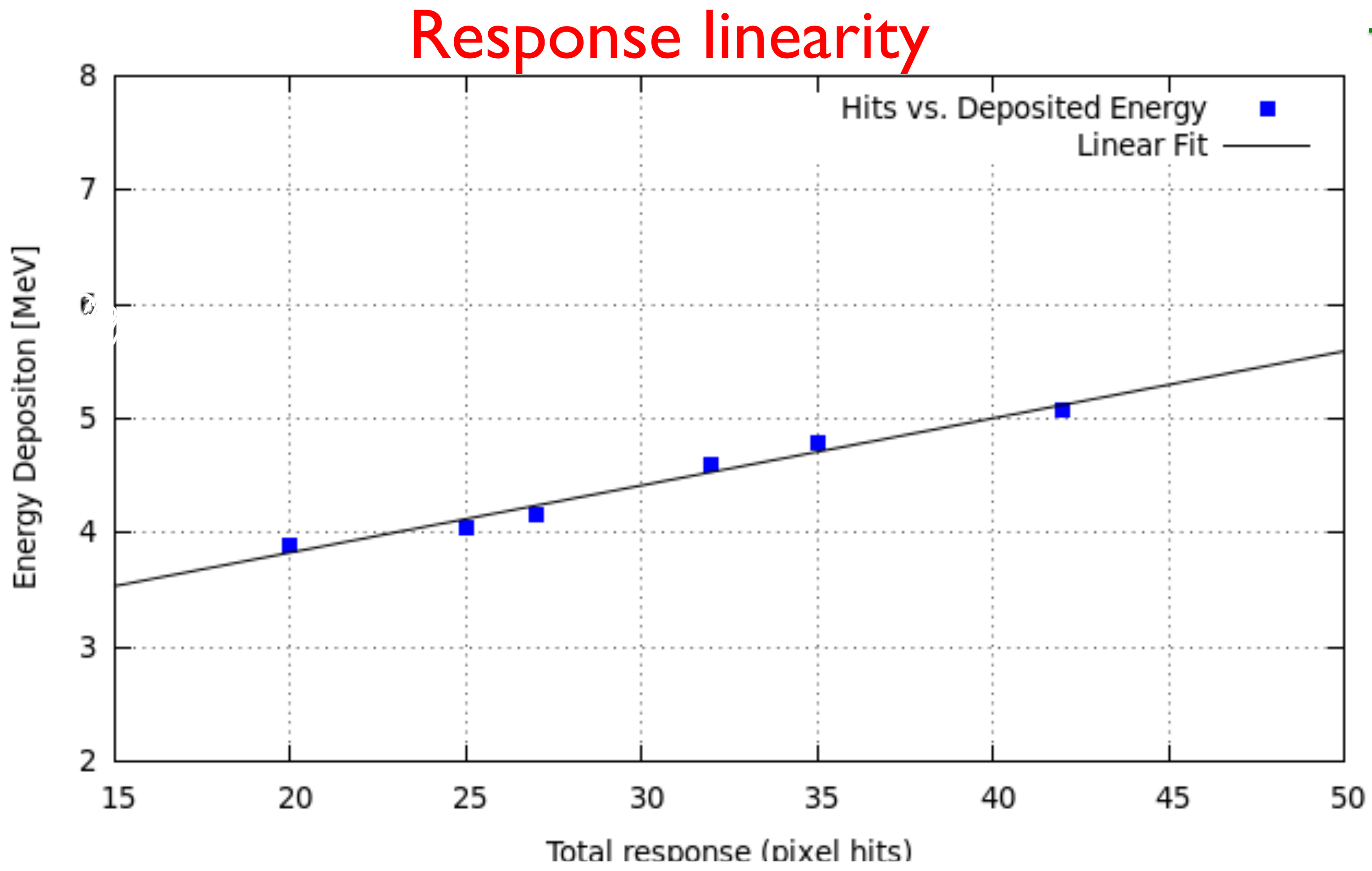
Strong point:

The tracking capabilities of the Forward Calorimeter [1] makes it a potential candidate, as proton therapy instrument, in medical imaging with protons for a possible reduced range error in treatment planning: from 3-10 mm to 1-3 mm [2]. The proton energy accuracy in position and resolution after traversing the patient are the key points to extract a precise information on the stopping power and reconstruction of the most likely path of the proton. The proposed digital calorimeter will provide unprecedented accuracy in position and energy resolution.

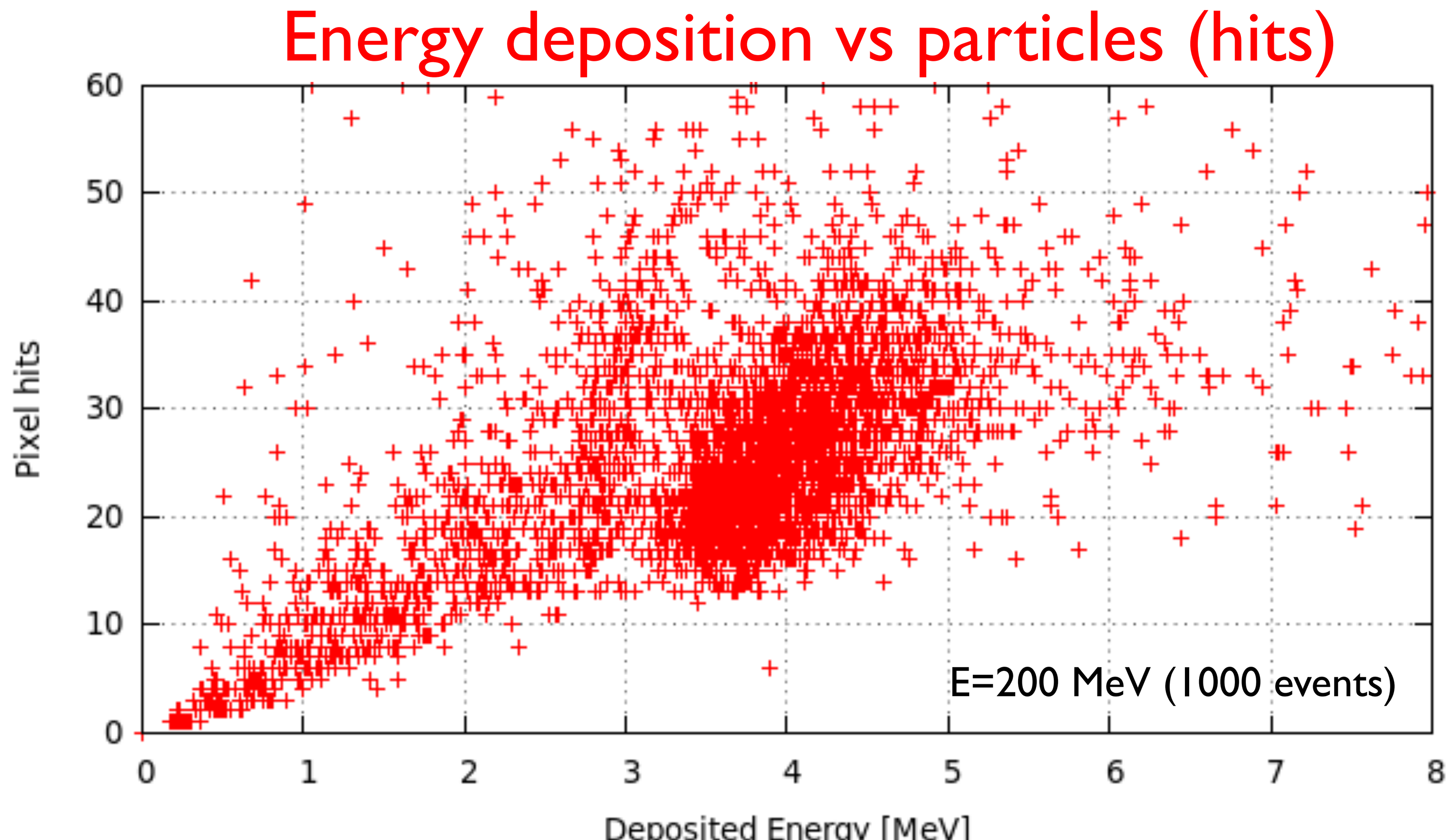
FLUKA simulations

The preliminary simulations are performed with a simplified model of the detector in the Monte Carlo simulation package FLUKA. The silicon layers have a pixel size of 30 μm x 30 μm. The aim has been to study the relationship between pixel hits and deposited energy for protons which are stopped inside the detector, i.e. for energies in the range of ~ 180-250 MeV. The response and pixel broadening in the vicinity of the Bragg peak is not yet simulated for heavily ionizing protons, but beam tests will be carried out in the near future.

Response linearity

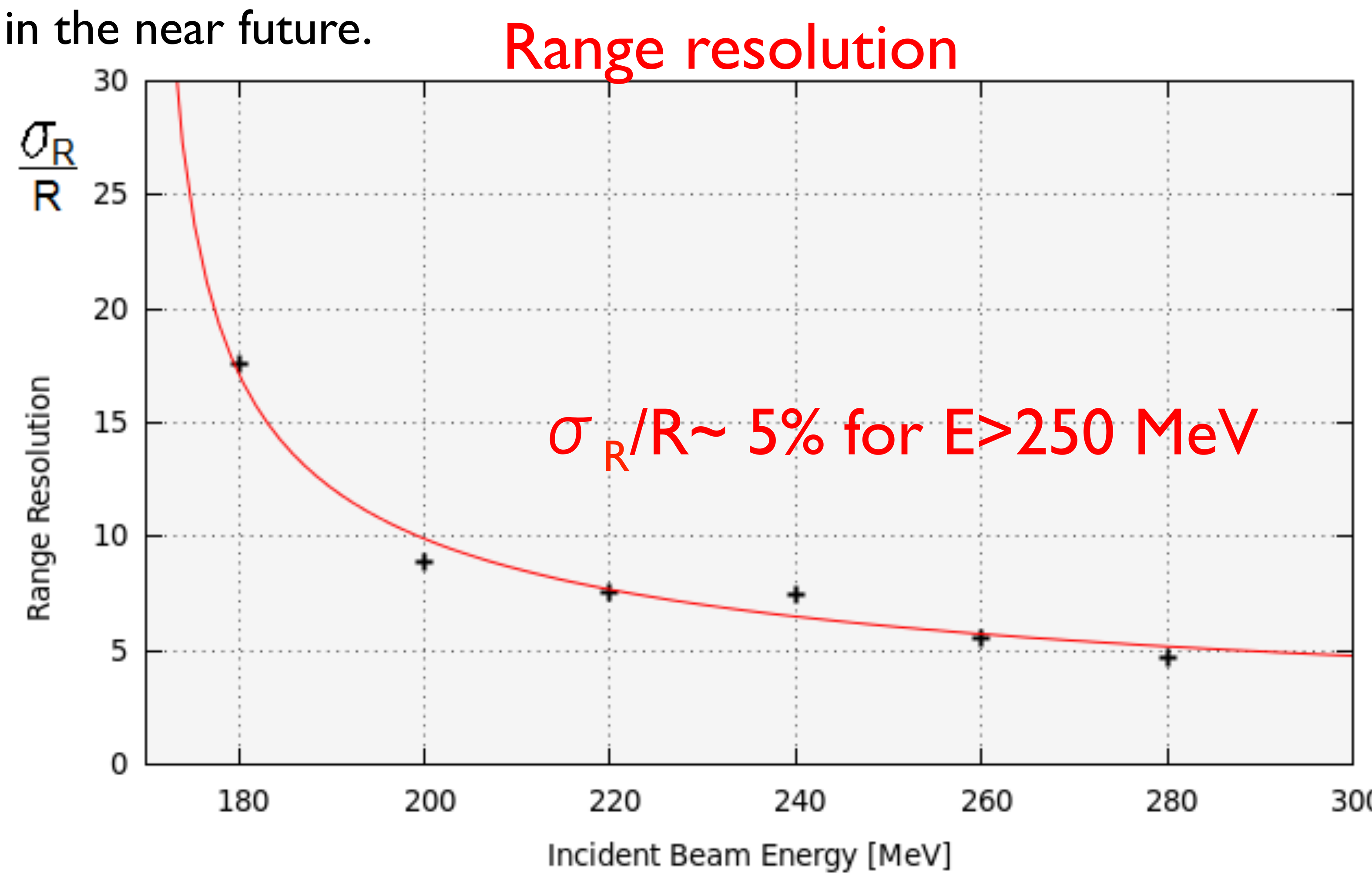


Energy deposition vs particles (hits)

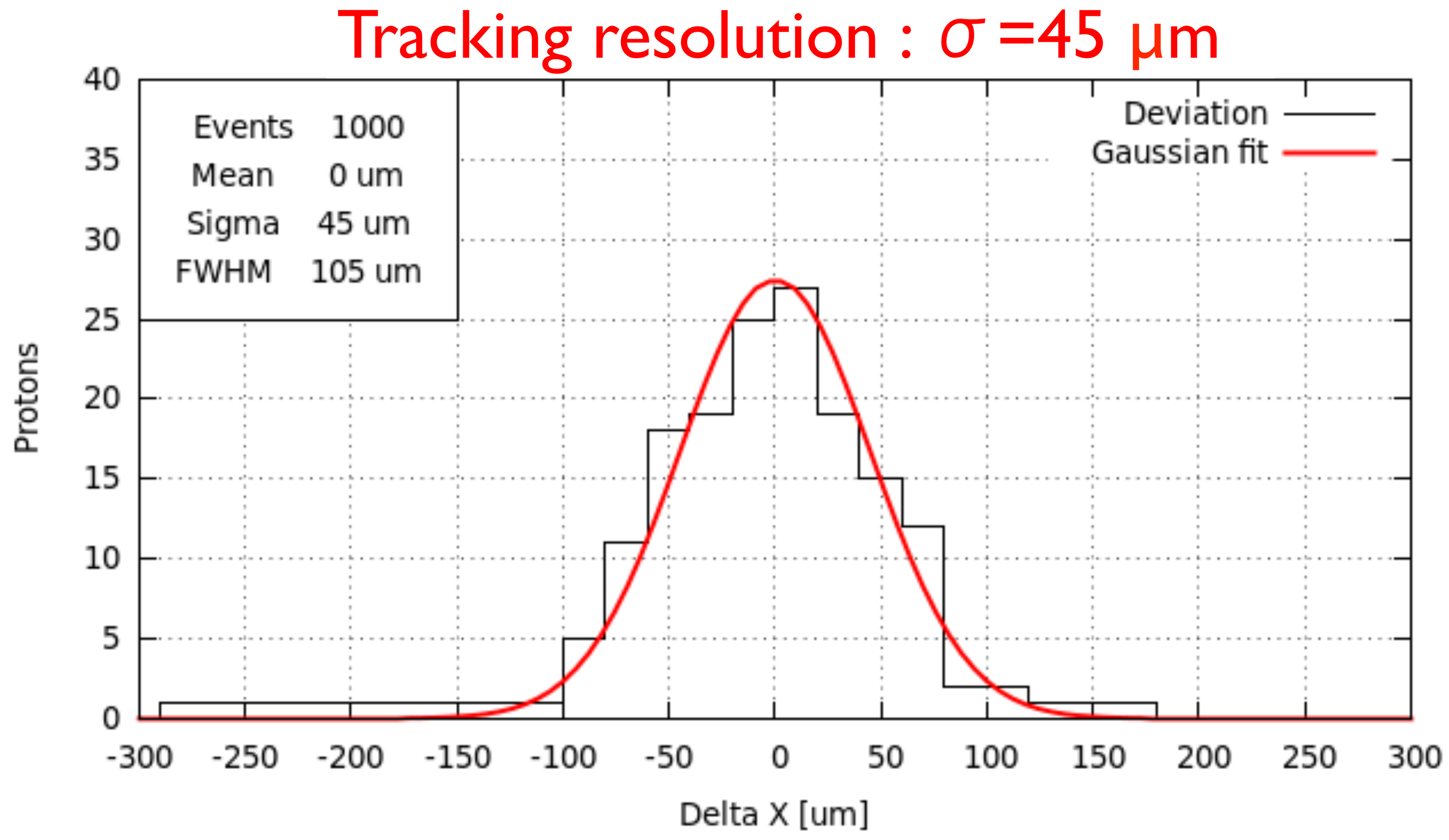


Energy deposition by particles counting

Range resolution



Tracking resolution : σ =45 μm



Future plans: test beam with proton energies from 180 to MeV for comparison with the simulation studies
construction of new prototype with optimised (for proton therapy) absorber material

[1] T. Peitzmann, Nucl. Phys. A904-905 (2013) 929c-932c.
[2] M. Petterson, N. Blumenkrantz, J. Feldt, J. Heimann, D. Lucia, A. Seiden, D. Williams, H.-W. Sadrozinski, V. Bashkirov, R. Schulte, et al., "*Proton radiography studies for proton CT*," in Nuclear Science Symposium Conference Record, 2006.