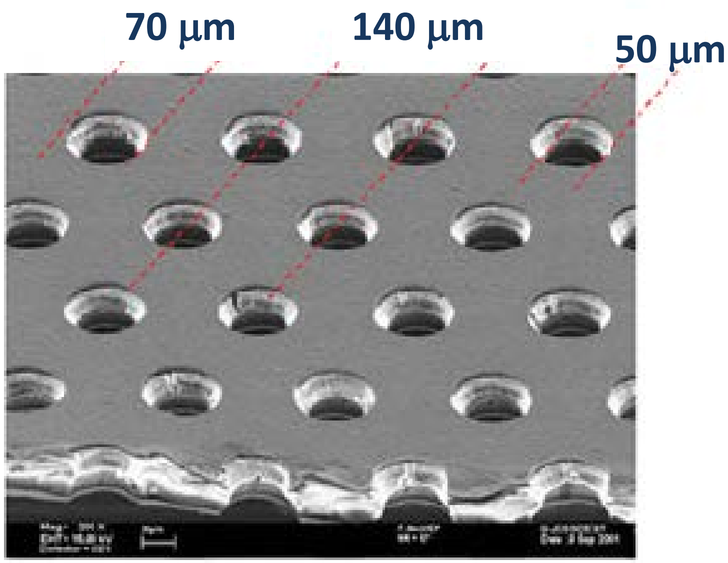
GEM and GEMPix measurements at CNAO

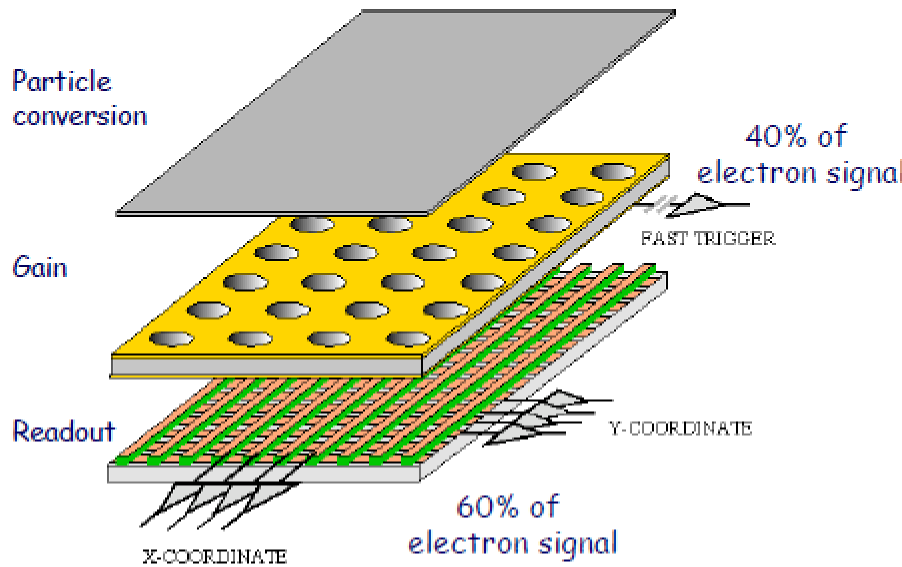
Outline

- GEM
  - Setup
  - Linearity
  - FWHM
  - Homogeneity of irradiation field

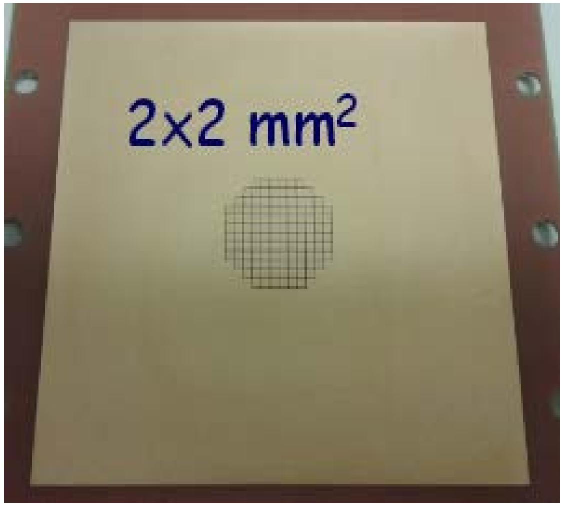
- GEMPix
  - Set up
  - Linearity
  - Measurements in water phantom

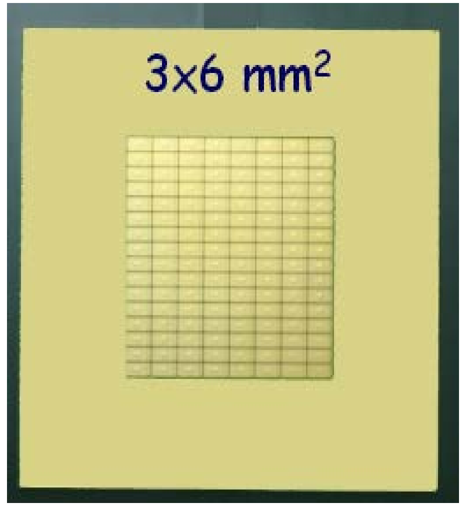
- Monolithic Silicon Telescope
  - Microdosimetric characterization of a clinical carbon ion beam
  - Comparison with TEPC

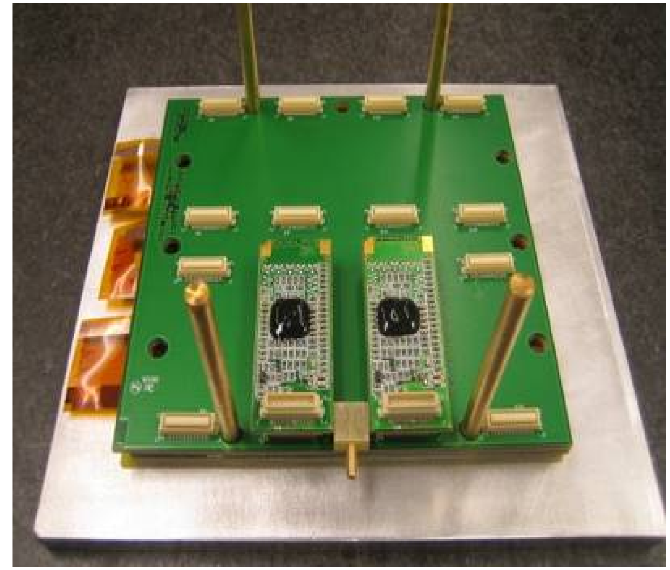




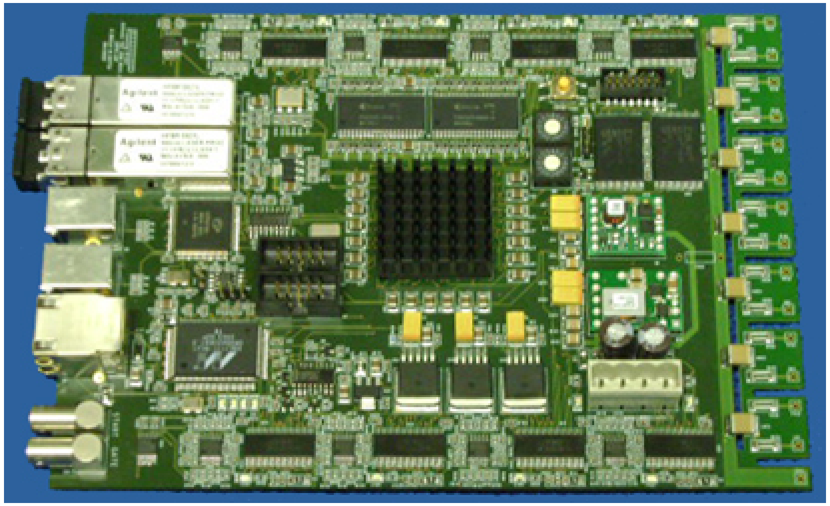
- Particle conversion, charge amplification and signal induction zones are physically separated
- Time resolution: **9.7 ns** for Ar-CO_2 (70-30)
- Spatial resolution: up to **200 μm** - limited by readout
- Dynamic range: **from 1 to 10^8 particles/cm^2 s**
- Effective gain is given by the formula: $G_{eff} \propto \sum V_{G_i}$







- Circular anode: 128 pads 2x2 mm^2 ~ 9 cm^2 of sensitive area
- Square: 128 pads 3x6 mm^2 ~ 25 cm^2 of sensitive area
- 8 chip CARIOCA to set the threshold on 16 channels and reshape the signal
- FPGA-based DAQ: 128 scaler and TDC channels, in → gate and trigger, out → signals
- HVGEM power supply with 7 independent channels and nano-ammeter



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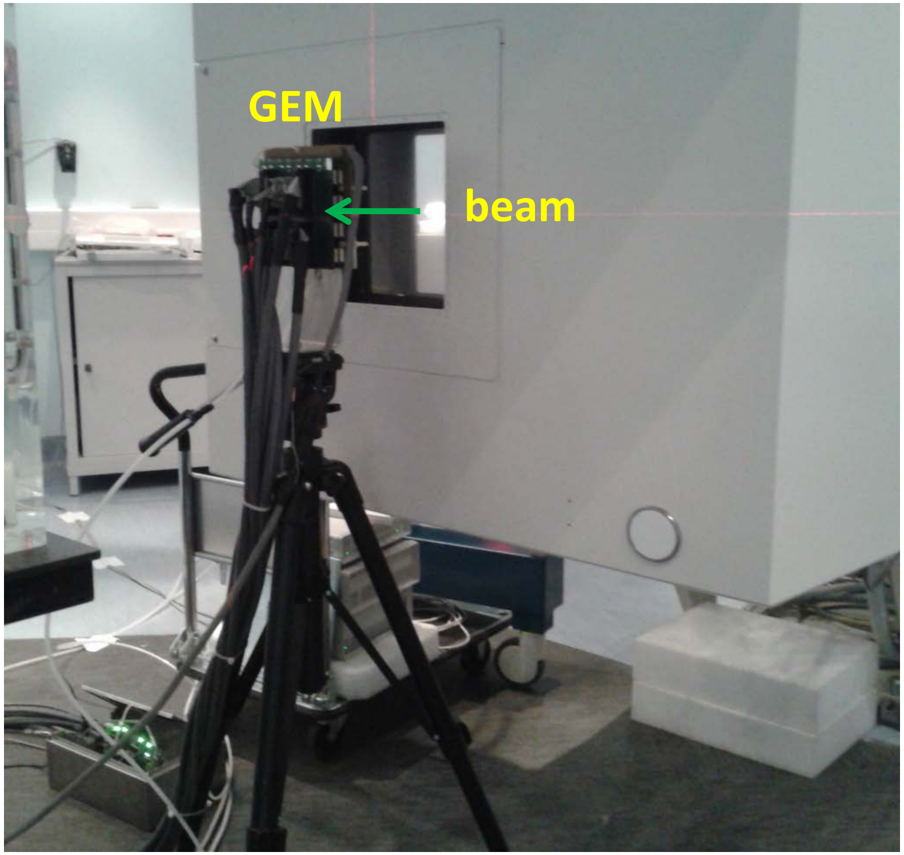
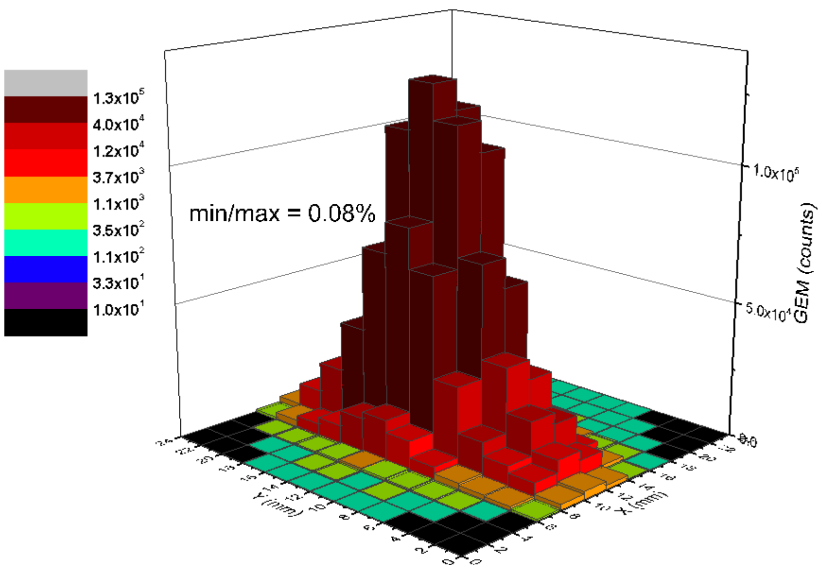
Detectors and set up for CNAO measurements

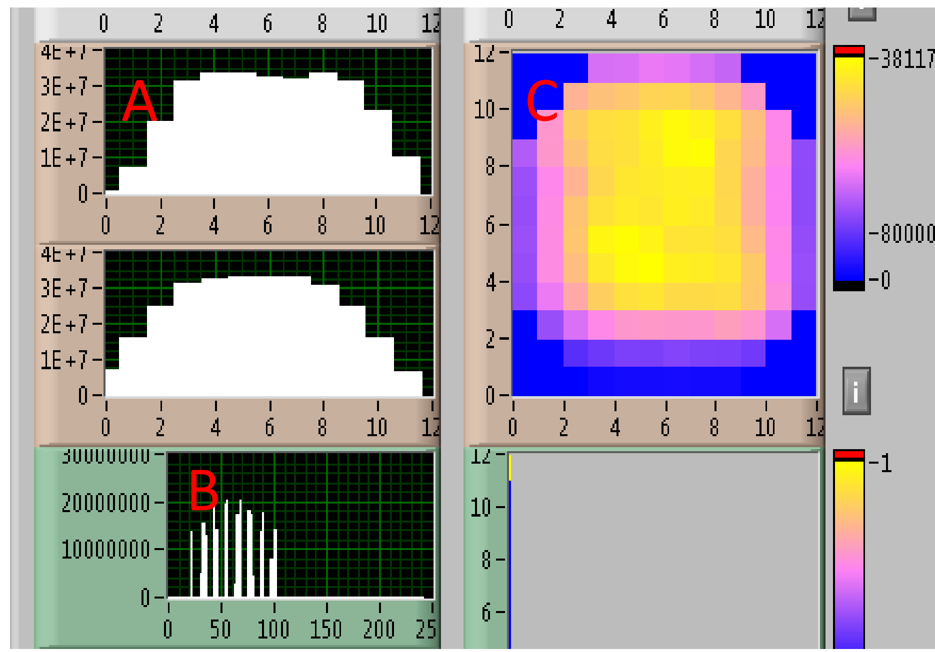
- Measurements done with scanned C-12 beams (and protons)
- Linearity test
- Paint procedure with a radiochromic foil in front of the GEM



Paint procedure reconstruction with triple GEM

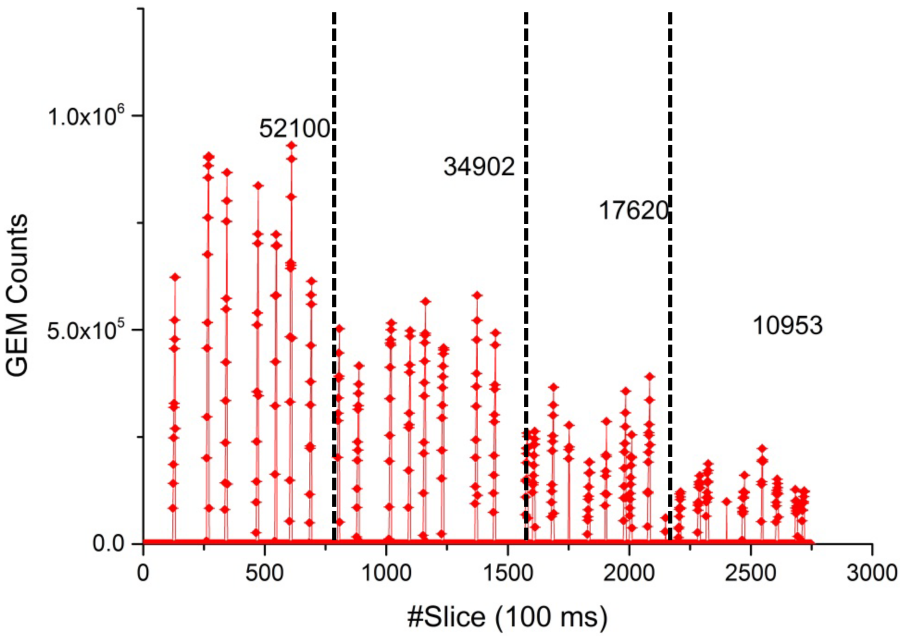
- The paint procedure can be recorded and reconstructed offline through the data acquisition system [5, 6]
- The result of the complete scan procedure is shown in the acquisition program

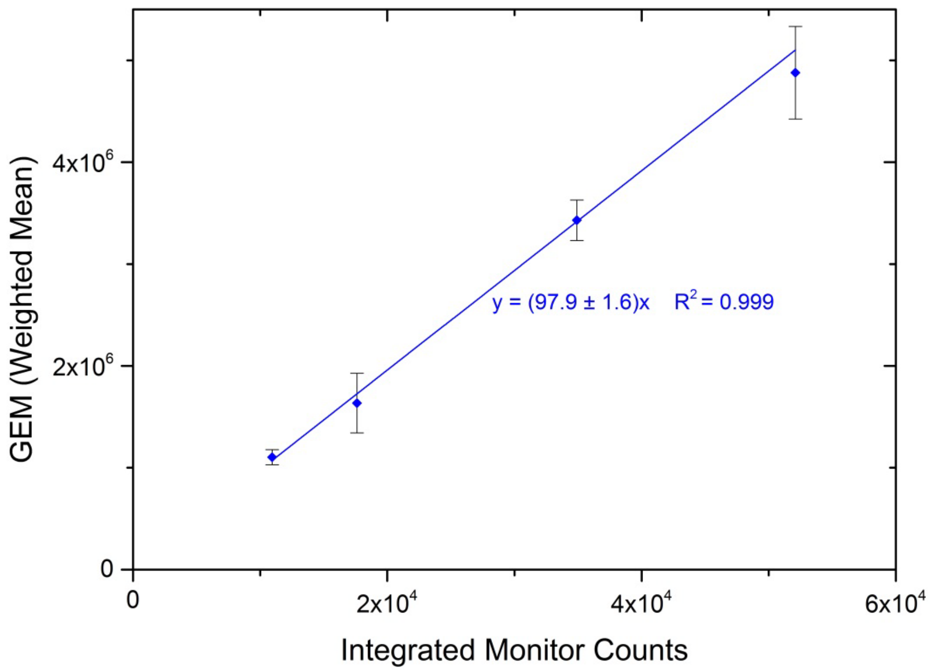




Linearity

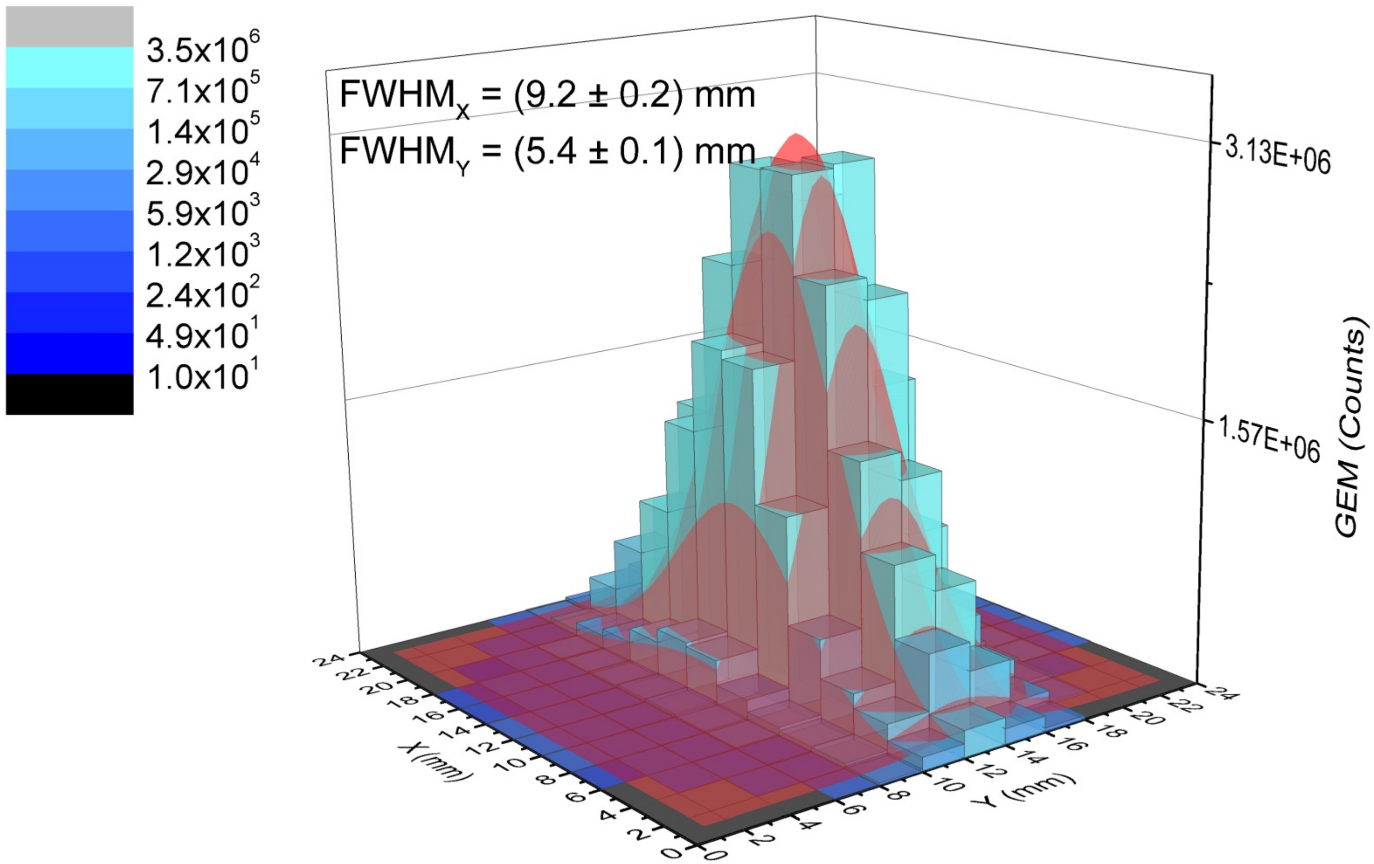
The intensity scan of the beam was performed to check the linearity of the response of the detector versus beam intensity





FWHM of the pencil beam:

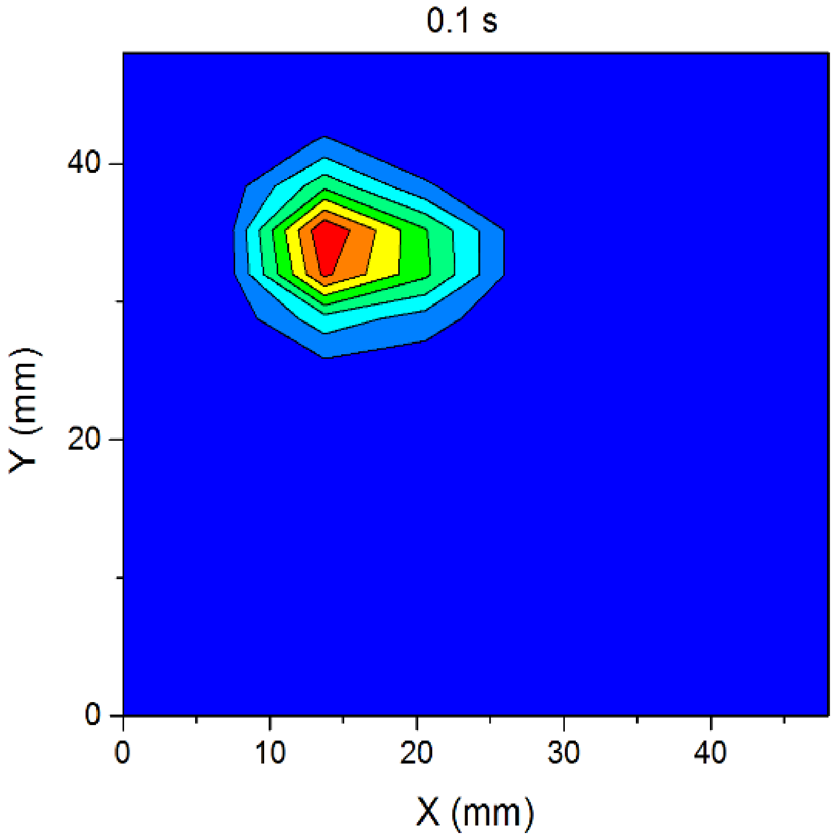
- The tolerance for the FWHM measurements is 1 mm [1]
- The control room gave a FWHM of 10 mm in one of transverse direction
- GEM measures 9.2 ± 0.2



X-Y scan procedure:

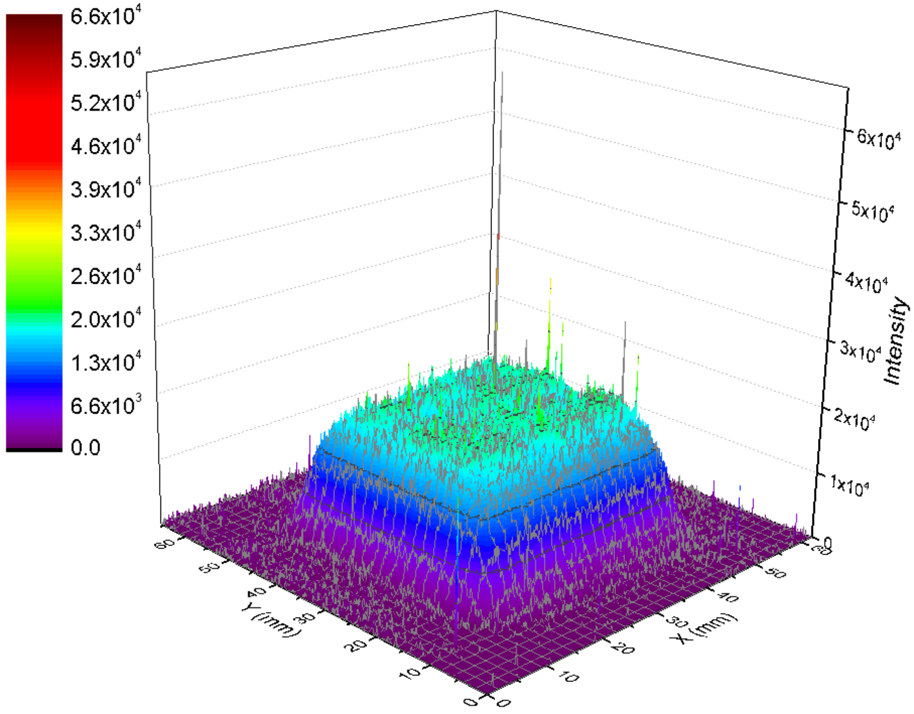
- The cancer area is scanned with the hadron beam along the X-Y axis
- The dose is uniform over the treated area
- The scan is possible also in the Z direction (not in this study)

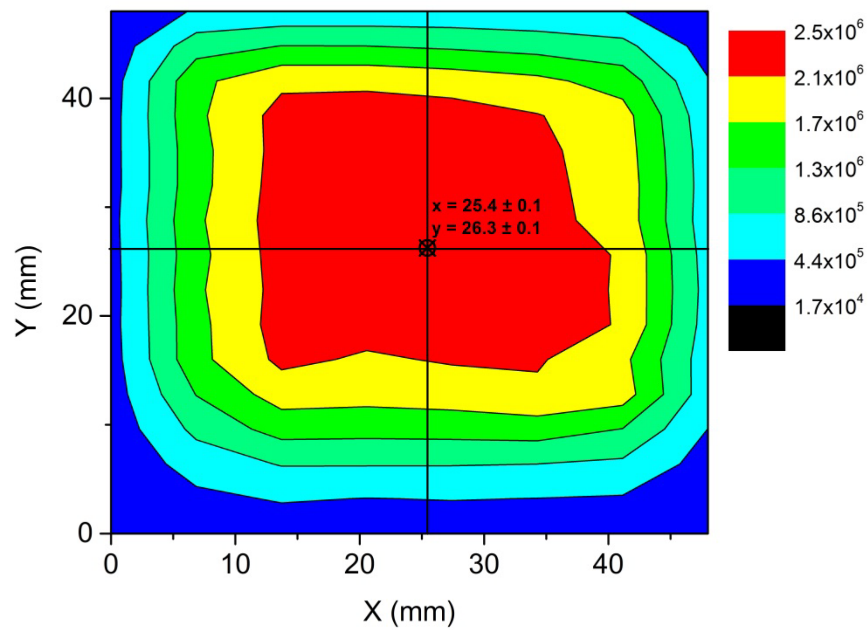
- Offline **Triple GEM [2, 3]** reconstruction of the paint procedure.
- 45 frames of 100 ms.
- **Negligible** dead time [4]



Beam characteristics

	Carbon Beam	
X-Y scanned area (cm^2)	2x2	4x4
Energy (MeV/nucl)	252	252
Depth in H_2O (mm)	126	126
Intensity (part/spot)	5e6	1e6

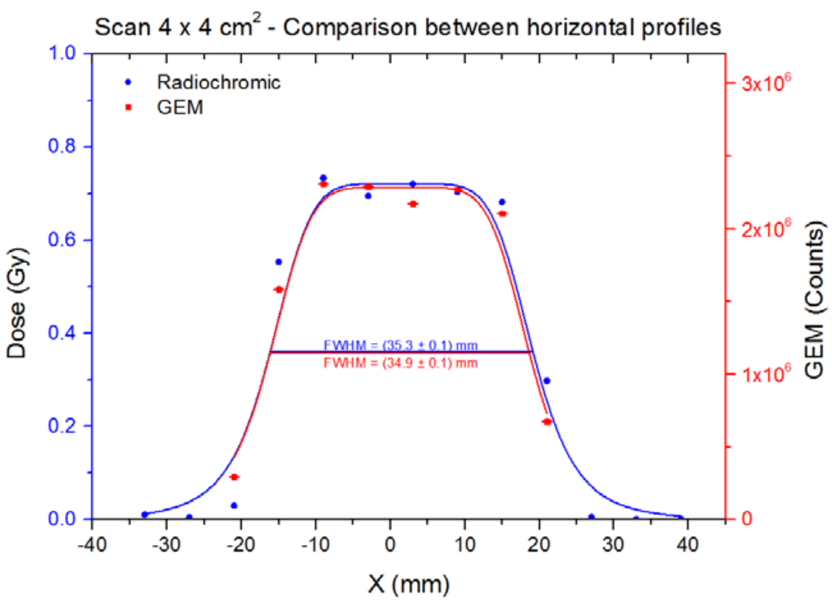


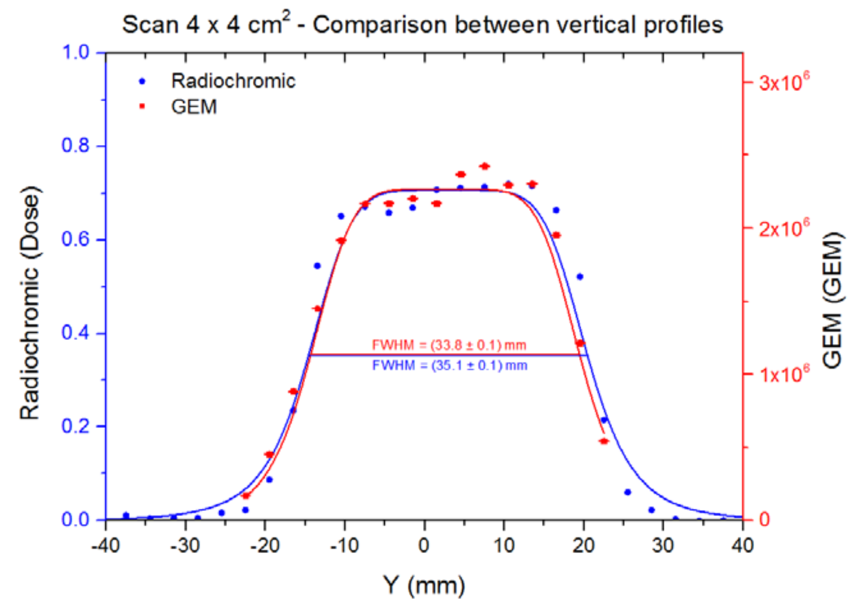


Radiochromic foil & GEM 3x6 mm^2 pads.

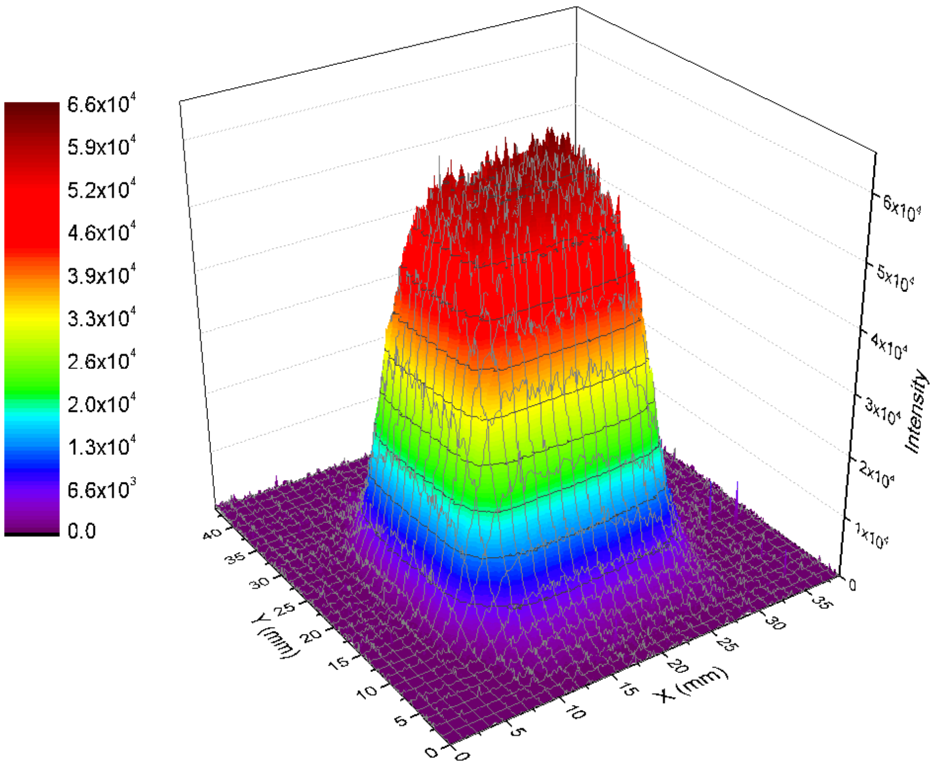
Beam 126 mm depth in water, 1e6 part per spot. Paint 4x4 cm^2

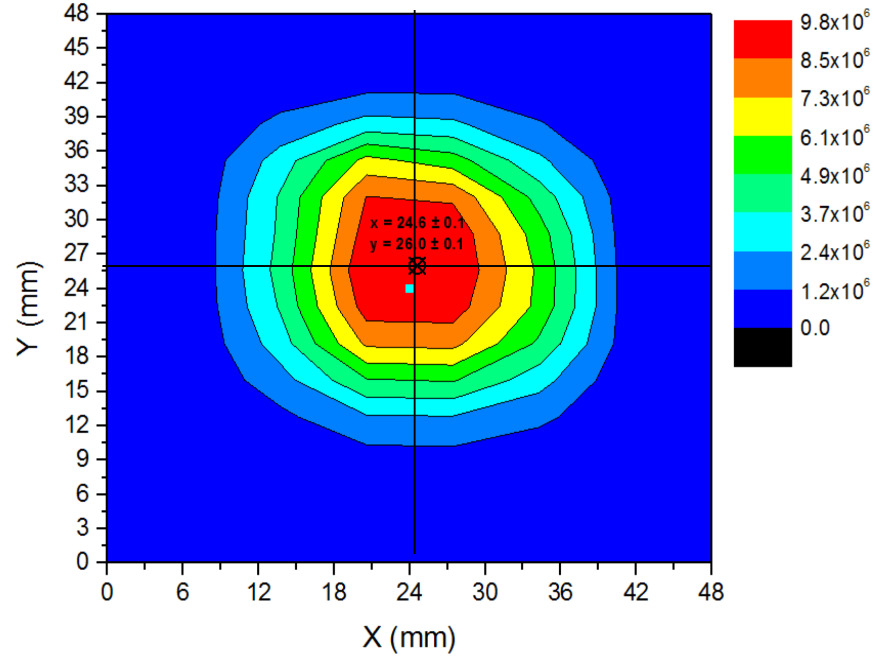
Pad 3x6 mm^2 X-Y scan 4x4 cm^2





Left: horizontal profile for Radiochromic and GEM
Right: vertical profile for Radiochromic and GEM





Radiochromic foil & GEM 3x6 mm^2 pads.

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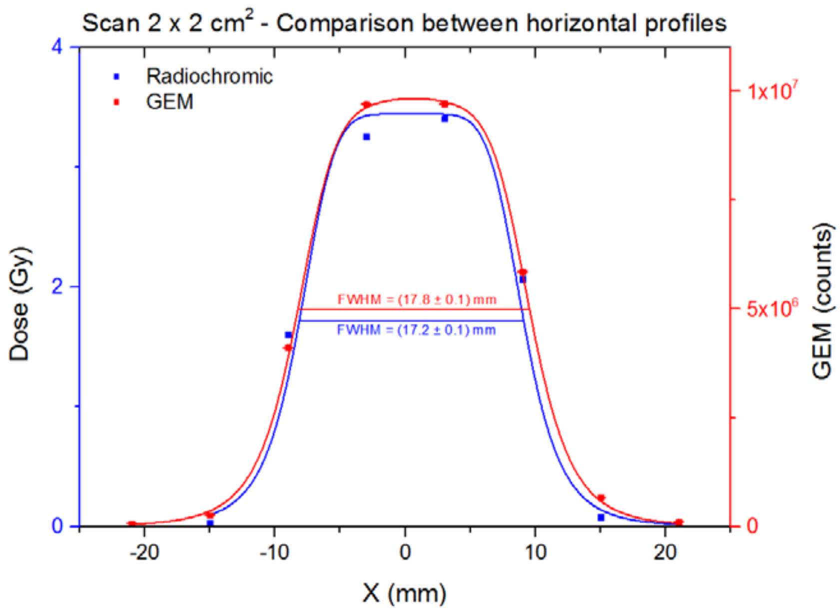
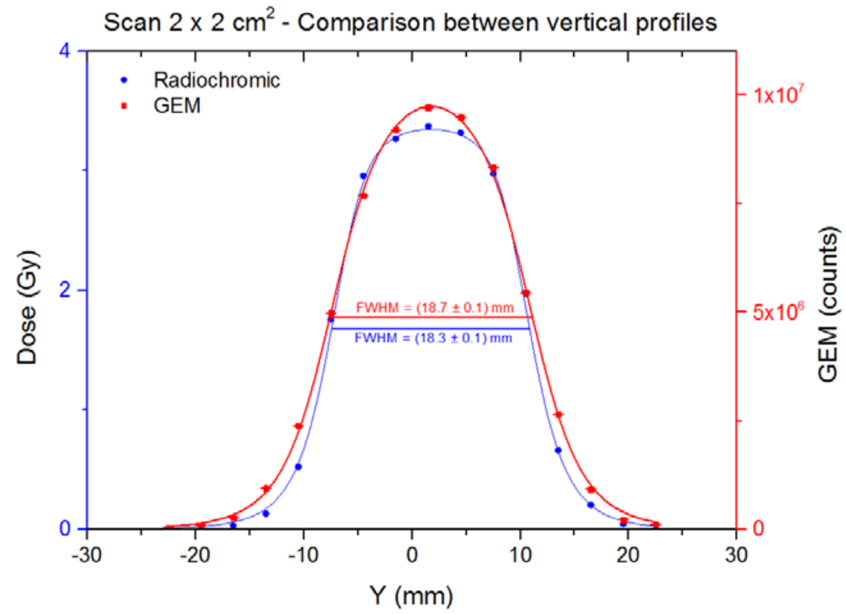
Pad 3x6 mm^2 X-Y scan 2x2 cm^2





Left: horizontal profile for Radiochromic and GEM
Right: vertical profile for Radiochromic and GEM

Conclusions:

- Timing, profiles and image of the x-y scan procedure are shown on line
- A more accurate timing can be performed with a trigger from the synchrotron
- The offline analysis shows a good agreement with the radiochromic foils, both in terms of area and beam profile
- The GEM showed capability to measure beam intensity down to very low values. Could it be of interest as beam monitor in the experimental room?

References:

[1] M. Ciocca et al., *Quality assurance Protocol at Centro Nazionale di Adroterapia Oncologica (CNAO)*, https://ulice.web.cern.ch/ulice/cms/documents/Protocol_1-QA-CNAO.pdf

[2] F. Sauli, *GEM: A new concept for electron amplification in gas detectors*, Nuclear Instruments and Methods in Physics Research A386, p 531, 1997

[3] M. Alfonsi et al., *The triple-Gem detector for the M1R1 muon station at LHCb*, N14-182, 2005 IEEE-NSS

[4] E. Aza et al., *The triple GEM detector as beam monitor for relativistic hadron beams*, JINST 9 P06006, 2014

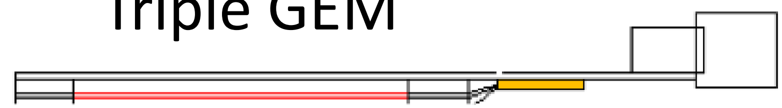
[5] W. Bonivento et al., *Development of the CARIOCA front-end chip for the LHCb muon detector*,
Nuclear Instruments and Methods in Physics Research A491, pp. 233–243, 2002

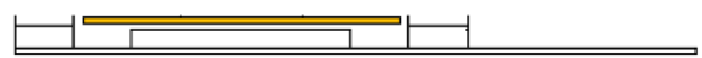
[6] F. Murtas et al., *Applications in beam diagnostics with triple GEM detectors*,
Nucl. Instrum. Meth. A
617 (2010) 237.

Gas Electron Multiplier (GEM) Technology

- Micro pattern gas detector
- Thin holes are etched in a metallised kapton foil and a potential is placed across it
- Very large electric field around the holes (40 kV/cm) which creates a localised electron avalanche
- Couple a timepix asic for readout

Triple GEM





Quad Timepix ASIC

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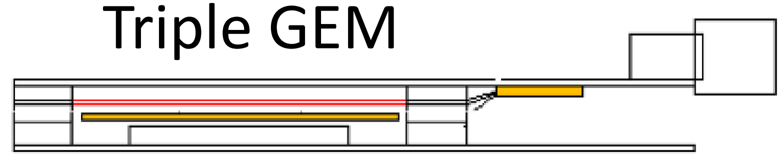
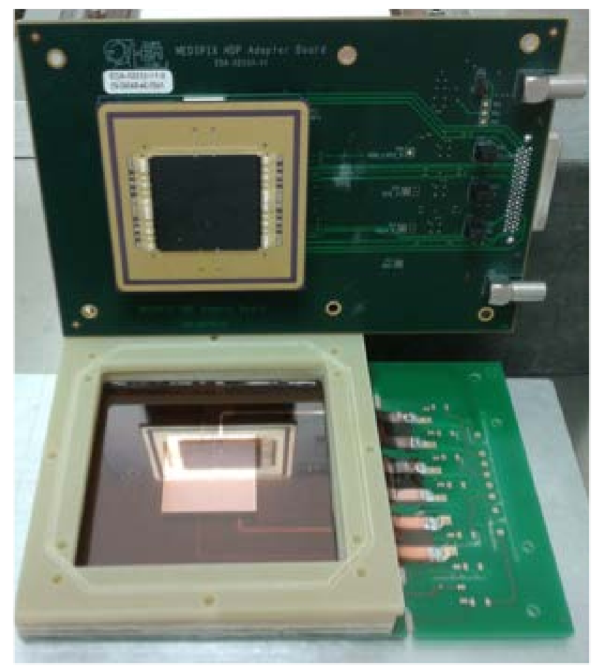


Quad Timepix ASIC



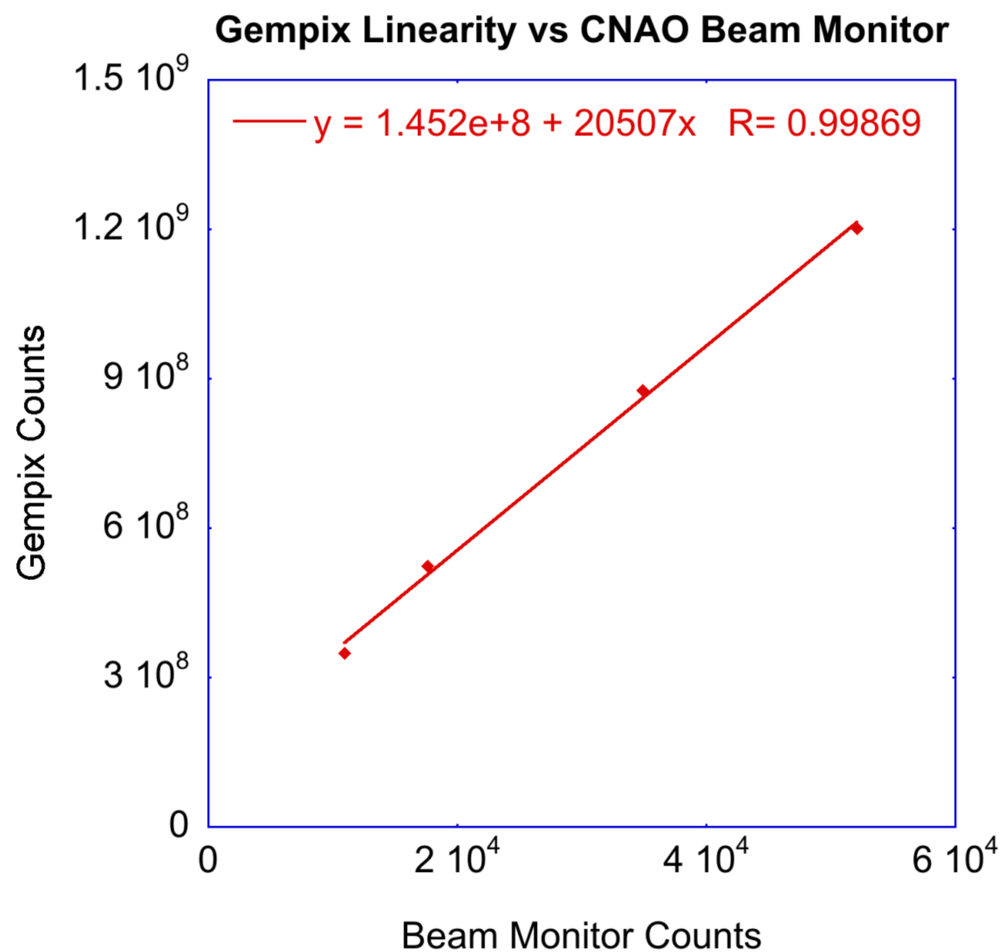
Detector Linearity

90 s measurement, 1 s spill, spill every 5 seconds

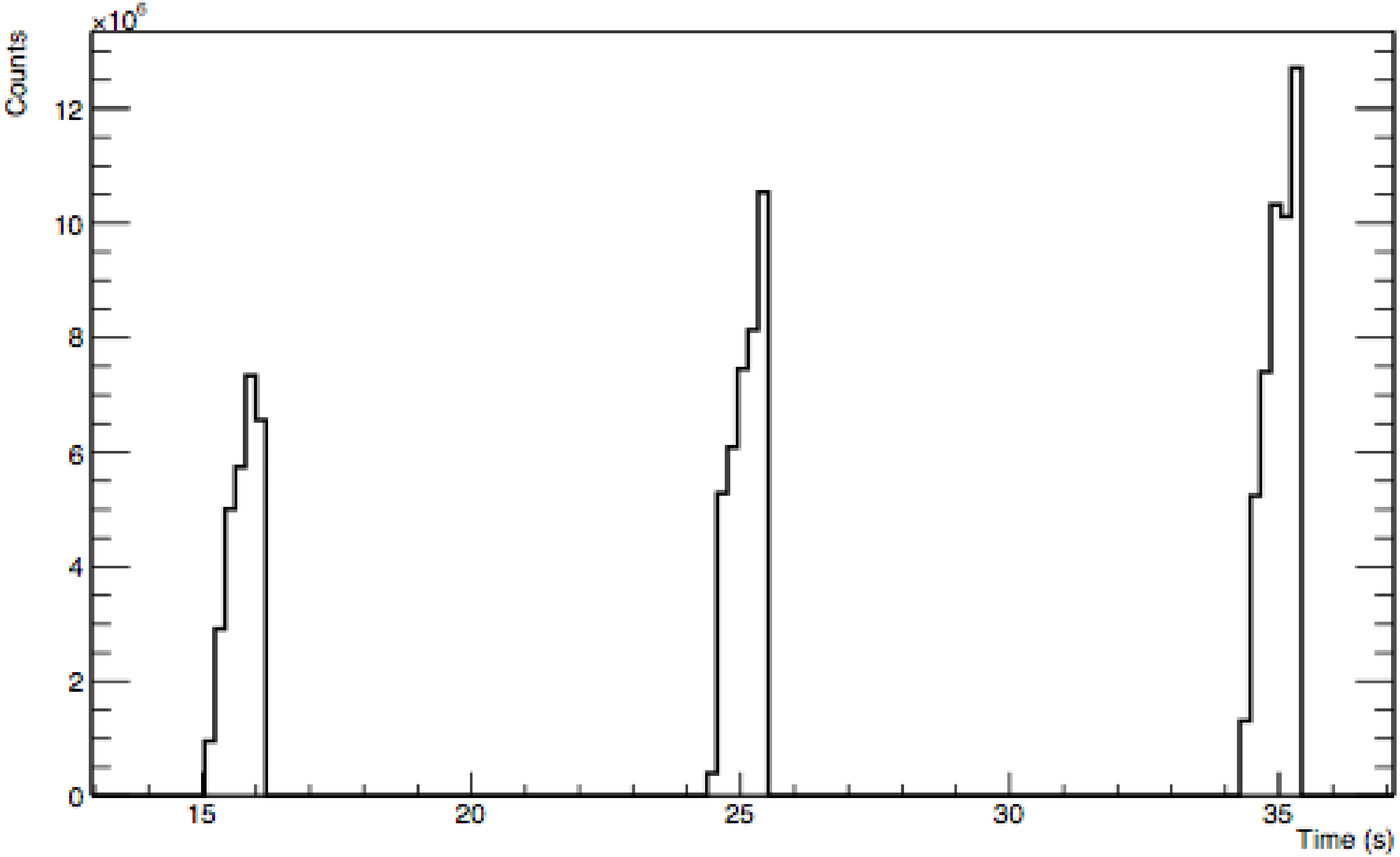
Counts are the integral over the total 90 s period

Number of ions is the counts/average carbon cluster size (~130 pixels)

(Dead time is significant however ~1/10)

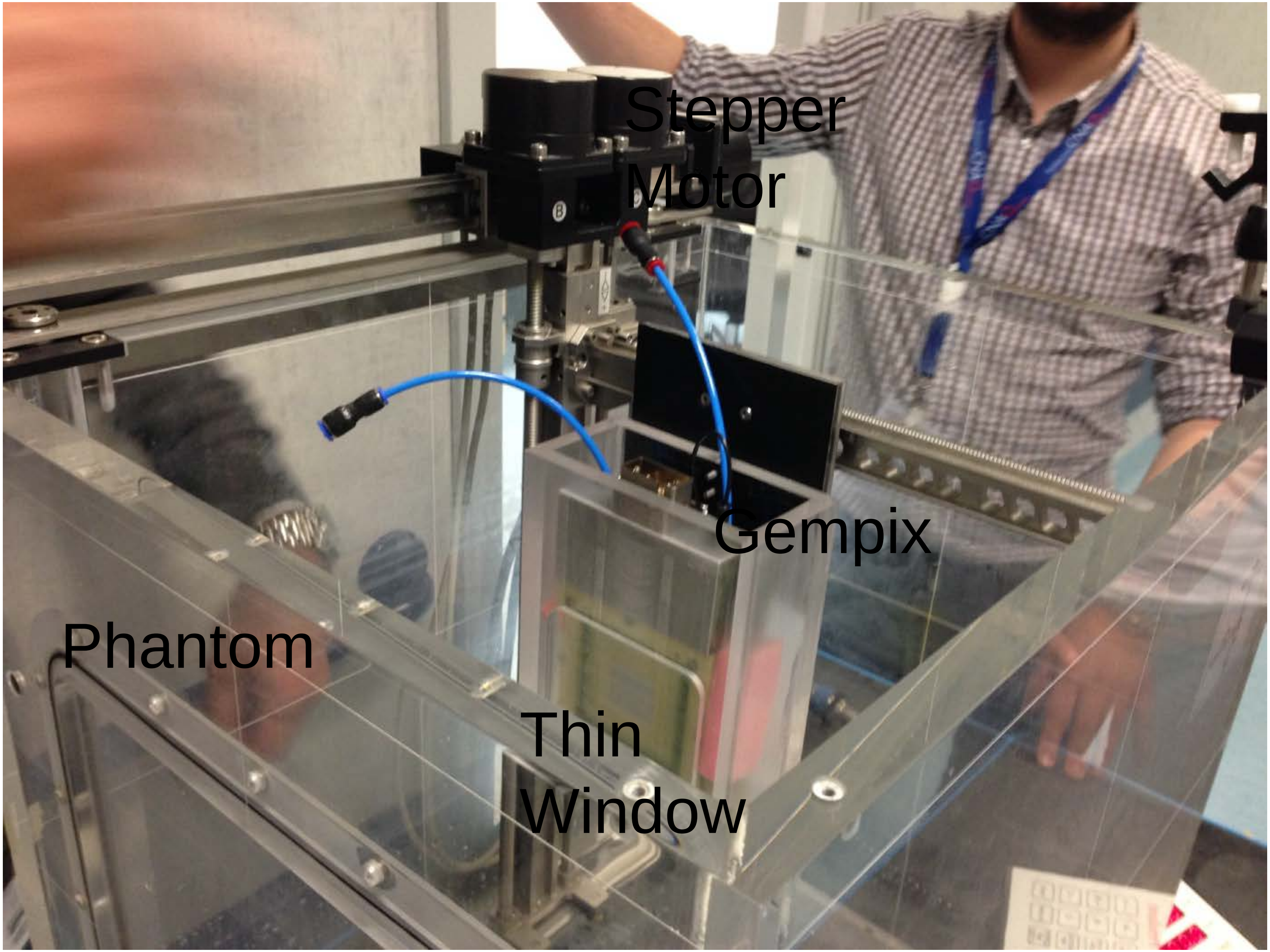


Time Profile of Particle Spill



Energy Deposition Measurements for Hadron Therapy

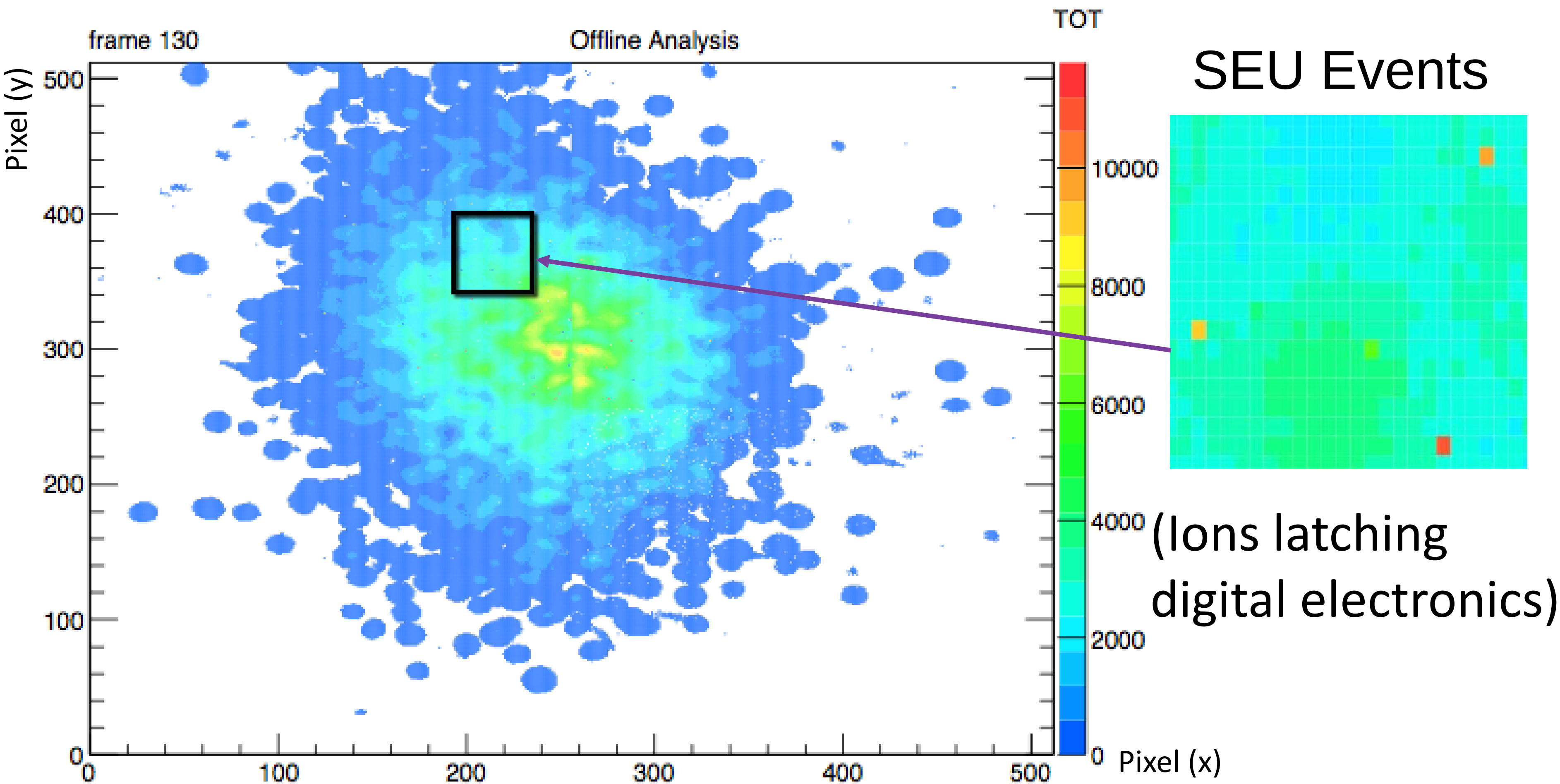
- 252 MeV/A Carbon Ion Beam at CNAO
- 23 different depths throughout water phantom
- Each position given spot 5.10^8 carbon ion treatment (clinical treatment intensities)
- Frame length = 1 ms, gas = $ArCO_2$, gain = 750 (0.43 keV/TOT)


Stepper
Motor
Gempix
Phantom
Thin
Window

Beam characteristics for Bragg peak measurements

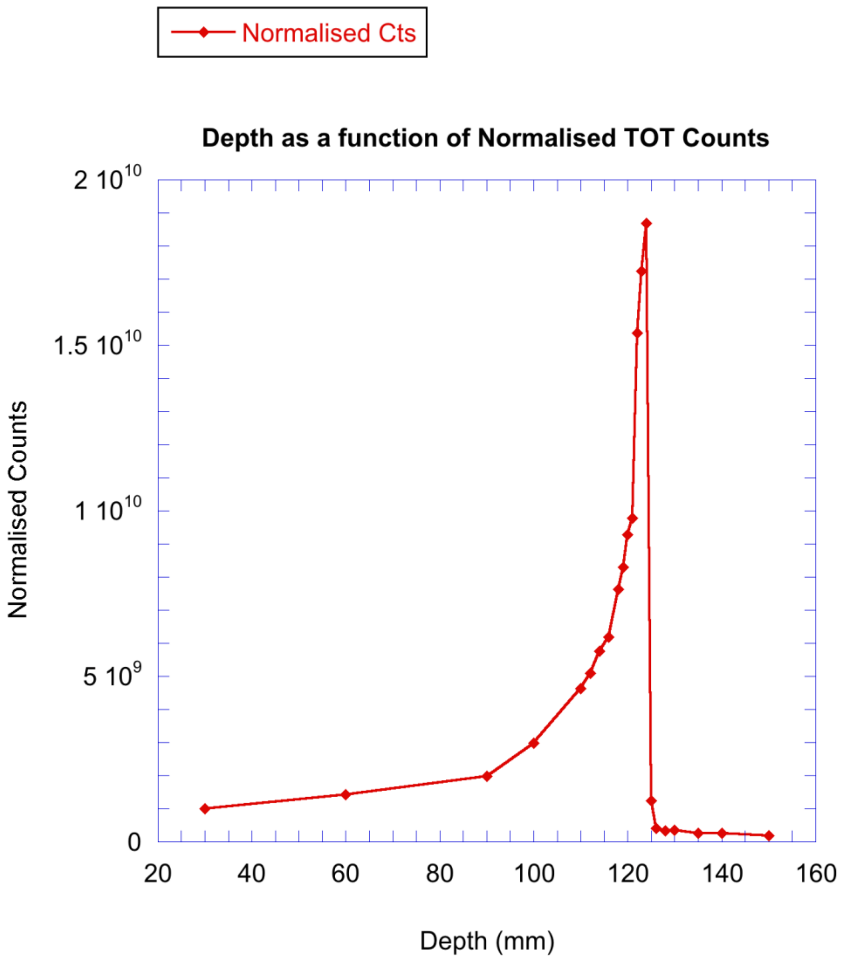
	Carbon Beam
Energy (MeV/nucl)	252
Depth in H_2O (mm)	126
Intensity (part/spot)	5e8

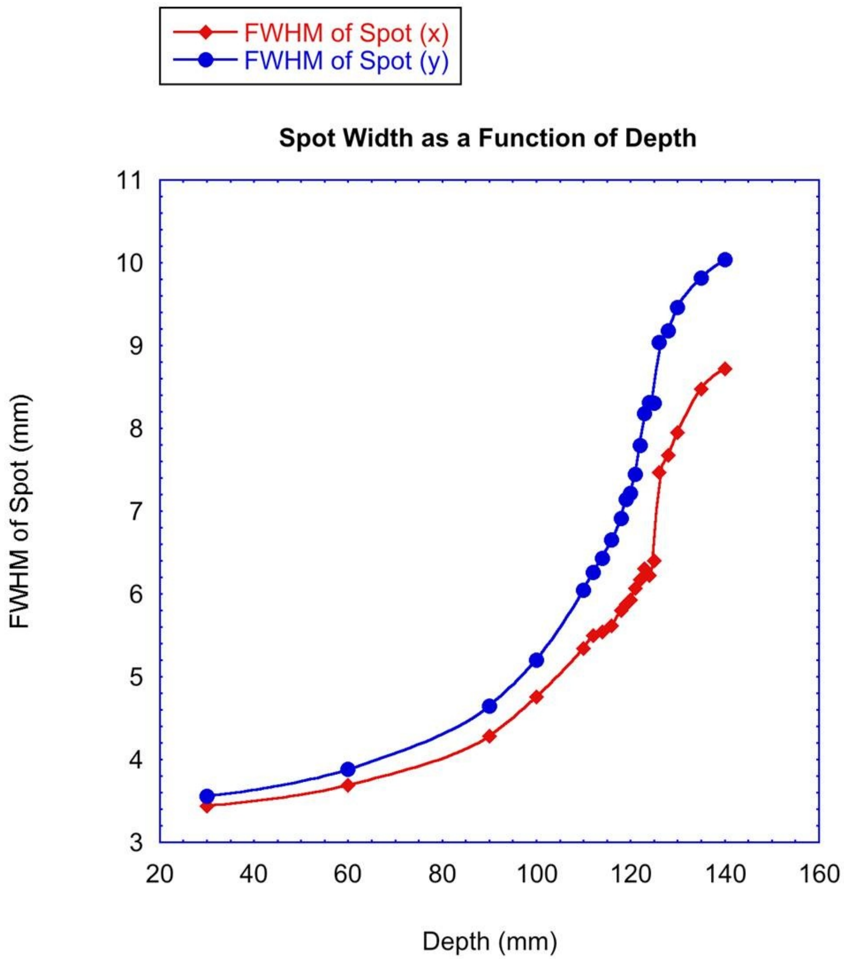
Typical Frame



Depth = 124 mm (In Bragg Peak), 0.43 keV/Count (9.6 MHz, TOT mode), IKrum = 1, 0.001 s frame

Results - Bulk

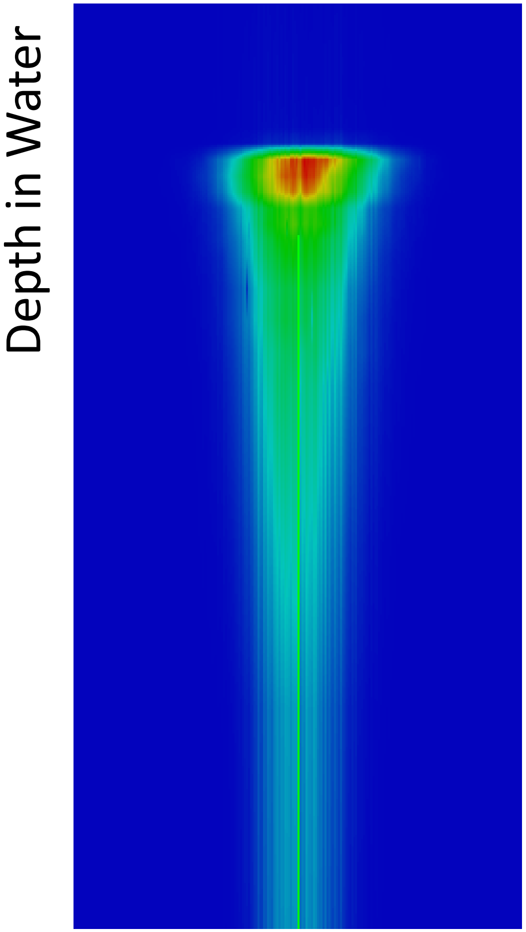




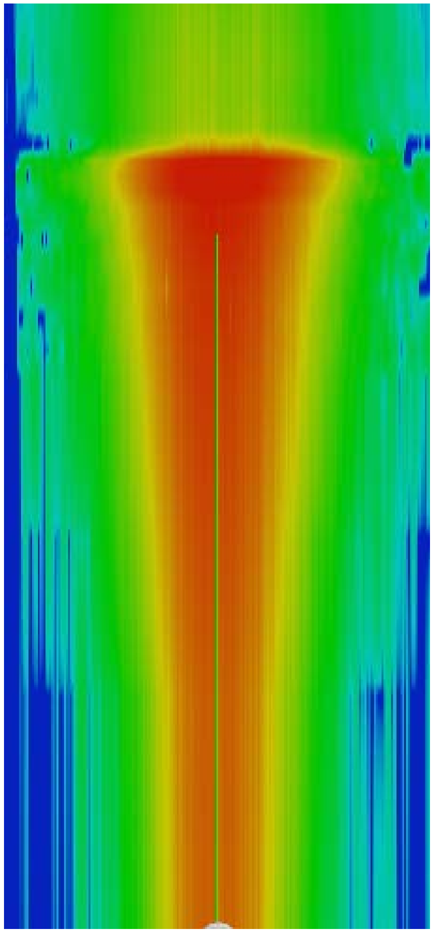
Energy deposition is 0.43 keV/TOT

Spot width here is sigma of gaussian (FWHM = 2.3 sigma)

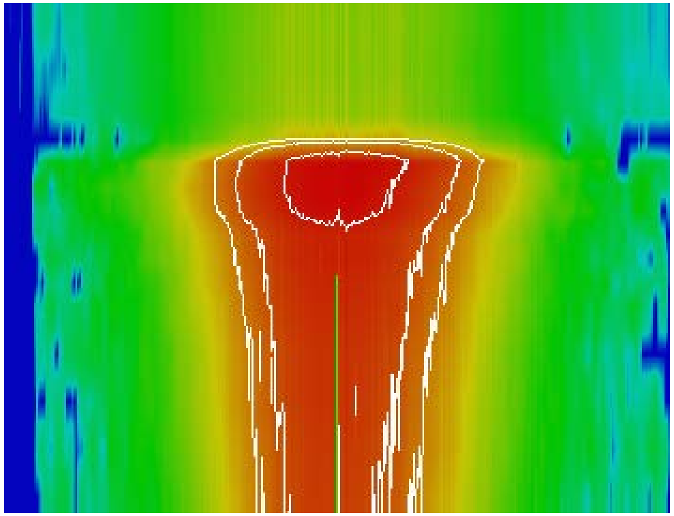
Reconstructed Dataset



Linear

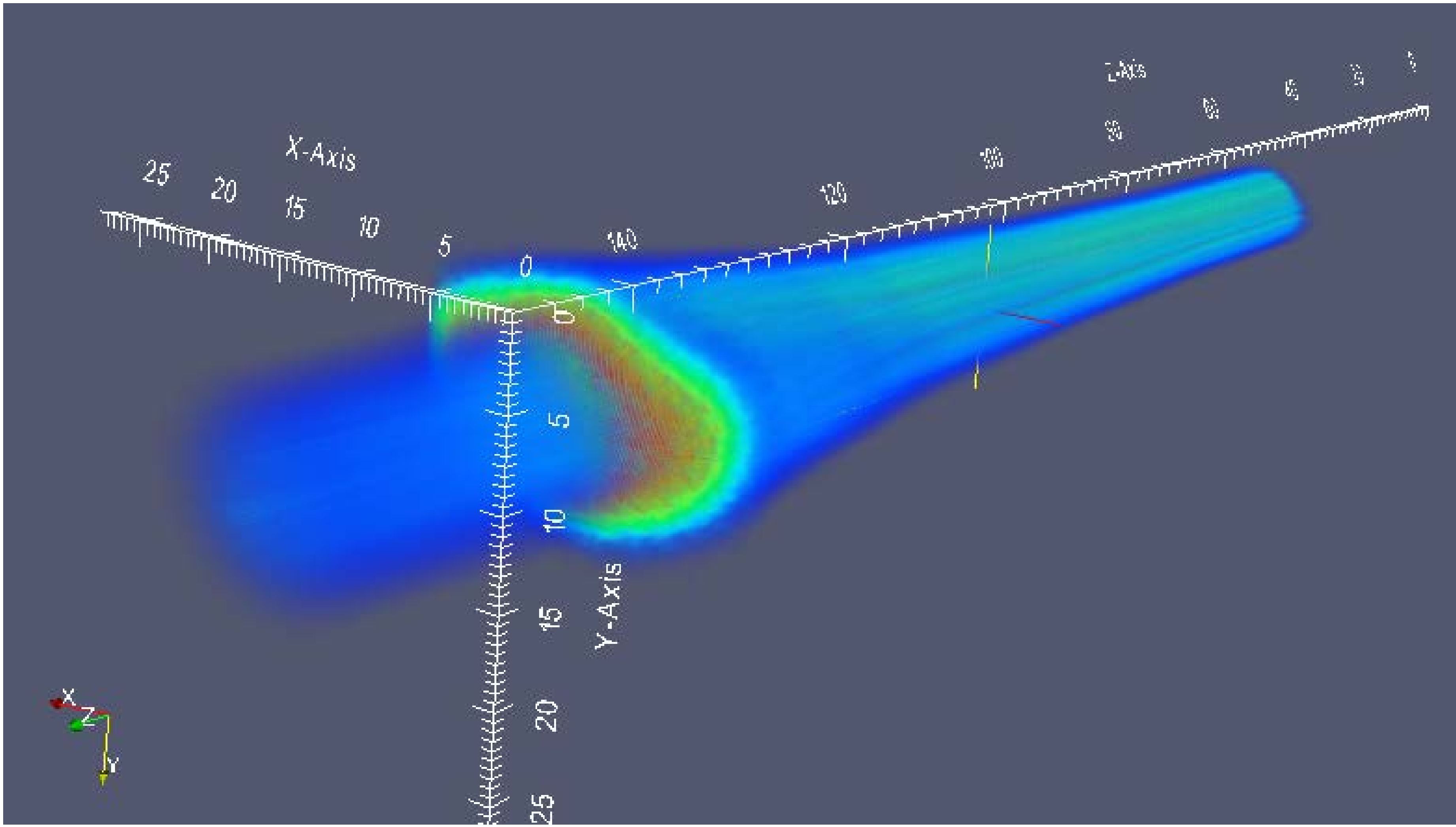


Log



Log with log spaced contours/isodose (3)

Reconstructed Dataset



Beam enters from right, carbon fragmentation tail on left

Conclusions:

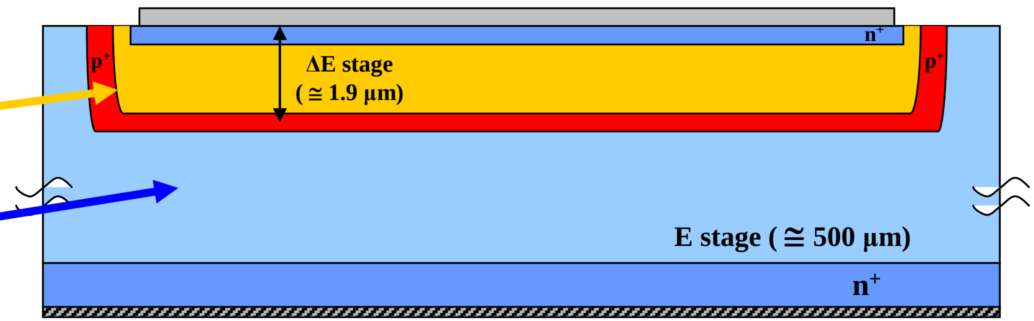
- GEMPix allows reconstructing the Bragg peak in the water phantom. The procedure allows measuring also the tail of the beam after the Bragg peak, useful to have a dosimetric measurements

- The idea would be to incorporate GEMPix in a 3D motorized water phantom and operate it for routing QA

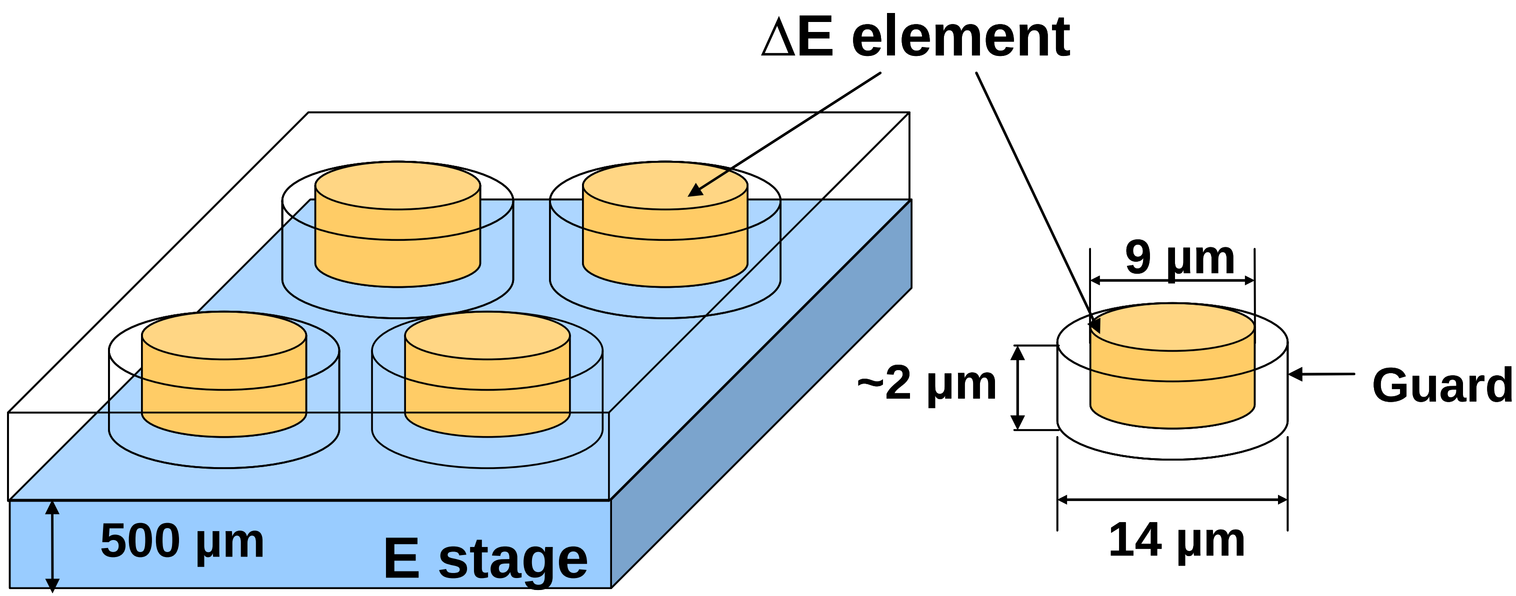
- To be studied: the potential of GEMPix for microdosimetry

SEGMENTED SILICON TELESCOPE FOR MICRODOSIMETRY

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.

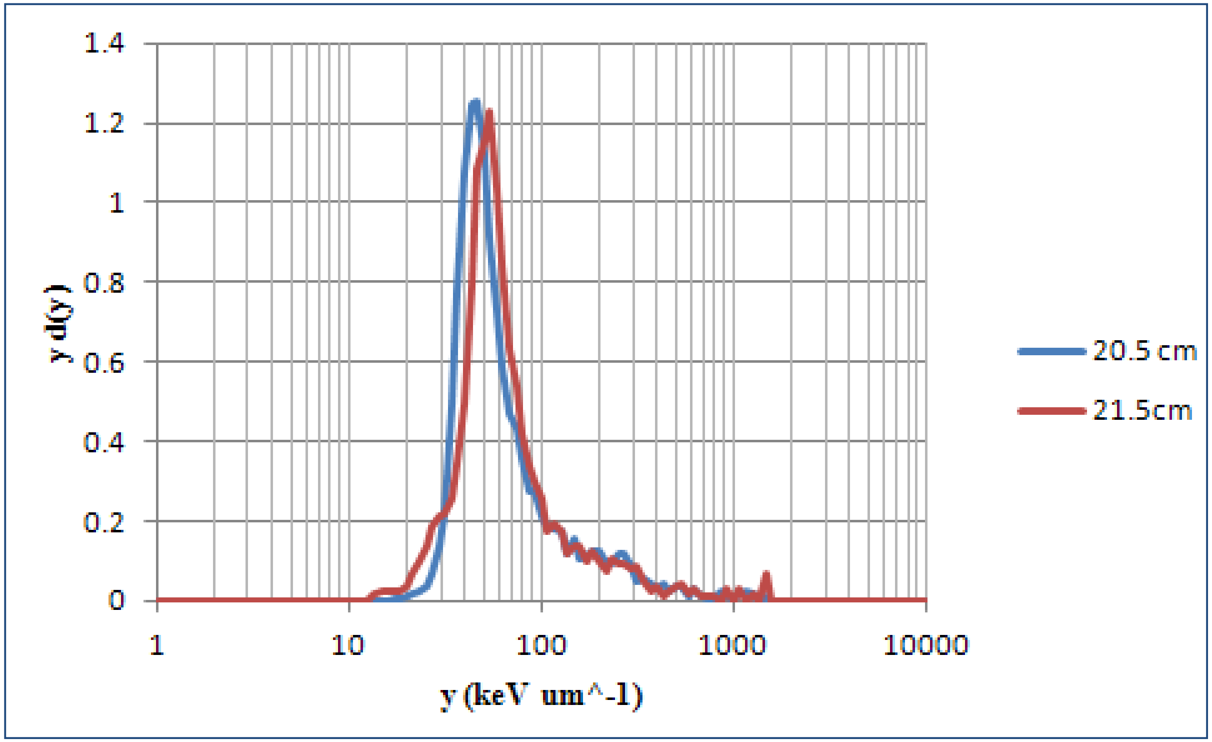


ΔE stage : matrix of cylindrical diodes (h = 2 μm , d = 9 μm)

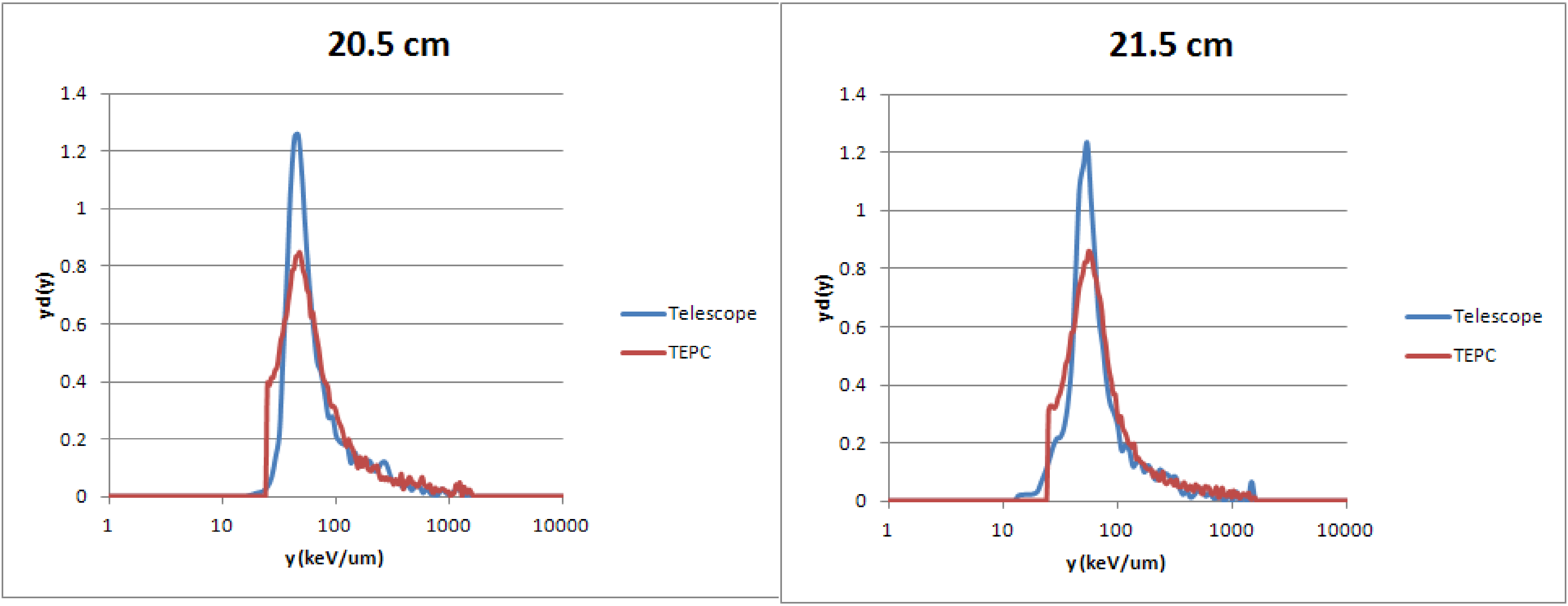


More than 7000 pixels are connected in parallel to give an effective detection area of the ΔE stage of about 0.5 mm^2

Monolithic Silicon Telescope: measurements at different depths in water phantom



Comparison with a miniaturized cylindrical TEPC



Conclusions

1) **Capability of measuring microdosimetric spectra of carbon ion beams**
2) **Good agreement with TEPC results**
3) **Easy operation**