A Water Phantom using Silicon Pixel Detectors

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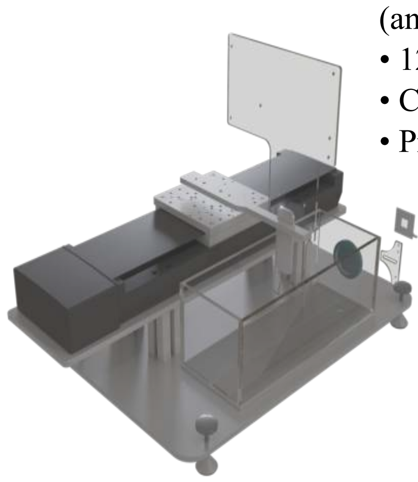
Introduction

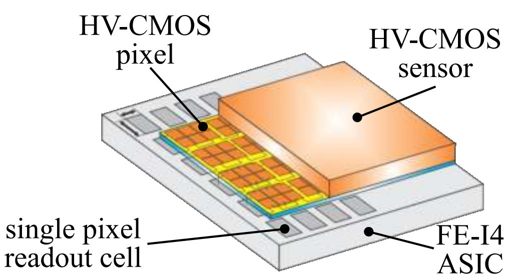
The rise in demand for proton therapy treatment is due to the potential to accurately deliver therapeutic doses to the tumor while decreasing the dose delivered to surrounding critical structures. The targeted dose deposition capabilities of hadron beams (sharp Bragg peaks) make this possible. Proton therapy beams are typically in the energy range 60-250 MeV and involve the use of high fluences, for which novel instrumentation for particle therapy facilities with high precision capabilities is required. This project aims to develop a water phantom using HV-CMOS technology as active detector providing high detection speed, high resolution and low mass while allowing accurate measurements on an event-by-event basis.

Prototype phantom and pixel sensors

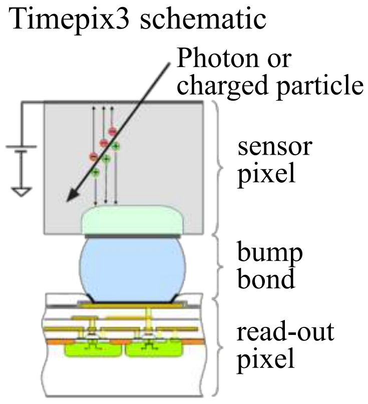
A prototype water phantom was designed and constructed using silicon hybrid pixel technology as sensors for measuring the position, direction and dose characteristics of the beam. The phantom prototype uses a precision linear stage (with ~1 μm repeatability) that moves an aluminum arm holding either two FE-I4 [1] pixel sensors and readout boards or one Timepix3 [2] sensor for proton counting, tracking and energy deposit measurements. The readout boards and pixel sensors are conformally coated with the polymer substrate *Parylene* as a water barrier.



FE-I4 schematic



Timepix3 schematic



- 26880 hybrid pixels
- 80 columns by 336 rows
- Pixel pitch 250 μm by 50 μm

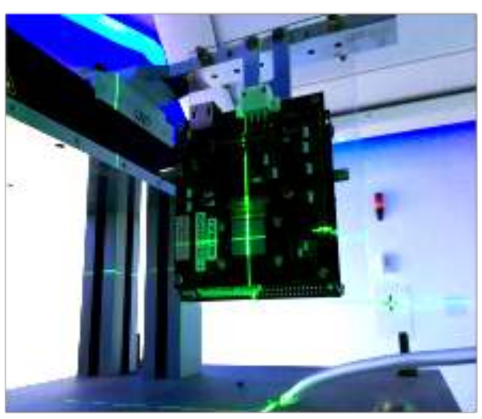
- 65536 hybrid pixels
- 256 columns by 256 rows
- Pixel pitch 55 μm by 55 μm

Each pixel contains an independent amplification stage with adjustable shaping, followed by a discriminator with independently adjustable threshold.

Beam test at The Rutherford Centre

The water phantom was taken to The Rutherford Centre in Newport and in Northumberland, both operated by Proton Partners International.

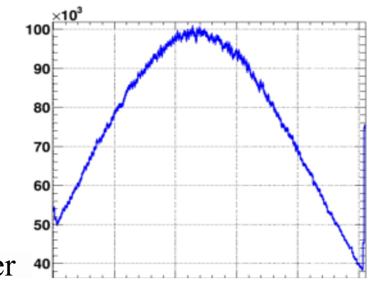
- IBA ProteusOne synchrocyclotron
- Spot scanning beam
- Energy range 70 MeV to 226 MeV
- 220 deg partial gantry (185 to -35 deg)
- Laser alignment system
- FE-I4 chip and readout boards

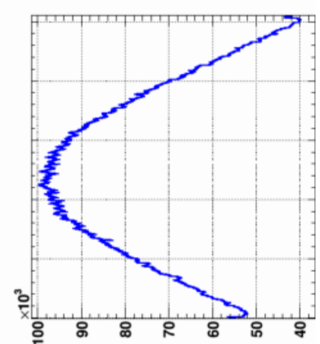


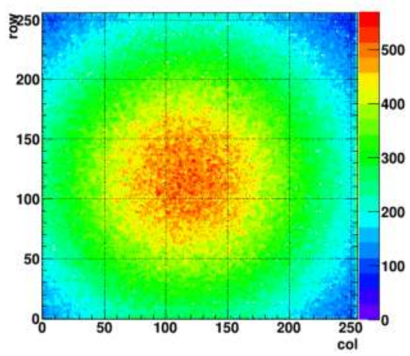
Beam test preliminary results

The IBA ProteusOne synchrocyclotron at The Rutherford Centre Newport and Northumberland was set up to deliver pristine proton beams with a beam spot size of 3.5 mm in diameter for 229 MeV of energy up to 7.5 mm diameter for 70 MeV energy. By scanning a set of FE-I4 or Timepix3 chips through a water tank into which the treatment beam is directed, measurements of the beam position, direction and proton energy deposition of the treatment beam as a function of depth are performed. The Time Over Threshold (ToT) measures the time that the signal is above the discriminator threshold and can be used as a measurement of the dE/dx or dose.

- Timepix3 chip
- 2-D proton counting hit-map (and projections)
- 120 MeV proton beam
- Chip was submerged in water
- Protons traversed 108 mm of water



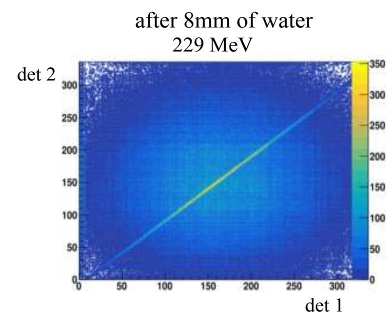




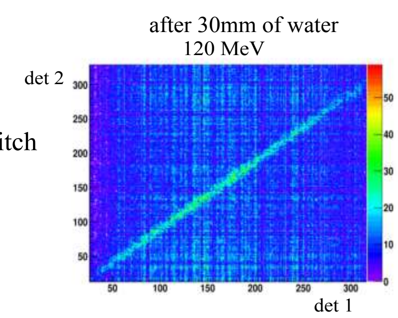
Spatial correlations of two FE-I4 pixel chips for protons traveling through water. The correlations represent protons that can be tracked through both sensors and their direction (angles) calculated.

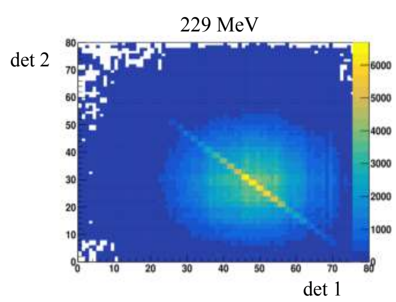
- Correlations for 229 MeV beam
- After traversing 8 mm of water

- Correlations for 120 MeV beam
- After traversing 30 mm of water

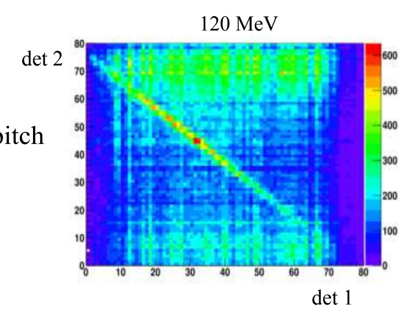


50 μm pitch





250 μm pitch



New sensor design using HV-CMOS technology

HV-CMOS technology is widely regarded as a promising choice for the instrumentation of future high-energy physics experiments, particularly those which require high precision tracking and energy deposition measurements. Many of the advantages of HV-CMOS technology lie in its ability to be fully monolithic and mass-produced on thin substrates at a lower cost than other pixel detector technologies. A new chip is currently under design that will be better suited to the time structure and fluence characteristics of the IBA ProteusOne. The optimisations in the design will allow accurate measurements of high fluxes, and accurate dE/dx reconstruction with limited bandwidth.

[1] T. Poikela et al.,Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout, 2014JINST9C05013.

[2] M. Barbero et al. The FE-I4 pixel readout chip and the IBL module, PoS(VERTEX 2011)038.

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