Usability of ATLAS IBL Pixel Detectors for daily quality assurance in PBS proton therapy

J. Weingarten[1,*], C. M. Bäcker[1,2,3,4], C. Bäumer[1,2,3,4,6], C. Behrends[1,2,3,4], K. Kröninger[1], I. Schilling[1], and B. Timmermann[2,3,4,5,6]

[1]TU Dortmund University, Department of Physics, D-44221 Dortmund, [2]West German Proton Therapy Centre Essen, D-45122 Essen, [3]West German Cancer Center, D-45122 Essen, [4] University Hospital Essen, D-45122 Essen, [4]University Hospital Essen, Clinic for Particle Therapy, D-45122 Essen, [6]German Cancer Consortium, D-69120 Heidelberg

technische universität dortmund

MERCUR Mercator Research Center Ruhr

University Medicine Essen
West German Proton Therapy Centre

Introduction

- Proton therapy is very effective for tumor treatment → deposit prescribed dose in well-defined range
- Preferred dose delivery mode is Pencil beam scanning (PBS) → small diameter beam ((5-10) mm) is scanned in energy layers across target volume (using apertures can lead to sharper gradients at field edges)
- AAPM Task Group 224 has published comprehensive quality assurance (QA) guidelines for proton therapy centers → ensure safety of patients and efficiency of treatment (1)
- Need to verify spot shape, output constancy and range of pencil beam field during the daily QA
- Commonly used detectors: Lynx PT detector IBA Dosimetry (spot shape characterization) & DailyQA3 Sun Nuclear (output constancy verification)
- Possibilities of improving daily QA: perform all measurements with one detector & with higher spatial resolution
- HEP Pixel Detectors , e.g. ATLAS IBL Pixel detector, address issue by having high spatial resolution and ability to measure individual protons (2)

Experimental setup

- ATLAS IBL Pixel detectors (hybrid):
  - 200 µm thick n-in-n silicon sensor, 80 x 336 pixel with a pitch of (250x50) µm², bump bonded to FE-I4B readout chip
  - Designed to track charged particles: hit efficiency in excess of 99%
  - Readout chip provides information on charge deposition in the sensor (time-over-threshold method, ToT) (3)
  - Determination of dynamic range for the measurement of the energy deposition: set amplifier gain & discriminator threshold for every pixel (in this case adjusted to cover a range of (100-750) keV)
- Asses the applicability of the ATLAS IBL detectors for daily QA through characterizing measurements of a single pencil beam spot and a homogeneous field of (2.5 x 2.5) cm² (proton energy 100 MeV)
- All measurements were performed at the West German Proton Therapy Centre, Essen (WPE)
- Data is analyzed regarding required parameters for daily QA

Spot shape characterization

- Lateral beam profile of a single PBS spot → expected width measured with

  Lynx PT σ_{Lynx}= (5.5±0.5) mm

- Hitmap shows 2D Gaussian fit to fluence profile (fig. 1)

  → yields width of the beam profile σ = (5.78±0.03) mm (4)

- Uncertainties an order of magnitude smaller than that of standard measurements

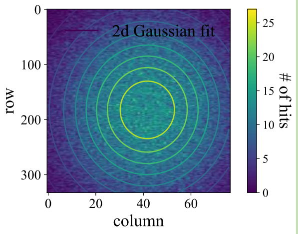

Fig. 1: Hitmap of a single pencil beam spot. The intensity profile is fitted with a two-dimensional gaussian function.

Dose consistency testing

- Dose accuracy of 3% during daily QA is required
- Fluence dependent detector response needs to be calibrated: detector is irradiated with varying doses (Monitor Units, MU)
- Linear dependency between total averaged hits and dose (fig. 2)

  → measure dose with an uncertainty of 2.6%

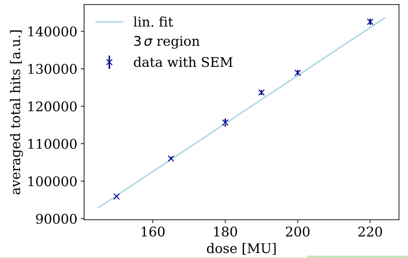

Fig. 2: Total hits summed across the sensor as a function of the irradiated dose (MU).

Range verification/ accuracy of delivered beam energy

- Using a PMMA absorber consisting of four regions with different thicknesses (5 mm – 12.5 mm) (fig. 3) & 51 mm WET plate

  → exploiting the pixelated sensor structure (high spatial resolution)

- ToT distributions of different regions provide information about mean energy deposition in the sensor (fig. 4)

  → peak shifts to higher ToT values as the absorber gets thicker

  → protons with lower energies deposit more charge in the sensor

- Parameter to monitor proton energy during QA: ratio of most likely ToT in different regions
- Promising agreement between a simulated (Geant4) and measured ratio → further investigation ongoing

Fig. 3: Picture of the sensor and the segmented PMMA absorber.

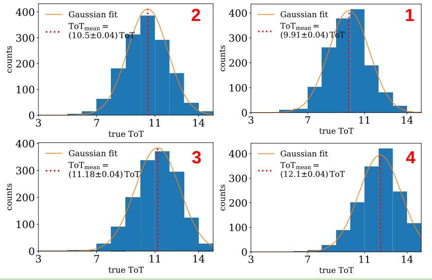

Fig. 4: Comparison of the ToT distribution for the different thickness regions of a PMMA absorber.

Conclusion

- Present application of a high energy physics detector for daily QA measurements in proton therapy
- Characterized beam profile of a small spot with an order of magnitude higher spatial resolution
- Requested output constancy verified (uncertainties <3%)
- Proof-of-principle measurements using an absorber with different thicknesses and the ToT information regarding range verification show promising results
  - Need to perform repetitions to determine detection limit for range variances
- Validate methods for different beam energies & field sizes

References

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* contact: jens.weingarten@tu-dortmund.de