Estimating a proton's position in a pencil beam for proton imaging

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Single Sided Proton CT

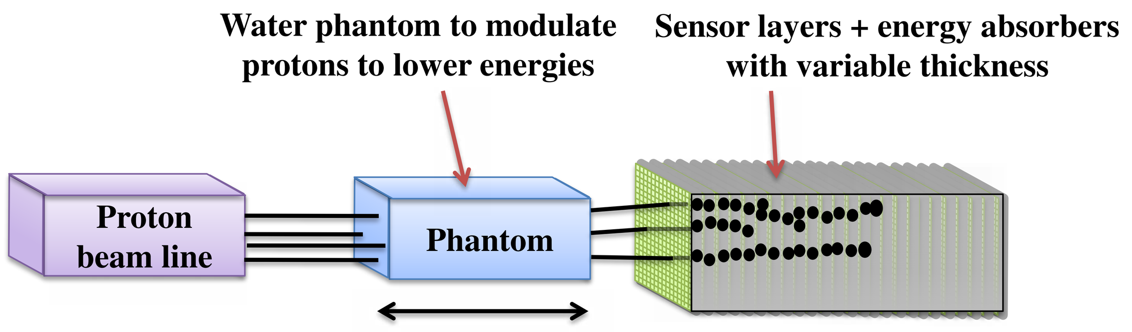

Figure 1: A single sided proton CT setup from [1].

Proton Computed Tomography (pCT) is a prototype imaging modality for measuring a patient's Relative Stopping Power, this to reduce the conversion uncertainties inherent in X-ray CT.

A high-granularity pixel-based range telescope pCT is described in [1]. 10–200 simultaneous protons can be separated by track reconstruction, allowing estimated pencil beam proton rates of >10 million protons per second.

It is non-trivial to connect the multiple tracks from the range telescope to a front tracker. The initial proton trajectories need to be estimated from the available measurements.

The goal of this work is to find the error in the path estimation in a single sided pCT setup.

Most Likely Path

During pCT image reconstruction, a Most Likely Path (MLP) of a proton is calculated, usually from the front/back trackers together with its initial and residual energy. In [2] the Bayesian MLP framework is extended to account for uncertainties in the various measurements.

Here we use the uncertainty of a initial pencil beam for single sided pCT. The initial position t_0 is calculated using the extended MLP framework, combined with a cubic spline path (CSP) for efficiency.

Monte Carlo simulations

The study is performed with GATE 8.1.p01 / Geant4 10.04.p02 / ROOT 6. The builder list `QGSP_BIC_EMZ` is used together with a maximum step size of 1 mm.

An idealized setup of [1] is modeled: a 230 MeV pencil beam of varying Gaussian σ, a box phantom of different materials and thicknesses and finally a set of ideal back trackers.

Three scenarios are considered for each proton's entry position: perfect knowledge from front trackers (for comparison); the mean lateral position of the pencil beam (TPS); and the estimated entry position t_0.

The resulting CSP are compared to MC truth, with examples in fig. 1 and average errors in fig. 2. In figs. 3 and 4, different initial pencil beams and phantoms are considered.

Results: Path Estimation Techniques

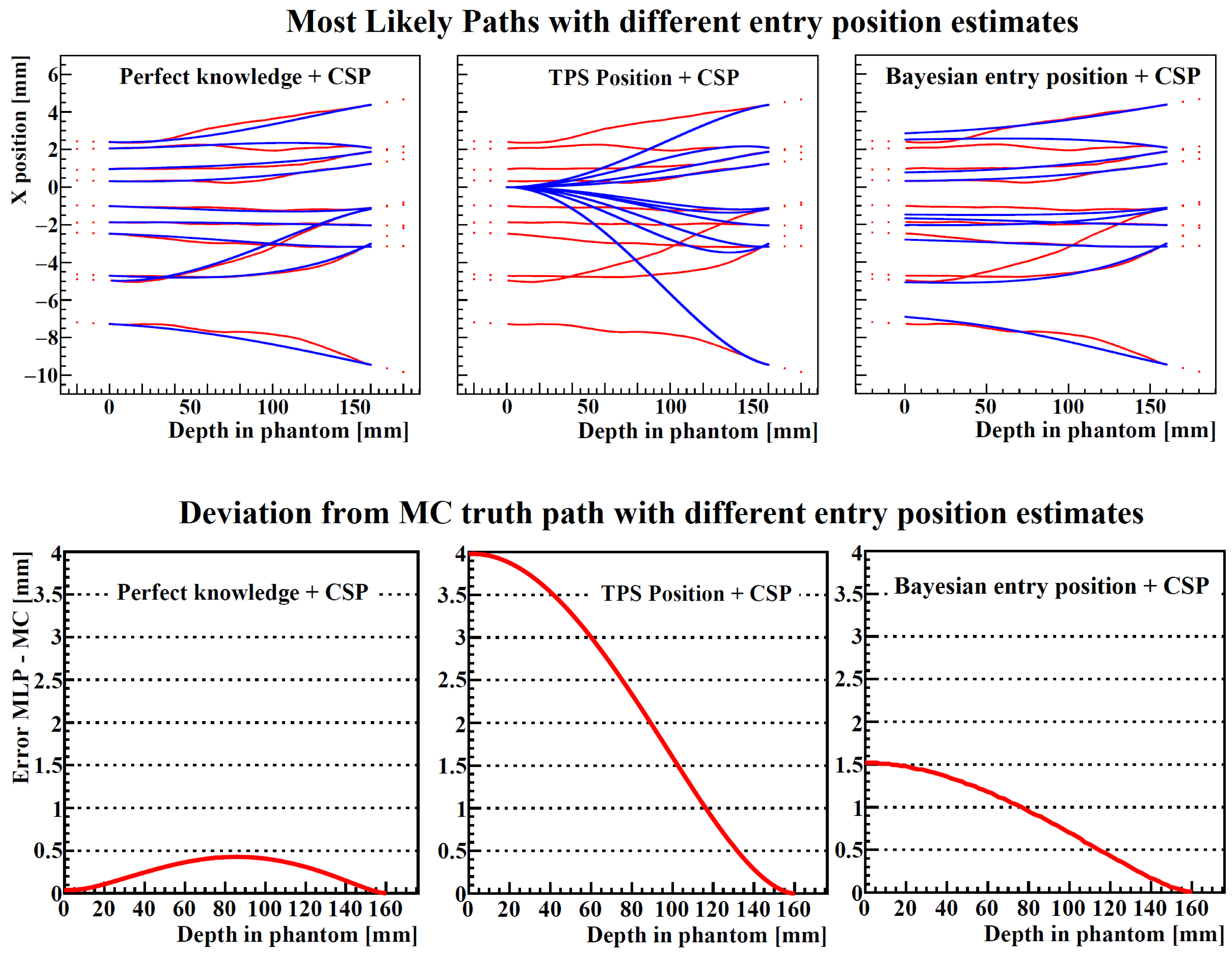

Figure 2: Examples from different path estimations (top) and their respective mean absolute errors (bottom) in a 16 cm water phantom. The circular pencil beam spot size is σ = 4 mm.

Results: Proton Beam Sizes

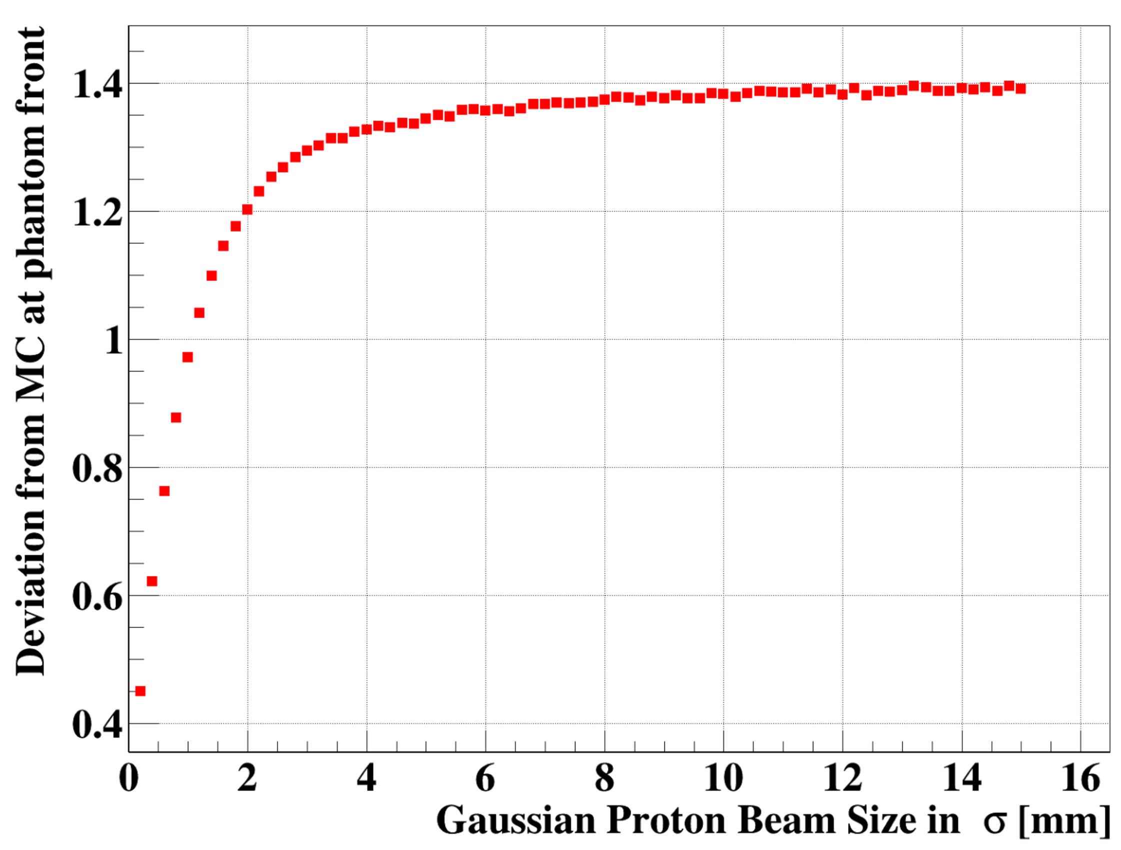

Figure 3: Errors from the Bayesian estimation with different beam sizes in a 16 cm water phantom.

Results: Different Materials

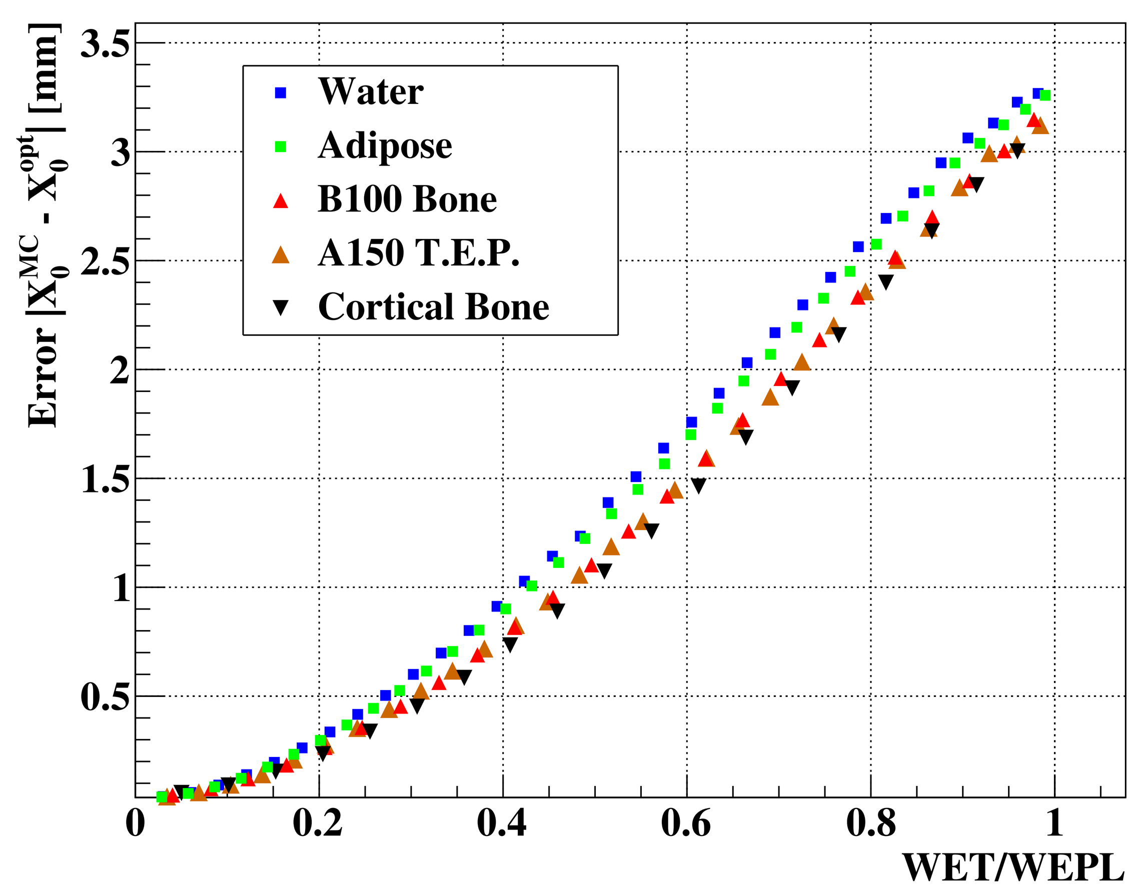

Figure 4: Errors from the Bayesian estimation. WET/WEPL is the ratio of the phantom's thickness to the total range of the initial proton and σ = 4 mm.

Conclusion

A single side pCT setup has been evaluated on basis of the path estimation error. In the example setup, the error is a factor 2.5 below the pencil beam's spot size. In many cases the maximum error is kept below 1.5 mm. The error has an asymmetric depth-dependency, and the impact (and possible mitigation) of this on reconstructed images are currently being considered.

References

[1] H. E. S. Pettersen, *A Digital Tracking Calorimeter for Proton Computed Tomography*, University of Bergen, PhD thesis (2018) Substitute this for the optimization article if it's done by then

[2] N. Krah *et al.*, *A comprehensive theoretical comparison of proton imaging set-ups in terms of spatial resolution.* Phys. Med. Biol. 63 (13) (2018) Schulte (2008)? Charles-Fekete