Criteria for spot asymmetry in proton radiotherapy pencil beam scanning – a Monte Carlo study

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Aim of work

In proton therapy units with pencil beam scanning (PBS) dose is deposited in energy layers, spot by spot. Treatment Planning Systems (TPS) calculate a treatment plan basing on measured beam characteristics which includes spot sizes. Spot distortions like asymmetry or spot rotation occuring during the delivery of the beam are not taken into account in the TPS and can disturb planned dose distribution. The aim of this study was to verify spot asymmetry criteria within which target dose conformity can be kept in agreement with the TPS.

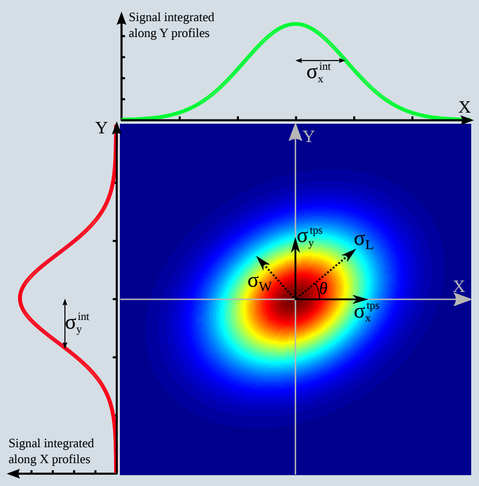
Materials & methods

During daily QA procedure at Bronowice Cyclotrone Centre (CCB) at IFJ PAN proton beam spot size and spot asymmetry are verified by horizontal and vertical profiles analysis from spot in-air measurements. The spot asymmetry is defined here as:

$$S = 100\% * \frac{\sigma_x - \sigma_y}{\sigma_x + \sigma_y}$$

where σ_x and σ_y describe spot size in orthogonal directions. Our acceptance criteria for spot asymmetry, based on the vendor recommendations, is 10%.

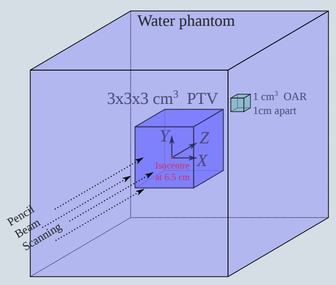
However, the spot size, can be calculated in several ways by fitting Gaussian shape to shape to (*cf.* **figure**):



- vertical and horizontal profiles of the spot (σ_x^{tps} and σ_y^{tps})
- profiles integrated over one vertical or horizontal direction (σ_x^{int} and σ_y^{int})
- profiles extracted from major and minor axis of the spot (σ_L and σ_W with rotation angle θ)

During beam delivery spot distortions (e.g. asymmetry) are controlled by Multi-layer Ionisation Chamber (MLIC) mounted in the scanning nozzle. Due to the large distance of the MLIC from the treatment isocentre (~2 m), only significant spot deformation can pause the beam during the delivery. To verify the effect of spot distortions on dose distribution various combinations of beam size and rotation angle were evaluated to 10% in beam asymmetry with following conditions:

treatment planning



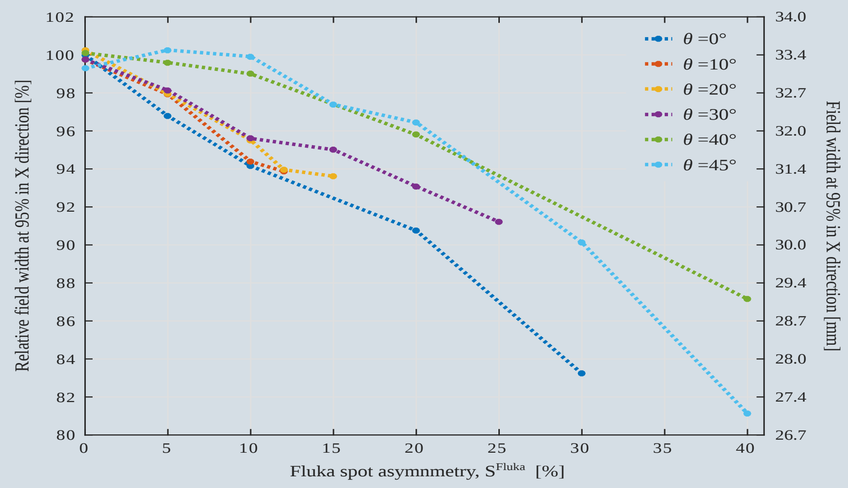
- Eclipse TPS (VMS Inc.)
- $3 \times 3 \times 3\ cm^3$ cubic target from 5 cm depth defined in a water phantom
- 1 Gy of prescribed physical dose to the target region
- $1\ cm^3$ organ-at-risk (OAR) at depth 6.5 cm, 1 cm away from the target
- commissioned beam data for CCB IFJ PAN gantry room

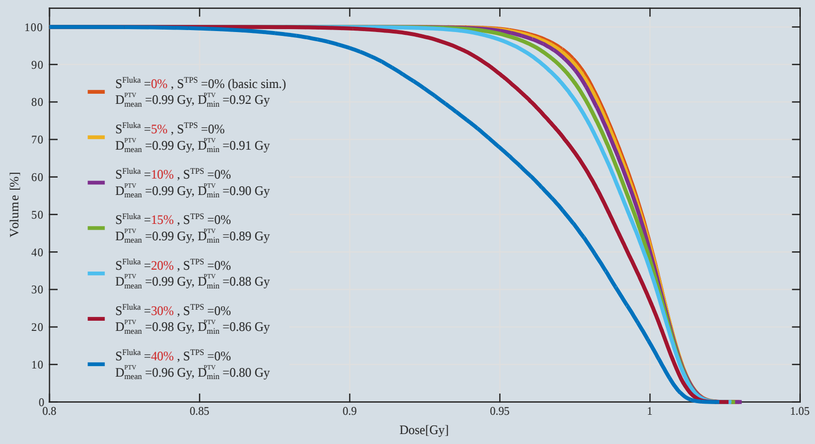
simulation & analysis

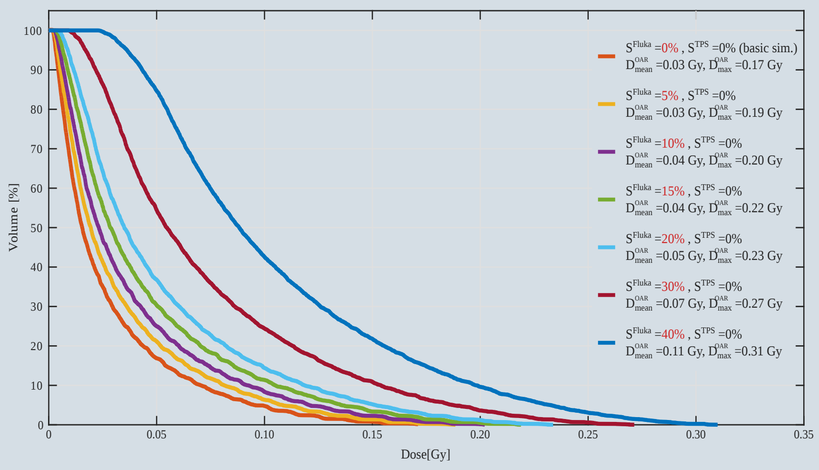
- FLUKA MC particle transport code [1,2]
- corresponding commissioned beam model
- spot asymmetry up to 10% (based on with σ_x^{int} and σ_y^{int} values)
- investigated spot rotation angles: $0°, 10°, 20°, 30°, 40°, 45°$
- dose-volume-histograms (DVH) calculated from target region and OAR
- field width analysis perforemd at the 95% level
- $1\ cm^3$ OAR dose analysed for plan malformation

Results

The field width analysis at the 95% level was performed at the isocentre transversal palne (6.5 cm depth). Strong dependence on the spot rotation was observed, exceeding 15% of the field width relative difference in reference to the initial plan (**top figure**). For 3D analysis, largest DVH differences are visible for spot rotation of $45°$, where according to integral spot size calculation, spot asymmetry is constantly 0% for both target region (**middle figure**) and adjacent OAR structure (**bottom figure**). For the utmost considered case, maximal dose in OAR rises from 0.2 Gy to 0.3 Gy when compared to the initial plan results (for $45°$ spot rotation angle and 40% S^{Fluka} asymmetry).







Conclusions

Considered limit of 10% in spot asymmetry was found appropriate for TPS plans for spot rotation angle below 30 deg. For higher rotation angles, however undesirable dose variations were observed, both in the target region and neighboring OAR. Therefore, daily QA spot analysis performed at CCB IFJ PAN is to be extended to include analysis of the spot rotation in order to avoid dose discrepancies not taken into account by the TPS.

Acknowledgements

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[1] T.T. Böhlen, et al., The FLUKA Code: Developments and Challenges for High Energy and Medical Applications", Nuclear Data Sheets 120, 211-214 (2014)
[2] A. Ferrari, et al., FLUKA: a multi-particle transport code, CERN- 2005-10 (2005), INFN/TC_05/11, SLAC-R-773

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