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G4beamline simulation of Collimation and Spills between T2 and TNF in BL1A

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Abstract: This note summarized the simulation results regarding the beam spills and beam collimation from T2 to TNF in BL1A. Initially, we conducted a comparison of the two rms envelopes of the beam using both the G4Beamline model and TRANSOPTR. The results demonstrated a consistent agreement between the two models. Based on the G4 model, we investigated spills with varying target lengths. Finally, we examined the impact of geometry parameters and alignment errors of the collimator on beam spills and collimation.

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1 Introduction

The T2 target in BL1A is a thick target (maximum 102 cm Be), leading to significant angular scattering and energy straggling after the beam passes through it. A quadrupole triplet following the target refocuses the beam to reduce the beam envelope from T2 to TNF. However, due to the long scattering tails in the beam angular distribution fall outside the acceptance of the quads, the beam in the tails eventually gets lost along the beamline. To localize spills and protect the quads downstream of the T2 target, a collimation system consisting of two collimators was designed. The geometry of the longer collimator, collimator B, is optimized as a compromise between increasing the transmission from T2 to TNF and reducing spills downstream of the collimators. [1]

The design process for the collimator section employed the REVMOC tool. However, REVMOC does not accurately account for energy loss in the collimator, as the rate of energy loss is based on the on-axis particle, which remains unaffected in a collimator. According to Templeton's test, the error in slit scattering caused by energy error was 20%. To enhance the simulation, we utilized the up-to-date Monte Carlo tool G4Beamline to model the beamline from T2 to TNF. The model is constructed and updated based on Fred's BL1A model [2] and verified by comparing scattering and energy straggling with analytical results [3].

2 Model

The layout of the components is shown in the upper plot in Figure 2. The magenta cylinders represent the collimators, while the green ones are the quads. Following the triplet, there are three scraper boxes; the first scraper is shorter, designed to minimize back scattered neutrons.

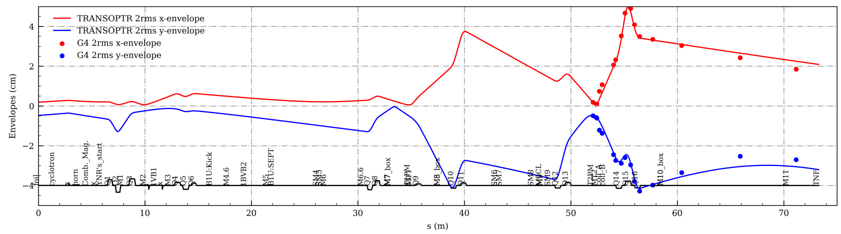


Figure 1: Beam envelopes calculated using TRANSOPTR and G4Beamline. The G4 simulation model starts from T2 protection Monitor, and the initial beam distribution is Gaussian with the sigma matrix parameters obtained from TRANSOPTR. In this note, T2 is default a 5 cm Be target in the simulation. The discrepancy in the envelopes arises from the non-Gaussian distribution after the beam passes through the T2 target. The difference between the two simulation models is within 15% along the beam line.

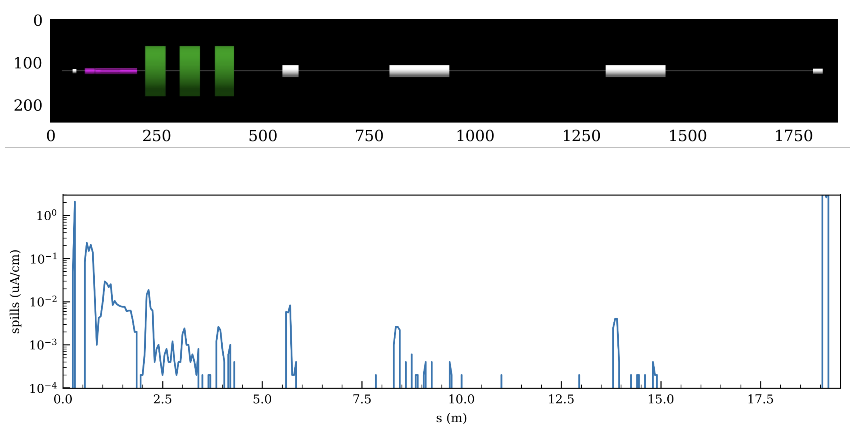


Figure 2: Layout of the components and beam spills along the beamline between T2 and TNF. The beam loss rate on the T2 target is approximately 2 uA/cm with a primary beam intensity of 100 uA, resulting from non-elastic nuclear reactions. The second peak, at around 0.2 uA/cm, represents the collimated beam on COL A. The loss rate on COL B is ten times smaller than A, attributed to its larger aperture. In the post-collimation section, the maximum loss rate is approximately 0.02 uA/cm, occurring at Q14, the first quads following the collimator. Beam loss downstream of the triplet is confined to the scraper box, with a loss rate of less than 0.01 uA/cm.

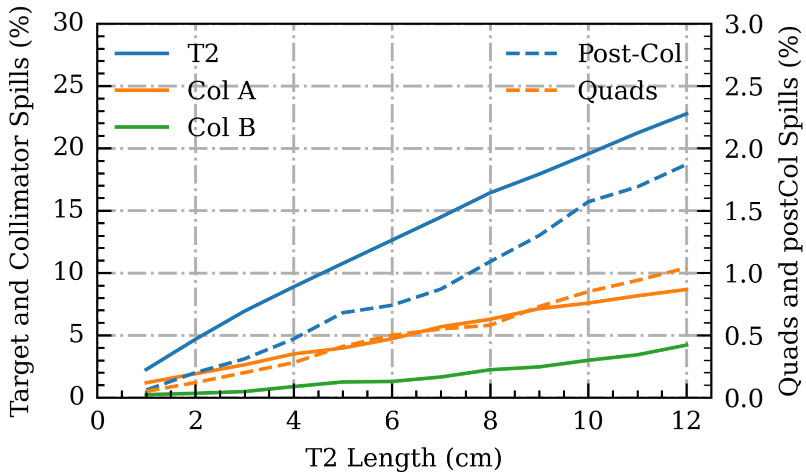
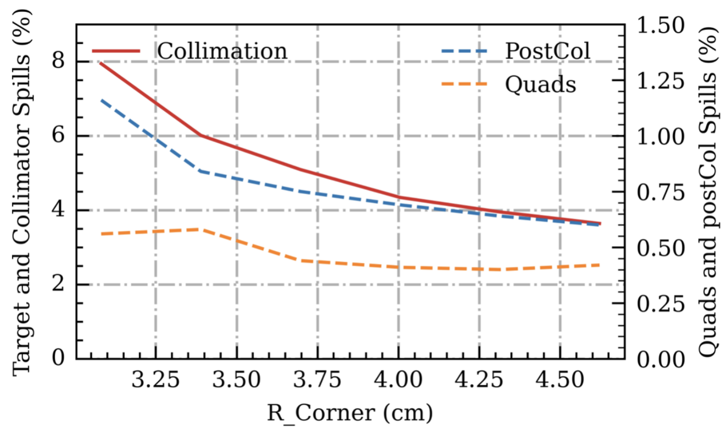


Figure 3: Spills vs. target length. The results demonstrate a linear dependence of all spills on the target length.

3 Geometry of Collimator B

The current geometry of collimator B is optimized for the 10 cm target. We explored the influence of geometry parameters of the collimator on beam spills and collimation with a 5 cm target in this note.

(a) 5 cm T2 target



(b) 10 cm T2 target

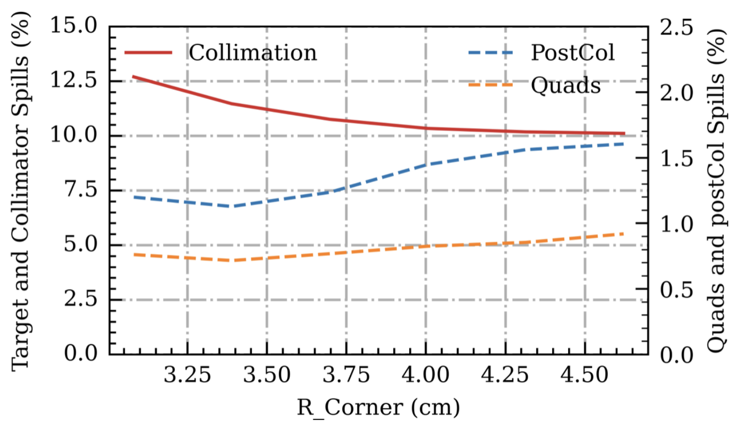
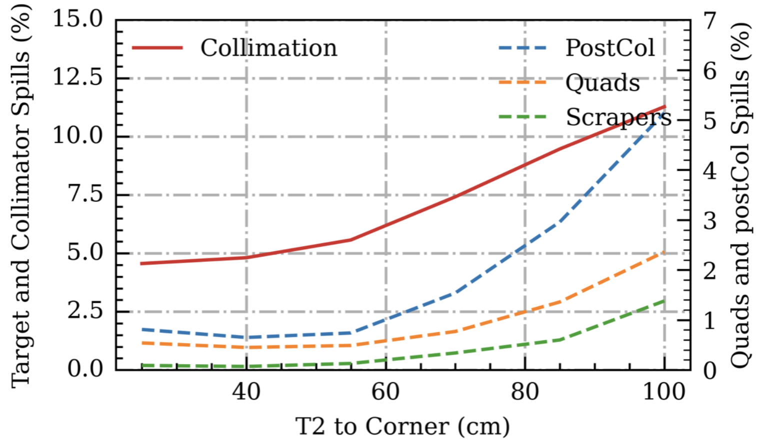


Figure 4: Beam spill vs. aperture of the COL B. (a) 5 cm T2. (b) 10 cm T2. R_Corner is the radius of the aperture at the corner point in COL B, which is the smallest aperture in COL B. With a reduced aperture, the beam loss in the collimation section increases, which is expected. The beam loss downstream the collimator section consists of two components. One involves particles with large scattering angles and energy straggling resulting from passing through the target. The other component is particles scattered by the collimator. If the latter one dominates, the beam loss downstream the collimation section increases as the collimators cut the beam. When using a 10 cm target, beam losses after the collimation section are primarily dominated by target scattering. Conversely, when employing a 5 cm target, scattering caused by the collimator become the dominant factors.

(a) 5 cm T2 target



(b) 10 cm T2 target

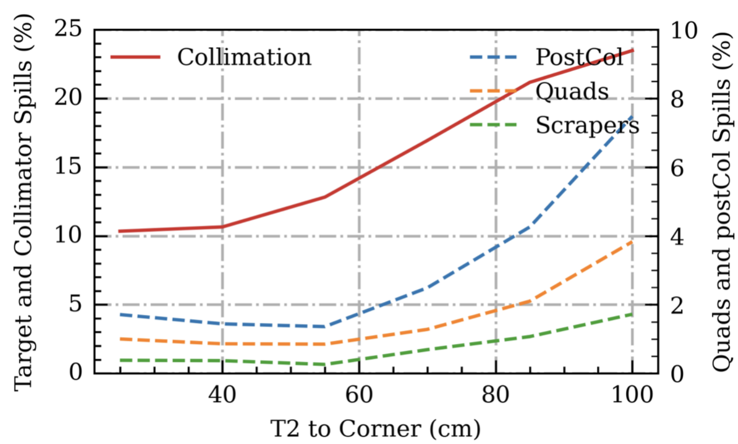


Figure 5: Beam spill vs. position of the COL B throat. (a) 5 cm T2. (b) 10 cm T2. For both target lengths, placing the throat of COL B more upstream is preferred.

4 Misalignment

This simulation involves analyzing the effects of misalignment on beam spills and collimation efficiency. A typical centering error of the beam on T2 is within the range of several millimeters and less than 10 mrad [4]. The misalignment of COL B with respect to the centerline of T2 is at a similar level. By systematically introducing misalignments in the collimator's positioning and studying their impact on spills, we acquire a preliminary understanding of the system's sensitivities.

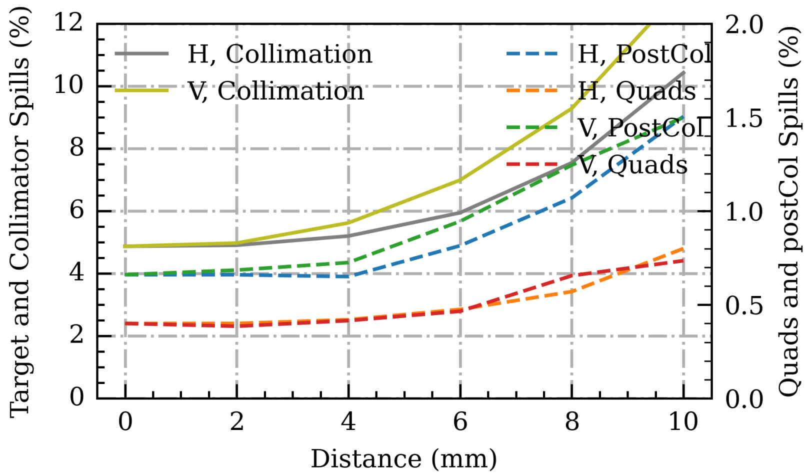


Figure 6: Spills vs. misalignment of COL B entrance. V in the legend means result with vertical misalignment, H is the one with horizontal misalignment. The spills increases with the alignment error. Notably, spills has a higher sensitivity to vertical misalignment, due to the larger vertical beam size present in the collimator section. Because the corner point, which has the smallest aperture in COL B is more close to then entrance of COL B, the spills and beam collimation are more sensitive to the misalinment of COL B entrance comparing with Fig. 7.

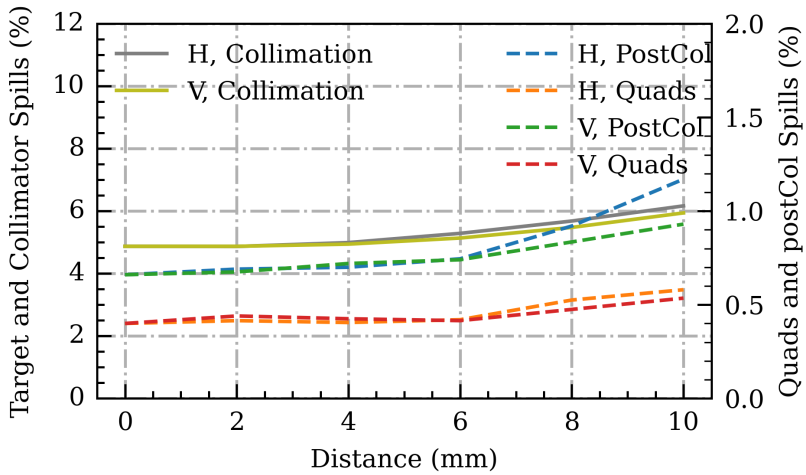


Figure 7: Spills vs. misalignment of COL B exit. According to the collimator alignment note dated back to 2009, the entrance of collimator B is aligned with the center line of the target. However, there is a misalignment of 0.3 inches vertically and 0.1 inches horizontally at the exit. This misalignment is expected to result in an increase in post collimation spills by approximately 20%.

5 Conclusions

The beam spills exhibit a linear dependence on the target length.

The current geometry parameters of COL B is optimized for a 10 cm Be target, which is not optimal for a 5 cm Be target.

Misalignment of COL B by several millimeters can noticeably increase transmission loss and lead to a rise in spills in the post-collimation section.

References

[1] T. Templeton, A. Arrott, P. Reeve, Spill Calculations and Ceam Collimation in Beam Line 1a between T1 and TNF, Tech. Rep. TRI-BN-77-18, TRIUMF (1977).

[2] F. Jones, BL1A Simulation Model in G4Beamline, Tech. Rep. TRI-BN-19-03, TRIUMF (2019).

[3] L. Zhang, BL1A Study Using G4Beamline and TRANSOPTR: Calibrate the Beam Parameters on the Target, Tech. Rep. TRI-BN-19-03, TRIUMF (2020).

[4] Y.-N. Rao, BL1A T2 Issue, Tech. Rep. TRI-BN-17-23, TRIUMF (2017).

6 Appendix

6.1 TRIUMF gitlab repository

https://gitlab.triumf.ca/beamphys/G4T2TNF.git