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UPGRADE SCENARIO FOR THE RHIC COLLIMATION SYSTEM

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Abstract

The RHIC collimation system is used to reduce background levels in both STAR and PHENIX detectors. With a push for higher luminosity in the near future, it becomes critical to check if and how the level of performance of the collimators can be improved. The following reviews a proposal for additional collimators placed further downstream of the current system and designed to intercept the tertiary halo coming out of the IR8 insertion before it can reach the triplet quadrupoles in either STAR or PHENIX.

INTRODUCTION

Using live data from previous runs, the RHIC collimation system allowed benchmarking the extended version of SixTrack for collimation studies [1]. This software can now be used to study an upgrade scenario to the current system. Table 1 lists the center position and active plane (i.e. the beam direction that is intercepted by the collimator jaw) for each collimator in both Blue and Yellow beamlines in the main ring of RHIC. The collimation system is located between Q3 and Q4 downstream of the PHENIX experiment in IR8, with all four collimators installed over a drift space of roughly 20 meters.

Table 1: Location (from IP6) and active plane of RHIC collimators in the current system.

	Blue		**Yellow**	
Name	S [m]	Plane	S [m]	Plane
COL0	680.752	Hor. + Vert.	3236.649	Hor. + Vert.
COLH1	690.533	Horizontal	3246.430	Horizontal
COLV1	696.706	Vertical	3252.603	Vertical
COLH2	697.728	Horizontal	3253.625	Horizontal

Table 2: Twiss function $\beta_{x,y}$ for Run FY09 at E_{store} = 100 GeV at the RHIC collimators.

	Blue		**Yellow**	
Name	β_x [m]	β_y [m]	β_x [m]	β_y [m]
COL0	1486.007	483.661	1534.254	504.750
COLH1	845.084	201.805	871.956	210.945
COLV1	533.168	86.653	549.741	90.768
COLH2	488.422	72.266	503.527	75.737

Another characteristic of the collimation for RHIC is the behavior of the optic functions along the system: as shown in Table 2, $\beta_{x,y}$ decrease rapidly between the primary collimator COL0 and the secondary jaws. Assuming a normalized emittance of 20 π, one gets σ_x = 6.81 mm and σ_y = 3.90 mm at COL0, while σ_x = 3.89 mm at COLH2 and σ_y = 1.65 mm at COLV1. Optimizing the positions of the secondary collimators to capture the halo coming from the primary can therefore prove difficult to achieve.

Table 3: Collimator openings for Run FY09 at E_{store} = 100 GeV in unit of sigmas and in millimeters. Blue and Yellow use the same normalized settings.

Name	$\mathbf{N}_{x,y}$ $[\sigma_{x,y}]$	$\mathbf{n}_{x,y}^{\mathrm{Blue}}$ **[mm]**	$\mathbf{n}_{x,y}^{\mathrm{Yellow}}$ **[mm]**
COL0 Hor.	5.866	39.97	40.61
COL0 Vert.	4.583	17.82	18.20
COLH1	7.533	38.71	39.32
COLV1	6.0265	9.92	10.15
COLH2	8.131	31.76	32.25

In order to increase the efficiency of the current system, one could find the optimal locations for additional collimators that would be designed to absorb most of the secondary halo (from COLH1, COLH2 and COLV1 for each beamline) before it reaches the triplet quadrupole in STAR or PHENIX. Such locations can be determined based on the theory of beam collimation (reviewed in [2]) and the available space in RHIC. One major change would be the use of two-sided tungsten jaws, as opposed to the current one-sided copper collimators. This would allow the system to be less sensitive to a new working point in the future.

PROPOSED NEW LOCATIONS

As mentioned above, the plan for the mask collimators is to provide additional protection against background in STAR and PHENIX. The motivation behind installing mask collimators comes from the fact that the STAR experiment is the very next insertion downstream of the collimators following the Yellow beam. The baseline for finding the optimal locations for those masks should therefore be the Yellow lattice; an equivalent solution will then be applied to the Blue lattice. The constraints to be considered are the optic functions between IR8 (collimation insertion) and IR6 (STAR insertion) and the available space for the new equipment that would have to be installed.

Phase advance from COL0

To find the location of the new collimators (that could be called either tertiary jaws or masks), one could define a *golden* situation for the collimation. Let us consider the following case: the RHIC collimators are setup according

Table 4: Mask collimator properties; the optics functions values are taken from Run FY09 at E_{store} = 100 GeV settings. S locations are in reference to IP6 going clockwise.

Ring	Name	S [m]	L [m]	β_x [m]	β_y [m]	$N_{x,y}$	$n_{x,y}$ [mm]	Material
Blue	TCTH.TS1.B1	1129.061	0.45	25.853	21.625	N_x = 9.658	n_x = 8.68	Tungsten
	TCTV.TS1.B1	1132.561	0.45	37.696	13.703	N_y = 4.655	n_y = 3.05	Tungsten
Yellow	TCTH.TS2.B1	3684.958	0.45	24.722	21.891	N_x = 9.767	n_x = 8.58	Tungsten
	TCTV.TS2.B1	3688.458	0.45	35.920	14.130	N_y = 4.650	n_y = 3.09	Tungsten

to their settings during Run FY09 (see Table 3), and the beam hits the primary jaw COL0 with an impact parameter of 1 μm in each plane (since COL0 is L-shaped to work in both planes at once). From [2] and SixTrack sample runs, one can calculate the resulting transverse kicks Δxp and Δyp that a particle gets from the iteraction with the primary copper jaw:

$$\Delta xp = \Delta yp = -155 \ \mu\text{rad}, \tag{1}$$

with xp and yp the horizontal and vertical angle (respectively) of a particle motion along the s axis. To calculate the phase advance $\Delta\mu$ generated by such a transverse kick, one can use the following normalized coordinates expression:

$$\tan(\Delta\mu_z) = \frac{\Delta ZP}{Z_{\text{coll}}}\ , \tag{2}$$

with Z (ZP) either of the transverse normalized coordinates X (XP) or Y (YP), and Z_{coll} the opening of the primary collimator in normalized coordinates in the corresponding plane. With β_z and α_z the twiss functions at the location of the primary collimator and ϵ_z the beam emittance in the considered transverse plan, one finds:

$$Z_{\text{coll}} = \frac{z_{\text{coll}}}{\sqrt{\beta_z\ \epsilon_z}} \tag{3}$$

and:

$$\Delta ZP = \frac{|\Delta\mu_z + \frac{\alpha_z\ z_{\text{coll}}}{\beta_z}|}{\sqrt{\epsilon_z/\beta_z}}\ . \tag{4}$$

Inserting Eq. 3 and 4 in Eq. 2, it yelds:

$$\tan(\Delta\mu_z) = \frac{\beta_z}{z_{\text{coll}}}.\left|\Delta\mu_z + \frac{\alpha_z\ z_{\text{coll}}}{\beta_z}\right|\ . \tag{5}$$

With Eq. 1 and Table 2, along with the corresponding values of α_x and α_y at the location of COL0, one gets:

$$\begin{aligned} \Delta\mu_x(\text{Blue}) = 0.2450 \qquad \Delta\mu_y(\text{Blue}) = 0.2381\ , \\ \Delta\mu_x(\text{Yellow}) = 0.2451 \quad \Delta\mu_y(\text{Yellow}) = 0.2386\ . \end{aligned} \tag{6}$$

Mechanical design and available space

The new collimators for the considered upgrade scenario would feature two jaws per plane, centered around the beam path. The current choice for the jaw material is tungsten, which would provide very good absorption rate for the incoming secondary halo. The motivation behind tungsten is its succesful use for the LHC tertiary collimators, designed to protect the experimental triplet magnets from beam induced quenches; using tungsten to reduce halo backgrounds in RHIC experiments should therefore carry similar efficiency. The mechanical design of the collimator tank should follow the current scheme with 45 centimeters long jaws; the total flange-to-flange lenght of a collimator tank is approximately 1.5 meters.

As stated above, the critical item for this upgrade is reducing the background in STAR following the Yellow beamline, since it is the experiment immediately downstream of the current collimation system for that beam. The goal when trying to locate the new mask collimators is to find a stretch of open space large enough to fit both a horizontal and a vertical mask (plus all required space for installation purposes) upstream from the first triplet quadrupole when getting into IR6, which lattice name is $yi6 - qf3$). One can find two potential locations:

- between $yi6 - dh9$ and $yi6 - qf9$: roughly 7.5 meters available and $\Delta\mu_x$(COL0) = 3.1577, $\Delta\mu_y$(COL0) = 3.9552;
- between $yi6 - qd8$ and $yi6 - qf7$: roughly 13.1 meters available and $\Delta\mu_x$(COL0) = 3.4156, $\Delta\mu_y$(COL0) = 4.1773;

the phase advance values being calculated at the centre of the empty space. The two locations listed above are the ones that fit Eq. 6 requirement the closest. Even though the first location is the shortest, this is the location that was used for the study reported in this article, based on the fact that there is a smaller difference in phase advance compared to the target value in the horizontal plane.

Eq. 6 shows very similar values between the Blue and the Yellow beam; for practical reasons it was decided to use the location in Blue equivalent to the one selected for Yellow, which corresponds to the space between $bi9 - dh9$ and $bi9 - qf9$. Table 4 summarizes all the characteristics (optics and mechanical) of the mask collimators for the studied upgrade; N_x and N_y are the calculated openings of each mask collimator in units of sigmas using the baseline of Table 3 for the COL0 settings.

SIMULATION RESULTS

Figure 1 shows the result of simulations performed with SixTrack using Run FY09 settings and optics, respectively without and with the new mask collimator from the studied upgrade scenario, following the Yellow beam moving from left to right (i.e. going counter-clockwise around RHIC). For these simulations, we track separately the horizontal and the vertical plane of the beam, using "pencil" distributions of 24000 protons. The tracked particles are all generated as a point-like beam arriving on the primary collimator jaw with an impact parameter of 1 μm, meaning that all particles are generated at a normalized amplitude of (primary collimator opening) + 1 μm. This is done so as to simulate the interaction of the beam halo with the collimation system.

In each figure, the bars labeled "cold losses" correspond to the amount of protons lost in the machine aperture; the "collimator losses" lines list the number of protons absorbed at the collimtators, i.e. the ones suffering inelastic scattering interactions with the jaw material (copper for the existing system, tungsten for the new masks). One can clearly see the effect of the additional collimators, the losses incoming into IR6 being nearly completely removed. Table 6 provides a list of the largest losses around the ring, without and with the upgrade. Losses immediately downstream of the collimators in IR8 are identical between the 2 simulation scenarios because (1) the random seed used was the same (for practical purposes, to provide a "what would have happened" representation) and (2) losses in that area are unavoidable since they come from direct showering from the collimators to the nearby magnets located a few meters down the beamline. Predicted beam loss statistics downstream of the IR8 collimators are therefore not included for comparison in Table 6. Figure 2 shows the data of simulations for the Blue beam again with Run FY09 optics with and without the new mask collimators. Table 7 reviews the statistics for these simulations.

Table 5: Working point settings for all three simulation cases studied.

	$\mathbf{Q}_x$	$\mathbf{Q}_y$
Case 1: design working point	28.695	29.685
Case 2: ΔQ = +1	29.695	30.685
Case 3: ΔQ = -1	27.695	28.685

The previous results are for an ideal case only, based on optics from RHIC Run FY09. In order to assess the efficiency of the proposed upgrade, it is worth checking how the longitudinal loss pattern changes when the working point is changed. Table 5 lists the tune parameters for the ideal case and the two considered tune shifts. All other optics parameters (β^*, design orbit, collimator positions) are identical. Figures 3 and 4 present the results of simulations for Case 2, while Case 3 is shown in Figures 5 and 6. All statistics are compiled in Table 8, 9, 10 and 11.

CONCLUSION

Simulations have been peformed to quantify the efficiency of additional collimator jaws in RHIC. Each figure presented in this article clearly shows that the additional mask collimators provide the expected reduction in losses around the machine, and especially to the incoming triplet to the STAR experiment (IP6), for the Yellow bema as much as for the Blue beam. Looking at compiled statistics for all three working point cases studied, proton losses around the machine are reduced by roughly one order of magnitude: at most a factor 30 for magnet losses, and at most a factor 40 for losses in spaces between magnets.

REFERENCES

[1] G. Robert-Demolaize, A. Drees, "Benchmarking of collimation tracking using RHIC beam loss data", Proc. EPAC 2008.

[2] G. Robert-Demolaize: "Design and performance optimization of the LHC collimation system", CERN-LHC-PROJECT-REPORT-981, 2006.

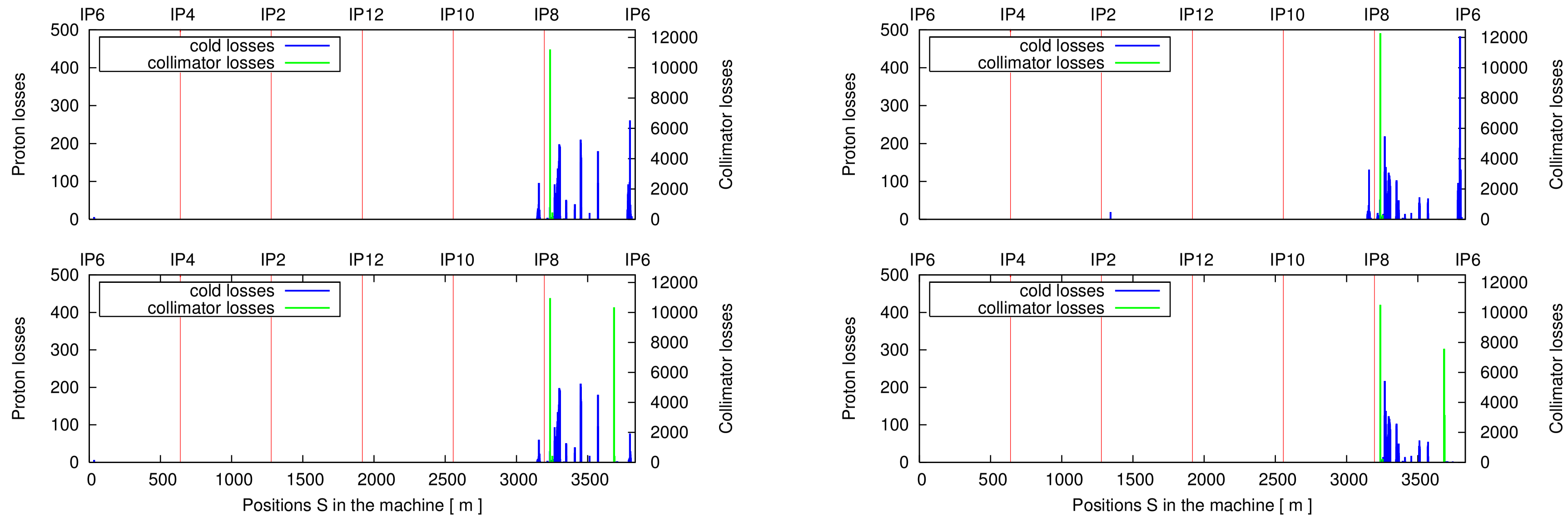

Figure 1: Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Yellow Horizontal (left) and Vertical (right) beam, using the design FY09 working point.

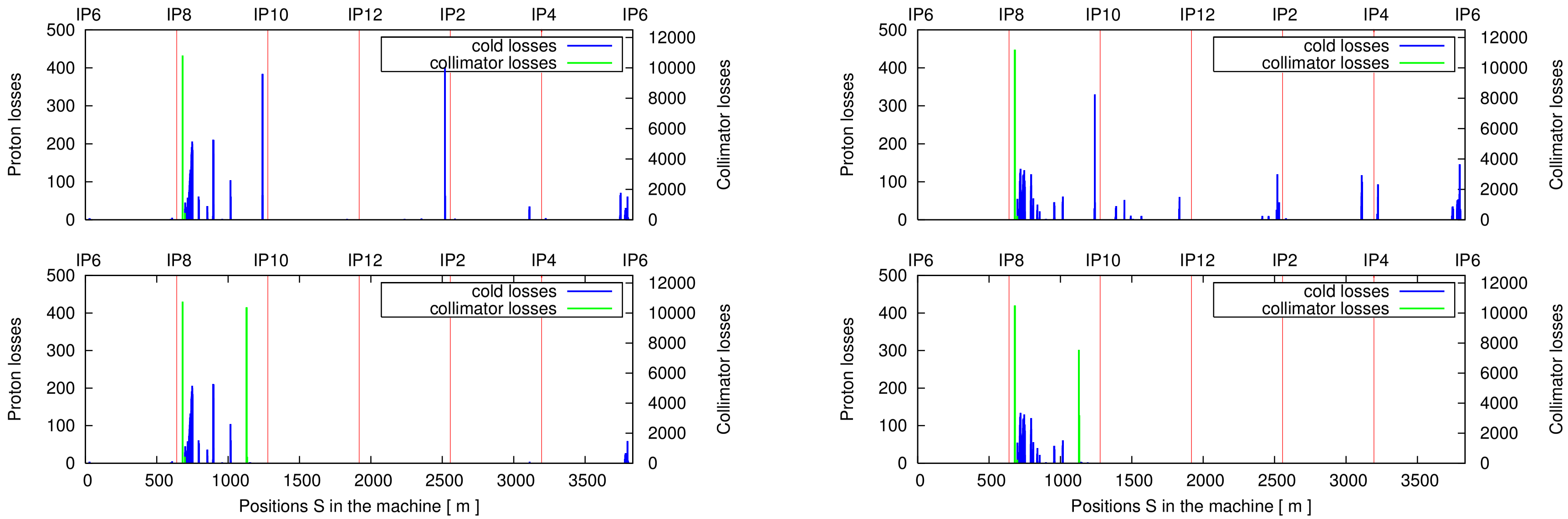

Figure 2: Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Blue Horizontal (left) and Vertical (right) beam, using the design FY09 working point.

Table 6: Top five loss locations (left: magnets; right: drift spaces) in which Yellow protons get lost without and with the new mask collimators from the considered upgrade scenario. Statistics derived from Fig. 1. The closest magnets downstream of the collimation system are not included.

PROTON LOSSES IN MAGNETS			
Current system		**Upgrade scenario**	
Name	N_{loss}	**Name**	N_{loss}
yi6-qf3	476	yi6-qf3	85
yo8-qd3	108	yo8-qd3	43
yi6-qd2	97	yi6-qd2	20
yi7-dh0	67	yi6-dh8	19
yo8-qf2	21	yo8-qf2	8
Total number of protons lost			
N_{loss}^{tot}	$N_{magnets}$	N_{loss}^{tot}	$N_{magnets}$
802	9	197	12

PROTON LOSSES IN DRIFTS			
Current system		**Upgrade scenario**	
Location	N_{loss}	**Location**	N_{loss}
upstream yi6-qf3	5071	upstream yo8-qd3	203
upstream yo8-qd3	1132	upstream yi6-qf3	202
upstream yi6-qd2	490	upstream yi6-qd2	92
upstream yo8-qf2	128	upstream yo8-qf2	61
upstream yo1-qf4	19	upstream yi6-qf7	16
Total number of protons lost			
N_{loss}^{tot}	N_{spaces}	N_{loss}^{tot}	N_{spaces}
6876	9	593	13

Table 7: Top five loss locations (left: magnets; right: drift spaces) in which Blue protons get lost without and with the new mask collimators from the considered upgrade scenario. Statistics derived from Fig. 2. The closest magnets downstream of the collimation system are not included.

PROTON LOSSES IN MAGNETS			
Current system		**Upgrade scenario**	
Name	N_{loss}	**Name**	N_{loss}
bi5-dh5	304	bi9-dh8	24
bo3-dh5	211	bi5-qf3	19
bi4-qd2	156	bo7-qf2	5
bi5-qf3	107	bo6-qf2	4
bo10-dh6	43	bi9-dh5	3
Total number of protons lost			
N_{loss}^{tot}	$N_{magnets}$	N_{loss}^{tot}	$N_{magnets}$
897	21	64	11

PROTON LOSSES IN DRIFTS			
Current system		**Upgrade scenario**	
Location	N_{loss}	**Location**	N_{loss}
upstream bi5-qf3	2190	upstream bi5-qf3	482
upstream bi9-qf3	995	upstream bi5-qd2	17
upstream bi1-qf3	797	upstream bo7-qd3	13
upstream bo3-qd5	667	upstream bi9-qf7	13
upstream bi5-qf5	540	upstream bo3-qd5	8
Total number of protons lost			
N_{loss}^{tot}	N_{spaces}	N_{loss}^{tot}	N_{spaces}
6024	25	552	16

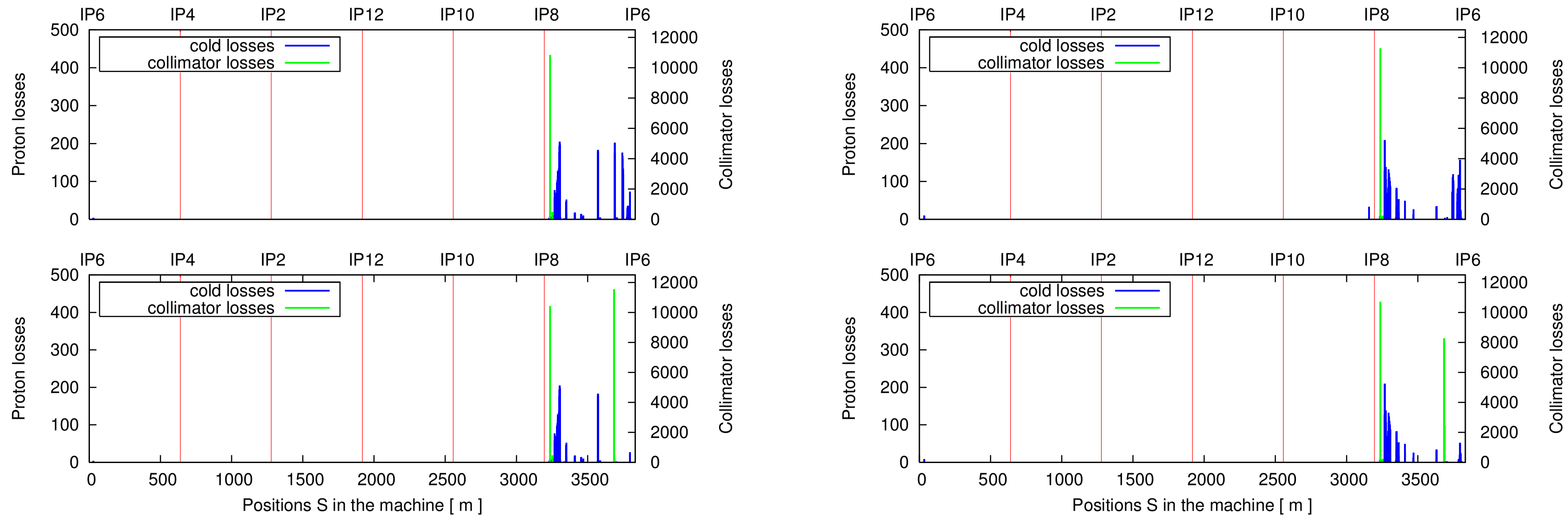

Figure 3: Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Yellow Horizontal (left) and Vertical (right) beam, using the design FY09 working point with $\Delta Q_{x,y} = +1$.

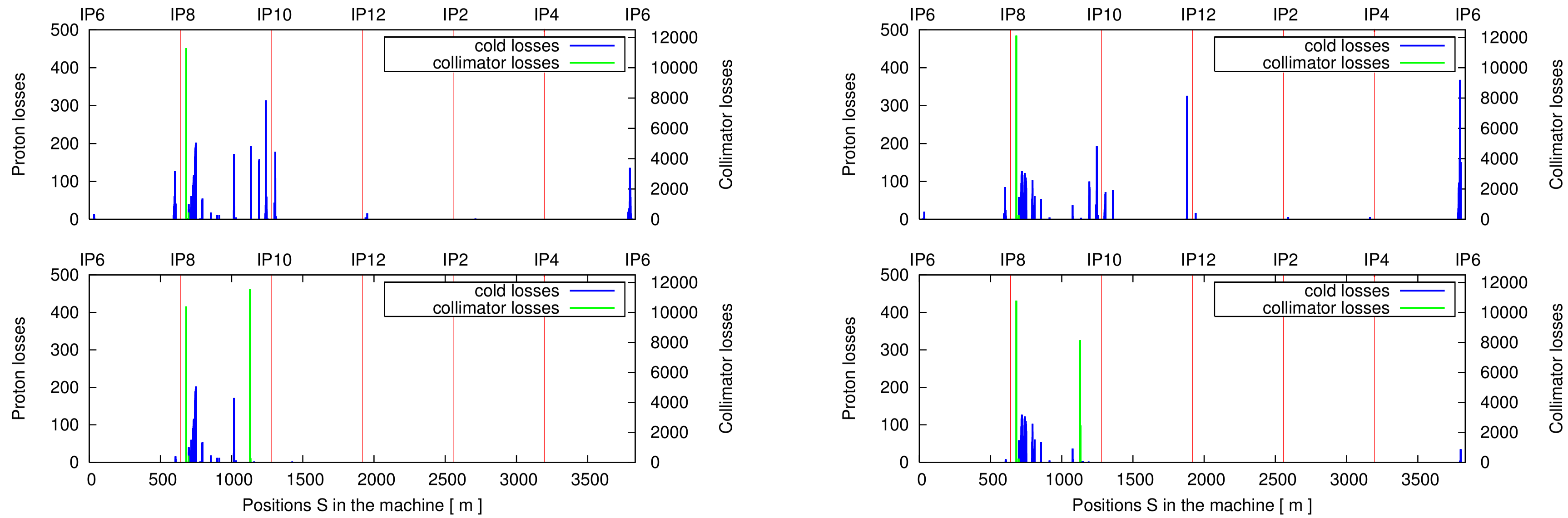

Figure 4: Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Blue Horizontal (left) and Vertical (right) beam, using the design FY09 working point with $\Delta Q_{x,y} = +1$.

Table 8: Top five loss locations (left: magnets; right: drift spaces) in which Yellow protons get lost without and with the new mask collimators from the considered upgrade scenario. Statistics derived from Fig. 3. The closest magnets downstream of the collimation system are not included.

PROTON LOSSES IN MAGNETS			
Current system		**Upgrade scenario**	
Name	N_{loss}	**Name**	N_{loss}
yi6-dh5	2355	yi6-qf3	68
yi6-qf3	116	yi6-dh8	21
yi6-qd2	21	yi6-qd2	19
yo5-qd3	18	yo5-qd3	16
yo5-qf2	5	yo5-qf2	5
Total number of protons lost			
$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{magnets}}$	$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{magnets}}$
2522	8	140	10

PROTON LOSSES IN DRIFTS			
Current system		**Upgrade scenario**	
Location	N_{loss}	**Location**	N_{loss}
upstream yi6-qf3	3080	upstream yi6-qf3	241
upstream yi6-qf5	1324	upstream yi6-qd2	69
upstream yi6-qf9	589	upstream yi6-qf9	10
upstream yi6-qd2	75	upstream yi6-qf7	8
upstream yo8-qd3	44	upstream yi6-qd8	3
Total number of protons lost			
$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{spaces}}$	$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{spaces}}$
5136	9	343	12

Table 9: Top five loss locations (left: magnets; right: drift spaces) in which Blue protons get lost without and with the new mask collimators from the considered upgrade scenario. Statistics derived from Fig. 4. The closest magnets downstream of the collimation system are not included.

PROTON LOSSES IN MAGNETS			
Current system		**Upgrade scenario**	
Name	N_{loss}	**Name**	N_{loss}
bi5-qf3	745	bi5-qd2	29
bo10-qf2	322	bi9-dh8	21
bi9-qd2	248	bo7-qd3	10
bo7-qd3	221	bo7-qf2	9
bo10-dh0	202	bi9-dh5	3
Total number of protons lost			
$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{magnets}}$	$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{magnets}}$
2226	23	74	7

PROTON LOSSES IN DRIFTS			
Current system		**Upgrade scenario**	
Location	N_{loss}	**Location**	N_{loss}
upstream bi5-qf3	2918	upstream bi5-qd2	107
upstream bi9-qf5	1266	upstream bo7-qf2	61
upstream bo7-qd3	927	upstream bi9-qf9	10
upstream bi9-qf9	692	upstream bi5-qf3	8
upstream bi5-qd2	683	upstream bi9-qd8	6
Total number of protons lost			
$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{spaces}}$	$\mathbf{N_{loss}^{tot}}$	$\mathbf{N_{spaces}}$
8815	22	212	14

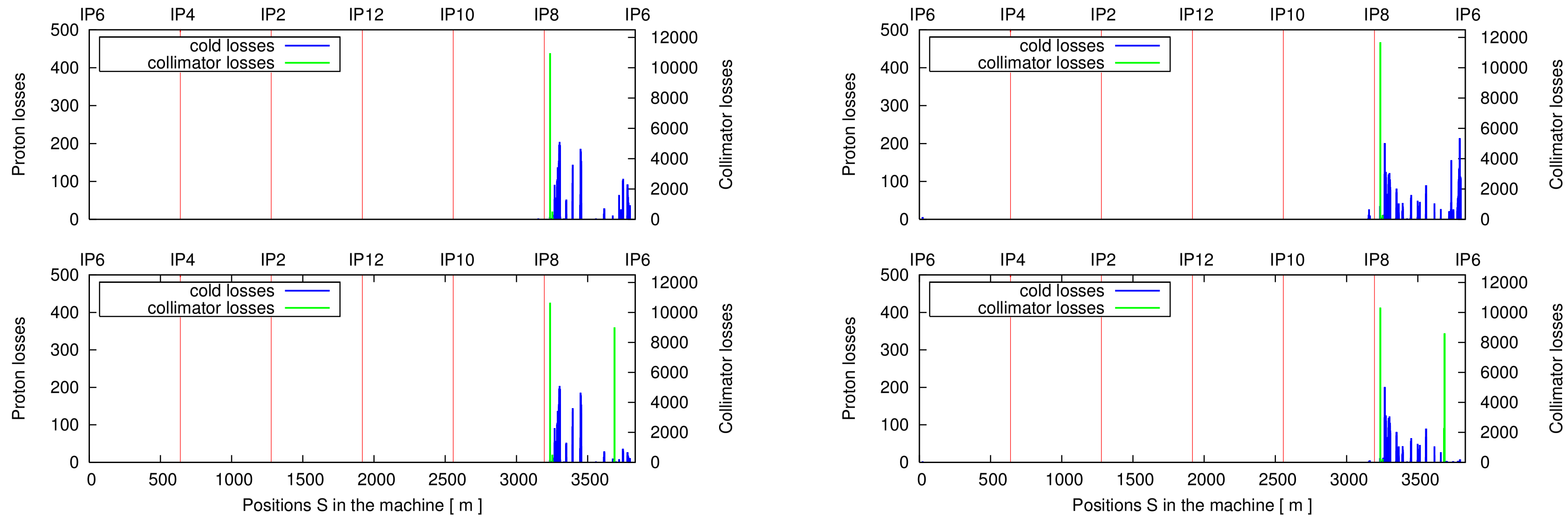

Figure 5: Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Yellow Horizontal (left) and Vertical (right) beam, using the design FY09 working point with $\Delta Q_{x,y}$ = -1.

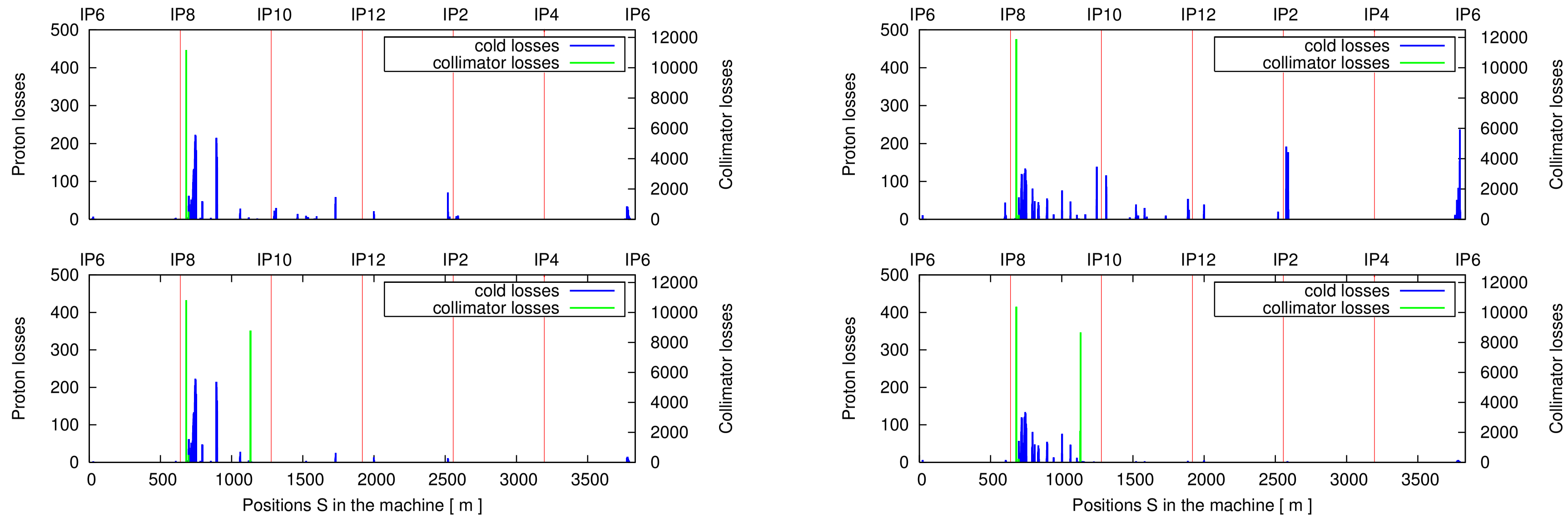

Figure 6: Comparison of longitudinal loss patterns between the current RHIC collimation system (top) and its proposed upgrade (bottom) for Blue Horizontal (left) and Vertical (right) beam, using the design FY09 working point with $\Delta Q_{x,y}$ = -1.

Table 10: Top five loss locations (left: magnets; right: drift spaces) in which Yellow protons get lost without and with the new mask collimators from the considered upgrade scenario. Statistics derived from Fig. 5. The closest magnets downstream of the collimation system are not included.

PROTON LOSSES IN MAGNETS			
Current system		**Upgrade scenario**	
Name	N_{loss}	**Name**	N_{loss}
yi6-qf3	438	yi6-dh8	24
yi6-dh5	166	yo8-qd3	7
yi6-qd2	42	yi6-dh5	7
yi6-qf7	29	yo5-dh0	6
yo5-dh0	17	yo8-qf2	4
Total number of protons lost			
N_{loss}^{tot}	$N_{magnets}$	N_{loss}^{tot}	$N_{magnets}$
725	11	56	9

PROTON LOSSES IN DRIFTS			
Current system		**Upgrade scenario**	
Location	N_{loss}	**Location**	N_{loss}
upstream yi6-qf3	4918	upstream yi6-qf3	345
upstream yi6-qf5	688	upstream yi6-qf5	187
upstream yi6-qd6	585	upstream yi6-qf7	27
upstream yi6-qd2	313	upstream yo8-qf2	15
upstream yi6-qf7	135	upstream yo8-qd3	14
Total number of protons lost			
N_{loss}^{tot}	N_{spaces}	N_{loss}^{tot}	N_{spaces}
6756	8	603	9

Table 11: Top five loss locations (left: magnets; right: drift spaces) in which Blue protons get lost without and with the new mask collimators from the considered upgrade scenario. Statistics derived from Fig. 6. The closest magnets downstream of the collimation system are not included.

PROTON LOSSES IN MAGNETS			
Current system		**Upgrade scenario**	
Name	N_{loss}	**Name**	N_{loss}
bo2-dh0	651	bi9-dh8	26
bo10-qd3	282	bo6-dh0	10
bo2-qd3	262	bo7-qf2	8
bi9-qd2	208	bi12-qf5	7
bo11-qf2	96	bo11-qf2	6
Total number of protons lost			
N_{loss}^{tot}	$N_{magnets}$	N_{loss}^{tot}	$N_{magnets}$
1796	24	73	11

PROTON LOSSES IN DRIFTS			
Current system		**Upgrade scenario**	
Location	N_{loss}	**Location**	N_{loss}
upstream bi5-qf3	2785	upstream bi5-qf3	270
upstream bo11-qf12	316	upstream bo11-qf12	74
upstream bo2-dh0	273	upstream bi12-qf5	47
upstream bo2-qd3	268	upstream bi1-qf3	30
upstream bi9-qd2	234	upstream bo7-qf2	21
Total number of protons lost			
N_{loss}^{tot}	N_{spaces}	N_{loss}^{tot}	N_{spaces}
5014	30	502	16