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A HIGHER MOMENTUM APERTURE LATTICE PROPOSED FOR THE sPHENIX BACKGROUND PROBLEM*

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Abstract

During the 2024 Au+Au 100 GeV physics run, the sPHENIX MVTX detector experienced background issues originating from the Yellow beam, leading to frequent auto-recoveries during streaming mode operation. One hypothesis attributes the background to the loss of off-momentum particles. An evaluation of the momentum apertures in both RHIC rings revealed that the Yellow ring had a worse momentum acceptance compared to the Blue ring. To address this, a new lattice design with a reduced W-function was proposed. This report presents the momentum aperture comparison between the two rings, the proposed new lattice design considering additional constraints, and the resulting momentum and dynamic apertures.

INTRODUCTION

The Monolithic Vertex Tracker (MVTX) is a crucial component located at the center of the sPHENIX detector, designed to provide high-precision vertex tracking. The MVTX 1 consists of 48 staves arranged in three layers (Fig. 1), all centered at the interaction point (IP) and extending ±13.5 cm along the beam axis. If any of the staves become overloaded with charge, the entire stave enters an auto-recovery mode, initiating a 20-second reboot process to reset and reinitialize the system. During this period, no data is recorded, leading to a temporary loss of tracking information. The primary source of excessive charge deposition is the Yellow beam [1], which generates significantly higher hit rates compared to the Blue beam. The MVTX auto-recovery display is shown Fig. 1 where the red triangles correspond to staves in auto-recovery state.

STUDY OF THE MOMENTUM APERTURE

Off-momentum particle losses were hypothesized to be the primary source of the observed background [2]. However, a notable asymmetry was present, with the Yellow ring exhibiting significantly higher losses than the Blue ring. This raises the question: from an accelerator physics perspective, why is the momentum aperture substantially more limited in the Yellow ring?

The momentum aperture is evaluated in Mad-X [3] without implementing the physical aperture. The method is to scan the momentum deviation and check beam stability. When the beam is unstable, Mad-X would fail to find Twiss parameters, and in the following plot, the tune stays at an initial value, while the tune would vary in the stable region.

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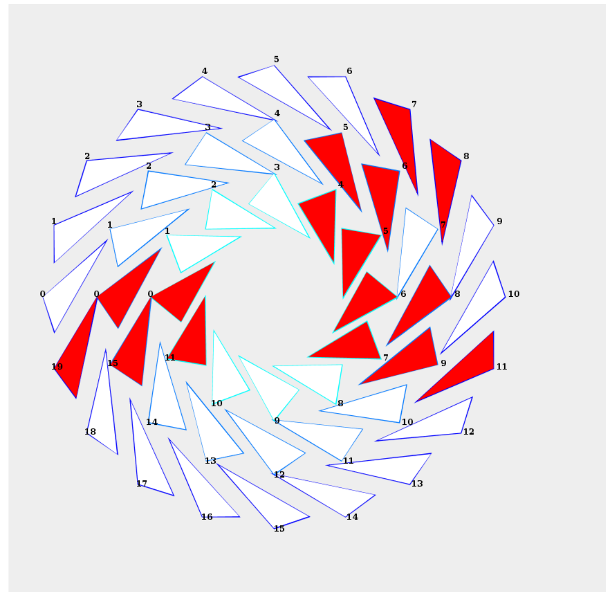

Figure 1: : The cross-section of the MVTX detector. Each triangle represents one stave. The red triangles are the staves in auto-recovery mode, which takes 20 seconds before the stave can take data.

As shown in Fig. 2, the Yellow ring lattice has a narrower stable region, therefore a smaller momentum aperture.

Higher-order chromaticity—specifically, second- and third-order components—is intrinsically linked to the momentum aperture. Generally, increased higher-order chromaticity corresponds to a reduced momentum aperture. Nevertheless, direct measurements of chromaticity did not reveal a significant difference in higher-order terms between the two rings.

An alternative approach to quantifying chromatic nonlinearities is through the chromatic beta-beating, characterized by the W function [4]. A lower value of the W function indicates reduced chromatic distortion and, consequently, improved dynamic performance.

The W-function of the two RHIC rings (Blue vs Yellow) is shown in Fig. 3.

One approach is to employ sextupole magnets not only for linear chromaticity correction but also for optimizing the W function. Alternatively, the lattice can be designed such that the chromatic contributions from the two interaction regions (IRs)—which are the dominant sources—effectively cancel each other [5]. The latter strategy is adopted in this study.

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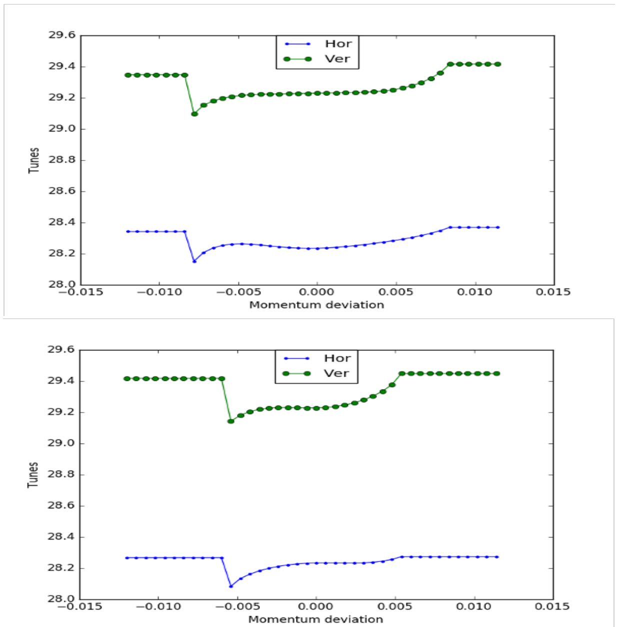

Figure 2: Comparison of the momentum scan in the two RHIC rings. The momentum scan shows a larger acceptance in the Blue ring (upper plot) than the Yellow ring (lower plot) with their original lattice design. The flat tunes on both ends with large momentum deviation indicate beam instability; therefore, no stable tunes were found.

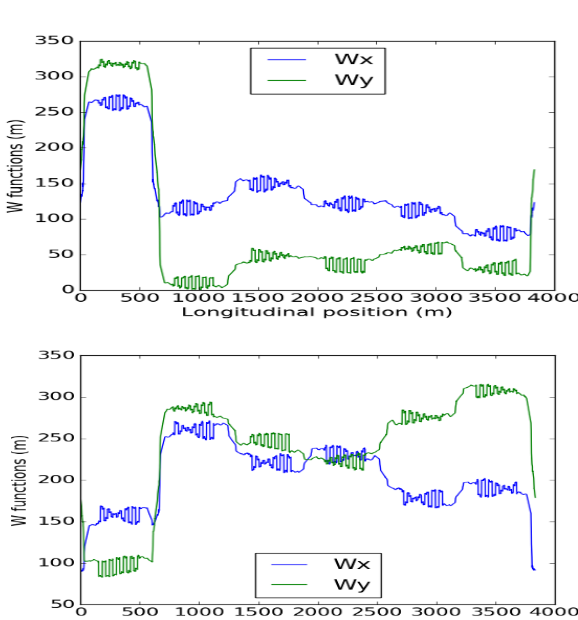

Figure 3: Comparison of the W function of the two RHIC rings. The upper plot shows the W function in the Blue ring where the phase advances between the two IPs are close to $\pi/2$. The lower plot shows the W function in the Yellow ring.

LATTICE DESIGN WITH REDUCED W-FUNCTION

There are multiple constraints for the lattice design with reduced W-function. Firstly, the phase advances in the transverse planes from IP6 to IP8 need to be PI/2 for the chromatic effect to cancel. In addition, one would like to keep the beta stars to be 0.7 m at both IPs, and the phase advances from Stochastic cooling pickup and kicker set are PI/2 as well for cooling efficiency.

The W-functions for the old and new Yellow ring lattice are shown in Fig. 4. It is worth noting that the X-axis starts from IP10 instead of IP6 in the previous plot.

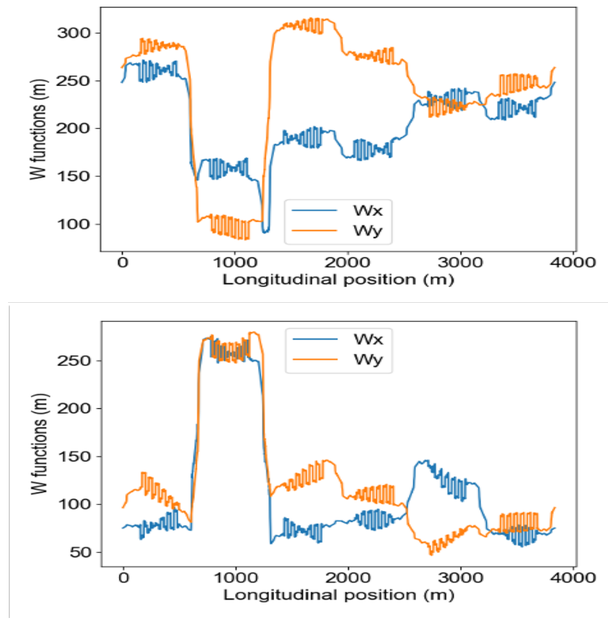

Figure 4: Comparison of the W function of the Yellow ring, with the upper plot for the original lattice, while the lower plot is for the redesigned lattice. The phase advances between the two IPs in both planes are set to $\pi/2$ in the redesigned lattice.

The beta functions and dispersion functions of the new lattice are shown in Figs. 5 and 6.

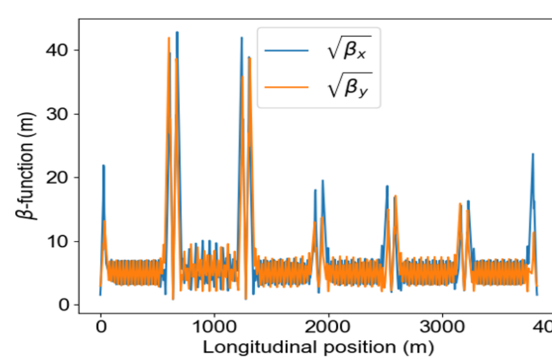

Figure 5: The beta functions distribution for the Yellow ring redesigned lattice. The beta wave is visible between the two IPs.

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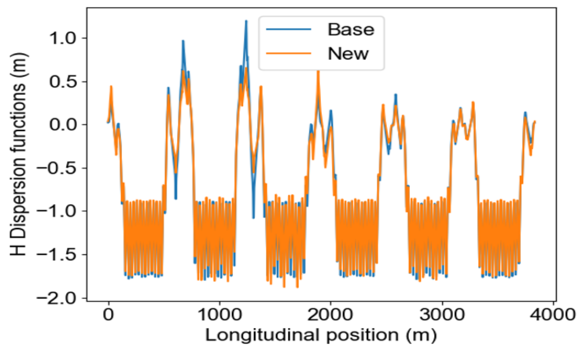

Figure 6: The dispersion functions distribution for the Yellow ring redesigned lattice. The maximum dispersion functions in IR6 and IR8 are both reduced compared to the original lattice.

SIMULATION OF DYNAMIC APERTURE

The dynamic aperture of the old and new lattices has been studied in tracking simulations. The comparison is shown in the following figure. It shows improvement of the dynamic aperture at higher relative momentum deviation ($> 0.2\%$).

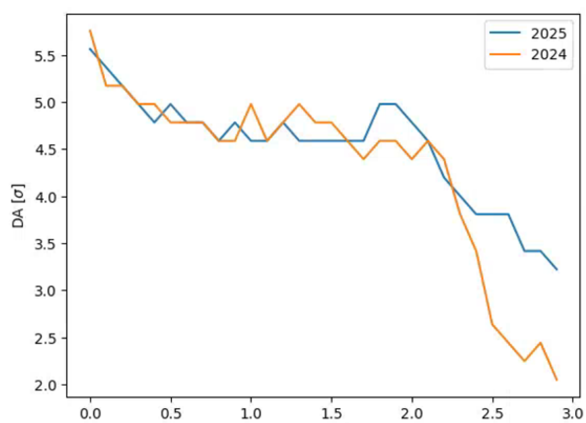

Figure 7: Dynamics aperture simulation results. 2024 represents the original Yellow ring lattice, and 2025 represents the redesigned Yellow ring lattice. The dynamic aperture for relative momentum deviation larger than 0.2% is improved for the redesigned lattice.

THE SUMMARY AND THE OUTLOOK

A less-than-optimal momentum aperture of the yellow ring lattice has been identified as a possible cause for the sPHENIX MVTX background. The proposal is to redesign the lattice to cancel out the chromatic contributions from the two IRs. The lattice with the W-function reduced has been designed with some other necessary constraints. In addition, the dynamic aperture simulation was performed and showed an improvement for off-momentum particles. During the operation in 2025, the background issue was alleviated with the removal of a limiting aperture near sPHENIX. Therefore, the proposed lattice with reduced W-function was not implemented operationally.

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