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Bayesian Optimal Experimental Design for AGS Booster Magnet Misalignment Estimation†

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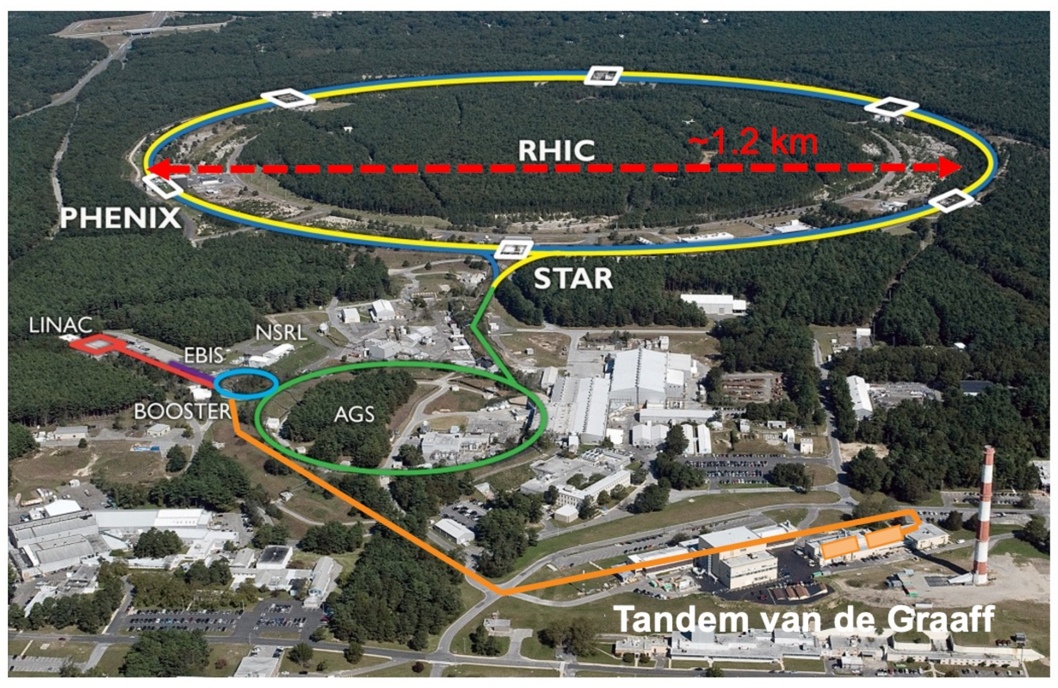
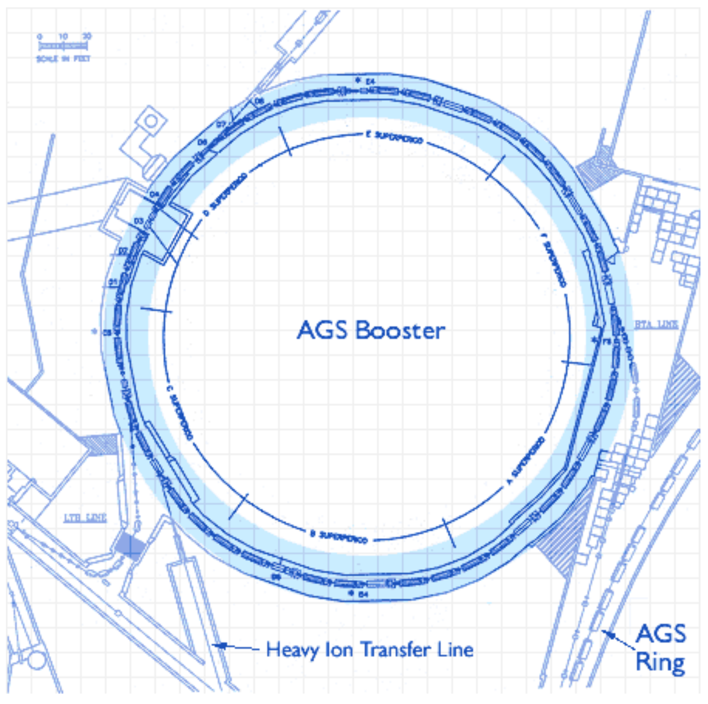
Motivation

- **Alternating Gradient Synchrotron** (AGS) and its **Booster** serve as part of the **injector compound** for RHIC and future EIC, providing pre-acceleration to particles before they enter the ion collider ring.
- **Bright beams** in the AGS and Booster are required to:
  - improve polarization transport;
  - increase luminosity in RHIC;
  - achieve electron cooling at AGS extraction energy in the EIC pre-cooler.

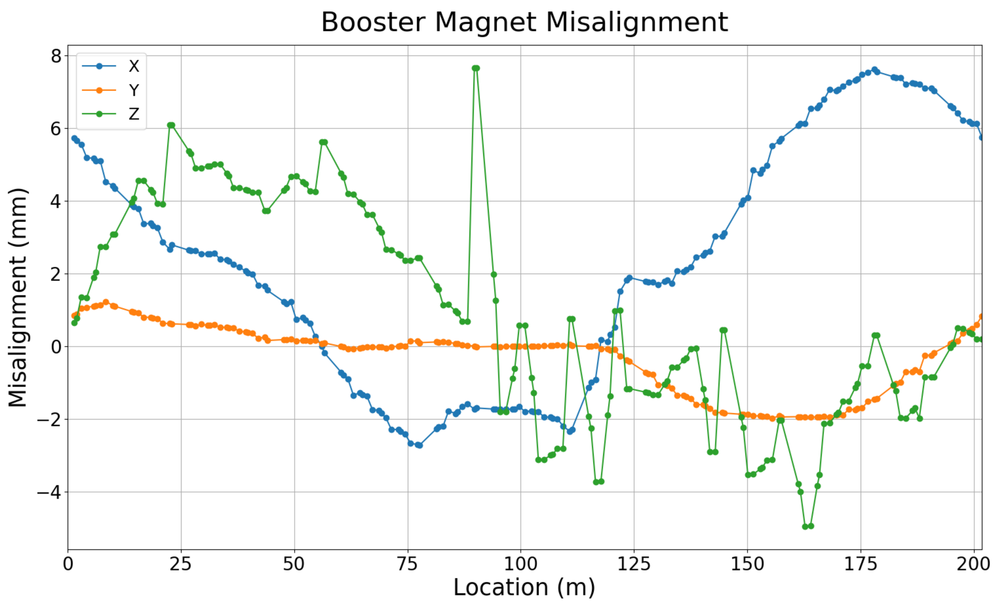


- Obtaining bright ion beam requires **more accurate beam control** in the injector compound, which is currently mostly hand tuned by operators.
- The final goals of this project are:
  - Establish **more accurate models** for Booster and AGS to better understand and predict how beam behaves in the rings.
  - Develop more **streamlined tuning routines** so desirable beam status can be obtained more efficiently.

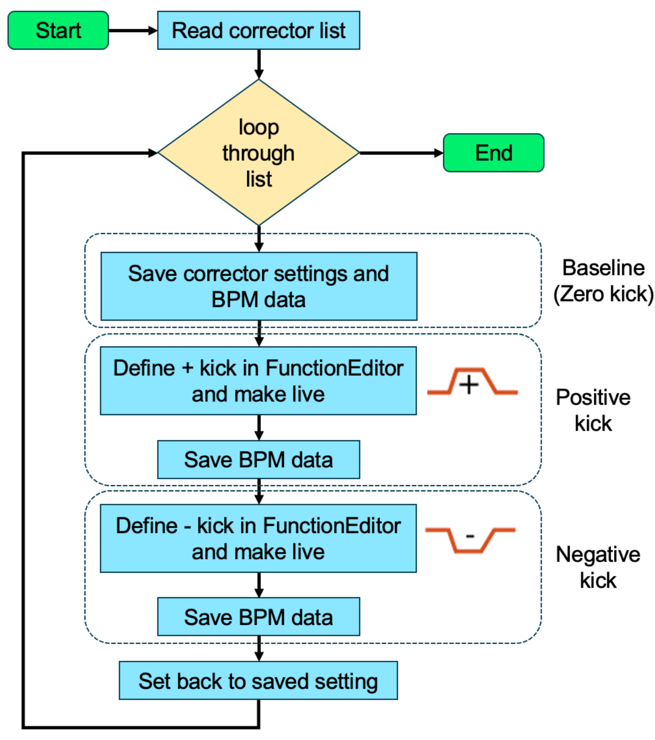


Magnet Misalignment in the AGS Booster

- Survey data from 2015 measured the magnet locations in real machine.
- Survey results showed **misalignment** from model locations for dipoles and quadrupoles.
- There has been trouble with making physics simulation with misalignment agree with real orbit data.
- Newer survey data from 2023 is being processed.

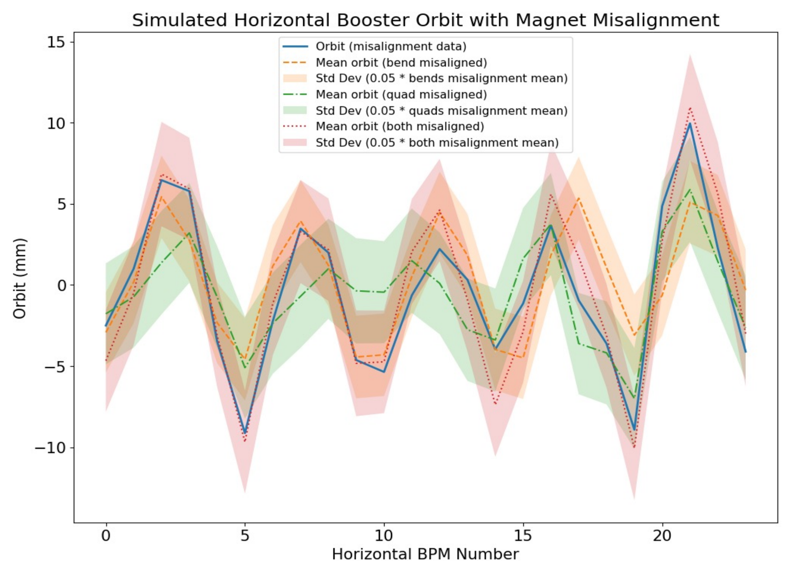


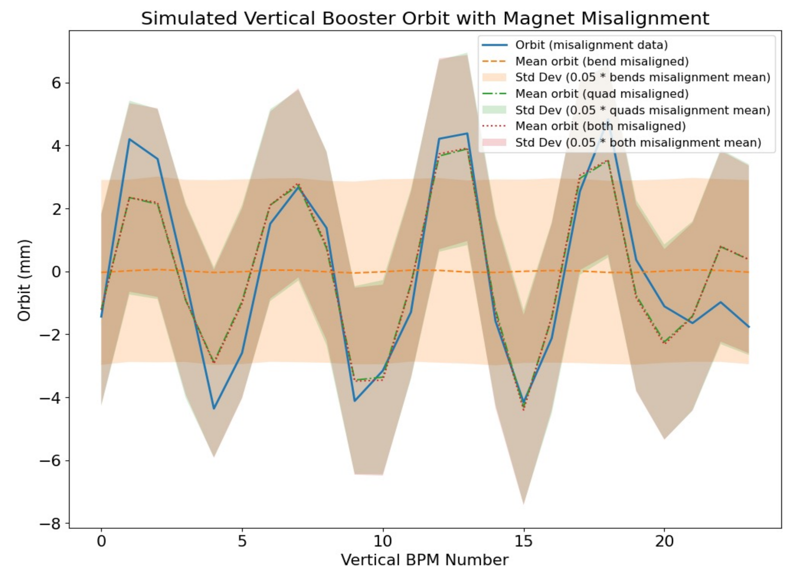
- A script is developed to gather real machine orbit responses.
- Script sets three corrector settings: positive, zero, negative; and save corresponding orbits.
- Given observed orbit data, a Bayesian optimal experimental design (BOED)-based approach can determine magnet settings which are expected to return orbit data that most reduces uncertainty in the magnet misalignment parameters.



Misalignment Data Analysis

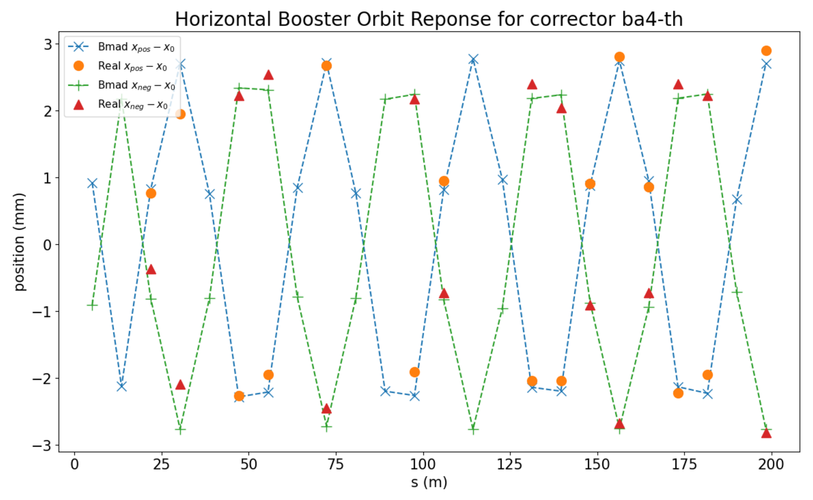
- Simulation studies were done using Bmad Booster model to see how magnet misalignments affect the bare orbit.
- Survey misalignments from 2015 were used as the baseline values in the model, resulting distorted bare orbits are shown as blue lines in the plots below.
- Three scenarios were studied: only misalign dipoles, only misalign quadrupoles, and misalign both.
- Using survey data as mean, normal distributions of misalignment values with 5% standard deviation were simulated.

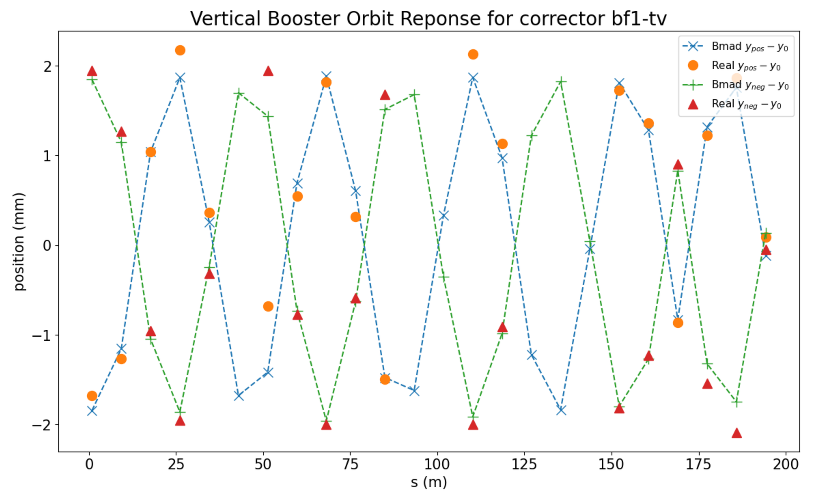




Orbit Response Data Analysis

- The orbit response script was tested with both horizontal and vertical correctors in the Booster.
- Collected data includes both orbit data and magnet settings.
- Saved magnet settings are loaded into Bmad physics model to produce simulated orbit data.
- Initial comparison of the differential orbit (orbit difference between positive, zero, and negative corrector settings) shows good agreement, validating the status and calibration of real Booster BPMs.





Future Work

- The simulation studies need to explore bigger ranges of misalignment values, with main magnet settings that are close to normal operation values.
- Orbit response data collected with the script can be used as the ground truth for determining misalignment values, but more factors such as the radial steering and B-dot effect need to be considered in the model to make it more accurate so we can perform Bayesian inference.

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