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Beam Dynamics of the Muon g-2 Experiment

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The Muon g-2 Experiment (E989) at Fermilab aims to measure the muon anomalous magnetic moment a_μ with unprecedented precision, potentially uncovering physics beyond the Standard Model of particle physics. The result based on Runs 1-3, released in 2023, achieved a precision of 0.20 ppm. The experiment circulates muons in a storage ring, measuring a_μ from decay positron time and energy measurements collected with calorimeters. To achieve the required accuracy, it is crucial to measure and control the magnetic field in the ring with high precision. Beam dynamics corrections are necessary for muons not orbiting exactly in the midplane, for their oscillations, and for electric field effects. Highly accurate beam dynamics simulations are instrumental for quantifying and validating the beam dynamics corrections, ultimately improving the precision of the a_μ measurement and facilitating the achievement of the ambitious 70 ppb systematic uncertainty goal. The measured field data was incorporated into models for simulations using three codes: `gm2ringsim` (an internal *Geant4*-based code), *COSY INFINITY*, and *BMAD*. The advantages of `gm2ringsim` include using CAD-based geometry and modelling the detector effects. *COSY INFINITY* is a highly accurate and efficient code that uses high-order differential-algebraic transfer maps, precise fringe field calculations, and advanced symplectification methods. Symplectification is important for maintaining the physical correctness of the muon beam behaviour with high precision over the storage time, ensuring conservation of phase space volume and preventing artificial damping or excitation of particle motion. The experiment completed its final Run 6 in July 2023, collecting 21 times more data than the previous BNL experiment. Analyses of data from Runs 4-6 are ongoing, with results planned for release in 2025, potentially resolving the current tension between experiment and theory.

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