IOTA-FAST

A Leading US Facility for Beam Physics and Accelerator Technology R&D:

Long-Term Research Opportunities

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The Integrable Optics Test Accelerator (IOTA) is a storage ring for advanced beam physics research at Fermilab [1]. It operates with electron and ion/proton beams with momenta between 50 and 150 MeV/c. The facility includes the electron injector, FAST [2] (a normal conducting 5 MeV electron RF photoinjector, two 1.3 GHz SRF booster cavities CC1 and CC2, a magnetic chicane, a 12-m long 1.3 GHz SRF ILC-type cryomodule), a 2.5 MeV RFQ proton injector, the IOTA ring, dozens of meters of electron beam lines and absorbers. The design and main parameters of the facility can be found in [1]. IOTA is dedicated to three main areas of beam physics research: (1)address the challenges posed by future high-intensity machines, such as instabilities and losses; (2) carry out basic research in beam physics; and (3) support education and training for scientists and engineers.

IOTA is unique in its research mission, as well as in its flexibility and performance. It has a circumference of 40 m and a relatively large aperture (50 mm). It is easily reconfigurable to accommodate the installation of 1-3 concurrent experiments. Because of the quality of the instrumentation, the magnetic beam focusing lattice can be precisely controlled. In addition, the lattice was designed to have significant flexibility to enable a wide variety of studies. IOTA can store electrons up to 150 MeV or protons at 2.5 MeV.

Because of synchrotron-radiation damping, electrons are suited to the study of linear and nonlinear single-particle effects. Proton dynamics, on the other hand, is dominated by space charge. Electrons were circulated for the first time in August 2018. Proton beams will become available in 2021 and will open up research opportunities with high-intensity beams.

The IOTA research program [3] currently includes the experimental study of nonlinear integrable focusing systems based on special magnets or on electron lenses. Because of their nonlinearity, these systems generate a betatron tune spread that protects the beam from instabilities through Landau damping. Integrability ensures that the nonlinear system does not reduce the dynamic aperture of the machine, therefore preserving beam lifetime and emittance. Several other topics will be studied in IOTA, such as the experimental demonstration of optical stochastic cooling and the compensation of space-charge effects. In addition, IOTA has the capability of storing single electrons and single ions (in the future).

We would like to call attention of the particle physics and the accelerator communities to additional unique opportunities offered by the IOTA/FAST facility along four major categories:

I. Beam physics (beyond current program):

   a. Artificial Intelligence (AI), advanced control systems and machine learning [4]

   b. Quantum Science with cold ions and single particles [5]

   c. Beam cooling

II. Accelerator technology:

a. Wakefields and high average current studies and optimization [6,7]. Long-range wakefields (LRWs) including higher-order modes (HOMs) and short-range wakefields (SRWs) generated in TESLA-type cavities due to off-axis steering can cause unwanted beam-size and emittance-dilution effects. Time-resolved diagnostics to display these effects at FAST include an array of bunch-by-bunch-capable rf BPMs and a synchroscan streak camera viewing optical transition radiation (OTR) screens. These techniques have been used with two single cavities to show beam-size dilution and can be extended to the cryomodule-2 effects. They also could be applied to the high gradient >60 MV/m cavities. Machine learning training for emittance dilution mitigation is another avenue to explore in the future.

c. Advanced superconducting RF >60MV/m cavities [8]

b. Novel *e-, p+, H-*, muon frontend setup tests [9]

d. Electron lens technology [10]

g. 200 T/s HTS rapid cycling magnets, possibly with a small prototype proton booster ring [11]

e. Advanced beam halo diagnostics for the dynamic range of up to 10^6

f. Muon beam diagnostics tests

h. DWA multi-bunch structure tests

III. Integration and design optimization studies

a. PIP-III design choices, input and optimization; tests of elements [12]

b. design and magnetized beam cooling studies for the EIC [13]

c. >1 GeV electron energy facility extension for next generation rare muon processes; studies for muon colliders [14], DM /axion searches; and possibly for the high-power Inverse Compton Scattering setup

e. Tests of advanced accelerator control systems

IV. Opportunities for accelerator education and “hands-on” training

a. e.g., as part of the US Particle Accelerator School [15]

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