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# Overview of the new beam physics research at the IOTA/FAST facility

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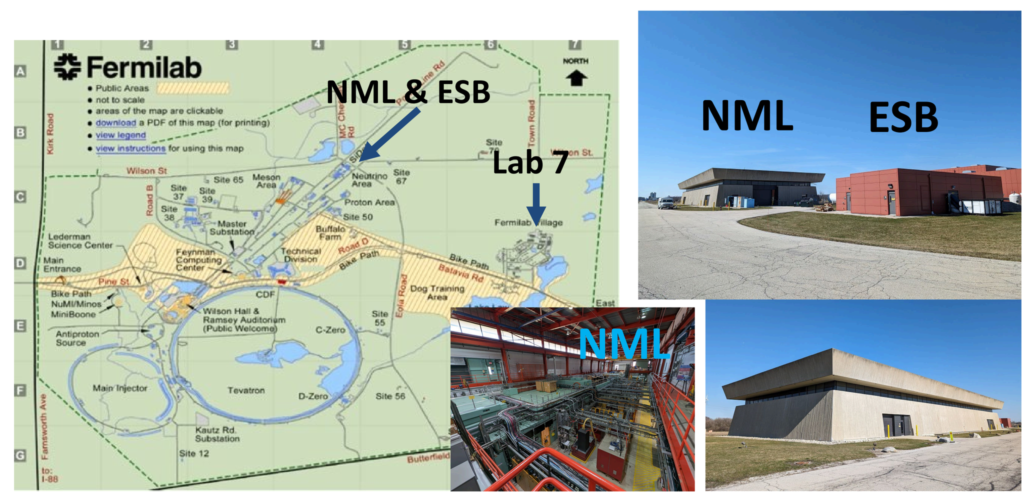
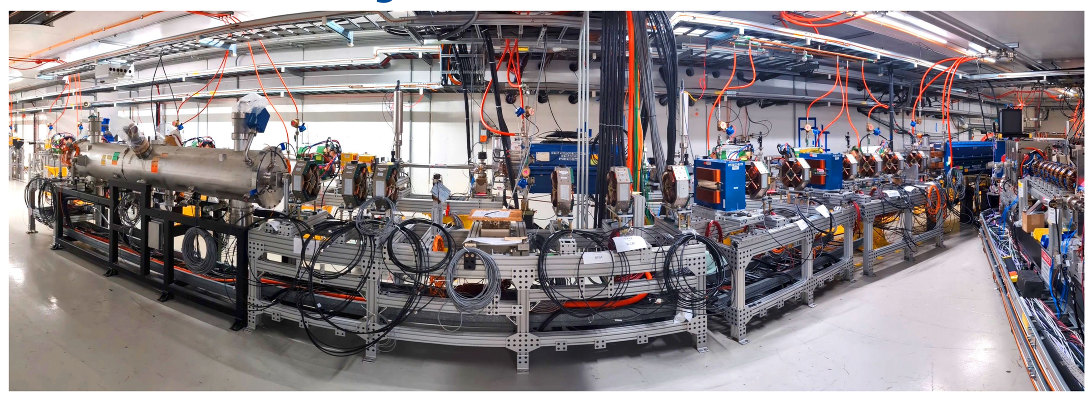
## Abstract

The Fermilab Accelerator Science and Technology (FAST) facility is dedicated to the exploration of novel concepts in accelerator and beam physics, and the development of a robust workforce, in order to enable and enhance next-generation particle accelerators. FAST comprises a high-brightness superconducting electron linac, and a storage ring, the Integrable Optics Test Accelerator (IOTA). Experiments in the most recent operational run include studies of nonlinear integrable lattices; tracking of single electrons; precise characterization of undulator radiation; studies with low-momentum-compaction lattices; and ultra-wide range beam diagnostics based on Photomultiplier tubes. In the linac, experiments on noise in intense electron bunches were conducted. The IOTA proton injector, currently being commissioned, will enable a diverse program on space-charge-dominated beams. Research areas include non-invasive beam profile monitoring for proton beams; beam dynamics with electron lenses; halo suppression, feedback systems, and electron cooling. In this presentation, we provide an overview of the recent results and highlight future plans together with opportunities for collaboration.

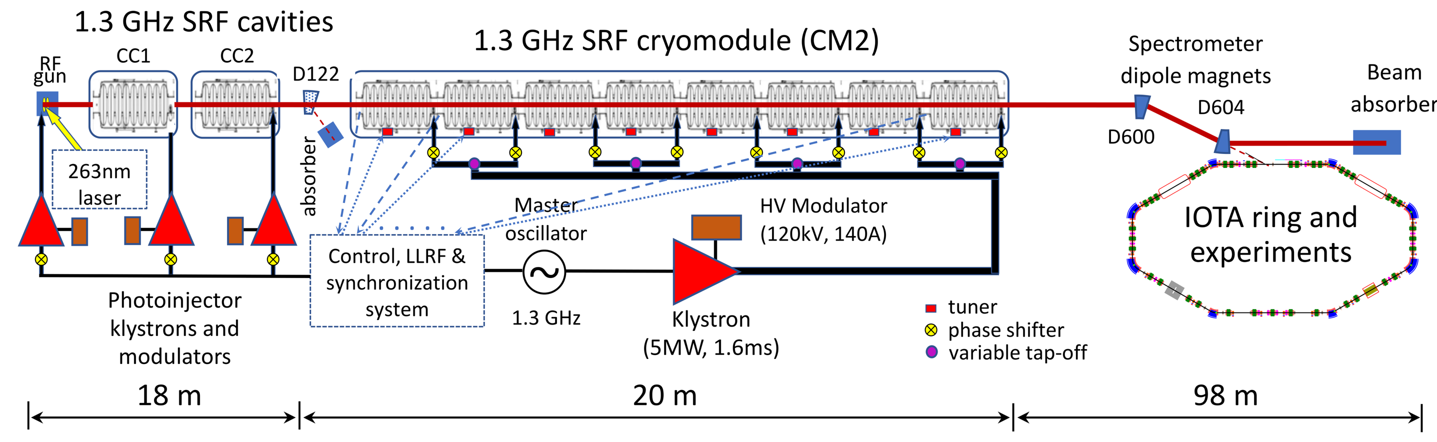
## Locations




## Proton injector



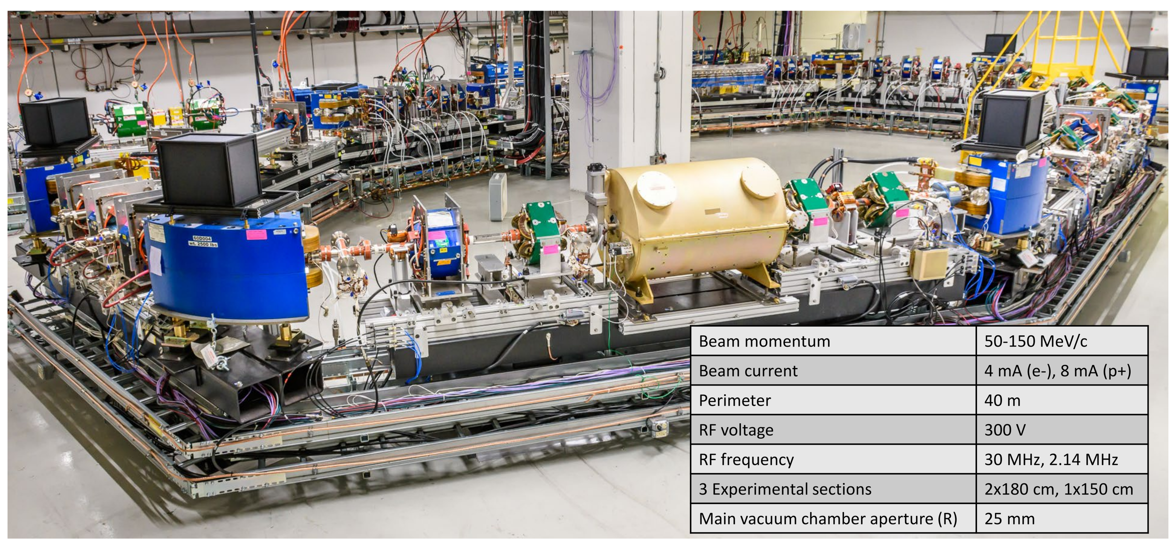
## IOTA/FAST accelerator complex




The electron injector comprises a number of components, including a 5 MeV electron RF photoinjector, a 25-meter-long low energy (≤40 MeV) beamline and a ~100-meter-long high energy (≤300 MeV) beamline.

| *Parameter* | *Value* |
|---|---|
| **Beam Energy** | **20 MeV – 300 MeV** |
| **Bunch Charge** | **< 10 fC – 3.2 nC per pulse** |
| **Bunch Train (Macropulse)** | **0.5 – 9 MHz for up to 1 ms (3000 bunches, 3 MHz nominal)** |
| **Bunch Train Frequency** | **1 – 5 Hz** |
| **Bunch Length** | **Range: 0.9 – 70 ps (Nominal: 5 ps)** |
| **Bunch Emittance** 50 MeV, 50 pC/pulse | **Horz: 1.6 ± 0.2 μm Vert: 3.4 ± 0.1 μm** |

## IOTA ring



| | |
|---|---|
| Beam momentum | 50-150 MeV/c |
| Beam current | 4 mA (e-), 8 mA (p+) |
| Perimeter | 40 m |
| RF voltage | 300 V |
| RF frequency | 30 MHz, 2.14 MHz |
| 3 Experimental sections | 2x180 cm, 1x150 cm |
| Main vacuum chamber aperture (R) | 25 mm |

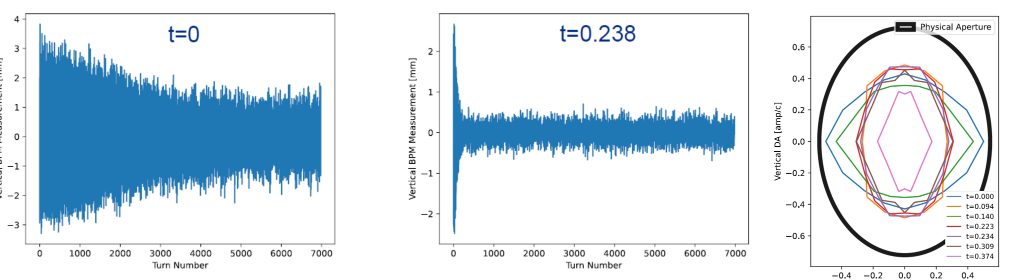
| | | | |
|---|---|---|---|
| Lambertson magnet | | 1 | Horizontal, injection in vertical plane |
| Kickers | | 1 hor. & 1 vert. | Horizontal for studies only |
| Main dipoles | | 4x60 deg & 4x30 deg | Powered in series with Lambertson |
| Quads | | 39 | Powered individually |
| Trims | Hor. | 8 | In main dipoles |
| | Vert. | 2 | For injection bump |
| | Hor. | 20 | Combined correctors |
| | Vert. | 20 | |
| Skew-quads | | 20 | |
| Pickups | | 21 | Turn-by turn position |
| Sync. light monitors | | 8 | Shape and position |
| RF | | 1 | Dual frequency |
| Solenoid | | 1 | For electron and McMillan lenses |
| Sextupoles | | 12 | In six families |
| DCCT | | 1 | Precision calibrated DC beam current |
| Wall current monitor | | 1 | Bunch currents and longitudinal shape |

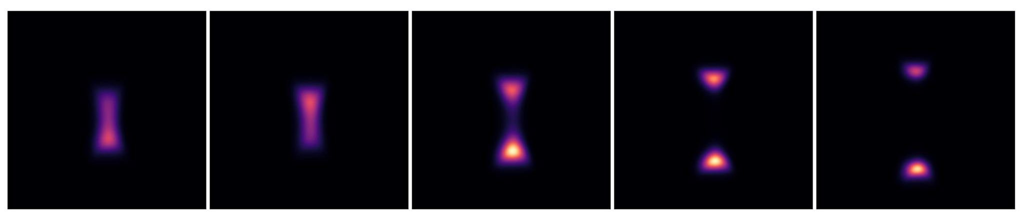

**Run-4 results were presented at the 2024 IOTA/FAST Collaboration Meeting: https://indico.fnal.gov/event/62181/**

## Integrable Optics Studies

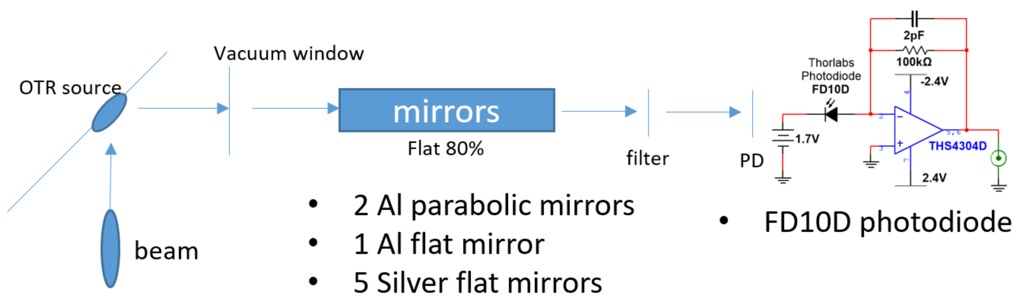
Nonlinear DN magnets:

- Fast decoherence
- Dynamic aperture scan vs DN strength
- Allow crossing integer resonance



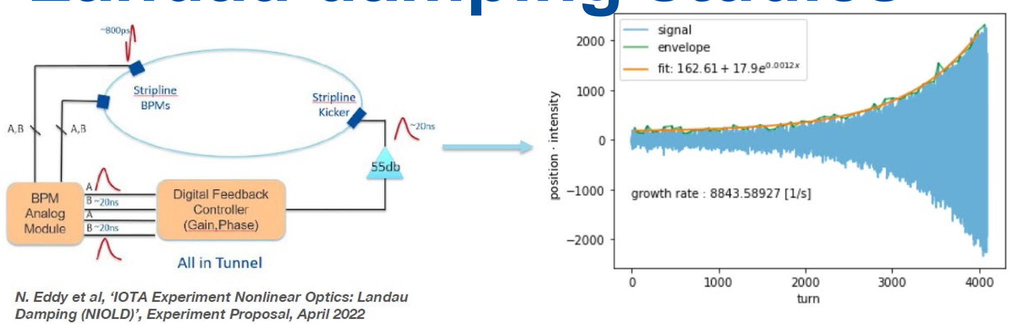



## Noise in beams




- 2 Al parabolic mirrors
- 1 Al flat mirror
- 5 Silver flat mirrors
- FD10D photodiode

## Landau damping studies




*N. Eddy et al, 'IOTA Experiment Nonlinear Optics: Landau Damping (NIOLD)', Experiment Proposal, April 2022*

**Requesting facility time: https://fast.fnal.gov/?p=experimental_program**

Run 4 (1 April 2022 - 23 October 2023)

IOTA

| ID | Acronym | Title | Spokesperson / Fermilab Liaison | LOI (optional) | Proposal | Presentation | Status | Beam Time | Reports |
|---|---|---|---|---|---|---|---|---|---|
| I-401 | NIOLD | IOTA Experiment Nonlinear Optics: Landau Damping | N. Eddy (FNAL) | | original revised final | Mar 25, 2022 | approved | 12 8-h shifts | FERMILAB-FN-1250-AD |
| I-403 | CLARA | Coherence Length of Undulator Radiation | S. Nagaitsev (JLAB) / A. Romanov (FNAL) | PDF | PDF | Sep 9, 2022 | approved | (18 x 8 h) + (3 x 4 h) shifts | FERMILAB-FN-1246-AD |
| I-405 | NIO | Nonlinear Integrable Optics | A. Valishev (FNAL) | | Beams-doc-9715 | Feb 24, 2023 | approved | (20 x 8 h) + (4 x 4 h) shifts | |
| I-406 | SETI | Single-Electron Tracking in IOTA | A. Romanov (FNAL) | | Beams-doc-9762 | June 16, 2023 | approved | (3 x 2 h) + (7 x 8 h) shifts | |
| I-407 | LADR | Low-Alpha Demonstration Research | J. Jarvis and M. Wallbank (FNAL) | | PDF | Sep 9, 2023 | conditional approval | 10 4-h shifts | Beams-doc-10172 |

FAST Linac

| ID | Acronym | Title | Spokesperson / Fermilab Liaison | LOI (optional) | Proposal | Presentation | Status | Beam Time | Reports |
|---|---|---|---|---|---|---|---|---|---|
| I-402 | FAST-GREENS | Tapering Enhanced Stimulated Super-Radiant Amplification: Gamma-Ray High Efficiency Enhanced Source | P. Musumeci (UCLA) / D. Broemmelsiek (FNAL) | | original final | Apr 4, 2022 | approved | 3 shift blocks, 10 x 8 h each | Cropp's PhD Thesis Instruments 7, 42 (2023) |
| I-404 | NEB | Noise in Intense Electron Bunches | S. Nagaitsev (JLAB) / J. Ruan (FNAL) | PDF | original final | July 14, 2023 | approved | (2 x 4 h) + (3 x 8 h) shifts | FERMILAB-FN-1248-AD |

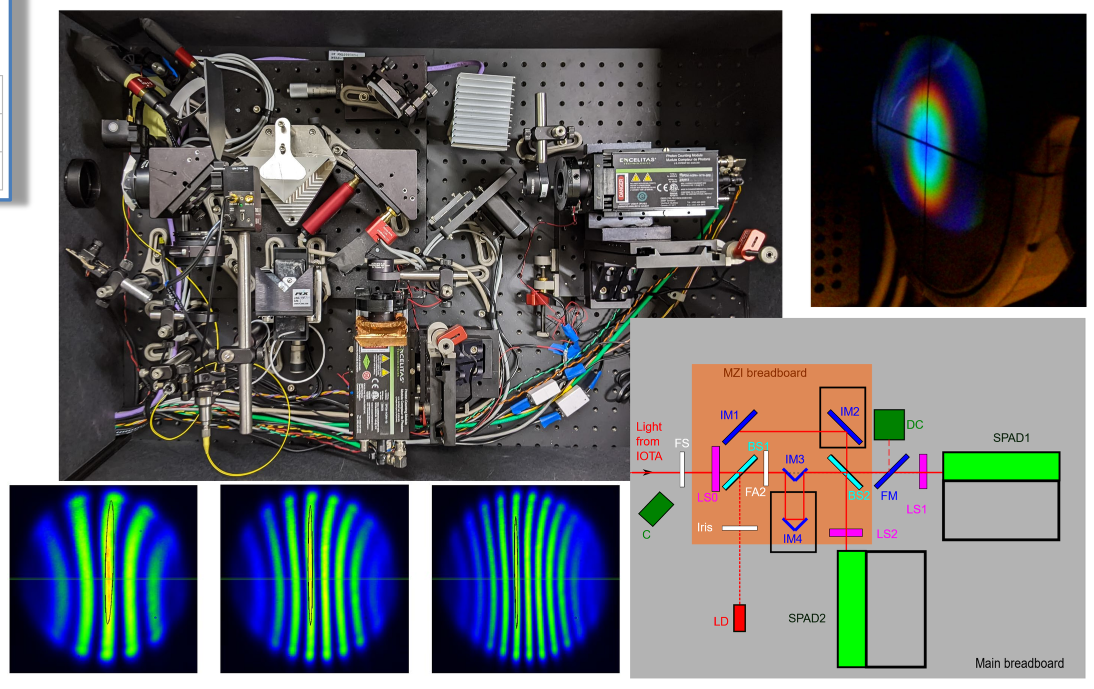
## Presentations at IPAC'24

- **SUPG016:** Measurement of stability diagrams in the IOTA ring at Fermilab, Mary Bossard et al.
- **SUPG021**: Proposal for a proton-bunch compression experiment at IOTA in the strong space-charge regime, Benjamin Simons et al.
- **MOZD1**: New advances in optical stochastic cooling, Jonathan Jarvis et al.
- **MOPS18:** Expansions of the integrability program for novel accelerators, Kevin Hamilton et al.
- **MOPS67:** Experimental verification of integrability in a Danilov-Nagaitsev lattice using machine learning, Nilanjan Banerjee et al.
- **MOPG05**: Low-alpha operation of the IOTA storage ring, Michael Wallbank et al.
- **MOPG06:** Undulator radiation of single electrons: coherence length and quantum-optical properties, Giulio Stancari et al.
- **TUPR48:** Sextupole misalignment and defect identification and remediation in IOTA, John Wieland
- **WEBN1:** Complete 6D tracking of a single electron in the IOTA ring , Alexander Romanov et al.
- **WEPG39:** Ionization profile monitors for the IOTA proton beam, Vladimir Shiltsev et al.
- **THPR32:** Commissioning of the IOTA proton injector, Alexander Romanov et al.
- **THPC20:** Experimental measurements for extracting nonlinear invariants, John Wieland et al.
- **THPC19:** Image based reconstruction of the Danilov-Nagaitsev integrable potential, John Wieland et al.
- **THPC21:** Measured dynamic aperture and detuning of nonlinear integrable optics, John Wieland et al.
- **THPC68:** Proton beam dynamics in bare IOTA with intense space-charge, Nilanjan Banerjee et al.

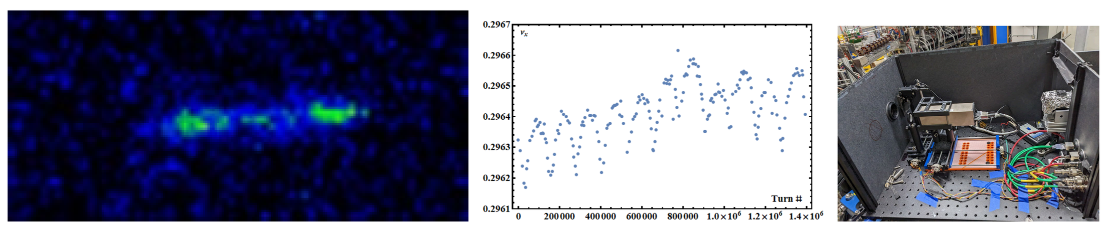
## Next upgrades and experiments at IOTA/FAST

- Experiments
  - NIO with protons
  - Active OSC
  - GREENS
  - Electron lens
  - Single electrons studies
- Facility
  - Laser lab at ESB
  - Refurbishing and/or replacing power supplies
  - Collaboration with ACORN project for testing improved controls
  - Recruiting specialists and students

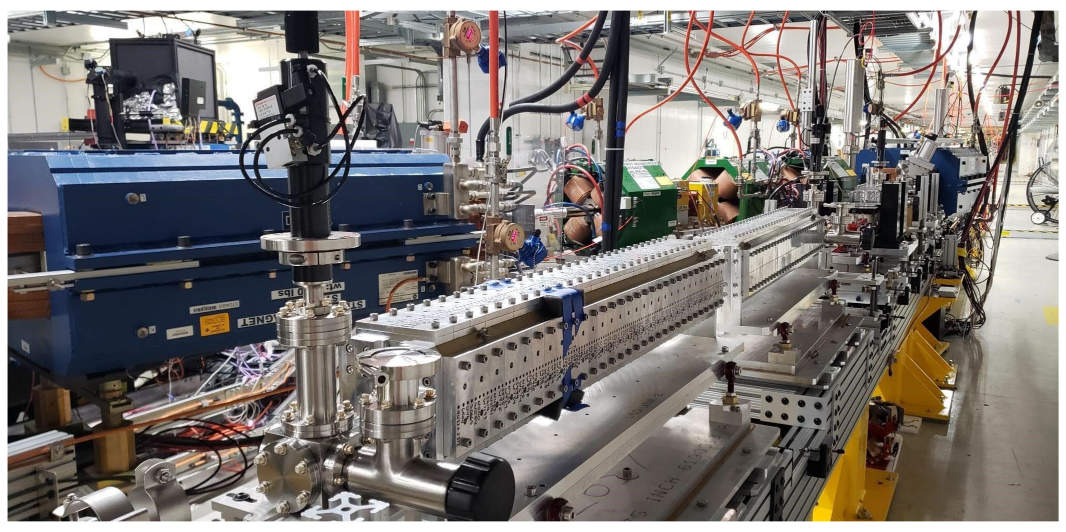
## Coherence length of undulator radiation




## Single electron studies



## Installation of tapered undulators





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