Practical implementations of nonlinear focusing in rings

Alexander Valishev

GARD ABP Roadmap Workshop #1

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Motivation for Experimental R&D on Nonlinear Focusing Lattices for Rings

- Theory work discussed in T.Zolkin's talk
- We aim to construct accelerator focusing systems that are fully nonlinear 'by design' and not as a perturbation
- This talk discusses
  - Experimental verification of novel theoretical concepts
    - Advance physics of accelerators and beams to enable future accelerators
    - Guide and help to fully exploit science at the GARD beam facilities and operational accelerators
  - Practical implementations in future HEP (and possibly other) facilities
    - Develop conventional and advanced accelerator concepts and tools to disrupt existing costly technology paradigms in coordination with other GARD thrusts

Goals of Experimental NIO Research

- Experimentally demonstrate viability of theoretical concepts
  - Most importantly, show whether nonlinear focusing lattices offer practical benefits relative to linear lattices
  - Very strong academic interest – stability of nonlinear systems
- Establish limits of applicability
  - Are requirements to implementation tolerances supported by present-day technology?
- Develop practical solutions for circular accelerators pushing the envelope in beam brightness without significant cost increase

Relevance to HEP Missions

Potential applications of strongly nonlinear focusing rings

- Intensity frontier – high-intensity and high-brightness rapid cycling synchrotrons.
  - Mitigation of ultra-fast coherent instabilities via Landau damping*
  - Mitigation of space-charge related losses*
- Energy frontier – circular colliders (e.g. FCC)
  - Cost-effective mitigation of coherent instabilities via Landau damping*

*discussed by V.Shiltsev

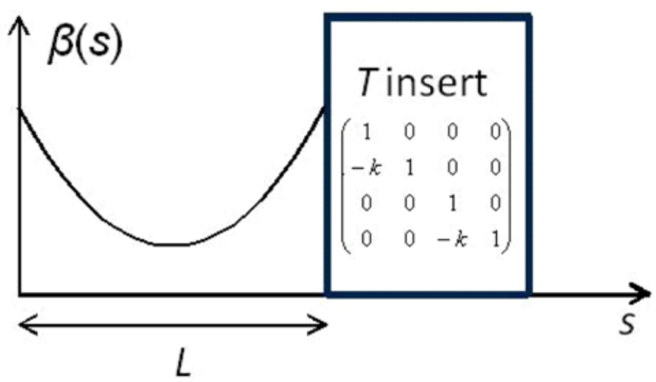
There are strong synergies with other SC offices

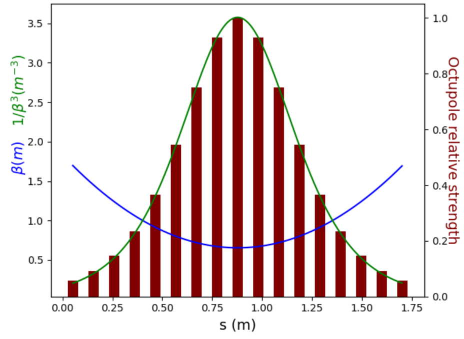
- Nonlinear systems can find application in
  - EIC
  - Ion traps
  - Light sources
- Technologies and tools used and developed as part of experimental NIO research include
  - Machine learning and controls
  - Advanced beam instrumentation
  - Simulation and modeling

} Workshop #2

Present Status of Nonlinear Integrable Optics (NIO) Experiments

- Two R&D facilities pursue implementation of solutions based on insertion of a nonlinear potential to a fraction of ring circumference
  - UMER (UMD)
  - IOTA (Fermilab)
- Present concepts are based on precise control/tuning of linear part of the machine and accurate realization of the nonlinear potential – the two main risks

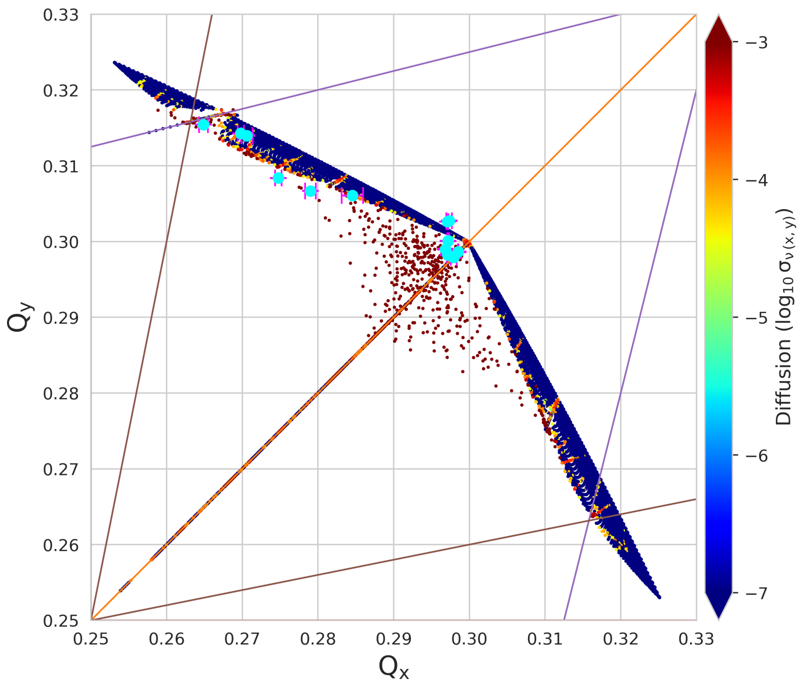


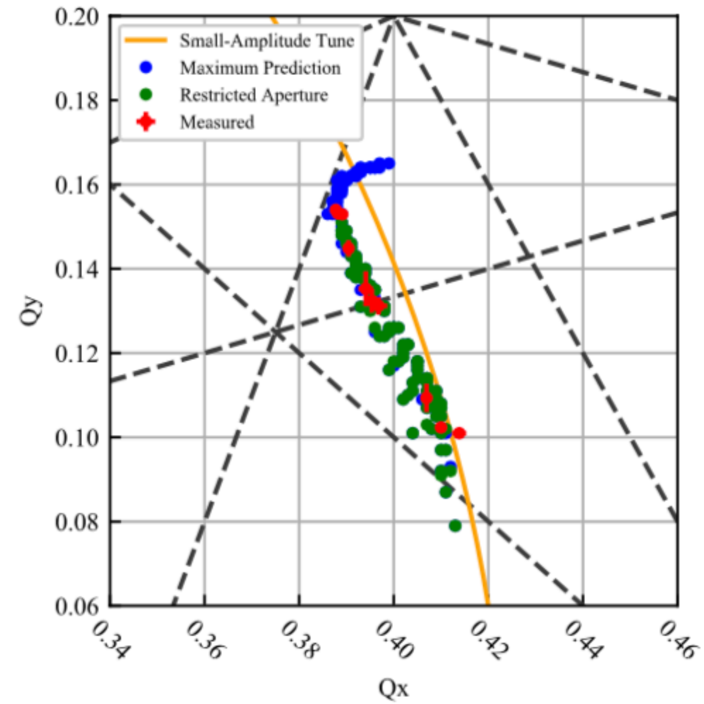


Fermilab

Present Status of NIO Experiments

- IOTA Run-1 showed strong potential
  - Nonlinear amplitude-dependent tune shifts of 0.05-0.1 without degradation of dynamic aperture

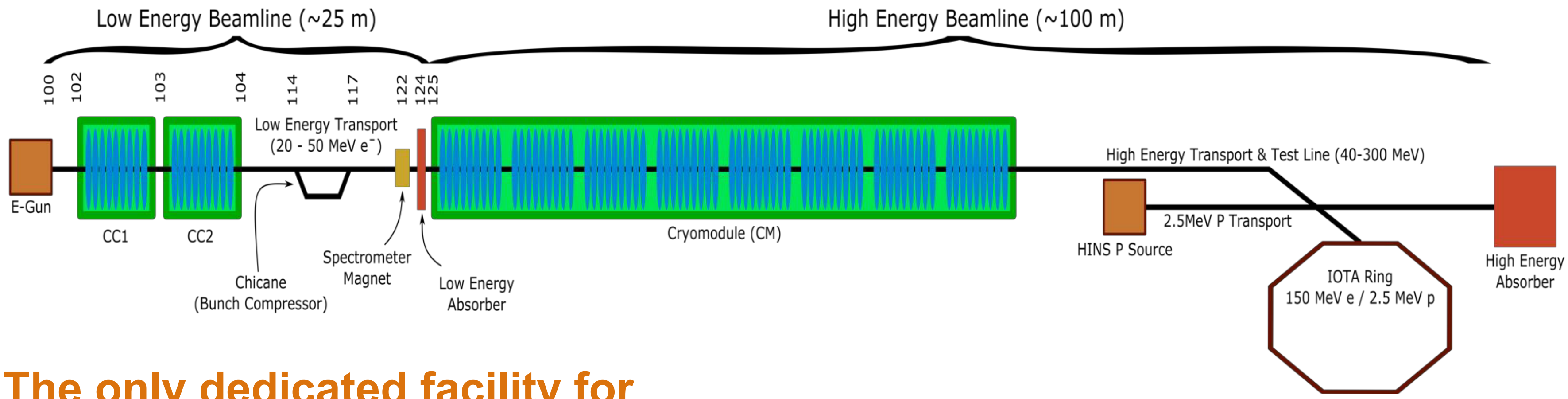




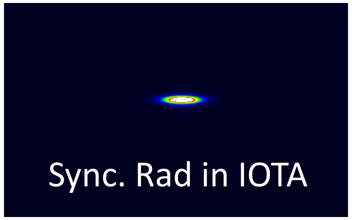
Facilities

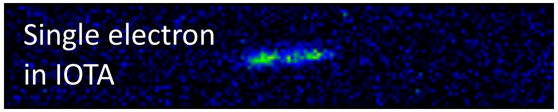
- Small size dedicated R&D machines for proof-of-principle research
  - IOTA
  - UMER
- Large scale tests could be conducted in production machines
  - RHIC
  - LHC
  - Fermilab RCS
  - Light sources

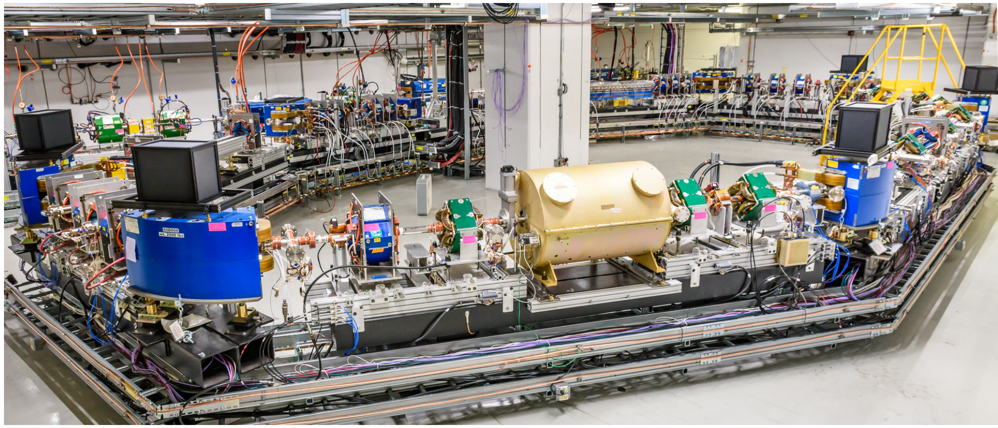
IOTA/FAST Facility: a center for Acc. and Beam Physics



- **The only dedicated facility for intensity-frontier accelerator R&D; ranked as top facility ("Tier 1") for acc. & beam physics thrust by recent GARD review**
- **Adequate for tests of many concepts that have been proposed to date**
- **Could benefit from**
  - **Upgrades to improve flexibility**
  - **Strengthening of operations**



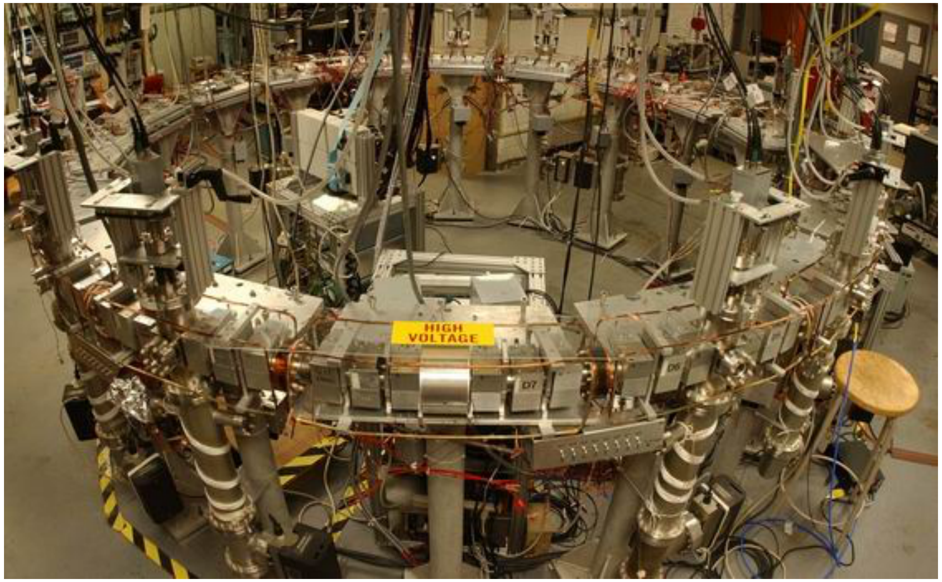




UMER

- Using a scaled low-energy electron beam, UMER cleverly accesses the intense, high-brightness, regime of beam operation in accelerators, at a much lower cost than larger and more energetic machines.

- **Very good for training students; development of instrumentation**
- **Limited application for studies of single-particle dynamics**
- **Possible considerations**
    - **Bunched-beam operation**
    - **Ultra-low intensity / high sensitivity instrumentation**



Possible Timeline

- IOTA Proof-of-principle experiments with electrons (single-particle regime)
  - Presently considered systems
    - 1 invariant of motion (Octupoles) 2019-2021
    - 2 invariants of motion (Danilov-Nagaitsev) 2019-2022
    - 2 invariants of motion (McMillan e-Lens) 2021-2025
  - New/future proposals 2021-2027
- IOTA research with proton beams 2021-2027
- Large machine / scalability studies 2021-2030

IOTA/FAST Collaboration

~30 Partner Institutions:

- ANL, Berkeley, BNL, BINP, CEA/Saclay, CERN, Chicago, Colorado State, Fermilab, DESY, IAP Frankfurt, JAI, JLab, JINR, Kansas, KEK, LANL, LBNL, ORNL, Maryland, U. de Guanajuato Mexico, NIU, Michigan State, Oxford, RadiaBeam Tech, RadiaSoft LLC, Tech-X, Tennessee, Vanderbilt, SLAC
- NIU-NICADD: strategic ties
- EIC/MARIE/BES: many R&D opportunities