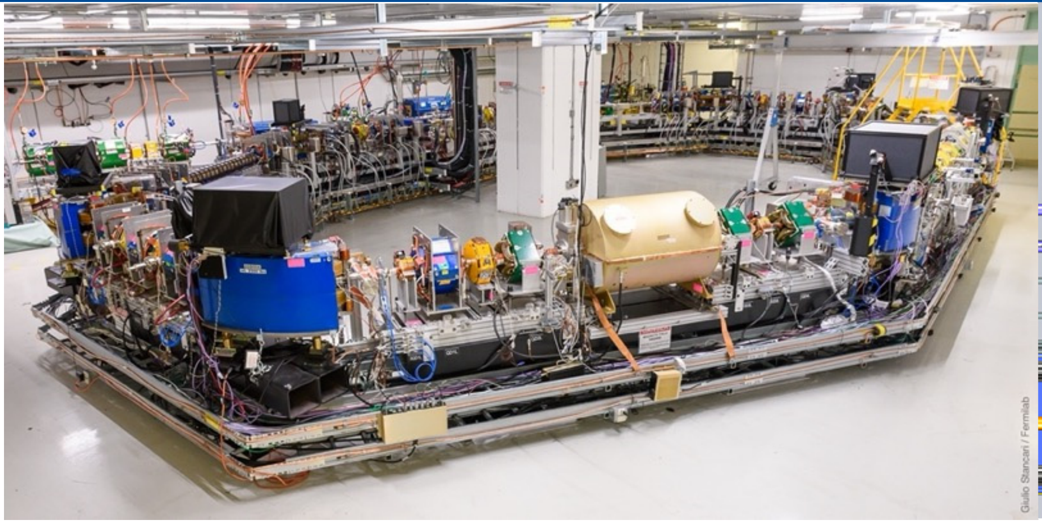
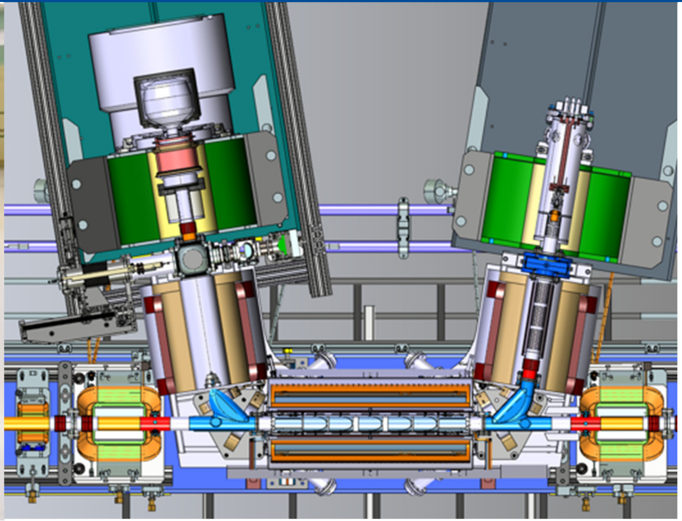




Electron Cooling Experiment for Proton Beams With Intense Space-Charge in IOTA

Nilanjan Banerjee, MaryKate Bossard, John Brandt, Brandon Cathey, Young-Kee Kim, Sergei Nagaitsev, Giulio Stancari

In partnership with:

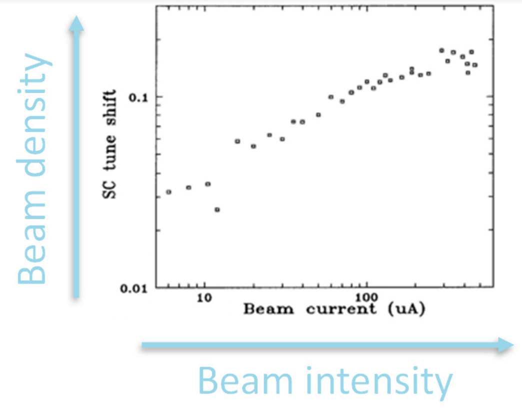
THE UNIVERSITY OF CHICAGO

Overview

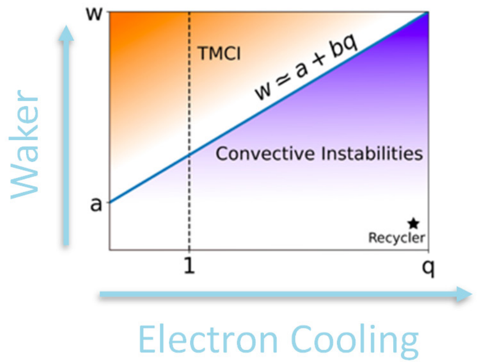
- Beam physics goals
- Design Considerations
- Simulations
- Hardware
- Conclusion

Beam Physics Research Goals

- Driven by necessity!
  - Counter emittance growth in 2.5 MeV proton beam.
  - Achieve low energy spread and other manipulations.
- Study large incoherent tune shift
  - Space-charge forces limit the incoherent tune shifts to < 0.01 – 0.1. Explore the intense space-charge regime.
- Study instabilities
  - Interplay of wakefields, space-charge and electron cooling.
  - Electron cooling as a knob for space charge parameter.
- Non-linear Integrable Optics with SC and cooling
  - Realize NIO in the multi-particle regime.



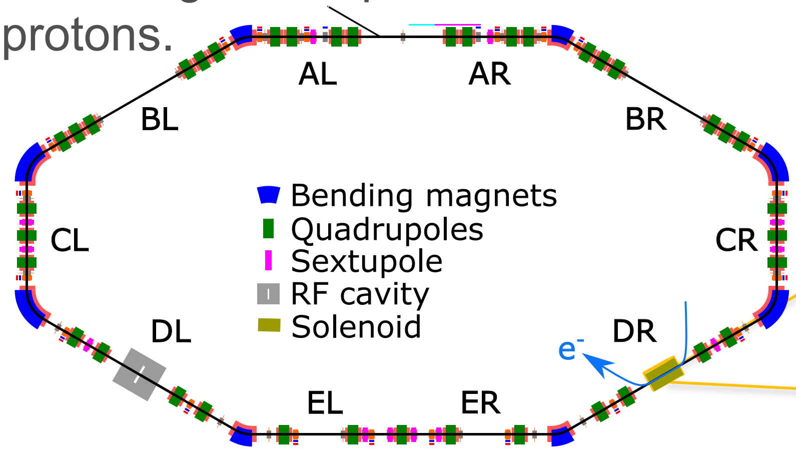
S. Nagaitsev et al., Proceedings Particle Accelerator Conference, 1995, pp. 2937-2939

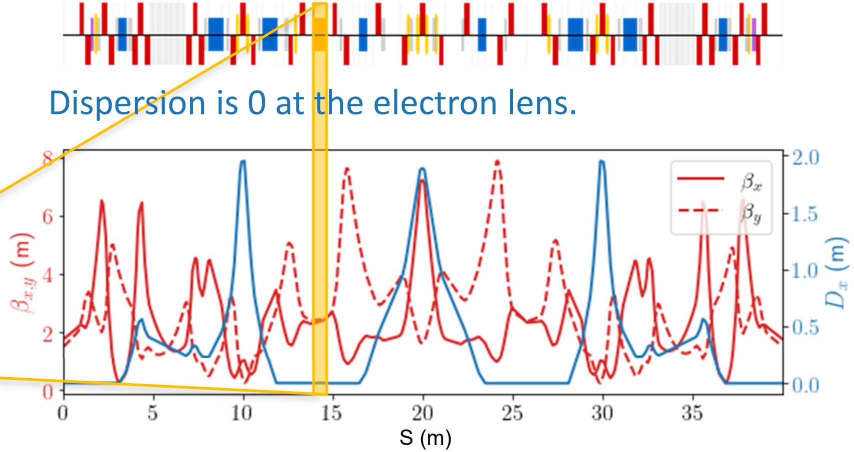


A. Burov, Phys. Rev. Accel. Beams 22, 034202, 2019

Design Considerations: IOTA

The Integrable Optics Test Accelerator will be configured to recirculate 2.5 MeV protons.





C	KE	τ_{rev}	h	N_{bunch}	$A_{x,y}$	$\nu_{x,y}$
39.96 m	2.5 MeV	1.83 μs	4	Coasting or 4	87, 78 μm	4.117, 3.632

G. Stancari et al, JINST 16 P05002, 2021, https://doi.org/10.1088/1748-0221/16/05/P05002

Design Considerations: IOTA parameters

$\epsilon_{x,y}$ (μm)	σ_p/p	σ_s (m)
4.3, 3.0	1.32 x 10^{-3}	0.79

Major sources of emittance growth: **Space charge**, Intra Beam Scattering, Residual Gas Scattering.

	Coasting		Bunched	
Current (mA)	1.25	6.25	0.248	1.24
Bunch Charge (nC)	2.28	11.4	0.113	0.565
Tune Shifts ($\Delta\nu_{x,y}$)	-0.076, -0.10	-0.38, -0.50	-0.076, -0.10	-0.38, -0.50
RGS	$\tau_{RGS,single}$~ 30 hrs, τ_{RGS,ϵ_x}~ 40 mins, τ_{RGS,ϵ_y}~ 27 mins			
IBS $\tau_{IBS,x,y,s}$ (s)	32.0, 20.9, 40.4	6.40, 4.19, 8.08	43.4, 29.9, 115	8.69, 5.97, 23.01

Emittance growth and beam loss due to space-charge under active investigation.

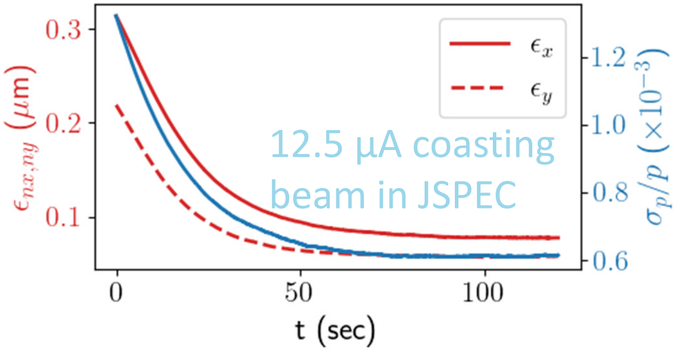
Simple Cooler

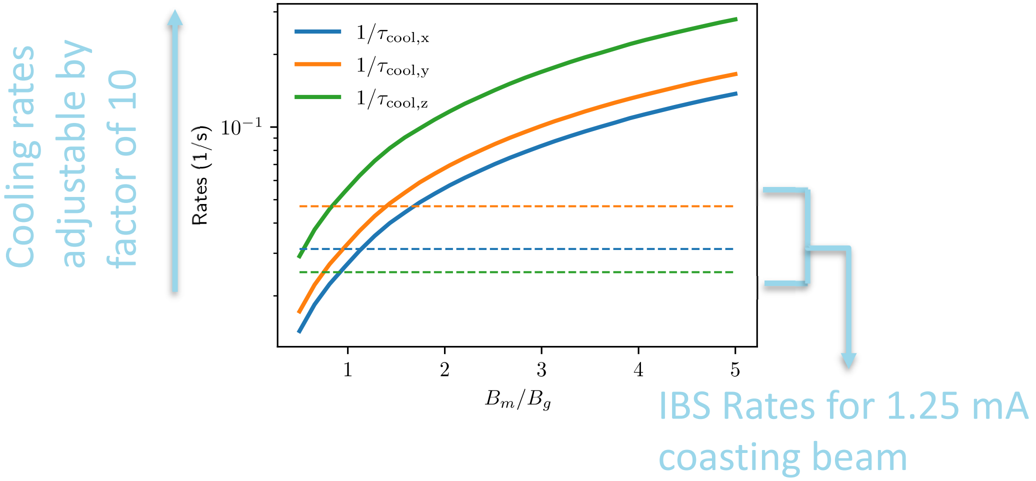
A tool for other experiments at IOTA, example NIO, electron-lens, etc. Design goals:

- Compensate for emittance growth due to Intra-Beam Scattering.
- Various beam manipulation.
- Easy configuration.

Parameters:

- Electron source: DC 1.36 kV, 1 mA, ϕ 40 mm, 1 V jitter, 1400 K
- Main solenoid: 0.1 – 0.5 T, 0.7 m, flatness: 2 x 10^{-4}

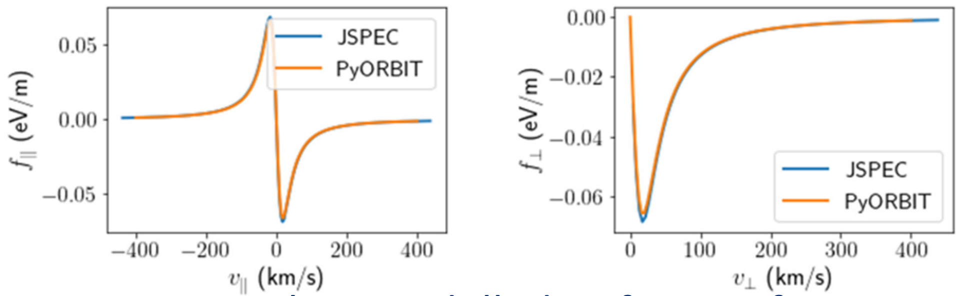




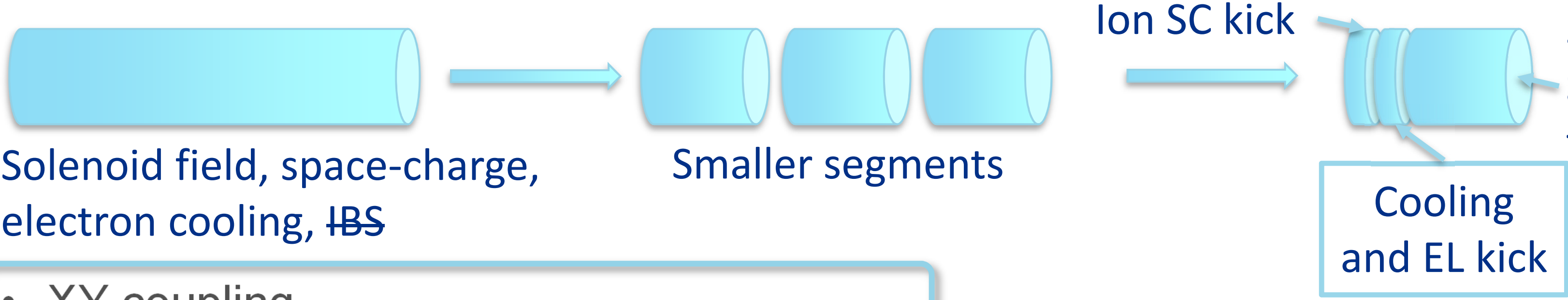
Strong Cooler

Cooler parameters

- Electron source: DC 1.36 kV, 40 mA, ϕ24 mm, 1 V jitter, 1400 K
- Solenoid: 0.1 T, 0.7 m, flatness: 2 x 10^{-4}



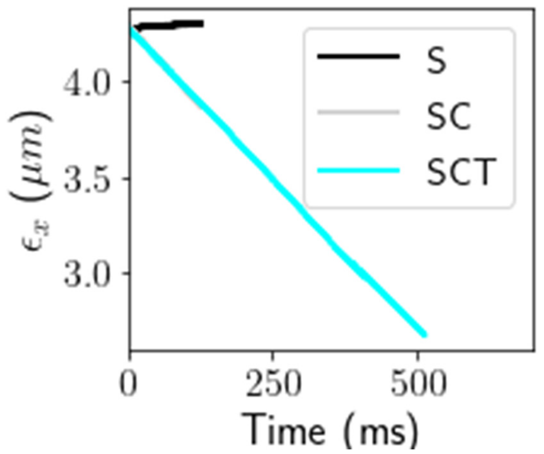
E Cooling modelled as friction forces

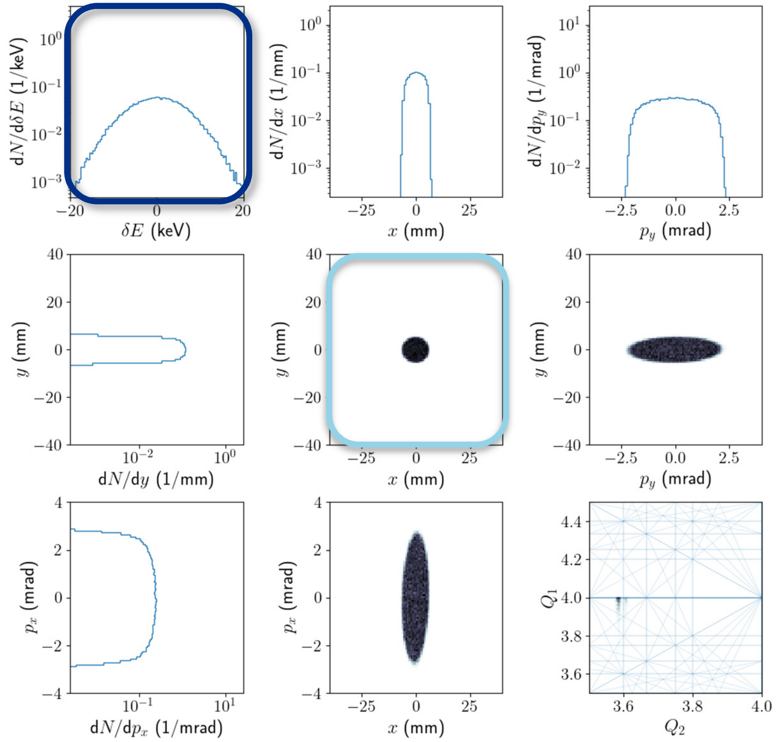


- XY coupling
- Static space charge of the electron beam.
- Dynamic space charge of ion beam.

Implemented this in PyORBIT!

Cooling simulation with Space Charge

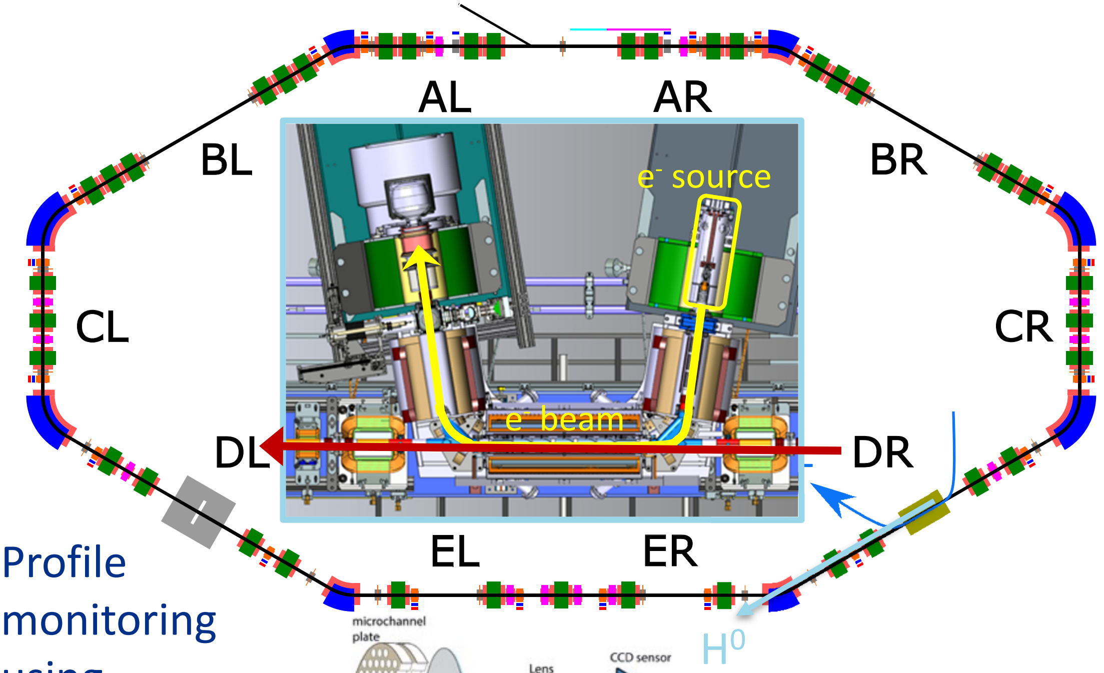


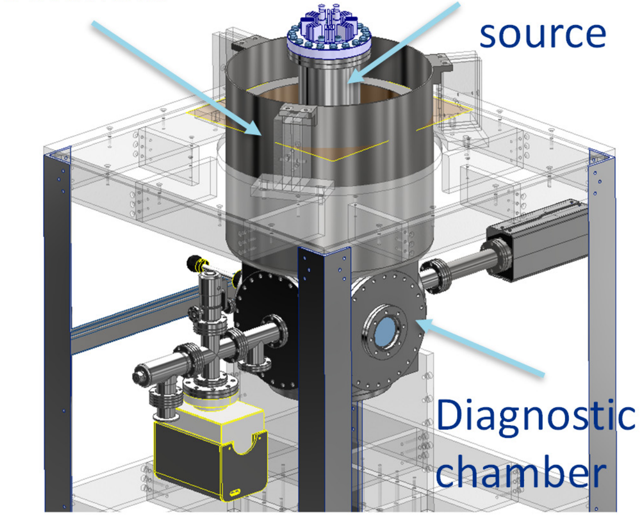


- Emittance decreases with time. Cooling time ~ 1 s.
- Transverse beam size decreases.
- Energy spread becomes smaller.

Rich incoherent dynamics to observe!

Beam Diagnostics and Testing



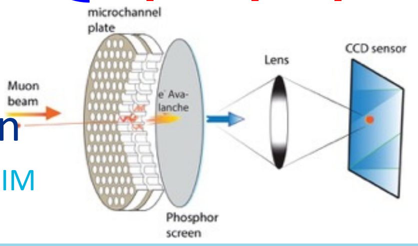


Test stand for thermionic source

- Thermal and Vacuum
- Beam profile

Profile monitoring using recombination

Bongho Kim et al., NIM A, 899, 22-27, 2018



Schottky monitor under consideration.

Conclusion

- Electron cooling can improve beam quality for low to medium energy hadron beams.
- At the Integrable Optics Test Accelerator, we will explore the high-intensity regime of electron cooling to understand the effect of space-charge and instabilities.
- Designed two configurations, one for low space-charge regime for protons, one for the strong space-charge regime.
- Developed simulations which incorporates space charge, electron cooling and x-y coupling. **Ongoing studies.**
- Plan of experiments and final design of electron source in progress!

Acknowledgements

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