PHYSICS & ASTRONOMY
TEXAS A&M UNIVERSITY

A cooling storage ring for an electron-ion collider

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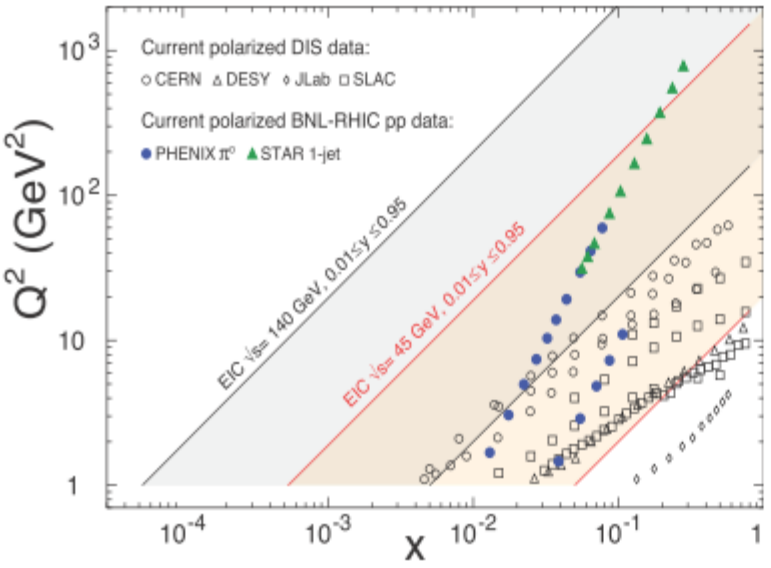
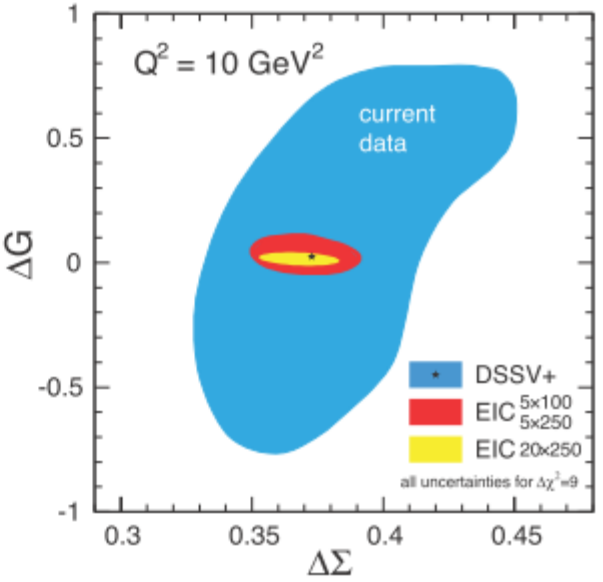
Slides available at http://www.github.com/jgerity/talks

Why an EIC?

- An EIC would provide a powerful probe of unexplored regions of nuclear parameters



Accessible Q^2 with different parameter regimes



Uncertainties on gluon and quark helicity contributions to the proton spin

Figure from 2014 community whitepaper “Electron Ion Collider: The Next QCD Frontier” (arXiv:1212.1701)

Questions to be answered

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- Where does the saturation of gluon densities set in?
- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?

See 2014 community whitepaper “Electron Ion Collider: The Next QCD Frontier” (arXiv:1212.1701)

What is MEIC?

- The **Medium-energy Electron-Ion Collider** is Jefferson Lab's EIC design
- Fig. 8 geometry preserves spin polarization *naturally*

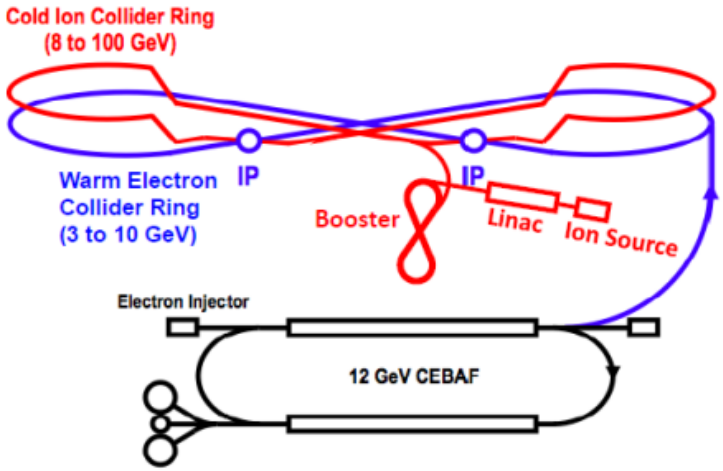


Figure from 2014 community whitepaper "Electron Ion Collider: The Next QCD Frontier" (arXiv:1212.1701)

Electron cooling

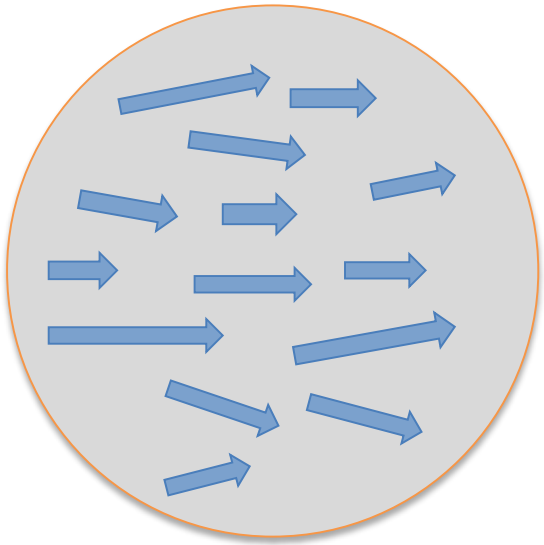
- Luminosity is inversely proportional to normalized emittance (phase space area):

$$\mathcal{L} \propto \frac{N_p}{\sqrt{\varepsilon_{N,x}\varepsilon_{N,y}}}$$

- **Liouville's theorem** means we can't increase phase space density (shrink ε_N) using any of the periodic elements of our system (i.e. focusing)

Electron cooling

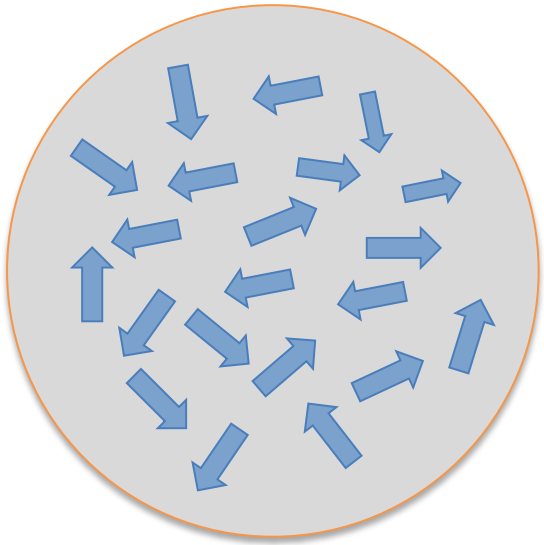
- In any accelerator, our beam of particles has a finite velocity spread.



Ion beam seen from stationary (lab) frame

Electron cooling

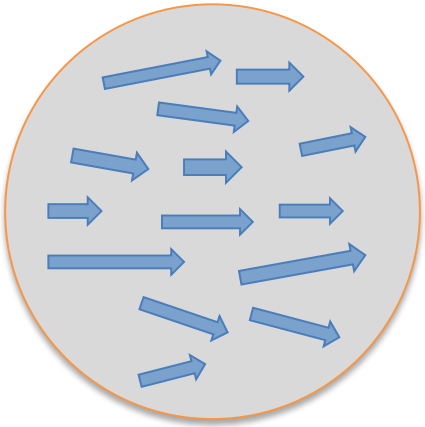
- In any accelerator, our beam of particles has a finite velocity spread.
- In a frame moving with the average velocity $\bar{v}$, the motion is analogous to that of a gas!



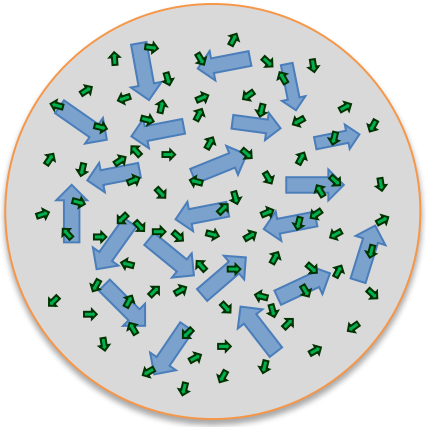
Ion beam seen from moving frame

Electron cooling

- How to cool a gas? Mix with a colder one!
- Coulomb collision with ‘cold’ electrons drives velocity profiles to equilibrium



Ion beam seen from stationary (lab) frame



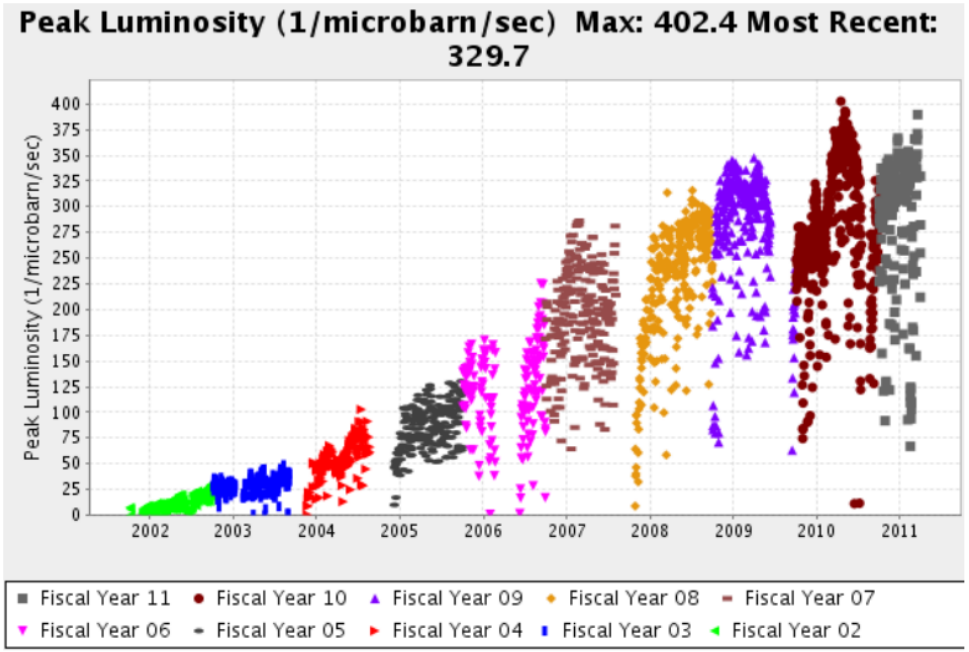
Ion beam seen from moving frame, with electrons

Cooling ring motivation

- Existing EIC concepts rely on cooling for performance, but…
- The cooling strategies employed are heavy R&D subjects!
  - Energy recovery & circulator @ MEIC
  - Coherent cooling @ eRHIC
- Can more conventional cooling help offset the technical risk?

Cooling ring motivation

- From FY'02 to FY'11, Tevatron peak luminosity was increased by an order of magnitude
  - Cooling and *stacking* of beam in the Recycler was essential to this success

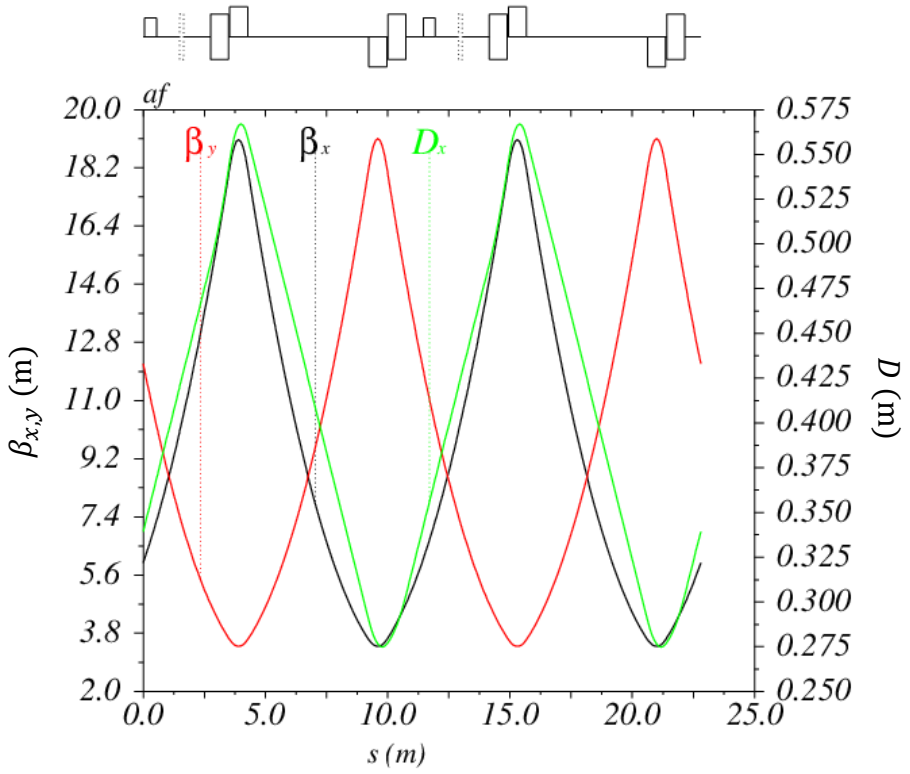


Motivation for a *dedicated* cooling ring

- Marginal cost can be achieved with low-field magnets, use of existing space
- Low risk in terms of R&D; extends current technology *directly*
- Augments existing approach, works together with ERL

Cooling ring parameters and optics

- Cooling rate $\propto \gamma^{-2}$
- Space charge effects $\propto \gamma^{-3}$
- $E \sim 6 - 8$ GeV
- $B_{\text{dipole}} \sim 0.25$ T



Stacking and injection optics

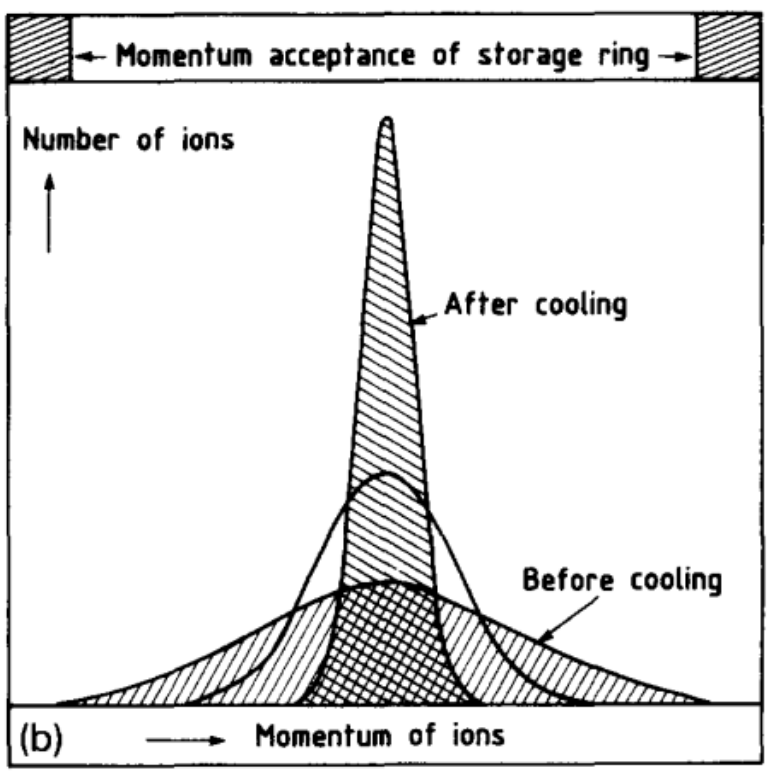
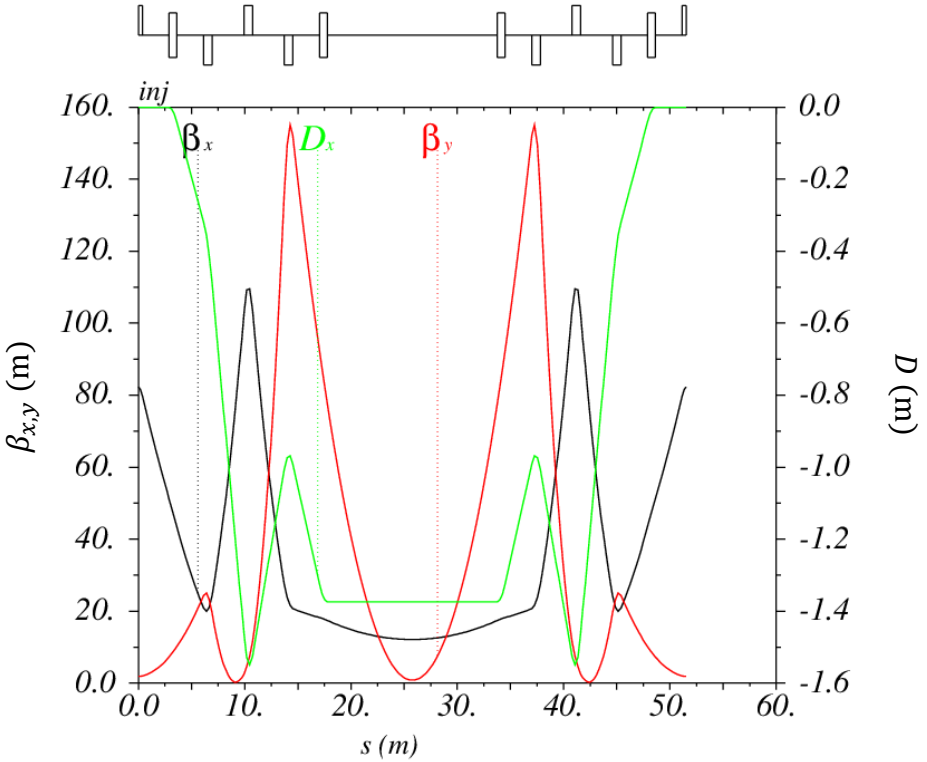


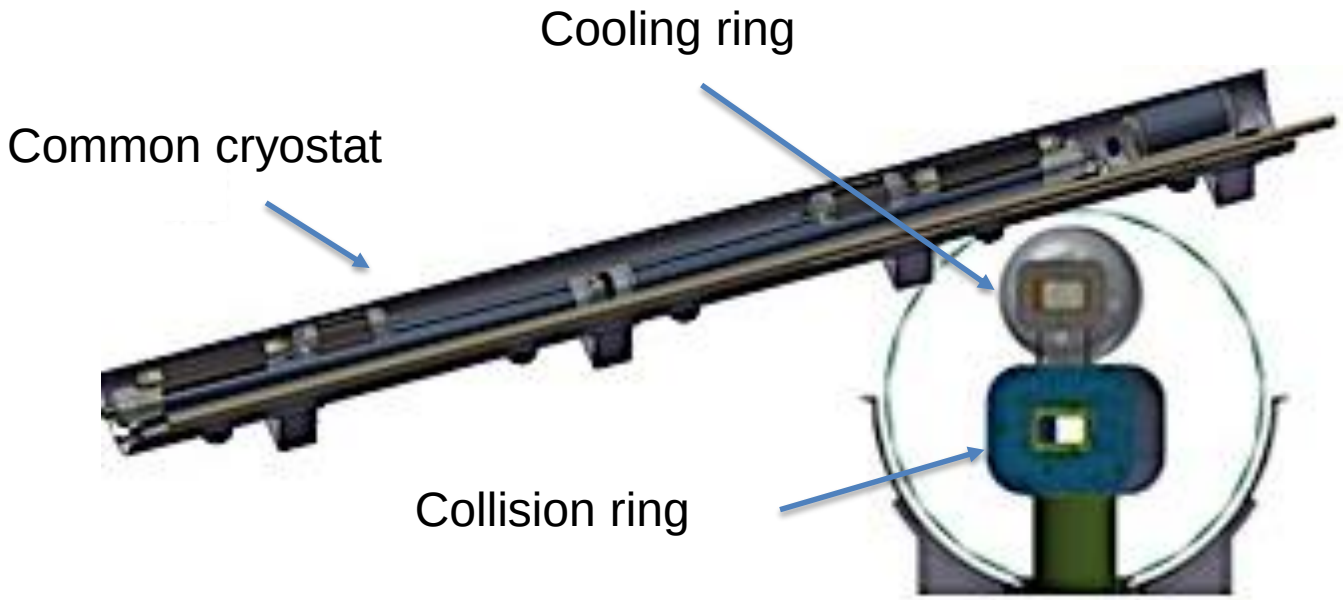
Figure from H. Poth, Electron cooling: Theory, experiment, application, Physics Reports, 196 (1990) 135-297.



Dispersive insertion, allowing side-by-side injection of new beam

Cooling ring

- There is unallocated space in the existing cryostat layout for this additional ring

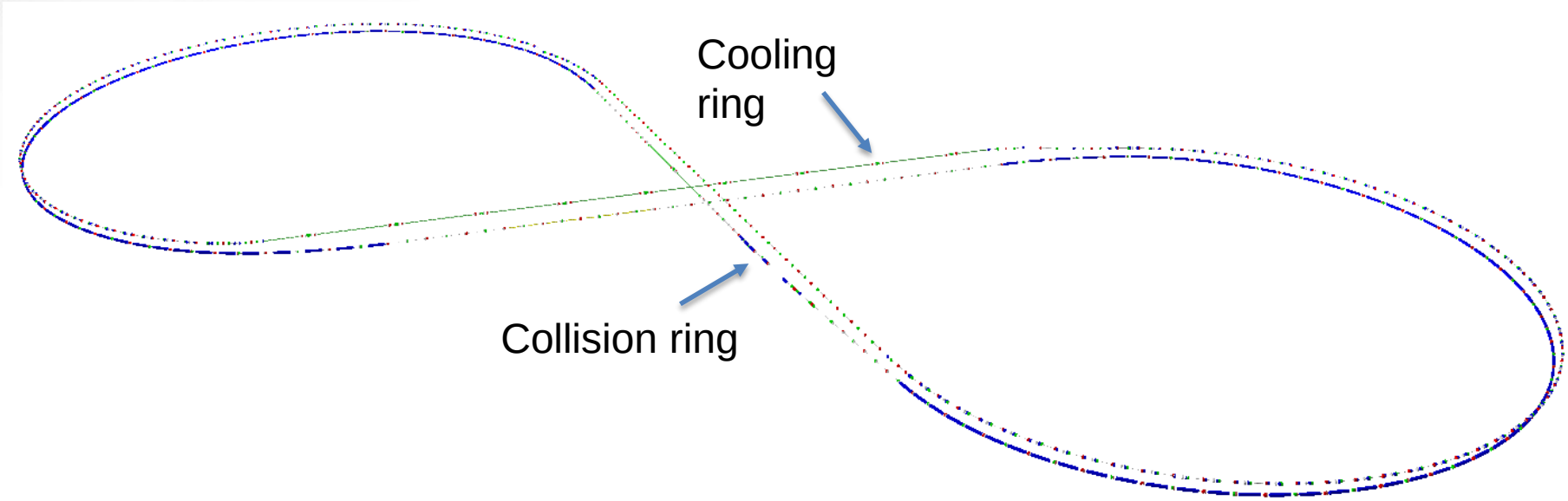


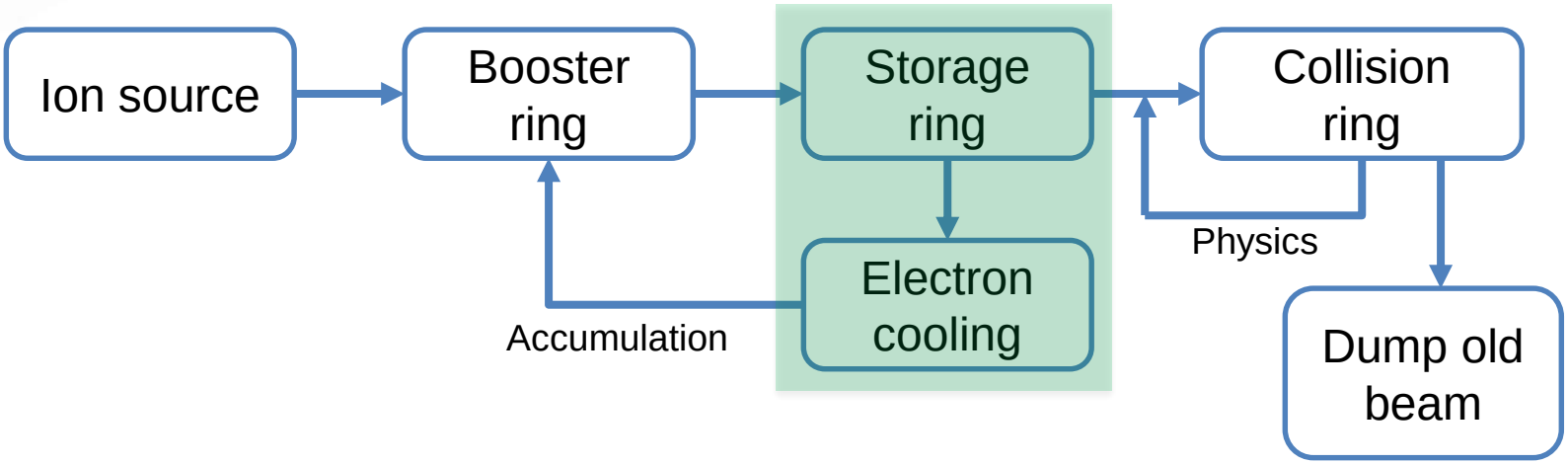
Future Work

- Simulation of strongly magnetized and neutralized cooling to understand cooling rates
  - SBIR submitted
- Hard characterization of performance benefit to MEIC design
  - Most importantly, increase in $\mathcal{L}$ possible

Thank you!

Backup slides


Cooling
ring
Collision ring


Ion source
Booster ring
Storage ring
Collision ring
Physics
Electron cooling
Accumulation
Dump old beam

Electron cooling

- We can associate a temperature with this behavior. For an isotropic Gaussian distribution:

$$f(\vec{v}) \propto \frac{e^{-v^2/\sigma_v^2}}{\sigma_v^3} \propto \frac{e^{-mv^2/2kT}}{(kT)^{3/2}}$$

- Note: it is common to give “temperature” as kT in units of eV for convenience, but the concept is unaltered.

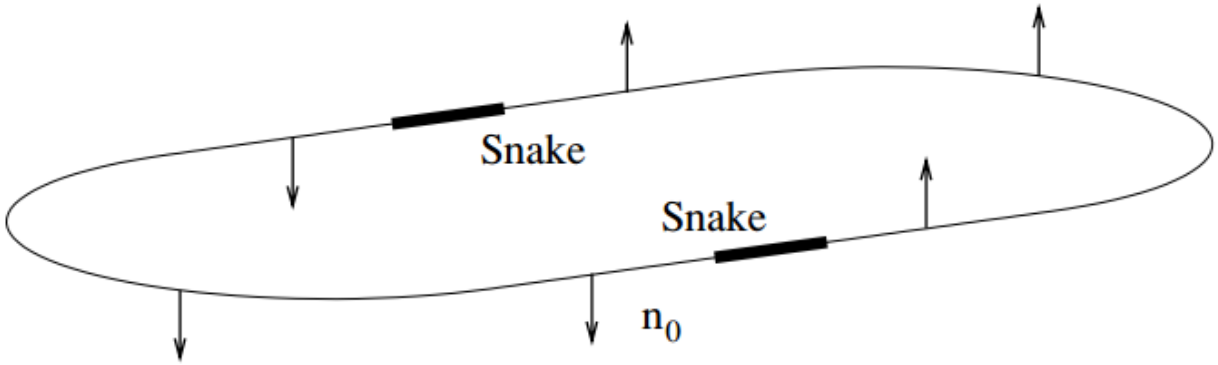


Figure from “Siberian Snakes in high-energy accelerators” Mane et. al (2005)
http://dx.doi.org/10.1088/0954-3899/31/9/R01