Toroidal merger simulations for the JLEIC bunched beam electron cooler ring*

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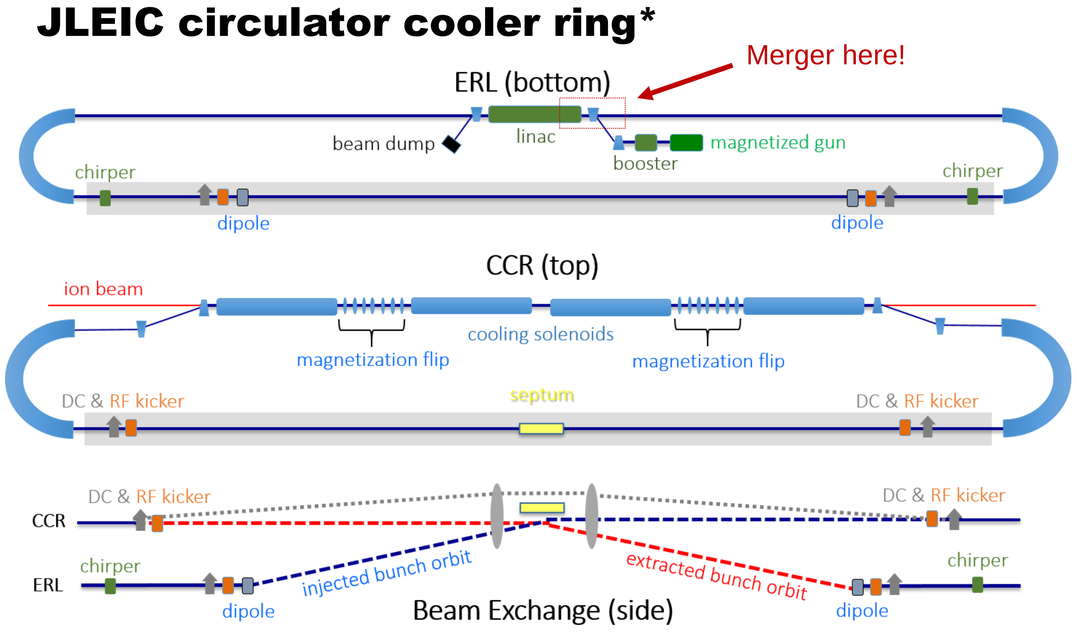
Abstract

The bunched beam electron cooler ring for the Jefferson Lab Electron-Ion Collider (JLEIC) requires a merger system to transport magnetized electron beams of two different energies to the same energy recovery linac (ERL) beamline. The system is especially challenging compared to existing mergers for ERL or hadron cooling applications (as at COSY) due to the small separation in energy between the two beams; for the JLEIC bunched beam cooler, the two beam energies may only differ by a factor of 4. An additional complication is the use of a magnetized beam. A toroidal merger system is studied using G4Beamline/GEANT4. Preservation of the quality of the low energy beam from the injector is especially vital for efficient cooling performance and compatibility with the ERL. Effects of the toroidal system on transverse and longitudinal emittances of the magnetized beams, as well as space charge effects, are presented and discussed.

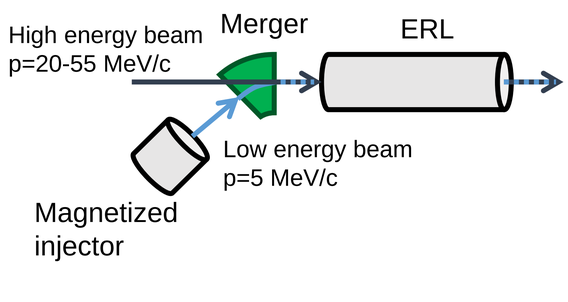
JLEIC circulator cooler ring*



*see MOPMK015

- Provides 20-55 MeV/c magnetized electrons for hadron cooling
- Energy recover the cooling electron beam
- Needs to merge low energy beam from injector and high energy beam returning from cooler into same ERL beamline
- Electron bunch charge as high as 3.2 nC

Injector merger schematic

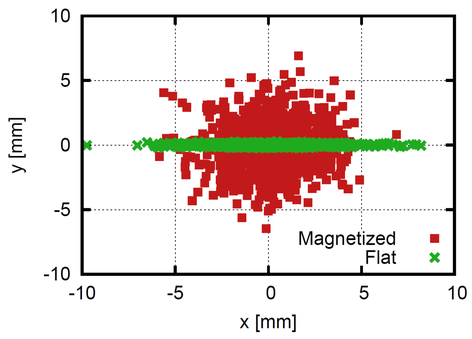


Magnetized beam distribution

- Flat beam transform used to generate magnetized beam distribution

$$\overleftrightarrow{T} = \frac{1}{2}\begin{pmatrix} \vec{M}+\vec{N} & \vec{M}-\vec{N} \\ \vec{M}-\vec{N} & \vec{M}+\vec{N} \end{pmatrix} = \frac{1}{2}\begin{pmatrix} m+\alpha p & \beta p & p-\alpha m & -\beta m \\ -\gamma p & m-\alpha p & \gamma m & p+\alpha m \\ p-\alpha m & -\beta m & m+\alpha p & \beta p \\ \gamma m & p+\alpha m & -\gamma p & m-\alpha p \end{pmatrix}$$

$$m = \cos\mu - \sin\mu$$
$$p = \cos\mu + \sin\mu$$



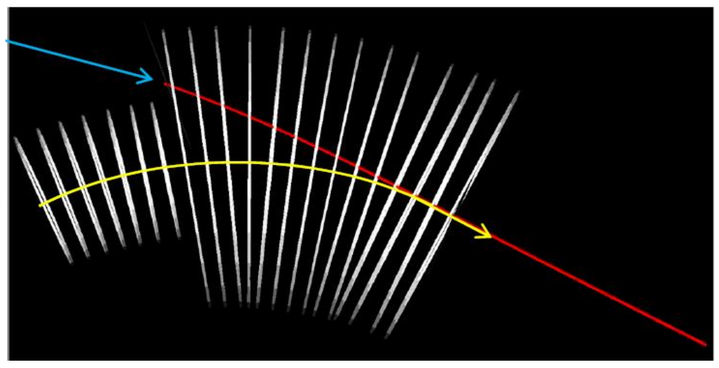
- Convert flat beam to magnetized beam for transport simulations
- Convert magnetized beam back to flat beam to evaluate emittance growth

Simulation setup

- Simulations in G4Beamline/GEANT4
- Toroidal merger to preserve magnetization of beams
- Ideal sector bend field superimposed on toroidal field region
- Tilt individual solenoid coils about local x, y axes for additional transverse fields
- Radius of curvature 1 m, 45 degree bend in horizontal plane
- Front solenoid coils with radius 13 cm
- Back solenoid coils with radius 26 cm

High energy beam returning from cooling section
p=20 MeV/c

Low energy beam from injector
p=5 MeV/c



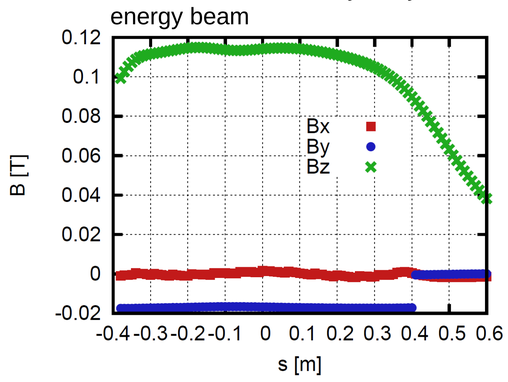
Matched solenoid parameters

	p=5 MeV/c	p=20 MeV/c
B_z [T]	0.1	0.1
ρ_{Larmor} [mm]	166.78	667.13
β [mm]	333.56	1334.25
ε_x (geom) [mm-mrad]	20	5.1
ε_y (geom) [mm-mrad]	0.2	0.05

Low energy beam

- Preservation of low energy beam quality is crucial to cooling performance
- Growth of Larmor emittance especially should be avoided
- Evaluate Larmor emittance by looking at vertical emittance after round-to-flat beam conversion
- Space charge effects included with G4Beamline module – uses Lienart-Wiechert potentials

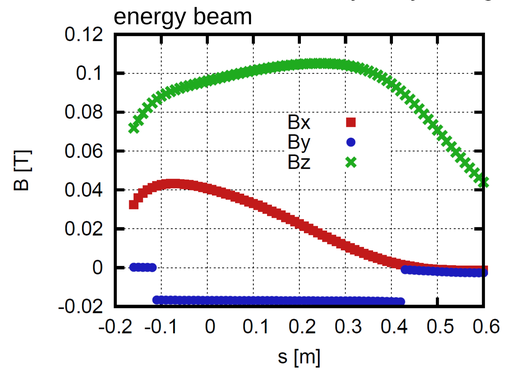
Fields on reference trajectory for low energy beam



High energy beam

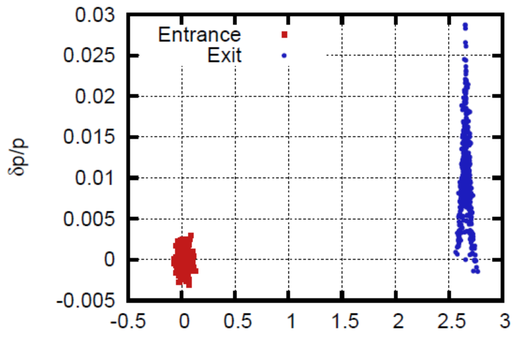
- High energy beam does not traverse full length of toroidal merger
- Injected in region of high transverse magnetic field
- Larger coils in second half of merger to accommodate high energy beam
- Space charge effects not an issue – even for bunch charge of 3.2 nC, negligible additional growth of transverse or longitudinal emittance

Fields on reference trajectory for high energy beam



Beam parameters after transport through toroidal merger

p=5 MeV/c	Generated	Exit, No SC	Exit, 3.2 nC
σ_x [mm]	2.58	2.36	2.41
$\sigma_{x'}$ [mrad]	7.74	6.03	6.15
ε_x (geom) [mm-mrad]	20	14.25	14.82
σ_y [mm]	0.26	0.34	0.37
$\sigma_{y'}$ [mrad]	0.77	1.08	1.12
ε_y (geom) [mm-mrad]	0.2	0.37	0.41
σ_t [ns]	3.33e-2	3.62e-2	3.61e-2
$\sigma_{dp/p}$	1e-3	1.02e-3	2.88e-3



Energy spread of low energy beam with space charge effects enabled

Beam parameters after transport through toroidal merger

p=20 MeV/c	Generated	Exit, no SC	Exit, 3.2 nC
σ_x [mm]	2.61	2.39	2.39
$\sigma_{x'}$ [mrad]	1.96	3.13	3.14
ε_x (geom) [mm-mrad]	5.1	7.5	7.5
σ_y [mm]	0.26	1.33	1.33
$\sigma_{y'}$ [mrad]	0.2	0.4	0.4
ε_y (geom) [mm-mrad]	0.05	0.52	0.53
σ_t [ns]	3.33e-2	3.2e-2	3.2e-2
$\sigma_{dp/p}$	1e-3	9.76e-4	1.06e-3

Results

- With space charge effects included, horizontal focusing effect in x, 2x growth in vertical emittance for low energy beam
- 3x growth in energy spread for 3.2 nC bunch charge
- High energy beam has emittance growth in both horizontal and vertical planes, over 10x for vertical emittance
- May be an issue for energy recoverability of the high energy beam

Future work

- Include more realistic bunch distribution from injector region; possibly less bunch charge
- Explore ways to reduce the transverse fields seen by the high energy beam

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