Quad/dipole Ring Coolers*

Nufact'03

Columbia University

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The Process

Strategy

- Explore ring cooling designs
- Simplify designs
  - Avoid solenoids where possible
  - Use only quads & dipoles
- Obtain longitudinal cooling
  - Utilize beam dispersion
  - Maintain/reduce horizontal emittance
- Linear lattice design (SYNCH)
- Cooling simulation (ICOOL)

The Cooling Process

The basic emittance evolution equation:

$$\frac{d\varepsilon_N}{ds} = -\frac{1}{\beta^2}\left|\frac{dE_\mu}{ds}\right|\frac{\varepsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

Heating Cooling

Setting $\frac{d\varepsilon_N}{ds} = 0$ yields,

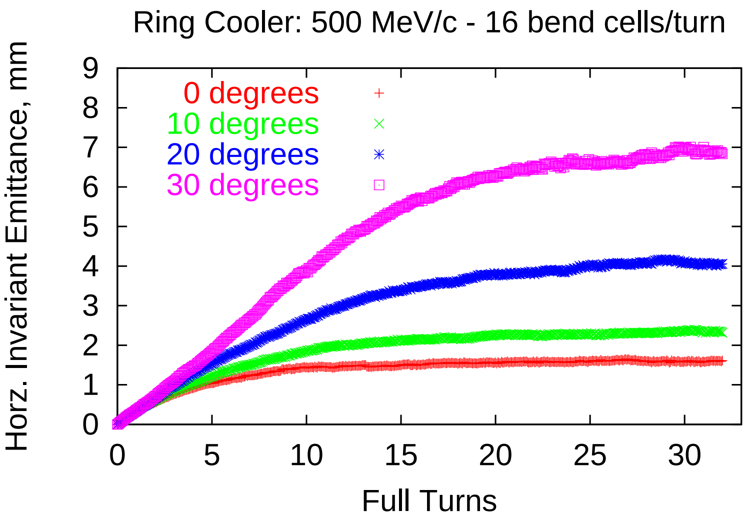
$$\varepsilon_{x,N,equil.} = \frac{\beta_\perp (0.014\ \mathrm{GeV})^2}{2\beta m_\mu X_0 \left|\frac{dE_\mu}{ds}\right|}$$

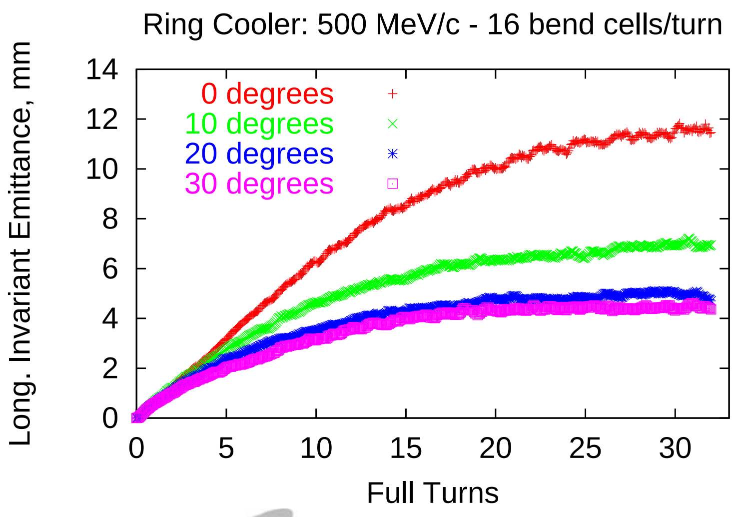
Focusing Properties

Material Properties

Equilibrium Emittances

Horizontal equilibrium emittance increases with wedge angle but 0^0 wedge angle behaves as expected





Longitudinal equilibrium emittance declines with increasing wedge angle

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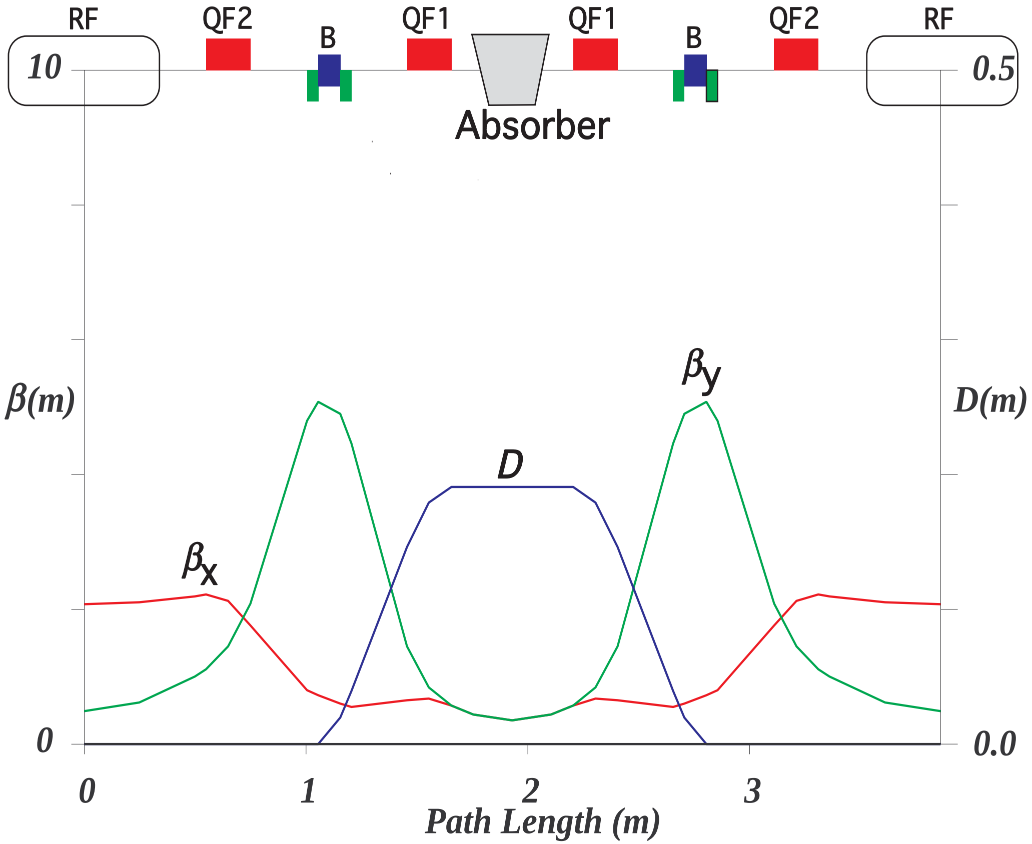
A Quad/dipole Lattice

- Compact Chasman-Green lattice
- 1 m drift available for rf
- Low β (25 cm) at absorber
- Combined function dipole simulated
- Dispersion only at absorber
- Allows for matching straight sections--injection/ejection
- 45^0 bending cell
- $\beta_{y\,max} > \beta_{x\,max}$
- Cell tune is ~ ¾



Chasman-Green Lattice Performance

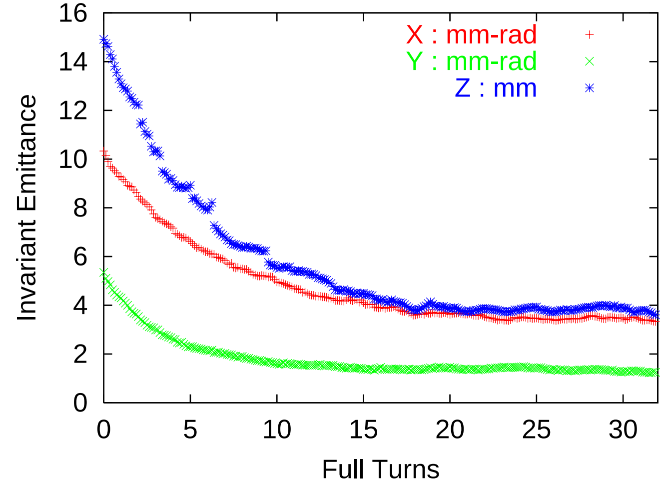
Beam momentum 250 MeV/c

25 cm LH_2 wedges

Wedge angle 20^0

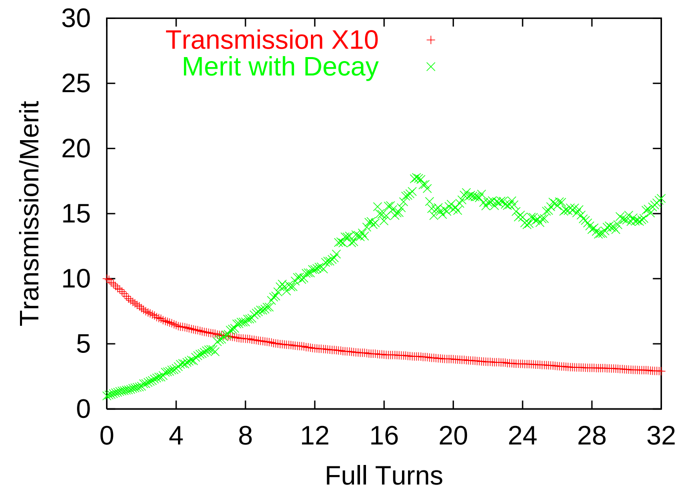
Rf frequency 201.25 MHz

E_{max} = 16 MV/m



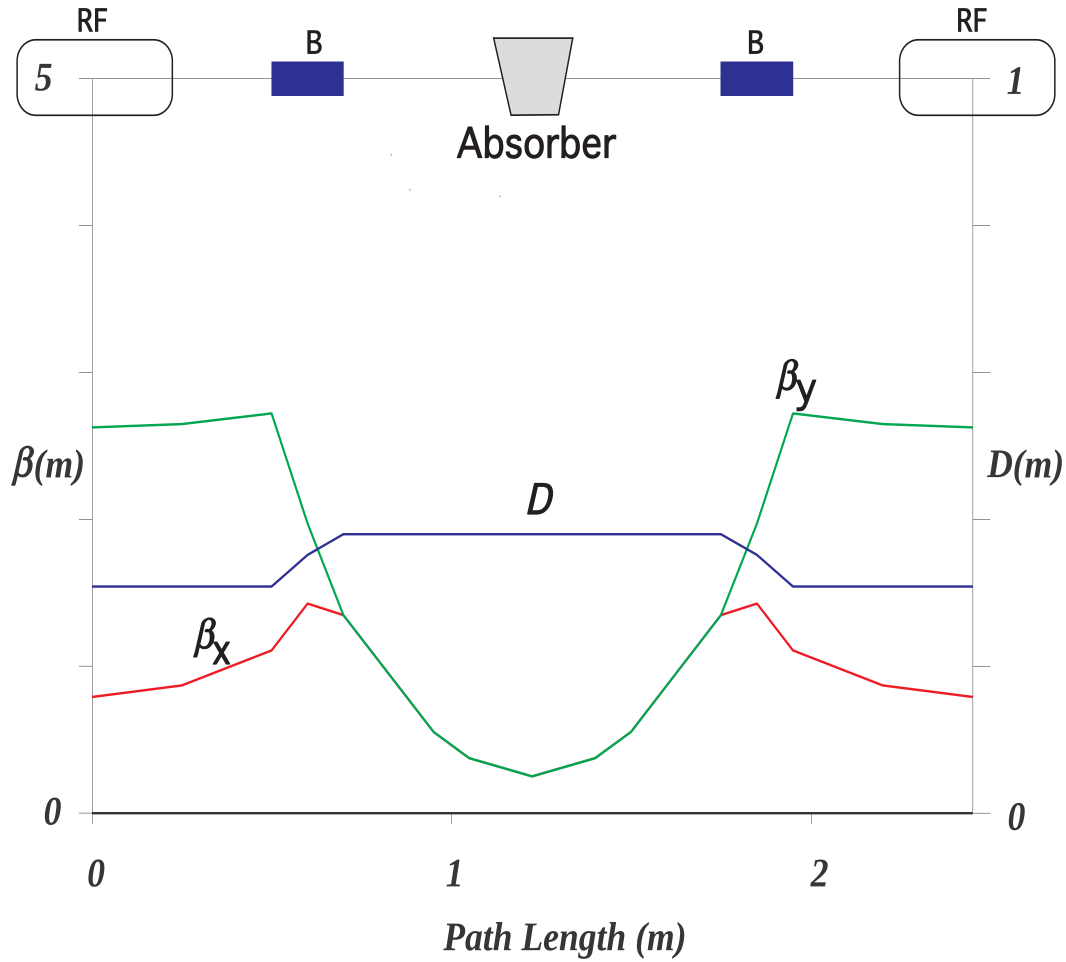
- ε_x, ε_y, and ε_z all decrease
- Transmission 50%

Total Merit = *Transmission* x $(\varepsilon_x \varepsilon_y \varepsilon_z)_{initial} / (\varepsilon_x \varepsilon_y \varepsilon_z)_{final}$

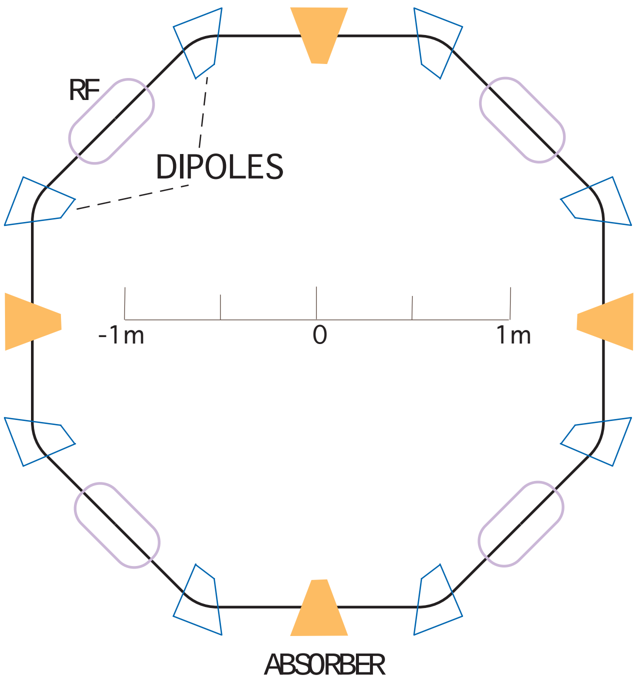


A Dipole-only Lattice

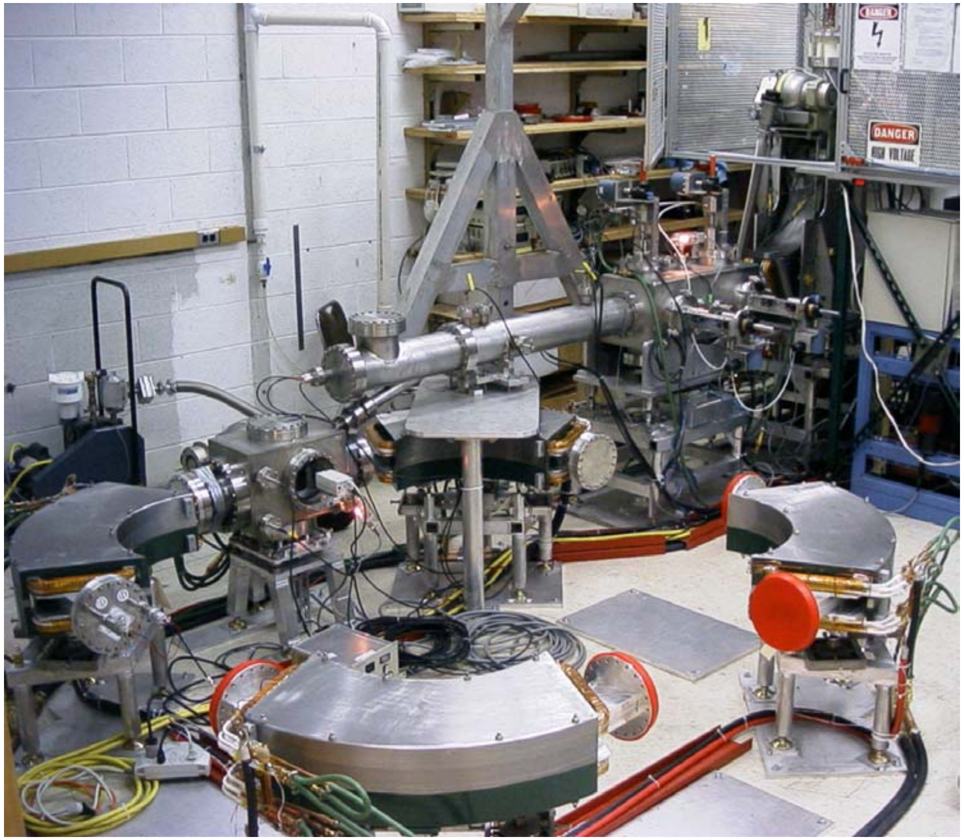
- 1 m drift available for rf
- Low β (25 cm) at absorber
- Edge focusing
  - 22^0 entrance angle
  - -7^0 exit angle
- Dispersion throughout cell
- 45^0 bending dipoles
- Very compact (9.8 m circumference)



Dipole-only Ring Layout



- 9.8 m ring circumference
- 4 cells
- 45^0 bending dipole



NSCL at Michigan State Isochronous Ring
26^0 face angles and 7 cm gaps
2 cells 90^0 bending dipoles

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Dipole-only Lattice Performance

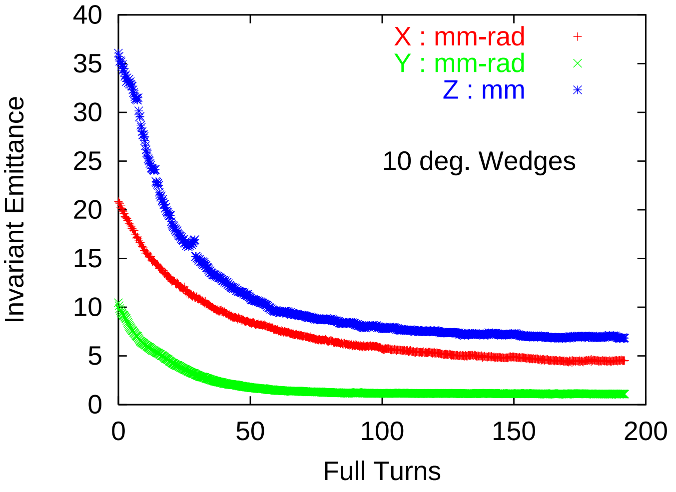
Beam momentum 500 MeV/c

24 cm LH_2 wedges

Wedge angle 10^0

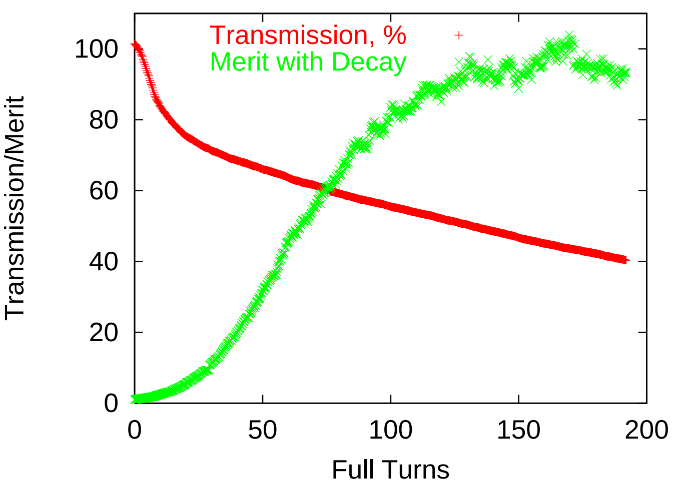
Rf frequency 201.25 MHz

E_{max} = 16 MV/m



- ε_x , ε_y , and ε_z all decrease
- Transmission 50%

Total Merit = *Transmission* x $(\varepsilon_x \varepsilon_y \varepsilon_z)_{initial} / (\varepsilon_x \varepsilon_y \varepsilon_z)_{final}$ = **100**



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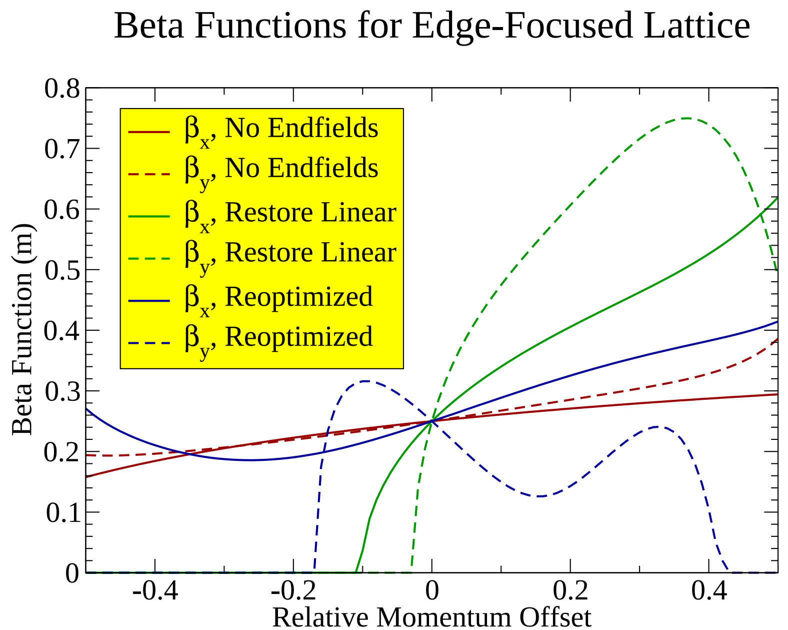
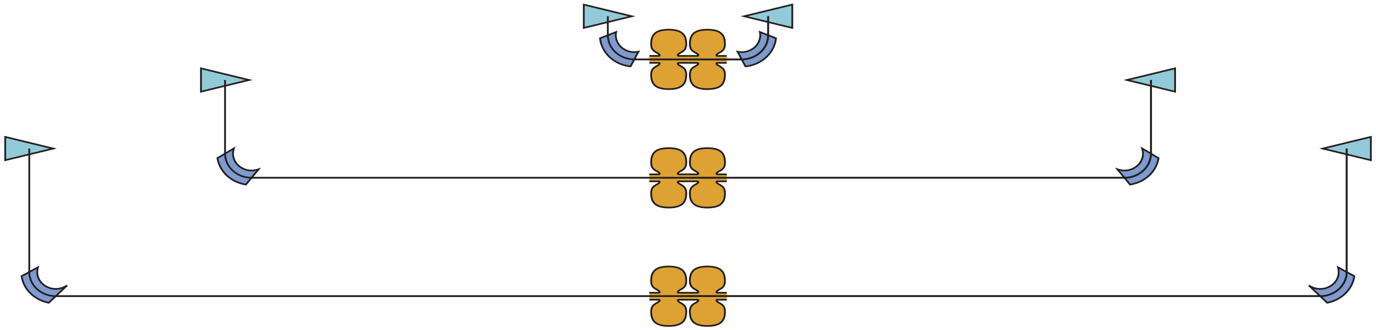
Edge Effects Considerations

Scott Berg – PAC03

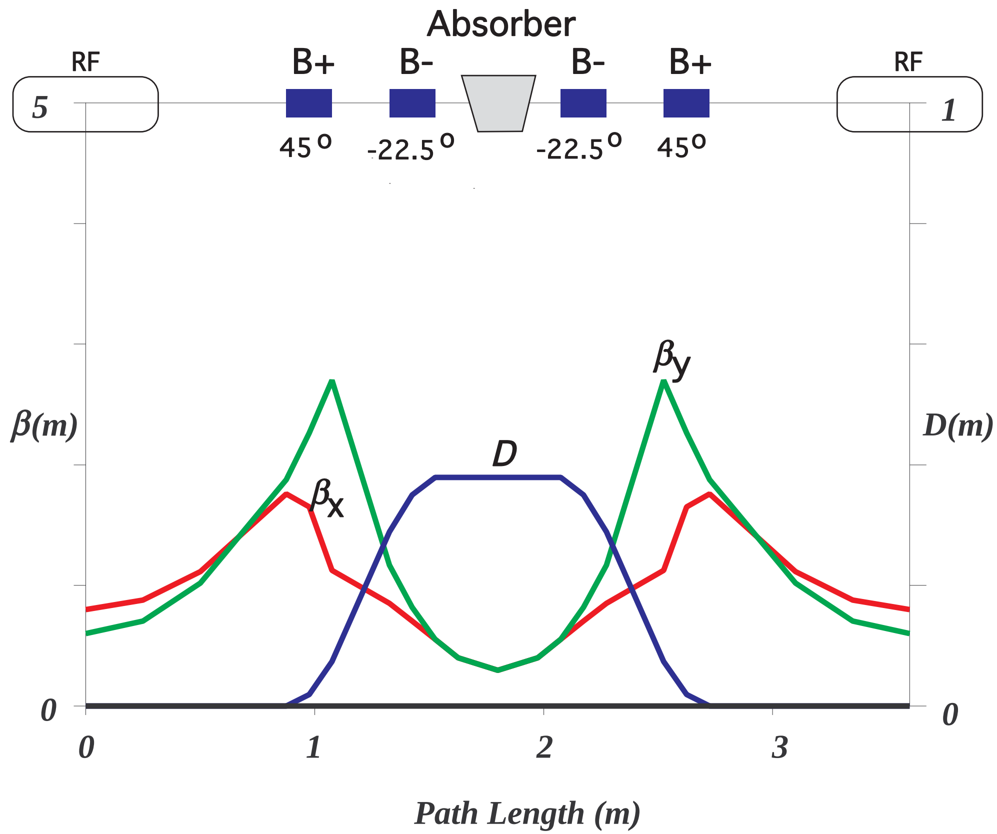
- Uses COSY infinity fringe fields
- End fields greatly affect tunes
- Lattice dimensions must change
- May require reducing apertures and therefore acceptances

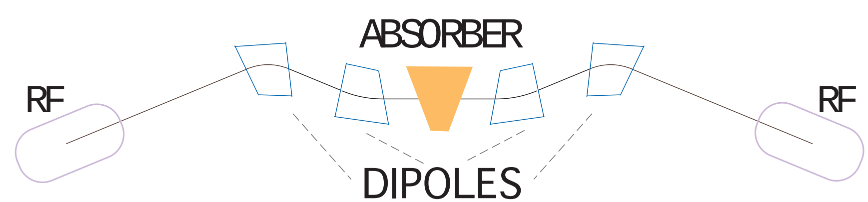




A Reverse-bend Dipole-only Lattice

- Edge focusing
  - 30^0 / -3^0 face angles
  - 11^0 / 11^0 face angles
- No dispersion at cell edges
  - Simplify adding injection/ejection sections
- 45^0 and -22.5^0 bending dipoles
- 28.8 m circumference without straight sections
  - Allow longer bunch trains





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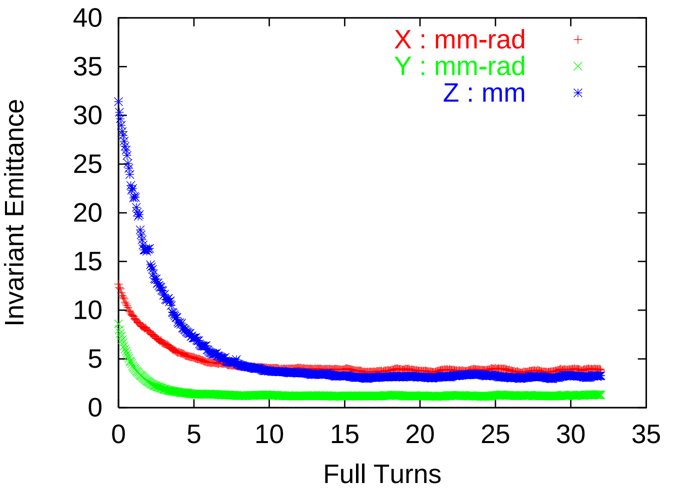
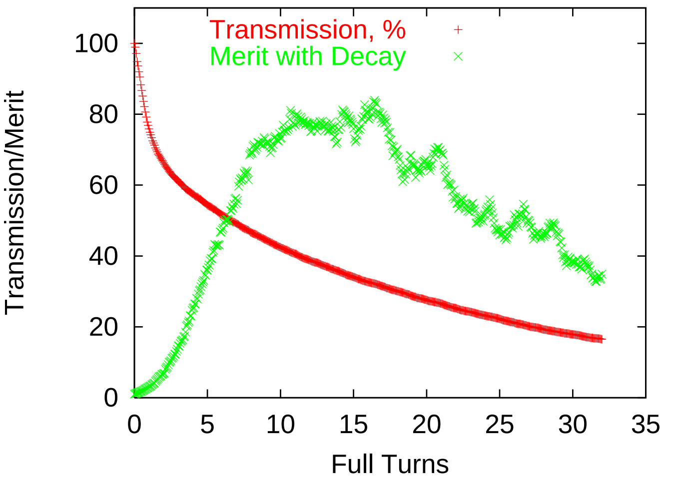
Reverse-bend Lattice Performance

Beam momentum 250 MeV/c
40 cm LH_2 wedges
Wedge angle 18^0
Rf frequency 201.25 MHz
E_{max} = 16 MV/m



After 10 full turns

- Transmission 40%
- Merit = **80**



The Lithium Rod

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Consider again the equilibrium emittance condition:

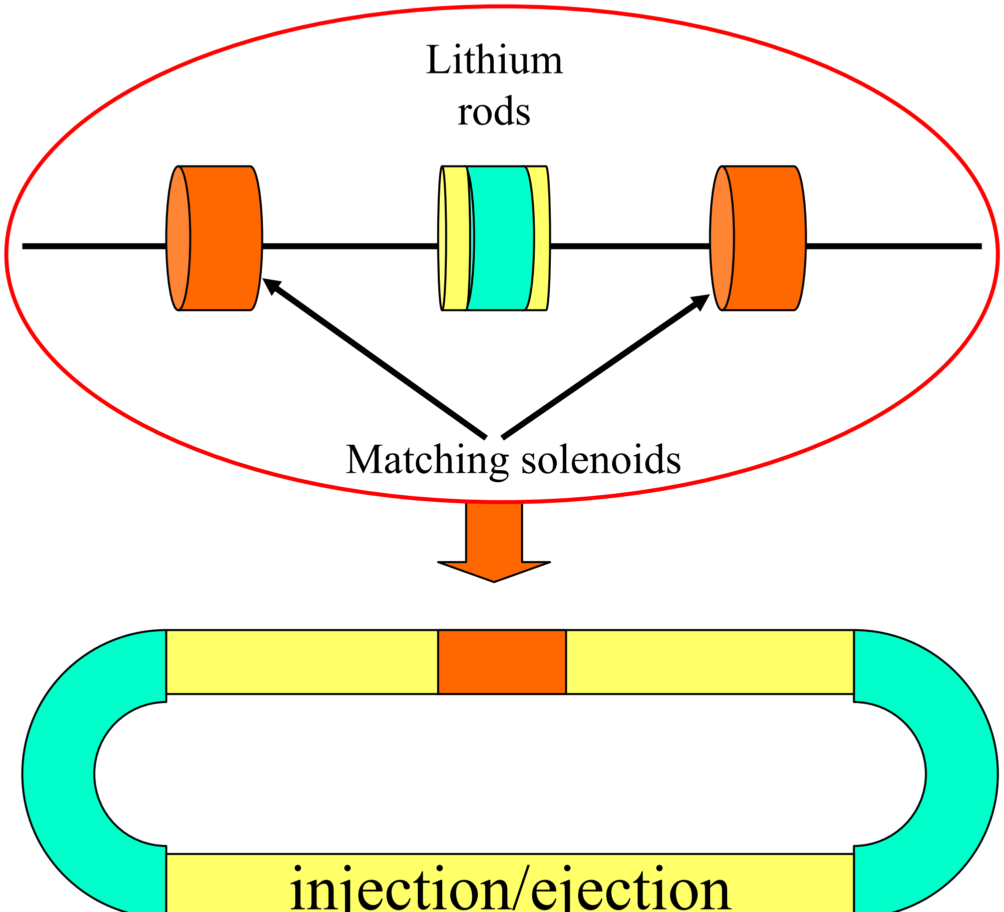
$$\varepsilon_{x,N,equil.} = \frac{\beta_{\perp}(0.014\,\mathrm{GeV})^2}{2\beta m_{\mu} X_0 \left|\frac{dE_{\mu}}{ds}\right|}$$

Focusing Properties

Material Properties ⇒ $\frac{LH_2}{Li} = 1.9$

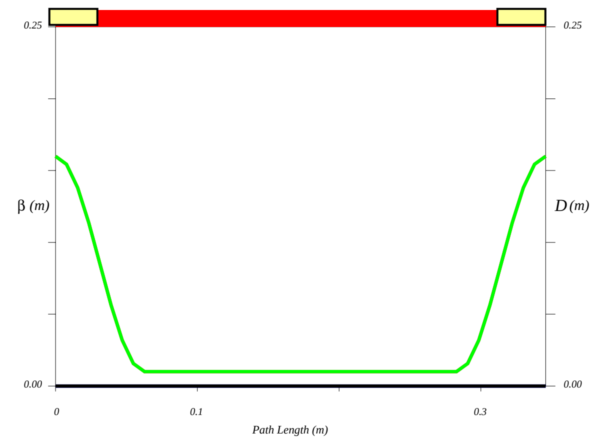
But for Li rods a $\beta_{\perp}$ of <u>1cm</u> can be achieved.

Lithium Rod Ring Concept



The basic idea

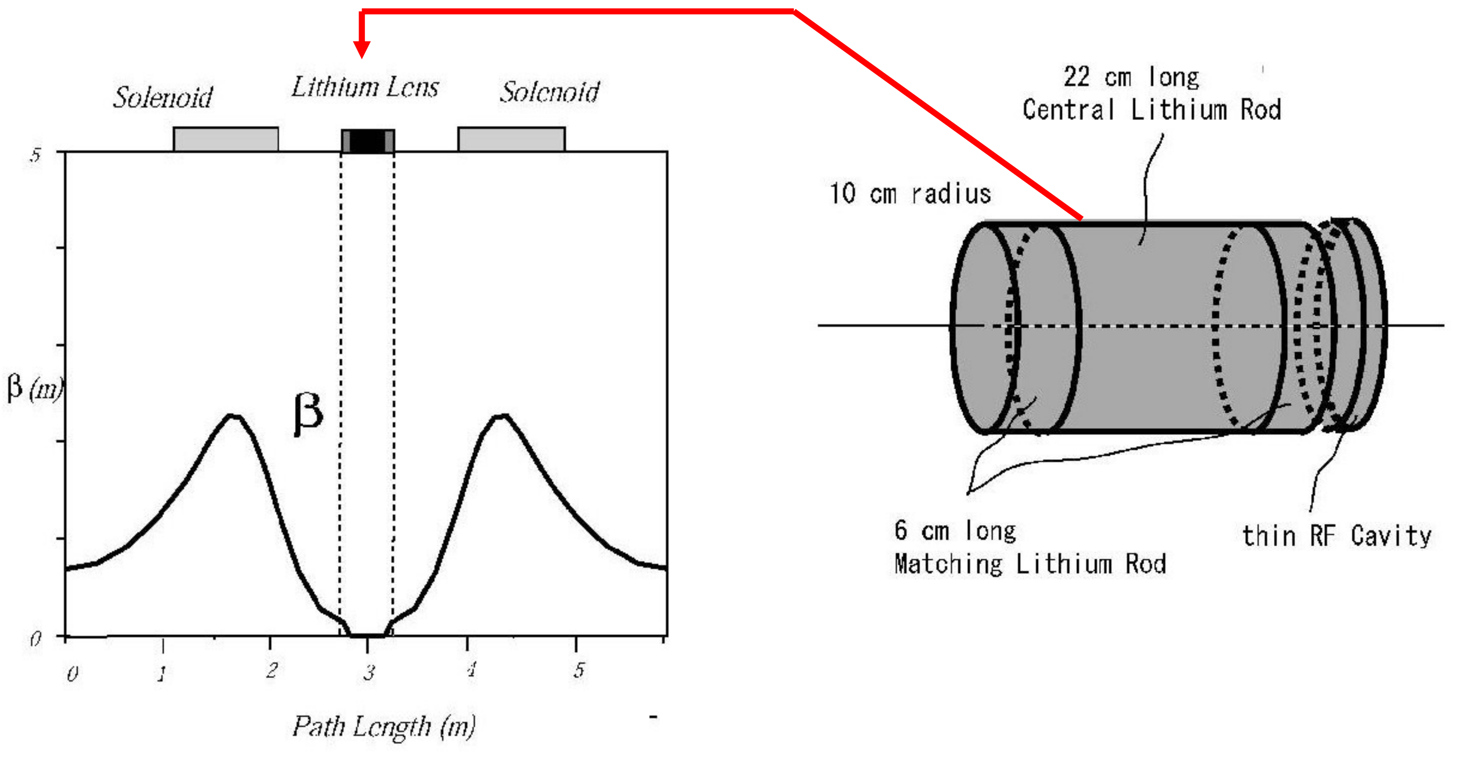
- Use solenoid focusing to achieve $\beta_\perp = 16$ cm
- Use matching Li rods to achieve $\beta_\perp = 1$ cm



- Disperse compensating rf throughout remainder of the ring
- Include injection/ejection straight section

ICOOL Simulations

The simulations to date (Y. Fukui):



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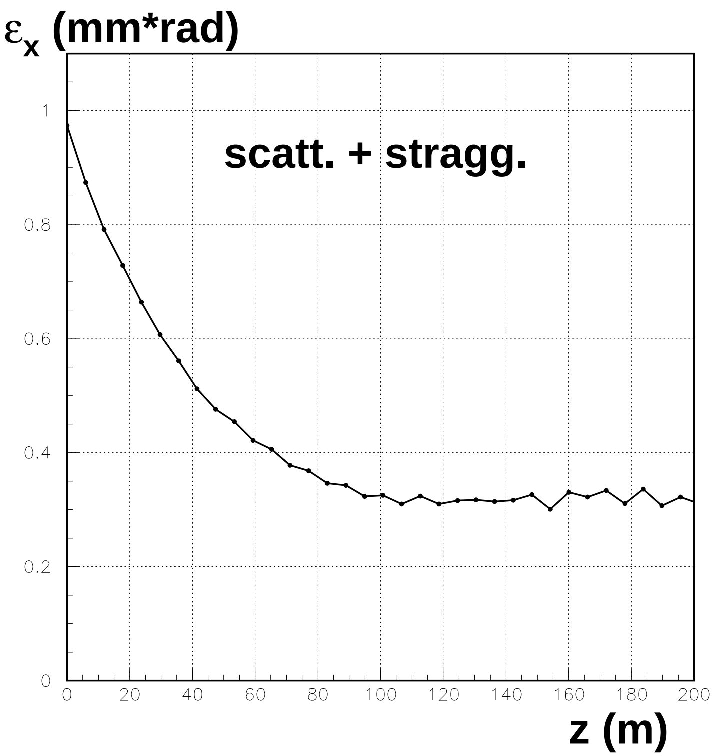
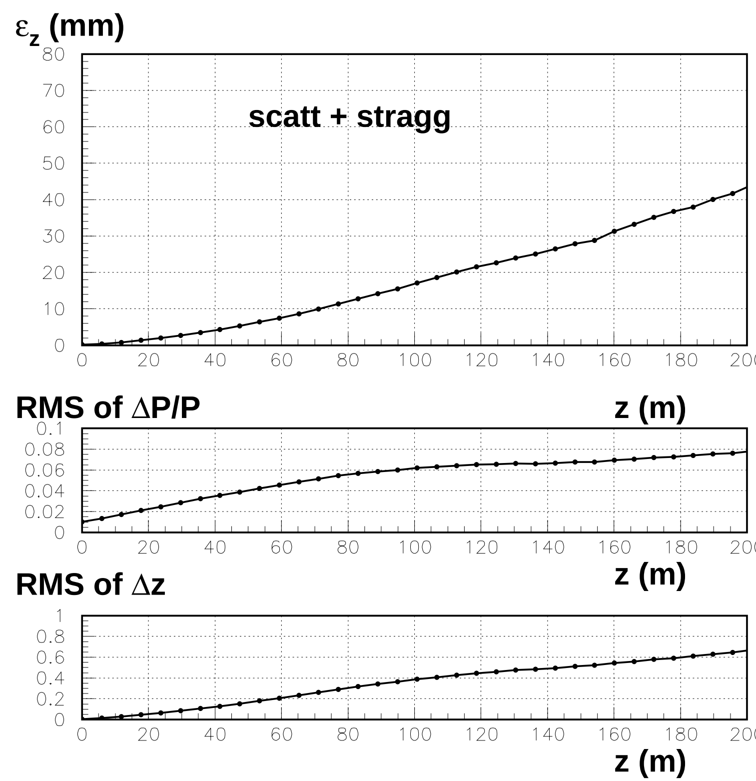
Li Rod Performance

The transverse emittance reduces while the longitudinal emittance grows.





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Summary

- The SYNCH + ICOOL approach works
- Emittance exchange has been demonstrated
- With quadrupole/dipole rings and dipole-only rings, invariant phase-space density (N/ε_6) increases of up to to 100 have been simulated
- The analysis of fringe fields of magnet ends show significant effects and must be considered
- Initial studies with rings which contain Li rods point toward the possibility of further transverse emittance reduction