Low Emittance Lattice Design for e-ring

Dong Wang, Fuhua Wang
MIT-Bates

- Low emittance lattice
- Chromaticity corrections

May 29, 2003, at BNL

Issues in lattice design

Inter. region: many open questions associated to ion-ring and detector conditions. *Fuhua&Vadim' talks*

Low emittance: lattice flexibilities
new studies on lattice and DA

Rotator&SM: rotators are there (for 5-10Gev).
should add (Bates) snake for ~2GeV.
SOM(Spin-Orbit Matching) installed

Injection&cost: Under discussion

General features of e-ring lattice

- Circumference: ~1/3 of RHIC(~1278m)
- Interaction region: Beta*, 0.08/0.12m
- Spin rotators: Asymmetric, 7.5 GeV(5~10GeV), snake for 2GeV
- ARC: 64 dipoles, 28 cells + dispersion suppressors

Dip. bending radius: 68 m (~13kw/m)

Low emittance lattice

In electron ring, emittance is determined by

$$\varepsilon = C_q \frac{\gamma^2}{\rho J_x} \frac{1}{2\pi\rho} \int_{dipoles} H\, ds = C_q \gamma^2 \frac{I_5}{I_2 - I_4}$$

where $H = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$,

For a certain cell structure,

$$\varepsilon = F(\nu_x, \text{lattice}) \frac{E^2[\text{GeV}]}{J_x N_d^3} \quad m-rad,$$

Generally, a large circumference is needed to obtain very low emittance. But cost……
So we have to play with low emittance structures.

Lattice Type	F_{min}	N_d/cell	Example
FODO*	7.28×10^{-4}	2	SPEAR
DBA (Chasman-Green)	2.36×10^{-5}	2	NSLS VUV
Isomag. Matched TBA**	1.56×10^{-5}	3	BESSY II
Theor. Minimum Emit.*	7.84×10^{-6}	1	

J. Murphy,
Sync. Light Source
Data Book

Low emittance collider vs. light source

Common problems:

difficulty for low-emit lattice: Dynamic Aperture.

(strong focusing, high chromaticity, strong sextupoles, etc)

Differences:

Collider: Interaction Region(huge chromaticities).
Multi-operation modes(eRHIC, TCF).

Light Source: Need dispersion-free(or like) sections.
Good periodicity.

Low emittance collider lattice may be more complicated.

Different lattice structures

Optimal e-ring emittance
(rms, at 10 GeV)

e-p:
40~90 nm rad

e-Au:
18~36 nm rad

Most difficult mode: low emit.

FODO: reliable
large emit.

DBA: low emit
few location for
chrom. corrections

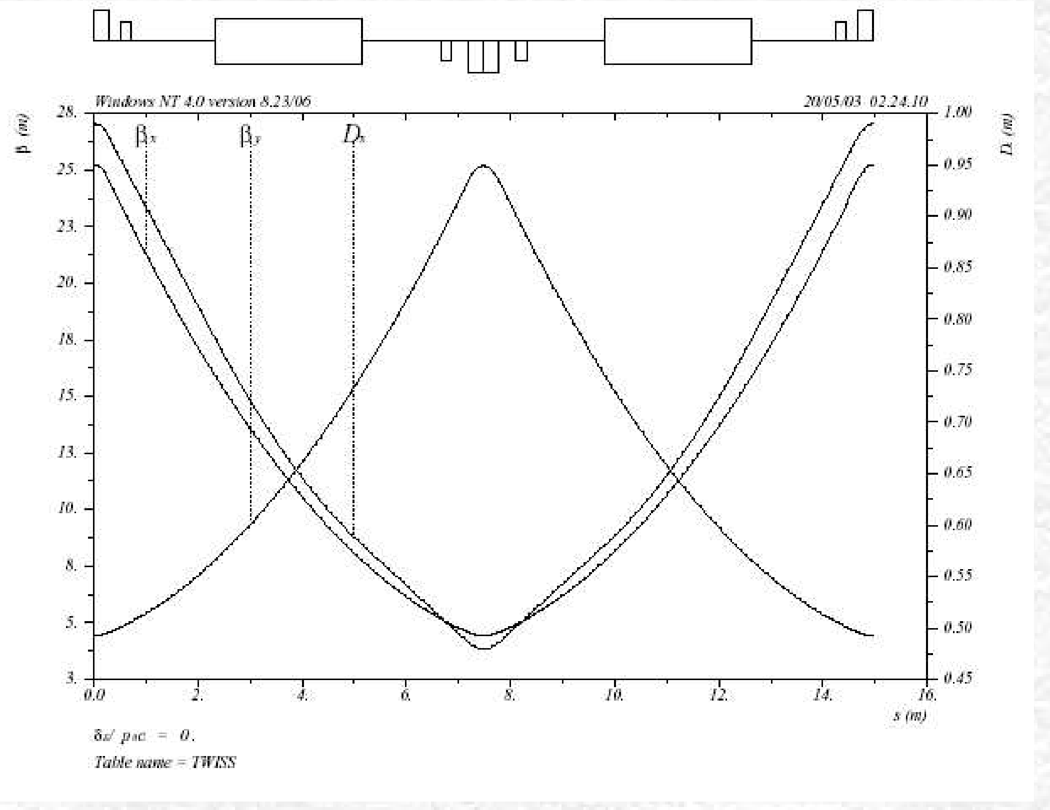
Others: Hybrid type

low emit. + reasonable DA

Cell structure (1)

FODO

- e.g., 90-degree cell
- Emit: ~100 nm rad
- weak sextupoles
- hard to get low emit

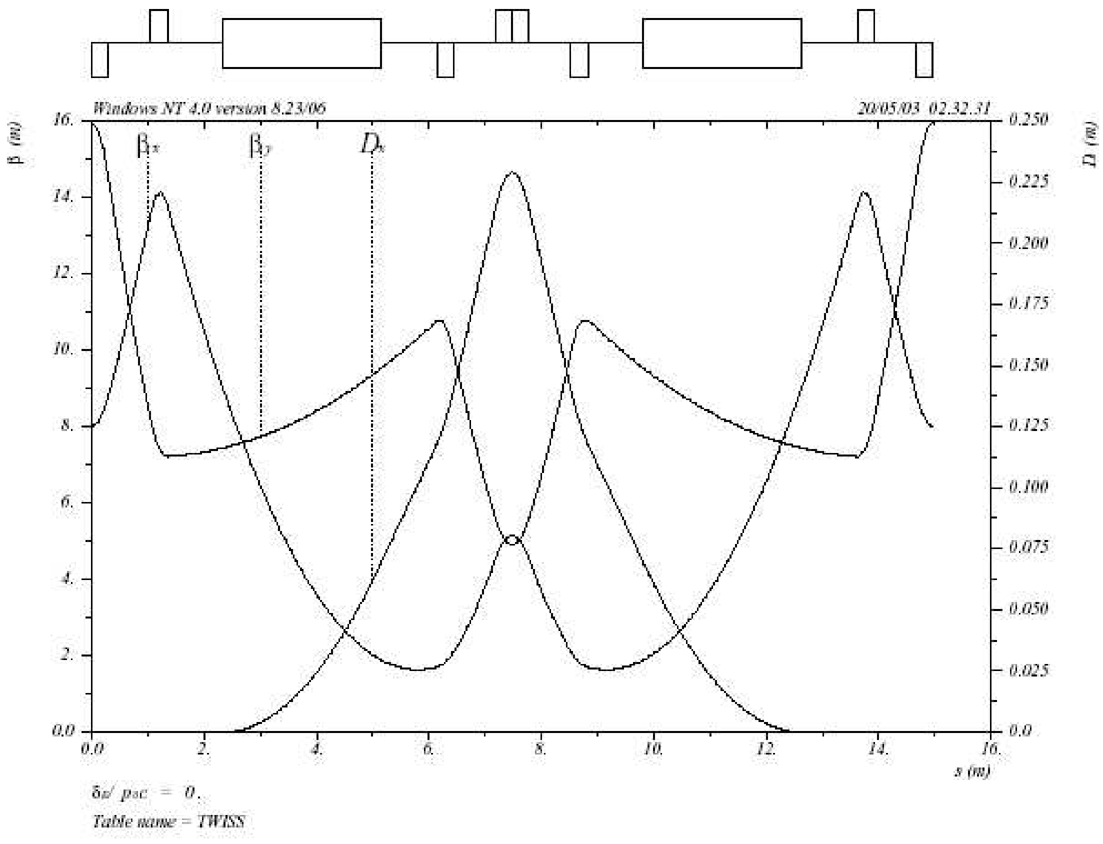


Cell structure (2)

DBA
(Double Bend Achromat)

• low emittance
  ~ 10 nm rad

• hard to find places
  for sextupoles.
  no DA.



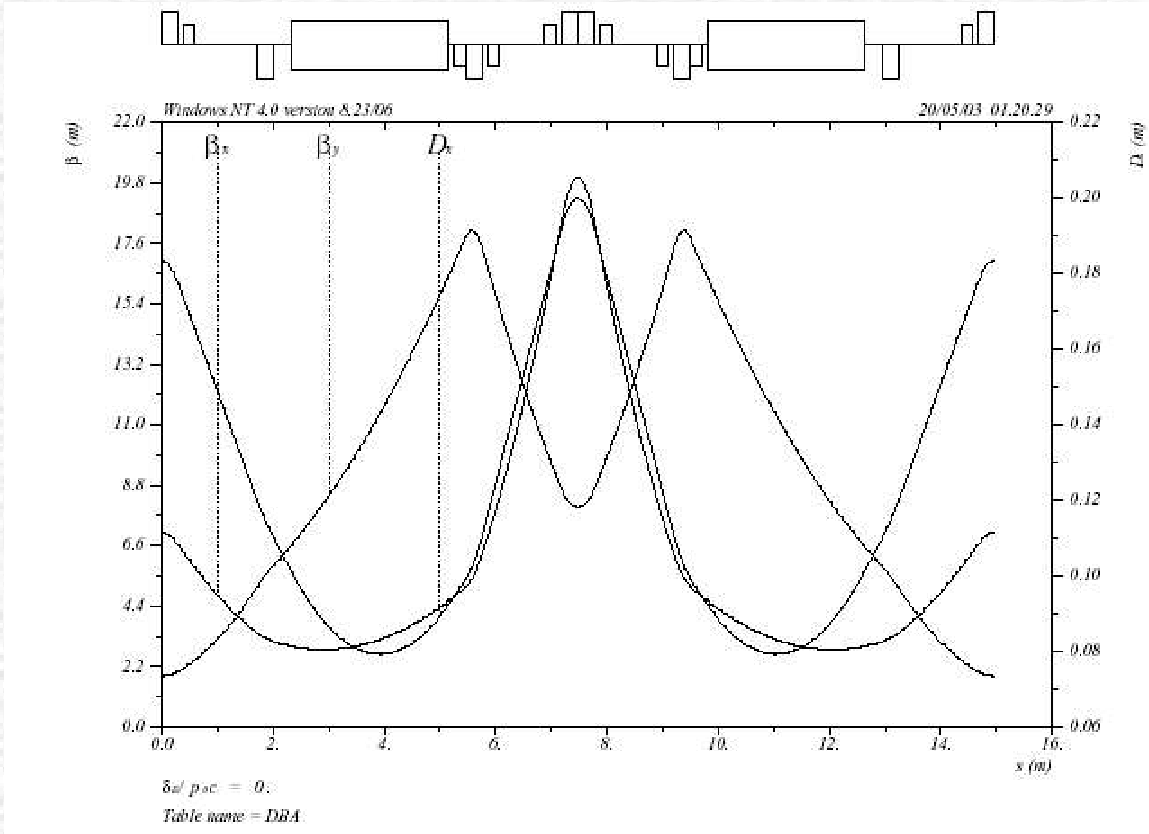
Cell structure (3)

In fact: dispersion-free is unnecessary inside arc of collider

Hybrid type(1)
'WM'

Optimized for both Emittance and DA

- 17 nm rad at 10 GeV
- More locations for Sextupole(4 families)
- DA: promising (preliminary results)



Preliminary tracking results with new lattice

Natural Chromaticity:

-105/-64

Sextupole strength:

SF1: 14.3 1/m^3
SD1: -26.5 1/m^3
SF2: 26.4 1/m^3
SD2: -22.4 1/m^3

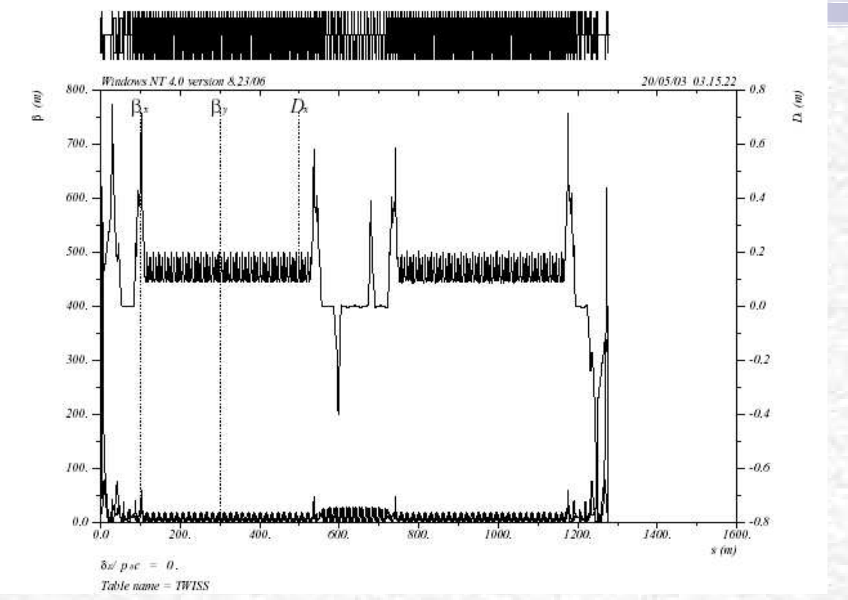
Tracking with MAD

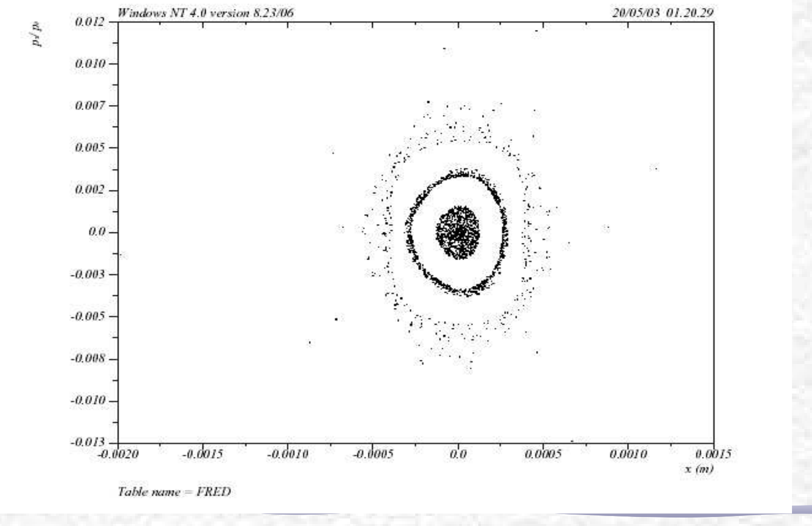
on mometum,

bare lattice.

~10 sigma aperture

need more.



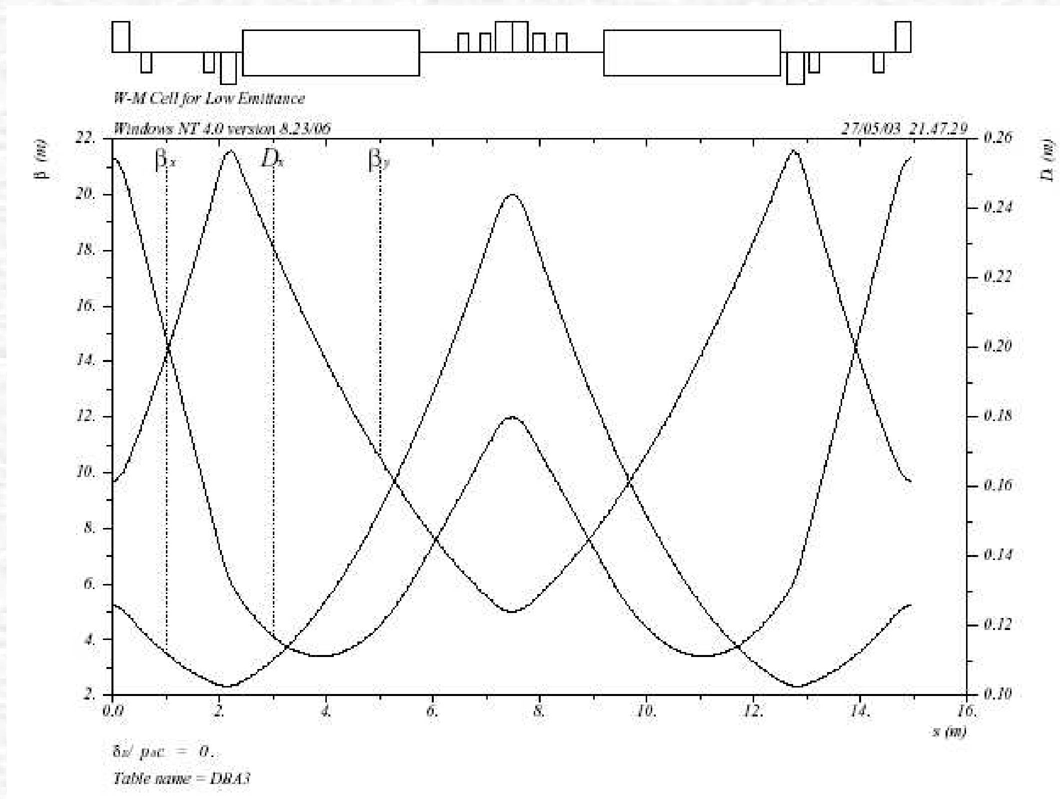


Cell structure (4)

Hybrid type(2)

- 17 nm rad at 10 GeV
- Reduced chromaticity (-87/-57)
- Reduced sextupole strengths (half)
- DA: so far similar to hybrid type(1) (preliminary results)

Simplified 'WM' cell



Lower emittance

Hard
Other dipoles' contributions become significant.

Larger emittance

Easy
Relax optics, lattice functions similar in shapes but larger eta.

	Area	#	An.(mrad)	L(m)	Type
B1	IR	2	22.6	0.66	
B2	IR	2	23.6	1.5	
B3	Rotator	4	23.1	4.74	
B	Arc	16	49.1	3.3	D.S.
B	Arc	112	49.1	3.3	cell
B4	Utility	4	44.3	2.5	D.S.

Work underway

Improve dynamic aperture

(HERA: ~20 sigma for FODO-72, but poor for FODO-90, change freq. to reach 20 nm rad. G. Hoffstaetter)

- optimize linear optics, tune scans
- more sextupole families, momentum acceptance.
- local corrections, harmonic corrections
- optimize IR, (big impact on optics issues.)

Other problems

- Tight circumference. (what's the limit)
  current lattice: 1277m, 1/3 of RHIC.
  unnecessary? (Can't match bunches)
  short magnets: dipole: rho=57m
  quads: ~ 40 T/m
- Layout: reversed field dipoles
  effect on polarization is to be checked
  with spin-matching.
- Add a Bates snake for low energy

Polarization at 2 GeV for e-ring of eRHIC

In case physicists are interested in experiments at this energy:

We can offer polarized e- beam at tiny cost.

To realize it,

1, Pre-polarized beam

Polarized gun + linac = 2 GeV e- with ~ 80% polarization

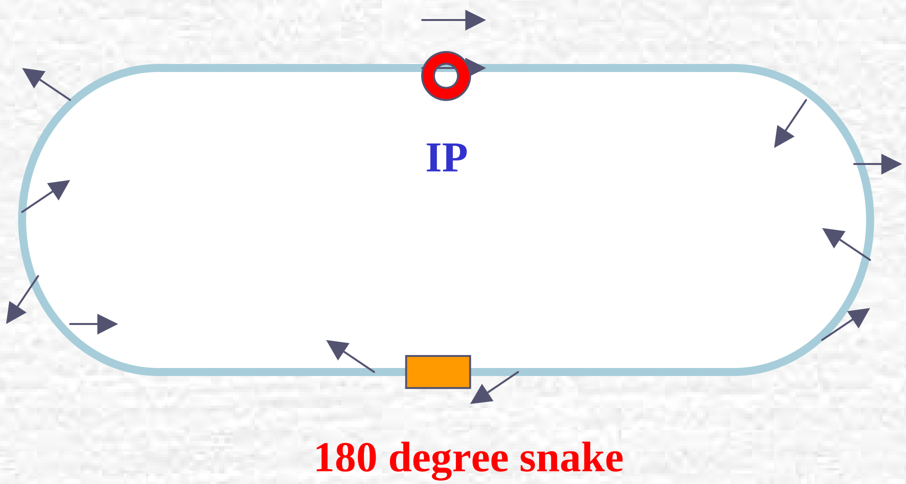
gun: like Bates'. linac: existing

2, 180 degree snake + sufficiently long depolarization time

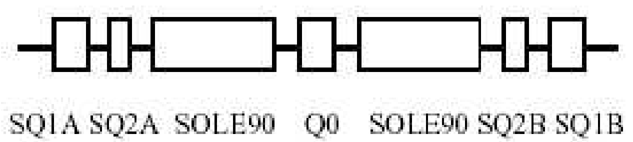
snake: routine operation at Amps, Bates.

depolarization effect: OK at 2 GeV in eRHIC

How Siberian scheme works for e-ring of eRHIC



A typical design for such a snake



	S90	SQ1	SQ2	Q0
Length(m)	1.5	0.2	0.4	0.4
B and K	7Tmax	±2.599	±1.9875	0.8916

Total length
of all elements,
<7.0 m,
for use at 2 GeV

Depolarization time with Siberian snake scheme

In general $$P(t) = P_0 e^{-t/\tau_p} + P(1 - e^{-t/\tau_p})$$

$$\tau_p = \frac{\tau_0}{c_+} \qquad c_+ = \frac{1}{I_3} \oint \frac{ds}{|\rho(s)|^3} \left[1 - \frac{2}{9} (\vec{n} \cdot \vec{e}_v)^2 + \frac{11}{18} \left| \gamma \frac{\partial \vec{n}}{\partial \gamma} \right|^2 \right]$$

In case of Siberian snake scheme:

Spin vector is perpendicular to B field: i.e., ***extremely tilted***.

Analytical approach is fine here. (agree with simulation)

Since, $$\left| \gamma \frac{\partial \vec{n}}{\partial \gamma} \right|^2 = (\gamma a \theta(s))^2$$ we have, $$c_+ \approx \frac{8}{9} + \frac{11}{18} \frac{(\pi \gamma a)^2}{3}$$

Depolarization time with Siberian snake scheme

For e-ring of eRHIC: C ~ 1300 m, Bending radius = 68 m

Depolarization time with snake at low energy

Energy (GeV)	1.0	2.0	3.0
τ_pol (hours)	26333	823	108
C+	11	42	94
τ_depol (hours)	2393	19.6	1.2

De-polarization time is much longer than luminosity life time (~ 5hours)

With ~80% polarization for injected e- beam,

high average polarization (>60%) can be achieved at 2GeV
(at little extra cost)