Summary of the UCLA Ring Cooler Workshop at Tucson, on Dec 3/4, 2001

Yasuo Fukui
UCLA, e-mail: fukui@slac.stanford.edu

- Overview
- Agenda
- Highlights
- Thisgs-to-do list
- Conclusion

Muon Collaboration

UCLA

Ring Cooler Workshop

Tucson, AZ
December 3-4, 2001

Organizers:
Yasuo Fukui and Sylvia Vartan

Overview

The idea of the UCLA Ring Cooler, a storage ring with conventional (non-solenoid) magnetic elements with wedge absorbers, was created by Dave Cline in Feb. 2001 in a meeting with Al Garren and Yasuo Fukui at Berkeley.

Originally, the cooling device was Lithium lens (which will be revisited) in one of the larger storage ring which can contain the long muon mini-bunch train of the neutrino factory. Transversely super-cooled muon mini-bunch will then be picked-up and transversely stacked in a smaller storage ring which exercise the longitudinal to transverse emittance exchange there. The final single muon bunch in the smaller ring will be accelerated and then be injected into a Higgs muon collider.

More sophisticated tracking simulation has been performed by using ICOOL with the initial design parameters by SYNCH by a team of collaborators, Harold Kirk, Yasuo Fukui, where we can now see the emittance exchange and positive 6 dimensional phase space cooling, we have more understanding of the mechanism of the particle loss.

Other linear simulation code, OPTIM and MAD which are similar to the SYNCH, were used by Alex Bogacz and Ping He. We now have alternative lattice designs, different number of lattices in a ring, and the effectiveness of sextupoles in containing muon beams in a ring was demonstrated.

We also discussed using Lithium lens in the UCLA Ring Cooler or in a FFAG, for much smaller equilibrium normalized emittances. Matching the beam into/from Lithium lens can be an issue.

Workshop Agenda

Dec. 3rd(Mon)

Dave Cline	9:00 - 9:20	Ring Cooler Study and the Muon Collider Future
Al Garren	9:30 - 9:50	Studies of Quadrupole Focused Muon Cooling Rings
Ping He	10:00 - 10:20	Lattice Study with MAD
Harold Kirk	10:30 - 10:50	Quad Ring Cooler Progress
Alex Bogacz	11:00 - 11:20	Alternative Lattice Design
Discussion	14:00 - 16:00	

Dec. 4th(Tue)

Yasuo Fukui	9:00 - 9:20	Tracking Study of the UCLA Ring Cooler
Alex Bogacz	9:30 - 9:50	Large aperture beam dynamics of the UCLA Ring Cooler
Debbie Errede	10:00 - 10:20	FODO-based Quadrupole Cooling Channel
(Debbie was absent, but contributed talk material.)		
Fred Mills	10:30 - 10:50	Magnets Design
Discussion	11:00 - 12:00	

Participants list

Alex	Bogacz	bogacz@jlab.org
Dave	Cline	dcline@physics.ucla.edu
Deborah	Errede	derrede@uiuc.edu (absent)
Yasuo	Fukui	fukui@slac.stanford.edu (scientific secretary)
Al	Garren	aagarren@lbl.gov
Ping	He	phe@sun2.bnl.gov
Harold	Kirk	hkirk@bnl.gov
Fred	Mills	FredMills@aol.com
Sylvia	Vartan	Sylvia@physics.ucla.edu (secretary)

Tusa
Dec 2, 2001

Ring Cooler Study and the Muon Collider Future

D. Cline / UCLA

1. Higgs Factory Physics

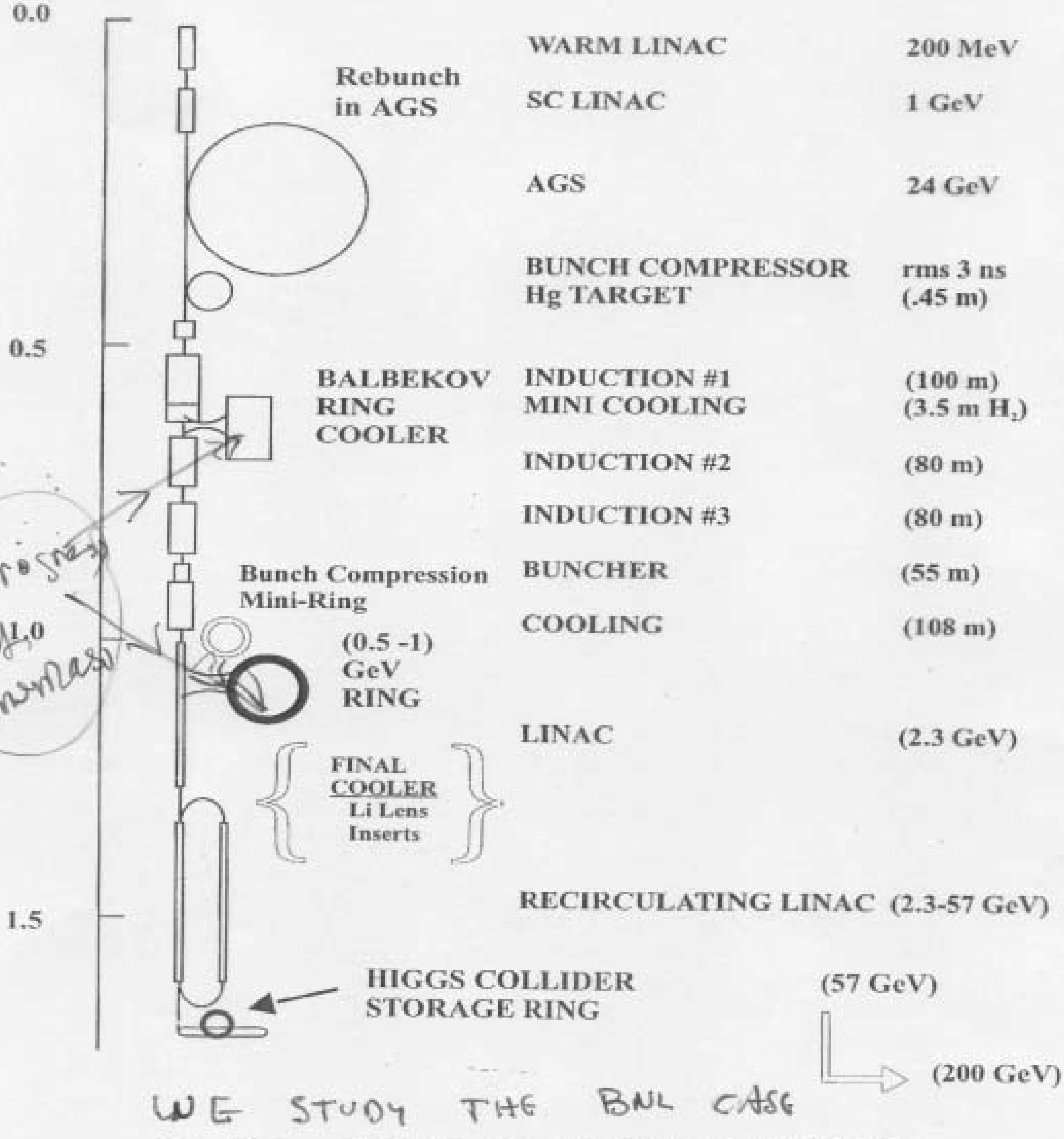
2. Conversion of a Neutrino Factory to a Higgs Factory

3. The Ring Cooler as a FINAL Cooler

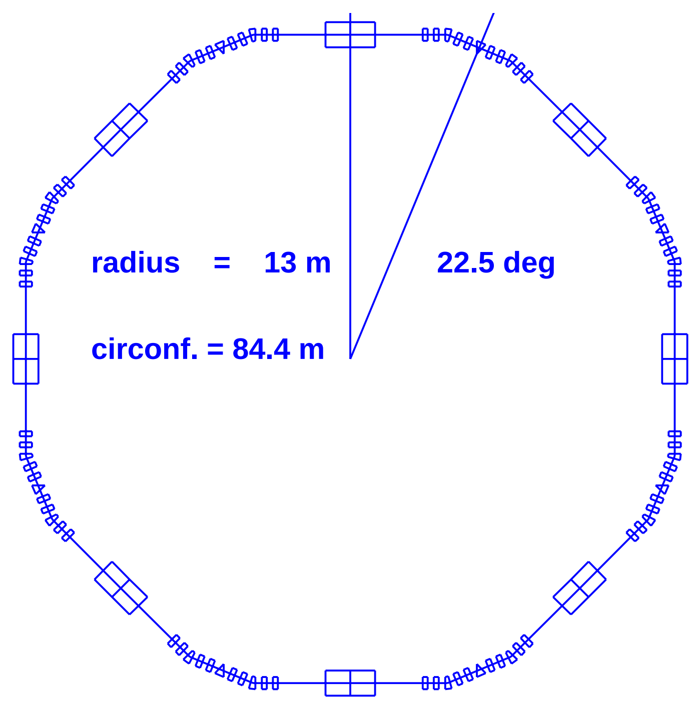
4. Meeting at UCLA in March to see how the Ring Cooler could ~~help~~ help bring down cost of ν Fact UCC

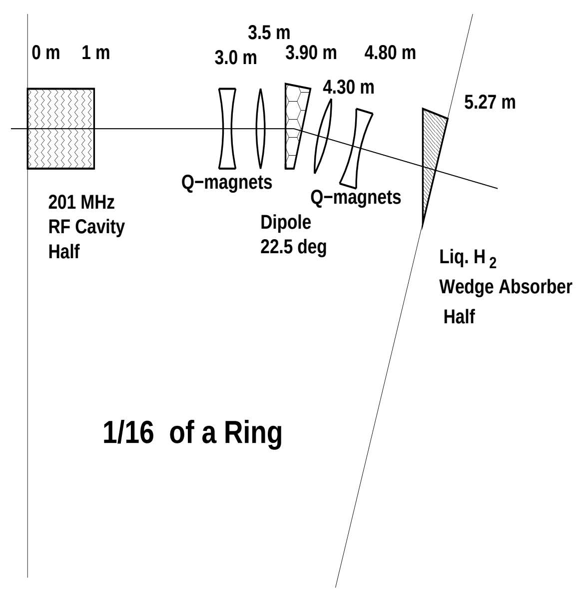
Issues: The USA is in recession - there will be deficits > 2005 - there is NO MONEY FOR A LINEAR COLLIDER IN THE WORLD (LHC problem as well) - By we can keep working on the Higgs Factory and bring the COST DOWN - !! it could still be approved!!

CONVERSION OF A NEUTRINO FACTORY TO A HIGGS FACTORY



WE STUDY THE BNL CASE
SINCE STUDY II IS MOST ADVANCED
STUDY OF A NEUTRINO FACTORY


radius = 13 m
22.5 deg
circonf. = 84.4 m


0 m
1 m
3.0 m
3.5 m
3.90 m
4.30 m
4.80 m
5.27 m
Q−magnets
Q−magnets
201 MHz
RF Cavity
Half
Dipole
22.5 deg
Liq. H 2
Wedge Absorber
Half

1/16 of a Ring

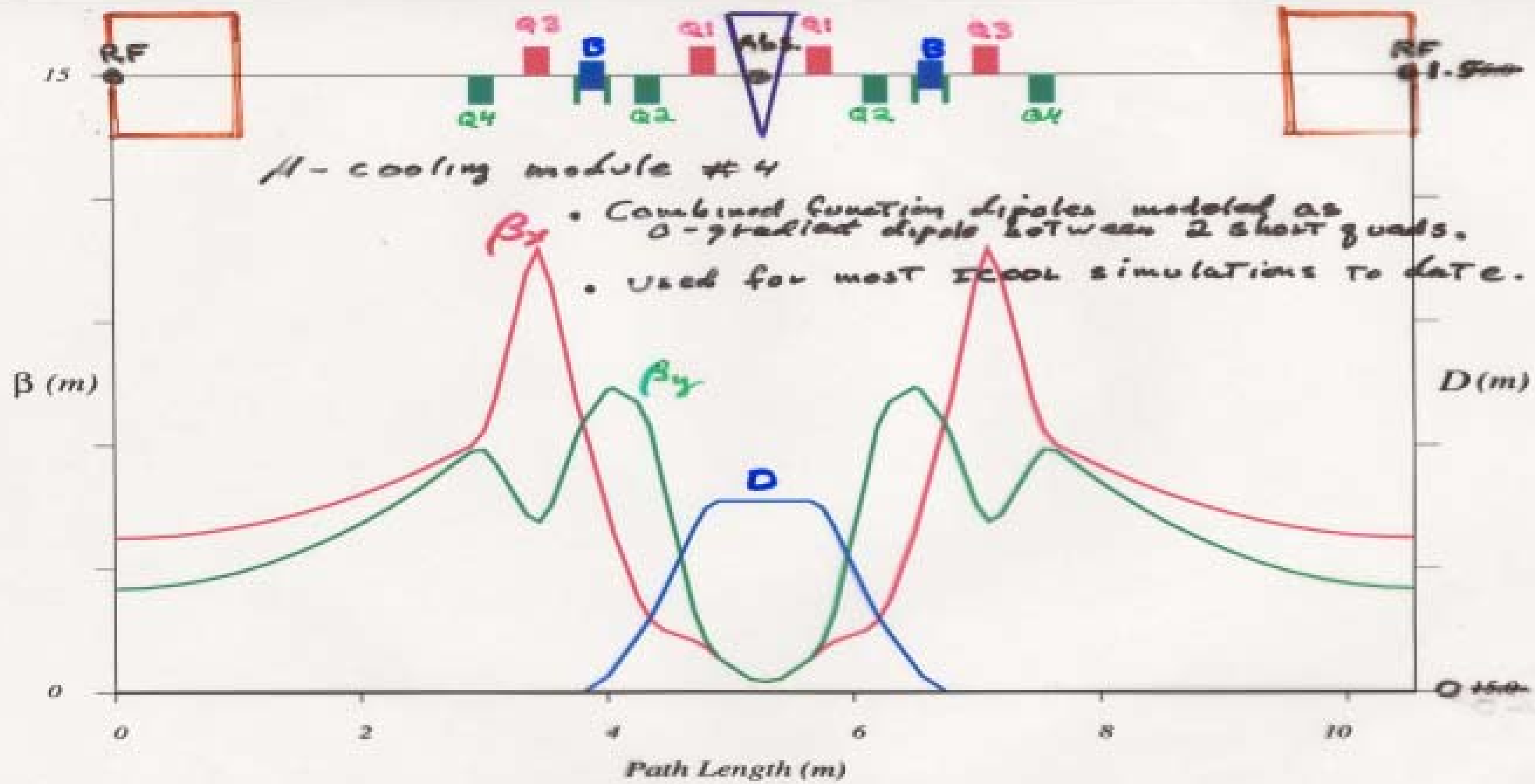
A muon storage ring configured for ionization cooling is an attractive option due to the possibility of 6-D cooling and economy from multiple passes through absorbers and RF acceleration cavities.

The transverse cooling mechanism is the ionization slowing of particles in absorbers coupled with RF acceleration.
The longitudinal cooling mechanism involves use of wedge-shaped absorbers in dispersed regions of the lattice.

Muon cooling is counteracted by heating due to multiple coulomb scattering and energy straggling in the absorbers. The straggling unfortunately causes emittance growth in absorbers in dispersed regions.

The effect of scattering is minimized by placing the absorbers at low-beta points of the lattice. But these low beta points tend to reduce the dynamic aperture of the lattice, which leads to particle losses.

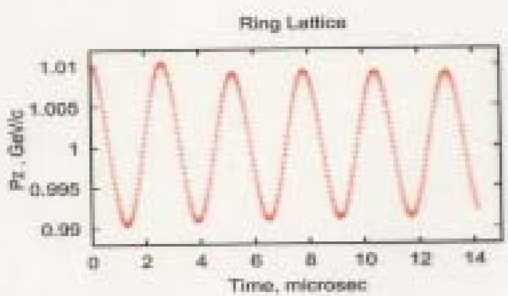
These often-contradictory requirements make for a considerable design challenge.



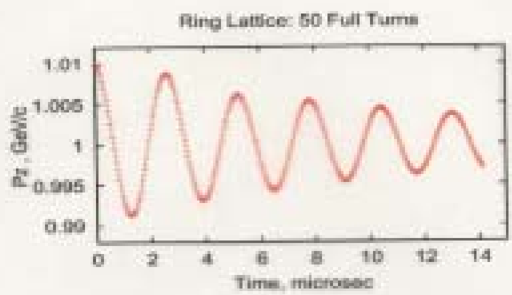
RF
Q3
B
Q1
Abs.
Q1
B
Q3
RF
Q4
Q2
Q2
Q4
μ- cooling module #4
• Combined function dipoles modeled as 0-gradient dipole between 2 short quads.
• Used for most ICOOL simulations to date.
β_x
β_y
D
15
0
β (m)
D (m)
0
2
4
6
8
10
Path Length (m)

1 GeV/c Cooling Ring: Fifty Full Turns

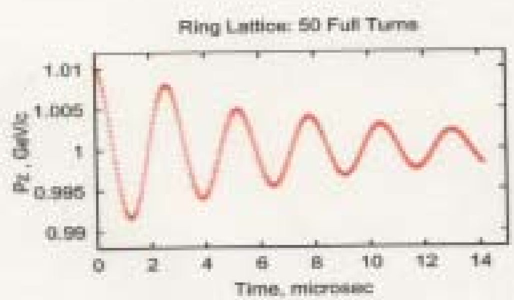
0° Absorber



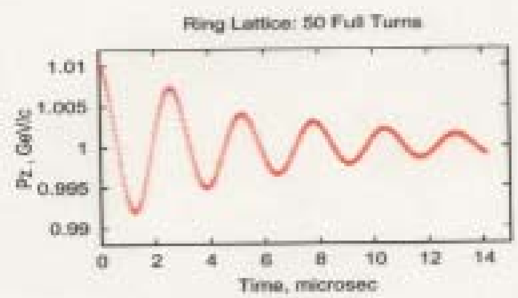
10° Wedge



15° Wedge

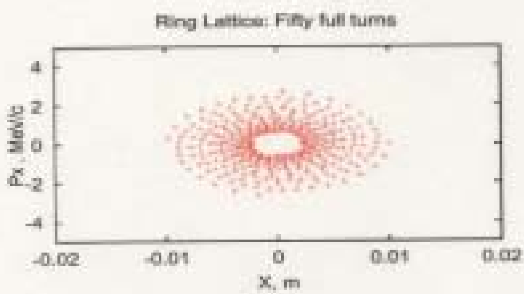


20° Wedge

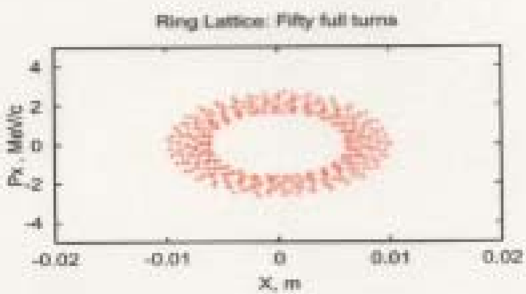


1 GeV/c Cooling Ring: Fifty Full Turns

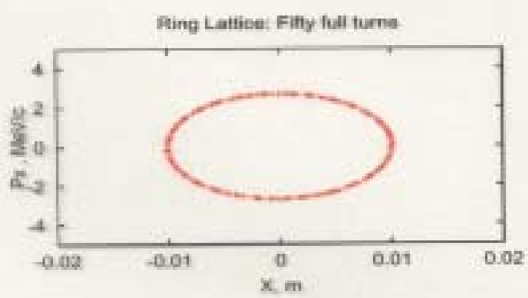
0° Absorber



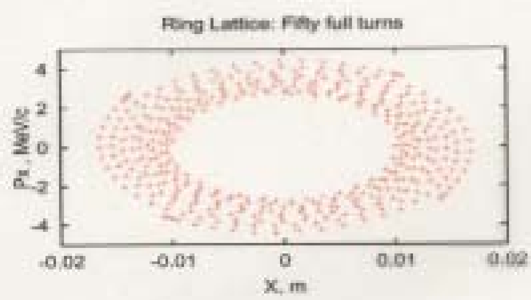
10° Wedge



15° Wedge



20° Wedge

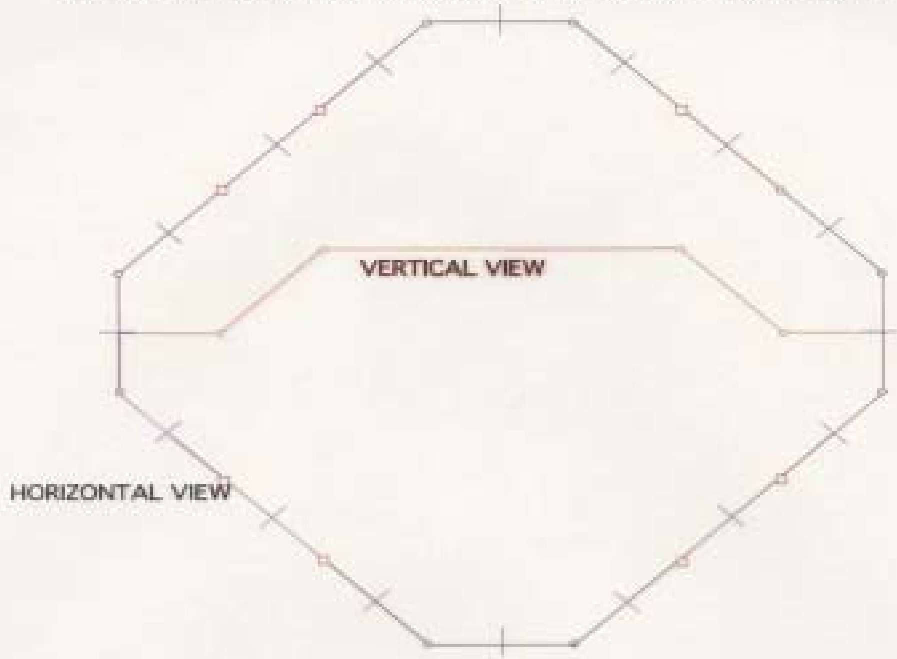


	e **Dumping Ring**		
phase space	x	y	z
Dumping	x' synch.rad. + RF	y' synch. rad. + RF	synchrotron radiation $\Delta E \propto E^4$
Excitation	x-x'orbit change with Dispersion		quantum fluctuation $\propto E^{3.5}$
Partition #	$(1 - \mathcal{D})$	1	$2 + \mathcal{D}$

	μ **Cooling Ring with Wedge Absobers**		
phase space	x	y	z
Dumping	x' Ionization Cooling	y' Ionization Cooling	$\Delta E \propto$ E in Wedge
Excitation	x-x'orbit change with Dispersion mult.scat.	mult.scat.	$\frac{dE}{dx}$ struggling $\propto E^2$
Partition #	2-d	2	d

Table 1: Comparison of the electron dumping ring and the Muon Cooling ring

MUON COOLING RING WITH 8 HORIZONTAL AND 8 VERTICAL BEND CELLS

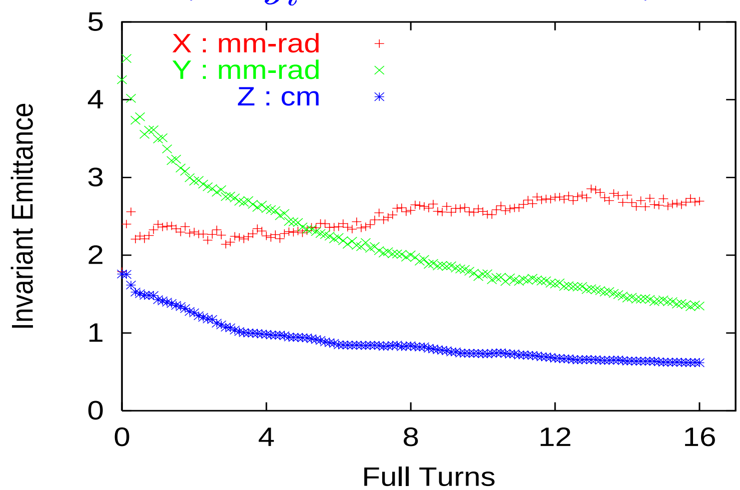


500 MeV/c Cooling Ring

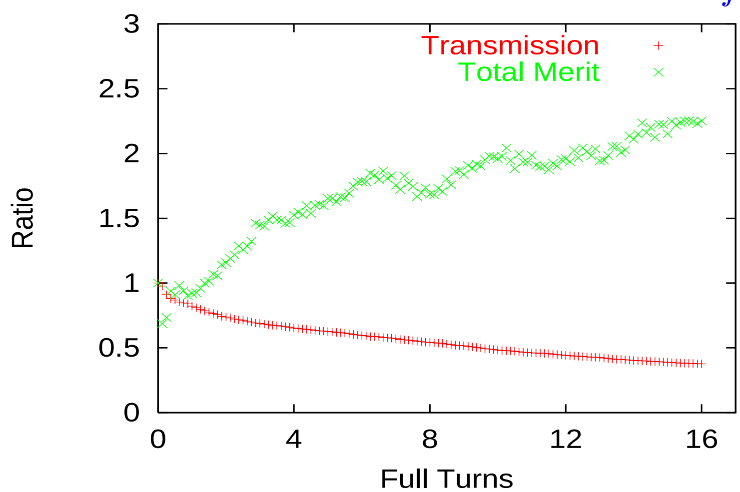
Eight Bend Cells/Turn – 10° Wedges

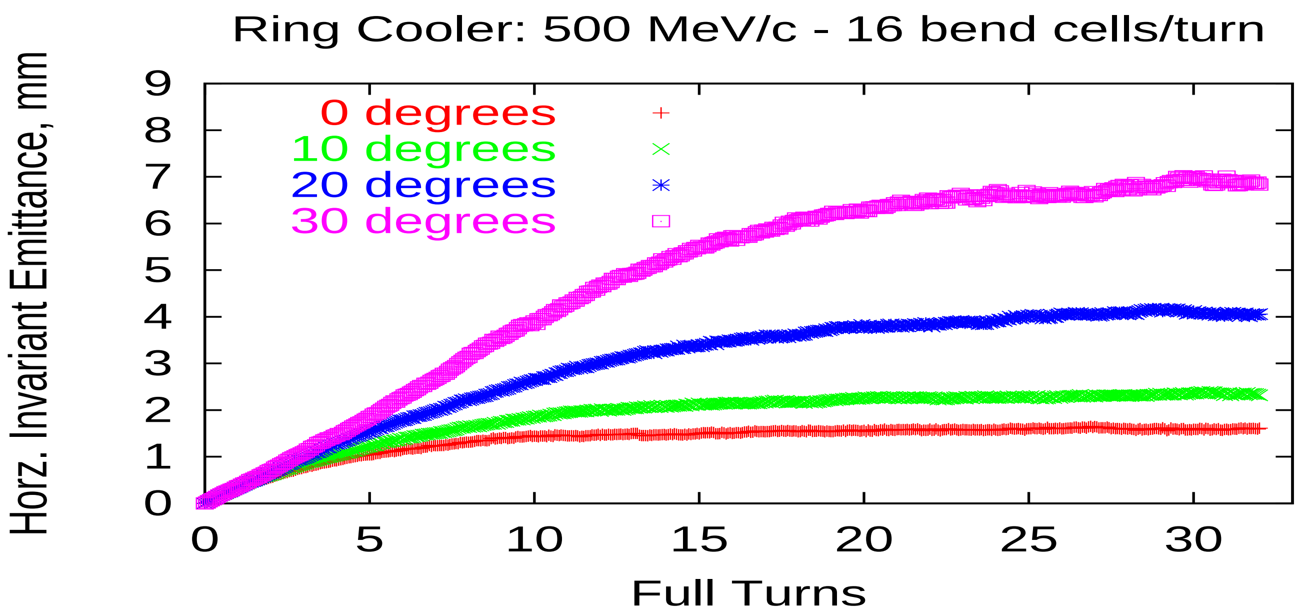
With Multiple Coulomb Scattering and Straggling

$\gamma\beta\epsilon_{x_i} = 1.8mm;\ \gamma\beta\epsilon_{y_i} = 4.4mm\ ;\ \gamma\beta\epsilon_{z_i} = 18mm$



$$\text{Total Merit} = \text{Transmission} \times \frac{\epsilon x_i}{\epsilon x_f}\frac{\epsilon y_i}{\epsilon y_f}\frac{\epsilon z_i}{\epsilon z_f}$$





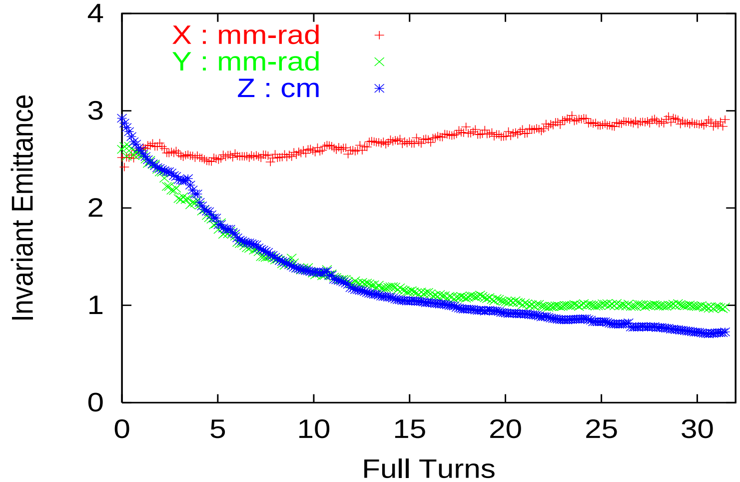
Ring Cooler: 500 MeV/c - 16 bend cells/turn
Horz. Invariant Emittance, mm
Full Turns
0 degrees
10 degrees
20 degrees
30 degrees
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30

500 MeV/c Cooling Ring

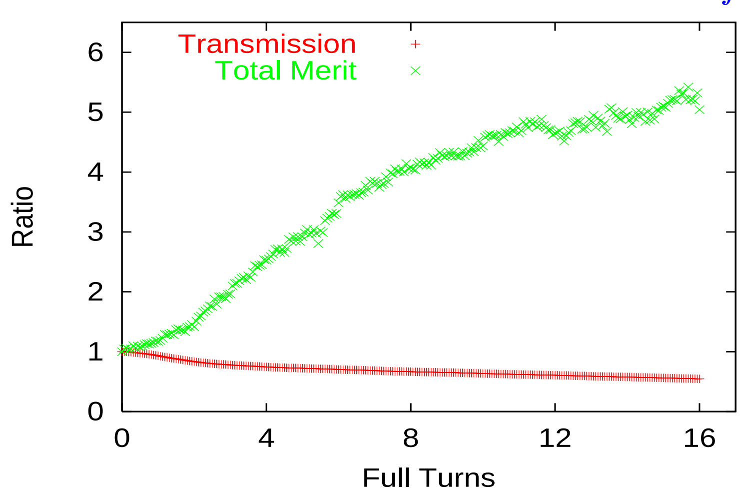
Sixteen Bend Cells/Turn – 20° Wedges

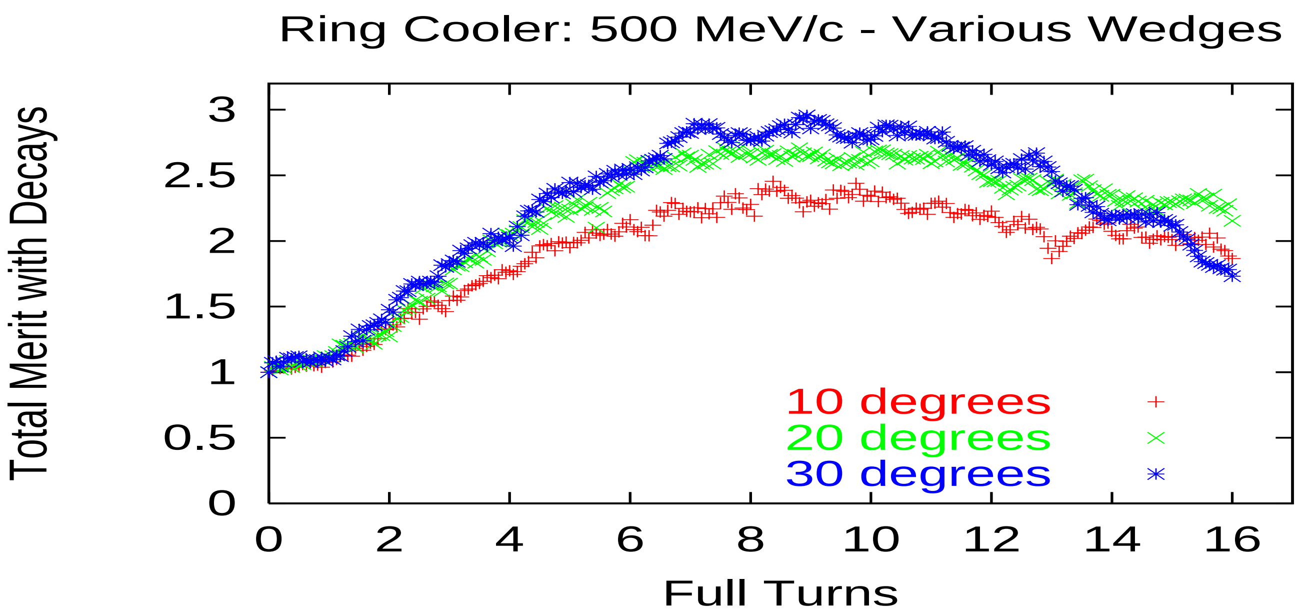
With Multiple Coulomb Scattering and Straggling

$$\gamma\beta\epsilon_{x_i} = 2.5mm;\ \gamma\beta\epsilon_{y_i} = 2.6mm\ ;\ \gamma\beta\epsilon_{z_i} = 29mm$$



$$\text{Total Merit} = \text{Transmission} \times \frac{\epsilon_{x_i}}{\epsilon_{x_f}}\frac{\epsilon_{y_i}}{\epsilon_{y_f}}\frac{\epsilon_{z_i}}{\epsilon_{z_f}}$$



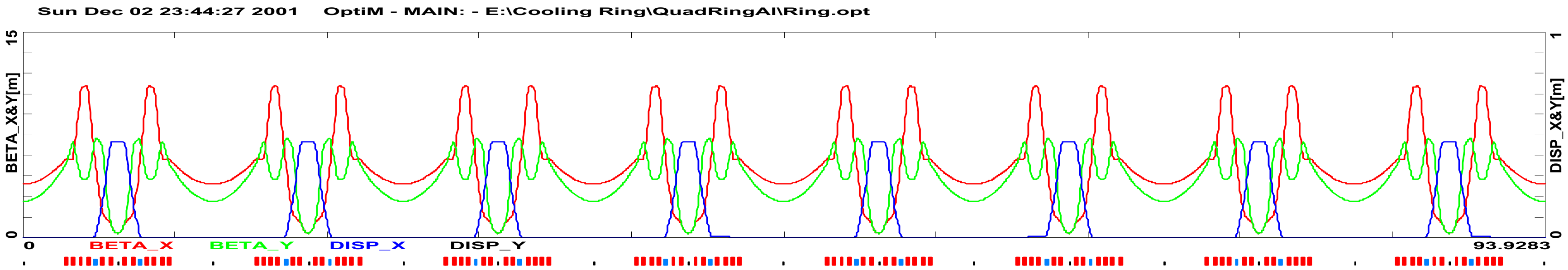

Ring Cooler: 500 MeV/c - Various Wedges
Total Merit with Decays
Full Turns
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10
12
14
16
10 degrees
20 degrees
30 degrees

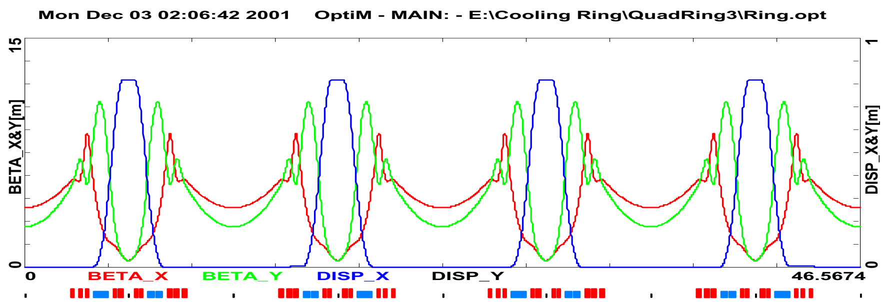
Quadrupole Ring Cooler – Beam Dynamics Issues

Alex Bogacz

- Original 8–cell ring lattice (Al Garren's design)
- Alternative 4-cell ring lattice
  - double bending compact ring
  - shorter cell architecture
  - longer lower field dipoles (3 Tesla)
- Comparison of both designs (8-cell vs. 4-cell)
- Longitudinal Nonlinearity Compensation with Sextupoles

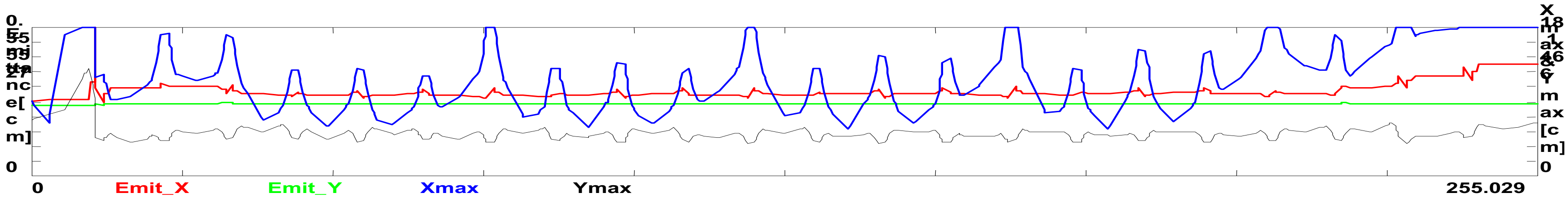
Comparison of both designs (8-cell vs. 4-cell)



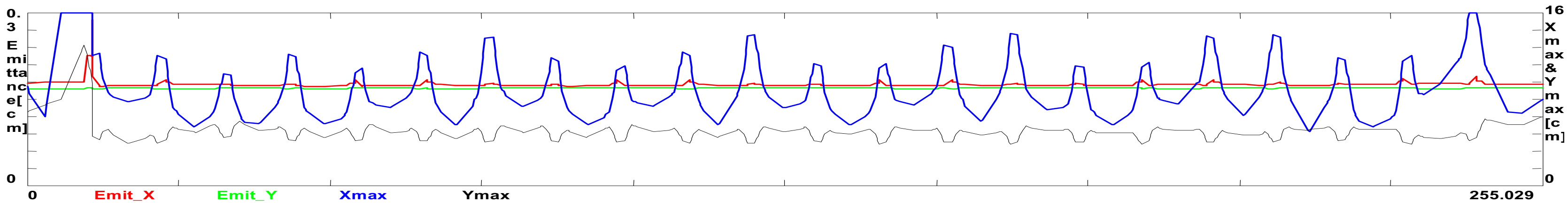


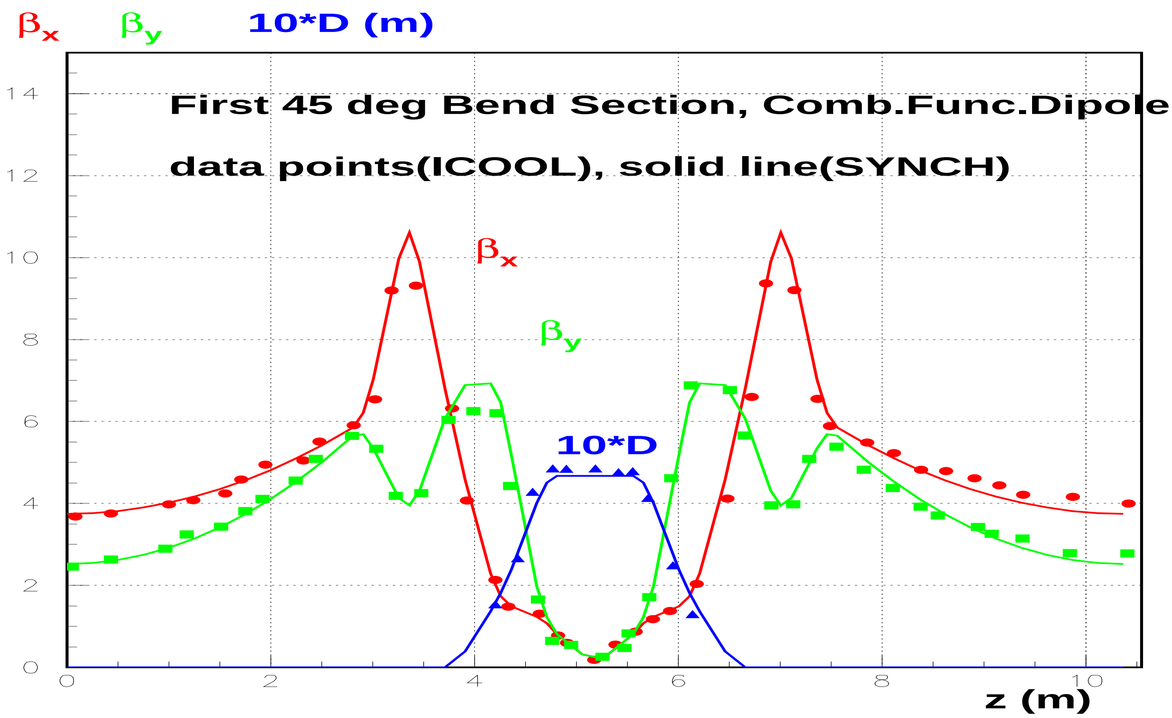
Chromatic Corrections

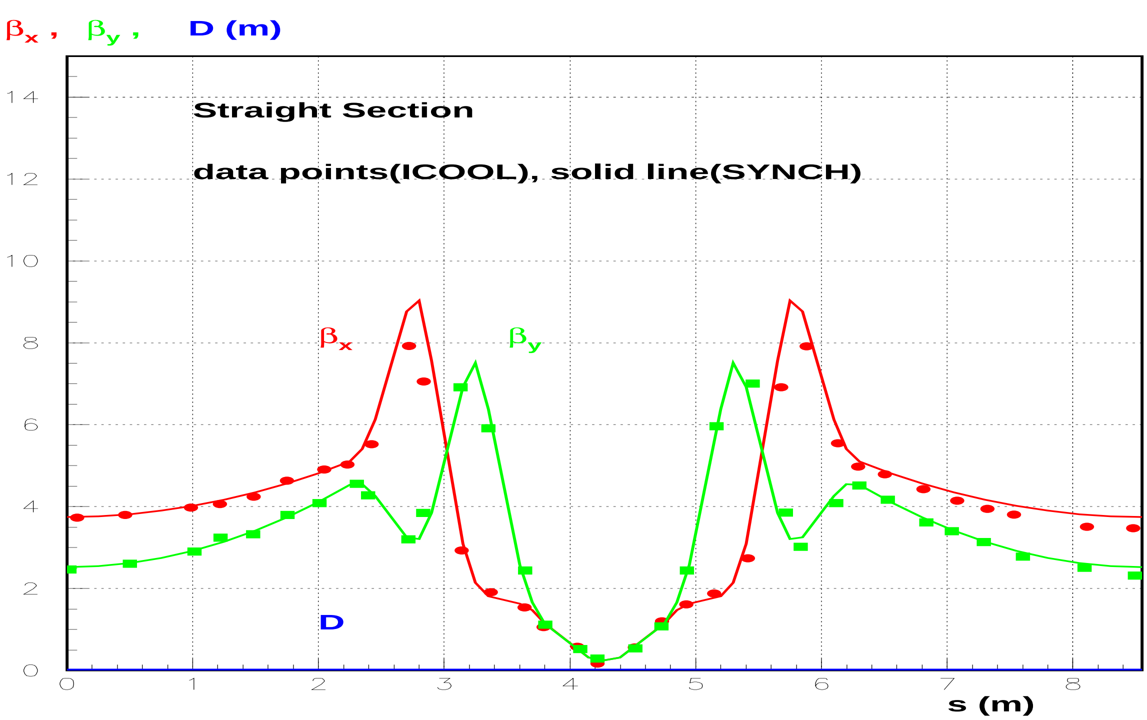
- Alternating sign sextupole correction every other cell
- 4 focusing quads have build-in sextupole component, SdL=0.16 kG/cm
- it corresponds to S=1 G/cm^2 or ≈5% correction for G at r = 20 cm
- The sextupole gradient is chosen to minimize the total emittance growth
- Particle displacement for uncompensated and compensated chromaticity It does not correspond to the best possible dispersion correction



Multi-particle tracking without any sextupole correction, < 1% of particles lost on 12 cm aperture




βx βy 10*D (m)
First 45 deg Bend Section, Comb.Func.Dipole
data points(ICOOL), solid line(SYNCH)
βx
βy
10*D
z (m)


βx , βy , D (m)
Straight Section
data points(ICOOL), solid line(SYNCH)
βx
βy
D
s (m)

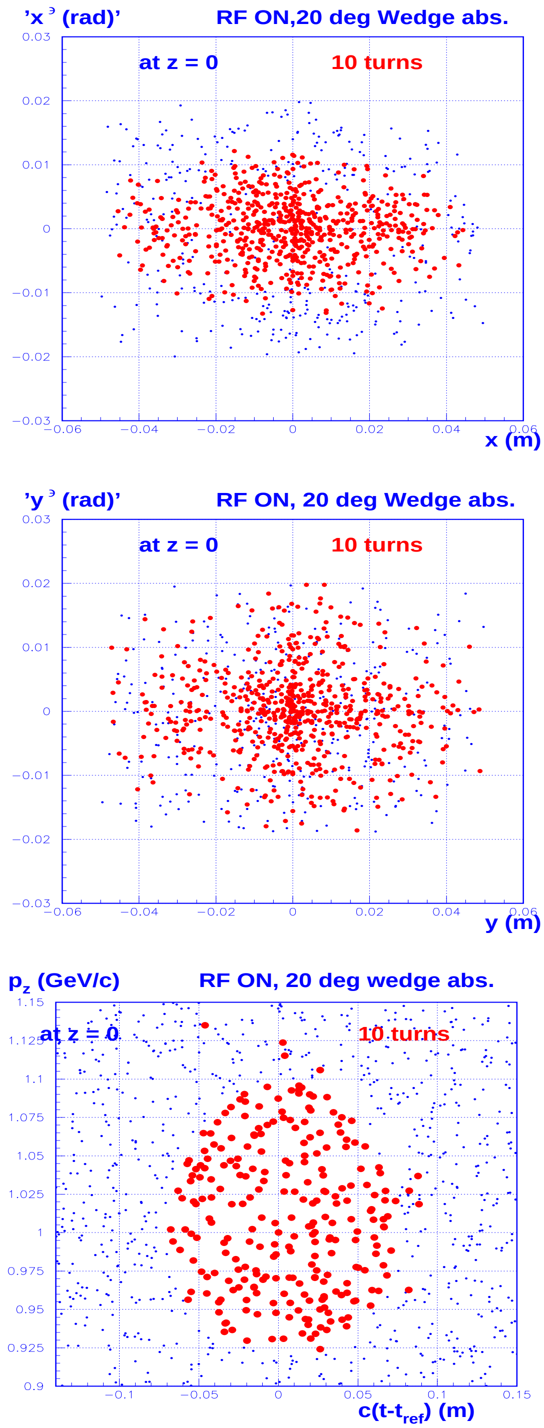


Figure 1: Acceptance of a Ring with RF ON, 20 deg Wedge Absorber without scattering, struggling

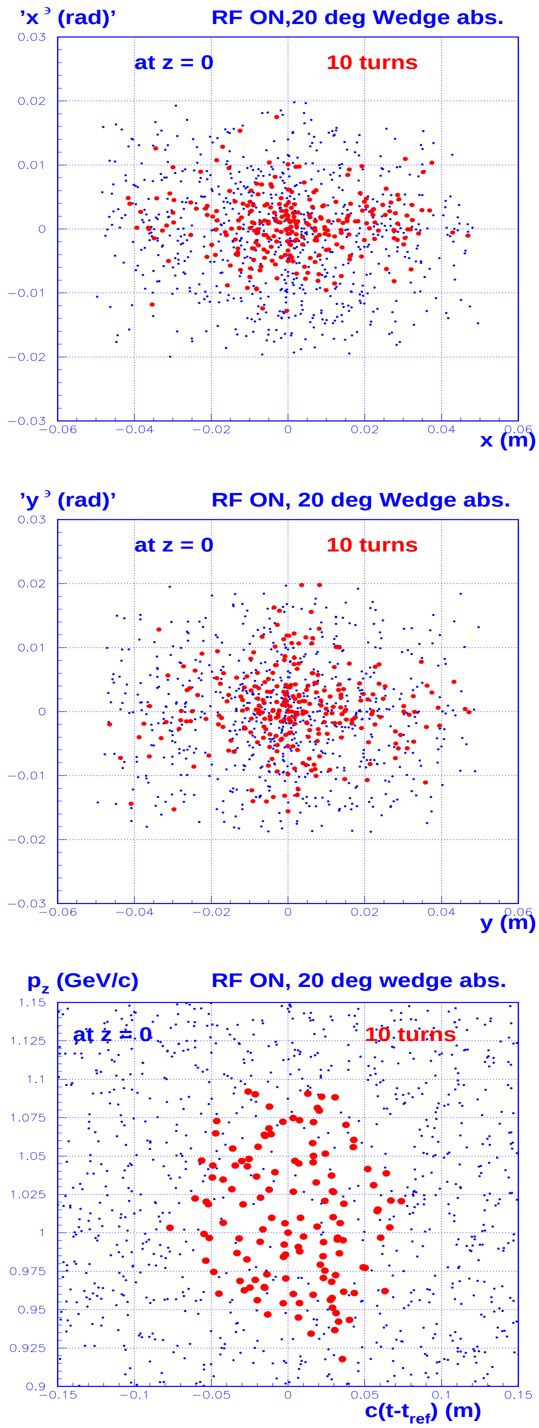
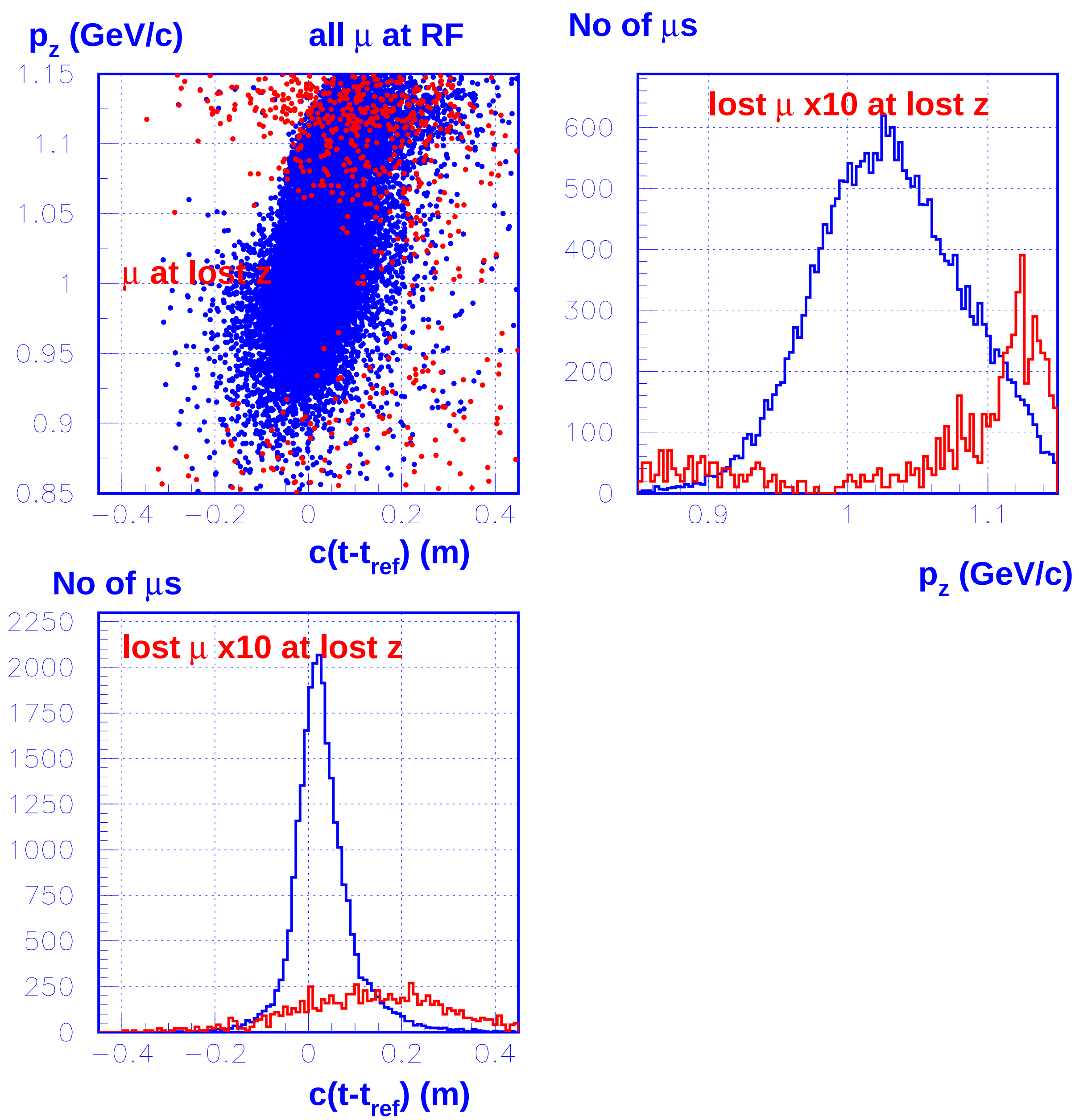
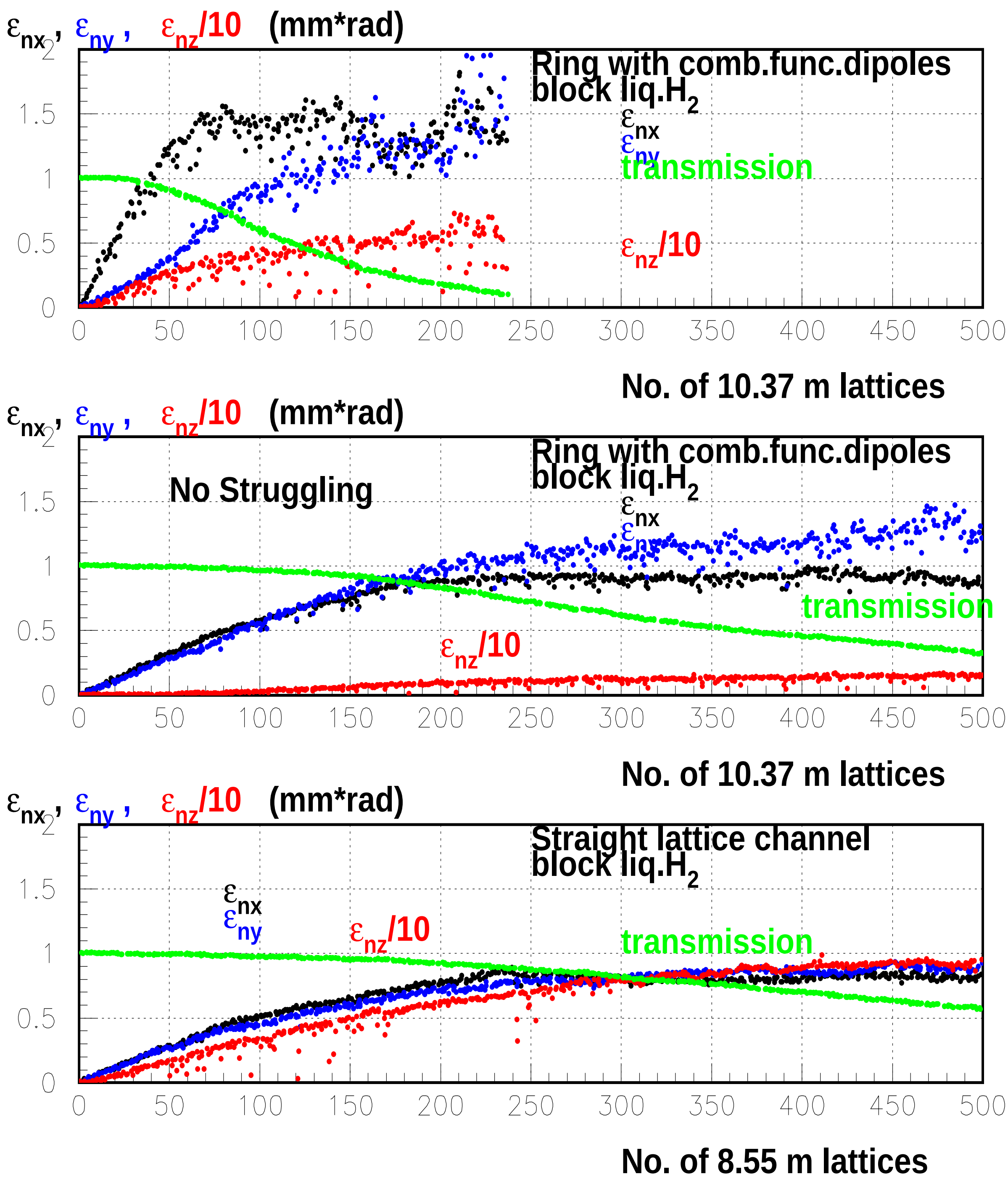


Figure 2: Acceptance of a Ring with RF ON, 20 deg Wedge Absorber



p_z (GeV/c)
all μ at RF
μ at lost z
c(t-t_ref) (m)
No of μs
lost μ x10 at lost z
p_z (GeV/c)
No of μs
lost μ x10 at lost z
c(t-t_ref) (m)



ε_{nx}, ε_{ny}, $\varepsilon_{nz}/10$ (mm*rad)
Ring with comb.func.dipoles
block liq.H_2
ε_{nx}
ε_{ny}
transmission
$\varepsilon_{nz}/10$
No. of 10.37 m lattices
ε_{nx}, ε_{ny}, $\varepsilon_{nz}/10$ (mm*rad)
Ring with comb.func.dipoles
block liq.H_2
No Struggling
ε_{nx}
ε_{ny}
transmission
$\varepsilon_{nz}/10$
No. of 10.37 m lattices
ε_{nx}, ε_{ny}, $\varepsilon_{nz}/10$ (mm*rad)
Straight lattice channel
block liq.H_2
ε_{nx}
ε_{ny}
$\varepsilon_{nz}/10$
transmission
No. of 8.55 m lattices

Things-to-Do List

1. Contact FFAG working group of JHF so that we can collaborate on a FFAG option for the phase rotation, and possible muon cooling. Invite representative to the Ring Cooler mini-Workshop at UCLA on March 7 and 8, 2002.

2. Identify the output of the Balbekov ring cooler with official tracking simulation so that we can get a whole picture of a Higgs Factory by connecting all 6 dimensional cooling elements and accelerators.

3. Work to improve the performance of the Ring Cooler. ICOOL tracking simulation needs to be done on all items.

   (a) Make the 16 cell ring design with combined function bending magnets as a baseline model.

   (b) Apply skew quads in the baseline model to couple the x and y emittances.

   (c) Implement sextupoles in a ring.

   (d) Design magnets and generate realistic magnetic fields with an aperture radius of 21 cm.

   (e) Use COSY to get the initial parameters of a ring with fringe fields (soft edges) of dipoles and quadrupoles.

   (f) Study on storage rings with various number of lattices, where the sizes of dispersion at the absorber with low β_x, β_y are different.

   (g) Check the performance of a ring with vertical bend lattices and horizontal bend lattices.

Conclusion

- Emittance Exchange and 6D cooling was demonstrated with the conventional magnet ring by using ICOOL simulation. So far the 16 cell Cooling Ring with 40-60 degree wedge opening angle at 500 MeV/c gives the best performance.
- Plan to use FFAG type ring for the phase rotation and for the final stage cooling with Li lens.
- Plenty of things to do before the March 2002 mini-workshop on the Ring Cooler at UCLA.