Ring Coolers and Emittance Exchange Simulations

Rajendran Raja

Fermilab

April 7, 2003

Simulations and Theory Committee

R. Raja (FNAL)	Chair
H. Kirk (BNL)	Targetry Simulation Co-ordinator
R. Fernow (BNL)	Phase Rotation Simulation Co-ordinator
R. Raja (FNAL)	Emittance Exchange/Ring Cooler Co-ordinator
S. Berg/ C. Johnstone (BNL)/(FNAL)	Acceleration Simulation Co-ordinators
A. Sessler (LBNL)	Theory Co-ordinator
M. Berz (MSU)	
E. Keil (FNAL)	
D. Neuffer (FNAL)	
R. Palmer (BNL)	

Charge to the Committee

- **Charge to The Theory and Simulation Board**
- *The committee will meet periodically to review simulation and theory progress, set priorities, and make plans to further this work. Minutes should be kept to document the main conclusions from the discussion*
- **The committee will include the leaders of the simulation sub-groups covering:**
- Target
- Phase Rotation
- Cooling and Emittance Exchange
- Acceleration
- Theory
- **These subgroup leaders plus a few other members will be chosen by the chairman of the committee in consultation with the MC Spokesperson(s).**
- *The committee should:*

1. Assure that each Sub-group holds workshops with the appropriate frequency.
2. Co-ordinate proposals to use collaboration funds for post docs and visitors doing simulation work. The committee chairperson will present these proposals to the Technical Board at the appropriate time each year.
3. Advertise, interview and select Post-Docs and visitors for any open positions approved by the MC Spokesperson(s), and make a recommendation of where best they should be based and the topic(s) they should work on.
4. Maintain a list of all people within the MC contributing to simulation and theory activities, and identify which areas they are contributing to.
5. Consider any other activities that might further simulation and theory work.

- December 10, 2002.
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Simulation Activity and personnel

Production/Phase Rotation/Bunching	**Ring Coolers**
Rick Fernow /BNL 20%	Rajendran Raja /FNAL 20%
Debbie Errede /UI 20%	Zafar Usubov /FNAl 100%
Kevin Paul /UI 100%	Valery Balbekov /FNAL 40%
Carol Johnstone /FNAL 15%	Steve Kahn /BNL 15%
Dave Neuffer /FNAL 50%	Amit Klier 50%
	Bob Palmer /BNL 30%
Acceleration	Romulus Godang /U Miss 50%
Carol Johnstone /FNAL 15%	Don Summers /U Miss 10%
Scott Berg /BNL 30%	Lucien Cremaldi /U Miss 10%
Steve Kahn /BNL 15%	Steve Bracker /U Miss 5%
Dan Trebojevic 10%	Juan Gallardo /BNL 30%
	Rick Fernow /BNL 30%
Linear Coolers	
Carol Johnstone /FNAL 20%	Al Garren /LBNL 50%
Kyoko Makino /UI 50%	Harold Kirk /BNL 30%
Martin Berz /MSU 20%	Scott Berg /BNL 30%
Targetry Simulations	**Linear Theory**
Harold Kirk /BNL 20%	Andy Sessler /LBNL 10%
Nick Simos /BNL 30%	Eberhard Keil
	Dave Neuffer /FNAL 20%
	Martin Berz /MSU 10%
	Scott Berg /BNL 30%

Ring Coolers in Geant

- Balbekov Ring
- Palmer RFOFO ring
- Garren/Kirk Graded Dipole ring

Equations of motion in presence of electric and magnetic fields

$\vec{p}, E$ is the particle 4 vector, $\vec{u}$ is the tangent to the trajectory, s the arc length,

v the velocity, η is the Lorentz factor

c the velocity of light,

m_0 the particle mass, q the charge

$\vec{\varepsilon}$ is the electric field, $\vec{B}$ is the magnetic field

$$\frac{d\vec{p}}{dt} = q(\vec{\varepsilon} + \vec{v} \times \vec{B})$$

$$\frac{d\vec{p}}{dt} = \frac{d\vec{p}}{ds} \times \frac{ds}{dt} = v\frac{d\vec{p}}{ds}$$

$$\vec{p} = \vec{u} m_0 c \eta$$

$$p\frac{dp}{ds} = \vec{p} \circ \frac{d\vec{p}}{ds} \Rightarrow \frac{dE}{ds} = q(\vec{\varepsilon} \circ \vec{u}) \quad (1)$$

$$\frac{d\vec{u}}{ds} = \frac{d^2\vec{x}}{ds^2} = \frac{q}{p}\left(\vec{u} \times \vec{B} + \frac{\vec{\varepsilon}}{v} - \frac{\vec{\varepsilon} \circ \vec{u}}{v}\vec{u}\right) \quad (2)$$

$$\frac{dt}{ds} = \frac{1}{v} \quad (3)$$

Runge-Kutta Equations

- Runge-Kutta is performed on 3 equations simultaneously.Nystrom algorithm

$$y'' = f(y', y, x)$$

solves to

$$y(x+h) \;=\; y(x) + hy'(x) + (h^2/6)(K_1 + K_2 + K_3) + O(h^5)$$

$$y'(x+h) = y'(x) + (h/6)(K_1 + 2K_2 + 2K_3 + K_4) + O(h^5)$$

$$K_j = f(y'_j, y_j, x_j) \text{ for } j = 1,2,3,4$$

$$x_1 = x, x_2 = x_3 = x + h/2, x_4 = x + h$$

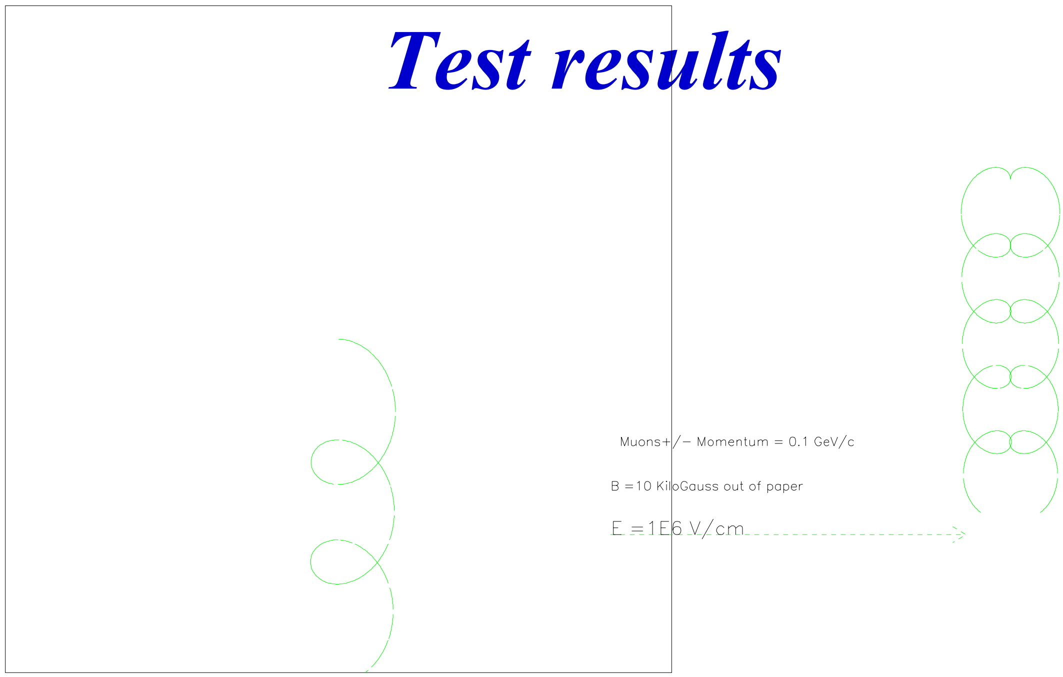
$$y_1 = y(x), y_2 = y_3 = y(x) + (h/2)y'(x) + (h^2/8)K_1$$

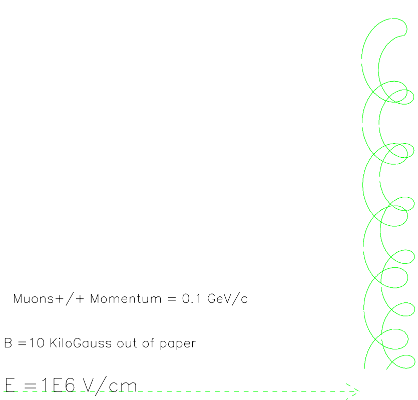
$$y_4 = y(x) + hy'(x) + (h^2/2)K_3$$

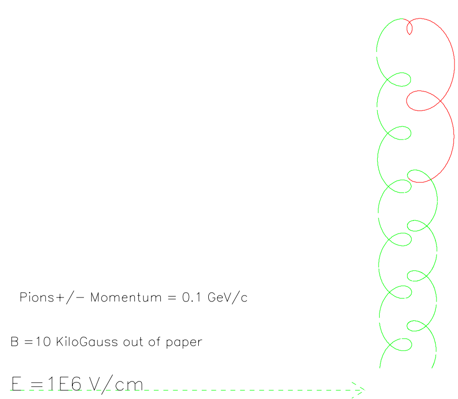
$$y'_1 = y'(x), y'_2 = y'(x) + (h/2)K_1, y'_3 = y'(x) + (h/2)K_2,$$

$$y'_4 = y'(x) + hK_3$$

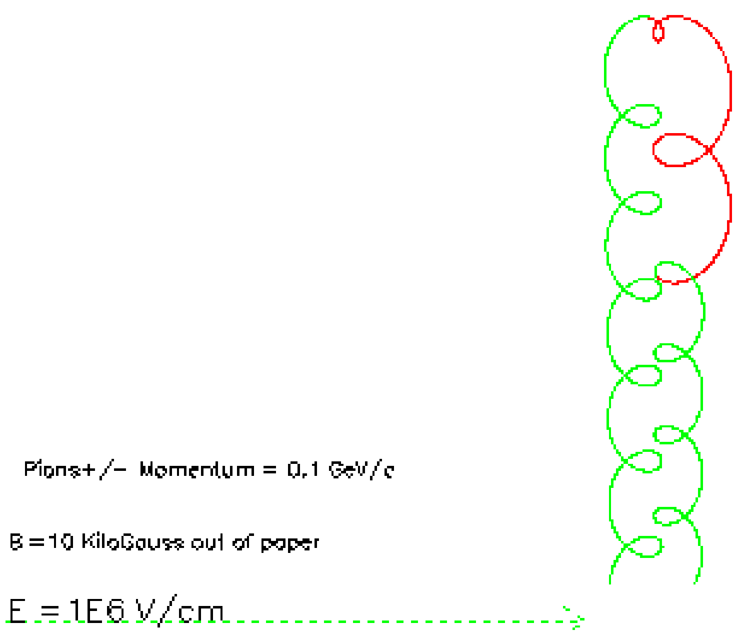
Test results



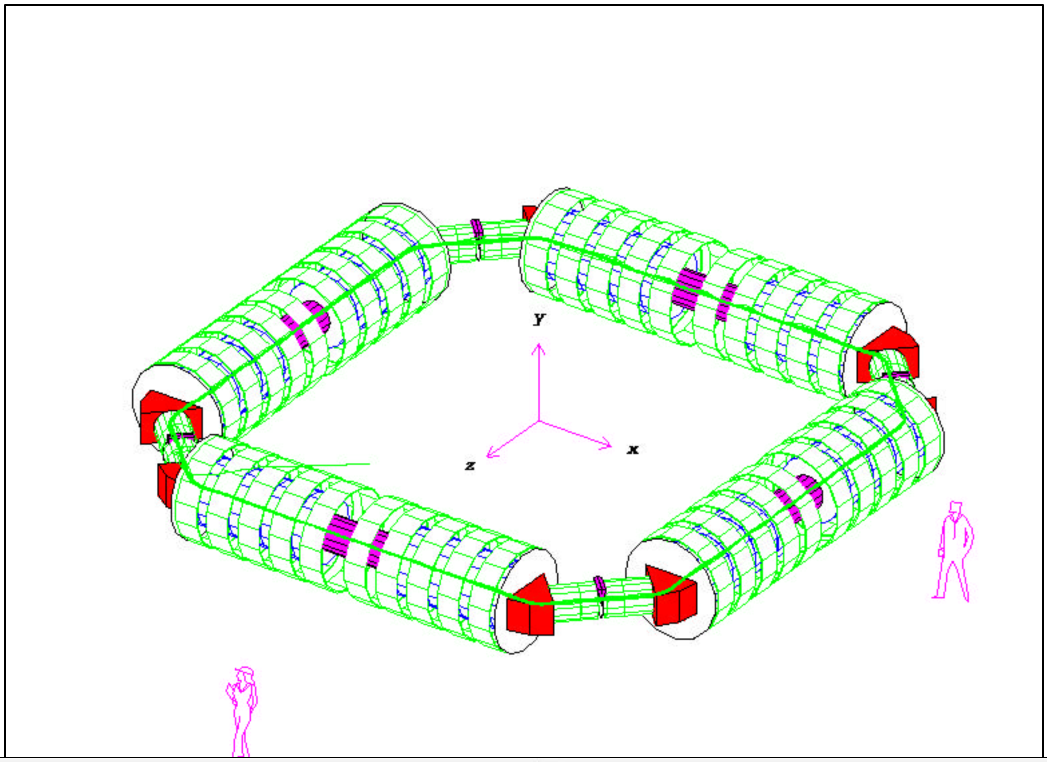


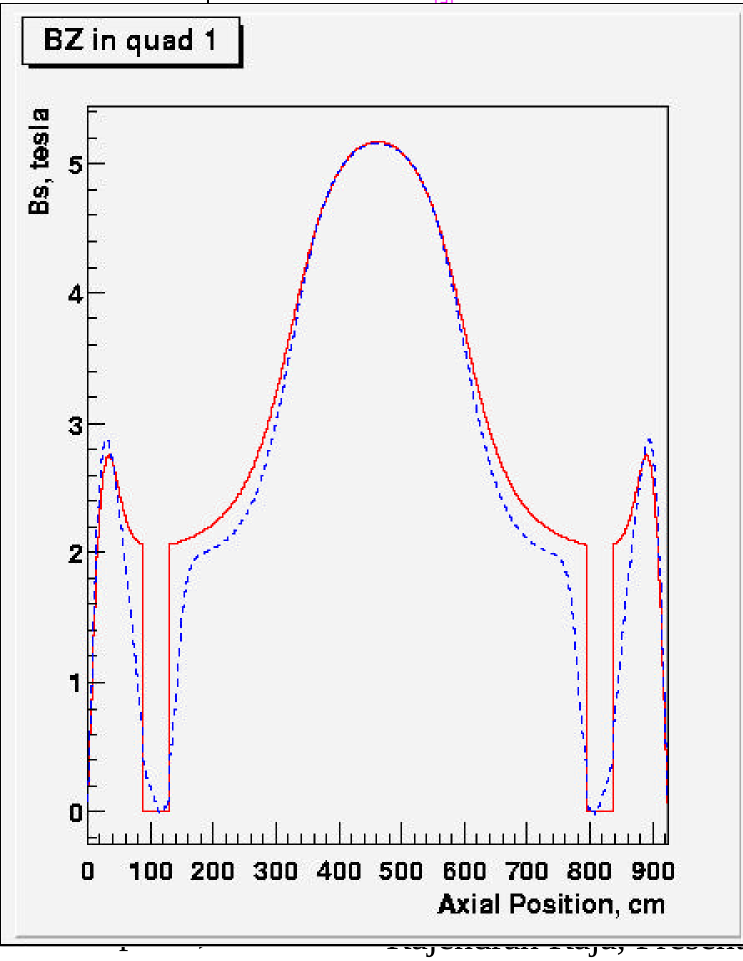


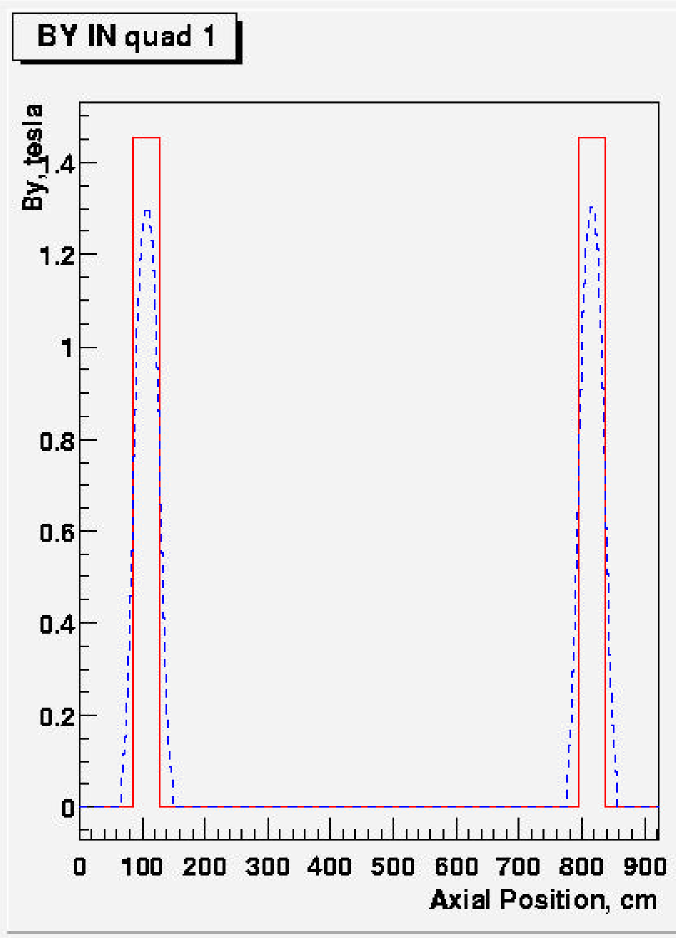
Test results



Balbekov Ring

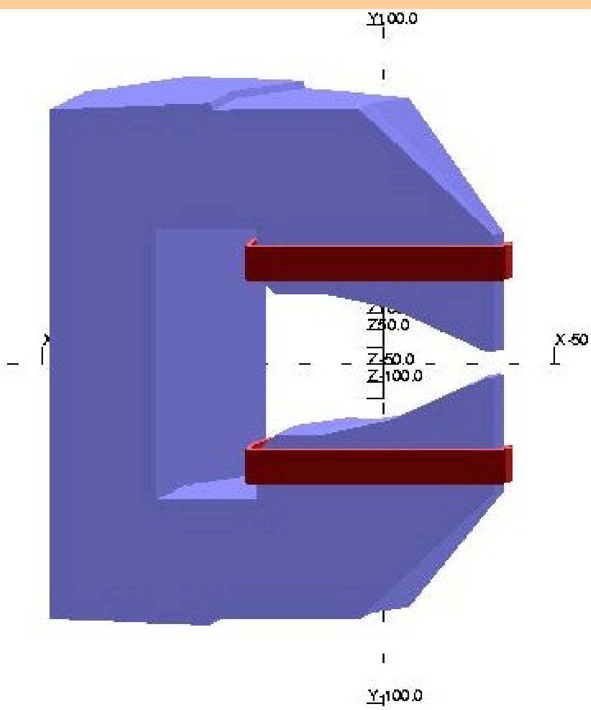


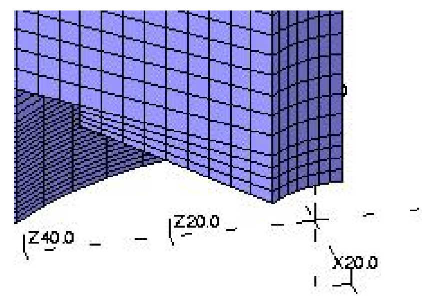




Magnet Design and calculations Steve Kahn(BNL), Peter Schwandt(Indiana)

Sketch of Dipole Magnet





Pole face is shaped to achieve required gradient

The design of the wedge magnet is from P. Schwant

(dated 30 Jan 01)

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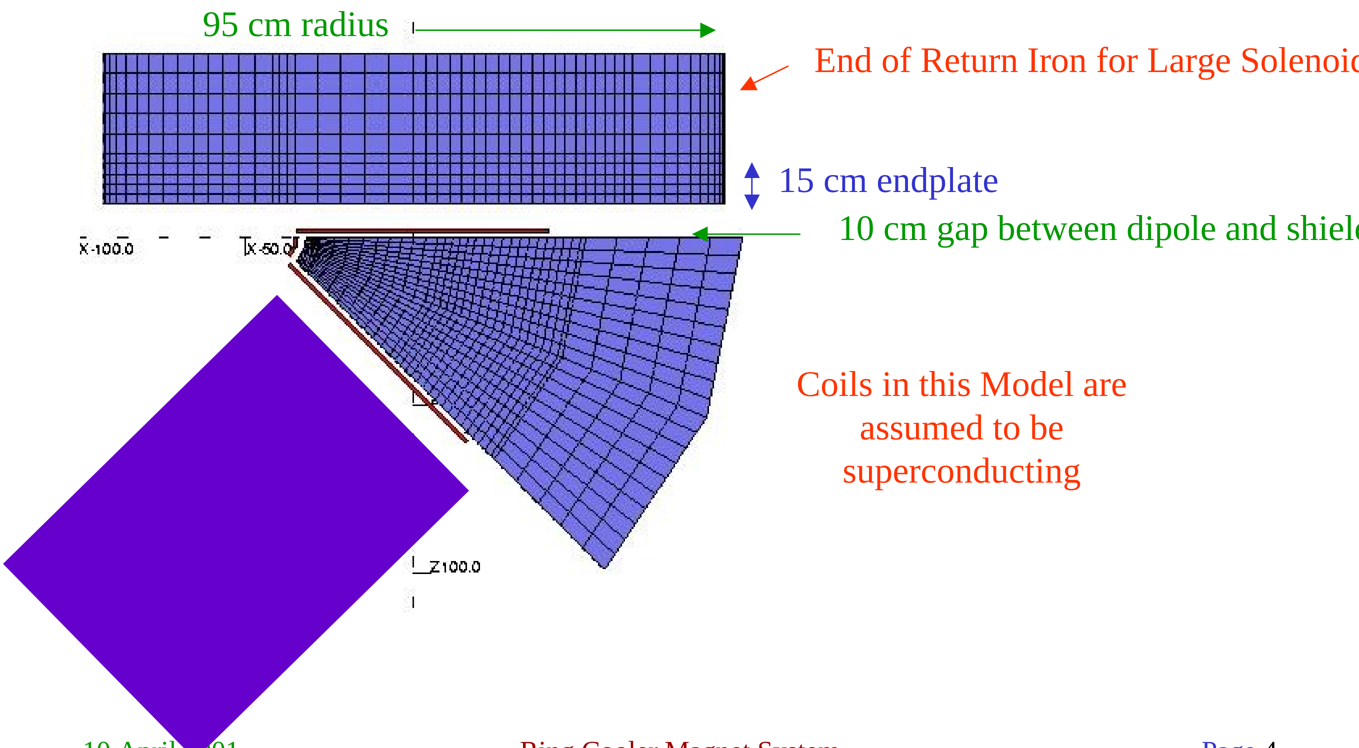
Magnet Design and calculations Steve Kahn(BNL), Peter Schwandt(Indiana)

Tosca Model for Wedge Dipole



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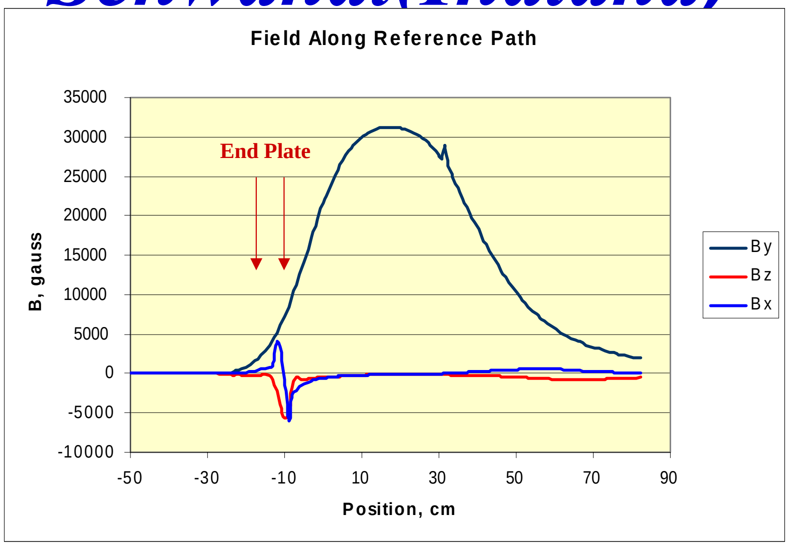
Magnet Design and calculations

B_y along Beam Path in Wedge Magnet



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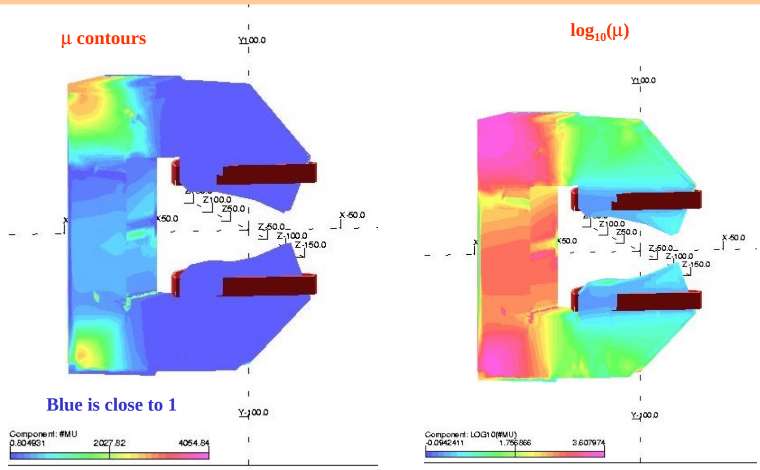
Permeability of Dipole



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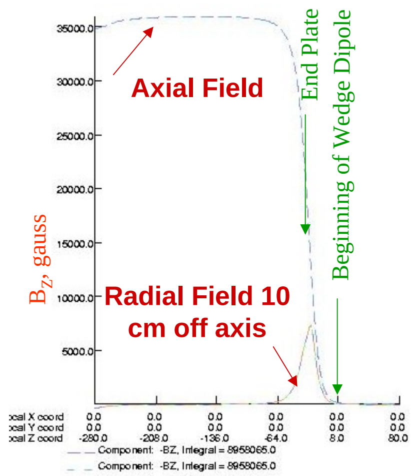
Magnet Design and calculations Steve Kahn(BNL), Peter Schwandt(Indiana)

Fields in Large Solenoid



- **Note: Coils are inside cavity R_c=18 cm.**
- Run with coils outside RF cavities failed and is being recalculated.

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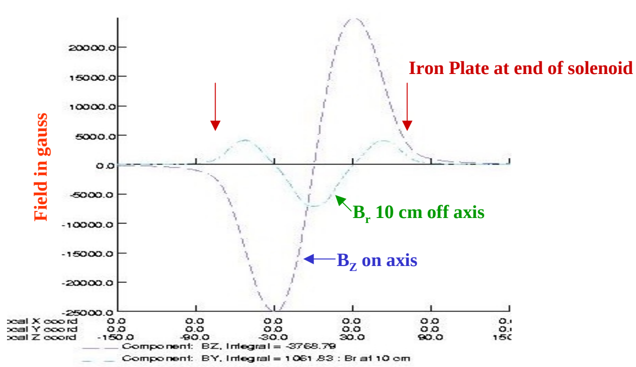
Field in Short Field Flip Solenoid



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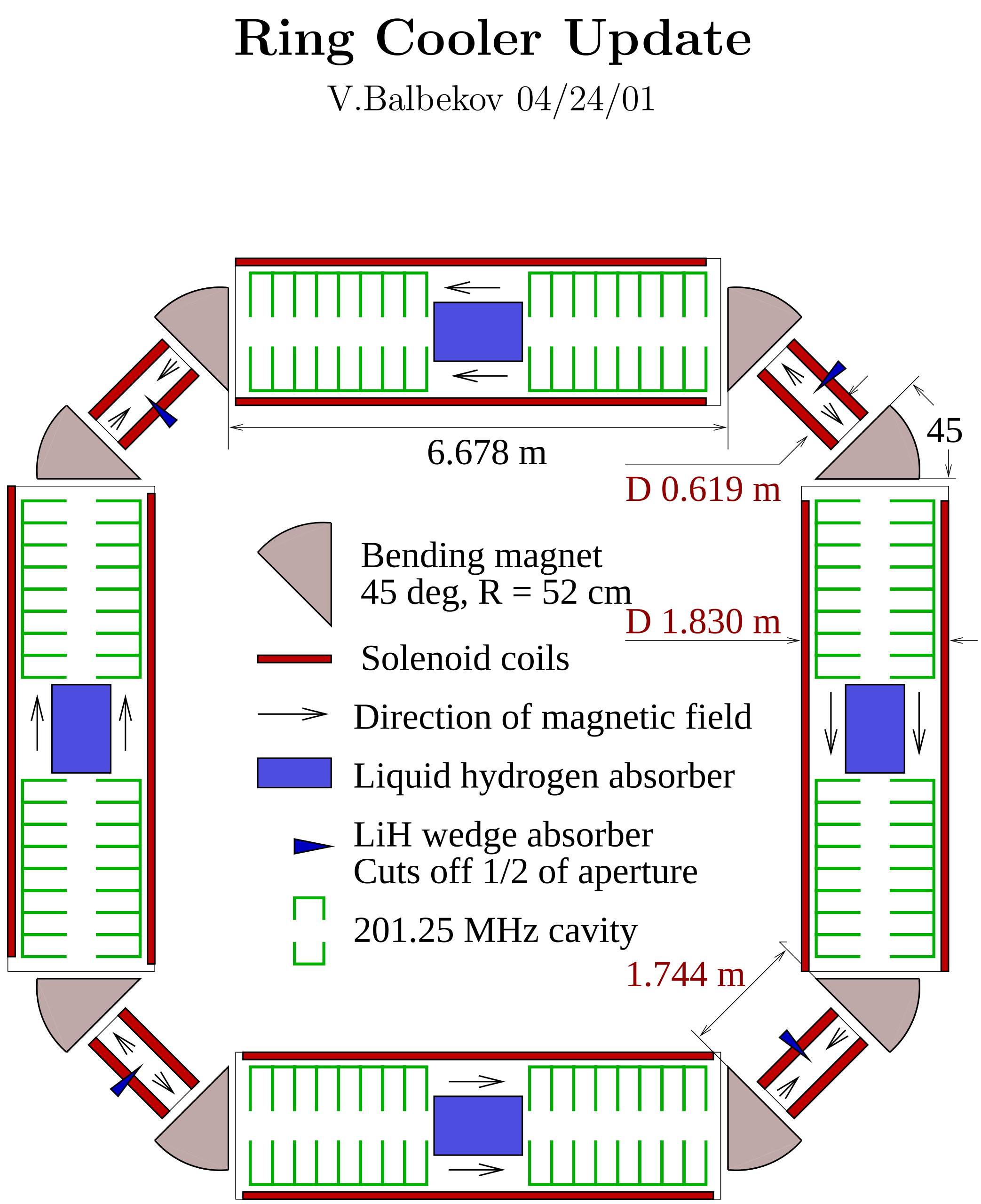
New design with bend magnet radius = 53cm



The ring cooler layout (new version, $R_{bend} = 52$ cm).

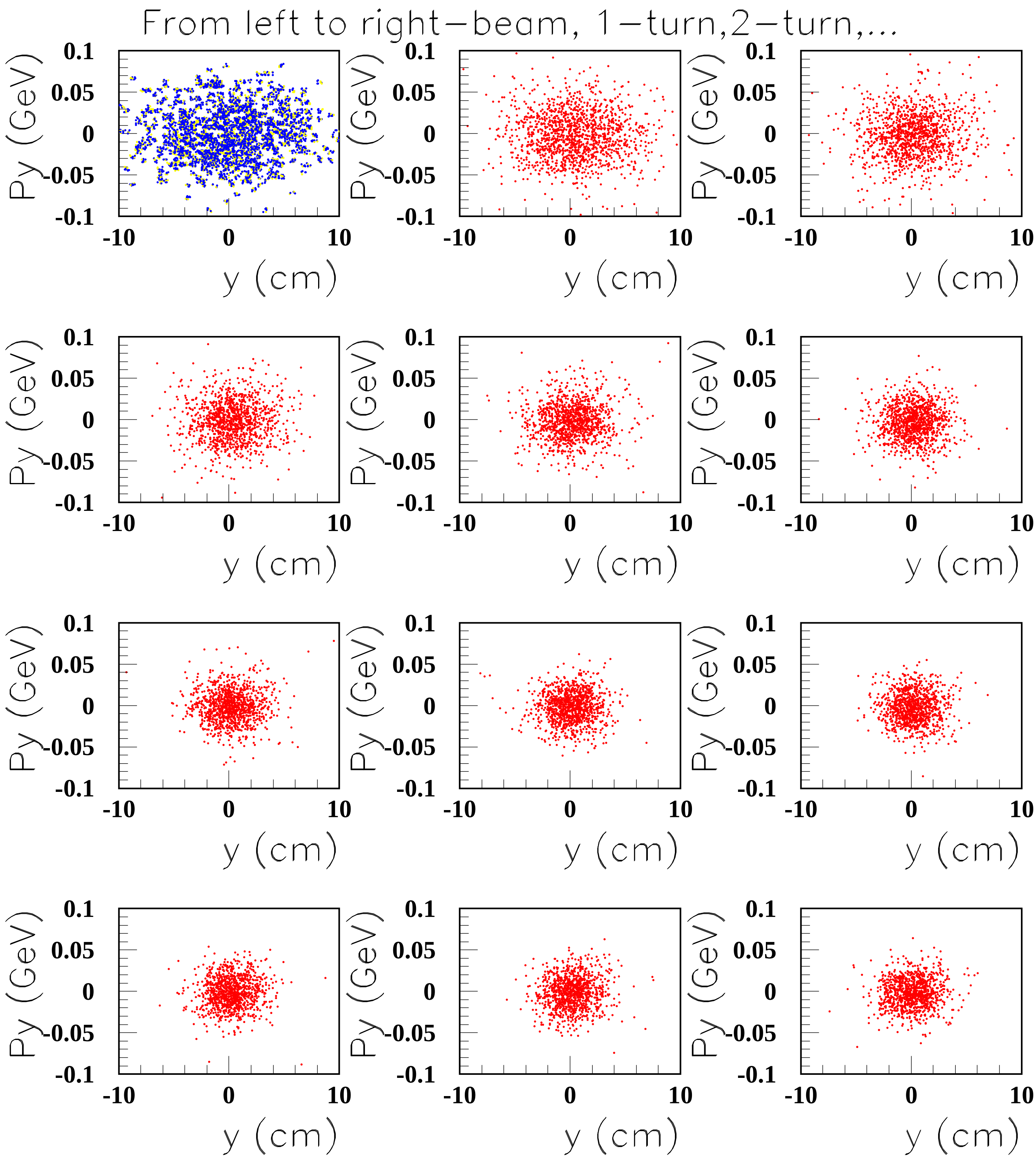


Figure 4: $Y - P_Y$ distribution turn by turn.

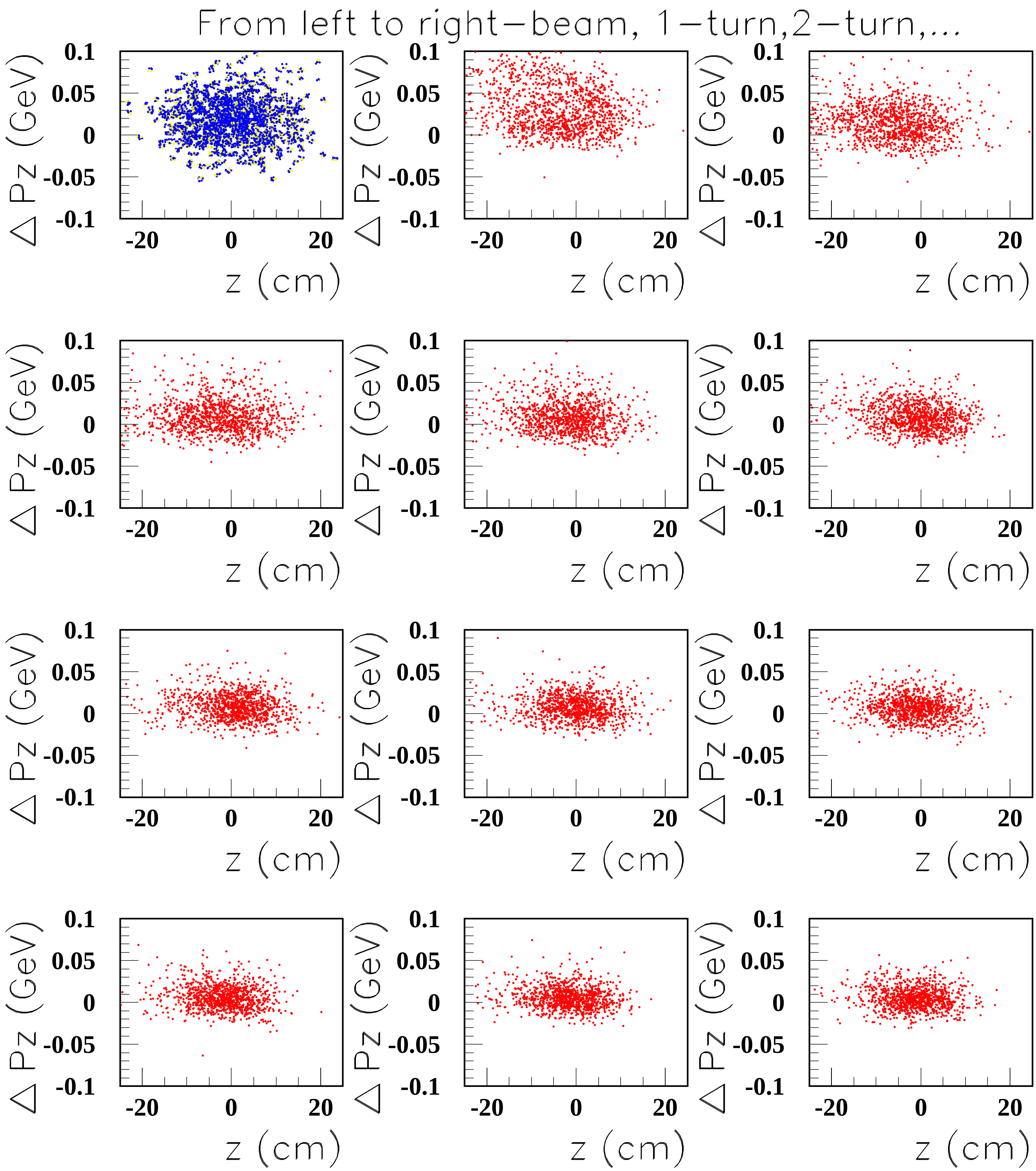


Figure 5: $Z - P_Z$ distribution turn by turn.

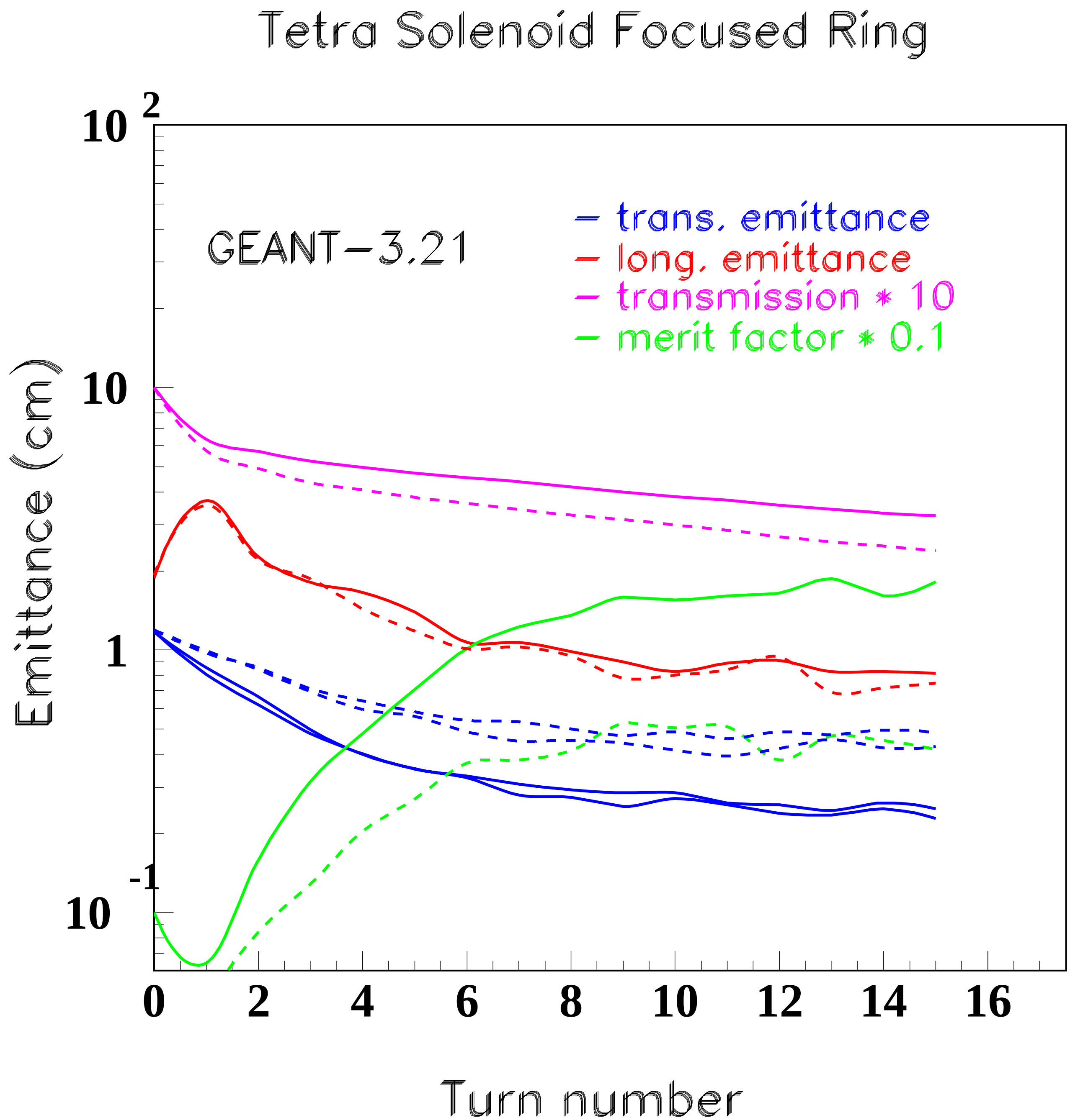


Figure 3: Comparison of berilium wedge absorber with LiH one.

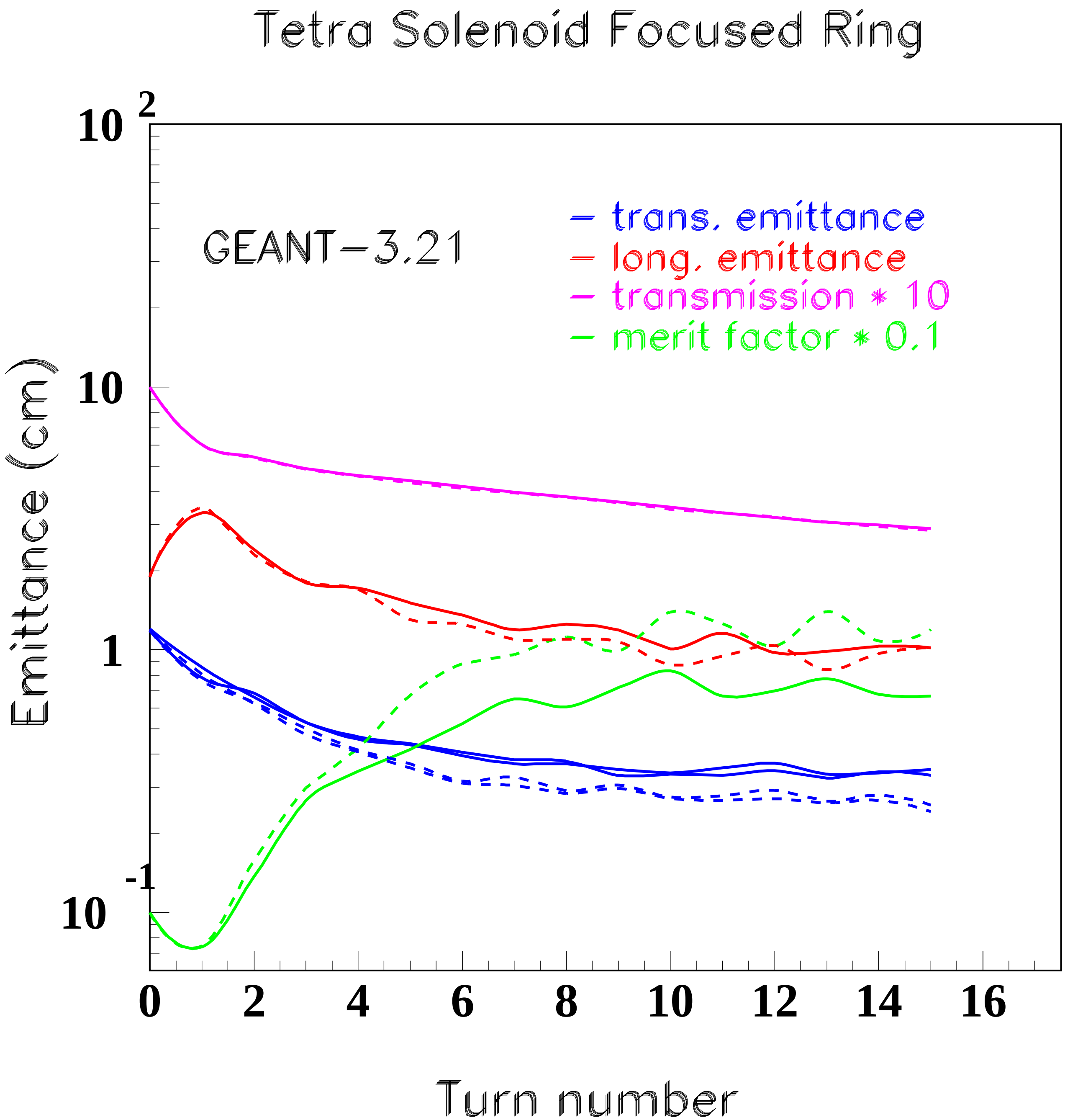
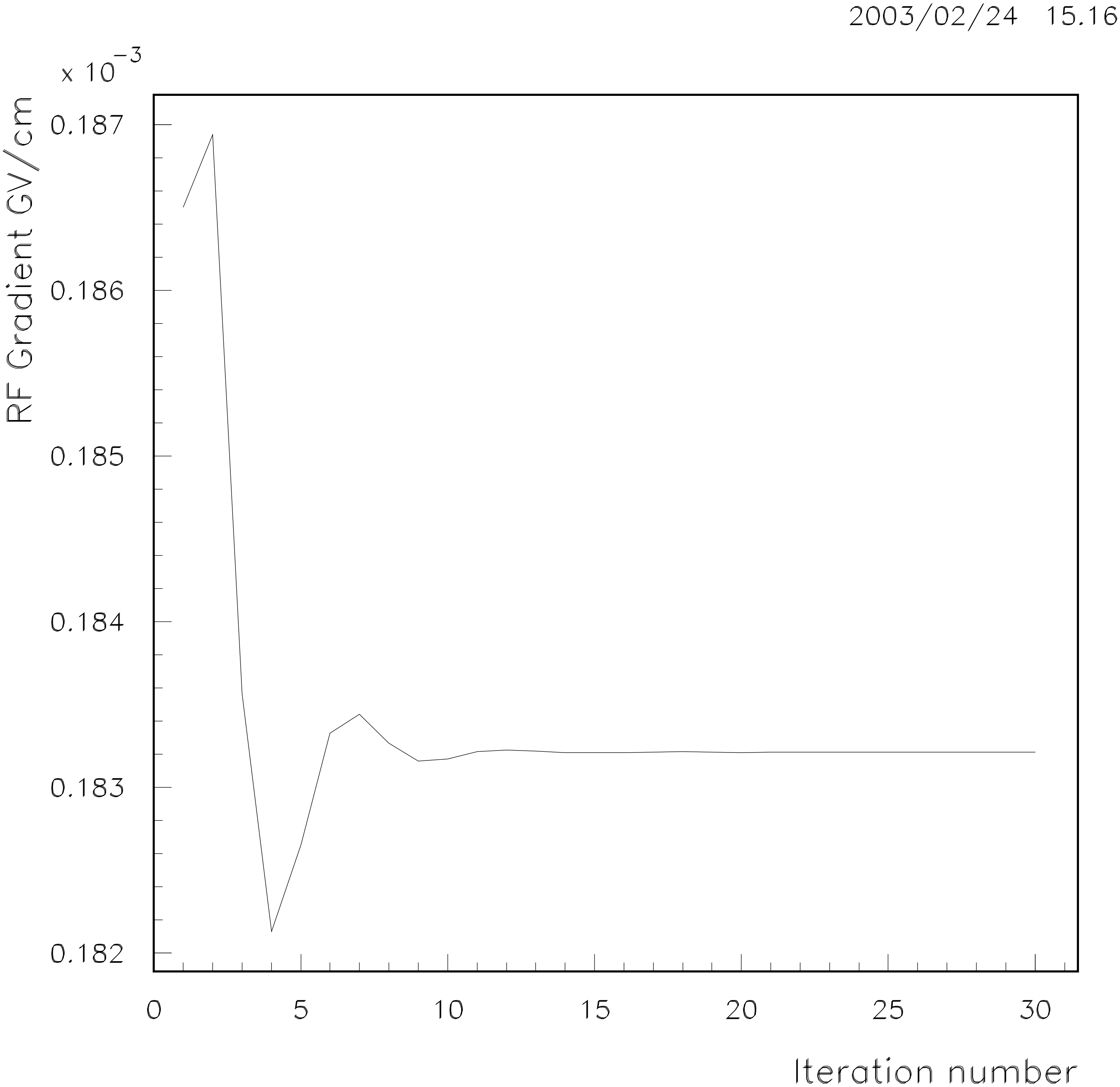


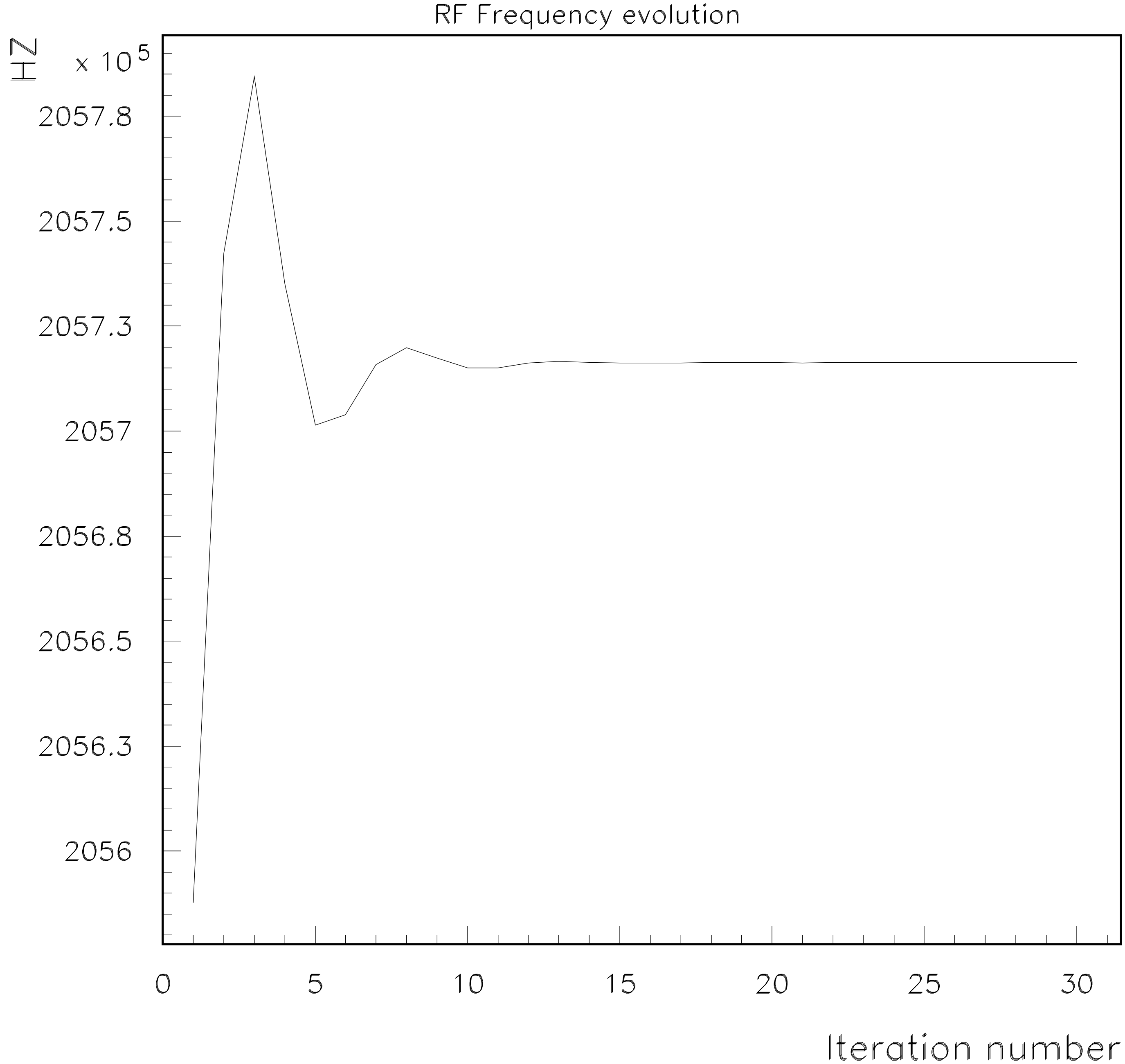
Figure 4: Comparison of aluminium and carbon (dashed) window results.

MITER

- Separate program that calls Geant.
- Has interface to MINUIT
- Present algorithm
- Remove all absorbers.
- Acquire times at which on momentum particle crosses all rf volumes (16x4)
- Start particle at beginning of quadrant and track one turn
- Work out rf frequency for a harmonic number =28
- Replace main absorbers. No wedges.
- Iterate One Turn with no straggling or multiple scattering or decay.
- Re-work out the times.
- Re calculate RF gradient such that loss per absorber = gain / quadrant.
- Re work out the rf frequency. Iterate 30 times till convergence.
- RF entry at –15 degrees and exit at ~ 75degrees. Sin Wave.


2003/02/24 15.16
x 10^-3
RF Gradient GV/cm
0.187
0.186
0.185
0.184
0.183
0.182
0
5
10
15
20
25
30
Iteration number

2003/02/24 15.16



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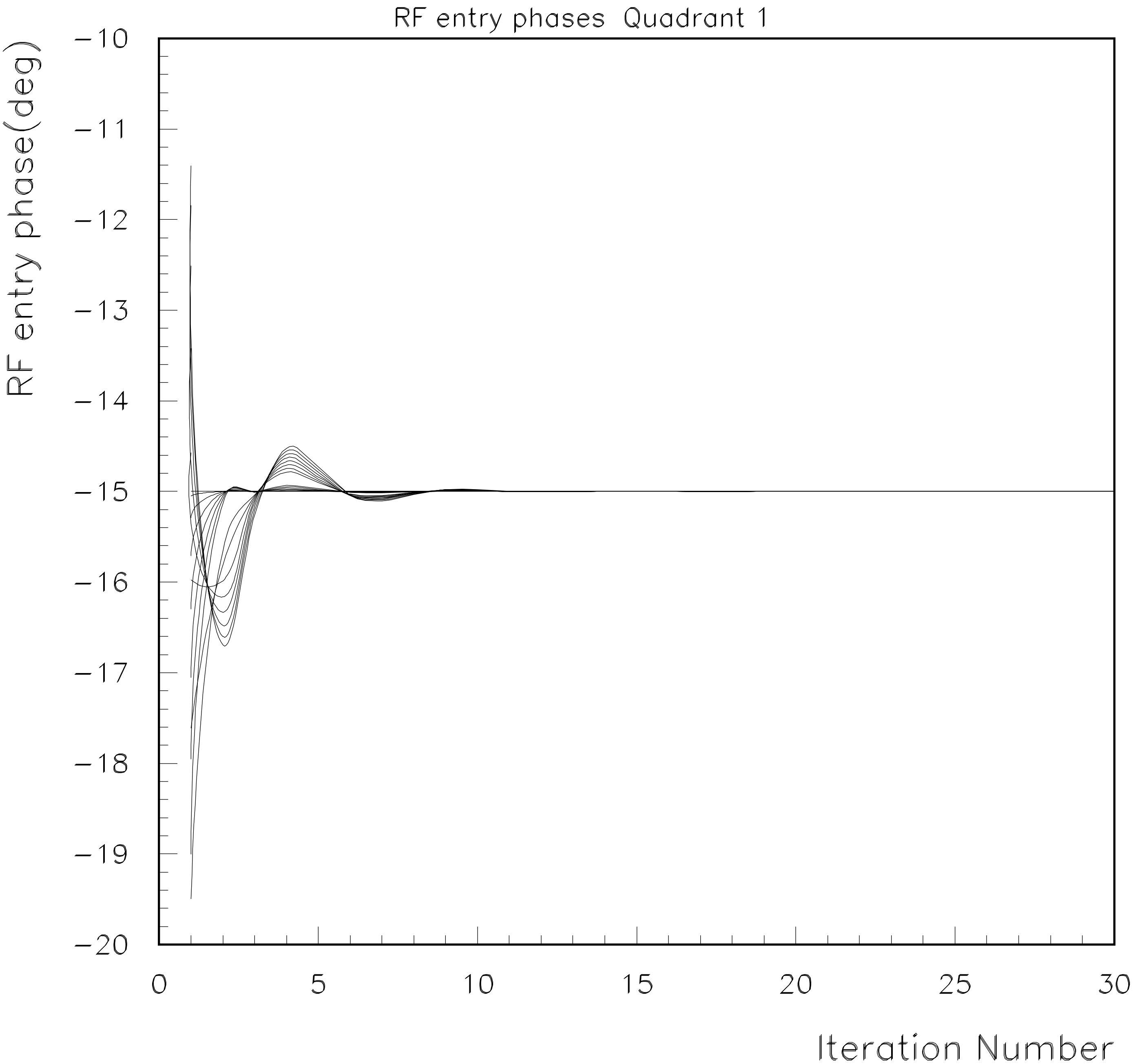


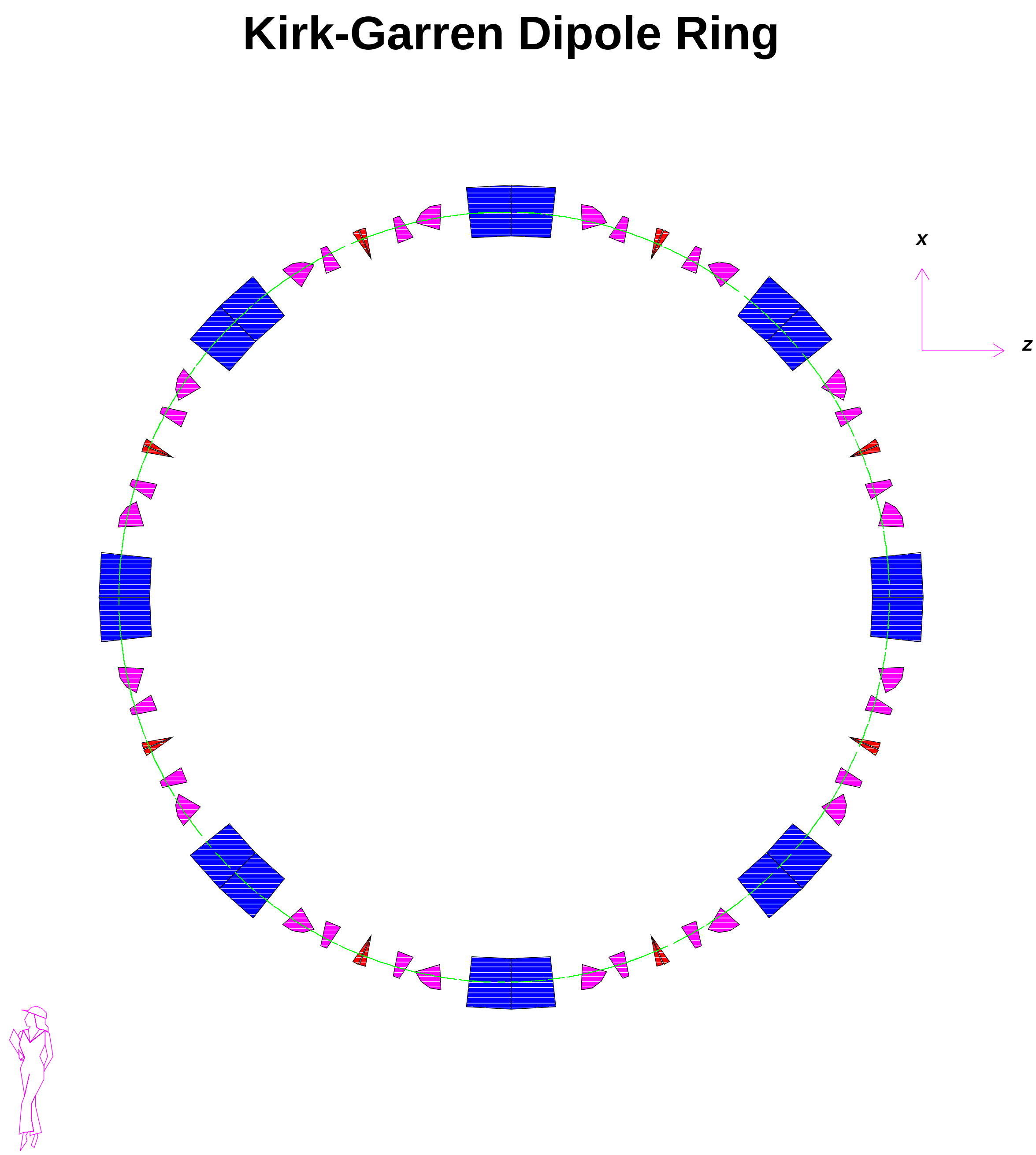
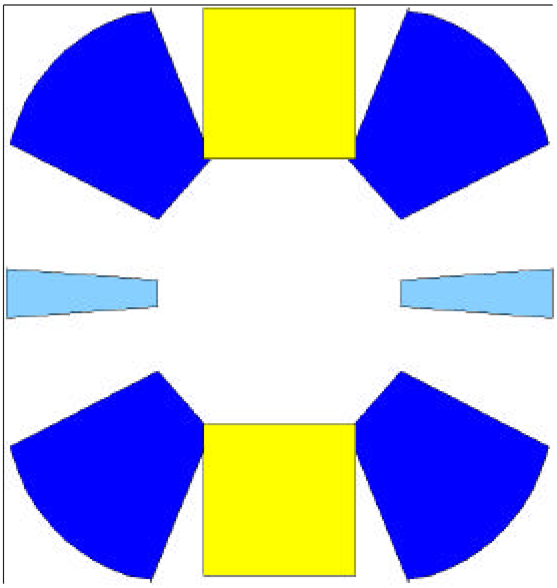
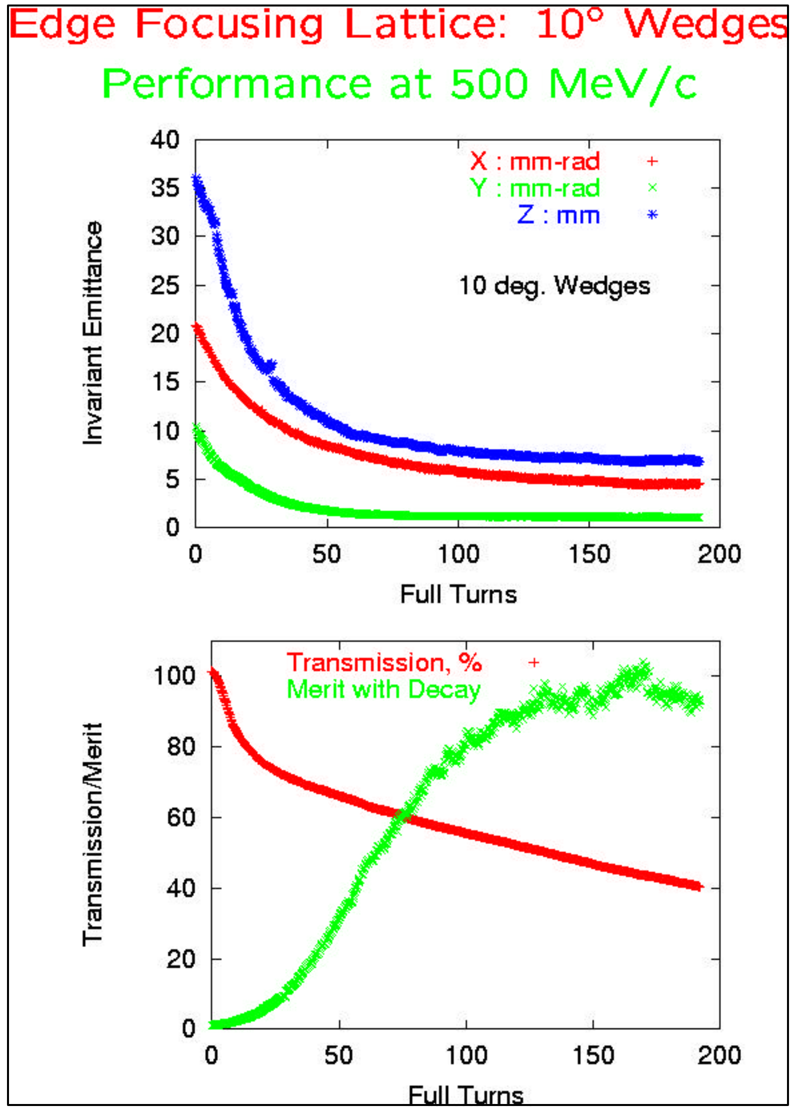


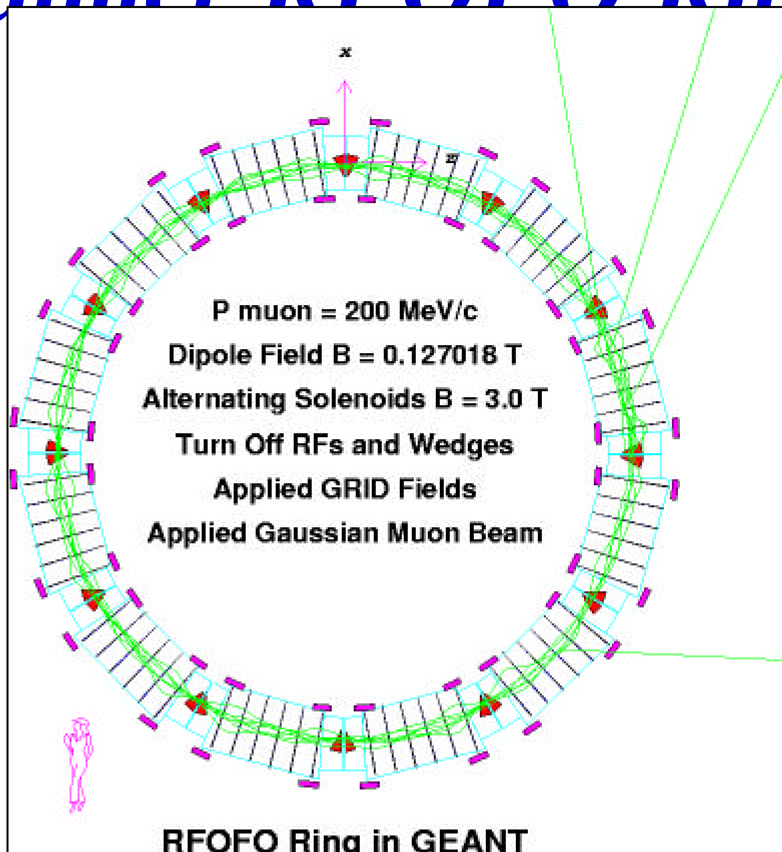
Figure 6: Top view of a dipole cooling ring. $B_y = -1.63574$, $E_m = .25\,GeV$.

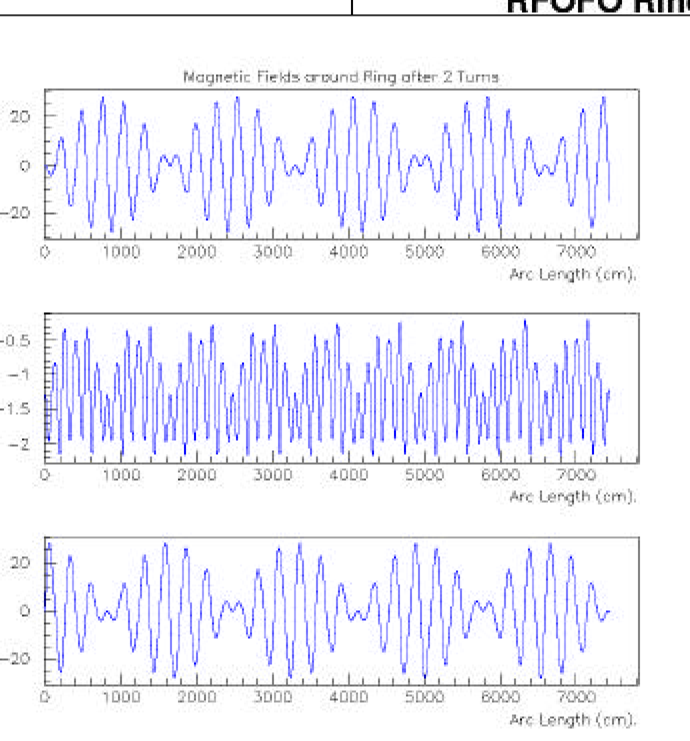
Garren/Kirk Graded Dipole ring

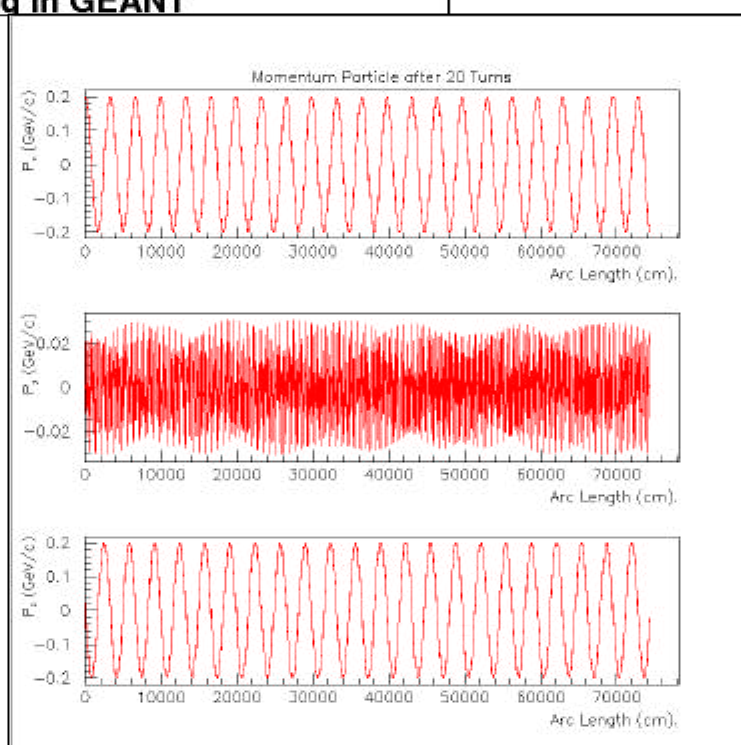




Palmer RFOFO Ring



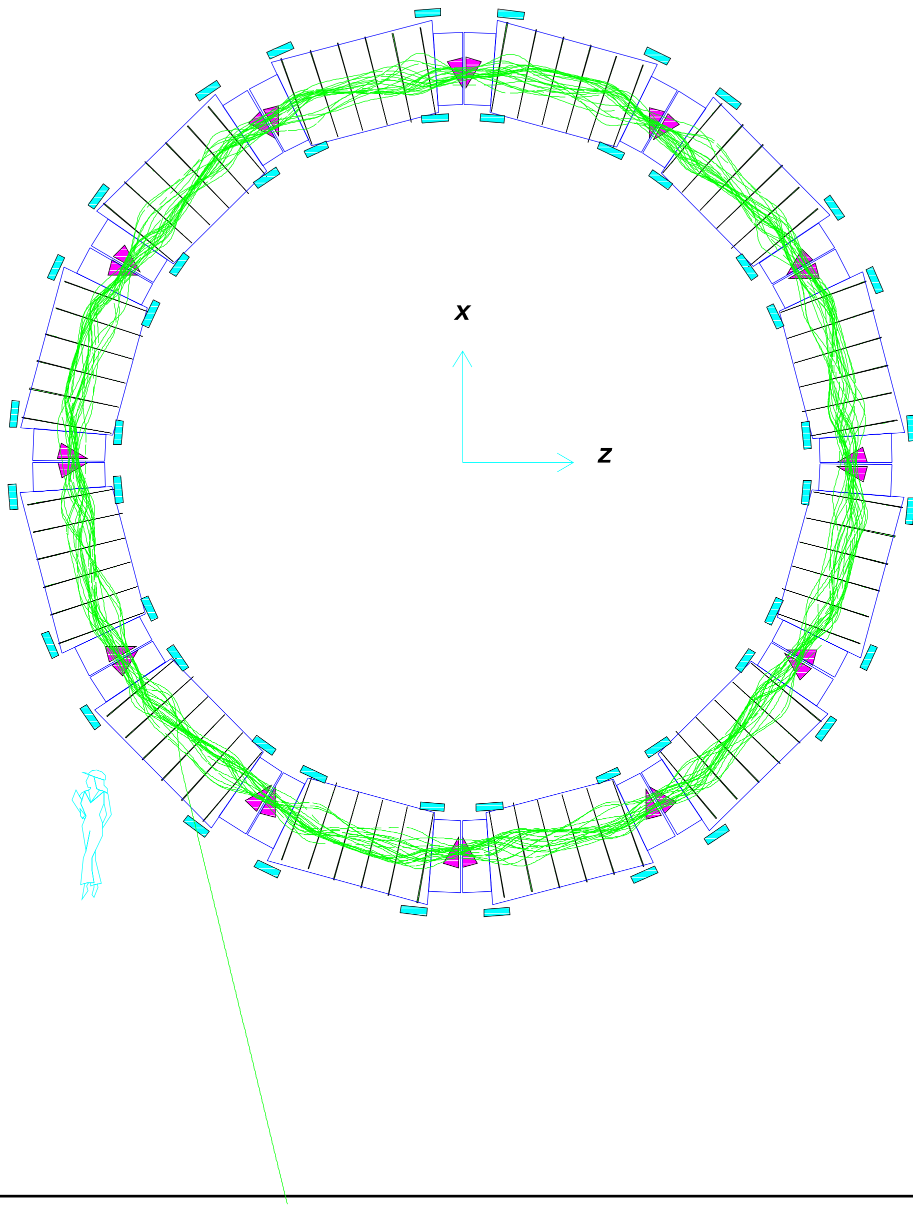




ARTE

RFOFO ring cooler

31/03/03



Future Plans

- Design and Simulate a detailed Injection/Extraction scheme into ring coolers. Geant with its general fields would fit in well here.
- Design a coherent acceleration scheme.
- A complete overall beginning to end simulation for a Neutrino Factory
- A complete overall beginning to end simulation for a Muon Collider.
- Need more Muon Collider/Neutrino Factory Fellows and Postdocs.