Collider Ring

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Muon Accelerator Program Review
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Design Goals

Initial Configuration in FY2012 and Interim Design Feasibility Study in FY2014 featuring:

- Luminosity ~ 10^{34} $cm^{-2}s^{-1}$ at 1.5 TeV c.o.m.
- Acceptable Detector Backgrounds
- Reliability
- Radiation Safety

Design Goals

- Luminosity ~ 10^{34} cm^{-2}s^{-1} at 1.5 TeV c.o.m.
  - β^* = 1 cm
  - 2 interaction points
  - as small as possible circumference C
  - low momentum compaction factor $|\alpha_c| \sim 10^{-5} \rightarrow \sigma_z \leq \beta^*$

$$\langle \mathcal{L} \rangle = f_0 \frac{N_\mu^2}{4\pi\varepsilon_\perp \beta^*} h \times \frac{1}{2} \tau f_{rep} \sim \frac{P_\mu \xi}{C\beta^*} h \tau$$

- Acceptable Detector Backgrounds
- Reliability
- Radiation Safety

Design Goals

- Luminosity ~ 10^{34} $cm^{-2}s^{-1}$ at 1.5 TeV c.o.m.
- Acceptable Detector Backgrounds
  - 1^{st} magnet distance from IP > 6 m
  - IR quad aperture sufficient to accommodate absorbers
  - IR quads cut in < 2 m long pieces with masks in between
  - IR quad displacement to provide dipole field
  - efficient collimation scheme (extraction actually)
- Reliability
- Radiation Safety

Design Goals

- Luminosity ~ 10^{34} $cm^{-2}s^{-1}$ at 1.5 TeV c.o.m.
- Acceptable Detector Backgrounds
- Reliability
  - B-field in magnets well below quench limit (>20% at 1.9°K)
  - magnet protection from heat deposition and radiation damage (open midplane dipoles?)
  - manageable sensitivity to field errors and misalignments (limit on βmax)
  - good beam stability margin
- Radiation Safety

Design Goals

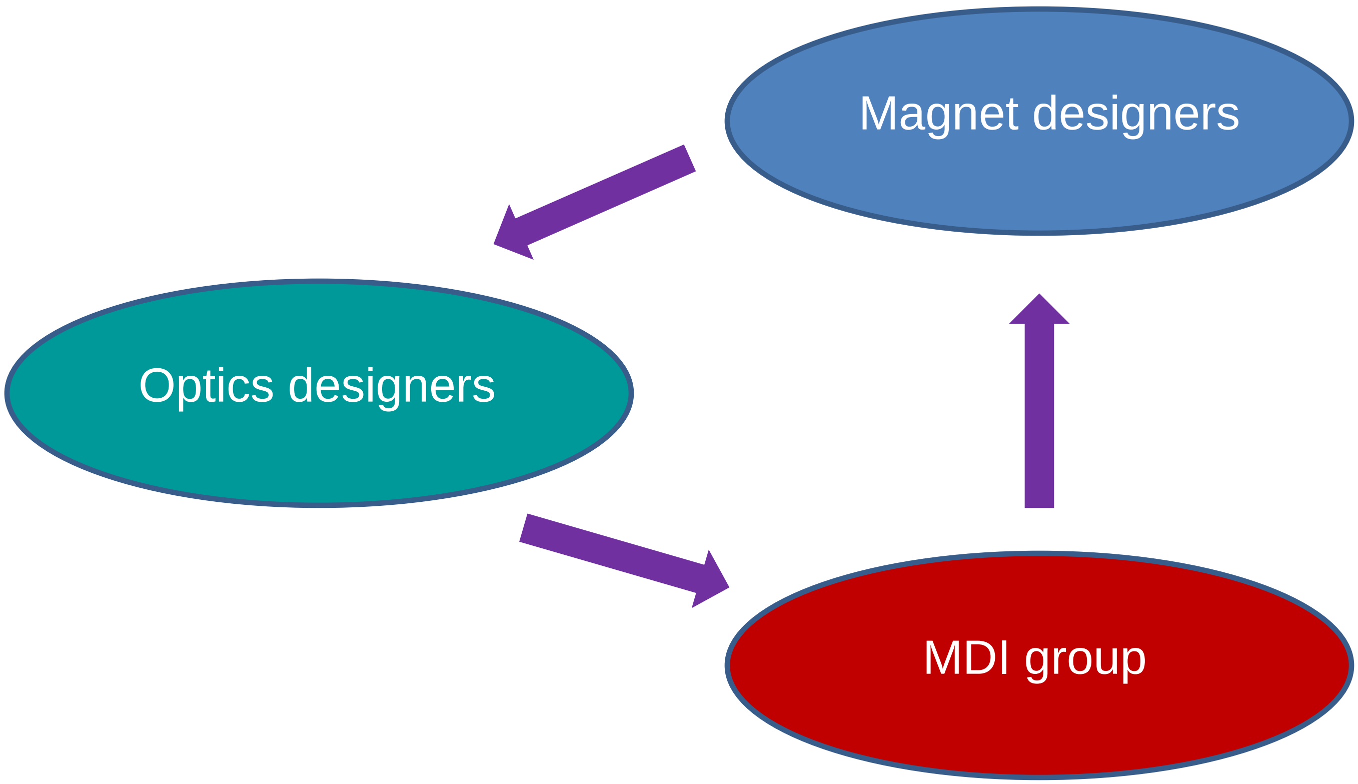
- Luminosity ~ 10^{34} cm^{-2}s^{-1} at 1.5 TeV c.o.m.
- Acceptable Detector Backgrounds
- Reliability
- Radiation Safety
  - avoid long high-beta straights to limit ν-induced dose

$$D_S[Sv] \approx 6.7\cdot 10^{-24}\frac{I_\mu t\, E^3 <B>}{d} l_S \qquad \text{(N.Mokhov, 1999)}$$

with E= 0.75 TeV, <B> =6.3 T, $I_\mu \cdot t = 3\times 10^{20}$ μ- per year, ring depth d = 135 m and l_S = 10 m
D_S~ 4×10^{-4} Sv/yr = 40 mrem/yr = 40% NRC limit for general public, but may be a problem with larger l_S.

1 Sv (Sievert) = 100 rem

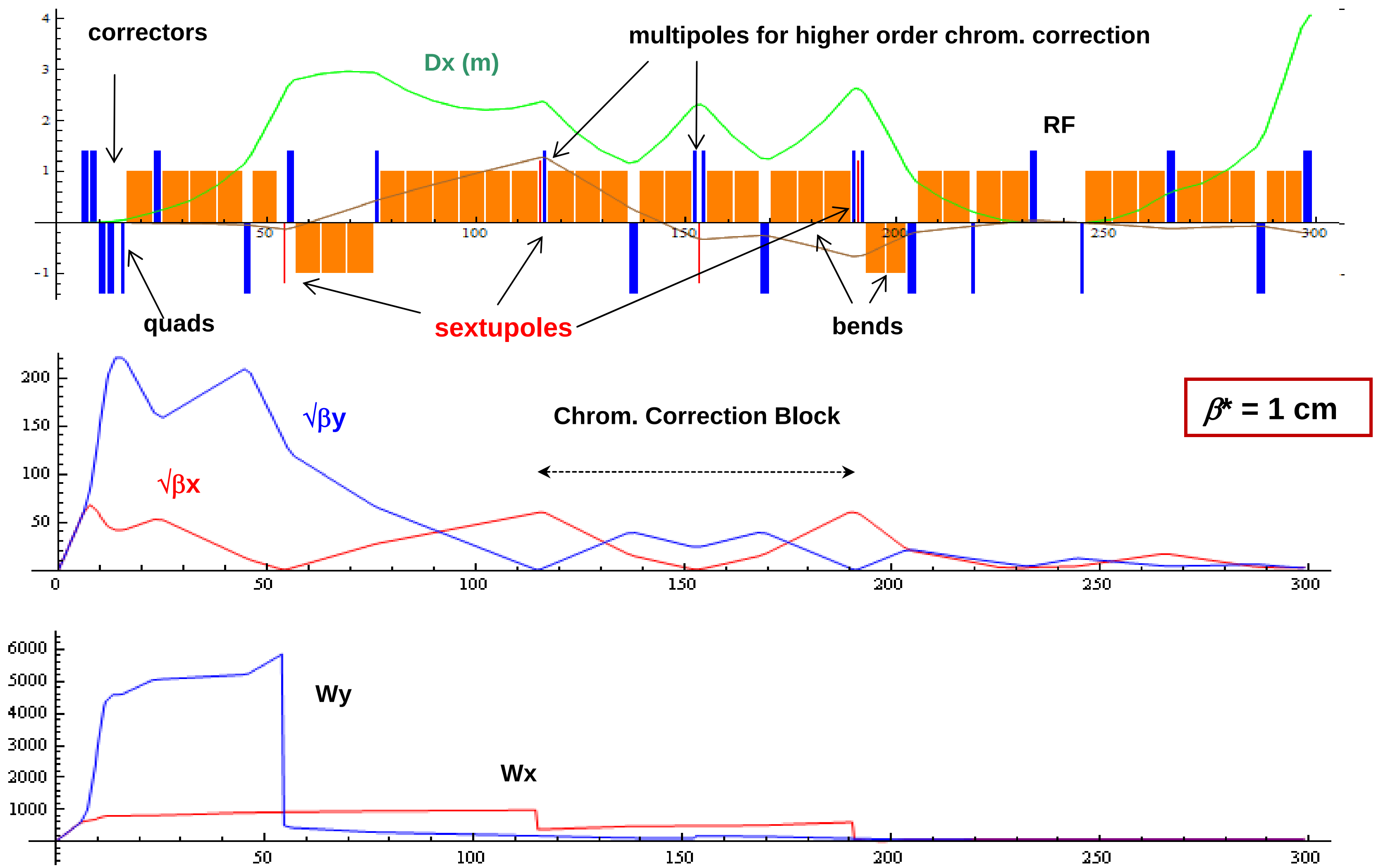
Iterative Approach



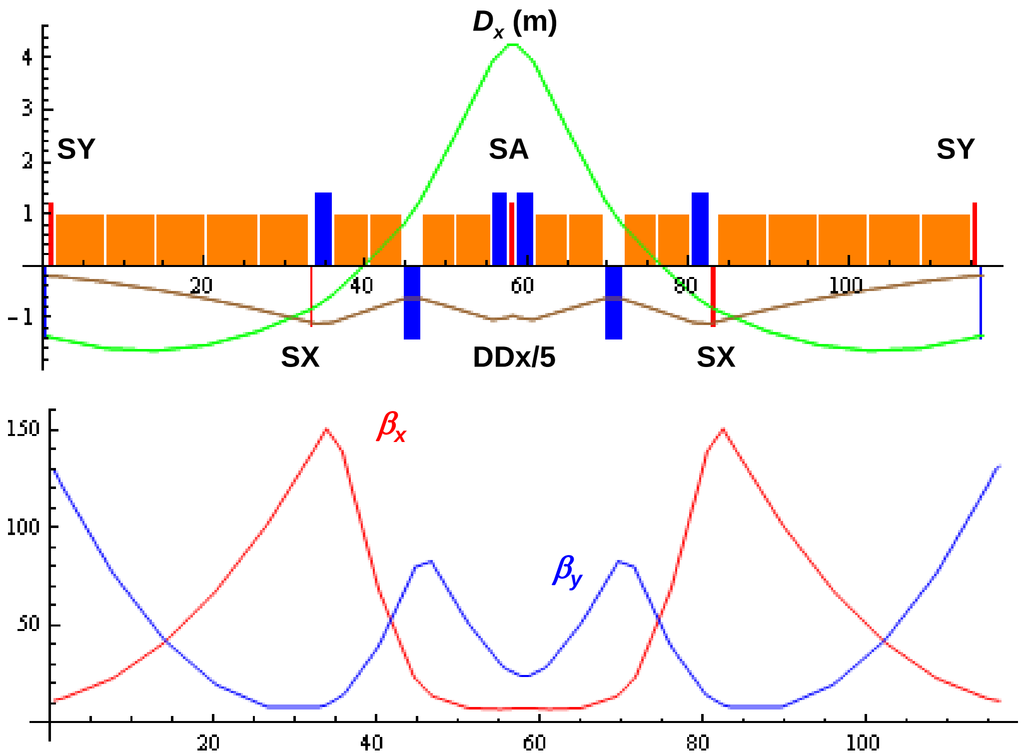
Current Status - Parameters

Beam energy	TeV	0.75
Average luminosity / IP	10^{34} cm^{-2} s^{-1}	1.25
Number of IPs, N_{IP}	-	2
Circumference, C	km	2.5
β*	cm	1
Momentum compaction, α_p	10^{-5}	–1.5
Normalized emittance, $\varepsilon_{\perp N}$	π·mm·mrad	25
Momentum spread	%	0.1
Bunch length, σ_s	cm	1
Number of muons / bunch	10^{12}	2
Beam-beam parameter / IP, ξ	-	0.09
RF voltage at 800 MHz	MV	16
Synchrotron tune	-	0.0006
Repetition rate	Hz	15

Current Status - IR



Current Status - Arcs

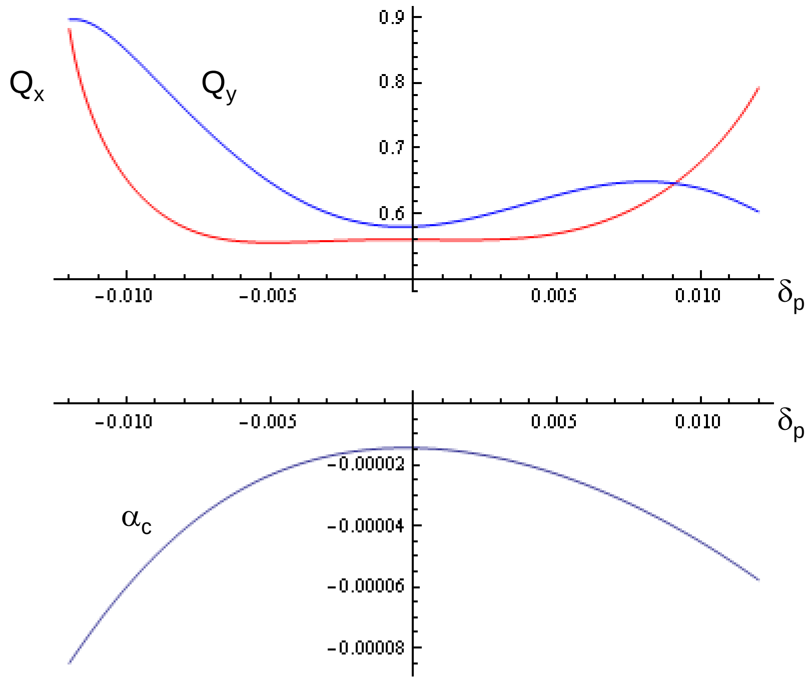


$$\alpha_c = \frac{1}{C}\int_0^C \frac{D_x}{\rho} ds,$$

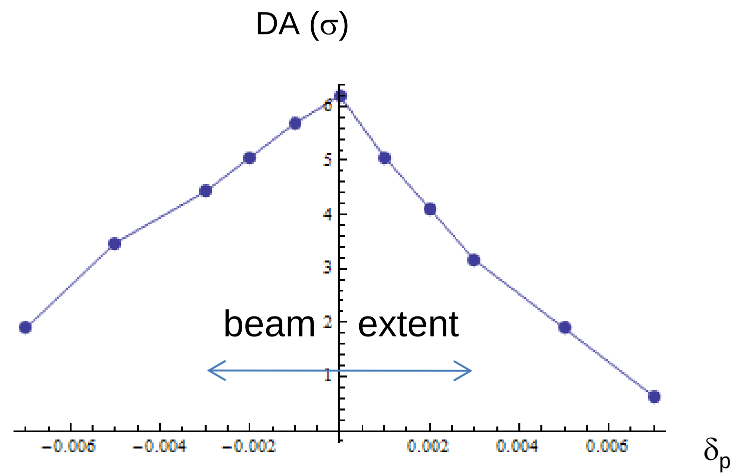
$$\frac{d\alpha_c}{d\delta_p} = \frac{1}{C}\int_0^C \left[\frac{DD_x}{\rho} + \frac{1}{2}(D_x')^2\right] ds$$

- Independent control of chromaticity (by sextupoles SX, SY) and of the momentum compaction factor and its derivative (via D_x and DD_x by central quad and sextupole SA)
- Phase advance 300°/ cell ⇒ spherical aberrations cancelled in arcs consisting of 6 cells
- Large dipole packing factor ⇒ small circumference (C=2.5 km w/o tuning section)

Current Status - Performance



Fractional parts of the tunes and momentum compaction factor vs. momentum deviation



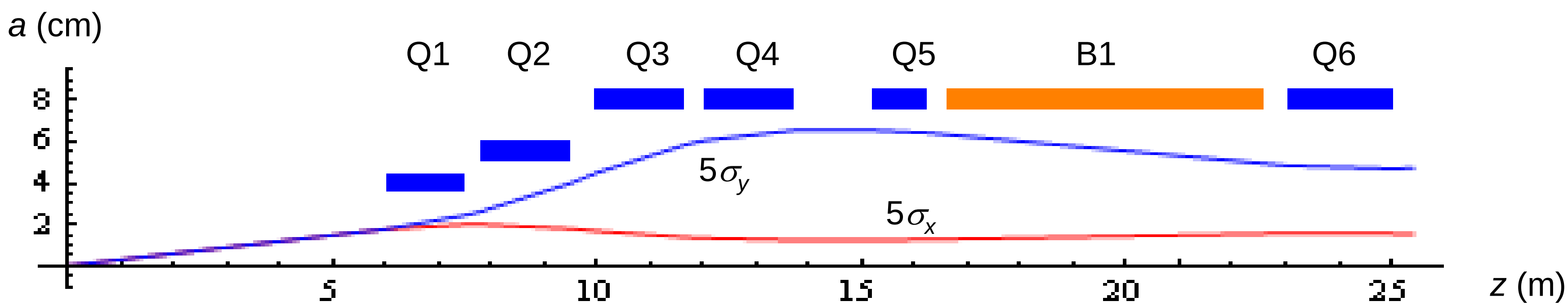
“Diagonal” Dynamic Aperture (Ax=Ay) vs. (constant) momentum deviation in the presence of beam-beam effect (ξ = 0.09/IP) for normalised emittance $\varepsilon_{\perp N}$= 25 μm

Only muons at bunch center tracked !

Current Status – IR Magnets

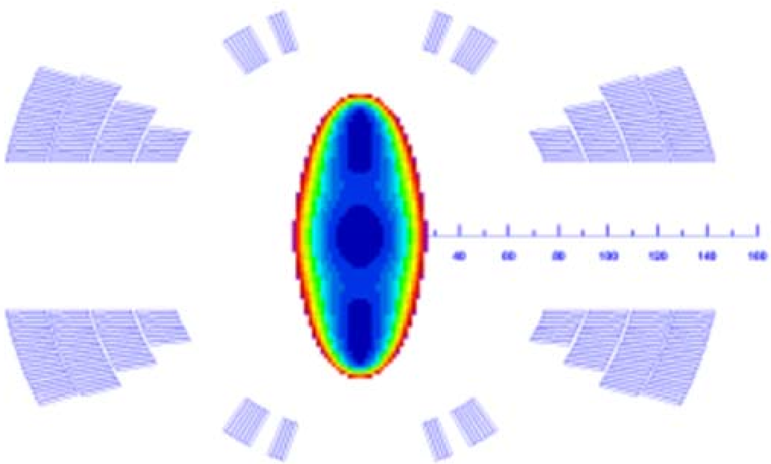
Requirements adopted for this design:

- full aperture 2A = 10sigma_max + 2 cm + 1 cm
- maximum tip field in quads = 10 T (G=200 T/m for 2A = 10 cm)
- bending field 8 T in large-aperture open-midplane magnets, 10 T in the arcs
- IR quad length < 2 m
- Quads Q1–Q6 are horizontally displaced by 1/10 aperture to produce a dipole component



	Q1	Q2	Q3	Q4	Q5	B1	Q6
Gradient (T/m)	250	187	-131	-131	-89		82
Quench @ 4.5°K	282	209	146	146			
Quench @ 1.9°K	308	228	160	160			
Margin @ 4.5°K	1.13	1.12	1.12	1.12			
Margin @ 1.9°K	1.23	1.22	1.22	1.22			
Coil aperture (mm)	80	110	160	160			

Current Status – IR Dipole



IR dipole coil cross-section
and good field region

Coil aperture	mm	160
Gap	mm	55
Nominal field	T	8
Nominal current	kA	17.85
Quench field @ 4.5 K	T	9.82

$$B_y(x,y) + iB_x(x,y) = B_{ref} \times 10^{-4} \sum_{n=1}^{\infty} (b_n + ia_n) \left(\frac{x+iy}{r_{ref}} \right)^{n-1}$$

Rref=40mm
b1=10000
b3=-5.875
b5=-18.320
b7=-17.105

Effect of sextupole component can be completely compensated, effect of higher multipoles is not studied yet.

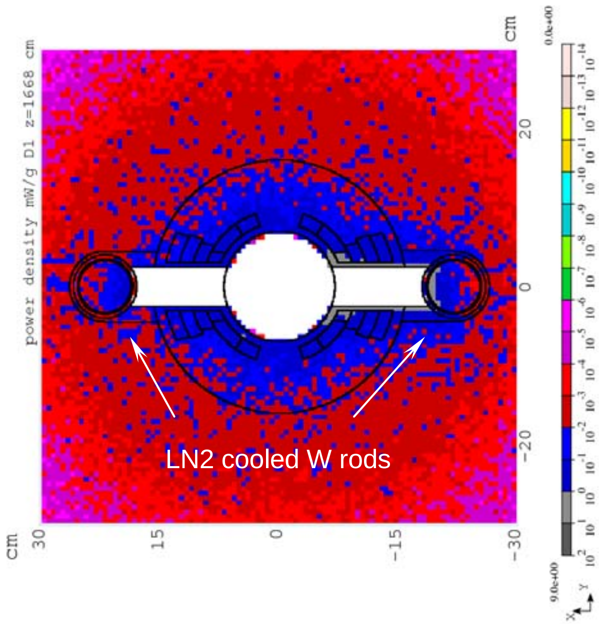
Current Status – Heat Deposition

MARS simulations for three cases :

(i)"standard": 10-cm thick W masks with $\pm 5\sigma_{x,y}$ elliptic openings between IR magnets;

(ii)"standard" + IR quads displacement horizontally by 0.1 of their aperture

(iii)"standard"+ additional W liners inside the IR quads with a $\pm 5\sigma_{x,y}$ elliptic aperture;



MARS model and power density (mW/g) in B1 dipole for case (ii) from two beams dumped after 1000 turns

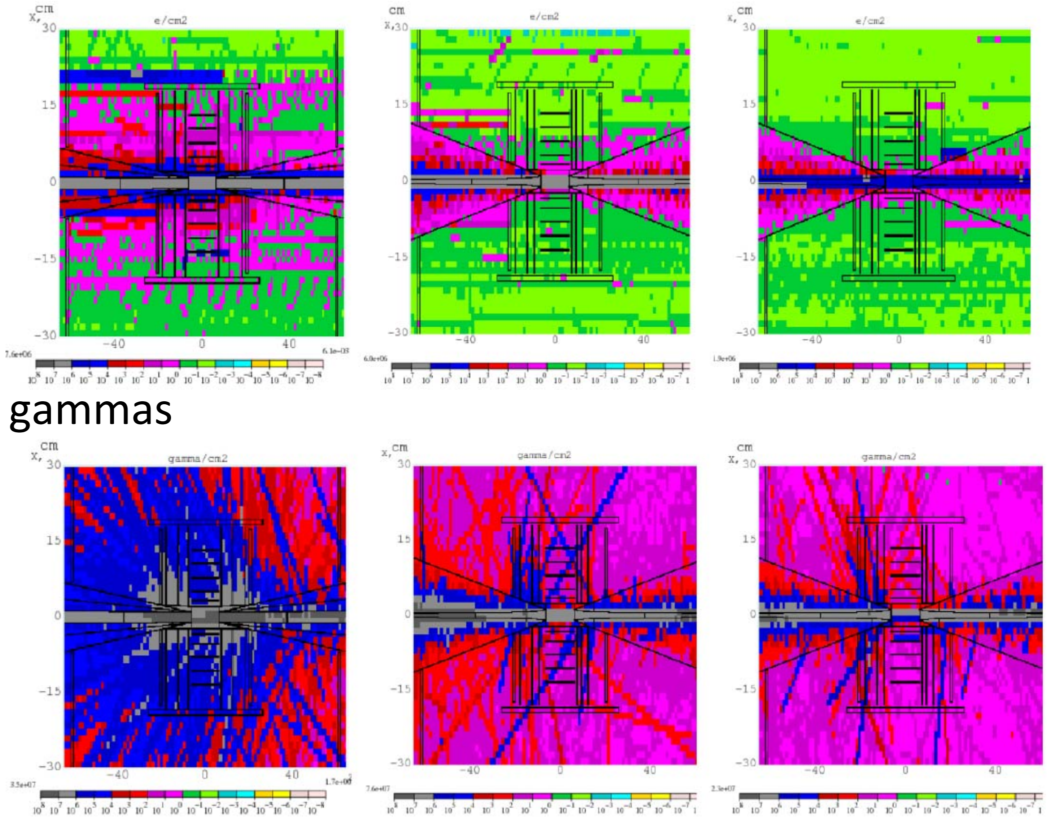
Magnet	(i)	(ii)	(iii)
Q1	5.0	3.0	1.0
Q2	10.	10.	1.0
Q5	3.7	3.7	2.0
B1	3.0	1.9	2.6
Q6	3.6	2.0	2.6

Maximum power density (mW/g) from two beams (limit for Nb_3Sn quads is ~5 mW/g at $J/J_c = 0.9$)

Clearly combination (ii)+(iii) should be used – not simulated yet.

Current Status – Backgrounds

electrons



(a) (b) (c)

Electron and gamma fluxes from 1 beam

Cases:

(a) no masks between magnets, 6° cone with a 5σ radius liner up to 2 m from IP;

(b) 5σ masks inserted between FF quads, cone angle increased to 10°, 5σ liner up to 1 m from IP;

(c) same as (b)plus FF quad displacement

Overall backgrounds are ~ half that in LHC at the same luminosity, will be reduced with further optimization

Pressing Issues

We have a good 1st approximation but the following may significantly change the ring lattice:

- Collimation scheme (extraction in fact – N. Mokhov 1999) may require additional special sections
- β^*-tuning sections: we have a preliminary design with 4 such sections ~70 m long $\rightarrow$ must be shorter for luminosity and neutrino radiation
- Stability of coherent beam-beam oscillations may require unequal phase advances between IPs (n·π in IP1$\rightarrow$IP2 vs (n+1)·π in IP2$\rightarrow$IP1)

Plans - I

- Lattice Design
  - fringe field & systematic multipole correction
  - β^*-tuning sections
  - collimation scheme
  - closed orbit & optics correction scheme
  - injection & abort
  - monochromatization scheme (?)
- RF system
  - accelerating structure design
  - high-order mode analysis
  - impedance & wakefield calculations
  - longitudinal dynamics simulations

Plans - II

- Beam-Beam & Collective Effects
  - incoherent beam-beam simulations
  - transverse impedance & wakefield calculations
  - coherent beam-beam modes stability
  - plasma beam-beam compensation (?)
- Designs for Different Energies/Species
  - IR for 3 TeV c.o.m. collider
  - Higgs / Top Factory (?)
  - μ-p collider (?)

Plans - MDI

- Design & optimization of detector shielding
- Background simulations for 1.5 and 3 TeV c.o.m.
- Radiation & heat load calculations for 1.5 and 3 TeV c.o.m.
- Beam halo collimation
- Auxiliary systems design

The following items will be covered by a parallel Physics-Detector Study

- Detector performance via fast Monte-Carlo simulations
- Full detector simulations, ILCRoot & SiD

Summary

- We have a good 1st approximation for the ring lattice, magnet and detector protection design
- Fermilab has the necessary expertise to complete – in collaboration with other labs – the Interim Design Feasibility Study in FY2014