STUDIES FOR A MUON COLLIDER OPTICS

Contents:

- "Dipole First" Optics
- Oide Optics
- Non-interleaved correction for Dipole First Optics

Eliana GIANFELICE

eliana@fnal.gov

Machine Parameters

Tentative Design Parameters (high transv. emittance scenario)	
E_{beam}	750 GeV
$N_b \times$ Num. of muons/bunch	$1 \times 11.3 \cdot 10^{11}$
ϵ_N	12.3 μm
Δp/p	0.2 %
Bunch length	10 mm
RF Voltage @ 800 MHz	$5.6\times10^3\alpha_p$ GV
Lenght	3141 m
Average Luminosity	2×10^{34} cm^{-2} s^{-1}
β_x^*, β_y^*	10 mm
Number of IPs	2
beam-beam tune shift/IP	0.100

Design Issues

Large β at strong quadrupoles (consequence of the extremely small β^*):

- large chromatic effects $\longrightarrow$ strong sextupoles $\longrightarrow$ reduced DA
- sensitivity to misalignments and field errors

“Advantage” (wrt. hadron machines): long term stability is not required !

Goal is an optics design fullfilling required

- luminosity
- energy acceptance
- DA
- very small $|\alpha_p|$

The design must be robust enough against

- misalignments and field errors

The particular nature of muons makes interactions with Energy Deposition group to finalize the design of the IR extremely important, even more than for electron or proton machines.

Design constraints

Design constraints	
β_x^*, β_y^* $(\epsilon_x = \epsilon_y)$	10 mm
free space around IP	$\pm$ 6 m
$\lvert\alpha_p\rvert$	$\leq 1 \times 10^{-4}$
$\hat{g}$	$\leq$ 220 Tm^{-1}
	$\downarrow$
	k $\leq$ 0.09 m^{-2} @ 750 GeV
$\hat{B}$	10 T

Why 6 m free space?

"Bogacz law":

$$s = f = \frac{1}{K\ell} \simeq \sqrt{\hat{\beta}\beta^*}$$

AN ALTERNATIVE DESIGN ATTEMPT

Previous designs have considered a non local IR chromaticity correction.

Montague chromatic functions describing the change of the twiss parameters with momentum $\delta \equiv \Delta p/p$

$$B \equiv \frac{\Delta\beta}{\beta} \qquad \text{and} \qquad A \equiv \beta\Delta\left(\frac{\alpha}{\beta}\right)$$

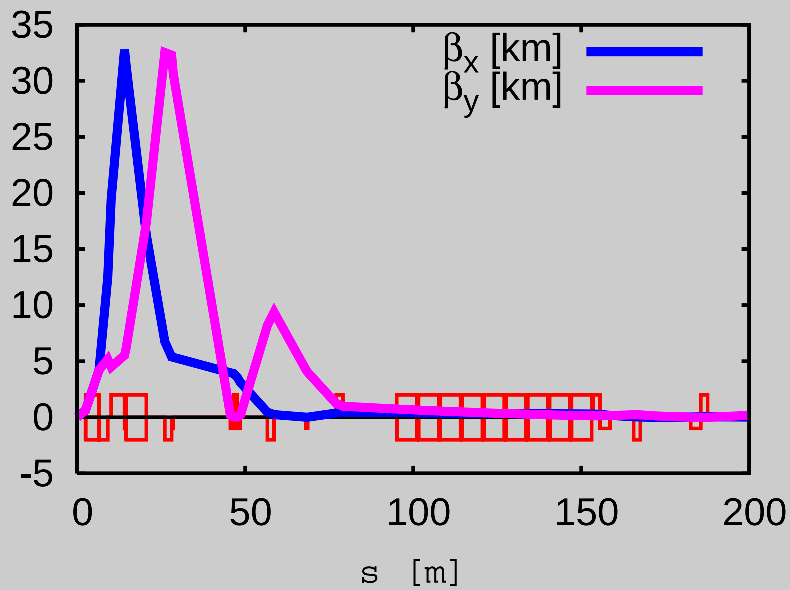
$$\frac{dB}{ds} = -2A\frac{d\mu}{ds} \quad \text{and} \quad \frac{dA}{ds} = 2B\frac{d\mu}{ds} + \sqrt{\beta(0)\beta(\delta)}\Delta K$$

$\Rightarrow$ Introduce bending magnet close to the IP and compensate chromatic beta wave "in loco", that is before the phase advance changes after the first quadrupole.

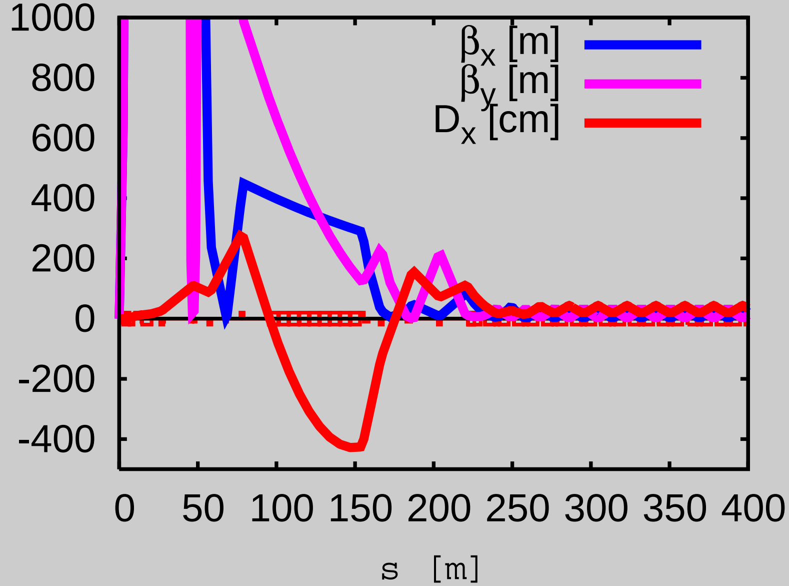
In addition, by introducing large bending angles (with $D_x = D'_x = 0$ at the IP), it is possible to get a negative α_p section which allows to decrease the arc length.

"Dipole First" Optics

Introduce a dipole (B=7.5 T, ℓ=4 m) before the first quadrupole to increase the dispersion at the IR sextupoles. Free space: $\pm$ 2.5 m



IR

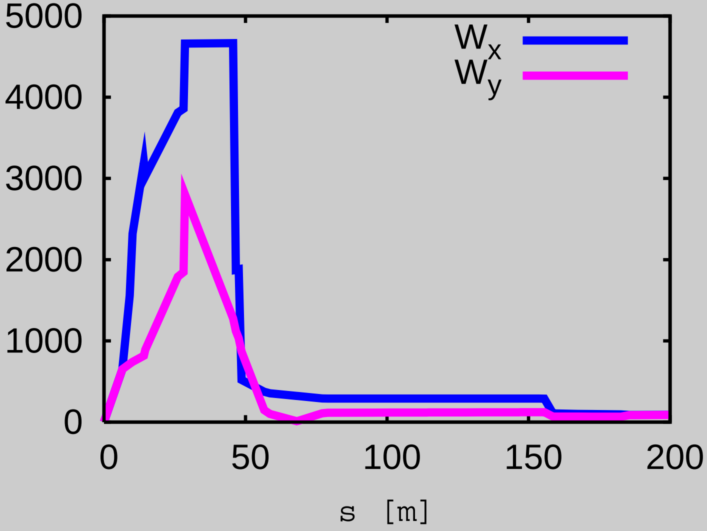


Matching section

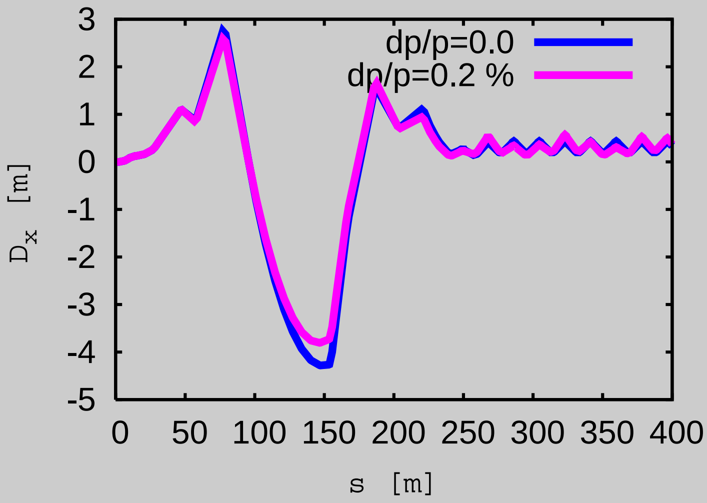
4 sextupoles located at 15, 29, 47 and 69 m correct the chromatic beta.

2 sextupoles at 158 and 185 m correct the 2th order dispersion.

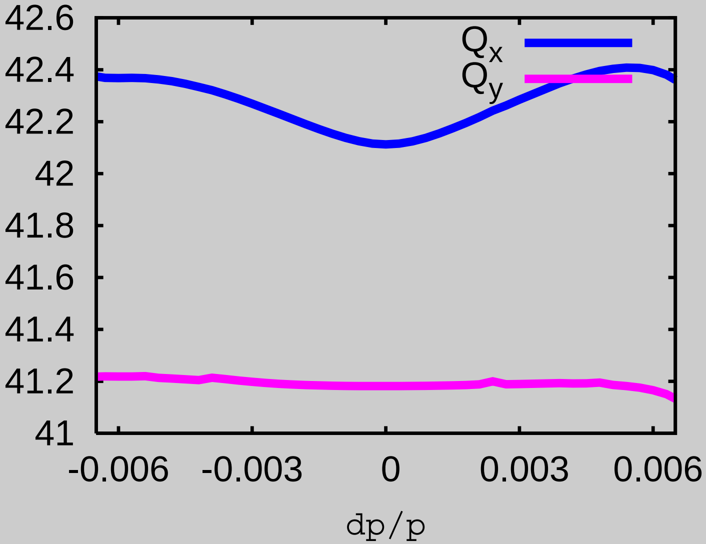
Octupoles are located at 10, 21 and 26 m (detuning correction) and 154 m (2th order chromaticity).



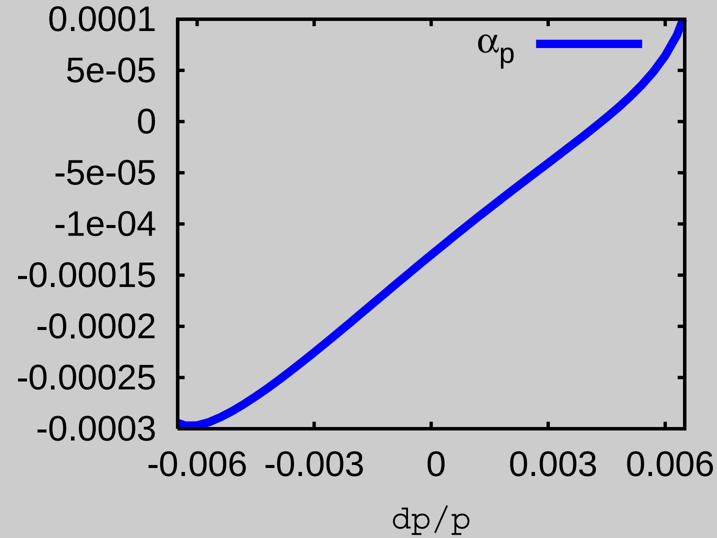
W_x and W_y vs. s



Dispersion



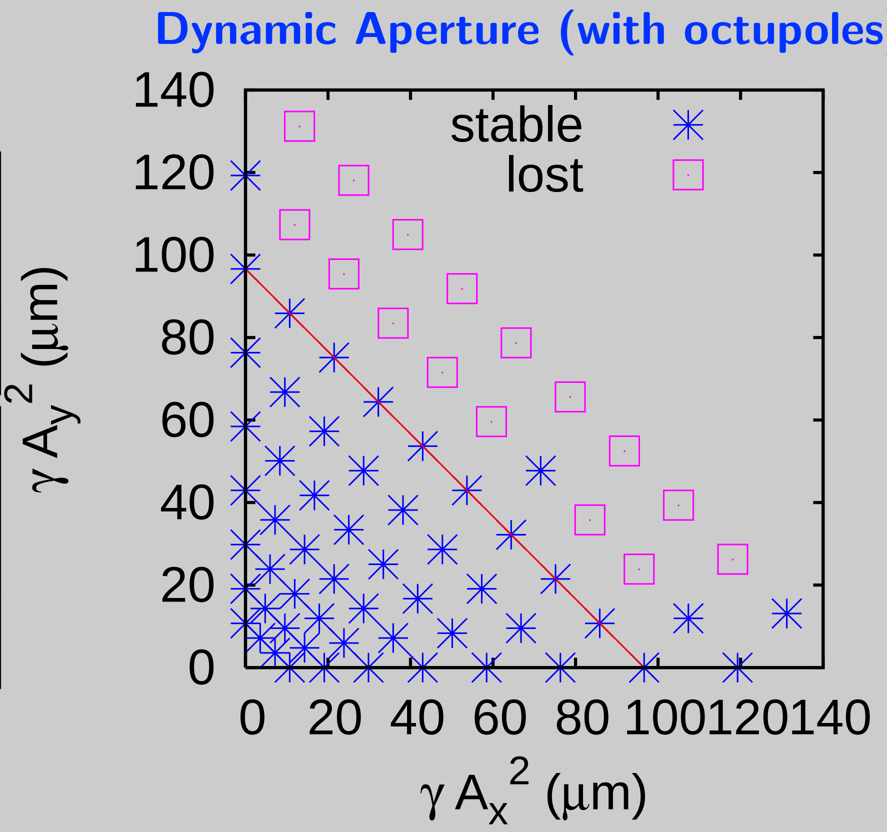
Tunes vs. dp/p



α_p vs. dp/p

(adjustments needed!)

Tune Dependence on Amplitude (with octupoles) (MAD8 STATIC)	
dQ_1/dE_1	0.4×10^8
dQ_1/dE_2	0.2×10^8
dQ_2/dE_2	0.1×10^8



$\simeq$ **2.8** σ

Oide design for a 3 mm β^* optics (1996?).

It uses KEK-B Factory modules for the arcs: 2.5 π phase advance cells

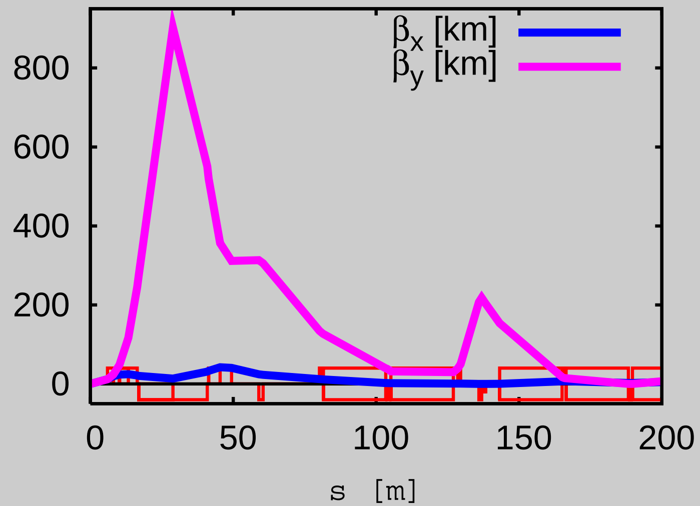
- dispersion (and thus α_p) tunability
- one IP
- *no local* IR chromaticity correction (!)
- non-interleaved sextupole correction: convenient for DA
- 10 families of sextupoles per plane
- octupoles and decapoles included in the optimization

$$L = 5700 \text{ m}$$

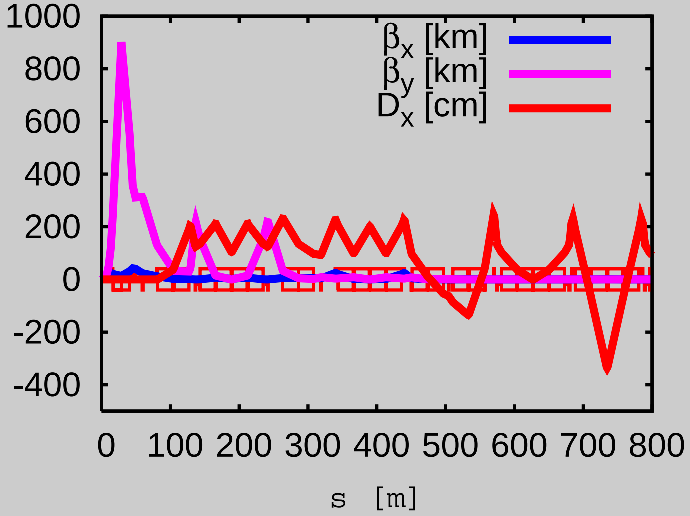
$$\alpha_p = 5 \times 10^{-5}$$

$$Q_x = 31.55 \qquad \xi_x^{nat} = -1237$$

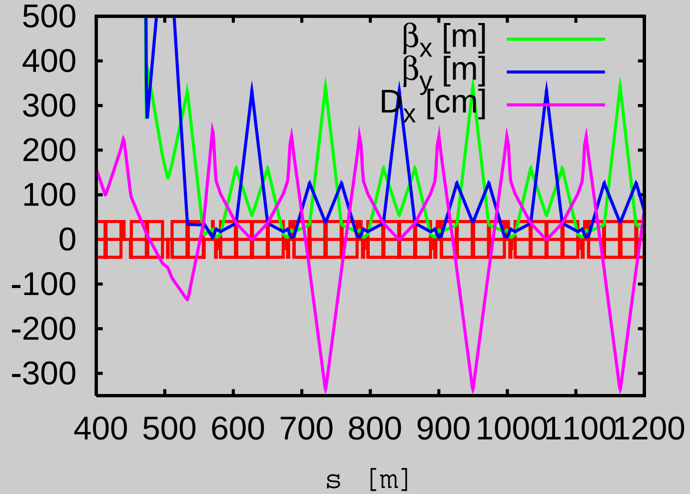
$$Q_y = 31.56 \qquad \xi_y^{nat} = -13249 \ (\hat{\beta}_y = 900 \text{ km!})$$



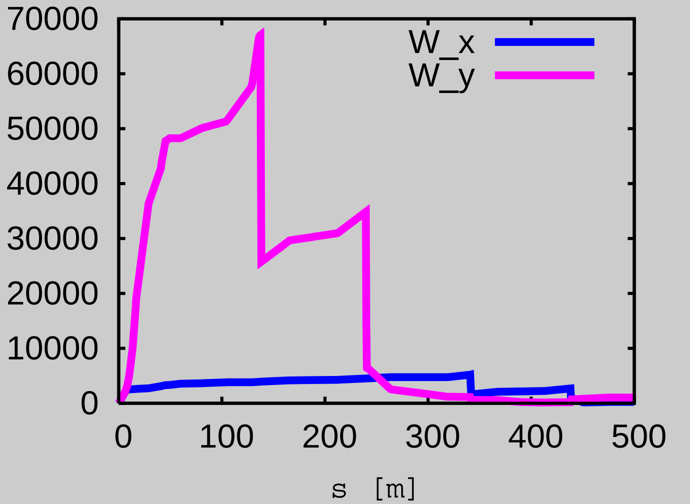
IR



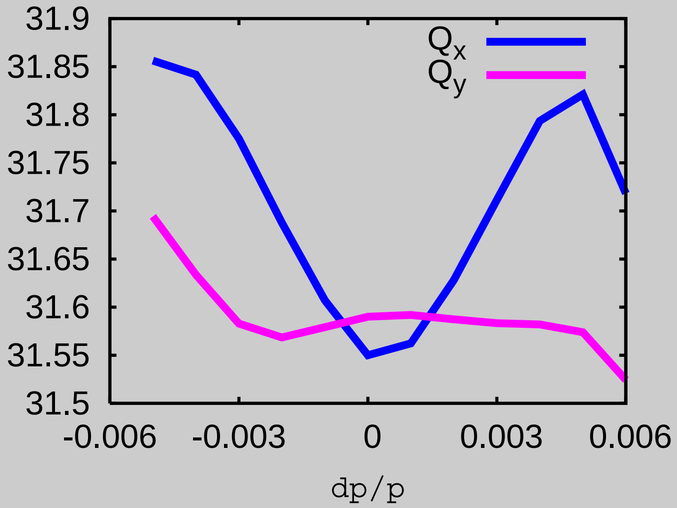
Matching section



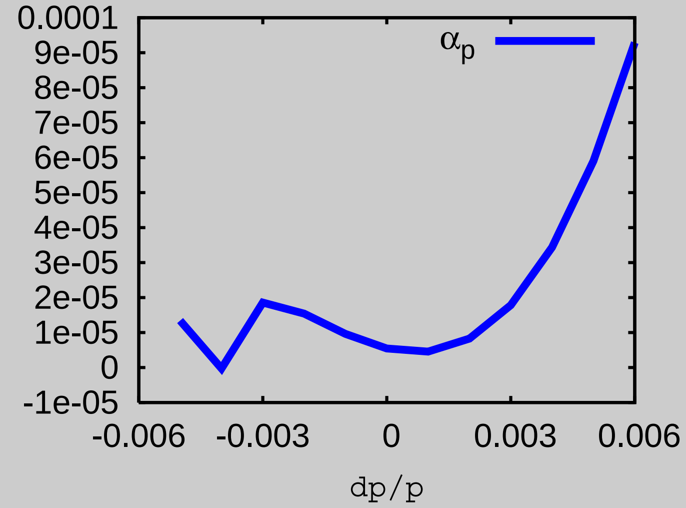
Arc



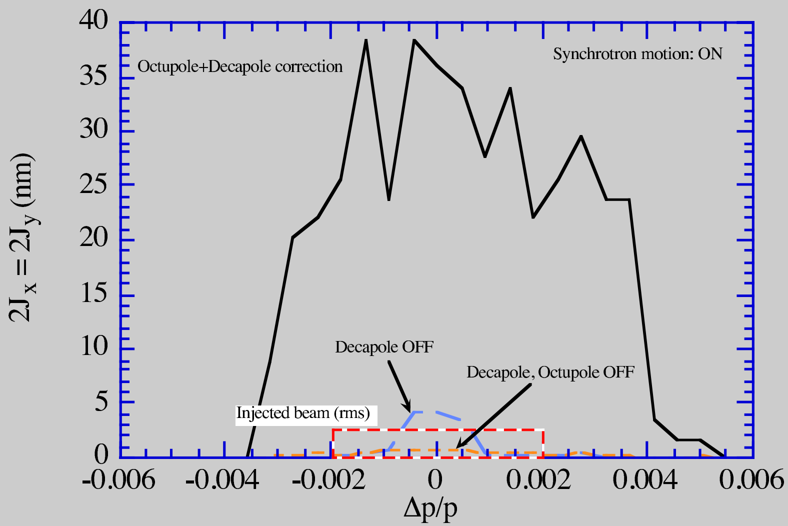
W_x and W_y vs. s



Tunes vs. dp/p



α_p vs. dp/p



$\Leftarrow$

Dynamic aperture with synchrotron oscillations, SAD calculation including quadrupole fringe fields: 4.5 σ at $\Delta p/p = 0$

(K. Oide courtesy)

The Oide design fullfills all requirements with β^*=3 mm (!) But it is not a feasible design[a] because of the large sensitivity to errors.

What can we learn?

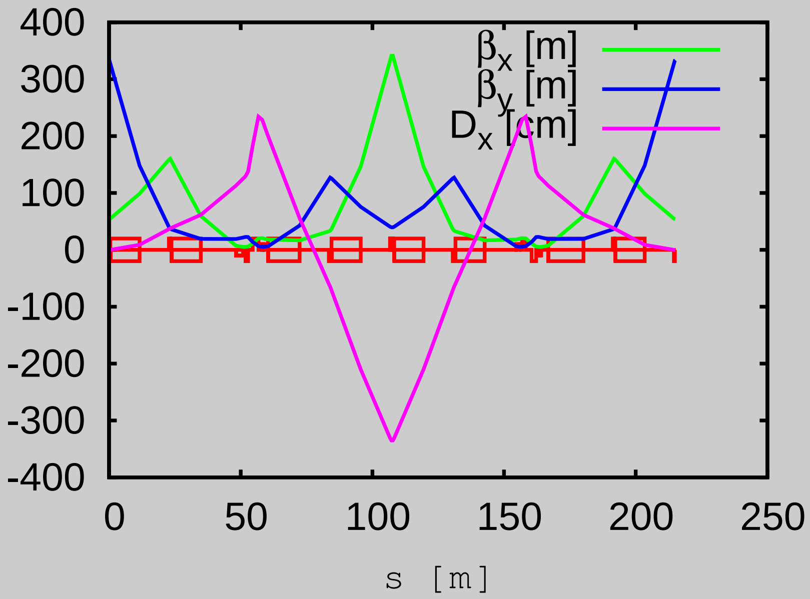
- **keep "conservative" design of β^*=10 mm (better against errors!)**
- **look to a non-interleaved chromaticity correction**

Let's have a closer look.

[a] see Yuri talk at BNL Workshop in Dec 08

Chromaticity Correction in Oide design

The idea: the transfer matrix between couple of sextupoles is a pseudo[a] $-I$ in both planes so that the kicks on a particle going through the two sextupoles cancel each other.



Oide cells have 2.5π phase advance. Each cell is made out of 5 modified FODO cells and includes 4 sextupoles.

[a] $\alpha_1 \neq \alpha_0$

cell #n
QD1 QF1 SD$_n$ QD2 QF2 SF$_n$ QD3 QF3 QD3 SF$_n$ QF2 QD2 SD$_{n+1}$ QF1 QD1

The Oide β functions in the Oide arc cells are unnecessary large, but attempts to reduce them did not work: 6 variables and 11 conditions.

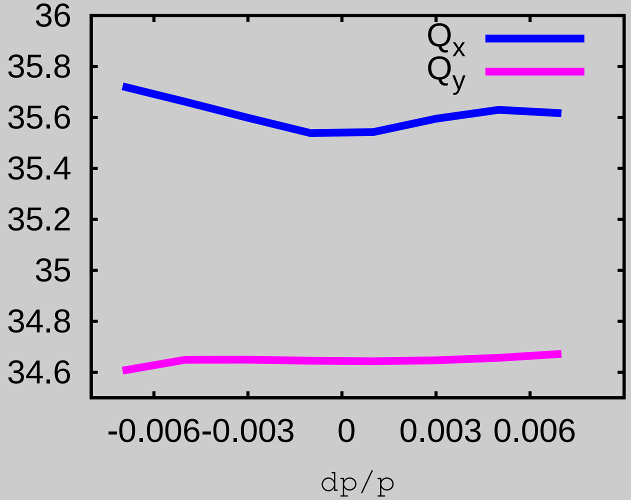
A quick way to get desired transformation is to combine 90 degrees FODO cells.

As first step the "dipole first" IR design has been kept unchanged, including the "in loco" chromaticity correction.

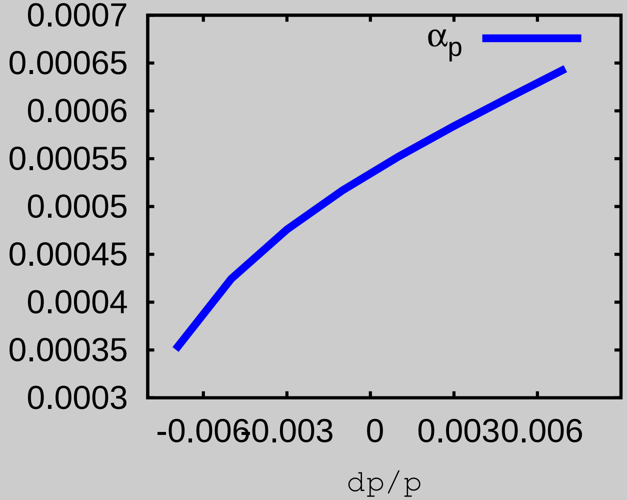
- 1 IP
- Arcs: 2 $\times$ 61 FODO cells, ℓ_B=9 m (large D_x)
- L=3815 m
- Q_x=35.524, Q_y= 34.643, α_p=5$\times 10^{-4}$ (!)
- 48 sextupoles per plane, up to 12 families possible if needed

cell 1	cell 2	cell 3	cell 4	cell5	...	cell 61
SFA	-	SFA SDA	-	SDA	...	SDN

3 sextupole family per plane used to correct arc linear chromaticity and to control tunes vs. momentum; no attempt done to control α_p.



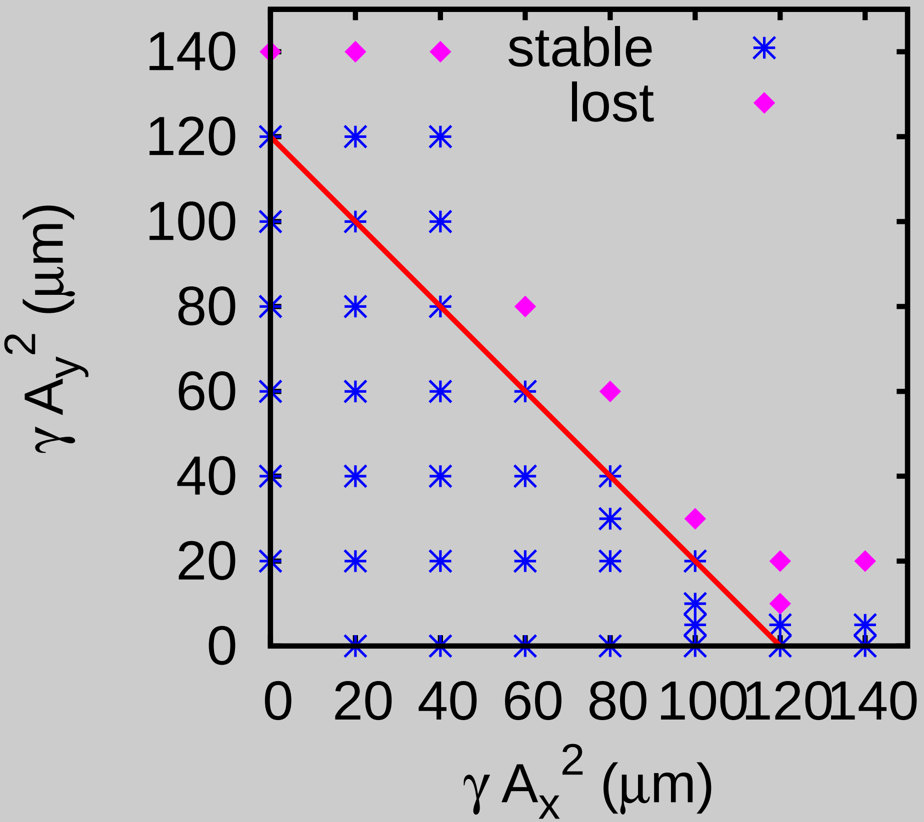
Tunes vs. dp/p



α_p vs. dp/p

Dynamic Aperture with octupoles (MadX-PTC)

Tune Dependence on Amplitude (with octupoles) (MAD8 STATIC)	
dQ_1/dE_1	**0.1×10^6**
dQ_1/dE_2	**0.2×10^4**
dQ_2/dE_2	**-0.2×10^7**



SUMMARY AND OUTLOOK

Energy (GeV)	Dipole First	Oide (96)	Dipole First with 90 deg.FODO
L (m)	3132	5670	3815
B_{dip} (T)	9.6	3.7	9.7
Tunes	42.11/41.18	31.55/31.56	35.52/34.64
β^* (mm)	10	3	10
$\hat{\beta}$ (km)	33	901	33
# of IPs	2	1	1
distance to first quad (m)	$\pm$6 (2.5)	$\pm$6	$\pm$6 (2.5)
DA (# of σ)	2.8	4.5	3
momentum aperture	$\pm$ 0.6 %	$\pm$ 0.6 %	$\pm$ 0.7 %
α_p	-1.3$\times 10^{-4}$	5$\times 10^{-5}$	5$\times 10^{-4}$
length of RF sections (m)	-	2 $\times$ 1.5	-

- **The IR of the Dipole first optics has been matched to 90 degrees FODO cells; only 1 IP has been included with “in loco” chromaticity correction.**
- **The arc chromaticity has been corrected by non-interleaved sextupoles.**
- **The dynamic aperture is 7.5 σ when the motion is purely horizontal and 3 σ otherwise.**
- **One of the IR sextupoles has been identified to be the reason for the limited stability of the vertical motion: y=17 σ is stable, when the sextupole is switched off.**
- **An improvement of the DA of the “in loco” chromaticity correction being likely not feasible, a non-interleaved correction of the IR chromaticity will be considered next. This implies a re-design of the IR.**

Acknowledgments

Yuri Alexahin