SLAC effort in the collider design

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U.S. DEPARTMENT OF ENERGY
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SLAC NATIONAL ACCELERATOR LABORATORY

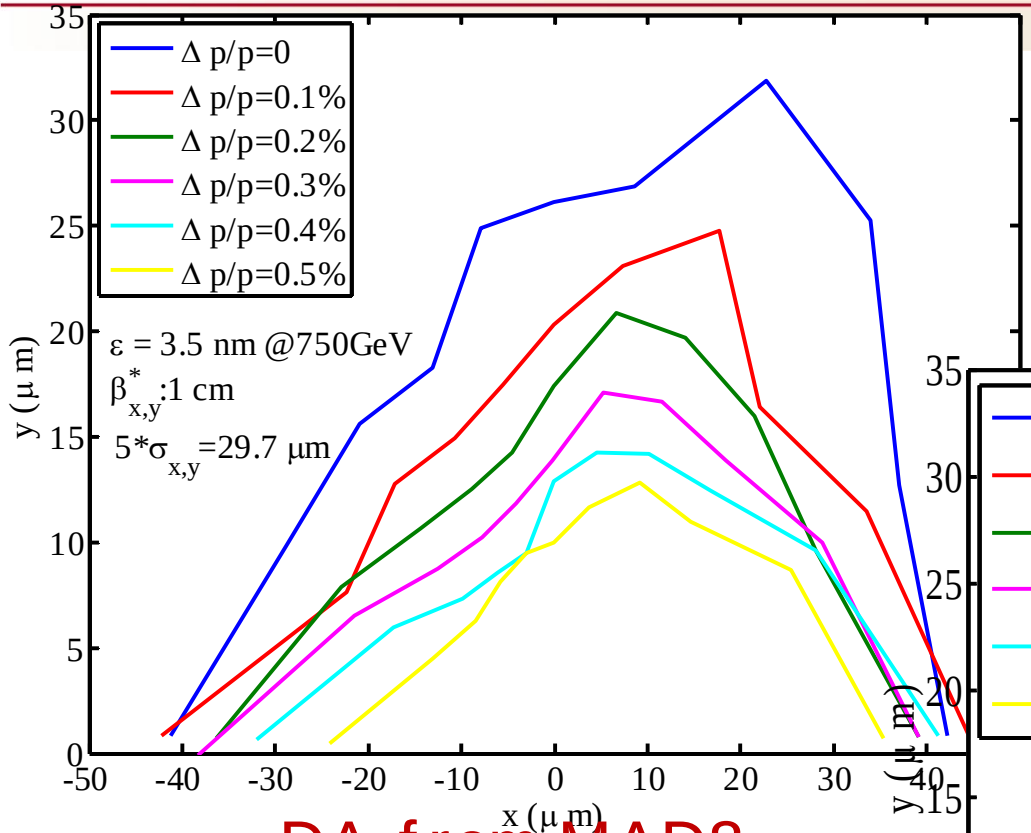
Outline

- Introduction
- Choosing of IP beta
- Linear optics
- Chromatic correction
- Beam dynamics properties
- Summary

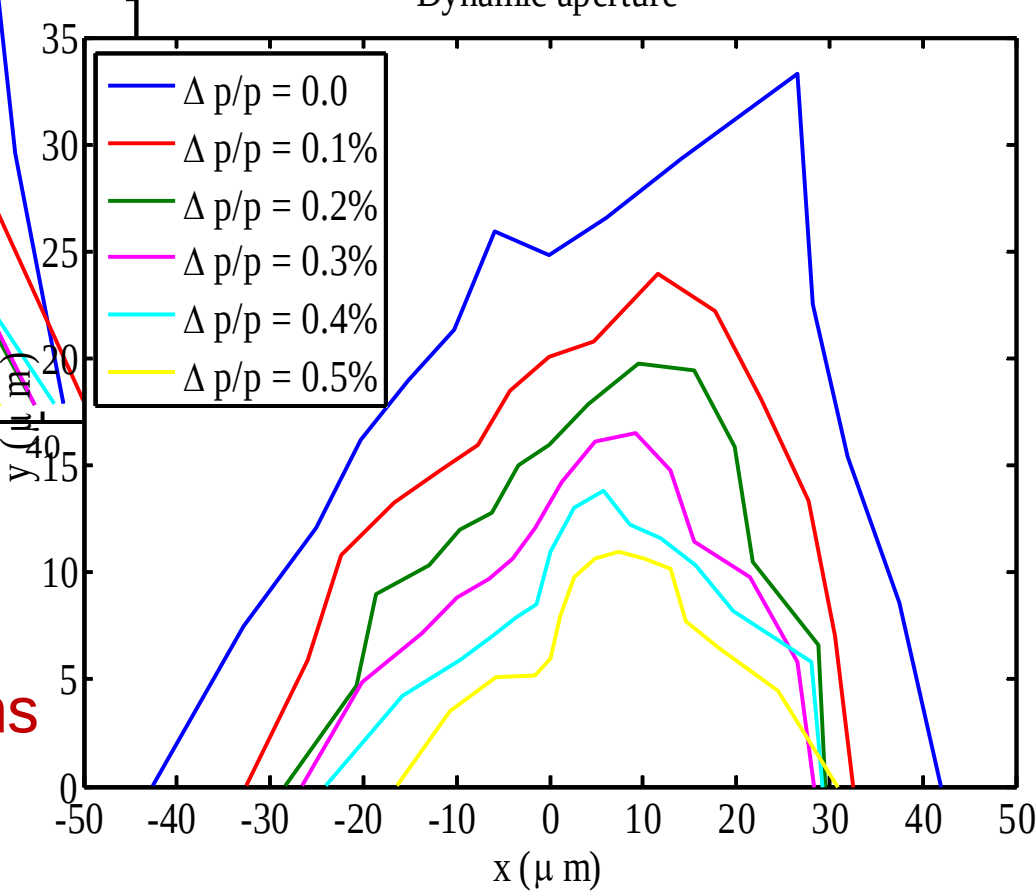
Introduction

- CMS energy 3 TeV
- High luminosity
- Low β^*
- Small circumference
- Sufficient momentum acceptance (~1%)
- Sufficient dynamic aperture for a beam with normalized emittance of ~25 μmrad
- Absence of long straight to avoid hot spot of neutrino radiation

Benchmark of 1.5 TeV Muon Collider design
(by Y. Alexahin et al)



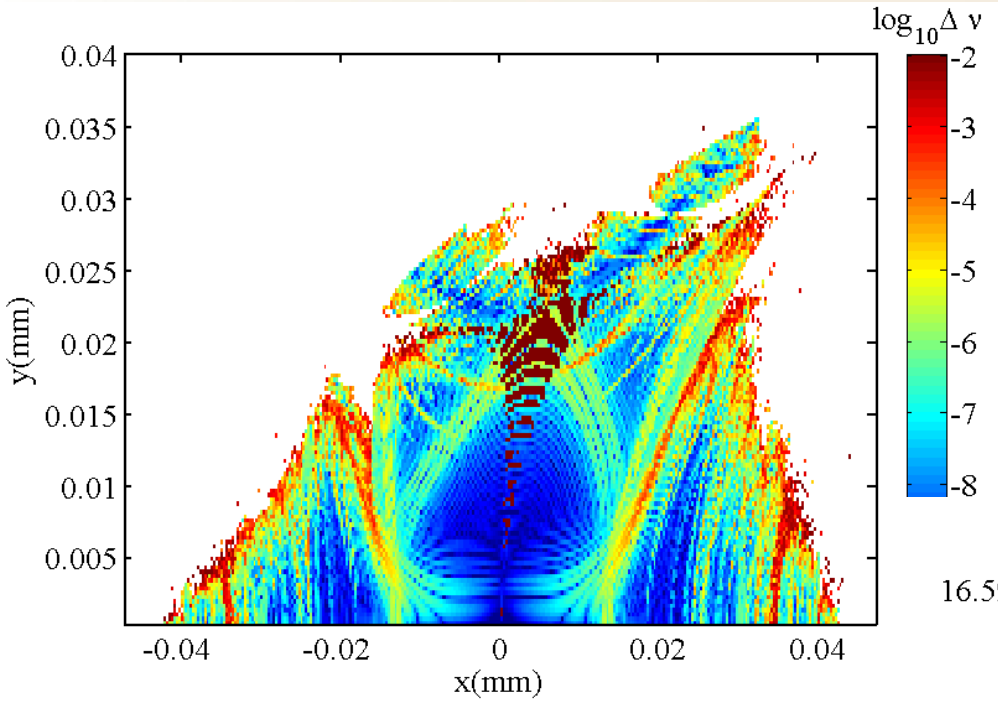
DA from MAD8



DA from LEGO

5σ in X, Y and δp dimensions

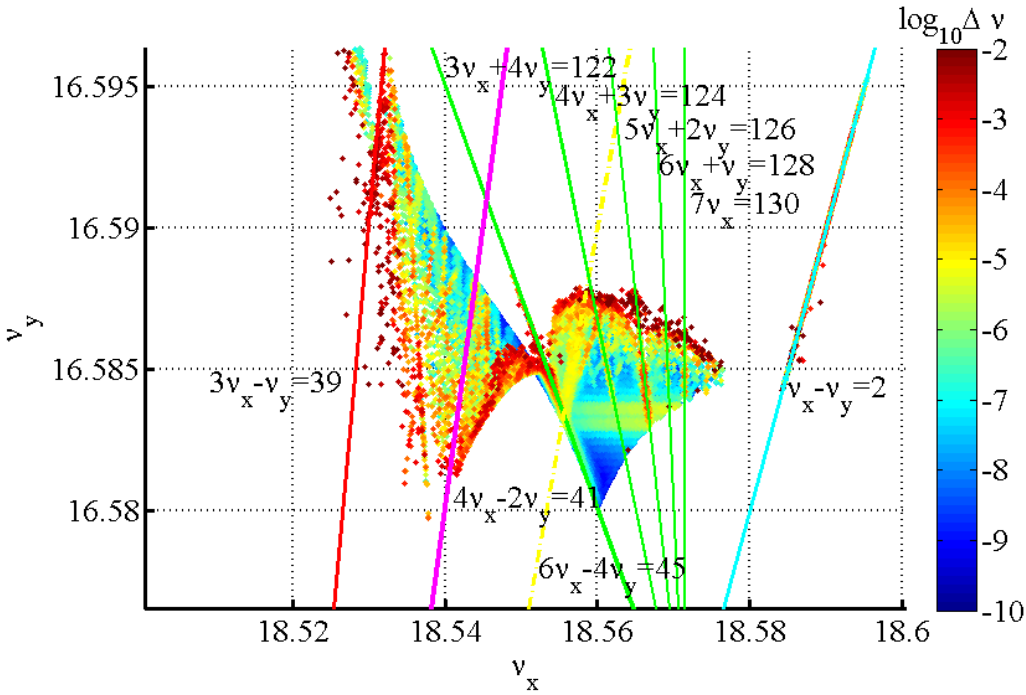
Frequency Map for the 1.5 TeV design



7th order sum resonances $3\nu_x+4\nu_y$, $4\nu_x+3\nu_y$, $5\nu_x+2\nu_y$, $6\nu_x+\nu_y$, and $7\nu_x$

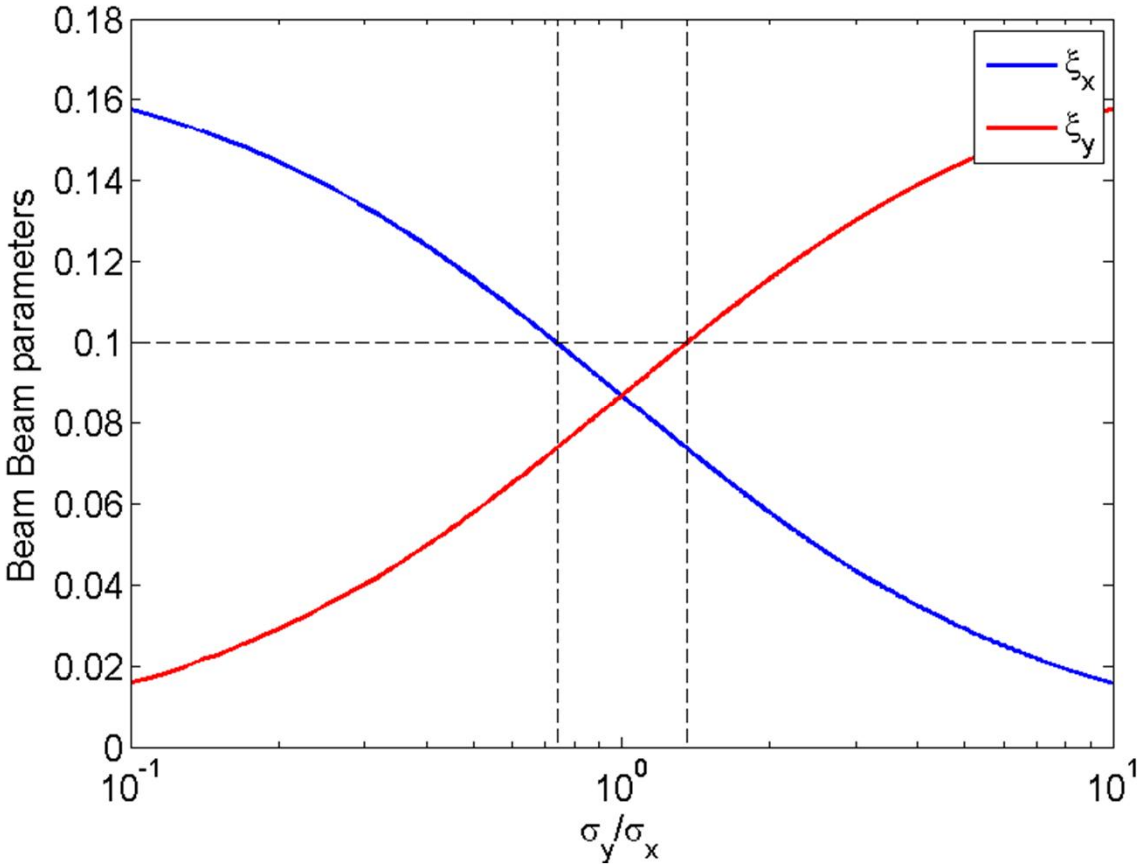
Difference resonances $\nu_x-\nu_y$, $3\nu_x-\nu_y$, $4\nu_x-2\nu_y$, $6\nu_x-4\nu_y$

Tune footprint



Beam-Beam parameter versus x&y beam size

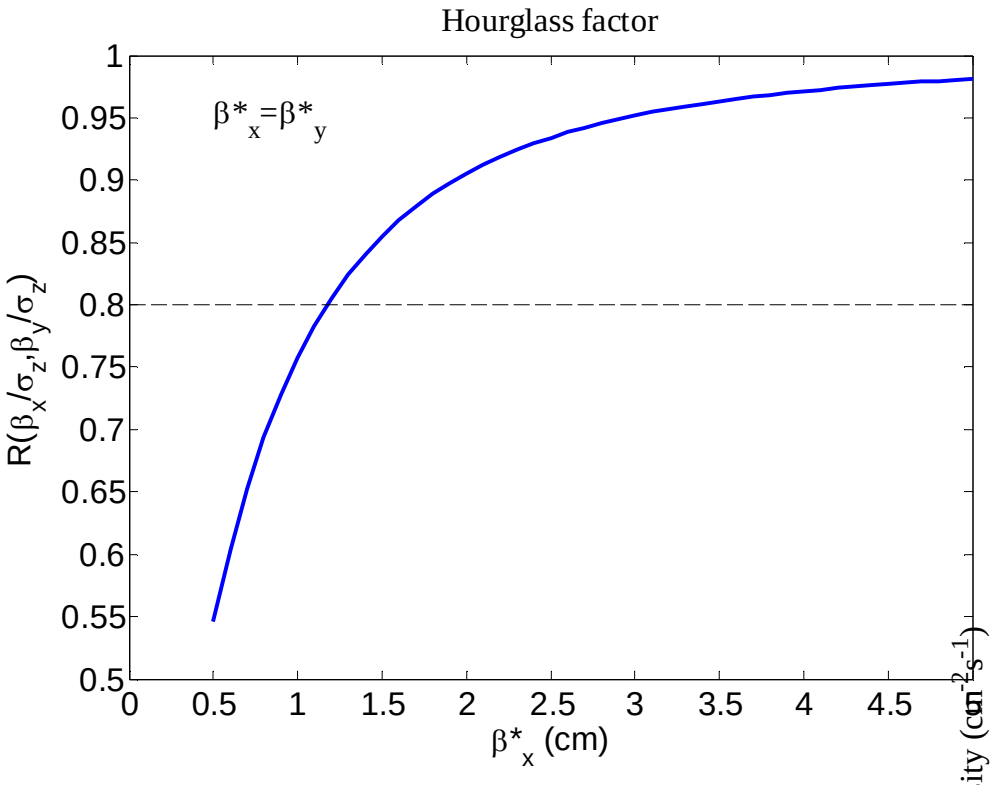
- Muon energy 1.5 TeV
- Normalized rms x & y emittance 25 μm.rad
- Bunch length 1 cm
- Particles per bunch 2e12
- Limit beam-beam parameter at IP to ≲0.1 → $\sigma_x \approx \sigma_y$



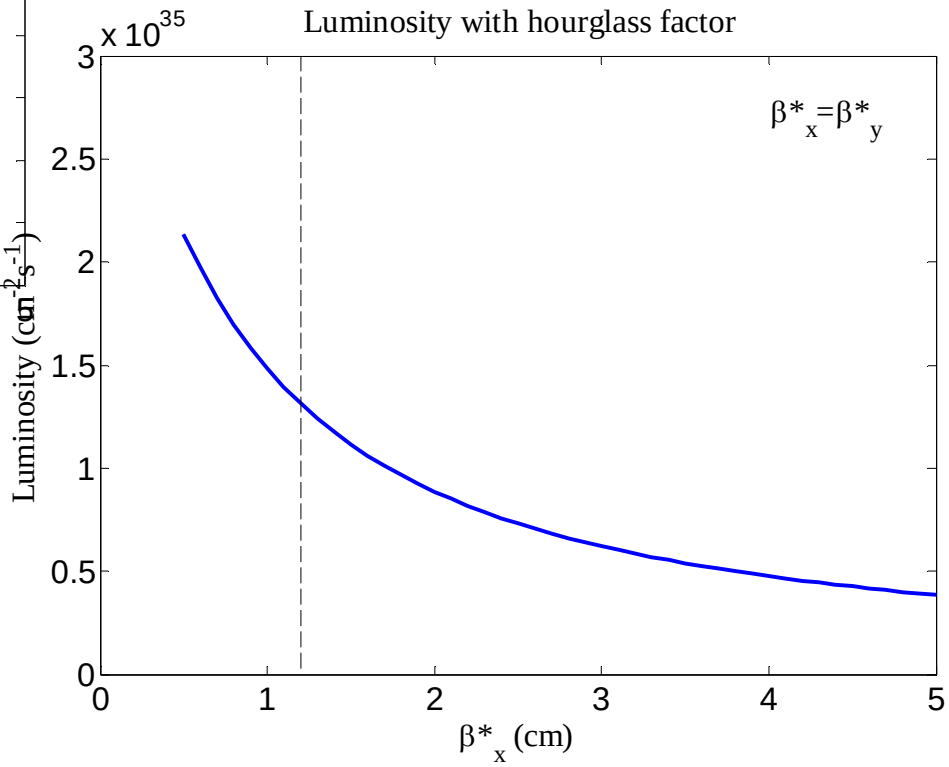
$$\xi_x = r_{muon} N_b / (2\pi\, \varepsilon_{nx}(1+\frac{\sigma_y}{\sigma_x}))$$

$$\xi_y = \frac{\sigma_y}{\sigma_x}\frac{\varepsilon_y}{\varepsilon_x}\xi_x$$

Choosing of IP beta



Assume a reasonable hourglass factor of ≥ 0.8



Choose $\beta^* = 1$ cm

→ $L_{peak} = 1.5\ 10^{35}\ cm^{-2}s^{-1}$

IR linear optics for 3 TeV design

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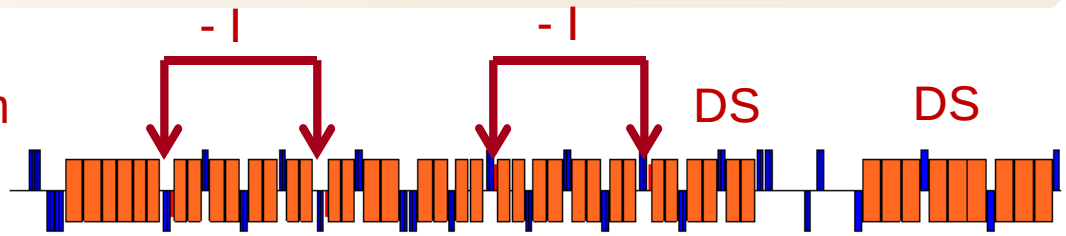
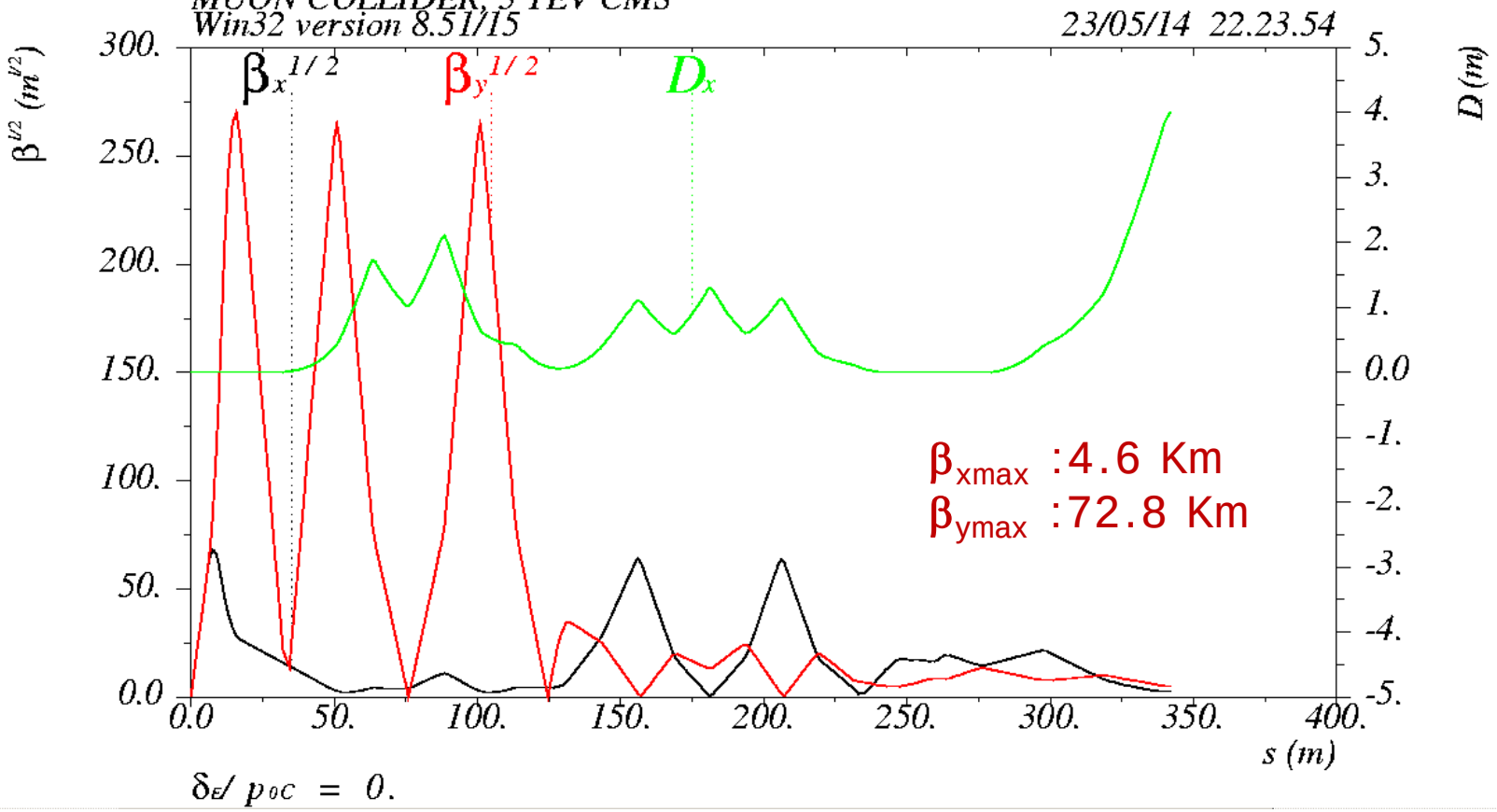
$\beta^*_{x,y}$ =1 cm

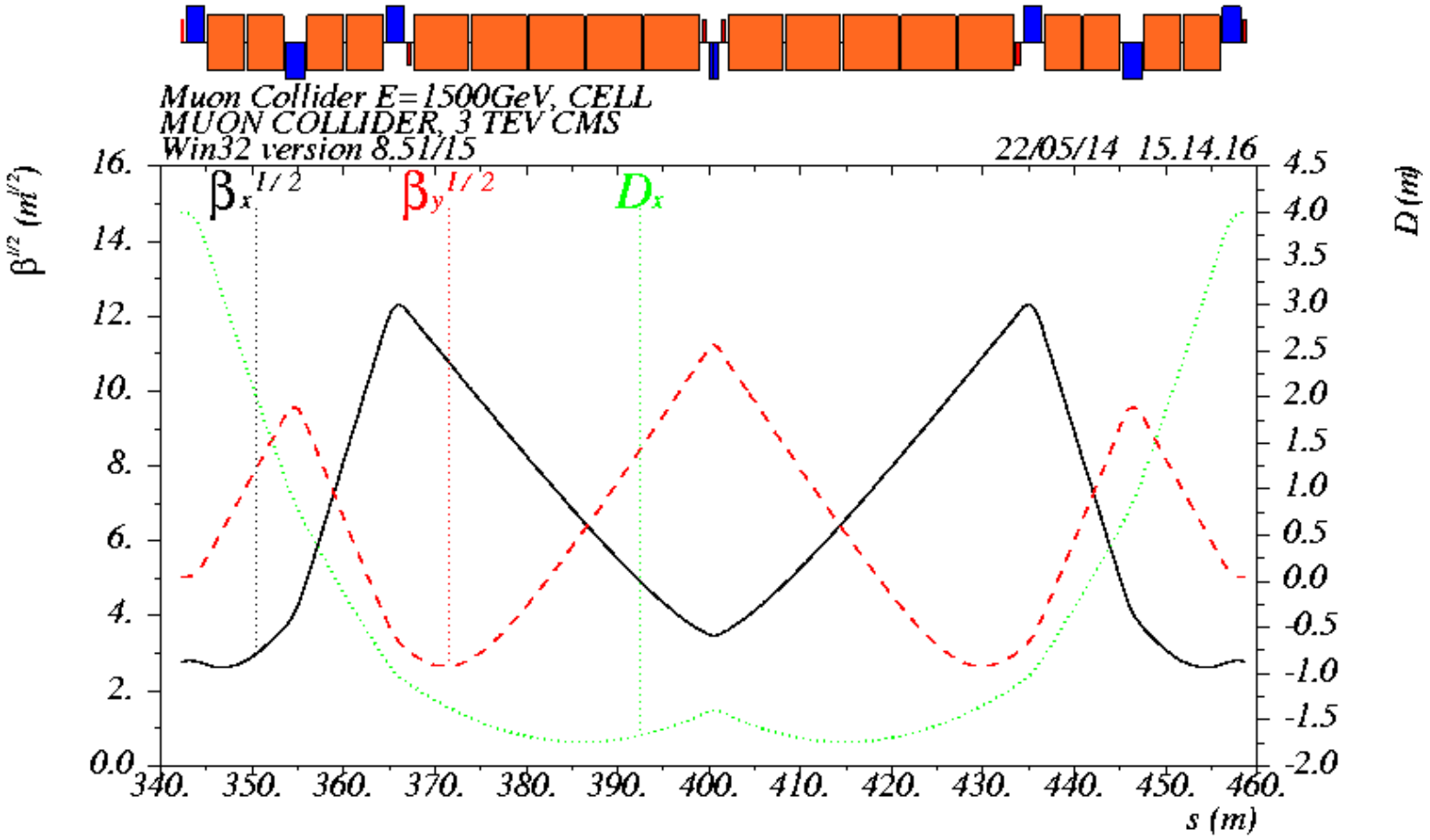


Field:
<15 T in quads
<20 T in bends



β_{xmax} :4.6 Km
β_{ymax} :72.8 Km

Arc cell linear optics for 3 TeV

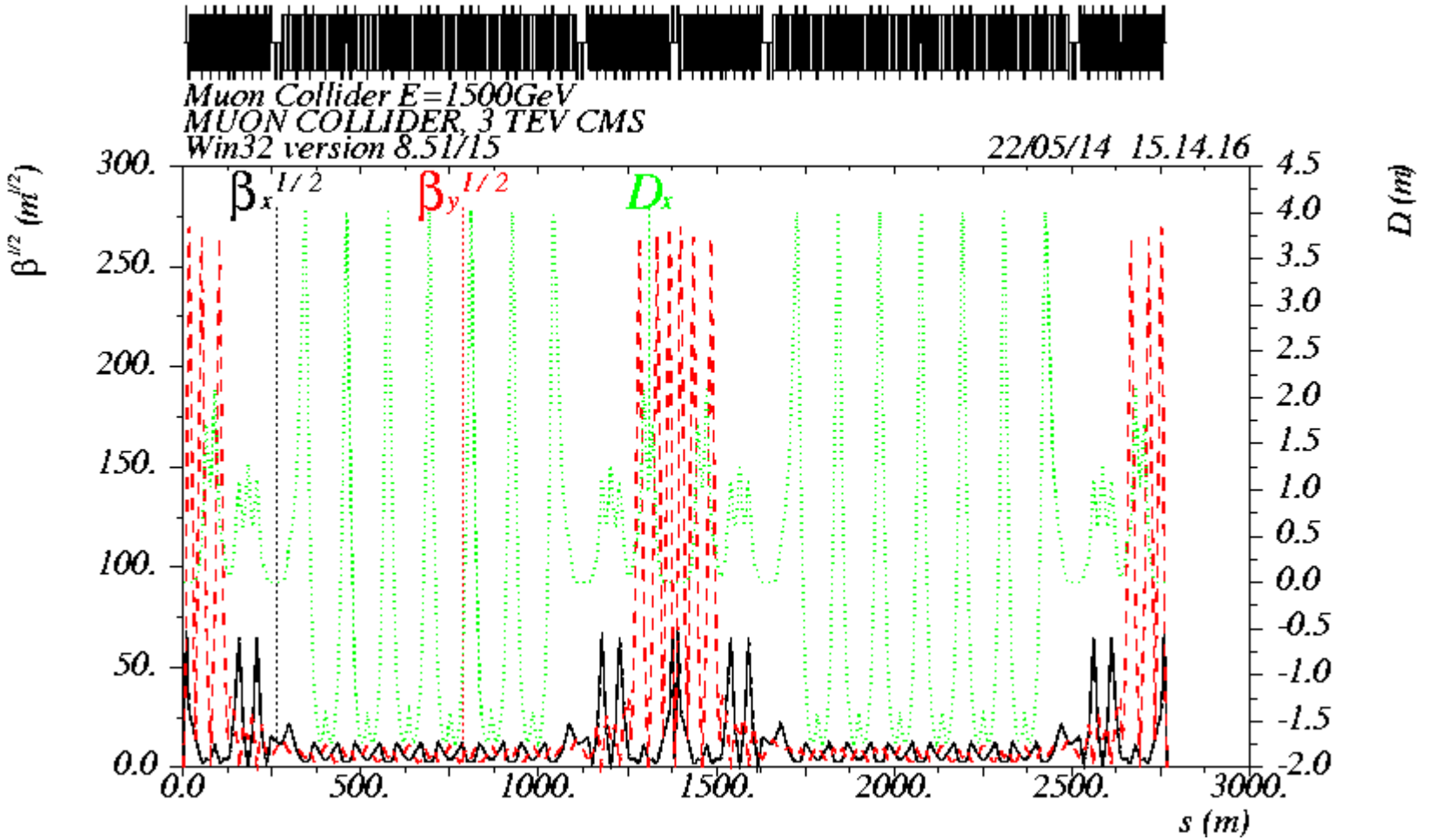


$\mu_x/\mu_y = 0.833/0.833$

Based on 1.5 TeV design by Y. Alexahin et al

Field increased with energy: < 15T in quads, < 20T in bends

3 TeV Collider Ring linear optics



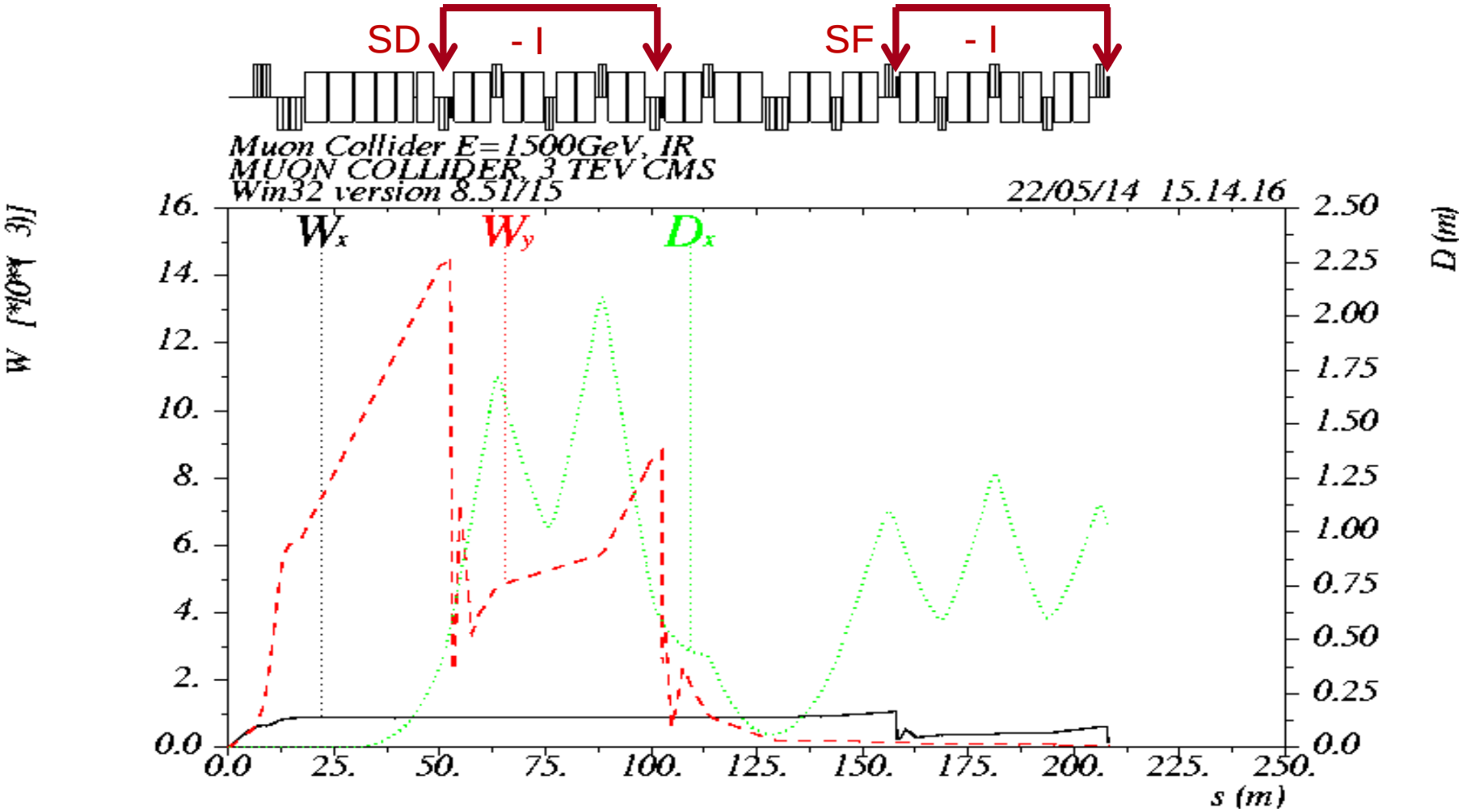
Two IPs twofold symmetry

Circumference: 2.77km; ν_x/ν_y = 20.13/22.22

Chromatic correction

- Local correction of chromatic beta beat and higher order chromatic tune shift created by the final focus quads
- Two pairs of –I x and y correction sextupoles placed $n\pi$ in x or y phase from the final focus quads
  - large x/y or y/x beta ratio at the IR sextupoles for orthogonal correction
  - cancellation of IR sextupole geometric aberrations
  - no other sextupoles within each IR sextupole pair to minimize octupole-like tune shift with amplitude
- Arc cell design and the arc sextupole correction scheme at this moment are based on 1.5 TeV design (by Y. Alexahin et al)

IR chromatic W-function

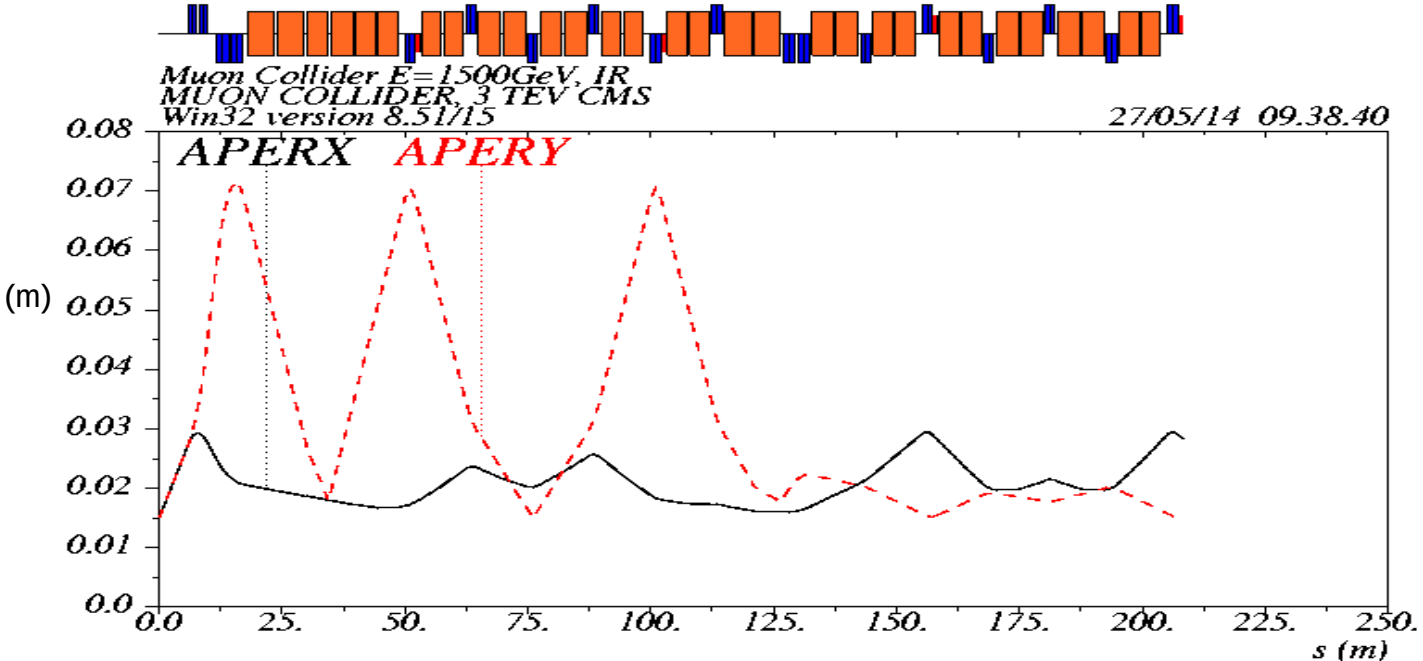


IR sextupoles cancel W-function at the IP

Arc sextupoles correct the tune linear chromaticity

IR Magnets

magnet	Half-aperture (mm)	Pole tip field (T)	Length (m)
QIR01A	30	14.94	1.6
QIR01B	45	14.94	1.6
QIR02A	75	-14.92	2.45
QIR02B	75	-14.92	2.45
QIR#	50	< 15	2
Dipole	50(66)	< 20	4/4.5/5.5



The half aperture calculation in IR is based on the 1.5 TeV design definition:

$5\sigma + 15$ mm

Main parameters

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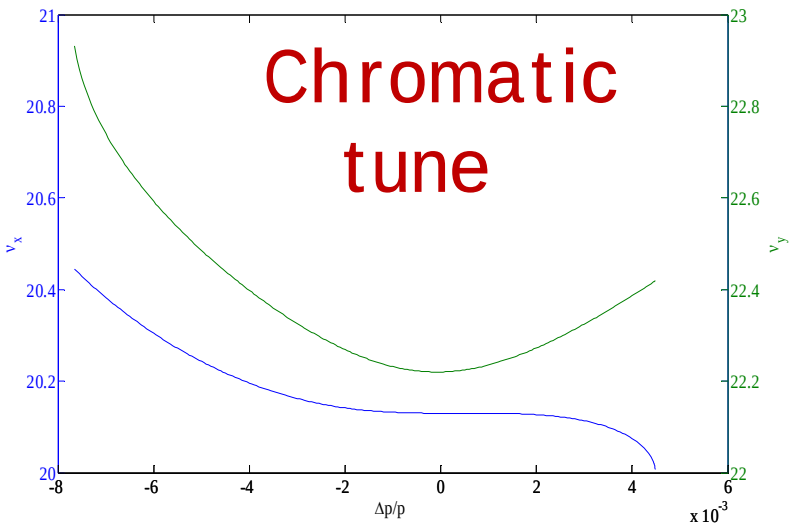
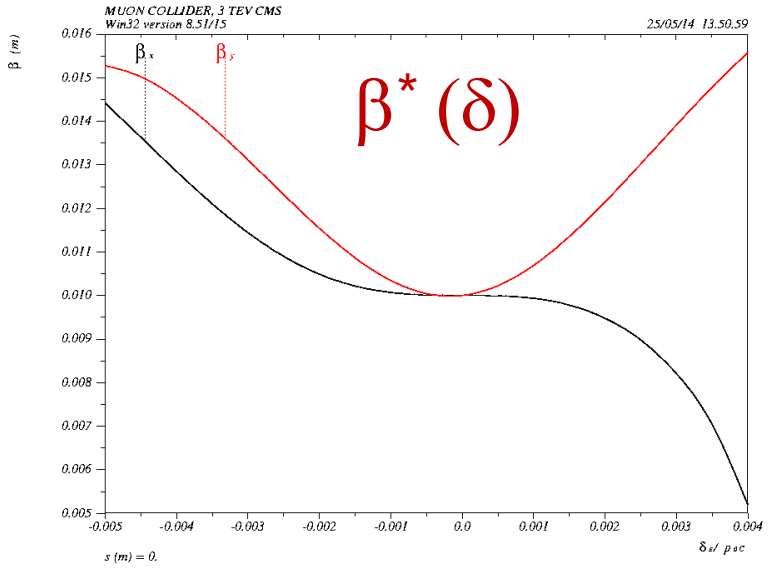
Parameter	Unit	1.5 TeV design	3 TeV design
Beam energy	TeV	0.75	1.5
Number of IPs		2	2
Circumference	m	2730	2767
β^*	cm	1	1
Tune x/y		18.56/16.58	20.13/22.22 (temporary)
Momentum compaction		-1.30E-05	-2.88E-04
Normalized emittance	(π)mm·mrad	25	25
Momentum spread	%	0.1	0.1
Bunch length	cm	1	1
Muons/bunch	10^{12}	2	2
Repetition rate	Hz	15	15
Average luminosity	10^{34} cm^{-2}s^{-1}	1.1	4.5

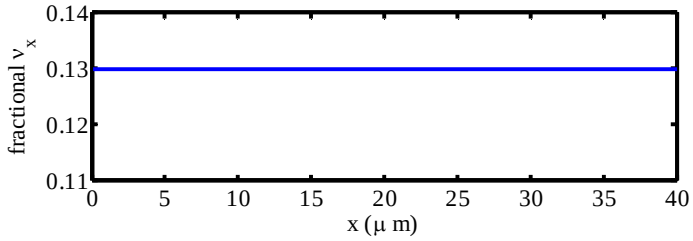
The average luminosity presented here does not take into account of BB or hourglass factor. The change of luminosity is due to muon beam energy.

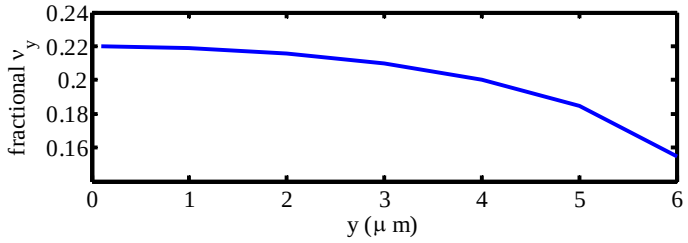
Lattice non-linear properties





Tune versus amplitude





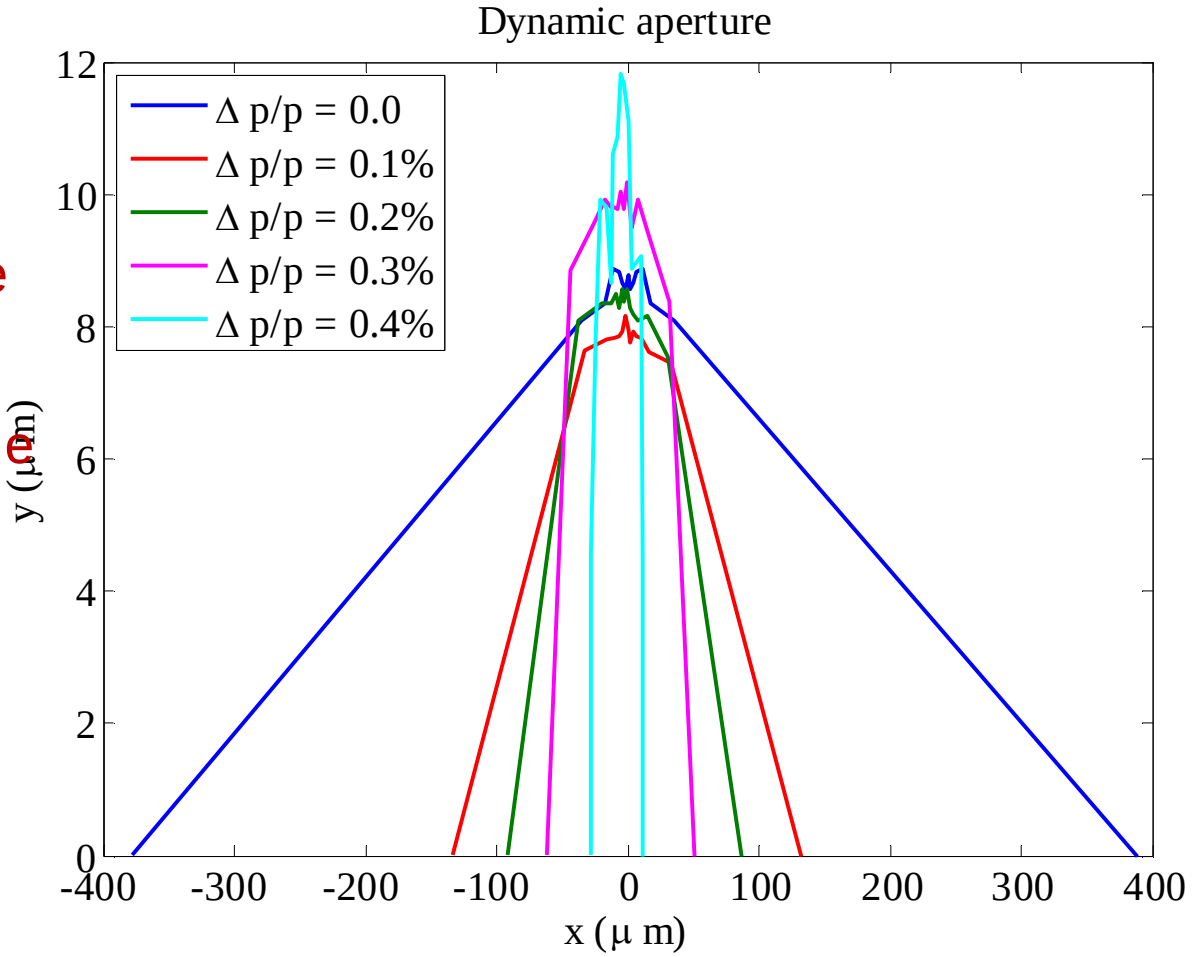
Dynamic aperture w/o errors

Dynamic aperture from LEGO

The on-energy aperture is ~ $90\sigma_x$ and $2\sigma_y$

The off-energy aperture at 0.4% is $5\sigma_x$ and $2\sigma_y$

→ Vertical aperture needs to be improved



Summary

- A preliminary design of 2.77 km 3TeV CM energy muon collider ring is presented
- The IR chromatic correction scheme uses –I non-interleaved pairs of sextupoles
- On-energy dynamic aperture currently is 90 sigma in x-plane and 2 sigma in y-plane
- Several improvements are being considered:
  - Improve IR nonlinear chromatic correction scheme
  - Investigate a new design of the arc cell
  - Adjust betatron tune to a more reasonable value above half integer

Reference

- Y. I. Alexahin et al., “Muon collider interaction region design”, PRST-AB 14, 061001 (2011).
- Y. I. Alexahin et al., “A 3-TeV muon collider lattice design”.
- A.V. Zlobin, et al., “Magnet designs for muon collider ring and interactions regions”, proceedings of IPAC’10, Kyoto, Japan.