An extremely-flat beam optics with large crossing angle for the LHC

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Flat beam optics

Peak luminosity $$L = \frac{N^2 n_b f}{4\pi\sigma_x\sigma_y} * F$$

Local chromatic correction in Y.
First time ever for LHC!

To increase luminosity:

-Reduce both σ_x^* and σ_y^*

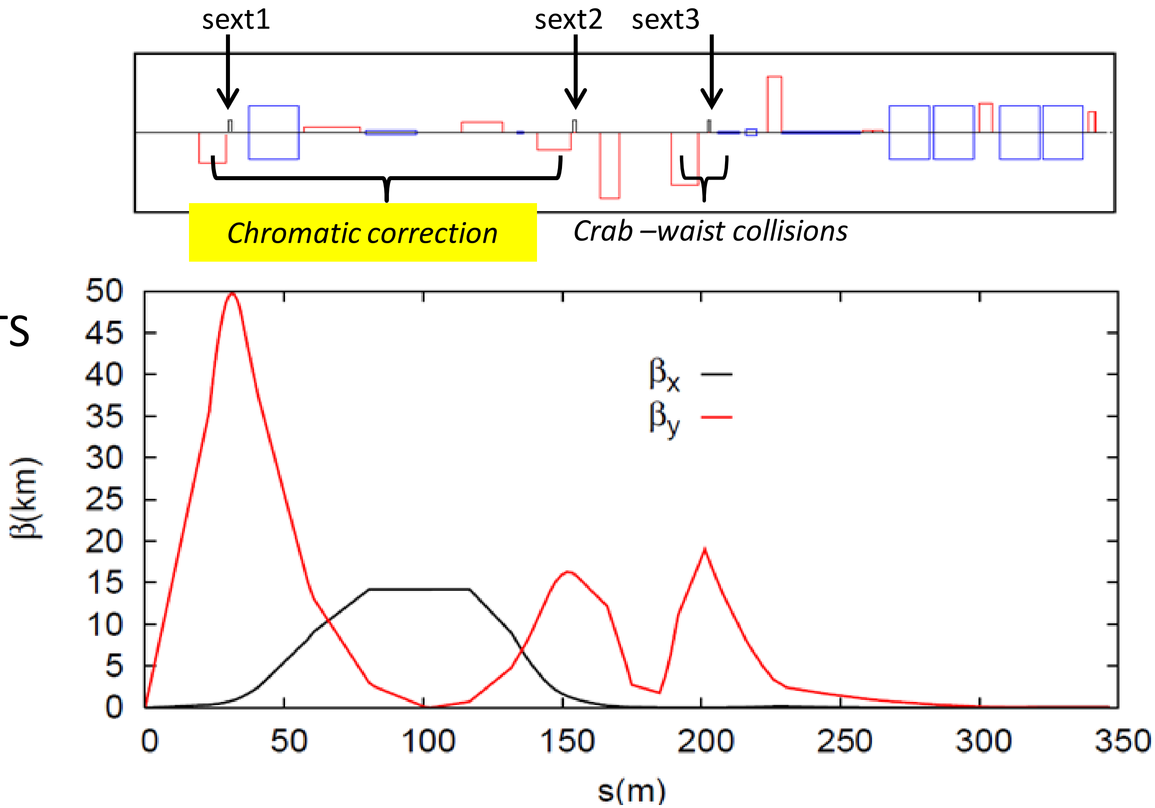
-Substantially reduce σ_y^*

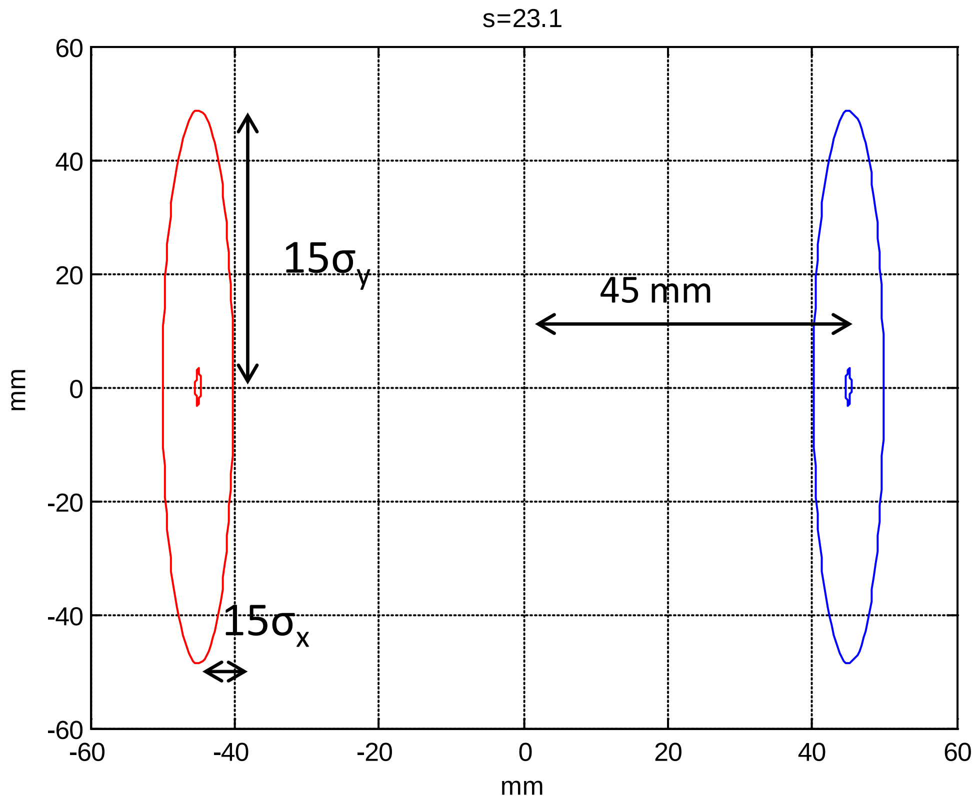
β_x^*=1.5 m

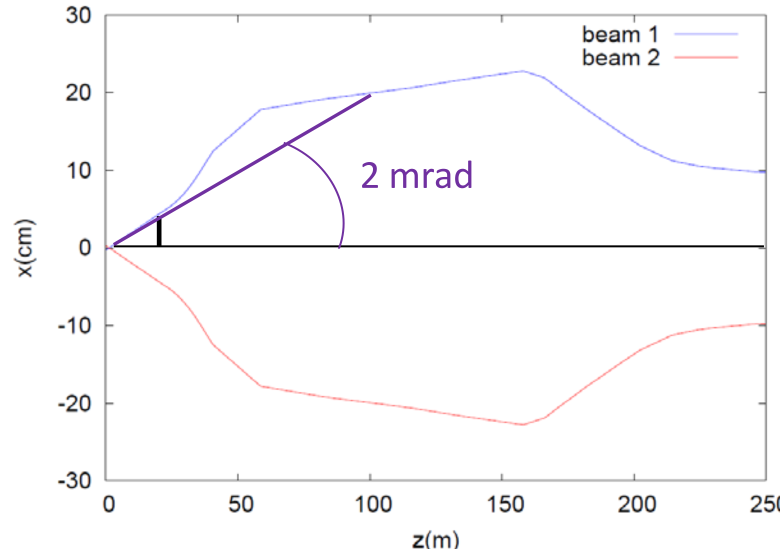
β_y^*= 1.5 cm

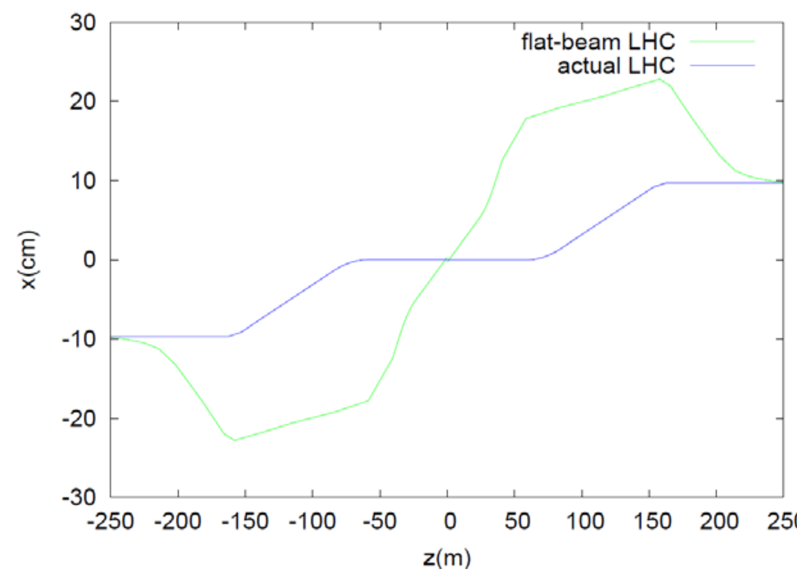
$\beta_x^*\beta_y^*$=15cmx15cm (nominal ATS optics with crab cavities)

	$\Delta\mu_x$	$\Delta\mu_y$
sext1	$\pi/2$	$\pi/2$
sext2	$\pi/2$	$3\pi/2$
sext3	π	$5\pi/2$







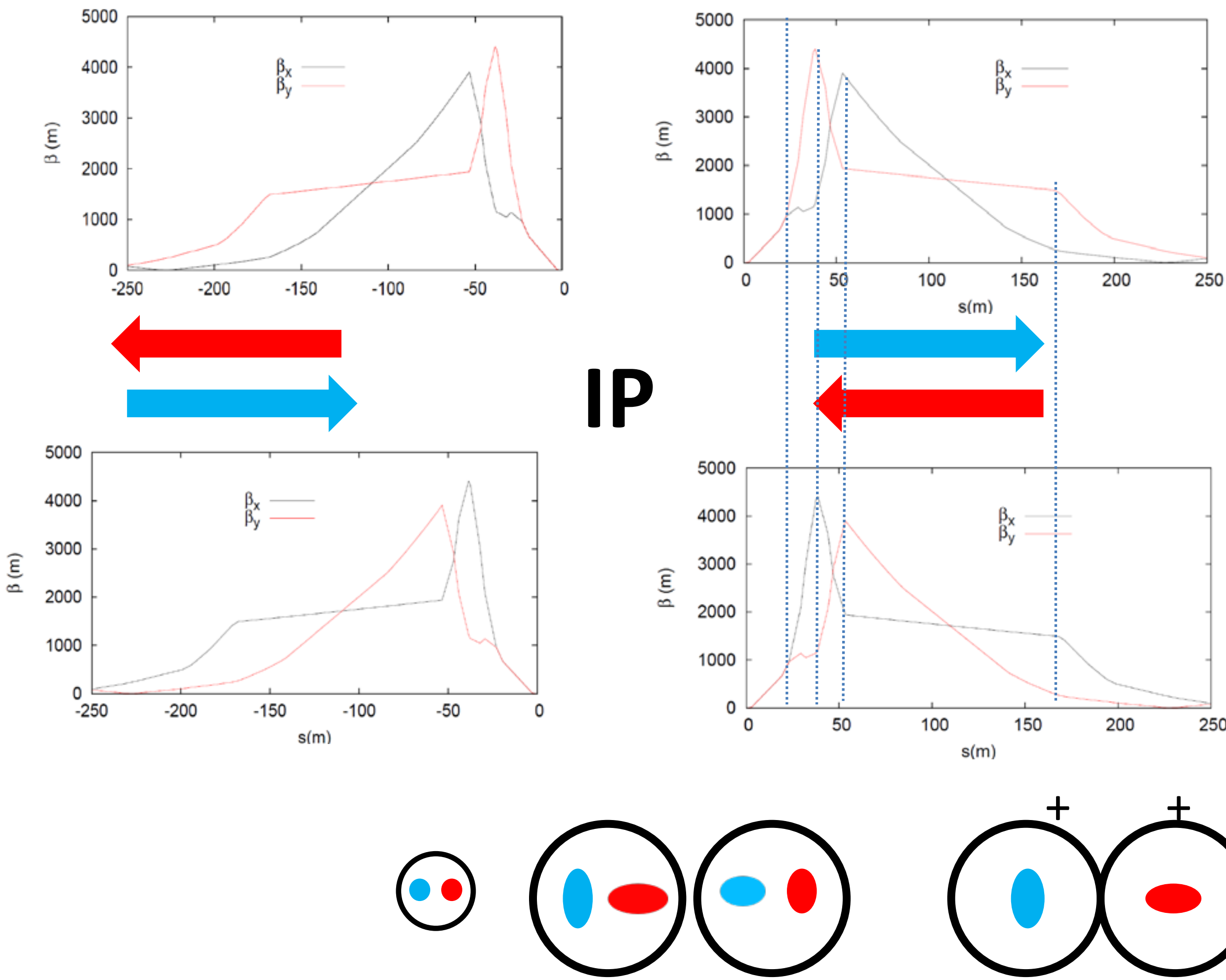


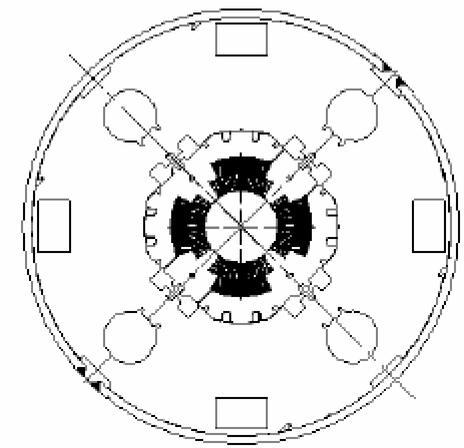
$\sigma_x / \sigma_y = 10$ Minimum required according to beam-beam simulations.

Large crossing angle-> large Piwinski angle

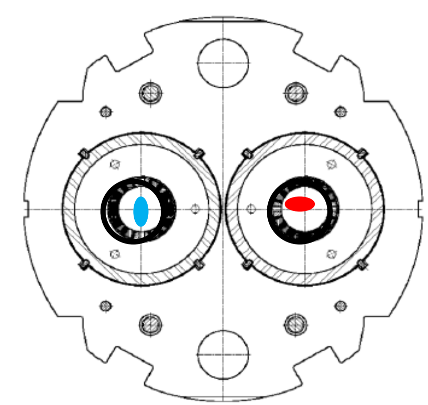
$$\phi = \frac{\theta \sigma_z}{2\sigma_x}$$

Actual LHC optics

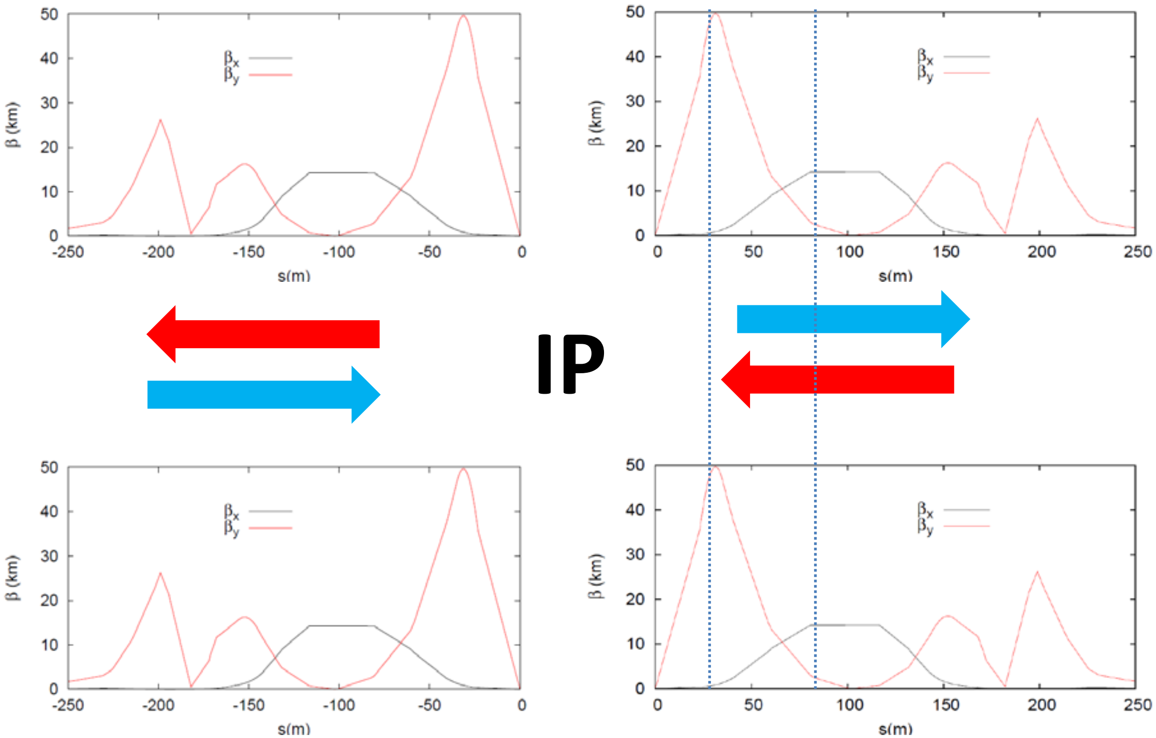


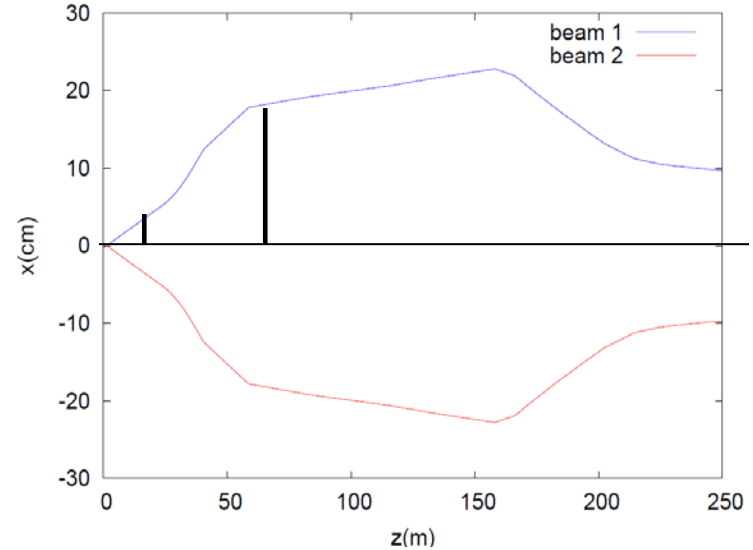


The 2 beams see opposite gradients



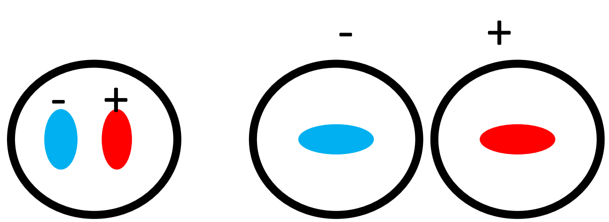
Flat beam LHC optics



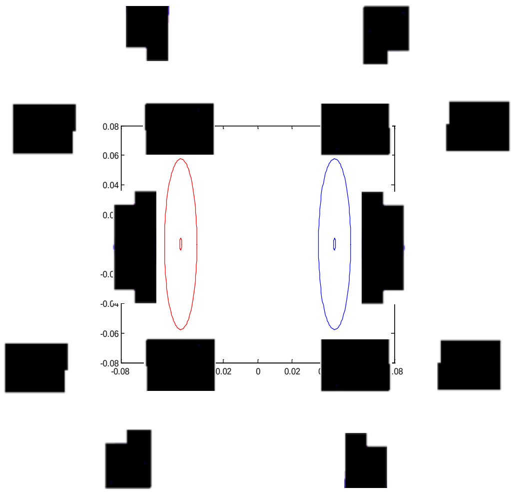


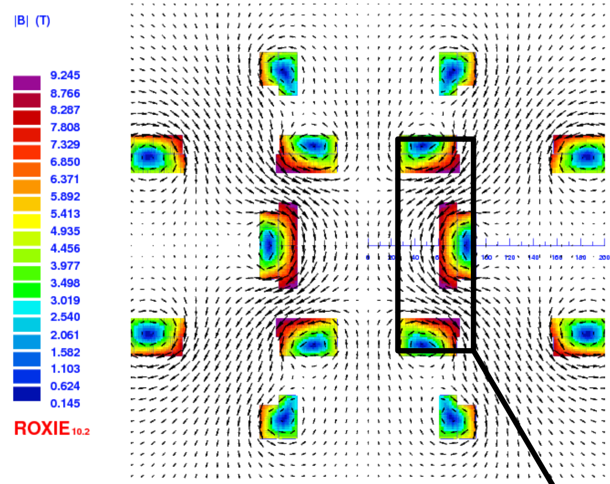
The 2 beams see the same gradients

How to produce opposite gradient in the same pipe?

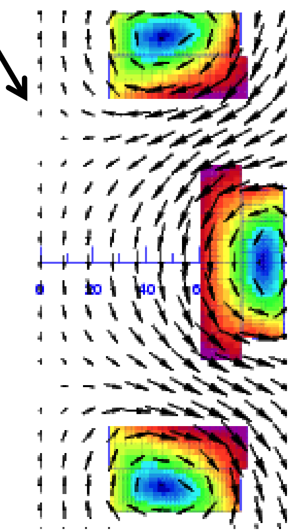


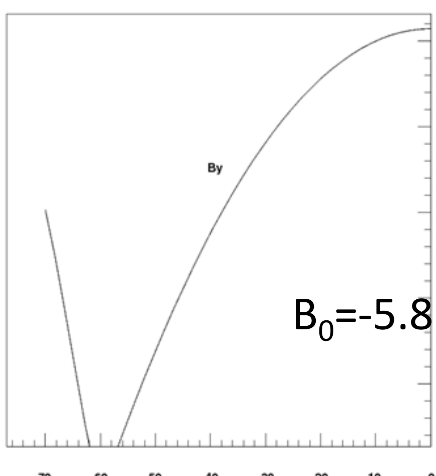
Double half-quad



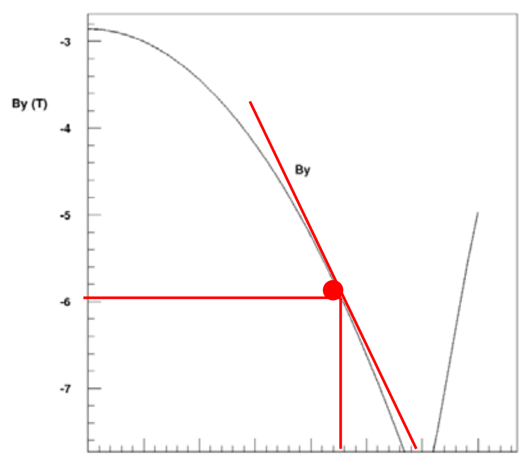


NbTi



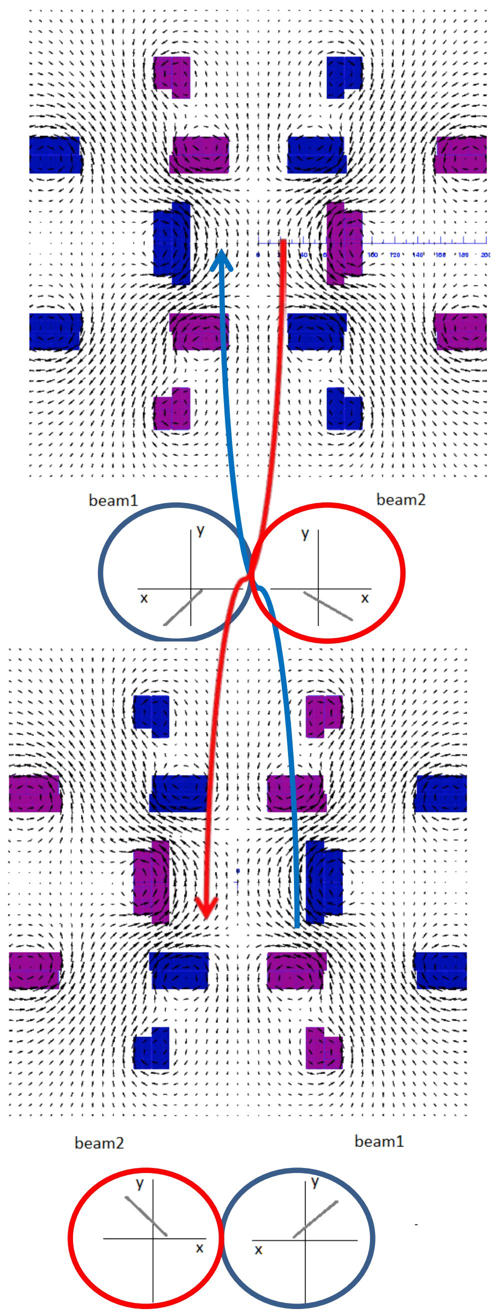


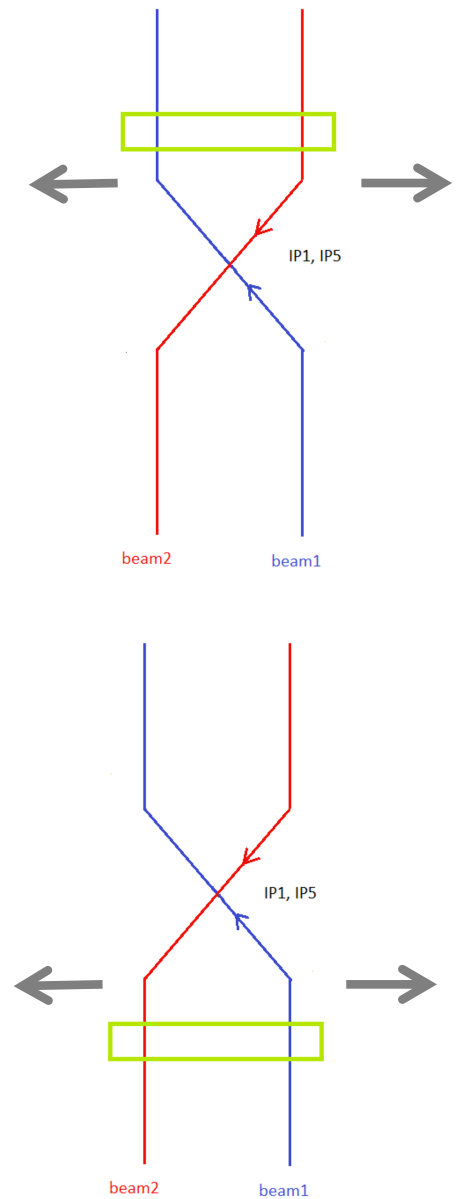
B_0=-5.8 T



g=115 T/m

S.Russenschuck



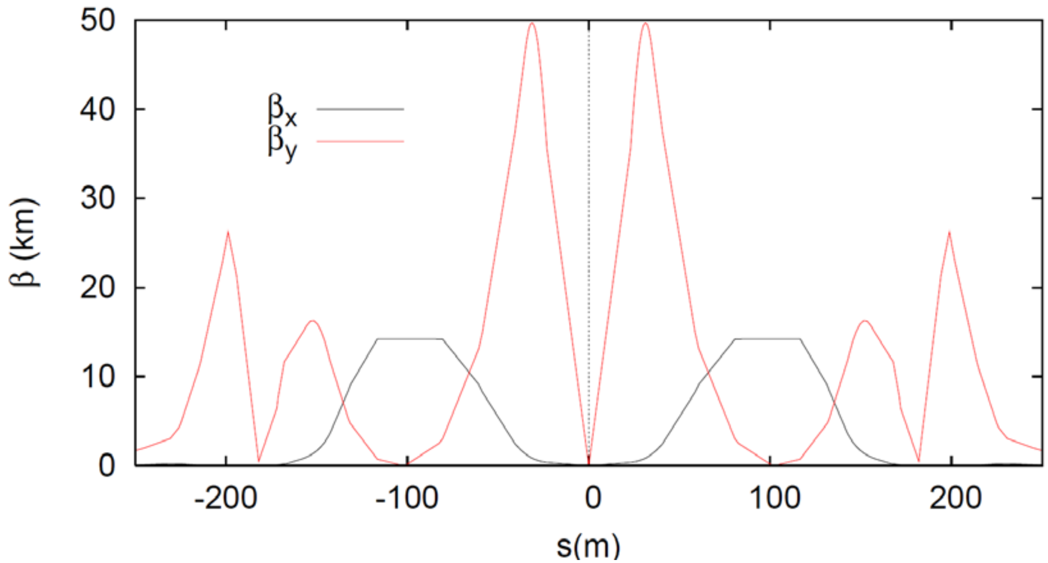


Kick due to the dipolar term

Matching

Arc (MQ11) ←

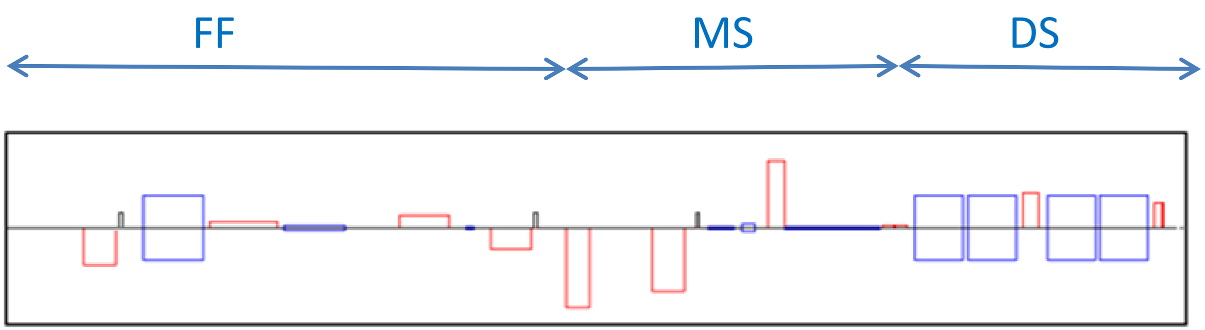
β_x=33 m
β_y=184 m

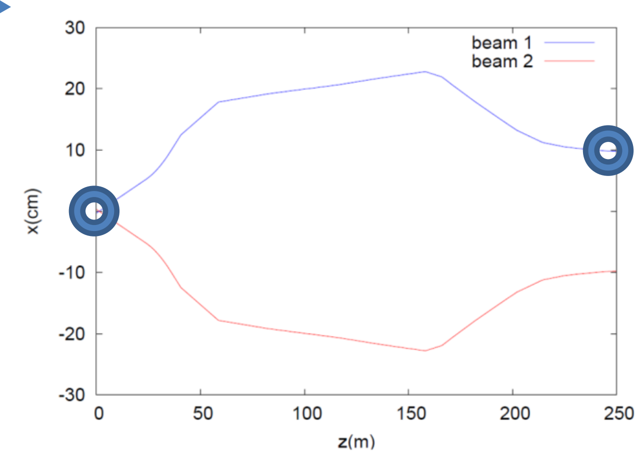


Arc (MQ11) →

β_x=184 m
β_y=33 m

Use of two different matching sections





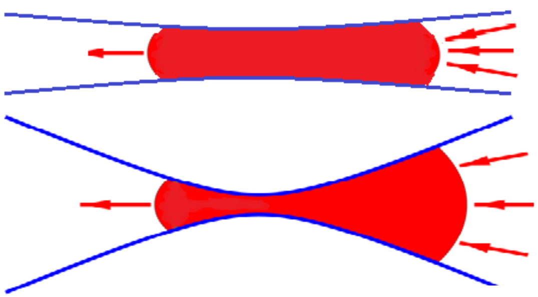
Dispersion matching D(sext2),D(sext3),D(IP)=0
with geometric constraints

Large Piwinski angle

$$L \propto \frac{N\xi_y}{\beta_y}; \quad \xi_y \propto \frac{N\beta_y}{\sigma_x \sigma_y \sqrt{1+\phi^2}}; \quad \xi_x \propto \frac{N}{\varepsilon_x (1+\phi^2)}; \quad \phi = \frac{\theta \sigma_z}{2\sigma_x}$$

Luminosity reduction through F but…

1-Decrease overlapping area. Lower β_y decrease



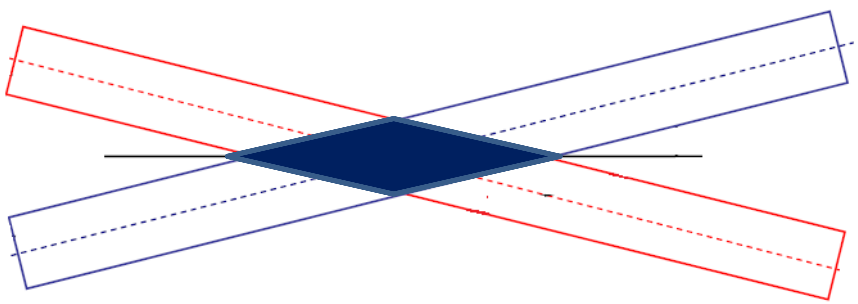
Hourglass effect limits β_y decrease $\beta_y > Area$

Head-on or small ϕ

$$Area \approx \sigma_z$$

Large Piwinski angle

$$Area \approx \frac{2\sigma_x}{\theta}$$



$$\frac{2\sigma_x}{\theta} \approx 1cm$$

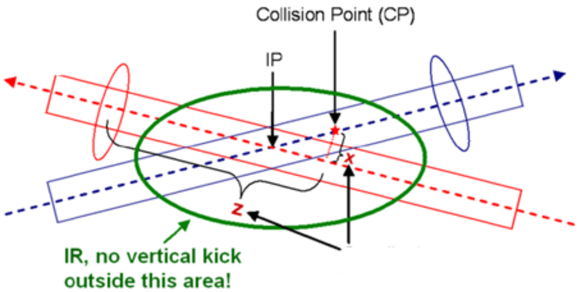
!

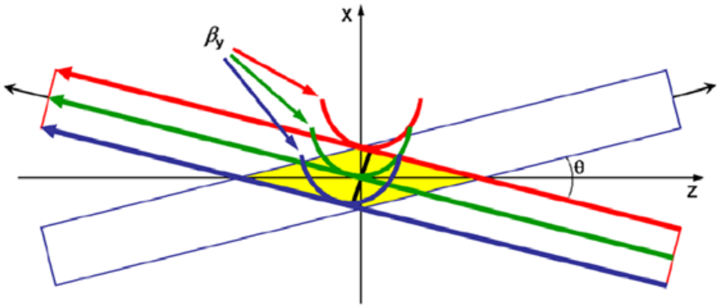
2-More particles N for the same beam-beam tune shift

3-It opens the possibility for crab-waist collisions

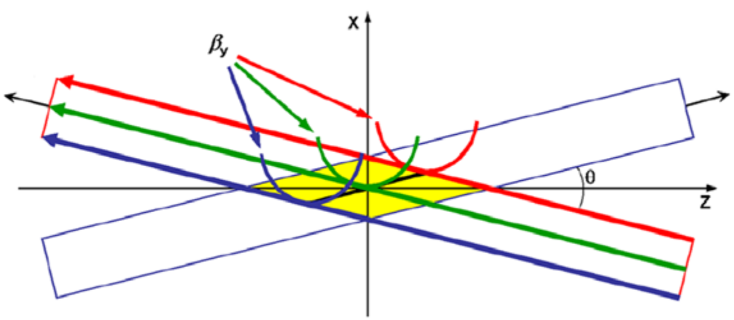
Crab-waist collisions

In Large Piwinski Angle
Collision Point ≠ Interaction Point





Normal collision scheme



Crab-waist collision scheme

P.Raimondi, D.Shatilov, M. Zobov

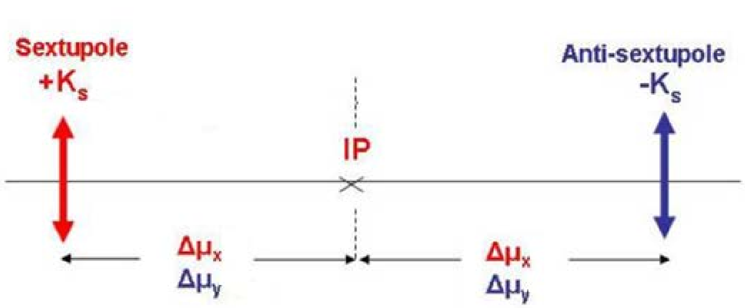
Crab-waist collisions

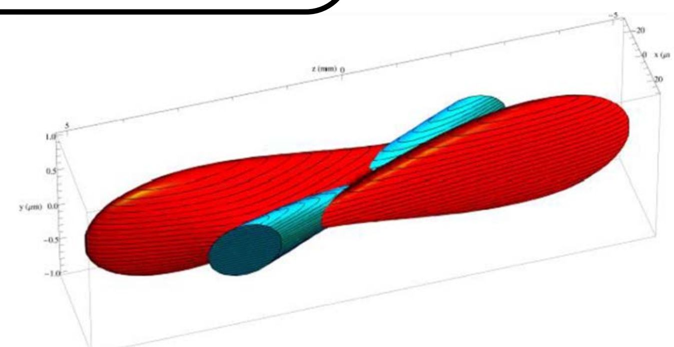
Conditions

$$\Delta\mu_x = \pi m$$

$$\Delta\mu_y = \frac{\pi}{2}(2n+1)$$

Sextupole strength $kl_s = \frac{\sqrt{\beta_x^* / \beta_x}}{\theta \beta_y^* \beta_y}$





In particular

$$\Delta\mu_x = \pi$$

$$\Delta\mu_y = \frac{5\pi}{2}$$

$$k_2 = 0.0313 m^{-3}$$

$$l_s = 8m$$

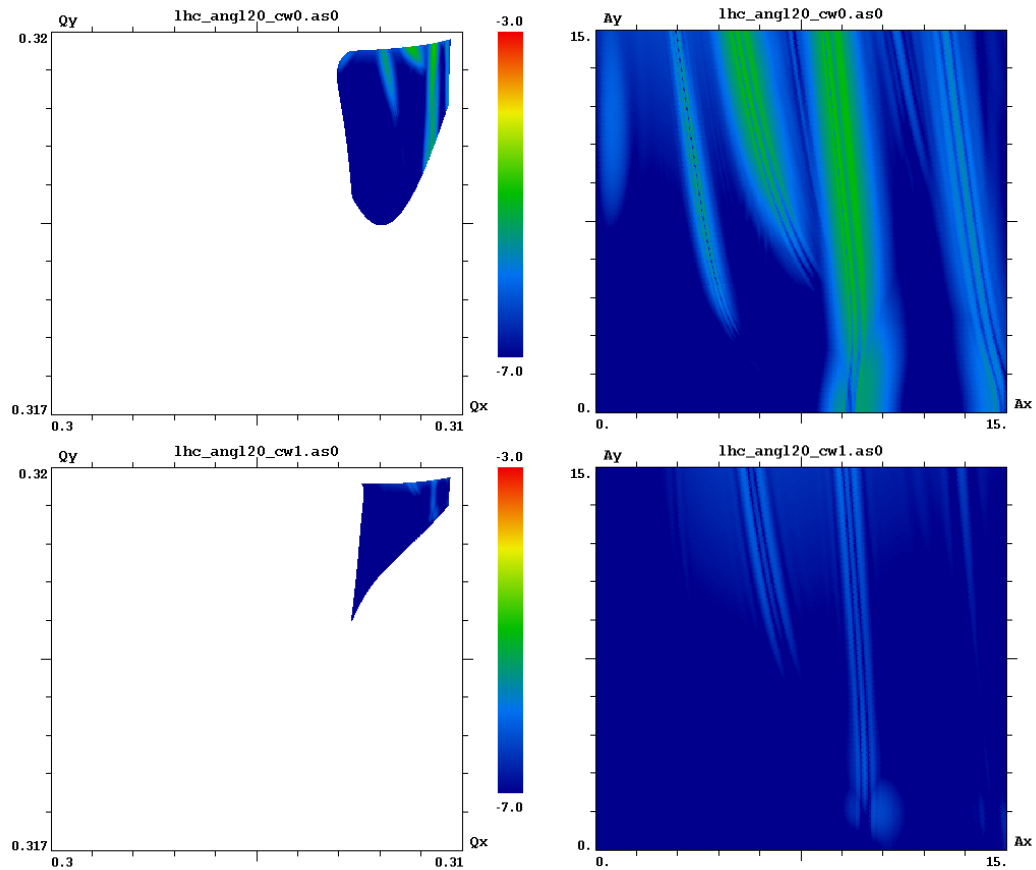
P.Raimondi, D.Shatilov, M. Zobov

Crab-waist simulations

Resonance suppression

CW = 0

CW = 0.5



Dmitry Shatilov, Mikhail Zobov

Luminosity gain

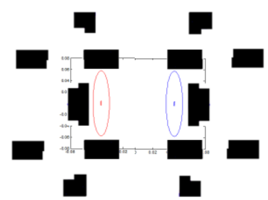
Luminosity in 10^{34} $cm^{-1}s^{-1}$

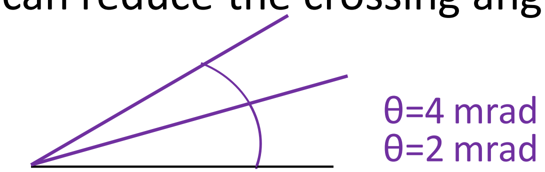
$\theta = 4mrad$

$Nx10^{11} \backslash \varepsilon_n(\mu m)$	3.75	3.5	3	2.5	2.2
1.15	0.6262	0.6721	0.7868	0.947	1.0776
1.5	1.0653	1.1435	1.3387	1.6111	1.8334
2	1.8939	2.0328	2.3798	2.8642	3.2594
2.5	2.9592	3.1763	3.7185	4.4753	5.0928
3	4.2613	4.5738	5.3546	6.4444	7.3336

Main limitation: the crossing angle due to the separation of the double half quad

Further improvements in the double half-quad. design can reduce the crossing angle (Nb_3Sn)

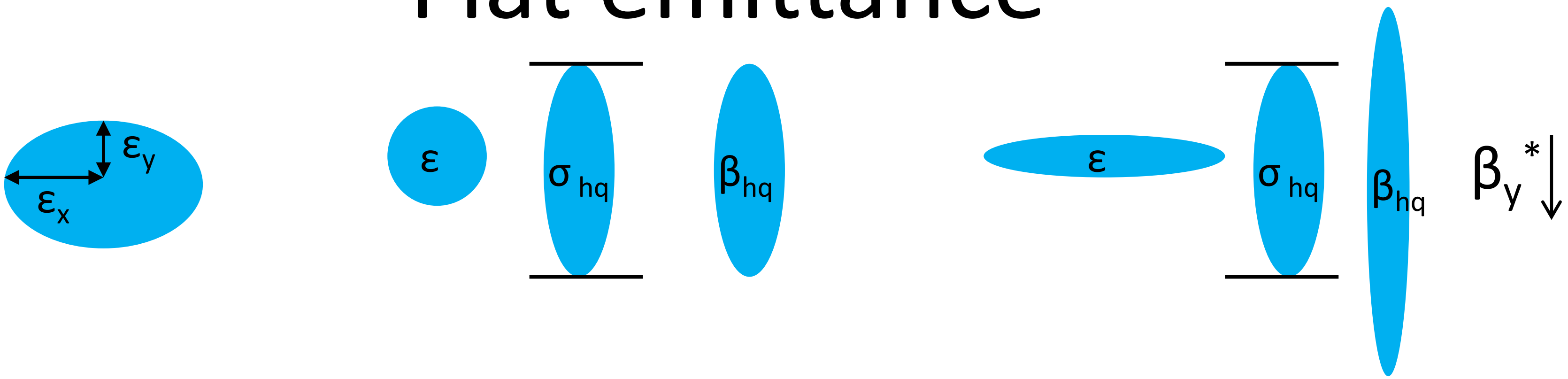




$\theta = 2mrad$

$Nx10^{11} \backslash \varepsilon_n(\mu m)$	3.75	3.5	3	2.5	2.2
1.15	1.1991	1.2938	1.5294	1.8563	2.1217
1.5	2.04	2.2012	2.602	3.1581	3.6097
2	3.6266	3.9132	4.6257	5.6144	6.4173
2.5	5.6666	6.1143	7.2276	8.7725	10.027
3	8.16	8.8046	10.4078	12.6324	14.4389

Flat emittance



Limitation: aperture of the half quad

Solution: reduce ε_y keeping constant $\varepsilon_x\,\varepsilon_y$

Squeeze of the emittance ellipse

β_y increase in the half-quad.->reduction on $\sigma_y^* = \mathrm{sqrt}(\varepsilon_y\,\beta_y^*)$

β_x decrease in the half-quad.->reduction of horizontal chromatic aberrations

-> increase on $\sigma_x^* = \mathrm{sqrt}(\varepsilon_x\,\beta_x^*)$

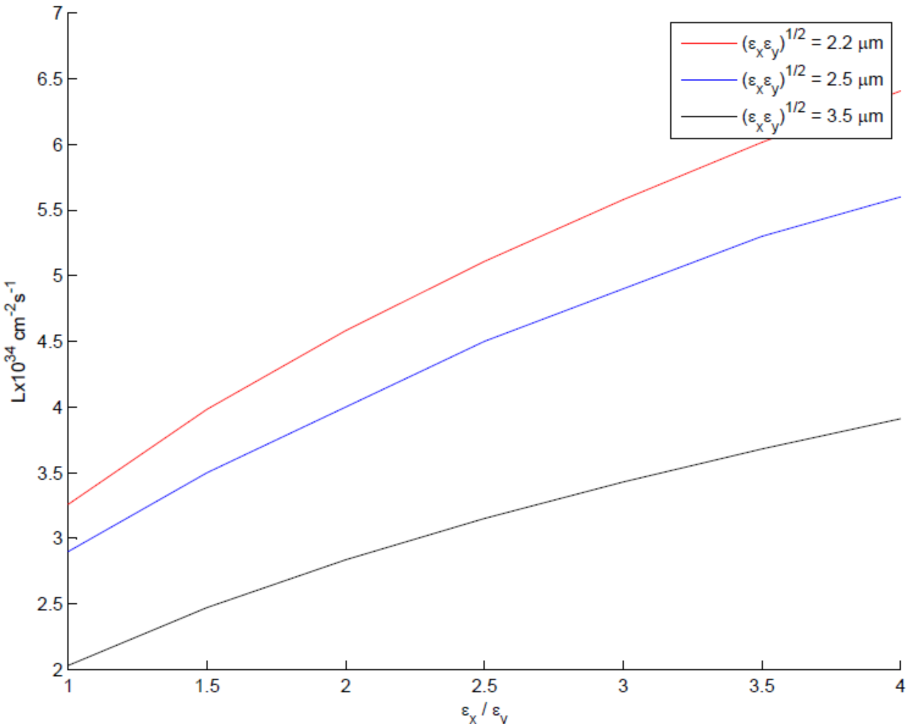
->Geometric reduction factor increased $F=(1+(\Theta/2)\sigma_z/\sigma_x)^{-1/2}$

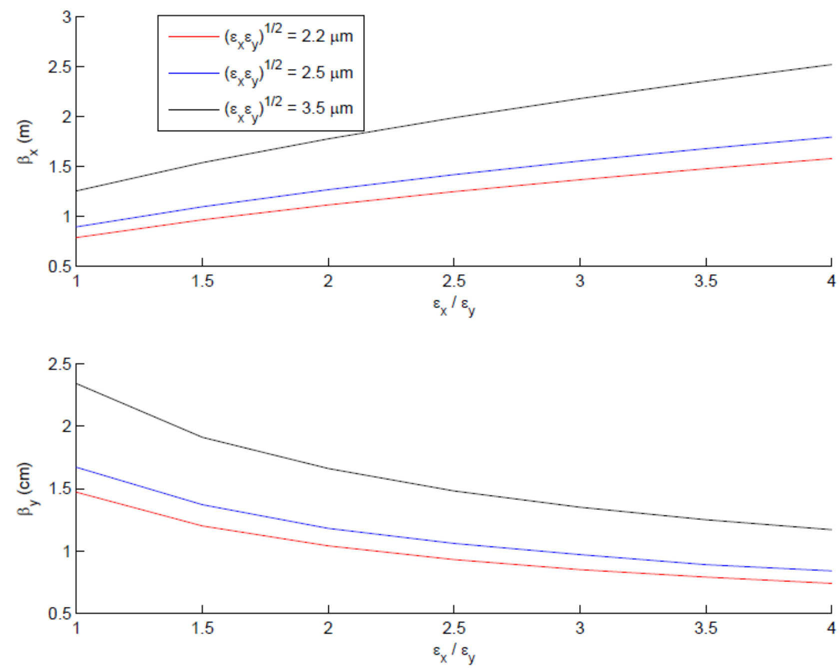
Luminosity increase through significant σ_y^* reduction and F increase

Flat emittance

Keep $\varepsilon_x\varepsilon_y$ and vary $\varepsilon_x/\varepsilon_y$

Θ=4 mrad





Luminosity

Conclusions

- An extremely-flat beam optics is possible for LHC
  - Large Piwinski angle, to reduce the collision area and allow for a lower β_y decrease
  - Local vertical chromatic correction
  - Possibility to have crab waist collisions that can increase luminosity and suppress resonances
- The performance of the new optics can be improved
  - Future half-quad designs (Nb_3Sn)
  - Using a flat emittance