Joint Snowmass-EUCARD/AccNet-HiLumi LHC meeting

Frontier capabilities for Hadron colliders

CERN, 22th February 2013

Flat-beam IR optics

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Thanks to: O.Domínguez. S Russenchuck, D.Shatilov, M. Zobov

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Crab-waist collisions (I)

An important limitation in hadron machines is beam-beam tune shift

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

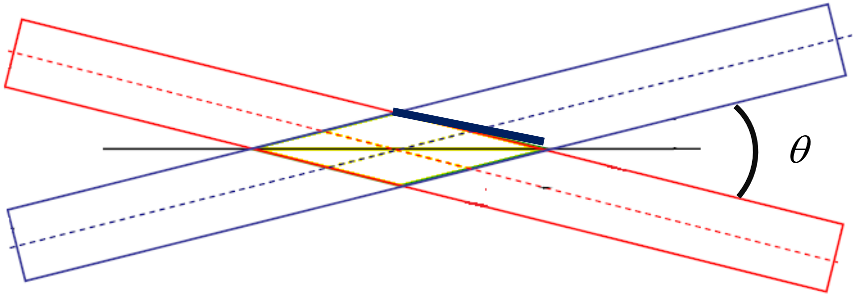
A **Large Piwinski Angle** Φ (LPA)

reduces tune shift, allowing N↑

reduces the length of the collision section, allowing β_y↓

More luminosity

Length of the Collision section



With Head-on collisions or small ϕ

$$l_{OA} \approx \sigma_z$$

But in LPA regime

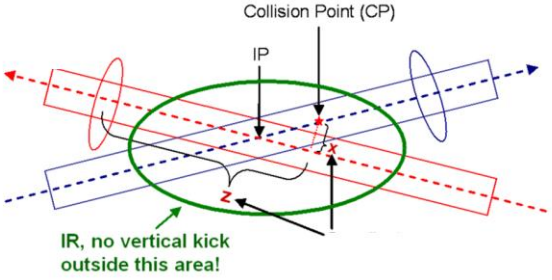
$$l_{OA} \approx \frac{2\sigma_x}{\theta}$$

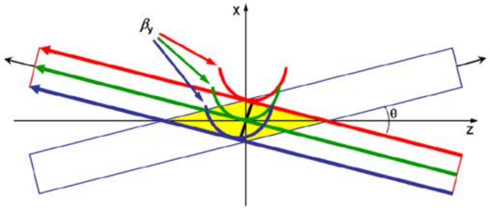
For LHC $\frac{2\sigma_z}{\theta} \approx 1\text{cm}$!

Crab-waist collisions (II)

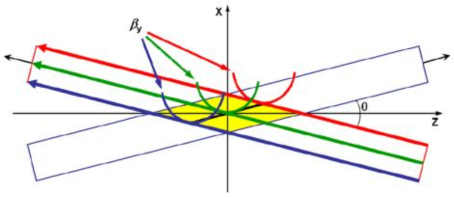
On the other hand, a LPA induces strong X-Y resonances

Suppressed by crab-waist scheme





Normal collision scheme



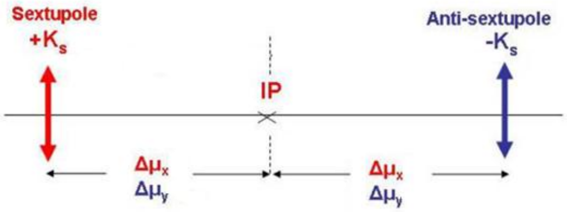
Crab-waist collision scheme

P.Raimondi,
D.Shatilov,
M. Zobov

Condition for cw collisions

2 sextupoles spaced from the IP

$$\boxed{\begin{aligned}\Delta\mu_x &\approx \pi m \\ \Delta\mu_y &\approx \frac{\pi}{2}(2n+1)\end{aligned}}$$



$$\boxed{\sigma_x^*/\sigma_y^* \geq 10} \xrightarrow[\varepsilon_x = \varepsilon_y]{} \boxed{\beta_x^*/\beta_y^* \geq 100}$$

Suitable for lepton machines

More challenging for hadron colliders

Flat beam optics for LHC

β_x^*=1.5 m
β_y^*=1.5 cm

Phase advance from IP

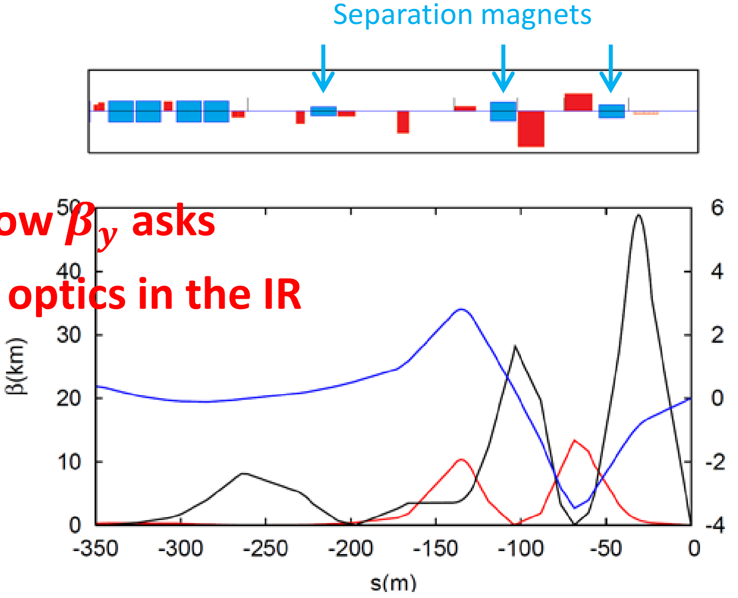
	$\Delta\mu_x$	$\Delta\mu_y$
sext1	π/2	π/2
sext2	π/2	π/2
sext3	3π/2	3π/2
sext4	3π/2	3π/2
sext5	2π	5π/2

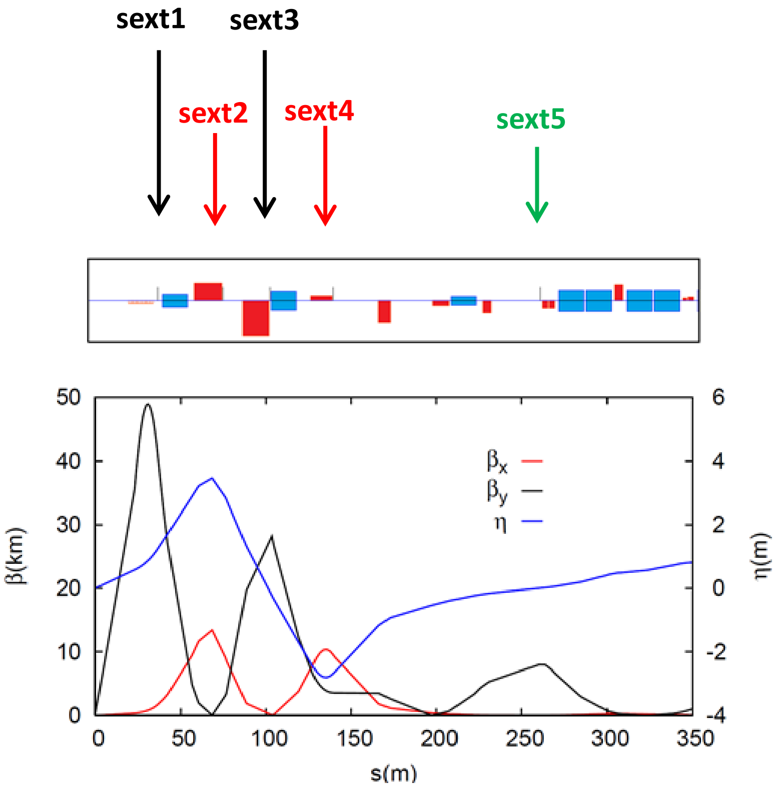
Local chromatic correction in both planes + crab-waist collisions

Chromatic correction

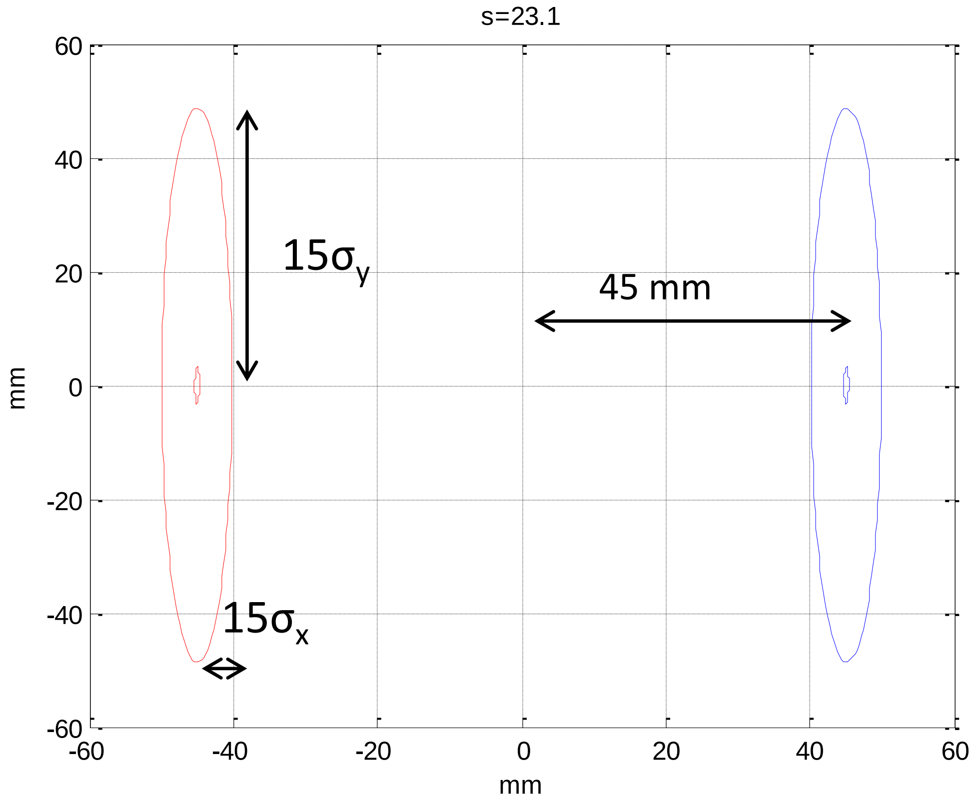
CRAB-WAIST SEXTUPOLE

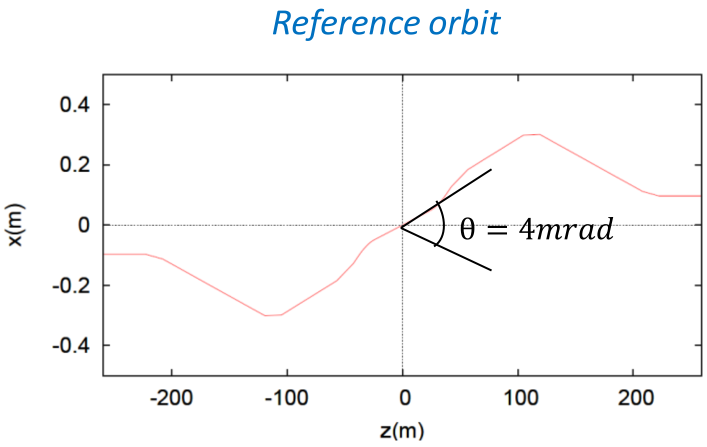
The extremely low β_y asks for a symmetric optics in the IR





Flat beam optics for LHC



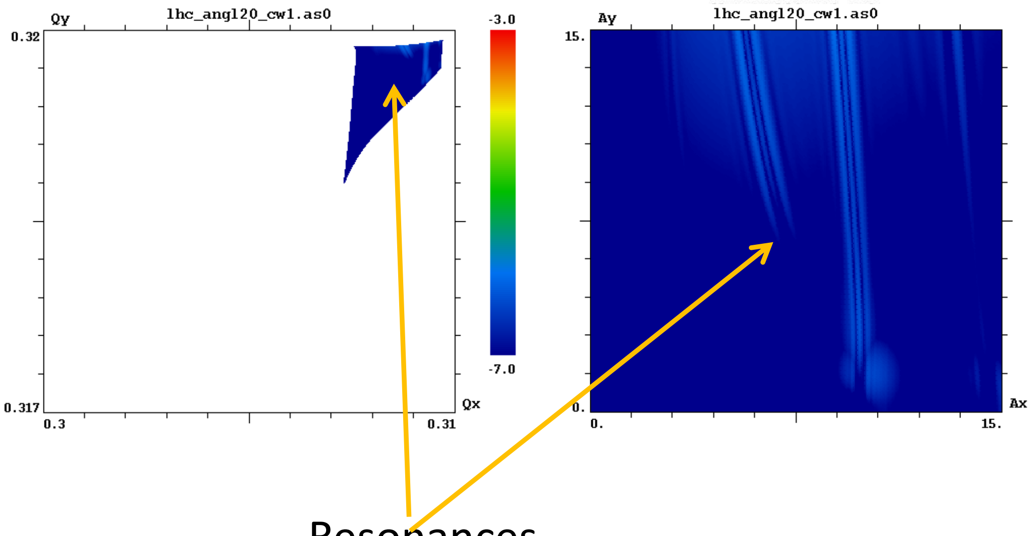

Reference orbit

$\sigma_x/\ \sigma_y=10$

Minimum required according to beam-beam simulations.

Crab-waist simulations

CW = 0.5



Resonances

Frequency Map Analysis (FMA)
Effective for the beam-beam resonance suppression.
Plot shown for $\theta_c = 1.5$ mrad

Dmitry Shatilov
Mikhail Zobov

Luminosity evolution

$$L = \frac{N(t)^2 n_b}{4\pi\sigma_x{}^*\,(t)\sigma_y{}^*(t)} \frac{1}{\sqrt{1+\Phi(t)^2}} \qquad \Phi(t) = \frac{\Theta}{2}\frac{\sigma_s(t)}{\sigma_x(t)}$$

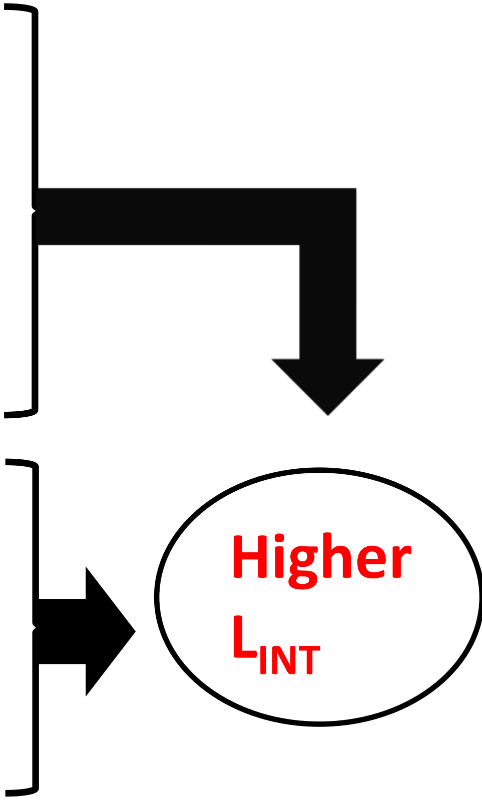
During a run, N(t) ↓
But there is a significant decrease in, $\sigma_x{}^*$, $\sigma_y{}^*$, and in Φ !
With low Φ, the limitation in the beam-beam tune shift obliges to introduce blow-up (longitudinal/horizontal).
With large Φ, the limitation is almost suppressed.

↘we just have to adjust the parameters to have SR damping as a compensator for the burn off

Beam lifetime due to burn off

$$\tau = \frac{N_0}{L_0 \sigma_p n_{IP}}$$

LPA allows a bigger N_0 for the same L_0. Contribution to L_{int}



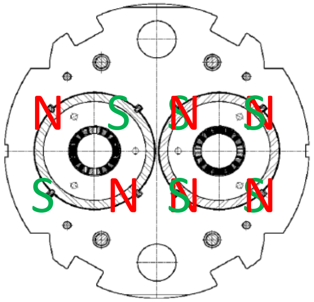
Symmetric optics

The lower $\beta_y{}^*$ allowed by the LPA creates a large beam divergence

-> last quadrupole must be defocusing for the four cases: b1l, b1r, b2l, b2r.

IR optics is symmetric. Two options

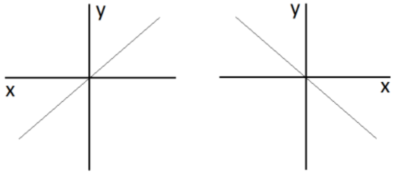
- Match the sym. IR optics to the antisymetric arc optics.
- Design a symmetric optics in the arcs.



In order to implement a symmetric optics in the IR, two options are proposed for the HE-LHC:

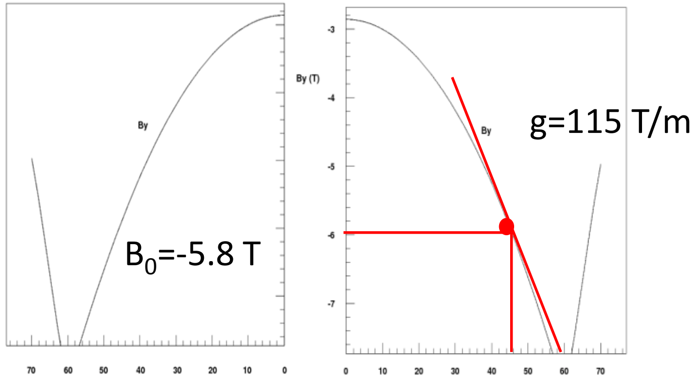
- θ=2mrad. Use a double-half quadrupole, like in c-w LHC
- θ=8mrad. Use a double aperture quadrupole with opposite sign.

Last quadrupole. θ=2 mrad

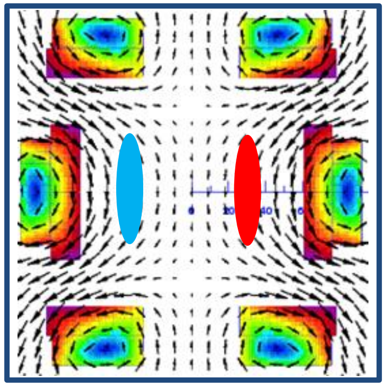


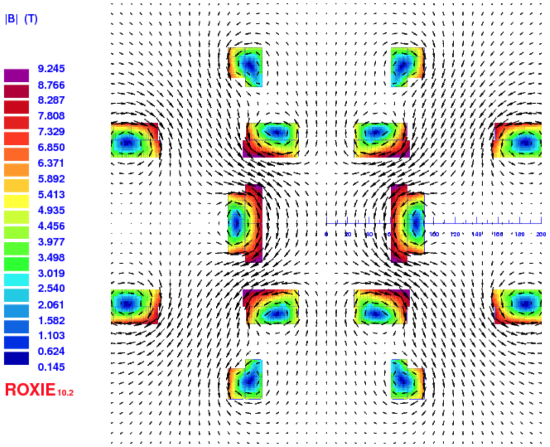
$B_y(x)$

proposed for c-w LHC as a solution to have diff pol quadrupoles for the 2 beams in a same aperture



Double half quadrupole



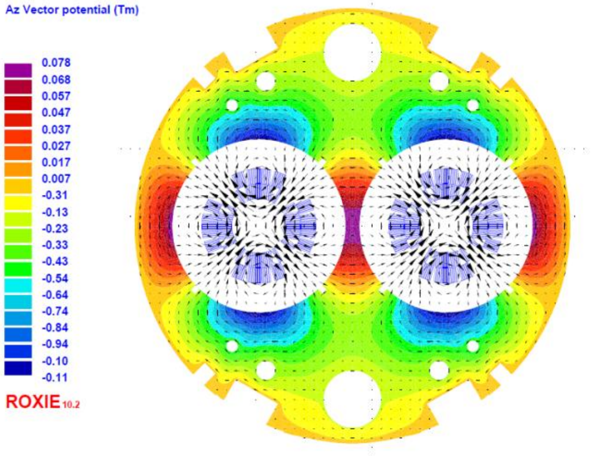


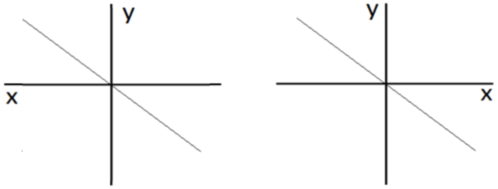
S. Russenchuck

Last quadrupole. θ=8 mrad

Double aperture magnets with same polarity (as in LHC arc quadrupoles)

Gradient : 220 T/m

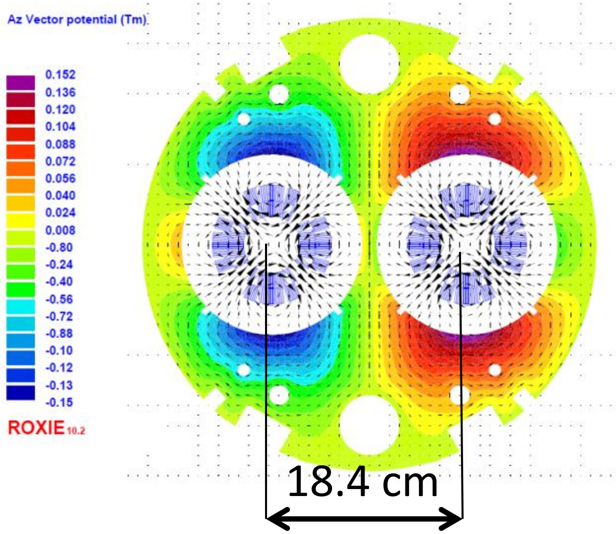


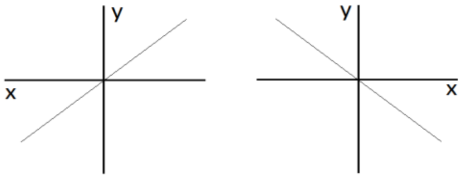


Double aperture magnets with same polarity for c-w HE-LHC

Gradient : 219 T/m

$B_y(x)$





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Parameters (I)

c.m. energy [TeV]	33
Circumference [km]	26.7
Dipole field [T]	20
Dipole coil aperture [mm]	40
Beam half aperture [mm]	13
Injection energy [TeV]	>1.0
Initial longitudinal emittance [eVs]	5.67
r.m.s. bunch length [cm]	7.7
peak luminosity [cm^{-2} s^{-1}]	$5x10^{34}$

O. Domínguez. HE-LHC/VHE-LHC parameters, time evolutions & integrated luminosities. This workshop

The initial beam size has been chosen to allow c-w from the beginning of a run

$$\sigma_x^*/\sigma_y^*=10$$

Due to the fast emittance shrink

Initial luminosity ≠ peak luminosity

Parameters (II)

	θ = 2 mrad	θ = 8 mrad
initial luminosity [$\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$]	$2.3\mathrm{x}10^{34}$	$2\mathrm{x}10^{34}$
N_0 [10^{11}]	2.45	3.05
Crossing angle [mrad]	2	8
Technology for last quad.	Double-half quad.	Double aperture quad.
IP beta function (H/V) [m]	3/0.03	
Norm. initial emittance (H/V) [μm rad]	2.1	
Initial beam size IP [μm]	19/1.9	
Number of bunches	1404	
Crossing scheme	horizontal at the two IP	
Initial Piwinski angle	4.1	16.3
Initial total tune shifts [10^{-3}]	3.2/1.3	0.3/0.4
maximum total tune shifts	8.9/2.4	1.1/1.2
Beam separation [σ]	317	12680

O. Domínguez.

Parameters (III)

	θ = 2 mrad	θ = 8 mrad
Long. SR emittance damping time [h]	1.01	
Transverse SR emittance damping time [h]	2.02	
Initial horizontal IBS emittance rise time [h]	37.51	21.1
Initial vertical IBS emittance rise time [h]	72.02	42.2
Initial longitudinal IBS rise time [h]	72.45	40.7
Beam intensity lifetime [h]	14.6	29.9
Optimum run time [h]	6	8.5
Opt. av. Int. luminosity/day [fb^{-1}]	1.63	1.93

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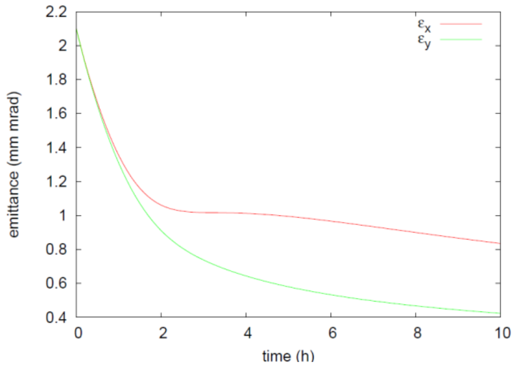
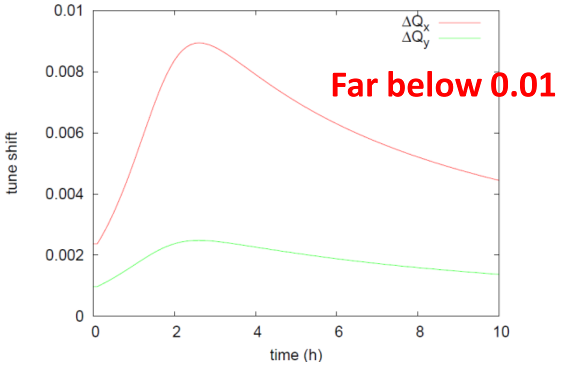
Time evolution. θ=2 mrad

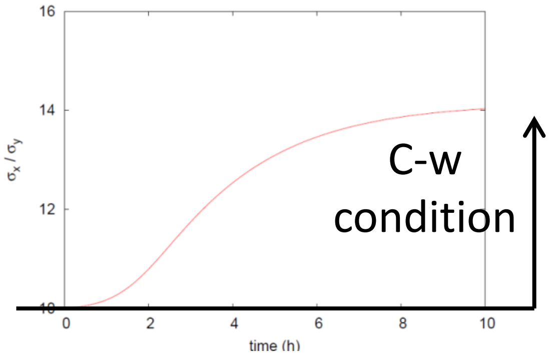


emittance



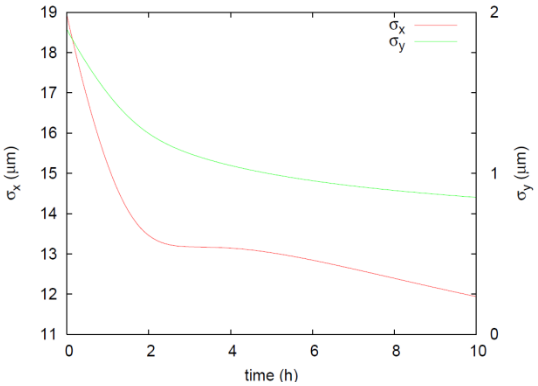
Far below 0.01

Total tune shifts

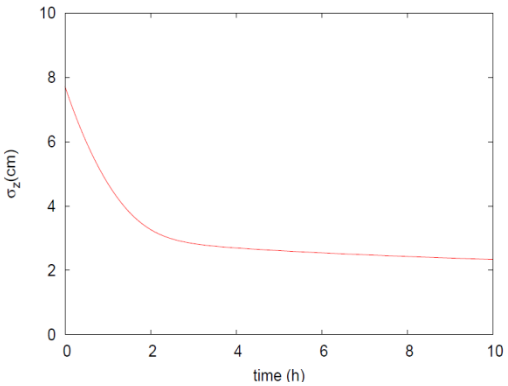


C-w condition

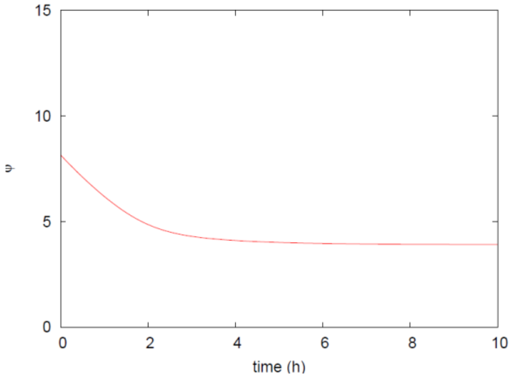
Beam size ratio



Transverse beam sizes



Long. Beam size

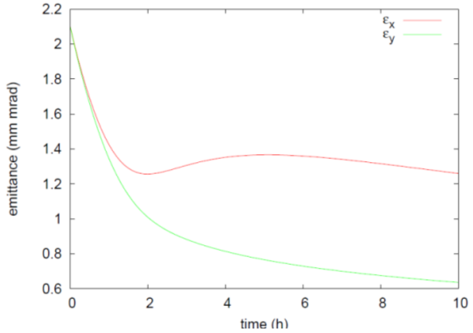


Piwinski angle

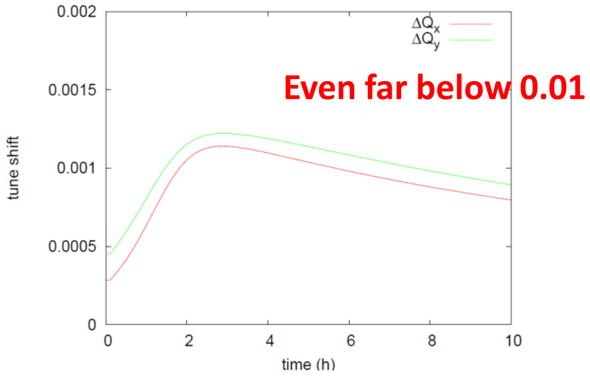
Luminosity ↑

O. Domínguez.

Time evolution. θ=8 mrad

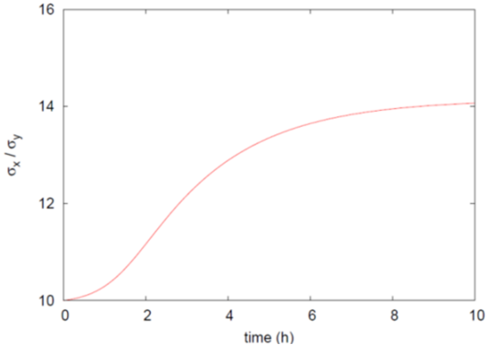


emittance

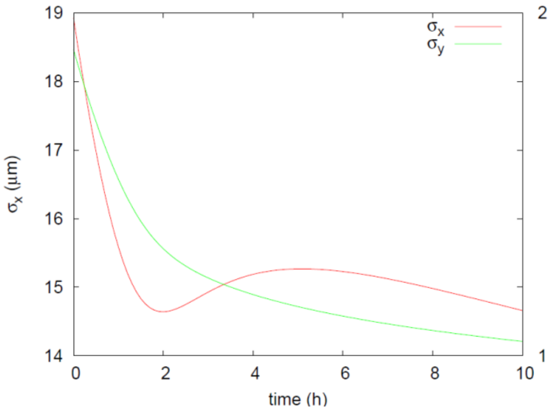


Even far below 0.01

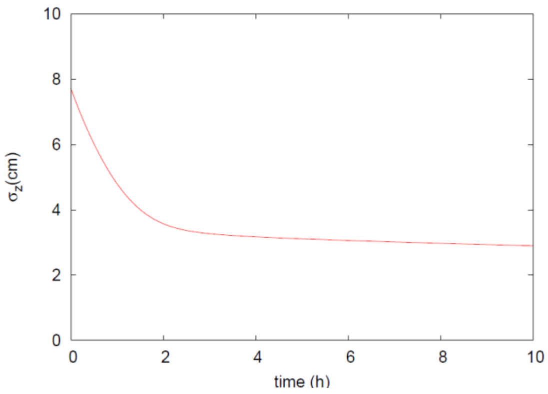
Total tune shifts



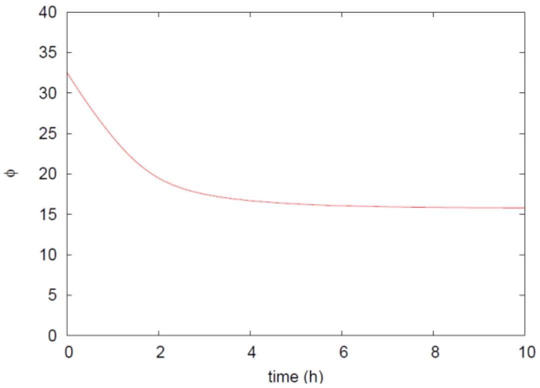
Beam size ratio



Transverse beam sizes



Long. Beam size



Piwinski angle

Luminosity ↑

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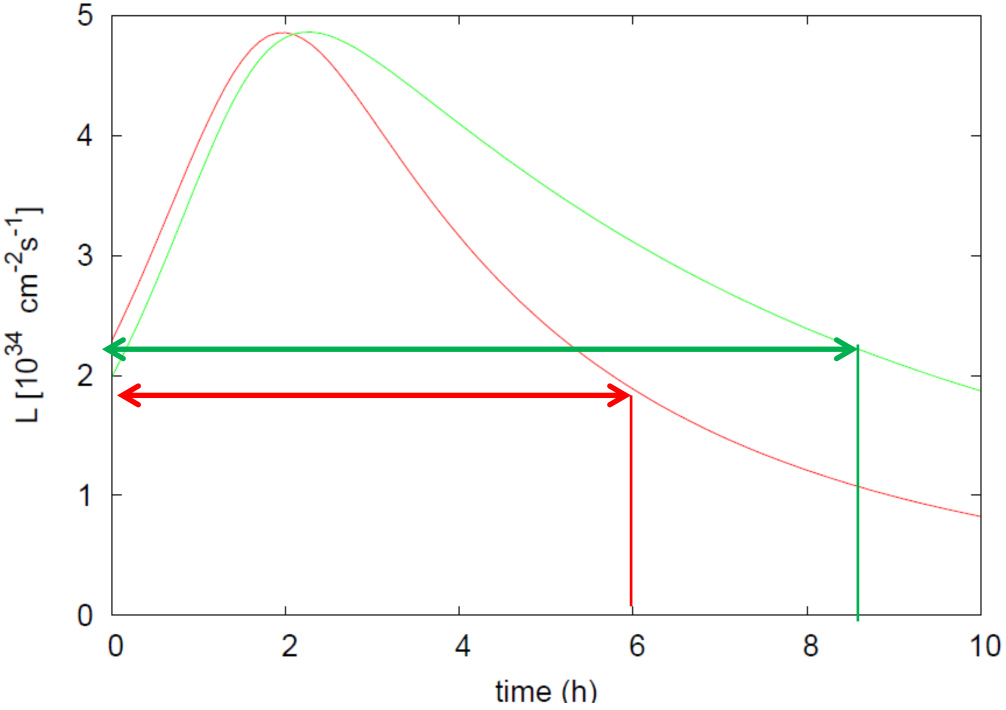
Luminosity evolution



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Conclusions

- An extremely-flat beam optics ($\beta_y^*/\beta_y^*=100$) is conceptual possible for LHC and HELHC
  - Large Piwinski angle, to reduce the collision area and allow for a lower β_y^*
  - Local chromatic correction
  - Possibility to have crab waist collisions that can increase luminosity and suppress resonances
  - Can accept higher brightness.
- With crab-waist collisions there is no tune shift limitation: no need for emittance blow up.
  - LPA allows for a higher brightness: increases beam lifetime
  - SR damping for the three planes increases luminosity
  - Significant increase in Lint

Thank you…

…For your attention