BROOKHAVEN NATIONAL LABORATORY

Flat beams and optics

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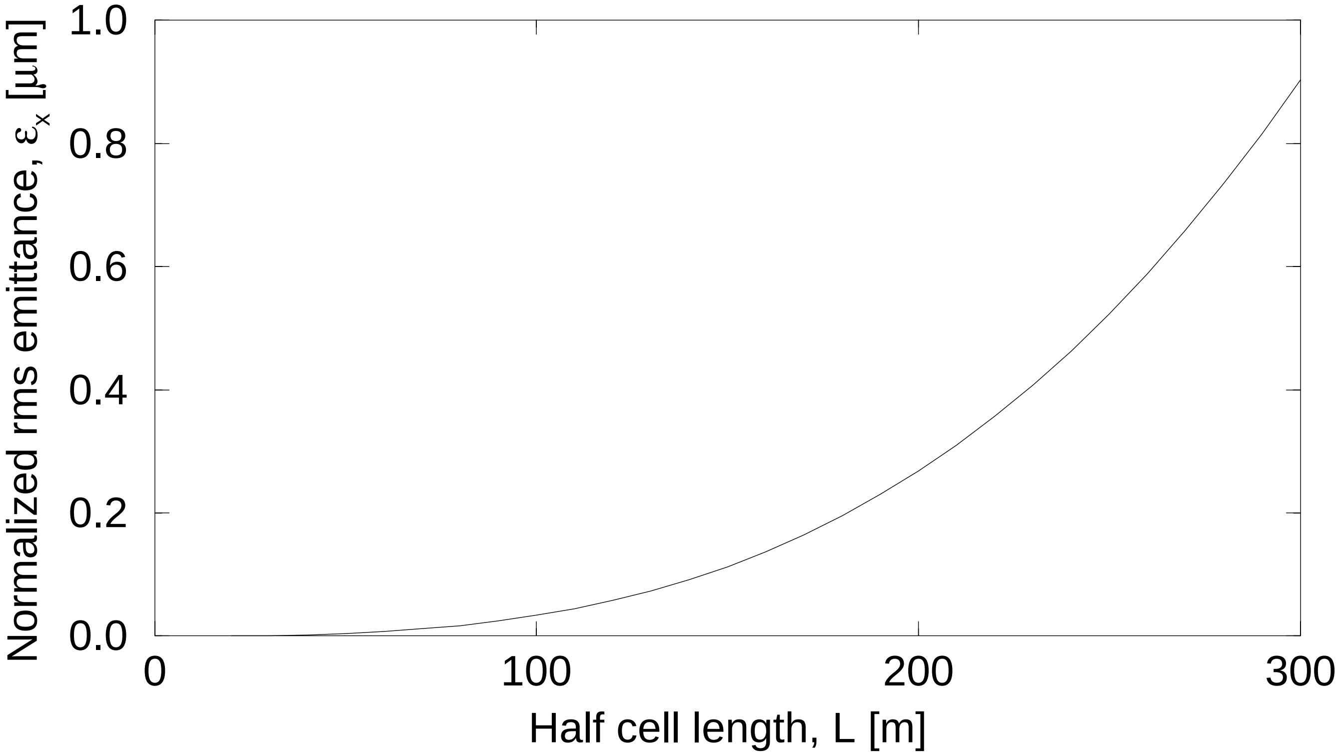
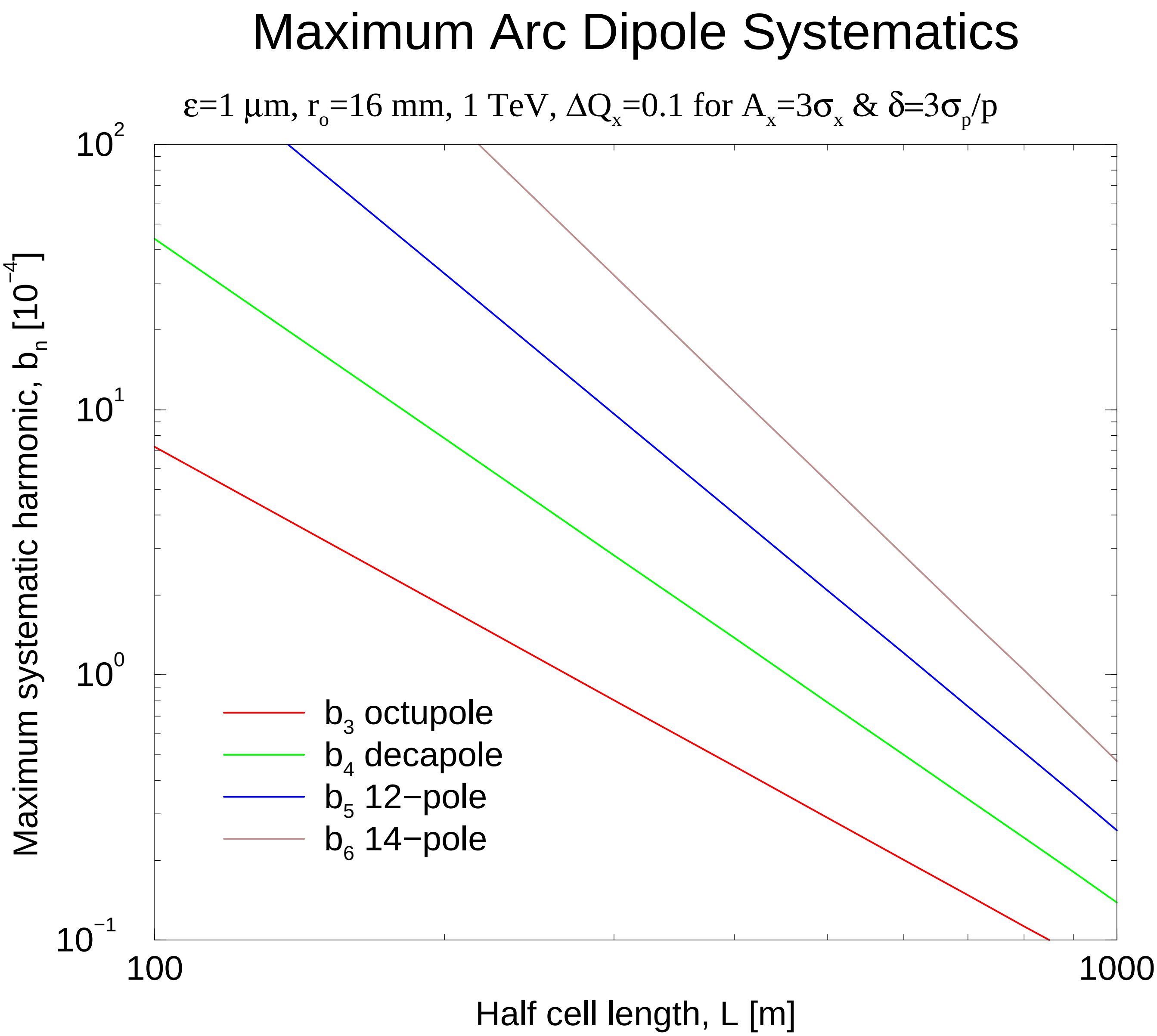
- **Equilibrium emittance, half cell length L_{hc}**
- **Luminosity performance**
- **Doublets or triplets?**
- **Beam-beam: head on and long range**
- **Intra Beam Scattering**
- **Inject flat beams?**
- **Conclusions**

Equilibrium emittance, half cell length L_{hc}



- VLHC (unlike SSC) has a "non-zero" equilibrium horizontal emittance $\epsilon_x \sim B^3 L_{hc}^3 \gamma^0$, where half cell length $L_{hc} \approx 260$ m.
- There is *some* freedom in selecting both ϵ_x, and the equilibrium emittance ratio $\kappa = \epsilon_y / \epsilon_x \approx 0.1$.
- **Are flat beams an advantage, or a liability?**



- The **magnet technology** could well limit L_{hc} and ϵ_x from above, eg through arc dipole systematic harmonics at injection ....

Luminosity performance

For flat beams, assume that

$$\kappa = \frac{\epsilon_y}{\epsilon_x} = \frac{\beta_y^*}{\beta_x^*} = \frac{\sigma_y^*}{\sigma_x^*} \ll 1 \tag{1}$$

so that the *flat* beam-beam tune shift parameter

$$\xi = \xi_x = \xi_y \approx \frac{N}{\epsilon_x}\frac{r}{2\pi\gamma} \tag{2}$$

and the *flat* luminosity is simply

$$L = \frac{M\xi^2\sigma_x'^{*2}}{\kappa}\left(\frac{\pi F\gamma^2}{r^2}\right) \tag{3}$$

where the term in brackets is “constant”.

The maximum value of the horizontal rms angular beam size $\sigma_x'^*$ is set by the IR quadrupole optics – **doublet or triplet?**

SUPPOSE that $8\widehat{\sigma}_x$ must fit in the quadrupole bore radius a, at the maximum beta location where

$$\widehat{\beta}_x \equiv \frac{\widehat{L}_x^2}{\beta_x^*} \tag{4}$$

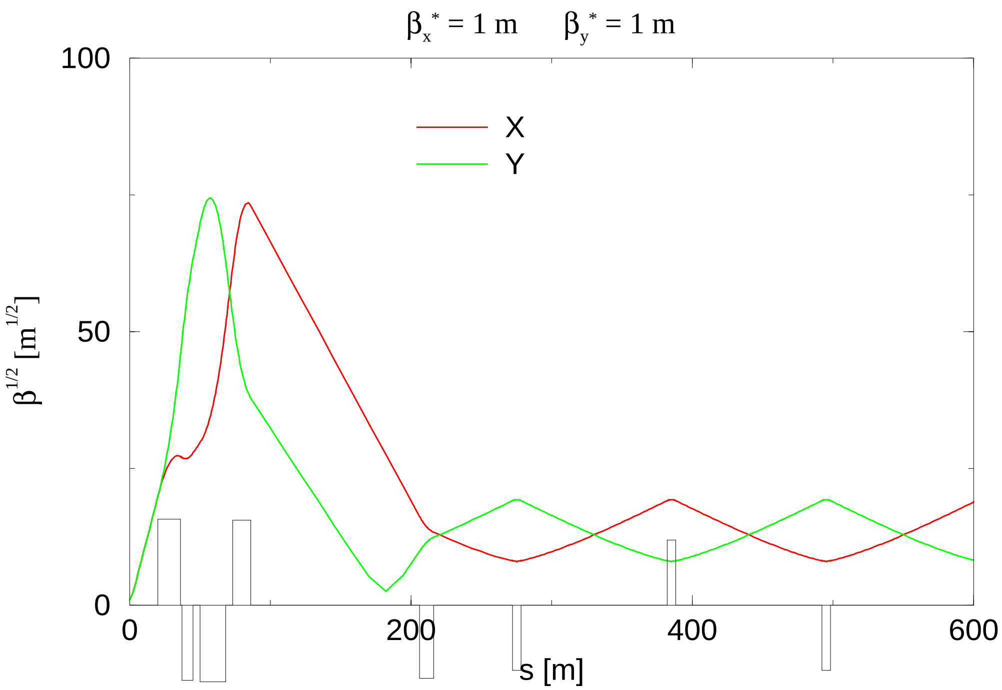
THEN simply

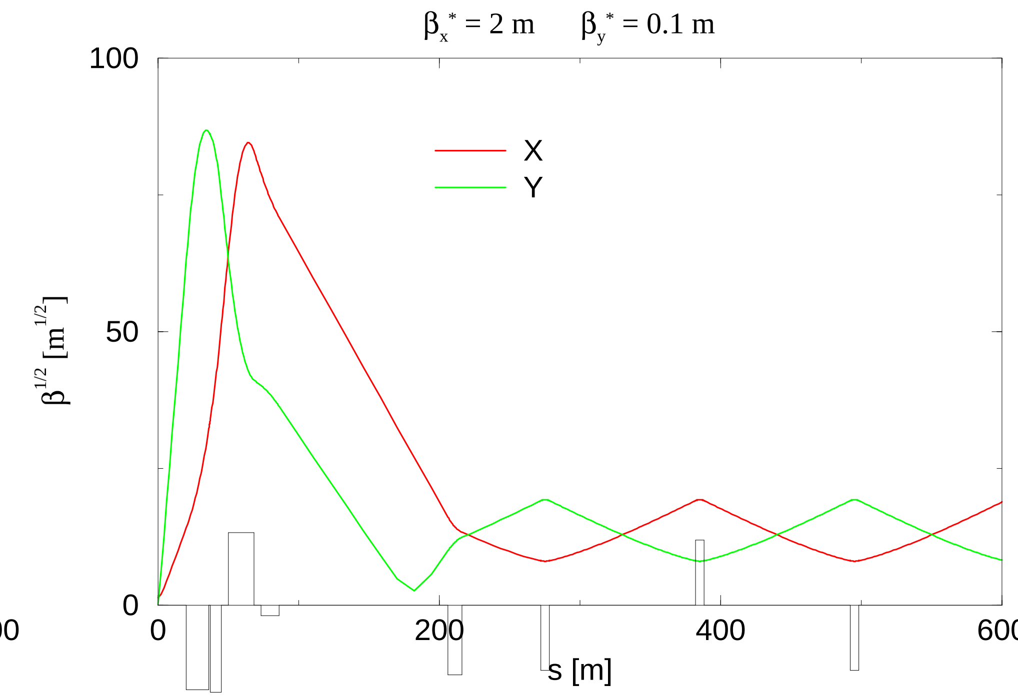
$$\sigma_x'^* \leq \frac{a}{8\widehat{L}_x} \tag{5}$$

and so luminosity scales like

$$L \sim \frac{1}{\kappa}\left(\frac{a}{\widehat{L}_x}\right)^2 \tag{6}$$

ALTERNATIVE IR OPTICS (with different κ values) should be compared on the basis of their effective optical distances, $\widehat{L}_x$.





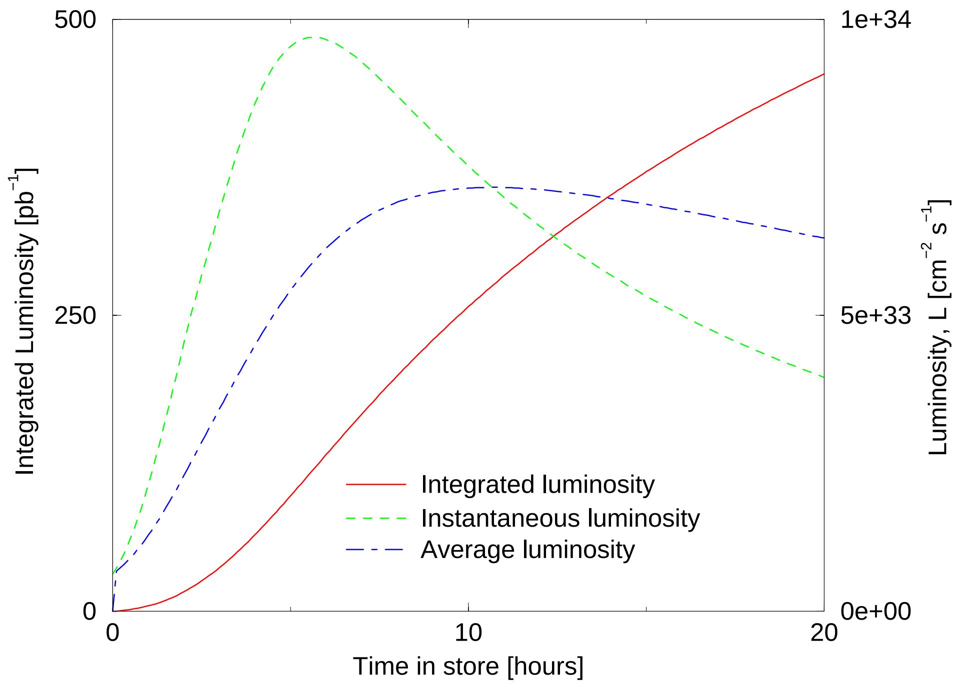
The same 4 quads ($G = 500$ T/m !) as a triplet ($\kappa = 1, \widehat{L}_x = 74$ m) on the left, and as a doublet ($\kappa = 0.05, \widehat{L}_x = 119$ m) on the right.

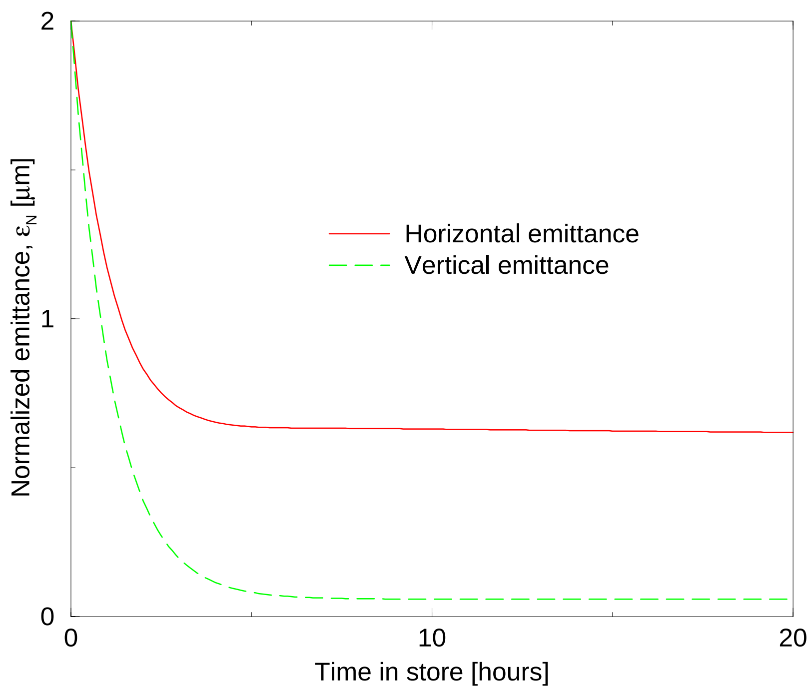
The doublet outperforms the triplet by a factor of $20 * (74/119)^2 = 7.7$ (but ...)

One quad is "off" in the doublet.

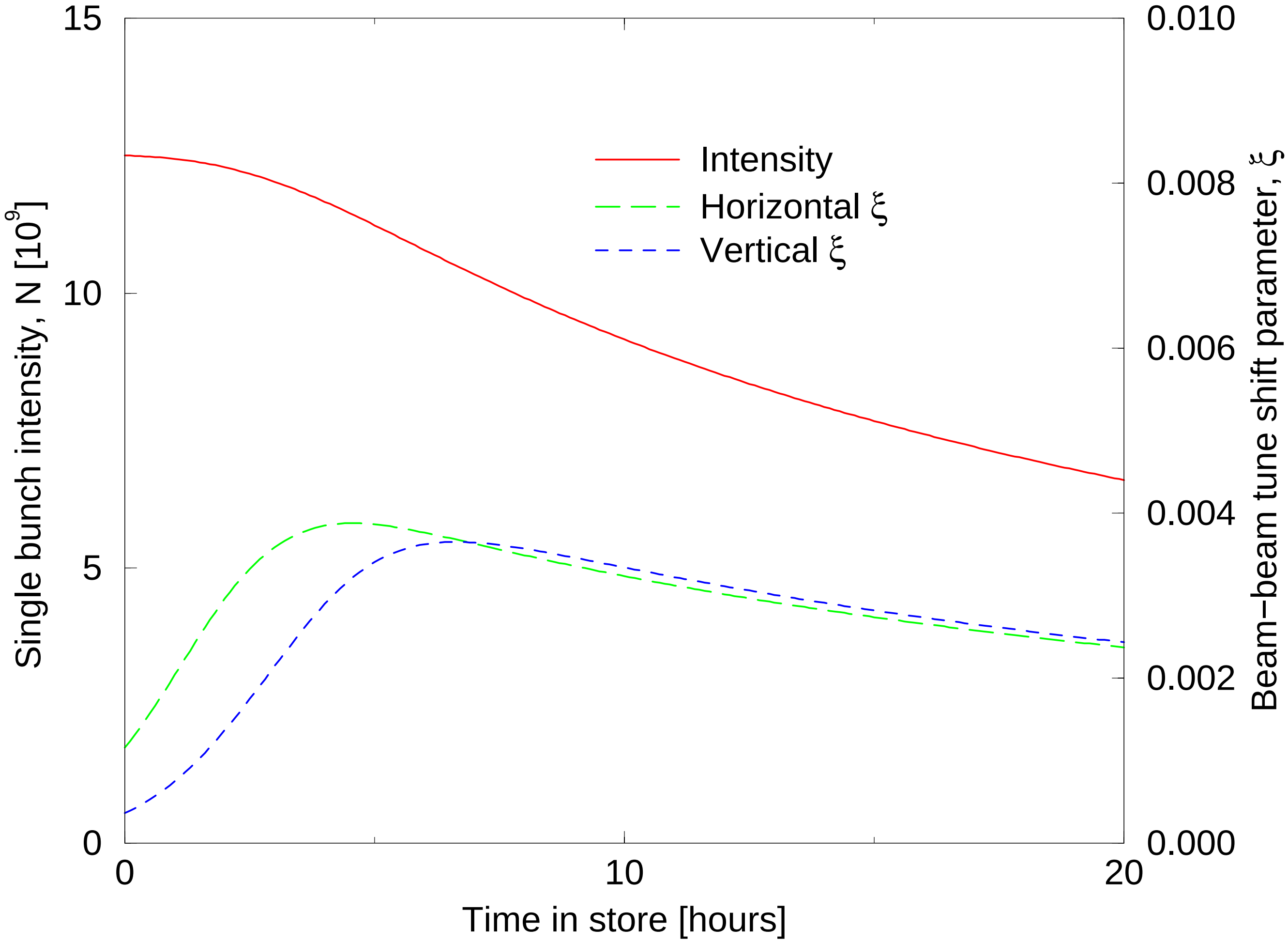
Store evolution using *almost* the same parameters as Mike Harrison ...

Energy, E_s	50.0	TeV
Peak luminosity, L	10^{34}	$\mathrm{cm^{-2}s^{-1}}$
Circumference, C	89.0	km
Dipole field, B	12.5	T
Number of bunches, M	20,000	
Initial bunch intensity, N	$12.5\,\mathrm{x}10^{9}$	
Half cell length, L	260	m
Number of collision points	2	
Collision betas, β_x^*, β_y^*	5.0, 0.5	m
Natural emittance ratio, κ	0.1	
Full crossing angle, $\alpha/\sigma_y'^*$	10.0	
Separation distance, L_{sep}	50.0	
Bunch spacing	4.45	m
Stored energy	2.00	GJ
Synchrotron radiation power	492	kW
Dipole heat load	5.87	W/m
Damping time, τ_0	2.26	hr
Norm. rms H emittance, ϵ_x	0.59	μm
Natural mmtm. spread, σ_p/p	$5\,\mathrm{x}10^{-6}$	


500
250
0
1e+34
5e+33
0e+00
0
10
20
Integrated Luminosity [pb^-1]
Luminosity, L [cm^-2 s^-1]
Time in store [hours]
Integrated luminosity
Instantaneous luminosity
Average luminosity


2
1
0
0
10
20
Normalized emittance, ε_N [μm]
Time in store [hours]
Horizontal emittance
Vertical emittance

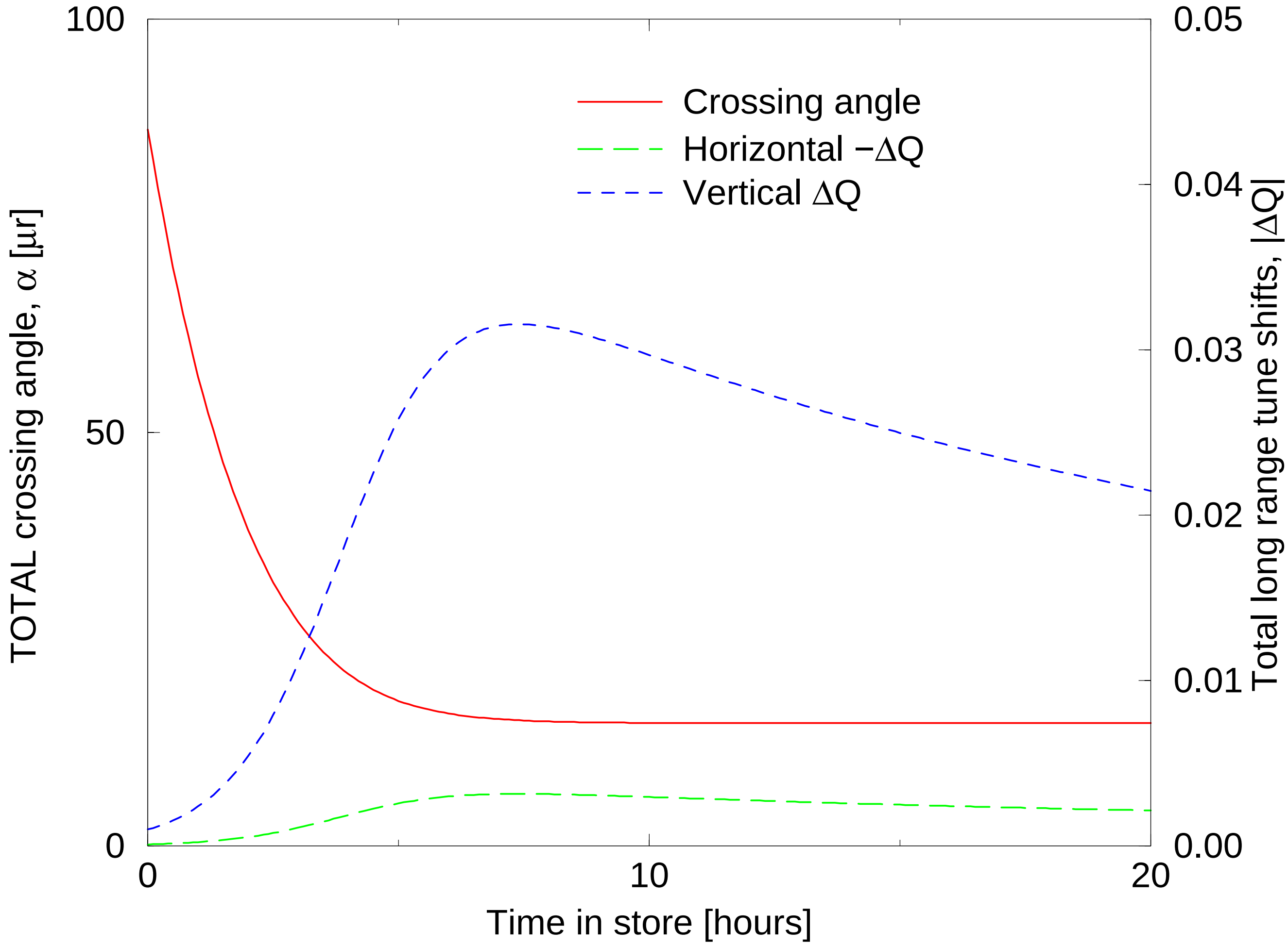
Beam-beam tune shift parameter ξ



Horizontal and vertical ξ's are well behaved.

How about long-range beam-beam?

Long Range Beam-beam

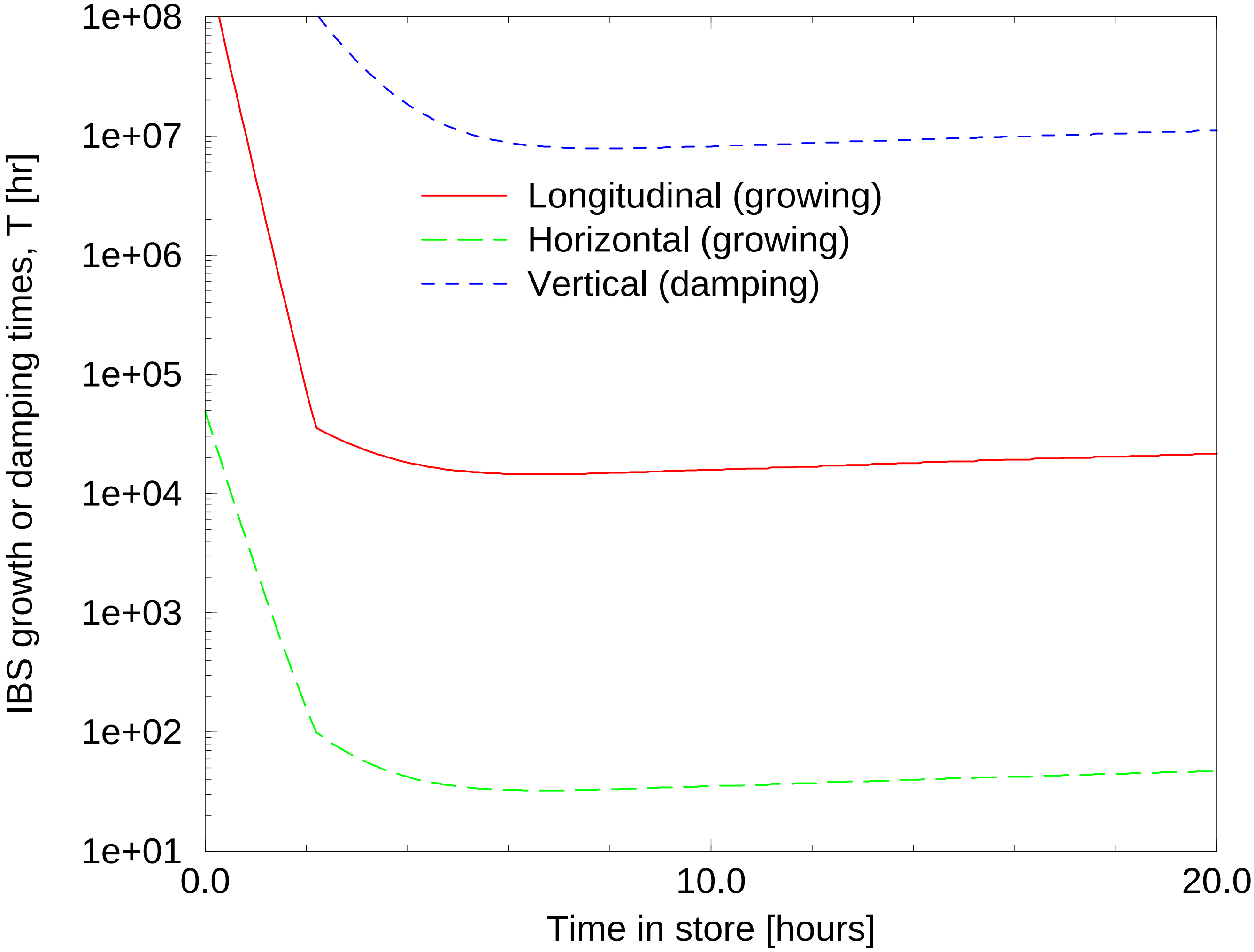


The VERTICAL long range tune shift ΔQ_y is much larger than the horizontal:

$$\Delta Q_x \;\approx\; -\kappa \Delta Q_y \;\approx\; n_{LR} \frac{\xi_y}{(\alpha/\sigma_y'^*)^2} \qquad (7)$$

A superficial(?) flat beam disadvantage!

Intra Beam Scattering



- The beam is heated longitudinally to maintain $\sigma_p/p \geq 10^{-4}$, avoiding stronger IBS effects.
- Recall: the natural damping time $\tau_0 = 2.26$ hr.
- IBS damps the vertical and grows the horizontal emittance – another (mild) source of flat beams!

Inject flat beams?

Can a transfer line make a round beam flat? NO.

It can be shown that AT BEST, emittances ϵ_1, ϵ_2 in the injector become ϵ_x, ϵ_y in the high energy ring, where

$$\epsilon_x = c^2\epsilon_1 + s^2\epsilon_2 \quad (8)$$
$$\epsilon_y = s^2\epsilon_1 + c^2\epsilon_2 \quad (9)$$

where $c = \cos(\psi)$, $s = \sin(\psi)$, and ψ is tunable.

If $\epsilon_1 = \epsilon_2 = \epsilon$, then
at best a round beam remains round, with no emittance blow up!

Conclusions

1. Flat beams produce denser bunches, allowing larger β^* values, and leaving room for further performance enhancement.

2. Luminosities in the range of $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ may be considered by reducing β^* values.

3. Flat beams permit doublet IR optics, with more modest magnetic strength demands, lower maximum betas, easier beam separation, and tolerable long range tune shifts.

4. Intra Beam Scattering also flattens the beam. Longitudinal beam heating is required.

5. Transfer lines cannot make round beams flat – except through emittance blow-up!