Luminosity loss due to LHC Collimator Impedance

$$Z_{\perp}^{\rm coll} \sim \frac{L_{\rm coll} \times \sqrt{\rho_{\rm coll}}}{a_{\rm coll}^3}$$ critical for squeezed optics

The collimator aperture $a_{\rm coll}$ can be increased by increasing β^* and reducing the crossing angle $\theta_{\rm c}$, at constant relative beam separation:

$$\theta_{\rm c} \simeq 10\,\sigma_\theta = 10\sqrt{\frac{\varepsilon}{\beta^*}} \quad \Longrightarrow \quad \frac{\Delta\theta_{\rm c}}{\theta_{\rm c}} = -\frac{1}{2}\,\frac{\Delta\beta^*}{\beta^*}.$$

$\hat{x} \simeq \ell^*\,\theta_{\rm c}$ transverse beam offset at Q2

$\hat{\sigma} = \sqrt{\epsilon \times \hat{\beta}} \simeq \ell^* \sqrt{\frac{\epsilon}{\beta^*}}$ r.m.s. transverse beam size at Q2

$$\Longrightarrow \quad \frac{\Delta\hat{x}}{\hat{x}} = \frac{\Delta\hat{\sigma}}{\hat{\sigma}} = -\frac{1}{2}\,\frac{\Delta\beta^*}{\beta^*}$$

With nominal LHC parameters, $\hat{x} = 8\,\mathrm{mm}$ and $\hat{\sigma} = 1.6\,\mathrm{mm}$.

The tertiary beam halo extends to a betatron amplitude $n_\mathrm{r} \simeq 1.4\, n_1$, larger than the aperture $n_1 \simeq 6\,\sigma_\mathrm{coll}$ of the primary collimators.

To increase the collimator aperture by $1\,\sigma_\mathrm{coll} \simeq 0.2\,\mathrm{mm}$ we need to reduce $\hat{x} + 1.4 \times 6\,\hat{\sigma}$ by $1.4 \times \hat{\sigma} \simeq 2.2\,\mathrm{mm}$. Thus

$$-\Delta(\hat{x} + 1.4 \times 6\,\hat{\sigma}) = 2.2\,\mathrm{mm} = \frac{1}{2}\,\frac{\Delta\beta^*}{\beta^*}\,(\hat{x} + 1.4 \times 6\,\hat{\sigma}),$$

and

$$\frac{\Delta\beta^*}{\beta^*} = -2\,\frac{\Delta\theta_\mathrm{c}}{\theta_\mathrm{c}} = \frac{2 \times 2.2}{8 + 8.4 \times 1.6} \simeq 22\%.$$

The additional effect of a 21% β-beating leads to a luminosity loss $\Delta L/L \simeq -\Delta\beta^*/\beta^*$ of 25%. This value becomes nearly 20% owing to the smaller spurious dispersion caused by smaller crossing angle and larger β^* (we assume up to 4 mm maximum dispersive orbit at Q2):

$\sim$ 20% lumi reduction for a $1\,\sigma_\mathrm{coll}$ increase of collimator aperture

The impedance estimated by Luc Vos for the baseline graphite collimator scheme is 1 GOhm/m. This value could be reduced by a factor ~ 5 by increasing the primary collimator aperture from 6 to $10\,\sigma_{\rm coll} \Longrightarrow$ the luminosity would be reduced by a factor 1.8.

More accurate values of β^* as a function of primary collimator aperture, computed by Bernard Jeanneret taking into account the effect of β-beating, but not of the smaller residual dispersion

n_1	β^* [m]	Relative Lumi $L/L_{\rm o}$	Luminosity Loss $\frac{L_{\rm o}-L}{L} = \frac{\beta^*-\beta^*_{\rm o}}{\beta^*_{\rm o}}$
6	0.5000	1.0000	-
7	0.6248	0.8003	0.2496
8	0.7634	0.6549	0.5268
9	0.9160	0.5459	0.8320
10	1.0824	0.4619	1.1648

‘Challenge’ from Fritz Caspers:

- a step in the direction of a 3D collimator impedance estimate
- assume that collimator jaws are electrically isolated from the surrounding vacuum chamber (isolated vacuum feedthroughs for water cooling and support, but jaws should be grounded!) $\Longrightarrow$ at least for low frequencies, i.e. when length of the jaw $< 0.1\,\lambda$, collimator jaws can be considered as capacitive PU’s with some external termination or maybe as $\lambda/4$ stripline PU’s
- there will be very little image current at low frequencies (say up to 10 or 20 Mhz) and thus a rather small resistive surface related longitudinal and transverse impedance
- an additional advantage is that we have external access to the induced signals on this ‘transverse stripline PU’ or ‘capacitive PU’ and can measure the position of the beam wrt the jaws directly. However beam losses $\longrightarrow$ noisy signal (Ralph Assmann)

- moreover we could use some external loading circuits to act as cavity mode damper for high frequencies
- apart from that, the idea of rotated jaws (X-shaped with say 5° angle) should help to reduce the high frequency impedance

Can we quickly decide whether Fritz is right or wrong?

- what about segmenting the beam pipe of any large accelerator $\Longrightarrow$ suppress resistive wall instability? what about higher frequences, i.e. multiples of the bunch frequency?
- why not isolating the many low-gap inserts used in synchrotron light sources and boost their performance?
- are we sure that the solution of Fritz does not create additional problems (resonances, more longitudinal impedance)?
- what can be concluded from existing measurements with beam?