RF Constraints on Gamma at Transition in PS2

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Background

The new PS2 machine is proposed to be double the size and double the energy of the existing PS. The usual rule of thumb,

$$\Gamma = \frac{2\pi R\rho}{V_{\mathrm{RF}}}\frac{dB}{dt} < 0.5$$

implies roughly double the accelerating rf voltage if a comparable ramp rate is to be maintained. In addition, keeping the same upper frequency limit for this tuneable rf system means that all harmonic numbers will also be doubled. Taking into account all such factors of 2 between the original PS and the new machine, the old-to-new synchrotron frequency ratio reduces to

$$\frac{f_{\mathrm{s}}^{(1)}}{f_{\mathrm{s}}^{(2)}} \approx 2\left(\frac{V_{\mathrm{RF}}^{(1)}}{V_{\mathrm{RF}}^{(2)}}\right)^{1/2}\left(\frac{\eta^{(1)}}{\eta^{(2)}}\right)^{1/2}$$

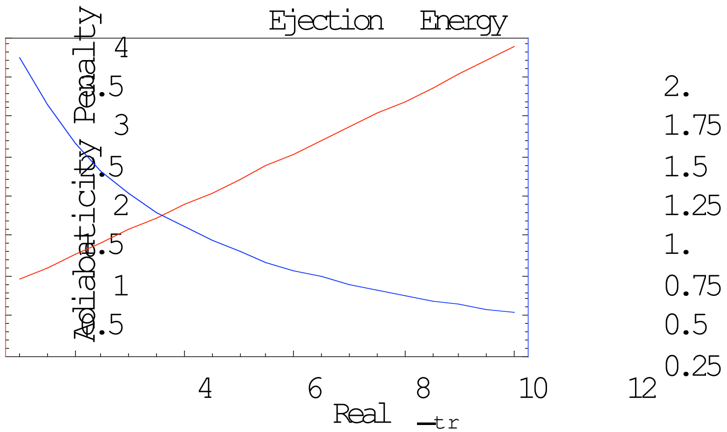
While the longitudinal acceptance ratio between the two machines is

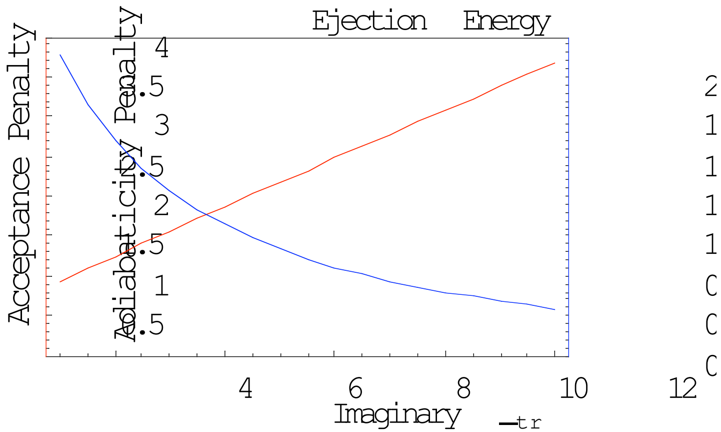
$$\frac{A_{\mathrm{L}}^{(1)}}{A_{\mathrm{L}}^{(2)}} \approx \left(\frac{V_{\mathrm{RF}}^{(1)}}{V_{\mathrm{RF}}^{(2)}}\right)^{1/2}\left(\frac{\eta^{(2)}}{\eta^{(1)}}\right)^{1/2}$$

This means that some compromise between adiabaticity and acceptance during rf gymnastics is inevitable in the choice of γ_{tr}.

Trends at Given Voltage (1)

An early objective was to establish whether the high-frequency cavities used to split the proton bunches at high energy for the LHC beam could be retained without an upgrade in voltage performance. Fixing the voltage ratio at unity yields the following trends as functions of real or imaginary γ_{tr}:



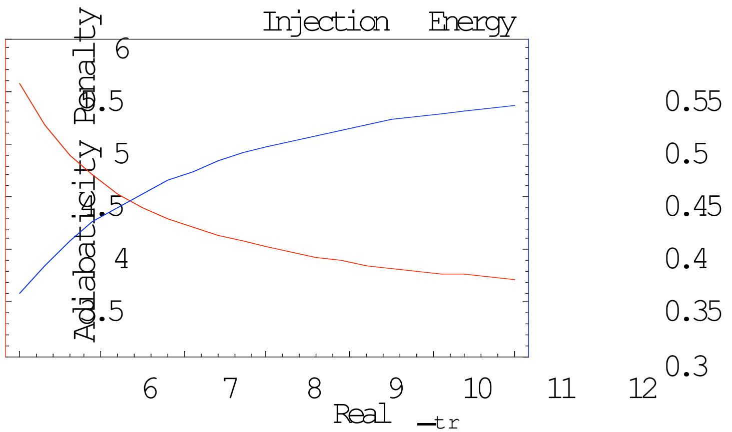


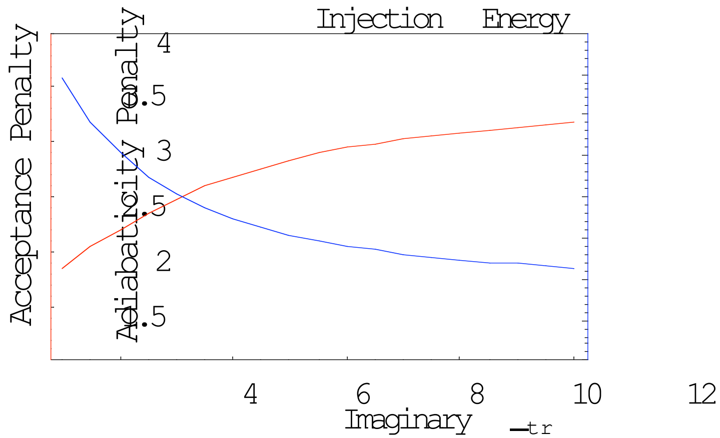
Here, an adiabaticity penalty greater than unity means that rf gymnastics would have to be performed more slowly in the new machine, while an acceptance penalty greater than unity means that less acceptance would be available so that a bunch of given emittance would be longer than in the existing PS.

Clearly, real or imaginary γ_{tr} makes little difference to these trends.

Trends at Given Voltage (2)

However, (triple) splitting is also currently performed at low energy to manufacture the LHC beam and the corresponding trends are then different:



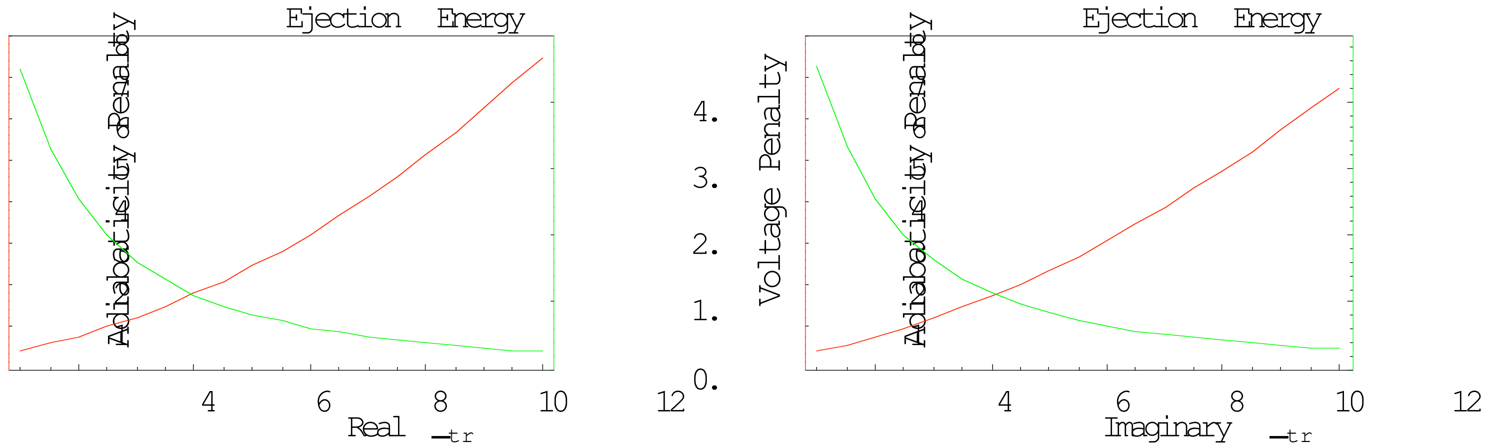


The adiabaticity penalty is large because γ is already 4.7 at injection in the PS2, but it could be improved by going to imaginary γ_{tr}.

The low acceptance penalty means that bunches would be shorter in the new machine. This could be a problem as splitting is sensitive to bunch length.

Trends at Given Bunch Length (1)

Fixing the bunch duration ratio at unity yields the following trends as functions of real or imaginary γ_{tr}:

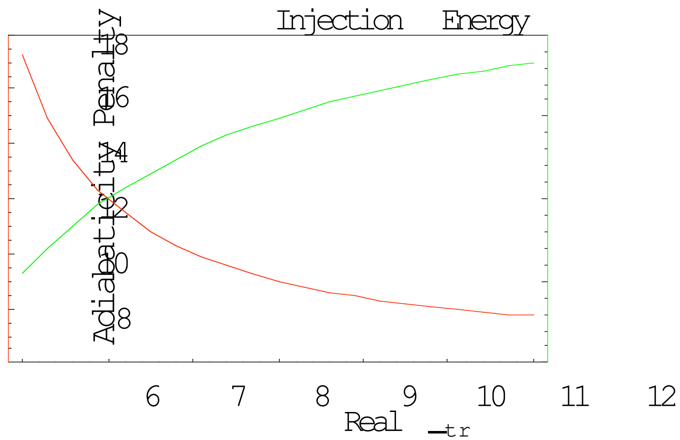


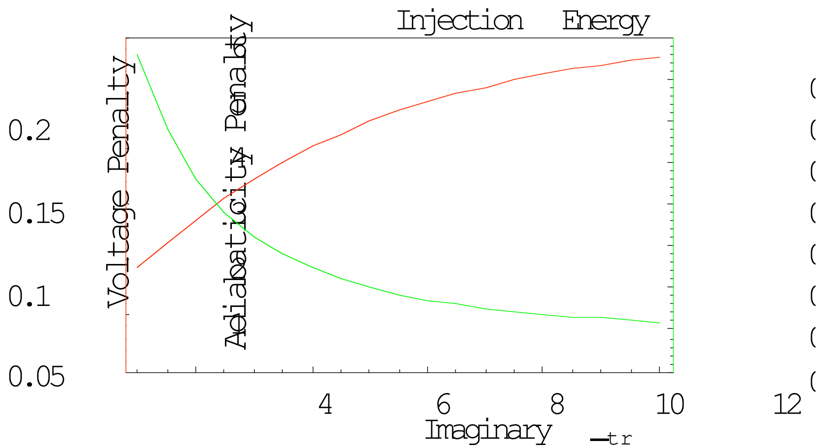
Here, a voltage penalty greater than unity means that more rf voltage would be required in the new machine to maintain the same bunch duration.

Adiabiticity is now worse – unless the magnitude of γ_{tr} is reduced below about 6, which must then be "paid for" with increased voltage.

Trends at Given Bunch Length (2)

In the low-energy case, the rf voltage is considerably lower in the PS2 – again, particularly for real γ_{tr} because γ is already 4.7 at injection – and this leads to a very large adiabaticity penalty. Consequently, the situation is significantly improved by going to imaginary γ_{tr}.





Imaginary γ_{tr} also has the distinct advantage of eliminating transition crossing.

Summary

This “grass-roots” rather than “blue-skies” approach suggests that, if the new PS2 machine is to emulate the flexibility of the existing PS, a judicious choice of (imaginary) γ_{tr} must be made. Otherwise considerable investment in rf hardware or much longer magnetic cycles are to be anticipated.

The consequences are less compelling if rf gymnastics can be avoided at low energy in the PS2. For example, building a linear injector would radically change the fabrication of all beams. Or even perhaps, in an interim period, the old PS could provide LHC-type beams that are already split before injection into the new one.