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"Phase Trombone" for Parity Experiments

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1. Motivation

The beam optics for HAPPEX and G0 experiments have essentially relied on 'damping' of the position differences inherent in the acceleration of the beam – the so called 'adiabatic damping'. To supplement that, one can provide additional suppression of betatron motion driven helicity asymmetries via careful control of beam optics near the target – the so called 'phase trombone'.

2. Adiabatic Damping

Reduction in the amplitude of the betatron motion as the beam momentum is adiabatically increased is referred to as adiabatic damping. The acceleration throughout the machine gradually reduces the amplitude of the betatron oscillation. The full expected adiabatic damping factor is often not achieved due to an optically mismatched beam transport system. In a perfectly matched system, the Twiss parameters after passing through each beam-line element match the design parameters. At a given location, the phase-space ellipse preserves its area, but in a badly matched system the ellipse becomes distorted leading to larger betatron amplitude ('orbit blow-up') than ideal adiabatic damping would predict. In practice, correction elements are used to restore the envelope after sections of the beam-line (e.g. linac, arc, etc.). Finally, the transverse displacement from the central orbit can be reduced further at a given point by controlling the overall accumulated betatron phase.

In the G0 experiment, the relatively large bunch charge (running at 31 MHz pulse rate) required a non-standard setup of the injector optics, which made reduction of the helicity correlated beam position differences with the standard damping difficult to achieve. Nominally, with 3 GeV incident energy, the damping from the injector to the target would be 3GeV/355 keV= 95. However, the damping factors measured in the x and y directions were typically 25 and 10, respectively. In the G0 experiment, active feedback was used with some success to reduce the position and angle differences, although changing beam conditions required periodic adjustments.

As HAPPEX ran with the standard bunch charge (499 MHz pulse rate), the tuning of the injector was more standard and larger damping factors (though not the theoretical values of 95) were routinely obtained. In the most recent run of the HAPPEX experiments beam position differences were mitigated using the so called 'phase trombone' technique.

3. Phase Trombone

A group of eight quadrupole magnets in a non dispersive region (upstream of the arc) was used to 'add' the desired values of the horizontal and vertical phase advances at the target without altering the optics (Twiss functions) in the arc-through-target region (hence the name 'phase trombone', or 'closed beta bump'). The implemented optical insert allowed us to independently change the horizontal and vertical phase advances in ±90 deg. region. This results in trading off helicity correlated position and angle differences. The basic idea is to change the phase advance periodically during the experiment to trade, e.g., a large position difference for a large angle difference or even to reverse the sign of a position difference to cancel the effect in an earlier part of the run. Technically, this amounts to rotating the phase space ellipse that describes the beam envelope.

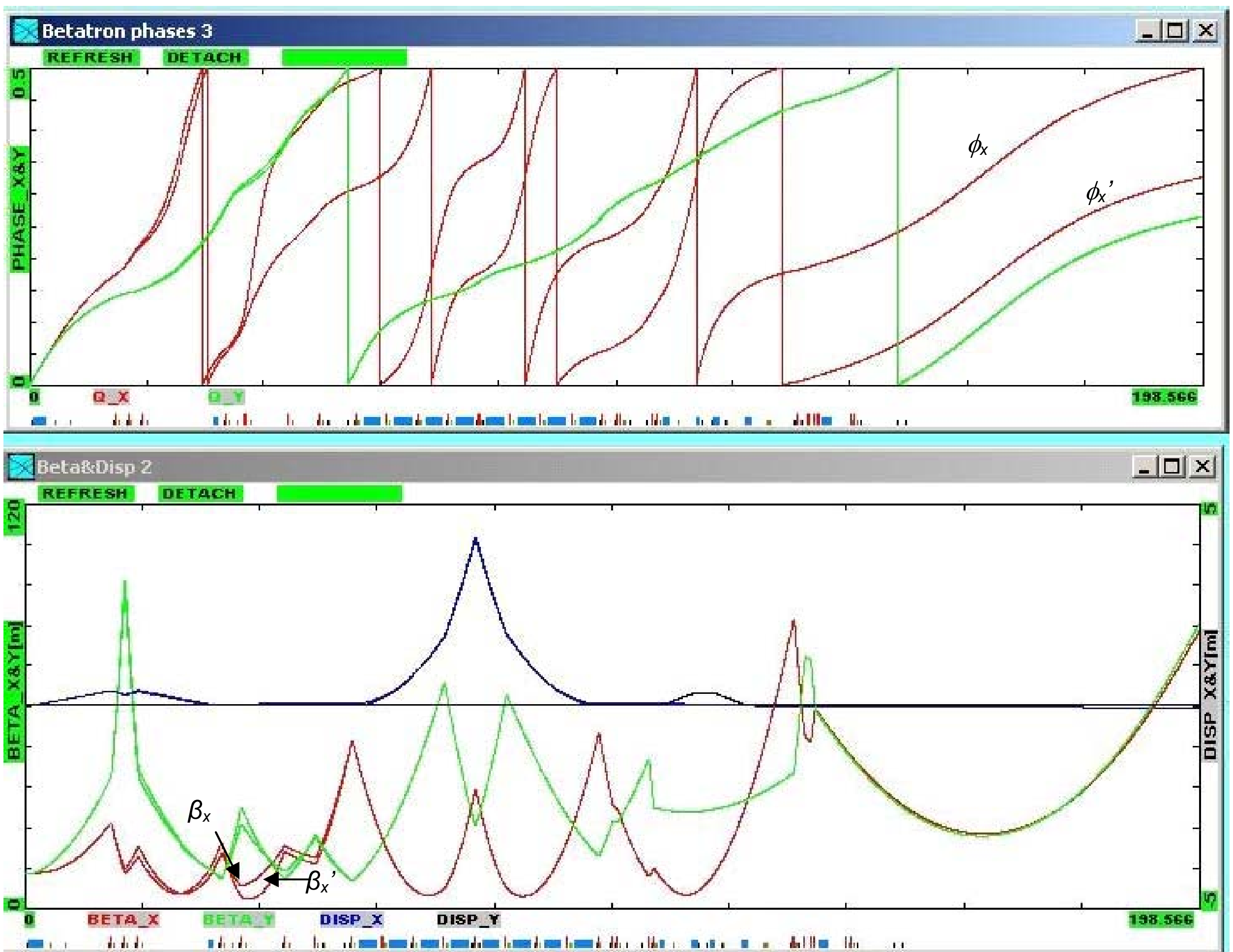

Figure 1 Calculated effects of the phase trombone in the Hall A beam line – horizontal 'phase trombone' example. The upper graph shows a shift in the horizontal betatron phase, ϕ_x , by 60 deg. ('red' curves at right: ϕ_x and ϕ_x') with no change to the vertical phase ('green' curve) for two different

quadrupole tunings. The difference in the optics can be seen in the lower graph where two distinctively different curves β_x and β_x' in the tuning region (upstream of the arc) merge into identical design optics in the arc making the Twiss functions (beam envelopes) unaffected while shifting only the horizontal betatron phase by 60 deg. (the vertical phase remains unchanged).