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# Tune Correction for the SPS Ramp

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**Abstract**

The tune corrections applied in the ramp for a large palette of SPS cycle used in 2007 has been analyzed to evaluate the reproducibility and the dependence on the supercycle composition. The data highlights the excellent reproducibility of the SPS tune above momenta of 50 GeV/c, with little dependence on the injection momentum or the ramp speed. Difference are concentrated at lower momenta, but for similar cycles, the corrections are very reproducible and show only a small dependence on the supercycle composition. The data also underlines the positive impact on fixed target beams of the improvement in the tracking of the main power converters of the SPS that was obtained by reducing the point spacing in the ramp from 30 ms to 6 ms

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## 1 Introduction

In 2006 an analysis of the SPS main power converter tracking errors during the fast ramps used for fixed targets beams revealed tracking errors that could be traced to the coarse time interval of the function points [1]. The analysis also indicated that a reduction of the time interval between points of the functions from 30 ms to 5 or 6 ms would lead to a reduction of the tracking errors by at least one order of magnitude. The tracking errors of the main dipole and quadrupole converters was also suspected to be at the origin of the poor reproducibility of the tune corrections during the early part of the ramp. In 2007 advantage was taken of the improved flexibility provided by the new LSA control system to reduce the time interval for function points from 30 to 6 ms. At the same time the generation of point was improved and smoothed. This change immediately improved the convergence and quality of the so-called 'Autotrim' procedure (see Ref [1]). The tracking errors were indeed reduced by more than order of magnitude. The tune corrections in the ramps became significantly smoother in the early parts of the fixed target (FT) beam ramps. Furthermore it was for the first time possible to copy tune correction from an existing cycle to a new cycle and immediately obtain ramp transmissions well over 90% on the new cycle without additional trims. The tune corrections were stable over long periods (at constant beam current) and no longer required frequent re-adjustments. In some cases no tune trim was performed for many weeks. This was a major breakthrough in tune control for the SPS ramp.

This note compares the final tune correction functions for a variety of cycles in order to better quantify the reproducible and non-reproducible part of the corrections.

## 2 Tune Corrections in the Ramp

The tune corrections that were applied to reach the nominal tunes for FT beams (**26.62, 26.58**), LHC beams (**26.13, 26.18**) and LHC ions beams (**26.20, 26.25**) have been collected and analyzed to evaluate the SPS reproducibility and to be able to anticipate tune corrections for future cycles.

The tune corrections have been analyzed for the following cycles:

- **FT-LHCMD2** : the nominal FT cycle with a 1.26 second injection flat bottom and a momentum range of 14 to 400 GeV/c, followed by a short 26 GeV proton MD cycle to reduce the RMS power consumption. This cycle was mostly used overnight and on weekends.
- **FT-LHCMD37** : the nominal FT cycle with a 1.26 second injection flat bottom and a momentum range of 14 to 400 GeV/c, followed by a proton MD cycle with a ramp to 37 GeV.
- **FT-LHCPILOT** : the nominal FT cycle with a 1.26 second injection flat bottom and a momentum range of 14 to 400 GeV/c, followed by a 450 GeV LHC cycle with a fast 4.2 second long ramp designed for single bunches or pilot beams.
- **FT-LONG-3CNGS** : the nominal FT cycle with a 1.26 second injection flat bottom and a momentum range of 14 to 400 GeV/c with a long flat top (9.0 seconds instead of 4.8 seconds) followed by 3 CNGS cycles and an LHC ion MD cycle with a ramp to 100 GeV.

- **LHCNOM-2007** : the nominal LHC cycle with a 10.86 second injection flat bottom and a momentum range of 25.9 to 450 GeV/c that was used in 2007. This cycle has a 'de-gauss dip' to 14 GeV after the rampdown from 450 GeV that had some effect on the tune correction and that will be discussed later.
- **LHCNOM-2006** : the nominal LHC cycle with a 10.86 second injection flat bottom and a momentum range of 25.9 to 450 GeV/c that was used in 2006.
- **LHCPILOT-FAST** : a fast LHC cycle for pilot beams with a 60 ms injection flat bottom and a momentum range of 25.9 to 450 GeV/c.
- **LHCION-FB7860** : the last version of the LHC Lead ion cycle with a 7860 ms long flat bottom at 17.7 GeV/c (proton equivalent) and a standard LHC ramp to 450 GeV/c.
- **CNGS-CNGS1(2,3)** : the nominal CNGS cycles with a 1.26 second injection flat bottom and a momentum range of 14 to 400 GeV/c. The flat top length is 90 ms.

For the analysis the raw tune corrections have been corrected for any trim performed on the main bending magnets at the current level (which are not correctly propagated on the tune correction). Trims of $-1$ to $-1.5$ A were typically applied on the injection flat bottom of the FT and CNGS cycles to match the energy with the PS. This corresponds to setting the momentum at injection to 13.9 instead of 14 GeV/c. For cycle **LHCNOM-2007** a constant trim of $1.1$ A applied for "mysterious" reasons all along the cycle had to be corrected.

The tune corrections for the first part of the FT beam ramp is shown for the cycles mentioned above in Figure 1. The tune corrections are much smoother than in the past, where large oscillating corrections with amplitudes of up to 0.2 in tune units frequently crept in over time. The correction did not 'diverge' with time between the various cycles. One notes a residual systematic oscillation of the correction in the vertical plane, that may still be related to the power converter tracking.

The tune corrections as a function of the beam momentum are shown for the same FT cycles in Figure 2. The corrections are reproducible, in particular above 40 GeV/c. On the injection flat bottom the spread is larger, because of different super-cycle compositions, but the effect is rather modest, in the range of $\pm 0.02$. There is also a slight difference on the cycle with long flat bottom and CNGS, which could be due to the fact that the tune was not measured and corrected.

The FT and CNGS beams are in principle identical, except that the nominal CNGS beam intensity is higher which requires tune corrections in the range $0.01 - 0.025$ to compensate the tune changes due to collective effects. The cycles share the same injection flat bottom and ramp, only the length of the flat top is different. The tune corrections for the three consecutive CNGS cycles are very similar, with only minor differences in the first 200 ms of the ramp. On the injection flat bottom, the tune correction is not constant due to eddy currents [1]. Unfortunately the comparison of the different CNGS cycles could not be completed since the CNGS run was stopped due to radiation issue on electronic components near the target cavern. It is however likely that at least the corrections for the second and third CNGS cycles could be made identical.

The tune corrections are shown for all cycles listed before in Figure 3. The spread is small at momenta above 50 GeV/c, with one exception for the nominal LHC cycle used in 2007. At low energy, the corrections evolve differently depending on the injection momentum (14, 17.7 or 26 GeV/c) and on the ramp speed (LHC normal or fast). The large swing of the correction between 300 and 450 GeV/c correlates with a momentum (b1) error described in Ref [1]. The

2007 nominal LHC cycle with a degauss dip down to 14 GeV/c behaves somewhat differently. Its tune correction at low energy is much larger than for the other cycles, and the difference vanishes at higher energies. At 26 GeV the tune correction is larger by up to +0.1 with respect to the 2006 nominal LHC cycle or to the fast ramp cycle. The tune difference between the 2007 and 2006 nominal LHC cycles is shown in Figure 5 as a function of the inverse of the momentum.

The tune corrections averaged over the LHC type cycles used in 2006 (from Ref [1]) and over FT type cycles of 2007 are shown in Figure 6. For the FT beams the correction corresponds to a total beam intensity of $\approx 2.8 \times 10^{13}$ protons. For the LHC beams it corresponds to a low intensity beam of less than $10^{12}$ protons. The r.m.s. spread of the data is represented in the form of error bars. For the FT beams, the data from the cycle **FT-LONG-3CNGS** has not been included in the average for the horizontal tune.

The averaged data for LHC beams has been used in 2007 to to anticipate the tune correction for new LHC beam cycles. This functionality was included in the SPS **MultiQ** application. With the exception of the LHC cycle including a degauss to 14 GeV/c (**LHCNOM-2007**) and the large trim at the current level for the main bends, the prediction accuracy was excellent. The FT and ion beam tune data will be added for 2008.

## 3 Conclusion

The analysis of tune corrections for a range of cycles and cycle compositions confirms that the tune corrections for the SPS are very reproducible above 50 GeV/c and almost identical for all cycle types.

At low energy differences appear between cycles with injection momenta of 14 GeV/c, 17.7 GeV/c and 26 GeV/c. For a given class of cycles (same injection momentum and ramp shape), the corrections vary little from one cycle to another. Initial corrections for a new cycle can therefore be either copied from an existing cycle of the same type, or be obtained from an averaged correction via the MultiQ application.

The changes that were made to the LHC nominal cycle between 2006 and 2007 in the form of a degauss dip to 14 GeV on the other hand led to significant changes of the tune corrections. This effect highlights how a change of the minimum momentum between a down ramp and an injection plateau can influence the tune errors of the SPS.

## 4 Acknowledgments

The authors are grateful to K. Cornelis for discussions and constant support.

## References

[1] C. Arimatea, D. Jacquet, L. Normann, J. Wenninger, *Dipole Field, Tune and Chromaticity Correction at the SPS : from Converter Tracking to Eddy Currents*, AB-Note-2007-009 OP.

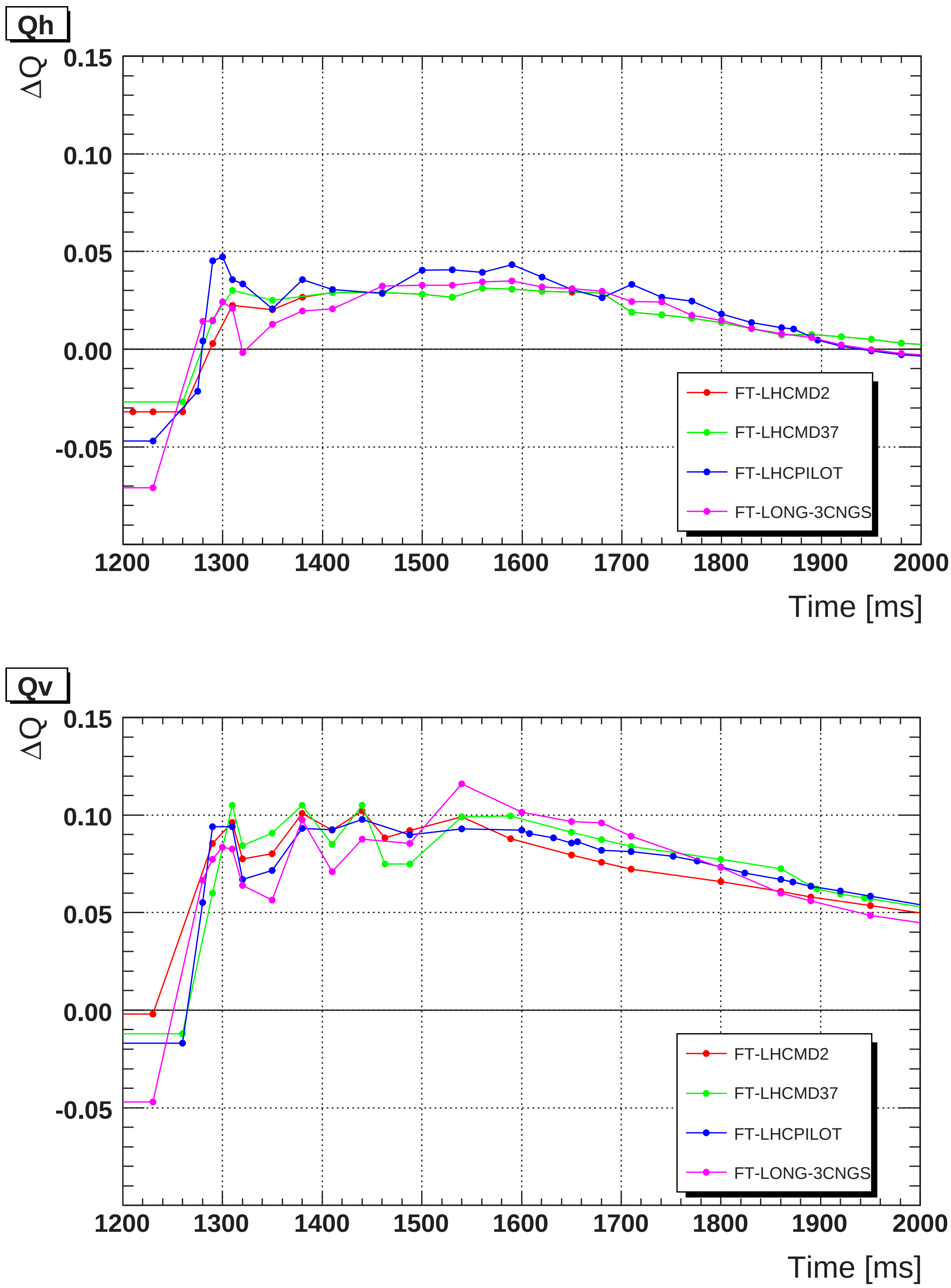



Figure 1: Tune trims as a function of the cycle time in the first part of the FT ramp for the horizontal (top) and vertical (bottom) plane for FT cycles used in 2007. The ramp starts at 1260 ms and the beam crosses transition around 1480 ms.

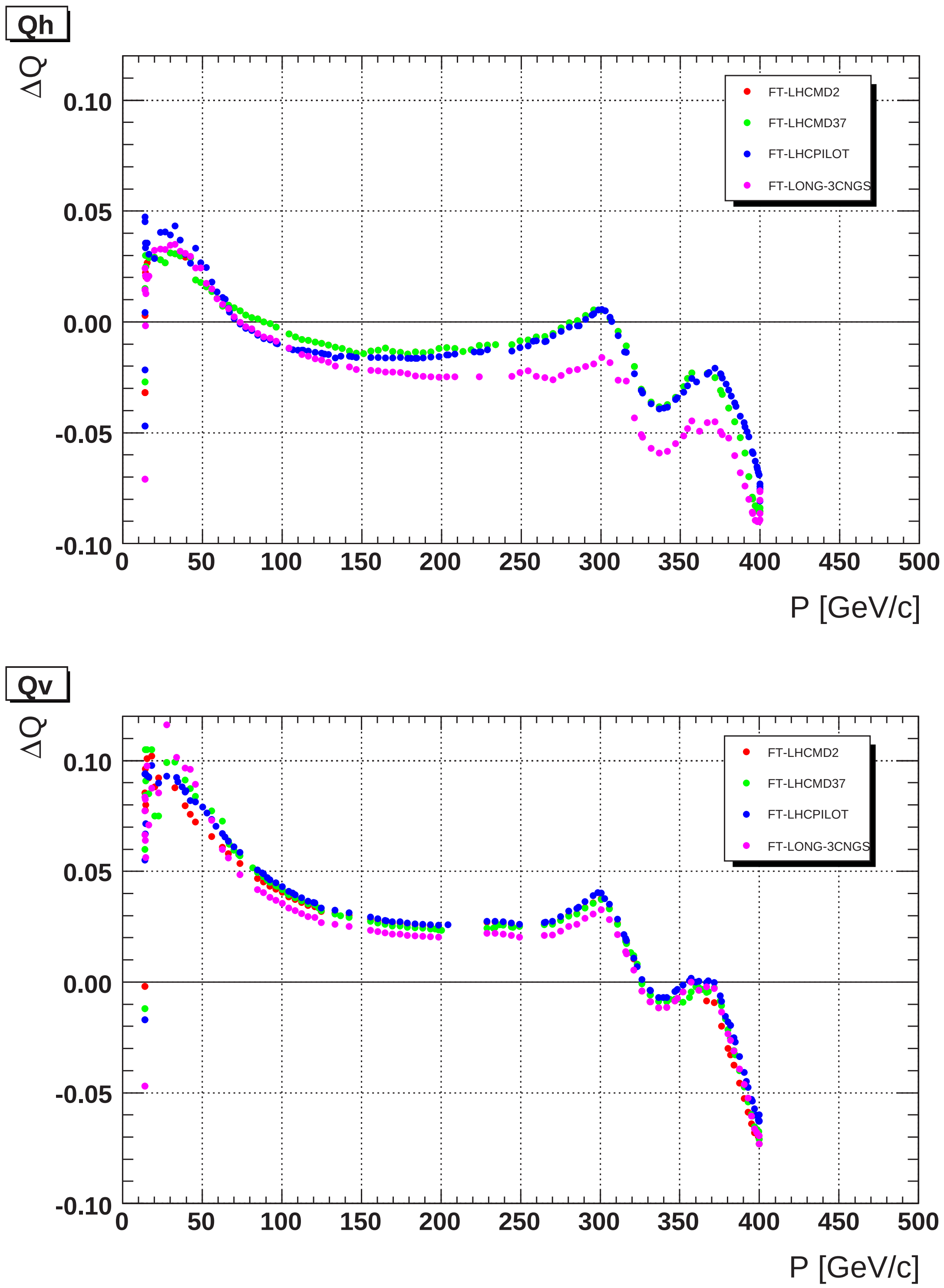
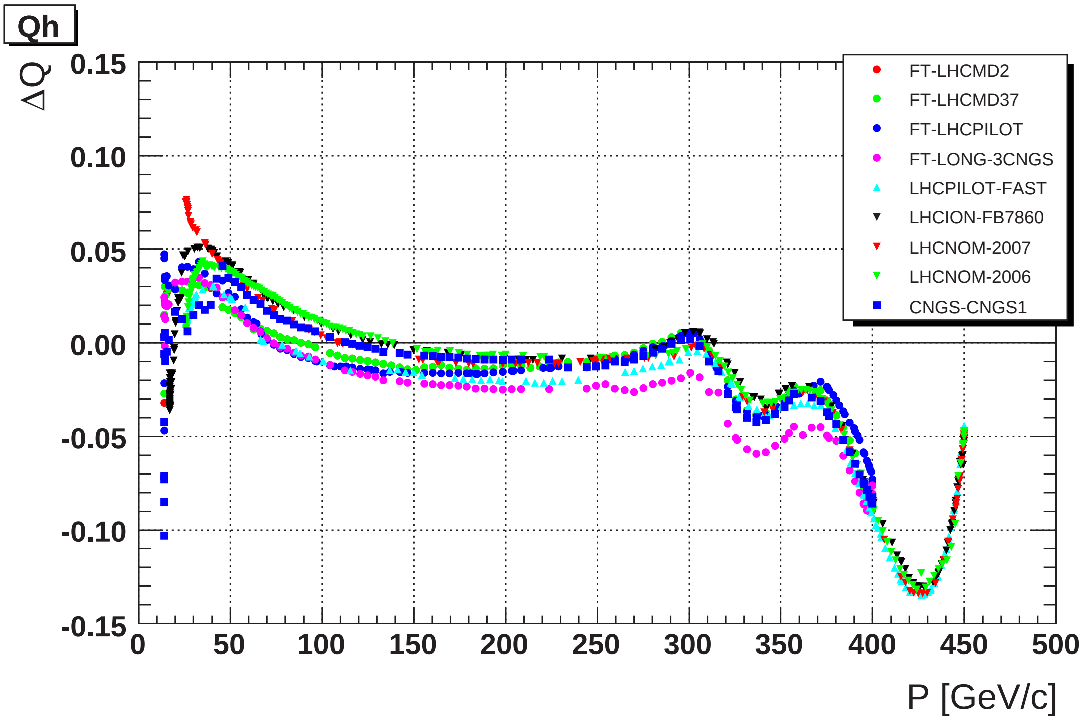



Figure 2: Tune trims for the horizontal (top) and vertical (bottom) plane for FT cycles used in 2007.



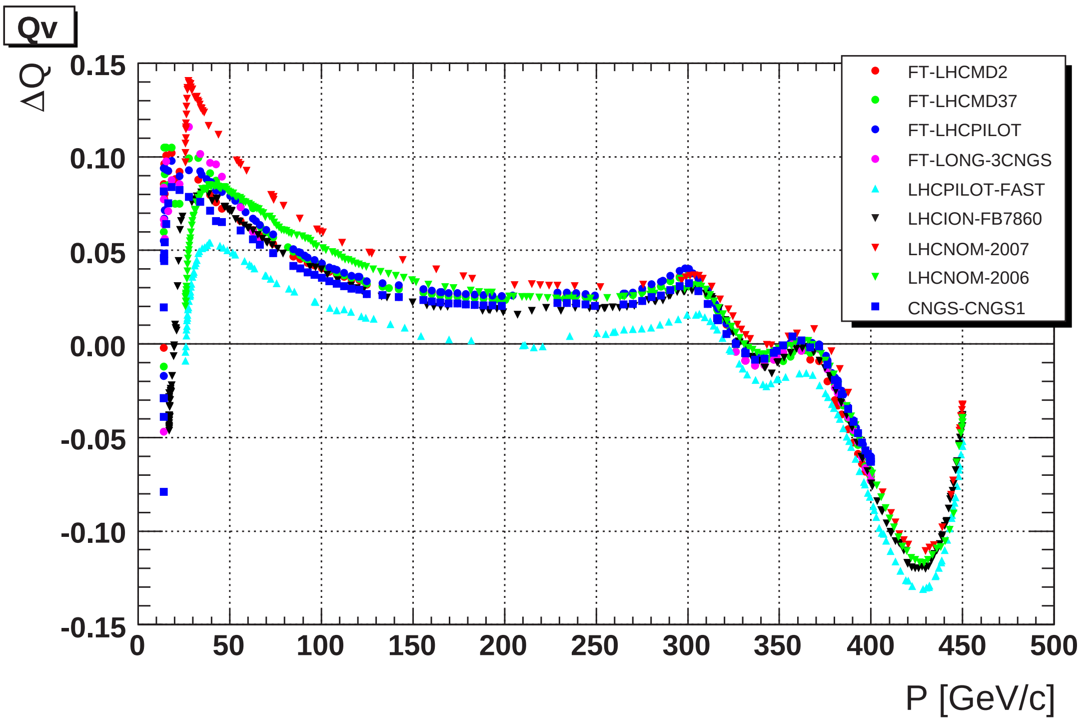




Figure 3: Tune trims for the horizontal (top) and vertical (bottom) plane for a palette of cycles used in 2007 and the nominal LHC cycle of 2006. One notes the difference between the nominal LHC cycle of 2007 and all the other cycles.

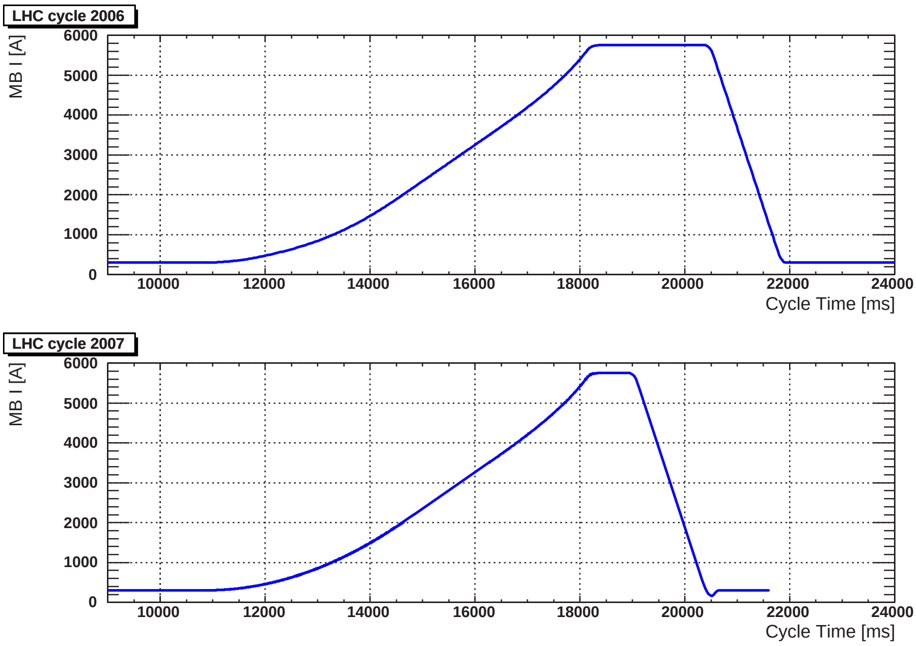



Figure 4: Comparison of the SPS main dipoles current function for the nominal LHC cycle in 2006 (top) and 2007 (bottom). Besides a difference in length of the 450 GeV/c flat top which is not relevant, the significant difference for the tune correction is arising from the small 'degauss dip' to 14 GeV/c (162 A) at the end of the ramp-down.

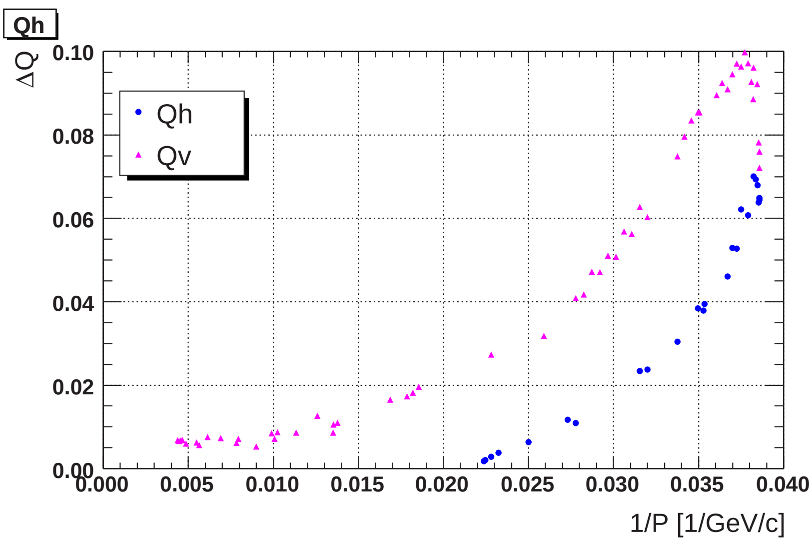
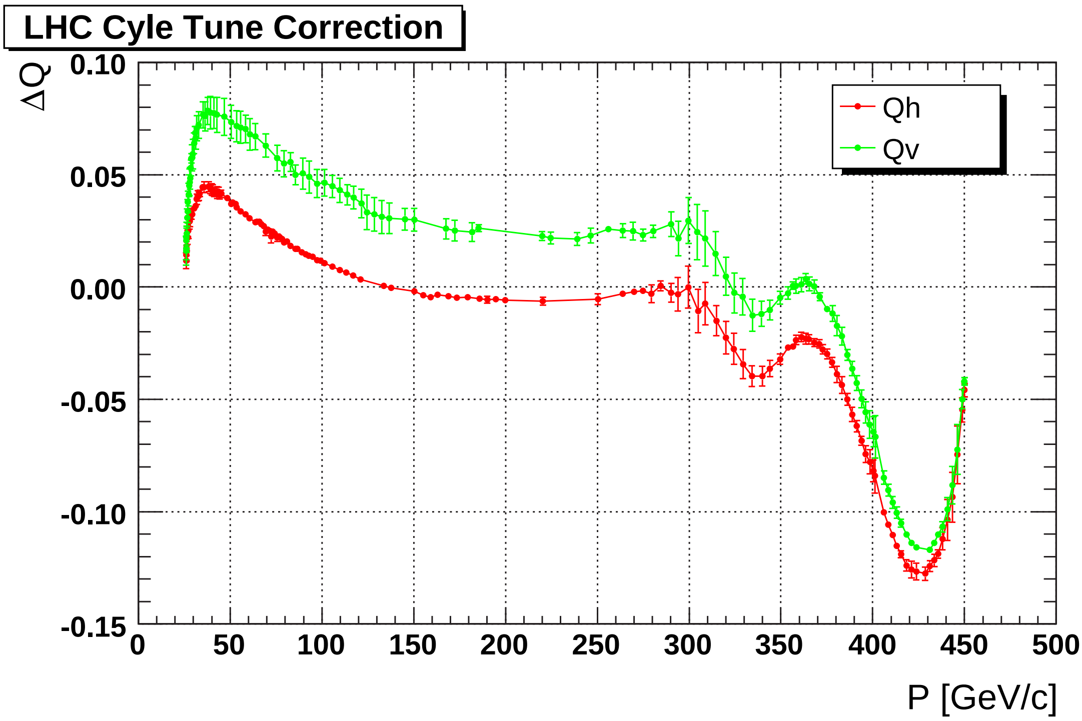



Figure 5: Tune difference $\Delta Q$ between the tune corrections for the nominal LHC cycle in 2007 and 2006. The difference decays roughly proportionally to the inverse of the momentum in the region of low momenta.



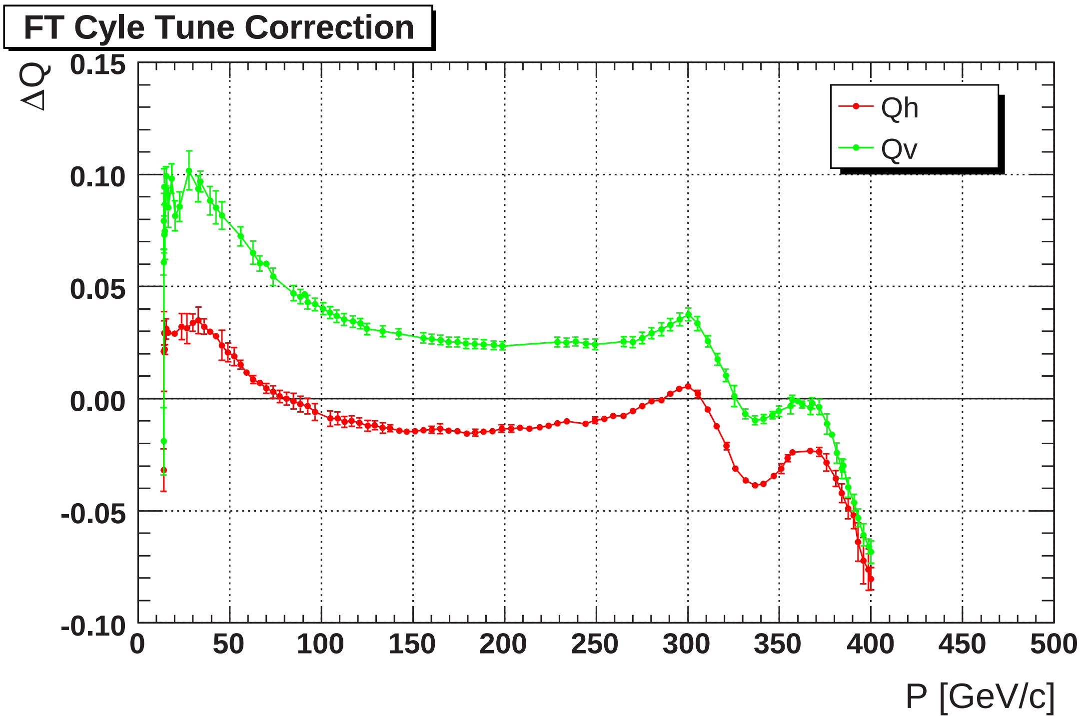




Figure 6: Average tune trims for the horizontal and vertical plane as a function of the beam momentum for the nominal LHC cycle (top) and FT cycle (bottom). For the FT beams the correction corresponds to a total beam intensity of $\approx 2.8 \times 10^{13}$ protons. For the LHC beams it corresponds to a low intensity beam of less than $10^{12}$ protons.