Feedback-based control of RHIC

Al Marusic

RHIC Retreat, July 20, 2011

Introduction

This run was quite different in certain ways from previous runs, this talk is about those differences, mostly feedback related, but not just feedback.

For this run we wanted to have RMS of the orbit in the arcs for every ramp lower than 0.3 mm. That implied that orbit feedback would have to be used on every ramp. Orbit feedback was developed in Run 10, tried on few ramps and at injection and store, therefore that goal seemed achievable. Also it seemed that we would have to use tune/coupling feedback on every energy ramp because we wanted vertical tune of 0.675 on the ramp (that is 0.008 away from 2/3 resonance). In the beginning of the run my assumption was that we would just do more of what we did before, i.e. more of orbit and T/C feedback. We ended up with much more far-reaching changes.

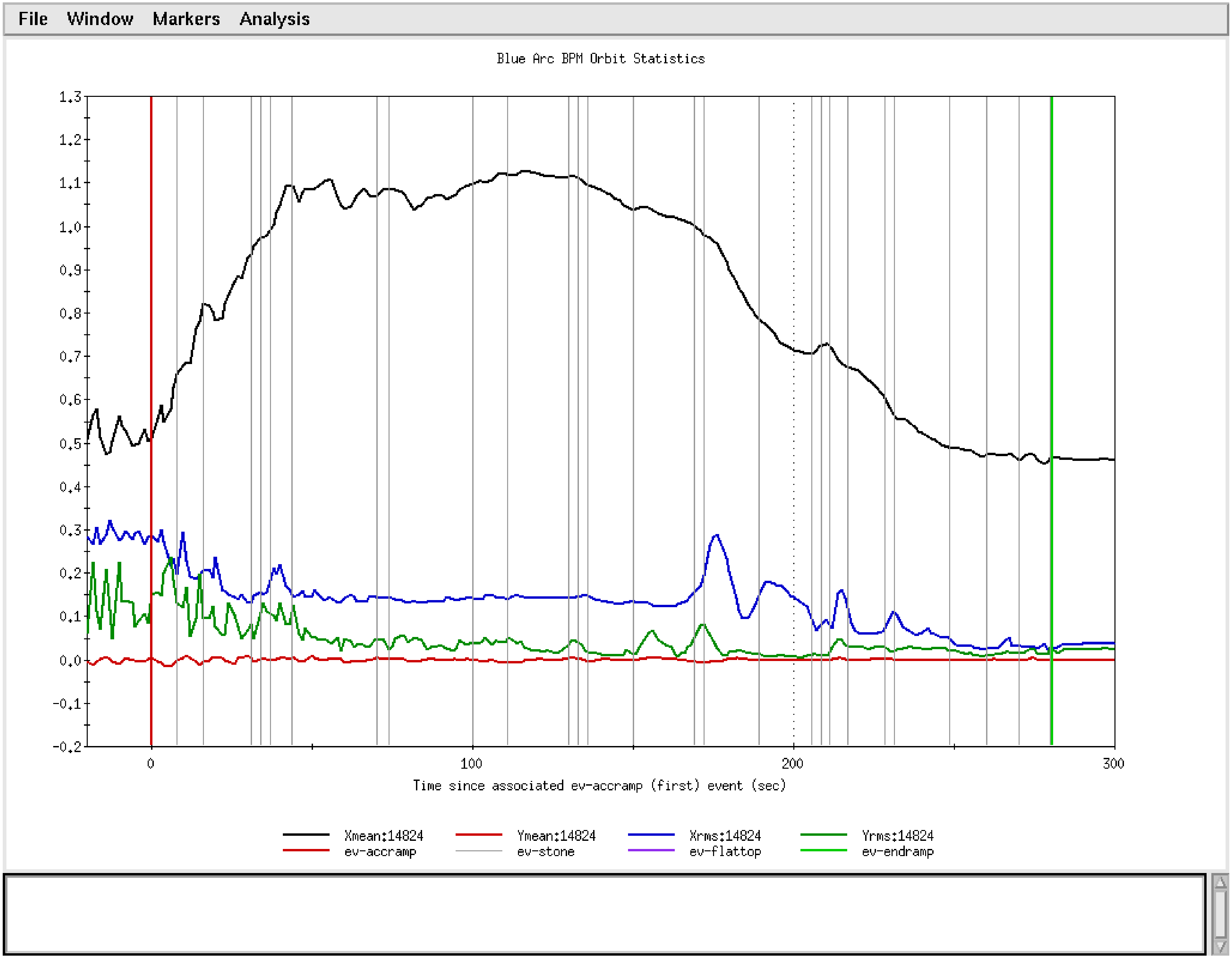

Figure 1: The blue orbit on the ramp after the first feed-forward of feedback corrections.

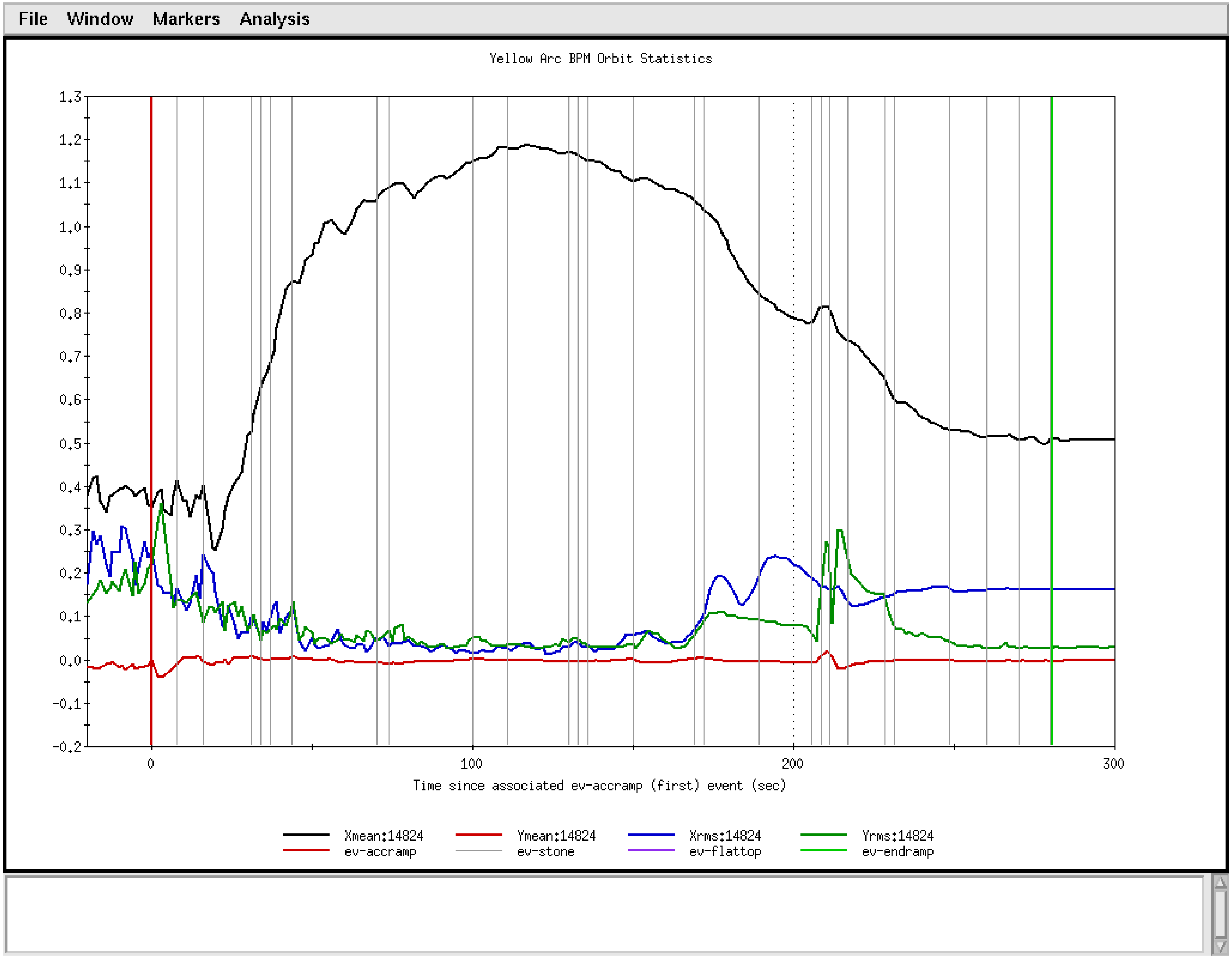

Figure 2: The yellow orbit on the ramp after the first feed-forward of feedback corrections.

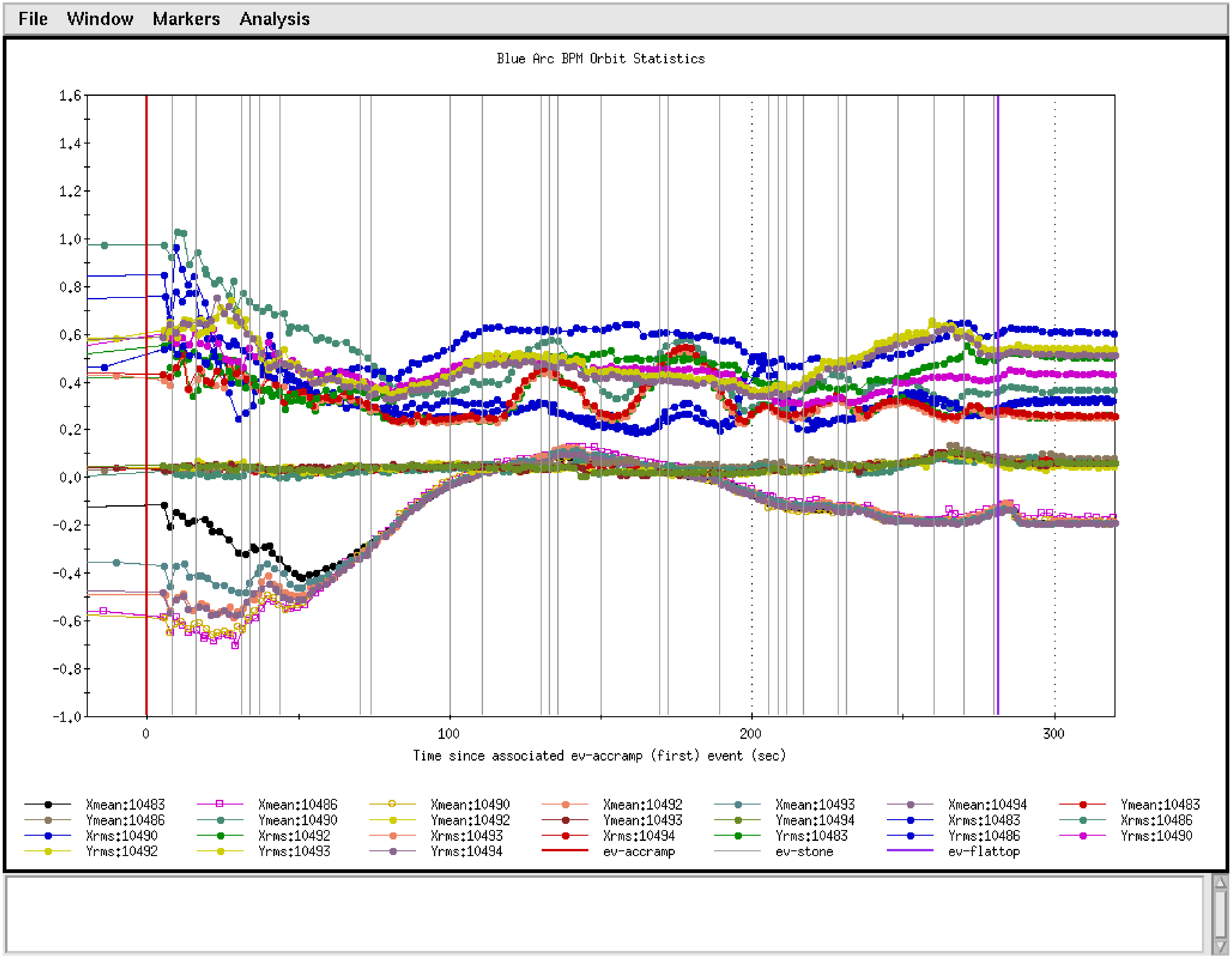

Figure 3: A weekend of blue orbits of ramp pp93 (ramp from which pp11 ramps were developed).

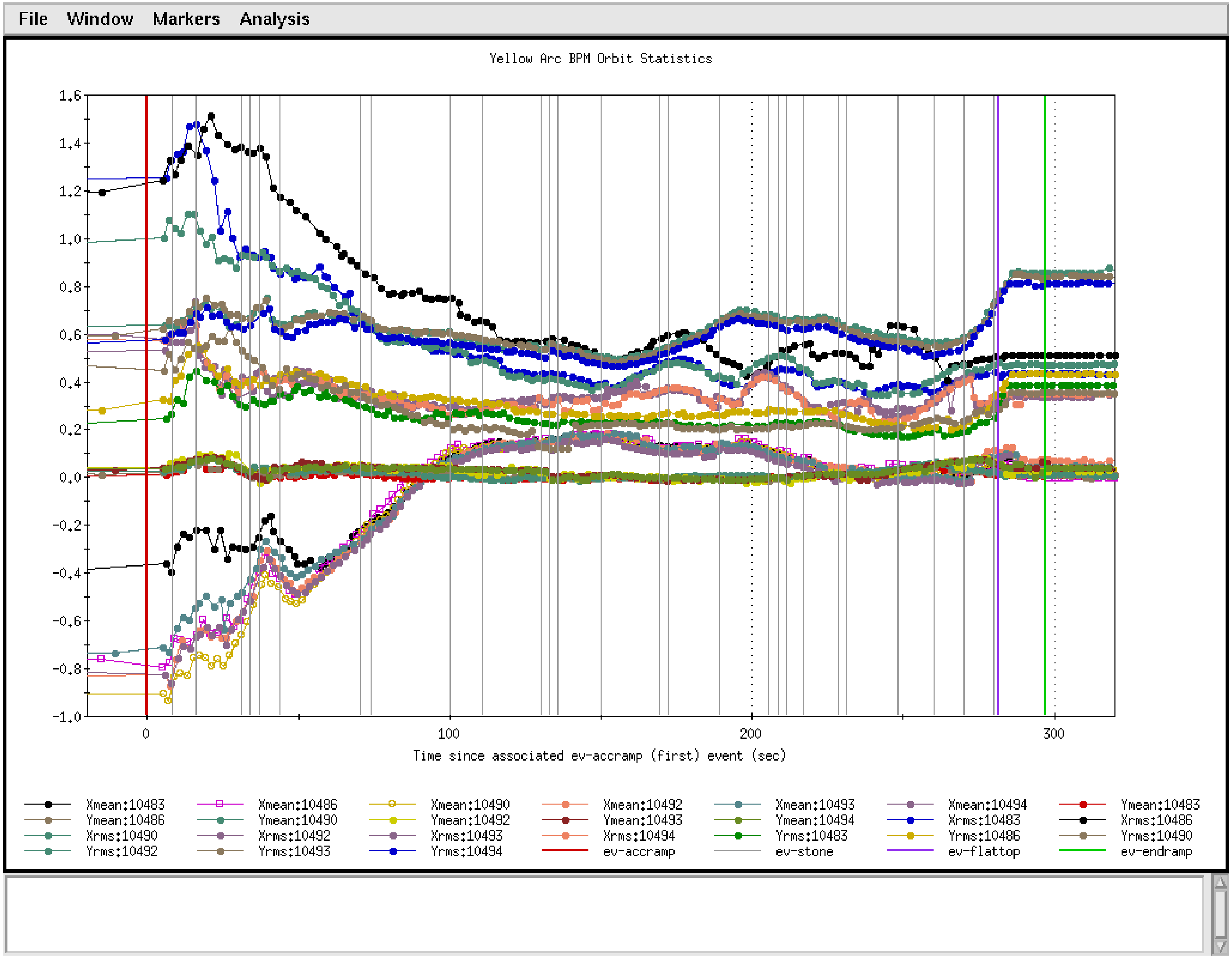

Figure 4: A weekend of yellow orbits of ramp pp93 (ramp from which pp11 ramps were developed).

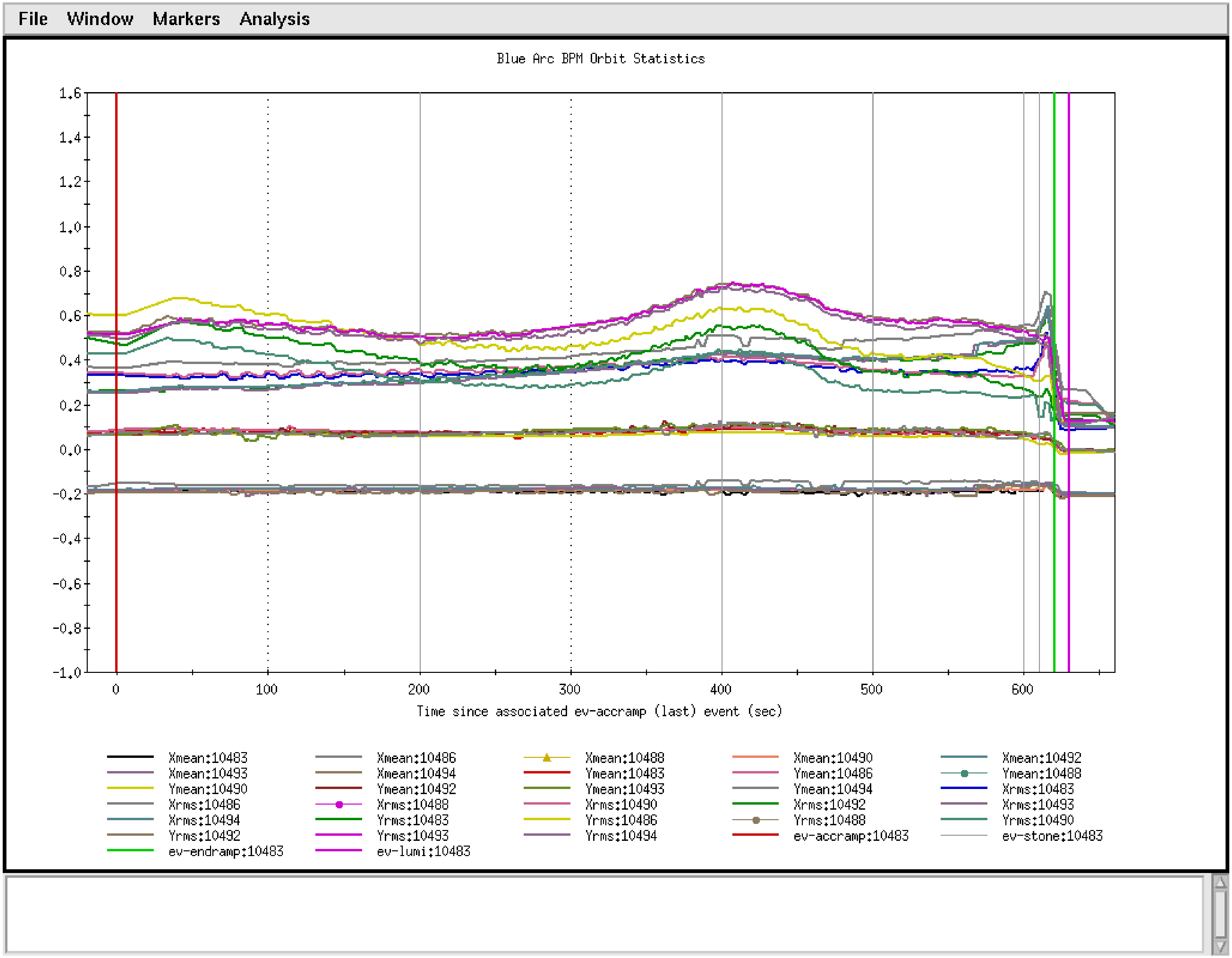

Figure 5: A weekend of blue orbits of ramp rot93 (ramp from which pp11rot ramps were developed).

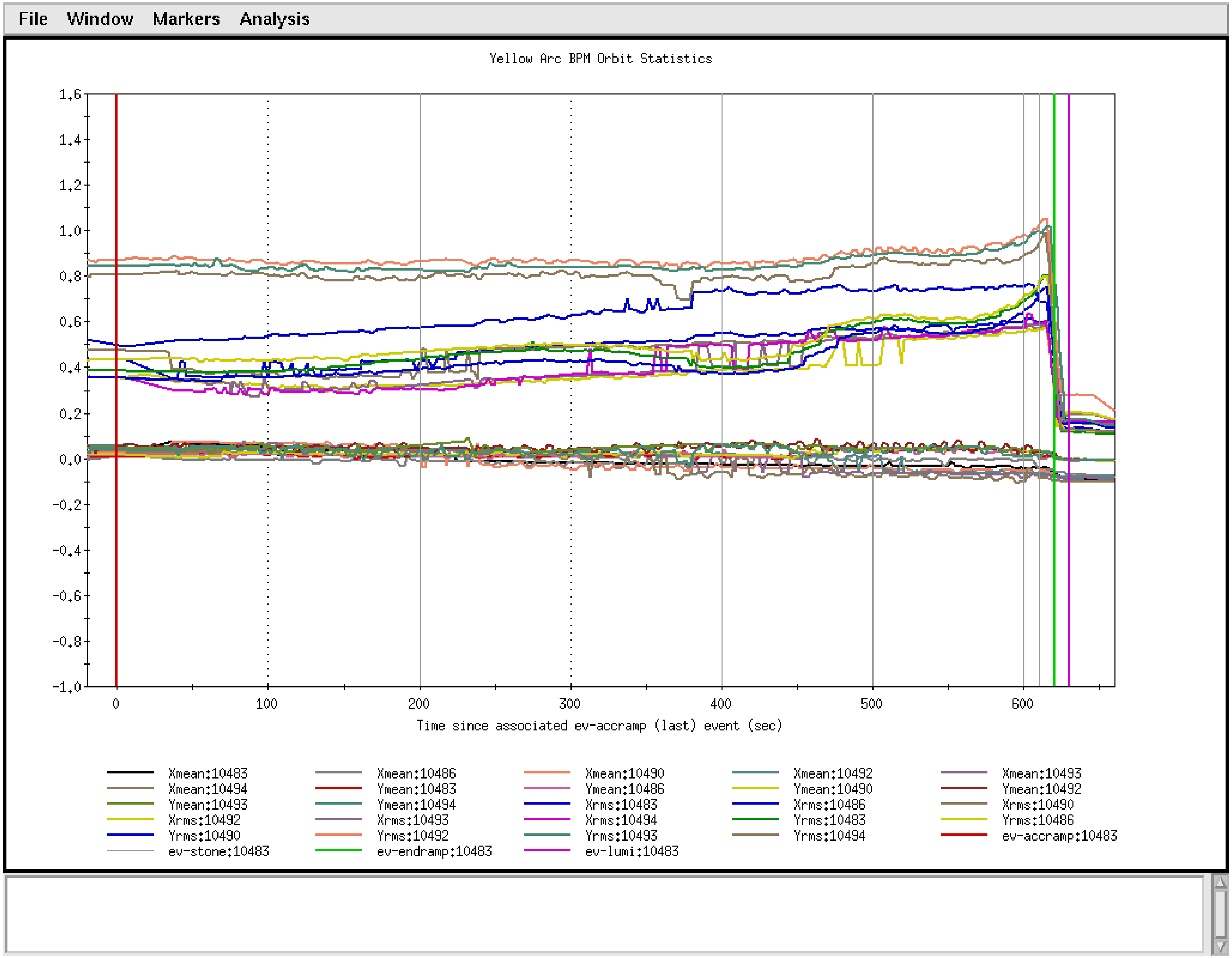

Figure 6: A weekend of yellow orbits of ramp rot93 (ramp from which pp11rot ramps were developed).

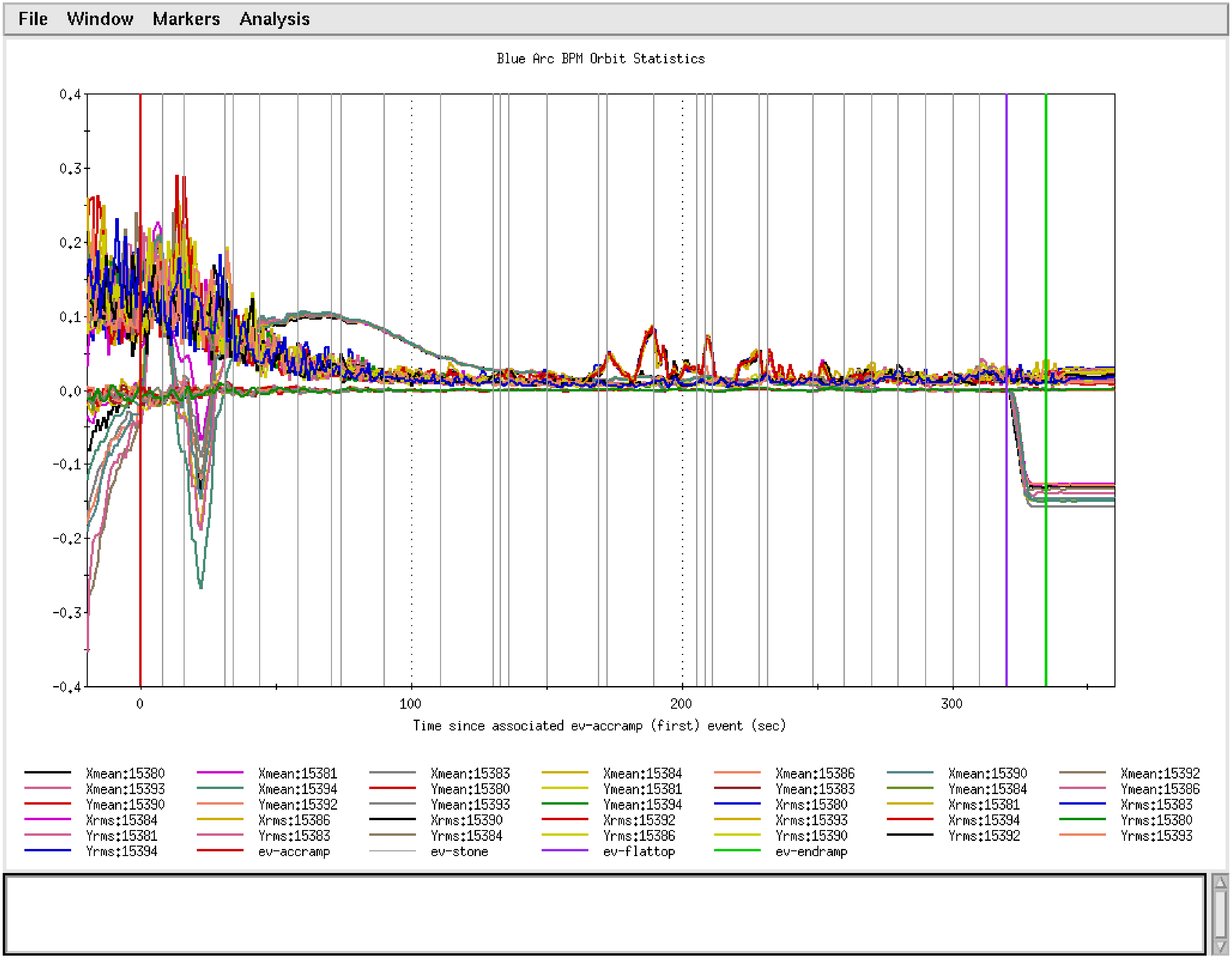

Figure 7: A weekend of blue orbits of ramp pp11v10.

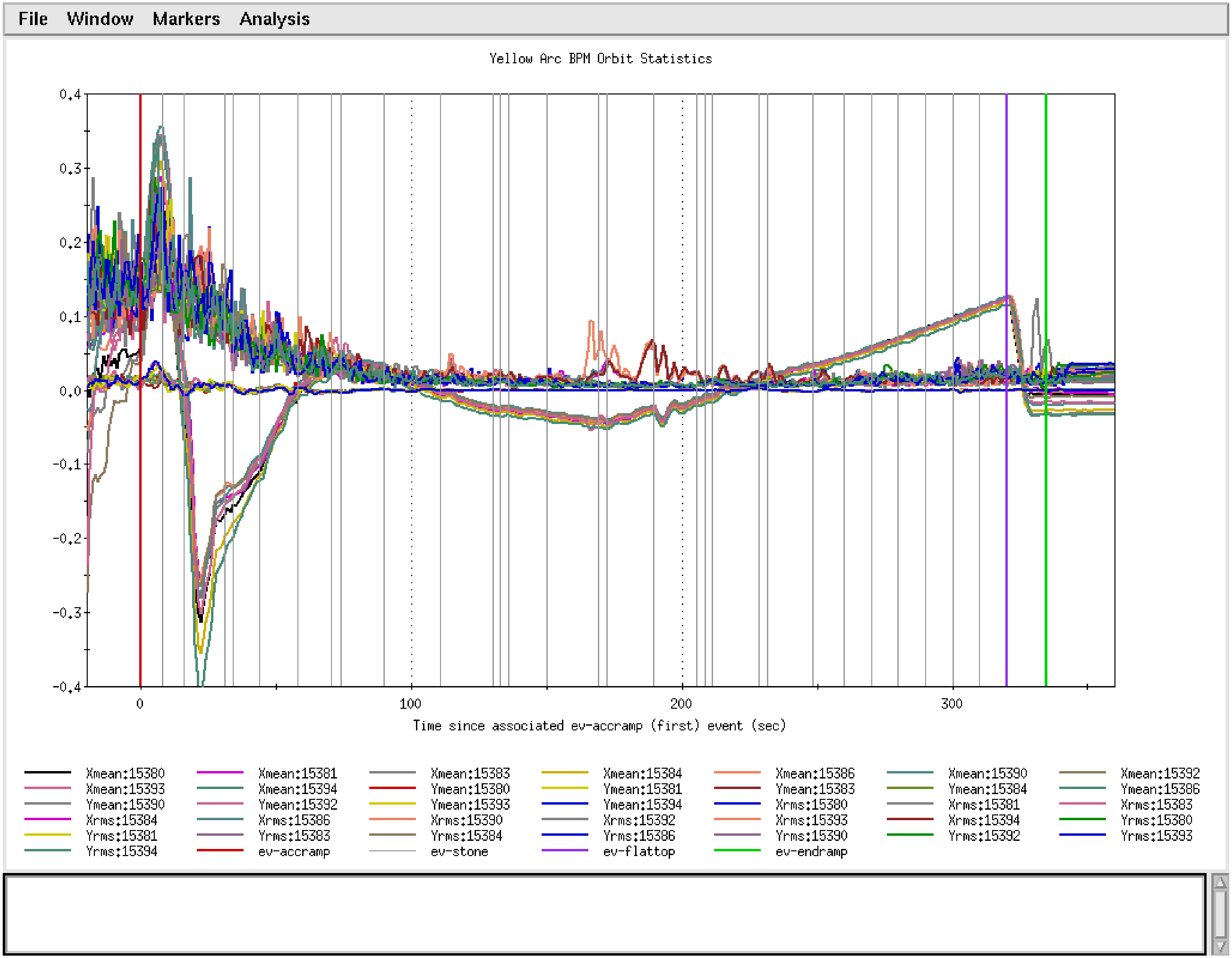

Figure 8: A weekend of yellow orbits of ramp pp11v10.

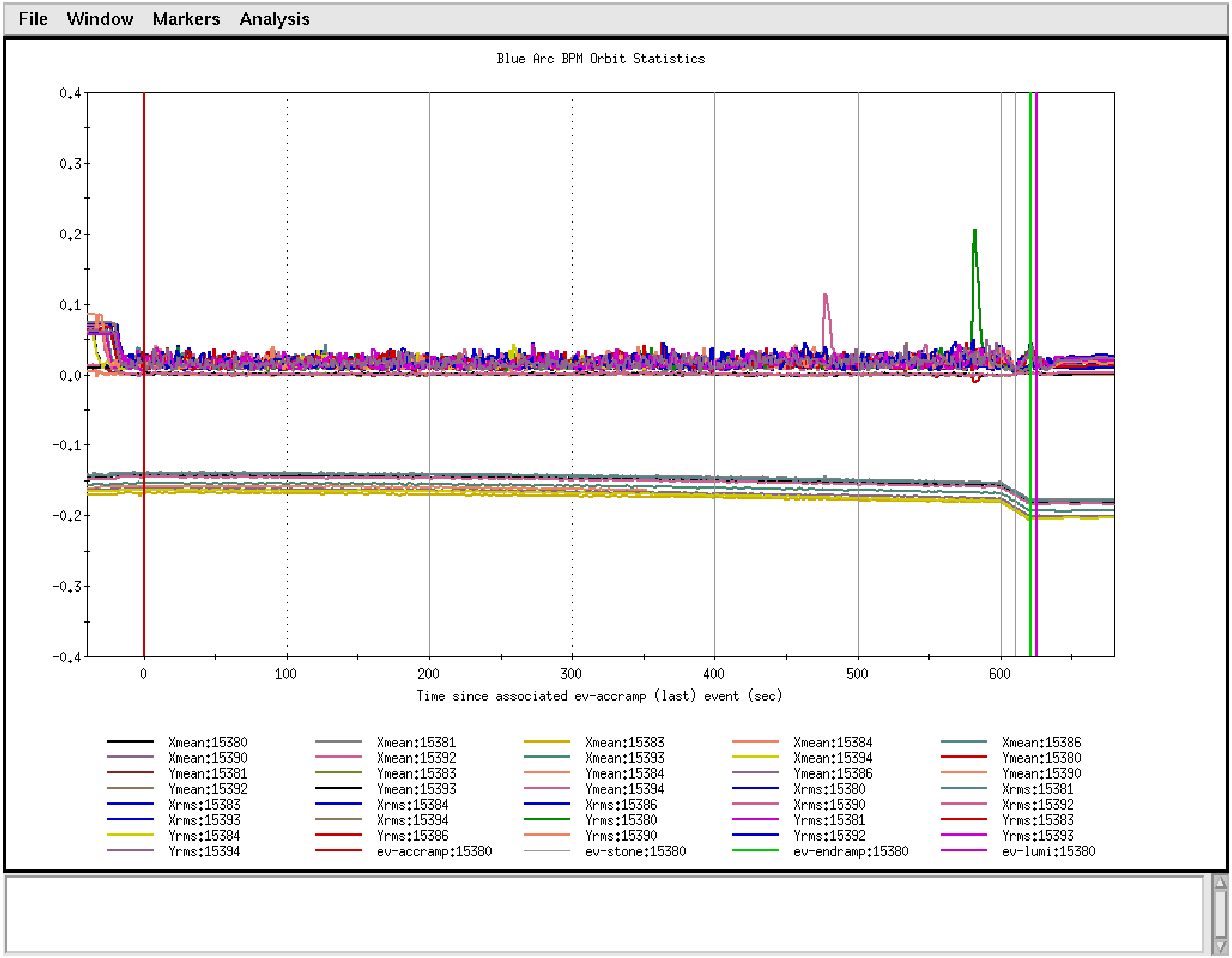

Figure 9: A weekend of blue orbits of ramp pp11rot5.

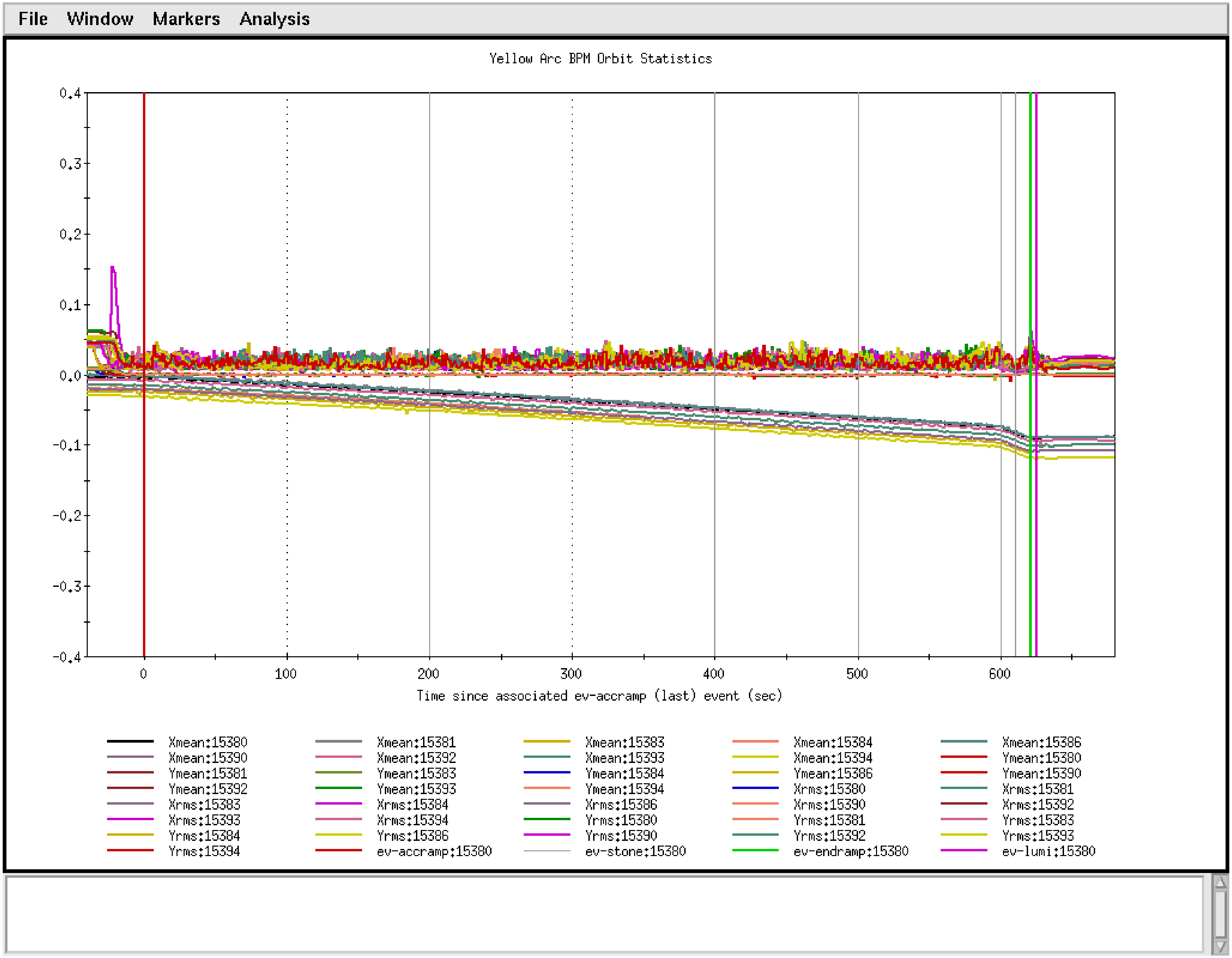

Figure 10: A weekend of yellow orbits of ramp pp11rot5.

Figures 1 and 2 show the blue and yellow orbits on the ramps after the first feed-forward of feedback corrections. Compare that with a weekend of orbits of ramp pp93 (ramp from which pp11 ramps were developed) (Figures 3 & 4). Notice different plot ranges. Figures 5 & 6 show a weekend of orbits of ramp rot93 (ramp from which pp11rot ramps were developed). Figures 7 & 8 show a weekend of blue and yellow orbits of ramp pp11v10, and Figures 9 & 10 show a weekend of orbits of ramp pp11rot5. Notice that orbits with orbit feedback exhibit much less variability.

The problems with orbit feedback

There were two problems with this simple plan. The first problem was that, after adjusting strengths of main dipoles and zeroing strengths of RF correctors, the achieved Xmean was not good enough and it changed from ramp to ramp.

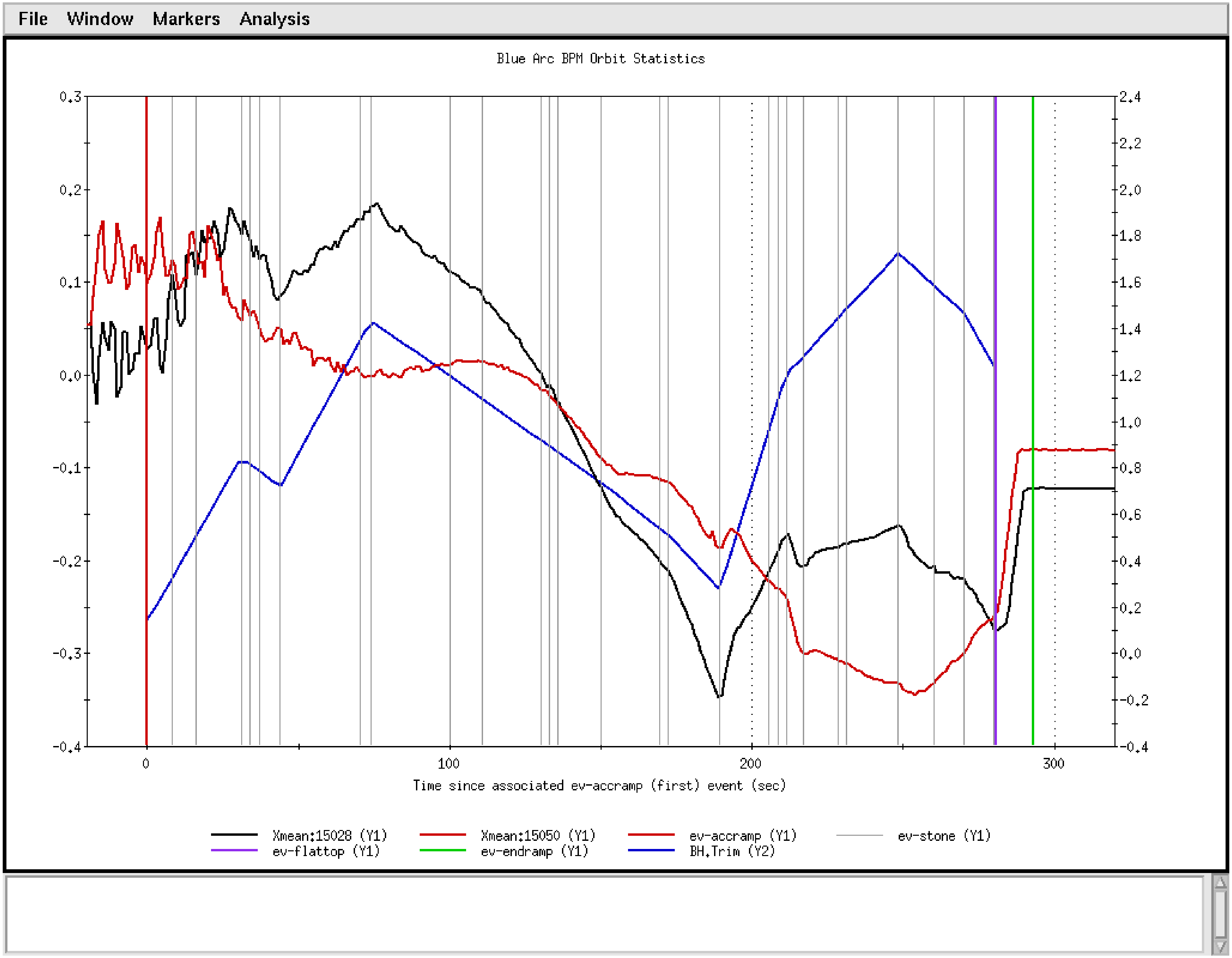

Figure 11: Xmean of the orbits with zero and non-zero sum of horizontal correctors' strengths and sum of horizontal correctors' strengths.

Figure 11 shows Xmean of the orbits with non-zero and zero sum of horizontal correctors' strengths and the sum of horizontal correctors' strengths. Notice that the kinks in the sum match the kinks in the orbit with non-zero sum.

Making orbit better required two changes:

– The sum of horizontal correctors' strengths has to be zeroed using RhicOrbitDisplay and the algorithm used by the orbit feedback had to be modified so that the sum of corrections generated by orbit feedback is always zero. That modification also solved the problem of drifting Xmean during orbit feedback at injection. Existing SVD algorithm for correcting orbit was designed not to correct dispersive orbit (it achieves that by adding scaled dispersion to the orbit to be corrected in such a way that Xmean of resulting orbit is 0), but that does not insure that the sum of correction strengths is 0.

– Xmean feedback had to be developed and used.

The final modifications to the orbit were: careful selection of step-stones to anchor dipole correctors' strengths, adjusting RF frequency at store to zero Xmean of yellow beam, and including RF correctors into orbit feedback.

The second problem was that in the beginning of the run we did not have a way (or knew a way) to ramp into orbit with collisions. The solution was replacing beam positions at IP6 and IP8 (or any other location) in design orbit with measured positions and then ramping into that orbit between the second to last and the last stone. This method was subsequently used to periodically correct orbit at store.

The implementation of this change was the turning point in the control of the tune and orbit in RHIC: after this, any changes of tune and orbit settings on the ramp have no effect any longer (because feedbacks will enforce their goal values).

The problems with the second ramp

In addition to the above mentioned problems with orbit feedback, we struggled with two problems related to using two ramps to ramp the beam to store.

The first problem was that tape sequences used to switch between energy and store ramps were not tested / made to work beforehand. At the time of dry run it was not clear we would run with 2 back-to-back ramps (instead of one very long one) and I performed no tests. Luckily, at the time in the run when we needed these sequences, one very important development was taking place, and that was the development, by Greg and others, of sequences which obtain data from RampStorageServer.

The second problem was that I was unprepared for using feedbacks during store ramp. After using temporary solution of not stopping feedbacks between ramps, T/C and orbit feedbacks were modified to allow restarting / pausing. That allowed inclusion of an option into RhicInjection to correct orbit feedback at injection using orbit feedback and made the use of T/C feedback for other purposes besides ramping much easier.

We came out of these troubles with much better system. Take deceleration ramp for example: it was made up of 3 ramps: ramp to 100 GeV, ramp from 100 to 250 GeV and ramp from 250 to 100 GeV. It took 6 ramps to successfully decelerate the beam (ramps failed mostly due to chromaticity feedback and sextupoles related problems and one due to tape not turning on chromaticity feedback). These ramps were almost completely controlled by tape sequences developed by Ian.

Gold run

It appeared we started good, but orbit feedback used wrong algorithm, bad BPMs were not excluded from the beginning, so work on orbit had to proceed while beam was being delivered to experiments (starting with RMS of 3 mm). Re-using previously used ramp meant that dipole correctors' strengths had to be flattened manually. Even after adding the ability to pause feedback during specified period of the ramp, feed-forward made orbit worse (requiring manual correction). The solution for that problem was adding of two shadow step-stones (one before and one after transition). Unfortunately, due to the limitation of RampManager / OptiCalc, there was no way to correct orbit at transition. After the run, RampManager was modified to allow obtaining ramp data at arbitrary times.

Figures 12 and 13 show one weekend of blue and yellow orbits of Au104 ramp. Figures 14 and 15 show blue and yellow orbits of Au104 ramp during previous weekend. Notice that orbits during previous weekend are much better. Figures 16 and 17 show one weekend of blue and yellow orbits of Au11v1 ramp. Figures 18 and 19 show blue and yellow orbits around transition during the same weekend. Figure 20 shows eight days of orbits of Au11v1 ramp during which orbit corrections were not feed-forwarded. These pictures demonstrate that orbit feedback brings stability.

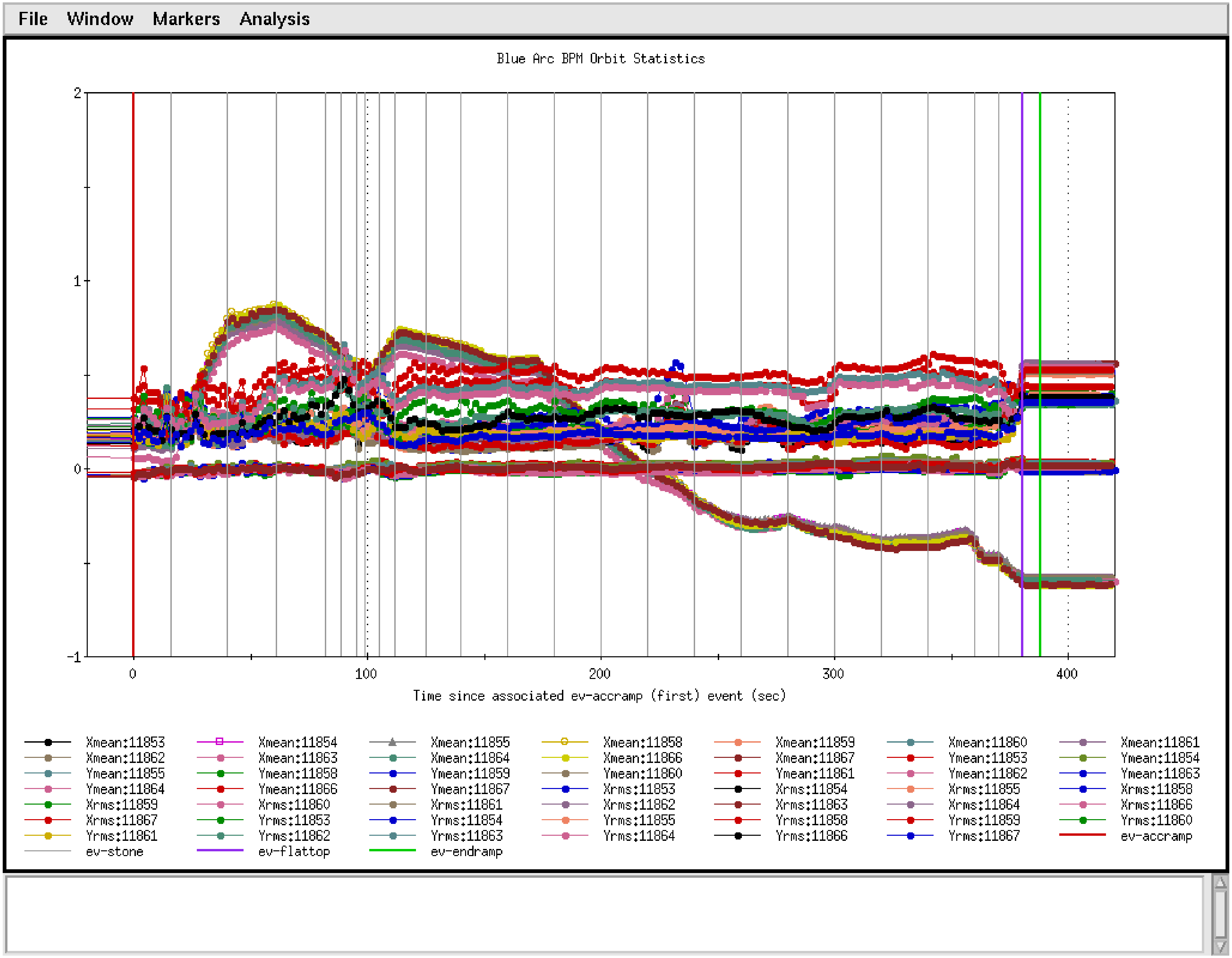

Figure 12: A weekend of blue orbits of Au104 ramp.

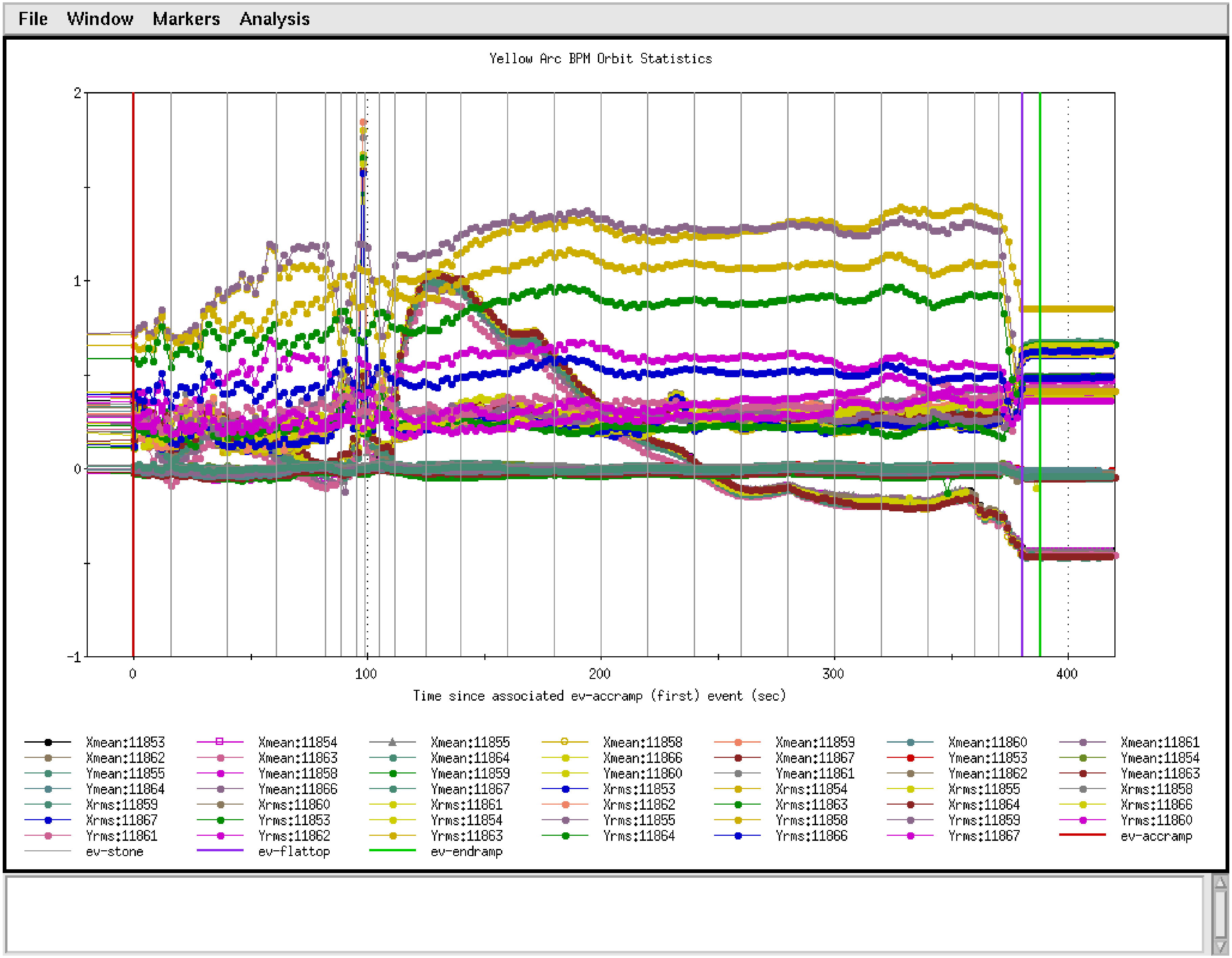

Figure 13: A weekend of yellow orbits of Au104 ramp.

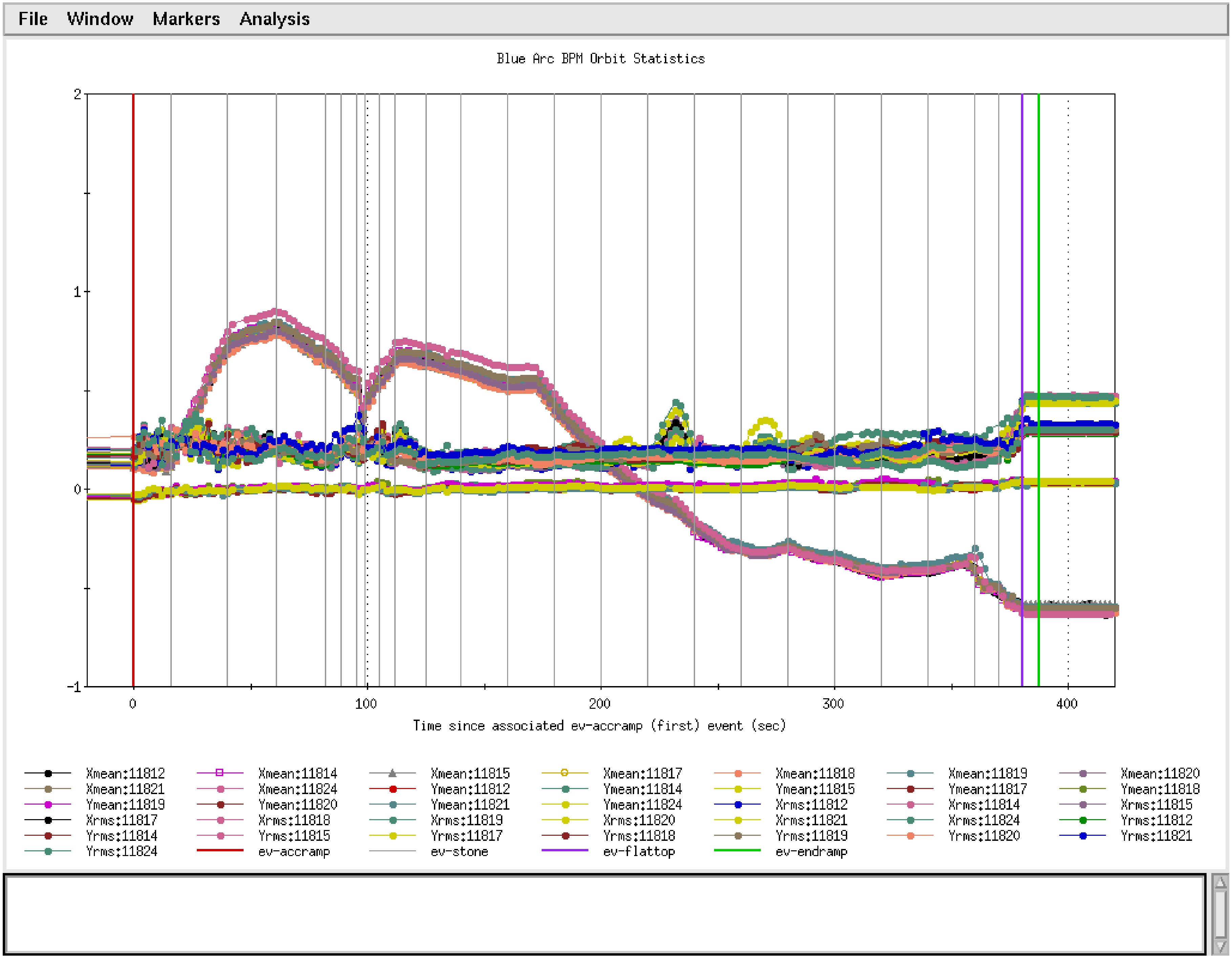

Figure 14: Blue orbits of Au104 ramp during previous weekend.

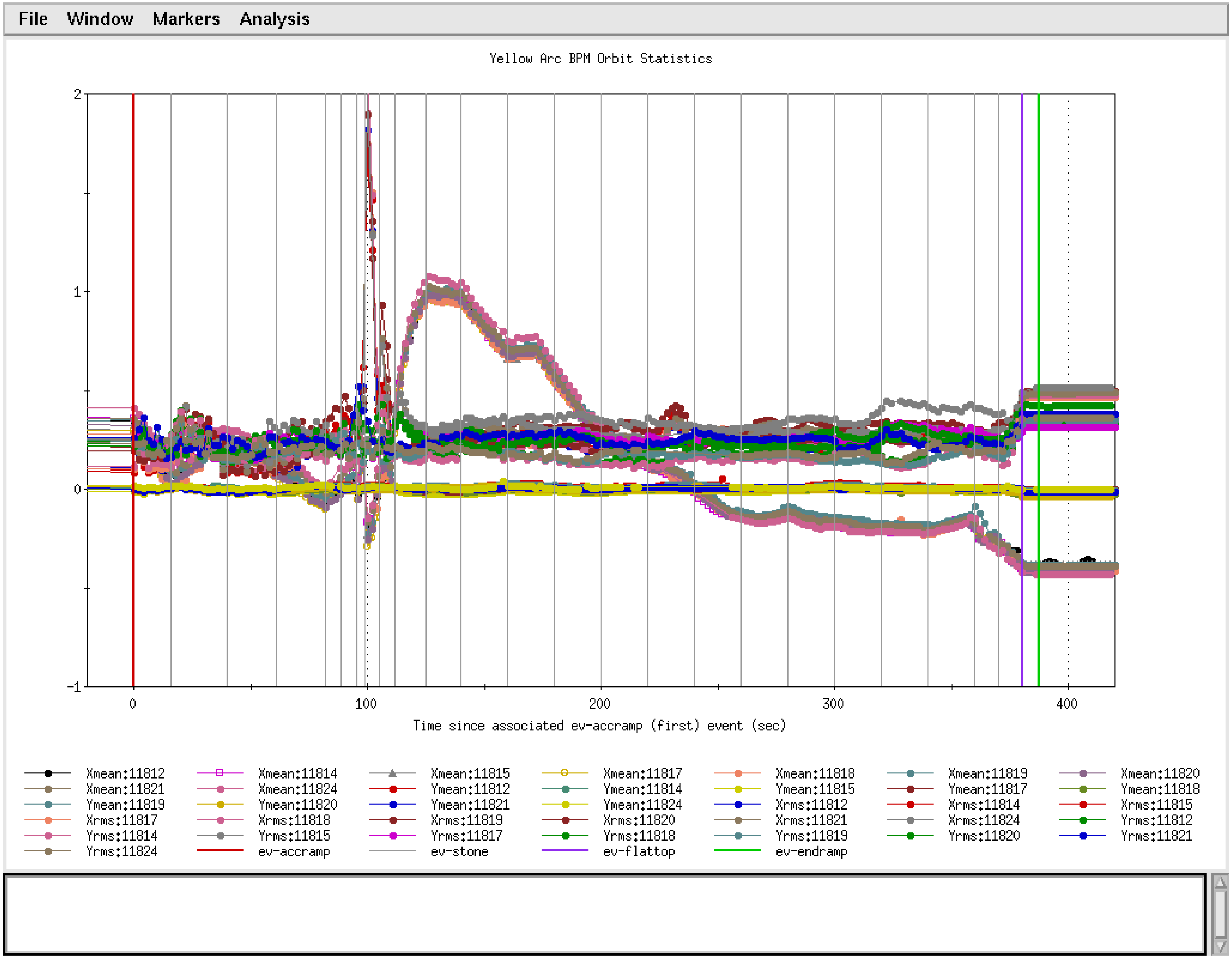

Figure 15: Yellow orbits of Au104 ramp during previous weekend.

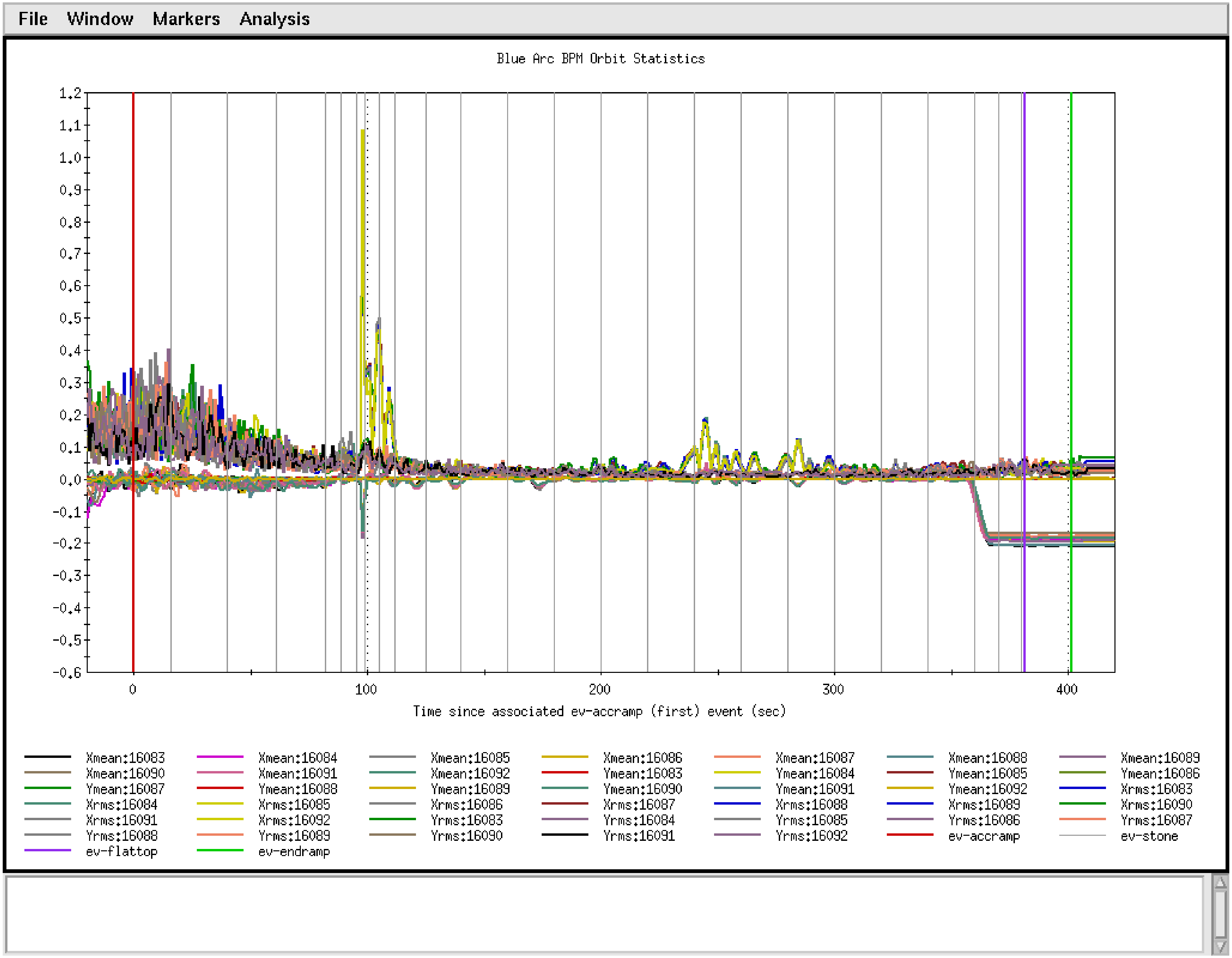

Figure 16: A weekend of blue orbits of Au11v1 ramp.

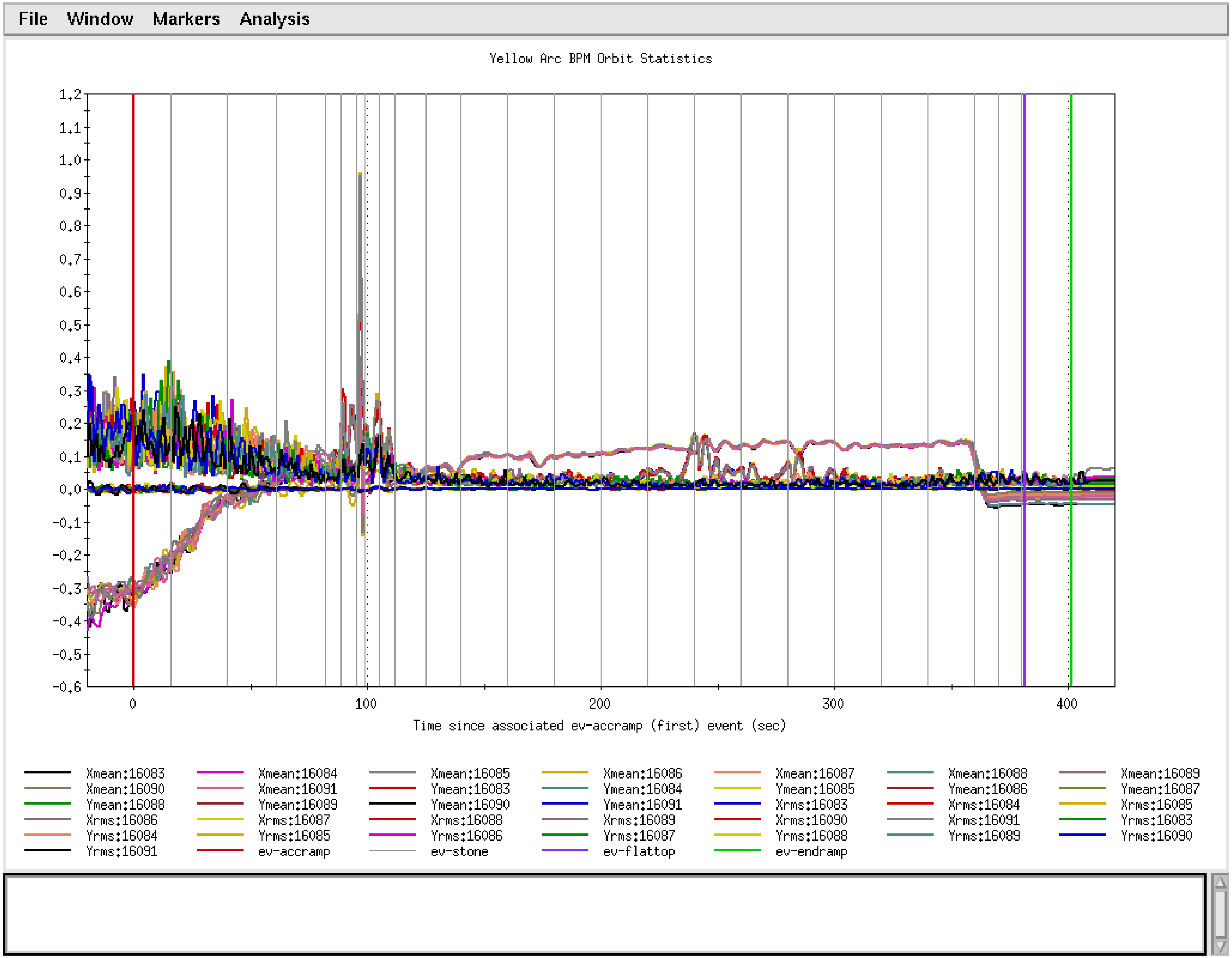

Figure 17: A weekend of yellow orbits of Au11v1 ramp.

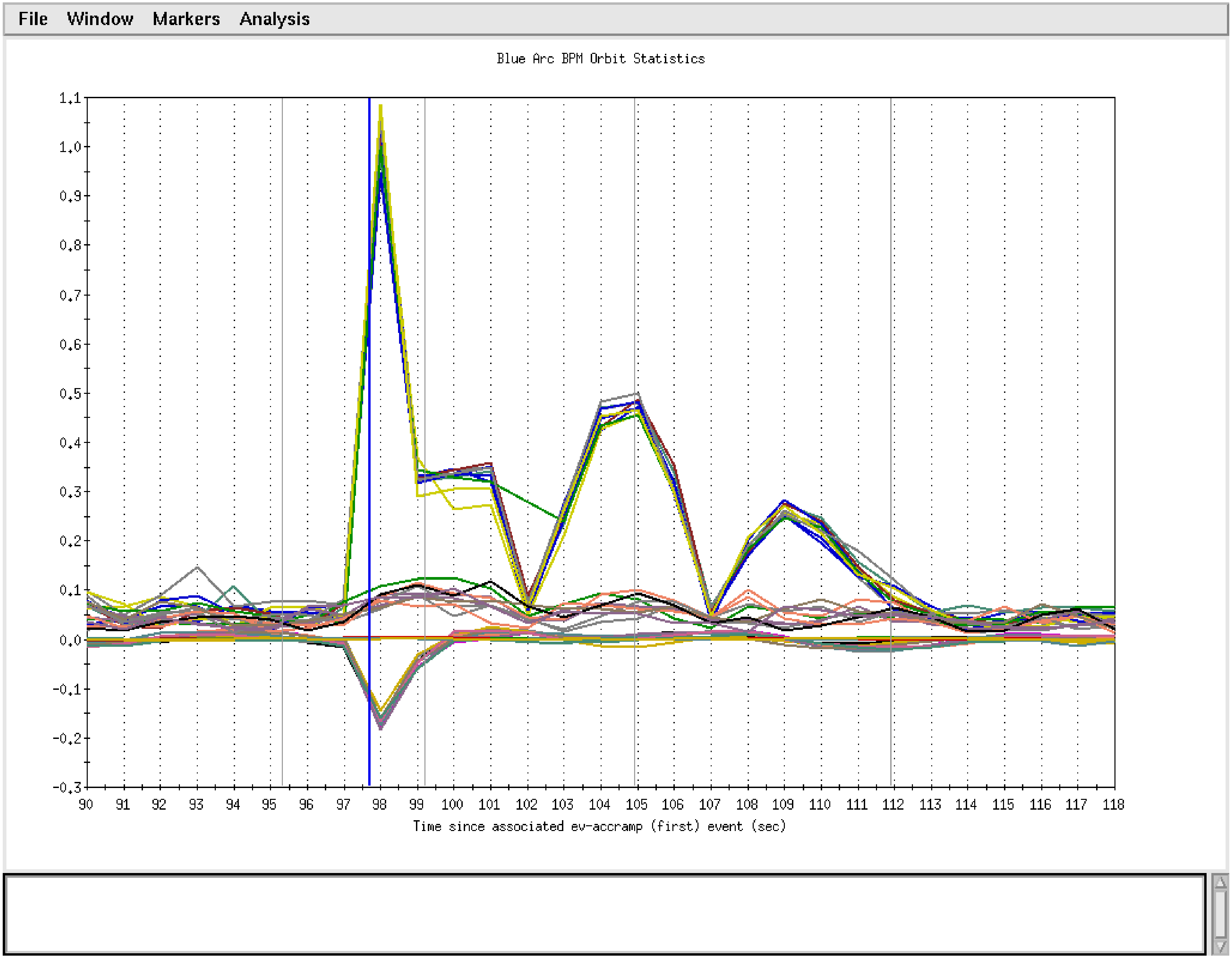

Figure 18: Blue orbits around transition during the same weekend as in Figure 16.

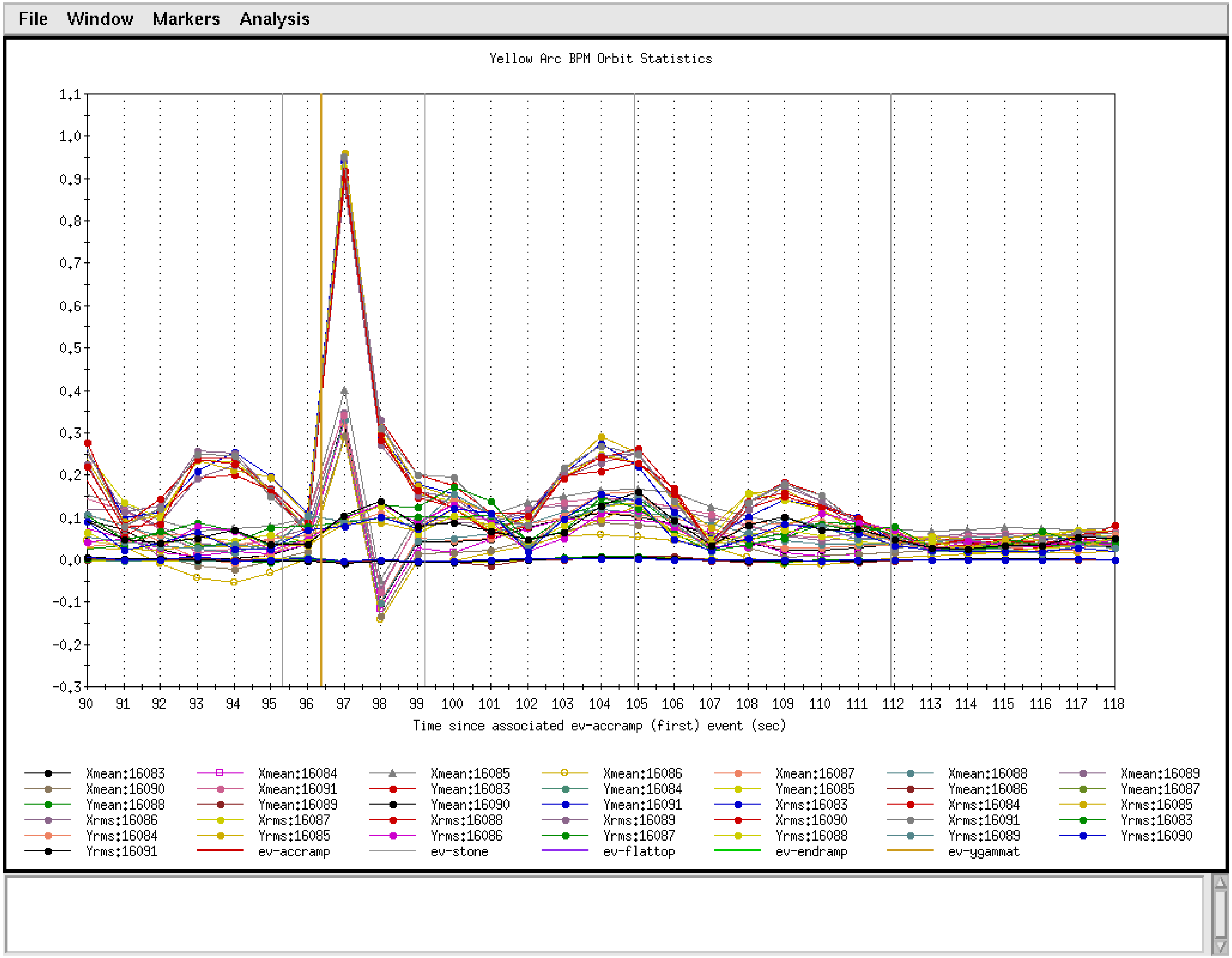

Figure 19: Yellow orbits around transition during the same weekend as in Figure 17.

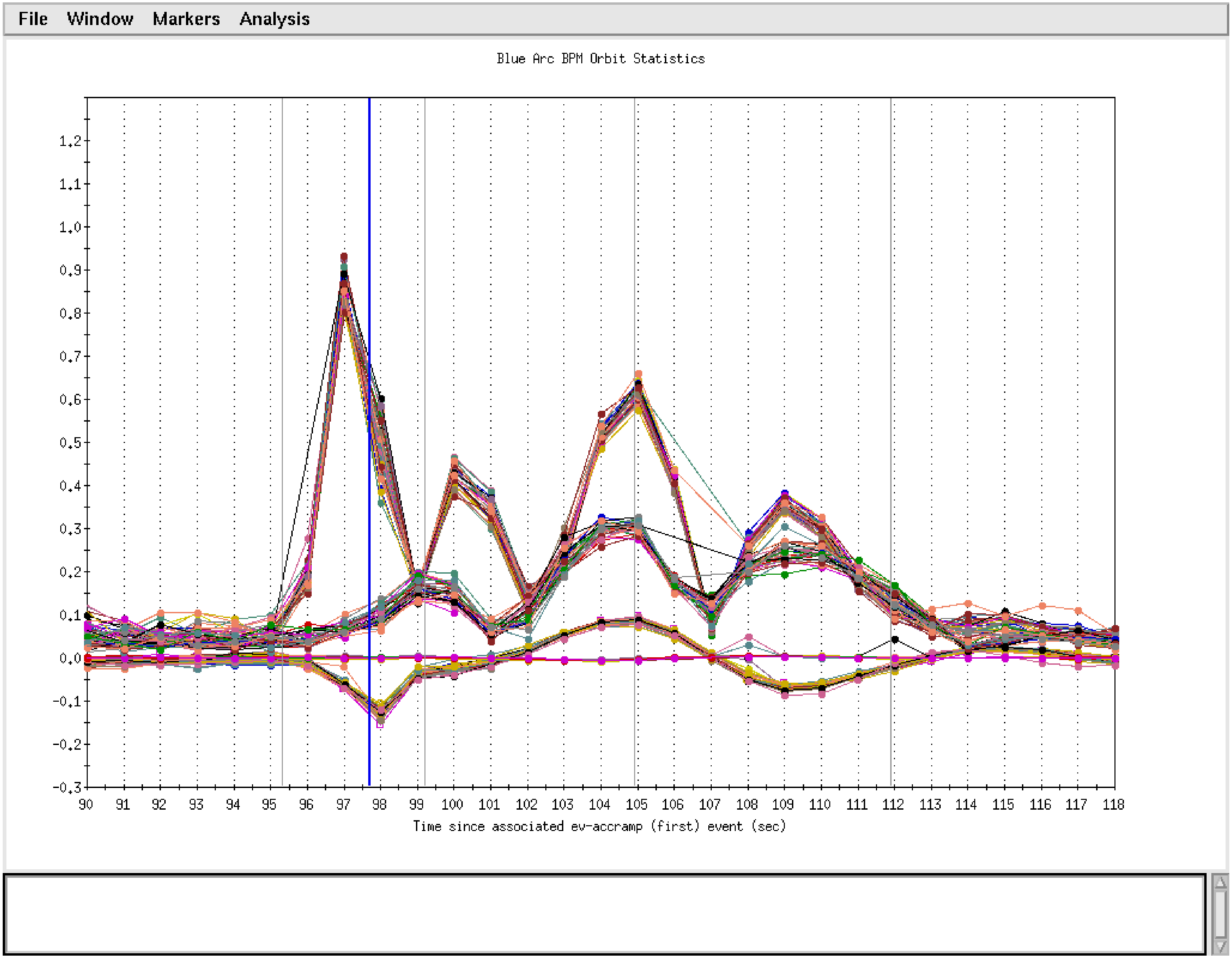

Figure 20: Eight days of orbits of Au11v1 ramp.

Distribution of tune corrections can be used as an indication that achieved orbits are the same from ramp to ramp. Figure 21 shows distribution of tune corrections during normal running conditions. Figure 22 shows distribution of tune corrections during problems with BPMs.

Various accidents (such as ramping with beam in blue while yellow dipole is not ramping, ramping with yellow dipole not on hysteresis, ramps during which tq PS tripped, ramp while one half of H-jet magnet tripped) showed the abilities of orbit and T/C feedbacks. Figure 23 shows corrections strengths of th2/th3 correctors in blue when yellow dipole did not ramp. Figure 24 shows distribution of tune corrections in blue when yellow dipole did not ramp (it also shows the tune distribution during normal running conditions for comparison). Figure 25 shows distribution of tune corrections in yellow when yellow dipole was not on hysteresis.

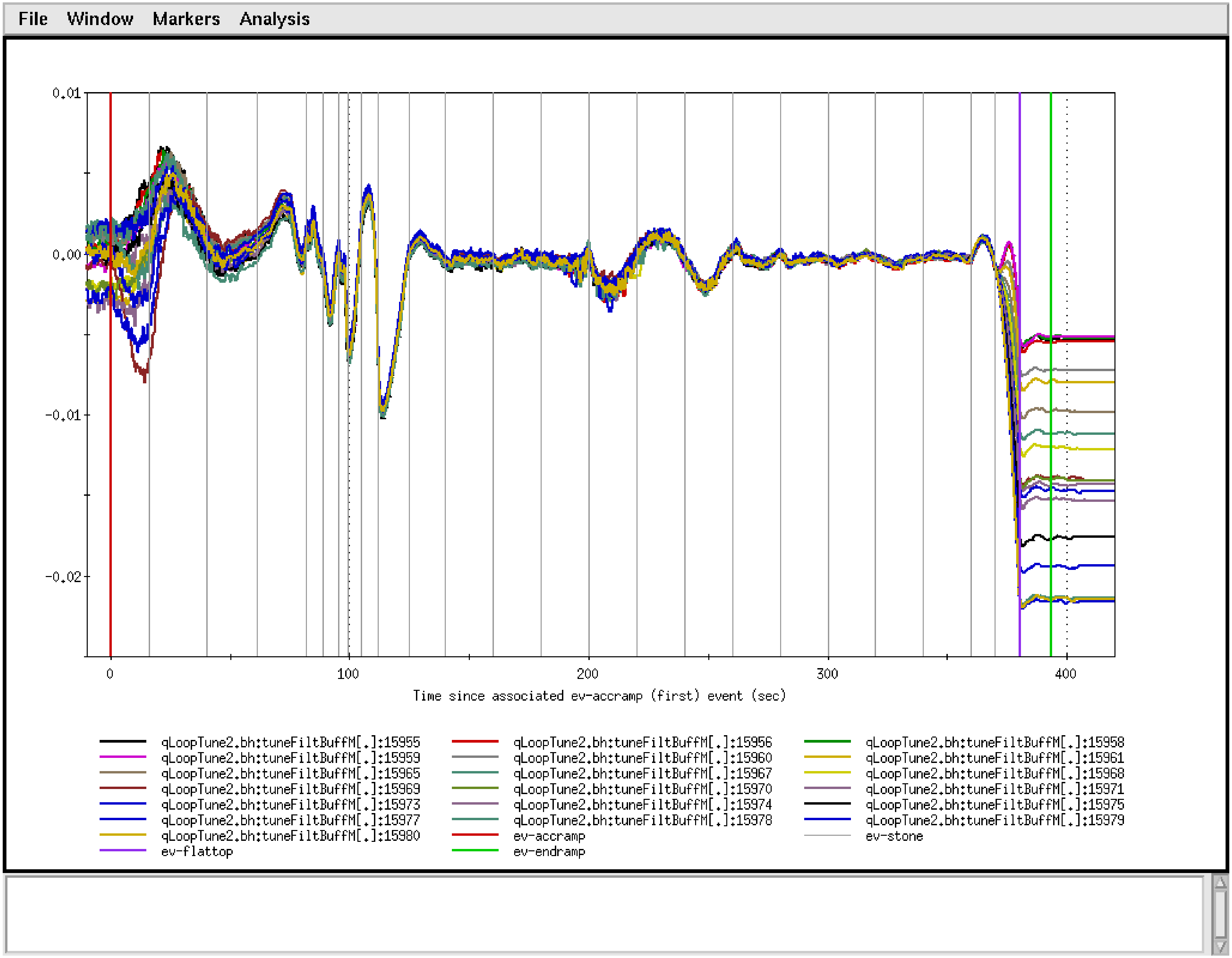

Figure 21: Distribution of tune corrections during normal running conditions.

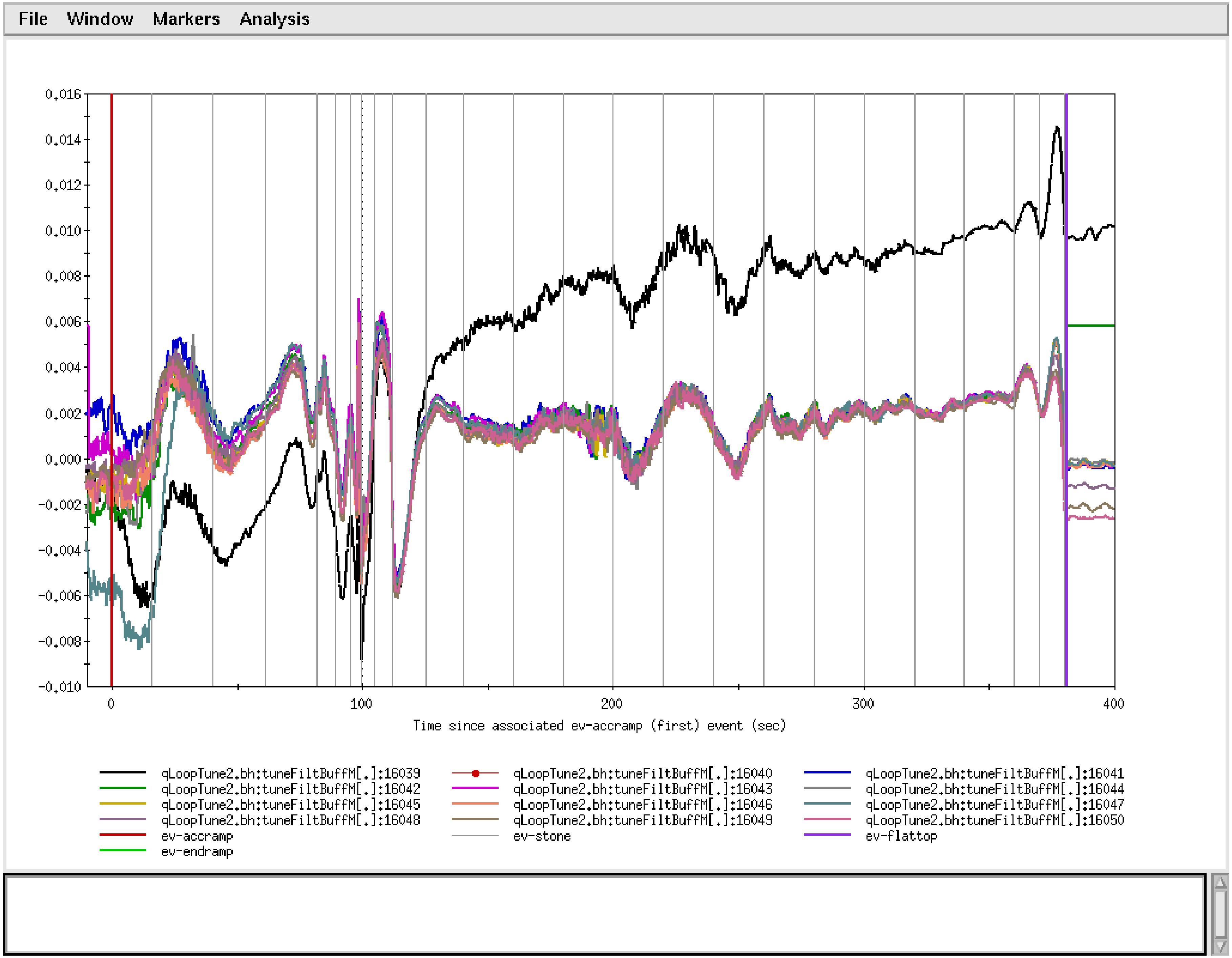

Figure 22: Distribution of tune corrections during problems with BPMs.

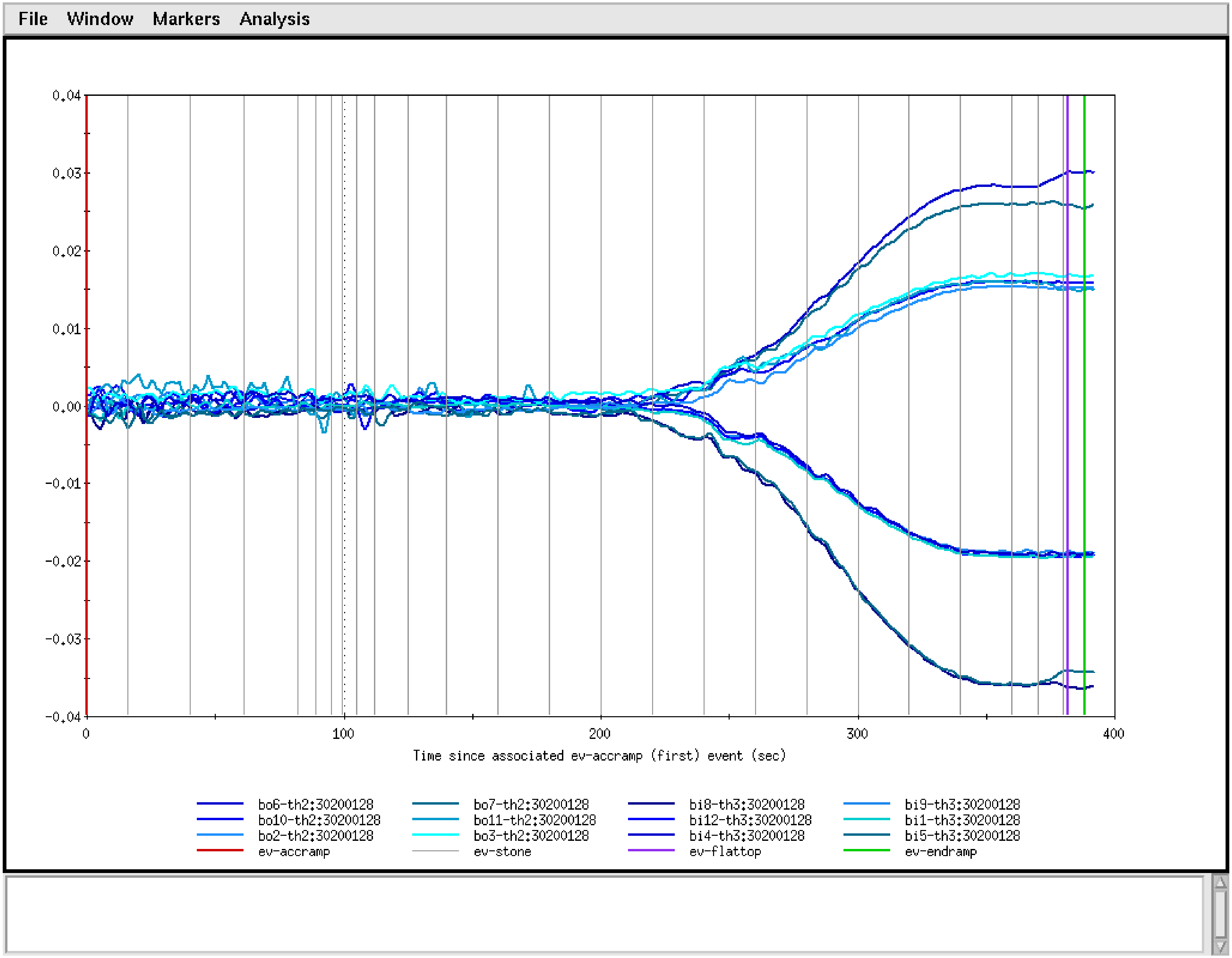

Figure 23: Corrections strengths of th2/th3 correctors in blue when yellow dipole did not ramp.

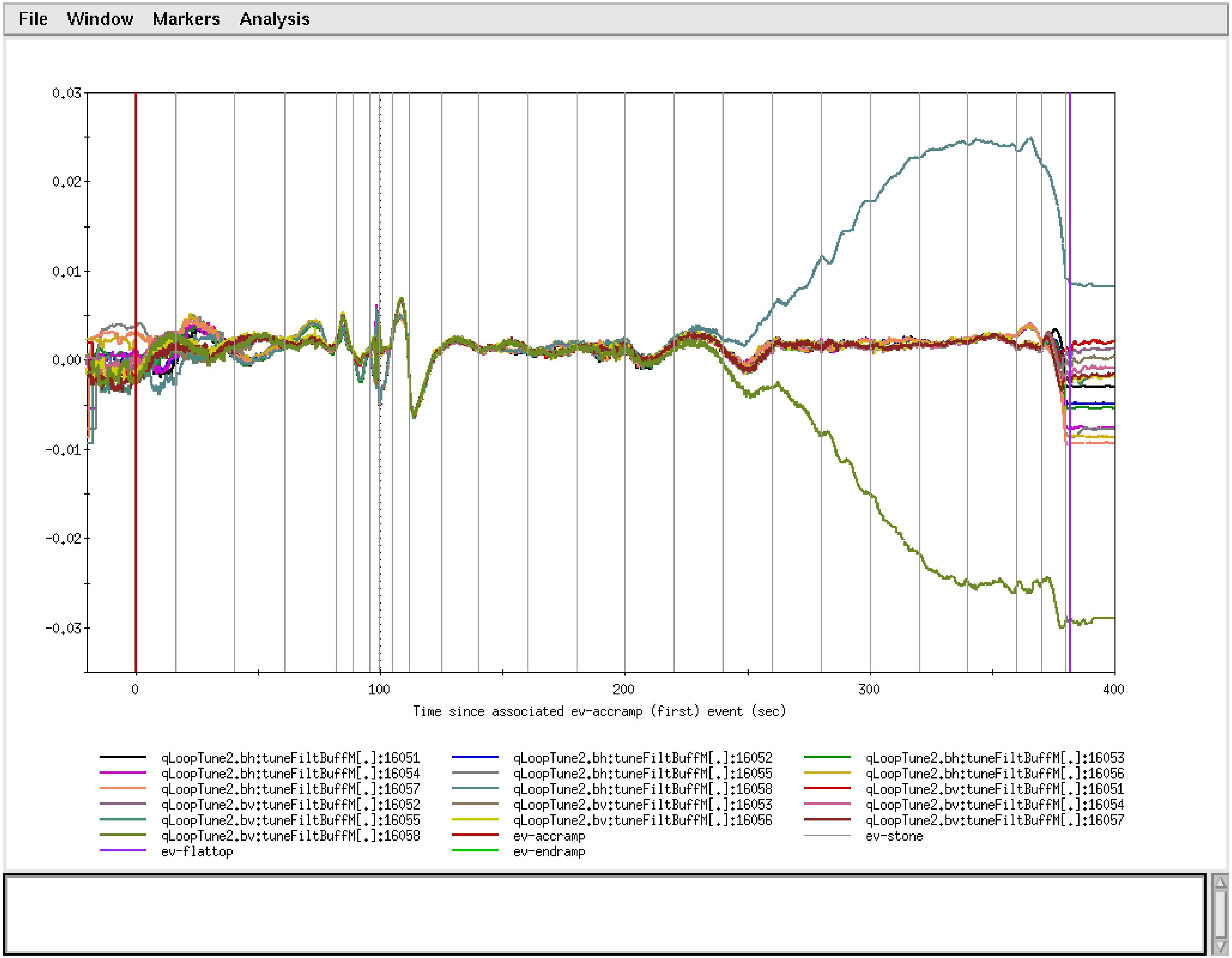

Figure 24: Distribution of tune corrections in blue when yellow dipole did not ramp (and tune distribution during normal running conditions for comparison).

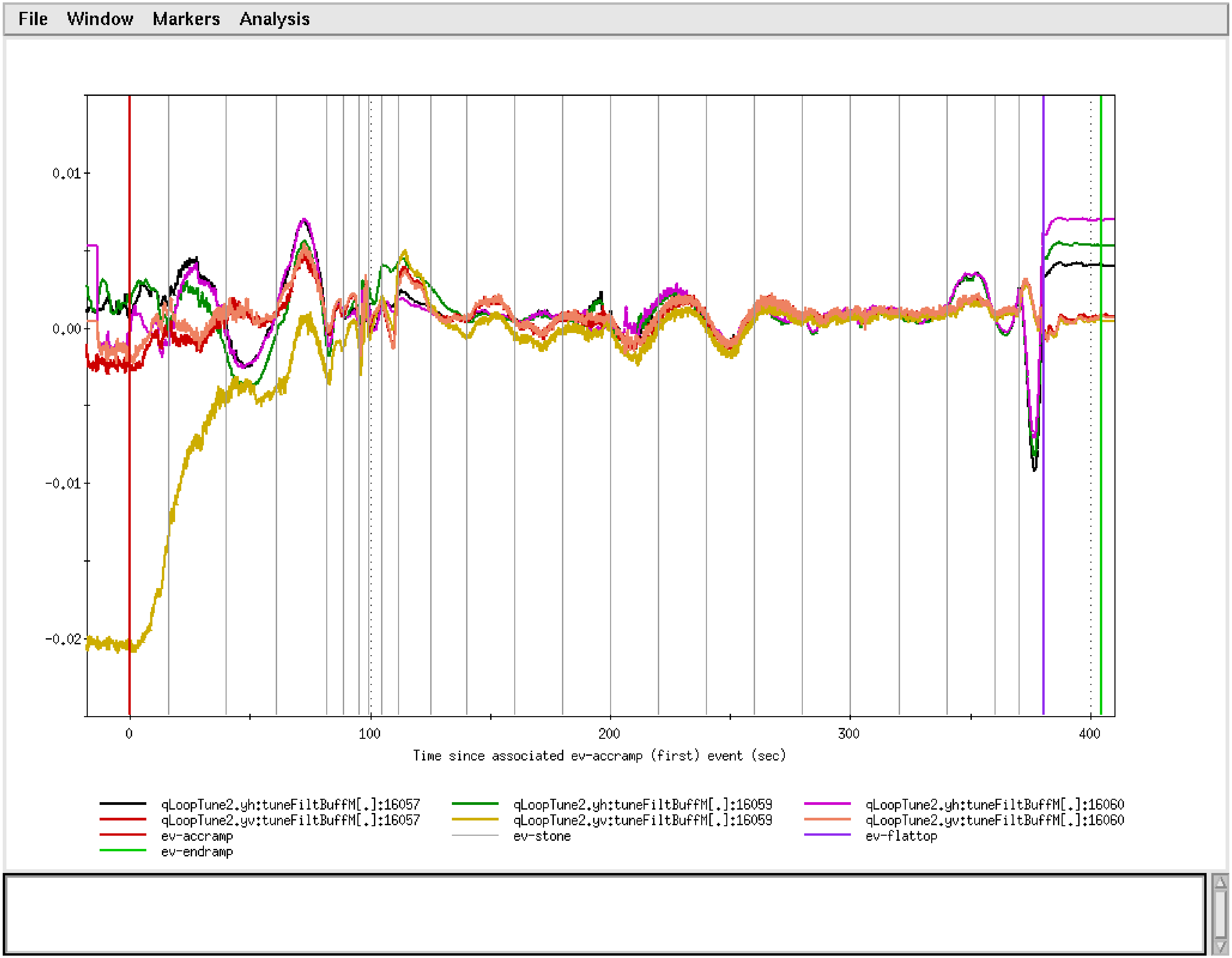

Figure 25: Distribution of tune corrections in yellow when yellow dipole was not on hysteresis (and tune distribution during normal running conditions for comparison).

Yellow dipole feedback

The performance of yellow dipole feedback was quite different in Run 11 in comparison with Run 10. That could be due to Xmean feedback keeping Xmean of blue beam zero. Figures 26 and 27 show yellow dipole correction for Au104 ramp and Au11v1 ramp, respectively. Notice that corrections for Au104 ramp are much larger than corrections for Au11v1 ramp. Also the ramp transmission efficiency of yellow beam was, as a rule, lower than transmission efficiency of blue beam.

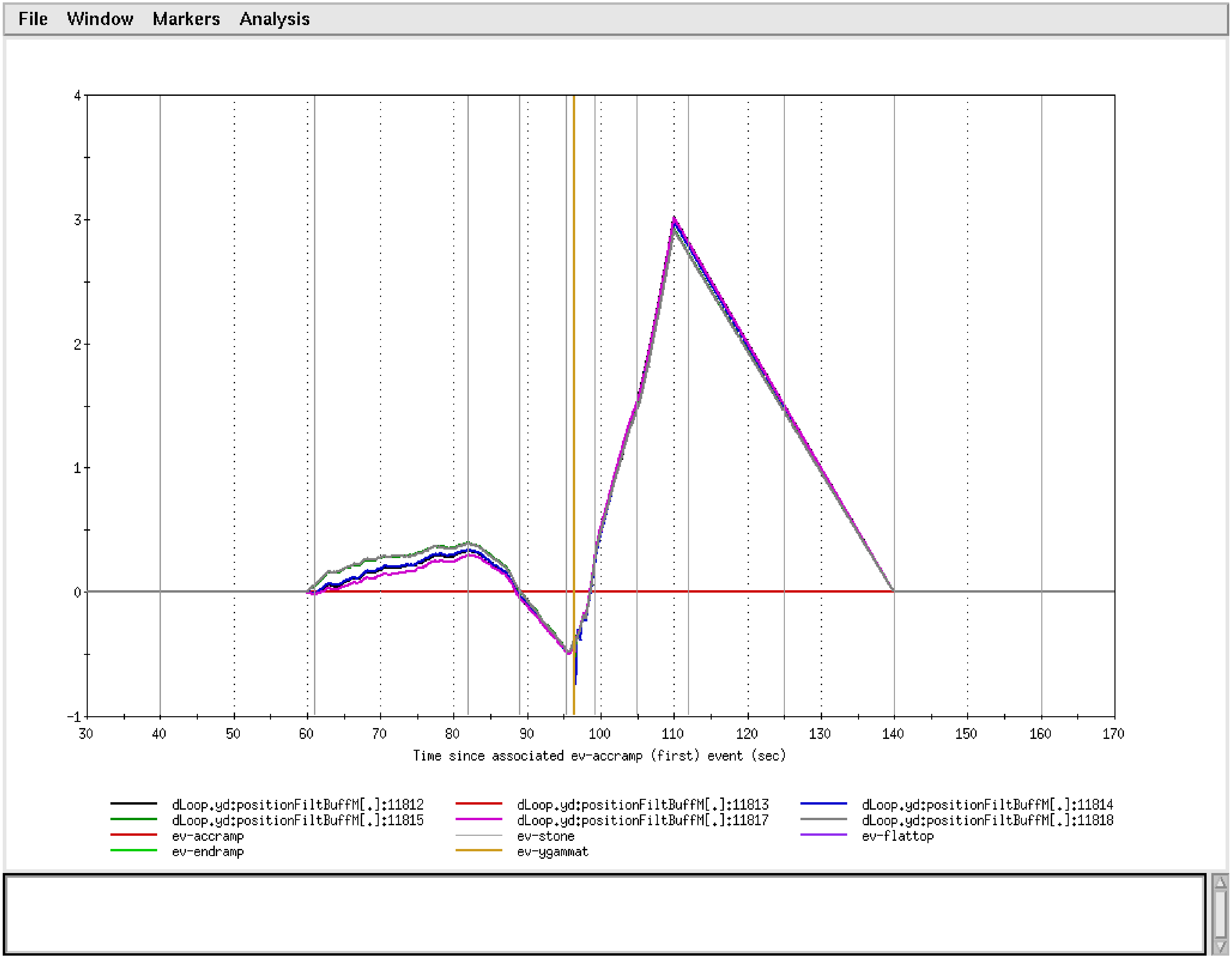

Figure 26: Yellow dipole correction for Au104 ramp.

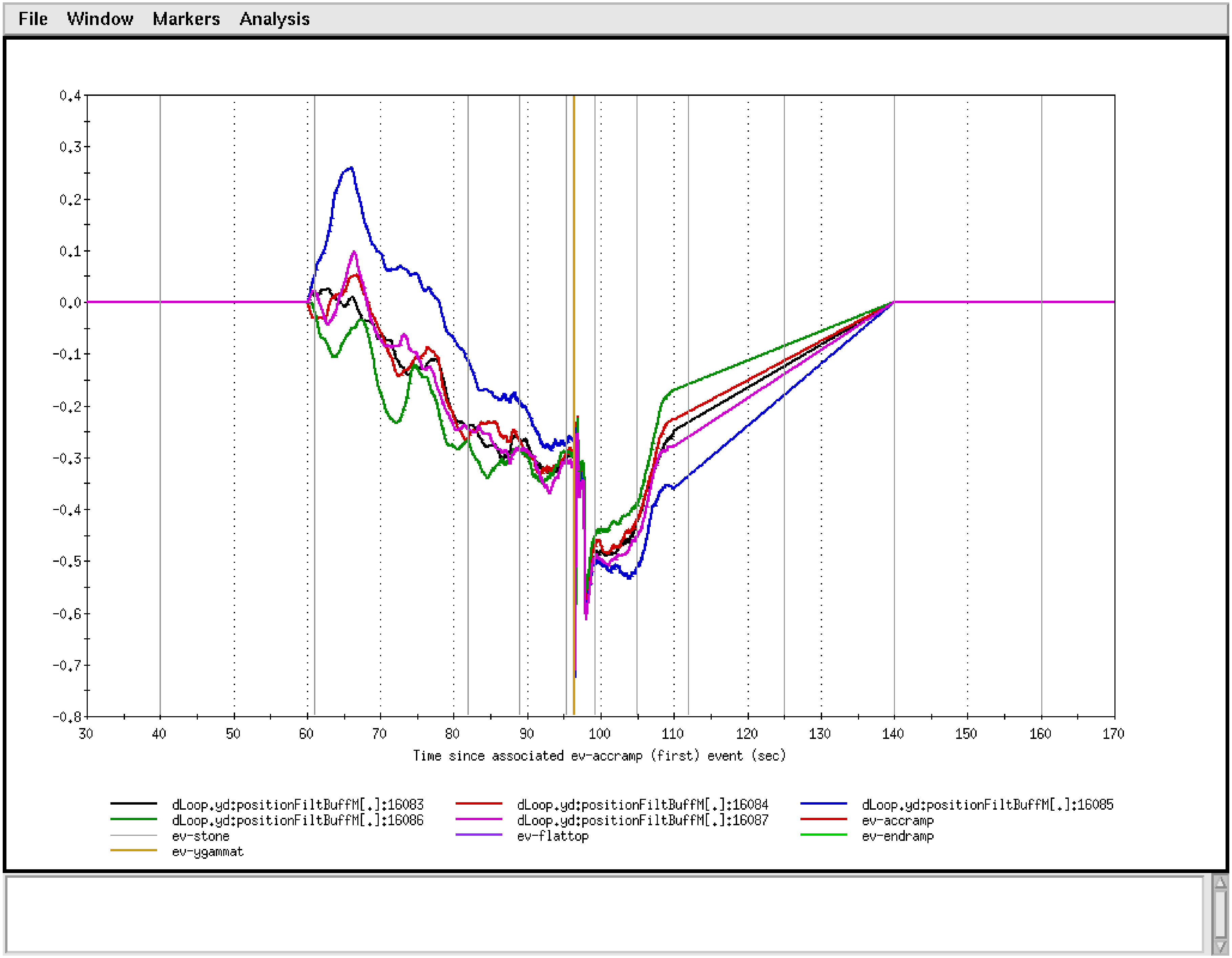

Figure 27: Yellow dipole correction for Au11v1 ramp.

Chromaticity feedback

It is good to have chromaticity feedback, but to ensure that it works, the rate limit handling in WFGs has to change: when a faster than allowed setpoint change is attempted, ramping should not stop, it should continue with maximum allowed rate.

Things to do

– Easy way to specify and view goal orbits will be added to RhicOrbitDisplay. Also the method to view modified captured orbits and select them for goal orbit at store will be added.

– wfgman has to be sped-up. See Figure 28 for improvements in last few days of the run.

– BPM / orbit managers should monitor positions reported by BPMs and alarm on unexpected changes.

– Reduce CPU load on BPM FECs, remove loggers, lisas.

– Fix RampManager / OptiCalc (even if Guillaume fails).

– Protect network, networking code.

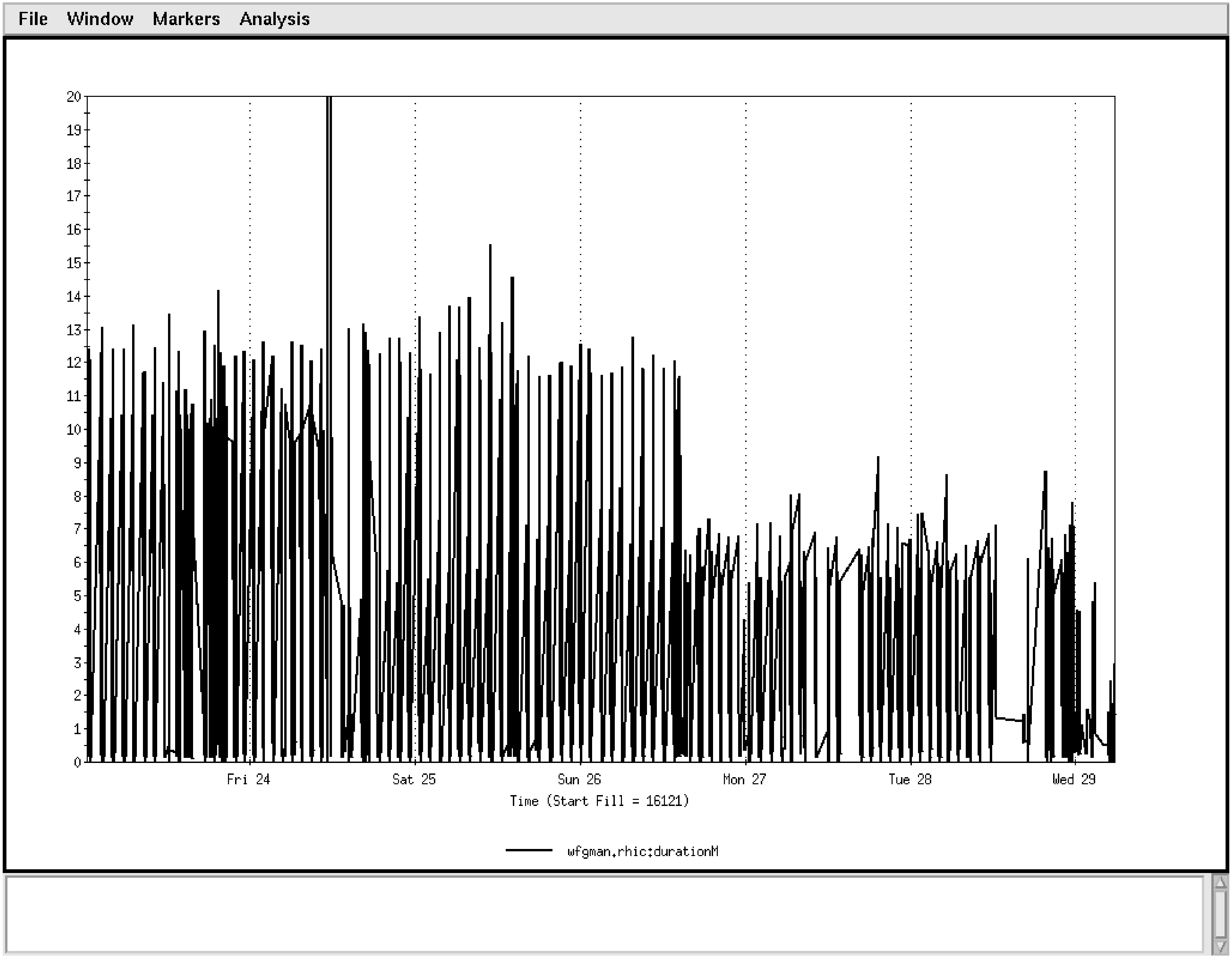

Figure 28: Durations of wfgman's commands.