Micro-instability in Space Charge PIC Codes

1) Why do we at CERN want to benchmark our space charge codes when the convergence tests in terms of emittance blow-up have been so successful?
2) How does the (PTC)-ORBIT fare in the benchmarking?
3) How well does SYNERGIA, the other space charge PIC code at our disposal, in the benchmarking?
4) Can it be explained and mitigated? (➔ talk L. Vorobiev)
5) What are our conclusions?

Motivation for the Benchmarking Effort I

1. We have long experience (29 years in my case!) with
   - non-linear single-particle dynamics for LHC and many other machines
   - particle simulations
   - benchmarking of codes and alternative approaches
   - excellent knowledge of LHC magnet to magnet quality (➔ talk E. Todesco)
   - Measuring the dynamic aperture of the LHC within 10% of the model prediction.
2. It has been understood both in the non-linear and the space charge community that it is time to join the best tools of both worlds. Both PTC-ORBIT and SYNERGIA are prime example for this trend. ➔ This may explain why at CERN we have chosen PTC-ORBIT, in particular since we have had excellent experience with PTC in conjunction with MAD-X. For various machines like the PS we are obliged to use PTC for the lattice design.

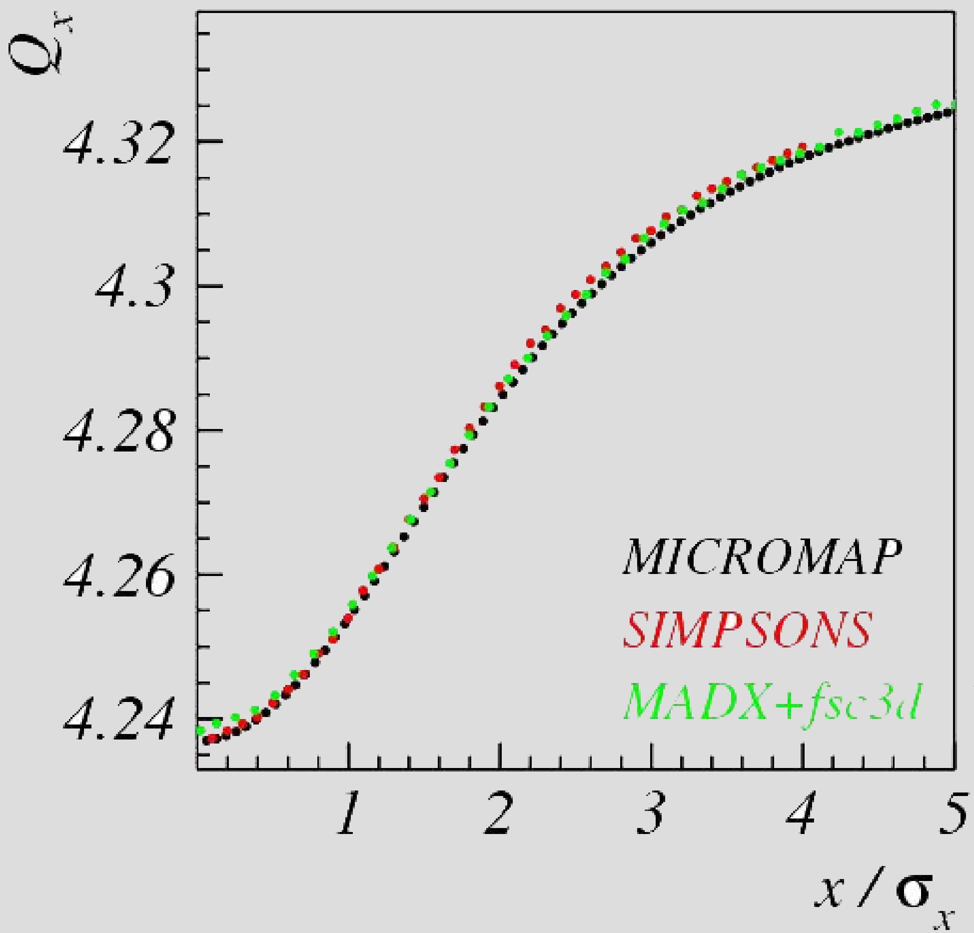
Motivation for the Benchmarking Effort II

3. Therefore I was naively entering the space charge field with this non-linear baggage and applying it to the benchmarking effort for PIC space charge codes.
4. Obviously, the problem with noise in PIC codes has been well know for a long time. But my interest was to find out how single particles fare under the self-consistent space charge force because that has shown to be relevant in benchmarking.
5. Up to now we have been using PTC-ORBIT as black box users and the simulations with this code have been justified with the so-called convergence test of the time evolution of the emittances.
6. With the beginning of the serious phase of simulating our machines and comparing the code predictions with the experiments we decided to:
   - Fully understand all aspects of the codes including noise and its effects on single particle motion ➔ Ownership of our codes
   - Preparing an alternative tool for cross benchmarking with PTC-ORBIT ➔ Synergia
   - Upgrading MAD-X with a frozen space charge model. (➔ talk V. Kapin)

Benchmarking for ORBIT

H-DETUNING GSI SIS18

$Q_{x0} = 4.338$



Giuliano Benchmark WEB page:

http://web-docs.gsi.de/~giuliano/

Giuliano Franchetti

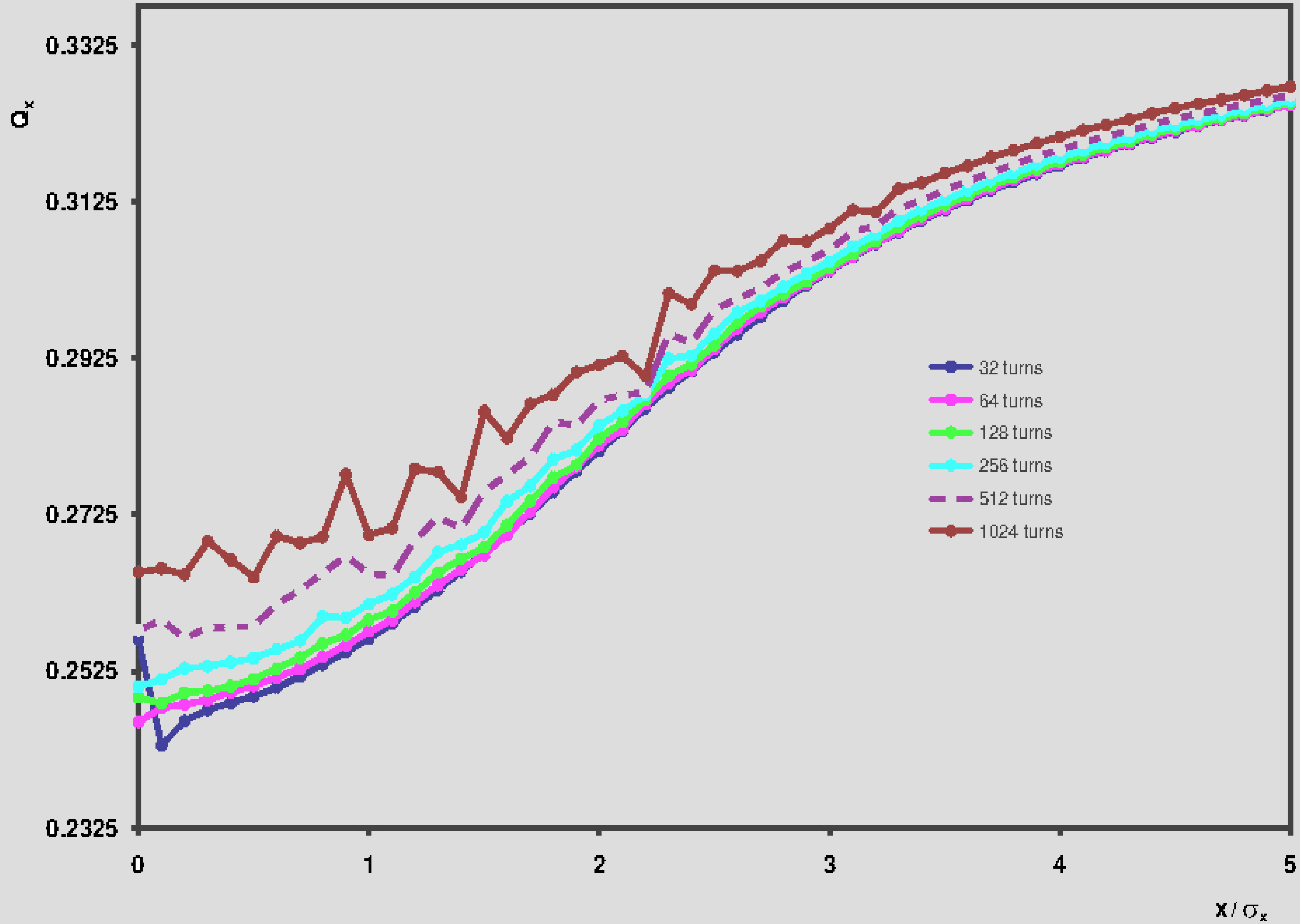
Shinji Machida

Valery Kapin (2008)

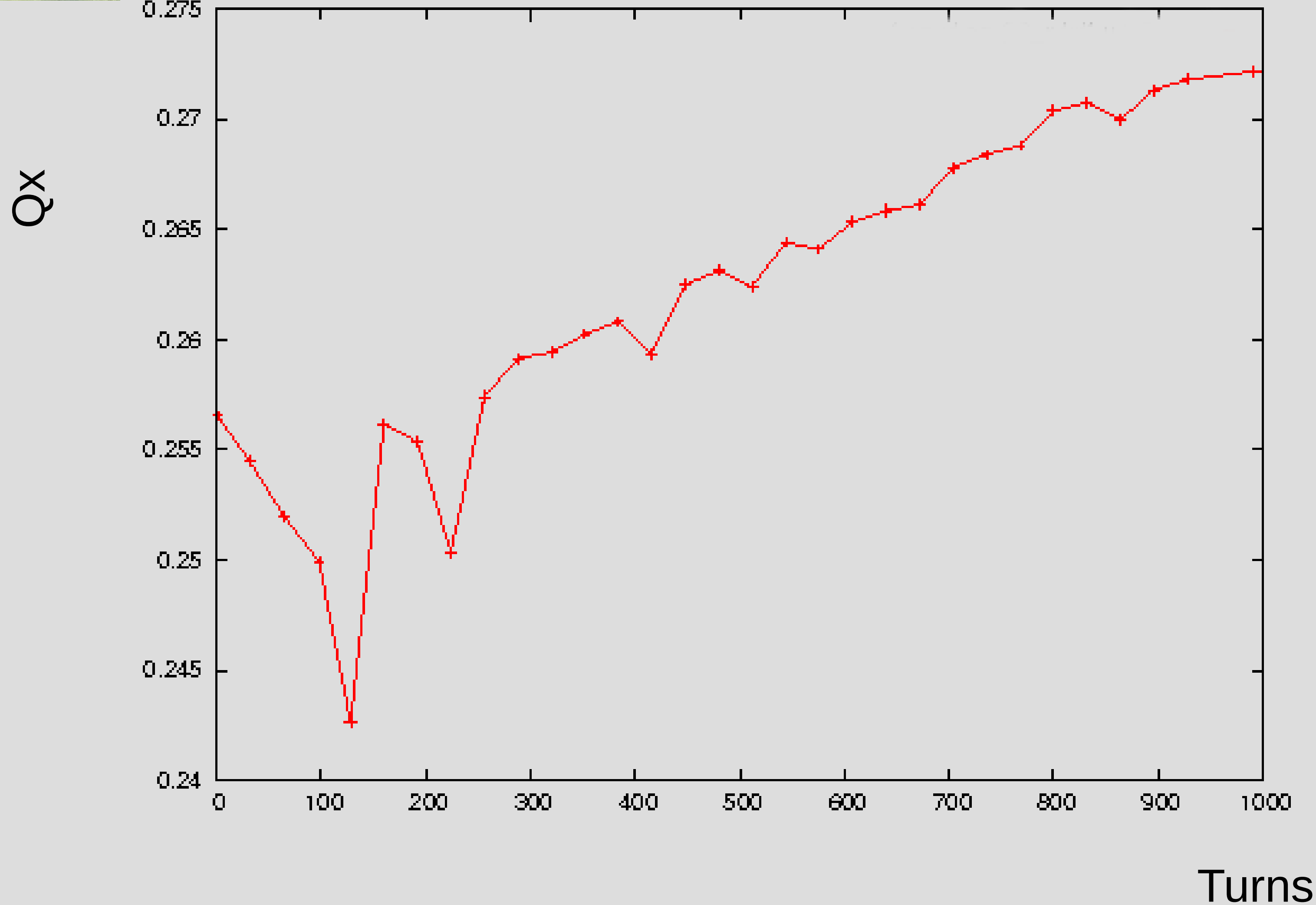
Equivalent to implementation directly in MAD-X 2012

(➔ talk of V. Kapin)

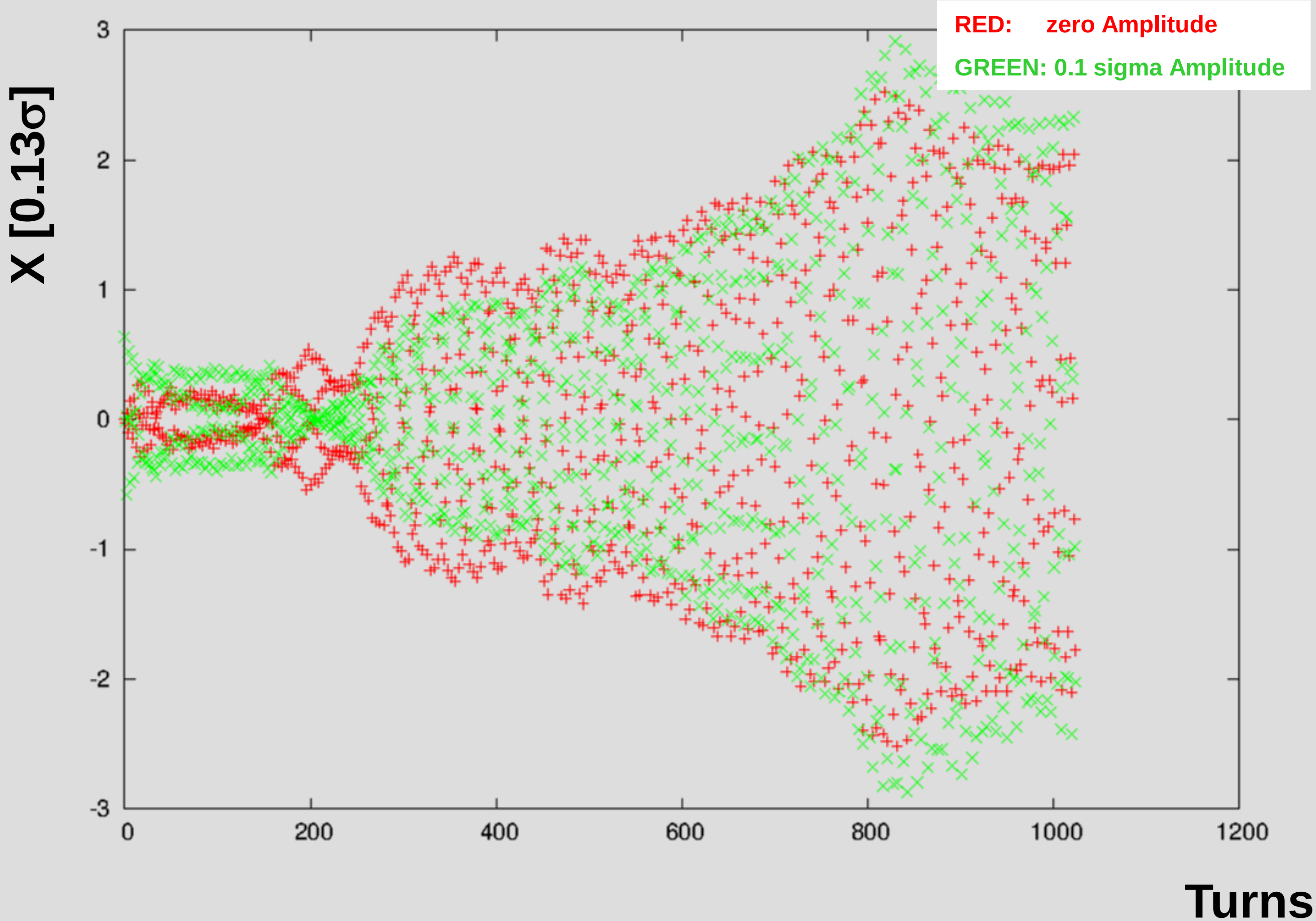
H-DETUNING PTC-ORBIT



Tune Evolution PTC-ORBIT

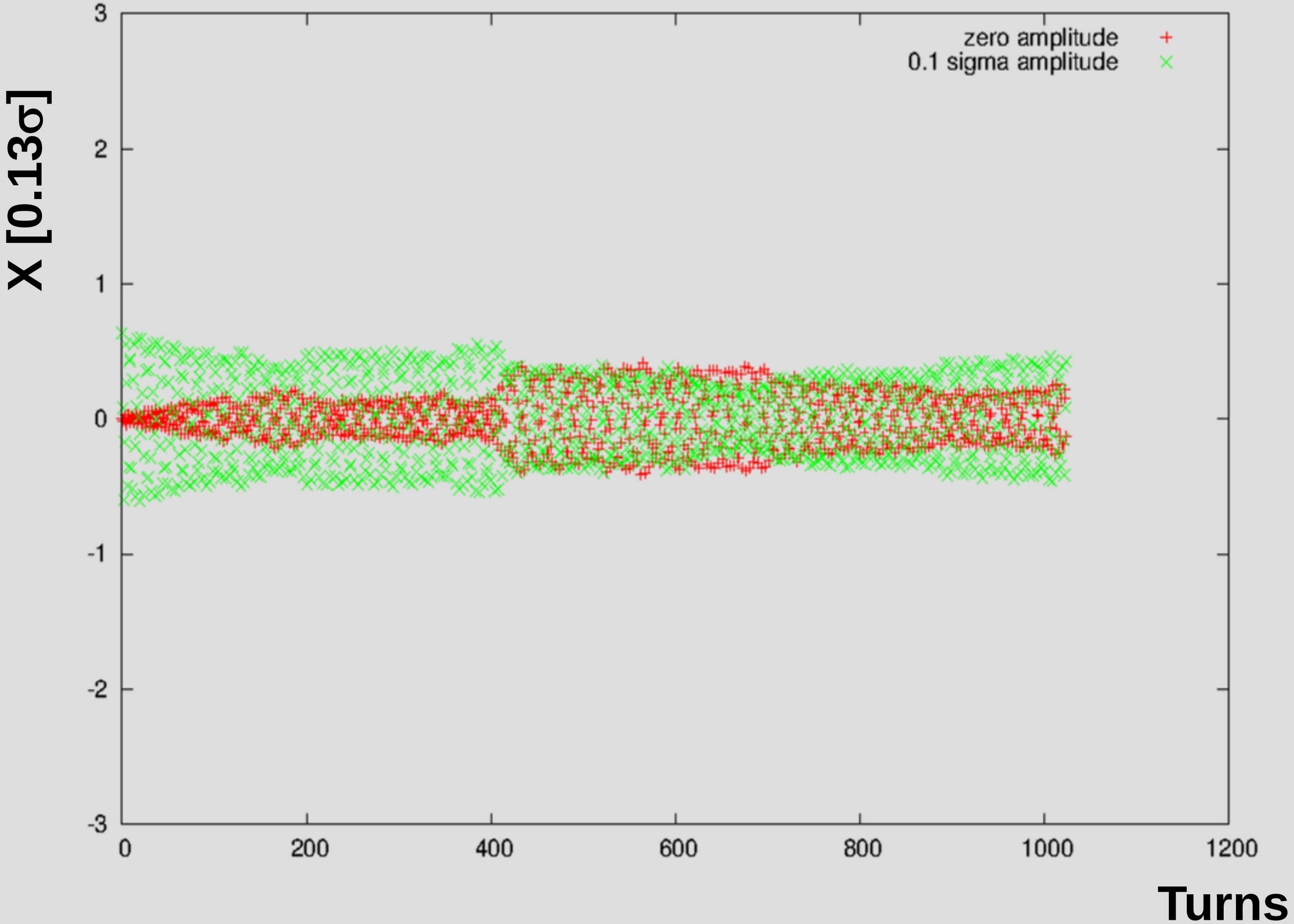


Amplitude blow-up PTC-ORBIT

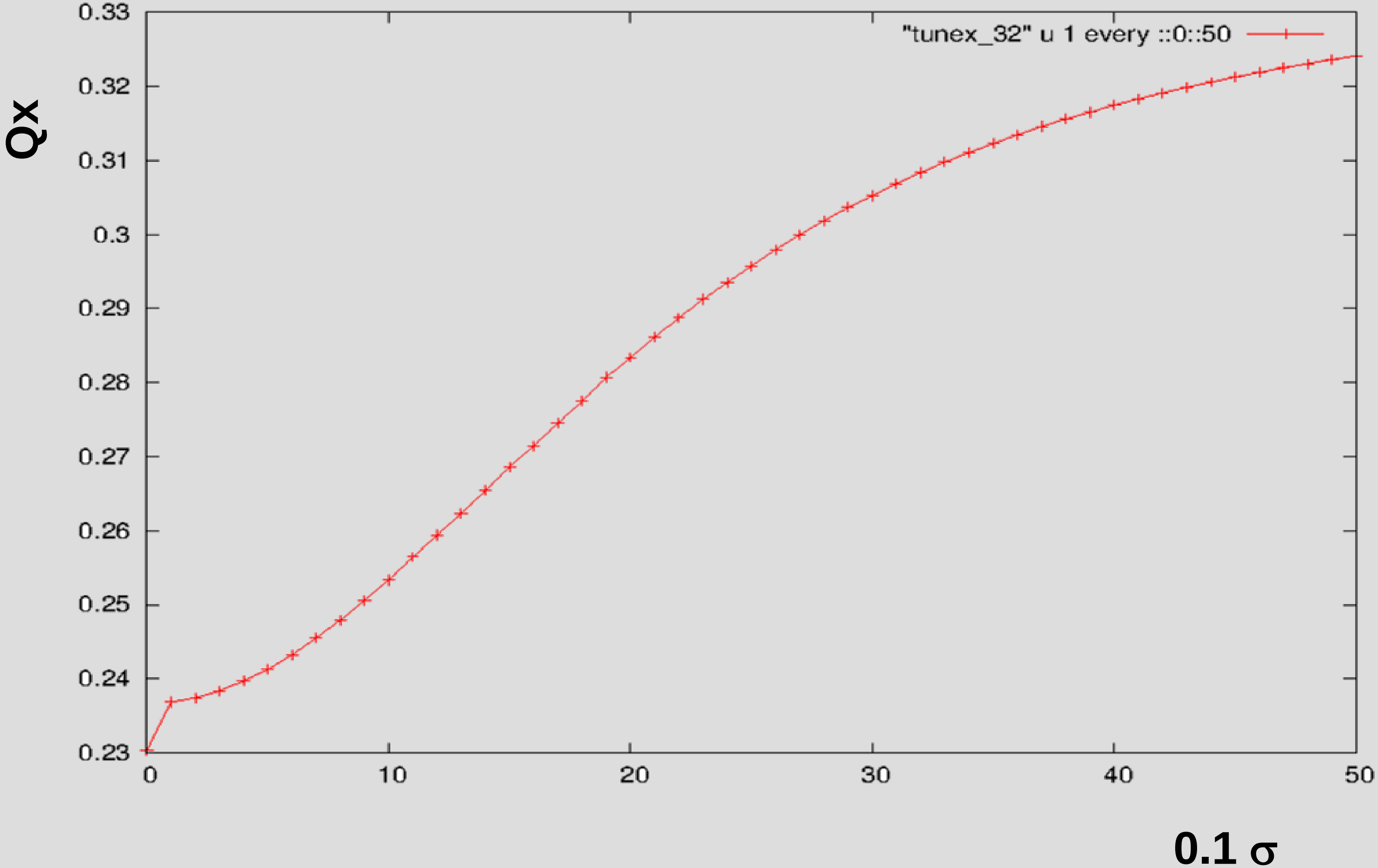


Benchmarking for SYNERGIA

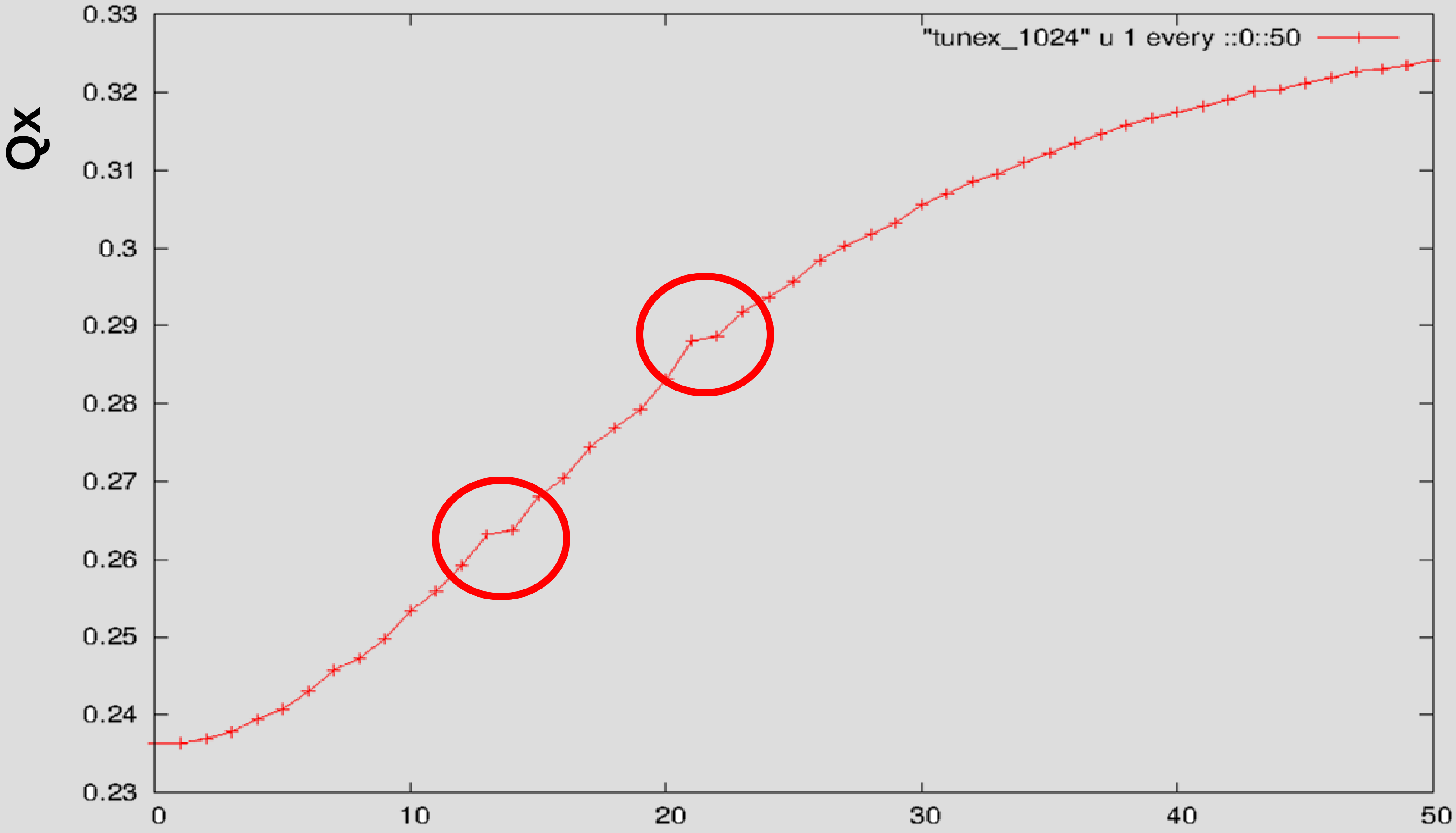
Small Amplitude blow-up SYNERGIA 1M Macro Particles



H-DETUNING SYNERGIA
1M Macro Particles 32 Turns

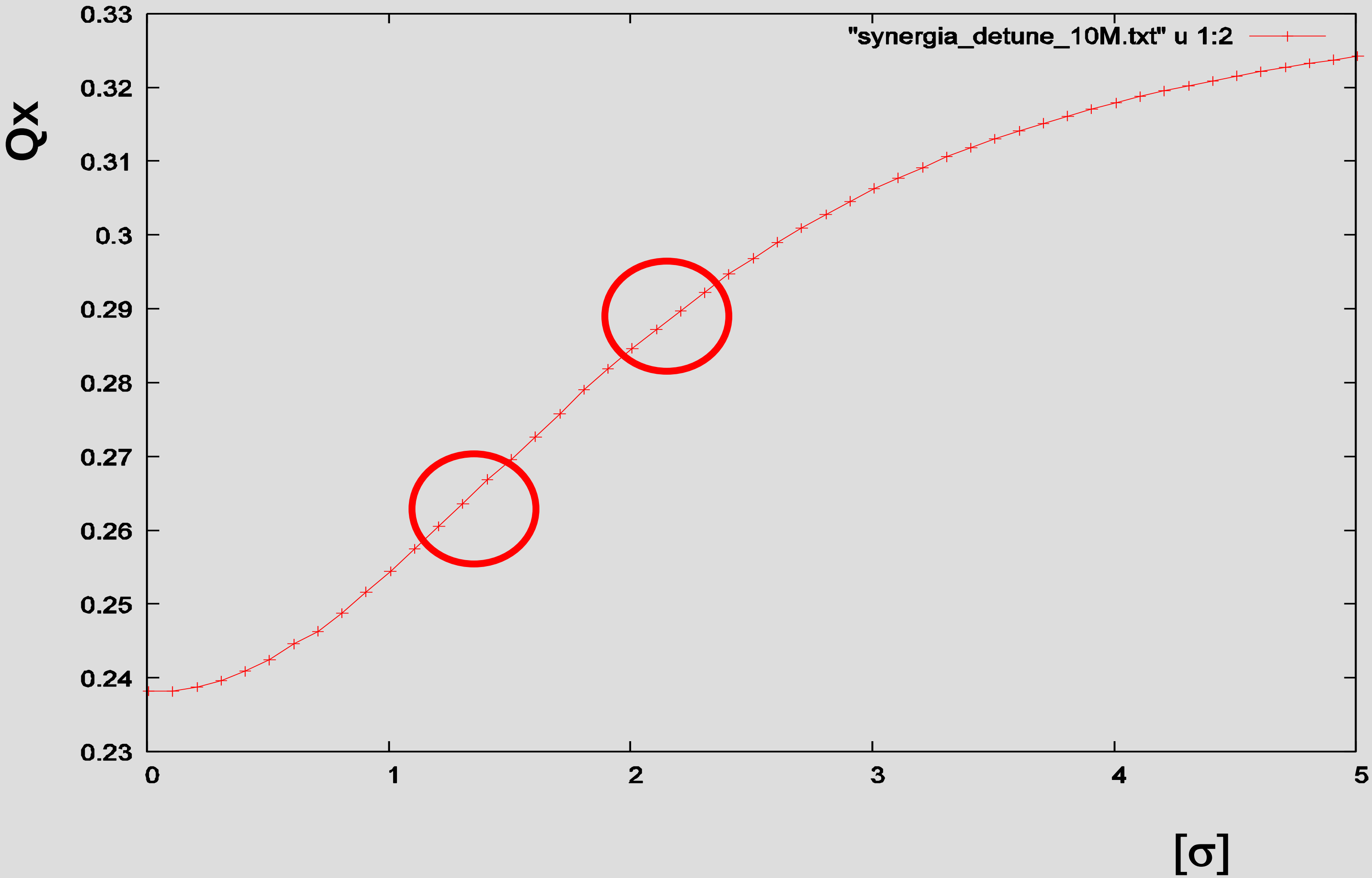


H-DETUNING SYNERGIA
1M Macro Particles 1024 Turns

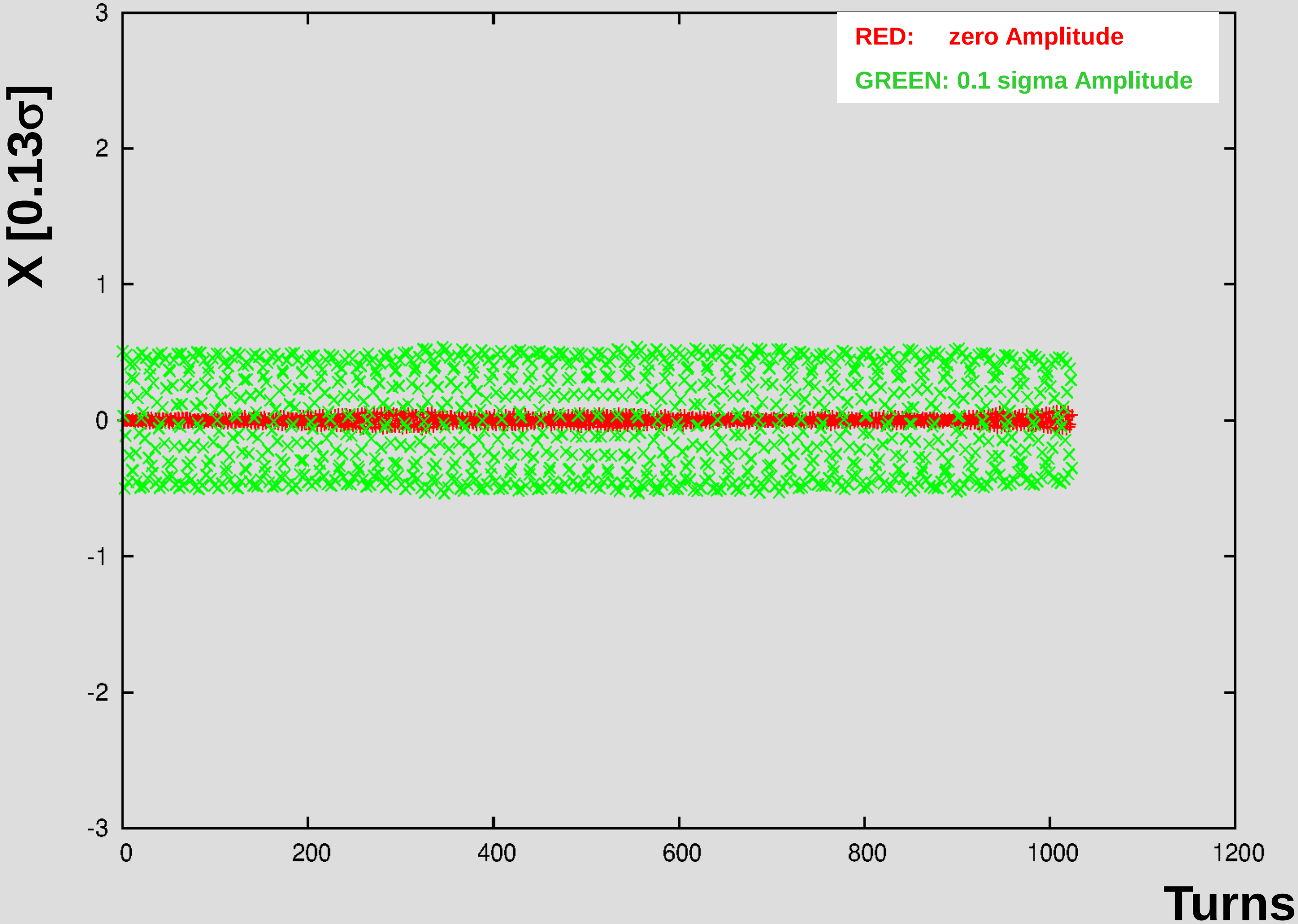


0.1 σ

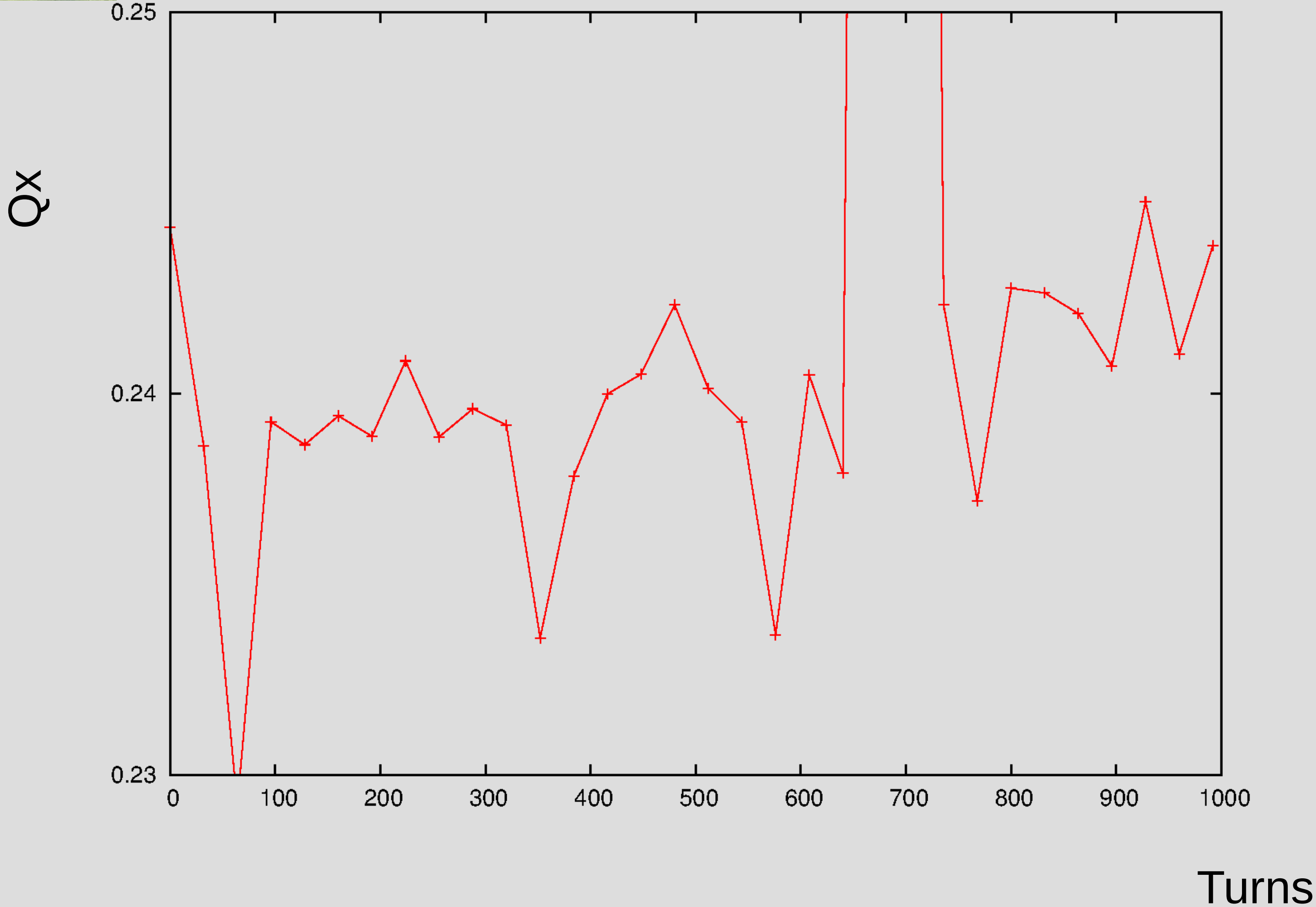
H-DETUNING SYNERGIA
10M Macro Particles 1024 Turns



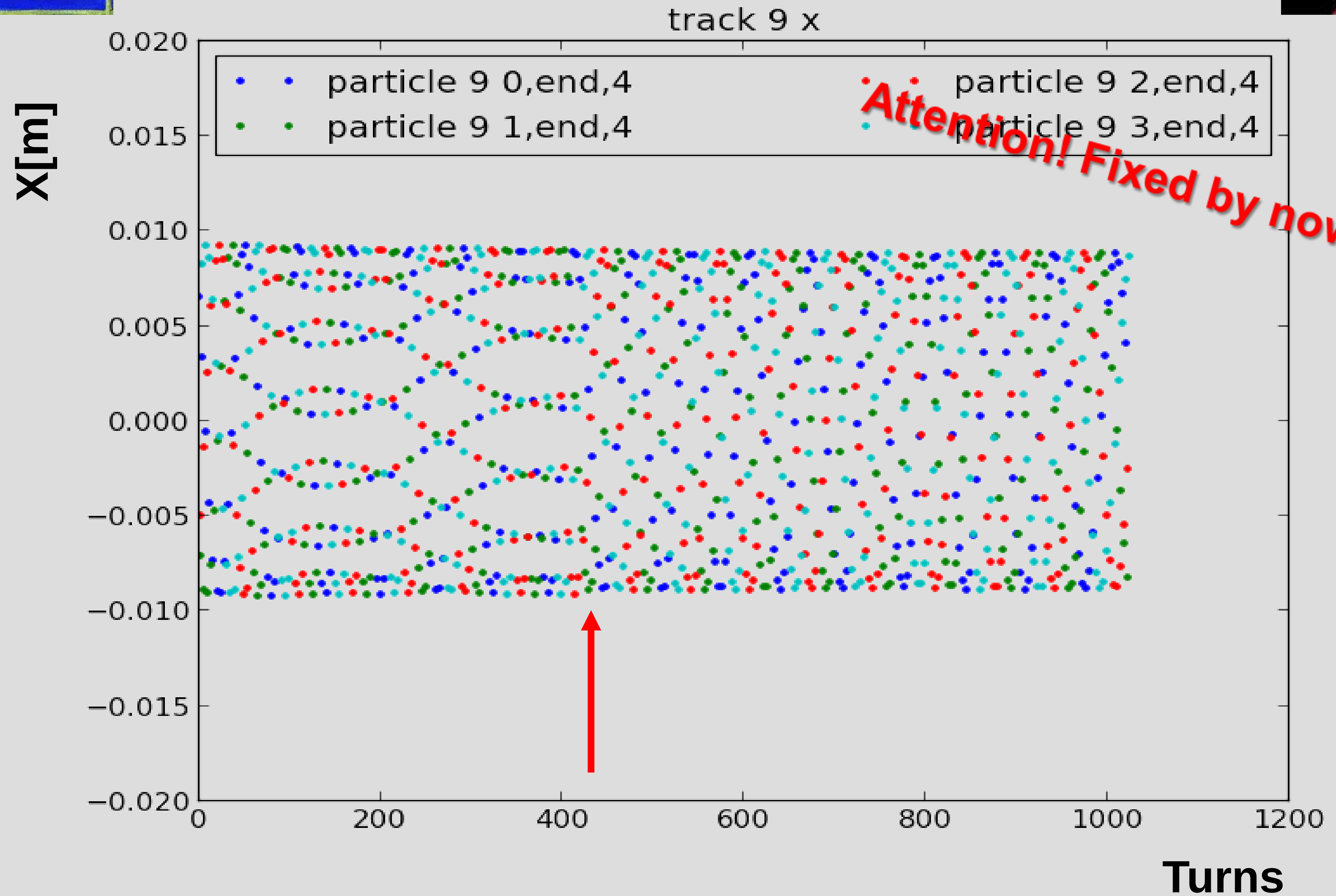
Small Amplitude blow-up SYNERGIA 10M Macro Particles



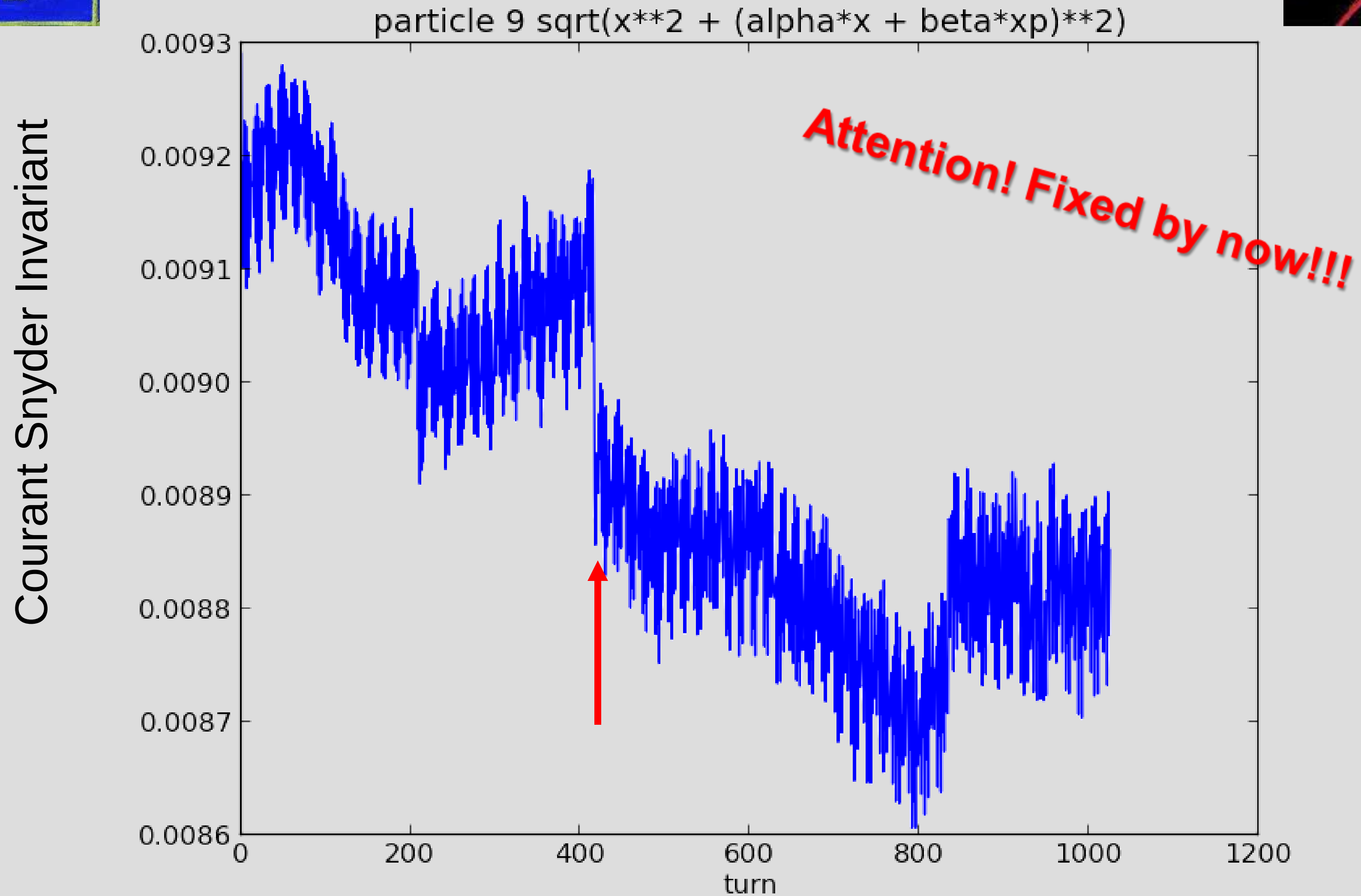
10M Tune Evolution SYNERGIA



Sudden shift in Tune SYNERGIA



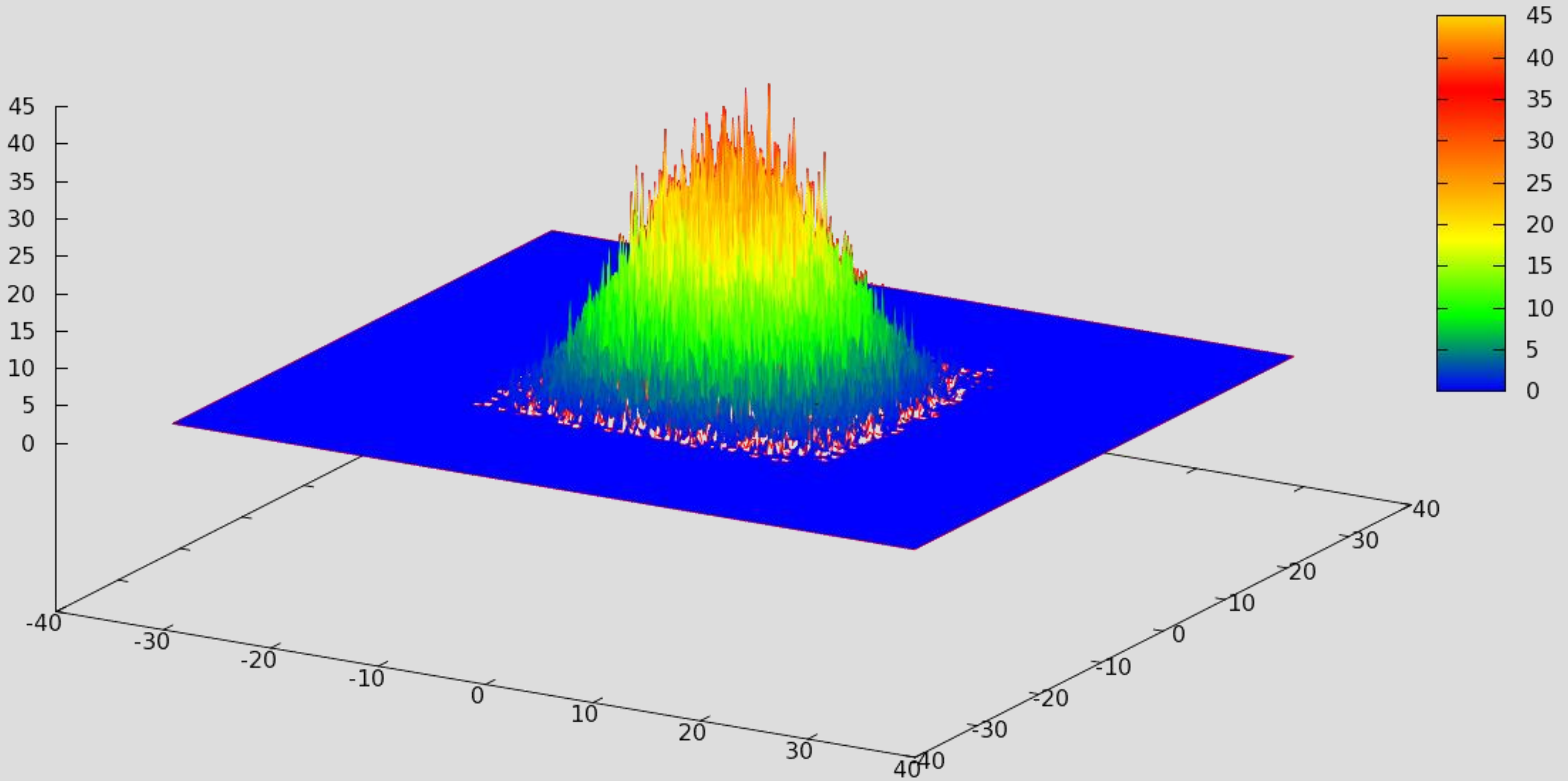
Evolution of Linear Invariant SYNERGIA



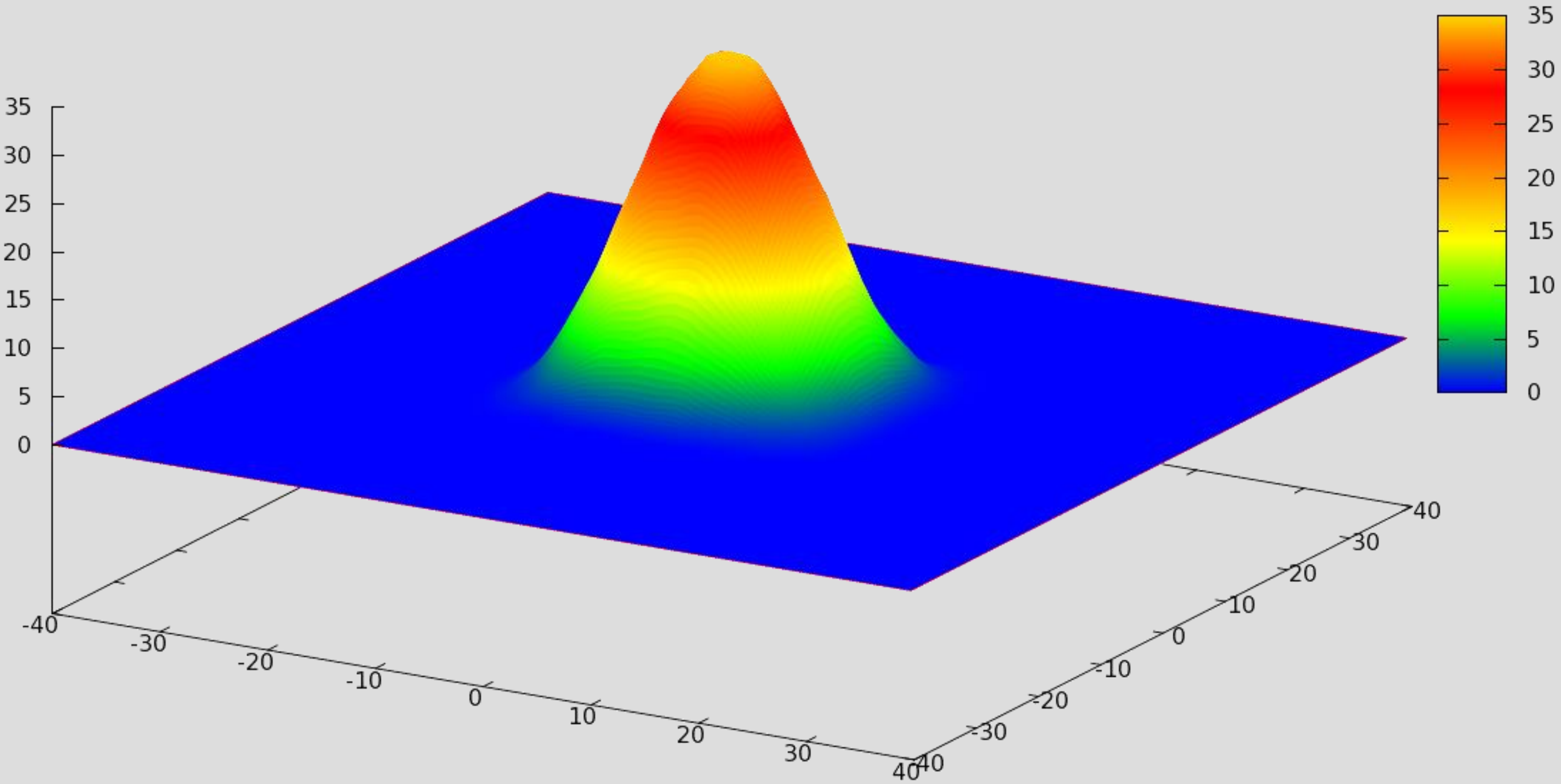
Amplitude Growth in ORBIT and possible Mitigation

- The issue of the growth of particles has been discussed at Fermilab in-depth with Leonid Vorobiev.
- We have verified that it is NOT due to some input issue or insufficient number of macro particles, grid binning, type of ORBIT routine. Moreover, it is purely ORBIT related and is not due to the PTC part.
- We also made sure that this is NOT due to the specific choice of the tunes.
- We then informed Jeff Holmes as the author of ORBIT and he confirmed that in an Email to me: "I set up a uniform focusing channel and a KV distribution. I observe the same numerical diffusion behavior seen by you and Leonid."

Original ORBIT Density



Reversed Parabolic Density (proposal L. Vorobiev)



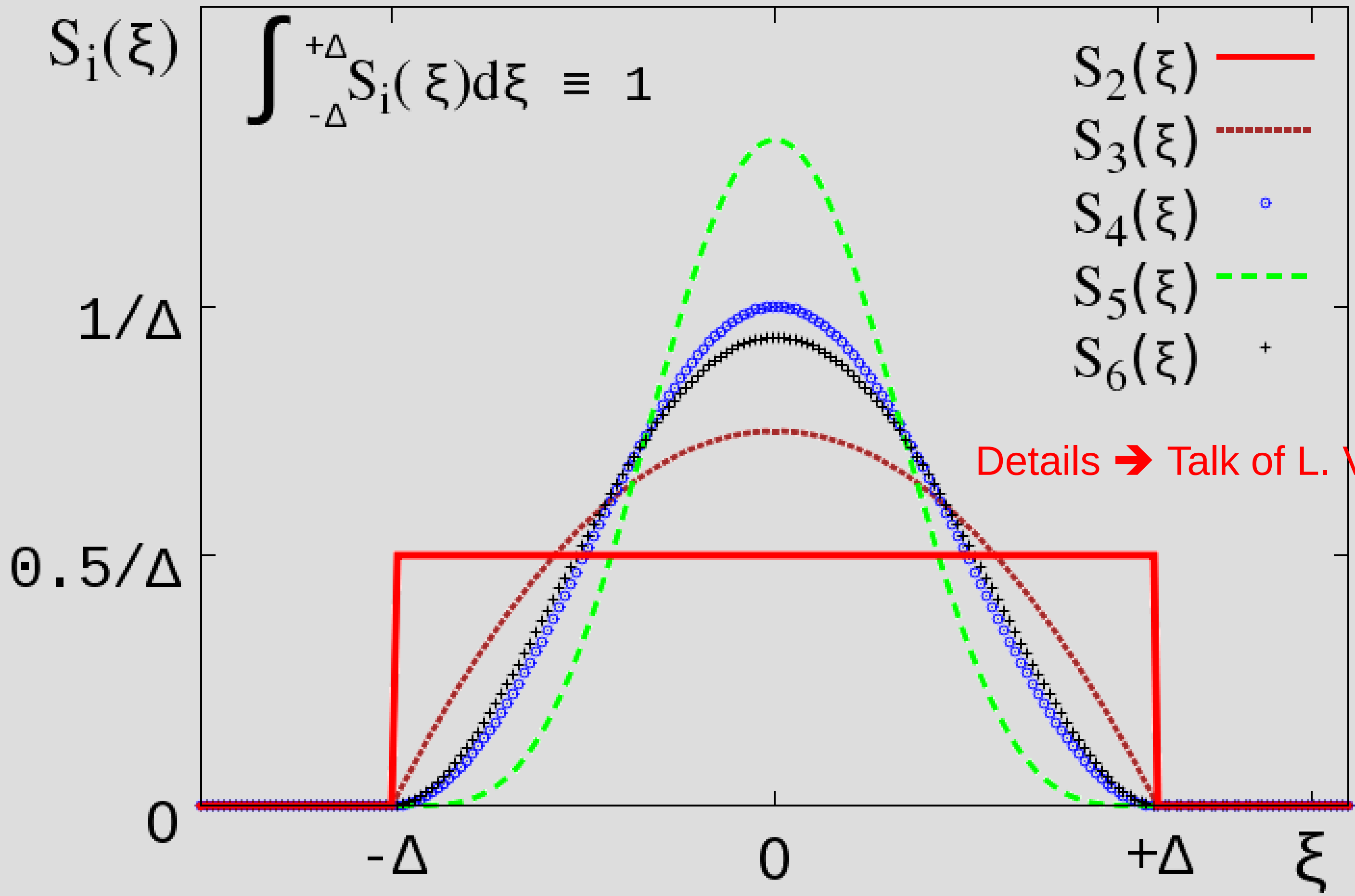
Conclusion

1. **For our CERN LIU studies we need an in-depth understanding about how the codes operate and if we can trust them and how their limits of validity can be defined. ➔ We must take ownership of our codes instead of a black-box usage!**
2. **We at CERN have invested into PTC-ORBIT and plan to continue with it but a second fully functional and benchmarked code is mandatory for trustworthy conclusions for the LIU upgrade studies.**
3. **We have found some diffusive growth at small amplitudes:**
   - **We should find ways to mitigate this problem**
   - **How relevant is the micro-scale chaotic motion of particles for the overall behavior of the particle distribution and in particular for the time evolution of emittance?**
   - **Can we realistically go to very high numbers of macro particles?**
   - **Over how many turns can we trust the PIC codes in storage rings?**

Reserve

Shapes of Distributions (Leonid)

Nov 08, 2012, SC Clouds in PIC



Details ➔ Talk of L. Vorobiew