First Demonstration of Optics Measurement and Correction during Acceleration

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Outline

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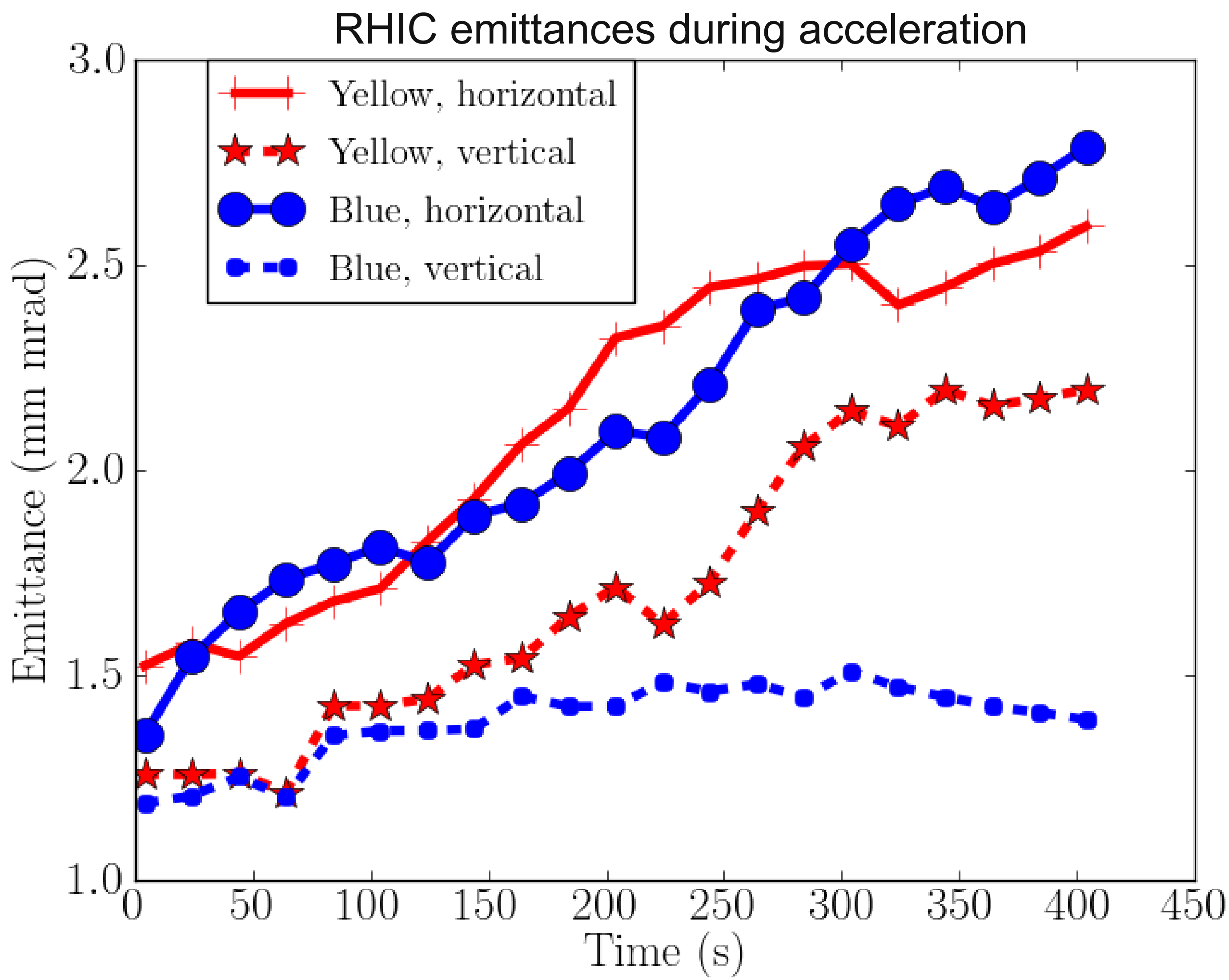
- RHIC overview.
- Optics measurement during acceleration.
- Optics correction during acceleration.
- Impact on beam emittance measurement.
- Summary

Motivation

- To improve the understanding of the evolution of beam parameters (e.g. beam emittances).
- To provide improved beam control since model-dependent beam-based feedbacks are used during acceleration.
- To improve the dynamic aperture for heavy ions and reduce the strengths of depolarization resonances for the polarized proton program.

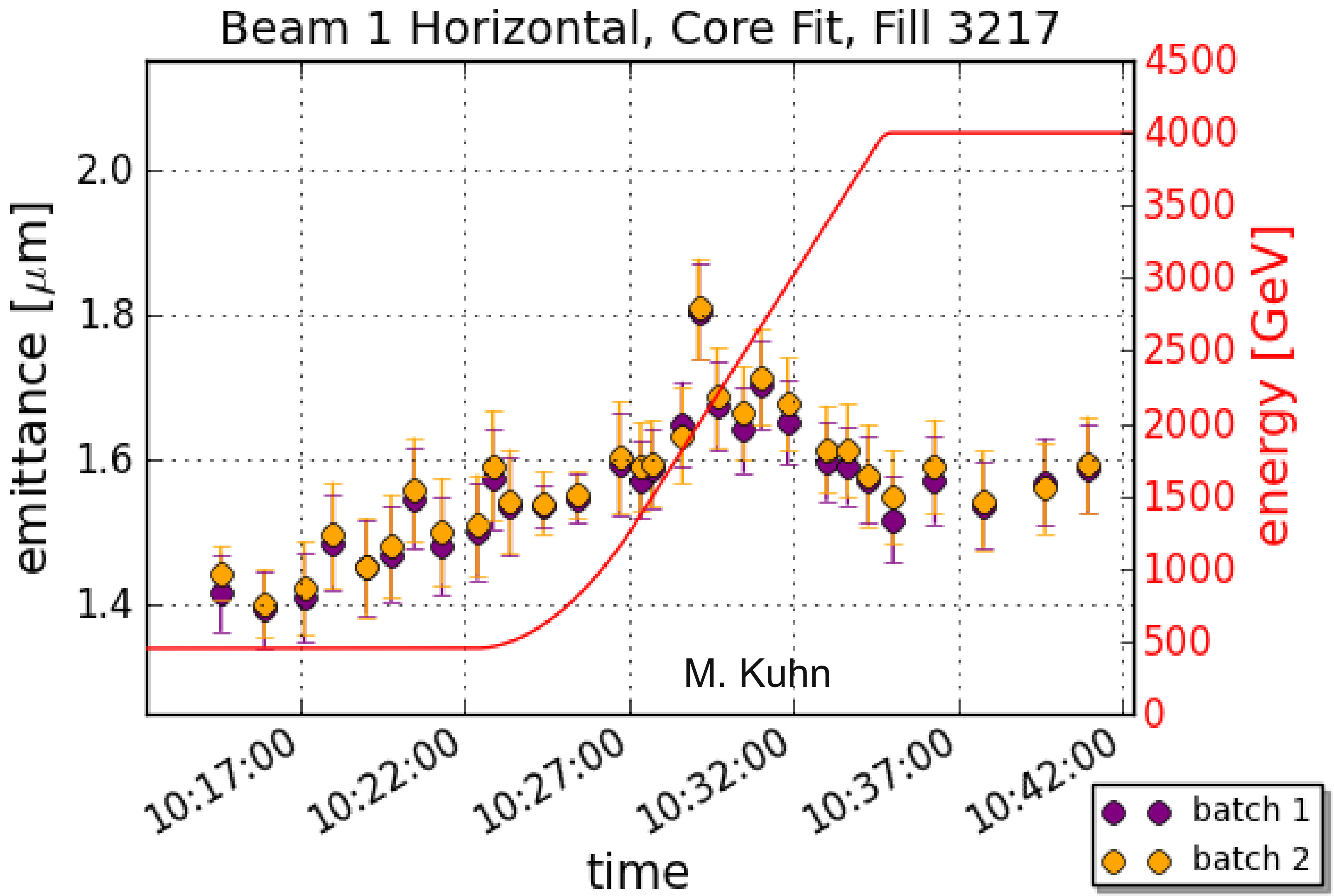
Note: It is time-consuming to pause at intermediate energies to allow measurement and correction of the optics, therefore, we need quasi-continuous, minimally invasive ramp optics measurement/correction.

Emittance evolution



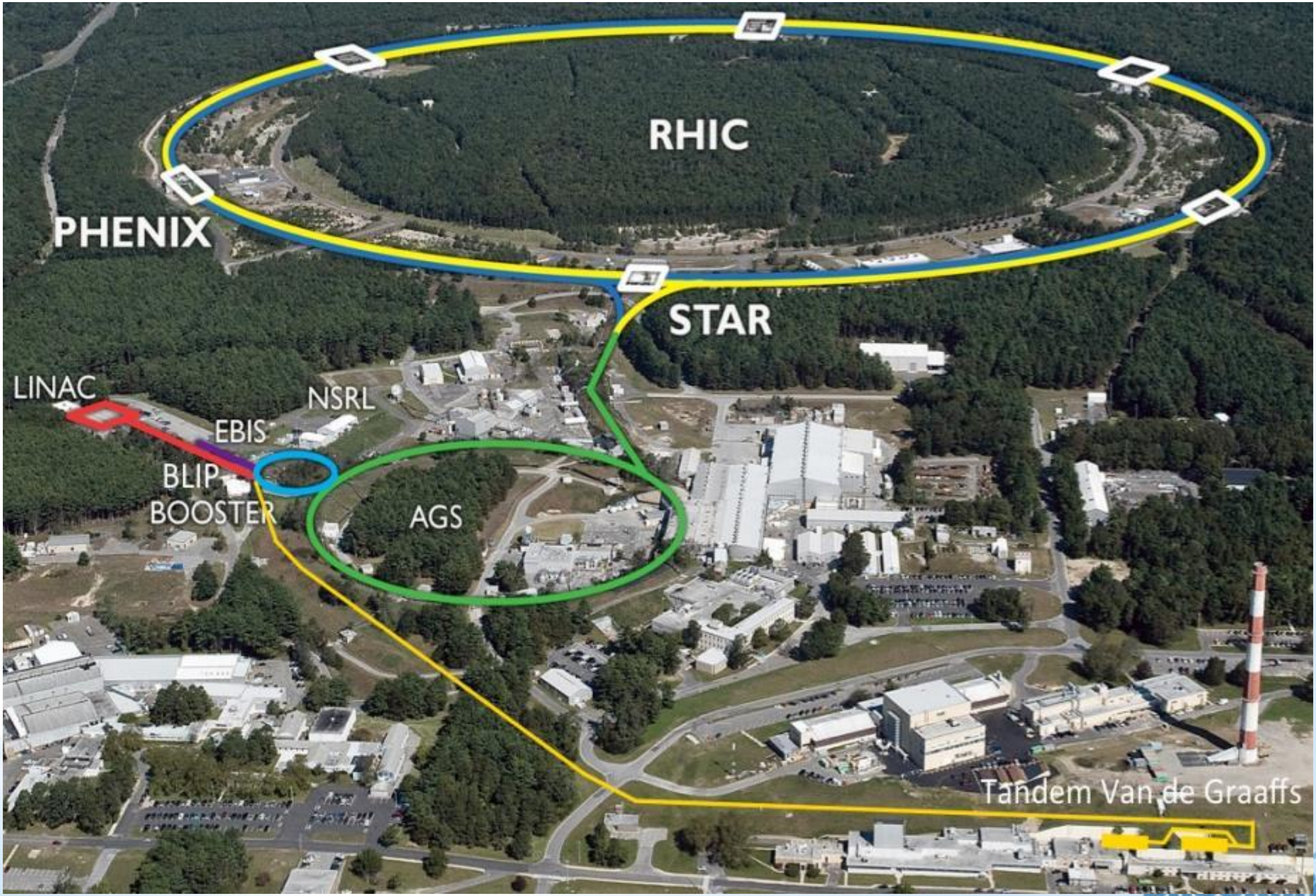
Non-physical emittance shrinking and growing observed during acceleration in RHIC

LHC emittances during acceleration

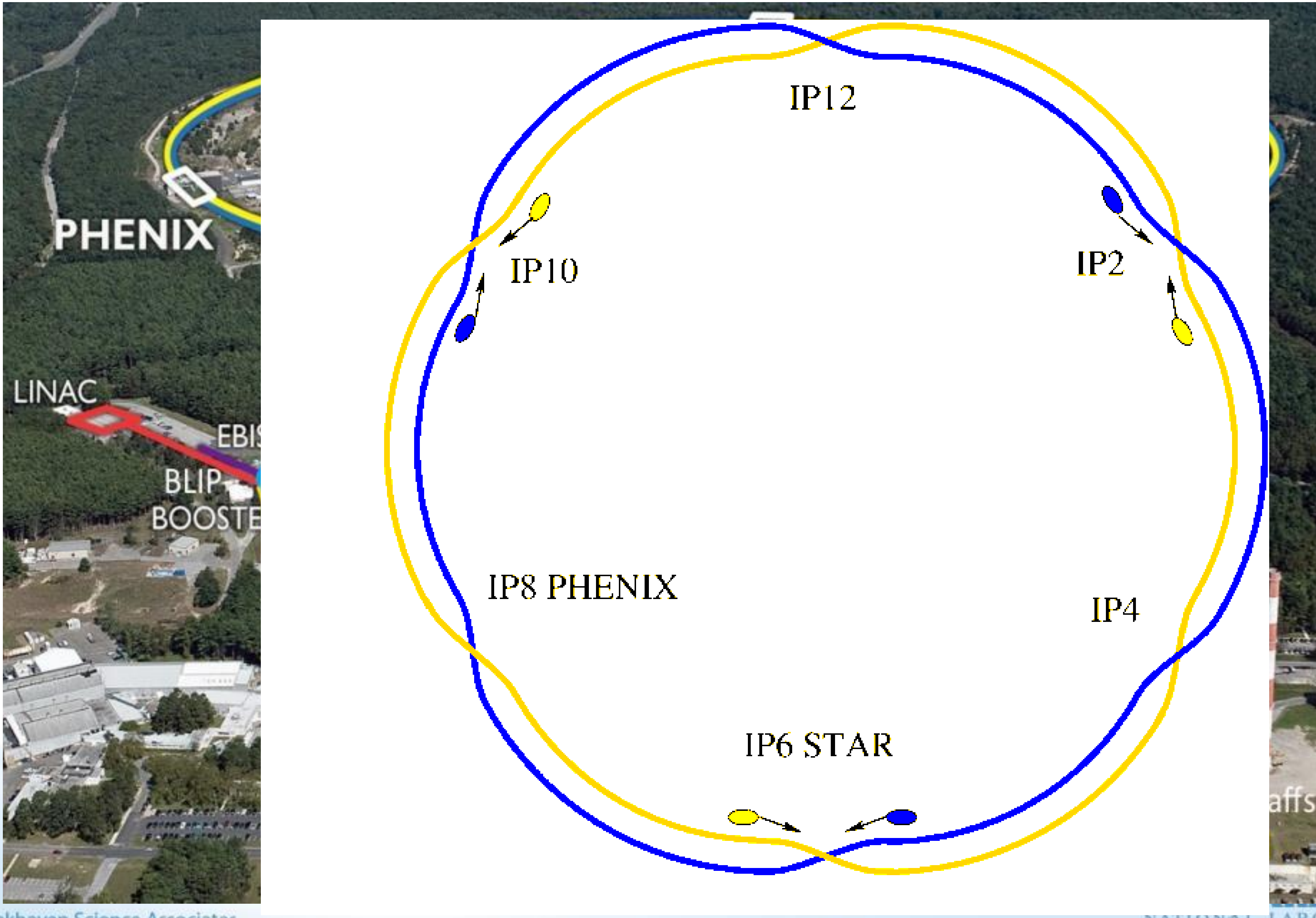


Non-physical emittance behavior observed during acceleration at LHC as well.
This makes the understanding of emittance evolution very challenging.

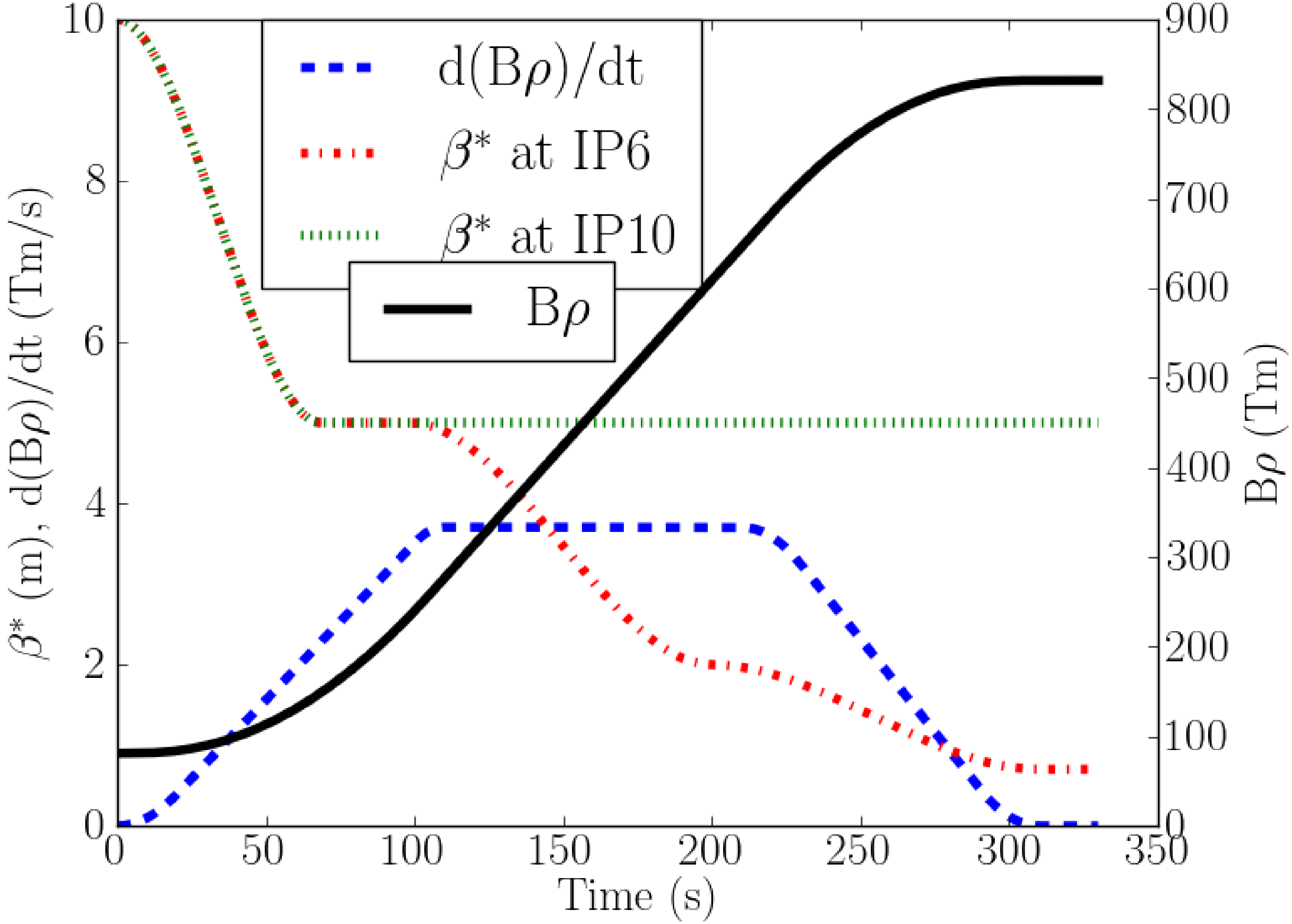
RHIC overview



RHIC overview



RHIC acceleration cycle



Beam sizes at IPs are squeezed down while beam acceleration.

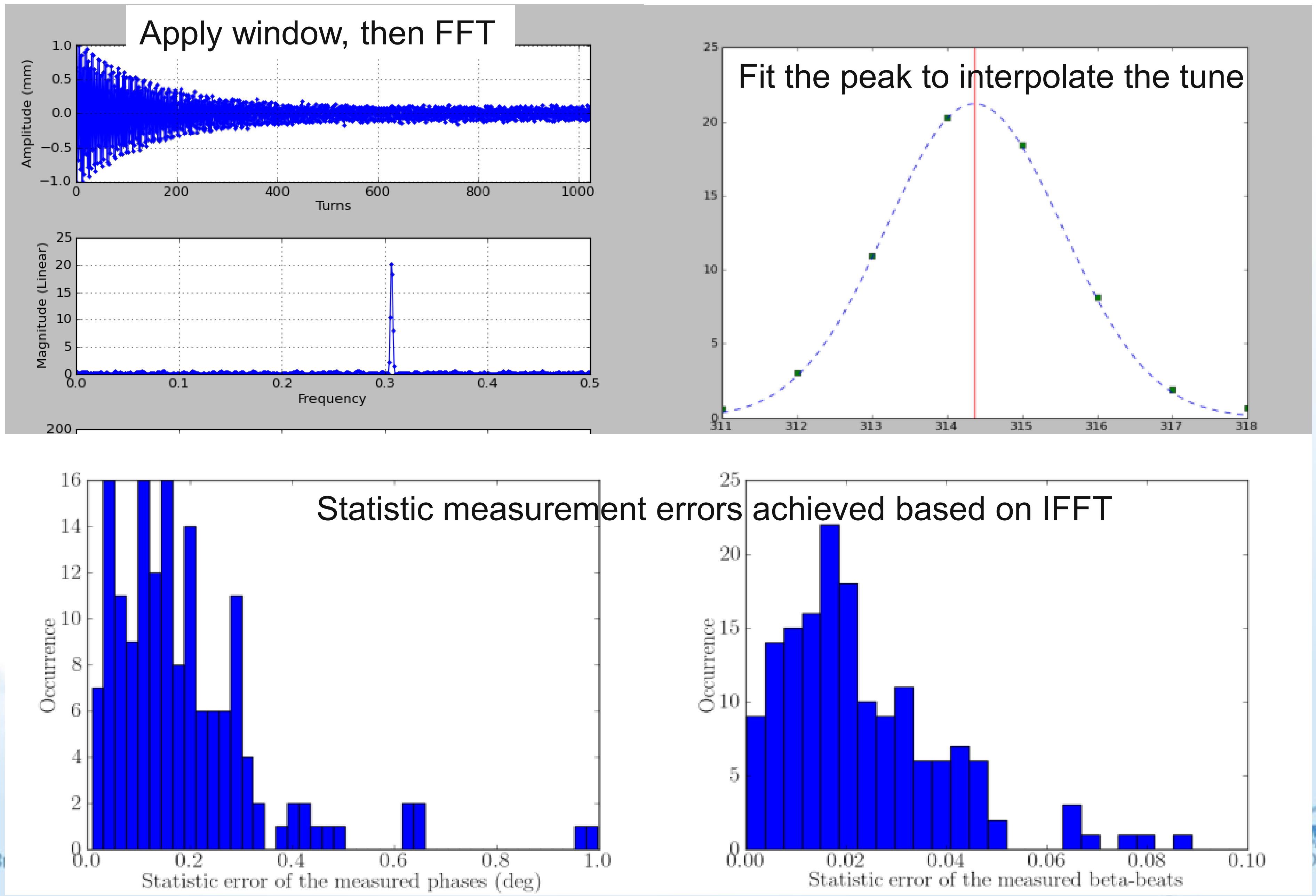
Measurement

- Tune meter kicker is used to excite coherent betatron motion of a single bunch.
- Turn-by-turn position measurements were taken every 4 seconds during acceleration.
- Proper staggering of delivery of the average and turn-by-turn beam position allows normal orbit feedback.
- Switch bunch if intensity is below the set threshold.
- Tuning of chromaticity during acceleration is crucial for both transmission efficiency (~4) and good signal-to-noise ratio of turn-by-turn BPM data (~0).

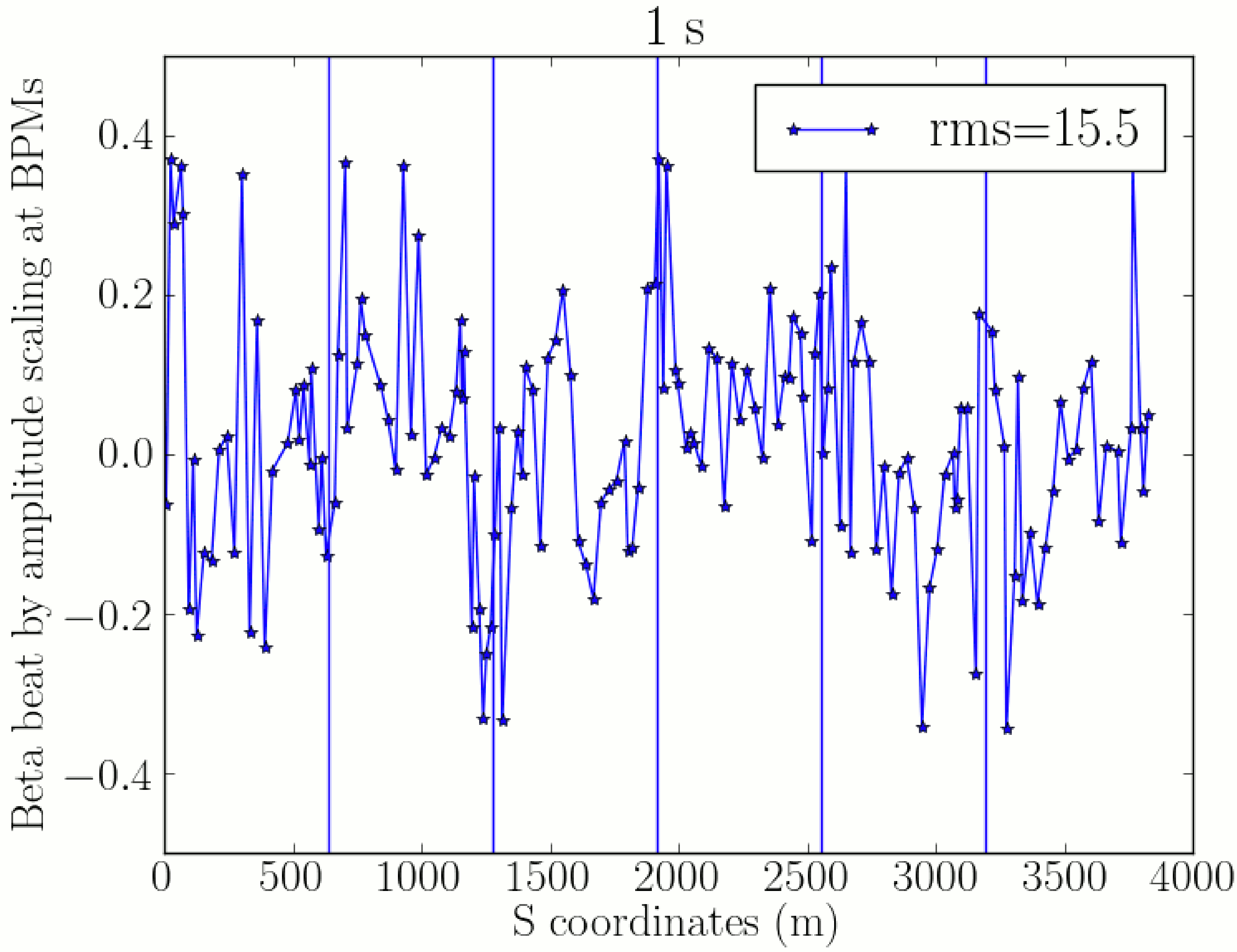
Analysis

- Time domain fitting.
- Frequency analysis, interpolated FFT or numerical analysis of the fundamental frequency (NAFF)
- Statistical methods (Principle Component Analysis, Independent Component Analysis)

Interpolated FFT

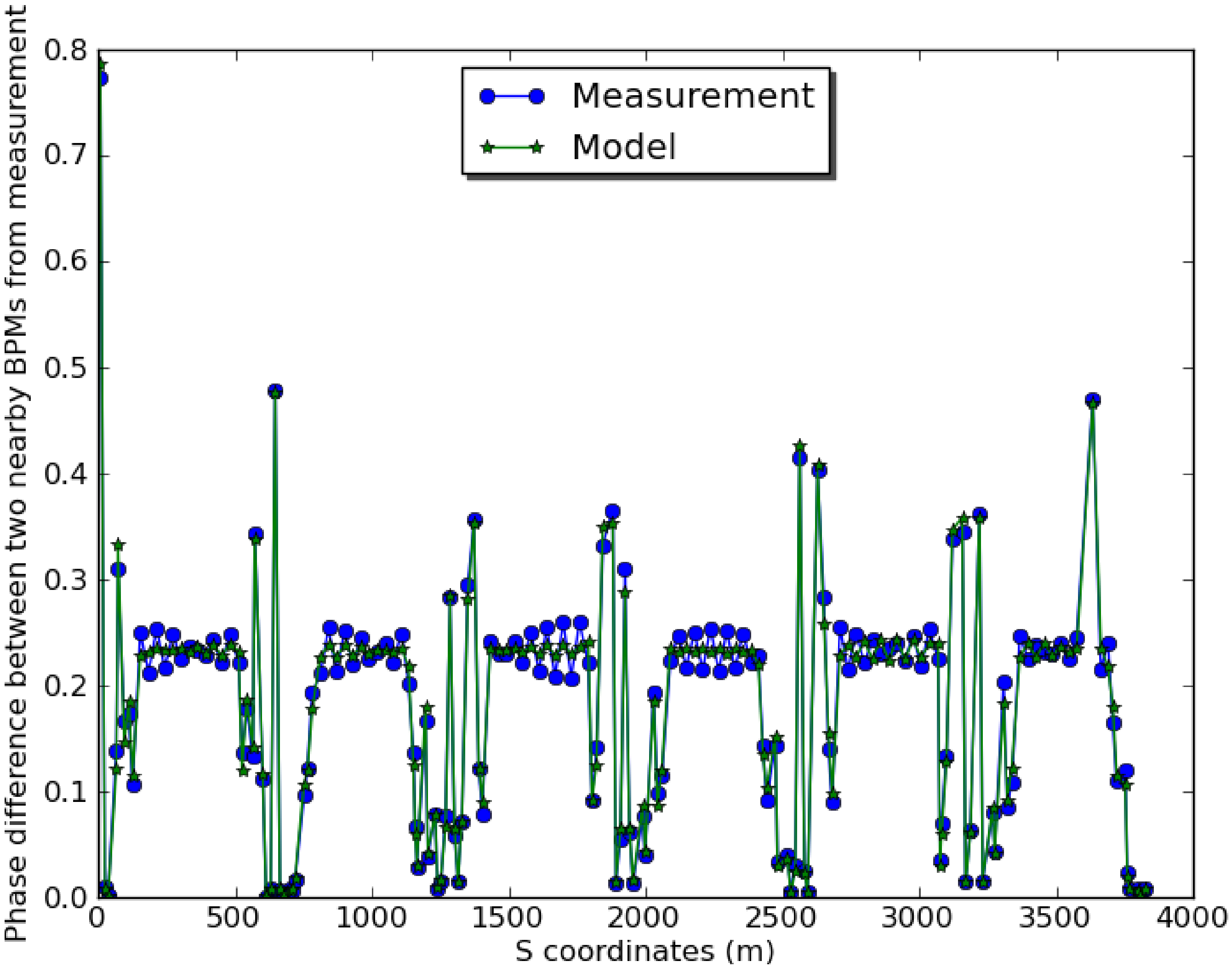


Beta-beat

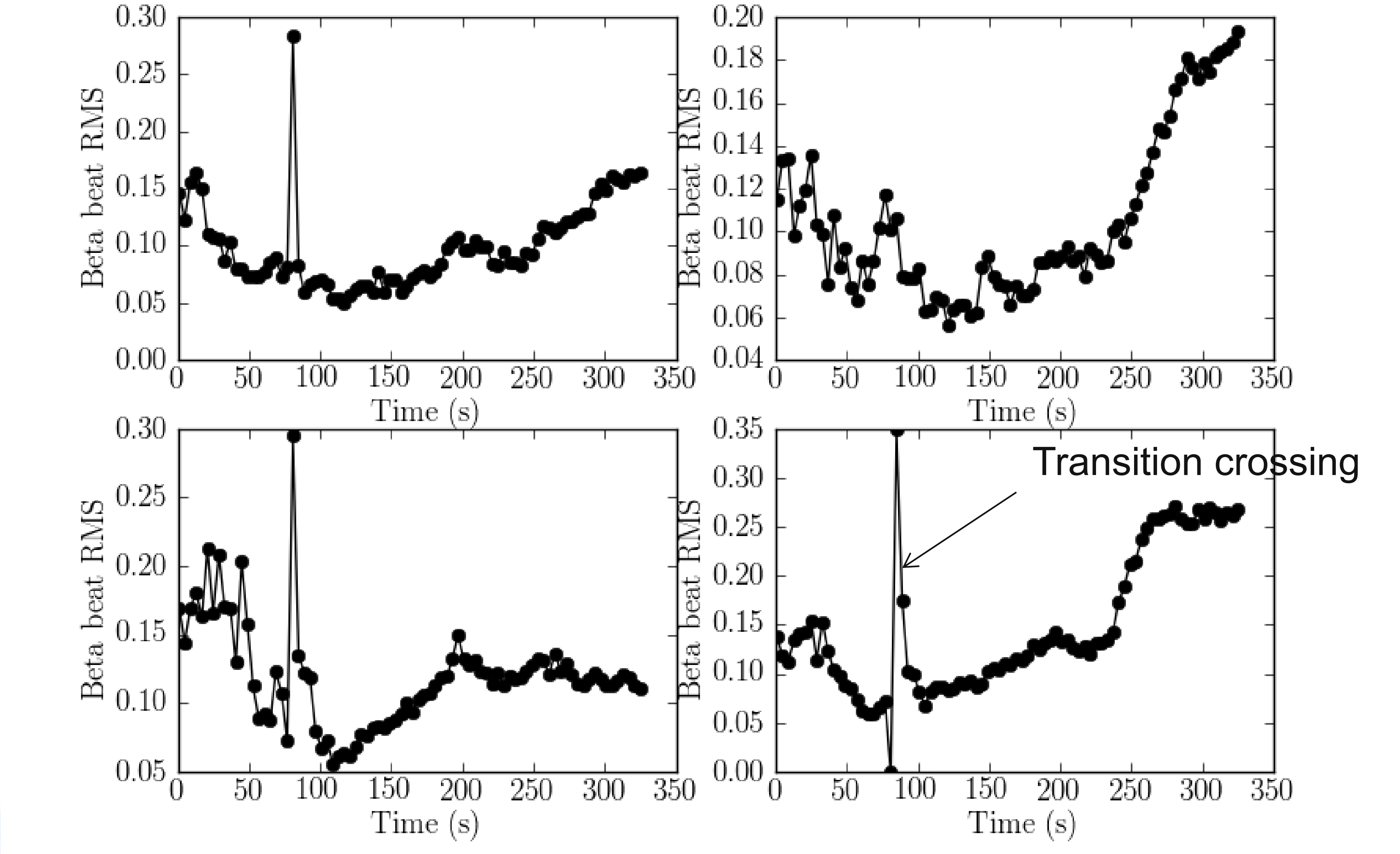


1 s
rms=15.5
Beta beat by amplitude scaling at BPMs
S coordinates (m)
0.4
0.2
0.0
−0.2
−0.4
0
500
1000
1500
2000
2500
3000
3500
4000

Phase advances

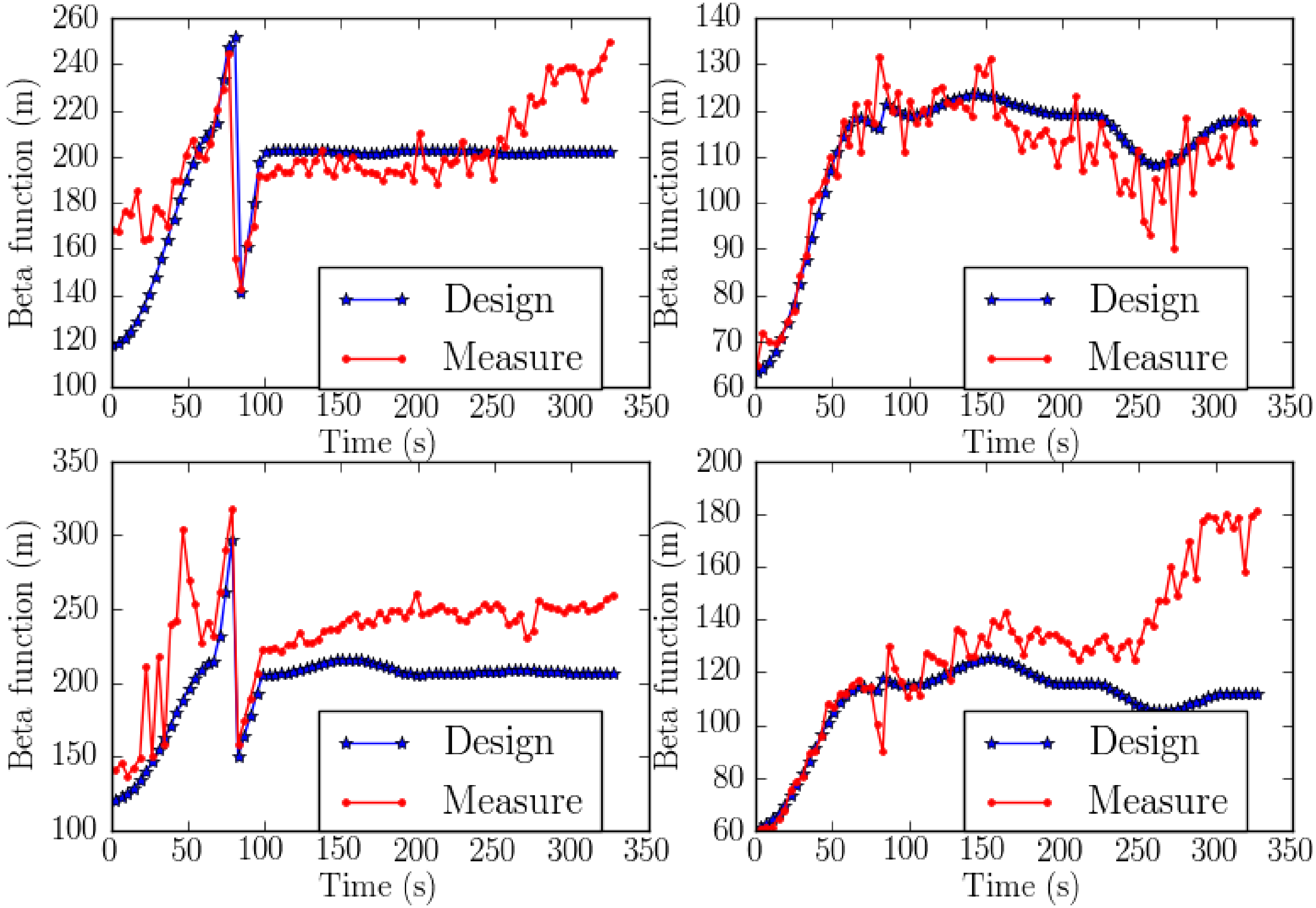


Beta-beat during acceleration



Betas @IPM during acceleration

Optical functions only measured at BPMs. Optical functions at locations of interest, for example, beta functions at ionization profile monitors (IPMs), phase advance at electron lens can be interpolated.

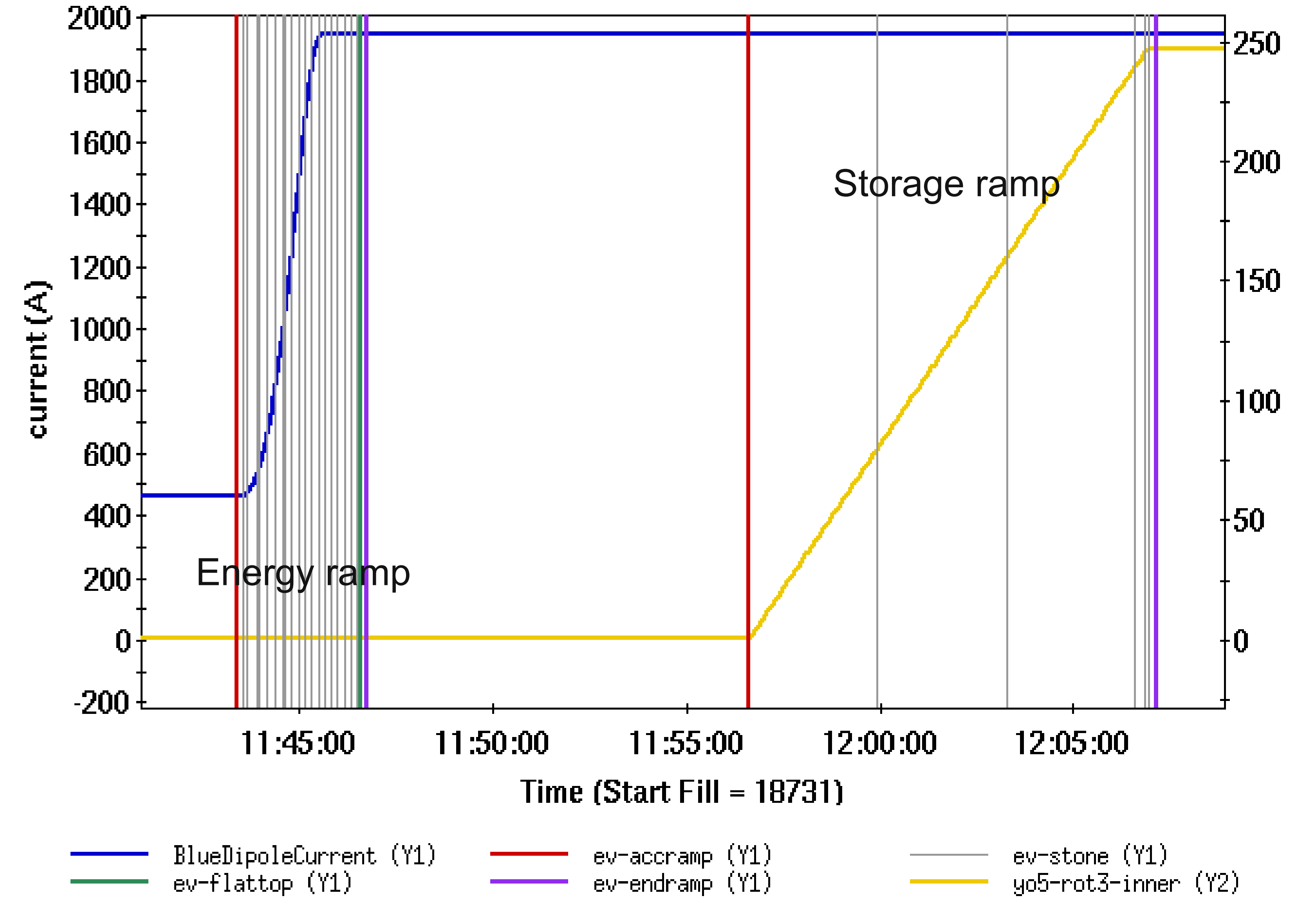


Challenges of ROC

- The ramping of the magnet power supplies can not be stopped and tuned.

- A large volume of corrections (typically 72 quadrupole power supplies at over 20 different times during the energy ramp), so requiring a time-efficient implementation method.

- The consequences of the optics correction, such as change of tunes and chromaticities must be predicted and simultaneously compensated for.

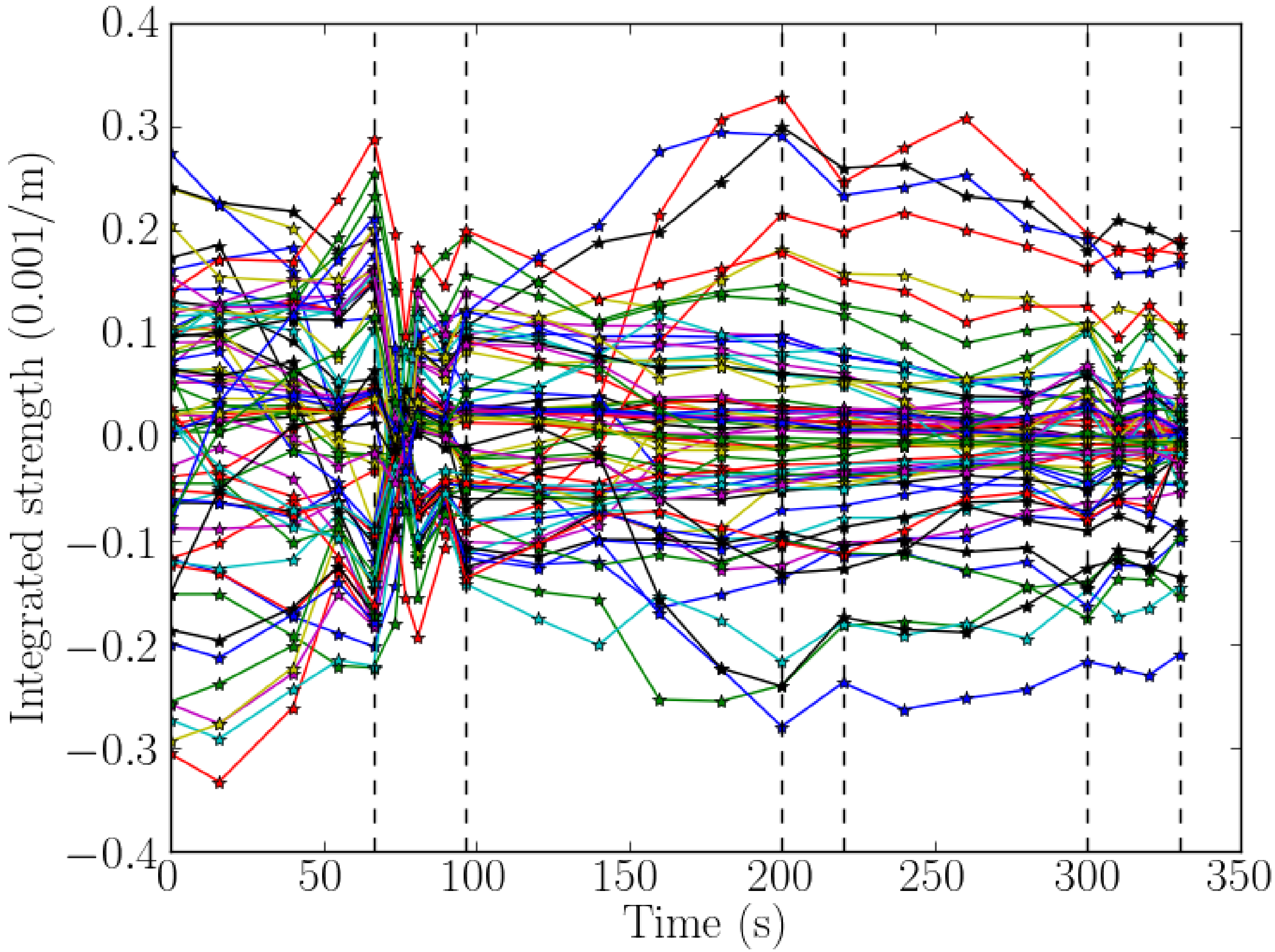


2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
current (A)
250
200
150
100
50
0
Storage ramp
Energy ramp
11:45:00
11:50:00
11:55:00
12:00:00
12:05:00
Time (Start Fill = 18731)
BlueDipoleCurrent (Y1)
ev-accramp (Y1)
ev-stone (Y1)
ev-flattop (Y1)
ev-endramp (Y1)
yo5-rot3-inner (Y2)

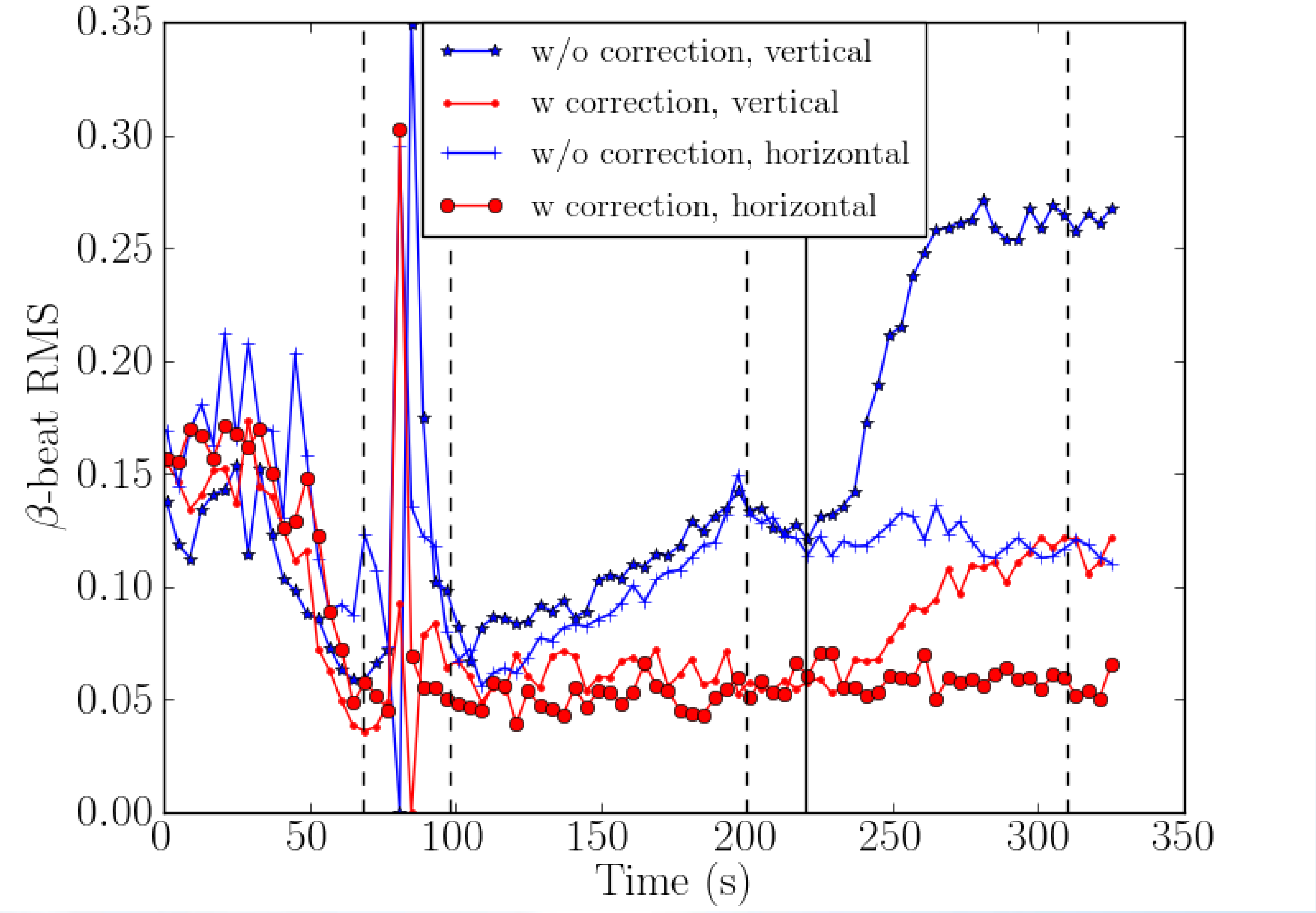
ROC during energy ramp

- There are ~20 intermediate points.
- The current curves for the magnet power supplies would change dramatically.
- With the corrections being applied, it caused the power supplies to exceed their limits.

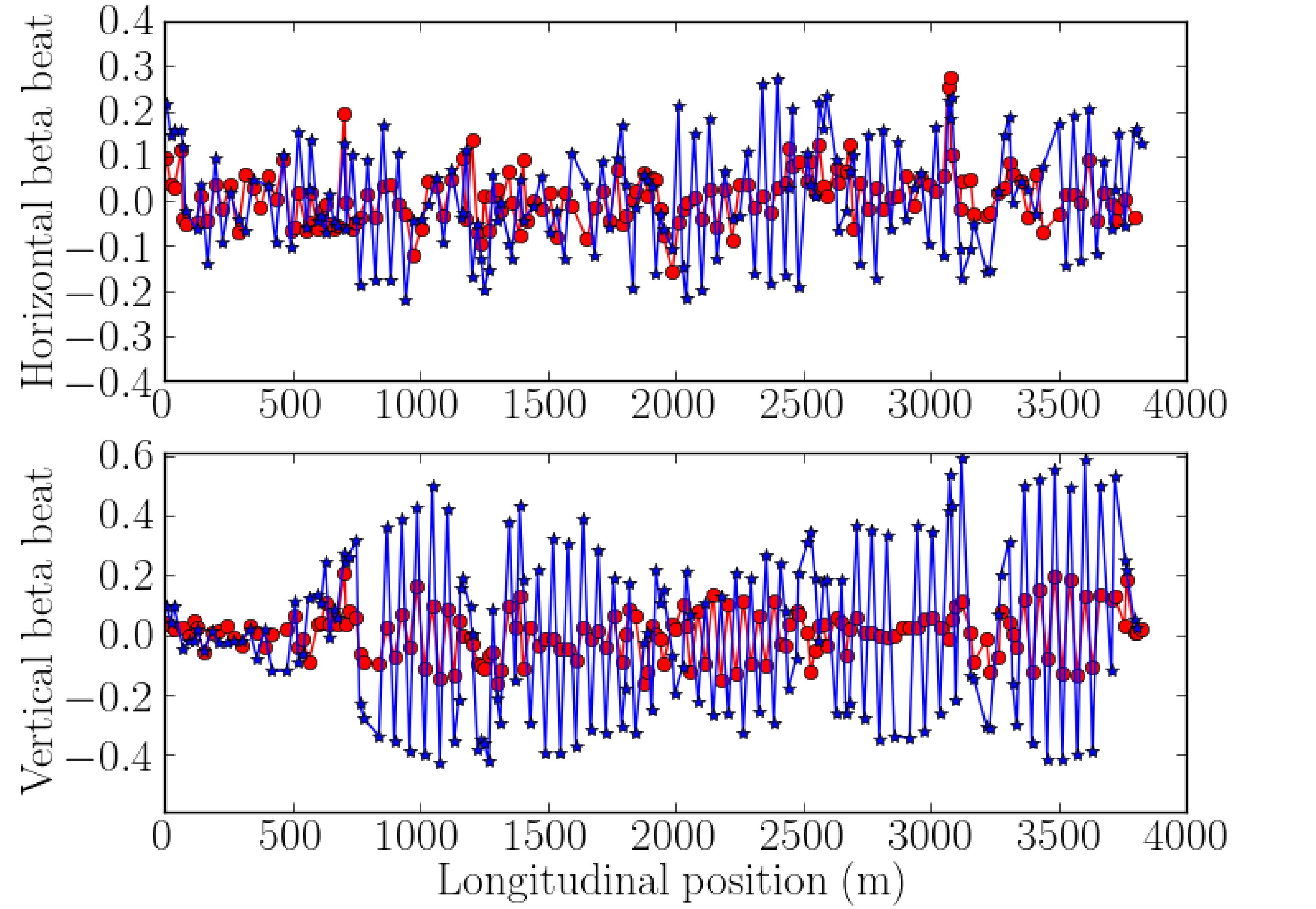
The corrections were applied for six intermediate points, the strengths were linearly interpolated in-between.



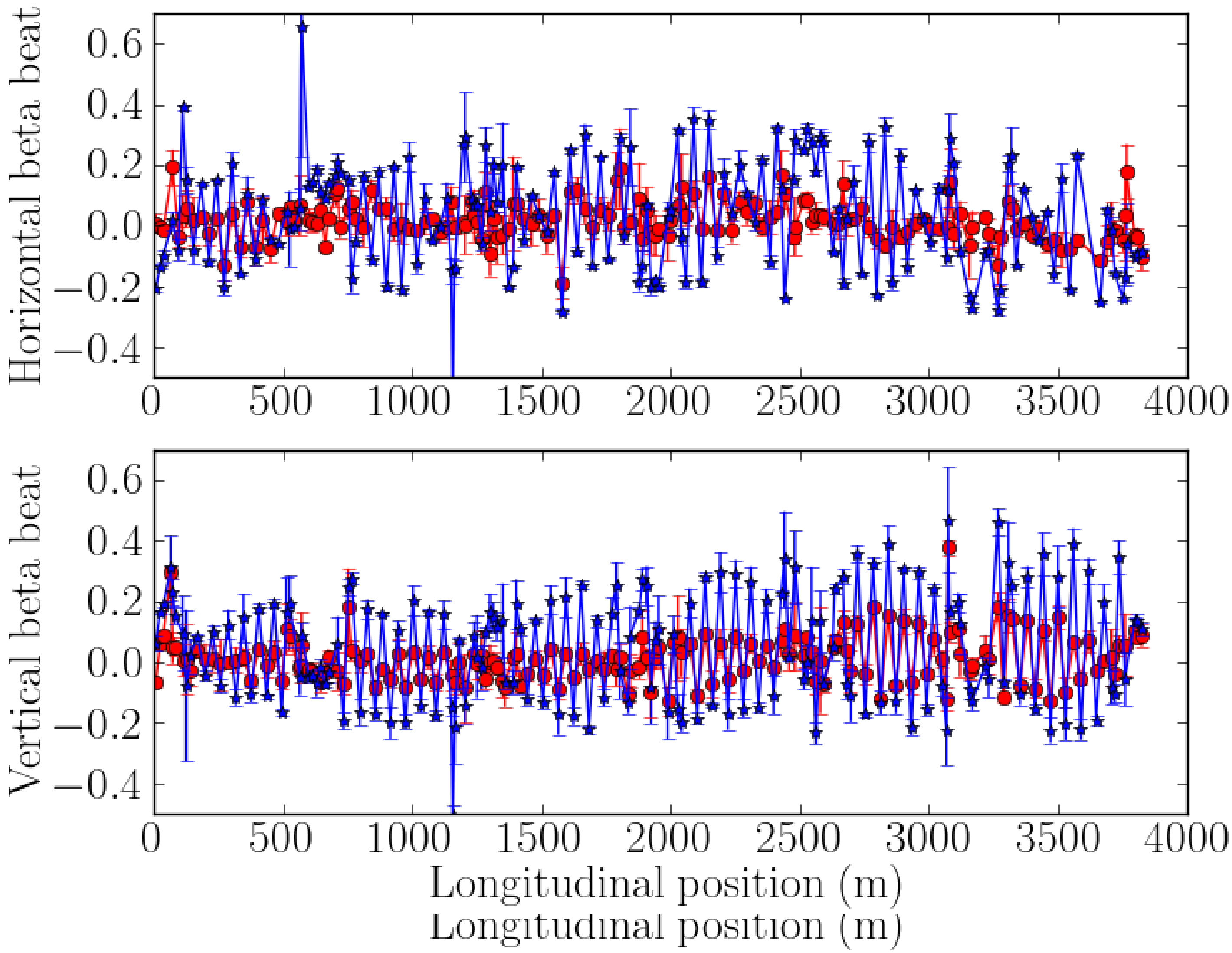
Beta-beat with ROC



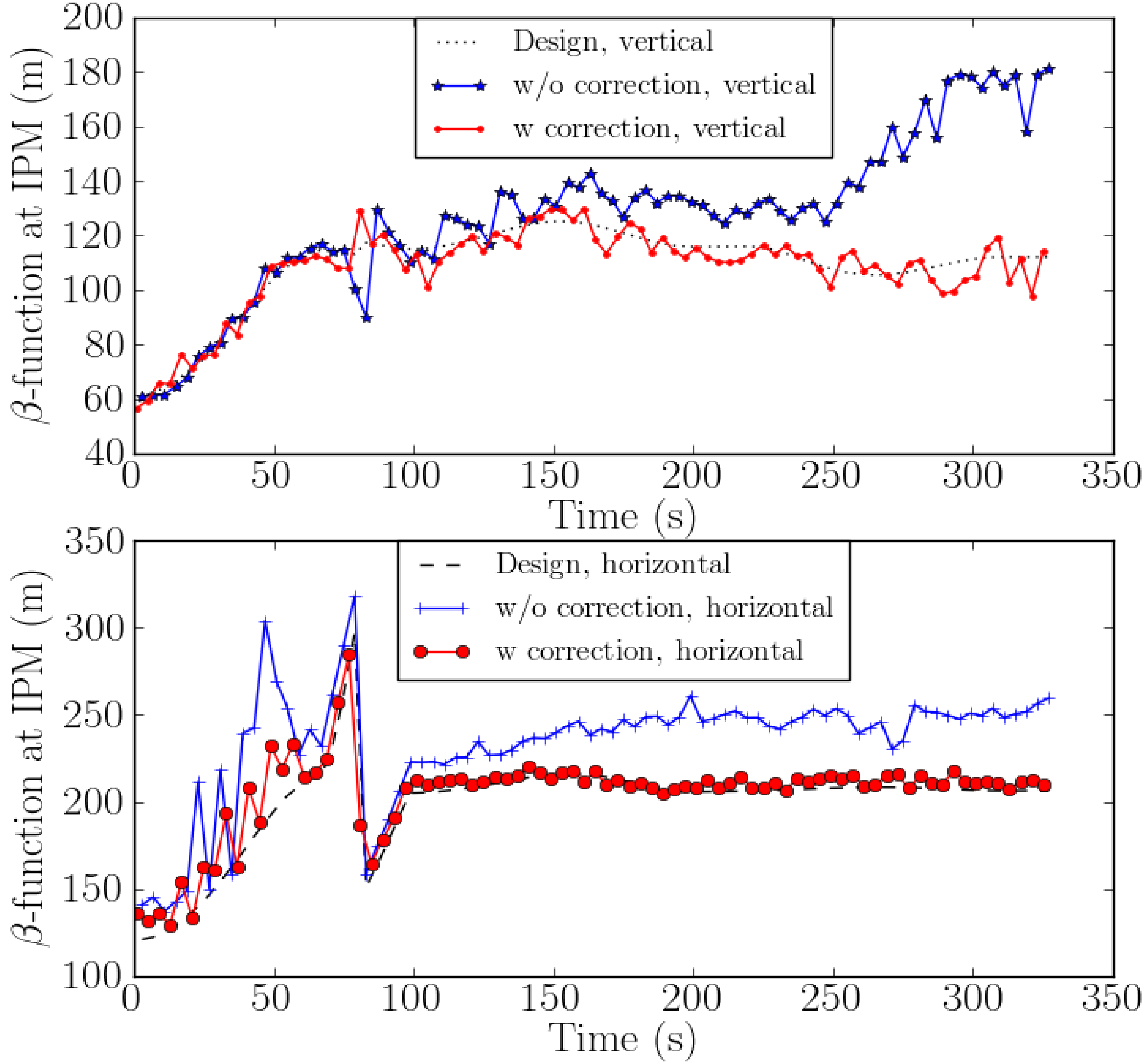
Beta-beat @ 260 s



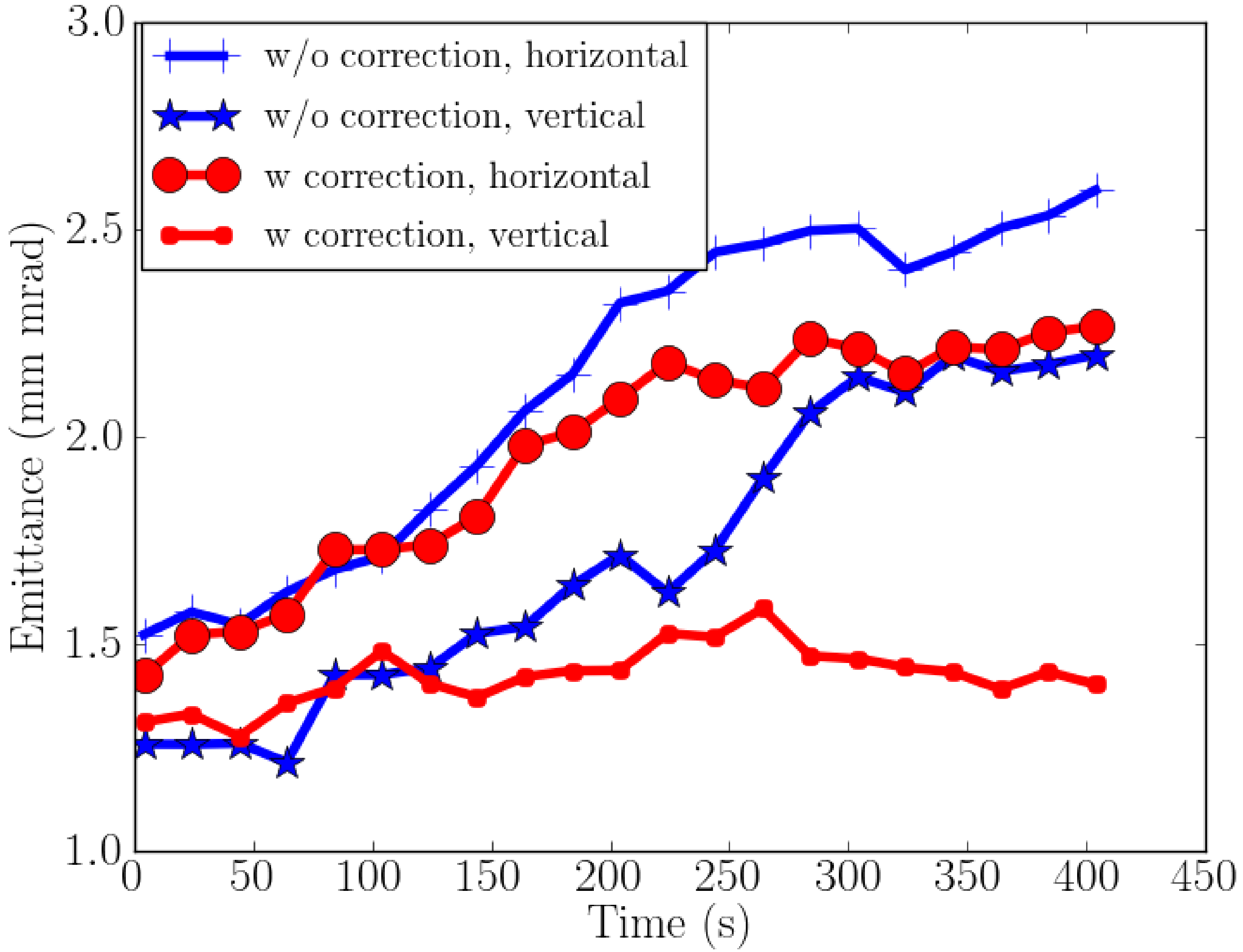
Beta-beat @ 260 s



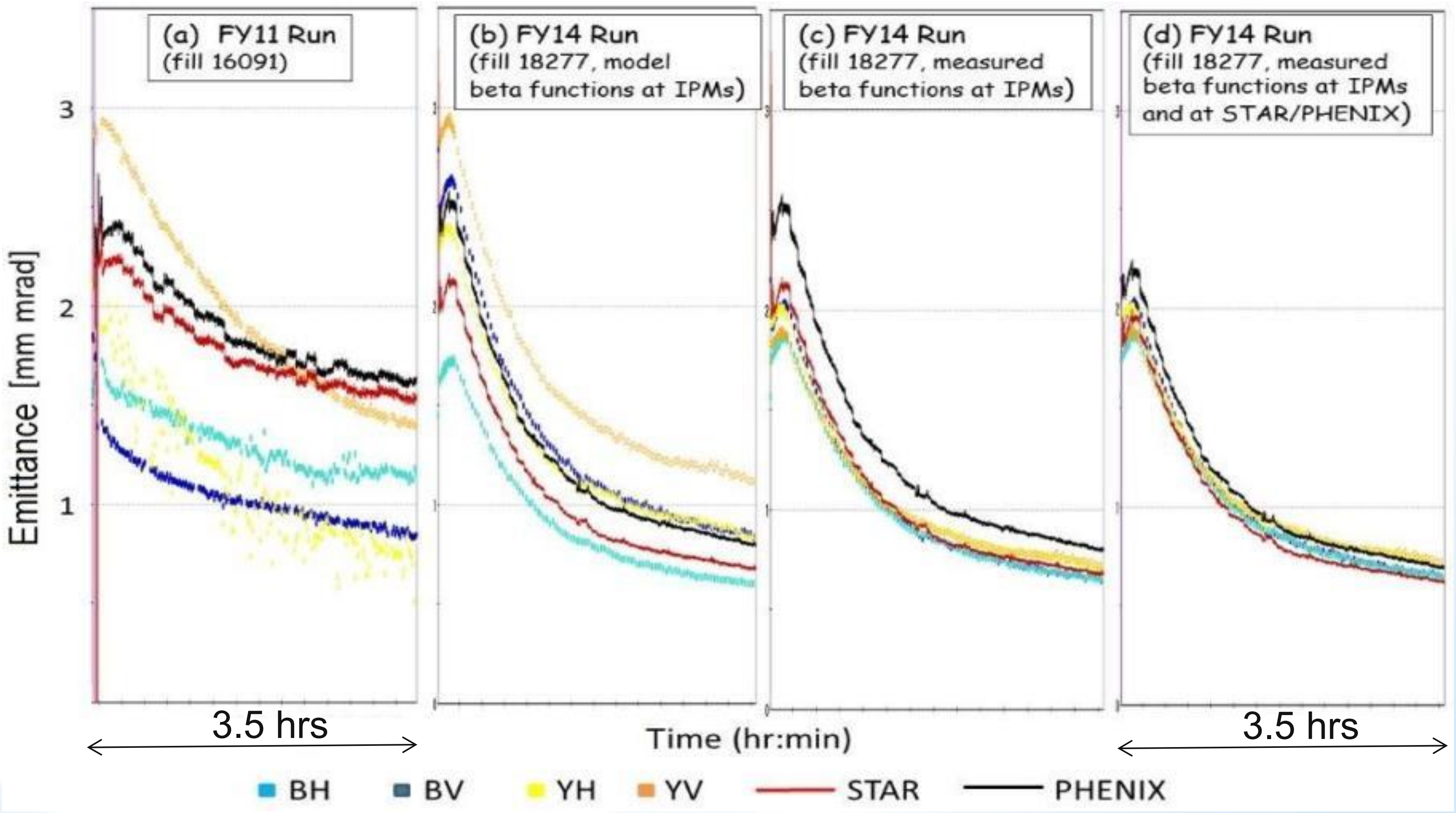
Beta @IPM with ROC



Emittances by IPM with ROC



Comparison of emittances



For the first time in RHIC, emittances reported by various devices agreed with each other.

Summary

- The optics measurement and correction during beam acceleration with beta-squeeze was demonstrated for the first time.
- The measurement results were used to determine gradient errors and corrections, interpolate the measured optical functions to intermediate locations (e.g. at IPMs and other devices), identify abnormalities in the ramp (for example, non-physical changes in emittance on the ramp), and facilitate the tuning of the acceleration ramp.
- The optics correction during beam acceleration was implemented for operation.
- The error in reported emittance by the IPMs due to use of imperfect model β-functions were significantly reduced with the corrected optics.

Future plans

- Steps for improved emittance measurement during acceleration: with optics measurement/correction, re-measure optics to interpolate beta functions at emittance monitors.

- Measurement of the optics during acceleration will be used to validate modification to the magnetic optics as applied to reduce the strength of depolarizing resonances for higher polarization transmission efficiency in future high energy polarized proton runs at RHIC.