Developments in Optics Measurement and Correction

C. Liu

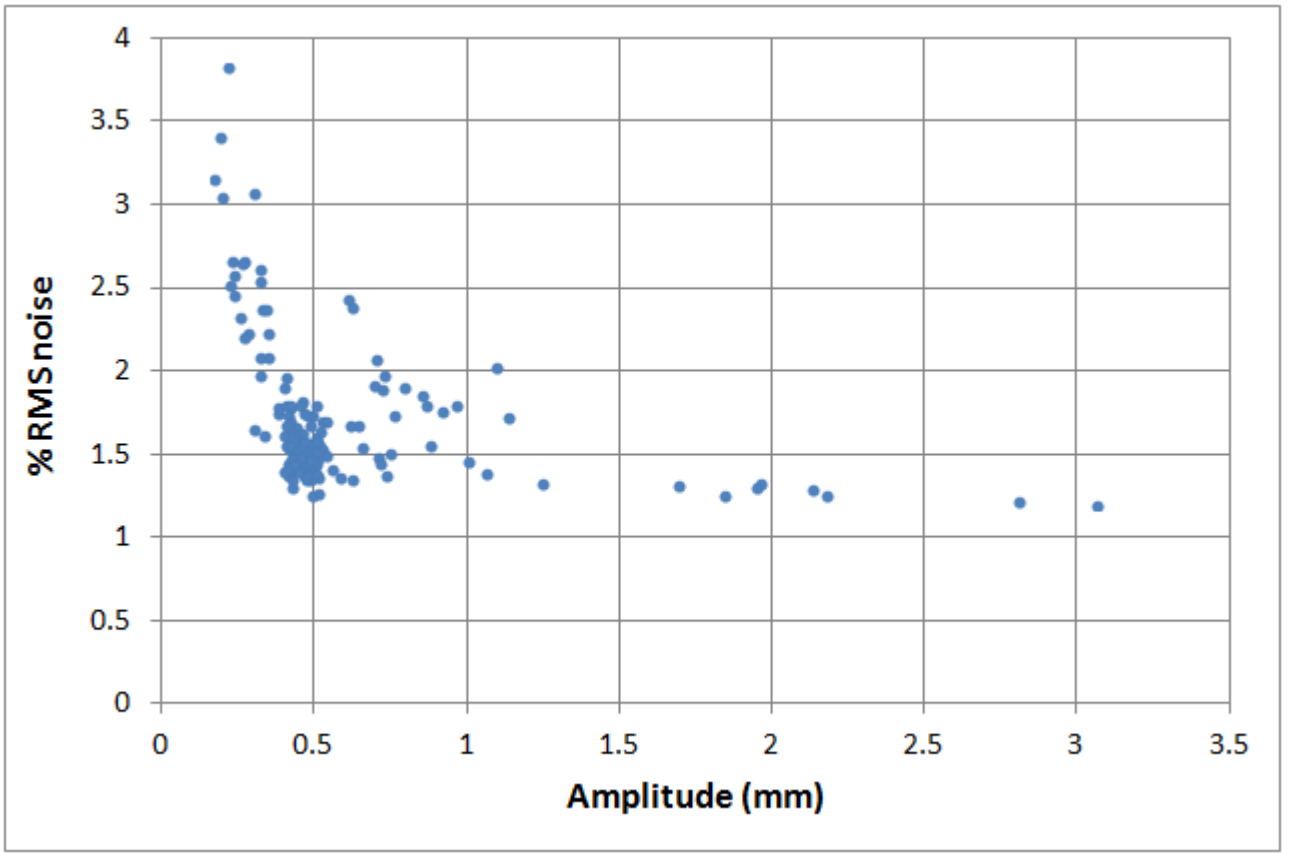
Jul. 25th, 2013

Outline

1. BPM data quality
2. Optics measurement
3. Optics correction
4. Ramp optics measurement
5. Ramp optics correction
6. Summary

BPM data quality

SNR of TBT BPM data



Courtesy by P. Thieberger

SNR < 2% for turn-by-turn BPM data with 1 mm oscillation amplitude,
the reported number for CERN SPS is ~10%.

BPM TBT Improvements

- 2009 - 2011
  - Time stamp and Interrupt Bugs Fixed
  - Firewire Optimization and Staggering of Data

- 2012 - 2013
  - Rewrite of ADC Interrupt Handler to Improve Timing
    - Verified that no turns are skipped due to CPU latency
  - 2K and 4K Turn Options Added
    - Verified again that no turns are missed during data acquisition

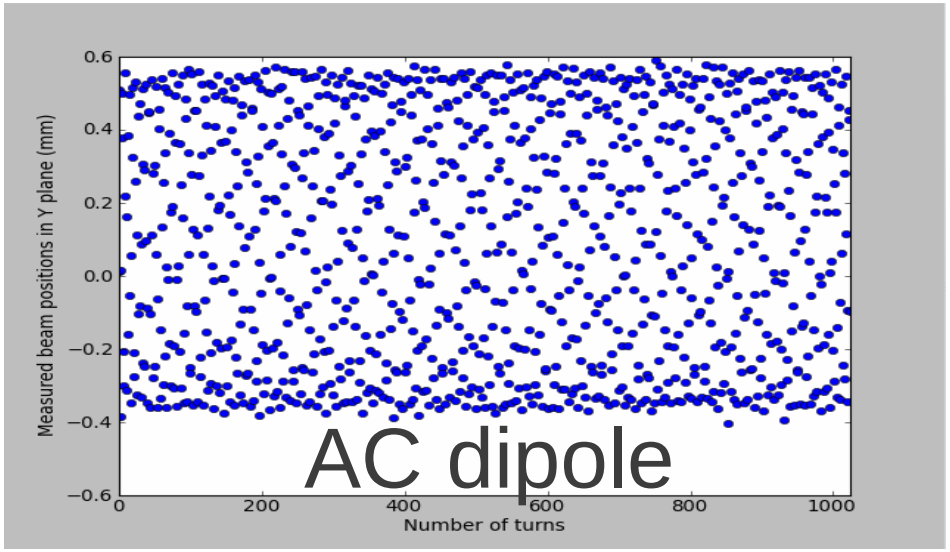
By R. Hulsart, R. Michnoff

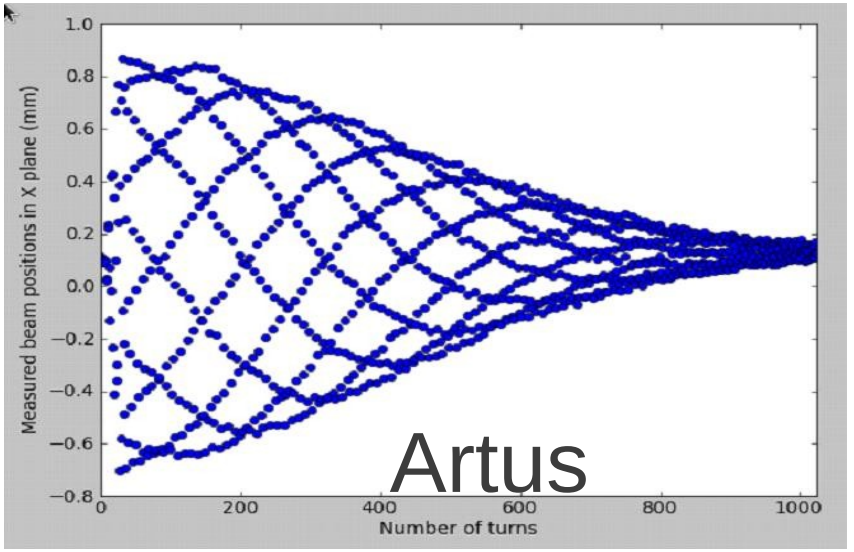
Optics measurements

Measurement techniques

– Data taking

- AC dipole, sustained driven oscillation
- Artus, free oscillation
- Injection oscillation





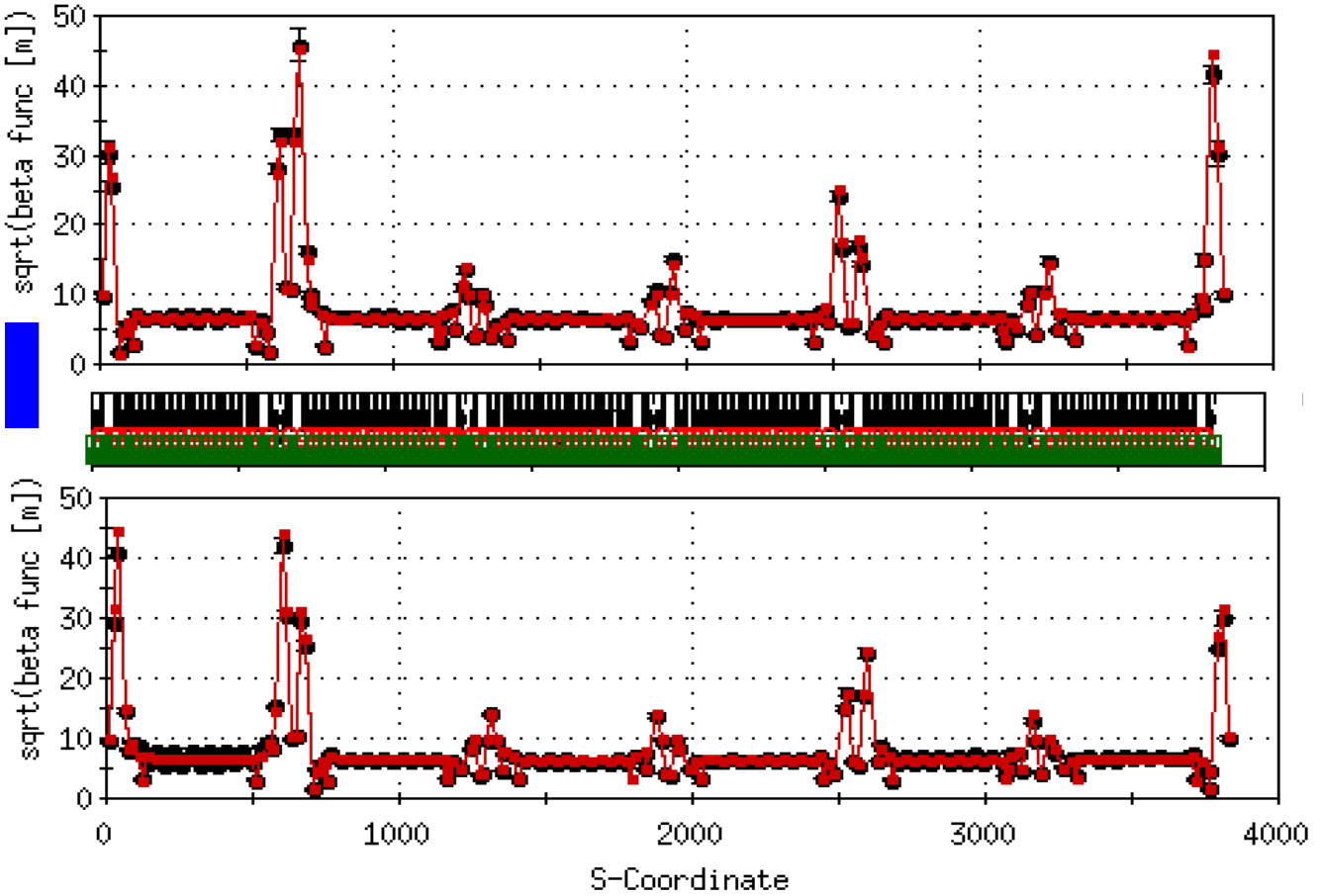
Measurement techniques

– Data analysis

- 1. Fitting in time domain, M. Bai (Loptics), P. Thieberger/A. Marusic (tbtOpticsAnalysis)
- 2. Interpolated FFT in frequency domain, C. Liu (tbtOpticsAnalysis)
- 3. ICA (Independent Component Analysis), X. Shen

Measurement results

--from AC dipole



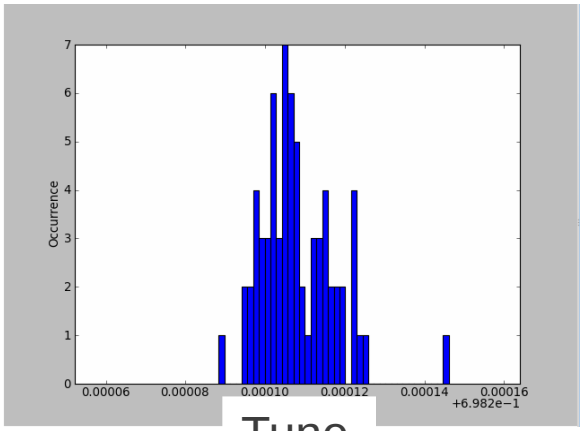
	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	2.23	6.05	0.68	0.58	6.82	6.01
H_bIP	2.26	6.06	0.68	0.59	6.95	6.04
H_s*	-0.26	-0.20	-0.02	0.08	-0.92	0.40

	IP2	IP4	IP6	IP8	IP10	IP12
V_b*	2.03	7.22	0.69	0.67	7.08	7.08
V_bIP	2.17	7.30	0.92	0.88	7.10	7.11
V_s*	0.53	0.78	0.39	0.37	-0.29	0.48

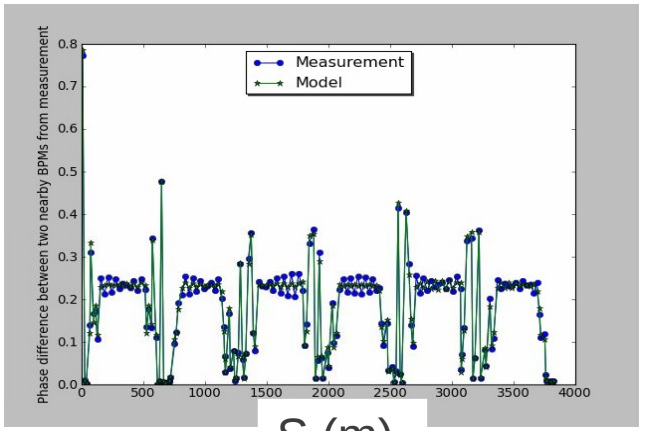
By AC dipole optics team

Measurement results

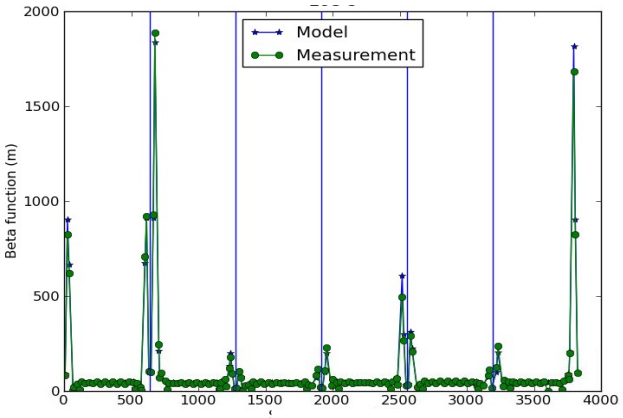
– from Artus data



Tune



S (m)



S (m)

```
csh
Number of Good BPMs for tune measurement:
69
Tune Measurement Spread:
2.15832076093e-05
Averaged Fractional Tune:
0.686889592345
Tune Measurement Spread after filtering:
2.15832076093e-05
Measured phase between IP8 and e-lens center in Y: 156.7
Model phase between IP8 and e-lens center in Y: 148.35
Measured beta Y at STAR: 0.75
Model Beta Y at STAR: 0.63
Measured beta Y at PHENIX: 0.8
Model Beta Y at PHENIX: 0.64
Measured beta Y at IP2: 2.06
Model Beta Y at IP2: 2.08
Measured beta Y at BH IPM: 153.53
Model Beta Y at BH IPM: 147.29
Measured beta Y at BV IPM: 268.38
Model Beta Y at BV IPM: 249.86
Measured beta Y at B Schottky: 73.44
Model Beta Y at B Schottky: 66.92
Measured beta Y at B button BPM: 94.72
Model Beta Y at B button BPM: 86.75
Measured beta Y at B CNI polar1: 16.94
Model Beta Y at B CNI polar1: 17.18
Measured beta Y at B CNI polar2: 17.88
Model Beta Y at B CNI polar2: 18.05
Measured beta Y at B BBQ kicker: 567.33
Model Beta Y at B BBQ kicker: 532.47
Measured beta Y at B BBQ pickup: 504.47
Model Beta Y at B BBQ pickup: 472.96
BPMs with exceptional high beta beat: []
Number of good bpms: 165
Number of bpms in beta beat plot: 165
acnuser01.pbn.bnl.gov 101:
acnuser01.pbn.bnl.gov 101:
acnuser01.pbn.bnl.gov 101:
acnuser01.pbn.bnl.gov 101:
acnuser01.pbn.bnl.gov 101:
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1. Precision tune measurement, rms of the tune distribution of a single measurement is 1.3×10^{-5}, the rms of the tunes is 1.6×10^{-5} from multiple data sets acquired during 1 min

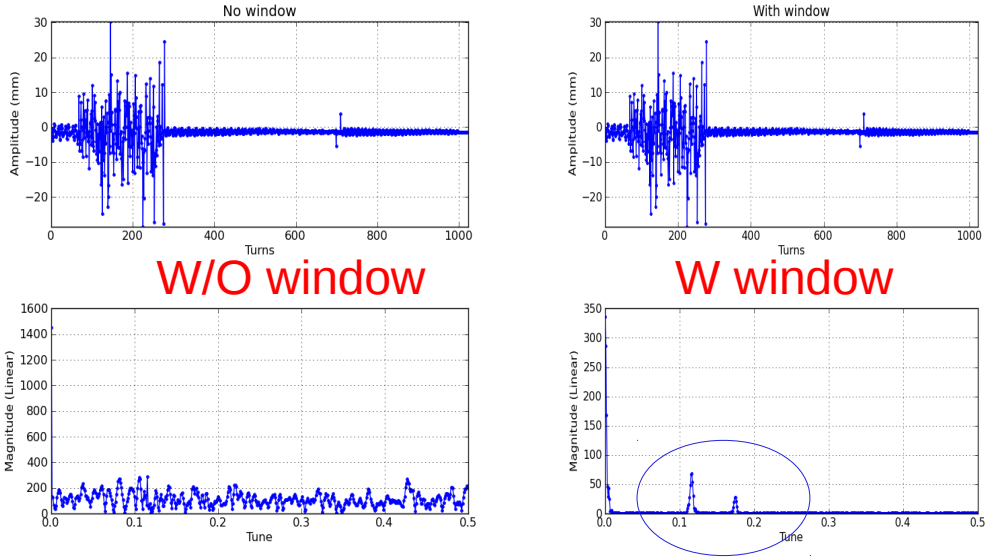
2. Precision phase measurement, the rms of phase measurement is ~0.2 deg

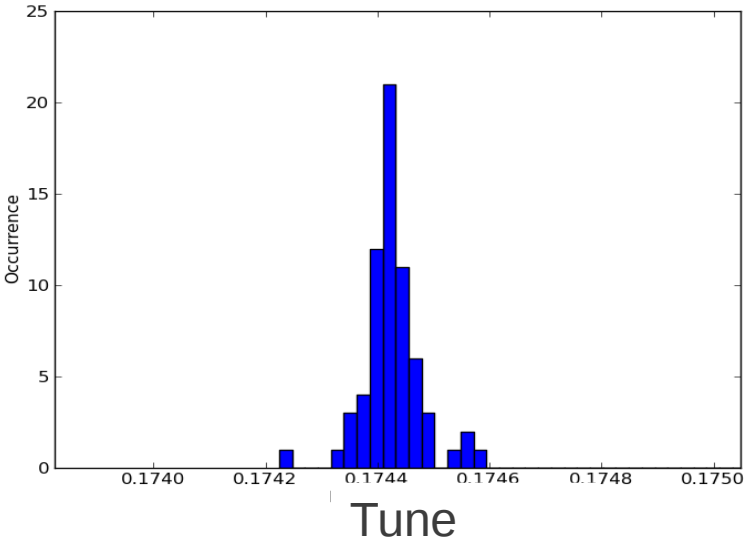
3. Option of less model dependent and amplitude scaling beta function measurement

4. Interpolation of phase between BPMs, phase advance between IPs and e-lens
5. Interpolation of beta function for STAR, PHENIX, IPMs, Schottky...

Optics measurement for low E run

– injection oscillation

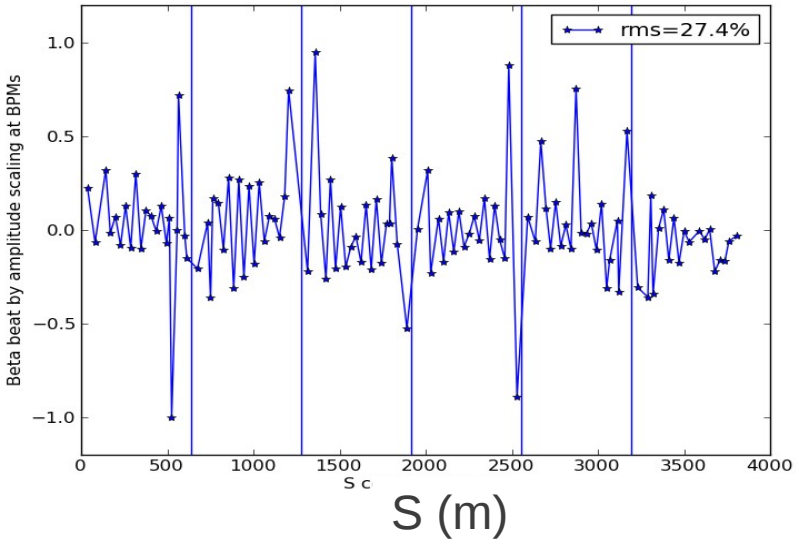




1. w/o window, the spectrum looks like pure noise; w Gaussian window, two peaks are visible due to residual coupling

2. Peaks for x/y are distinguished by tweaking one tune at a time in RampEidtor

3. Tune spread is ~10^{-4}, beta beat is ~20% (the outliers are excluded)



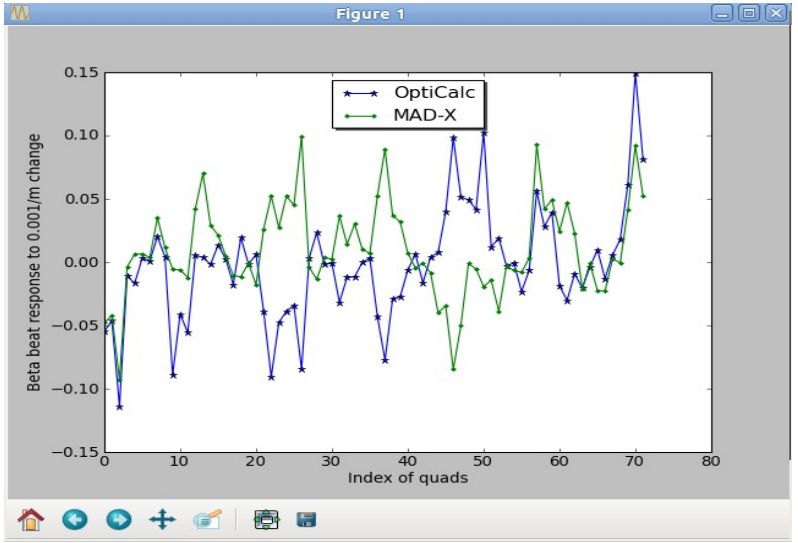
Optics correction

Correction technique

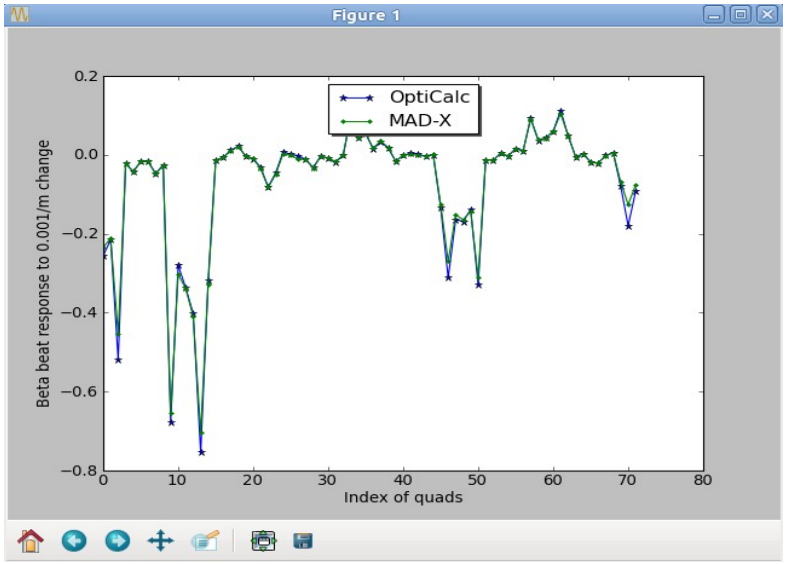
$$-\begin{pmatrix} \text{error} \end{pmatrix} = R \begin{pmatrix} \text{correction} \end{pmatrix}$$

$$\begin{pmatrix} \text{correction} \end{pmatrix} = \text{SVD}(R) - \begin{pmatrix} \text{error} \end{pmatrix}$$

1. The vector to be corrected in above can be phase error or beta beat, phase correction == beta correction?
2. Weighting can be applied in above to balance x/y correction; manipulation of eigenvalues can reduce excessive correction strength
3. Blue injection: No gammaT quads in model & machine; Yellow injection: GammaT quads not in model but machine; Snakes on at injection, but not in model for both rings
4. R calculated by OptiCalc and MAD-X are compared, huge differences are observed at injection; nice agreement for store



Injection, Yellow



Store, Yellow

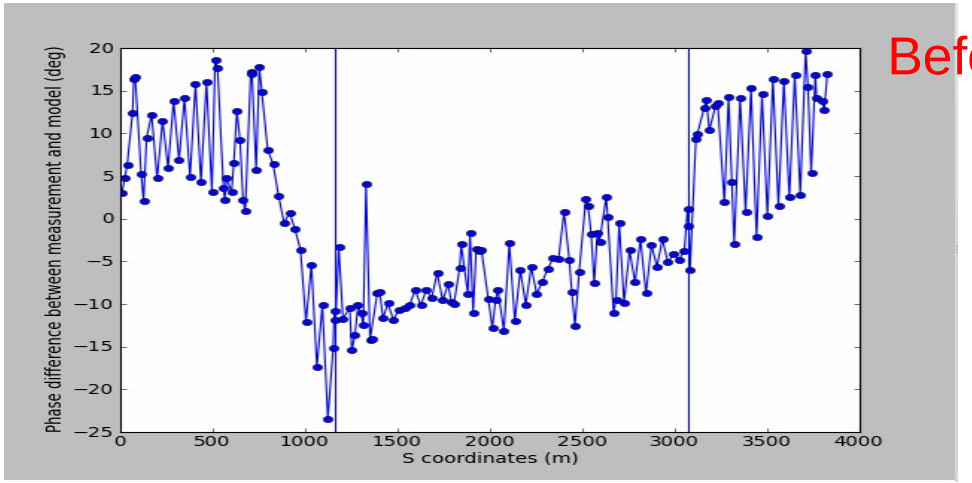
Phase beat correction

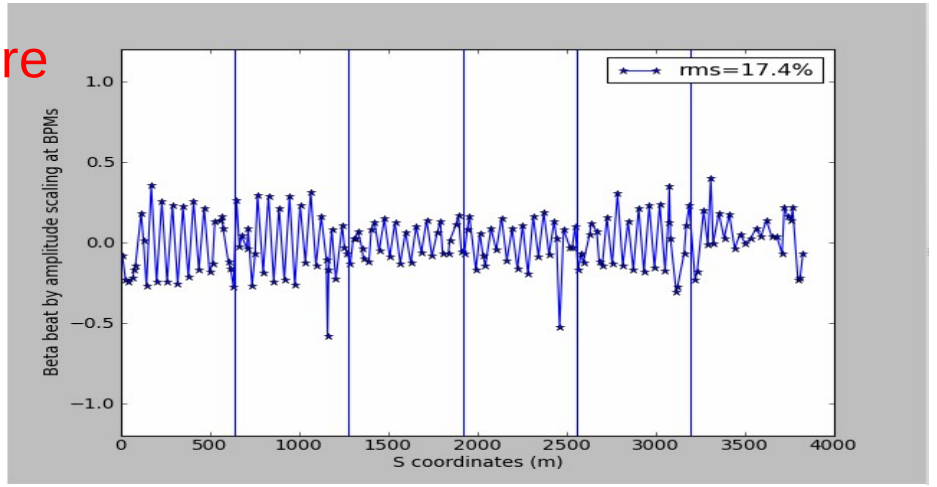
– with Artus

#02/26/13, blue ring at injection energy with pp13e-v4 (E-Lens) lattice

Phase error and beta beat:

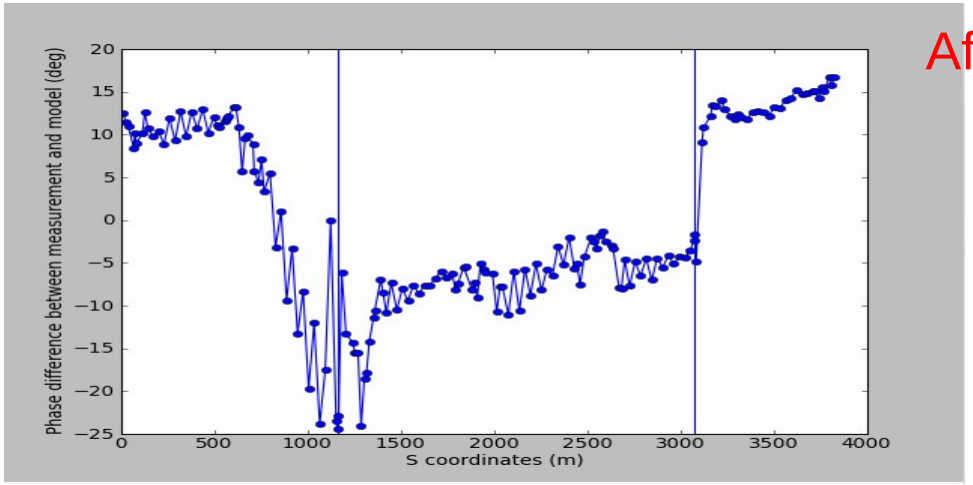
Before

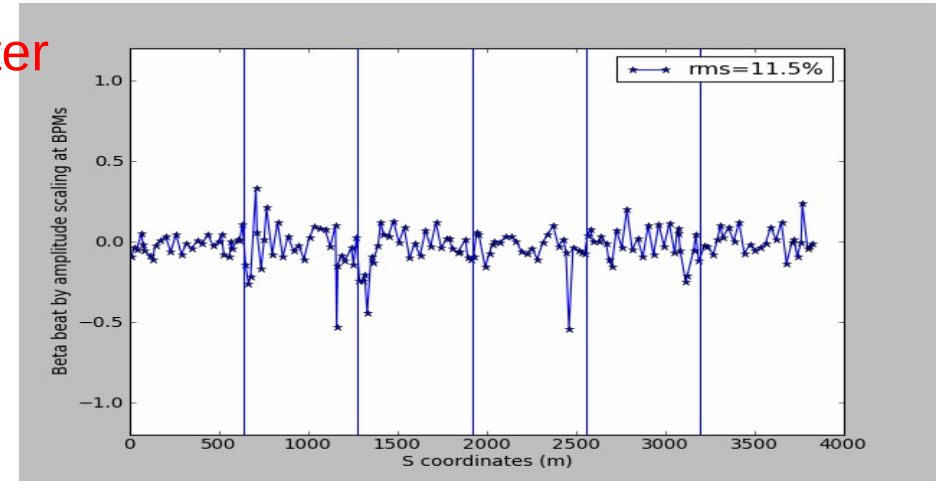




Phase error and beta beat:

After

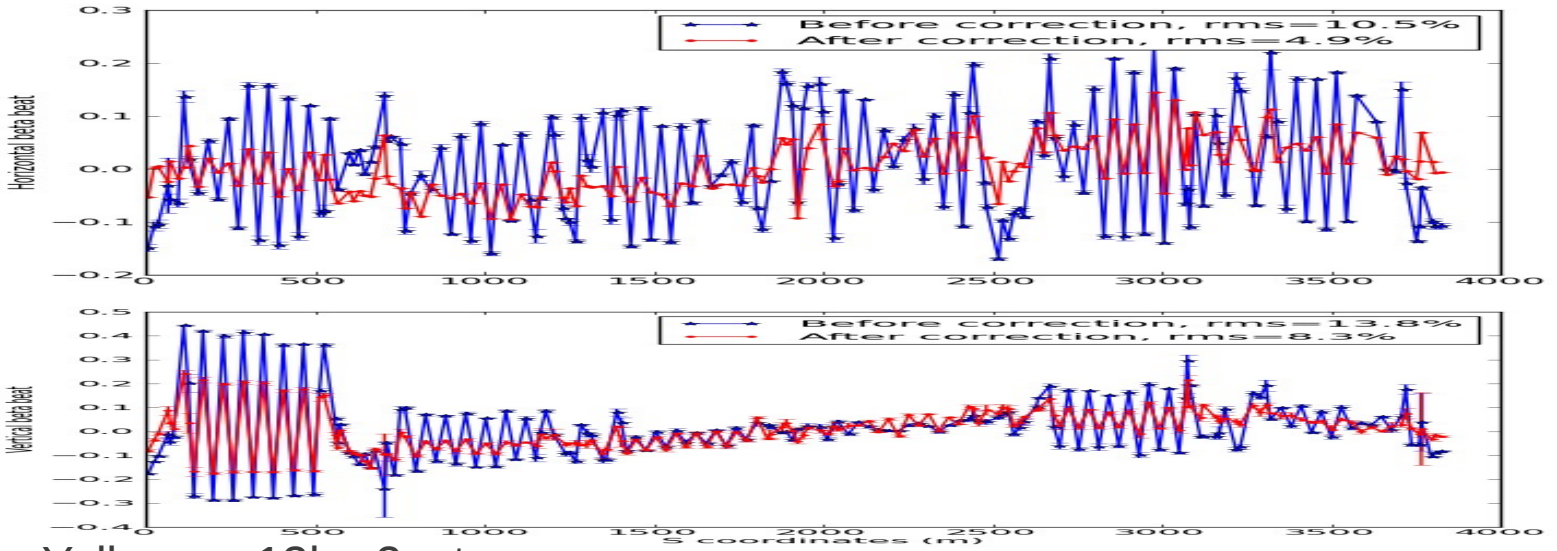




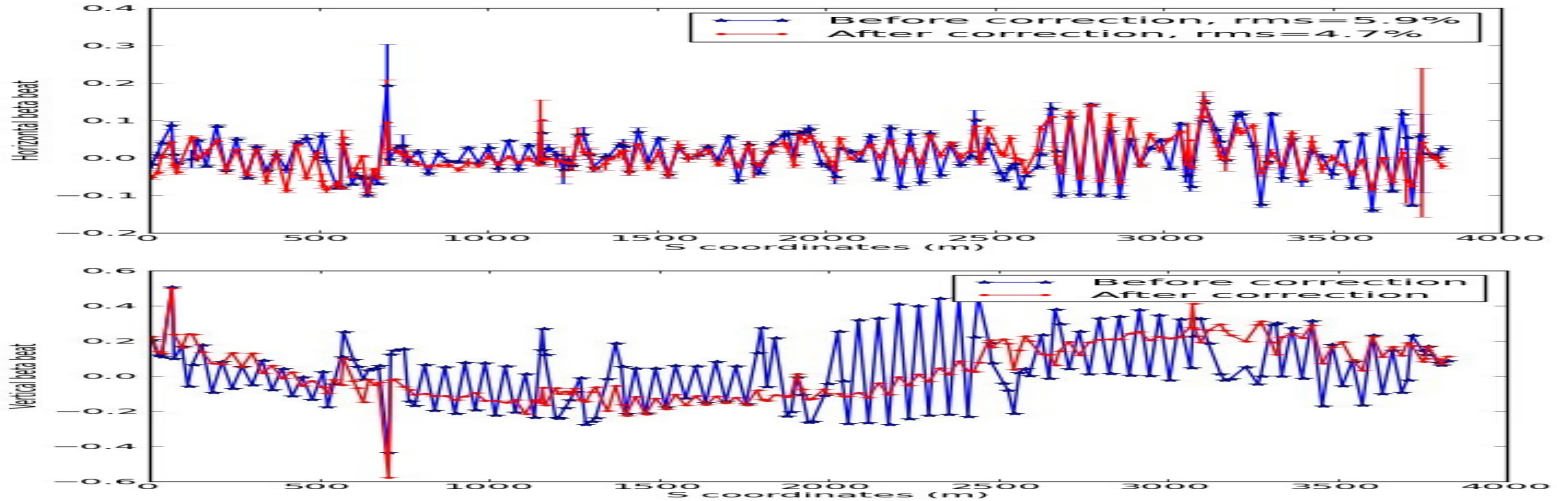
Beta beat correction

Blue, pp13b-v2, store

– with Artus



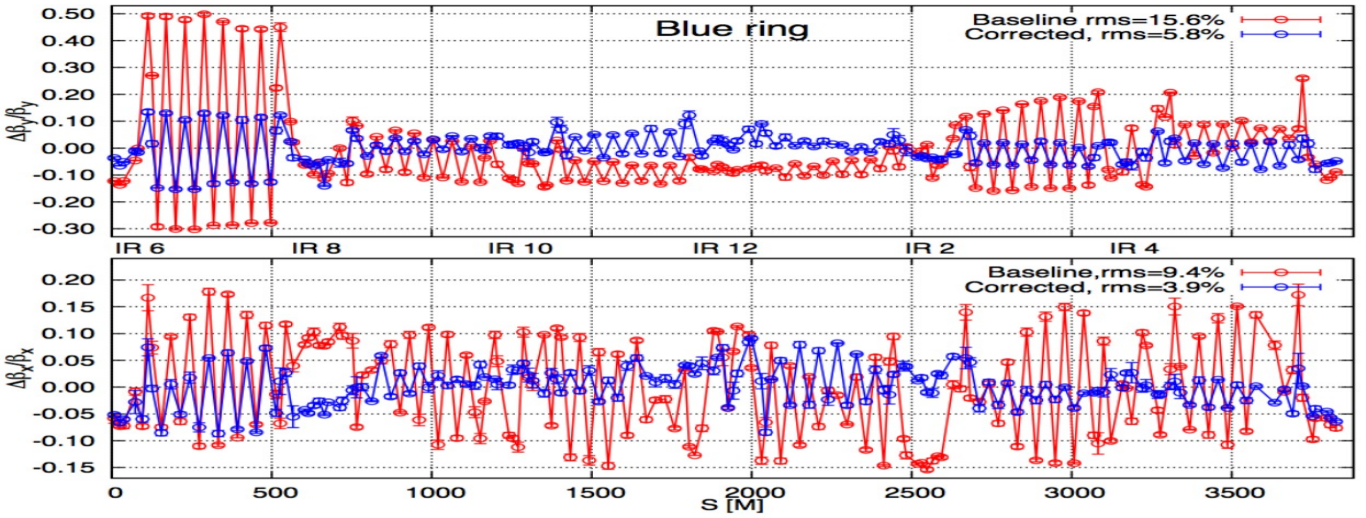
Yellow, pp13b-v2, store

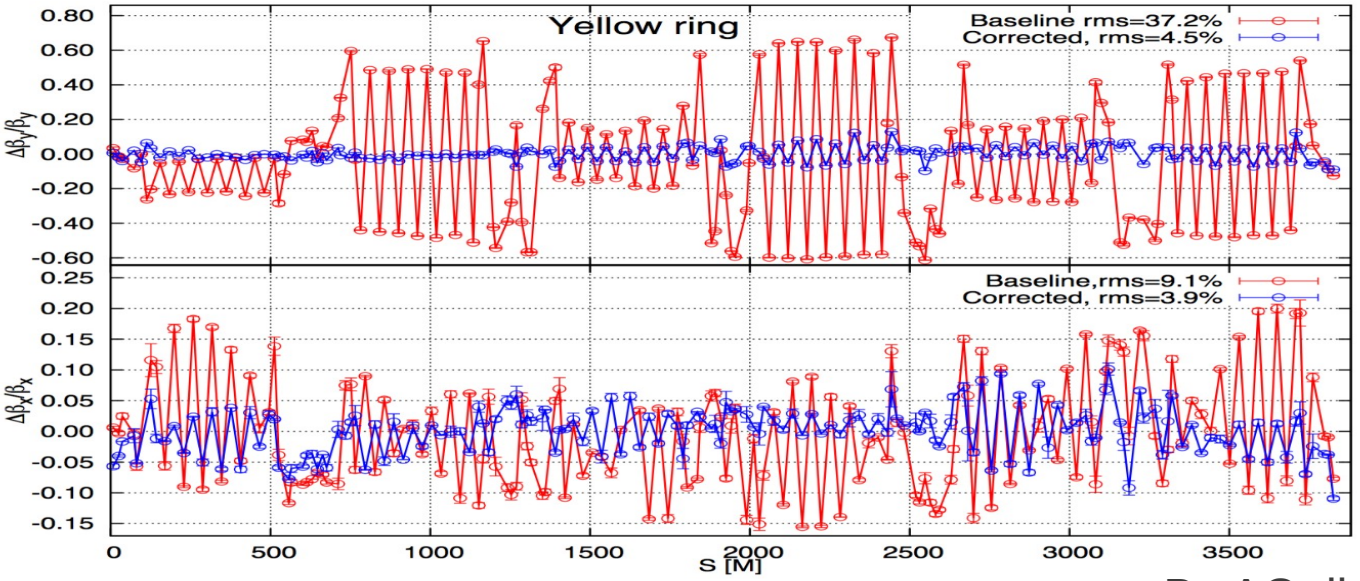


The beta beat was reduced significantly in both planes for both rings based on Artus turn-by-turn data despite the s-shapes due to coupling

Beta beat correction

– with AC Dipole

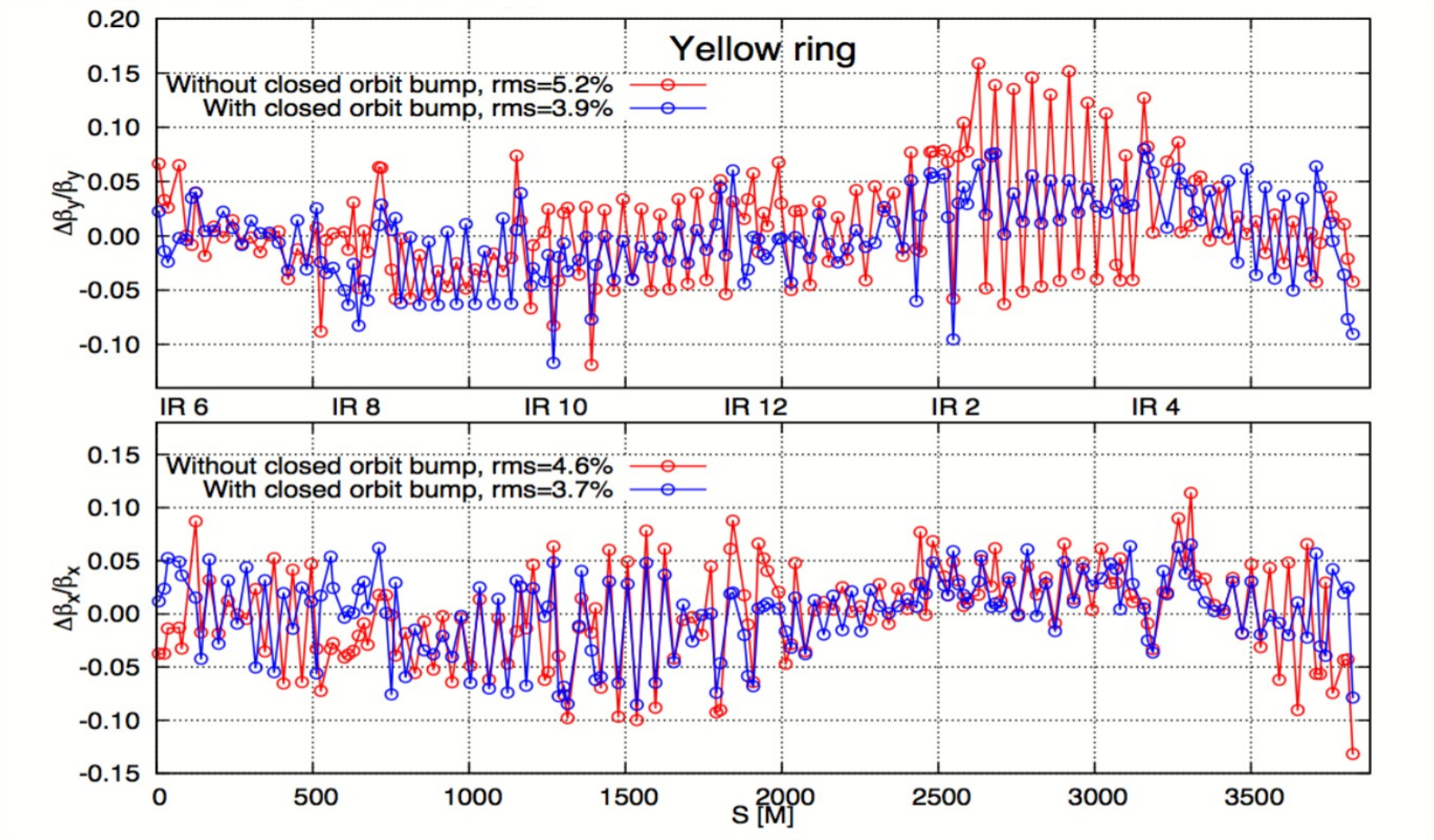




By AC dipole optics team

Beta beat correction

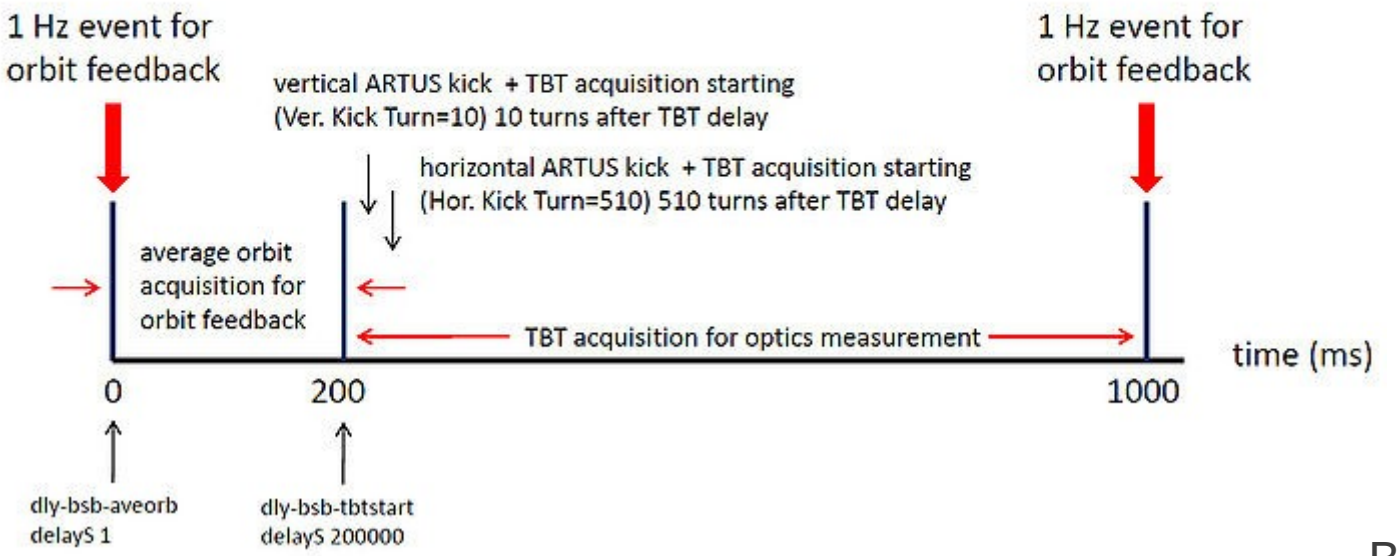
– global + orbit bump in sextupole



By AC dipole optics team

Ramp Optics Measurement

Measurement procedure



By M. Minty

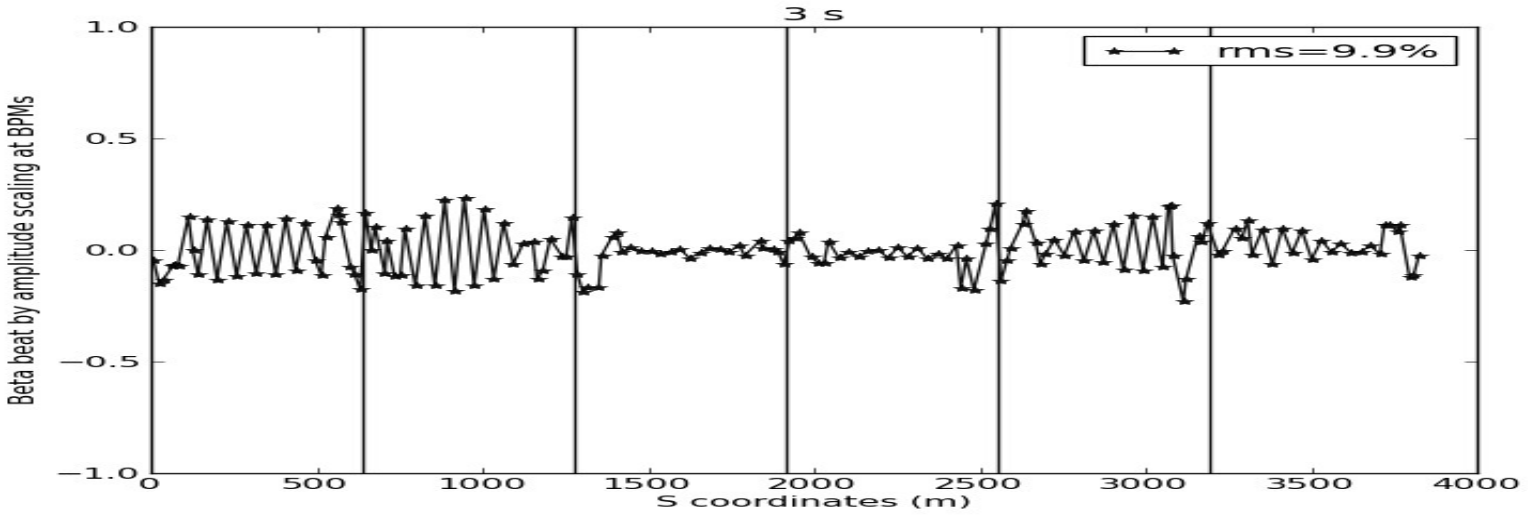
1. No interference of TBT data acquisition with average orbit acquisition for orbit feedback

2. Horizontal and vertical kick is 510 turns apart, cross-talk is marginal due to decoherence even with coupling

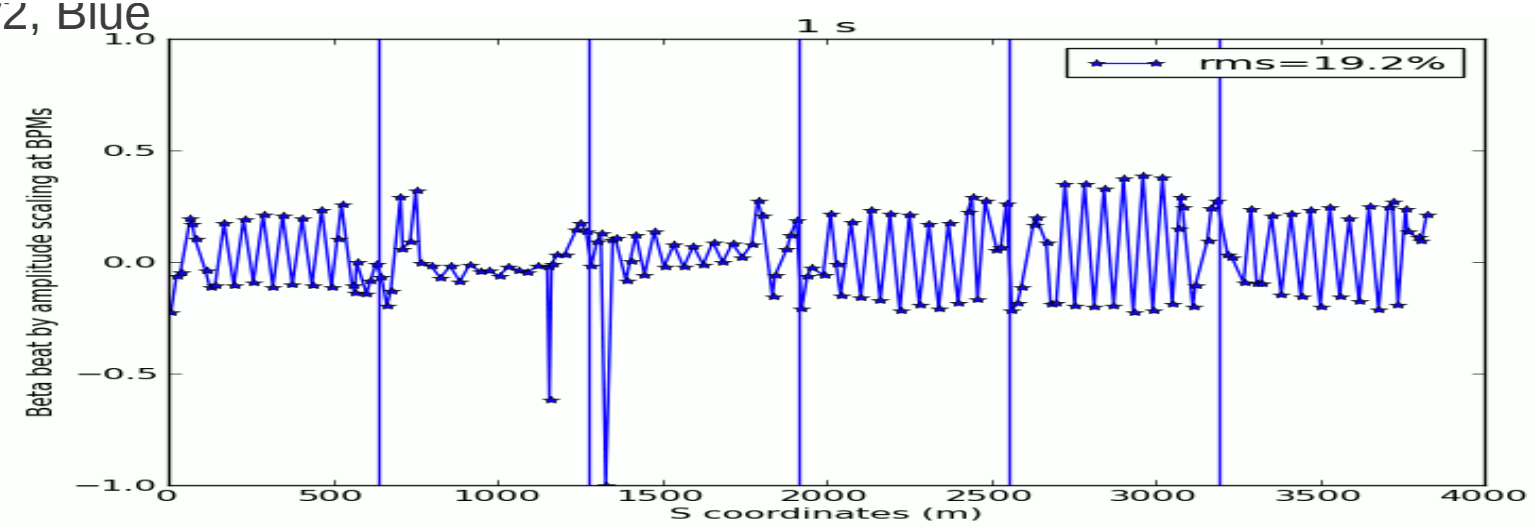
3. At full energy, sufficient oscillation amplitude can be achieved with adjustment to the number of kicks and Artus tunes (by A. Drees)

Beta beat

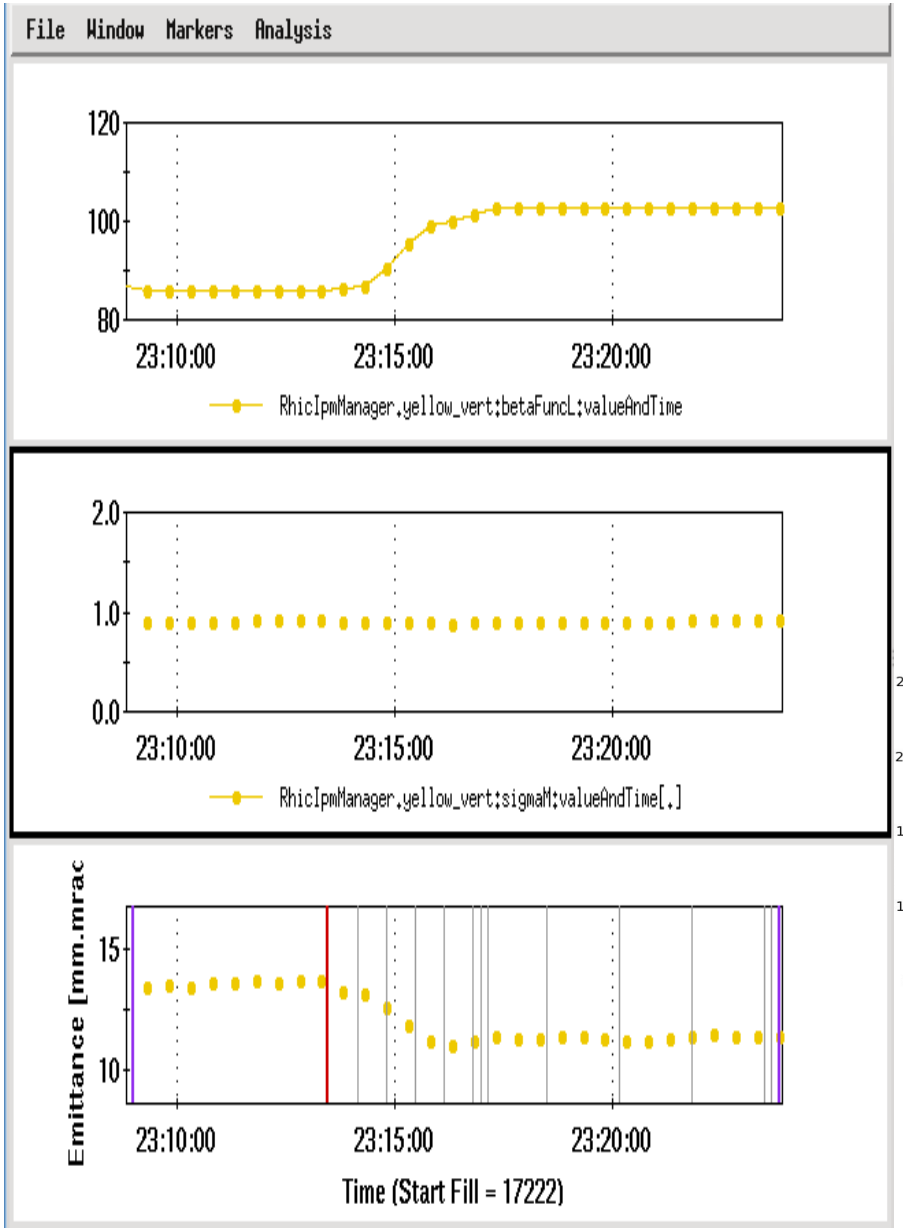
pp13e-v4, Blue



pp13b-v2, Blue

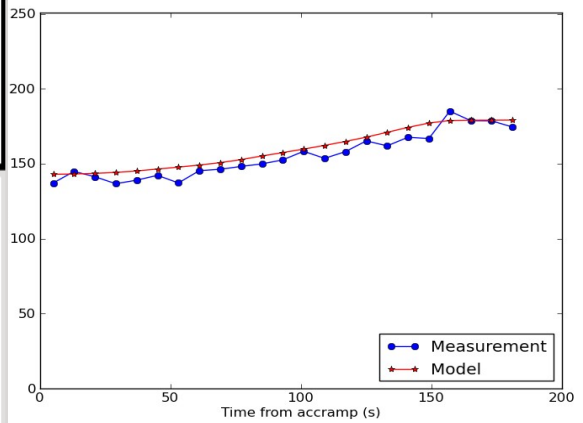


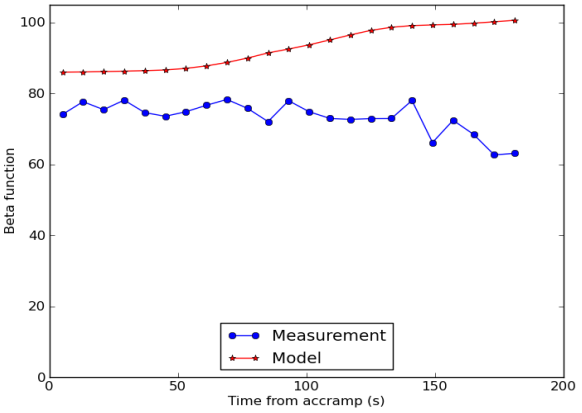
Beta at IPMs



Symptom: Yellow vertical profile at IPM stays more or less constant during beta squeeze, design vertical beta function at that IPM increases, thus the calculated emittance decreases as shown lower left, which is unphysical

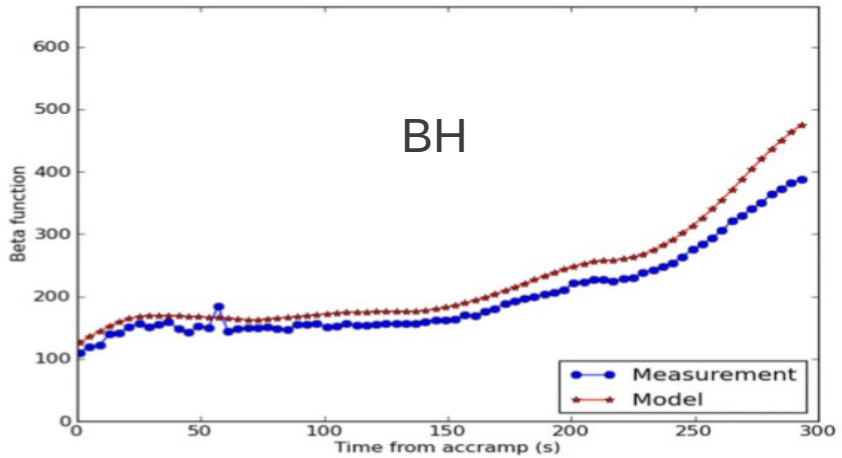
Diagnosis: With ramp optics measurement, the beta functions at yellow horizontal and vertical IPMs are interpolated (shown below), beta function at vertical IPM is slowly decreasing contradict to the design

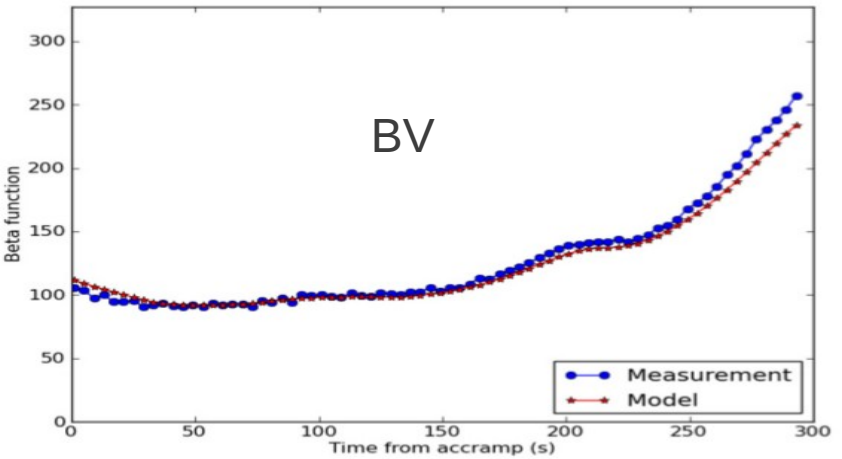


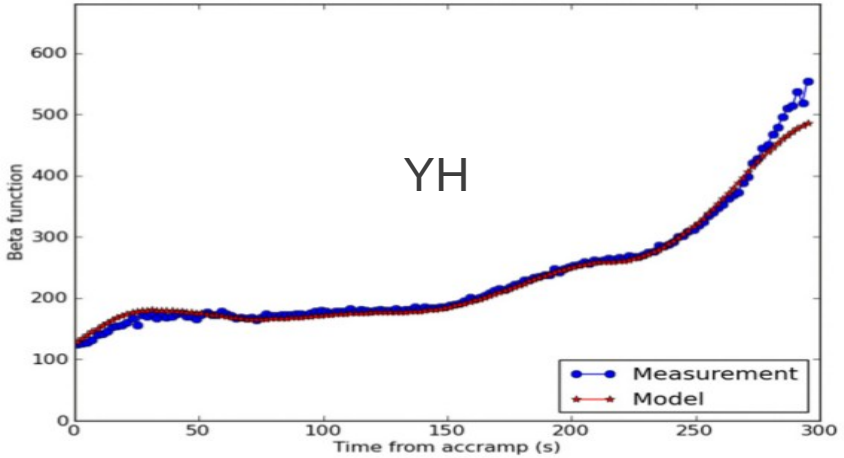


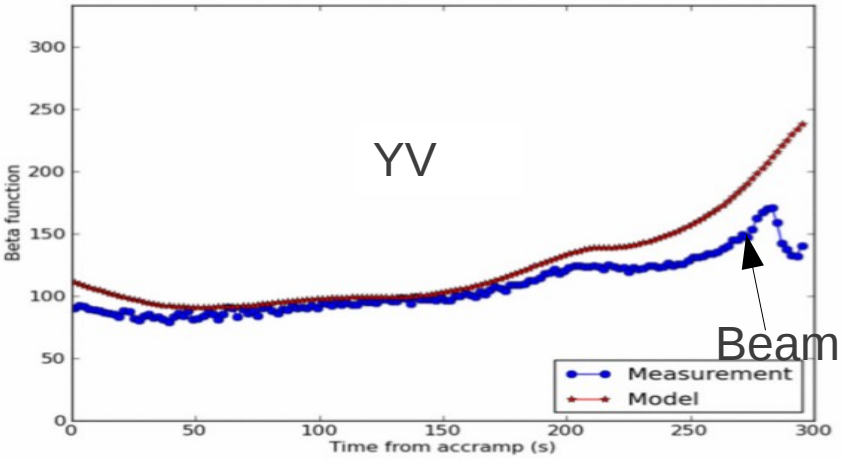
Further development: Implement measured beta for IPM emittance calculation (by M. Minty)

Beta at IPMs





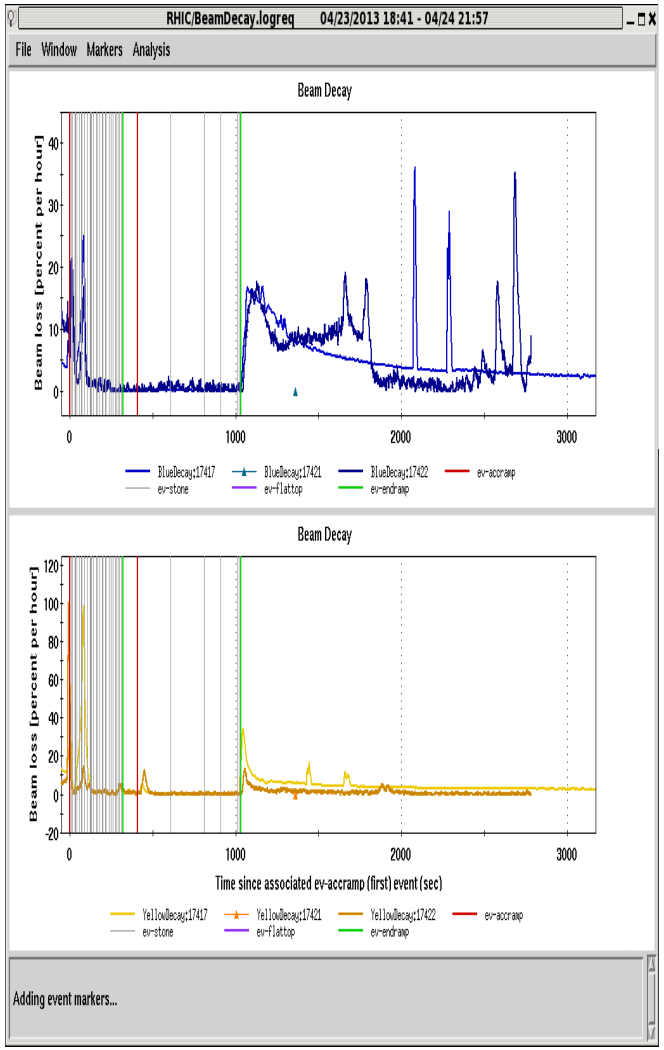


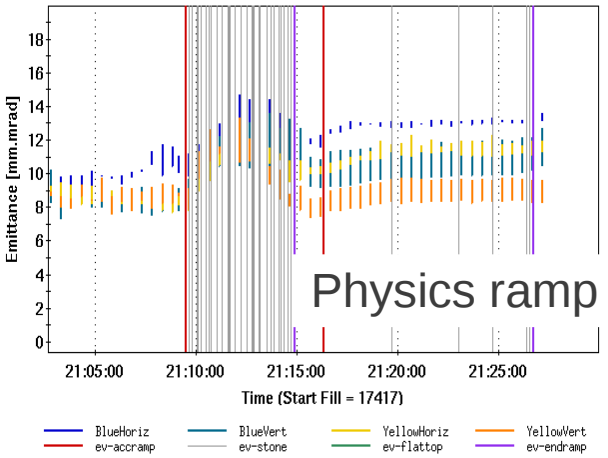


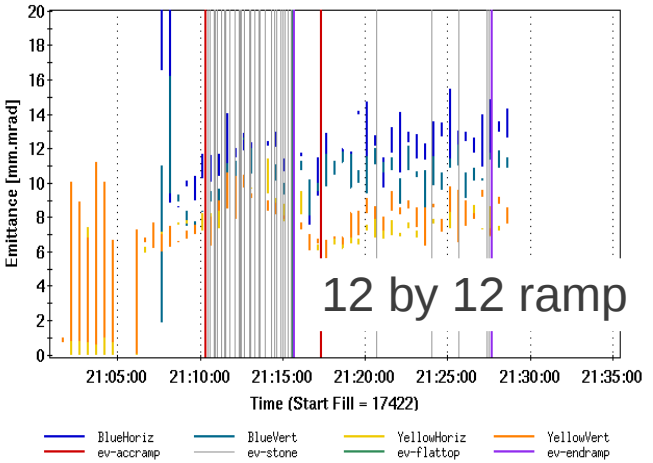
Beta function on the ramp at any location is available.

Ramp optics correction

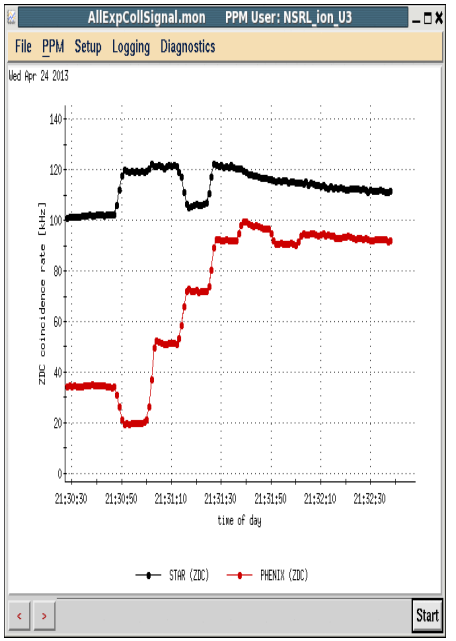
Ramp optics correction test



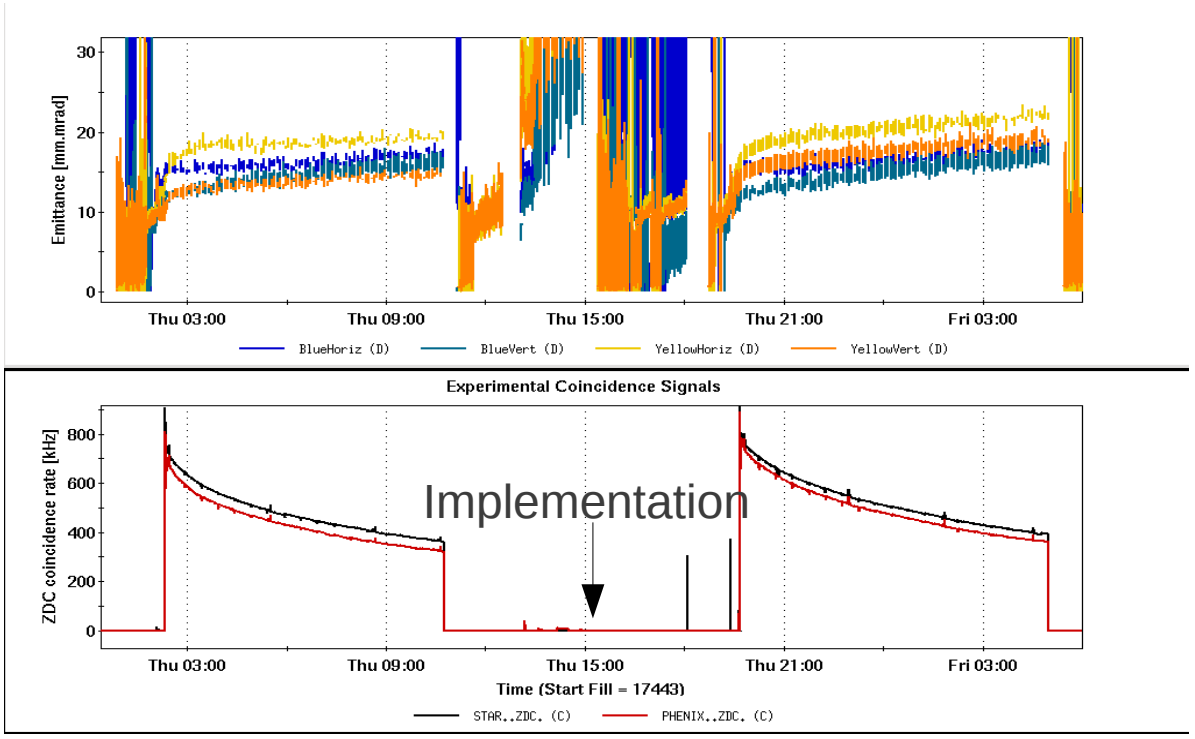




1. Back-propagated optics corrections at store into the rotator ramp in both rings
2. Tested 12 by 12 ramp, pp13b-v2 with standard protocol
2. Beam loss (left) is same as usual
3. IPM emittance (up right) is the same
4. Calculated emittance (by StoreAnalysis) is as good as good physics store
5. ZDC scaled rate reached 1070 kHz for STAR, ~15% increase of L



Rotator ramp correction



Starting on May 2nd, 2013, fillno 17451, optics correction for yellow rotator ramp has been implemented, it stayed in the machine without any complication

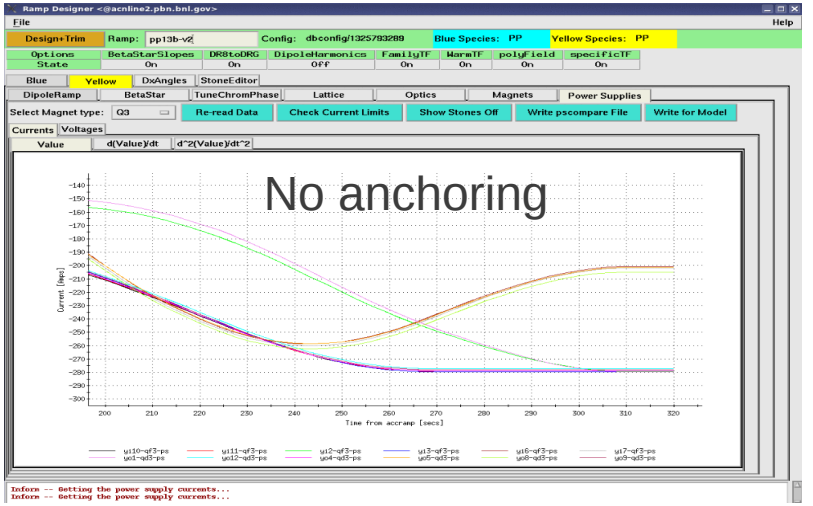
Energy ramp correction

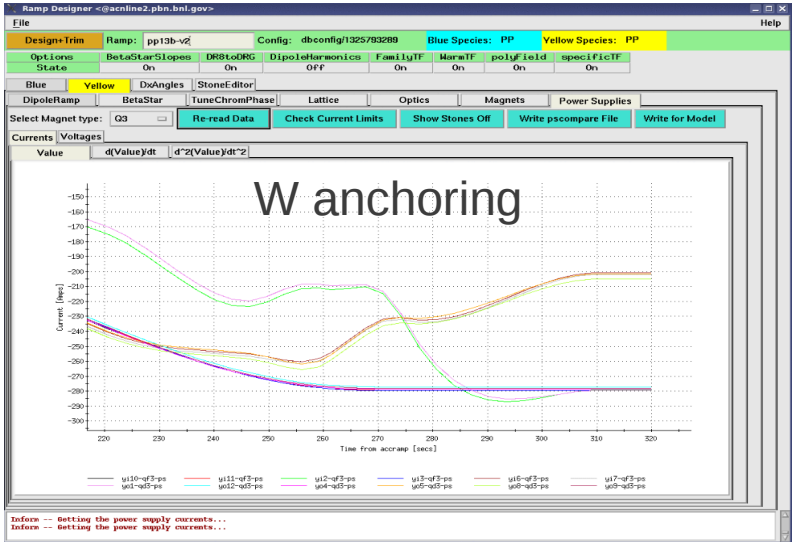
Plan: 12 by 12 ramp for ramp optics measurement, run script to select the TBT orbit file near stones and calculate optics corrections, run script to send correction strength to RampEditor, activate and ramp again

Problem #1: each time a set of strength was sent to RampEditor, it recalculates everything for the whole ramp, too time consuming

Solution: Send correction strengths for a stone once, not separately, or pre-anchor stones

Problem #2: Anchoring stones change the current curve for magnets dramatically, which causes magnet exceeding limits





Summary

- TBT BPM data quality significantly improved evidenced by optics analyses
- Three types TBT data (Artus data, AC dipole, injection oscillation), three analysis techniques (fitting, Interpolated FFT and ICA) in function
- Breakthrough of global optics corrections based on both Artus and AC dipole data
- Ramp optics measurement with Artus in operation
- Rotator ramp optics correction operational since May 2013
- Energy ramp optics correction in progress