Optics Measurements in the PSB: Progress and plans

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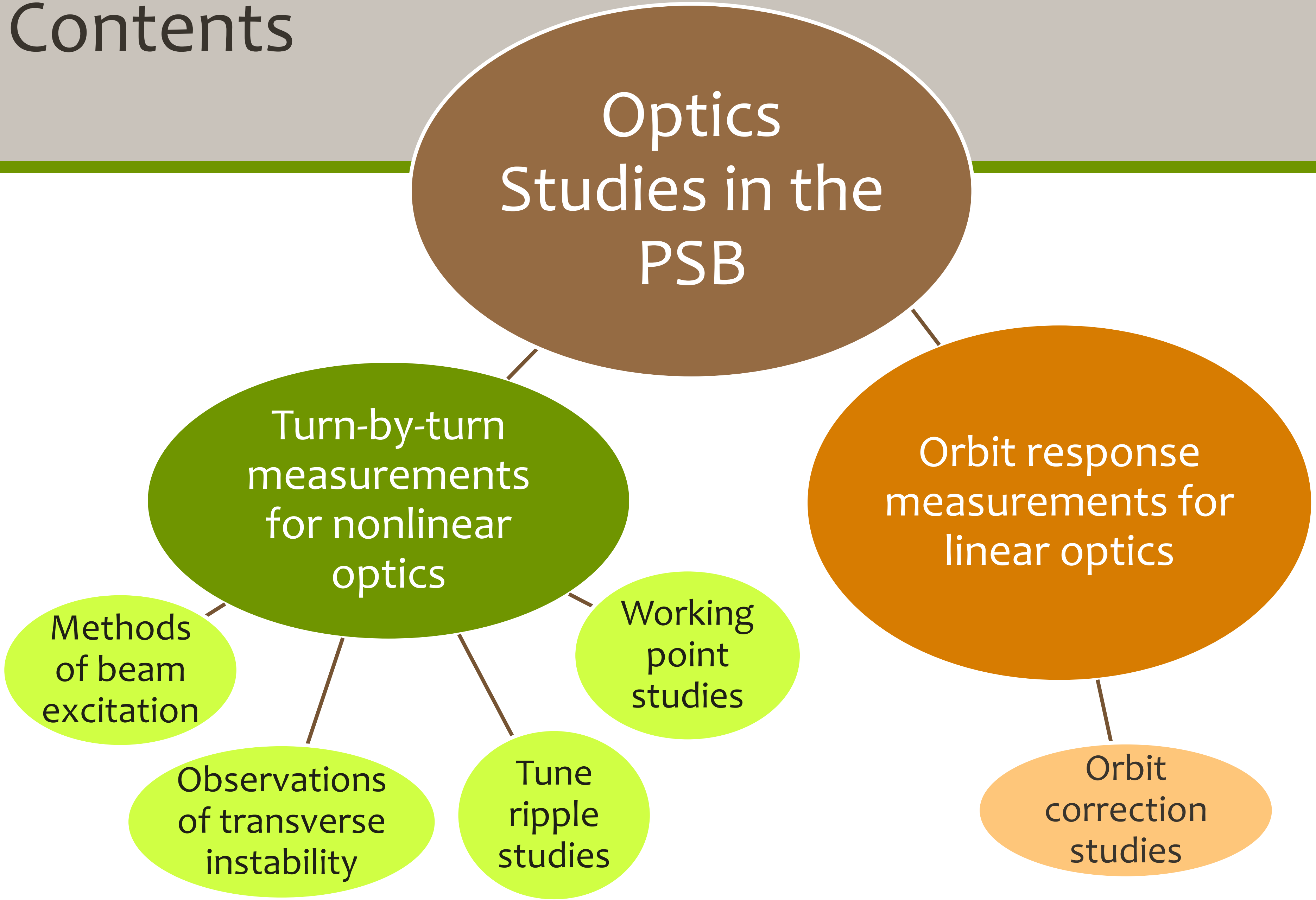
Contents

- Part I: Turn-by-turn measurements for nonlinear optics characterization and correction
  - Overview of goals and methods
  - First measurement results
  - Challenges encountered, related observations
- Part II: Linear Optics from Closed Orbits (LOCO)
  - Overview of goals and methods
  - First measurement results
- Part III: Plans for further studies after LS1

Contents



- Optics Studies in the PSB
  - Turn-by-turn measurements for nonlinear optics
    - Methods of beam excitation
    - Observations of transverse instability
    - Tune ripple studies
    - Working point studies
  - Orbit response measurements for linear optics
    - Orbit correction studies

Part I:
Nonlinear optics from turn-by-turn measurements

Part I: Nonlinear optics from turn-by-turn measurements

- Goal: Correct higher-order resonances so that intense beams can be accelerated without loss
- Method:
  - Turn-by-turn trajectory is measured at all BPMs around the ring while the beam undergoes coherent betatron oscillations
  - Nonlinear resonances can be characterized from amplitude and phase of higher-order lines in trajectory spectra
  - Resonances can then be compensated using multipole corrector elements

Part I: TBT measurements

Overview of status/progress

Done before LS1:

- Trials of turn-by-turn acquisition using three BPMs, on high-intensity (~5E12 ppp) H=1 cycles
- Investigation of methods for producing large coherent oscillations (tune kicker and AC dipole)

Ongoing:

- Investigation into effects of space charge, tune instability, working point, transverse coherent instability

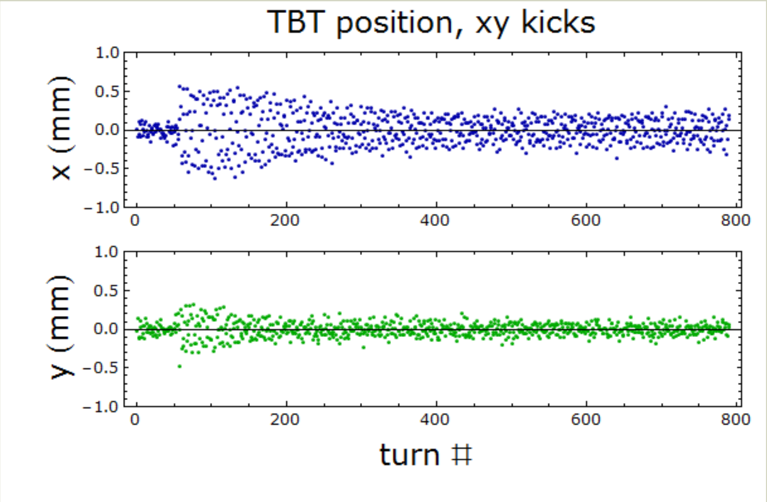
To do after LS1:

- Full measurements with all 16 BPMs
- Correction of measured resonances

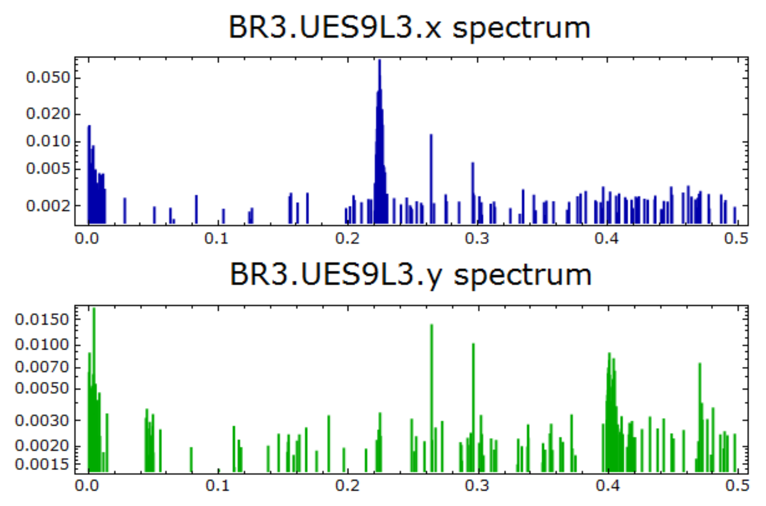
Part I: TBT measurements

Coherent oscillations from tune kicker

- Tune kicker set to 2 kV (using max of 5kV risks causing equipment failure)
- Chromaticity was corrected in one plane at a time
- Position resolution ~0.1 mm
- Oscillation amplitude from tune kicker insufficient (max ~1 mm peak-to-peak)



Beam trajectories after kick

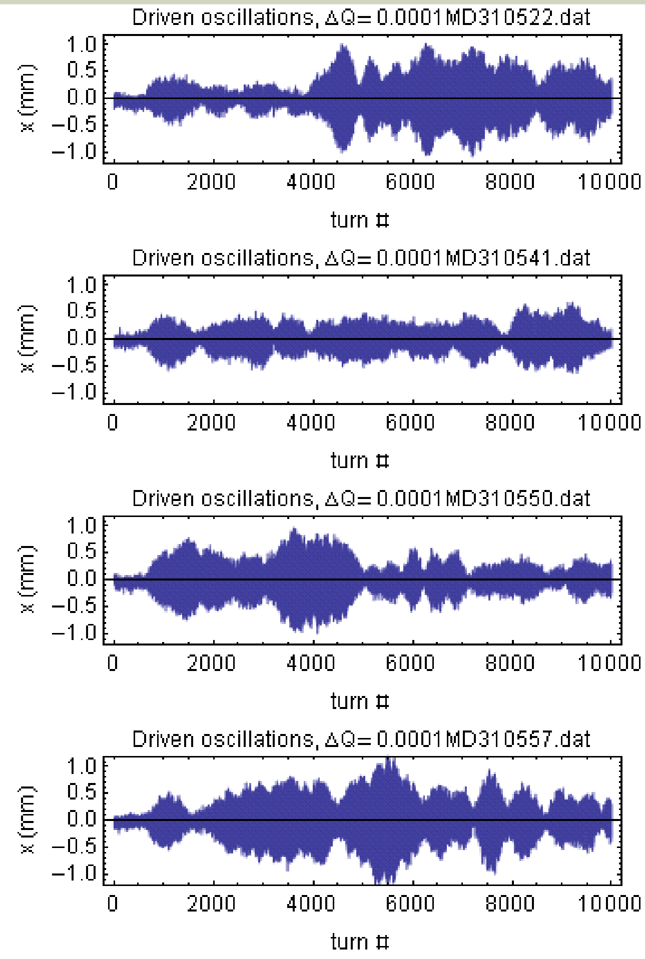


Spectra of kicked trajectories

Part I: TBT measurements

Driving oscillations w/ transverse damper

- Damper kicker used to drive beam w/ constant frequency close to betatron tune
- Envelope of driven beam is irregular, varies from pulse to pulse, and never exceeds 2 or 3 mm peak-to-peak
- Poor response to AC dipole may be due to inadequate kick strength, or to tune instability

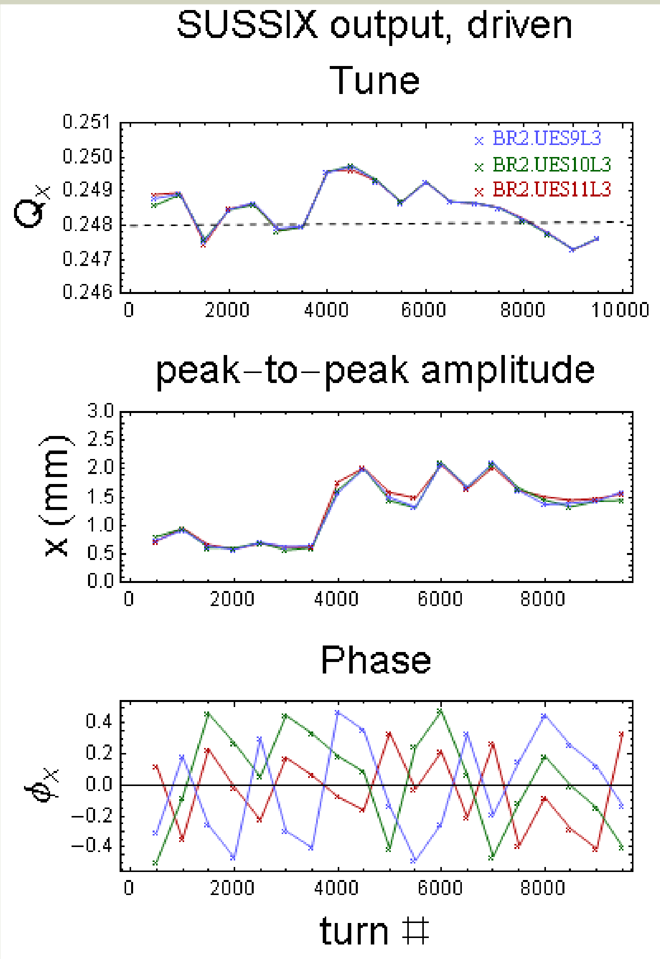


Driven trajectory on several pulses

Part I: TBT measurements

Driving oscillations w/ transverse damper

- Driven trajectories analyzed w/ SUSSIX in 500-turn increments
- Driving tune=0.248; natural tune 0.247-0.250
- Measured tune doesn't stabilize; natural tune changes too quickly for transients to decay?

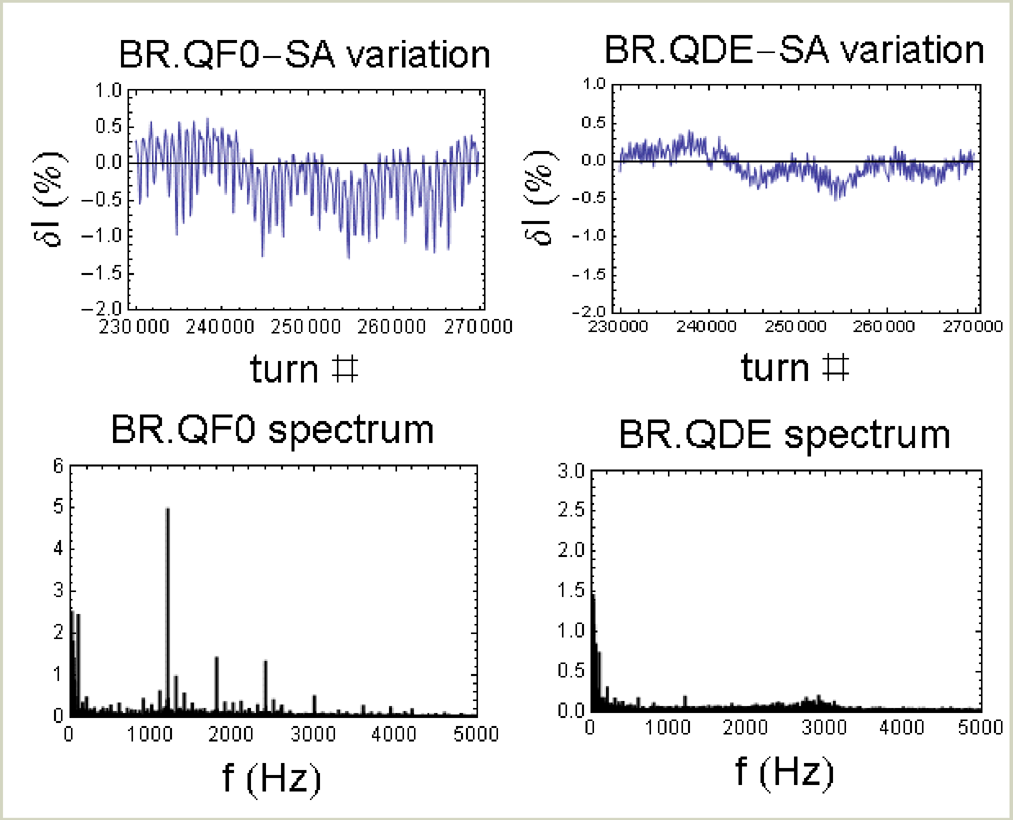


SUSSIX results from driven oscillations

Part I: TBT measurements

Cause of tune ripple

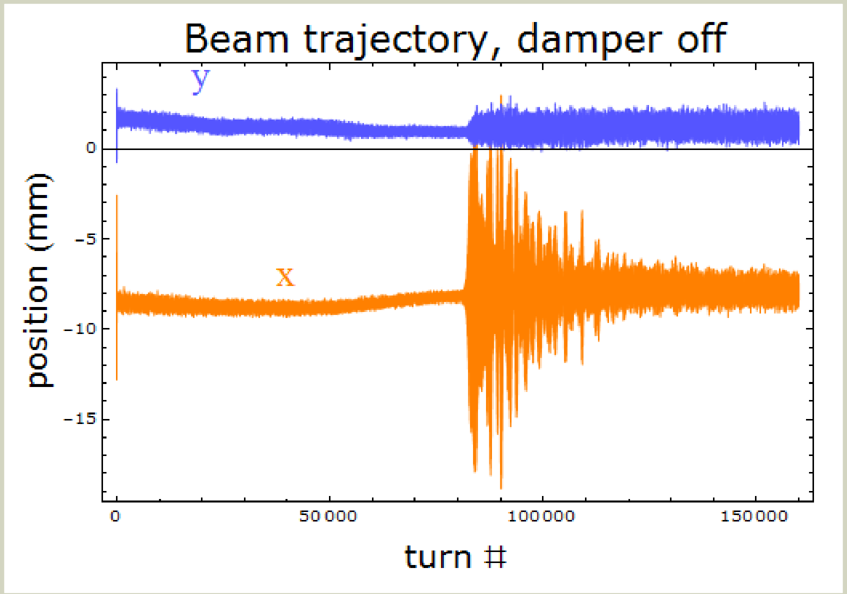
- Magnet current sampled at 0.1 ms intervals on 160 MeV flat-top (1 turn = 1 μs)
- QFO currents vary by ~ 2%, with largest component at 1.2 KHz (~800 turn period)
- Corresponds to expected tune ripple of ~0.005
- Power converter group is investigating



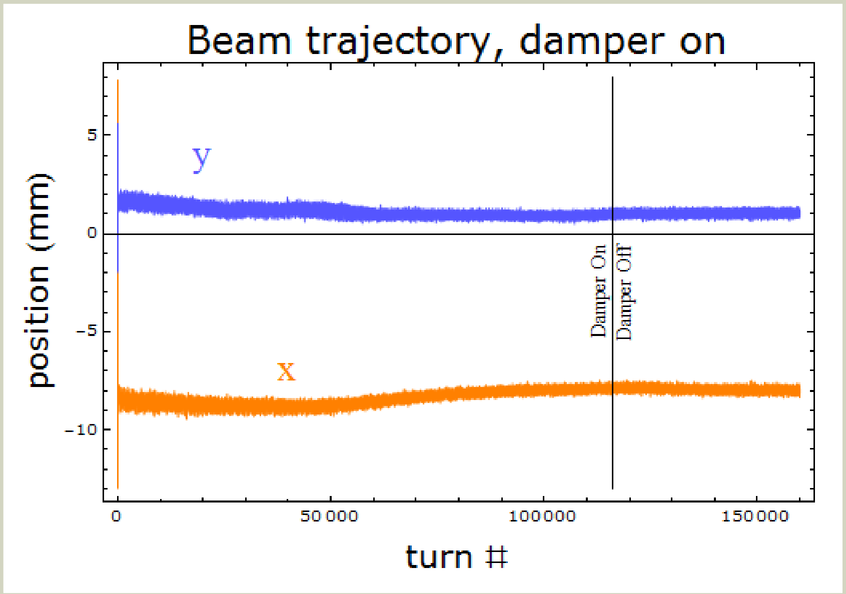
Triplet quadrupole current variation and spectra

Part I: TBT measurements
"Accidental" source of coherent oscillations

- Without transverse damper, beam becomes unstable at c~400 ms
- 2/3 of beam is lost (at high intensity)
- Instability is avoided if damper is left on until c~420 ms



Beam trajectory with transverse damper disabled

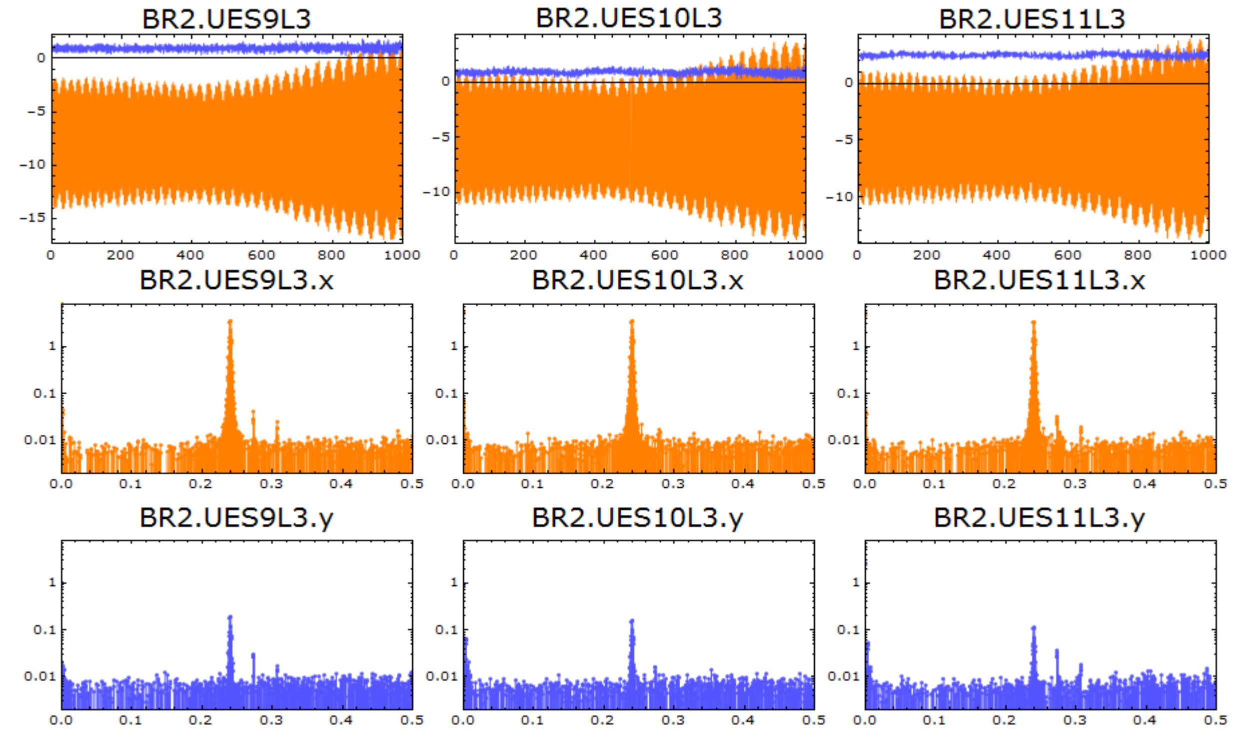


Beam trajectory w/ transverse damper active until c=424 ms

Part I: TBT measurements

Spectra from transverse instability

- Two noise peaks visible: 263 kHz and 297 kHz
- Peaks seen clearly in BPMs 9 and 11, less in 10.
- Beat frequency (~60 turn period) visible in all three trajectories.

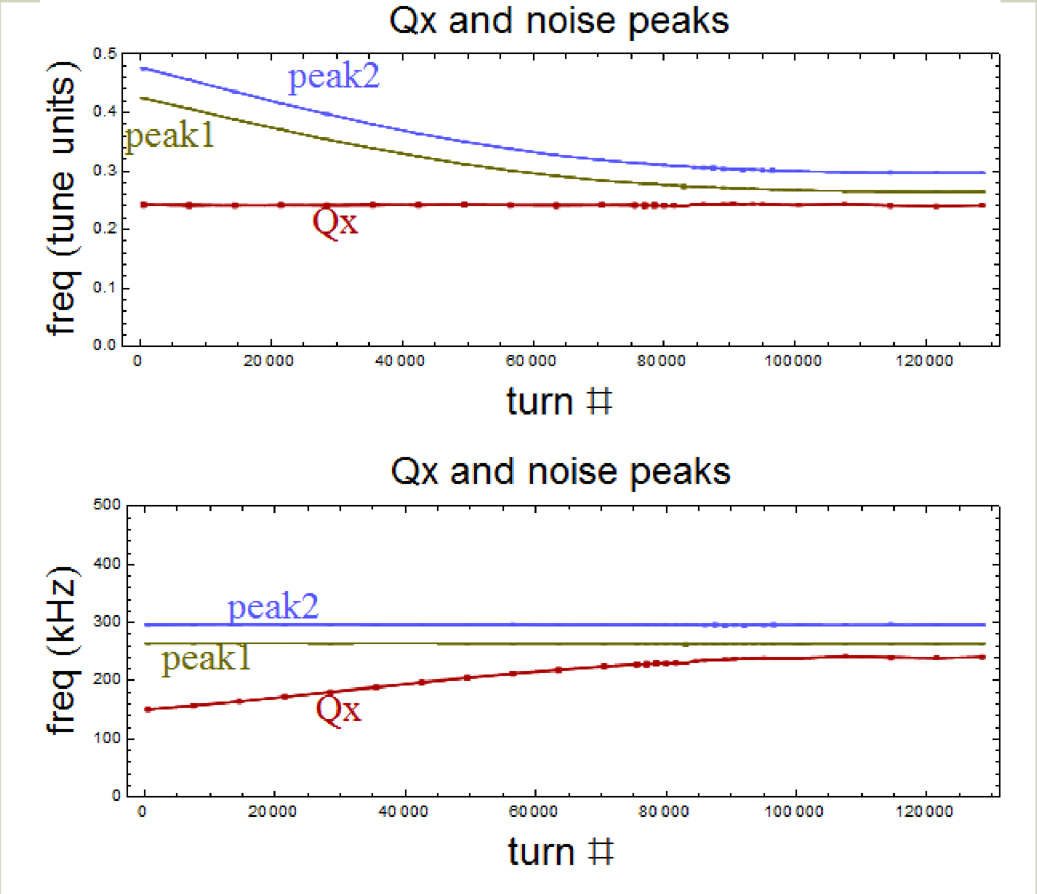


Trajectory and SUSSIX spectra during blowup (from five beam pulses)

Part I: TBT measurements

Frequencies from spectra during instability

- Plot shows x tune and two “noise” peaks through first 150 ms of acceleration cycle
- Peaks are at constant frequencies (f1~263 kHz and f2~297 kHz) while beam energy ramps up

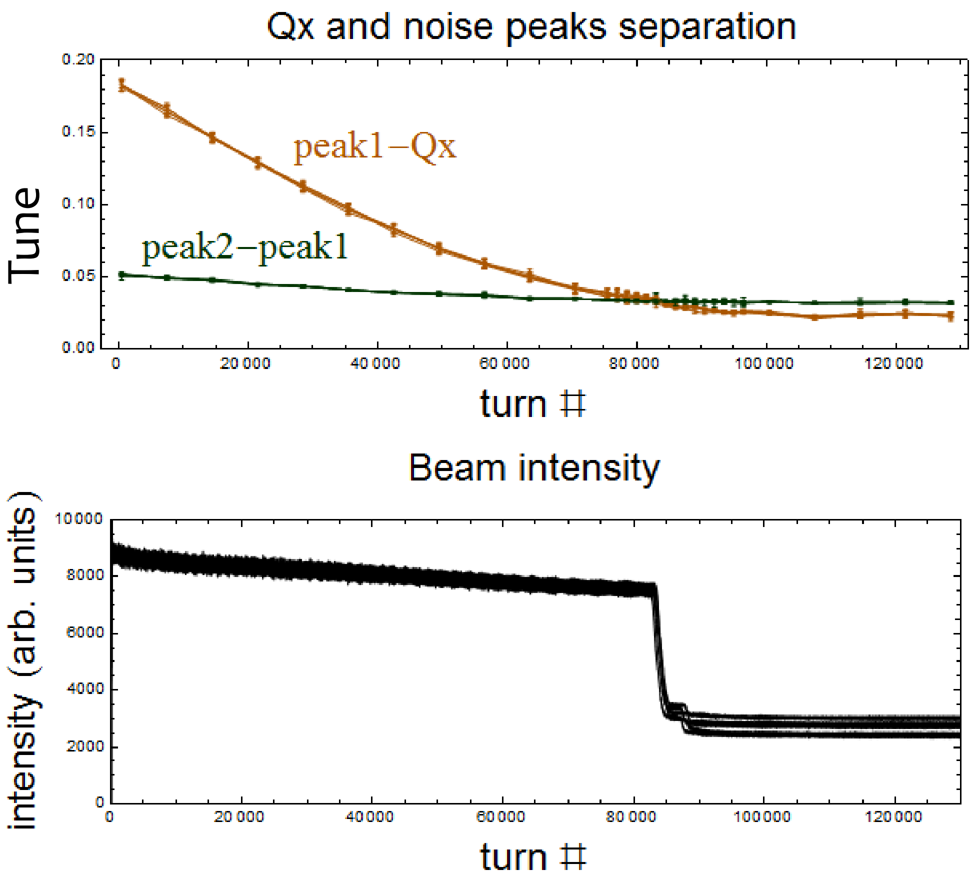


Tune and “noise” peaks during energy ramp

Part I: TBT measurements

Observation of transverse instability

- Beam instabilty occurs when (f1–Qx)=(f2–f1)
- If transverse damper is left on until just after this point (when noise is closer to Qx), instability is avoided

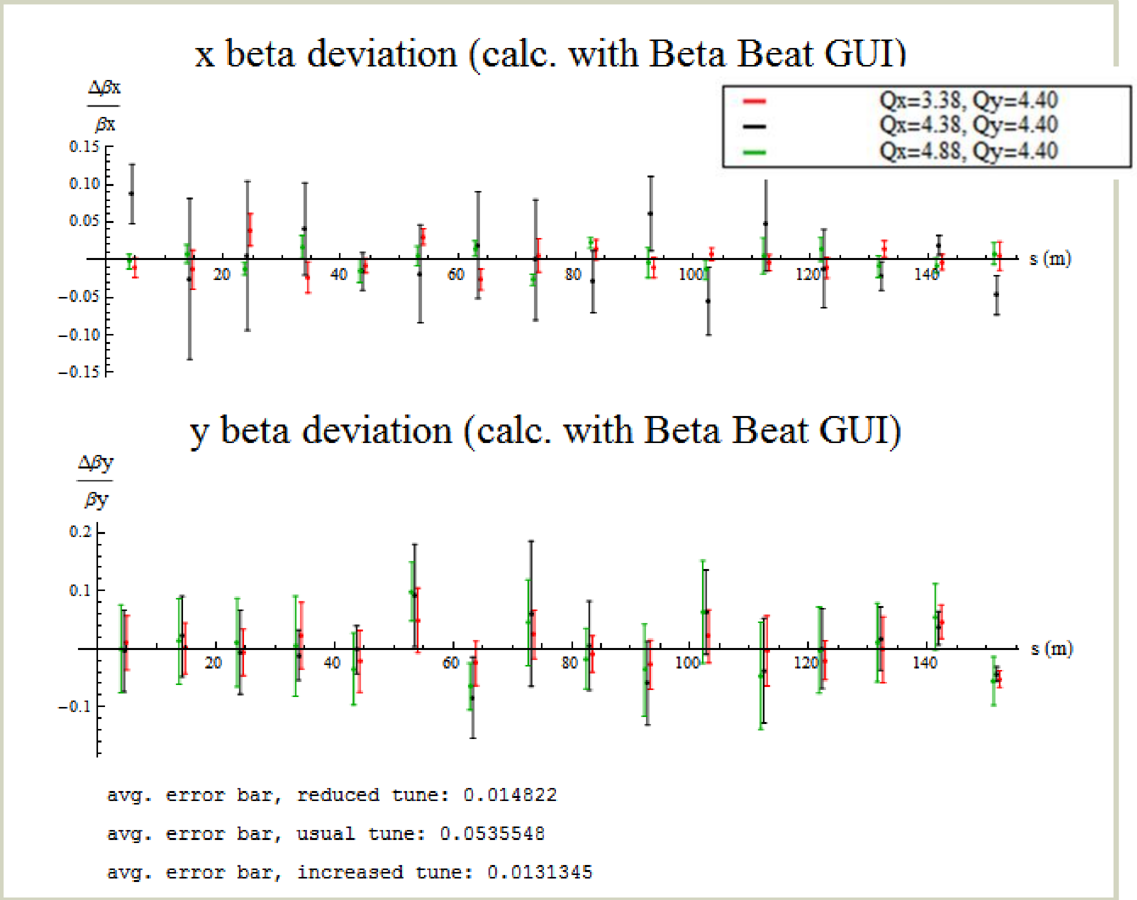


Tune and beam intensity during energy ramp

Part I: TBT measurements

Effect of working point on optics calculation

- At normal working point Δψ~90°
- Simulations show that changing working point by -1.0 or +0.5 is advantageous (reduces uncertainty of optics calculations)
- Both -1.0, +0.5 shift can be made w/ current QFO, QDE configuration at 160 MeV
- Spectra of measured trajectories at different working points on backup slide



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avg. error bar, reduced tune: 0.014822
avg. error bar, usual tune: 0.0535548
avg. error bar, increased tune: 0.0131345
```

Beta beating calculations with simulated data, multiple working points

Part II:

Linear Optics from Closed Orbits (LOCO)

Part II: Linear Optics from Closed Orbits (LOCO)

Goal:

- Allows to find distribution of linear errors in machine, resulting in more accurate lattice model for simulations
- More precise than TBT analysis for linear optics because measurements contain info about optics at location of correctors as well as at location of BPMs

Procedure:

- Measure orbit response to each of j corrector dipoles at each of i BPMs
- Define variable model parameters (quad tilts and strengths, BPM and dipole tilts and gains)
- Fit for values of parameters that minimize difference between model and measured response:

$$F = \sum_{i,j} \left(\left(\frac{\partial x_i}{\partial \theta_j} \right)_{Meas} - \left(\frac{\partial x_i}{\partial \theta_j} \right)_{Model} \right)^2 \frac{1}{\sigma_{ij}^2}$$

Part II: LOCO
Overview of status/progress

Done before LS1:

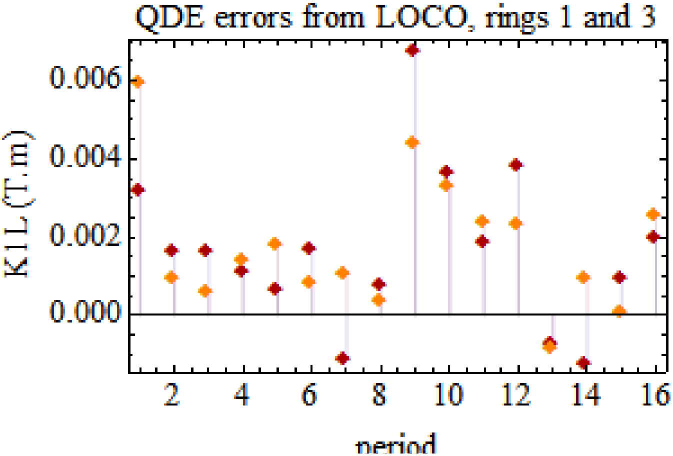
- Orbit response matrix (26 dipoles x 32 BPMs) and dispersion measured in each rings
- MADX model updated to include surveyed alignment errors
- Distribution of linear errors estimated from measurements and added to MADX model

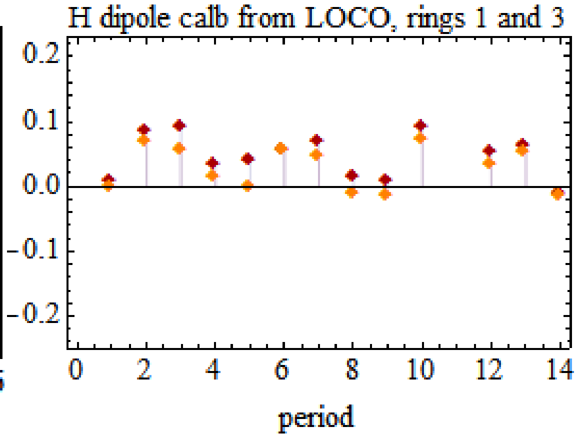
To do after LS1:

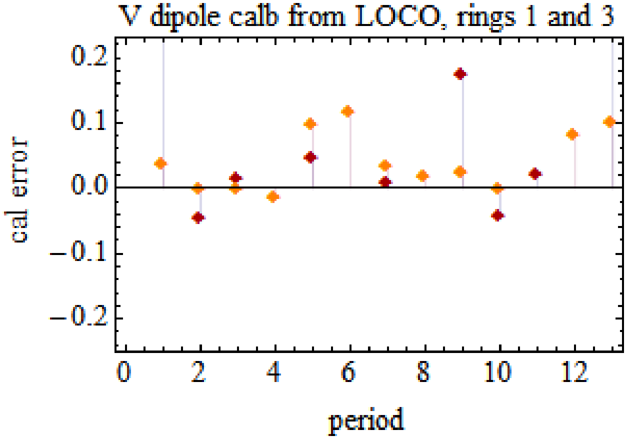
- Repeat measurements after realignment of magnets
- Measure at different working points
- Automate data collection process to make measurements more precise, MDs more efficient

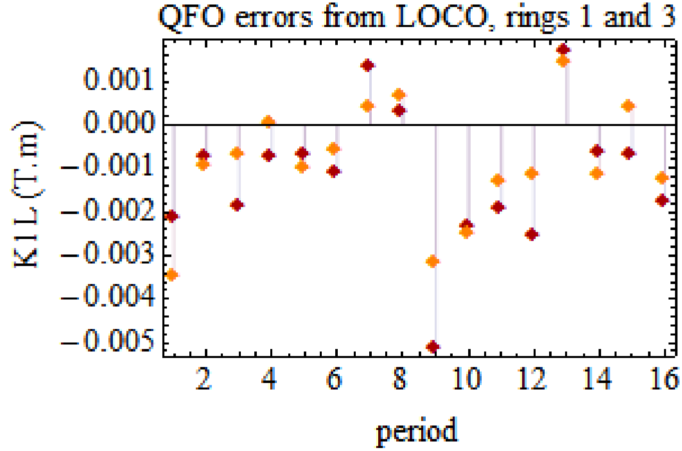
Part II: LOCO

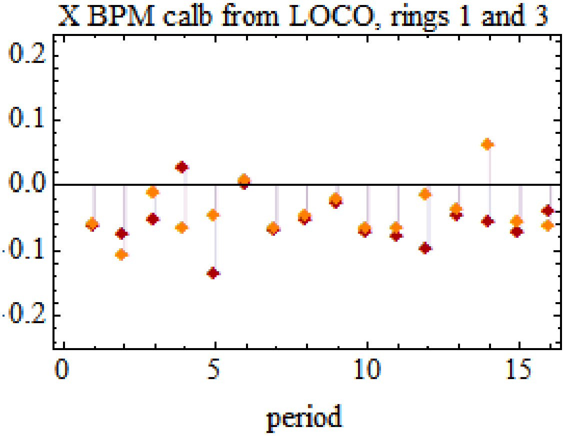
Model calibration parameters (rings 1 and 3)

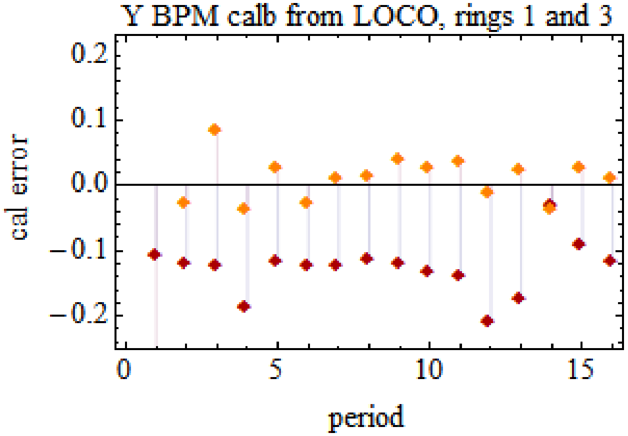

QDE errors from LOCO, rings 1 and 3


H dipole calb from LOCO, rings 1 and 3


V dipole calb from LOCO, rings 1 and 3

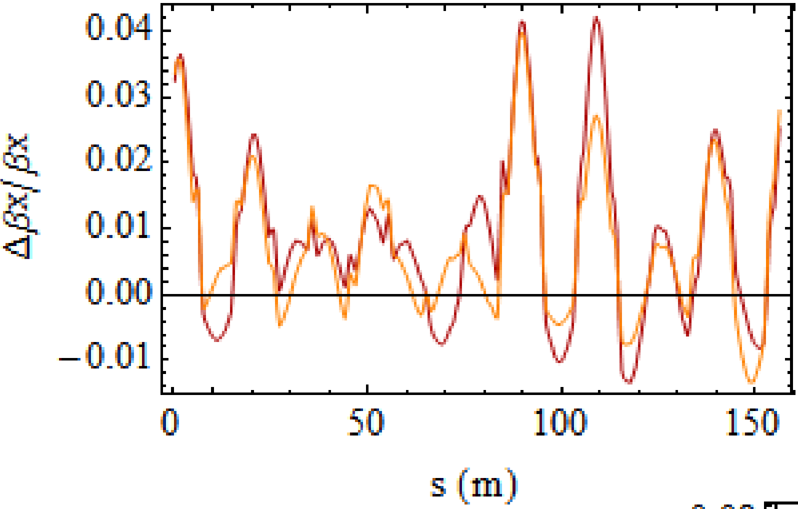

QFO errors from LOCO, rings 1 and 3


X BPM calb from LOCO, rings 1 and 3

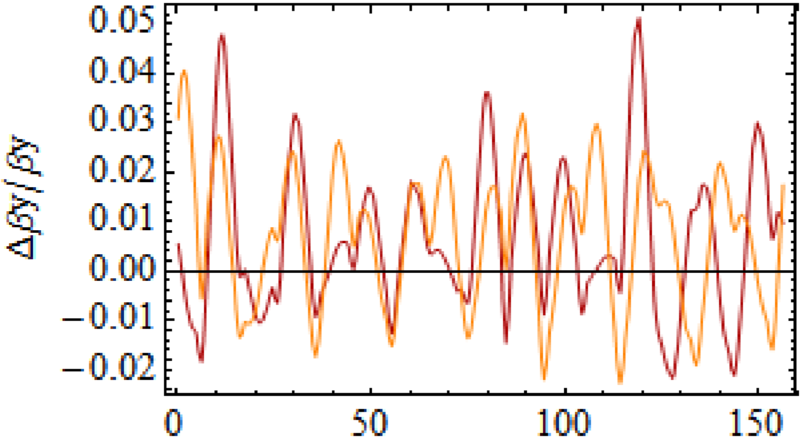

Y BPM calb from LOCO, rings 1 and 3

Part II: LOCO

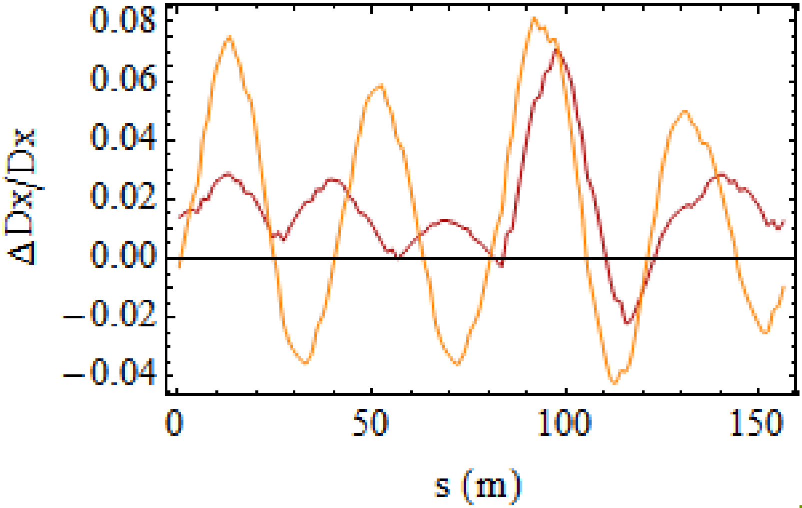
Optics from calibrated model (rings 1 and 3)



X beta beating, rings 1 and 3



Y beta beating, rings 1 and 3



X disp beating, rings 1 and 3

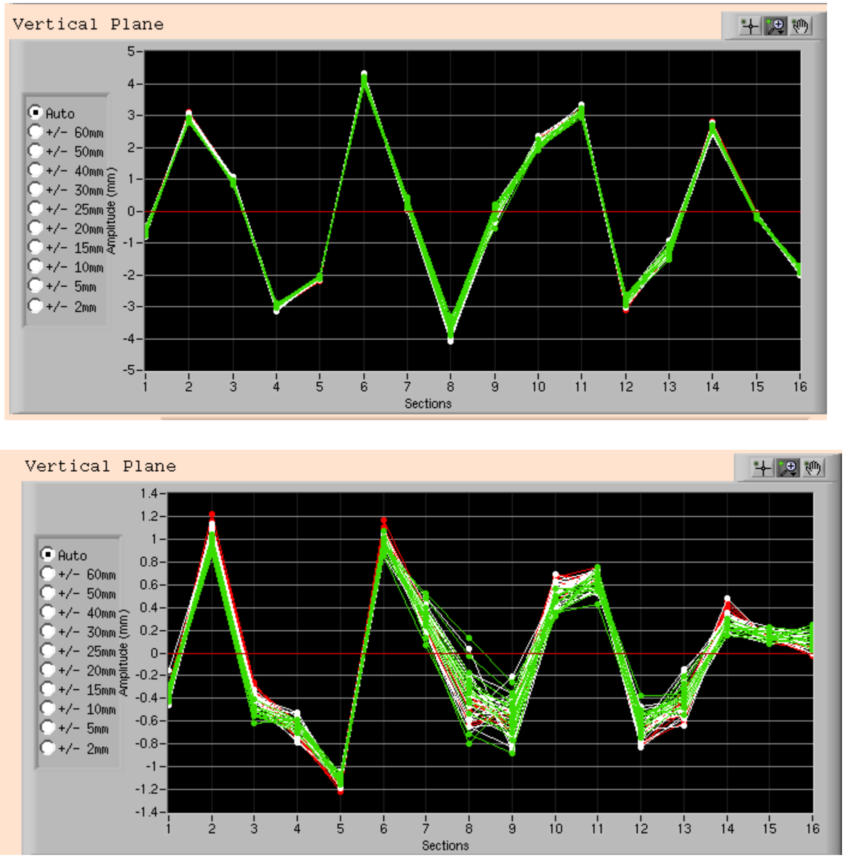
- Optics distortions are small
- Beta beating ~ 5%
- Disp. Beating ~ 10%

Part II: LOCO

Orbit correction with YASP

(J. Wenninger, J.F. Comblin, G. Kruk, B. Mikulec, M. McAteer et. al.)

- Orbit response measurements identified several polarity reversals in orbit corrector dipoles and BPMs, allowing for correct definition within YASP
- Corrected orbit will be beneficial future ORM measurements



First test of orbit correction with YASP

Part III:
Plans for continuation of machine studies

Part III: Plans for further studies

Studies for nonlinear optics from TBT trajectories:

- Measure trajectories with all 16 BPMs per ring
- If possible, use tune kicker at higher voltage (if spare can be made or found)
- Repeat tests with AC dipole (if tune can be made more stable)
- Try measurements with chromaticity corrected (mostly) in both planes
- Measure trajectories with tune altered by 0.5 or 1 (to move phase advance between bpms away from 90 degrees, reducing systematic error of optics calculations)

Part III: Plans for further studies

Studies for linear optics from orbit response:

- Measurements should be repeated after realignment campaign of LS1
- Data acquisition process will be automated (possibly using Matlab), allowing for faster collection and more precise measurements
- Measurements will be made at multiple working points

Summary

- First tests with trajectory measurement system have already given interesting insights into machine behavior (tune ripple, transverse instability)
- Means of creating a larger coherent oscillation must be found; transverse damper as AC dipole is a likely solution
  - Increased kick strength (upgrade to amplifiers of transverse feedback kicker, or at least repair of those that were non-functional) would be beneficial
  - Reduction of current ripple in QFO would be beneficial
- LOCO measurements show small beta beating, and give estimate of distribution of errors that is useful for beam dynamics simulations

Thank you for your attention

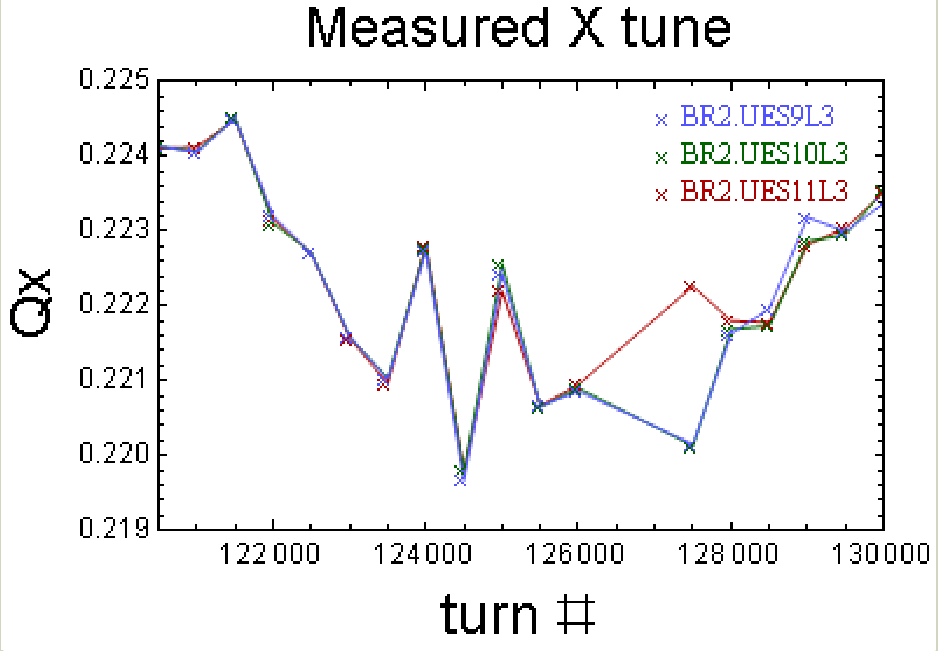
Thanks to:
J. Belleman
C. Carli
A. Findlay
B. Mikulec
R. Tomas
PSB ops group

Backup Slides

Backup Slide:

Measured tune w/ free oscillations

- Transverse oscillations due to beam instability
- Trajectories analyzed w/ SUSSIX in 500-turn increments
- Tune varies by ~0.005 over several hundred turns
- Excellent agreement of measured tune among three BPMs

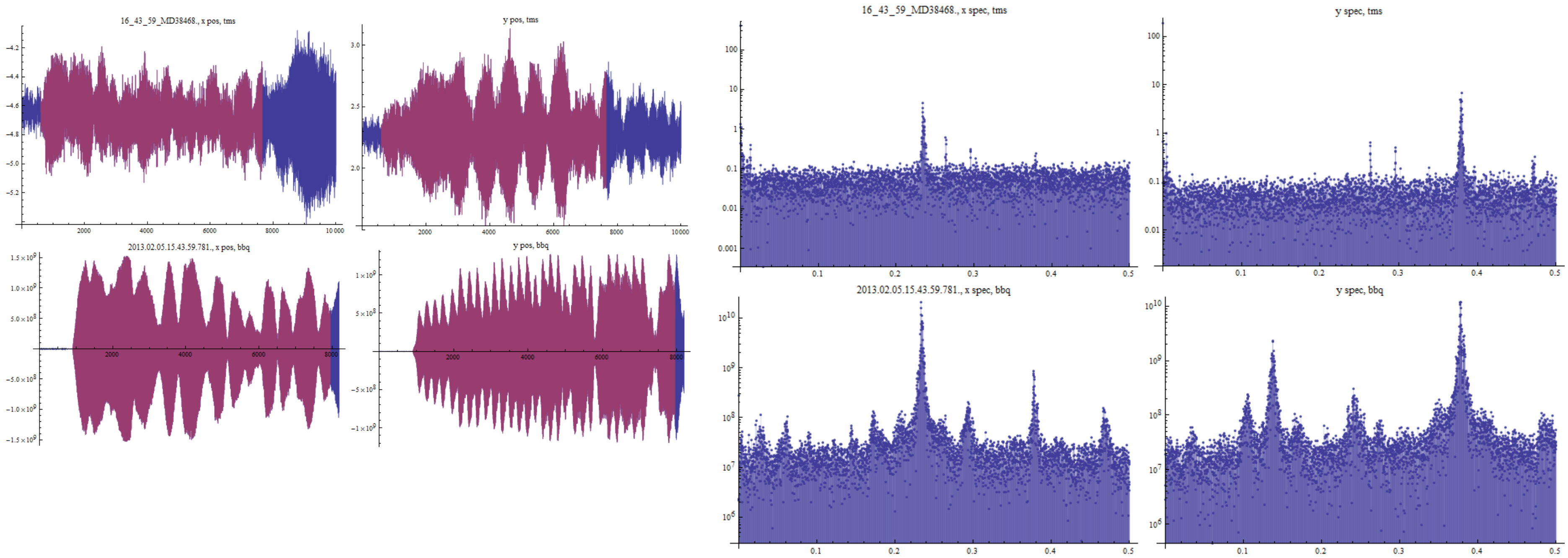


SUSSIX tune, with free oscillations

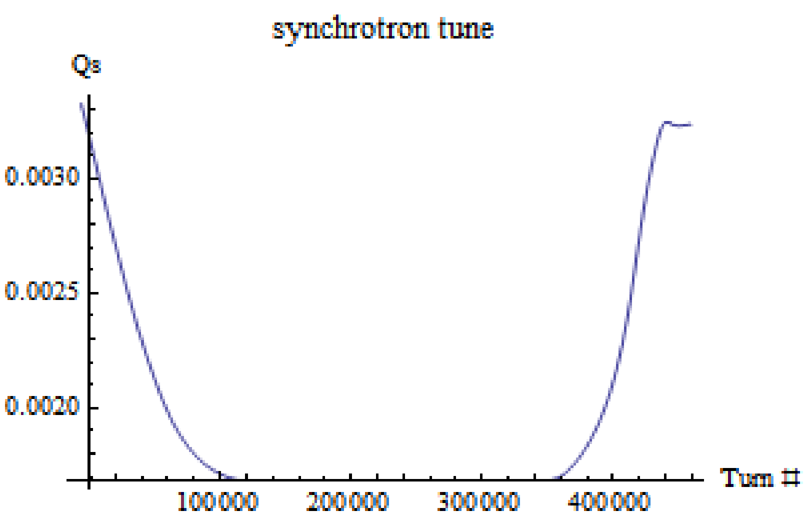
Backup slide:

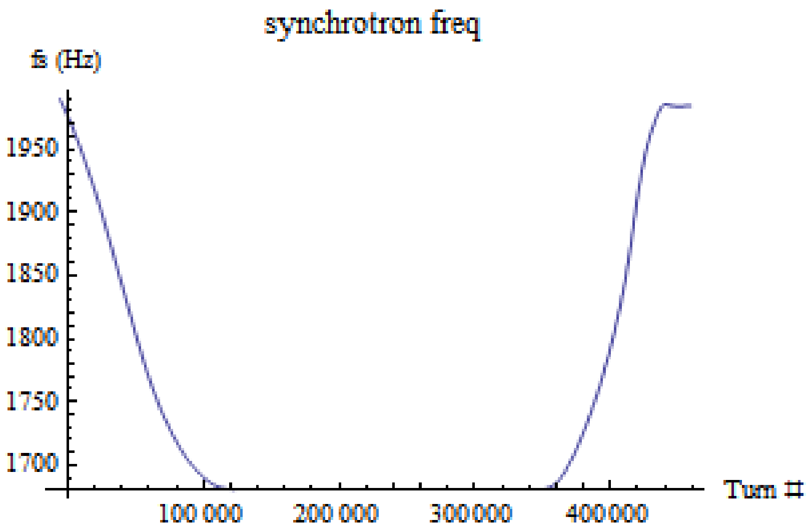
Comparison of TMS and Qmeter

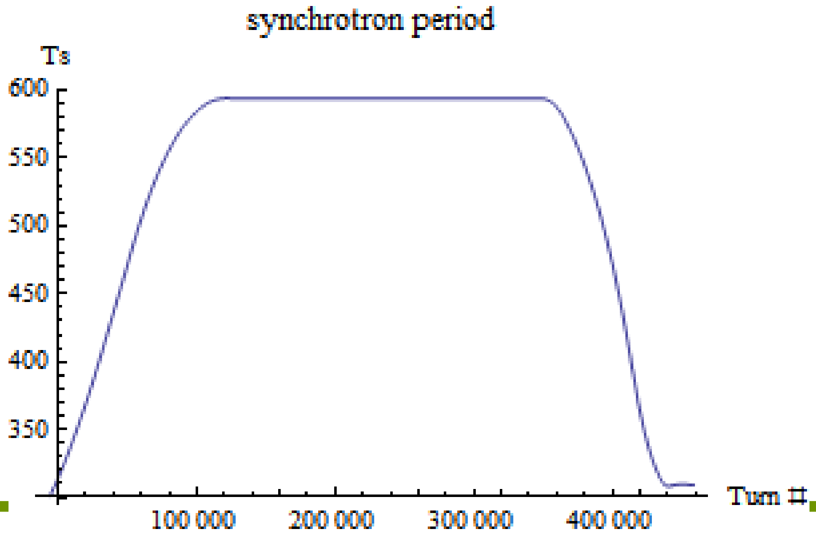
- Trajectories and spectra from TMS (upper plots) and from Q meter (lower plots)
- Beam driven very close to Qx and Qy



Backup slide:
Synchrotron motion, 160 MeV cycle



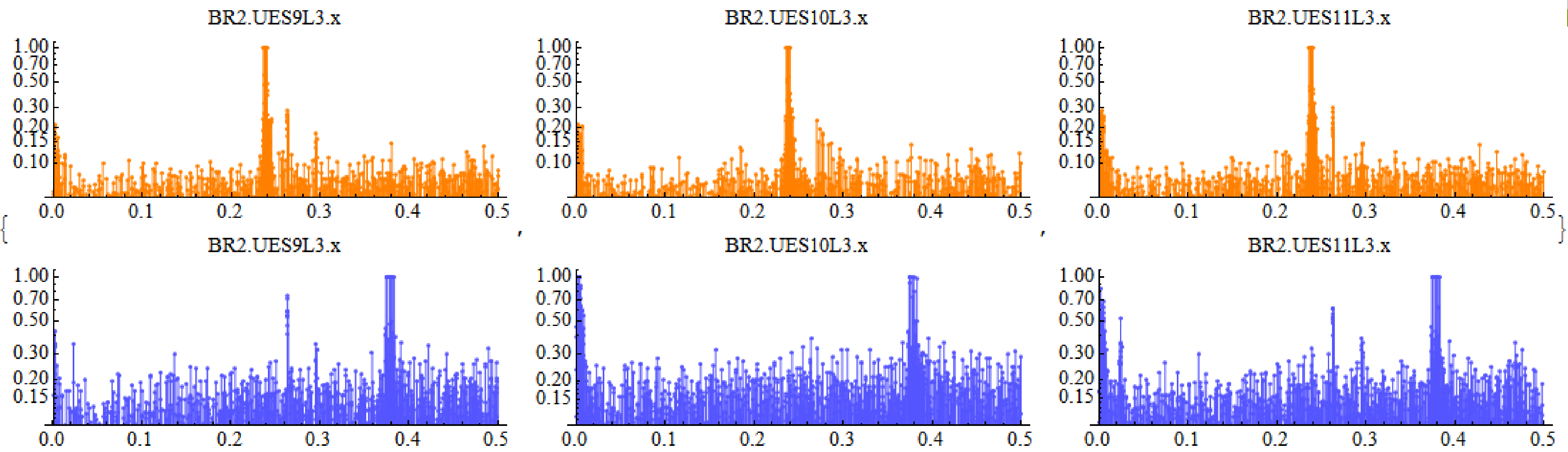




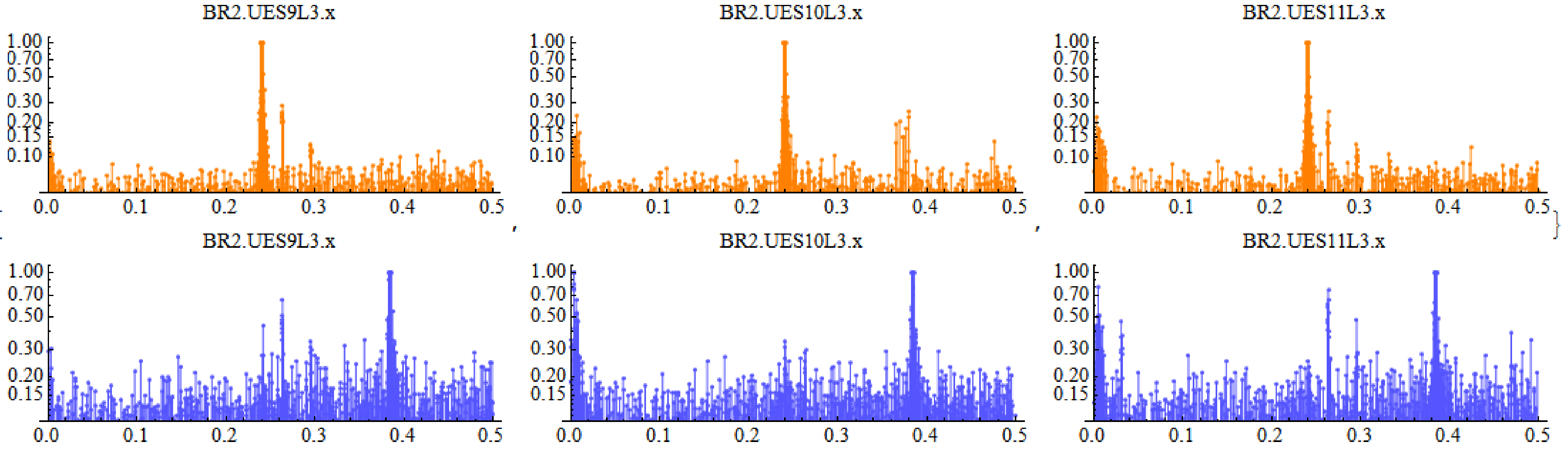
Backup slide:

Spectra w/ different working point (dQx=-1.0)

Spectra, altered tune (Qx=3.23, Qy=4.38)



Spectra, normal tune (Qx=4.23, Qy=4.38)



Backup slide:

Quad currents w/ dQx=-1.0