Linear optics measurements and preparations for nonlinear optics measurements in the PSB

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  - Overview of goals and methods
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- Part III: Plans for further studies after LS1

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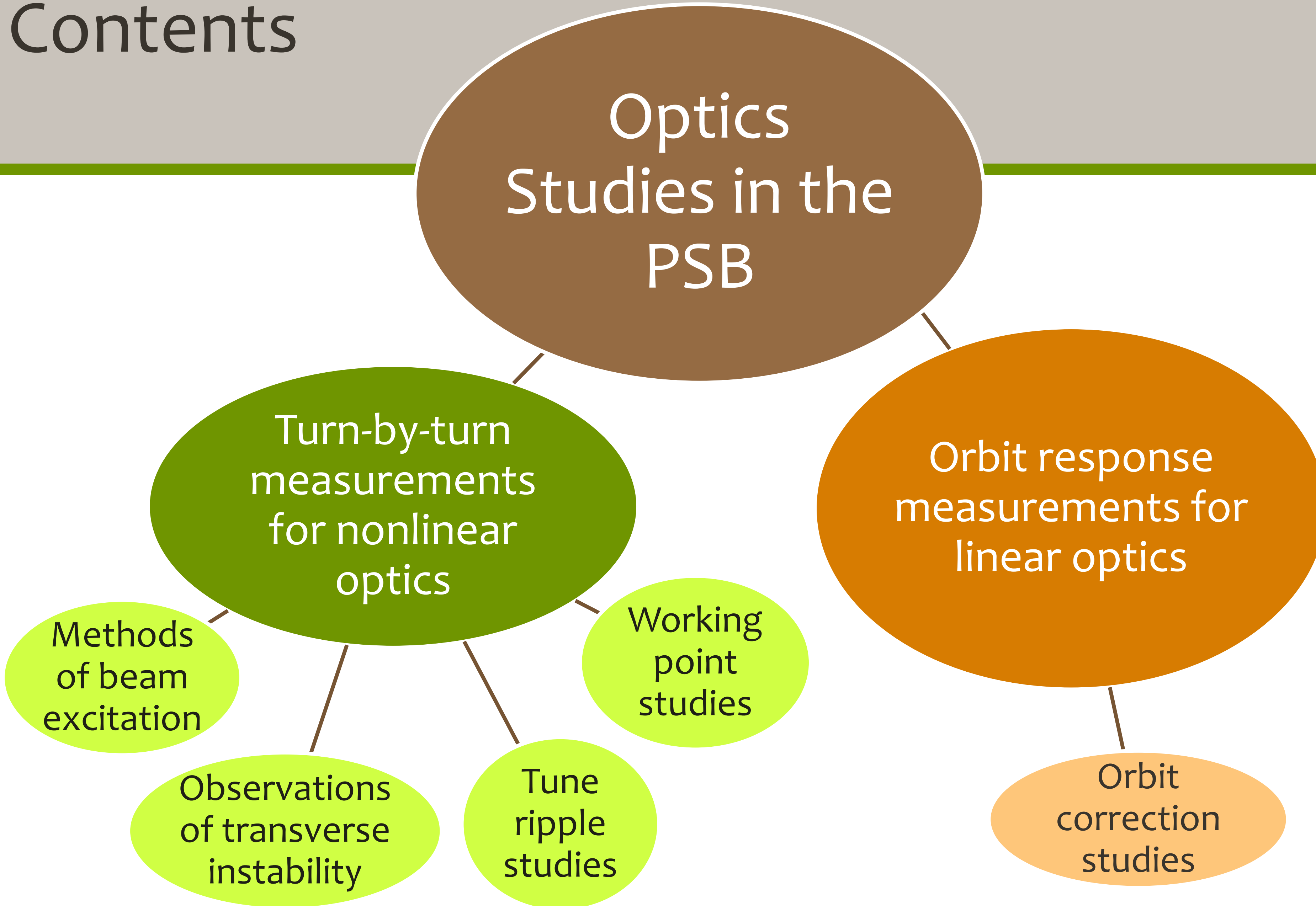
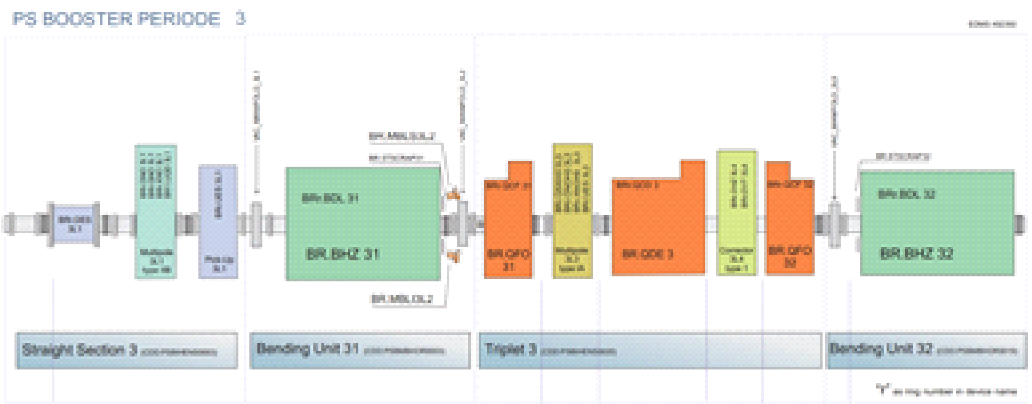
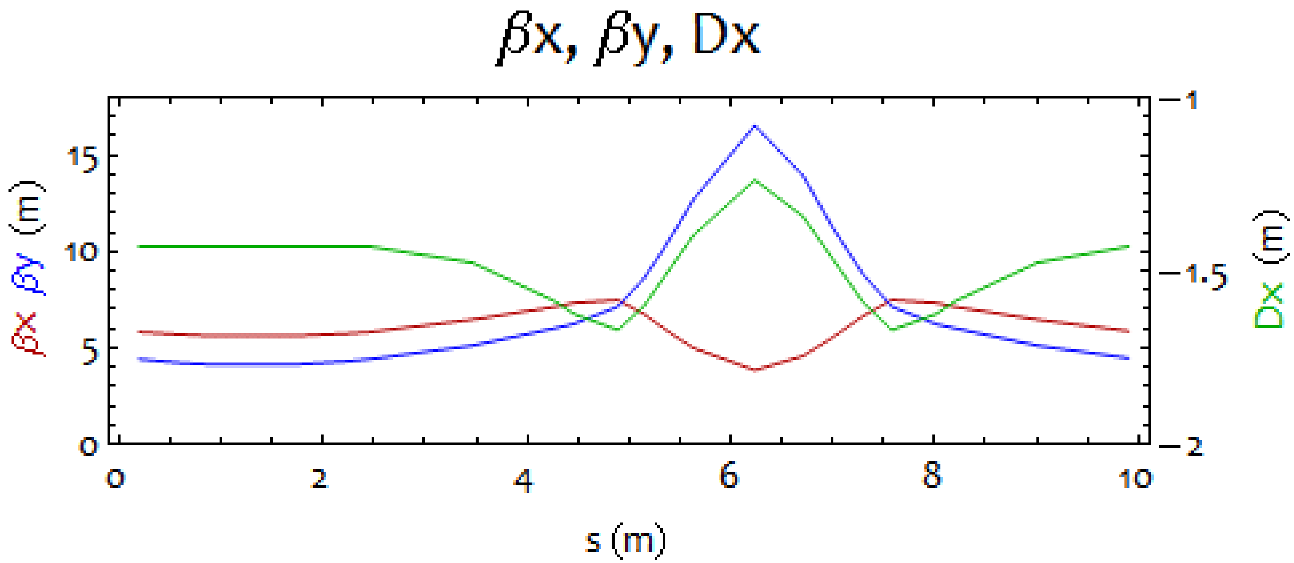

Optics Studies in the PSB
Turn-by-turn measurements for nonlinear optics
Orbit response measurements for linear optics
Methods of beam excitation
Observations of transverse instability
Tune ripple studies
Working point studies
Orbit correction studies

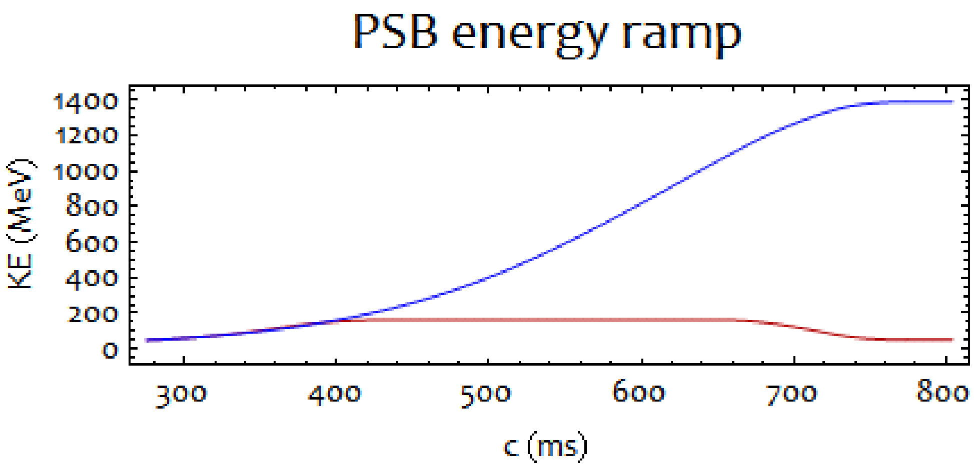
Introduction: The PS Booster

- 157 m circumference
- 16-period triplet structure





Introduction: The PS Booster



- Normal acceleration cycle is from 50 MeV to 1.4 GeV
- Turn-by-turn measurements done on special cycle with 160 MeV energy flat-top
- Future acceleration ramp will be from 160 MeV to 2 GeV

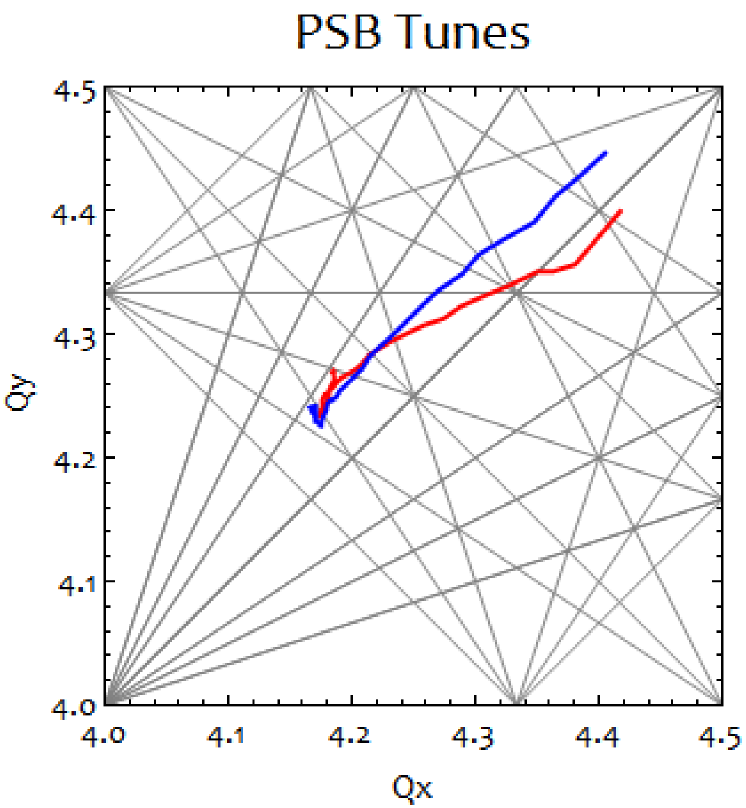


Figure: Tunes through acceleration cycle
Blue: LHC beam, ~150e10 ppp;
Red: Orbit response MD beam, ~30e10 ppp

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

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 ripple, working point, transverse coherent instability

To do after LS1:

- Increase oscillation amplitude for trajectory measurements
- Measure trajectories with all 16 BPMs
- Correct measured resonances if peaks are clearly visible

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)

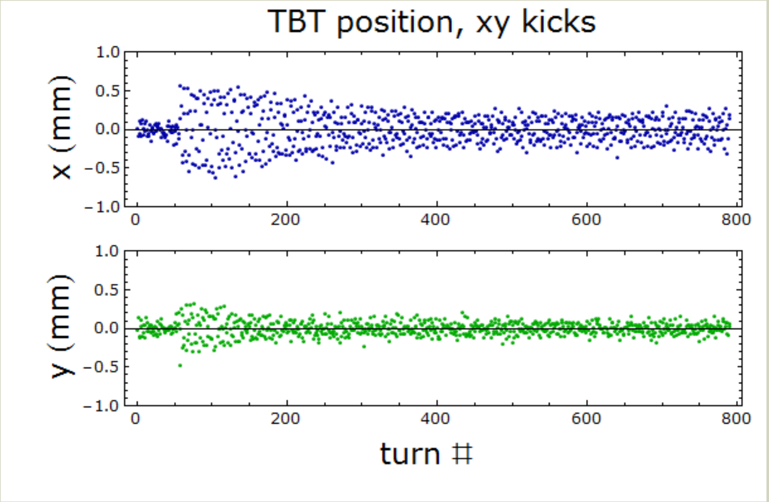


Figure: Beam trajectories after kick

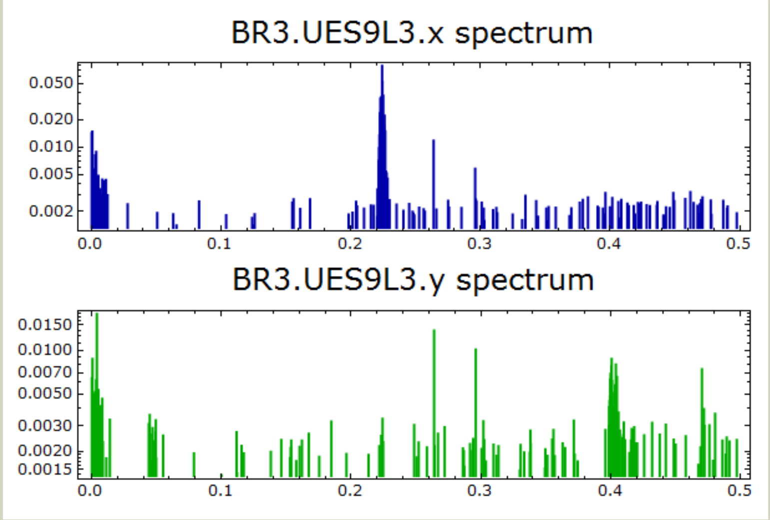
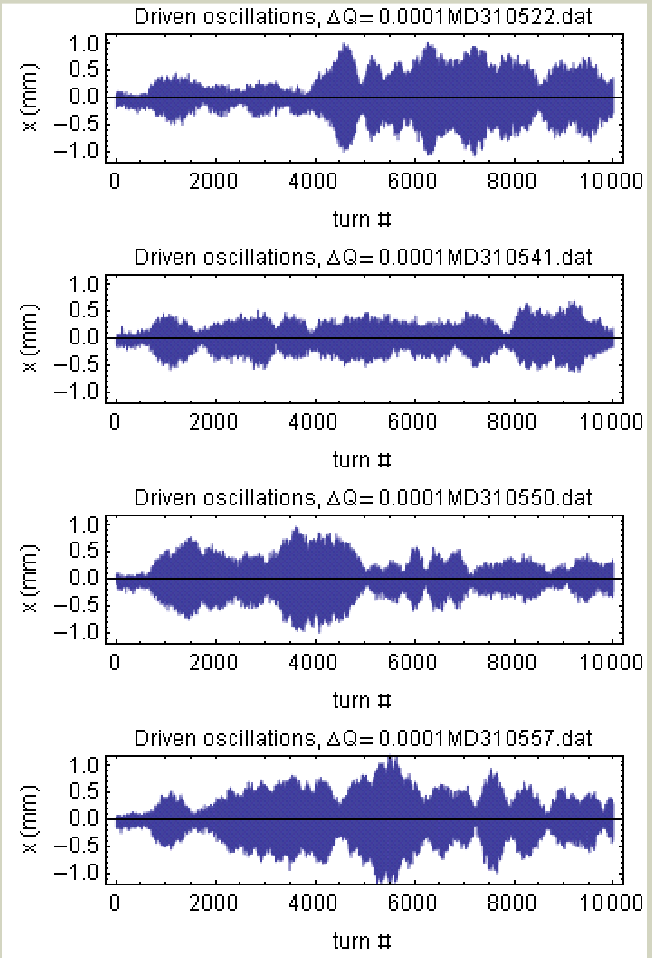


Figure: Spectra of kicked trajectories

Part I: TBT measurements

Driven 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 ripple

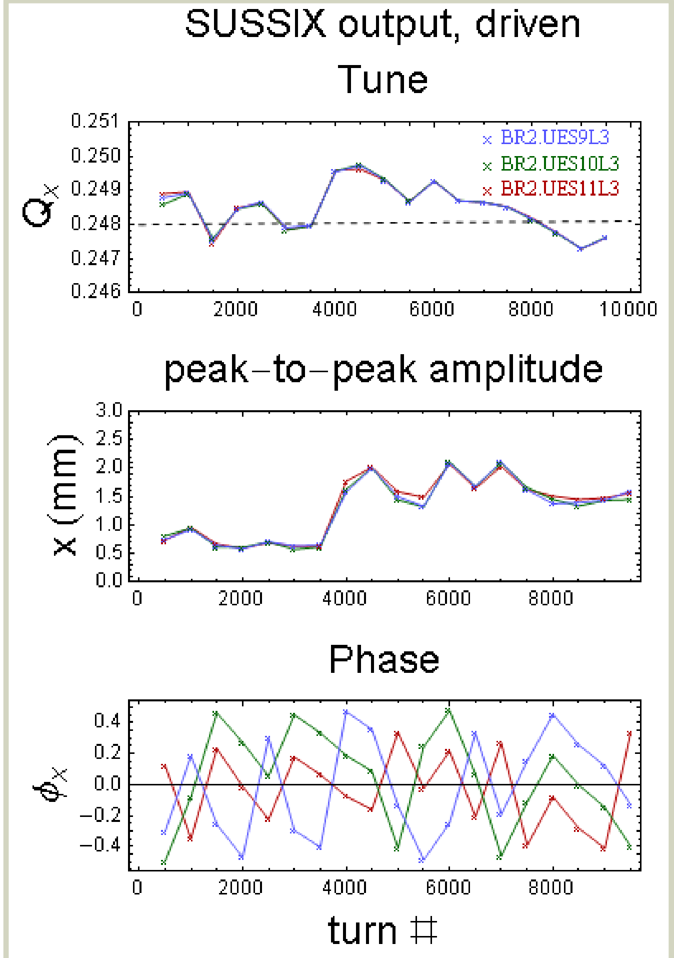


Driven trajectory on several pulses

Part I: TBT measurements

Driven oscillations w/ transverse damper

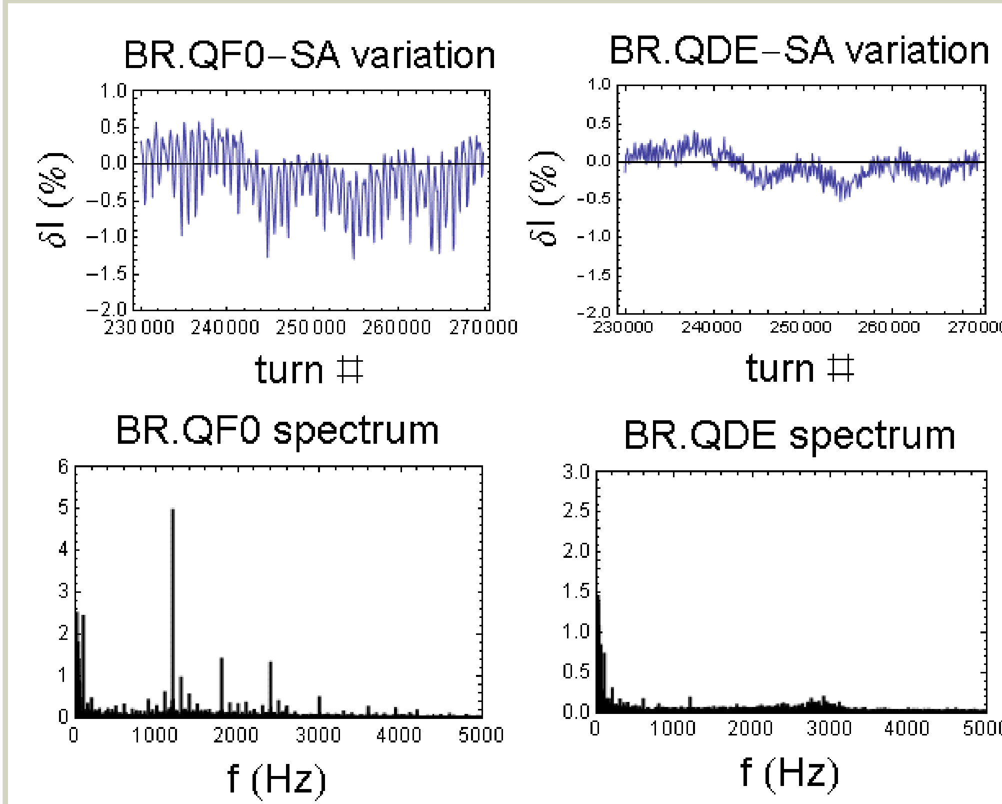
- Driven trajectories analyzed w/ SUSSIX in 500-turn increments
- Driving tune=0.248; natural tune 0.247-0.250
- Measured tune doesn't stabilize; natural tune changes too quickly for transients to decay?



SUSSIX results from driven oscillations

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 variation of ~0.005
- F. Boattini et. al. have found and fixed problem with active filter

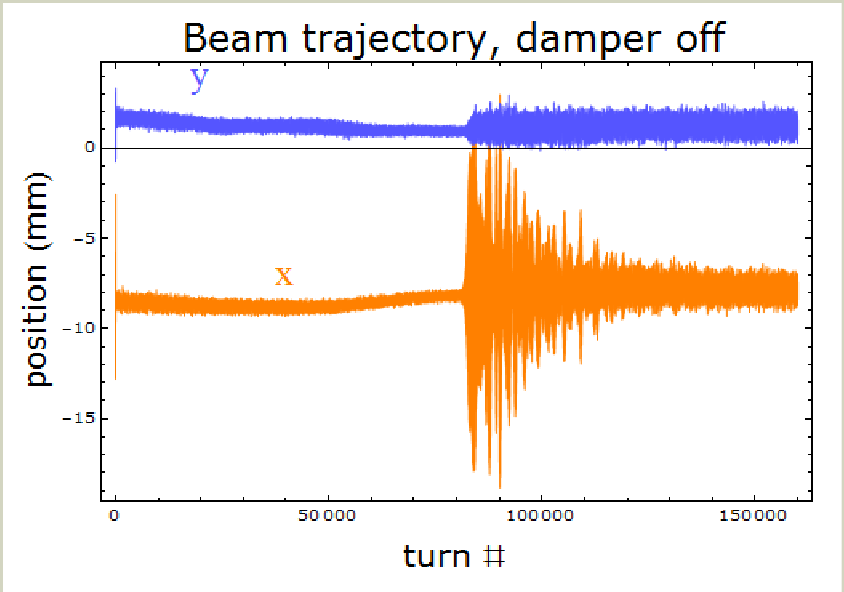


Triplet quadrupole current variation and spectra

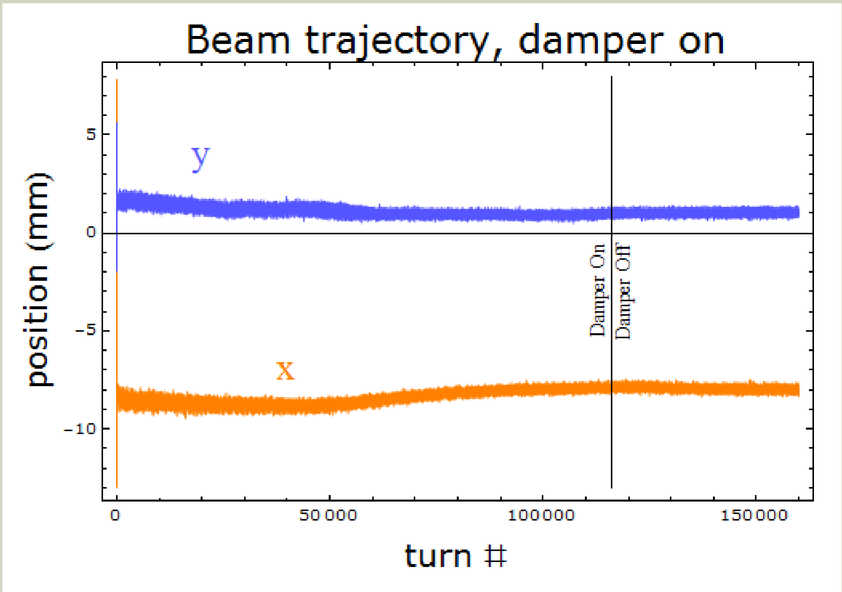
Part I: TBT measurements

"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

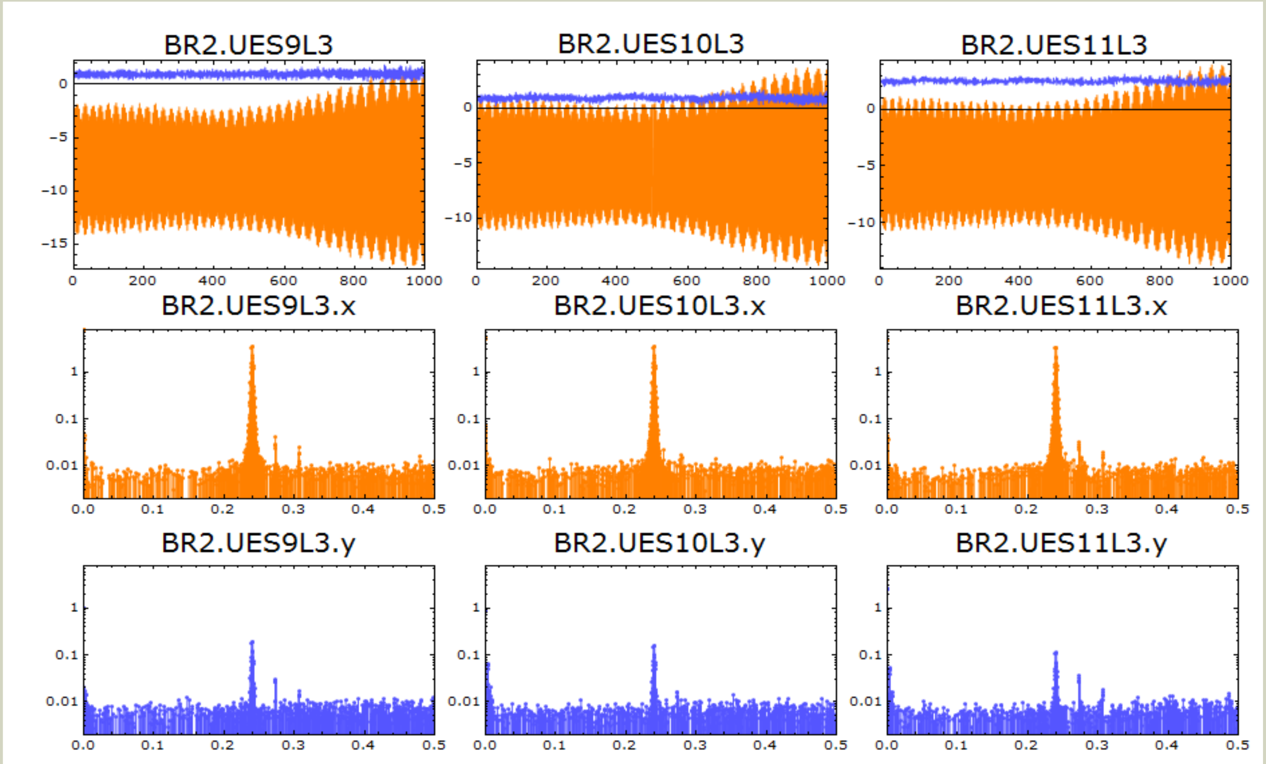


Beam trajectory with transverse damper active until c=424 ms

Part I: TBT measurements

Spectra from transverse instability

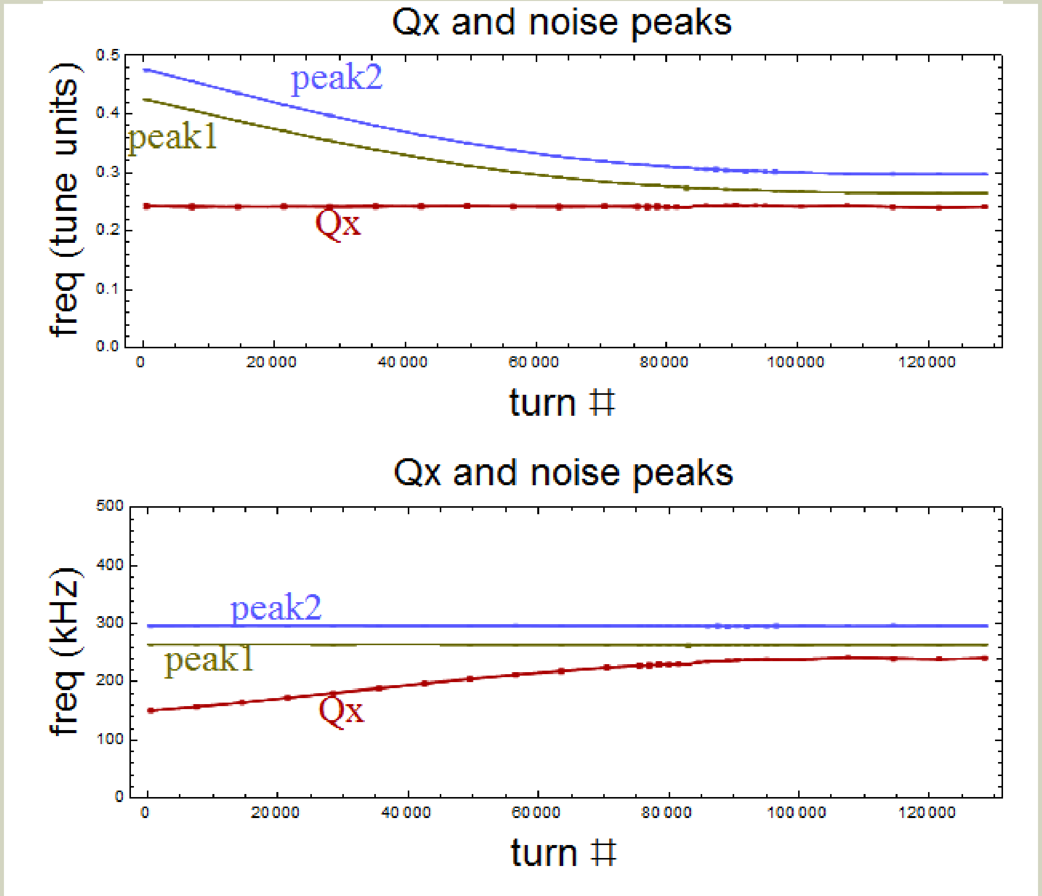
- Two noise peaks visible: 263 kHz and 297 kHz
- Peaks seen clearly in BPMs 9 and 11, less in 10.
- Beat frequency (~60 turn period) visible in all three trajectories.



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

Frequencies from spectra during instability

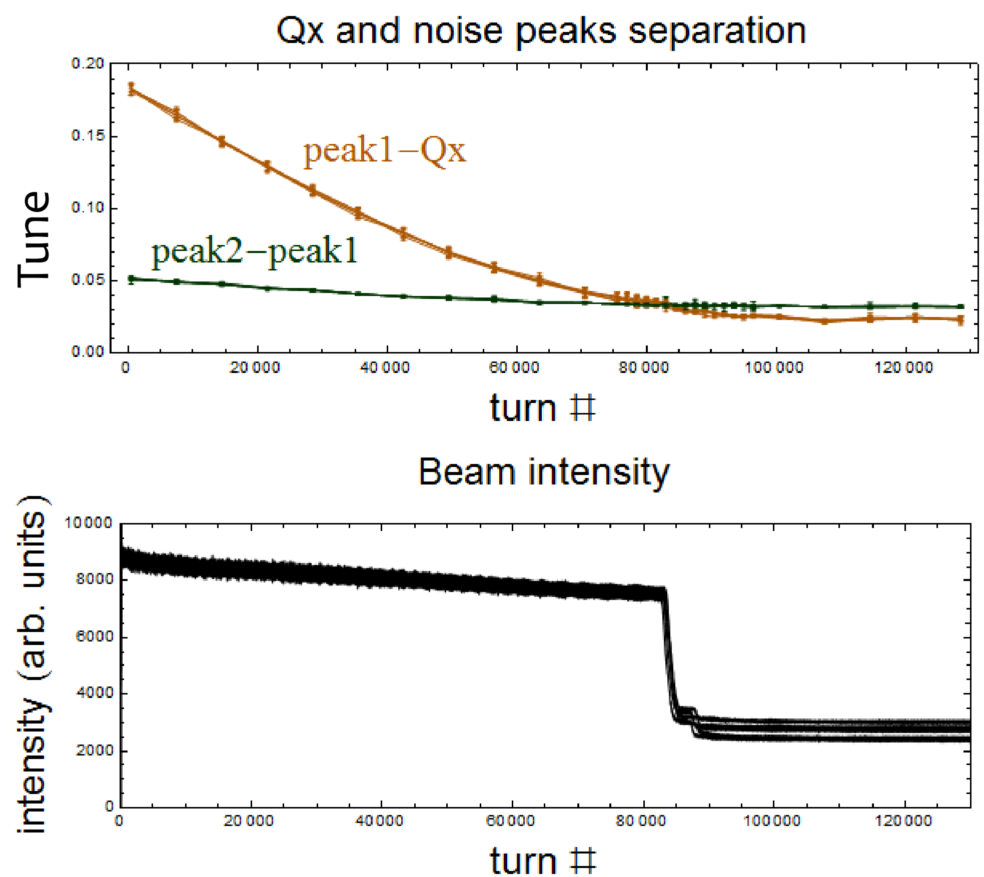
- Plot shows x tune and two "noise" peaks through first 150 ms of acceleration cycle
- Peaks are at constant frequencies (f1~263 kHz and f2~297 kHz) while beam energy ramps up



Tune and "noise" peaks during energy ramp

Observation of transverse instability

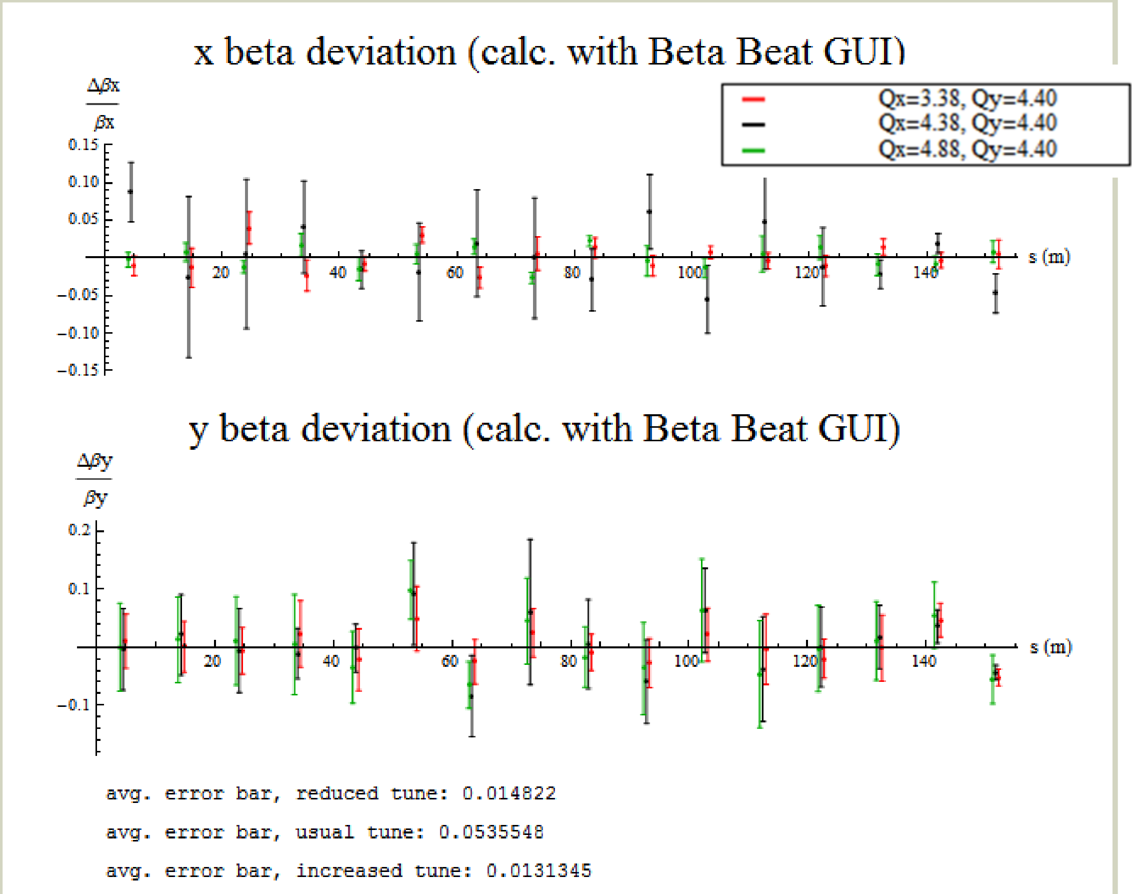
- Beam instability occurs when (f1–Qx)=(f2–f1)
- If transverse damper is left on until just after this point (when noise is closer to Qx), instability is avoided



Tune and beam intensity during energy ramp

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



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:

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

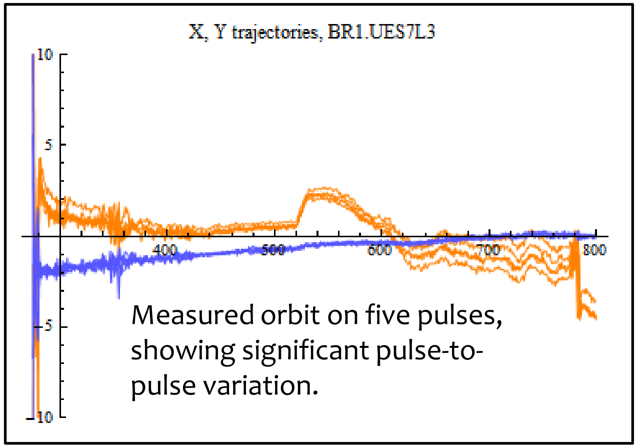
Part II: LOCO
Overview of status/progress

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

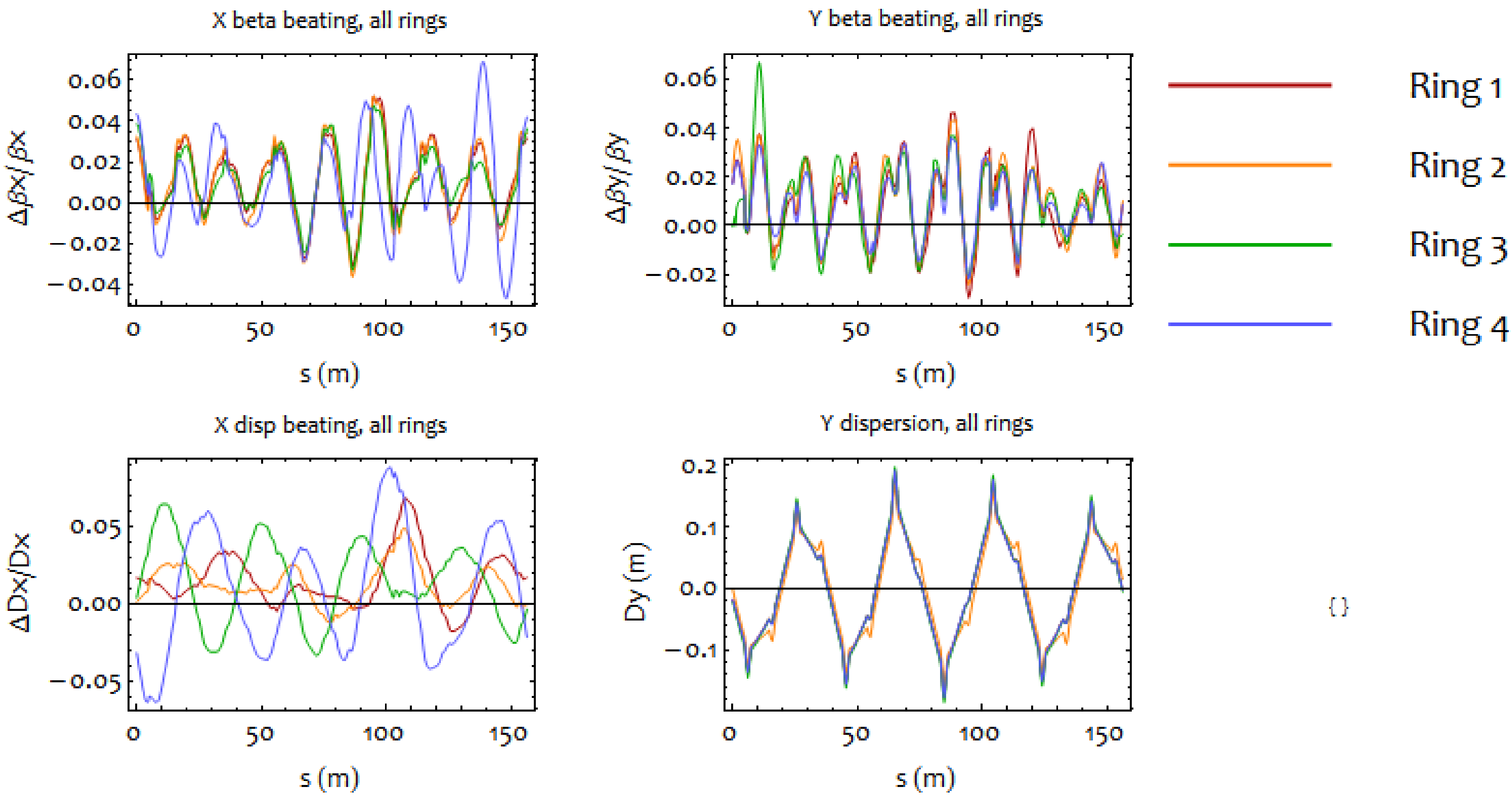
To do after LS1:

- Repeat measurements after realignment of magnets
- Measure at different working points
- Automate data collection process to reduce random errors and make MDs more efficient



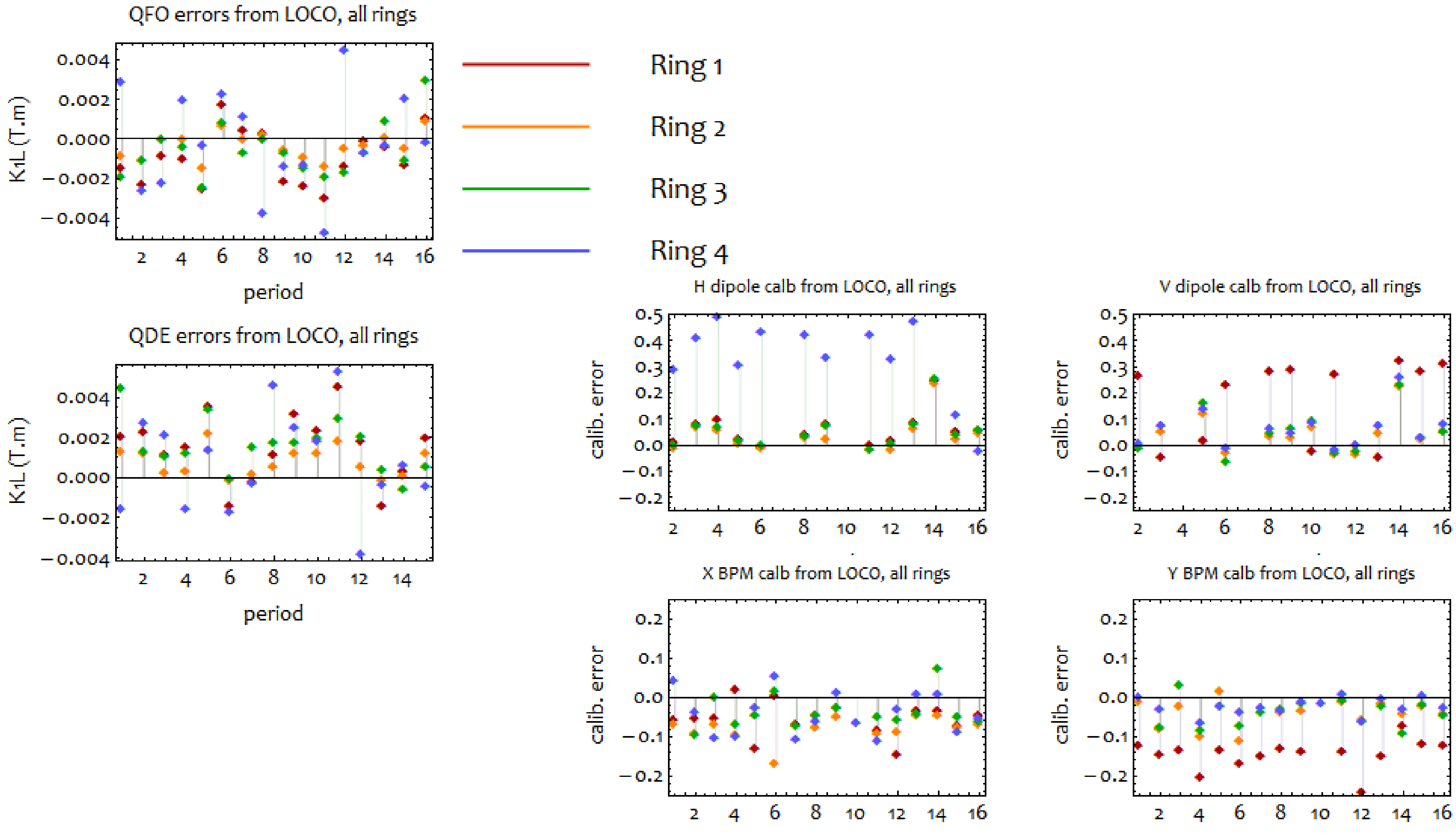
Measured orbit on five pulses, showing significant pulse-to-pulse variation.

Optics from calibrated model



Part II: LOCO

Model calibration parameters from LOCO

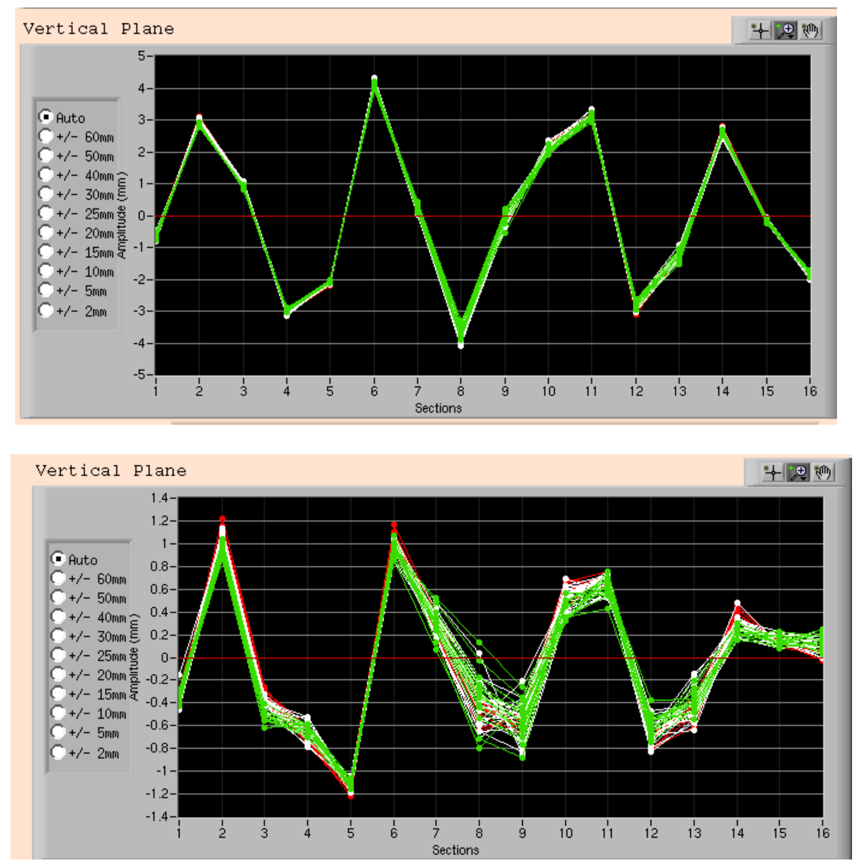


Part II: LOCO

Orbit correction with YASP

(J. Wenninger, J.F. Comblin, G. Kruk, B. Mikulcek, 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)
- 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)
  - Speed up data collection and make MDs more efficient
  - Allow for collection of more data points, to reduce effects of random orbit fluctuations and make measurements more precise
- Measurements will be made at multiple working points
- BPMs will be restricted to measuring trajectory at relatively high intensity; investigating effects of space charge on driven beam spectra (with E. Benedetto)

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

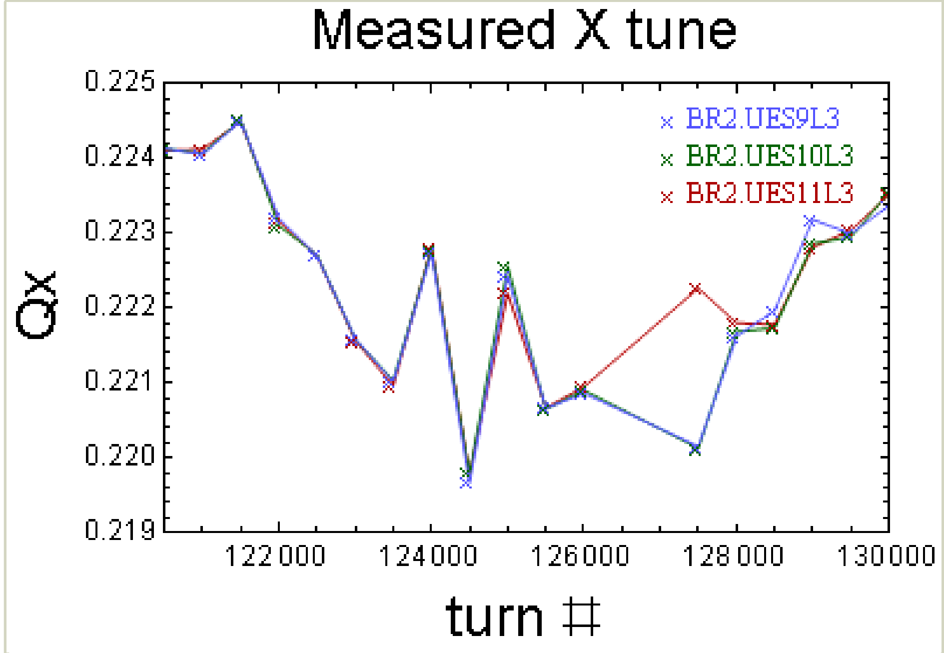
Thanks to:
J. Belleman
C. Carli
A. Findlay
B. Mikulec
R. Tomás
PSB ops group

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

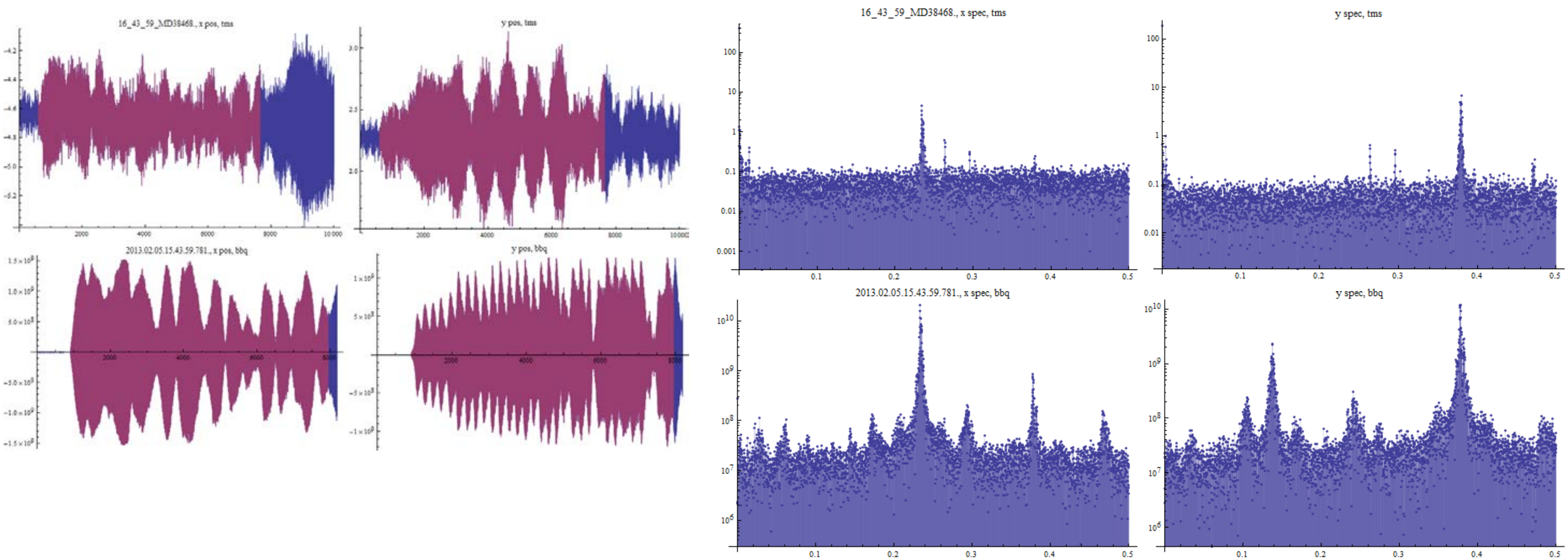


SUSSIX tune, with free oscillations

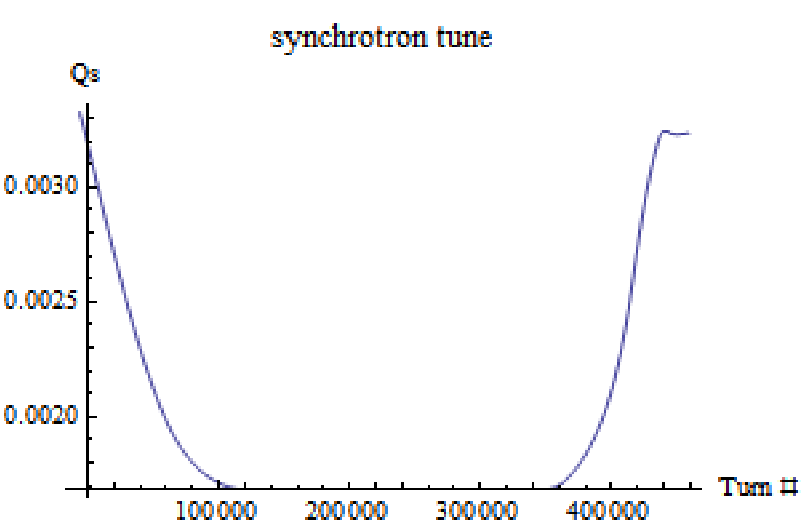
Backup slide:

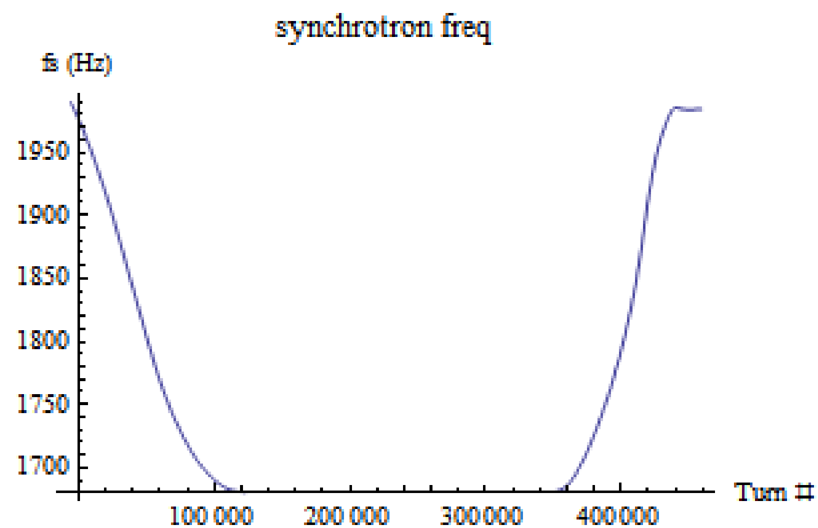
Comparison of TMS and Qmeter

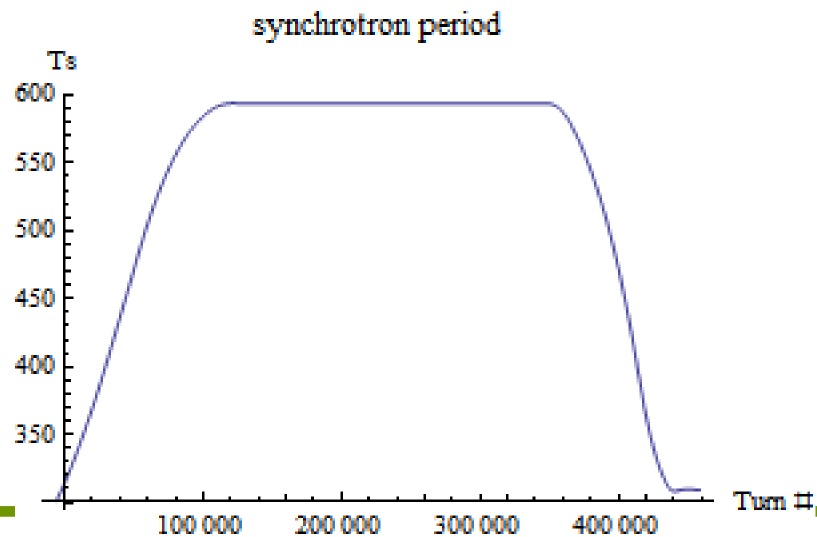
- Trajectories and spectra from TMS (upper plots) and from Q meter (lower plots)
- Beam driven very close to Qx and Qy



Backup slide:
Synchrotron motion, 160 MeV cycle



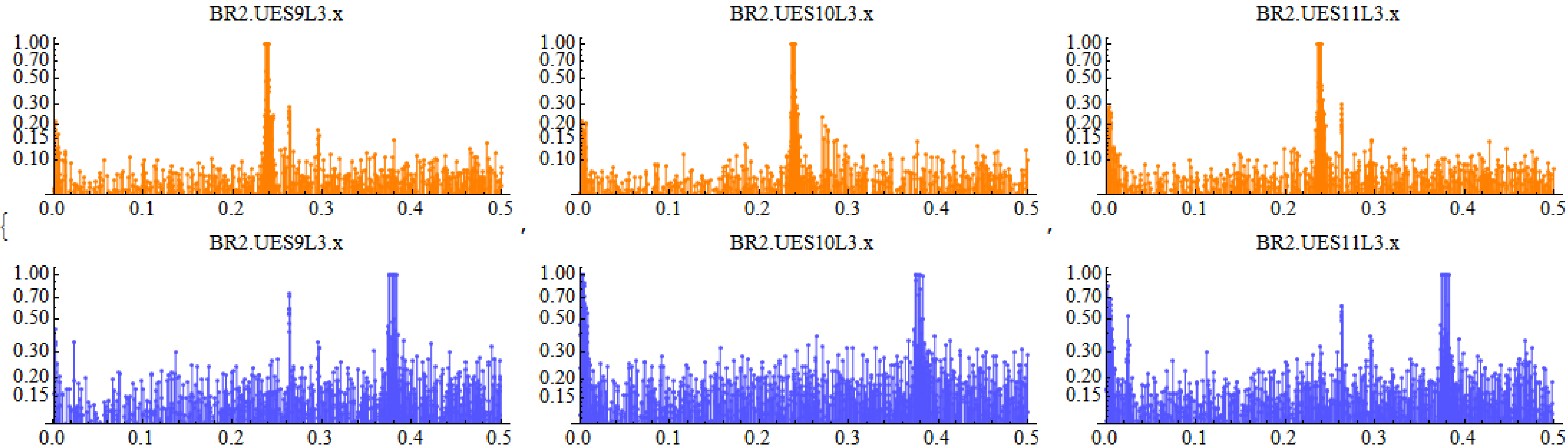




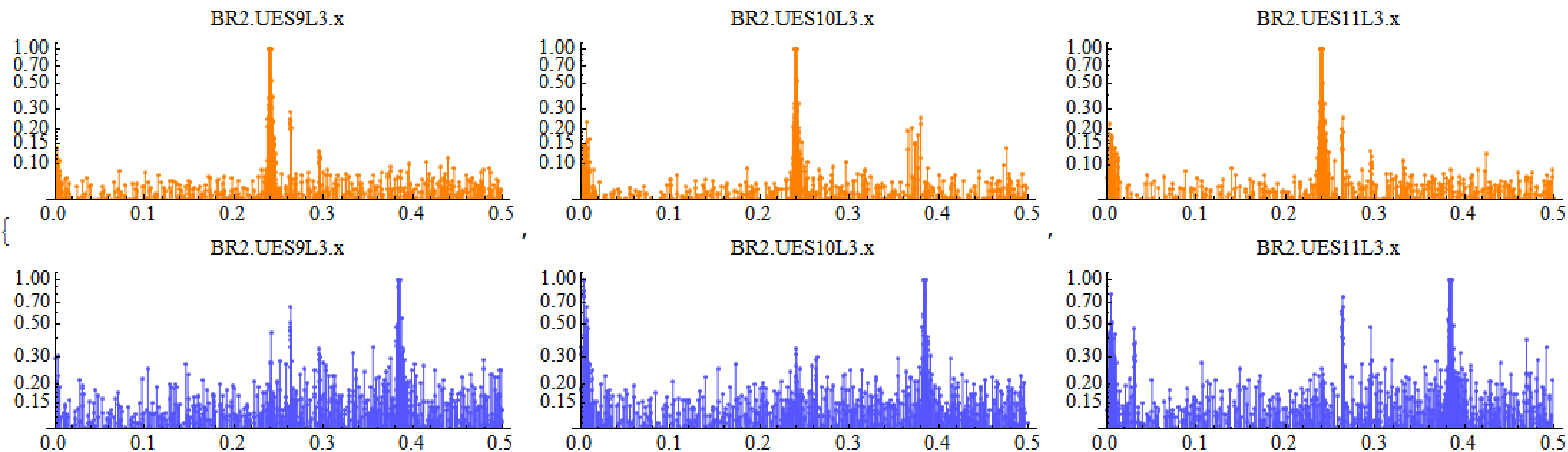
Backup slide:

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

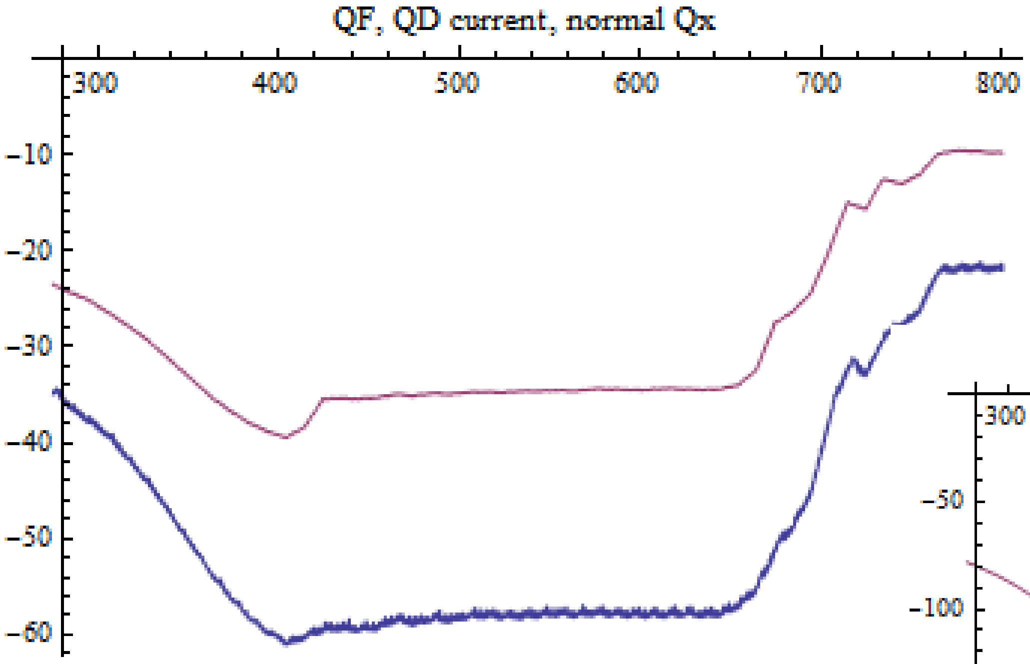
Spectra, altered tune (Qx=3.23, Qy=4.38)

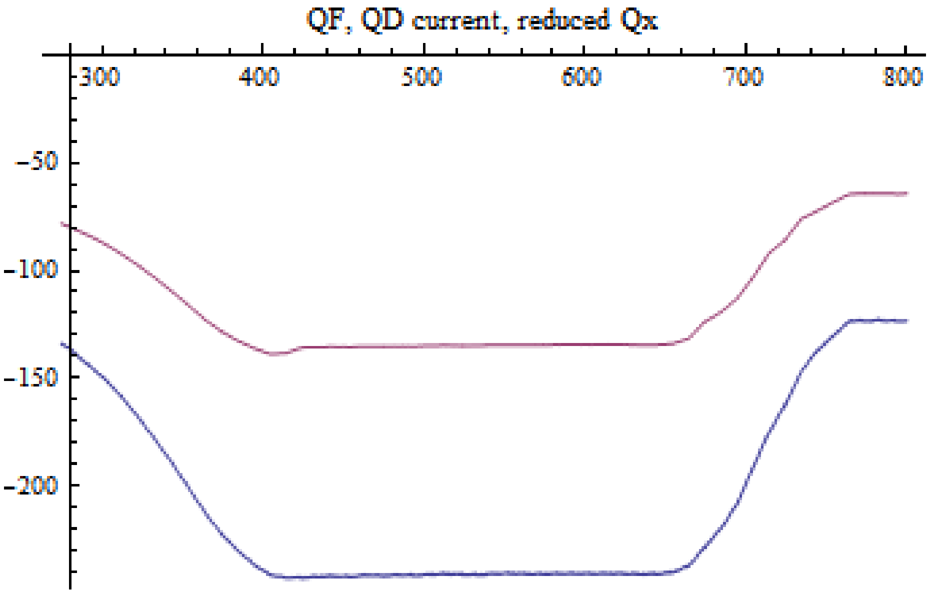


Spectra, normal tune (Qx=4.23, Qy=4.38)

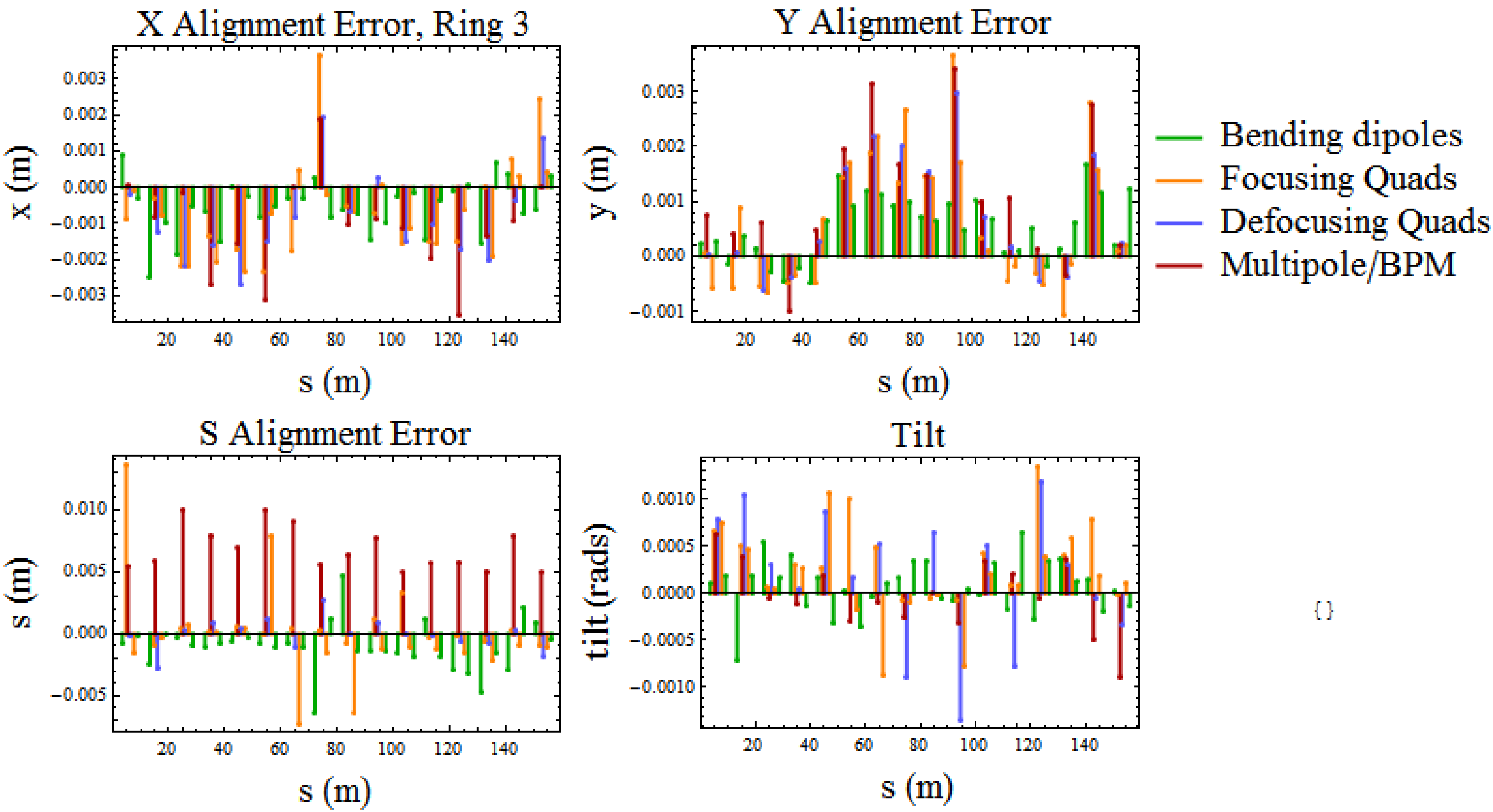


Backup slide:
Quad currents w/ dQx=-1.0





Backup slide:
Alignment survey (before LS1 realignment)



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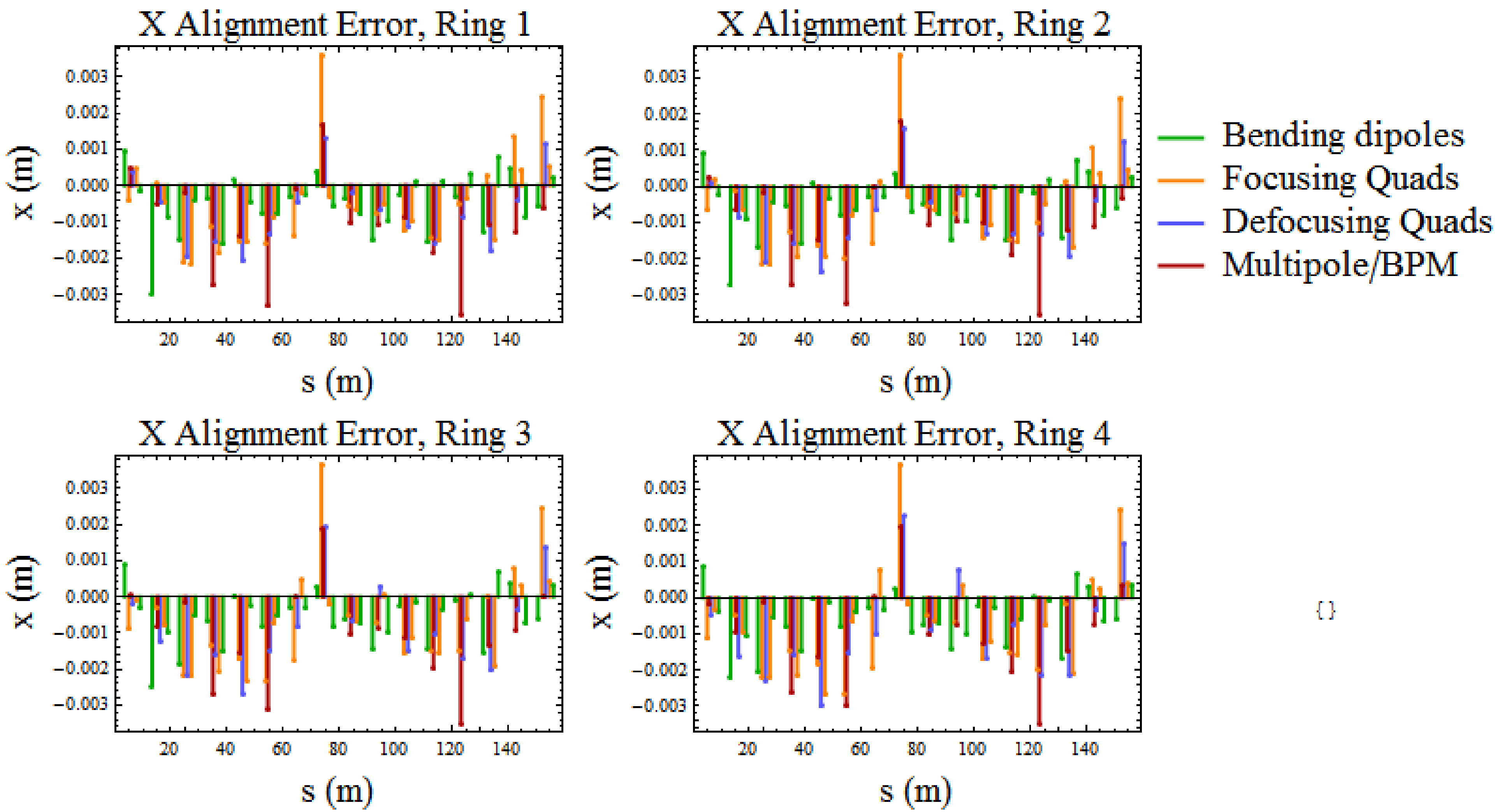

Backup slide:
Optics with alignment errors