Status of optics measurements

Piotr Skowronski &

Ana Garcia-Tabares Valdivieso &

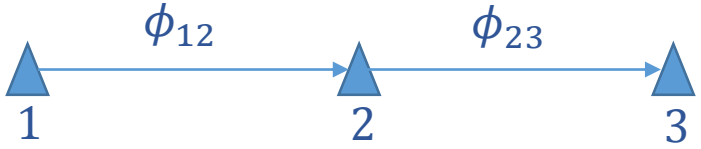
2018 September 10

Large Hadron Collider Injector Upgrade - Proton Synchrotron Booster Beam Dynamics Working Group

Intro

- The problem:
  Phase advance between consecutive BPMs in the nominal Q4Q4 optics is too close to $\pi/2$

$$\beta_{2me} = \beta_{2mo} \frac{cot\phi_{12me} + cot\phi_{23me}}{cot\phi_{12mo} + cot\phi_{23mo}}$$



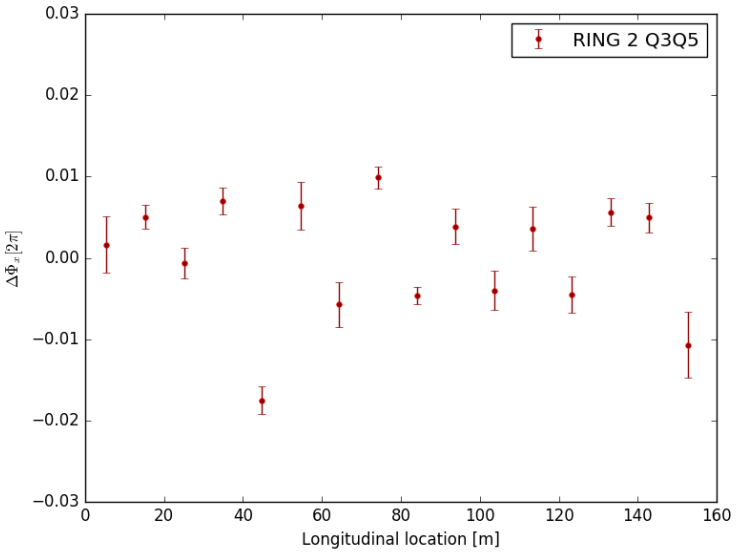
- Recent measurements
  - 160 MeV (Ana):
    - Q3Q5 optics to find BPM calibration factors as accurate as possible
    - Q4Q4 with the same intensity right after, getting beta from amplitude
      - The same intensity and BPM gains in both measurements
  - 1.4 GeV (Piotr):
    - Do saturation effects induce any beta beating at flattop?

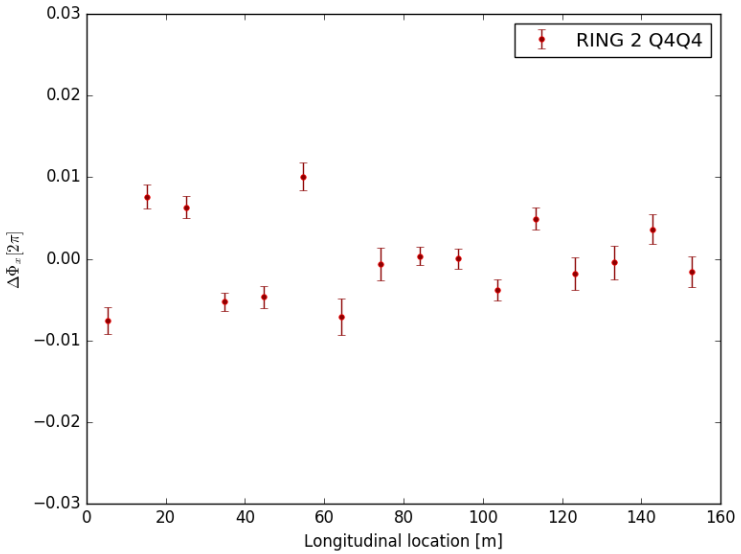
160 MeV measurements

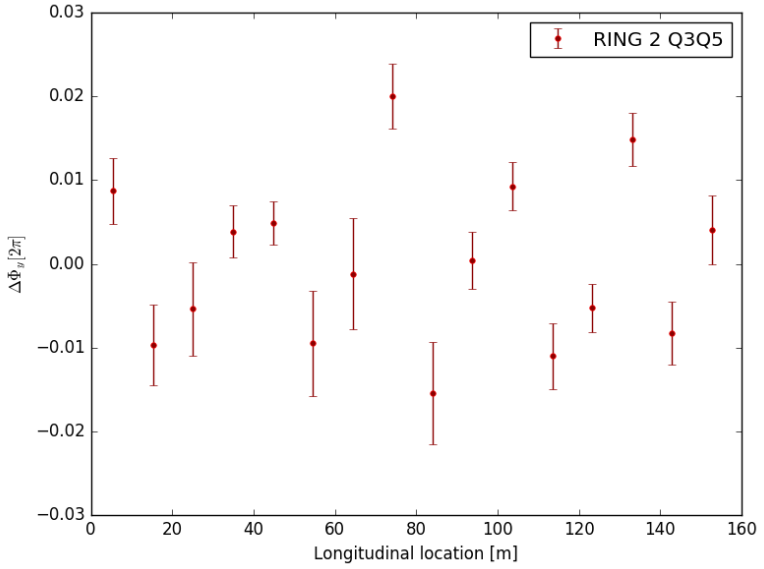
- The calibration measurements performed on 08/08/2018
  Ring 2 @ two different working points:
  - Q3Q5 to compute the BPM calibration factors
  - Q4Q4 to measure beta from amplitude using the correct BPM calibration factors
- Data quality
  - On the 4 BPMs attached to radial feed-back there were spikes
  - Larger fluctuations (between consecutive measurements) have also been observed in Q3Q5 optics
- Analysis of beta-beating
  - The number of BPMs using in the analysis has been reduced to 5
    - 2 to the left and 2 to the right of the BPM being analyzed
  - It increases the error bar but has less dependency on the model knowledge

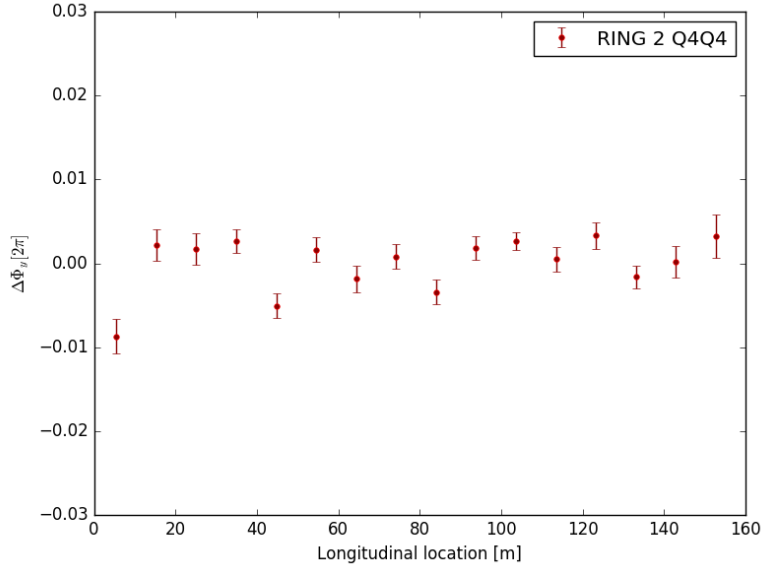
Analysis of the phase stability

- Difference between measured phase advance between
  - consecutive BPMs and
  - phase advance given by MADX model
- **LEFT**: Q3Q5 working point
- **RIGHT**: Q4Q4 working point
- Average phase advance uncertainty
  - Q3Q5
    - horizontal 2.33e-03 [2pi]
    - vertical **4.39e-03** [2pi]
  - Q4Q4
    - horizontal 1.64e-03 [2pi]
    - vertical 1.66e-03 [2pi]
- The Q4Q4 working point is more stable



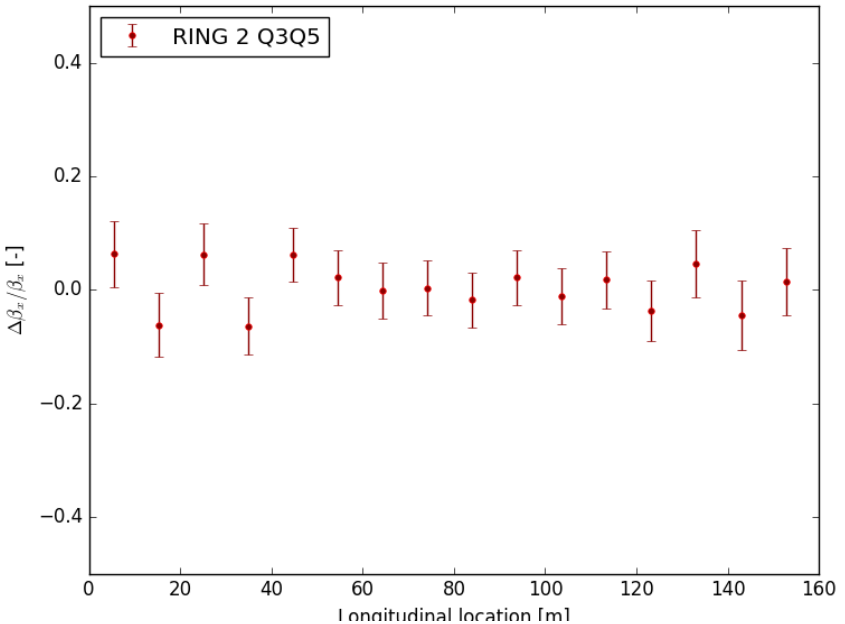


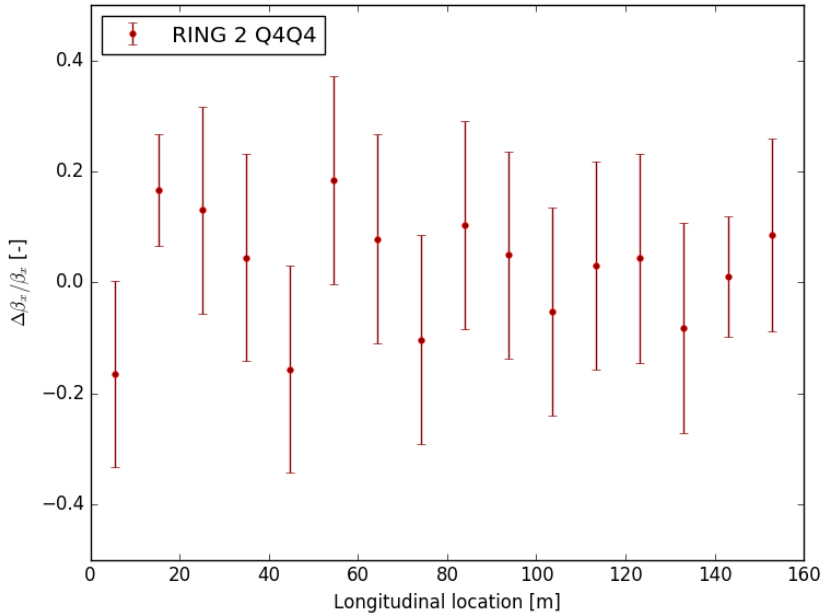


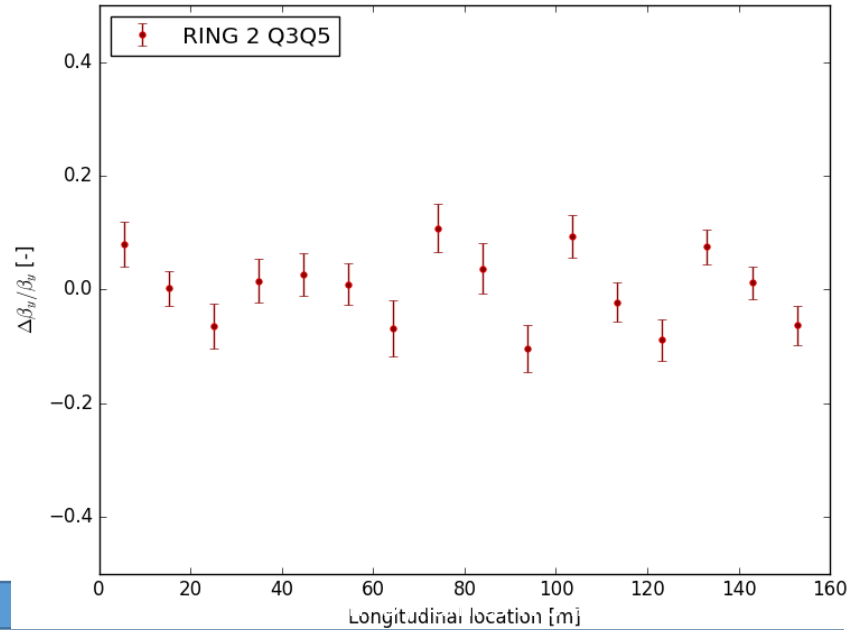


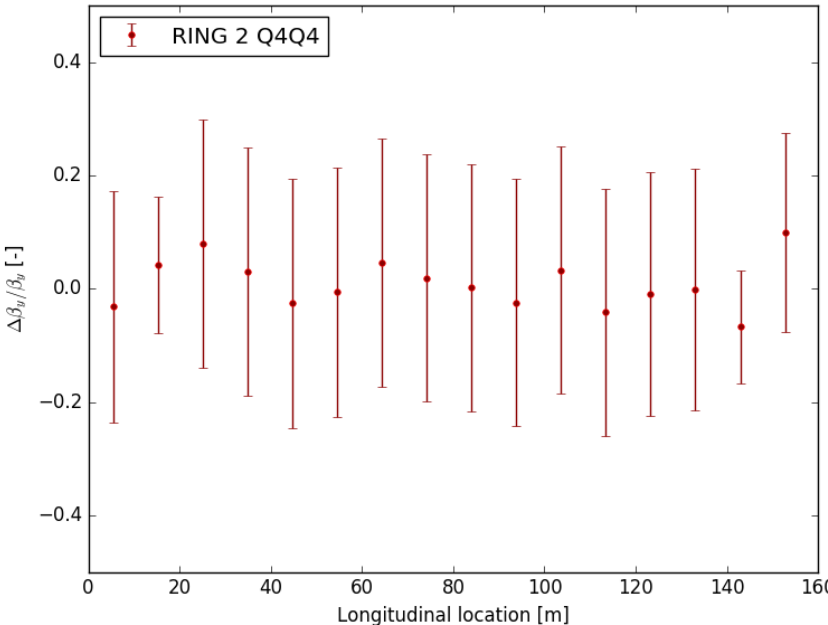
Beta-beating from phase

- Average beta error
  - Q3Q5
    - H: 7.9% for 7.9% beta-beat
    - V: 4.5% for 6.7% beta-beat
  - Q4Q4
    - V: 17% for 10.6% beta-beat
    - V: 20% for 4.5% beta-beat
- Smaller beta-beating error bars in the Q3Q5 are due to the phase advance that is less sensitive to errors.
- Nonetheless, a better stability of this working point would improve the quality of the beta reconstruction

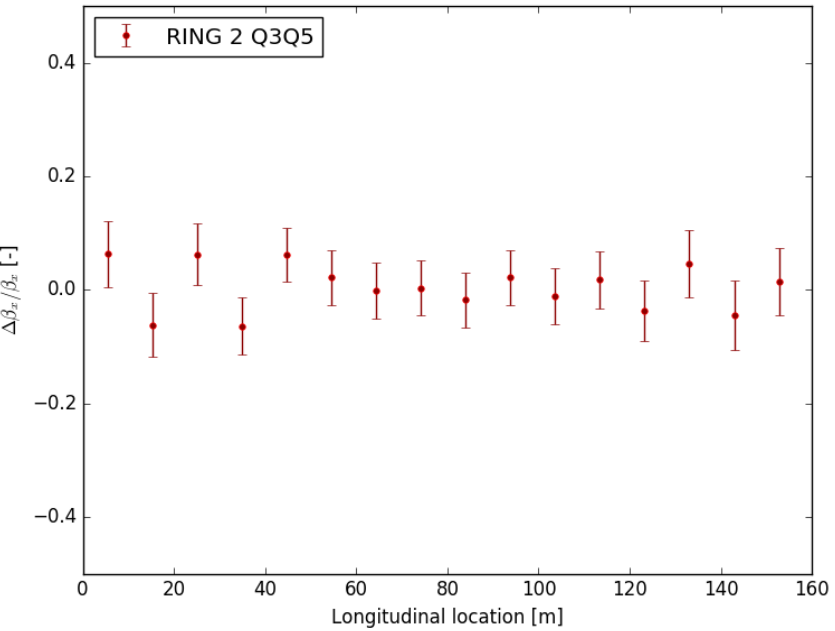


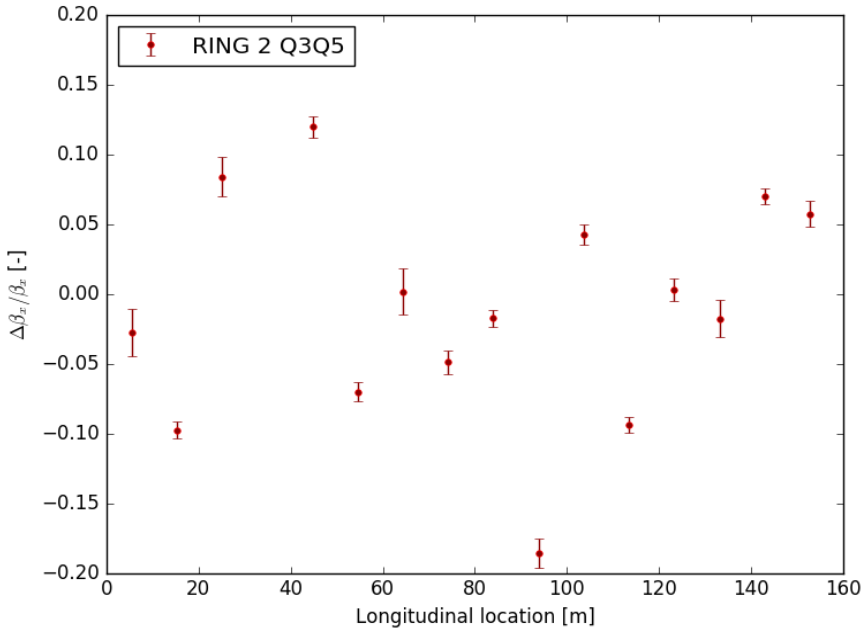


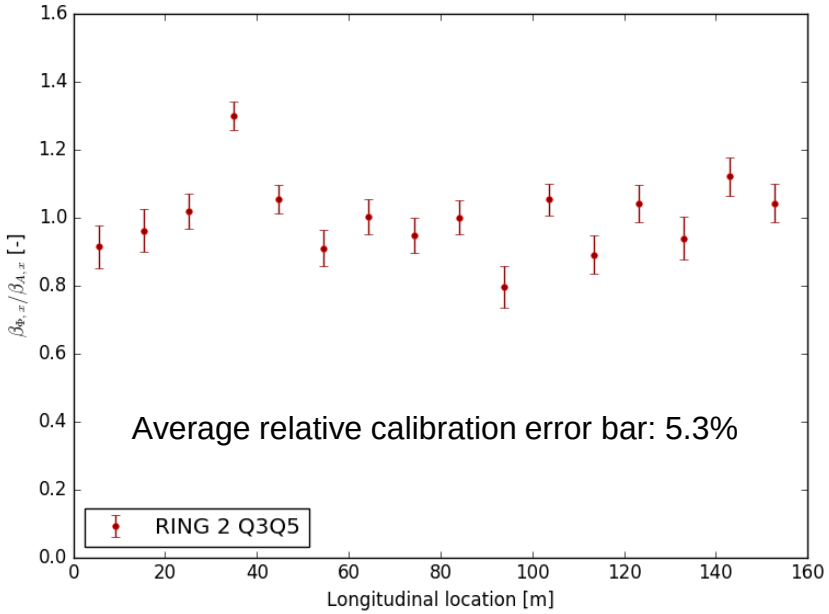


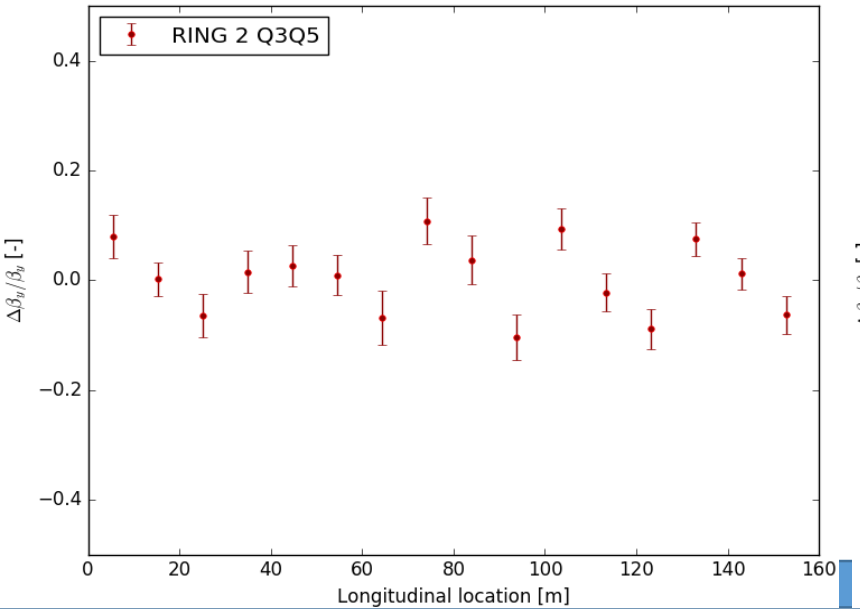


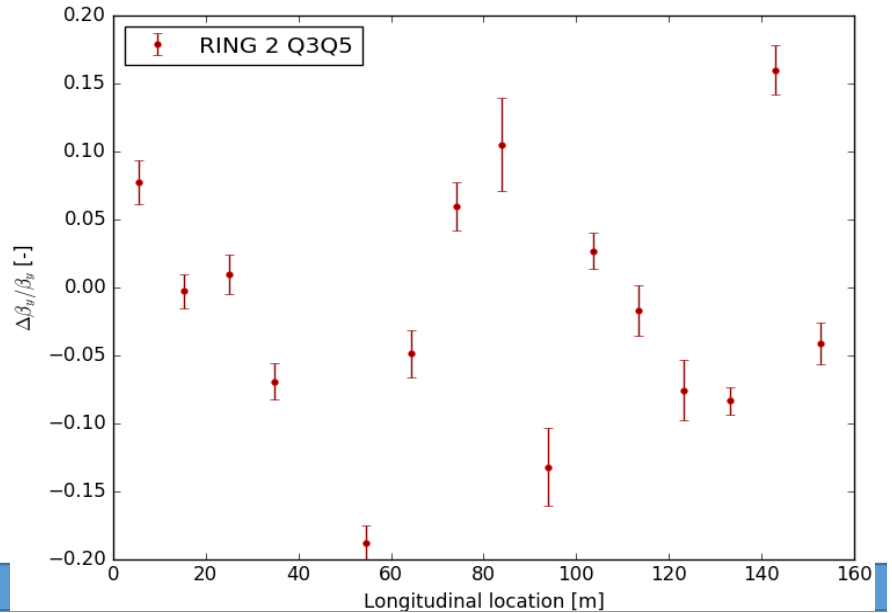
β from phase / β from amplitude = cal. factors

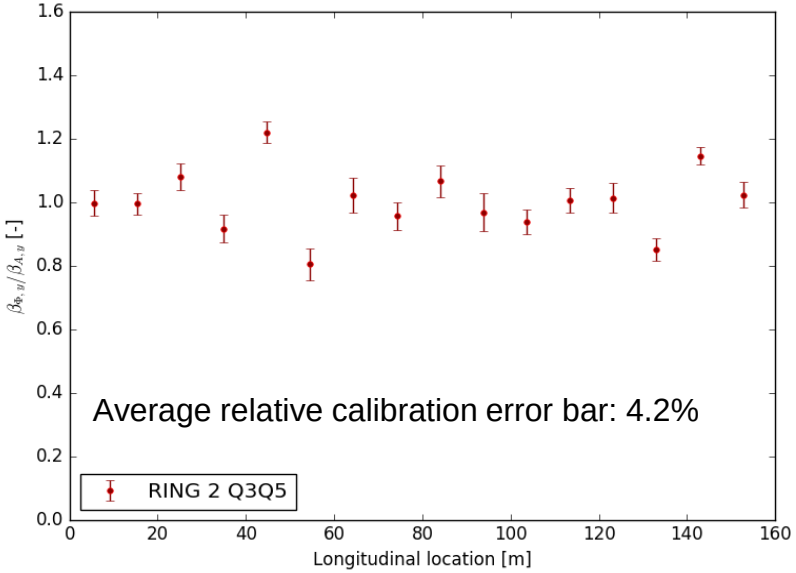






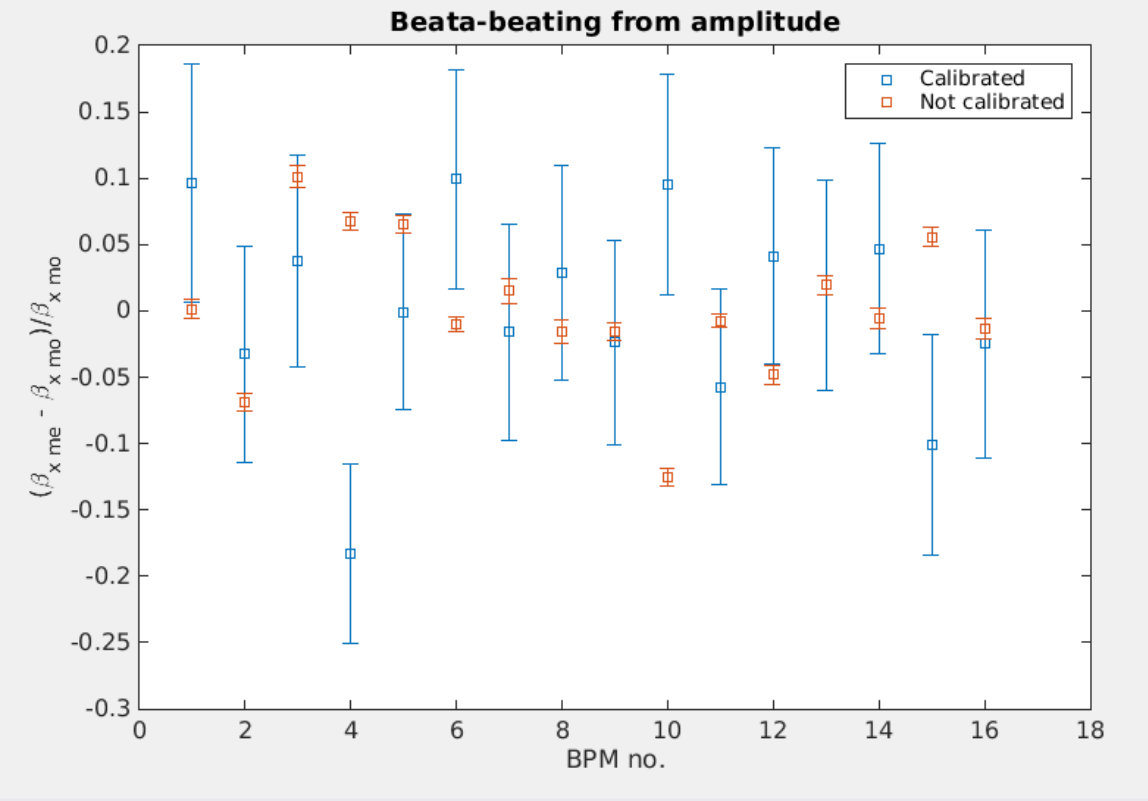


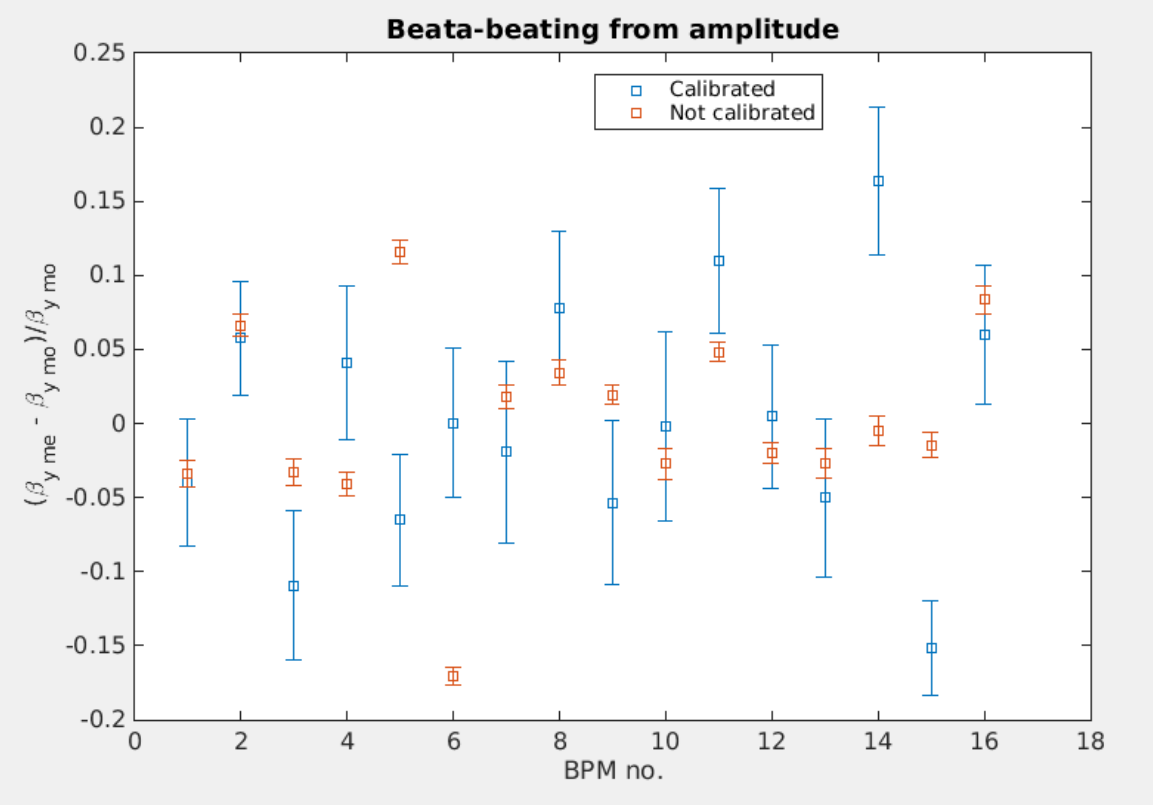




Q4Q4 Beta-beating from calibrated amplitude

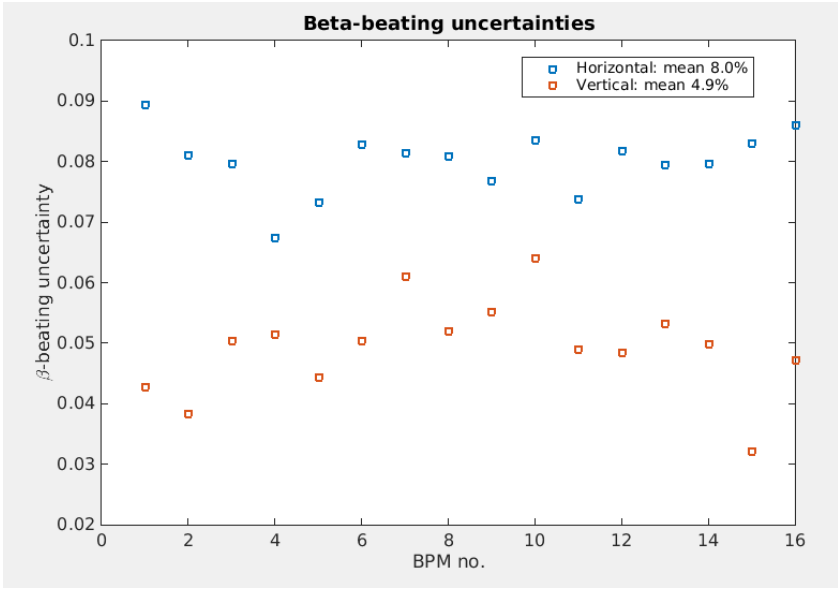
- The average beta-beating increases after applying the calibration factors
  - Horizontal
    - Q4Q4 not calibrated : 5.3%
    - Q4Q4 calibrated : 7.3%
    - Q3Q5 : 9.4%
  - Vertical
    - Q4Q4 not calibrated : 6.3%
    - Q4Q4 calibrated : 7.8%
    - Q3Q5 : 10.8%

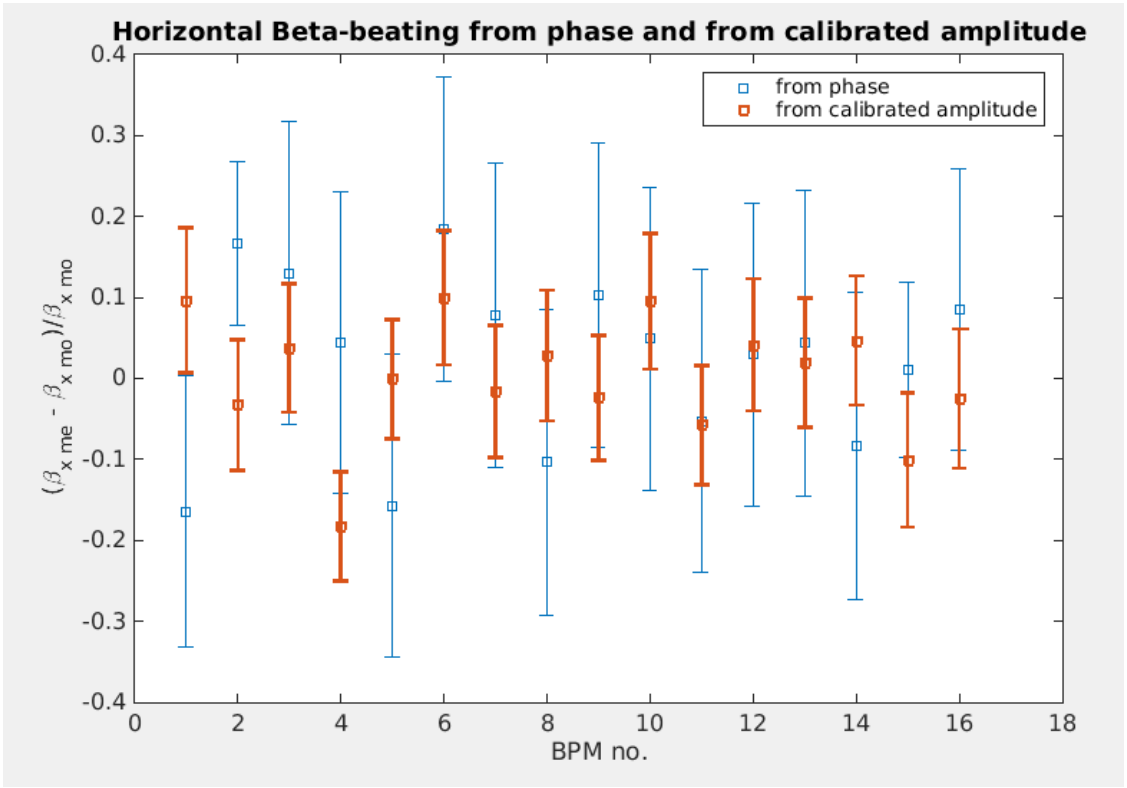


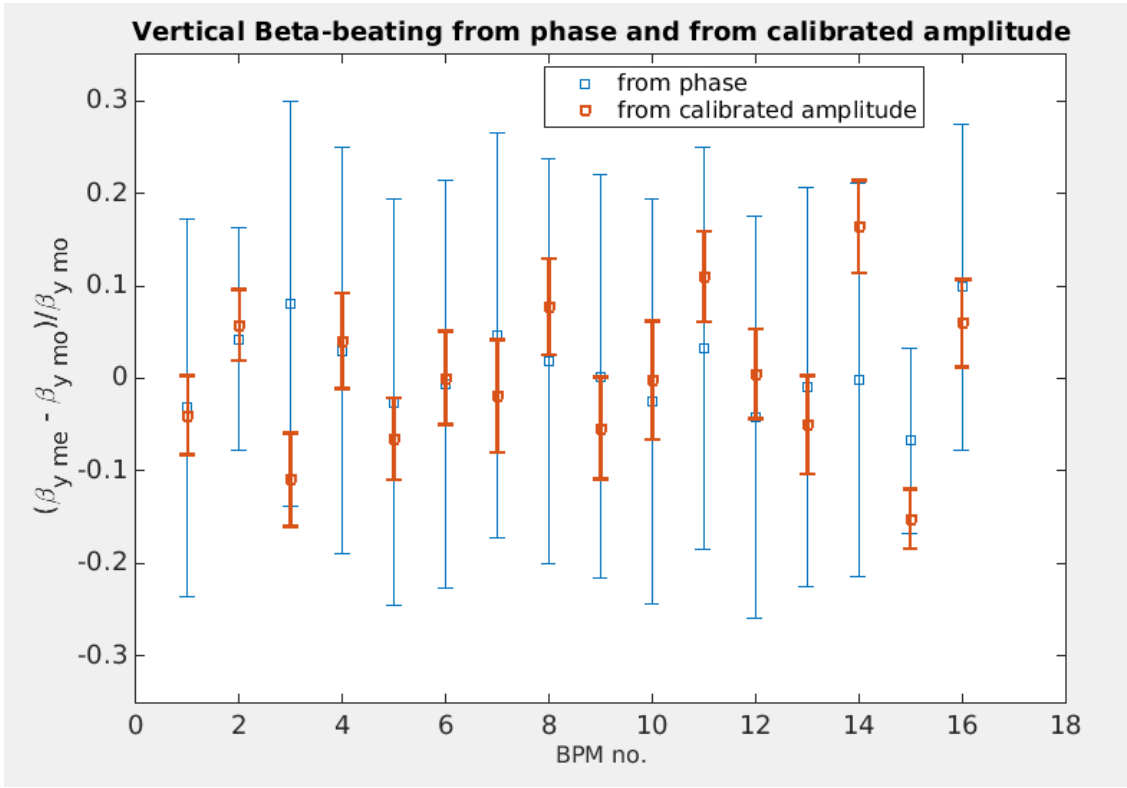


The result

- Uncertainty is reduced to
  - 8% in horizontal
  - 5% in vertical







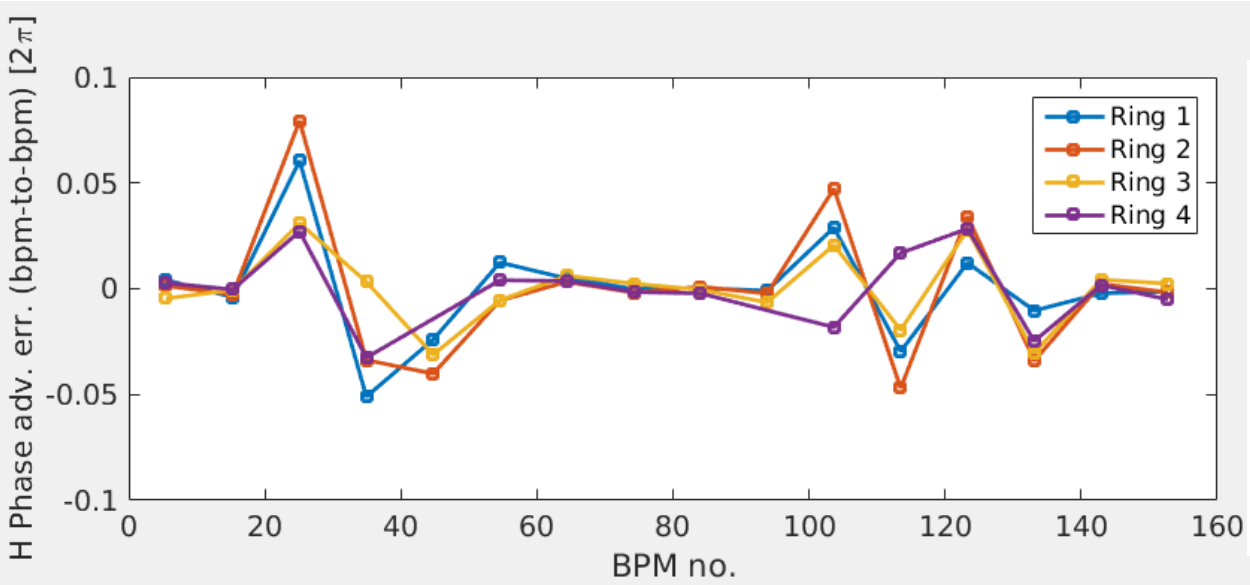
Error bars to do

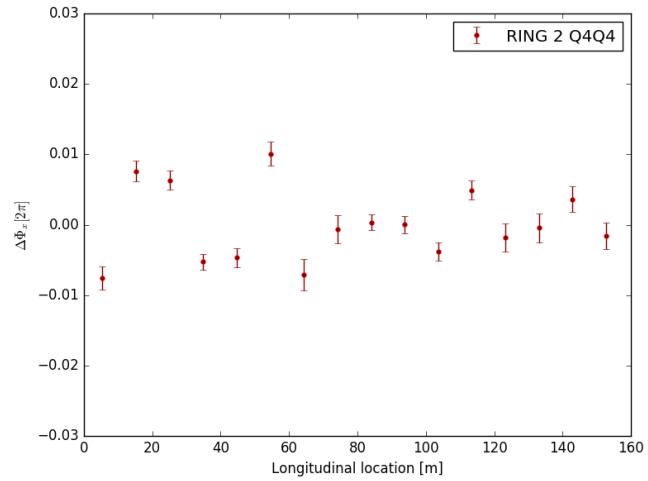
- Currently we use RMS for error bar
  - Because it describes what is the spread of the beta-beating
- For determination of the calibration factor rather error of the mean should be used
  - The mean phase and amplitude is better determined when measuring more pulses
- And we should select only the best shots for the analysis

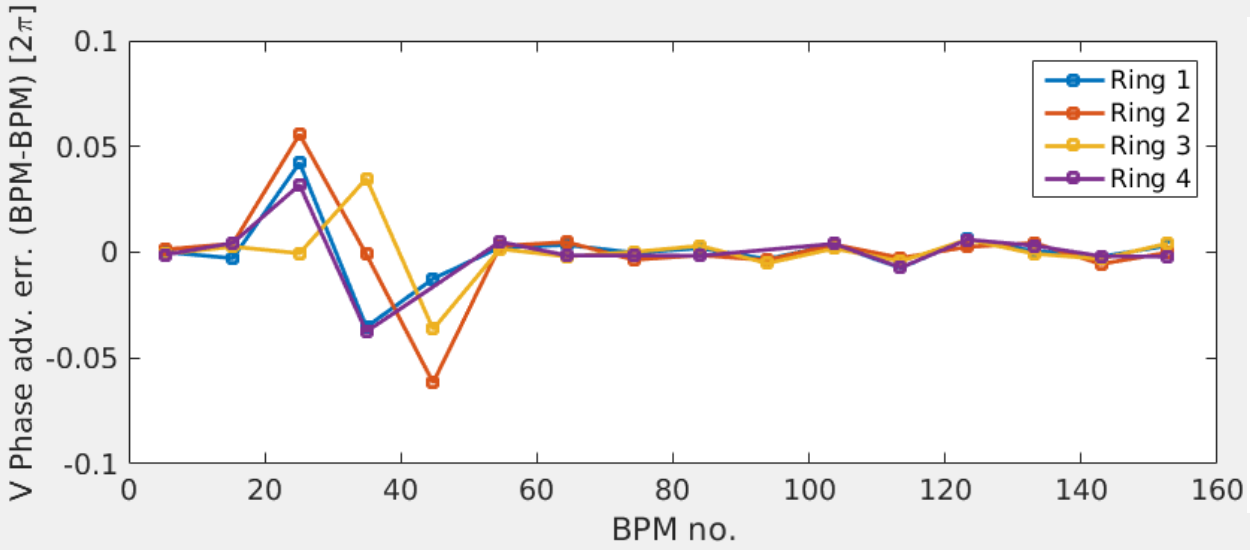
1.4 GeV: phase beating (BPM-to-BPM)

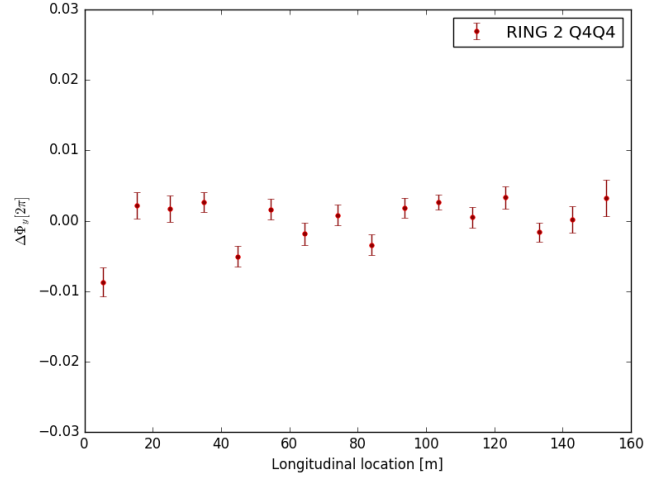
- Order of magnitude larger than at 160 MeV

160 MeV



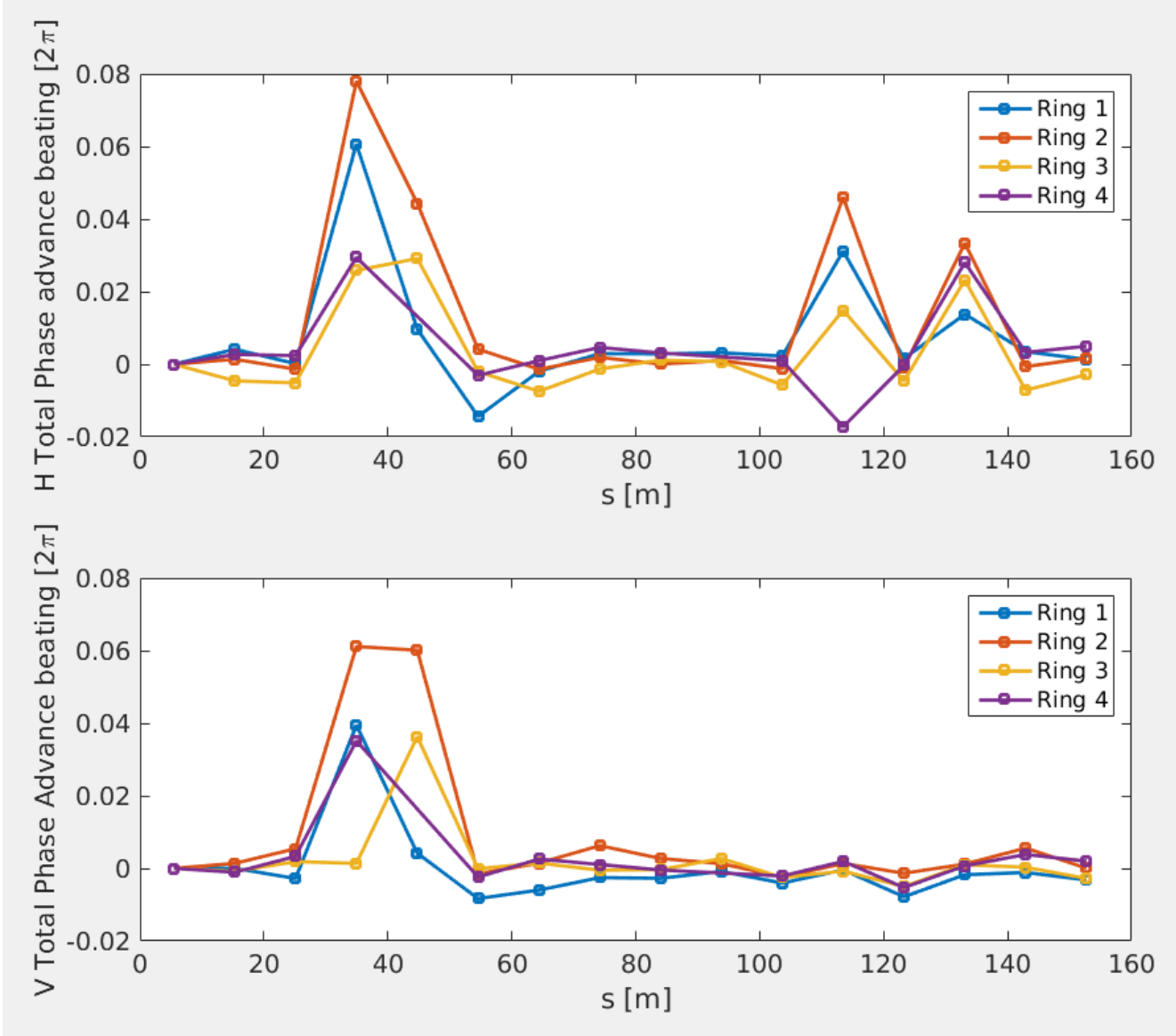






1.4 GeV: phase beating (total)

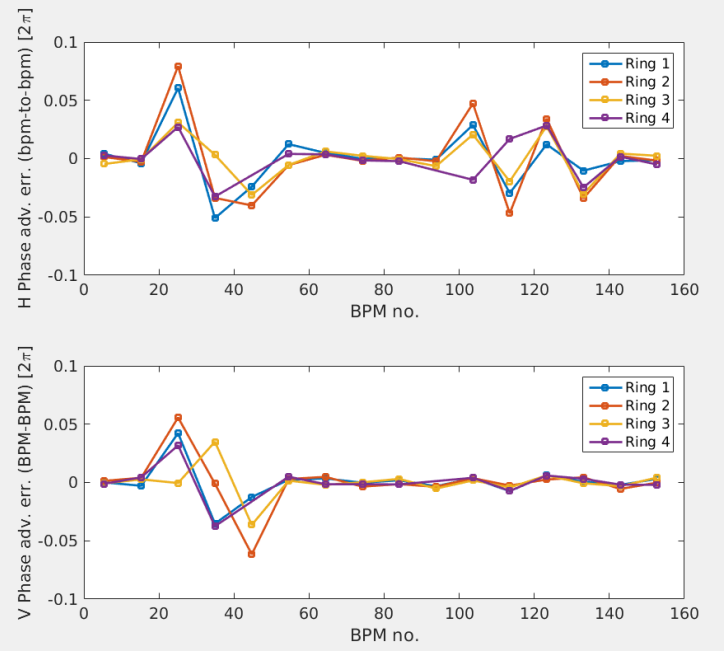
- Order of magnitude larger than at 160 MeV
- Localized within 3 sectors
- Injection and wire-scanner locations have small errors
- Accident or intentional setup?
  - That nobody remembers now

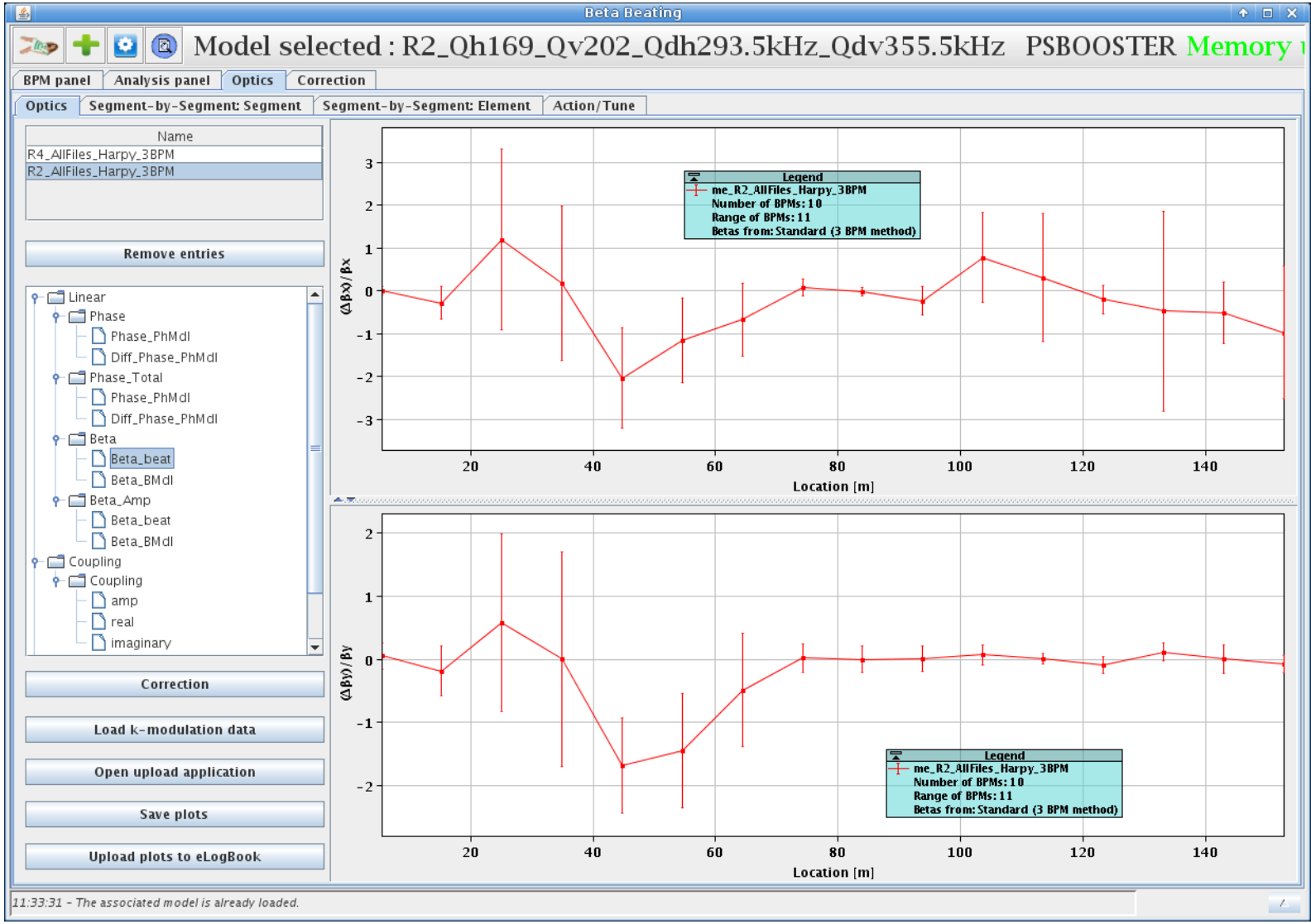


Beta from phase

- **Formula fails: unphysical negative beating**

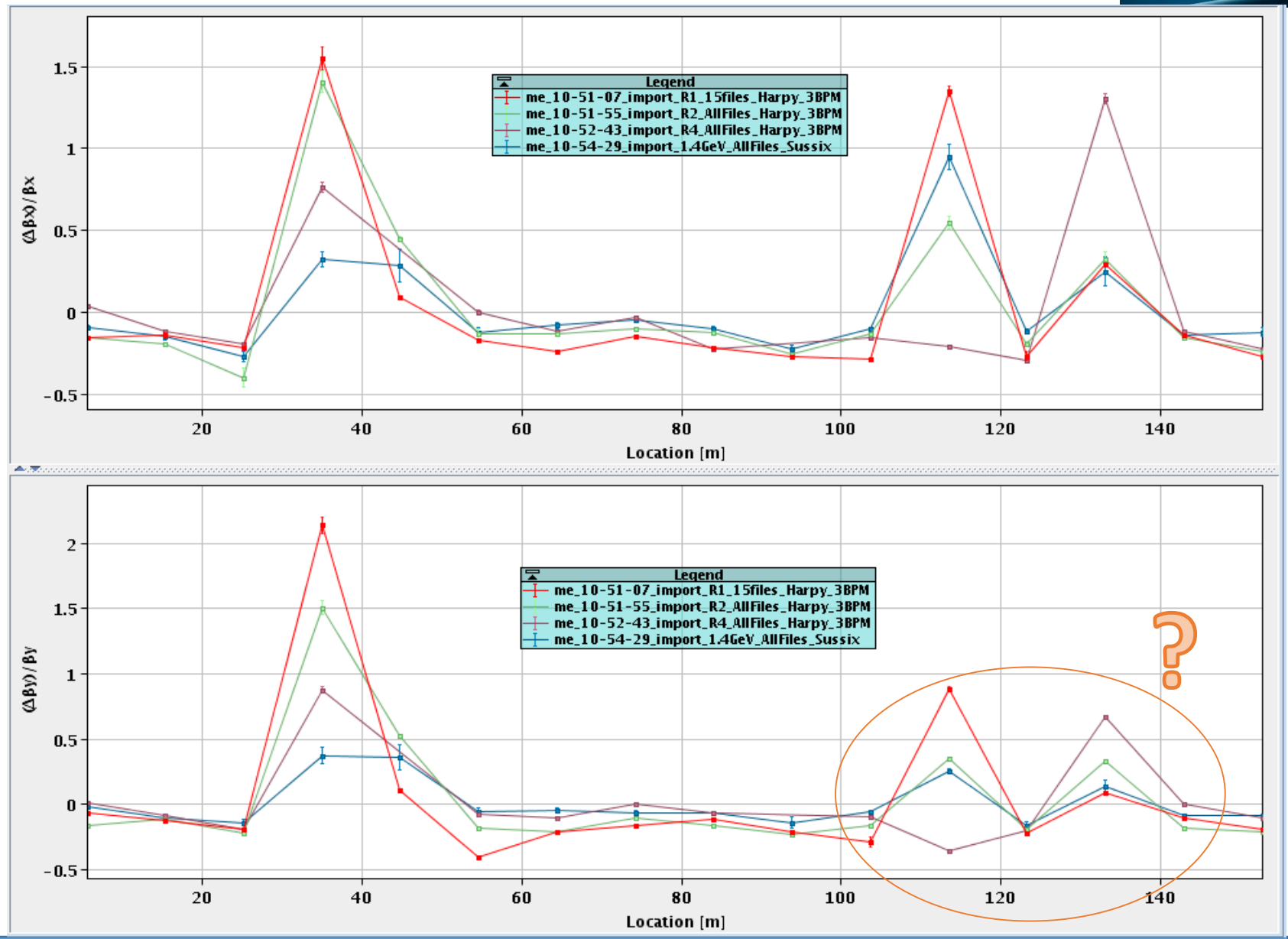
$$\beta_{2me} = \beta_{2mo} \frac{cot\phi_{12me} + cot\phi_{23me}}{cot\phi_{12mo} + cot\phi_{23mo}}$$





Beta from amplitude

- Beta from amplitude (no special calibration) confirms the pattern
- Puzzling vertical beating in the 2nd half of the rings
  - Being investigated
    - Coupling?
    - A bug?

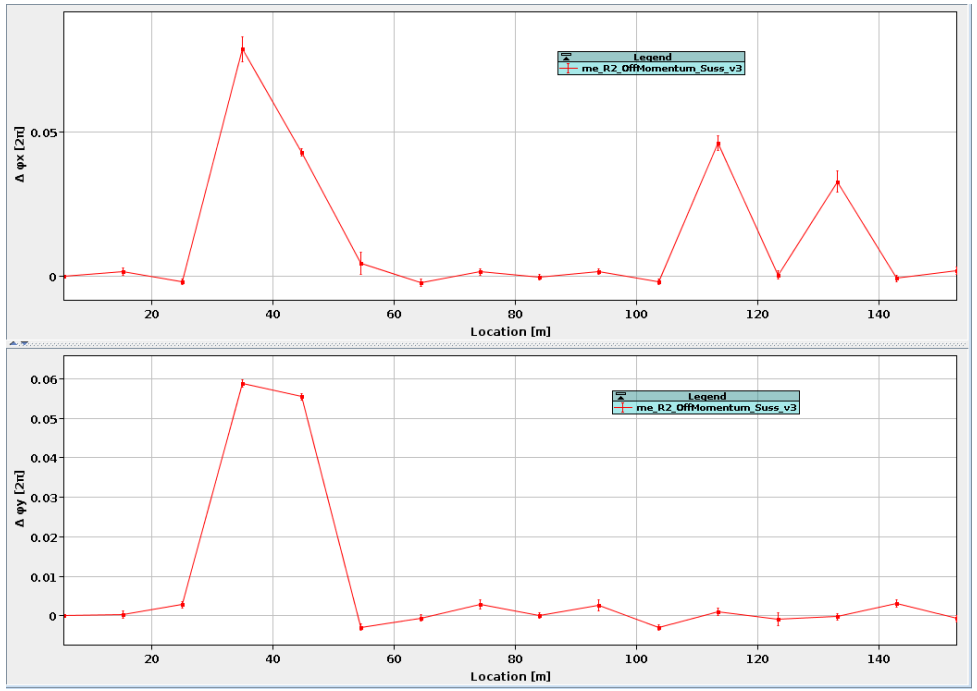


Fitting the model to the measured data

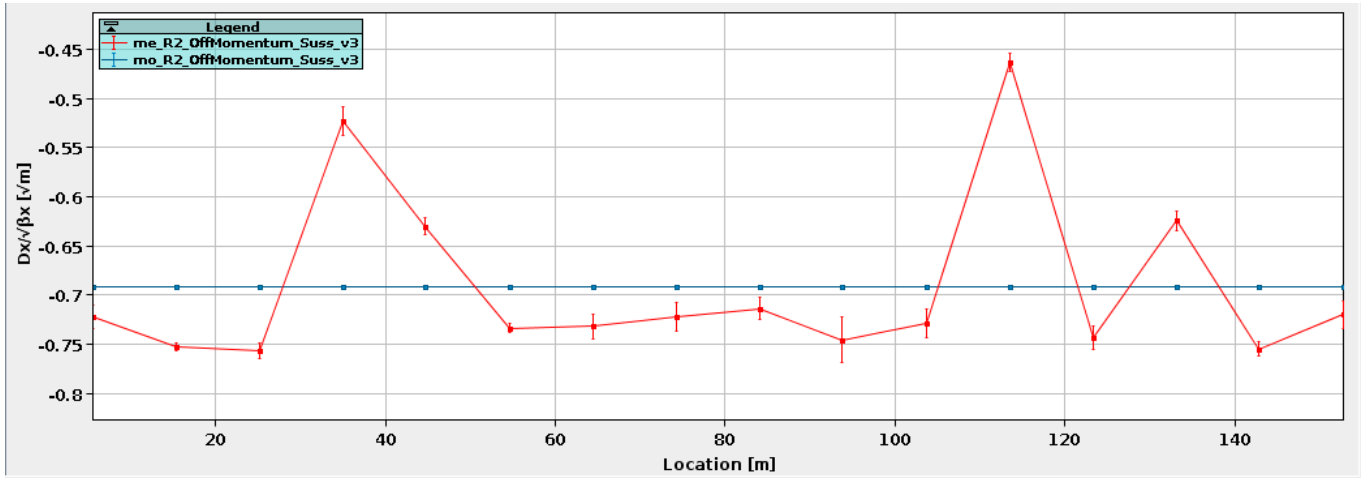
- Attempted to match the model to reproduce the measured phase beating
  - Letting all quadrupoles to vary
- It converged, however the resulting dispersion beating was too huge to trust the result
- Therefore, repeated measurement on Ring 2 including off-momentum data

1.4 GeV off-momentum

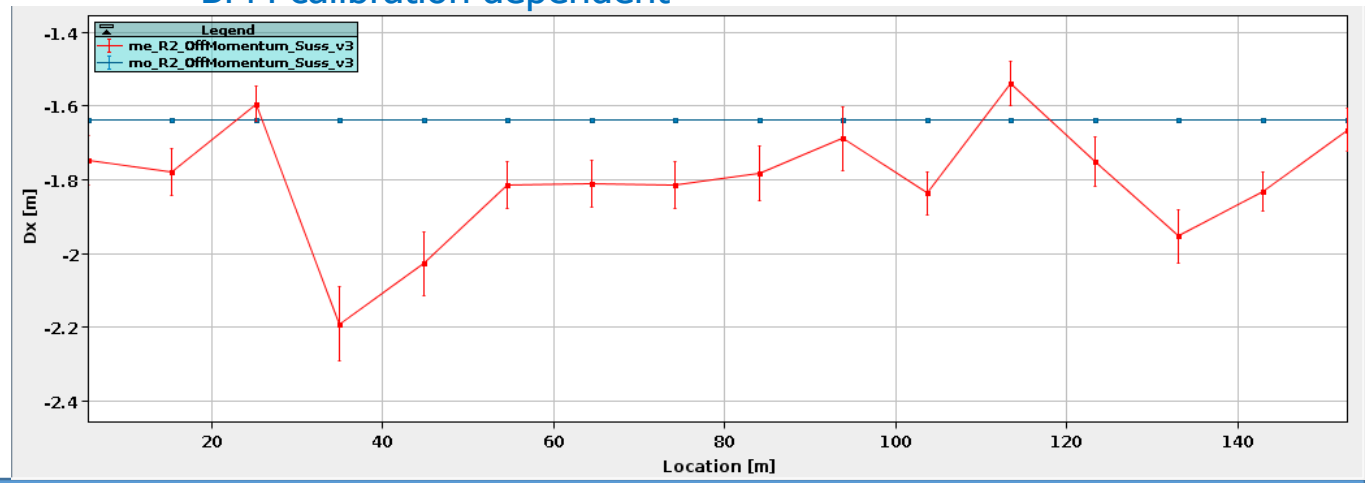
- The phase beating is confirmed



- Normalized dispersion
  - BPM calibration independent



- Dispersion
  - BPM calibration dependent



Fitting the model to the measured data

- Could not match the model to reproduce both phase and dispersion at the same time
  - Letting all quadrupoles to vary
  - Letting k1 error in every bending magnet
- Will continue to investigate:
  - Dispersion measurement using the standard MatLab script with regular orbit data (not turn-by-turn)
  - Orbit response at 1.4 GeV with several amplitudes
    - Looking for non-linearities
  - Repeat the measurement with corrected orbit and coupling

Conclusions

- Using calibration factors derived from Q3Q5 improved precision of the beta-beating measurements
  - But not as much as we hoped for (yet)
- The beam stability is one of the limitations
- Naturally, stronger ADT and more precise BPMs would also help

TO DO

- Measure at 160 MeV other rings with Q3Q5 and Q4Q4 right after
- Try to improve and stabilize the beam
  - Orbit, dispersion
- More on analysis
  - Selecting best shots, more statistics
- Attempt phase (thus beta) corrections at 160 MeV
- Measure at 1 GeV
  - To see how the beating evolves when approaching the flattop
  - The cycle is already prepared
- Try to bring Q3Q5 to 1.4 GeV
  - Additional, independent, measurement to understand the source of the beating
  - Check if BPM calibration factors are energy dependent

Fresh from the oven: 1 GeV ring 3

- No big phase beating
- Beta from amplitude also as in 160 MeV