# KEK Optics Commissioning

## An overview of linear non-linear optics

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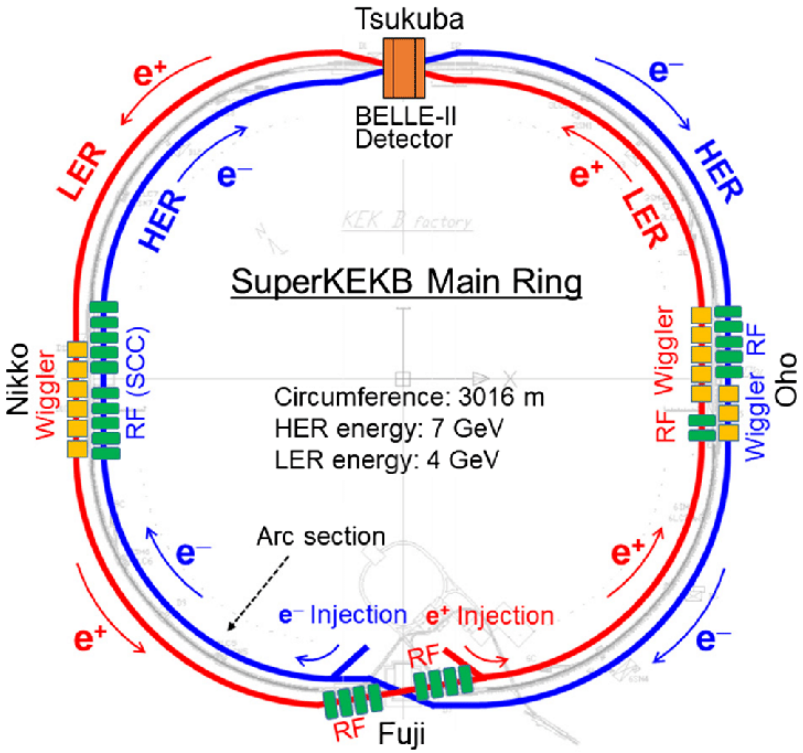
Thanks to everyone at KEK who helped us achieve nice results!

# Plan

# Context

Spent last February at KEK in Japan for commissioning

- HER and LER rings
  - Electrons and Positrons
  - Fixed energy
- One IP: Belle-II detector
  - Studies of B meson $(u\bar{b},\ d\bar{b},\ s\bar{b},\ c\bar{b})$
- From "detuned" to squeezed optics
- Linear Optics ($\beta$-beating)
- Non-Linear (chromaticity, amp.det.)



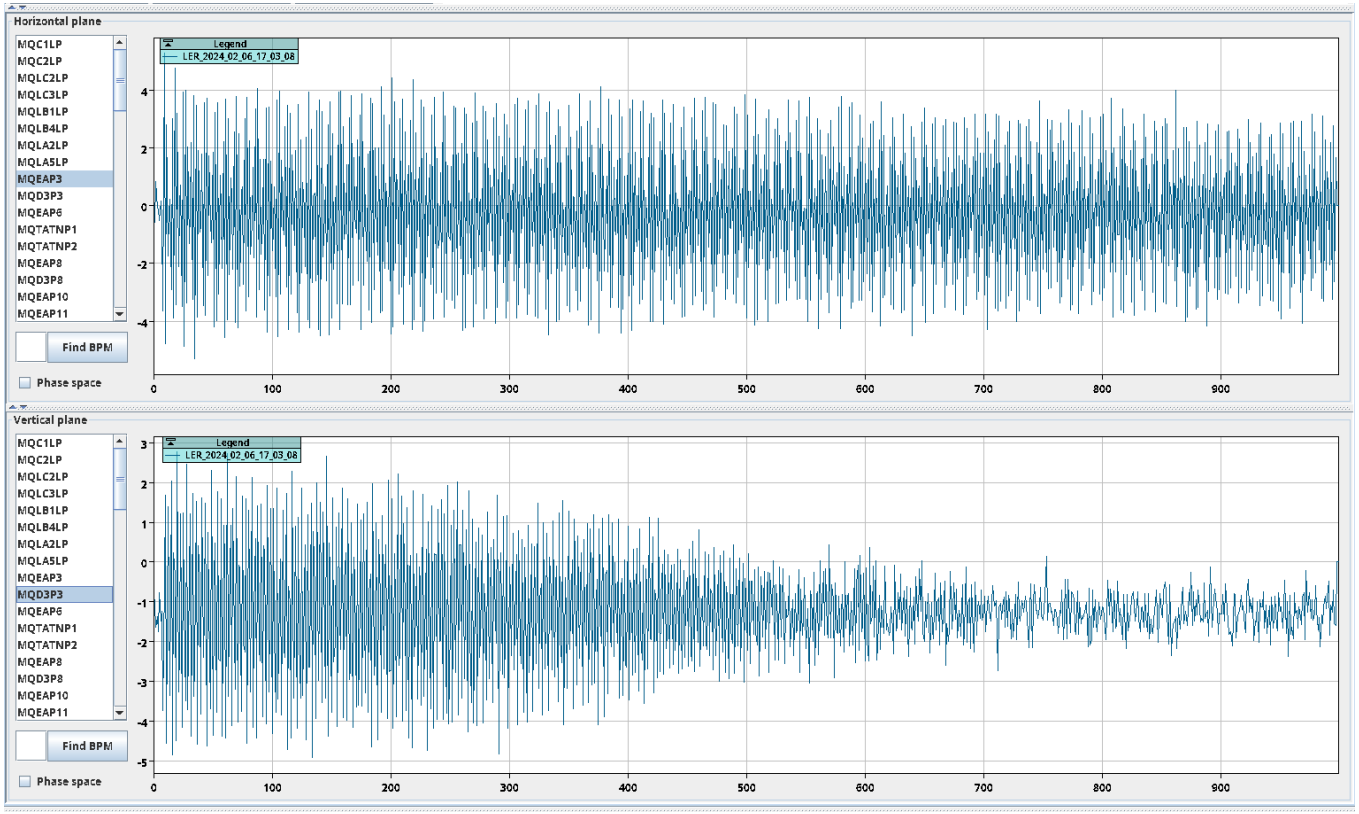
# Measurements

- A few turn-by-turn measurements were done at each configuration

| Ring | Day | $\beta_x*$ [mm] | $\beta_y*$ [mm] | $Q_x$ | $Q_y$ |
|---|---|---|---|---|---|
| LER | 06 | 384 | **48.6** | 44.556 | 46.635 |
| | 09 | 384 | **48.6** | 44.553 | 46.621 |
| | 20 | 200 | **8** | 44.527 | 46.604 |
| | 22 | 200 | **8** | 44.535 | 46.590 |
| | 29 | 100 | **3** | 44.523 | 46.580 |
| HER | 06 | 400 | **81** | 45.572 | 43.616 |
| | 04 | 60 | **1** | 45.532 | 43.598 |
| | 20 | 200 | **8** | 45.530 | 43.595 |
| | 22 | 200 | **8** | 45.535 | 43.596 |
| | 26 | 200 | **8** | 45.535 | 43.596 |
| | 27 | 200 | **8** | 45.537 | 43.591 |
| | 29 | 100 | **3** | 45.532 | 43.587 |

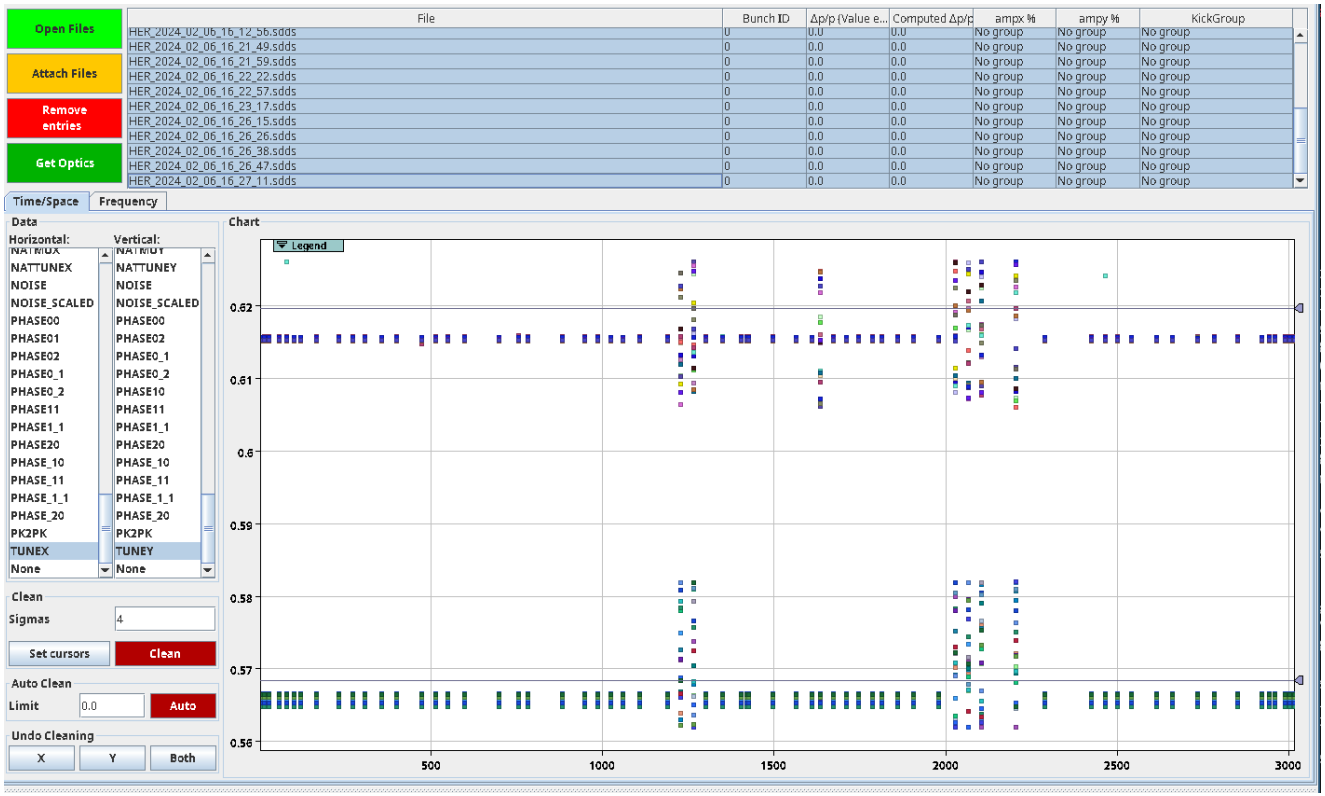
# Plan

# Turn By Turn Data




- A few ways to excite the beam
  - Injection kicker in H plane
  - Injection oscillations via offset

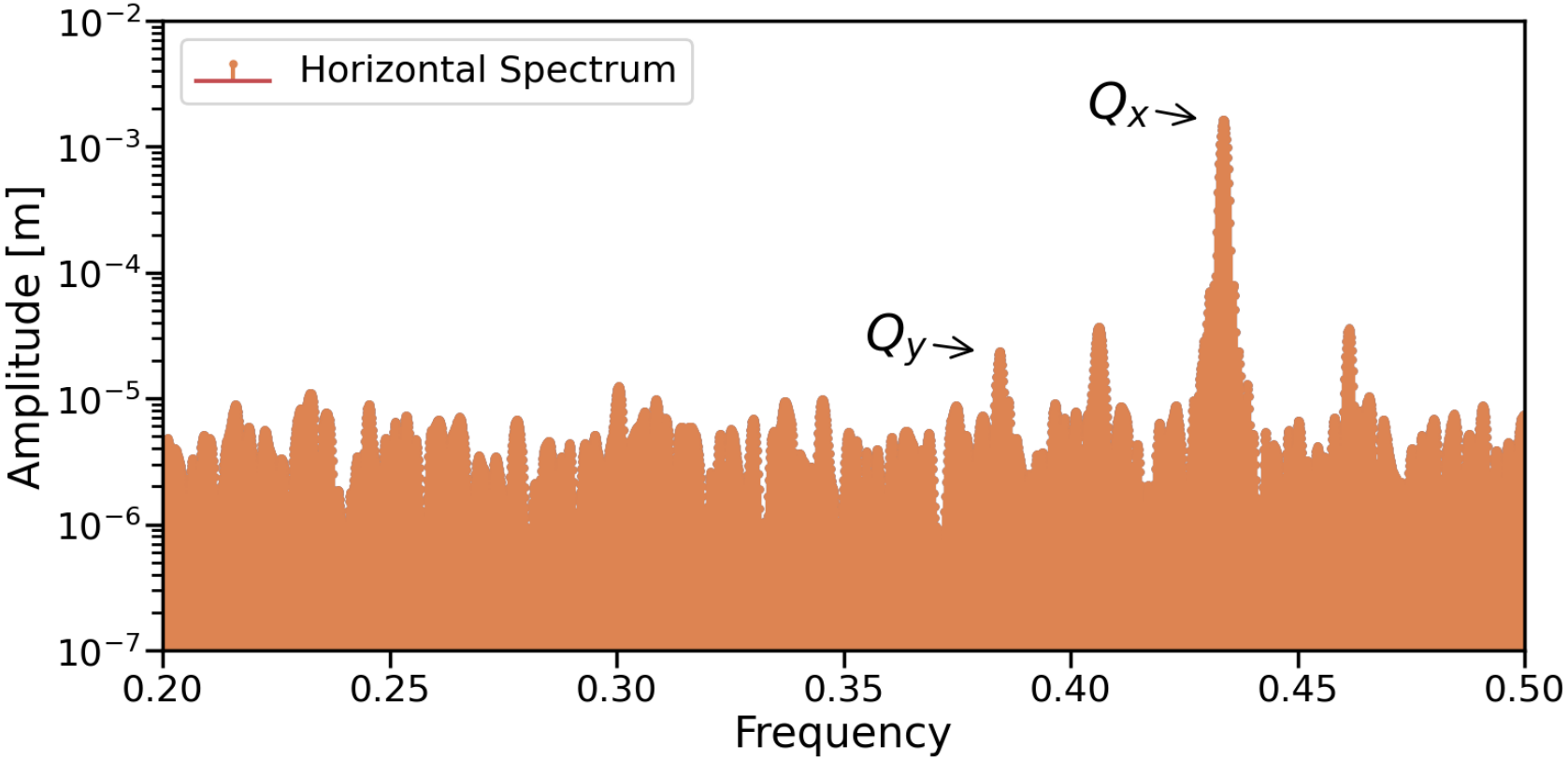
# GUI




- Integrated SuperKEK in OMC's GUI
- Makes things easier
  - Like the identification of consistently bad BPMs

# Spectrum

With high amplitude kicks, the tunes are visible



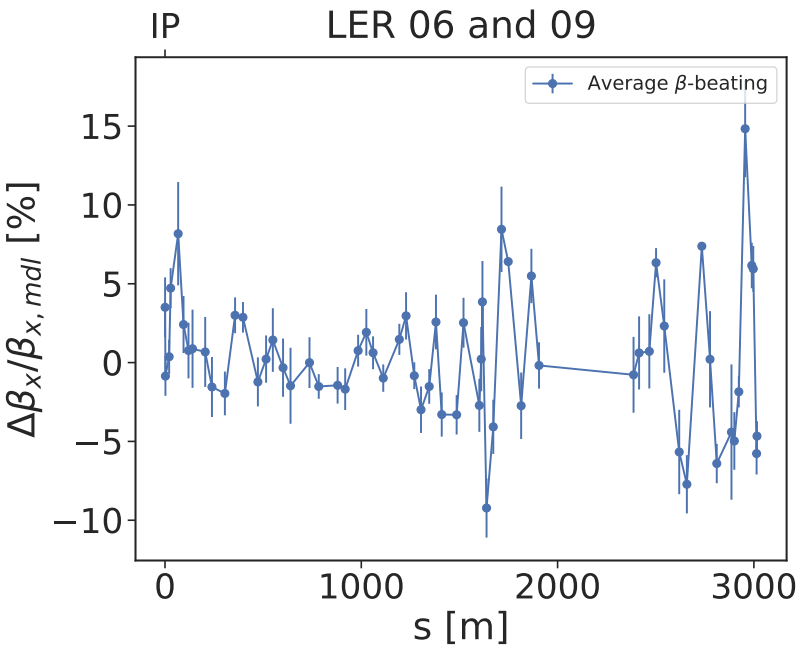
# $\beta$-Beating

Let's consider two configurations for each ring

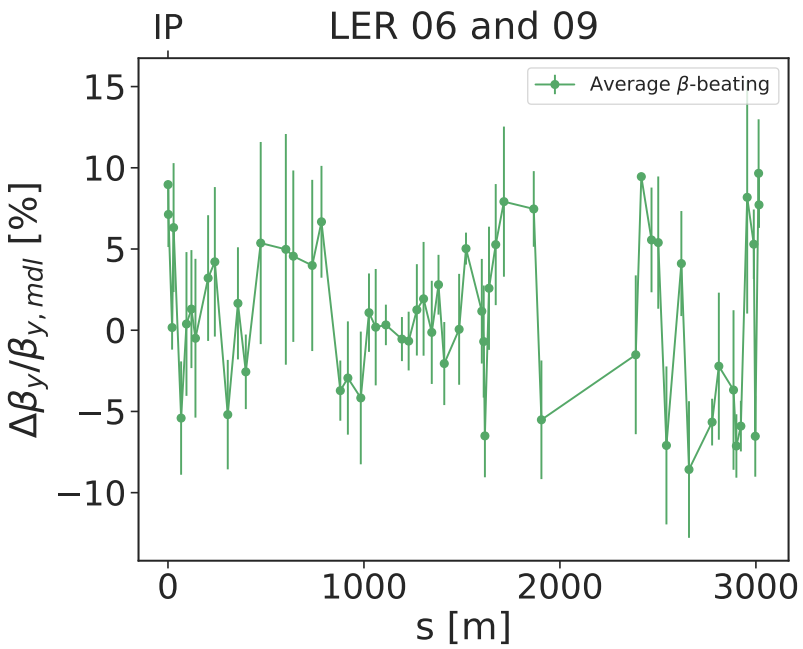
- *Detuned*
- Squeezed at $\beta_y = 8$mm

| Ring | Day | $\beta_x*$ [mm] | $\beta_y*$ [mm] | $Q_x$ | $Q_y$ | Kicks |
|---|---|---|---|---|---|---|
| LER | 06 | 384 | **48.6** | 44.556 | 46.635 | H & V |
| | 09 | 384 | **48.6** | 44.553 | 46.621 | H |
| | 20 | 200 | **8** | 44.527 | 46.604 | H |
| | 22 | 200 | **8** | 44.535 | 46.590 | H |
| HER | 06 | 400 | **81** | 45.572 | 43.616 | H & V |
| | 20 | 200 | **8** | 45.530 | 43.595 | H |
| | 22 | 200 | **8** | 45.535 | 43.596 | V |
| | 26 | 200 | **8** | 45.535 | 43.596 | V |

# LER Detuned



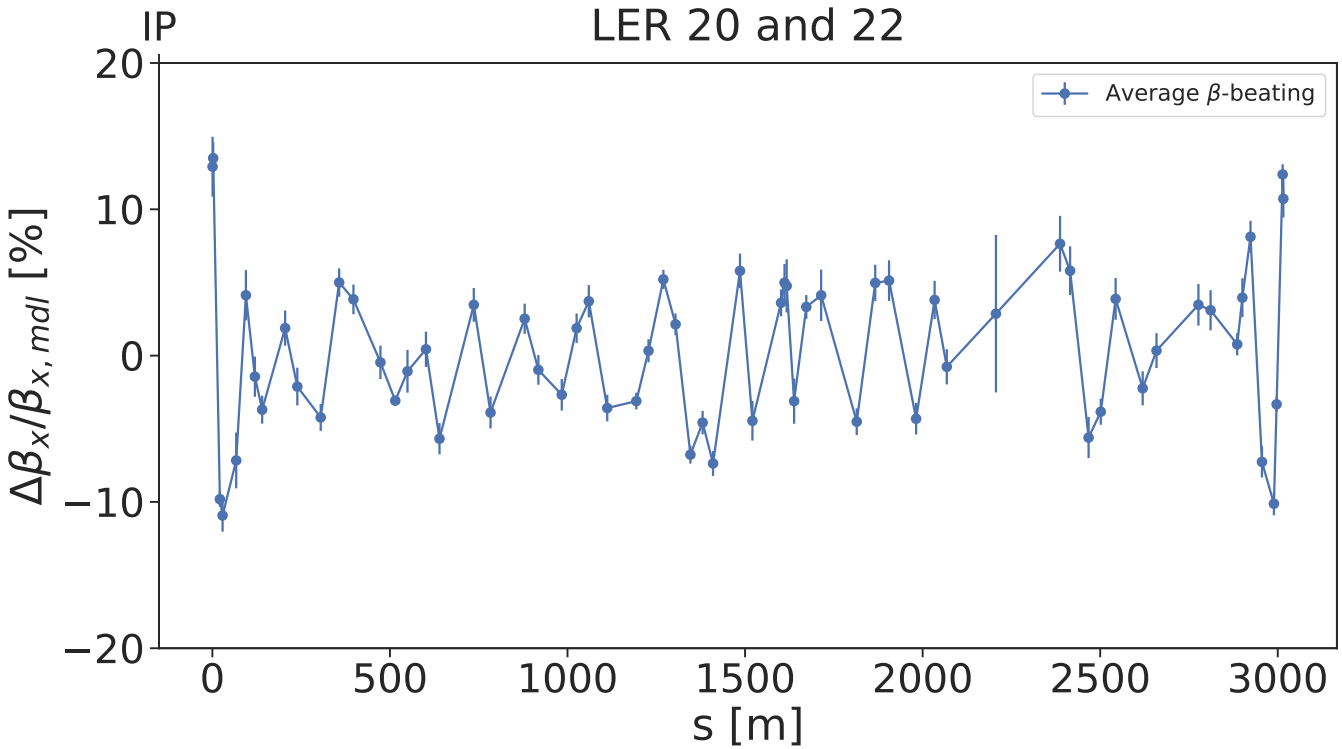

Horizontal RMS $\beta$-beating $\approx$4%




Vertical RMS $\beta$-beating $\approx$4%

- Vertical plane noisy
  - action 5 times lower than horizontal

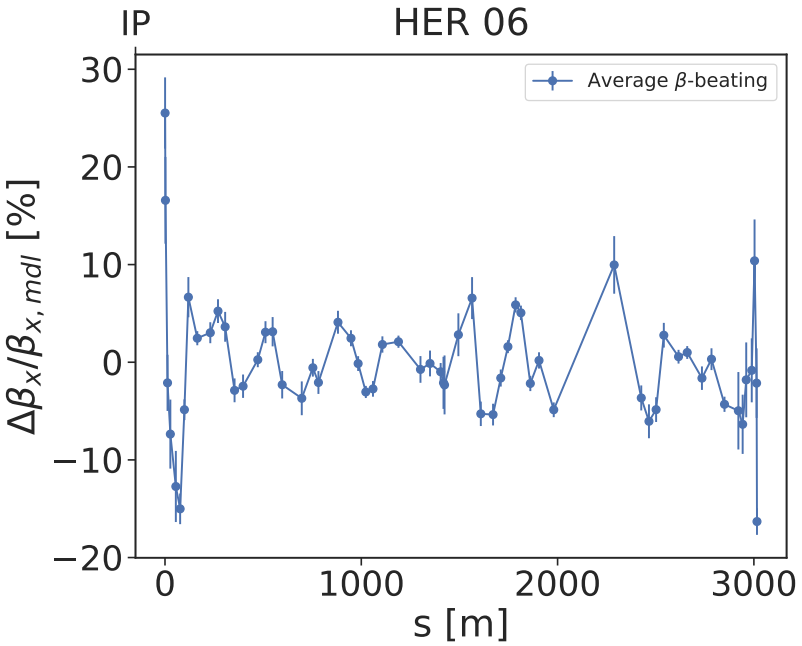
# LER Squeezed 8mm



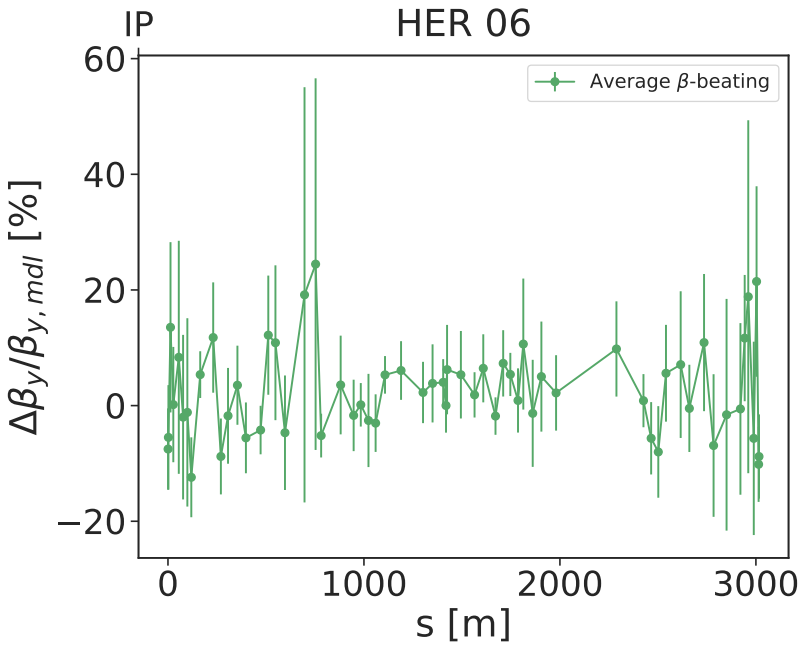

RMS $\beta$-beating ≈6%

- Beating near IP? Analysis artefact or real?
  - K-Modulation would be more precise

# HER Detuned



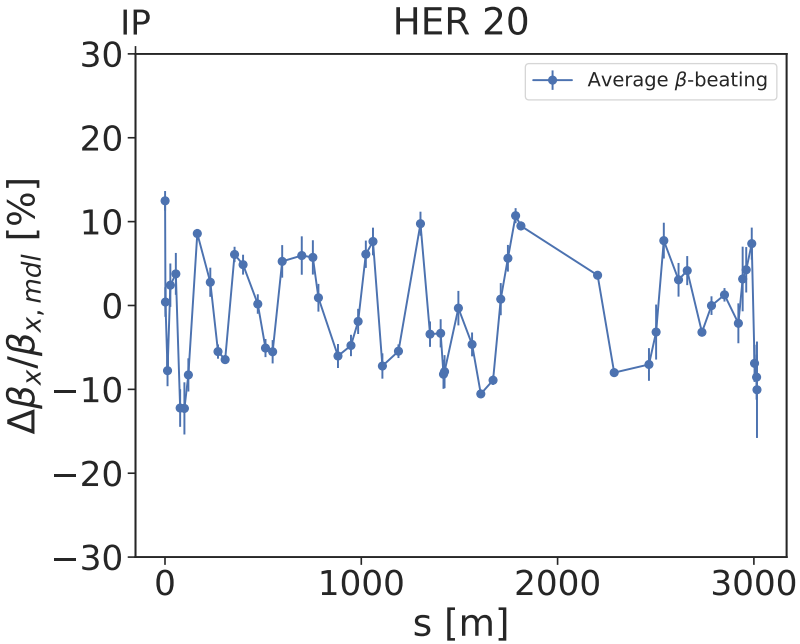

Horizontal RMS $\beta$-beating $\approx$6%



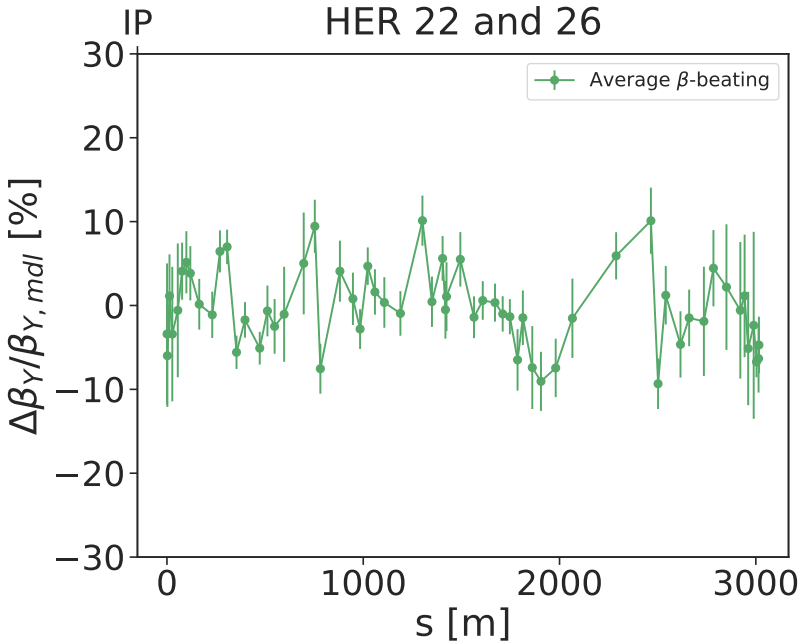

Vertical RMS $\beta$-beating $\approx$8%

- Vertical plane very noisy
  - action 4 times lower than horizontal

# HER Squeezed 8mm




Horizontal RMS $\beta$-beating ≈7%




Vertical RMS $\beta$-beating ≈5%

- Some BPMs are removed
  - Non-ideal phase advance of BPMs

# Recap

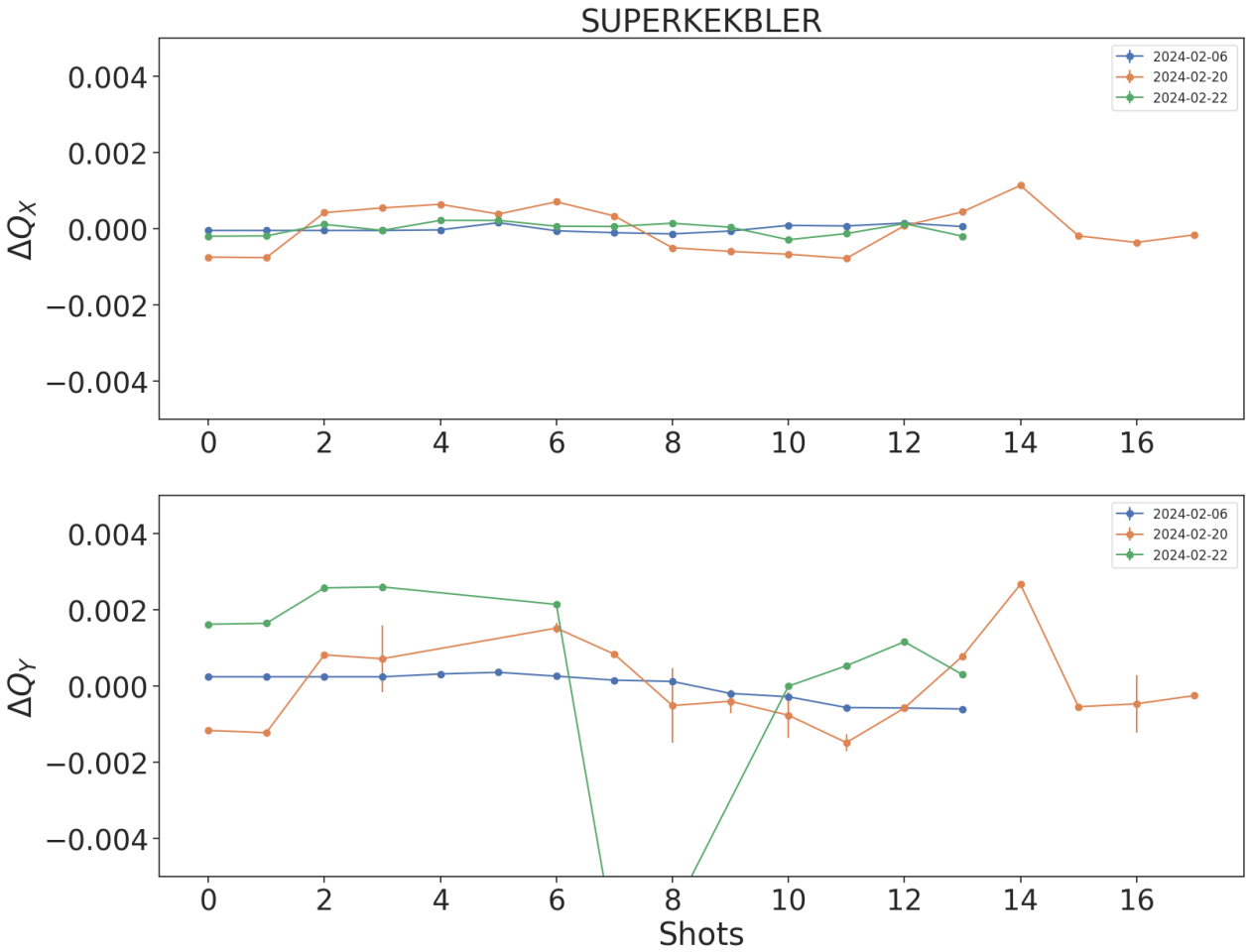
- Good reproducibility between kicks
  - Clean data in horizontal
  - Noisier but exploitable in vertical
- Measurements fairly reproducible
- One region with bad BPMs

- $\beta$-beating below 10% for all configurations and both rings

| Ring | Configuration | $\beta$-b. rms H | $\beta$-b. rms V |
|---|---|---|---|
| LER | Detuned | 4% | 5% |
| | Squeezed 8mm | 6% | |
| HER | Detuned | 6% | 8% |
| | Squeezed 8mm | 7% | 5% |

# Plan

# LER Shots

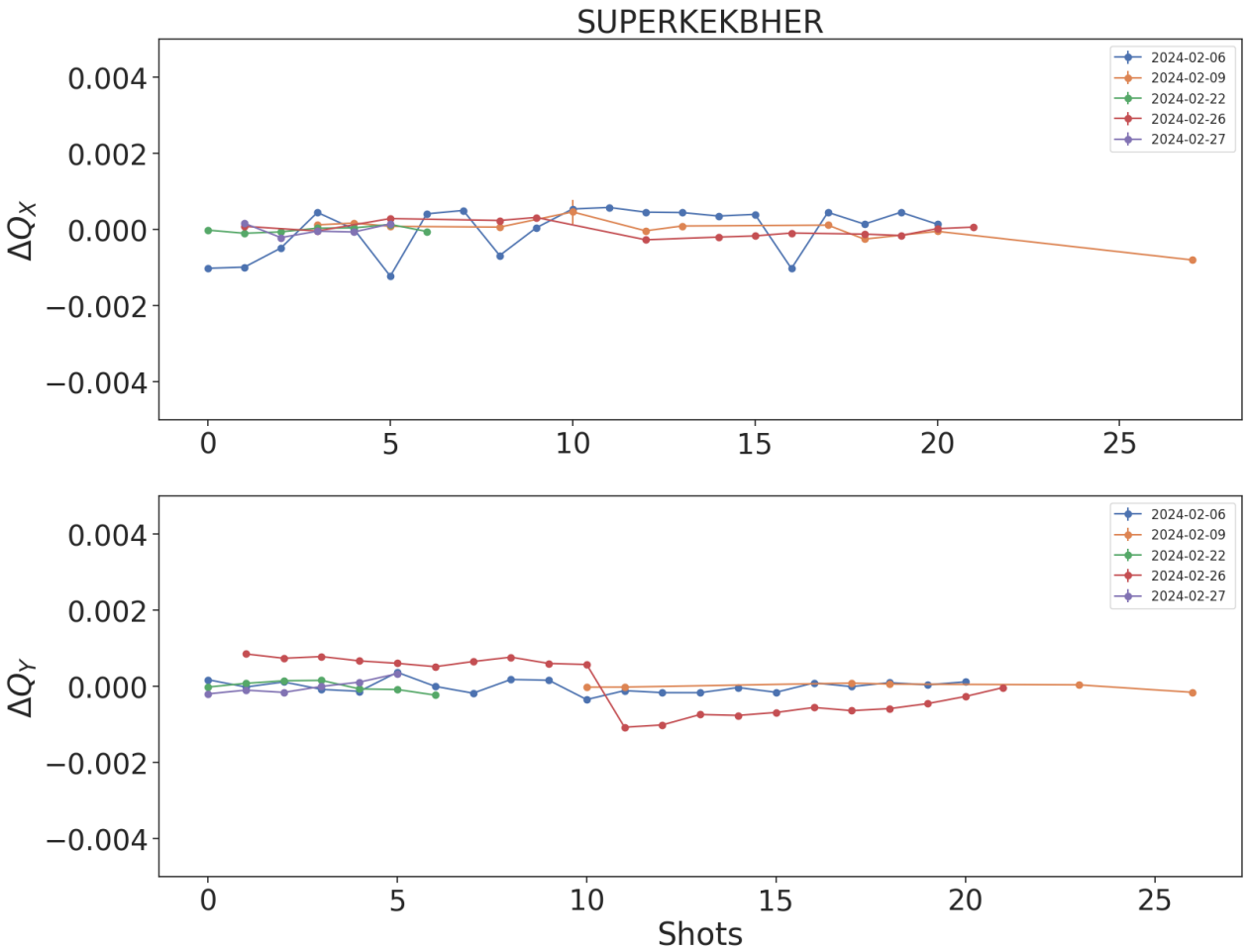



RMS $3 \cdot 10^{-4}$

RMS $1.5 \cdot 10^{-3}$

- Tune stability is good in H, not that much in V
  - Bad tune measurement due to low amplitude oscillations

# HER Shots

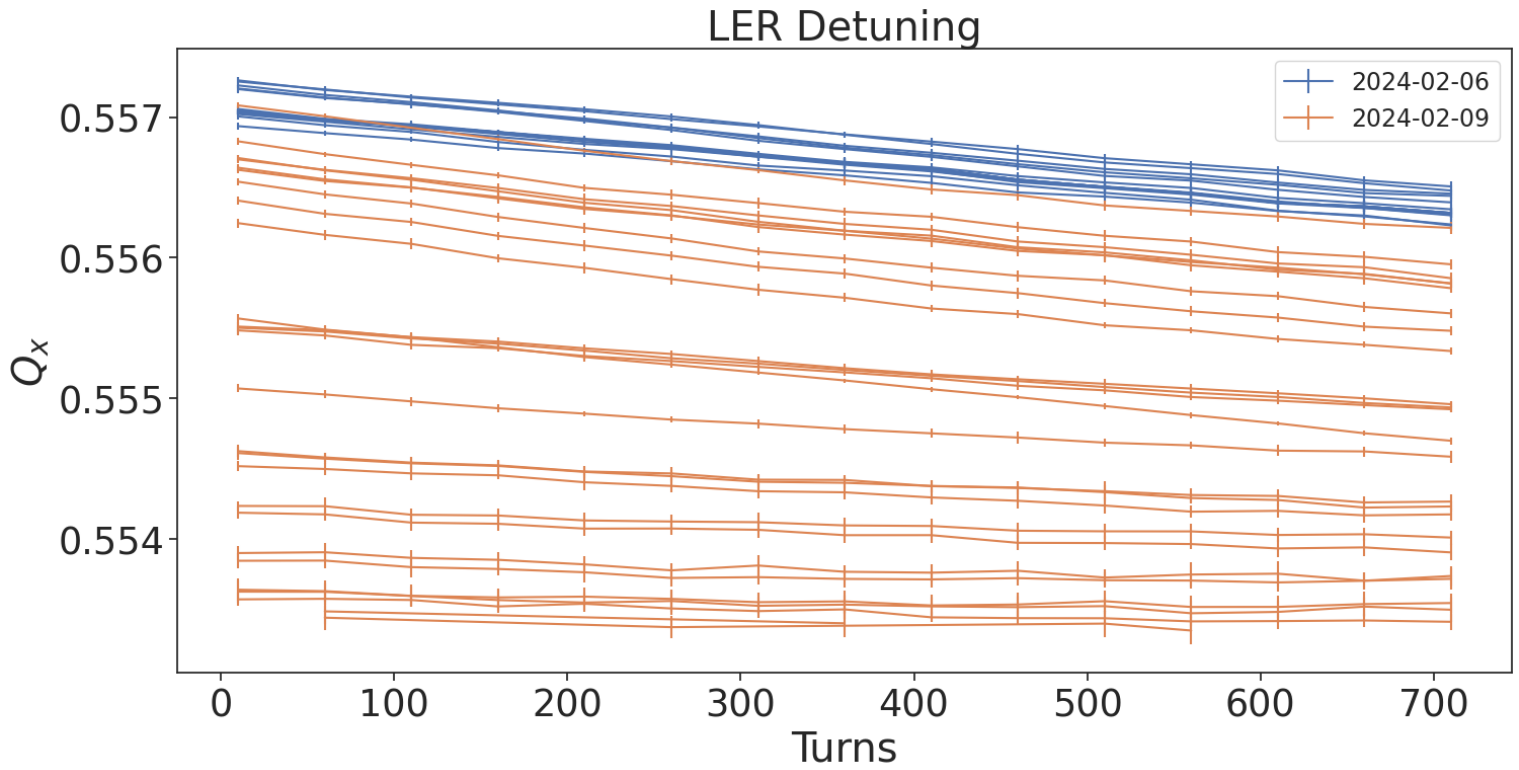



RMS $3 \cdot 10^{-4}$

RMS $2 \cdot 10^{-4}$

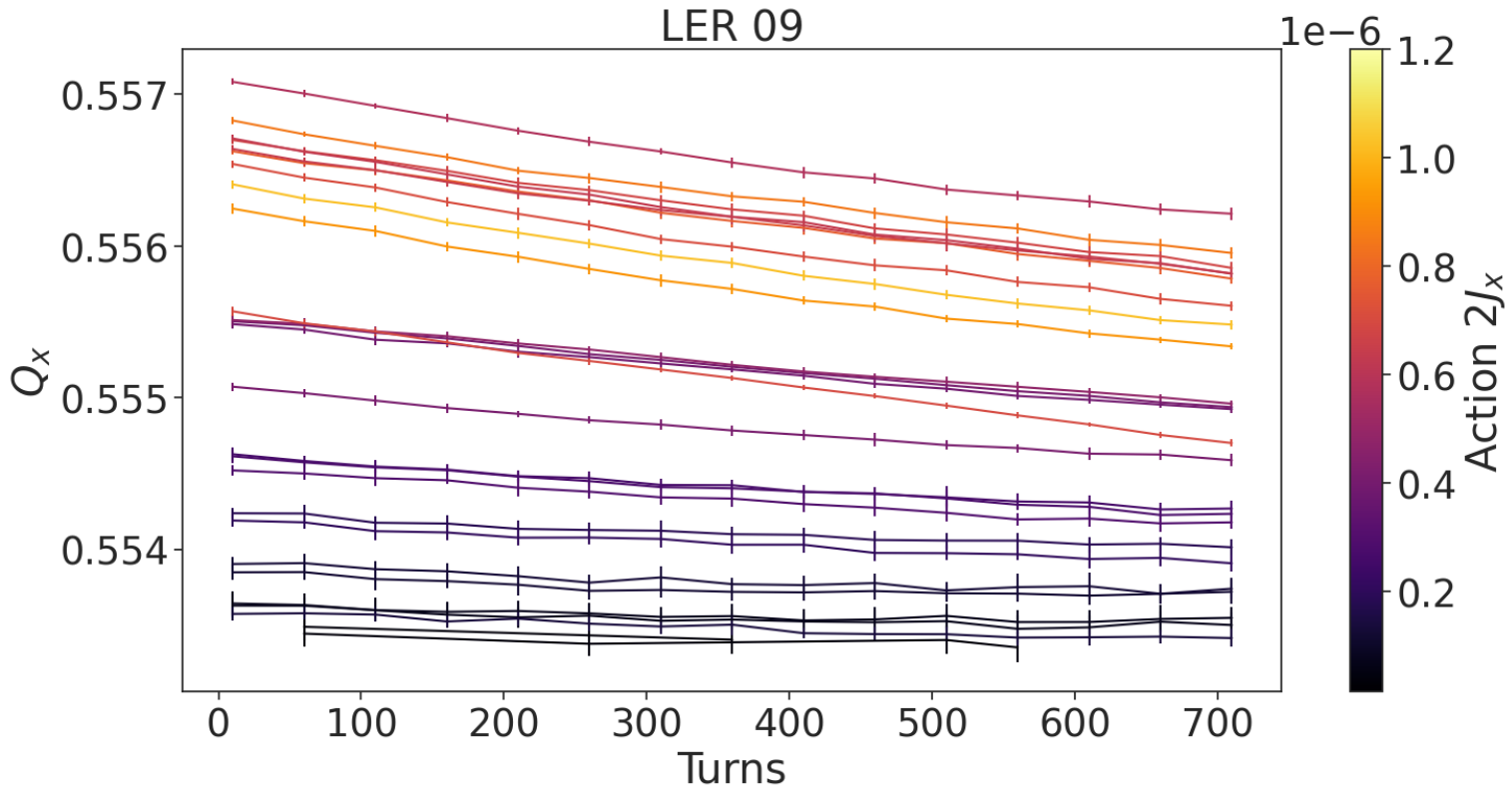
- Better measurements and stability is achieved in HER

# Kicks and Method



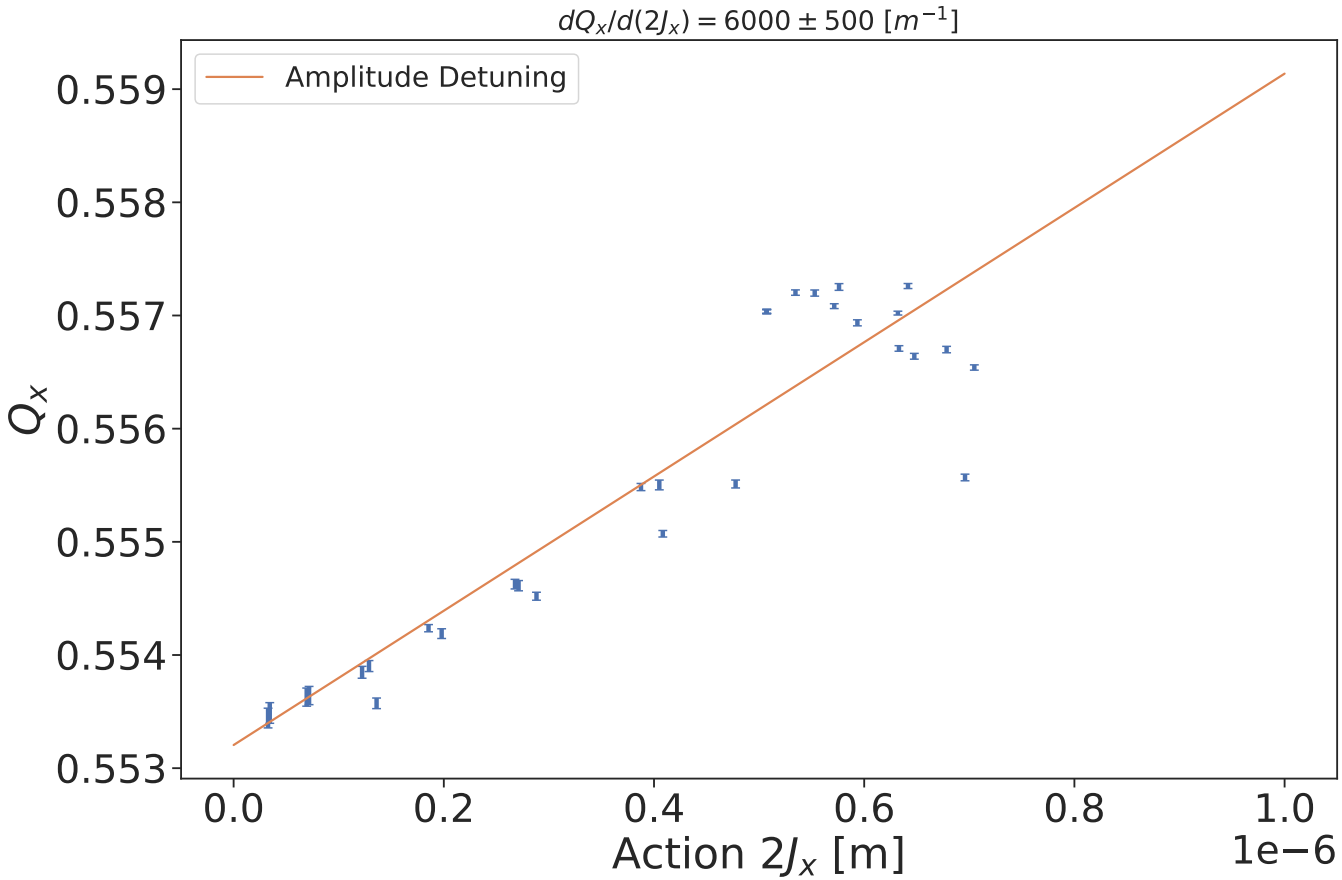

- Tune computed as a running window over 200 turns
- Noticeable detuning after each kick

# Detuning and Action Dependence




- Tune shift seems correlated to the kick amplitude

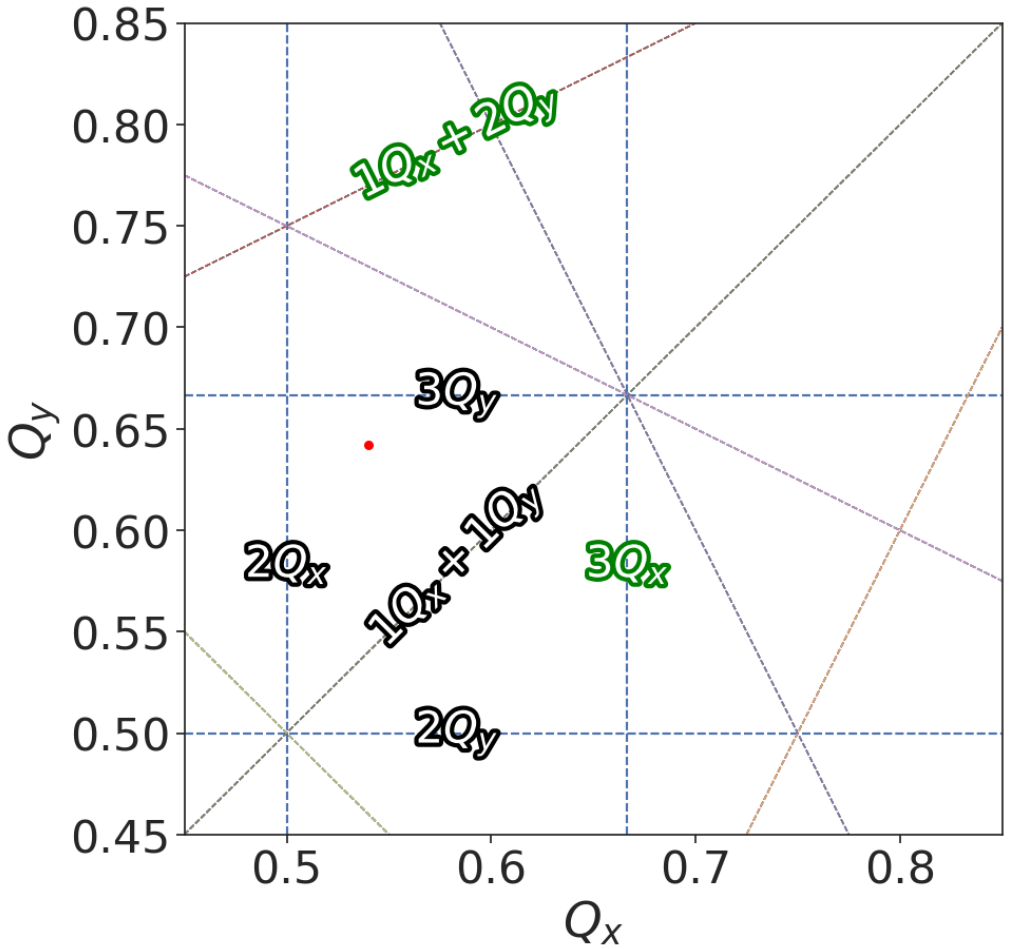
# Amplitude Detuning




- Tune taken from the first 200 turns
- Amplitude detuning term $\frac{\partial Q_x}{\partial 2J_x}$ can be measured

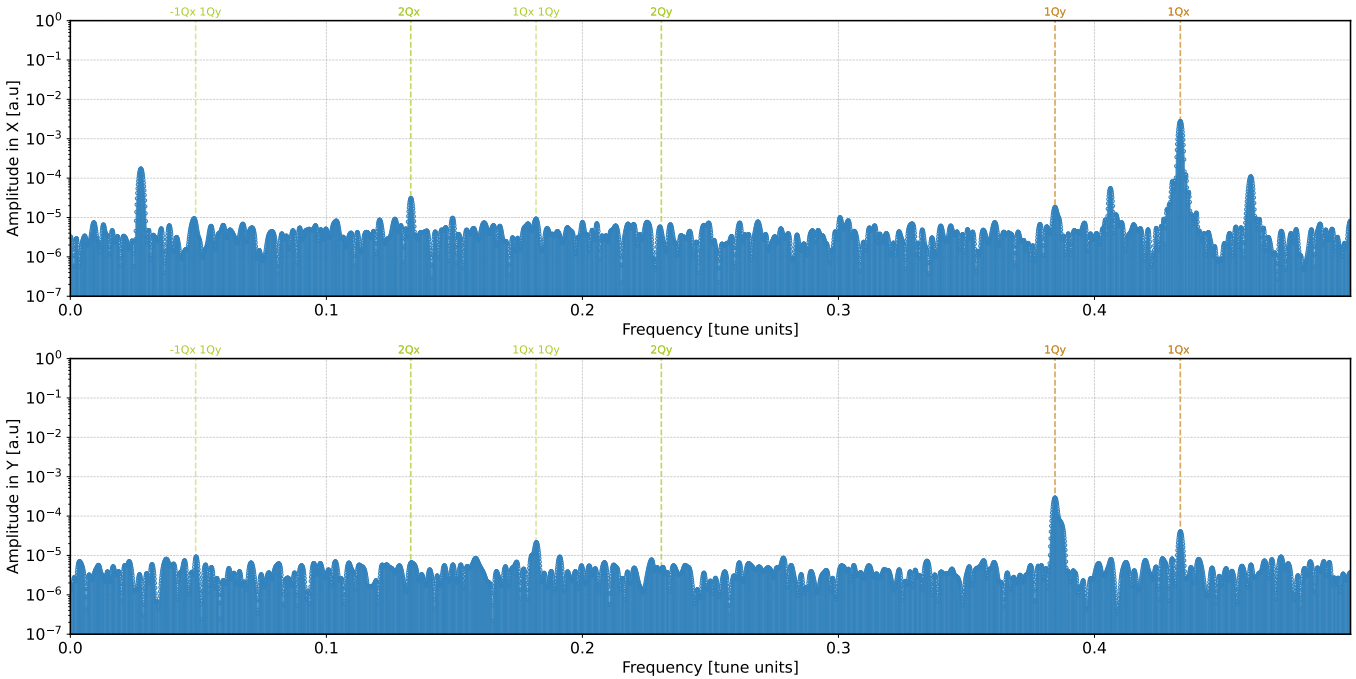
# Plan

# Tune Diagram



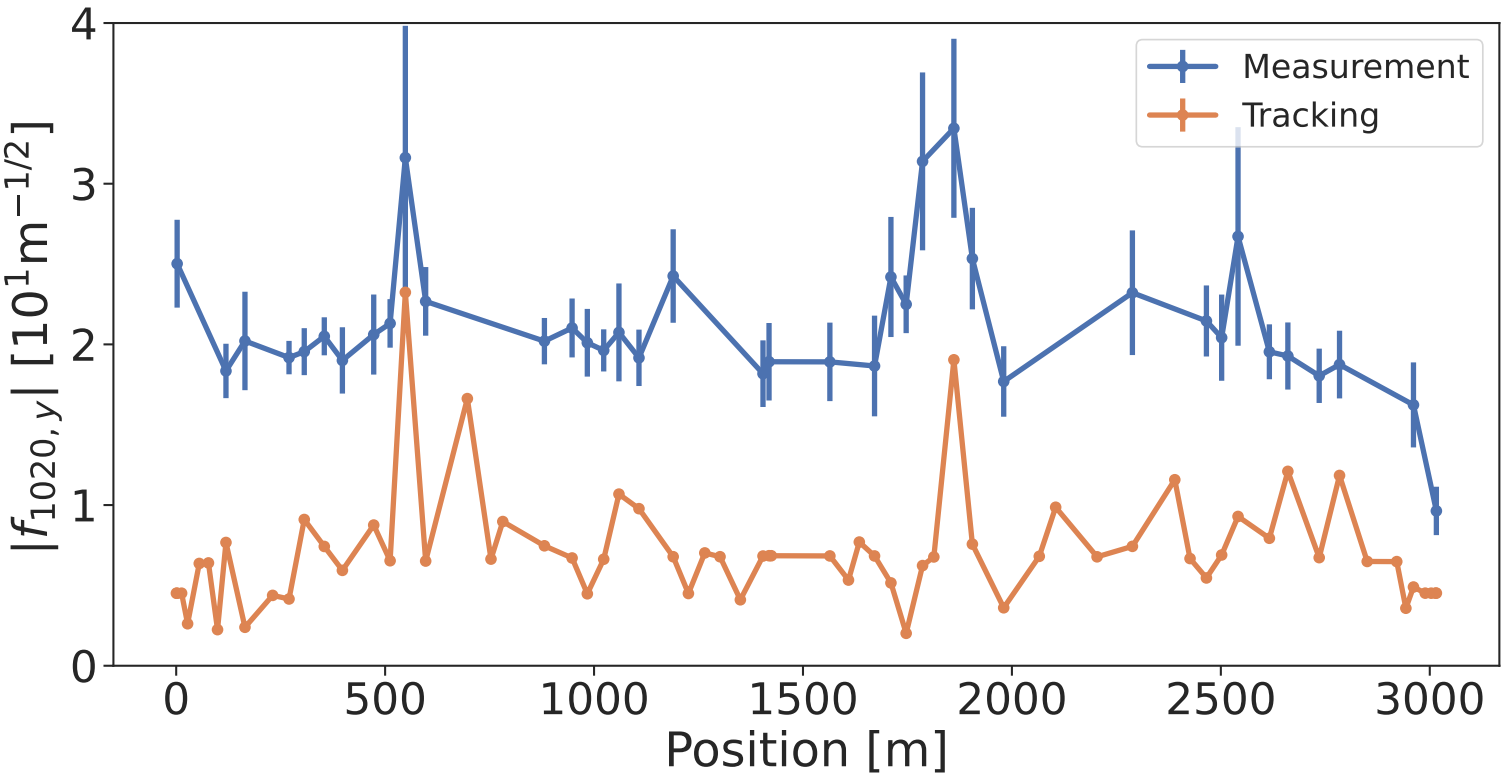

- Many resonances exist around the working point
- Two of interest: $Q_x + 2Q_y$ and $3Q_x$, from sextupoles

# Spectrum



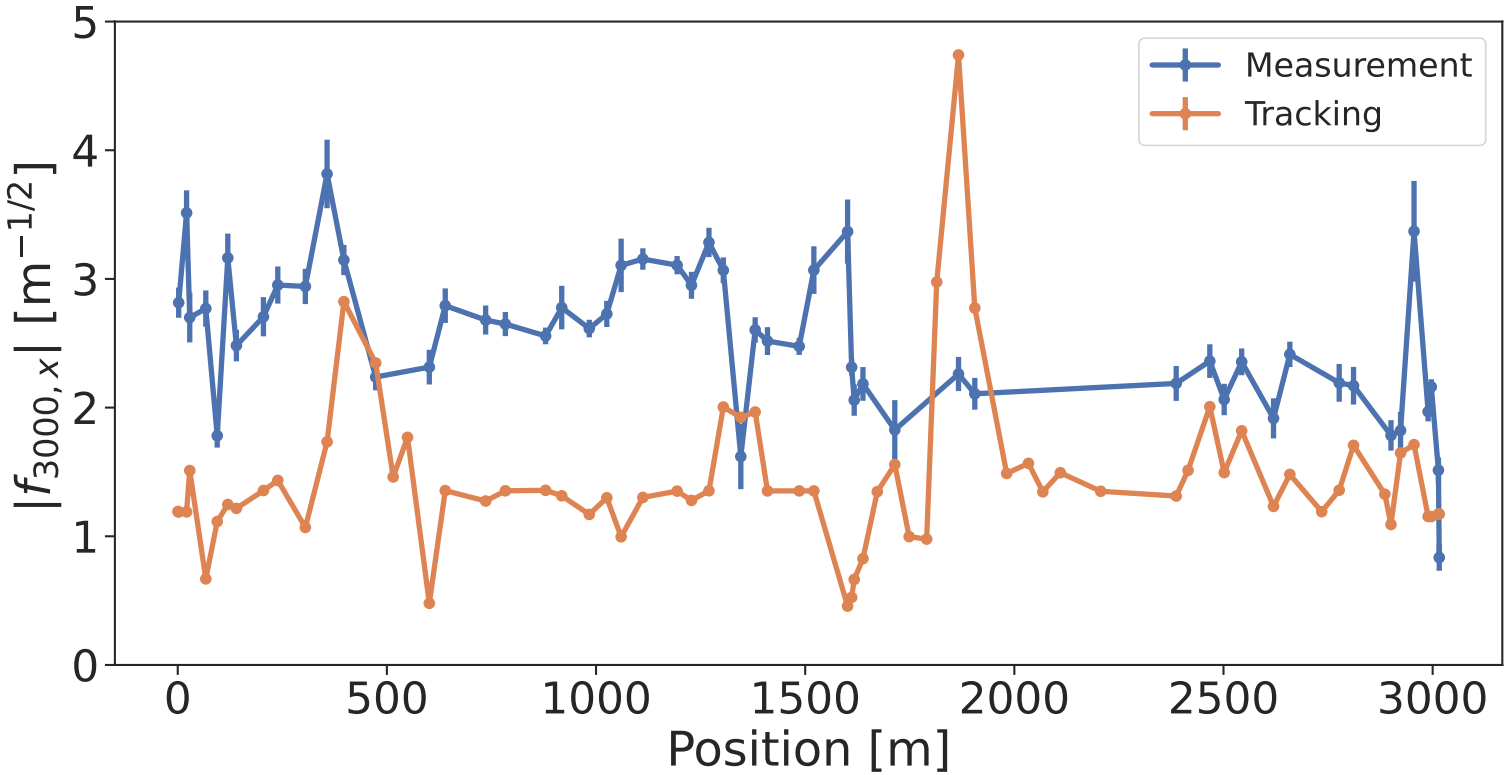

- Resonance $3Q_x$:
  - $-2Q_x$ in horizontal: $f_{3000,x}$
- Resonance $1Q_x + 2Q_y$:
  - $-1Q_x - 1Q_y$ in vertical: $f_{1020,y}$

# HER 06 - $f_{1020,y}$




- Measured RDT about 3 times larger than expected from the model
- Decoherence factor not yet taken into account in analysis

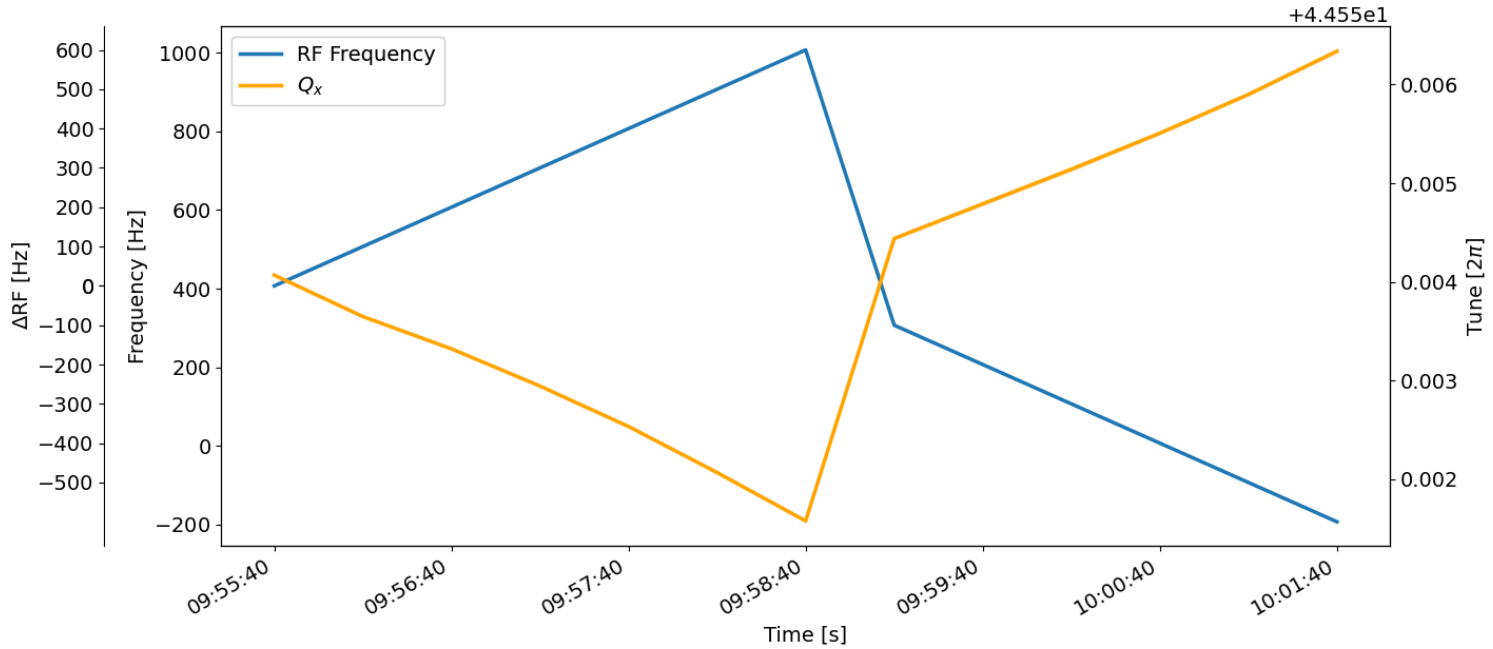
# LER 06 - $f_{3000,x}$




- Measured RDT *also* about 3 times larger than expected
- Decoherence smaller than for HER

# Plan

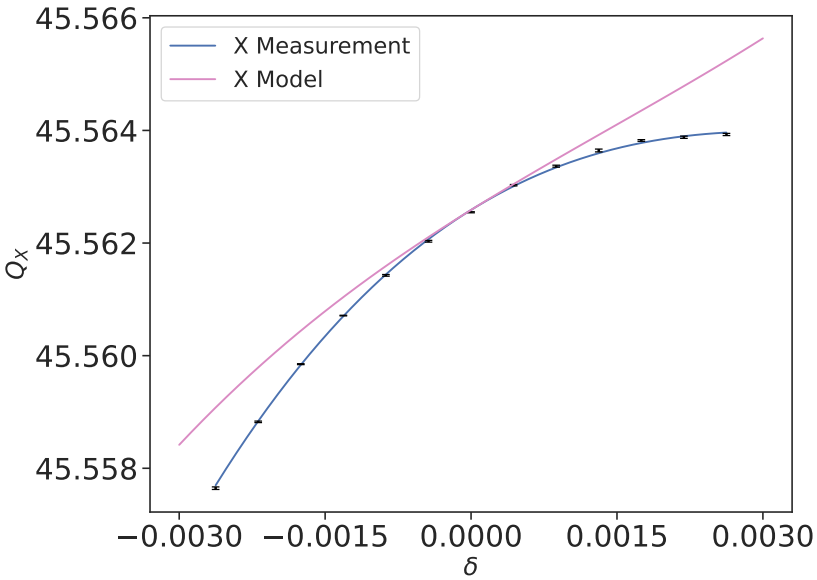
# Procedure

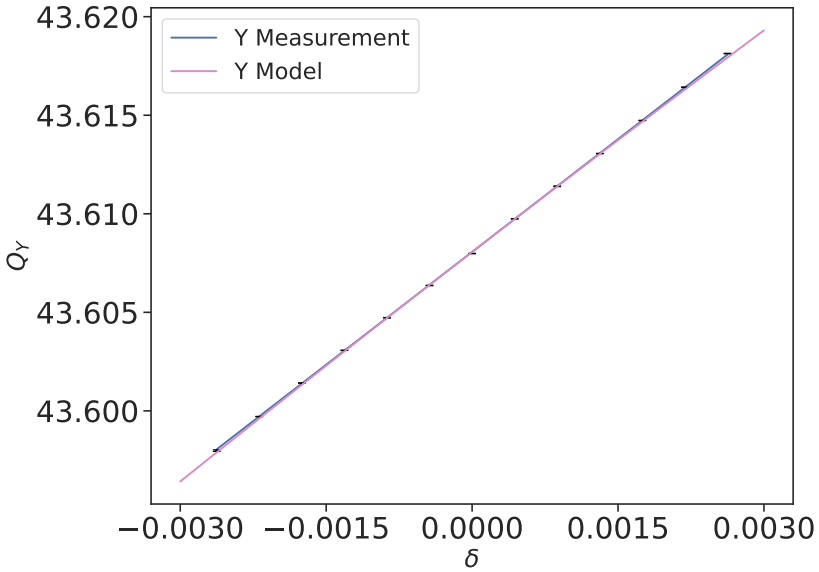



Varying the RF induces a change in the momentum offset $\delta$
A detuning then occurs due to chromaticity:

$$Q(\delta) = Q_0 + Q'\delta + \frac{1}{2!}Q''\delta^2 + \frac{1}{3!}Q'''\delta^3 + \mathcal{O}(\delta^4)$$

# HER - Detuned



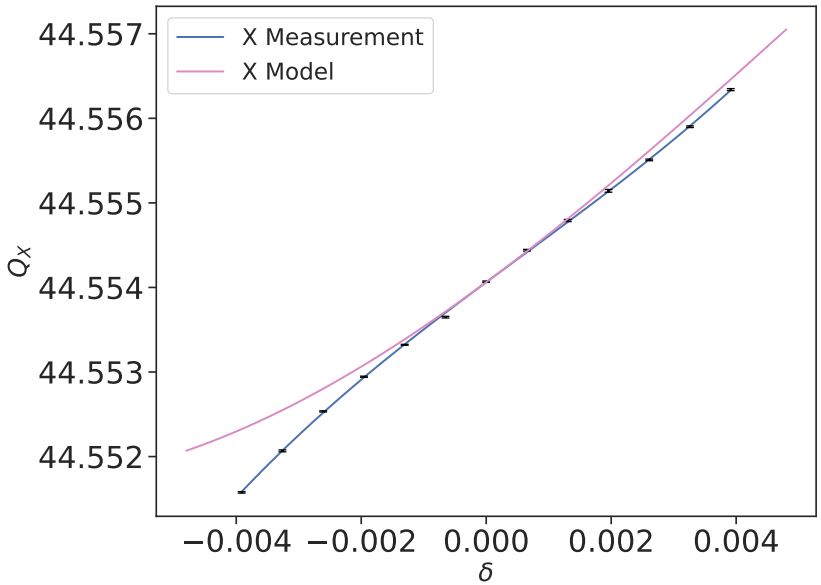



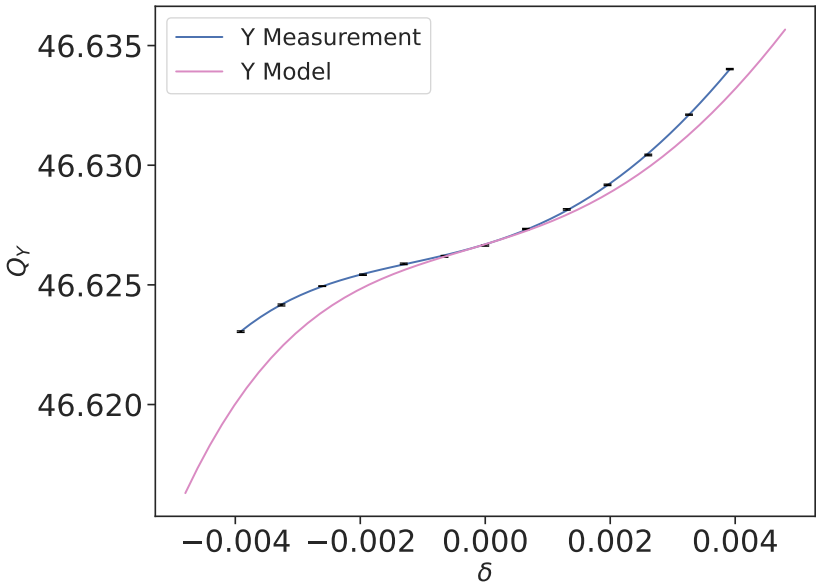

| | $Q''[\times 10^3]$ | $Q'''[\times 10^6]$ |
|---|---|---|
| Meas. | -0.51 ± 0.01 | 0.11 ± 0.02 |
| Model | -0.12 ± 0.00 | 0.09 ± 0.00 |

| | $Q''[\times 10^3]$ |
|---|---|
| Meas. | 0.00 ± 0.0 |
| Model | -0.04 ± 0.0 |

$\rightarrow$ Differences in $Q''$

# LER - Detuned




| | $Q''[\times 10^3]$ | $Q'''[\times 10^6]$ |
|---|---|---|
| Meas. | -0.01 ± 0.0 | 0.02 ± 0.0 |
| Model | 0.04 ± 0.0 | -0.01 ± 0.0 |

| $Q''[\times 10^3]$ | $Q'''[\times 10^6]$ | $Q^{(4)}[\times 10^9]$ |
|---|---|---|
| 0.35 ± 0.01 | 0.24 ± 0.01 | -0.09 ± 0.01 |
| 0.10 ± 0.00 | 0.32 ± 0.00 | -0.09 ± 0.00 |

→ Differences in $Q''$

→ Differences in $Q'''_y$

→ $Q^{(4)}$ matches well

# Plan

# Conclusion

- Nice reproducibility of linear optics
  - Quite better in horizontal with a kicker
  - Across several days
  - Shot to shot
- Sextupolar RDT measurements in both rings
  - Could not achieve clean measurements all the time
  - Some discrepancies yet to be explained
- Good chromaticity measurements for both rings
  - Discrepancy for $Q''$ coming from octupolar(-like) sources
  - Discrepancy for LER's $Q''_y$, from decapolar(-like) sources
- Amplitude detuning measured for LER with *detuned* optics
  - Model comparison would give a more detailed outlook on $Q''$