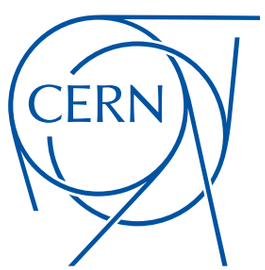
# Optics model

**Andy Langner, on behalf of the OMC Team**

European Organization for Nuclear Research (CERN) & Universität Hamburg

6th Evian Workshop, 15.12.2015

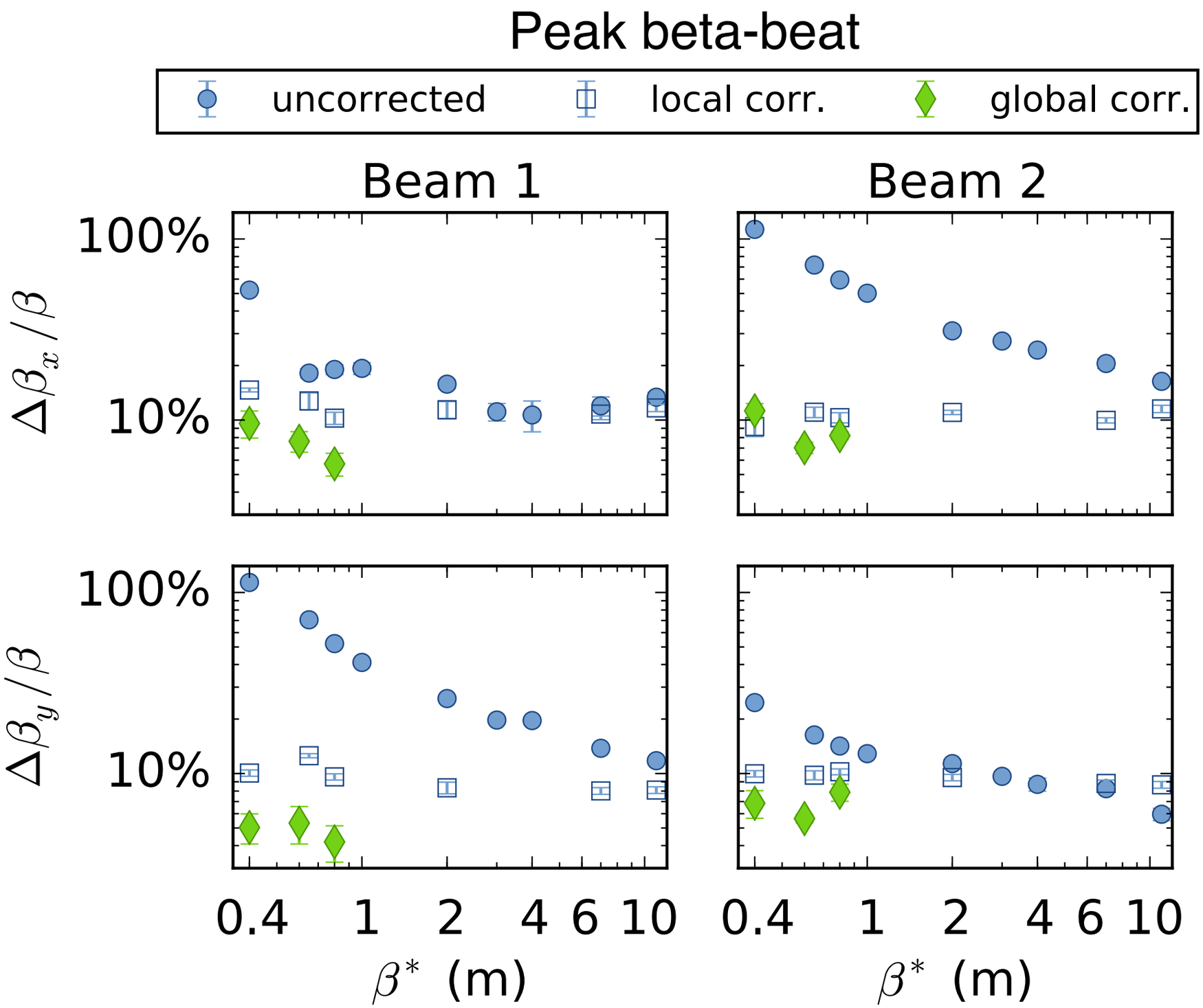

# References


- „Outcome of optics measurements“, R. Tomás, LMC, 17.06.15
- „Updated results from triplet k-modulation“, M. Kuhn, LBOC, 24.11.15
- „Beta* corrections strategies“, T. Persson, LBOC, 24.11.15
- „MD result: alignment optics“, A. Garcia-Tabares Valdivieso, 60th HiLumi WP2 Task Leader Meeting, 20.11.15
- „MD results: non-linear corrections“, E. Maclean, 60th HiLumi WP2 Task Leader Meeting, 20.11.15
- „Optics errors in ballistic optics“, L. Malina, OMC meeting, 10.12.15
- Segment-by-segment with beta* and alpha* constraints, J. Coello de Portugal, OMC meeting, 10.12.15

# Outline

- **Optics quality in 2015**
- **Issues during the optics commissioning**
  - β*, waist shift
  - Dispersion
- **Proposed strategy for 2016 commissioning**
  - Ballistic optics
  - Optics situation for combined ramp & squeeze
  - How stable are the optics
  - Non-linear errors in the interaction region

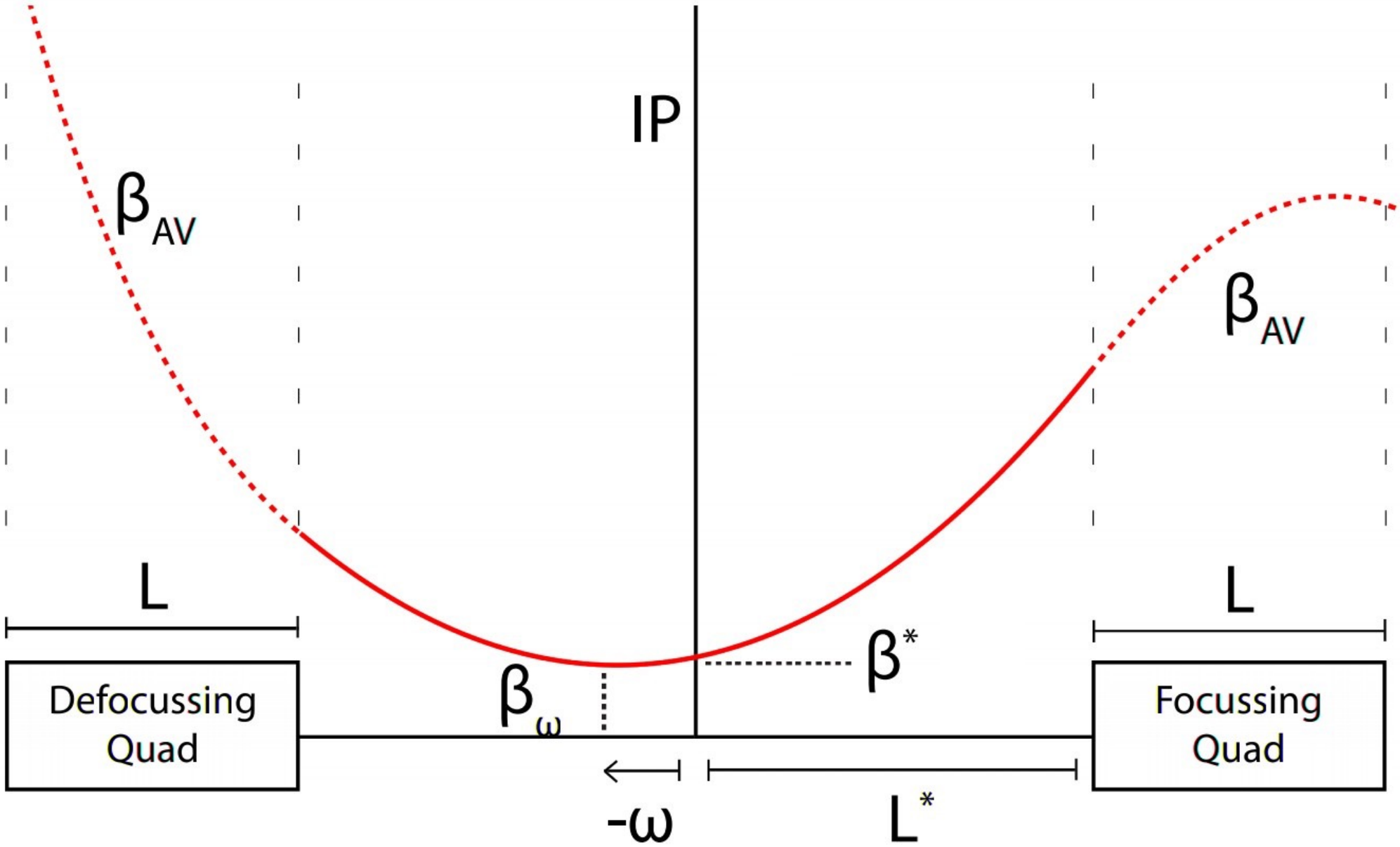
# Optics quality in 2015




- Peak beta-beat below 10% (below 5-6% in vertical planes)
- Constant local and global corrections from 80 cm to 40 cm

# Beta-function at IPs

Notation to differentiate between β at the IP and the actual minimum β at the waist ω



# Beta-function at IPs

| Proton run $\beta^*_{design} = 80$ cm | | $\beta^*$ (cm) horizontal | $\beta^*$ (cm) vertical | $\omega$ (cm) horizontal | $\omega$ (cm) vertical |
|---|---|---|---|---|---|
| Beam 1 | IP1 | 87.8 ± 1.3 | 86.5 ± 0.7 | 24 ± 1 | 23 ± 1 |
| | IP5 | 86.2 ± 1.1 | 86.4 ± 4.9 | 20 ± 1 | 15 ± 1 |
| Beam 2 | IP1 | 81.9 ± 1.3 | 82.7 ± 0.6 | 17 ± 2 | 21 ± 1 |
| | IP5 | 86.7 ± 1.4 | 82.7 ± 2.0 | 22 ± 1 | 11 ± 1 |

- $\beta^*$ was larger than design
  - directly translates into luminosity
- Waist was shifted by ~20 cm
- Will become more critical for a squeeze to 40 cm in IP1/5

# Waist shift correction demonstration

| | | Proton Run ω (cm) | | Ion Run ω (cm) | |
|---|---|---|---|---|---|
| | | horizontal | vertical | horizontal | vertical |
| Beam 1 | IP1 | 24 ± 1 | 23 ± 1 | 2 ± 4 | 5 ± 2 |
| | IP5 | 20 ± 1 | 15 ± 1 | -4 ± 5 | 1 ± 2 |
| Beam 2 | IP1 | 17 ± 2 | 21 ± 1 | 4 ± 3 | -4 ± 2 |
| | IP5 | 22 ± 1 | 11 ± 1 | 2 ± 4 | -9 ± 3 |

- Waist shift correction was successfully demonstrated during Ion run commissioning
- Increased expected luminosity by 3-5%

# Waist shift correction

**Required improvements:**

- Change our codes to take β* and waist position as additional constraints when calculating corrections

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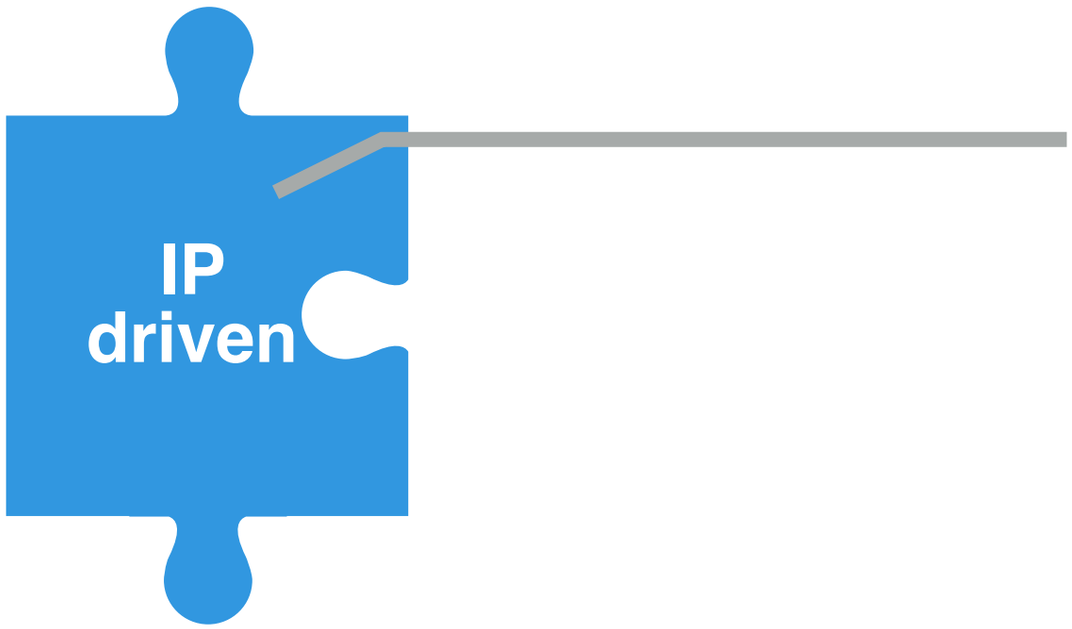
- Fully online k-modulation measurements




In contrast to magnet driven

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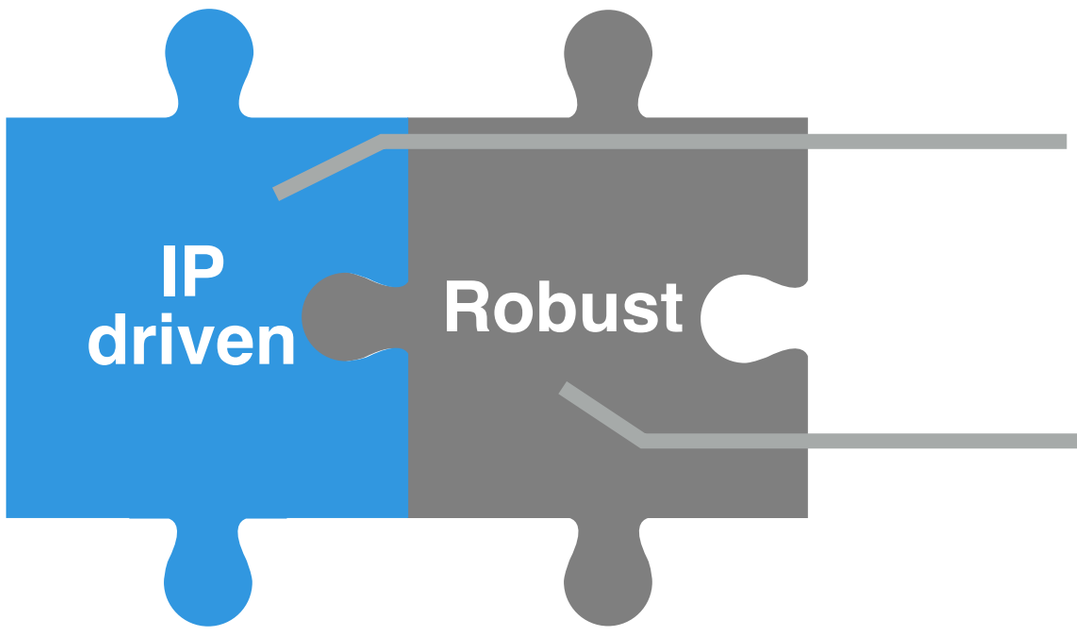


In contrast to magnet driven

Better, the fewer manual actions are needed

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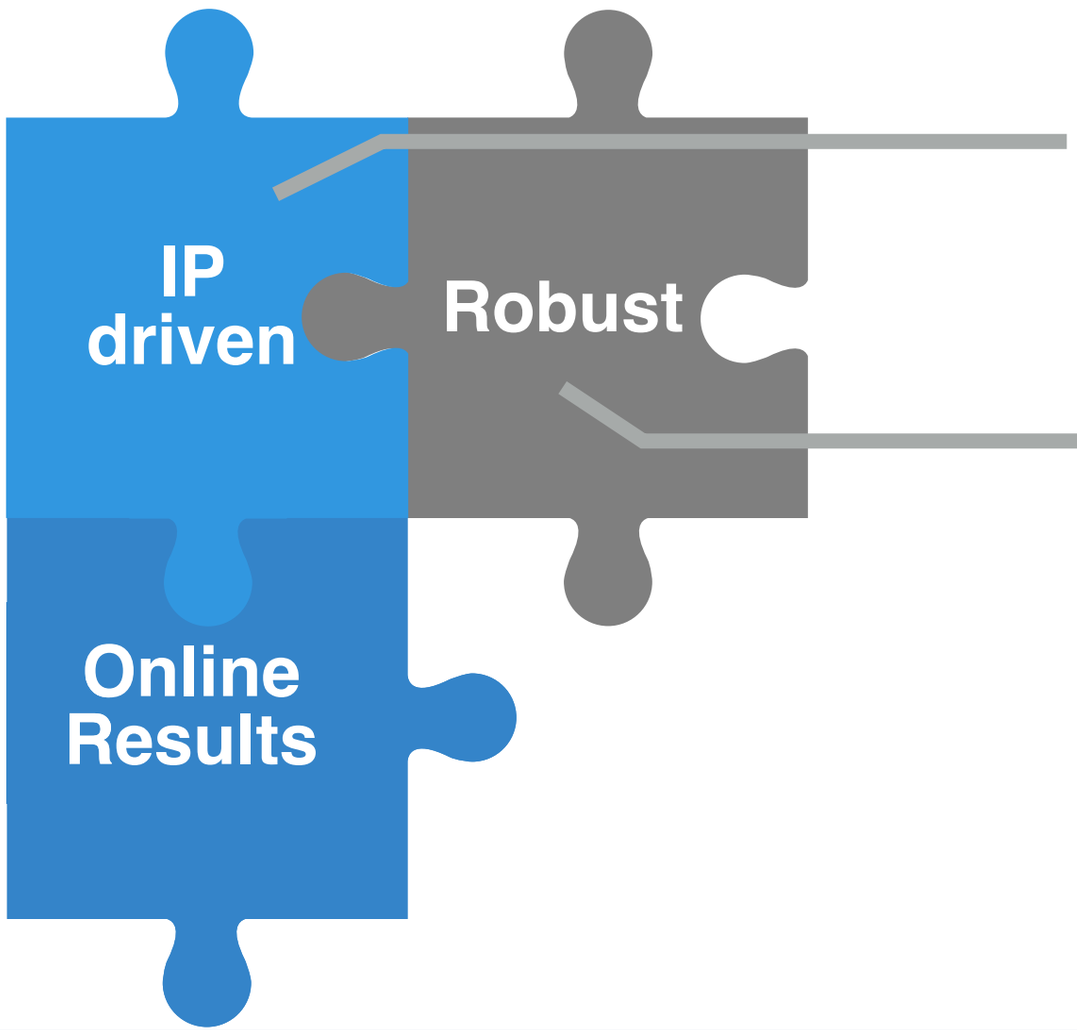


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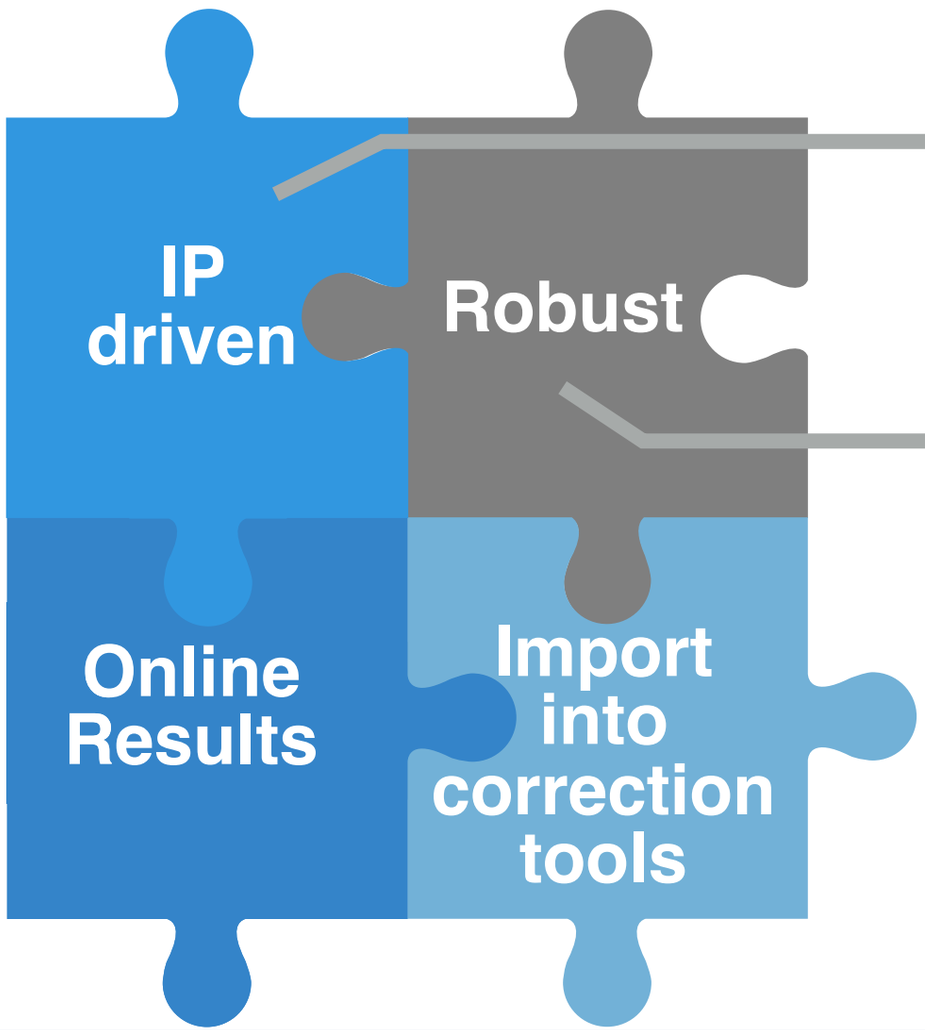


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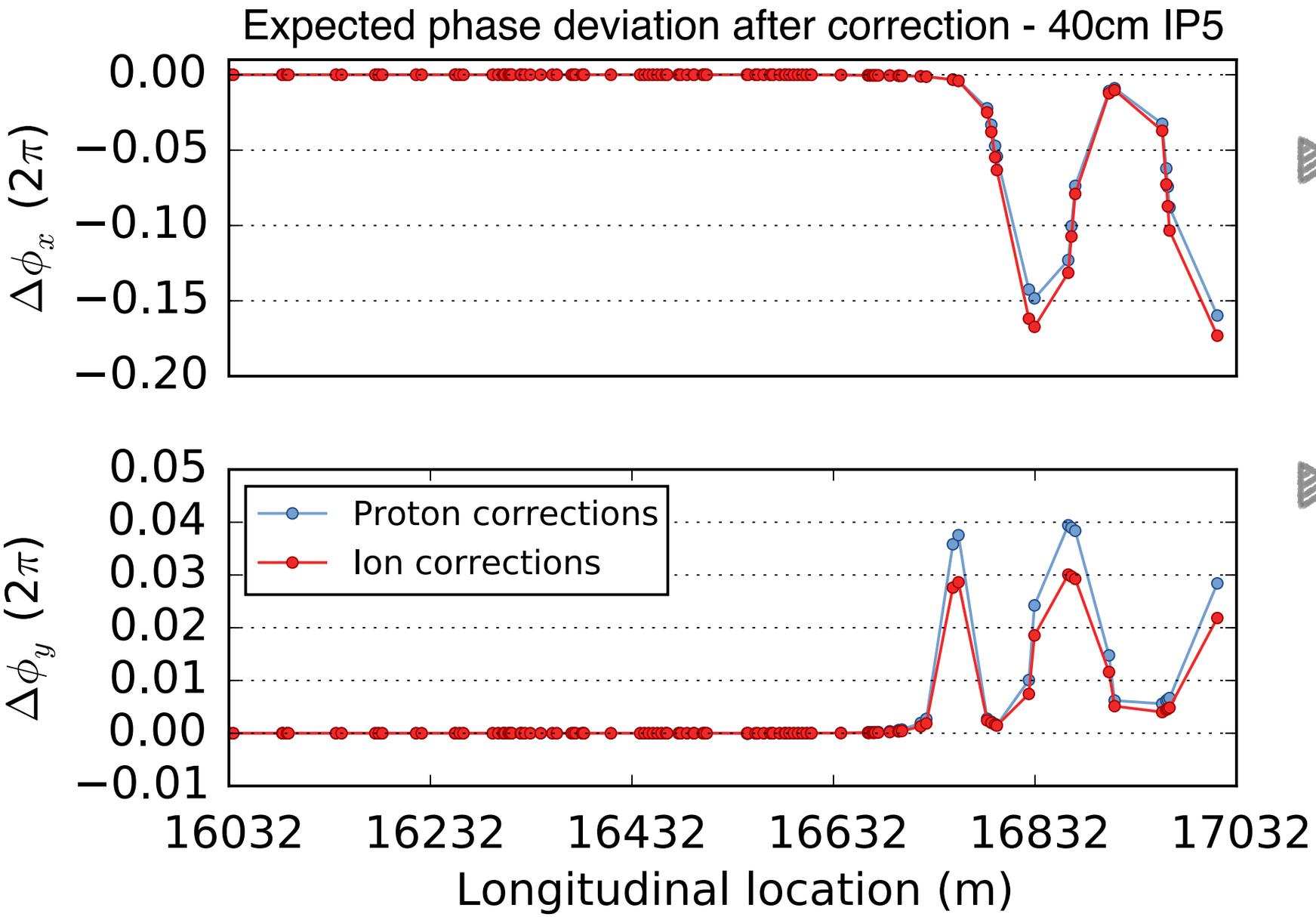
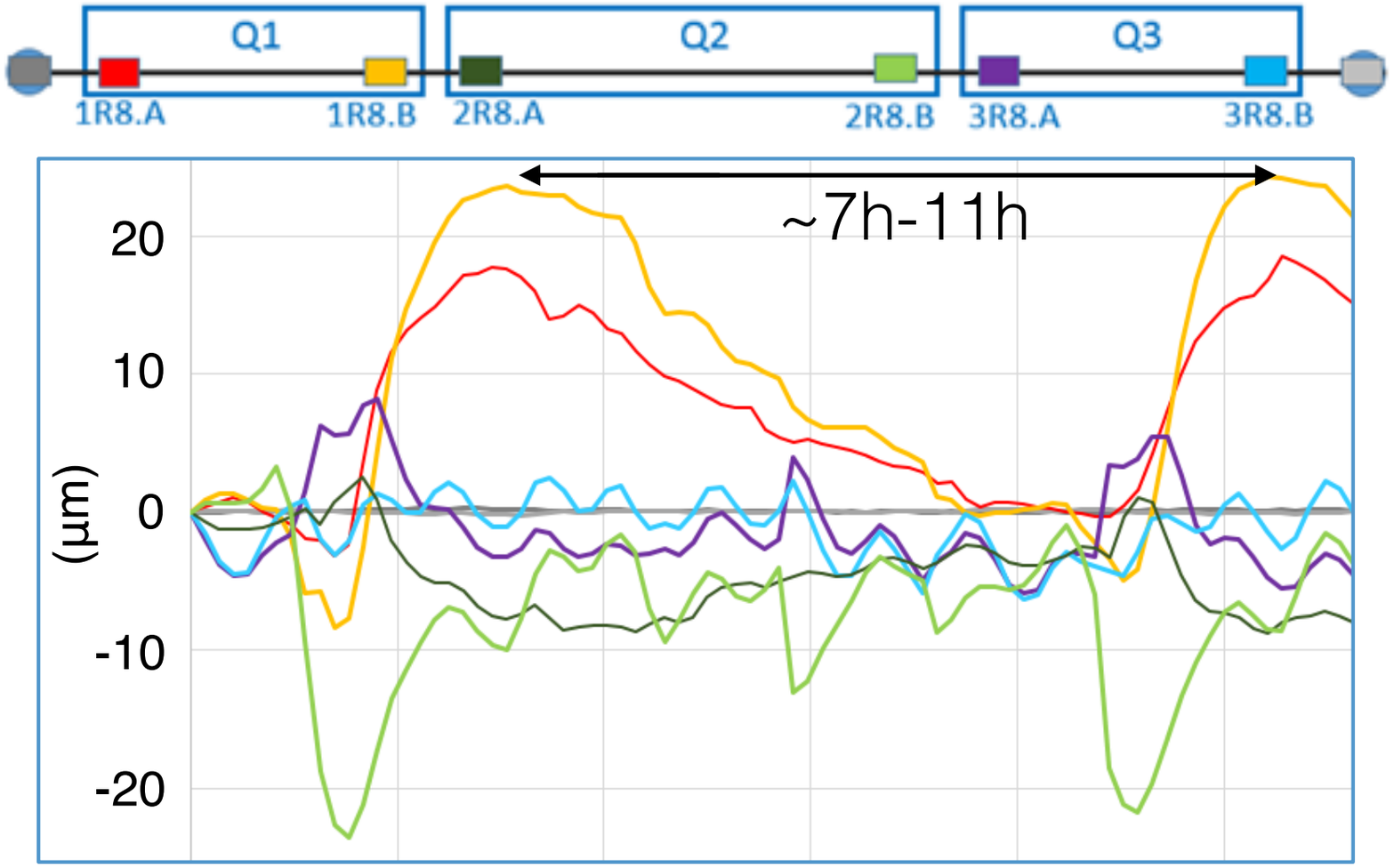
# Ion run corrections for protons




- Ion corrections will not work for 40 cm optics
- Need to derive corrections for phase + waist simultaneously

# Dispersion measurements




Quadrupole movement in IR8

presented by
H. Mainaud Durand
in LMC 07.10.2015

- Q1 movement (~30 µm) disturbed many dispersion measurements

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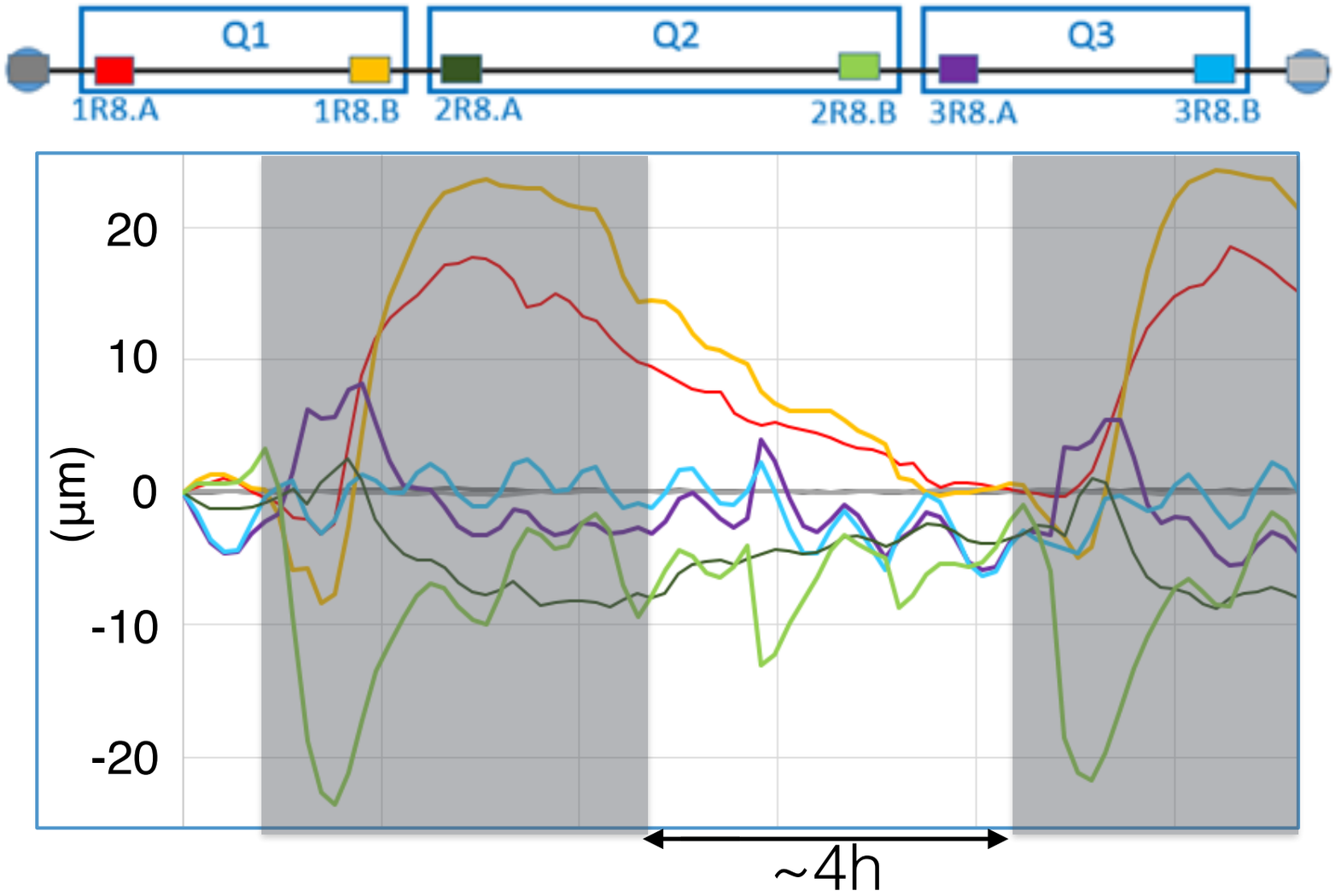


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- For future dispersion measurements need to avoid periods where Q1 is moving fast

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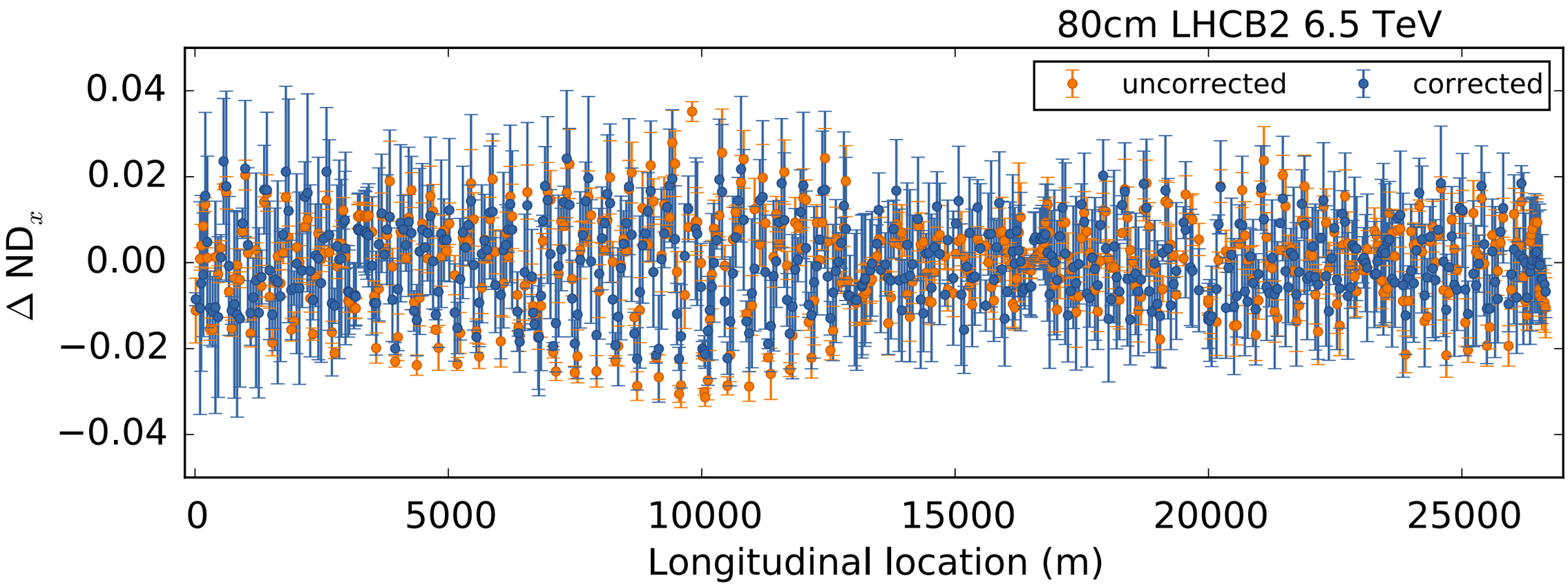


- Many dispersion measurements during 2015 commissioning were spoiled due to IR8 quadrupole movements
- Limited global correction quality

# Optics commissioning strategy

**uncorrected machine**

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Measure
K-mod

Measure
Turn-by-turn

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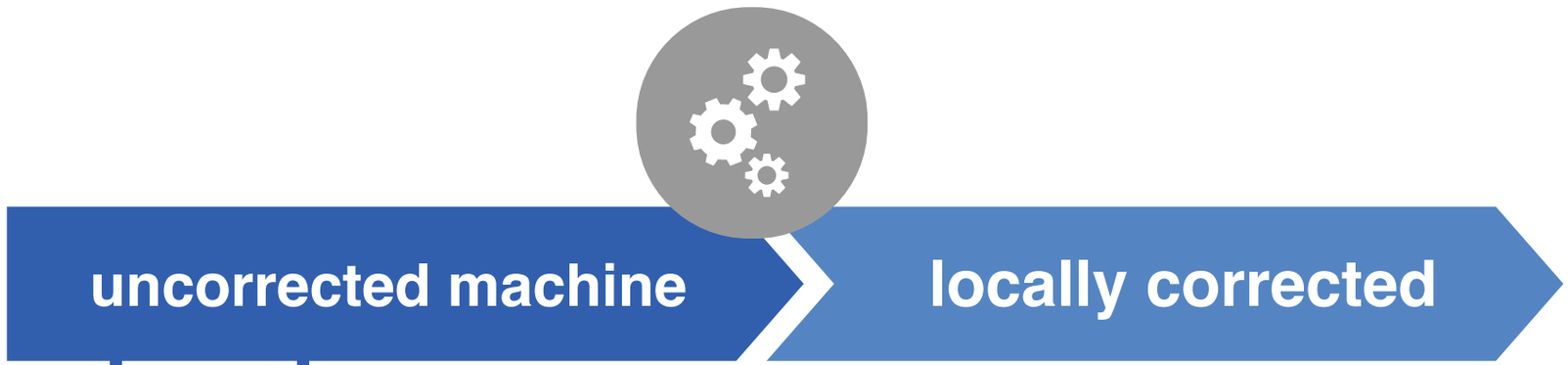


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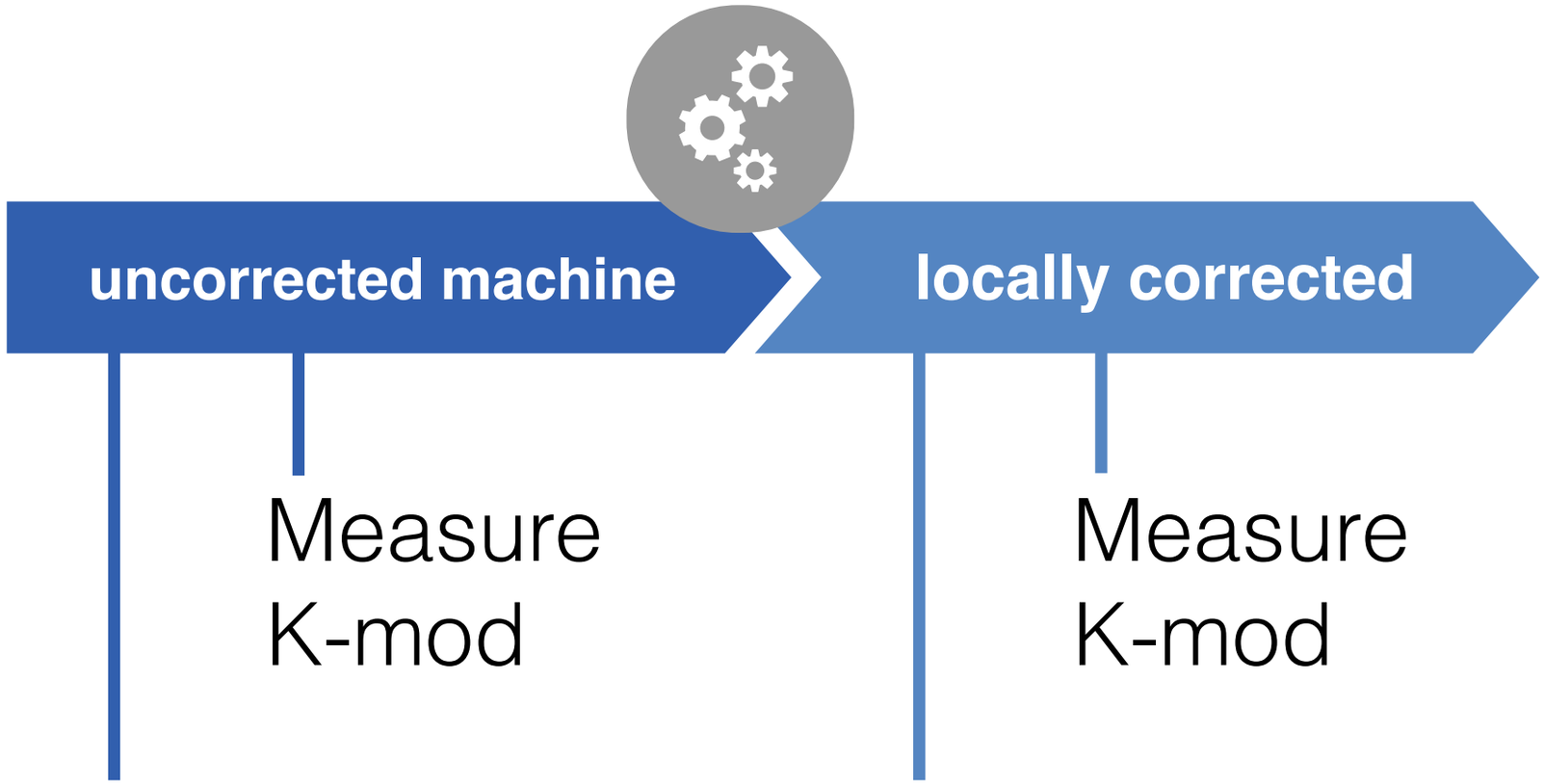

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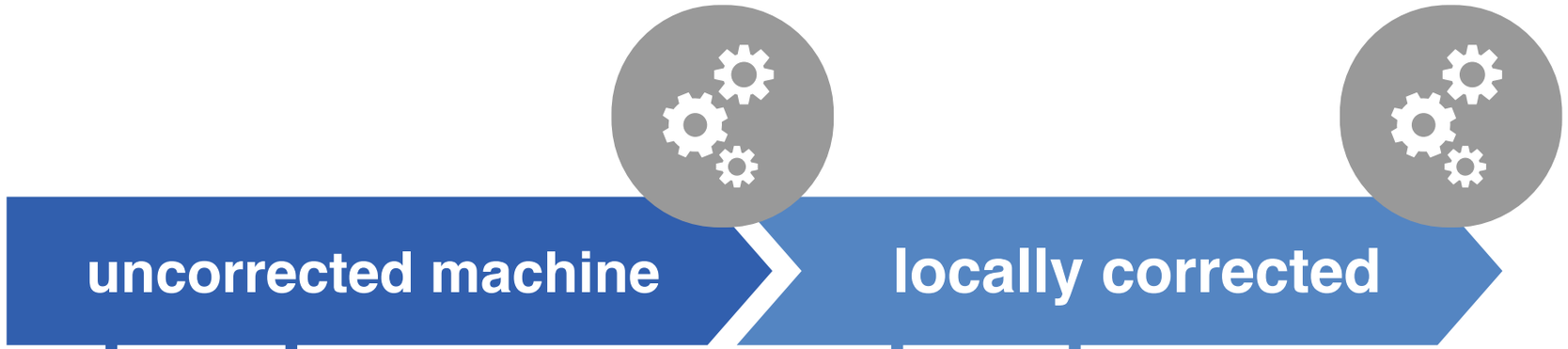


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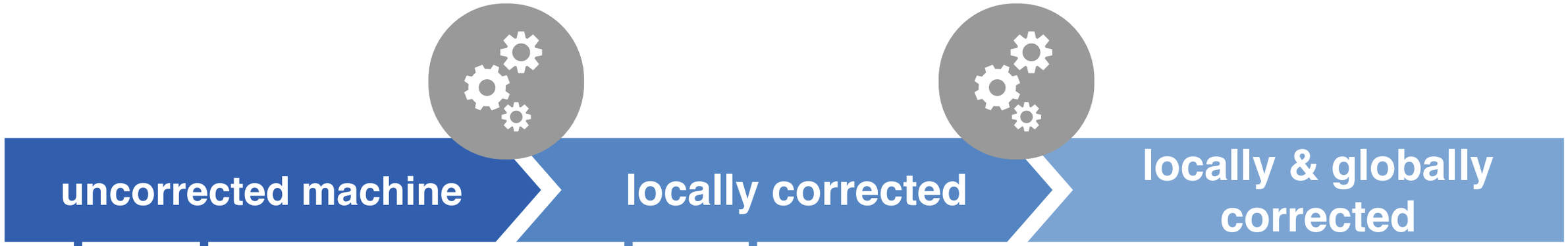


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# Optics commissioning strategy

Calculate
**local** corrections

Calculate
**global** corrections

**uncorrected machine** → **locally corrected** → **locally & globally corrected**

Measure
K-mod

Measure
Turn-by-turn

Measure
K-mod

Measure
Turn-by-turn

Verify with
K-mod

Verify with
Turn-by-turn

- **3-4 shifts** for 40 cm / 50 cm commissioning

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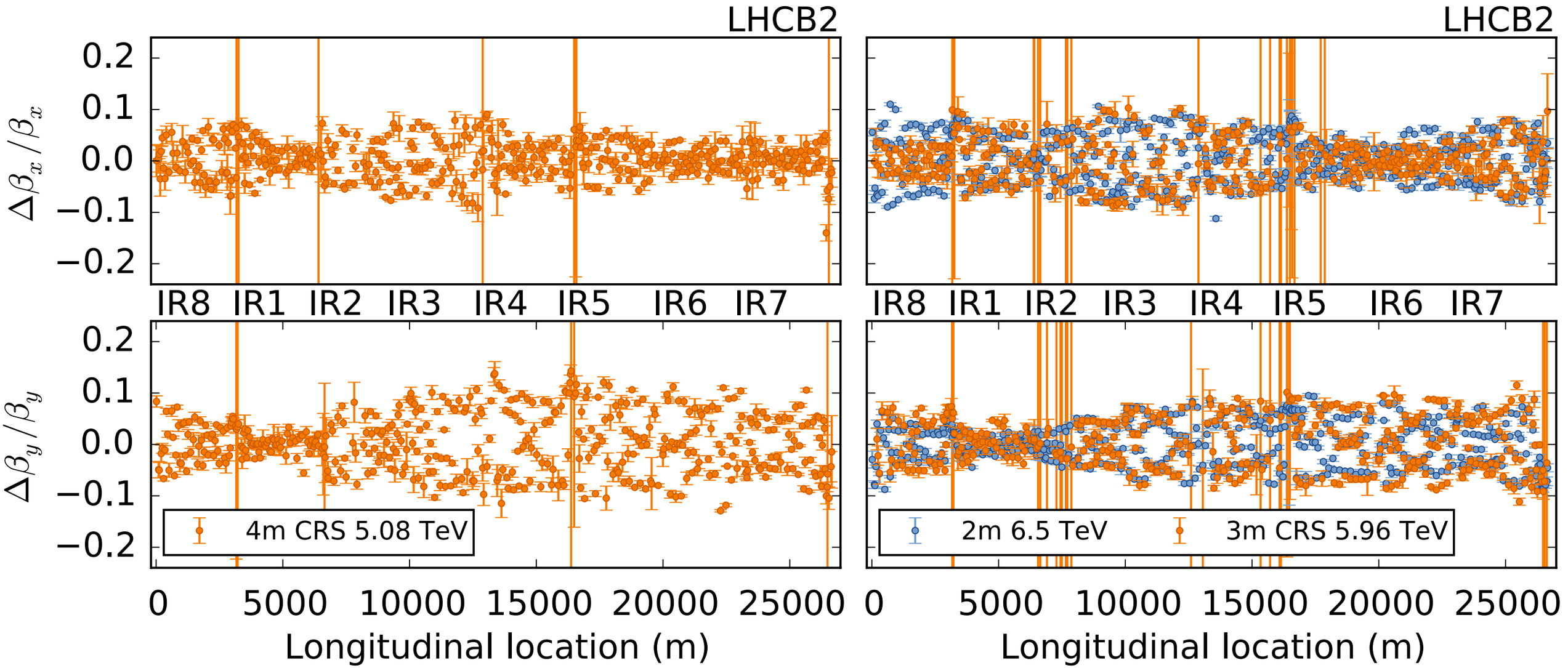
**1.5 shifts** needed for a complete set of measurements (both beams) at 6.5 TeV

# Combined ramp and squeeze (CRS)




MD323, c.f. CERN-ACC-NOTE-2015-0023

- Optics behaved very well during CRS to 3 m
- They do not pose a limit to squeeze to even smaller β*

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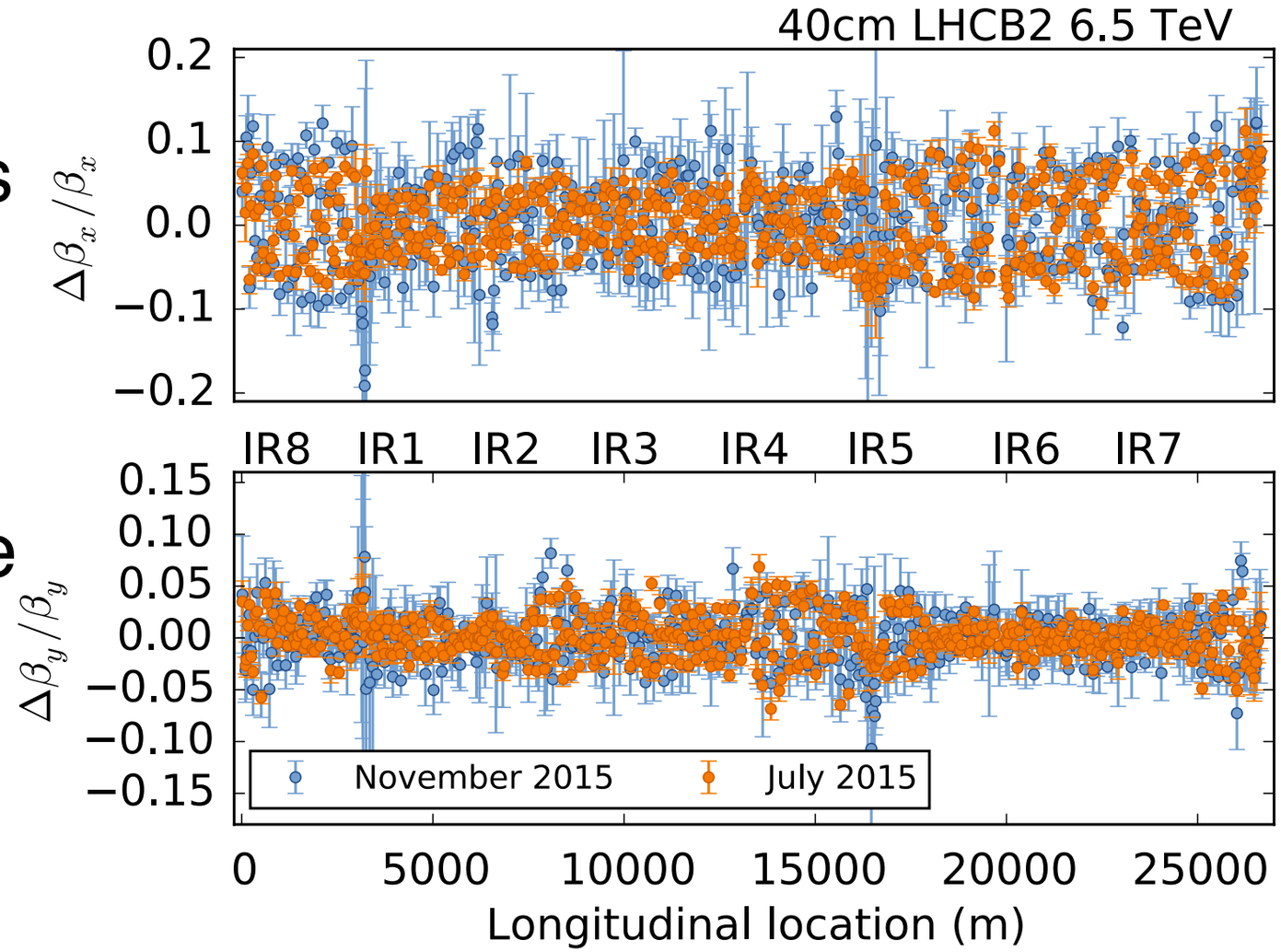
- We have various examples of good reproducibility for injection optics after time periods **~6 months**

- We are lacking good data of repeated measurements for squeezed optics

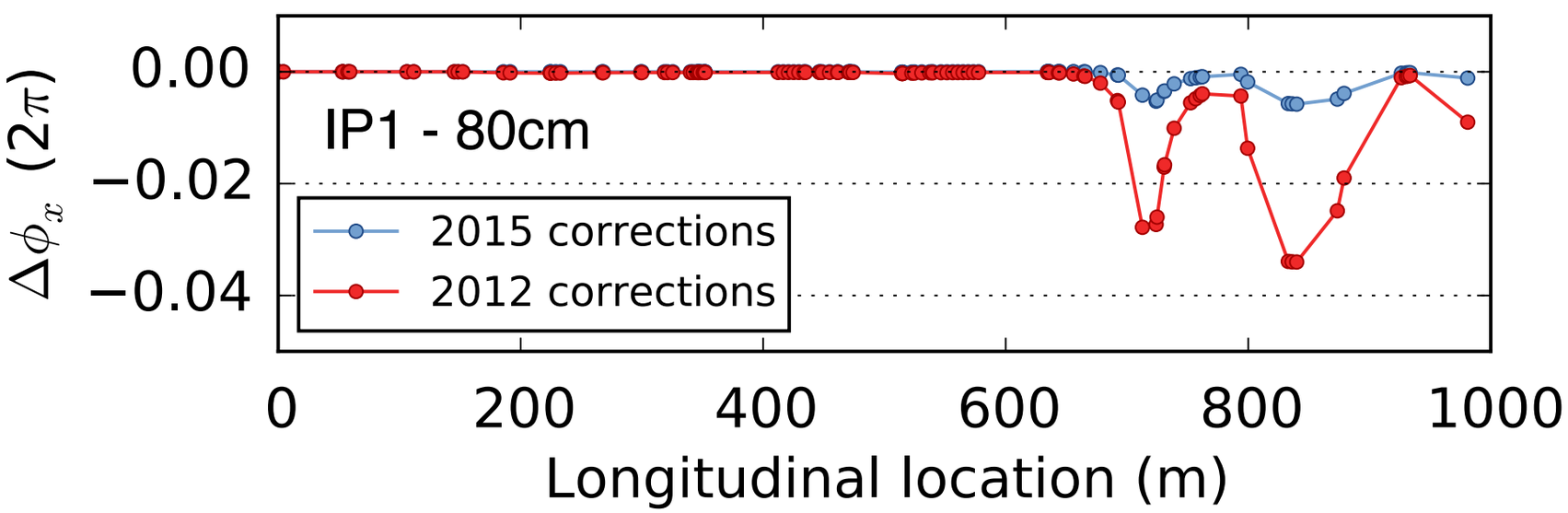
- 40 cm measurement after **~ 4 months** are compatible within (large) error bars



# Optics stability

## Triplet corrections - 2012 (4TeV) vs 2015 (6.5TeV)

| Region | Circuit | Δk ($10^{-5}$ $m^{-2}$) | |
|---|---|---|---|
| | | 2012 | 2015 (protons) |
| IP1 | ktqx1.r1 | 1.00 | |
| | ktqx2.l1 | 1.00 | 0.35 |
| | ktqx2.r1 | -1.40 | -0.70 |
| IP5 | ktqx1.l5 | | 2.00 |
| | ktqx1.r5 | | -2.00 |
| | ktqx2.r5 | 1.05 | 1.90 |
| | ktqx2.l5 | 0.70 | -0.09 |




- Corrections are deviating significantly
- 2012 corrections could not be re-used after 3 years

# Optics stability

Possible reasons for the difference 2012 vs 2015

? Energy related (4 TeV vs. 6.5 TeV)

- Optics errors at 2.51 TeV (2015) were compatible with 6.5 TeV

? Effects from the long technical stop

? New longitudinal misalignments

? Magnet ageing

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Quick optics checks on a **yearly** basis would be proposed

# Non-linear IR errors

**Motivation:**

- Improve dynamic aperture → longer lifetime → more integrated luminosity
- At RHIC 10- and 12-pole correctors increased integrated luminosity by 4%,

  c.f. IPAC'10 THPE099

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b3 in IR2

b3+a4 in IR1

b4 in IR1+IR5

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| Corrections ready for testing | Not understood | Not studied |
|---|---|---|
| b3 in IR2 | a3 in IR1 | a3+a4 in IR5 |
| b3+a4 in IR1 | b3 in IR5 | |
| b4 in IR1+IR5 | | |

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|---|---|---|
| b3 in IR2<br>b3+a4 in IR1<br>b4 in IR1+IR5 | a3 in IR1<br>b3 in IR5 | a3+a4 in IR5 |

- **2 shifts** should allow commissioning of some of these corrections.
- 1 after optics commissioning, 1 later (not a bottle-neck to delay high intensity commissioning)

# Recap on the 2016 commissioning

1. Ballistic optics ▶ 1.5 shift
2. Ramp & Squeeze ▶ 0.5 shift
3. 40cm/50cm optics ▶ 3-4 shifts
4. Non-linear IR ▶ 2 shifts

**7-8 shifts**

# Conclusions

- Globally well corrected optics achieved in 2015
- Improved strategy for 2016
  - Mitigate β* waist shift & dispersion issue
    - Ballistic optics
      - Improve local corrections
      - More precise β* from turn-by-turn measurement
    - Correction of IR non-linear errors

# Thank you for your attention!

**OMC Team:**
**Felix Carlier, Jaime Coello de Portugal, Ana Garcia-Tabares Valdivieso, Andy Langner, Ewen Maclean, Lukas Malina, Tobias Persson, Piotr Skowronski, Rogelio Tomás**

# Backup

# Ballistic optics - BPM calibration