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BBWC commissioning and operation for 2024[1]

G. Sterbini, P. Bélanger, S. Fartoukh, M. Hostettler and A. Rossi

We thank **G. Iadarola** *for his help with xsuite's matching module,* **J. Wenninger** *and* **S. Redaelli** *for the discussions,* **D. Mirarchi** *for the wires polarity check at injection. We acknowledge* **BE-ABP/CEM/OP**, **EN-MME** *and* **SY-BI/STI** *for their technical support.*

1. Introduction and context
2. Proposal for the B1/2 and IR1/5 knobs
3. Summary

[1] https://www.overleaf.com/read/fpjdrkktjtmw#daf6a5

HL-LHC wire demonstrators

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HL-LHC wire demonstrators

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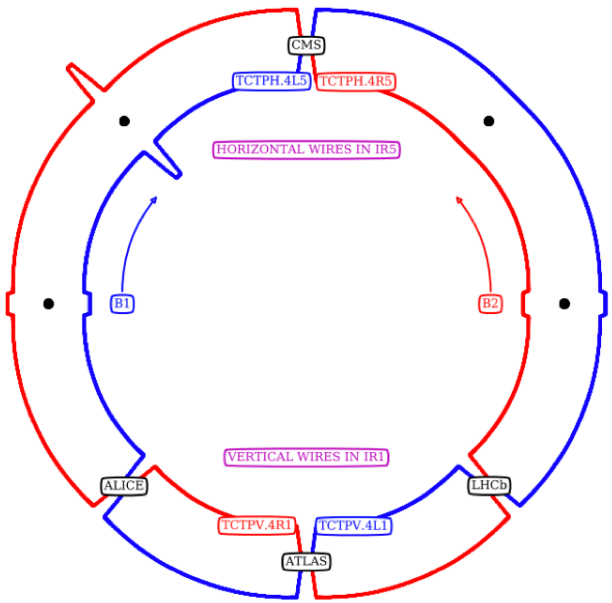
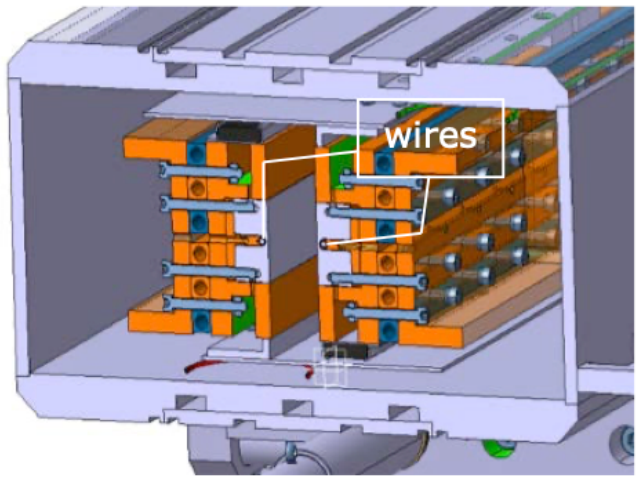
- → **embedded in operational TCTs**
  - **L1B1** and **R1B2** (V-TCT, $s_{IP}^{center} = -145.945$ m)
  - **L5B1** and **R5B2** (H-TCT, $s_{IP}^{center} = -147.945$ m)
- → each jaw has a **1 m** long, ∅**=2.48 mm** Cu wire carrying **350 A**.





From EDMS 1705791 and 2054712.

A bit of history

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- In 2022, following the **failure of B1 (F8146) and B2 (F8399)** wires, a consolidation studies was launched by EN-MME, SY-BI/STI, BE-ABP (LMC 456). Results presented at Chamonix 2023.

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- **B2 wires were repaired** in EYETS22-23 (8-9 March 2023, after LHC-BBLR-EC-0001 approval at LMC 457). **They were used successfully in 2023** in production fills (see 13^{th} HL CM).
- **B1 wires were repaired** in EYETS23-24 (20-24 Nov 2023, after LHC-BBLR-EC-0002 approval at LMC 474). The **B1 wires powering commissioning** was done in the tunnel by A. Rossi's team.

2024 Run and wire compensation

We propose to use the **B1 and B2 wires** in

1. **2024 production fills** as done in 2023 for B2 wires (at the end of the fill with β^*=30 cm),
2. **2024 MD** to explore their potential for **22 cm** $< \beta^* <$ **30 cm**, and depending on the results, consider their use also in this segment (e.g., after TS1).

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Following the decision of deploying RP optics in 2024, the IR1 Q4s were locked-out (LMC 479). We reconsidered the Q-feedforward knobs, and we propose a **full-fledged matching**[2] using the following 9 quadrupoles (on the **TCT's IP side**)

- Q5-6-7-8-9-10-11-12-13 for IR1,
- Q4-5-7-8-9-10-11-12-13 for IR5.

[2] 2022/23 knobs were based just on tune correction using Q4L/R.

These knobs

- are **tele-index independent** (e.g., see β^* <30 cm segment),
- are **very linear and local** perturbation,
- do **not affect the IP → Roman-Pots matrices**,
- Crossing and separation bump extends up to Q4-5. Trimming those quadrupoles will have an **effect on the closed orbit**. We assume that the closed orbit feedback will be active and correct it,
- in 2024, R1B1 IPQs used for the β^* reconstruction[3].

[3] In 2023, the L1B1 IPQs were used: **J. Wenninger** modified the 2023 approach to avoid "cross-talk" with these knobs.

[4] see EDMS 2384198.

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At LBOC 164, the knobs' strategy was endorsed and the use of the BBCWs in 2024 operational cycle (at β^*=30 cm) was approved at LMC 482.

We will focus on the wires beam **readiness for STABLE BEAMS** and the MPP BBCW checklist[4].

[3] In 2023, the L1B1 IPQs were used: **J. Wenninger** modified the 2023 approach to avoid "cross-talk" with these knobs.

[4] see EDMS 2384198.

WIC commissioning

All the **WICs of the 4 BBWC were tested** on the 26 March 2024.

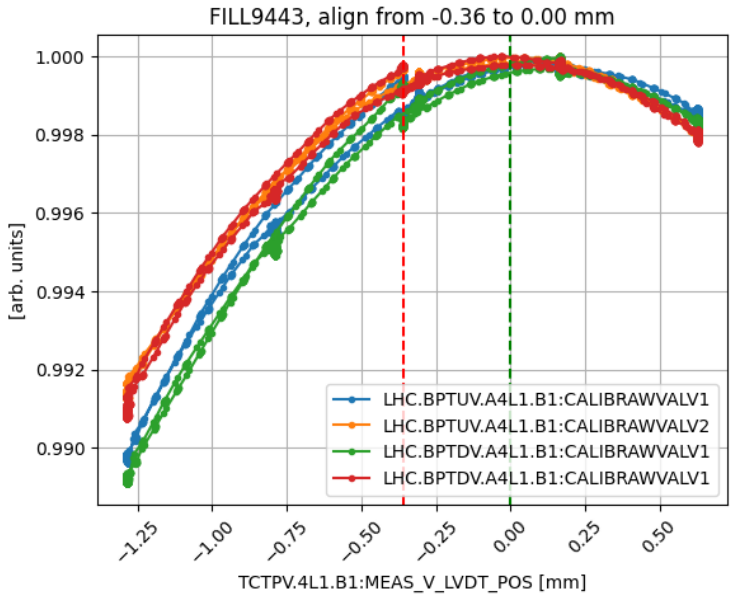
Following the procedure, the wire current was set to 375 A (removing during the test the SIS interlock and the FGC limit to 350 A.)

The WIC behaved as expected (see TIMBER snapshot).

5th axes' alignments

The 5th axis alignment scan was performed on 30 March evening.[5]

- TCTPV.4L1.B1: from -0.36 to 0.00 mm
- TCTPV.4R1.B2: from +0.50 to +0.60 mm
- TCTPH.4L5.B1: from +1.16 to +1.35 mm
- TCTPH.4R5.B2: from +0.02 to +0.35 mm



Alignment was deployed on the 3 April[6].

[5] See TIMBER snapshot and https://github.com/sterbini/5th_axis_tct_alignement/.
[6] See TIMBER snapshot.

Interlock chain test with beam

The **TCTPH.4L5.B1** interlock chain with beam was tested in FILL9456 (3 April).

The **TCTPV.4R1.B2** interlock chain with beam was tested in FILL9461 (4 April).

Summary

- After the decision to lock-out the Q4s in IR1, we reconsidered the knobs for the wire demonstrators. We propose matching **4 knobs using 9 quads on the TCT sides**
  - Q5-6-7-8-9-10-11-12-13 for IR1,
  - Q4-5-7-8-9-10-11-12-13 for IR5. We had the green light from LMC to power the BBCW at β^*=30 cm pending MPP's OK.
- We show the **linearity** of the knobs with respect to I_W and the β^*.

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- **First beam tests of the wires** took place: polarity check at 450 GeV done (17 March, D. Mirarchi), first check of knobs at 6.8 TeV done (25 March, 3 and 4 April). Optics measurement scheduled today.
- HW test **done** on the repaired B1 BBCWs, WIC test **done** of the 4 BBCWs, 5th axis alignement **done**, L5.B1 and R1.B2 interlock chain with beam **done**, LM **done** (**to be analyzed**), **optics measurement to be done** (some residual tune shift).

Thank you for your attention.


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References (I)

A. Poyet, A. Bertarelli, F. Carra, S. D. Fartoukh, N. Fuster-Martínez, N. Karastathis, Y. Papaphilippou, M. Pojer, S. Redaelli, A. Rossi, K. Skoufaris, M. Solfaroni Camillocci, and G. Sterbini.
First Experimental Evidence of a Beam-Beam Long-Range Compensation Using Wires in the Large Hadron Collider, April 2023. arXiv:2203.08066 [physics].

S Kostoglou, S Fartoukh, G Sterbini, H Bartosik, I Efthymiopoulos, G Iadarola, Y Papaphilippou, A Poyet, X Buffat, and M Hostettler.
Beam-beam effects in Run 3, November 2021.

Wires configurations considered

- The optics considered is the $\beta^* = 30$ **cm** (courtesy of S. Fartoukh).
- The TCT opening assumed is **8** σ_{coll} (to be confirmed during commissioning), and the beam total energy 6.8 TeV.
- With the wire retraction with respect to the jaw's face of 3.0 mm, the wire's center to beam's center distance is → **7.71 mm for IR1** and **11.82 mm for IR5**.

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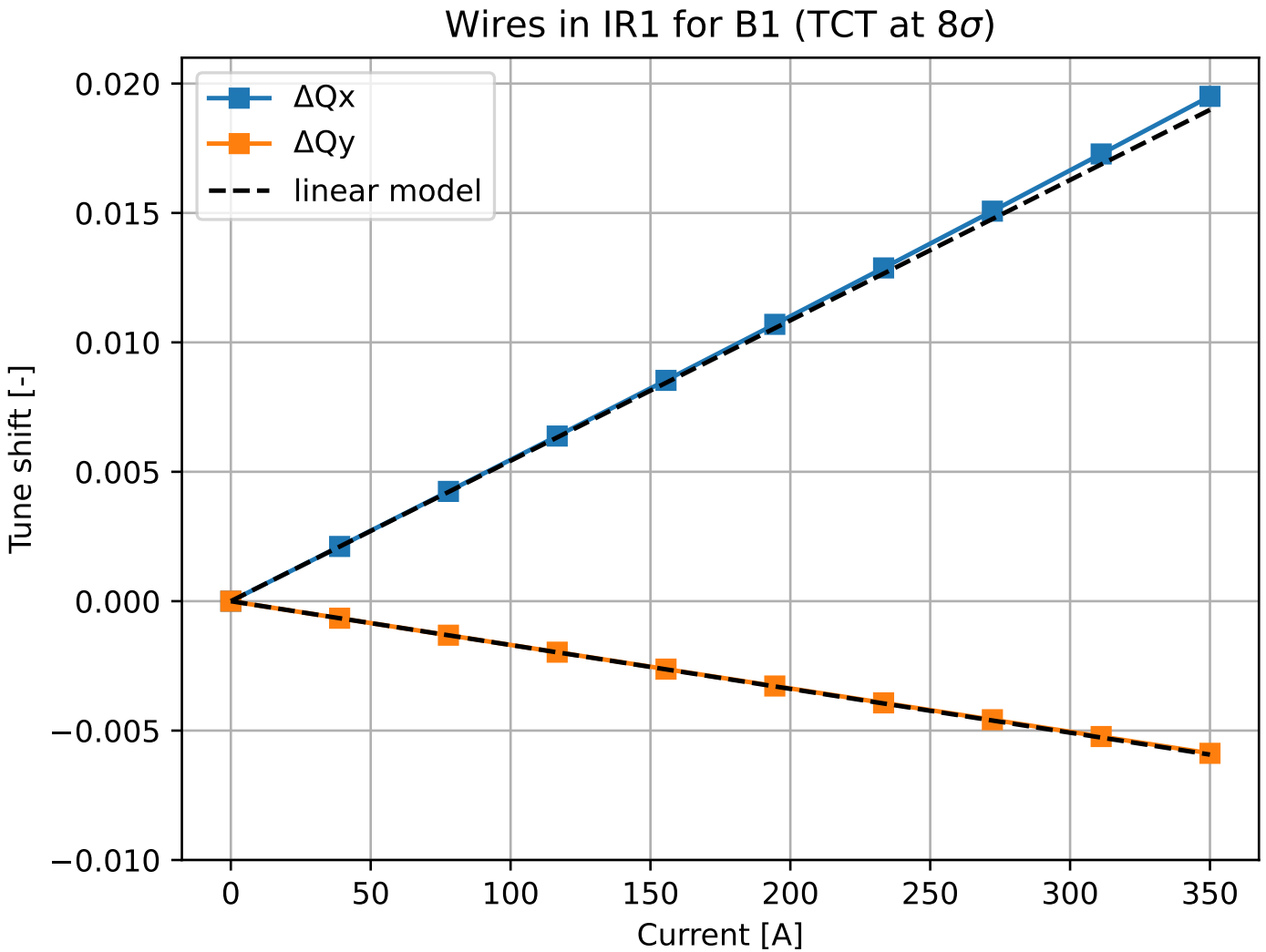
- With the wire retraction with respect to the jaw's face of 3.0 mm, the wire's center to beam's center distance is → **7.71 mm for IR1** and **11.82 mm for IR5**.
- if the beam is centered in the TCT and the 5th-axis is aligned, **no dipolar effect** is expected by the wires.
- a **quadrupolar effect** is expected (for I_w= 350 A, $K1L_{IR1}$ =1.05E-4 m^{-1}, $K1L_{IR5}$ =-0.44E-4 m^{-1}) and the knobs we are discussing aim to compensate for it.

Tune shift induced by the wires (w/o correction)



Effect on the tunes of **wires in IR1**.

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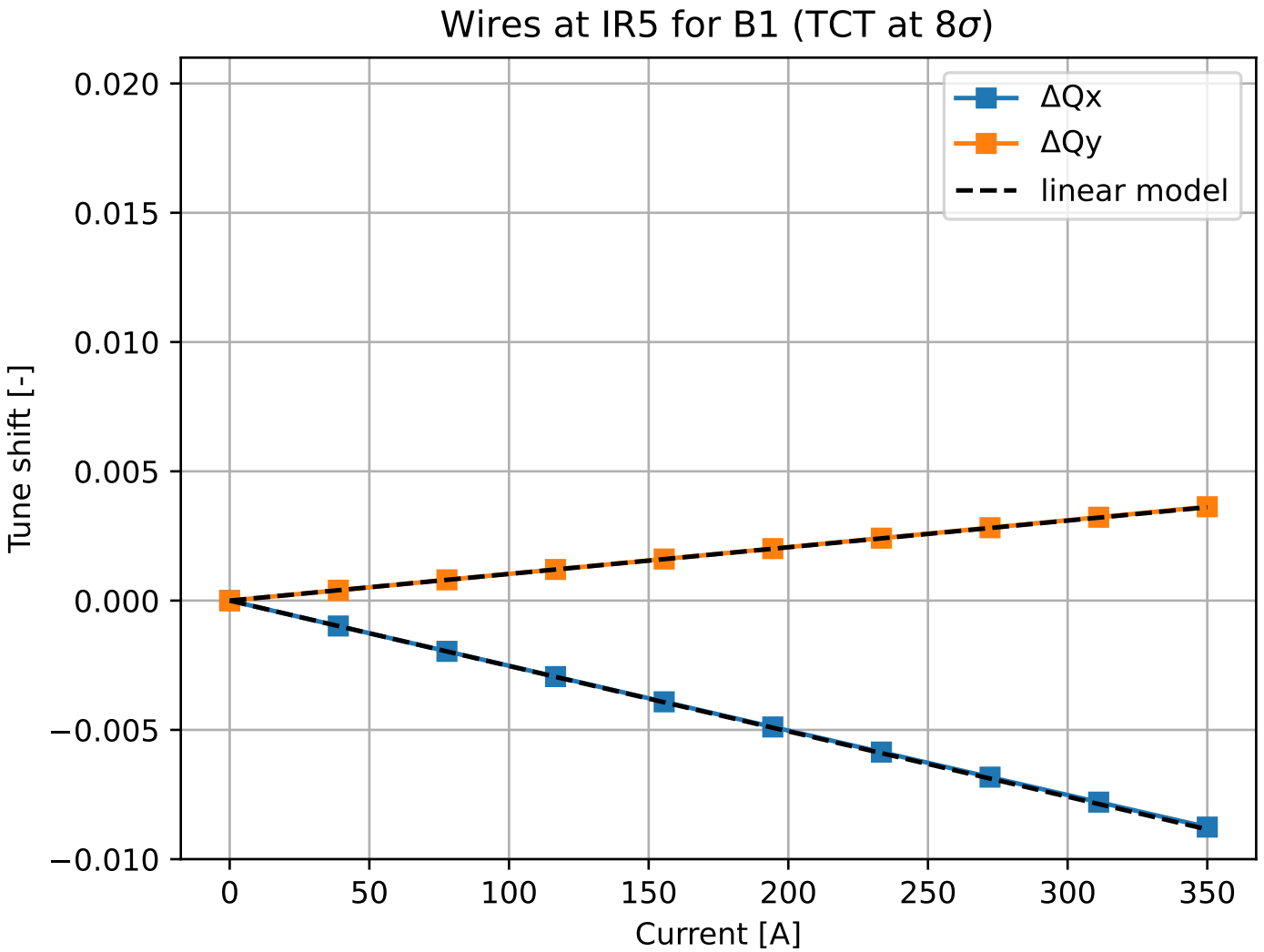
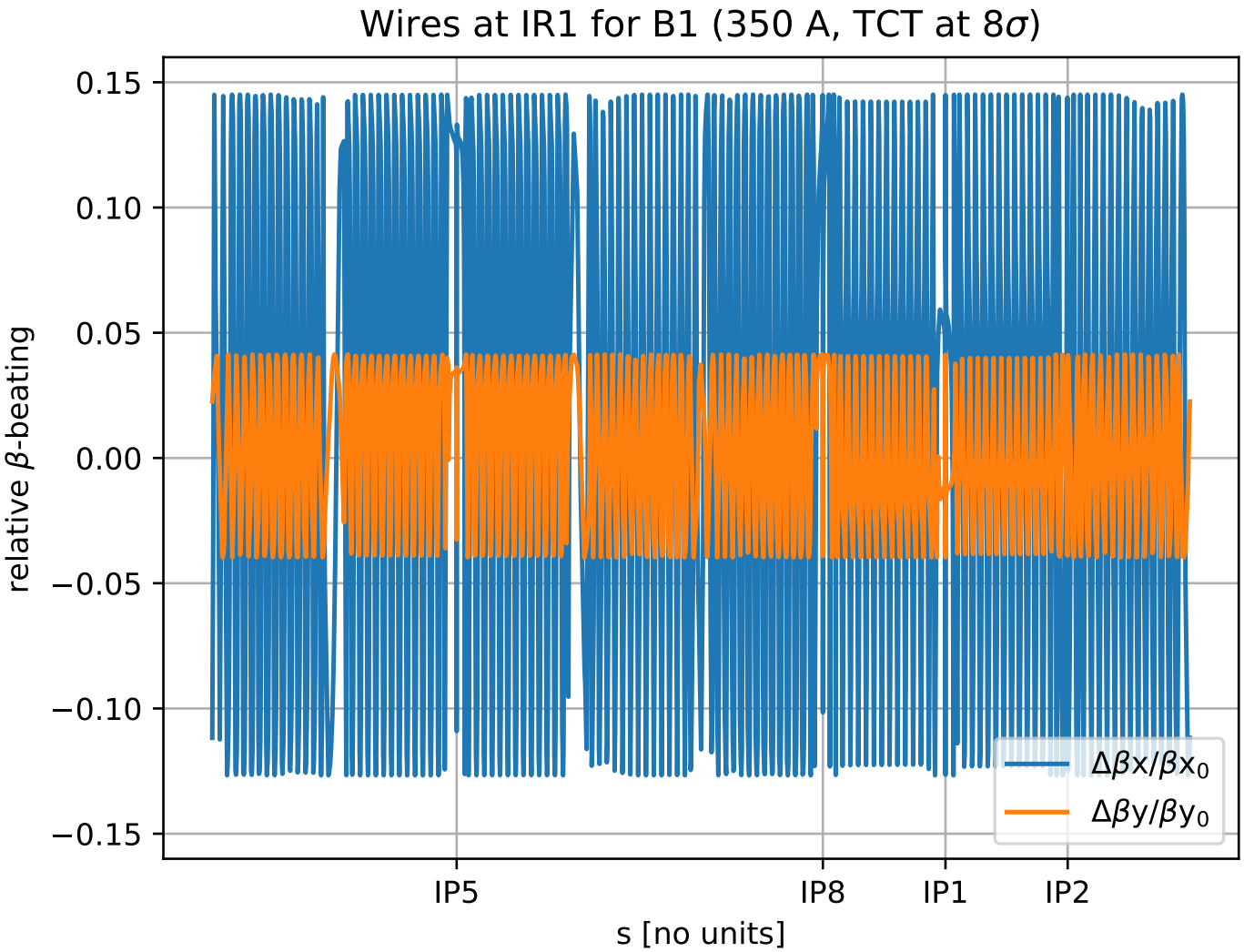


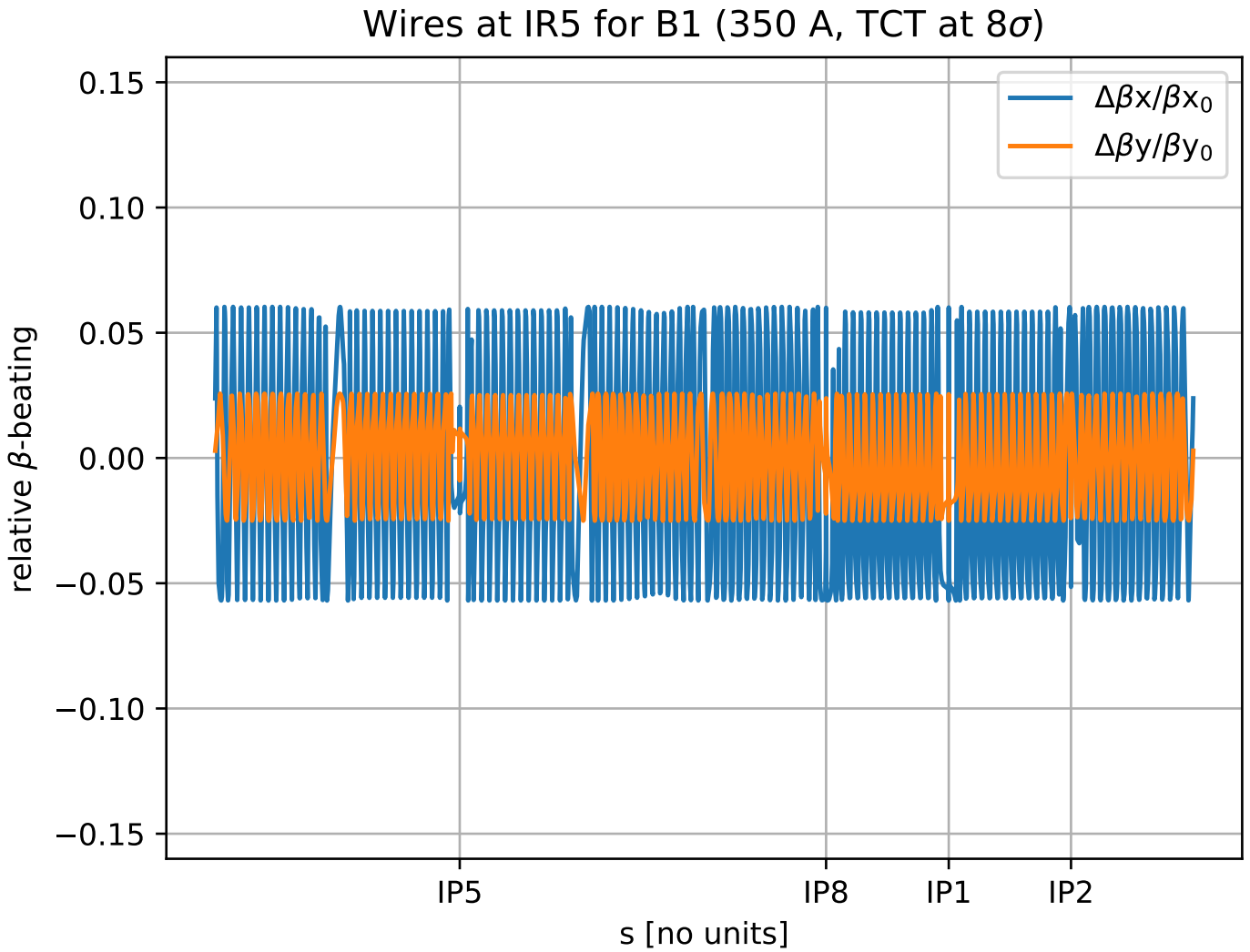
Effect on the tunes of **wires in IR5**.

β-beating induced by the wires (w/o correction)



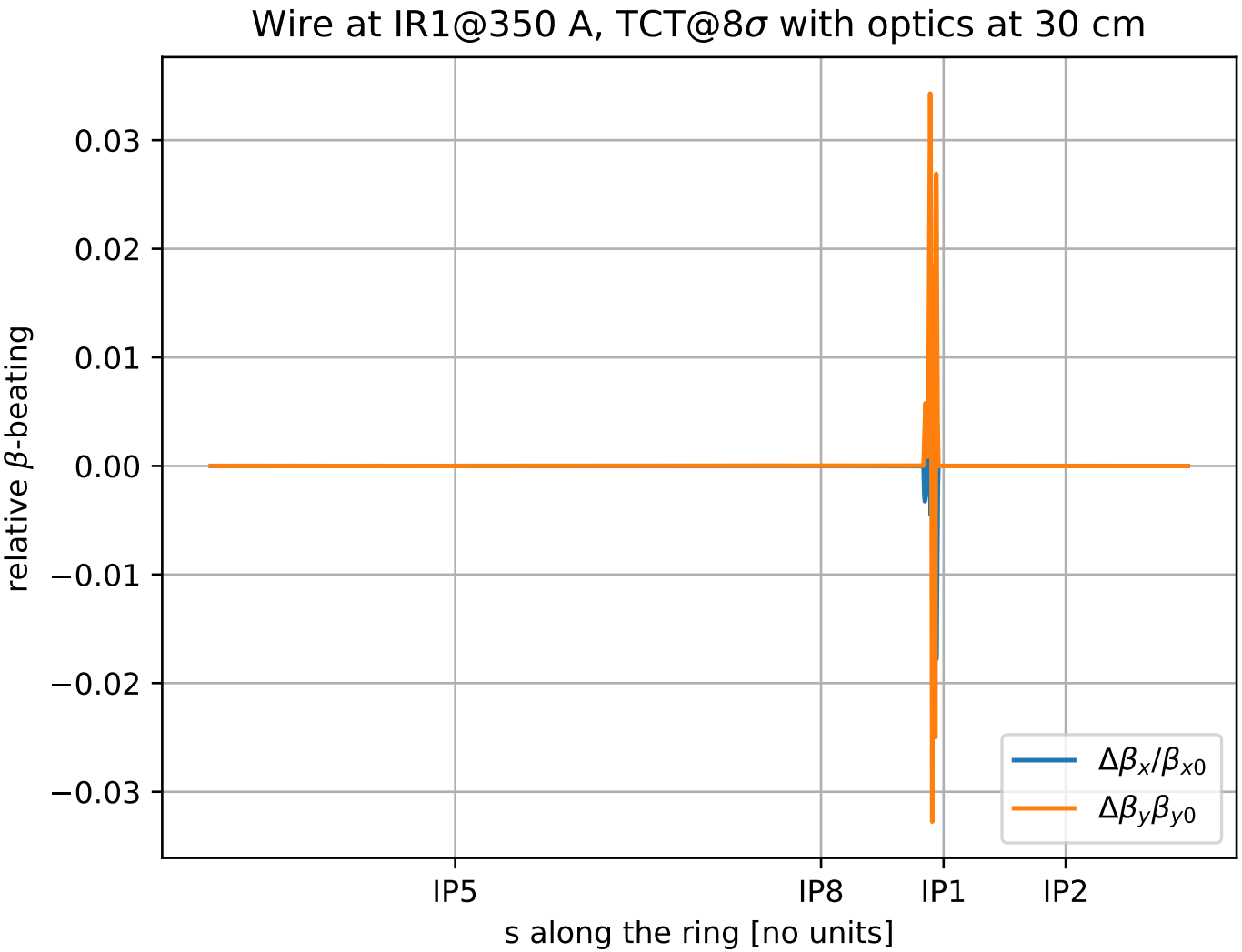
β-beating induced by $\mathbf{I_W}$**=350 A in IR1**.

β-beating induced by the wires (w/o correction)



β-beating induced by $\mathbf{I_W}$**=350 A in IR5**.

Correction in IR1



The proposed knobs consist in a **local correction**.

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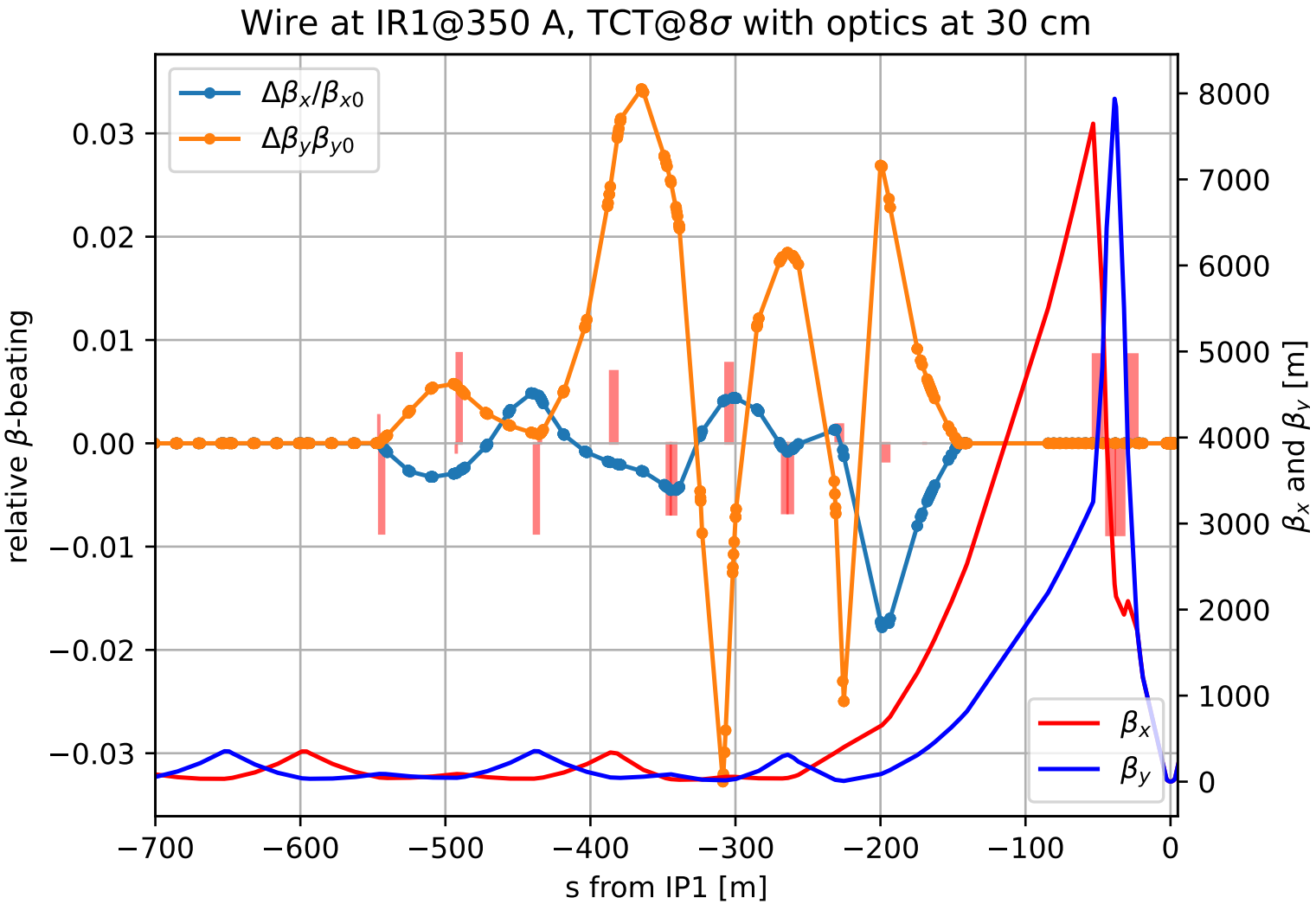

Matching $\beta_{X,Y}, \alpha_{X,Y}$, *dx*, *dpx* at the IP and $\mu_{X,Y}$ in Q13-IP (TCT side).

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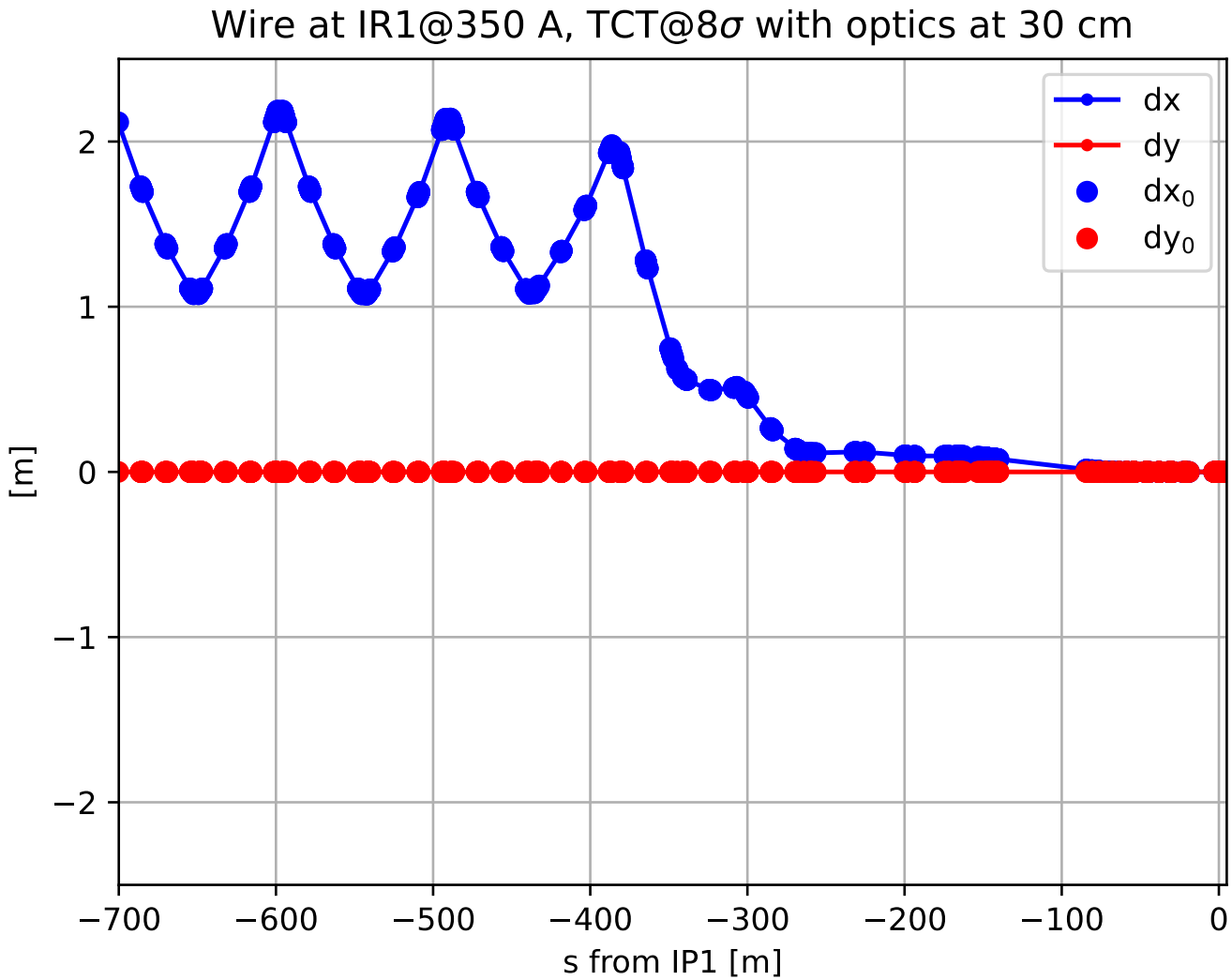
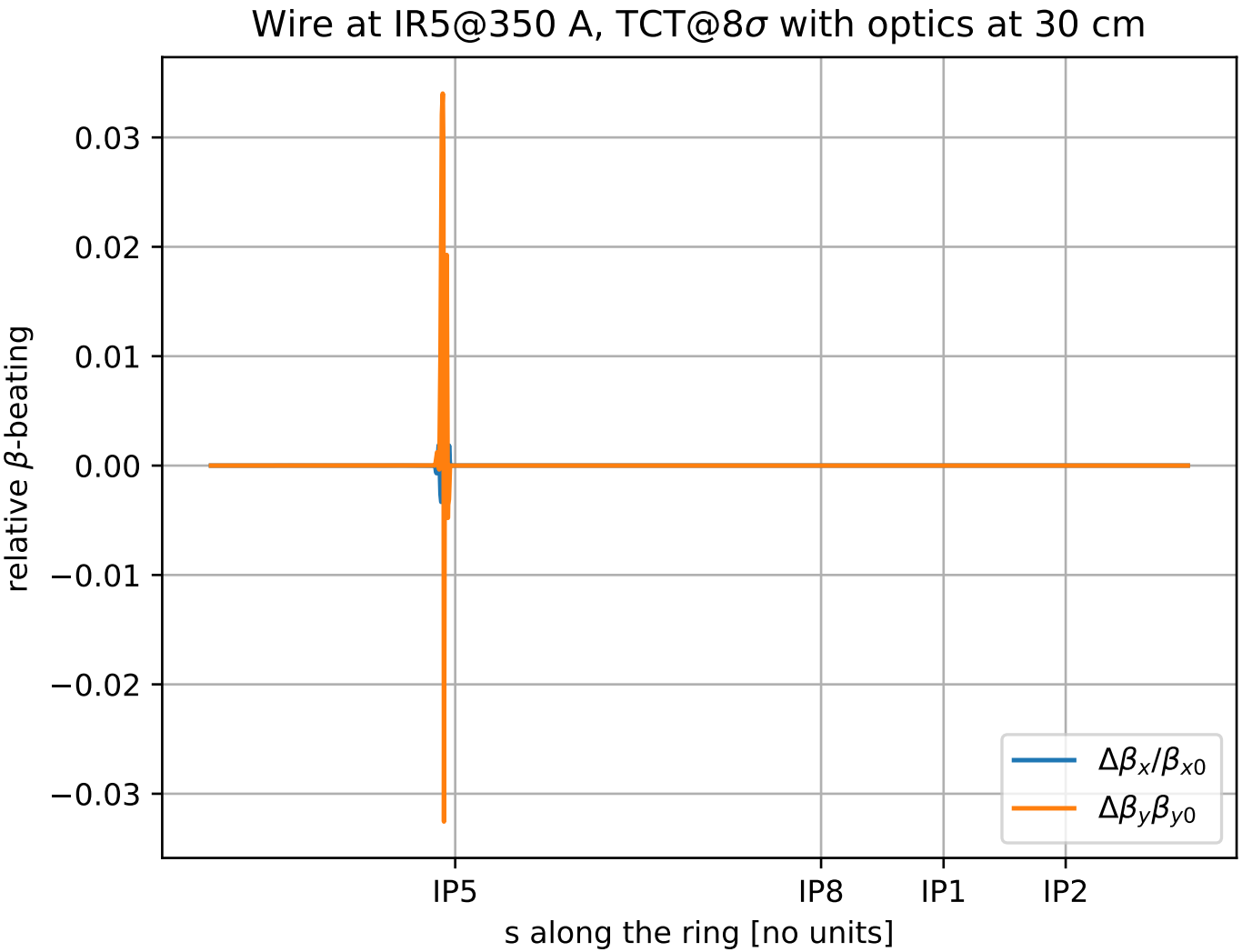


Matching $\beta_{X,Y}, \alpha_{X,Y}$, *dx*, *dpx* at the IP and $\mu_{X,Y}$ in Q13-IP (TCT side).

Correction in IR5



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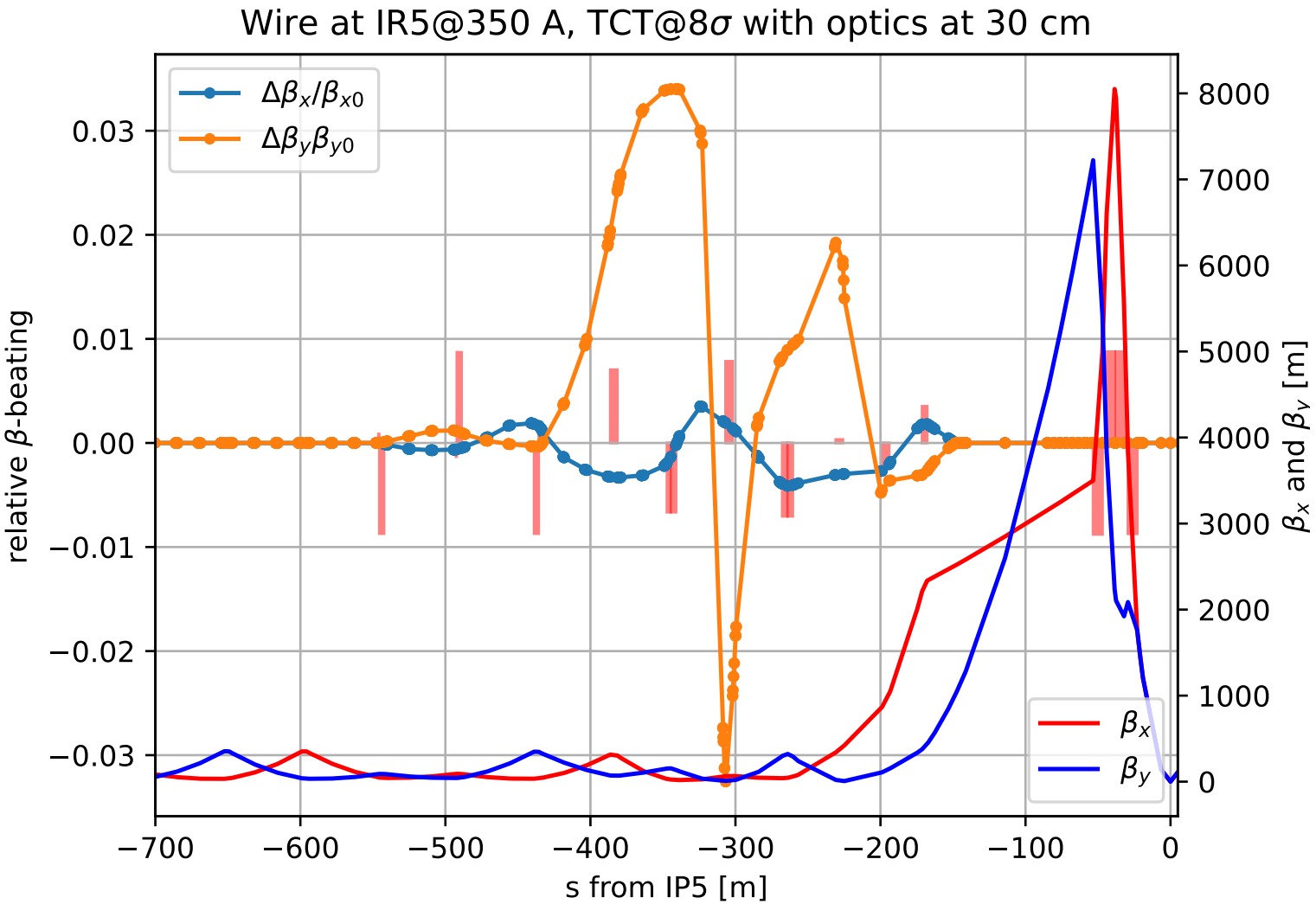

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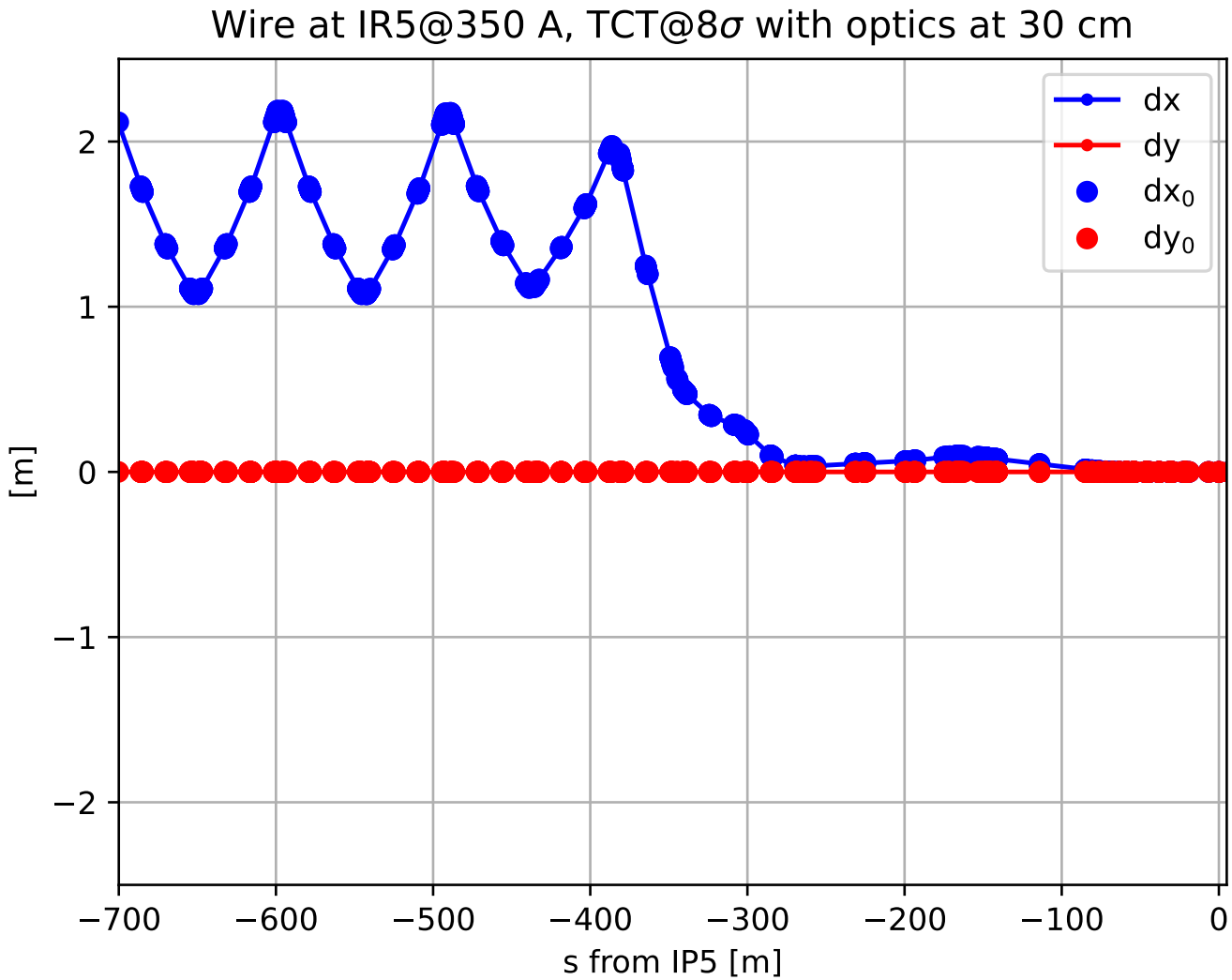
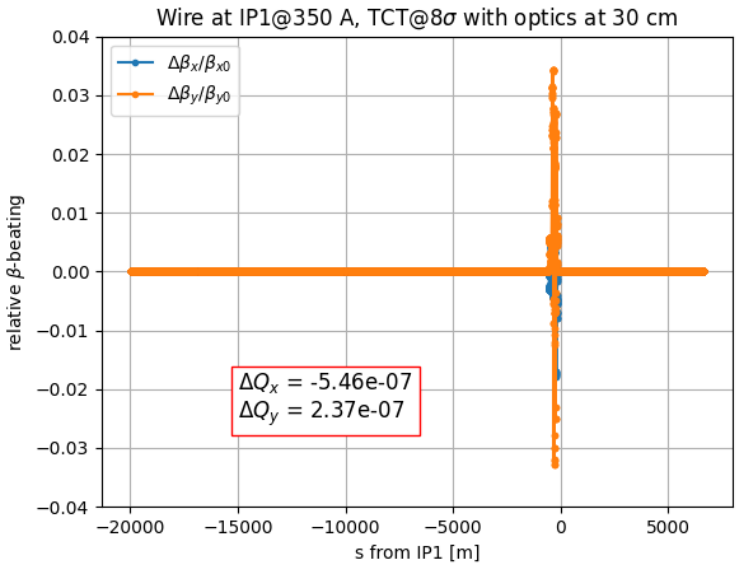


Matching $\beta_{X,Y}, \alpha_{X,Y}$, *dx*, *dpx* at the IP and $\mu_{X,Y}$ in Q13-IP (TCT side).

Linearity check vs I_w

$I_{W,IR1}$=350 A, $I_{W,IR5}$=0 A



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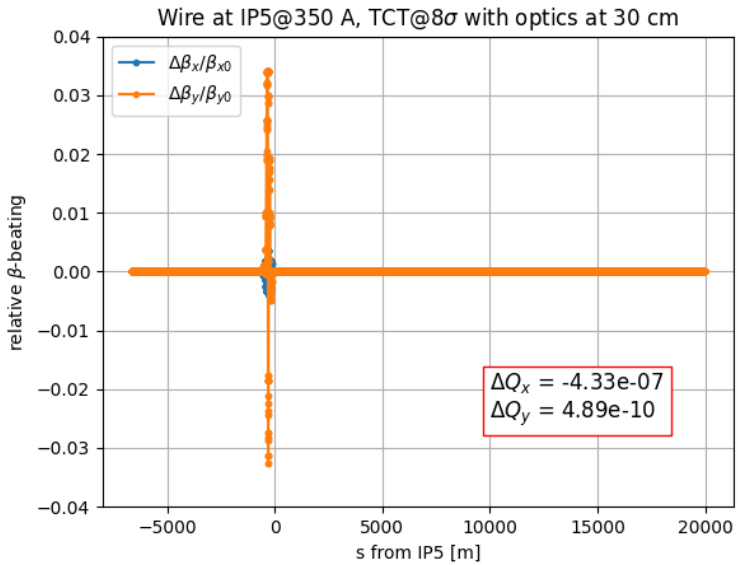
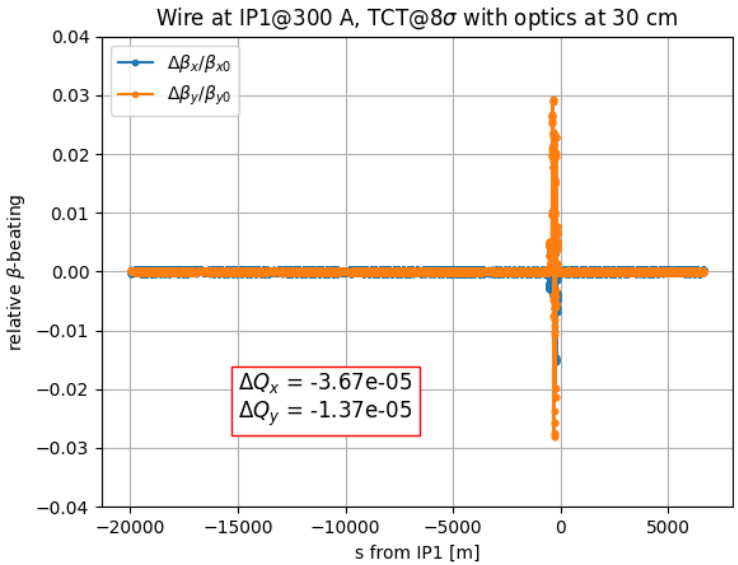


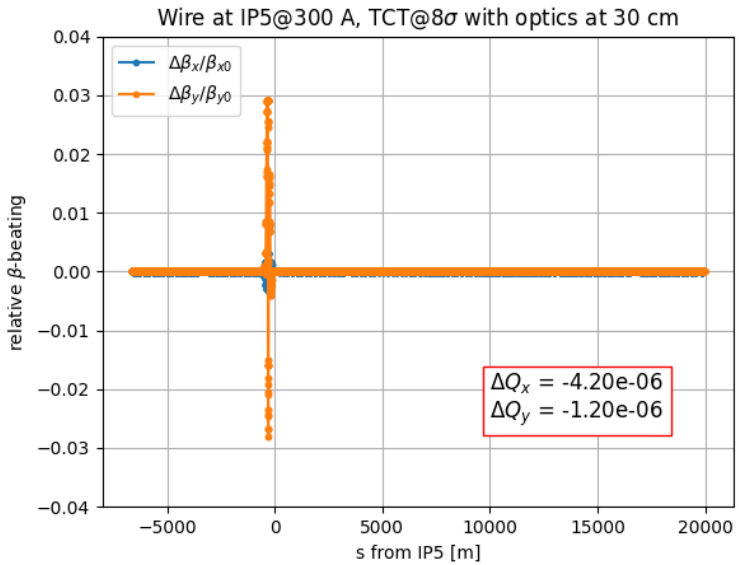
- The knob is matched at I_W=350 A.
- It is **very linear wrt the I_W** (β-beating leakage <0.2%).

Linearity check vs I_W

$I_{W,IR1}$=300 A, $I_{W,IR5}$=0 A



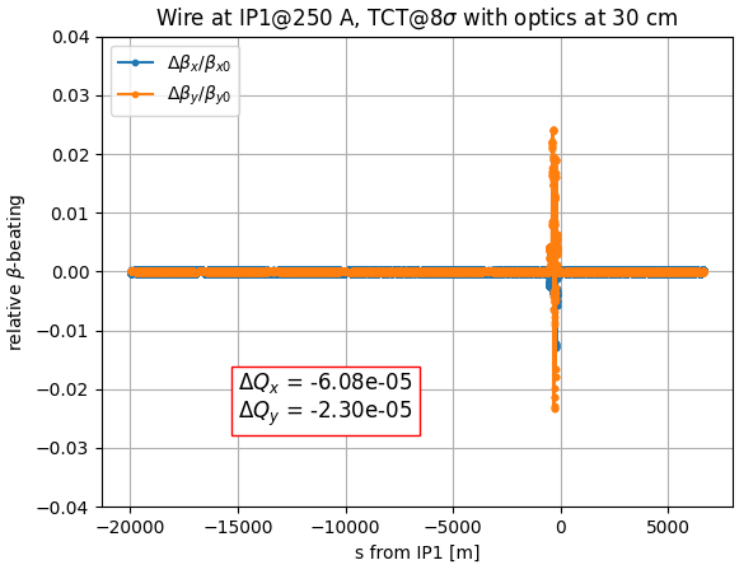
$I_{W,IR1}$=0 A, $I_{W,IR5}$=300 A



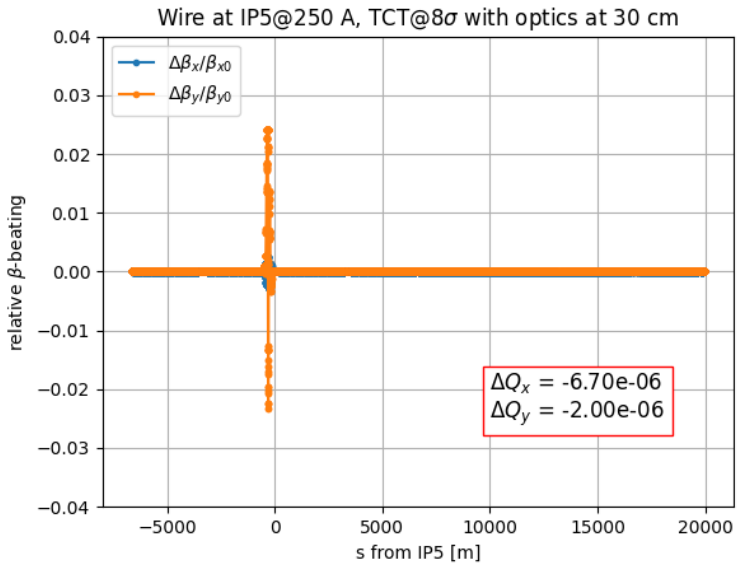
- The knob is matched at I_W=350 A.
- It is **very linear wrt the I_W** (β-beating leakage <0.2%).

Linearity check vs I_W

$I_{W,IR1}$=250 A, $I_{W,IR5}$=0 A



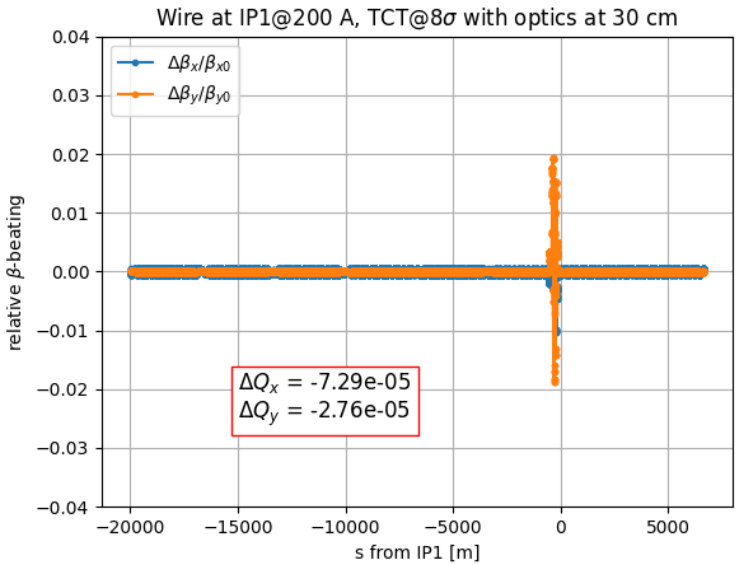
$I_{W,IR1}$=0 A, $I_{W,IR5}$=250 A



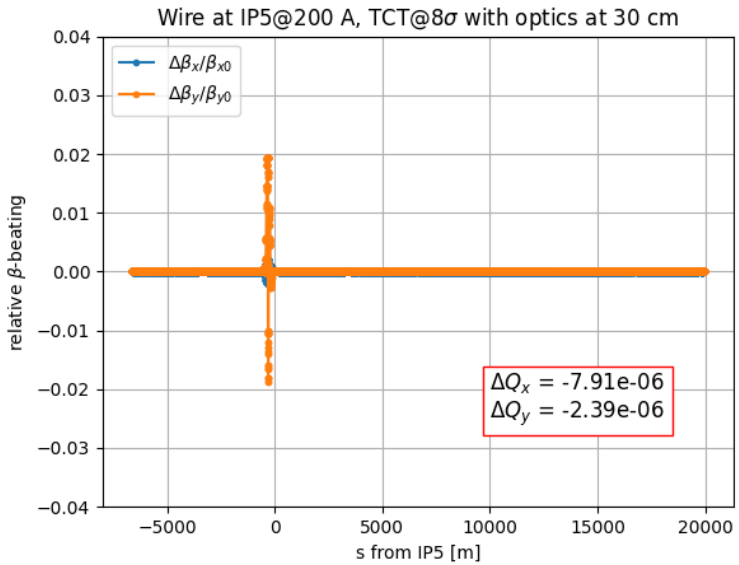
- The knob is matched at I_W=350 A.
- It is **very linear wrt the I_W** (β-beating leakage <0.2%).

Linearity check vs I_W

$I_{W,IR1}$=200 A, $I_{W,IR5}$=0 A



$I_{W,IR1}$=0 A, $I_{W,IR5}$=200 A



- The knob is matched at I_W=350 A.
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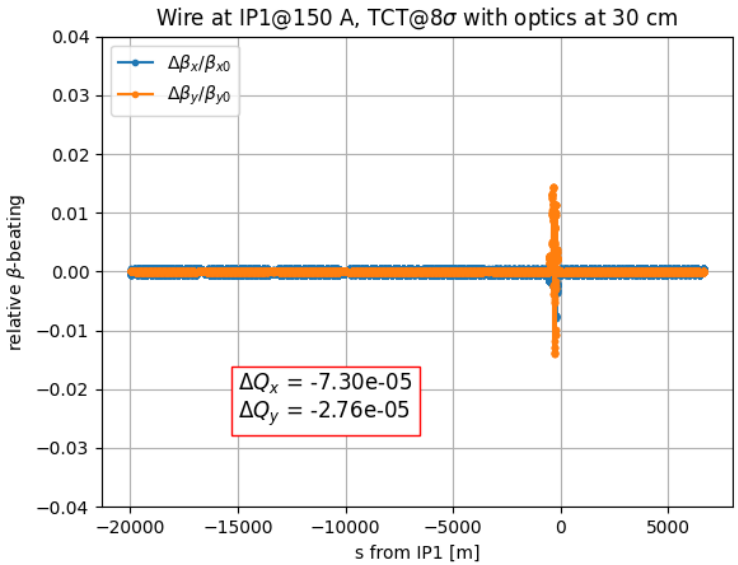
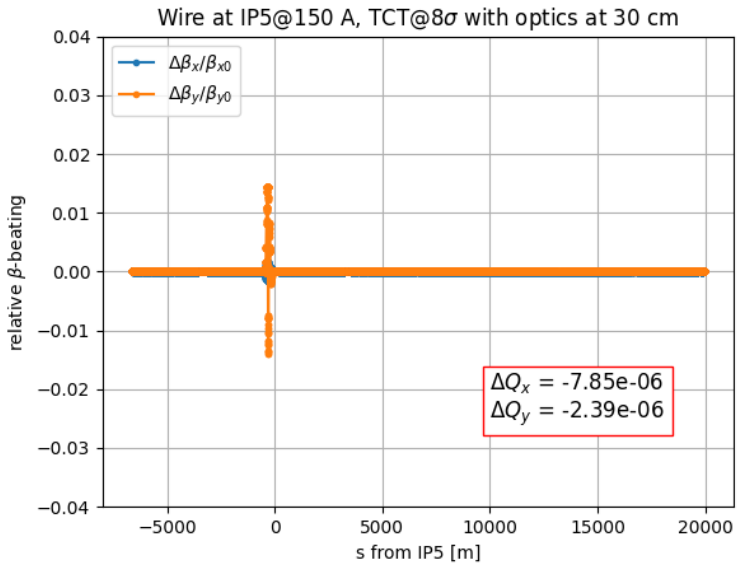
Linearity check vs I_W

$I_{W,IR1}$=150 A, $I_{W,IR5}$=0 A



$I_{W,IR1}$=0 A, $I_{W,IR5}$=150 A



- The knob is matched at I_W=350 A.
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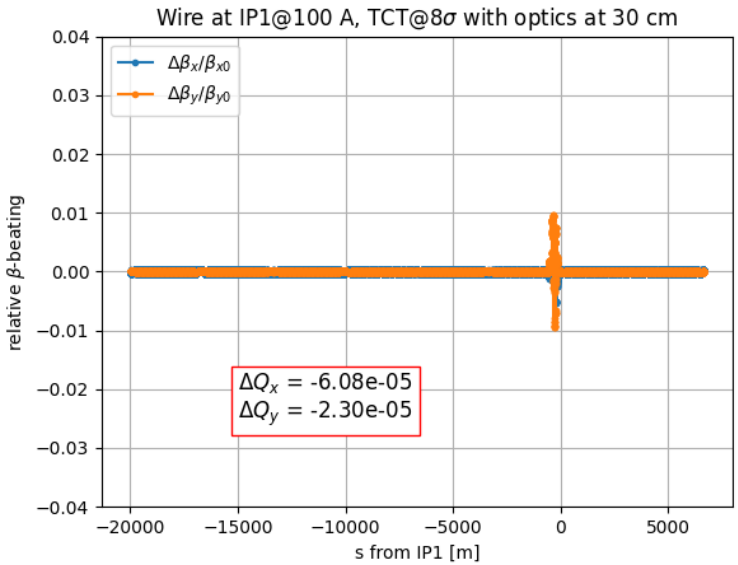
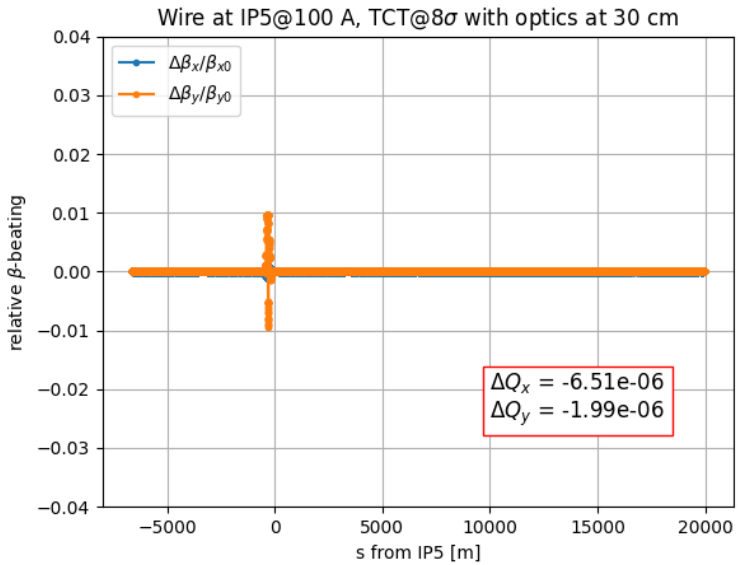
$I_{W,IR1}$=100 A, $I_{W,IR5}$=0 A



$I_{W,IR1}$=0 A, $I_{W,IR5}$=100 A



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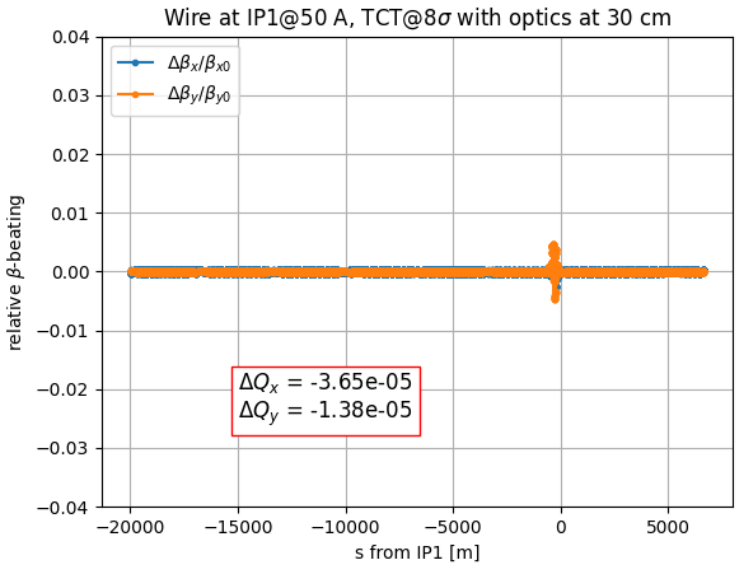
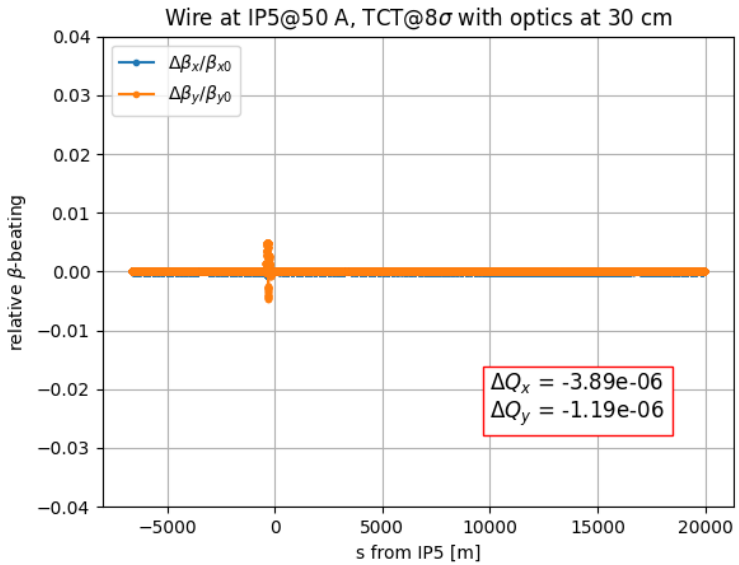


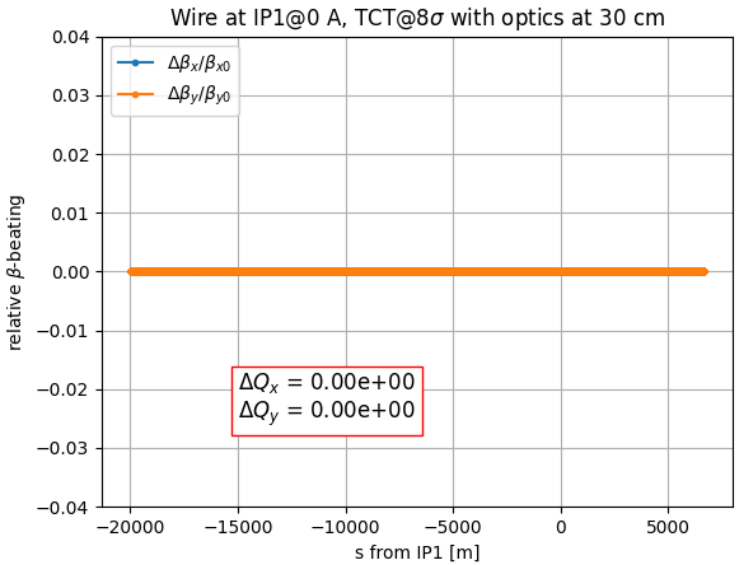
$I_{W,IR1}$=0 A, $I_{W,IR5}$=50 A



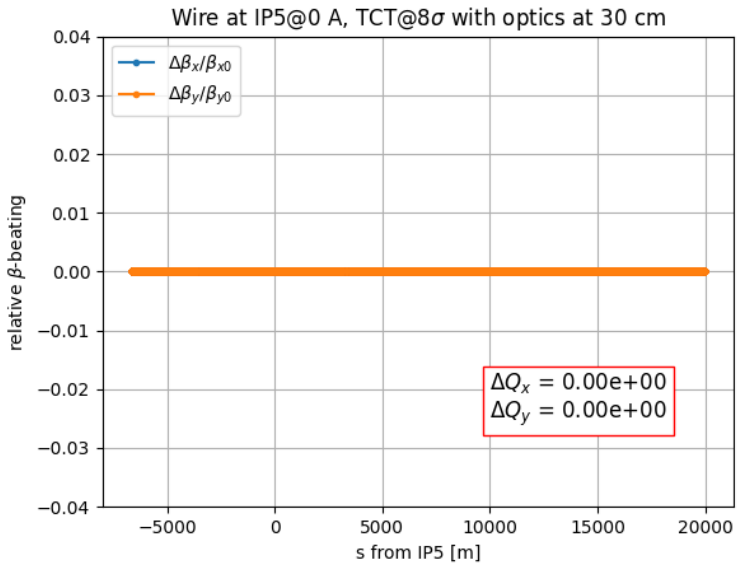
- The knob is matched at I_W=350 A.
- It is **very linear wrt the I_W** (β-beating leakage <0.2%).

Linearity check vs I_w

$I_{W,IR1}$=0 A, $I_{W,IR5}$=0 A



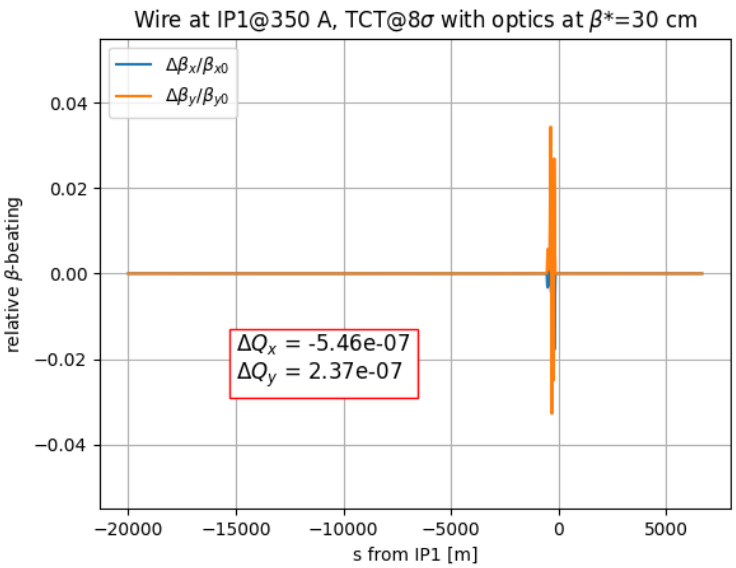
$I_{W,IR1}$=0 A, $I_{W,IR5}$=0 A



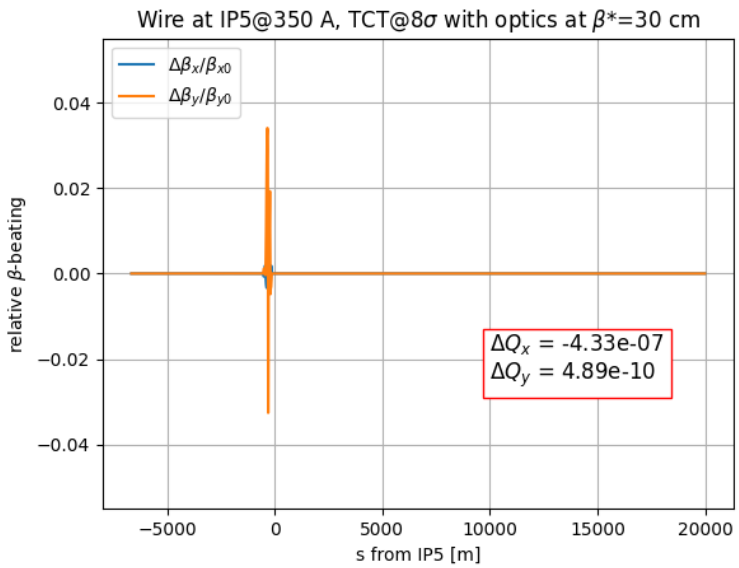
- The knob is matched at I_W=350 A.
- It is **very linear wrt the I_W** (β-beating leakage <0.2%).

Linearity check vs β^*

$I_{IR1/IR5}$=350/0 A, β^* = 30 cm



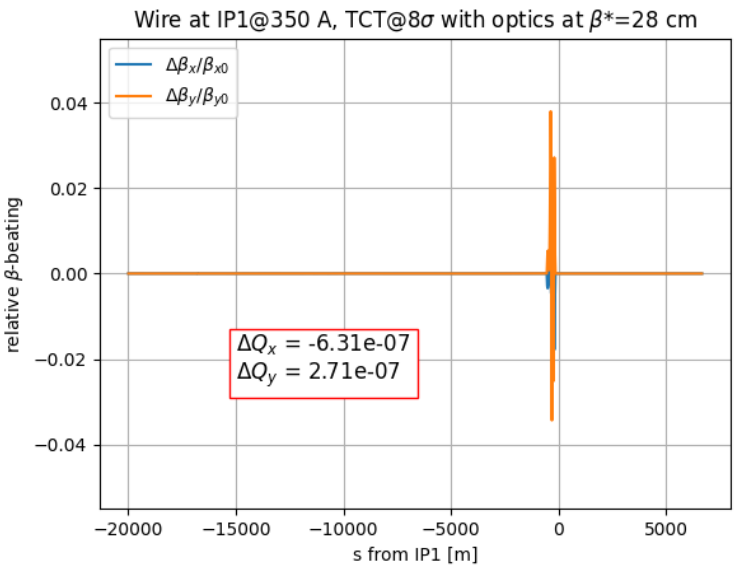
$I_{IR1/5}$=0/350 A, β^* = 30 cm



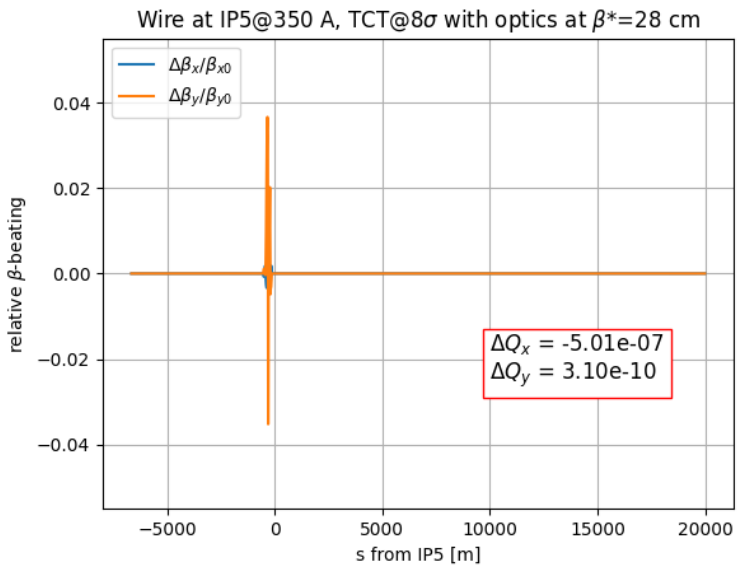
As expected, the knobs are **tele-index independent**.

Linearity check vs β^*

$I_{IR1/IR5}$=350/0 A, β^* = 28 cm



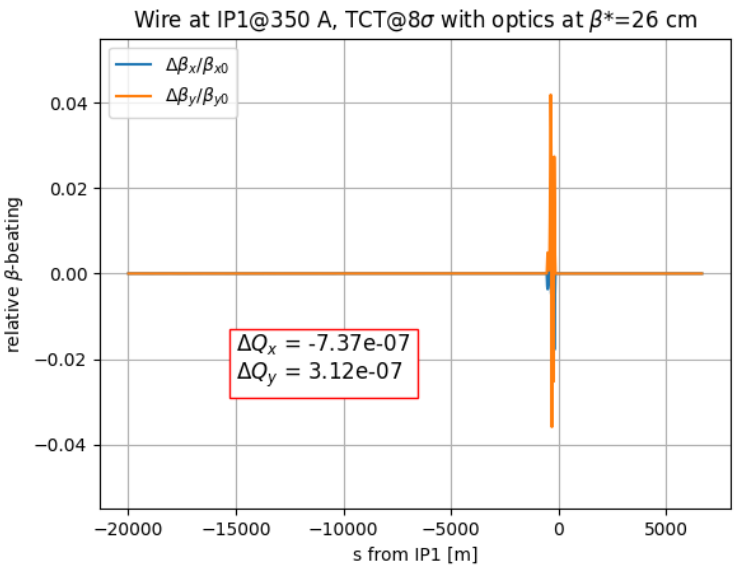
$I_{IR1/5}$=0/350 A, β^* = 28 cm



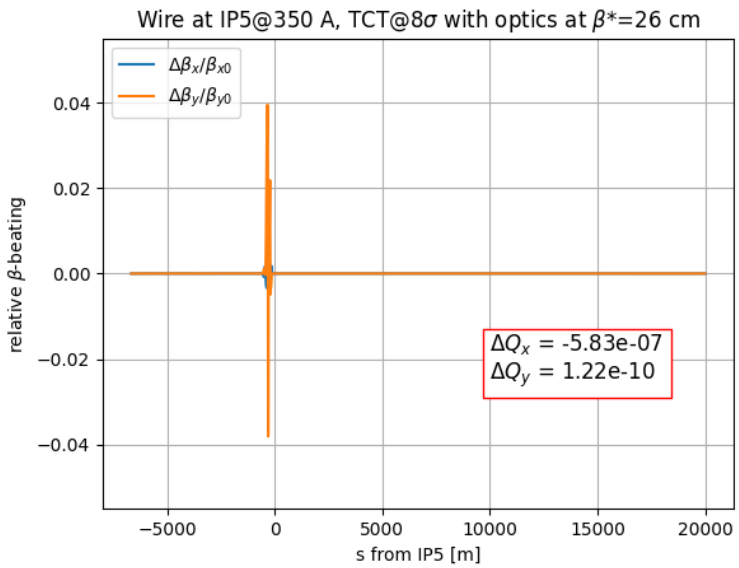
As expected, the knobs are **tele-index independent**.

Linearity check vs β^*

$I_{IR1/IR5}$=350/0 A, β^* = 26 cm



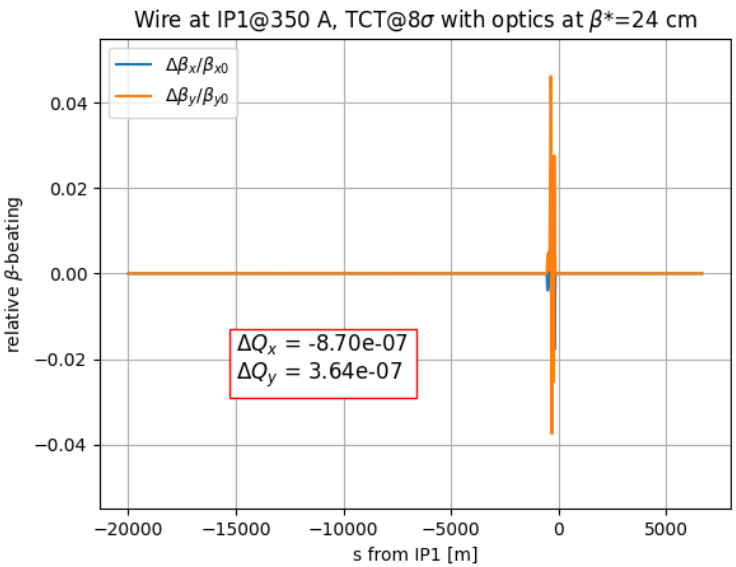
$I_{IR1/5}$=0/350 A, β^* = 26 cm



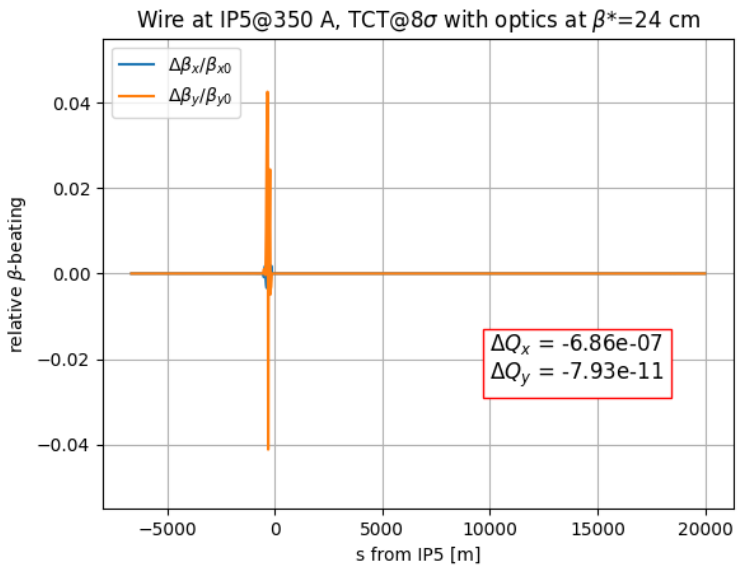
As expected, the knobs are **tele-index independent**.

Linearity check vs β^*

$I_{IR1/IR5}$=350/0 A, β^* = 24 cm



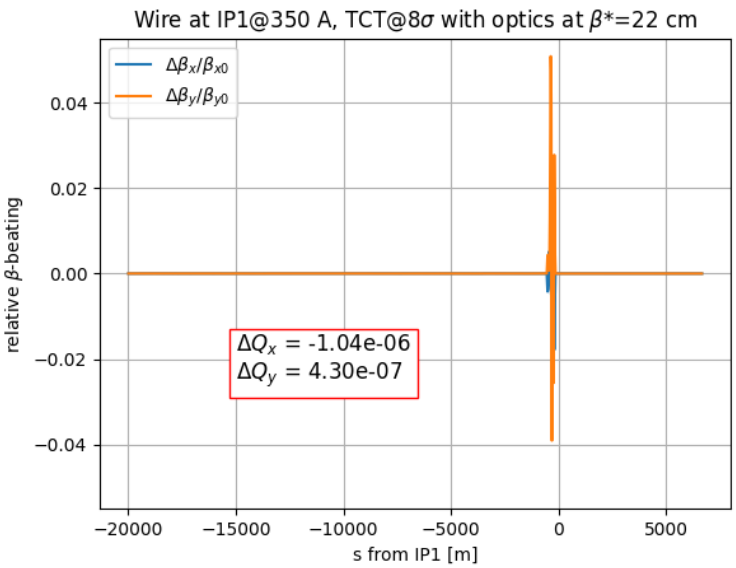
$I_{IR1/5}$=0/350 A, β^* = 24 cm



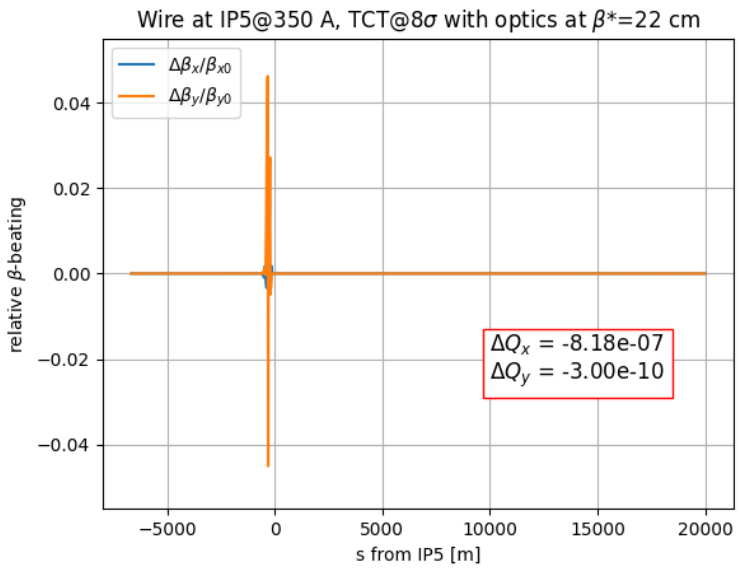
As expected, the knobs are **tele-index independent**.

Linearity check vs β^*

$I_{IR1/IR5}$=350/0 A, β^* = 22 cm

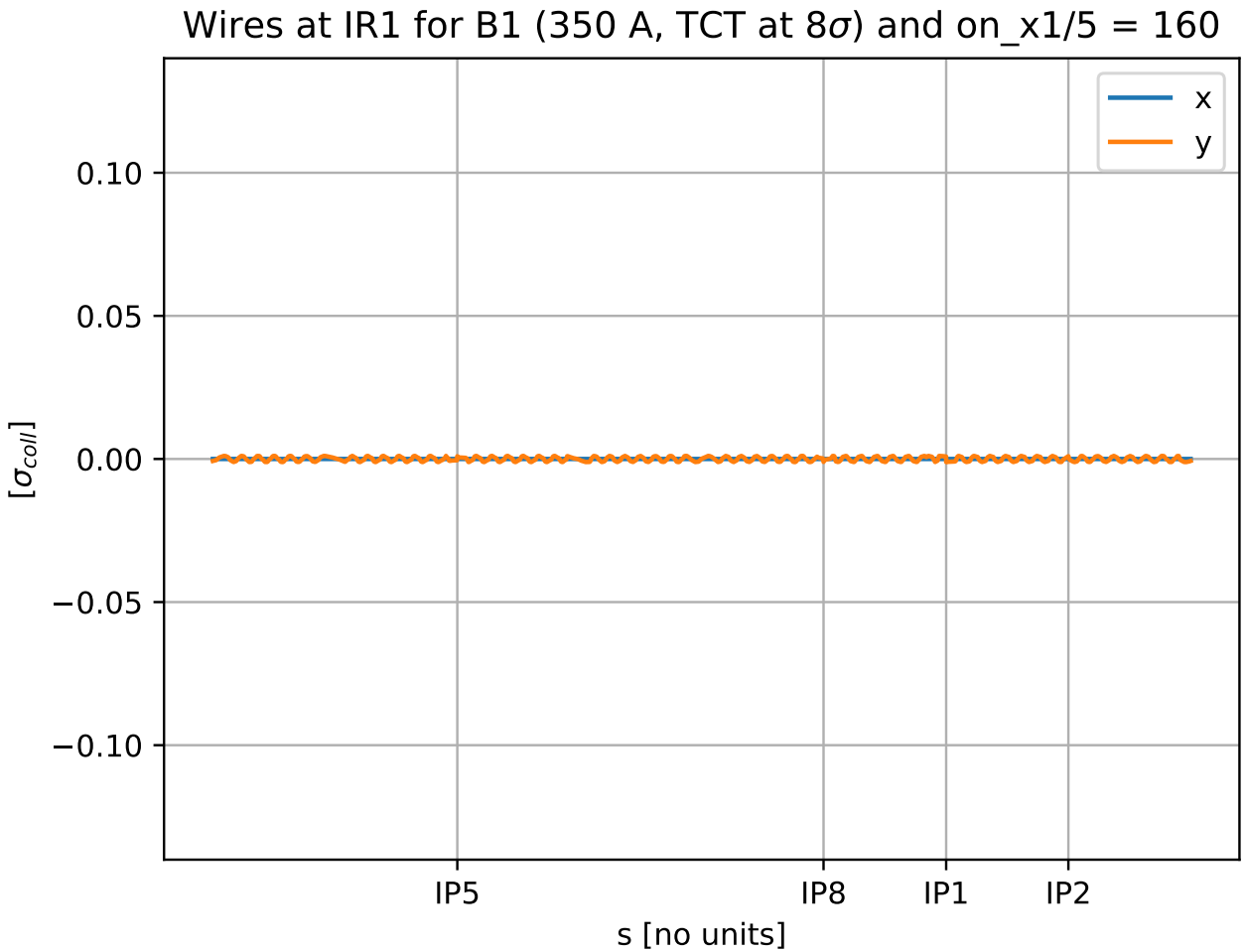


$I_{IR1/5}$=0/350 A, β^* = 22 cm



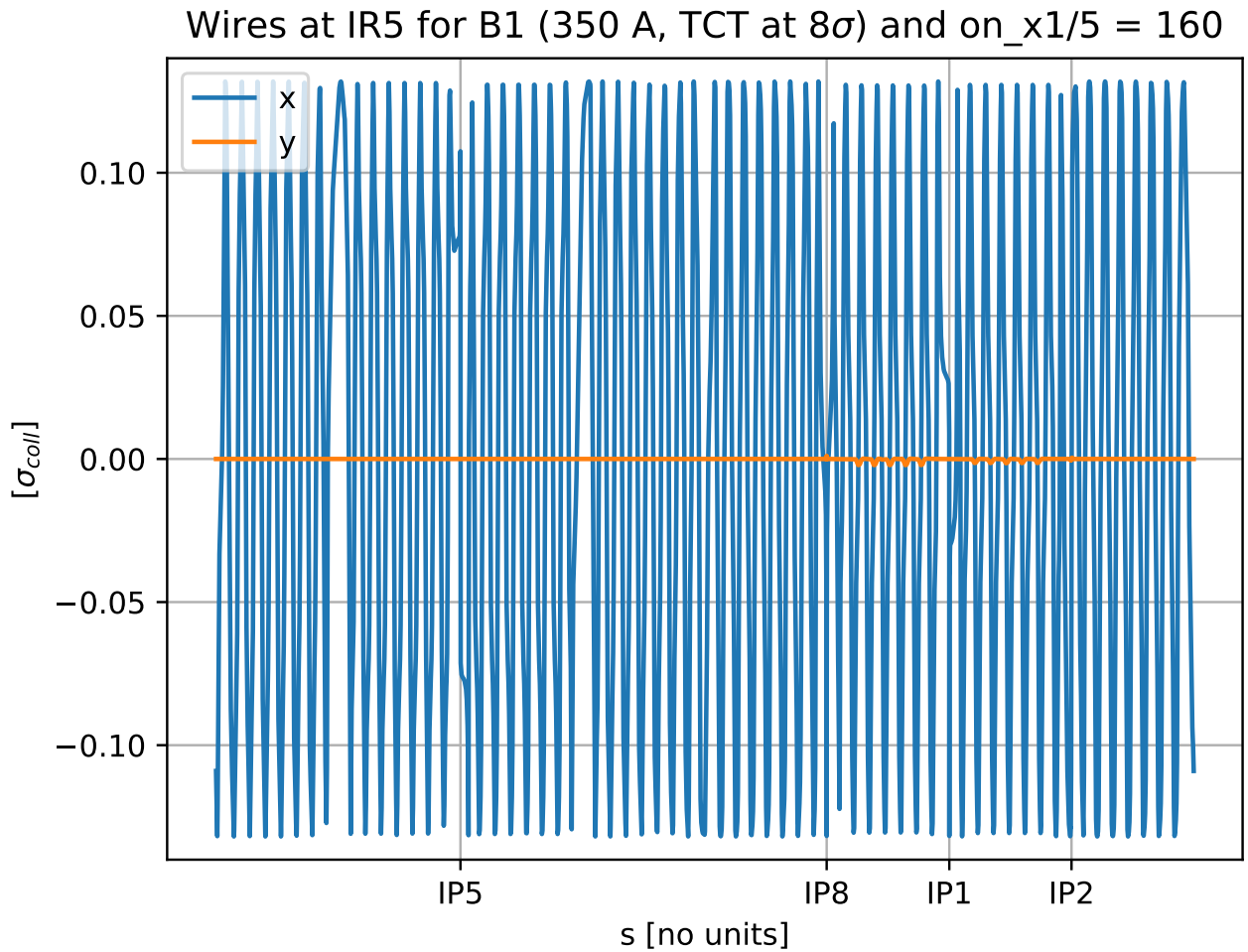
As expected, the knobs are **tele-index independent**.

Orbit effect of the knobs



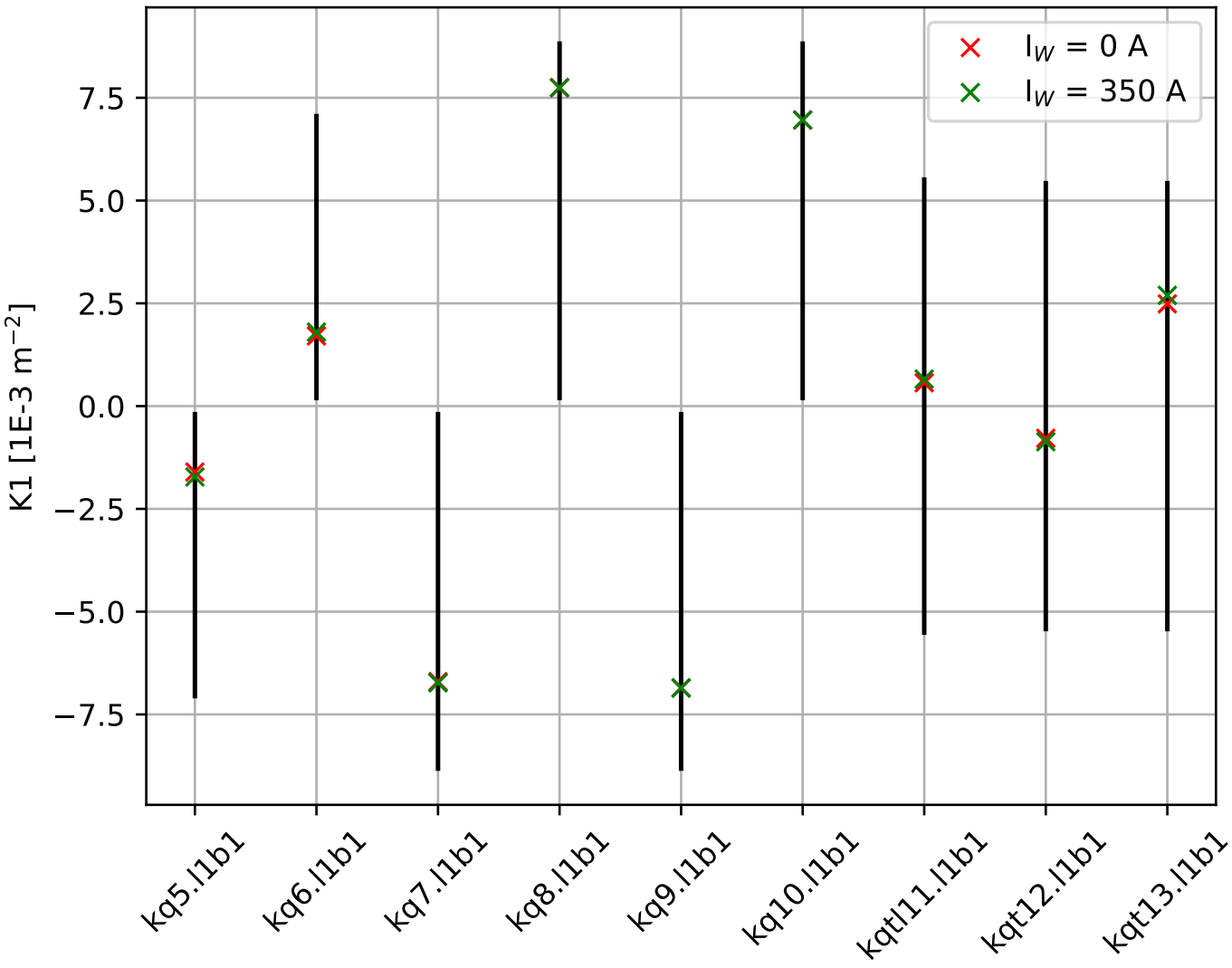
With the crossing angles in IP1/5, knobs affect the orbit (mostly for IR5 knobs). We assume it will be corrected by the CO-feedback.

Orbit effect of the knobs



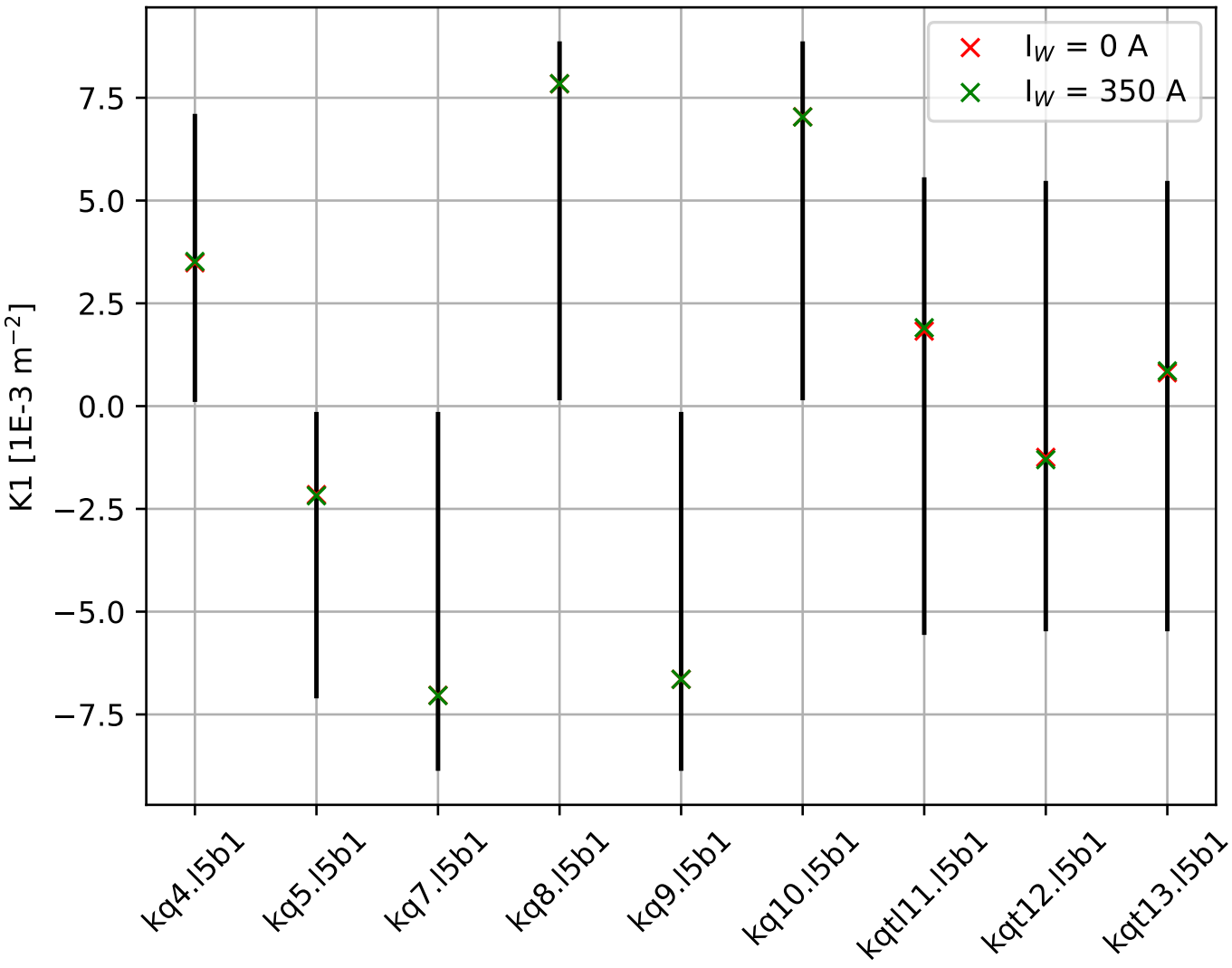
With the crossing angles in IP1/5, knobs affect the orbit (mostly for IR5 knobs). We assume it will be corrected by the CO-feedback.

PC current limits and IR1 B1 knob



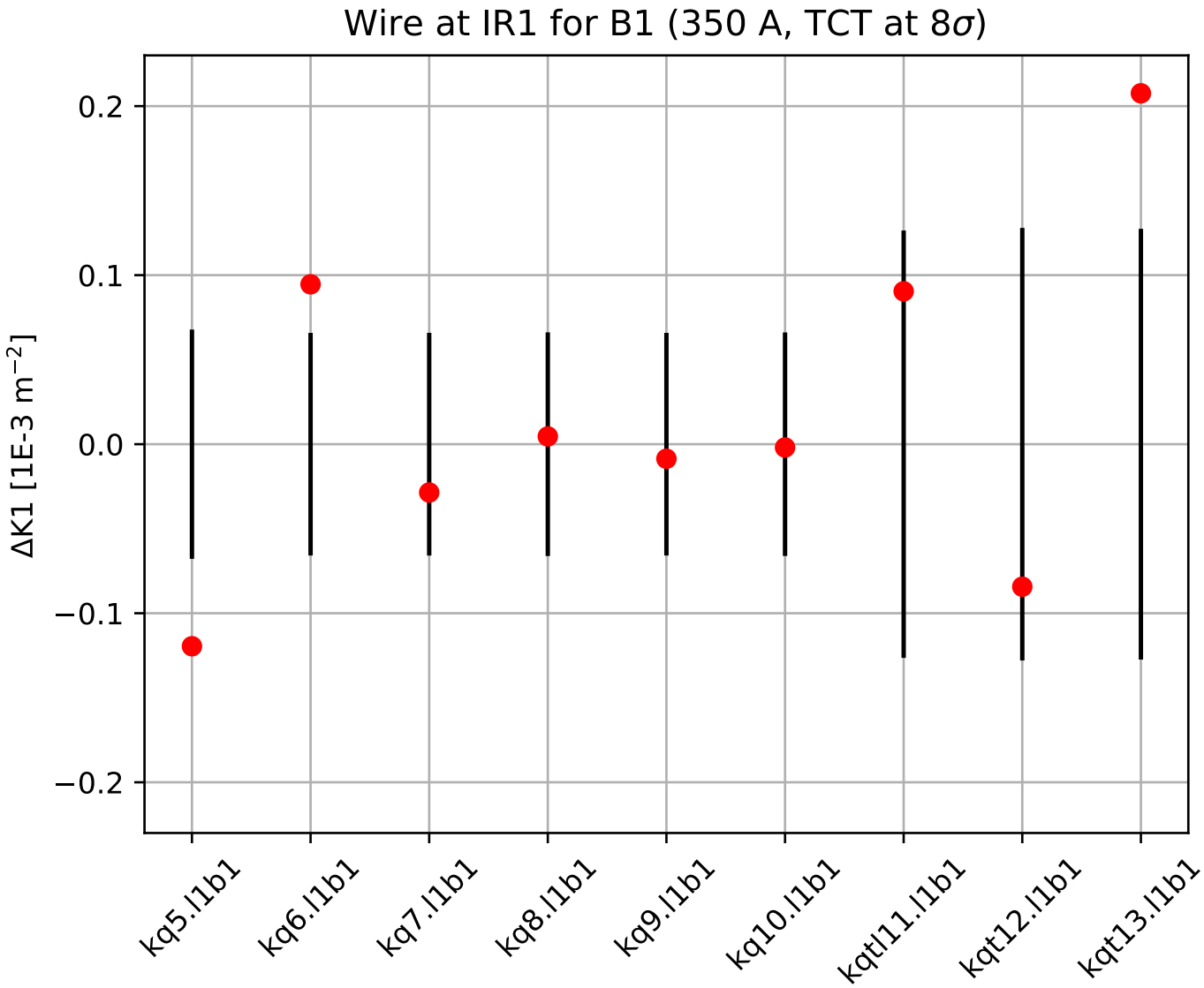
The trims are small if compared with the PCs capabilities.

PC current limits and IR5 B1 knob



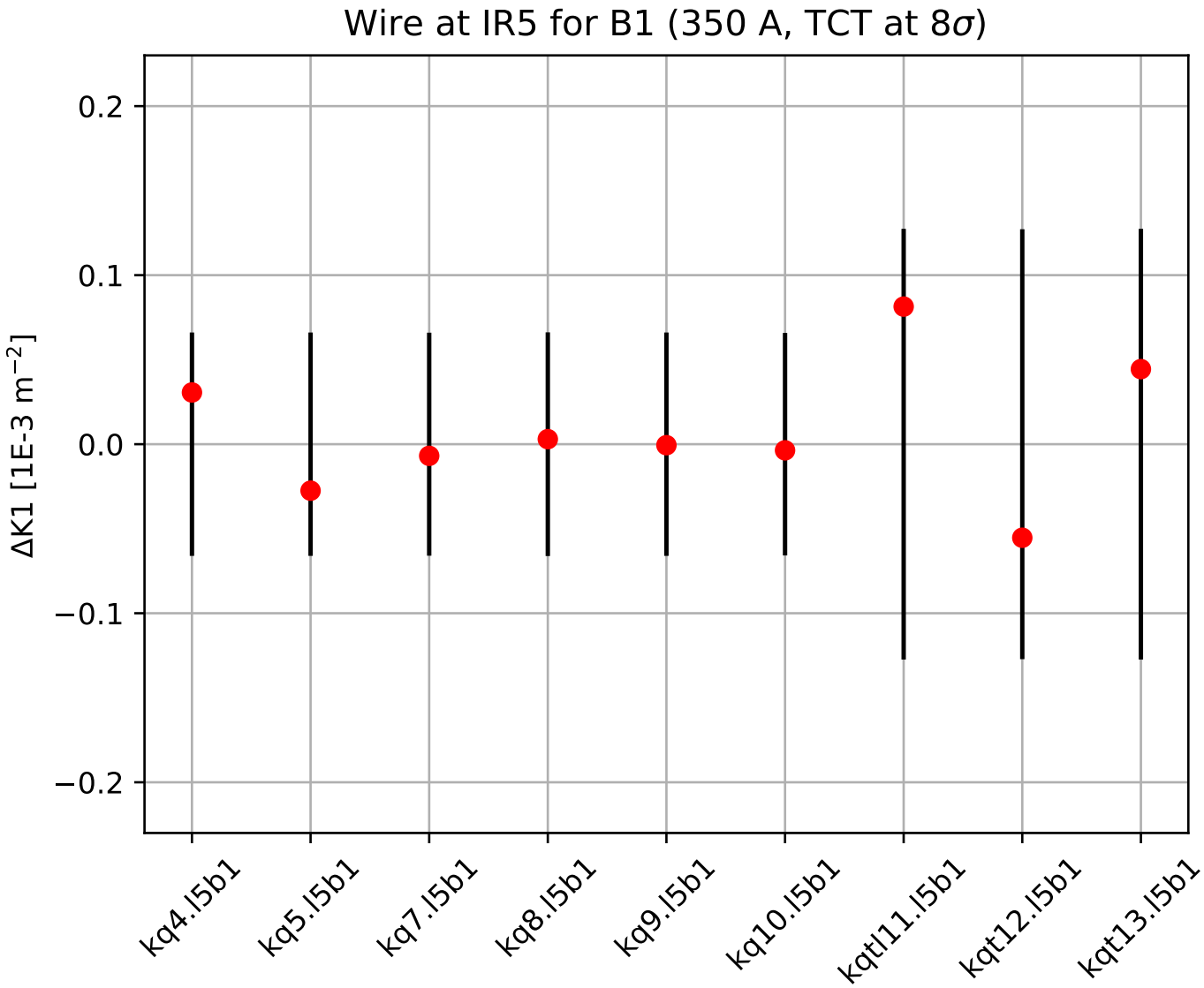
The trims are small if compared with the PCs capabilities.

PC interlock and IR1 B1 knob (**preliminary**)



The trims are comparable with the PC Interlock limits but OUTSIDE.

PC interlock and IR5 B1 knob (**preliminary**)



The trims are comparable with the PC Interlock limits.