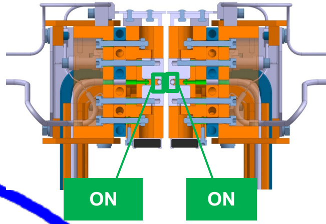
Wire compensation feed-forward in RUN3

Y. Papaphilippou, **A. Poyet**, A. Rossi, K. Skoufaris, M. Solfaroli and **G. Sterbini** on behalf of the HL-LHC wire compensation team.

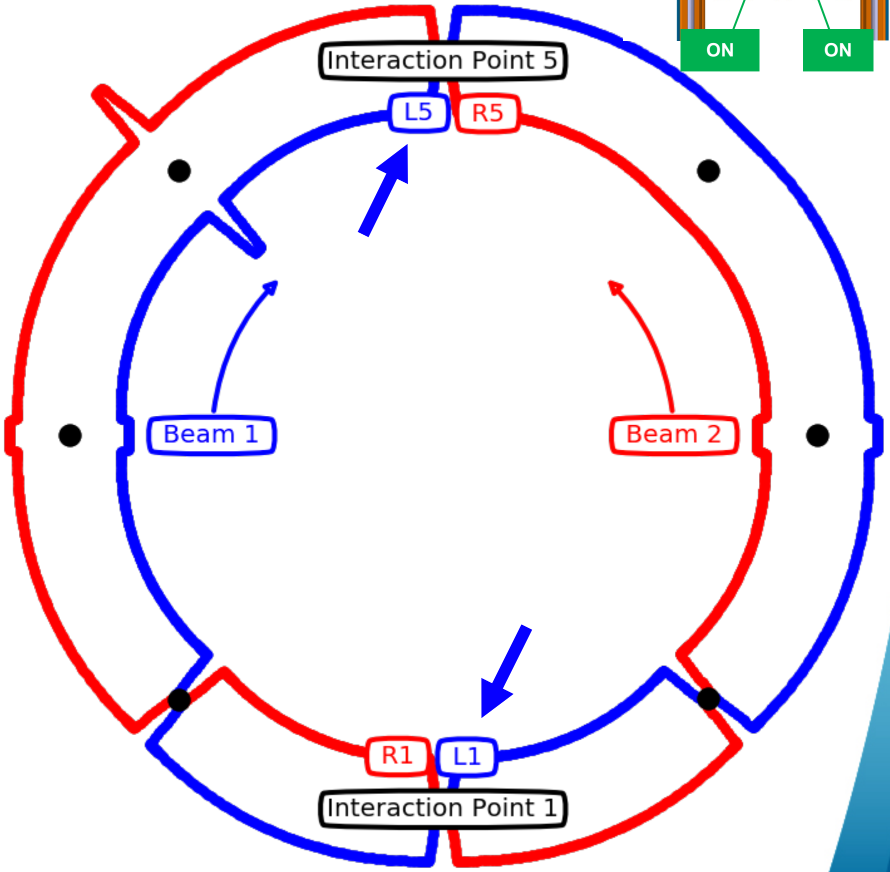
Main sources are the B1/2 analysis at
http://lhcmaskdoc.web.cern.ch/ipynbs/wires_run3/b1_checks/
http://lhcmaskdoc.web.cern.ch/ipynbs/wires_run3/b2_checks/

19th June 2020

Run3 and wires demonstrators



- Following Run2 encouraging results, it was proposed
  - **to equip also the Beam 1** with wires.
  - **to use the wires routinely** during the Run3.
    Feasibility/limits still under discussion (with OP, machine protections, collimations…)



ECR https://edms.cern.ch/ui/file/2054712/1.0/LHC-TC-EC-0019-1-0.pdf

MPP https://indico.cern.ch/event/808988/

LBOC, https://indico.cern.ch/event/863458/

LHC MD DAY, https://indico.cern.ch/event/867177/

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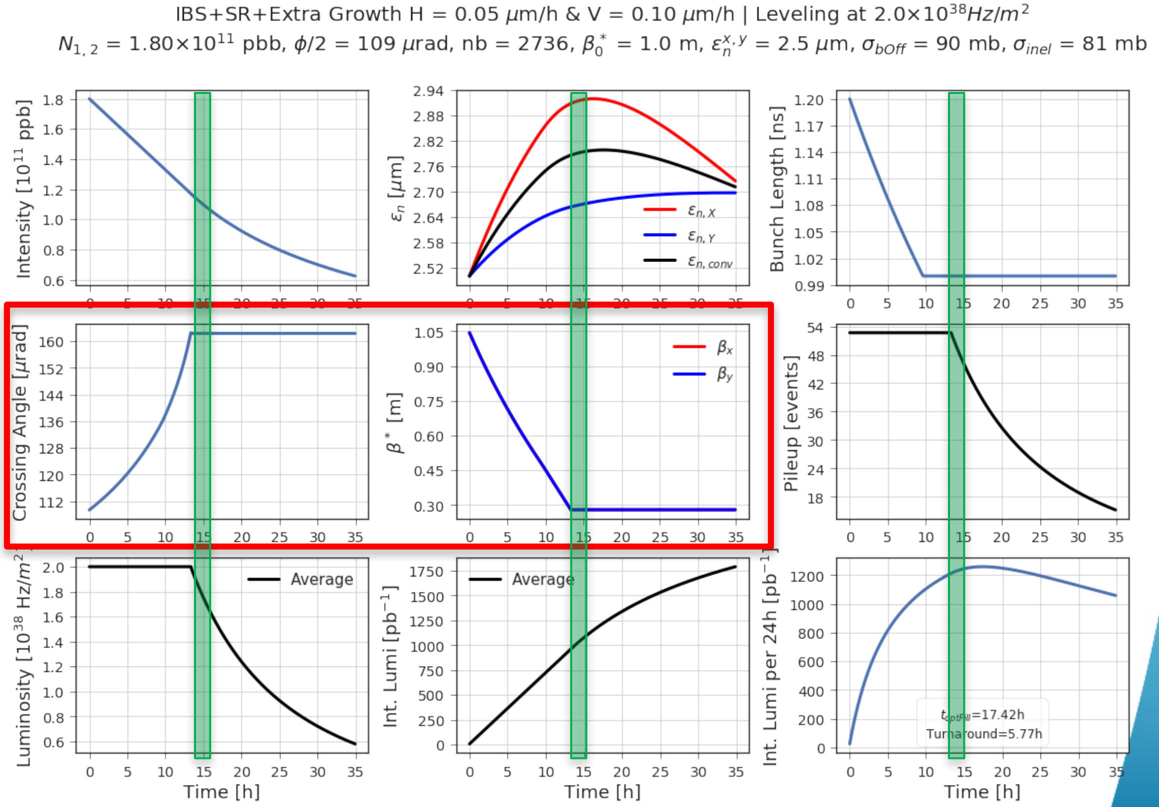
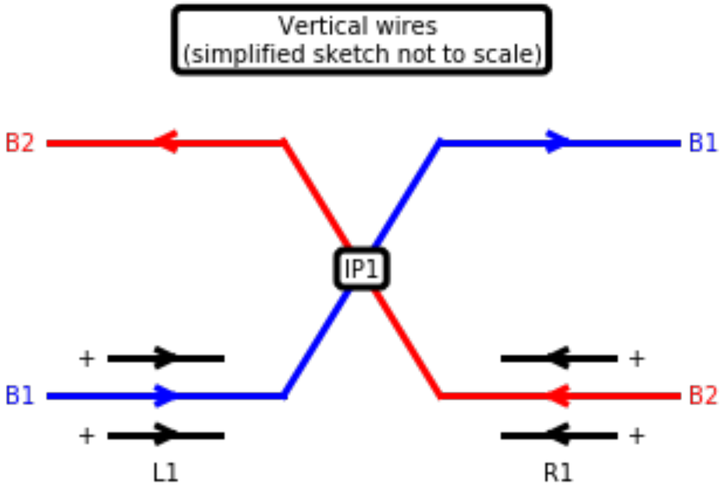
Run3 Fill Profile, tbc (2022-23)

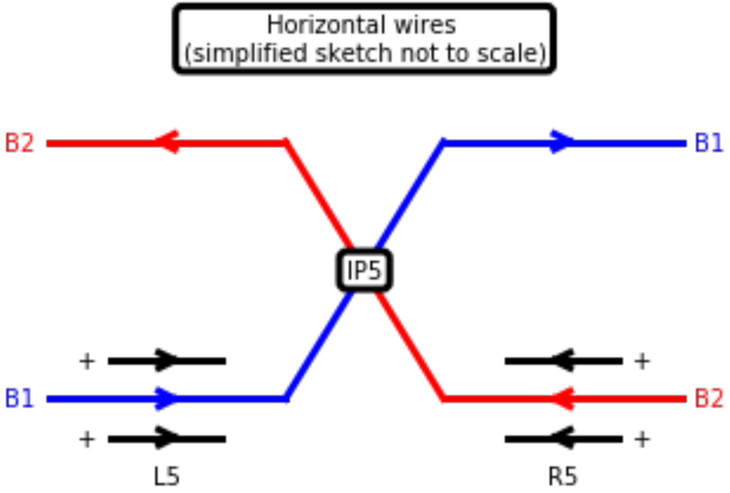
- In 2022: **round optics** with IP1 crossing in V-plane and IP5 crossing in H-plane.
- The wires could be switched on at the **end of the leveling**.
- We assume Run3 collimation settings similar to Run2 ones.



Courtesy of S. Fartoukh and N. Karastathis

Run3 and wires demonstrators





- **Left wires on B1** and **right wires on B2**.
- Assuming tertiary at 8.5 σ (ε=3.5 μm) and 7 TeV machine (for β*=30 cm with 2022_V1 optics): wires at 9-12 mm from the beam. **Induced tune shift up to 1.4e-2!**
- **→correction is needed (Q-feedforward)**

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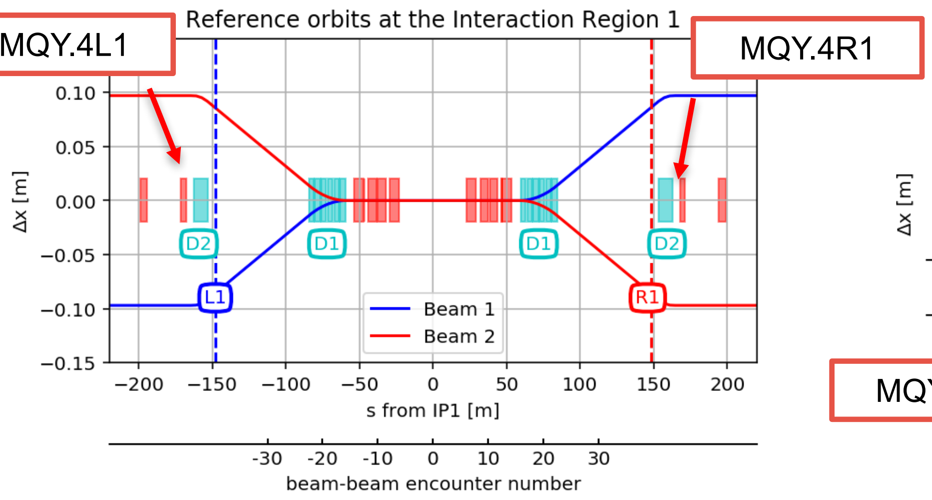
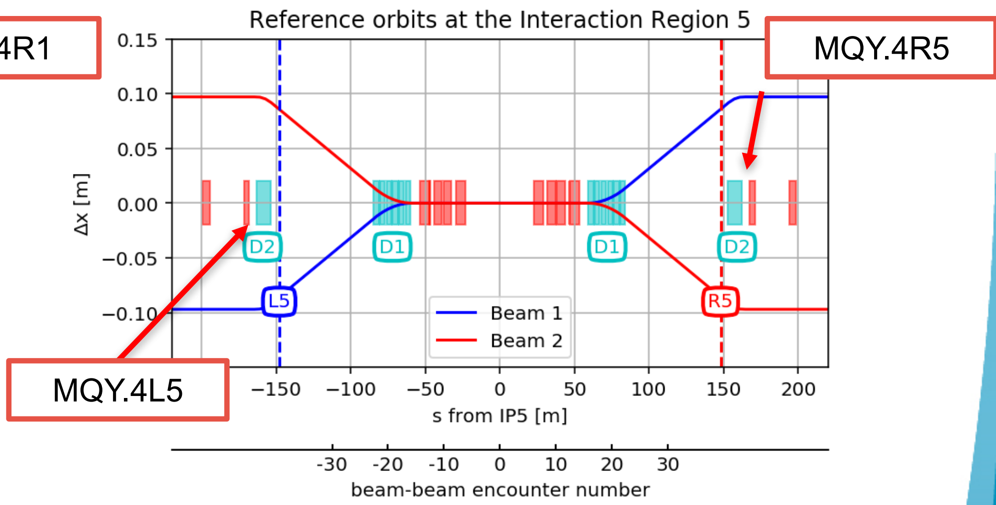
Run3 and wires demonstrators

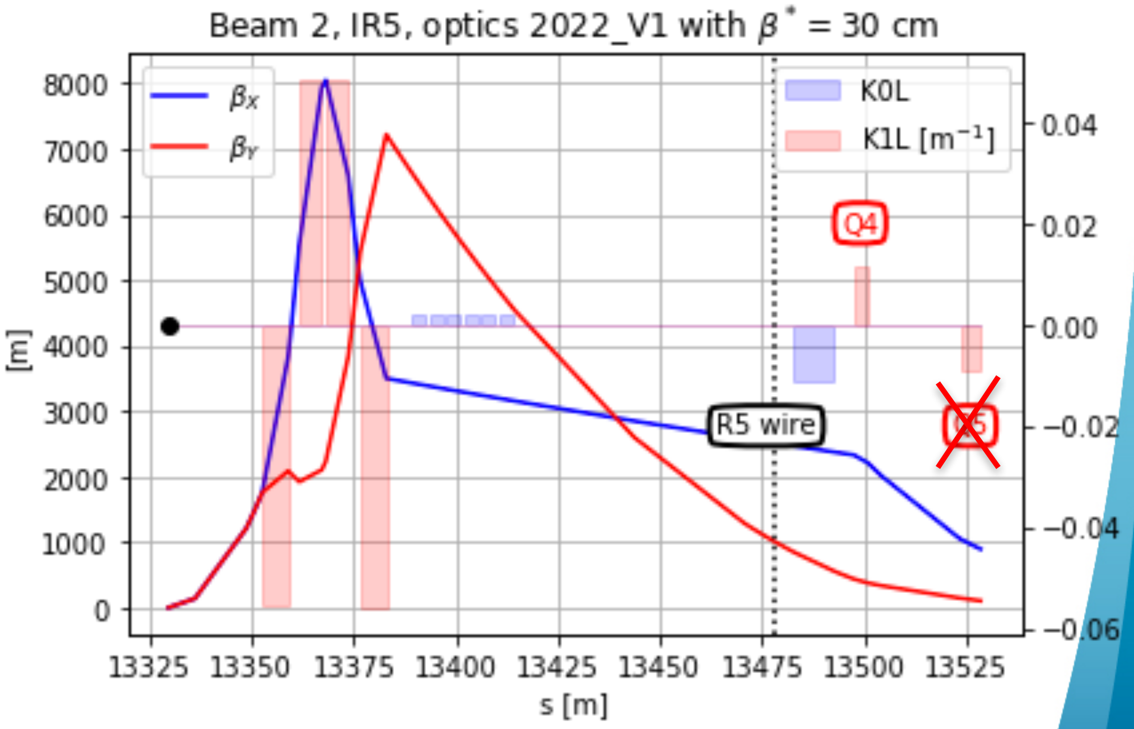




BEAM	IR	S from IP [m]	NAME	Power Converter
BEAM 1	IR1	-145.945	TCTPV.4L1.B1	RPMC.UL14.RBBCW.L1B1
BEAM 1	IR5	-147.945	TCTPH.4L5.B1	RPMC.USC55.RBBCW.L5B1
BEAM 2	IR1	145.945	TCTPV.4R1.B2	RPMC.UL16.RBBCW.R1B2
BEAM 2	IR5	147.945	TCTPH.4R5.B2	RPMC.UL557.RBBCW.R5B2

Q- feedforward

- IF the beam/wire are aligned, no effect of the Closed Orbit → **no CO-feedforward** (there is always a CO-feedback).
- In Run2 we used the Q4 and Q5 for the Q-feedforward.
- For Run3 we propose to use the Q4L and Q4R (we need always two quads per wire collimation) .



Q- feedforward

BEAM 1

IR1

$$k_{Q4}^{L1} = 3.486 \cdot 10^{-3} - 2.257 \cdot 10^{-5} \frac{I_{w1}/(350\ \mathrm{A})}{(y_{w,l1}/(9.1\ \mathrm{mm}))^2}$$

$$k_{Q4}^{R1} = -3.486 \cdot 10^{-3} - 6.229 \cdot 10^{-6} \frac{I_{w1}/(350\ \mathrm{A})}{(y_{w,l1}/(9.1\ \mathrm{mm}))^2}$$

IR5

$$k_{Q4}^{L5} = 3.486 \cdot 10^{-3} + 1.233 \cdot 10^{-5} \frac{I_{w5}/(350\ \mathrm{A})}{(x_{w,l5}/(12.2\ \mathrm{mm}))^2}$$

$$k_{Q4}^{R5} = -3.486 \cdot 10^{-3} + 3.169 \cdot 10^{-6} \frac{I_{w5}/(350\ \mathrm{A})}{(x_{w,l5}/(12.2\ \mathrm{mm}))^2}$$

BEAM 2

IR1

$$k_{Q4}^{L1} = -3.386 \cdot 10^{-3} - 6.229 \cdot 10^{-6} \frac{I_{w1}/(350\ \mathrm{A})}{(y_{w,r1}/(9.1\ \mathrm{mm}))^2}$$

$$k_{Q4}^{R1} = 3.386 \cdot 10^{-3} - 2.256 \cdot 10^{-5} \frac{I_{w1}/(350\ \mathrm{A})}{(y_{w,r1}/(9.1\ \mathrm{mm}))^2}$$

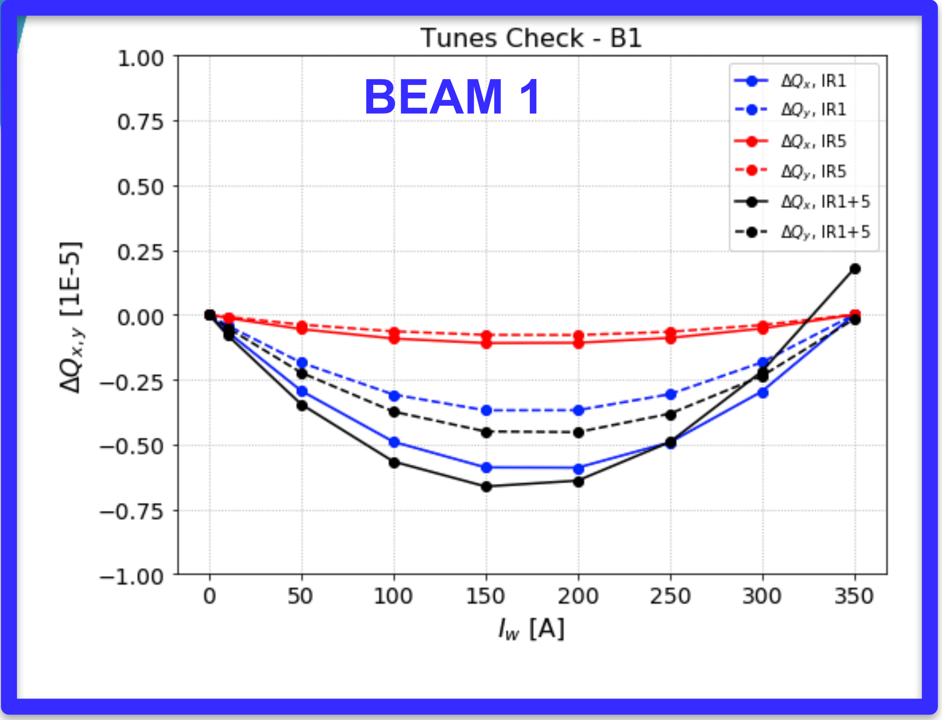
IR5

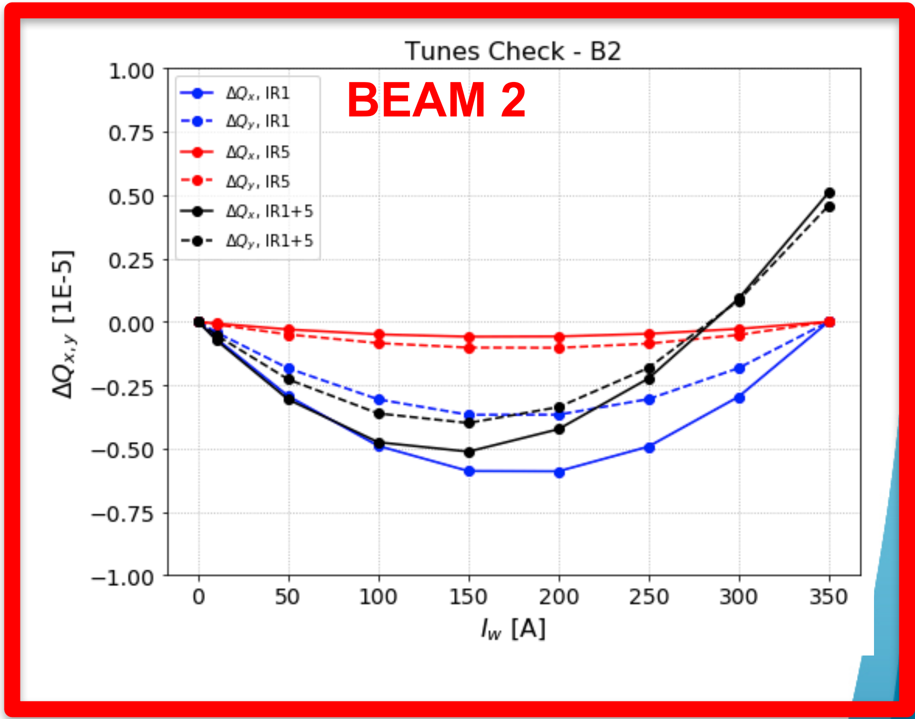
$$k_{Q4}^{L5} = -3.386 \cdot 10^{-3} + 3.140 \cdot 10^{-6} \frac{I_{w5}/(350\ \mathrm{A})}{(x_{w,r5}/(12.2\ \mathrm{mm}))^2}$$

$$k_{Q4}^{R5} = 3.386 \cdot 10^{-3} + 1.224 \cdot 10^{-5} \frac{I_{w5}/(350\ \mathrm{A})}{(x_{w,r5}/(12.2\ \mathrm{mm}))^2}$$

Needed trims less that 1% of the nominal Q4 gradient.

Knob linearity with the current



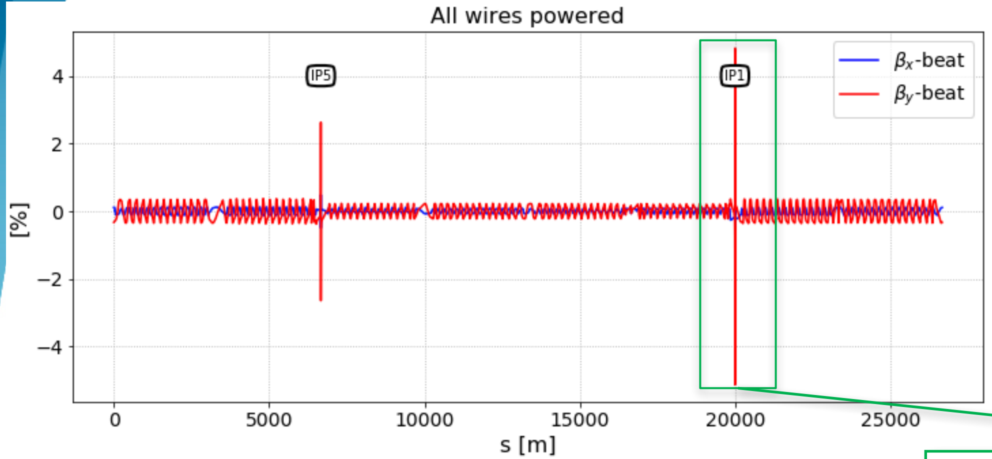


Very good knobs linearity

Small perturbation, the residual non-linearities sum up when powering both wires

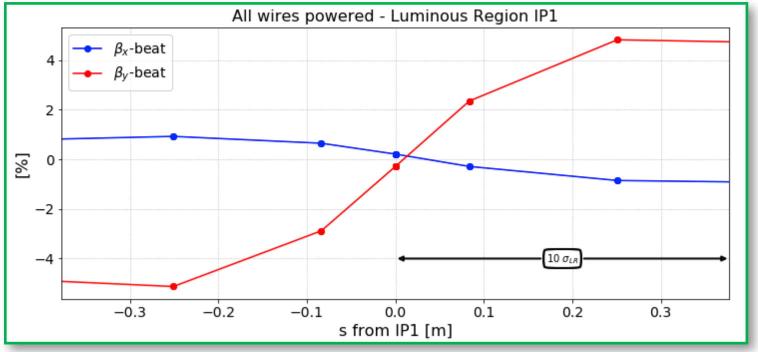
Beta-beating (B1)

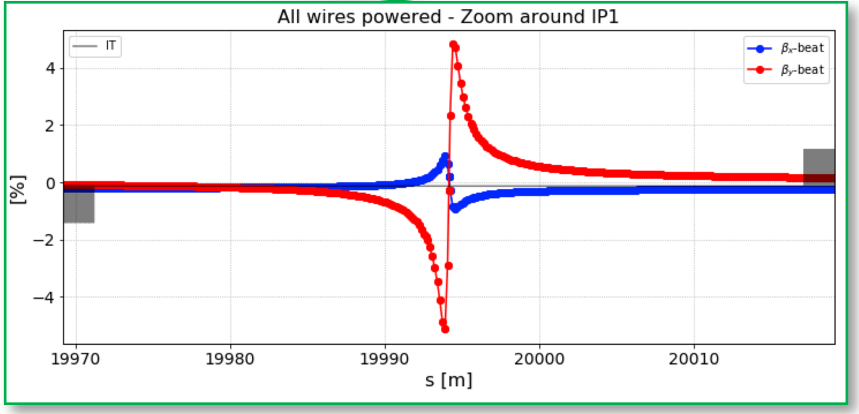
All wires powered
@ 350 A + FF



Mild beta-beating along the machine.

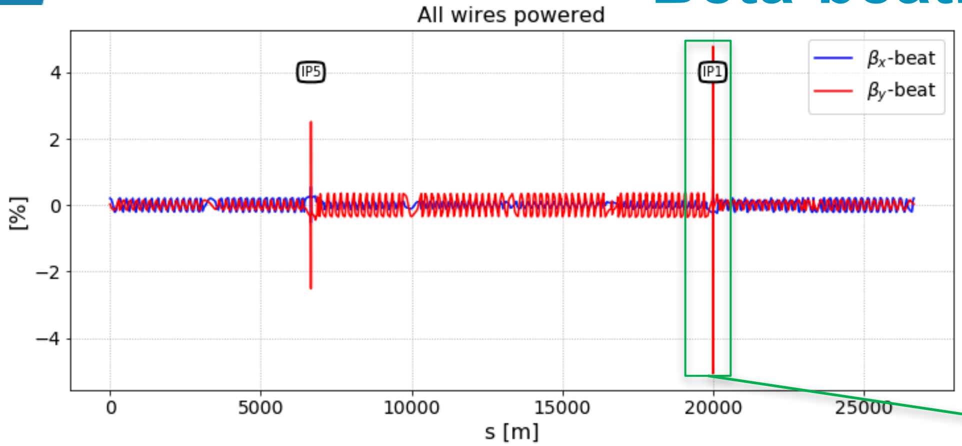
Peak of ~5% at the IP (~25 cm from IP)





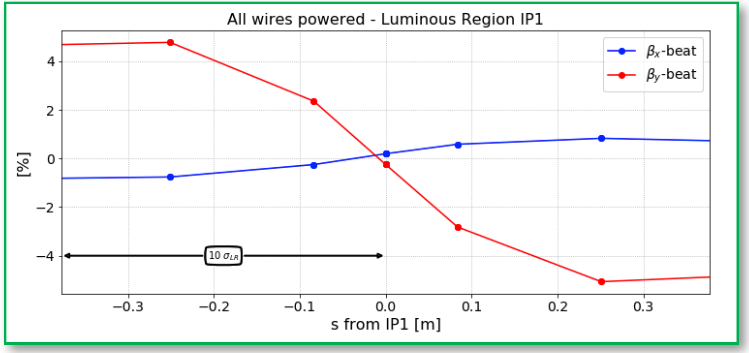
The max beta-beating is localized in a region with significant aperture margin

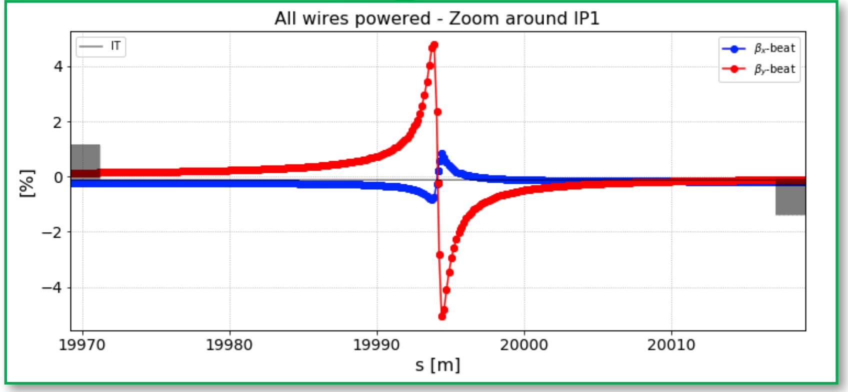
Beta-beating (B2)



All wires powered
@ 350 A + FF

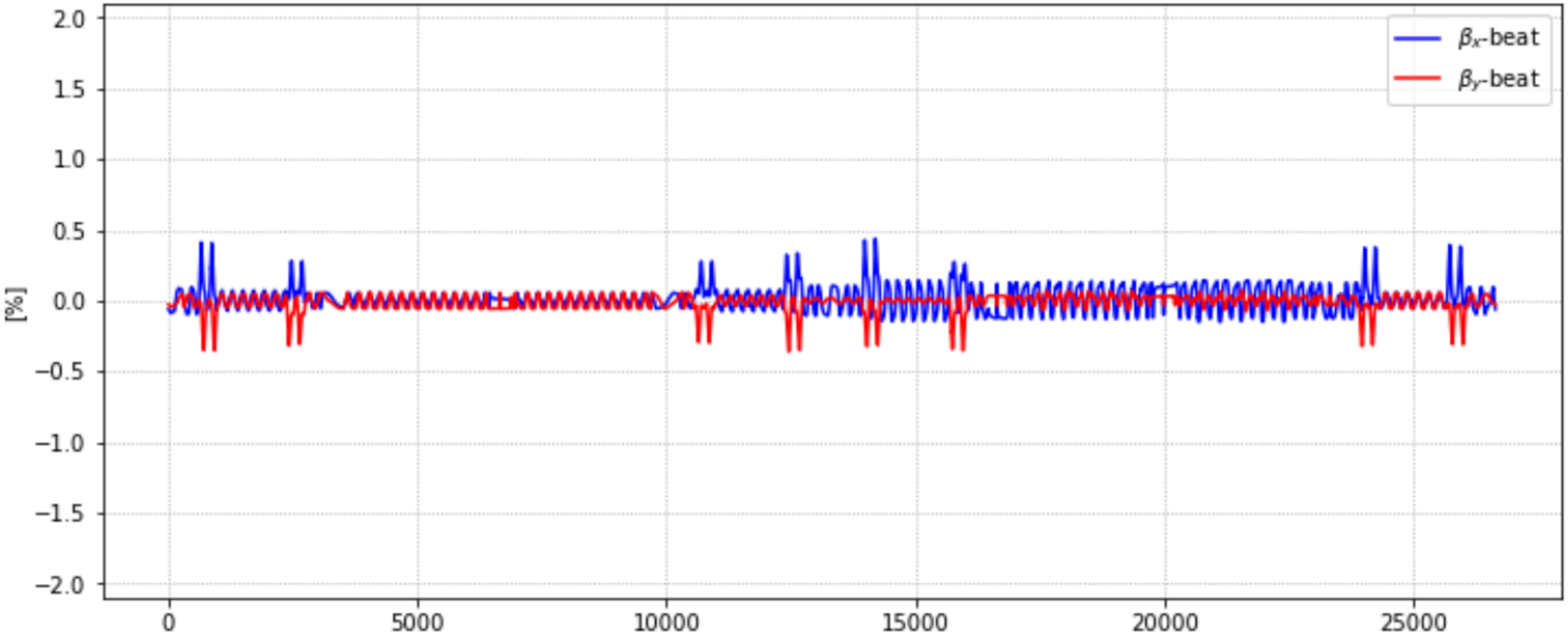
Mild beta-beating along the machine.
Peak of ~5% at the IP (~25 cm from IP)





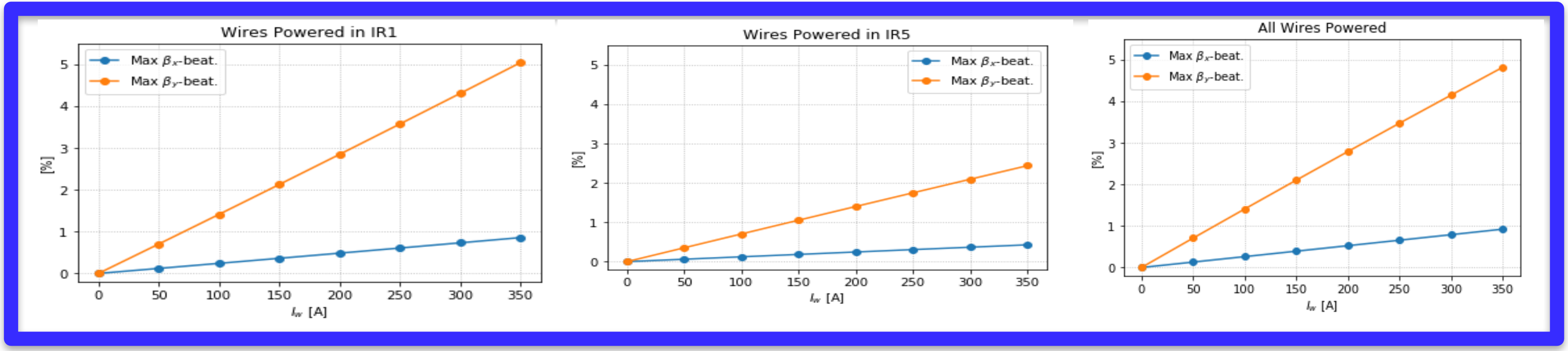
The max beta-beating is localized in a region with significant aperture margin

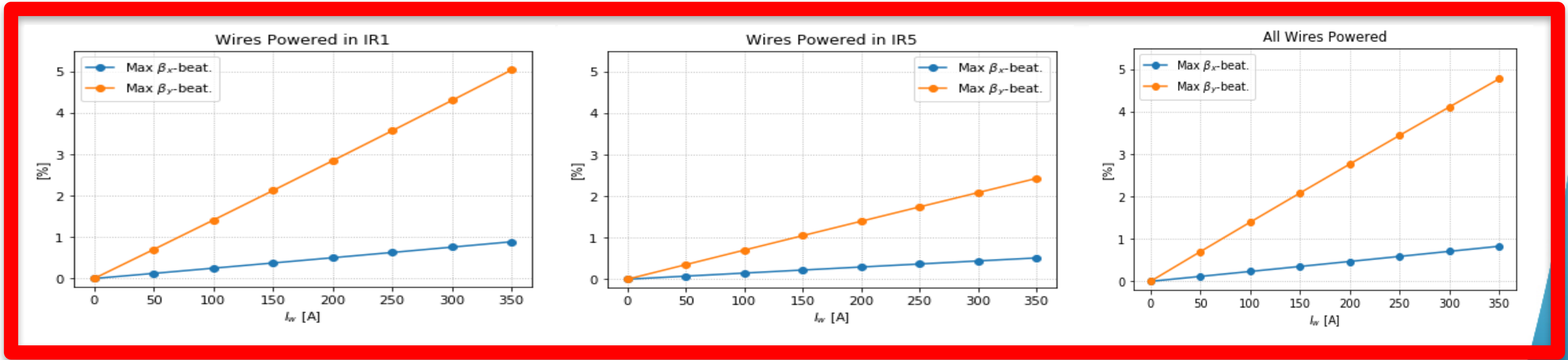
Beta-beating of the Qtrim (+0.01, -0.01), B1



As comparison with the beta-beating of the tune trim.

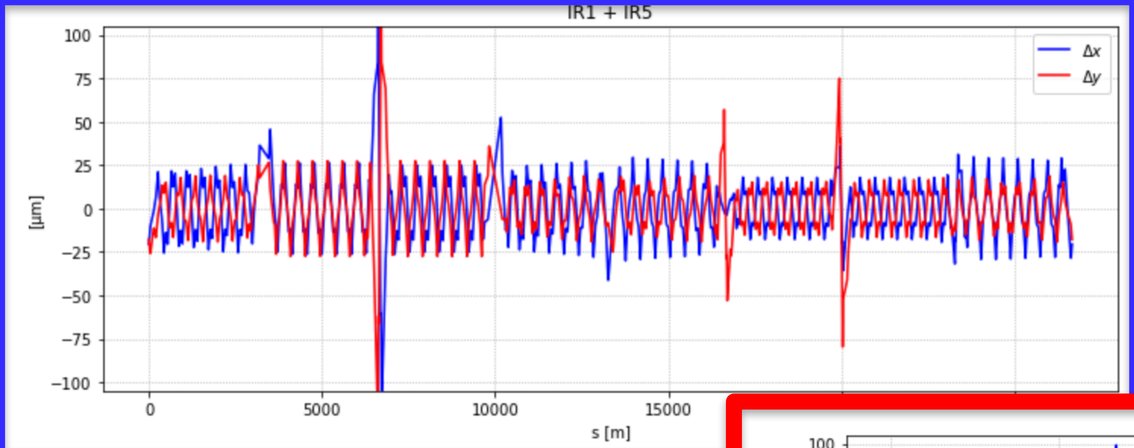
Beta-beating wire by wire

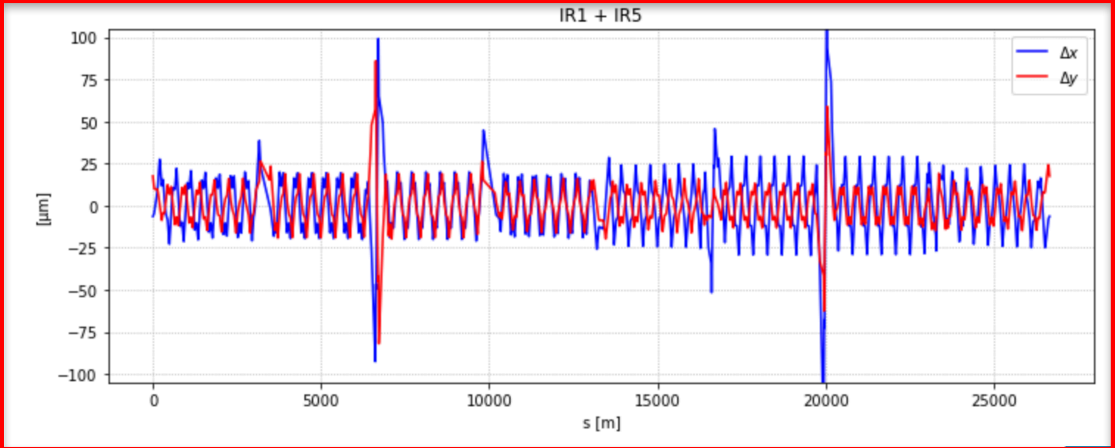




Max beta-beating linear with the wire currents

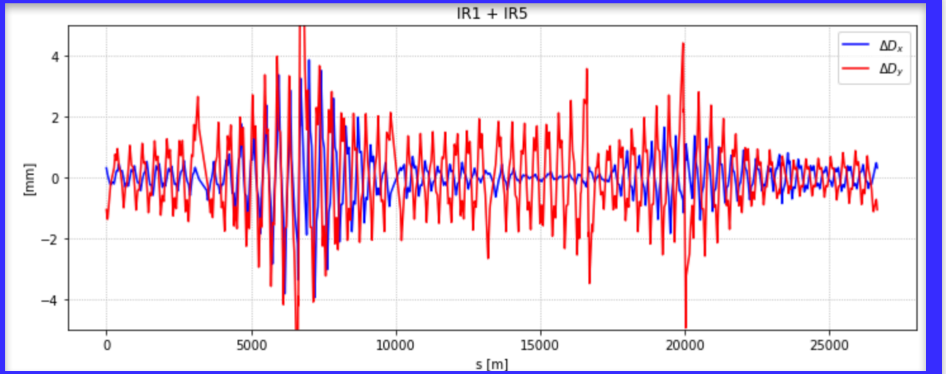
Orbit effect

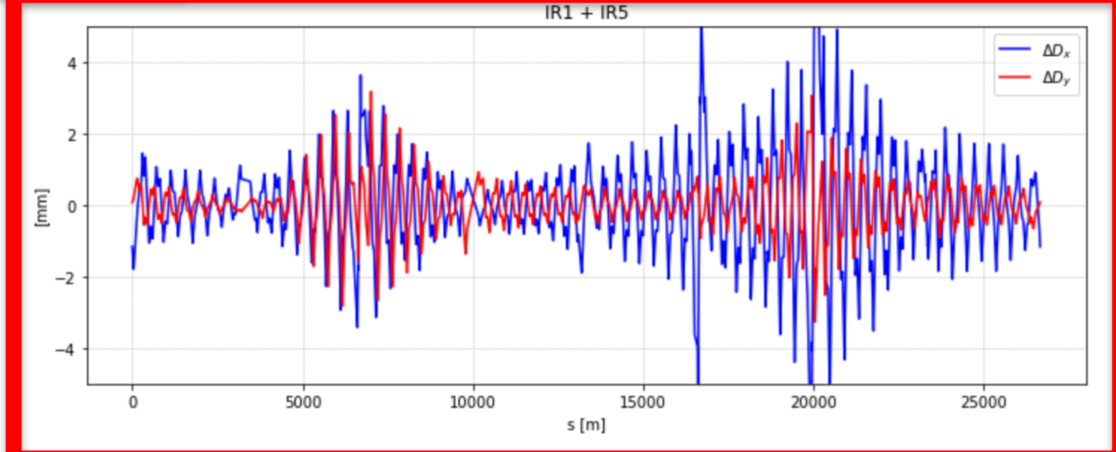




They should be significantly mitigated by the CO feedback

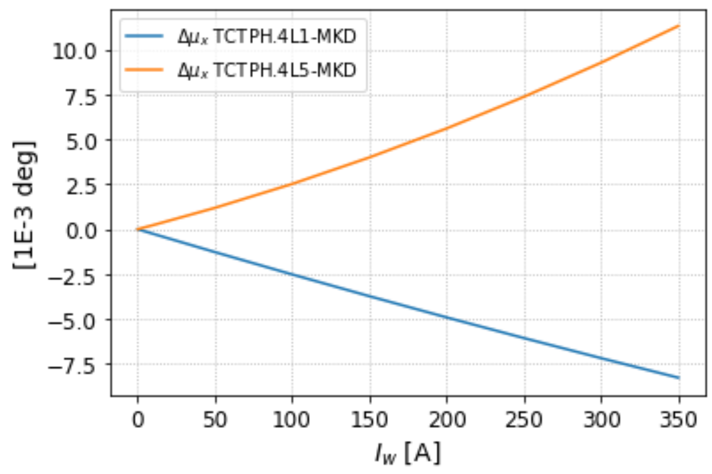
Dispersion effect

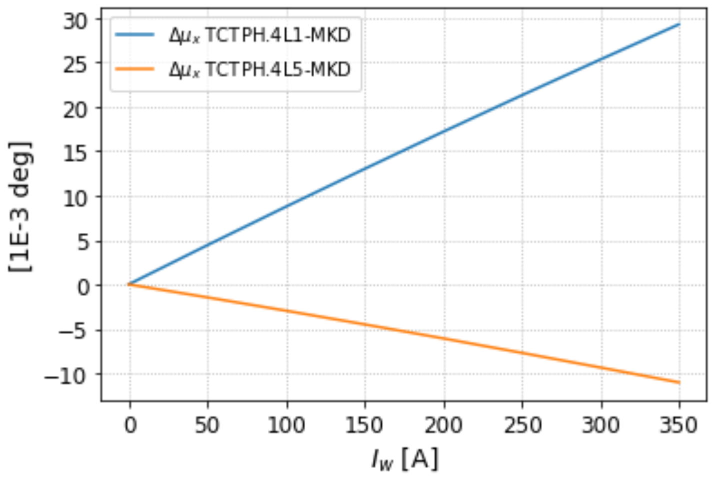




Minor effects to dispersions.

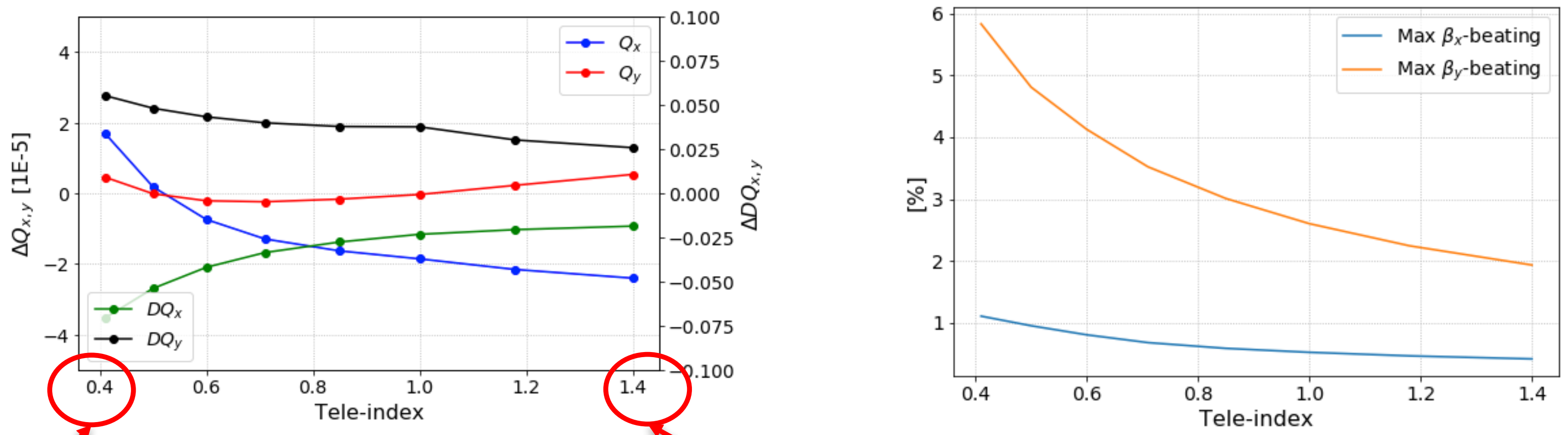
Phase effect (MKD →TCT)





Effect in the % of degree.

Impact of tele-index (B1)

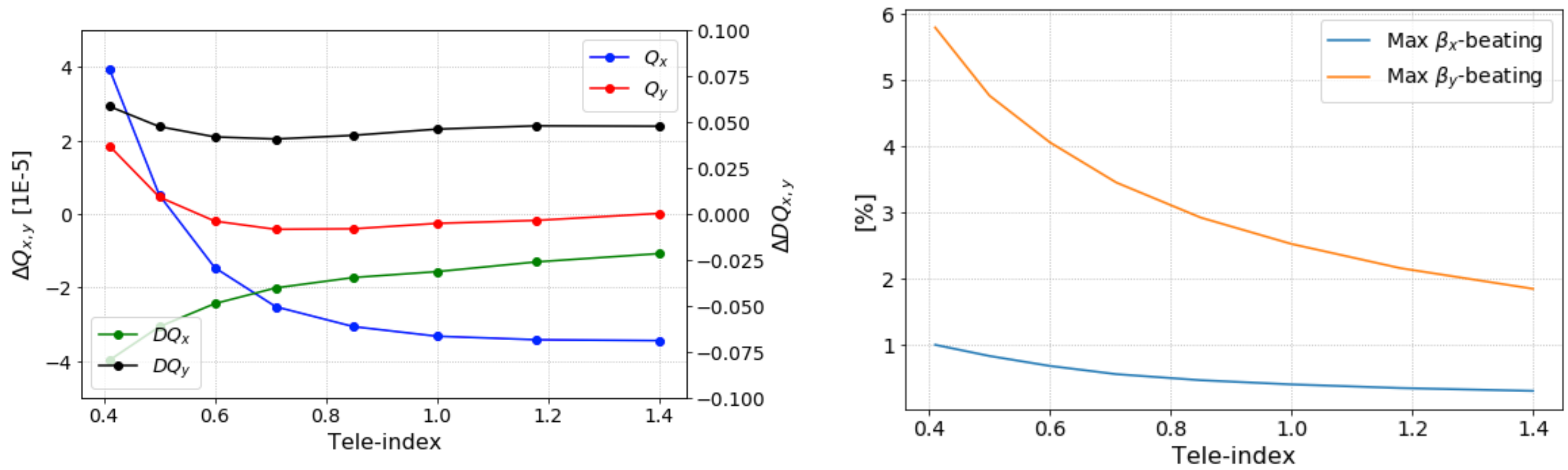


25 cm

84 cm

The FF is expected to be used at fixed tele-index (end-of-leveling).
Anyhow the FF performance vs tele-index were investigated.
The knobs are tele-index independent

Impact of tele-index (B2)



The FF is expected to be used at fixed tele-index (end-of-leveling).
Anyhow the FF performance vs tele-index were investigated.
The knobs are tele-index independent

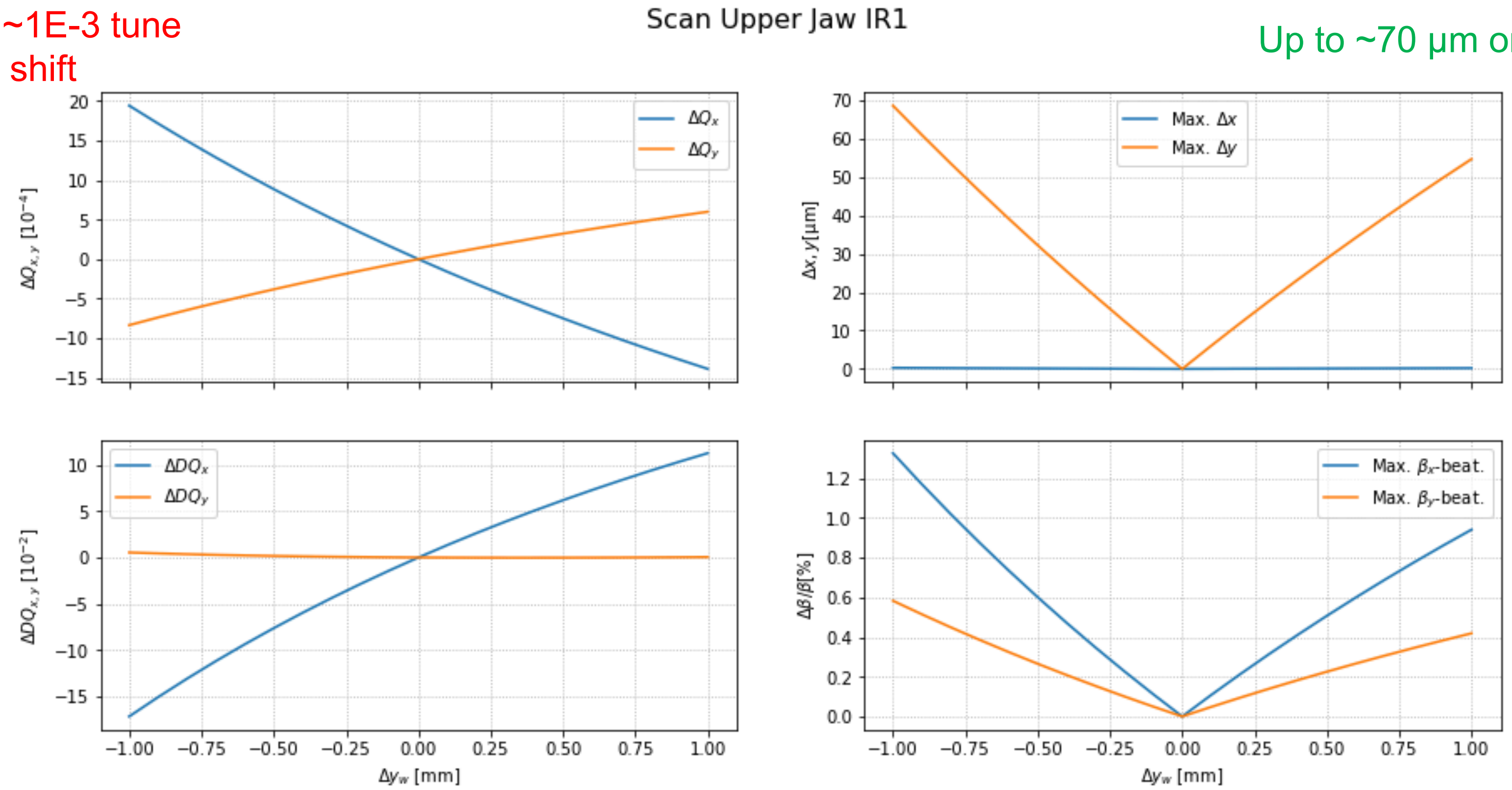
Effect of a non centered beam

- In case the beam would not be centered in between the jaws
- To study the relative misalignment between jaws and beam, we move the jaws, one by one, in the plane of installation
- We scan every jaw for +/- 1 mm from its original position
- We assume all the wires powered with 350 A, and in their operational position (except the one being scanned)

Effect of a non centered beam (B1)

Up to ~1E-3 tune shift

Up to ~70 μm orbit shift



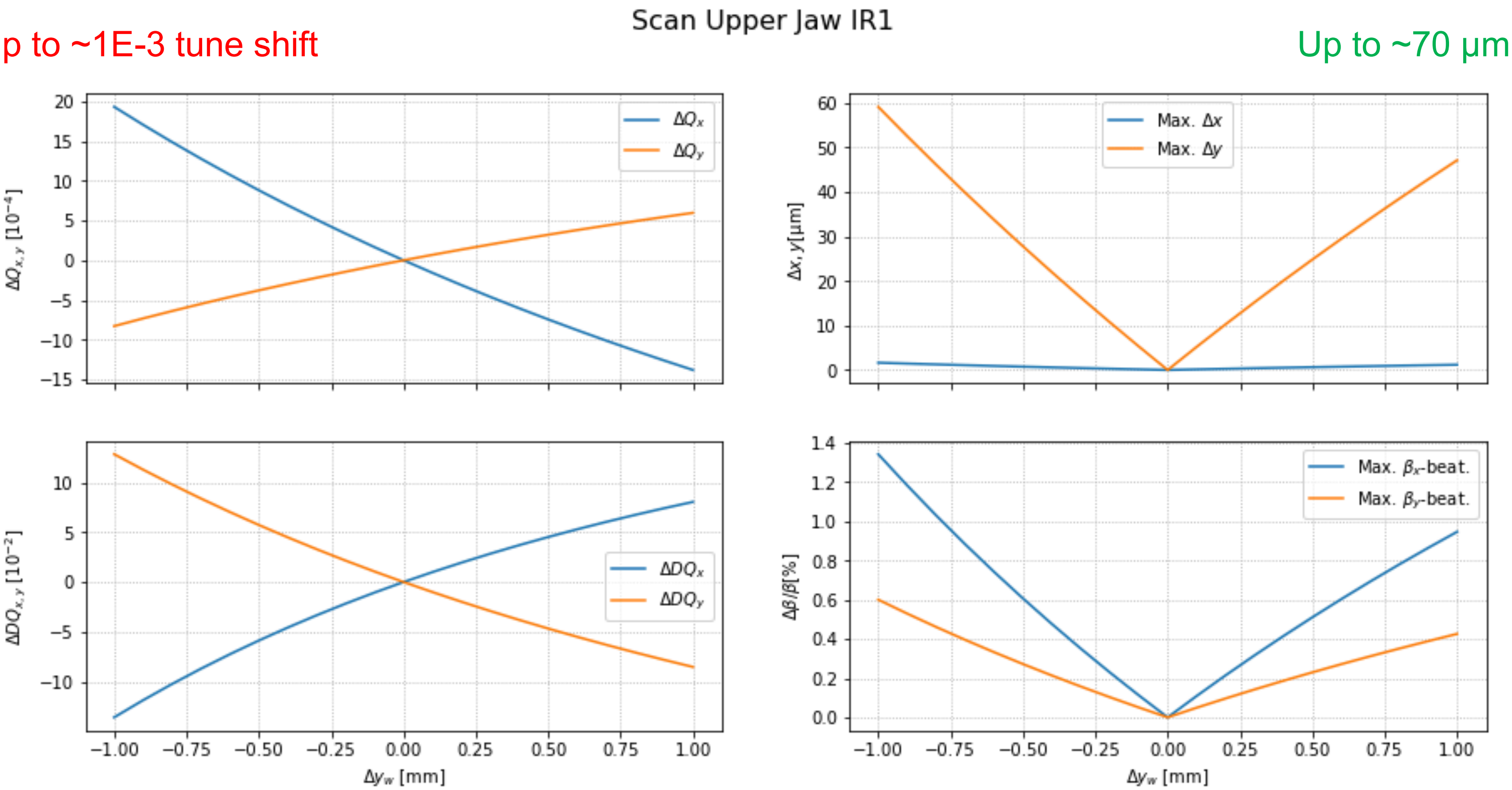
Minor chroma effect

Max 1% extra beta-beat

Effect of a non centered beam (B2)

Up to ~1E-3 tune shift

Up to ~70 µm orbit shift



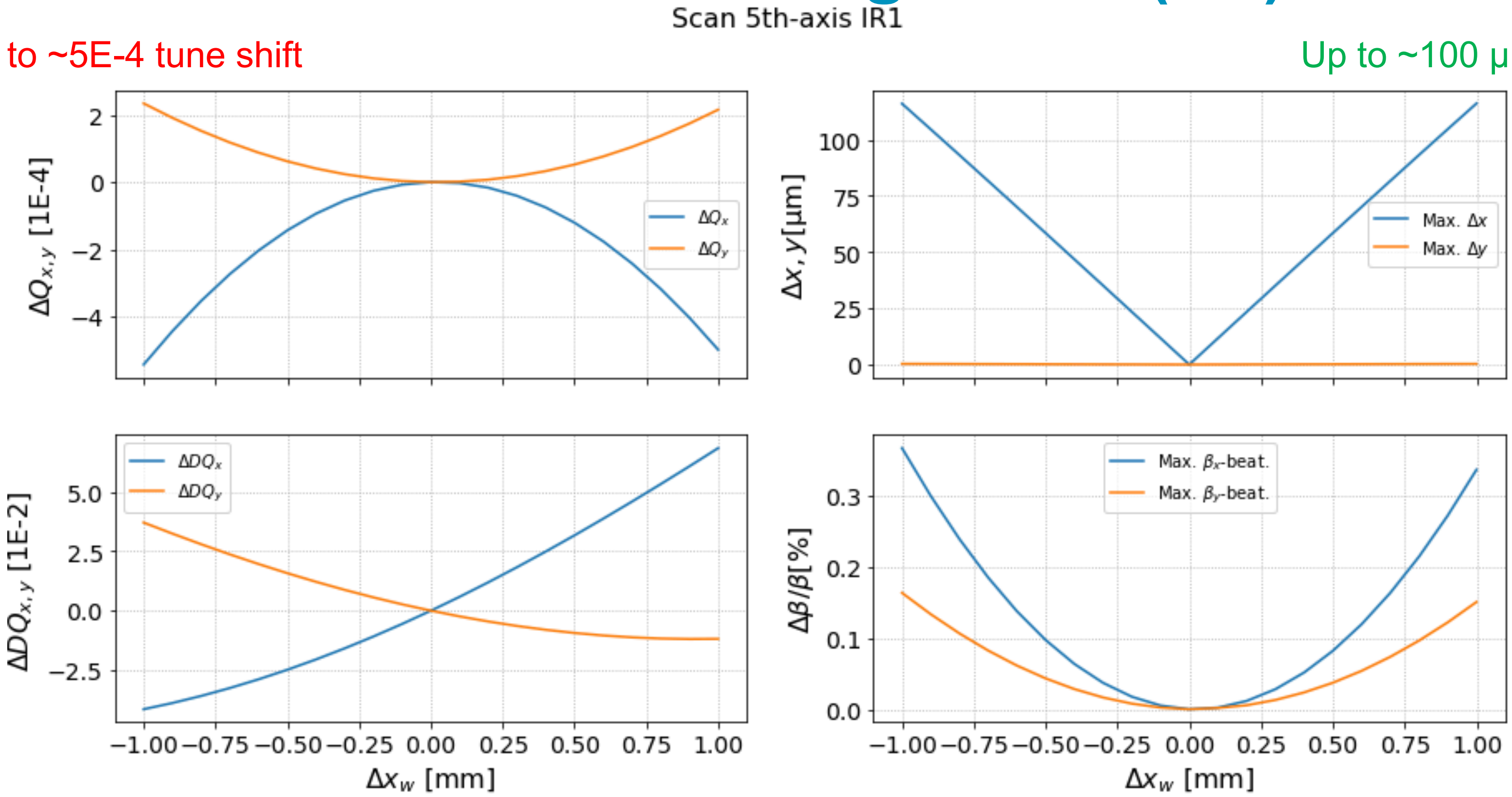
Minor chroma effect

Max 1% extra beta-beat

5th-axis misalignment (B1)

Up to ~5E-4 tune shift

Up to ~100 μm orbit shift



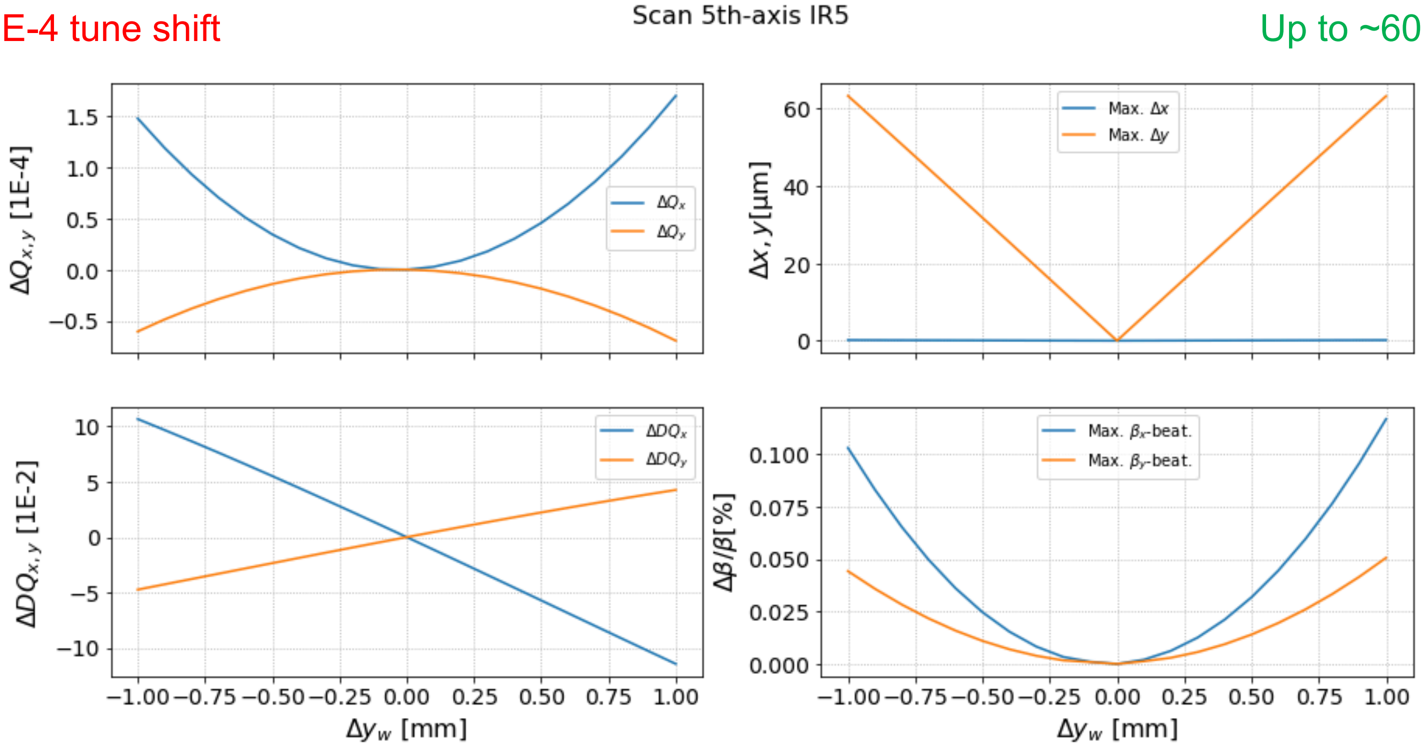
Minor chroma effect

Max 0.5% extra beta-beat

5^{th}-axis misalignment (B1)

Up to ~2E-4 tune shift

Up to ~60μm orbit shift



Minor chroma effect

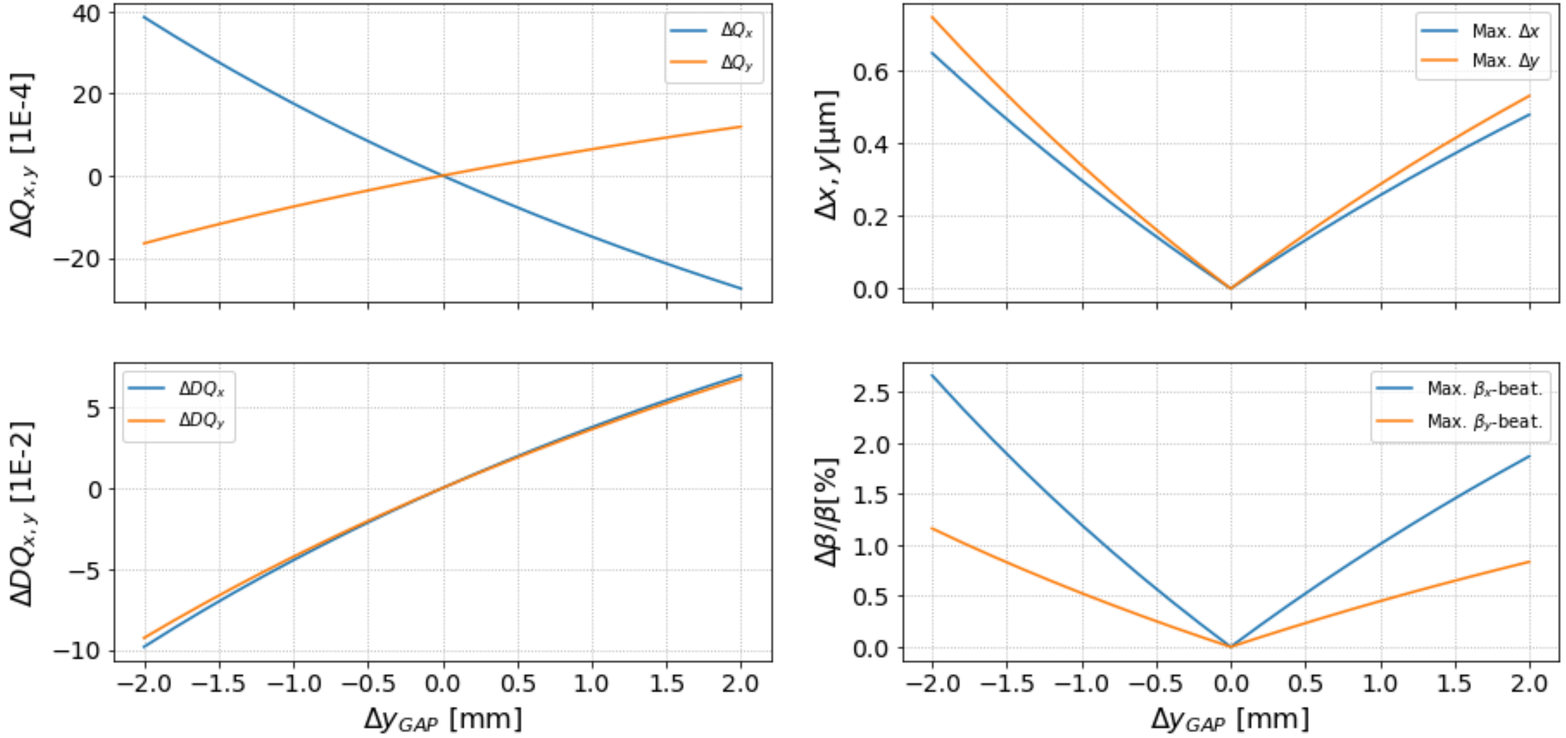
Max 0.1% extra beta-beat

Wrong Collimator Gap (B1)

Up to ~4E-3 tune shift

Minor effect on orbit

Scan Gap IR1



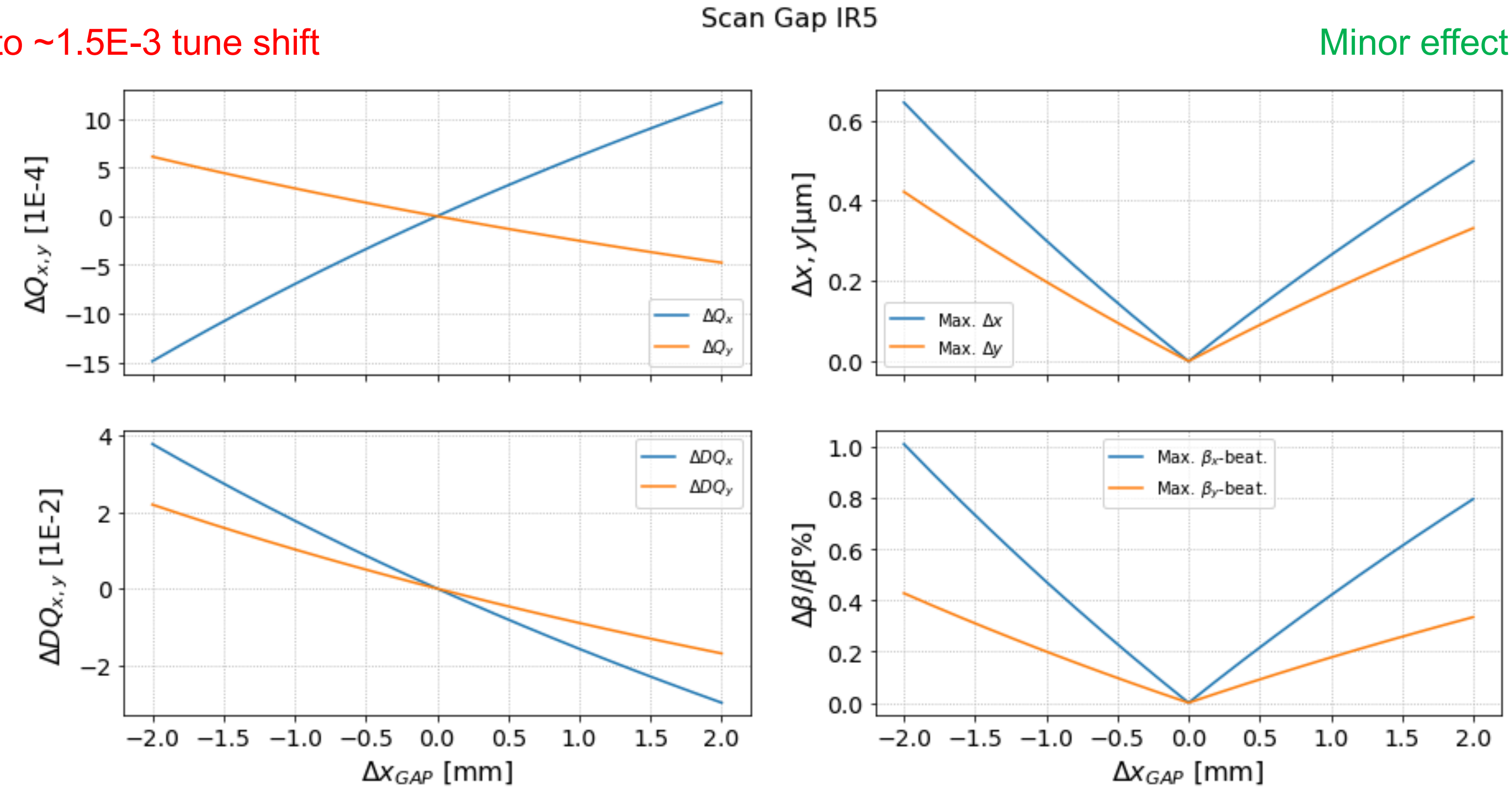
Minor chroma effect

Max 2.5% extra beta-beat

Wrong Collimator Gap (B1)

Up to ~1.5E-3 tune shift

Minor effect on orbit



Minor chroma effect

Max 1% extra beta-beat

Wrong Collimator Gap (B1)

Up to ~1.5E-3 tune shift

Minor effect on orbit

Plots missing for B2… But same behavior expected

Minor chroma effect

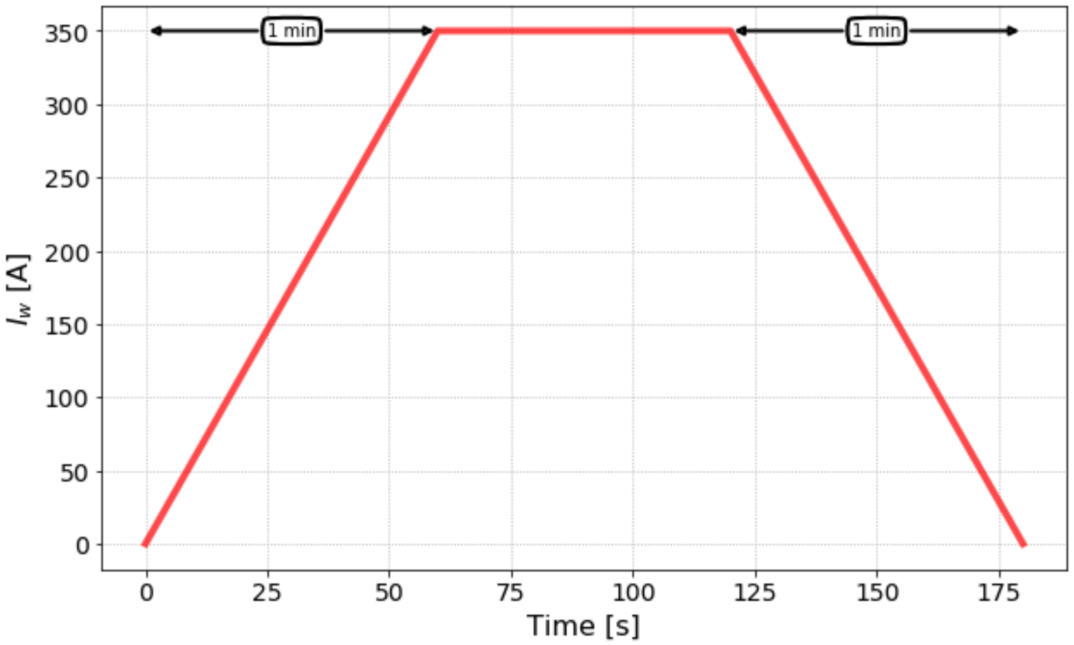
Max 1% extra beta-beat

Ramp proposal

From M. Solfaroli input:

- Delta K ~ 1E-5 (normalized)
- Delta I ~ 18 A (initial current in the Q4 ~ 1800A) → ~ 1%
- Need to be slow enough for the orbit FB

→ 1 min ramp up and down seems reasonable



Summary

- The wires could be switched on at the **end of the leveling**

- The proposed FF has been designed for β^*=30 cm and for 8.5 σ of jaws but is **ATS independent** and the knobs are designed such as a change in position of the wires could be possible.

- We report results about the efficiency of the FF in terms of
  - Linearity
  - β-beating
  - Orbit
  - Dispersion
  - MKD-TCT h-phase

- In case of non-centered beam in the collimator (up to 1 mm), **minor effects are expected** (except for the tune ~1E-3). Same kind of effect are expected in case of other types of misalignment (gap, 5th-axis).

- A **minimum ramping time of 1 minute** seems adequate.

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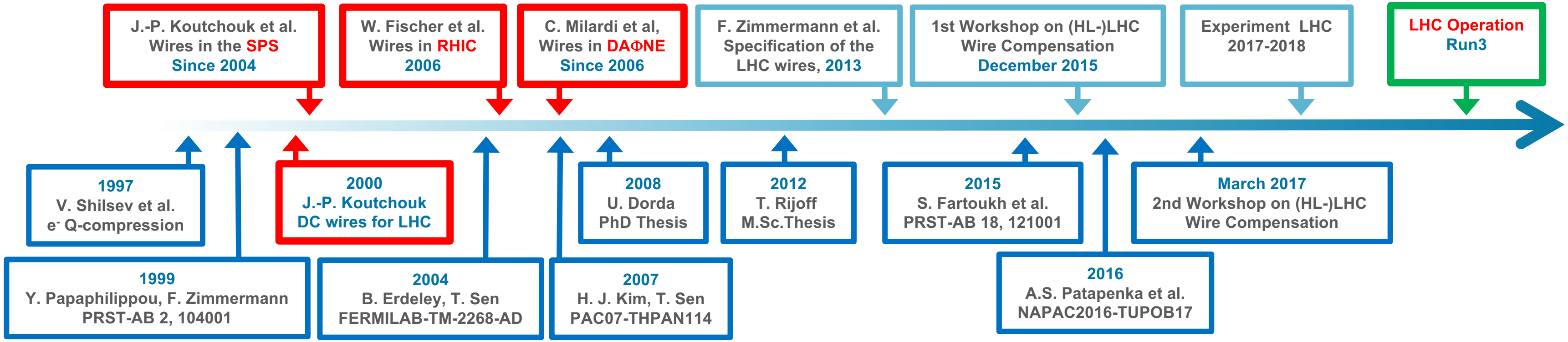
Thank you for the attention.

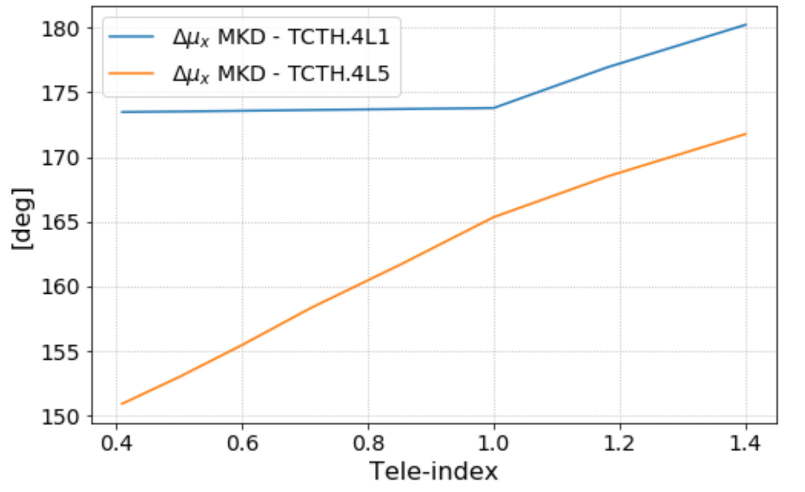


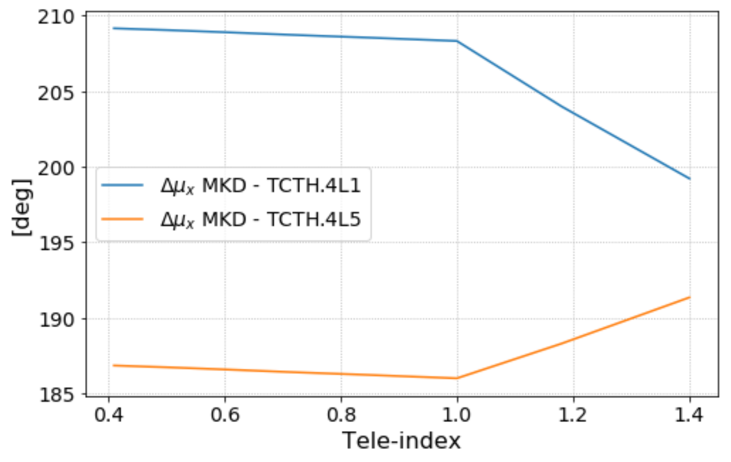
On behalf of the HL-LHC wire compensation team

D. Amorim, G. Arduini, H. Bartosik, A. Bertarelli, R. Bruce, X. Buffat, L. Carver, C. Castro, G. Cattenoz, E. Effinger, S. Fartoukh, M. Fitterer, N. Fuster, M. Gasior, M. Gonzales, A. Gorzawski, G.-H. Hemelsoet, M. Hostettler, G. Iadarola, R. Jones, D. Kaltchev, K. Karastatis, S. Kostoglou, I. Lamas Garcia, T. Levens, A. Levichev, L. E. Medina, D. Mirarchi, J. Olexa, S. Papadopoulou, Y. Papaphilippou, D. Pellegrini, M. Pojer, L. Poncet, A. Poyet, S. Redaelli, A. Rossi, B. Salvachua, H. Schmickler, F. Schmidt, K. Skoufaris, M. Solfaroli, G. Sterbini, R. Tomas, G. Trad, A. Valishev, D. Valuch, J. Wenninger, C. Xu, C. Zamantzas, P. Zisopoulos and all participants to the design, production and commissioning of the wire compensator demonstrators.

BACKUP SLIDES

Impact of tele-index (MKD-TCT)



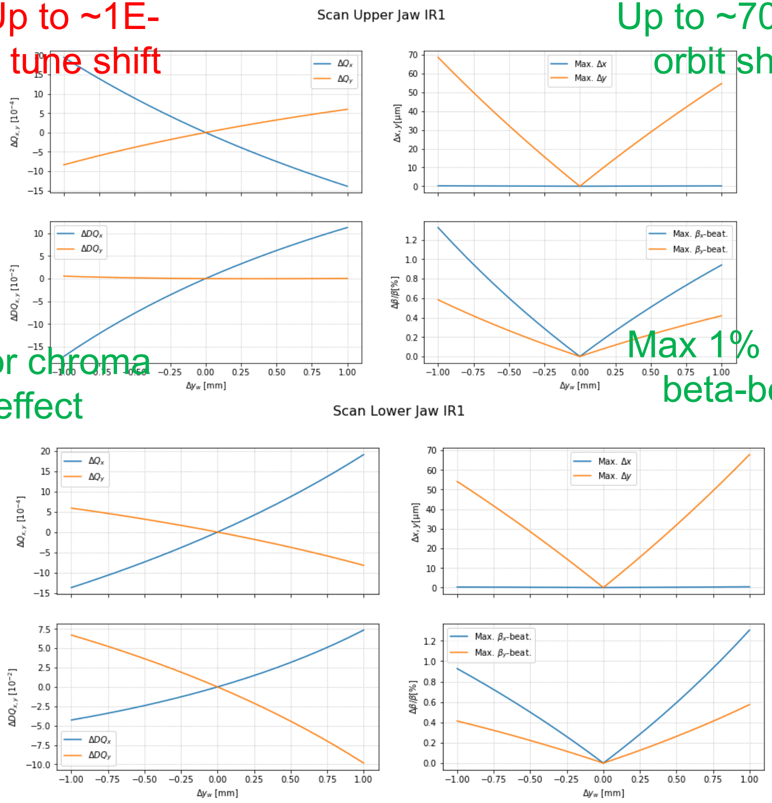


MKD-TCT phase advance within margins

Effect of a non centered beam (B1)

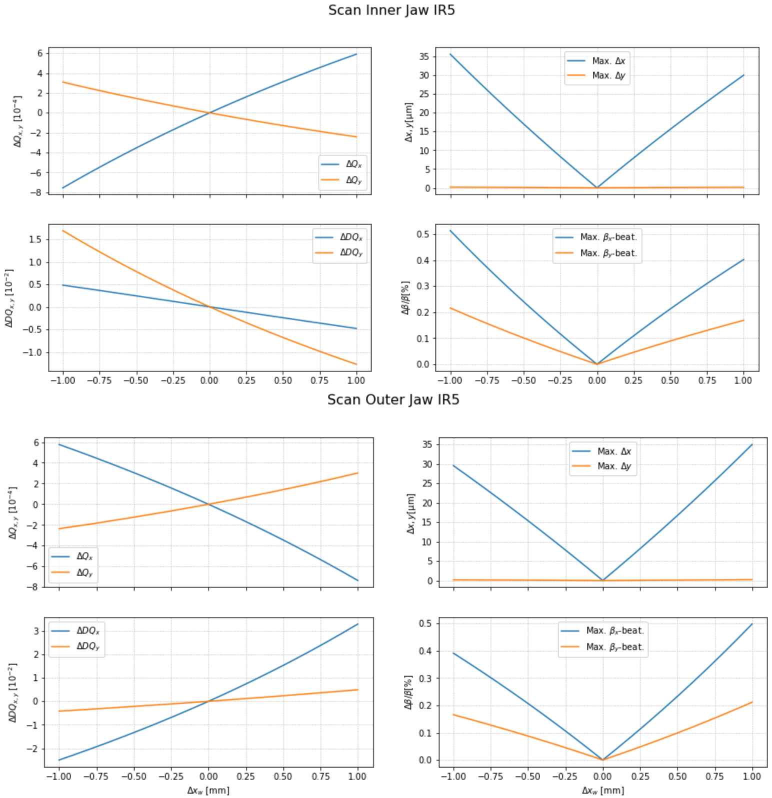
Up to ~1E-3 tune shift

Up to ~70 µm orbit shift



Minor chroma effect

Max 1% extra beta-beat



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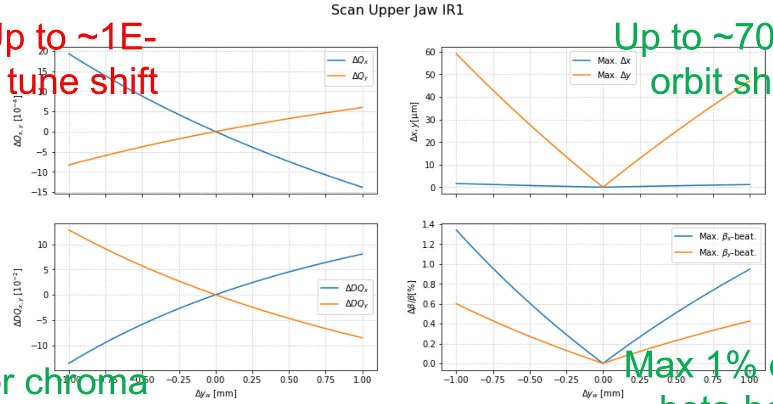
Effect of a non centered beam (B2)

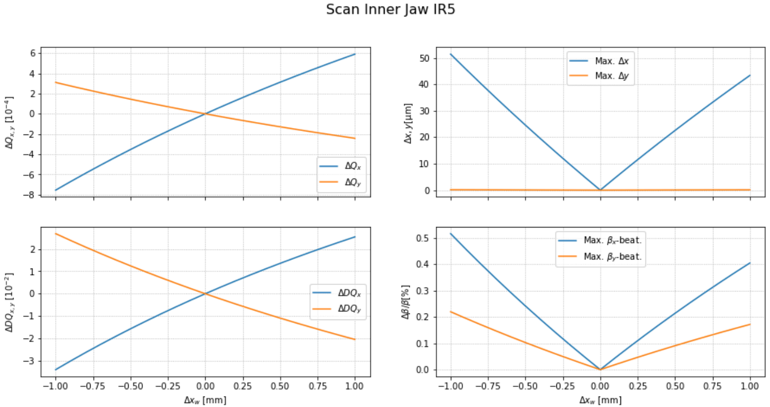


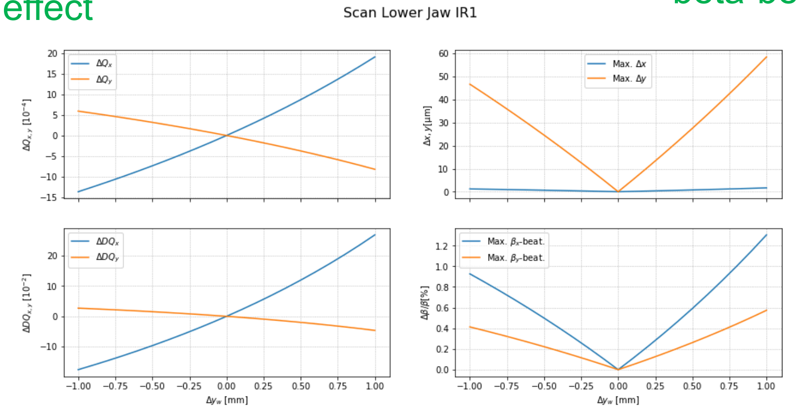
Up to ~1E-3 tune shift

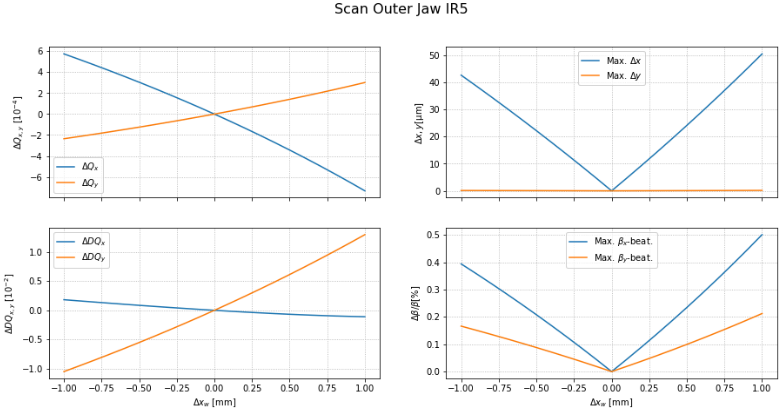
Up to ~70 µm orbit shift

Minor chroma effect

Max 1% extra beta-beat







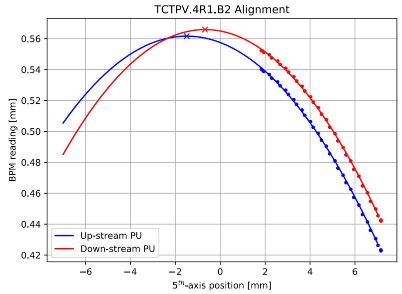
Failure scenarios under studies

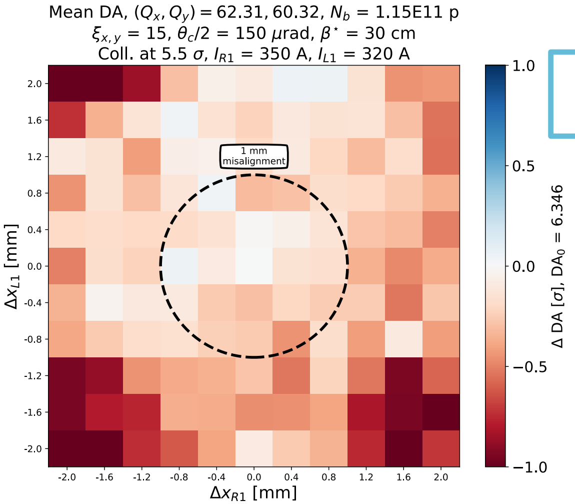
- Overheating of the wires
  - → interlocks (see Adriana's presentation)
- Failure of the wires converters
  - → interlocks (see Adriana's presentation)
- Drift of the converters
  - → phase interlock (to be discussed with OP and MPP)

Effect of a 5th-axis misalignment

- After installing the wire prototypes in IR1, **a misalignment of the 5th-axis was observed (~2mm)** [4]
- The first MD was an opportunity to **measure** this misalignment and to **partially realign** the collimator during the following technical stop
- DA study was done to understand **the sensitivity** on this alignment
- **Below ~1mm** misalignment, the effect on DA is negligible
- Results obtained after the re-alignment showed that it had a beneficial effect (misalignment < 1mm)

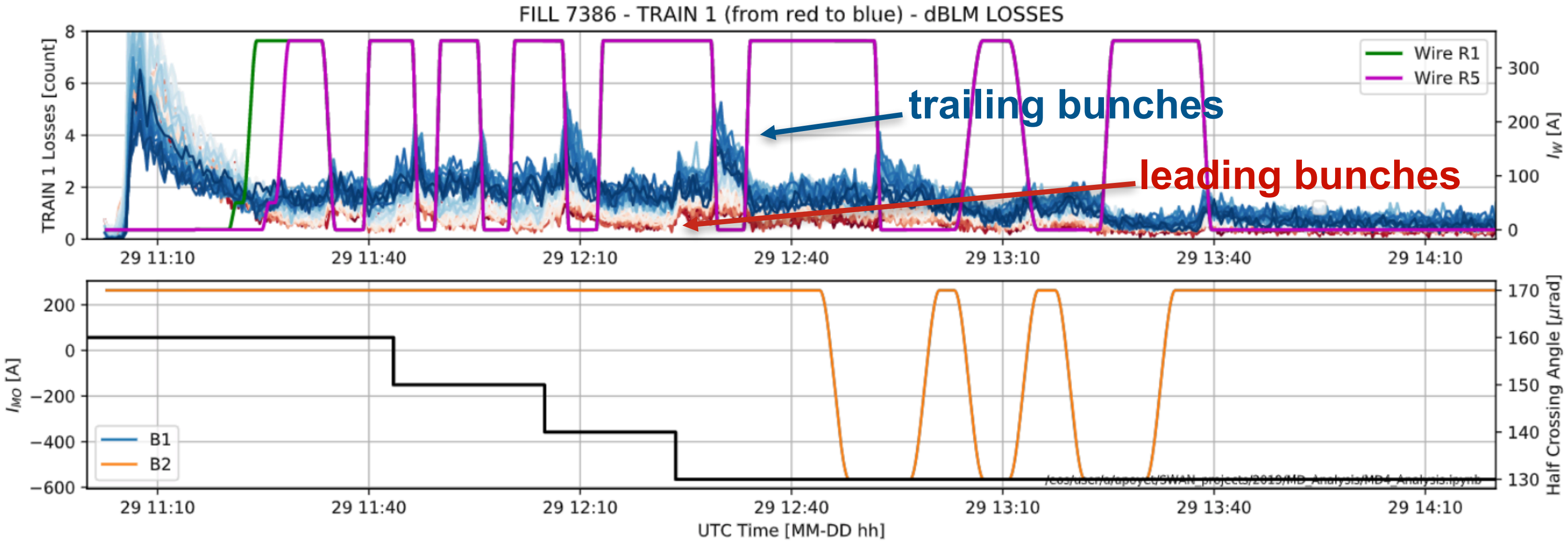
Alignment procedure during the MD
(courtesy of N. Fuster)





DA dependency on the misalignment

Bunch-by-bunch analysis (I)



- In the HI experiment the wire is more effective for the trailing bunches.

Bunch-by-bunch analysis (II)

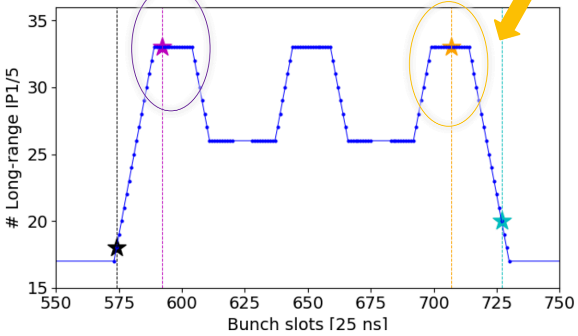
- Several observation during 2018 run showed indeed that the trailing bunches are the most critical in terms of losses.

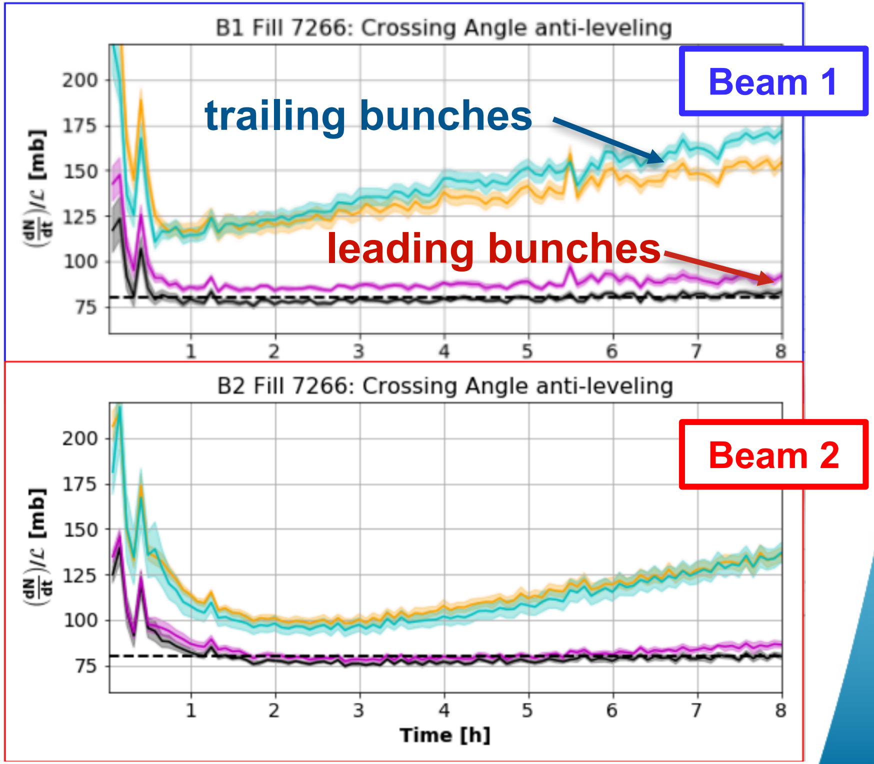
Classes:

I. NoBB
II. BB
III. BB-ecloud
IV. NoBB-ecloud

DA optimizations are based on **BB Class**

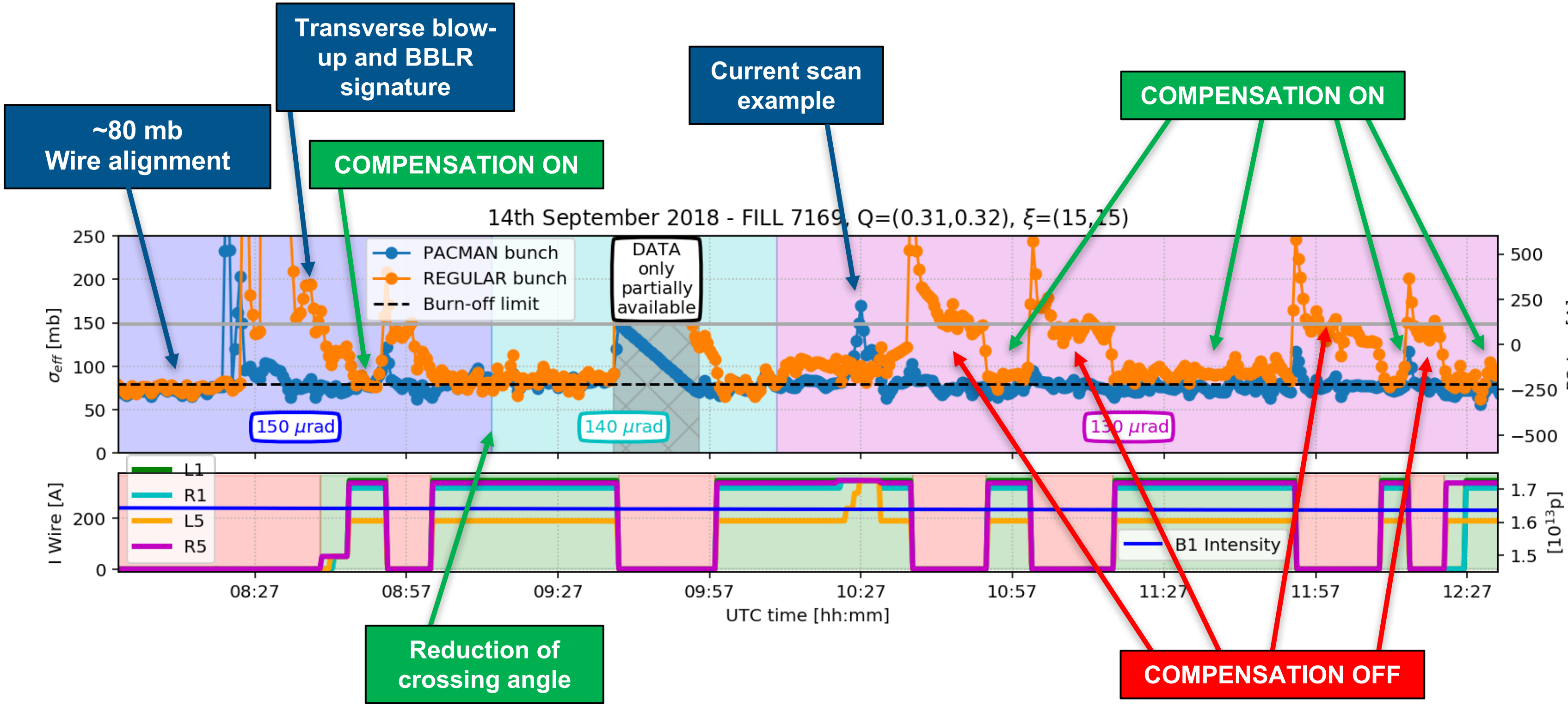
Applied on Class **BB-ecloud**





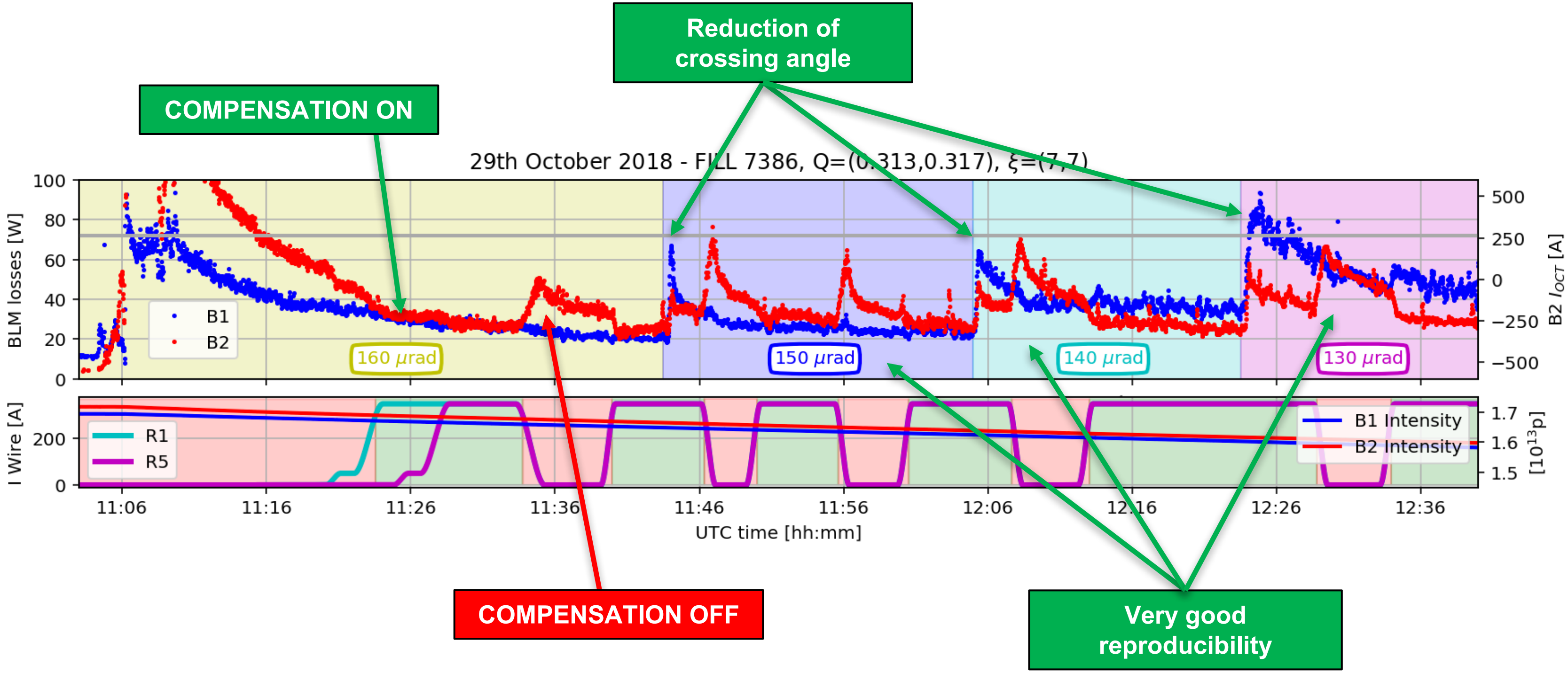
Courtesy of S. Kostoglou and S. Papadopoulous

Low-Intensity experiment



- **Almost full compensation, even at reduced crossing angle, for regular bunch whereas head-on bunch not degraded.**

HI experiment (operational conditions)



- **Compensation provides a reduction of B2 losses of ~20%.**