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HL-LHC PROJECT

Brainstorming of the wire MDs in 2018

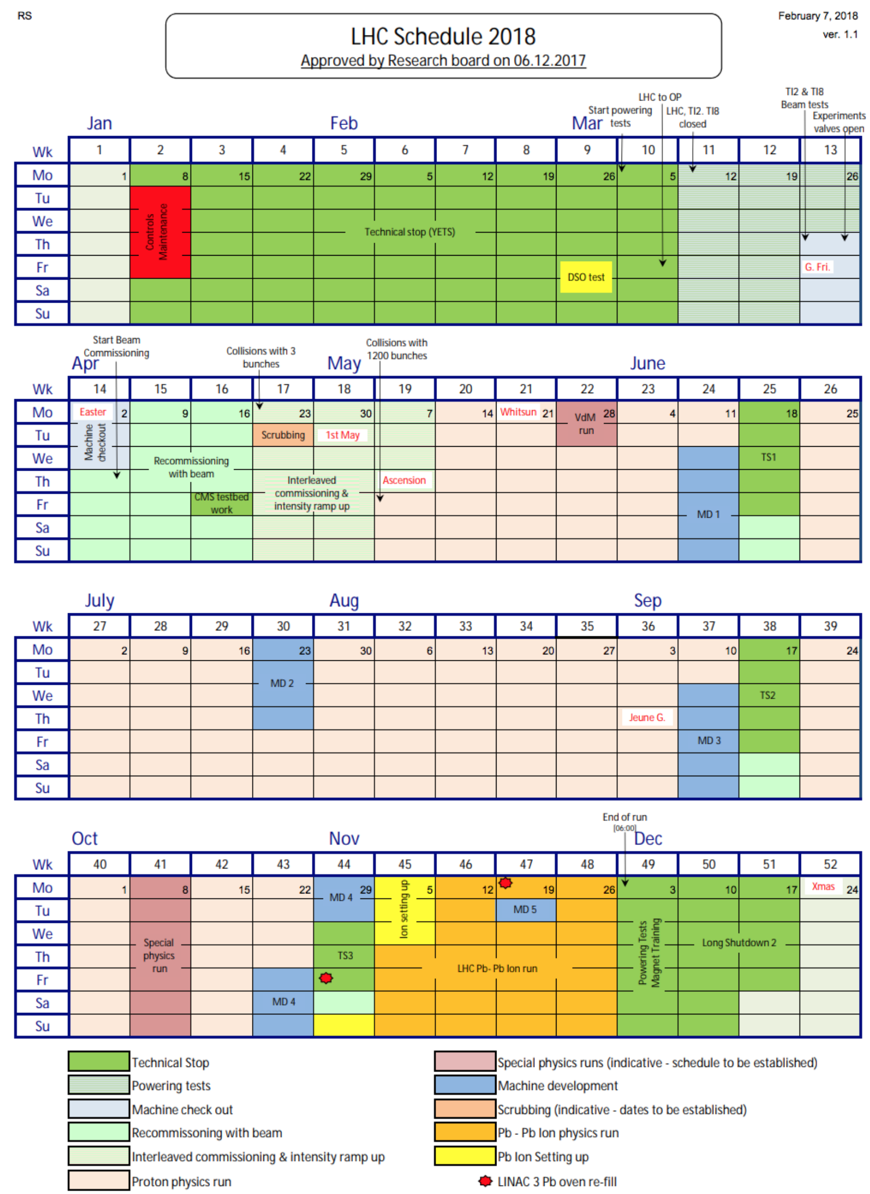
“Following Chamonix discussions, we decided that this year we will proceed differently than the Wire Workshop.
We would like to propose a meeting to have an initial brainstorming to see how far we can push the wire MD (intensity, trains, position?) in order to obtain the maximum results and demonstrate what we can do

- *with IP1 given the unfavorable position of 1 collimator,*
- *with the external wires,*
- *with trains,*
- *at end of fills…”*

⟹ **Inputs from other teams very important**

21 March 2018, CERN

- **42 h MD requested (~10 h per each MD block)**
- **Goal of the wire MD 2018**
  1. test the 2 IRs compensation with **round** optics (only IR5 was tested in 2017).
  2. Move from safe beam towards trains (e.g. EoF MD…).
- **Try to define a roadmap/strategy for the 4 MD blocks with the input of the specialists.**



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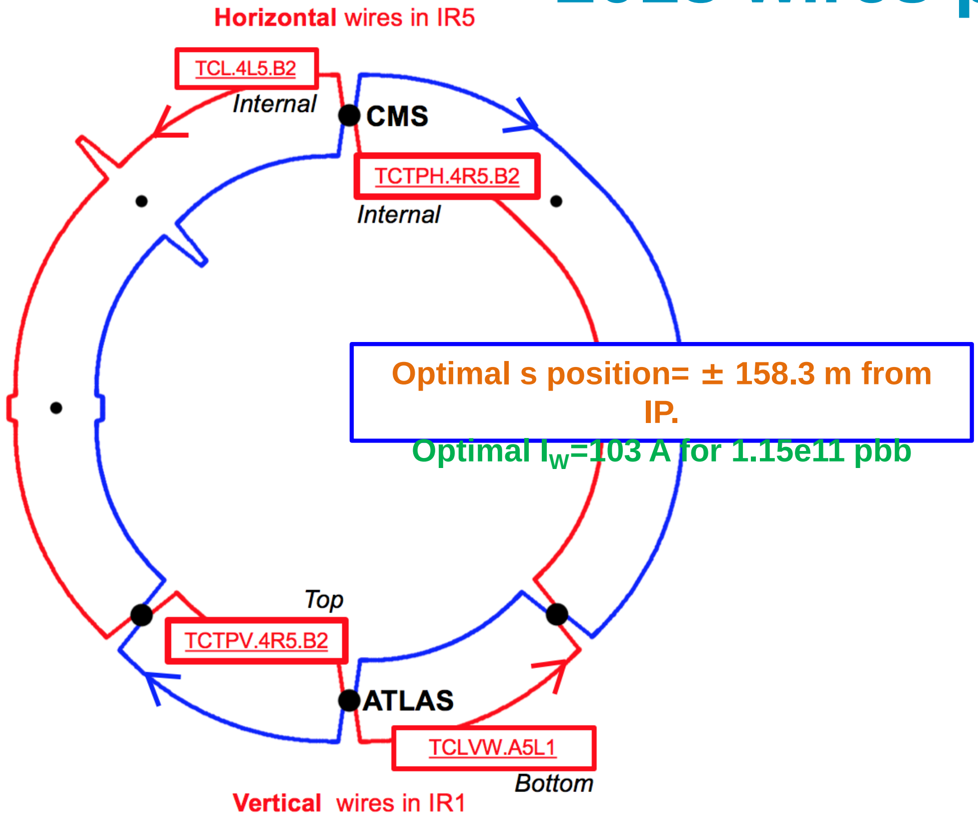
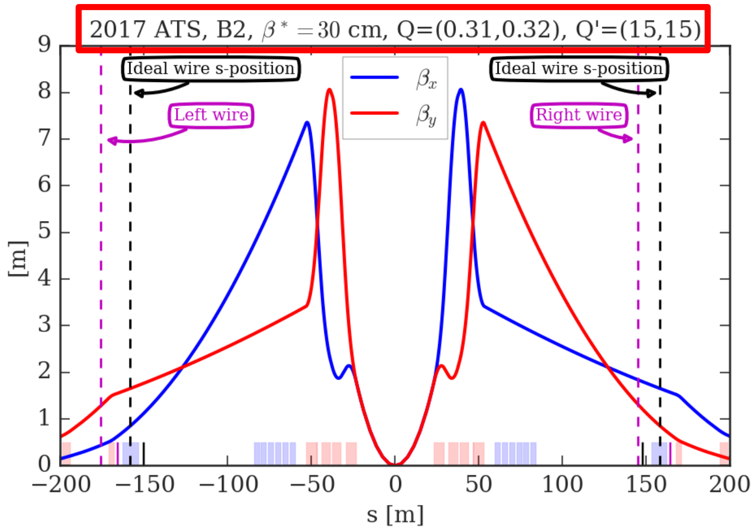
2018 wires prototypes



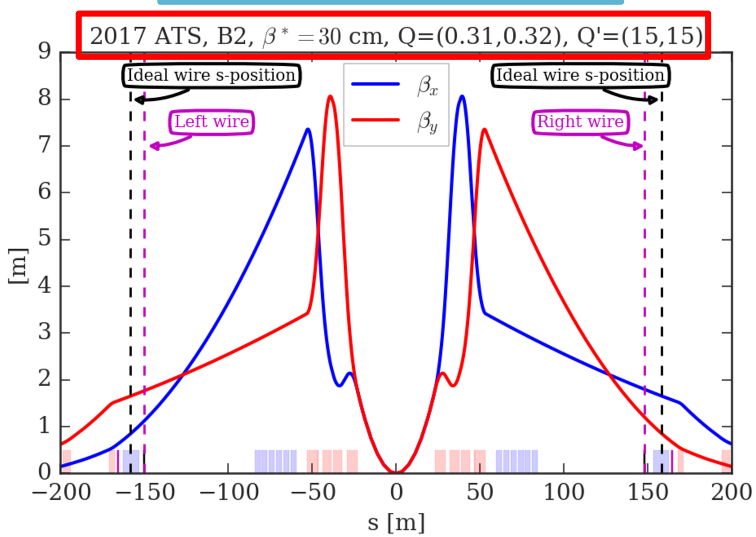
Optimal s position= ± 158.3 m from IP.

Optimal I_W=103 A for 1.15e11 pbb

Interaction Region 1



Interaction Region 5



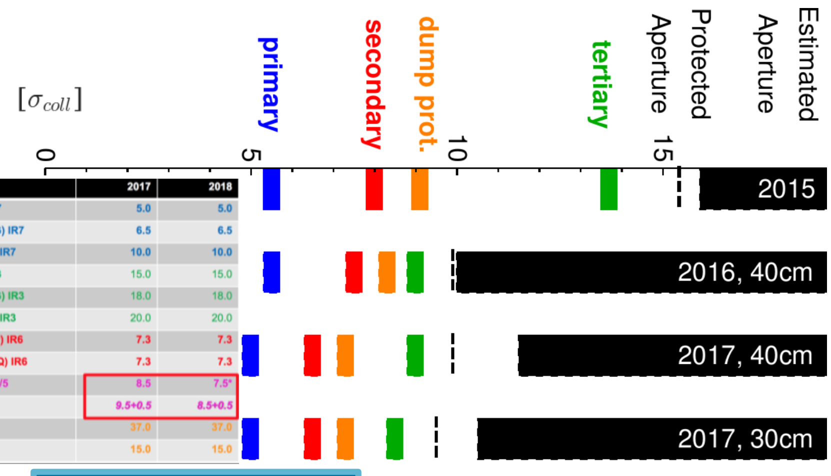
1. **In IR1 the s-position of the wires are sub-optimal: -176** and +145 m from the IP1 (symmetry broken).
2. The wire planes are compatible with round optics but not with flat ones (V/H wires in IR1/5).

The beam-wire distance “problem”

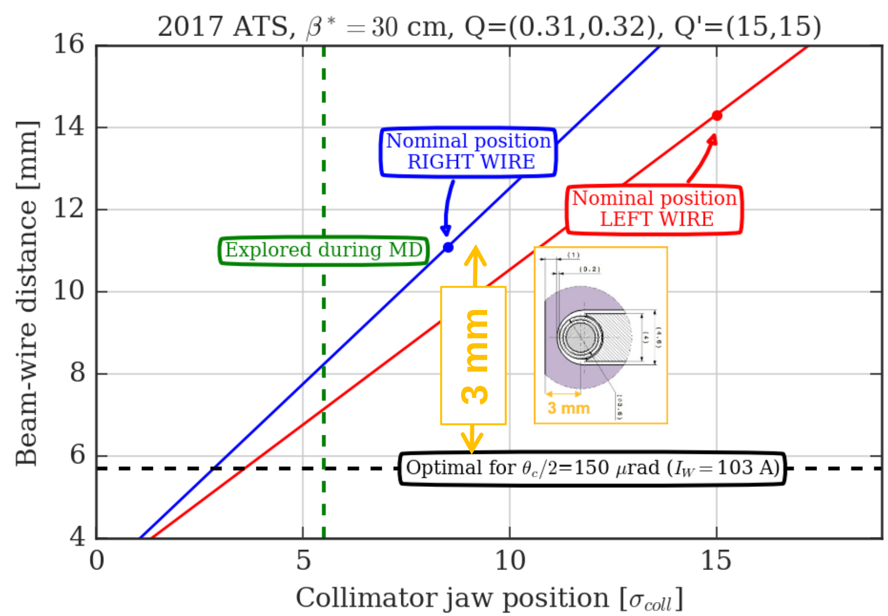
Optimal beam-wire distance= 5.7 mm

- The optimal beam-wire, d_w, is extremely challenging with the present prototype: collimator at **3-4 σ_{coll}**.
- **In 2017 we tested the 5.5 σ_{coll}** distance in IR5 (safe beam):results showed that we can have compensation effect (at least for ROUND optics) by addressing only two RDTs.
- **In 2018 to explore the 5 σ_{coll}.**

Collimator	2017	2018
Primary (TCP) IR7	5.0	5.0
Secondary (TCSG) IR7	6.5	6.5
Absorber (TCLA) IR7	10.0	10.0
Primary (TCP) IR3	15.0	15.0
Secondary (TCSG) IR3	18.0	18.0
Absorber (TCLA) IR3	20.0	20.0
Secondary (TCSP) IR6	7.3	7.3
Dump prot. (TCDQ) IR6	7.3	7.3
Tertiary (TCT) IR1/5	8.5	7.5*
Aperture 1/5	*9.5+0.5*	*8.5+0.5*
Tertiary (TCT) IR2	37.0	37.0
Tertiary (TCT) IR8	15.0	15.0



Courtesy of R. Bruce



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During beam commissioning

- We asked Jorg to have 4 h slot with LHCINDIV at injection orbit/tune response (polarity checks of the 4 wires). **VERY IMPORTANT.**
- **COLLIMATION:**
  - What is the position of the TCLVW at top energy? 15 $\boldsymbol{\sigma_{coll}}$?
  - Can the wire collimators be 5-axis centered with the beam at top energy?
- **COLLIMATION/OP:**
  - Is the TCLVW included in the Xing angle orchestration? Is it included in the standard Collimation GUI/VISTARs?
- **COLLIMATION/BI:**
  - PUs of TCLVW still not declared in CALS...
  - Are the dBLM being logged in CALS?

Before MD1

- **OP:**
  - Can you help us in implementing the CO and Q-feedforwards for the 4 wires (like was done in the 2017) and update the GUI? We plan to have independent feedforwards for each wire.
  - Can be the feedback be designed to work also when the beam-wire distance is varying?

A possible roadmap

MD1

- Compensation of IR5 and IR1(SEPARATELY) at 5 σ_{coll}, 2 FILLS (12 h?). If there is time I_W scan.
- Composition of SAFE BEAM: 1 pilot non colliding, 1 INDIV (HO+full BBLR), 1 INDIV (HO+ half BBLR), 1 INDIV (HO).
- **BI:** what is the tune precision with a pilot a top energy?

MD2

- Compensation of IR5 and IR1(together) at 5 σ_{coll}, 1 FILL. If there is time Xing scan with wire on.
- **COLLIMATION/OP**: can the jaw be moved with the wire on?

MD3

- Repeat MD2 using the wire of the opposite jaw. 1 FILL.
- **BI:** can the wire reconfiguration be organized between MD2 and MD3?

(MD1–MD3: SAFE B2)

EoF MD

- We would need to change the B2 tune to make it more sensitive to BBLR (or play other tricks) and power all 8 wires.
- **COLLIMATION/BI**: can we put the TCLs at the TCTPH/V position? powering the 8 wires?
- **OP**: can we power the wires? can we use the feedforwards? We need to mask some interlocks…

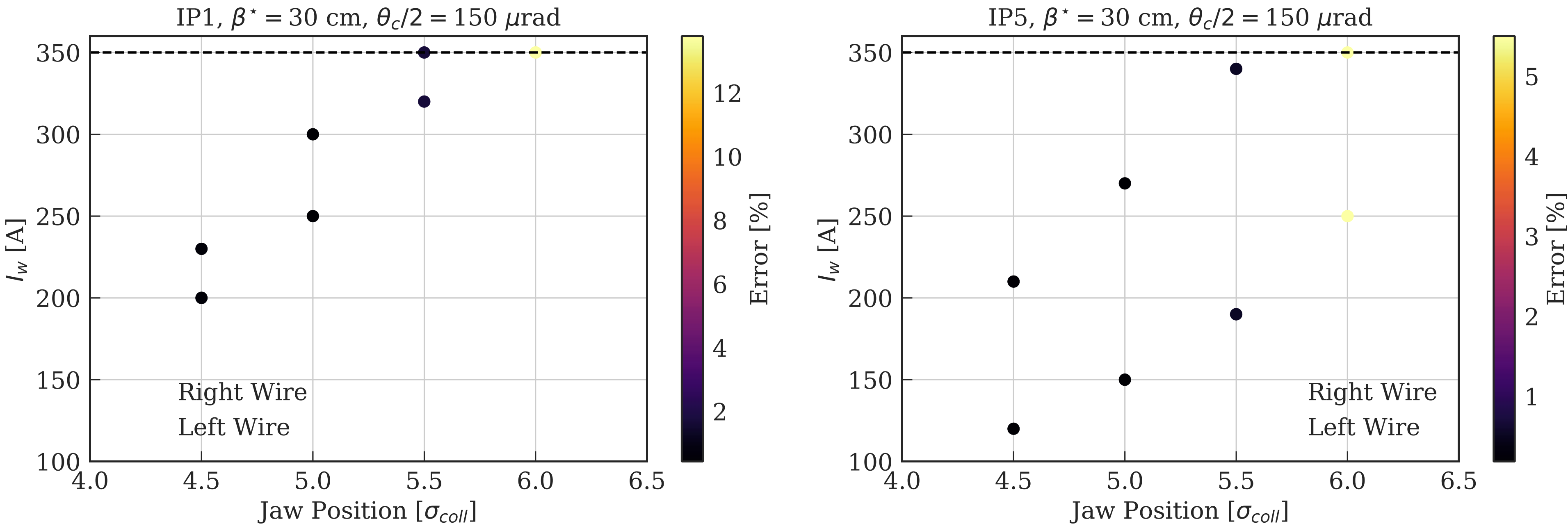
MD4

- OPTION 1 (preferred): repeat with a small train in B2 (>12 bunches) and possibly with tighter collimator settings than the EoF.
- OPTION 2: test the compensation by using different Xing angles in IP1/5 (170/120 urad) (loss of LR compensation of B2, B6,…).

(EoF MD–MD4: NOT SAFE B2)

MD1 and MD2: pushing to 5 σ_{coll}

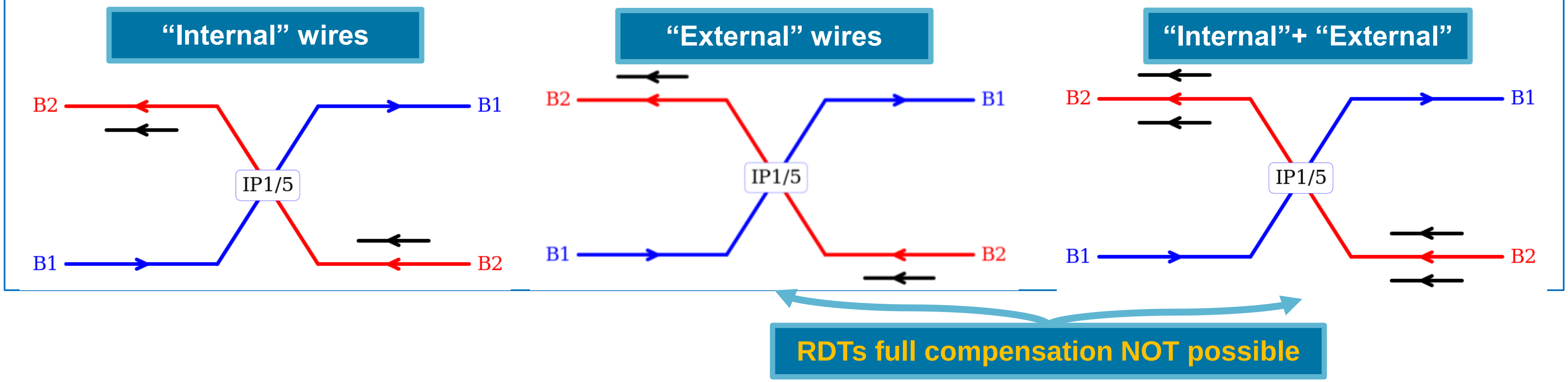
Constraint of present prototype, optics and setup: we dimension the experiment to correct **only two RDTs** with the 2 wires **at the same jaw position in σ_{coll}**.



Courtesy of A. Poyet

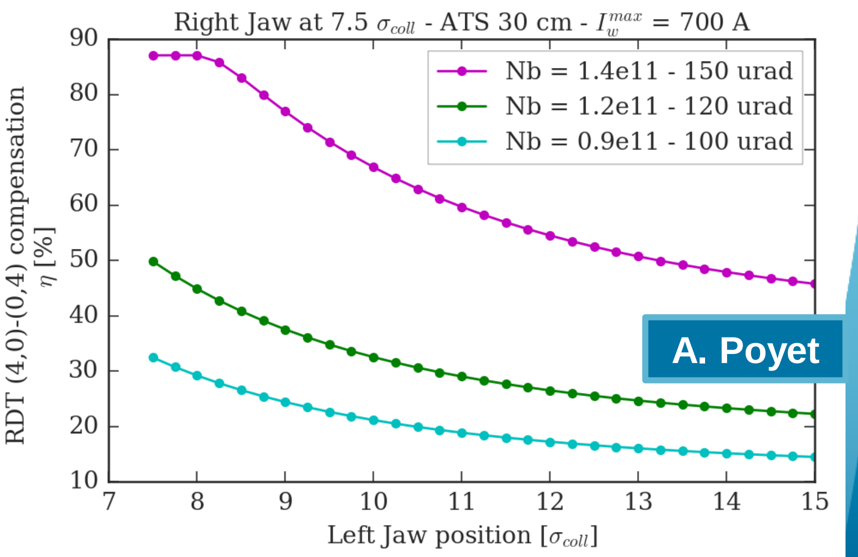
MD3, EoF and MD4 : opposite wire

Partial compensation of "even" RDTs



One **could** consider to put the two wires in series.

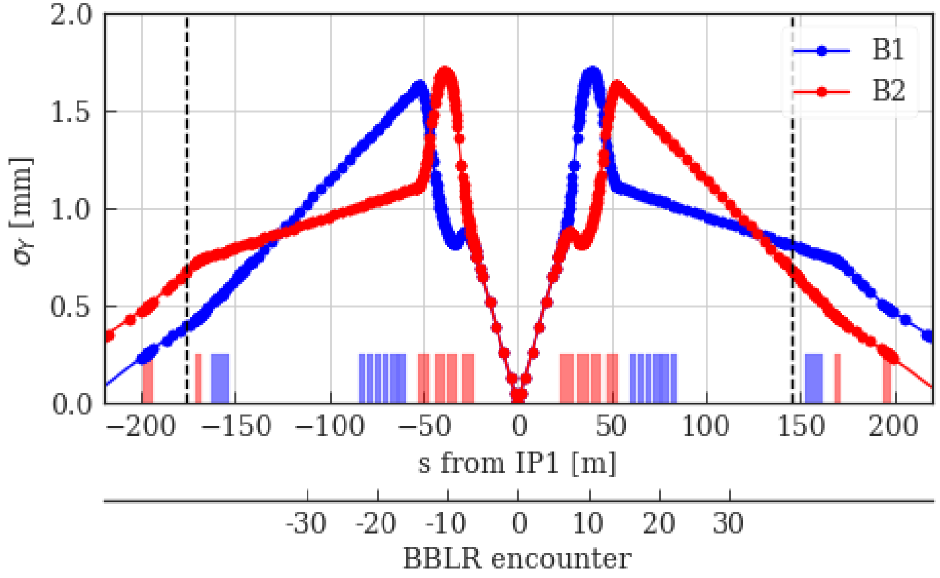
In this way (only for the "even" multipoles) one double the available I_w and **could** see an effect also at nominal position ⇒ end of fill MDs.



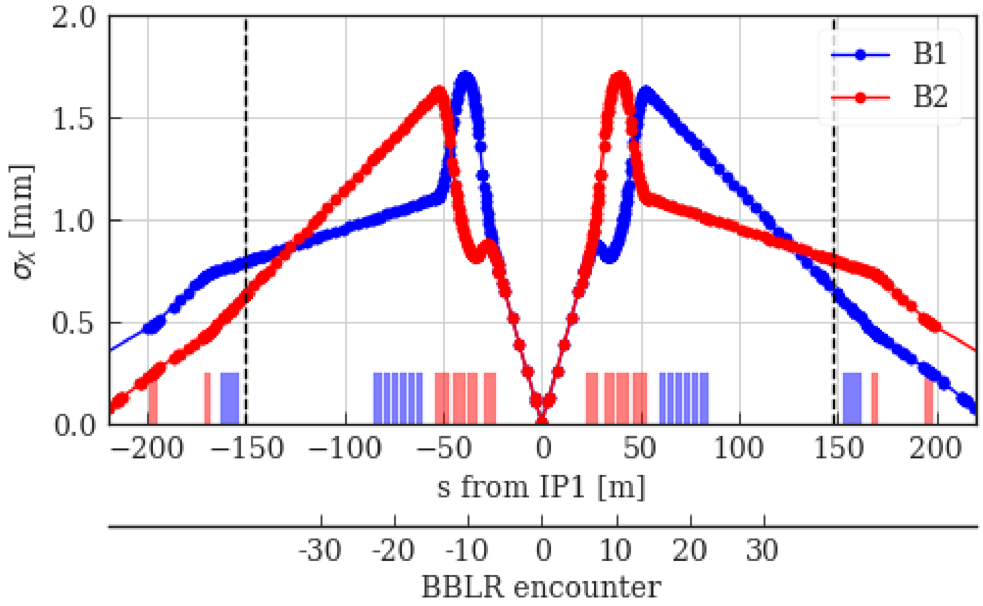
BACK-UP SLIDES

β*=30 cm, 150 μrad

VERTICAL beam size IR1, 2.5 μm, 6.5 TeV

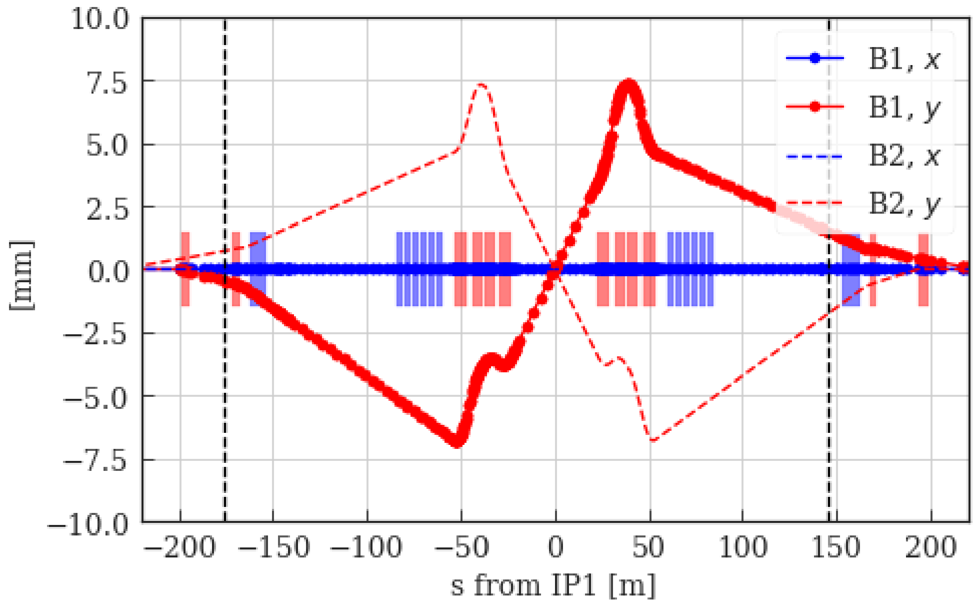


HORIZONTAL beam size IR5, 2.5 μm, 6.5 TeV

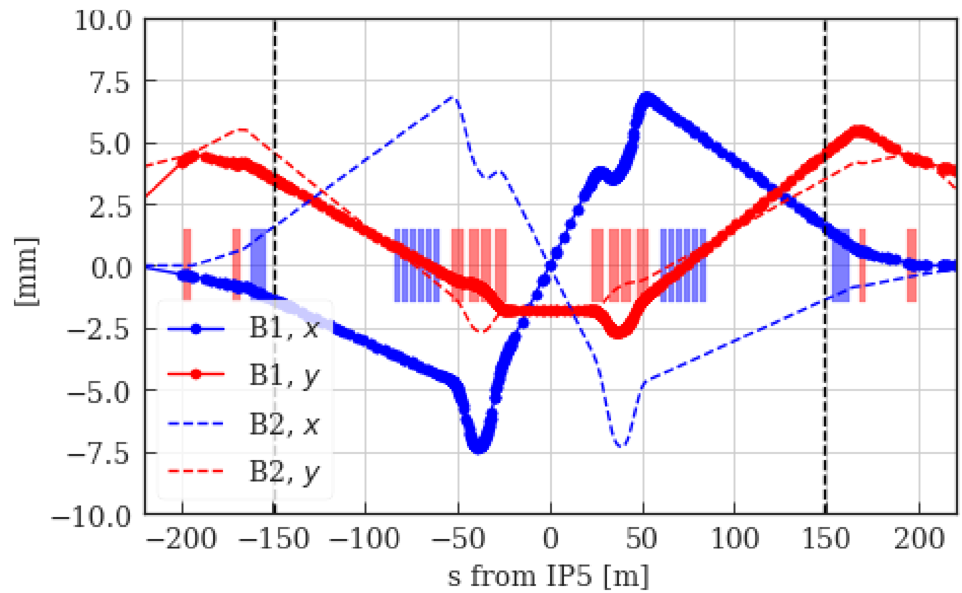


β*=30 cm, 150 μrad

Orbit IR1

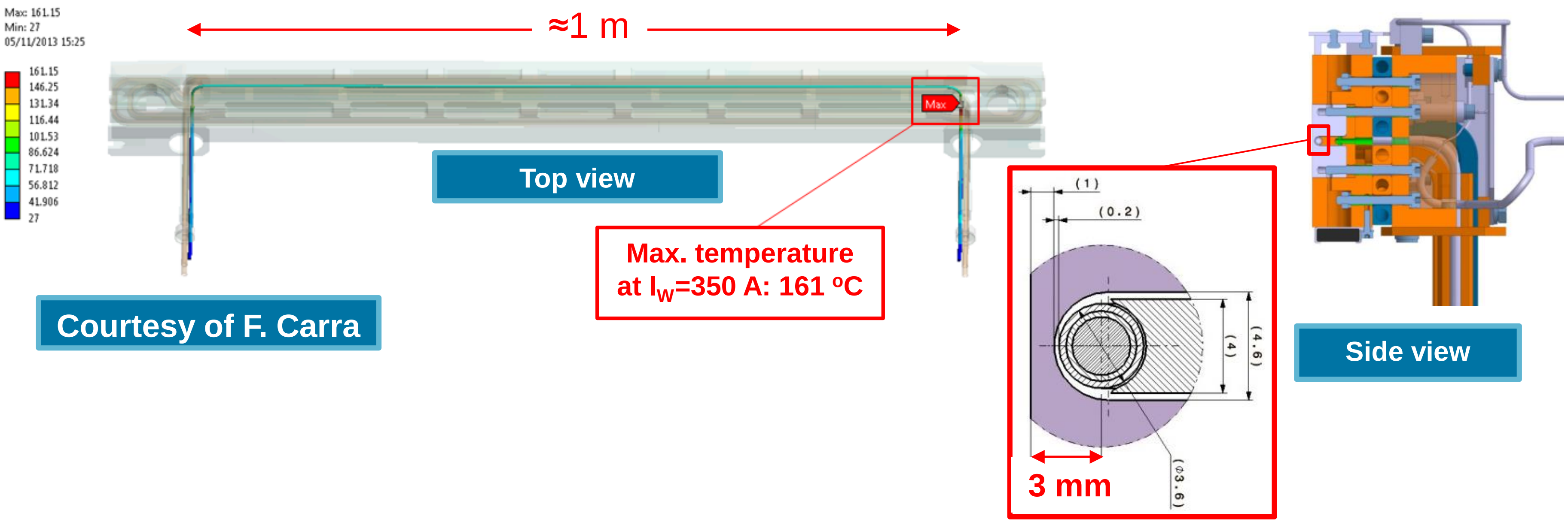


Orbit IR5



Integration of the wire in the collimator jaws

- The **wire-beam distance has to be of the order of few mm** (function of θ_c, s-position and machine optics): LHC wires prototypes are embedded in the jaw of two operational tertiary collimators.



- During the 2017, it was performed a complete test campaign to ensure the correct functioning of the wire interlocks, the collimator motors and PUs when the wire is powered therefore to preserve the full functionality of this device as collimator.

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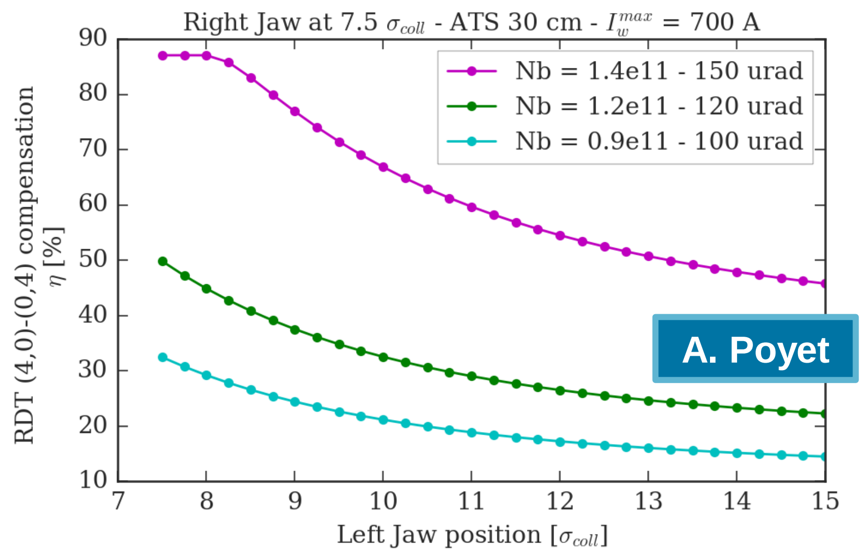
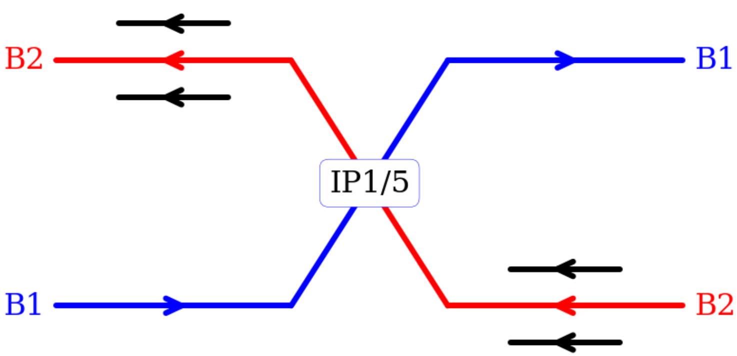
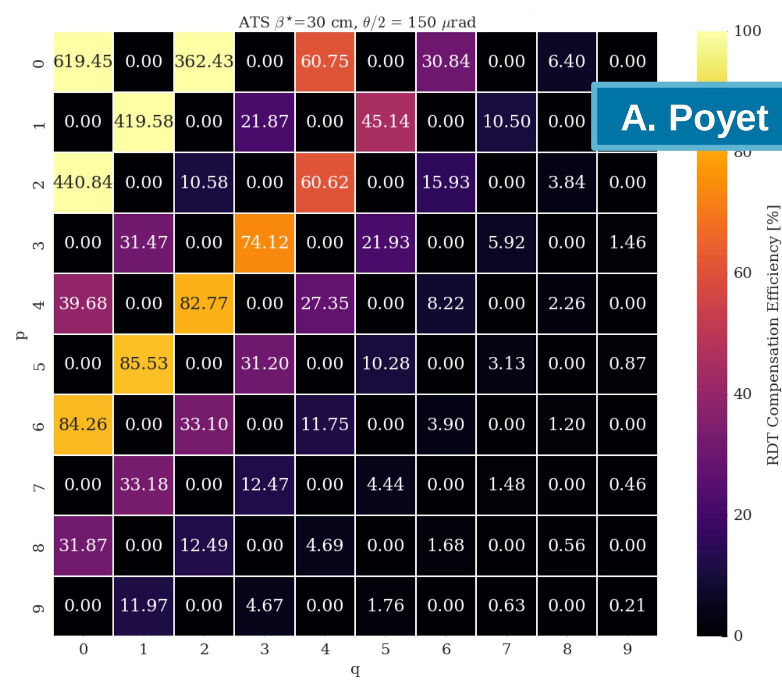
Can we use trains of bunches?

One **could** consider to put the two wires in series.

In this way (only for the “even” RDTs) one double the available I_w and **could** see an effect also at nominal position ⇒ end of fill MDs.







Objectives of the experiment

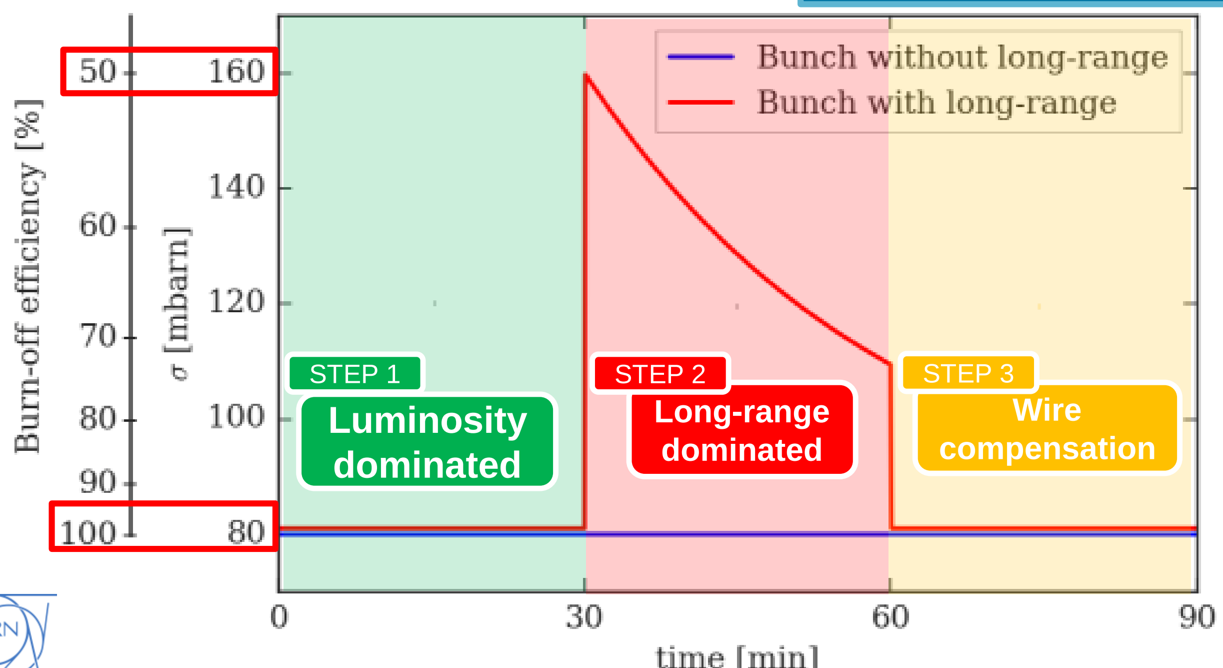
- **Prove the beneficial effect of the BBCW** in a regime dominated by long-range beam-beam effect, ensuring in the mean time that the linear effects of the wire (orbit and tunes) are compensated with feedforwards (credit to M. Solfaroli and G.-H. Hemelsoet).
- Our privileged observable is the bunch "**effective cross-section**":

$$\sigma_{EFF} = -\frac{1}{\sum_{IP} L_{IP}} \frac{dN}{dt}$$

Instantaneous luminosity

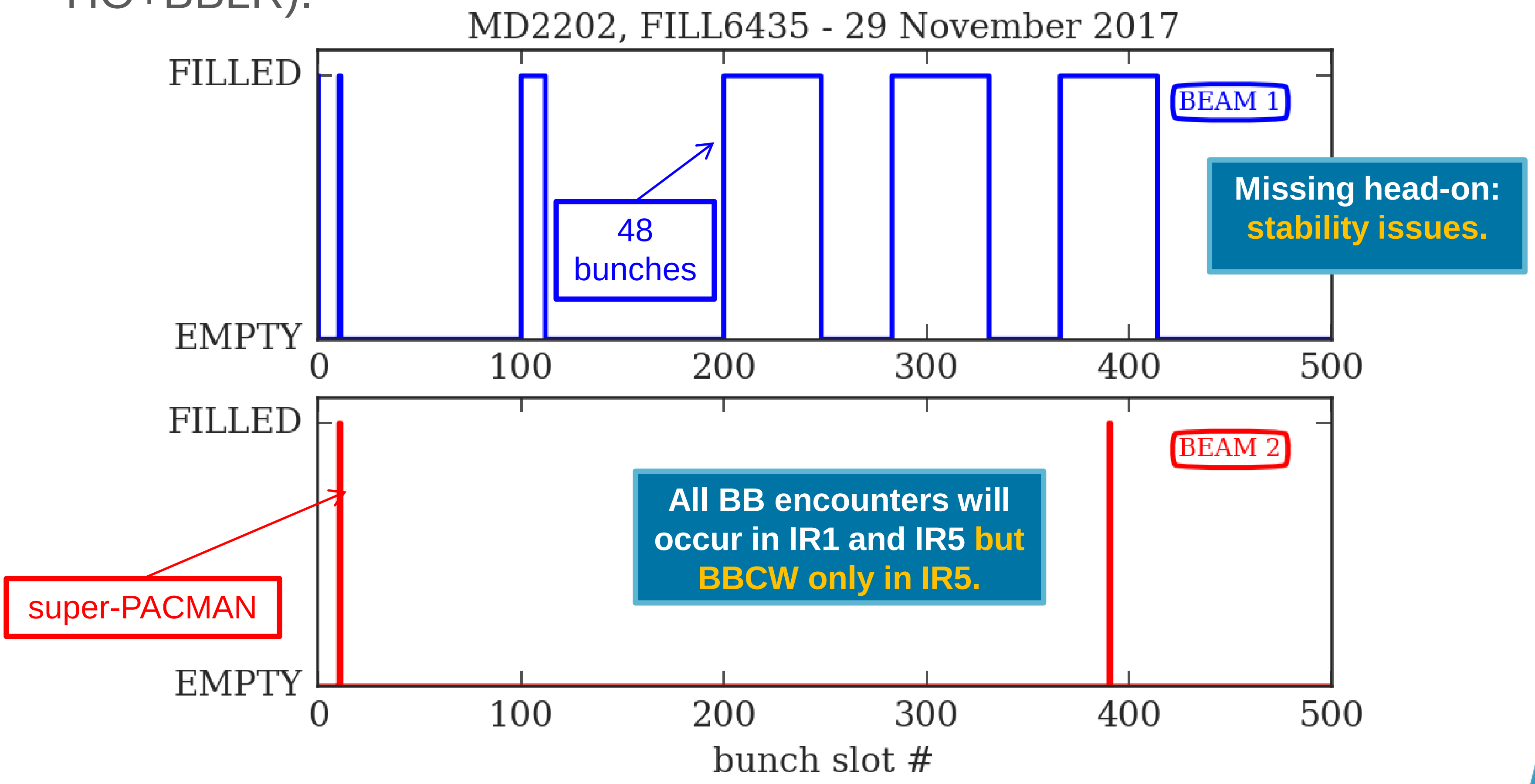
Intensity loss-rate

The IDEAL compensation, 2 bunches in B2



Asymmetric filling scheme

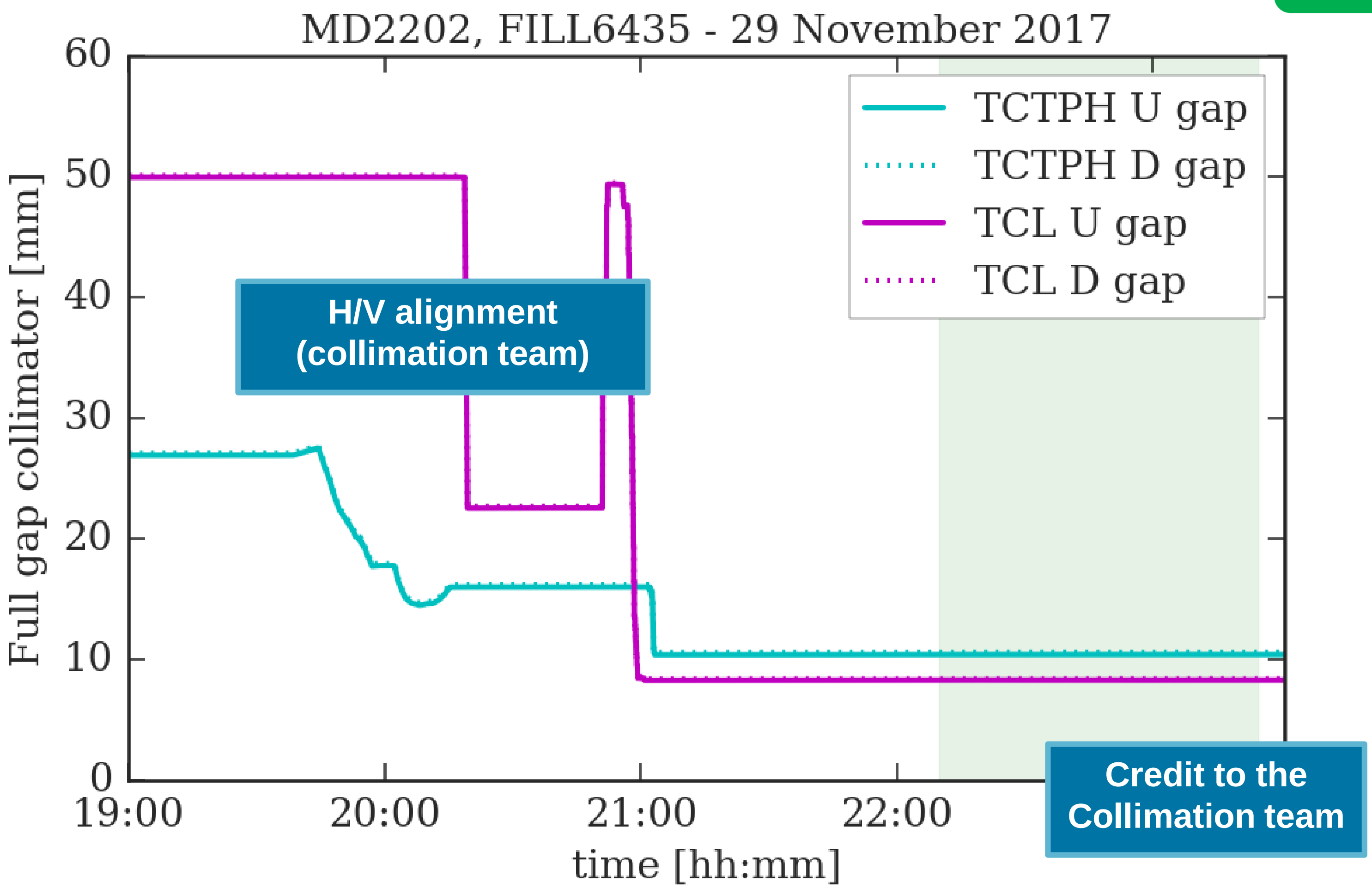
- To approach the wire to the beam the B2 has to be <3e11 p ("safe" limit).
- We will mainly concentrate on the two bunches of B2 (Only HO and HO+BBLR).



Vertical alignment of beam-wires

STEP 1

Luminosity dominated



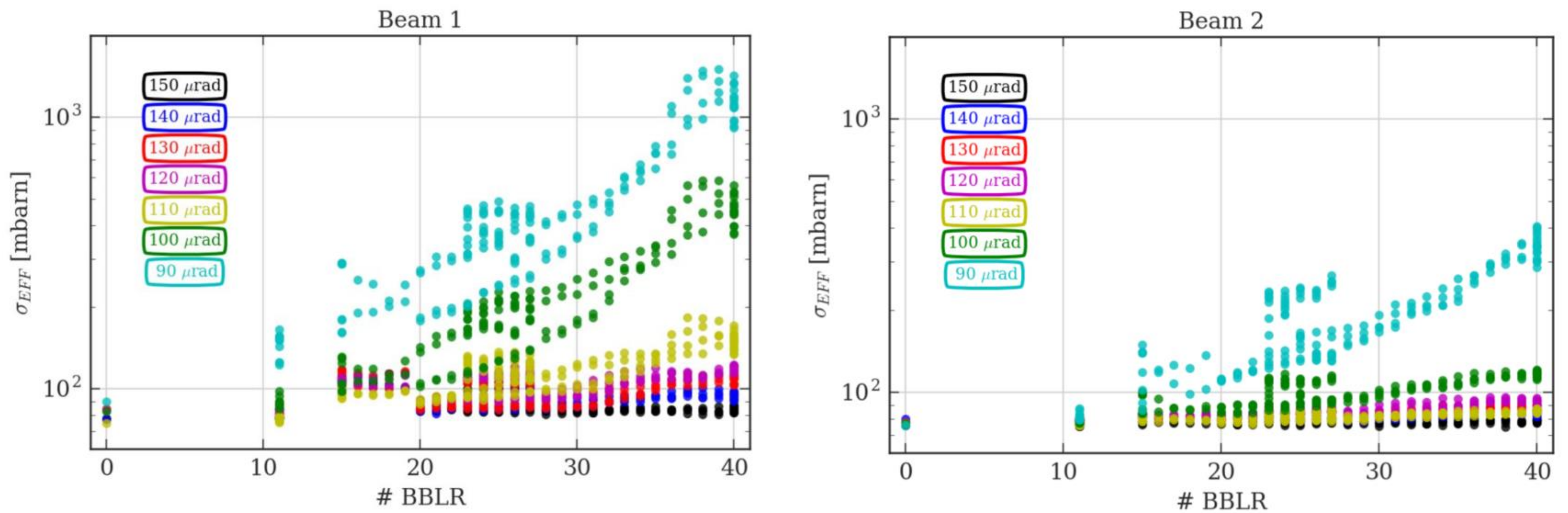
- Important vertical offset (up to 5 mm) to be corrected with the vertical alignment procedure. Not trivial due to lack of V PUs.

Pushing B2 to the BBLR regime

STEP 2

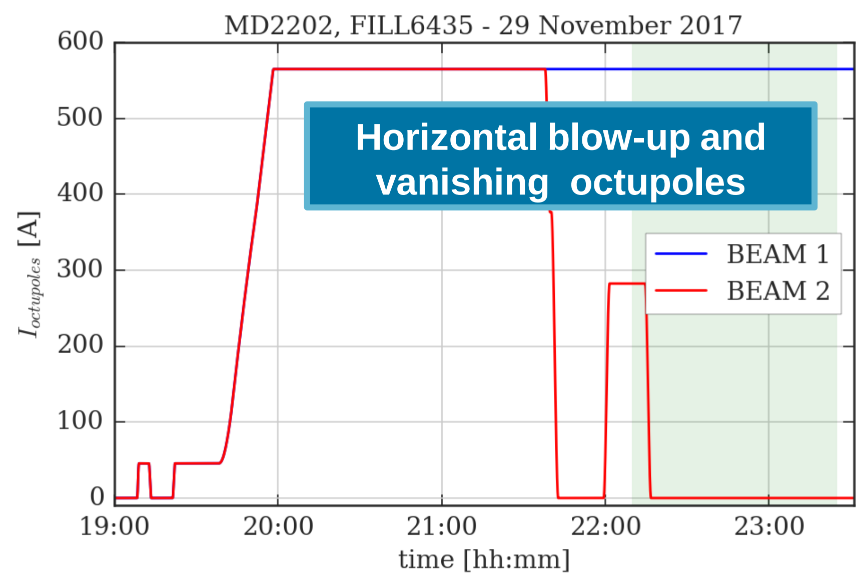
Long-range dominated

Interlude of B1 and B2 difference



To increase the BBLR effect:

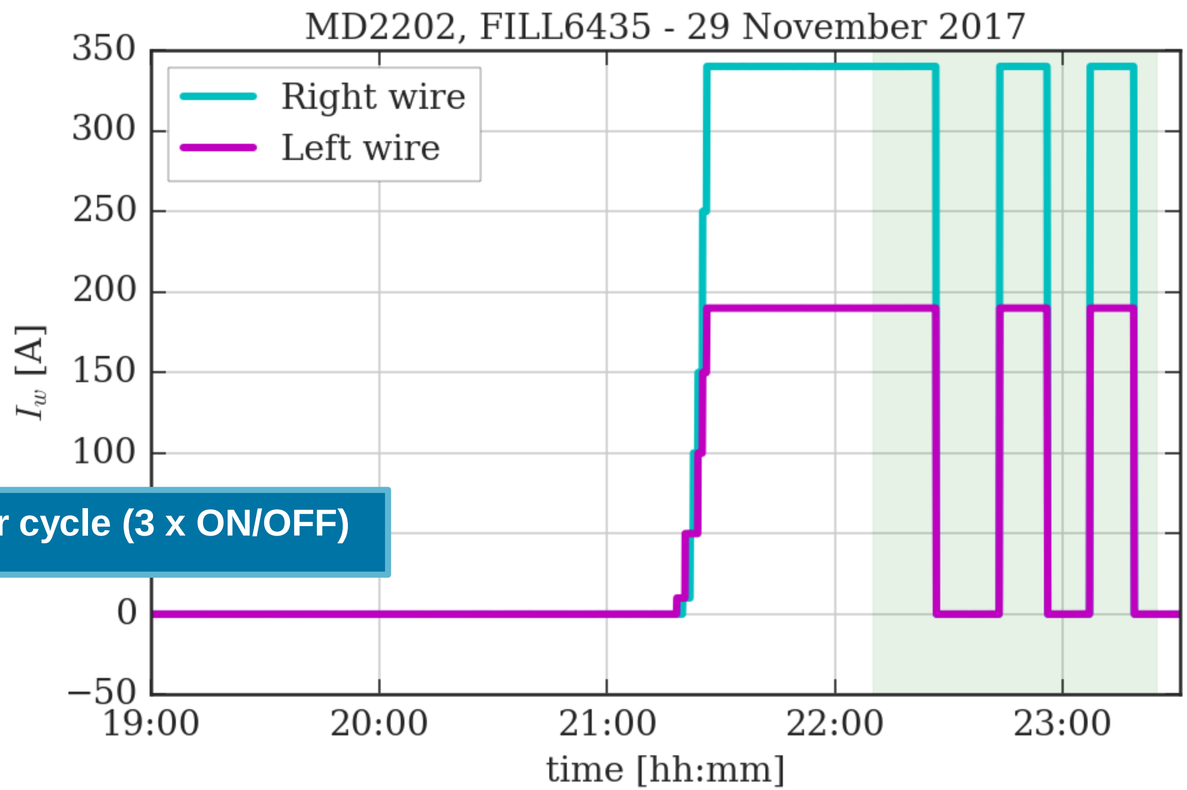
1. B2 **H-emittance blown-up** to 5-6 mm mrad [credit to D. Valuch, S. Papadopoulou and M. Fitterer].
2. The tunes were set to a **sub-optimal working point** (0.31, 0.32).



STEP 3

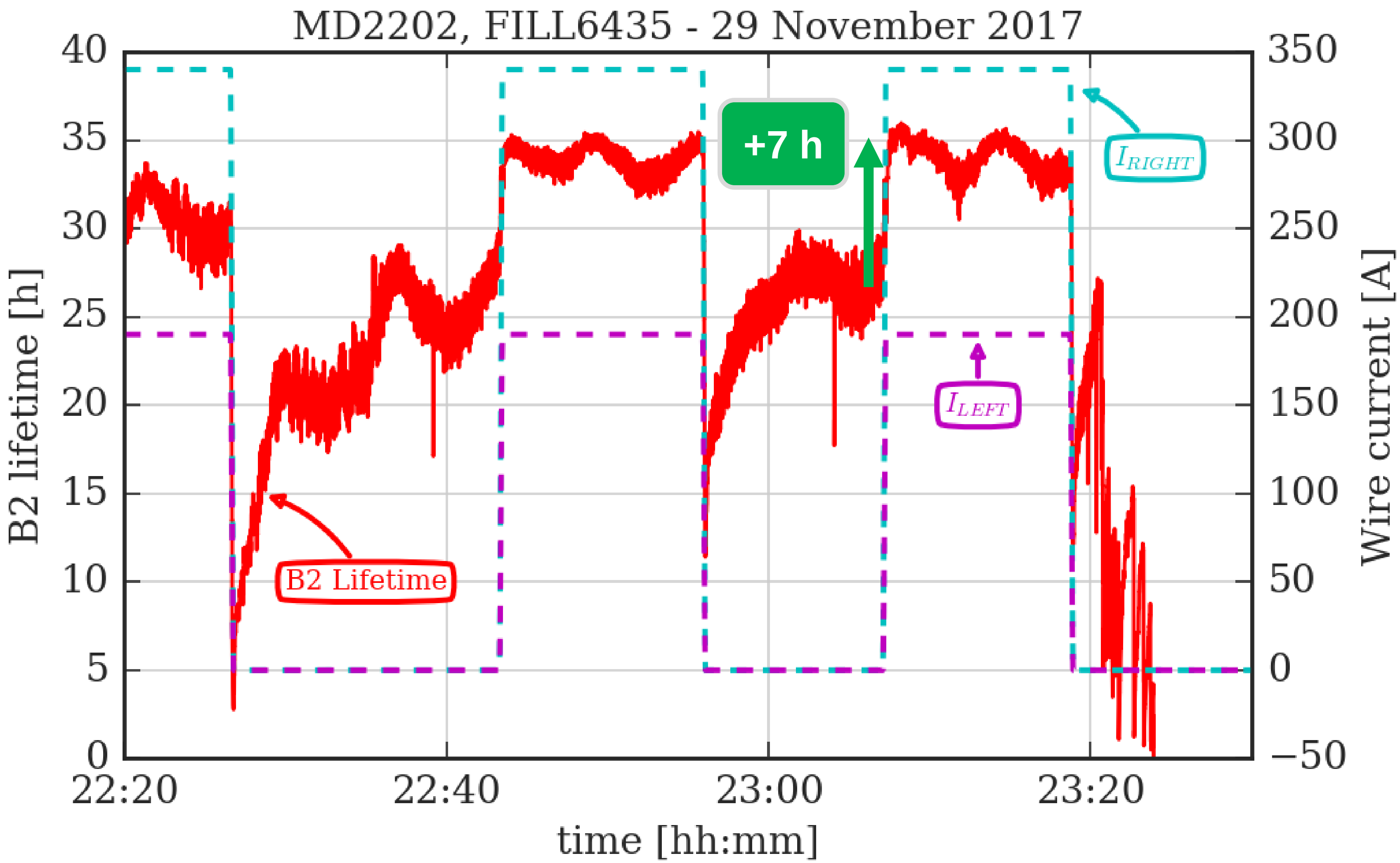
Wire compensation

Switching ON/OFF the compensation



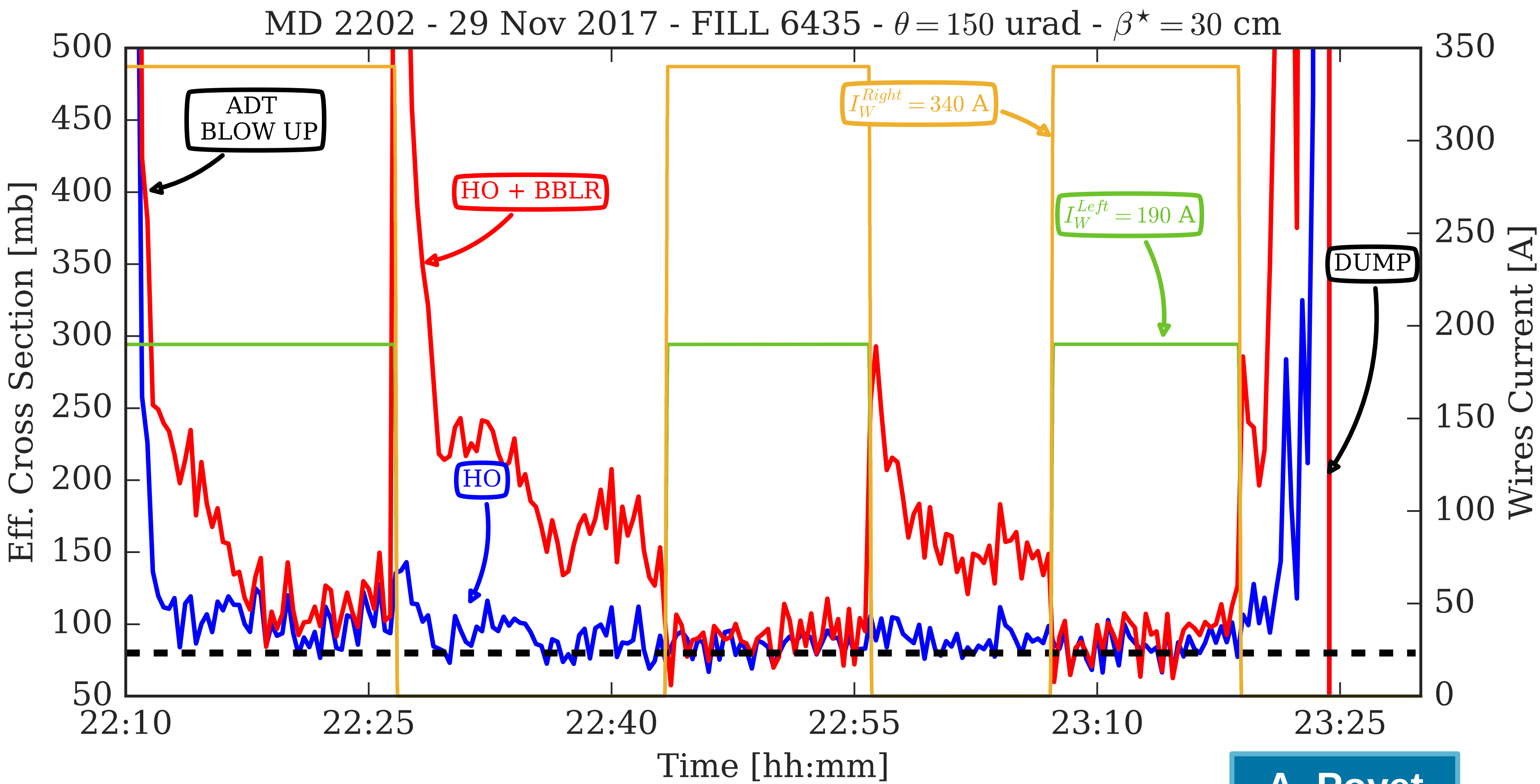
- The wires were switched ON-OFF for several powering cycles.
- During the powering of the wires, the tunes of the beam (and its position) has to be controlled with high precision: dipolar and quadrupolar contributions of the wires were compensated with feed-forward trims [credit to M. Solfaroli and G.-H. Hemelsoet].

Results at 340/190 A and jaw at 5.5 σ_{coll}



Positive effect of the wires visible on beam lifetime.

Results at 340/190 A and jaw at 5.5 σ_{coll}



A. Poyet

Positive effect of the wires visible on the bunch affected by the beam-beam long-range. Super-PACMAN unaffected.

BBLR wire compensator in 2018

2018 High Priority MDs

- Understand e-cloud & heat-load and prove 8b4e as back-up for HL; investigate / prepare doublets
- Define LHC Run 3 optics including operational modes
  - beta* levelling confirmed in operation, MDs if necessary
- Fully demonstrate HL-LHC optics and operational modes
  - Round and flat ATS, linear and non-linear optics corrections
- Quantify luminosity gain from BBLR wire collimators
- Prepare for LIU bunch intensities
  - Instabilities transverse and longitudinal, octupole strength and beam-beam
- Finalise demonstration of crystal ion collimation
- Emittance preservation, understand blow-up
- Understand beam loss dynamics and distribution causing magnet quenches including asynchronous dumps

42 h requested

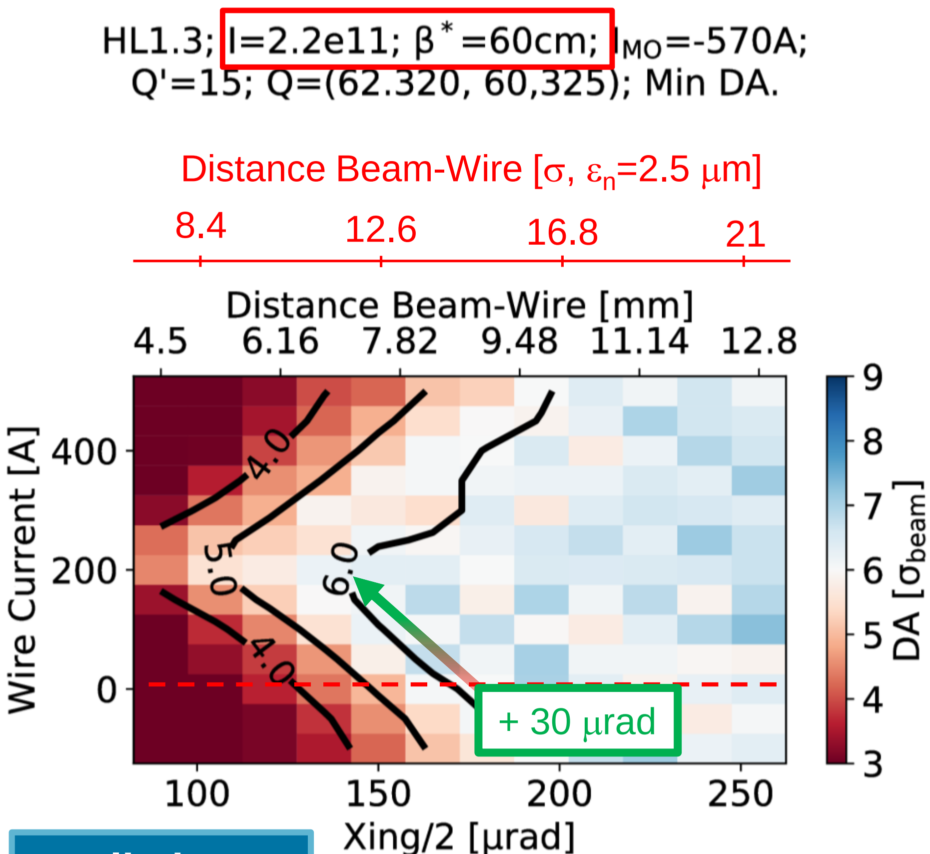
Courtesy of J. Uythoven

BBCW MD preparation meeting in March organized by A. Rossi: discussions/simulations are ongoing.

Compensation studies: from LHC to HL-LHC

- In the beam-beam team significant **efforts are put on the wire compensation tracking studies** with the two-fold aim to benchmark the LHC results and optimize the HL-LHC scenario with the wires.

- For HL-LHC, **preliminary results without a full optimization** of the longitudinal and transverse wire position, are showing an additional gain of the order of 30 μrad for the half-crossing angle.



Preliminary. HL-LHC start of the levelling

Courtesy of D. Pellegrini

Analysis of the BBCW compensation

- Given the constraint on the minimal beam-wire distance, it was not possible to compensate all the resonances excited by the B1.
- We used the maximum current of the wires (350 A) to attack as much as possible the BBLR octupolar term.
- The octupolar terms induced by the BBLR in IR5 was reduced by **75%**.

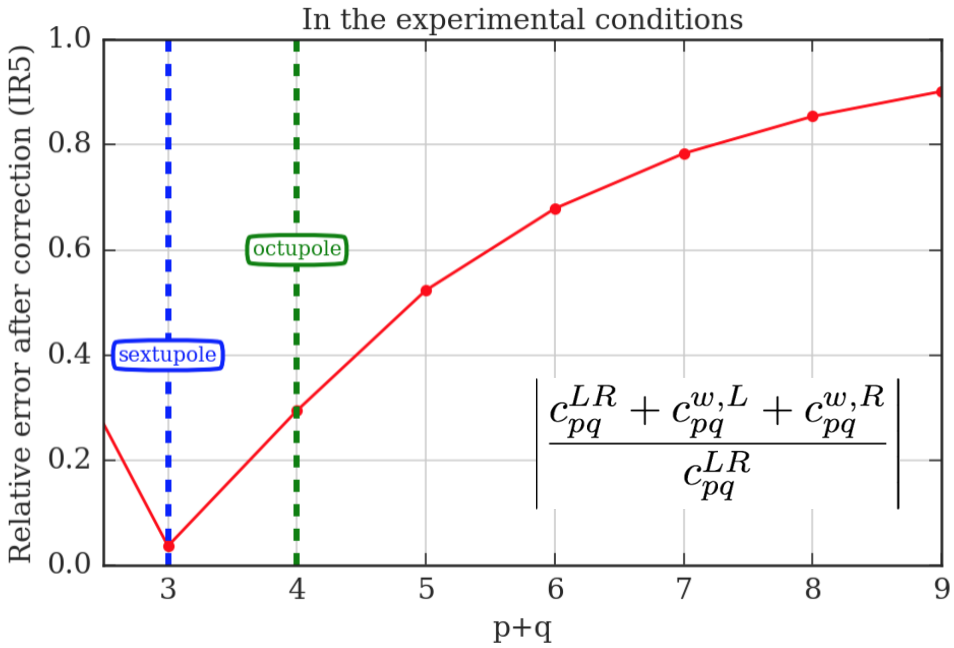
S. Fartoukh et al.
PRST-AB 18, 121001

Strong-beam driven resonance

$$c_{pq}^{\mathrm{LR}} \equiv \sum_{k\in \mathrm{LR}} \frac{\beta_x^{p/2}(s_k)\beta_y^{q/2}(s_k)}{d_{bb}^{p+q}(s_k)}$$

BBCW driven resonance

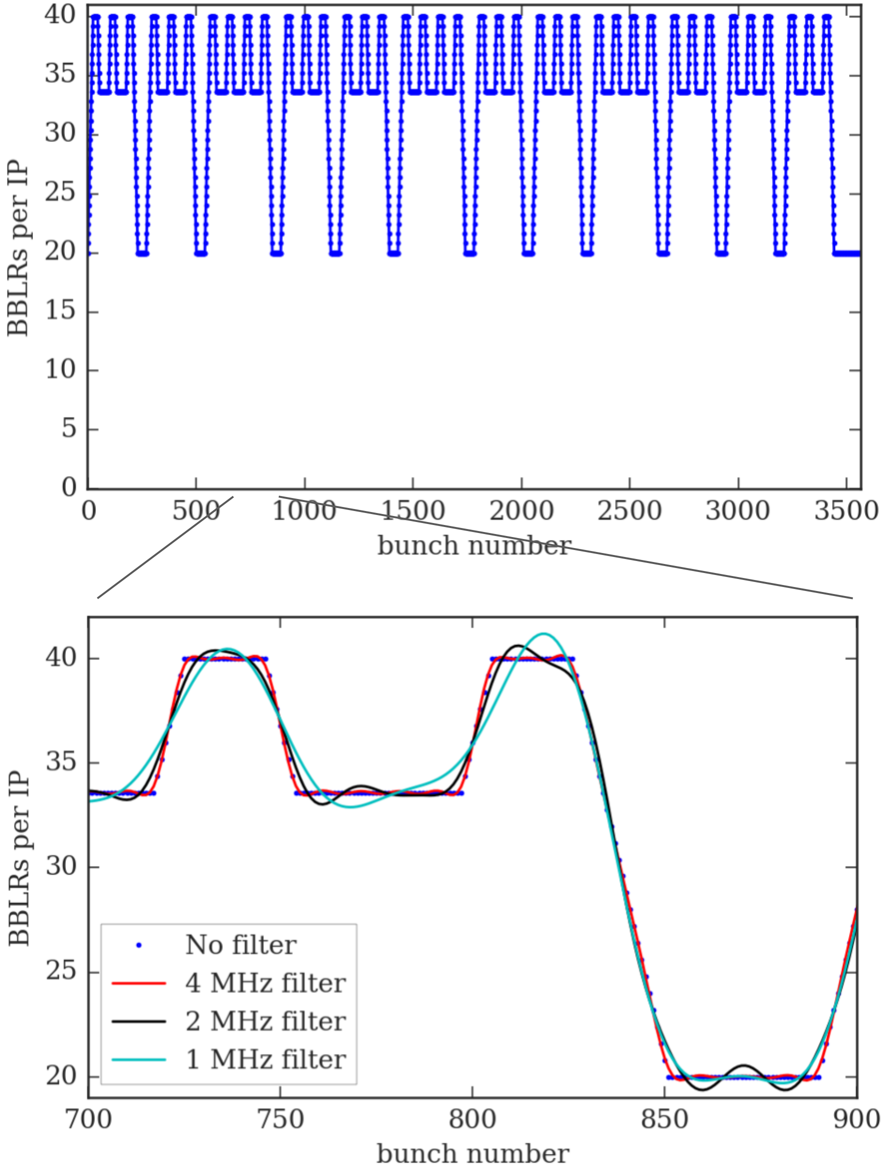
$$\begin{cases} c_{pq}^{w.\mathrm{L}} \equiv N_{w.\mathrm{L}} \times \frac{(\beta_x^{w.\mathrm{L}})^{p/2}(\beta_y^{w.\mathrm{L}})^{q/2}}{(d_{w.\mathrm{L}})^{p+q}} \\ c_{pq}^{w.\mathrm{R}} \equiv N_{w.\mathrm{R}} \times \frac{(\beta_x^{w.\mathrm{R}})^{p/2}(\beta_y^{w.\mathrm{R}})^{q/2}}{(d_{w.\mathrm{R}})^{p+q}} \end{cases}$$



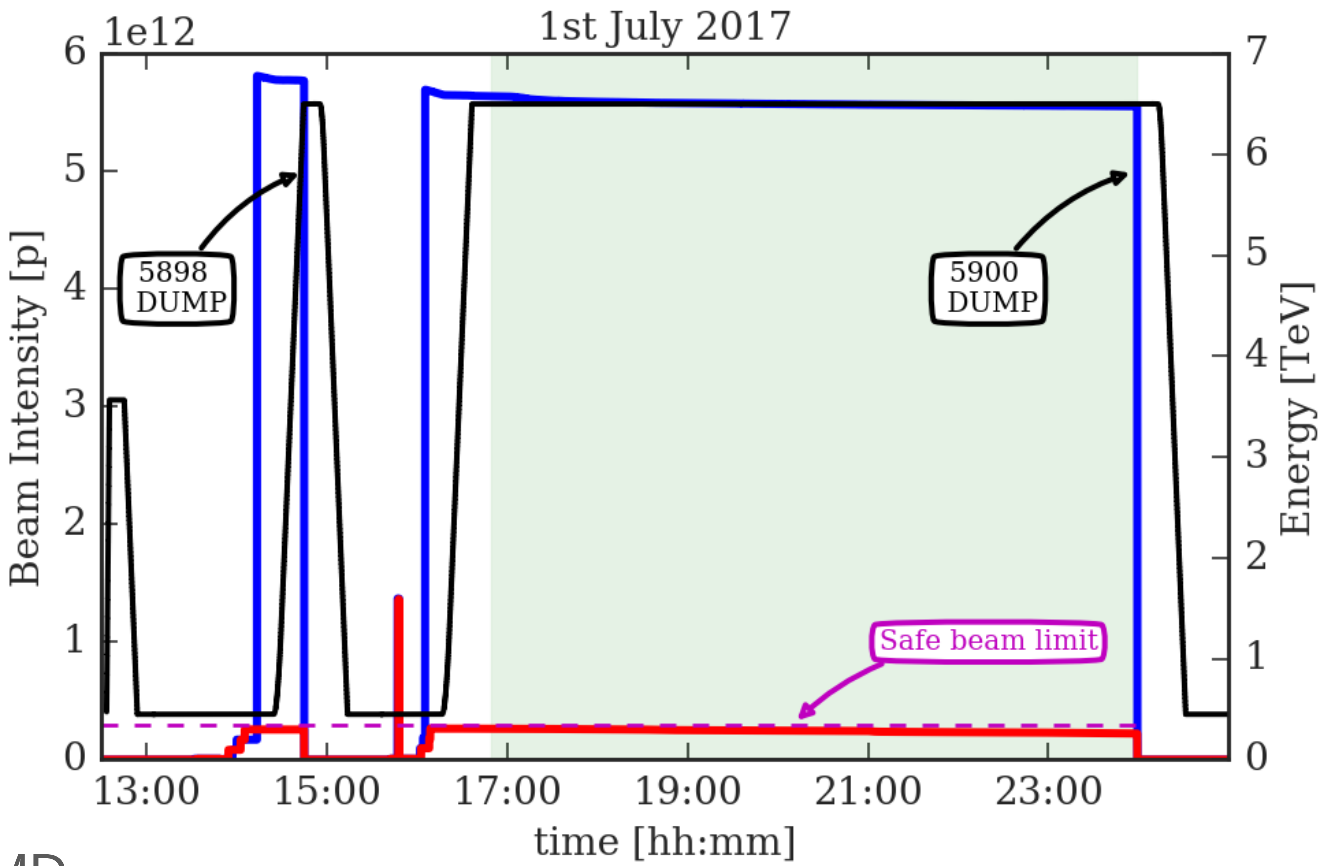
PACMAN bunches and I_w modulation

The needed I_w modulation BW is of the order of 4 MHz (x10 lower than the bunch frequency).

The wavelength in vacuum of a 4 MHz EM wave is ~75 m.



MD2202



- 10 h MD.
- The FILL5898 was dumped (RF on B1, not clear the reason, RF experts suggest a glitch on the interlock). Half-RF detuning.
- The observations we report concern the FILL5900. Full-RF detuning.

IDEAL CASE: 2 BBCW for IP at s_{opt}=+-159 m

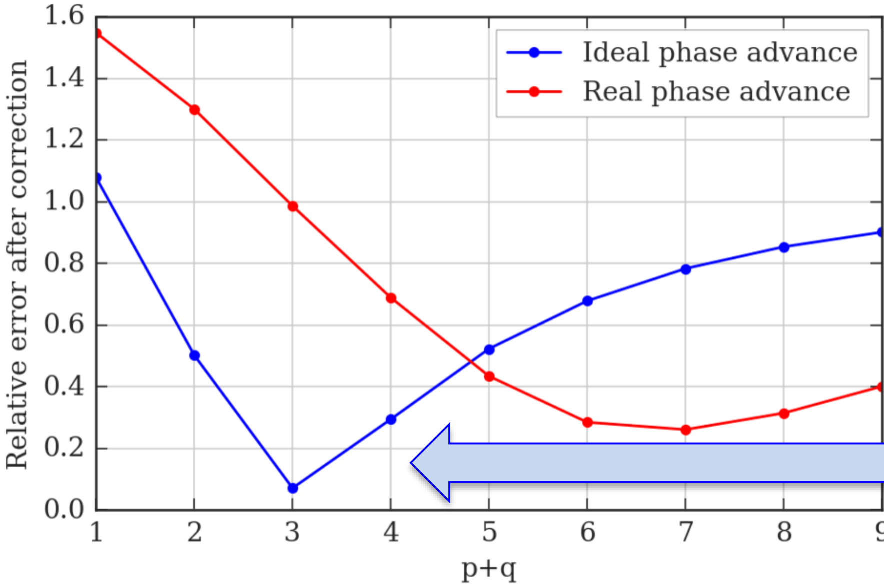
RDT compensation map

in color code

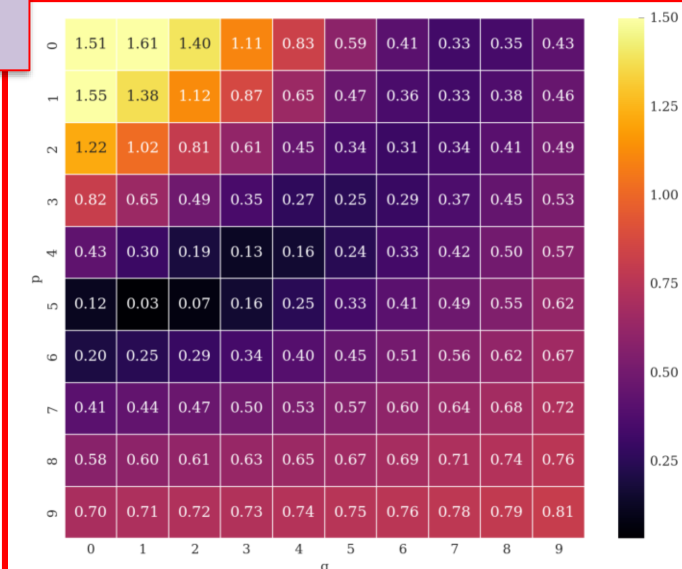
$$\left|\frac{c_{pq}^{LR}+c_{pq}^{w,L}+c_{pq}^{w,R}}{c_{pq}^{LR}}\right|$$

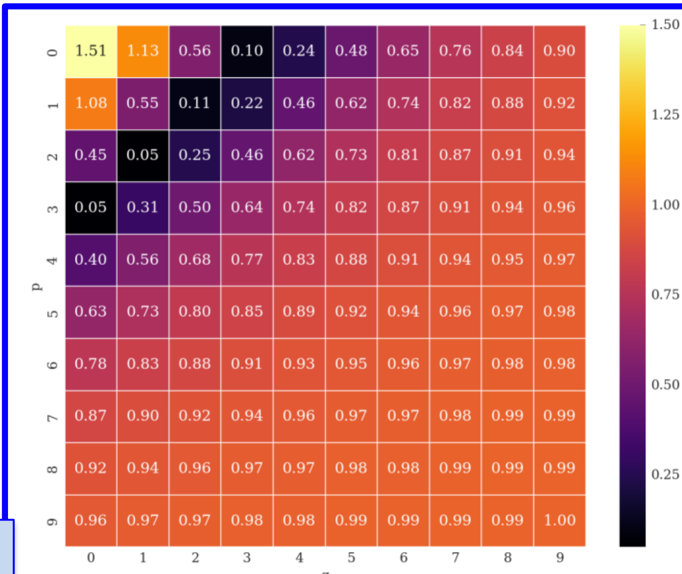
As expected (under the mentioned assumptions) the compensation is covering many more RDTs than the 4 used to set the BBCWs (green boxes). The p+q=1 and p+q=2 could be addressed by using “local” linear magnets (Q4s and the Q4 correctors).

The MD results and the RDT



Real phase advance considered



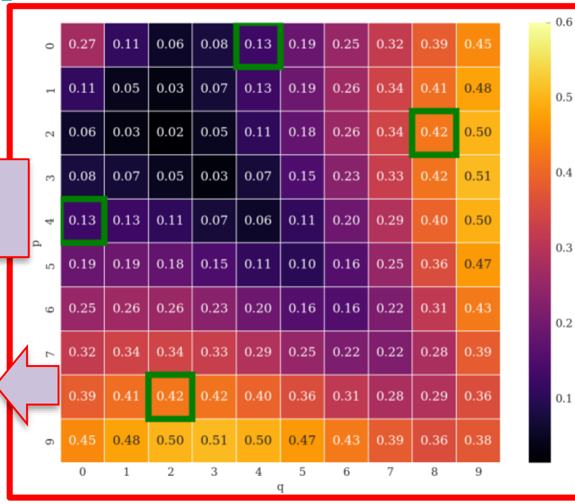


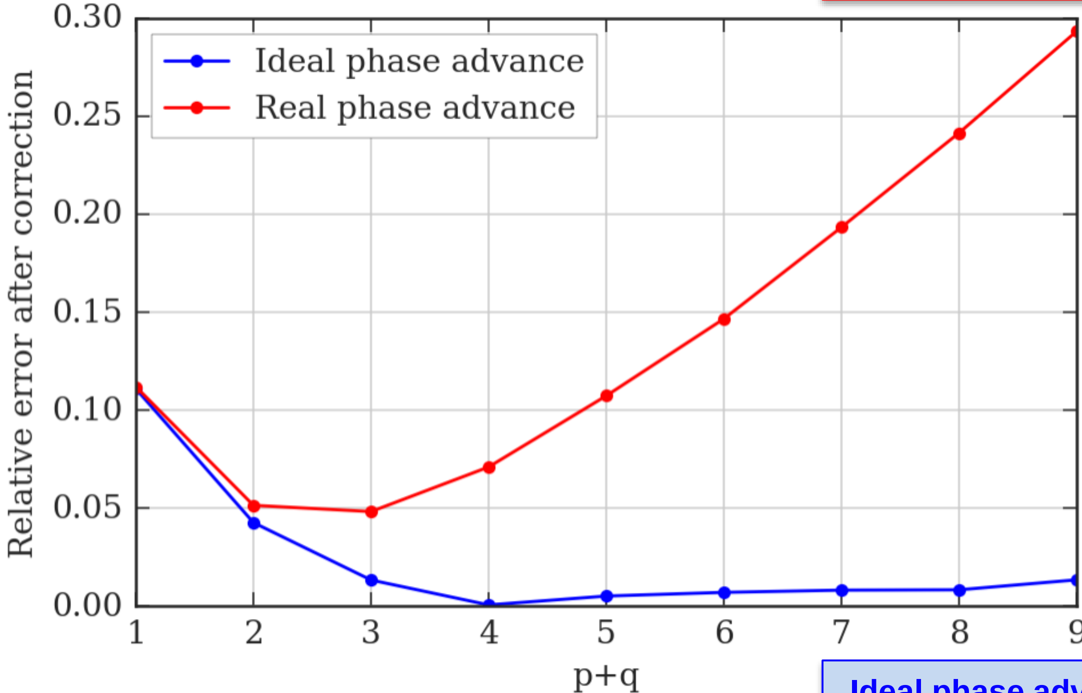
Ideal phase advance considered ($\beta^* \rightarrow 0$)

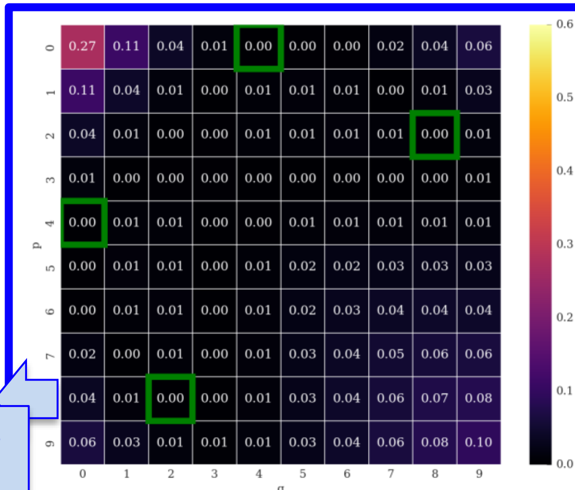
The observed effect of the BBCW can be related to a partial compensation of the detuning terms.

IDEAL CASE: considering the phase advance.

Real phase advance considered







Ideal phase advance considered ($\beta^* \to 0$)

One can quantify a posteriori the effect of the phase advance.

The compensation of the RDT does degrade. The compensation of detuning terms (Q-footprint compression) is not affected.

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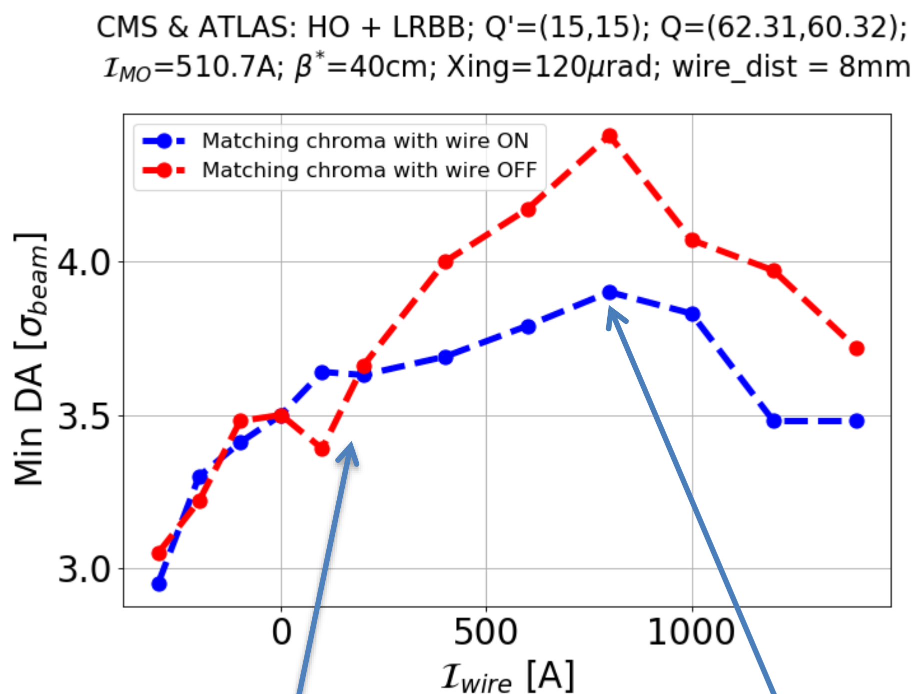
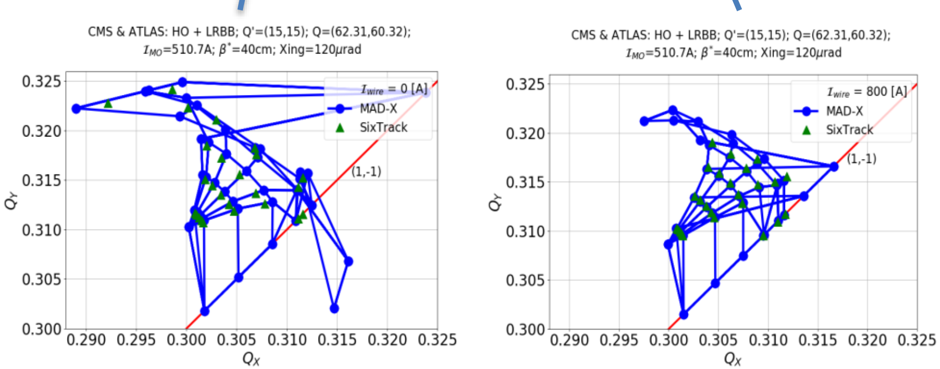
DA simulations with Wire in MD-like conditions I





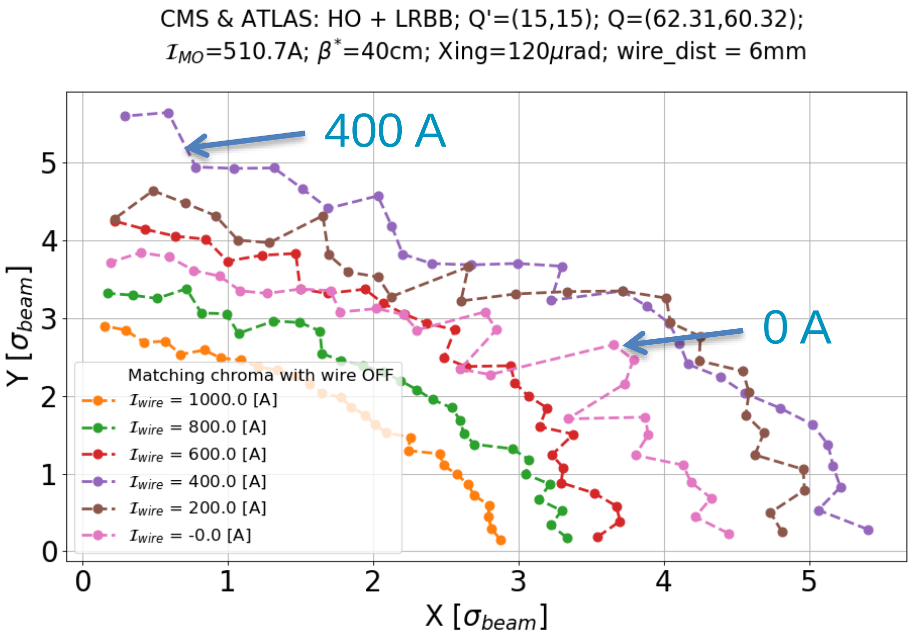
- MD-like conditions: d_w=8 mm. LR in IR1/5 but wire only in IR1, real aspect ratio at wire position, phase advances.
- A modest gain of DA is observed for 8 mm wire-beam distance.
- Optimal DA for 800 A.
- With no rematch of the chromaticity (as in the MD), the gain of DA is improved.

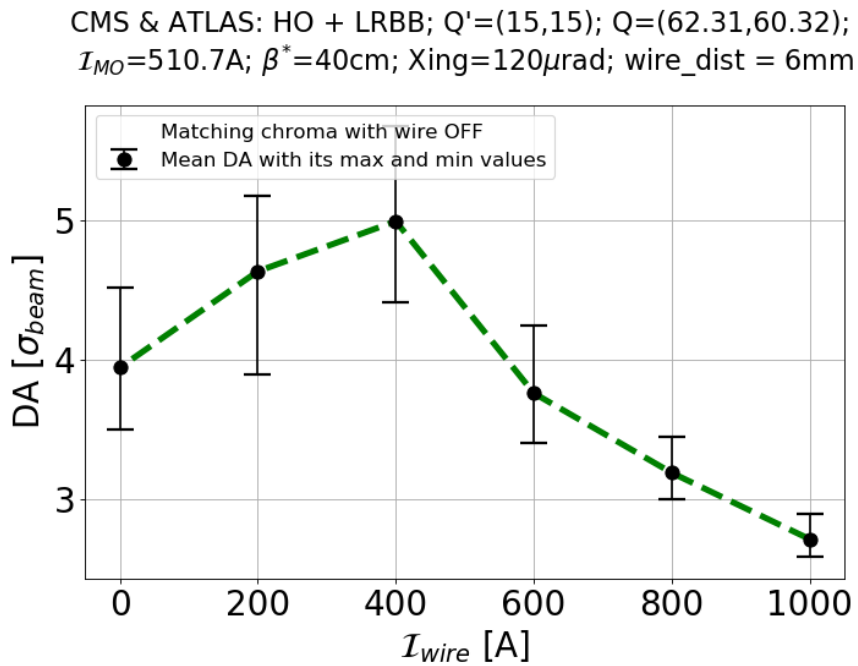
- Good agreement between footprints from MADX and Sixtrack.
- Improvement observed but no clear identification of the optimum.

K. Skoufaris

DA simulations with Wire in MD-like conditions II

- Push d_w to 6 mm
- Still not ideal conditions: LR in IR1/5 but wire only in IR1, aspect ratio at wire position, phase advances.
- **1σ** (@2.5 μm) DA gained for an optimal wire current of ~400 A.
- Clear improvement over all the angles.

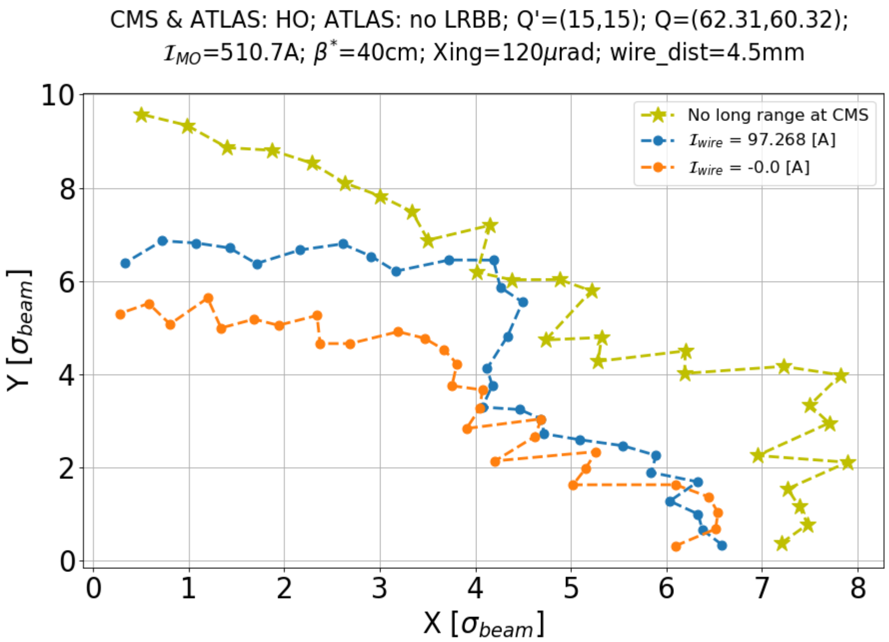




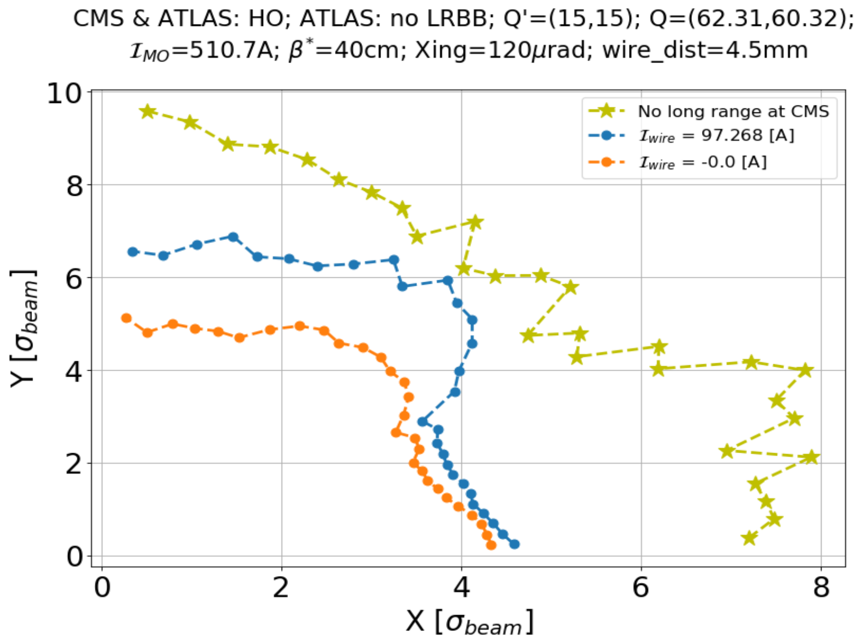
K. Skoufaris

“Strong beam”-wire equivalence: tracking

Standard Strong Beam



Zero-emittance-long-range Strong Beam

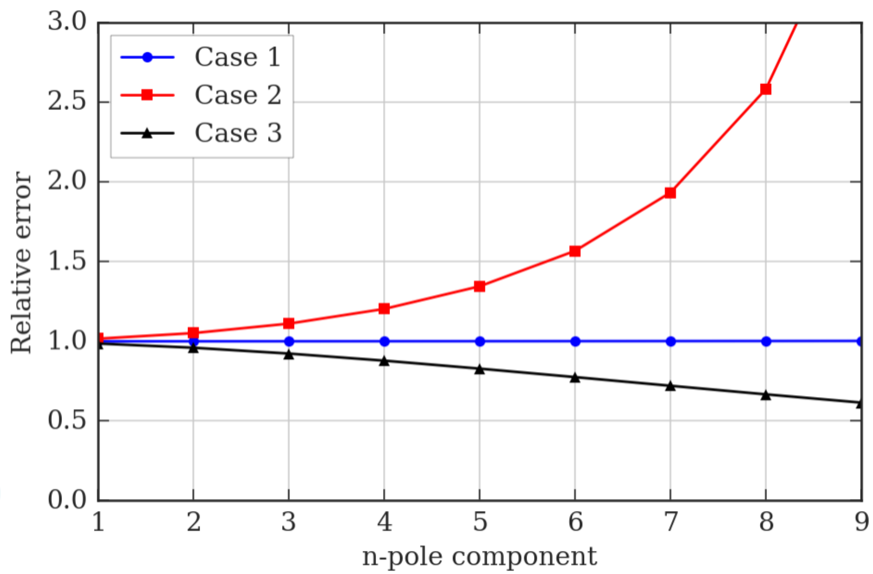


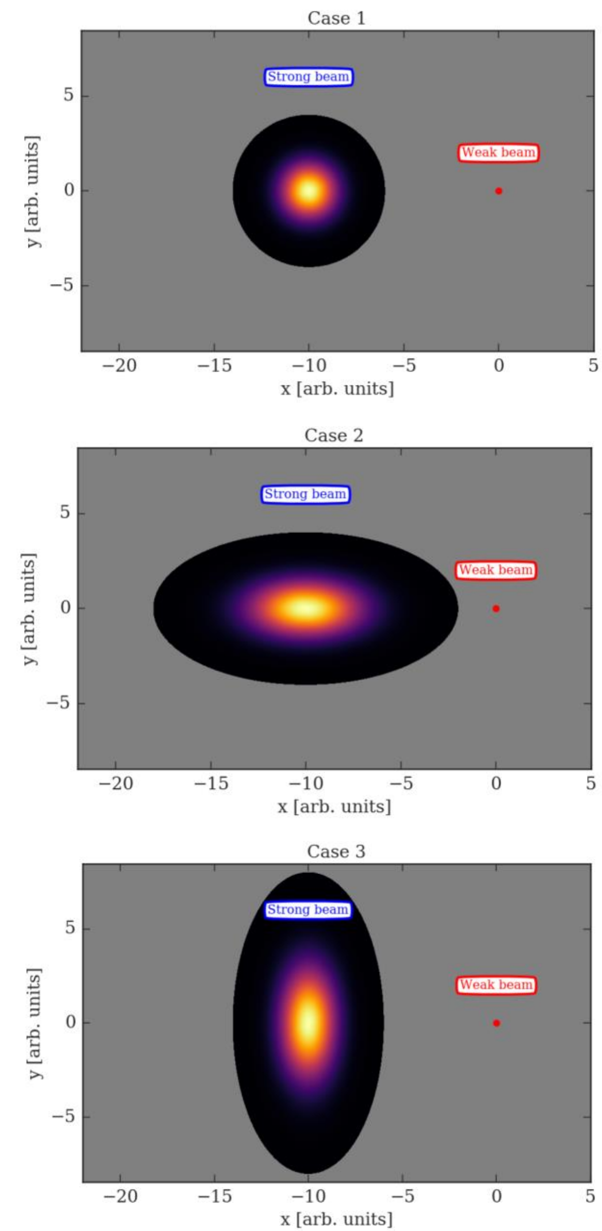
K. Skoufaris

- The zero-emittance-LR strong beam does not show a better DA.
- Effect of phase advance? Plans to test with the wire at ~70 m for better phases.

“Strong beam”-wire equivalence

- For $\beta_x \neq \beta_y$ the “strong beam”-wire equivalence is not valid anymore
- We compare the strong beam field and the wire field in terms of multipoles
- Case 1: $\beta_x = \beta_y$, perfect equivalence
- Case 2: $\beta_x = 4 * \beta_y$, see plot below
- Case 2: $\beta_y = 4 * \beta_x$, plot below
- We assume bi-Gaussian density (4 σ cut)





First attempts of BBCW in HLLHC1.3

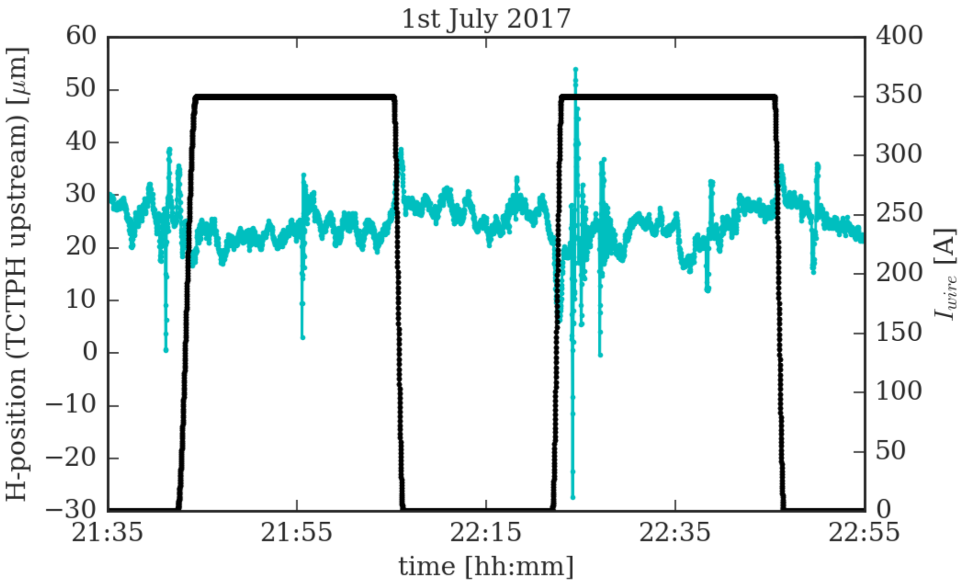
- B1 tracking with **operational settings** for emittance, tunes, chroma, octupoles.
- **4 wires** (L/R IP1/5) installed in the crossing plane.
- The wires are arbitrarily placed at **+/-150m** from the IPs.
- The **distance** is tuned so that the beam-wire normalised separation is the same as the normalised crossing.
- Likely a **suboptimal** configuration to be further refined.

β* = 60 cm	H Beta [m]	V Beta [m]
wire_l1.b1	1052	1181
wire_r1.b1	1178	1054
wire_l5.b1	1054	1182
wire_r5.b1	1181	1055

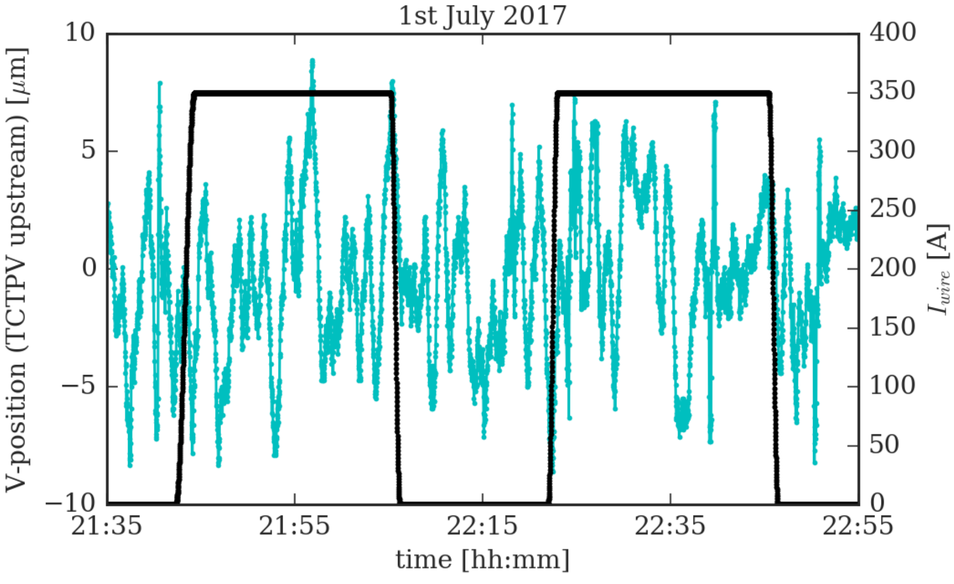
β* = 20 cm	H Beta [m]	V Beta [m]
wire_l1.b1	3006	3641
wire_r1.b1	3649	2999
wire_l5.b1	2995	3645
wire_r5.b1	3636	3003

BBCW MD: sanity checks on H/V-position

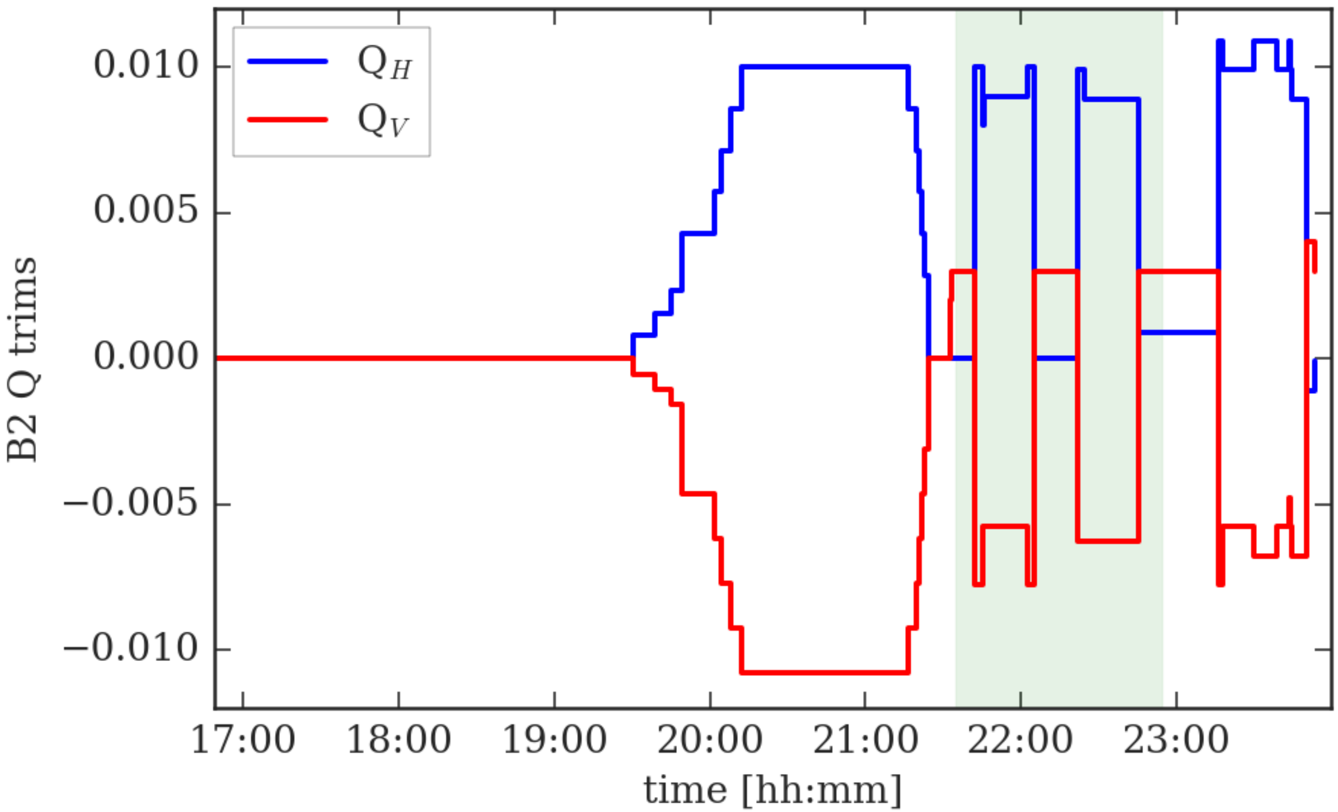
- The H-position of the beam is well under control.



- The V-position and correctors behaviour confirm a very good V-alignment of the BBCW.

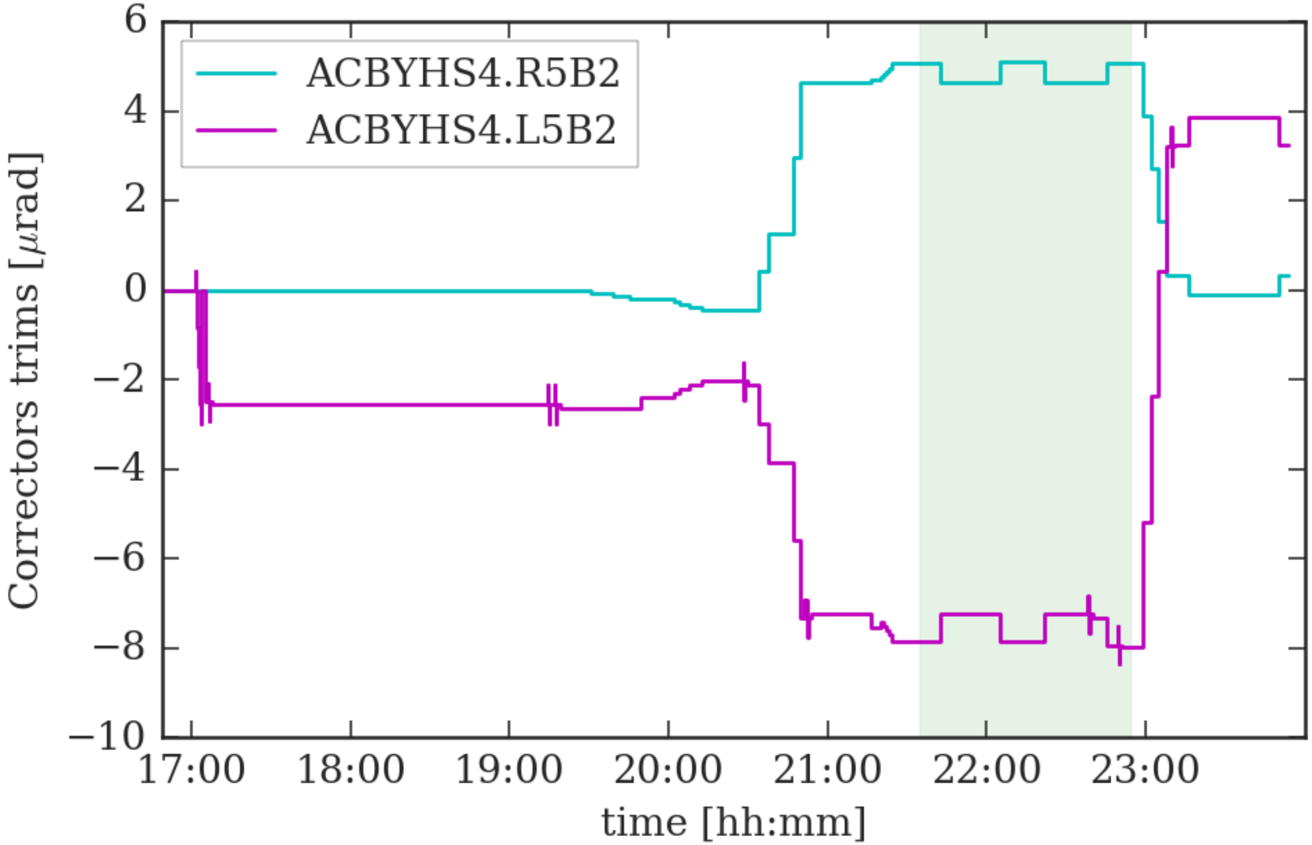


BBCW MD: Q trims



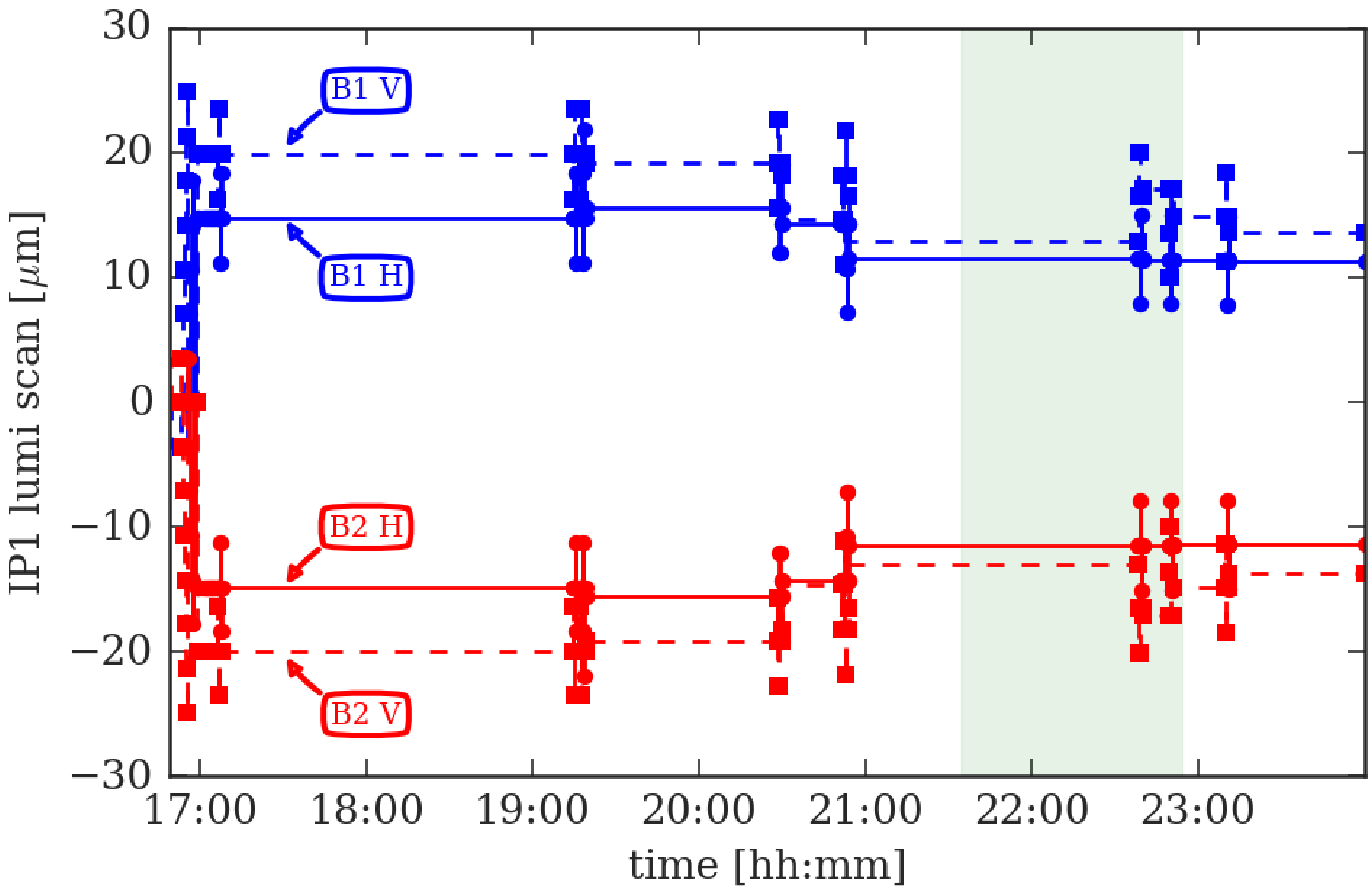
The Q-trims are mostly due to the feedforward.

BBCW MD: dipolar trims

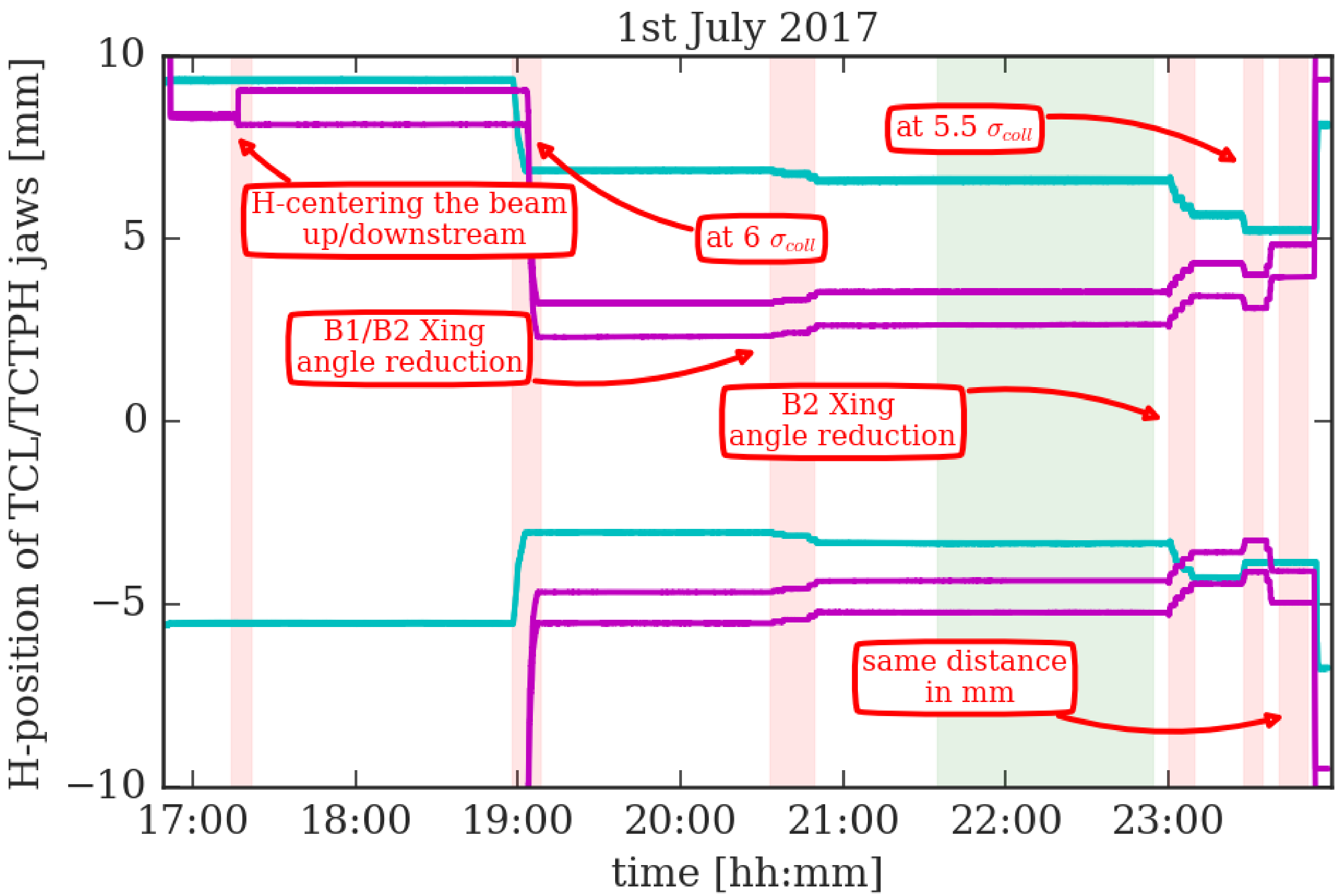


The correctors trims are mostly due to the crossing angle settings.

BBCW MD: optimizing HO collision

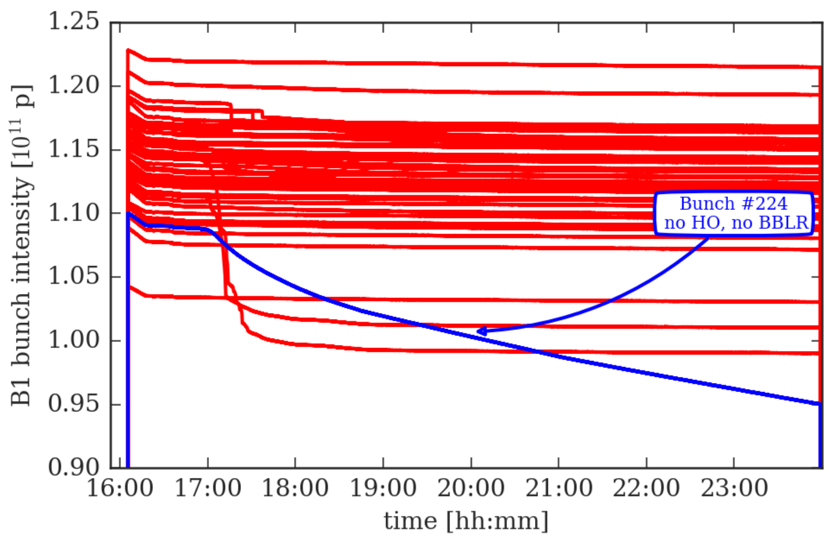


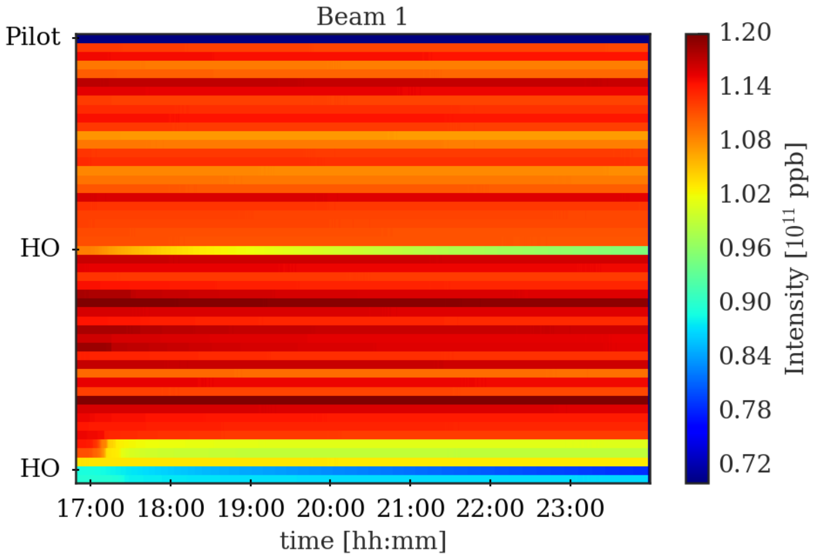
BBCW MD: wires H-positioning



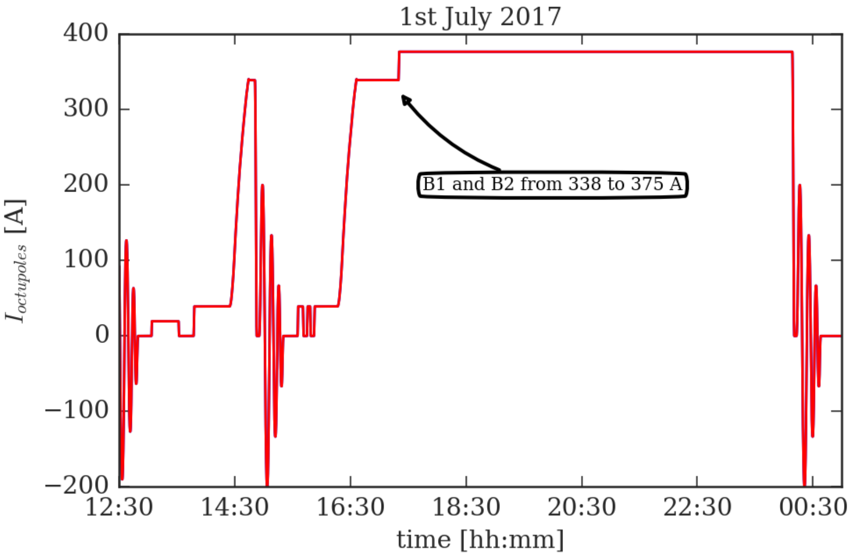
The hectic activity on the BBCW positioning.

BBCW MD: instability of B1



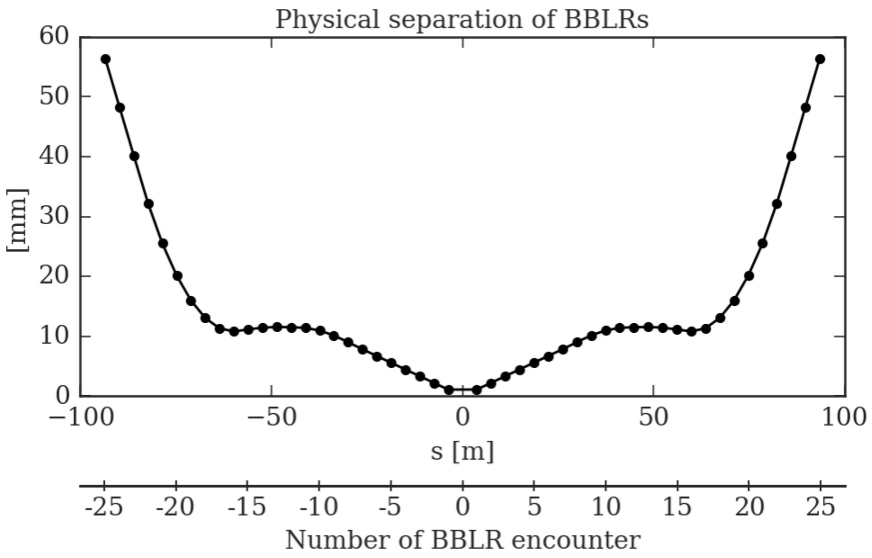


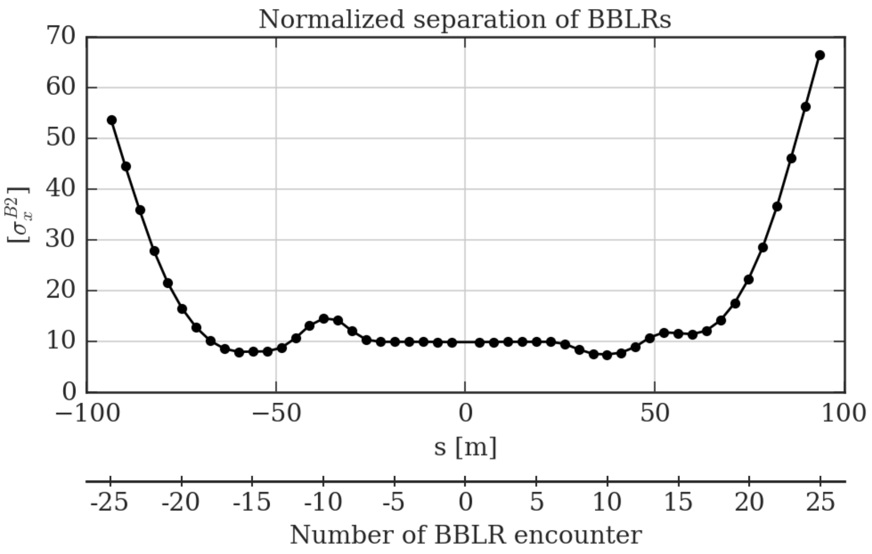
- During next MD we will use stronger octupole settings to avoid the instability of the non-colliding bunches in B1.



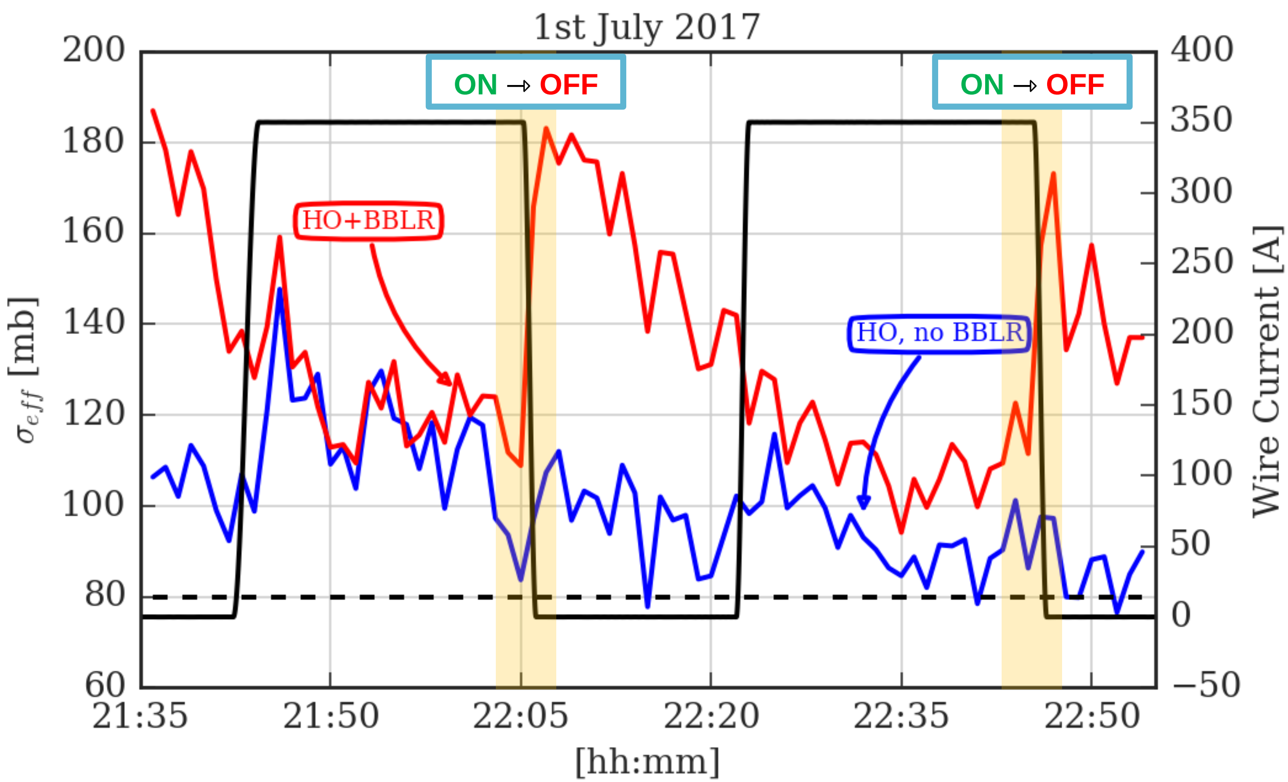
ATS 2017 optics

	NAME	X	PX	Y	PY	BETX	BETY	sigma_x at 3.5 um at 6.5 TeV [mm]
7062.030793	TCL.4L5.B2	1.527841e-03	0.000054	0.003836	-4.970527e-05	845.954861	1327.127536	0.653755
7212.060793	IP5	1.936385e-15	-0.000150	-0.001500	-9.267840e-15	0.400000	0.400000	0.014216
7360.005793	TCTPH.4R5.B2	-1.422381e-03	0.000034	0.002863	3.456410e-05	1349.329513	903.299673	0.825659



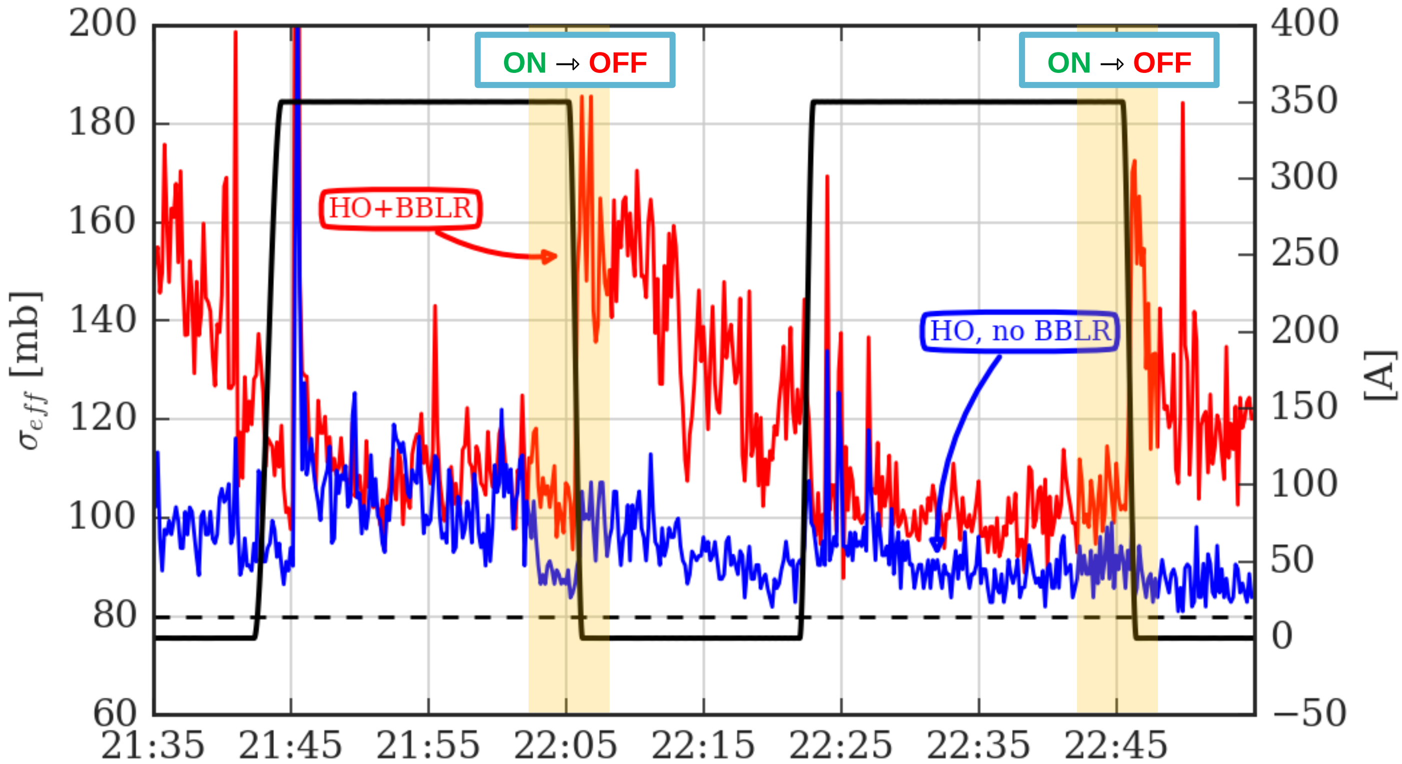


Results on the compensation (I)



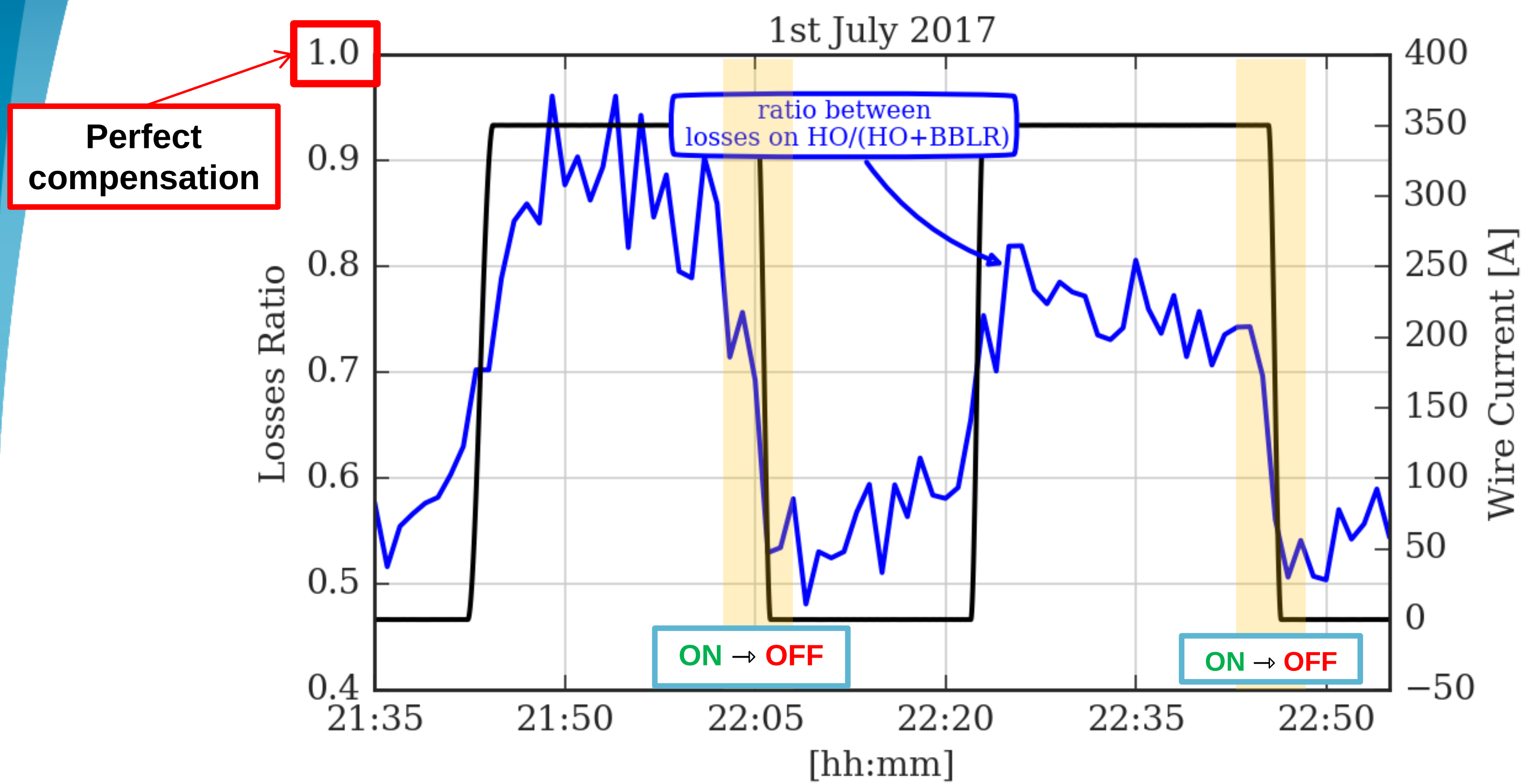
- Compensation seen from the σ_{eff} [credit to N. Karastathis].
- **Clear effect on the BBCW when switching-off: signal compatible with a contraction of the dynamic aperture of the machine.**

Result on the compensation (II)



- Using dBLM signals to compute the cross-section [credit to A. Poyet, A. Gorzawski]: **improved time resolution.**
- A constant calibration factor was adopted to rescale the BLM reading to the FBCT losses.

Result on the compensation (III)



- From the bunch-by-bunch intensity signals we can measure the effectiveness of the compensation on the losses [credit to M. Hostettler].
- **Clear effect of the BBCW.**