Results of BBCW operation in LHC Run 3

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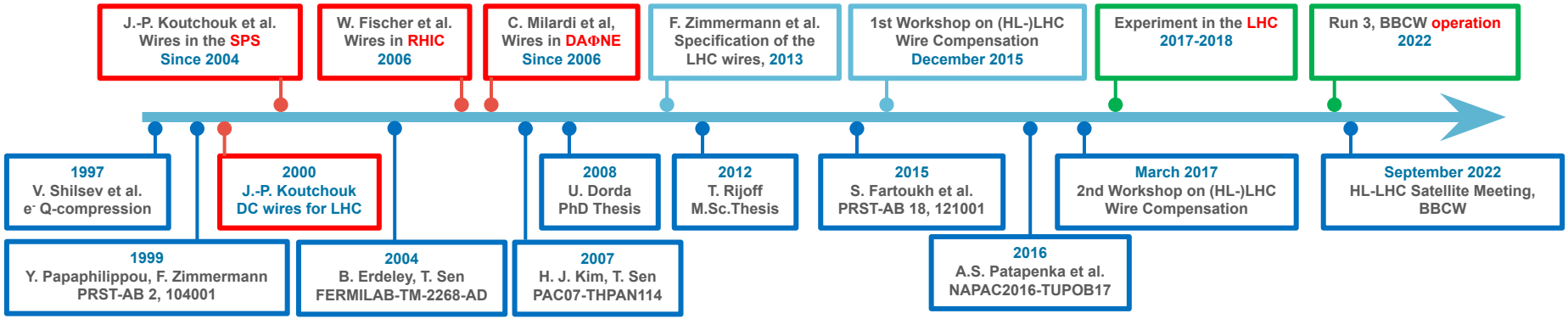
On behalf of the BBCW team

Special thanks to the **BE-OP** and **SY-BI** team for the continuous support, **MPP** for the guidance, the **Collimation Team** and **BE-CEM** for the 5th axis alignment, **OMC** for the optics validation, **SY-ABT** for the asynchronous dump validation, **TE-EPC** and **SY-STI** for the PCs and HW support.

HL-LHC Collaboration meeting, Sept. 23, 2022
https://indico.cern.ch/event/1168738/

Historical collaboration

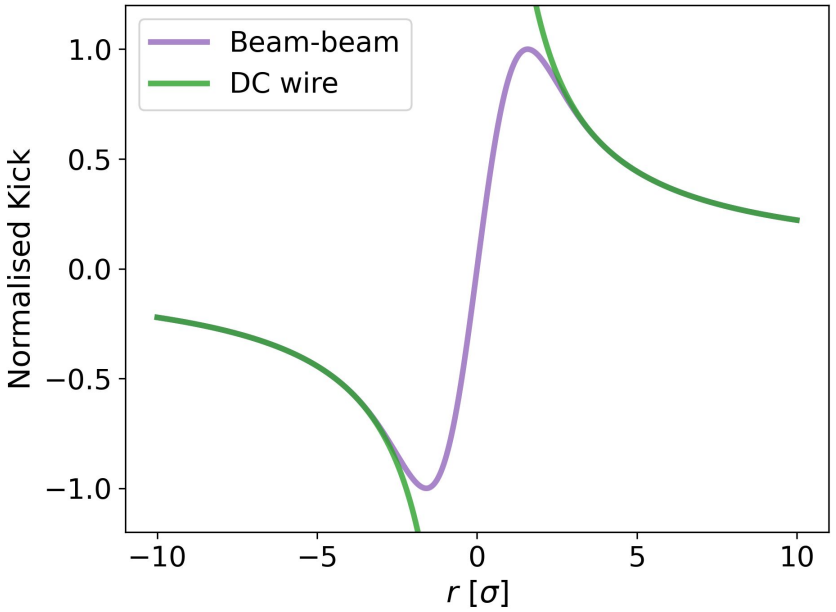


From G. Sterbini: https://indico.cern.ch/event/844153/contributions/3544317

Beam-Beam effect

- At the IPs : **Head-on collisions**
- On each side of the IPs : **Long-Range interactions** (BBLR)
- **Non-linear force**, strongly contributes to the tune spread
- Resonances and proton losses limit the **performance of the collider**, in particular the **integrated luminosity**
- Kick from a **DC wire** is completely equivalent to the BBLR kick.
- There is hope for **compensation**

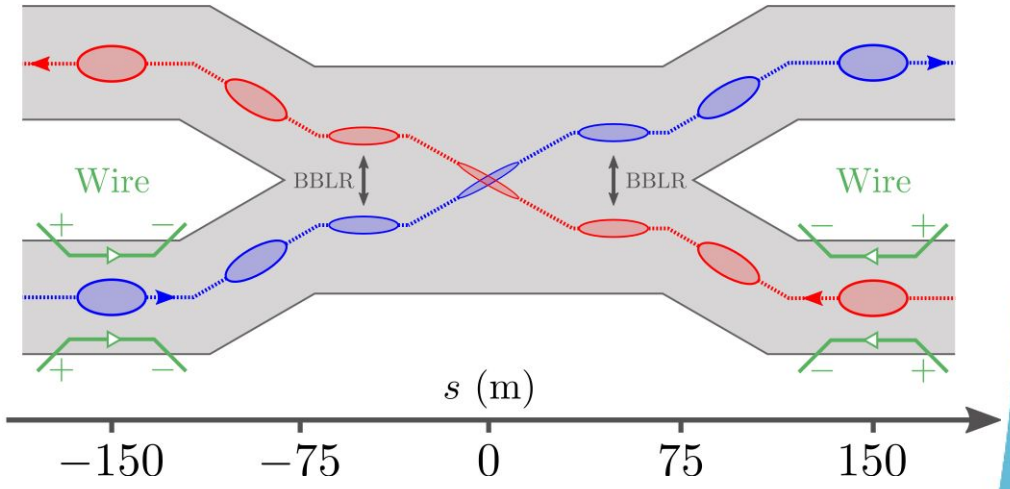
$$\frac{dp_r}{dt} = e\frac{\mu_0 I}{2\pi r}\frac{c\,(1+\beta_r^2)}{\beta_r}\left(1 - e^{-\frac{r^2}{2\sigma^2}}\right)$$



BB Long-Range compensation

- DC wire upstream of the IPs (Run 3) for **both beams**
- For natural compensation: placed in the **same crossing** plane as the IP
- Challenges for ideal compensation:
  - Cannot be in **common aperture**
  - Single wire to compensate the **integrated effect of ~40 LRs**
  - Compensate as **many multipolar terms** as possible
  - → Tackled with HL-LHC configuration

    (See S. Fartoukh et al. PRST-AB 18, 121001)
- For Run 3: **double wire** configuration focusing on **octupolar terms** compensation



"If the optics and layout conditions (β-aspect ratios, wire distance, etc.) **cannot be met**, wire currents and distances should be used for **cancelling the LR leading order effect**, i.e. **octupole-like tune-spread**."

Y. Papaphilippou - BBLR 2015 workshop (https://indico.cern.ch/event/456856/contributions/1968793)

Compressing the Tune Footprint

- Particles of **different amplitudes** experience **different tune shifts**
- Head-on collisions: **tie-like footprint** (well accommodated in tune space)
- LR interactions: **triangular footprint** (mainly **octupolar** tune spread)

➔ Lateral **wings** need to be compressed to **avoid resonances**
  - Use of octupoles or wires
  - Chromaticity and other higher effects need the wire, but not discussed with Run 3 configuration

- Footprint compression allows for more **tolerance on the configurations** of the machine

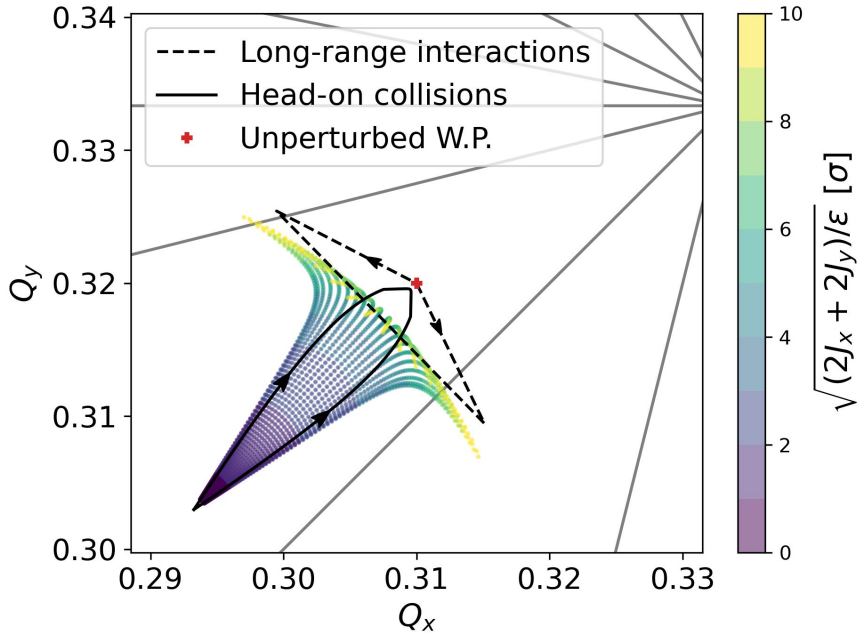


Figure of merit for BB compensation

- Resonances cause **losses**: **Effective cross section** can quantify the impact of BBLR on different bunches

$$\sigma_{\text{eff}} = -\frac{1}{\mathcal{L}}\left[\frac{dN}{dt}\right]_{\text{tot}} = \frac{1}{\mathcal{L}}\left[\sigma_{\text{LHC}}\mathcal{L} + \text{Others}\right]$$

- Measures the **efficiency of the collider**
- Lifetime **should be avoided**:
  - **No information** on lumi production

    (Can even mean less lumi production in some cases!)
- No losses, or **80 mb cross section**, means:
  - ➔ **Burnoff** dominated
  - ➔ **Integrated luminosity is maximised**

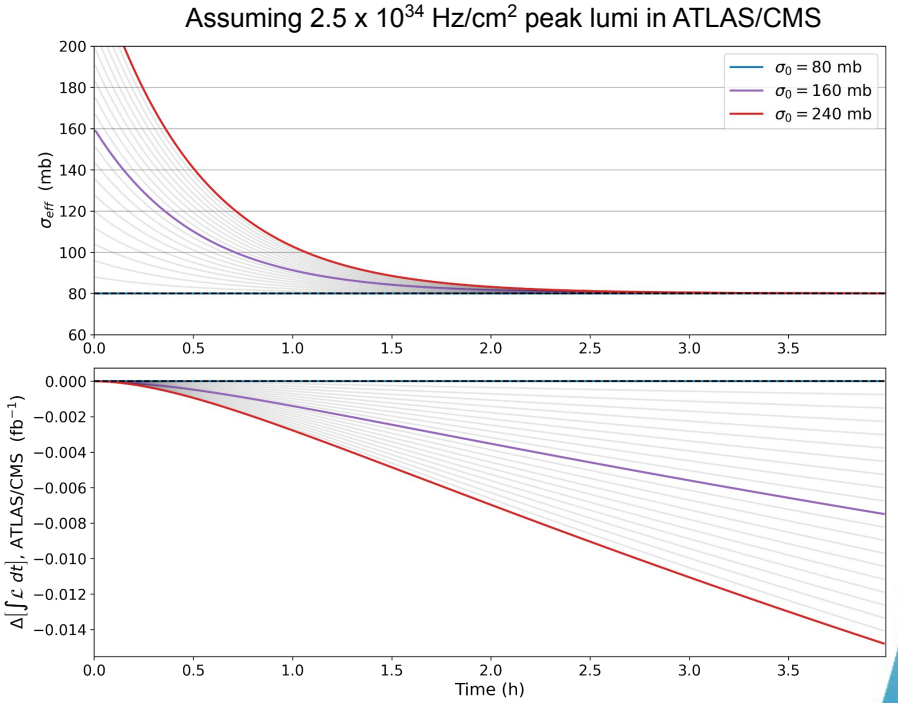


Figure of merit for BB compensation

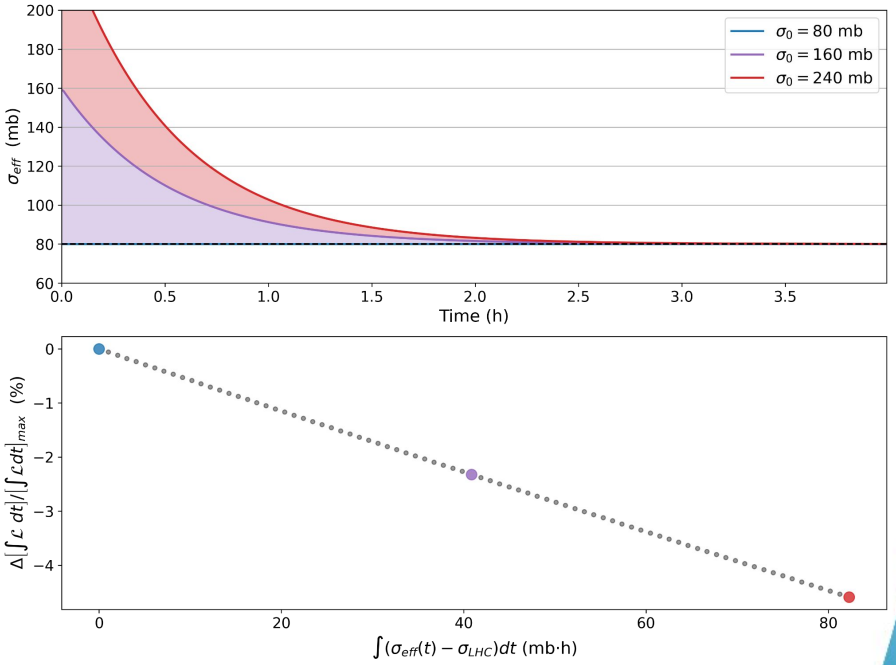
- In simple model with **no leveling**:

$$\frac{\Delta\left[\int_{\text{Fill}} \mathcal{L}\, dt\right]}{\left[\int_{\text{Fill}} \mathcal{L}\, dt\right]_{\max}} \propto -\int_{\text{Fill}} \left(\sigma_{\text{eff}} - \sigma_{\text{LHC}}\right) dt$$

- **Integral of the cross section** is linked to relative reduction of integrated luminosity

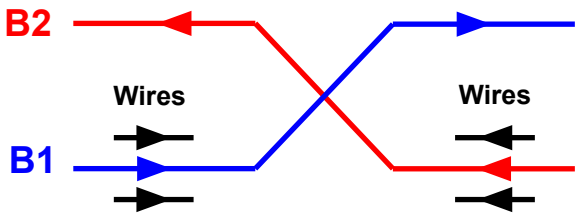
➔ Protons saved at the **start of the fill** significantly contribute to the **integrated luminosity**

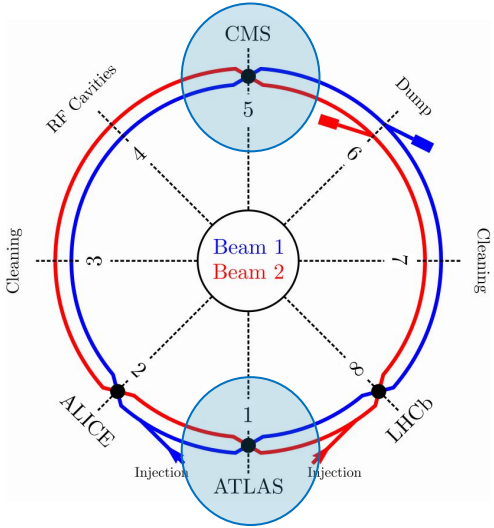
Assuming 2.5 x 10^{34} Hz/cm^2 peak lumi in ATLAS/CMS



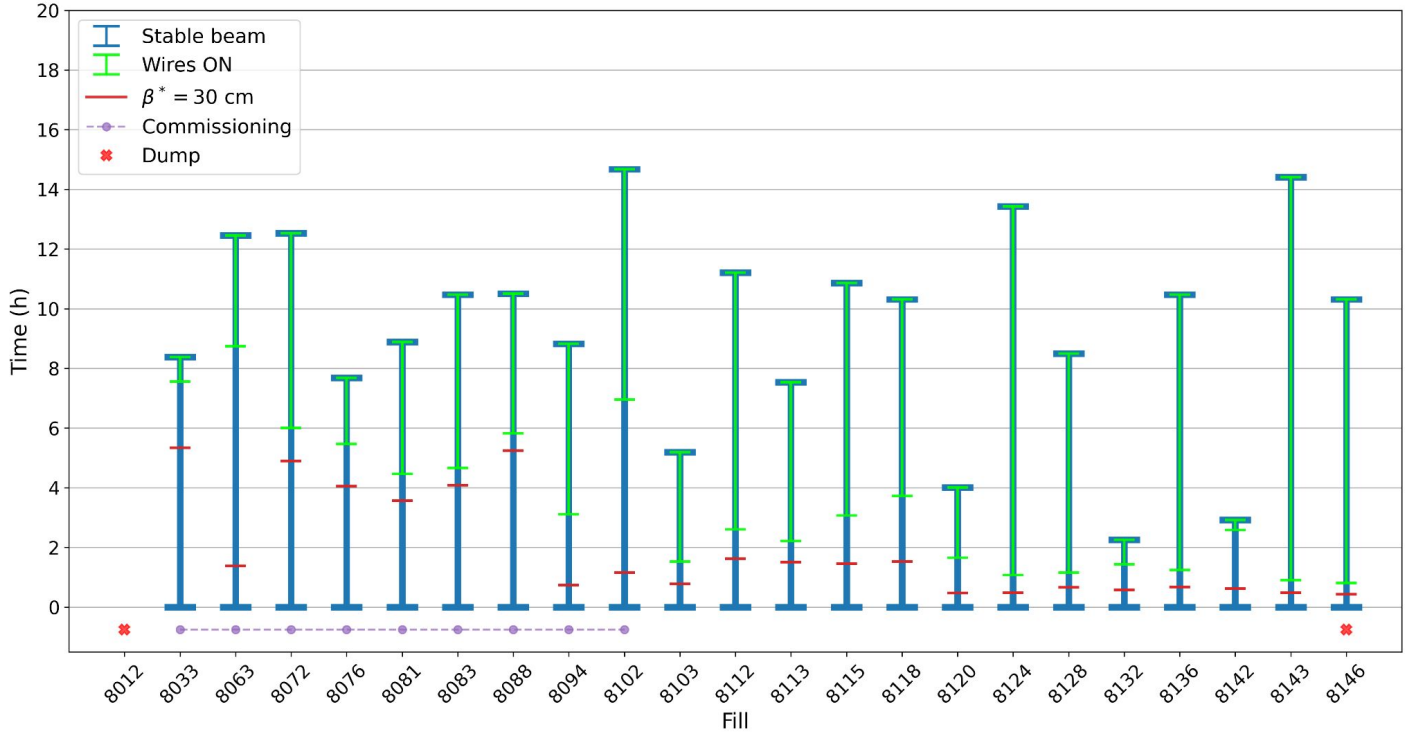
Run 3 BBCW operation scheme

- **Demonstration** hardware
- **Embedded** in IP1/IP5 TCT collimators
- Used in **two-jaws** configuration
- 5th axis aligned
- Q-Feedforward implemented
- **Wires** parameters
  - I_w = 350 A
  - d_w = 9.2/12.4 mm (IP1/IP5)(Vert./Hor.)
- **Beam** parameters
  - Nb = 1.15e11 protons
  - E = 6.8 TeV
  - β^* = 30 cm
  - $\phi_c/2$ = 160 µrad

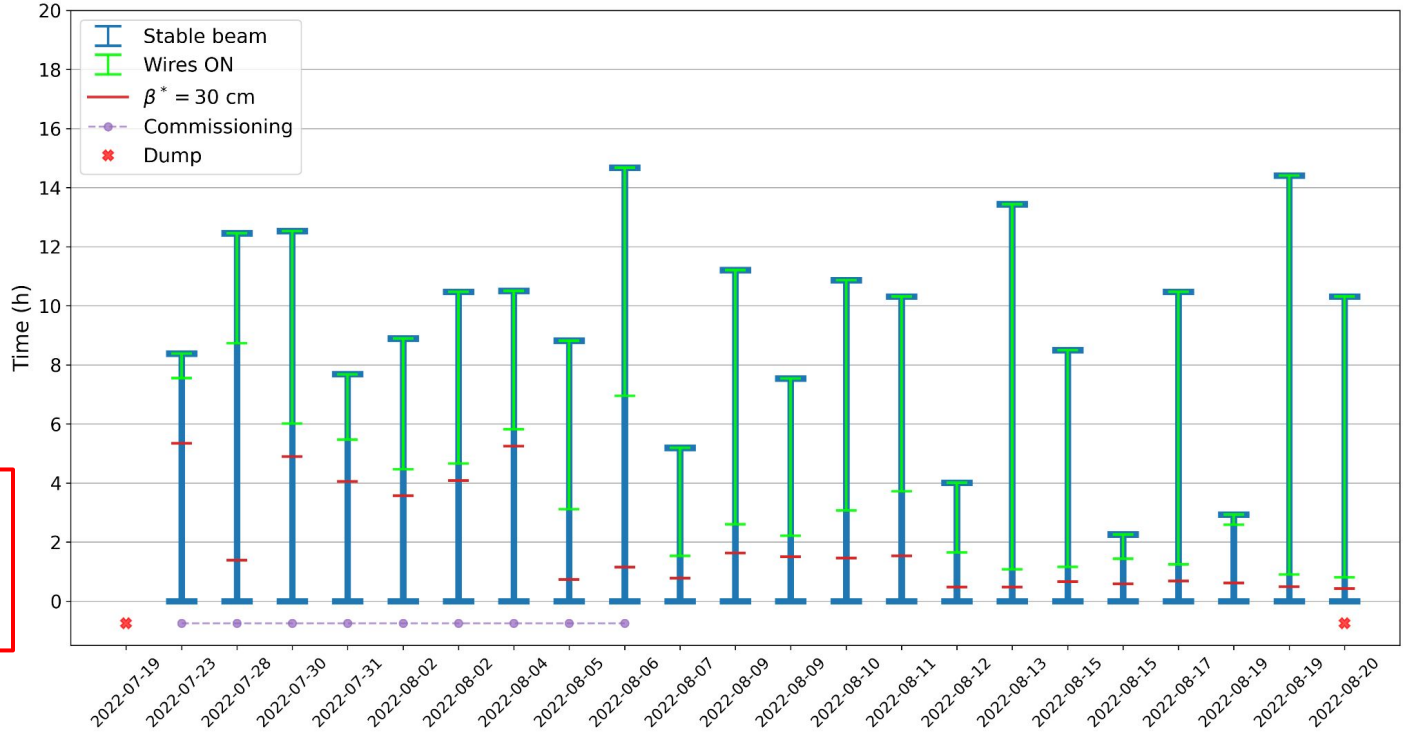




First month of operation



First month of operation

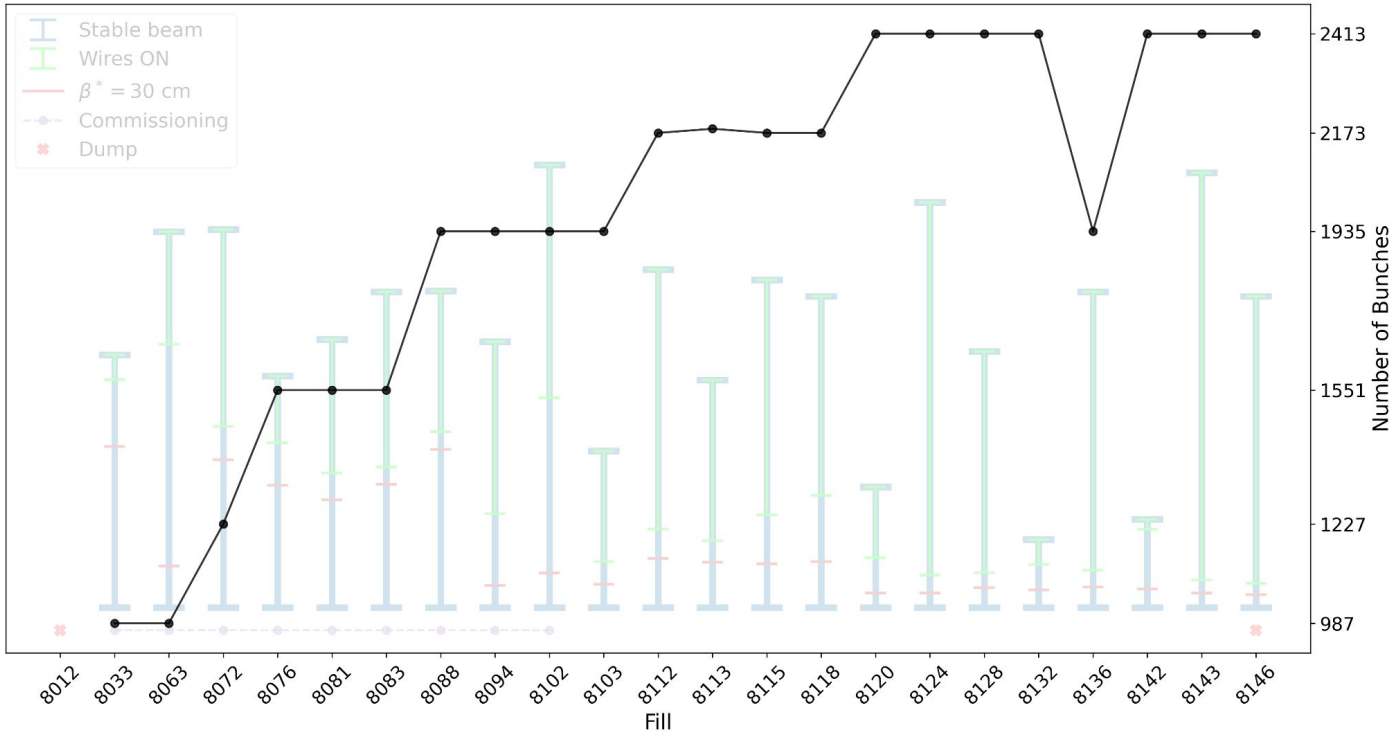


Dump:
Understood.
Transition from
OFF to IDLE

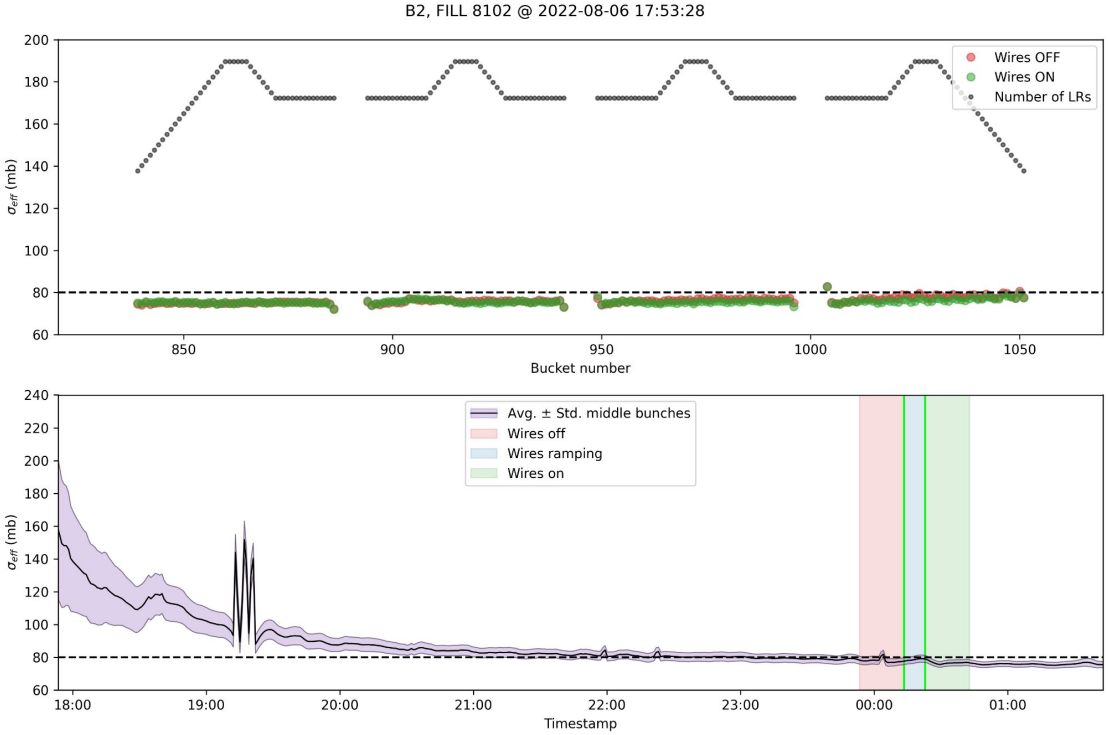
Dump:
Earth-FAULT
(L1B1)

14 days of **parasitic (end-of-fill)** commissioning

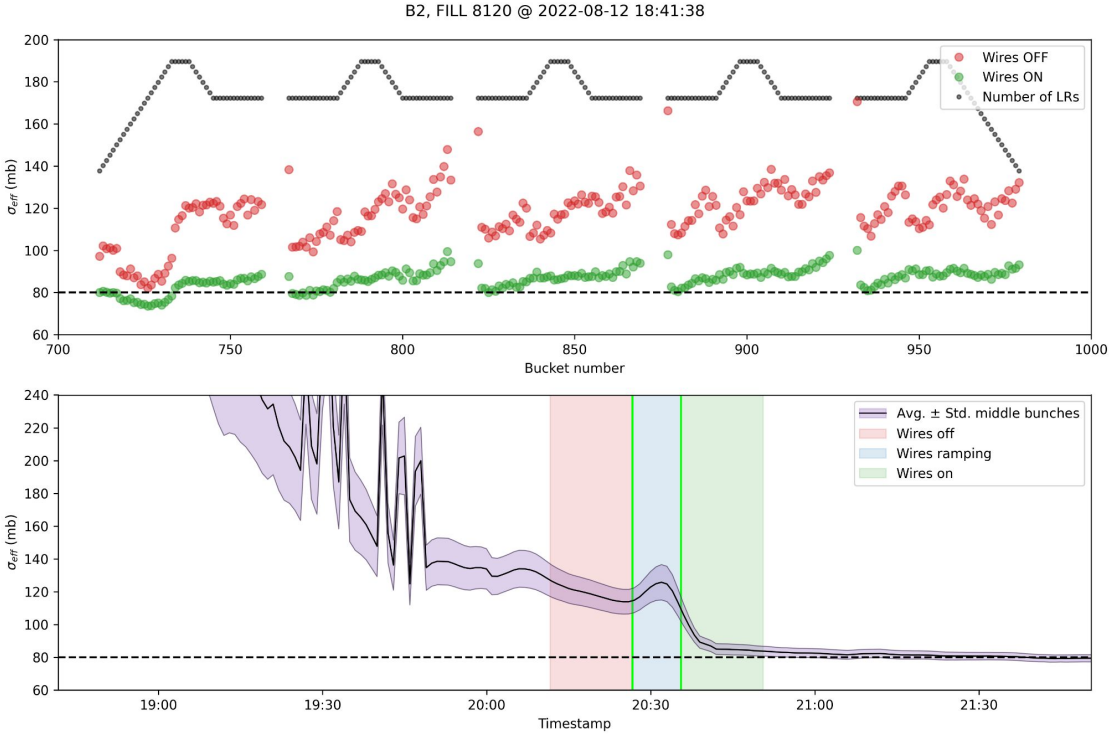
First month of operation: intensity



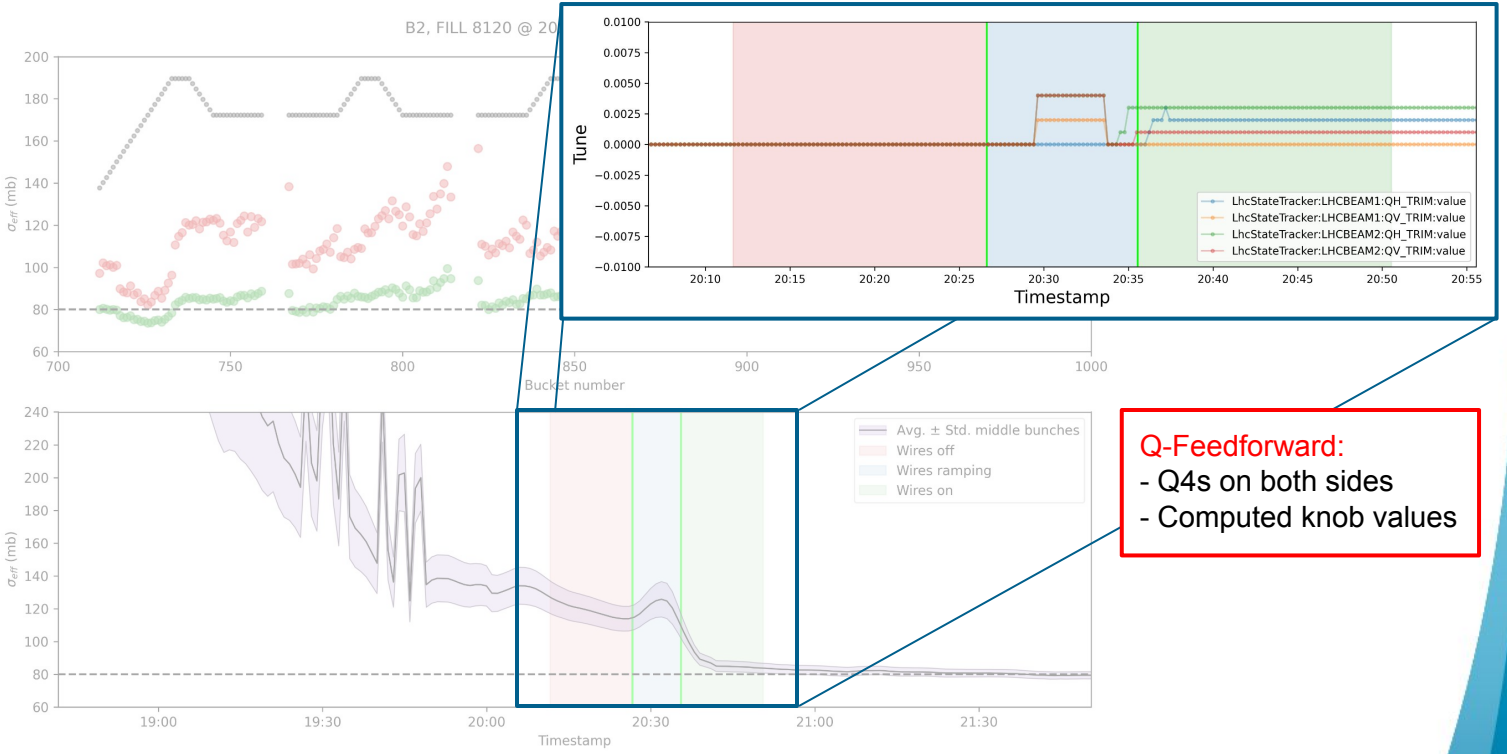
8102 : last fill of commissioning



8120 : Fills of 2413 bunches

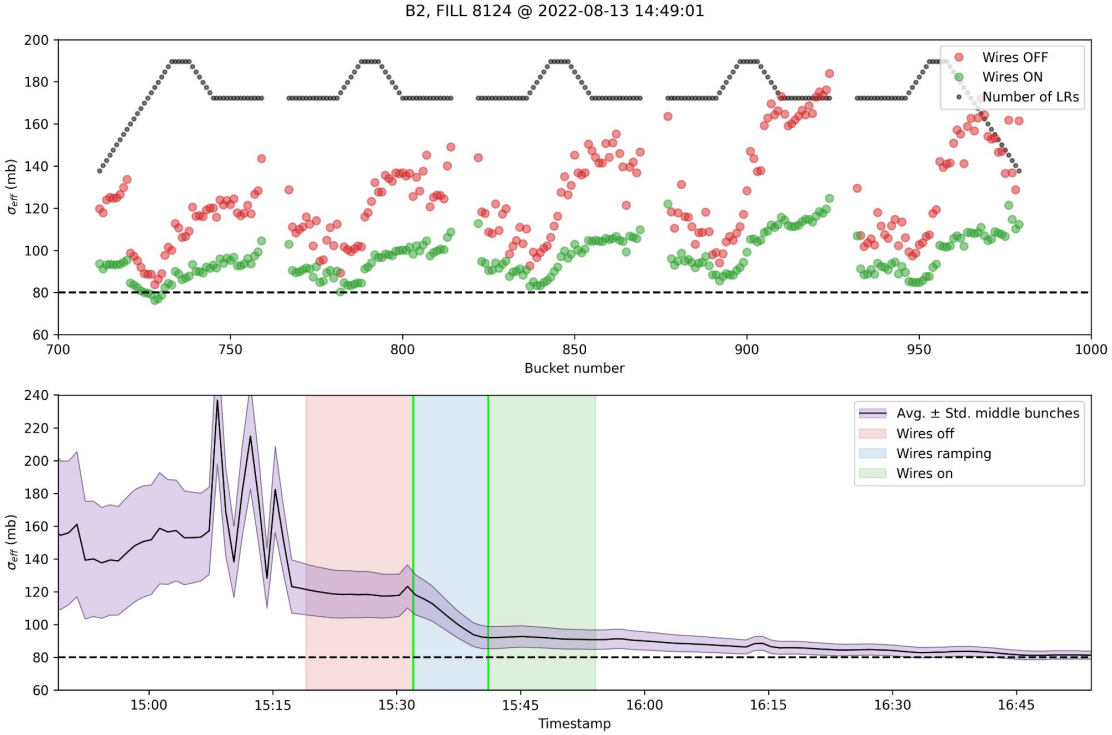


8120 : Fills of 2413 bunches

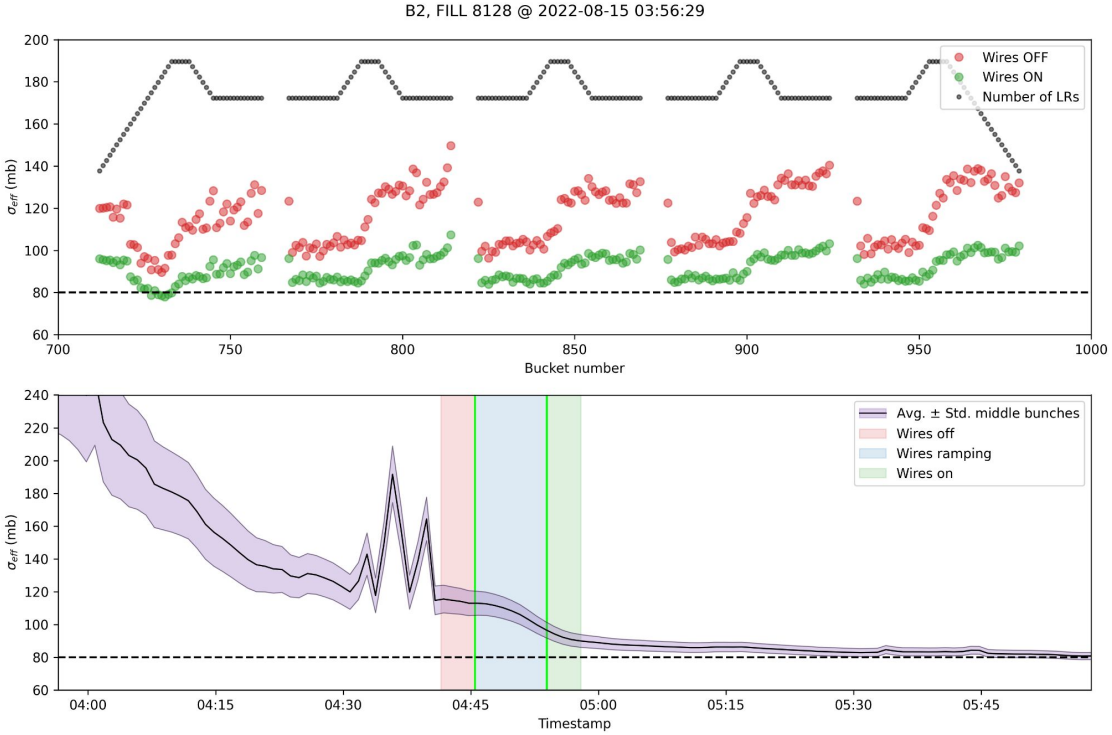


Q-Feedforward:
- Q4s on both sides
- Computed knob values

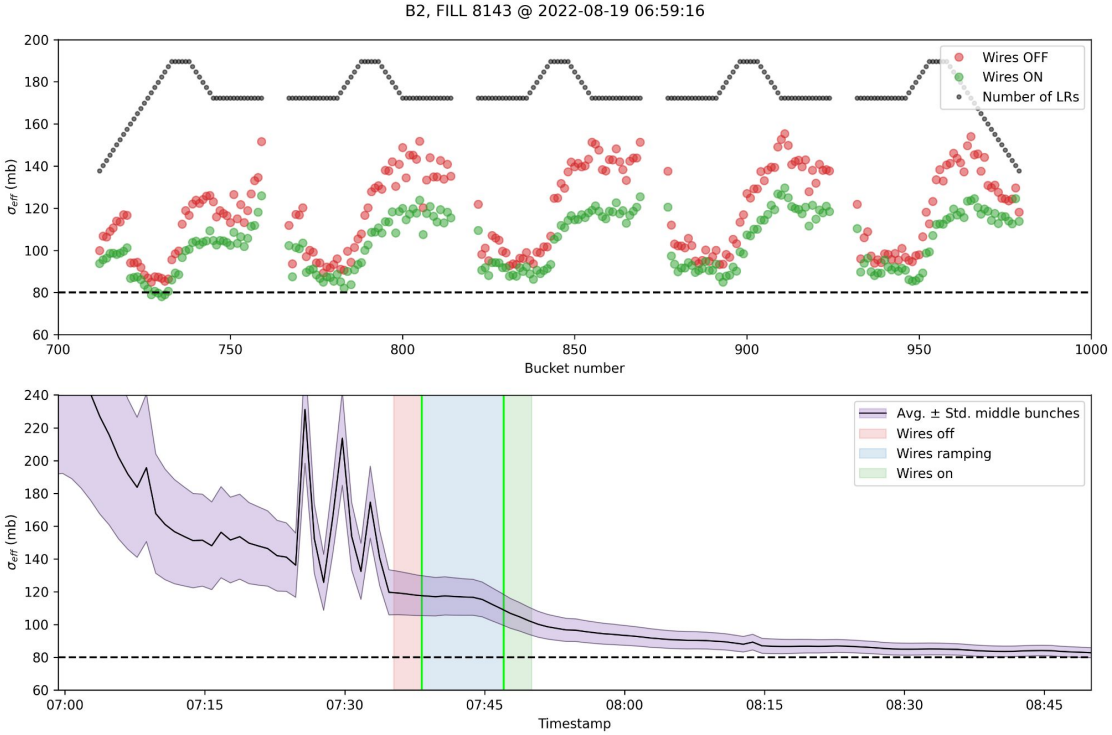
8124 : Fills of 2413 bunches



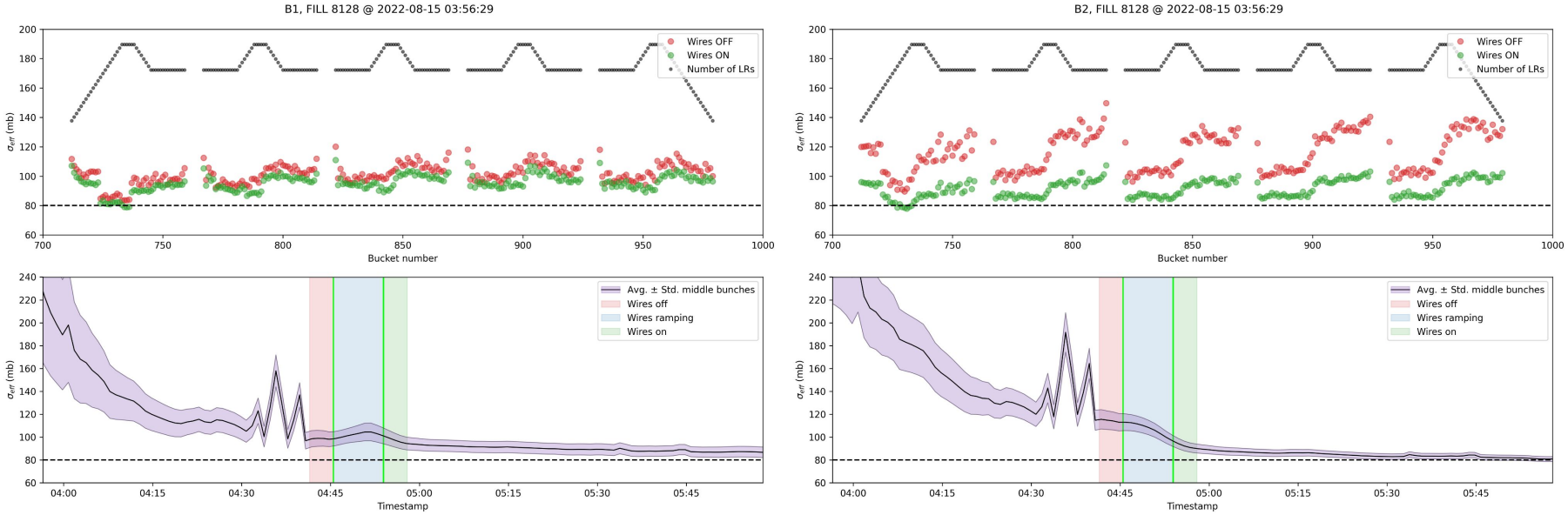
8128 : Fills of 2413 bunches



8143 : Fills of 2413 bunches

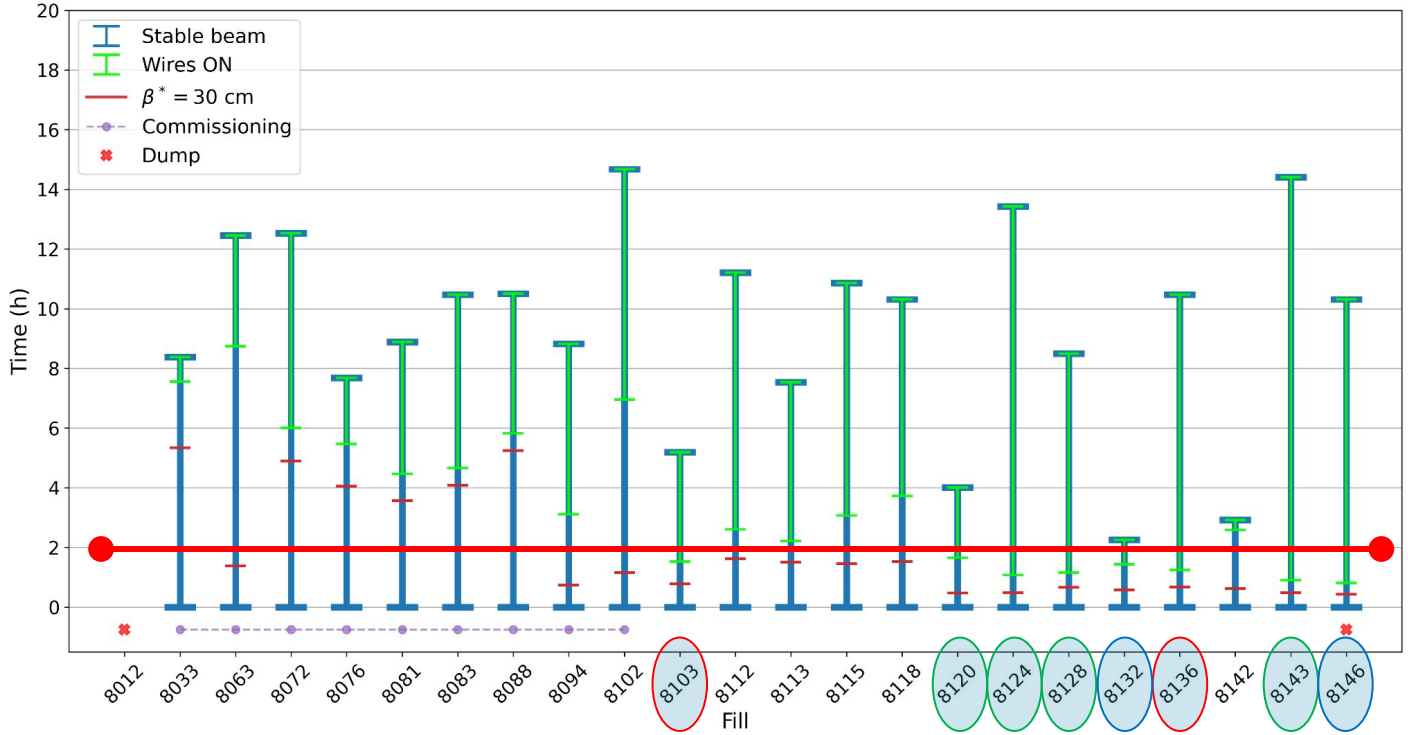


B1 observations



- B1 in general already better cross section, and wire effect less visible
- Bump due to tune trim in general higher in B1
- No other negative effect… (other than earth-fault)

The earlier, the better



Summary

- Reminders:
  - Wires currently used as **octupolar compensators**
  - **Far away** from the beam
  - Non-ideal **beta ratios**
- BBWC was made **operational** very **rapidly**, thanks to the support of many teams and the simplicity of the device.
  - April 8th - July 23rd : orchestration of BBCW operation
  - July 23rd - August 8th : commissioning with end-of-fill operation
- **Q-Feedforward** needs some **adjustments:** manual trim should be eliminated
- Despite the limited number of observation (22 fills), clear **beneficial effect on B2:**
  - Rapid reduction of σ_{eff}, much **faster** than the usual **relaxation time**
  - Reduction of the bunch-by-bunch variations (σ_{eff} spread)
- Unfortunately, **mitigated results on B1** and lost the wires on Aug. 28th to **earth fault**

Thank you!