Long Range Beam-Beam investigation using Weak-Strong beams in the LHC

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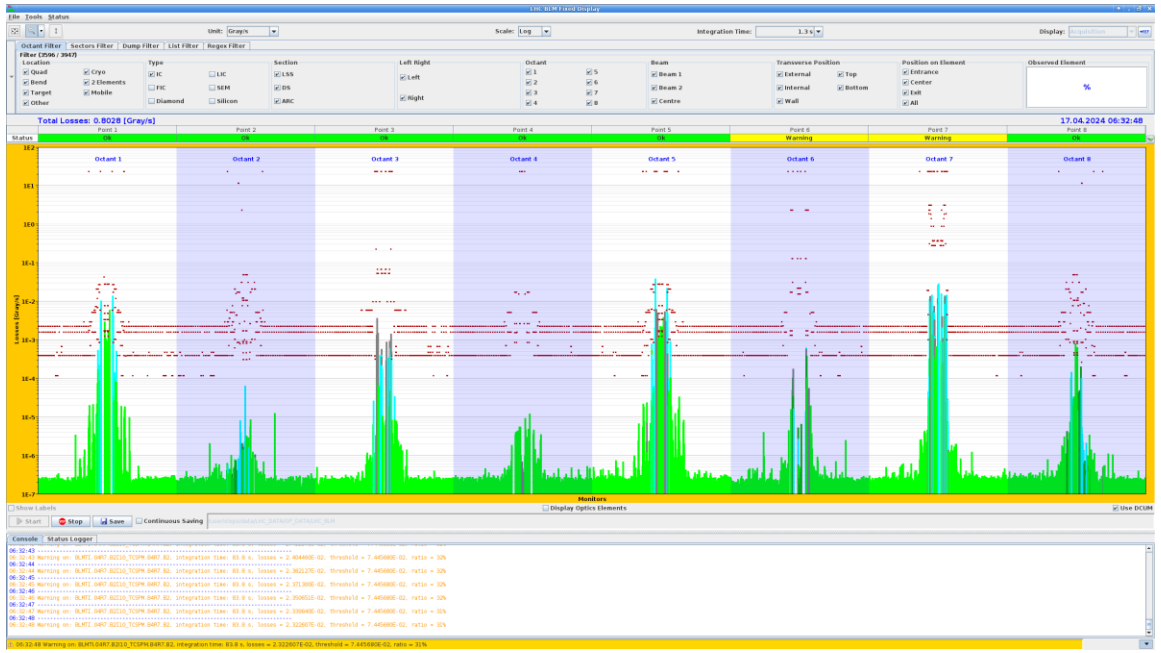
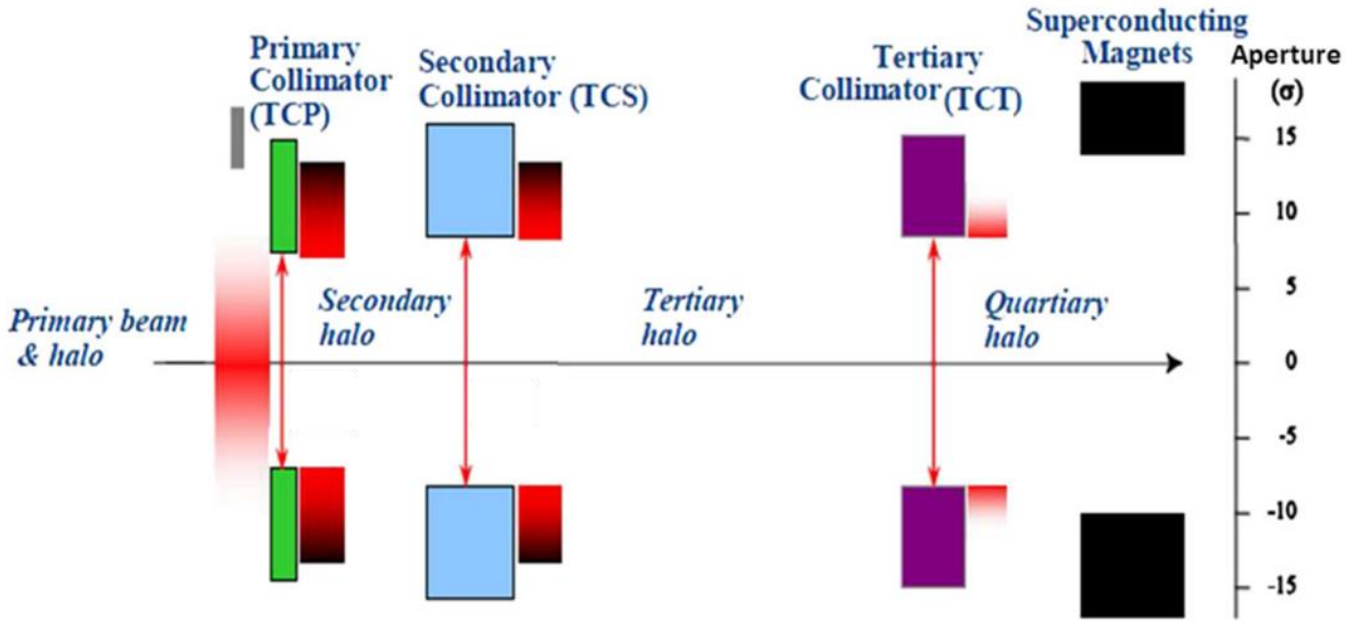
Motivation

- After the LHC commissioning there is a phase of **intensity ramp up**
- After we went to bunch trains a hierarchy breakage in the collimation system was observed in **beam 2**
  - Only at β* of 33cm and below (collisions start at 1.2m and around 60cm we start our physics production)
  - Only observed when we had trains and two beams in the machine
  - It was found that the collimation hierarchy was broken at **TCSG.D4R7.B2** (vertical secondary collimator)

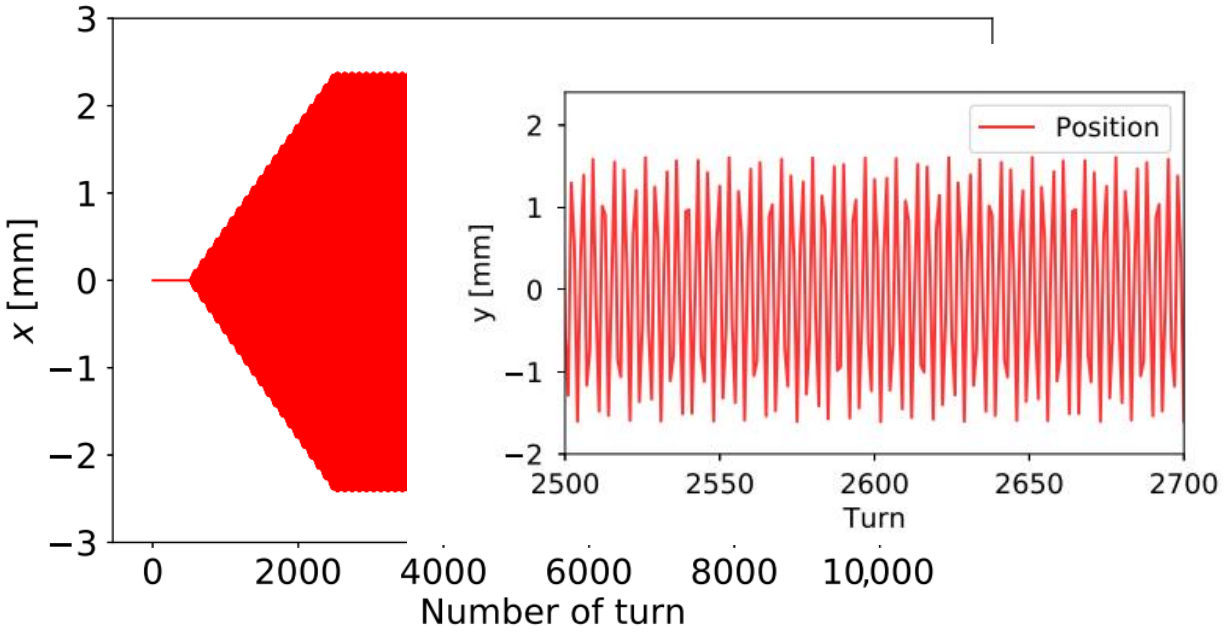


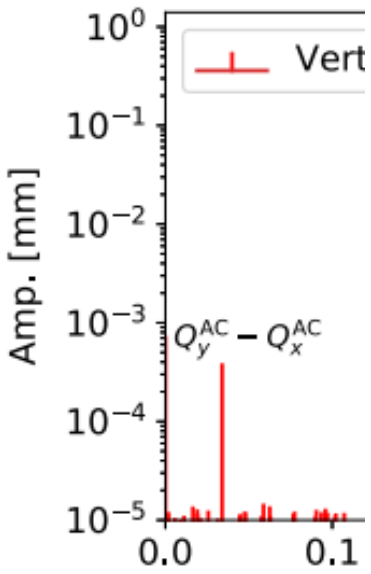
What does it mean that the collimation hierarchy was broken?

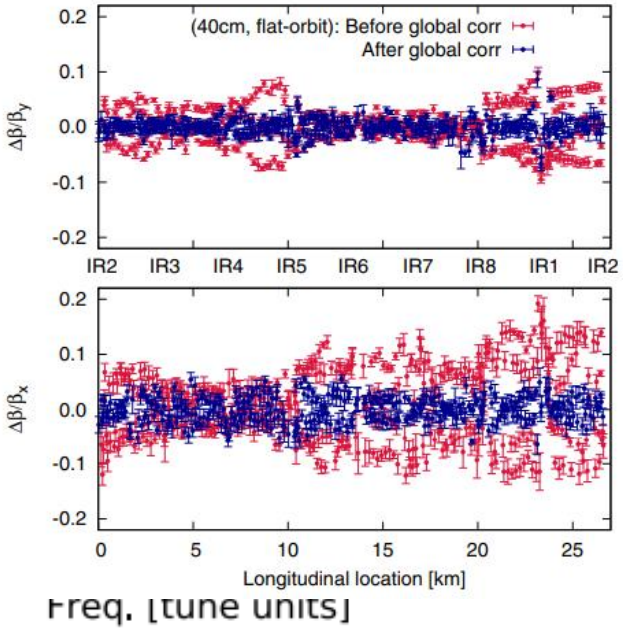
- LHC has a multistage collimation system
- The TCP should be the primary but for beam 2 it was the vertical secondary collimator **TCSG.D4R7.B2**
  - The design difference between the primary and secondary is **1.5 σ**
- The single beam didn't show this!



How we measure optics and Resonance Driving Terms (RDTs) in the LHC



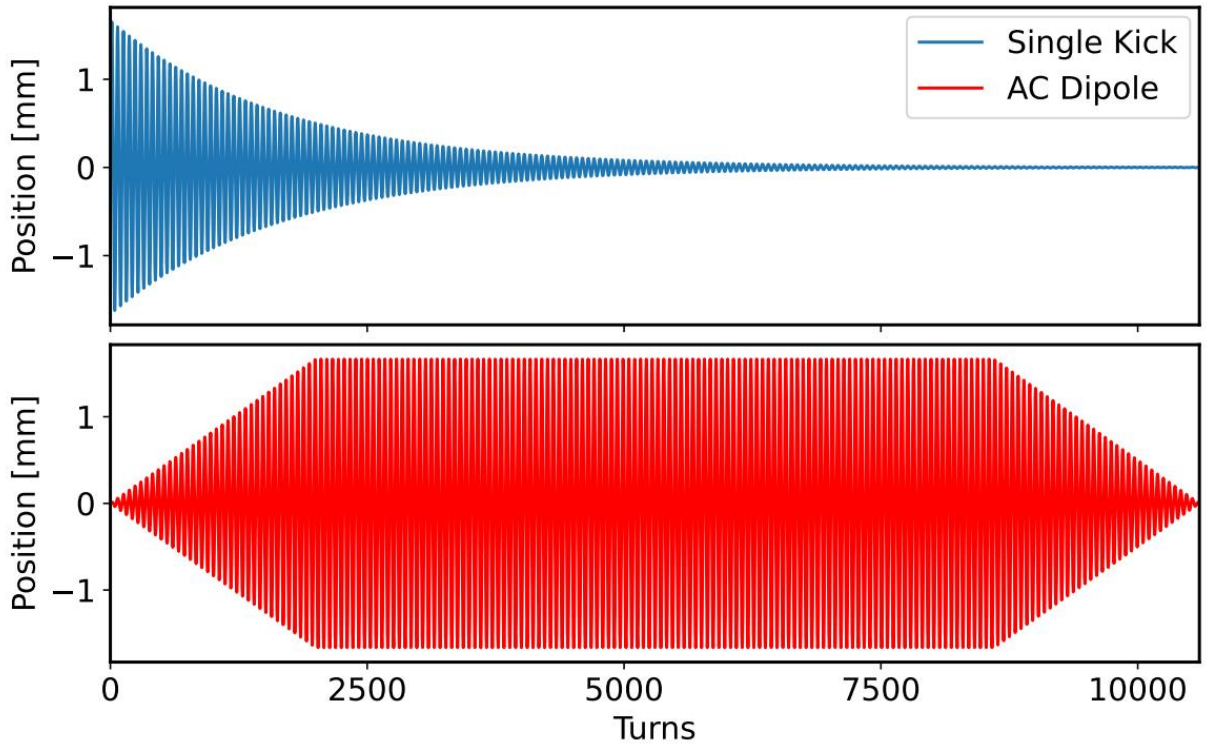




Freq. [tune units]

- We excite the beam with an AC-dipole and record the turn-by-turn data
  - Drive at different tunes different compared to the natural
  - 6600 turns of constant amplitude
  - To use the AC-dipole we can have **maximum 3 bunches of 10^{10}**
- Clean the data and remove bad BPMs
- Reconstruct the parameters such as β-beat, coupling and RDTs

Why an AC-dipole?



- The AC-dipole creates a coherent adiabatic oscillation of the beam

➔ **No emittance** increase

➔ We can excite with the same bunch many times

- The ADT (LHC damper) can create a similar excitation but limited in amplitude

Why do we want to measure the effect of the LRBB?

- The l**inear and nonlinear optics commissioning** is based on measurements of pilot bunches (single low-intensity bunches)
- The hierarchy breakage prevented us from going to the nominal β* of 30 cm -> Less **integrated luminosity**
  - Need a method to measure these effects and benchmark simulations (mentioned several times during the workshop)!
  - Will be even more important in HL-LHC where intensity is higher and β* smaller
    - Measuring with two strong beam is very difficult because when you excite on it has a strong impact on the other -> Difficult to measure and model correctly
    - Measure with Strong-Weak beam!

Operational setup and experience

- The LHC is almost like two separate machines where the beams only see each other close to the IRs
- Created a special sequence
  - High-intensity only for beam 1 (BPMs, RF-settings etc)
- 3 pilot bunches for beam 2 (maximum allowed when using AC-dipole)
  - **1 with no LR**, 1 with **IR1/2/5/8** and one only in **IR1/5**
- Removed the common BPMs from the orbit feedback since there could be strange effects having a strong and a weak beam
- Nominal collimators to 30 cm
  - Opened the collimators for Beam 2 using a sequence to the optics measurement settings
- Separated the beams by ~5 σ to only have LRBB (no head-on)
- Extremely smooth and no technical issues with this **new setup**!
  - Several new MDs proposed following a similar procedure

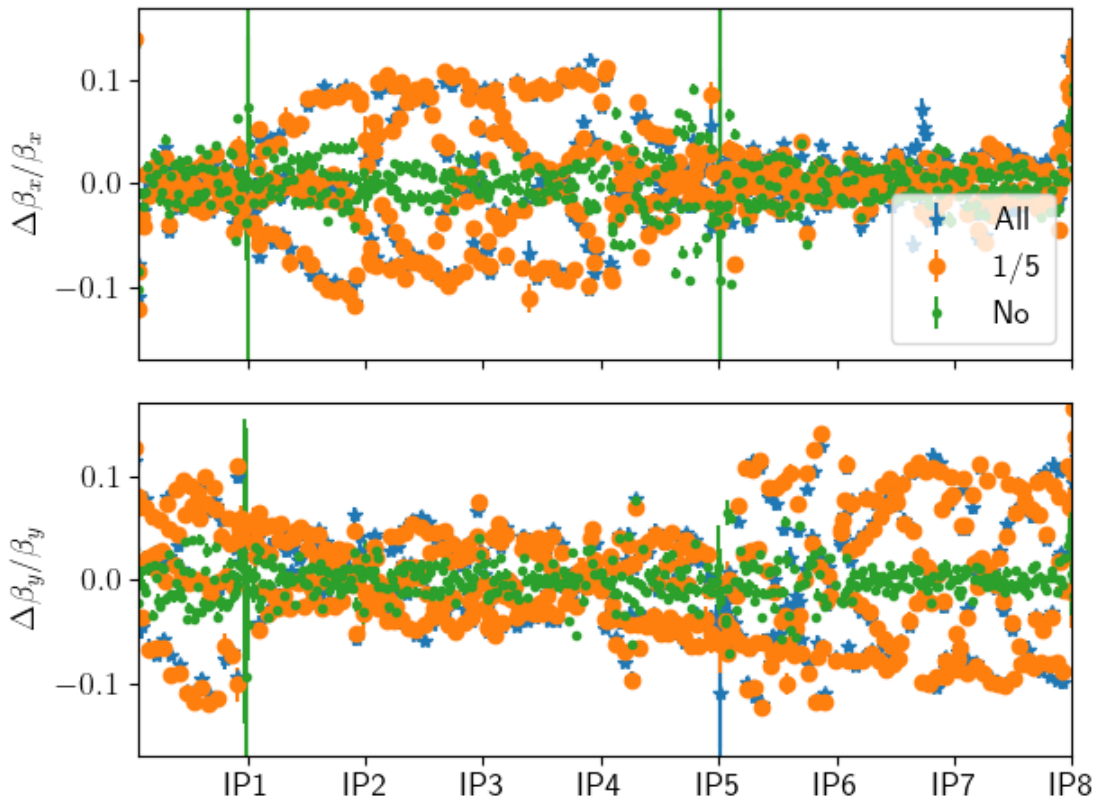
The setup in details

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	true
Beam Presence	true	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false

- The intensity per bunch was
  - Beam 1: 1.6×10^{11}
  - Beam 2: 10^{10}
- Normalized emittance:
  - Beam 1 around 1.8 um
  - Beam 2 around 3 um (some blow up during the measurement)
- Crossing angle:
  - 150urad (both beams)
- β^*
  - IP1 = IP5=30cm
  - IP2 = 10m
  - IP8 = 2m
- We were operating with 36 bunch trains
  - LHC can operate with longer trains but even with this configuration we have almost the maximum of long-range.

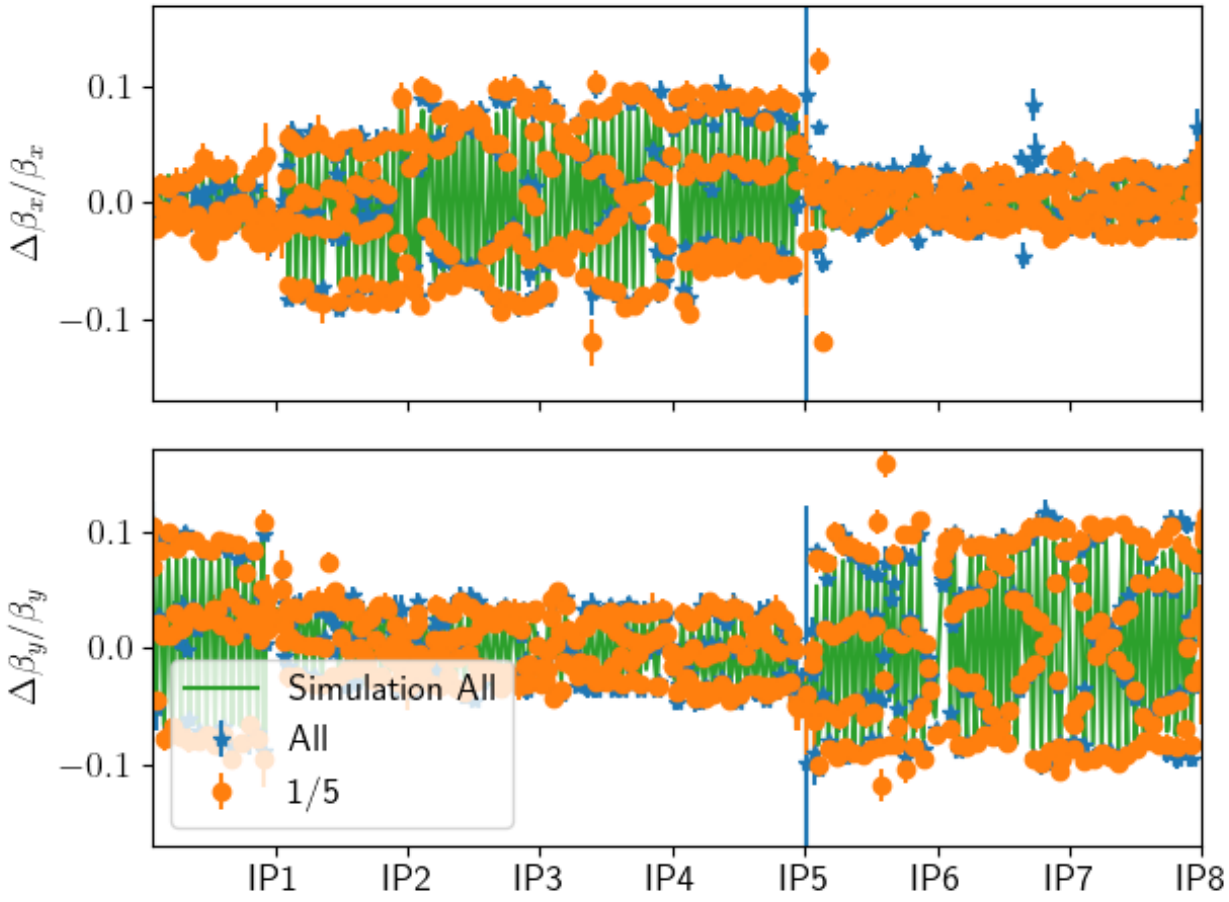
β-beat

- The long-range beam-beam has a significant impact on the β-beat
- We go from around 5% to more than 10%
  - Changes not enough at the collimators to explain the hierarchy breakage



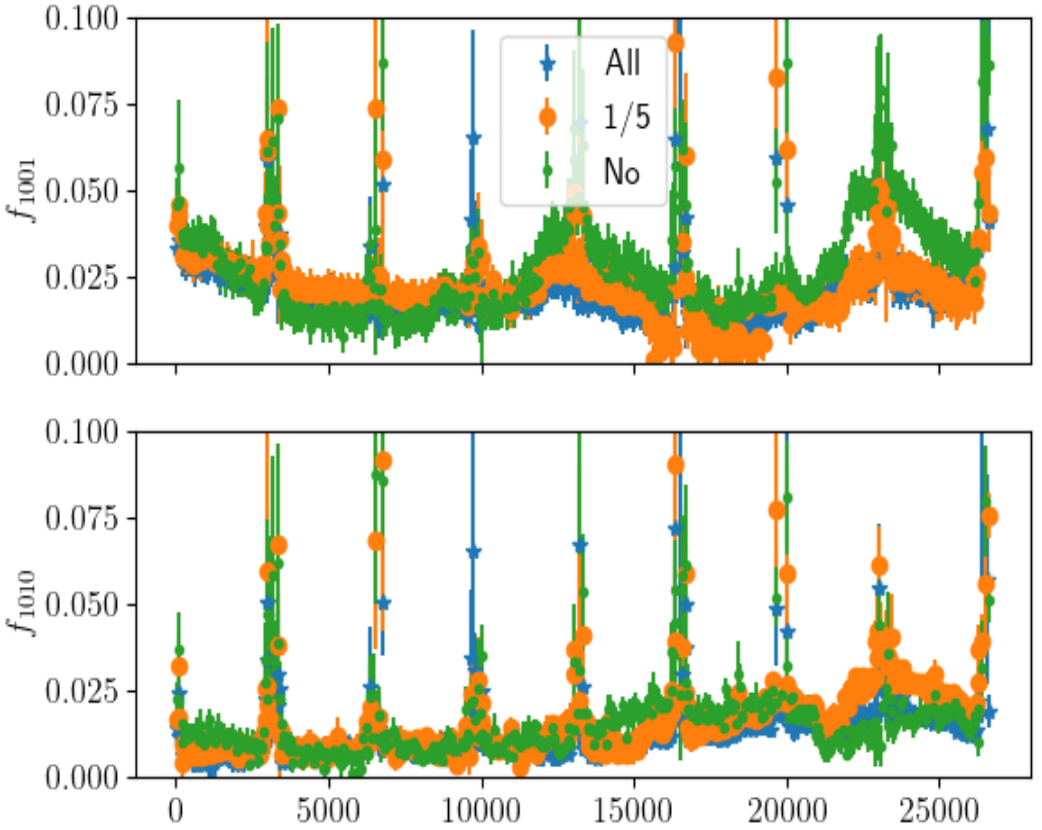
β-beat compared to simulations

- The plot shows the β-beat between the bunch with no long range and with
  - The green line shows the simulation from MAD-X very similar results from pyTrain (see Michi's talk on Thursday)
- Up to 10% difference in the β-beat



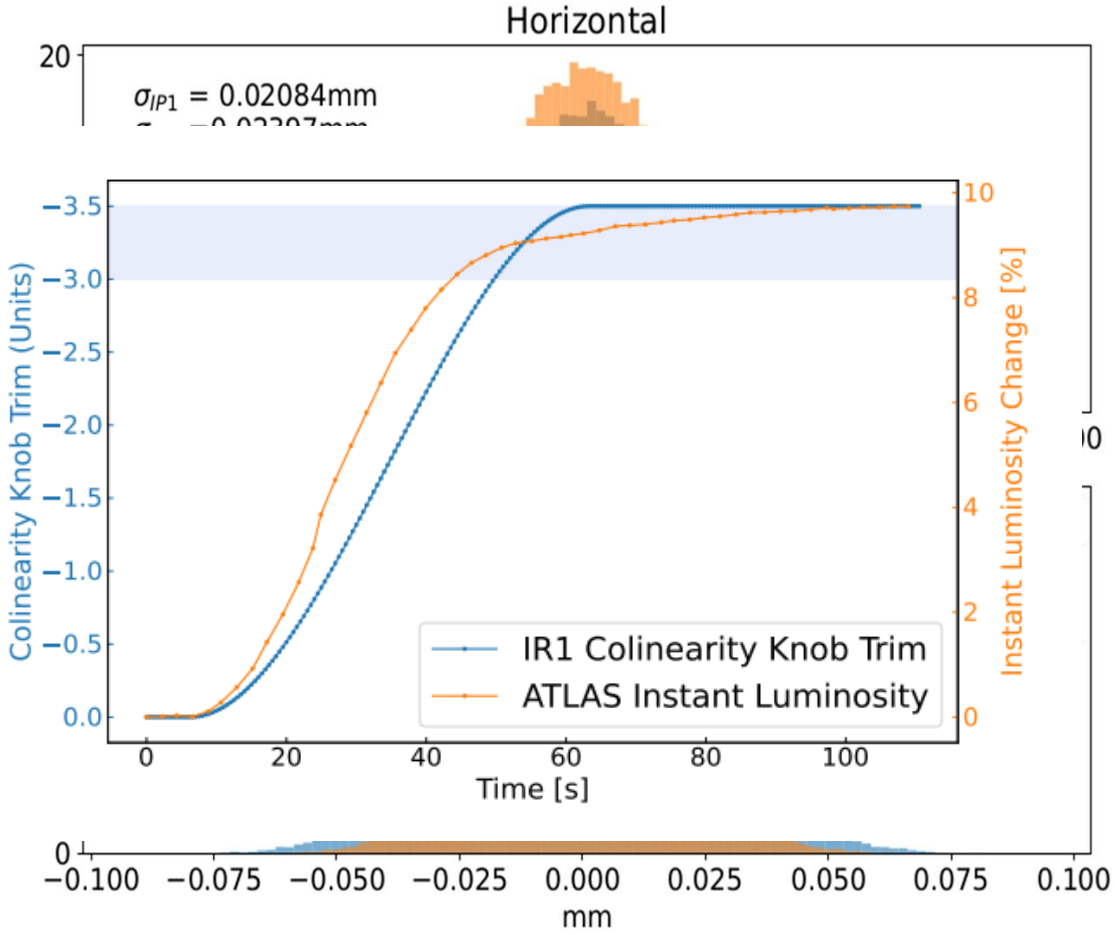
Transverse coupling

- Modest impact on the couplings RDTs
  - No significant contribution to the hierarchy breakage
- If there is a tilt (in IP1 and IP5) in the crossing angle then we would expect a change larger change to the coupling (LHC MD2877: Beam-beam long range impact on coupling measurements)



Beam size increase due to coupling

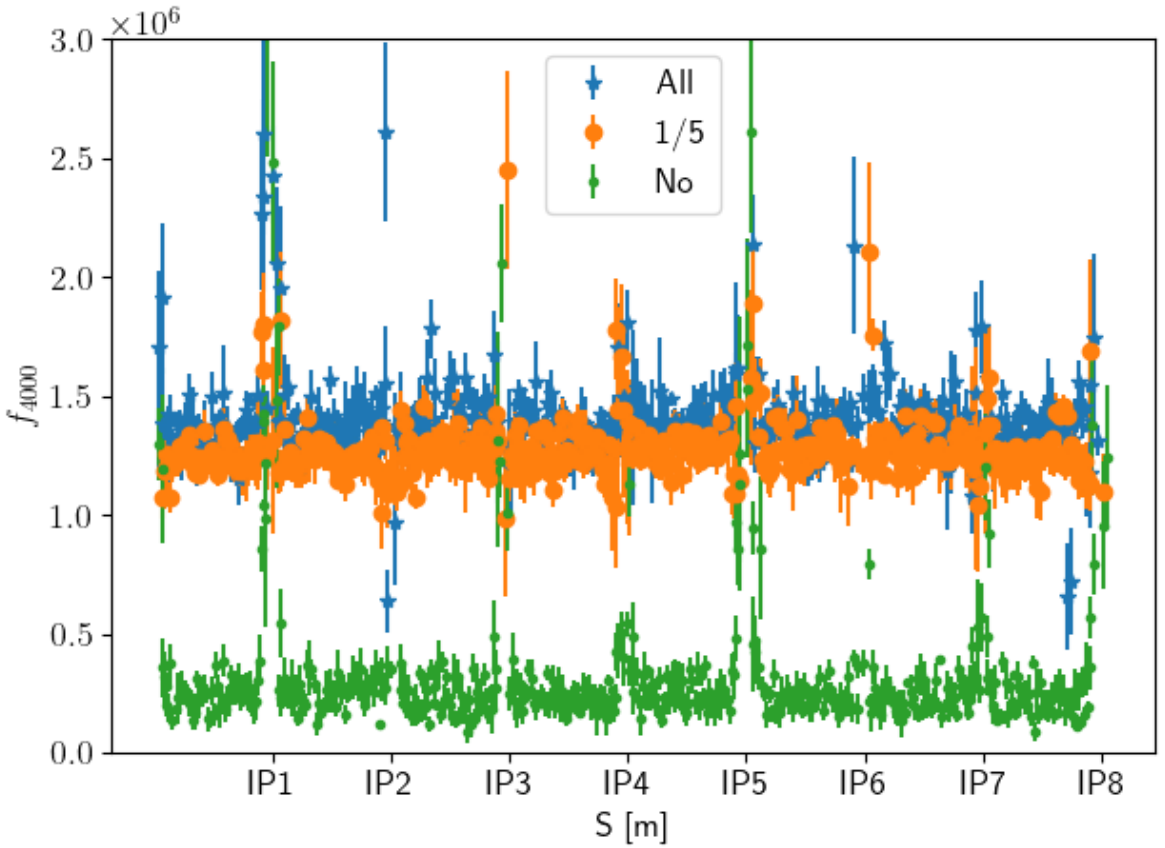
- The transverse coupling can increase the beam size
  - Normally we care about this at the IPs
  - If large it would have the same effect at the collimator
- The effect from the LRBB was small
  - -> Not the explanation for the hierarchy breakage



M. Hoffer, R. Tomas "Effect of local linear coupling on linear and nonlinear observables in circular
F. Soubelet, "Local Interaction Region Coupling Correction for the LHC"

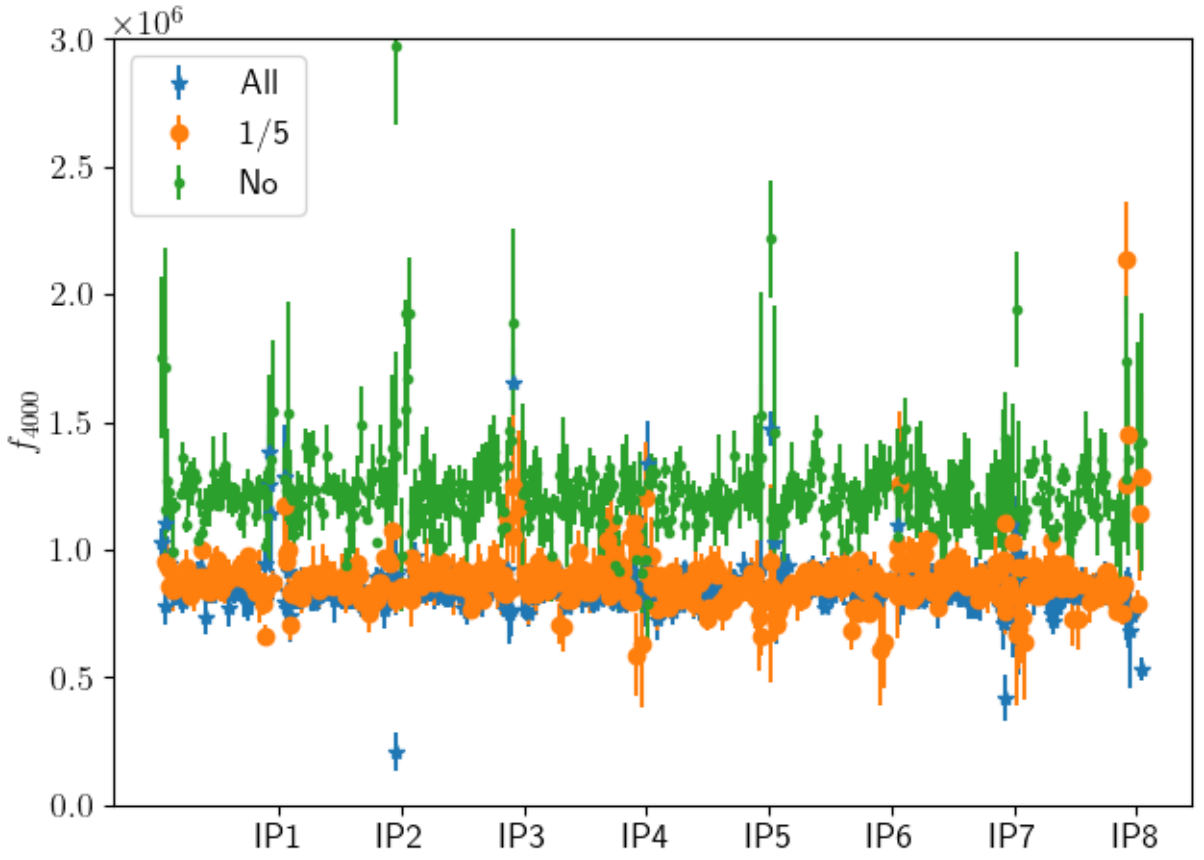
Octupoles RDTs (4Qx)

- A clear increase as expected of the octupolar RDT
- What is shown here is the driven f4000 (4Qx) meaning the effect of the AC dipole is not compensated for in the reconstruction
  - We are currently working to benchmark this in simulation

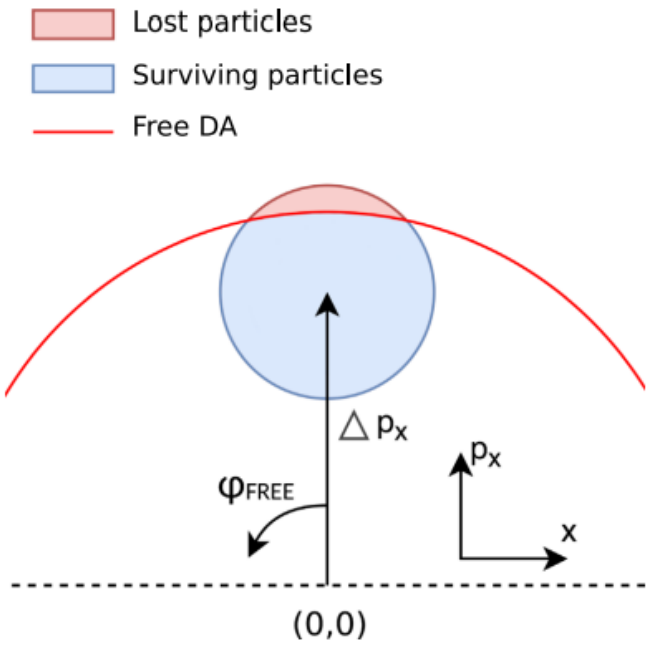


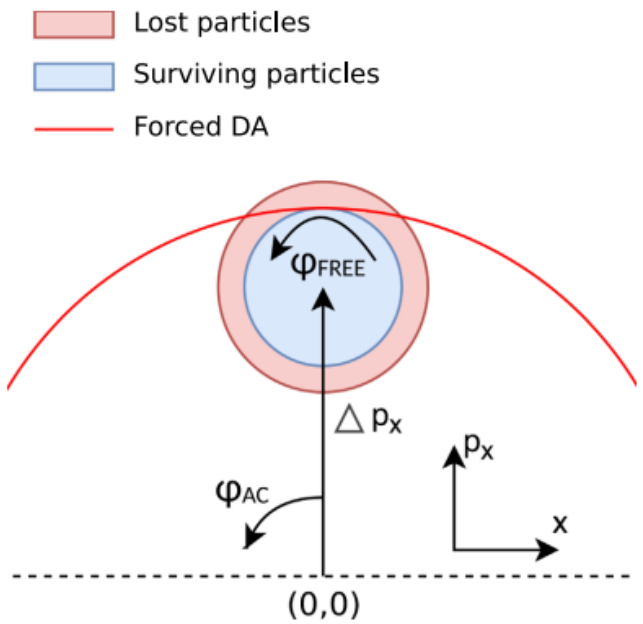
Octupoles RDTs with the LRBB Wire

- The LRBB wire is designed to reduce the negative impact of the beam-beam on lifetime (see talk from Guido)
- The driven f4000 is reduced from 1.5x10^{10} to ~1x10^{10}
- A clear increase of the bunch with no LRBB



Forced Dynamic Aperture



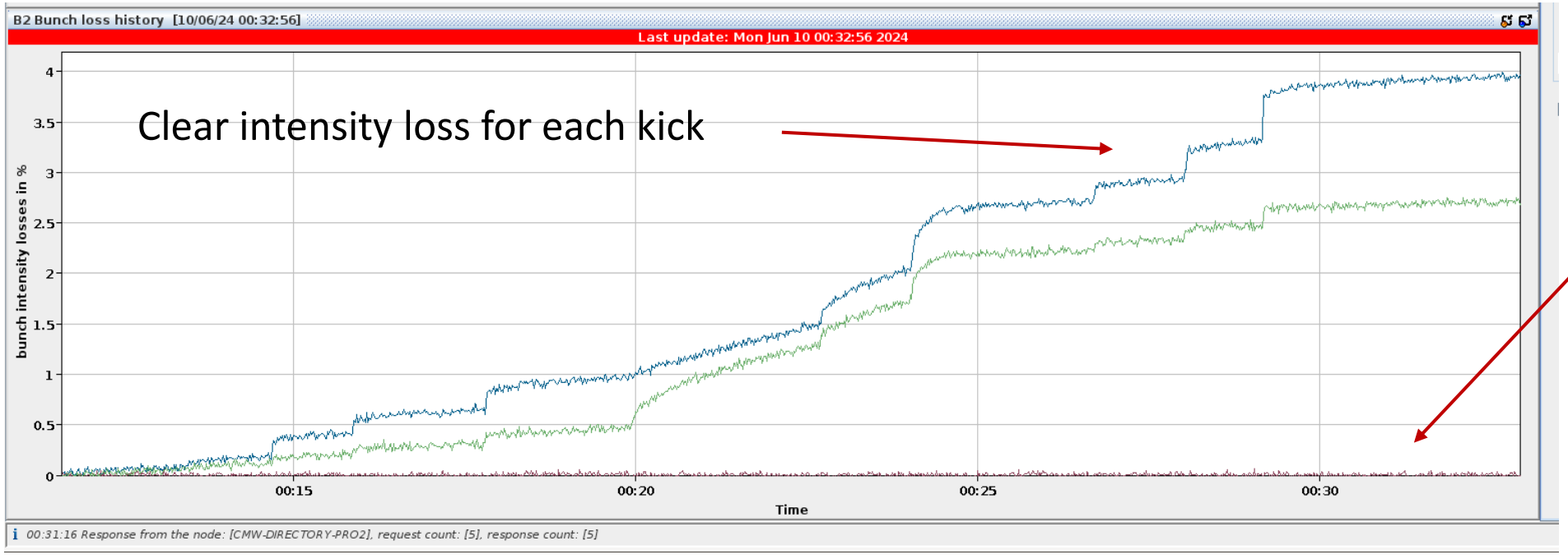


- It is possible to measure a forced dynamic aperture but difficult to relate it to the free
  - Possible to compare to tracking simulations

[7. Carlier, et al, First experimental demonstration of forced dynamic aperture measurements with LHC ac dipoles]

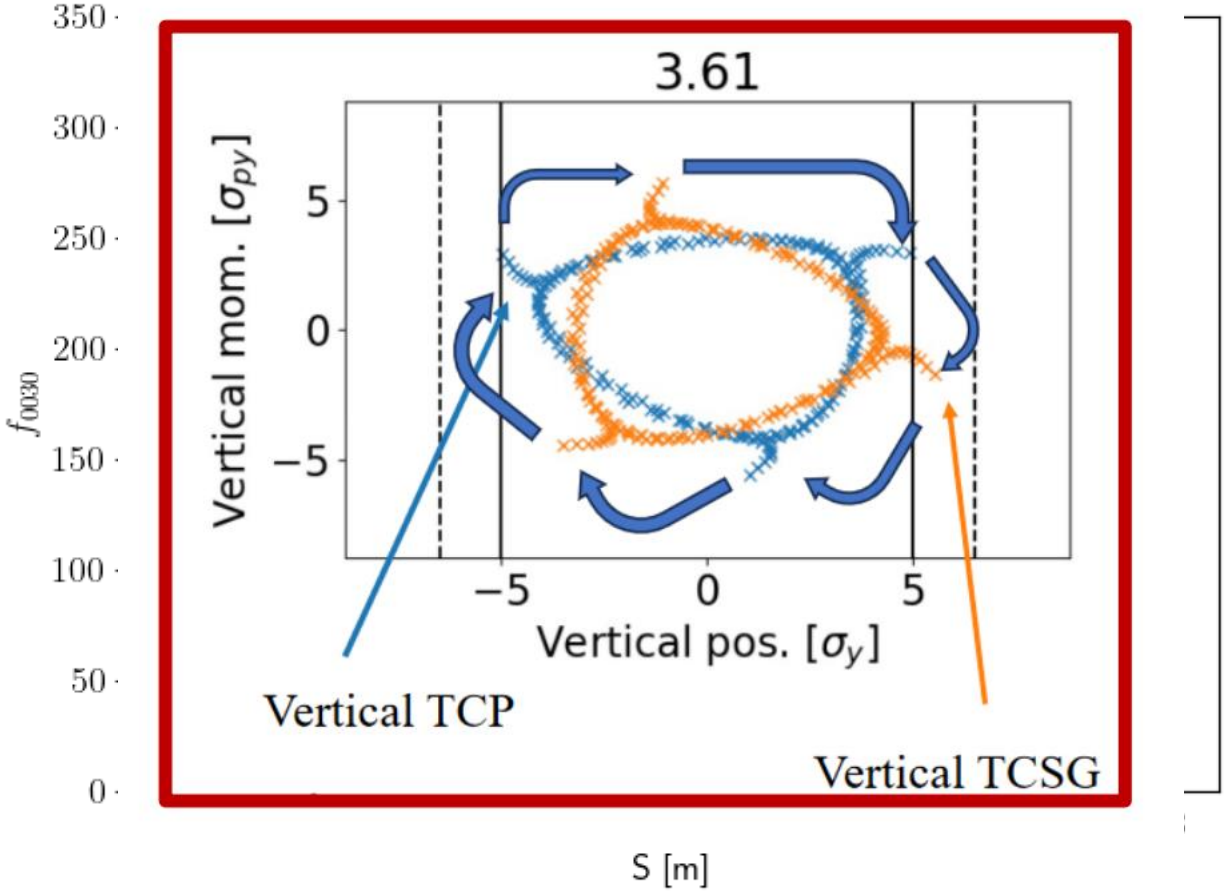
Forced Dynamic Aperture (without LRBB wire)

- Quantitatively there is a clear difference between bunches with and without LRBB
- Hard to make a quantitative assessment



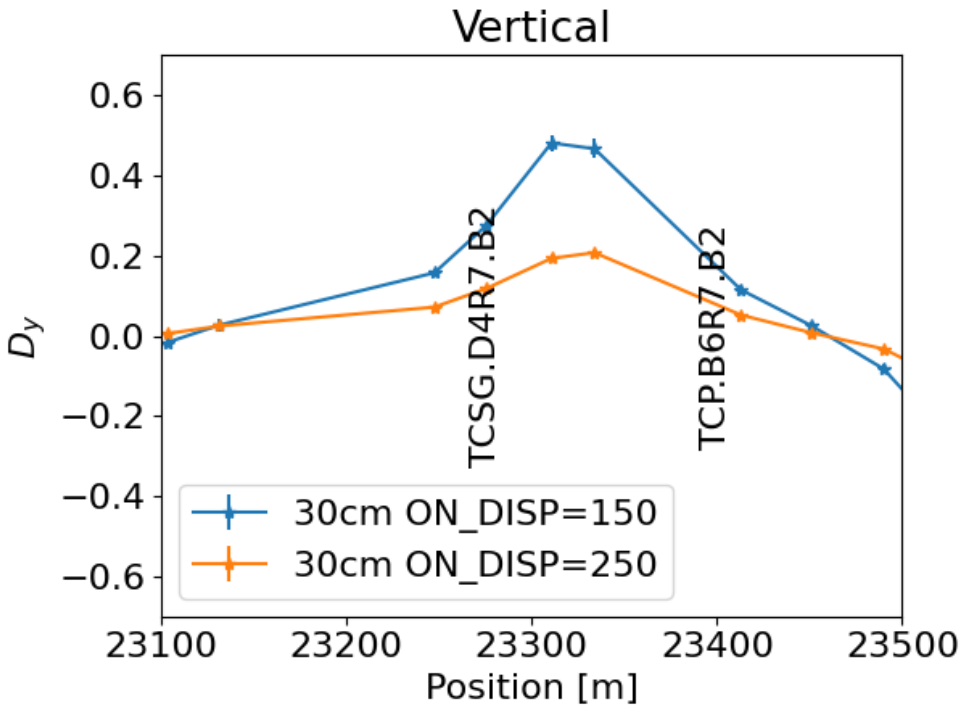
Beam-beam impact on 3Qy

- The hierarchy breakage was sensitivity to the tune
  - Increasing the vertical tune made the situation worse -> Sign that the 3Qy might play a role
  - When we implemented an a3 correction that also had a positive effect (~0.2 σ)
  - Simulation by K. Paraschou and X. Buffat showed that the 3Qy is of importance
- A clear increase of the 3Qy from LRBB
  - Working on a correction strategy, see Ewen's talk



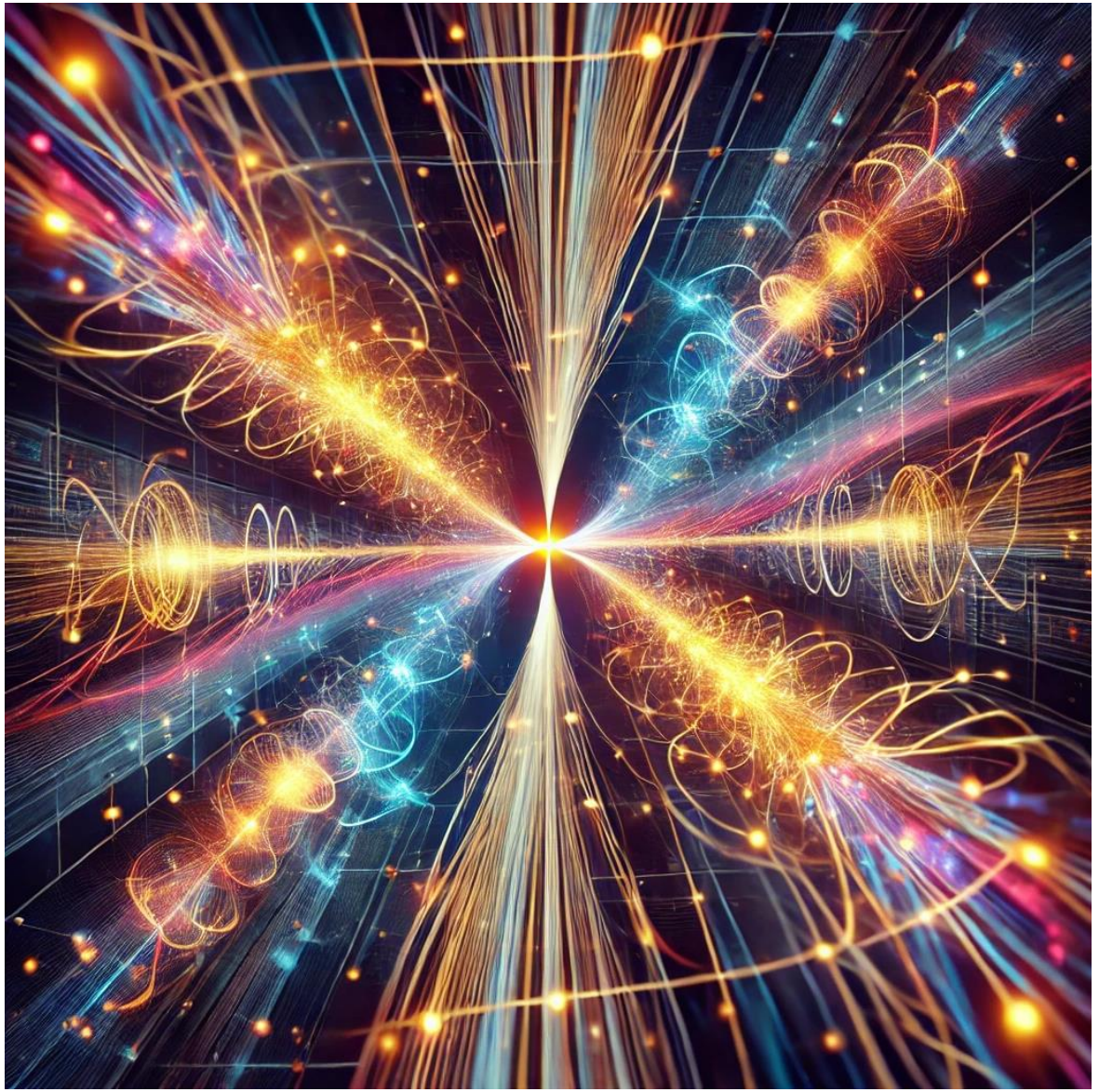
Beam-beam was not the only reason for the hierarchy breakage

- Other contributing factors were found to impact the hierarchy breakage (reduced margin)
  - Recuing the vertical dispersion at the collimators
  - **->**Increased the margin between the primary and the secondary with 0.4 σ (see D.Michari, LBOC)
  - A contributing effect but not the only one since not seen on loss maps or with a single beam
    - Still a two-beam effect is needed



Conclusion/Outlook

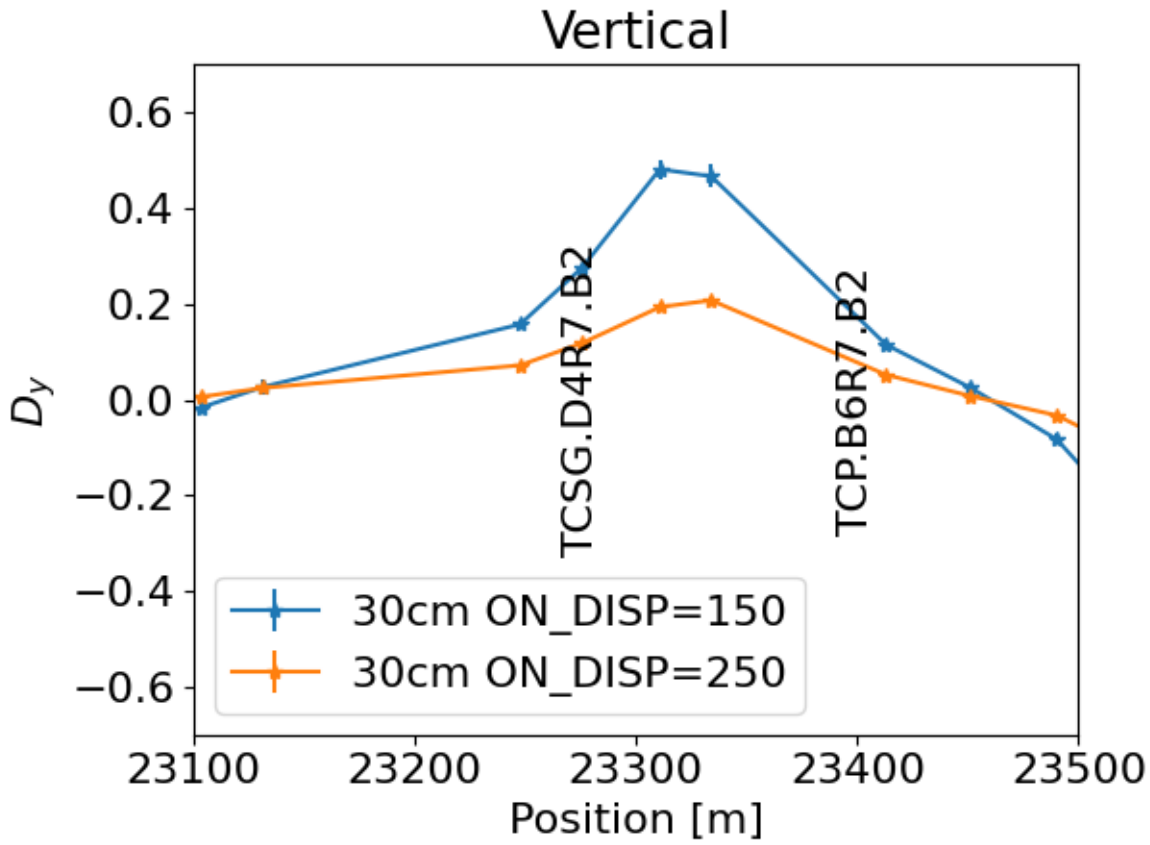
- A new setup to measure the effect of the LRBB has been demonstrated in the LHC
  - Opens up for other weak-strong studies
  - Excellent agreement with simulation for the change in β (β-beat)
  - The LRBB is already of importance but will be even more important when we go to smaller β* and higher intensities
    - Important to benchmark simulations
  - The plan is to include the strong-weak measurement for both beams in the next commissioning!
  - The 3Qy that was increased by the LRBB
    - Directly been linked to the collimator hierarchy breakage both in tests and simulations
    - The next step is to try to correct the 3Qy-driven by beam-beam (Next talk!)



Backup

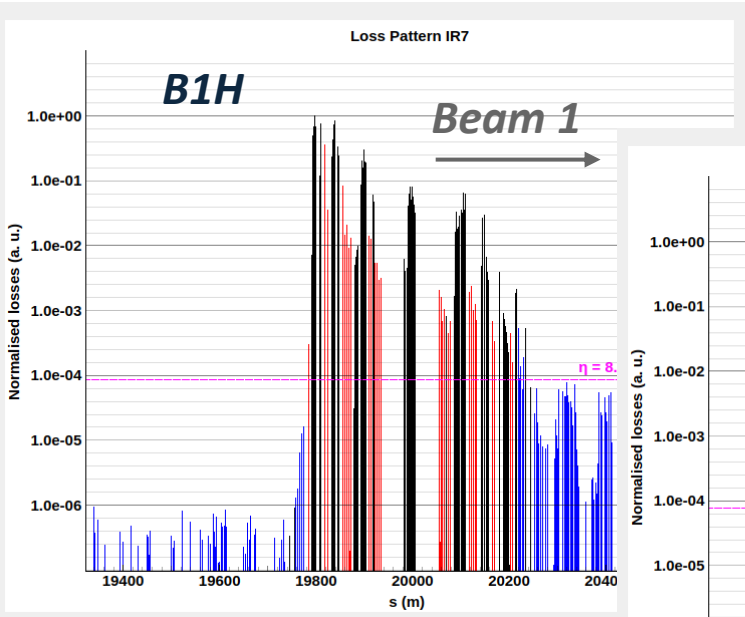
Vertical dispersion after correction

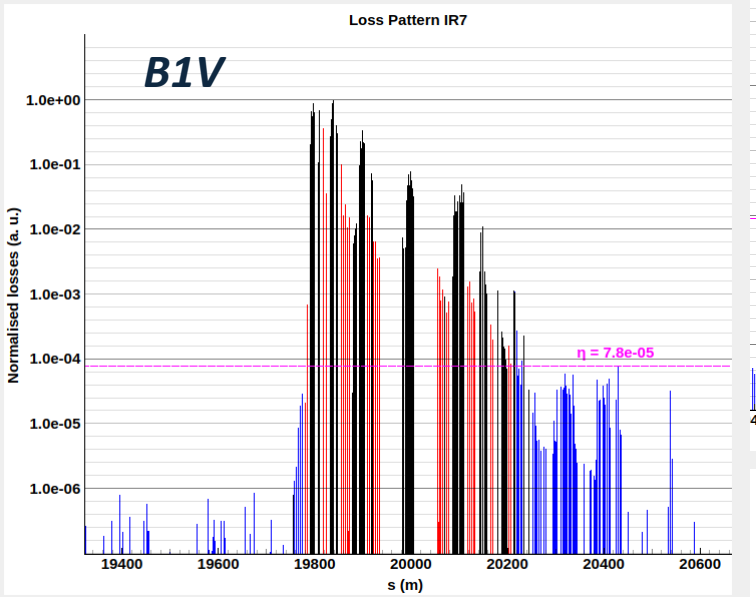
- Increasing the on_disp knob from nominal (150) to 250 reduces the vertical dispersion
  - Increased the margin between the primary and the secondary with 0.4 σ (see D.Michari, LBOC)
  - A contributing effect but not the only one since not seen on loss maps or with a single beam
    - A two-beam effect is need

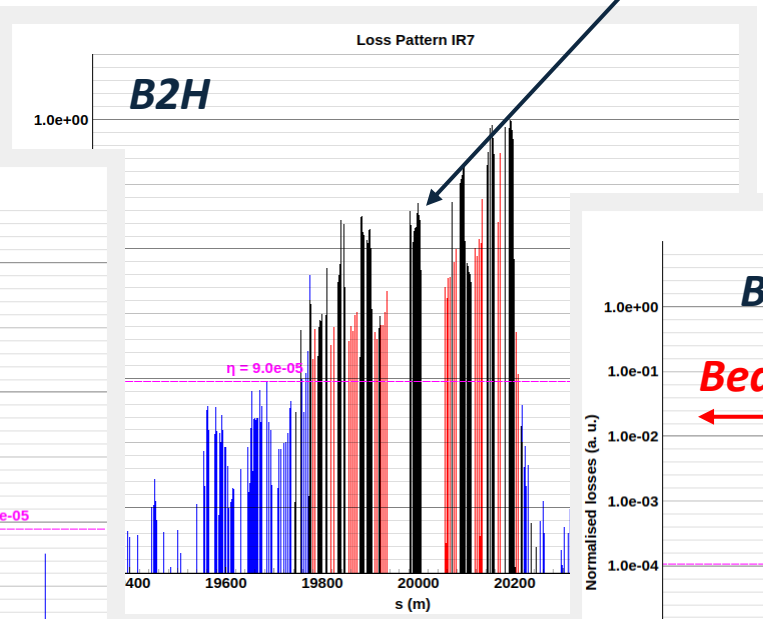


First investigation

- Perform a cycle to do loss maps with different MO and Q' settings

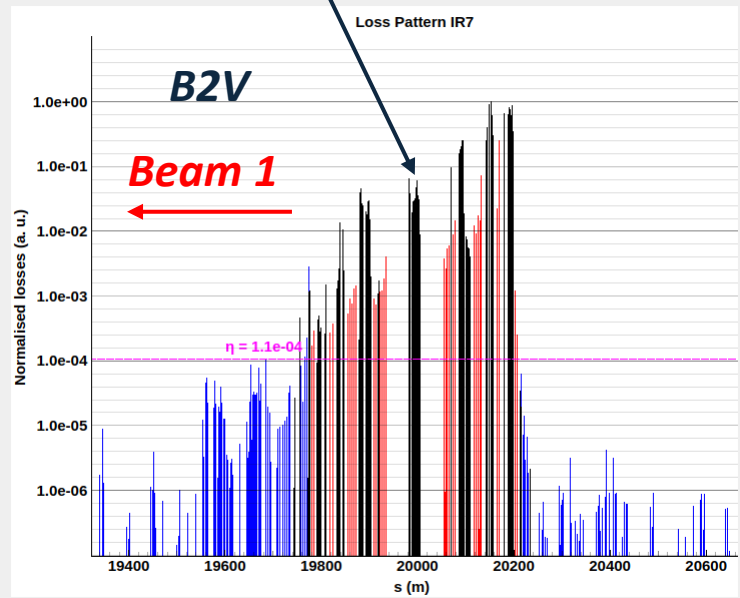






TCSPM.B4R7.B2

MO = -2
Q' = 20



Some of the cleanest loss maps ever observed: no hierarchy issues and excellent cleaning

Coupling

- The difference between the one without long range