OMC activities during the beam test

T. Persson on behalf of the
OMC-team

Date	Shift	Team	
10/21/2021	1		
	M	OP/RF/BI	Injection, threading, parasitic splashes
	M	OP/RF/BI	Injection, threading, parasitic splashes
	A	OP/RF/BI	Closed orbit and RF capture, tune, Q' ,coupling, BI setup
	A	OP/RF/BI	Closed orbit and RF capture, tune, Q' ,coupling, BI setup
	N	OP	Orbit corrector & BPM polarity
	N	OP	Orbit corrector & circuit polarity
10/22/2021	2		
	M	OP	Reference orbit with probe, energy matching to SPS
	M	OP/BI	Orbit & tune FB commissioning, BI setup, AC dipole
	A	OP/BI	Orbit & tune FB commissioning, BI setup, AC dipole
	A	COL	Coarse setup for probes
	N	OP	Kmodulation - triplet BPM offsets
	N	OP	Kmodulation - triplet BPM offsets
10/23/2021	3		
	M	OP	Splashes
	M	OP	Splashes
	A	OMC	AC dipole, optics at injection
	A	OMC	Optics measurement & correction
	N	OMC	spare
	N	OP	FMCM tests
10/24/2021	4		
	M	RF	Cavity phasing and ADT setup
	M	RF	Cavity phasing and ADT setup
	A	ADT	ADT setup with probes, ADT excitation
	A	OMC	Optics measurement & correction
	N	OMC	Optics measurement & correction
	N	OMC	spare

Do the essential checks of equipment and software

10/25/2021	5		
	M	COL	Collimator setup, global injection aperture
	M	COL	Collimator setup, global injection aperture
	A	ABT	Injection and dump aperture
	A	ABT	Injection and dump aperture
	N	OP	Feedback tests
	N		
10/26/2021	6		
	M	MPS	BLM dump trigger tests
	M	MPS	BLM dump trigger tests
	A	ABT	Kick response line + ring, MKI2 waveform
	A	ABT	14/15 kickers knob
	N		
	N		
10/27/2021	7		
	M	OP/RF/BI	Nominal bunch injection, BI, RF tuning
	M	OP/RF/BI	Nominal bunch injection, BI, RF tuning
	A	OP	Collision setup with nominal bunches, ALICE to +/+
	A	OP	Collision setup with nominal bunches
	N	OP/ABT	MKB waveform
	N		
10/28/2021	8		
	M	COL	Collimation setup nominal bunch
	M	COL	Global aperture with nominal bunch
	A	COL	Loss maps
	A	RF	ADT setup
	N	RF	ADT setup
	N		

10/29/2021	9		
	M	OP	Preparation first stable beams
	M	OP	ALICE -, Stable beams at injection
	A	OP	Stable beams at injection
	A	OP	Xing levelling test
	N	OMC	OMC tests
	N	OMC	OMC tests
10/30/2021	10		
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	A	OP	ALICE pol +, Stable beams at injection
	N	OP	Stable beams at injection
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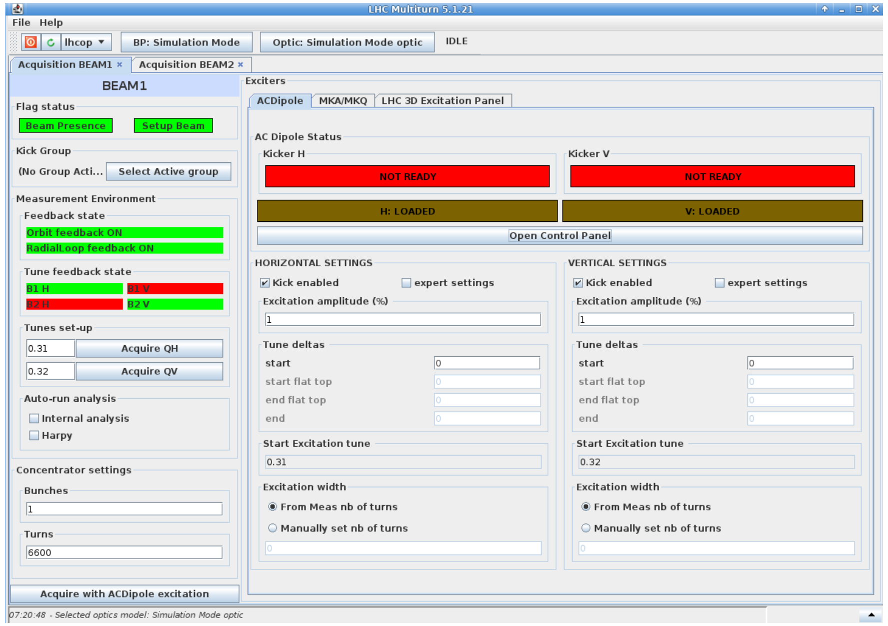
	N		
	N		

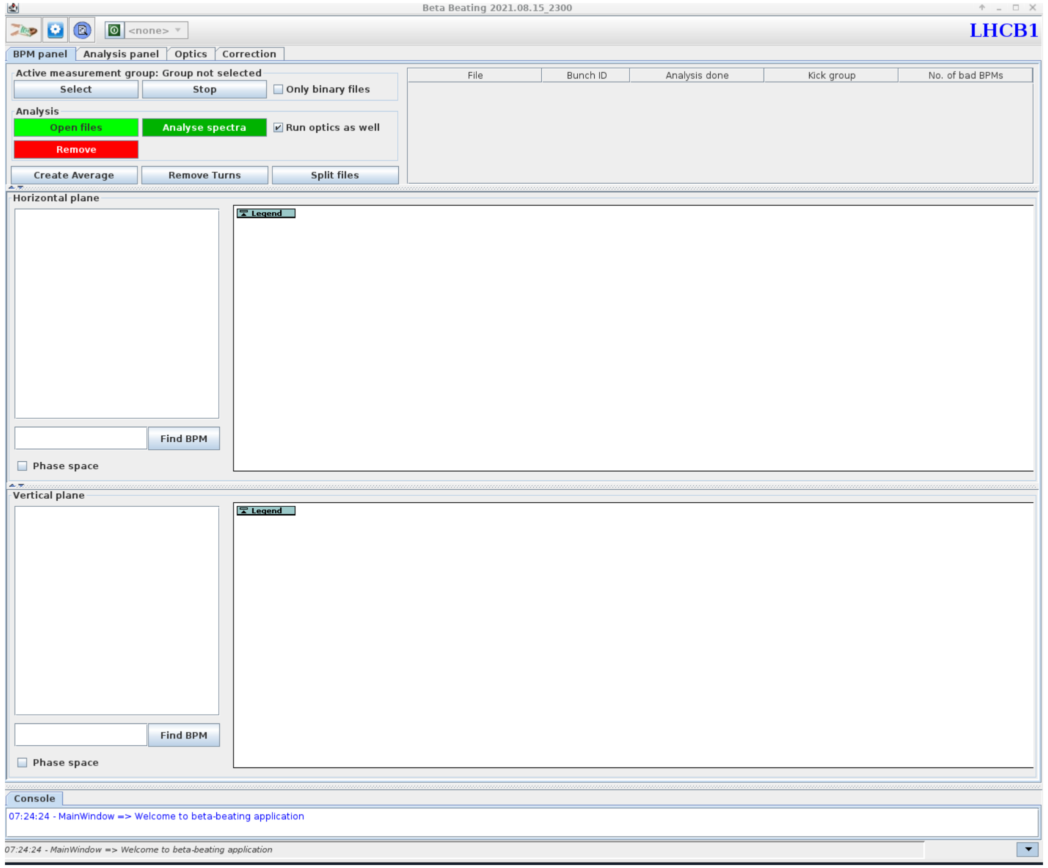
Note that the dates are likely to shift. Already starting day could potentially be 2 days ahead of schedule!!

Essential

- The first thing is to excite with the AC-dipole and record with the BPMs
  - In 2015 there were some issues with the phasing of the BPMs
  - New multiturn and changes to the AC-dipole potential source of issues
    - Could be 5 min but could also be days
  - ADT-AC dipole
  - K-modulation
  - MKQ, MKA (without changing setting in the tunnel)
- Important checks at injection
  - 3D-excitation

New software and functionalities

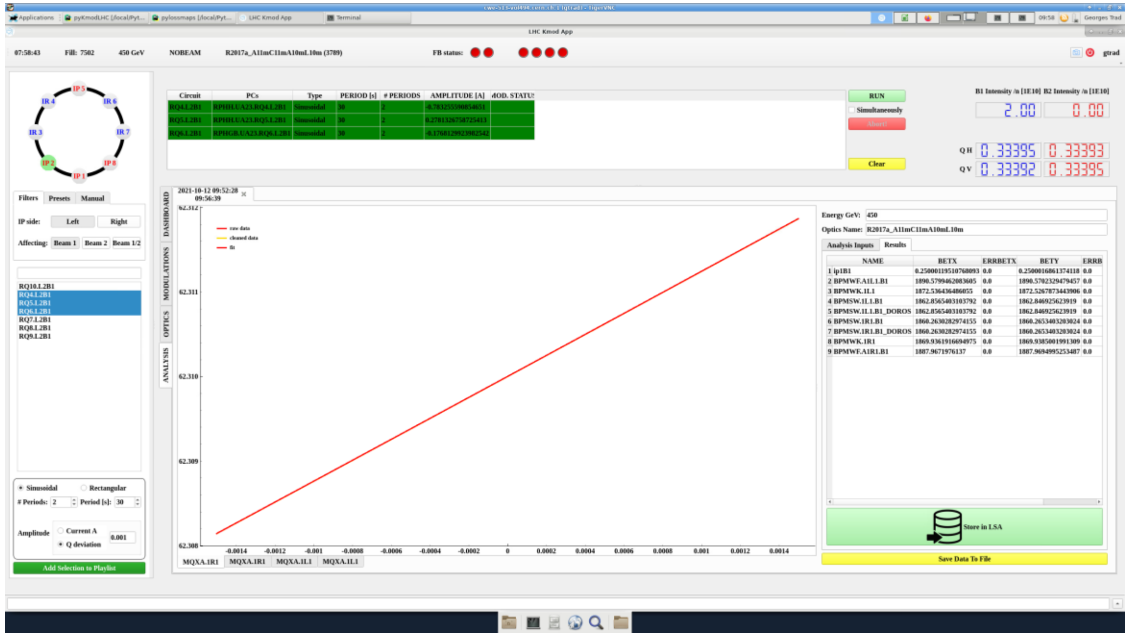


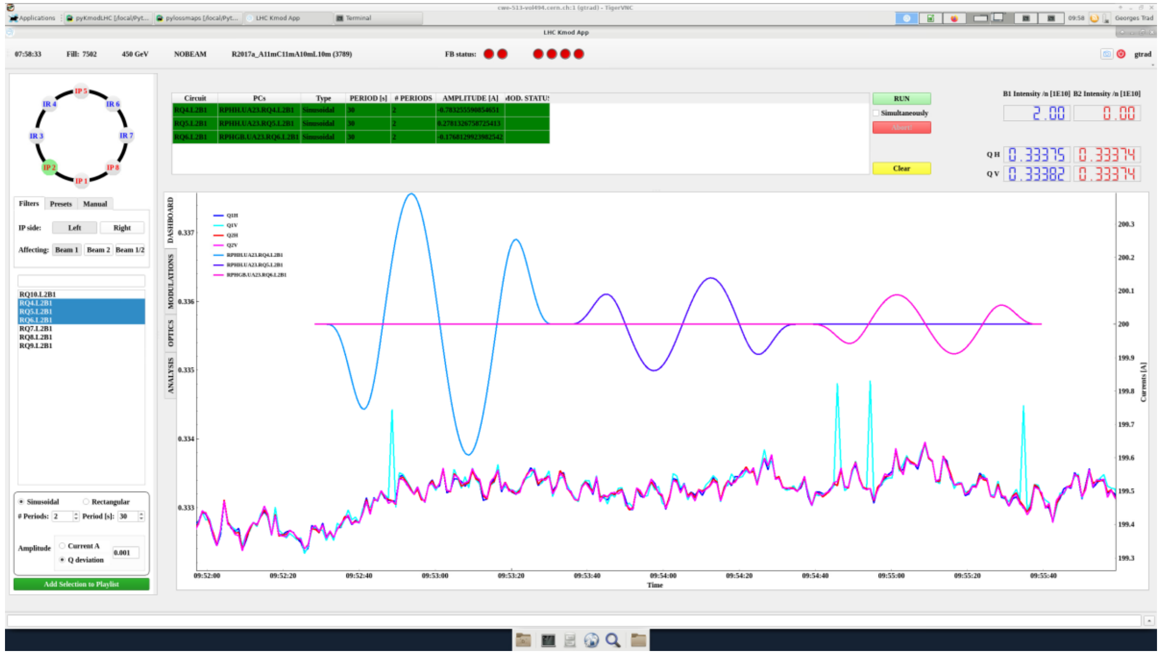


- New multiturn application
  - Made by LHC-OP
- New functionalities added to the AC-dipole
- New OMC-GUI
- The code to analyse the data is also re-written (OMC3)

<u>Status: The kicker has been pulsed so looks promising</u>

K-modulation

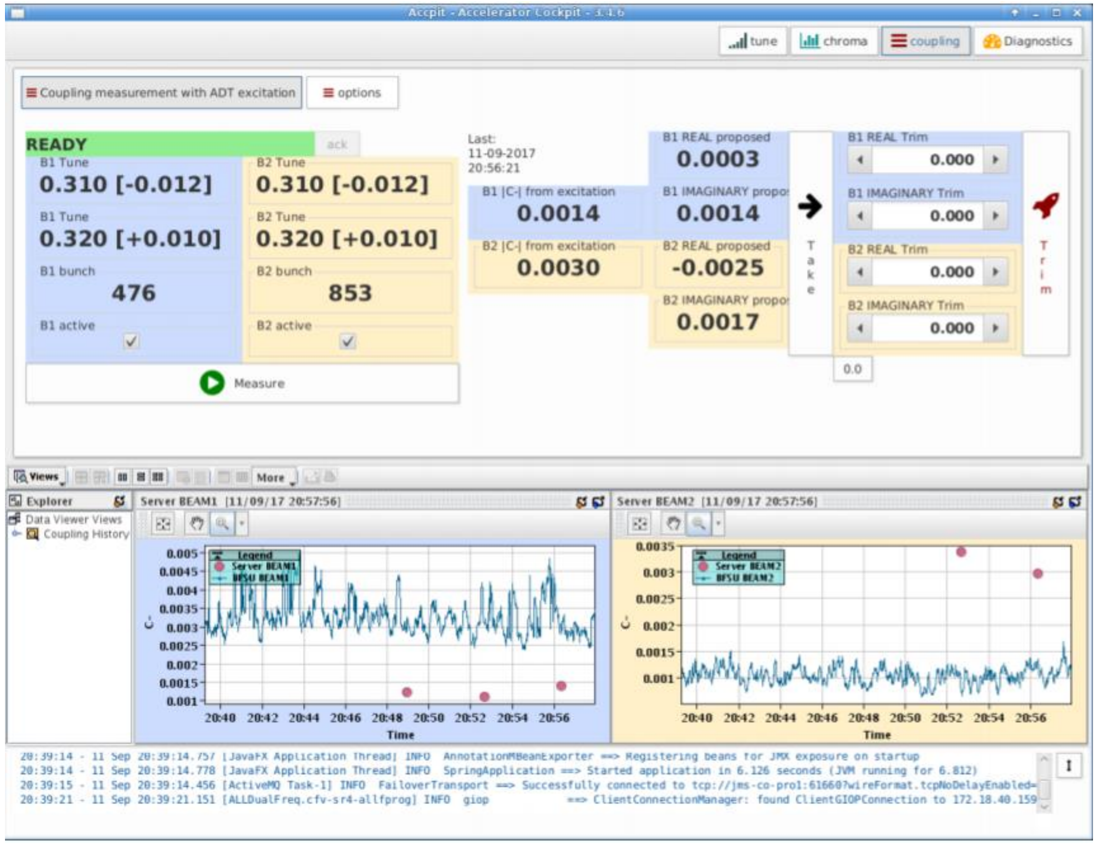




- New GUI developed in Python by Georges Trad in close collaboration with Michael Hofer to interface our analysis
- Enables the modulation of more magnets including Q2, Q3 and even an entire arc!

<u>Status: Has been tested to drive magnets</u>

ADT AC - dipole

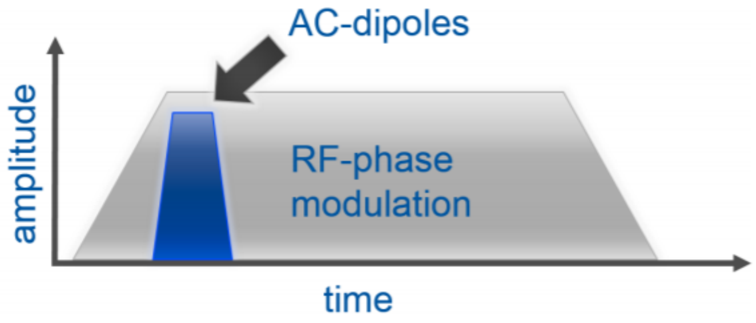


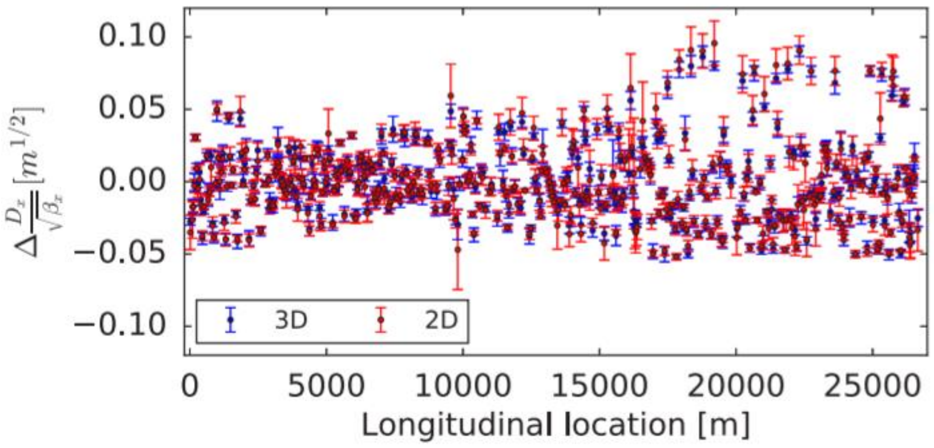
- New protocol to transfer the data
- Using the new code base (OMC3) and [different compensation method](#)for the driven motion.

[A. Calia, et al “Online coupling measurements and correction throughout the LHC cycle”](#)

Status: Has been deployed and tested with fake data. The ADT class is not yet tested.

3D – kicks





- The RF phase is modulated at the same time as the AC dipole excites the beam
  - Can enable measurement of dispersion and chromatic functions during the ramp
  - This is implemented in the Multiturn application

L. Malina

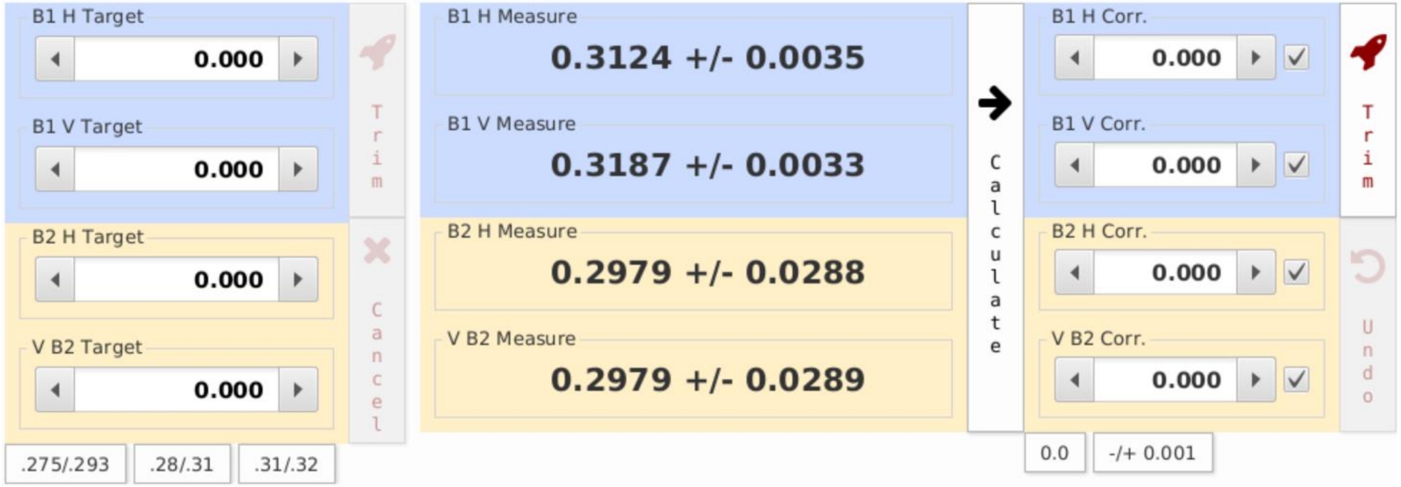
Status: Is implemented but still needs to be tested

Close collaboration with OP

- The new applications are developed and maintained mainly by LHC OP
  - When it comes to access hardware devices, RBAC etc, this is much more efficient since they have more experience in these area.
  - We still need to collaborate closely since we are the expert on what to expect for many of the applications.
  - A very fruitful collaboration!
- A personal reflection is that the OMC-OP Workshop was very beneficial to increase our understanding of the common challenges
  - In the next slide I will mention one of them

Target and Correction

- One of the difficulties with re-create the state of the machine at a given time has been that it is not known from the logging why a setting was change.
  - E.g., The tune knob is changed in LSA: Was this a change of working point or was this simply a correction of the tune back to the nominal?
  - In the OMC-OP workshop different possibilities were discussed but, in the end, the main was to use the two different properties in LSA: Target and Correction.
    - E.g., Target when you want to change the working point and correction when you want to correct the tune back to nominal
    - This is now adopted in the accelerator cockpit application and the idea is to use this principle throughout the run



Back to the beam test

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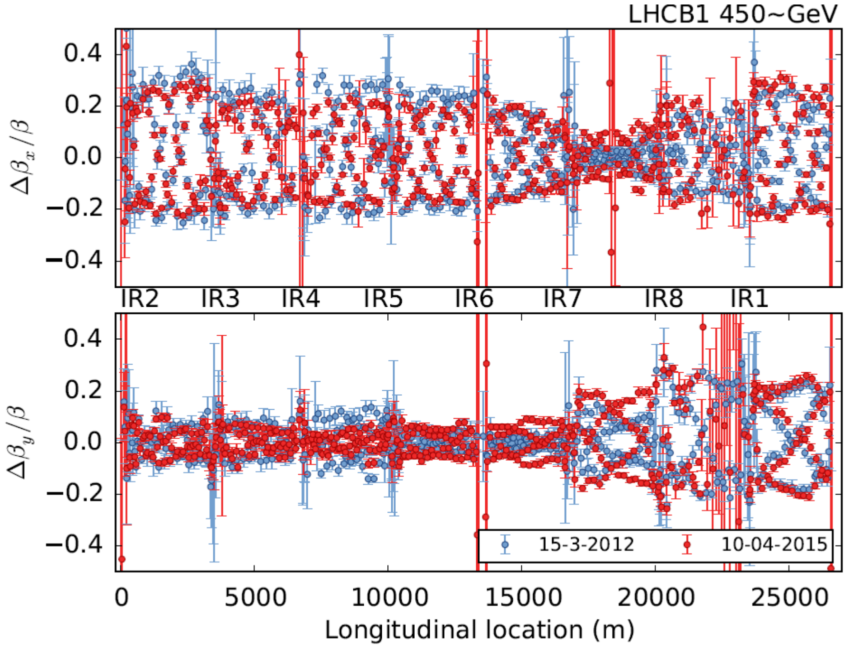
	N		

Do the essential checks of equipment and software

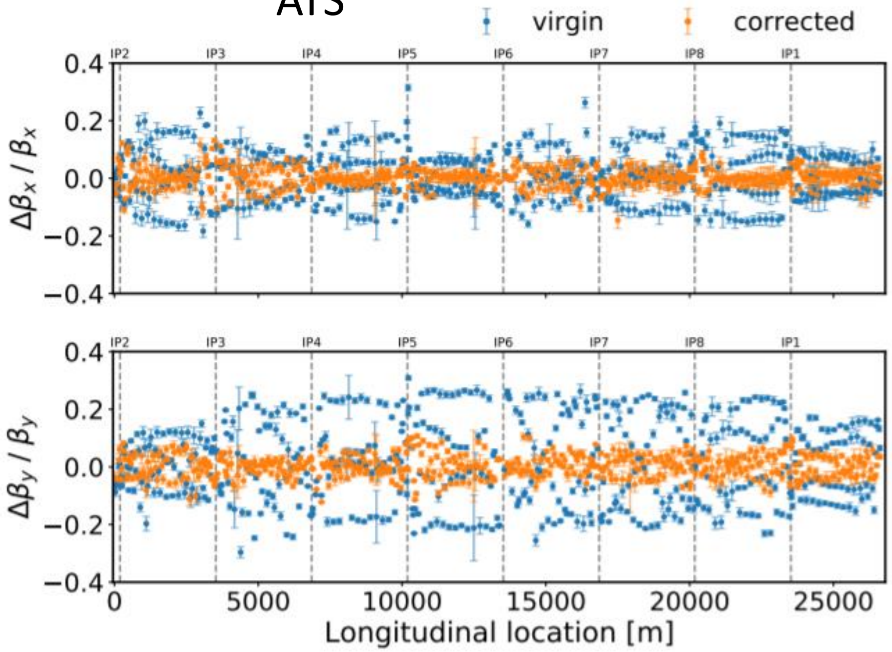
Calculate the corrections: Local coupling and global beta-beat

β-beating at injection

Virgin machine (non ATS)



ATS

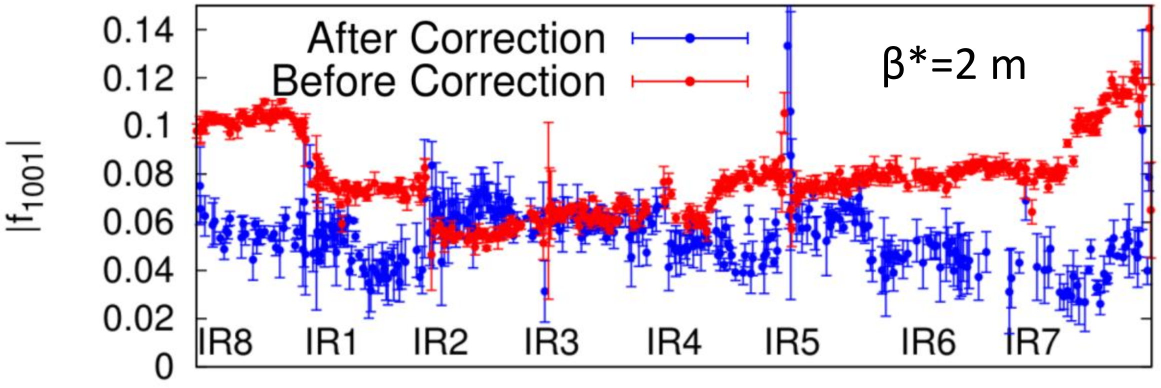


- The β-beat at injection has stayed relatively similar between Run 1 and Run 2
- If we measure and correct during beam test we can most probably use the same corrections in 2022

Local coupling

- The local coupling corrections did not change so much from end Run 1 to Run 2
  - Two data points are not much statistics! Rotations might have changed this time..
  - A rough correction at injection can be made
- Before local correction and arc-by-arc corrections (when needed) are applied the BBQ coupling measurement is less reliable

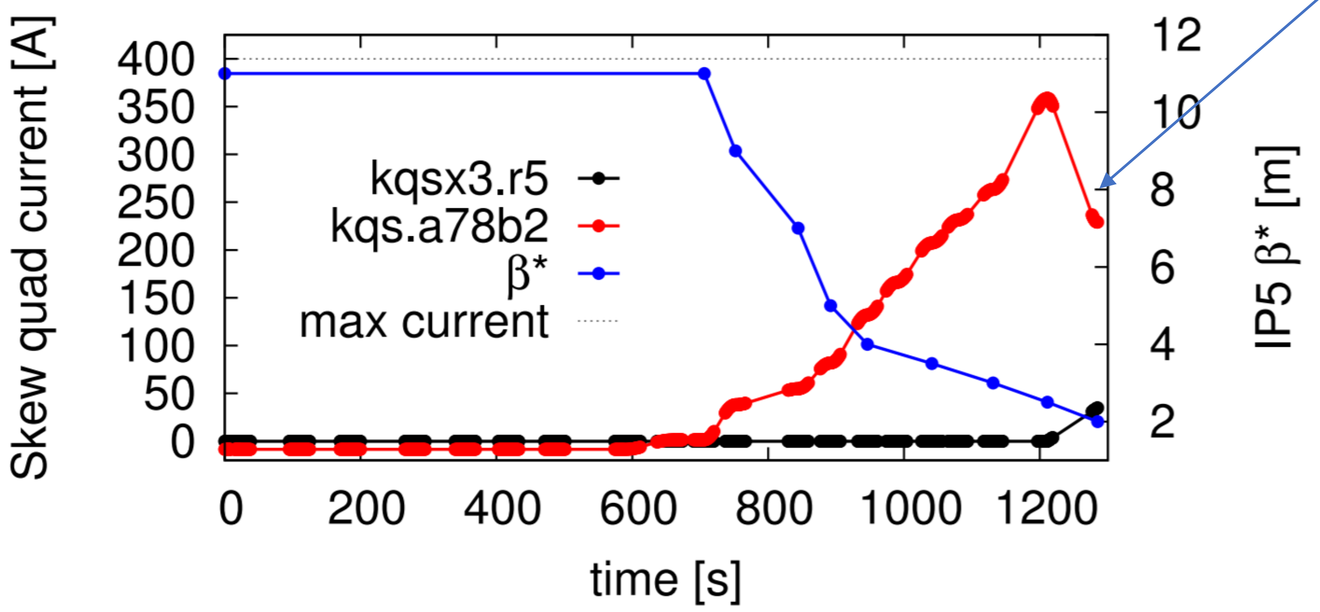
Before and after local coupling correction. Note that the global knobs also have been readjusted.



	Circuit	Δk (10^{-4}m^{-2})		
		2012	**2015**	**2016-2018**
IR1	**RQSX3.L1**	8.0	8.7	11.0
	RQSX3.R1	8.0	8.7	7.0
IR2	**RQSX3.L2**	-9.0	-16	-14.0
	RQSX3.R2	-9.0	-16	-14.0
IR5	**RQSX3.L5**	6.0	7.0	7.0
	RQSX3.R5	6.0	7.0	7.0
IR8	**RQSX3.L8**	-7.0	-5.0	-5.0
	RQSX3.R8	-7.0	-5.0	-5.0

If we don't correct the local coupling

- In 2010 (3.5 TeV) the strength of the arc skew quadrupoles were almost maxed out before the local coupling corrections were implemented
  - Local corrections needed for the first ramp and squeeze



β * = 2 m

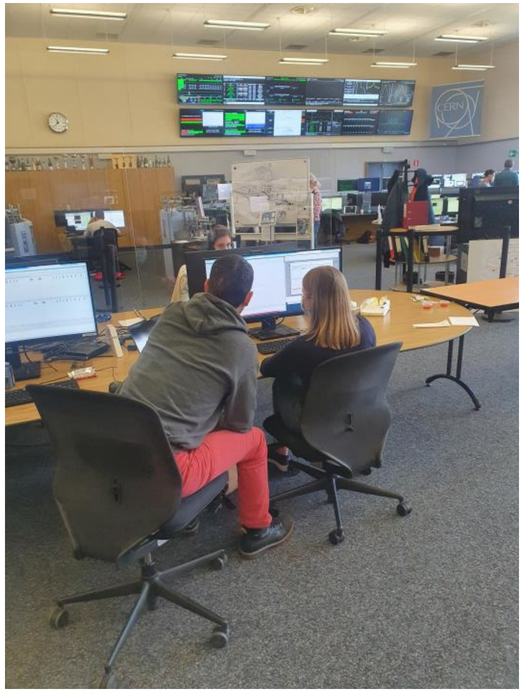
Beam 1 Delta knob|C-|	**0.046**
Beam 2 Delta knob|C-|	0.022

Glenn Vanbavinckhove

How do we prepare for this?

Testing in the CCC

- Two purposes:
  - Finding issues and bugs
  - Train new people and remind the rest of us how to use the applications and calculate the corrections
- We already had one session but split into 3 different time slots.
  - We are now in the middle of a second iteration.



Beta-beat.src and OMC3

- Beta-beat.src was used extensively used in Run 1 and Run 2 so well tested
- OMC3 more flexible but still needs so more testing and still missing some functionalities
  - Will use the beam test to continue testing the OMC while using the beta-beat.src as the reference

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	N	OMC	spare
	N	OP	FMCM tests
10/24/2021	4		
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	M	RF	Cavity phasing and ADT setup
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10/25/2021	5		
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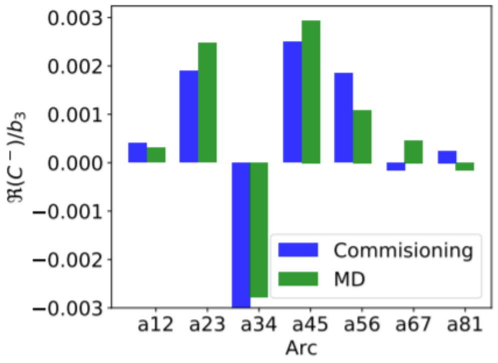
Do the essential checks of equipment and software

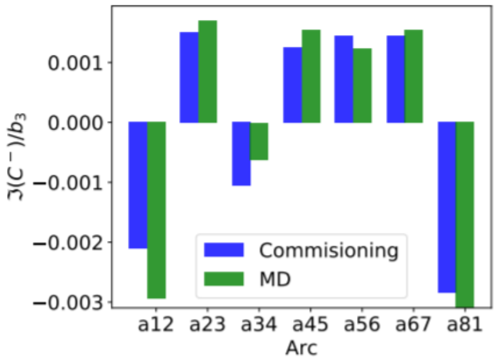
Calculate the corrections: local coupling and global beta-beat

MCS, Q'' and potentially a re-validation of the corrections if needed

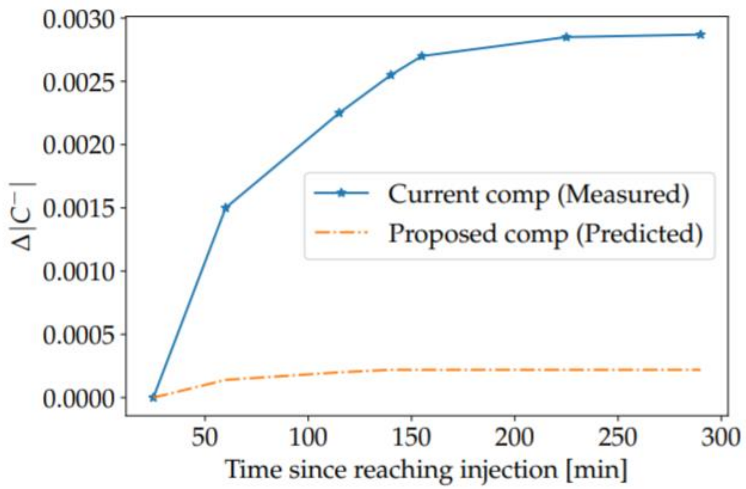
Counteract the coupling drift at injection



(a) Real part of the C^-



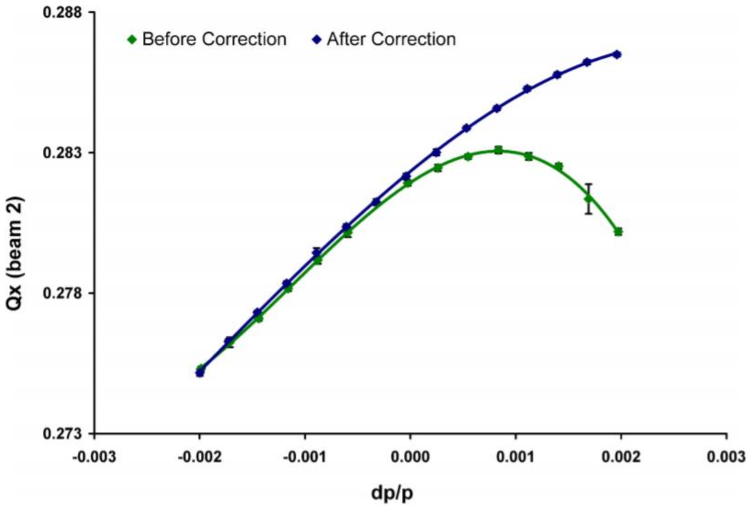
(b) Imaginary part of the C^-



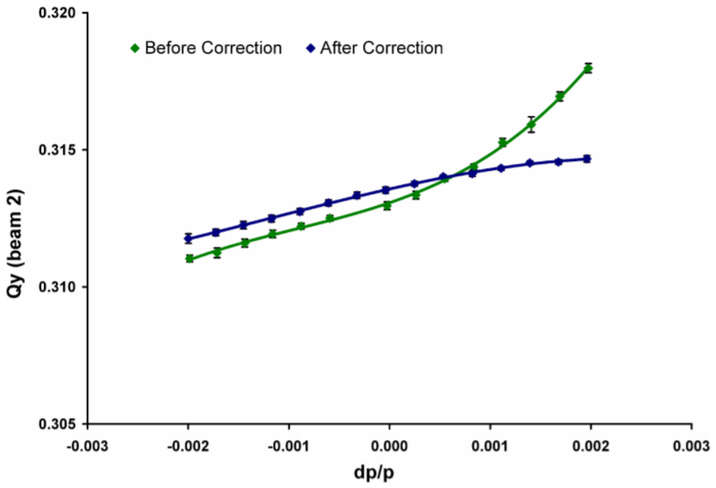
- We change the setting of each of the MCS arc-by-arc
  - Measure the change to C-
  - Stayed constant between 6 months in Run 2.
- Based on this measurement we could potentially have an uneven dynamic b3-compensation

T. Persson

Measuring Q'' and Q'''

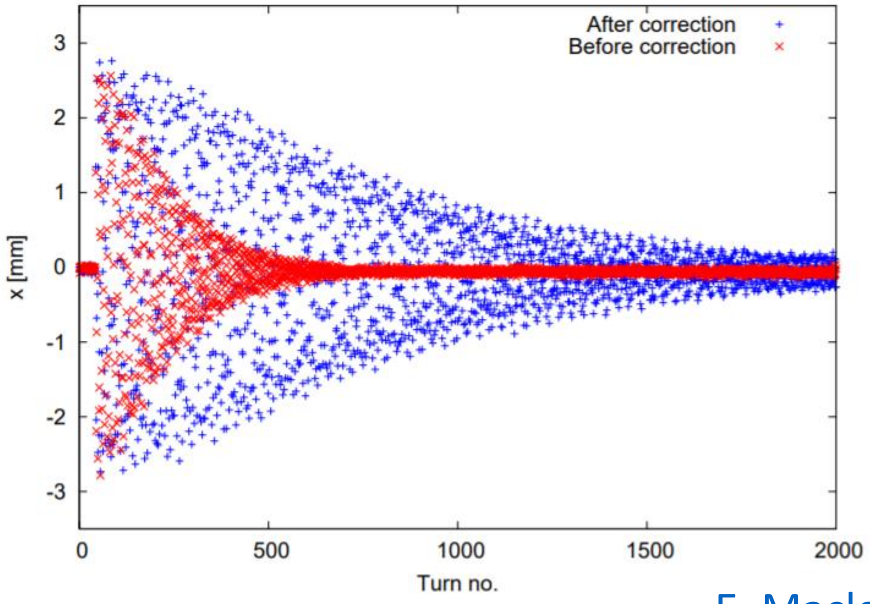


(a) Horizontal chromaticity



(b) Vertical chromaticity

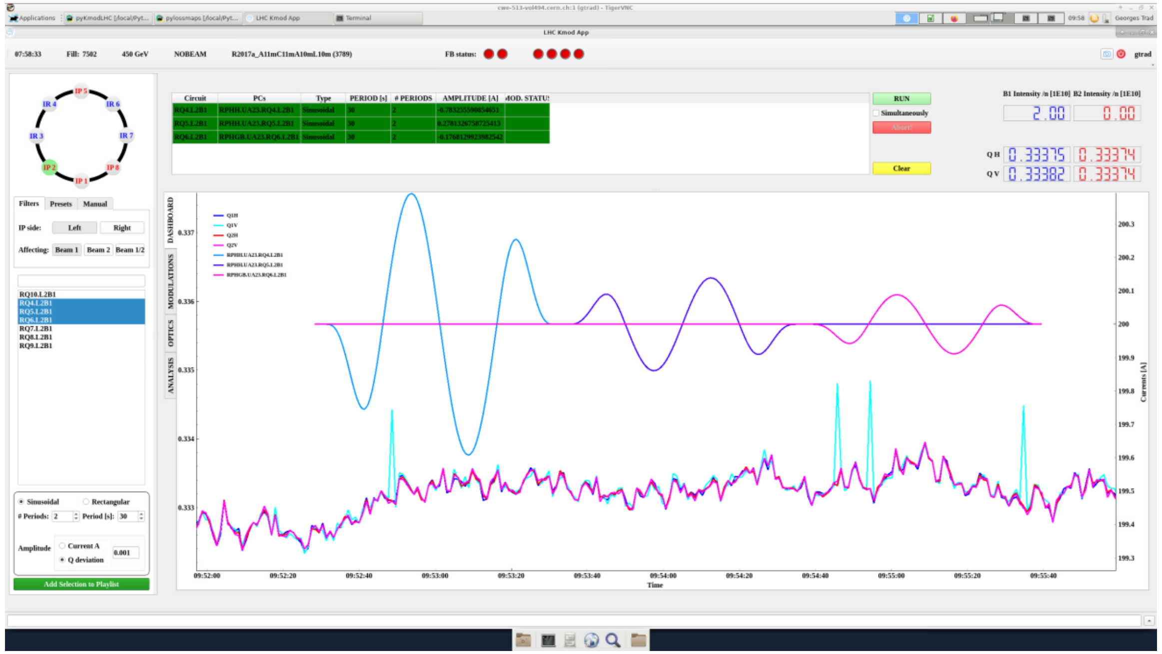
- Interesting to compare to previous years
  - Help to constrain a beam-based corrections



E. Maclean

Exotic K-modulation

- K-modulation sector-by-sector (4h)
  - Will give an independent measurement of the average beta-function
  - Also try the functionality to trim the Q2 for example



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Potentially the 60 deg phase advance (4 people needed + collimation experts)

Do the essential checks of equipment and software

Calculate the corrections: local coupling and global beta-beat

MCS, Q'' and potentially a re-validation of the corrections if needed

60 deg phase advance optics

- Try the 60 deg phase advance optics (8h)
  - Designed for a higher energy LHC (replace every third dipole to 11 T) but would also probe the errors differently and would help to constrain the corrections further
  - Significant different so will also help understand orbit errors
  - Could bring insight into BPM calibration errors as well

60 deg phase advance optics

- Would be a different optics with different settings
  - Help identifying underlying alignment and magnetic errors
  - In particular the momentum compaction factor is different

Parameter [Unit]	**60°LHC**	**90°LHC**
β_{min}/β_{max} [m]	63/182	32/177
η_{min}/η_{max} [m]	2.5/4.1	1.1/2.2
Momentum Compaction [10^{-4}]	6.9	3.5
Transition Energy [GeV]	40.0	53.6
Natural Chromaticity at 450 GeV	- 60	- 83
Corrected Chromaticity at 450 GeV	2	2
Sextupole Strength at 450 GeV [Tm^{-2}]	56	142
Tune at Injection Optics (H,V)	45.28/44.31	62.28/60.31

J. Keintzel

Mom. Comp. Factor Measurements

- Fit of relative energy (momentum) offset over frequency
- Problem: no device in LHC to measure energy → Use TbT measurements

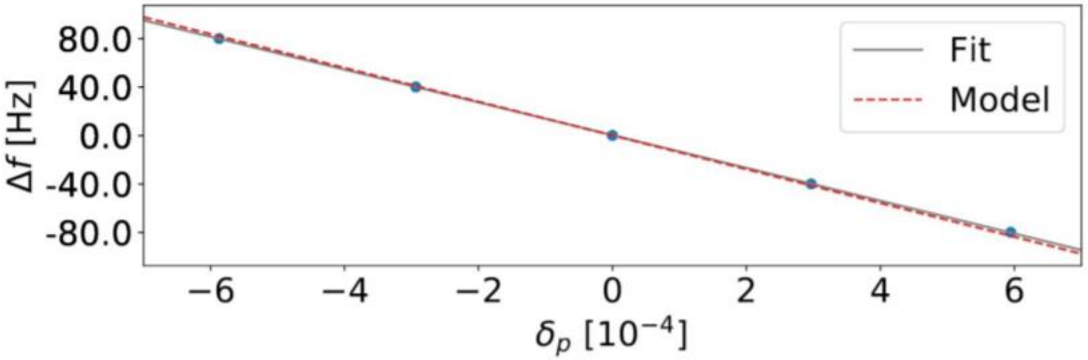
$$\delta_p = \frac{\langle \eta_x^{\mathrm{mdl}} CO_x \rangle}{\langle (\eta_x^{\mathrm{mdl}})^2 \rangle}$$

Measured closed orbit and model dispersion at arc BPMs

- Fit using

$$\delta_p = -\left(\frac{1}{\gamma_{\mathrm{rel}}^{-2} + \alpha_C} \right) \frac{\Delta f}{f}$$

E = 6.5 TeV and therefore the relativistic gamma is negligible



Relative error between measurement and model about ***-3 %***

J. Keintzel

Beam Position Monitor Errors

- Measured closed orbit used for momentum offset calculation

$$\delta_p = \frac{\langle \eta_x^{\text{mdl}} CO_x \rangle}{\langle (\eta_x^{\text{mdl}})^2 \rangle}$$

Measured closed orbit not necessary real orbit

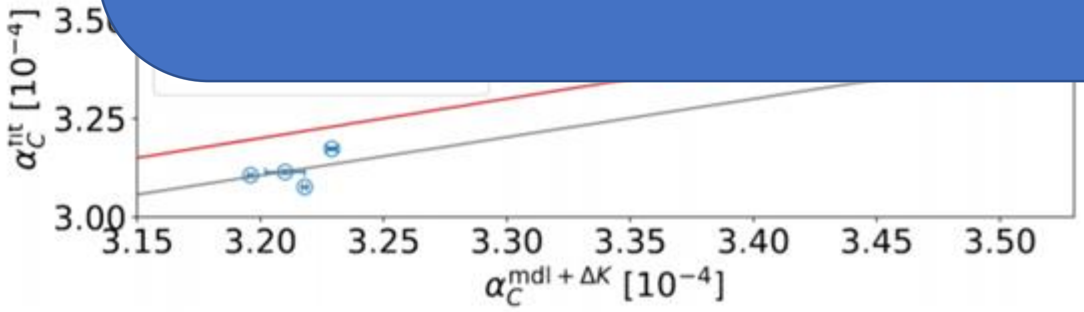
$$CO_x^{\text{meas}} = C \times CO_x^{\text{real}}$$

BPM calibration C can modify real orbit to measured one

- What would ca
- If average C_i o
- → δ_p^{meas} would
- → Slope of δ_p o
- → Momentum

$x,i\rangle$

, 2020



Takeaway: Around 3% error tentatively attributed to the arc BPMs -> IR BPM calibration from ballistic optics are also off because the method uses the arc BPMs

Keintzel

Beam Stay Clear at 450 GeV

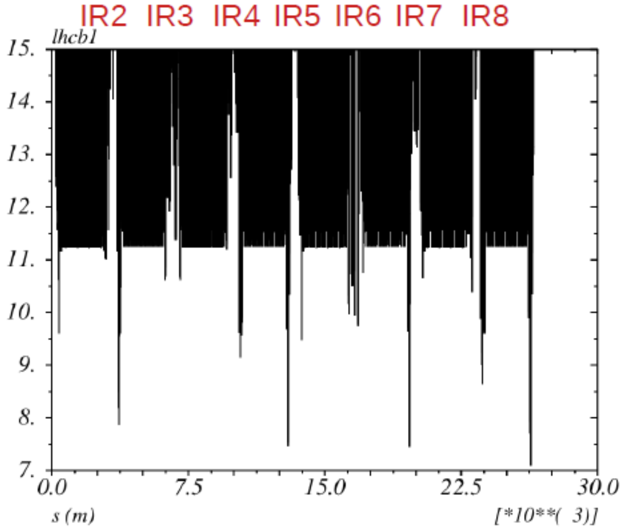
- Aperture and aperture tolerances loaded
- Using rather **pessimistic estimates**
- **Minimum about 7.1σ/6.8σ** for B1/B2

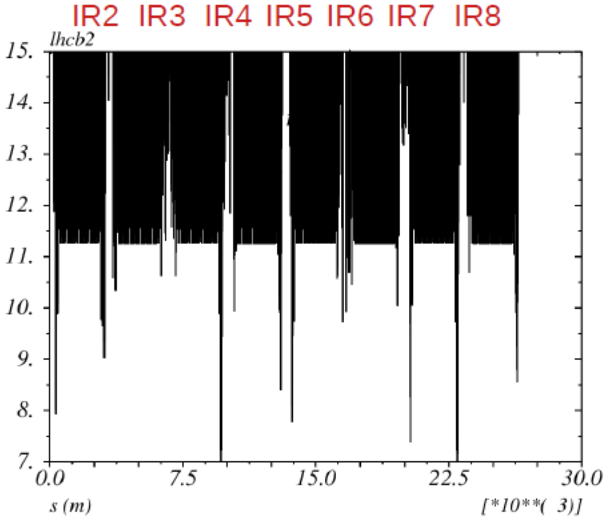
Beam:
energy = 450 GeV

sige = 4.5 x 10^{-4}
exn = eyn = 2.5 x 10^{-6} m

Aperture:
cor = 0.002 m
dp = 8.6 x 10-4
halo = (6,6,6,6)
*Bbeat = **1.20 (44% β-beating)***
dparx = dpary = 0.14

Probably increases for 60deg optics
Probably does not decrease BSC too much as no crossing angles foreseen





Increase to 0.28
Would leads to
6.8σ/6.6σ for B1/B2

At the moment we are only interested in a single pilot bunch

Date	Shift	Team	
10/21/2021	1		
	M	OP/RF/BI	Injection, threading, parasitic splashes
	M	OP/RF/BI	Injection, threading, parasitic splashes
	A	OP/RF/BI	Closed orbit and RF capture, tune, Q' ,coupling, BI setup
	A	OP/RF/BI	Closed orbit and RF capture, tune, Q' ,coupling, BI setup
	N	OP	Orbit corrector & BPM polarity
	N	OP	Orbit corrector & circuit polarity
10/22/2021	2		
	M	OP	Reference orbit with probe, energy matching to SPS
	M	OP/BI	Orbit & tune FB commissioning, BI setup, AC dipole
	A	OP/BI	Orbit & tune FB commissioning, BI setup, AC dipole
	A	COL	Coarse setup for probes
	N	OP	Kmodulation - triplet BPM offsets
	N	OP	Kmodulation - triplet BPM offsets
10/23/2021	3		
	M	OP	Splashes
	M	OP	Splashes
	A	OMC	AC dipole, optics at injection
	A	OMC	Optics measurement & correction
	N	OMC	spare
	N	OP	FMCM tests
10/24/2021	4		
	M	RF	Cavity phasing and ADT setup
	M	RF	Cavity phasing and ADT setup
	A	ADT	ADT setup with probes, ADT excitation
	A	OMC	Optics measurement & correction
	N	OMC	Optics measurement & correction
	N	OMC	spare

10/25/2021	5		
	M	COL	Collimator setup, global injection aperture
	M	COL	Collimator setup, global injection aperture
	A	ABT	Injection and dump aperture
	A	ABT	Injection and dump aperture
	N	OP	Feedback tests
	N		
10/26/2021	6		
	M	MPS	BLM dump trigger tests
	M	MPS	BLM dump trigger tests
	A	ABT	Kick response line + ring, MKI2 waveform
	A	ABT	14/15 kickers knob
	N		
	N		
10/27/2021	7		
	M	OP/RF/BI	Nominal bunch injection, BI, RF tuning
	M	OP/RF/BI	Nominal bunch injection, BI, RF tuning
	A	OP	Collision setup with nominal bunches, ALICE to +/+
	A	OP	Collision setup with nominal bunches
	N	OP/ABT	MKB waveform
	N		
10/28/2021	8		
	M	COL	Collimation setup nominal bunch
	M	COL	Global aperture with nominal bunch
	A	COL	Loss maps
	A	RF	ADT setup
	N	RF	ADT setup
	N		

10/29/2021	9		
	M	OP	Preparation first stable beams
	M	OP	ALICE -, Stable beams at injection
	A	OP	Stable beams at injection
	A	OP	Xing levelling test
	N	OMC	OMC tests
	N	OMC	OMC tests
10/30/2021	10		
	M	COL	Local aperture triplets
	M	COL	Local aperture triplets
	A	COL	Selected local aperture checks
	A	OP	ALICE pol +, Stable beams at injection
	N	OP	Stable beams at injection
	N		
10/31/2021	11		
	M	COL	Crystal collimation test
	M	COL	Crystal collimation test
	A	OP	ALICE 0, Stable beams at injection
	A	OP	Stable beams at injection
	N		
	N		

Potentially the 60 deg phase advance (4 people needed + collimation experts)

Do the essential checks of equipment and software

If there is interest, we could also try the aperture measurements with the AC-dipole -> Amplitude detuning for free

MCS, Q'' and potentially a re-validation of the corrections if needed

Conclusion

- An extensive program ahead of us!
- A lot of modifications have been done during the shutdown
  - The beam test provides a great opportunity to test modifications to system and software
  - Challenging also in the view of our own detraining (not only magnets can detrain)
- The outcome will also depend on the availability of the machines and experts
  - If everything goes well, we could still hope to test the 60 deg phase advance but we need your help for that!

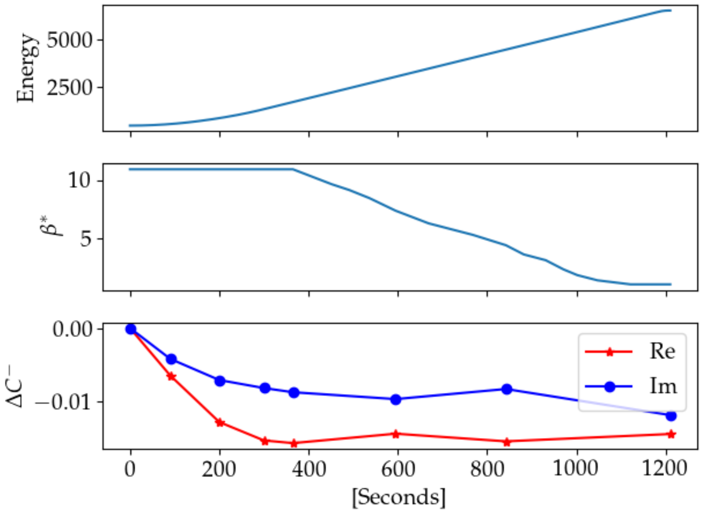
How did the coupling knobs change along the ramp and squeeze in 2018?

- Most of the change is in the beginning of the ramp before the squeeze

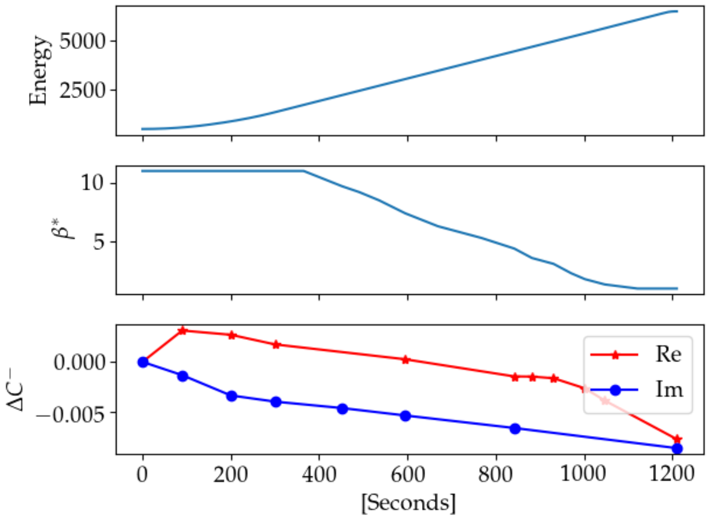
  -> Effect is coming from the arcs

  - |C-| change up to **0.02**
  - Small changes in the later part even with the squeeze
    - -> The local coupling corrections worked well

Beam 1



Beam 2



Without local coupling corrections

- No measurements of the coupling as a function of β* in Run 2 but can use the local coupling corrections to estimate the situation
  - Correct with knobs to |C-| = 0.001 at injection
  - After squeezing to 7m we would have expected a |C-| ~0.01