Optics control in 2016

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on behalf of the OMC-team

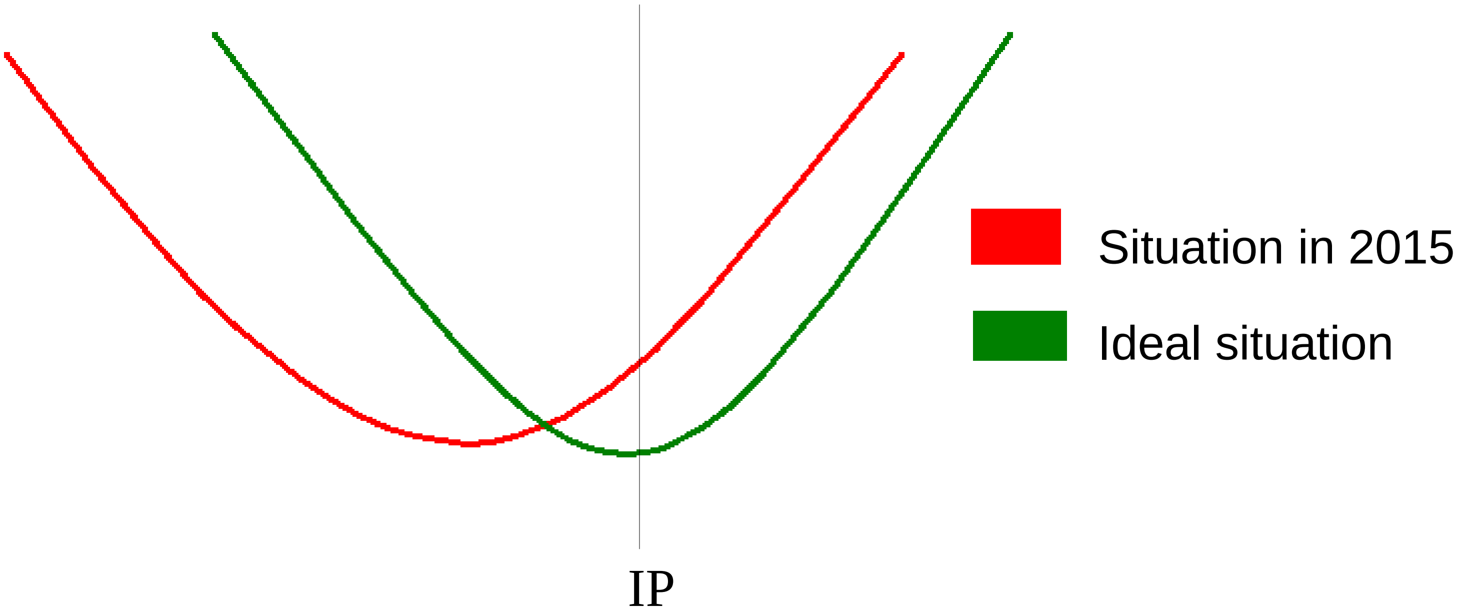
Many thanks to:
G. Baud M. Gasior, M.Giovannozzi, J. Olexa, D. Valuch

Outline

1. A reminder of the situation in 2015 (proton run)
2. What did we change for the 2016 commissioning?
3. Results from the 2016 comissioning
4. What do we request for the 2017 commissioning?

A reminder of the situation in 2015 (protons)

- The β at the IP was larger than design
- The waist was systematically shifted (both IP1 and IP5)

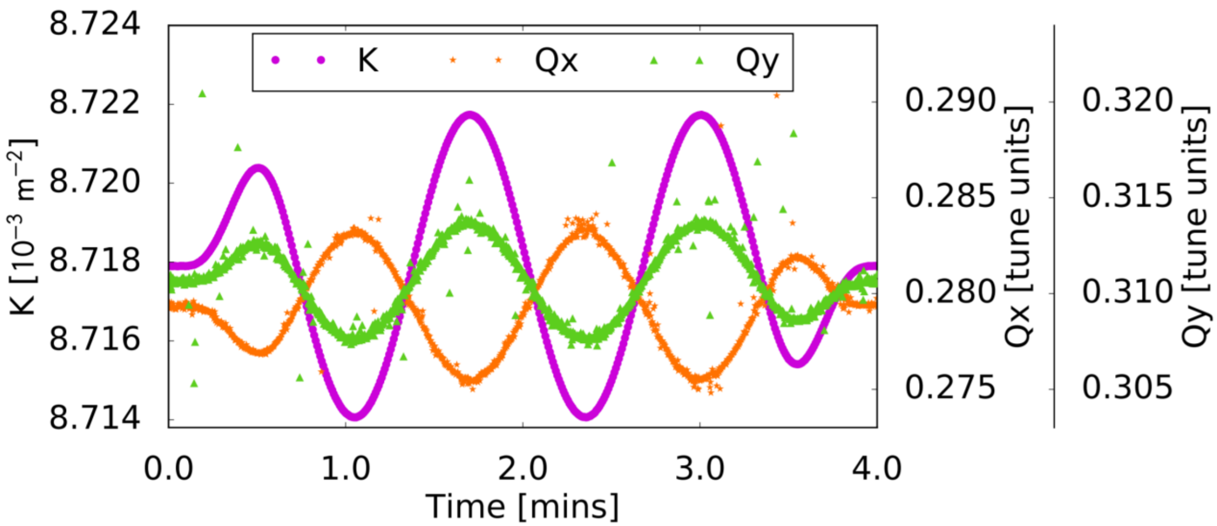


What was new in 2016?

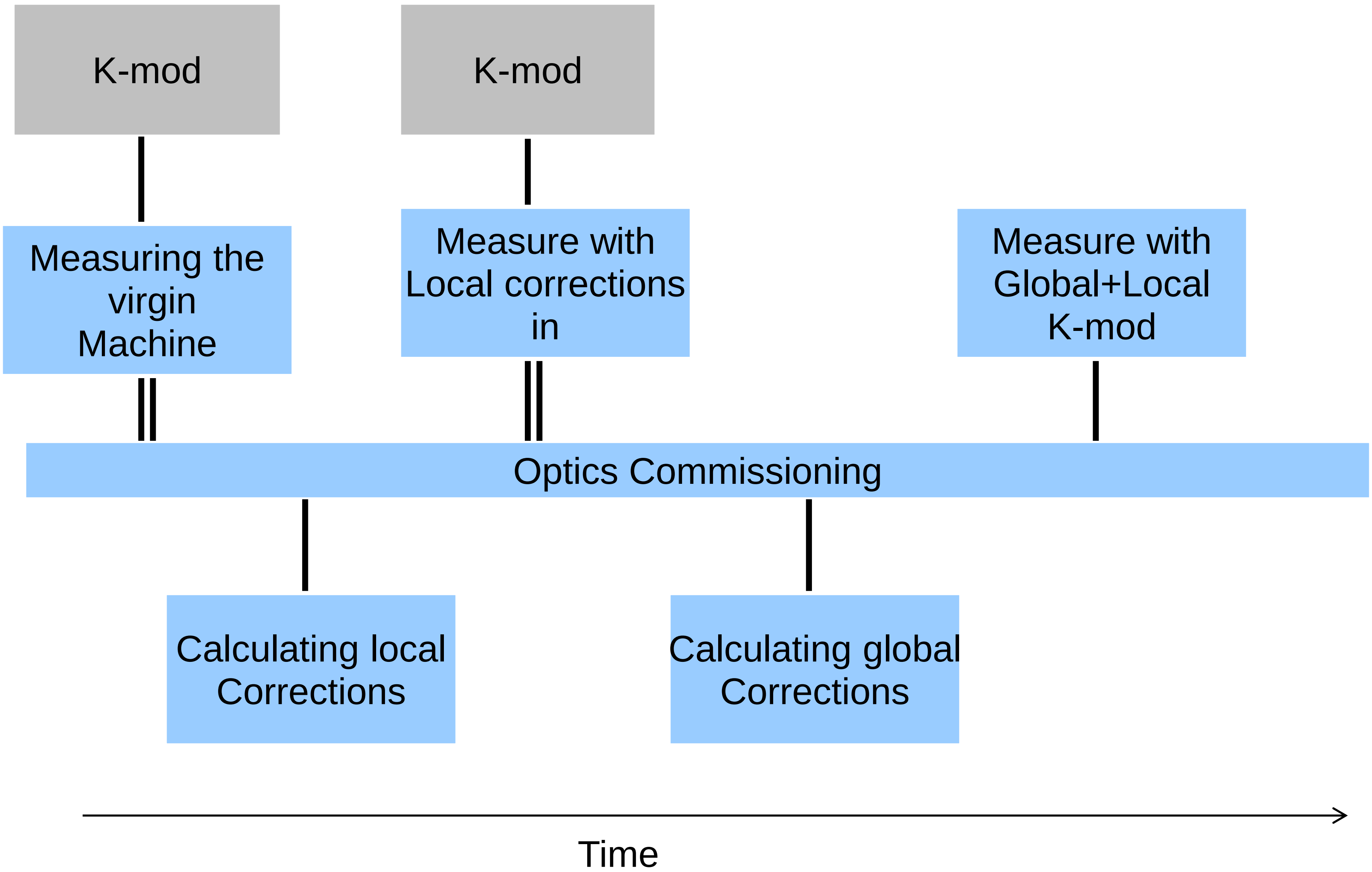
- Using direct constraints in order to correct the $\boldsymbol{\beta}_{\mathbf{IP}}$
- Online k-modulation
  - Results used for corrections
- Improved global corrections (with the uncertainty of the measurements taken into account)
- β-functions from calibrated BPMs (ballistic optics)
- Automatic calculation of local coupling corrections

Updated the K-modulation softwared

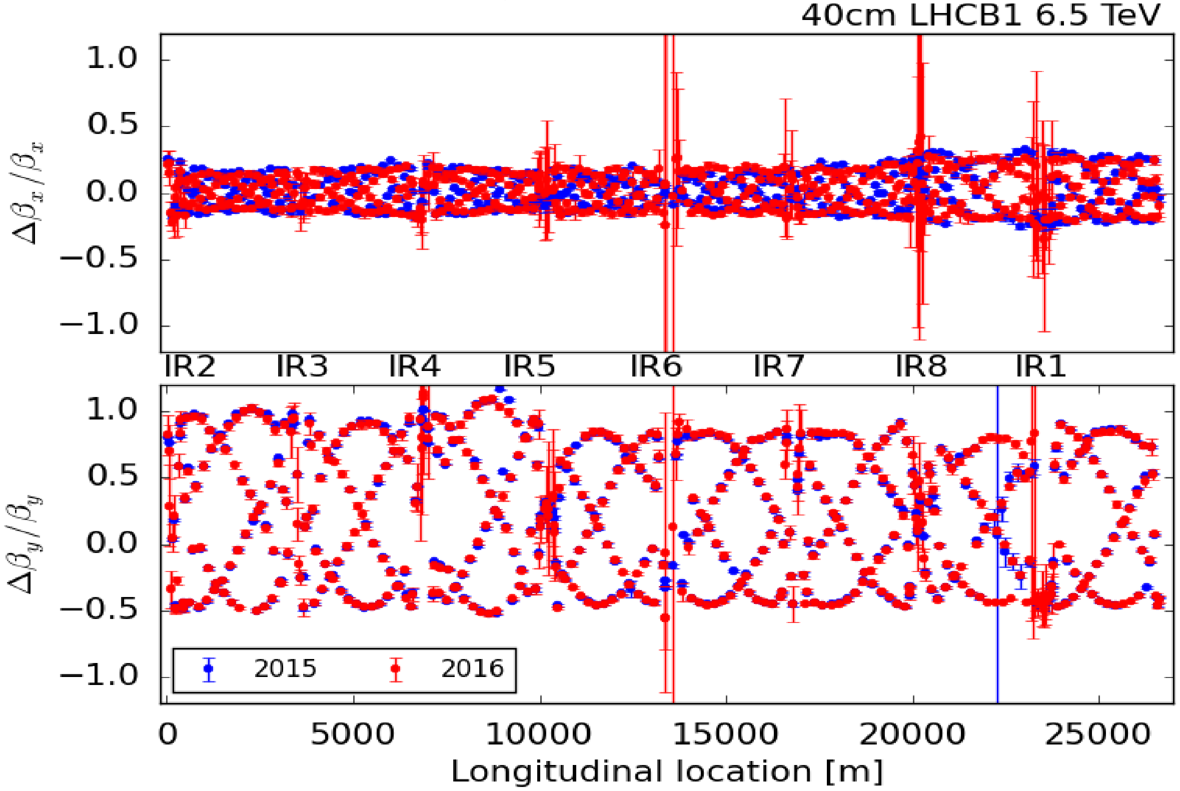
- An upgrade of the K-modulation software
  - IP Driven
  - On-line analysis
    - Results within 1 min after data taking
  - Directly imported as a constraint for the corrections



Correction procedure for 40cm



Virgin machine

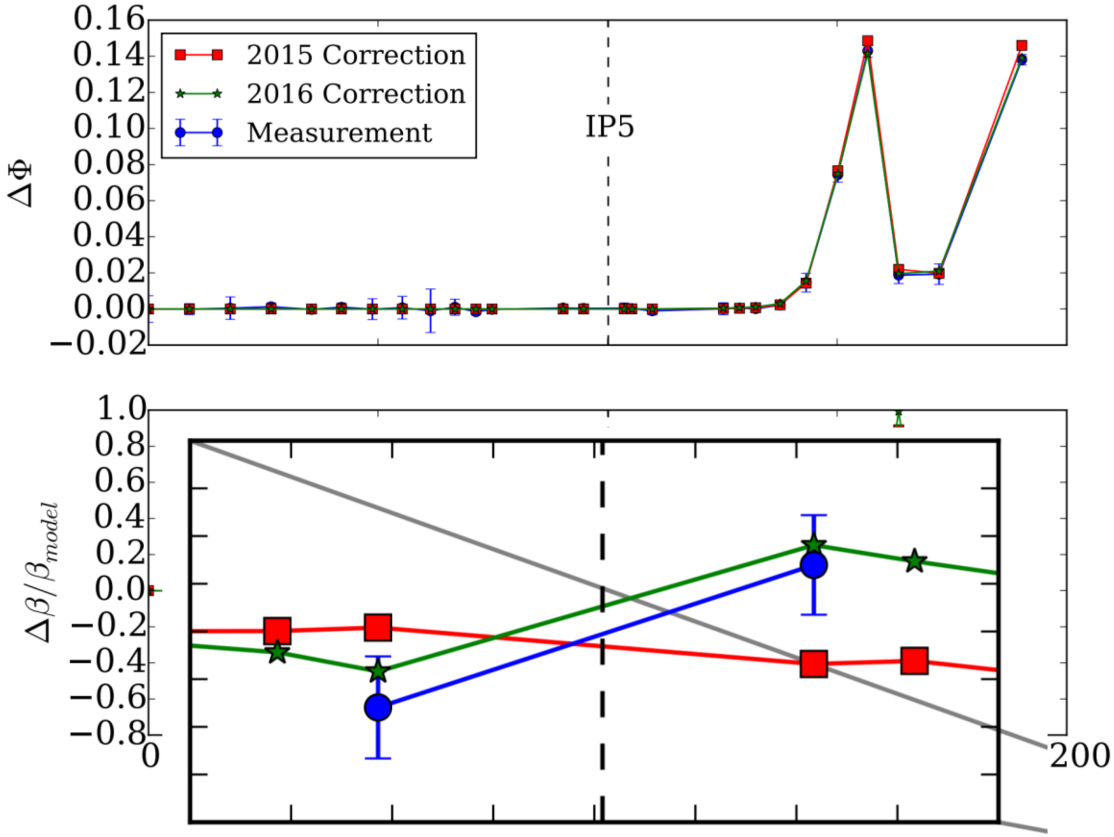


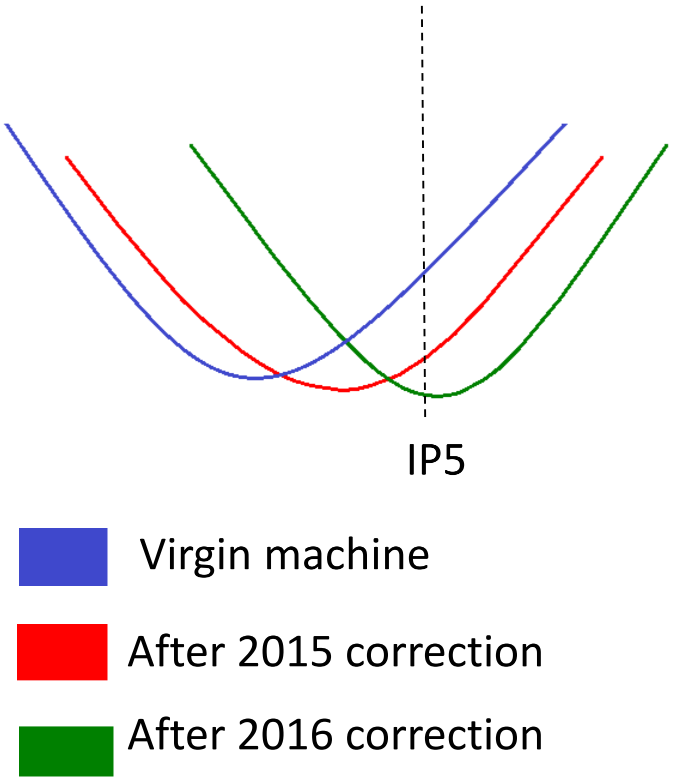
	β_{IP}	$\sigma_{\beta_{IP}}$	**Waist**	σ_W
Average	**0.528**	**0.010**	**0.168**	**0.013**
RMS beta-beat IP %	**52.0**			

No major differences between 2015 and 2016

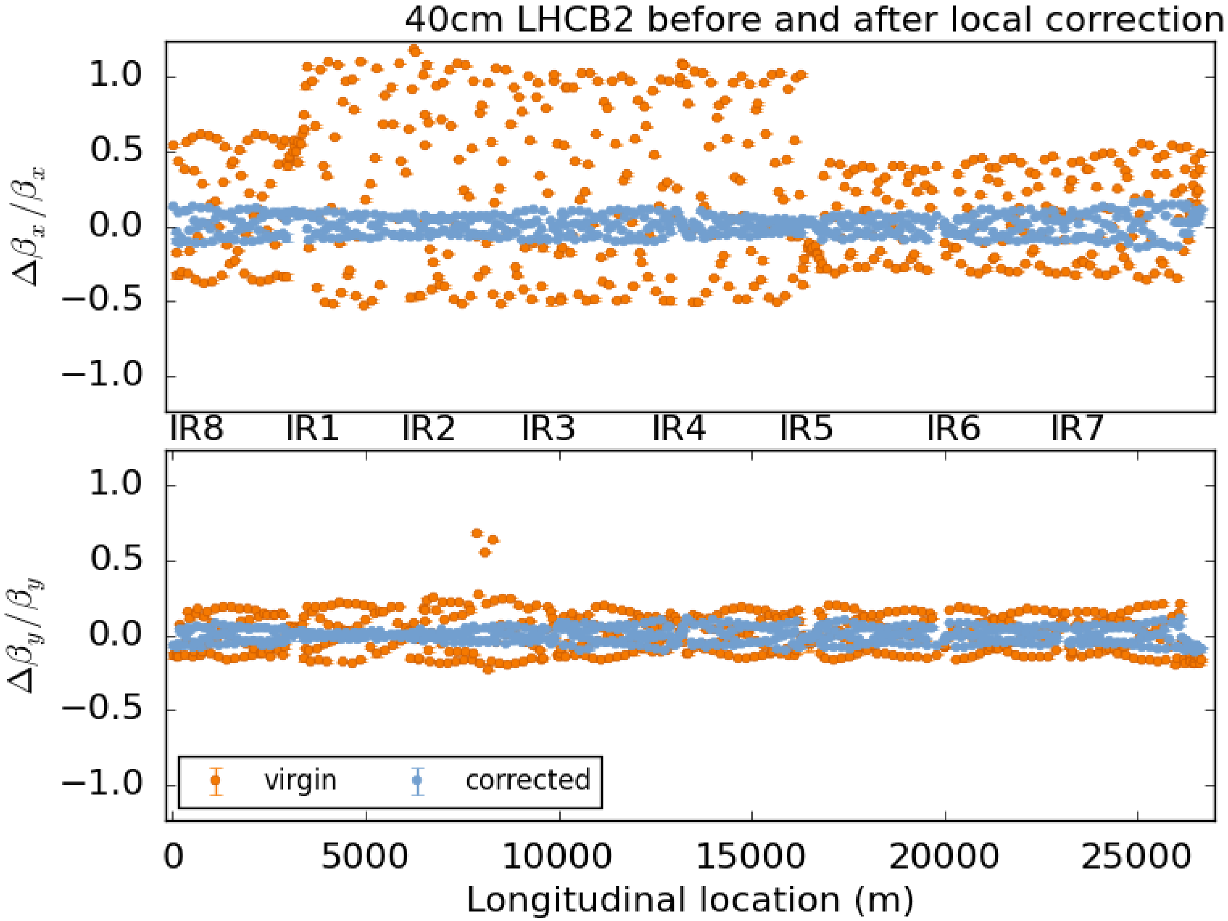
Local corrections

- The local phase corrections are degenerated. Possible to find several combinations that correct the phase
  – No guarantee that the waist or β_{IP} is well corrected





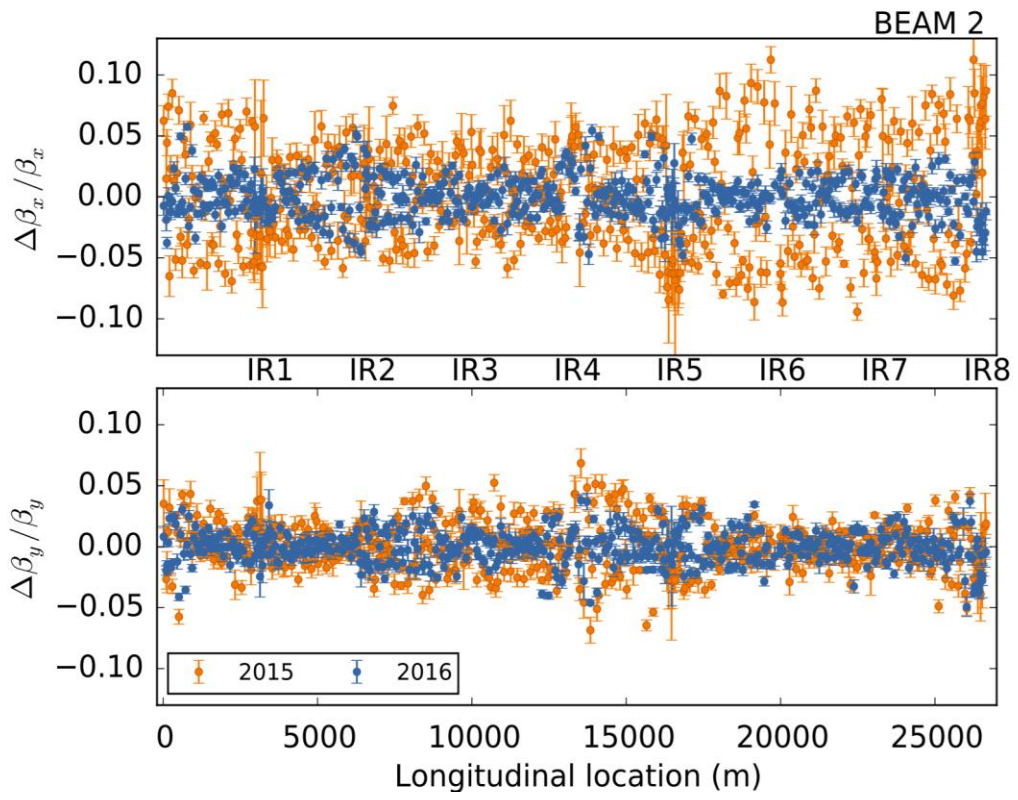
After Local Corrections



	β_{IP}	β_{IP} err	w	w err
Average	**0.396**	**0.002**	**0.011**	**0.009**
RMS β-beat in %	**5.1**			

Final Corrections

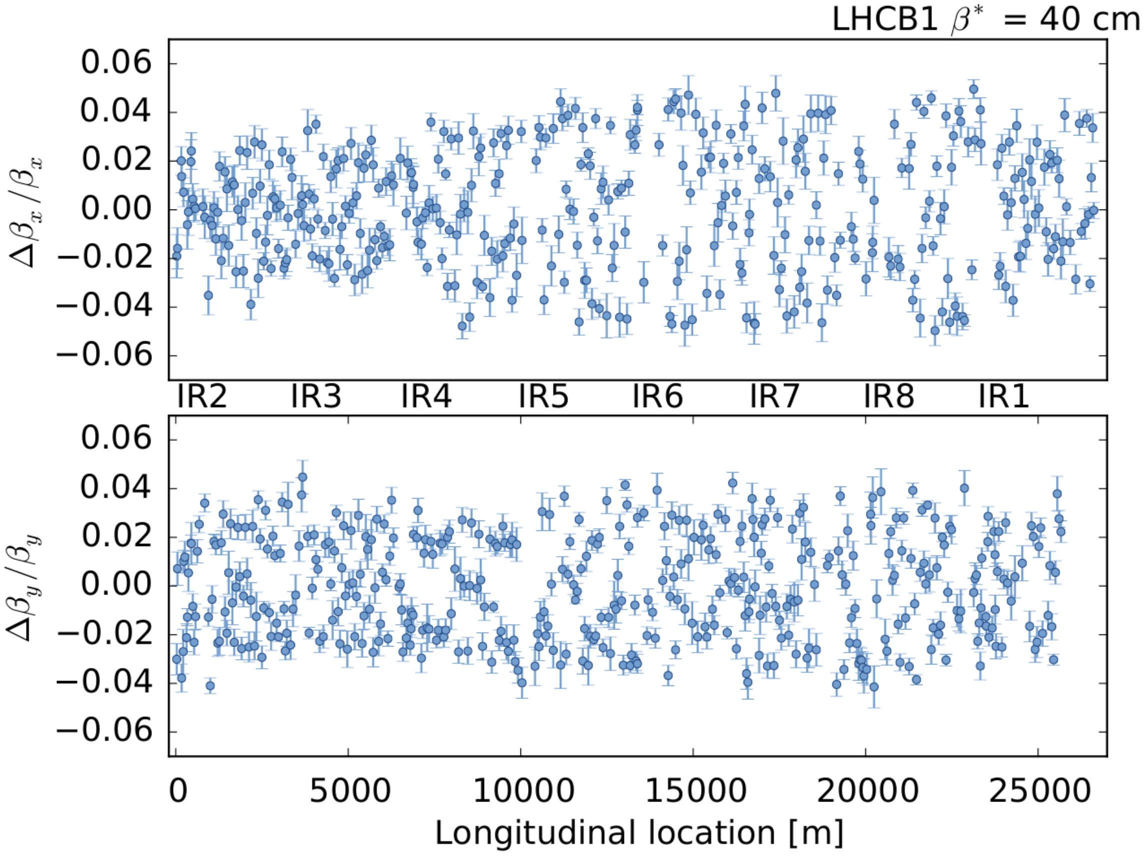
IP	β_{IP} [m]	β_{IP} err [m]	Waist [m]	waist err [m]
ip1b1.X	0.398	0.007	0.047	0.009
ip1b1.Y	0.401	0.002	-0.009	0.009
ip1b2.X	0.398	0.001	0.009	0.011
ip1b2.Y	0.402	0.001	0.072	0.010
ip5b1.X	0.399	0.003	-0.009	0.008
ip5b1.Y	0.400	0.001	-0.028	0.010
ip5b2.X	0.395	0.003	0.070	0.013
ip5b2.Y	0.396	0.004	-0.025	0.011
Average	**0.403**	**0.003**	**0.016**	**0.010**
RMS β-beat in IP %	**1%**			



Lowest β-beat in the LHC so far!

Effect of crossing angles

- Optics measured in June (comissioning without crossing angles in April)
  - **Difference between the two measurements shown in plot below**
- Consistent with simulation of the IR sextupoles errors + crossing angles
- **No issue for machine safety**
- Could contribute to a luminosity imbalance
- **Possible to correct with the IR correctors**



An increase of the peak beta-beat in the order of ~**3%** due to crossing angles + IR sextupole errors.

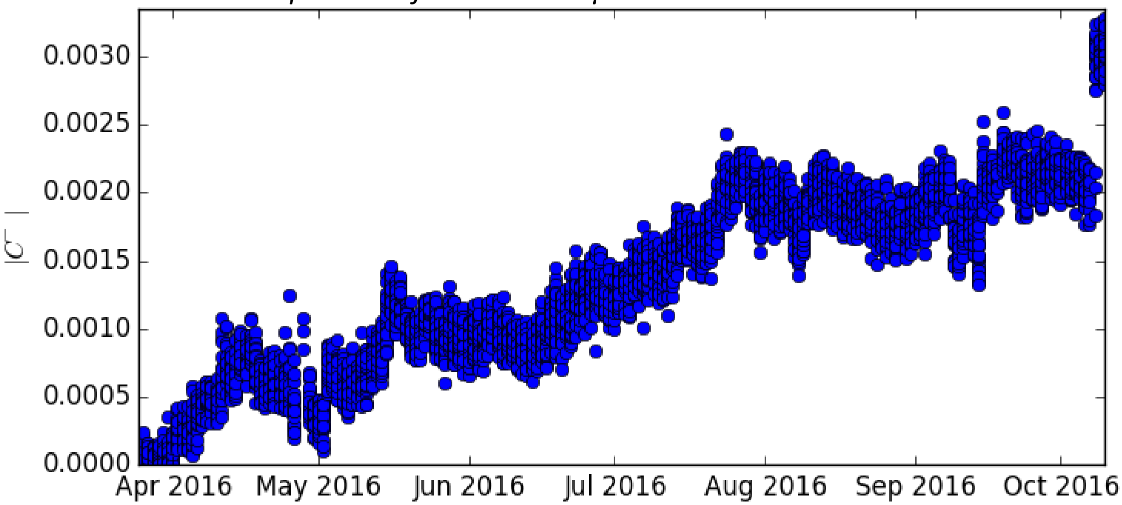
Note that the measurements are taken within months between them! This will also contribute to the difference

Coupling Changes

- The measured tilt of the triplets predicts a change in the |C-| of $3*10^{-3}$ in 6 months
  - The BBQ is not reliable when there is too much noise, at low beta-star, strong octupoles, etc...

-> Need for an **easy-to-use-tool** to correct coupling after, *i.e.*, a technical stop

**Triplet data from: Dominique Missiaen via Massimo Giovannozzi*

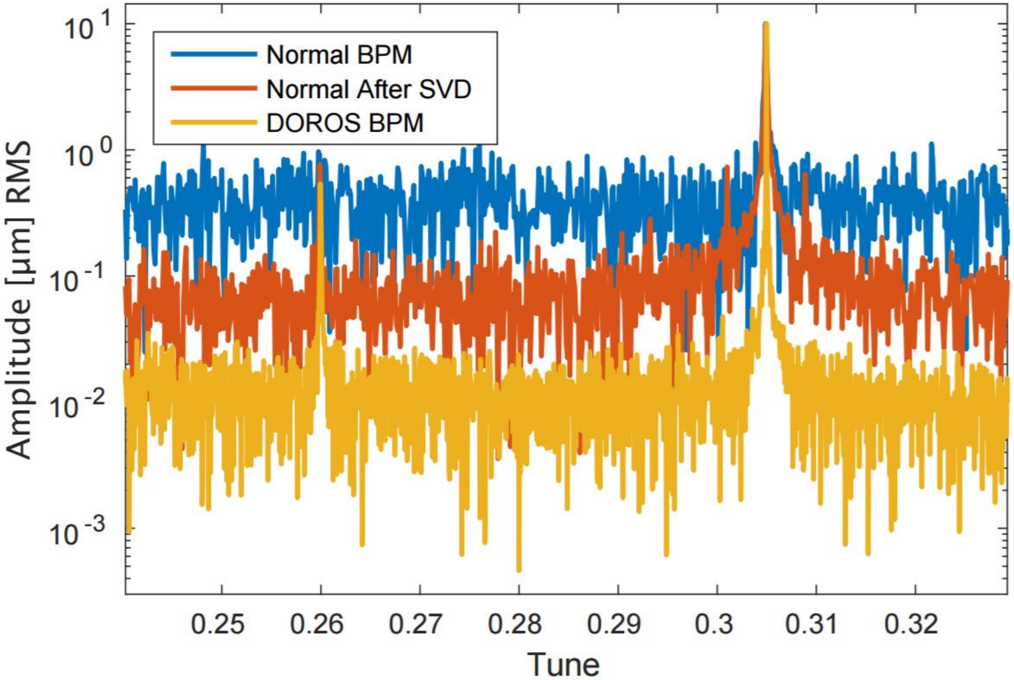


We have demonstrated correction of the |C-| ≈ $2*10^{-4}$

[Demonstration of coupling correction below the per-mil limit in the LHC]

Towards a new coupling tool

- Uses the ADT as an AC-dipole
  - Can excite individual bunches without emittance increase
- Data Recorded with DOROS-BPMs or/and Normal BPMs
- Succesfully demonstrated in MD
- The goal is to have a very first version for the 2017 comissioning

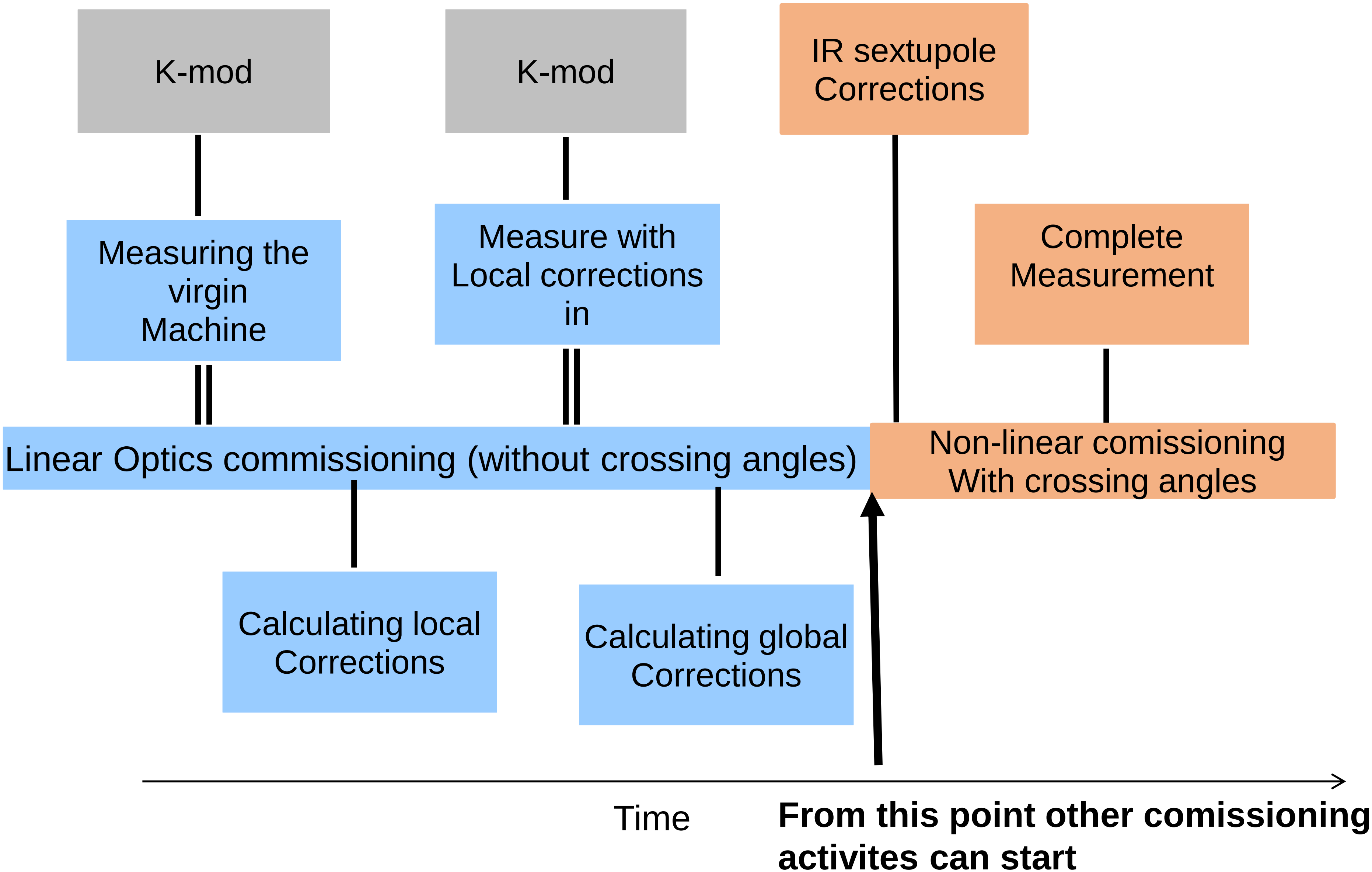


2017

2017 Commissioning

- Number of shifts estimated for linear optics
  - Optics unchanged ≈1 shift (revalidation)
  - 2016 ATS ≈2 shifts
  - New ATS or Nominal ≈3 shifts
- Nonlinear comissioning
  - 2 shifts, *see E. Maclean talk in this session*
- **No difference for the optics corrections with ATS or Nominal**
- Additional requests:
  - Automatic coupling correction commissioning ≈1 shift (distributed)
  - Ballistic optics ≈ 0.5 shift

Correction 2017 (new optics)



When should we change to collision tunes?

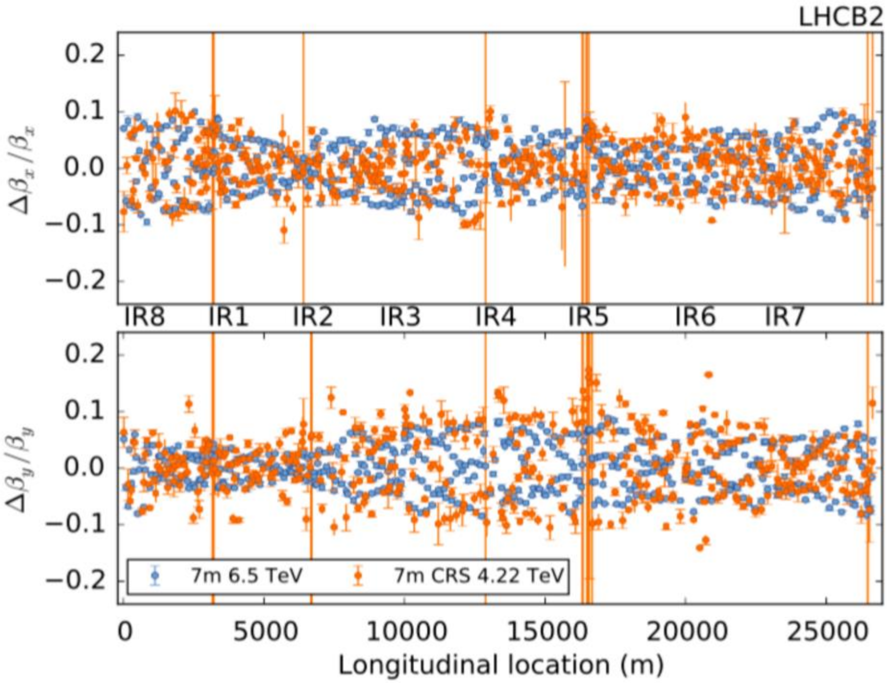
- **Important that the coupling is well corrected during the squeeze**

-> Can decide later when in the squeeze to change the tunes

- Pros to do it at the final β* :
  - Provide more margins for coupling errors through the squeeze (however the smalles β* is in general the most challenging)
- Cons:
  - Will cross resonances at the smallest β*
    - Could be simulated but should be checked with beam

Ramp & Squeeze

- Significant experience in 2016
  - We measure the optics close to the match points
  - The optics corrections are at the same level as with only squeeze
- **For the optics corrections** there is no limit on β* during the ramp & squeeze
  - Full Ramp & Squeeze? When?



Summary

- The new approach using k-mod as input for corrections resulted in:
  - **Smallest β-beat ever achieved in LHC**
  - **1% RMS β-beat at the IP1 and IP5 (without crossing angles)**
- Coupling corrected to ≈ $2*10^{-4}$ in MD
  - A non expert tool to reach this level is planned

2017 commissioning:

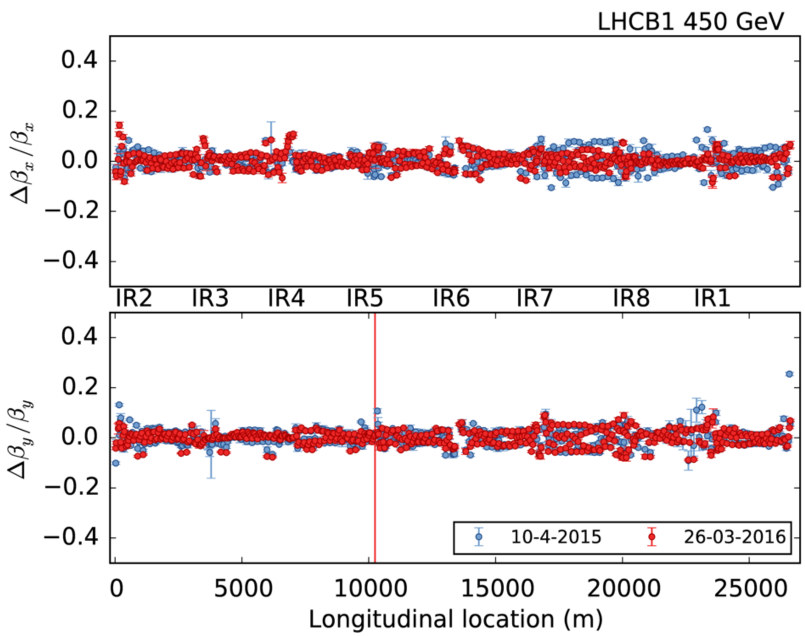
- Suggest non-linear correction proccedure to correct the sextupoles errors in the IR (*see E. Maclean's talk for details*)

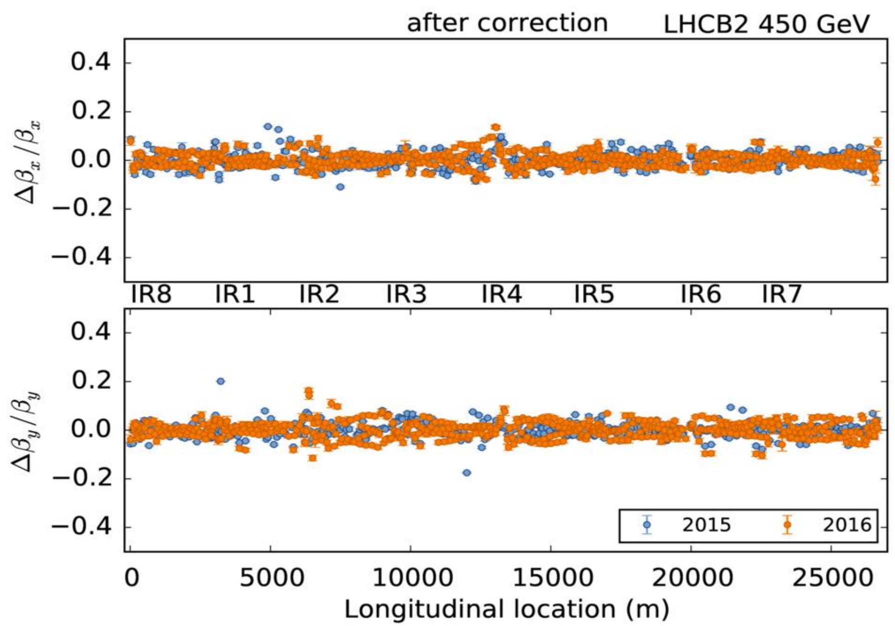
  -> No β-beat from the change of crossing angles
  - Backup solution: Correct with the crossing angles in

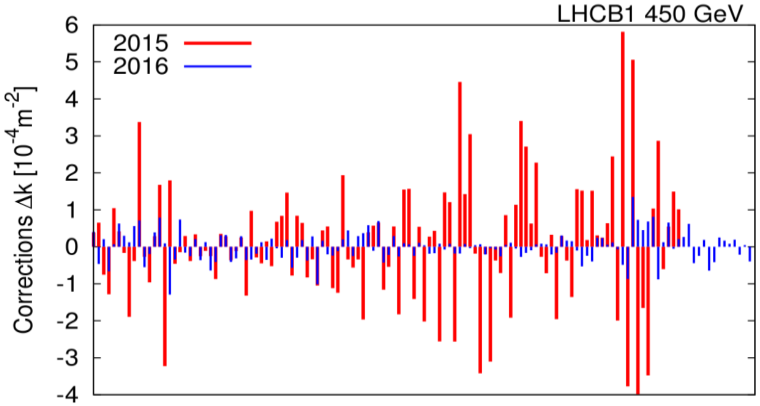
- **ATS or nominal optics will not impact the quality of the optics corrections in 2017**

Backup slides

Injection After Correction



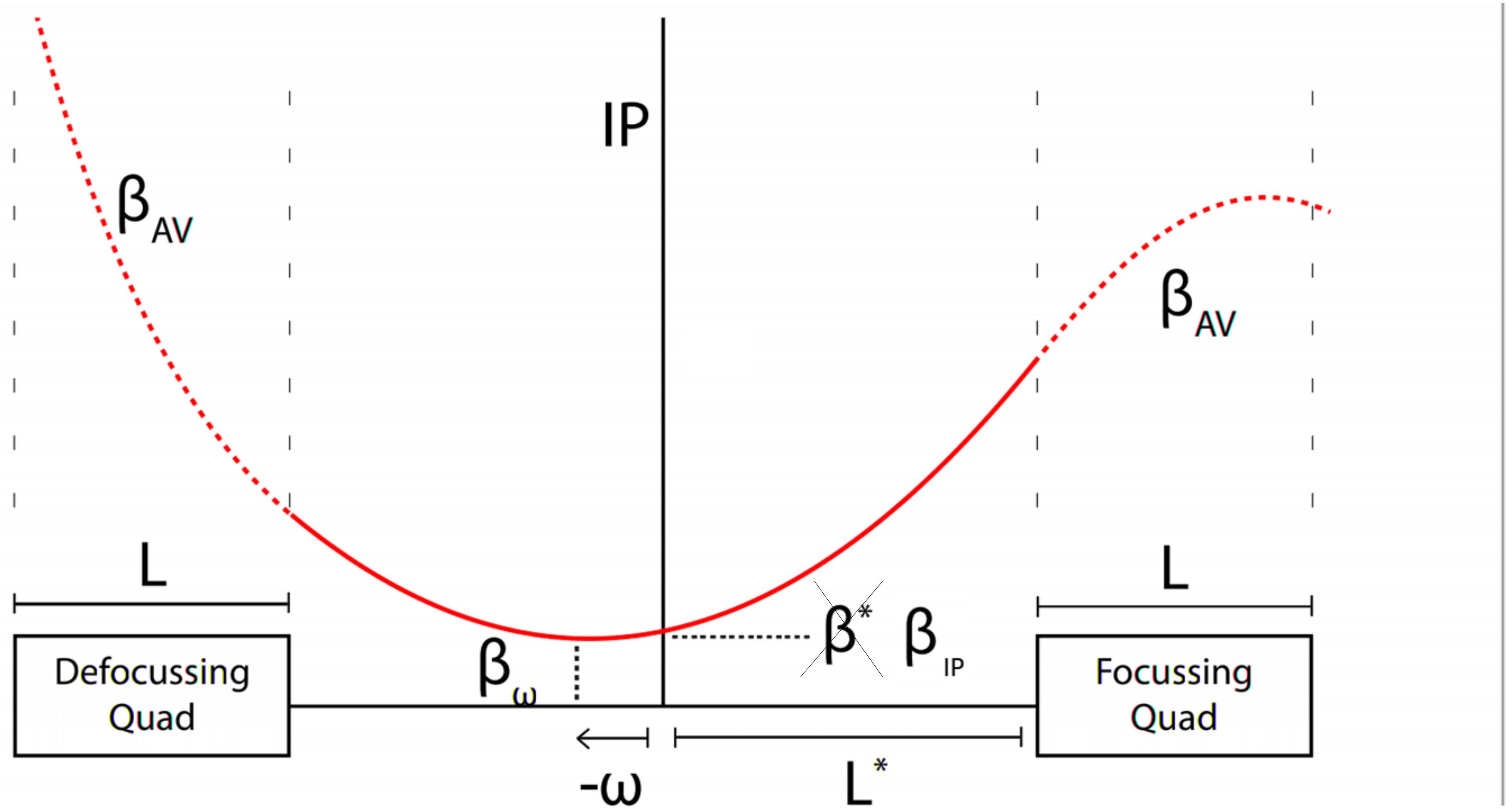




Ballistic Optics

- The triplets are turned off
- Motivation:
  - To calibrate the BPMs close to the IP
- Later use them to constrain the corrections
  - Help us understand where the errors originate

Nomenclature



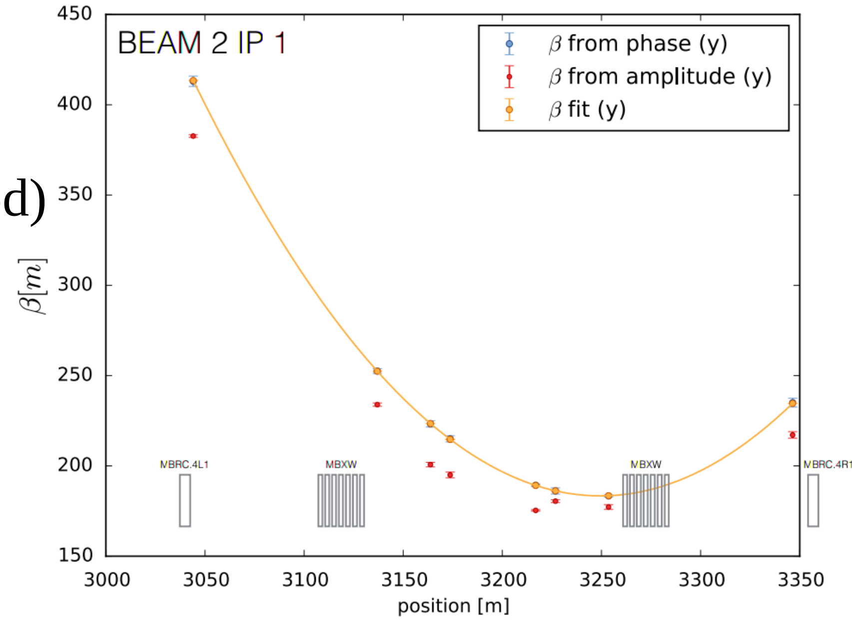
In order to avoid confusion I will use the notation beta at the IP ,β_{IP}

β_{IP} from BPMs

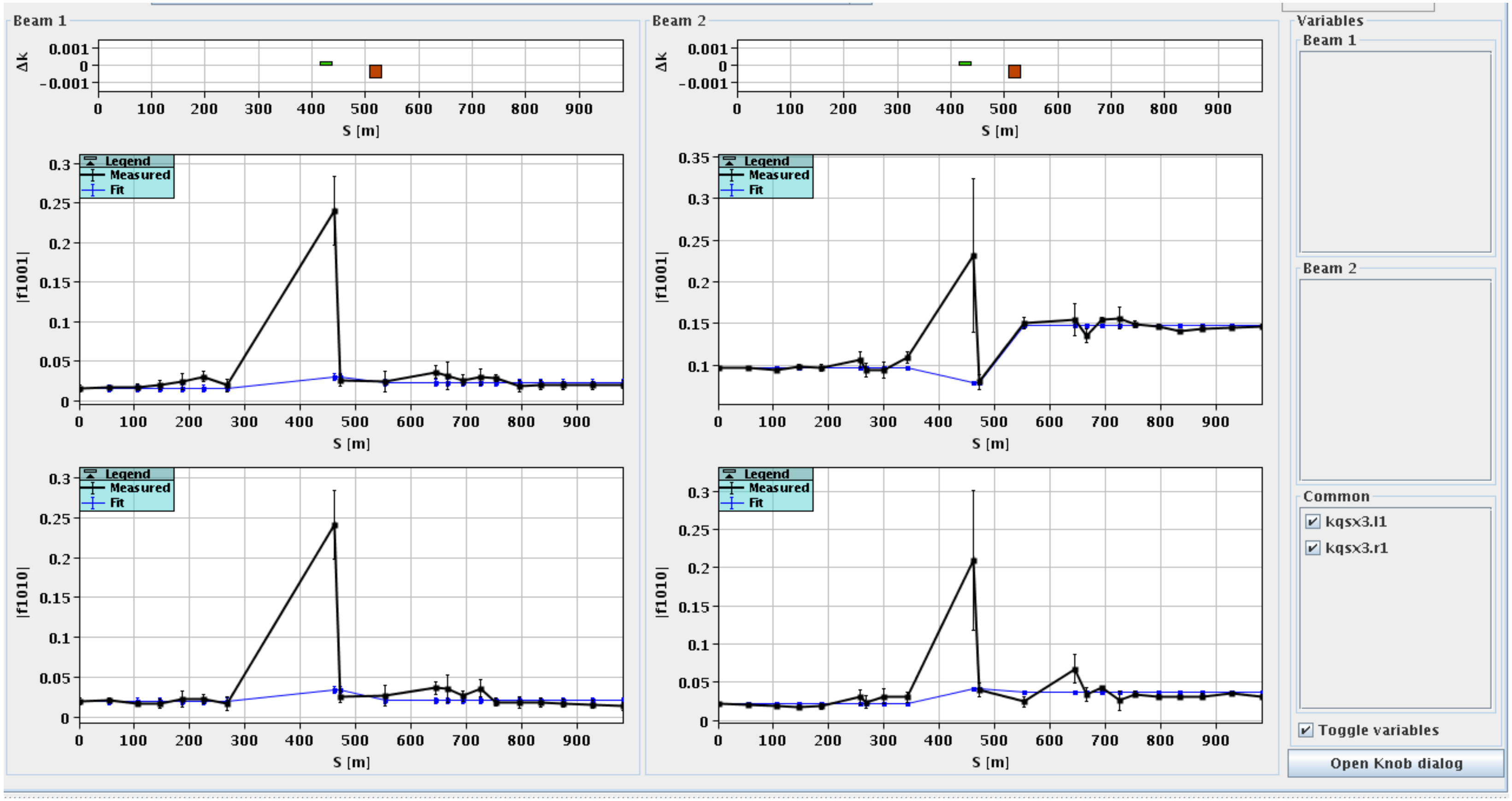
- Can reconstruct the β at a BPM and propagate it to the IP
– Needs very precise calibration of the BPMs
– Used the ballistic MD to calibrate the BPMs close to the IP

β-function is being computed using two different methods:

- N-BPM phase advance method.
- Transverse oscillation amplitude (Amplitude method)
- Doesn't work if the β-beat is too large

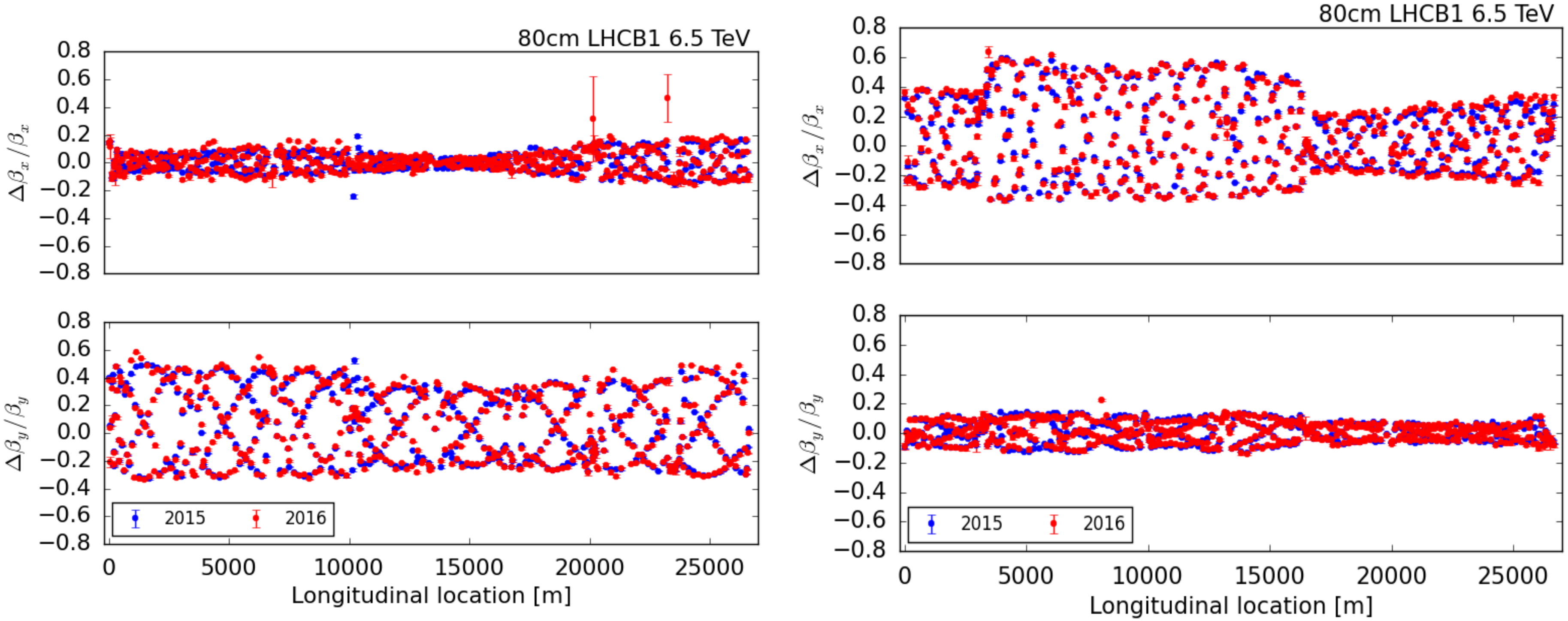


Local coupling corrections



Based on matching the change in the RDTs (f_{1001})

80cm before Correction



Waist shift

			Proton Run			Ion Run			
			waist [m]	Uncertainty [m]	Expected Change [m]	shift [m]	uncertainty [m]	Diff with expected Shift [m]	Uncertainty [m]
	IP 1	**B1H**	0.24	0.01	-0.23	0.02	0.04	0.02	0.04
		B1V	0.23	0.01	-0.23	0.05	0.02	0.06	0.02
		B2H	0.17	0.02	-0.22	0.04	0.03	0.09	0.04
		B2V	0.21	0.01	-0.22	-0.04	0.02	-0.03	0.02
	IP 5	B1H	0.20	0.01	-0.18	-0.04	0.05	-0.07	0.05
		B1V	0.15	0.01	-0.19	0.01	0.02	0.04	0.02
		B2H	0.22	0.01	-0.18	0.02	0.04	-0.03	0.04
		B2V	0.11	0.01	-0.18	-0.09	0.03	-0.03	0.04
	Mean		0.19			-0.005			

• β_{IP}

		Proton run		Ion run	
		β_{IP} [m]	Uncertainty [m]	β_{IP} [m]	Uncertainty [m]
IP 1	B1H	0.878	0.013	0.810	0.005
	B1V	0.865	0.007	0.840	0.003
	B2H	0.819	0.013	0.824	0.003
	B2V	0.827	0.006	0.825	0.003
IP 5	B1H	0.862	0.011	0.830	0.007
	B1V	0.864	0.049	0.842	0.005
	B2H	0.867	0.014	0.766	0.002
	B2V	0.827	0.020	0.812	0.006

Local coupling corrections

		2012 [10^{-4}m^{-2}]	2015 [10^{-4}m^{-2}]	2016 [10^{-4}m^{-2}]
IR1	kqsx3.r1	8	8	6
	kqsx3.l1	8	8	11
IR2	kqsx3.r2	-9	-16	-14
	kqsx3.l2	-9	-16	-14
IR5	kqsx3.r5	6	7	7
	kqsx3.l5	6	7	7
IR8	kqsx3.r8	-7	-5	-5
	kqsx3.l8	-7	-5	-5

Comparing the global coupling knobs

	Injections		3m	
	2016	2015	2016	2015
LHCBEAM1/CMINUS_IM.IP7	-0.012	-0.014	-0.0082	-0.017
LHCBEAM1/CMINUS_RE.IP7	-0.0235	-0.0175	-0.0125	-0.0063
LHCBEAM2/CMINUS_IM.IP7	-0.05359	-0.0529	-0.0081	-0.02799
LHCBEAM2/CMINUS_RE.IP7	4.999E-4	0.00449	-0.003	-0.00399
sum in quadrature	**0.05901**	**0.0575**	**0.0173**	**0.0335**

A reminder of the situation in 2015 (protons)

- The β at the IP was larger than design and the waist was shifted (both IP1 and IP5)

		β_{IP} [m]	Waist shift [m]
IP 1	B1H	0.878	0.236
	B1V	0.865	0.227
	B2H	0.819	0.166
	B2V	0.827	0.207
IP 5	B1H	0.862	0.201
	B1V	0.864	0.154
	B2H	0.867	0.221
	B2V	0.827	0.113

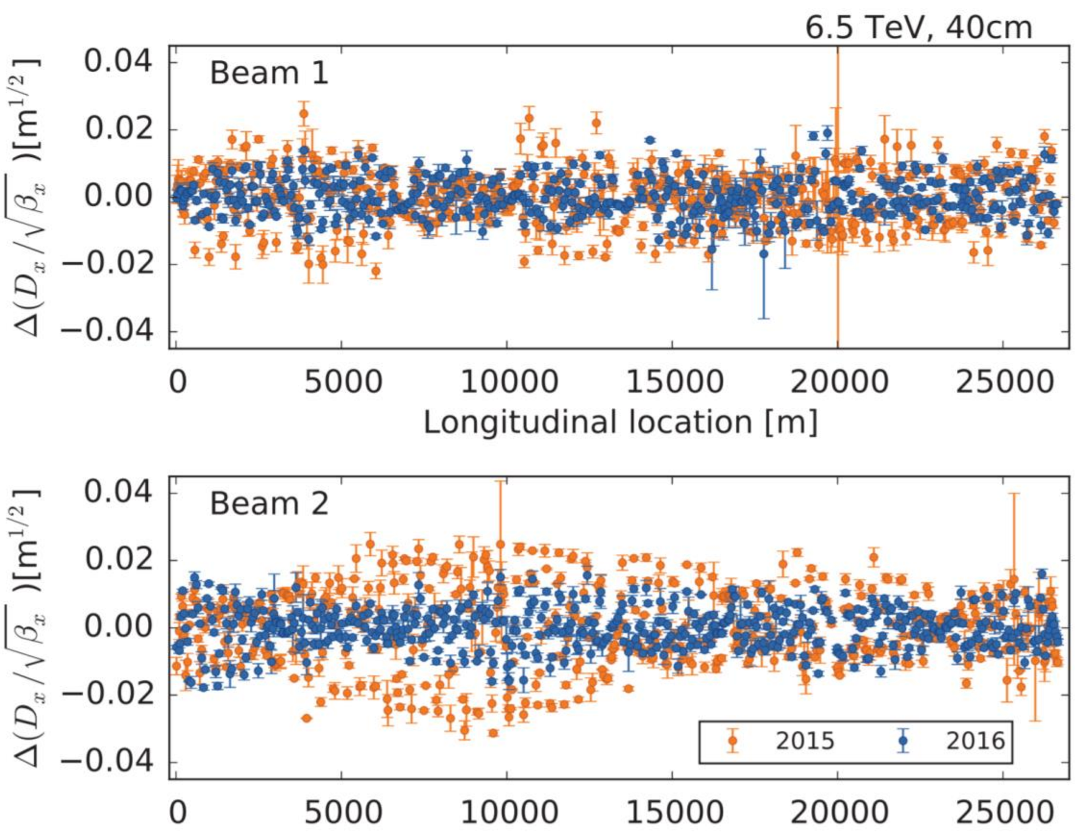


Figure 6: Improvement in dispersion beating at 40 cm β^*.

The local corrections

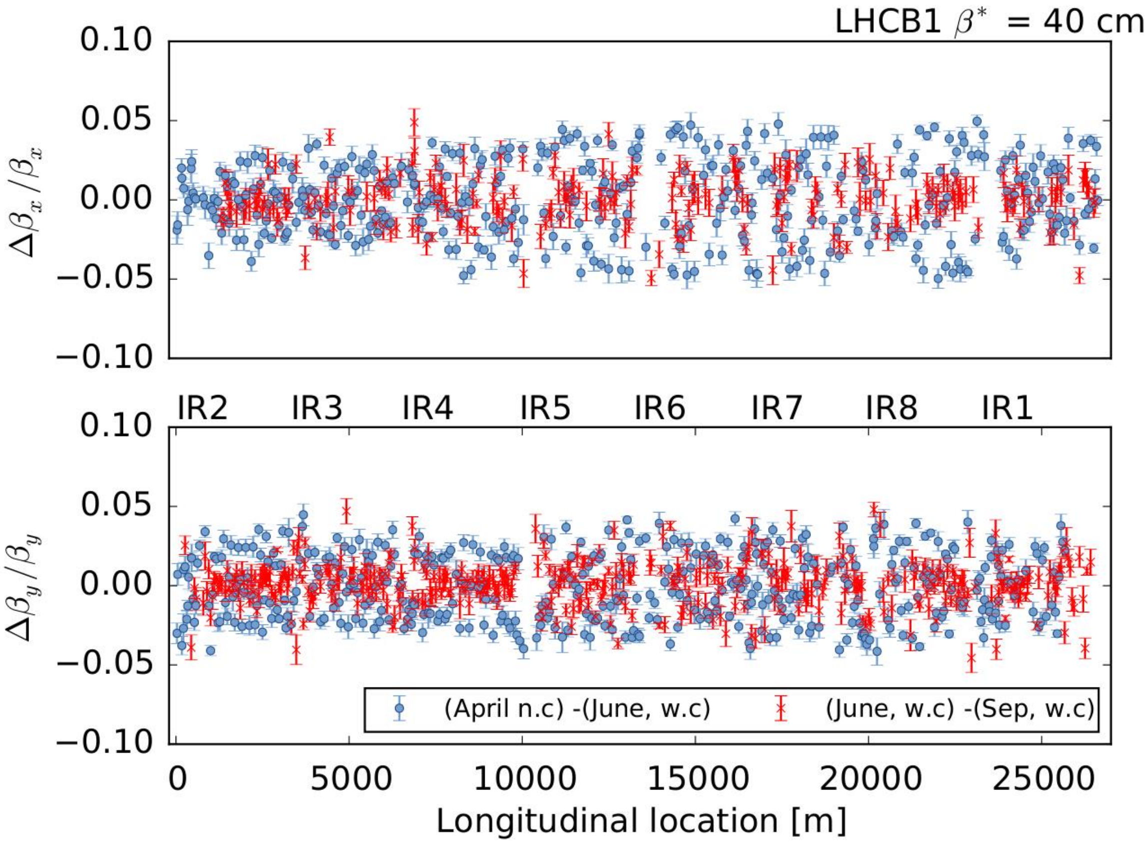
IP1

Magnet	2015 (protons) [m^{-2}] 10^{-5}	%	2016 [m^{-2}] 10^{-5}	%
MQXA1. L1/K1			1.23	-0.14
MQXA1. R1/K1			-1.23	-0.14
MQXB2. L1/K1	0.35	-0.040	0.65	-0.07
MQXB2. R1/K1	-0.7	0.080	-1.00	0.11
MQXA3. L1/K1			1.22	-0.14
MQXA3. R1/K1			-1.22	-0.14

IP5

Magnet	2015 (protons) [m^{-2}] 10^{-5}	%	2016 [m^{-2}] 10^{-5}	%
MQXA1. L5/K1	2.00	-0.23	2.00	-0.23
MQXA1. R5/K1	-2.00	-0.23	-2.00	-0.23
MQXB2. L5/K1	-0.09	-0.01	0.27 (0.2)	0.036 (0.027)
MQXB2. R5/K1	1.90	0.22	1.48 (1.60)	0.13 (0.14)
MQXA3. L5/K1			1.50	-0.17
MQXA3. R5/K1			-1.50	-0.17

IP1 and IP5 same as in ions except MQXB2.R5 values for ion correction in parentheses ()



LHCB1 β^* = 40 cm
0.10
0.05
0.00
−0.05
−0.10
$\Delta\beta_x/\beta_x$
IR2
IR3
IR4
IR5
IR6
IR7
IR8
IR1
$\Delta\beta_y/\beta_y$
(April n.c) -(June, w.c)
(June, w.c) -(Sep, w.c)
0
5000
10000
15000
20000
25000
Longitudinal location [m]