Chromatic Coupling Correction

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Overview

- Chromatic β-beat for β^* 60 cm.
- Introduction linear/chromatic transverse coupling.
- Measurements, simulations and corrections of chromatic transverse coupling.

Montague Functions

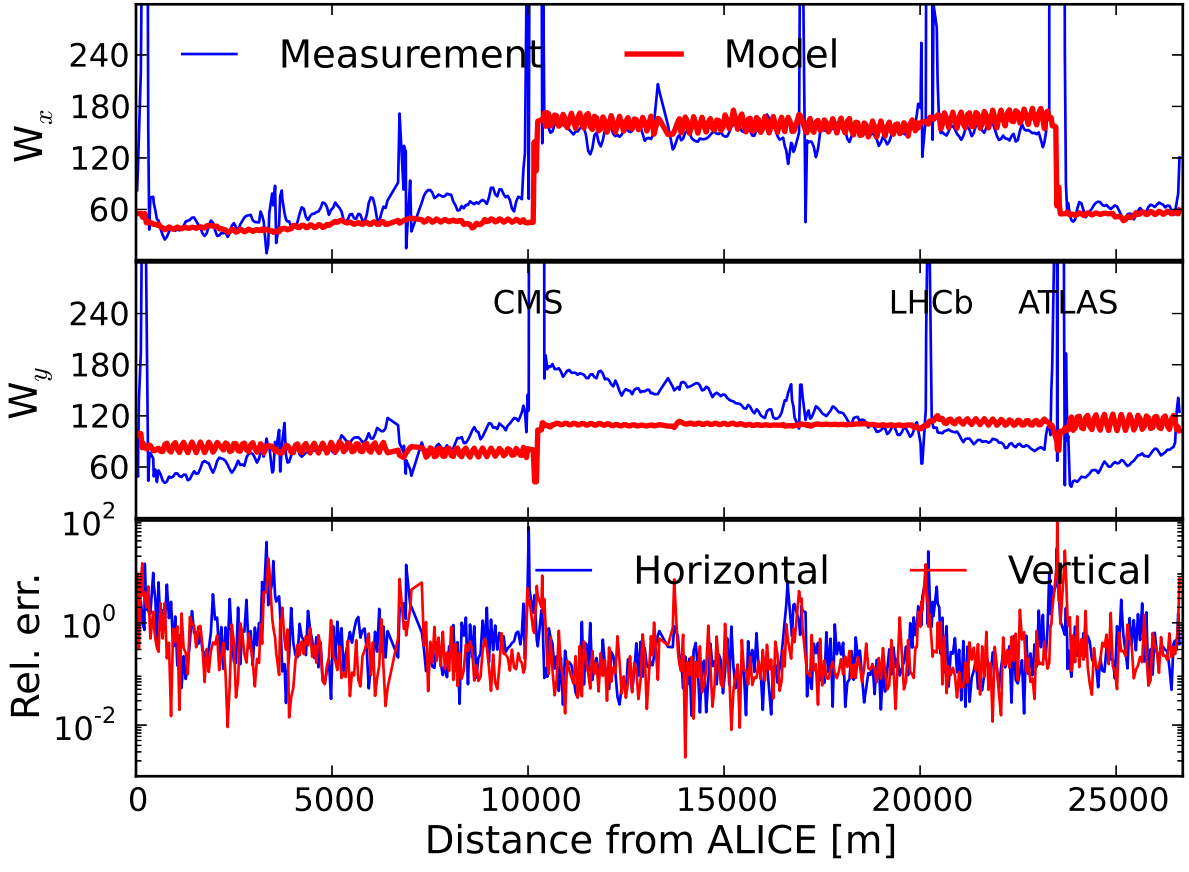
$$a = \frac{1}{\beta}\frac{\partial \beta}{\partial \delta_p} \tag{1}$$

$$b = \frac{\partial \alpha}{\partial \delta_p} - \frac{\alpha}{\beta}\frac{\partial \beta}{\partial \delta_p} \tag{2}$$

$$\mathbf{W} = \frac{\mathbf{1}}{\mathbf{2}}\sqrt{\mathbf{a^2} + \mathbf{b^2}} \tag{3}$$

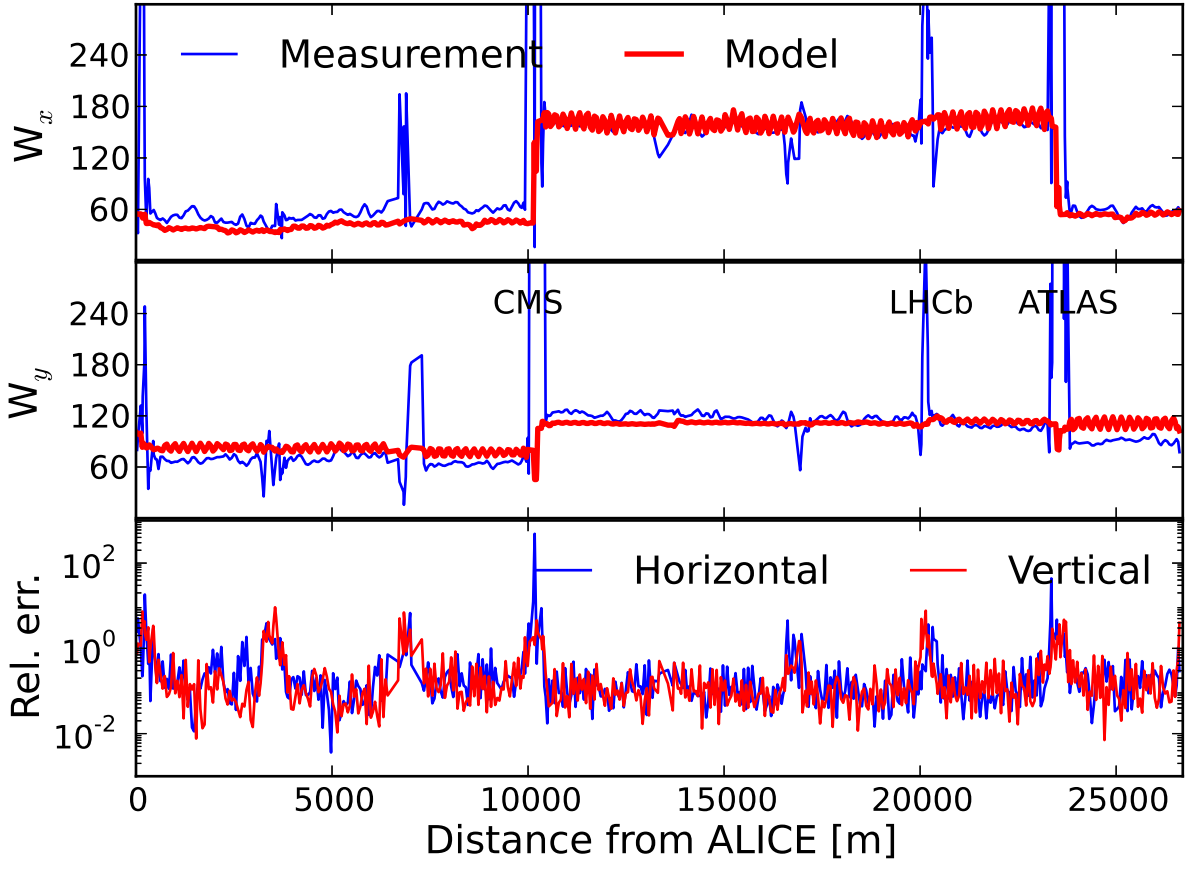
Derivations can be found in [1].

Measurements March, 2012, β^* 60 cm



Before corrections

Measurements March, 2012, β^* 60 cm



After corrections

See also [2]

Linear Transverse Coupling

$$A(Q) = -\frac{1}{4(1 - e^{2\pi i Q})} \tag{4}$$

$$B(I, \phi) = k_I \sqrt{\beta_x^I \beta_y^I} e^{i\phi} \tag{5}$$

Resonance Driving Terms

$$f_{1001} = A(Q_x - Q_y) \sum_I B(I, \Delta\phi_x - \Delta\phi_y) \tag{6}$$

$$f_{1010} = A(Q_x + Q_y) \sum_I B(I, (\Delta\phi_x + \Delta\phi_y) \tag{7}$$

Worth noting:

- $\mathrm{mod}(Q_x + Q_y) \sim 0$ -> sum resonance f_{1010} is strong (not LHC)
- $\mathrm{mod}(Q_x - Q_y) \sim 0$ -> diff. resonance f_{1001} is strong (**LHC**)

Chromatic Coupling

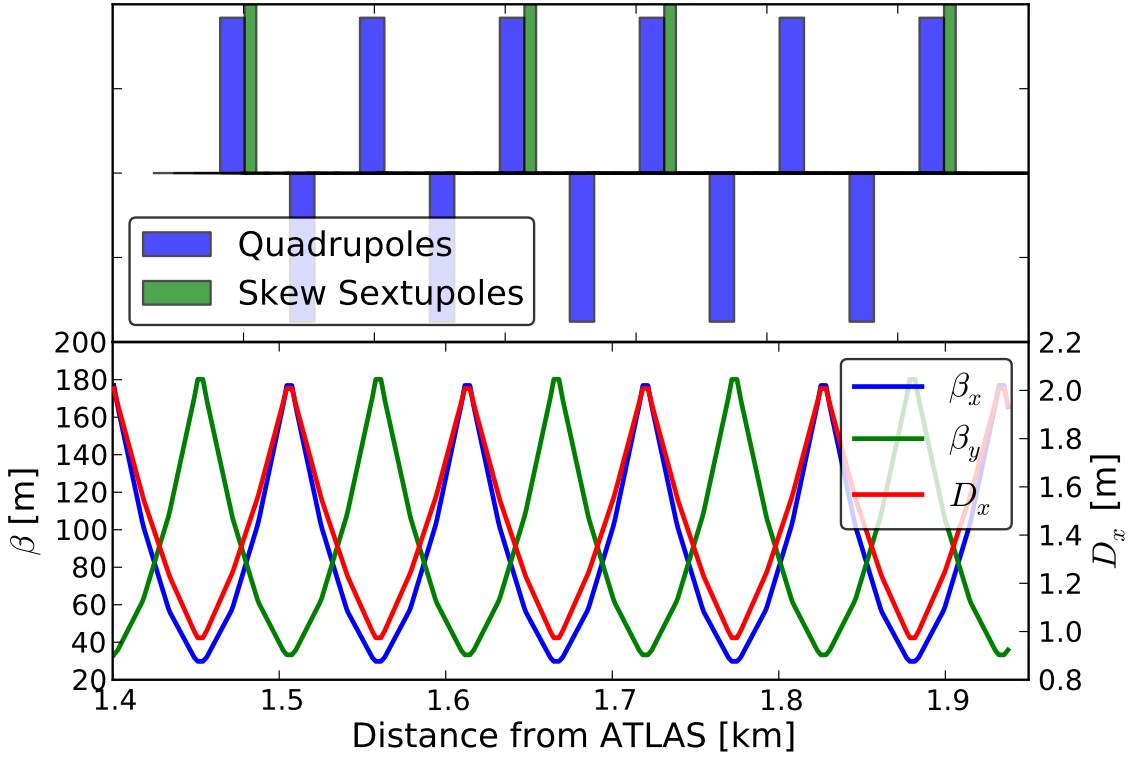
We define chromatic coupling as the transverse coupling as a function of change in momentum.

$$f^{chr}_{1001} \equiv \frac{\Delta f_{1001}}{\Delta \delta}$$

Skew Sextupoles (MSS)

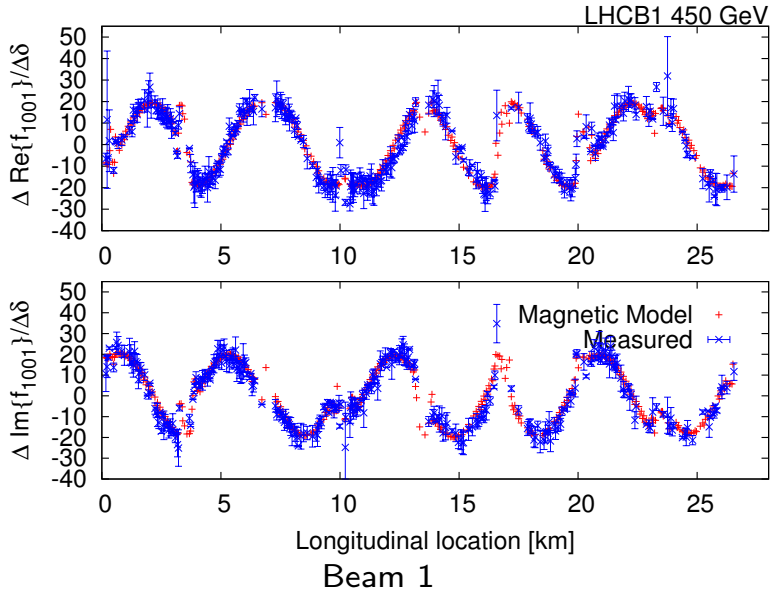
Four sextupoles (1 family) per arc
-> 8 correctors per beam.

Phase advance approx. 180-90-180
(-> designed to correct chromatic difference coupling)

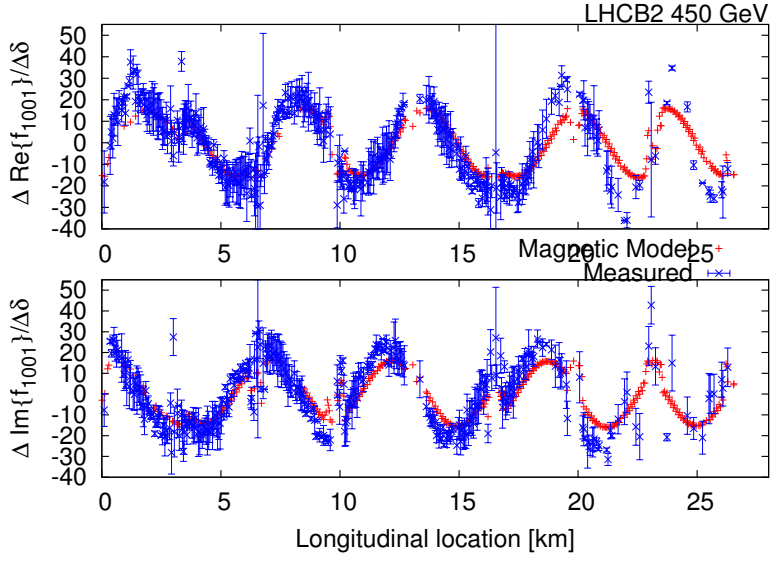


Expectations from Model

- Injection data for both beams compared to the magnetic model
- Very good agreement -> main sources of a_3 are known.

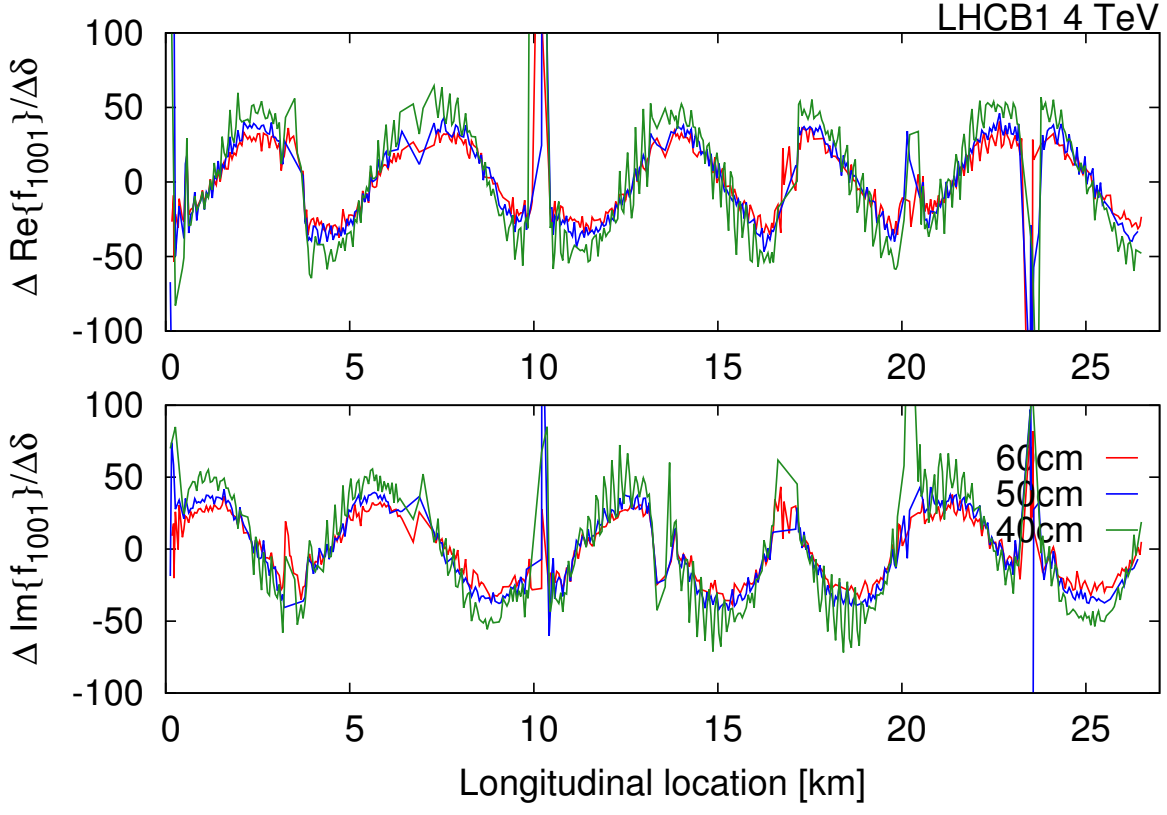


Beam 1



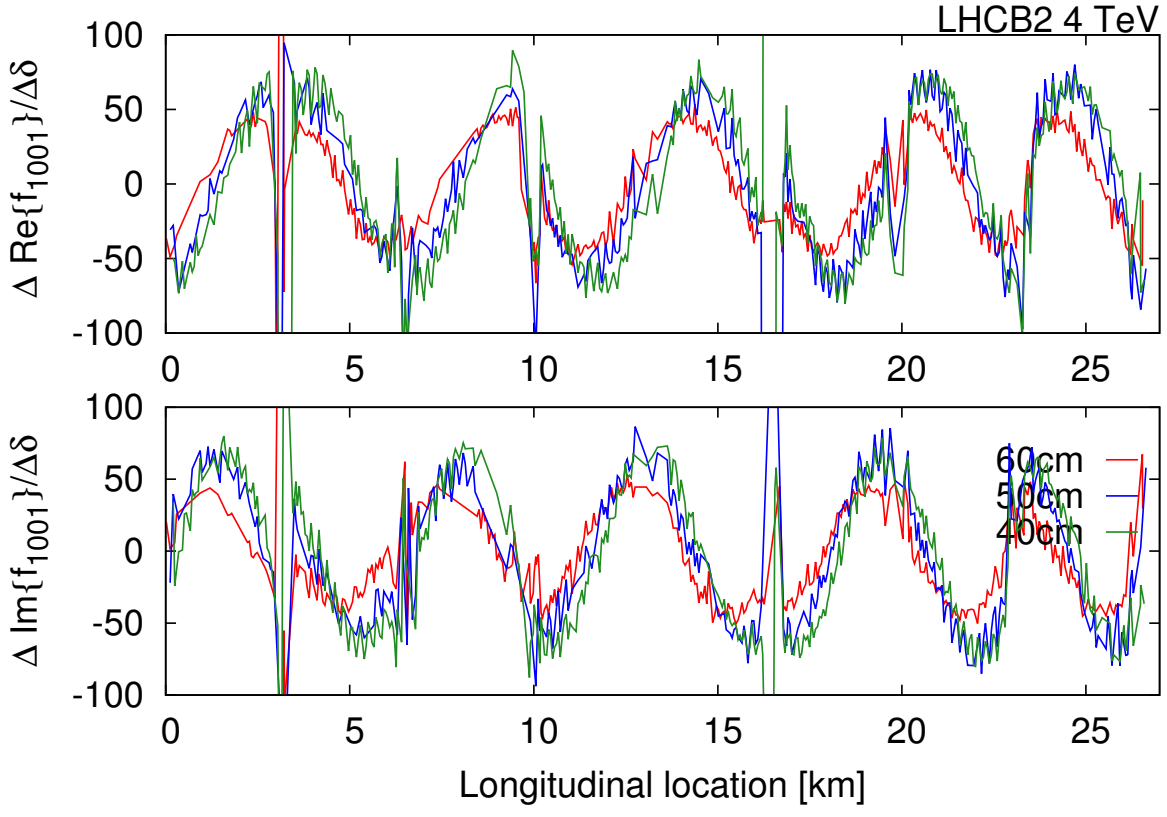
Beam 2

Measurement



The measured Beam 1 chromatic coupling for different β^* at 4 TeV.

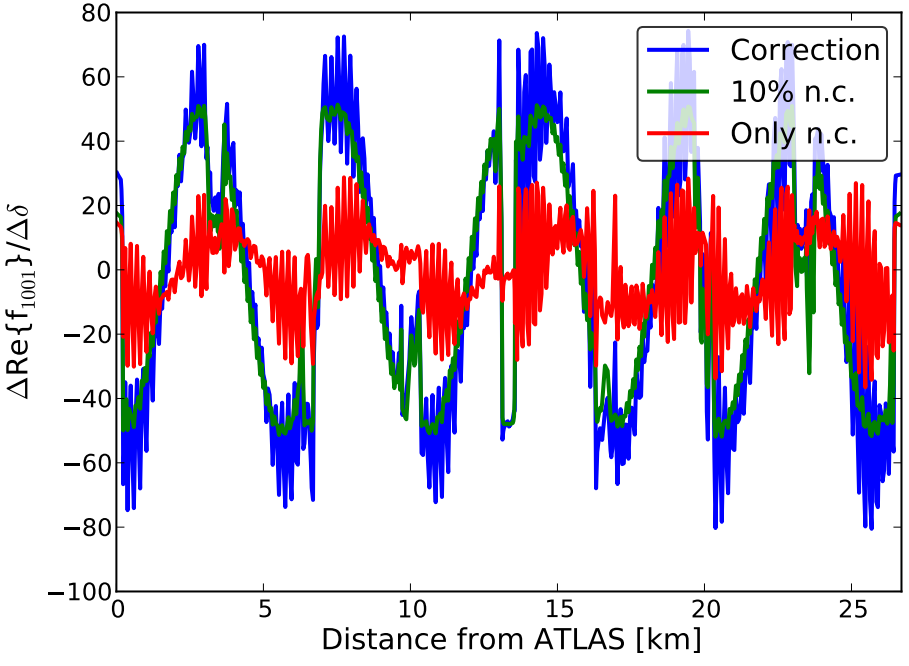
Measurement



The measured Beam 2 chromatic coupling for different β^* at 4 TeV.

Simulations of Linear+Chromatic Coupling

Both tracking simulations and our model (twiss) shows that a normal coupling will add a beating to the chromatic coupling measurement.



Correction Algorithm

An arc-by-arc algorithm was available from S. Fartoukh.

Currently we use a response matrix algorithm, applying similar principles as correction of linear coupling.

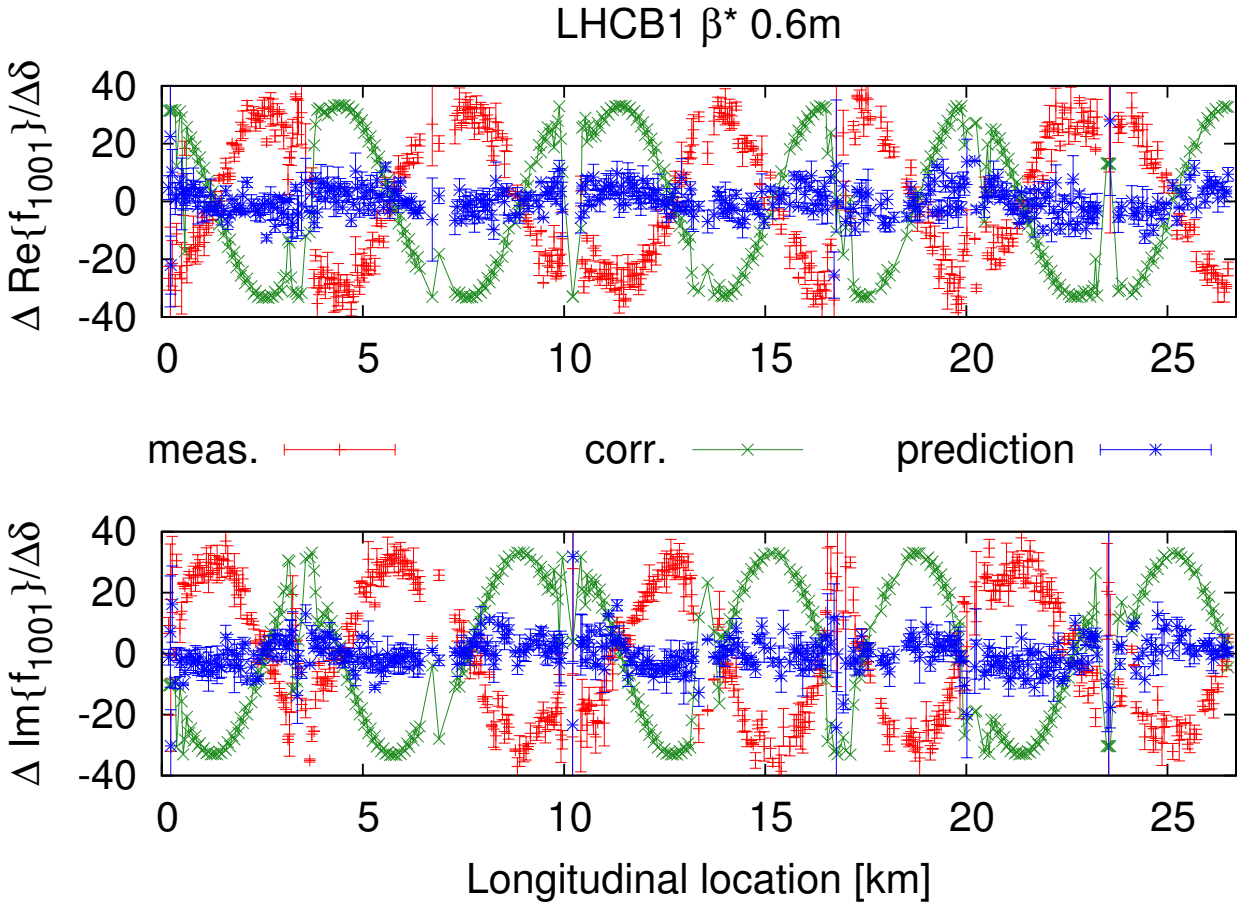
New procedure is currently preferred, as it better takes into account the cancellation between arcs, resulting in lower average powering of the skew sextupoles.

Correction Algorithm

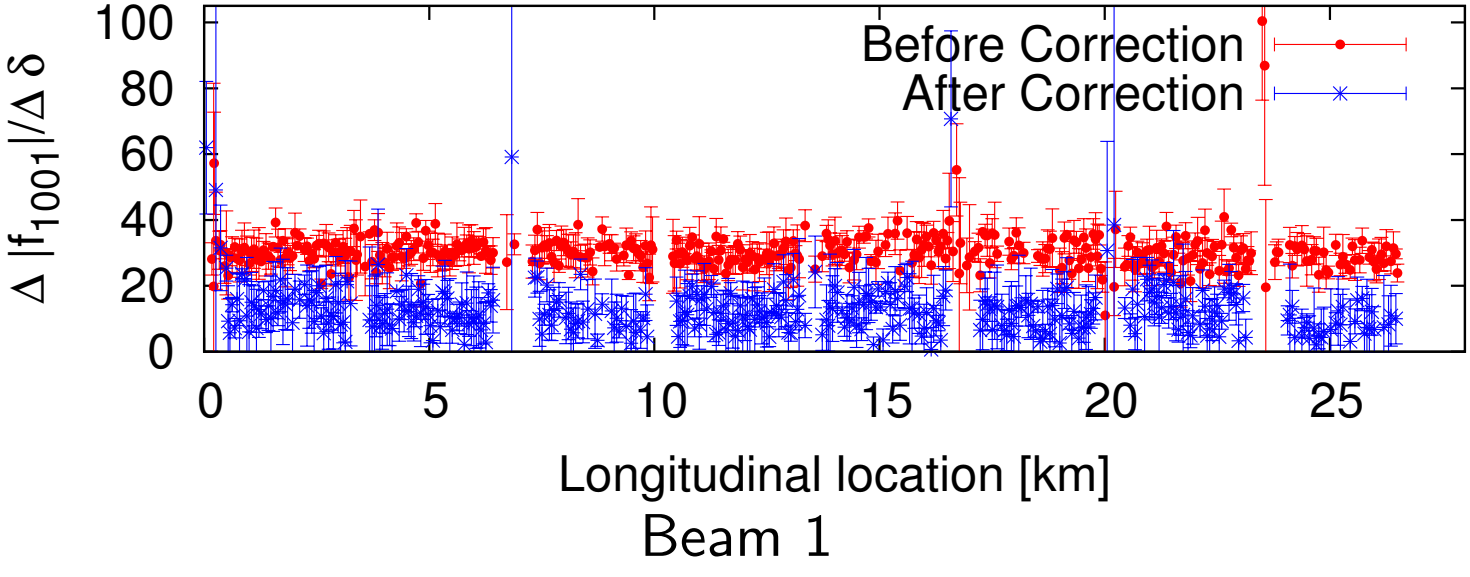
The calculated knob values from the two algorithms.

Arc	Response Matrix		Arc-By-Arc	
	Beam 1	Beam 2	Beam 1	Beam 2
	$[10^{-3}\ m^{-3}]$			
12	-7.57	-10.5	-52.3	54.5
23	8.8	10.2	-33.6	36.6
34	2.79	0.296	-32.6	31.3
45	-4.9	-6.95	-31.3	24
56	-0.319	2.39	-2.15	3.86
67	-7.76	-9.85	-6.84	2.26
78	-5.77	-7	-35.6	33.6
81	-	9.89	-15.3	18.3

Expected Correction Performance [60 cm]

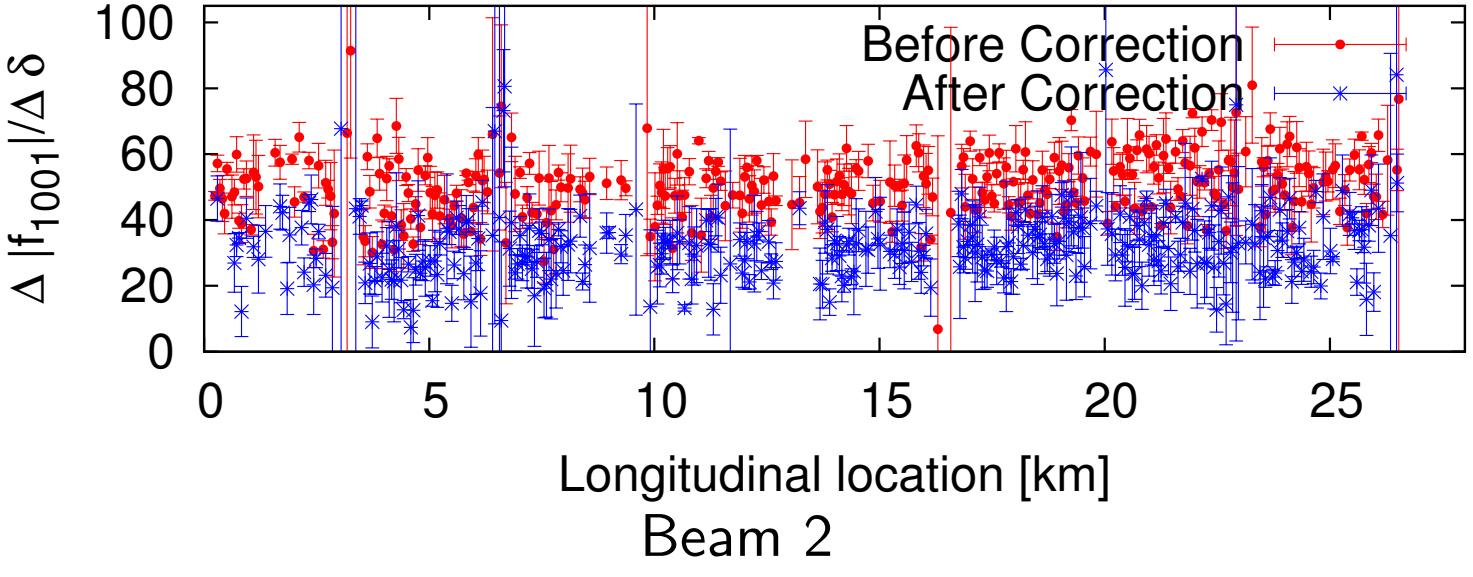


Result of Correction [60 cm]



The absolute value of the chromatic coupling before and after correction.

Result of Correction [60 cm]



The absolute value of the chromatic coupling before and after correction.

Result of Correction

	Before Correction		After Correction	
	$\frac{\overline{\lvert\Delta f_{1001}\rvert}}{\Delta\delta}$	Error (σ)	$\frac{\overline{\lvert\Delta f_{1001}\rvert}}{\Delta\delta}$	Error (σ)
Beam 1	31.5	5.4	12.5	5.3
Beam 2	50.1	8.5	31.4	9.0

Summary

- Chromatic β-beat is well corrected when β-beat is corrected.
- Chromatic coupling measured & corrected during MD in 2012.
- About 20 units were corrected for both beams.
- Important to correct linear coupling before chromatic coupling.
- Corrections has not yet been used during normal operation.

References

[1] B. W. Montague.
Linear Optics For Improved Chromaticity Correction.
Technical Report CERN-LEP-Note-165, CERN, Geneva, 1979.

[2] R. Tomás, T. Bach, R. Calaga, A. Langner, Y. Inntjore Levinsen, E. H. Maclean, T. H. B. Persson, P. K. Skowronski, M. Strzelczyk, G. Vanbavinckhove, and R. Miyamoto.
Record low β beating in the LHC.
Phys. Rev. ST Accel. Beams, 15:091001, Sep 2012.