LHC experience

Beta-beat team

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June 20, 2011

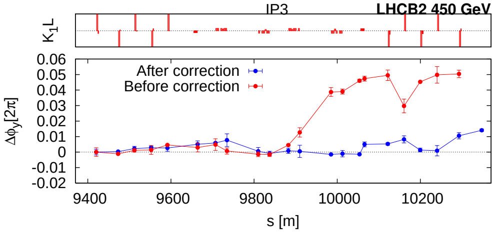
Tools

- Segment-by-Segment
- Global corrections using response matrix

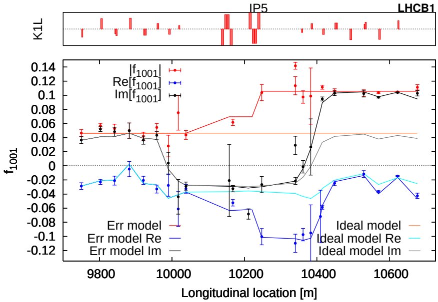
The segment-by-segment technique.

- Used to identify local errors.
- Part of the LHC is treated as a beam line.
- Initial conditions are measured optic values.
- Can be used to identify beta, coupling, dispersion and chromatic errors.

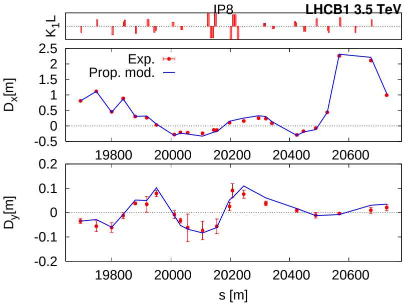
Example S-B-S phase:



Example S-B-S coupling:

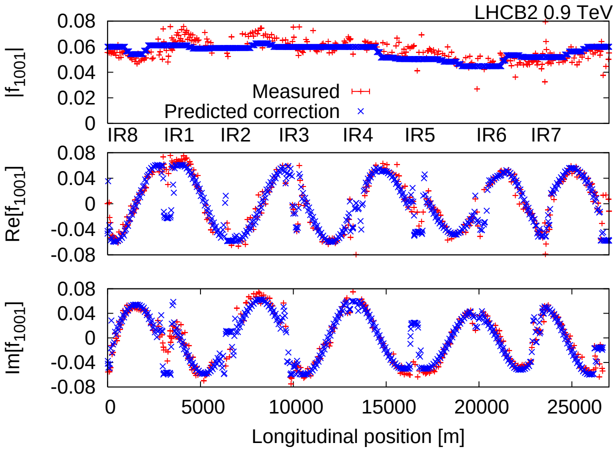


Example S-B-S dispersion:



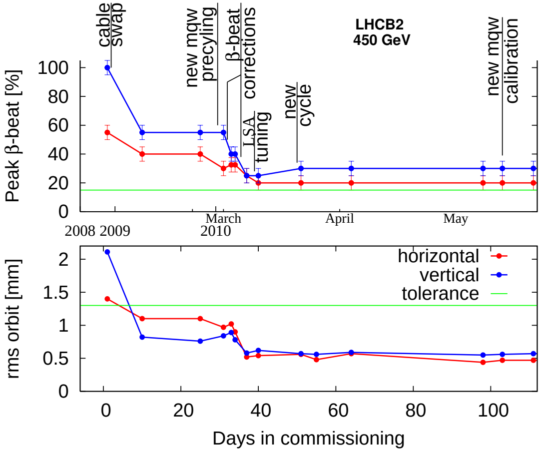
Global corrections using response matrix.

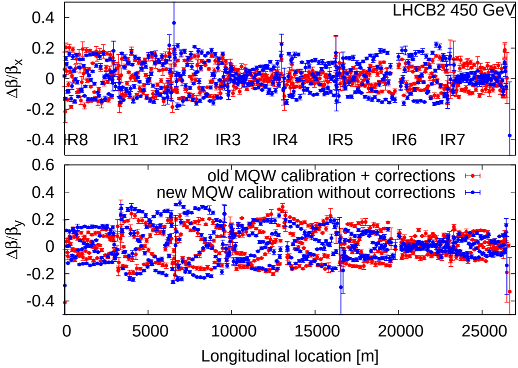
- $\Delta\vec{\phi_{x,y}}, \Delta\vec{\beta_{x,y}}, \Delta\vec{D_x}, Q_{x,y} = \mathbf{R}\Delta\vec{k_1}$
- $\Delta\vec{f_{1001}}, \Delta\vec{f_{1010}}, \Delta\vec{D_y} = \mathbf{R}\Delta ks_1$



Injection

- large $\frac{\Delta\beta}{\beta}$ in 2008 due to cable swap.
- "LSA tuning" adjustments in the polynomials used to model some magnets.
- Local corrections in IP_2 and IP_8.
- Corrections are zeroed out at 700 GeV.





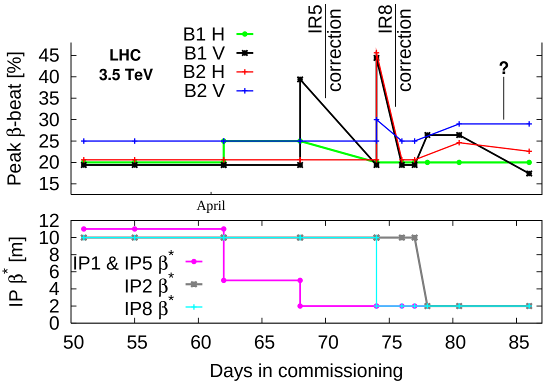
- New calibrations based on magnetic measurements.
- Warm quadrupoles left and right from IP_3 and IP_7.
- Errors are reduced by factors 2 and 2.5 (except MQWA4.LR3).

Squeeze

In 2010 and 2011 three different optics settings were explored:

- In 2010:
  - All IP's at 2 m.
  - All IP's at 3.5 m.
- In 2011:
  - IP_1 and IP_5 at 1.5 m, IP_8 at 3 m and IP_2 at 10 m.

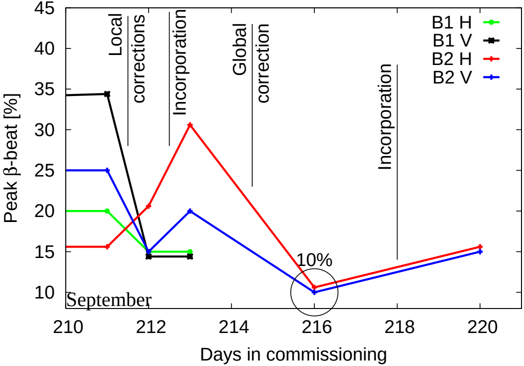
2010 squeeze commissioning $\beta^* = 2$m:



- IP's were squeezed in steps.
- Corrections in IP_5 and IP_8 were implemented.

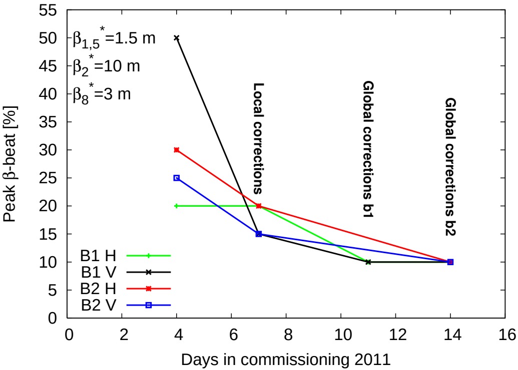
2010 squeeze commissioning $\beta^* = $3.5m:

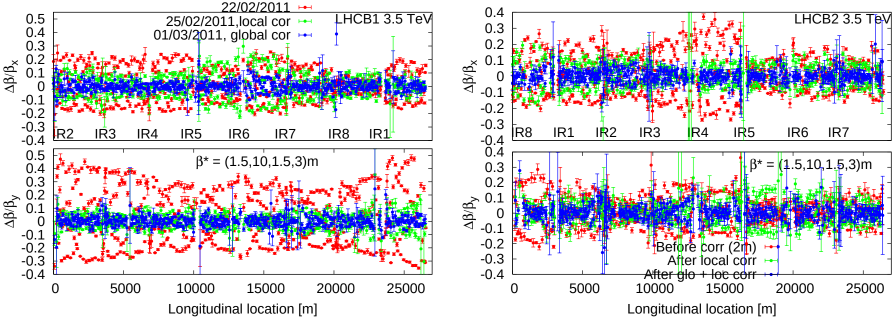
- Local corrections in IP_1,IP_2,IP_5,IP_6 and IP_8.
- Global correction for beam 2 reduced the $\frac{\Delta\beta}{\beta}$ in both planes to 10%.
- Incorporation gave an increase in $\frac{\Delta\beta}{\beta}$ because some corrections were not driven.



2011 squeeze commissioning $\beta^* = 1.5$m:

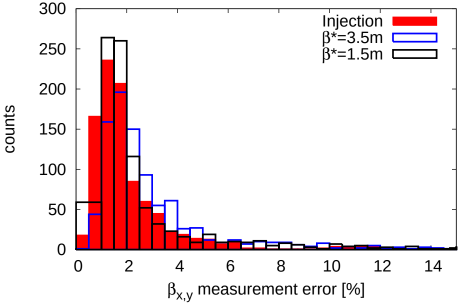
- Local corrections were implemented.
- Global corrections for beam 1 and beam 2 were implemented.



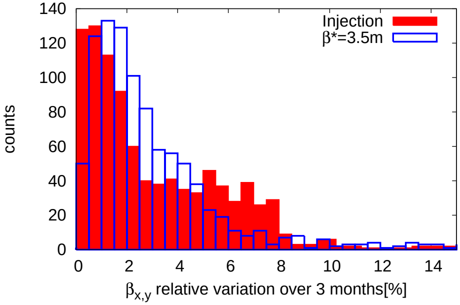

22/02/2011
25/02/2011,local cor
01/03/2011, global cor
LHCB1 3.5 TeV
Δβ/βx
IR2 IR3 IR4 IR5 IR6 IR7 IR8 IR1
Δβ/βy
β* = (1.5,10,1.5,3)m
Longitudinal location [m]
LHCB2 3.5 TeV
IR8 IR1 IR2 IR3 IR4 IR5 IR6 IR7
β* = (1.5,10,1.5,3)m
Before corr (2m)
After local corr
After glo + loc corr
Longitudinal location [m]

Observations

- Optics stability
- Corrections
- BPM performance

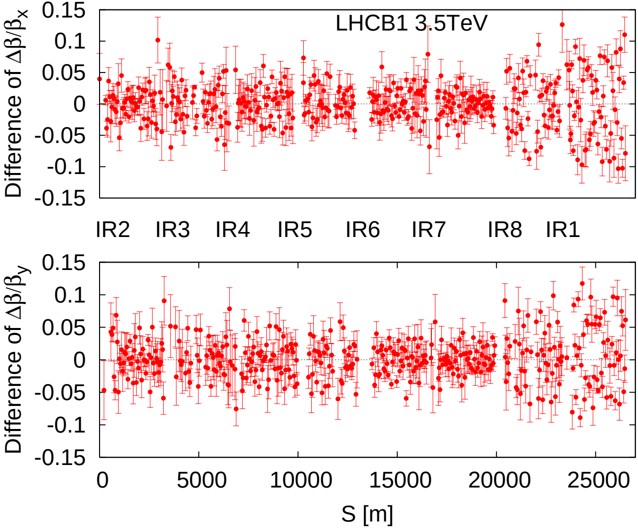


Injection
β*=3.5m
β*=1.5m
counts
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
$\beta_{x,y}$ measurement error [%]

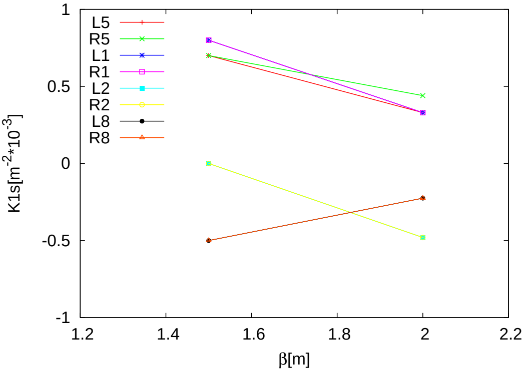


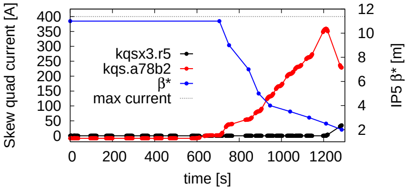
Injection
β*=3.5m
counts
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
$\beta_{x,y}$ relative variation over 3 months[%]

Difference in $\Delta\beta/\beta$ between beginning of fill and end of fill (30 hours).

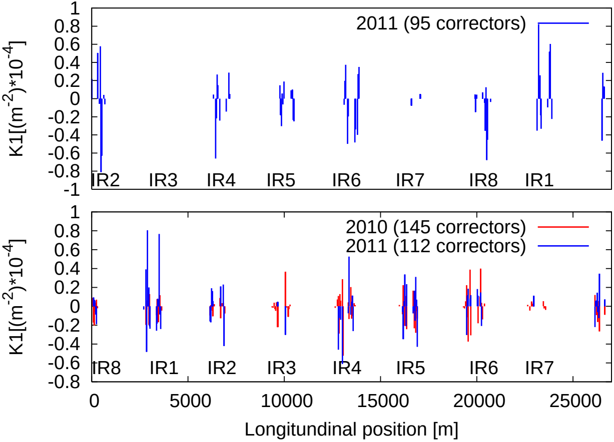


Coupling correction:

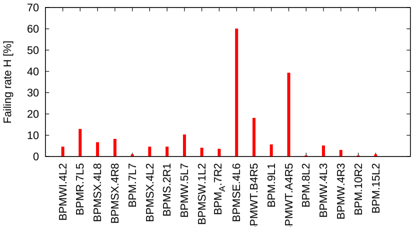


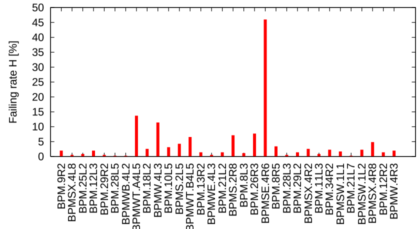


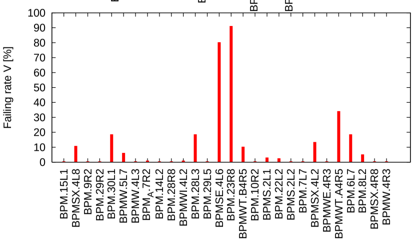
Distribution of correctors vs. s:

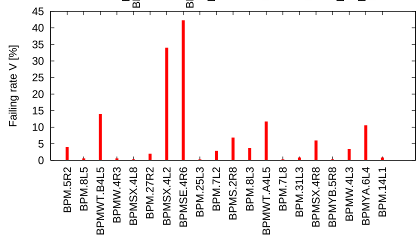


BPM performance is outstanding, histogram for 2011 shows low failing rate:



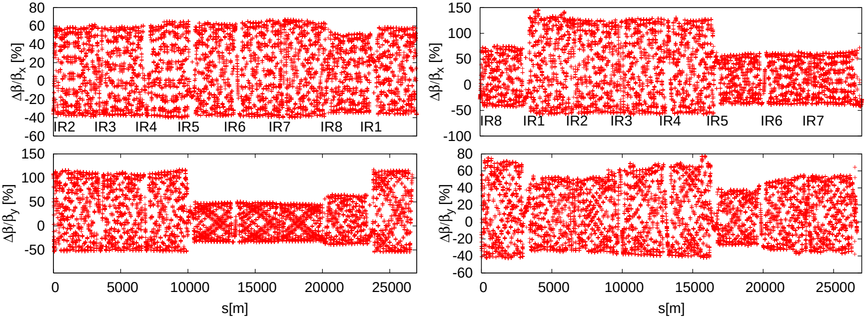




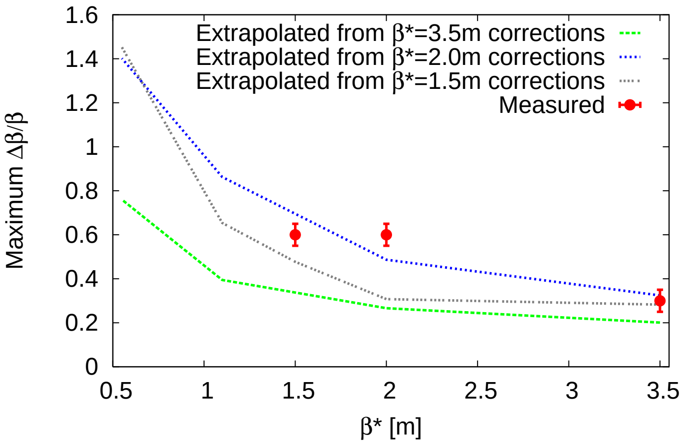


Outlook and Summary

Challenge for $7\,TeV\,\beta^* = 0.55cm$:



Challenge for $7\,TeV\,\beta^* = 0.55cm$:

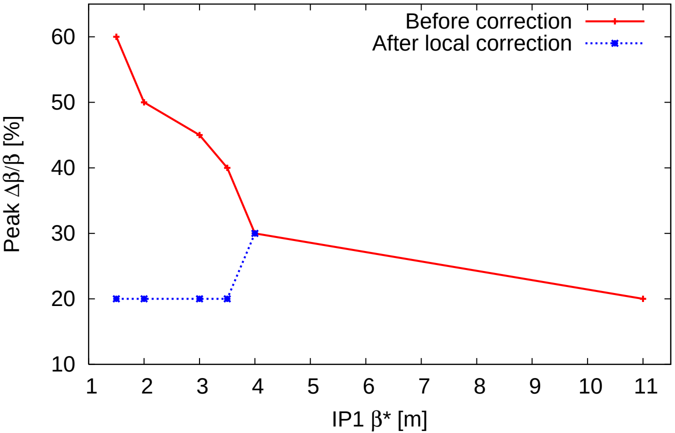


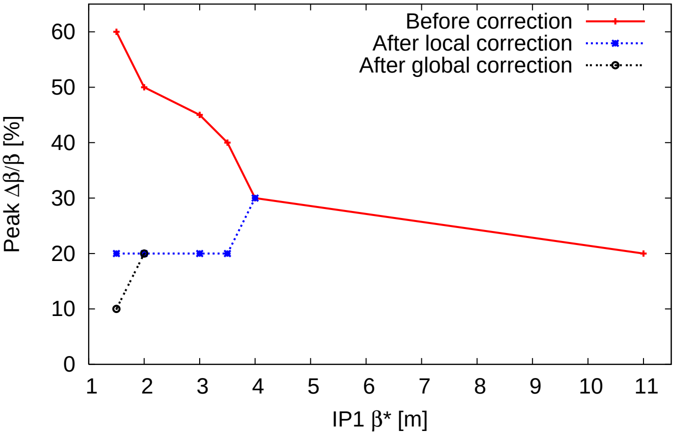
- Local and global algorithms have been successfully applied.
- $\frac{\Delta\beta}{\beta}$ at injection remains at 30%, but can be corrected if needed.
- Squeezed optics the $\frac{\Delta\beta}{\beta}$ is well within tolerances (10%) for 2011.
- Small difference in $\frac{\Delta\beta}{\beta}$ is observed for long fills and at injection.
- Challenge remains for $7\,TeV\,\beta^* = 0.55cm$.

Questions ?

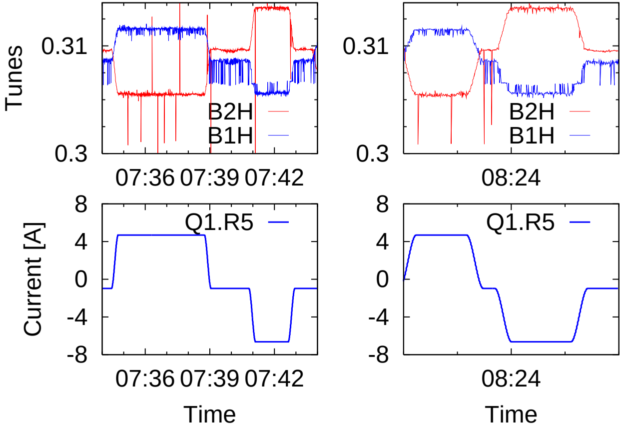
Local corrections are found to work similarly between $\beta^* = 3.5$m and 1.5m in IR1, IR5, IR6 and IR8:

Corrector	ΔK $[10^{-5} m^{-2}]$	Relative [%]
kq9.l1b1	3.8	0.60
ktqx2.r1	-0.8	0.09
ktqx2.l5	1.0	0.11
ktqx2.r5	1.3	0.15
kq5.l6b2	-4.6	0.70
ktqx2.l8	-2.3	0.26
ktqx2.r8	-0.5	0.06


Before correction
After local correction
Peak Δβ/β [%]
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
IP1 β* [m]



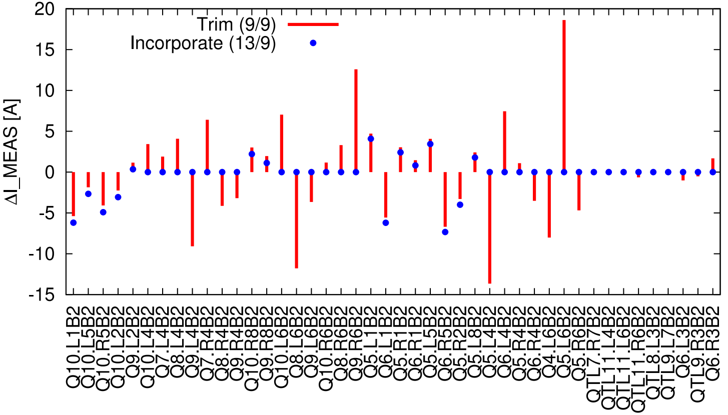
Before correction
After local correction
After global correction
Peak Δβ/β [%]
IP1 β* [m]
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11



Identical tunes after 1 hour of K-modulating.

case	IR1		IR5	
	Ave	rms	Ave	rms
B2H	1.57	0.11	1.48	0.11
B2V	1.57	0.09	1.52	0.09
B1H	1.53	0.15	1.50	0.15
B1V	1.50	0.06	1.52	0.06

Maximum β^*-beating $= 4.7\%$.
CMS gets $(2.5\pm8)\%$ more luminosity.


Trim (9/9)
Incorporate (13/9)
ΔI_MEAS [A]
20
15
10
5
0
-5
-10
-15
Q10.L1B2
Q10.L5B2
Q10.R5B2
Q10.L2B2
Q9.L2B2
Q10.L4B2
Q7.L4B2
Q8.L4B2
Q9.L4B2
Q7.R4B2
Q8.R4B2
Q9.R4B2
Q10.R8B2
Q9.R8B2
Q10.L6B2
Q8.L6B2
Q9.L6B2
Q10.R6B2
Q8.R6B2
Q9.R6B2
Q5.L1B2
Q6.L1B2
Q5.R1B2
Q6.R1B2
Q5.L5B2
Q6.R5B2
Q5.R2B2
Q5.L8B2
Q5.L4B2
Q6.L4B2
Q5.R4B2
Q6.R4B2
Q4.L6B2
Q5.L6B2
Q5.R6B2
QTL7.R7B2
QTL11.L4B2
QTL11.L6B2
QTL11.R6B2
QTL8.L3B2
QTL9.L7B2
Q6.L3B2
QTL9.R3B2
Q6.R3B2