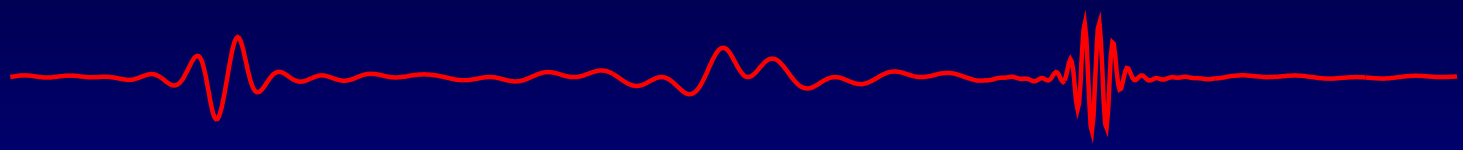
LHC optical model and necessary corrections (aperture model, tune, β-beat, coupling, chromaticity...)



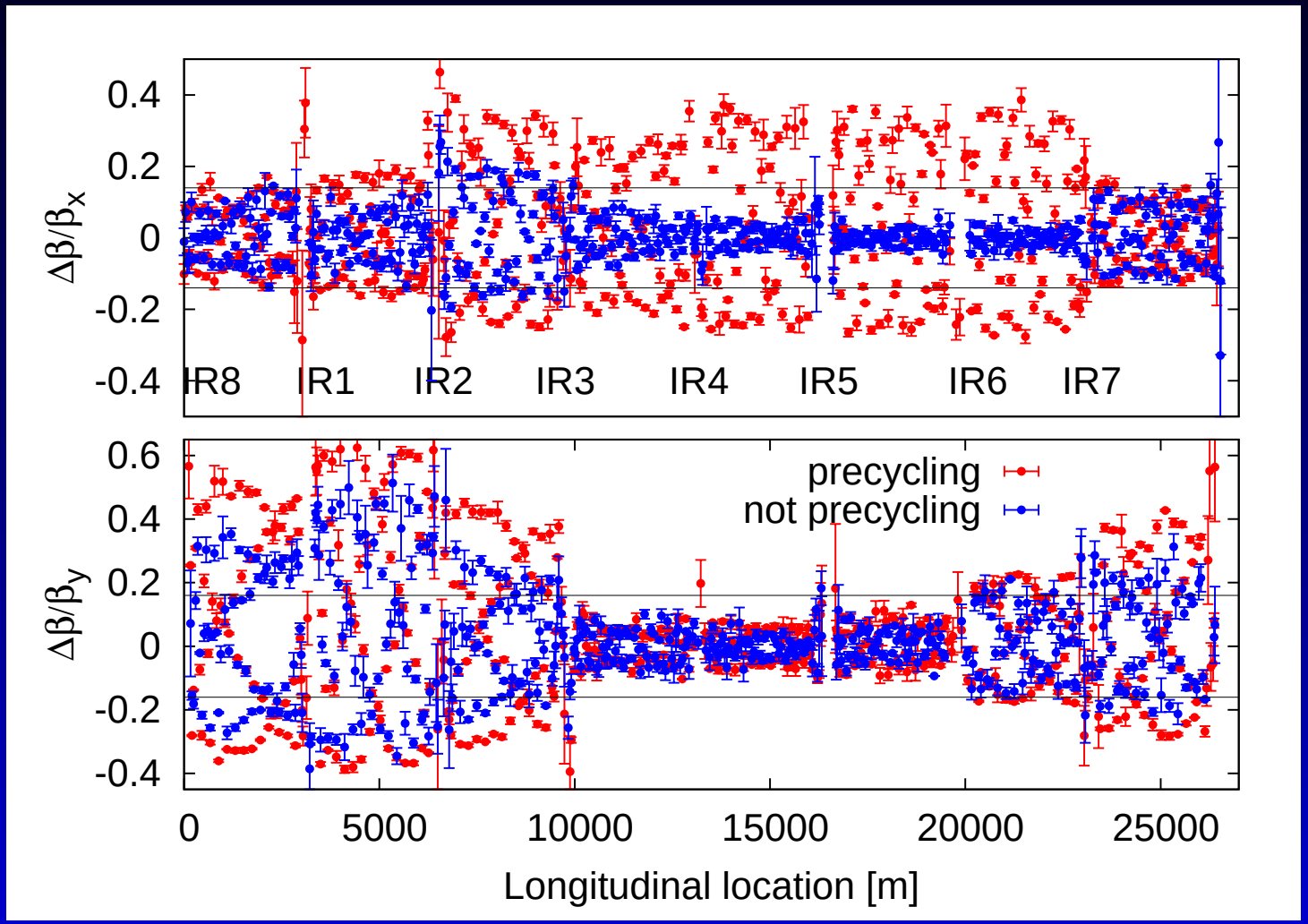
M. Aiba, C. Alabau, R. Calaga, J. Cardona, O. Dominguez, M. Giovannozzi, S. Fartoukh, V. Kain, M. Lamont, E. Mcintosh, R. Miyamoto, G. Mueller, S. Redaelli, F. Schmidt, R. Tomás, G. Vanbavinckhove, J. Wenninger, S. White and F. Zimmermann

LHC beam commissioning workshop - 2010

Contents

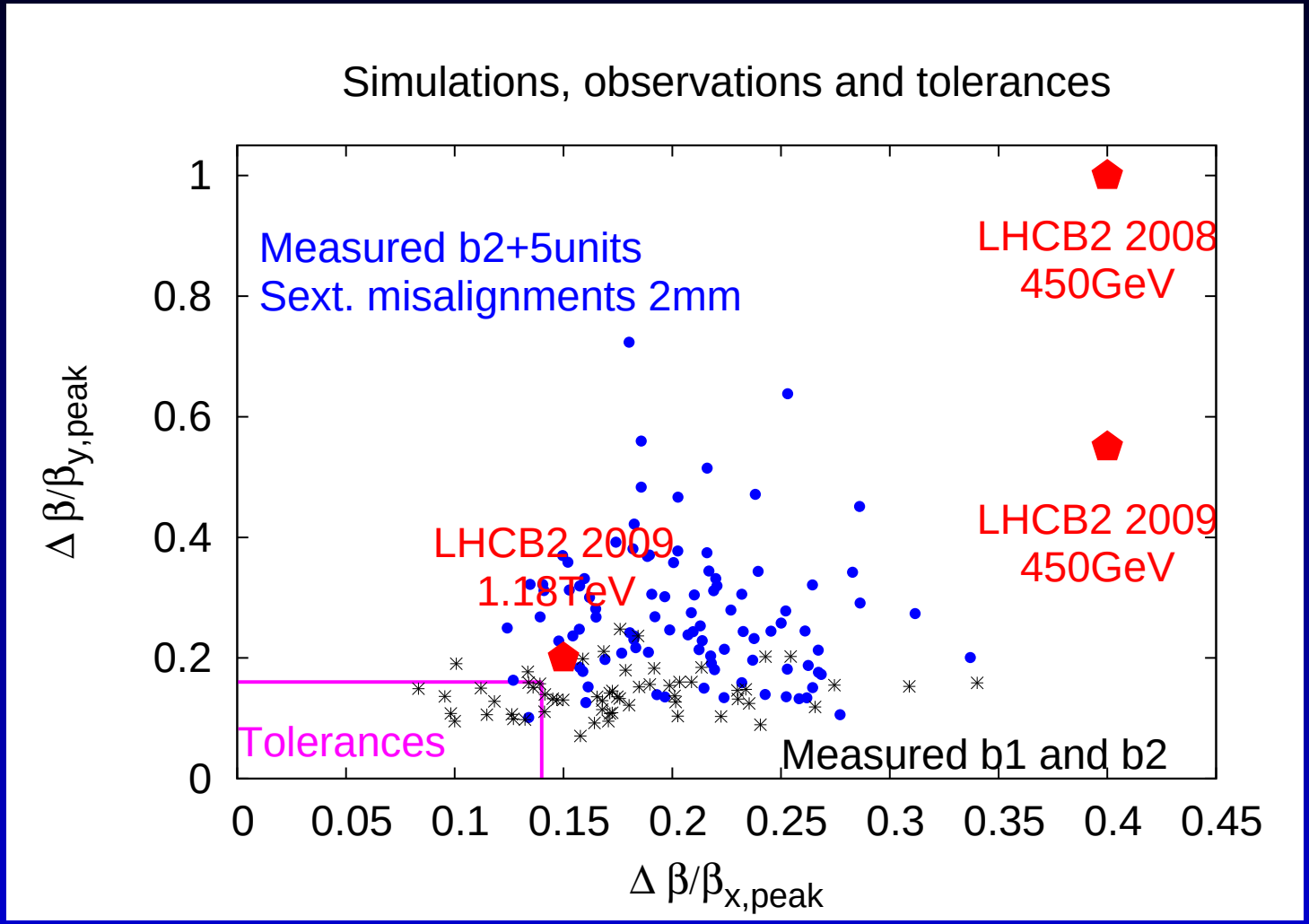
- Effect of precycling (prehistory)
- LHC status (optics and aperture)
- Optics error sources at injection:
  - Errors in IR3 and IR7 (warm)
  - Triplet errors in IR2 and IR8
  - Dipole b_2 correction
- IR5 squeeze
- Software needs
- Commissioning needs

The effect of precycling - Beam 2



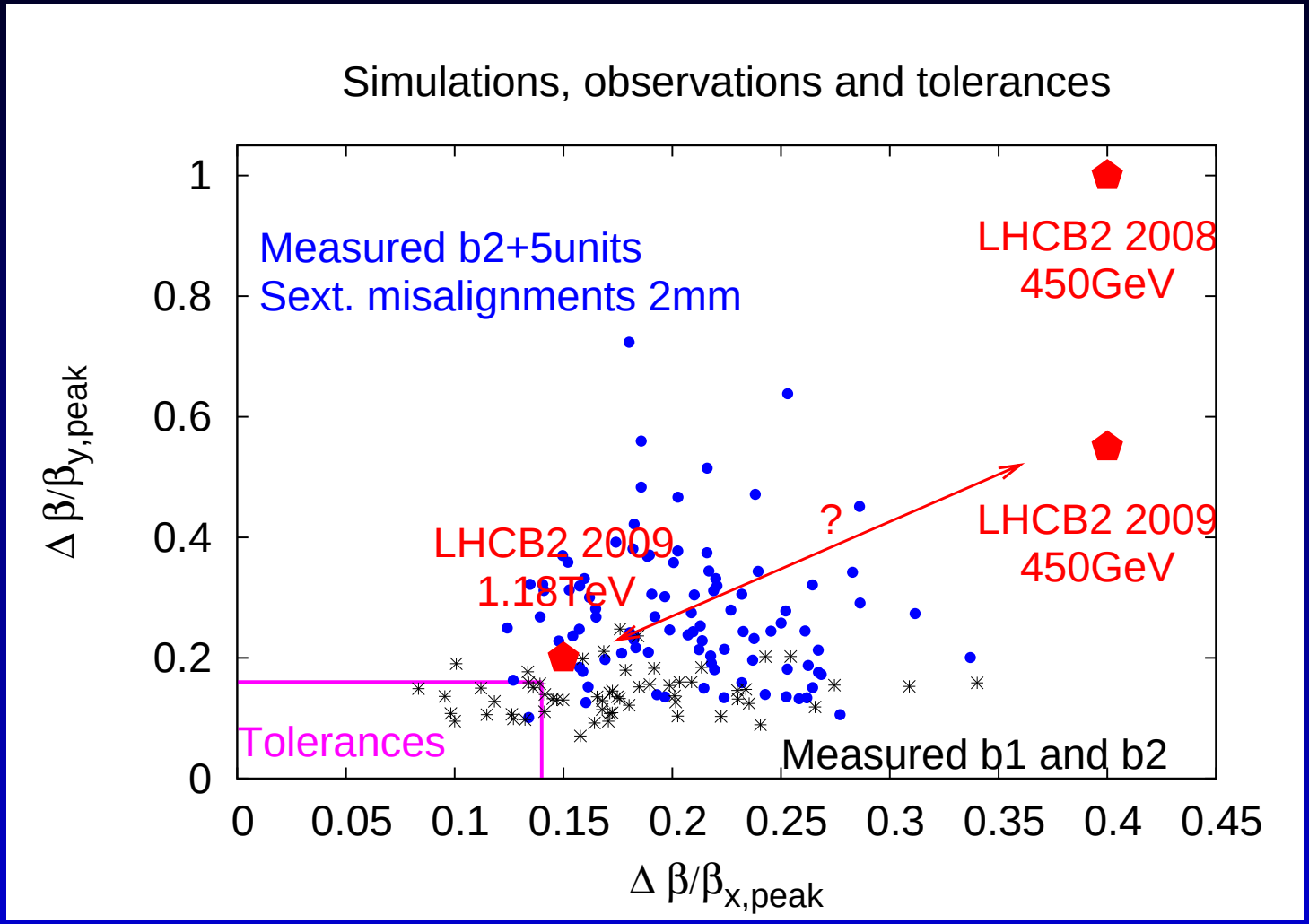
Large differences! → Must precycle

Beam 2, 2008-2009



Injection optics still far from tolerances

Beam 2, 2008-2009



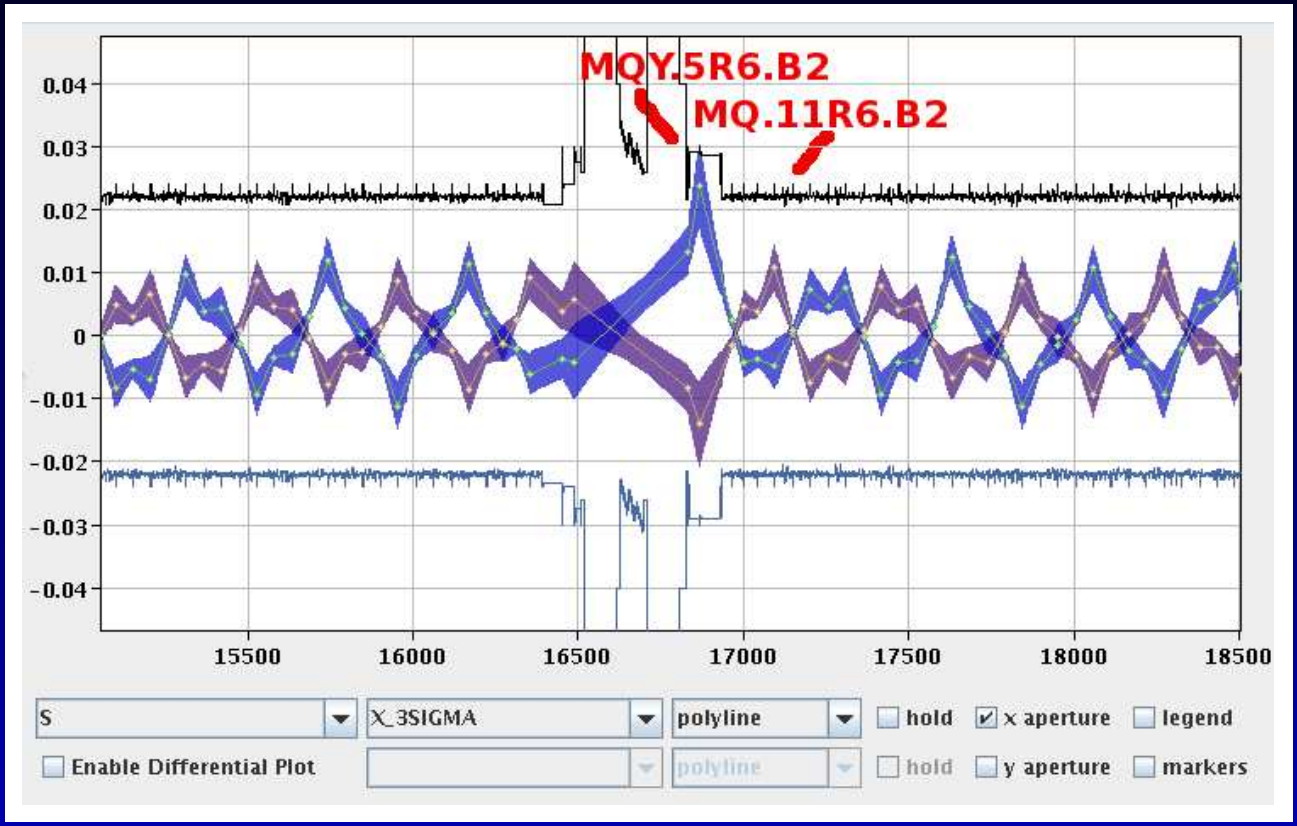
Why the large difference between 450GeV and 1.18TeV?

LHC optics status summary

		Beam 1		Beam 2		Tol.
E	[TeV]	0.45	1.18	0.45	1.18	
$\Delta\beta_x/\beta_x$	[%]	35	20	40	15	14
$\Delta\beta_y/\beta_y$	[%]	50	16	55	20	16
$\Delta D_x^{q_f}/D_x^{q_f}$	[%]	19	11	16	?	30
$\Delta D_y^{q_d}/D_x^{q_f}$	[%]	8	12	11	?	28

Dispersion is within tolerances even at injection!

Aperture measurements (IR6 example)



$+8\sigma$
-7σ

Measured closed orbit + 3σ envelope using measured optics and $\epsilon_{x,n} = 3.5\mu$m. 5R6 losses expected, 11R6 losses to be understood.

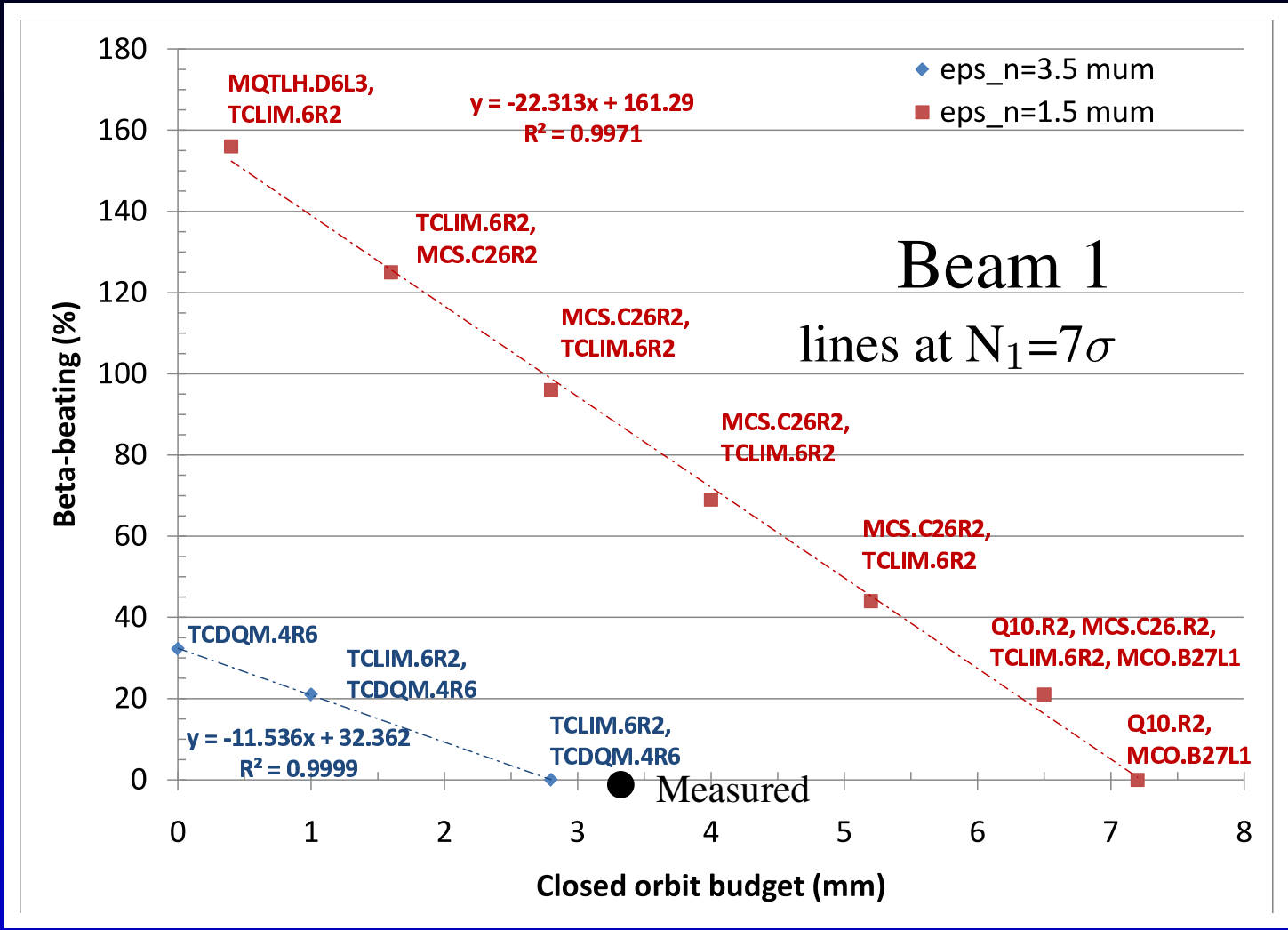
Summary of aperture measurements

Aperture measurements

Bump amplitude limited to:
Main losses at:

	Horizontal	Vertical
Beam 1	+7 / -7 sigma MQM.6R2 smaller peak: MQM.6R8 / MQY.4R6 MQY.5R6	+8 / -9 sigma MQY.4L6 MQ.31L1 smaller peak: MQ.13L5 / MQY.4L6
Beam 2	+8 / -7 sigma MQY.5R6 MQ. 11R6 / MQY.4L6 MQY.5R6 MQM.6L8	+7 / -7.5 sigma MQ.12R8 MQ.29L2 / MQ.20L3 MQ. 16R8 smaller peak: MQY.5L6

Aperture tolerance with measured β-beat



Traditional values $\epsilon_n = 3.75\ \mu$m, and CO_{budget}=4mm.

Aperture is out of budget due to β-beating $\begin{pmatrix}\text{measured CO and}\\ \text{lower } \epsilon_n \text{ help}\end{pmatrix}$

LHC aperture status

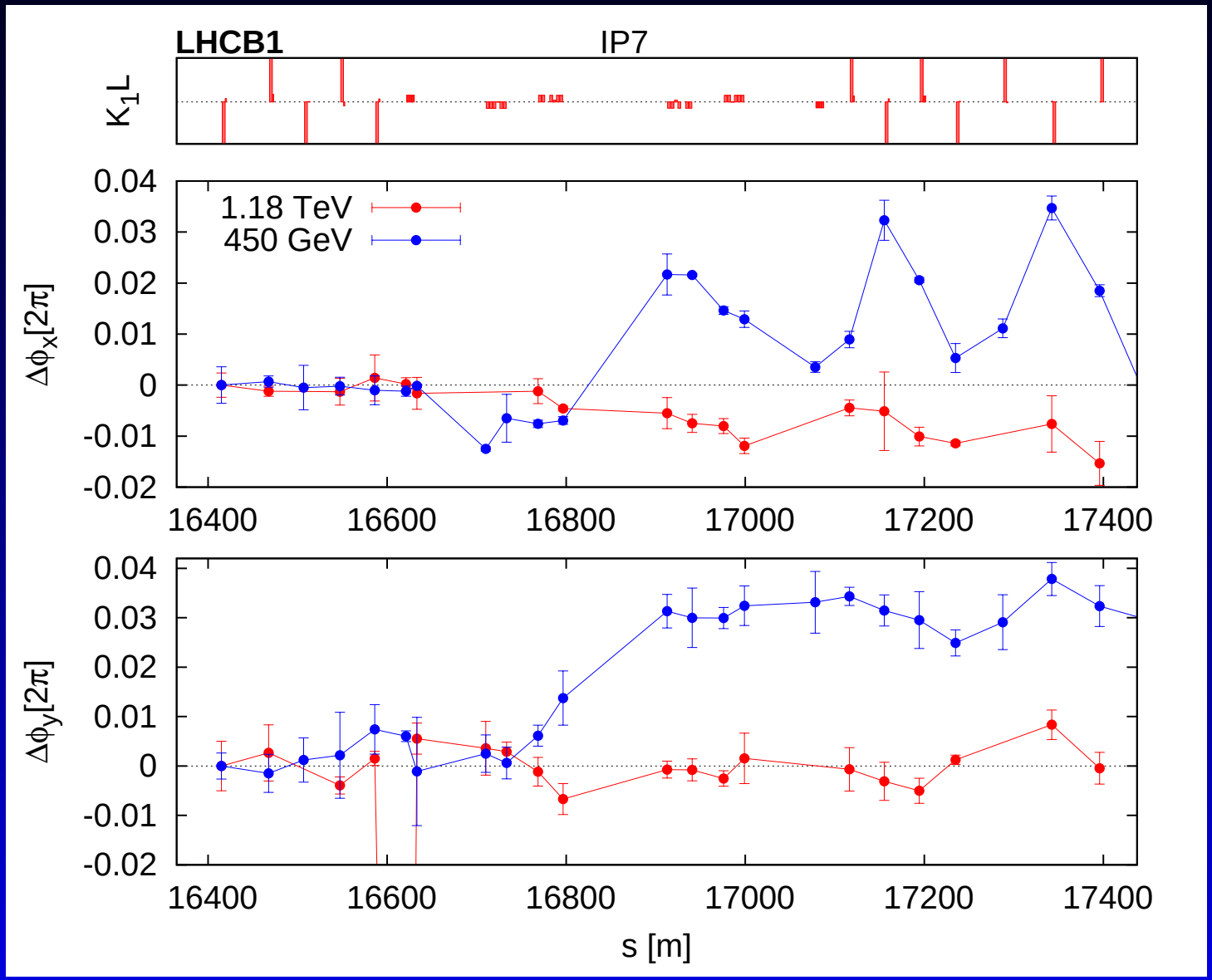
- Beam clearance seems to be OK, above or equal to 7σ.
- Some measured bottlenecks agree with model predictions using measured β functions.
- Aperture is out of budget due to the large β-beating, $N_1 < 7\sigma$ even reducing the CO_{budget} to the measured $\approx$3.2mm peak CO.
- Correcting β-beating is mandatory.

Error sources @ injection

Estimated impact of sources ordered by size:

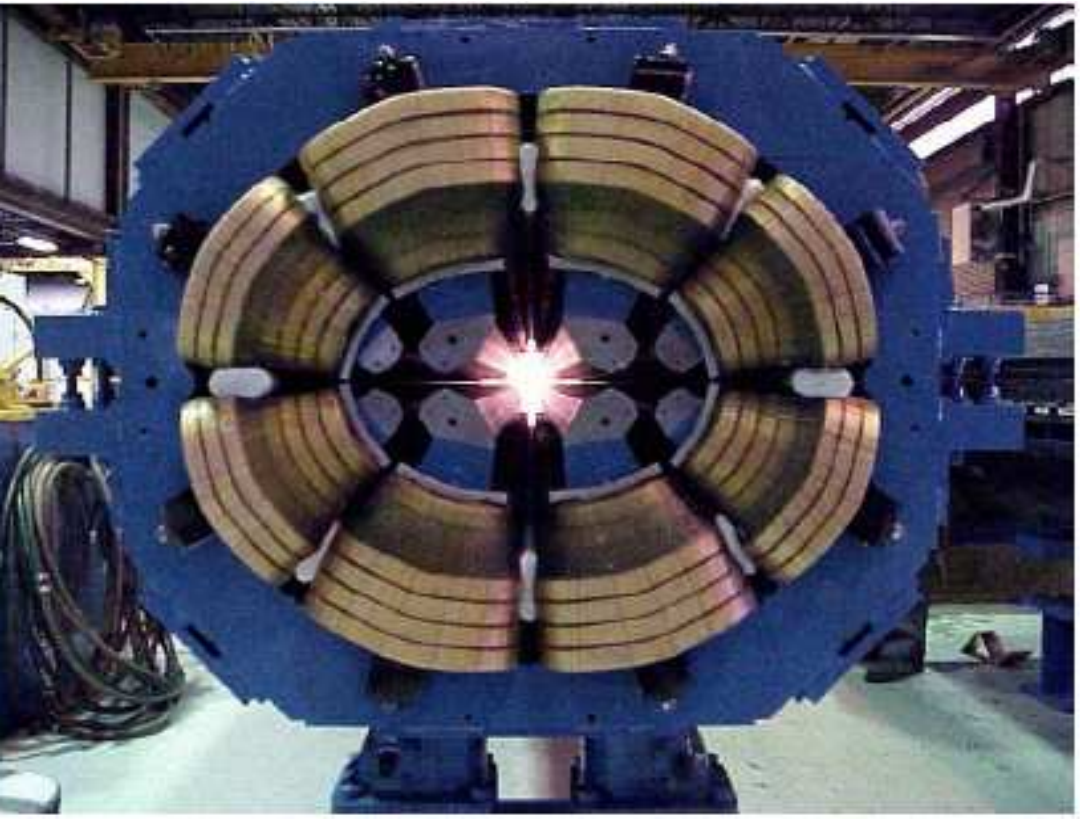
	Beam 1		Beam 2	
	$\Delta\beta_x/\beta_x$	$\Delta\beta_y/\beta_y$	$\Delta\beta_x/\beta_x$	$\Delta\beta_y/\beta_y$
IR3	15	10	15	10
IR7	15	6	12	8
IR2	6	9	6	10
IR8	8	8	8	8
dip. b_2	6	7	5	9

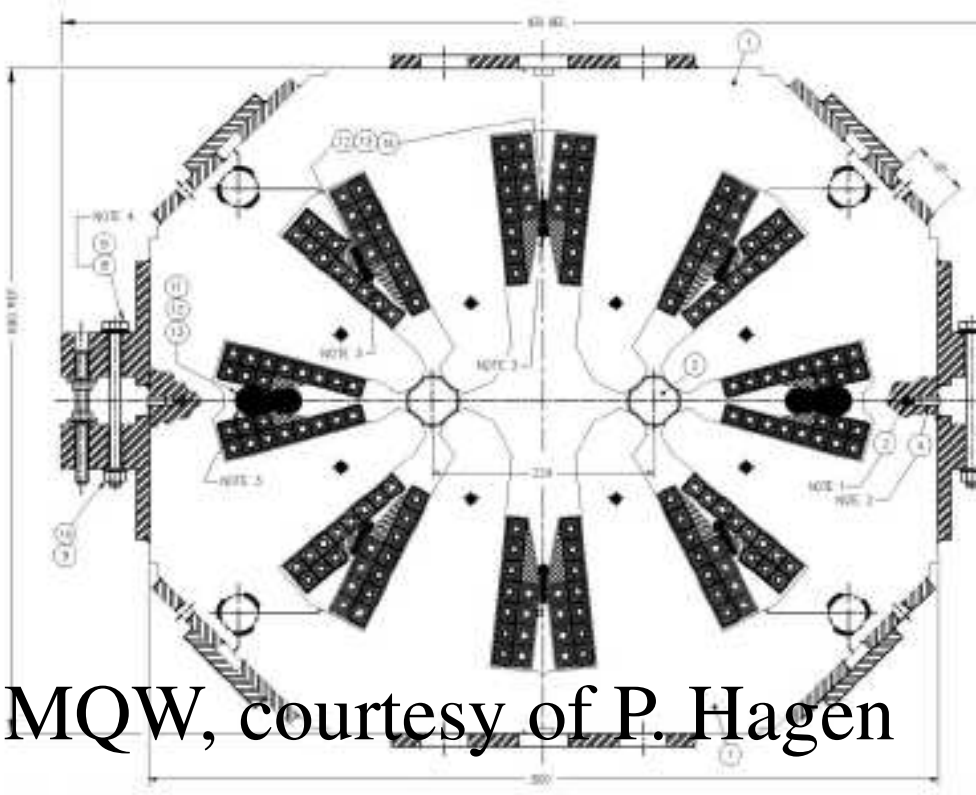
IR7 local error @ 450GeV & 1.18 TeV



IR3 and IR7 errors disappear at 1.18 TeV, why?

Suspects of IR7 and IR3 errors

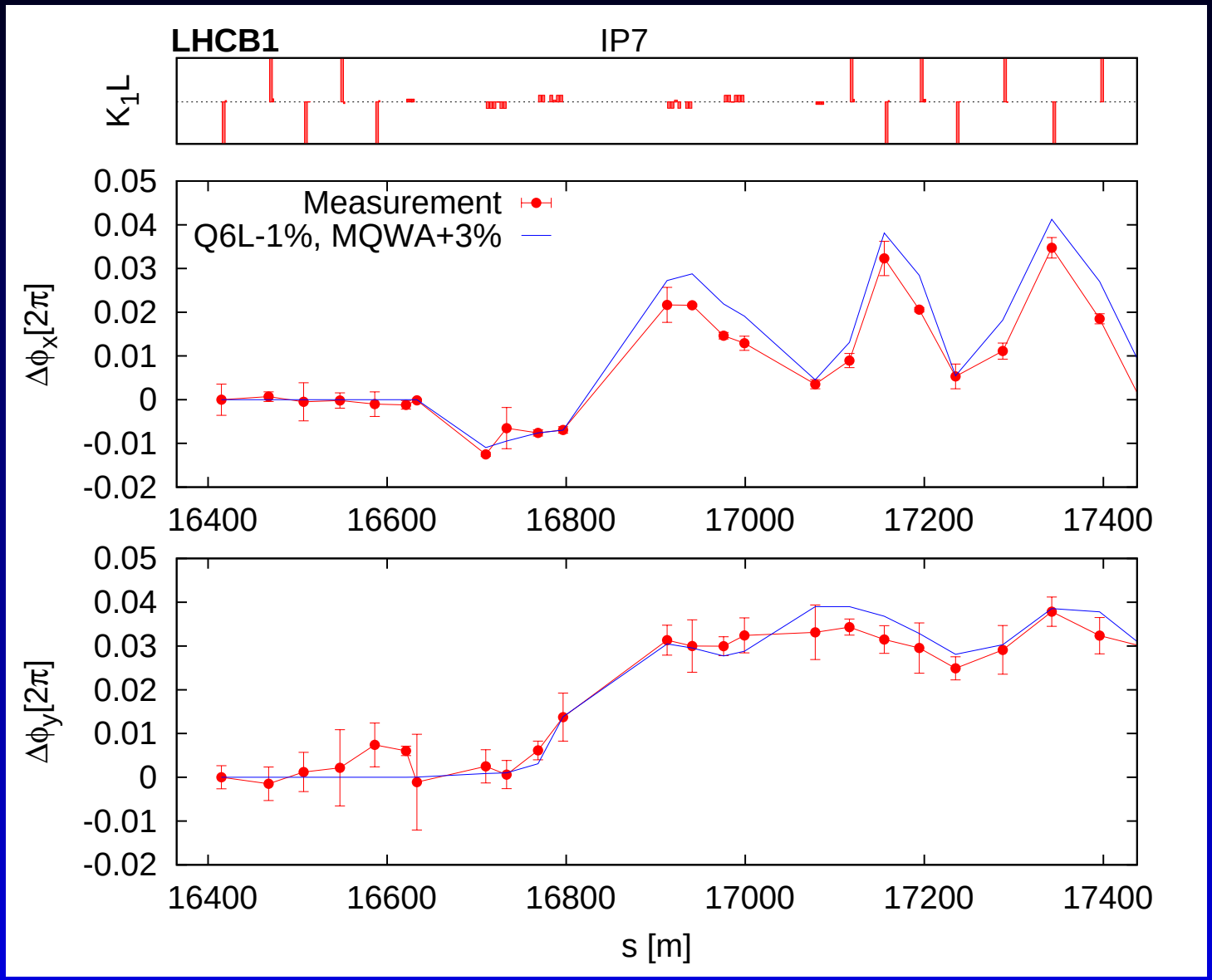




MQW, courtesy of P. Hagen

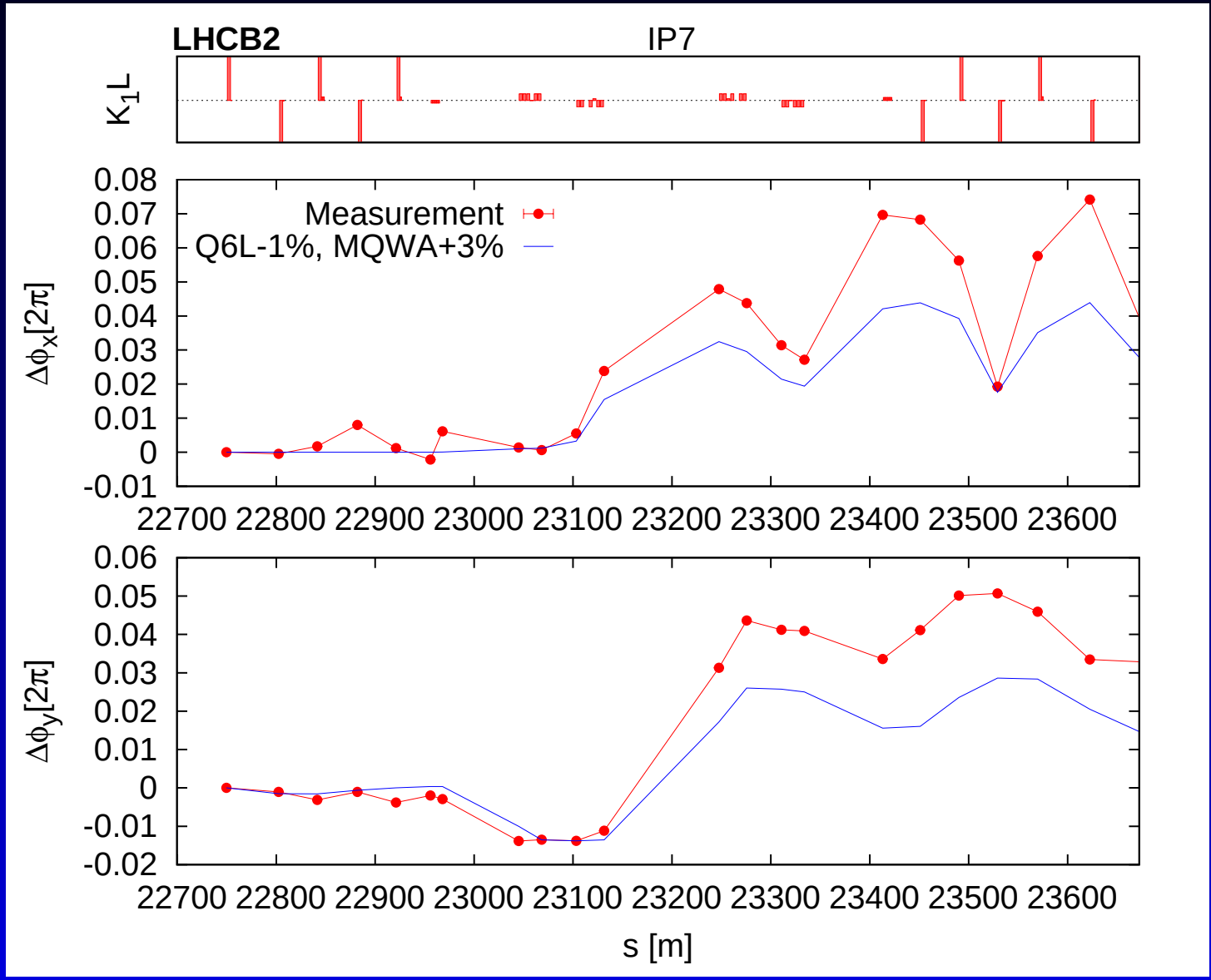
- Q6 in IR7 and IR3 are also suspects since they were not precycled

IR7 proposed local correction - Beam 1



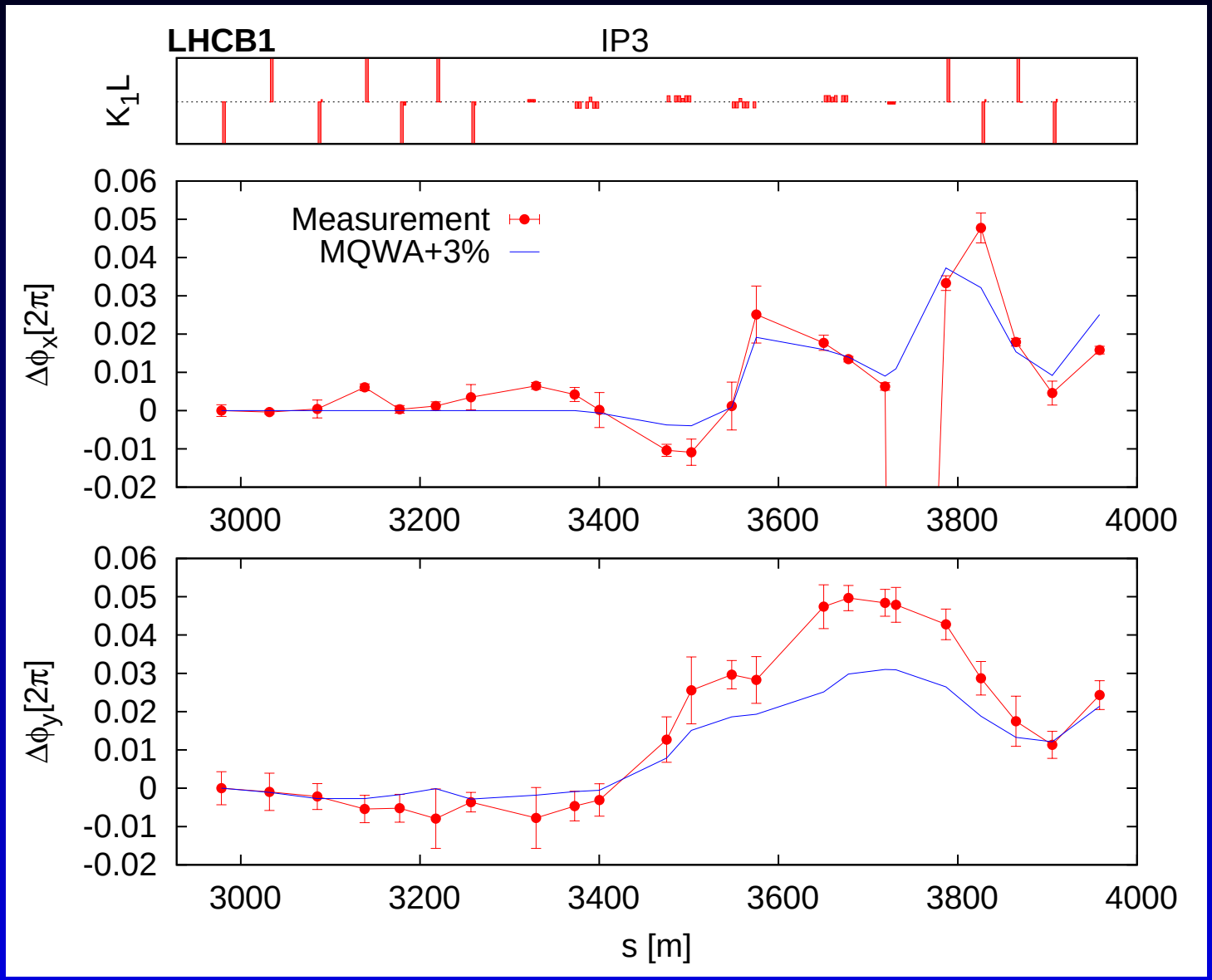
Q6 and MQWA seem to correct IR7 beam 1

Same IR7 corr for Beam 2



Same correction is not fully satisfactory for beam 2

What about IR3?

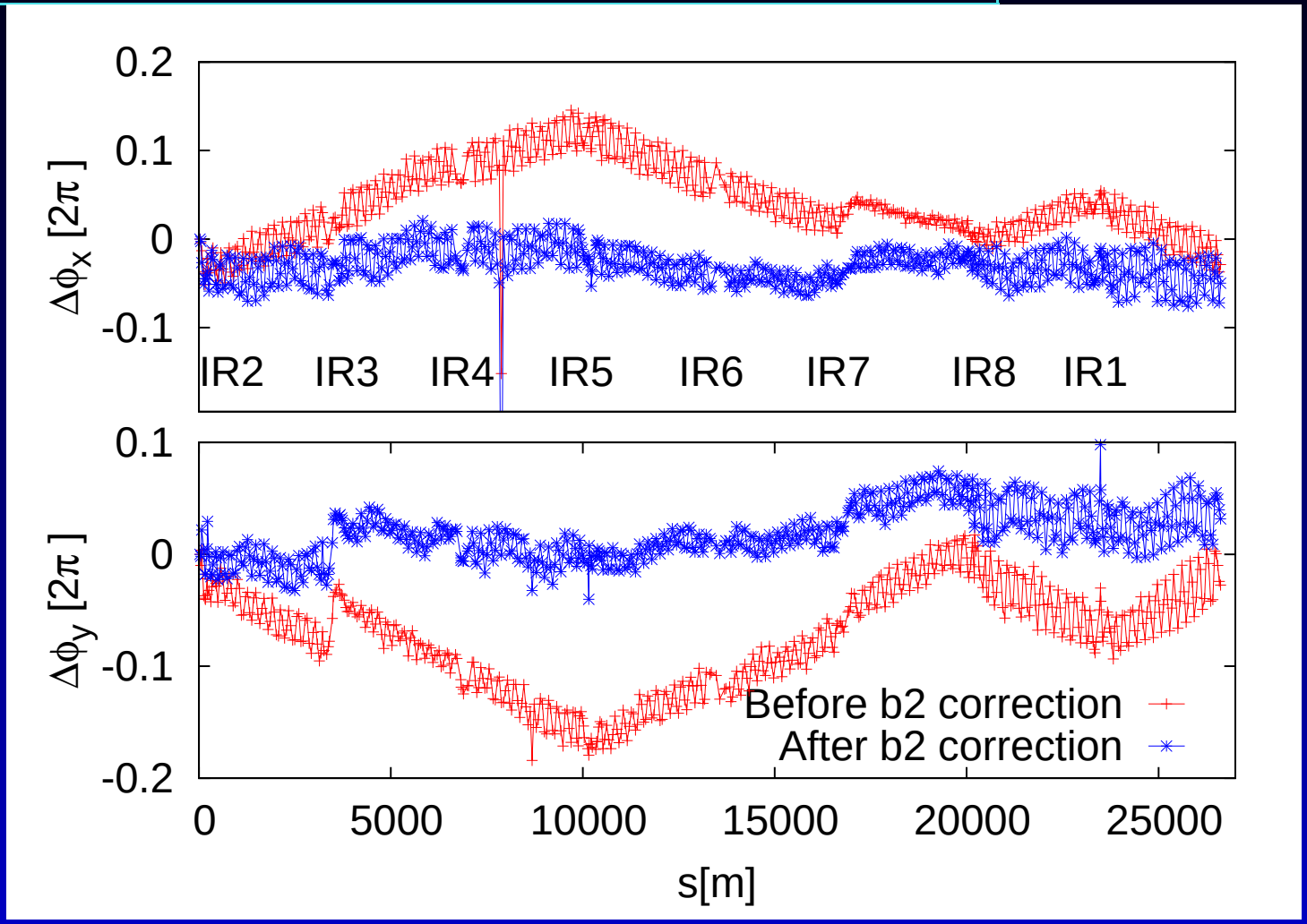


Similar correction in IR3 (MQWA+3%) rather effective

IR3 and IR7 local error summary

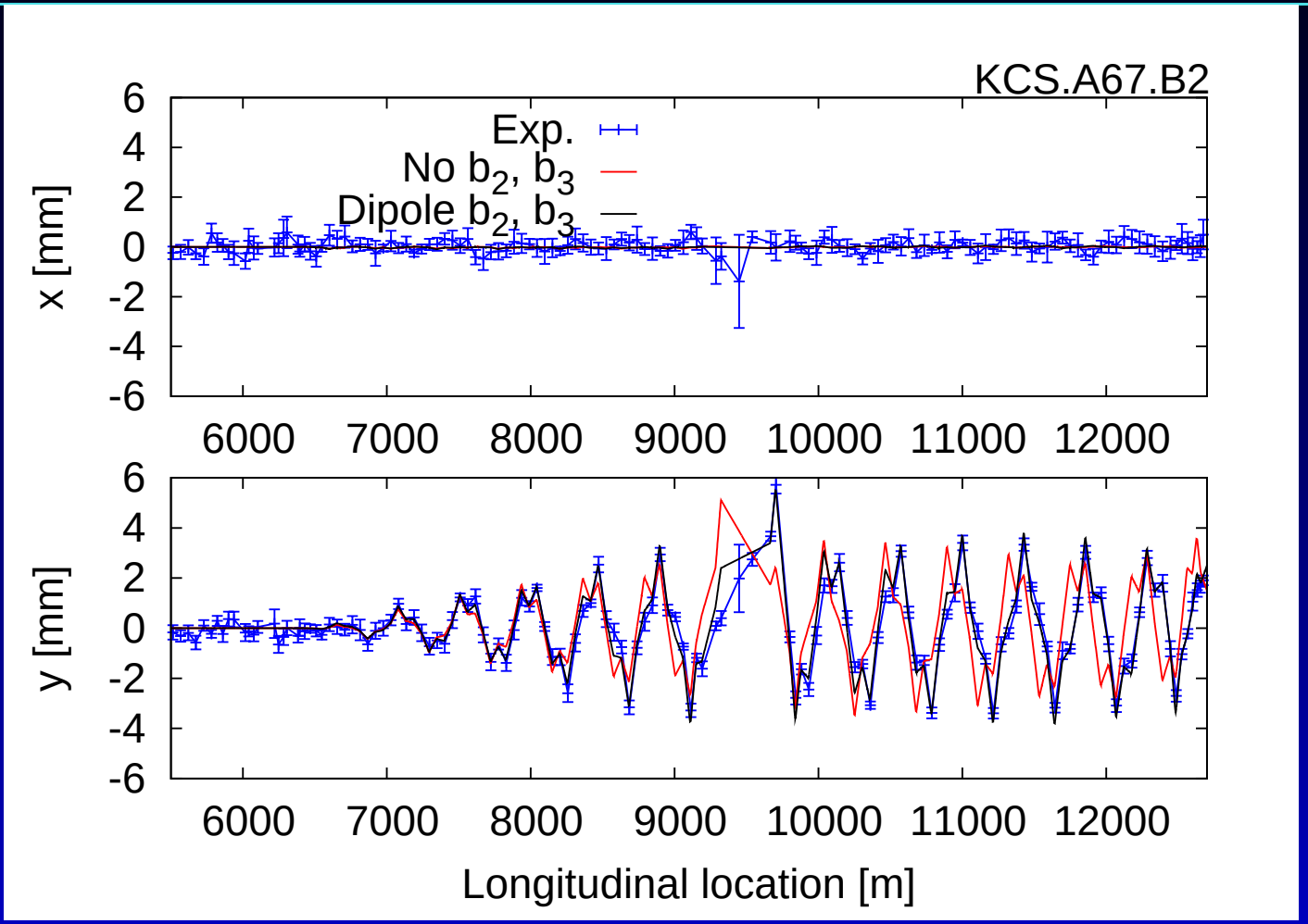
- MQWA (main quads) seem to be effective for a good fraction of the correction
- Q6 also effective to a lesser extent
- The precycling of Q6 should be attempted in 2010 (even if in MD mode)
- The residual errors should be corrected iteratively with MQWB (the IR3/7 trims)

Dipole b_2 correction - Beam 1



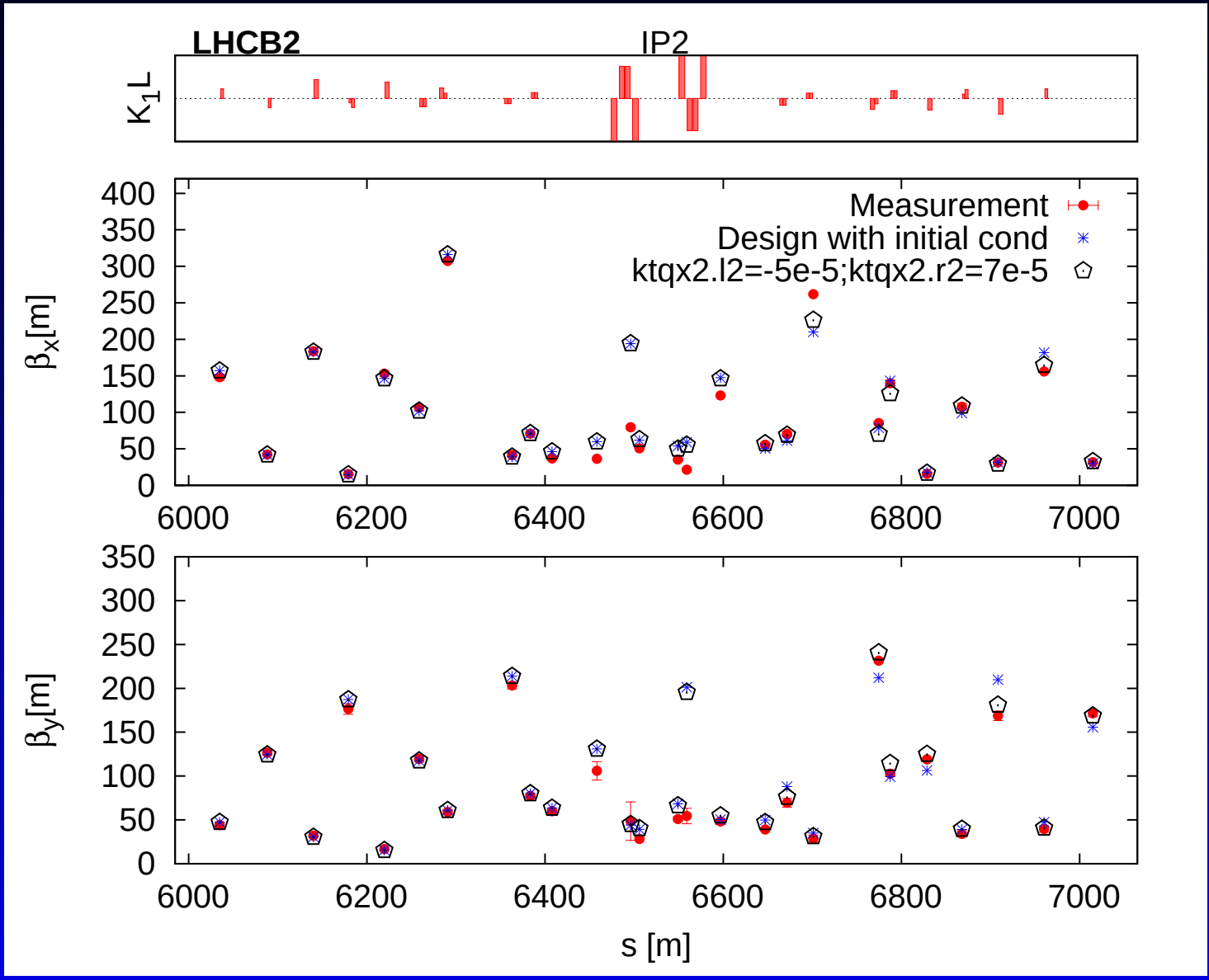
The magnetic dipole b_2 is used to compute the required correction with KQT $\rightarrow$ Excellent agreement!

Also from injection tests - Beam 2 arcs8-6



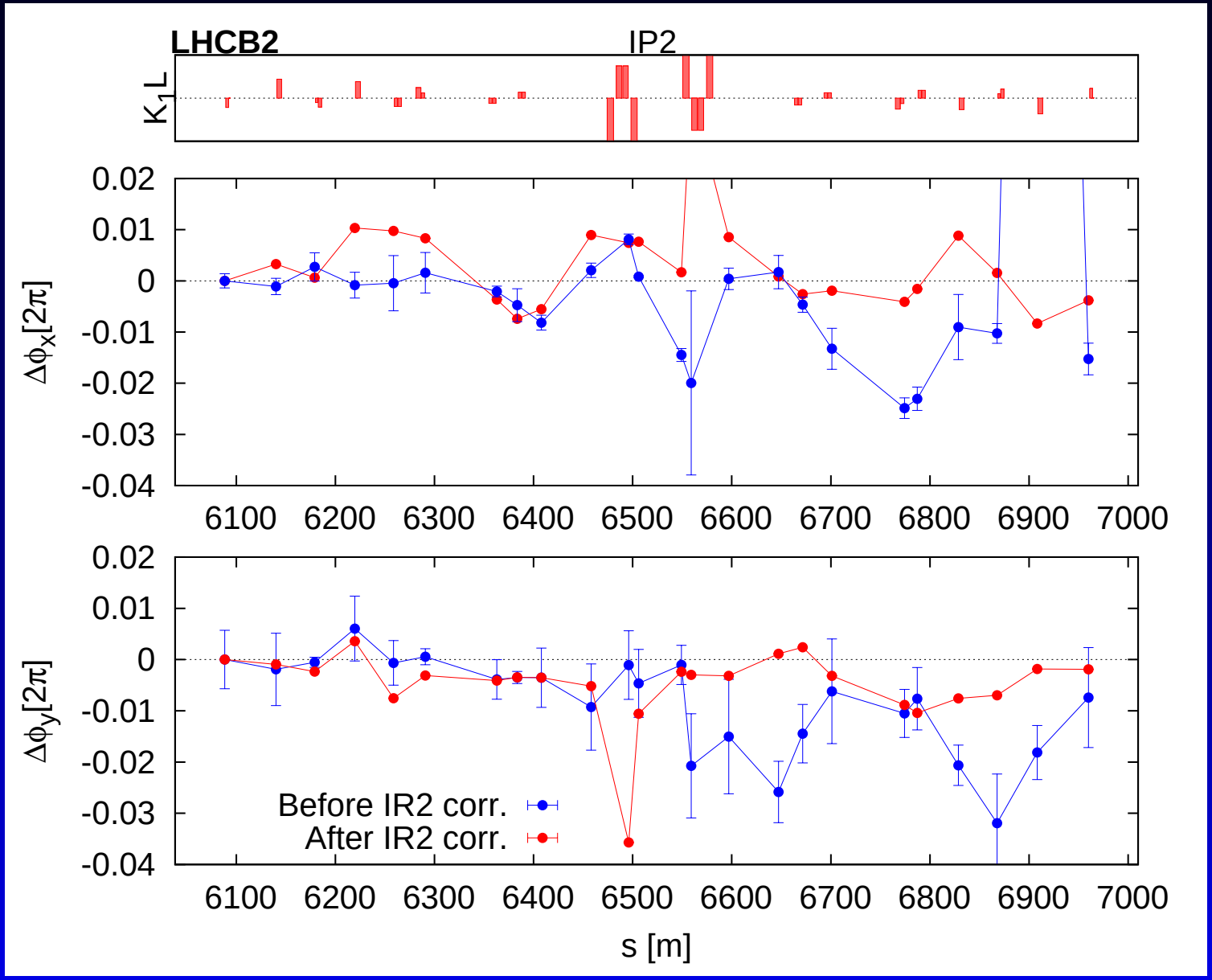
The magnetic dipole b_2 and b_3 were also confirmed during sector tests. Congratulations to magnet experts and MAD modelers!

Predicted IP2 local correction - Beam2



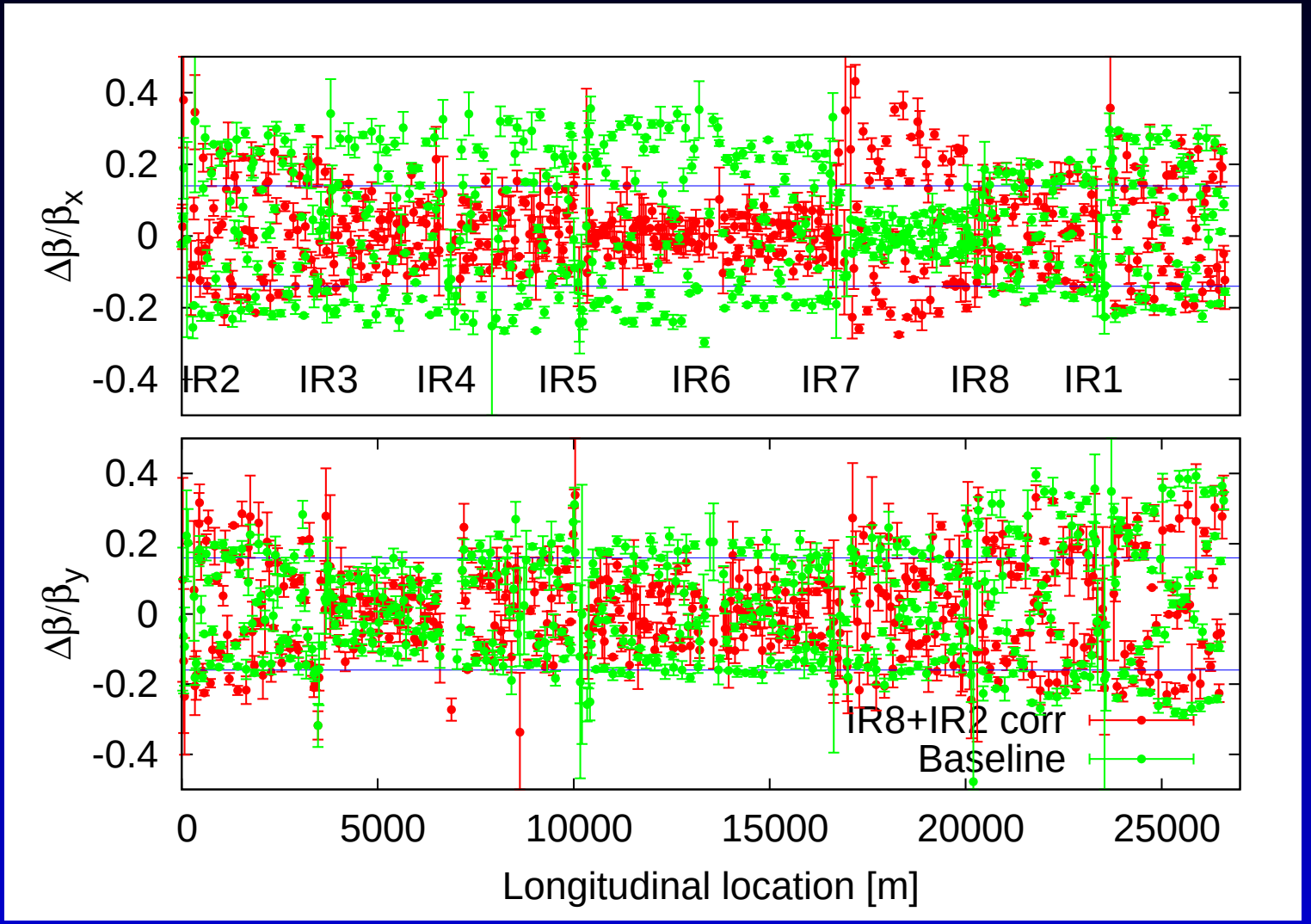
50/70 units in QX2R/L seemed to correct IR2

Measured IP2 local correction - Beam2



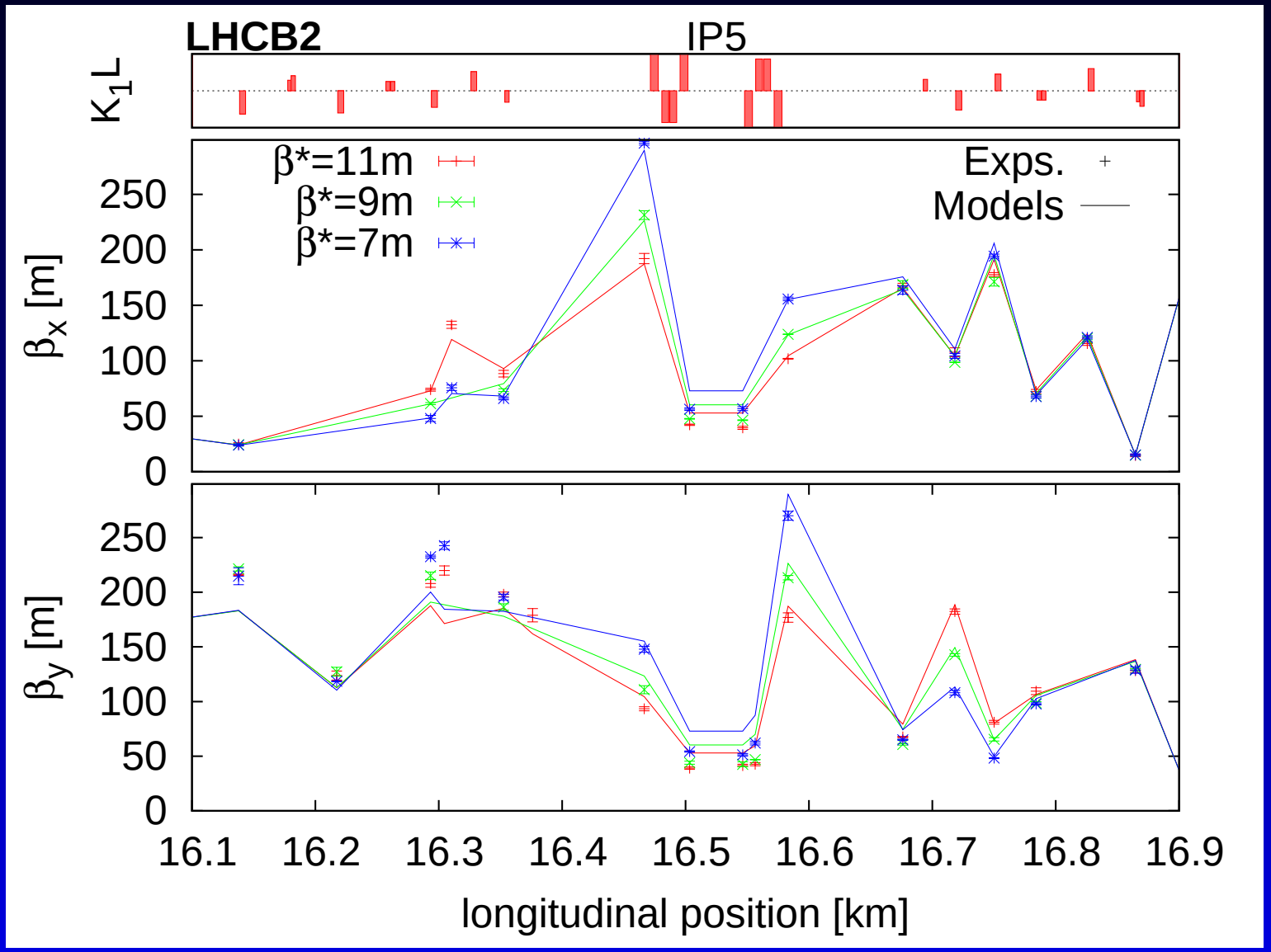
The measurement confirmed a good correction

Beam 1 β-beat after b_2,IR8,IR2 correct.



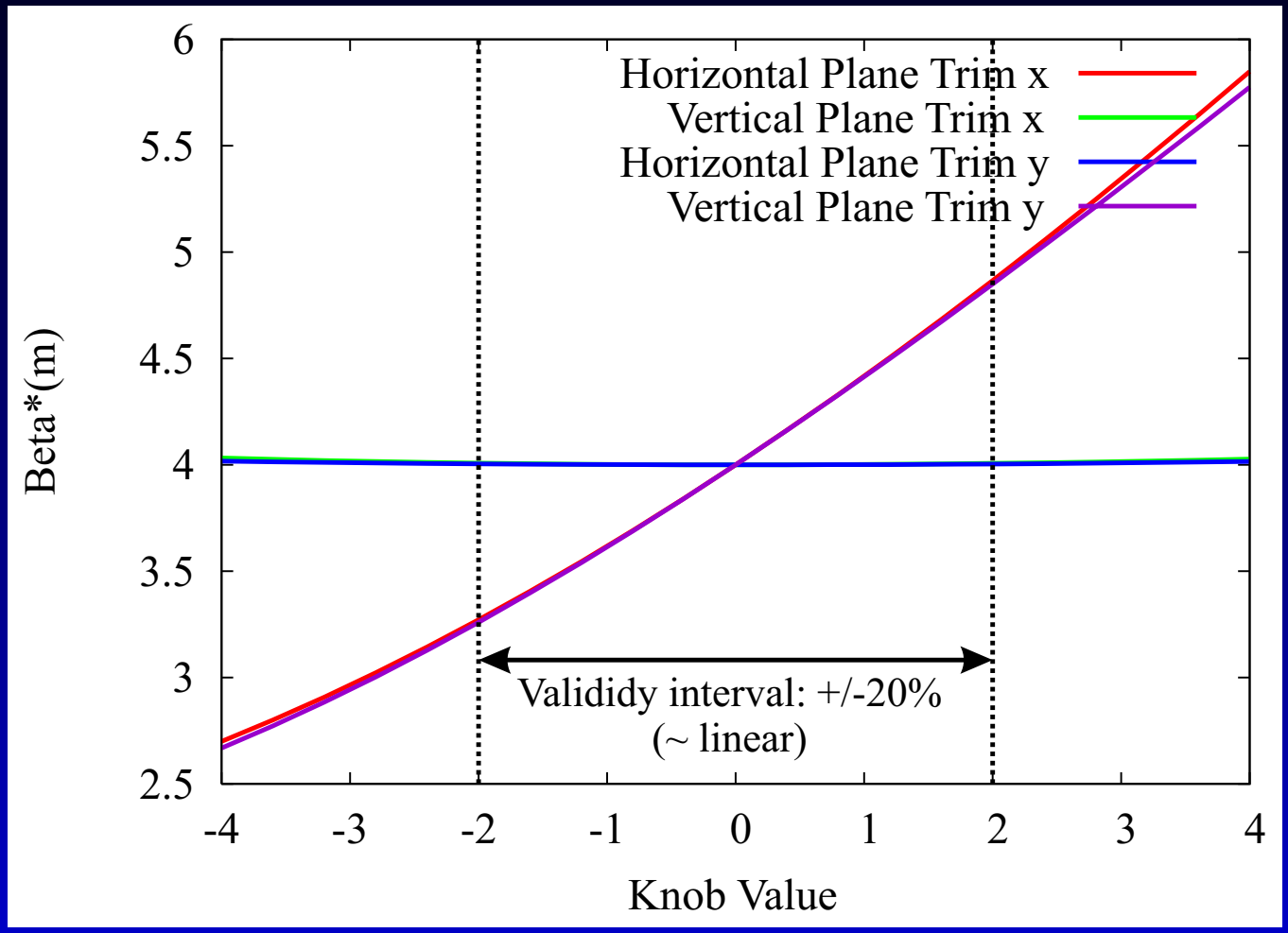
Good steps towards full correction but large errors remain in IR7 (hor.) and IR3 (vert.)

Squeeze in IR5 - Beam 2, 1.18 TeV



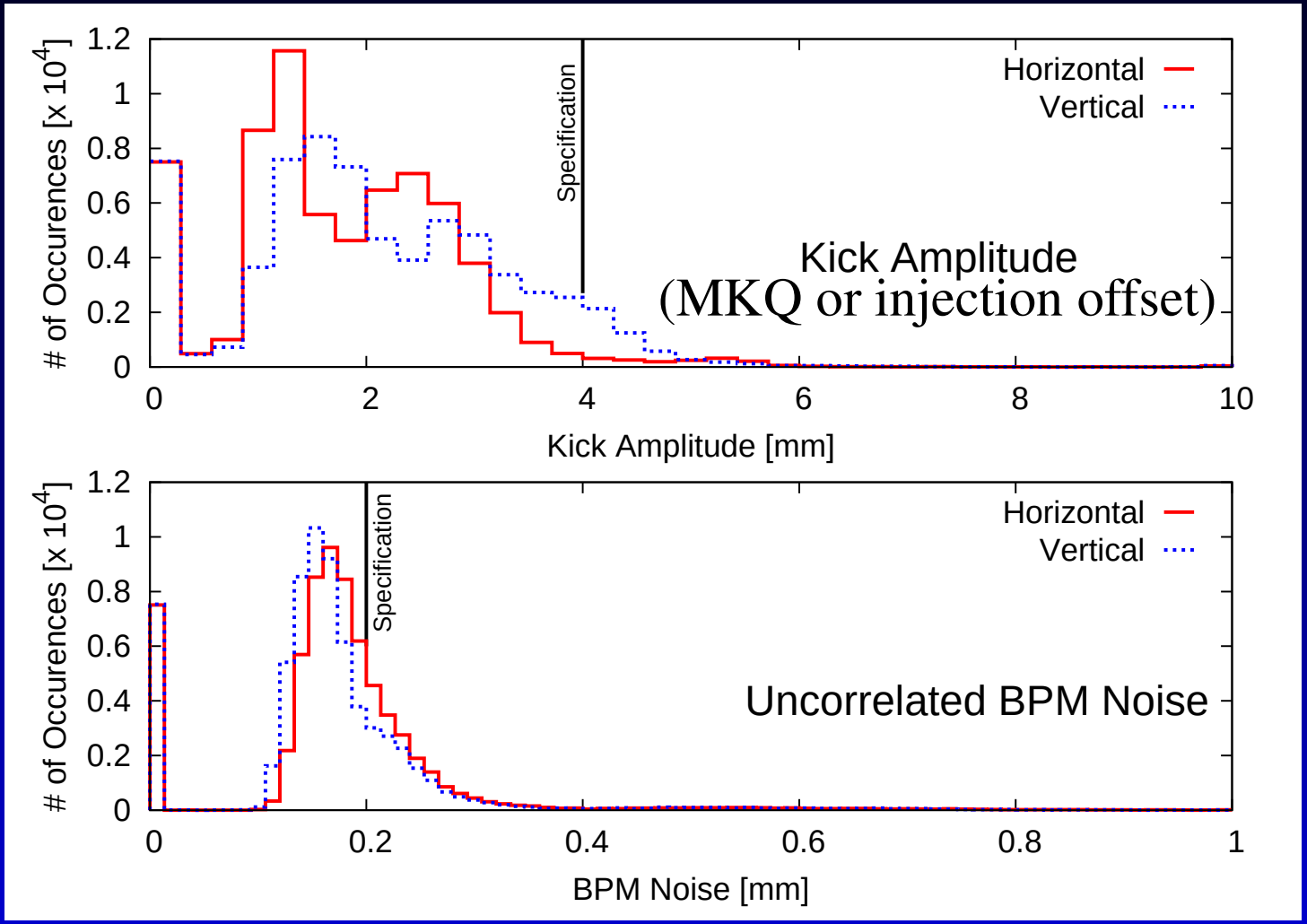
Excellent! (see Stefano's talk for more details)

β^* knobs



β^* knobs were tested without beam... to be validated in 2010 with measurements

Kick amplitude and BPM noise in 2009



We need larger kicks, MKA (hardware tested last week!) and/or AC dipole (not tested).

Software needs

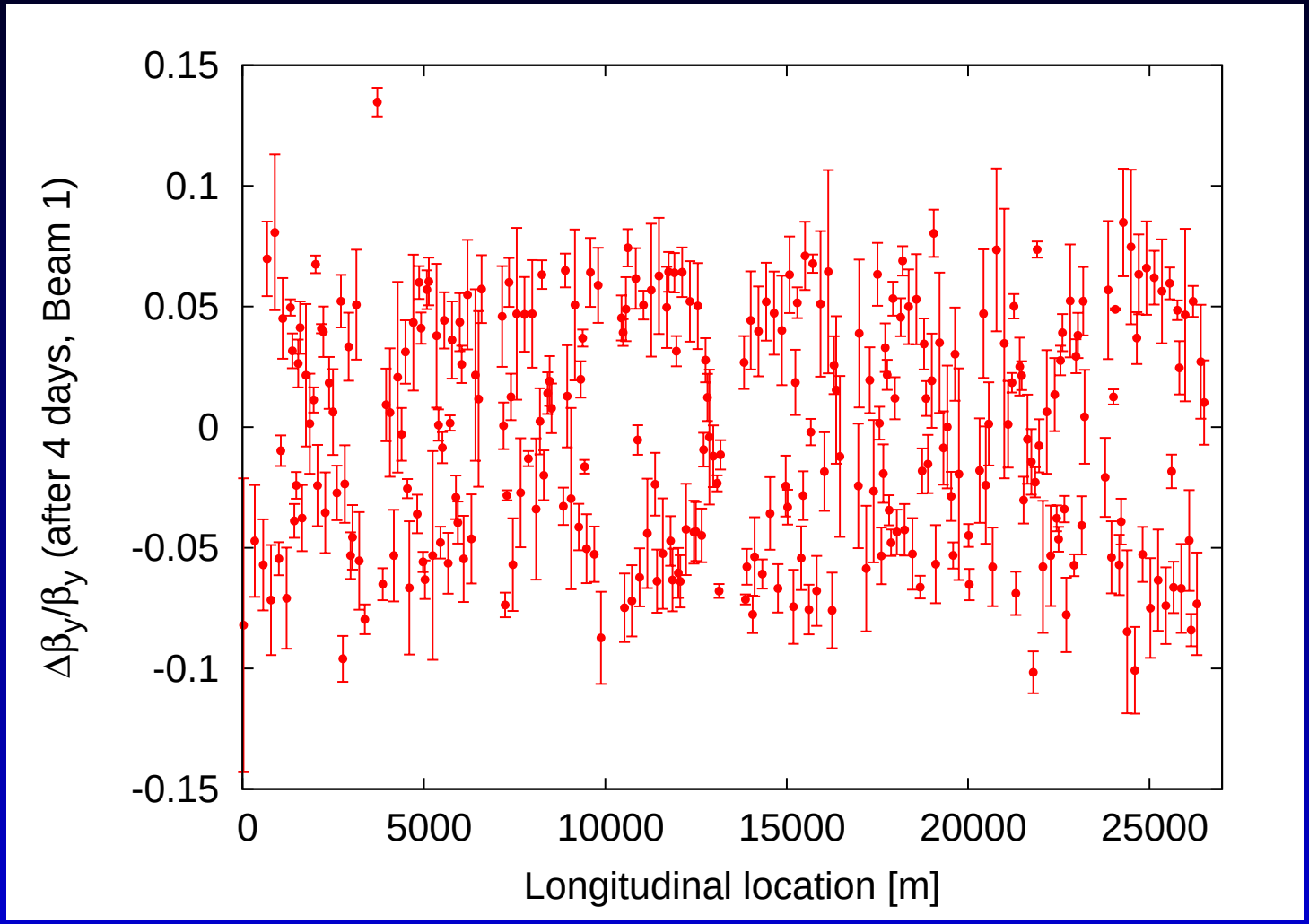
- BPM-bunch synchronization changed between exps:
  - BI expert needs single bunch for this synchronization
  - Could this be automatized and run everyday?
- Kick-bunch synchronization via OASIS usually takes 30min! Any idea?
- Presently measured optics is made available via a web page, should this be put in LSA database?

Commissioning needs

- Dipole b_2 correction could be on from day 1
- Shall we try to precycle Q6?
- Aperture kicker and/or AC dipole absolutely required for 2010.
- After every β-beating correction tunes, coupling, chromaticity, injection settings and collimators need adjustments.
- The IR3 and IR7 local corrections will require various shifts and iterations
- IR2 and IR8 seem to be much easier

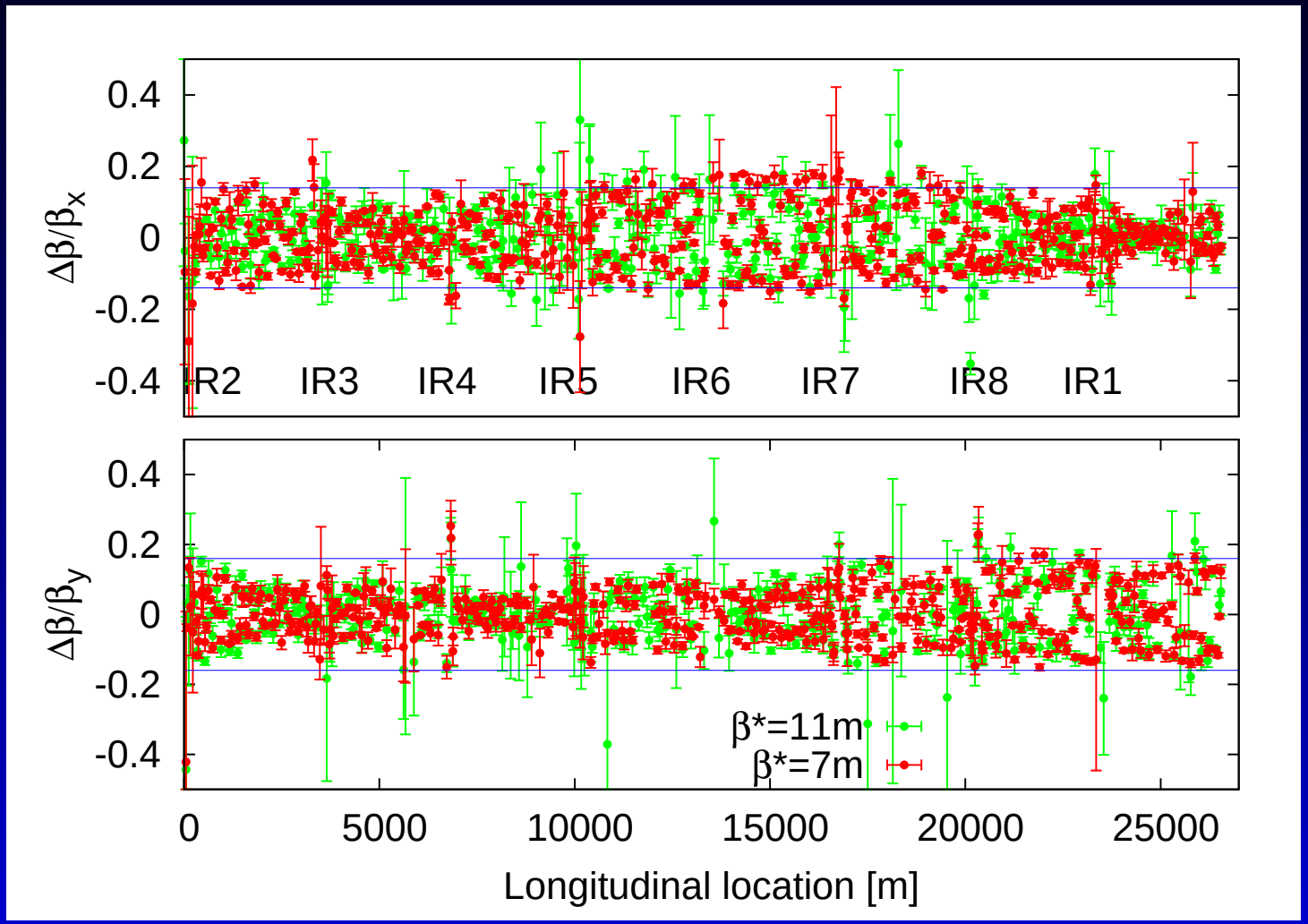
Support slides

Reproducibility - worst case difference



≈5% β-beat difference in 4 days. Source very hard to spot with this poor measurement, need 1000 turns

β-beating during squeeze - Beam 1



β-beating during squeeze - Beam 2