LHC Beam Optics Measurement and Correction with the AC Dipole

LARP CM 14, April 26th 2010

R. Miyamoto & G. Wang (BNL)

On behalf of LARP AC Dipole Collaboration (in the past and present):

M. Bai, R. Calaga, P. Oddo (BNL), H. Schmickler, J. Serrano, R. Tomas (CERN), A. Jansson, M. Syphers (FNAL), S. Kopp (UT Austin)

& many thanks to

M. Cattin, V. Kain, F. Schmidt, J. Uythoven, G. Vanbavinckhove (CERN), M. Aiba (PSI)

Outline

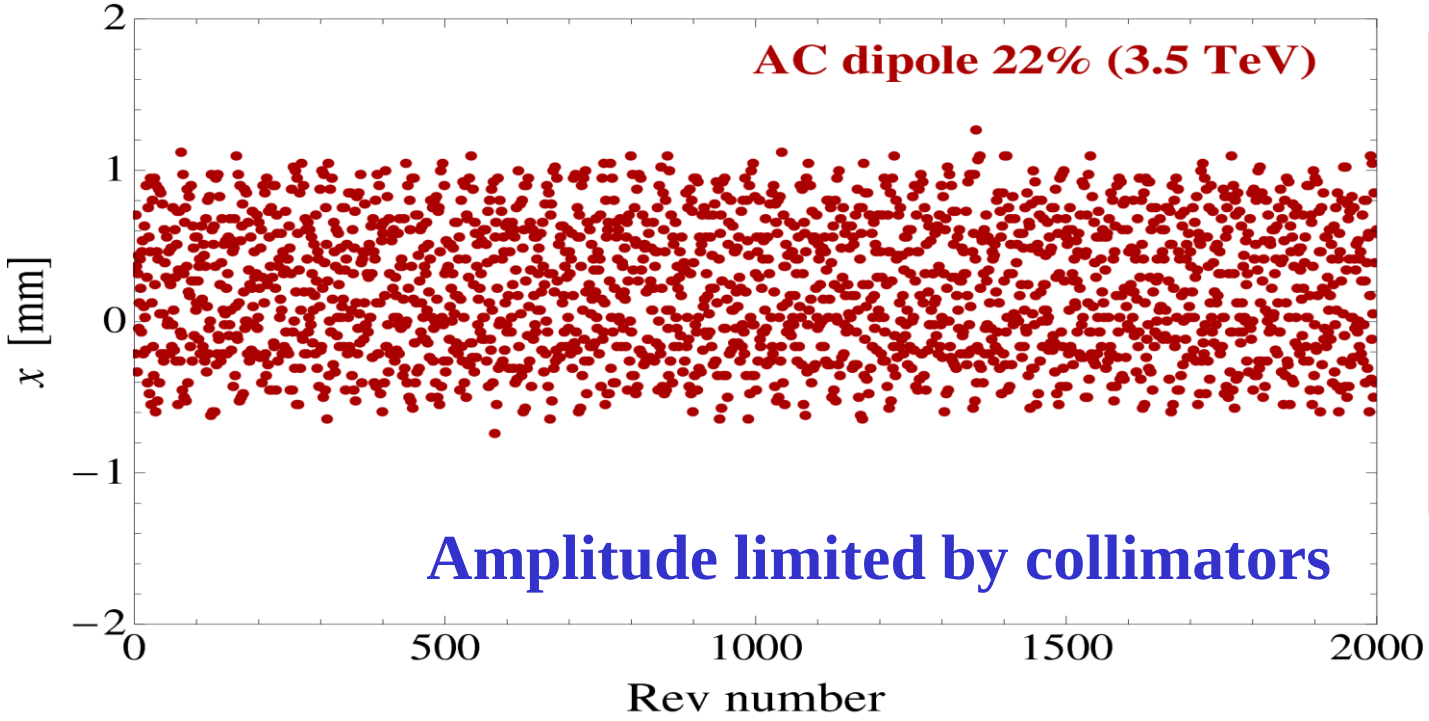
- Status of the LHC AC dipoles
- Status of LHC Optics
- An Example of LHC Optics Measurement and Correction with the AC dipole:
  - Commissioning of β-squeeze for IPs 1&5
- US Activities
- Summary

Status of the LHC AC dipoles

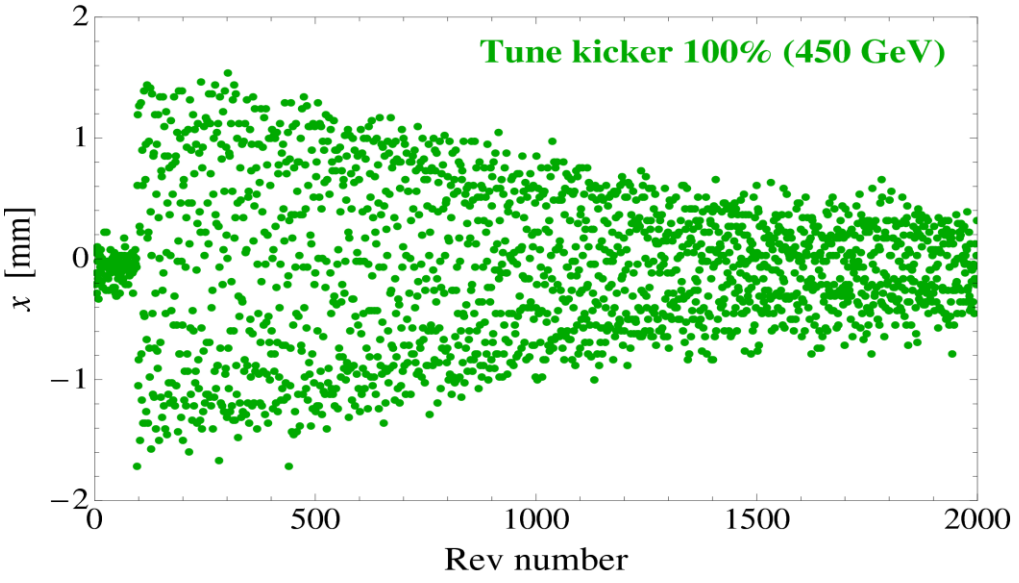
- All four AC dipoles are commissioned and in operational.
- Design specifications (field strength & band width) are achieved.
- Due to the LHC's slow cycle (~1 hr for ramp up, ramp down, squeeze, precycle…), the AC dipole (non destructive) is the only practical prove to beam optics above injection energy.
- β-beating and local coupling have been measured and corrected for β-squeeze with the AC dipole.

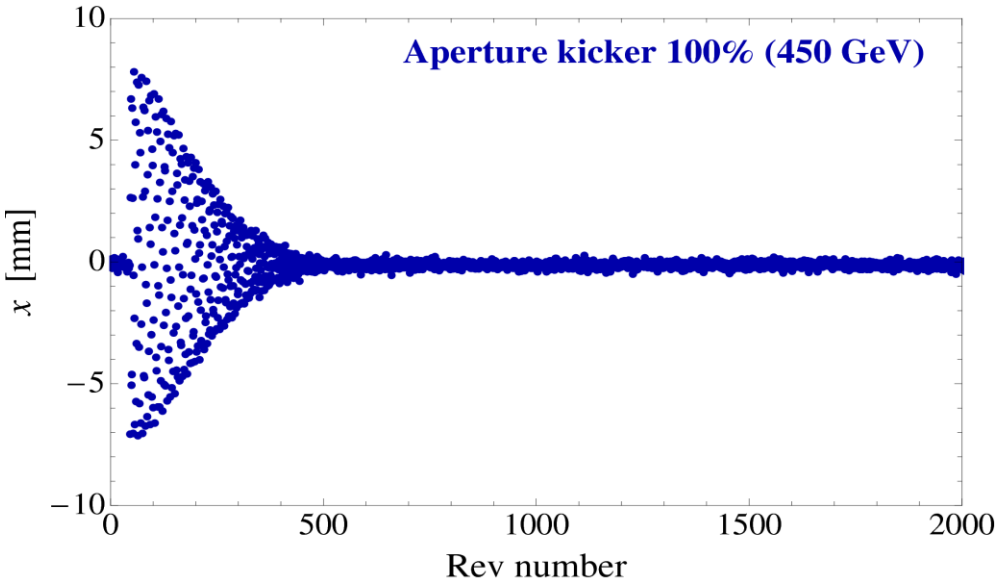
Machine	RHIC	Tevatron	LHC
E [GeV]	250	980	7000
σ [mm]	0.75	0.5	0.3
$\lvert\nu_d-\nu\rvert$	≥ 0.01	≥ 0.01	≥ 0.01
β_{arc}, β_{acd} [m]	45, 11	80, 47	180, 260
$(Bl)_{acd}$ for 4σ [Gm]	140 (105)	140 (115)	200
f_{rev} [kHz]	78	48	11
ν, 1-ν	0.69, 0.31	0.58, 0.42	0.3, 0.7
f_{acd} [kHz]	55	20.5	3

AC dipoles produce clean signals with (almost no) emittance growth.

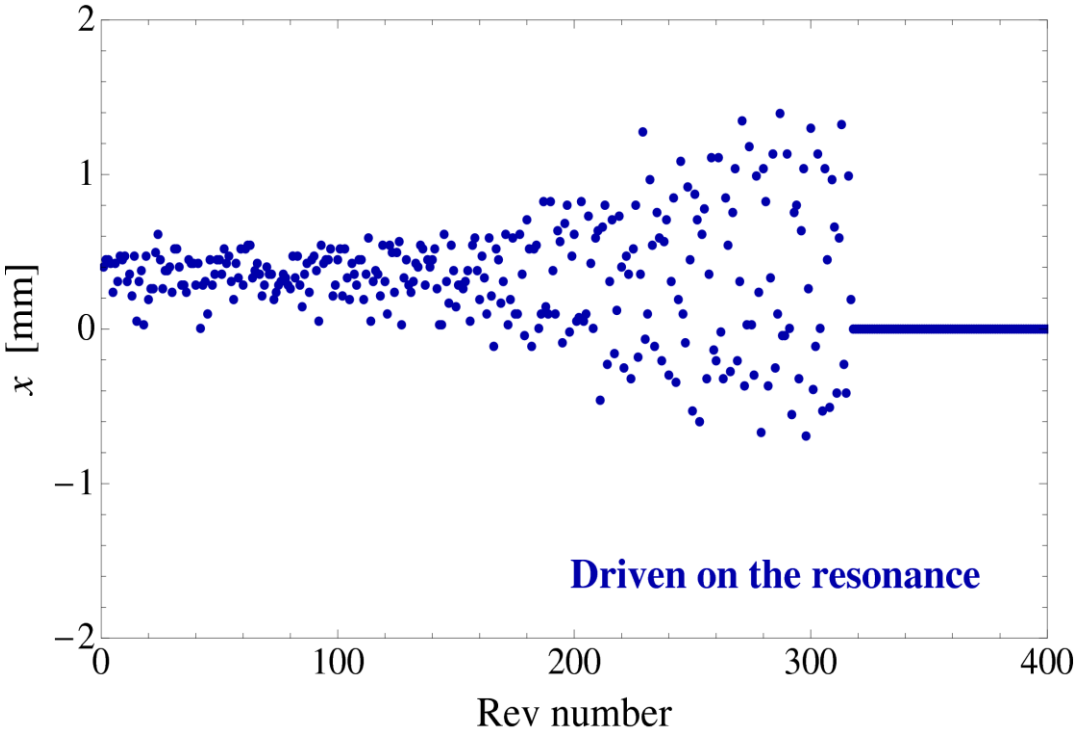


LHC has 4 kickers (HV ×2 beams). Each can be used as
- AC dipole
- tune kicker
- aperture kicker

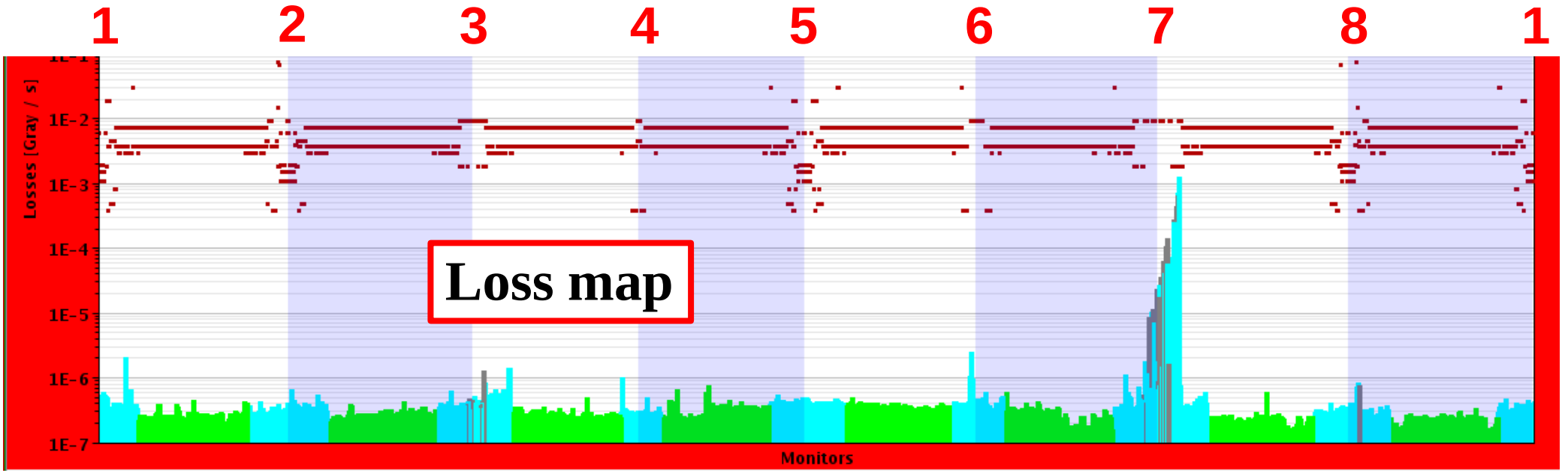




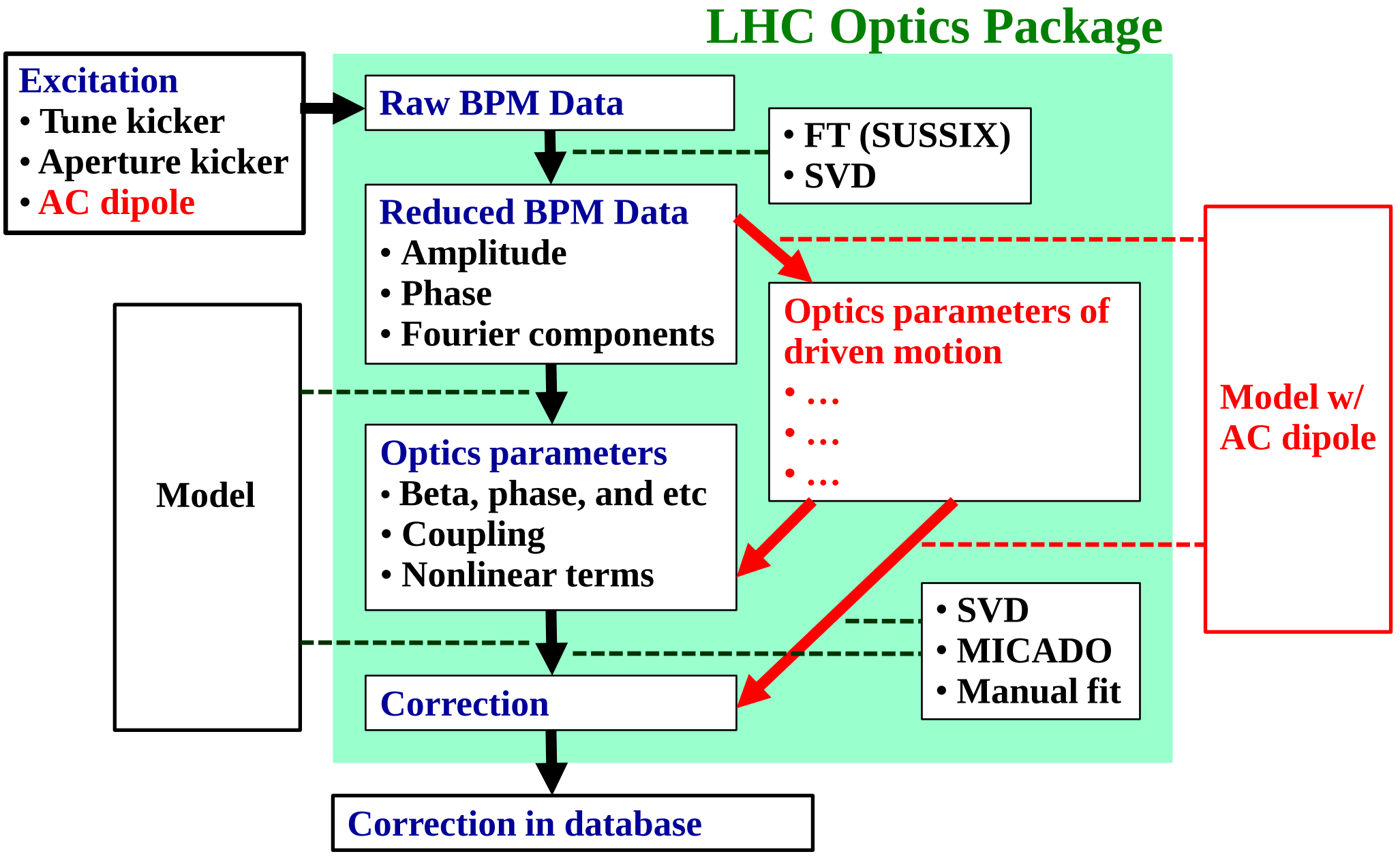
Test of the machine protection system.



- Assuming the worst case, the beam is driven on the resonance (450 GeV).
- The beam is dumped after ~300 turns (expected).
- Clean dump and losses only at primary collimators.
- <u>The AC dipole is preferred from the machine protection point of view.</u>



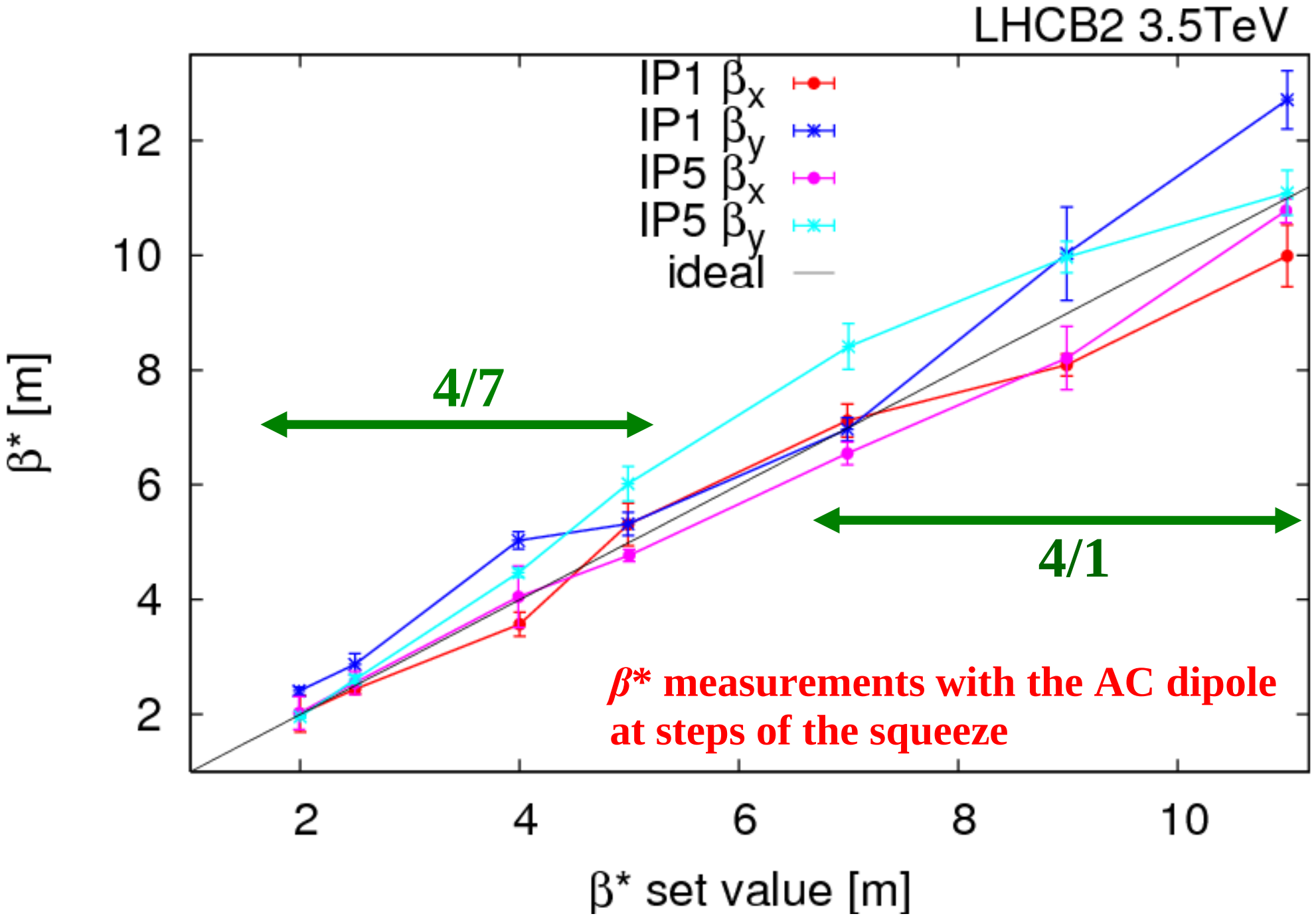
AC dipole is integrated into the LHC Optics Package



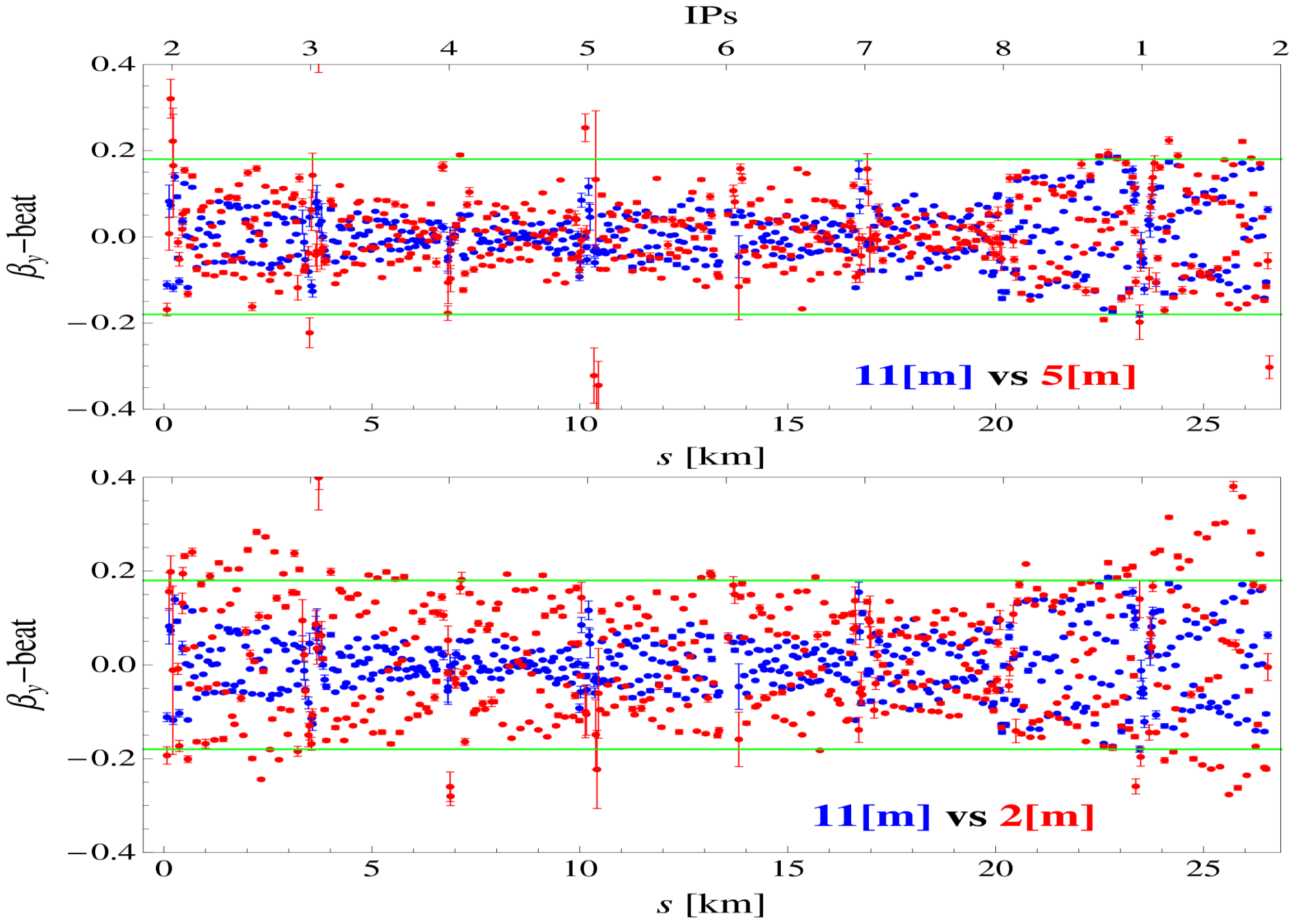
Status of LHC Optics

- Tolerance for β-beating (nominal): ~15%*
- Injection β-beating corrected: 20-30%
  - Local corrections of IRs 3, 7, 2, 8, 1, & 6.
  - Dipole b2 (b1 for US convention) corrections.
- Flattop: good as it is (20-30% β-beating)
- Beta-squeeze commissioned (β^* = 2 m)
  - β-beating corrections for IRs 2, 5, & 8.
  - Coupling corrections for IRs 1, 2, 5, & 8.
    (For some steps, $dQ_{\min}$ is as big as 0.02−0.03 and pushing tunes apart.)
- Global corrections tried but not applied yet.

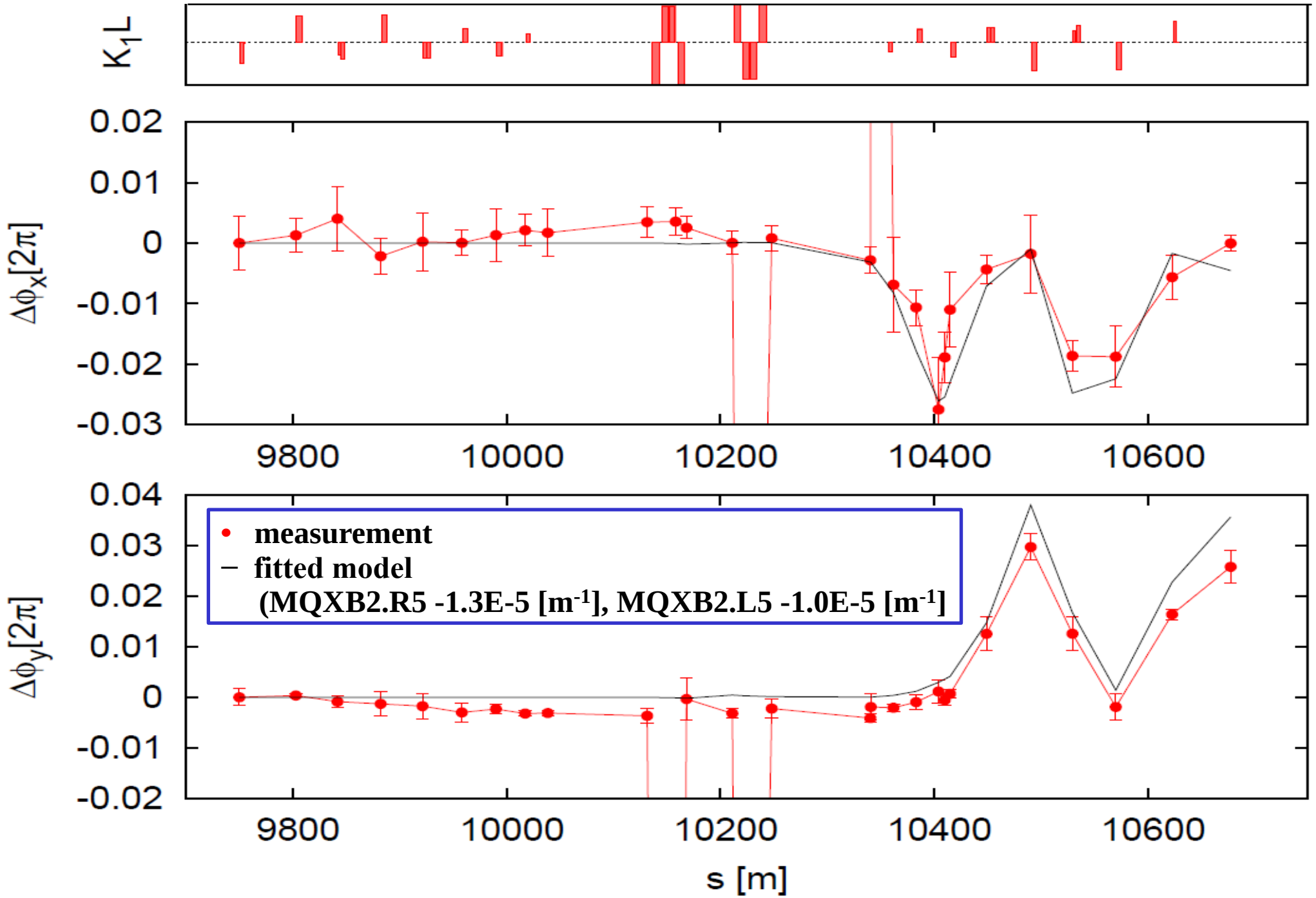
β-Squeeze Commissioning for IPs 1&5



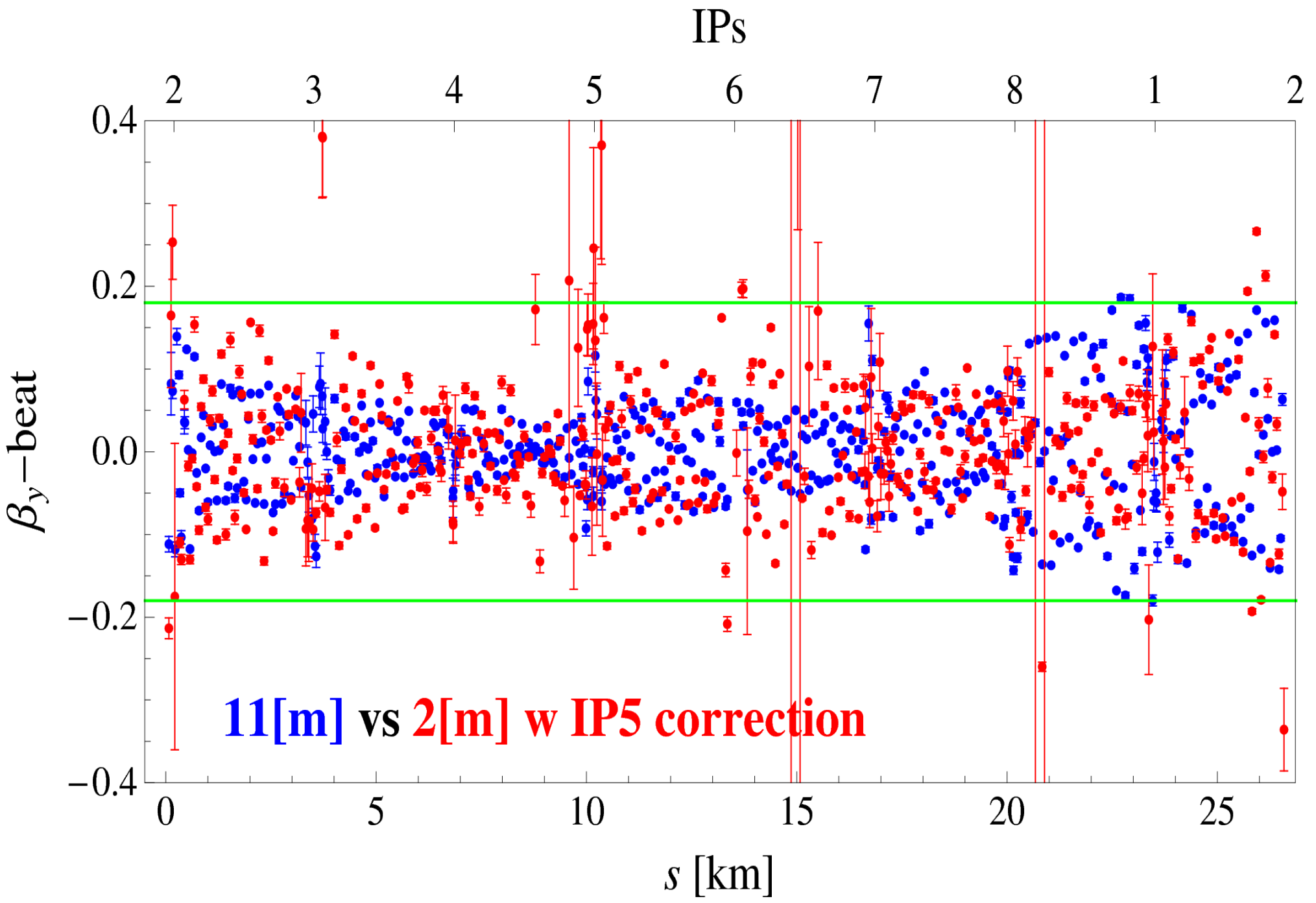
β-beating got larger during the squeeze.



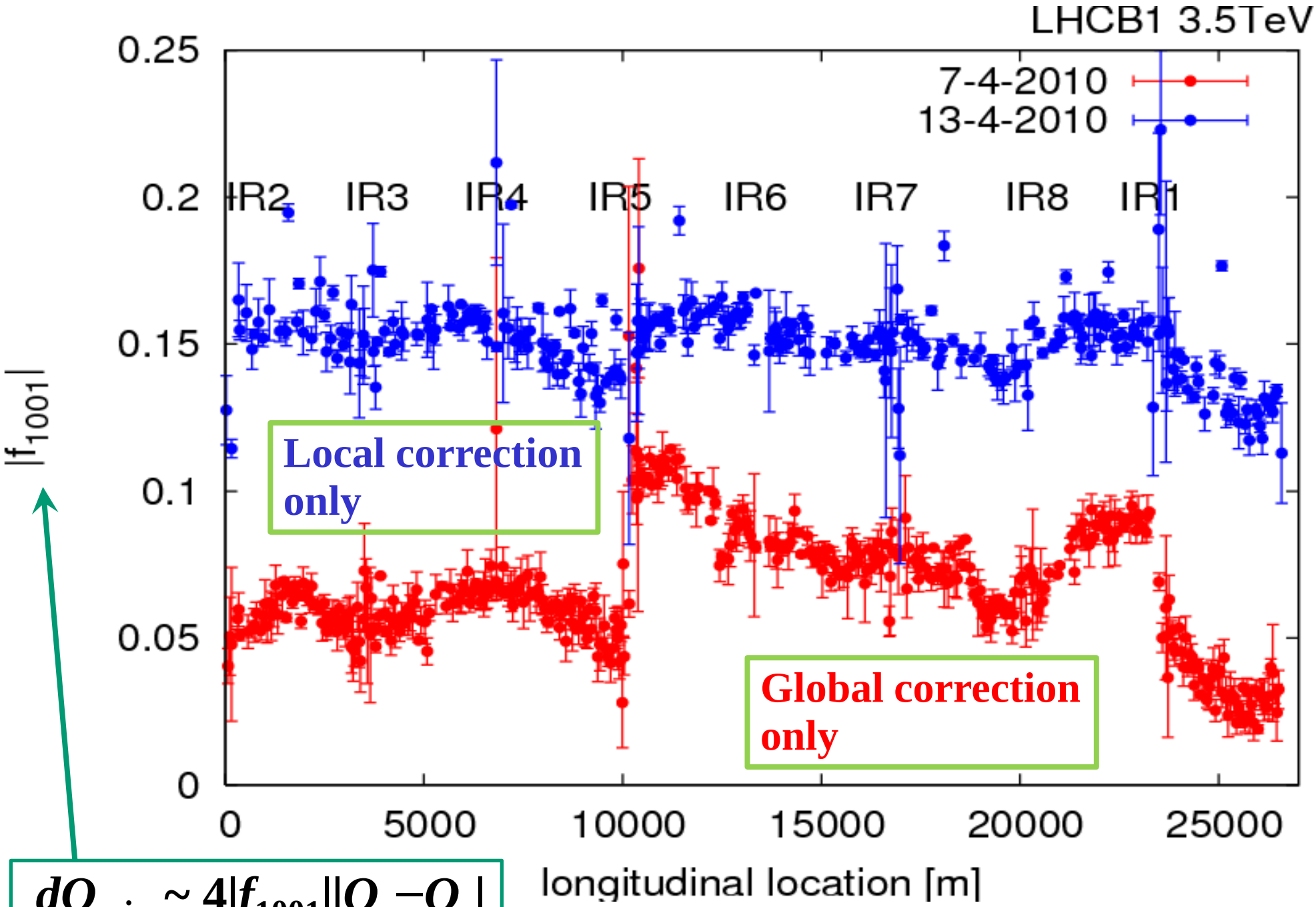
Local correction at IP5 based on phase error



β-beating after the IP5 correction



Local coupling also corrected



$$dQ_{\min} \sim 4|f_{1001}||Q_x - Q_y|$$

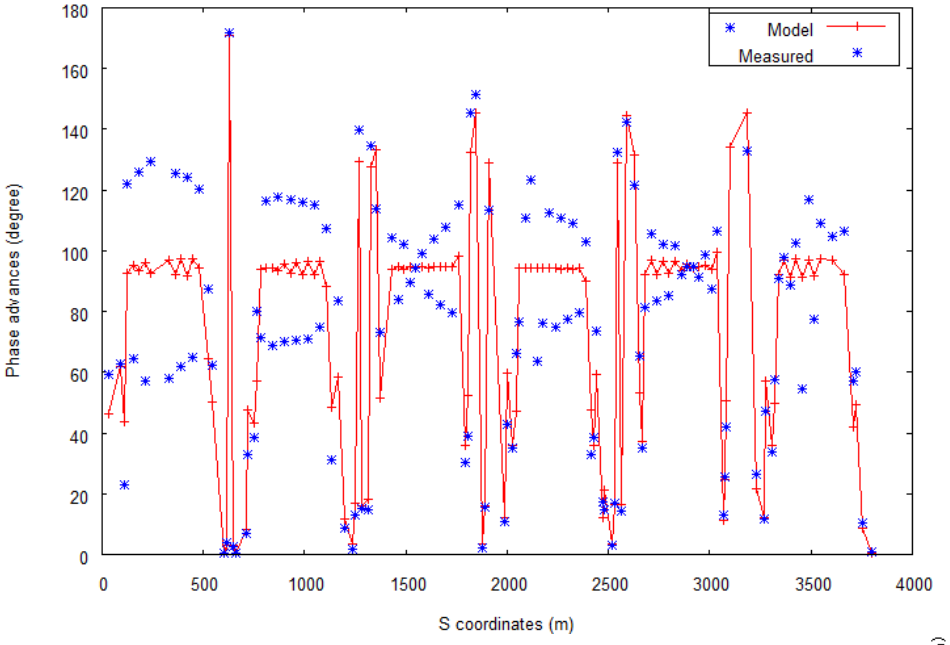
β^* measurements in RHIC using ac dipole

(Courtesy of Vadim Ptitsyn)

- Ac dipole was the major method for measuring RHIC beta function in run 10.
  - For run 10, RHIC collides Au-Au at 100GeV. The table below shows the measured β^* for the lattice with 0.6m of designed β^* in IP6 and IP8.
  - The ac dipole measurement agrees reasonablely with gradient variation method.

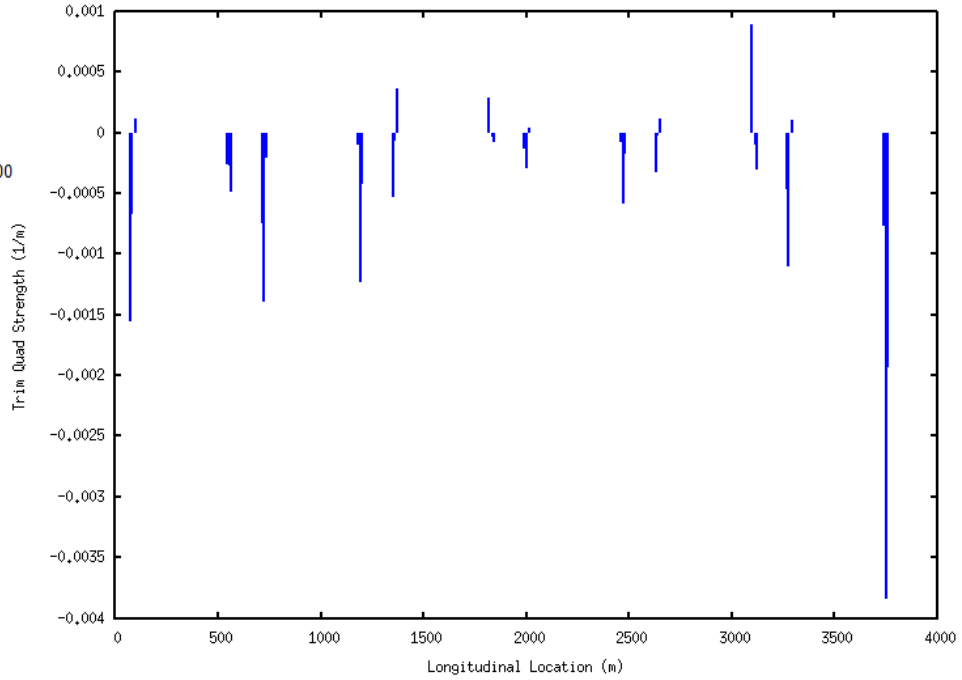
	Blue/Yellow			
	IR6 H	IR6 V	IR8 H	IR8 V
Gradient Variation (β*,m)	0.76/0.72 ±0.01	0.69/0.84 ±0.01	0.65/0.71 ±0.01	0.63/0.84 ±0.01
Ac dipole (β*,m)	0.62/0.65 ±0.04	0.65/0.83 ±0.04	0.695/0.87 ±0.04	0.625/0.84 ±0.04

Phase beating measurement using ac dipole



- In lattice with 0.7m designed β^*, 22% rms horizontal phase beating was measured in blue ring during store.
- SVD shows that the maximal correcting strength locates in IR6.

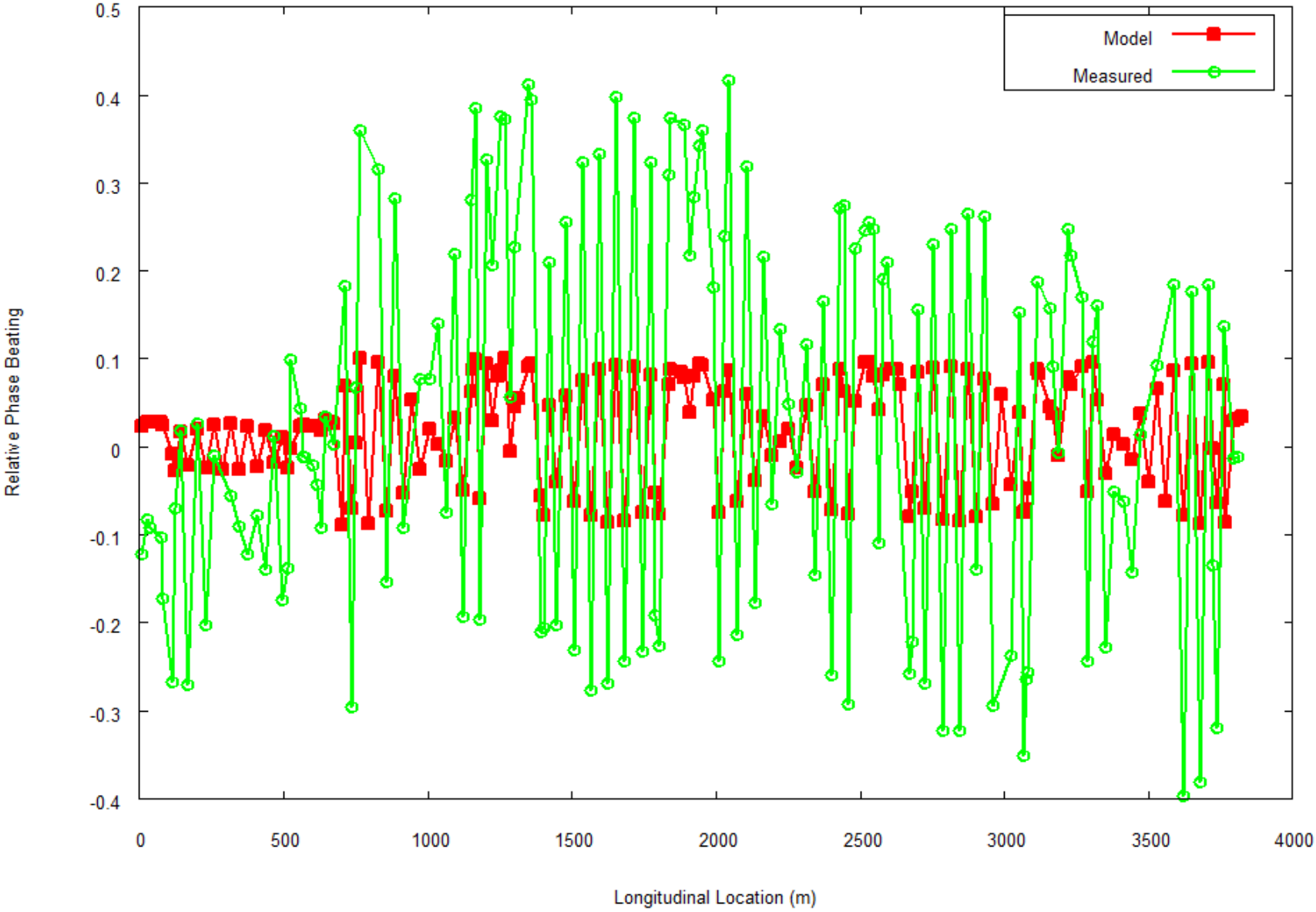
- Due to lack of APEX beam time, we were not able to apply any corrections at store during run 10.



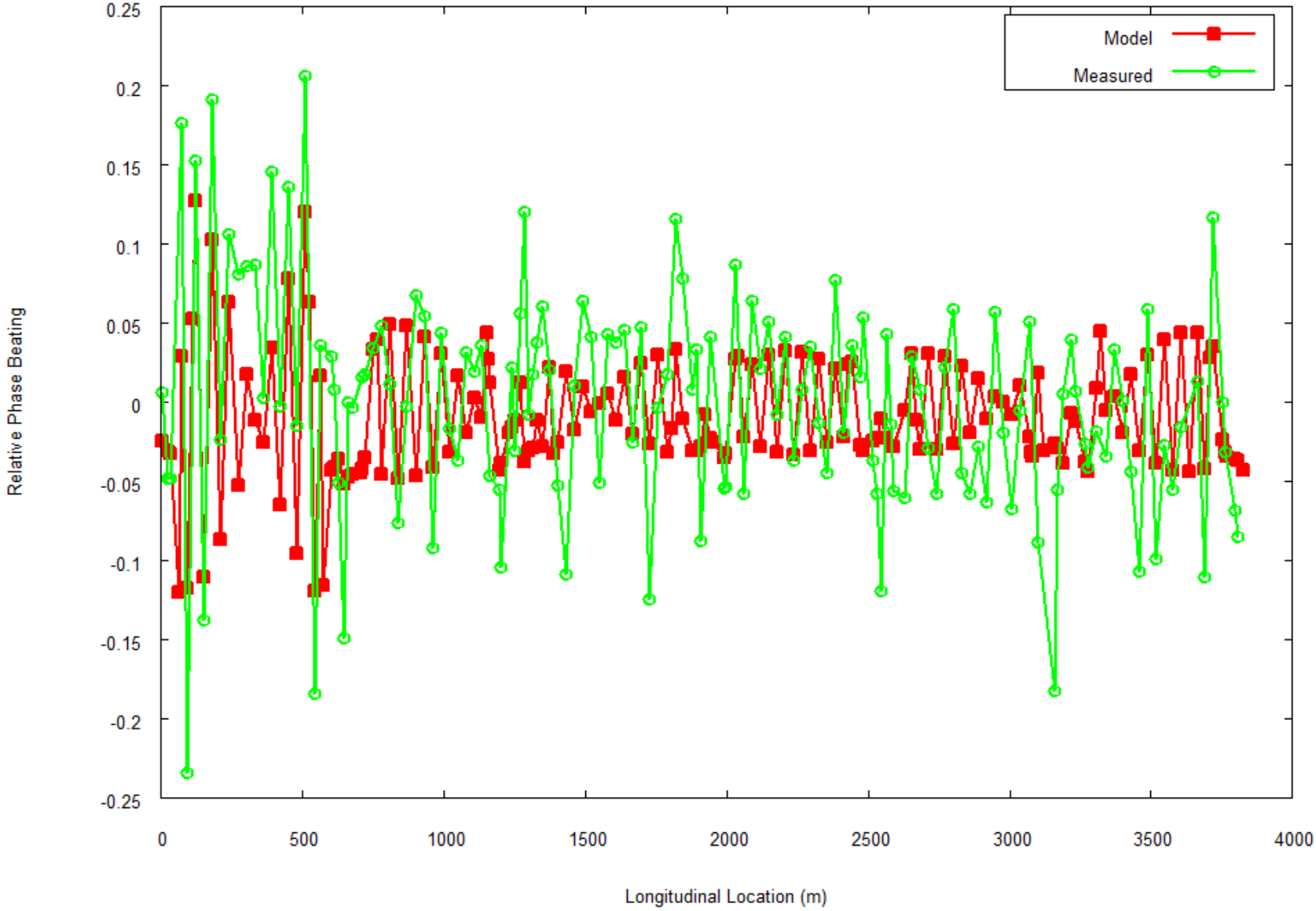
Chromatic β measurement

- ac dipole was used to measure RHIC off-momentum beta function in run 10.
  - RHIC experienced huge beam loss when doing re-bucketing after β^* squeezed to 0.6m. The beam loss is caused by smaller dynamic aperture at 0.6m β^* and was relieved when 0.7m β^* lattice was applied.
  - An factor of 3 disagreement was observed between model and measurement in RHIC yellow ring. Meanwhile Beam loss in yellow ring was more serious than what was observed in blue ring.
  - Further investigation is in working progress.

Yellow at store energy with 0.6m designed β^*



Blue ring at store energy with 0.6m designed β^*



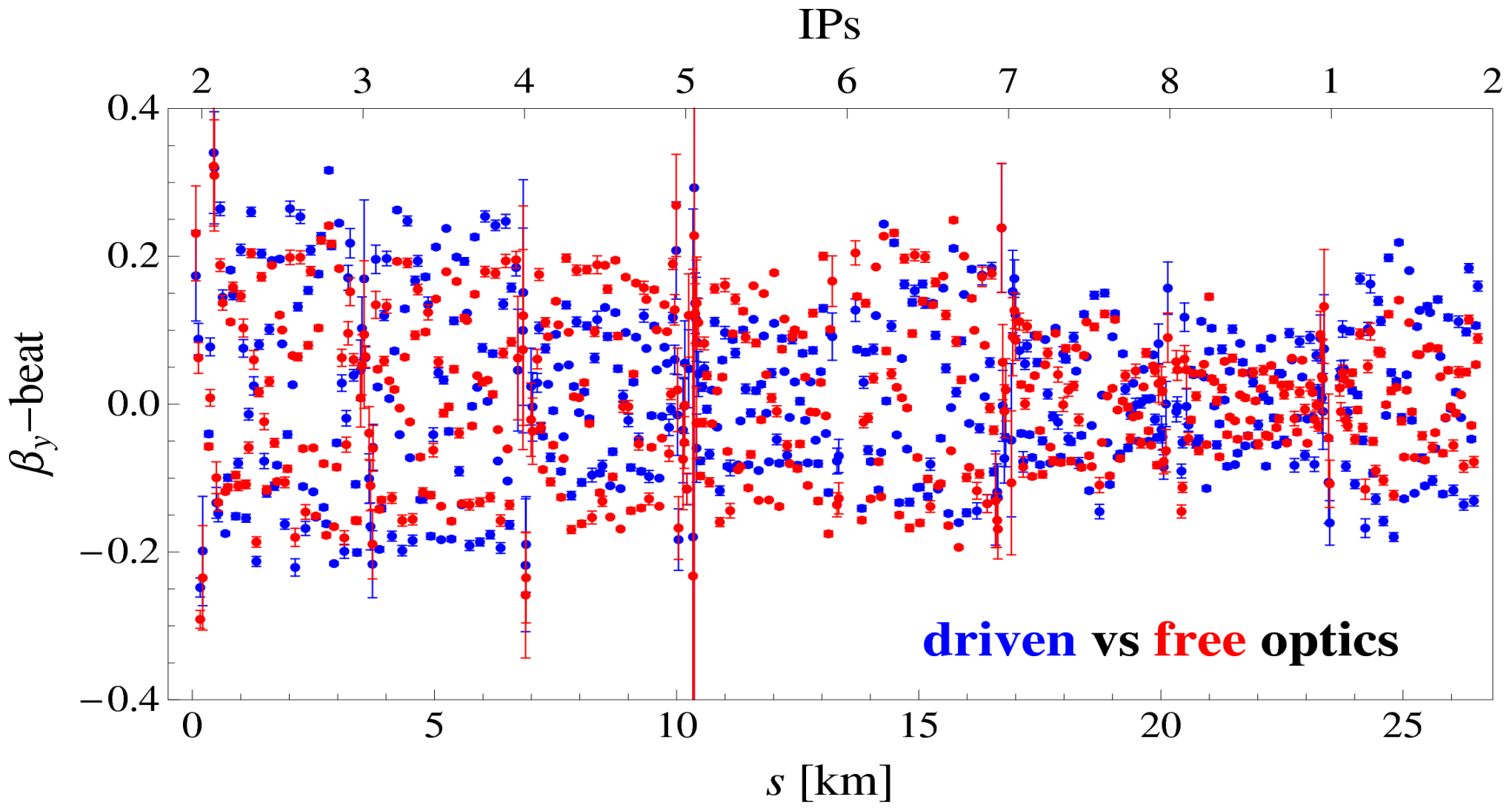
Summary

- **AC Dipole Task has been successfully completed.**
  - All four AC dipoles are commissioned and in operational.
  - Required specifications have been achieved.
  - The AC dipoles have been integrated into the operational system and beam optics package.
  - The AC dipoles are the primary probe of beam optics above injection.
- The next step is that CERN makes good use of them.
  - Linear diagnosis has been already established (more of less).
  - The next is RDT, detuning…
  - Off course, we're happy to keep in touch.

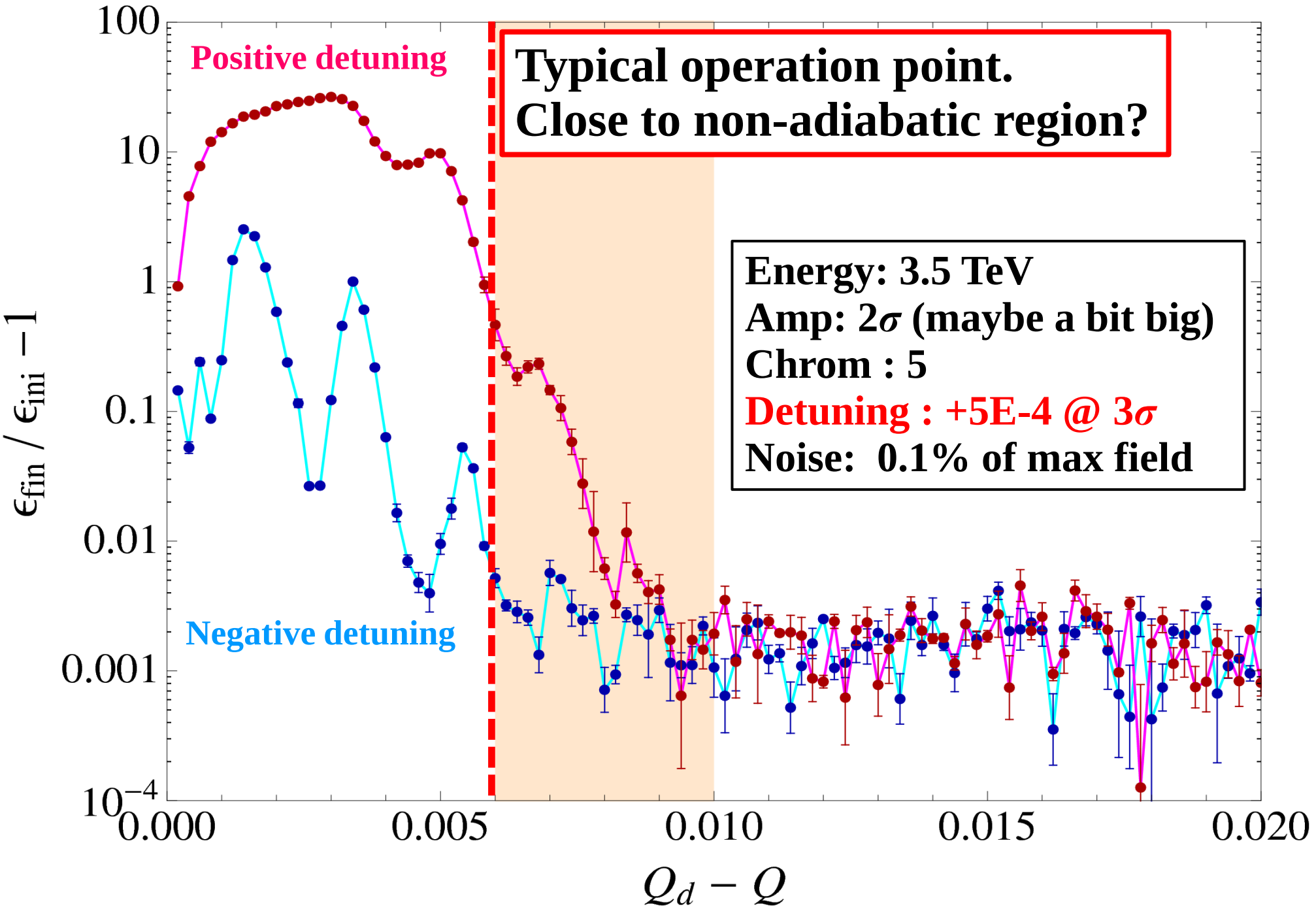
Backup Slides

Optics of driven motion ≠ Optics of free motion

- First observed in the Tevatron.
- Looks additional β-beating. Or, effectively, a thin focusing map.
- Small in LHC (3-4% β-beating in rms) but could be deceiving.

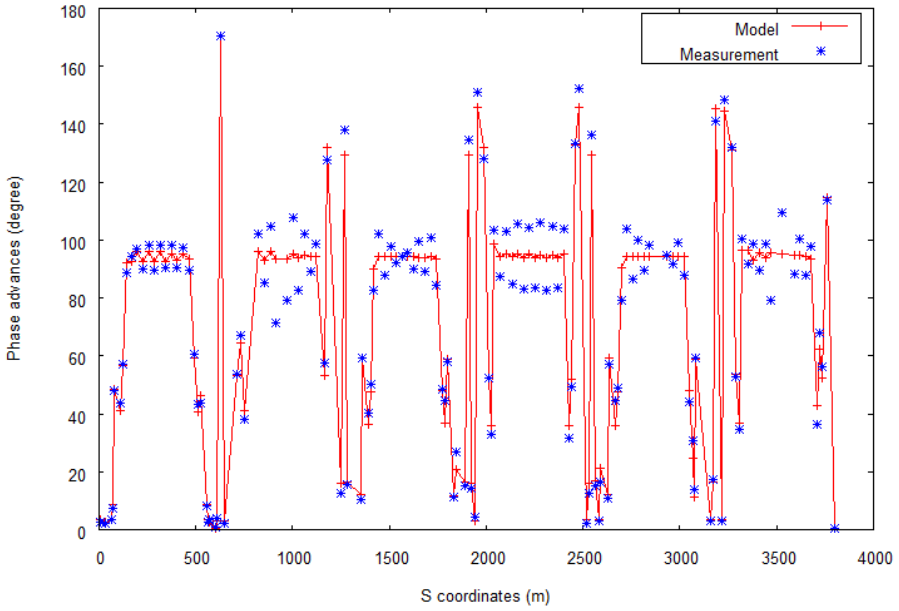


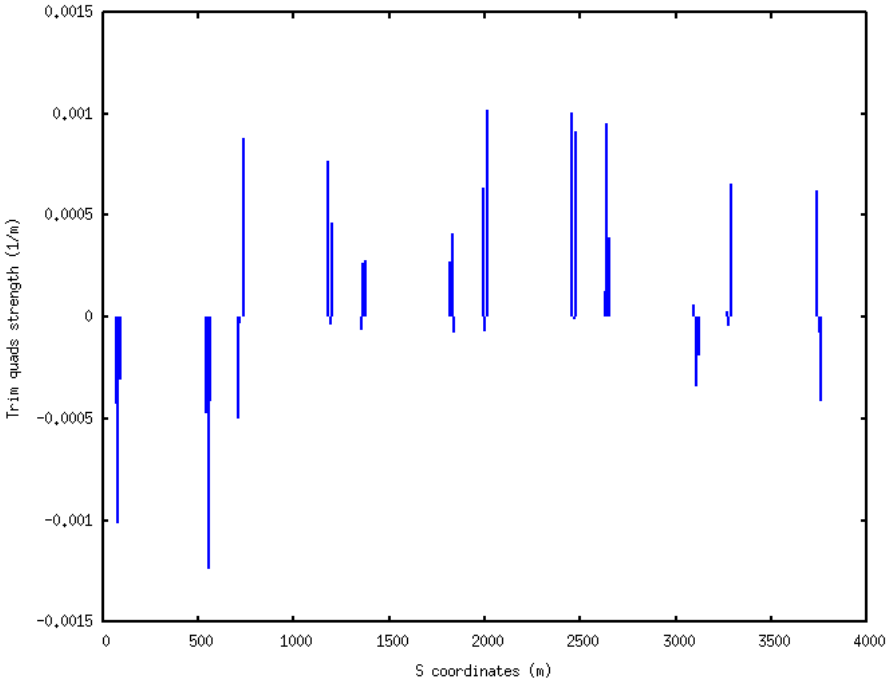
Parameters for the emittance simulation is updated.



Phase beating measurement of yellow at store with 0.7m designed β^*

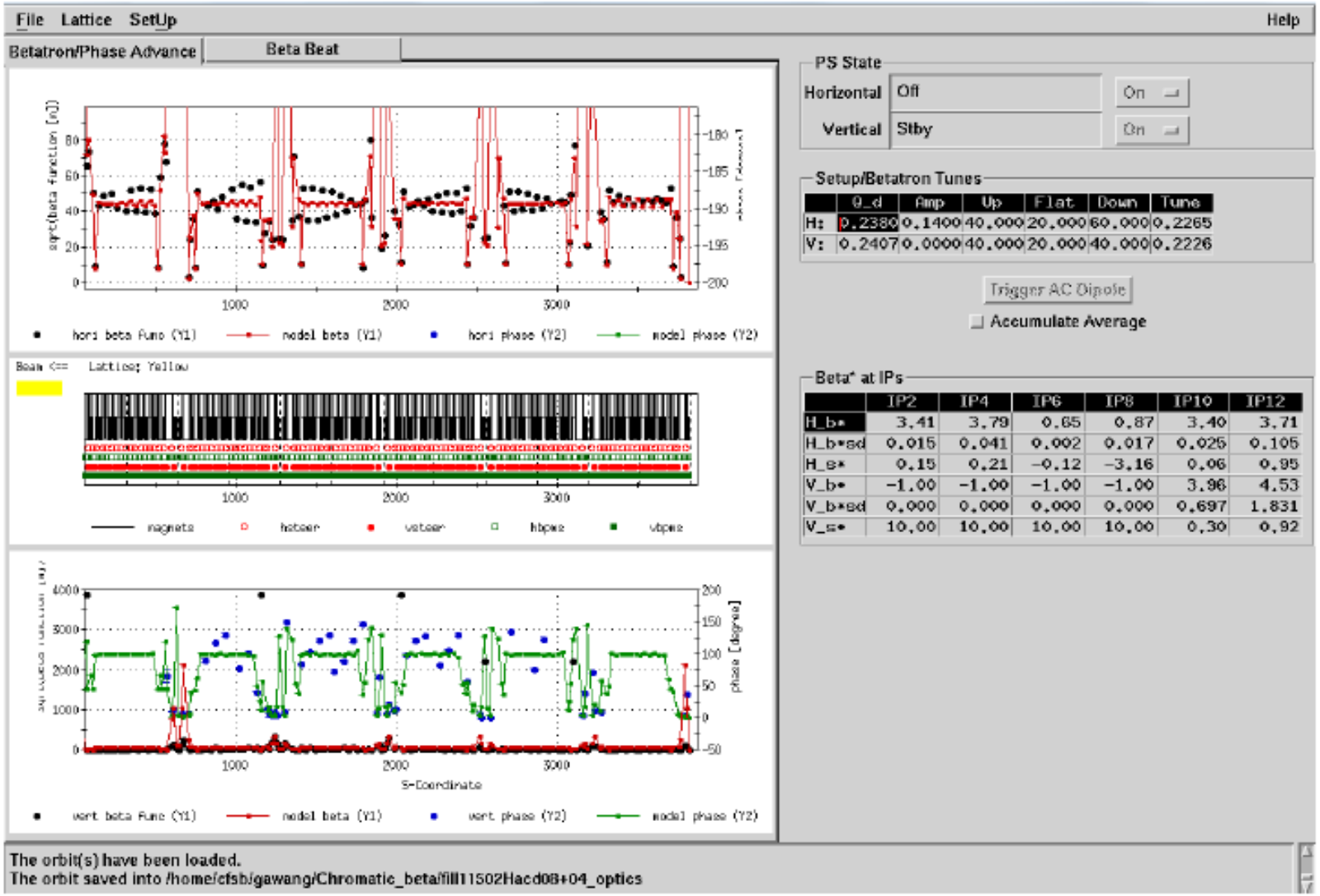
Rms phase beating is 11%





Yellow ring at store energy with 0.6m designed β^*

Fill 11502, Yellow store Hacd_04+08, no radial shift

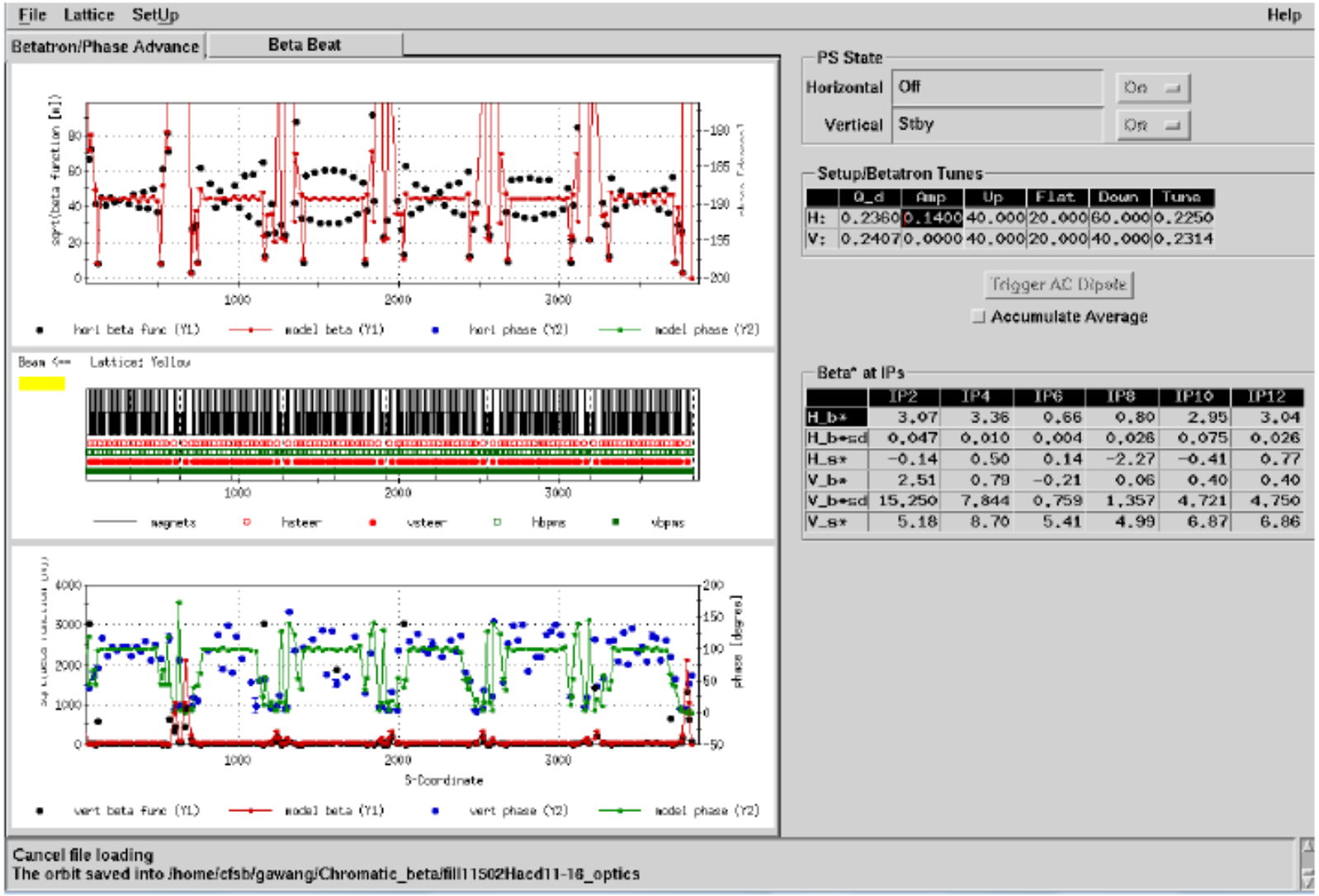


	Q_d	Amp	Up	Flat	Down	Tune
H:	0.2380	0.1400	40.000	20.000	60.000	0.2265
V:	0.2407	0.0000	40.000	20.000	40.000	0.2226

	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	3.41	3.79	0.65	0.87	3.40	3.71
H_b*sd	0.015	0.041	0.002	0.017	0.025	0.105
H_a*	0.15	0.21	-0.12	-3.16	0.06	0.95
V_b*	-1.00	-1.00	-1.00	-1.00	3.96	4.53
V_b*sd	0.000	0.000	0.000	0.000	0.697	1.831
V_a*	10.00	10.00	10.00	10.00	0.30	0.92

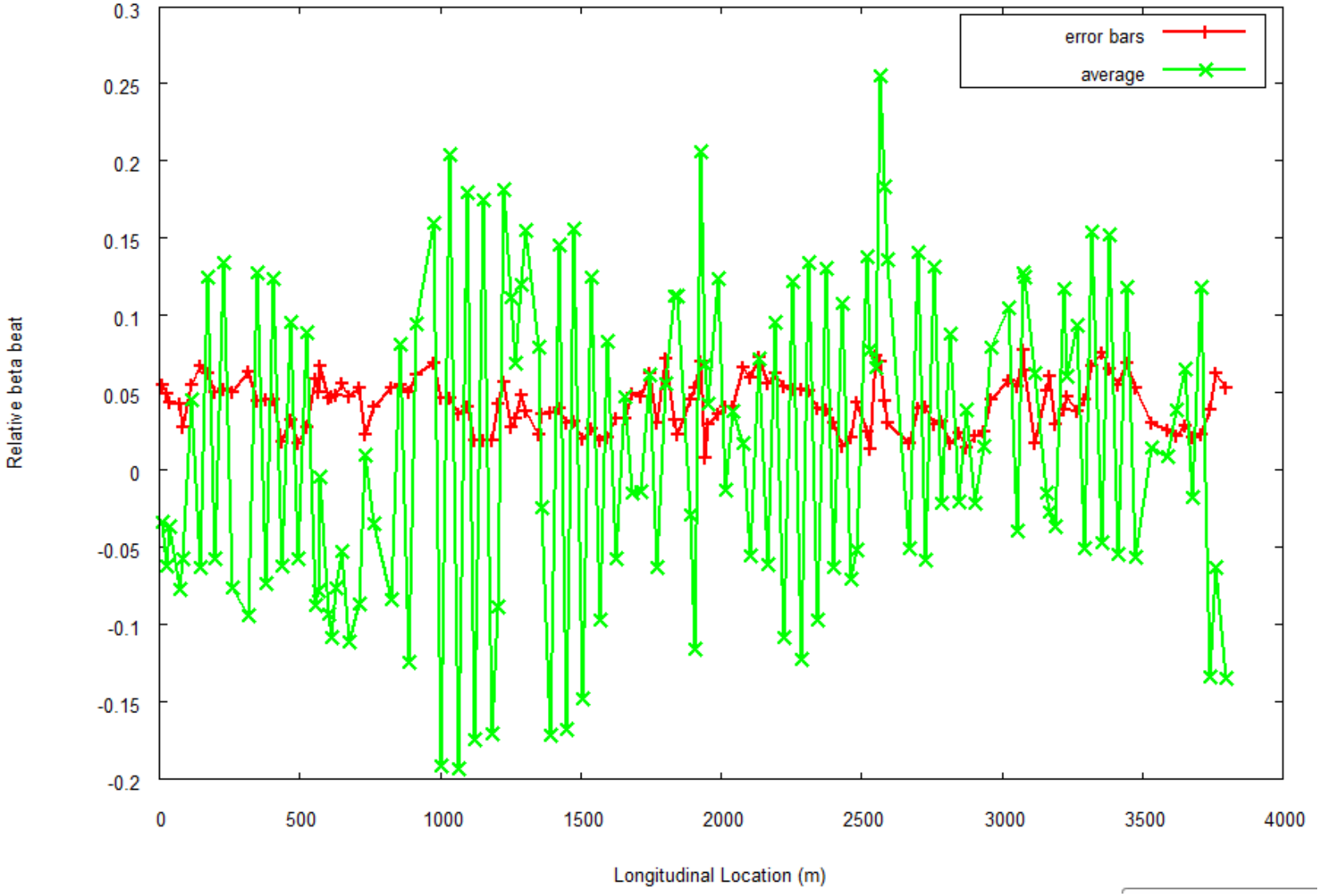
Yellow ring at store energy with 0.6m designed β^*

Fill 11502, Yellow store Hacd_11~16, with -0.3mm radial shift



Beta beating for on momentum beam.

Yellow ring at store energy with 0.6m designed β^*



Beta beating for off momentum beam

Yellow ring at store energy with 0.6m designed β^*