Chromatic Optics, Measurments

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- Motivation
- LHC measurements, 2010-11
- RHIC measurements, 2009 & 2011

Huge Ack: Operations at RHIC & LHC

Motivation

LHC:

For $\beta^* < 30$cm (upgrade), chromatic limit with existing sextupoles is reached and hierarchy of collimation system may not be preserved.
Correction of chrom β-beating, non-linear chrom and spurious dispersion with a new ATS scheme†.

- Arc cell phase adv (left & right of IP) $\rightarrow \pi/2$
- New phase adv at all 8 IRs & increased arc β-functions

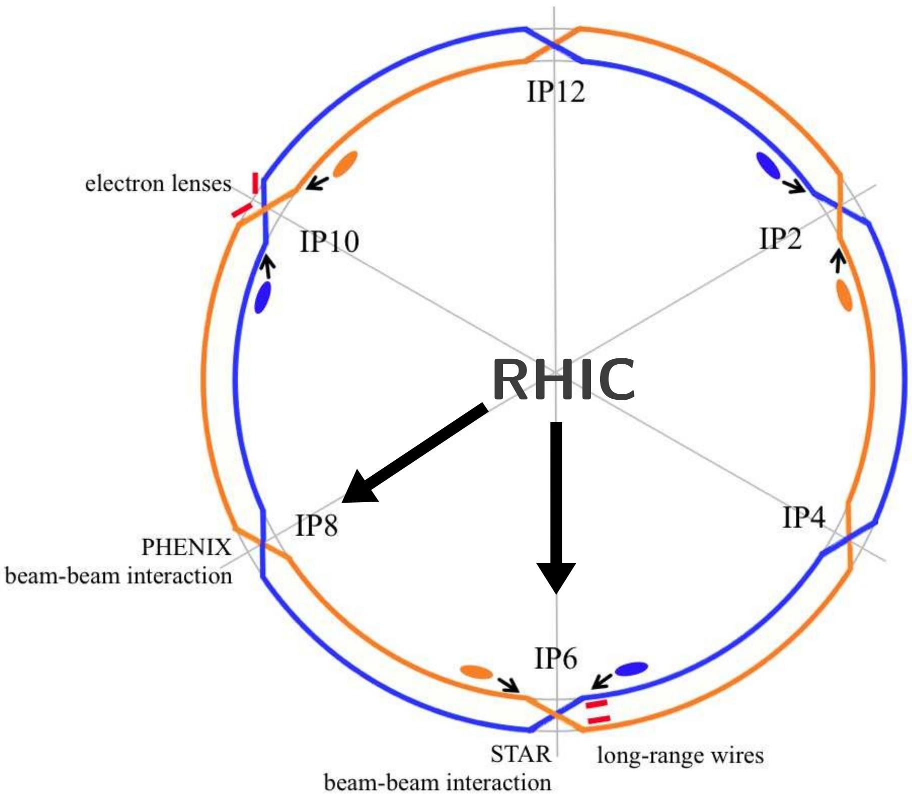
RHIC:

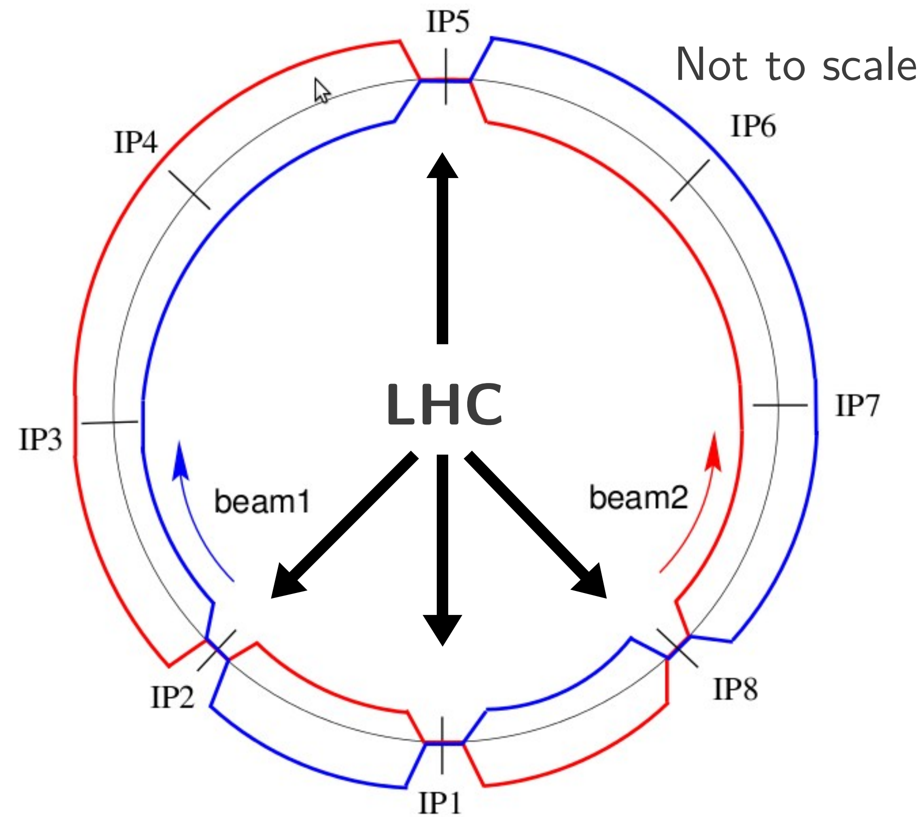
Large chromatic β-beat for ≤ 0.7m optics. Aiming at $\beta^* \sim 0.5$m

- With heavy ions, rebucketing at top energy increases momentum spread by x3
- For protons, tune space is limited for present working point (3rd & 10th). DA and lifetime "in principle" can be improved with chromatic corrections

† See S. Fartoukh, Optics Challenges

RHIC & LHC





2 IPs, $\beta^* = 65 - 70$cm

Recent tests, $\beta^* \leq 60$ cm

Future, $\beta^* \leq 50$ cm ?

4 IPs, $\beta^* = 150$ cm, 300-1000 cm

7 TeV, $\beta^* = 55$cm (perhaps less)

Upgrade, $\beta^* = 15$cm (perhaps less)

Definitions

Montague, LEP Note 165

Linear Chromatic functions:

$$W_{x,y} = \sqrt{a_{x,y}^2 + b_{x,y}^2}$$

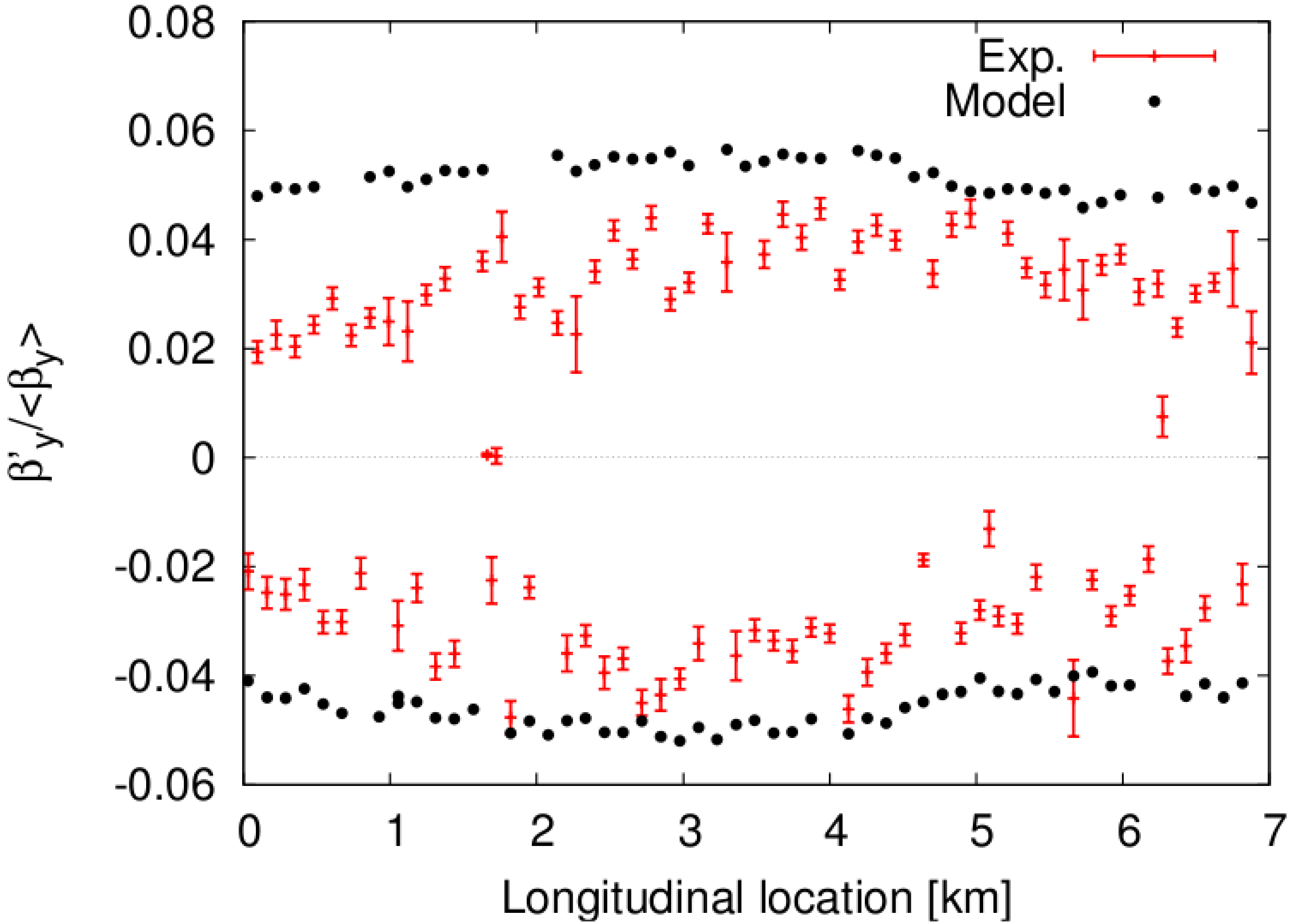
$$a_{x,y} = \frac{1}{\beta}\frac{\Delta\beta}{\Delta p/p} \qquad b_{x,y} = \frac{\Delta\alpha}{\Delta p/p} - \alpha * a_{x,y}$$

Typical Procedure

- Beam excitation (kicker/ac dipole) at different radial offsets
- Compute β-functions using standard tools (see Glenn's talk)
- Fit (typically linear) vs. dp/p to compute chromatic optics

SPS Measurment, 2003

Systematic difference between model & measurements, source unknown



G. Arduini et al. PAC05

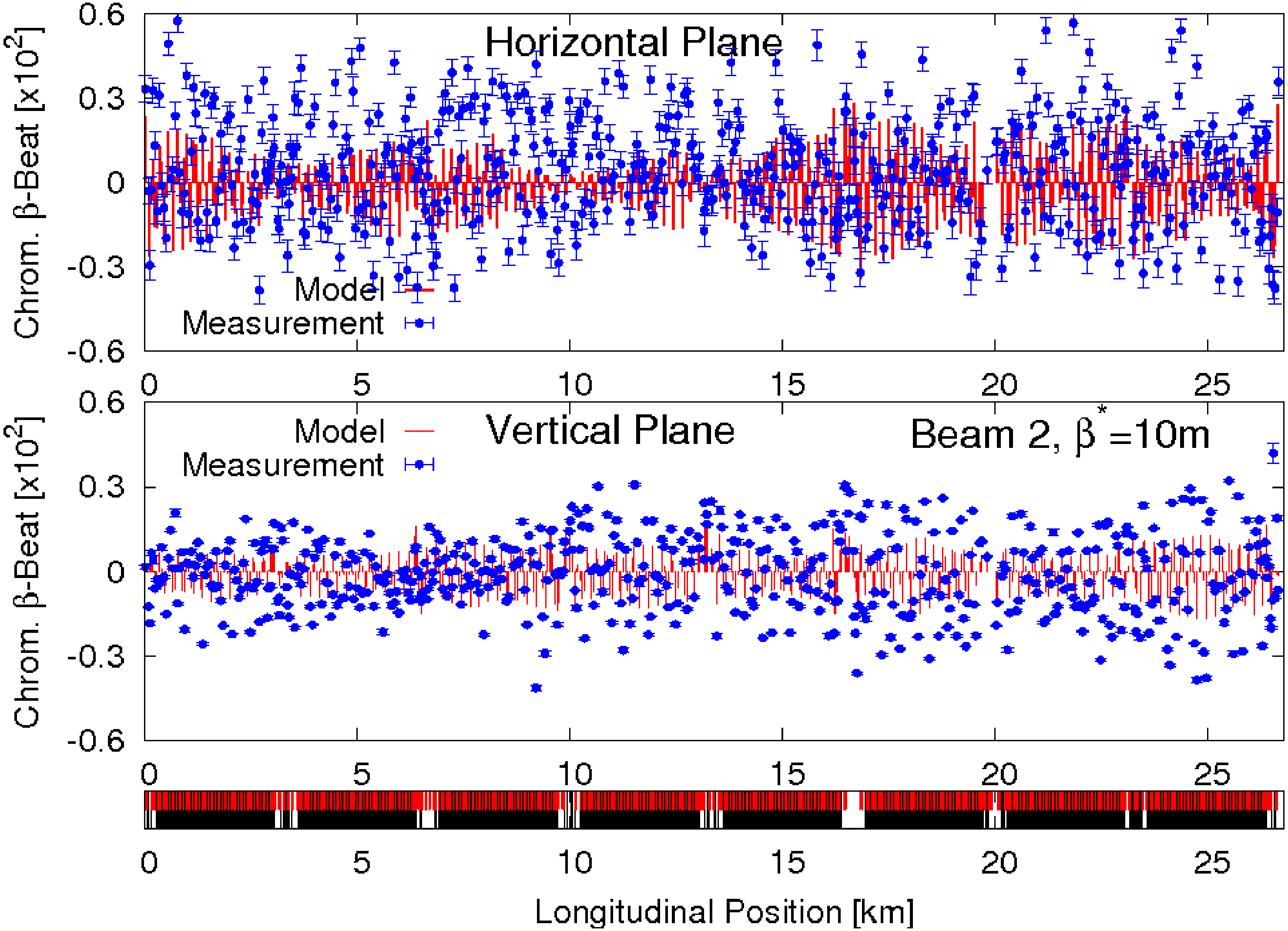
Chromatic Optics Measurements

	Year	E [GeV]	β^* [m]
LHC ($0.3\text{-}0.7 \times 10^{-4}$)	2010	450-3500	10-12, **3.5**
	2011		10-12, **1.5**†
RHIC ($1\text{-}2 \times 10^{-3}$)	2009	26-250	7.5, **0.7**
	2011	100	

†Data not useful, need to remeasure

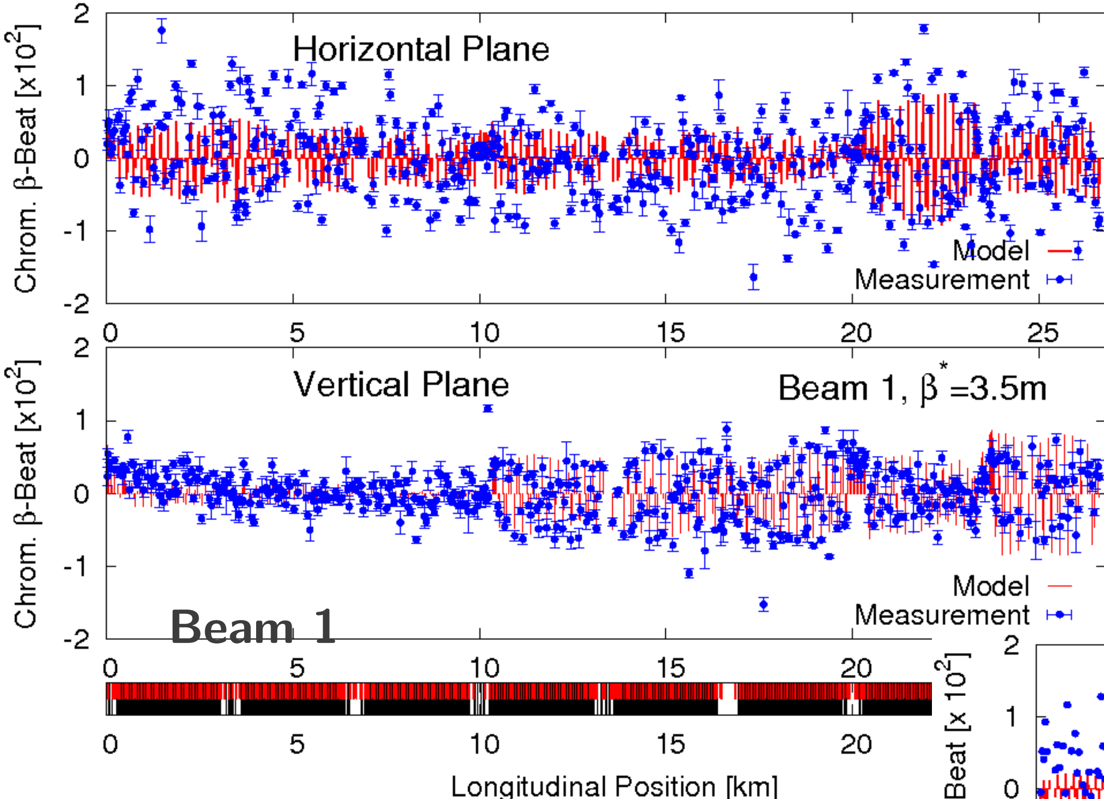
LHC: Chromatic β-beat @0.45 TeV

Error bars suppressed



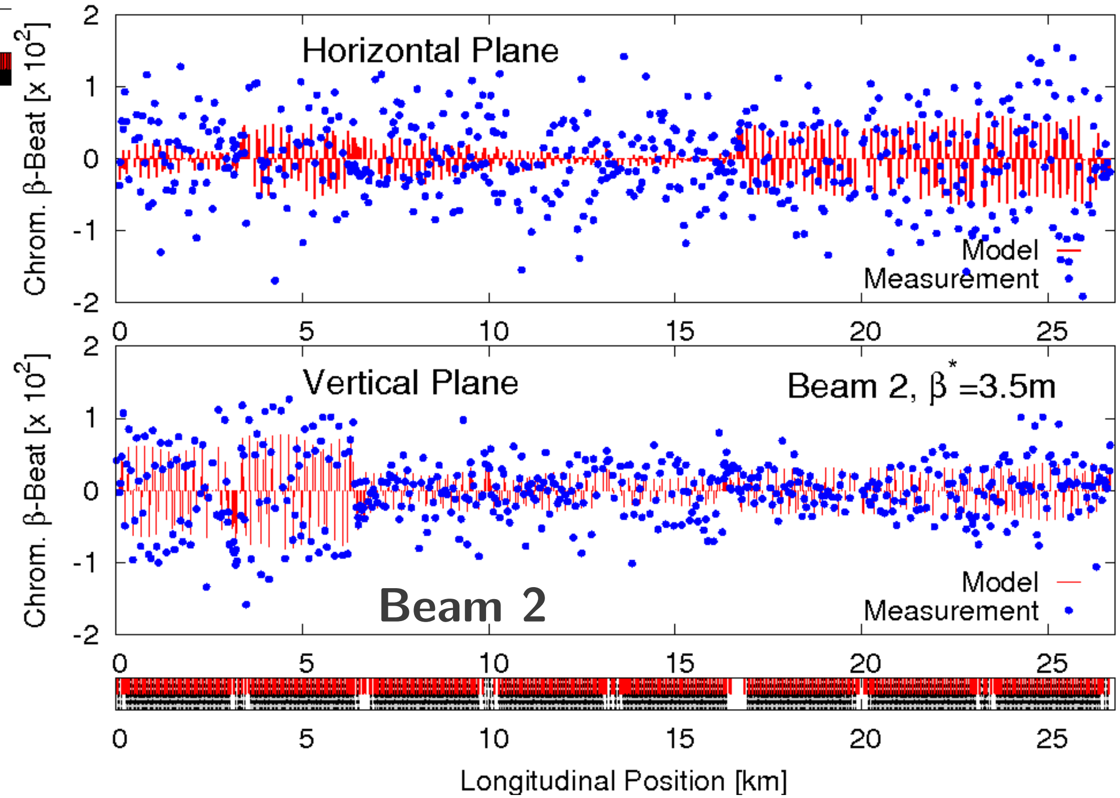
Approx ±3% at 1x10^{-3}

LHC: Chromatic β-beat @3.5 TeV

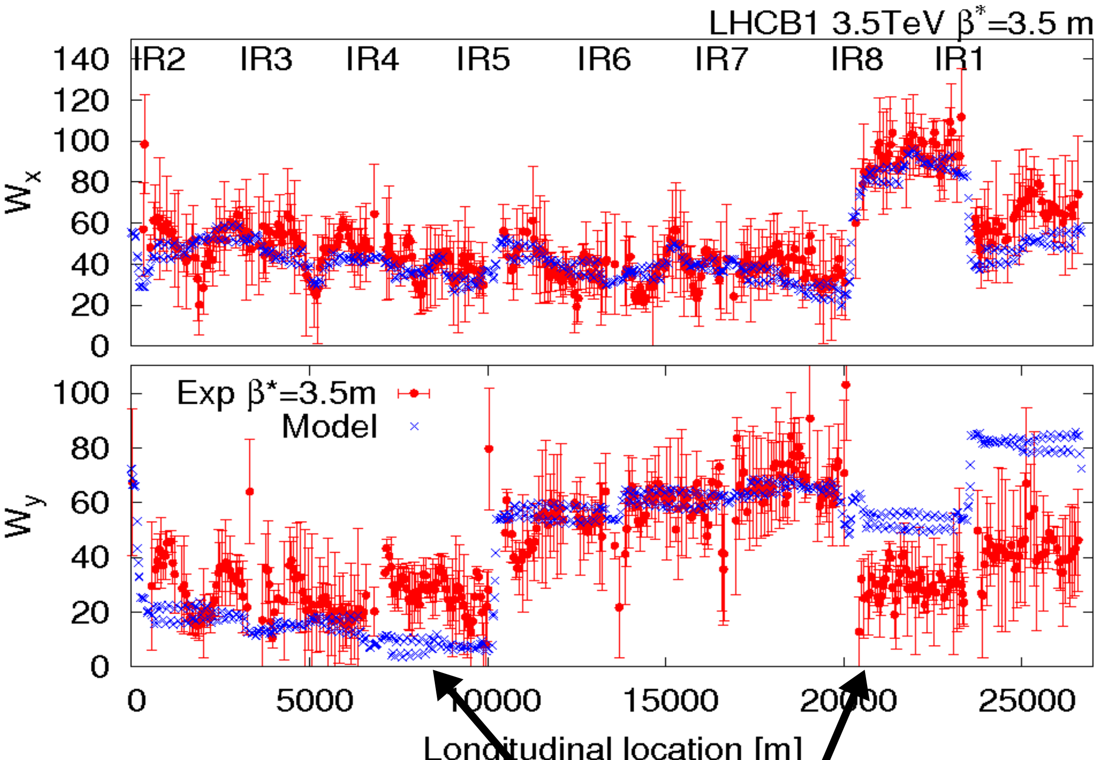


At **3.5 m**, the chromatic β-beat is less than ±10% @ $1x10^{-3}$

Agreement to model is not great in horizontal plane!



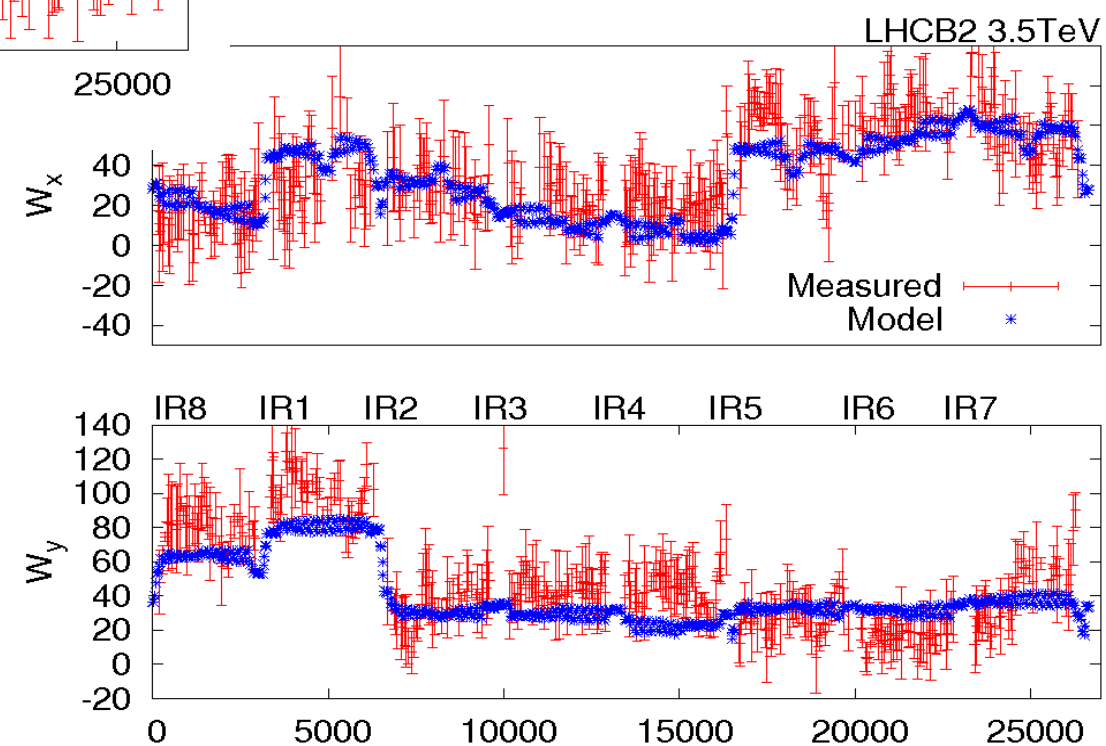
W-functions, LHC 3.5 TeV



β* = 3.5 m

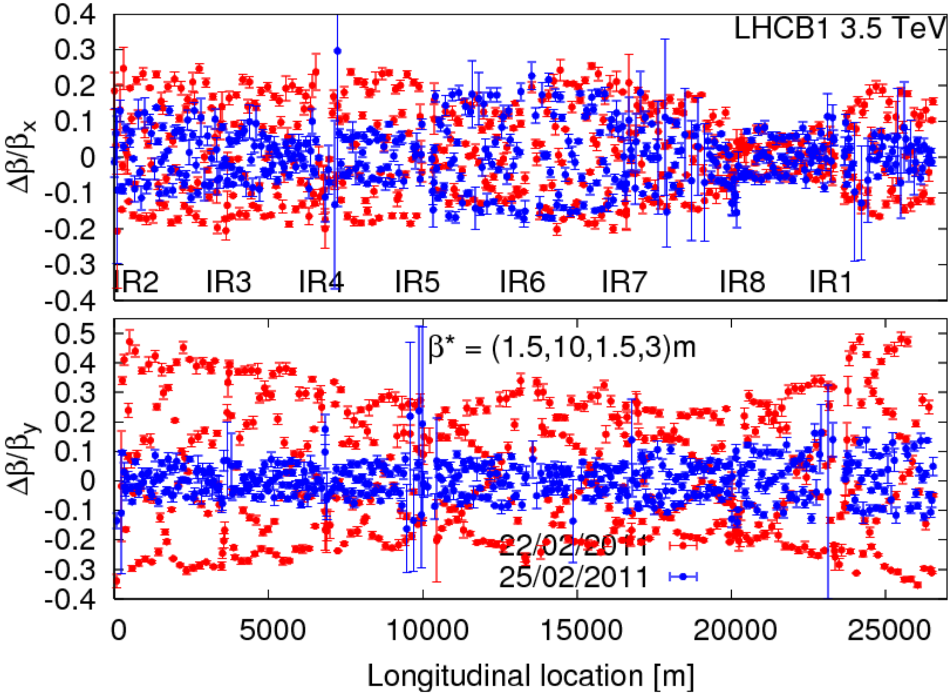
Using models at <u>each</u> dp/p

β-functions and W-functions are computed



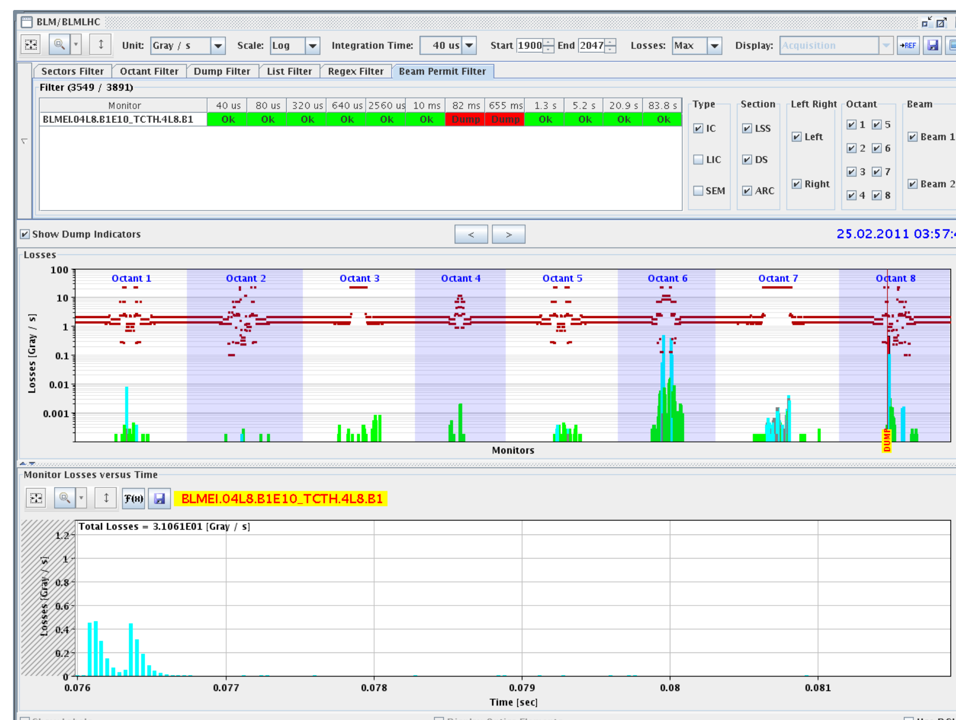
Agreement to model except for few places is quite good

2011, $\beta^* = 1.5$m @3.5 TeV



Beating-beating < 20% with local corrections between 3.5-1.5m

Unfortunately, beams lost due to loss monitor interlock, +50Hz



RHIC Measurements, 2009

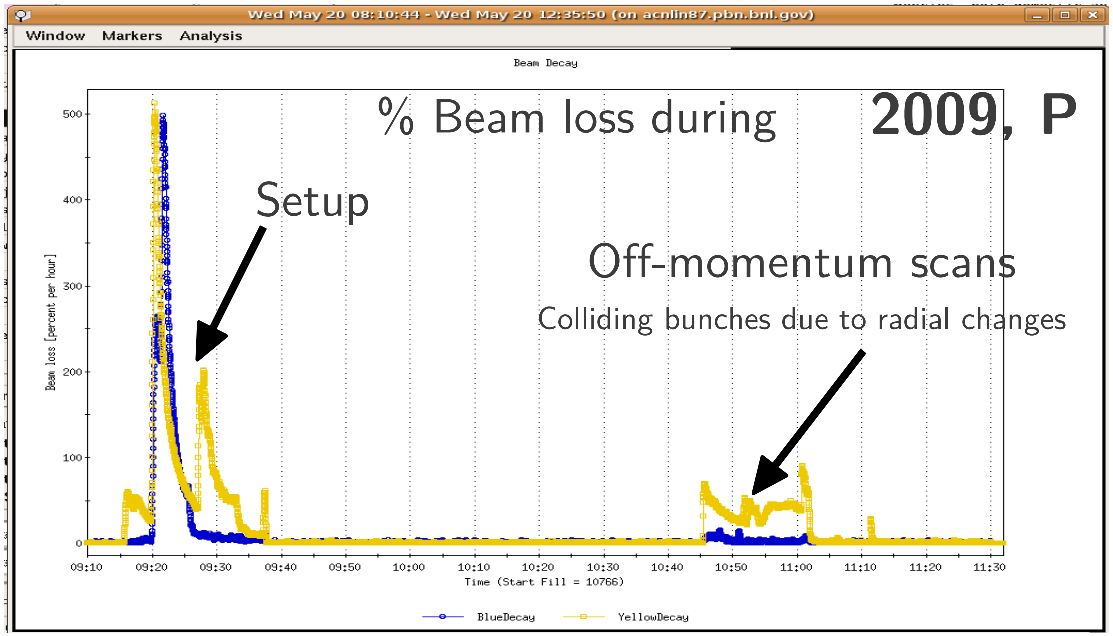
	Blue		Yellow	
	26	100/250	26	100/250
# bunches	6 x 6	12 x 12	6 x 6	12 x 12
Intensity [10^{11}]	0.01 (Gold) and 1.0 (protons)			
Emittances [μm]	12/20		10/?	
Tunes [Qx/Qy]	0.74/0.72	0.74/0.72	0.72/0.74	0.72/0.74
Chroms [ξx/ξy]	2.6/1.5	2.0	2.0	2.0
dp/p offsets	$\sim$ 1-2 x 10^{-3}			

For Au 2011:

Qx, Qy: 0.23, 0.22

Vertical Chromaticities: ?

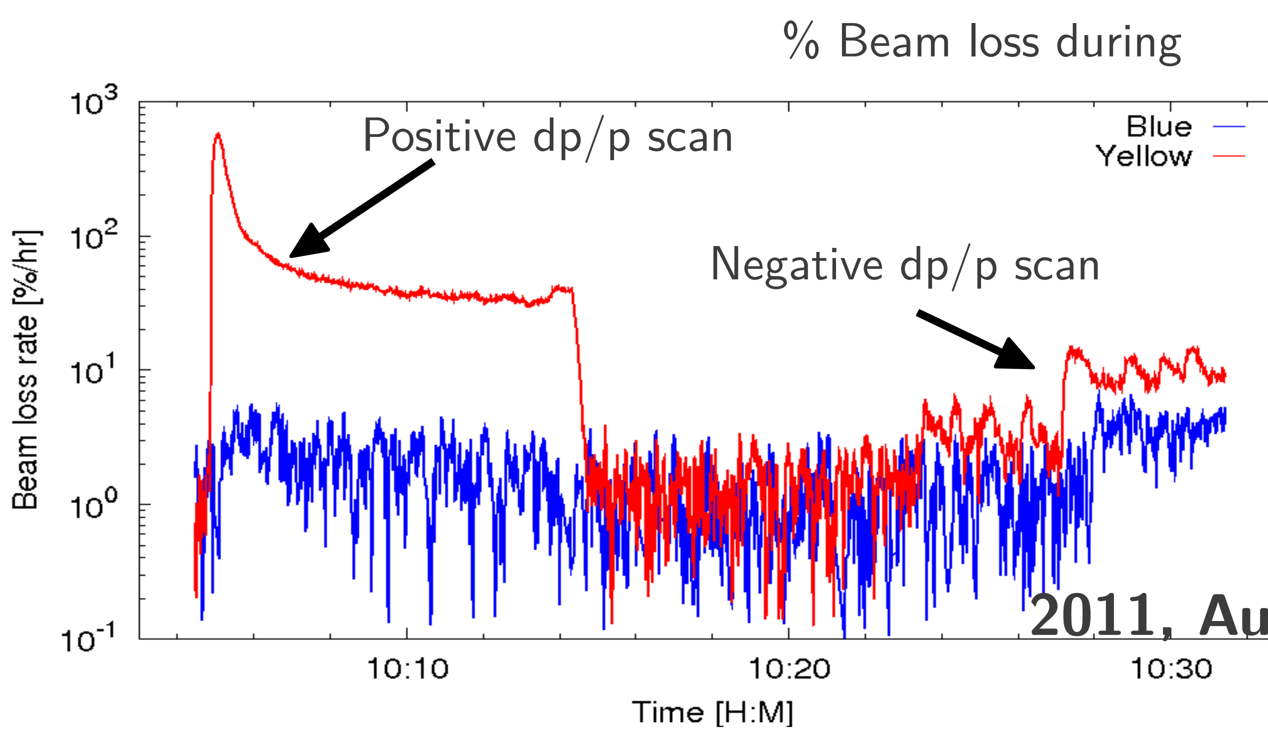
Beam Losses during Measurements



Restrict beam losses below 100% /hr

Large losses only in yellow already at 0.5 x 10^{-4}

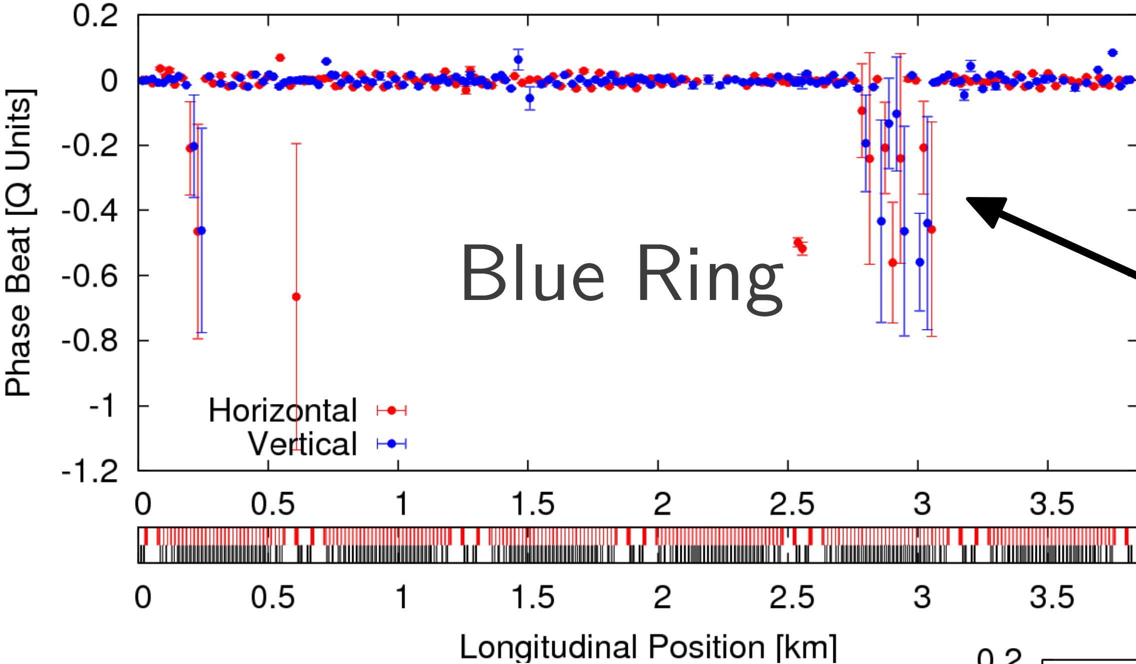
Negative scan much better



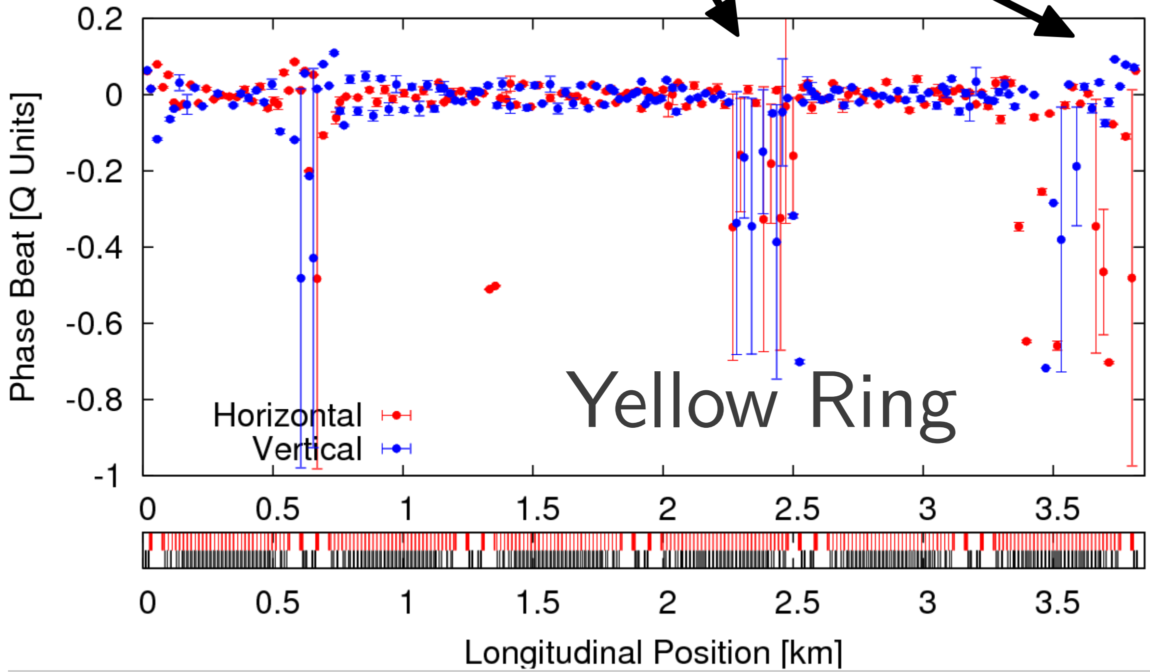
Phase-Beat @250 GeV

2009

$\beta^* = 0.7\text{m}$



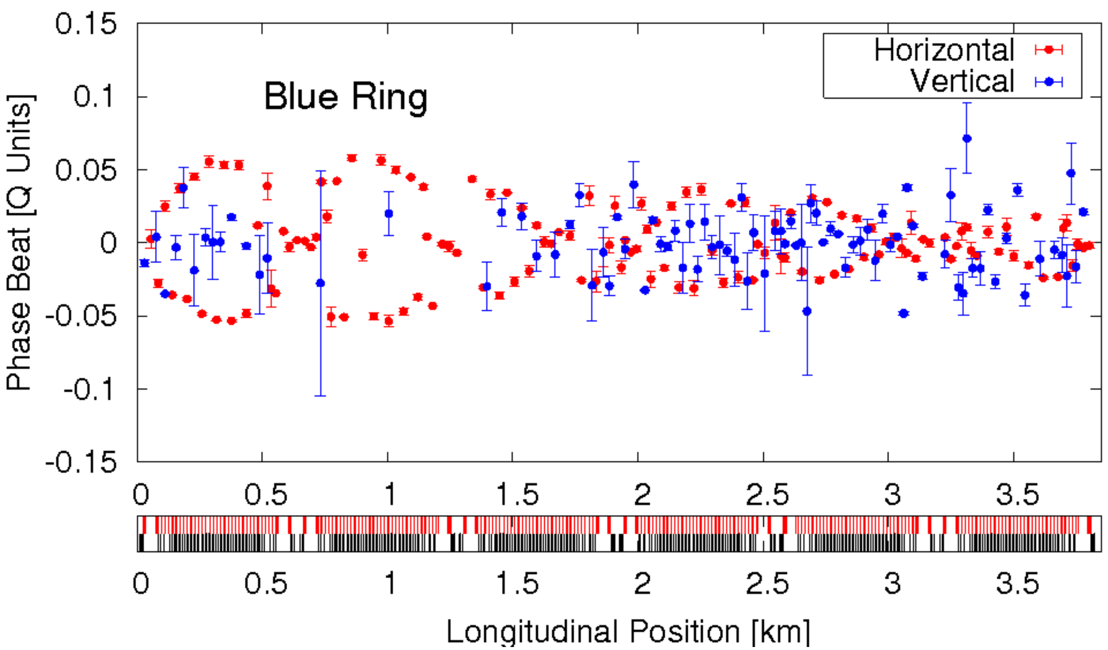
BPM Synchronization ?



Large beta-beating

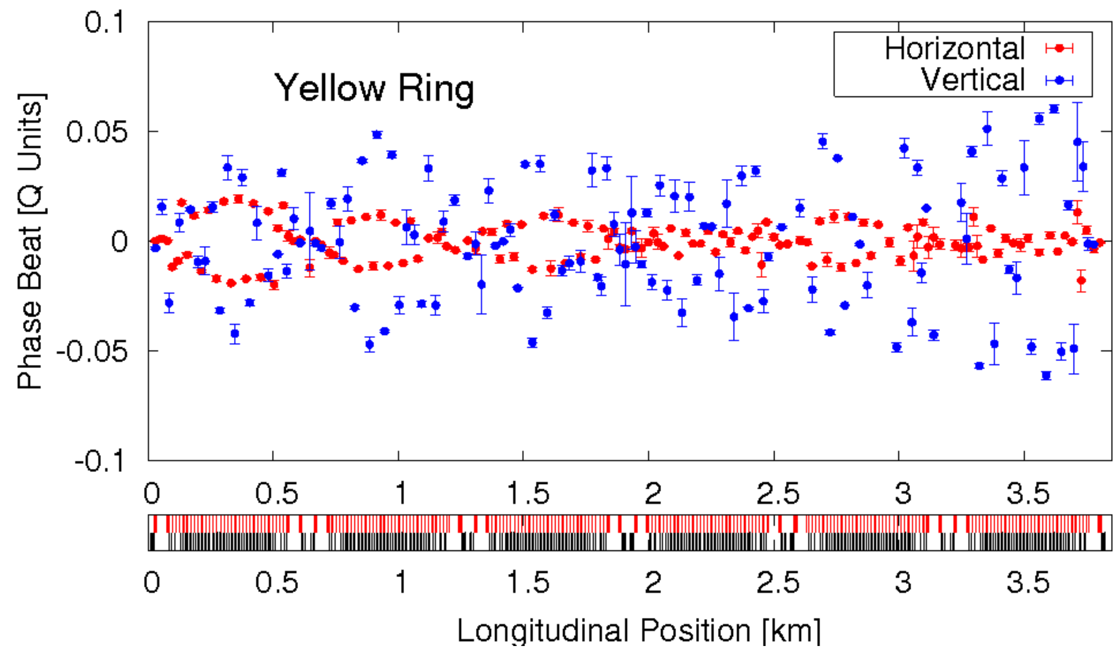
In Yellow

Phase-Beat @250 GeV



Au 2011

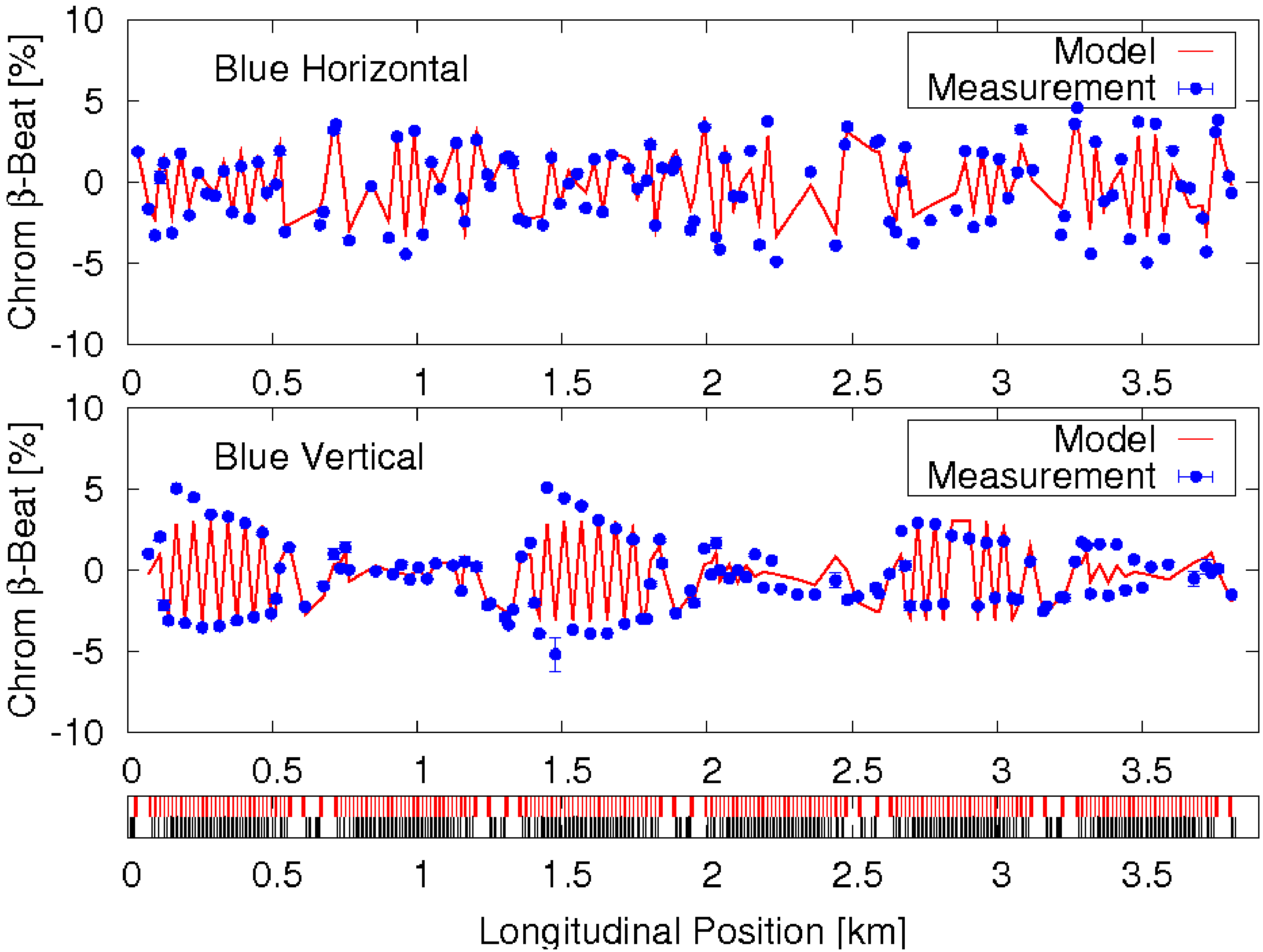
$\beta^* = 0.7\text{m}$



Beta-beating smaller than 2009

Chromatic β-beat Injection

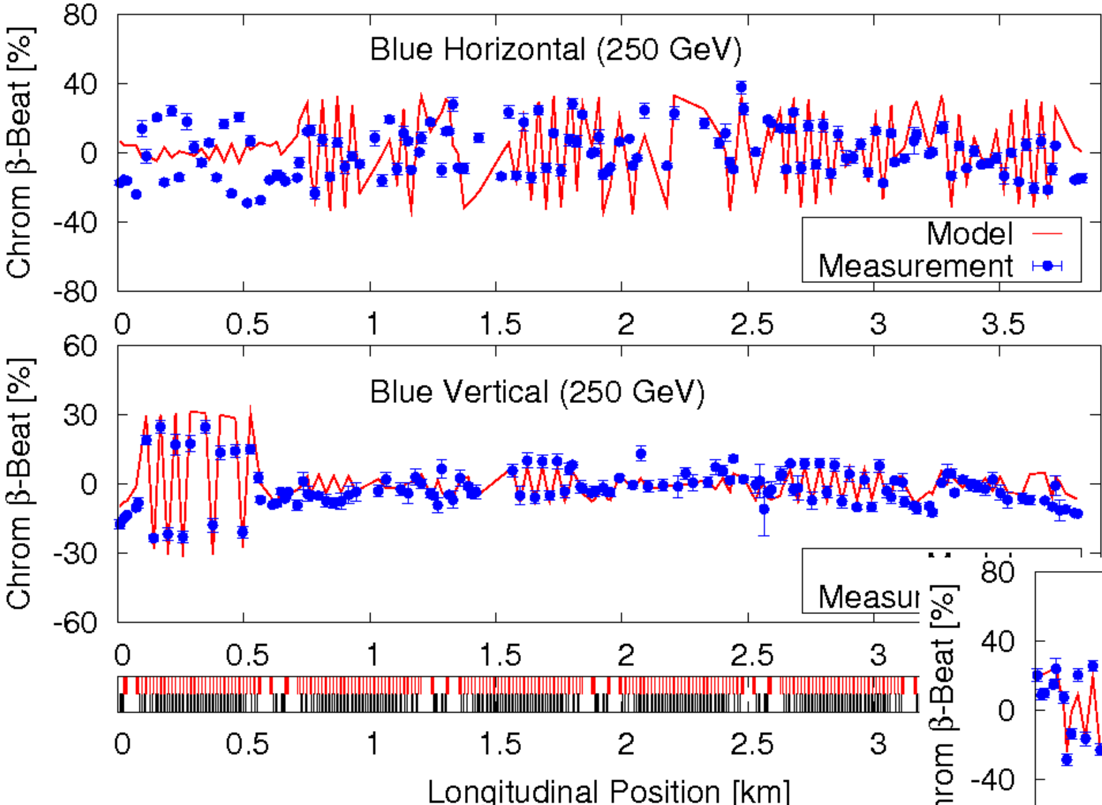
Protons, 2009



Only Blue ring available for injection measurements (± 5% beating at 1 x 10^{-3})

Published in the IPAC10 Proceedings

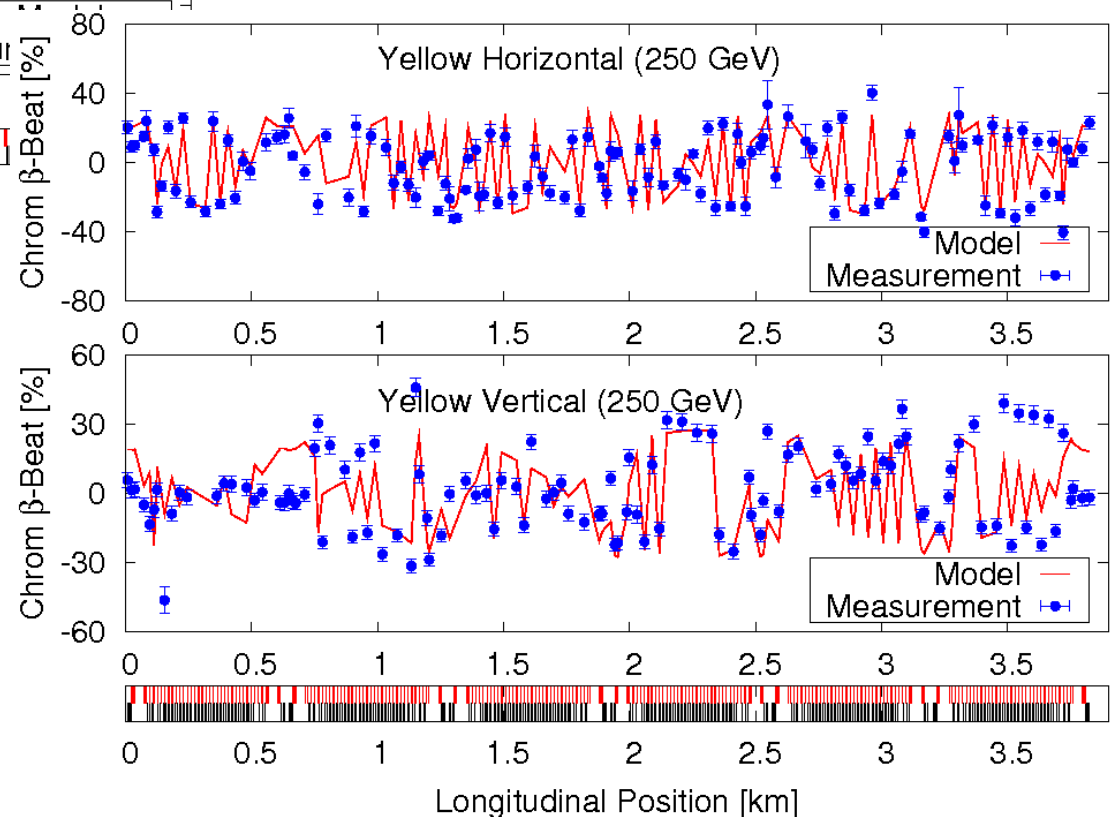
Chromatic β-beat at 250 GeV



Protons, 2009

Chromatic β-beating

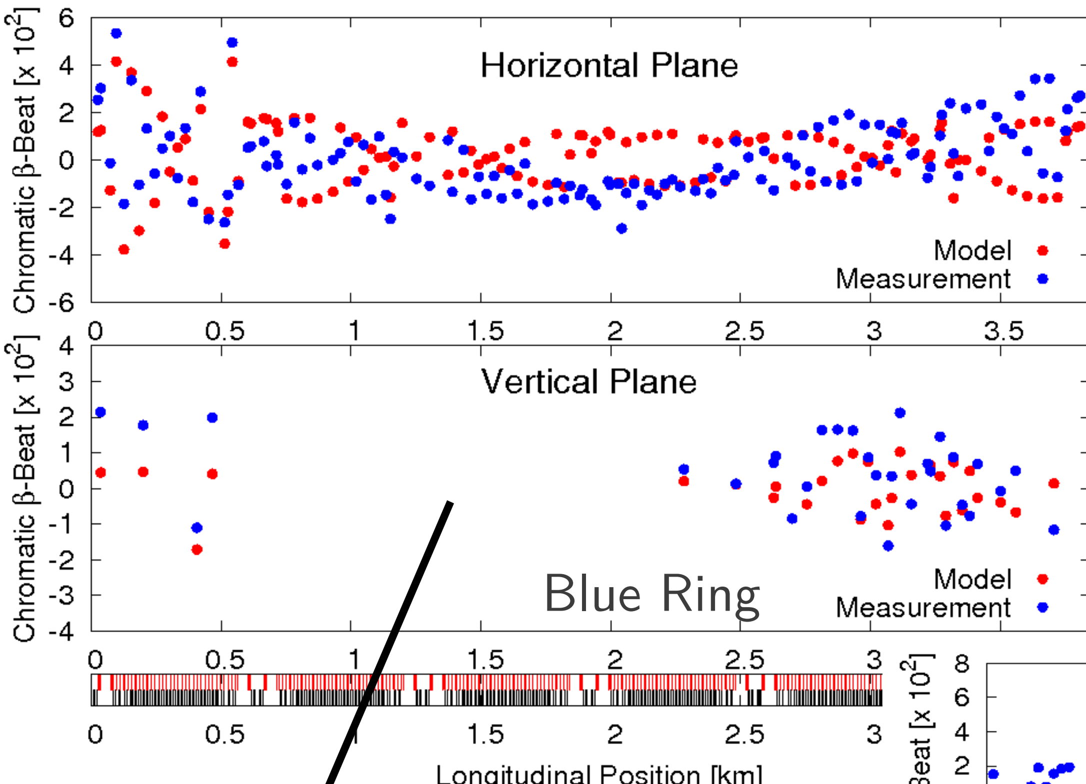
± 40% at 1 x 10^{-3}



Agreement is worse in

Blue-H & Yellow-V

Chromatic β-beat at 100 GeV

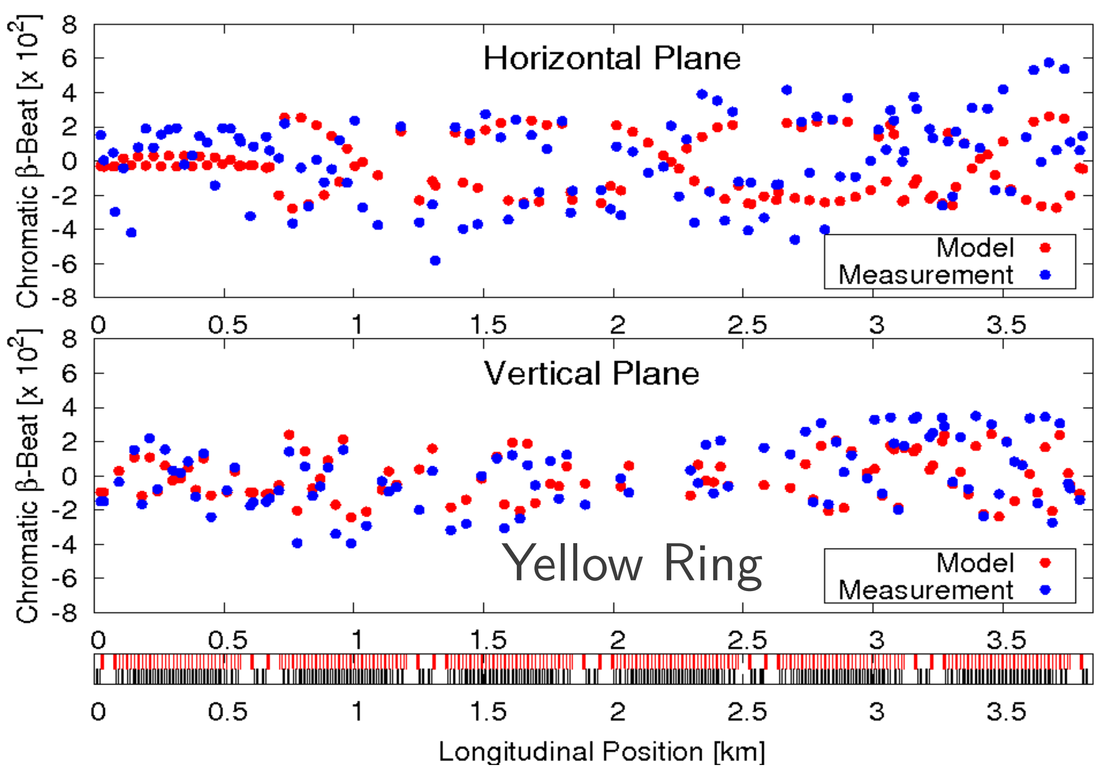


Au-2011, $\beta^* = 0.7$m

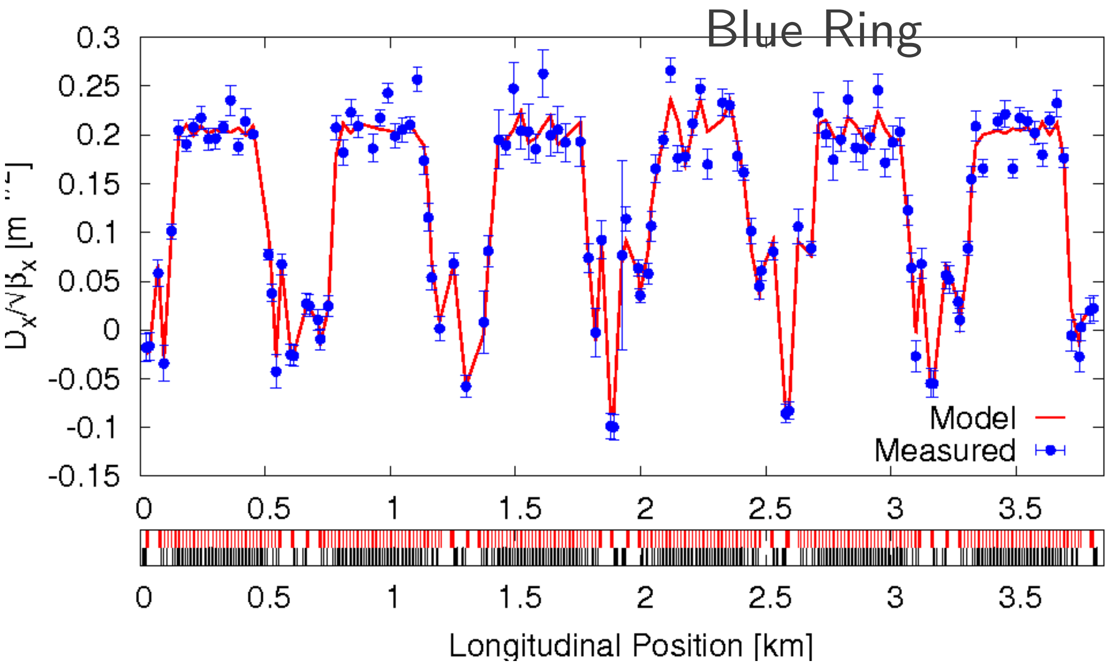
±50% @ 1x10^{-3}

(Reminder, yellow losses)

Many Blue v-BPMs do not pass our sanity cuts. (3 files/radial offset + >3 radial offsets)



Normalized Dispersion @100 GeV



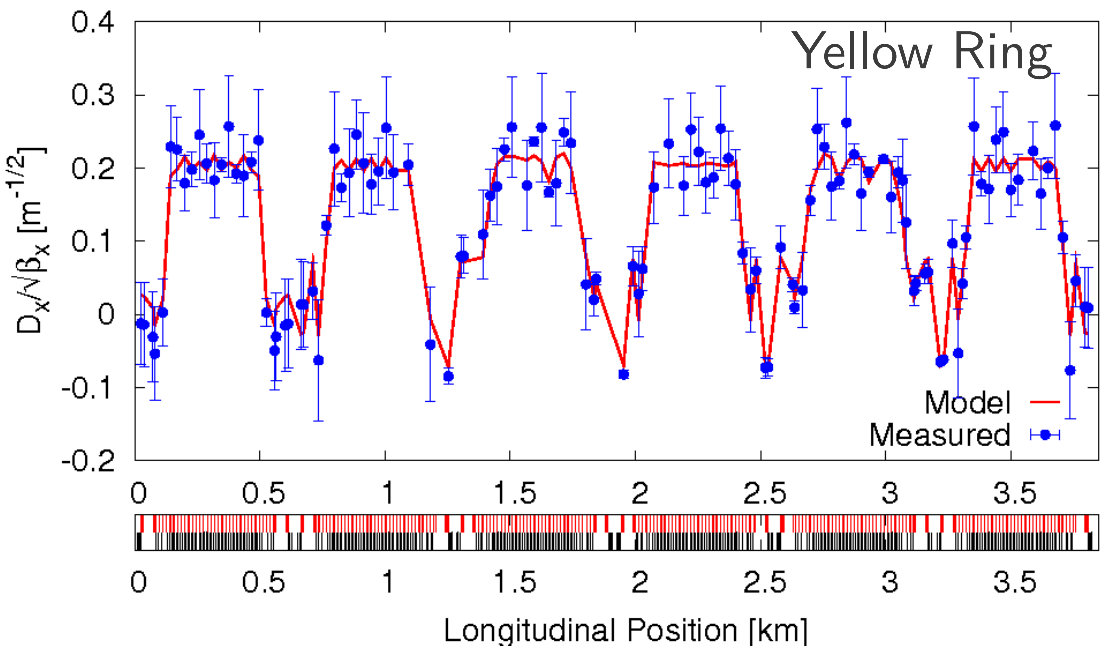
Dispersion, automatic

Outcome from measurement

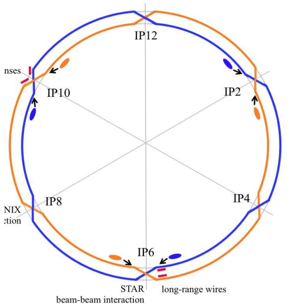
(**Au-2011**)

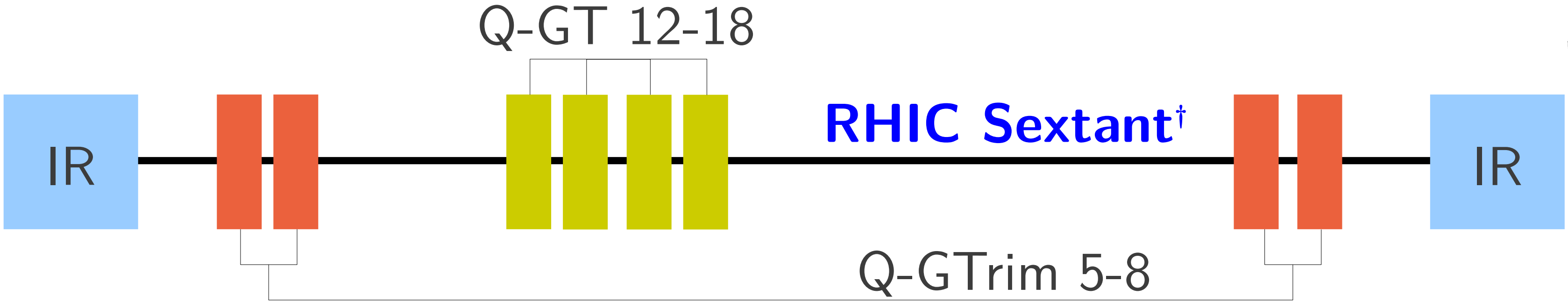
Dispersion beating is not negligible, ~15% rms

RMS Dy ~ 10 cm



First Idea at "Correction"





γ-T quads to locally perturb $\{\beta_{x,y}, D_x\}$ & compensate tunes

γ-T next to focusing quads & $\phi_{x,y} \sim 90^0$ & $\{\beta_{x,y}, D_x\}$ are approx equal

Use γ-T quads to adjust $W_{x,y}$ functions

In 2004, γ-T corrs were used for $\phi_{x,y}$ adjustments for beam-beam

$\rightarrow$ **LHC** corrections (see S. Fartoukh, optics challenges tomorrow)

†RHIC Design report

My 2 Cents

Motivation of chromatic corrections

- Looks good on paper for RHIC, but effect on $\int L.dt$?
- Some years before it may become a problem for the LHC

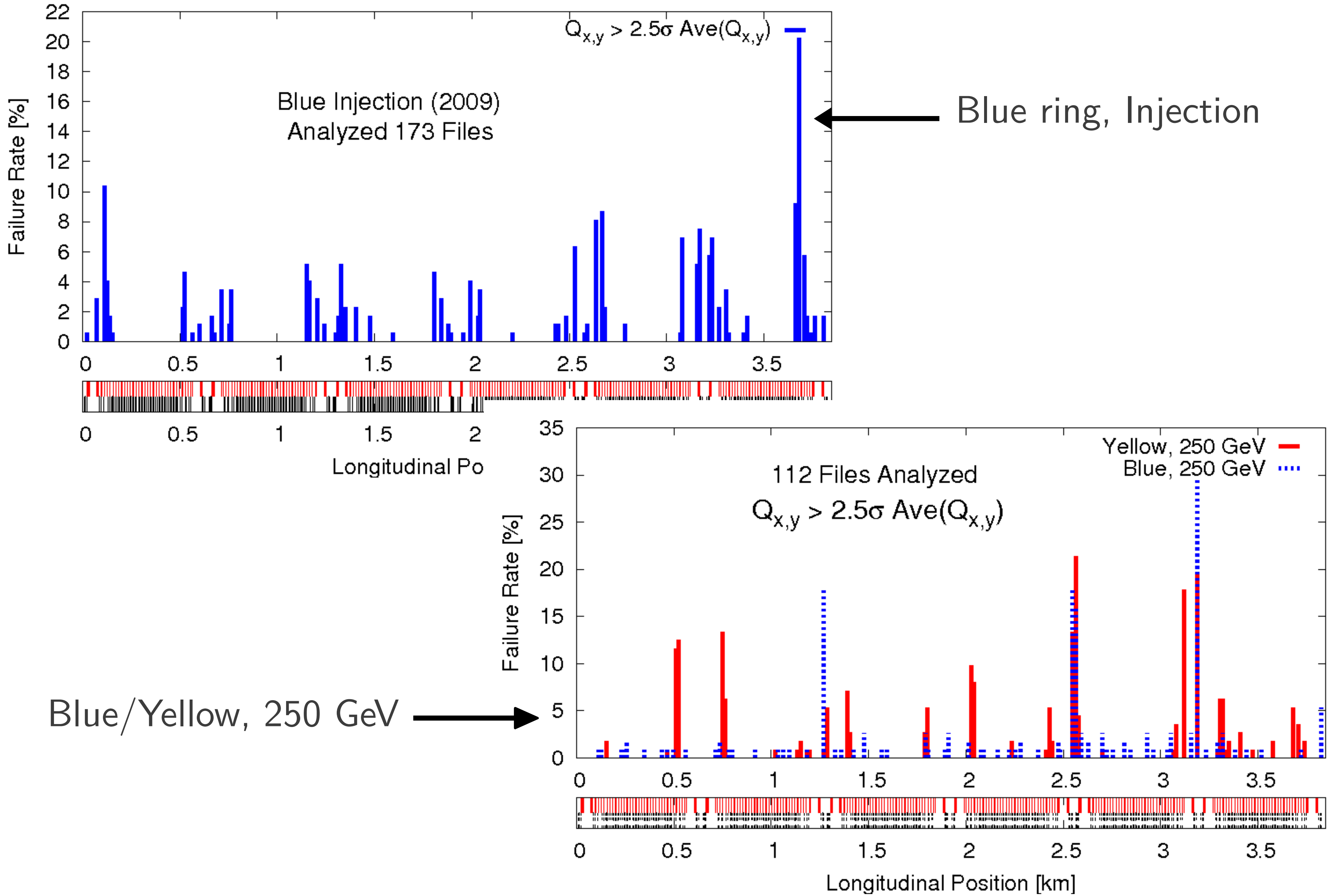
Measurements

- Few measurements in both machines show good agreement
- Precise model at each dp/p is nominal procedure now

Correction

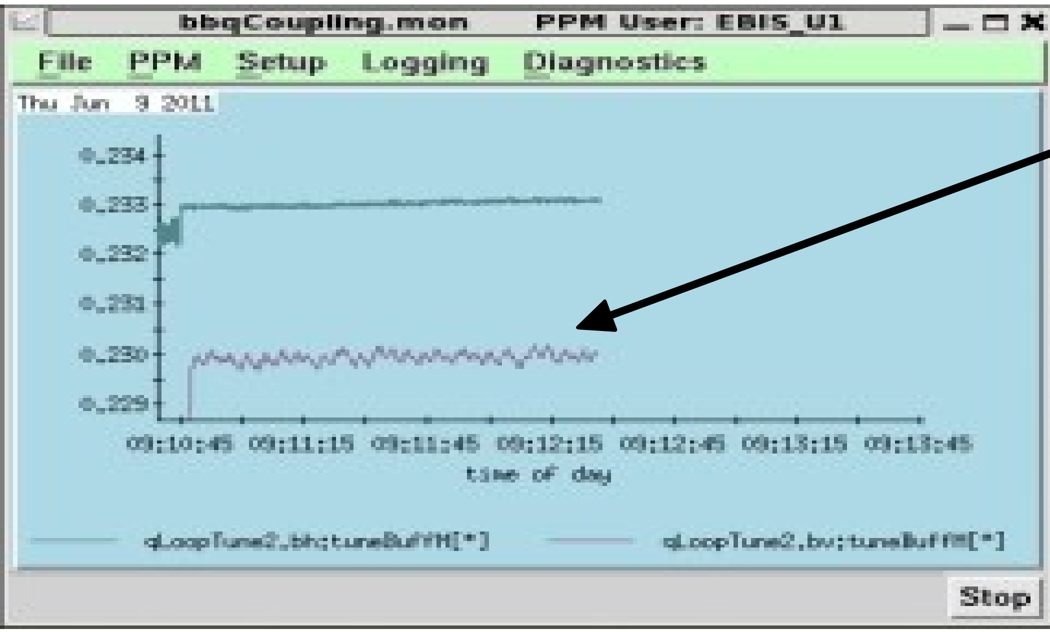
- RHIC will likely require a dedicated/careful effort
- Elaborate effort already in place for LHC (S. Fartoukh et al.)

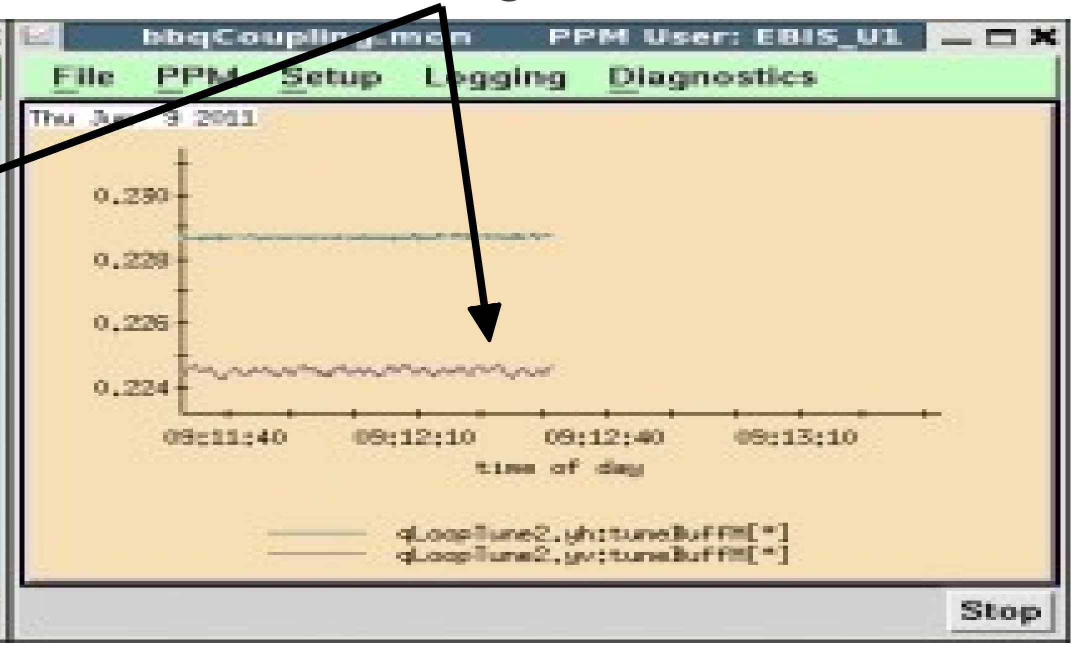
A1: BPM Failure (Only Tune Filtering)

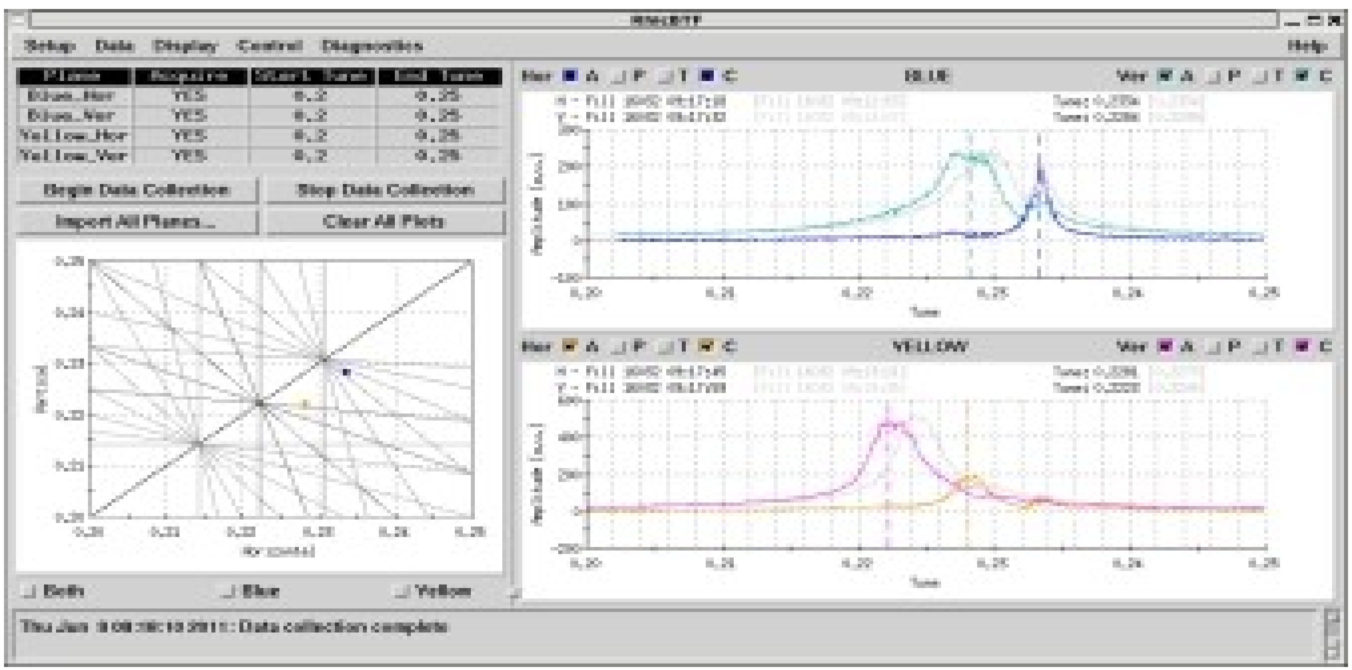


A2: Au-2011, Conditions Less Ideal

Strange vertical modulation

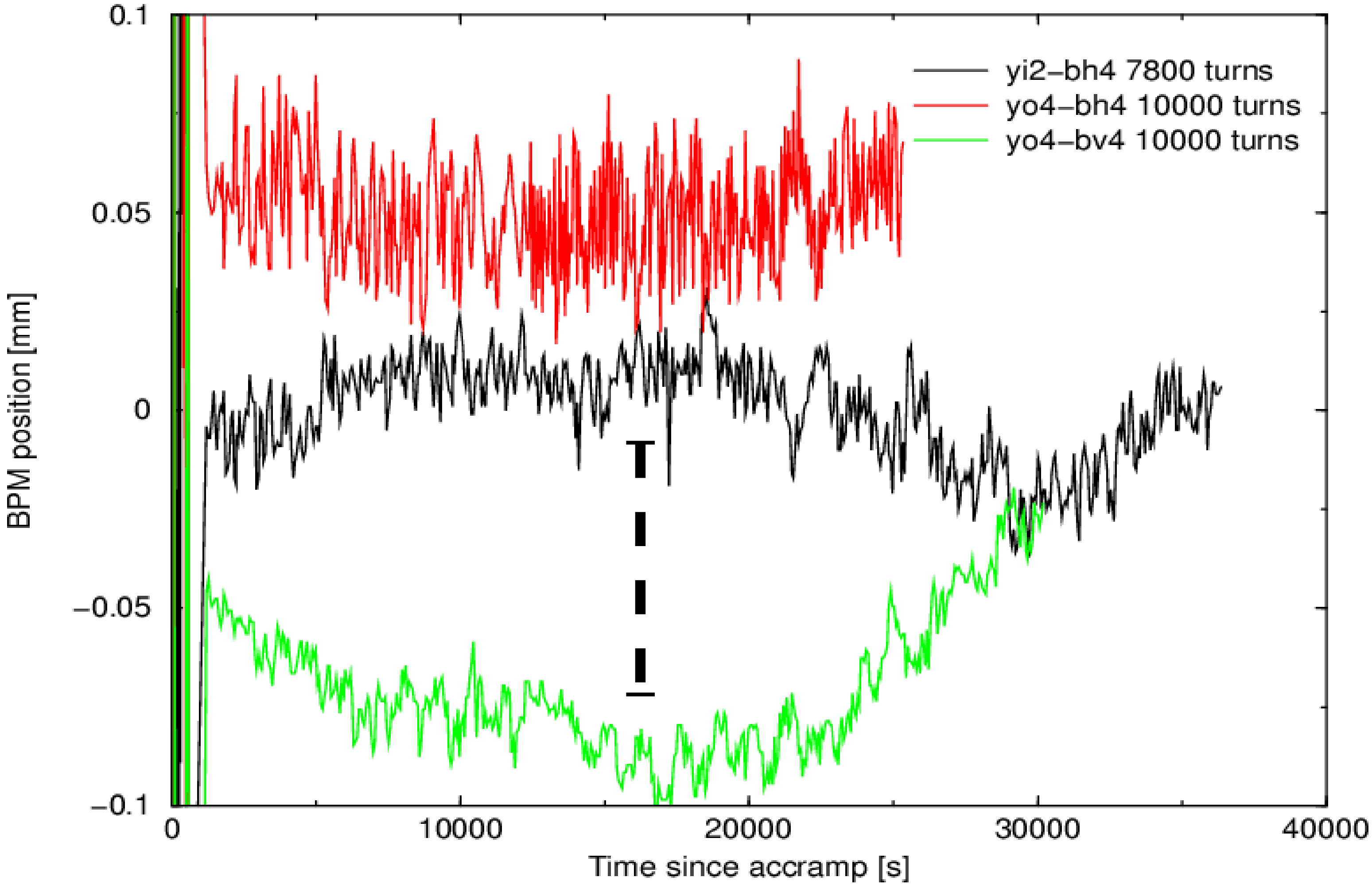






No change in v-BTF after several units of v-chromaticity change

A3: Orbit Noise and 10 Hz, RHIC



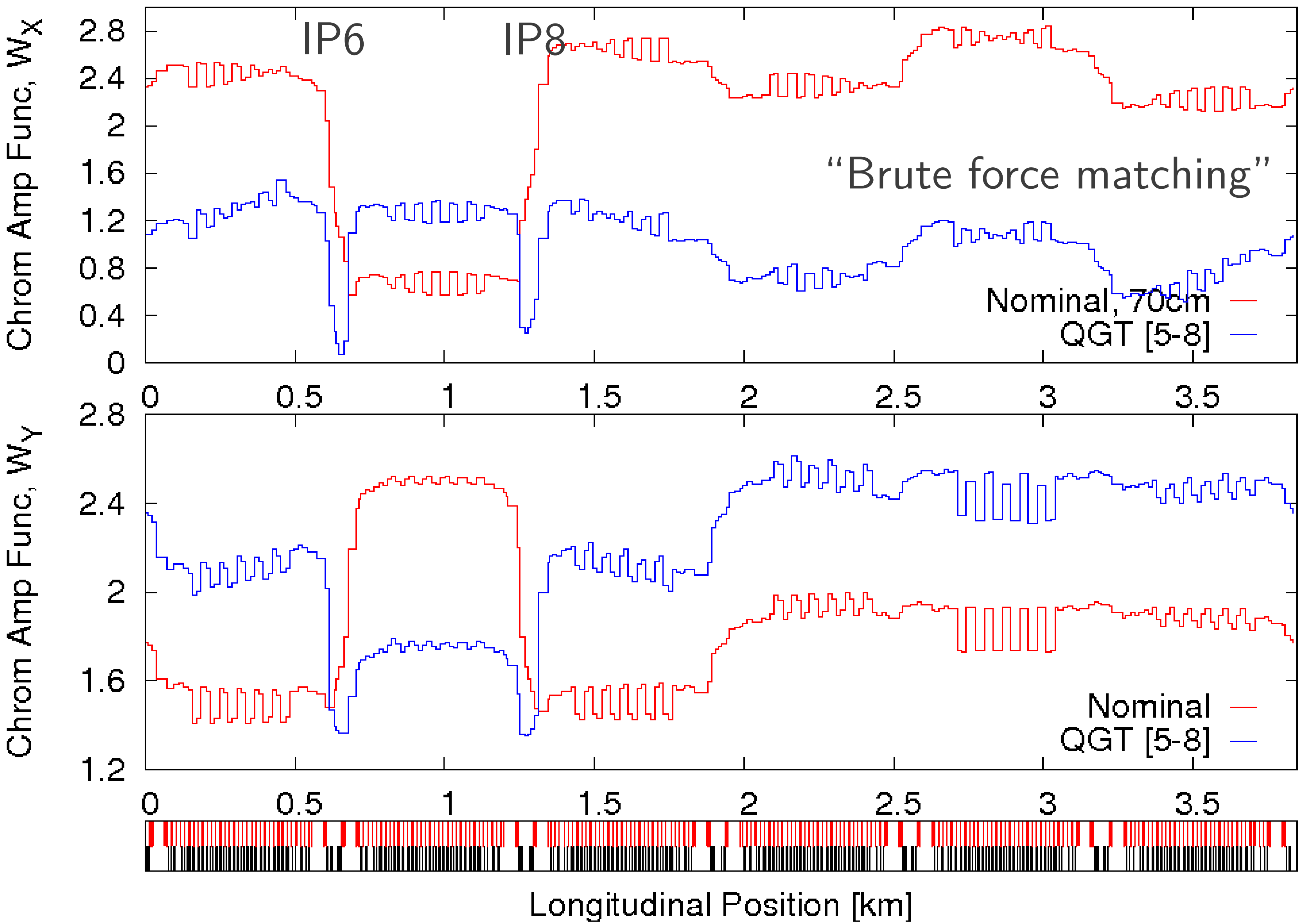
Average orbit noise at 50μm peak to peak (10 Hz)

A4: Chromatic Func, Wx,y

Reduction fairly effective with γT quads

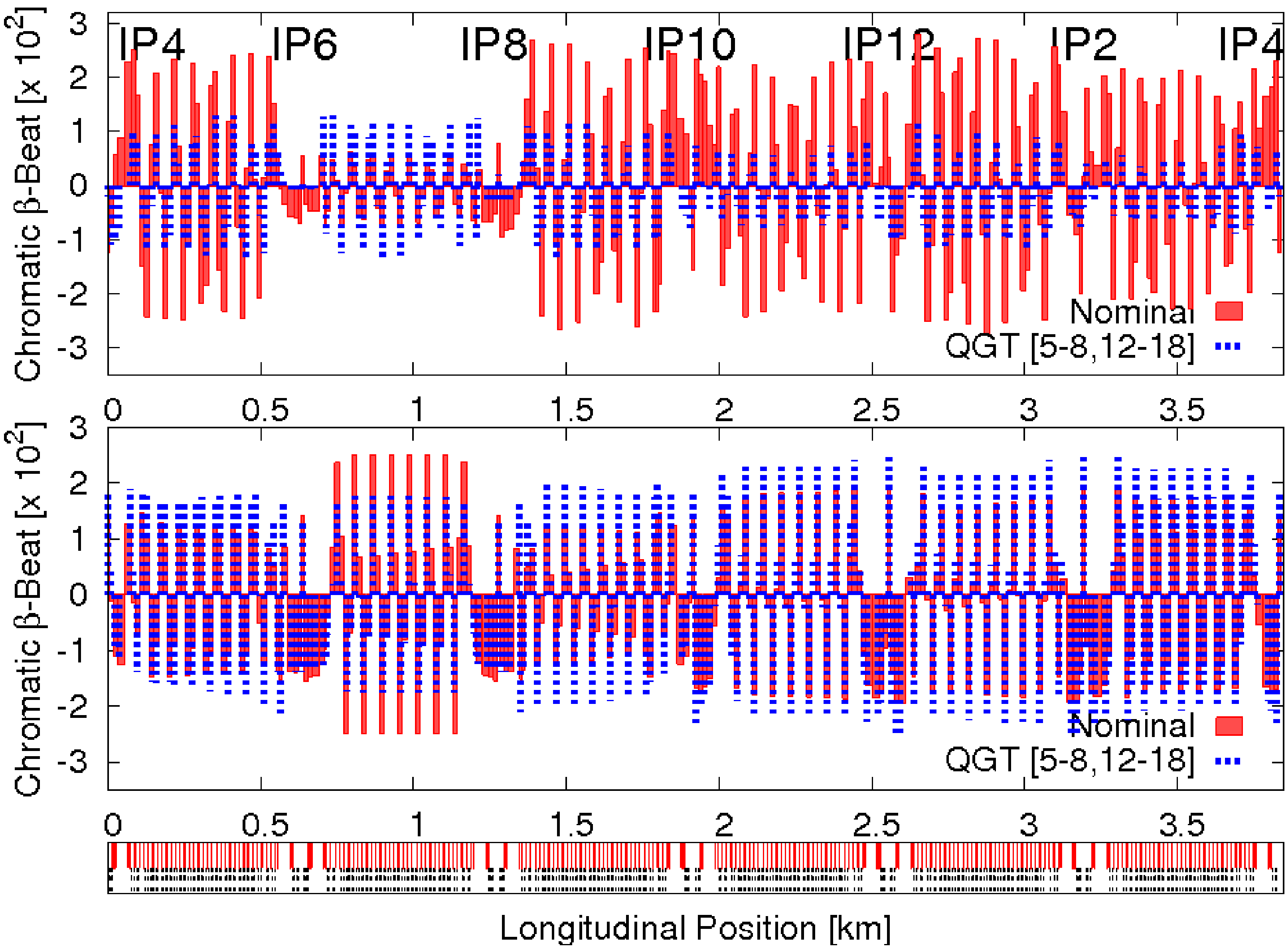
β* 0.71/0.32 → 0.78/0.73

Proton Parameters



A5: Chromatic β-beat

β^* 0.71/0.73 $\rightarrow$ 0.78/0.73



A6: GAMMA-T Quads Settings

β^* 0.71/0.73 → 0.78/0.73

ξ'' 1274 → -471

Protons, 2009

Name	kl_{init}	$kl_{final} \times 10^{-3}$	$kl_{final} \times 10^{-3}$
BO[6-7]_QGT[6-8, 12-18]	7.5×10^{-5}	-7.10	-7.31
BI[8,9]_QGT[5-7, 11-17]		3.16	-0.21
BO[10,11]_QGT[6-8, 12-18]		0.07	18.0
BI[12,1]_QGT[5-7, 11-17]		3.47	-10.3
BO[2,3]_QGT[6-8, 12-18]		1.80	3.82
BI[4,5]_QGT[5-7, 12-18]		3.48	5.81

Maybe not enough strength in GammaT quads (max kL ~2 x 10^{-3} m^{-1})

* Use tune feedback to avoid running into resonances

A7: GAMMA-T Quad Settings

β* 0.71/0.73 → 0.80/0.72

Au 2011

Name	kl_{init}	$kl_{final} \times 10^{-3}$	$kl_{final} \times 10^{-3}$
BO[6-7]_QGT[6-8, 12-18]	9.3×10^{-5}	-1.69	-
BI[8,9]_QGT[5-7, 11-17]		1.90	-
BO[10,11]_QGT[6-8, 12-18]		3.74	-
BI[12,1]_QGT[5-7, 11-17]		2.90	-
BO[2,3]_QGT[6-8, 12-18]		2.41	-
BI[4,5]_QGT[5-7, 12-18]		2.18	-