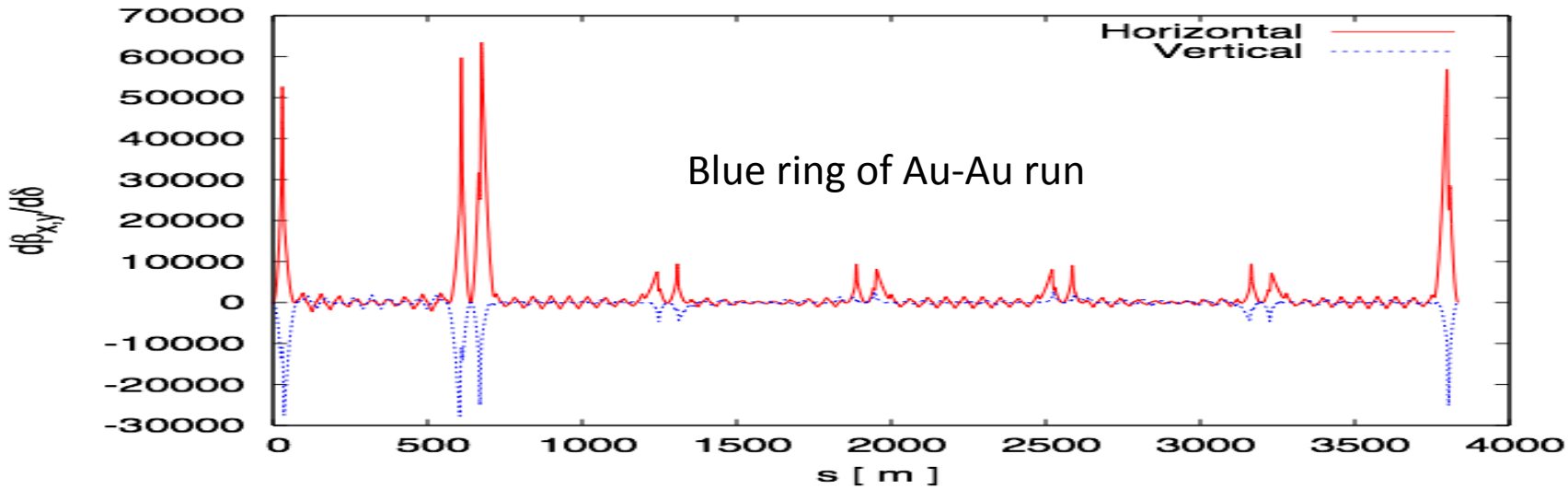
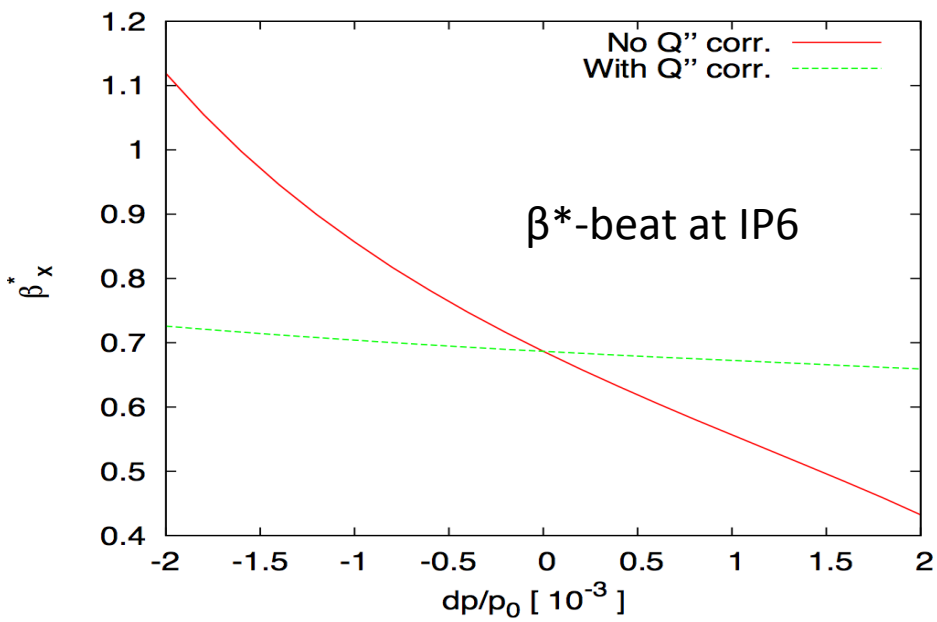
Off-momentum β–beat measurement and correction

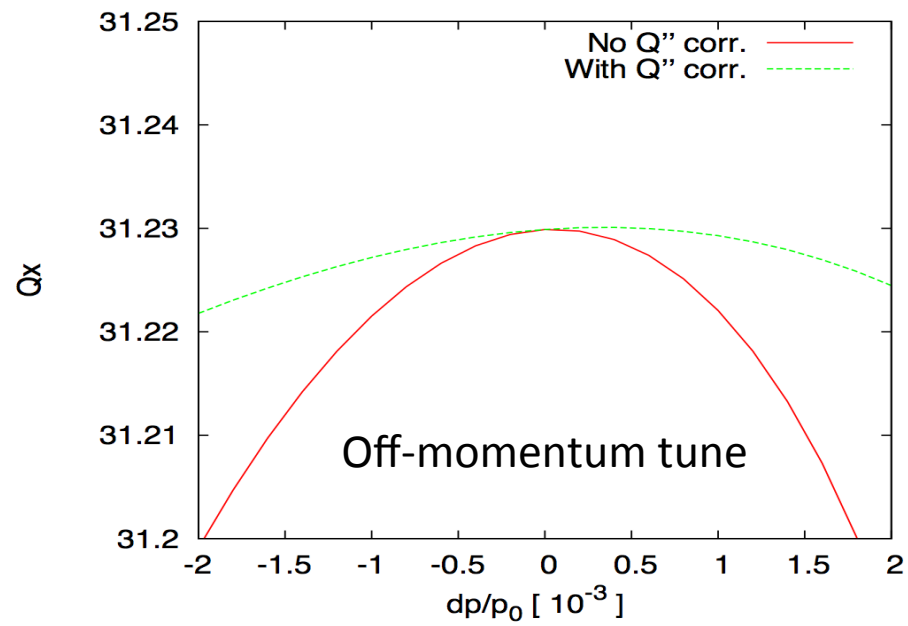
M. Bai, Y. Luo, S. White

(2011 RHIC APEX Workshop, BNL, Dec. 8-9, 2011)

Calculated off-momentum β-beat







Perturbation theory

According to Ref. [2], the second order chromaticities are given by

$$\xi^{(2)}_{x,y} = -\frac{1}{2}\xi^{(1)}_{x,y} + \frac{1}{8\pi}\oint[\mp K_1 \pm K_2 D_x]\frac{\partial\beta_{x,y}}{\partial\delta}ds + \frac{1}{8\pi}\oint \pm K_2\beta_{x,y}D^{(2)}_x ds, \tag{1}$$

where K_1 and K_2 are the strengths of quadrupoles and sextupoles. $\xi^{(1)}_{x,y}$ are the first order chromaticities. $\beta_{x,y}$ and $D^{(2)}_x$ are the betatron amplitude functions and horizontal dispersion. δ is the relative momentum deviation.

The second term in Eq. (1) is the dominant one which is determined by the off-momentum β-beat $\frac{\partial\beta_{x,y}}{\partial\delta}$. The relative off-momentum β-beat is

$$\boxed{\begin{aligned}&\frac{1}{\beta_{x,y}(s)}\frac{\partial\beta_{x,y}(s)}{\partial\delta} = \\ &\pm\frac{1}{2\sin(2\pi Q_{x,y})}\oint\beta_{x,y}(s')[\mp K_1(s') \pm K_2(s')D_x(s')]\cos(2|\phi_{x,y}(s) - \phi_{x,y}(s')| - 2\pi Q_{x,y})ds'.\end{aligned}} \tag{2}$$

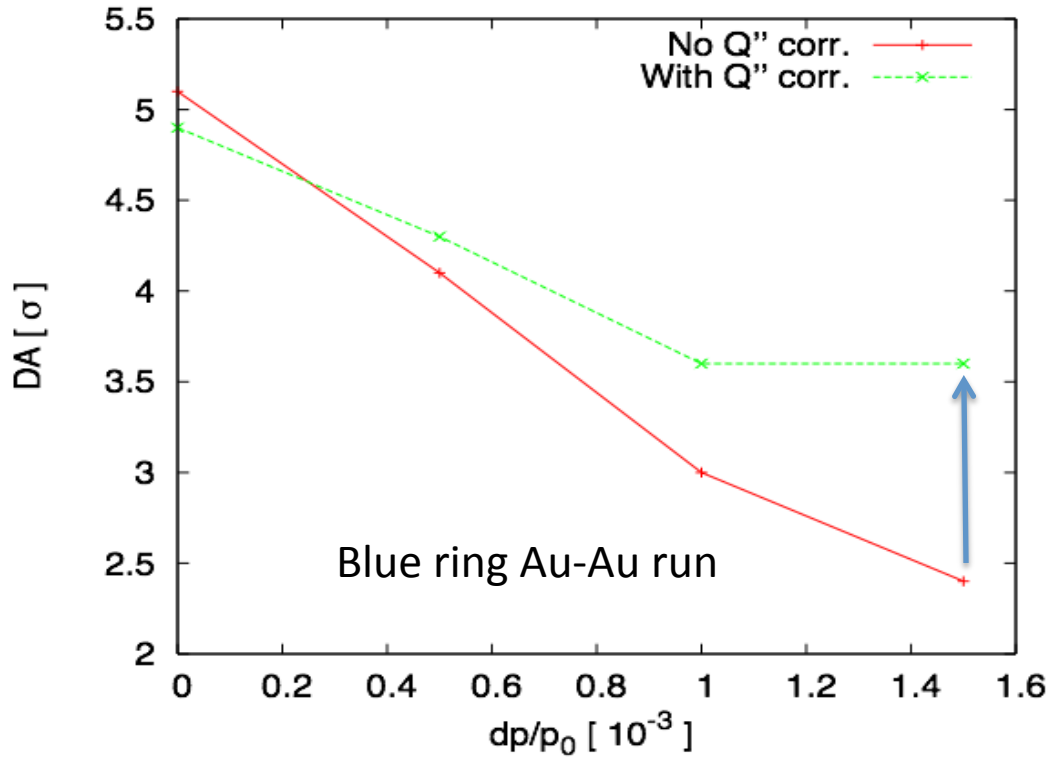
We define half integer resonance driving terms as

$$h_{20001} = \sum_i^N[-(K_1L)_i + (K_2D_xL)_i]\beta_{x,i}e^{-i2\phi_{x,i}}, \tag{3}$$

$$h_{00201} = \sum_i^N[+(K_1L)_i - (K_2D_xL)_i]\beta_{y,i}e^{-i2\phi_{y,i}}. \tag{4}$$

Here h_{20001} and h_{00201} are the horizontal and vertical half integer resonance driving terms. Comparing Eq. (2) to Eqs. (3)and (4), the relative off-momentum β-beat is governed by the half integer resonance driving terms.

Why to correct dβ/dδ



- Correcting off-momentum β-beat **globally** will reduce second order chromaticity and increase off-momentum dynamic aperture.
- Correcting off-momentum β-beat **at interaction points** will improve the beam-beam phase-average effect and increase luminosity(Tevatron).

Measurement of dβ/dδ

- Measurement of off-momentum β-beat is **the key** to correct it.

- To change dp/p_0, we can

  - shifting the RF frequency (RF group)
  - or generate a radial shift with horizontal dipole correctors (Al)
    (1mm radial shift about 0.001 dp/p_0 change)

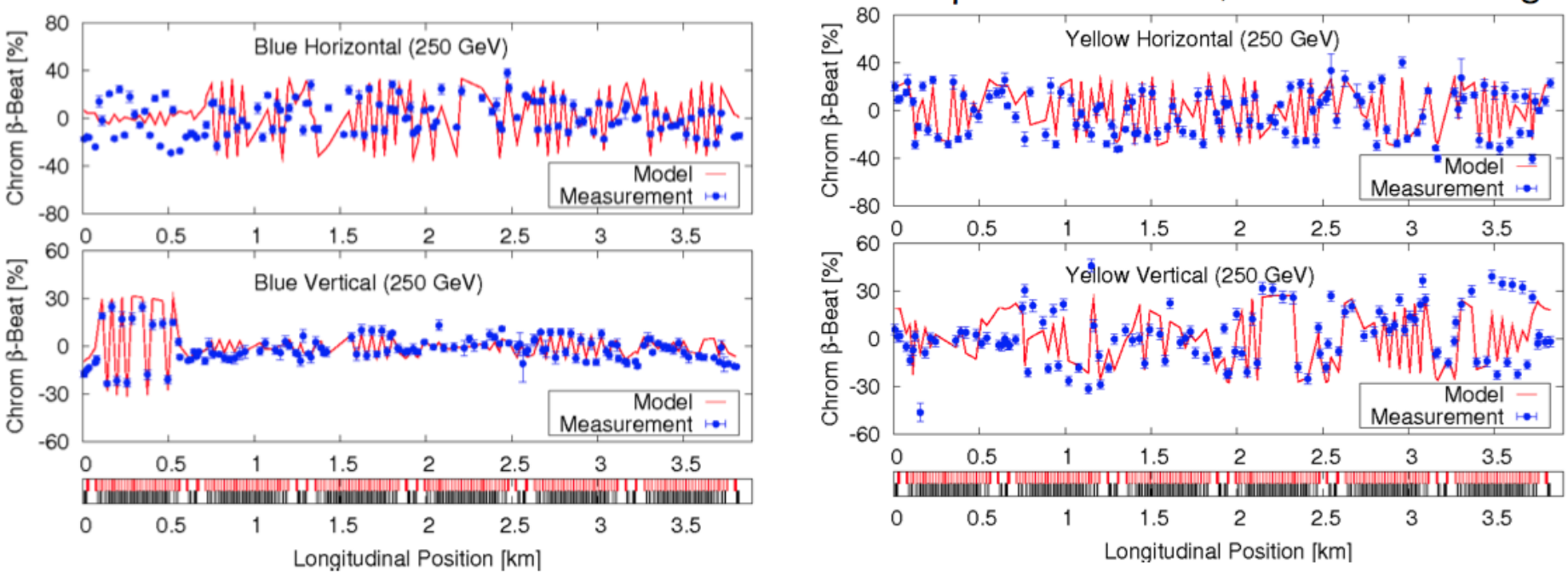
- The methods to measure β functions

  - AC dipole, mostly working with one beam (Mei)
  - tune meter kicking (Simon)
  - (traditional) quadrupole strength change (Yun)
  - ORM (Tasha)

Measured dβ/dδ in 2009 250 GeV p-p run

(Courtesy of Rama & Simon)

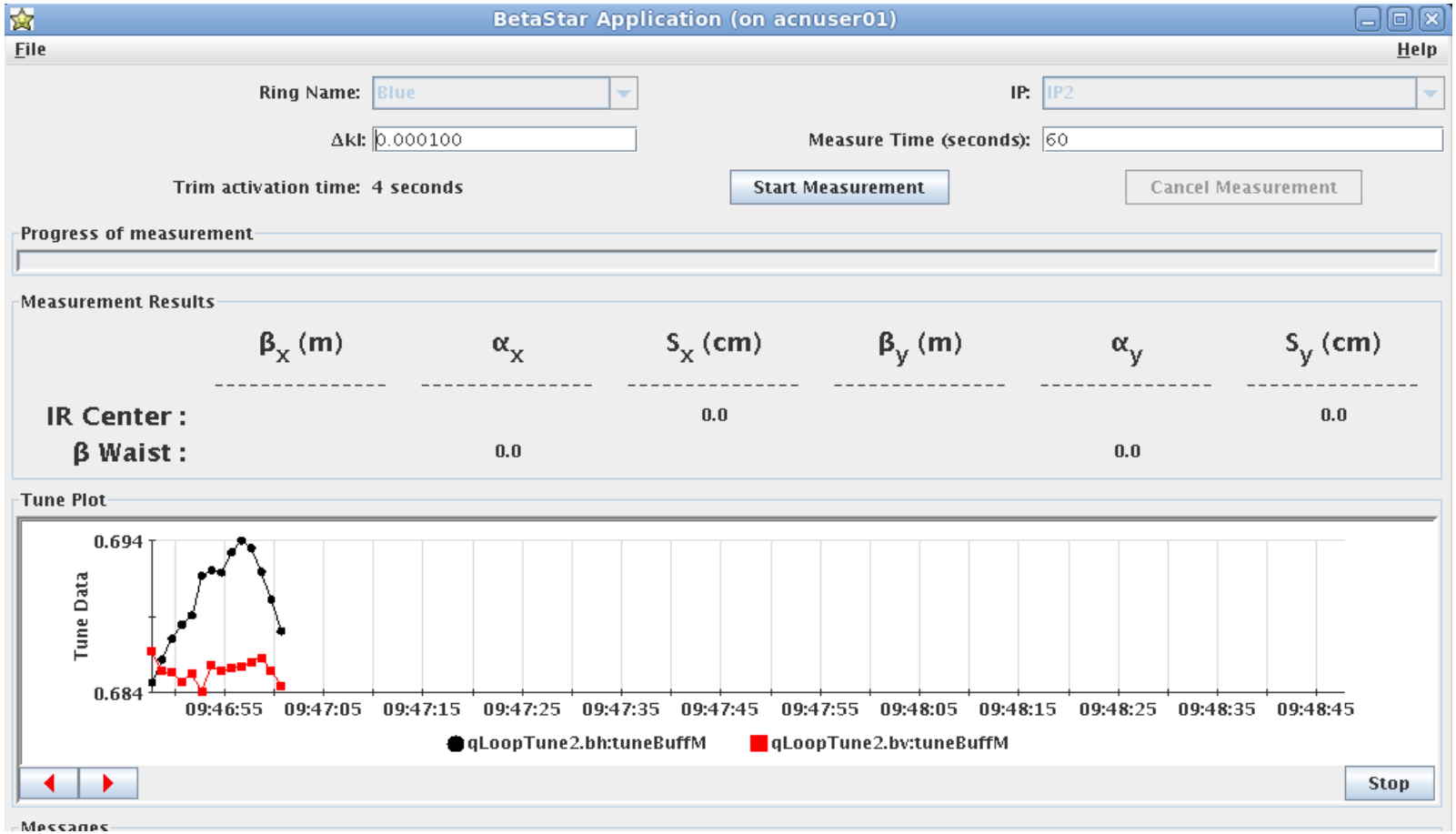
RHIC chromatic β-beat @250 GeV, IPAC10 Proceedings



<u>Observation</u>: Large chromatic β-beat for 0.7m optics (2009 measurements).

<u>FY11 Proposal</u> For reduced β* try phase advance scans between the two IPs to reduce the chromatic beta-beating in model and measure the chromatic β-beat (w/o deteriorating DA). Also, measure single beam lifetime and momentum aperture is compared to the nominal optics.

β* Measurement – BetaStar@Wenge



- ❑ Shifting the strengths of two Q1s in one IR to measure β* and its waist.
- ❑ To be tested in the beginning of next run.
- ❑ This method (K-Modulation)gives best resolution of β* measurement for LHC.

Correction scheme

- Local dβ*/dδ and global dβ/dδ correction
- Model-based and measurement-based correction

- Knobs:
  - adjusting phase advances between IP6 and IP8
  - using arc sextupoles

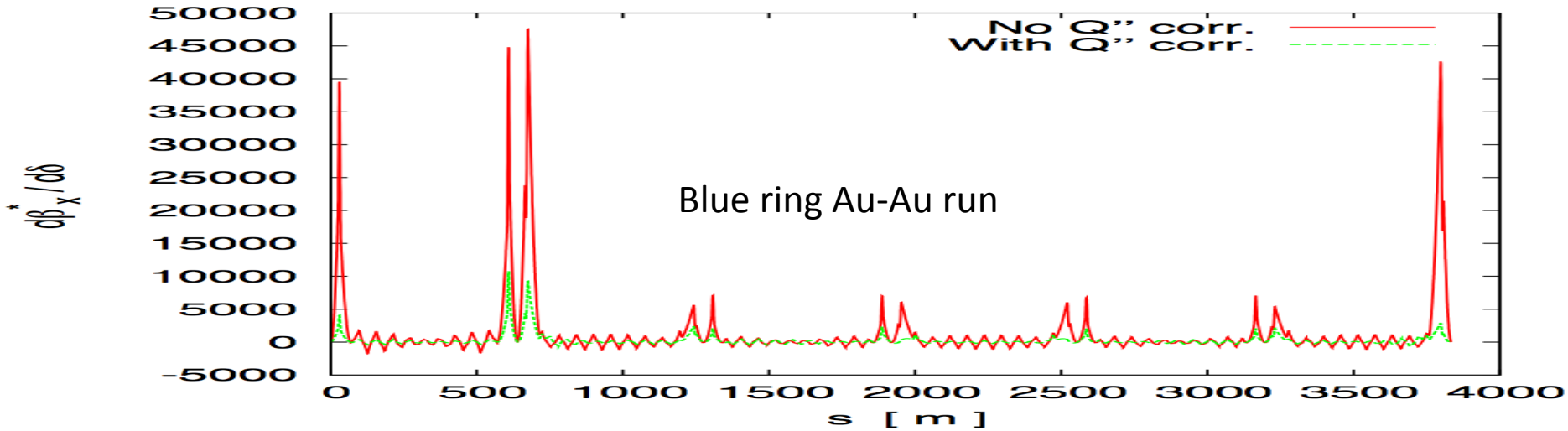
  Note: correction strength shouldn't change linear chromaticity

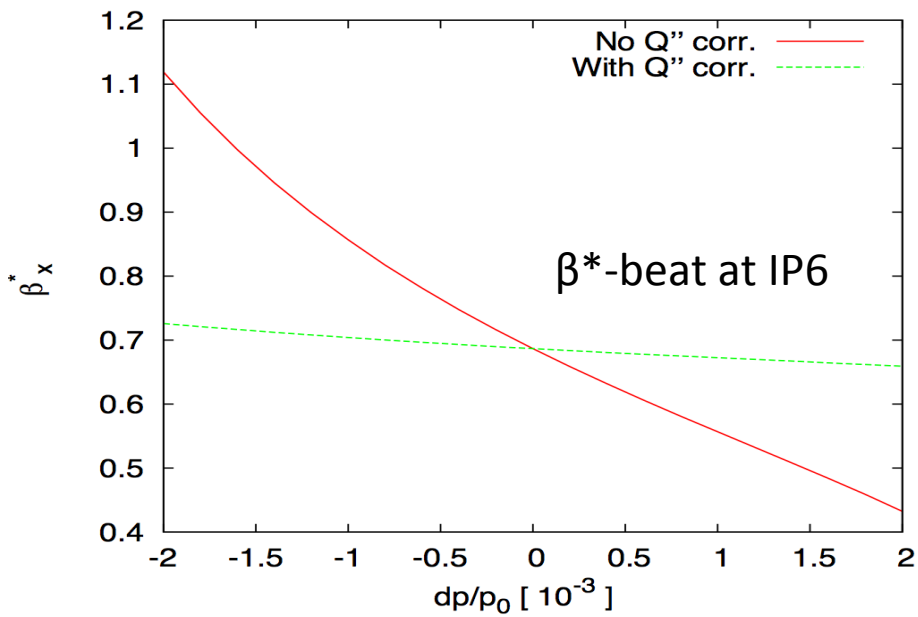
- One Example using arc sextupoles (SVD optimization

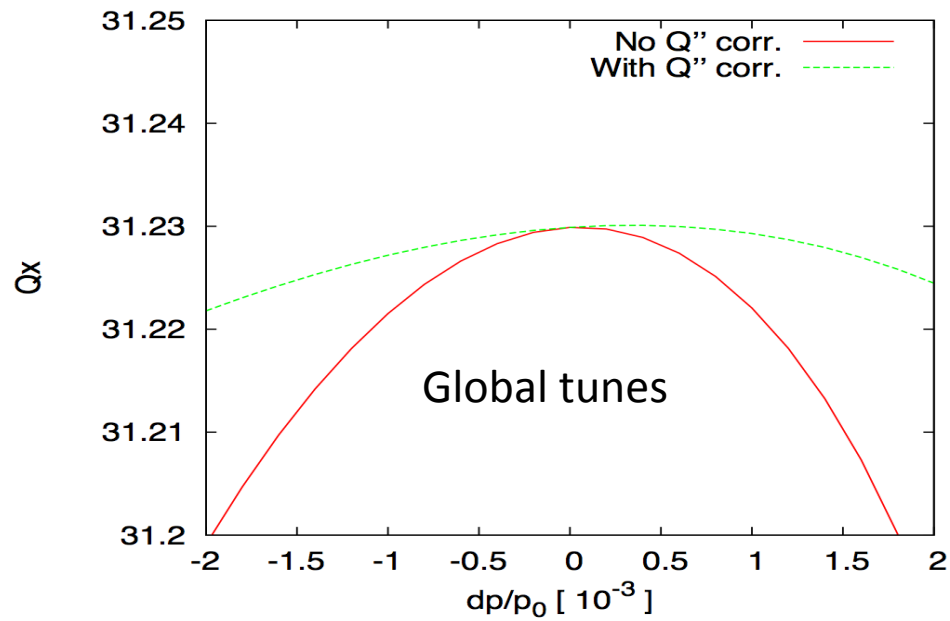
$$\begin{pmatrix} (d\beta/d\delta)_1 \\ (d\beta/d\delta)_2 \\ \dots \\ (d\beta/d\delta)_M \end{pmatrix} = A \begin{pmatrix} (\Delta K_2 L)_1 \\ (\Delta K_2 L)_2 \\ \dots \\ (\Delta K_2 L)_N \end{pmatrix}$$

M: number of dβ/dδ measurement locations
N: number of sextupole families
=>To keep Q' unchanges, link the two SF or SD families in one arc as one knob, then there will be 12 variables.

Simulation correction (SVD & local β*s)







Planning Beam Experiment

- Machine time: 2 sessions * 3 hours / session = 6 hours in the **p-p run**

- Session 1:

  - test β-beat / β*-beat measurement methods
  - measure β-beat / β*-beat
  - apply **model-based** corrections
  - measure β-beat / β*-beat again

- Session 2:

  - if model-based correction not satisfactory manage to correct with **on-line methods**

  - on-line methods: SVD or simple knobs