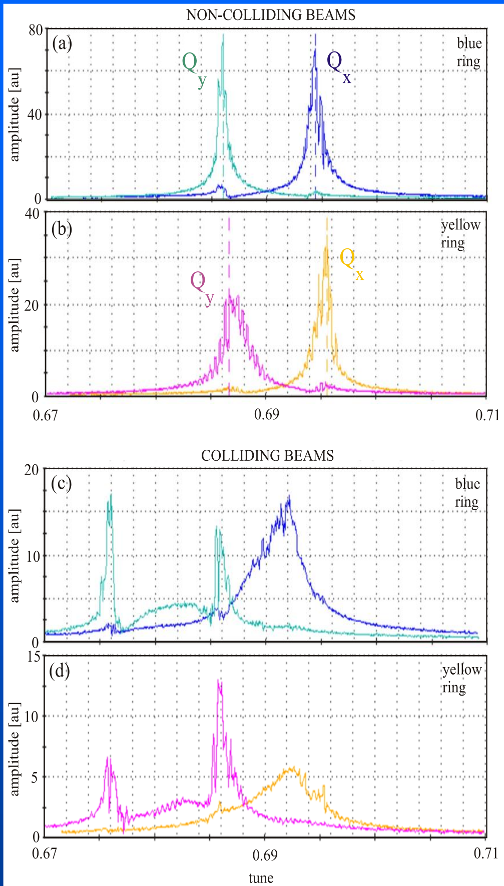
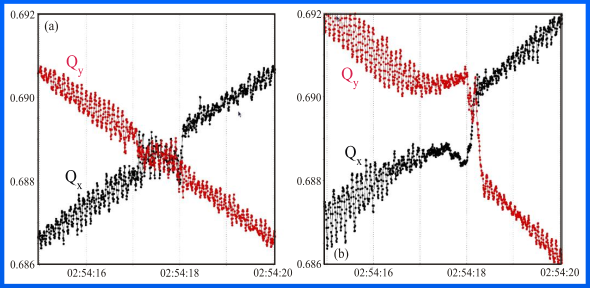
Effect of 10 Hz on RHIC performance at the (run-9) nominal WP



AP Seminar, December 18, 2009
M. Minty



$\Delta x \Leftrightarrow \Delta I$ (backgrounds)

$\Delta x \Leftrightarrow \Delta Q$

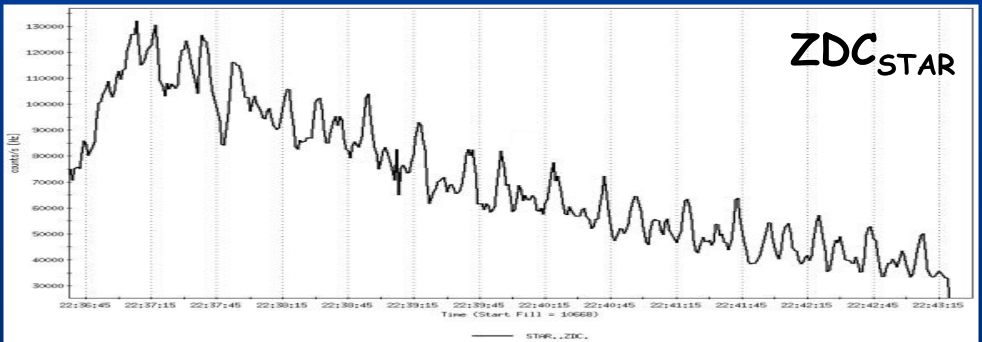
affect on measurement precision
(x/y, Q_x/Q_y, IR params, β^*, ξ , BTFs,…)

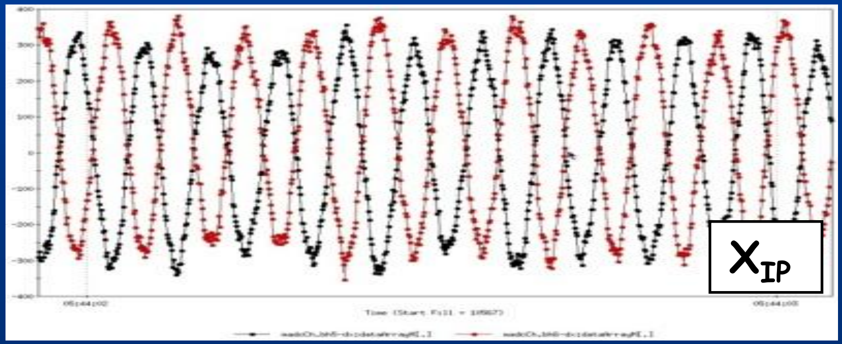
added: results of run-9 APEX studies with driven excitations

$\Delta x \overset{?}{\Leftrightarrow}$ LUMINOSITY

Summary and Outlook

since APEX09 workshop: work in progress on topic of
"modulated crossing angle"

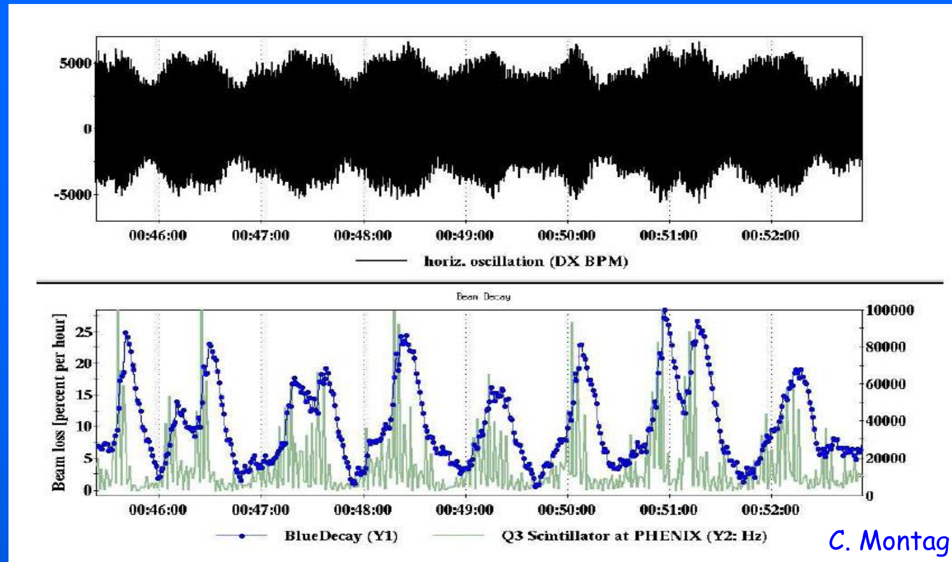




2008 :

$\Delta x \Leftrightarrow \Delta I$

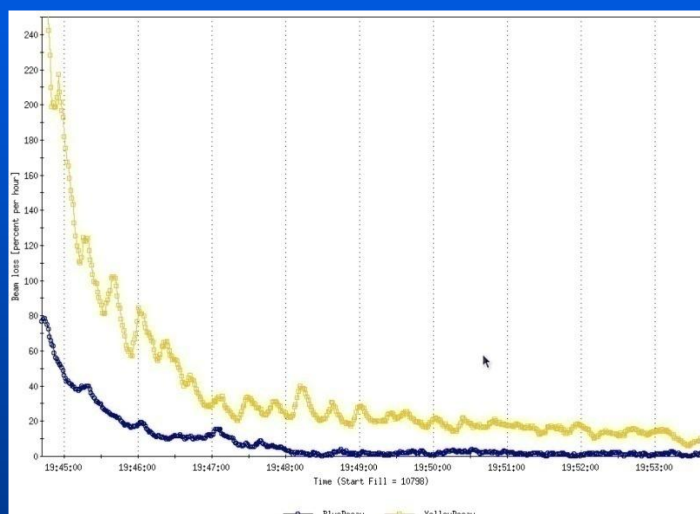
($Q \sim 0.93$)



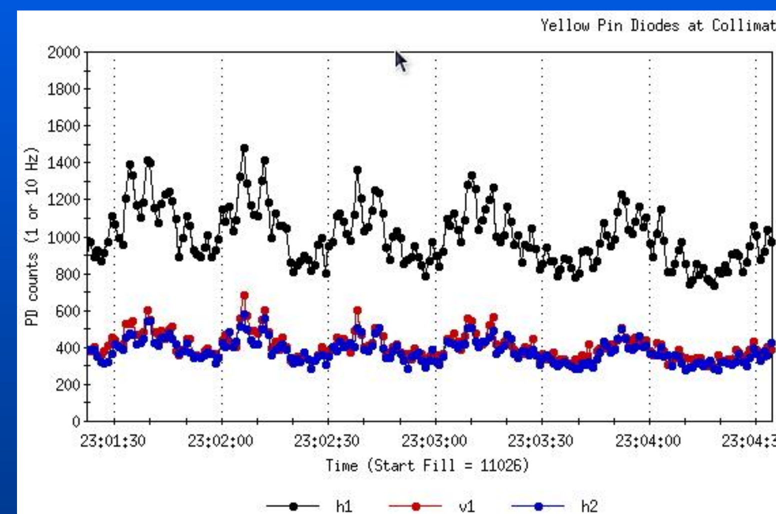
2009 :

$\Delta x \Leftrightarrow \Delta I$

($Q \sim 0.68$)



05/27/09, fill 10798 100 GeV, p+p



07/01/09, fill 110260 100 GeV, PP2PP

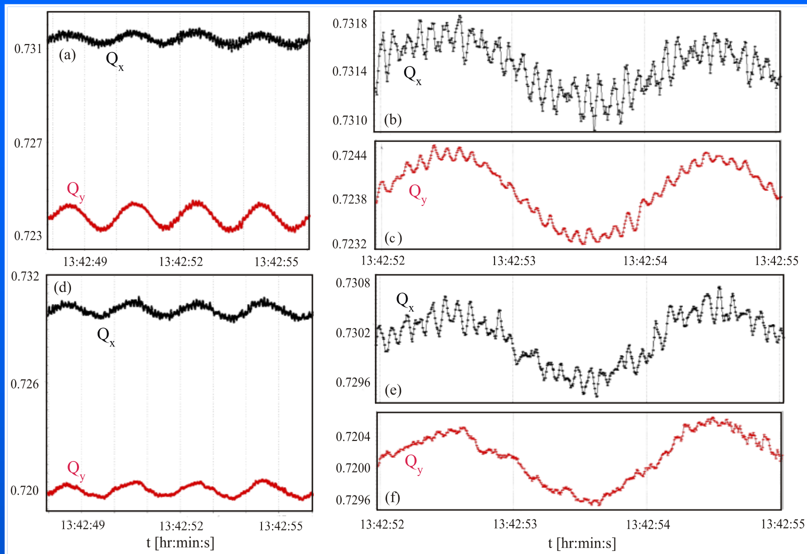
➡ particles driven to large amplitudes at end of store

➡ enhanced sensitivity due to detector geometry

➡ envelop modulation due to beat frequencies

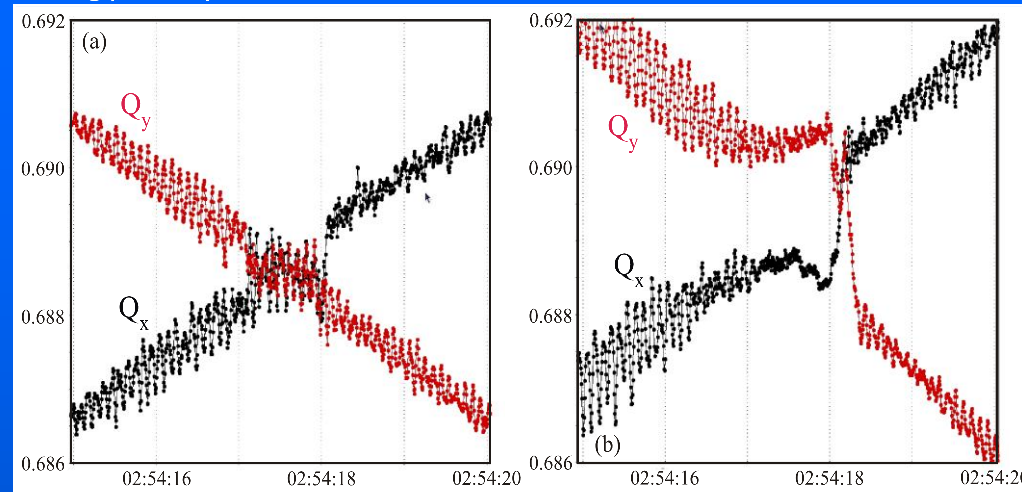
2009 : $\Delta x \Longleftrightarrow \Delta Q$

injection energy:



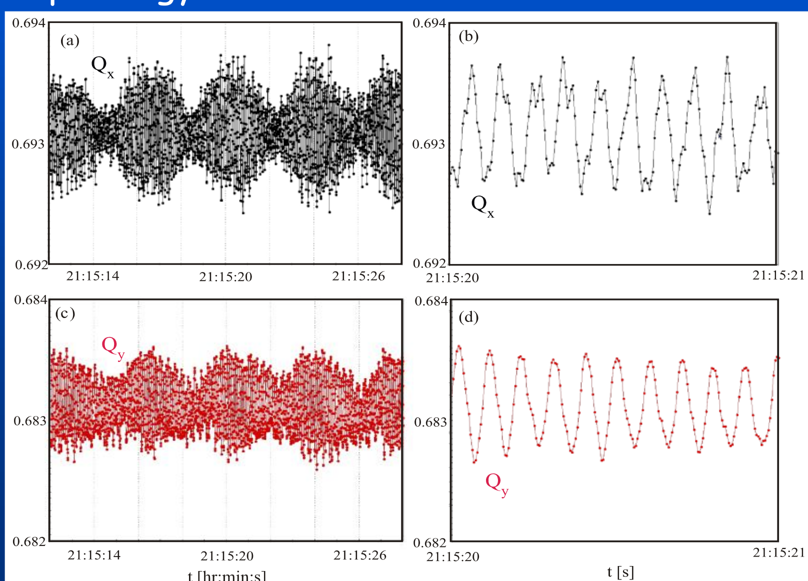
02/20/09, fill 10166 250 GeV, p+p

energy ramp:



03/18/09, fill 10384 250 GeV, p+p

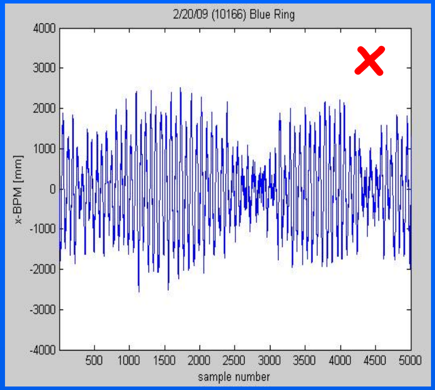
top energy:

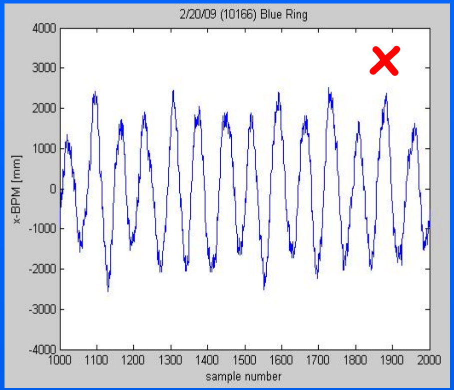


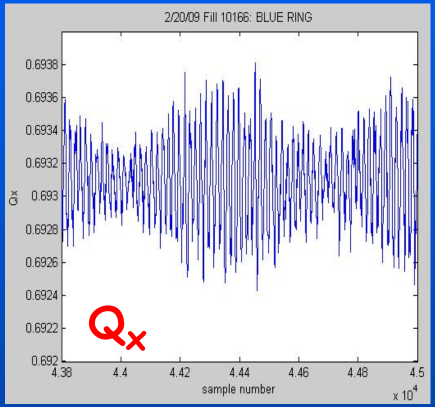
02/20/09, fill 10166 250 GeV, p+p

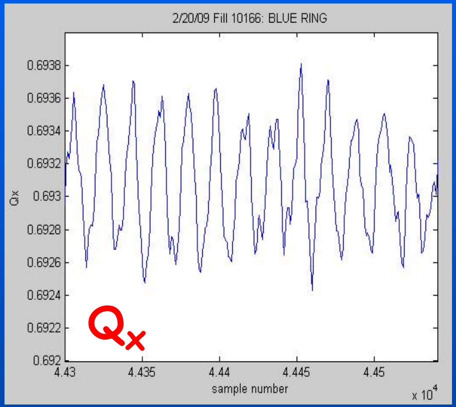
- tune modulations observed at all times:
  - injection energy (top left)
  - energy ramp (top right)
  - during store (bottom left)
- tune modulations observed in both planes
- tune modulations out of phase between x and y

2009 : $\Delta x \Longleftrightarrow \Delta Q$



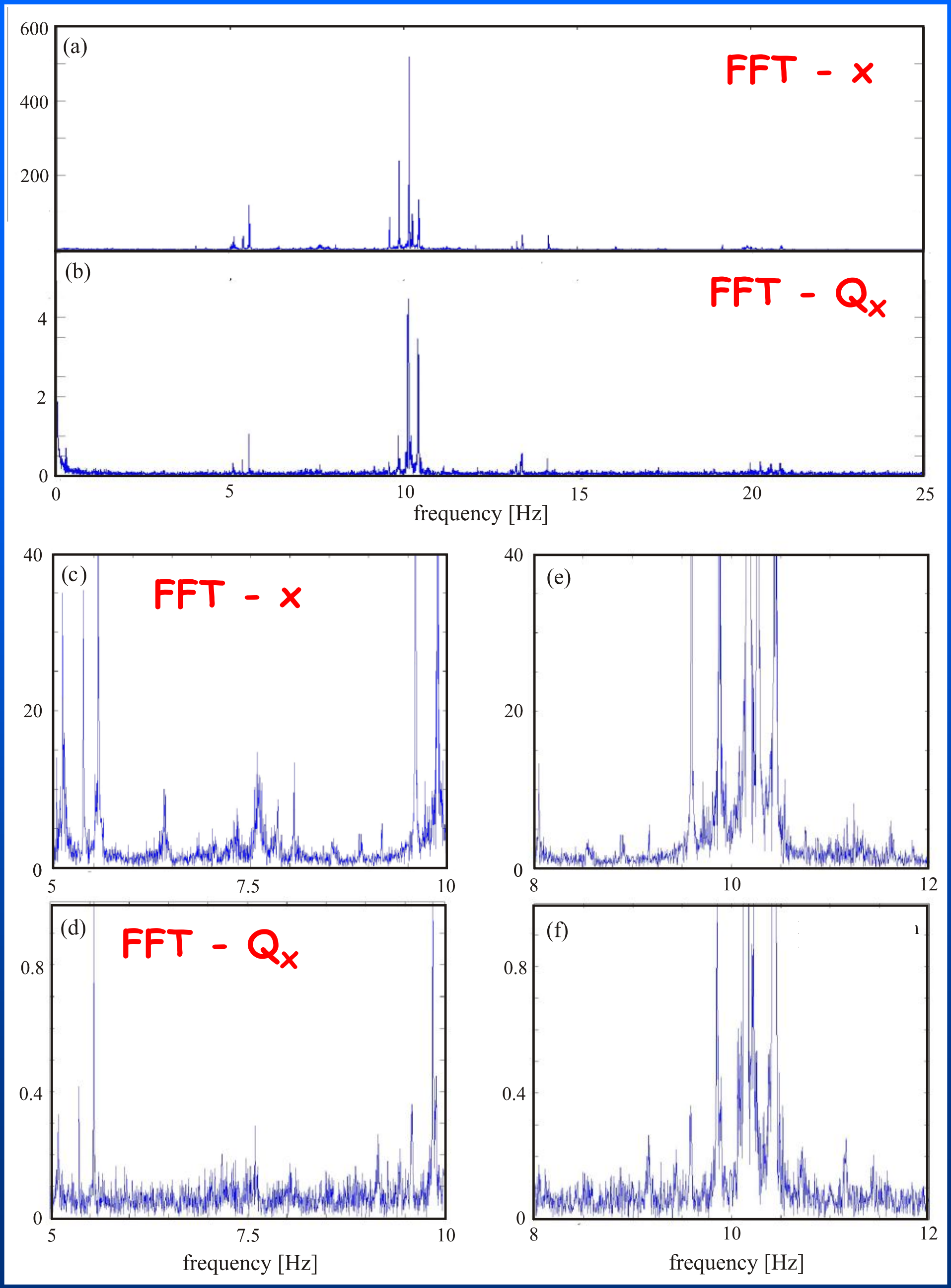






02/20/09, fill 10166

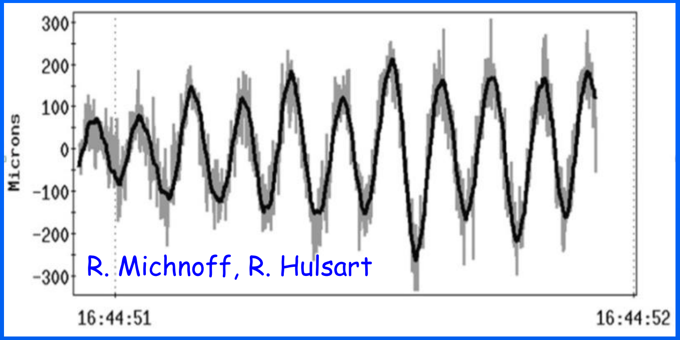
250 GeV, p+p



- tune modulations amplitude large (~ 1E-3)
- same set of discrete frequencies indicates a common source

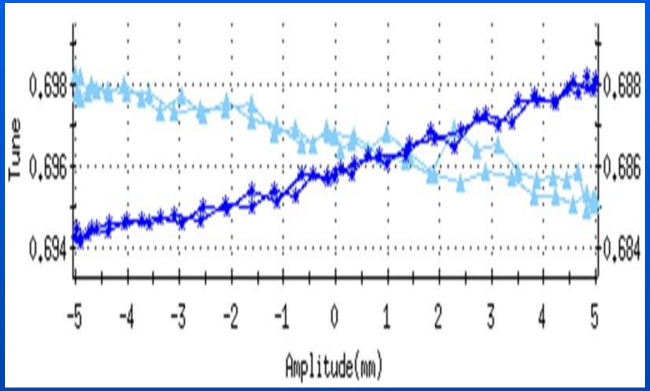
affect on measurement precision (fixed):

beam position

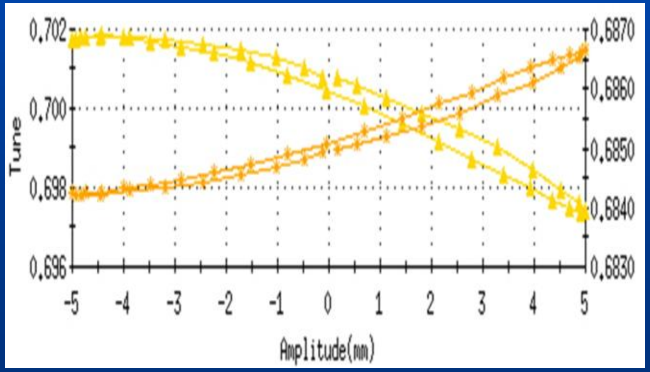


➡ (new and improved)
< x > used as reference for
beam steering

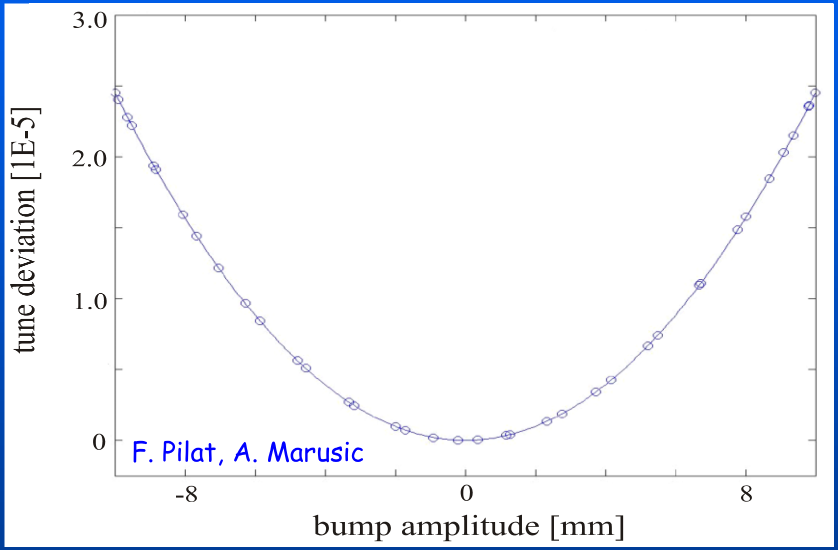
nonlinear IR correction



02/24/09, fill 10219 250 GeV, p+p



03/31/09, fill 10466 250 GeV, p+p



07/06/09, fill 11066 100 GeV, p+p

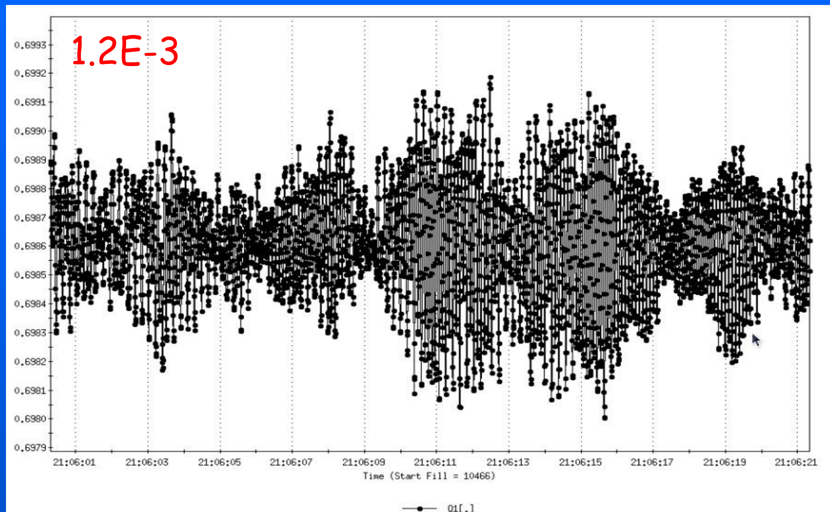
➡ < Q > used for applications requiring high precision measurements

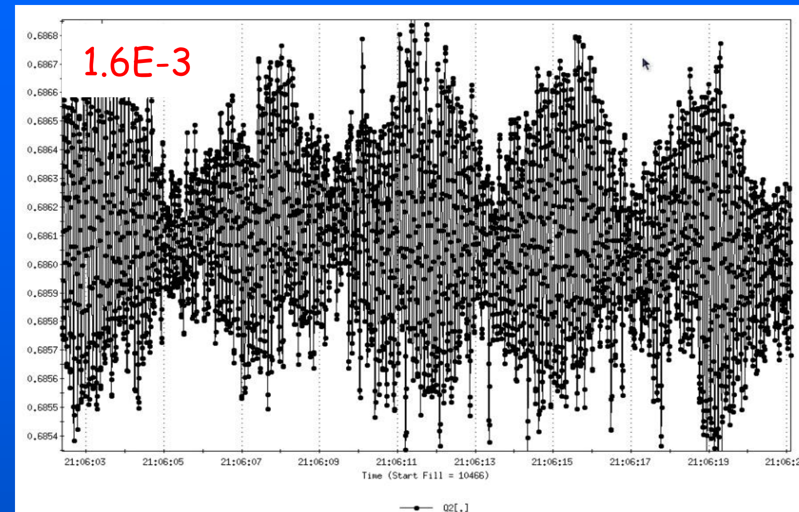
Comparison of tune modulation amplitudes before/after IR nonlinear corrections (all plots with 1.5E-3 full scale), Yellow Ring, 03/31/09

raw horizontal tune data

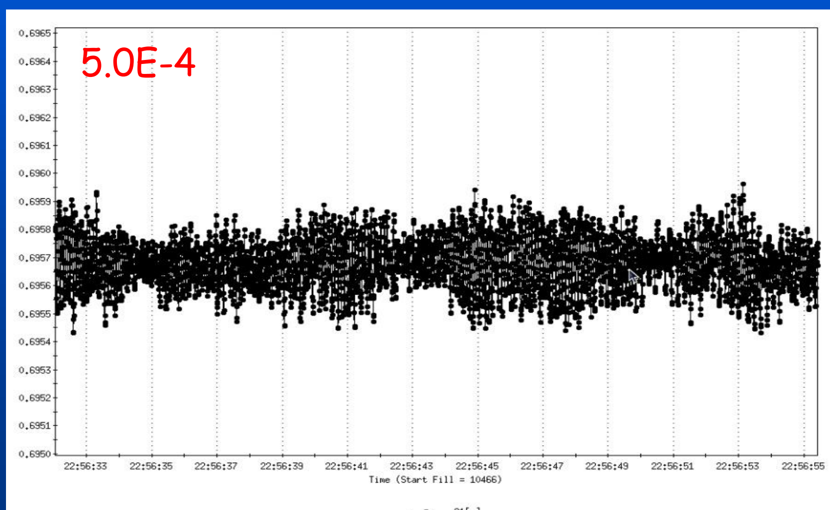
raw vertical tune data

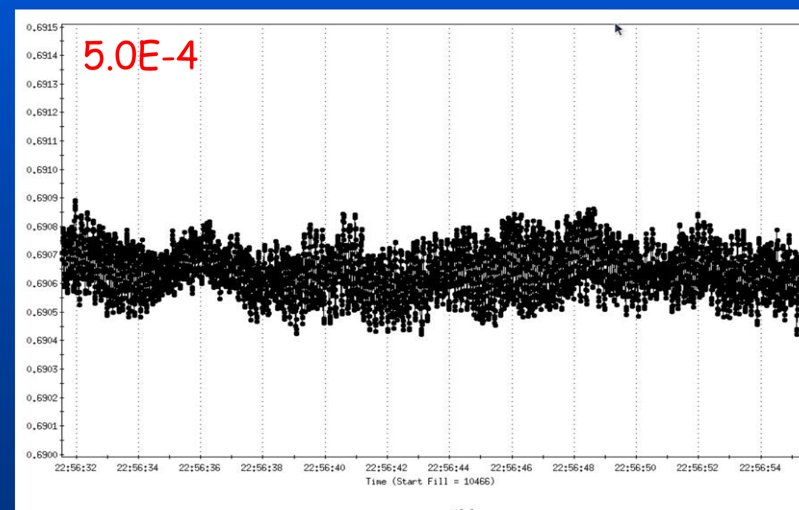
before correction





after correction

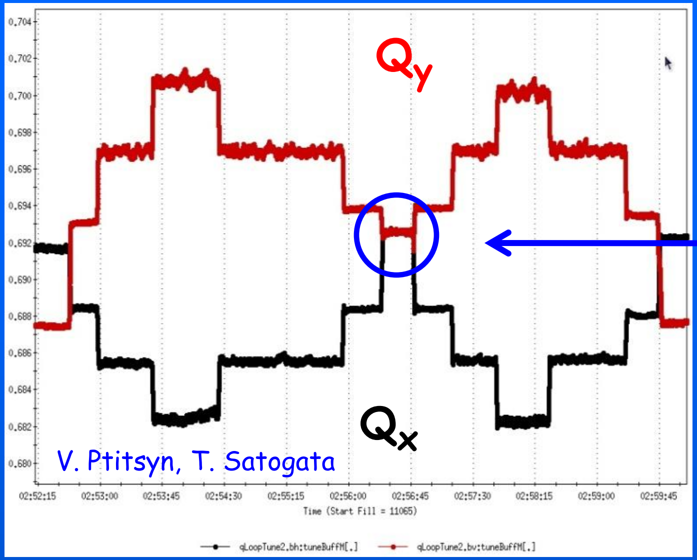


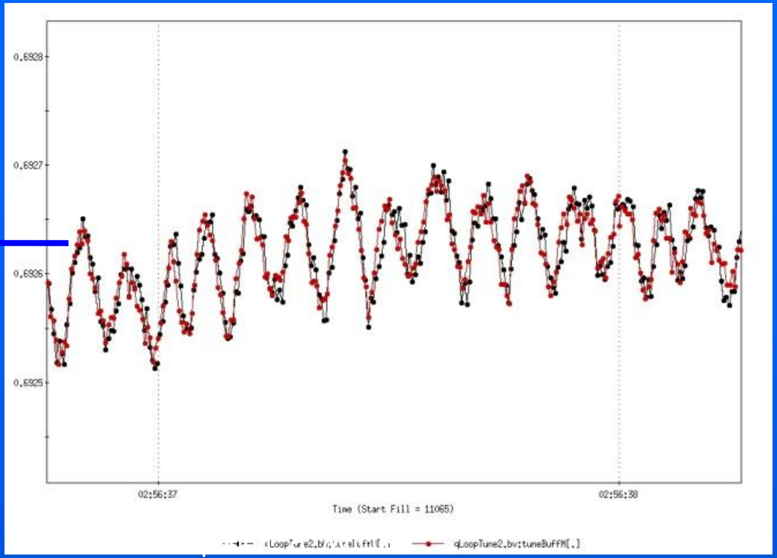


⇨ Tune modulation amplitudes reduced by factor 2-3 in both planes (peak-to-peak modulation amplitudes shown in red color in above plots)

affect on measurement precision (outstanding):

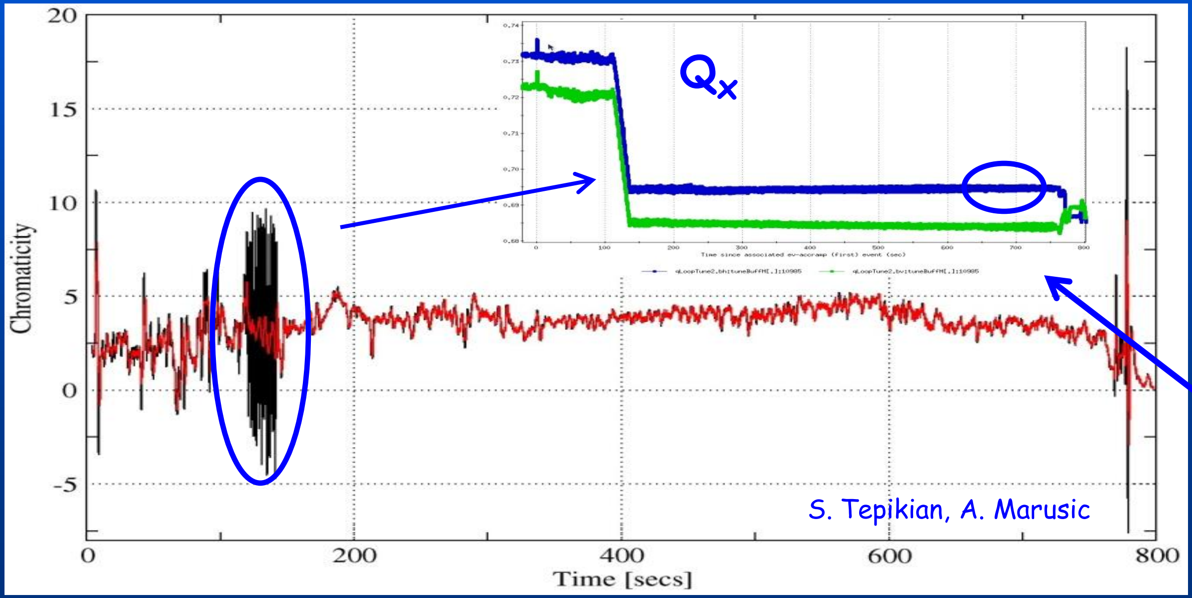
β^*

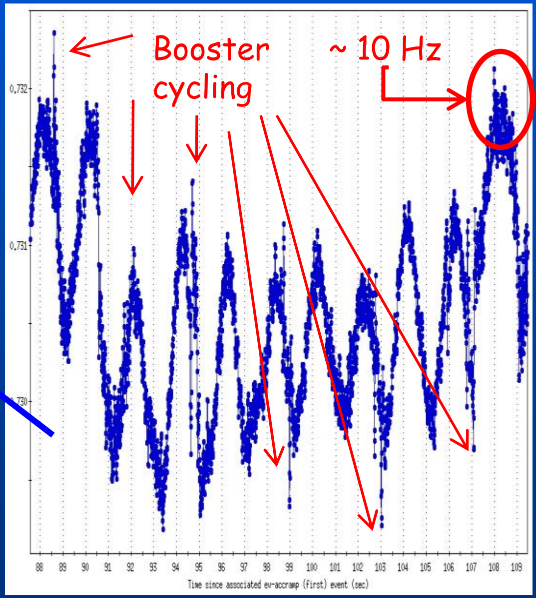




07/06/09, fill 11065 100 GeV, p+p

ξ



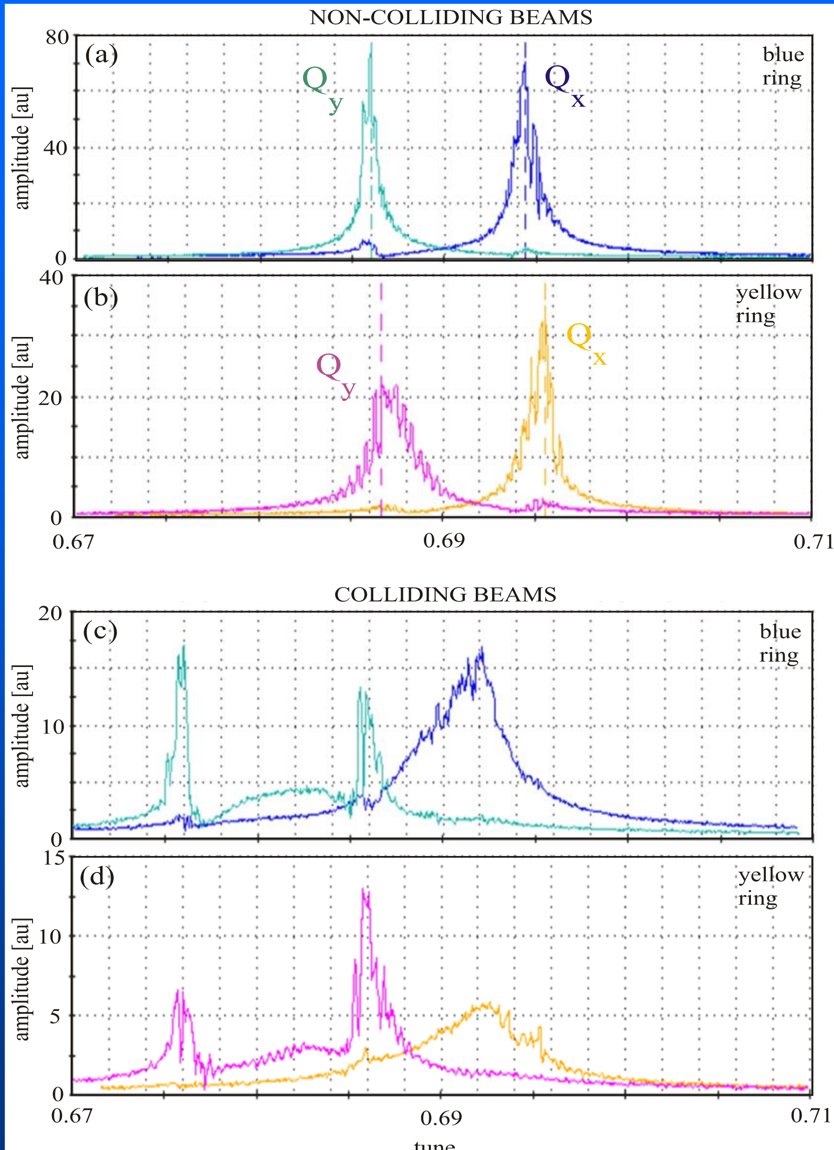


06/24/09, fill 10985 100 GeV, p+p

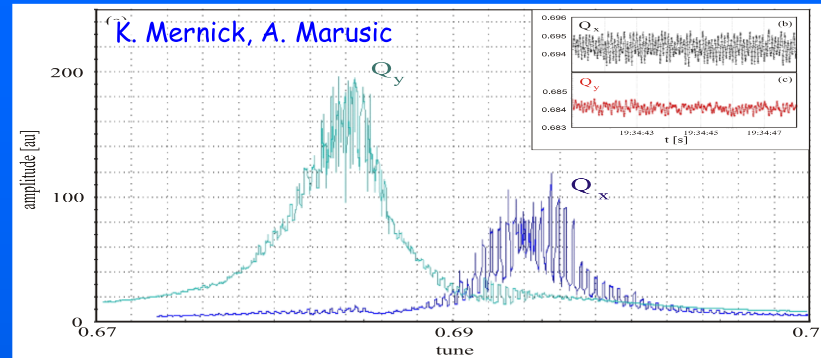
→ change in tune appears as "noise"

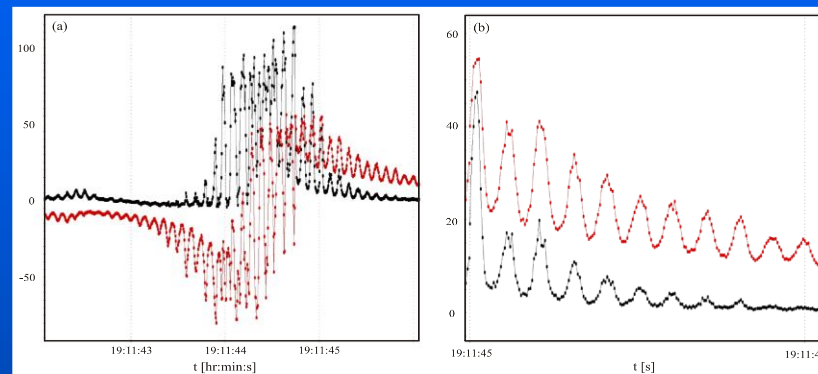
→ all structures identified

affect on measurement precision (outstanding): beam transfer function (BTF)

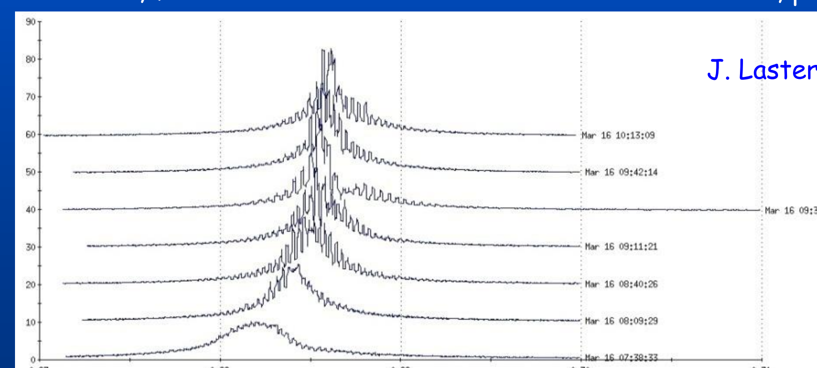


02/26/09, fill 10240 250 GeV, p+p





06/14/09, fill 10928 100 GeV, p+p



03/16/09, fill 10375 250 GeV, p+p

→ tune modulations not yet filtered (until confidence is gained to ensure no other systematic errors)

(aside: excerpt from C-A/AP/366)

In addition to the 50+ hardware changes made for run-9:

The old code delivered the last sample out of 16 to the magnet control loop while the new code delivers the average of 16 samples, resulting in a significant improvement of data quality (as shown in this document previously).

Other improvements in the data processing were also made:

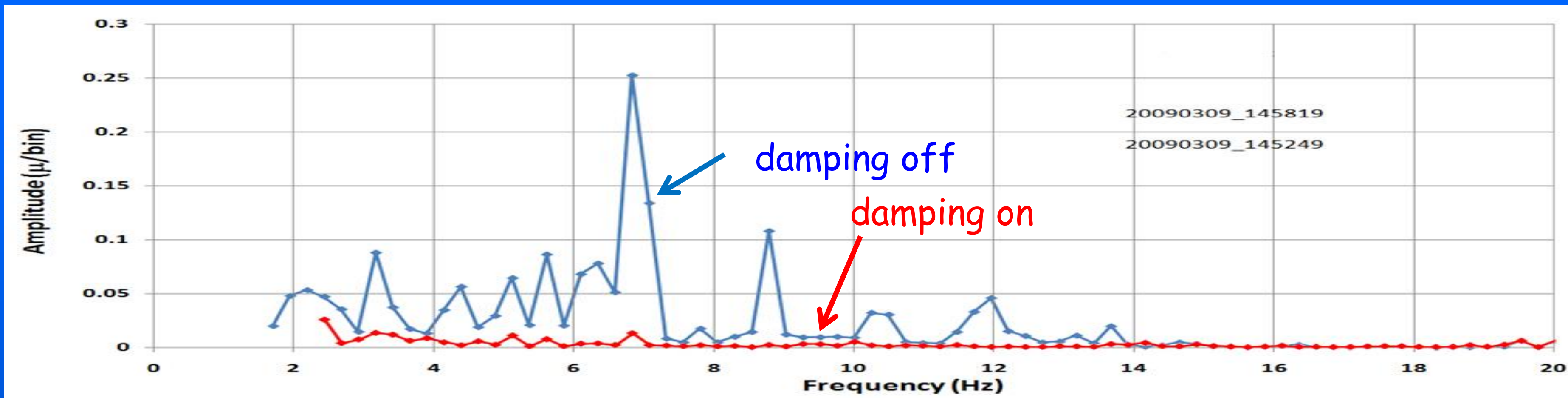
1. New diagnostic parameters were added to the code and the parameter which shows the number of interrupts processed per second (which should be proportional to the tune) revealed that not all the scans were being processed. This was diagnosed as competition for CPU-time from another process running on the same computer. This process, which was subsequently removed, was previously found to corrupt BTF data. This effect led to random corruption of up to every other tune measurement used with the old, rate-limited, code.
2. The code was also modified to be more deterministic in processing of the data in order to eliminate the possibility of being late to process new data (if the code is not waiting to process new data when the new data are available, the new data will not be processed; e.g. there is no "catch up").
3. For applications requiring just one measurement of the tune per second, instead of providing the last measured point acquired during one second as in the past, the average of all points acquired during that second is delivered, thus further improving data quality (mostly due to averaging out the 10 Hz modulations present on the beam).
4. During previous runs filters labeled 40 Hz and 20 Hz were used. Unfortunately their characteristics were not documented so simulations were performed to determine their response. With an input signal frequency of 25 kHz, the full width at half maximum (FWHM) of the passbands of the I/Q demodulator output with no filter, a 40 Hz filter, and a 20 Hz filter were found to be respectively 2310 Hz, 820 Hz and 420 Hz. During the run, only "20 Hz" filter, although very wide, was used. This filter was specified as a sequence of 11 numbers (i.e. taps), and therefore its characteristics changed in proportion to the scan frequency. That turned out to be very beneficial for near-integer operation, because at lower frequencies the passband of this filter became narrower, for example at 5 kHz the FWHM of the passband is 85 Hz, resulting in substantial reduction of all 60 Hz harmonics present in the beam signal.

These improvements also greatly benefited the resolution of the beam transfer function (particularly averaging using all delivered tune values). In addition:

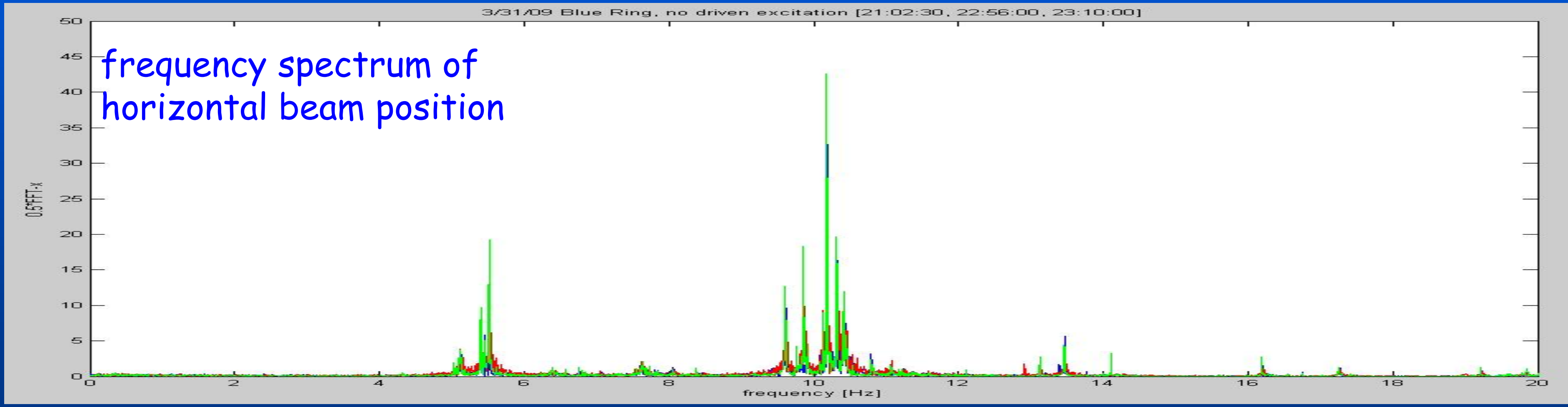
1. Frequency changes during the BTF measurement proper were synchronized with the data delivery leading to precise association of data with the frequency those data were taken at.
2. A programming error was found for which digital filter parameters used for one application were overwriting those of another application (causing spikiness in the BTF measurements).
3. Precision phase optimization and frequency-dependent phase correction were implemented.

resulting in tune measurement precision ~ 1E-7 (fractional tune units) as determined by the PLL

03/09/09, APEX (Minty, Montag, Thieberger): dynamic damping tests with mechanical position detectors (geophones and accelerometers) and triplet actuators



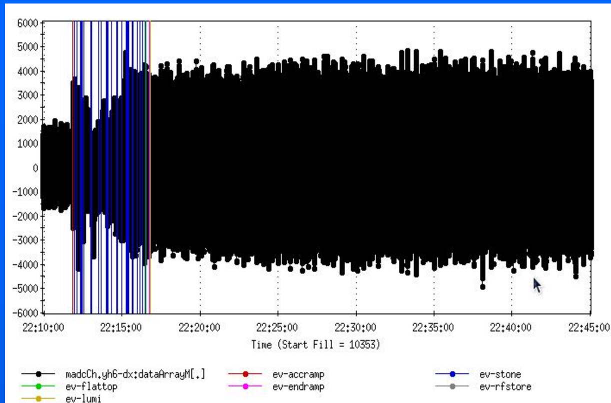
P. Thieberger, RHIC Weekly Meeting (~04/09)

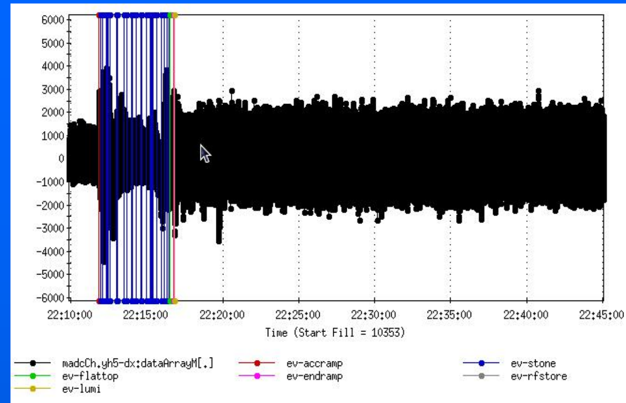


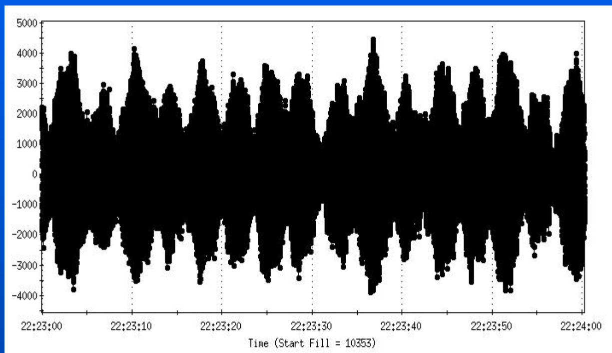
local dynamic damping works beautifully

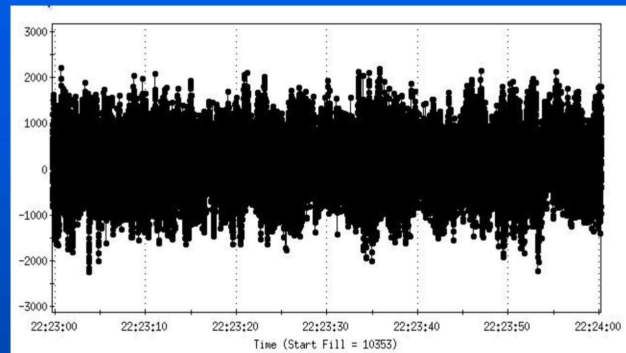
no discernable effect on frequency spectrum (not shown) however perhaps not surprising as only one of 12 triplets was equipped with dynamic damping

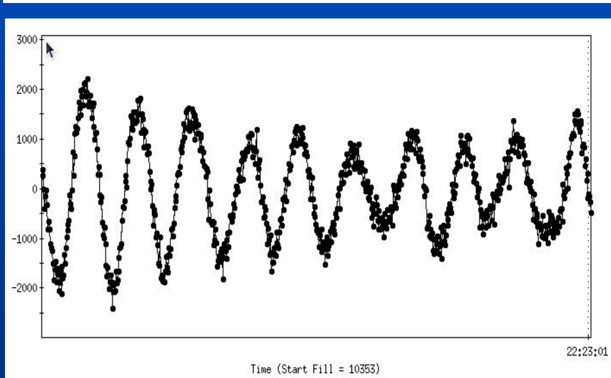
03/12/09 (Aside: check for 10 Hz with vertical BPM sampled at 720 Hz)

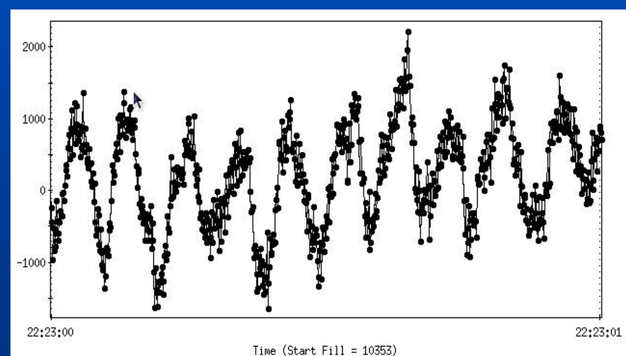




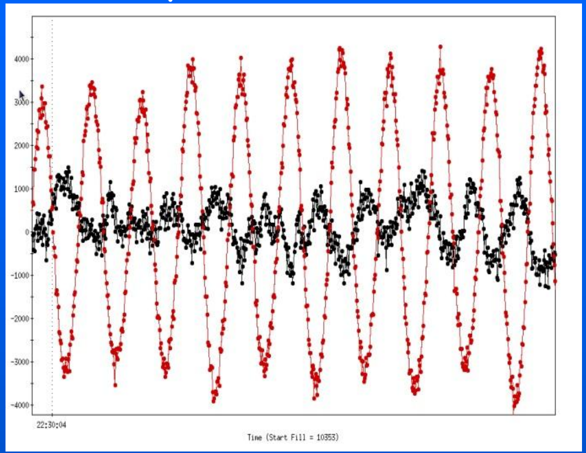


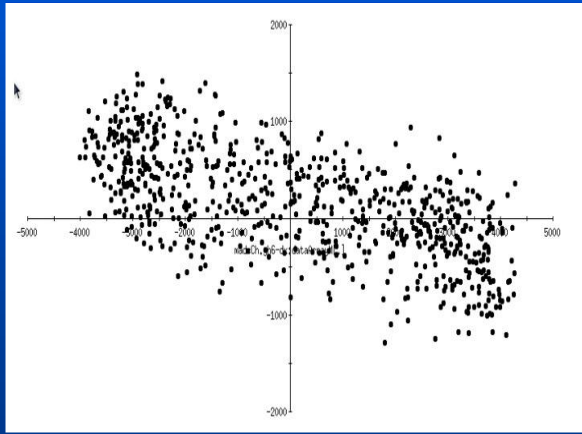




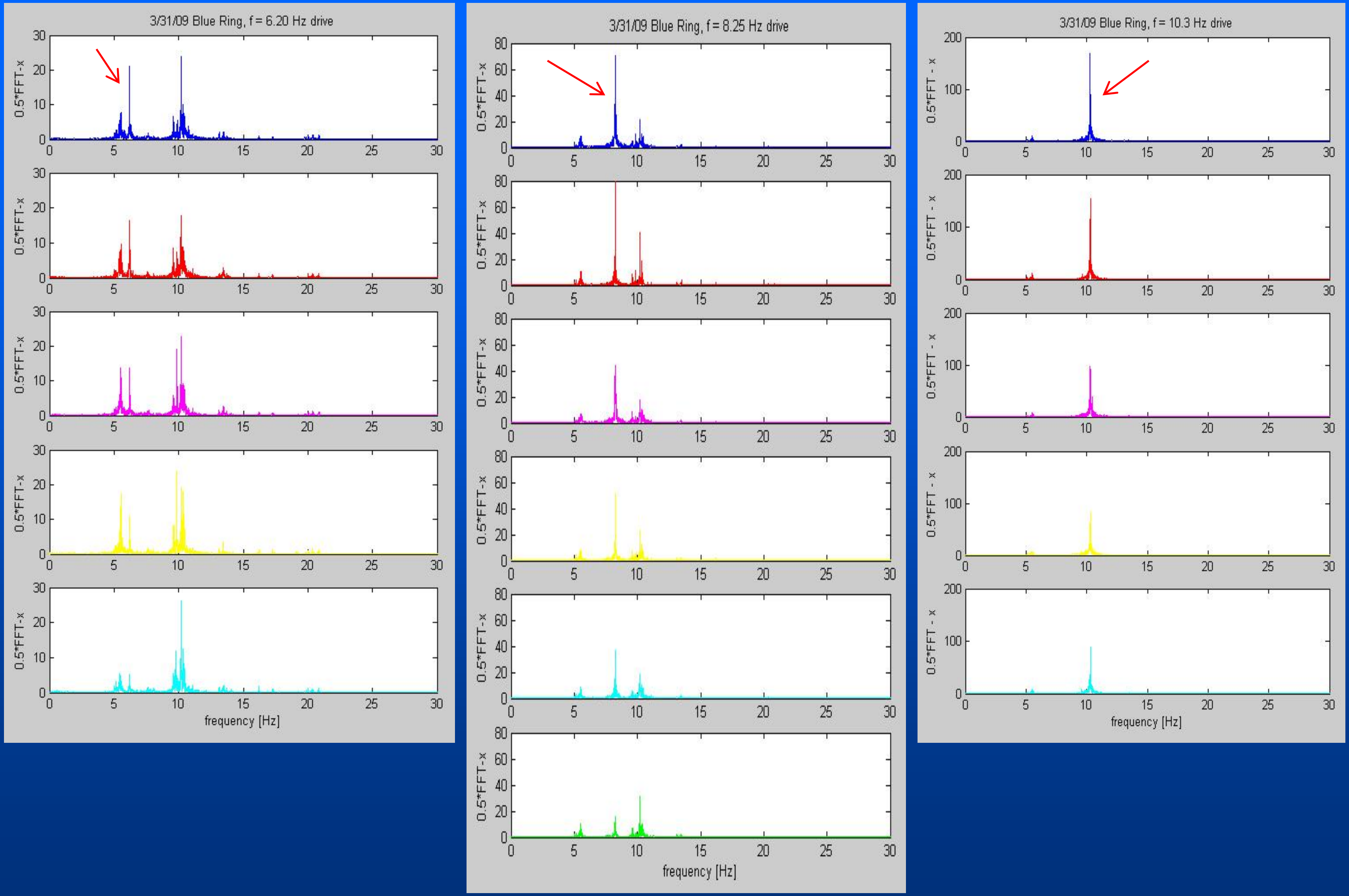


x-y correlations

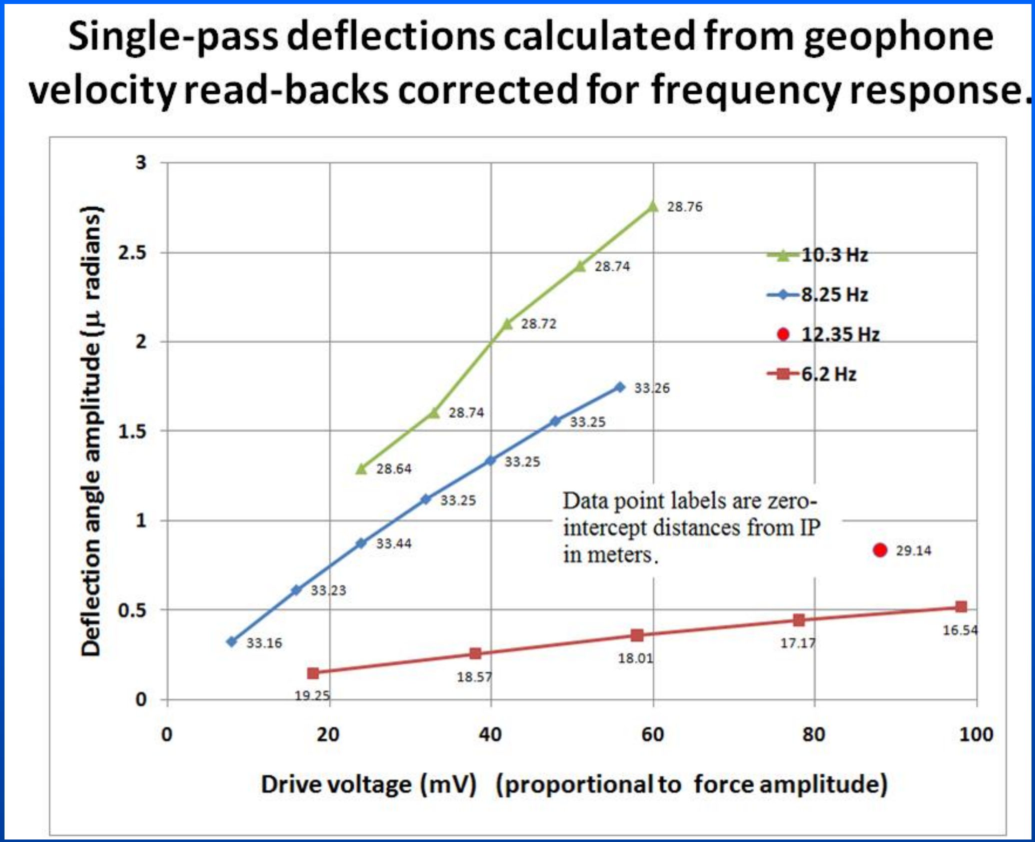




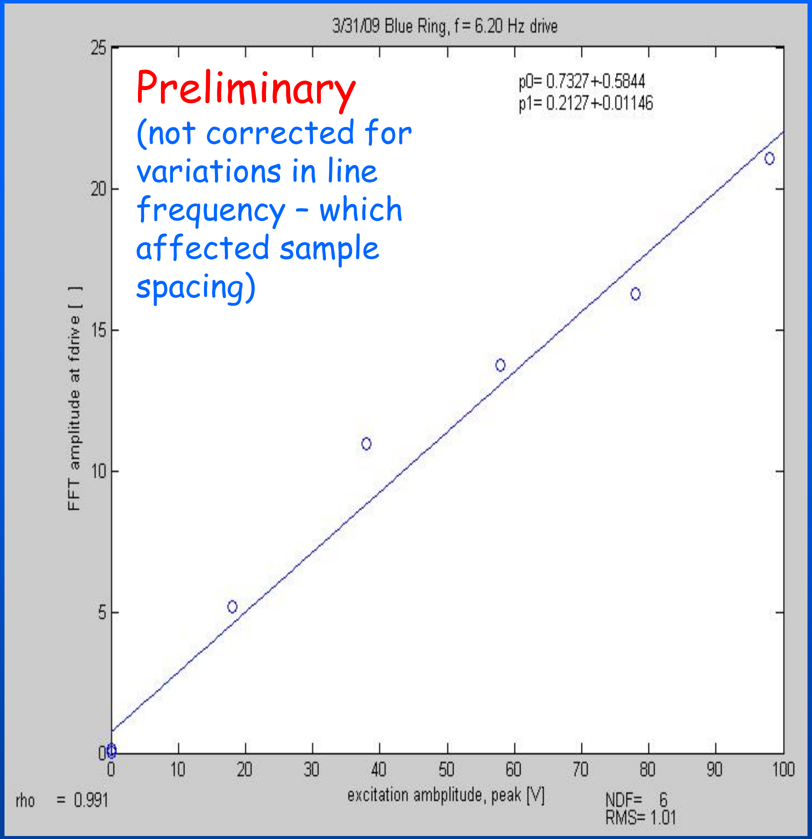
3/31/09, APEX (Fischer, Michnoff, Minty, Montag, Thieberger) : driven beam excitation using triplet actuators, measurements using BPMs ("10 Hz conditioner" modules)



3/31/09, APEX, cont'd

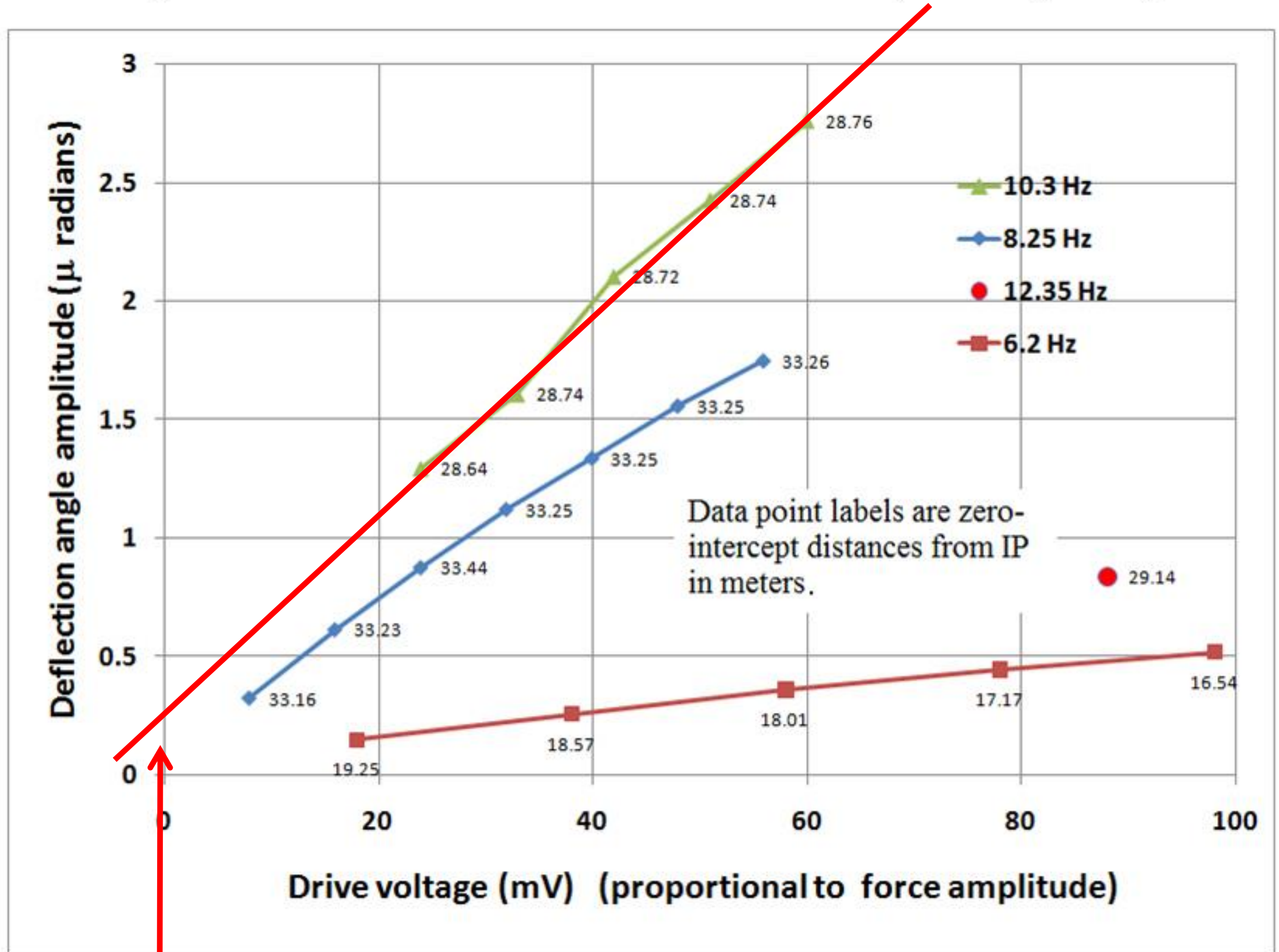


P. Thieberger (~04/09, unpublished)



cross-calibration data from BPMs

Single-pass deflections calculated from geophone velocity read-backs corrected for frequency response.



★ specification for "10 Hz feedback"

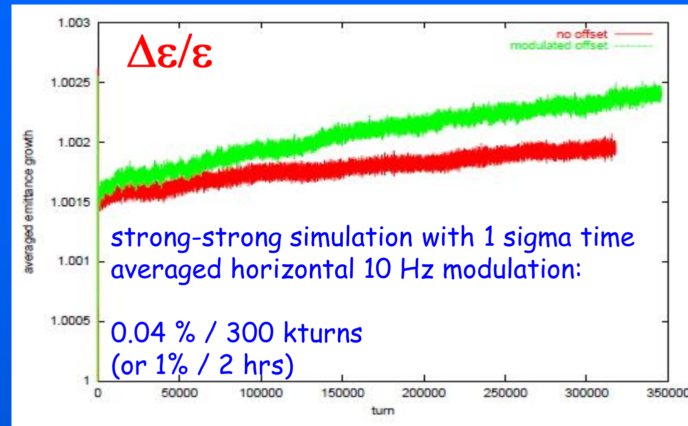
250 G-cm with 0.3 microradian deflection

Δ x ⟺ (?) LUMINOSITY: FINDINGS

2003:

TABLE 1. RHIC Physical Parameters for the Beam-Beam Simulations

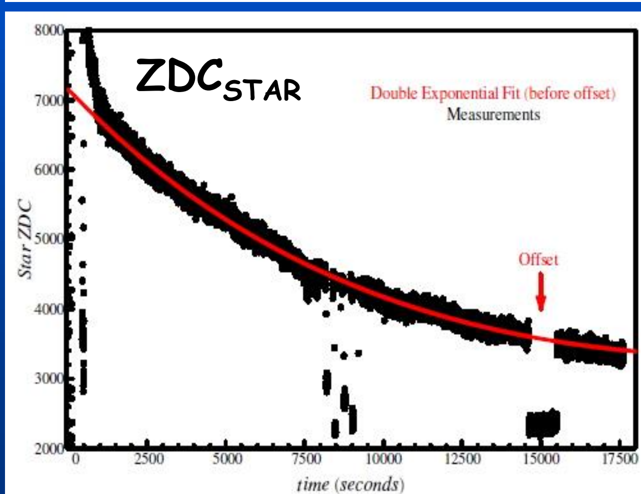
beam energy (GeV)	23.4
protons per bunch	8.4×10^{10}
β^* (m)	3.0
RMS spot size at the IP (mm)	0.629
betatron tunes (ν_x, ν_y)	(0.22, 0.23)
chromaticity (q'_x, q'_y)	(2, 2)
synchrotron tune ν_z	3.7e-4
RMS bunch length (m)	3.6
momentum spread	1.6e-3
offset (sigma)	1
oscillation frequency (Hz)	10

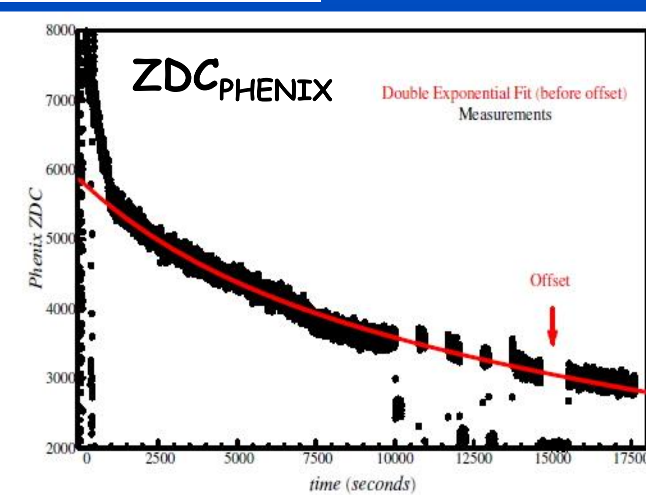


J. Qiang, et al (2003): "Parallel strong-strong/weak-strong simulations of BBI in hadron accelerators"

2007:

Exp#	fillno	species	N_{bunch}	ξ	Characteristics
3	5259	p-p	1.4×10^{11}	3×10^{-3}	1.12 σ horizontal in STAR and PHENIX and no bump in any other IP for 15 min





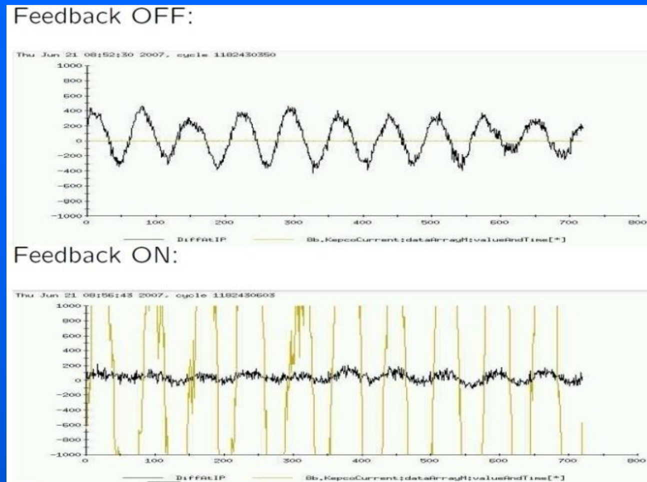
N.P. Abreu, W. Fischer (2007): "Emittance growth with offset beam-beam collisions and small beam-beam parameters"

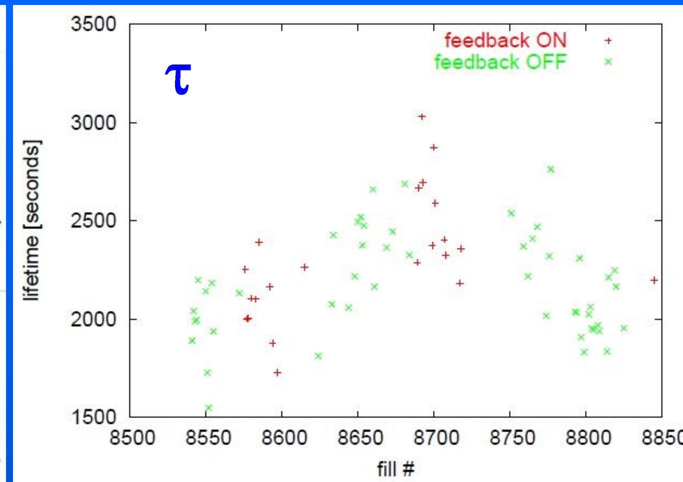
⇒ simulation and experiment both show negligible effect

(in the limit of <u>weak-weak</u> or <u>weak-strong</u> dynamics)

Δ x ⟺? LUMINOSITY: FINDINGS

2007: "10 Hz" feedback





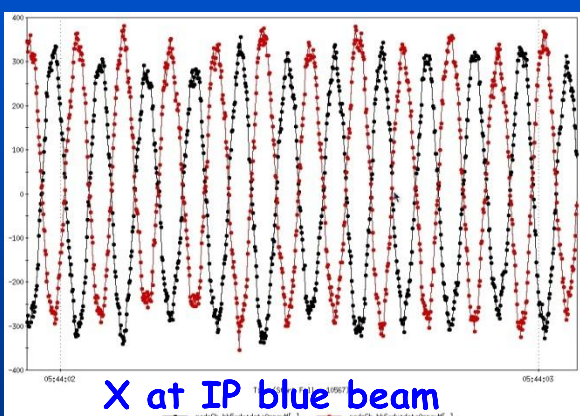
Double exponential fit;
shorter lifetime plotted

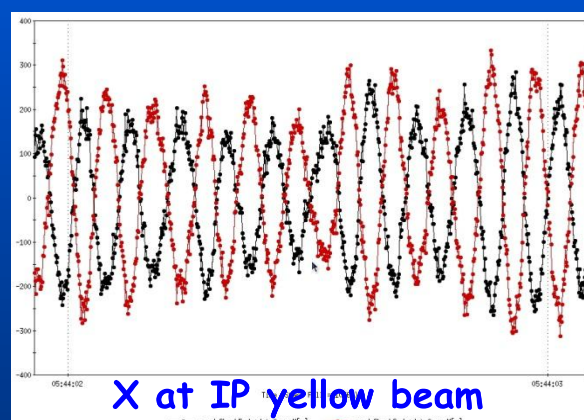
⇒ no strong evidence of luminosity improvement

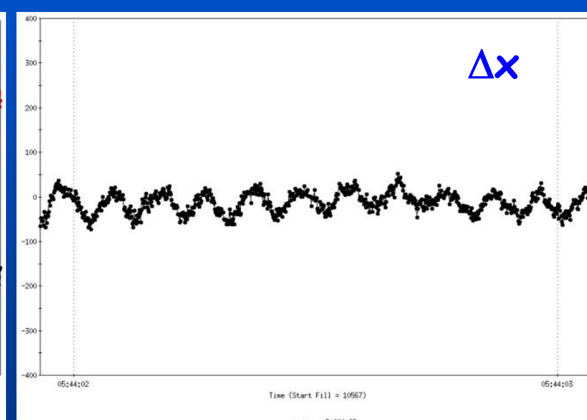
(in the limit of <u>weak-weak</u> dynamics)

06/21/07, fill ?   Au + Au   C. Montag, RHIC retreat 2007

2009: IR orbits







04/16/09, fill 10567   100 GeV, p+p

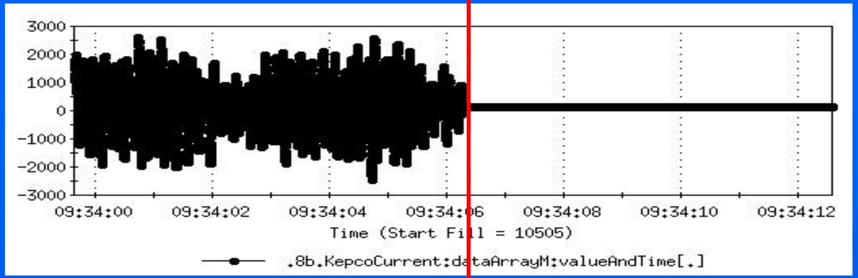
beams "tilting" with respect to one another due to 10 Hz
blue and yellow beams out of phase wrt tilt
residual CENTROID motion is small

Δ x ⟺? LUMINOSITY: FINDINGS

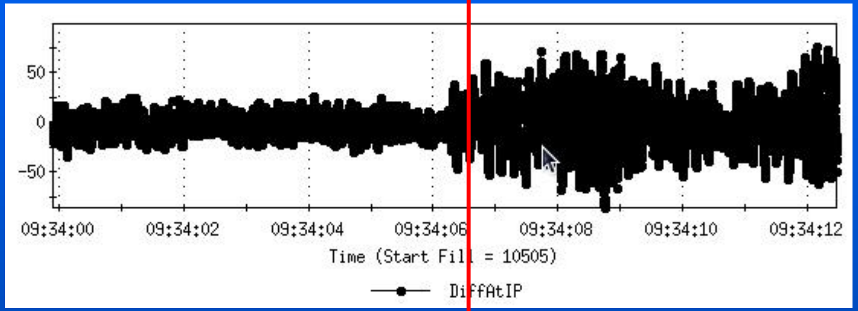
2009: "10 Hz" feedback

← FEEDBACK ON —— | —— OFF →

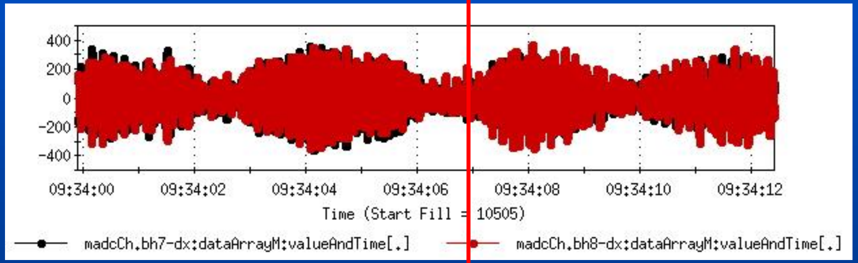
power supply current



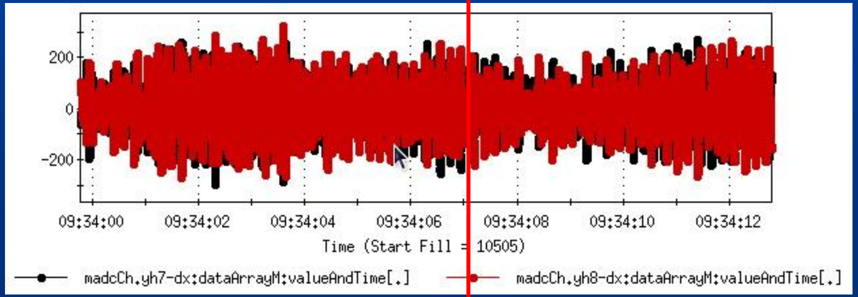
relative displacement at IP



blue beam positions



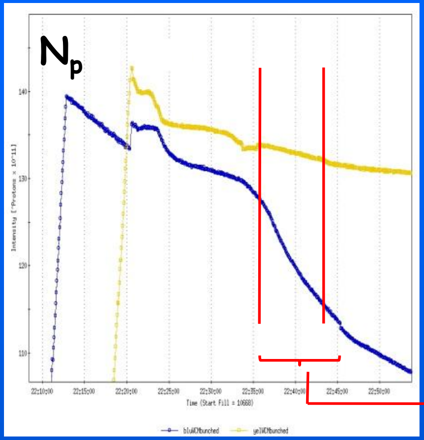
yellow beam positions

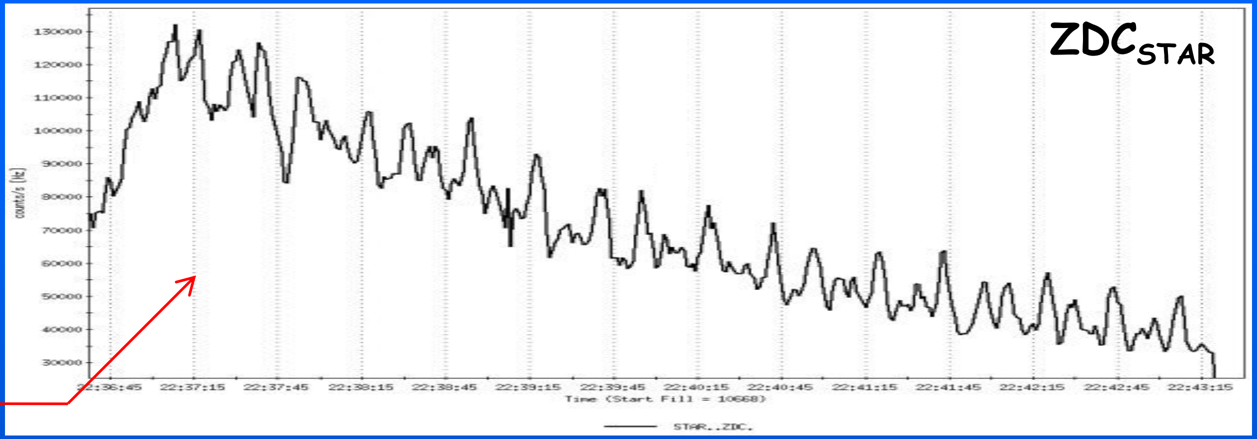


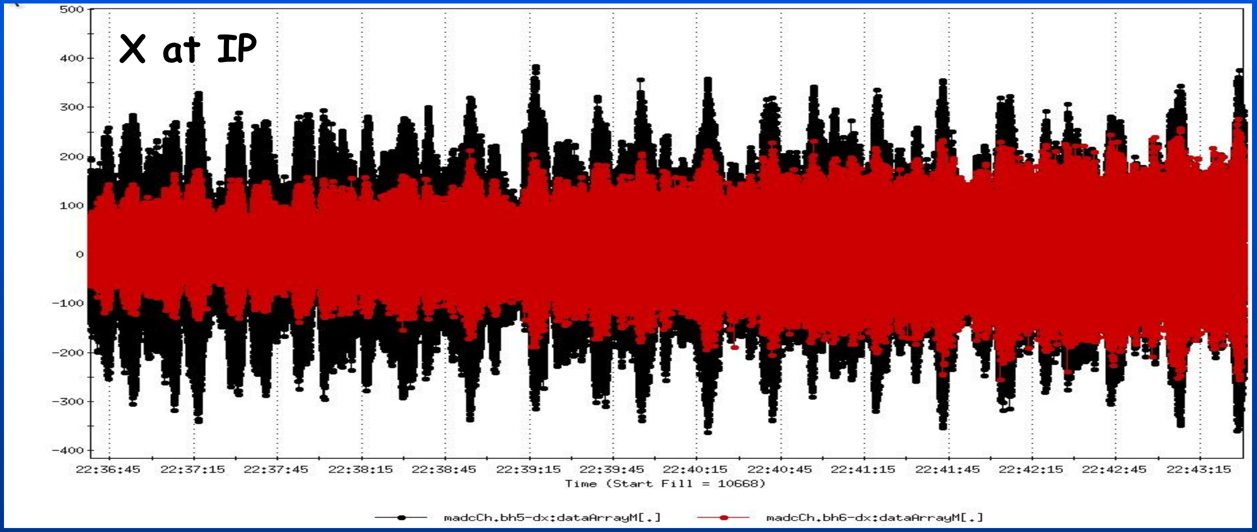
beams still "tipping"

Δ x ? LUMINOSITY: FINDINGS

2009: beam-beam interaction in strong-weak / strong-strong limit







⇨ beat frequencies in luminosity signal during time of rapid beam loss

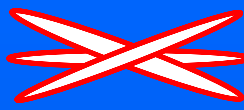
04/27/09, fill 10668 100 GeV, p+p

★ hypothesis: fast luminosity decay (“first” exponential (zeroth?)) due to long-range interactions between head of one beam and tail of other beam; e.g. modulated crossing angle
caveat: this is background-dominated signal

Δ x ? ⟺

LUMINOSITY: FINDINGS

hypothesis: fast luminosity decay ("first" exponential) due to long-range interactions between head of one beam and tail of other beam; e.g. modulated crossing angle

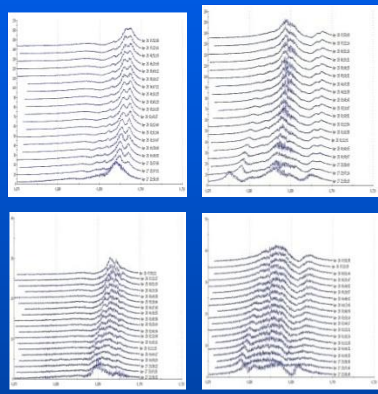


Remarks:

1) Previous studies (computational and experimental) not performed in strong-strong limit

2) Little influence of existing 10 Hz feedback on luminosity

Indirect supporting evidence:

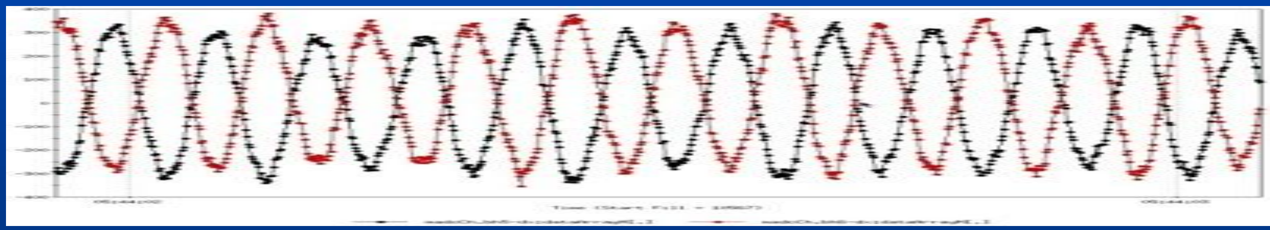


1) Beam loss rates are very large; large amplitude particles in tail/head would experience strongest long-range perturbations

2) Tune window is sufficient (even including coherent modes); incoherent tune shift OK

3) Some evidence of opposite-sign tune shift in BTF data (?)

Direct supporting evidence:



Possible alternatives:

1) Emittance growth during energy ramp (unlikely as culprit for ~40 % beam loss)

2) Beam-beam resonances and diffusion from head-on collisions in strong-strong regime
see N.P. Abreu et al (2009): "Diffusion Simulation and Lifetime Calculation at RHIC", C-A/AP/#346 (2009)

Numbers:

95 % normalized emittance: 10 pi mm-mrad

Beta* = 0.7 m

E = 250 GeV

- → Beam size at IP: 65 microns

Distance of BPMs from IP = 10 m

Peak amplitude of 10 Hz oscillation BPMs = 500 microns

- → 50 micro-radian tilt angle (deviation from straight trajectory)
- → i.e. 100 micro-radians between head of one beam and tail of other

Bunch length, sigma_z = 5 ns (FWHM)

At one sigma_z:

displacement is 30 microns per beam

relative displacement is 60 microns relative

i.e. 60 microns / sigma_z

120 microns / 2 * sigma_z

SUMMARY AND OUTLOOK

Measurement precision determined by 10 Hz modulations (not resolution)

Tune modulation (in both planes) measured and source identified (feed-down due to off-axis beams in sextupoles)

Observed beam-beam performance at RHIC postulated to be strongly affected by
- modulated crossing angles
- in consequence: long-range interactions between head of one bunch and tail of opposing bunch and vice versa
- in consequence, synchro-betatron resonances ?

Many puzzles solved:

- structure in beam decay signals (beat frequencies)
- (minimal) effect of "10 Hz" feedback on luminosity (relative centroid displacements small)
- fast decay in current and luminosity
- beam emittances derived from Vernier scans vs other emittance monitors (IPM, CNI) ?
- added 12/17/09: possibly earlier longitudinal Vernier scan data? (Roser, 11/12/09)

Next steps:

1) 3-macrobunch model of beam dynamics and/or weak-strong simulations
2) review phase-advance between IPs → next slides
3) obtain time-resolved luminosity data from experiments
4) develop diagnostics: high time resolution luminosity monitors, vertical BPMs, and BPMs at select other locations
5) develop online viewing capabilities: FFTs and integrated power spectra

since APEX09 workshop: work in progress on topic of "modulated crossing angle"

previously shown IP BPM data from E-log http://www.cadops.bnl.gov/cgi-bin/elog/view.pl?elog=rhic-pp_2009&shiftlog=Thu_Apr_16_2009_0:07:50_AM

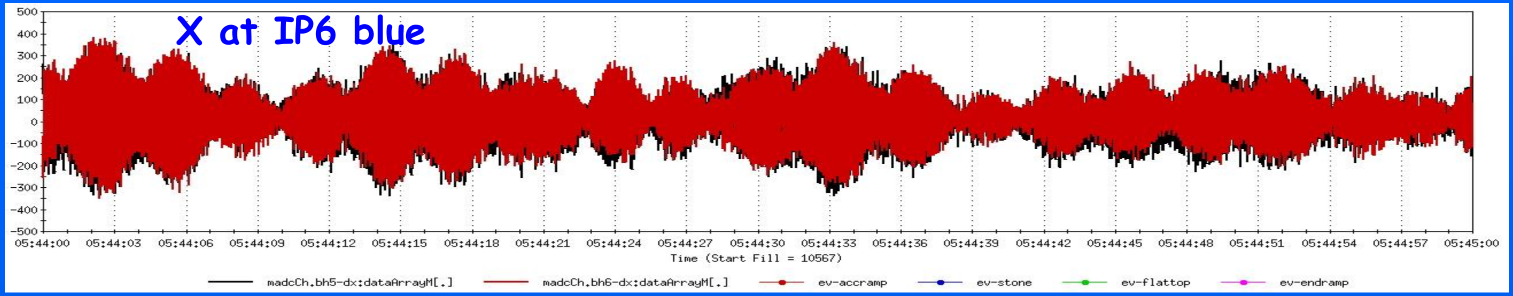
1) PHENIX (John Haggerty) looks for evidence of modulated crossing angle in luminosity data

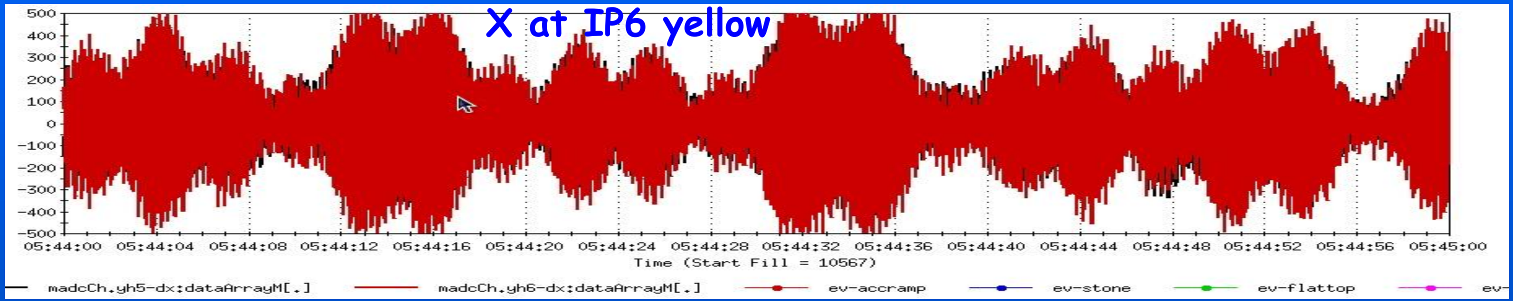
```
> -----Original Message-----
> From: Haggerty, John
> Sent: Saturday, November 14, 2009 10:11 PM
> To: Minty, Michiko
> Subject: 10 Hz at PHENIX
>
> Michiko,
>
> Your talk at the APEX meeting made me think of a trick that might
> enable us to see 10 Hz oscillations in certain scalers in PHENIX.  I
> tried it, and if I didn't make a mistake, I didn't see it, but there
> may be ways to pull a signal out if it's there.  The attached plot
> shows how far I got (without error bars on the points, which are ~10%
> or more).  These data are from a run in fill 10535 in the 500 GeV run.
> Are there fills that are worse than others?  (I looked for 10166 which
> you showed in your talk, but I didn't see any physics runs in that
> fill in our data.)
>
> I can tell you more about how I did this, but it's a pretty convoluted
> story to write out.
>
> --
> John Haggerty
> email: haggerty@bnl.gov
> voice/fax: 631 344 2286/4592
> http://www.phenix.bnl.gov/~haggerty
```

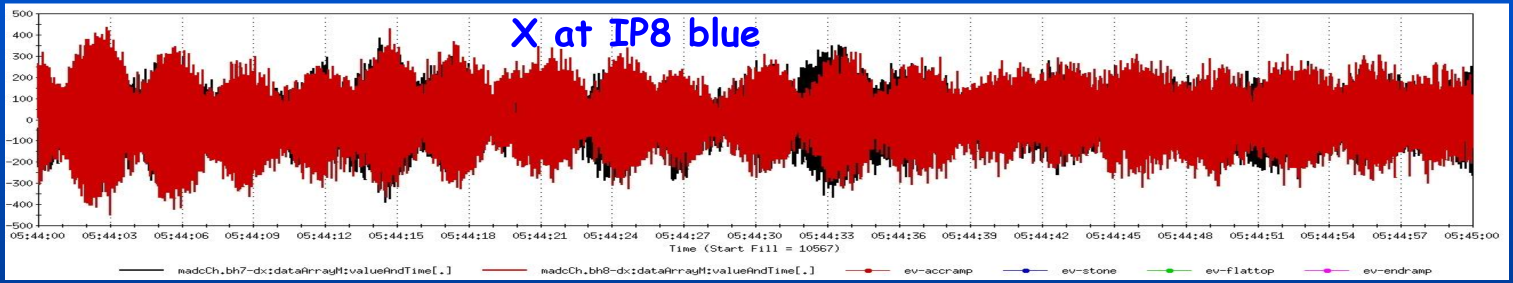
⇨ (preliminary) no evidence of modulated crossing angle in luminosity data

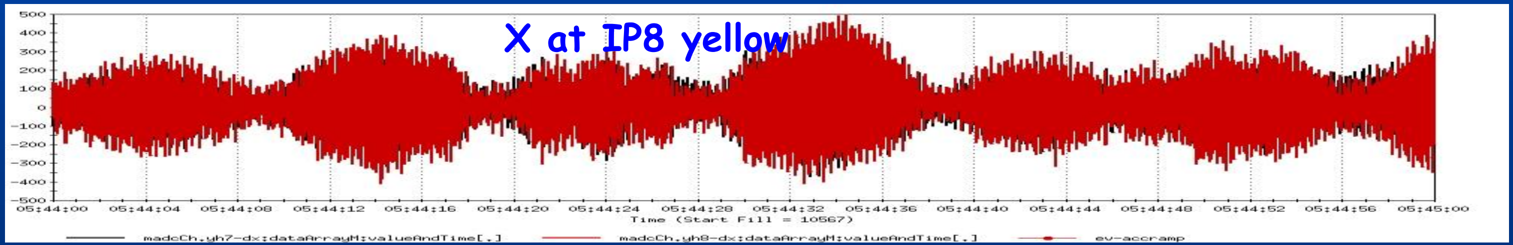
2) review various data sets to confirm that observation was not a random coincidence

example: fill 10567 (04/16/09: pp100-90 at store; 100 GeV)





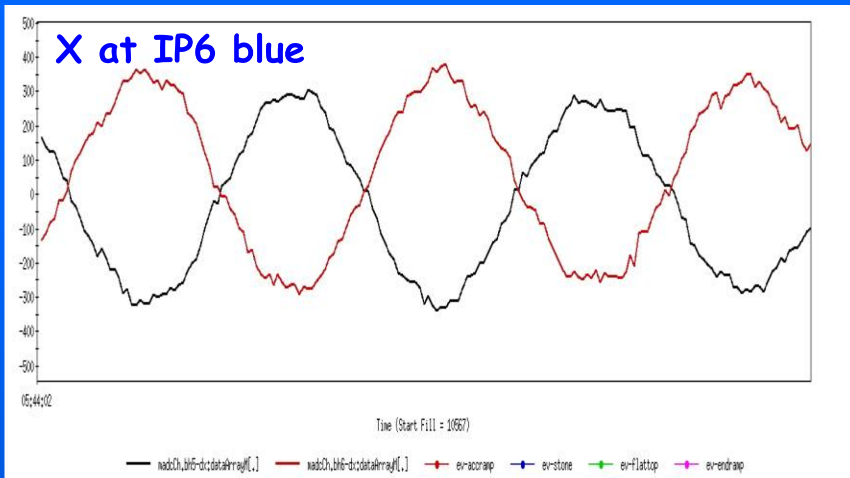


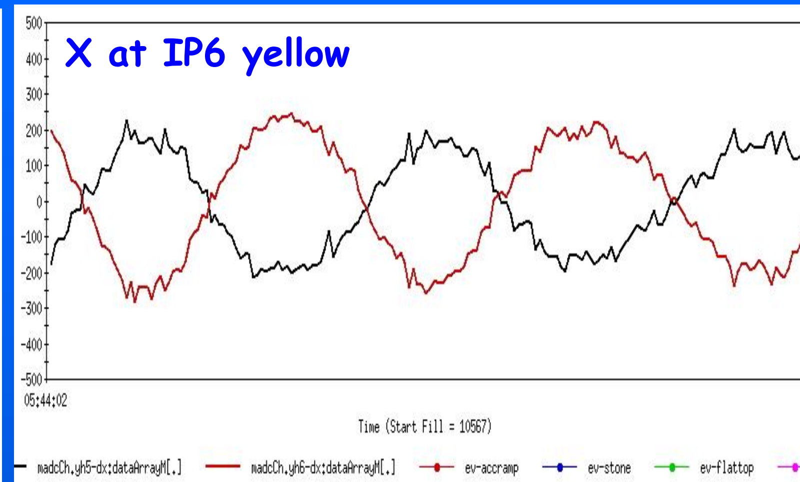


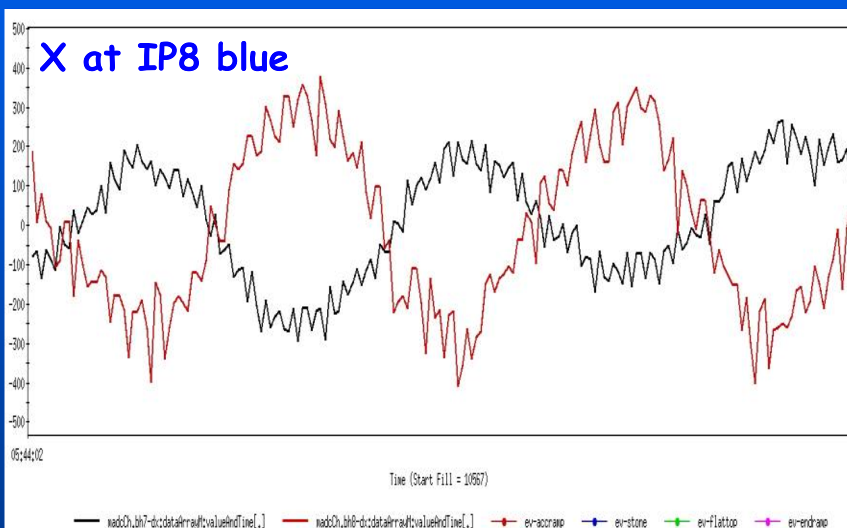
⇨ not a random coincidence

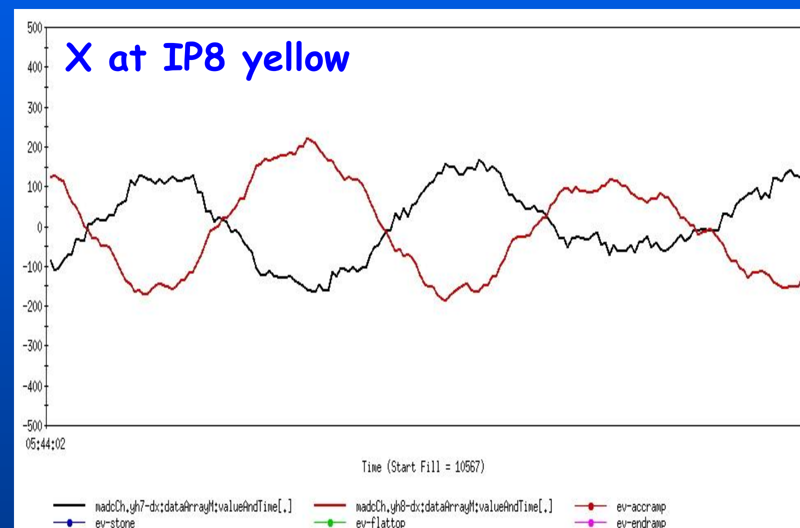
3) review data, with high time resolution, at both IPs and different optics, next slides

100 GeV run - FILL 10567 (04/16/09: pp100-90) AT STORE









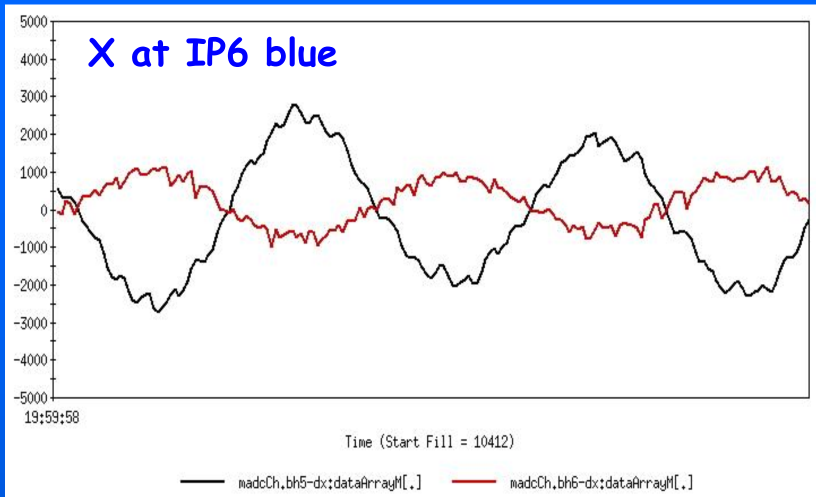
blue: $\Delta\varphi_{6\text{-}8}$ = 0.45 (*2π) ~ π

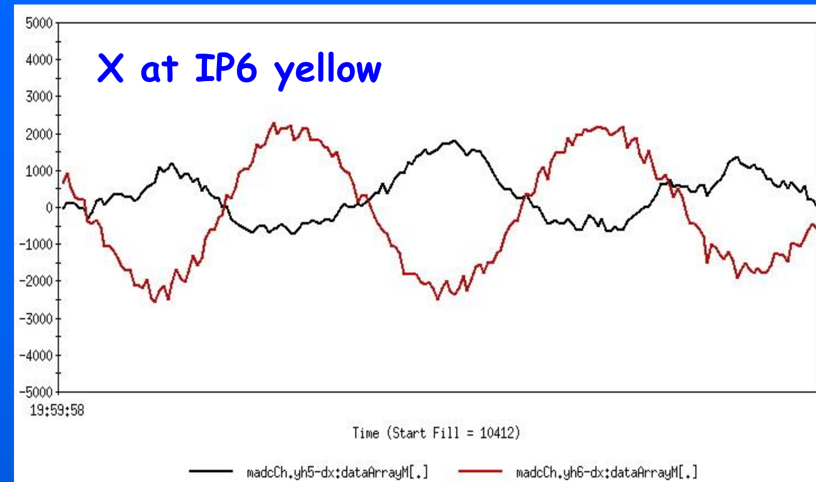
yellow: $\Delta\varphi_{6\text{-}8}$ = 0.08 (*2π) ~ 0

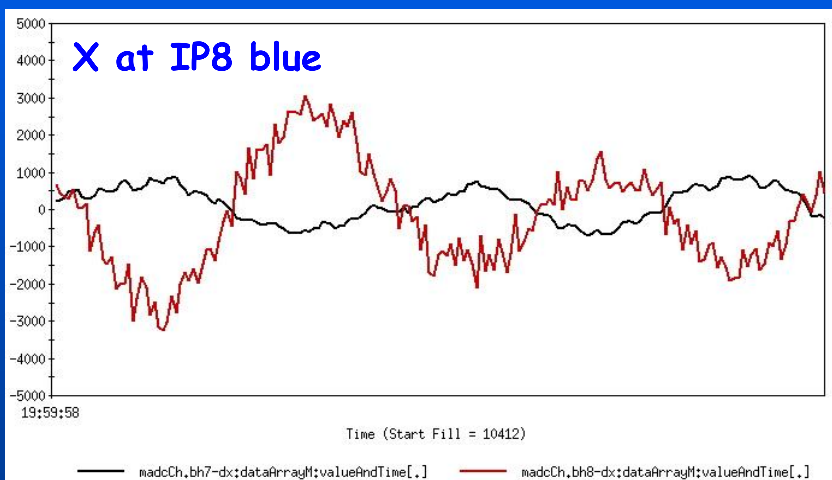
AND … blue and yellow out-of-phase at IP6
blue and yellow in-phase at IP8

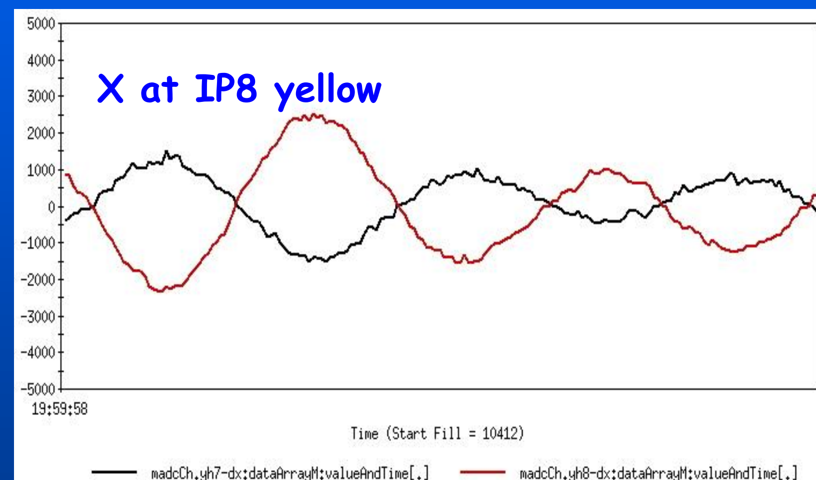
⇒ crossing angle is modulated at IP6 and not at IP8 ★

250 GeV run: FILL 10412 (03/22/09 rot93) AT STORE









blue: $\Delta\varphi_{6\text{-}8} = 0.31\ (*2\pi) \sim (6/7)\ \pi$

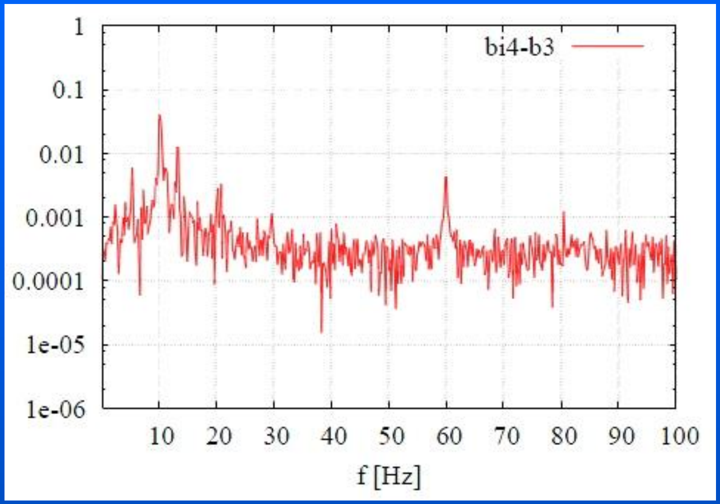
yellow: $\Delta\varphi_{6\text{-}8} = 0.14\ (*2\pi) \sim (3/10)\ \pi$

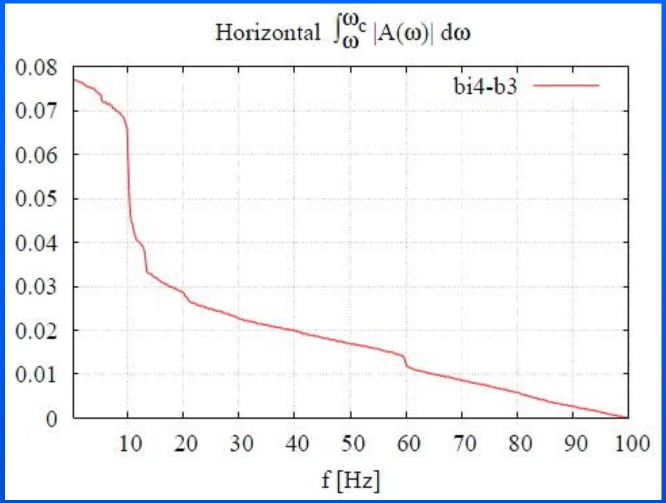
AND … blue and yellow out-of-phase at IP6
blue and yellow in-phase at IP8
(again!)

→ crossing angle is modulated at IP6 and not at IP8

Observations

effect appears to be the same in both lattices (surprising!)
taken together with integrated power spectra from turn-by-turn BPMs, perhaps could look for a single, dominant source





the integrated power spectra of multiple BPMs support postulation of dominant source

courtesy W. MacKay (08/09)

4) confirm yellow ring cabling (upstream/downstream cable swaps) outside of the tunnel

5) outstanding: confirmation of no upstream/downstream cable swaps with beam

6) simulation of modulated closed orbit distortion (look for needle in haystack)

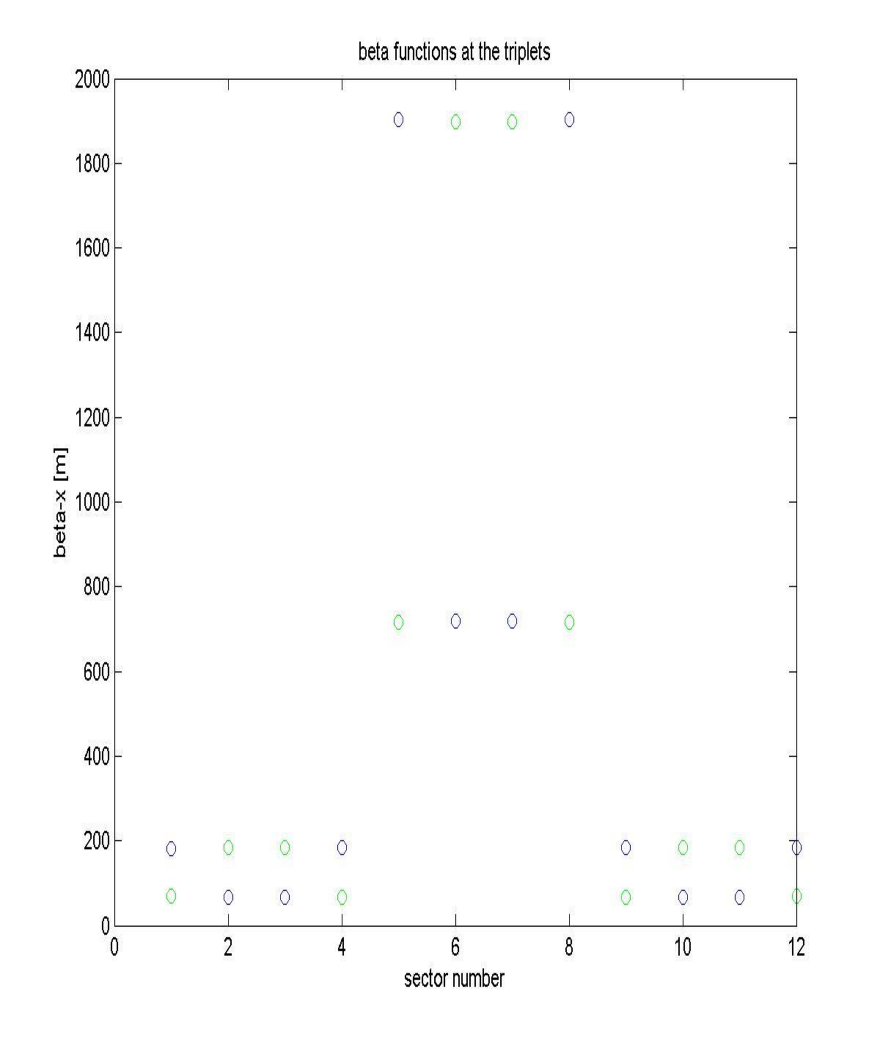
$$x_b{}^B(s) = \sum_t \theta^B{}_t \sqrt{\beta_b(s)\beta(s_t)} \frac{\cos(|\phi_b(s) - \phi(s_t)| - \pi Q)}{2\pi Q}$$

b = BPM
t = triplet
B = blue ring

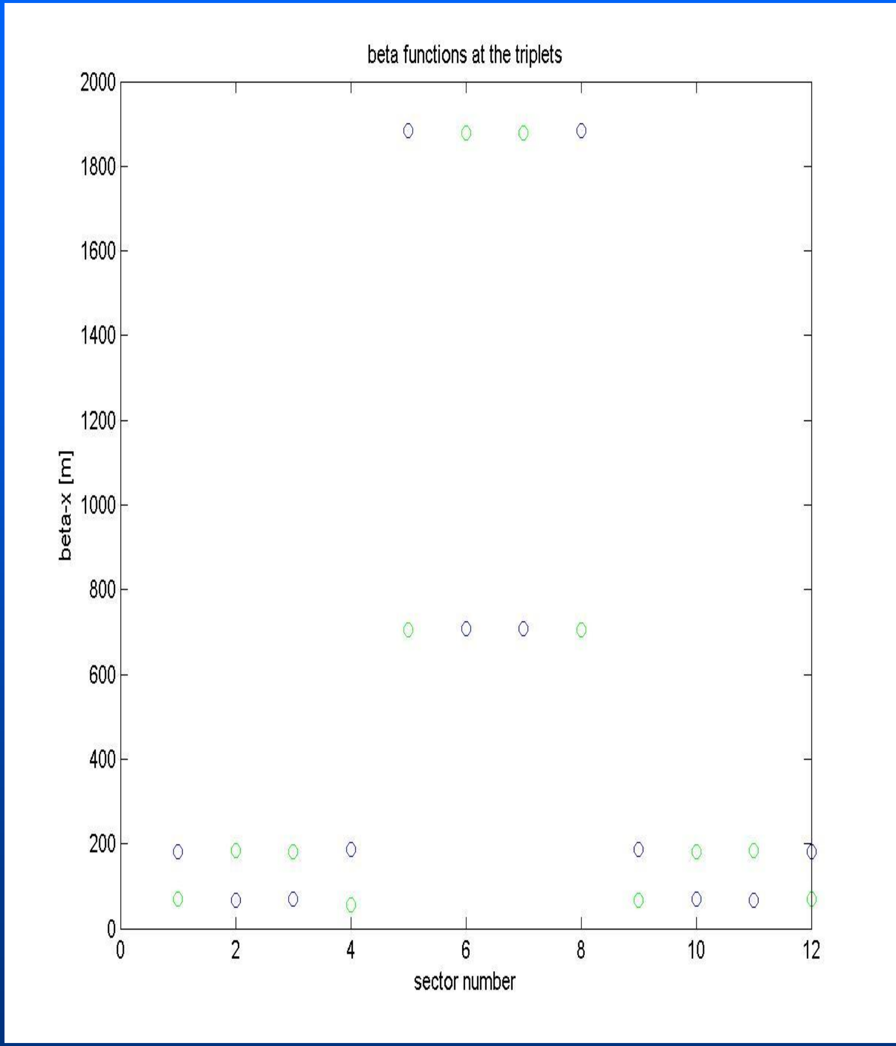
and similarly for the yellow ring (Y) – simplest case: modulation of single Q3, beta-function from mid-Q3

(aside: beta functions at the triplets for the two optics)

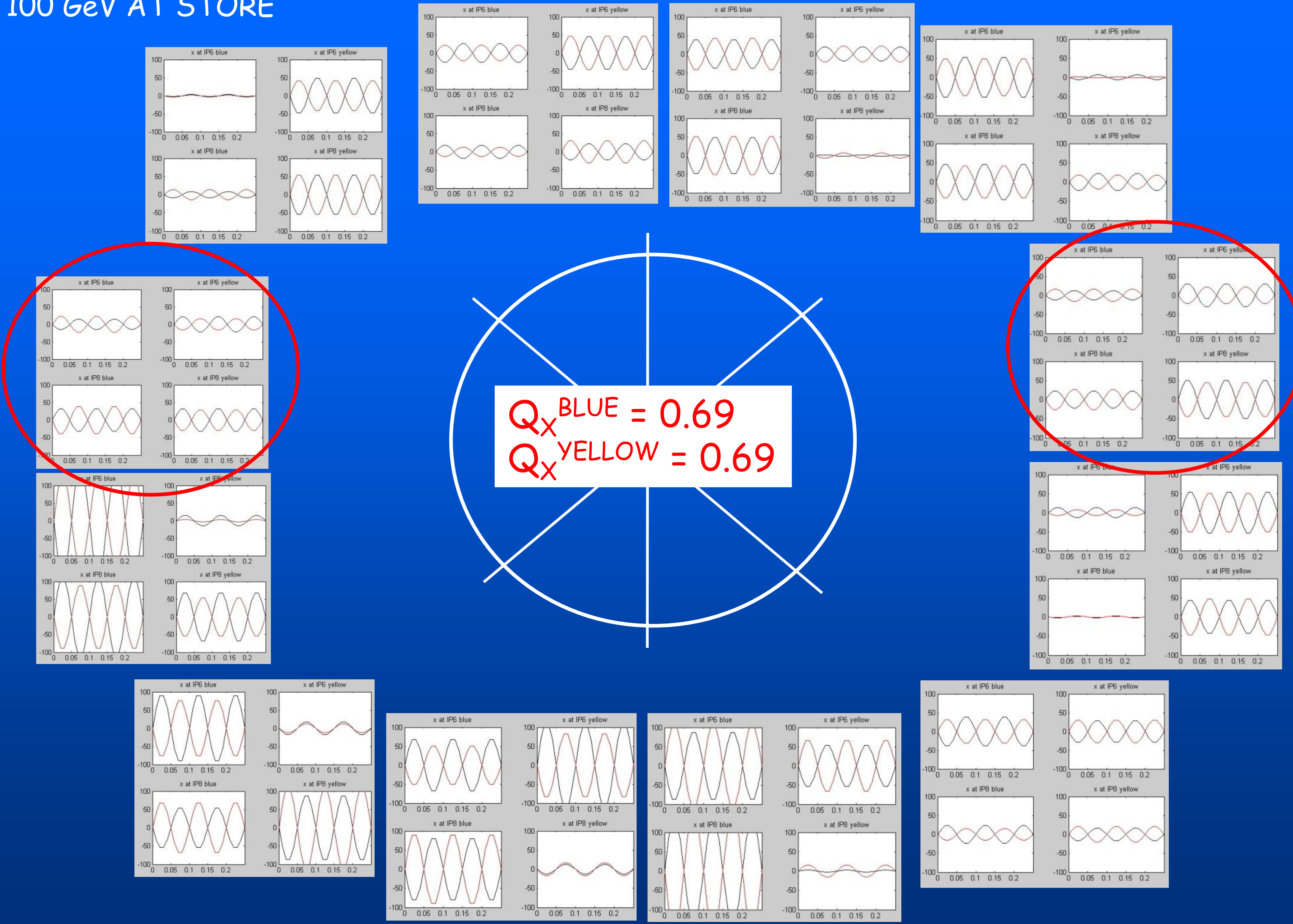
100 GeV AT STORE



250 GeV AT STORE

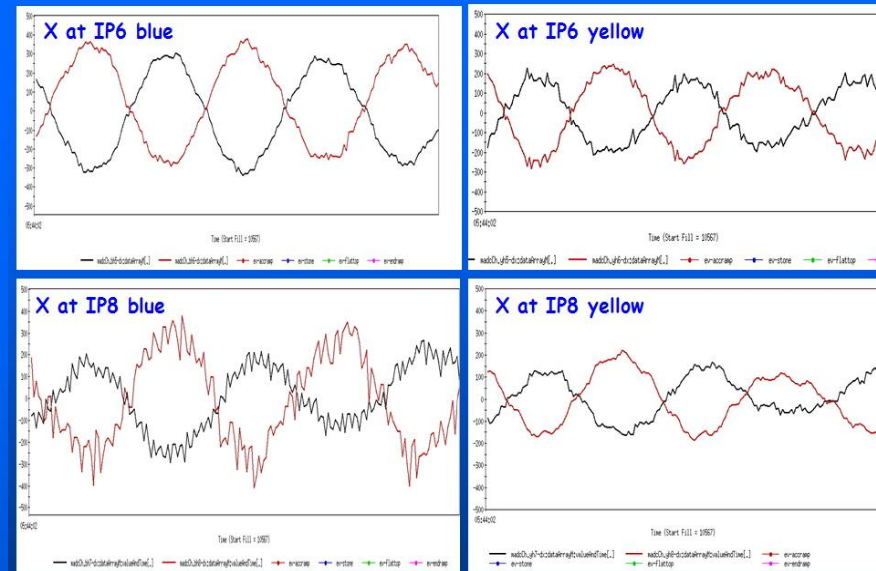


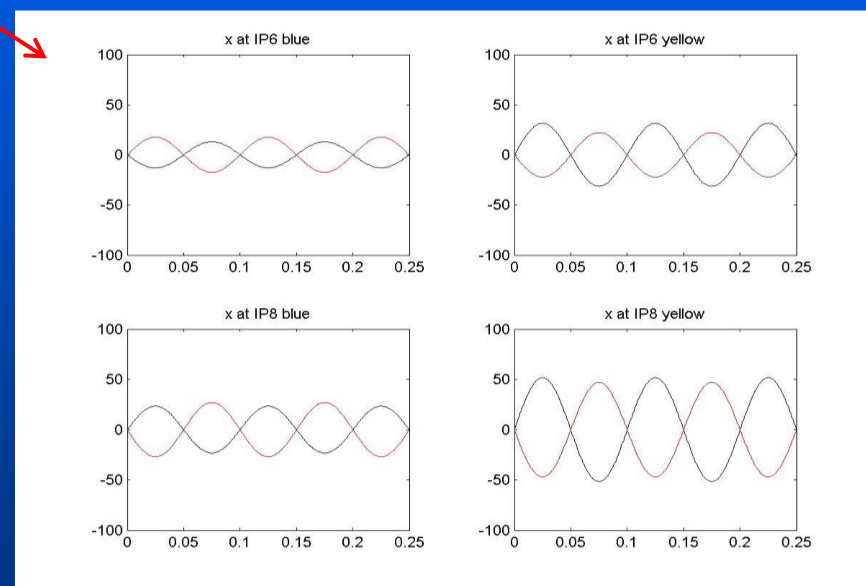
100 GeV AT STORE



TRIPLET	B6	B8	Y6	Y8	100 GeV
05	Y	Y	pi	N	
06	pi	pi	Y	N	
07	pi	pi	N	pi	
08	Y	Y	N	Y	
09	Y	Y	Y	Y	
10	N	pi	pi	pi	
11	Y	Y	pi	pi	
12	pi	pi	Y	Y	
01	Y	Y	pi	pi	
02	Y	Y	Y	Y	
03	pi	N	Y	Y	
04	Y	Y	pi	pi	

TRIPLET	B6	B8	Y6	Y8	250 GeV
05	Y	Y	pi	Y	
06	pi	pi	Y	pi	
07	pi	pi	Y	pi	
08	Y	Y	pi	Y	
09	pi	Y	Y	Y	
10	Y	pi	pi	pi	
11	Y	Y	pi	pi	
12	pi	pi	Y	pi	
01	pi	pi	Y	pi	
02	Y	Y	Y	Y	
03	pi	Y	Y	Y	
04	Y	pi	pi	pi	





… many, many assumptions in this simplest of models, but nonetheless perhaps worth a closer look in IR02