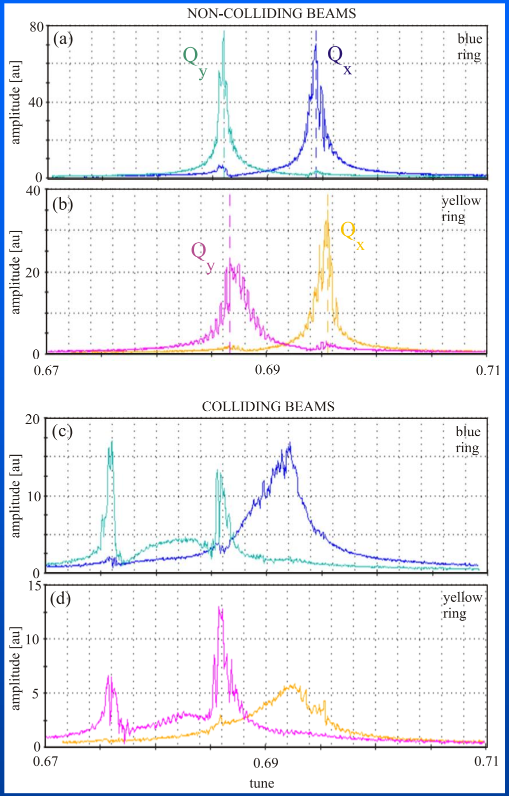
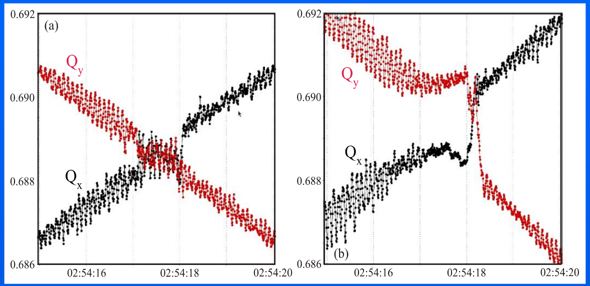
Effect of 10 Hz on RHIC performance at the nominal WP



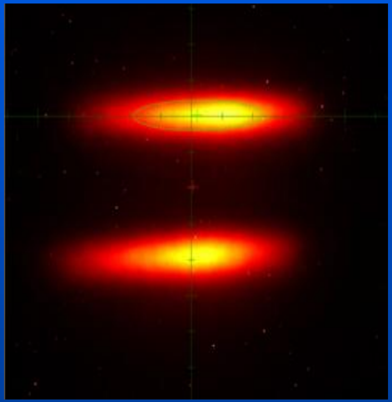
APEX Meeting, November 12, 2009
M. Minty



Δ x ⇔ Δ I (backgrounds)

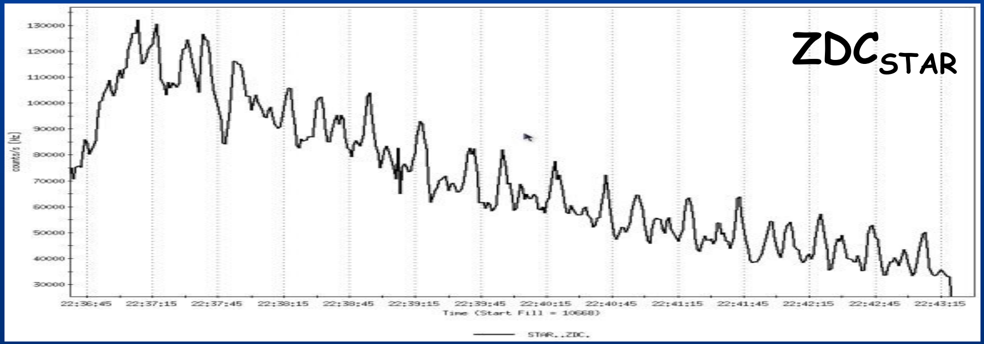
Δ x ⇔ Δ Q

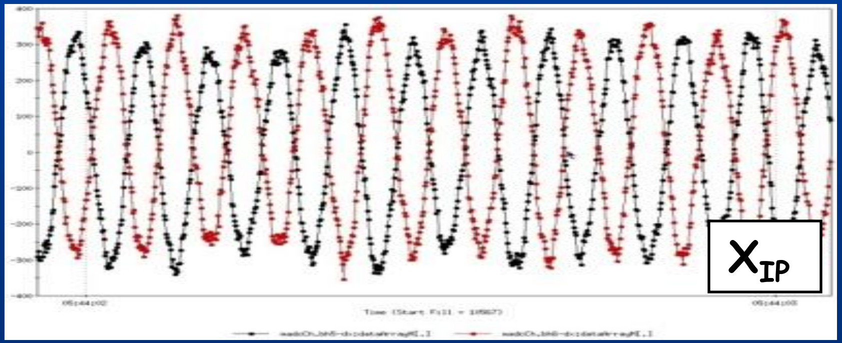
affect on measurement precision
(x/y, Q_x/Q_y, IR params, β^*, ξ , BTFs,...)



Δ x ⇔(?) LUMINOSITY

Summary and Outlook

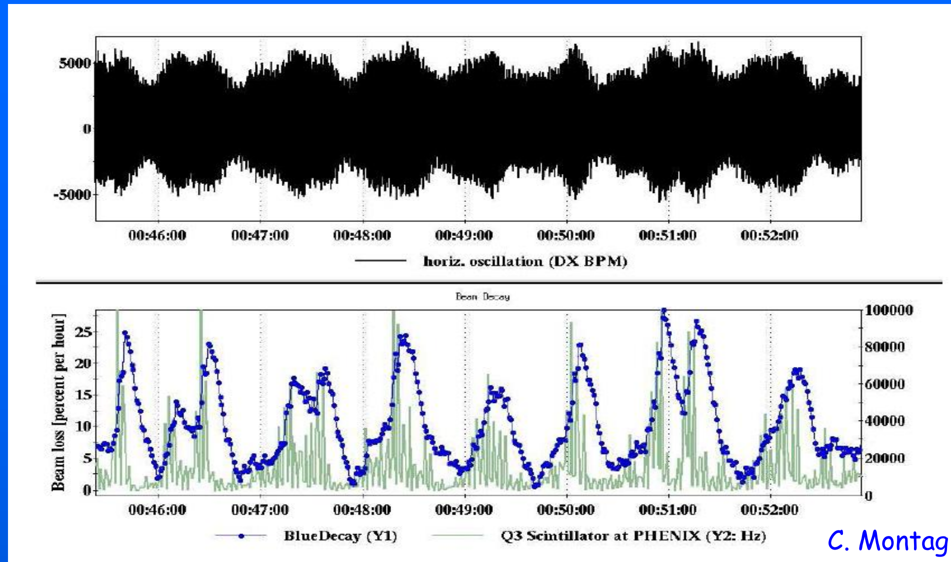




2008 :

Δ x ⟺ Δ I

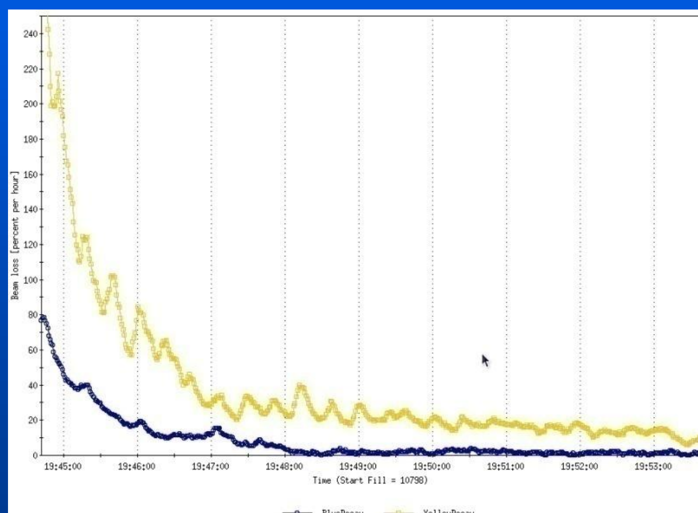
(Q ~ 0.93)



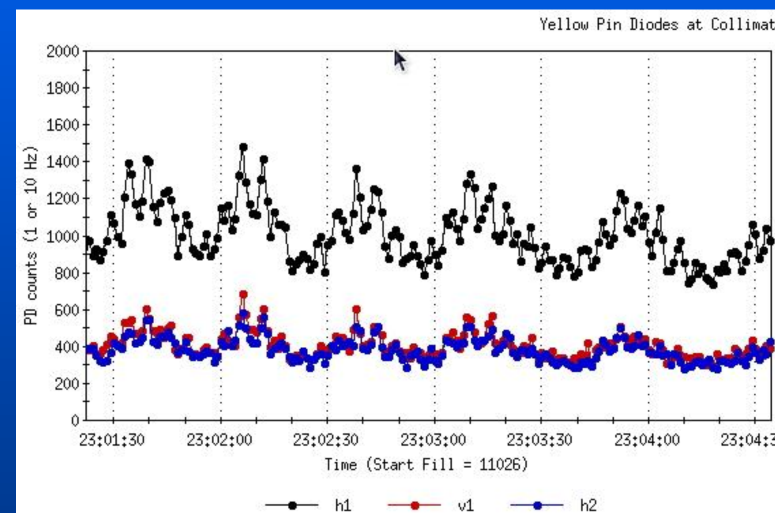
2009 :

Δ x ⟺ Δ I

(Q ~ 0.68)



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



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

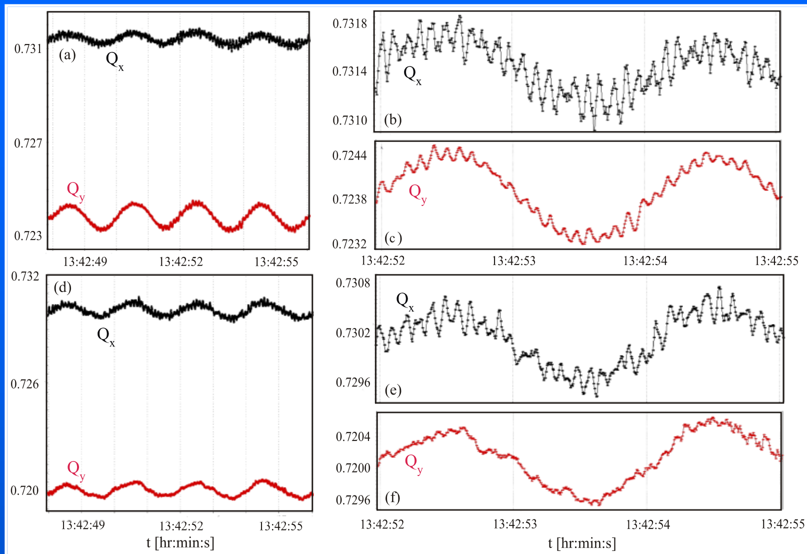
⇒ particles driven to large amplitudes at end of store

⇒ enhanced sensitivity due to detector geometry

⇒ envelop modulation due to <u>beat frequencies</u>

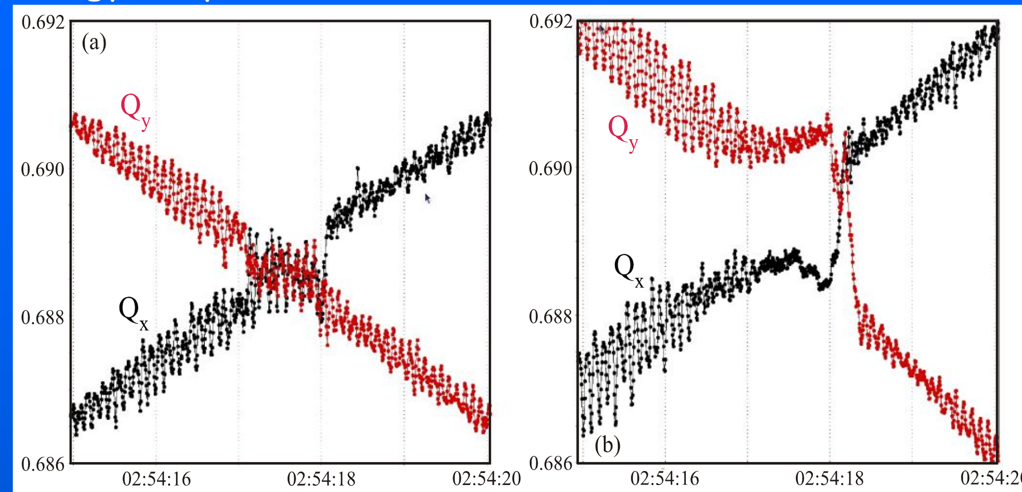
2009 : Δ x ⟺ Δ Q

injection energy:



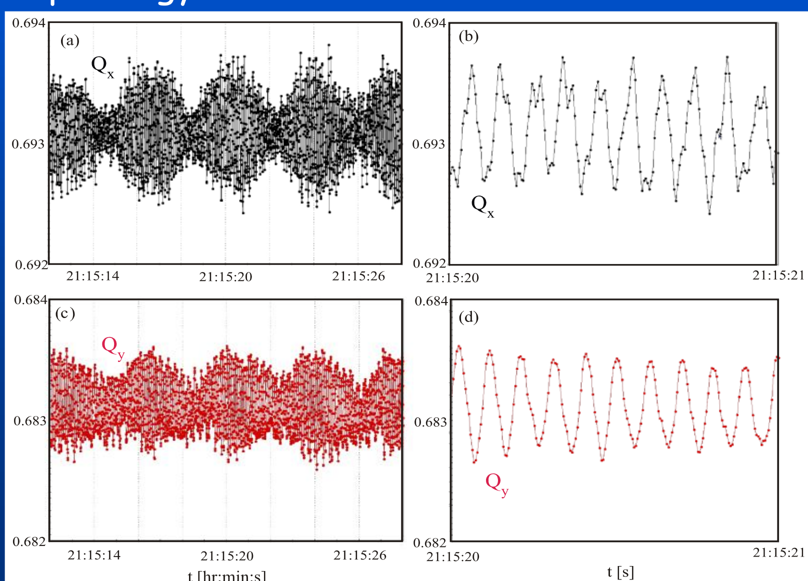
02/20/09, fill 10166 250 GeV, p+p

energy ramp:



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

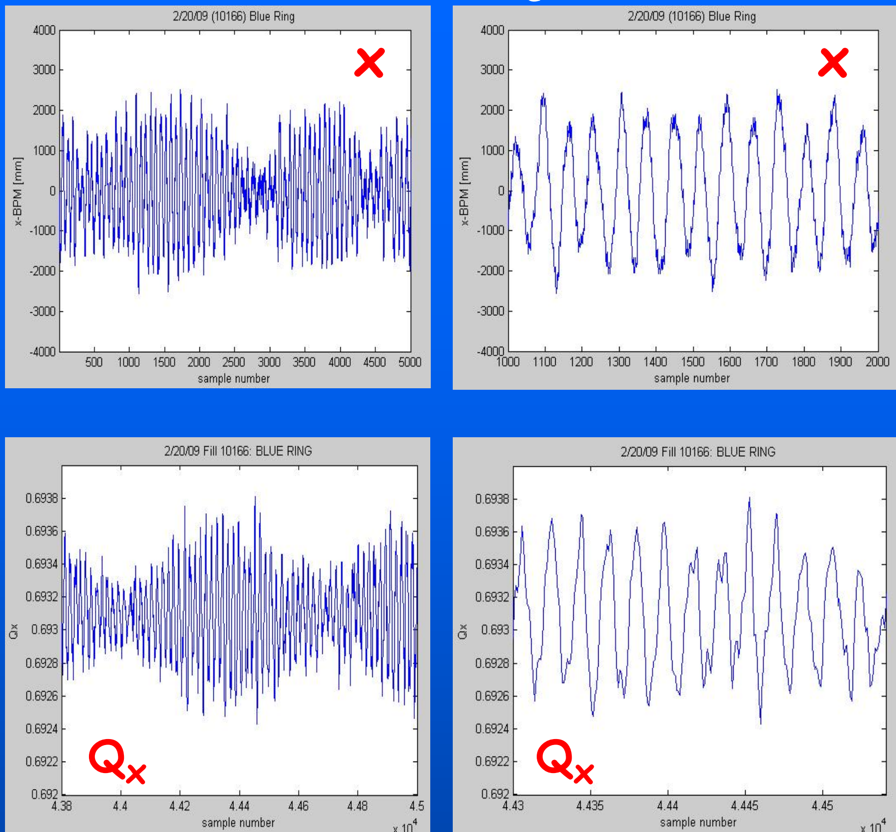
top energy:



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

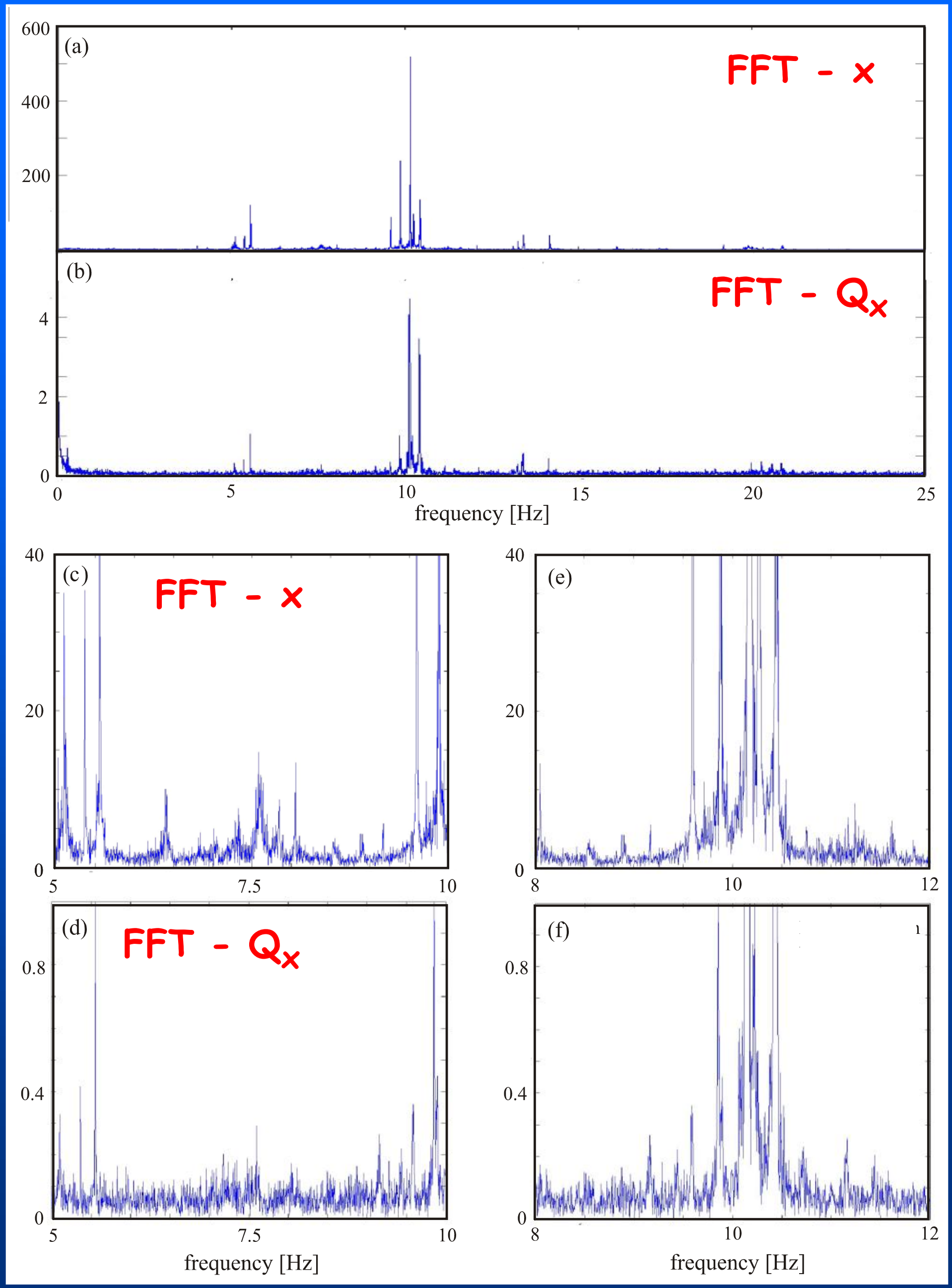
- tune modulations observed at all times:
  - injection energy (top left)
  - energy ramp (top right)
  - during store (bottom left)
- tune modulations observed in both planes
- tune modulations out of phase between x and y

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



02/20/09, fill 10166

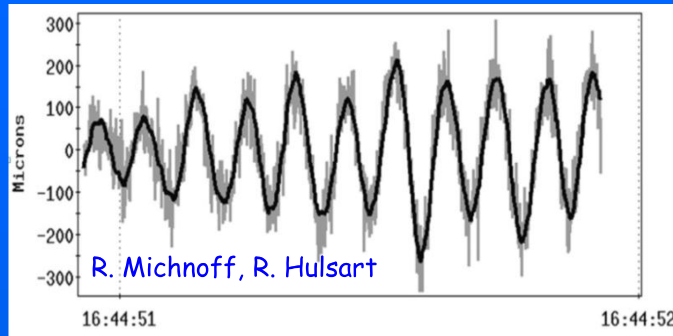
250 GeV, p+p



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

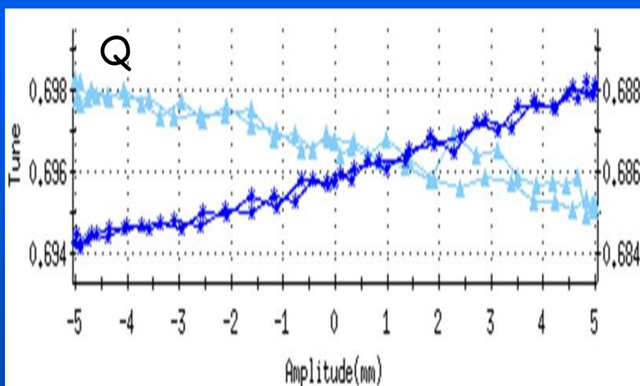
affect on measurement precision (fixed):

beam position

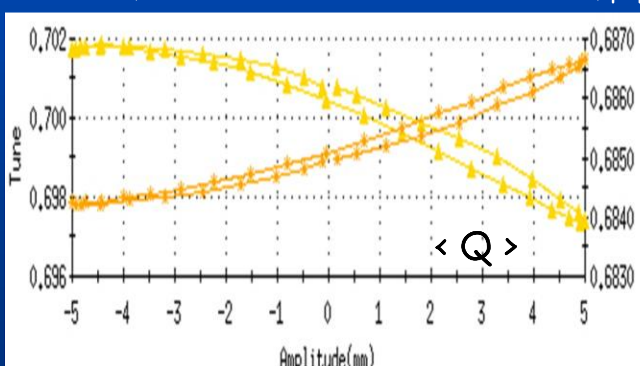


(new and improved)
< x > used as reference for beam steering

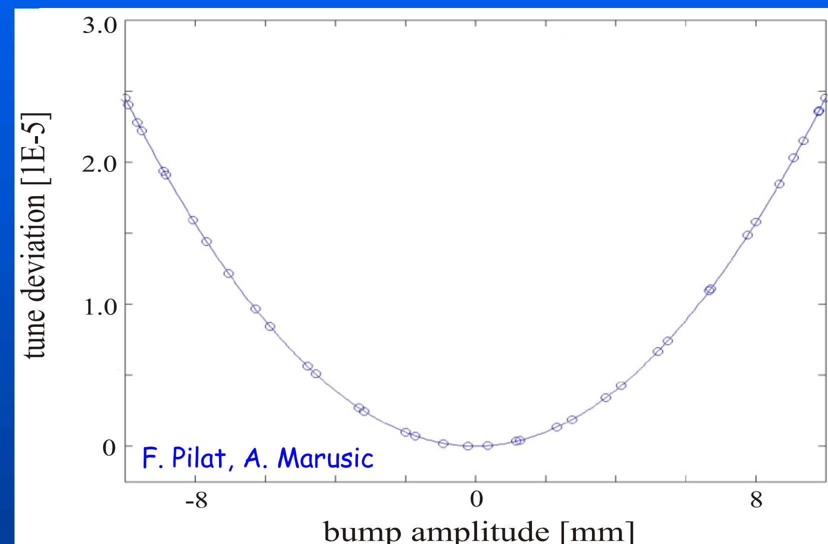
nonlinear IR correction



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

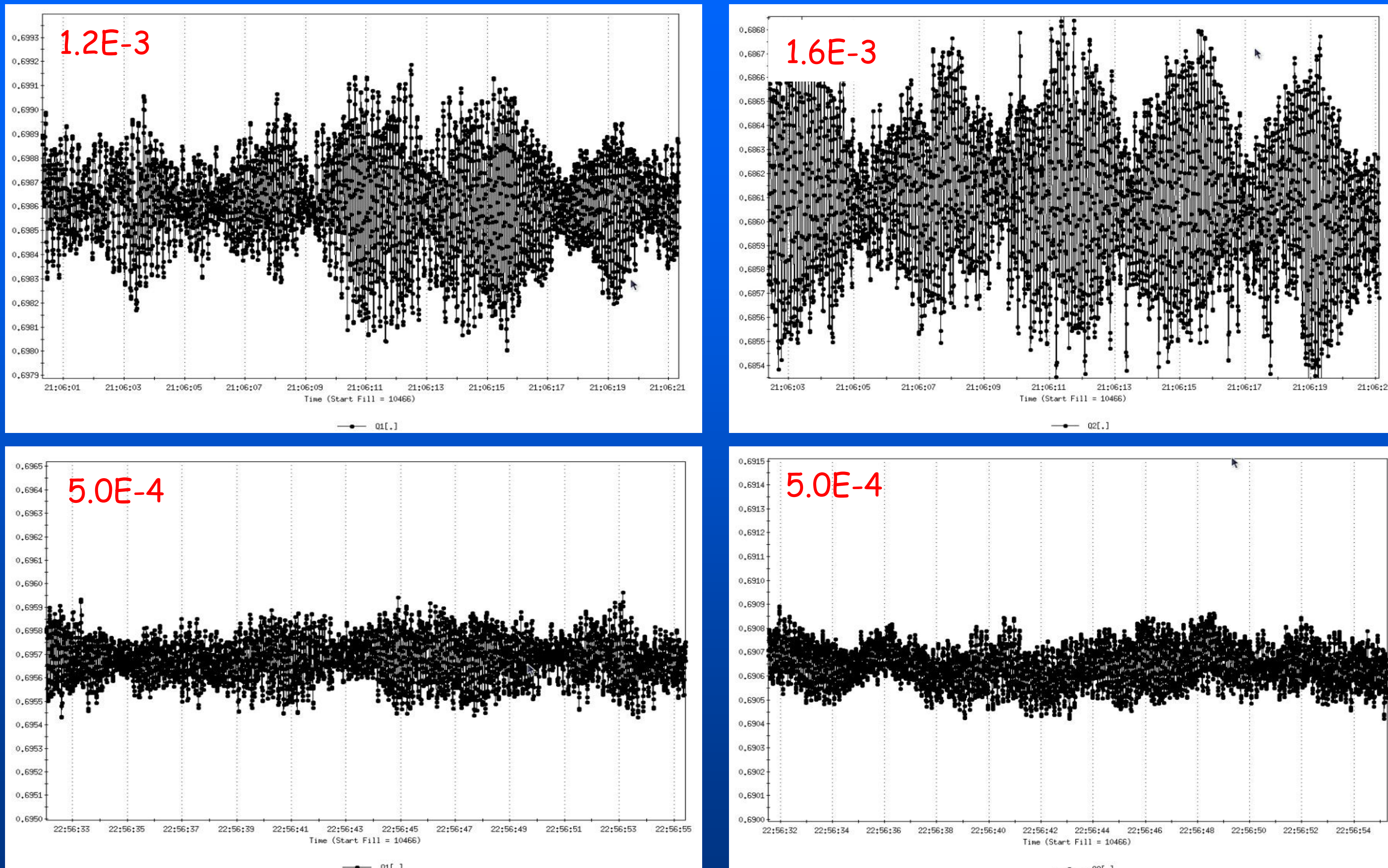
< Q > used for applications requiring high precision measurements

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

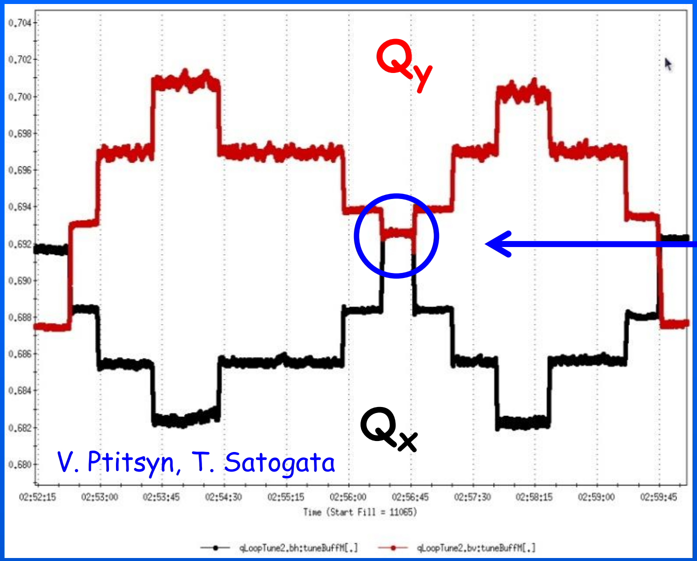
after correction

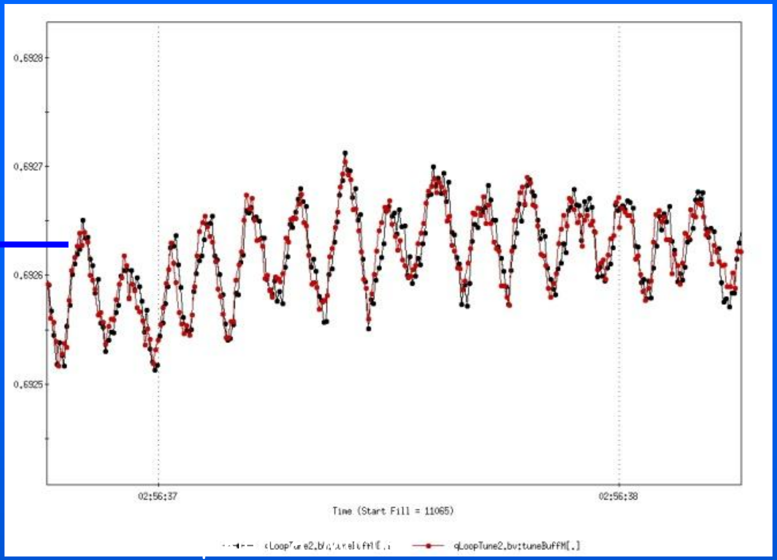


Tune modulation amplitudes reduced by factor 2-3 in both planes (peak-to-peak modulation amplitudes shown in red color in above plots)

affect on measurement precision (outstanding):

β*

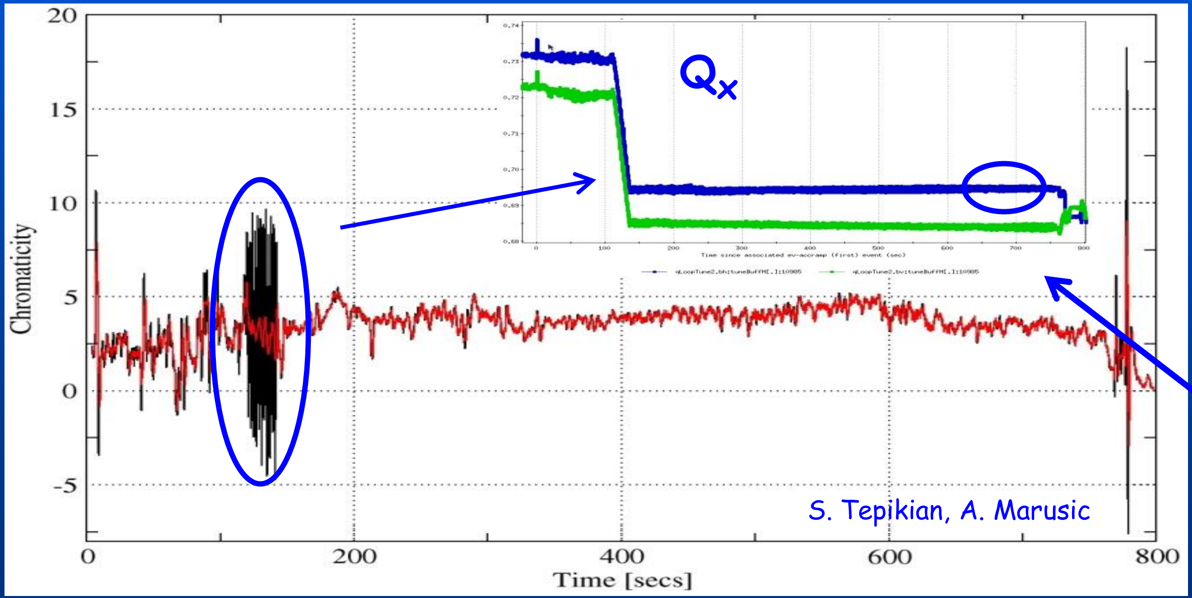


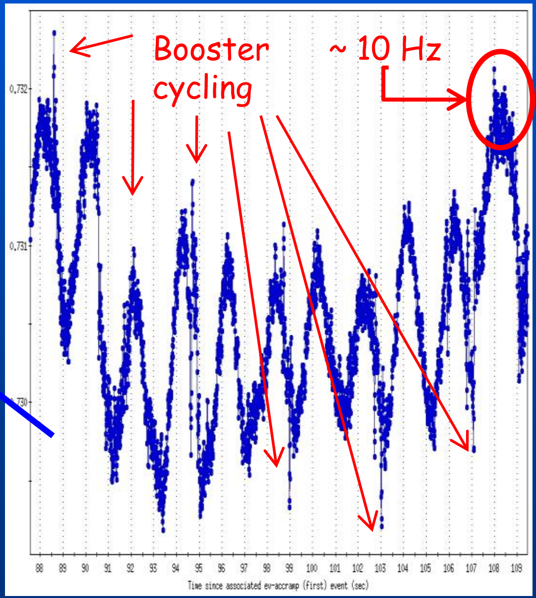


07/06/09, fill 11065

100 GeV, p+p

ξ





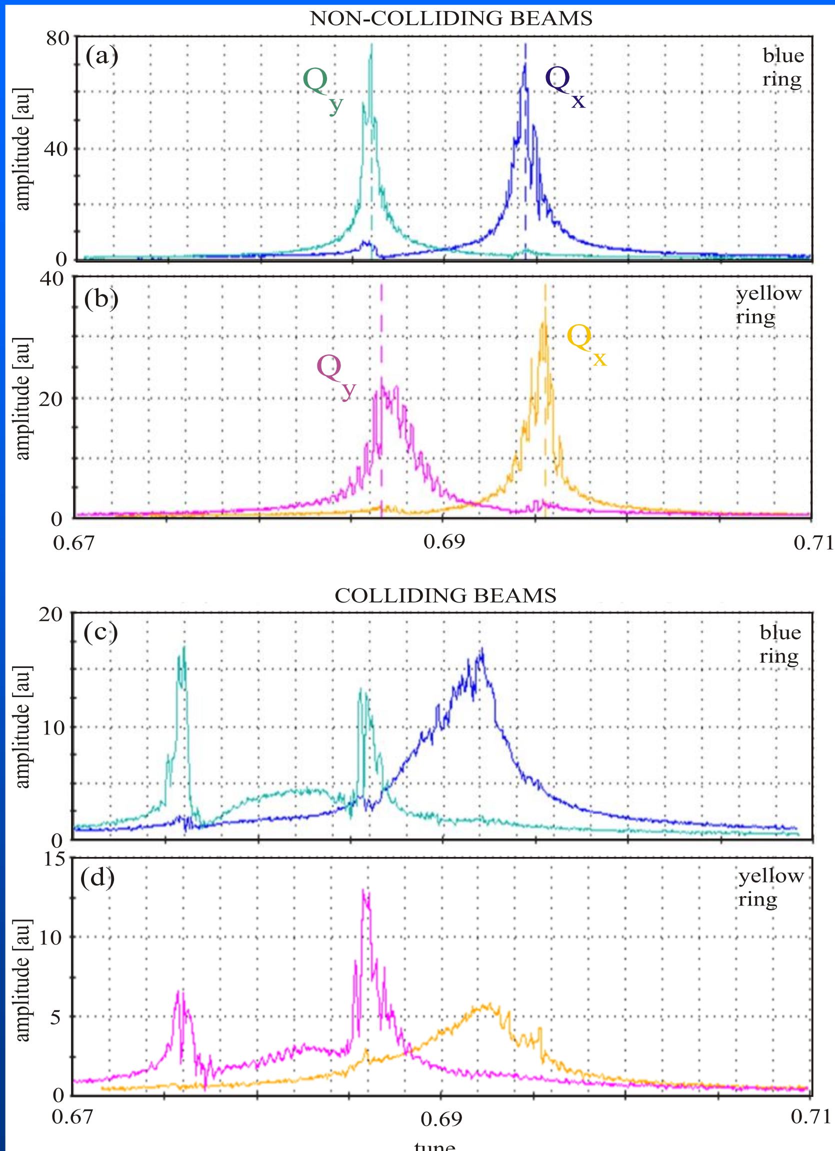
06/24/09, fill 10985

100 GeV, p+p

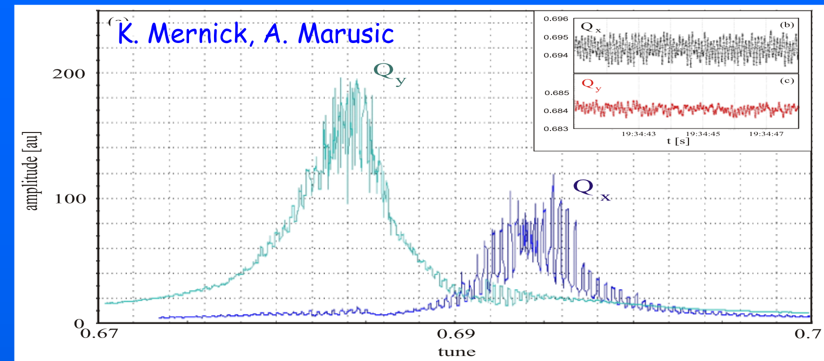
⇒ change in tune appears as “noise”

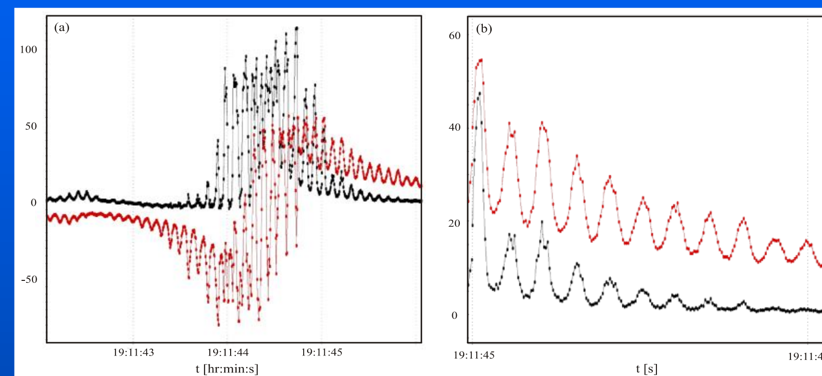
⇒ all structures identified

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

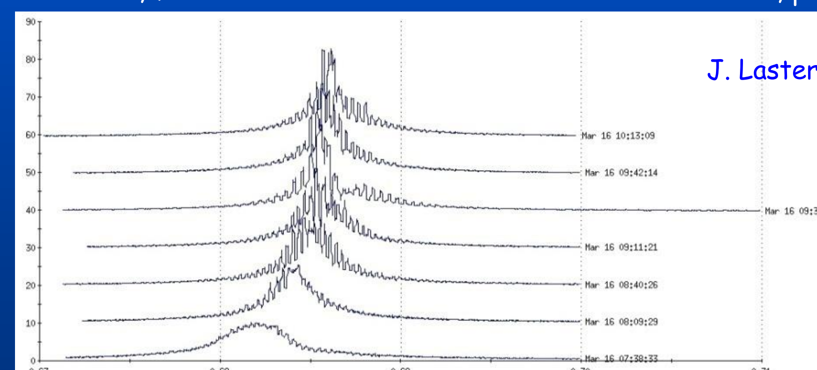


02/26/09, fill 10240 250 GeV, p+p





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



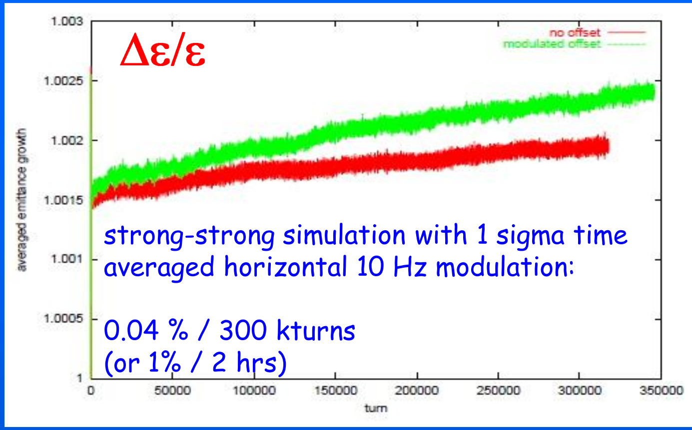
03/16/09, fill 10375 250 GeV, p+p

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

Δ x ⟺ (?) LUMINOSITY: FINDINGS

2003:

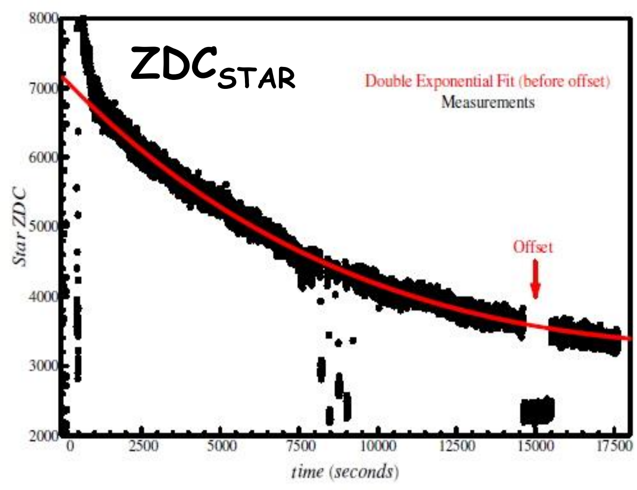
TABLE 1. RHIC Physical Parameters for the Beam-Beam Simulations	
beam energy (GeV)	23.4
protons per bunch	8.4×10^{10}
β^* (m)	3.0
RMS spot size at the IP (mm)	0.629
betatron tunes (ν_x, ν_y)	(0.22, 0.23)
chromaticity (q'_x, q'_y)	(2, 2)
synchrotron tune ν_z	3.7e-4
RMS bunch length (m)	3.6
momentum spread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

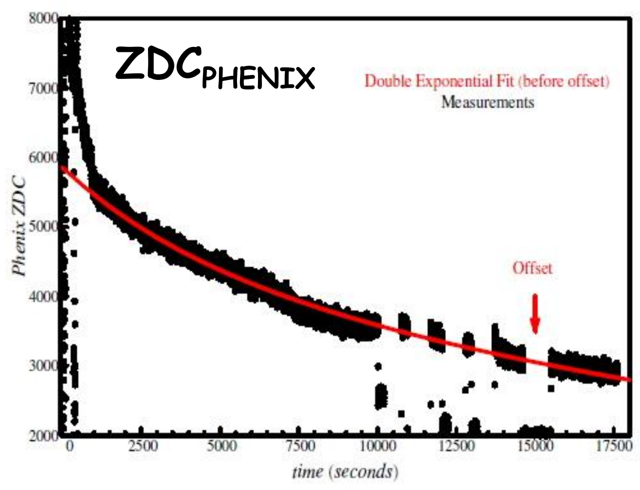


J. Qiang, et al (2003): "Parallel strong-strong/weak-strong simulations of BBI in hadron accelerators"

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





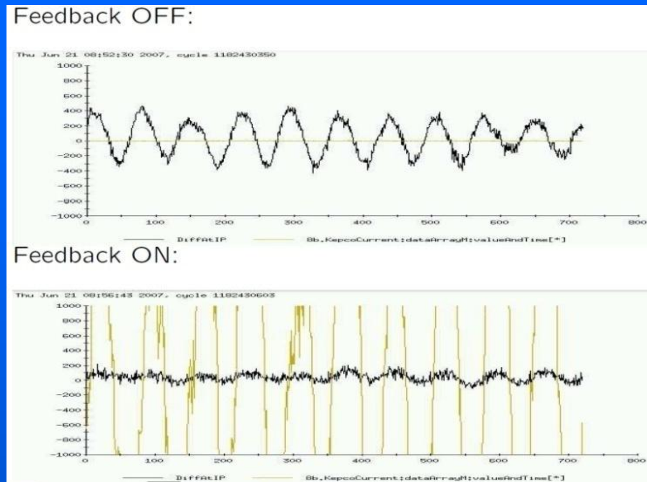
N.P. Abreu, W. Fischer (2007): "Emittance growth with offset beam-beam collisions and small beam-beam parameters"

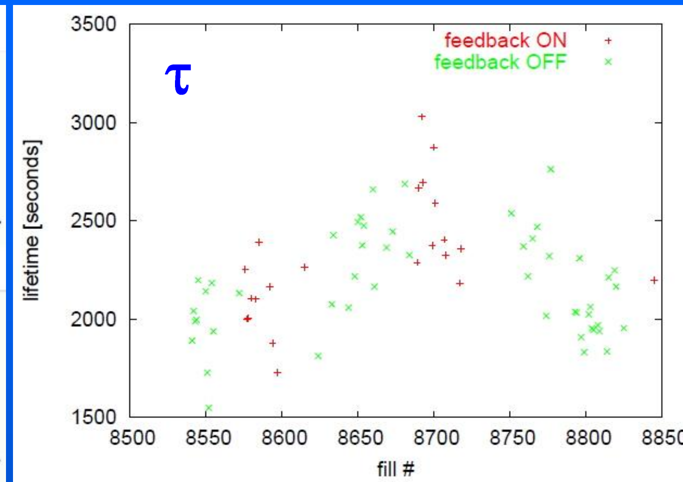
⇒ simulation and experiment both show negligible effect

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

$\Delta x \overset{?}{\Longleftrightarrow}$ LUMINOSITY: FINDINGS

2007: "10 Hz" feedback





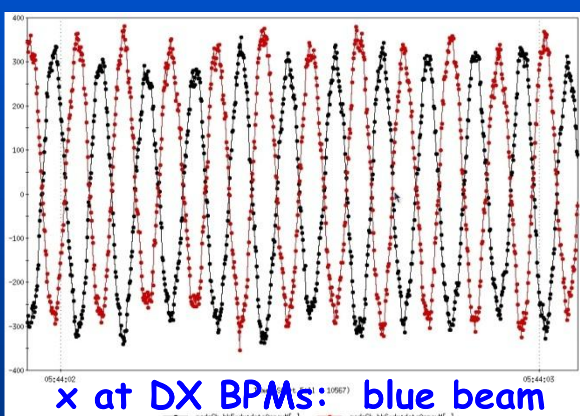
Double exponential fit;
shorter lifetime plotted

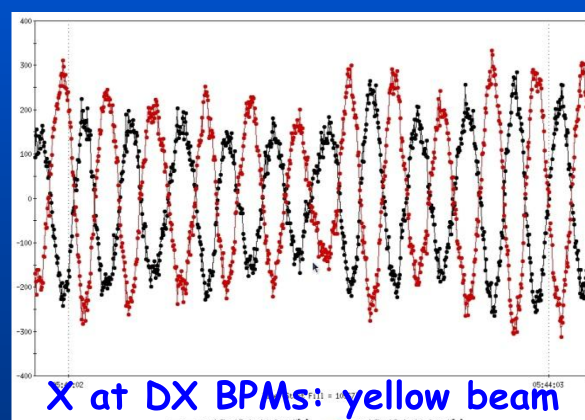
⇒ no strong evidence of luminosity improvement

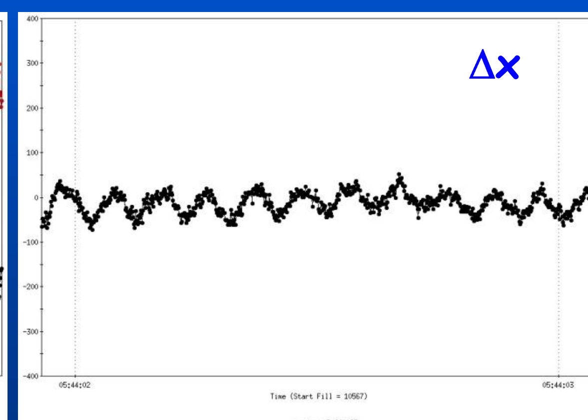
(in the limit of <u>weak-weak</u> dynamics)

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

2009: IR orbits







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

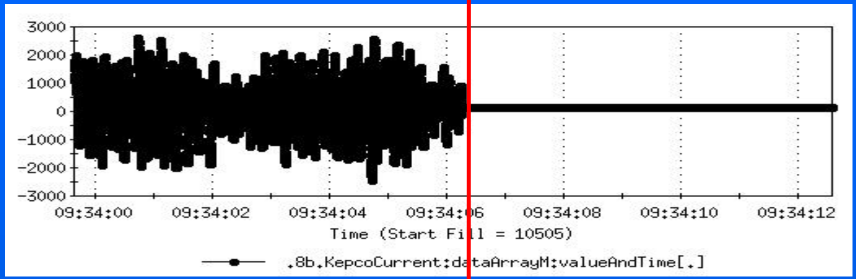
- beams "tilting" with respect to one another due to 10 Hz
- blue and yellow beams out of phase wrt tilt
- residual CENTROID motion is small

Δ x ⟺? LUMINOSITY: FINDINGS

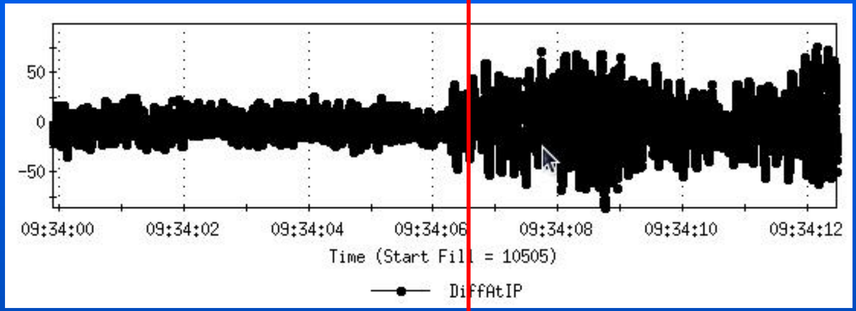
2009: "10 Hz" feedback

← FEEDBACK ON —— | —— OFF →

power supply current

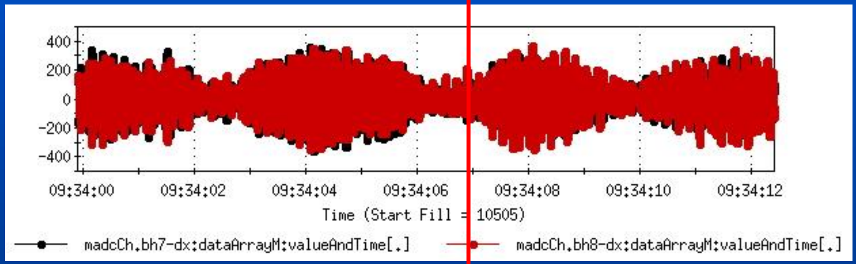


relative displacement at IP

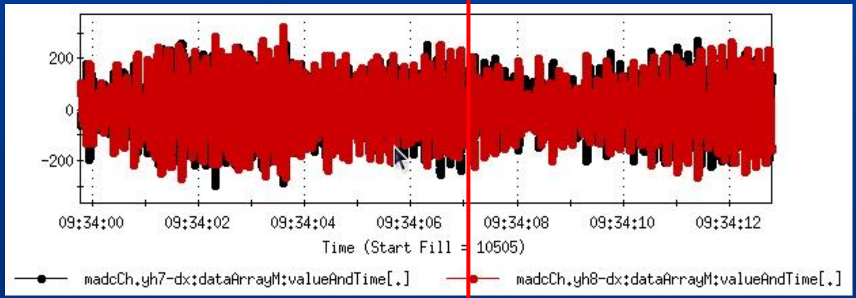


feedback works, but …

blue beam positions



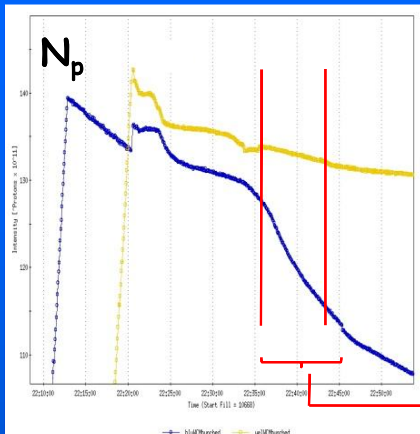
yellow beam positions

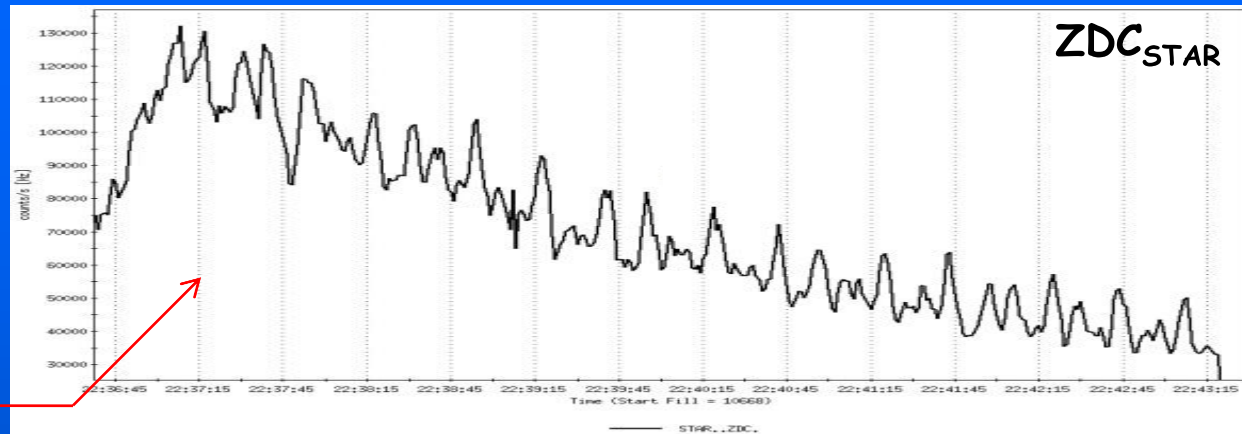


beams still "tipping"

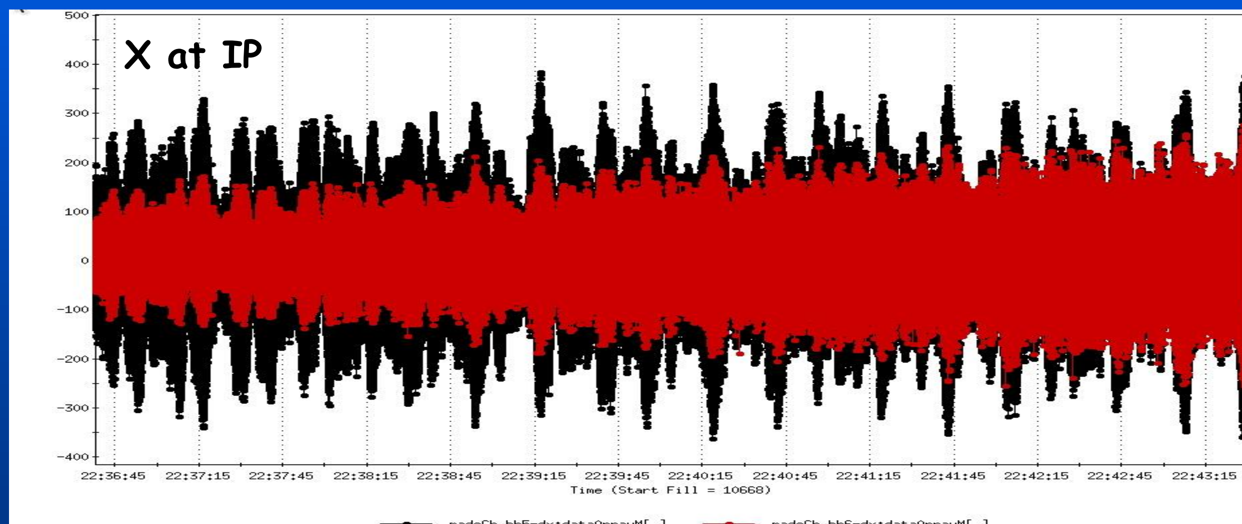
Δ x ? LUMINOSITY: FINDINGS

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





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



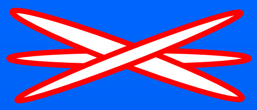
04/27/09, fill 10668

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 a background-dominated signal)

Δx ? 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

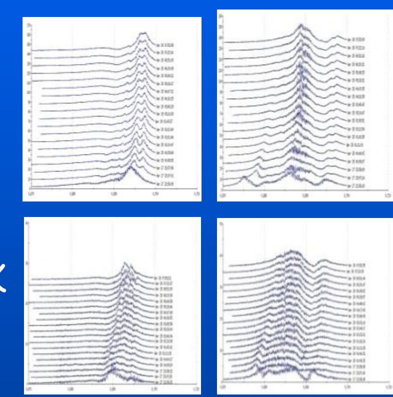


Remarks:

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:

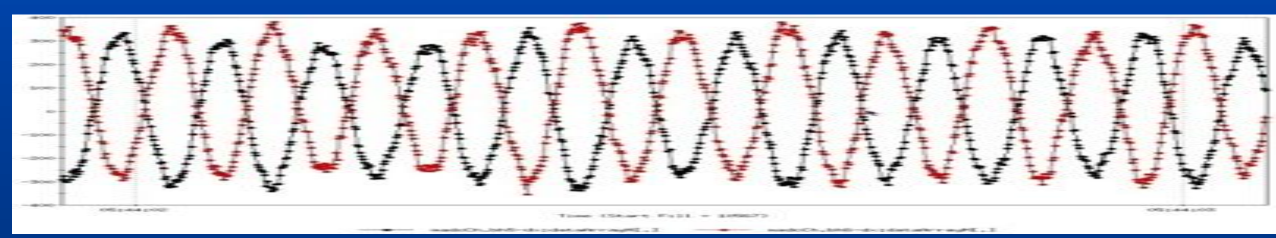


1) Beam loss rates are very large; large amplitude particles in tail/head would experience strongest long-range perturbations

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

3) Some evidence of opposite-sign tune shift (due to long-range BBI) 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

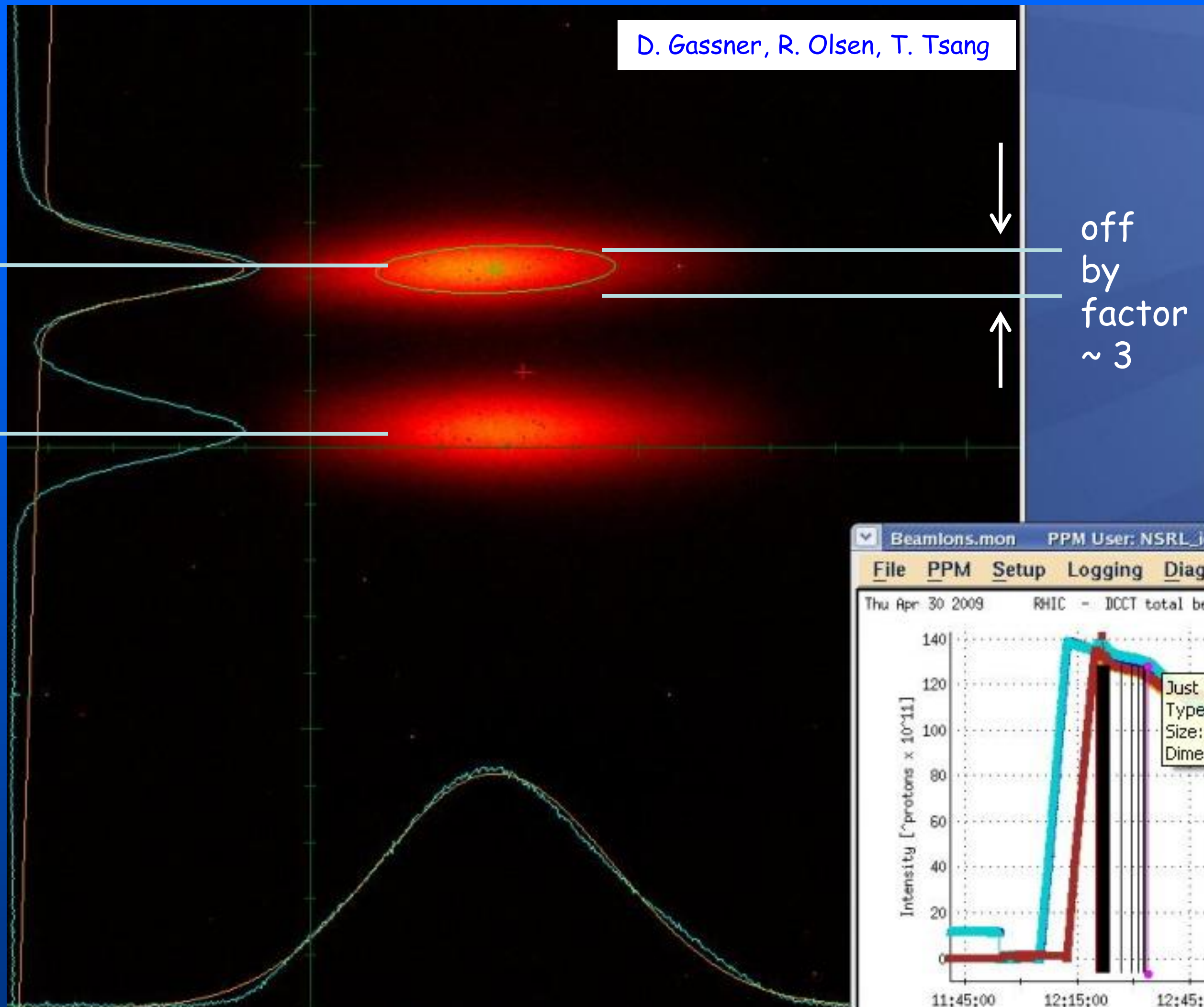
i.e. 60 microns / sigma_z

120 microns / 2 * sigma_z

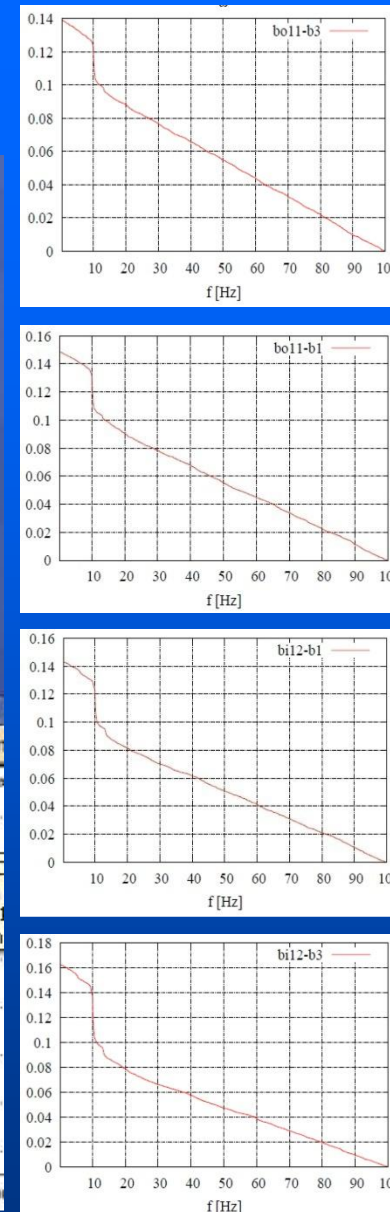
Δ x ? LUMINOSITY: FINDINGS

one more puzzle possibly solved: H- jet "resolution":

agrees with calibration



off by factor ~ 3



W. MacKay, T. Satogata

SUMMARY AND OUTLOOK

Precision of many measurement 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); modulates tune footprint / reduces available space in tune diagram

Observed beam-beam performance at RHIC postulated to be 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: reduced dynamic aperture, symmetry breaking (odd order beam-beam resonances)…, 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)
- "resolution" in fluorescence monitor (jet) images
- fast decay in current and luminosity (possibly)
- beam emittances derived from Vernier scans vs other emittance monitors (IPM, CNI) ?

Next steps:

1) 3-macrobunch model of beam dynamics and/or weak-strong simulations
2) review phase-advance between IPs
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