Beam-Beam Compensation in Tevatron

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II. MACHINE PHYSICS

A Theory and Tracking of the Beam-Beam Compensation

B Tevatron Electron Lens studies with 980 GeV protons

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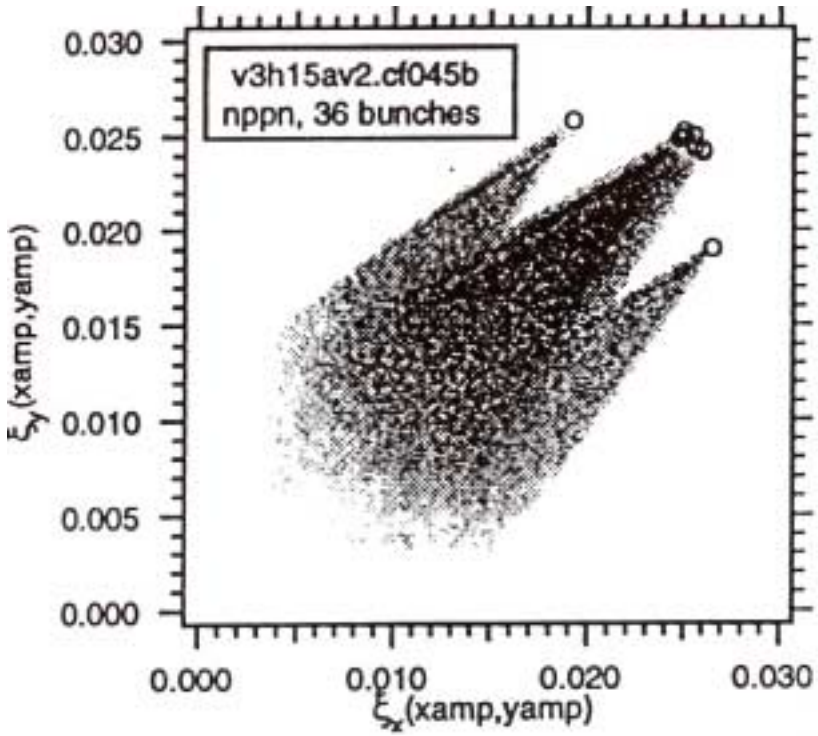
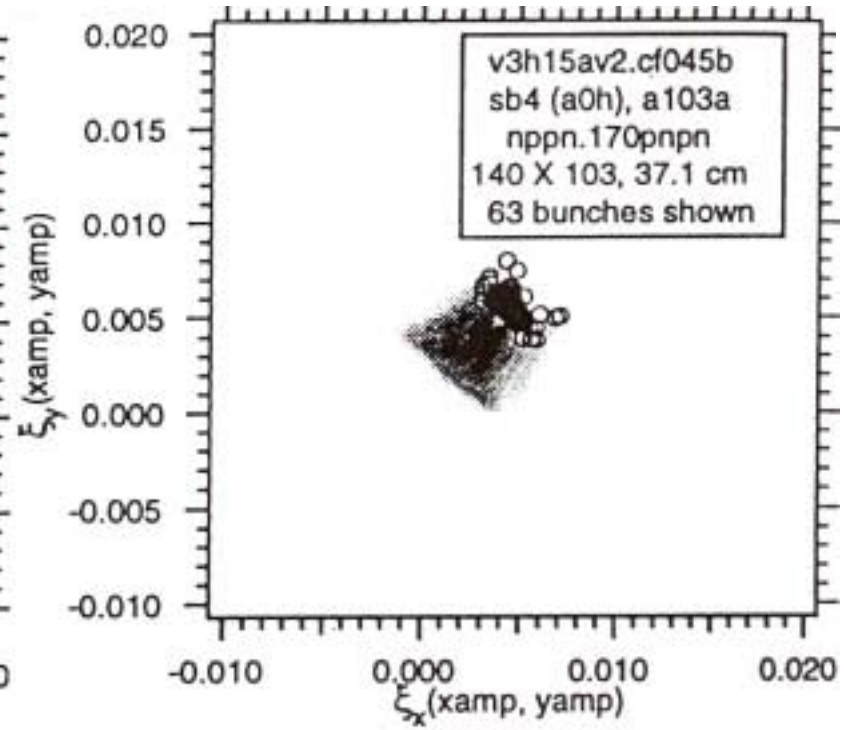
B.2 Proton tune shift due to TEL

B.3 Proton Lifetime with TEL

III. PLANS

Tev pbars will suffer from linear (bunch-to-bunch) and non-linear tuneshifts





P.Bagley
BNL-52601

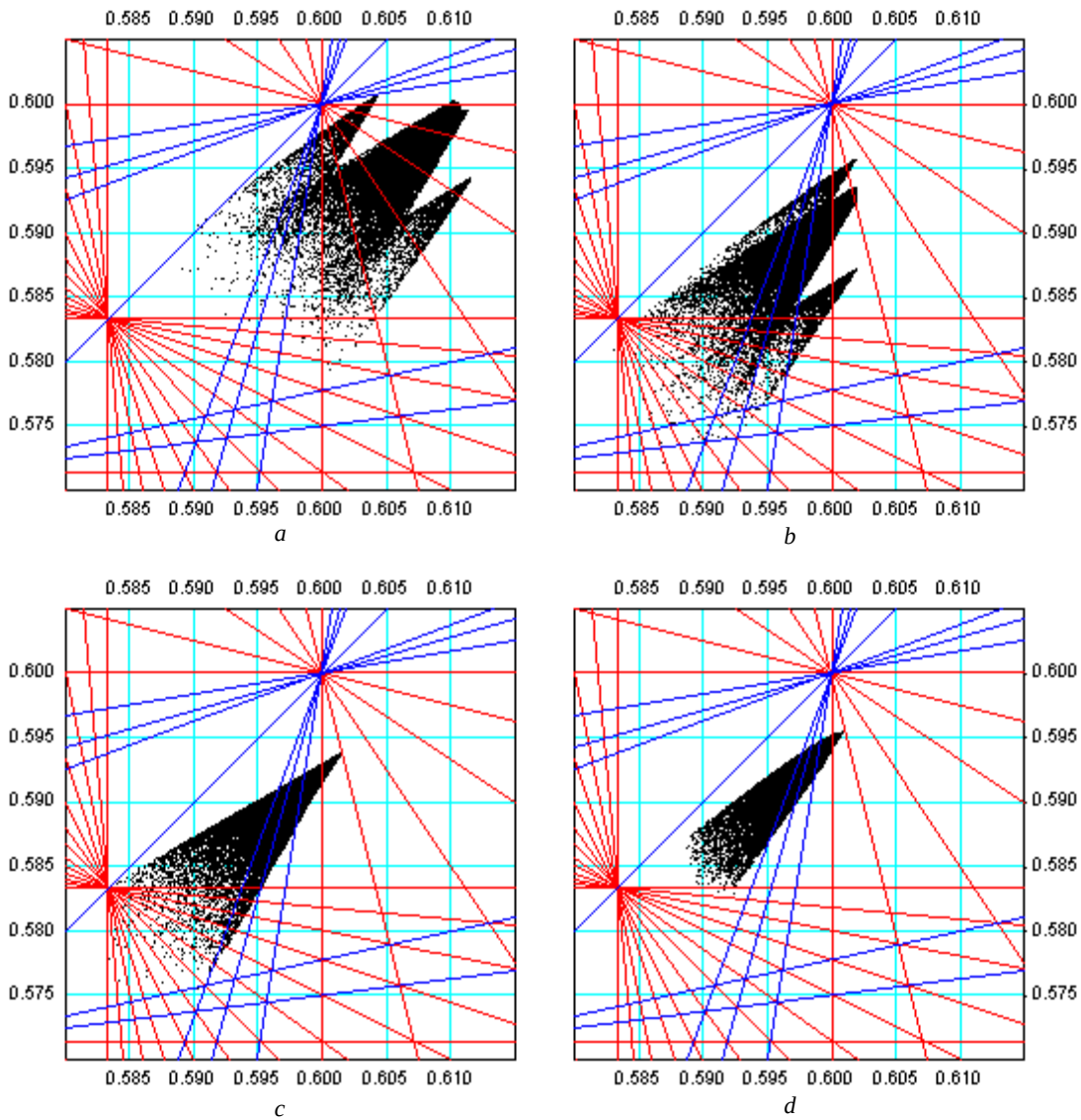
Run IIa

Run IIb

Linear dQ is proportional to N_P, nonlinear to N_P /ε - both contribute into peak luminosity as

$$L = \frac{3\gamma_r f_0}{\beta^*}(BN_{\bar{p}})\left(\frac{N_p}{\varepsilon_p}\right)\frac{F(\beta^*, \theta_x, \theta_y, \varepsilon_p, \varepsilon_{\bar{p}}, \sigma_z)}{(1+\varepsilon_{\bar{p}}/\varepsilon_p)}$$

What can be done with Tevatron Electron Lenses (TELs):



a) - Run IIa 36x36
b) - with one Linear TEL
c) - with two Linear TELs
d) – two Non-linear TELs

→ linear tunespread can be eliminate completely
→ non-linear tunespread can be reduced ~2 times

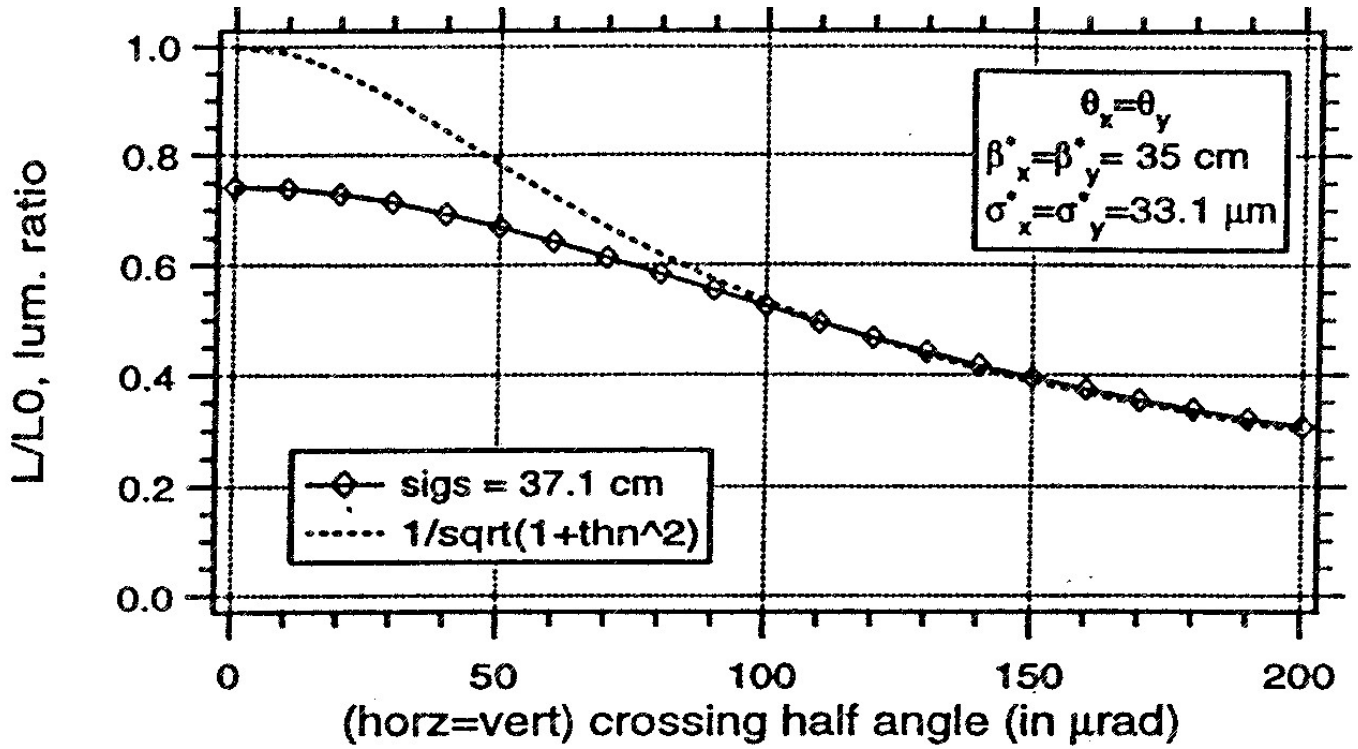
(Simplistic) estimate of peak luminosity increase
$L \propto \Delta\nu_{max} / (\Delta\nu_{BB} + \Delta\nu_{N\text{-}Lin})$

	L-BBC	NL-BBC
Run IIa	16%	60-100%
Run IIb	50%	60-100%

• assuming the same $\Delta\nu_{max}$ (no resonances added) and higher N-protons possible

Non-linear BBC promises additional 2-fold increase in *L* :

As it may make possible to eliminate the *crossing angle* by compensating 2 or 4 additional collision points around each IP, thus increasing geometrical luminosity factor L/L_o in Run IIb.



• note: potential increase in the integrated luminosity is more modest – 8-12% due to Linear BBC and some 40% due to Non-linear BBC

BBC: Theory and Tracking

The BBC was subject of thorough theoretical analysis and extensive numerical studies (at peak we employed 1/3 of FNAL computer power) since 1998 and the work is still in progress. Major achievements by now:

- effectiveness of linear BBC is confirmed
- electron beam size and charge distribution are optimized
- misalignment and noise effects are studied
- non-linear BBC analysis just started, preliminary results show possibility of 50% footprint compression without significant resonance excitation

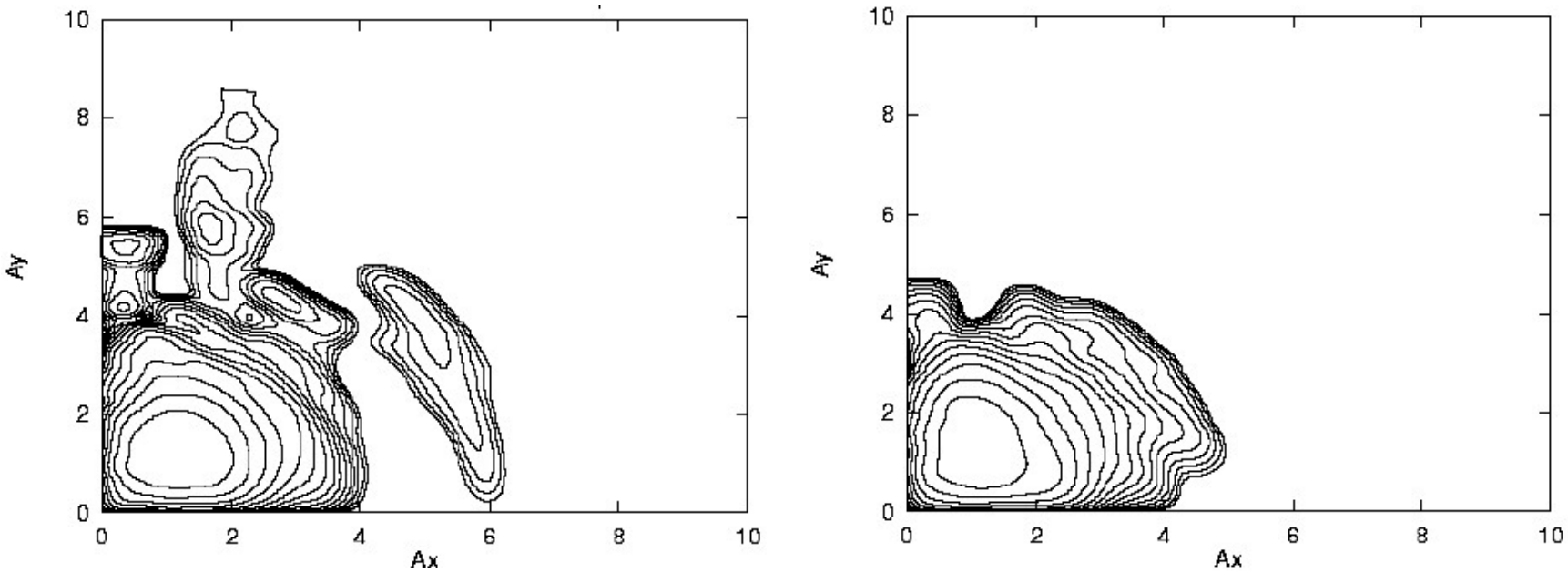
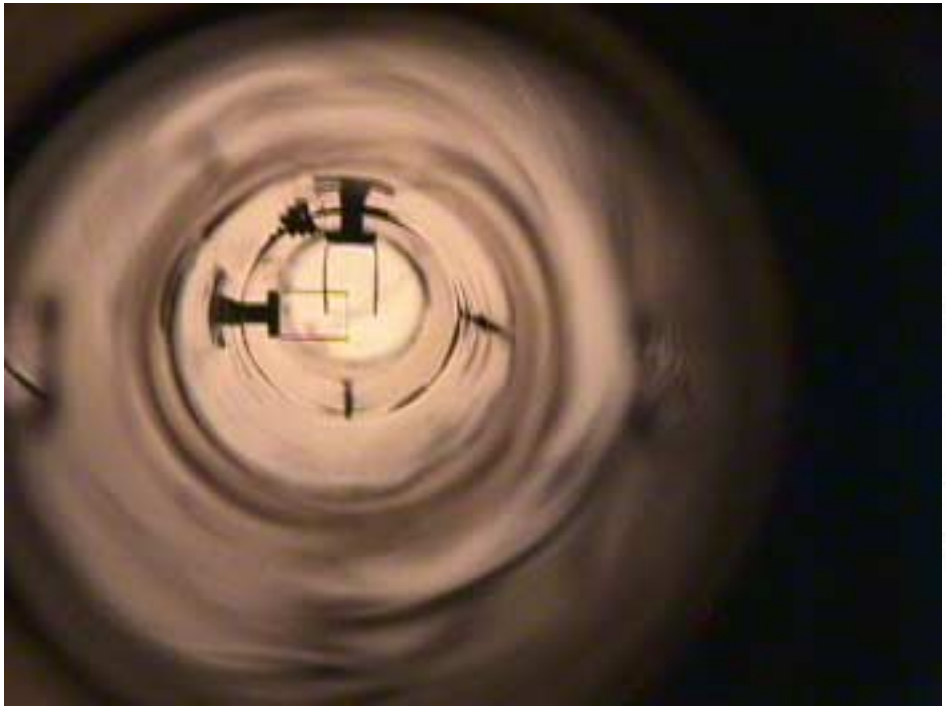
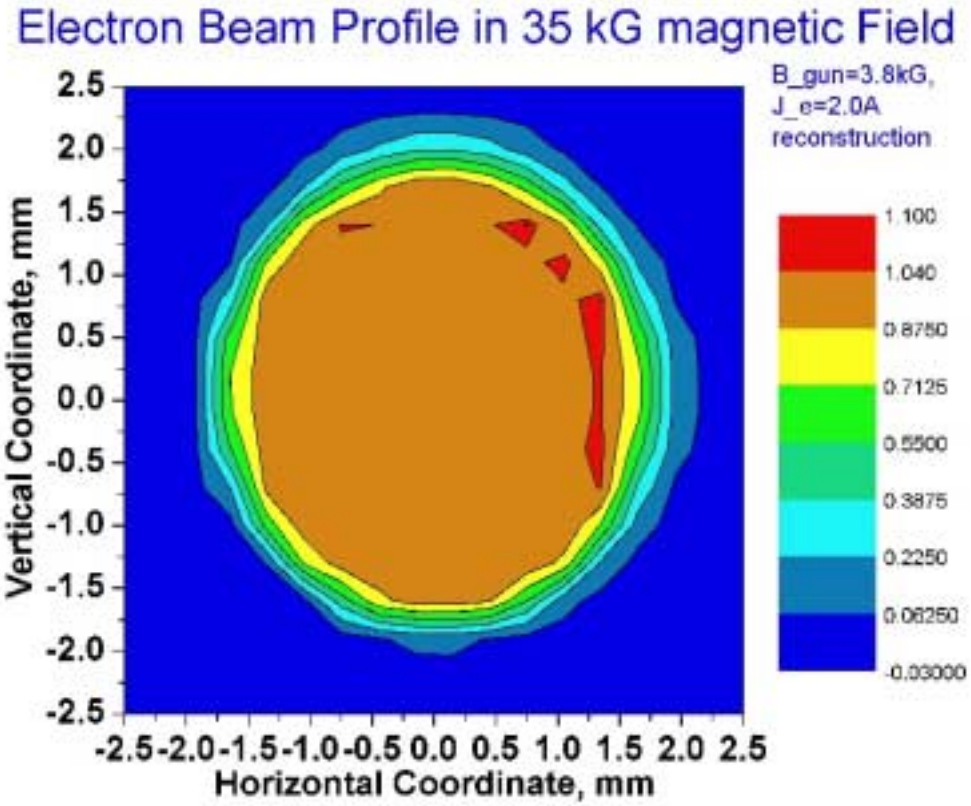


Figure: P-bar distribution in normalized betatron amplitude plane (A_X ,A_Y) after 1 min=3e6 turns [noise enhanced dynamics] without (left) and with TEL (right).

The 1st Tevatron Electron Lens at F48 (since 03/2001)

- from magnetic measurements we believe that electron beam is straight within ±0.10mm over 2.5 m of interaction length
- electron current distribution is ~flat, beam size variable by ratio B_{gun}/B_{main}





- max current 3.5A, beam energy ~10 kV, pulse width 800 (100) ns, $f_0 = n \cdot 48$kHz

Tuneshift due to Electron Lens

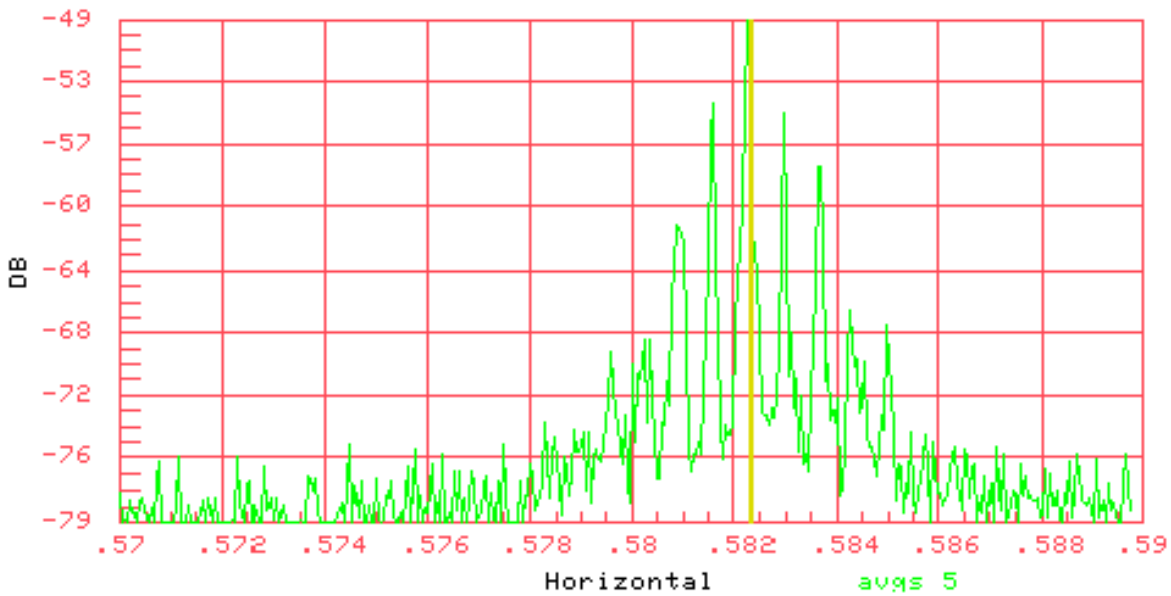
$$dQ_{x,y} = \mp \frac{\beta_{x,y}}{2\pi} \cdot \frac{1 \pm \beta_e}{\beta_e} \cdot \frac{J_e \cdot L_e \cdot r_p}{e \cdot c \cdot a_e^2 \cdot \gamma_p}$$

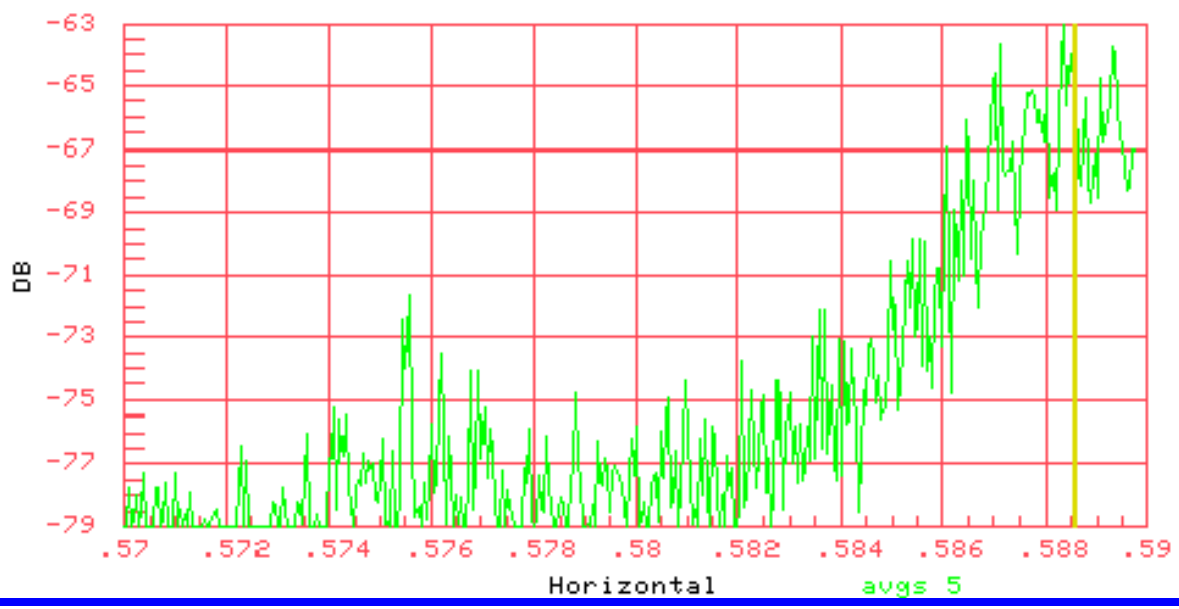
Signs reflect charge of particles and direction of the electron velocity.

L=2.5m long, J=3A, U=7.6 kV electron beam (β_e =0.13 – somewhat reduced by space-charge) with radius 1.5mm placed at β_x =101m produces positive tuneshift for 980 GeV antiprotons of about dQ=0.01

Note: So far we operated the 1st TEL on the protons only and electrons were moving in the same direction as protons →
For protons (co-moving) $1-\beta_e=0.87$; for pbars (collide) $1+\beta_e=1.13$

Therefore, we expect smaller and positive proton tuneshift 0.87/1.13=0.77 times the antiproton dQ.





Horizontal Schottky spectra of 980 GeV protons

without electron current

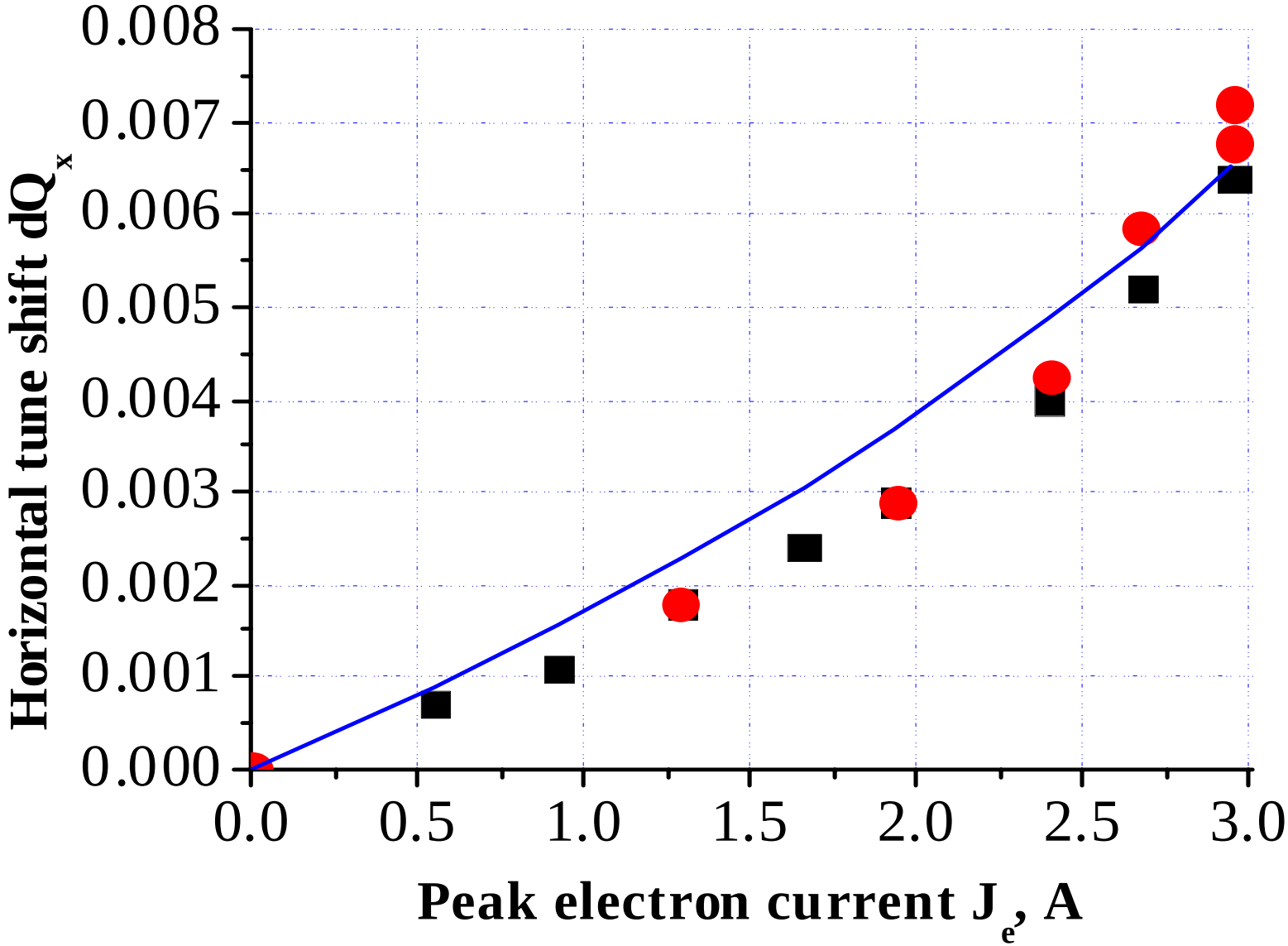
with 3A electron beam

- ***dQ_x*=+0.0065**

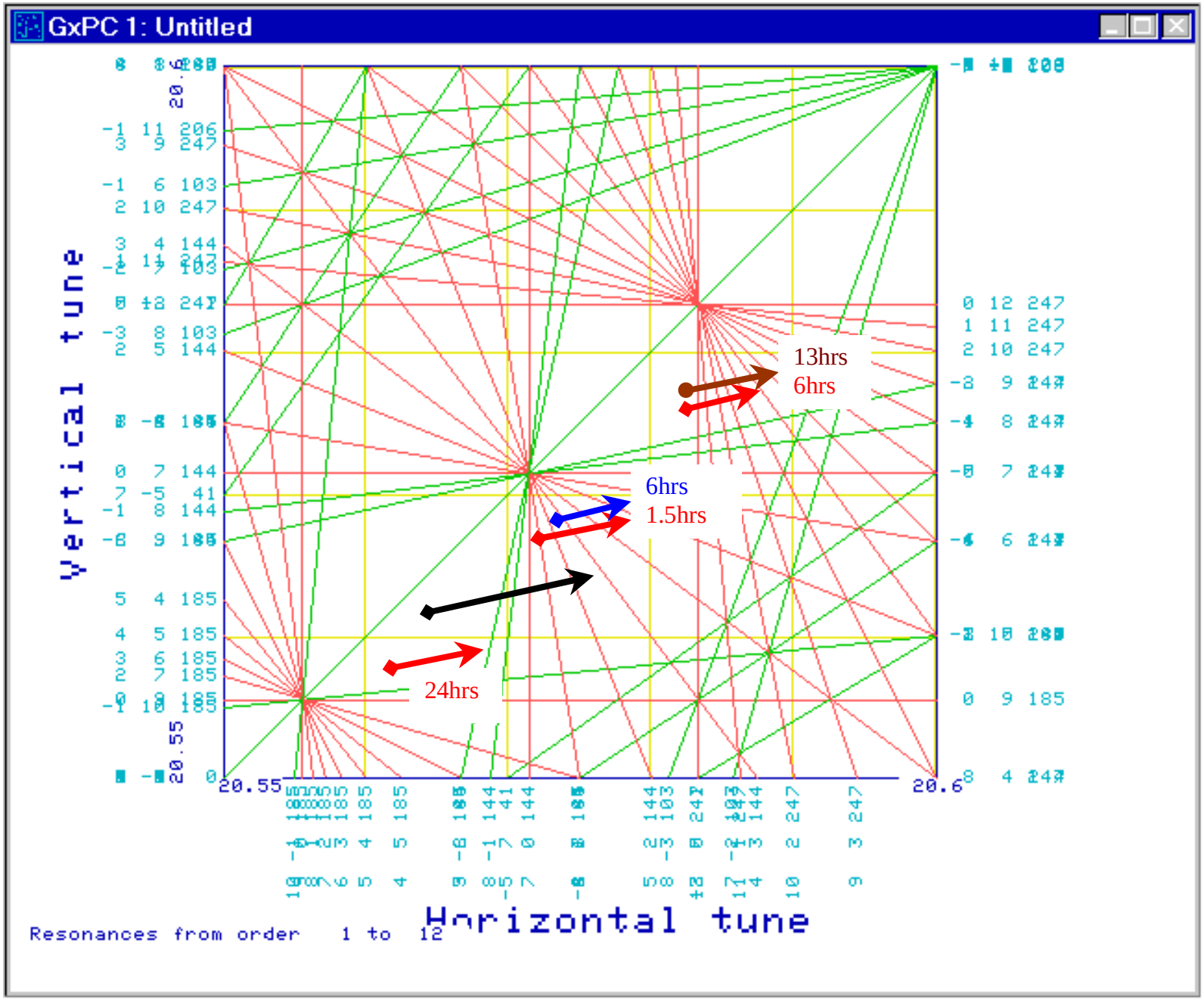
equivalent to dQ_x=-0.0085 for pbars

vertical tune is 4 times less

980 GeV proton hor. tuneshift: theory and experiment



p-tune shifts by TEL: 150GeV, 980 GeV



Status of studies: first results instill optimism

we know a lot about tuneshift –
vs J, U, time, position, angle, e-size

we know something about lifetime
vs position, angle, WP, J, e-size

we know nothing about emittance

we did not work with antiprotons

Next step: demonstrate pbar dQ=-0.01 without significant deterioration of luminosity lifetime. For that:

Find major factors affecting lifetime
Study emittance dynamics
Operate TEL on antiprotons
Improve e-p centering (BPMs, tickling, etc)
Diagnostics/hardware (b-b Q,ε-meter,6A gun, J,X,t-stabilization,etc)
Continue electron beam studies (e.g., space charge effects)

Time: 6-12 months at 3-4 shifts/months

Longer Term Scope of the BBC Project

1. (see short-term plan of studies)

2. Build and install the 2nd TEL, make the system for Linear BBC operational by Oct'03

3. Attack non-linear beam compensation (studies/hardware/commissioning) in FY'04+

4. Consider crossing angle elimination with TELs (2005?)