



Fermilab

Tevatron in Run II

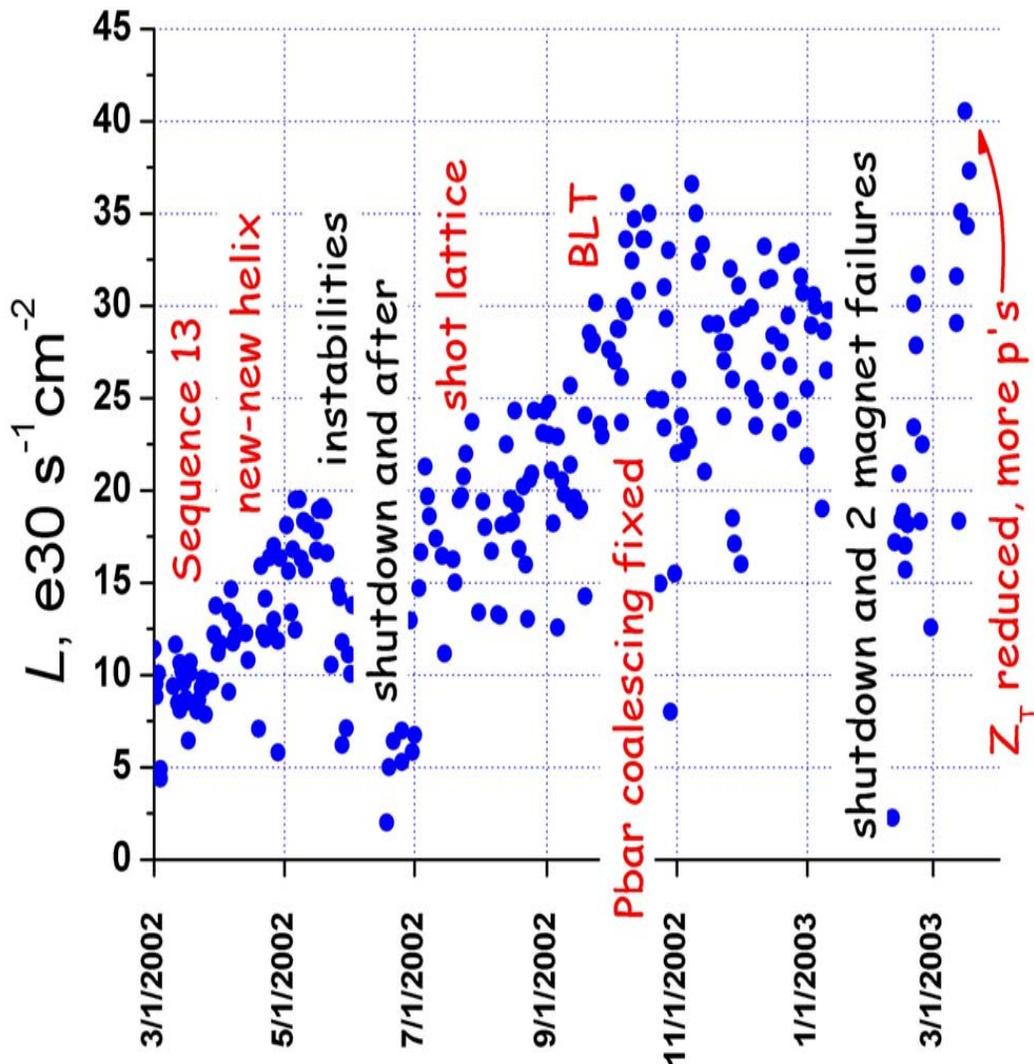
DoE Program Review
March 18-20, 2003

Vladimir Shiltsev

Goals and Current Performance

Parameter	Current Performance	FY03 Goal	Run II Goal	
Typical Peak Init. Luminosity	3.7e31	6.0e31	33e31	cm ⁻² sec ⁻¹
Integrated Luminosity	~6-7	12.0	70.0	pb ⁻¹ /week
Protons/bunch	205e9	240e9	270e9	
Antiprotons/bunch	26e9	31e9	135e9	
Proton emittance (95%, norm)	20	20	20	pmm-mr
Pbar emittance (95%, norm)	18	15	14	pmm-mr
Bunch length rms (prot, pbar)	0.6	0.54	0.54	meter
Peak Pbar Production Rate	11.5e10	18e10	45e10	/hr
Pbar: AA -> Low β efficiency	0.62-0.67	0.8	0.85	
Pbar: Inj. -> Low β efficiency	~ 0.8			
Number of bunches	36x36	36x36	36x36	
Beta @ IP	0.35	0.35*	0.35	meter
Beam Energy	980	980	980	GeV

A Year of the Tevatron



- 249 HEP stores
- 160 pb^{-1} to each detector
- Increase in luminosity from $12e30$ to $41e30$
- Run I record of $25.0e30$ broken on 7/26/2002
- Recent (20th) Run II record of $40.6e30$ set on 3/16/2002

... Increases tend to follow significant improvements, e.g., \rightarrow

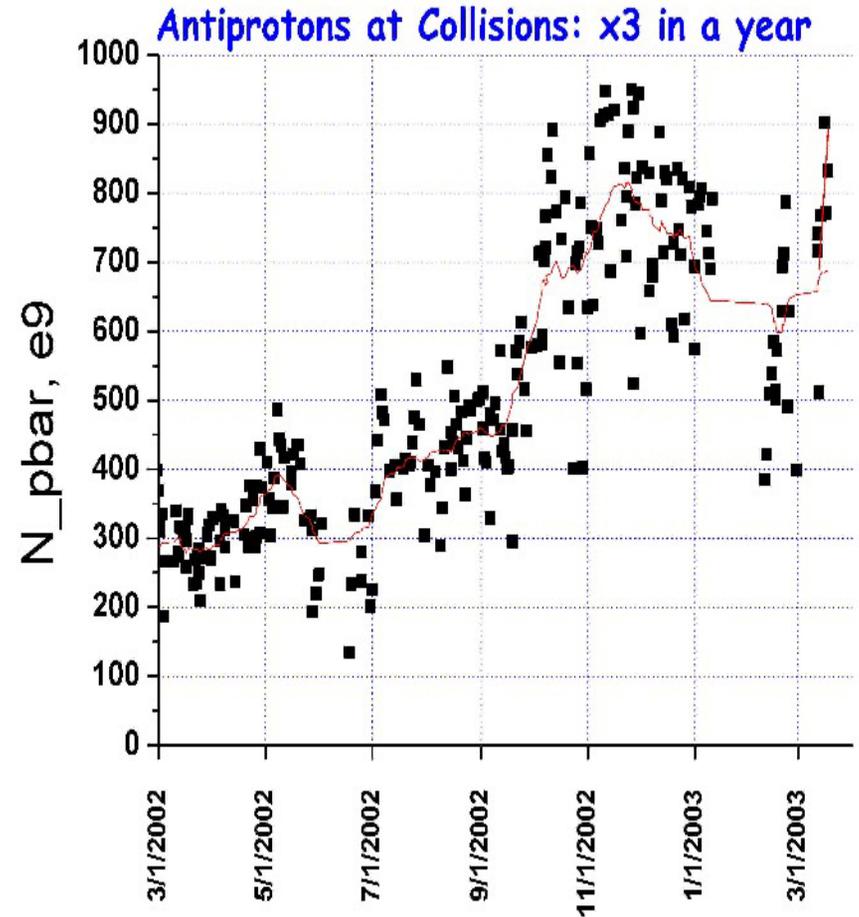
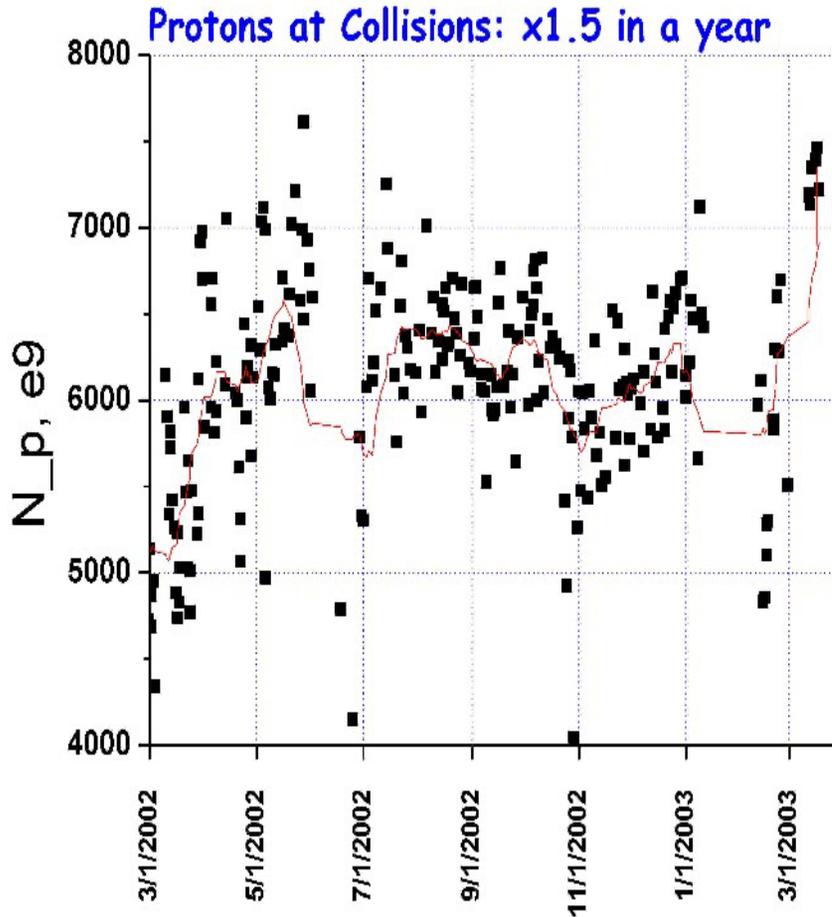
Reasons for \mathcal{L} -progress Since Mar'02

• "Sequence 13" fixed	Tev	x 1.40
• "New-new" injection helix	Tev	x 1.15
• "Shot lattice"	AA	x 1.40
• Pbar emittance at injection	Tev/Lines	x 1.20
• Pbar coalescing improvement	MI	x 1.15
• CO Lambertson removal	<u>Tev</u>	<u>x 1.15</u>
	total	x 3.6

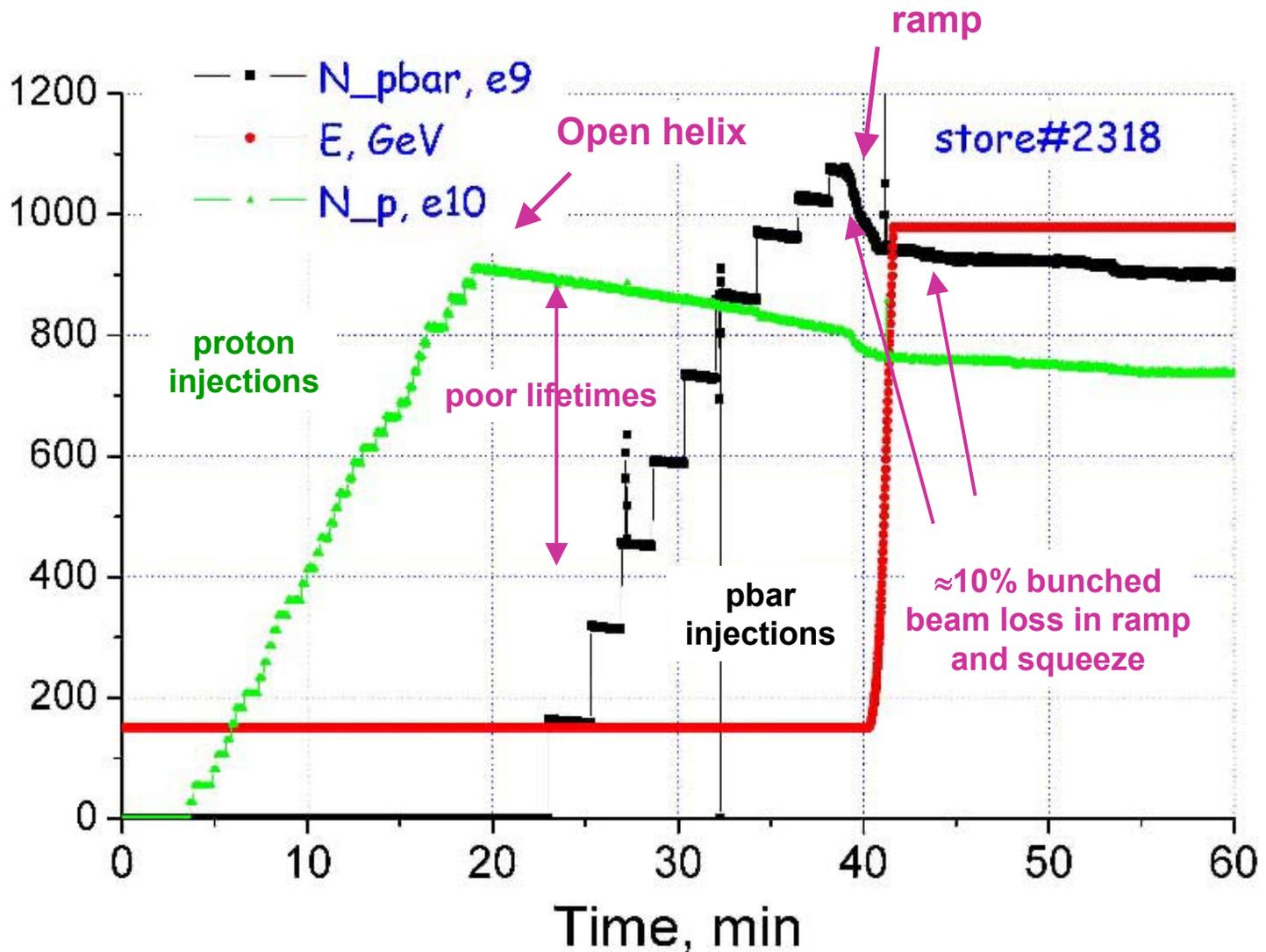
...plus additional improvements in the Tevatron:

- Tunes/coupling/chromaticities at 150/ramp/LB
- Orbit smoothing
- Longitudinal damper to stop σ_s blowup
- Transverse dampers improve 150 GeV lifetime
- Separator scans

Tevatron Beam Intensities



Tevatron Efficiencies



Tevatron Emittance

General comments on emittance blow-up from
Flying Wire measurement^{**}
(95%, normalized emittances):

- $< 1\pi - 2\pi$ at proton injection
- $\sim 4\pi - 6\pi$ at pbar injection
- $< (\text{negative}) 2\pi - 3\pi$ protons at 150 (scraping)
- $\sim (\text{negative}) 0\pi - 3\pi$ pbars at 150 (scraping)
- $2\pi / 5\pi$ blowup on ramp (protons/pbars)^{**}
- scallop emittances for (mistuned)pbars ($+20\pi$)
- occasional instability, $5\pi - 50\pi$, at 980 Gev

**** There remains uncertainty of FW emittance measurements.
(See later slides)**

Pbar Losses → Beam-Beam Interaction

- *Pbar transfer efficiency strongly depends on N_p , helix separation, orbits, tunes, coupling, chromaticity and beam emittances at injection*
- *Summary of progress with beam-beam since March 2002:*

	<i>Mar'02 *</i>	<i>Oct'02 **</i>	<i>Jan'03 ⁱ</i>	<i>Mar'03 ⁱⁱ</i>
<i>Protons/bunch</i>	<i>140e9</i>	<i>170e9</i>	<i>180e9</i>	<i>205e9</i>
<i>Pbar loss at 150 GeV</i>	<i>20%</i>	<i>9%</i>	<i>4%</i>	<i>4%</i>
<i>Pbar loss on ramp</i>	<i>14%</i>	<i>8%</i>	<i>12%</i>	<i>11%</i>
<i>Pbar loss in squeeze</i>	<i>22%</i>	<i>5%</i>	<i>3%</i>	<i>2%</i>
<i>Tev efficiency Inj → low beta</i>	<i>54%</i>	<i>75%</i>	<i>75%</i>	<i>80%</i>
<i>Efficiency AA → low beta</i>	<i>32%</i>	<i>60%</i>	<i>62%</i>	<i>65%</i>

** average in stores #1120-1128*

*** average in stores #1832-1845*

ⁱ average in stores #2114-2153 (9 stores)

ⁱⁱ average in stores #2315-2326 (5 stores)

Tevatron Reliability

- 151 stores from 6/1/2002 to 1/11/2003
- 99 (65%) ended intentionally
- 52 stores ended with failure
 - (10) Quench Protection Monitor (QPM) system
 - (7) Power glitch
 - (6) Cryogenics system
 - (4) Kicker pre-fire
 - (4) Quench on abort
 - (3) RF
 - (3) Tevatron Power Supply
 - (2) Power supply
 - (2) Kicker
 - (5) Controls, collimator, safety, studies
 - And 1 Earthquake in Alaska
- 2 magnets ground faulted → 2 weeks to replace

Planned Reliability Improvements <ul style="list-style-type: none">• QPM VFCs• Cryogenics• Kicker pre-fire

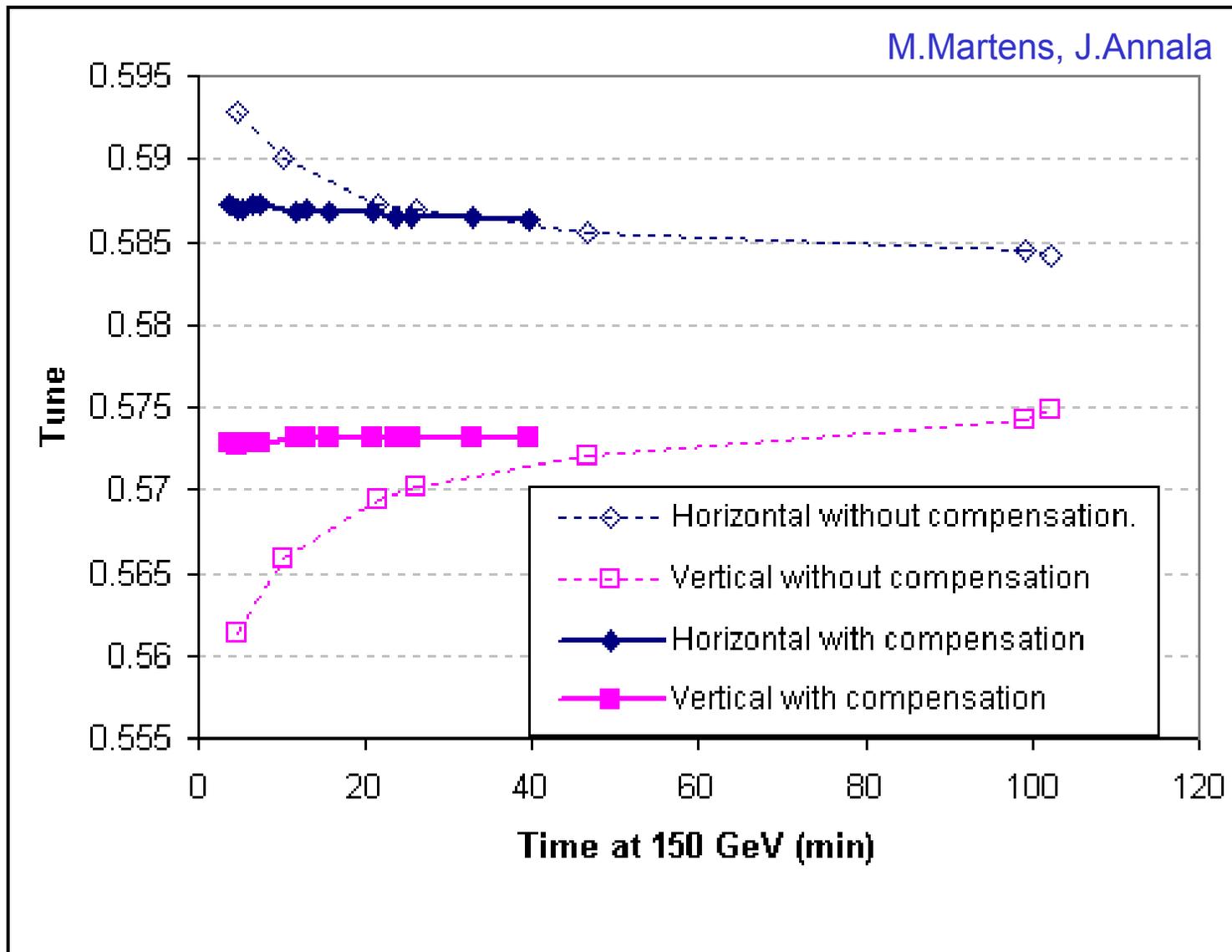
January 2003 Shutdown

- CO Lambertson Replacement - helped already, more to come
 - Increases aperture at CO
 - Leads to increased proton/antiproton helical orbit separation.
 - Reduces transverse impedance
- Schottky monitor - commissioning in progress
 - Measure chromaticity non-destructively
 - Measure tunes of individual bunches
- CDF Shielding - 50% count rates reduction
 - Add steel around low beta quads.
 - Should reduce backgrounds in muon chambers by factor of 5.
- New TEL electron gun. - lifetime doubled
 - Gaussian shaped emittance of electron beam
- Alignment Work - more to come

Tune/coupling/chromaticity/orbits

- Tune up is essential for consistent operations ...
 - Much effort during "Studies Periods" (used to be 5 shifts/week... now >halved) is actually maintenance (orbit smoothing and tune/coupling/chromaticity adjustments)
- ... and for understanding more complicated physics
 - Beam-beam effects, instabilities and dampers, beam lifetimes, beam halo rates, etc. are more difficult to understand when machine parameters drifting.
- Some troubles:
 - Tune/coupling drifts at 150 GeV. (Now compensated.)
 - Tune/coupling snapback on the ramp. (Now compensated.)
 - Chromaticity snapback? (Was measured. Is OK.)
 - Orbit drifts. (Started BPM and smoothing improvements)

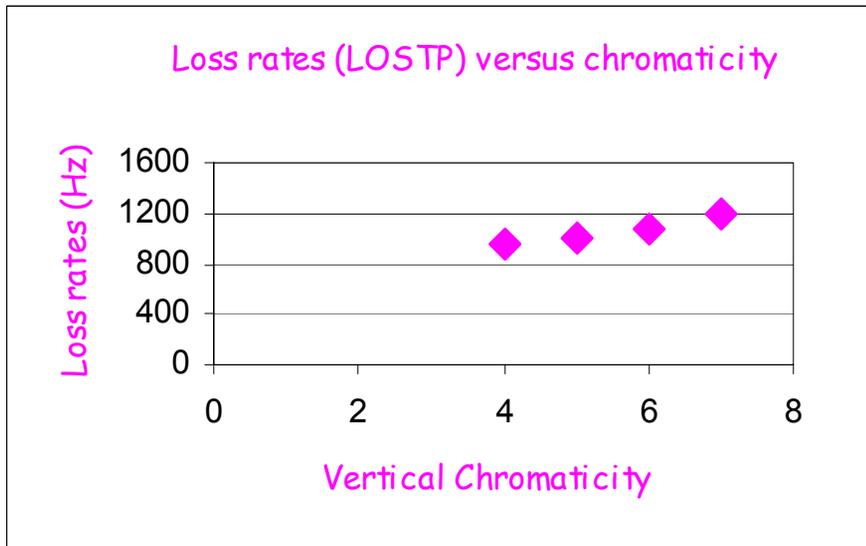
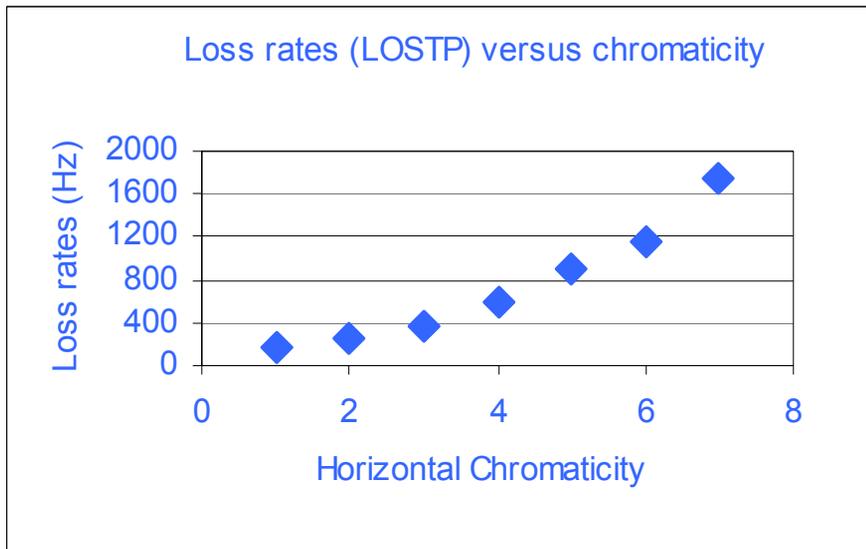
Tune Drift @ 150 Gev



Lifetime Issues at 150 Gev

- Poor Pbar lifetime at 150 Gev
 - Depends on emittances, N_p , $C_{v,h}$, and bunch number
 - Lifetime ~ 3-8 hrs (was <1 hr in 2002)
 - Original injection helix has been modified, separation increased and optimized to fit tight C0 aperture ("new-new helix")
 - Replace lambertsons @ C0 - gain 25 mm vertically
 - Modify high β section at A0 formerly used for fixed-target extraction
- Poor proton lifetime on helix ~ 3-4 hr (was ~ 2)
 - depends on chromaticity
 - Instability prevents lower chromaticity : now ~ 2
was ~ 8
 - Dampers help to keep beam stable (only mode 0)

Lifetime and Chromaticity at 150 Gev



Measured loss rates as function of chromaticity (with protons on the pbar helix)

- Lower chromaticity is better for lifetime

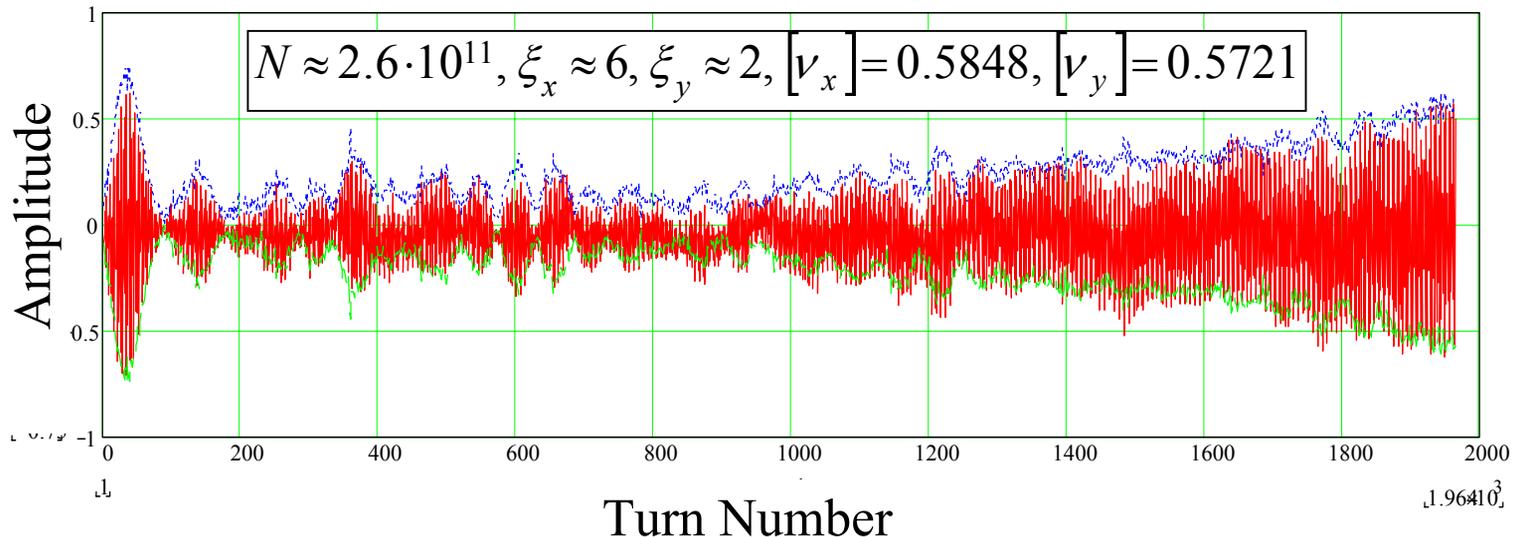
- Instabilities appear
 $\xi < 3-5$ (before)
 $\xi < 1$ (now)

- we did run with $\xi_H = 8$, $\xi_V = 8$ to avoid instabilities

- Dampers allow us to lower chromaticity and improve lifetime

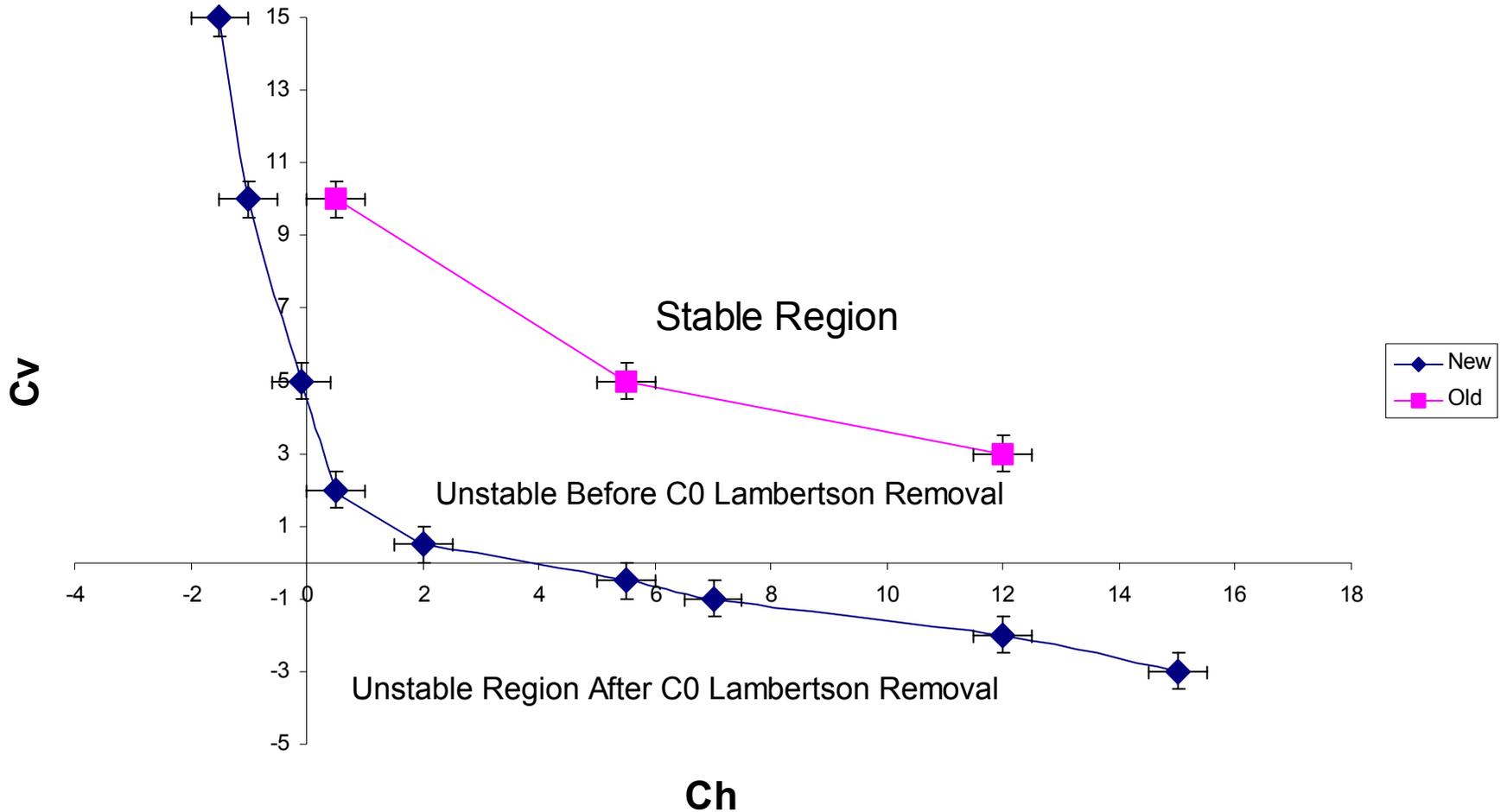
Unstable Head-tail Motion

Developing head-tail instability with dipole configuration
Beam is unstable for $\xi_x \approx 6$, $\xi_y \approx 2$
Longitudinal and transverse dampers OFF
 $N_p = 260E9$

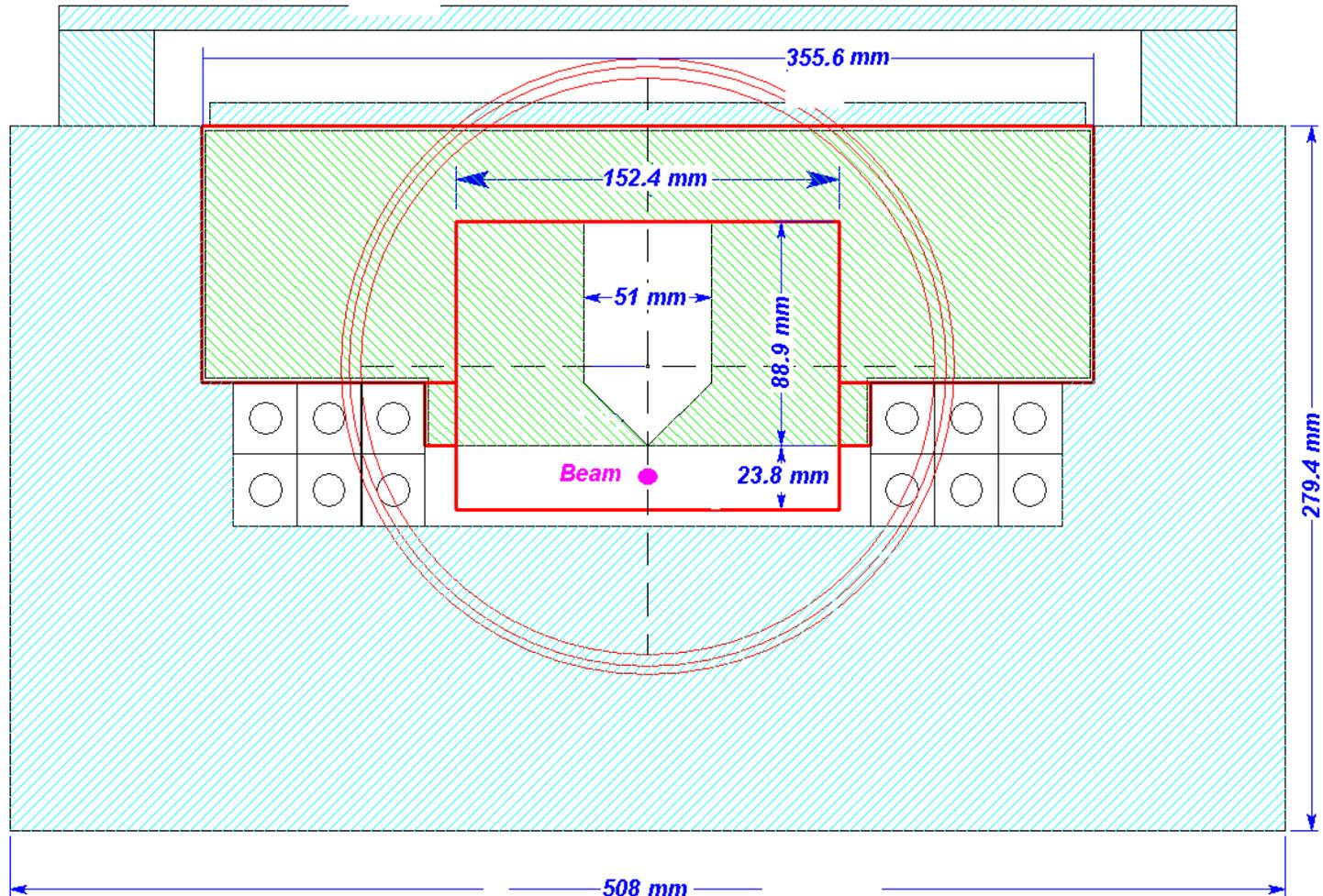


Weak Head-Tail Instability

Regions of Stability



CO Lambertson Magnet (removed)



...Was responsible for (est) >50% of transverse Tev impedance

Losses on Ramp

- Currently the biggest hit on Tev efficiency
 - 5-7% of protons, 10-12% of pbars
 - Losses are smaller for shorter bunches (~30% of longitudinal emittance reduction will reduce losses to ~ 3-4%)
 - Losses are smaller for smaller transverse emittance (almost no losses if emittances $< 12\pi$)
 - Pbars die due to insufficient separation > 500 GeV
- Dangerous DC beam losses at the beginning of the ramp
 - May quench the Tevatron
 - ~(2-16)% come from MI, ~2% created in Tev (dancing bunches)

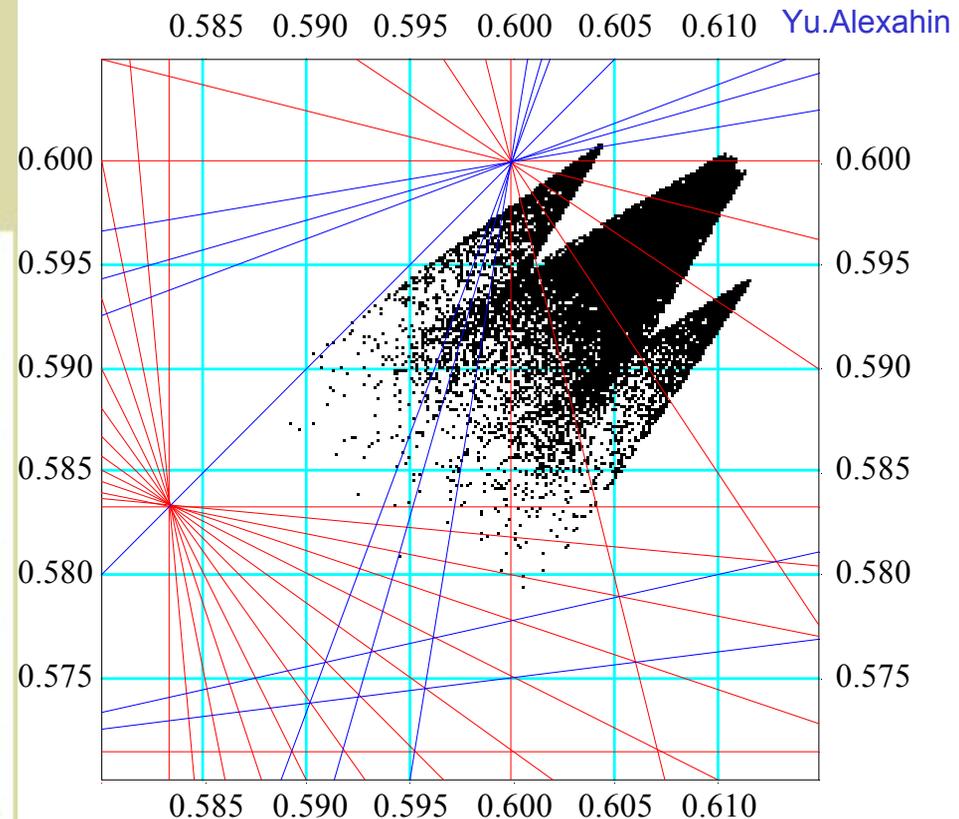
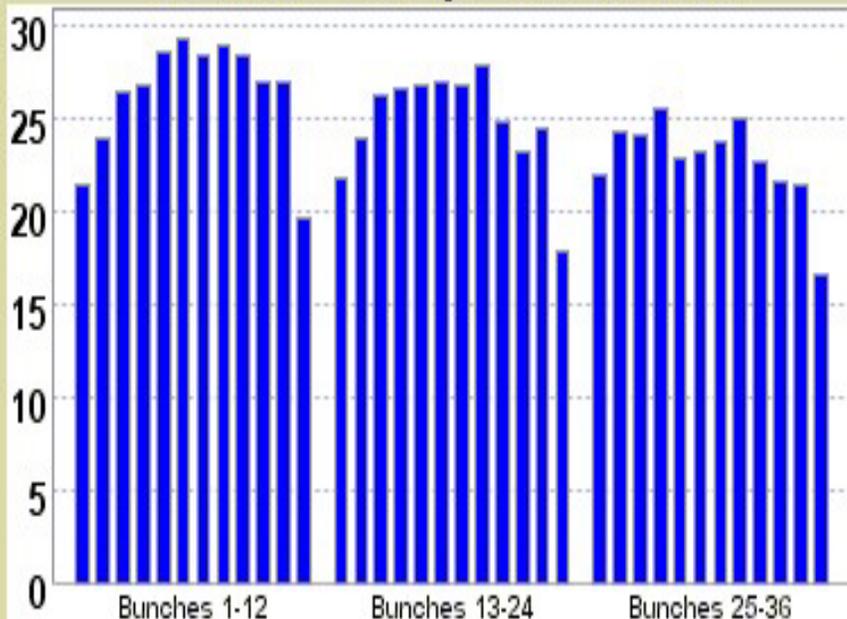
Beam-Beam Effects at 980 GeV

- Losses during squeeze and scraping are about 5% combined
- Pbar emittance blowup may occur in wrong WP
 - "Scallops" - big emittance variations bunch by bunch
 - slow - 5-15 minutes
- Since number of pbars at LB exceeded $700e9$, we get many stores with very high
 - few quenches (squeeze, cogging)
 - Sensitive to tunes
 - Bunch-to-bunch variations →
beam-beam effects on protons

Beam-beam Effects at 980 Gev (cont.)

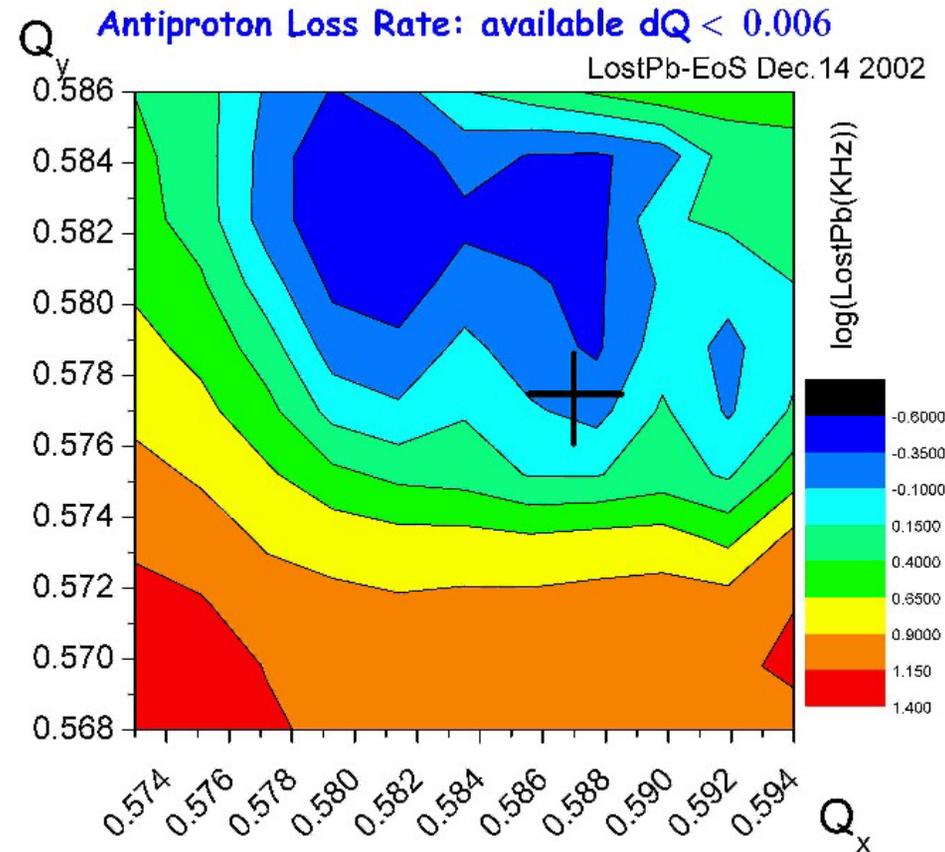
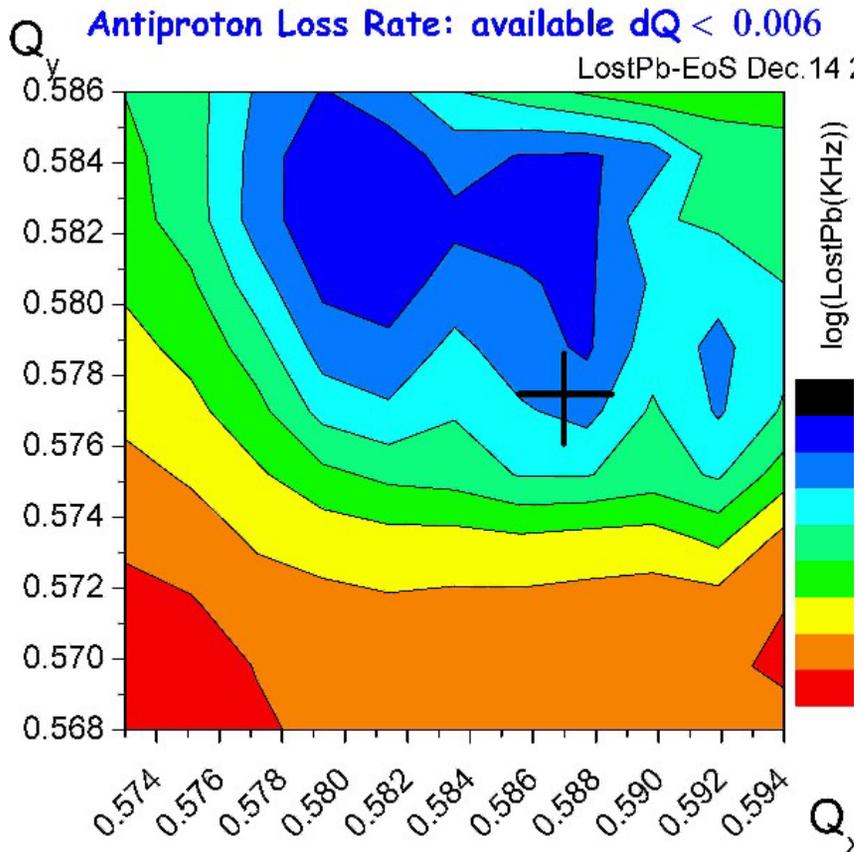
Pbar FW Horz Emittance

T:FWHEMI pi mm mrad



- Pbar bunches near abort gaps have better emittances and live longer
- Emittances of other bunches are being blown up to 40% over the first 2 hours – see scallops over the bunch trains
- The effect is (and should be) tune dependent - see on the right
- Recently, serious effects of pbars on protons – completely unexpected

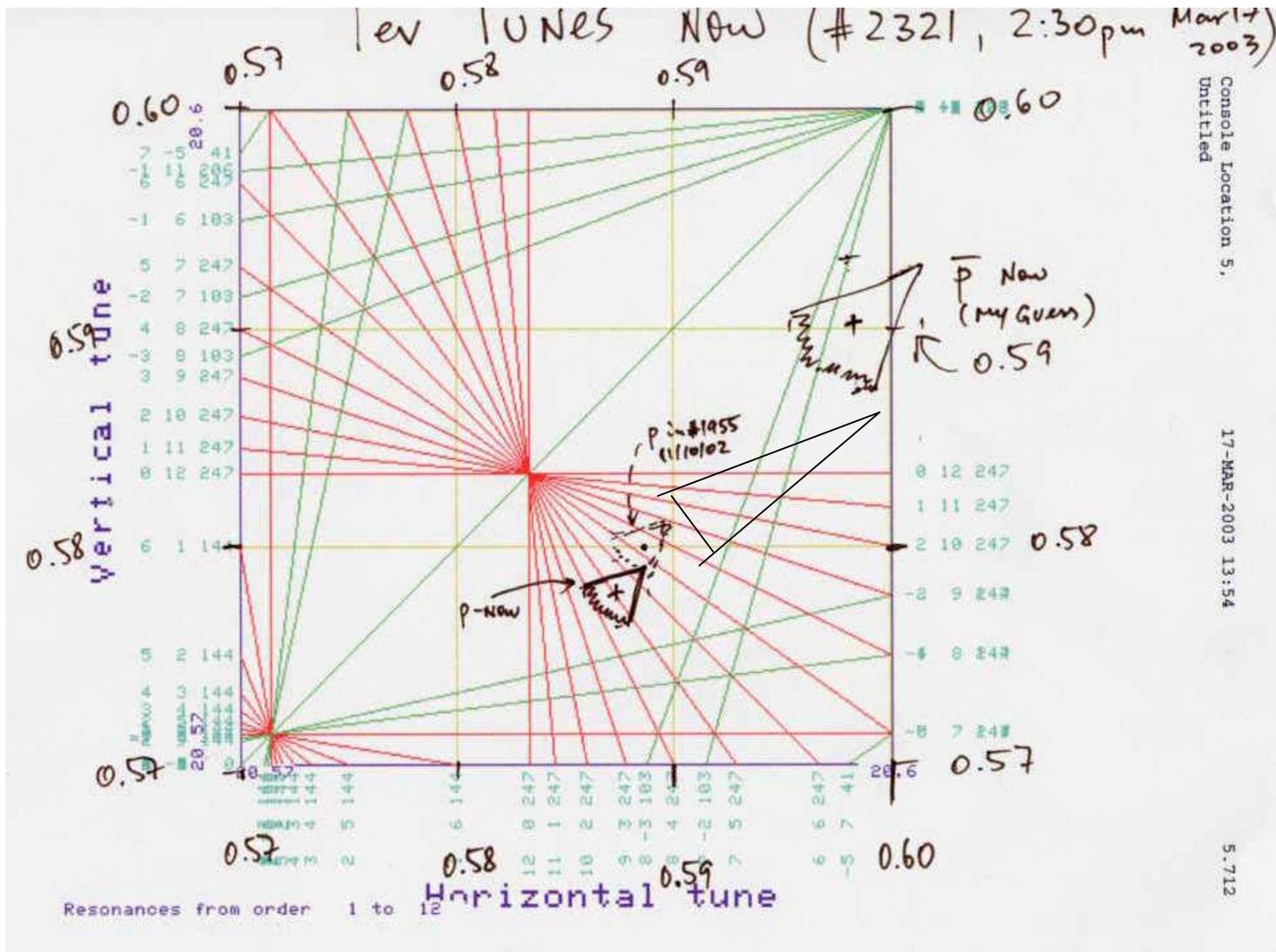
Beam-beam Effects at 980 Gev (cont.)



- At the beginning of the store available WP area is even smaller $dQ < 0.004$... and this is at $N_p = 180e9$
- No available tune WP space expected above $240e9$

Beam-beam Effects at 980 Gev (cont.)

Yu.Alexahin

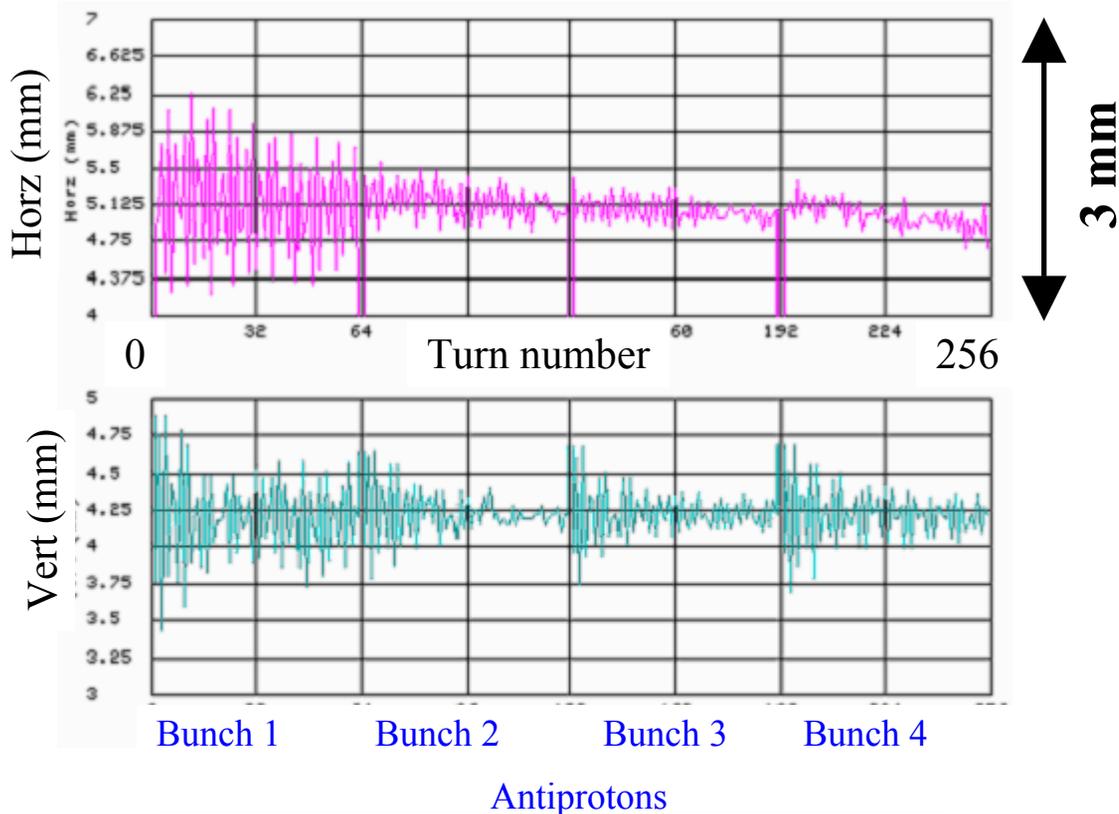


- Protons on 12th order, pbars between 12th and 5th order resonances

Future Steps in FY2003:

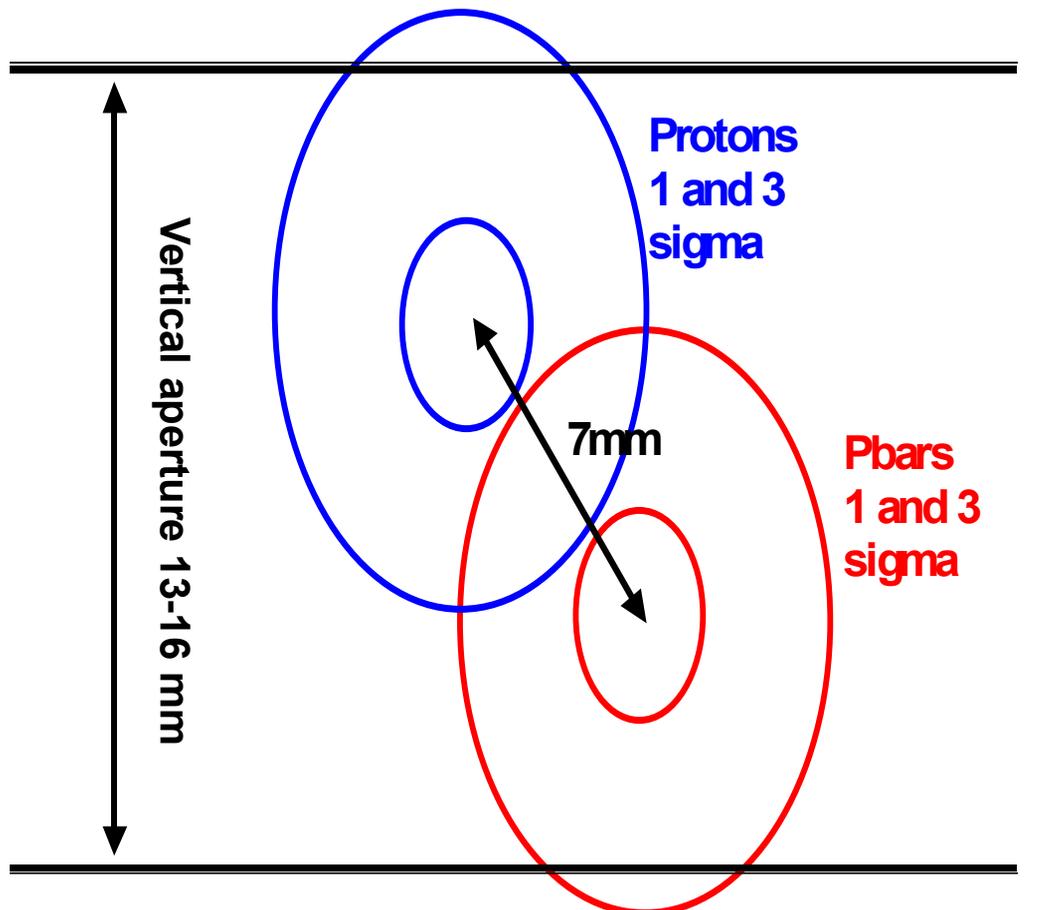
- Expect to deliver $0.2-0.32 \text{ fb}^{-1}$ in FY'03 (0.09 now)
 - Increase peak luminosity to $5-7e31$
 - +20% in proton intensity
 - +30% in pbar intensity
 - About the same emittances
- Projects and expectations gain in L
 - Fix injection issues ~10-15%
 - Open/optimize helix ~10-15%
 - zero chromaticity (dampers, octupoles) ~5-15%
 - Better focus at IPs ~0-5%
 - smaller b^* ; local decoupling; shorter bunchlength
 - Beam-beam tuneup ~0-5% ?
 - Tunes/coupling; TEL; smaller dp/p ; shave in MI; RF noise; vacuum
 - Diagnostics (tunes, $C_{v,h}$, IPMs)
 - Beam studies (beam-beam parametrization, etc)

Injection Oscillations in Tevatron



- Turn-by-turn position monitor, (and bunch-by-bunch for pbar)
- Use to tune up injection closure
- 1 mm corresponds to roughly $3-4\pi$ emittance blowup
- Improved Pbar emittance blowup by $\sim 3-5\pi$

CO Lambertson Replacement



Proton and pbar beam position and sizes on the helix at the location of CO Lambertson

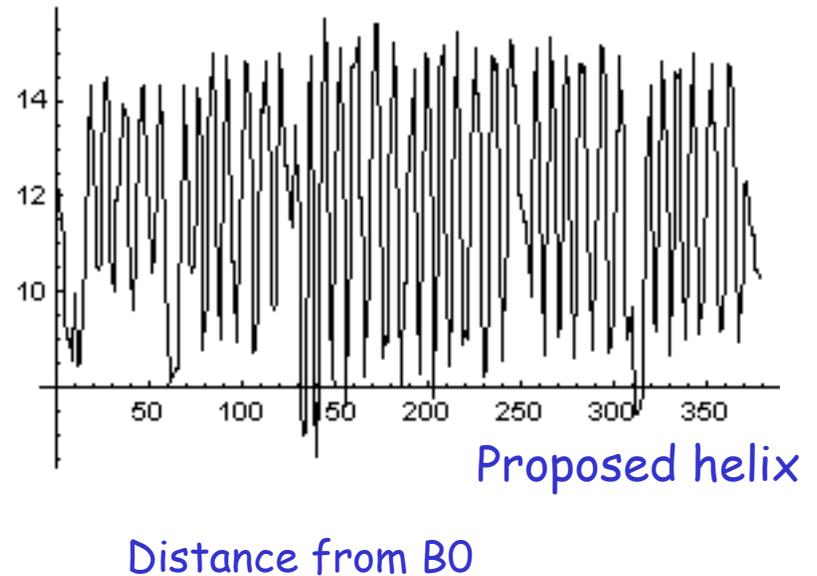
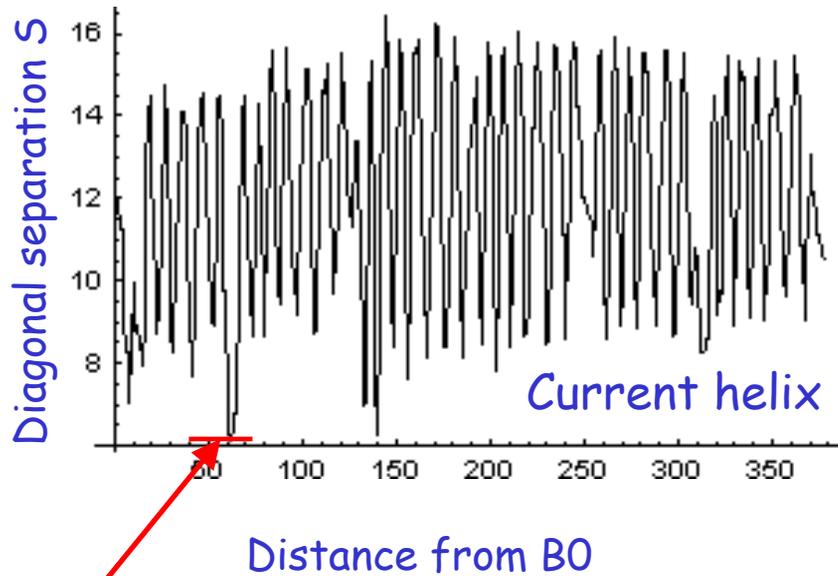
Pbar lifetime depends on emittances and helix size.

CO Lambertson is severest aperture restriction. (See picture)

Design injection helix modified and optimized to fit tight CO aperture ("new-new helix")

(Jan 2003)
Replace CO Lambertsons
Gain 25 mm vertically

Helix Improvement



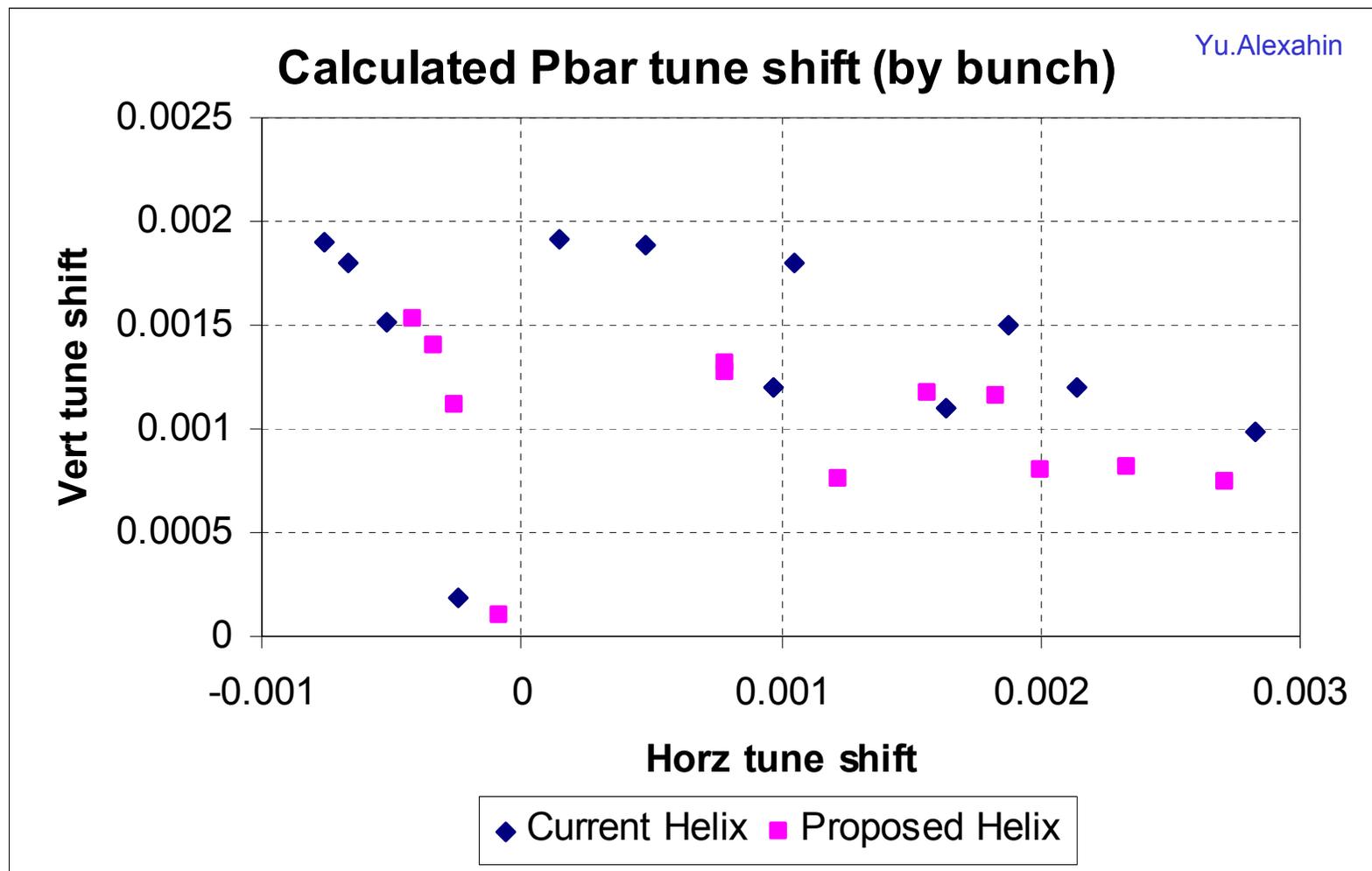
Aperture
limitation at
C0

$$S = \sqrt{(\Delta x / \sigma_x)^2 + (\Delta y / \sigma_y)^2}$$

Increasing proton/pbar helix separation

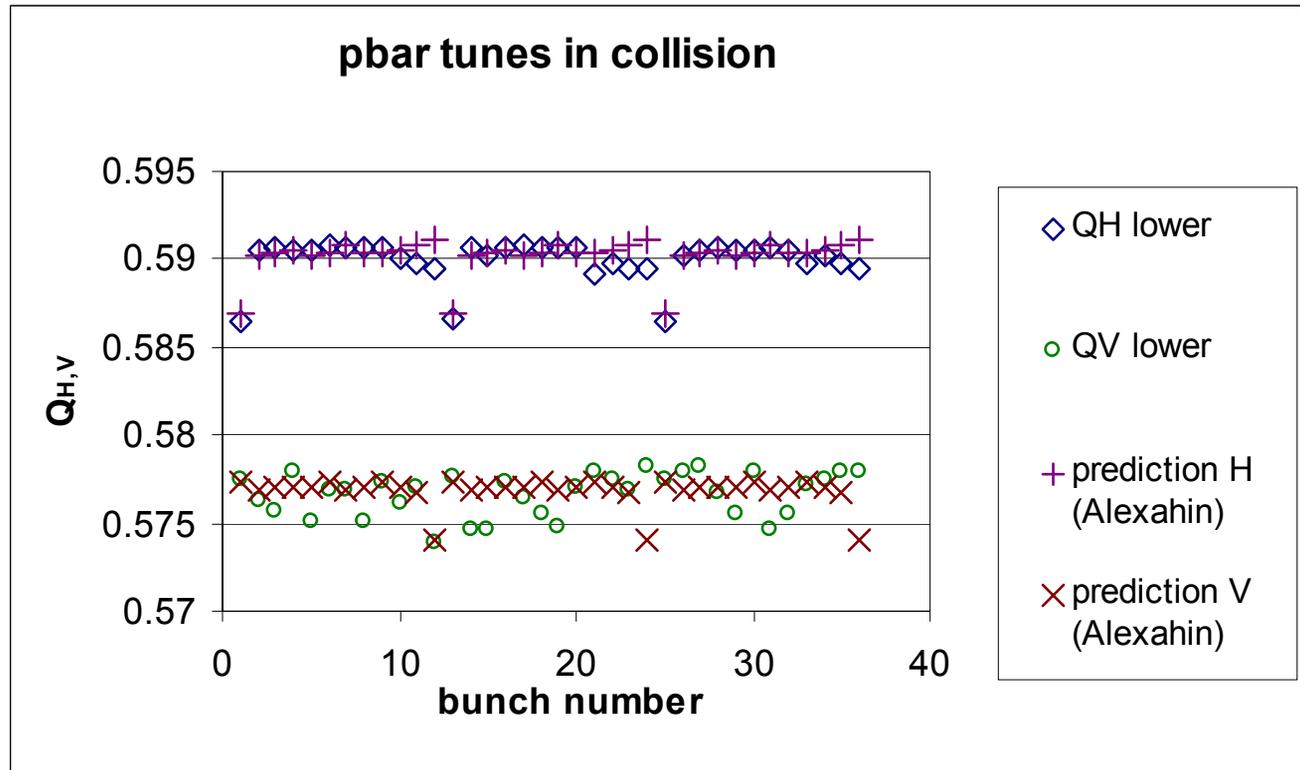
- Replace C0 Lambertson with MI magnets
- Increase vertical aperture at C0 from ~15mm -> 40 mm (but only ~30% larger helix due to other aperture limitations.)
- Modify helix to increase min separation, S_{\min} , from 5.5 to 6.6

Beam-beam Tune Shift Reduction



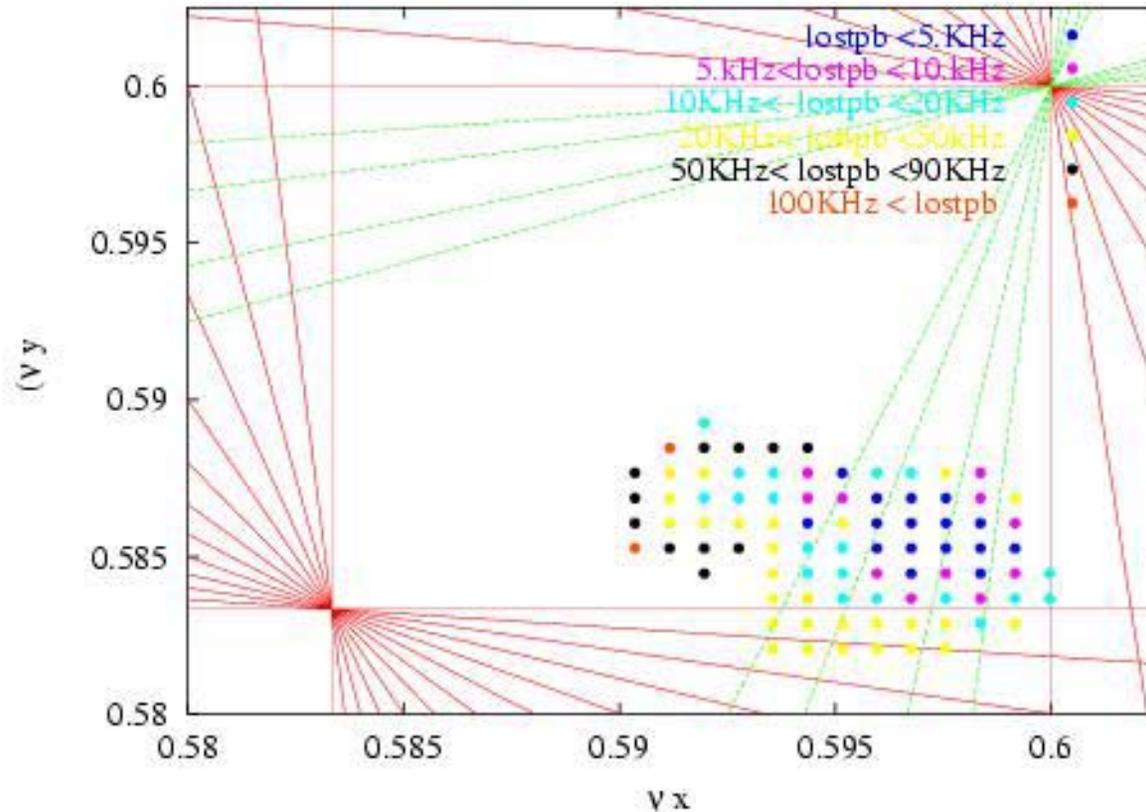
Proposed injection helix (with larger CO aperture) will reduce small amplitude tune shift of pbars

Beam-beam Tune Shift Measurement



- Measured and predicted pbar tune shift as function of bunch number at collisions.
- Used gated "tickler" to excite individual pbar bunches and measured tunes with schottky pickup

Working Point Tune Scans



Measured pbar halo loss rate during collisions as function of pbar tunes

Luminosity Since June 2002

Slides related to luminosity performance

- Luminosity formula
- Goals and current performance
- Peak luminosity plot
- Improvement in luminosity by factor of 1.9
- Beam intensities
- Transfer efficiencies
- Beam emittances
- Store reliability

Introduction

Parameter	Current Status	FY03 Goal	Run II Goal	
Typical Luminosity	3.2e31	6.6e31	33e31	cm ⁻² sec ⁻¹
Integrated Luminosity	6.0	12.0	70.0	pb ⁻¹ /week
Protons/bunch	170e9	240e9	270e9	
Antiprotons/bunch	22e9	31e9	135e9	

Higher intensity \Rightarrow Fundamental physics limitations

- Beam-Beam Effects
- Instabilities
- Beam Halo and Lifetimes

Understanding/Solving these issues requires ...

- Stable Tevatron Lattice
- Diagnostics
- Study Time

Luminosity Formula

$$L = \frac{10^{-6} f B N_p N_{\bar{p}} (6\beta_r \gamma_r)}{2\pi\beta^* (\varepsilon_p + \varepsilon_{\bar{p}})} H(\sigma_l / \beta^*) \quad (10^{31} \text{ cm}^{-2} \text{ sec}^{-1})$$

f = revolution frequency = 47.7 KHz

B = # bunches = 36

$\beta_r \gamma_r$ = relativistic beta x gamma = 1045

β^* = beta function at IR = 35 cm

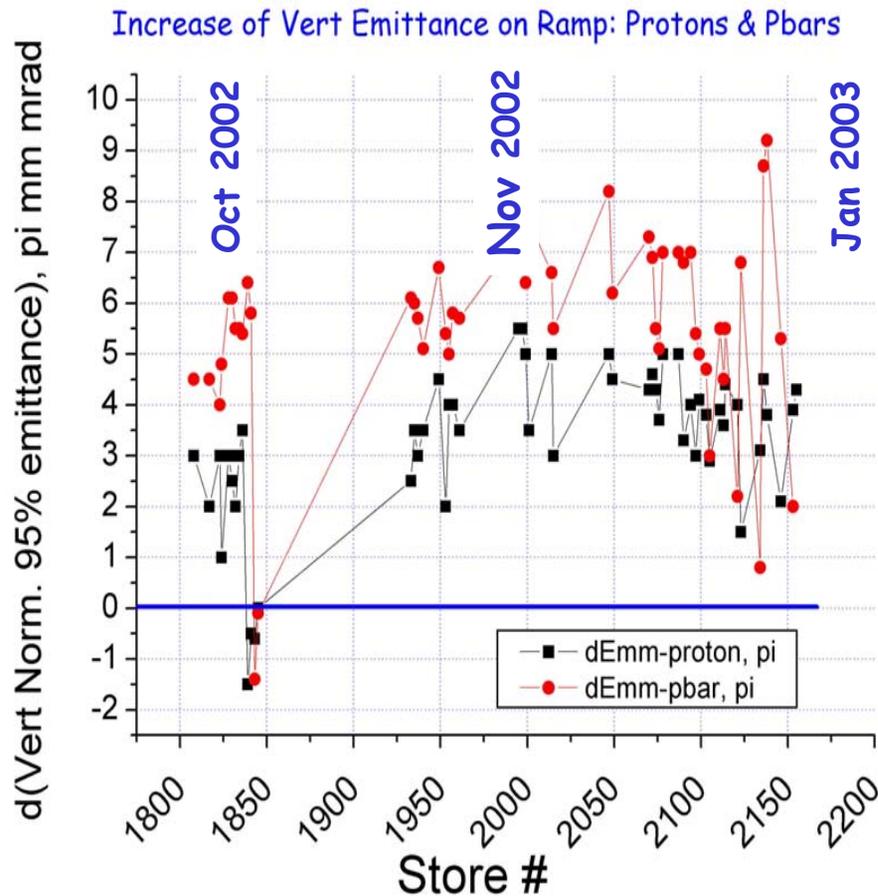
H = hourglass factor = .60 - .70

N_p, N_{pbar} = bunch intensities (E9)

$\varepsilon_p, \varepsilon_{pbar}$ = transverse emittances (π -mm-mrad)

σ_l = bunch length (cm)

Tevatron Emittance on the Ramp



Emittance blow-up on the ramp**

- In both p and pbars
- Same for coalesced and uncoalesced
- About $5-7\pi$ in vertical (not sure for horizontal)
- Worse after Nov.1
- WHY?
- Not due to dampers
- Tune adjustments did not help

**Note: Possible that this is a FW effect. (See later slides.)

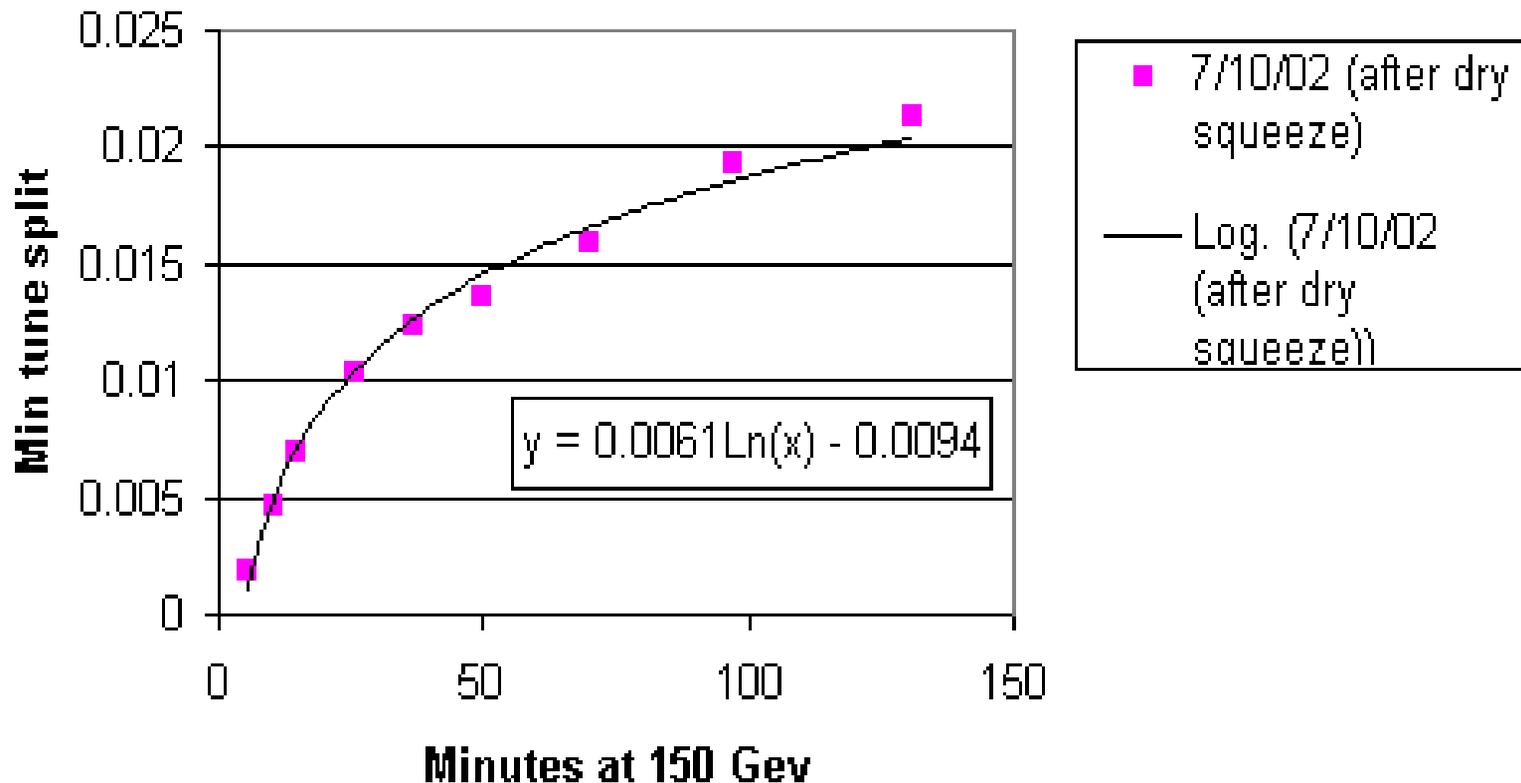
Tune and Coupling Drifts at 150 Gev

- From Run I: Known Chromaticity Drift
 - Chromaticity drift from b_2 component in dipoles
 - Compensated by automatically varying sextupole currents
- New for Run II: Tune and Coupling Also Drift
 - Tune and coupling vary logarithmically after returning to injection energy
 - Makes injection tune-up more difficult
 - Likely caused by persistent currents in the superconducting dipoles and quadrupoles
- Now compensating for Drift
 - Use normal, skew quads similar to chromaticity scheme
 - Tune drift now < 0.001 after 3 hours
 - Coupling drift is not measurable

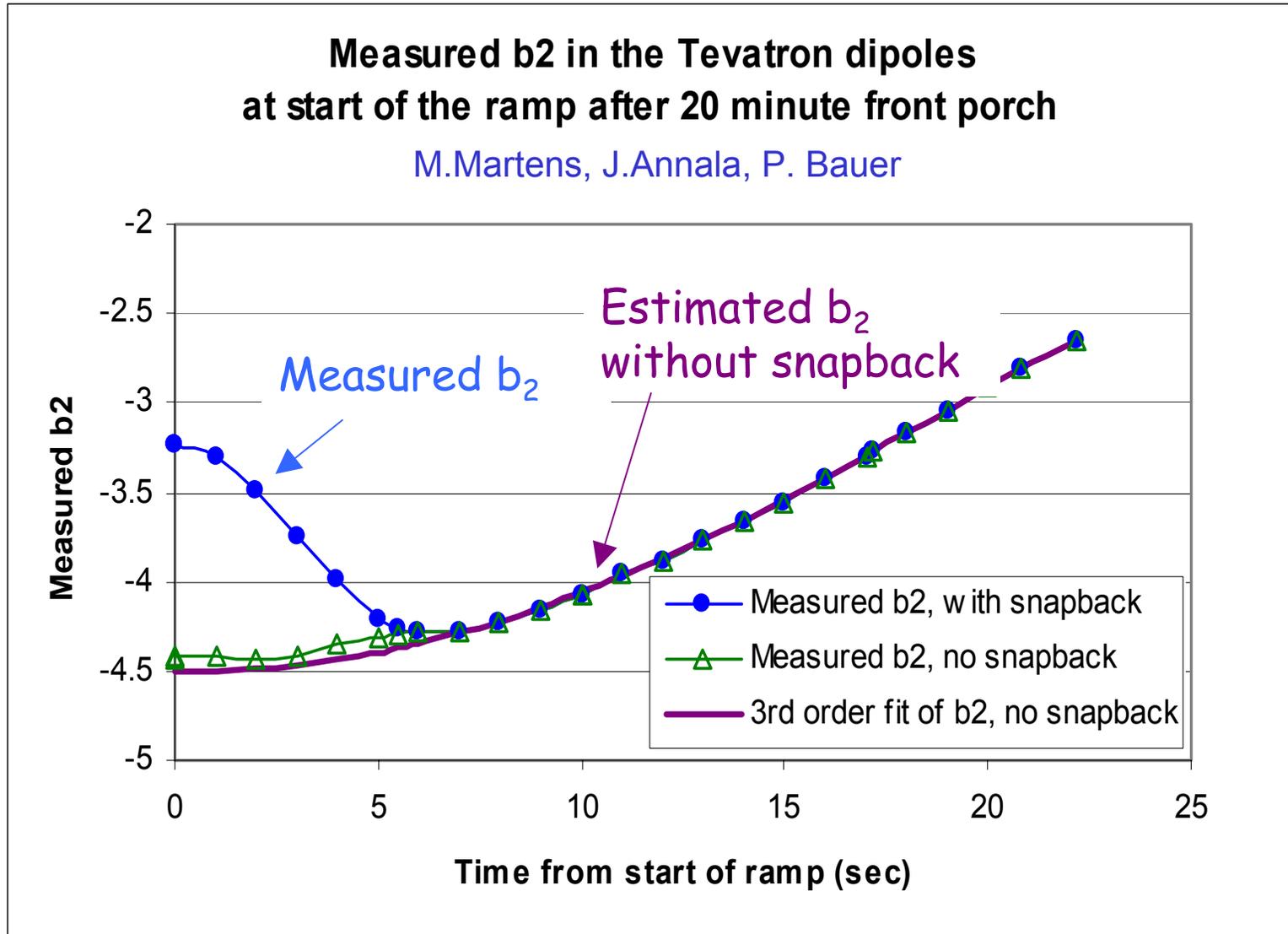
Coupling Drift @ 150 Gev

M.Martens, J.Annala

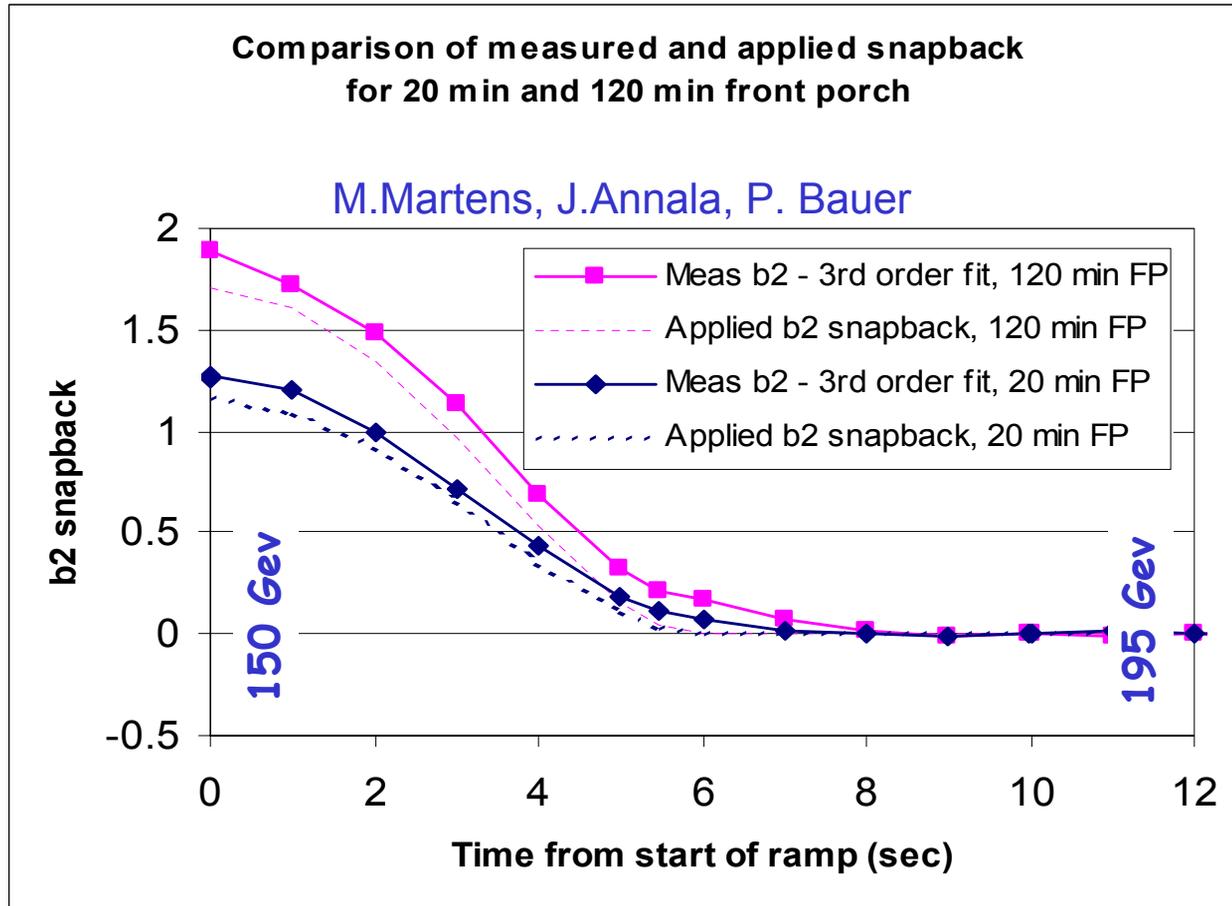
**Measured min tune split
7/10/02 (after dry squeeze)**



Chromaticity Snapback Measurements

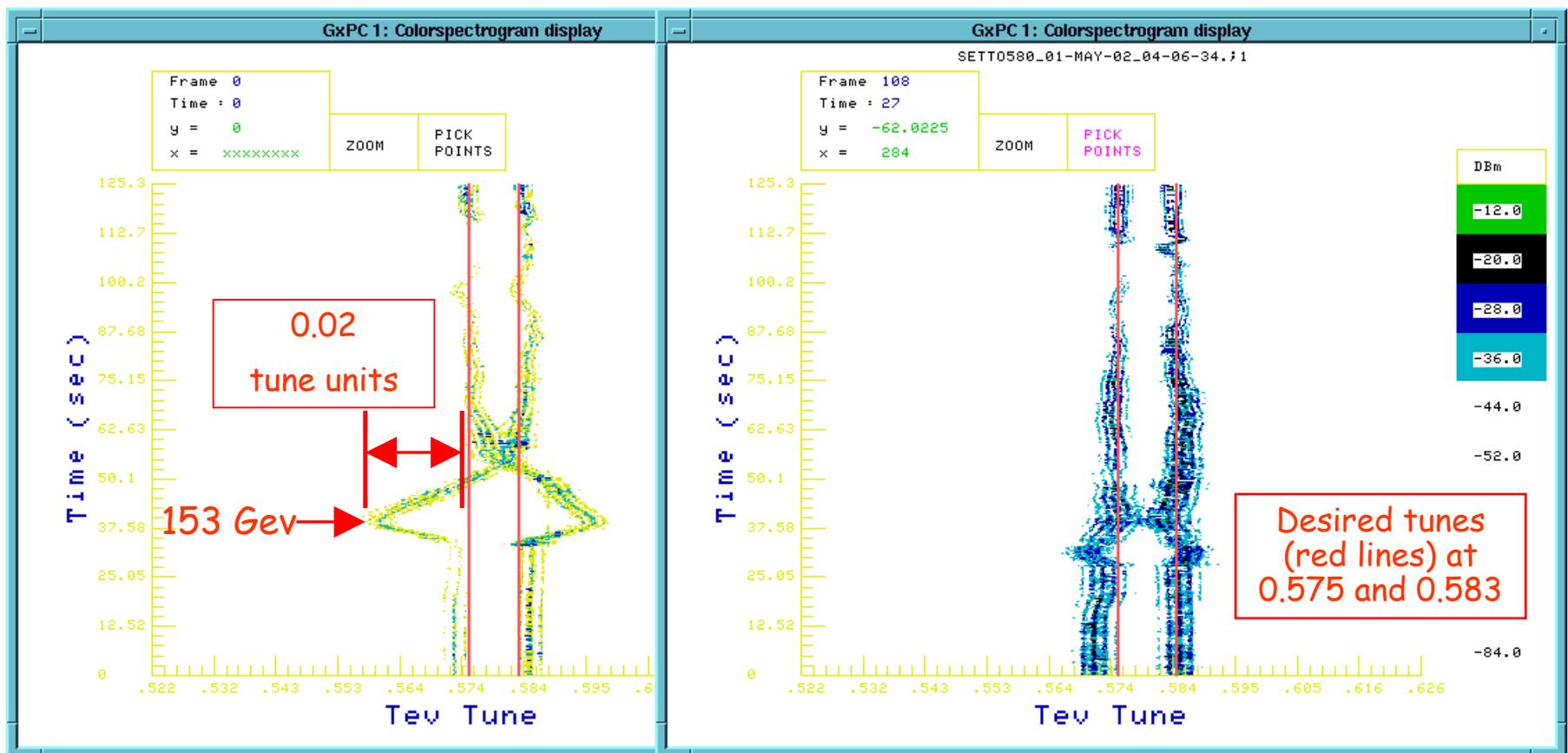


Chromaticity Snapback Compensation



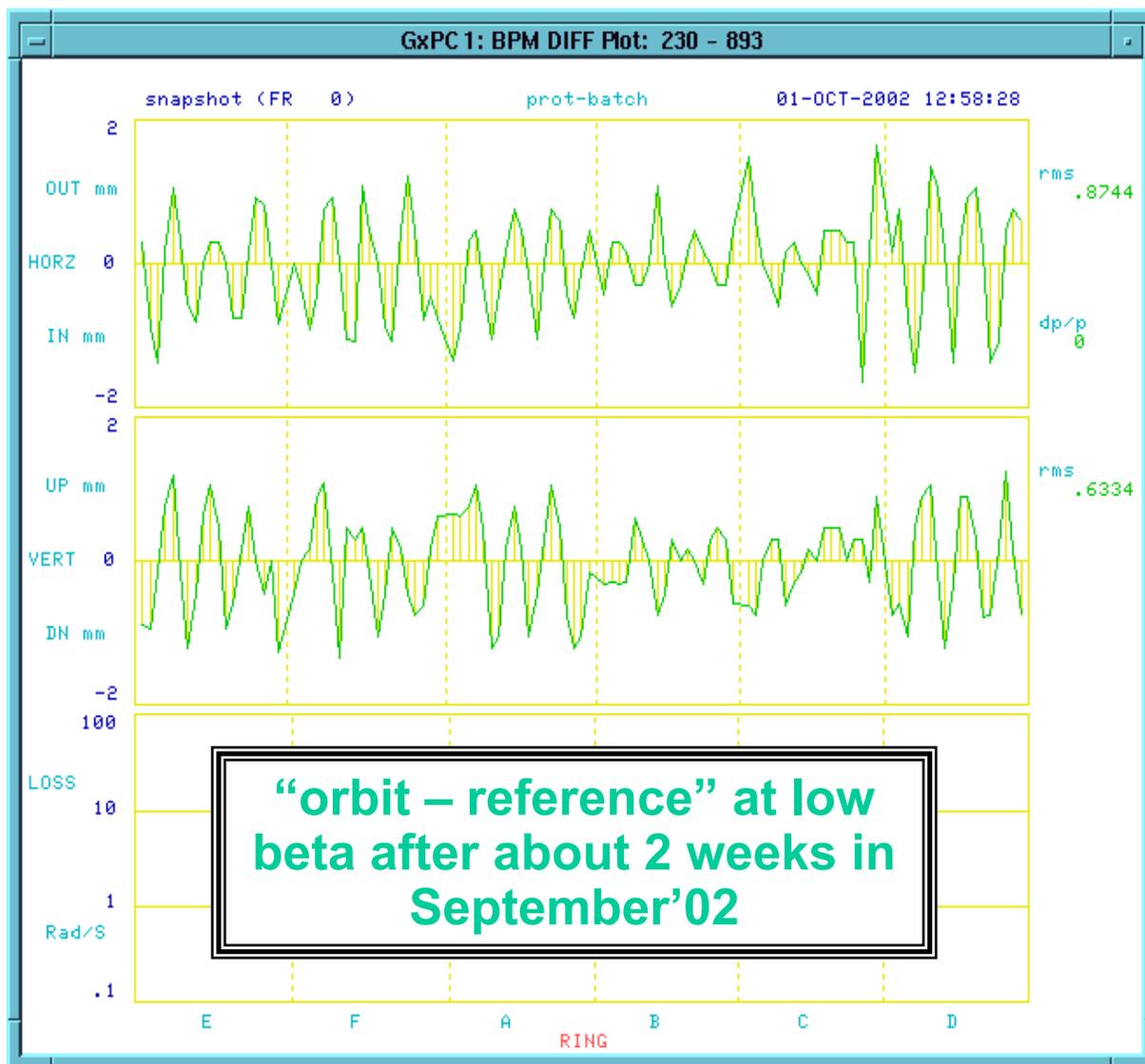
b_2 snapback is correctly compensated (for shot setup conditions.)

Tune Variations on Ramp/squeeze



- Near start of ramp (150 → 153 Gev): large tune/coupling excursions
- Tune/coupling changes of (0.02 tune units, 0.02 minimum tune split)
- Variations fixed with additional breakpoint at 153 Gev and tune/coupling snapback correction at start of ramp.

Orbit Drifts



Tunes, coupling, ξ vary with closed orbits distortions

“Rule of thumb” -- keep orbit drifts under 0.5 mm rms from “silver orbit”

Orbit drifts of that scale occur in 1-2 weeks (see picture)

Requires routine orbit smoothing at 150 GeV, ramp, flat-top, squeeze, and low-beta.

Orbit Smoothing

Goal: monitor orbit positions during shot setups and stores. (BPMs must work with coalesced beam.)

- Standard orbit smoothing procedure
 - Works well. (But some correctors near maximum strength.)
 - Requires uncoalesced protons
 - Takes time -- several hours for proton only store
 - BPMs are "less accurate" w/coalesced beam during store
- BPM system
 - Tune up/maintenance of BPMs has improved reliability
 - Position measurements not considered good enough with coalesced beam. (Under investigation)
 - Improvements are underway (Understanding electronics, removing "PSD" boxes, and BPM testing software)

Tevatron Alignment Measurements

- What are rolls of Tevatron dipoles and quads?
 - How do these affect coupling?
 - How do these affect understanding of lattice functions?
 - Do these contribute to emittance blow-up at injection?
 - Do rolled dipoles affect orbit, and therefore feedowns?
- Alignment Measurement is work in progress
 - Some dipoles with ~ 8 mrad roll, quads with ~ 4 mrad roll
 - Magnets typically rolled in same direction
- Additional measurements in Jan 2003 shutdown
 - Used a "portable tilt-meter" for quick roll measurements
 - Analysis still pending, but definite rolls
 - (See sample measurements on next slide)

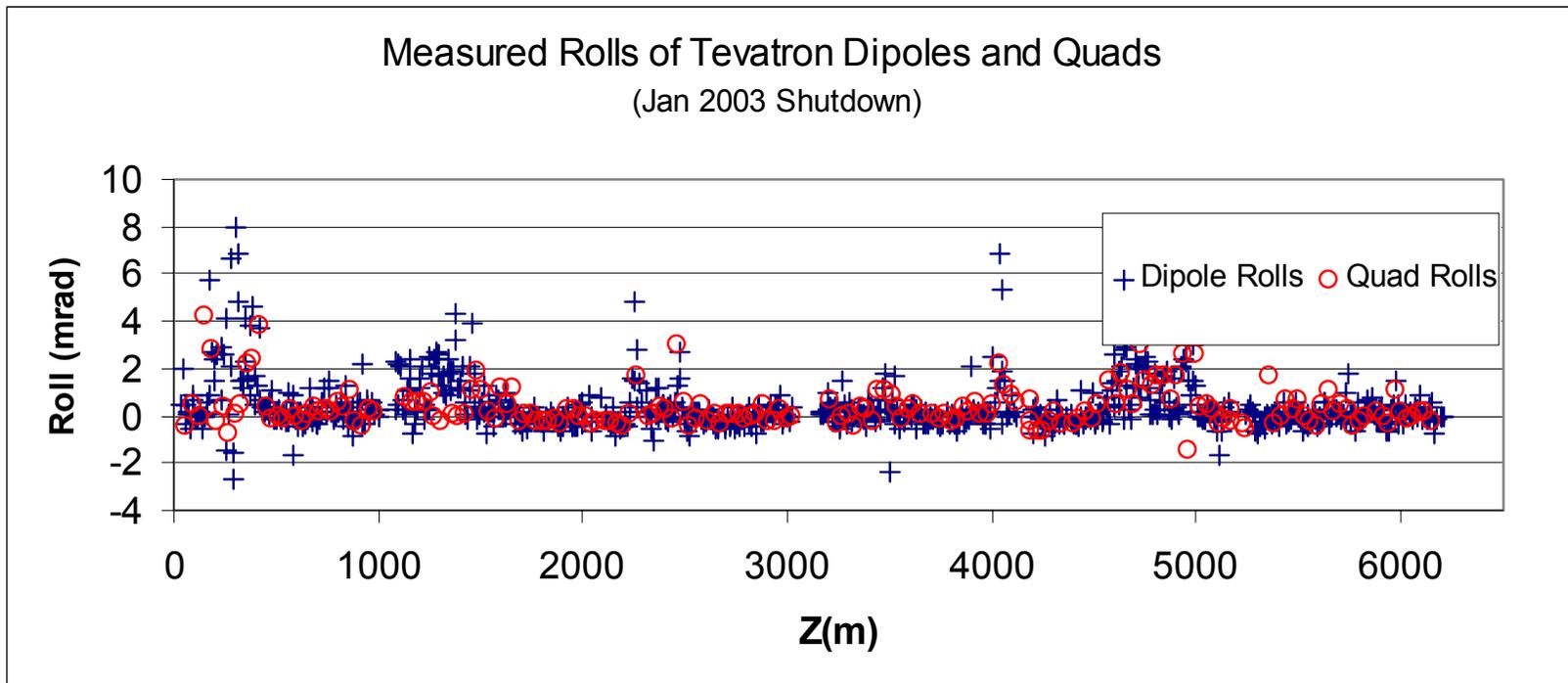
Tevatron Magnet Alignment

Sample data of surveyed rolls on dipoles (and quads)

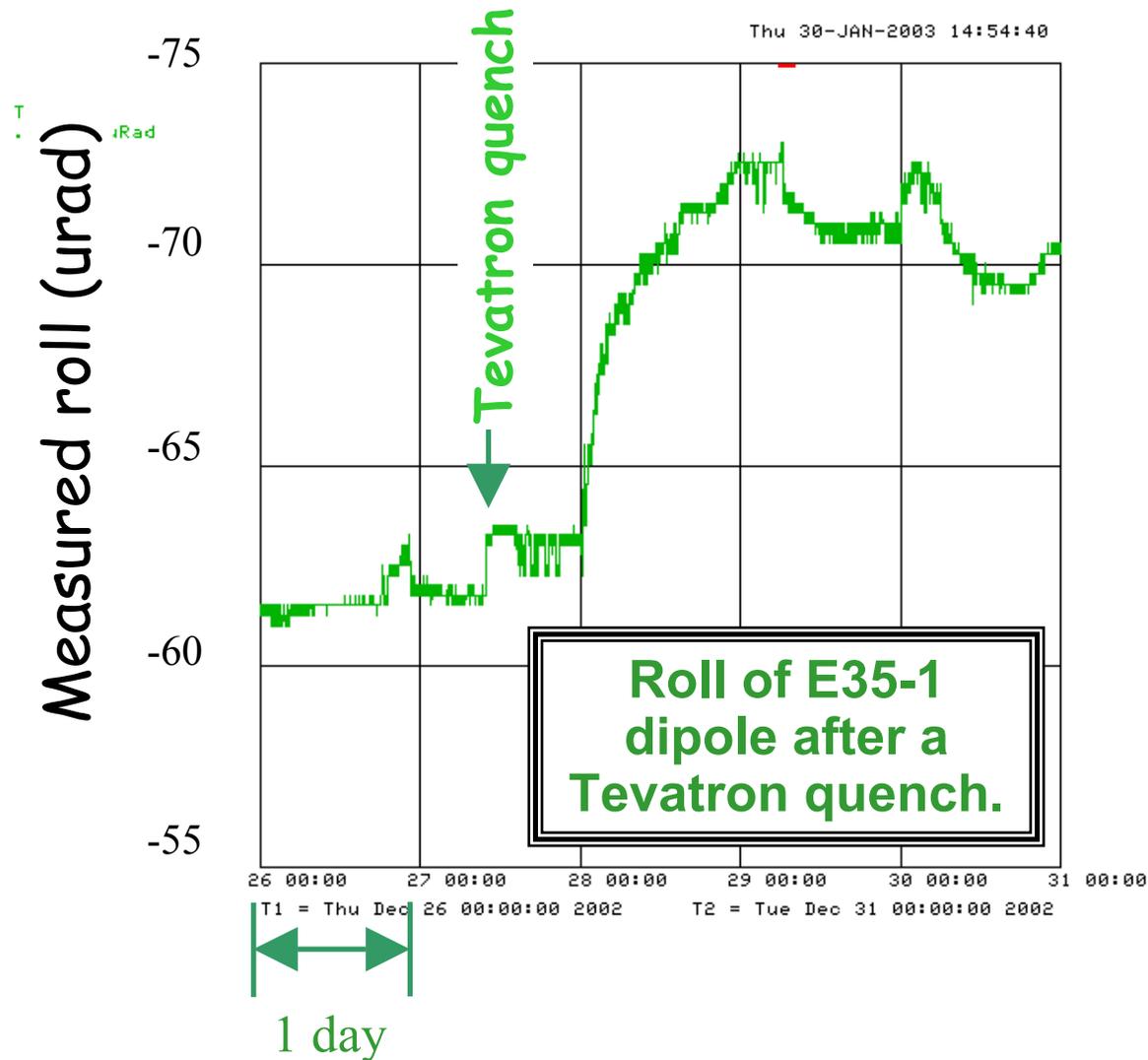
Magnet	Roll (mrad)		Magnet	Roll (mrad)
A19-1(Quad)	-0.67		A23-1(Quad)	2.41
A19-2	6.86		A23-2	1.65
A19-3	1.76		A23-3	3.95
A19-4	-4.44		A23-4	0.71
A19-5	-1.94		A23-5	4.89
A21-1(Quad)	0.19		A24-1(Quad)	2.98
A21-2	8.67		A24-2	1.49
A21-3	8.38		A24-3	0.81
A21-4	4.81		A24-4	1.17
A21-5	1.19		A24-5	3.70
A22-1 (Quad)	0.44		A25-1 (Quad)	3.68
A22-2	1.06		A25-2	0.60
A22-3	1.49		A25-3	0.33
A22-4	2.33		A25-4	0.14
A22-5	4.44		A25-5	0.37

Tevatron Magnet Alignment

- Measured rolls of dipoles and quads during Jan 2003 shutdown.
- Used “portable tilt-meter” for quick measurements
- Data roughly consistent with vertical dipole corrector strengths
- Dipoles rolled 4 mrad gives ~ 0.5 mm “scalloped” vert orbit
- Coupling from one quad rolled 4 mrad gives min tune split ~ 0.0025



Motion of Tevatron Dipole



Newly added a tiltmeter to a Tevatron dipole.

Observed 10 urad roll after a quench

Still watching!!

Larger rolls on other dipoles?

Long term drifts?

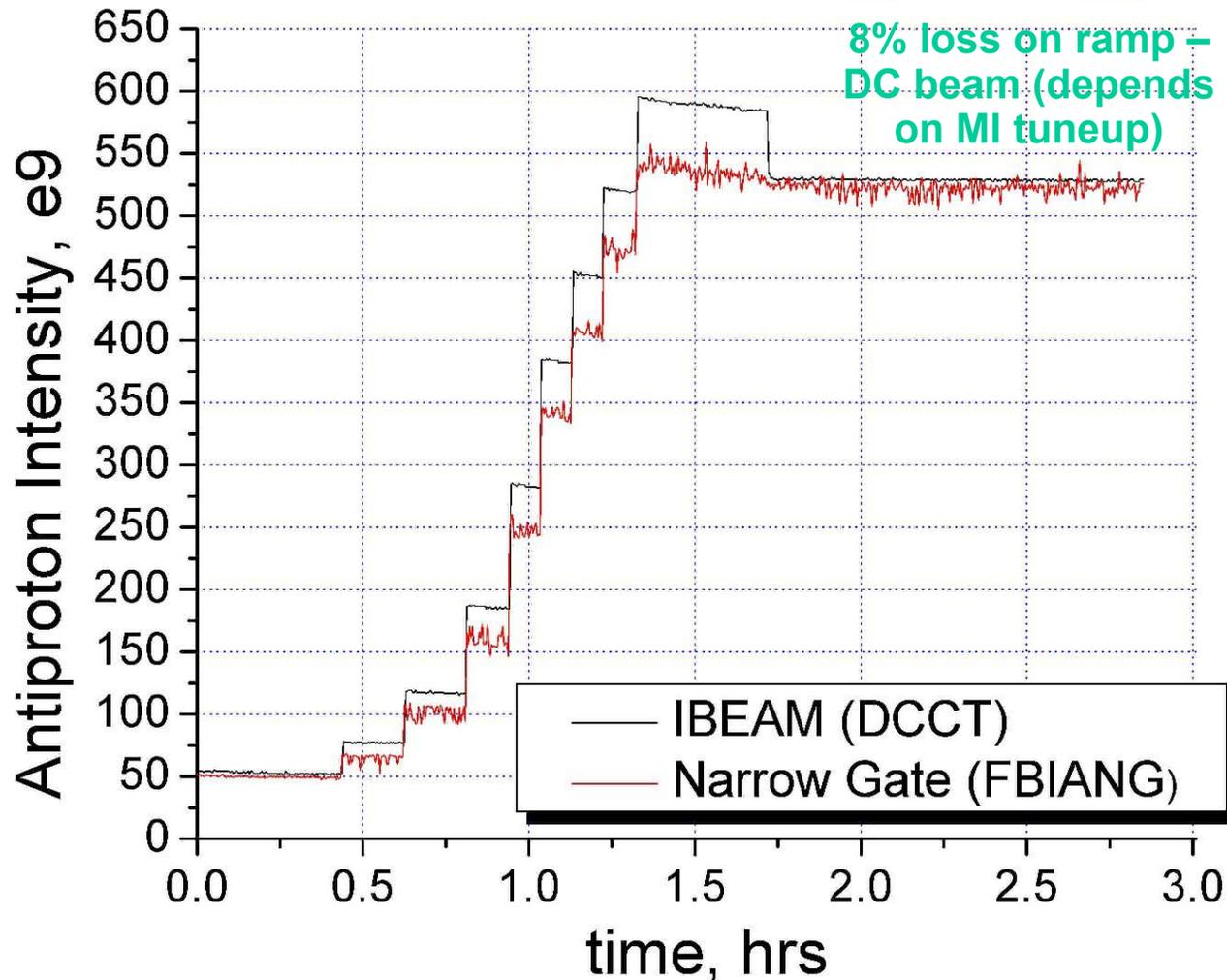
Beam-beam Interactions

Slides related to beam-beam interactions

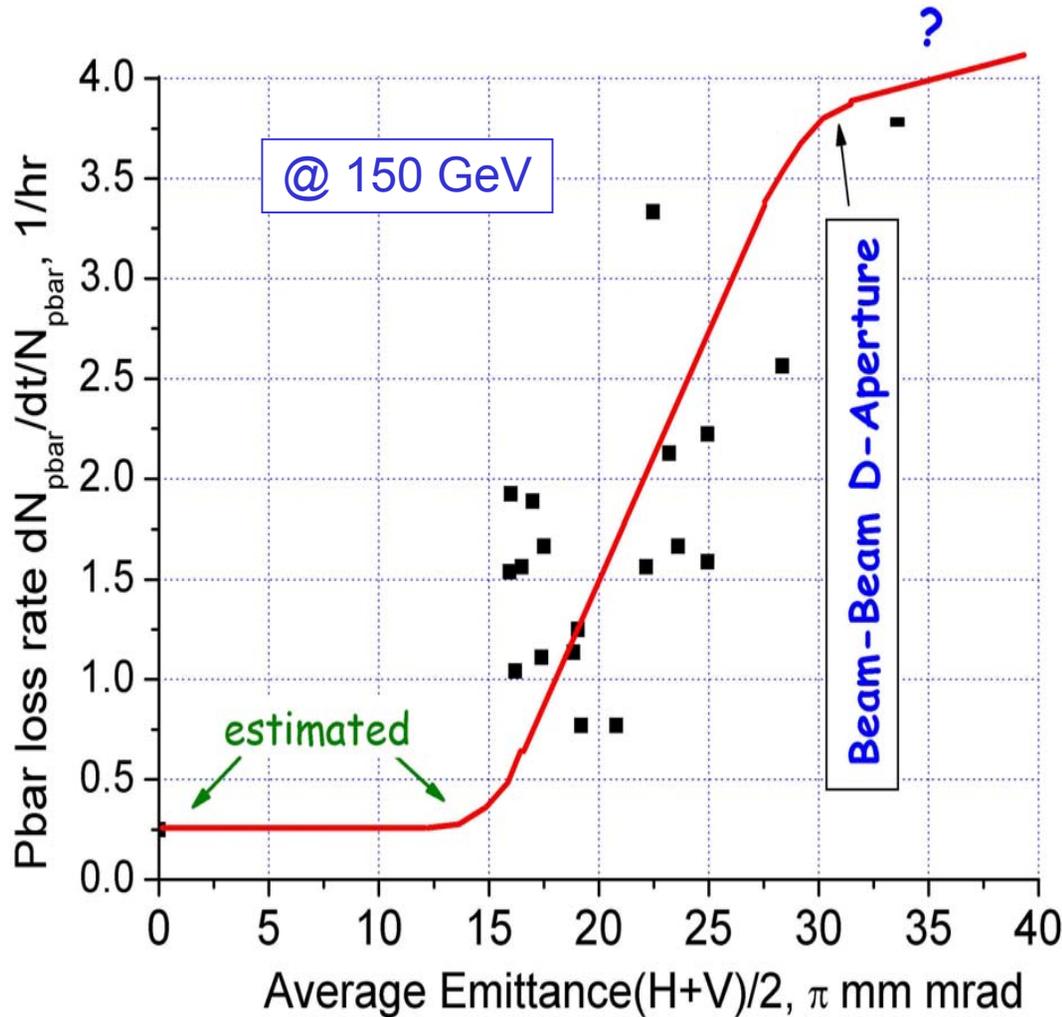
- Pbar intensity loss during store ~25%
- Pbar intensity loss during Pbar only store ~2%
- Pbar lifetime at 150 Gev
 - Pbar beam lifetime versus emittance
 - Lifetime versus chromaticity
- Progress/plan for improving pbar lifetime at 150 Gev
 - Smaller pbar emittances from accumulator improvements
 - Reduce injection oscillations (BLT) \Rightarrow smaller pbar emittances
 - Larger CO aperture \Rightarrow Larger helix \Rightarrow Lower pbar tune shifts
- Beam-beam at 980 Gev
 - Pbar emittance blowup depends on bunch number
 - Measured and predicted bunch-by-bunch pbar tunes
 - Working point tune scans

Beam-beam Effects: Pbar Only

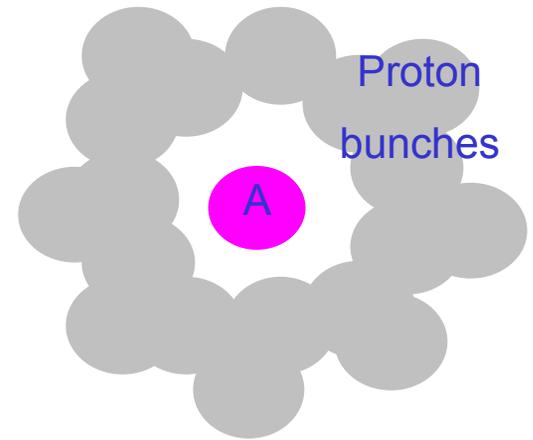
Antiproton Only Store: 1% loss on ramp, $\tau_{150} = 20$ hrs, $\tau_{980} = 160$ hrs



Antiproton Lifetime at 150 Gev

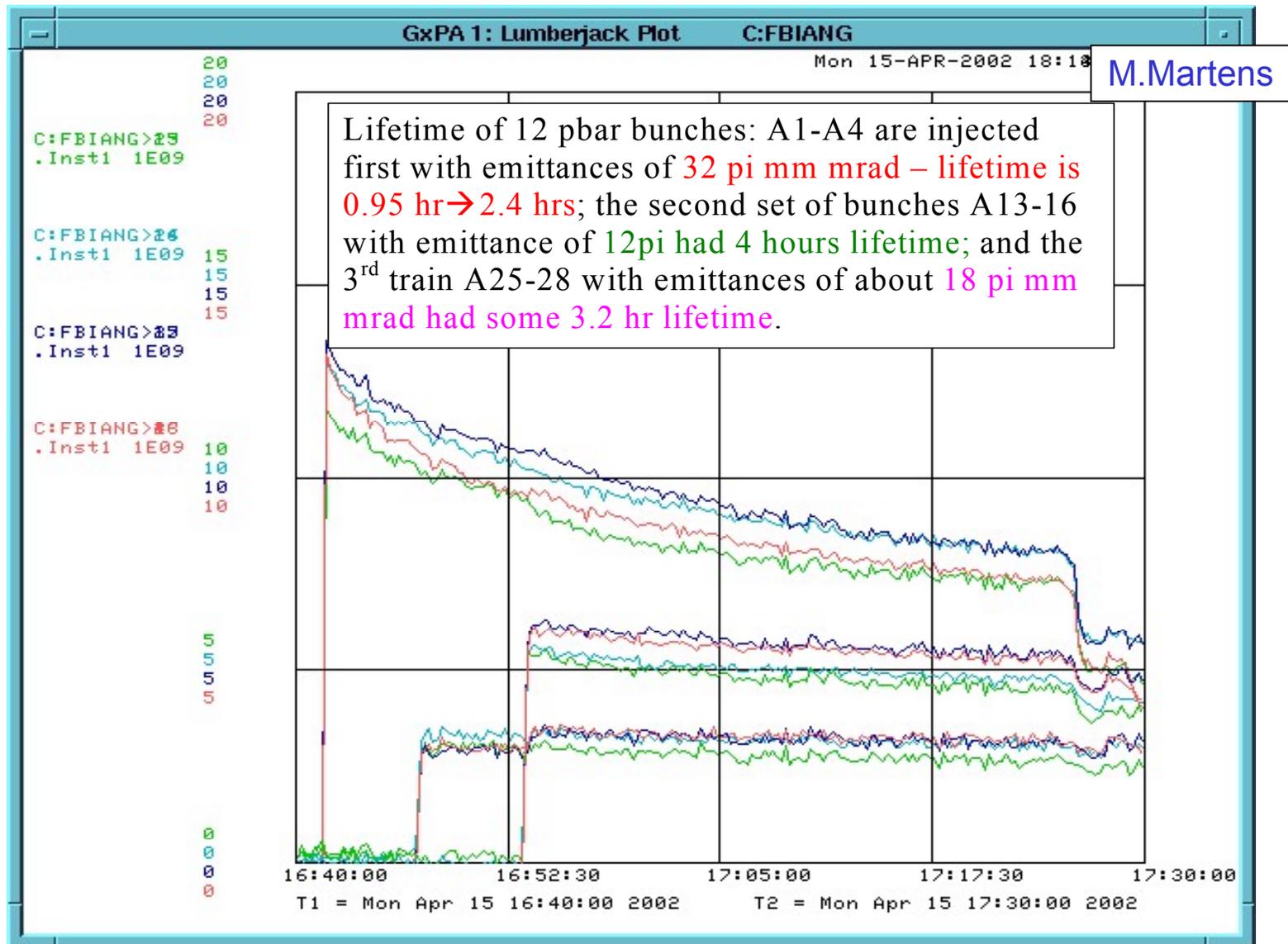


Pbar losses depend strongly on pbar emittances and N_p



Proton Beam as “Soft Donut Collimator”

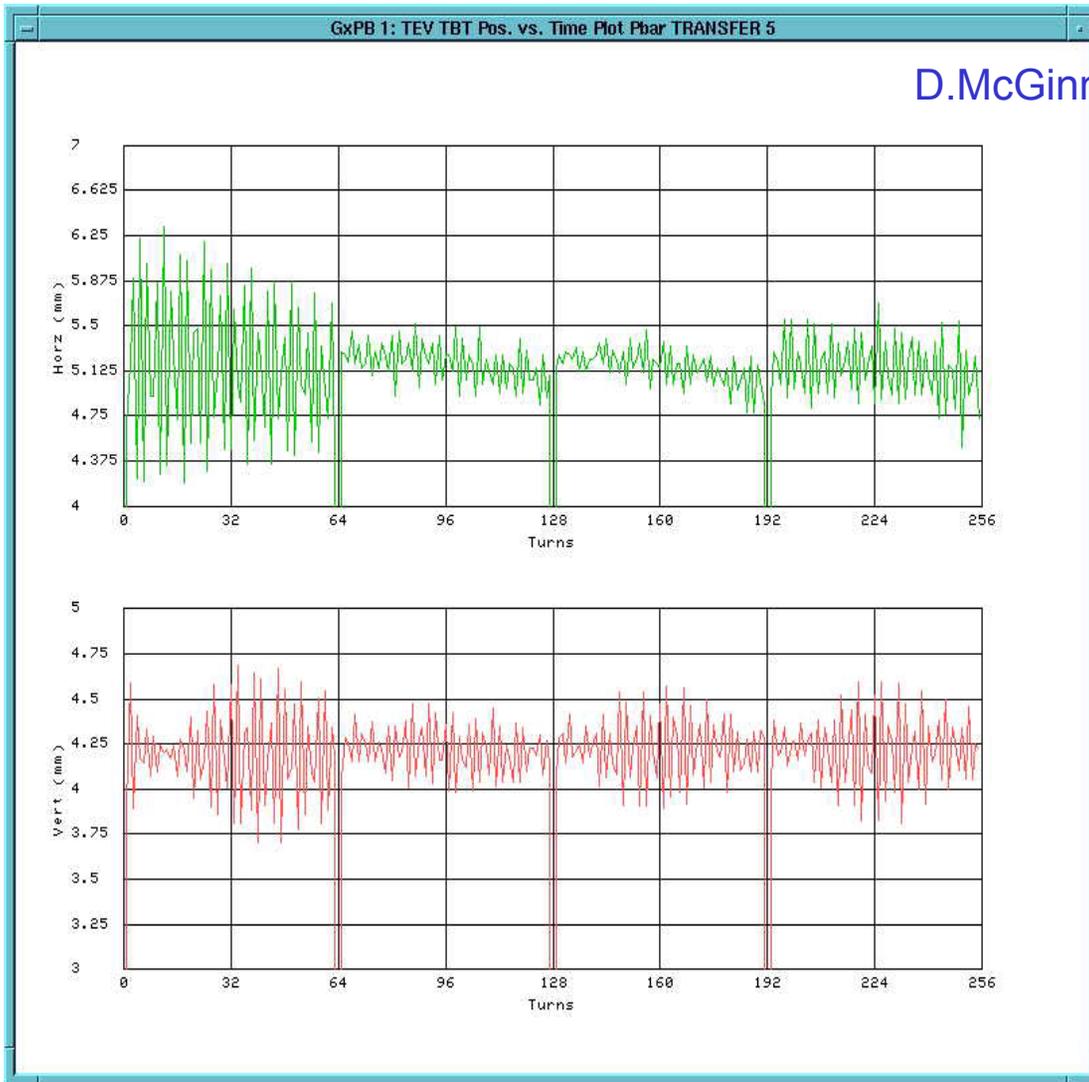
Beam-beam @ Injection Vs Emittance



Attacking the Beam-beam Effects

- Smaller emittances from AA ("AA shot lattice")
- Reduced injection errors
 - Beam Line Tuner
- Better control of orbits / tunes / coupling
 - Tunes up the ramp
 - Tune and coupling drift at 150 Gev
 - Orbit smoothing
- Larger injection helix
 - CO Lambertson replacement
 - New Separator settings

Diagnostics: Beam Line Tuner



Consists of striplines, DAQ, software and dipole correctors in A1/P1 lines

Old version (RF integrator) was too sensitive to time jitter (now improved but not in use)

New version based on segmented memory scope (now operational)

Instabilities and Dampers

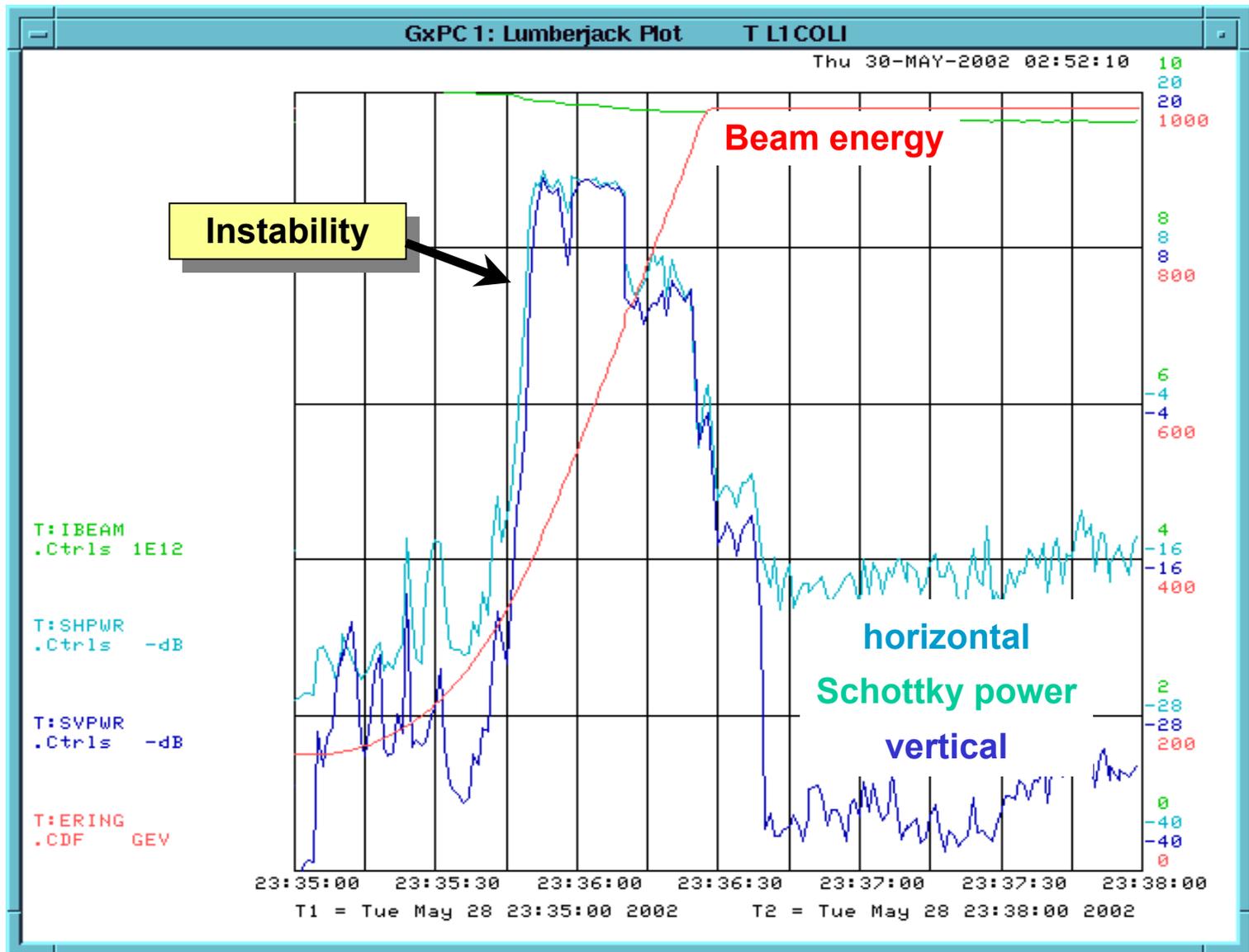
Slides related to instabilities and dampers

- Proton Transverse Instability
 - Head-Tail?
 - Instability on ramp
 - Head-tail instability measurement with TBT
- Tevatron Transverse Dampers
 - Schematic outline of transverse dampers
 - Demonstration of damping
- Tevatron Longitudinal Dampers
 - Dancing bunches
 - Schematic outline of longitudinal dampers
 - Demonstration of damping
 - Fixed bunch length blow-up during store

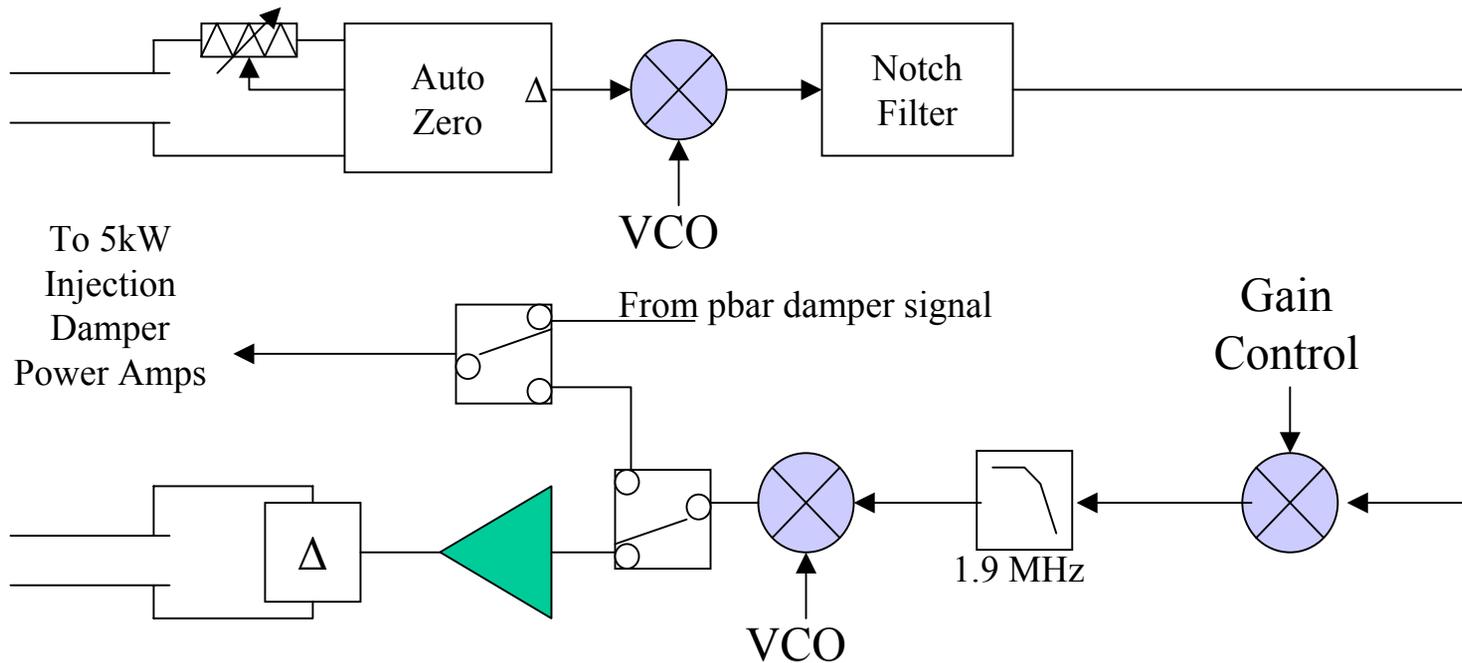
Proton Transverse Instability

- Intensity-dependent: appears above $\sim 170E9$ /bunch
 - Single bunch weak head-tail phenomenon
- Can occur at 150 GeV, up the ramp, at 980 GeV
 - Schottky powers rise quickly
 - p/pbar emittances blow up for individual bunches
- Try to prevent/control instability via:
 - Raising chromaticities (8 @150, >20 at 980)
 - Adjusting coupling and tunes
 - Limiting p intensity to $\sim 240E9$ /bunch at injection
 - More pbars help to stabilize protons
- Constructed bunch-by-bunch transverse dampers
 - hor chromaticity at injection lowered $8 \rightarrow 2$ at 150
 - ver chromaticity at injection lowered $8 \rightarrow 4$ at 150
 - ... but the problem is not solved yet...

Transverse Instability On Ramp

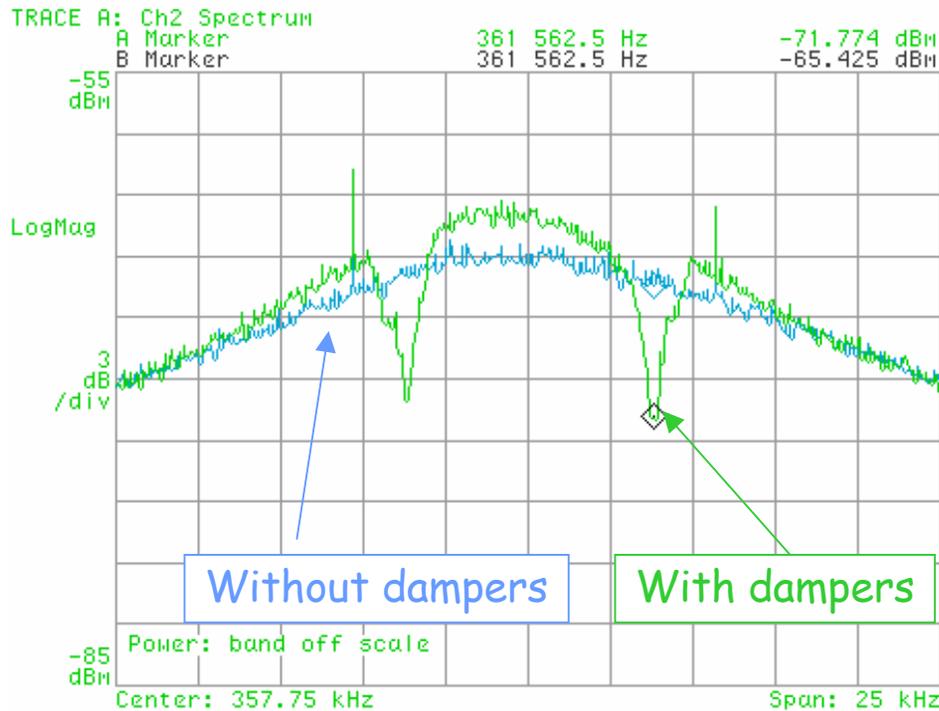


TeV Transverse Damper



Tev Transverse Damper

Date: 10-27-00 Time: 01:24 AM



- Damper Hardware completed
- See suppression of tune lines
- Can reduce ξ at injection with damper on. Beam is unstable otherwise.

Transverse damper hardware works.

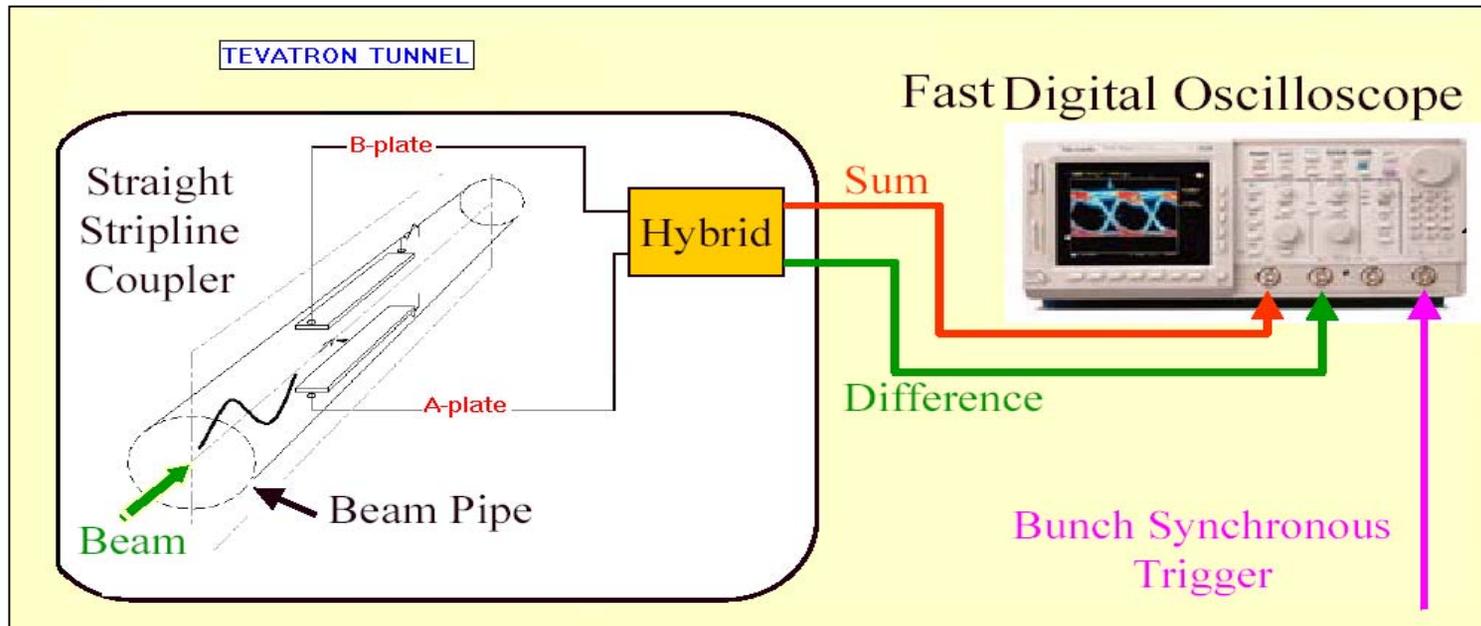
Dampers turned on after 36 proton bunches are injected.

With dampers can lower ξ_h from 8 \Rightarrow 2, ξ_v from 8 \Rightarrow 4 ...

... which improves proton & pbar lifetime ...

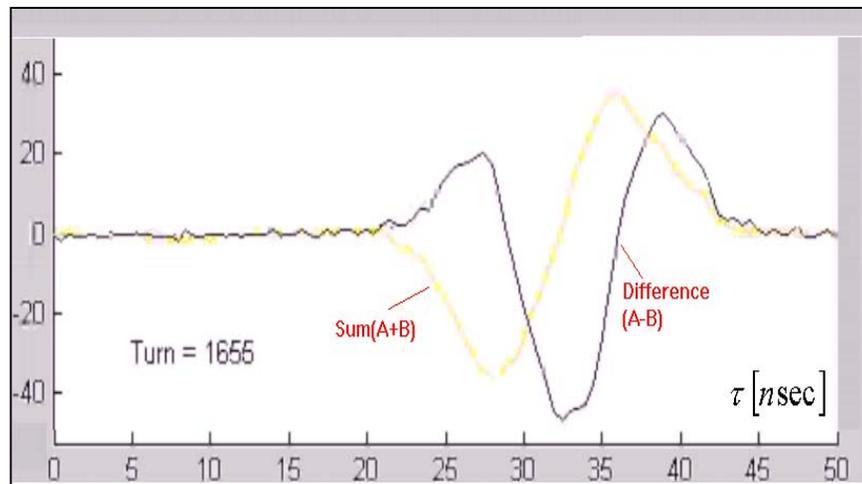
... which reduces pbar beam loss at 150 Gev from ~10% to ~2%.

Head-tail Monitor



Longitudinal configuration of the transverse dipole moment oscillations can be measured as

$$\bar{Y}(n, \tau) = \frac{A}{2} \cdot \frac{A(n, \tau) - B(n, \tau)}{A(n, \tau) + B(n, \tau)}$$



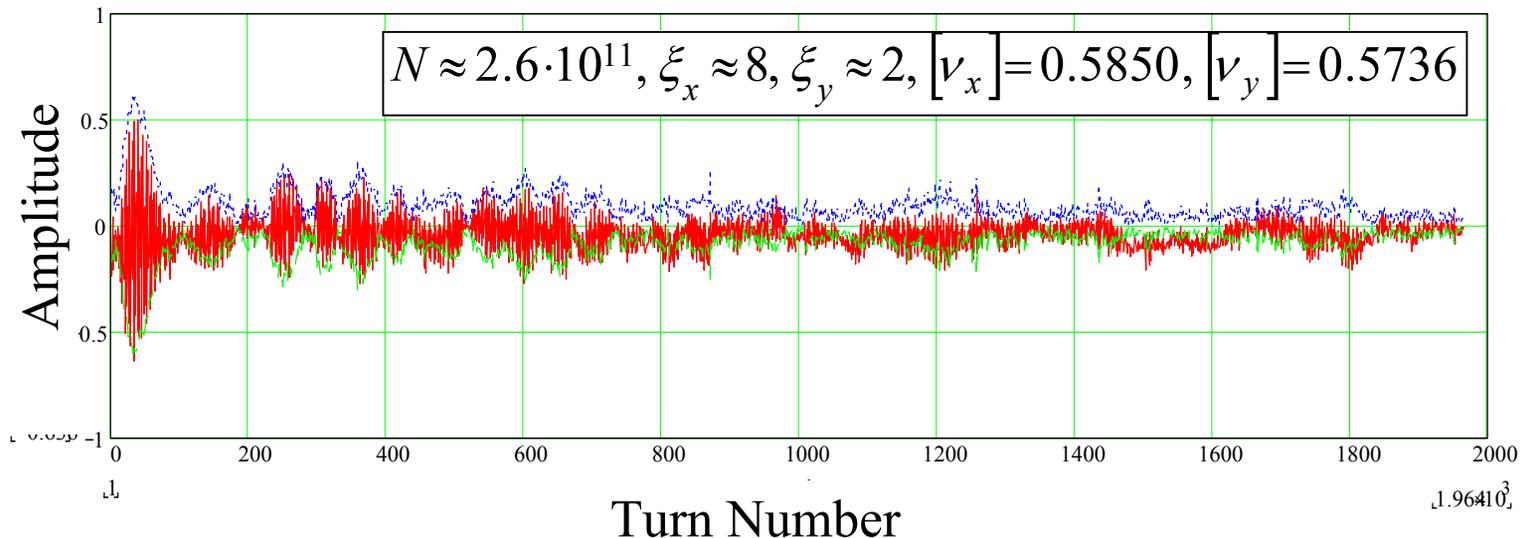
Unstable Head-tail Motion

Observed transverse oscillation for stable conditions

Beam is stable for $\xi_x \approx 8$, $\xi_y \approx 8$

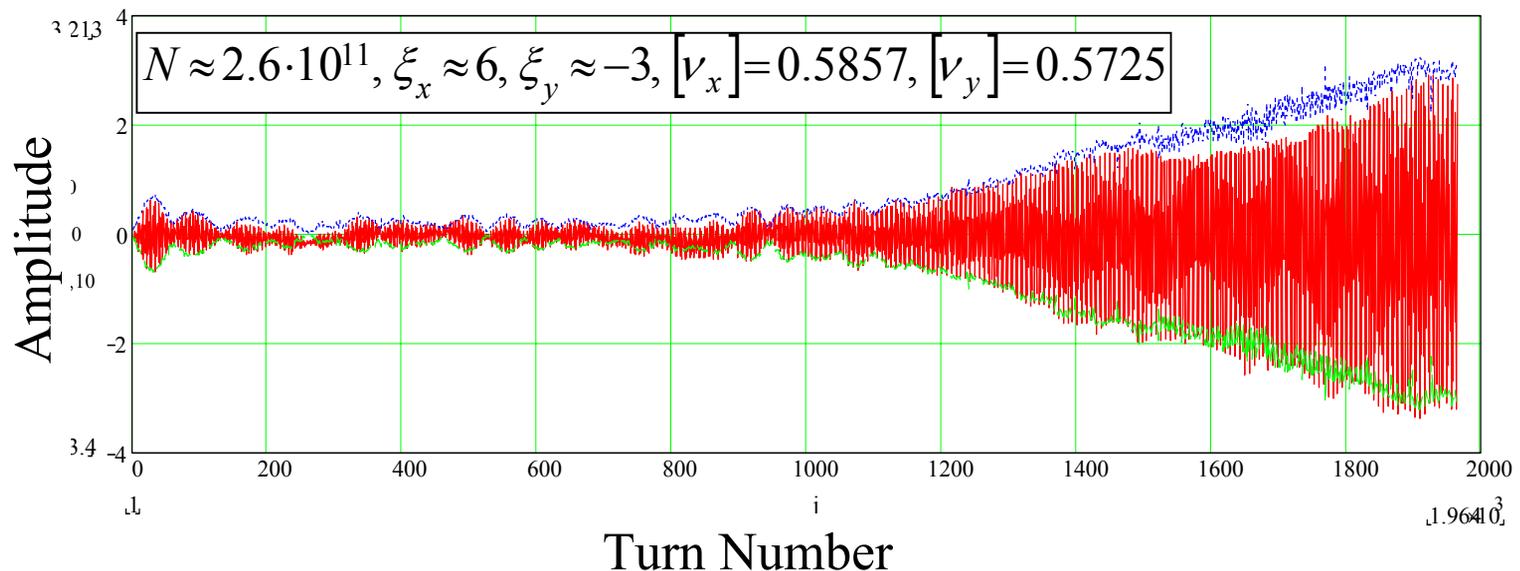
Longitudinal and transverse dampers OFF

$N_p = 260E9$

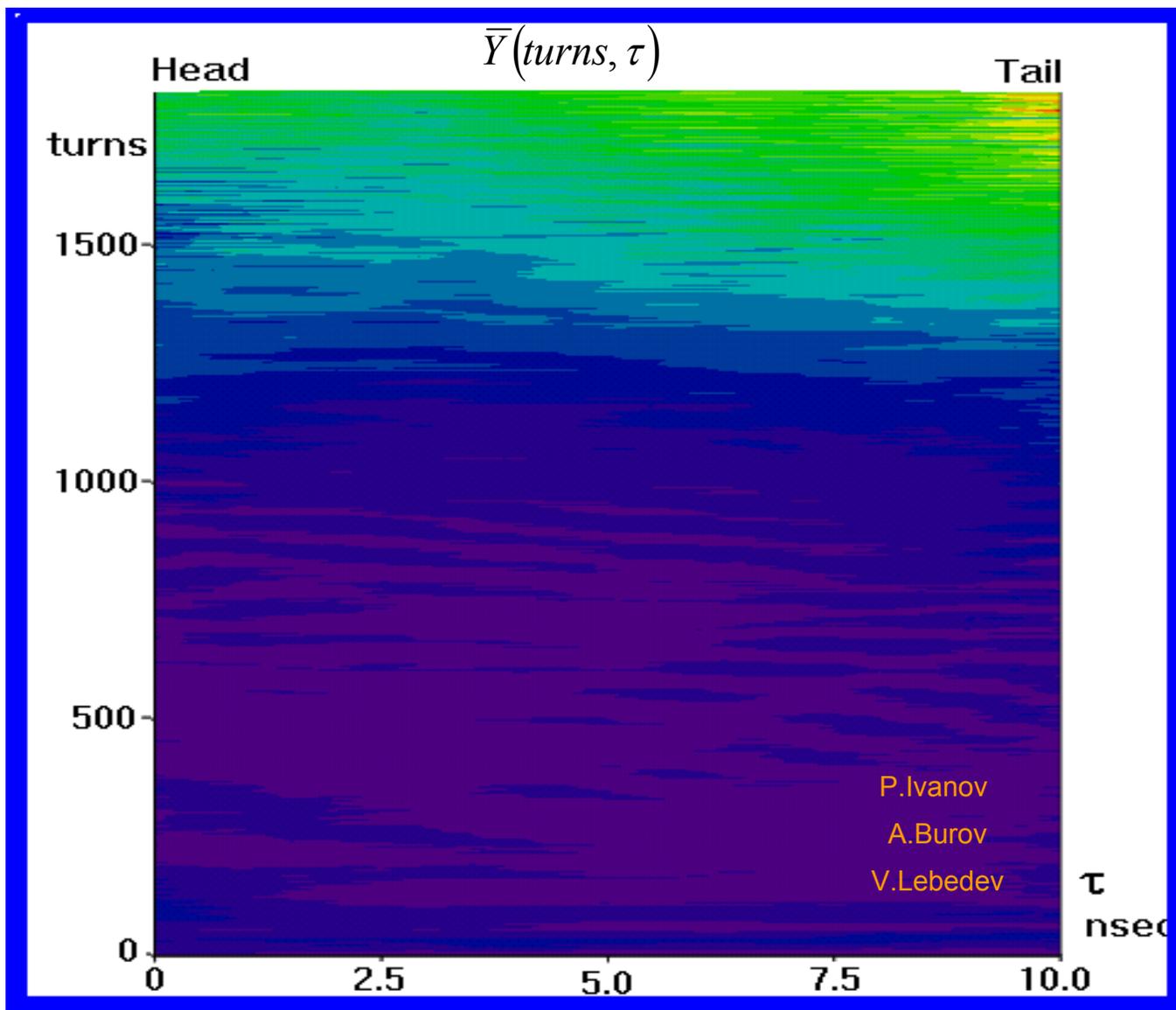


Unstable Head-tail Motion

Developing head-tail instability with monopole configuration
Beam is unstable for $\xi_x \approx 6$, $\xi_y \approx -3$
Longitudinal and transverse dampers OFF
 $N_p = 260E9$



Unstable Head-tail Motion



$$E = 150 GeV$$

$$N_{ppb} \approx 2.6 \cdot 10^{11}$$

$$\xi_y \approx -3$$

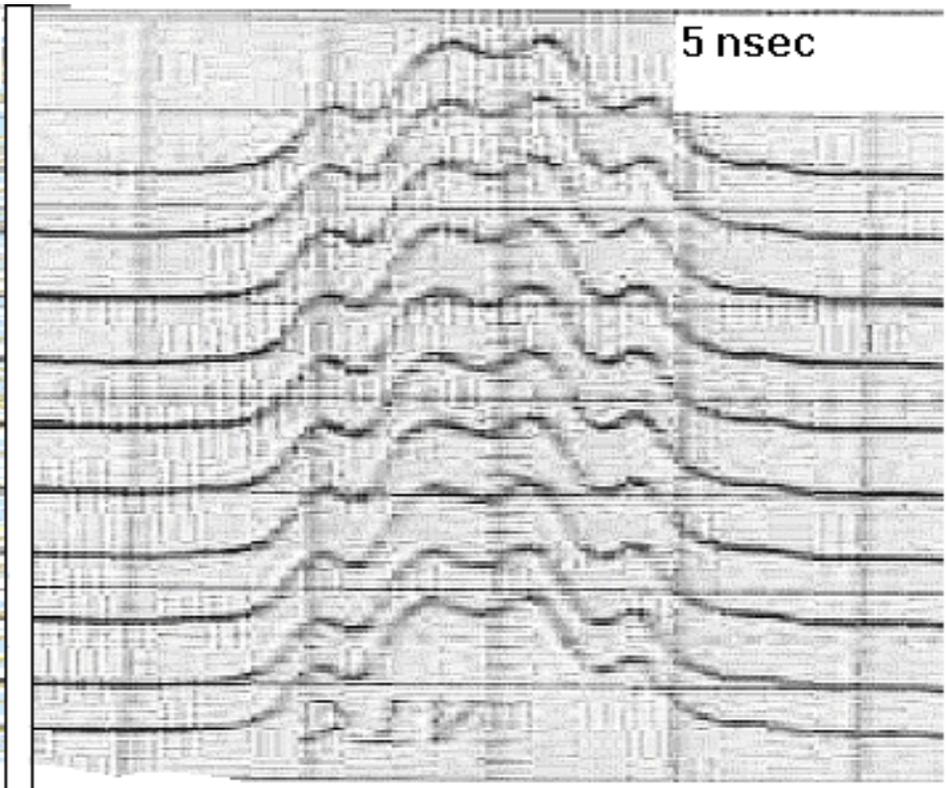
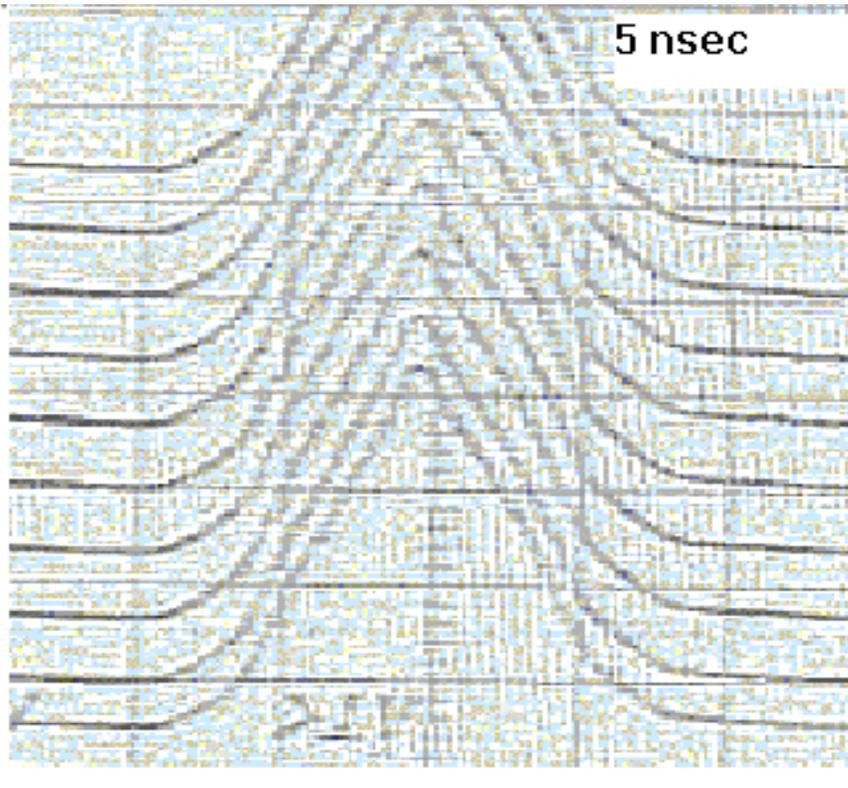
$$l_s = 0$$

Transverse Instability

- Beam remnants point to coherent betatron mode with $l=2$

$$N_{ppb} = 2.6 \cdot 10^{11} (\text{init. beam}) \quad \Rightarrow \quad N_{ppb} = 1.03 \cdot 10^{11} (\text{remain. beam})$$

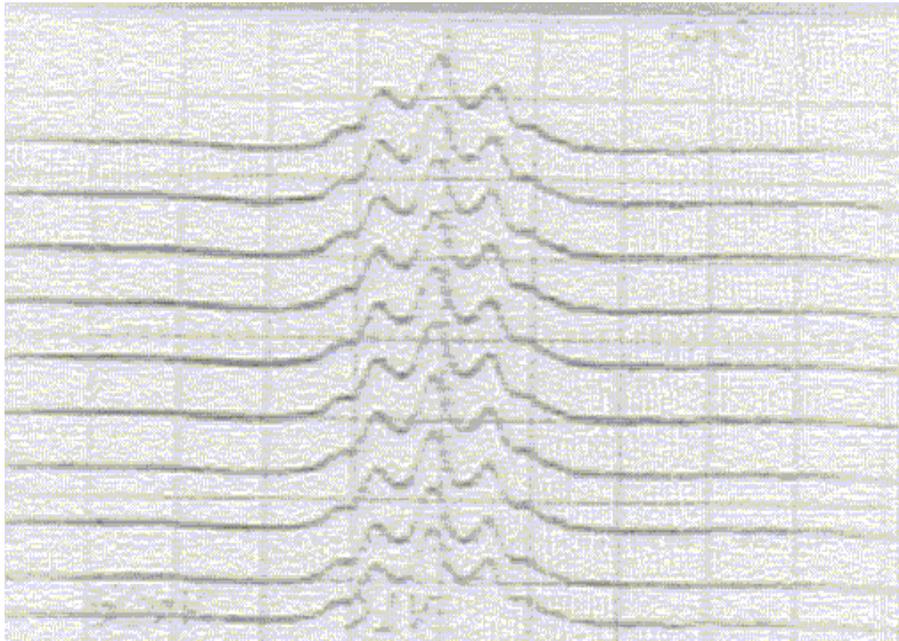
P.Ivanov, A.Burov



Transverse Instability

- Beam remnants point to coherent betatron mode with $l=1$

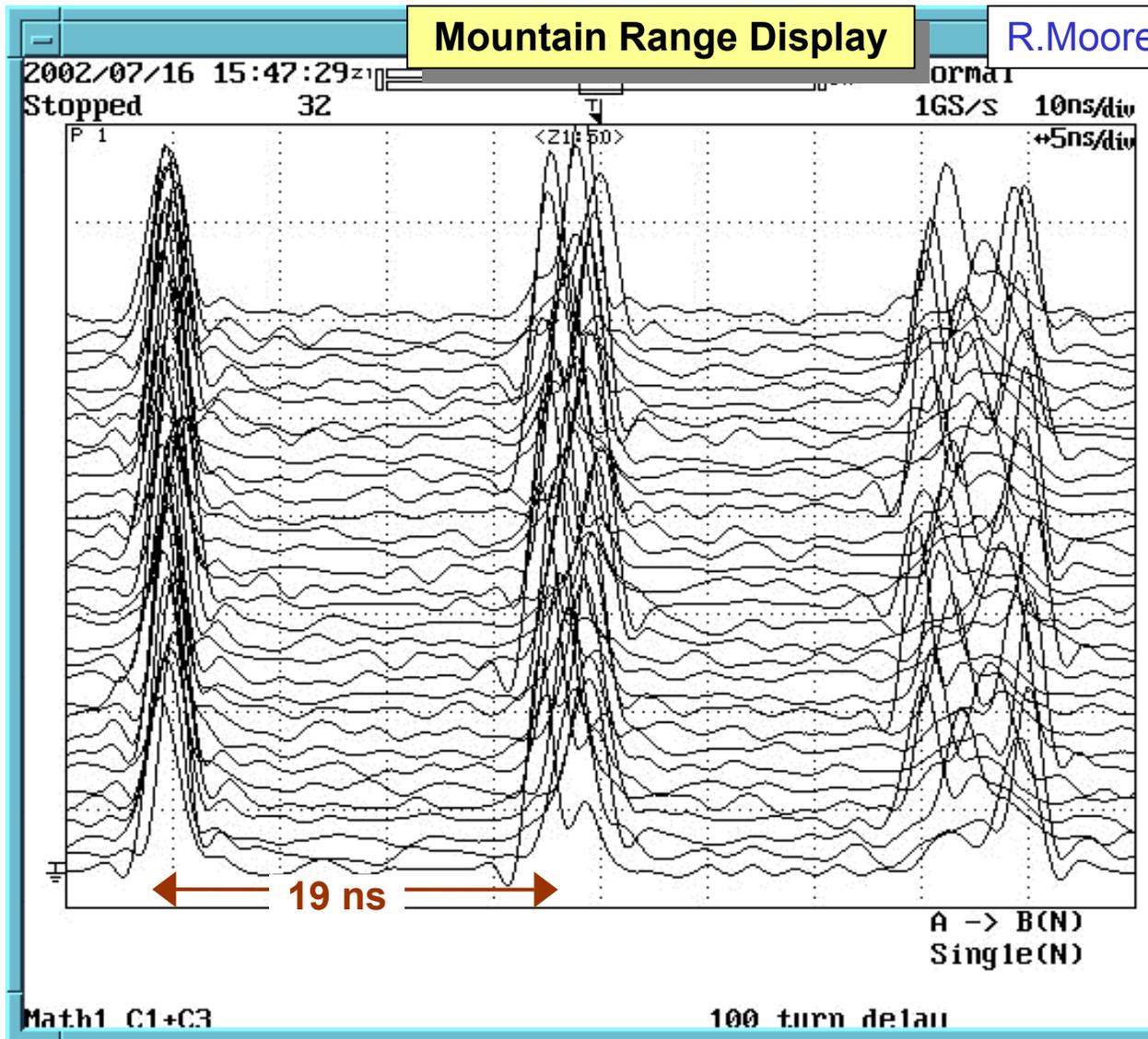
$$N_{ppb} = 2.65 \cdot 10^{11} (\text{init. beam}) \Rightarrow N_{ppb} = 0.7 \cdot 10^{11} (\text{remain. beam})$$



P.Ivanov, A.Burov

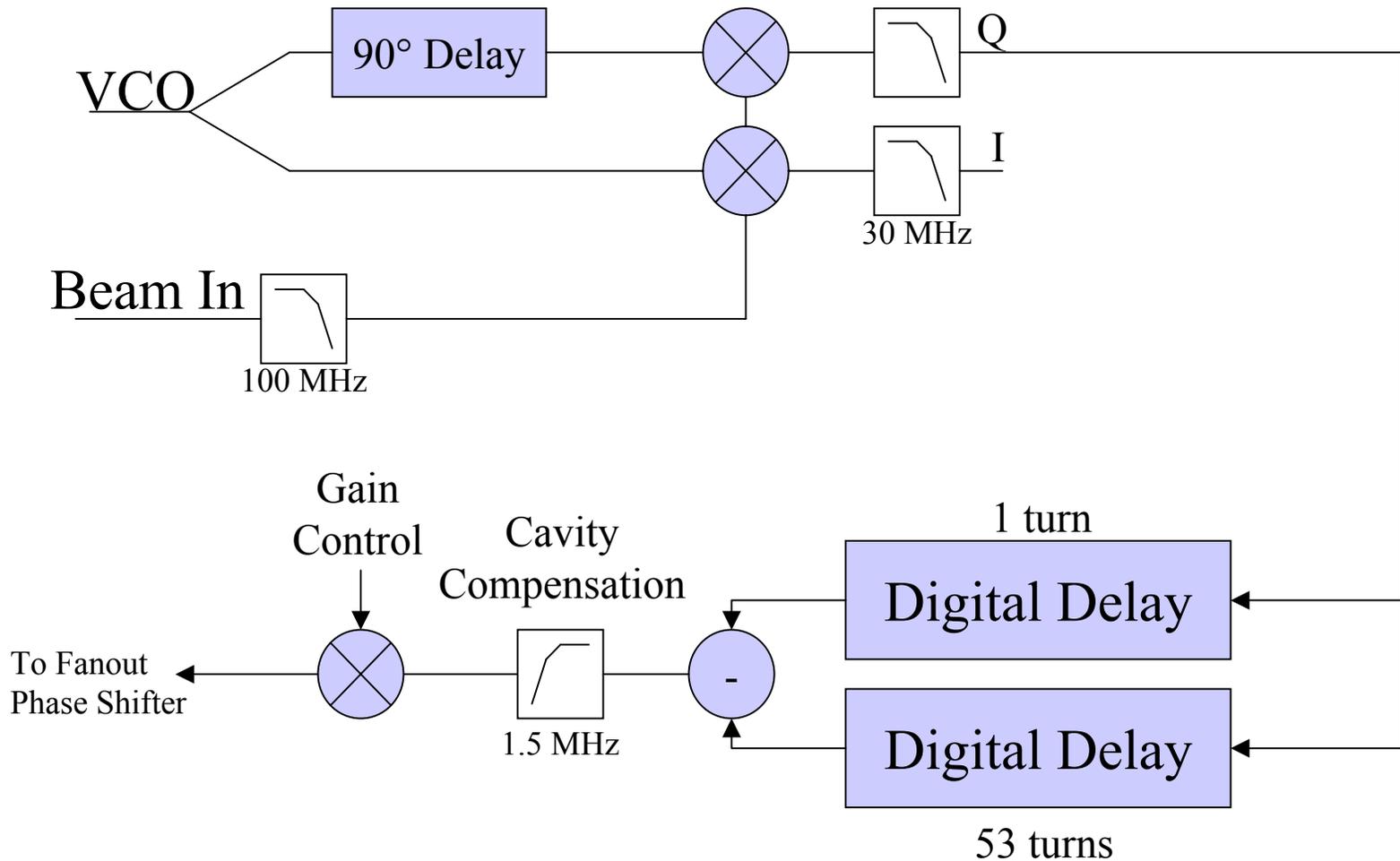
Structure of the remaining beam longitudinal density points qualitatively at excitation of the coherent vertical oscillations with the dipole longitudinal configuration $l=1$.

Longitudinal Impedance - "Dancing Bunches"

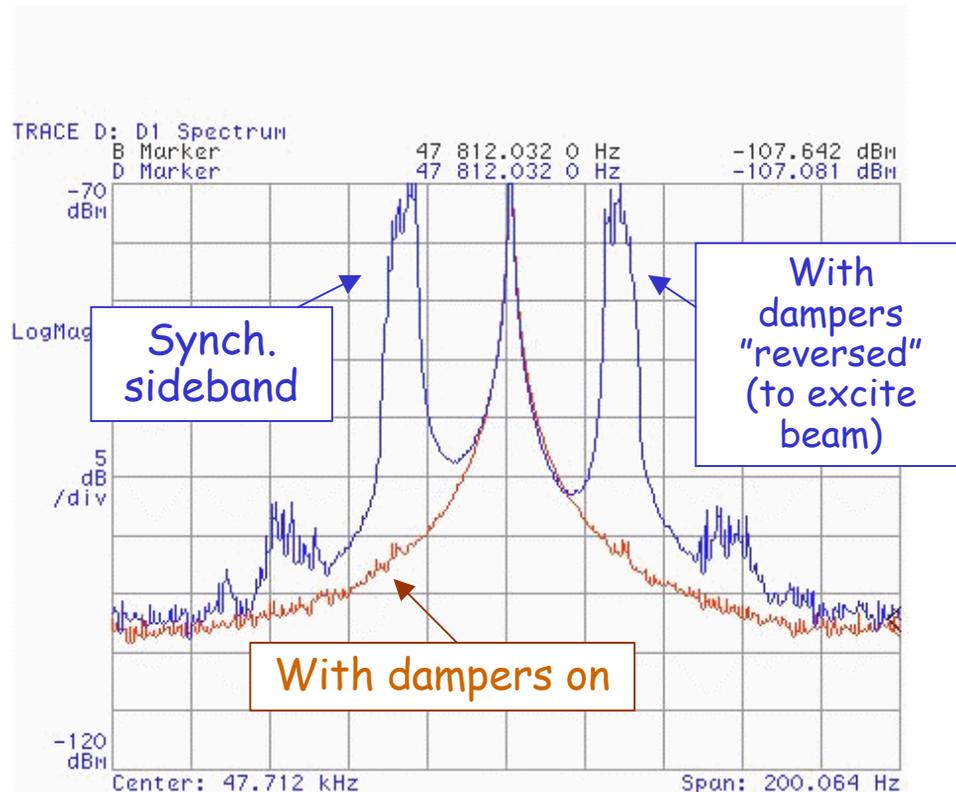


- Beam in 30 buckets
- 100 Tevatron turns (~2 ms) between traces
- Synch freq ~ 85 Hz
- Oscillation amplitude depends on bunch, changes slowly with time (minutes at 150 GeV, seconds at 980 GeV)
- Model needs inductive impedance $Z/n \neq 2 \text{ Ohm}$ interplaying with cavity impedance
- Coalesced bunches have dancing bumps

TeV Longitudinal Damper Block



Tev Longitudinal Damper

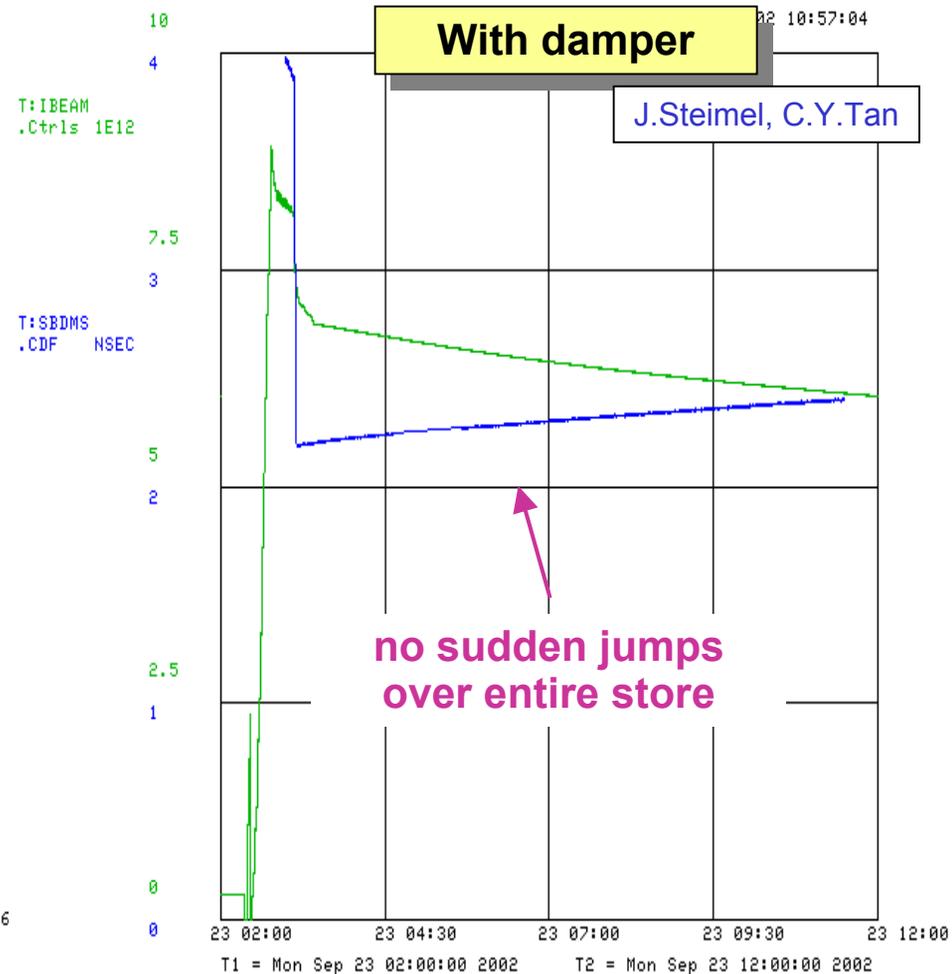
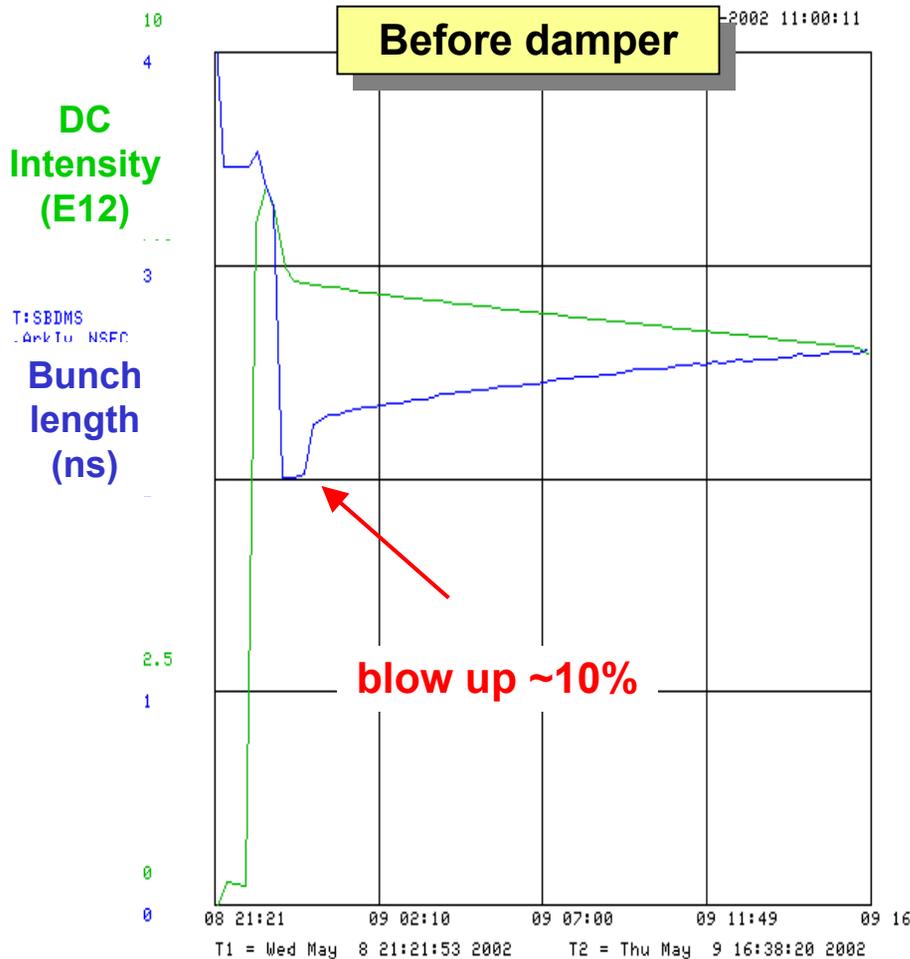


- Damper Hardware completed
- See excitation of synchrotron tune lines when damper is "reversed"
- Synchrotron sidebands damped when dampers are turned on.

Longitudinal dampers are on during a store.

No more sudden bunch length blowup is observed.

Bunch Length Blowup During Stores



- Intensity-dependent, leads to significant CDF background rise
- Usually only one or a few bunches would suffer
- **Problem solved** by bunch-by-bunch longitudinal damper

Diagnostics

Slides Related to Diagnostics and Instrumentation

- Summary of Diagnostics and Status
- Progress with Synchrotron Light Monitor
- Emittance measurement comparison
 - Scrapers
 - Synchrotron Light Monitors
 - Flying Wires
- New Schottky Monitor
- Head-tail instability diagnostics
- BPMs

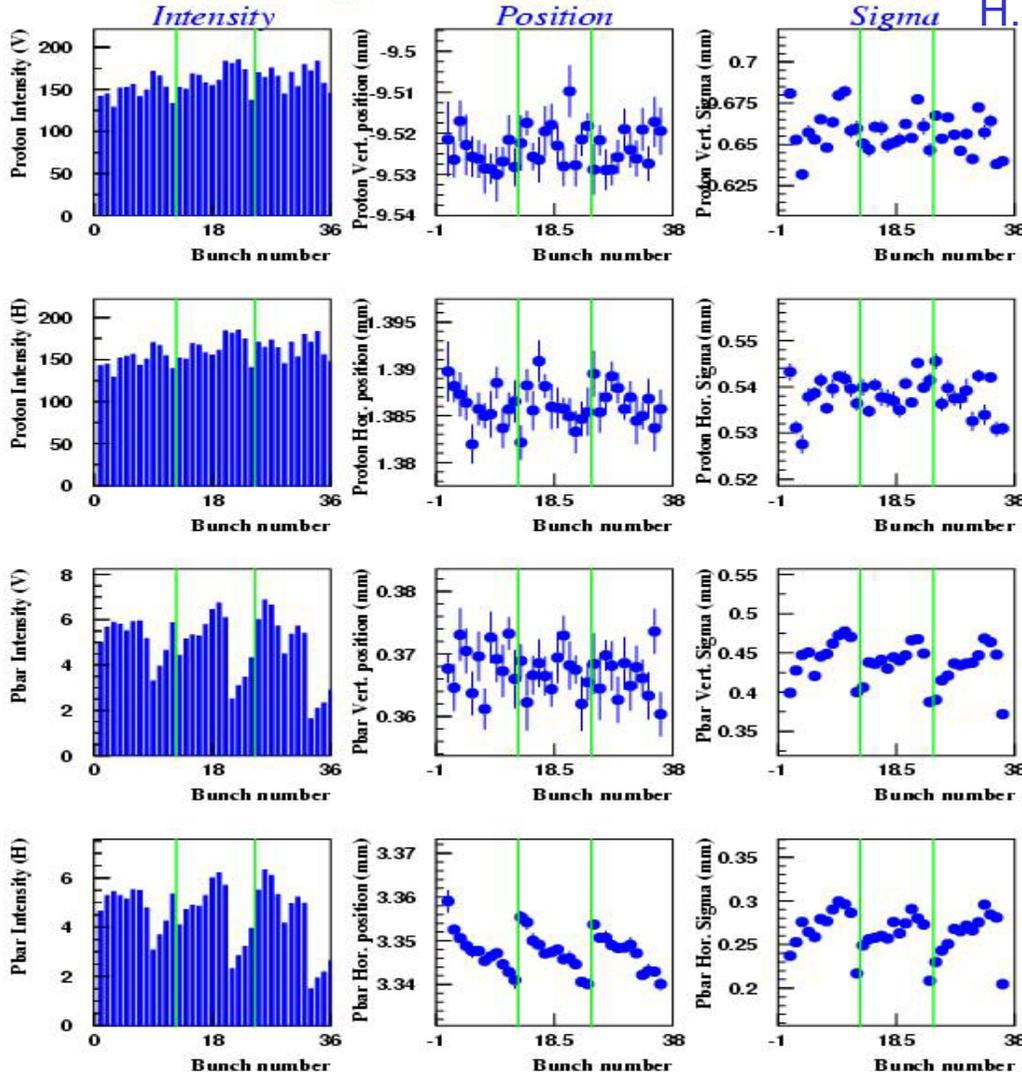
Diagnosics Progress/issues/needs

	<u>Priority</u>	<u>Status</u>
• BPMs	I	started
• Beam Line Tuner = BLT	I	good
• RF phase detector	I	good
• Flying Wires = FW	I	good
• SyncLite Monitor = SL	I	good-
• Single Bunch Display = SBD	I	good-
• Fast Bunch Integrator = FBI	I	good+
• Schottky Detector (21 MHz, + 1.5 GHz)	I	good
• Head-Tail Monitor	I	fair
• Tune-Meter, Tracker	I	fair
• On-line Chromaticity Measurement	I	started
• Digital Mountain Range	II	good-
• Fast Chromaticity Measurement	II	fair
• TEL Instrumentation	II	fair+
• RF Noise	II	good-
• BPM Upgrade	II	none
• Orbit Oscillations Monitor	III	fair
• Magnets motion	III	good

Diagnosics Progress: SyncLite Monitor

Values averaged over 10 mins from 18:33:51 10-4-2002

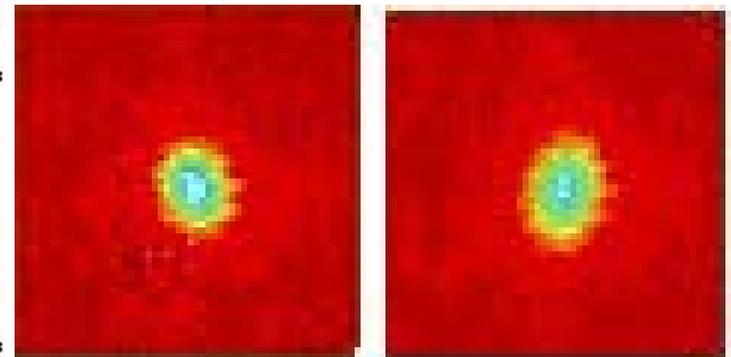
H.Cheung



- Works >800 GeV
- Significant progress since March '02
- Reports rms, mean, N, tilt bunch-by-bunch for both protons and pbars
- Invaluable instrument

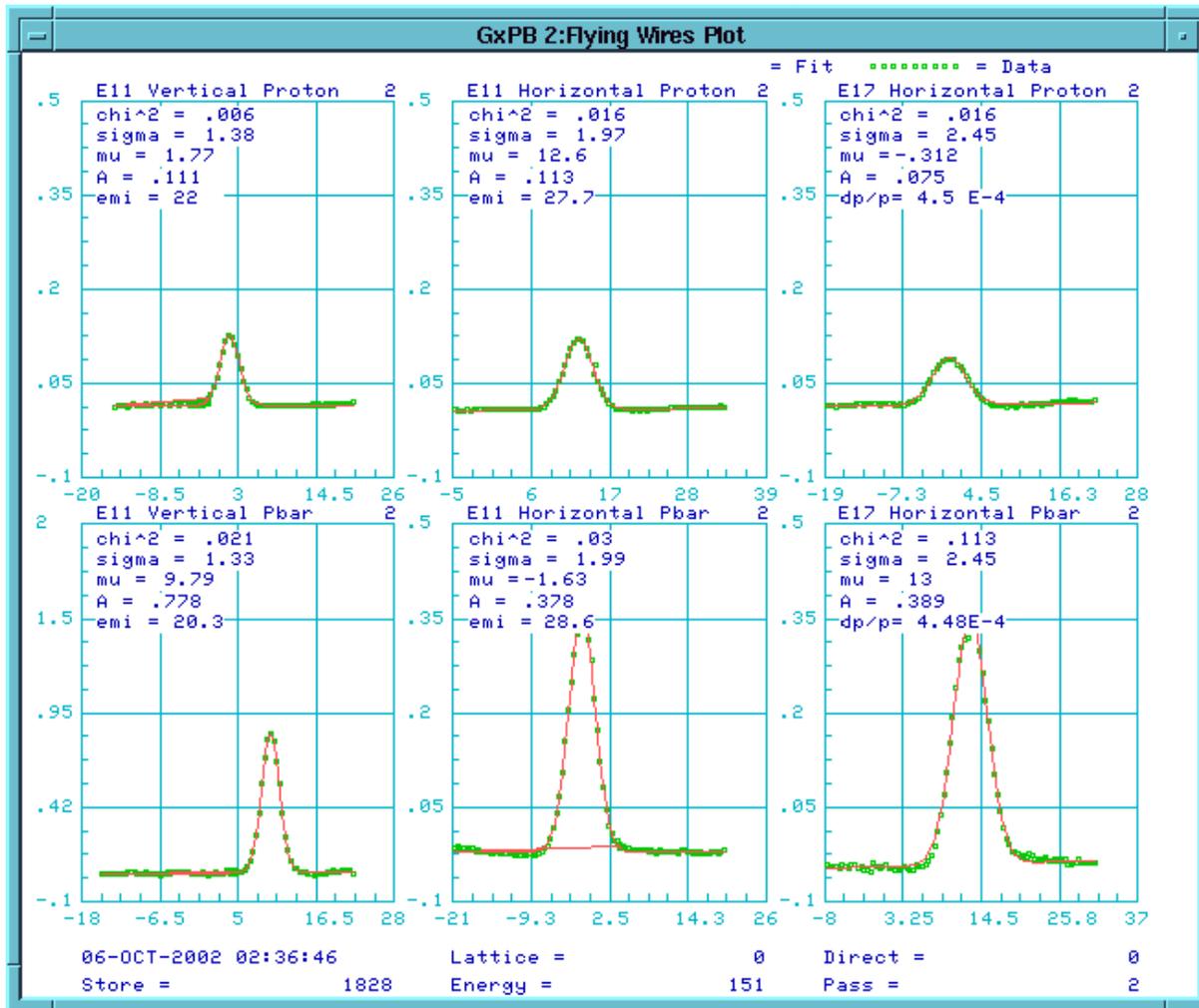
Bunch #1

Bunch #8



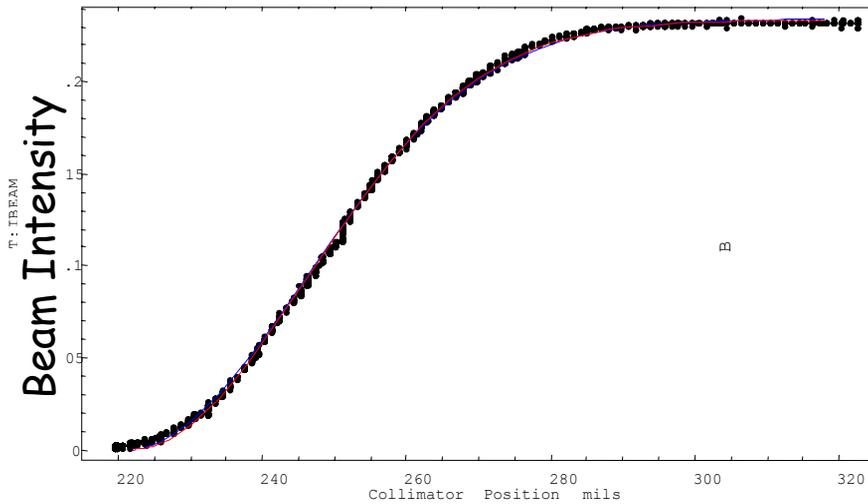
Diagnostics: Flying Wires

#1828, injection



- Proton channels tuned up in March
- Still some (15% ?) calibration needed
- Pbar channels data are subject of correction
- "Jumping" emittances
- (improper dP/P ?)
- Recalibration of both p and pbar channels is due
- Need raw data

Tev Scraping Studies



Collimator position (mils)

Intensity versus collimator position assuming Gaussian beam (1D scraping):

$$N = N_0 \left(1 - e^{-\frac{(x-x_0)^2}{2\sigma^2}} \right)$$

Vertical prot emittance measurement (95%, normalized)

Use scrapers to measure emittance. Then compare to FW and Sync. Lite

Scraping:	24-27 π
Flying Wire:	30 π
Sync. Lite:	34 π

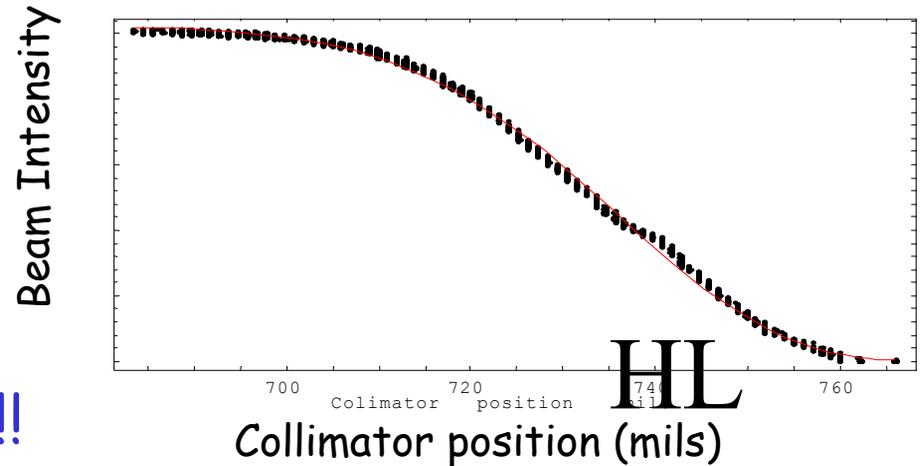
Need to know β function at monitors!

Tev Scraping Studies

Horizontal proton

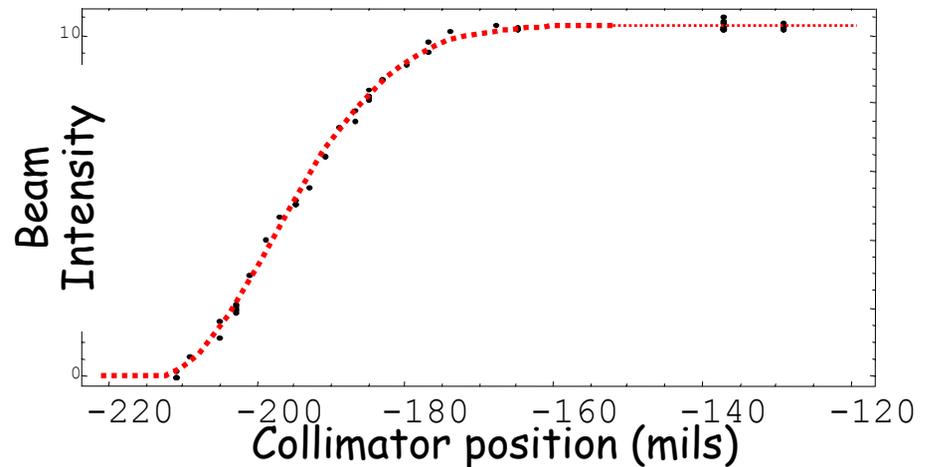
Scraping: 31-33 π
Flying Wire: 22-28 π
Sync. Lite: 34 π

Dispersion is an issue !!!

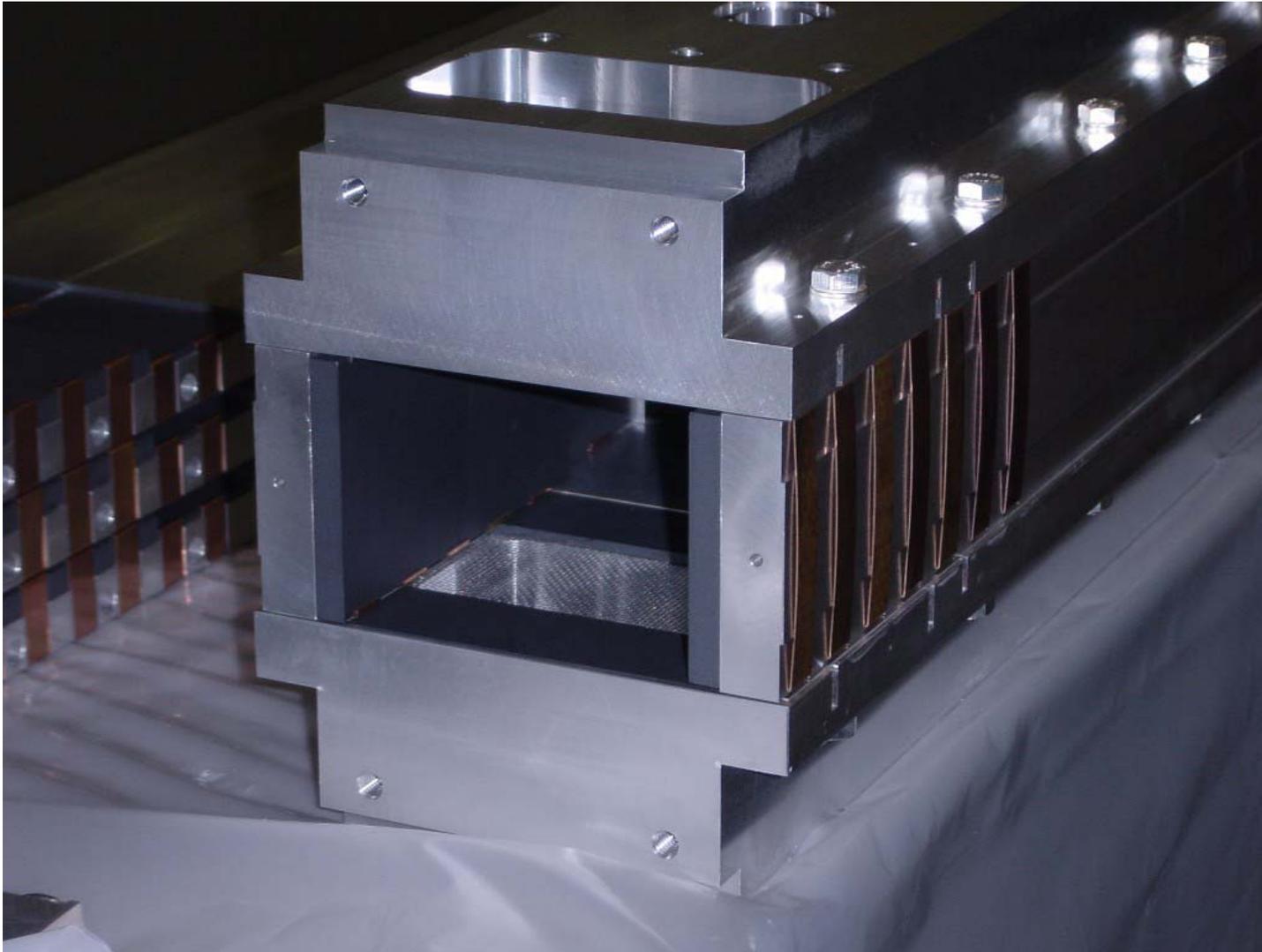


Vertical pbar

Scraping: 20-24 π
Flying Wire: 42 π
Sync. Lite: 44 π



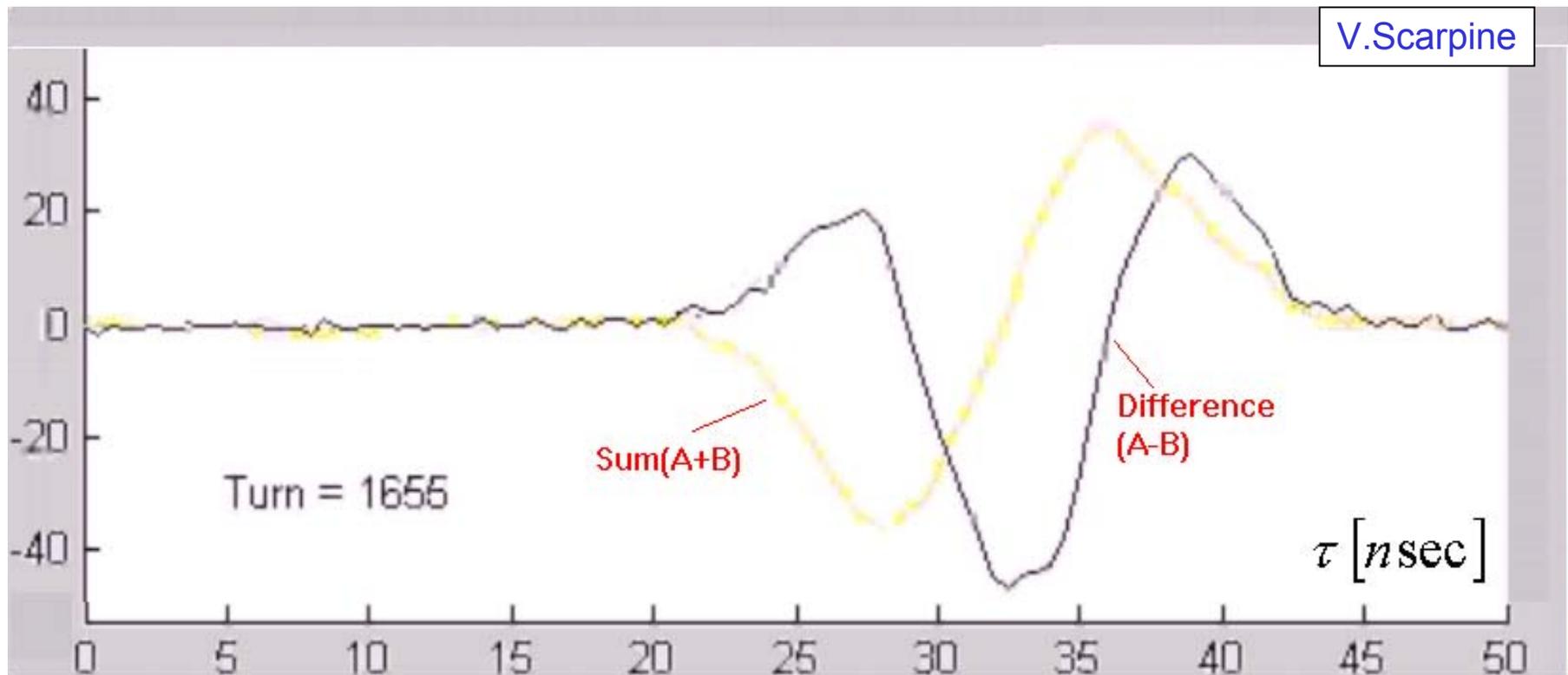
Schottky Monitor



Schottky Monitor

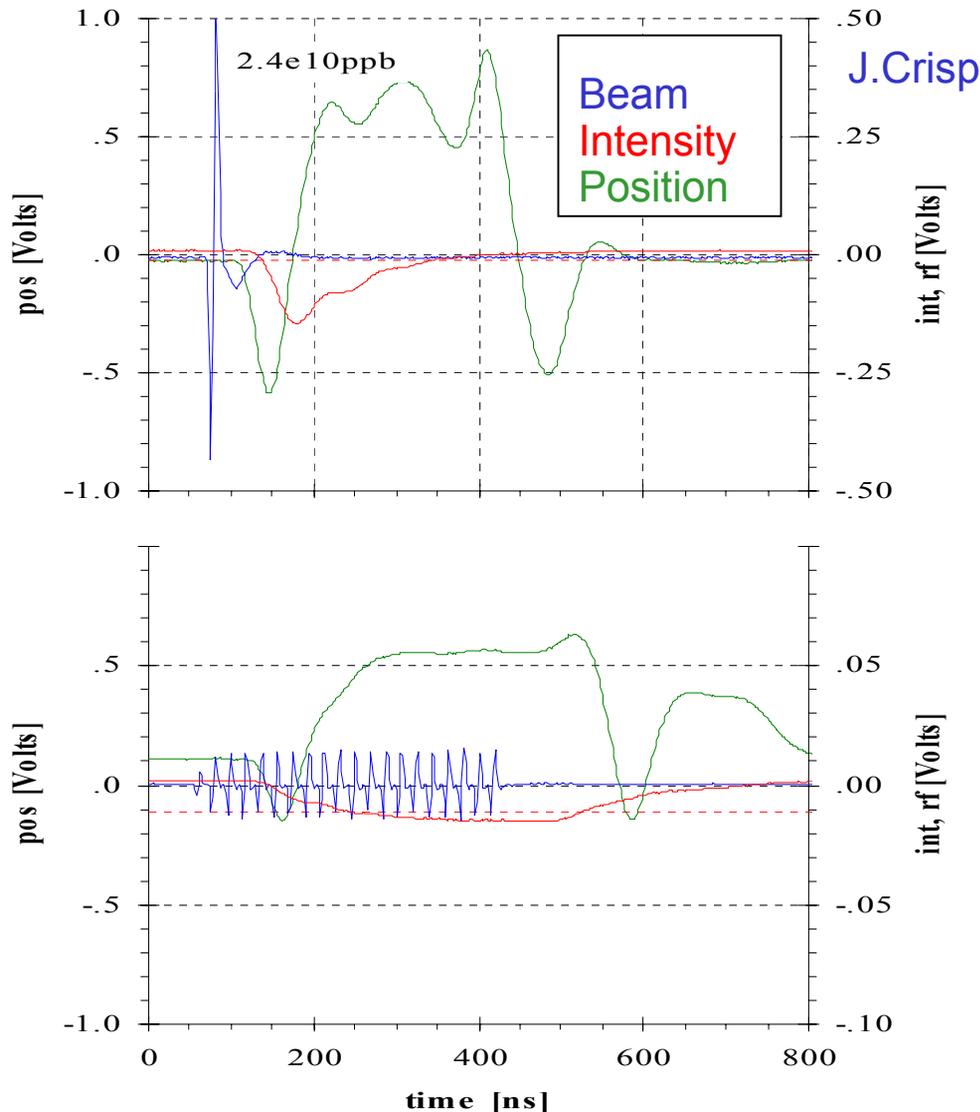
- 1.75 GHz center frequency
- 100 MHz Bandwidth
- Used to
 - Measure emittance
 - Measure chromaticity non-destructively
 - Measure tunes of individual bunches
- Tank installed in January 2003 shutdown

Diagnostics: Head-tail Monitor



- BLT hard- and software to measure position within one bunch
- Goal of the HTM - monitor higher order head-tail modes
- To be used for chromaticity measurements (non?-destructively)

Diagnostics: BPMs



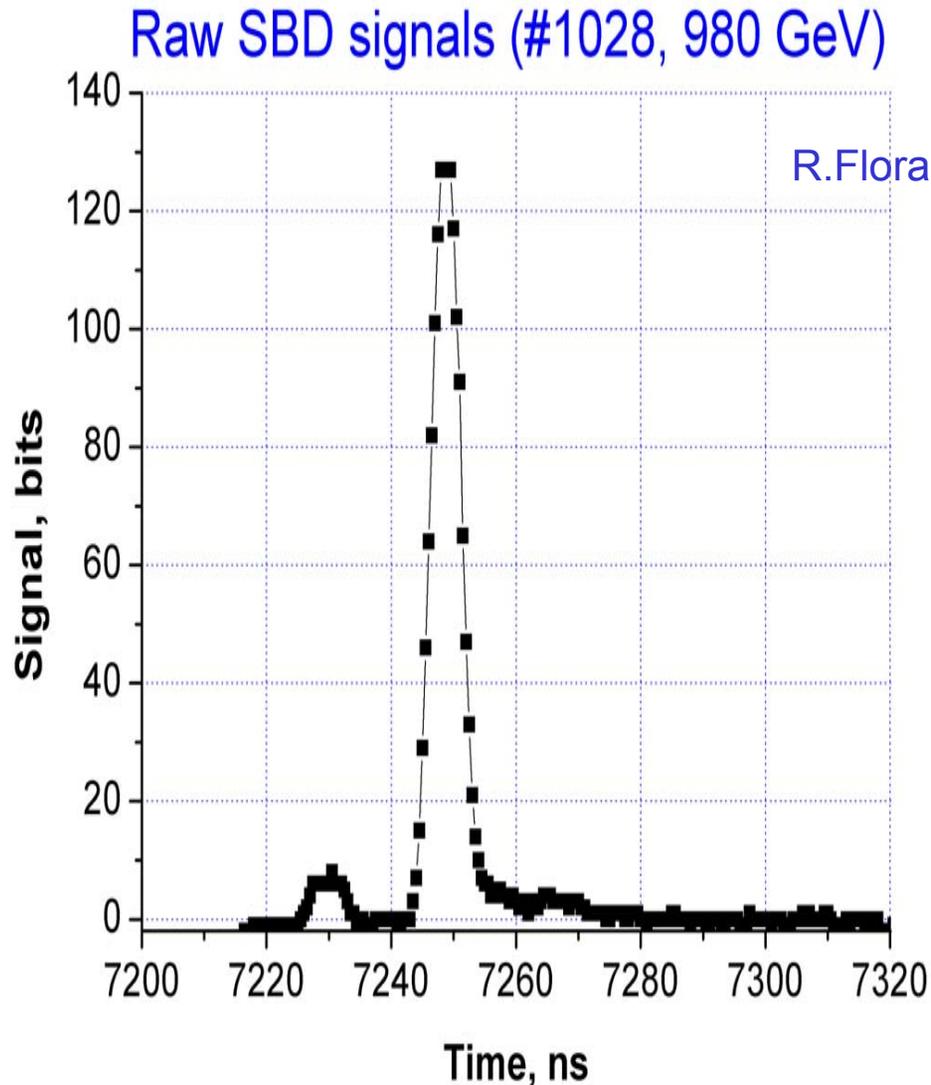
BPMs originally designed for 53 MHz beam structure

Work well now for uncoalesced beam

After some tuning BPMs worked in Run I with 6x6

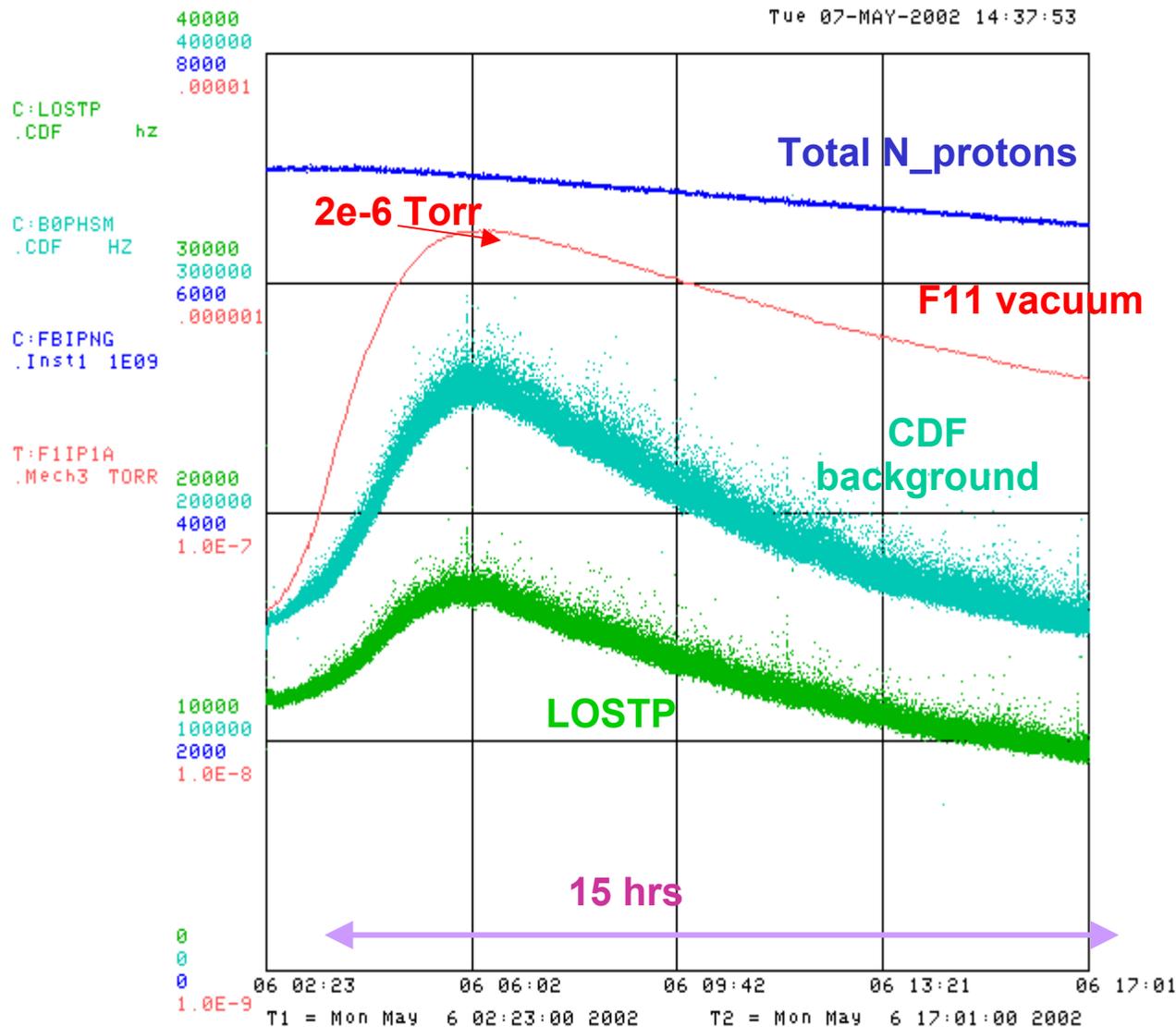
Do not work with 36x36 because of bunch separation is smaller than filter ringing time

Diagnostics: SBD, FBI



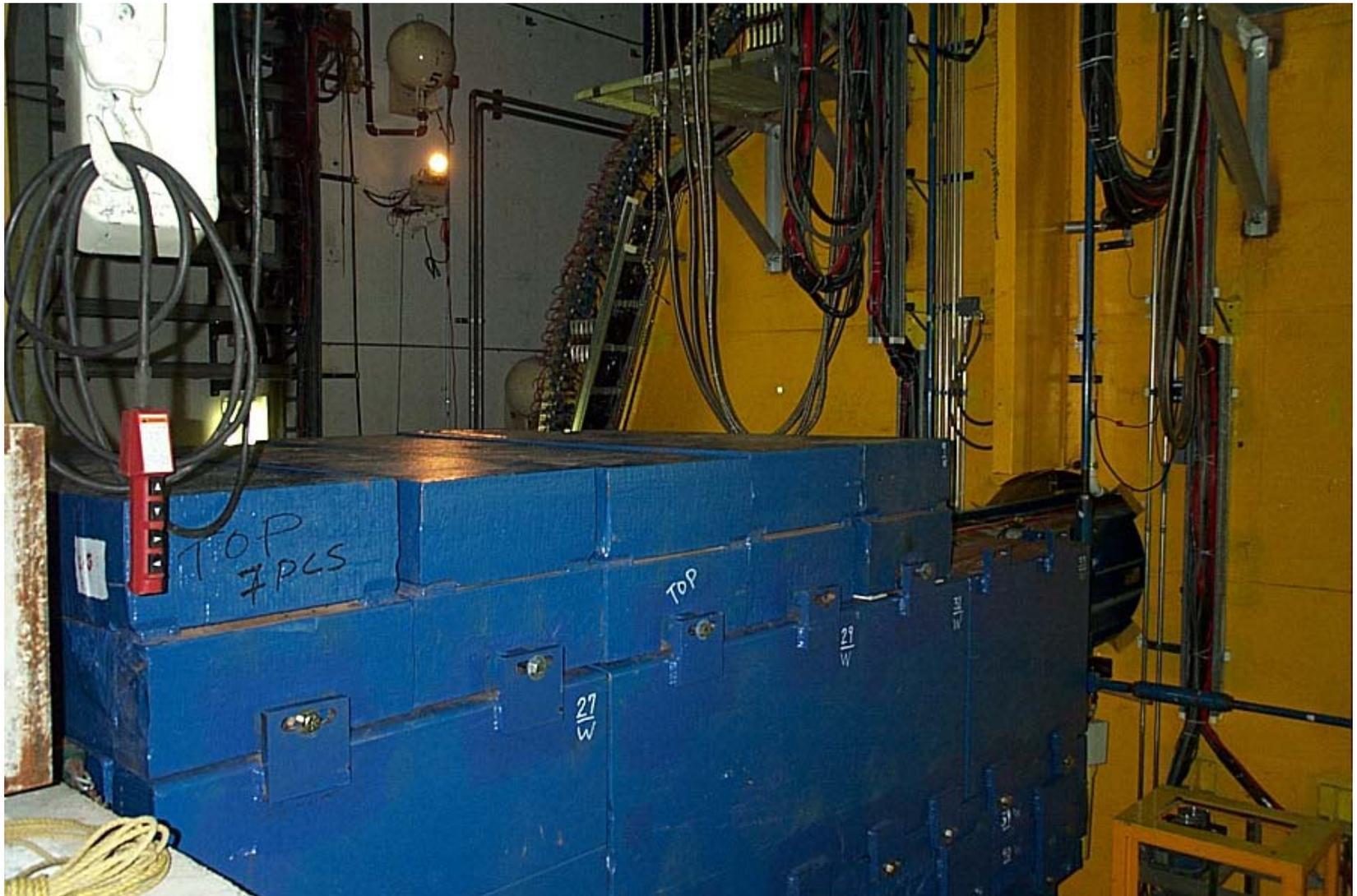
- Dispersion in long cable adds to σ_s , tails, satellites
- Raw data available On-Line
- Pbar channels affected by strong proton bunches
- Pbar bunch length not available in ACNET until final cogging (just fixed)
- FBI needs calibration (5%?) and proper offset subtraction especially in pbar channel
- FBI intensity depends on σ_s - need to be fixed
- Intensity from SBD

Vacuum and Background



- for several months the CDF losses had bump few hrs into stores
- reason was out-gassing of ferrite absorber in RWM due to beam heating
- fixed in June'02
- that allowed to estimate average equivalent Tev vacuum pressure to be $1e-9$ Torr (room T, N_2)

CDF Shielding



Performance: FY'03 Goals

Parameter	Current Performance	FY03 Goal	
Typical Luminosity	3.2e31	6.6e31	cm ⁻² sec ⁻¹
Integrated Luminosity	6.0	12.0	pb ⁻¹ /week
Protons/bunch	170e9	240e9	
Antiprotons/bunch	22e9	31e9	
Proton emittance (95%, norm)	20	20	pmm-mr
Pbar emittance (95%, norm)	18	15	pmm-mr
Bunch length rms (prot, pbar)	0.6	0.54	meter

- Most of the luminosity gain comes from more particles
- Higher N_p leads to beam-beam, instabilities, backgrounds
 - Need to understand these physics issues
 - Need time for studies

Tevatron Projects in FY'03

	project	Leader	Date	N_P	N_A	emm
1	Transverse dampers	<i>Steimel</i>	Nov'02	■		
1	Pbar emittance at injection: BLT,A1 line, inj.damper	<i>Scarpine Lebedev Steimel</i>	Nov'02 Dec'02 Feb'03	■	■ ■	■ ■ ■
1	C0 Lambertson replacement	<i>Garbincius</i>	Feb'03	■	■	
1	Tev Lattice (A0)	<i>Martens</i>	Feb'03		■	
1	Daily operations	<i>TeV coord</i>	daily	■	■	■
1	Operational orbit smoothing	<i>Martens</i>	Dec'02	■	■	
1	Beam-beam studies and calculations	<i>Sen</i>	Sep'03	■	■	■

Tevatron Projects in FY'03 (Cont'd)

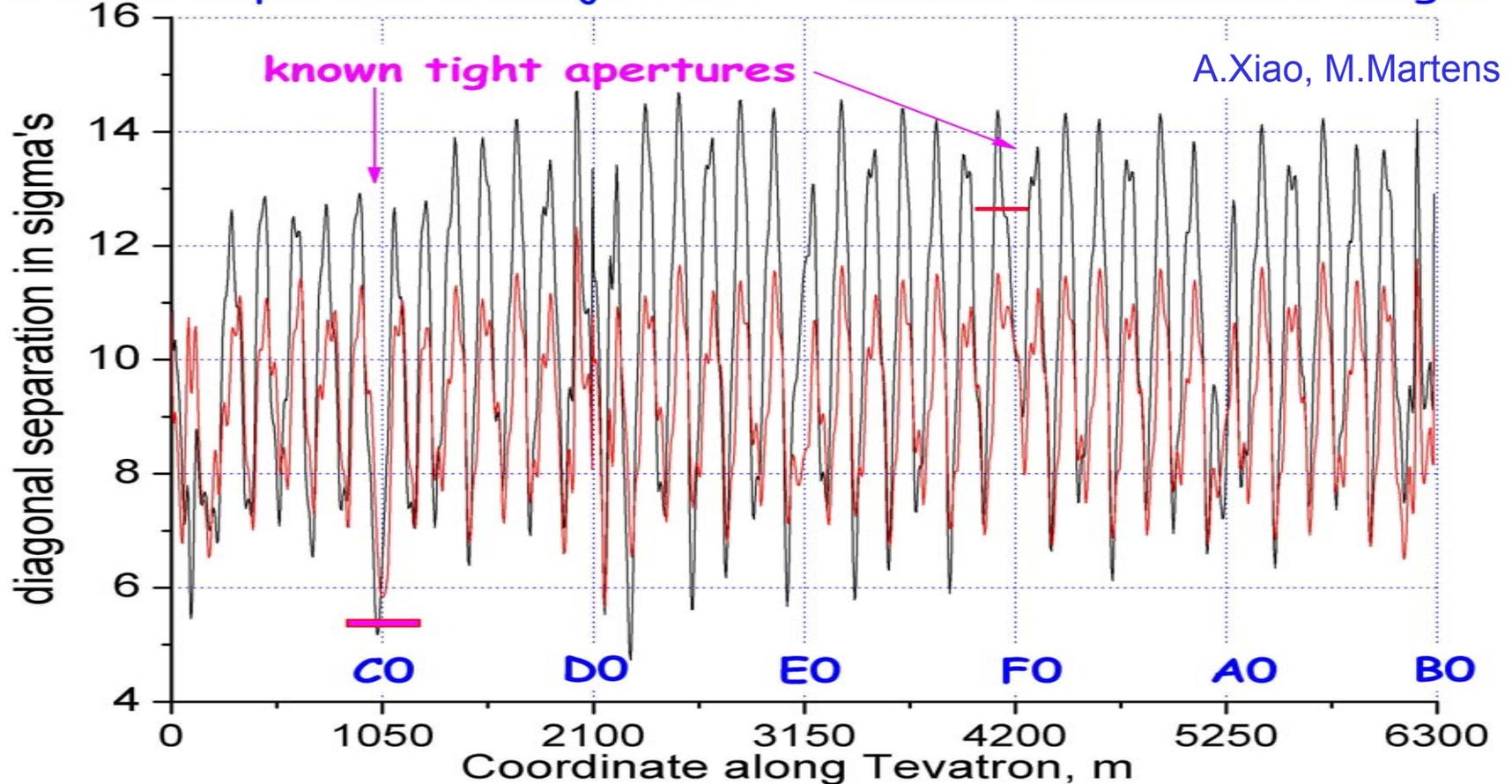
2	Instability studies	<i>Ivanov</i>	Dec'02	■	■	
2	150 GeV tunecoupling drift compns; b2 unwind	<i>Martens</i>	Oct'02		■	
2	TEL	<i>Shiltsev</i>	Feb'03	■	■	
2	Schottky detector at E17	<i>Pasquinelli</i>	Feb'03		■	
2	Tevatron alignment	<i>Stefansky</i>	Mar'03		■	
2	Longitudinal dampers	<i>Steimel</i>	Apr'03	■		
3	Tevatron vacuum	<i>Hanna</i>	Feb'03	■	■	
3	Losses/collimators	<i>Moore</i>	Feb'03	■		
3	DC Beam/RF noise	<i>Lebedev</i>	Apr'03	■		
3	SBD/FBI/FW (BPMs)	<i>Pordes</i>	Dec'02	■	■	■
3	SynchLite	<i>Cheung</i>	Dec'02	■	■	■
3	Chromaticity measurement	<i>Still</i>	Dec'02		■	
3	Orbit motion spectrometer	<i>Zhang</i>	Dec'02	■		■
3	Pbar tunemeter, feedback	<i>Tan</i>	Mar'03		■	

FY'03 Shutdown(s)

- Projects for FY'03:
 - Alignment work
 - A0 lattice modification (?)
 - Vacuum improvement (incl., warm two houses)
 - Install new collimator at A48 (?)

Lattice Modification at Sector A0

Beam-Beam Separation at Injection Now/After A0 Lattice Changes



A.Xiao, M.Martens

- Proposed modification promises 16% larger min separation at injection (5.6 vs 4.7 σ)
- Benefits still to be quantified given that C0 aperture will be opened for sure

Physics Progress

- **Beam-beam issues**
 - N_p effect (pbar only, efficiencies vs N_p)
 - Emittance+aperture effects (CO + FO + AO, t vs Aperture)
 - Tune, κ , $C_{v,h}$, orbit effects (variations, smoothing, compensation)
 - Lifetime/other effects in collisions (breakdown, b-to-b orbits, tilts, sigmas)
 - Beam-beam effects for protons (at LB)
 - IPs (luminous regions, separator scans, coupling)
 - TEL (better lifetime, Gaussian gun)
- **Instabilities/blowups**
 - Coherent transverse (coherent, b-to-b, HOMs, $C_{v,h}$, dampers, octupoles)
 - Coherent longitudinal (s_s blow-up, b-to-b, damper, dancing bunches)
 - Incoherent transverse (150 loss loss vs $C_{v,h}$, ds_s /dt , emittance growth)
 - Incoherent longitudinal (ds_s /dt vs N_p)
 - Orbit drifts (tides+Temperature +drifts)
- **Losses/background**
 - Vacuum (F11, IPs)
 - DC beam (DC loss rate in store)
 - Collimators (new at A48)

Summary on Tev Luminosity in '03

- Aggressive pursuit of pbar intensity at low-beta, moderate on protons, about same emittances
- projects and expectations gain in L
 - Transverse dampers ~15-20%
 - Fix A1/P1 inj lines ~10-20%
 - Open C0 aperture ~10%
 - Better focus at IPs ~0-10%
 - smaller β^* ; local decoupling; shorter bunch length
 - Beam-beam tuneup >5% ?
 - Tunes/coupling; TEL; smaller dp/p ; shave in MI; RF noise; vacuum
 - AO lattice modification 0-5% ?
 - Diagnostics improvement + in integr. L

Summary

- Significant luminosity improvement
 - 5 times since October'01
 - 3 times since March'02
- Complex running well lately
 - Now consistently above Run I peak luminosities
- Delivered 76 pb⁻¹ to each experiment in FY'03
- Made significant progress on many issues.

Summary

- Need to continue progress on
 - Beam-beam
 - Instabilities
 - Diagnostics
- Looking forward to delivering $0.2-0.32 \text{ fb}^{-1}$ in FY'03
 - increase peak luminosity to $(5-7)e31$
 - about +12% (stretched to 24%) more protons to collisions
 - about +35% (stretched to 60%) more antiprotons to collisions
 - about the same emittances