Tevatron Performance Since March'02 and FY'03 Plans

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Fermilab

Contents

- Luminosity progress
- Progress with :
  - Beam-beam effects
  - Instabilities
  - Background, etc.
  - Diagnostics
- FY'03: Luminosity Goal
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Luminosity Formula

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

(10^{31} cm^{-2} 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 - .75

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

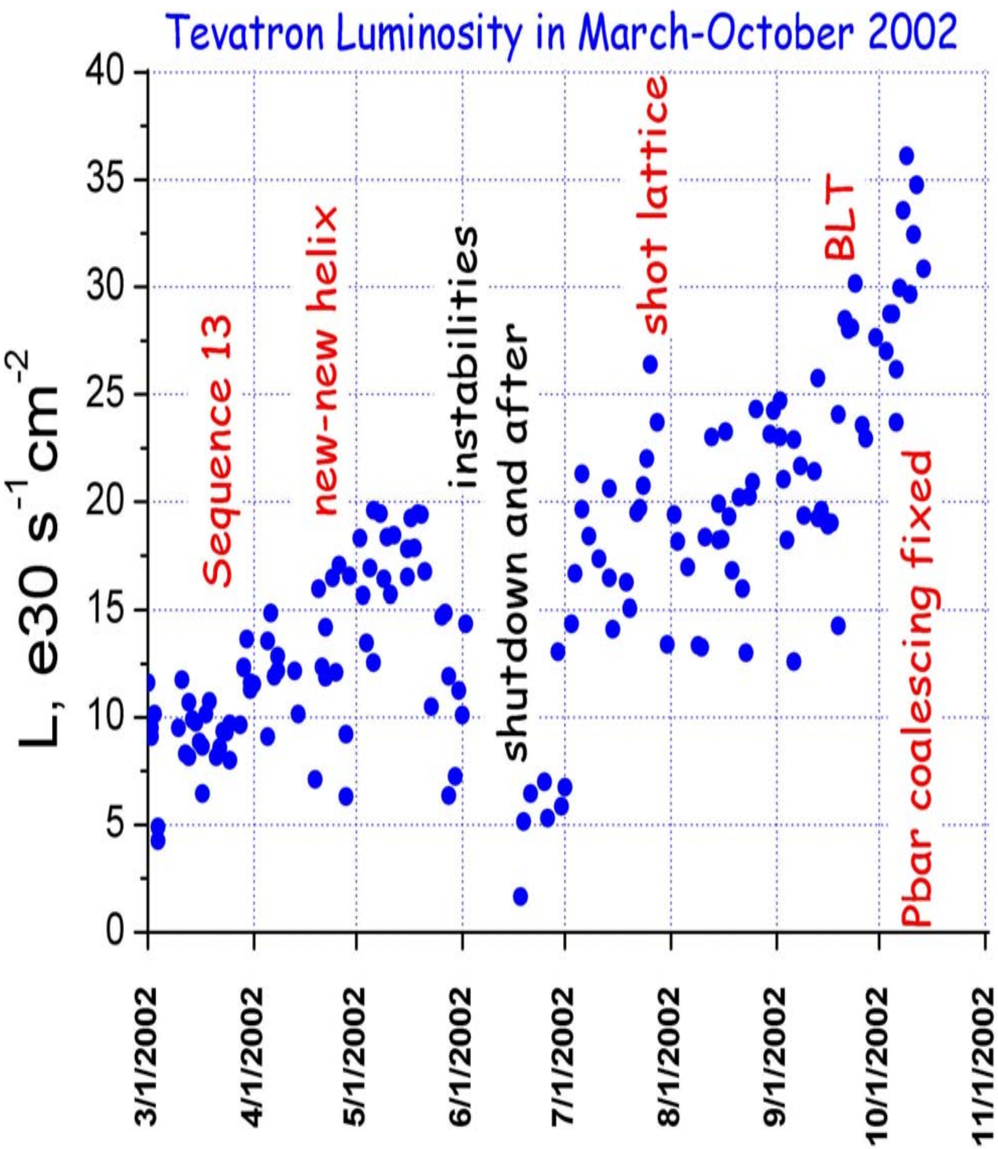
ε_p , ε_{pbar} = transverse emittances (π-mm-mrad)

σ_l = bunch length (cm)

Goals and Current Performance

Parameter	Run IIa Goals	Current Performance	
Protons/bunch	270e9	170e9	
Antiprotons/bunch	30e9	22e9	
Total Antiprotons	1080e9	800e9	
Peak Pbar Production Rate	200e9	120e9	/hr
Pbar: Inj. -> Low β efficiency	0.90	0.75	
Pbar: AA -> low β efficiency	0.81	0.60	
Proton emittance (95%, norm)	20	20	πmm-mr
Pbar emittance (95%, norm)	15	18	πmm-mr
Beta @ IP	0.35	0.35*	m
Beam Energy	1000	980	
Bunch length (proton, rms)	0.37	0.61	m
Bunch length (pbar, rms)	0.37	0.54	m
Form Factor (Hourglass)	0.74	0.62	
Typical Luminosity	8.1e+31	3.2e+31	$cm^{-2}sec^{-1}$
Integrated Luminosity	16.	6.7	pb^{-1}/week

Tevatron since March 2002



- 165 HEP stores
- >70 pb-1 to each detector
- 3-fold increase in peak luminosity from 11.8e30 to 36.1e30
- 18 peak luminosity records since 03/01/02
- Run I record of 25.0e30 broken on 7/26/2002
- 6 Tevatron L records afterwards
- 2 weeks between records in average…
- … though records come in bunches after significant improvements, e.g., →

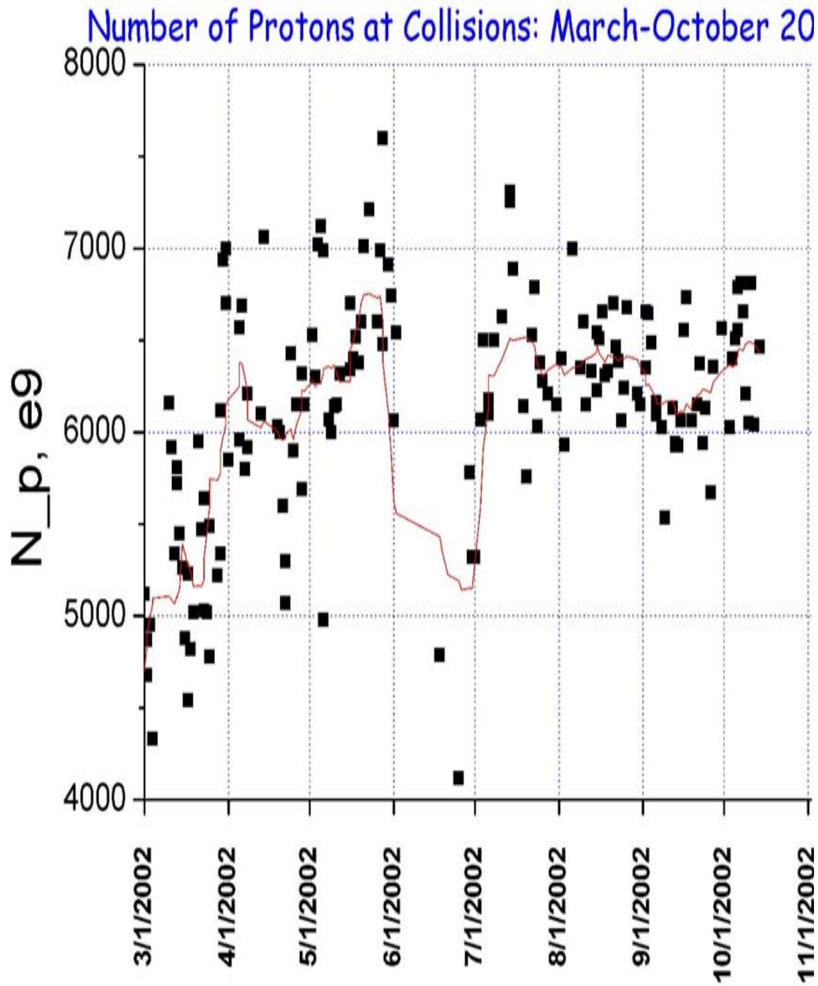
Major Reasons for $\mathcal{L}$-progress since Mar'02

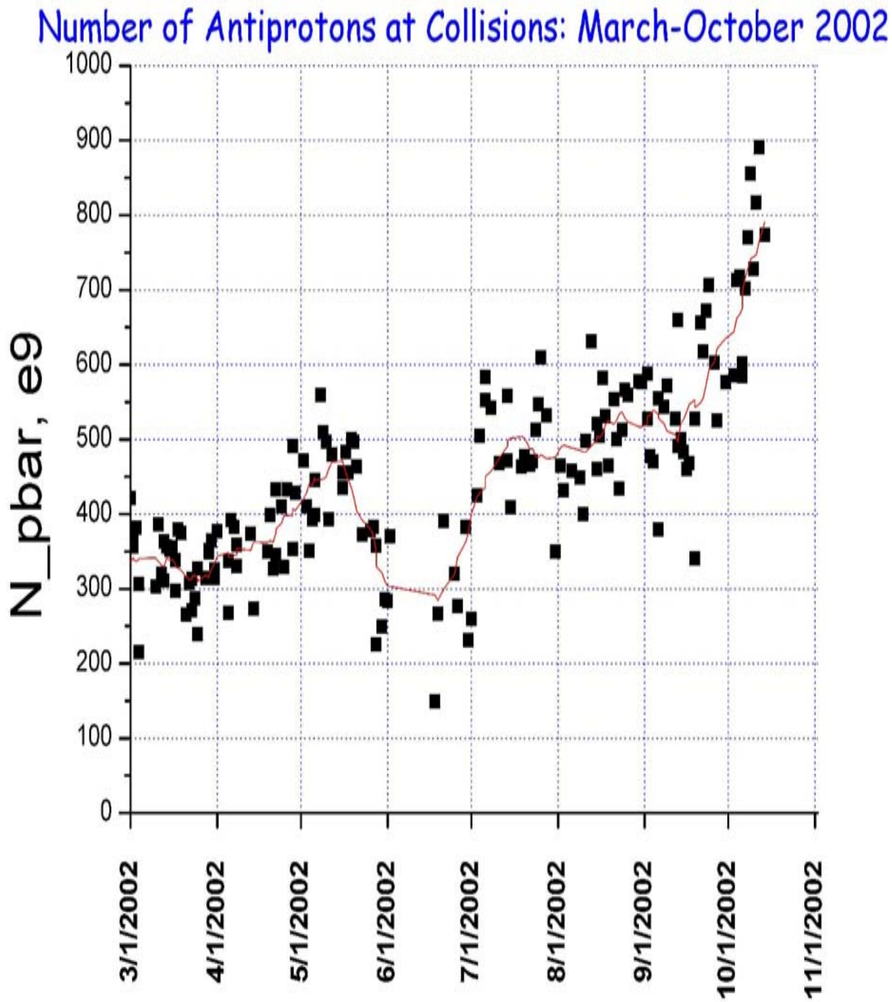
• "Sequence 13" fixed	Tev	x 1.40
• "New-new" injection helix	Tev	x 1.15
• "Shot lattice"	AA	x 1.40
• Pbar emittance at injection	Tev/Lines	x 1.20
• Pbar coalescing improvement	MI	x 1.15
	total	x 3.1

….plus additional improvements in the Tevatron:

- Longitudinal dampers to stop s_s blowup
- Tunes/coupling/chromaticities at 150/ramp/LB
- Orbit smoothing
- Separators scan
- F11 vacuum

Beam Intensities in 2002

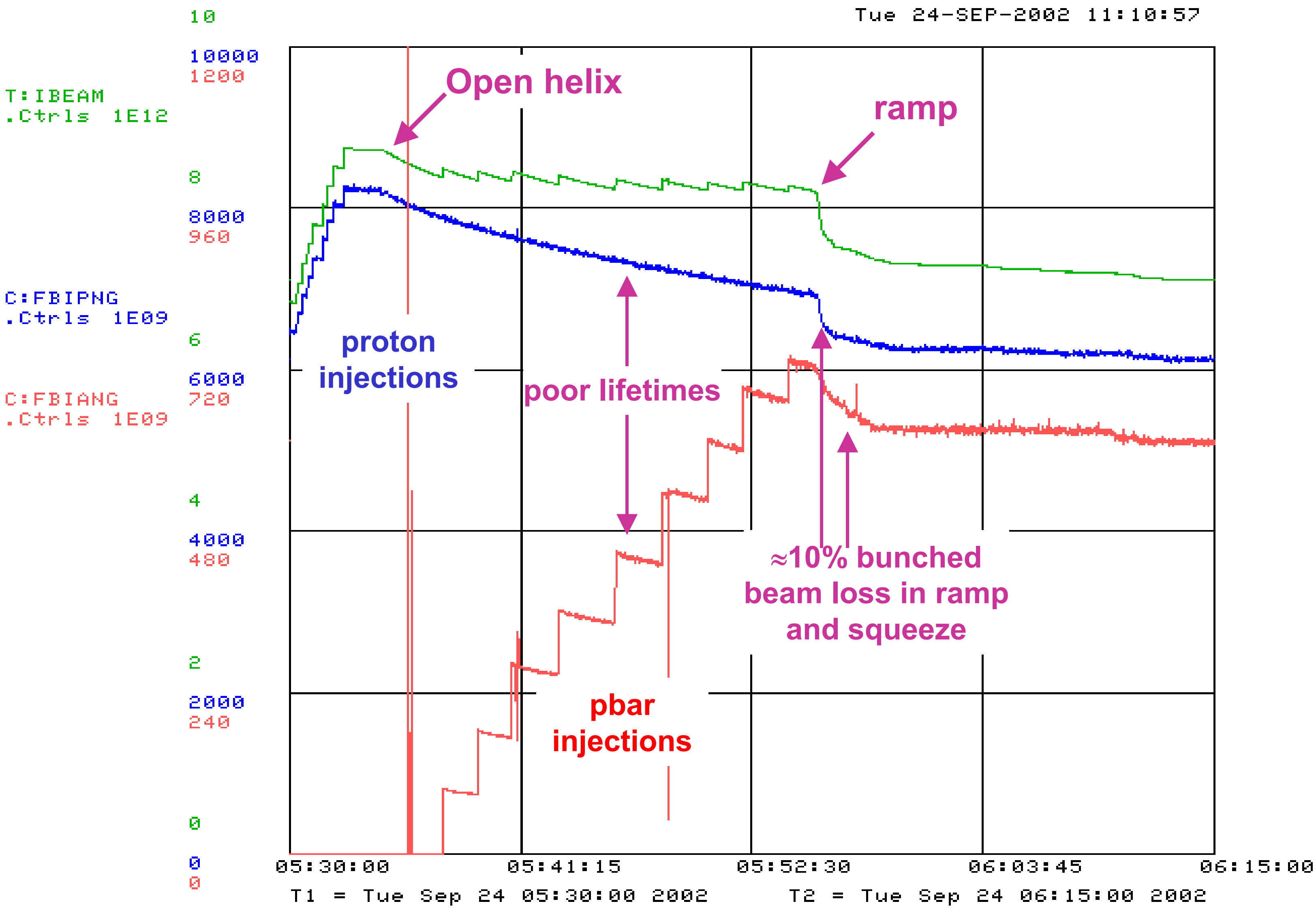




N_p : Oct/Mar=6500/4700=1.40

N_pbar : Oct/Mar=820/330=2.50

Tevatron Efficiencies



Beam-Beam Interaction As Major Factor

•*pbar transfer efficiency strongly depends on N_p, helix separation, orbits, tunes, coupling, chromaticities and beam emittances at injection*

• *summary of progress with beam-beam since March 2002:*

	*Mar'02 **	*Oct'02 ***
Protons/bunch	*140e9*	*170e9*
Pbar loss at 150 GeV	*20%*	*9%*
Pbar loss on ramp	*14%*	*8%*
Pbar loss in squeeze	*22%*	*5%*
Tev efficiency Inj→low beta	*54%*	*75%*
Efficiency AA→low beta	*32%*	*60%*

* *average in stores #1120-1128*
** *average in stores #1832-1845*

Attacking the Beam-Beam Effects

The progres beakdown:

- *increase of beam-beam separation during the squeeze*

  ("sequence 13")

- *increase of beam-beam separation at 150 GeV and ramp*

  ("new-new helix")

- *smaller emittances from AA*

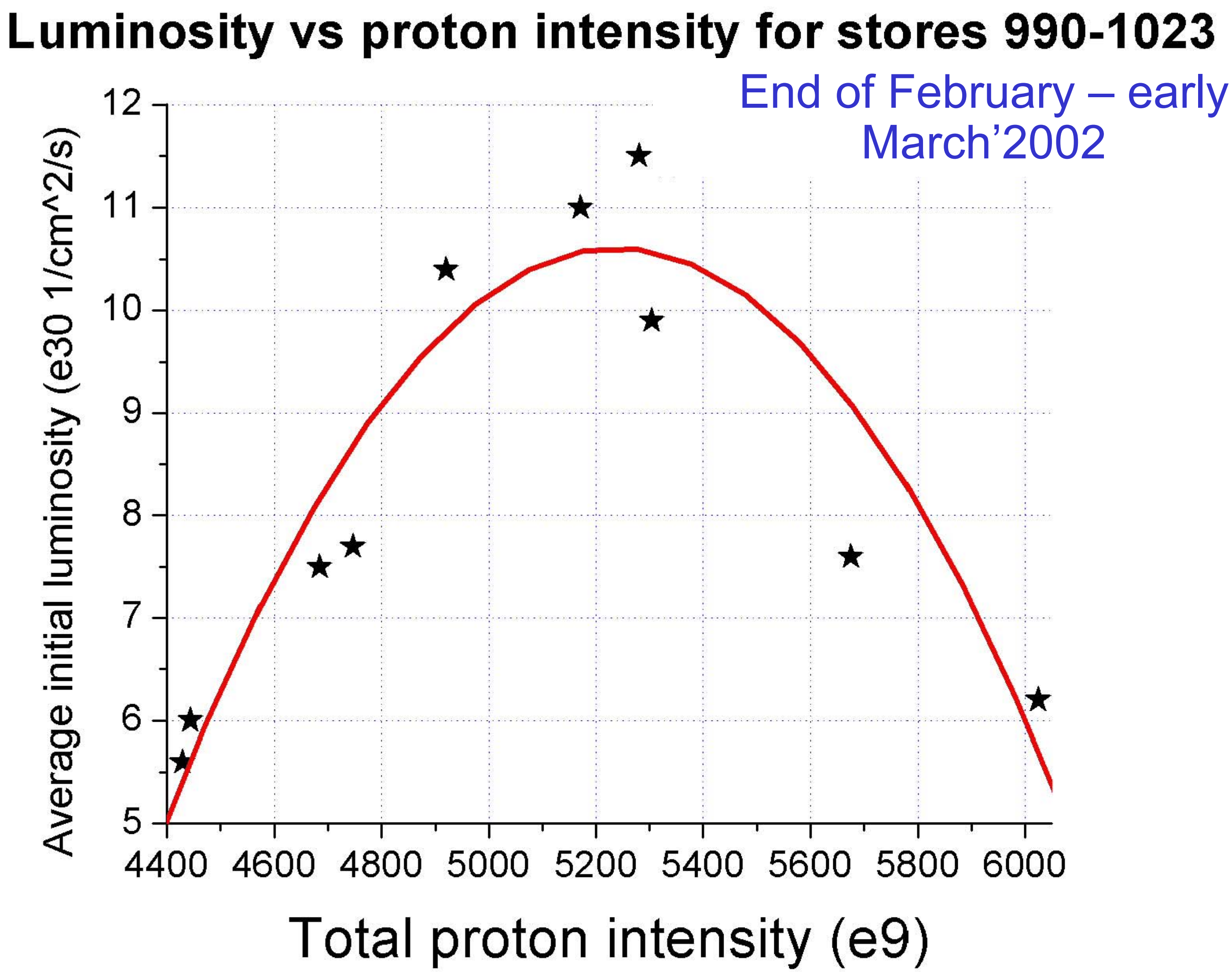
  ("AA shot lattice" – see D.McGinnis)

- *reduced injection errors*

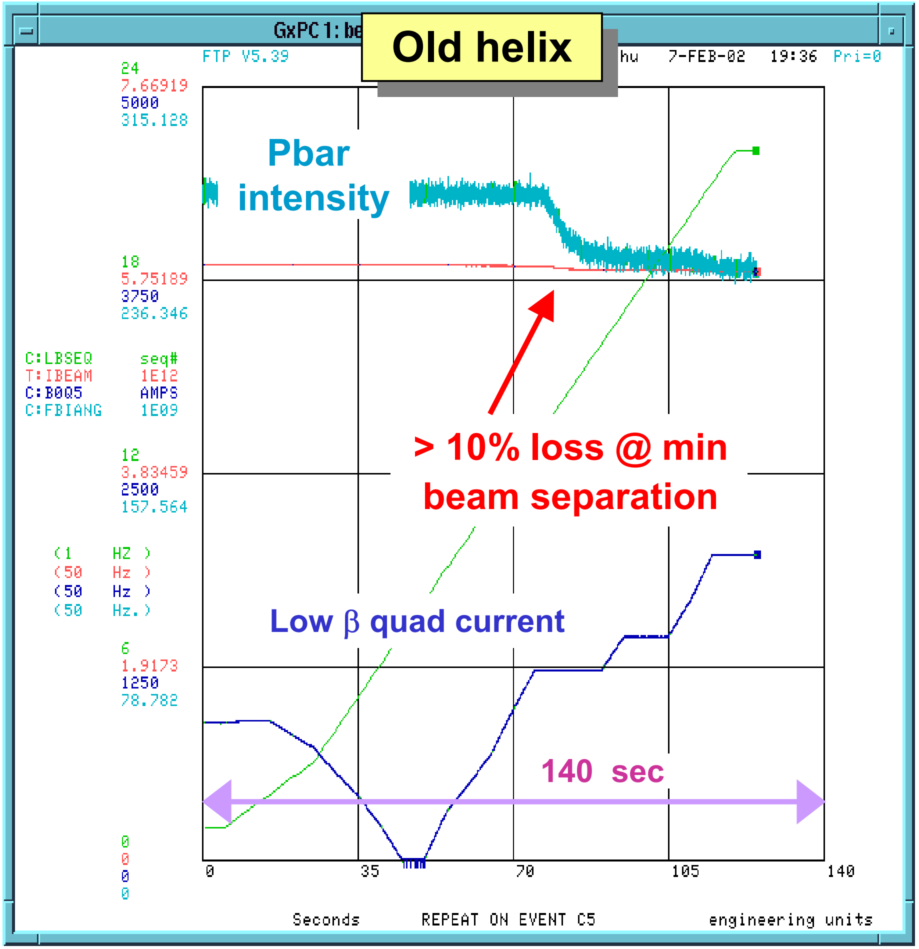
  ("BLT" – see V.Lebedev's talk)

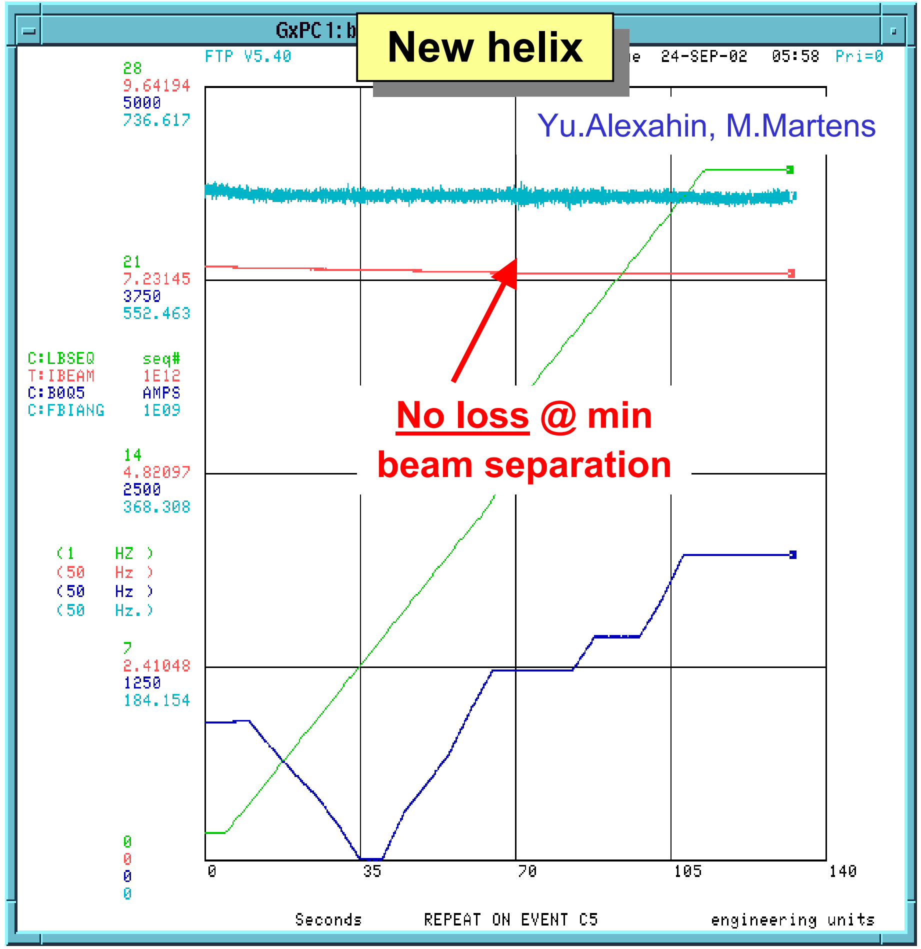
- *better control of orbits/tunes/coupling/IP*

"Sequence 13" Affects Luminosity



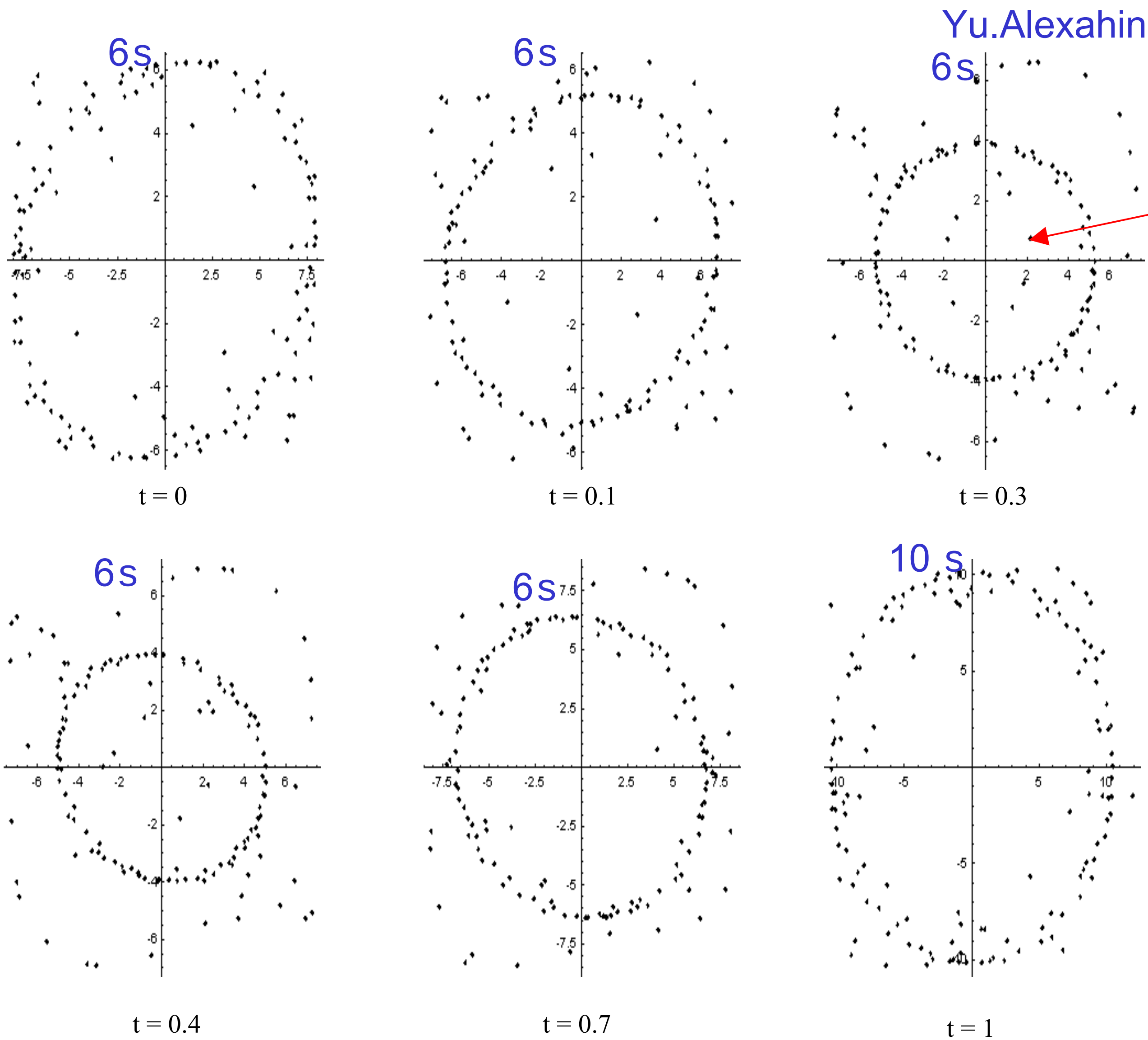
Pbar Loss During Squeeze ("Sequence 13")





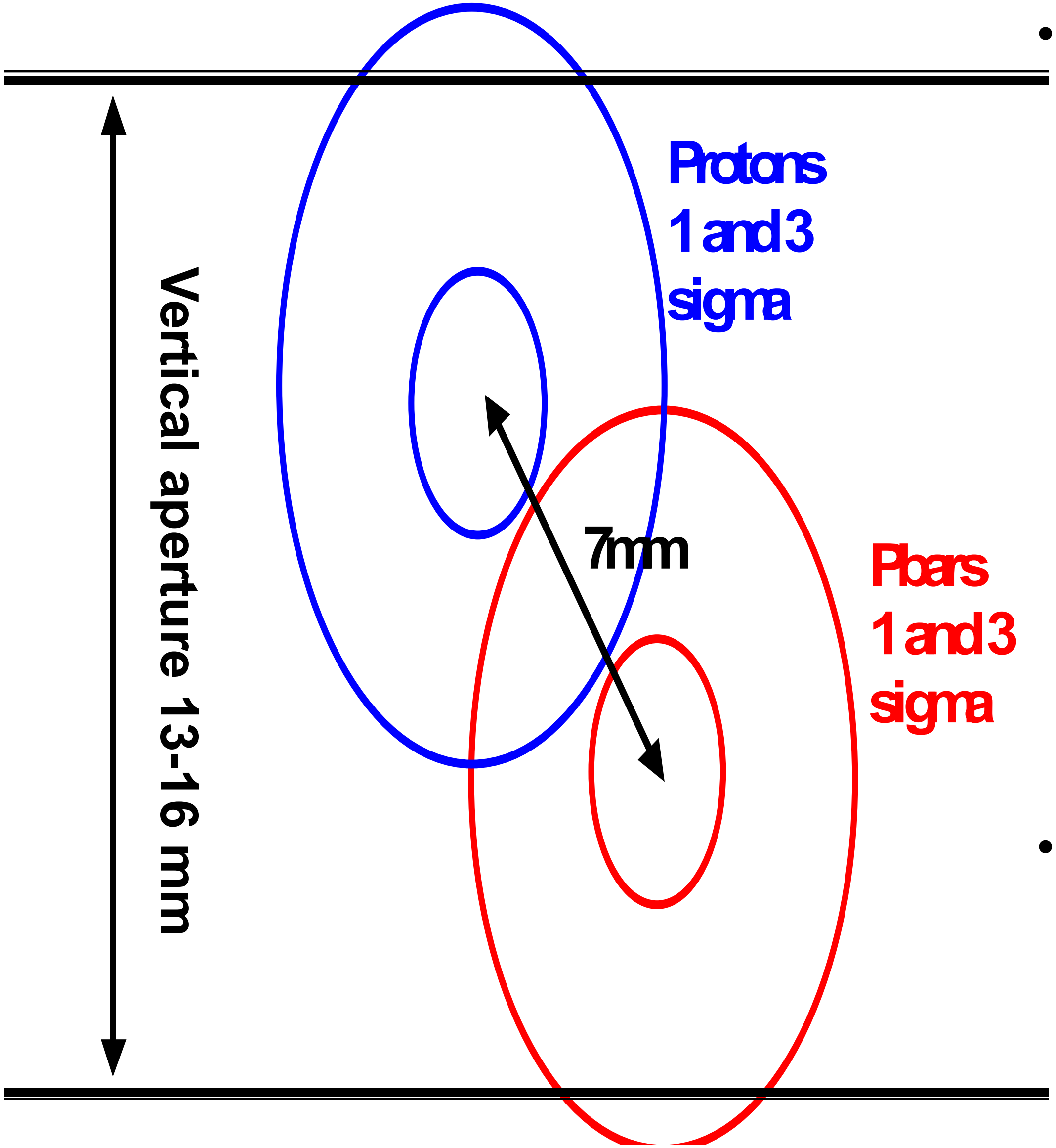
- Suffered 10-20% pbar loss during squeeze
  - During transition from injection to collision helix
  - Minimum beam separation was only ~1.8σ
  - New helix increased min beam separation to ~3σ, loss essentially eliminated

Beam-Beam Effects in Squeeze



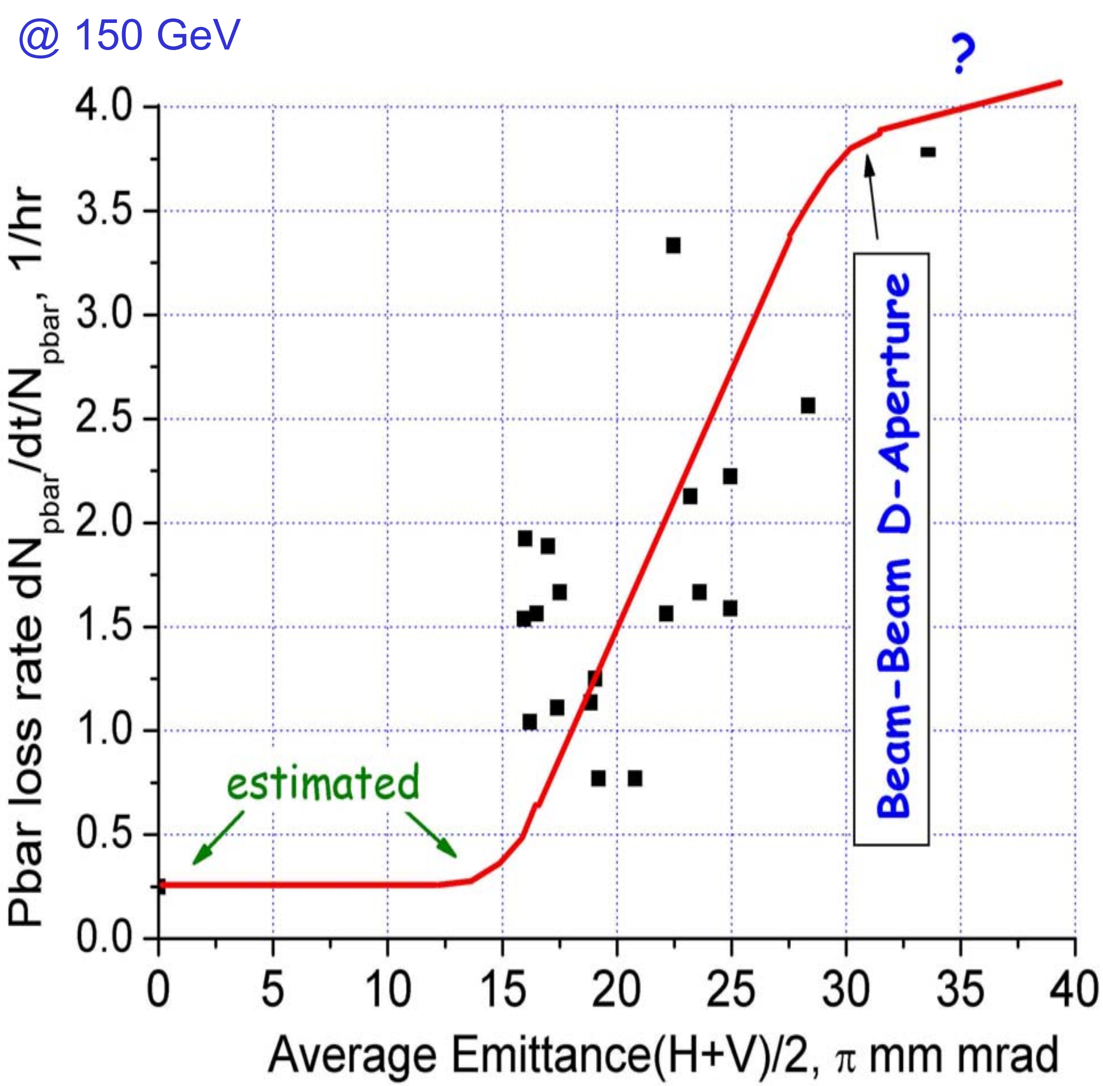
- Minimum beam-beam separation turned out to be only **1.8σ**
- Normalized separations $\Delta x/\sigma_x$, $\Delta y/\sigma_y$ at all possible IPs with 36×36 collision cogging in sigma's for the reference emittance ε_n=15π mm·mrad. t = 0 – seq13, t = 1 – seq14 (see plots)
- The separation has been increased to 2.7σ by adding 2 more breakpoints, also speed of the squeeze doubled there and the loss gone
- Lesson – only minimum separation matters

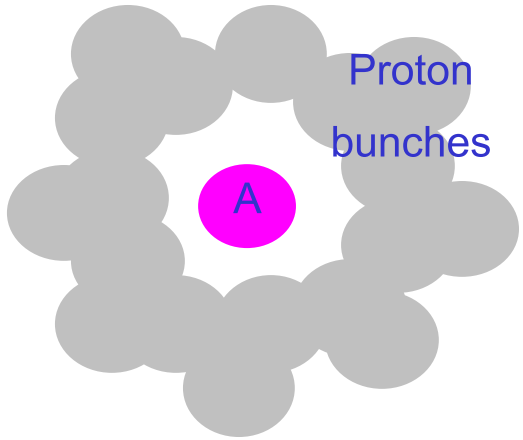
Lifetime Issues at 150 GeV



- LR beam-beam effects poor pbar lifetime 0.3-1 hr
  - Pbar lifetime depends on emittances, N_p and bunch number
  - 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 ~ 2 hr
  - depends on chromaticity
  - Instability prevents lower chromaticity (now 8)

Proton Beam as "Soft Donut Collimator"





- pbar losses strongly depend on pbar emittances and N_p
- measures taken to reduce emittances:

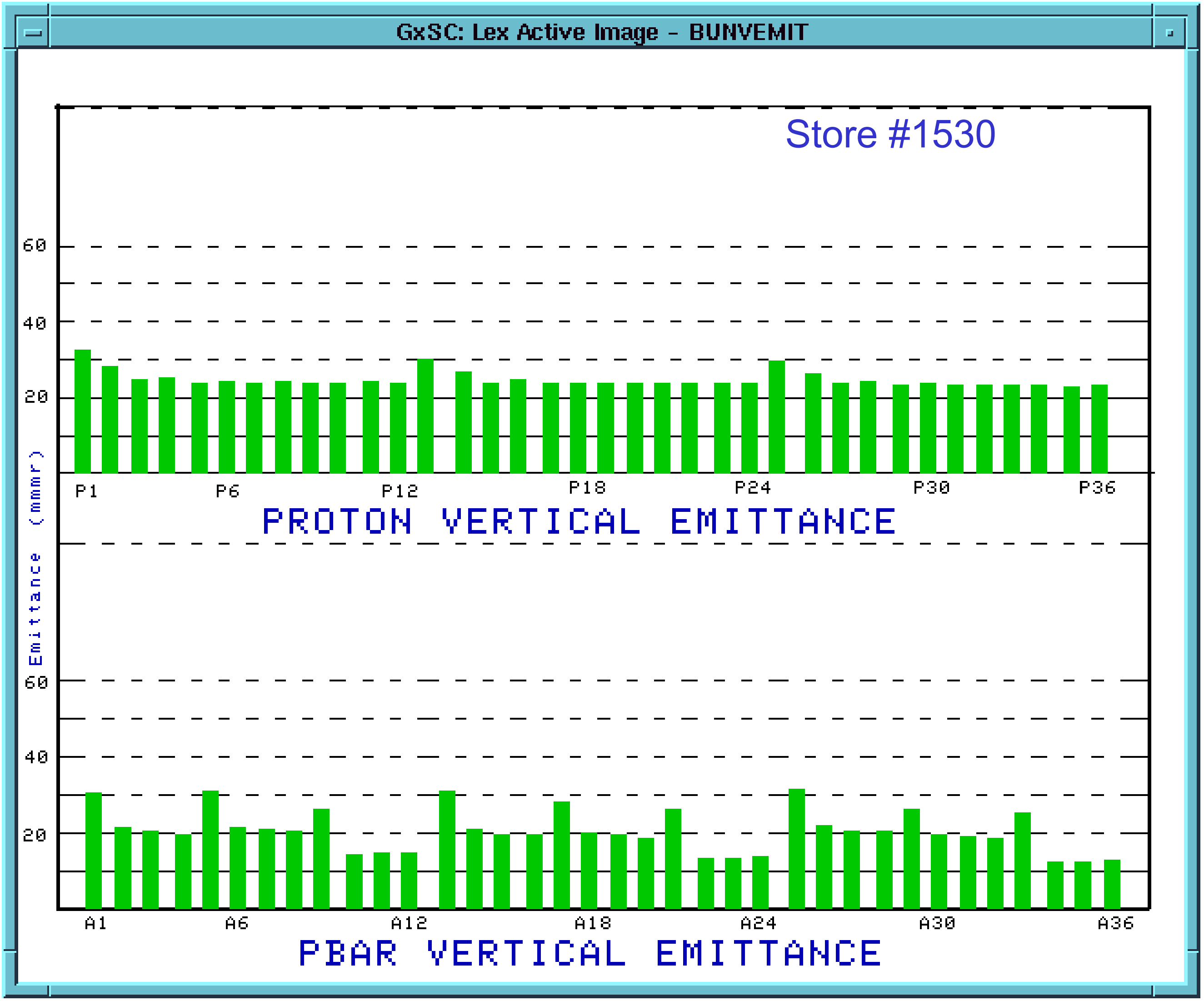
- AA "shot lattice"

- fix injection errors (BLT)

- match injection lines

- tuneup injection kickers

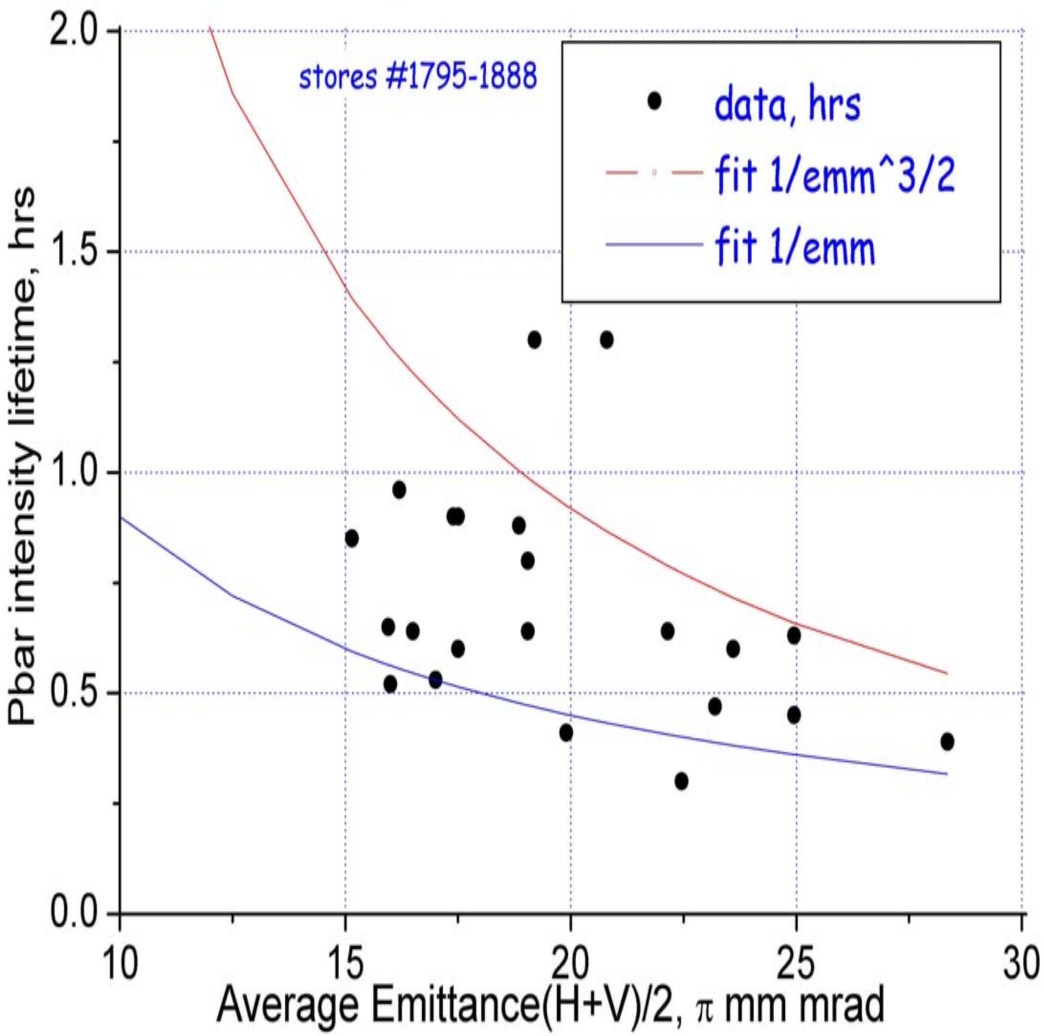
Transverse Emittance /Kicker Adjustment



- emittances of the 1st pbar bunches in each transfer were 6p larger than for other three due to AA→ MI injection kicker timing error and Tev injection kicker timing error – fixed
- emittances of P1, P13, P25 blown by pbar injection kickers – fixed by tuning "bumper" kickers (compensators)

Pbar Losses vs Emittance/Helix Size

Pbar Lifetime at Inj vs Emittance: Store-to-Store



- expected t ∂ $A^{(2-3)}$
- next steps – to increase beam-beam separation (helix size):

- C0 aperture: ~30% in A @150

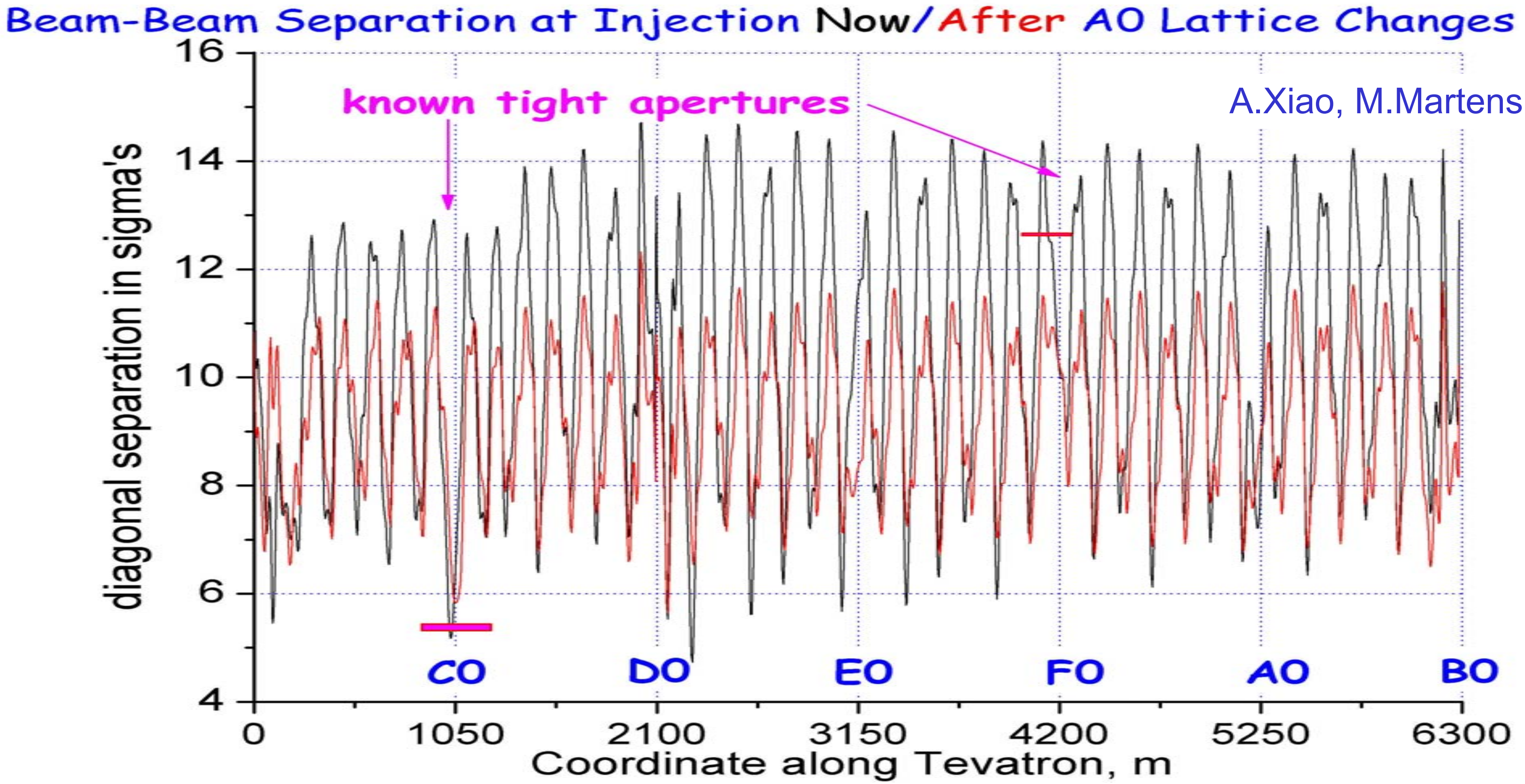
  –Replace lambertsons @ C0 – gain 25 mm vertically

  – that will allow some 30% larger sepration around the ring until the next aperture restriction (F0, A0, B0, D0, E0)

- A0 lattice: ~16%? in A @150&LB

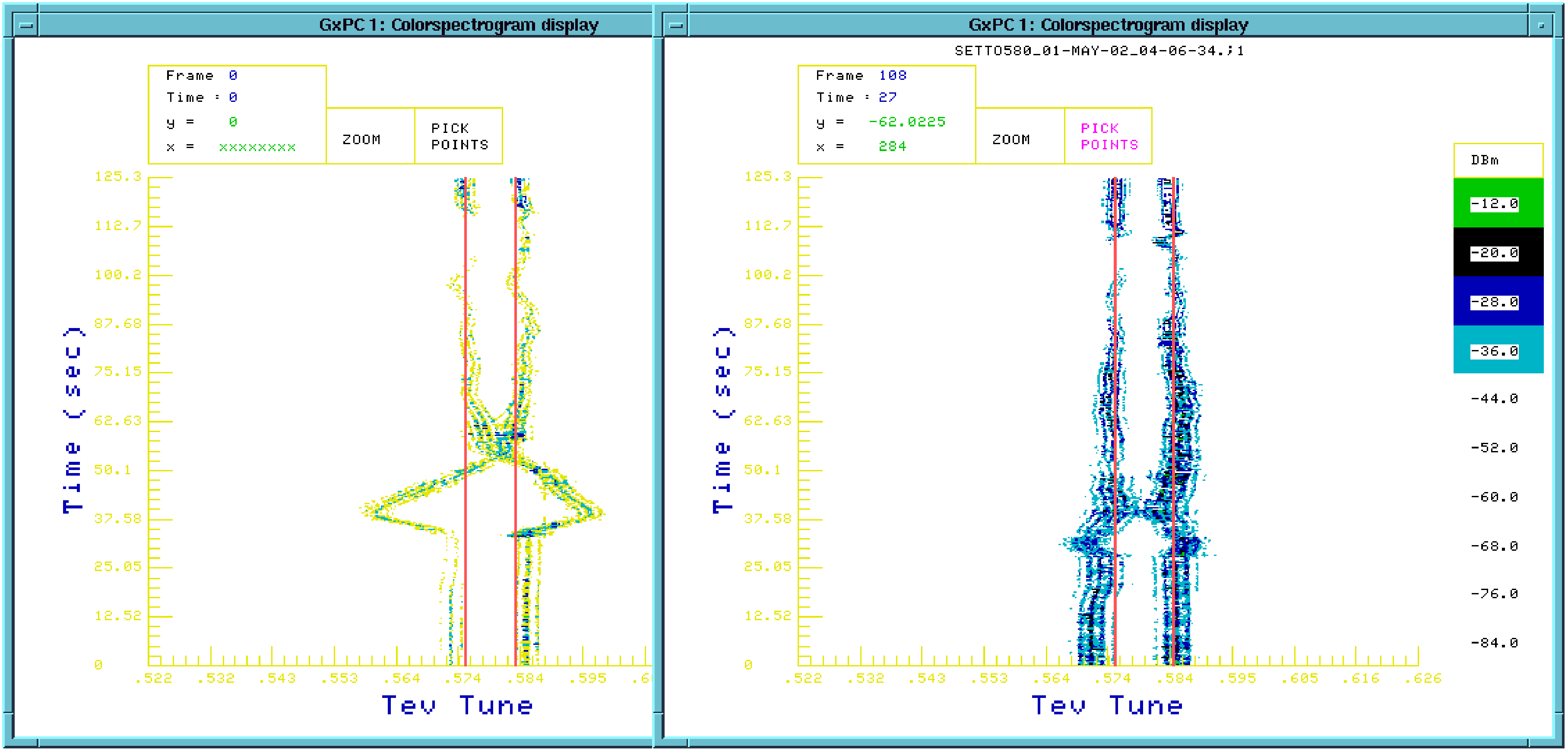
  –Modify high β section at A0 formerly used for fixed-target extraction

Lattice Modification at Sector A0



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

Tune Variations on Ramp/Squeeze

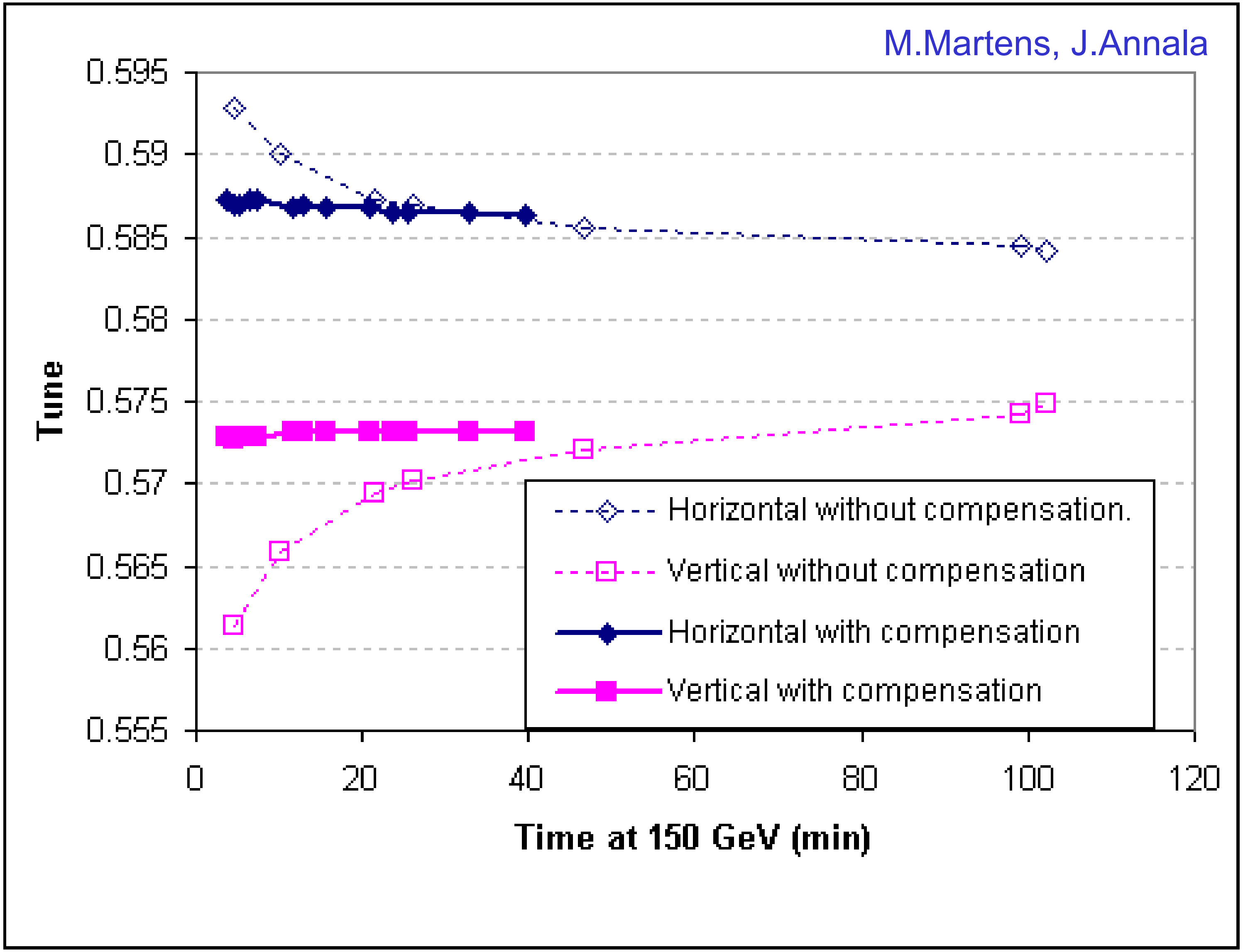


- antiproton losses at the ramp and in squeeze are due long-range beam-beam
- the losses depend on proton intensity, beam-beam separation (has been maximaized with given restrictions), tunes, coupling, chromaticities
- variations were corrected with additional break point at 153 GeV tunes

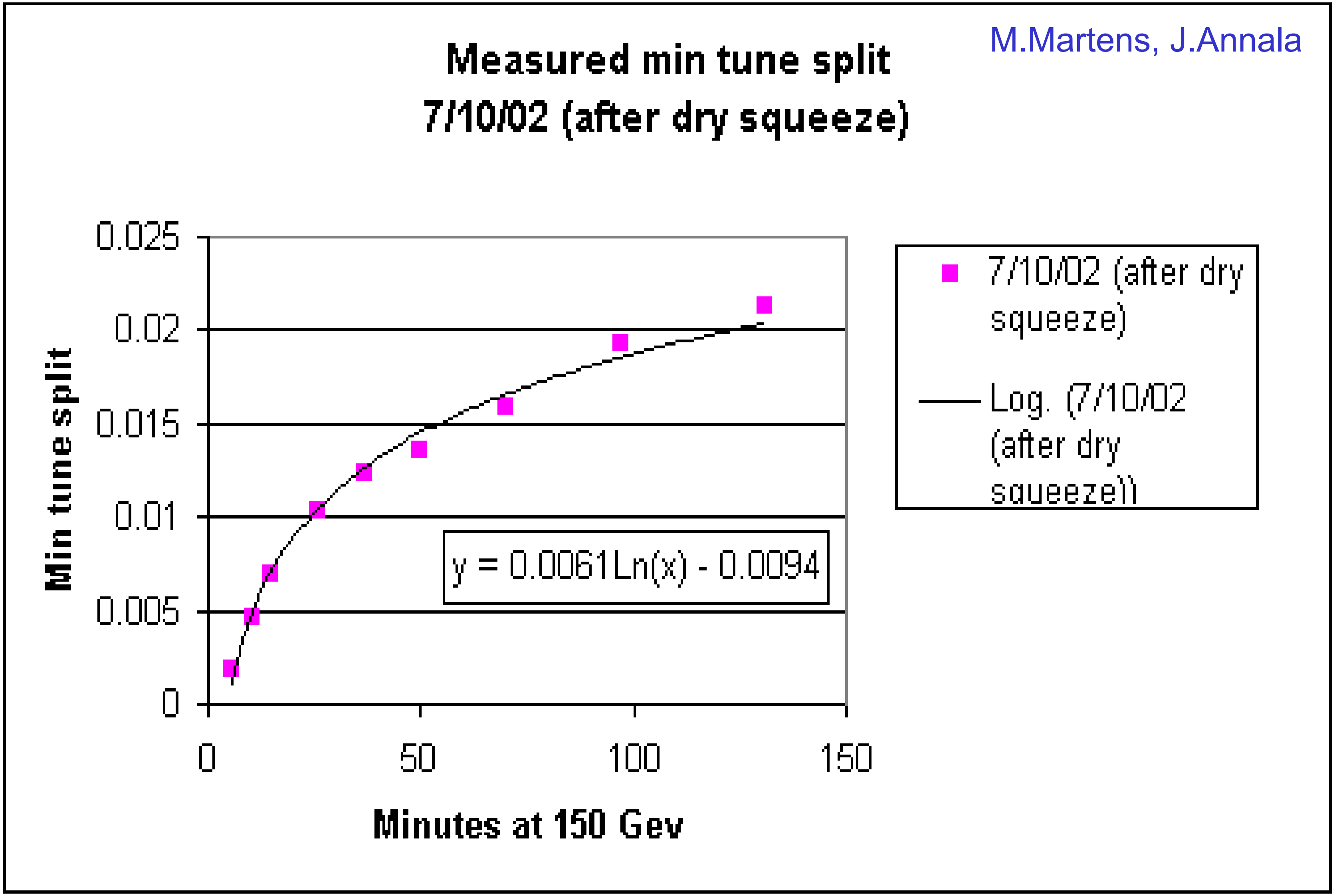
Tune and Coupling Drifts at 150 GeV

- Chromaticity drift from b_2 component in dipoles well-known from Run I
  - Compensated automatically by varying sextupole currents
- New for Run II, tune and coupling also vary logarithmically after returning to injection energy
  - Makes injection tune-up more difficult
- Likely caused by persistent currents in the superconducting dipoles and quadrupoles
- Recently implemented compensation with normal, skew quads similar to chromaticity scheme
  - Tune drift now < 0.001 after 3 hours
  - Coupling drift not measurable

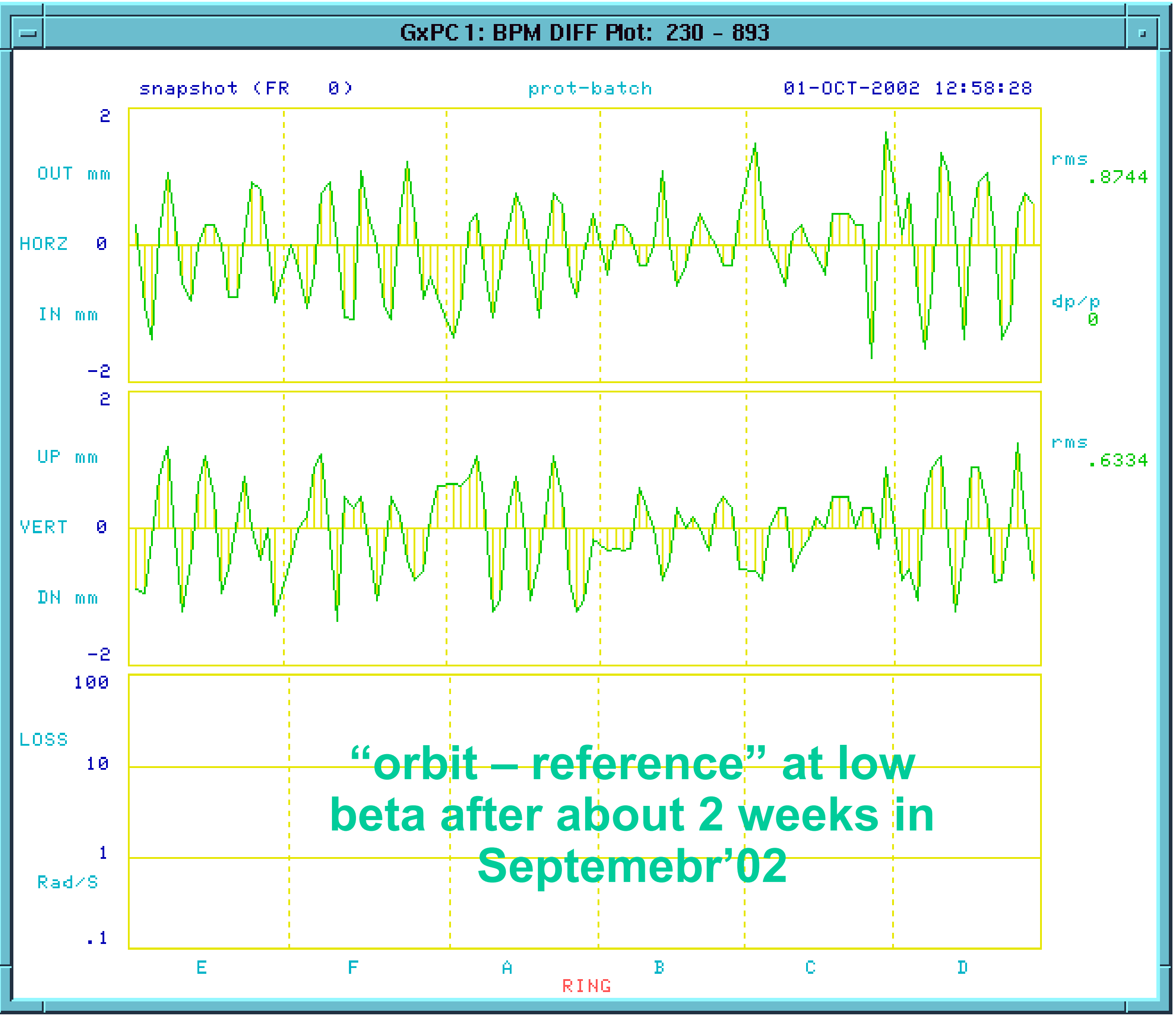
Tune Drift @ 150 GeV



Coupling Drift @ 150 GeV

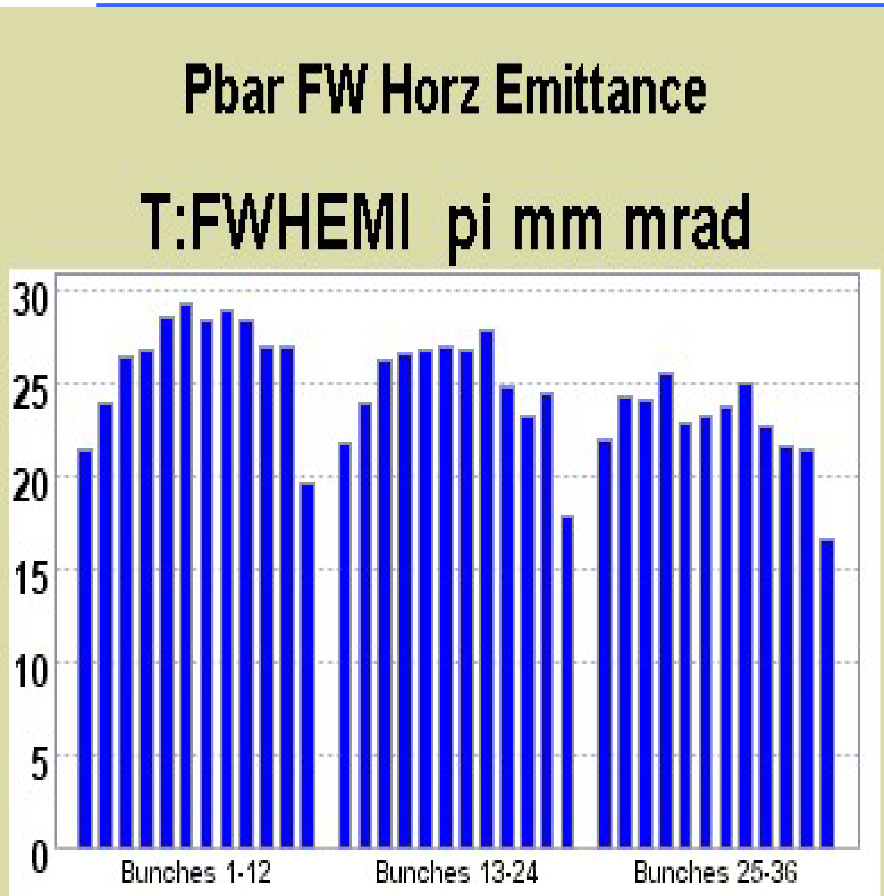


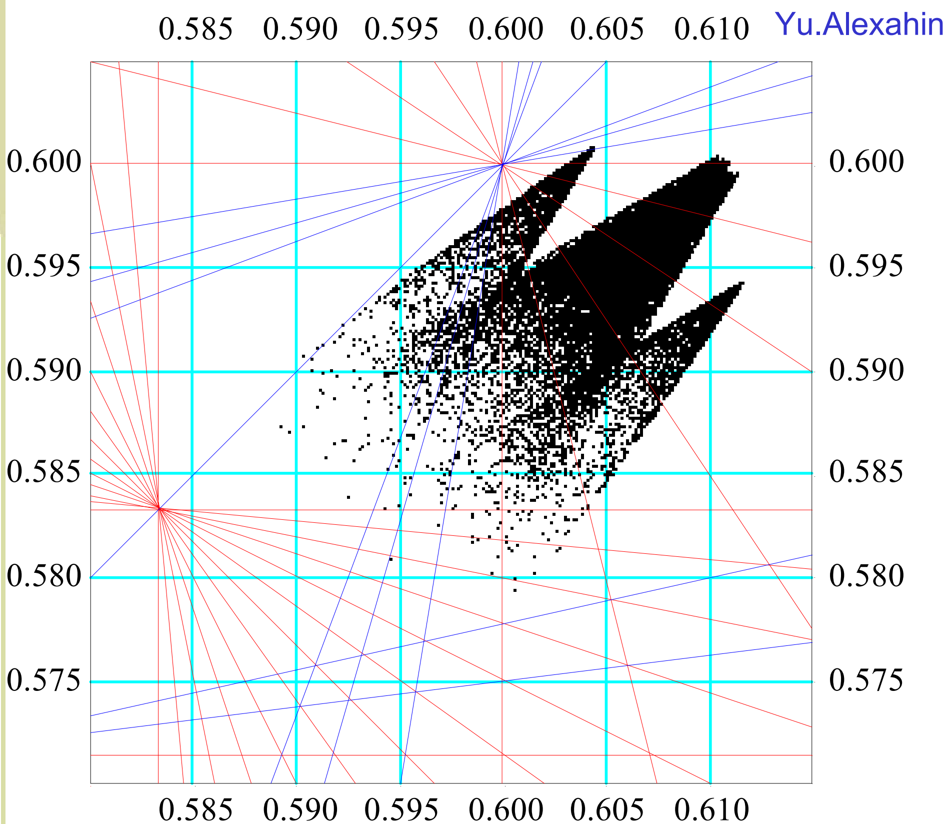
Orbit Smoothing



- proton and antiproton tunes, coupling, chromaticities significantly vary a lot with closed orbits distortions
- "rule of thumb" for stable operation to keep orbits under 0.5 mm rms from "sliver orbit"
- orbit drifts of that scale occur in 1-2 weeks
- that requires operational orbit smoothing at 150, ramp, flat-top, squeeze, low-beta.

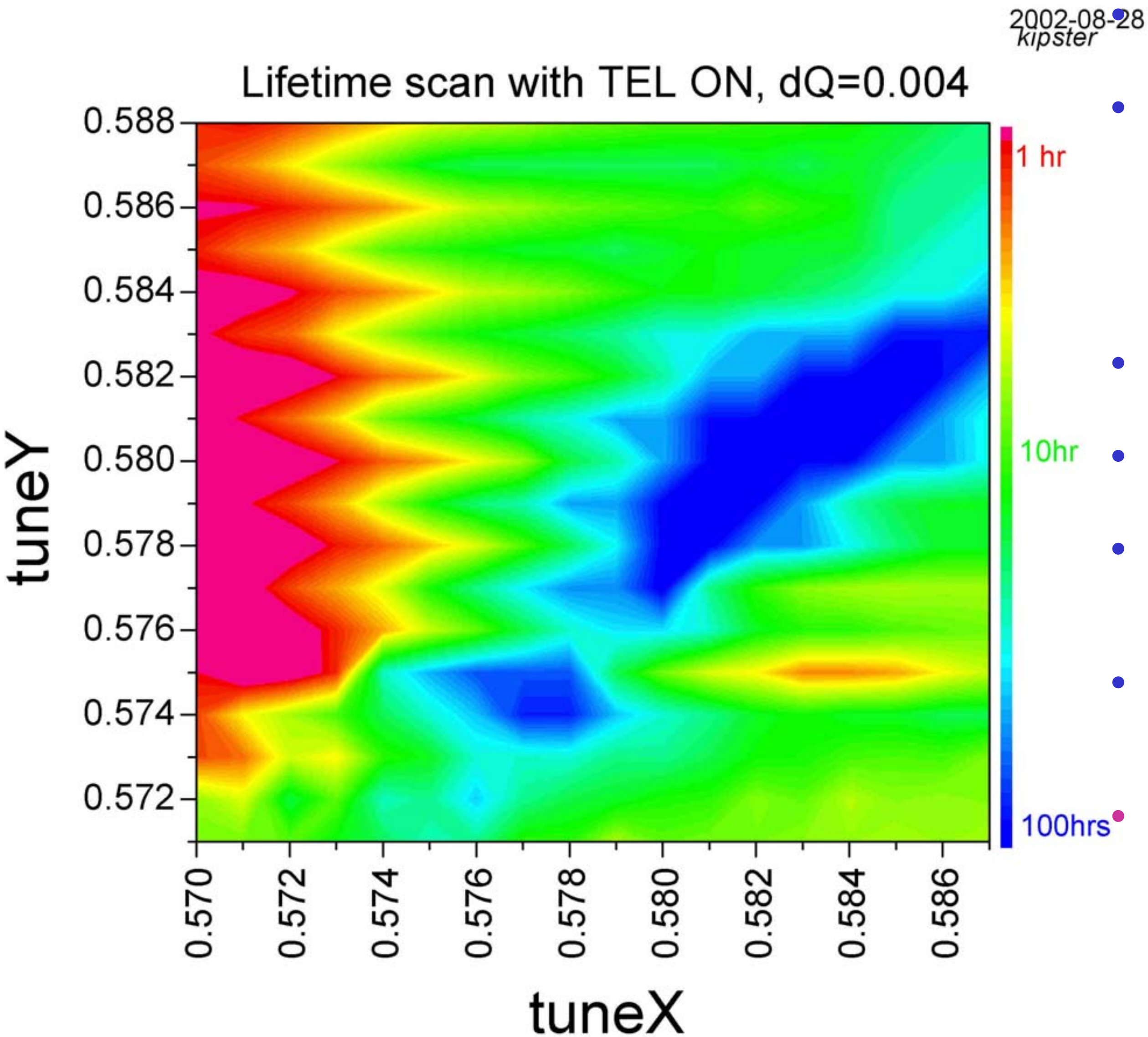
Beam-Beam Effects at 980 GeV





- 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 (small anti-scallops for protons)
- the effect is (and should be) tune dependent - see on the right
- recently, serious effects of pbars on protons – completely unexpected

Beam-Beam Compensation with TEL



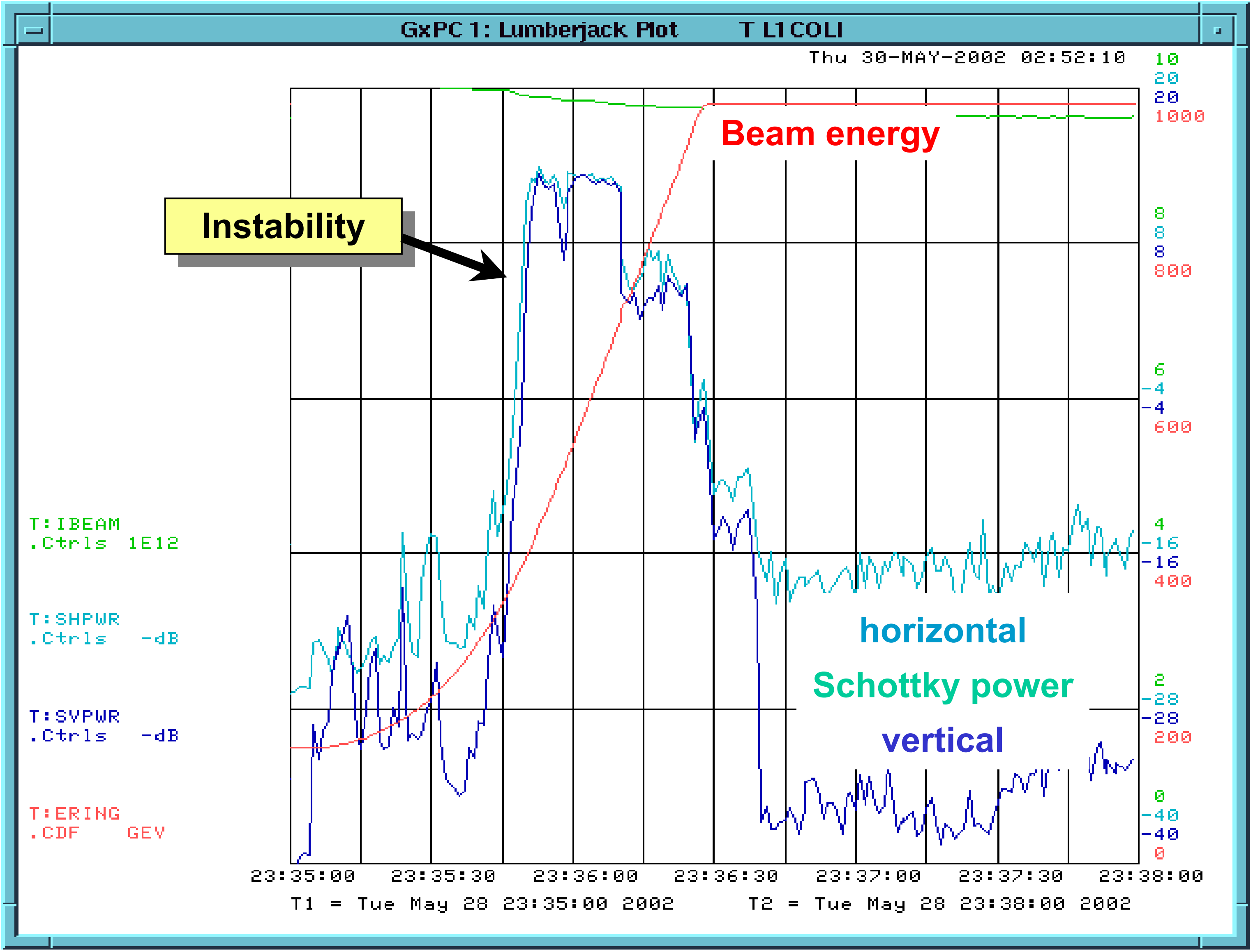
- TEL e-current noises are small
- p(pbar) lifetime reduction due to TEL comes from non-linear beam-beam effects - “donut collimator”
- Lifetime at good WPs is about 100 hrs
- e-beam positioning is important
- Smoother edge e-beam is needed → Gaussian gun
- Gun and magnets to be modified in Jan’03 shutdown
- Wire compensation? – to be considered in’03

Proton Transverse Instability

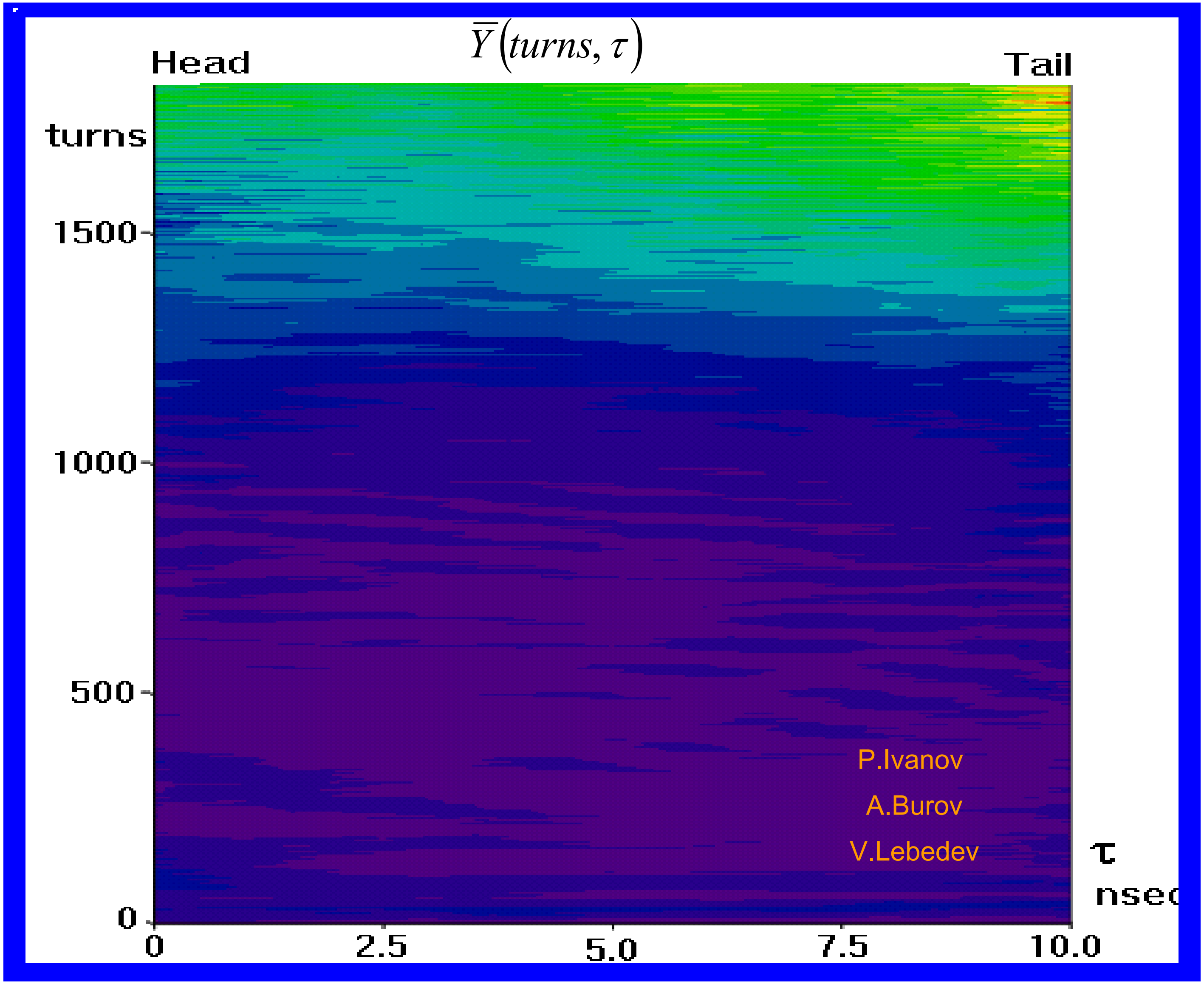
- Intensity-dependent: appears above ~170E9/bunch
  - Single bunch weak head-tail phenomenon (?)
- Can occur at 150 GeV, up the ramp, at 980 GeV
  - Schottky powers rise quickly
  - p/pbar emittances blow up for individual bunches
- Try to prevent/control instability via:
  - Raising chromaticities (8 @150, >20 at 980)
  - Adjusting coupling and tunes
  - Limiting p intensity to ~240E9/bunch at injection
  - More pbars help to stabilize protons
- Constructed bunch-by-bunch transverse dampers
  - hor chromaticity at injection lowered 8→ 3 at 150

… but the problem is not solved yet…

Transverse Instability On Ramp



Unstable Head-Tail Motion



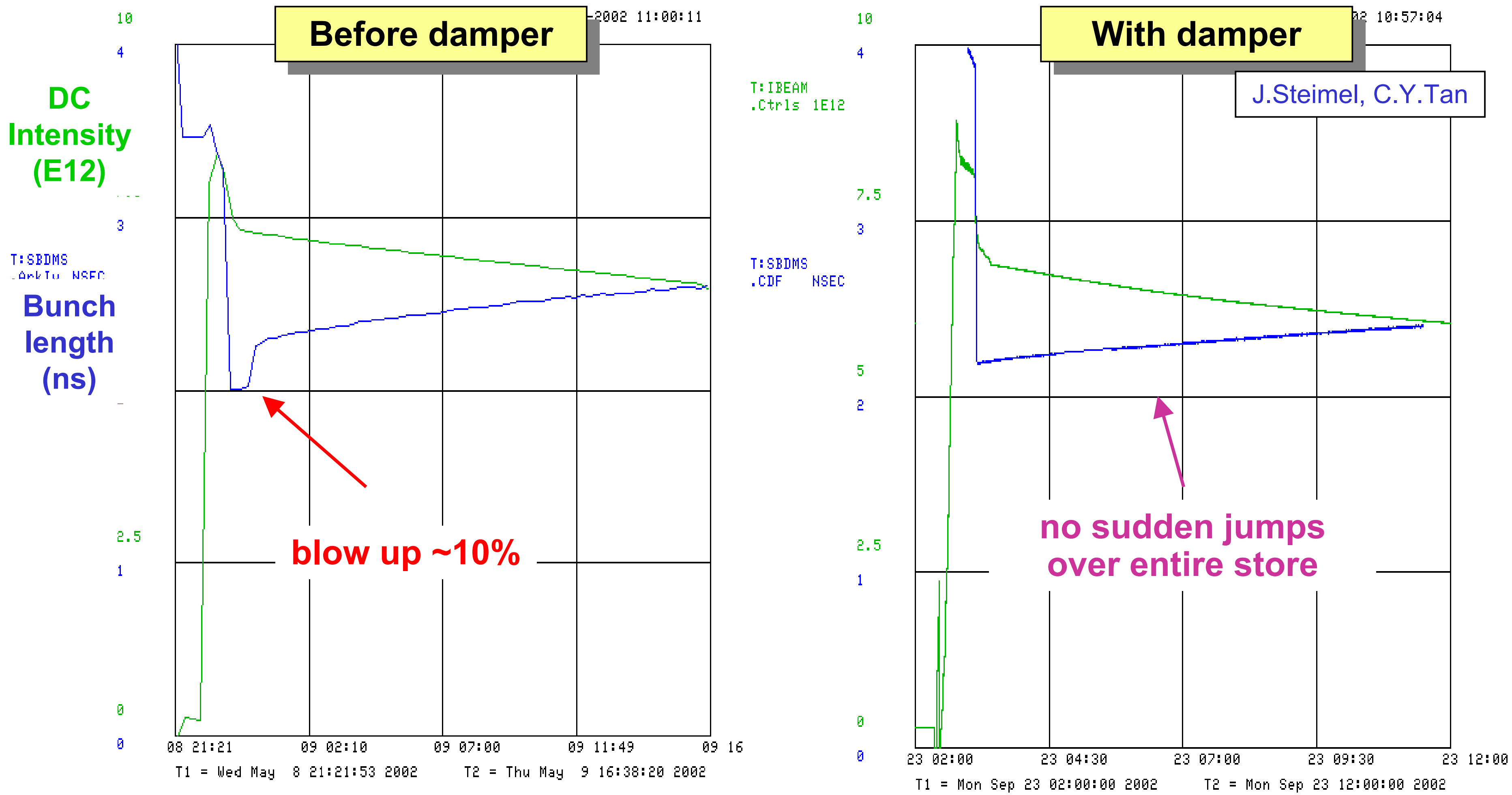
$E = 150 GeV$

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

$\xi_y \approx -3$

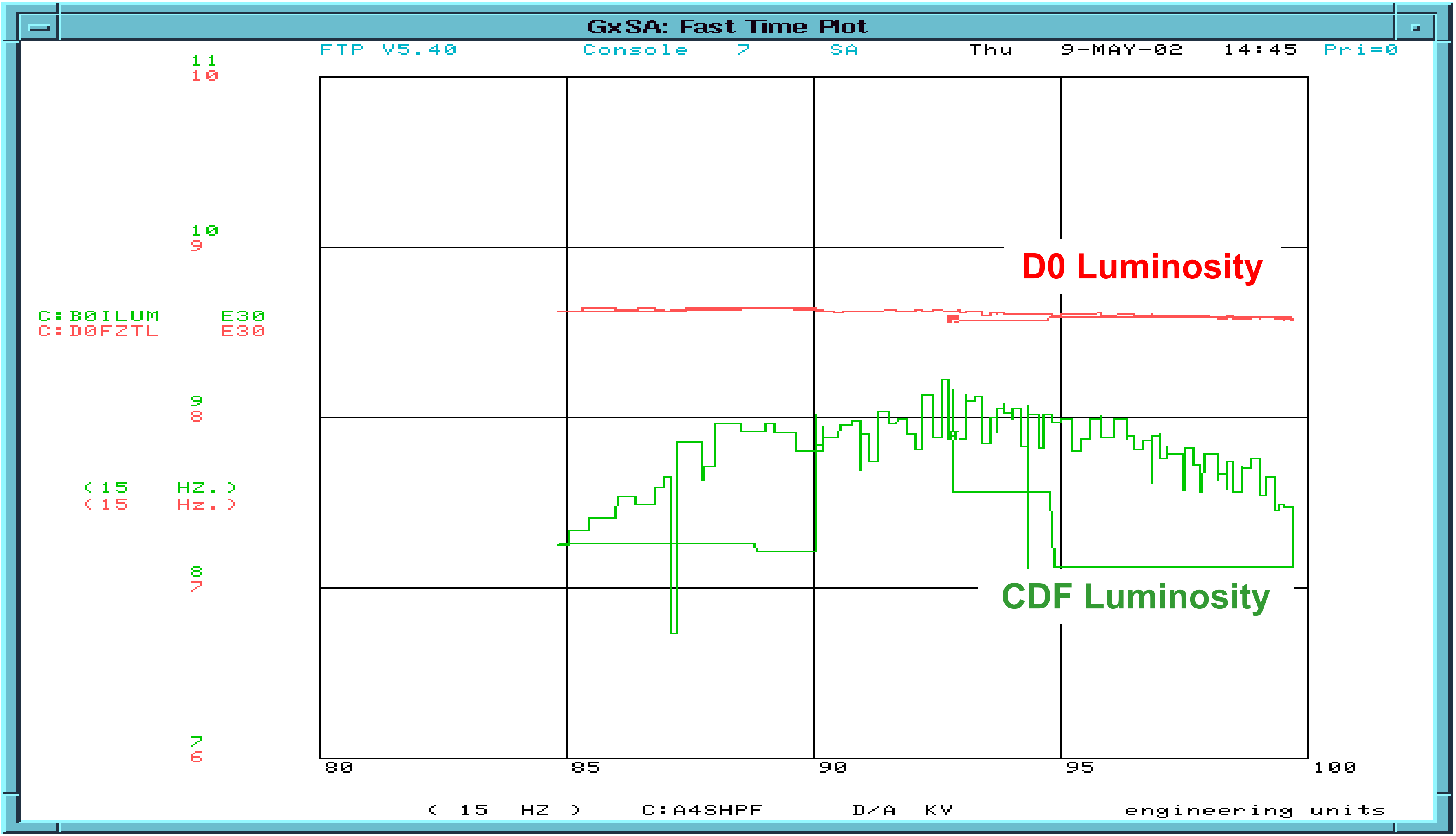
$l_s = 0$

Bunch Length Blowup During Stores



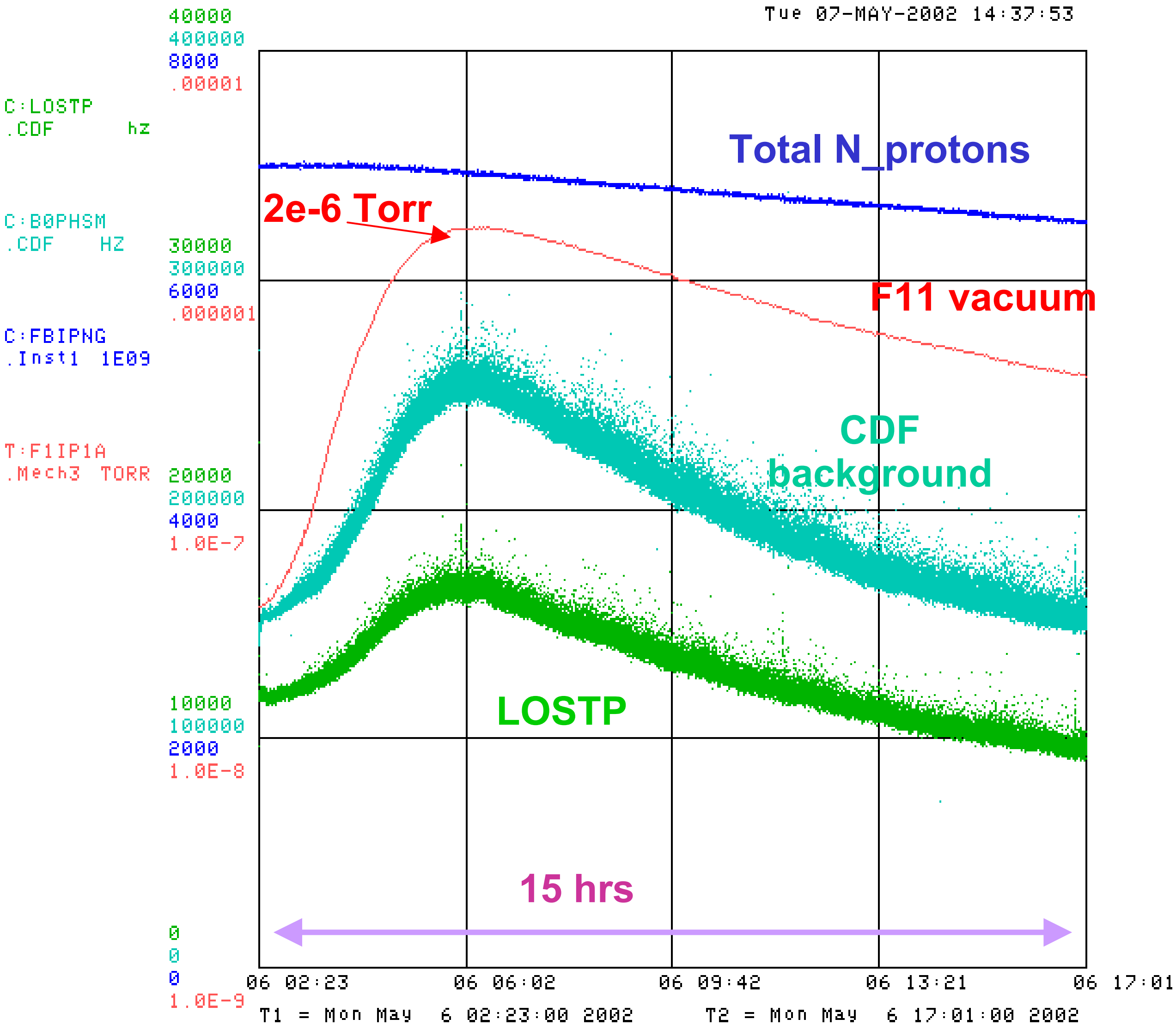
- Intensity-dependent, leads to significant CDF background rise
- Usually only one or a few bunches would suffer
- Problem solved by bunch-by-bunch longitudinal damper

IP Scan



• every once in a while we perform separators scan at IPs (like 5/10 resulted in +4% in the CDF luminosity

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)

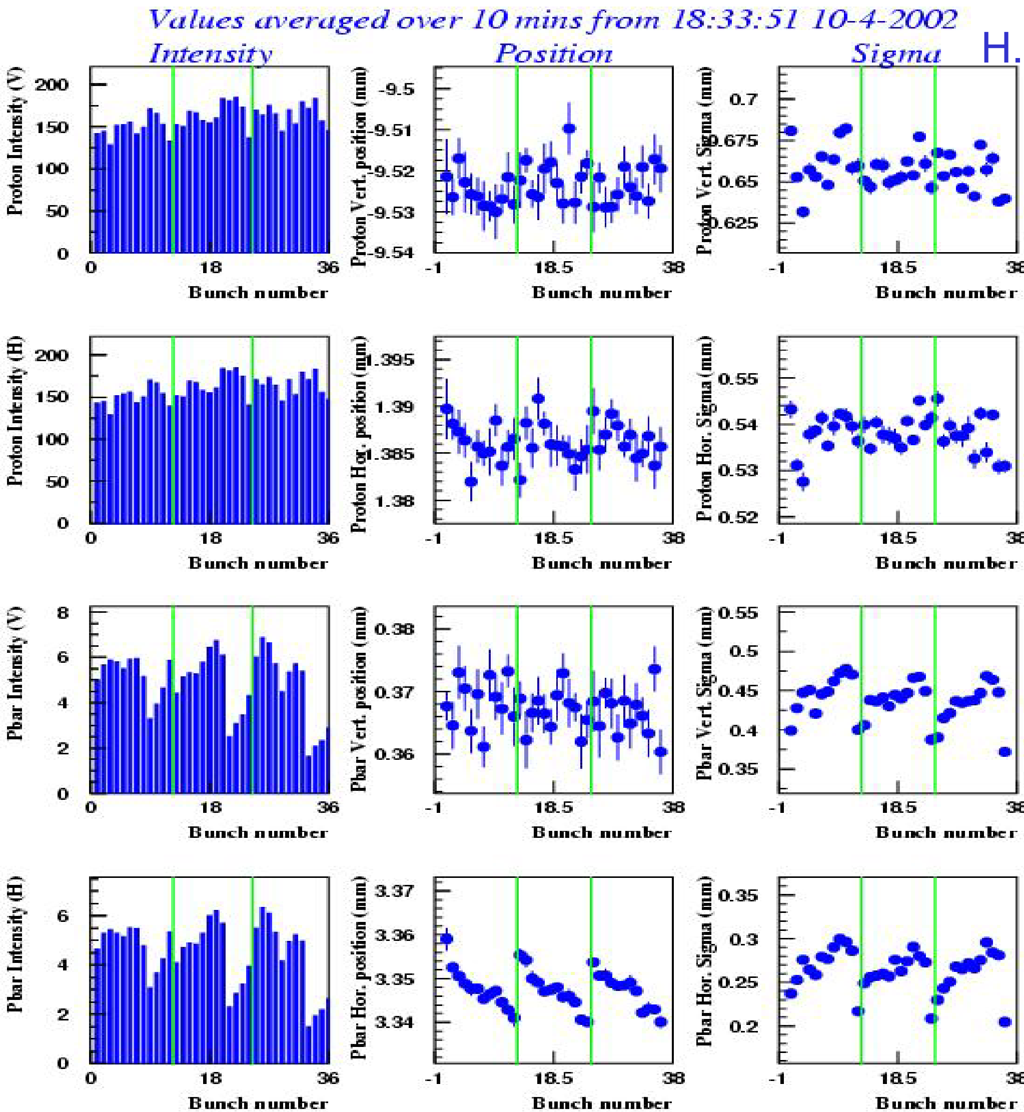
Physics Progress (see backup slides)

- Beam-beam issues
  - N_p effect (pbar only, efficiencies vs N_p)
  - Emittance+aperture effects (C0 + F0 + A0, 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)

Diagnostics Progress/Issues/Needs

	Priority	Progress since Mar'02
• BPMs	I	none
• 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	fair
• Schottky Detector (21 MHz, + 1.5 GHz)	I	good-
• Head-Tail Monitor	I	started
• Tune-Meter, Tracker	I	fair
• Digital Mountain Range	II	good-
• Fast Chromaticity Measurement	II	fair
• TEL Instrumentation	II	fair+
• RF Noise	II	good-
• Orbit Oscillations Monitor	III	fair
• Magnets motion	III	good

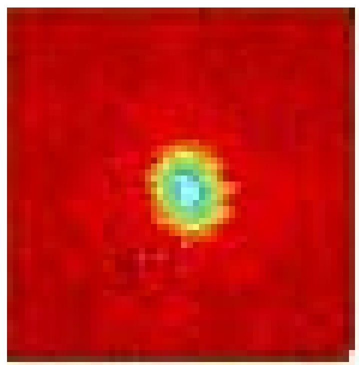
Diagnostics Progress: SyncLite Monitor



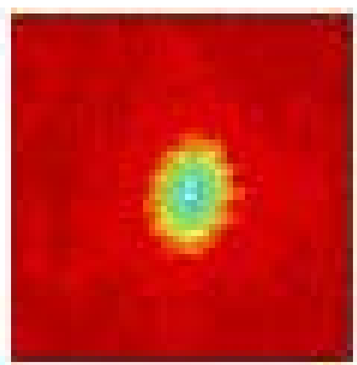
H.Cheung

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

Bunch #1



Bunch #8



Performance: FY'03 Goals

Parameter	Oct'02	Oct'03 base/stretched	change in L	
Protons/bunch	170e9	190/220e9	+12/24%	*
Total Antiprotons	800e9	1100/1300e9	+36/60%	**
P-emittance (95%, norm), π	20	20		
Pbar-emittance (95%, norm), π	18	18		
Beta @ IP, effective, m	0.39(?)	0.39/0.36	+0/8%(?)	***
Bunch length (proton, rms), m	0.61	0.61/0.57		
Bunch length (pbar, rms) , m	0.54	0.54/0.51		
Form Factor (Hourglass)	0.62	0.62/0.64	+0/3%	****
Typical Luminosity, $cm^{-2}sec^{-1}$	3.2e+31	5.0/7.0e+31		
Peak Luminosity, $cm^{-2}sec^{-1}$	3.6e+31	5.5/7.8e+31		
Integrated Luminosity, pb^{-1}/wk	6.7	10/15	+50/120%	*****

* Higher N_p leads to beam-beam, instabilities, backgrounds ...tough with less studies

** expect "no double benefit" due to smaller pbar emittances, N_pbar only

*** may come from either better decoupling at IP or changing beta*

**** not that easy for higher intensities

***** some 4% increase is possible due to better luminosity lifetime (Q_h,v, C_h,v, TEL)

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%
    - octupoles as alternative
  - Fix A1/P1 inj lines — ~10-20%
  - Open C0 aperture — ~10%
  - Better focus at IPs — ~0-10%
    - smaller b*; local decoupling; shorter bunchlength
  - Beam-beam tuneup — >5% ?
    - Tunes/coupling; TEL; smaller dp/p; shave in MI; RF noise; vacuum
  - A0 lattice modification — 0-5% ?
  - Diagnostics improvement — + in integr. *L*

FY’03 Shutdown(s)

- Projects critical for FY’03+ success:
  - Increase C0 aperture (replace Lambertsons)
  - Install 1.5GHz Schottky detectors at E17
  - Alignment work
  - Extra shielding for the CDF
  - TEL magnets/gun modification
  - A0 lattice modification (?)
  - Vacuum improvement (incl., warm two houses)
  - Install new collimator at A48 (?)

FY'02-'03 Resources

- Tevatron Department
  - staff of 15 + 2 Guests and 1 PhD student
- Out of 15 – 6 Physicists, 6 Appl.Sci+Eng, 3 Techs
- Most buried in operations and solving immediate (though physics) issues - "firefighters"
- Substantial help from outside:
  - V.Lebedev (formally in AA and Beam Lines, one of Tev Physics coordinators)
  - from Beam Physics Department: significant progress since Mar'02: Y.Alexahin then T.Sen, B.Erdelyi, V.Balbekov, M.Xiao, J.Johnstone, S.Drozhdin, N.Mokhov; A.Burov of BD/Ecool helps with instabilities
  - From PPD: A.Tollerstrup, H.Cheung; CD: P.Lebrun; TD: T.Khabibulin, G.Romanov, I.Gonin, N.Solyak, P.Bauer
  - Short term visitors (4-6 weeks): W.Fischer (BNL), F.Schmidt (CERN), coming - F.Zimmermann (CERN)
- Tev efforts >doubled over the last 9 months:
  - 16 FTE (20 people) in Jan'02, 36 FTE (67 people) now

Tevatron Projects in FY'03

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

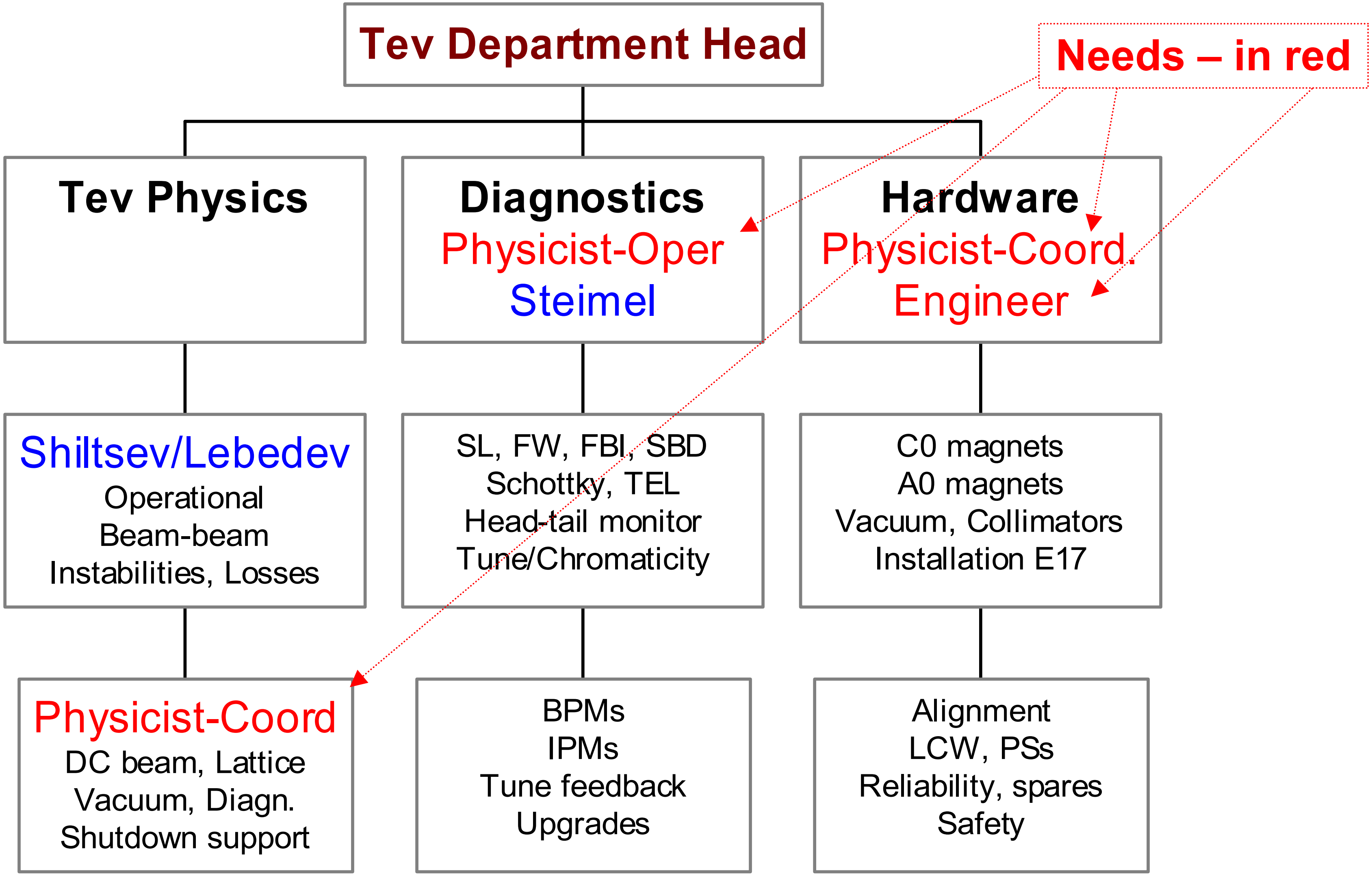
Tevatron Projects in FY’03 (cont’d)

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

FY'02-'03 Resources (cont'd)

- That gives us 21 projects (27 including subprojects): 10 focused on protons, 16 on antiprotons, and 6 on their emittances
- 10 projects out of 21, including 4 out of 7 highest priority projects, experience need of the study time, especially after recent 2-fold reduction (5 shifts every other week). Weekly studies or/and better planning and use of reduced time and end of stores are needed to keep fast pace in luminosity. Better diagnostics should help in that, too, allowing "in store studies"… but we were not good in that so far, so dedicated studies is a sure way.
- Concentration of physicists actively working on Run II would benefit the Collider progress ("Run II Center")
- 17 people are in charge of the projects (and several more for subprojects), all of them report to Tev Dept Head → restructuring needed →

FY'03 Resources (cont'd)



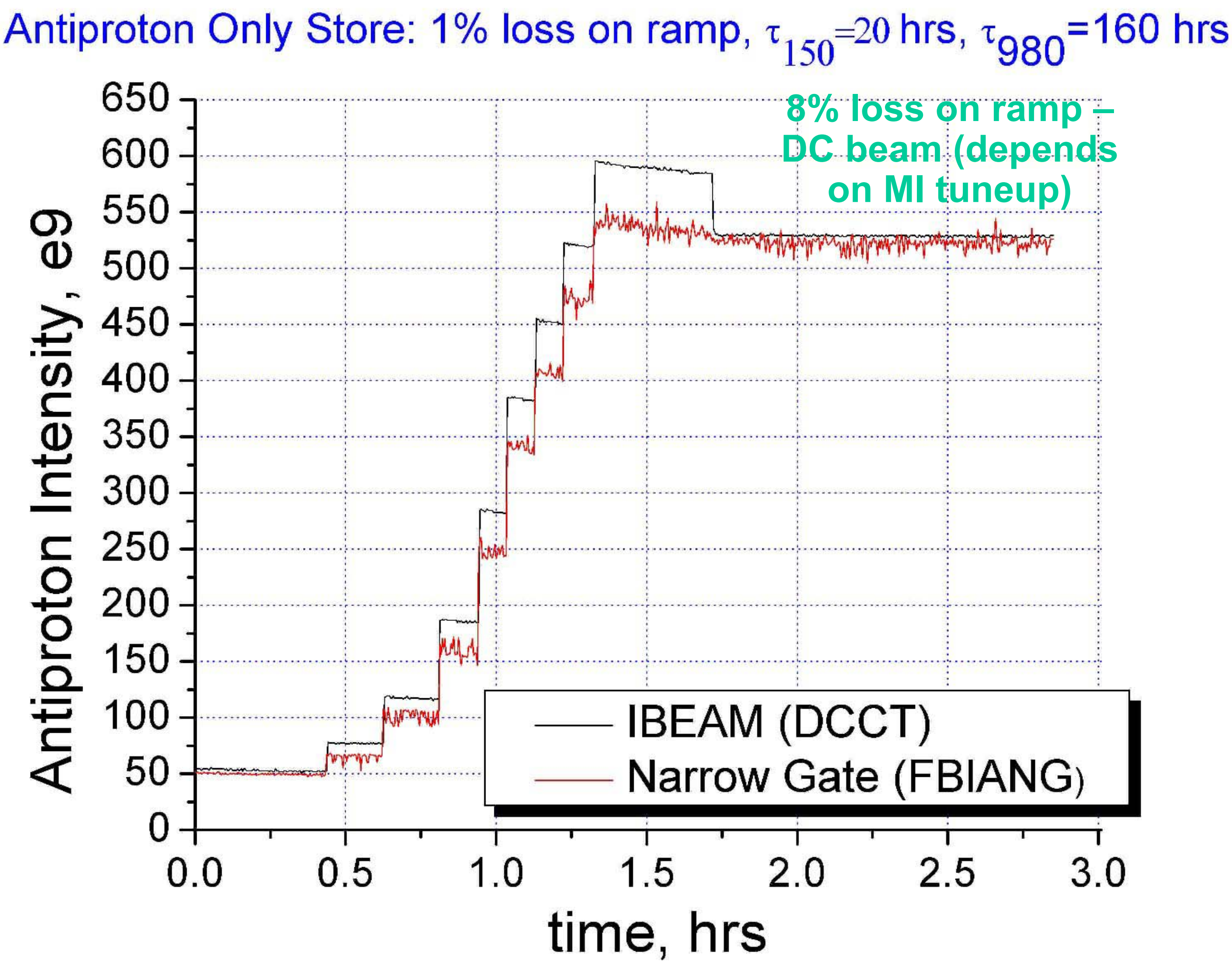
Summary

- 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 >80 pb^{-1} to each experiment in FY'03
- Beam-beam effects and transverse instability and hampering performance, but know how to remedy
- Looking forward to delivering 0.2-0.32 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

Back-up Slides

- Physics Issues
  - Beam-beam effects, TEL
  - Instabilities
  - Emittance growth
  - Beams at injection
  - Interaction points
  - Losses/background, DC beam
  - Orbit motion
- Diagnostics
  - BPMs
  - BLT
  - RF phase
  - FWs
  - SyncLite
  - SBD
  - Schottky detector
  - Tune meter
  - Chromaticity Measurements
  - Head-Tail Monitor
  - Scintillator paddles
  - Orbit Oscillation Detector
  - RF Noise
  - Tilt Meters/Geophones

Beam-Beam Effects: Pbar Only

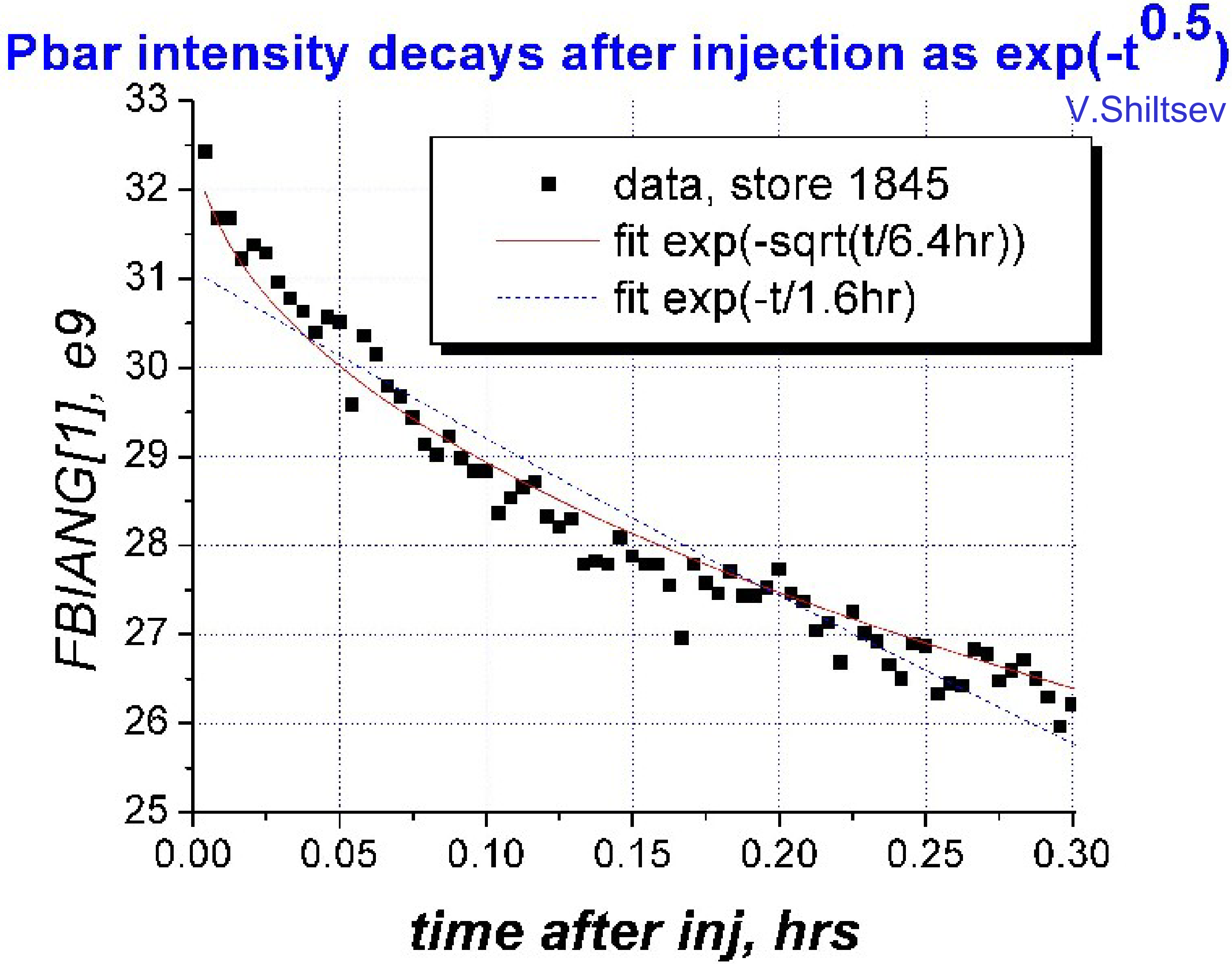


Beam-Beam Effects: Antiprotons Suffer

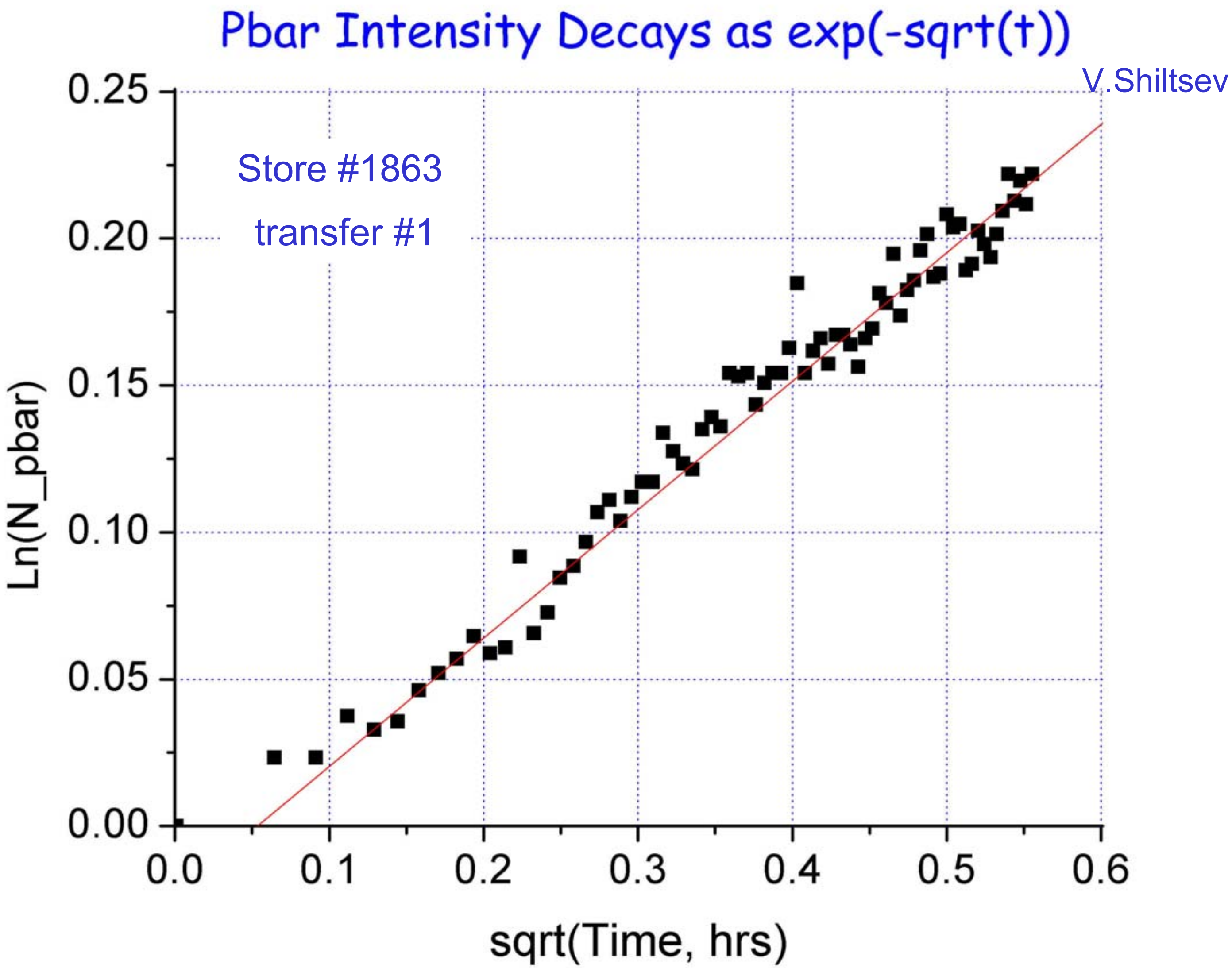
Store	*N_p, e9*	*Out of AA, mA*	*Loss at 150*	*Loss on ramp*	*Loss in squeeze*	*Pbars at low-beta*	*L, e30*
Mar'02	5100	90	20%	14%	22%	251	9.4
1303	6070	103	16.4%	11.6%	3%	476	19.5
1289	6990	105	18%	20%	11%	387	19.6
Oct'02	6430	132	9%	8.3%	5%	790	32.4

- Pbar intensity lifetime at low-beta is 15 to 50 hrs (50-70 due to luminosity)
- Pbar emittance lifetime at low-beta is 10 to 40 hrs
- Some effects are seen in protons (see below)

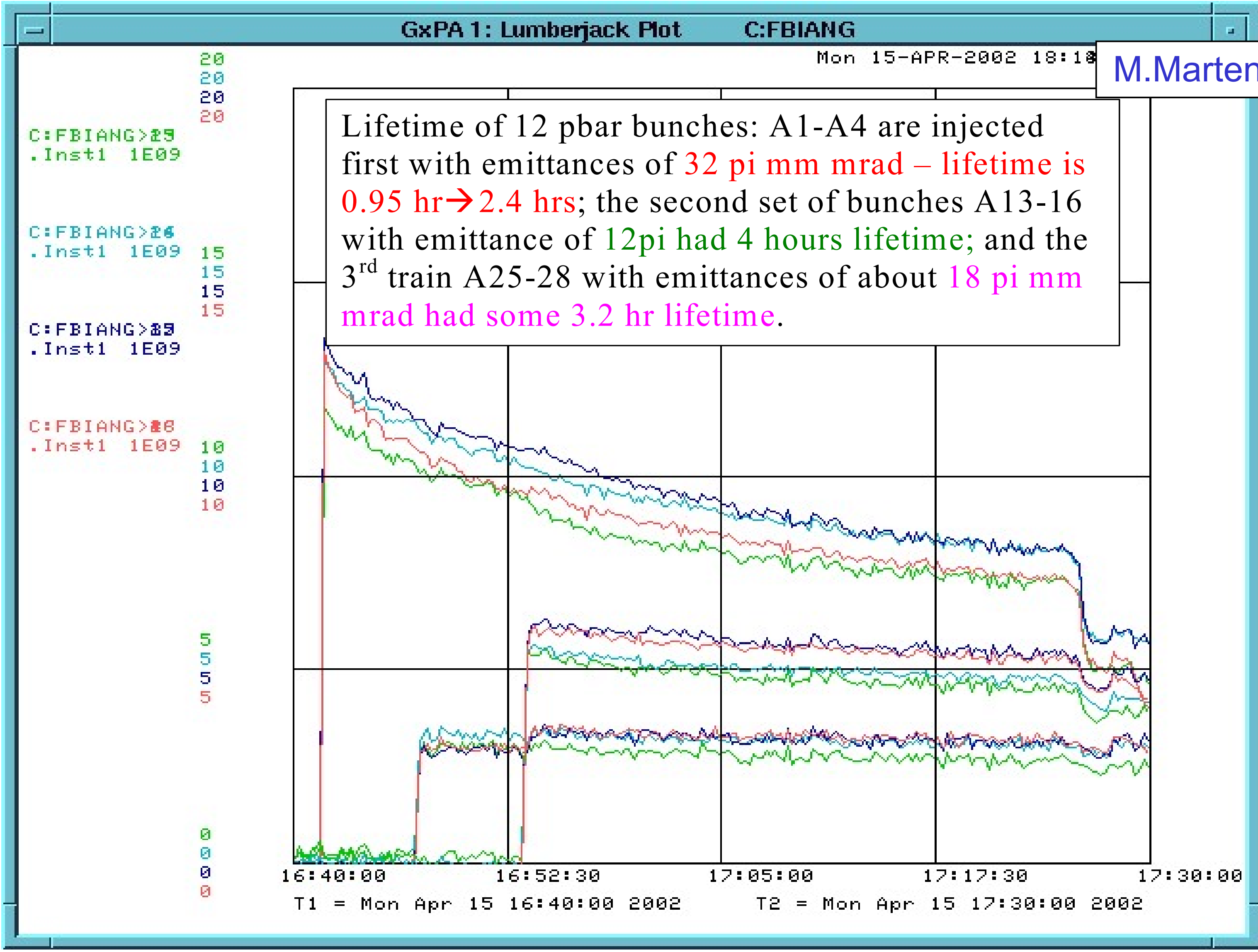
Beam-Beam @ Injection: Shaving



Injection Loss ("Shaving") in Detail



Beam-Beam @ Injection vs Emittance

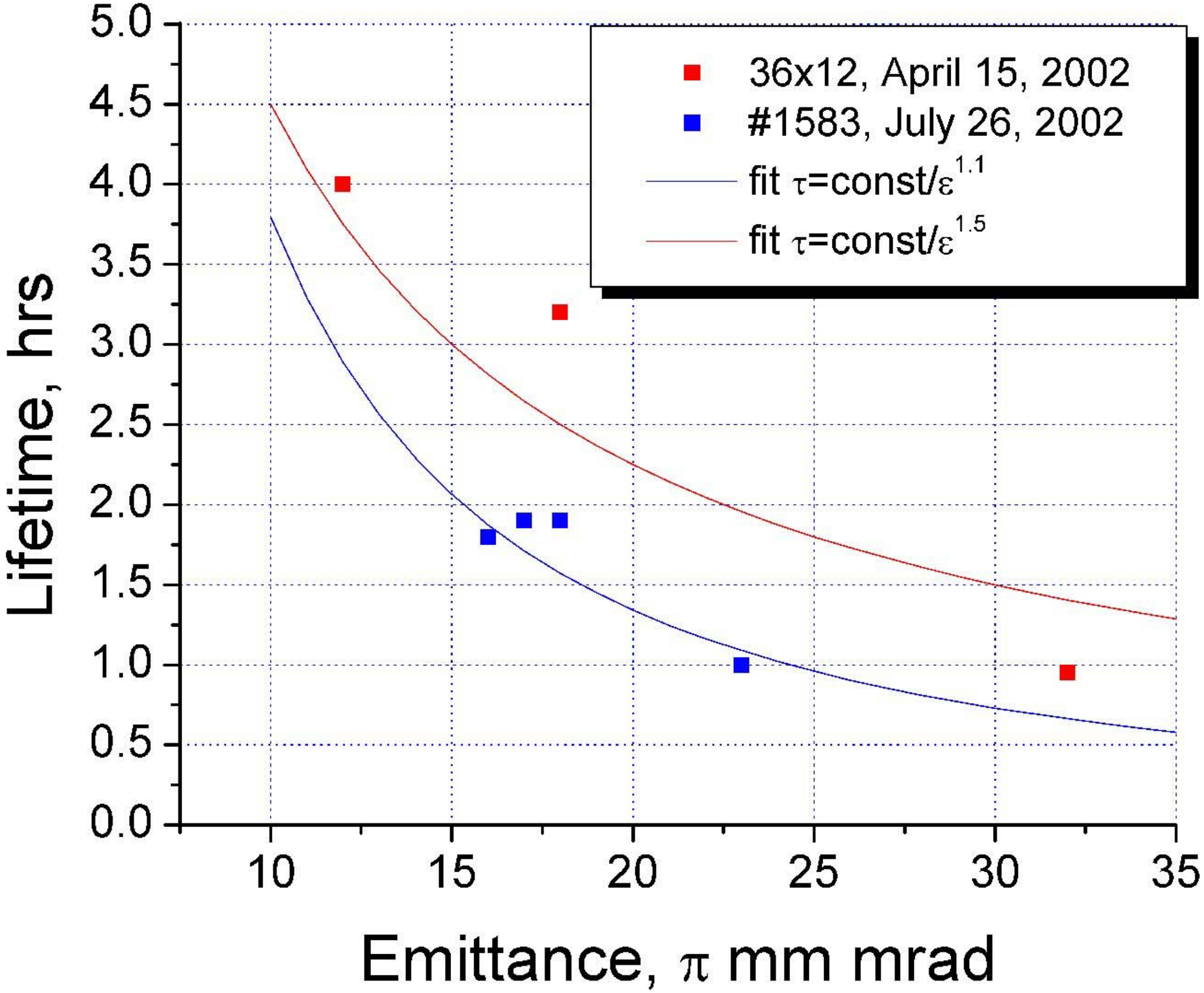


M.Martens

Lifetime of 12 pbar bunches: A1-A4 are injected first with emittances of 32 pi mm mrad – lifetime is 0.95 hr→2.4 hrs; the second set of bunches A13-16 with emittance of 12pi had 4 hours lifetime; and the 3rd train A25-28 with emittances of about 18 pi mm mrad had some 3.2 hr lifetime.

Beam-Beam @ Injection vs Emittance

Pbar lifetime vs emittance at injection scales as $1/\varepsilon^{(1.1-1.5)}=1/A^{(2.2-3)}$



Beam-Beam @ Injection (cont'd)

Combining

$$(dN/dt)/N = -(\varepsilon_0/\varepsilon)^{\alpha}/\tau_1$$

where a = *1 π 1.5, and*

$$N \approx N_0 e^{-\sqrt{t/\tau_2}}$$

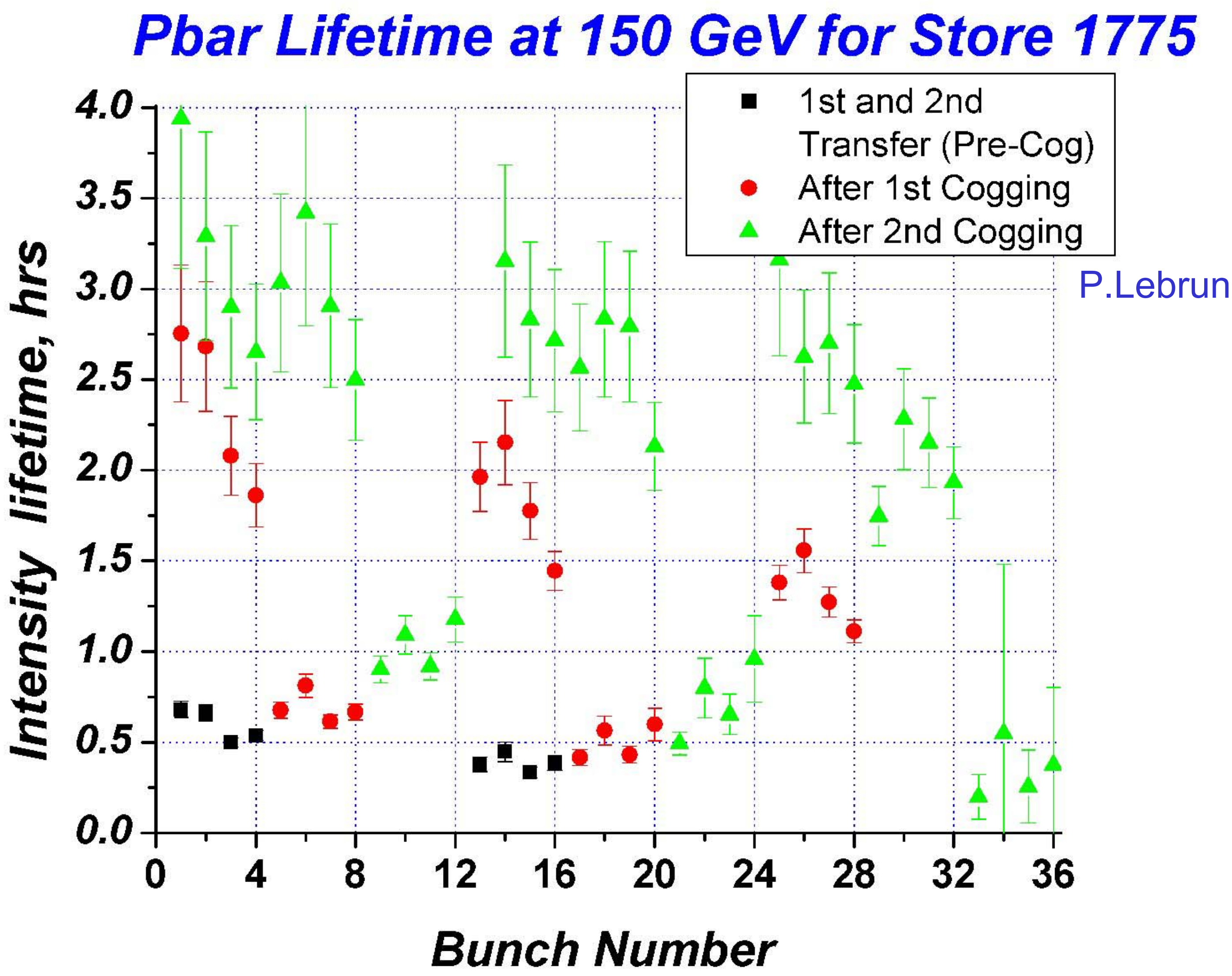
one gets

$$\varepsilon \propto (t/\tau_{\varepsilon})^{-\beta}$$

where b = *1/(2*a*)= 1/2 π 1/3, and* $t_e = t_1^2/(4\,t_2)$,

i.e., we have shaving on aperture or "soft collimator"

Beam-Beam @ Injection: Bunch-by-Bunch

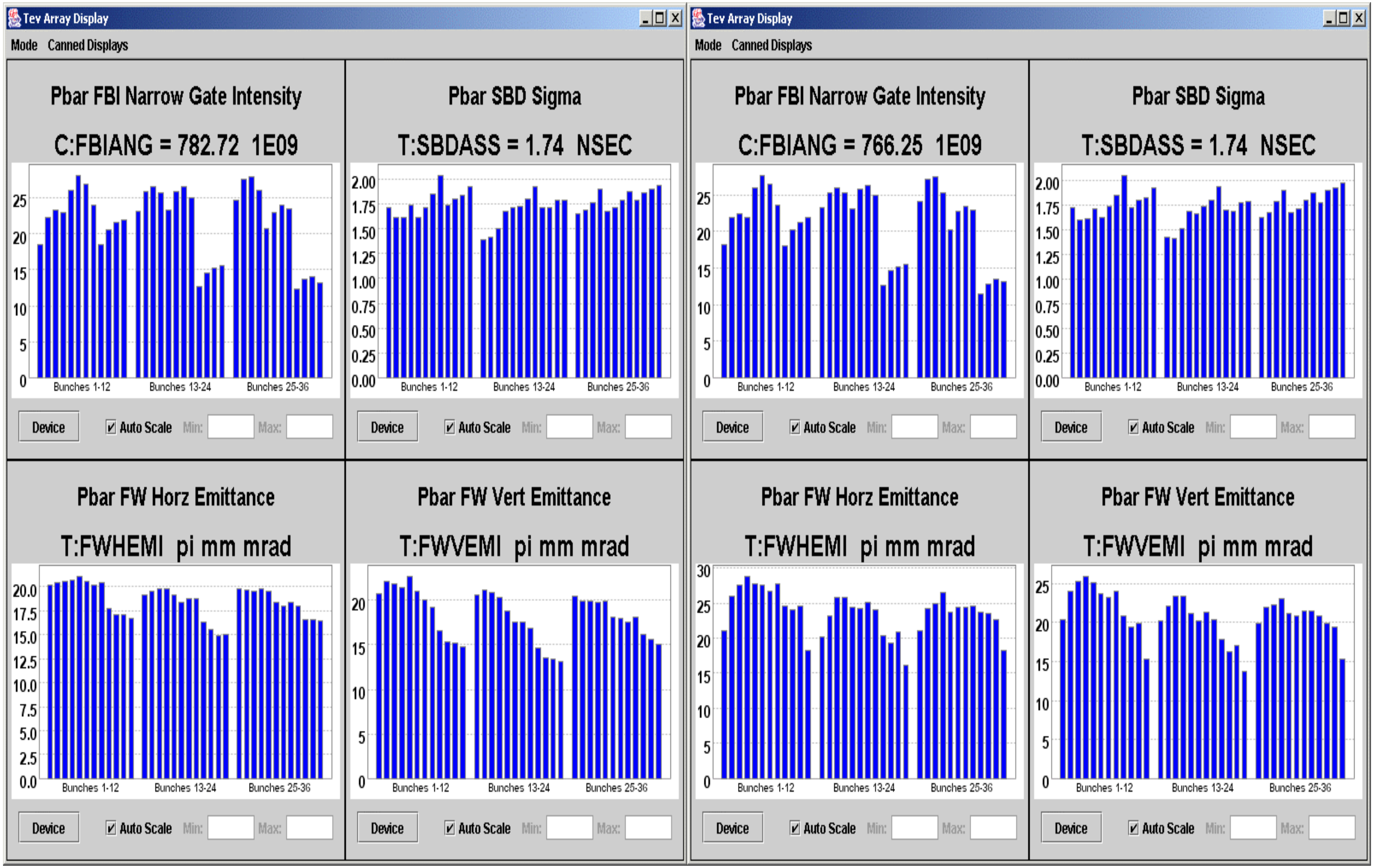


Beam-Beam Effects at 980 GeV

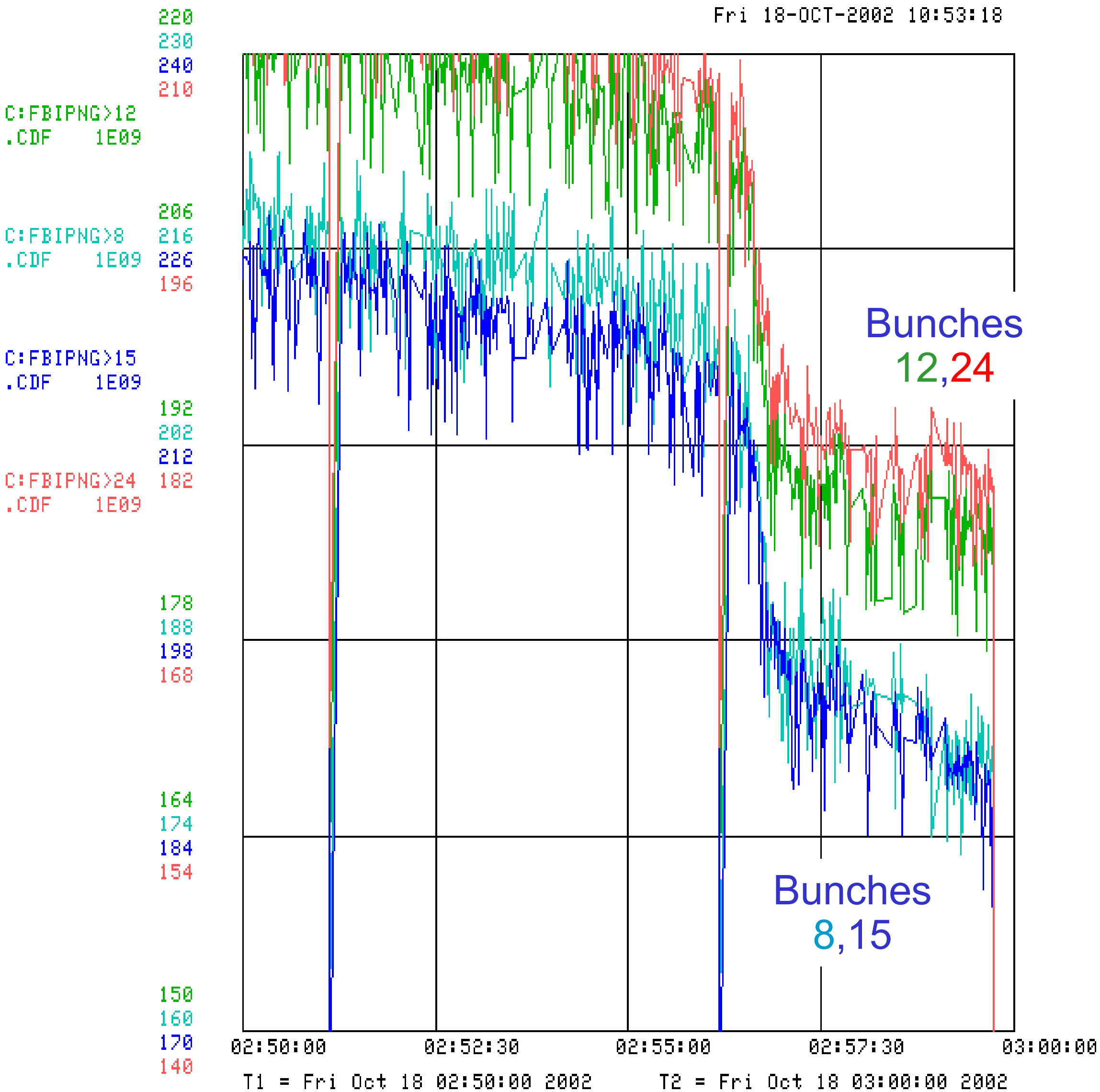
- Suffered 10-20% pbar loss during squeeze
  – During transition from injection to collision helix
  – Minimum beam separation was only ~1.8σ
  – New helix increased min beam separation to ~3σ
  – Pbar loss during essentially eliminated

- ☹ lifetime ≈ 9-10 hrs in first two hours of store
  – Increase helix separation to reduce long-range beam-beam effects? (72 "parasitic" crossings)
  – Pbar tune shift depends position in train ⇒ optimize tunes for most bunches
  – Use electron lens to compensate pbar tune shifts

Pbar Emittances: The First 10 Minutes

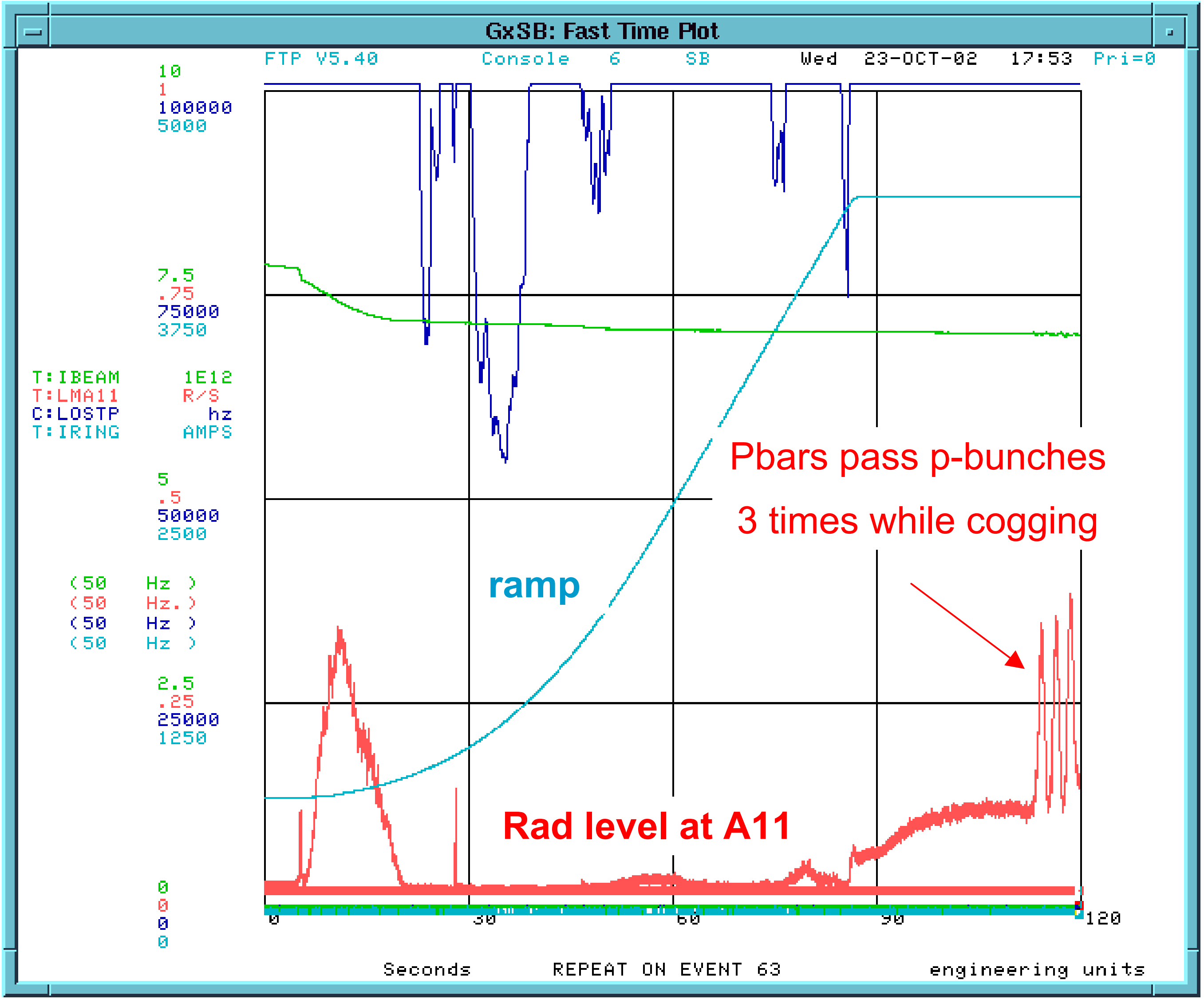


Beam-Beam Effects in Protons

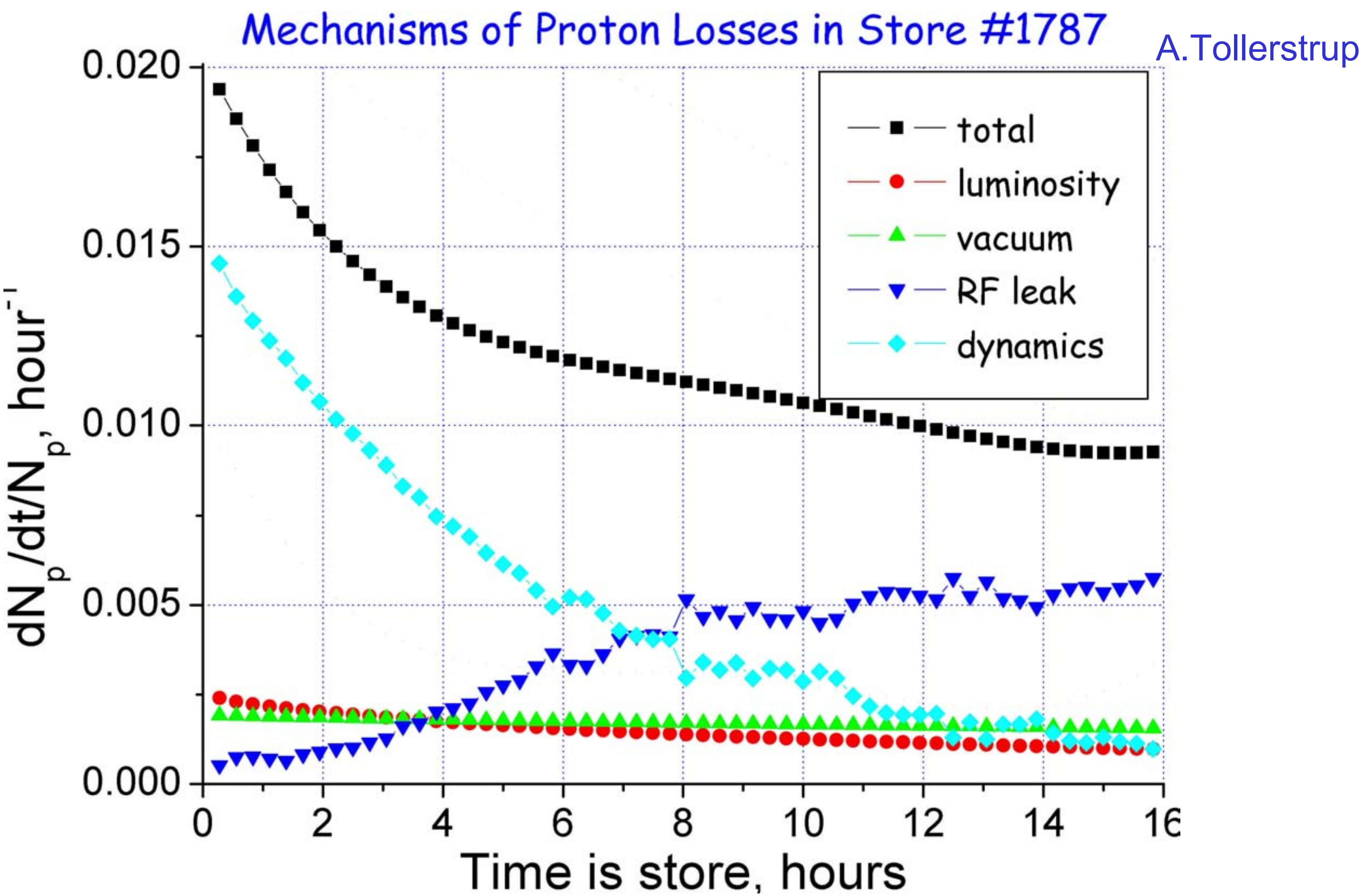


- See losses in squeeze in store #1868
  - Losses of bunches #12,24,36 were small (1e9/min)
  - All other bunches lost intensity very fast (4e9/min)
  - That resulted in quench at A11
- We have small “anti-scallop” (“smile”) effect in proton emittances at HEP
  - Bunches #1,12,13,24,25,36 have 1-2 pi larger emittances than others after being 1-few hours in collisions
  - Their intensity lifetime is smaller, too
- Antiprotons also help to make protonbeam more stable on ramp and squeese
  - Proton instability is rarely observed in 36x36 stores compared to the same intensity 36x0 stores
  - Tune spread due to pbars is about (few)e-4

Proton Losses While Cogging Pbars

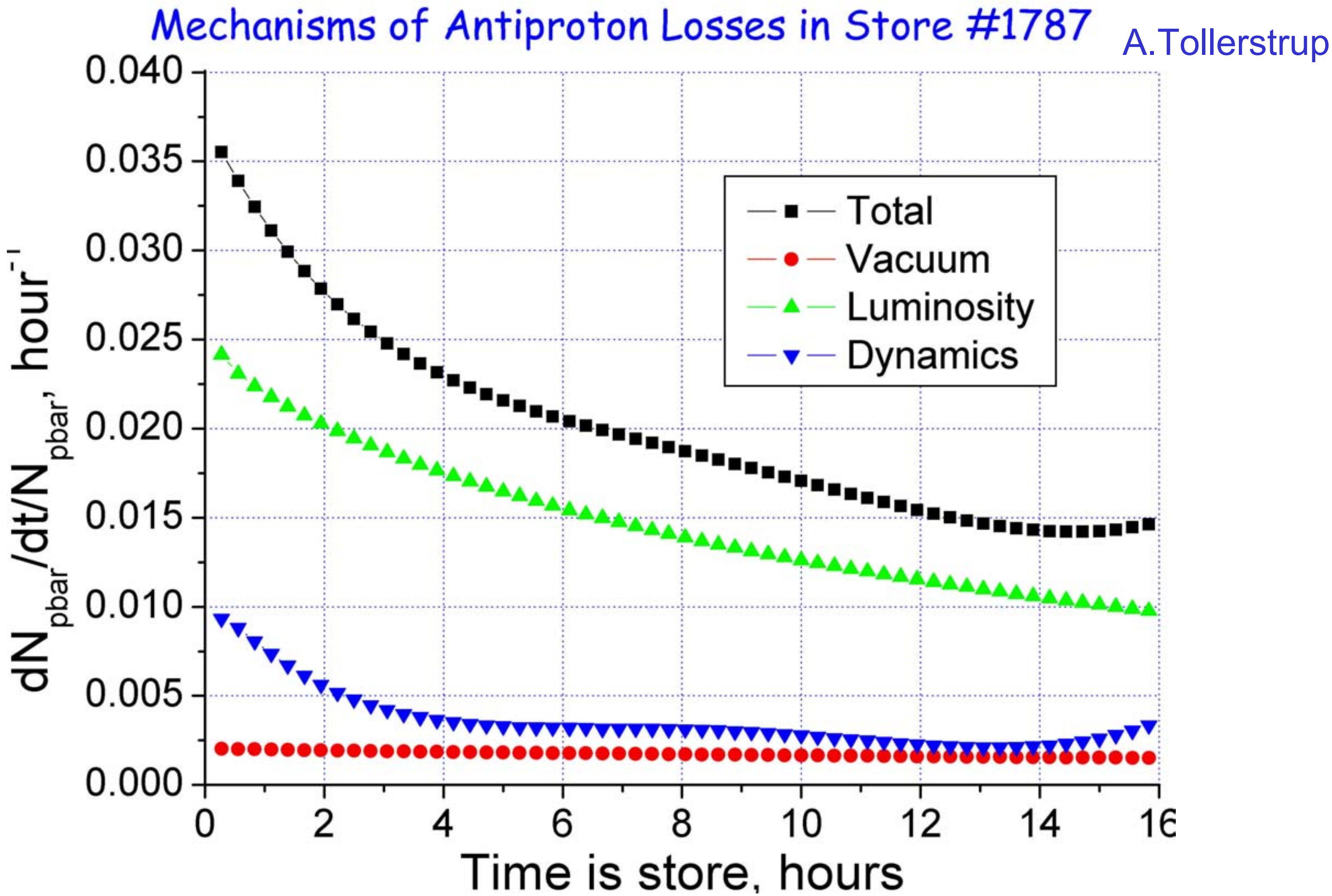


Beam Losses - Protons



- Proton lifetime of about 50 hours is dominated by dynamics and, later, RF leaks

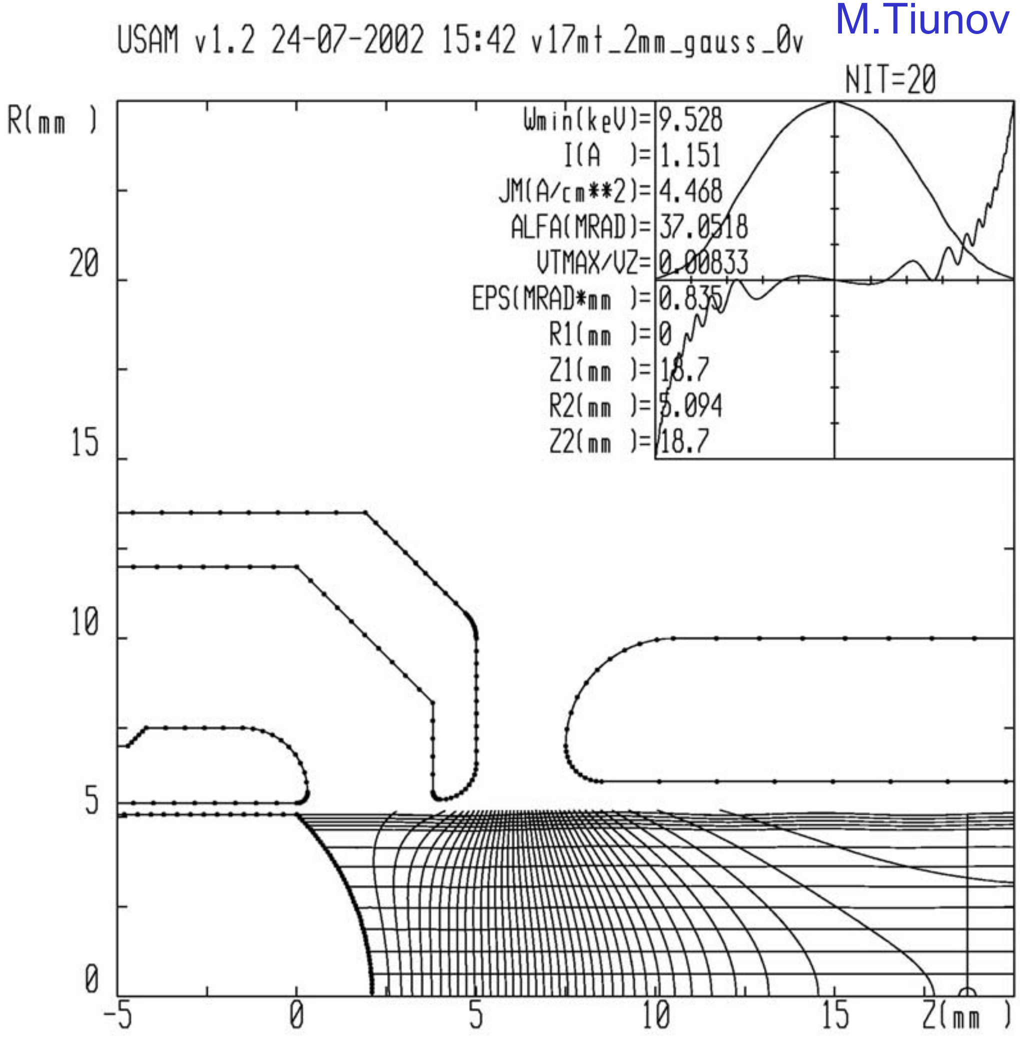
Beam Losses - Antiprotons



- Pbar lifetime of about 30 hours is dominated by luminosity losses

Gaussian Gun for TEL

M.Tiunov

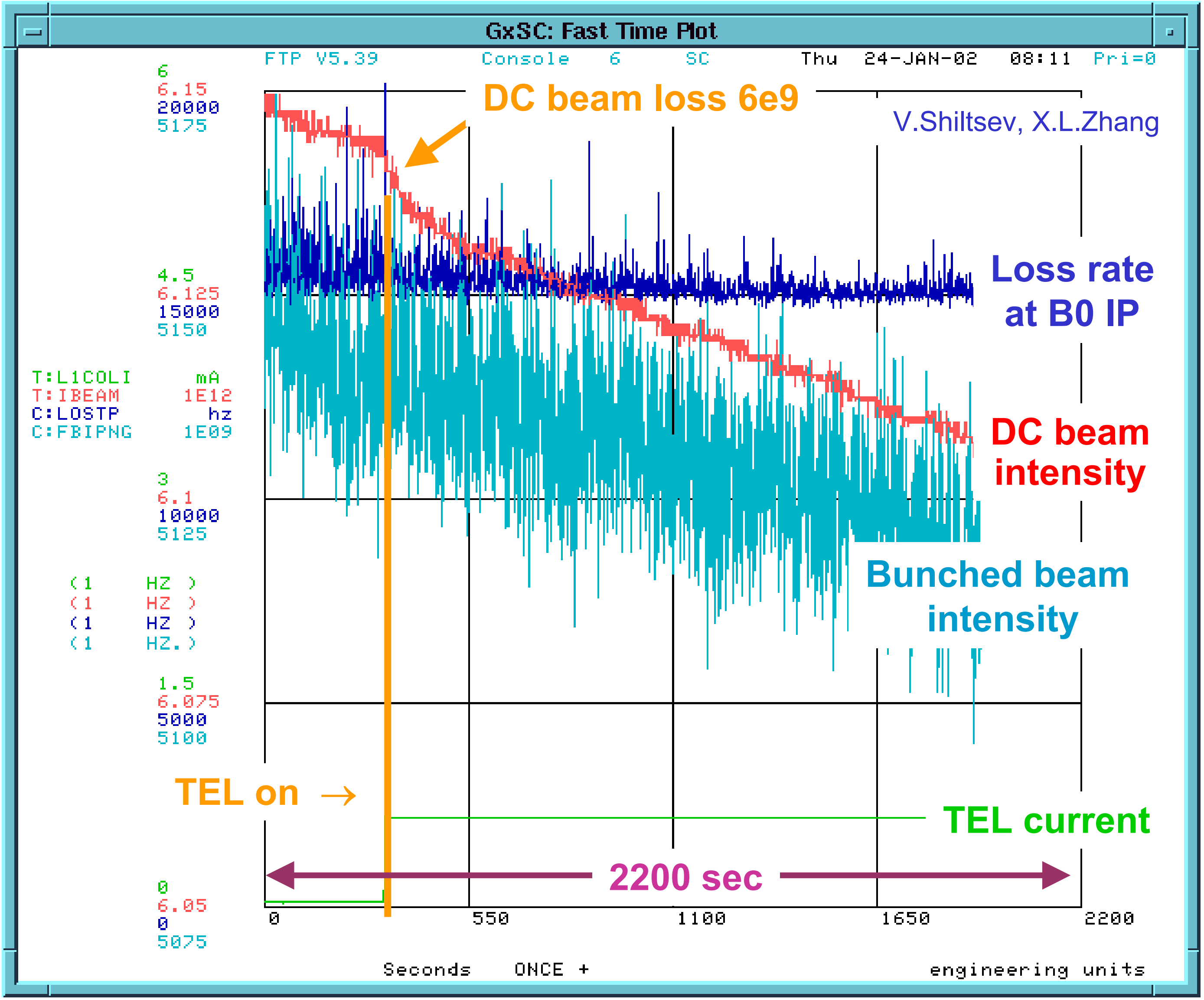


- Profile controlled by special electrode
- Somewhat reduced current density in the center → need of higher voltage
- Under fabrication
- To be installed in Jan'03 shutdown

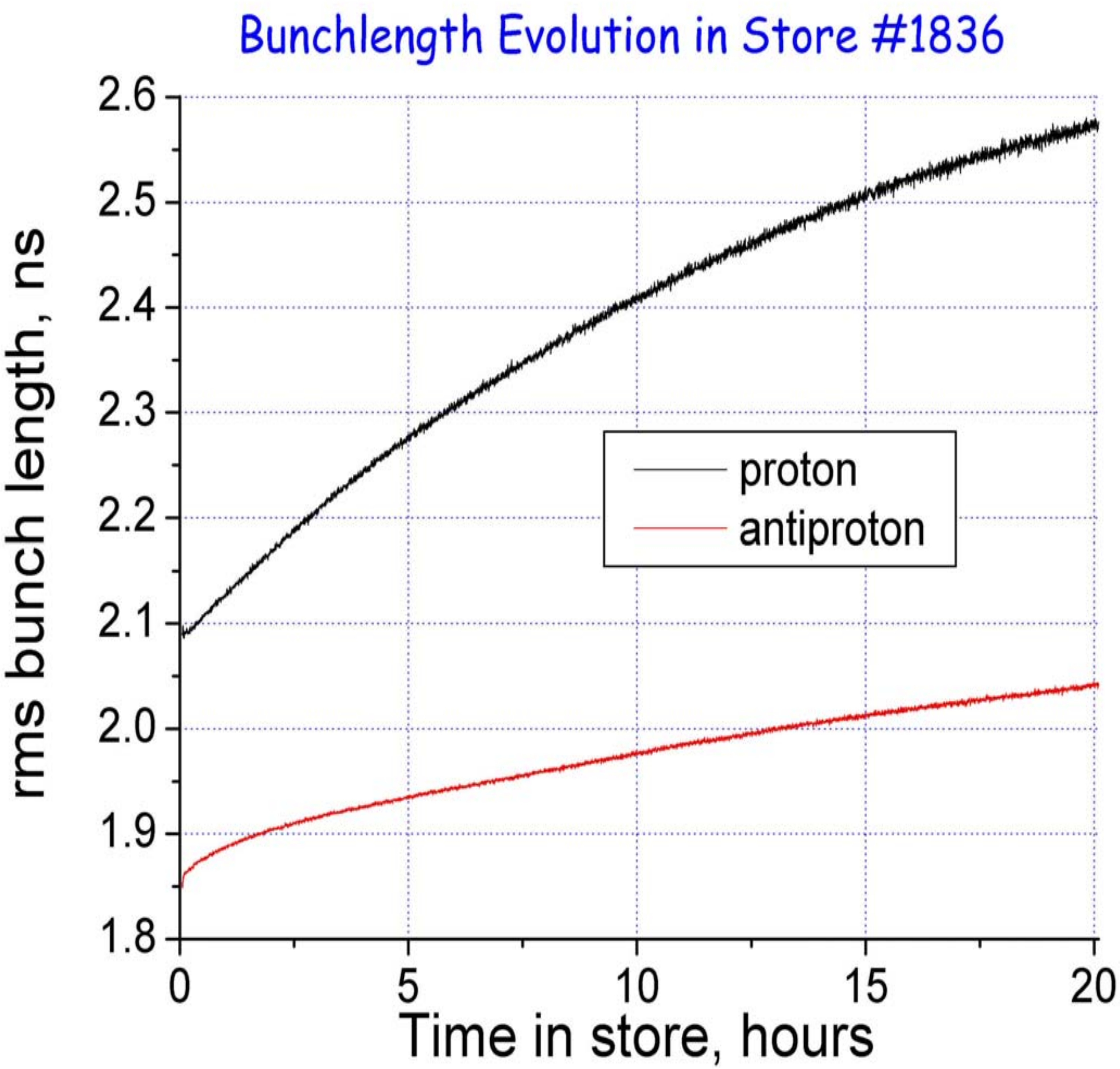
TEL as the DC Beam Cleaner

- Phenomenon not yet understood causing beam to leak out of RF buckets
- At the end of store there is anough of the DC beam in the abort gap to cause quench on abort , >$6x10^9$ or ~0.1% of N_{total}
- e-beam placed to edge the p-orbit helix
- Fire TEL in 3 gaps every 7 turns to excite resonance
- TEL is equivalent to 100kW "tickler" (vs 50W in Q-mtr)
- TEL reduces DC beam intensity and eliminates spikes in the CDF losses
- currently TEL is operational: now it is turned ON early into each store, then OFF after store terminated (no TEL at injection as the DC beam is not a problem there)
- When needed, TEL is used for p/pbar bunch removal

Removing DC beam with TEL

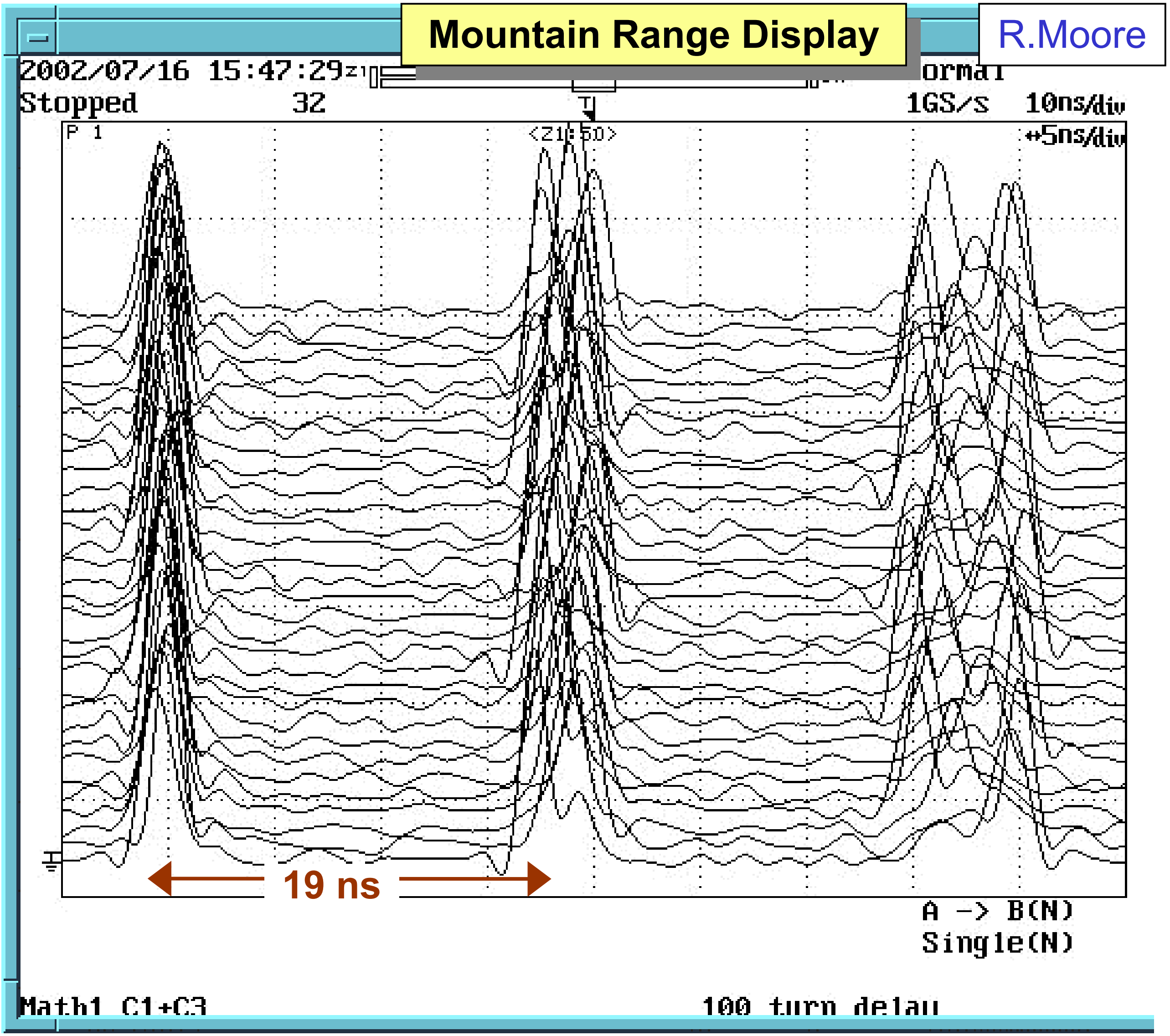


Bunch Length Growth



- Early in stores the rms bunch length growth time is about 50 hours for protons and 100 hours for antiprotons
- Pbar bunch length growth can be suppressed by beam-beam effects, e.g. sometimes it goes down a bit due to beam-beam "shaving"
- Proton bunch length growth correlation with intensity is not proven yet, so, it quite may be due to noises (some 50 microrad RF phase fluctuations are needed for that)

Longitudinal Impedance – "Dancing Bunches"



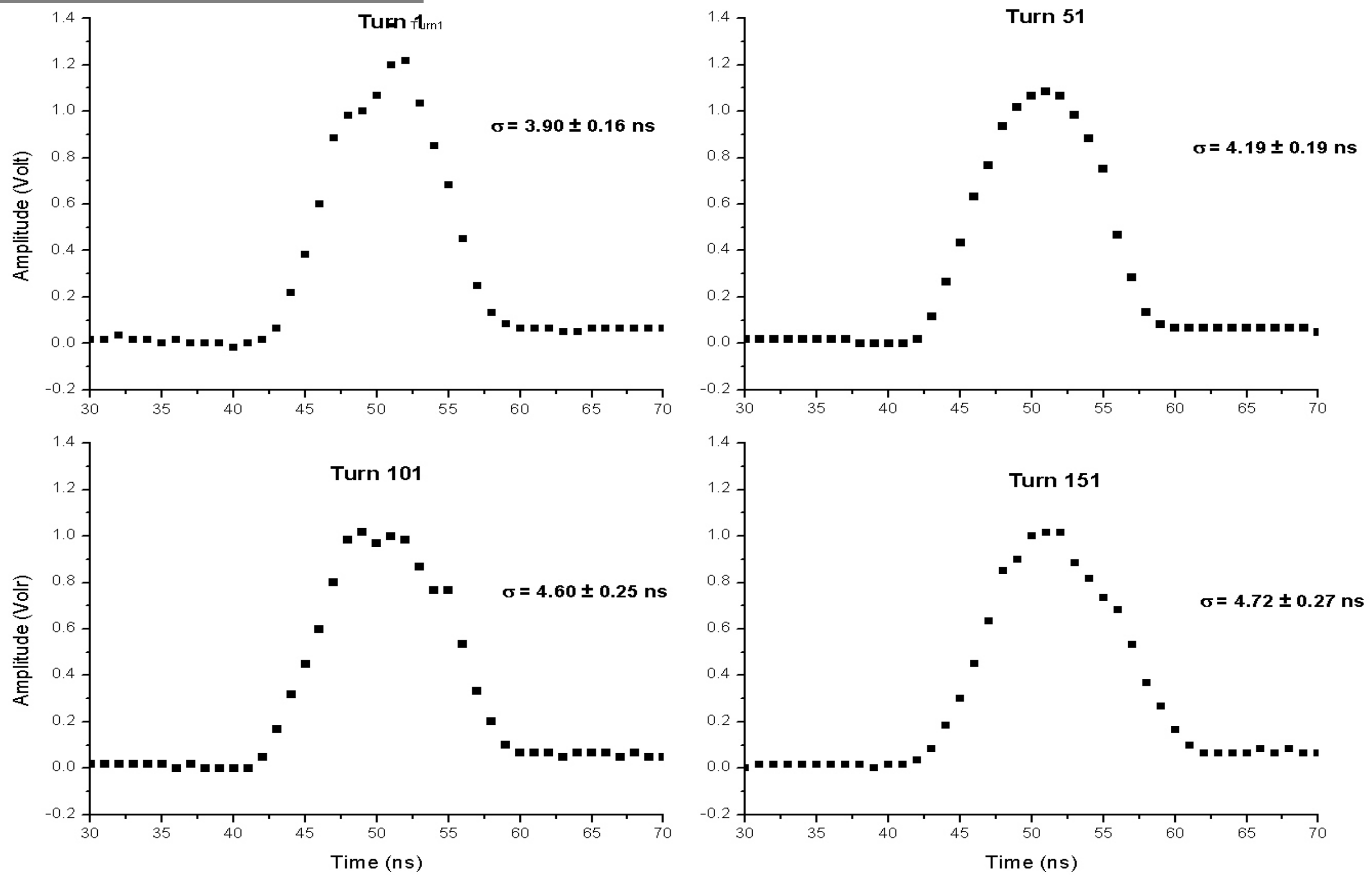
- Beam in 30 buckets
- 100 Tevatron turns (~2 ms) between traces
- Synch freq ~ 85 Hz
- Oscillation amplitude depends on bunch, changes slowly with time (minutes at 150 GeV, seconds at 980 GeV)
- Model needs inductive impedance Z/n¥2 Ohm interplaying with cavity impedance
- Coalesced bunches have dancing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

"Dancing Nipples" in Coalesced Bunches

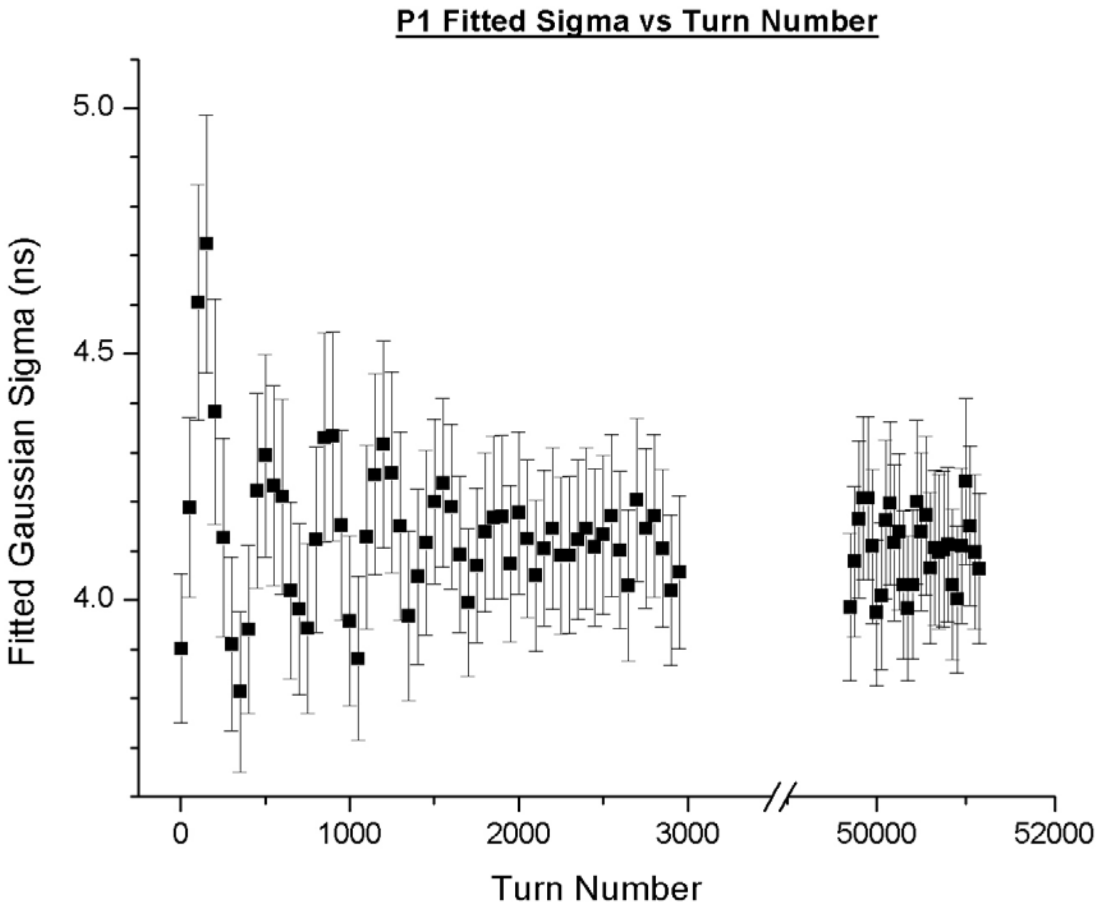
Mountain Range Display

R.Moore

P1 @ injection



Beams at Injection – Longitudinal



R.Moore

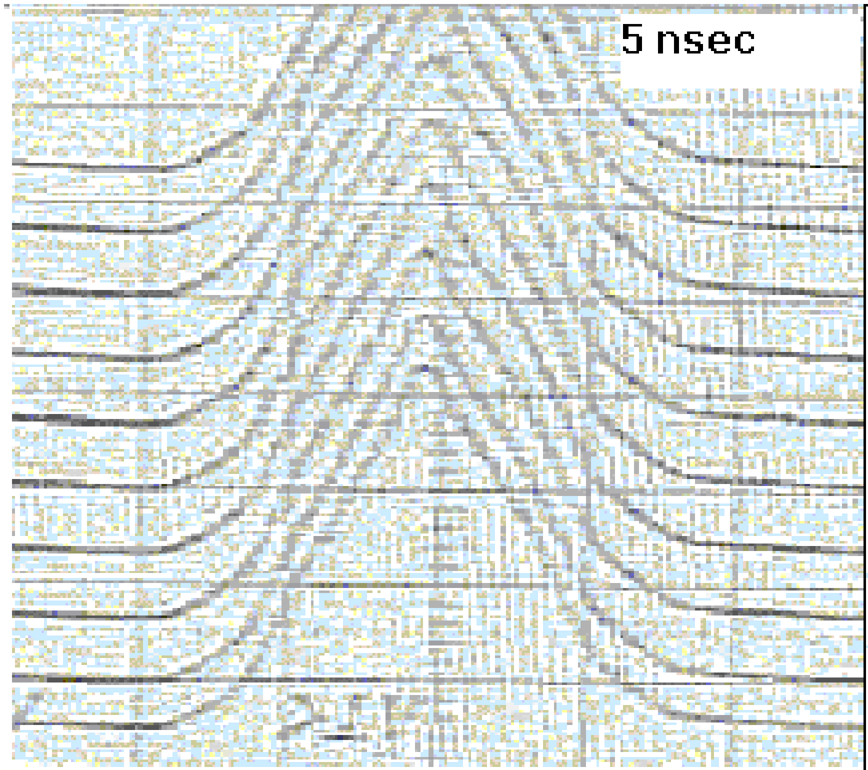
- No significant longitudinal emittance growth (<10%) – full bucket from MI
- Some <10 degree RF phase oscillations, 10% sigma oscillations, 1 s decay

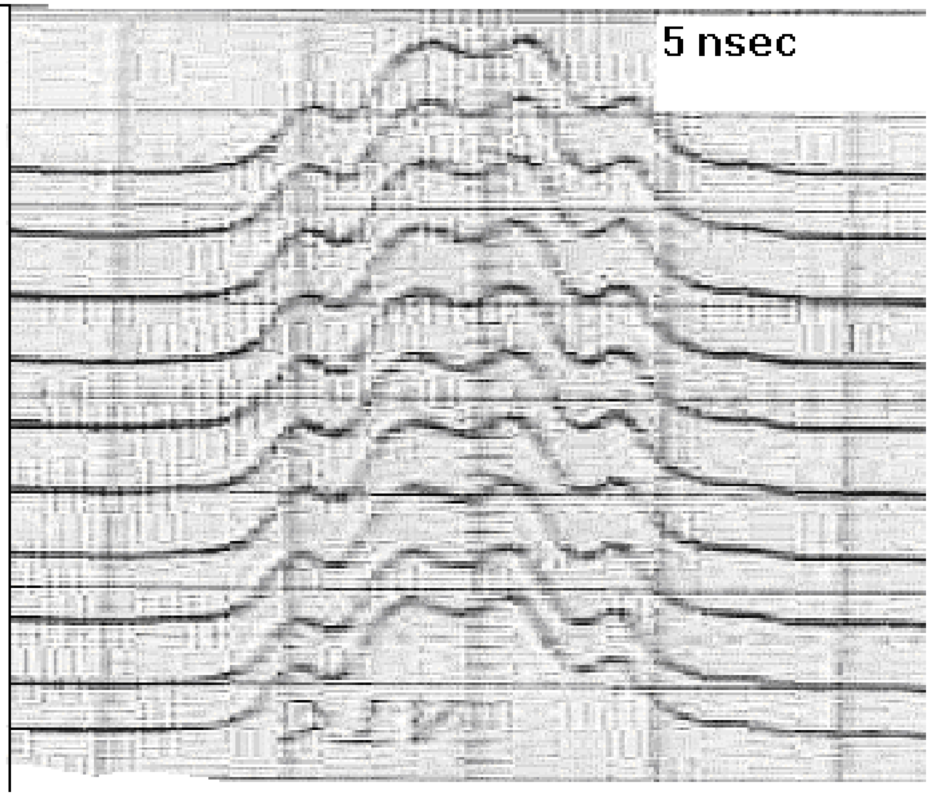
Transverse Instability

- Beam remains point to coherent betatron mode with ***l*=2**

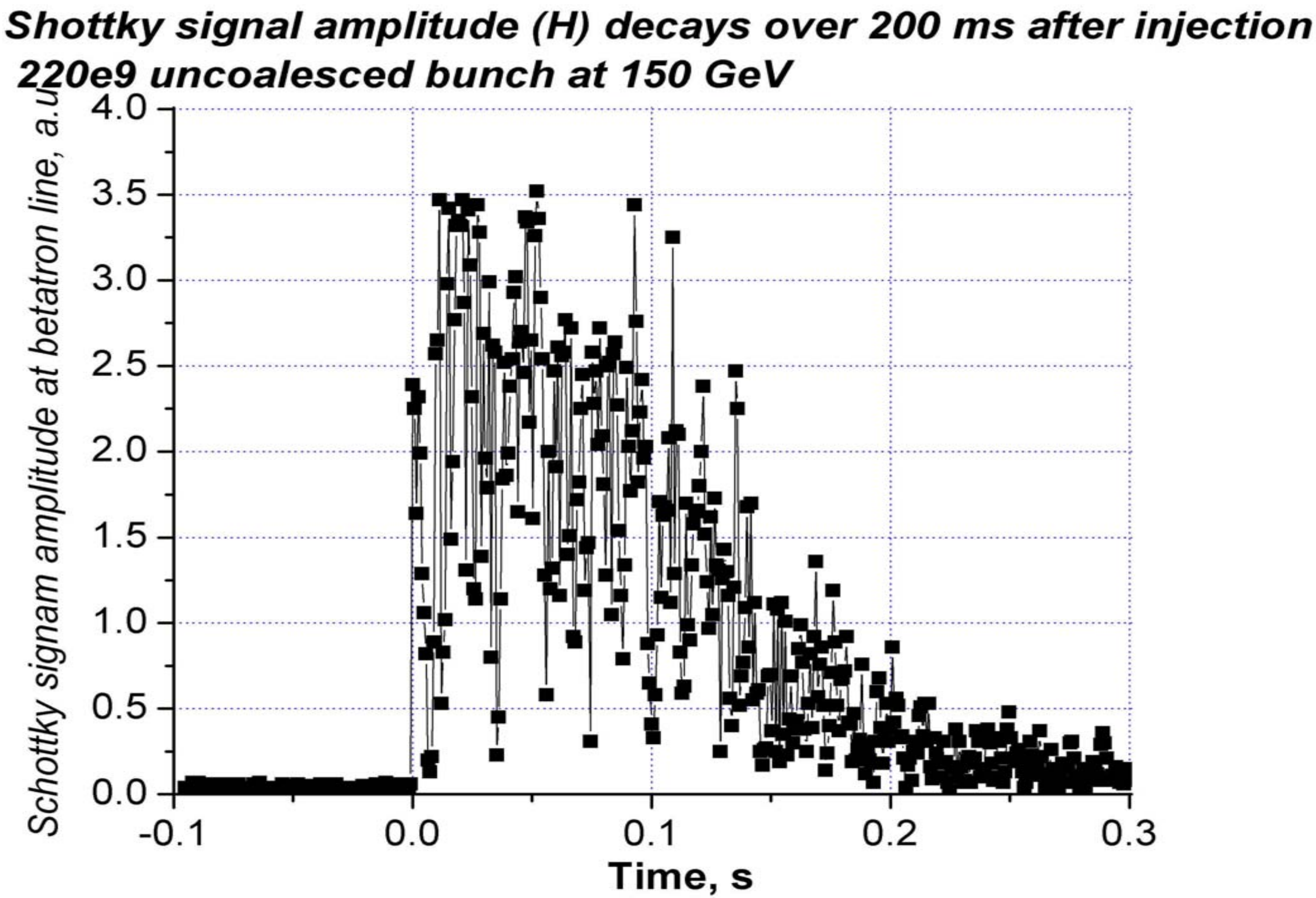
$$N_{ppb} = 2.6 \cdot 10^{11} (init.\, beam) \quad \Rightarrow \quad N_{ppb} = 1.03 \cdot 10^{11} (remain.\, beam)$$

P.Ivanov, A.Burov



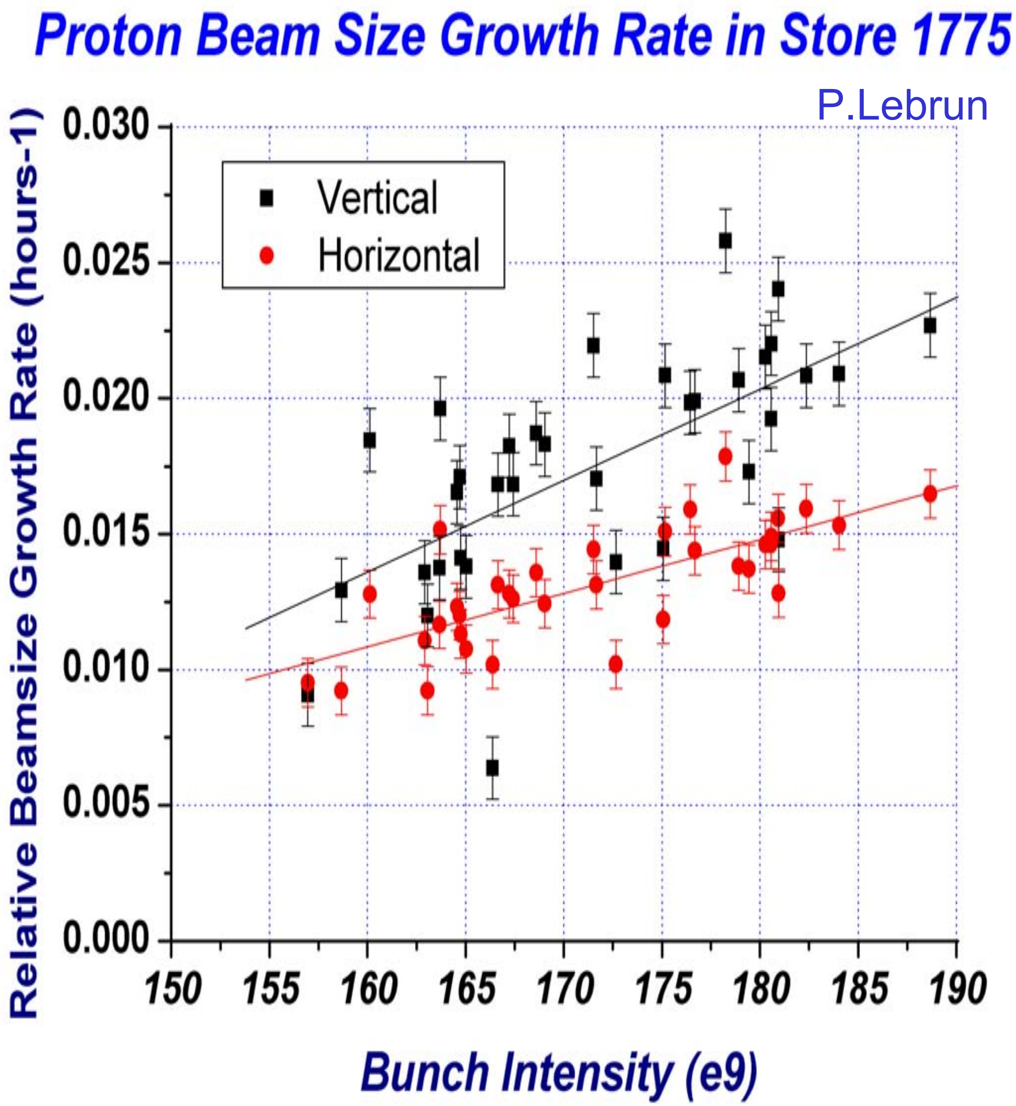


Beams at Injection – Transverse Emittance



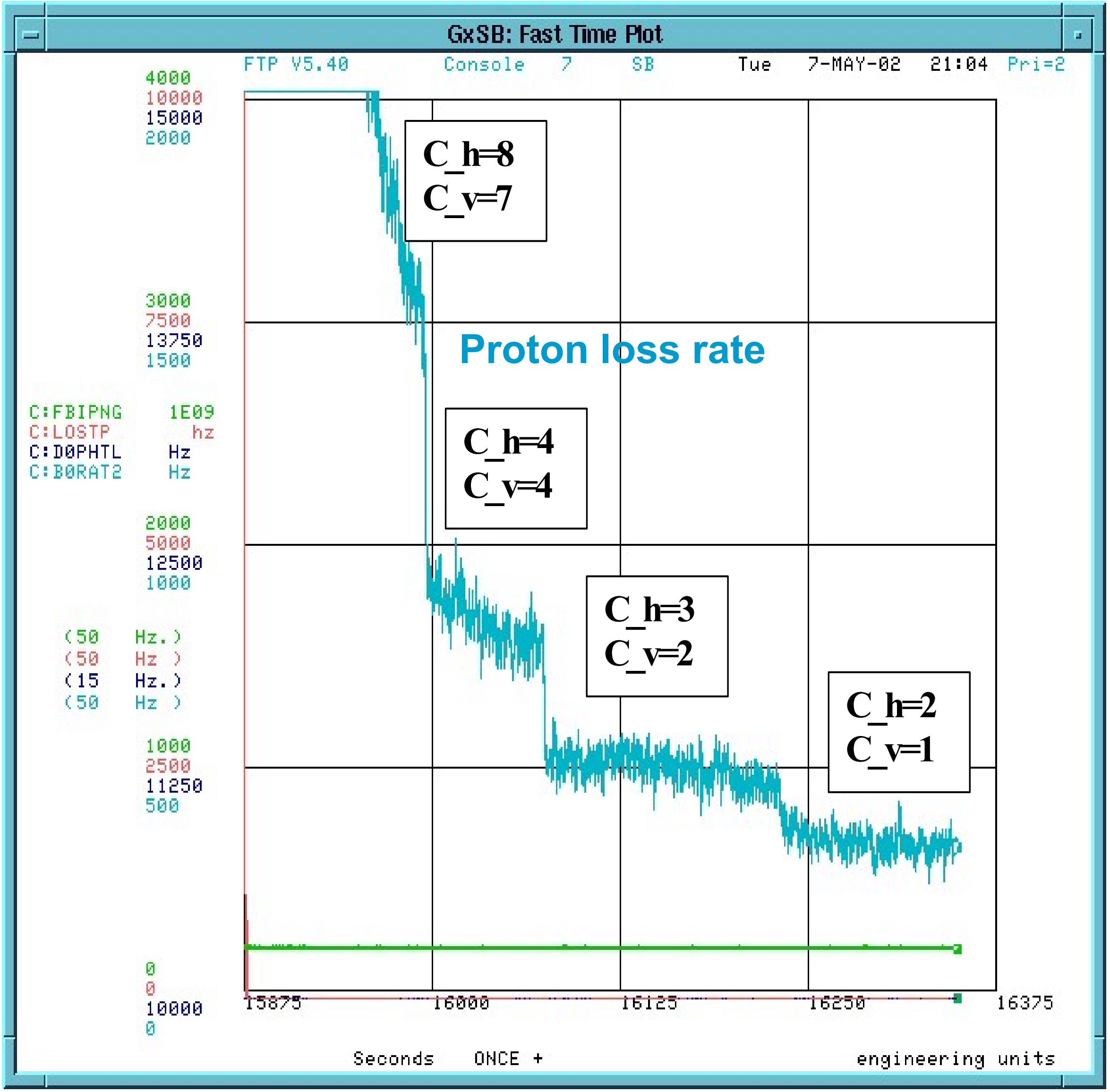
- coherent signal decay (n_xp emittance dulution) time is about 10^4 turns

Transverse Emittance Growth



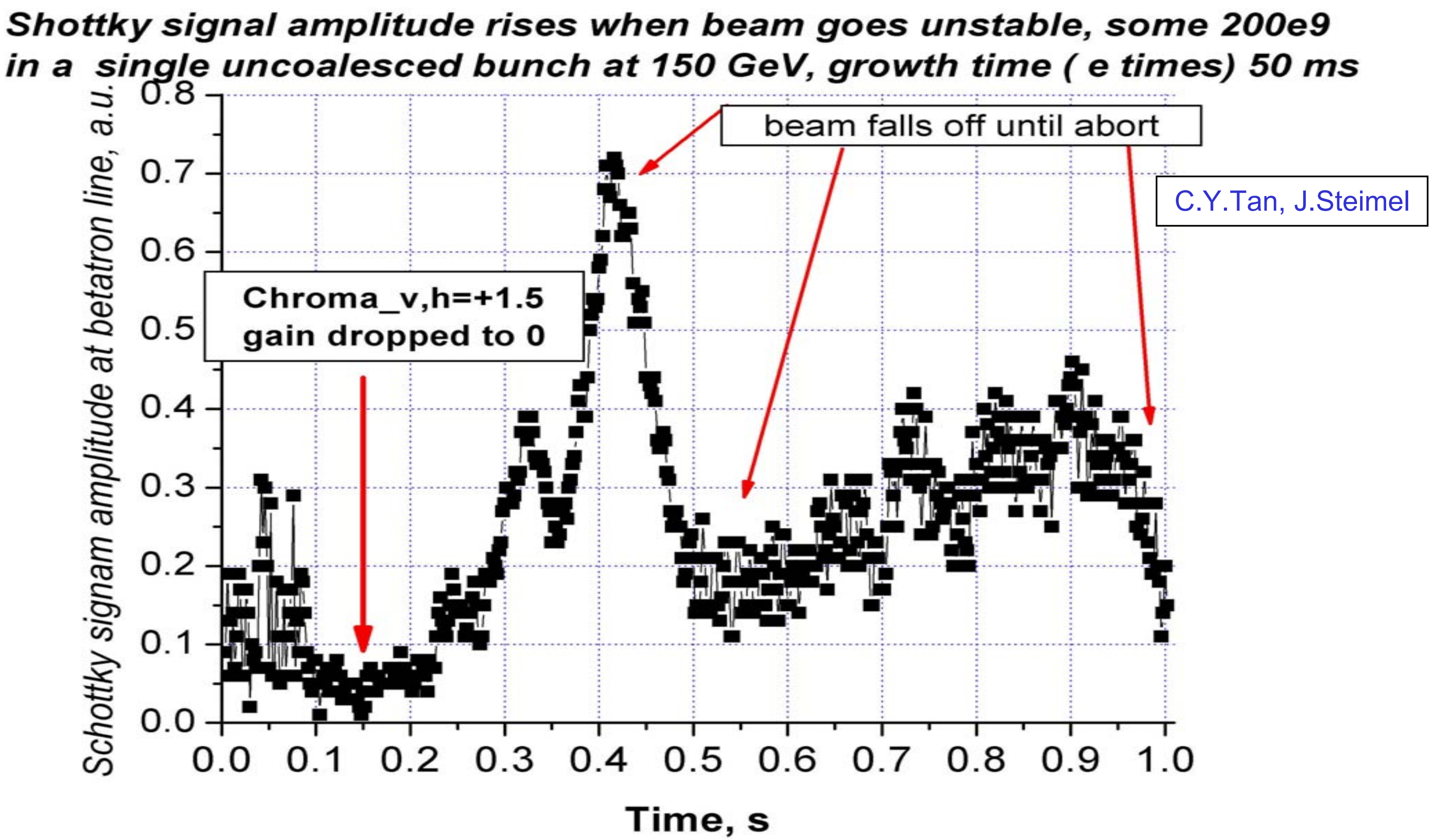
- Proton emittance lifetime is about 50 hours or 0.5 p mm mrad/hr
- About 0.2 p mm mrad/hr mm rate is intensity independent – consistent with known “equivalent” vacuum ~1e-9 Torr (and noises?)
- The rest is intensity dependent, consistent with intrabeam scattering

Beams at Injection – p-Lifetime



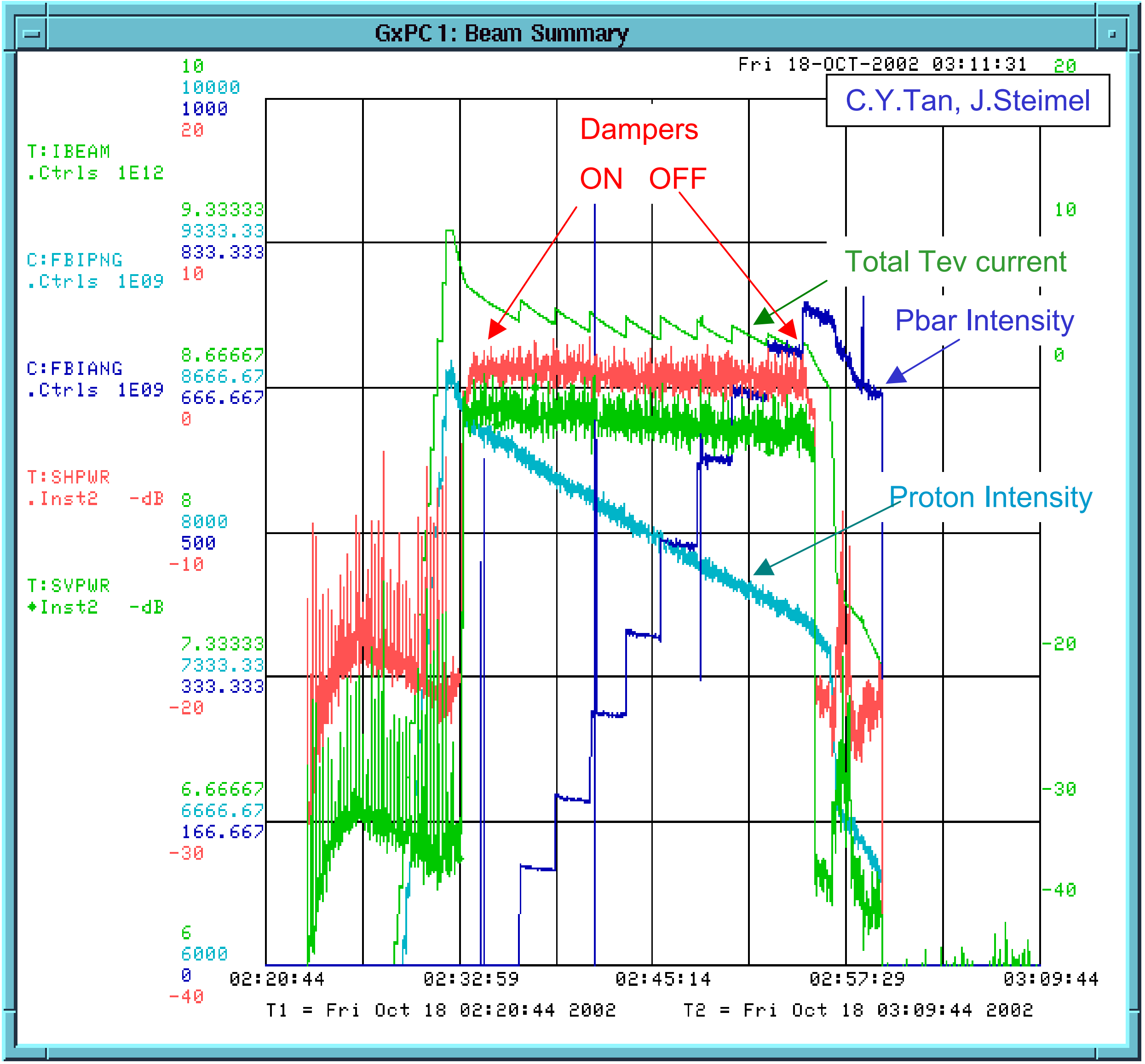
- Large dQ due to chromaticity in limited good working point space (tune aperture)
- p-loss rate (dN/dt) goes down for smaller chromaticities *C_v,h*
- with 36 p-bunches the only way to keep C_v,h=4 is to introduce tune spread by octupoles, or have effective dampers, otherwise beam is unstable (weak head-tail)

Beams at Injection – Transverse Dampers



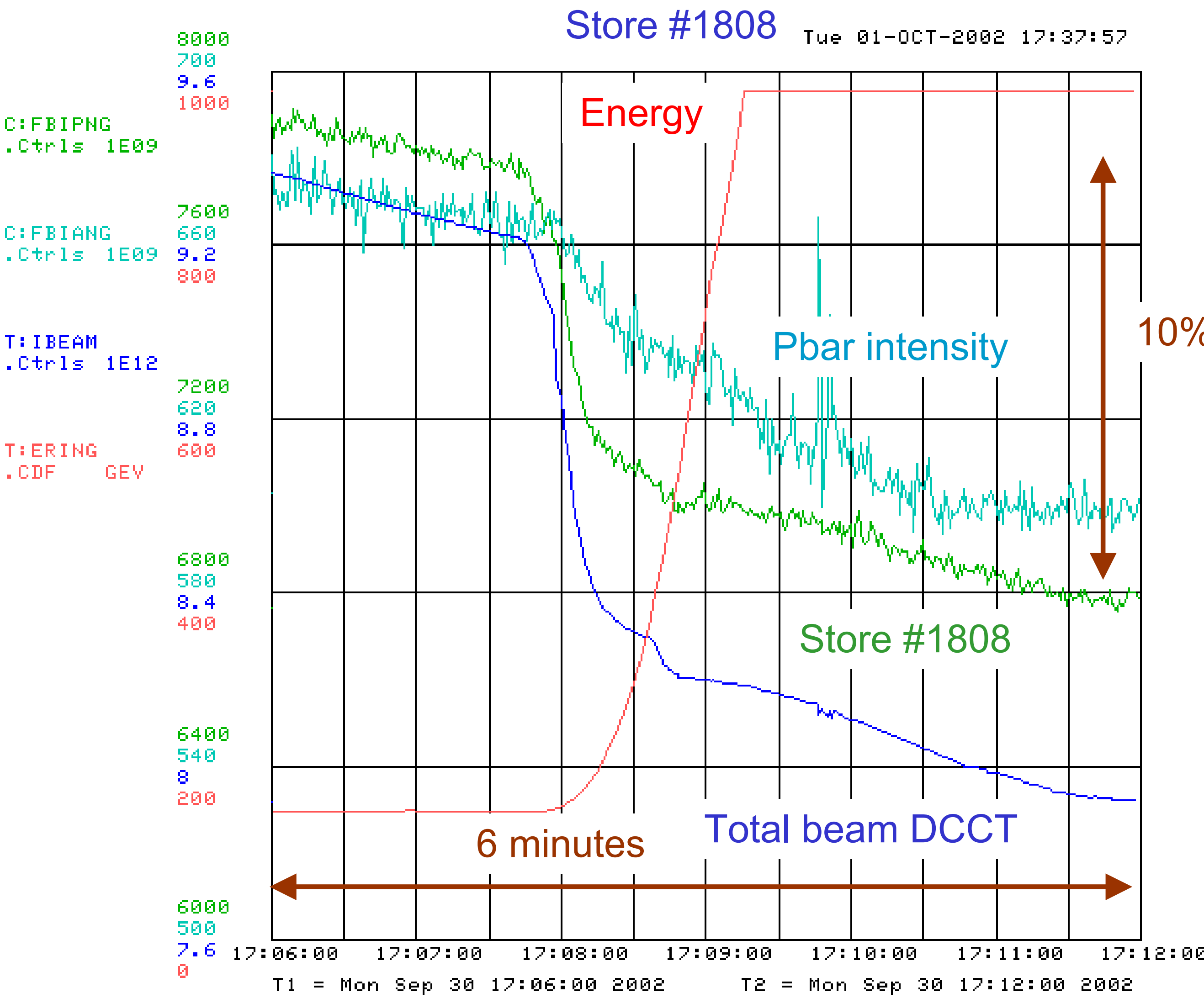
- dampers allow to reduce chromaticity significantly from usual $C_{v,h}$=8 and still have stable protons (*work in progress*)
- instability (*weak head-tail*) growth rate is about 2500 turns

Transverse Dampers Helpful at 150 GeV



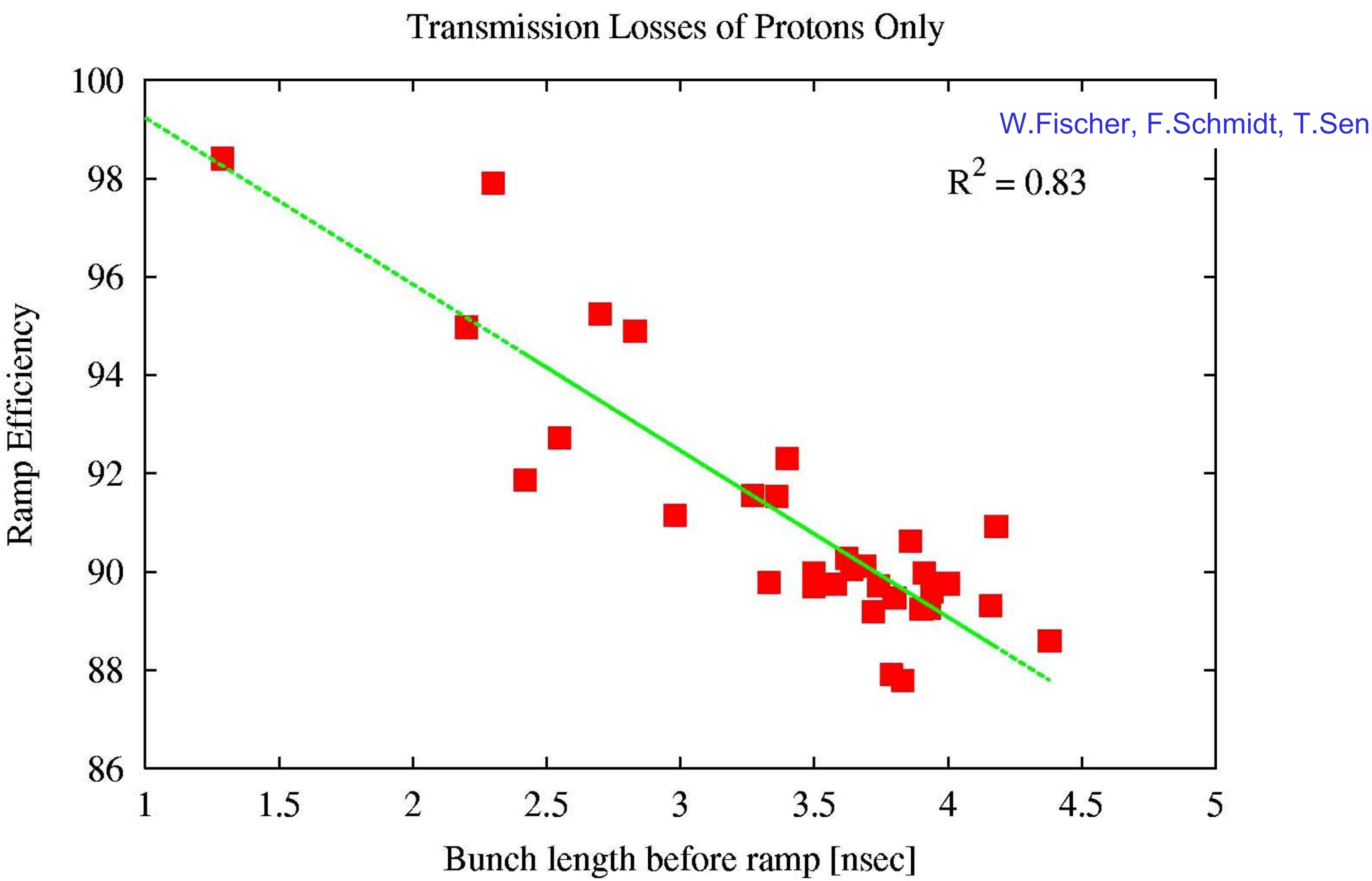
- dampers provide some 3ms damping time in both planes, coherent mode only
- dampers allow to operate high proton intensities with small chromaticities, e.g. C_h=8→3, C_v=8→5 at 150 GeV in #1868
- that resulted in >2 fold lifetime improvement (from 0.5-1 hr to 2.5 hr)
- dampers are proven to allow reduced C_v,h at flat top but not by much (-5 units from 20-24)
- emittance growth due to the dampers is tolerable at all energies

Beam Loss on Ramp



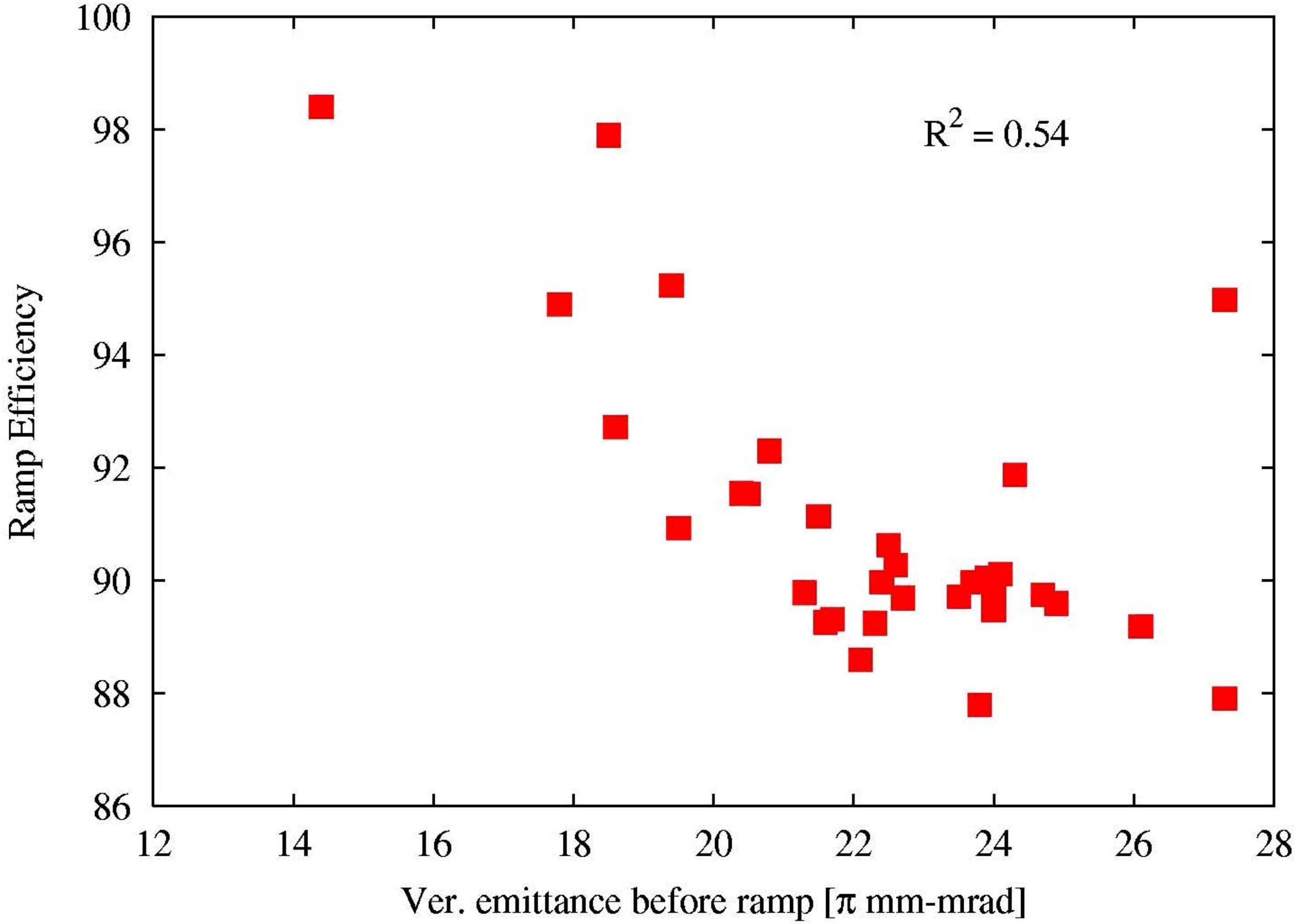
- (intensities are zero-suppressed)
- at the very beginning of the ramp DC beam is lost (some 2-3% in both p and pbars, depends on injected longitudinal emittance)
- then we have significant beam loss on ramp which – at smaller rate – continues at flat top and in squeeze
- For pbars, the reason is beam-beam interaction
- For protons - ? →

Proton Loss on Ramp



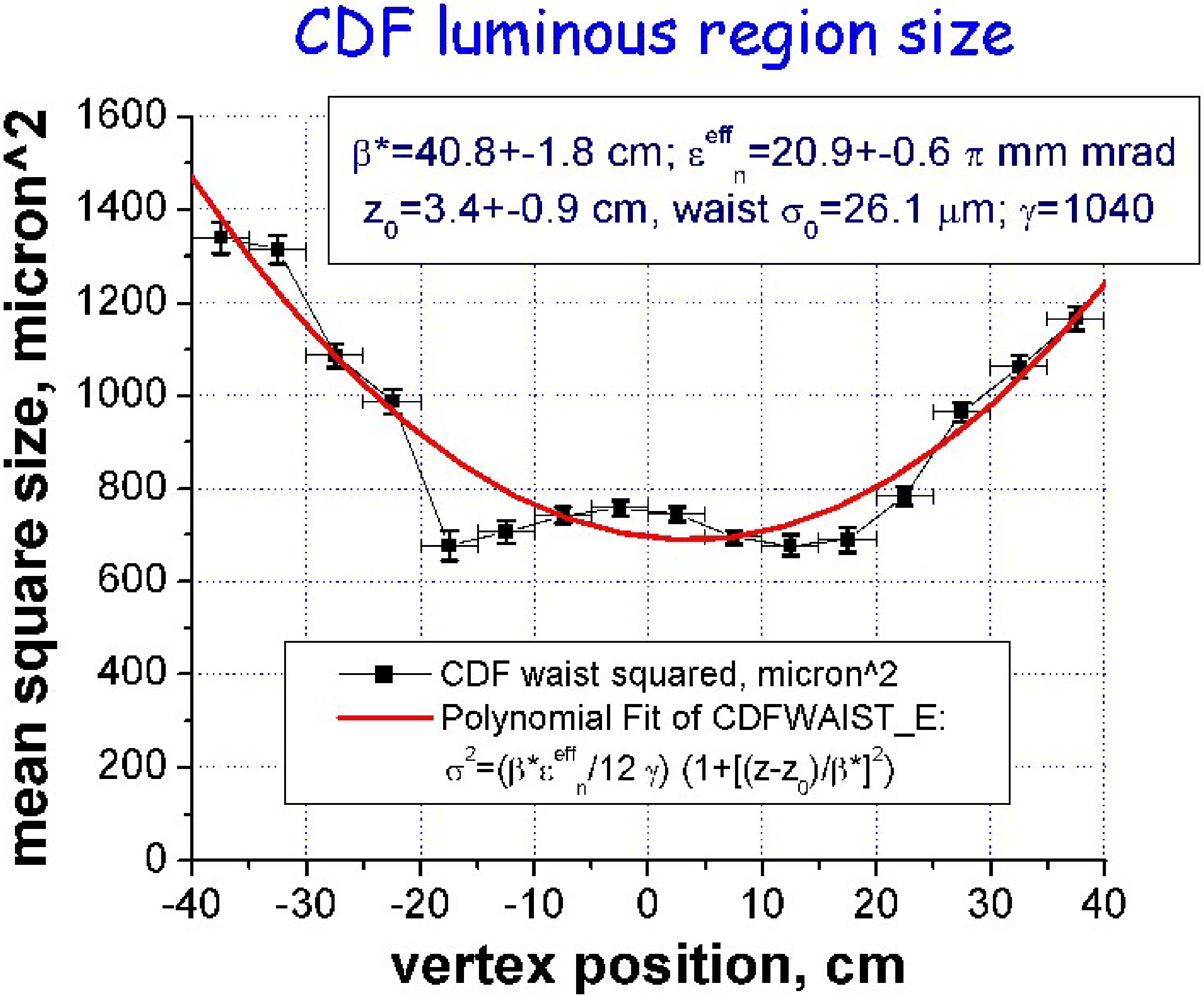
• ramp efficiency also anticorrelates with N_p, vertical emittance and Dl-emittance

Proton Loss on Ramp vs Emittance

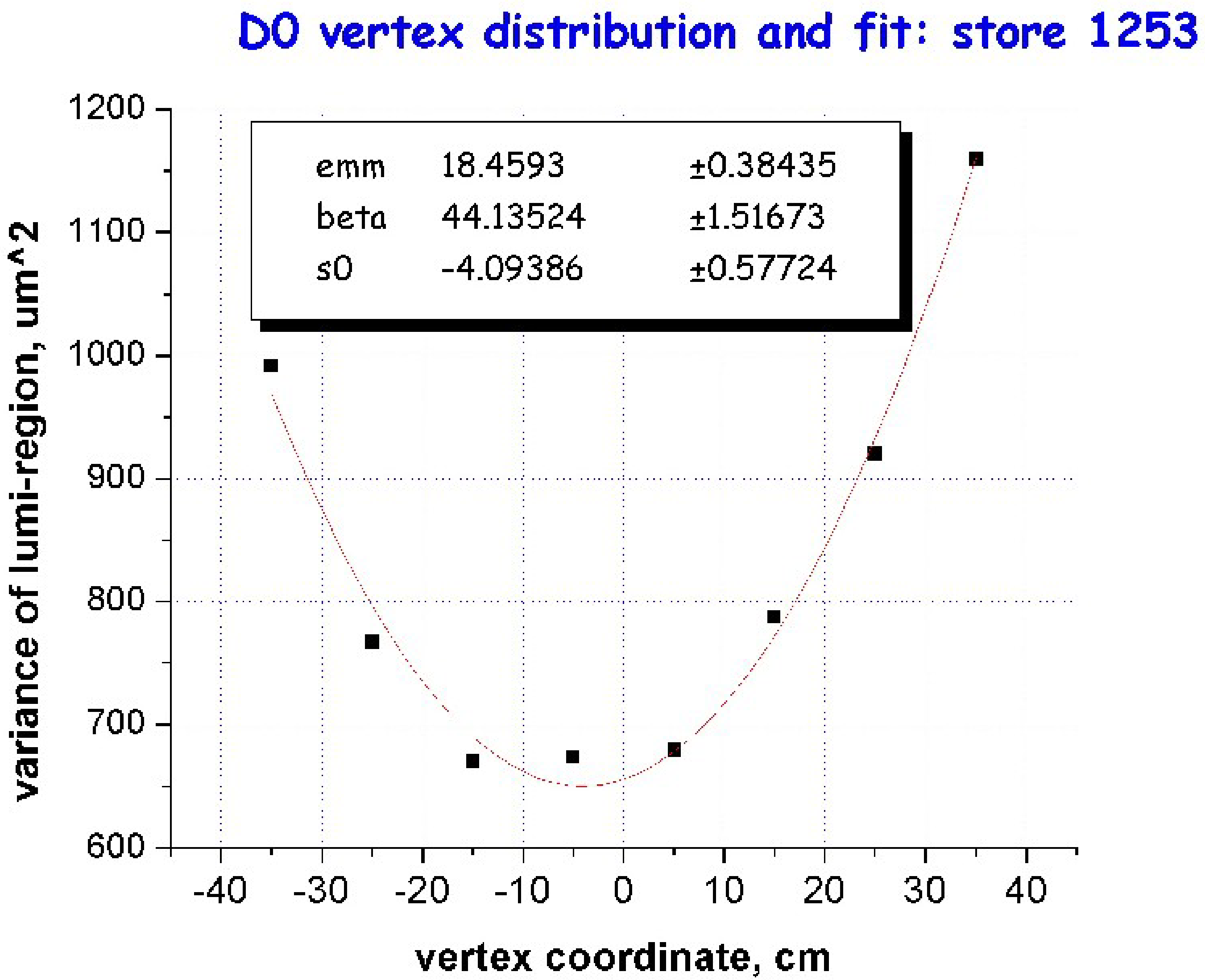


W.Fischer,
F.Schmidt,
T.Sen

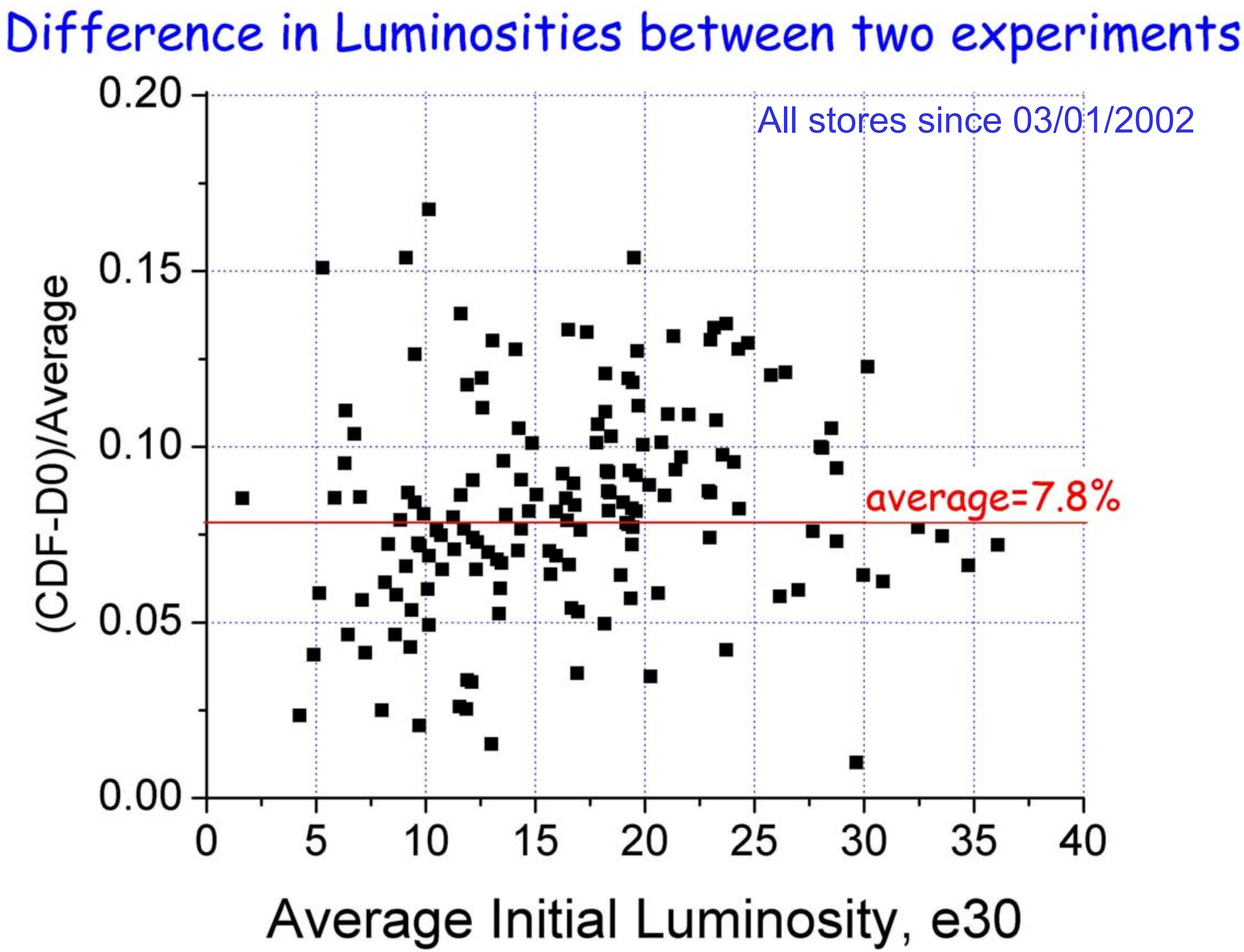
Interaction Points: CDF



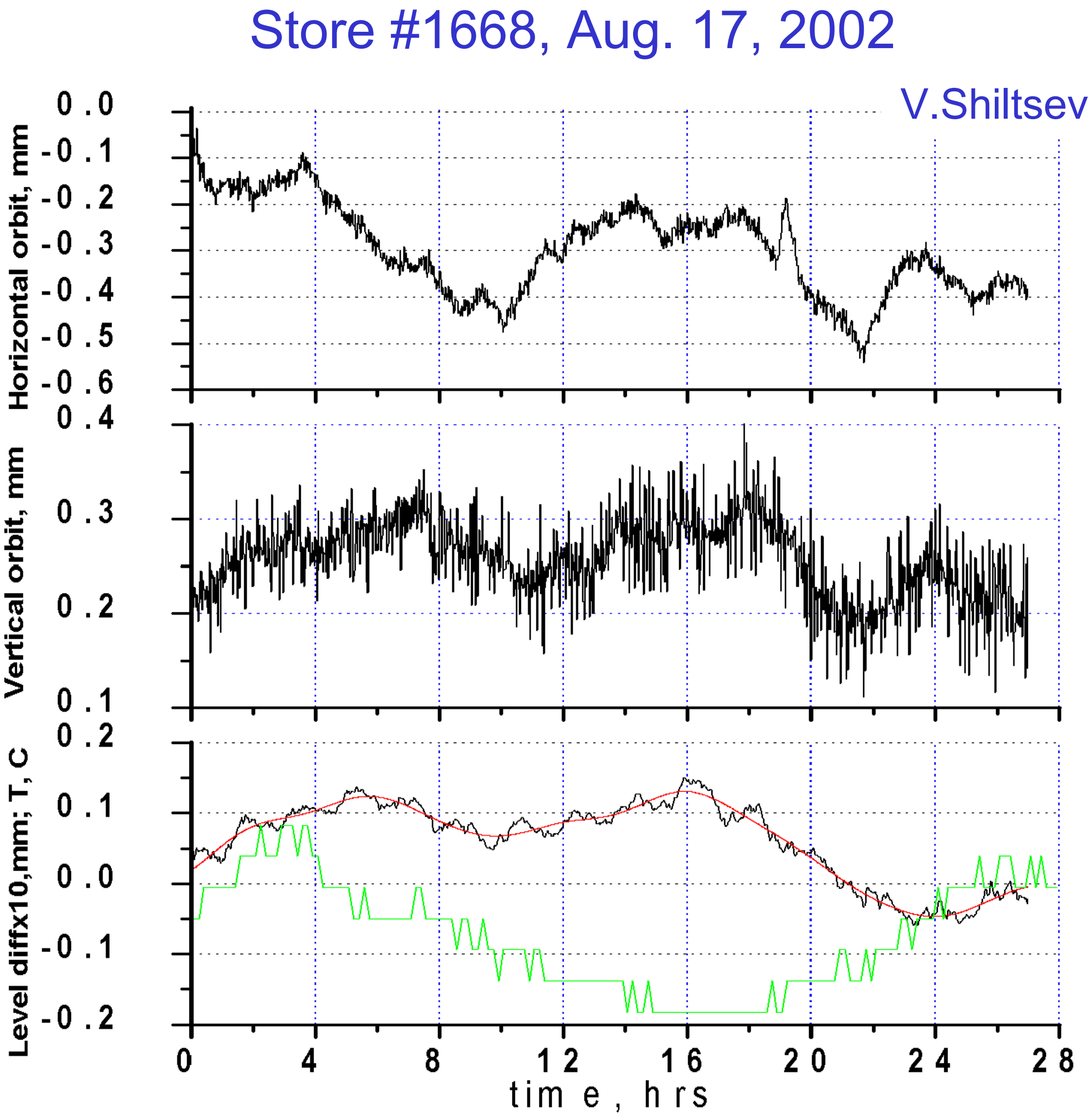
Interaction Points: D0



Luminosity: CDF vs D0

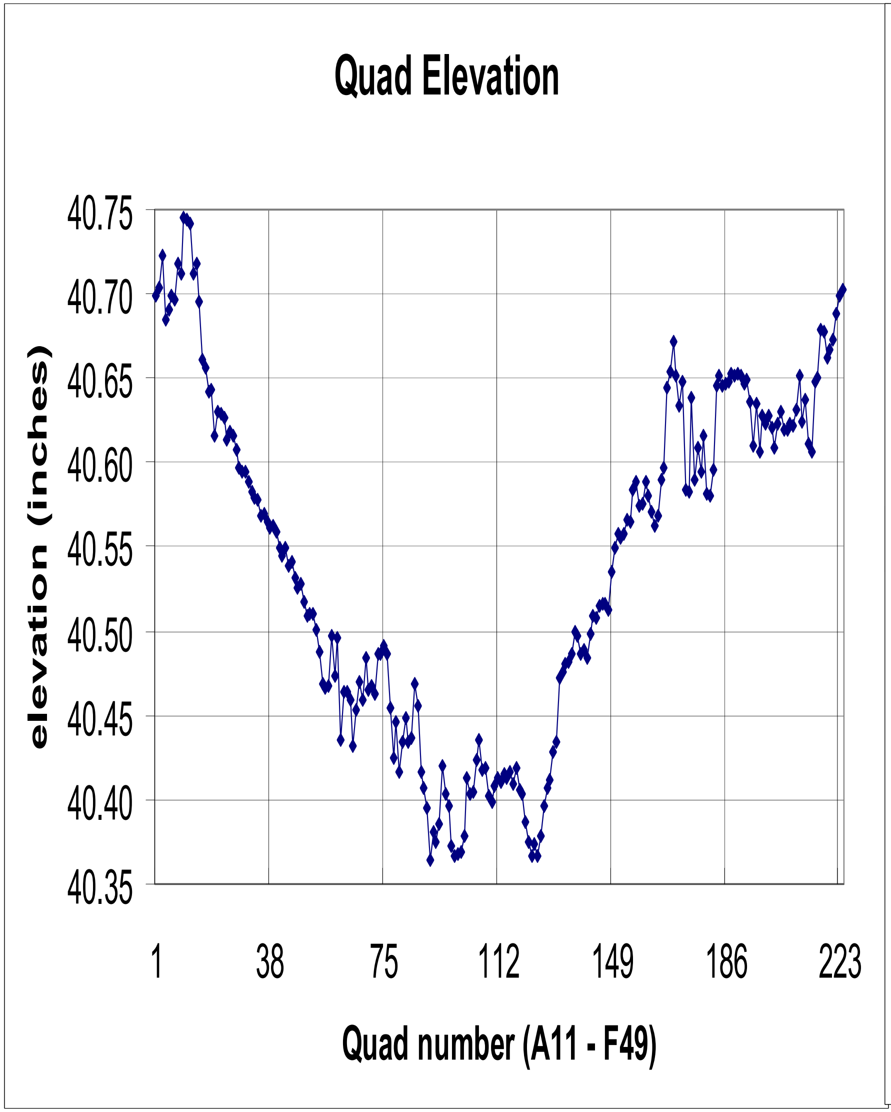


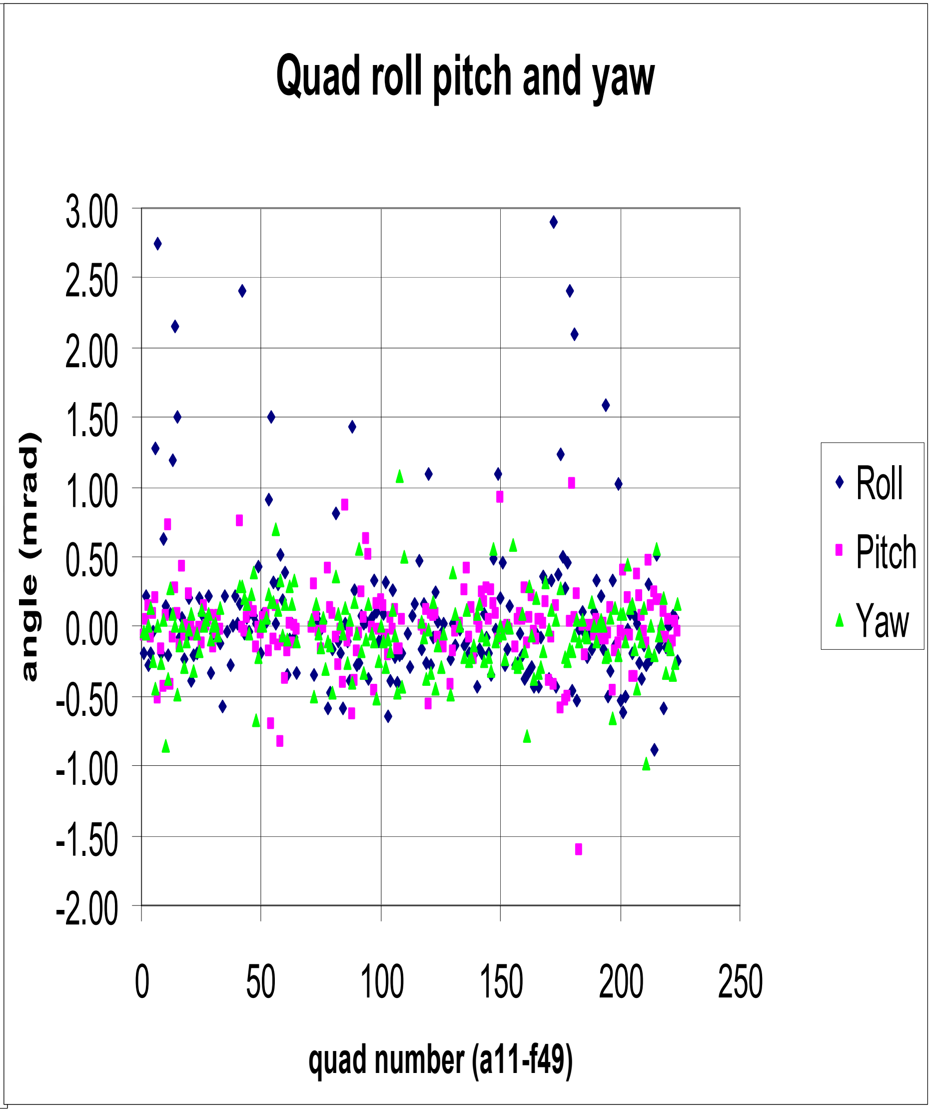
Tevatron Orbit Movements



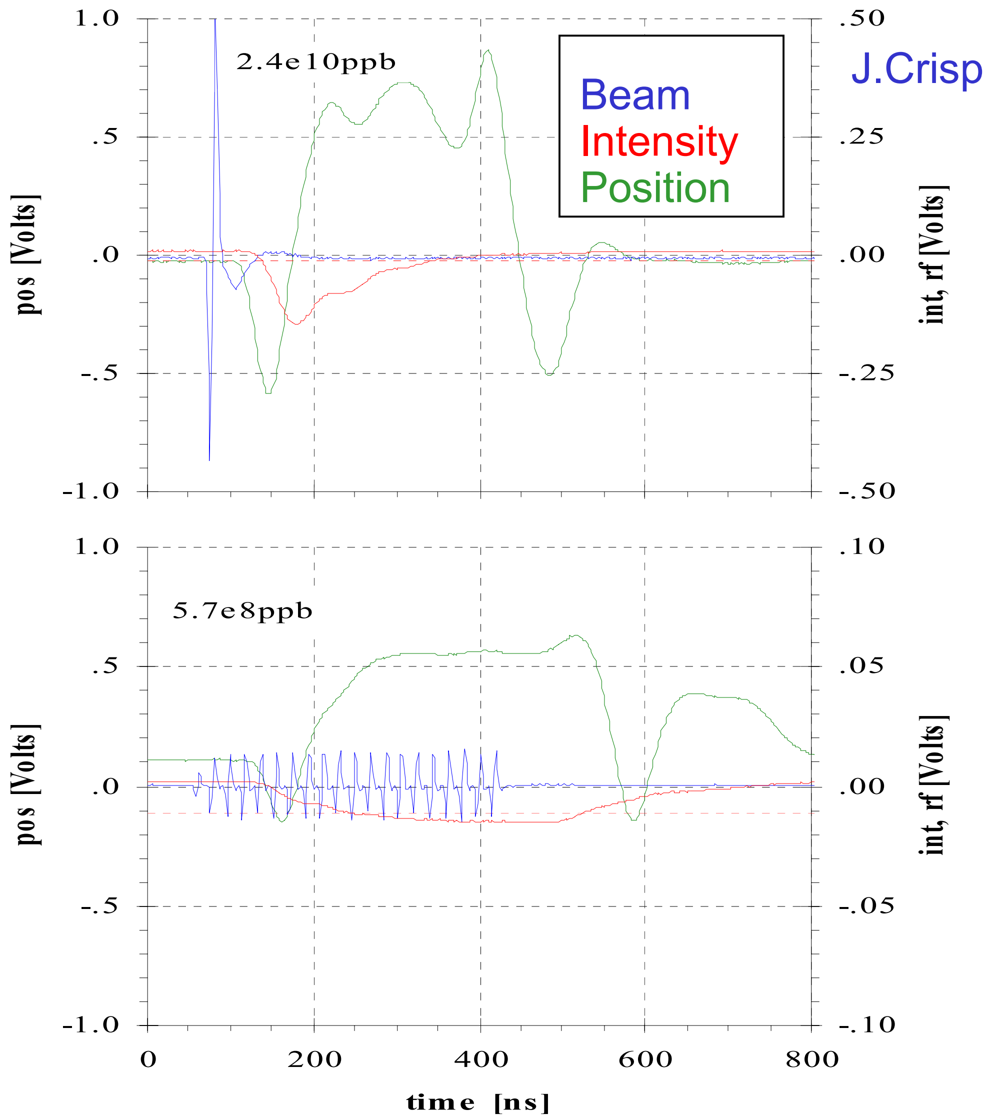
- Long-term orbit distortions are about 1 mm/week$^{1/2}$ and 2mm/ month$^{1/2}$
- Movements during stores are under 0.5 mm and contain 12-hr period due to Earthtides and 24-hr due to temperature variations
- Earthquakes are rare but seen
- High-frequency (1-400 Hz) oscillations are <30 microns in H and <10 microns

Tev Alignment Issues



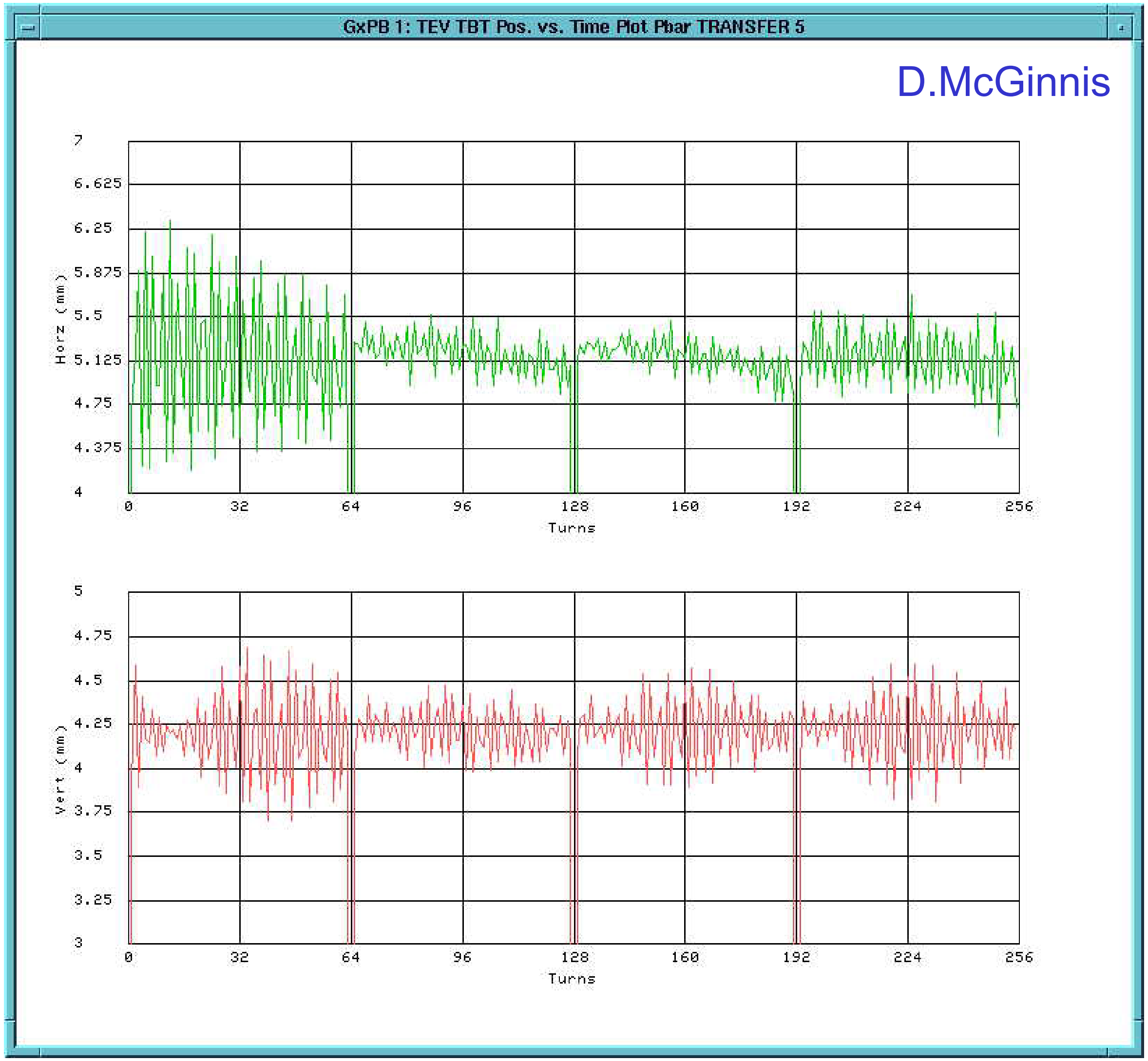


Diagnostics: BPMs



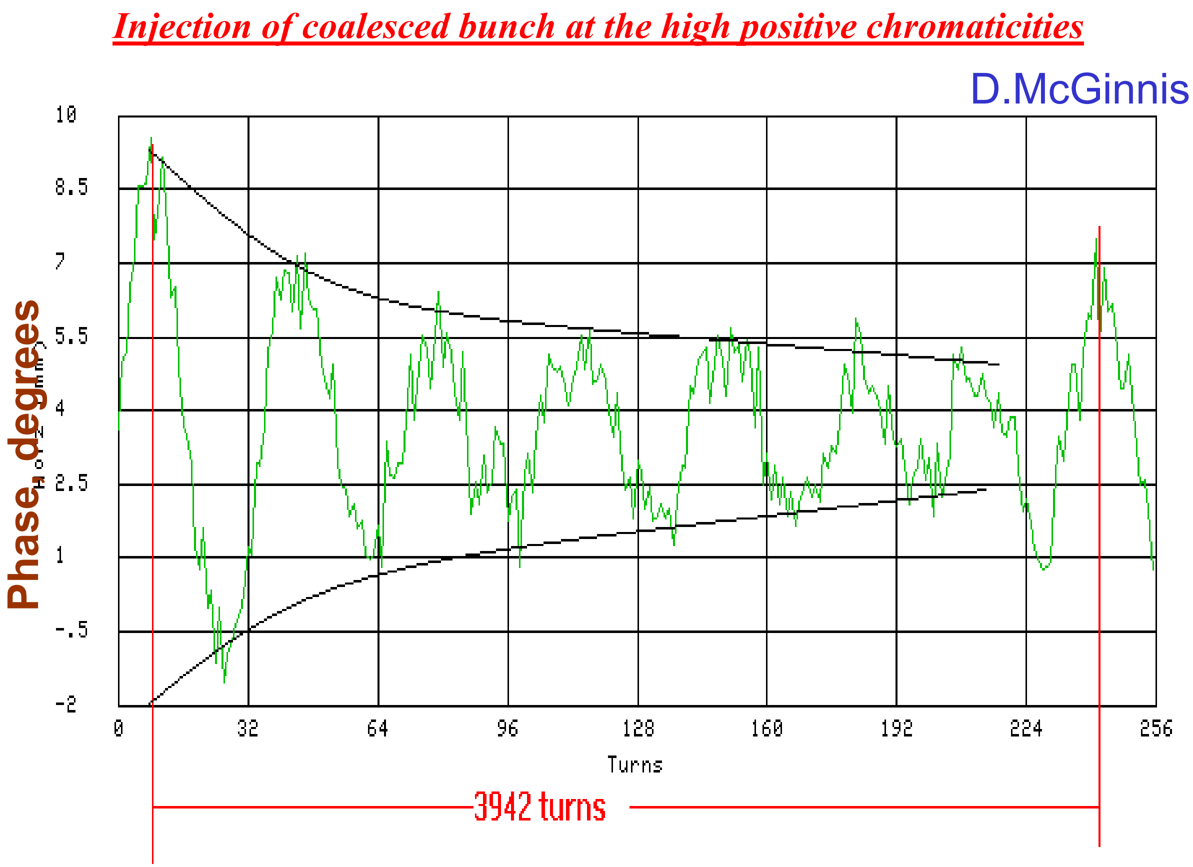
- BPMs originally designed for 53 MHz beam structure
- Work well now for uncoalesced beam
- After some tuning BPMs worked in Run I with 6x6
- Do not work with 36x36 because of bunch separation is smaller than filter ringing time

Diagnostics: Beam Line Tuner



- Consists of strip-lines, 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 just commissioned and operational

Diagnostics: RF Phase Detector

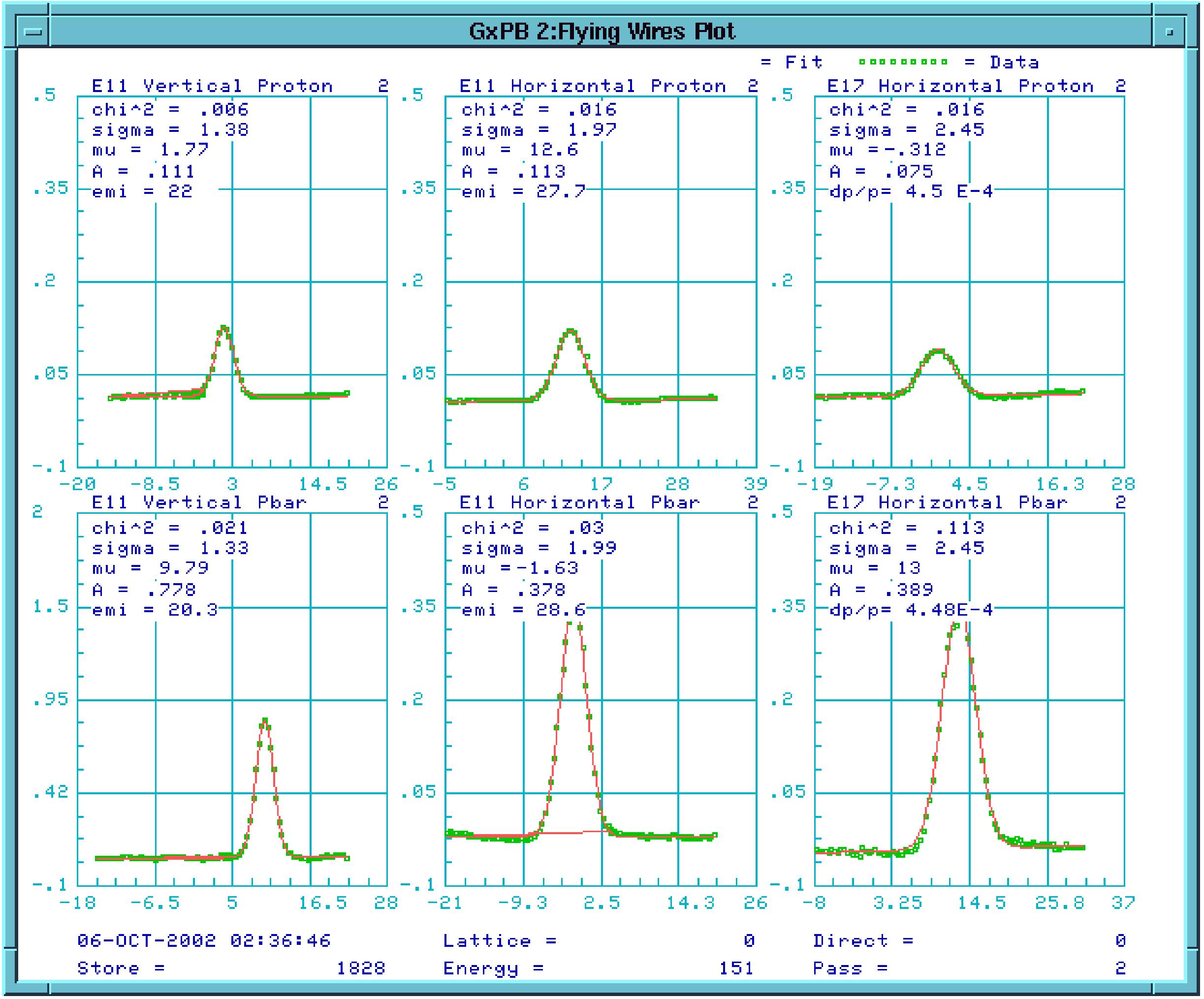


$$(\nu_s)_{coh} = \frac{7}{3942\ turns} \approx 1.78 \cdot 10^{-3},\ \xi_y \approx 8,\ \xi_x \approx 8,\ [\nu_y] = 0.5750,\ [\nu_x] = 0.5830$$

- Did not exist in March’02
- Horizontal BPMs were used to qualify phase/energy offsets at injection
- Later, longitudinal damper would be used for that purpose (needed modified DAQ)
- New detector on base of segmented memory scope is just commissioned

Diagnostics: Flying Wires

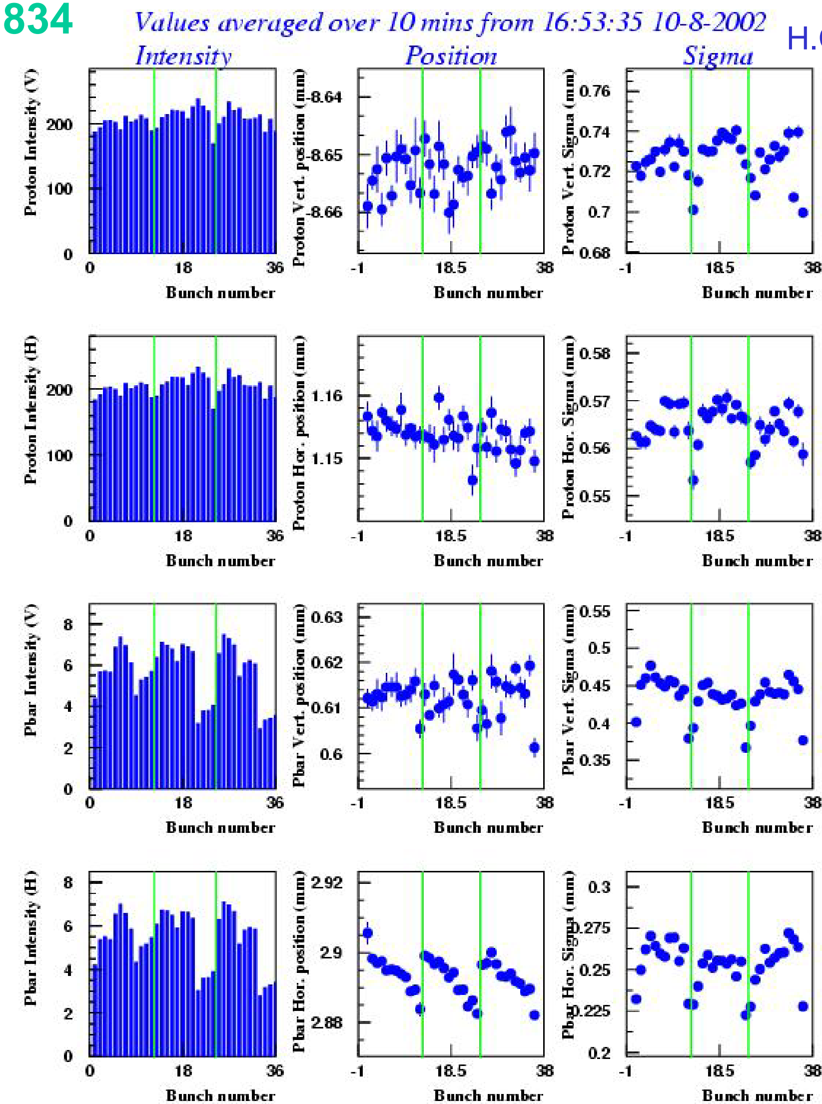
#1828, injection



- 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

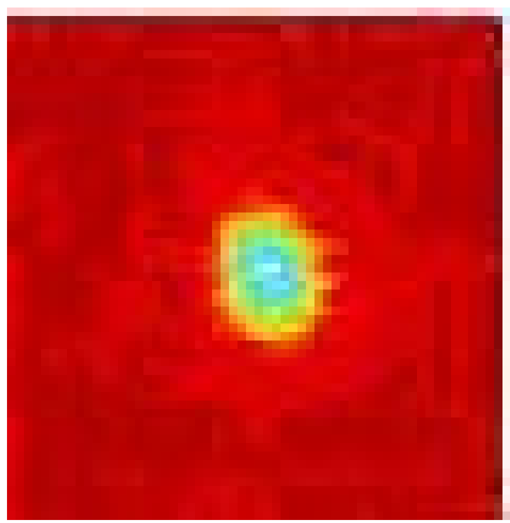
Diagnostics: SyncLite Monitor

1834

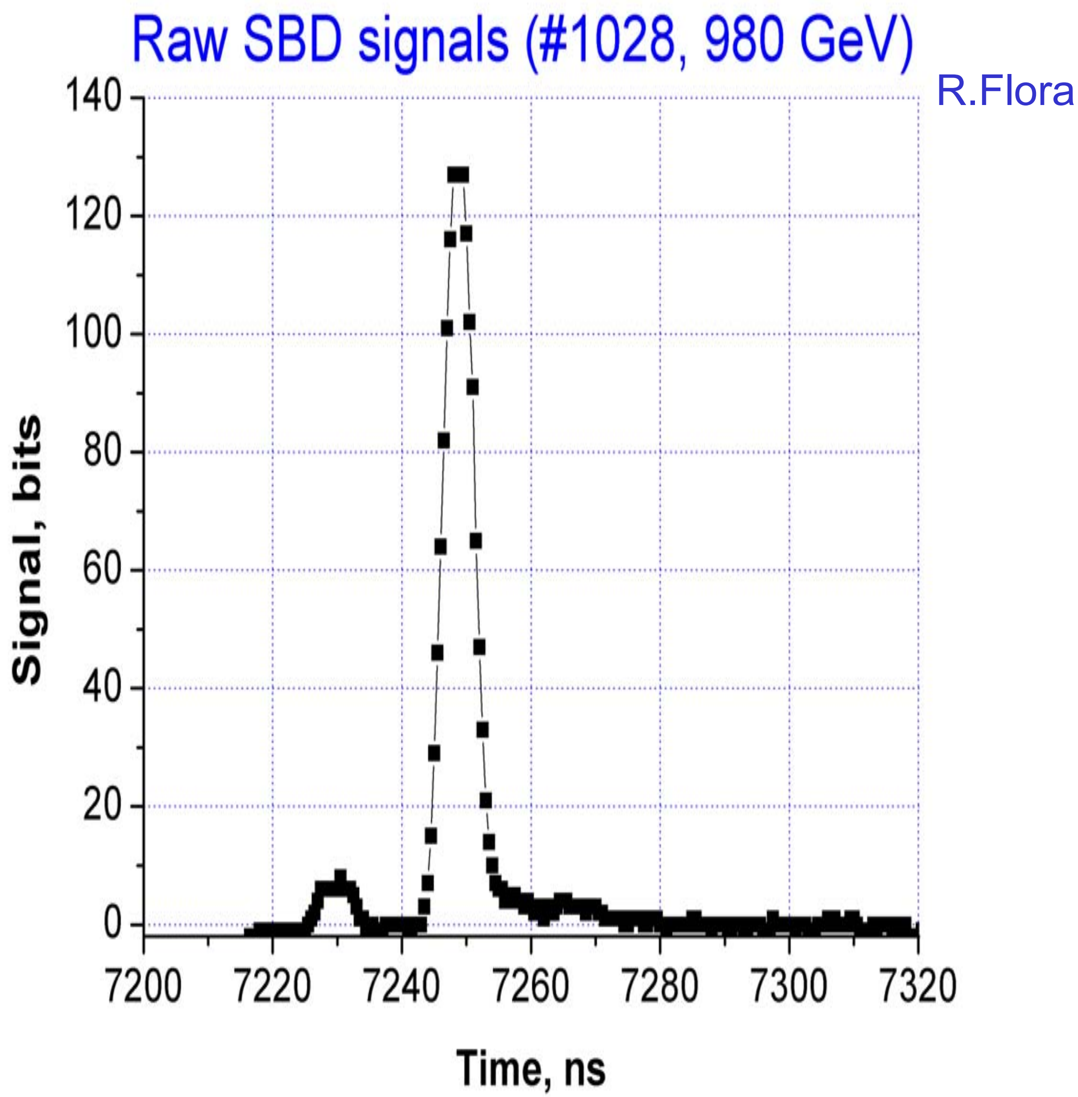


H.Cheung

- Works >800 GeV
- Significant progress since March'02
- Reports s, mean, N, tilt bunch-by-bunch for both protons and pbars
- Invaluable instrument
- Recalibration of both p and pbar channels is due
- Need raw data
- Tails? Head-tail?



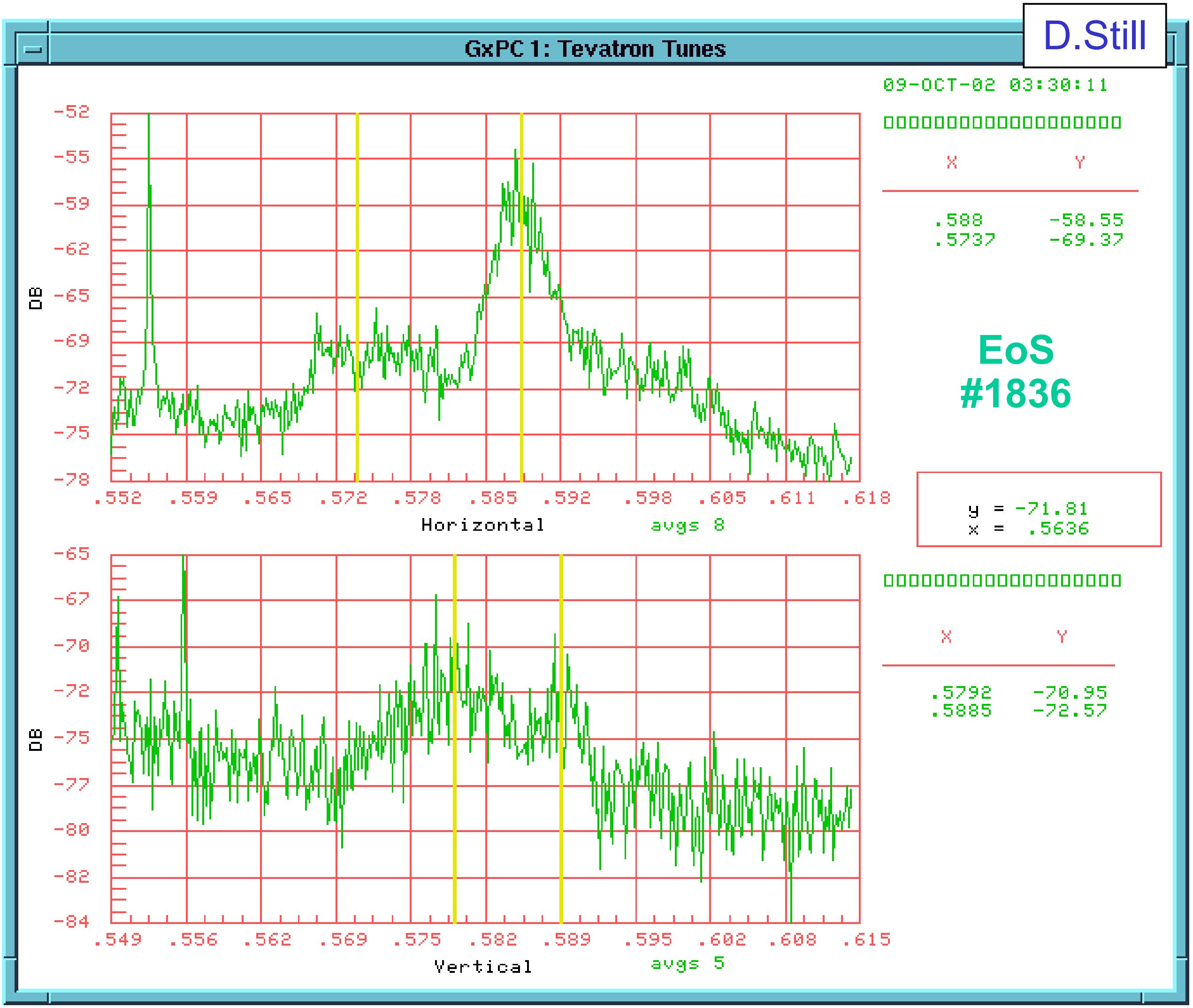
Diagnostics: SBD, FBI



- Dispersion in long cable adds to 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 s_s - need to be fixed
- Intensity from SBD – coming soon

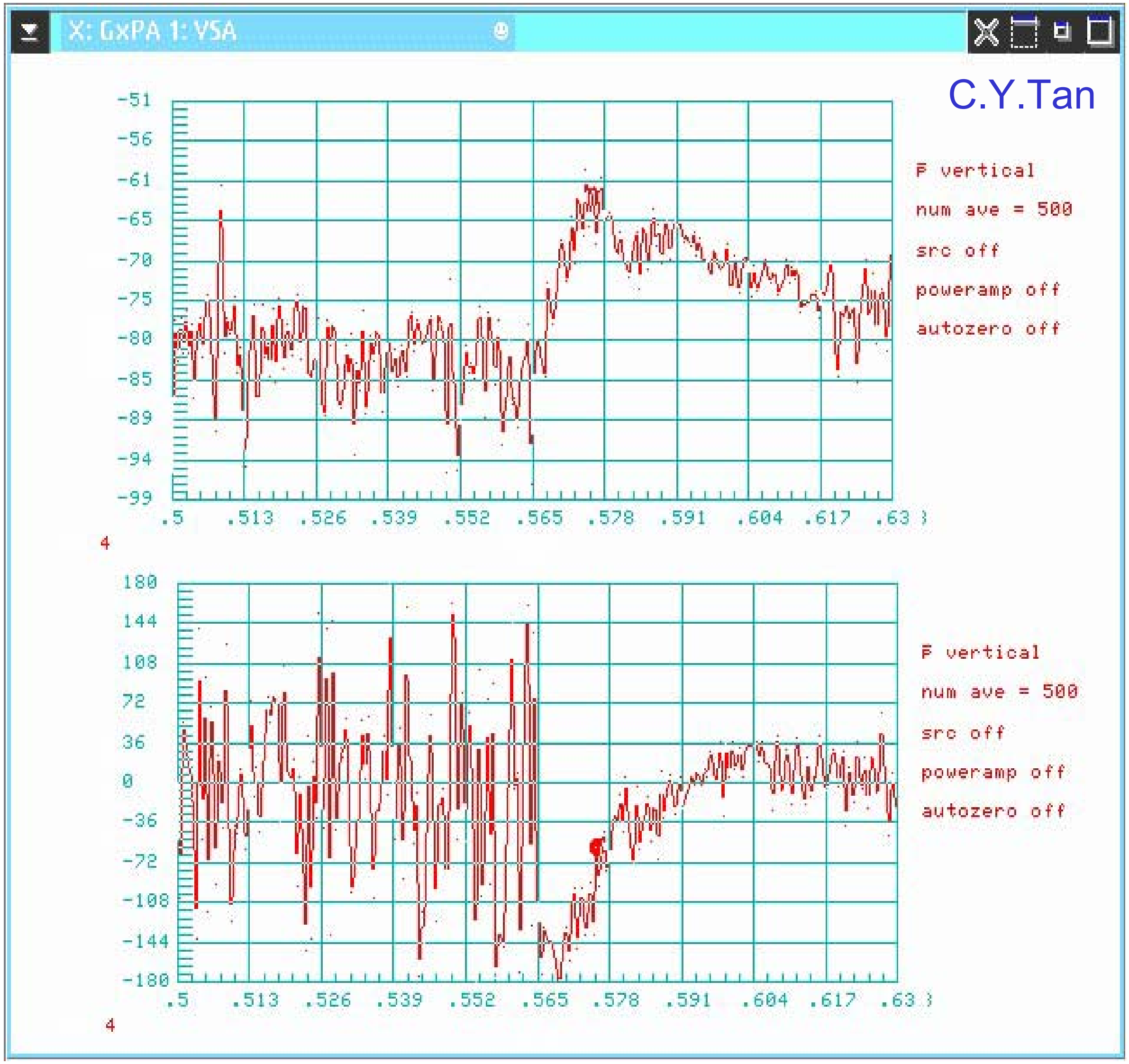
Diagnostics: Schottky Monitors

- 21 MHz resonant curcuit, 20 kHz band covered, V/H
- Used for tune measurements
- Reports V and H power over 20 kHz
- Does not see pbars or individual bunches
- "ghost" line - real
- Data in ASCII
- New Schottky detector at E17
  - 1.5 GHz
  - Pbars and protons
  - Bunch-by-bunch



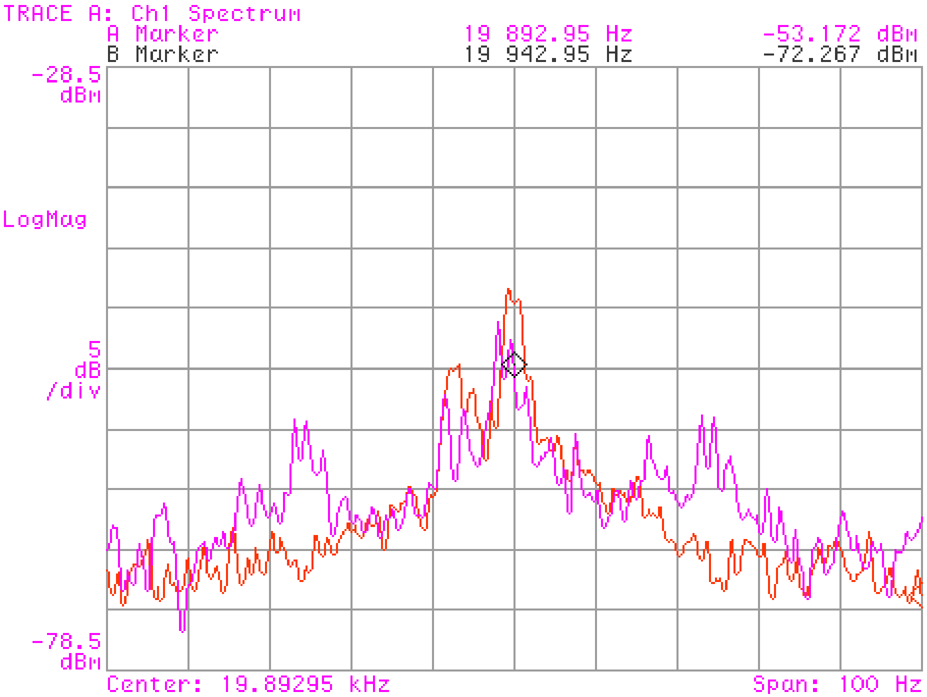
Diagnostics: Tune Meter

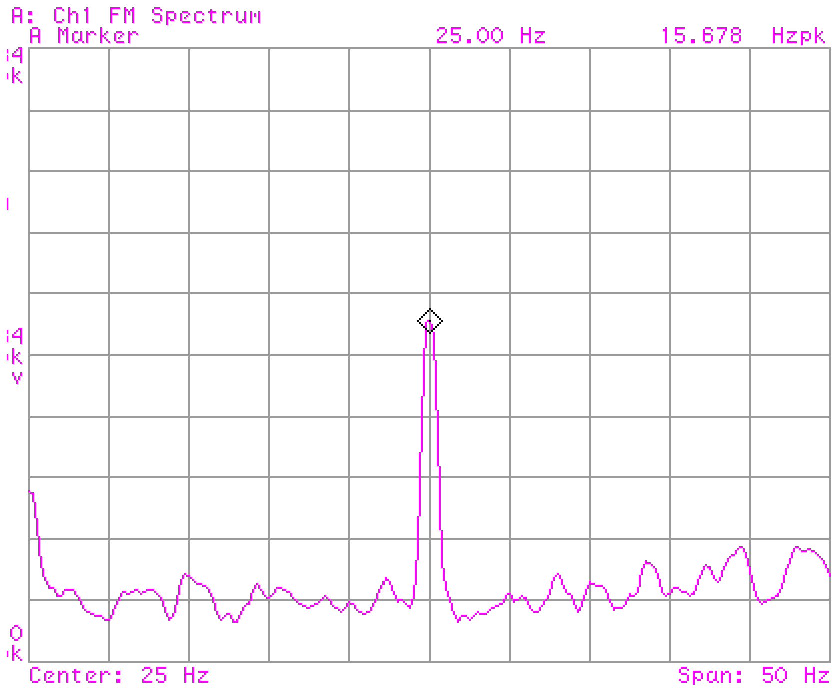
- Bunch-by-bunch
- Significant progress since March : cabling clean-up, reduced excitation
- Destructive (over 10's of minutes)
- Has been used for dedicated pbar tune measurements
- Recently disassembled – parts used in vertical damper
- To be re-assembled
- Need protons tunemeter
- Need raw data



Diagnostics: Chromaticity Measurements

D.McGinnis

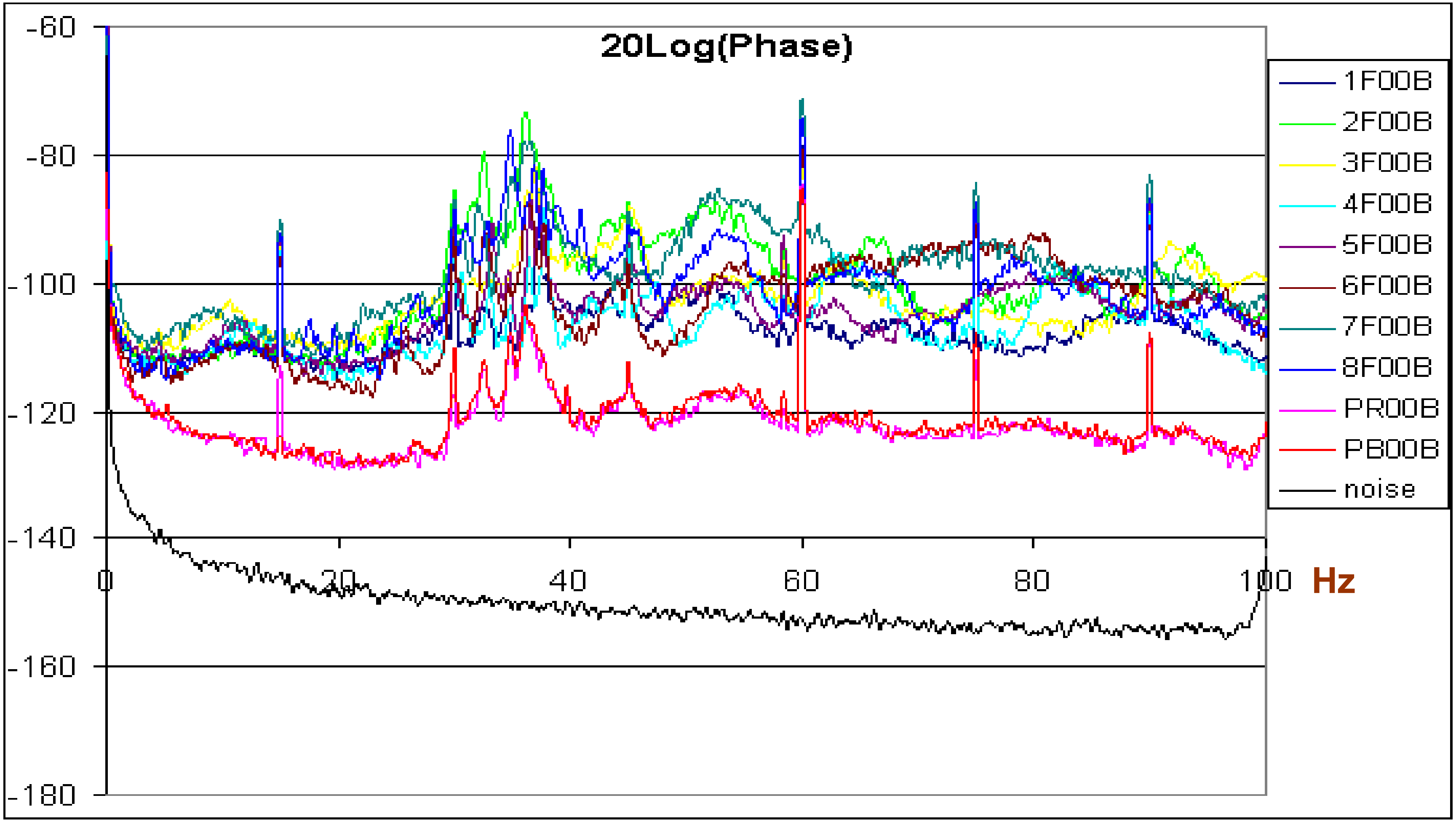




- Df_{RF} used for routine C_v,h measurements – slow
- RF phase modulation method $C= DQ\ h\ f_m /(f_{RF}\ Dj)$ – faster, 10 times less destructive
- Not tested yet with coalesced beam, and anywhere except 150 GeV
- Plans to deduct C_v,h from natural Schottky spectra analysis

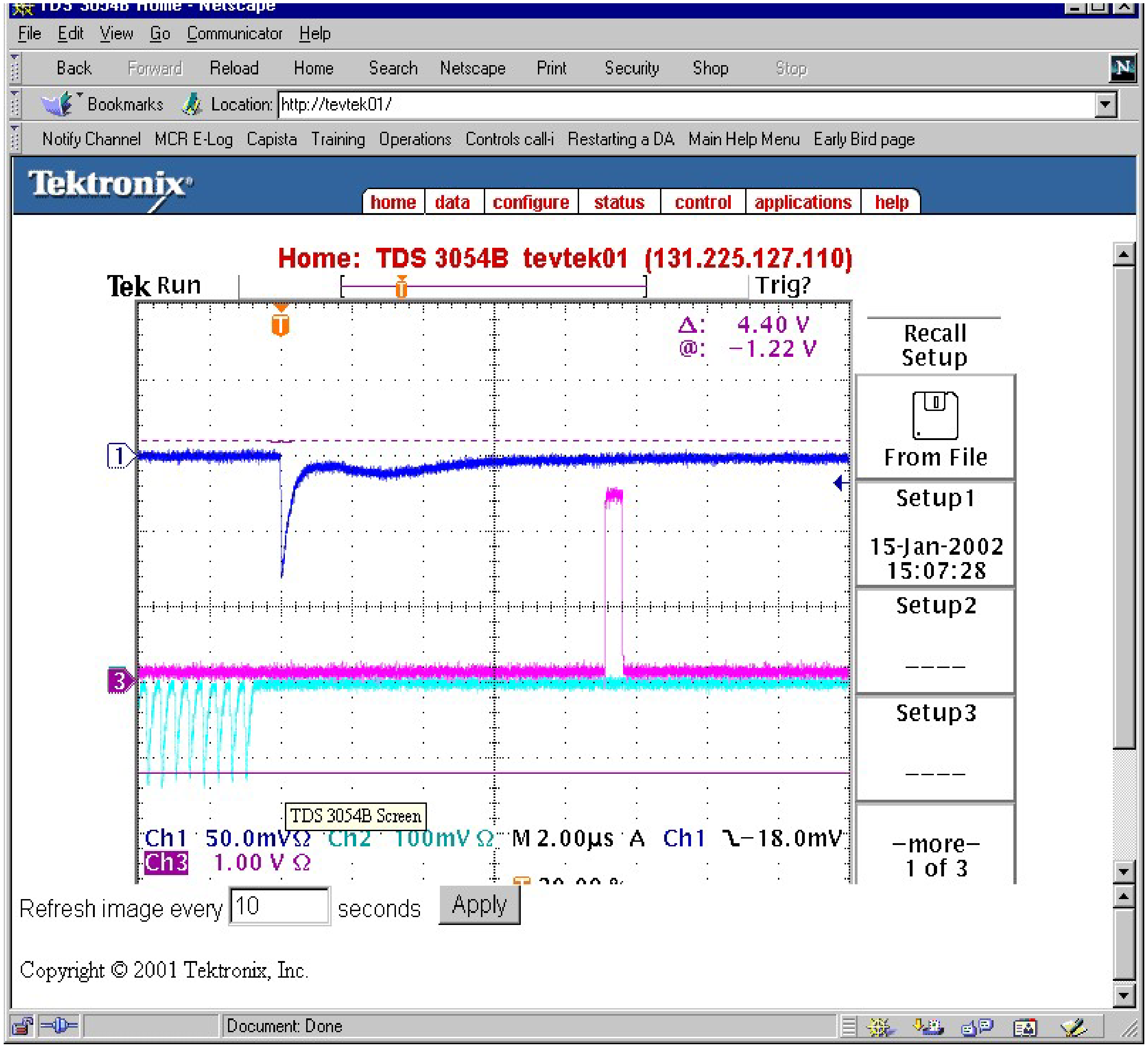
Diagnostics: Advanced RF Diagnostics

Spectra of RF Phase Noise in 8 Tevatron Cavities T.Khabibulin



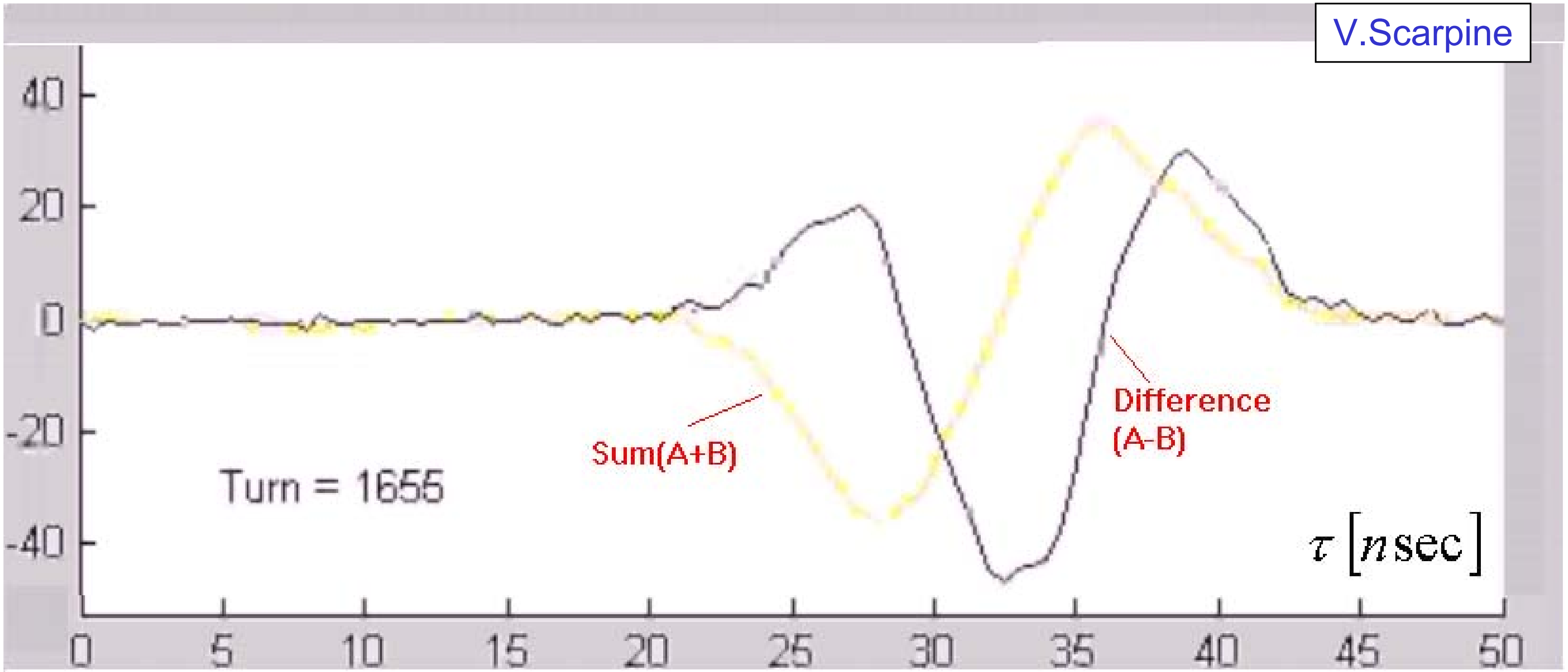
- RF voltage and cavity t° are logged, other diagnostics possible at F0
- RF noise investigations just started, phase jitter tolerance 50-70 urad rms

Diagnostics: Loss Monitors/Scintillators



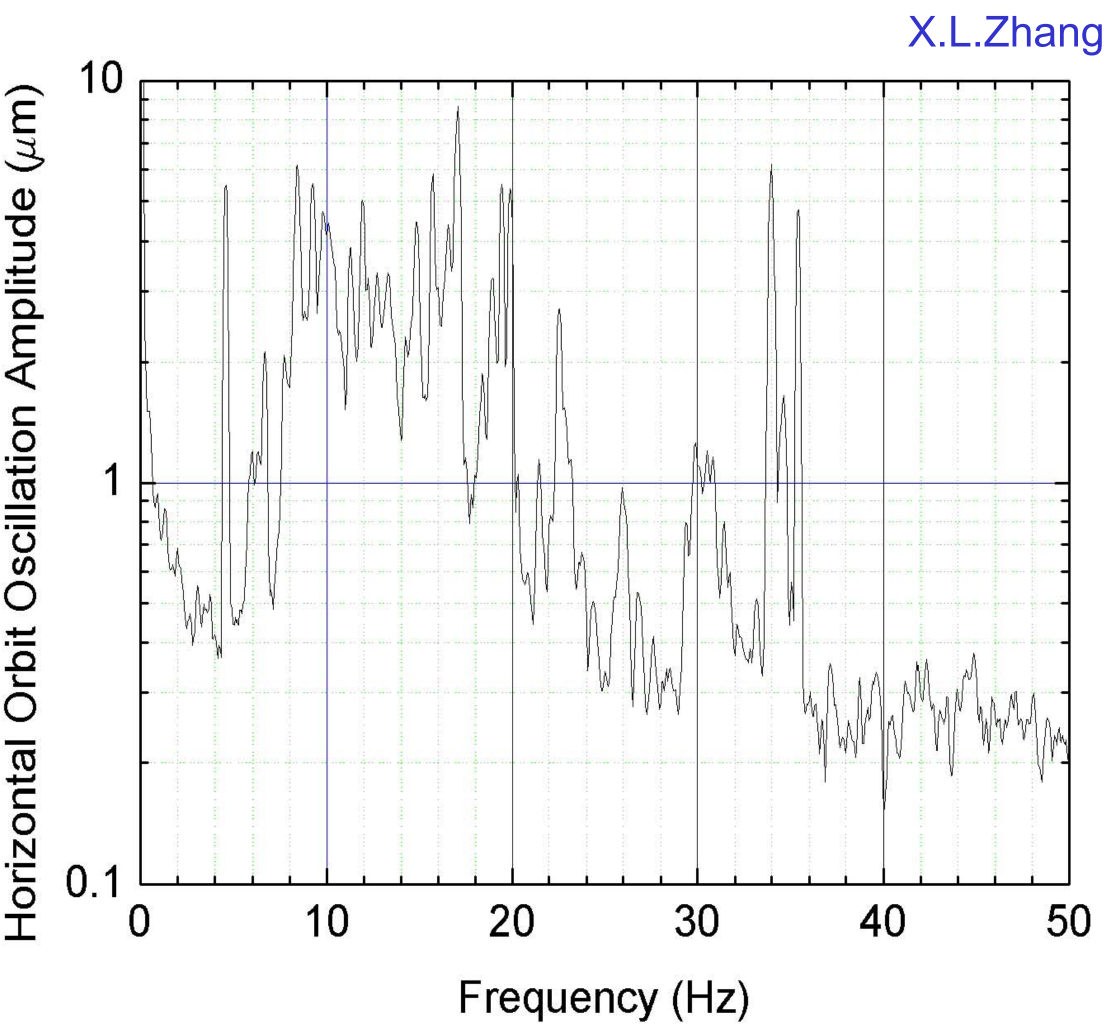
- Dozens of counters at CDF and D0
- Since March – new ones to monitor losses from bunches, between bunches and abort gaps
- Dedicated scintillator paddle on B0 LB quad
- More paddles on collimators

Diagnostics: Head-Tail Monitor



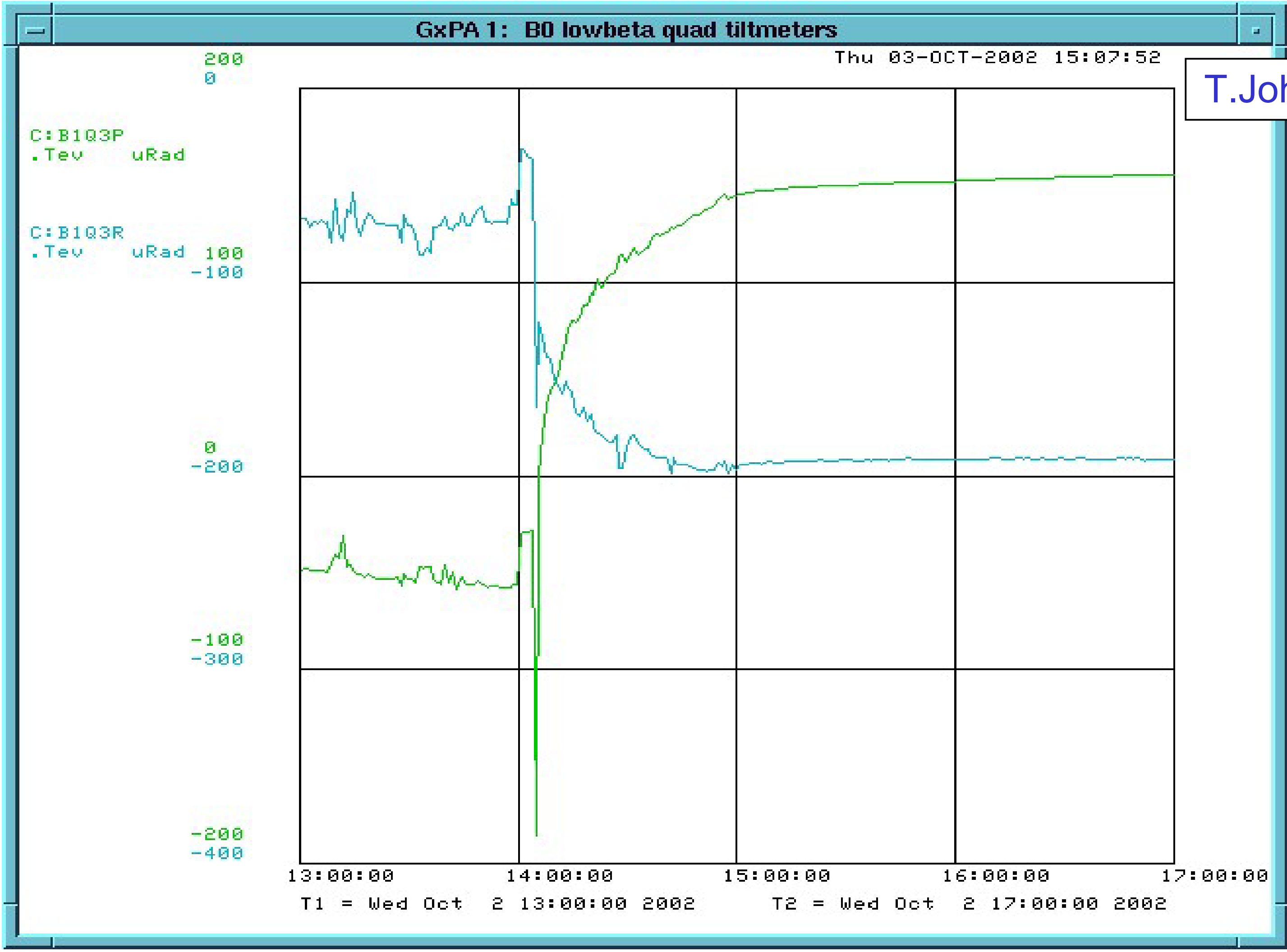
- BLT hard- and software to measure position within one bunch
- goal of the HTM – monitor higher order head-tail modes
- to be used for chromaticity measurements (non?-destructively)

Diagnostics: Orbit Oscillation Monitor



- Straightforward analysis of the BPM signal spectra
- Interesting first results 1-400 Hz
- Needs to be developed to become useful (e.g., ACNET)

Diagnostics: Tiltmeters/Geophones



T.Johnson

- Tiltmeters and geophones installed on low-beta quads, RF cavities