Tevatron Performance Since March’02 and FY’03 Plans

Vladimir Shiltsev

Fermilab

Contents

- Luminosity progress
- Progress with :
  - Beam-beam effects
  - Instabilities
  - Background, etc.
  - Diagnostics
- FY'03: Luminosity Goal
- FY'03: Projects/Shutdowns/Resources

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)

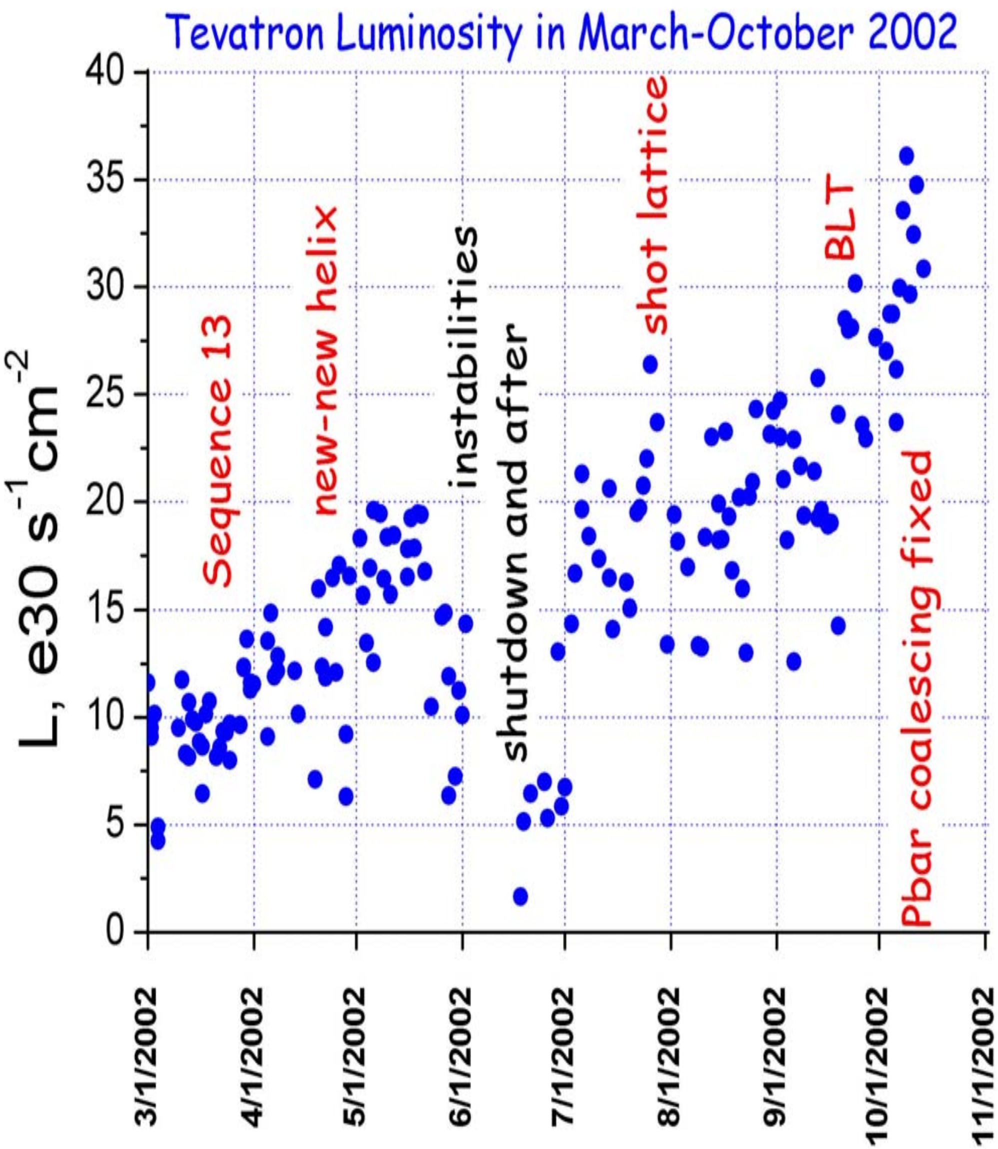
ε_p , ε_{pbar} = transverse emittances (π-mm-mrad)

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., →

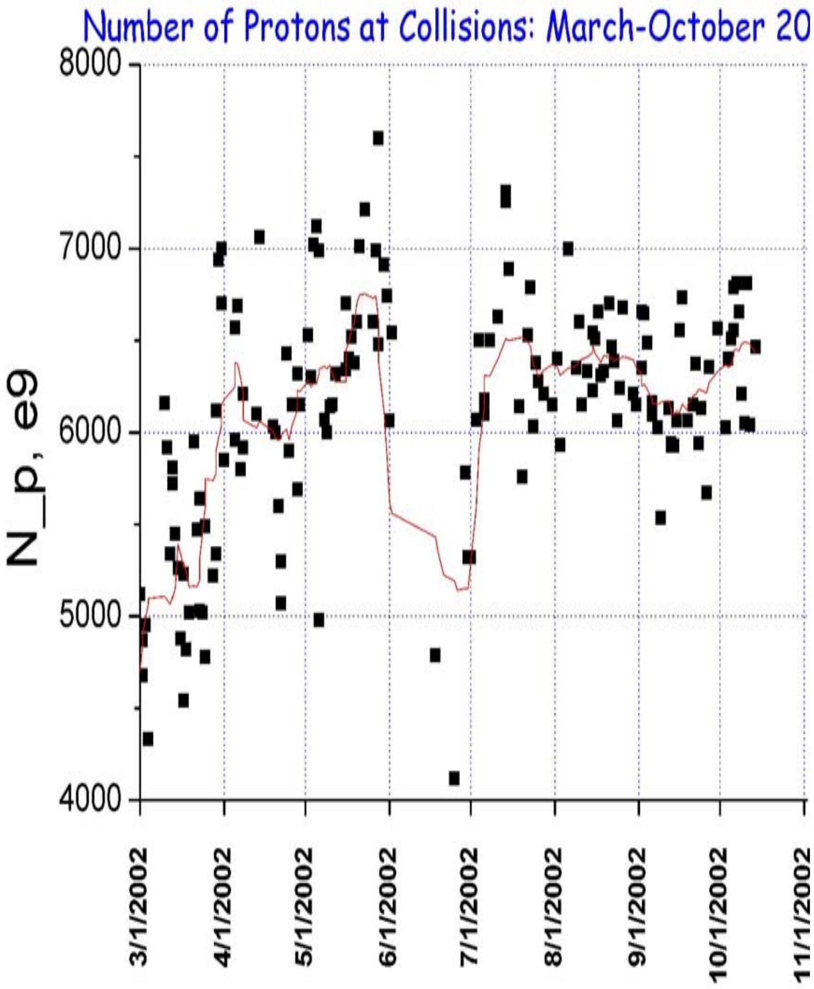
Major Reasons for $\mathcal{L}$-progress since Mar'02

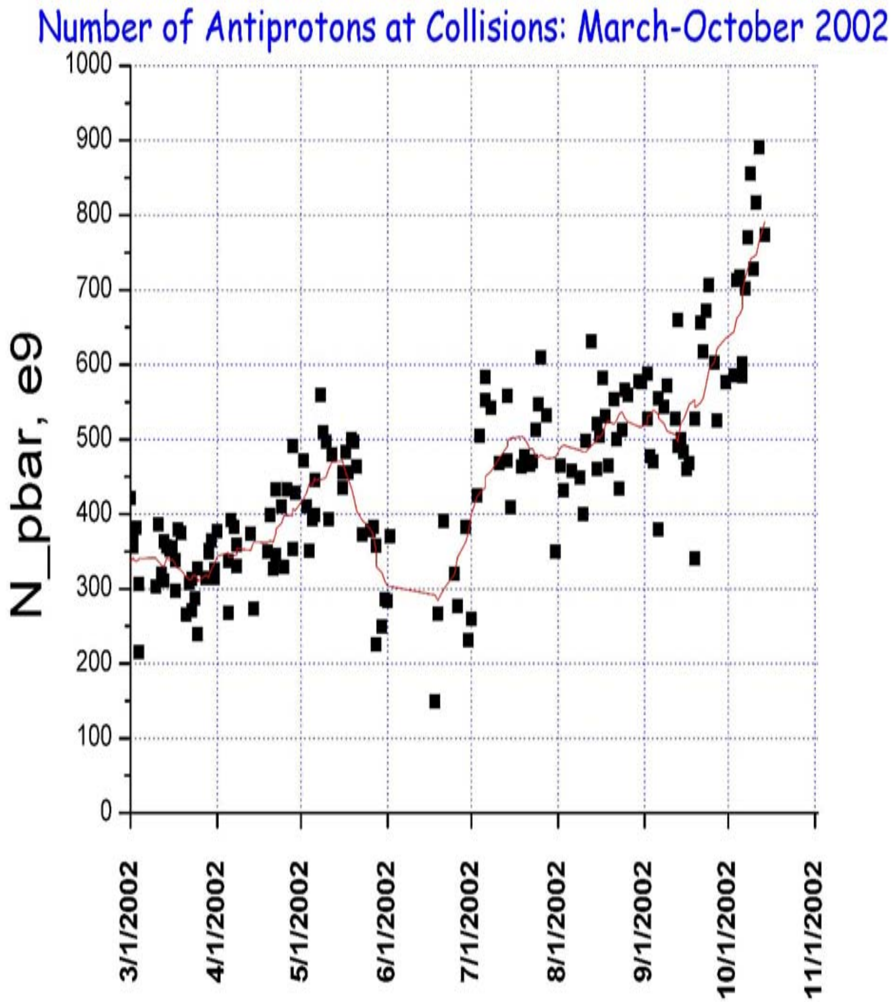
• "Sequence 13" fixed	Tev	x 1.40
• "New-new" injection helix	Tev	x 1.15
• "Shot lattice"	AA	x 1.40
• Pbar emittance at injection	Tev/Lines	x 1.20
• Pbar coalescing improvement	MI	x 1.15
	total	x 3.1

….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

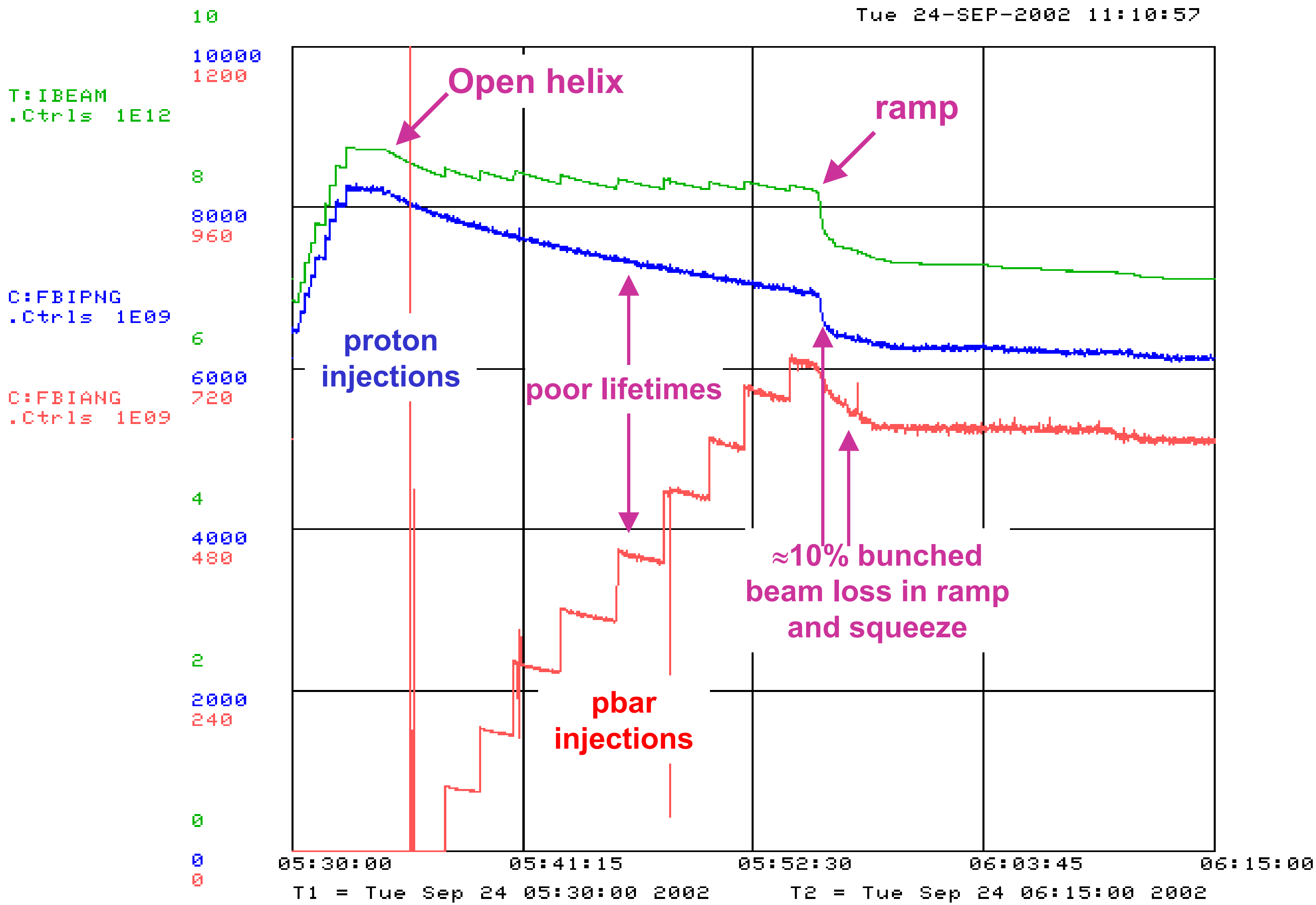




N_p : Oct/Mar=6500/4700=1.40

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

Progress came from

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

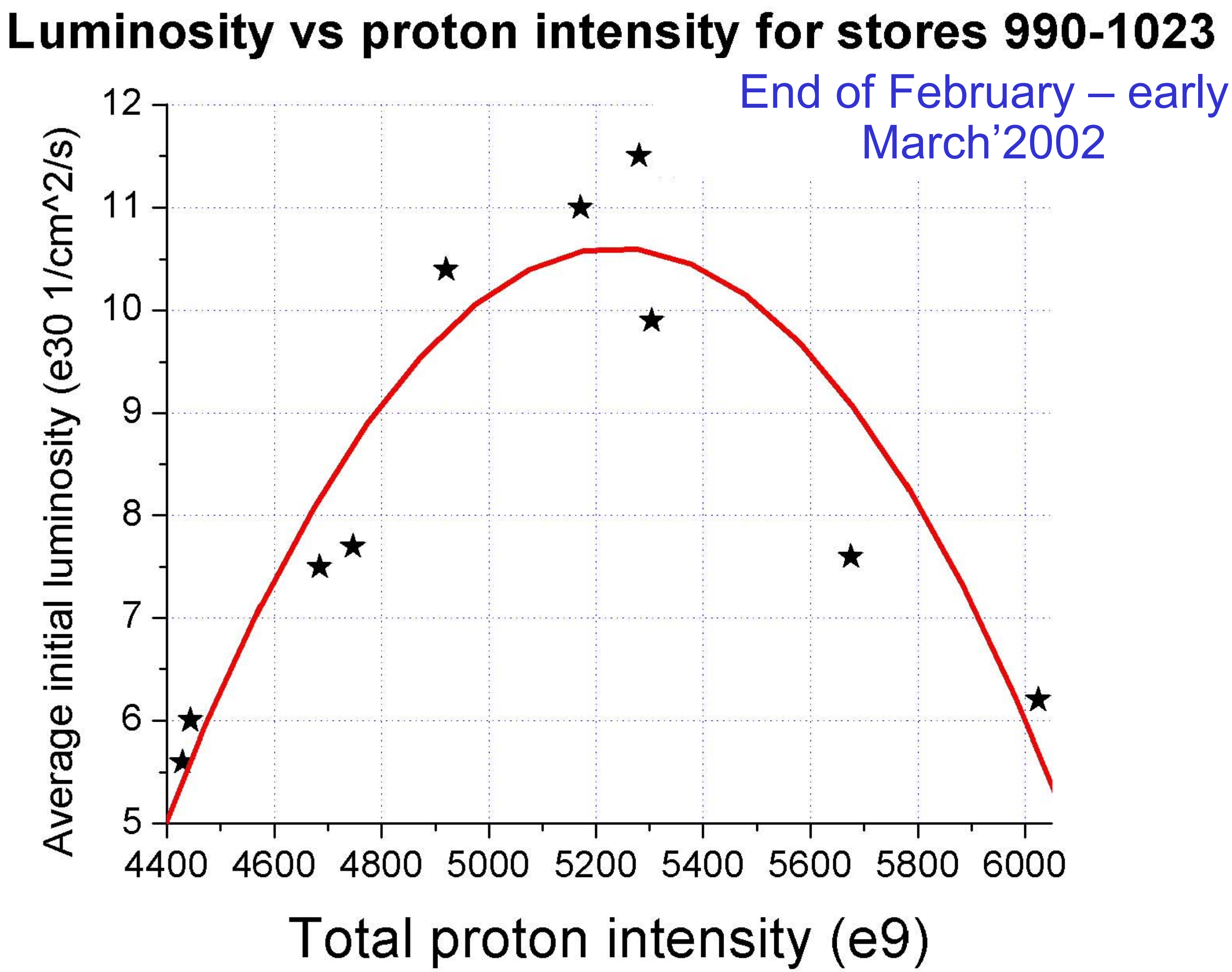
  ("sequence 13")
- *increase of beam-beam separation at 150 GeV and ramp*

  ("new-new helix")
- *smaller emittances from AA*

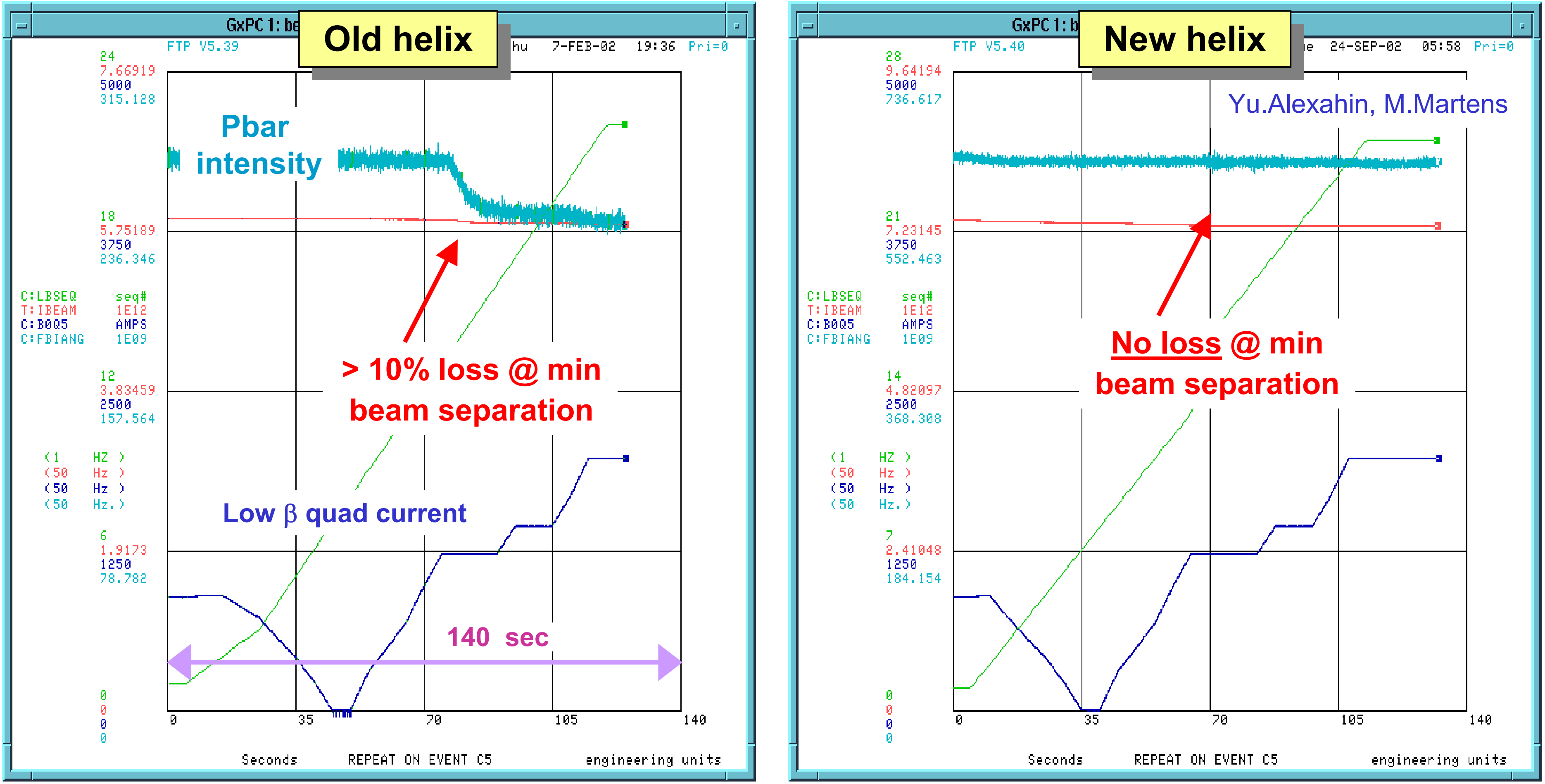
  ("AA shot lattice" – see D.McGinnis)
- *reduced injection errors*

  ("BLT" – see V.Lebedev's talk)
- *better control of orbits/tunes/coupling/IP*

"Sequence 13" Affects Luminosity



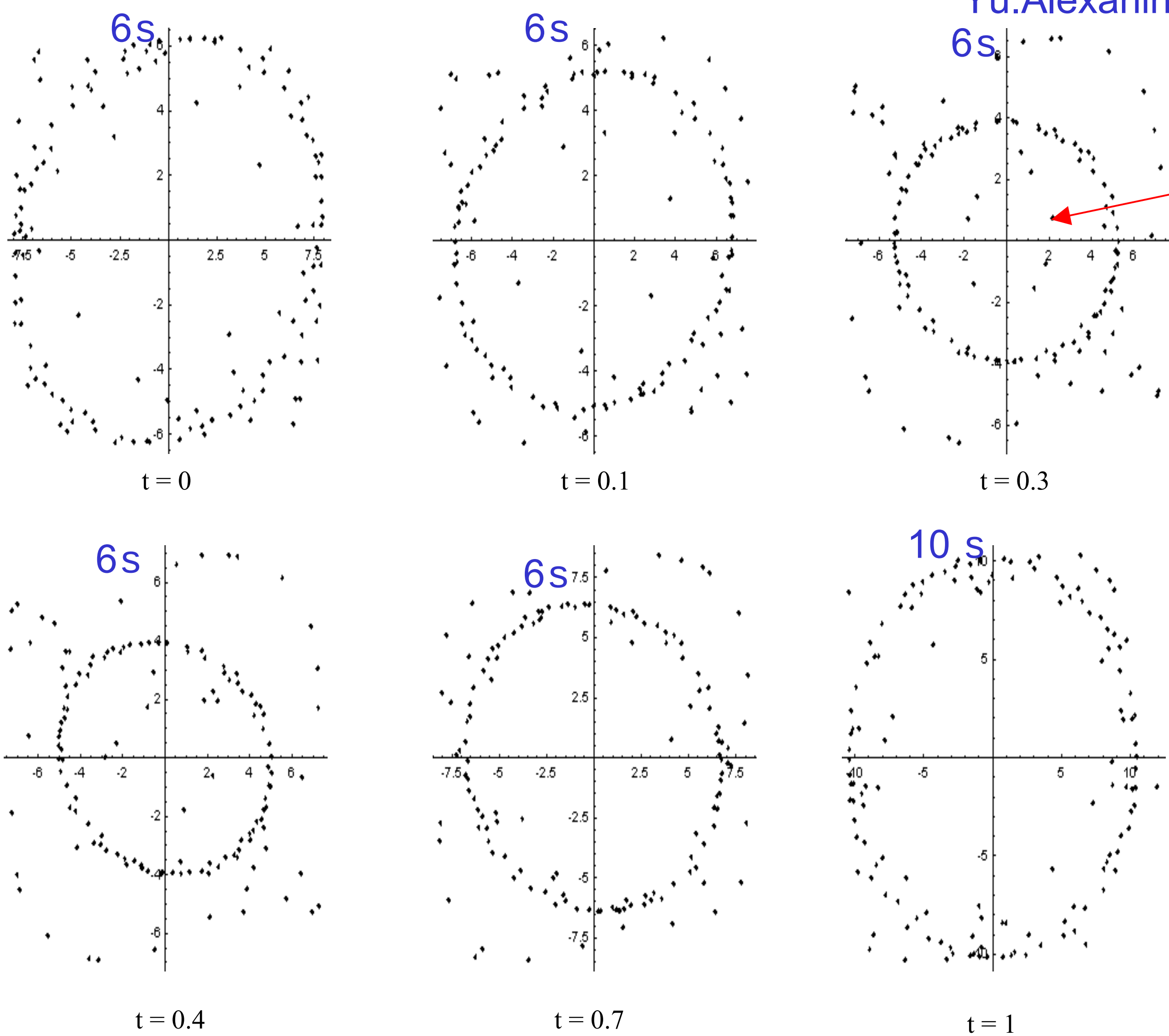
Pbar Loss During Squeeze ("Sequence 13")



- 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

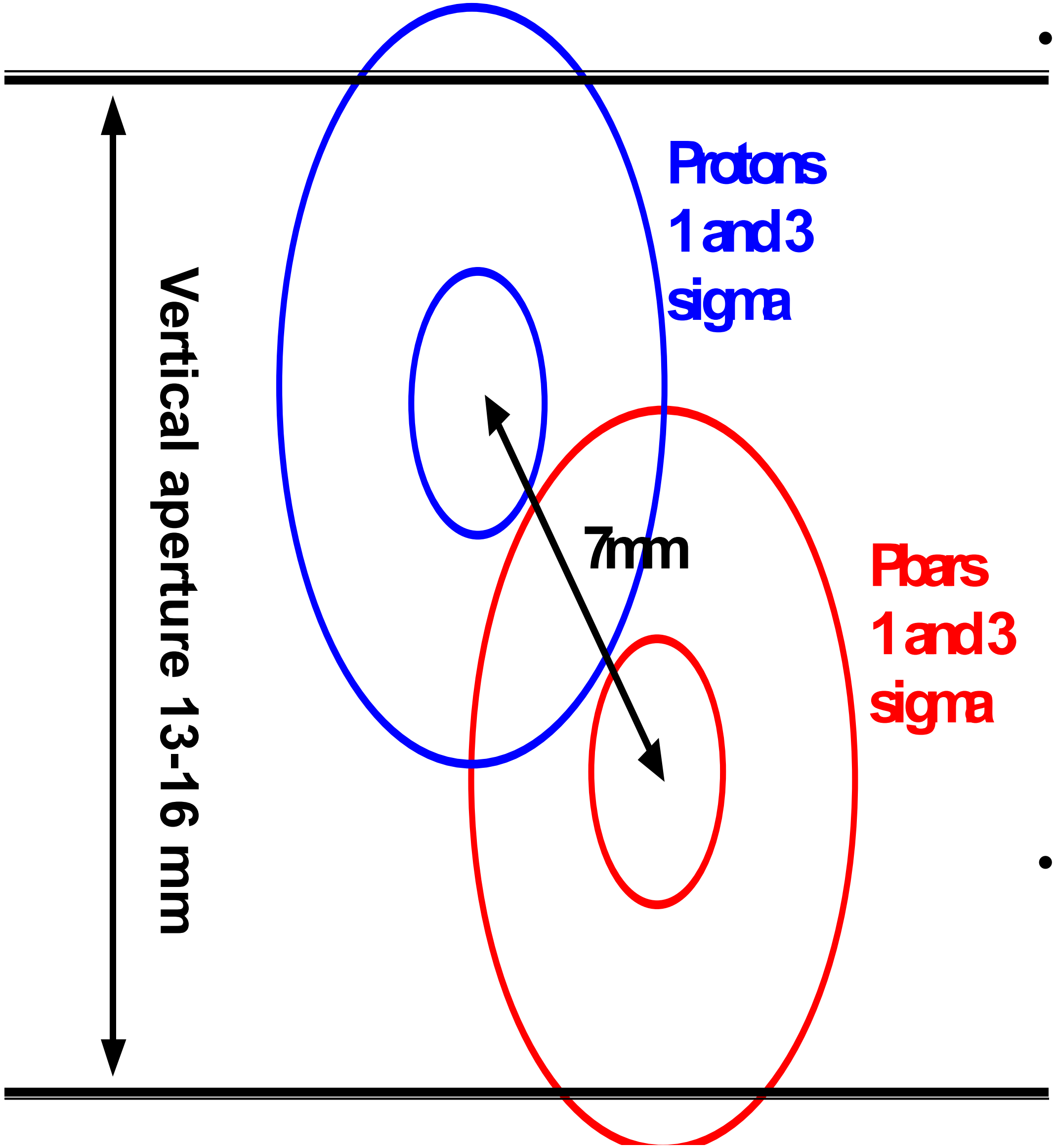
Beam-Beam Effects in Squeeze

Yu.Alexahin



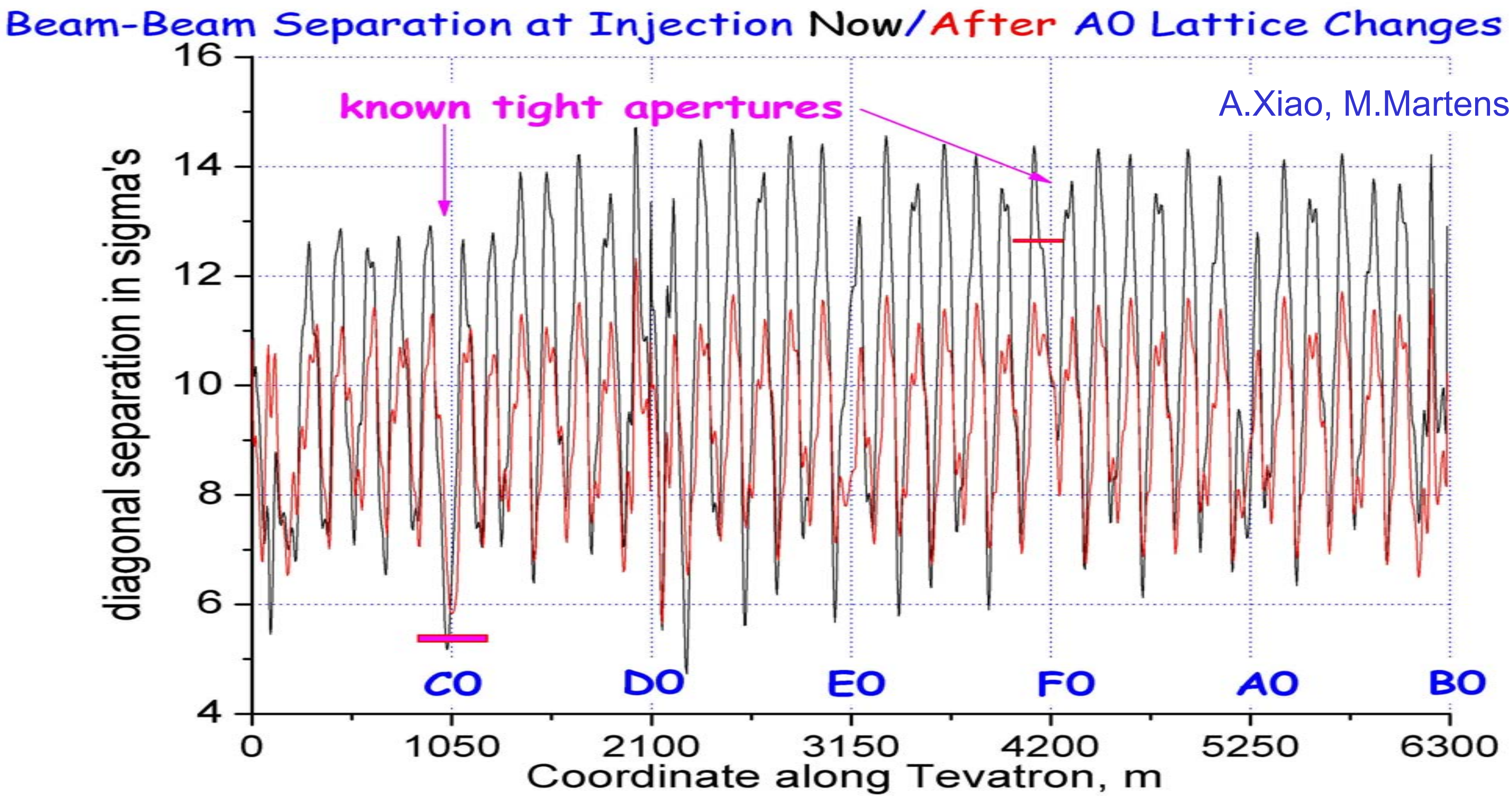
- Minimum beam-beam separation turned out to be only **1.8σ**
- Normalized separations $\Delta x/\sigma_x$, $\Delta y/\sigma_y$ at all possible IPs with 36×36 collision cogging in sigma's for the reference emittance ε_n=15π mm·mrad. t = 0 – seq13, t = 1 – seq14 (see plots)
- The separation has been increased 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 1-2 hr
  - Pbar lifetime depends on emittances, N_p and bunch number
  - Tried to modify and expand the helix, until limited by apertures (“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)

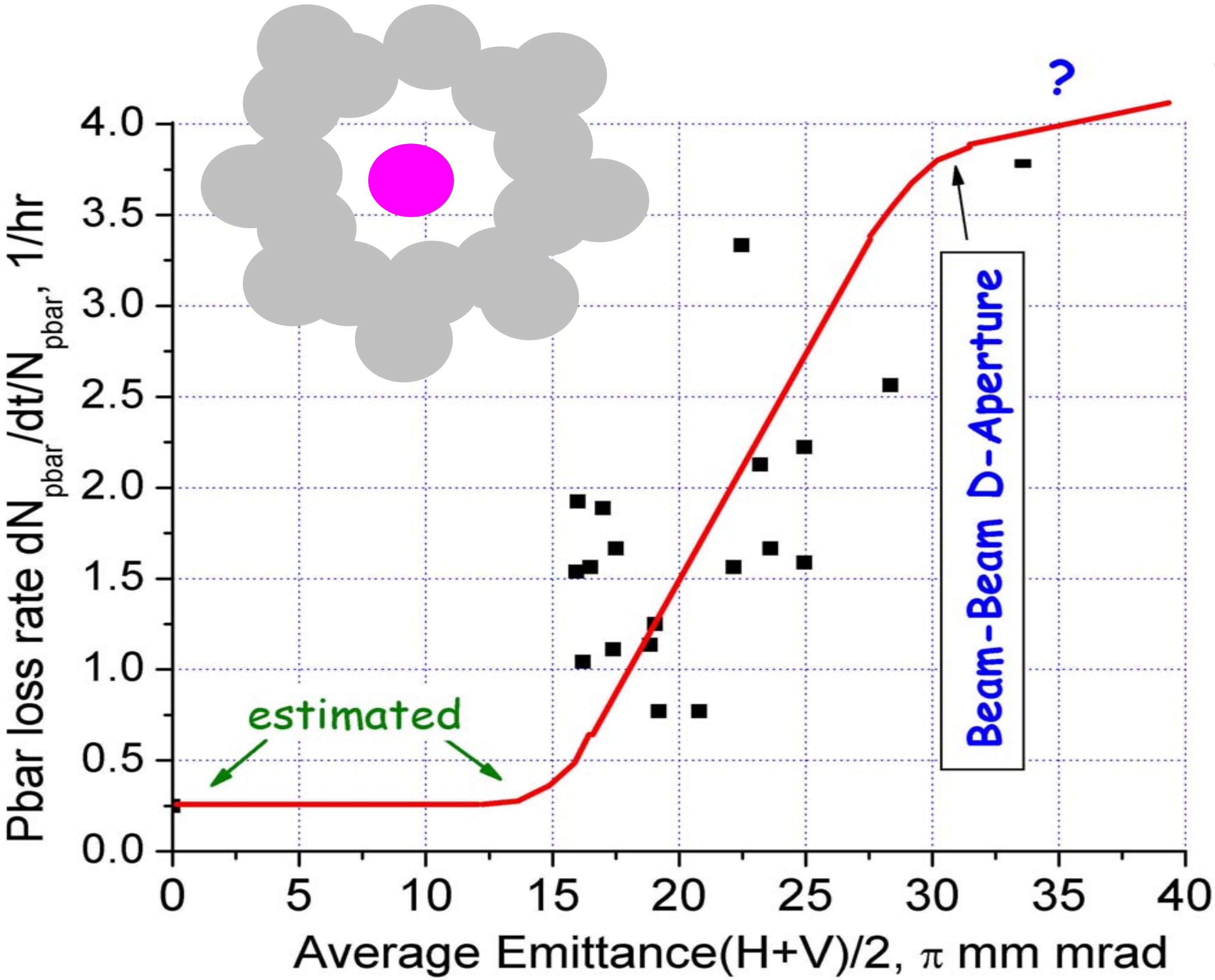
Lattice Modification at Sector A0



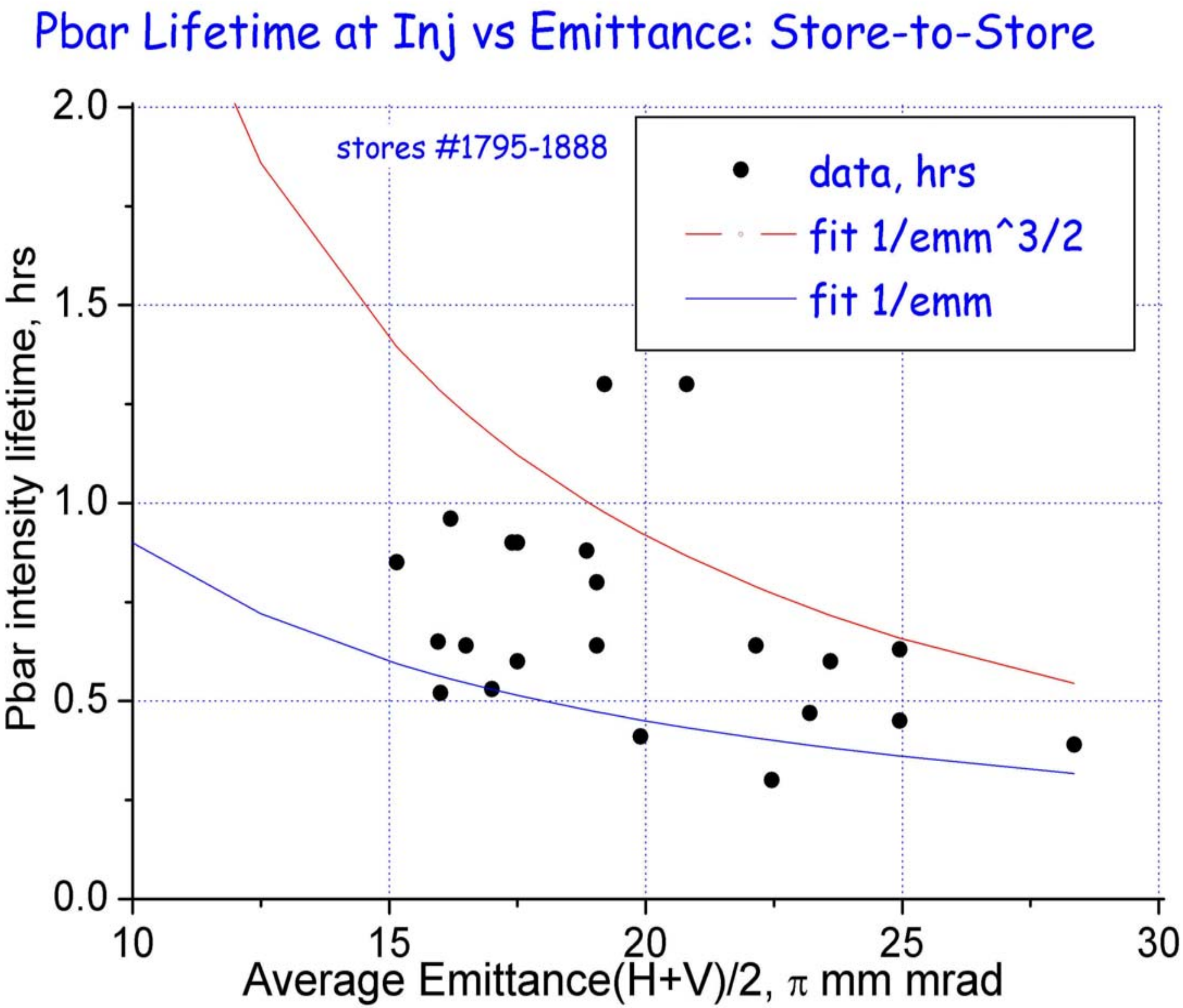
- Proposed modification promises 16% larger minimum separation at injection (5.6 vs 4.7 σ) and similar at collisions
- very important at injection where aperture is tight – new lattice reduces maximum beam-beam separation by about the same 16%

Proton Beam as "Soft Donut Collimator"

@ 150 GeV



Pbar Losses vs Emittance

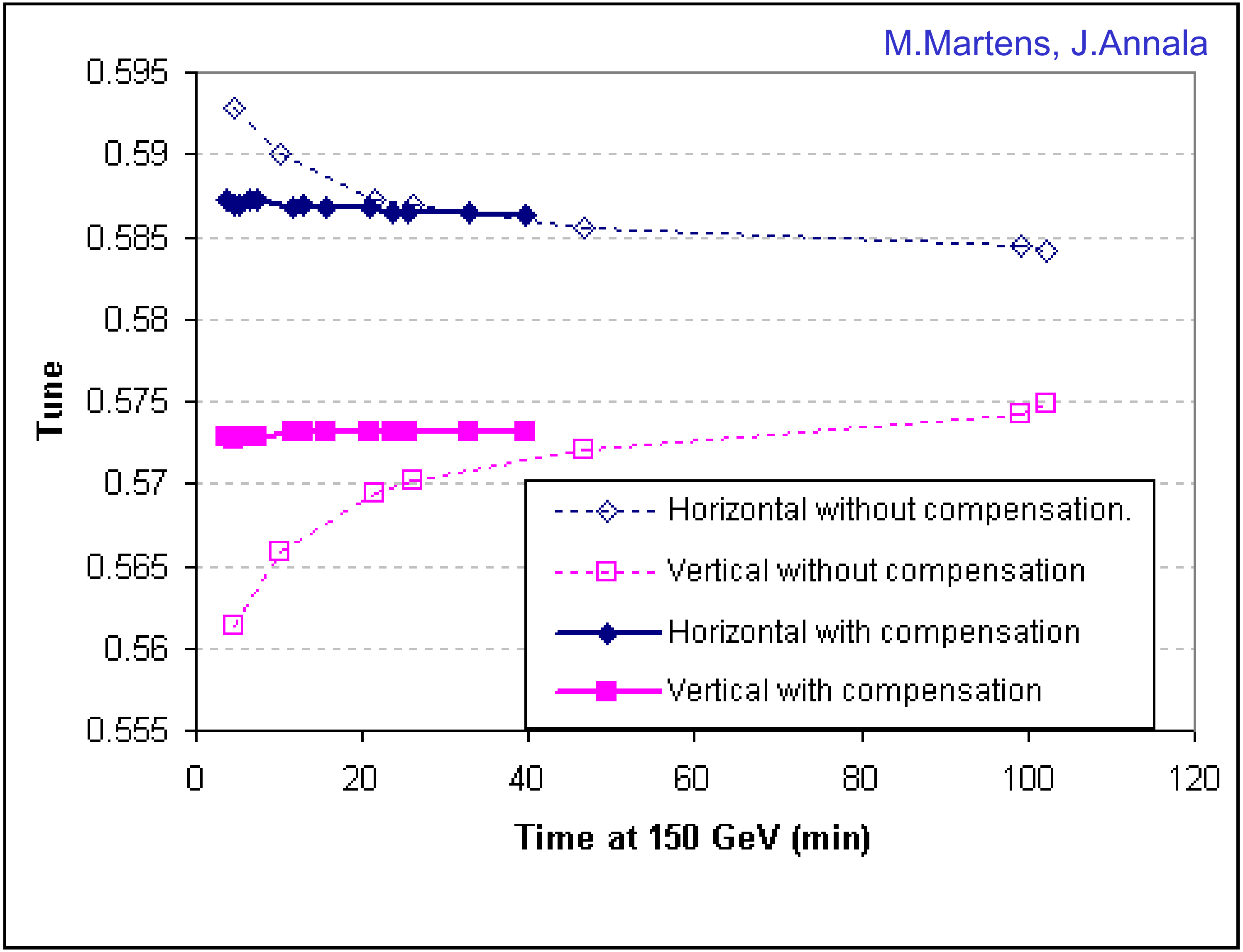


- pbar losses strongly depend on N_p and pbar emittances
- → reduce emittances – AA "shot lattice", fix injection errors, match injection lines
- increase beam-beam separation (helix) → C0 aperture, A0 lattice
- expected $t \partial A^{(2.2-3)}$

Tune and Coupling Drifts at 150 GeV

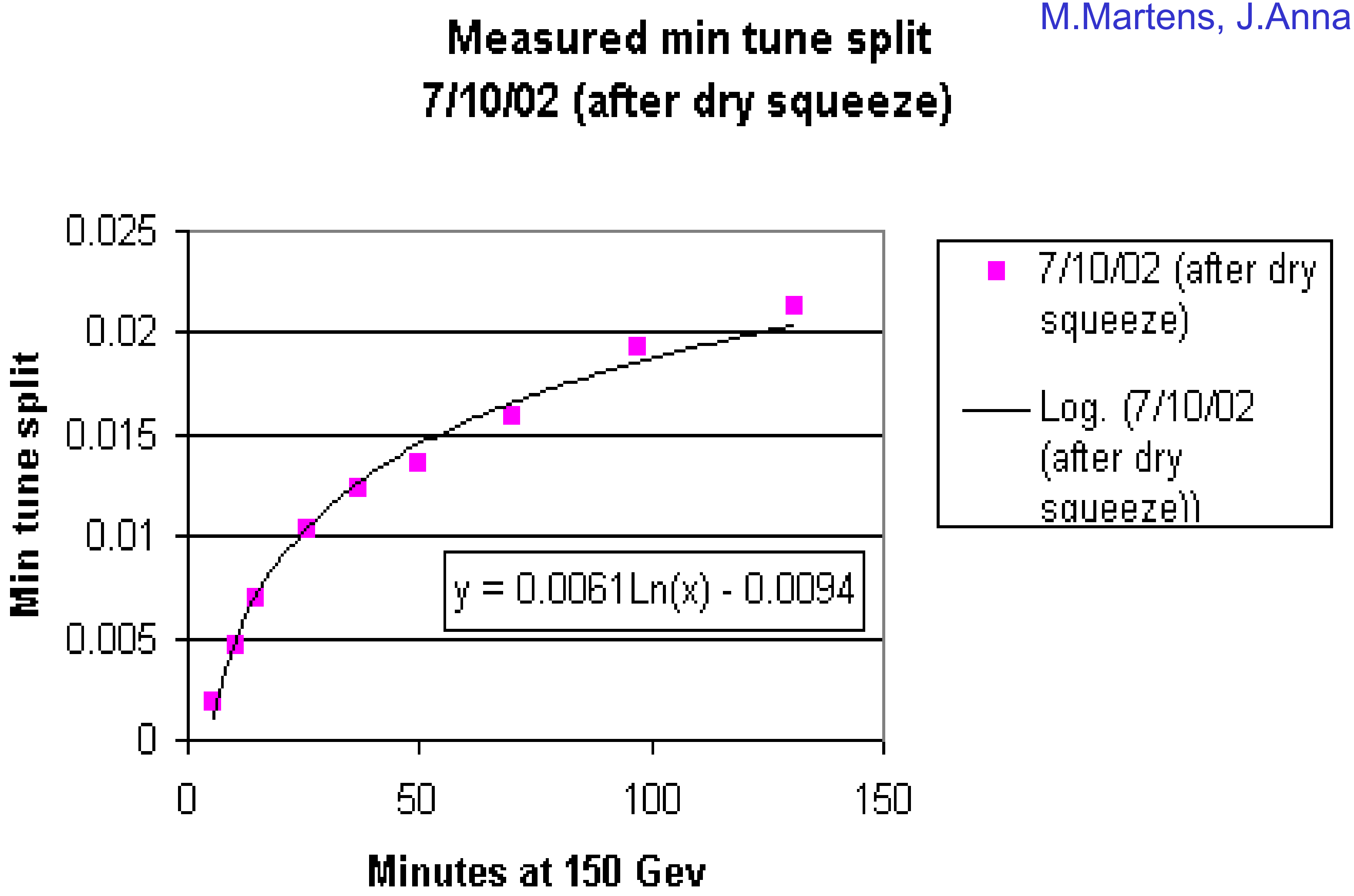
- Chromaticity drift from b_2 component in dipoles well-known from Run I
  - Compensated automatically by varying sextupole currents
- New for Run II, tune and coupling also vary logarithmically after returning to injection energy
  - Makes injection tune-up more difficult
- Likely caused by persistent 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

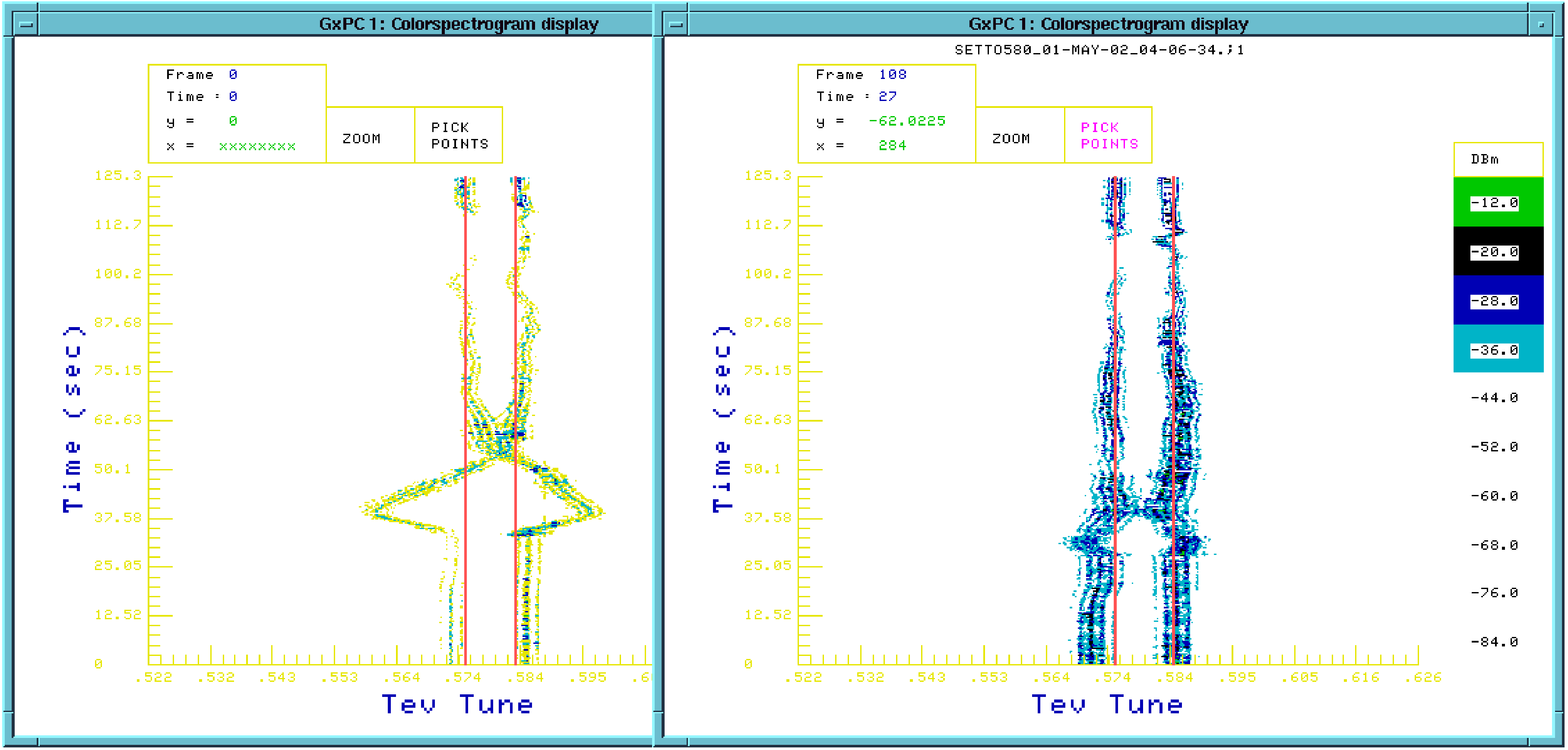


Coupling Drift @ 150 GeV

M.Martens, J.Annala

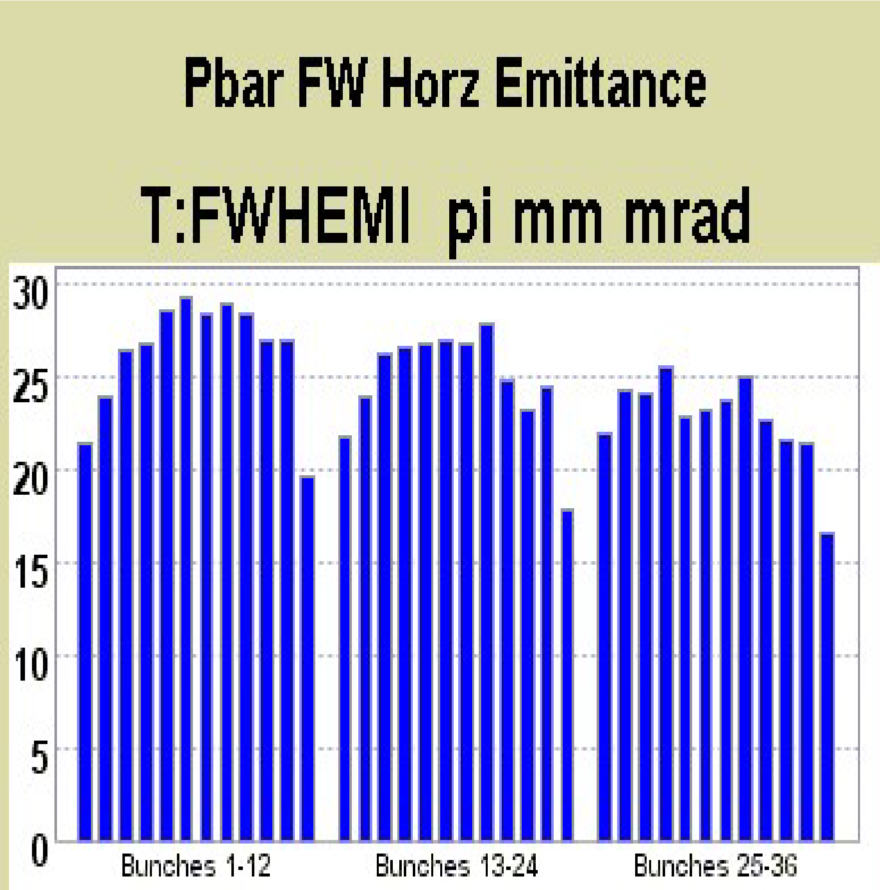


Tune Variations on Ramp/Squeeze

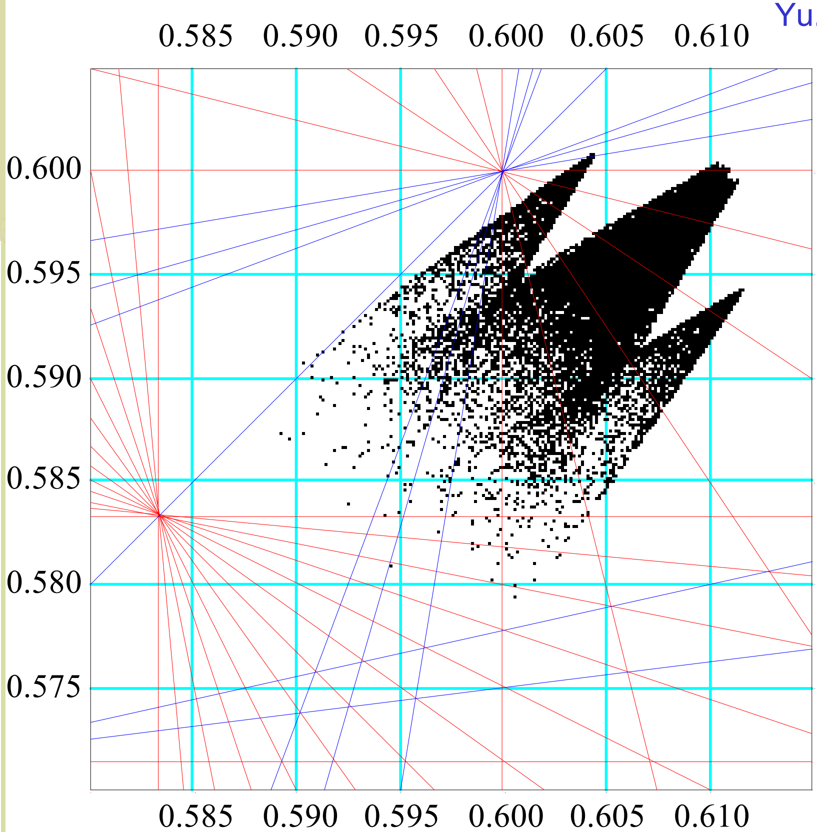


- Pbar loss at the ramp is due long-range beam-beam forces
- The loss depends on proton intensity, beam-beam separation (has been maximaized with given restrictions), tunes, coupling, chromaticities
- variations were corrected with additional break point at 153 GeV tunes)

Beam-Beam Effects at 980 GeV

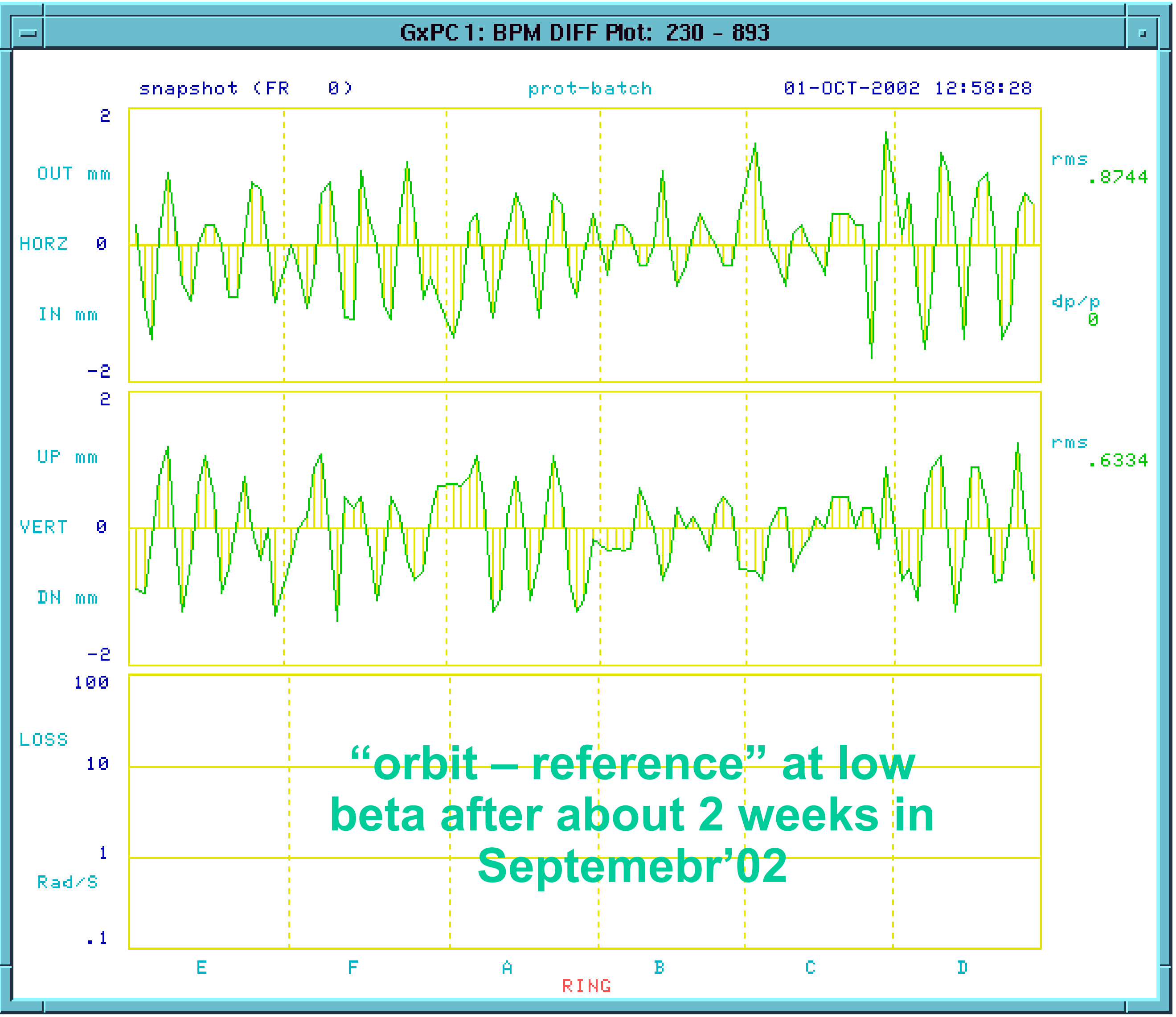


Yu.Alexahin



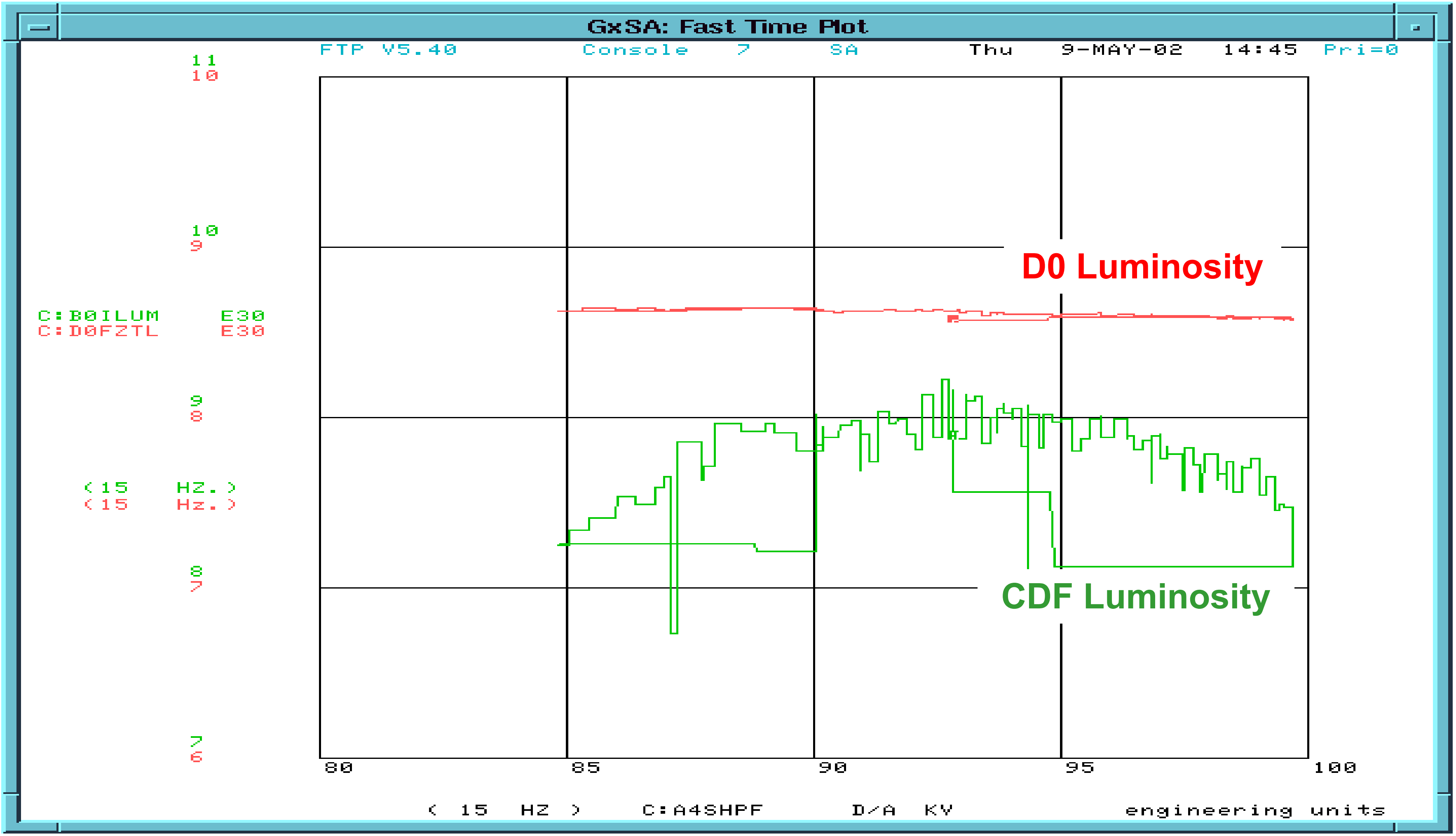
- Pbar bunches near abort gaps have better emittances and live longer
- emittances of other bunches are being blown up to 40% over the first 2 hours – see scallops over the bunch trains (small anti-scallops for protons)
- the effect (should be) tune dependent - see on the right

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.

IP Scan



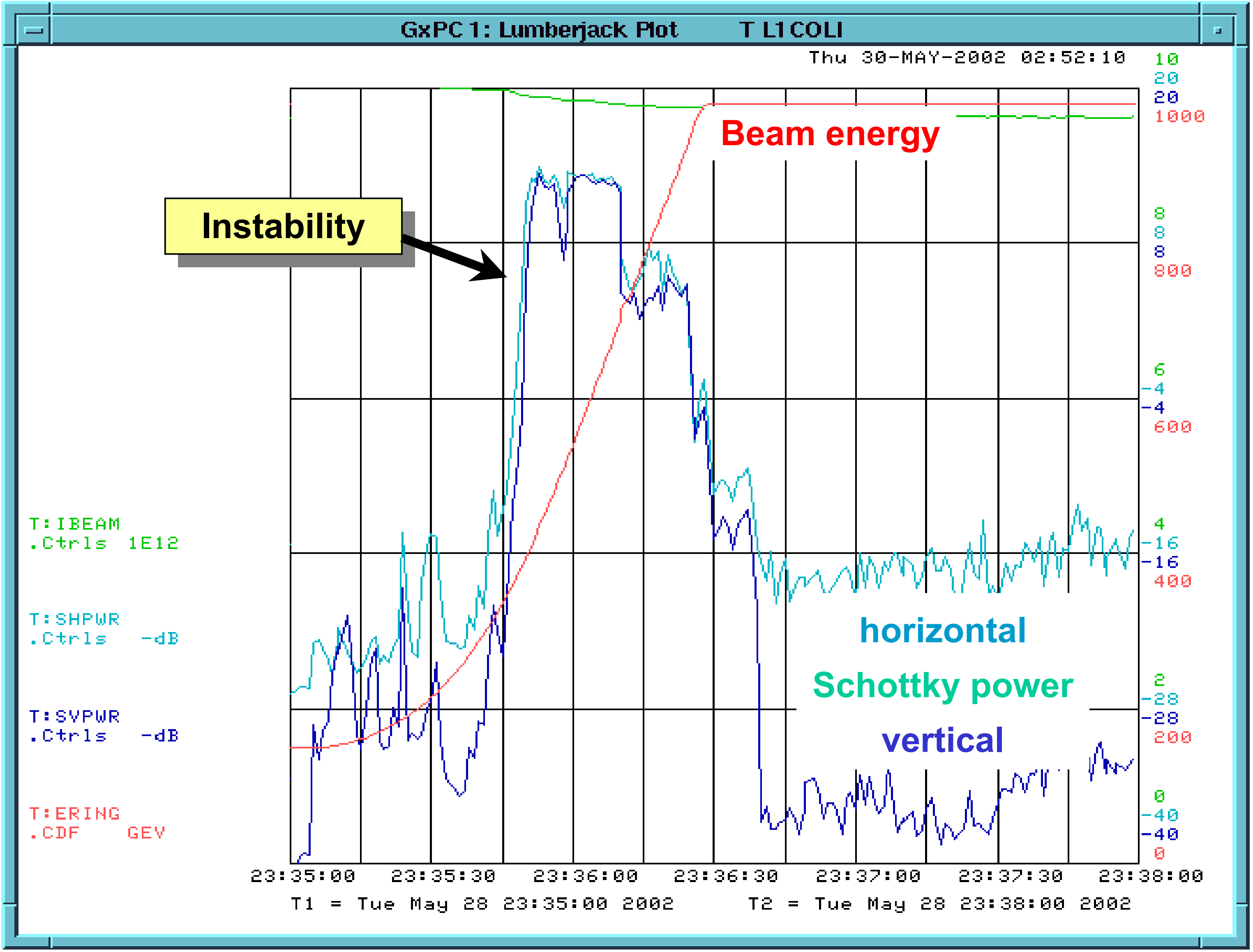
• every once in a while we perform separators scan at IPs (like 5/10 resulted in +4% in the CDF luminosity

Proton Transverse Instability

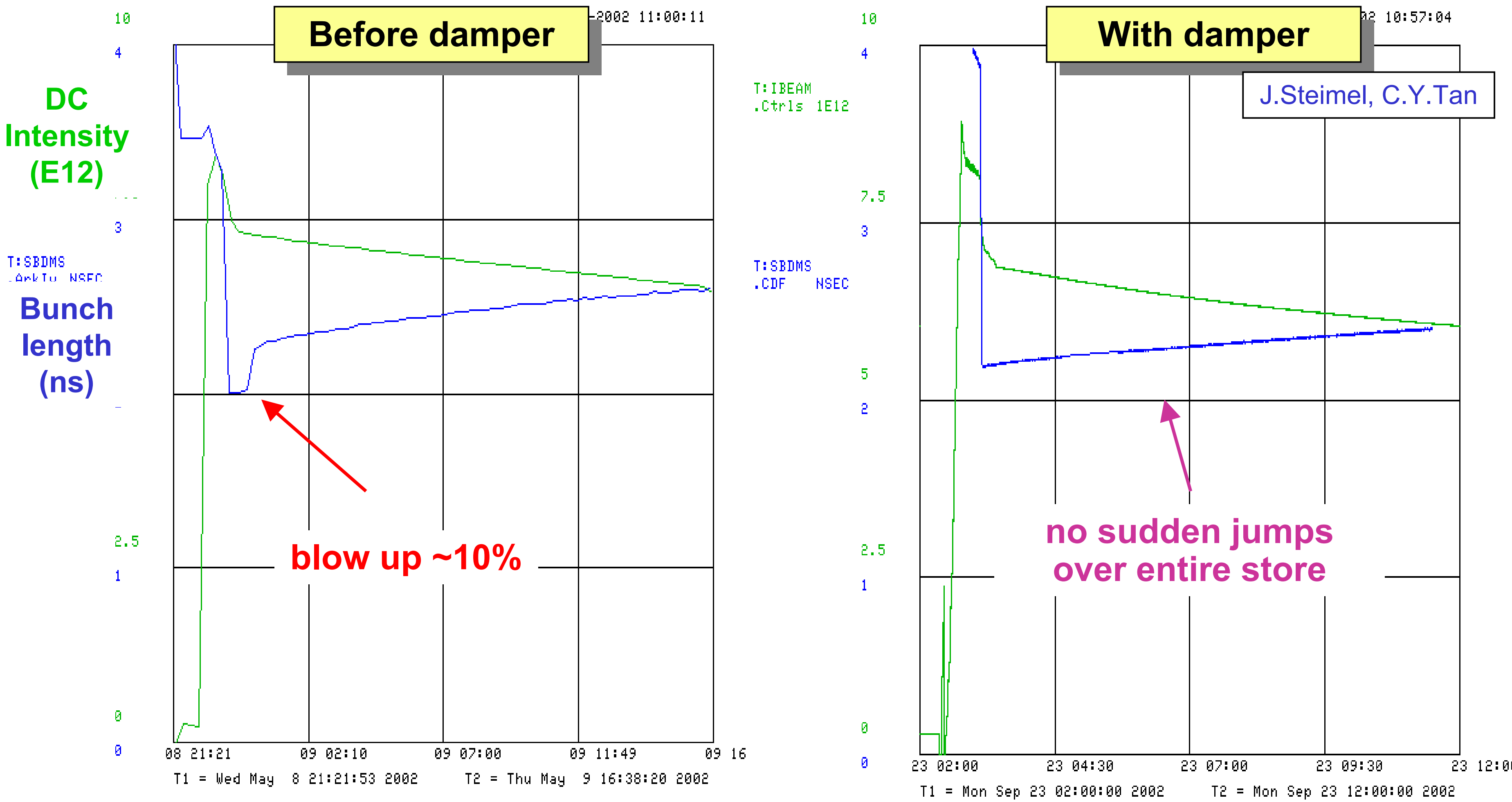
- Intensity-dependent: appears above ~170E9/bunch
  - Single bunch weak head-tail phenomenon (?)
- Can occur at 150 GeV, up the ramp, at 980 GeV
  - Schottky powers rise quickly
  - p/pbar emittances blow up for individual bunches
- Try to prevent/control instability via:
  - Raising chromaticities (8 @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

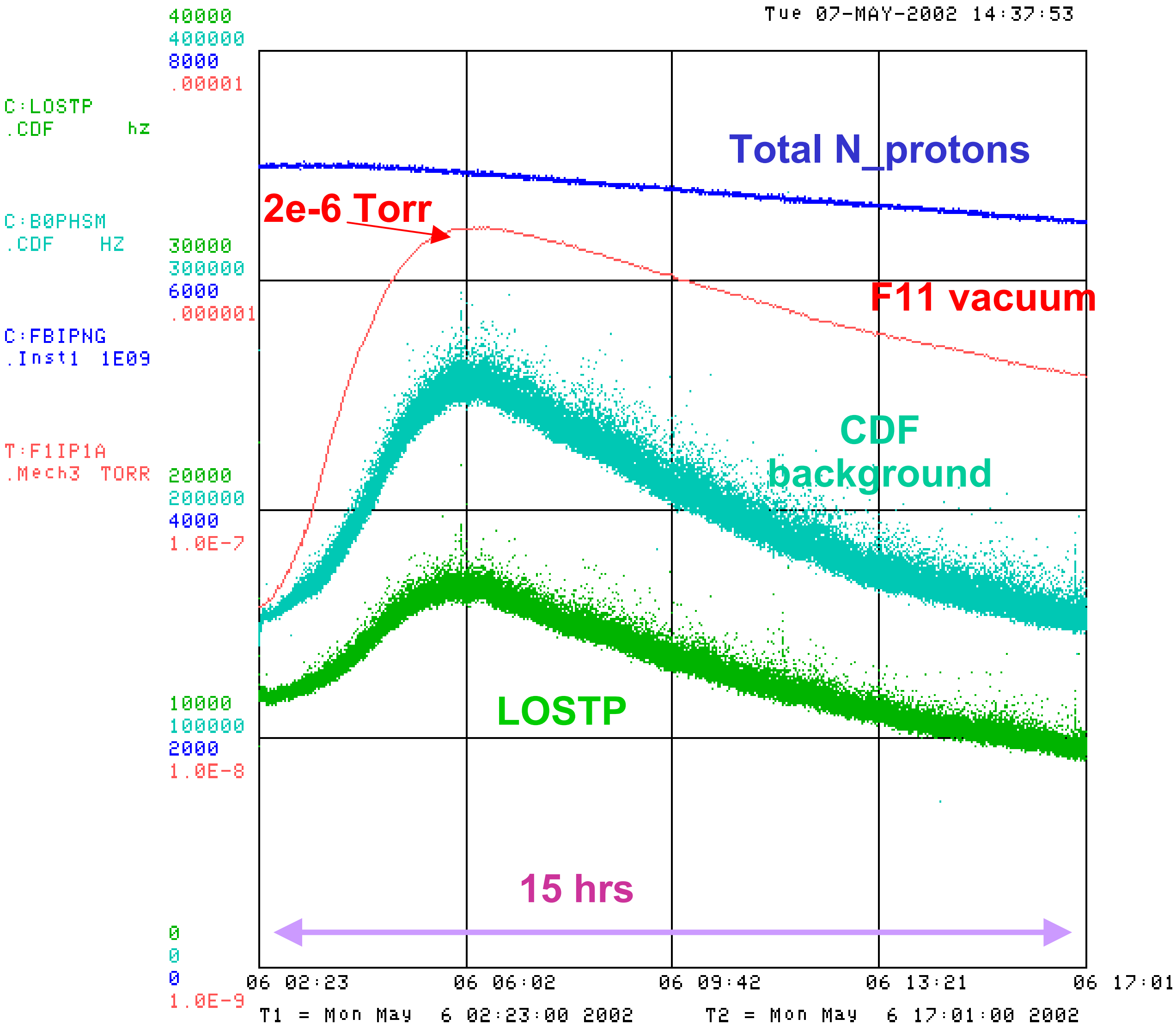


Bunch Length Blowup During Stores



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

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)

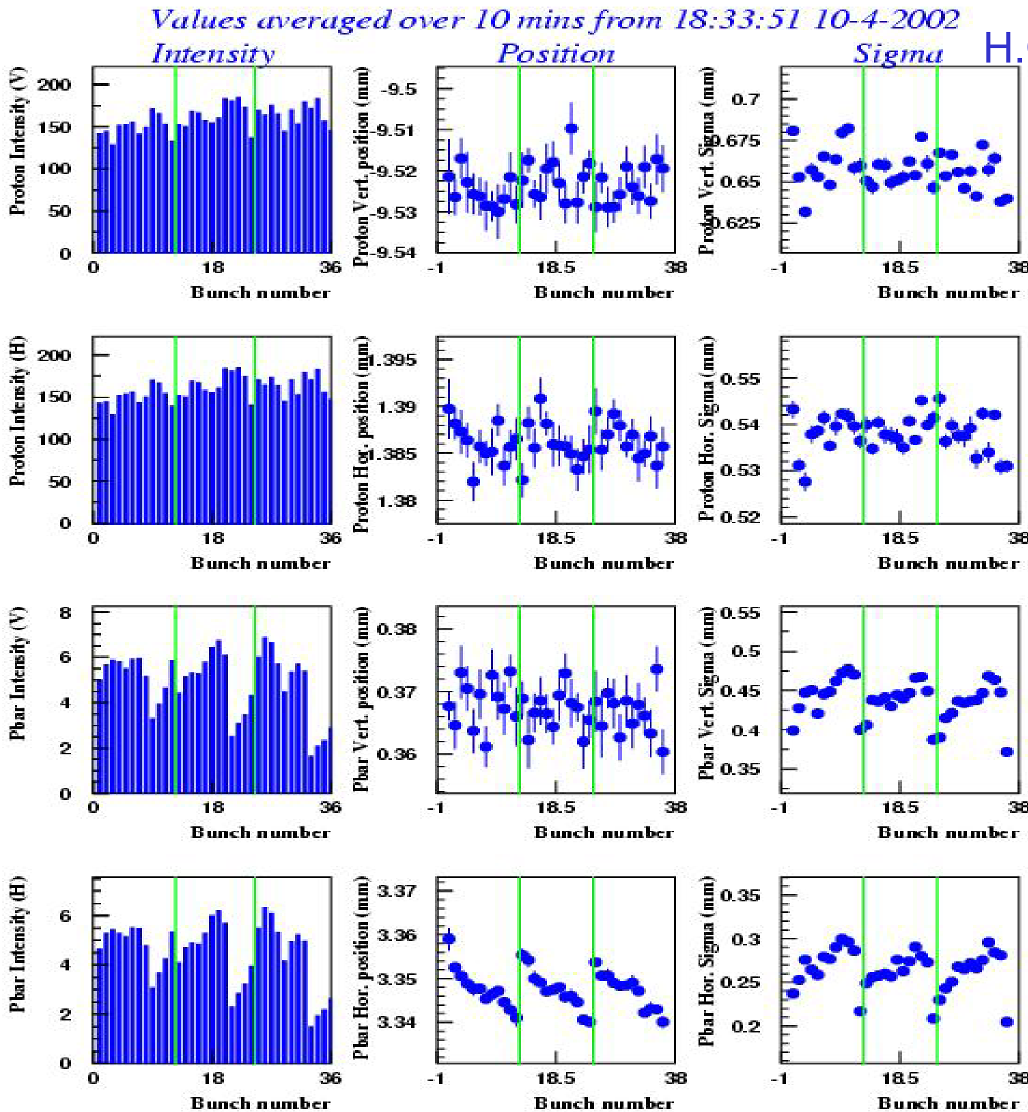
Physics Progress (see backup slides)

- 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

[0 – not exists, 1 – poor, 2- fair, 3- good]	Mar'02	Oct'02
• BPMs	1	1
• Beam Line Tuner = BLT	1	3
• RF phase detector	0	3
• Flying Wires = FW	1	2.5
• SyncLite Monitor = SL	1	2.5
• Single Bunch Display = SBD	1.5	2
• Fast Bunch Integrator = FBI	1.5	2
• Schottky Detector (21 MHz, + 1.5 GHz)	1.5	2
• Tune-Meter	1	2
• Digital Mountain Range	0	2
• Fast Chromaticity Measurement	0	1.5
• Head-Tail Monitor	0	1
• Orbit Oscillations Monitor	0	1
• RF Noise	0	1
• Magnets motion	1.5	2

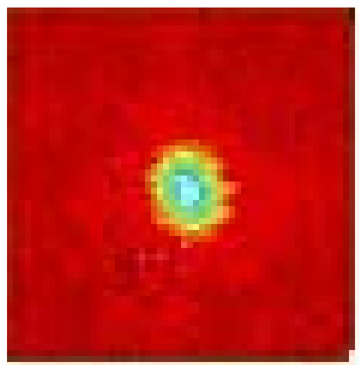
Diagnostics Progress: SyncLite Monitor



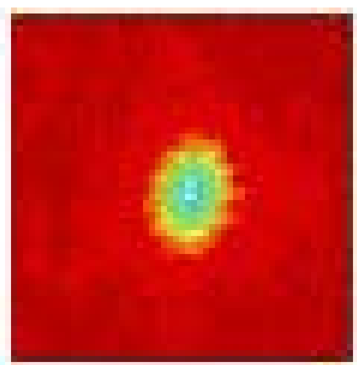
H.Cheung

- 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



Shutdowns

- 2 week shutdown in June'02:
  - F11 RWM ferrites replaced
  - Aperture of F0 BPMs and striplines opened
  - A-sector collimator moved
  - TEL gun and HV modulator replaced

- 6 weeks shutdown in January'03
  - Increase C0 aperture (replace Lambertsons)
  - Install 1.5GHz Schottky detectors at E17
  - A0 lattice modification
  - TEL modification
  - Vacuum improvement (incl., warm two houses)
  - Install new collimator at A48
  - Alignment work

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)*

FY’02-’03 Resources

- Tevatron Department
  - staff of 16 + 2 Guests and 1 PhD student
- Out of 16 – only 6 Physicists
- All 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, P.Bauer
  - Short term visitors (4-6 weeks): W.Fischer (BNL), F.Schmidt (CERN), coming - F.Zimmermann (CERN)

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	▪	■	■

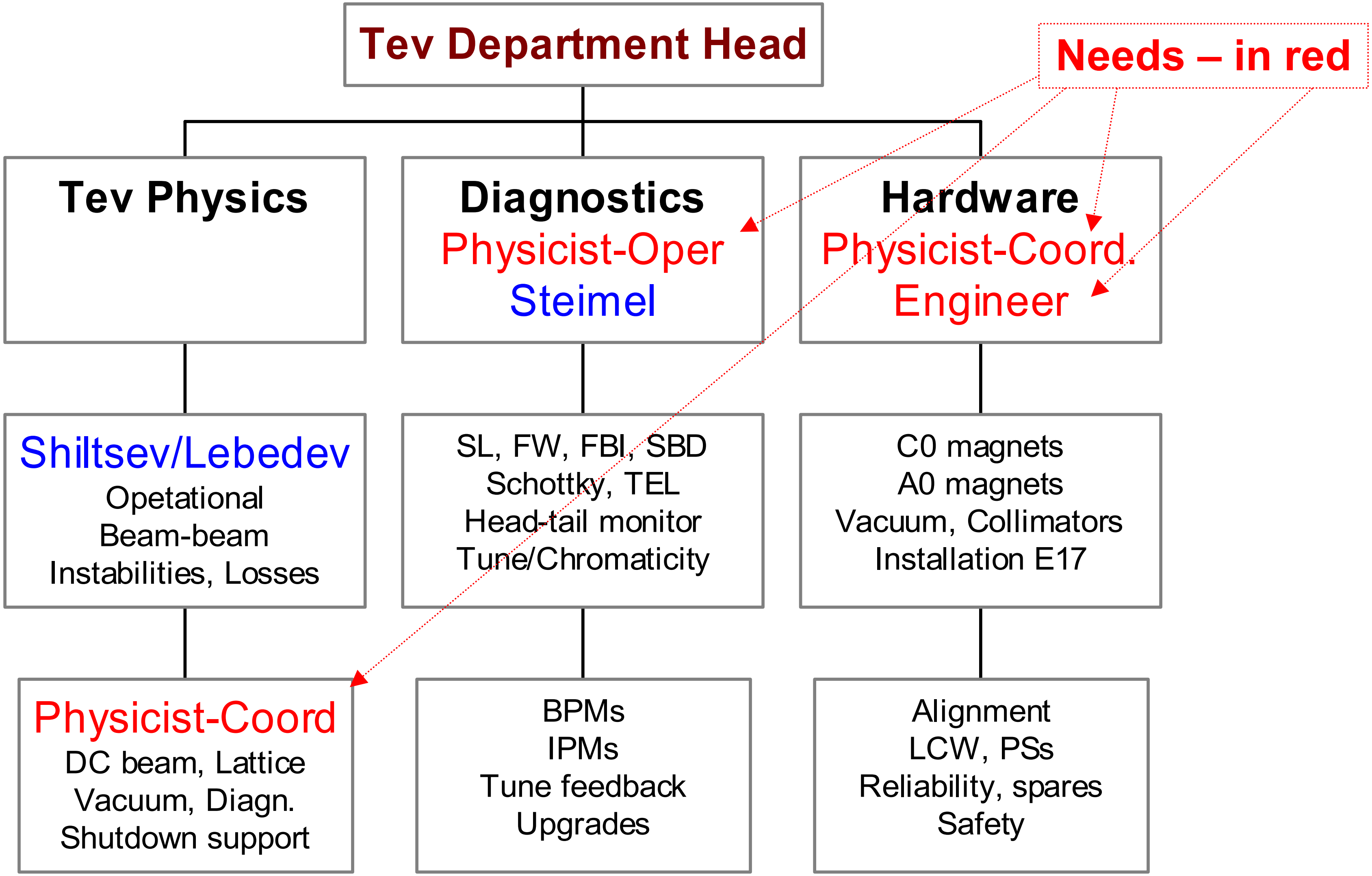
Tevatron Projects in FY'03 (cont'd)

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 are needed to keep fast pace in luminosity.
- 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