



Fermilab

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# One Year in the Life of Tevatron or

## A Cinderella Story

Vladimir Shiltsev  
Fermilab

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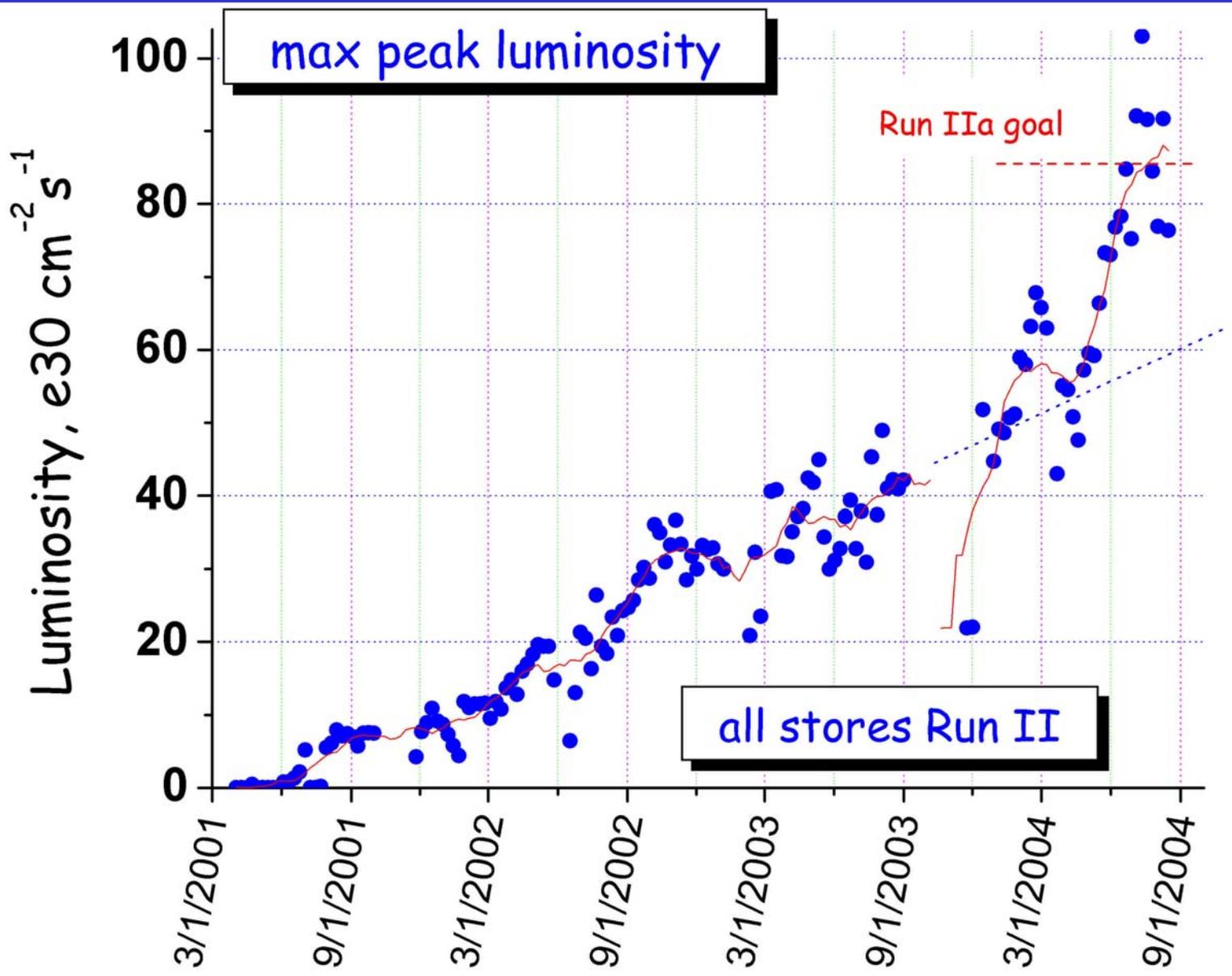
# What's all this fuss about?

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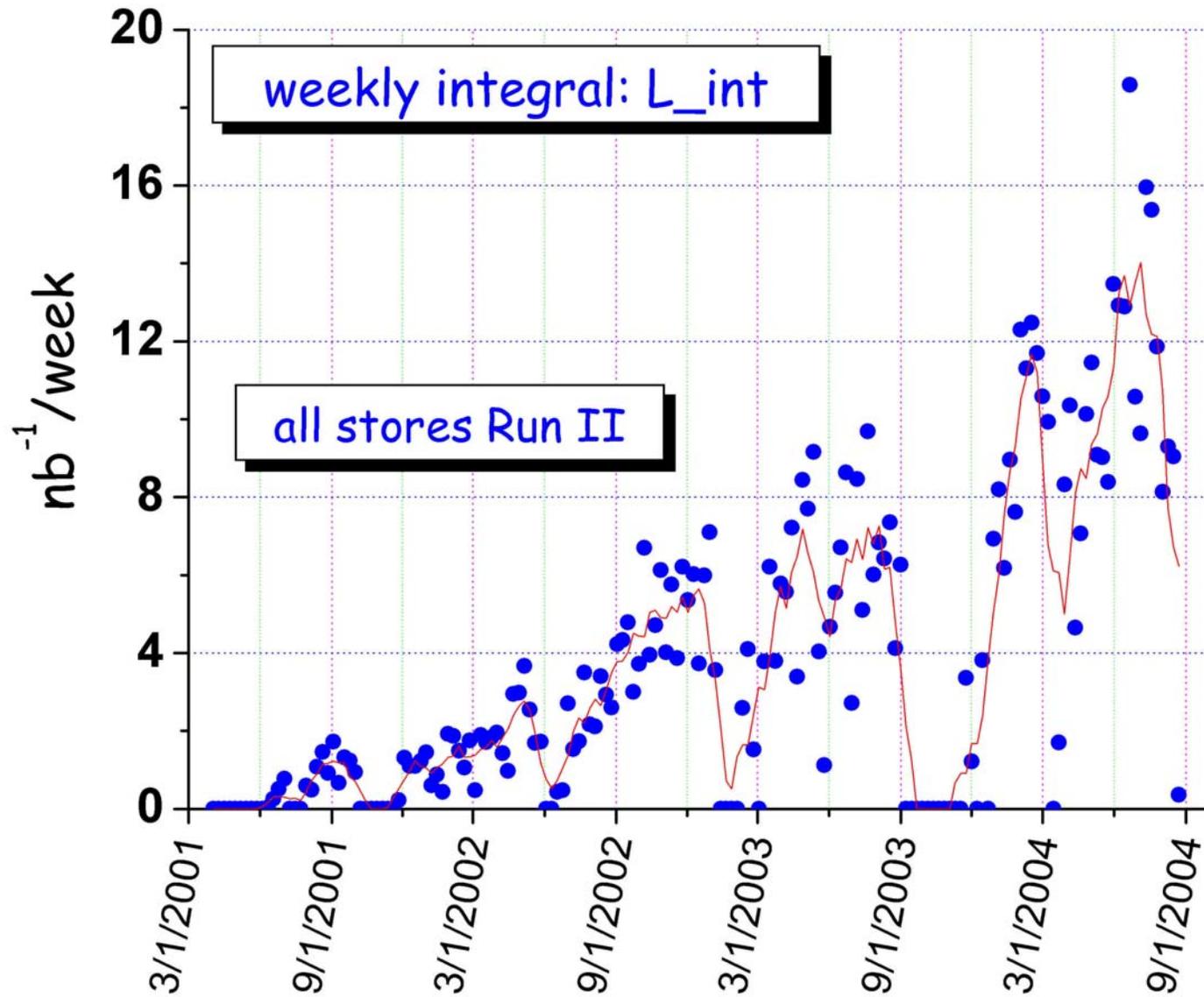
Miracle year of 2004  
(for an external observer)

	FY'03	FY'04	gain
▪ Peak Luminosity	49e30	103e30	2.10
▪ Weekly integral	9.7 pb <sup>-1</sup>	18.6 pb <sup>-1</sup>	1.92
▪ Total integral	236 pb <sup>-1</sup>	343 pb <sup>-1</sup>	1.45

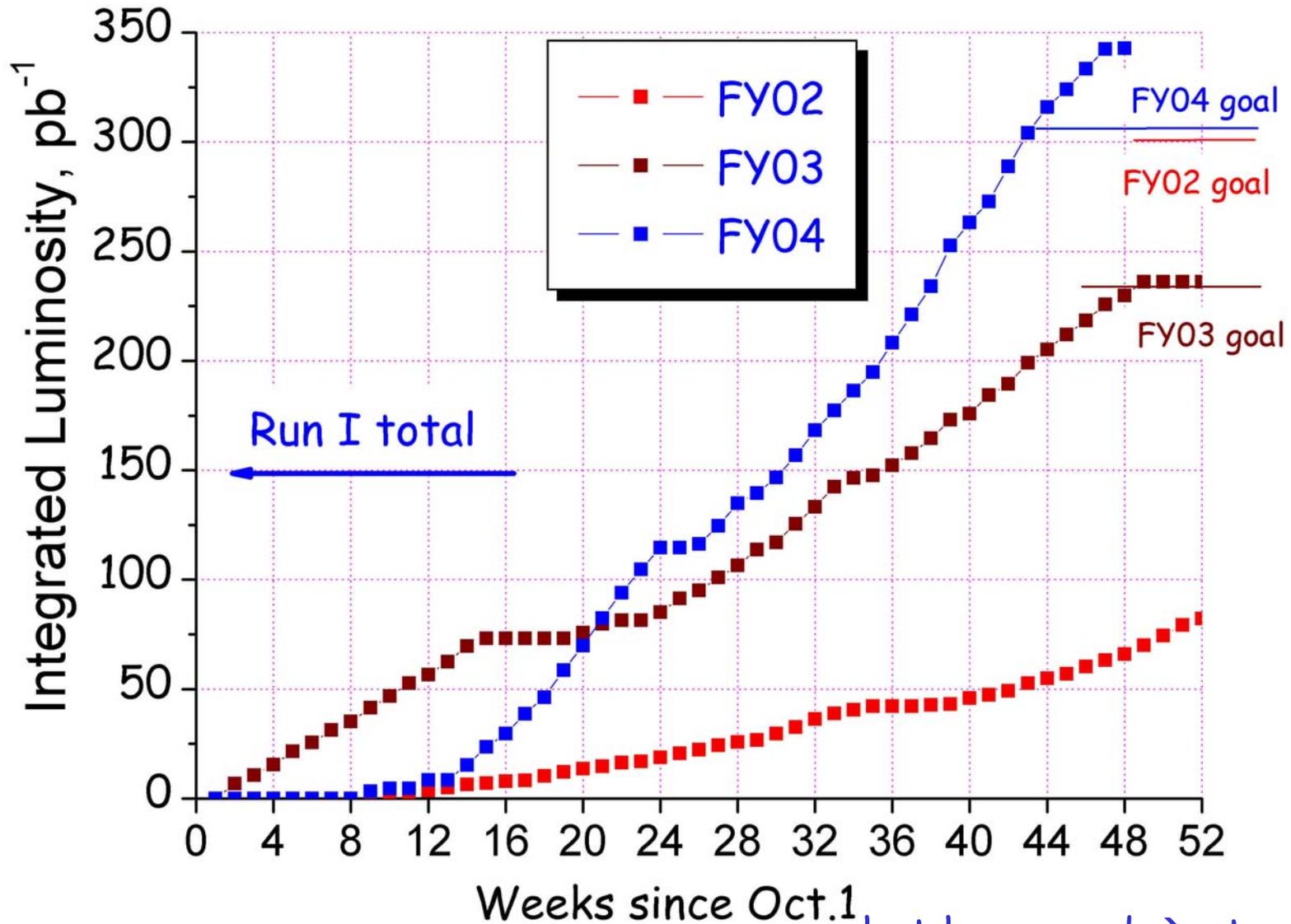
# Tevatron Peak Luminosity Progress



# Weekly Integrated Luminosity



# Integrated Luminosity



what happened → story of...

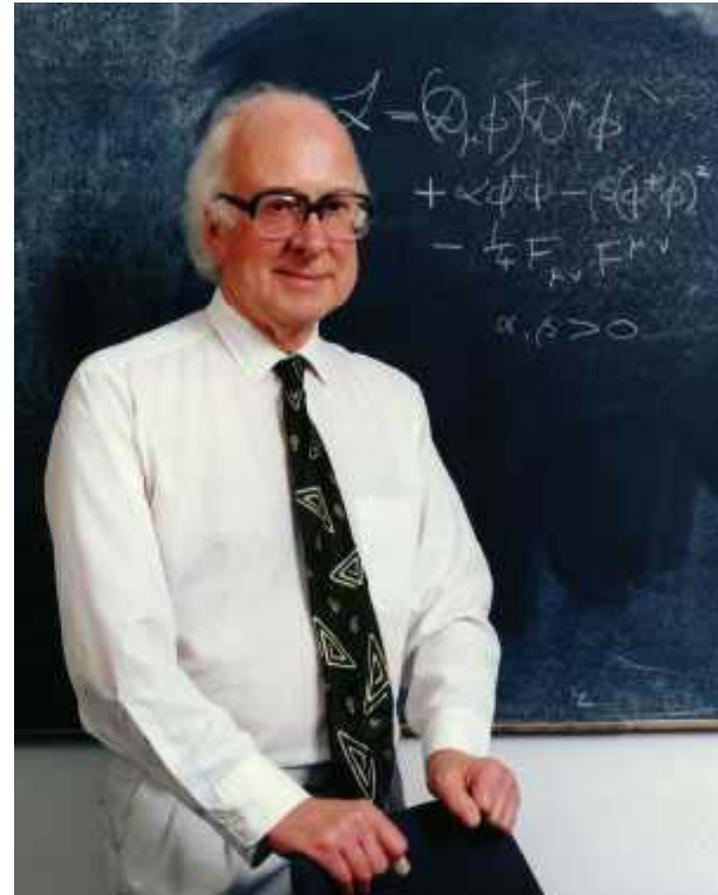
# Cast: Cinderella

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## Tevatron

# Prince Charming



Higgs...

not here yet (expct '09 ?)  
see substitutes →

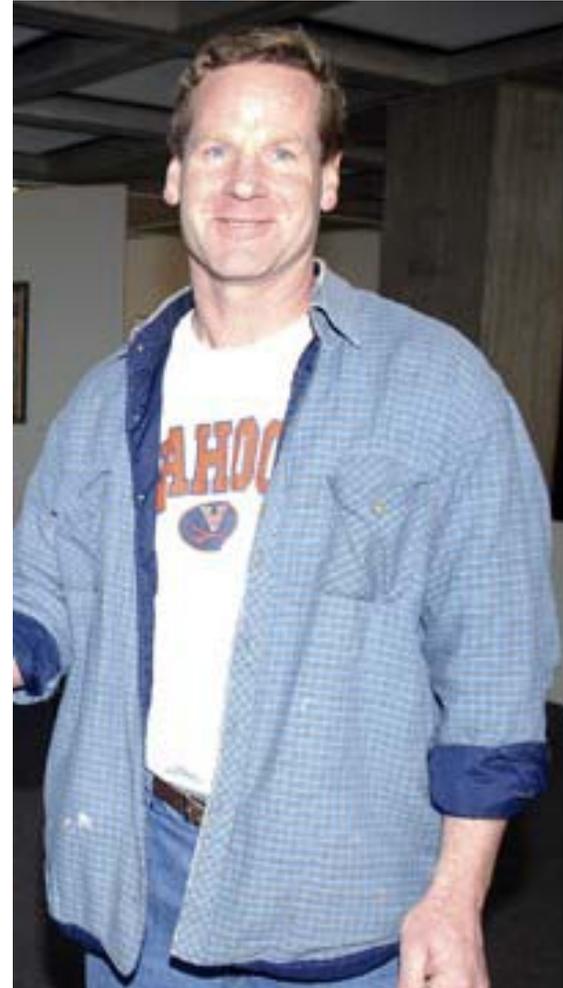
# “Prince C.” - Substitutes



CDF and D0

# Stepmother

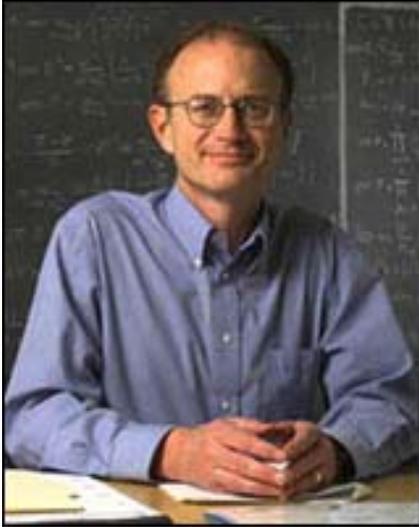
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... or a magic wand?

# King

# Grand Duke



# Fairy Godmother

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Tevatron Team

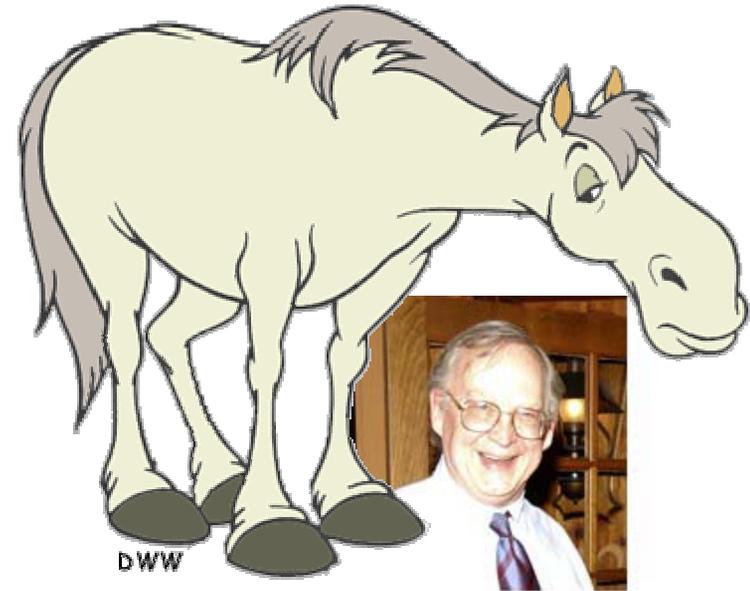
# Father



# Coach



# Support Cast



MI  
Pbar Source  
P-source

EE  
MechSupp  
Alignment



# What Has Happened in FY'04?

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- Shutdown work - Reshimming
- Shutdown work - Alignment
- Shutdown work - Liner
- MI improvements - 2.5MHz trnsf, BLCompns
- Longer stores - Bigger Stacks
- Beta\* function at IP
- IP move at CDF
- Recycler shots

# Introductory Notes: Lumi and Integral

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$$L = \frac{3\gamma f_0 B N_{\bar{p}} N_p}{\pi\beta^* (\epsilon_p + \epsilon_{\bar{p}})} H(\sigma_l / \beta^*)$$

- Peak Luminosity: primary factors
  - Beta\* at IP and bunchlength:  $H(x)/\beta^*$
  - Emittances
  - Number of protons:  $N_p$
  - Number of antiprotons:  $BN_{\bar{p}}$

# Example: Lots of Pbars in Store #3657

FTP V5.46 Console 106 SA Fri 16-JUL-04 10:42 Pri=0

1.4  
12000  
1600  
60

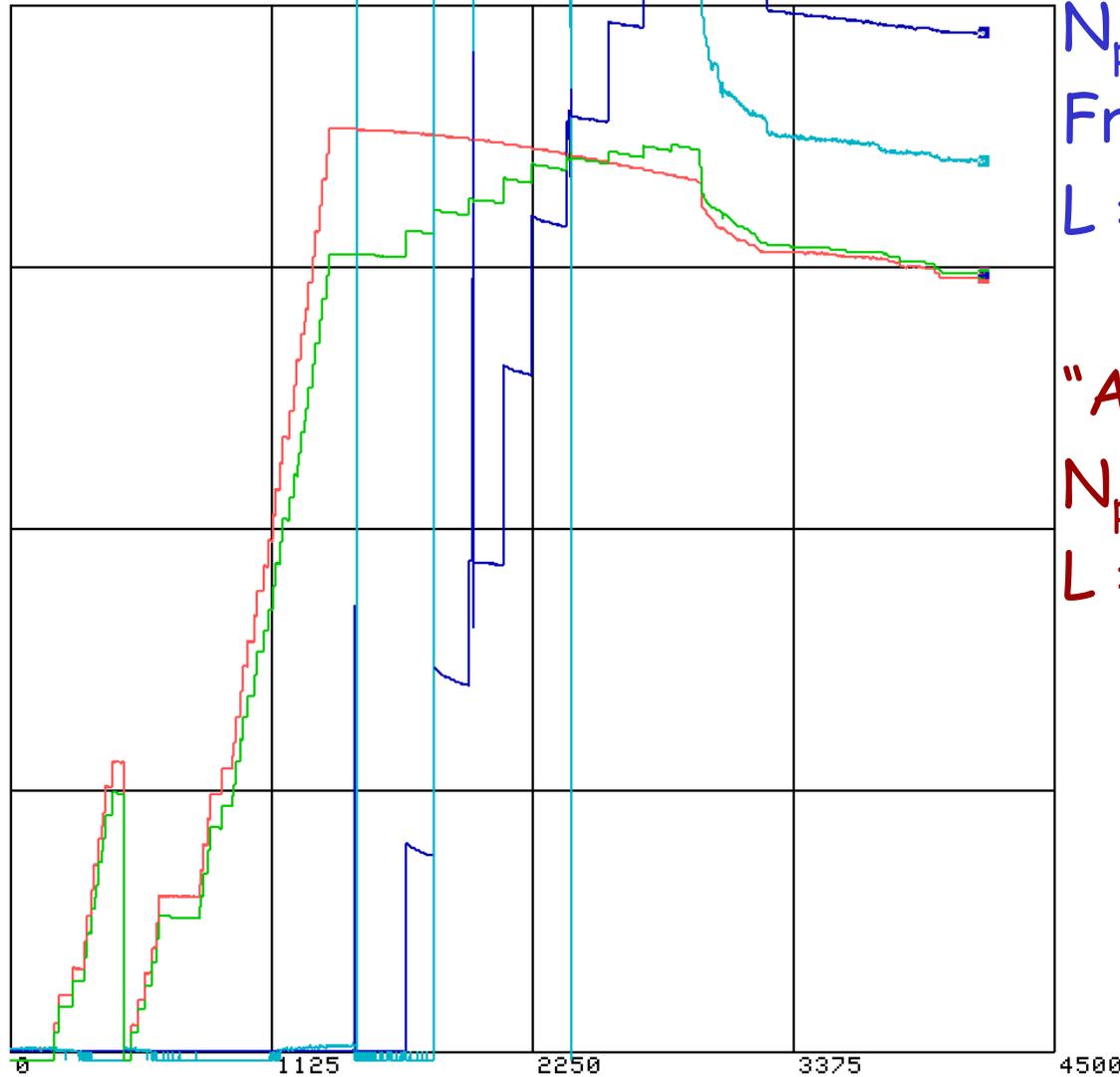
1.05  
9000  
1200  
45

.7  
6000  
800  
30

.35  
3000  
400  
15

(1 HZ.)  
(1 HZ.)  
(1 HZ.)  
(1 HZ.)

0  
0  
0  
0



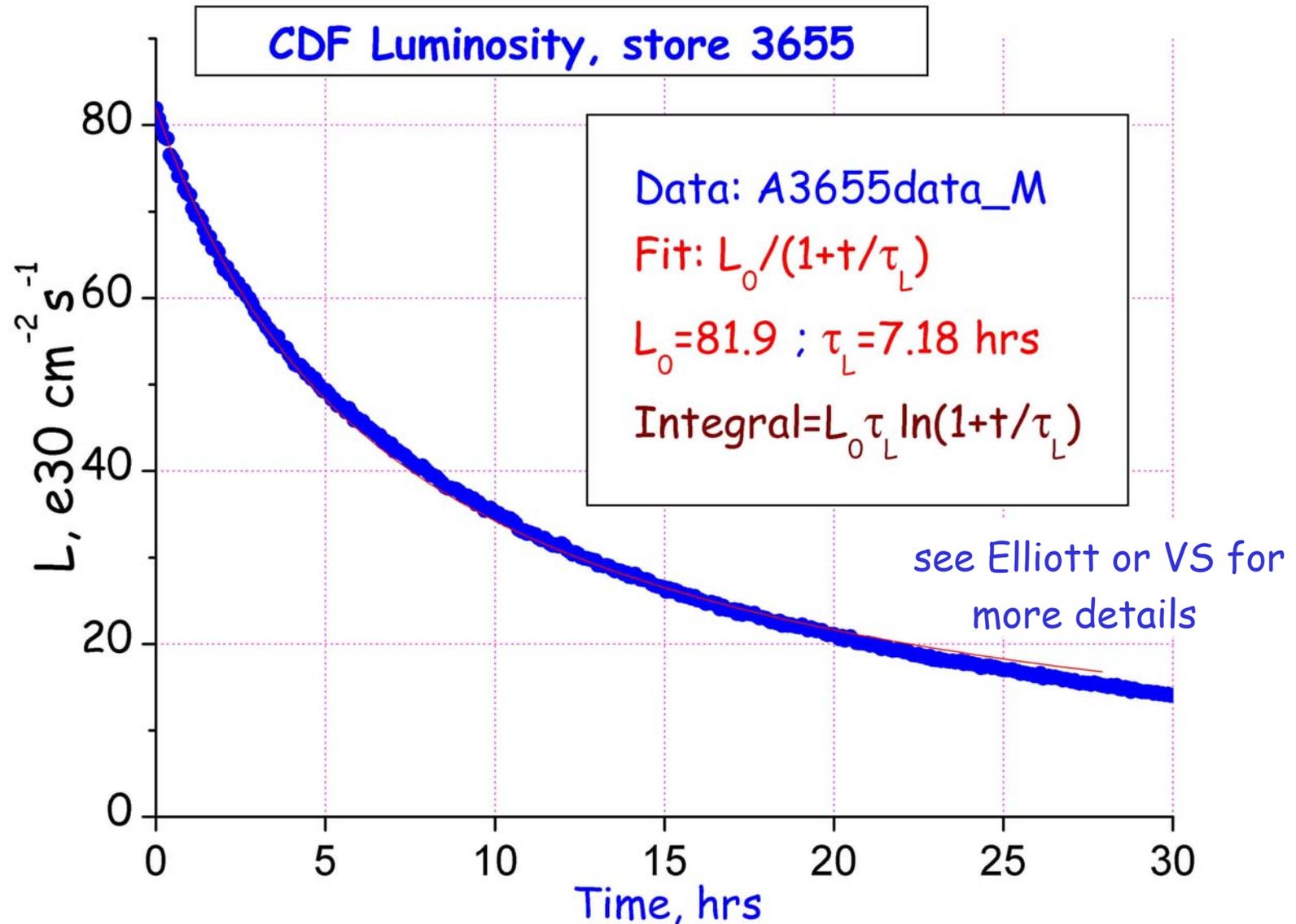
$N_{\text{pbar}} = 1556 \text{ e}9$   
From AA+RR  
 $L = 103 \text{ e}30$

"AA only" record  
 $N_{\text{pbar}} = 1265 \text{ e}9$   
 $L = 85 \text{ e}30$

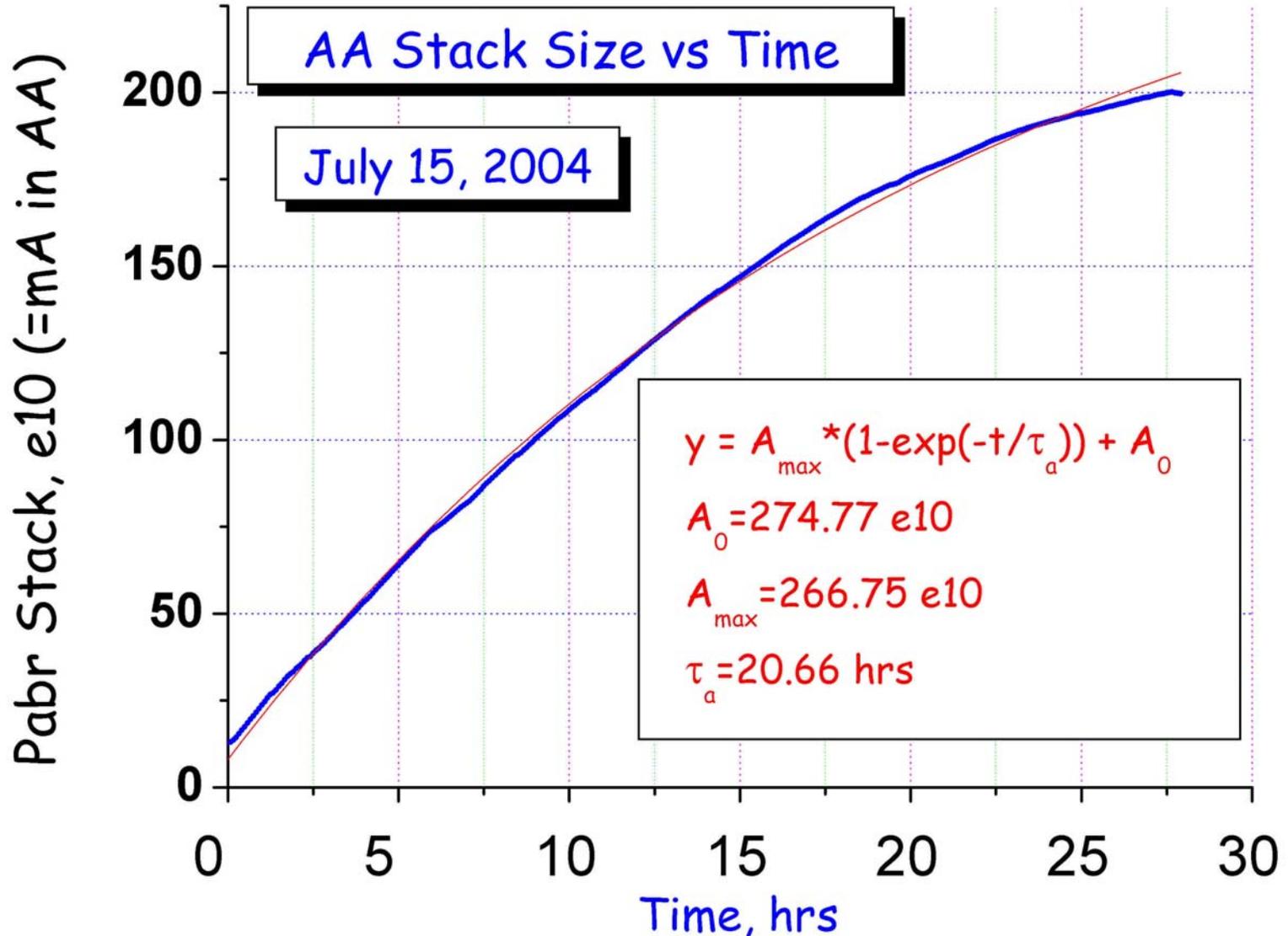
Seconds ONCE +

engineering units

# Integral: Log in time, $\propto L_0$ and Lifetime



# Integral: $N_a$ Exponentially Saturates



# Luminosity Integral

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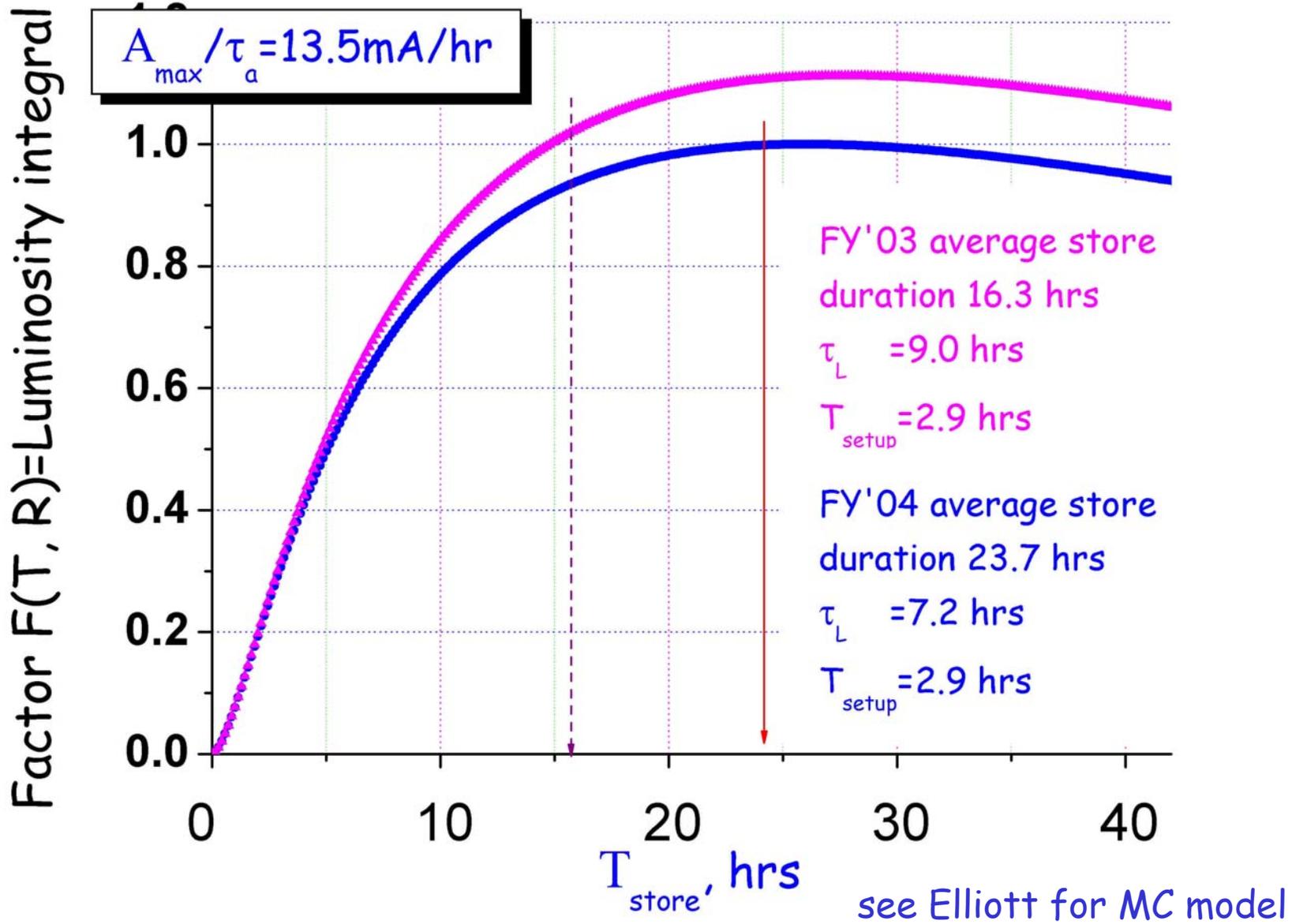
$$I = \int L dt = N_{stores} \tau_L L_0 \ln(1 + T / \tau_L)$$

$$\propto N_{weeks} \eta_{up} \frac{H\left(\frac{\sigma_l}{\beta^*}\right) N_p \eta_a A_{max}}{\beta^* (\epsilon_p + \epsilon_{\bar{p}})} F(T, \tau_L, \tau_A, \tau_{SS})$$

$$F = \frac{\tau_L}{T + \tau_{SS}} \ln(1 + T / \tau_L) [1 - \exp(-T / \tau_A)]$$

see next slide

# Store Length Optimization Factor $F$



# Luminosity Integral

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- Integrated Luminosity: primary factors
  - Peak Luminosity:
    - Max stack size and stacking rate
    - Pbar transfer efficiency
    - Beta\*, emittances, H(x), protons
  - Luminosity lifetime
  - # weeks x store time/wk
  - Store length optimization factor, setup time

# How to Reduce $\beta^*$ at CDF&D0?

Final results for optics correction see V.Lebedev, beams-doc-1311

Next changes were performed to correct optics and dispersion

B0Q2 and B0Q3 were decreased by 6 A

B0Q2: from 4722 to 4716

B0Q3: from 4666 to 4660

D0QT3 was decreased by 2.7 A from 24.06 to 21.3

QA42 was changed by -2.5 A from -44.24 to 46.86

AQ7\* was changed by -5 A from 607.4 to 602.6

CQ7\* was changed by -7 A from 607.4 to 600.9

DQ0 was changed by -3.5 A from 49.82 to 46.28

DQ7 was changed by -25.6 A from 680 to 654.4

\*AQ7 and CQ7 made minor dispersion correction in both IPs

**from the model:**

B0  $\beta^*47/42 \rightarrow 30/33 \pm 5\text{cm}$

D0  $\beta^*38/39 \rightarrow 33/30 \pm 2\text{cm}$

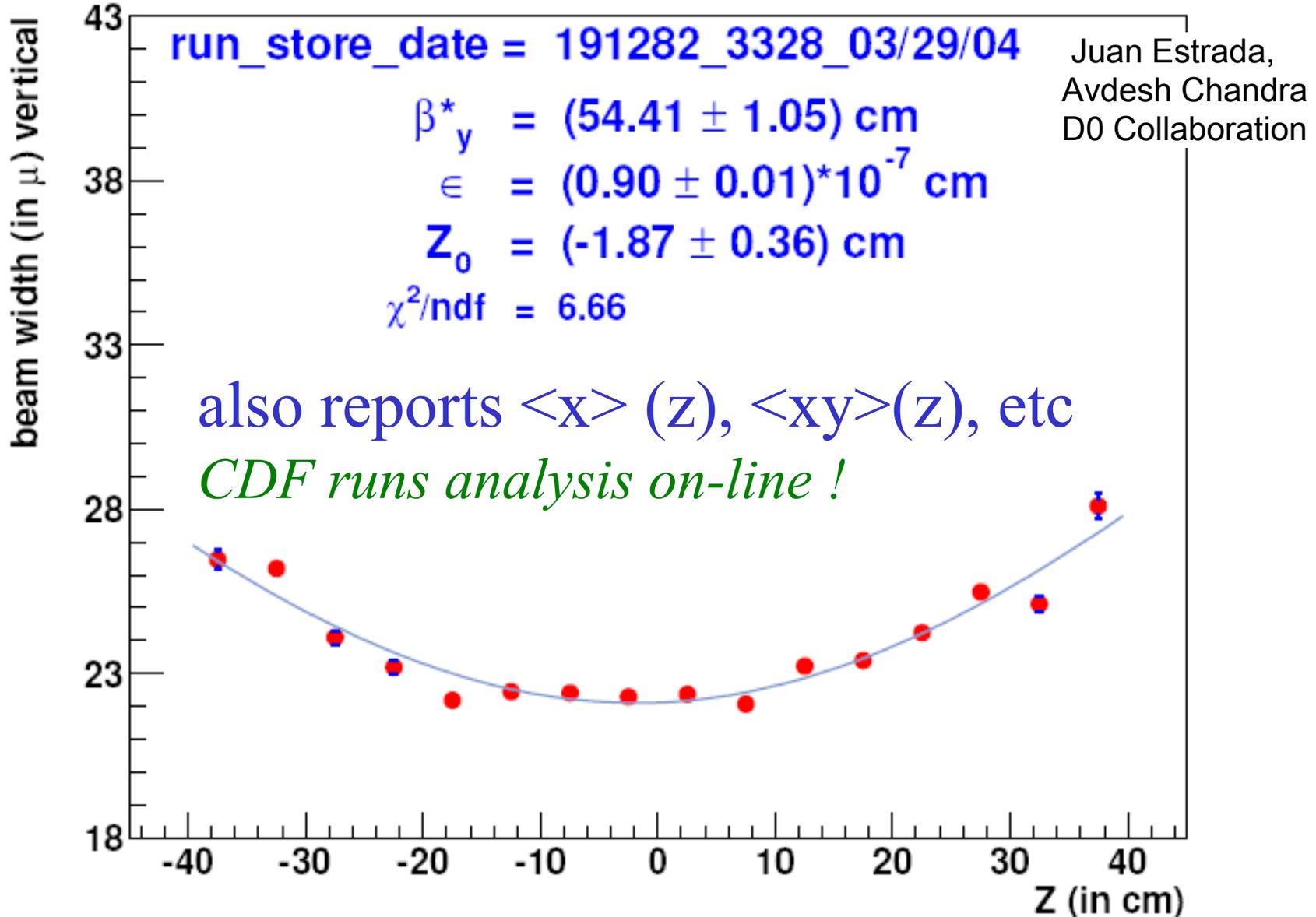
- Then do "alpha-bumps" (center waist z-position)
- Then optimize separators for head-on collisions
- Then adjust correction circuits
- Then fix all the mess (losses, etc)

Yuri Alexahin

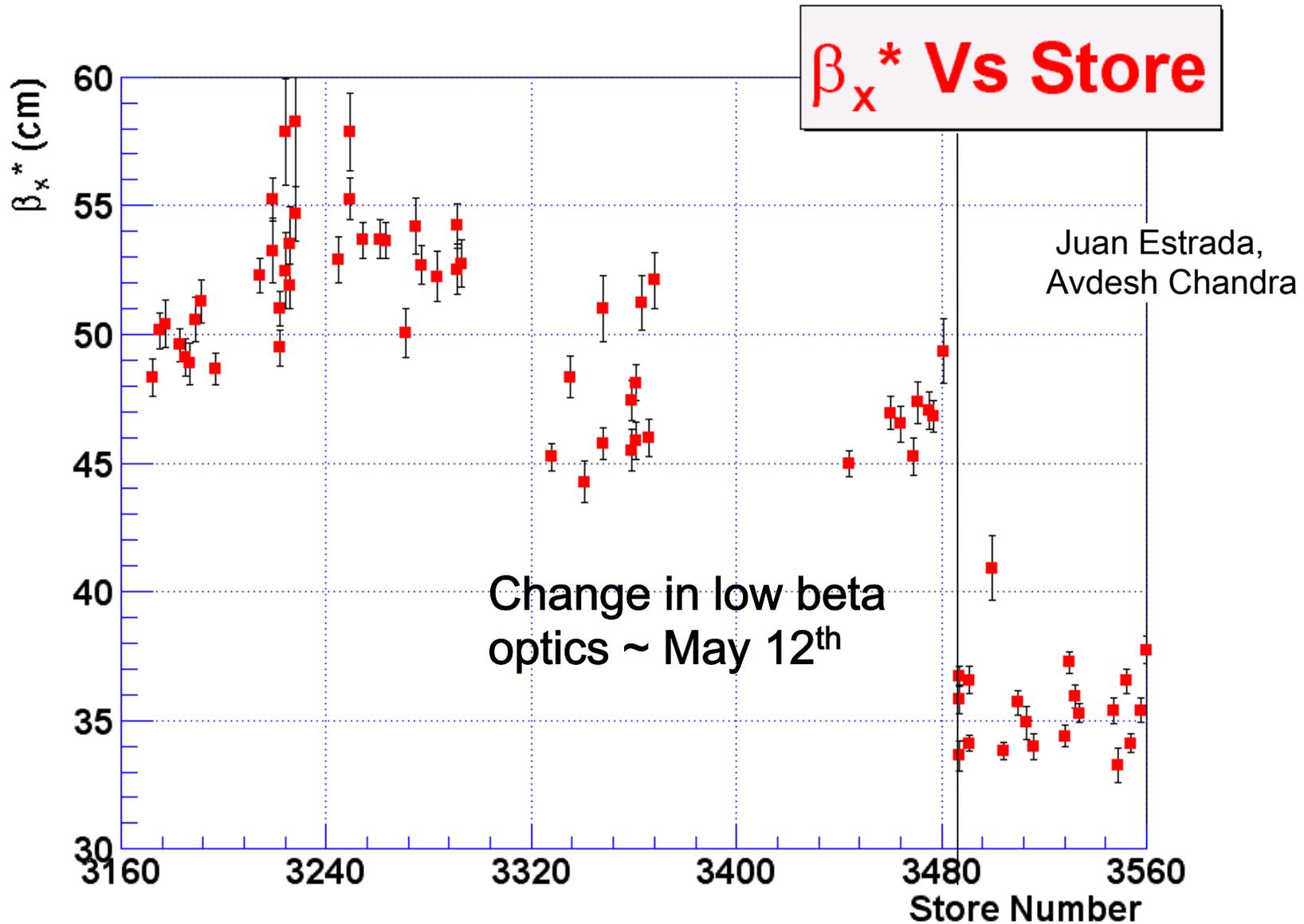
Jerry, Dean,

Coordinator, et.al

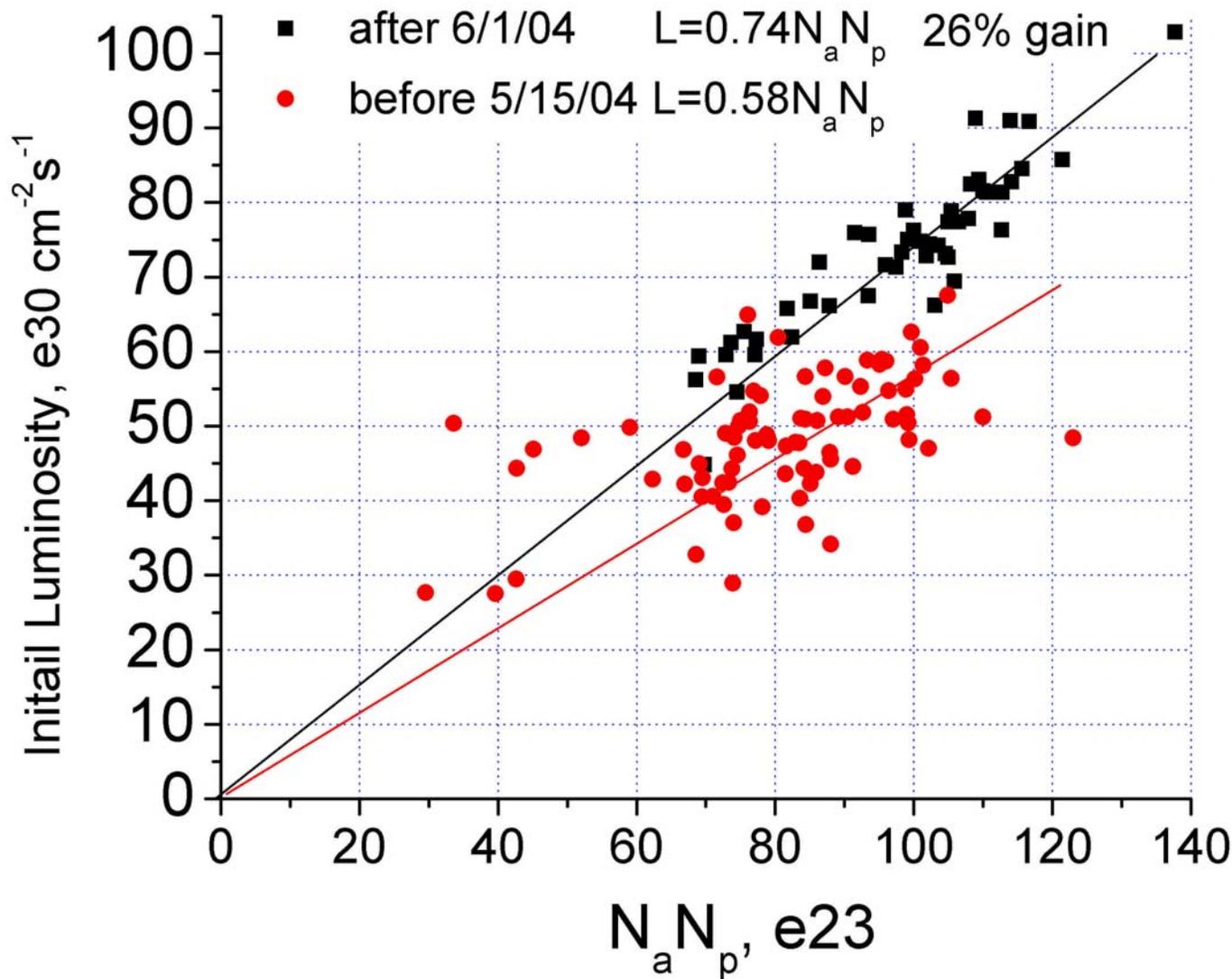
# $\beta^*$ from Luminous Region Analysis



# $\beta^*$ Reduction Confirmed by Detectors

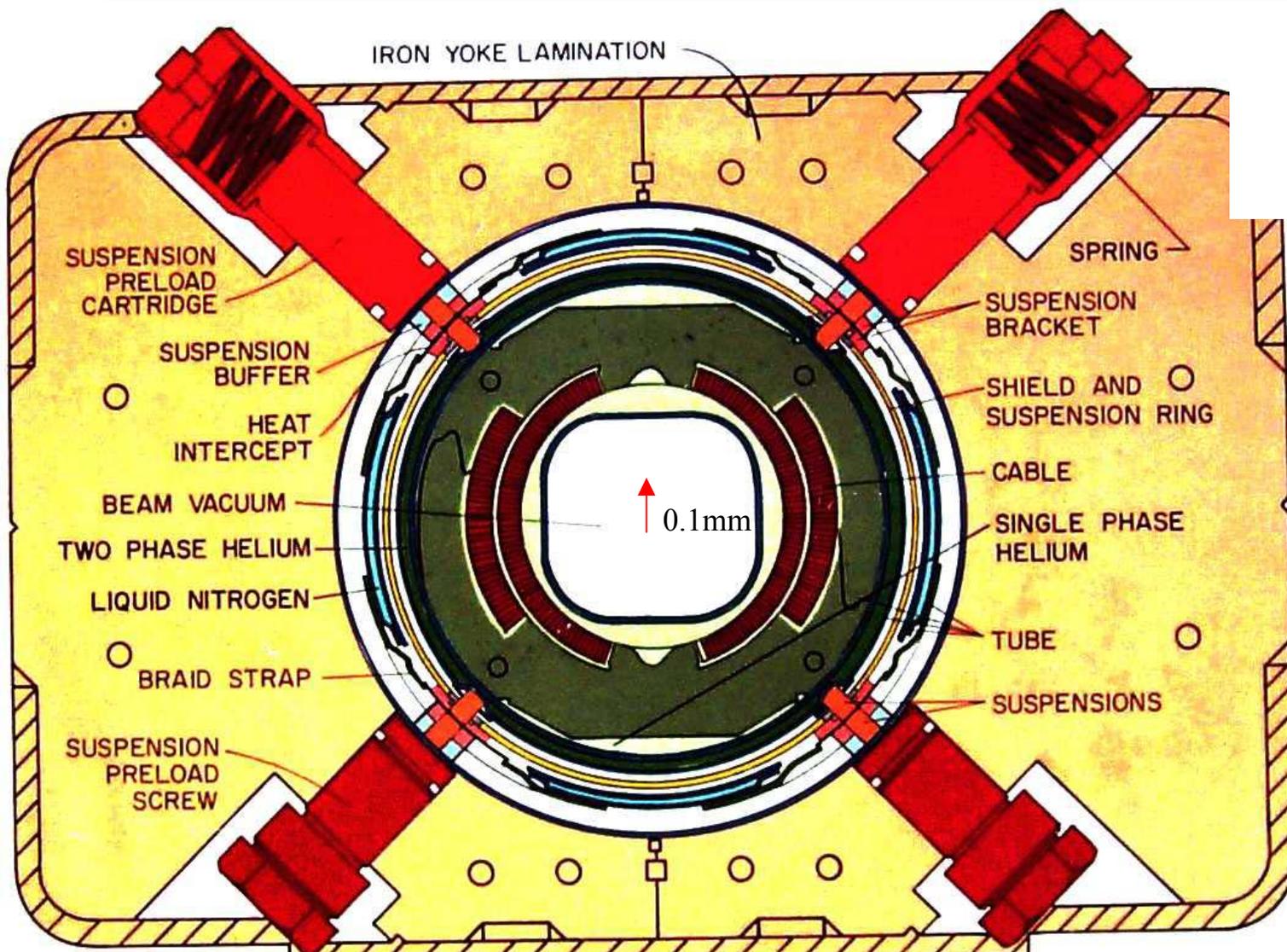


# ...and You Get 26% in Peak Luminosity



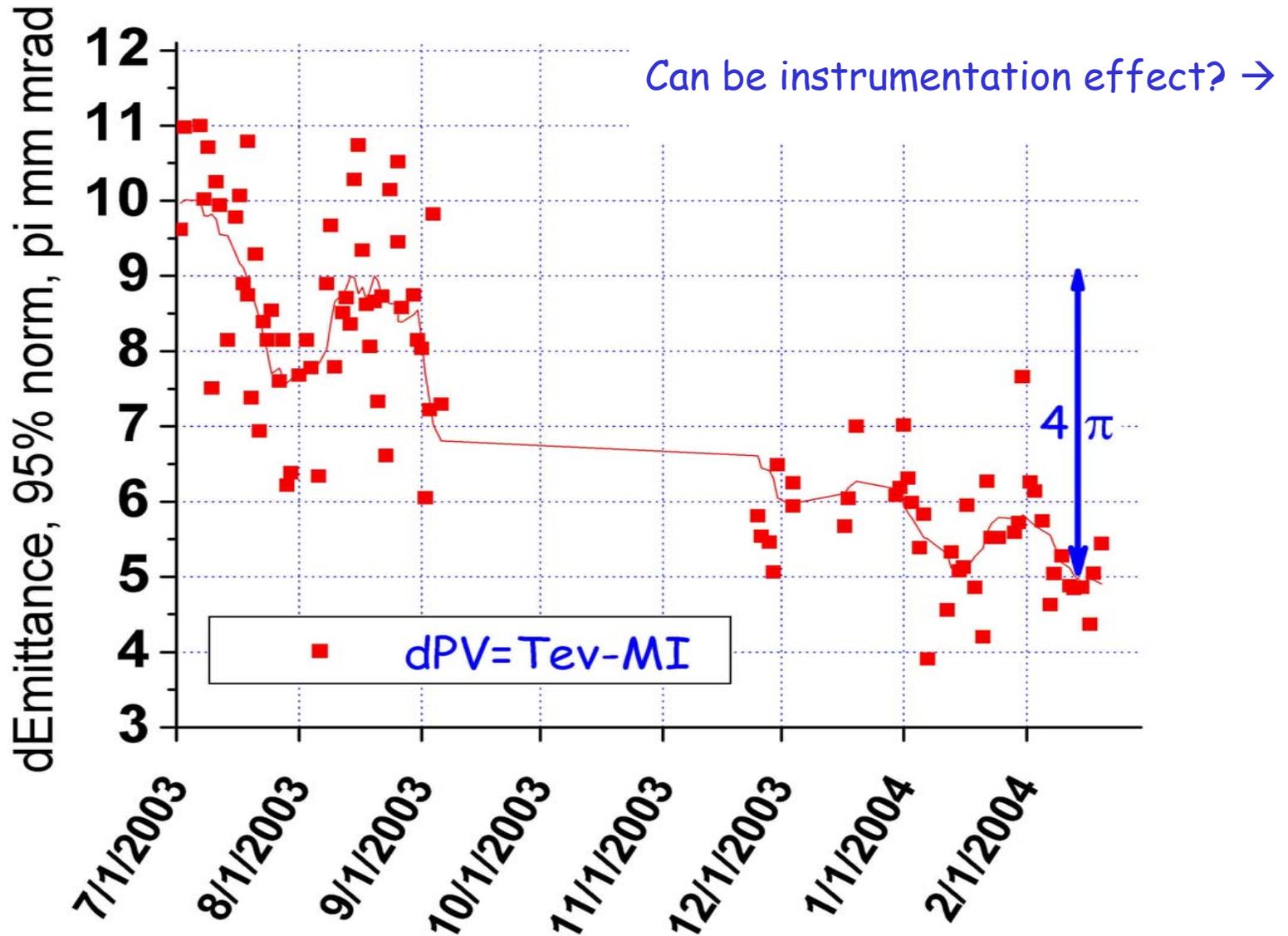
# Reshimming=Lifting Up SC Coils

M.Syphers,  
D.Harding,TD  
team

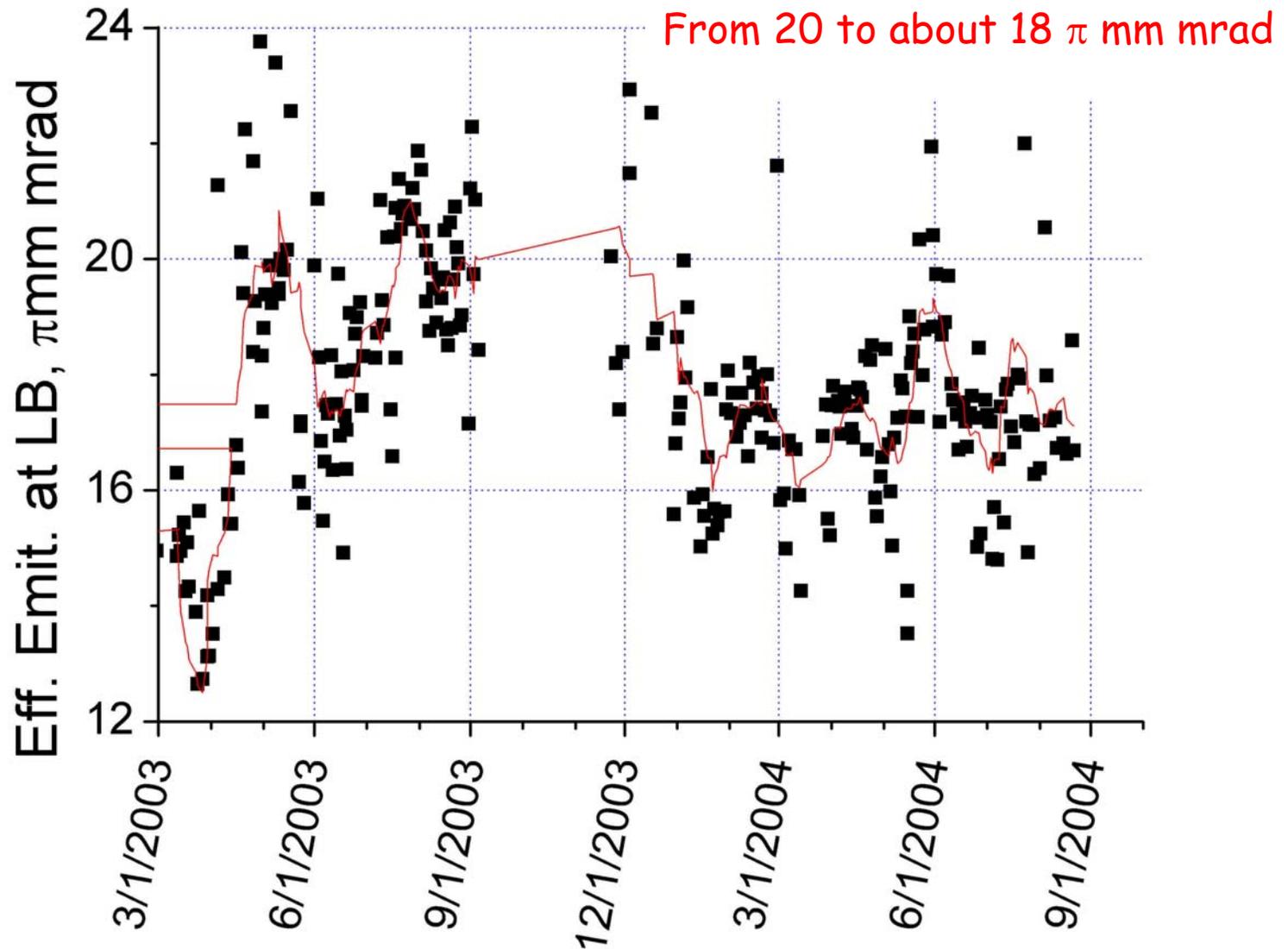


Reshimming of 108 most needed dipoles were supposed to reduce  $d\epsilon$  at inj

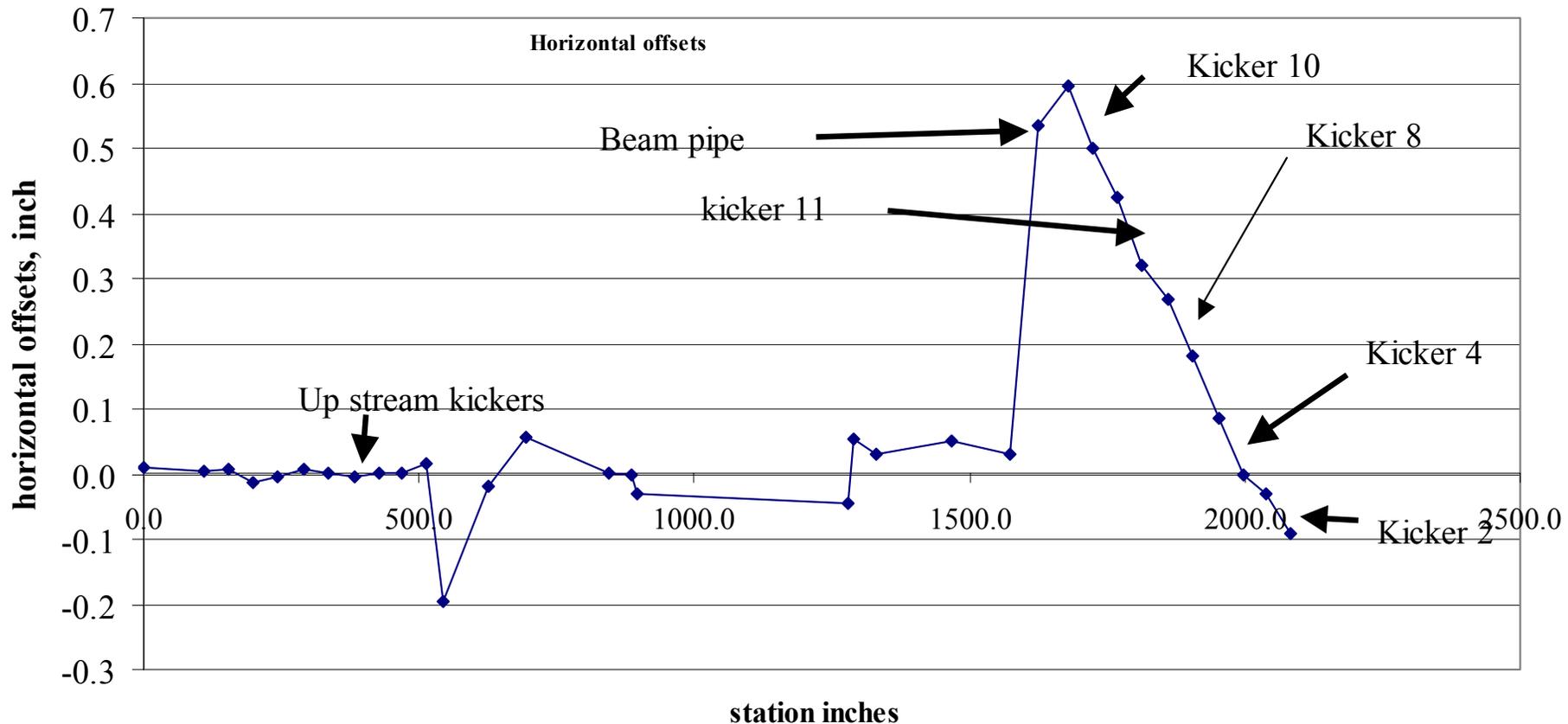
# Emittance Dilution in MI $\rightarrow$ Tev Transfer



# Seen Well in Luminosity



# Alignment: Open Apertures

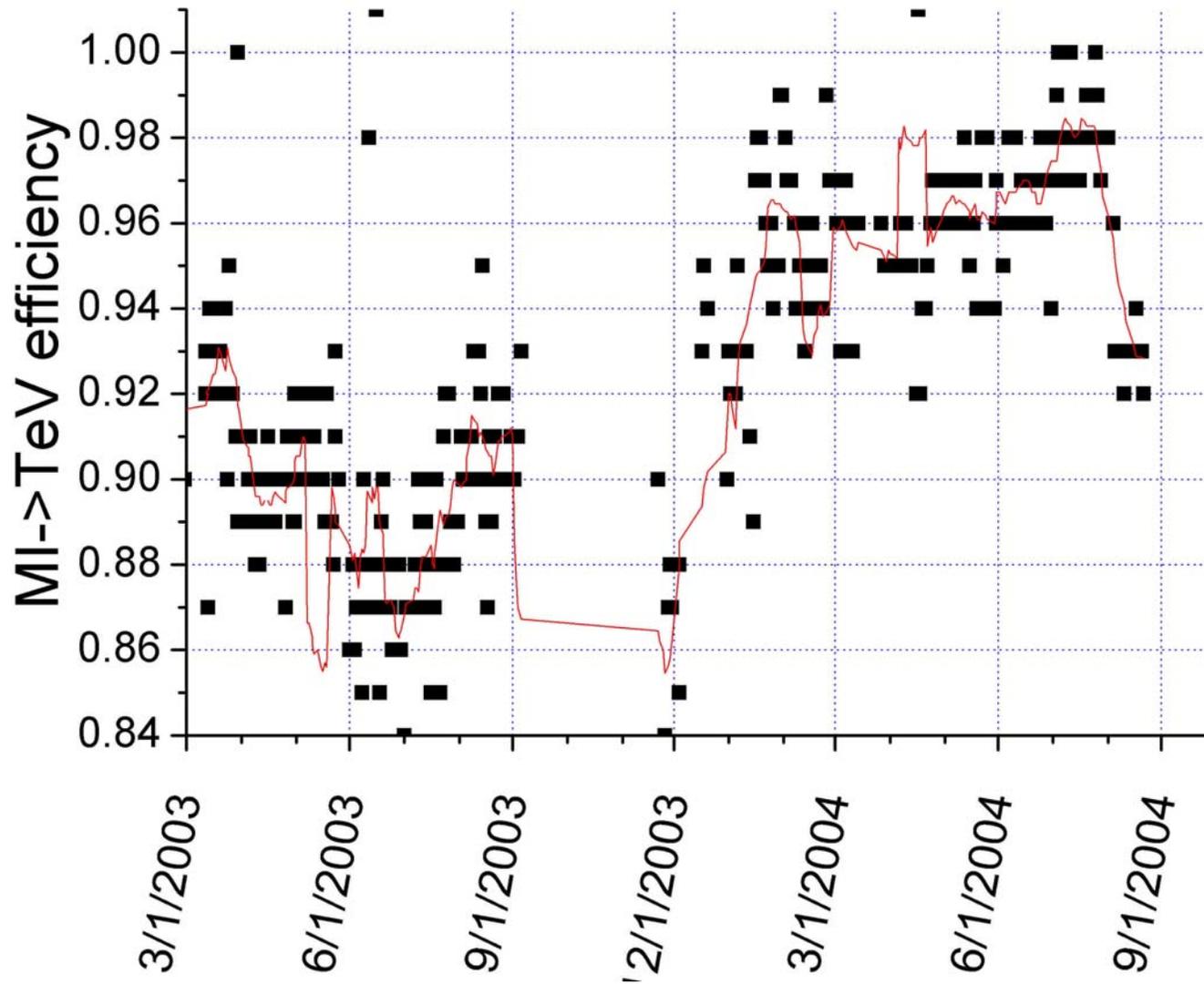


- Another  $\frac{1}{4}$ " misalignment fixed at D0
- Rolls  $>2\text{mrad}$  ~complete
- # of dipole correctors running  $>35\text{A}$  out of  $50\text{A}$ :  $26 \rightarrow 6$

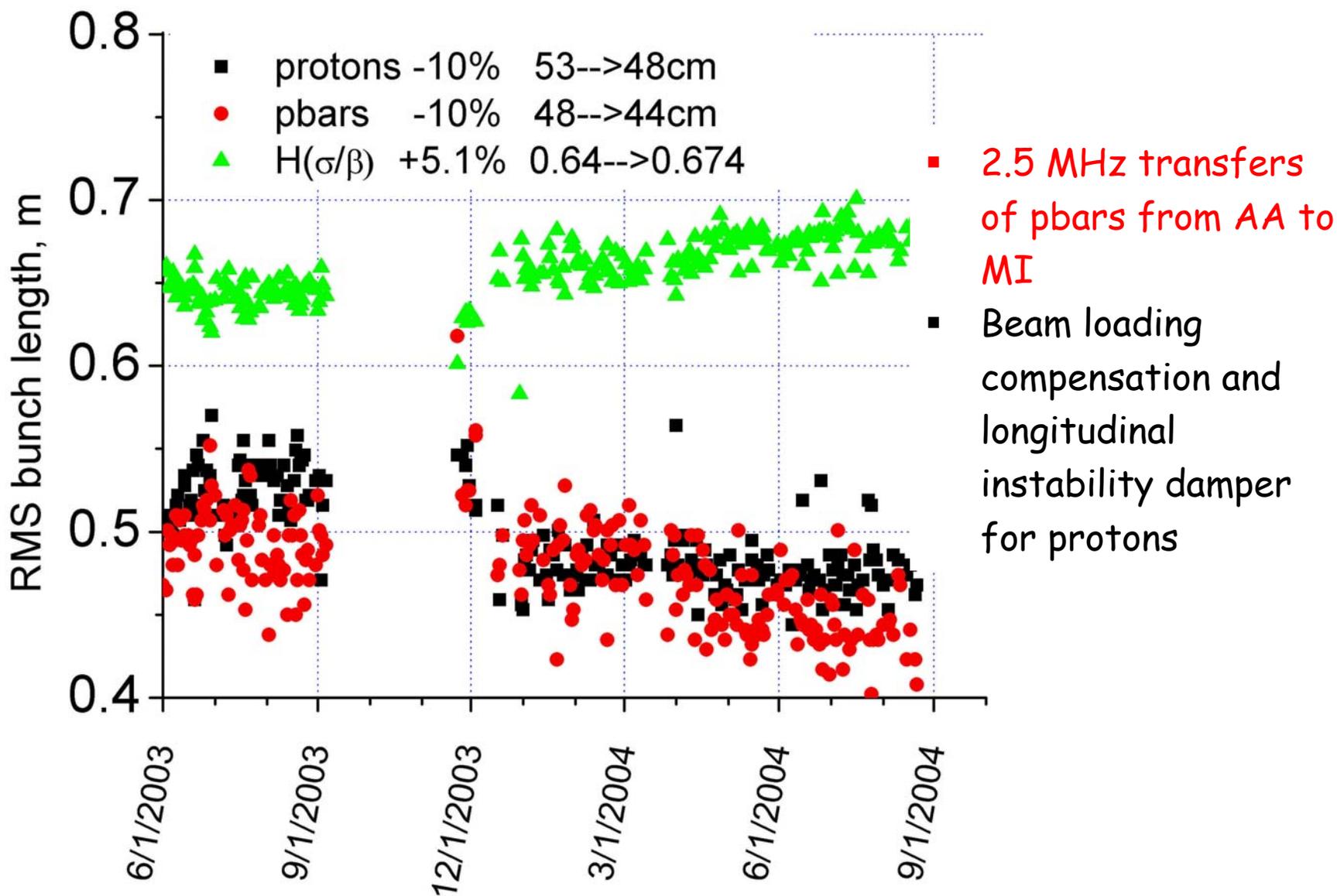
# Alignment: What it really means...



# All That Pays Off in Transfer Efficiency



# Hard Work of MI Pays Off, Too!

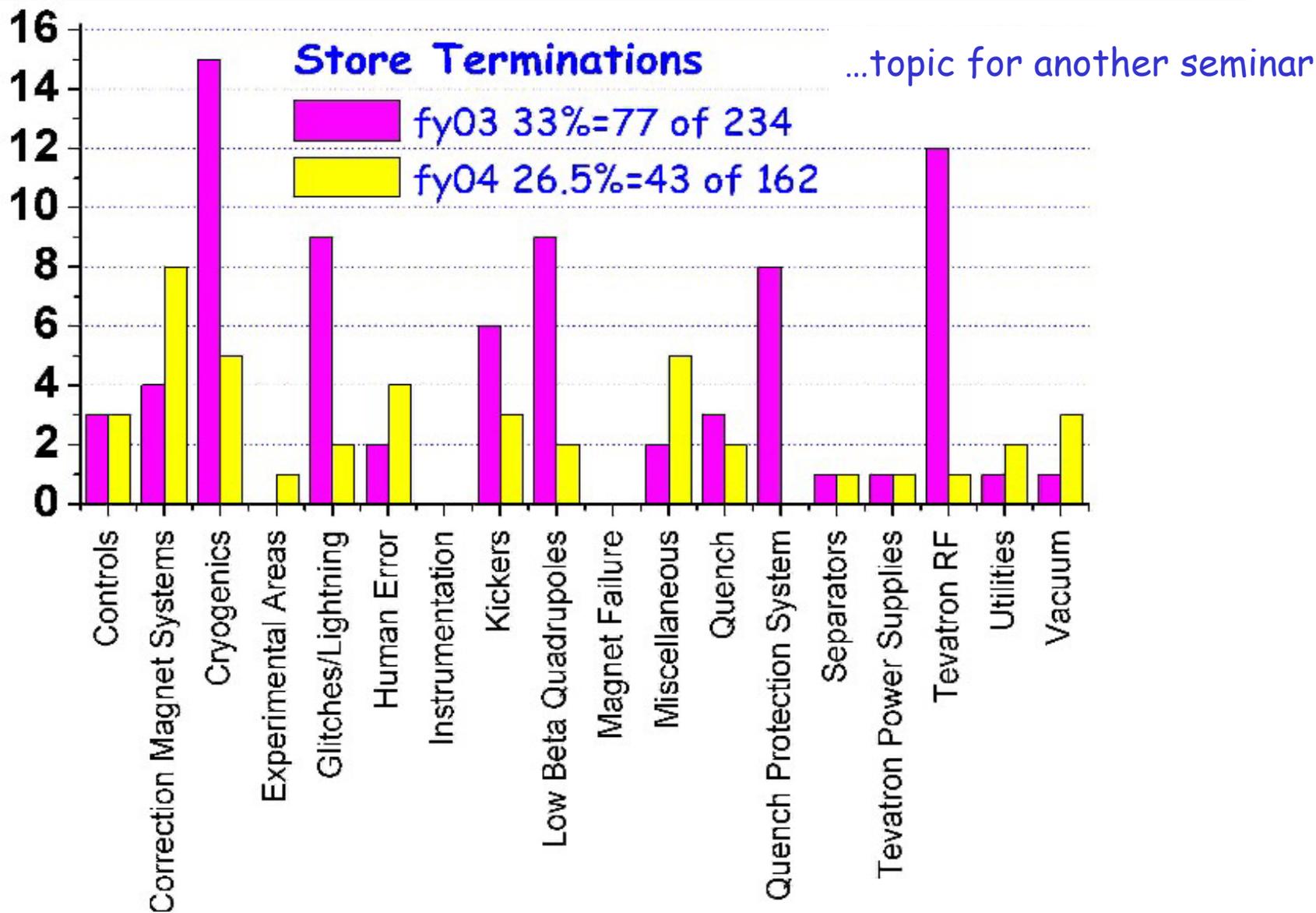


# Another Factor: Machine Availability

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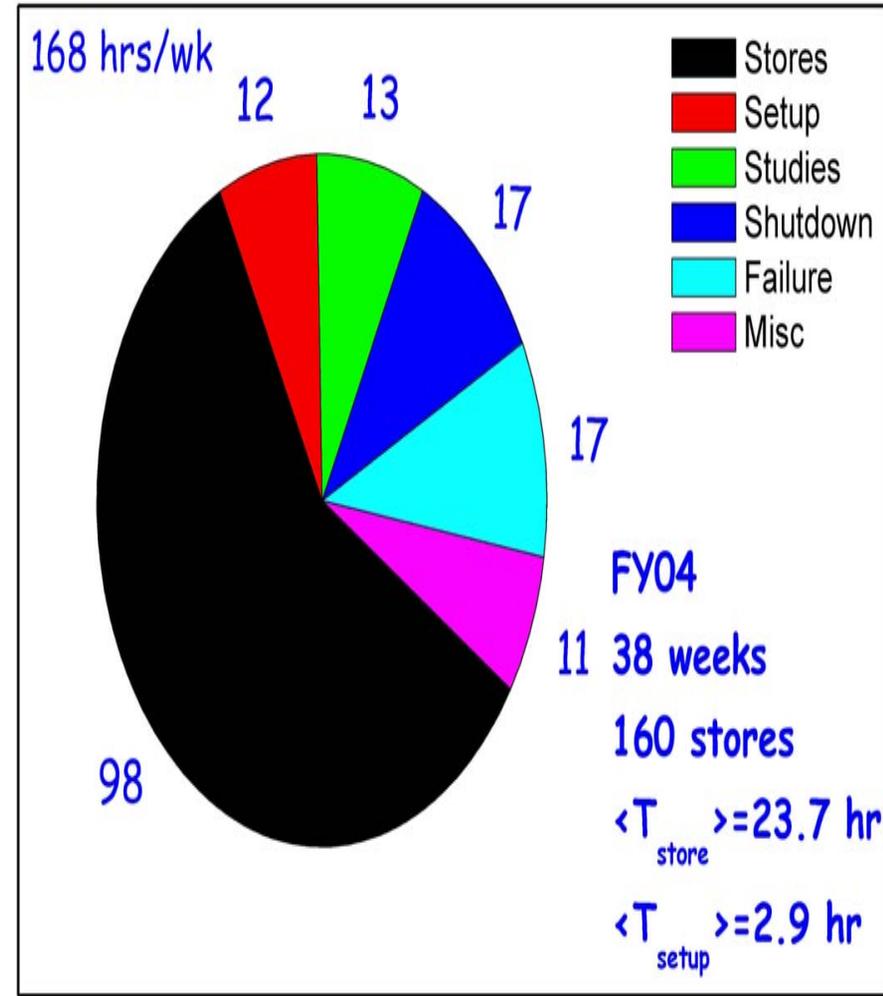
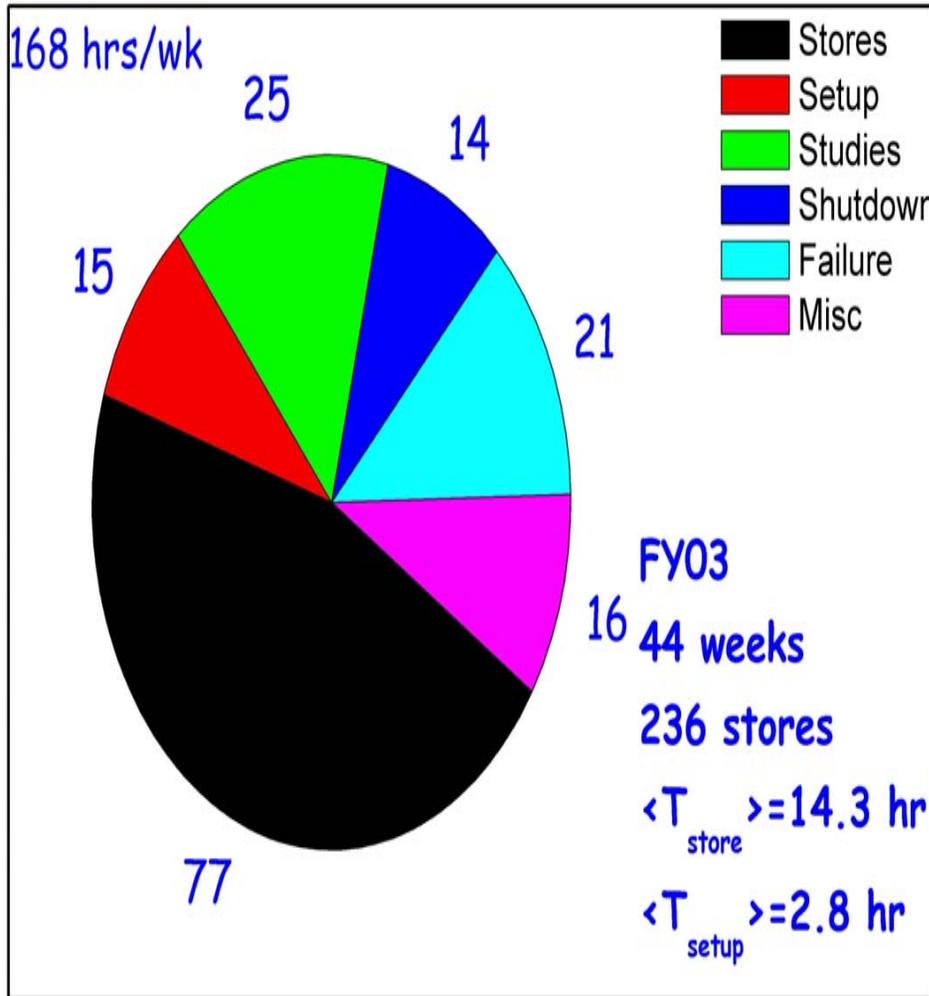
- In FY04 we had lost (major events, "L-to-L" time):
  - 21 days - magnet failures in Dec
  - 13 days - AA Cooling Upgrade in March
  - 3 days - power glitch in May
  - 2 days - searching for ground fault in Aug
- We ran for 38 weeks vs 44 in FY03
- Still, the total store time went up 4% - ??
  - better reliability
  - 2-times reduction of beam studies time
  - "proton stabilization"
  - preventive measures and "helpful" diagnostics

# Store Termination Statistics

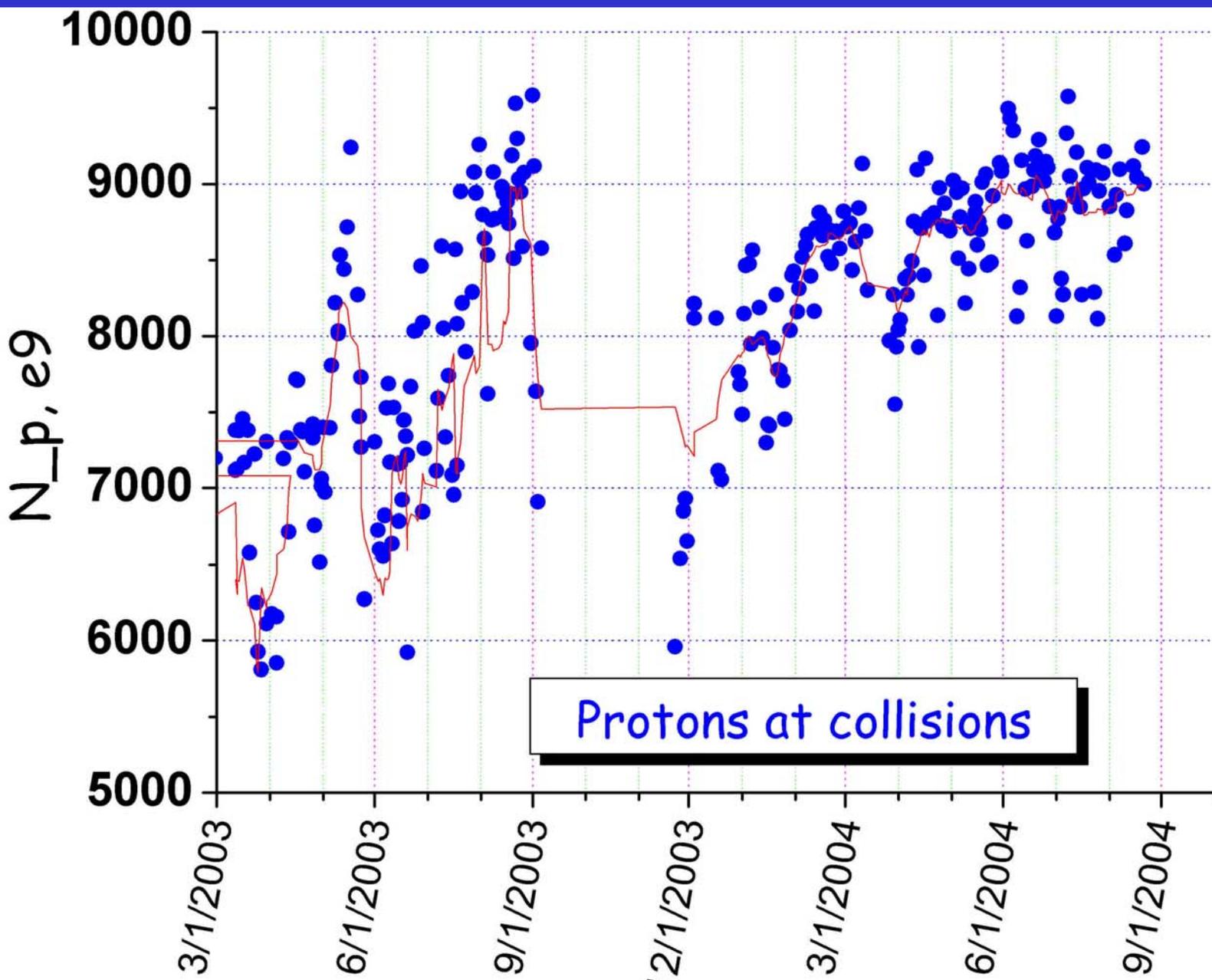


# Tevatron Time Breakdown

Courtesy of J.Crawford



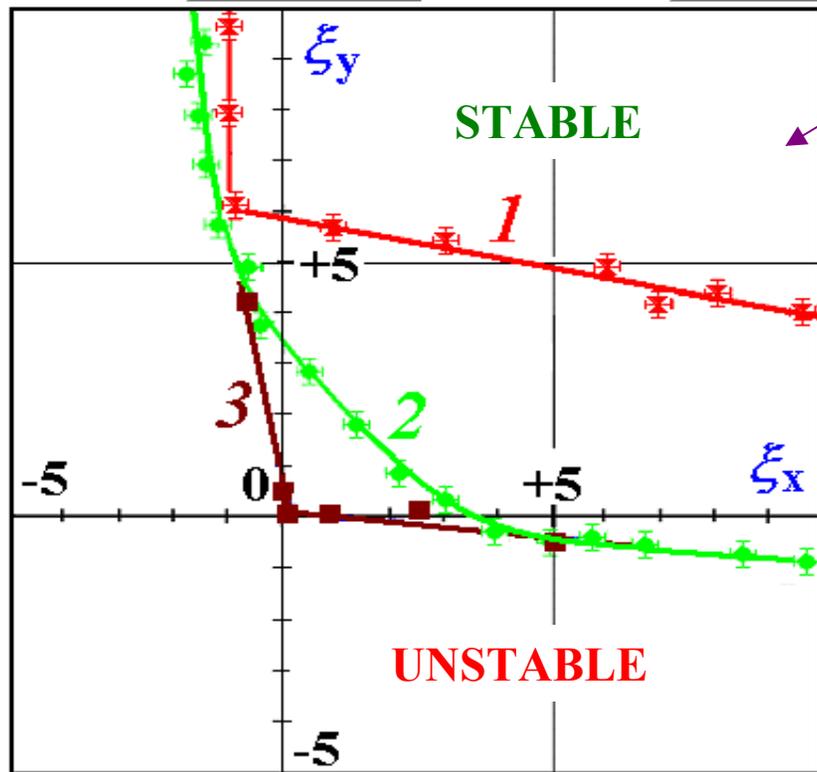
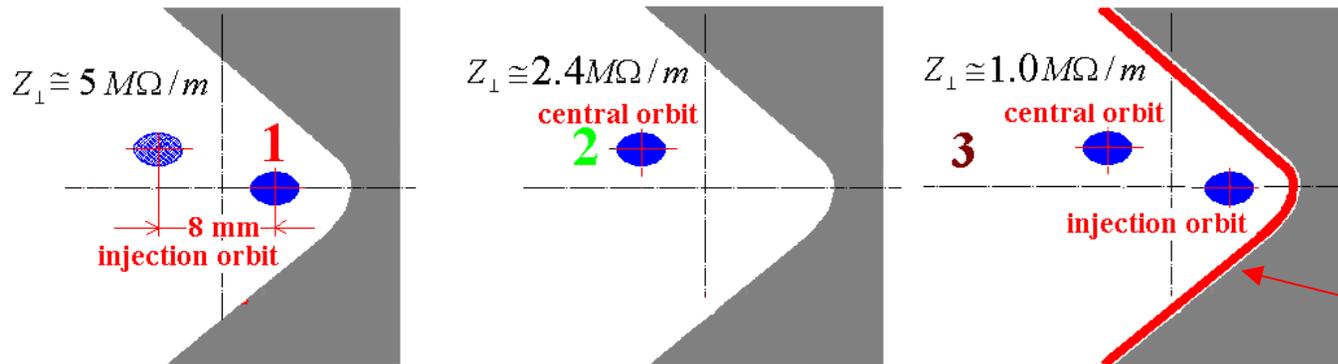
# Proton Intensity Stabilized in FY04



# Tevatron Impedance Reduced by Liners

P.Ivanov  
A.Burov  
A.Chen

0.4 mm liner  
CuBe (98+2%)



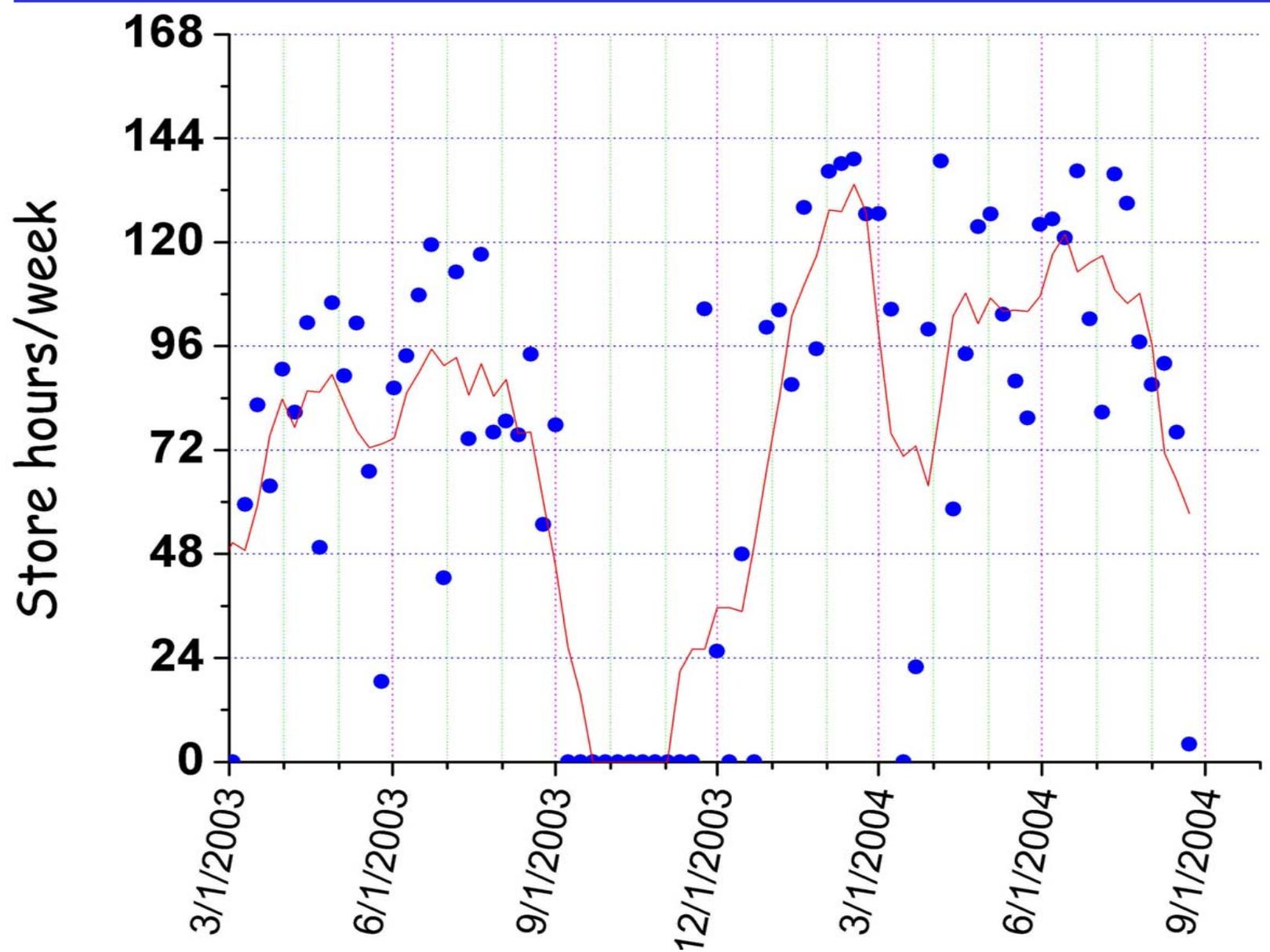
Region of stability of high intensity coalesced bunches ( $\sim 230e9$ ) on chromaticity plane before (#1 and #2) and after (#3) installation of conducting liner in F0 Lambertson magnets

Total transverse impedance reduced from 5-2.4 MOhm/m to 1 MOhm/m

Losses at 150 ~ Chromaticity 4  $\rightarrow$  2

Octupoles for safety at  $C_{vh}=0$

# Fantastic! - 140 Store-Hours a Week!

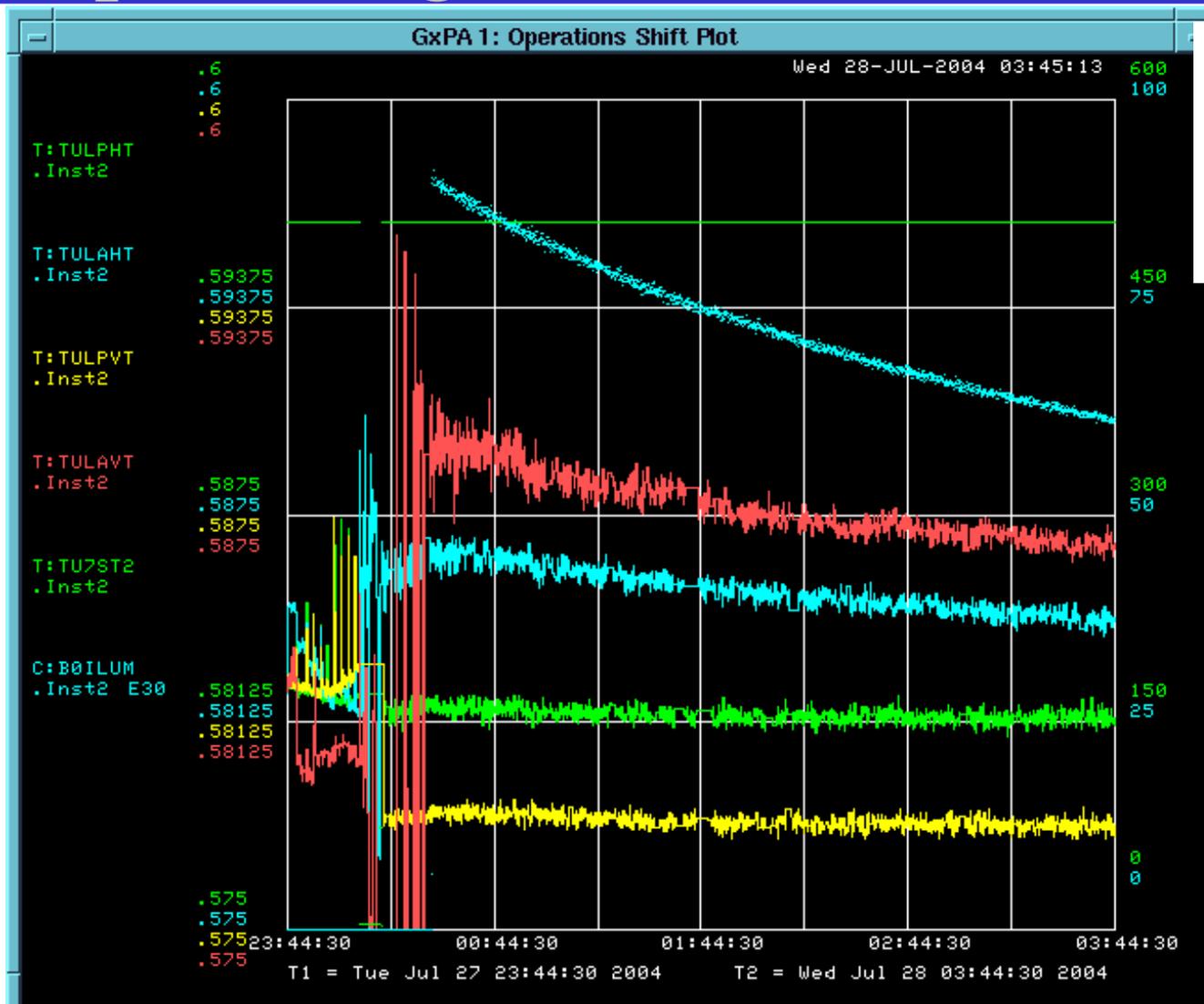


# Other Helpful Actions

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- S3 circuit used to increase differential p- pbar tune at LB
- Double scrape
- QPM code upgrade for faster quench detection (16→2 ms)
- A48collm 3 mm closer to beam
- AGM and 1.7 GHz Schottky <sup>slide</sup>

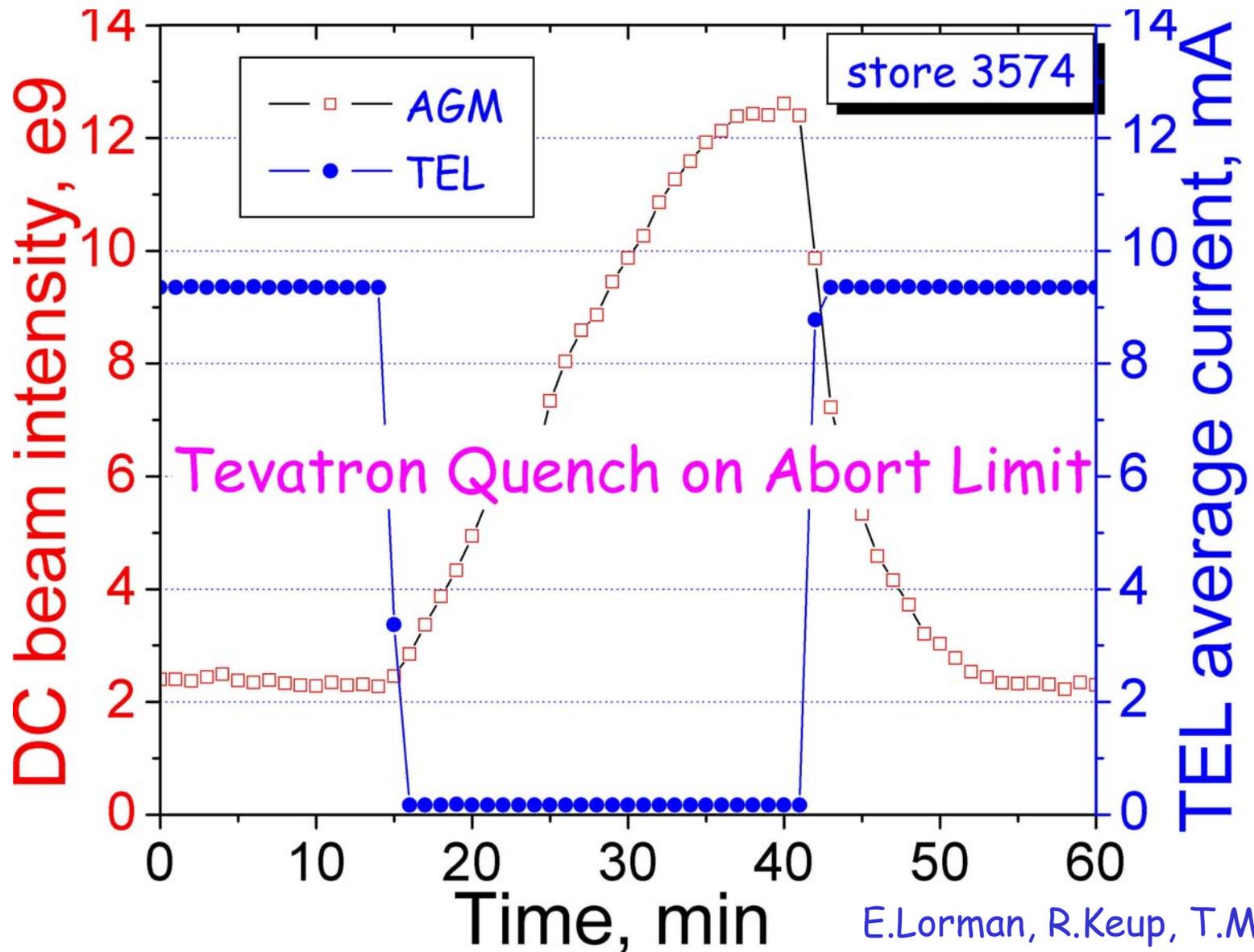
# Helpful Diagnostics: 1.7 GHz Schottky



R.Pasquinelli  
A.Jansson  
P.Lebrun

On-line  $P$  and  $P_{bar}$  tune measurements help to reduce tuneup time at LB

# Abort Gap Monitor





# Compare with Other Hadron Colliders

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FNAL-Conf/04-126

*Average time to  
double luminosity*      *L, e30*

Tev Run I	8 mos	25
Tev Run II a	12 mos	103
ISR Run I	13 mos	32
SppS	17 mos	5.5
RHIC	18 mos	58
HERA	30 mos	35
ISR Run TT	36 mos	140 <sup>1982</sup>

...so, Tev is the fastest growing h-machine

# Another Look: FY04 vs FY03

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+45% in Integrated Luminosity=

18  $\pm 3\%$  from beam studies

14  $\pm 3\%$  from shutdown work

12  $\pm 3\%$  from reliability and  
up time

# *“Country Should Know Its Heroes!”*

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beta\* reduction - Valery Lebedev and Jerry Annala

Reshimming - Mike Syphers, Dave Harding and TD

CDF IP move - Mike Syphers, Valery and Norm Gelfand

S3 circuit at LB - Yuri Alexahin and Jerry Annala

Alignment - Jim Volk & Task Force (R.Stefanski)

FO Lambertson liners - Alex Chen and Petr Ivanov

AGM - Randy Keup, Eugene Lorman, Tom Meyer

1.7GHz Schottky - R.Pasquinelli, A.Jansson, P. Lebrun

Double scrape - Dean Still

Shorter bunches - Main Injector

# So, What's In FY'05?



1952

“Life is Merrier with Every Day!”

# FY'05 Goals

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DOE/CDF/D0      Goal:

470 pb-1/yr

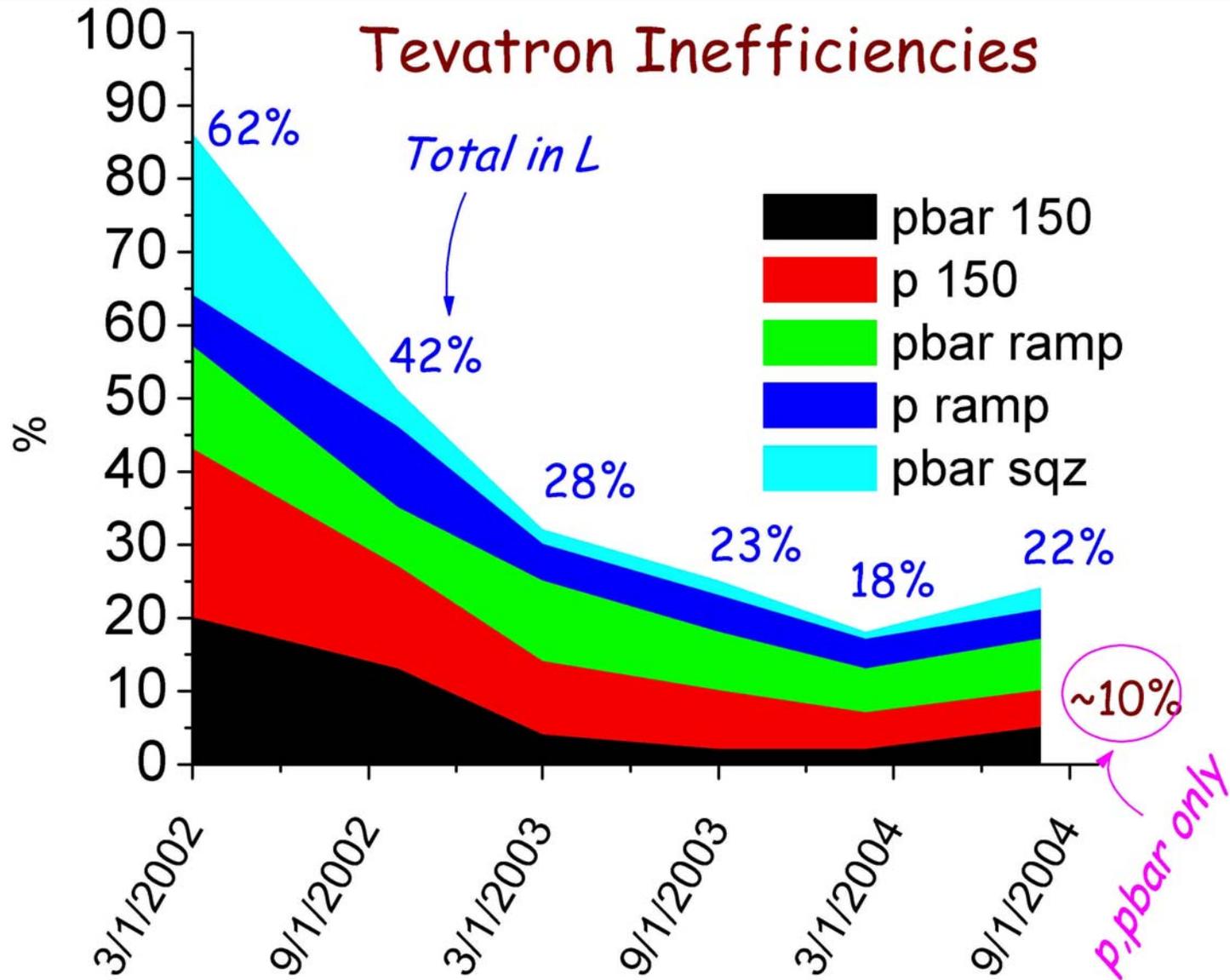
Goal for Tev: break ISR record

140e30 cm-2 s-1

# What the Tevatron Can Contribute:

- Improve Transfer Efficiency 10-12%
- Reduce Emittances and  $\beta^*$  10-12%
- Improve Lifetime 7-9%
- Improve Availability 3-5%

# Total $N_a N_p$ Inefficiency in Tevatron



# How to Improve Efficiencies

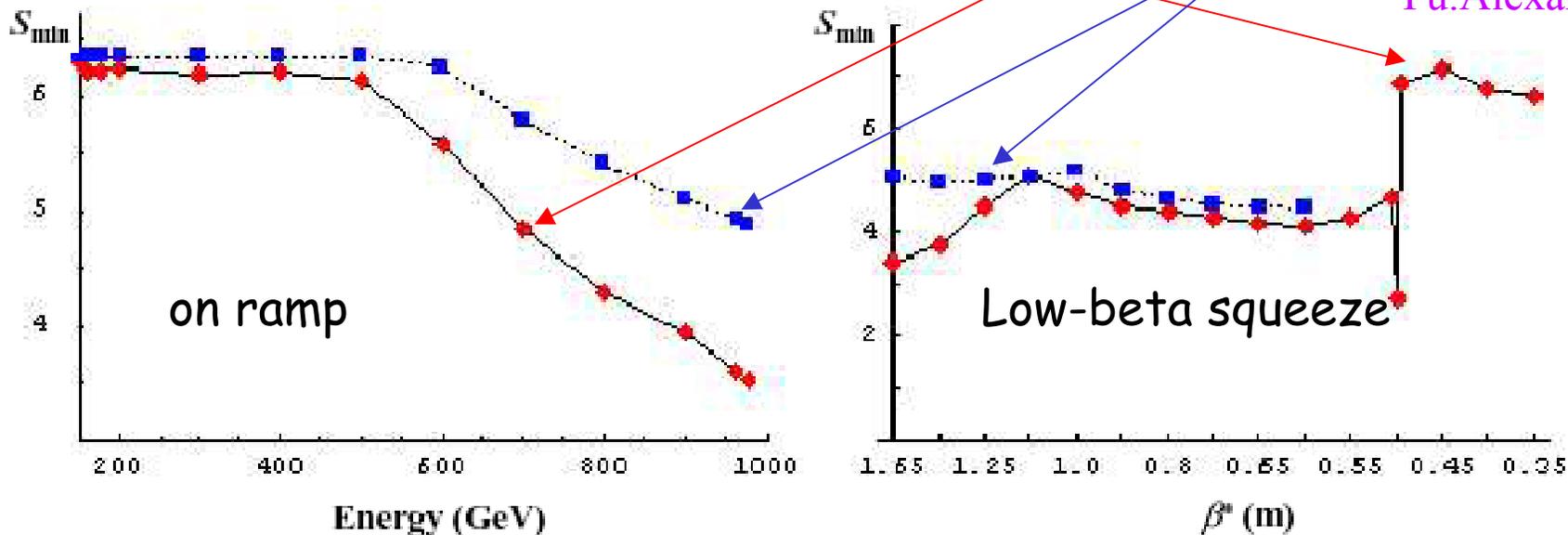
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- Drop Chromaticity at 150:  $Q'=2-4$  to 0
  - Use octupoles pending study time
- Drop Chromaticity on ramp:  $Q'=8-16$  to 0
  - Use transverse dampers pending study time
  - Or use octupoles pending study time
  - Proper b2-snapback compensation almost there
- Larger Separation on Ramp and Squeeze slide
  - Use new separators two installed at D17
  - Increase separator voltages R&D MP9, studies
- Open Apertures
  - Separators around IPs shutdown

# Separation Smaller on Ramp & Squeeze

Minimum beam-beam separation in sigmas: old vs "5-star" (08/03)

Yu.Alexahin



Tune shift  $dQ = \sum \frac{2\xi}{S^2}$  where  $S = \frac{d}{\sigma}$  - separation is sigma's

note that  $d \propto V/\gamma$  while  $\sigma \propto \sqrt{1/\gamma}$

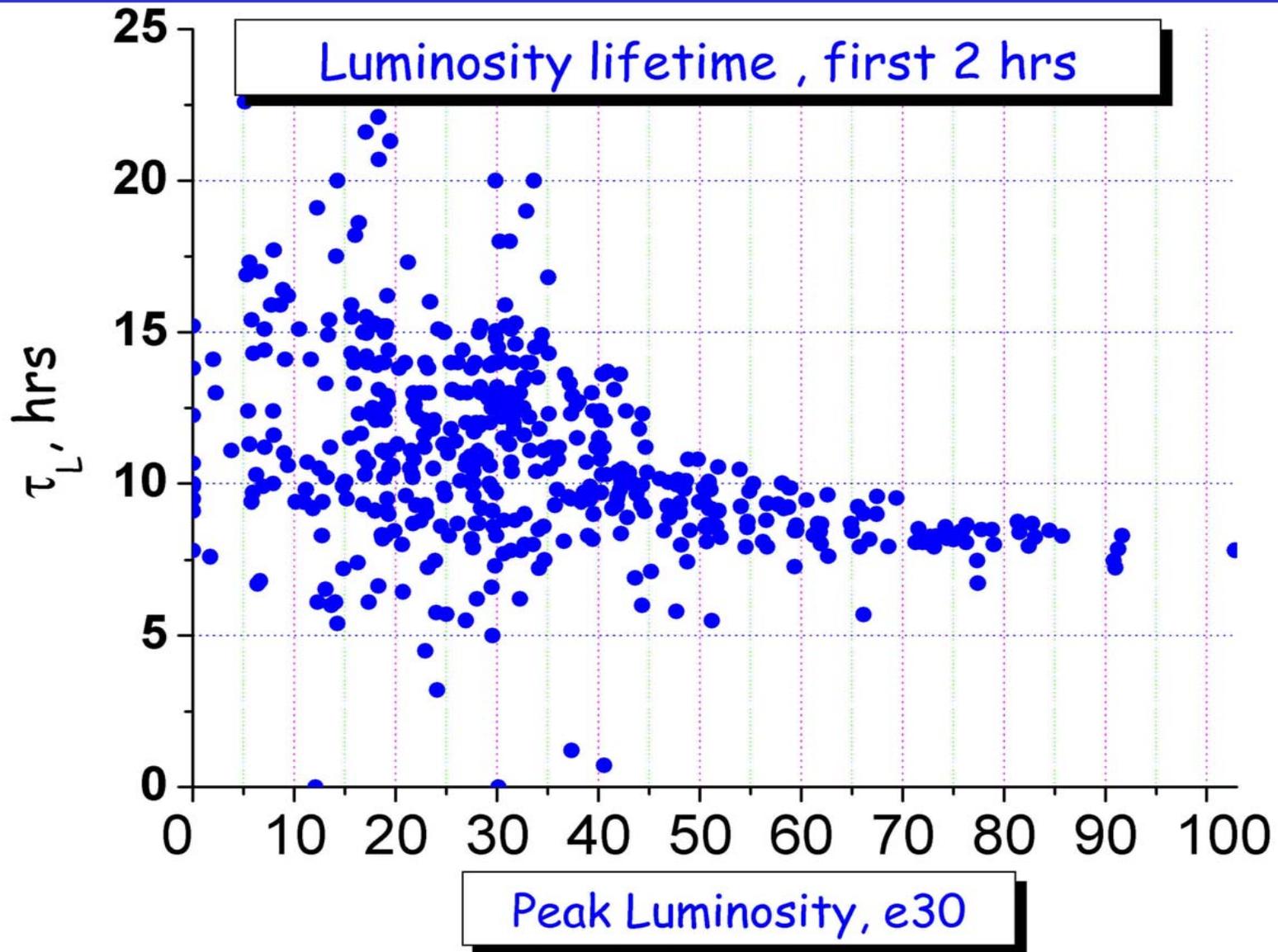
one needs  $V \propto \sqrt{\gamma}$  i.e. increase by  $\sqrt{\frac{980GeV}{500GeV}} = 1.4$

# Reduce IP Size: $\beta^*$ and Emittances

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- $\beta^*$  reduction from 33 to 28 cm
  - 8% in peak Luminosity      modeling  $\rightarrow$  study time
- Commission injection dampers
  - Bunch-by-bunch,  $0.5-2\pi$  for pbars,  $0.25\pi$  for protons
  - ~2% in peak L      pending study time
- Fix coupling at D16
  - Reduce  $D_y$  from 0.6  $\rightarrow$  0.3 m
  - 0.5% in peak L      shutdown
- Improve vacuum by 20%
  - $4\pi/\text{hr} \rightarrow 3.2\pi/\text{hr} = 1\%$  in peak L      shutdown(s)

# Luminosity Lifetime is a Big Issue



# Lifetime Constituents

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$$\tau_L^{-1} = \tau_\varepsilon^{-1} + \tau_a^{-1} + \tau_p^{-1} + \tau_H^{-1}$$

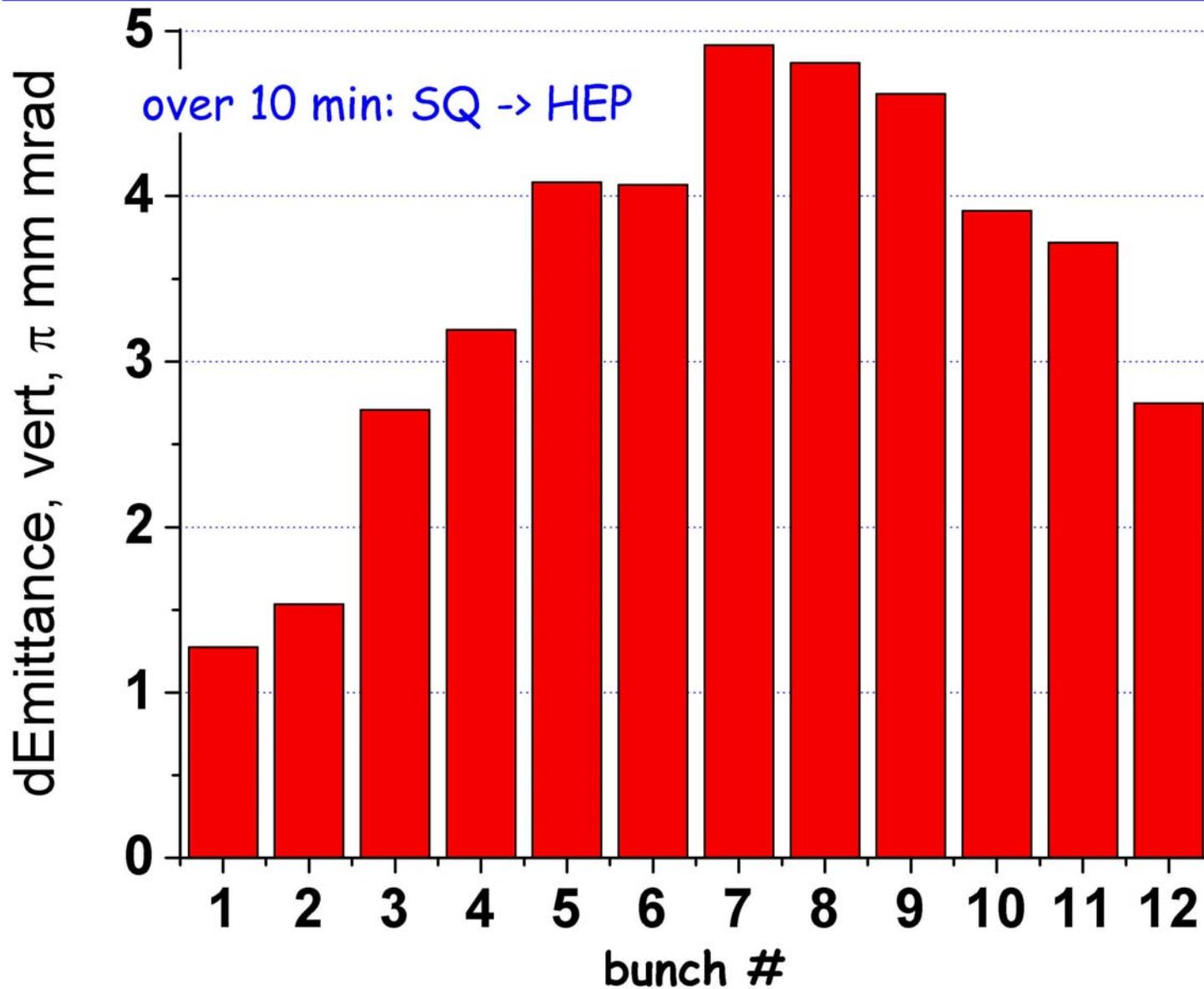
(15-20) + (20-25) + (35-210) + (70-80) = (7.5-9.0)hrs

- Emittance growth = 90% IBS + 10% Beam-Beam Effects slide
- Pbar lifetime = (70-80)% burnup + (20-30)% Beam-Beam slide
- Proton lifetime = 80% Beam-Beam + 20 % burnup slide
- Houghrass lifetime = 90% IBS + 10 % Beam-Beam

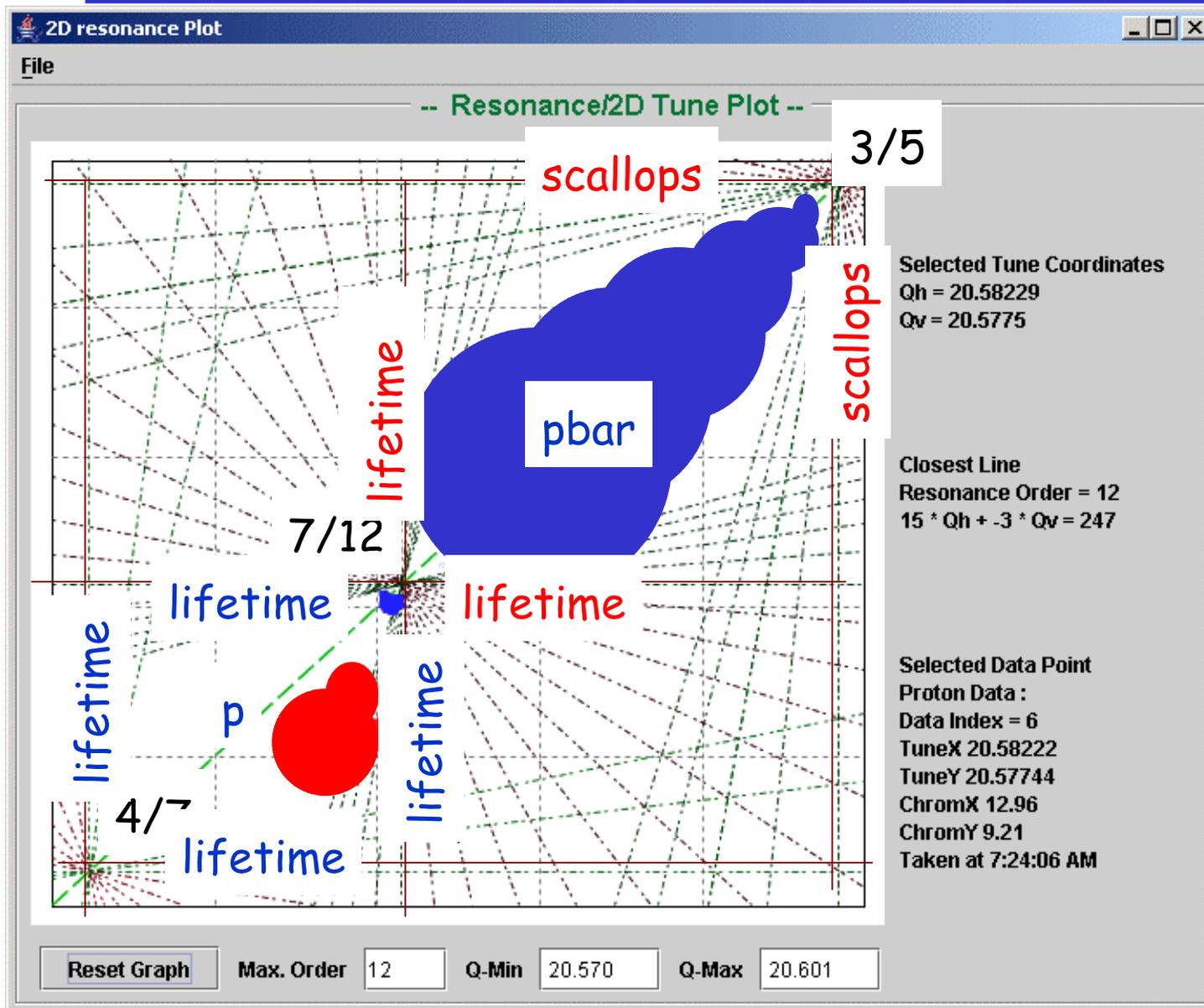
slide

Beam-Beam Interaction reduces luminosity lifetime by 15-20%

# Pbar Bunch Emittance Growth



# Betatron Tunes (Working Points)

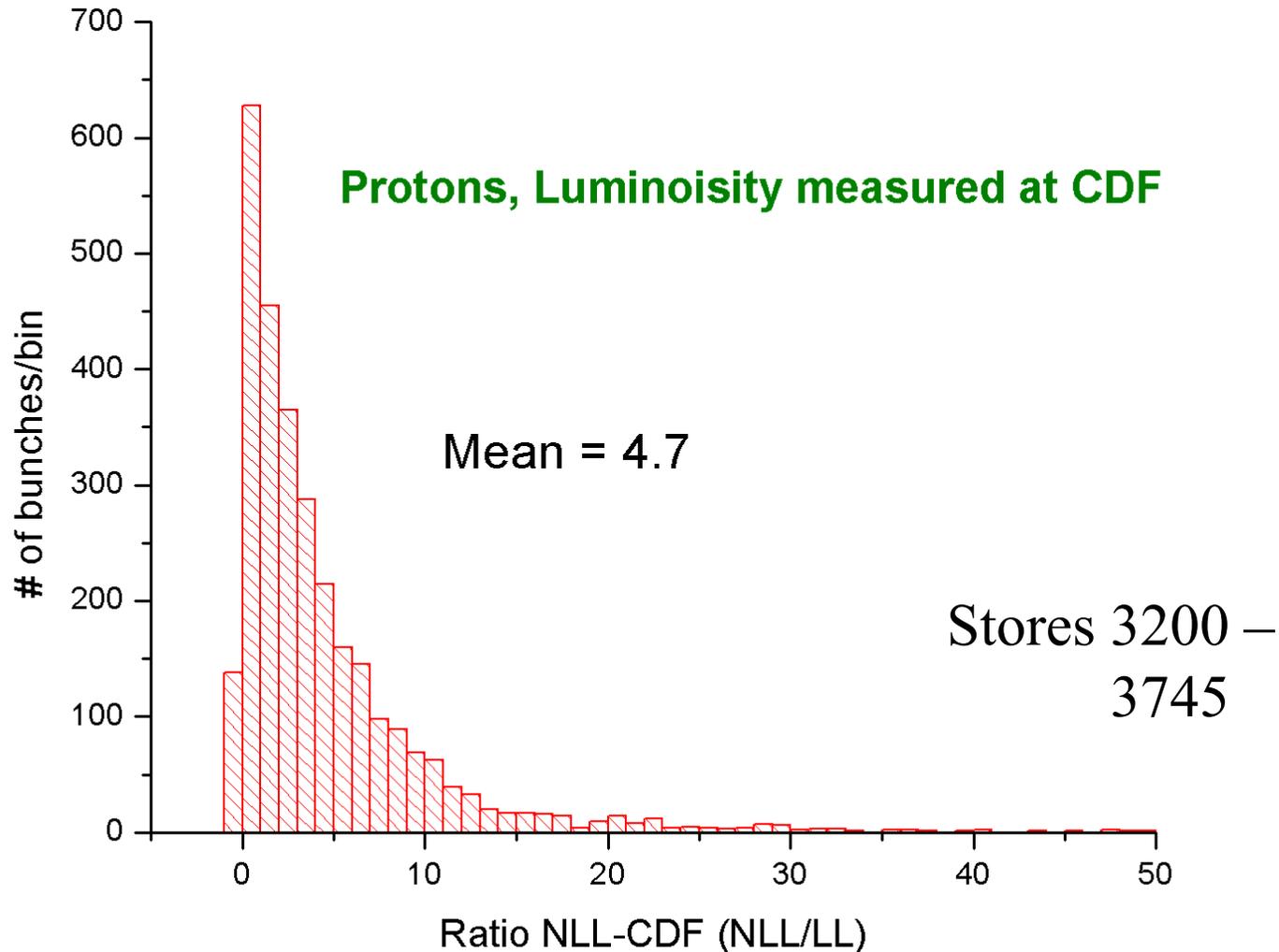


- Balancing btw major resonances

# Proton Losses Mostly Induced by Pbars!

Ratio of Non-Luminous Losses over Luminous Losses.

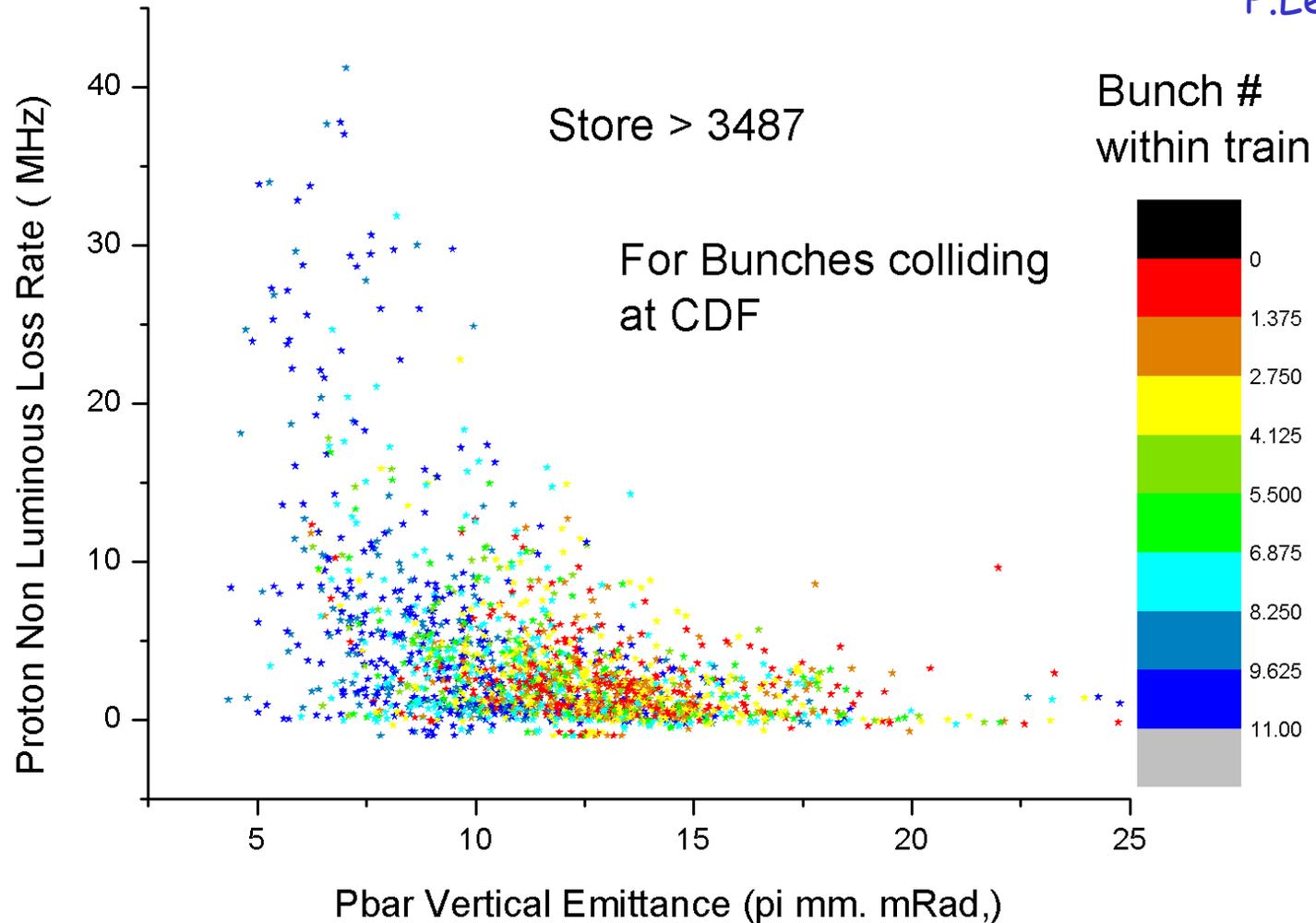
P.Lebrun



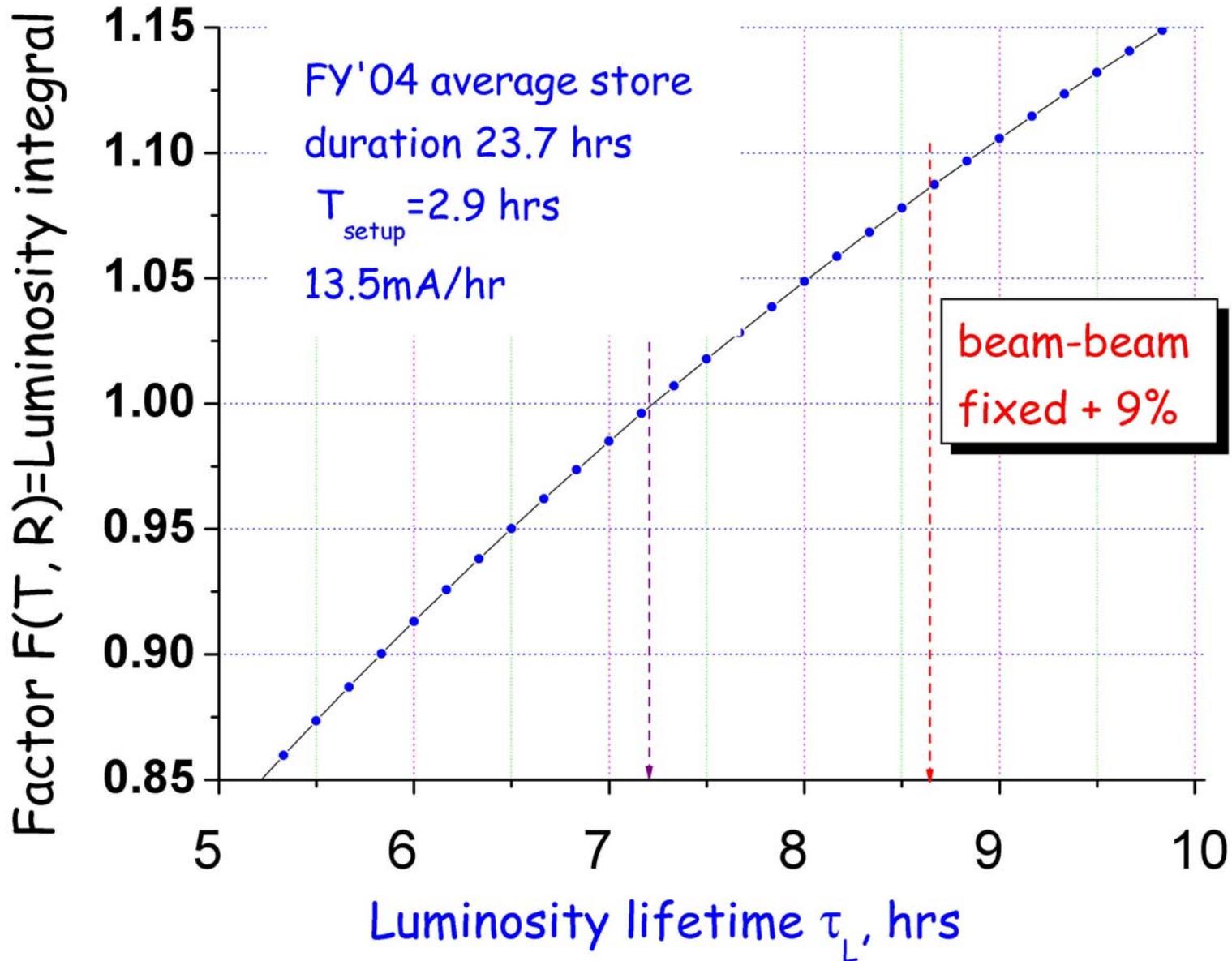
# P-loss Rate Up for Smaller Pbar-size

## Proton Losses vs Pbar Emittance

P.Lebrun



# Beam-Beam Spoils Lifetime – 9% Effect



# How to Improve $L$ -Lifetime

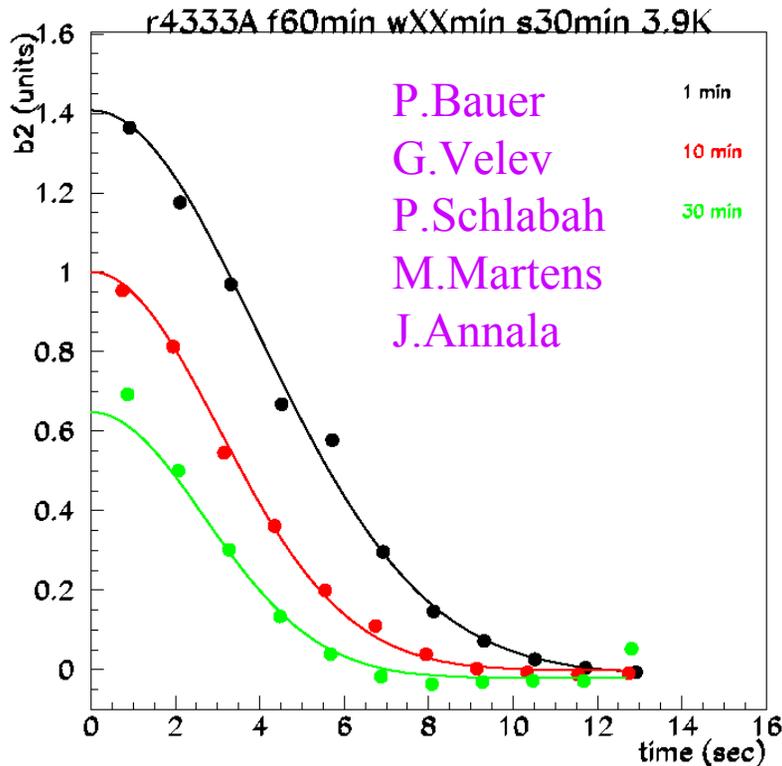
- Drop Chromaticity at Low Beta:  $Q'=10-18$  to 0
  - Octupoles pending study time
  - Transverse Dampers ? pending study time
- New Helix at Low Beta
  - Use new separators two installed at D17
  - Increase separator voltages R&D MP9, studies
- Automatic tuneup at LB pending study time
- New ideas:
  - 23 RFC spacing, 33x33 pending study time
- Reduce long-emittance growth rate
  - Separate heaters from cavities shutdown
  - Fix long damper, reduce gain shutdown
- Beam-Beam Compensation
  - New gun (shutdown), TEL-2 pending study time

# Reliability/Uptime: Next Steps

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- Correct b2-snapback compensation saves 2% <sup>slide</sup>
- Upgrade Beam Loss Monitors, unmask them
- Faster detection of valve moves shutdown
- Transient recorder for quenches shutdown
- PMTs around CDF for prefires ongoing
- Background reduction
  - CrystalCollimator shutdown → studies
  - Orbit stabilization @ 12 Hz pending study time
- Stabilize CDF LB quad girder shutdown

# Sextupole Field Variations: MTF and Studies



## • Tev dipole b2 snapback meas'ts → recommendations:

- Fix back-porch time, it's the most important parameter → fixed 96 sec
- Reduce # of beam-less pre-cycles after Tevatron quench from 6 to 1;
- Improve b2 snapback fit → Gaussian
- Saturation of flat-top duration effect on drift amplitude and absence of effect of front-porch duration → foundation for elimination of pre-cycle

## • beam studies in FY'04 :

- backporch time fixed at 90s for >1 hr stores, 5 min for <1hr
- pre-cycle eliminated in store #3645 – no loss

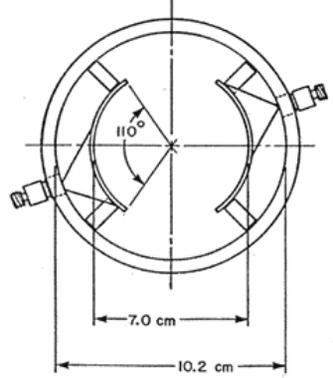
## • MTF quadrupole field msmnt results – Fall, 2004

# Better Diagnostics Saves Beam Time

- Est 2-3% in Luminosity integral
  - BPM Upgrade slide
  - HLS at CDF and D0 slide
  - Ionization Profile Monitors, OTR
  - Tune Tracker slide
  - Q' and Coupling msmt system
  - Improve FWiress, SLite, RWCM, CPMs

# Tevatron BPM Upgrade

S.Wolbers  
R.Webber  
J.Steimel  
CD Team



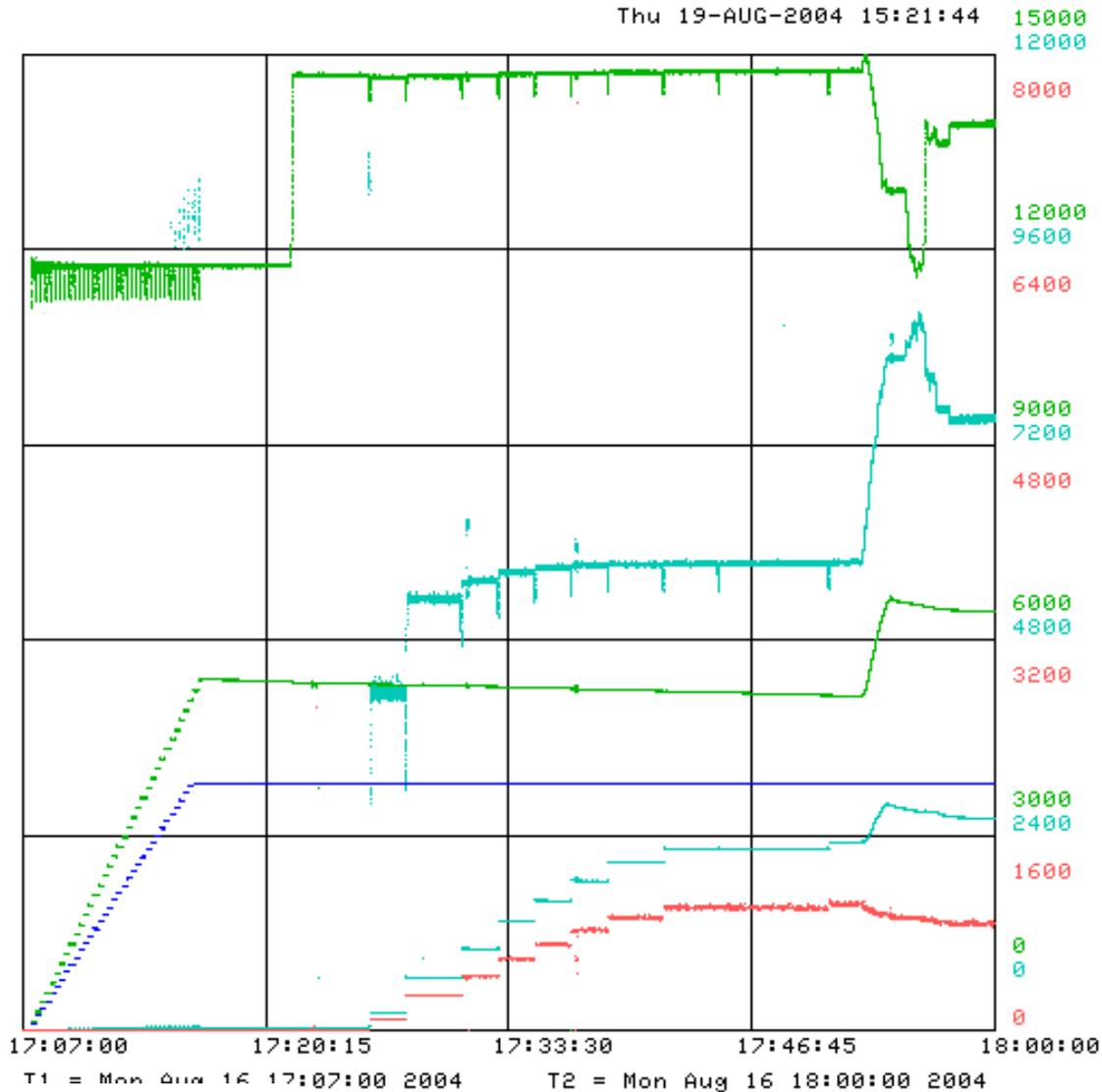
T:HAAA34 -2  
0  
+TevSA pbar 32

T:IBEAM  
.Ctrls 1E12  
-7  
-5  
24

T:HPPA34[E1] -12  
.TevSA prot -10  
16

T:HAAA34[E1]  
.TevSA pbar  
-17  
-15  
8

T:FBIANG  
.Inst2 E09 -22  
-20  
0



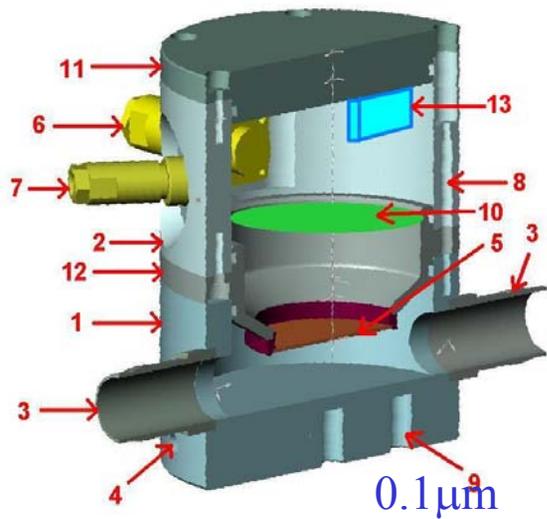
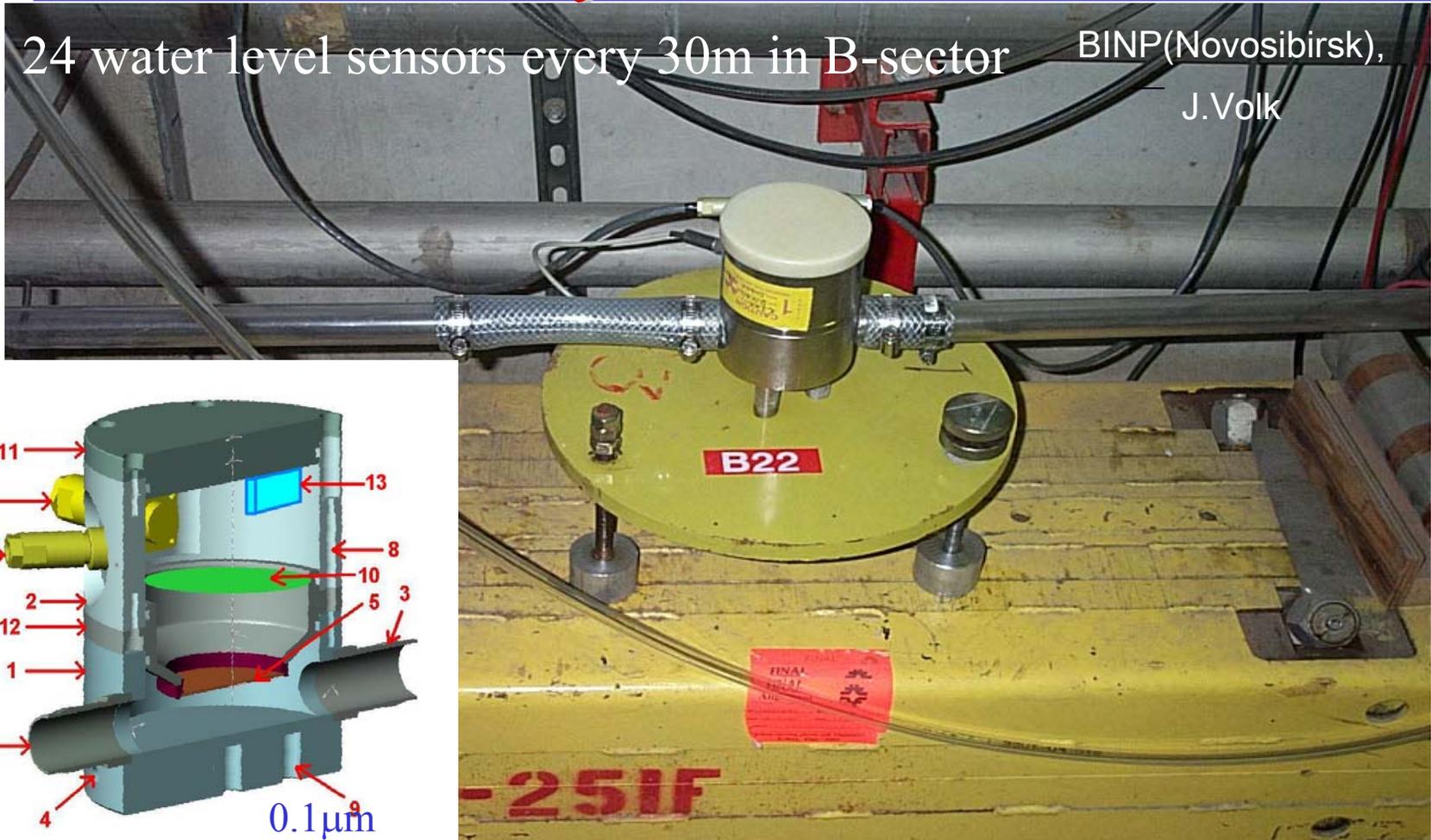
Tested @  
HA34, VA34  
Orbit resolution  
<8 micron p's  
<13 micron a's  
Turn-by-turn  
<50 micron  
Be done by  
April'05  
Need 8 MD  
shifts

beams-doc-1310

# On-Line Survey: B-sector + B0 + D0

24 water level sensors every 30m in B-sector

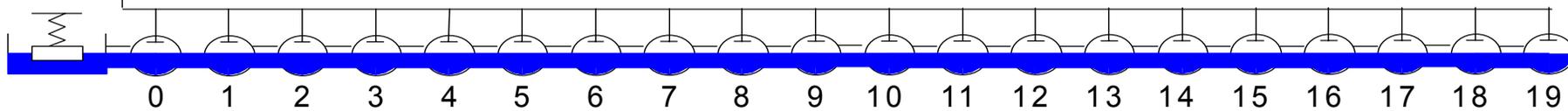
BINP(Novosibirsk),  
J.Volk



PC

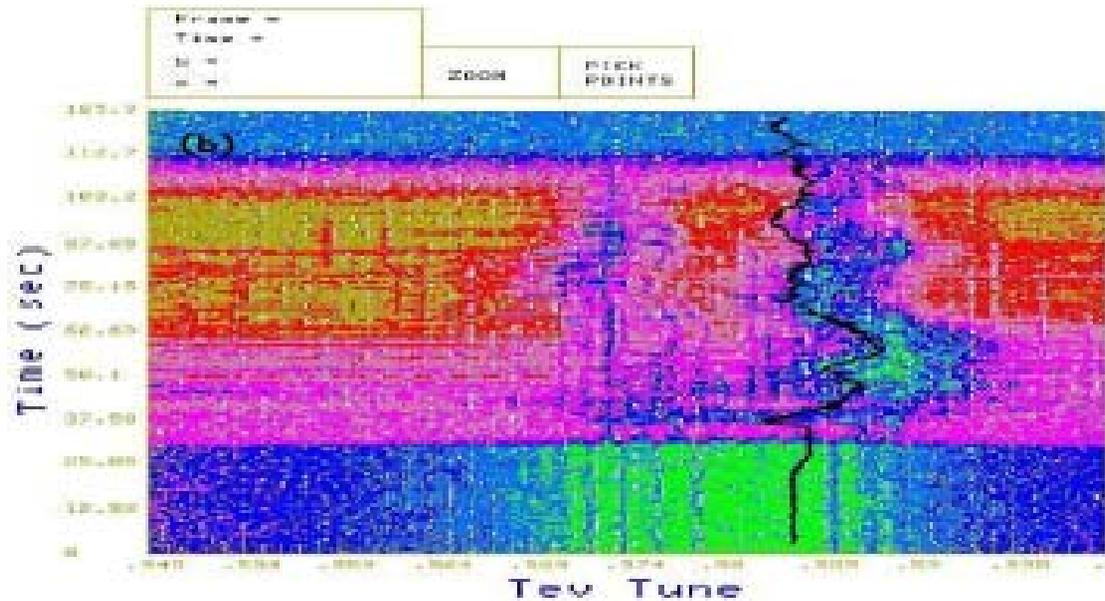
0.1 μm  
resol'n)

Data Flow



# TuneTracker: Promising Results

C.Y. Tan



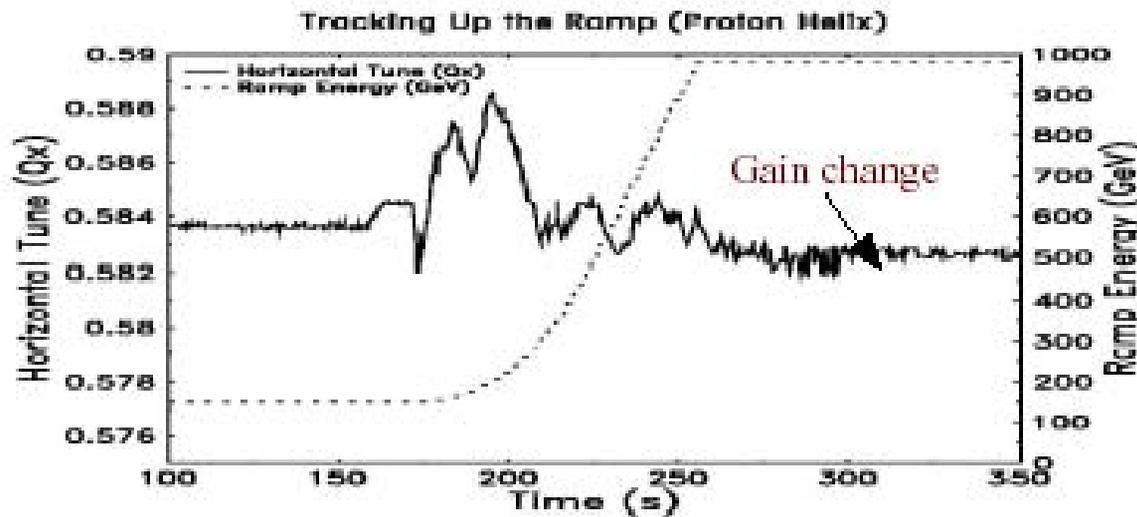
1<sup>st</sup> Tests in FY04

Tune resolution

$dQ \sim 3e-5$

3-15 Hz bandwidth

Needs 3 MD shifts



# So, Tevatron Alone Can Give 30-40% ...in FY'05 Luminosity integral

- We know what to do
- We have people to do that
- We have \$\$ to do that

... "All we need is Love!"

actually, MD study time →

# 54 Shifts = 430 hrs = 10 hr/wk

	<b>FY'05 Tev Study Time Estimate</b>	<b>Final</b>
<b>#</b>	<b>Project</b>	<b>MD Shifts</b>
1	New Helix/Separators	5.875
2	New BPMs	7.75
3	Lattice/28 cm beta*	4.5
4	Octupoles/Instabilities	5
5	TEL	2.75
6	Injection Dampers	5
7	Tune Tracker	3
8	Dampers on Ramp	1
9	IPM	0.875
10	Q' x,y /Coupling on Ramp	0.875
11	Orbit Stabilization	2
12	b2 Studies	4
13	Crystal Collimator	5
14	23 RFC bunch spacing and Other Beam-Beam	1.875
15	FWs/SL/OTR/Other diagnostics	2.125
16	BLM Upgrade/Other Controls	1
17	TBT/Coupling/Nonlinear/beta* CPM	1.25
	<b>Total shifts</b>	<b>53.875</b>

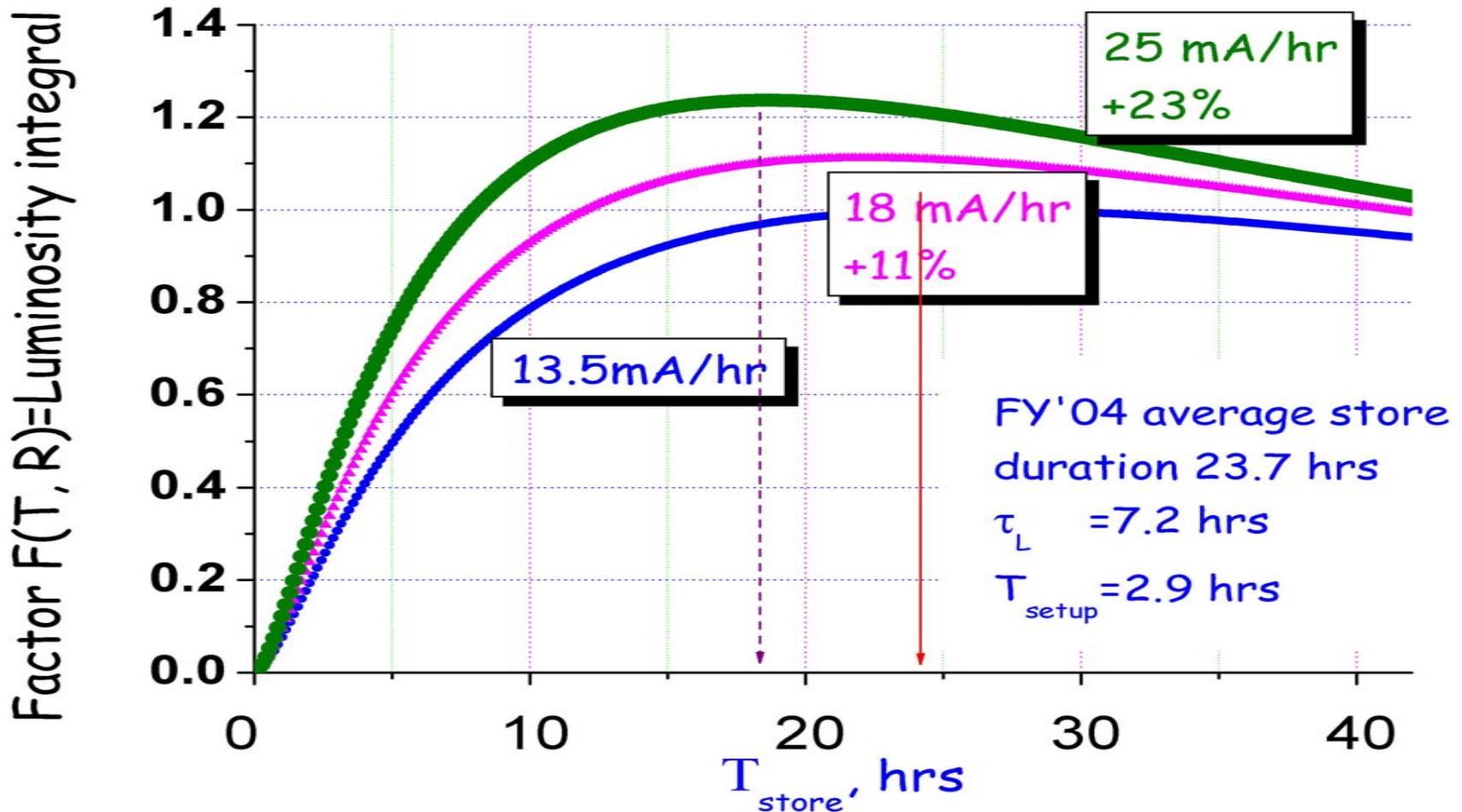
# 10 hrs/week – Is That A Lot?

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- In FY'04 we had:
  - 100 hr/wk of Store Time
  - 11 hr/wk for Tev Maintenance
  - 5.3 hr/wk for MD and Hardware
- So,  $10 - 5.3 = 4.7$  hr/wk more in FY05
- Assuming the same store and maintenance time, 4.7 more hours mean 4.7% hit on Integrated Luminosity in the worst case.
- Intelligent planning (4.7 hrs = terminate store in avg 1 hour earlier, continue stacking till usual stack size and do studies) will reduce the hit to  $1/(24+7) = 3\%$  for 24-hr stores and 7hrs lifetime

# Is 30-40% Gain Worth of 3-5% Investment?

- Let's see what other approaches can offer:
  - With a single A-source Stacking rate gives Cubic Root Effect



# What Else in FY'05 ?

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- Main Injector may reduce longitudinal emittance
  - It's again "cubic root effect": even reduction of both proton and pbar emittances by factor of 2 will increase peak luminosity by 27% and integrated luminosity by 14%
- D0 will fix their luminosity counters
  - Can not rely on that, but may get 3-4% in average peak luminosity and 0% in integrated (because we report CDF integral)
- Recycler will work as additional pbar source:
  - Not clear yet how much we'll gain in integral
  - Once or twice a week "mixed source" shots
    - Max may get AA+RR=200mA+90mA → peak  $L > 140 e30$
  - E-cooling for luminosity in FY'06

# Summary/Prediction

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- We have everything in place to integrate 470 pb<sup>-1</sup> in FY'05
  - 40 weeks x 12 pb<sup>-1</sup>/wk
- We can break  $L_{\text{peak}} = 140 \text{ e30}$  in FY'05
  - improbable without shots from Recycler
- With additional 5% investment ( MD time from 5→10 hrs /wk ) Tevatron can deliver upto 100 pb<sup>-1</sup> more

# Believe In A Happy End!

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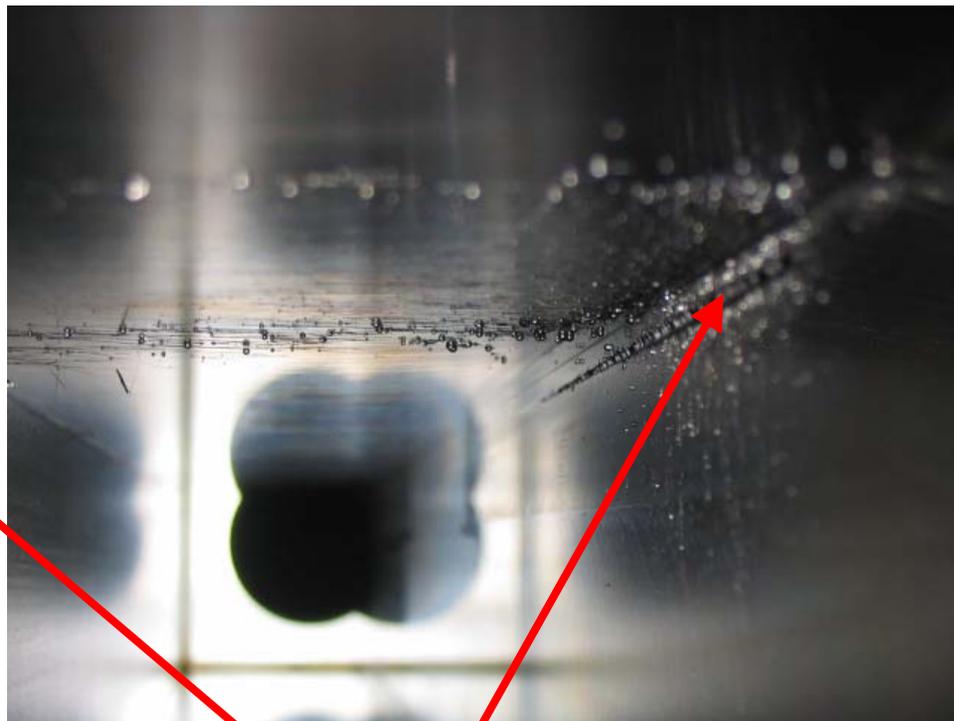
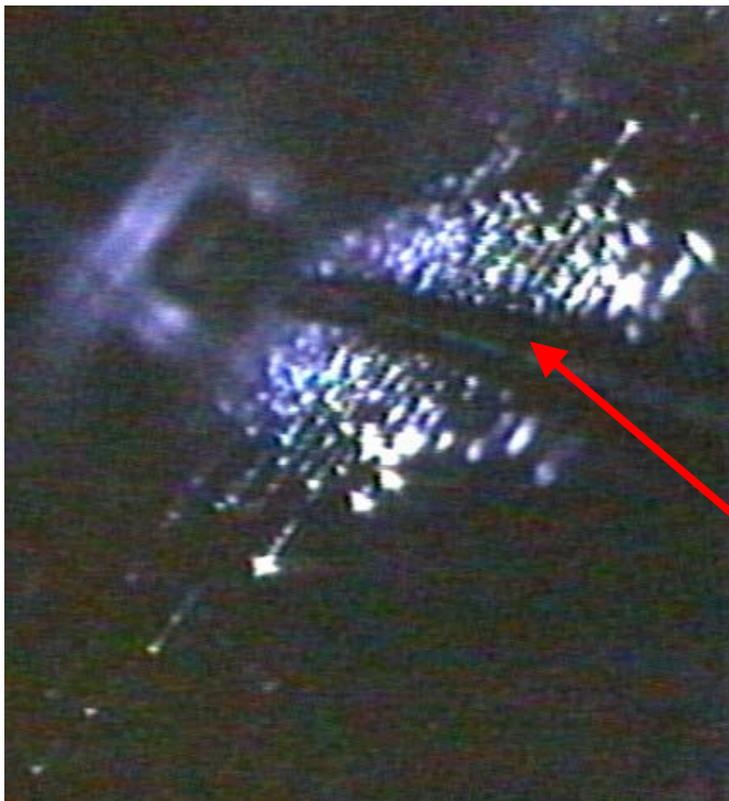
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**That's the End, Folks!**

**Backup Slides**

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# Horror Stories: Collimator Damage



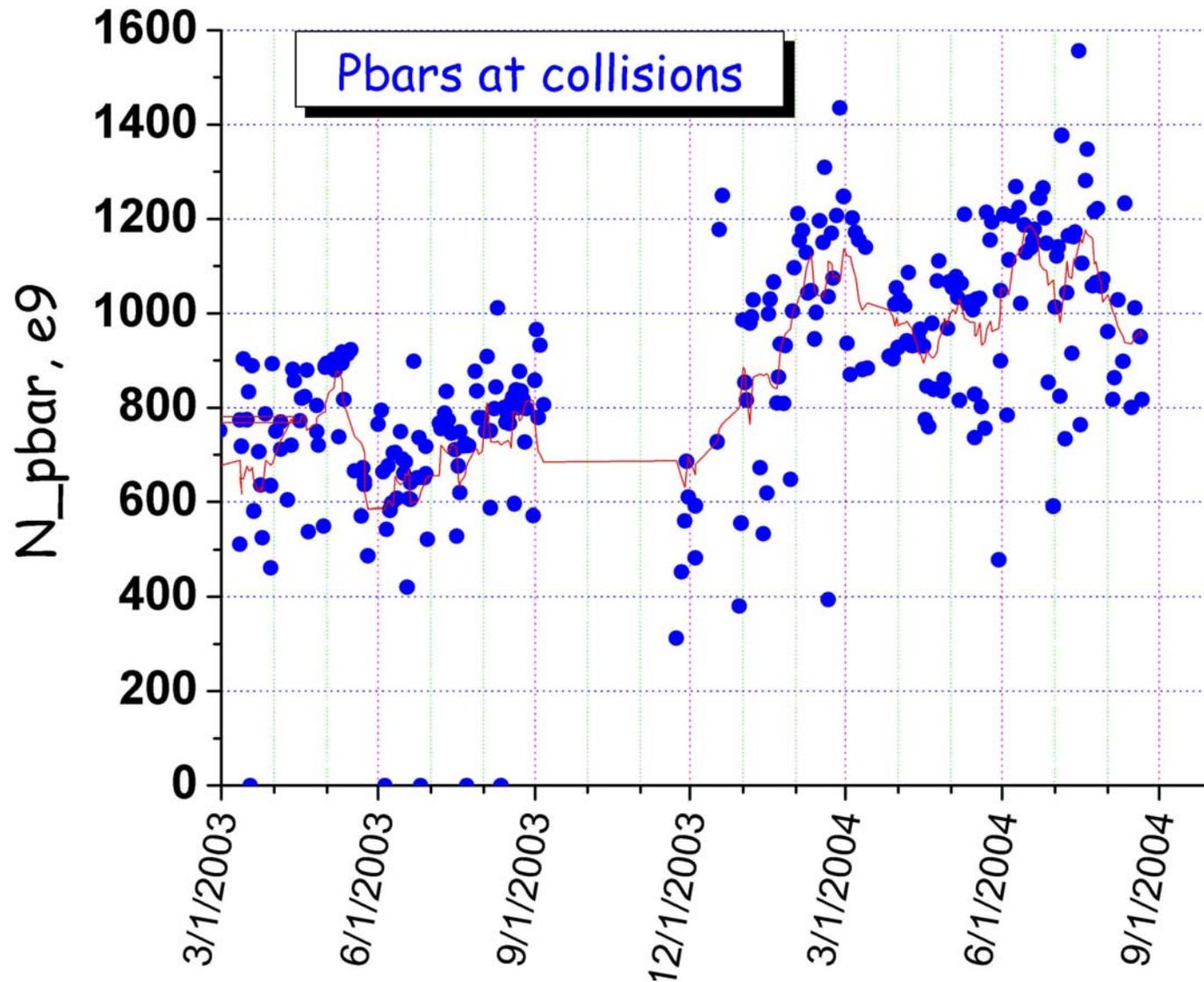
Protons

## E03 1.5m Collimator

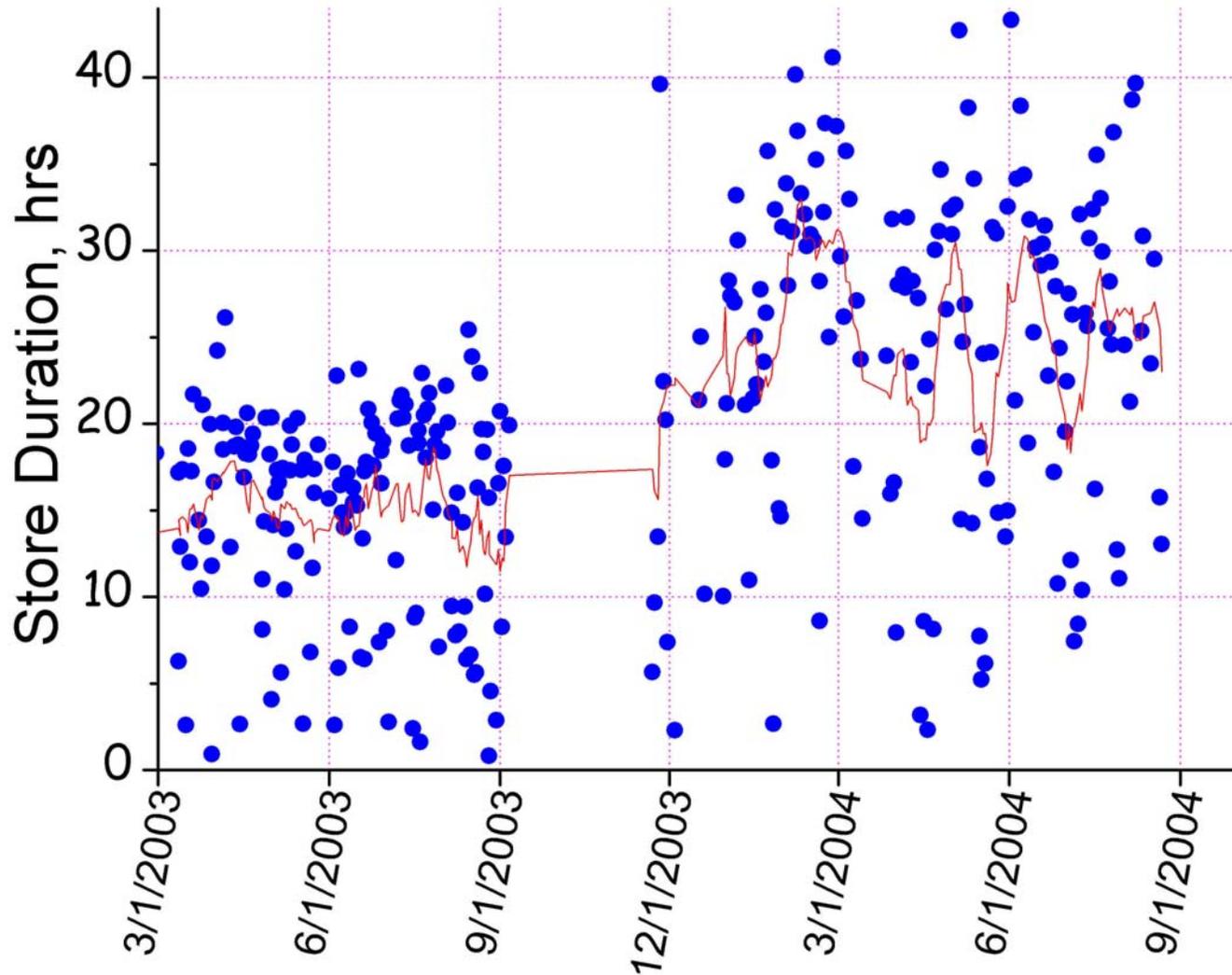
12/05/2003

5/15/2004

# Tevatron Luminosity Progress



# Tevatron Luminosity Progress



# 1.7GHz Schottky Spectra

R.Pasquinelli  
P.Lebrun  
A.Jansson

-- Tune Measurement All Beam, All Bunches --

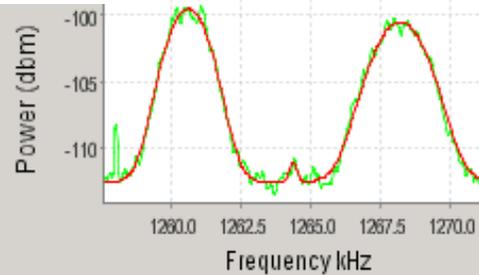
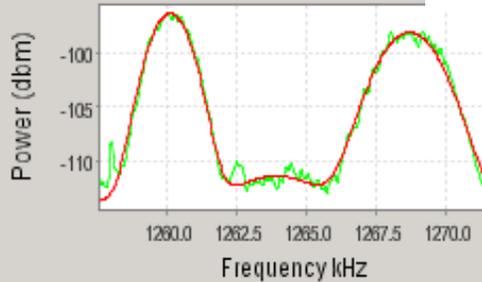
- Measurement completed -

#3226

02/11/04

Proton Horizontal

Proton Vertical



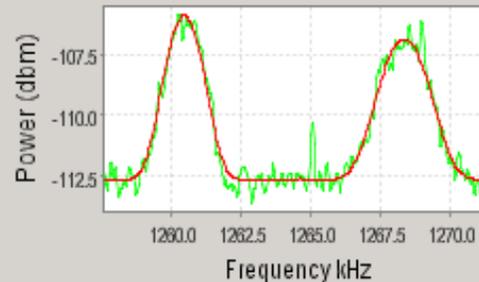
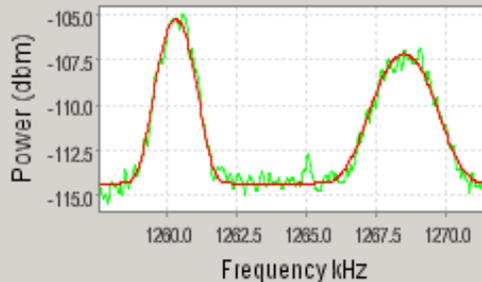
Raw Fit

Raw Fit

Proton ----- Tune ----- Chromaticity ---- Momentum spread --- Emittance --  
Horizontal --- 0.5897 ----- 20.604 ----- 1.657 ----- 10,026.47  
Vertical --- 0.5794 ----- 11.91 ----- 1.574 ----- 5,108.28

AntiProton Horizontal

AntiProton Vertical



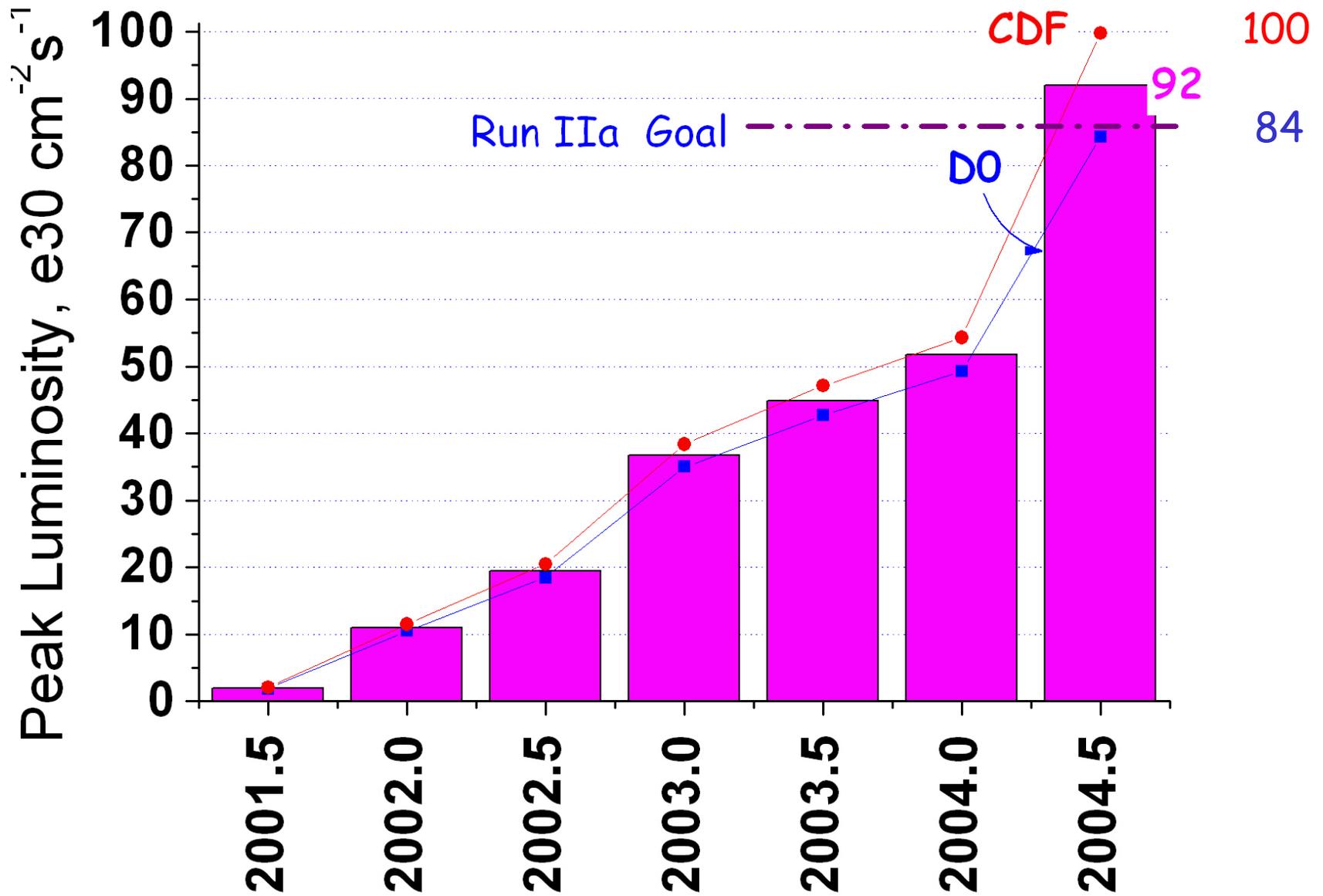
Raw Fit

Raw Fit

AntiProton --- Tune ----- Chromaticity ---- Momentum spread --- Emittance --  
Horizontal --- 0.5859 ----- 25.361 ----- 1.442 ----- 2,141.2  
Vertical --- 0.5821 ----- 13.117 ----- 1.365 ----- 1,296.35

- Q and 1-Q lines are seen
- Fit gives:
  - Betatron frequency
  - $dP/P \propto$  sum of two widths
  - $C_{vh} \propto$  difference of two widths
  - Emittance  $\propto$  area under the peaks
- Can do that for each bunch

# Tevatron Luminosity Progress



# Luminosity 2002-2004: $1.15^{15} = 8$

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- First 9 months Mar-Nov'01
- Optics AA→MI lines fixed Dec'01
- Quenches on abort fixed by TEL-1 Feb'02
- 20% pbar loss in Sequence 13 fixed Apr'02
- "New-new" injection helix May'02
- Shot lattice, AA cooling reduces IBS July'02
- Tev BLT helps at injection Sep'02
- Pbar coalescing improved in MI Oct'02
- C0 Lambertsons Removed Feb'03
- S6 cuircuit tuned/SEMs removed June'03
- "5 star" helix on ramp Aug'03
- Reshimming/Alignment Dec'03
- MI dampers/Longer Stores Feb'04
- 2.5MHz AA → MI transfer/Cool shots April'04
- Reduction of beta<sup>\*</sup> to 35 cm May'04
- Pbar shots from both AA and Recycler July'04

# Run II : Now and Upgrade

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980 GeV/beam, 36 x 36

Parameter	Now	Upgrade w Recycler	
Initial Luminosity	92e30	270e30	cm <sup>-2</sup> sec <sup>-1</sup>
Integrated Luminosity	13	47	pb <sup>-1</sup> /week
Total Int. Luminosity	0.67	4.1-8.2	fb <sup>-1</sup>
Protons/bunch	260e9	270e9	
Antiprotons/bunch	38e9	127e9	
Proton emit. (95%, norm)	19	20	πmm-mr
Pbar emit. (95%, norm)	17	20	πmm-mr
Beta @ IP	0.35	0.35	meter
Hourglass factor	0.68	0.65	
Peak Pbar Production Rate	13.5e10	45e10	1/hr

# Tevatron BPM Upgrade Project

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- M&S: \$1.7 Million, including:
  - Electronics boards, analog filters, VME crates , slot 0 controllers, timing and calibration systems, BLM cards, software licenses
- Progress, Major Milestones:
  - Summer'03: Joint AD/CD project formed - leader S.Wolbers
  - Sep 17, 2003: review of the requirements document
  - FY'03 shutdown: cabling antiproton ends of the pickups
  - Dec 16, 2003: technology choice review - a modified RR Echotek ECDR-GC814/8-SV board
  - Jan-Feb, 2004: prototype test
  - Feb 13, 2004: order for electronics and VME crates placed

# Tevatron Helix/Separator in FY'04

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- Beam studies showed significant lifetime improvement from additional beam separation
  - Helix scaled from 85% to 115% → luminosity lifetime up by some 30-40%
- Construct 12 new separator power supply polarity switches (TD)
  - Need 7 so that all separators will have switches
  - Will allow protons on pbar helix @ low beta
- Install spare separators into Tevatron during long shutdown
  - Optimize helix designs using additional separators
  - Prepare up to 5 spares for installation (1 yet to be conditioned)
- Pursue higher voltage operation of the separators
  - Can we run @ 150 kV up ramp and squeeze? 120 kV during HEP stores?
  - What are actual limits of existing separators? Do we need new design, procedures, electrode material?
- Make decision to build "mini" separators to augment kick from separators around the interaction points

# Orbit Drifts

profile (| 1 mm)      HORZ prot-bunch      17-FEB-2004 15:07:51      # 89.9

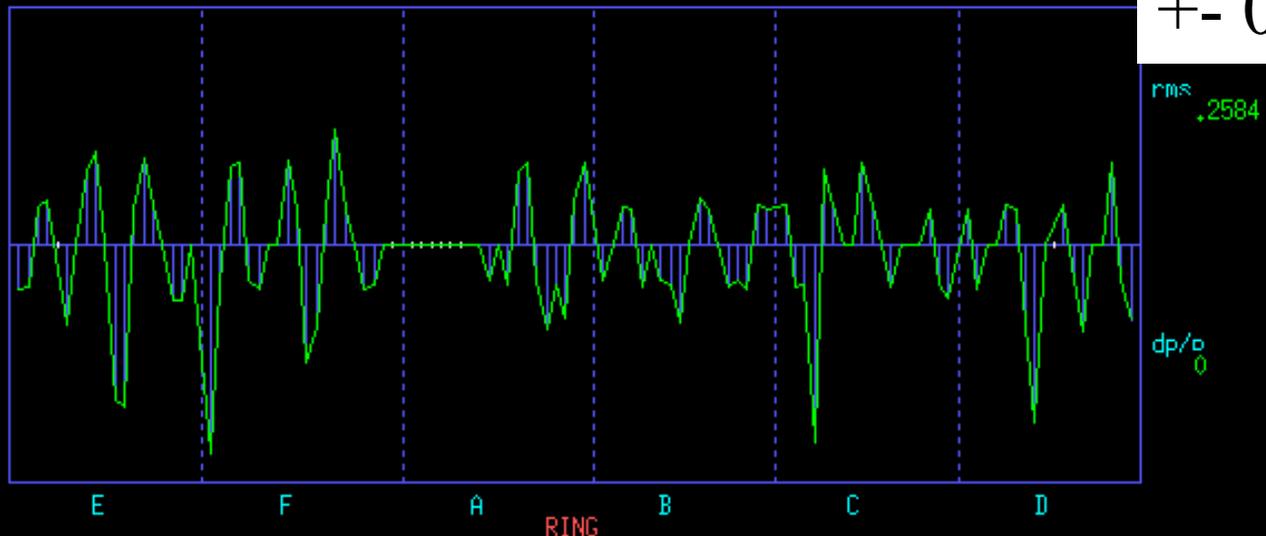
	E	F	A	B	C	D
11	-.18	-.16	NoBeam	-.15	.17	.15
13	-.17	.33	NoBeam	0	-.17	-.18
15	.16	.35	NoBeam	.16	-.16	0
17	.19	-.15	NoBeam	.15	-.83	0
19	NoBeam	-.18	NoBeam	-.17	.32	.17
22	-.33	0	0	0	.17	.15
24	0	0	0	-.15	0	-.33
26	.31	.36	-.15	-.16	0	-.74
28	.4	.15	0	-.32	.35	0
32	0	-.49	-.16	0	.17	NoBeam
34	-.65	-.34	.31	.2	0	.17
36	-.68	.15	.35	.15	-.17	-.15
38	.15	.49	-.15	0	0	-.36
42	.37	.15	-.35	-.17	0	0
44	.17	0	-.16	-.15	0	0
46	0	-.18	-.3	-.18	.15	.35
48	-.23	-.16	.19	.17	-.16	-.15
49	-.23	0	.35	.15	-.22	-.31
A0		NoBeam	NoBeam			
F0	0	-.8773				

store 3240  
minus  
store 3206

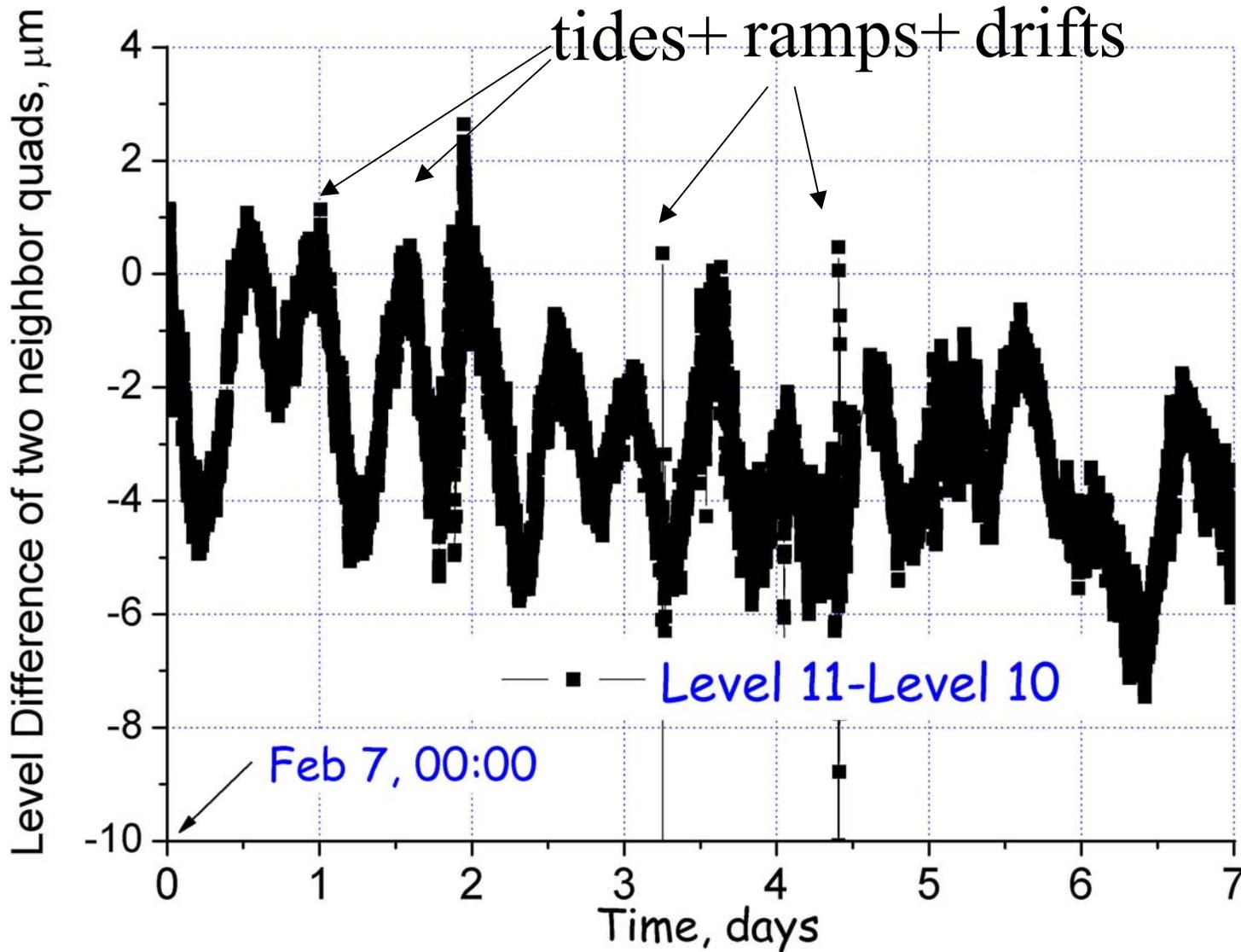
19 days →  
0.26 mm rms  
+- 0.7 mm p-p

+1 mm

-1 mm

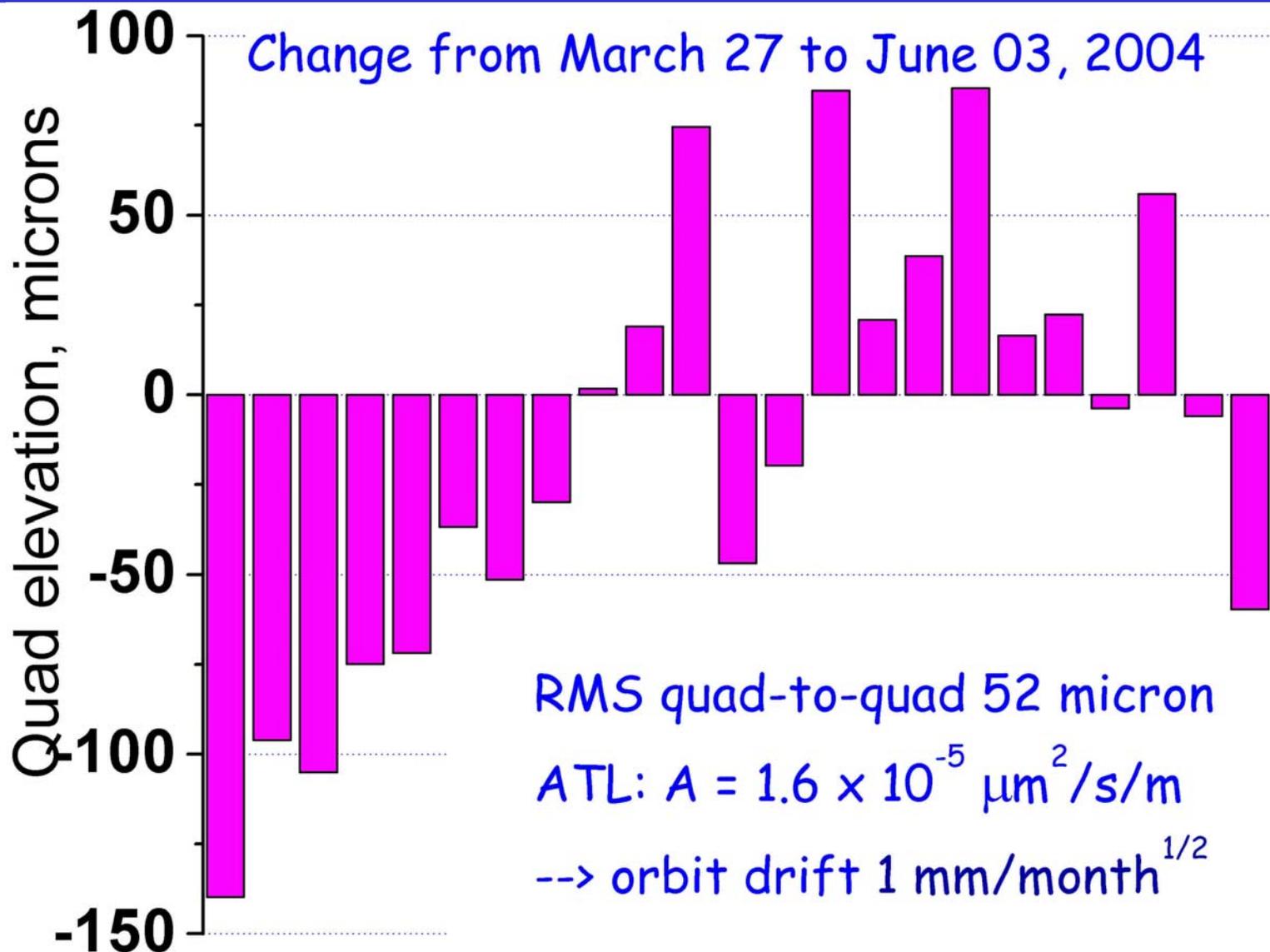


# Drift of Quad Positions : 1 week

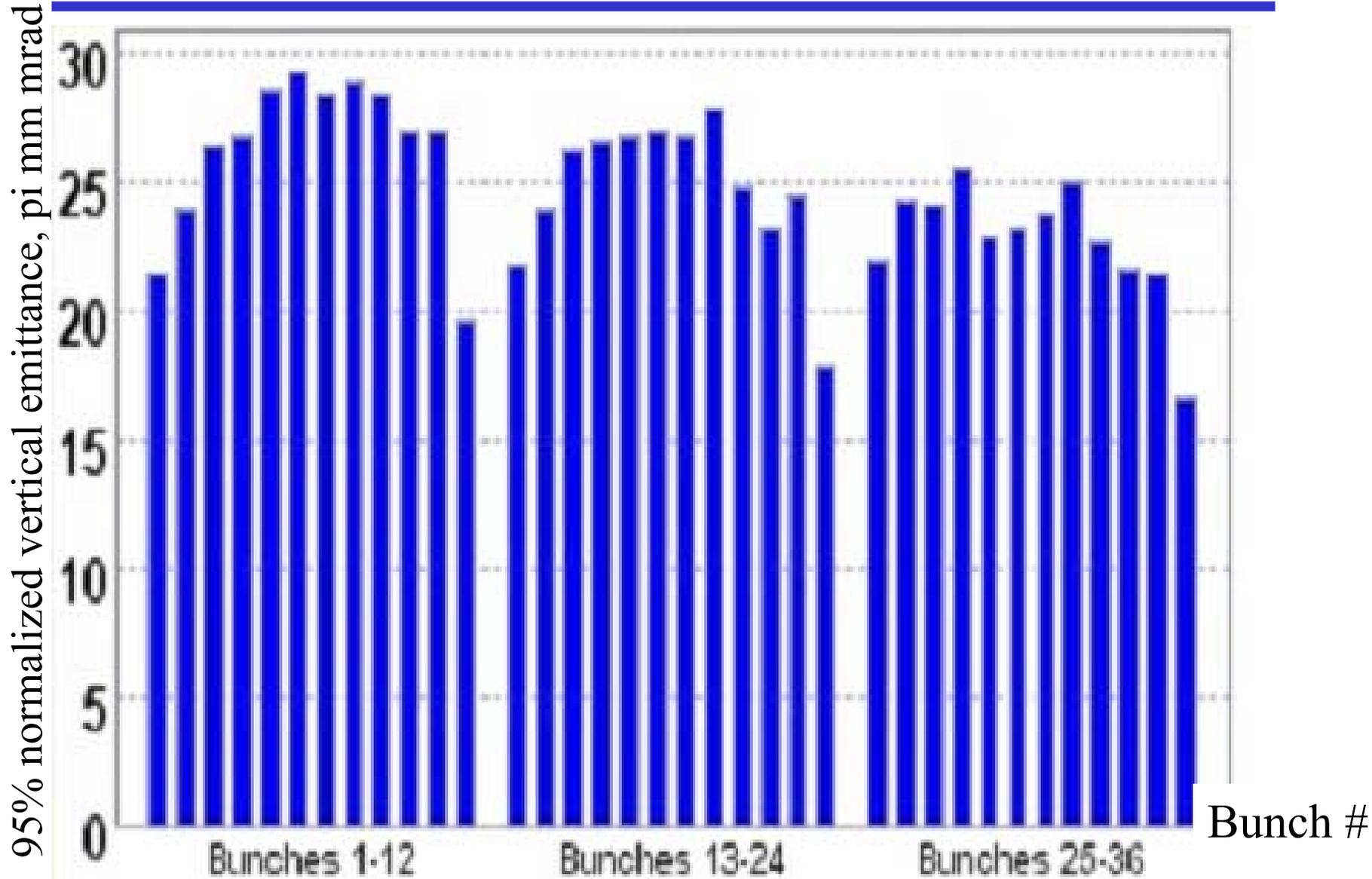


A.Chupyra  
and BINP,  
T.Johnson  
T.Bolshakov

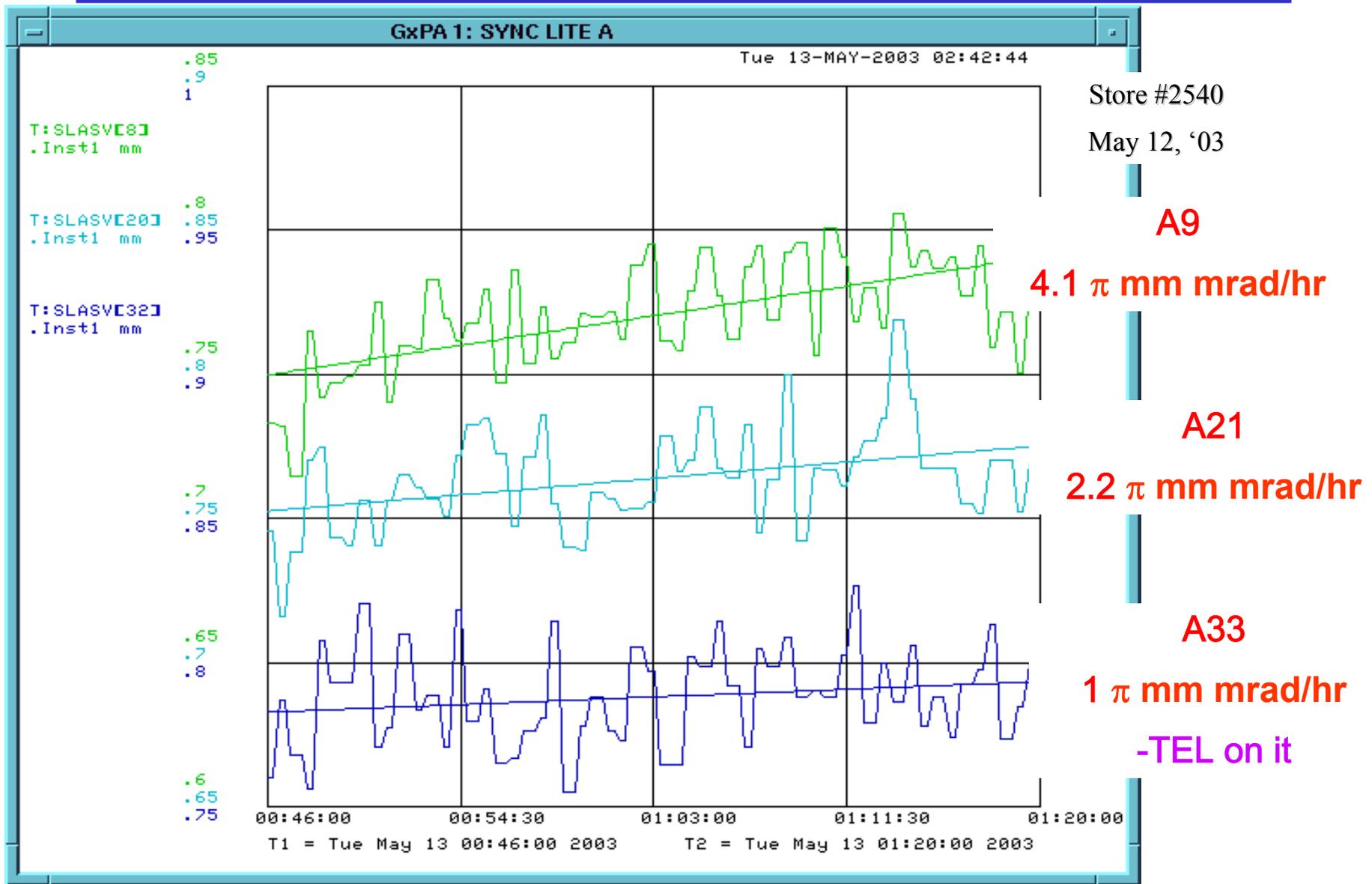
# Drift of Quad Positions : 2 mos



# “Scallops” in Pbar Bunch Emittances

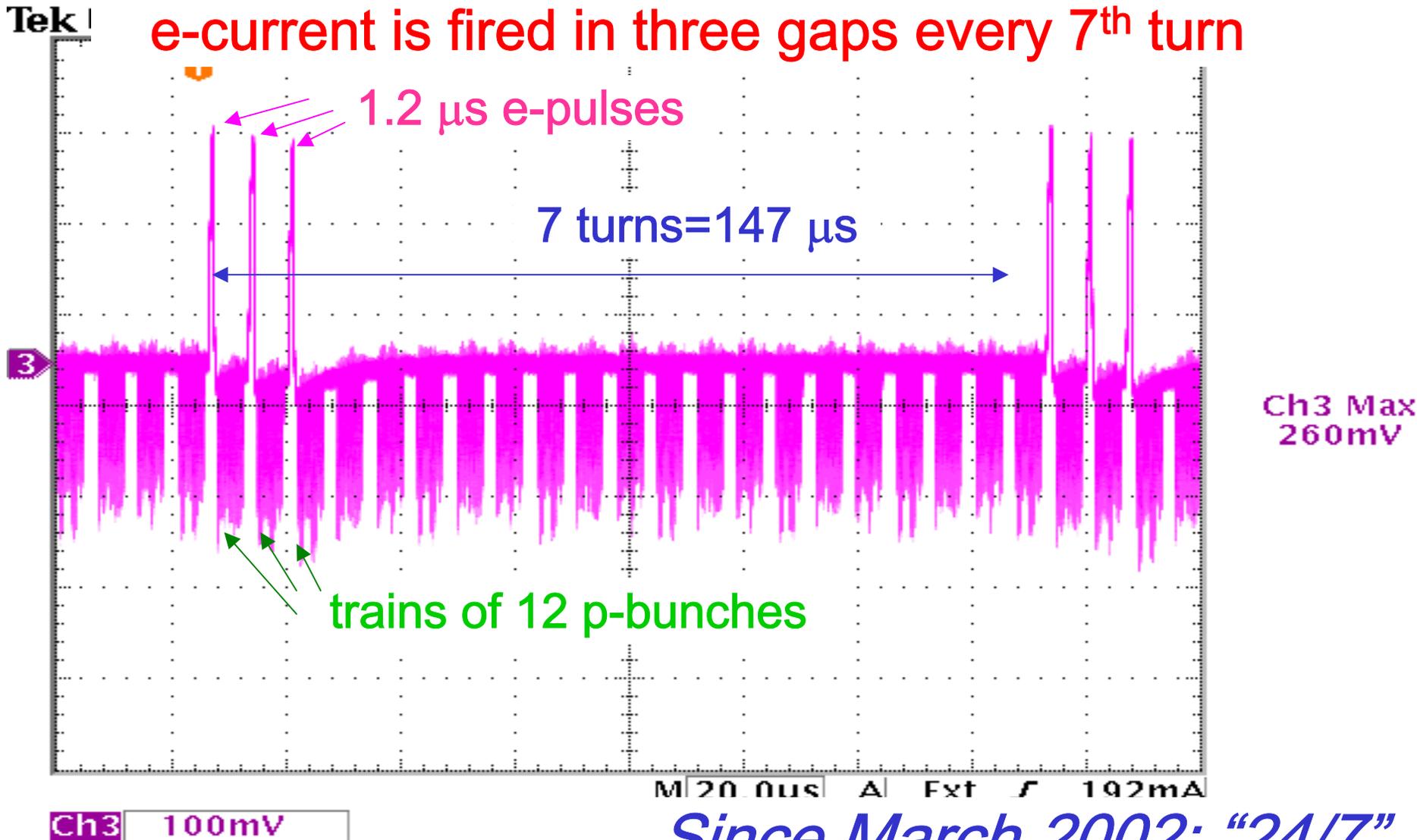


# Emittance Growth of A33 Suppressed by TEL



# Another Function: “DC Beam Killer”

e-current is fired in three gaps every 7<sup>th</sup> turn



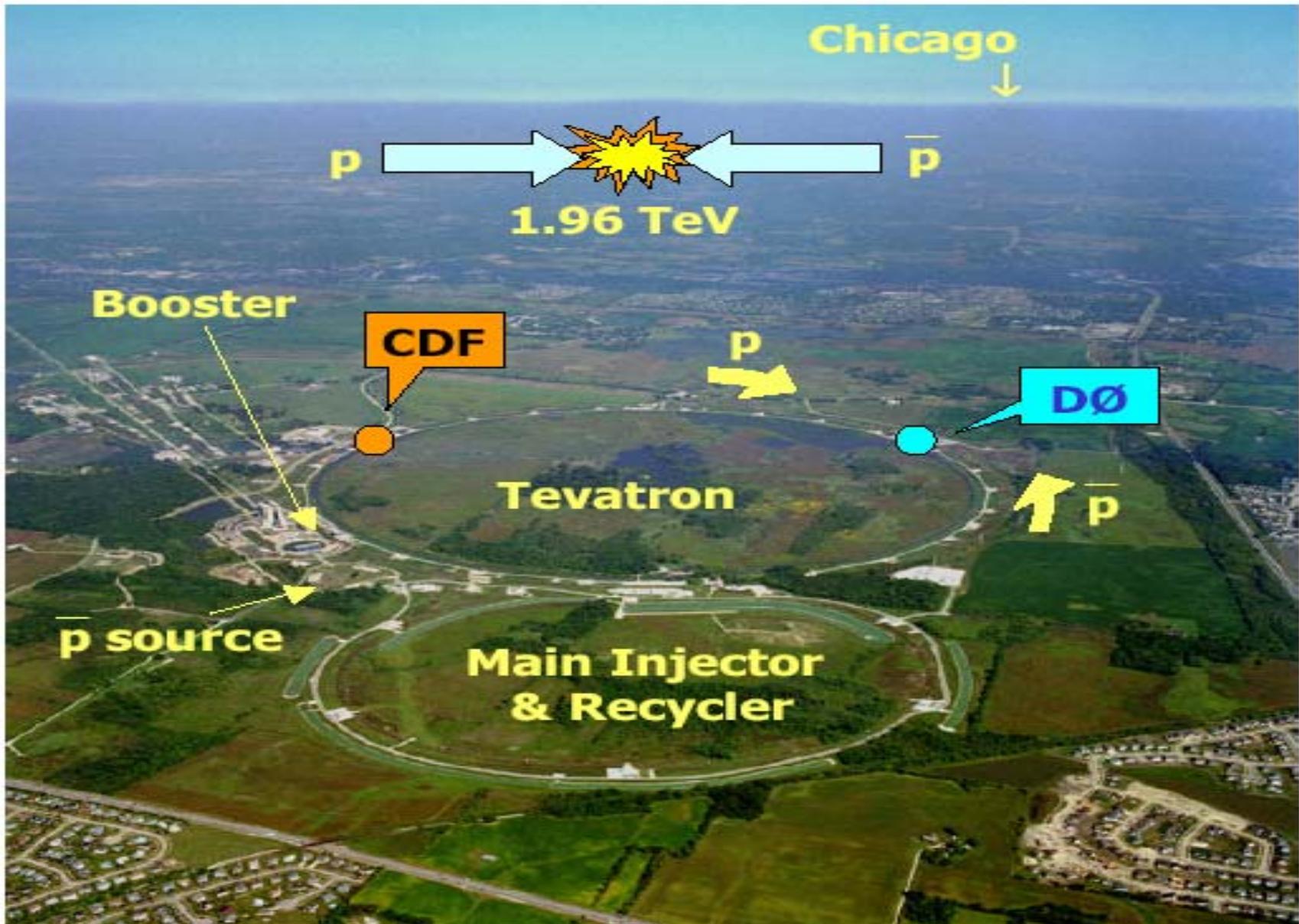
*Since March 2002: “24/7”*

# Conclusions

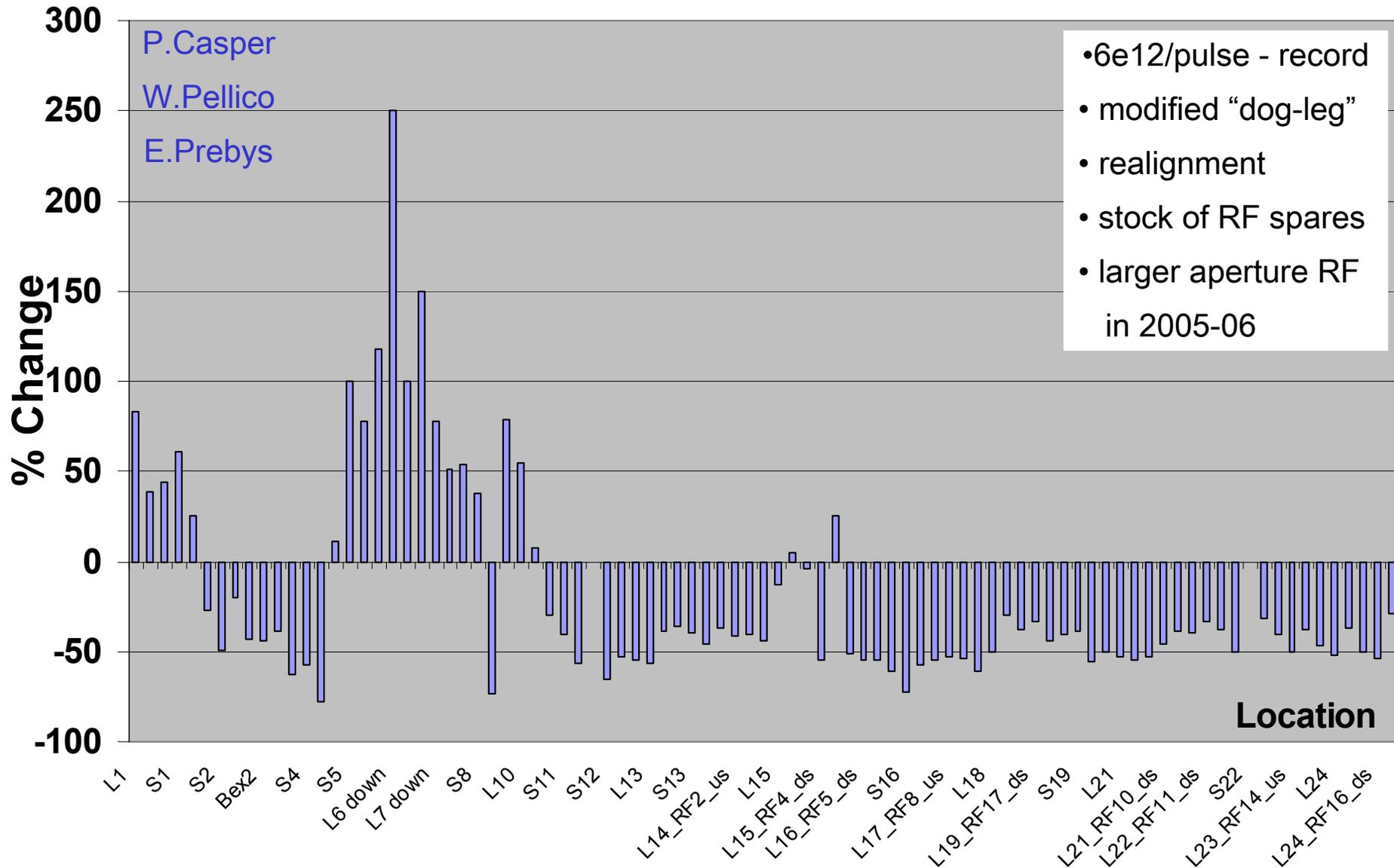
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- Tevatron luminosity:
  - Great progress in recent years, Run IIa goal exceeded
  - 3-fold luminosity upgrade needs e-cooling in Recycler
- Upgrade projects ongoing in all machines :
  - Booster, Main Injector and A-Accumulator -  
to generate 3x higher antiproton flux
  - Recycler - install Electron Cooling system in 2004
  - Tevatron - accommodate more antiprotons:
    - Better diagnostics
    - Larger beam-beam separation
    - R&D on Beam-Beam Compensation with Electron Lenses

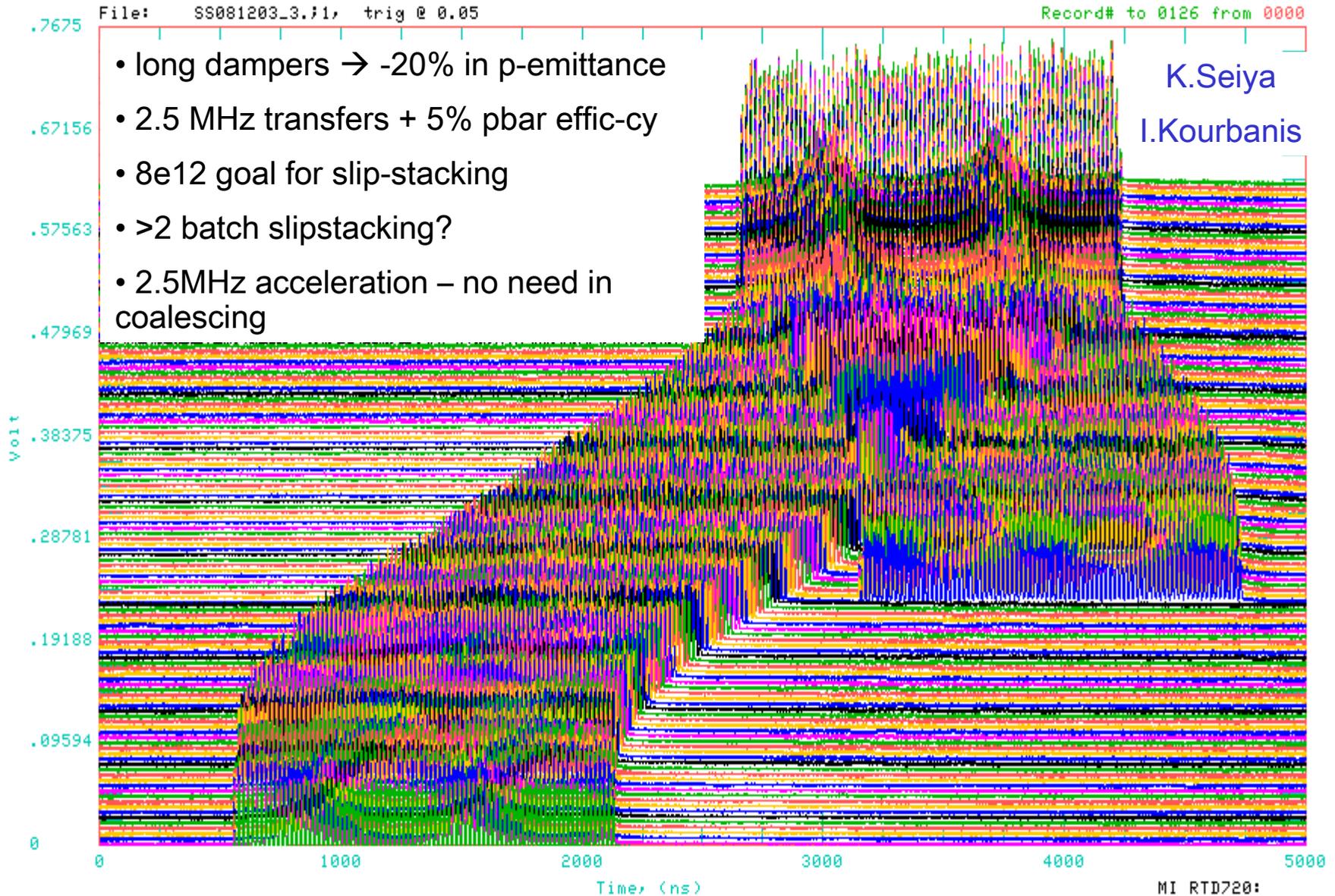
# Tevatron Collider Complex in Run II



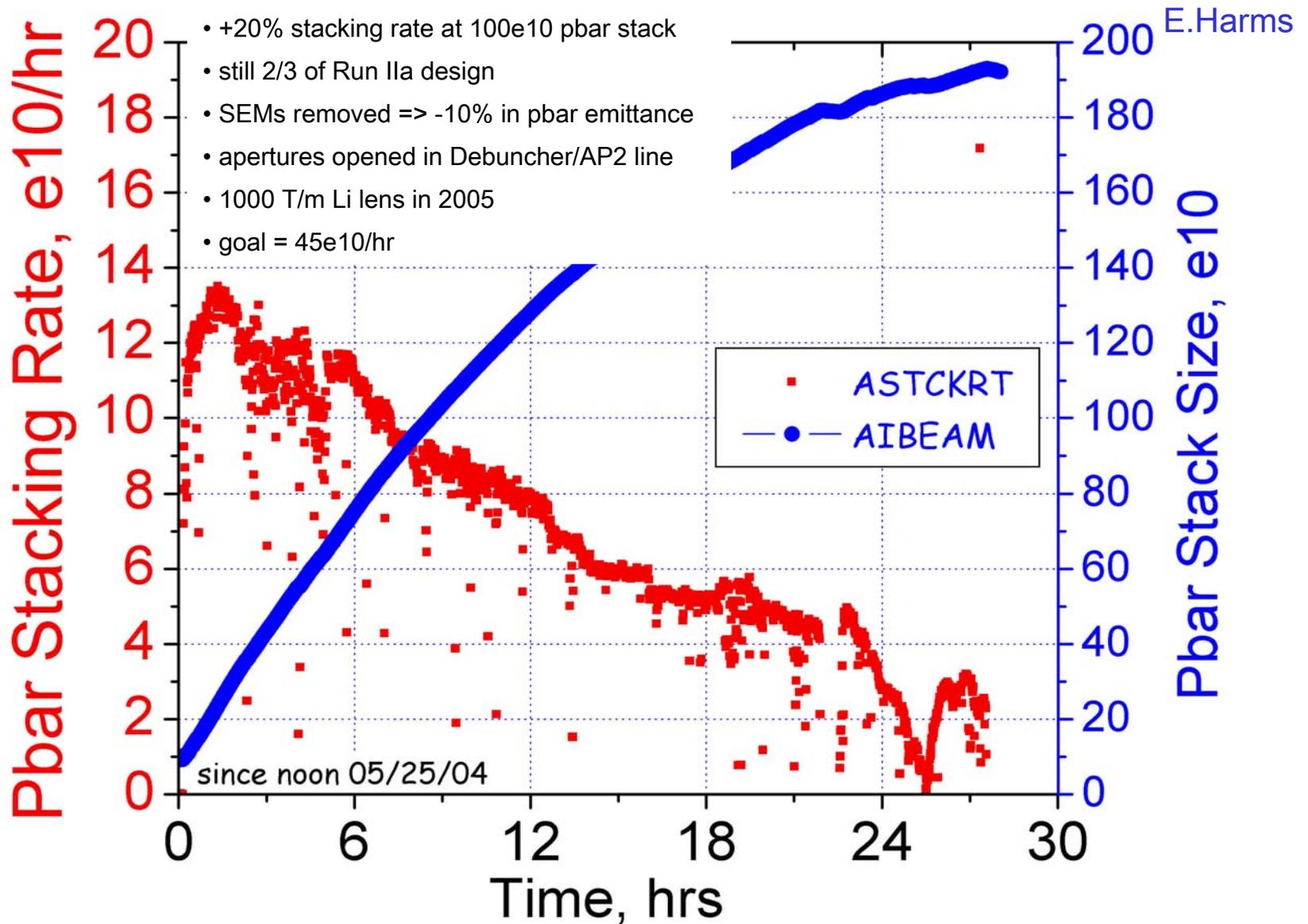
# Booster Activation (since collimators)



# Slip Stacking 6e12 p's in Main Injector



# Antiproton Accumulator



# Polarity Switch Assembly



Glenn Smith (TD) preparing to test the fit of a polarity switch tank and its lid.

Polarity switch HV feedthrough

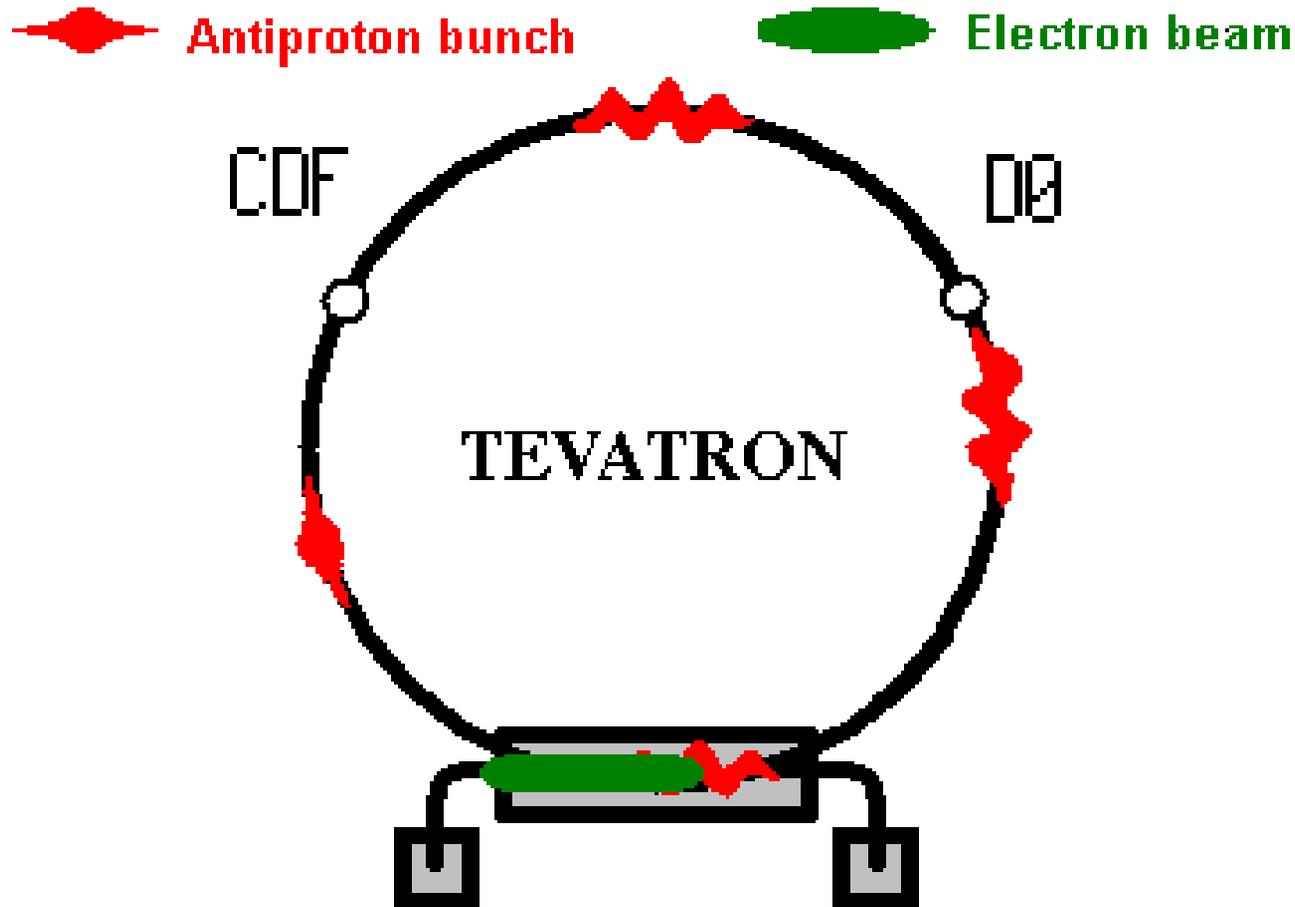


# Recycler Ring = Key Upgrade

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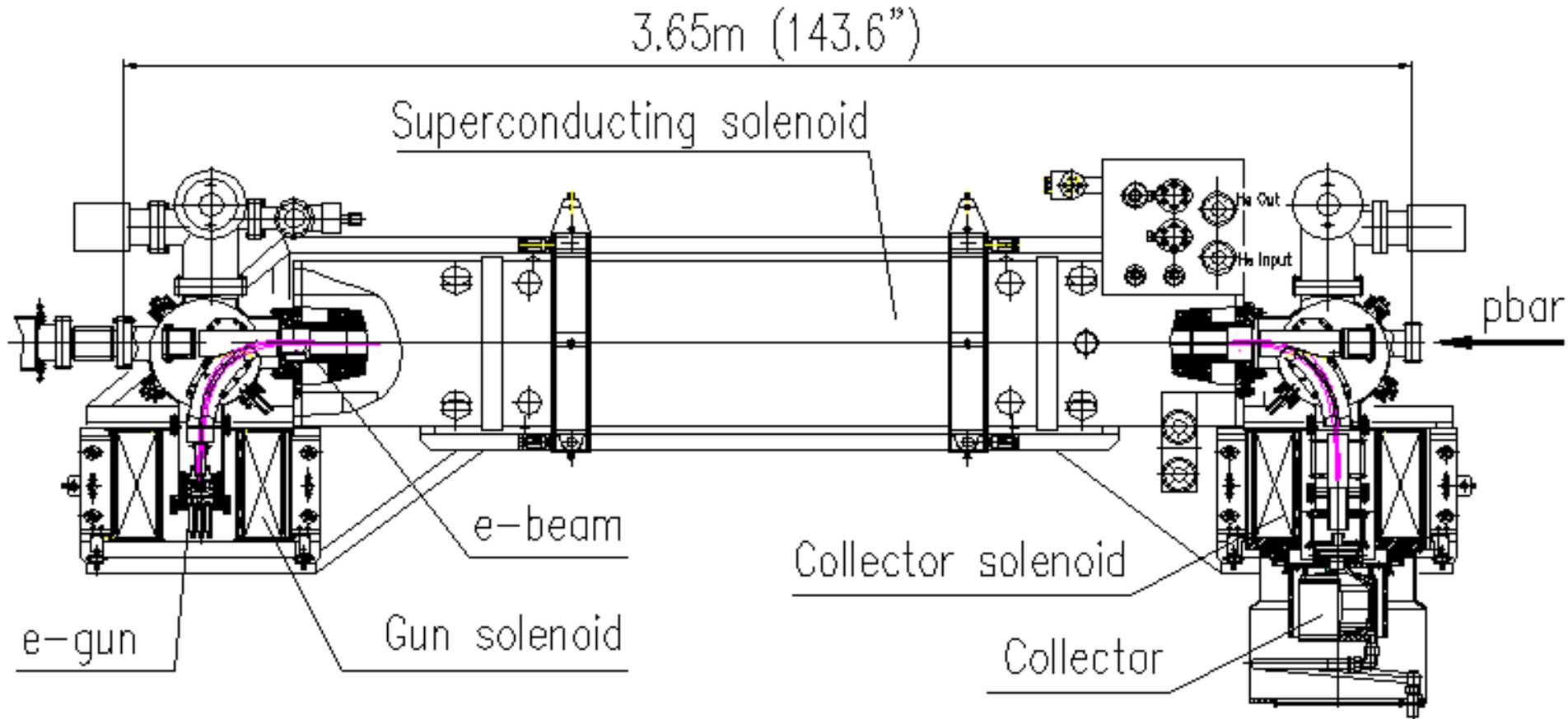
- Will serve as 2<sup>nd</sup> antiproton storage ring
- Will store up to 600e10 pbar (now 200e10 in AA)
- Will accept 40e10 pbars every hour from AA
- Will need both electron and stochastic cooling
- Stochastic cooling works now (60eVs at 150e10 pbars)
- 4.3 MeV Electron Cooling to be installed in Fall'04
- Recycler vacuum greatly improved (500hrs, <3pi/hr)
- >90% efficient transfers AA → RR and RR → MI
- 200 BPMs upgraded to 10 micron rms resolution
- Instabilities studied, MI ramp effects compensated
- RR studies take some 20% of pbar production timeline
- Currently supports "mixed source" shots AA+RR
- Talk and 2 posters at EPAC'04

# Beam-Beam Compensation Idea



“...to compensate (in average) space charge forces of **positively** charged protons acting on **antiprotons** in the Tevatron by interaction with a **negative** charge of a low energy high-current electron beam “ (1997)

# Tevatron Electron Lens (TEL-1)

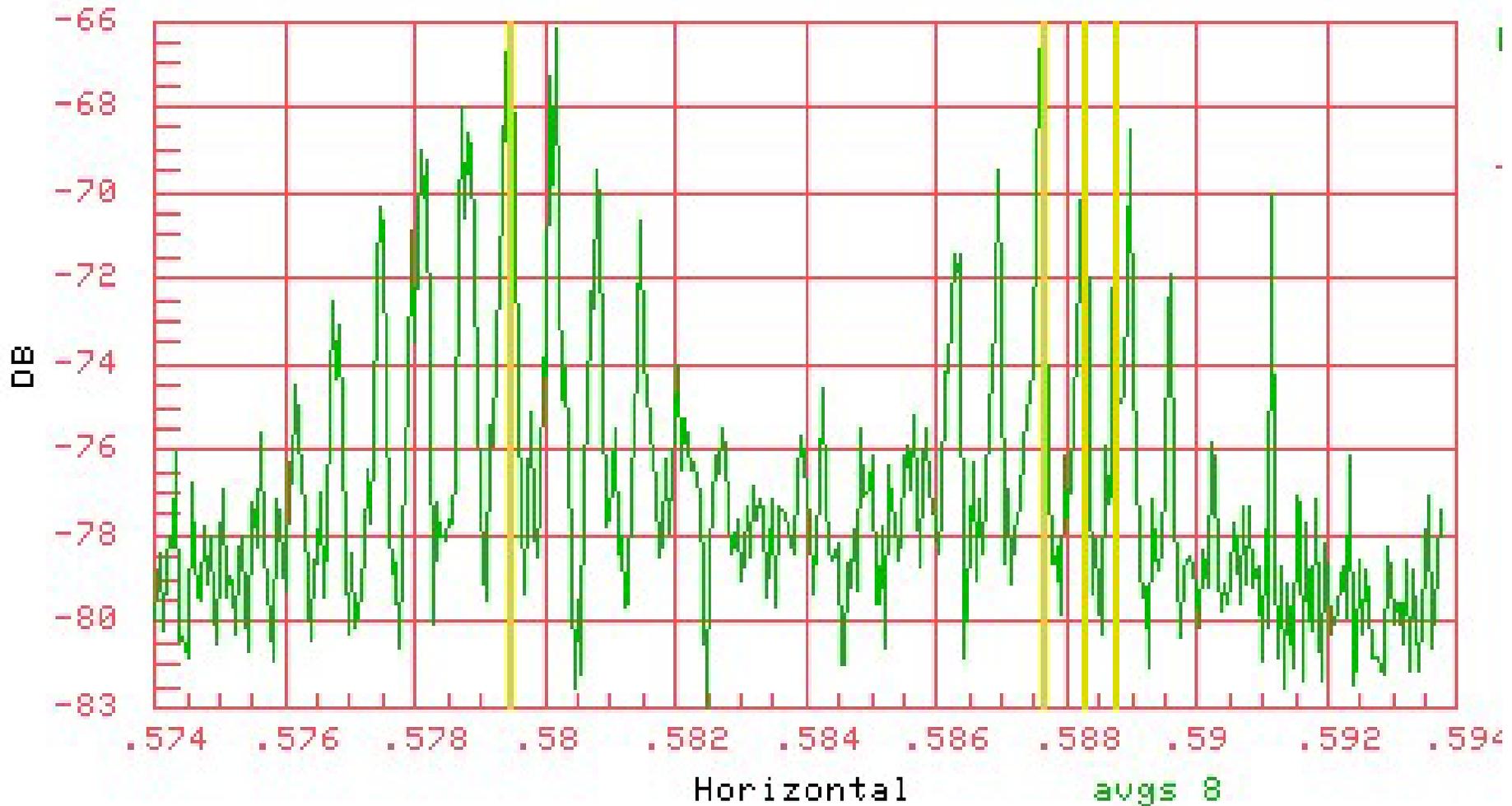


*+ HV Modulator, HV+HC PSs, Cryo, QPs, Vacuum, Controls, Diagnostics, Cables*

# Tevatron Electron Lens #1



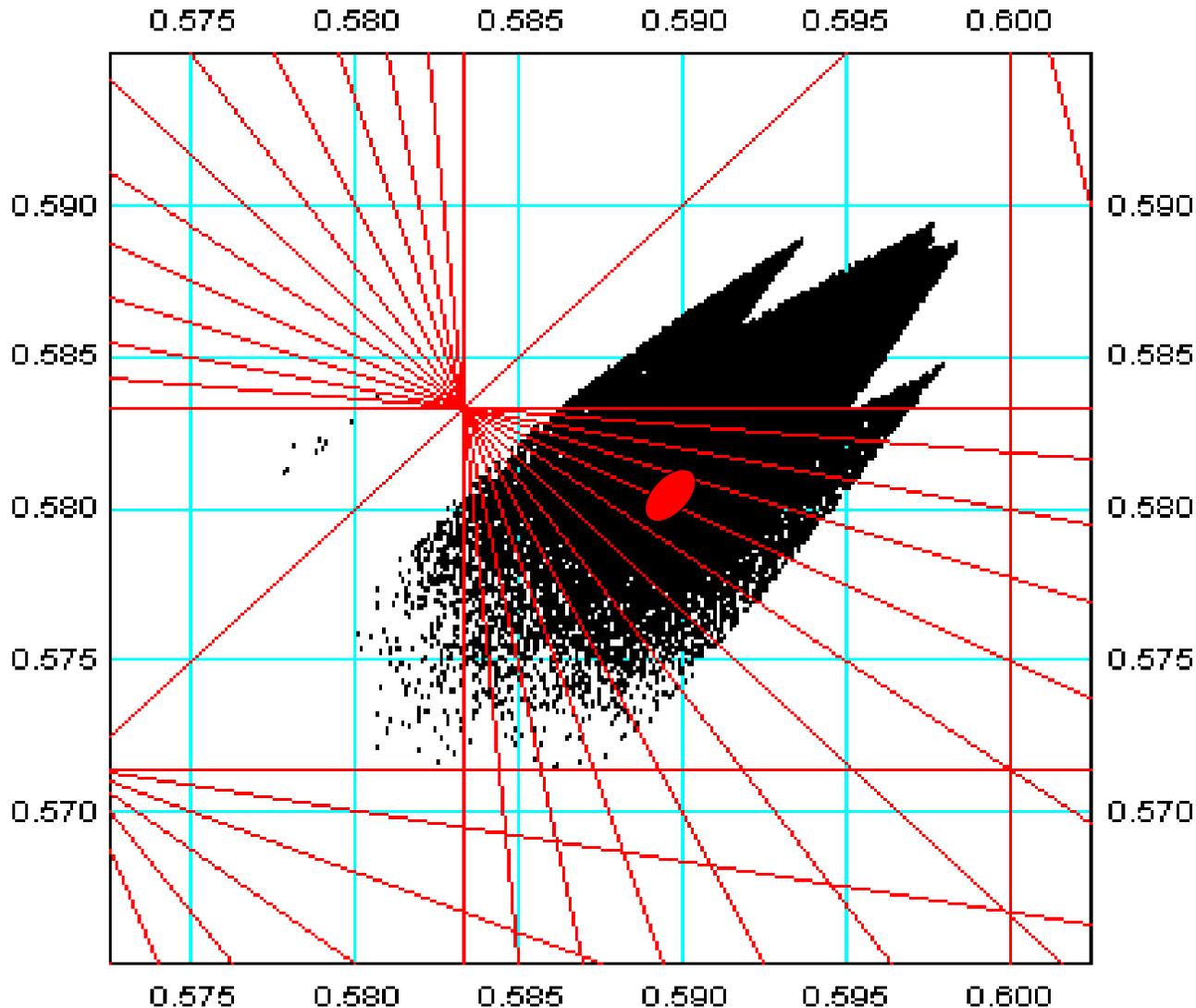
# Tuneshift $dQ_{hor} = +0.0009$ by TEL



Three bunches in the Tevatron, the TEL acts on one of them

# Antiproton Tune Distribution

Yu. Alexahin



36x36

36=3x12

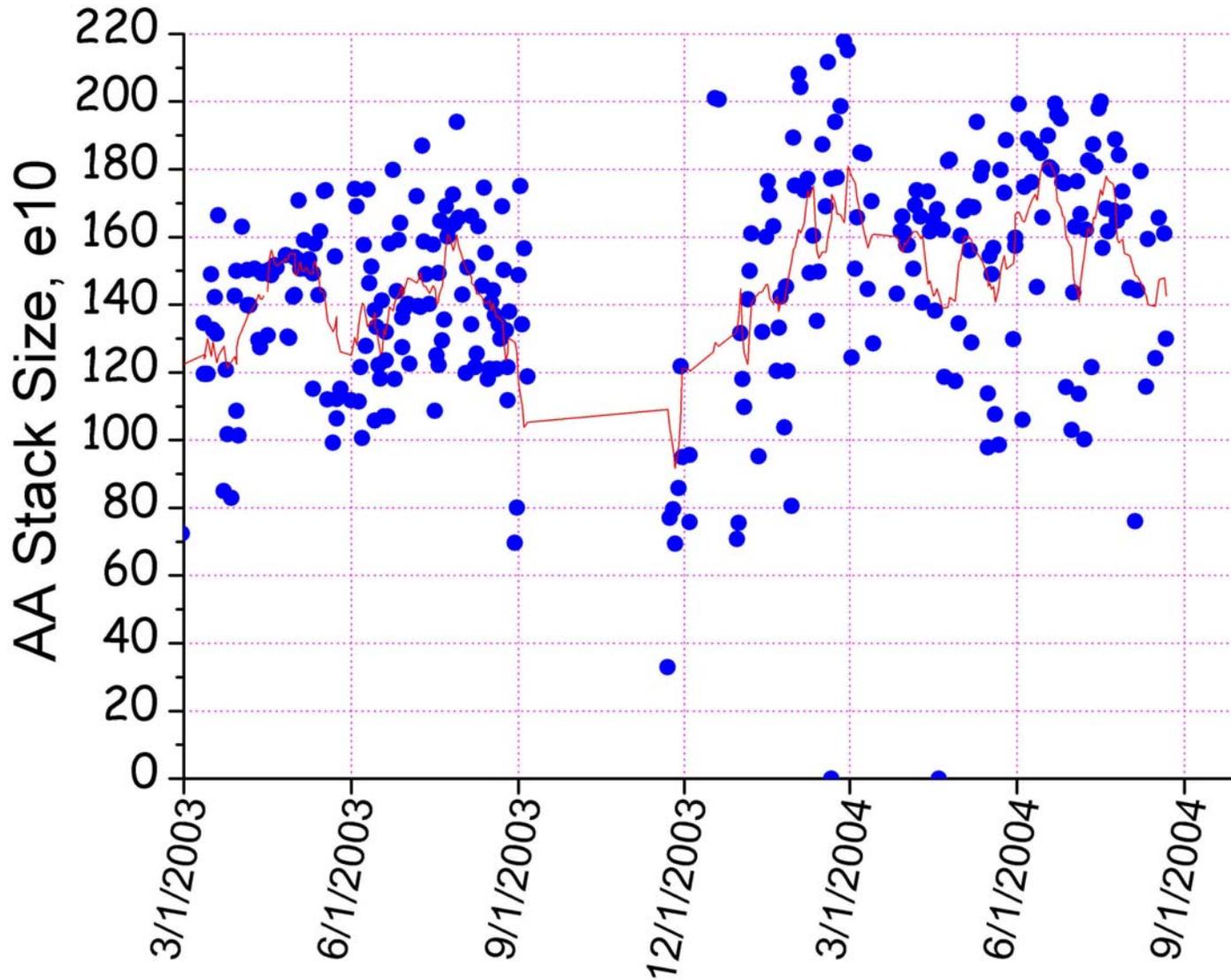
Head-On 2 IPs

$\xi=0.019$

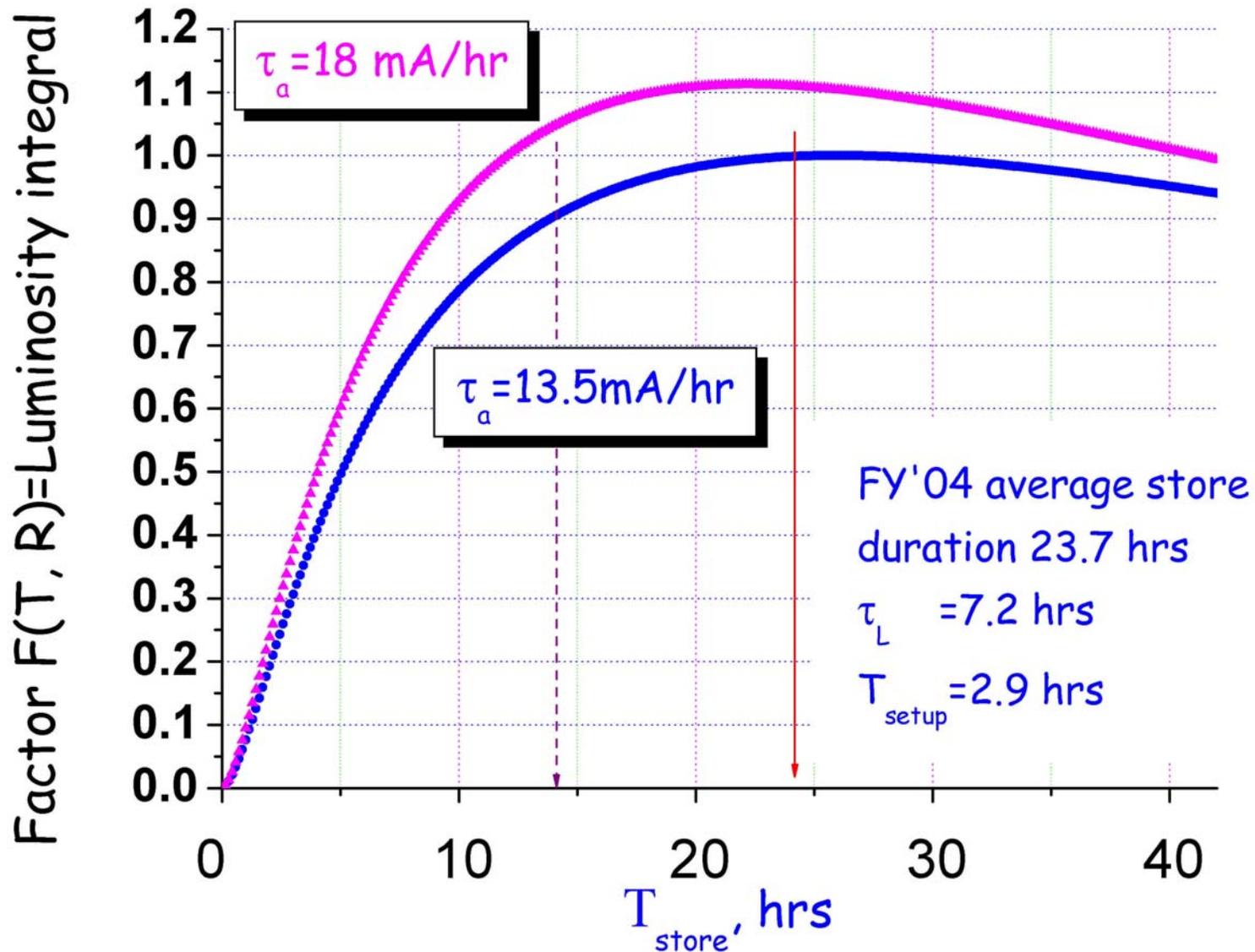
Bunch-by-bunch  
(parasitic IPs)

$dQ=0.006$

# Tevatron Luminosity Progress

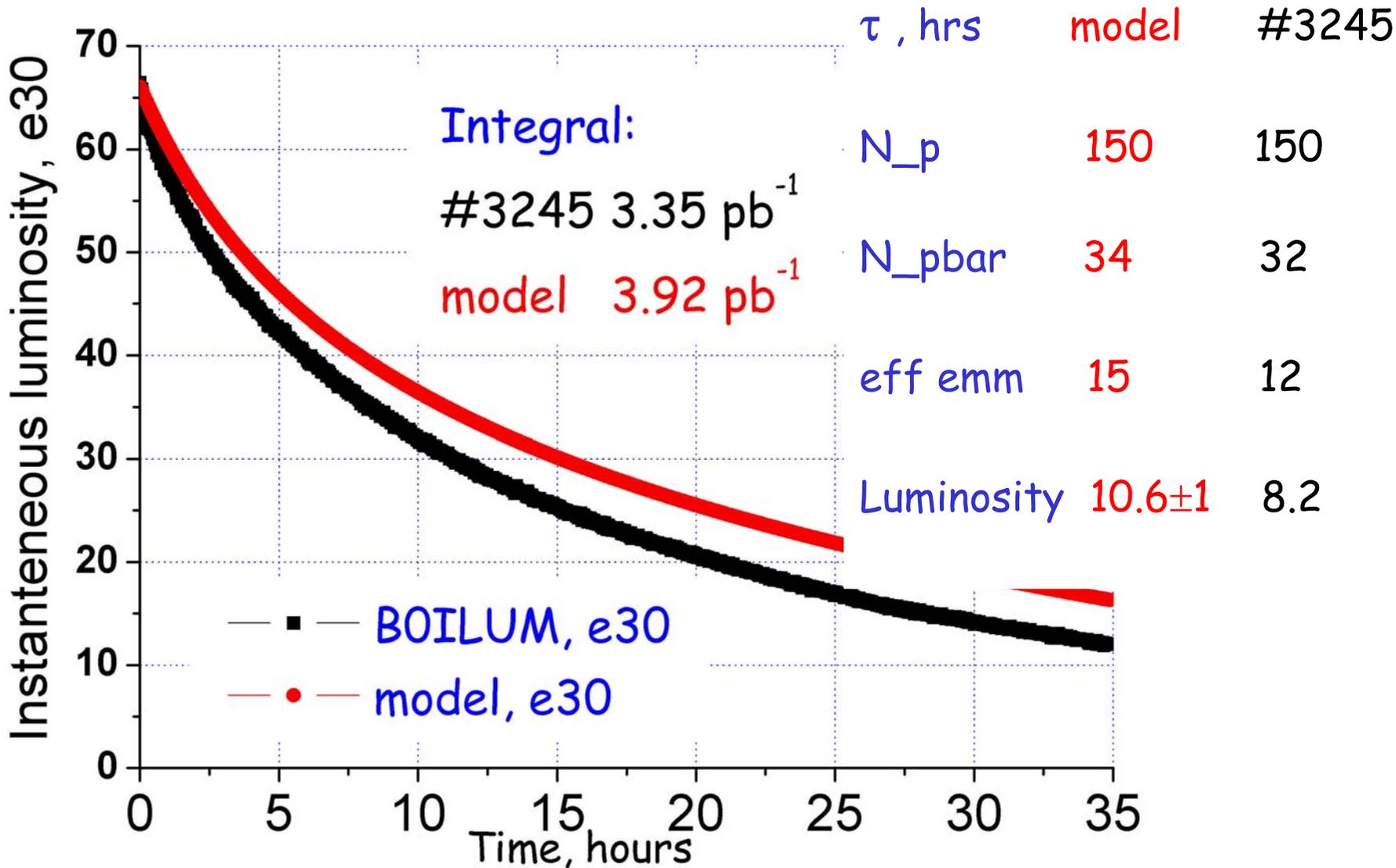


# Tevatron Luminosity Progress



# Model w/o Beam-Beam and Store

## 3245



# Beam-Beam Tune Shifts

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$$\xi = \frac{N_p r_p}{4\pi\epsilon_p}$$

*head-on tune shift per IP, now with  
N<sub>p</sub>=245e9 and 95% emittance 20p  
total max head-on tuneshift is 0.018  
for pbars, 0.004 for protons*

*tune shift for separated beams is smaller:*

$$\Delta\nu = \sum_i \frac{\beta_i N_p r_p}{2\gamma\pi d_i^2} = \sum_i \frac{2\xi}{(d_i / \sigma_i)^2}$$

*but: a) always present*

*b) MANY near-misses  $i = 70$*

*c) different bunch-by-bunch*

*d) HV separator limited:  $gd^2$  scales as  $V^2 / g$*