Fermilab

One Year in the Life of Tevatron

or

A Cinderella Story

Vladimir Shiltsev

Fermilab

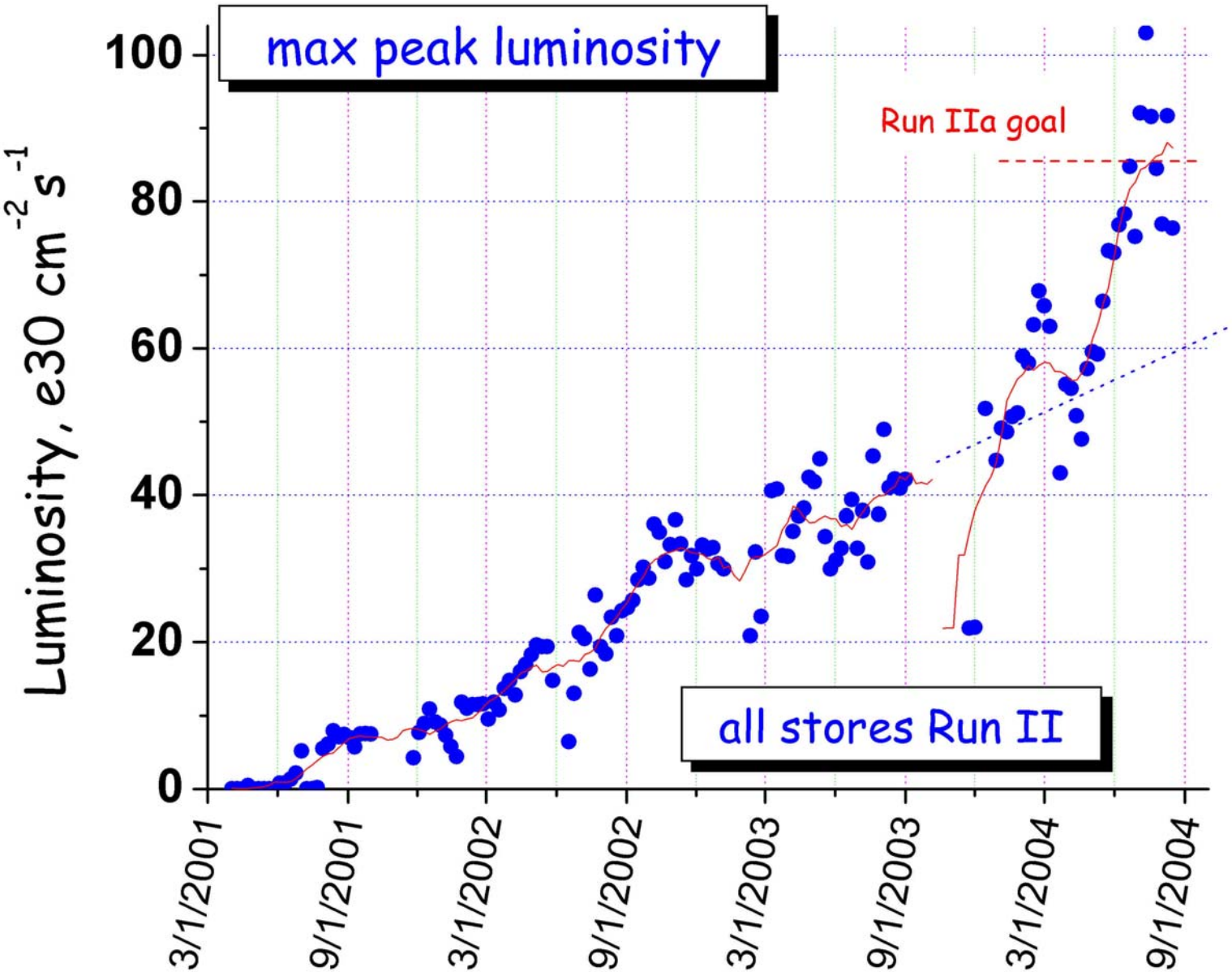
What's all this fuss about?

Miracle year of 2004

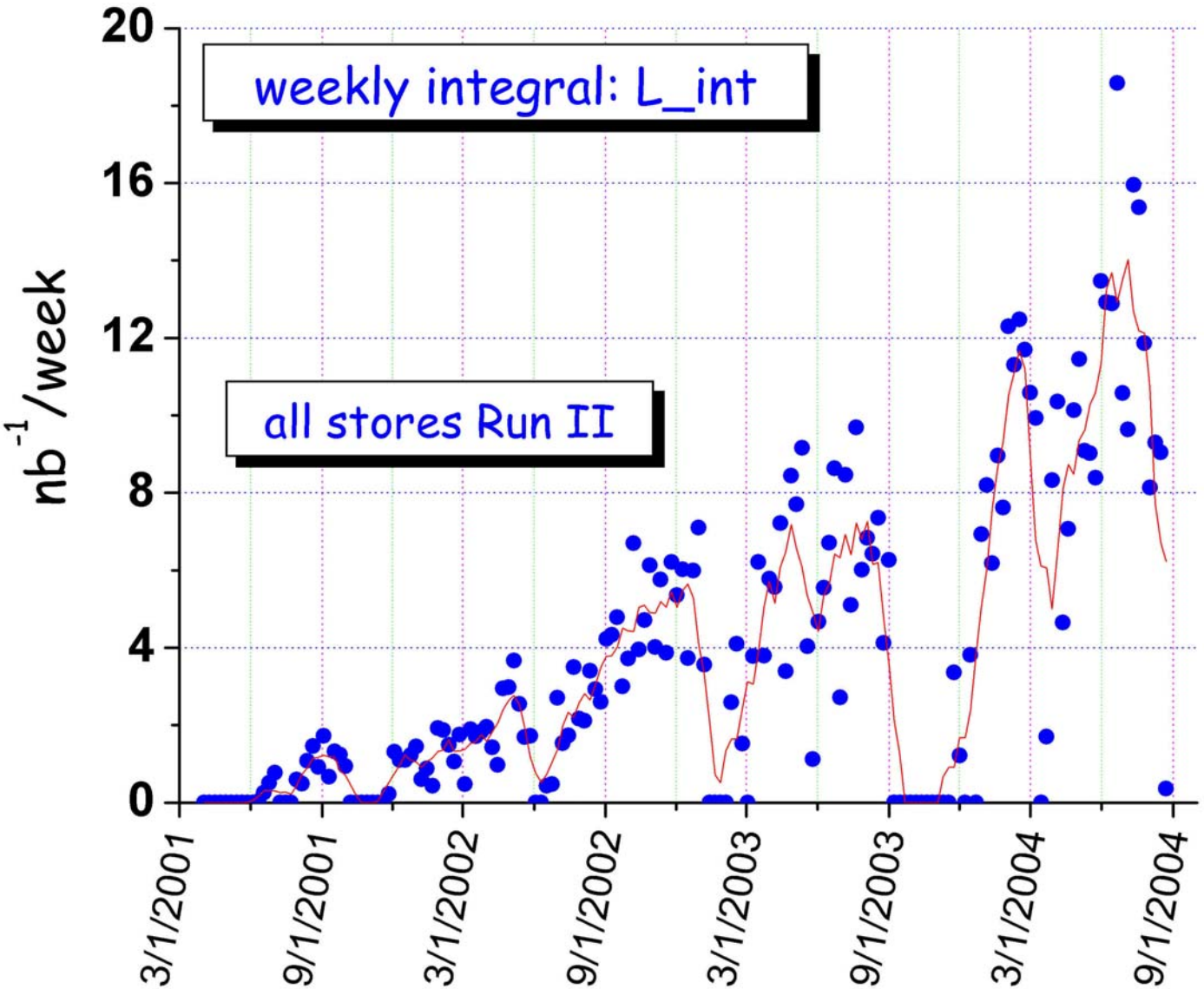
(for an external observer)

	FY'03	FY'04	gain
▪ Peak Luminosity	49e30	103e30	2.10
▪ Weekly integral	9.7 pb^{-1}	18.6 pb^{-1}	1.92
▪ Total integral	236 pb^{-1}	343 pb^{-1}	1.45

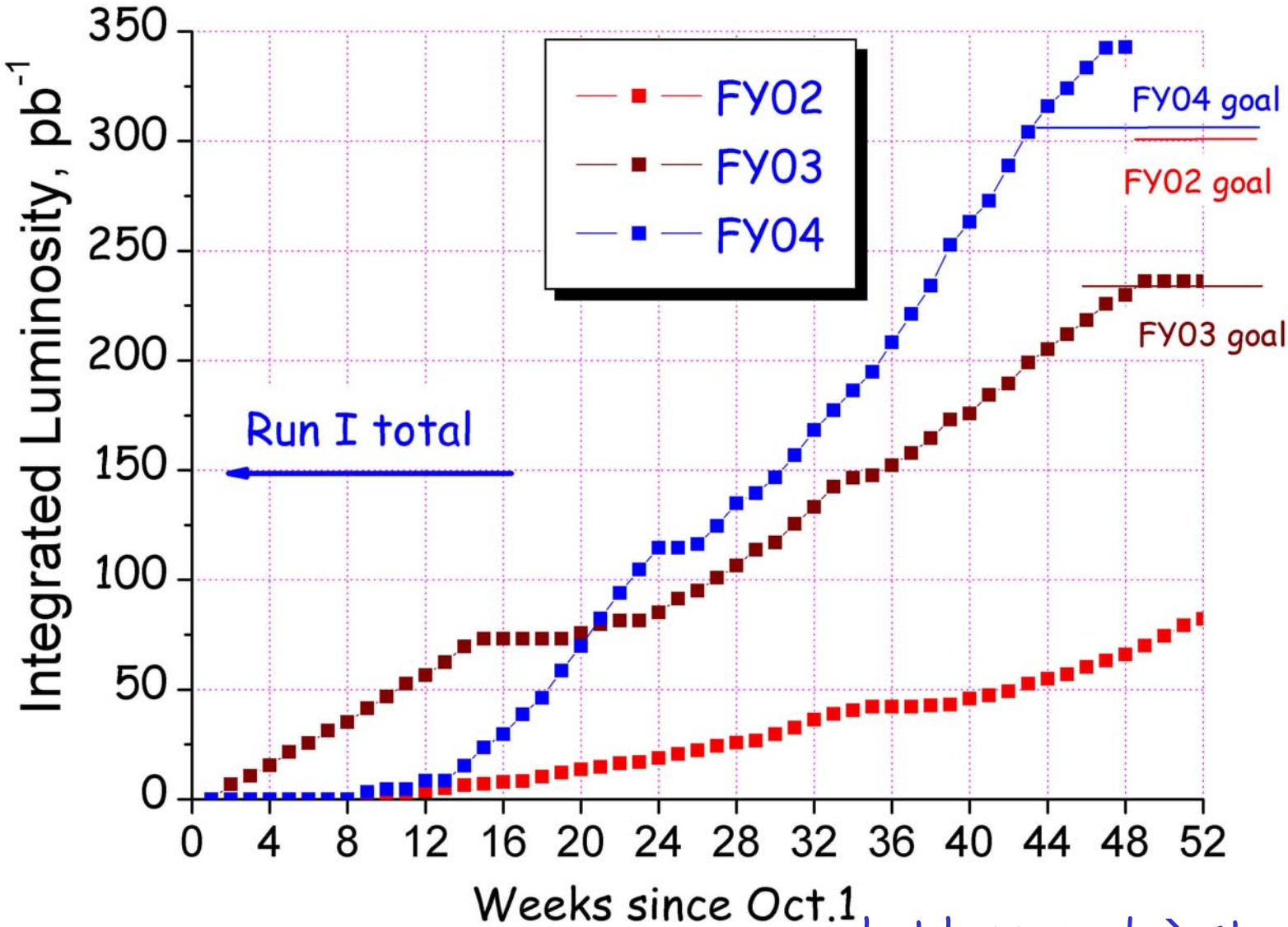
Tevatron Peak Luminosity Progress



Weekly Integrated Luminosity



Integrated Luminosity



what happened → story of…

What Has Happened in FY'04?

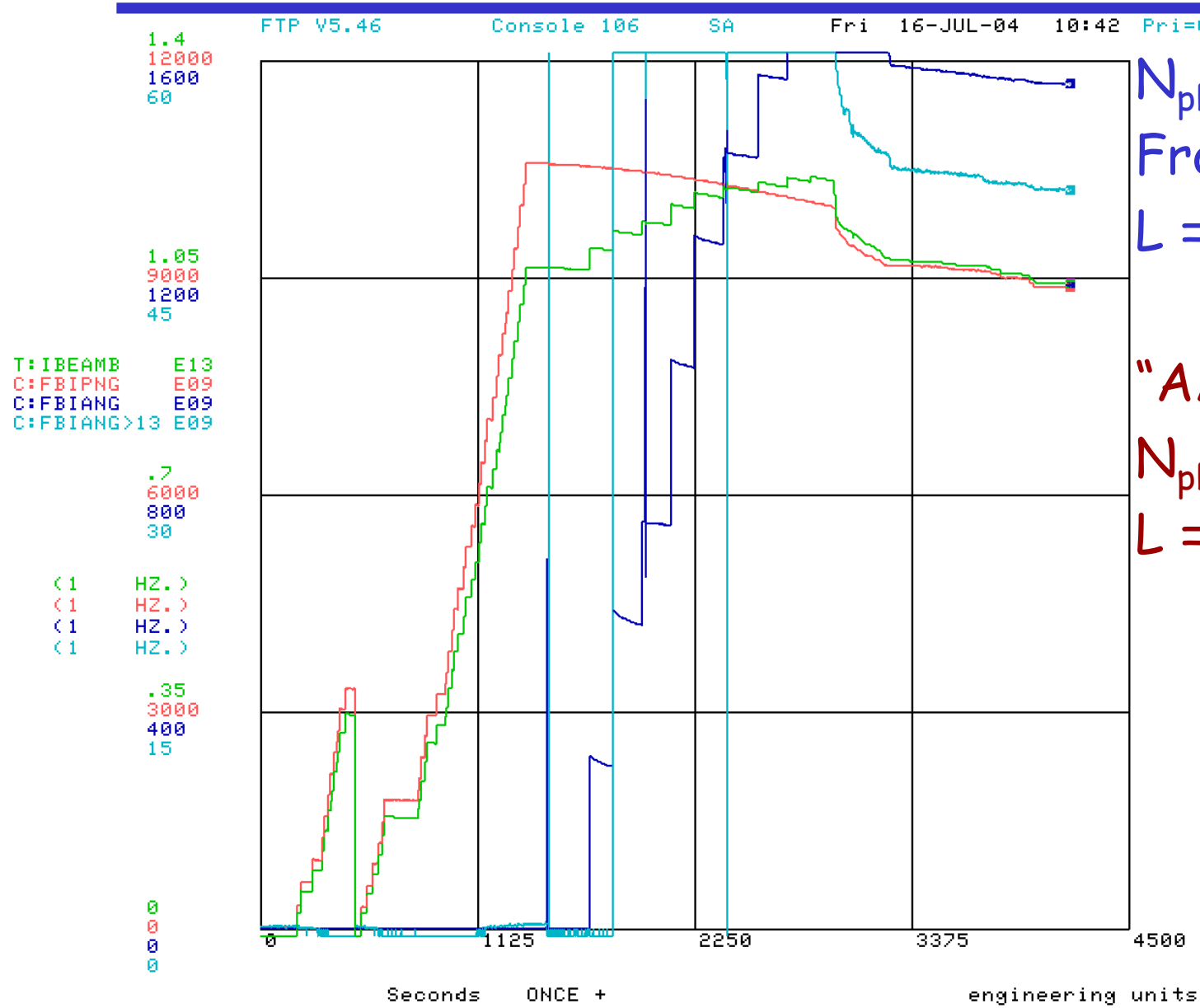
- Shutdown work – Reshimming
- Shutdown work – Alignment
- Shutdown work – Liner
- MI improvements – 2.5MHz trnsf, BLCompns
- Longer stores – Bigger Stacks
- Beta* function at IP
- IP move at CDF
- Recycler shots

Introductory Notes: Lumi and Integral

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

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

Example: Lots of Pbars in Store #3657



N_{pbar}=1556 e9

From AA+RR

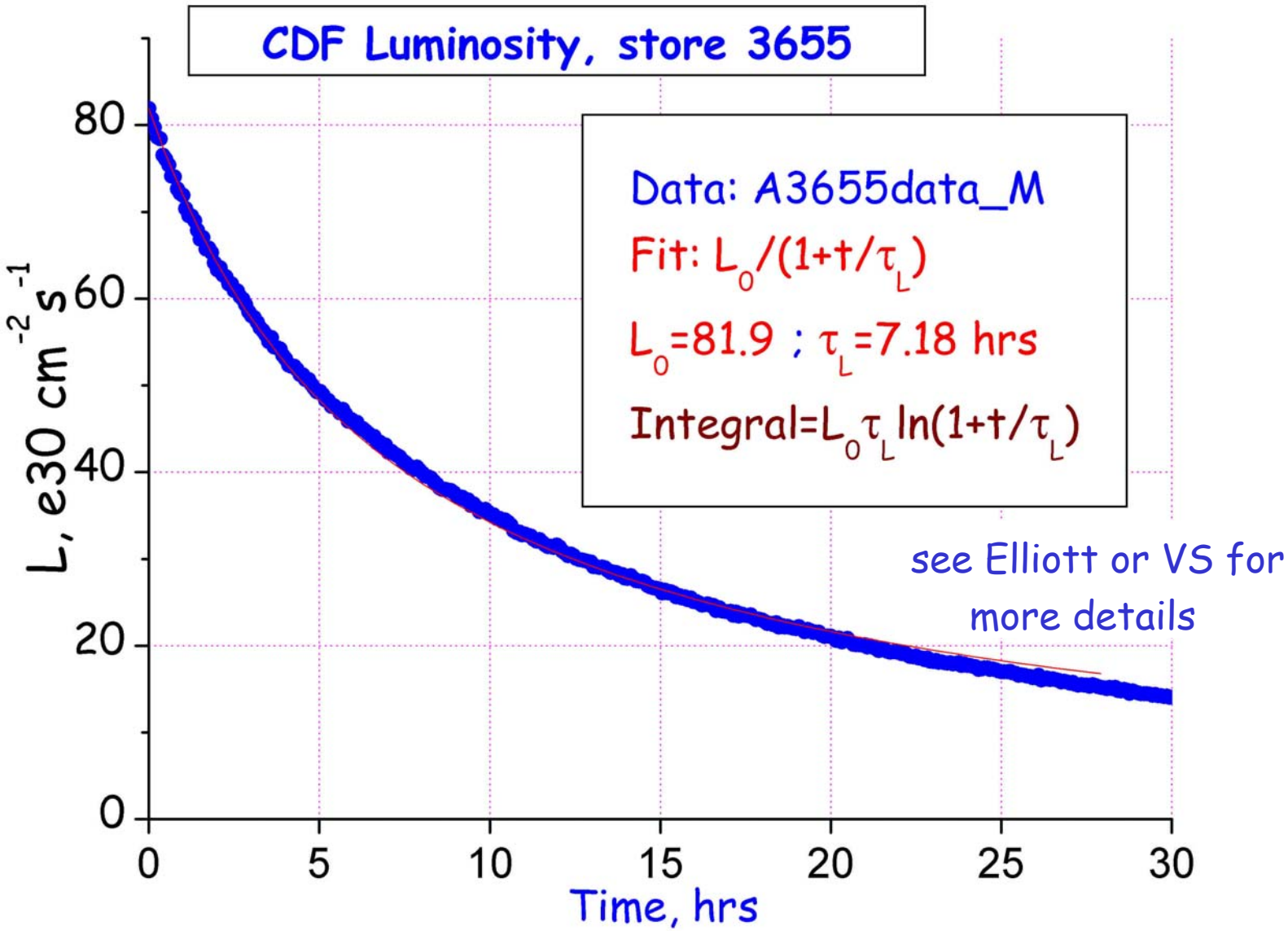
L = 103 e30

"AA only" record

N_{pbar}=1265 e9

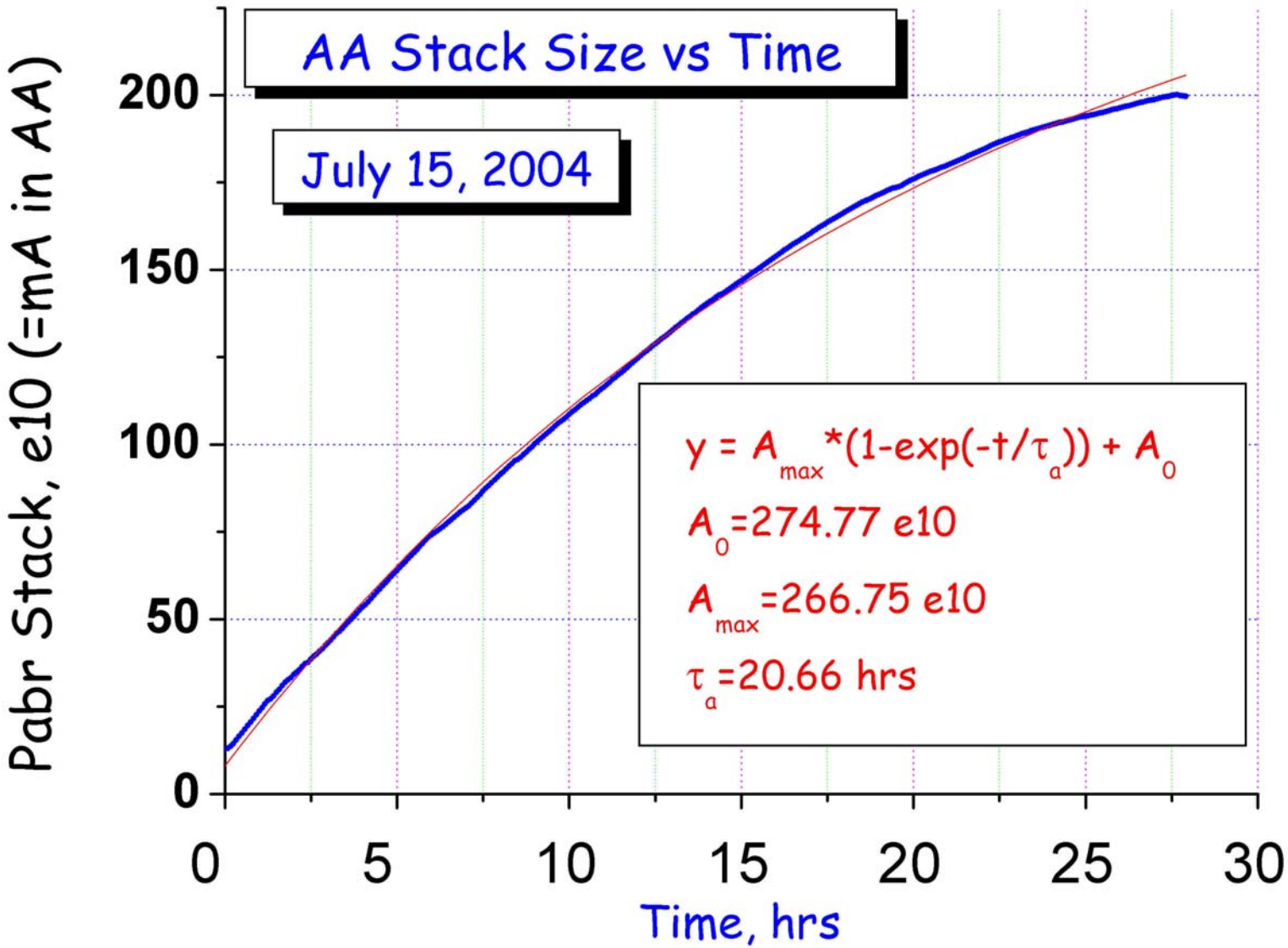
L = 85 e30

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



see Elliott or VS for more details

Integral: N_a Exponentially Saturates



Luminosity Integral

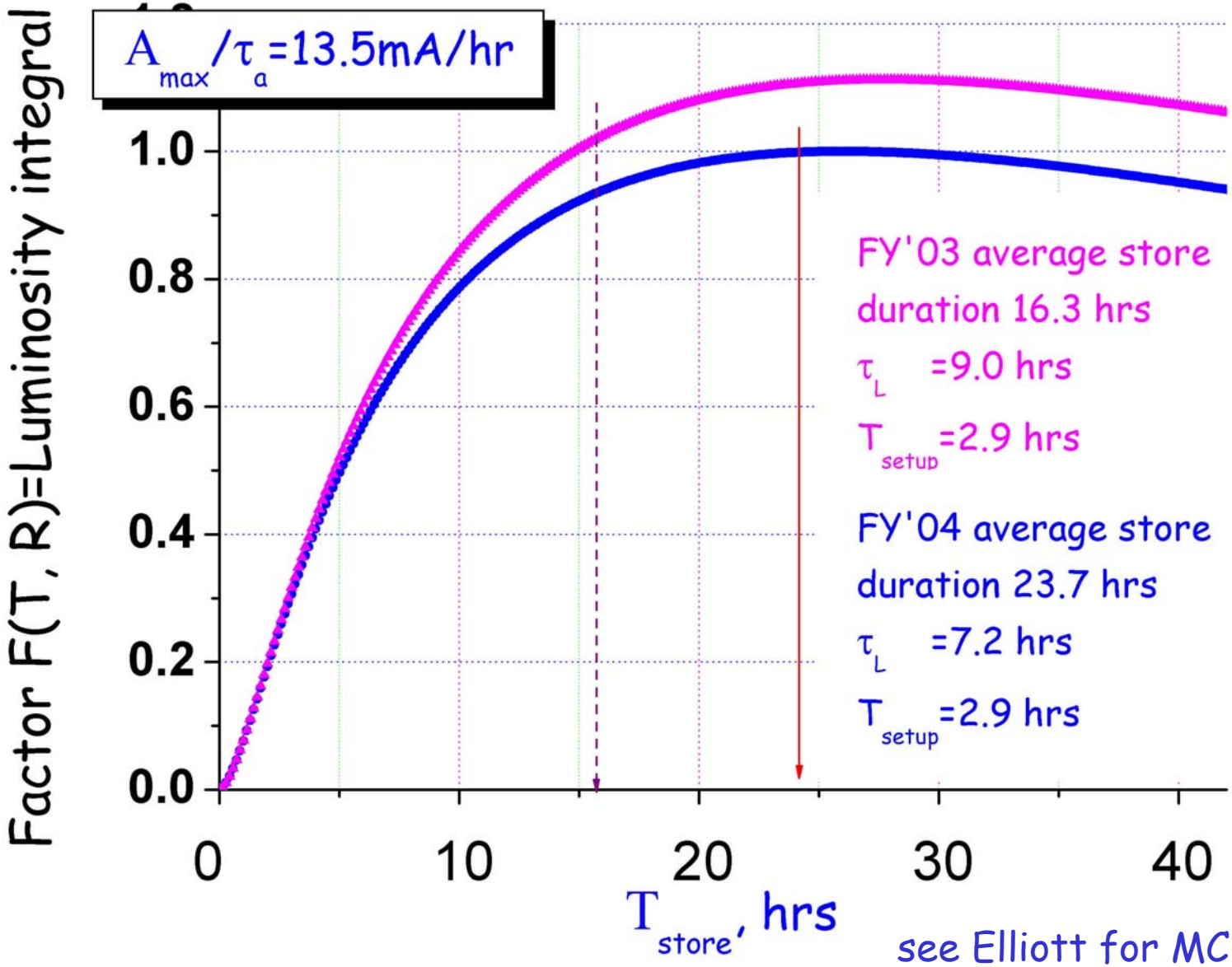
$$I = \int L dt = N_{stores} \tau_L L_0 \ln(1 + T/\tau_L)$$

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

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

see next slide

Store Length Optimization Factor *F*



see Elliott for MC model

Luminosity Integral

- 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 β* 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 β*47/42 → 30/33 ±5cm

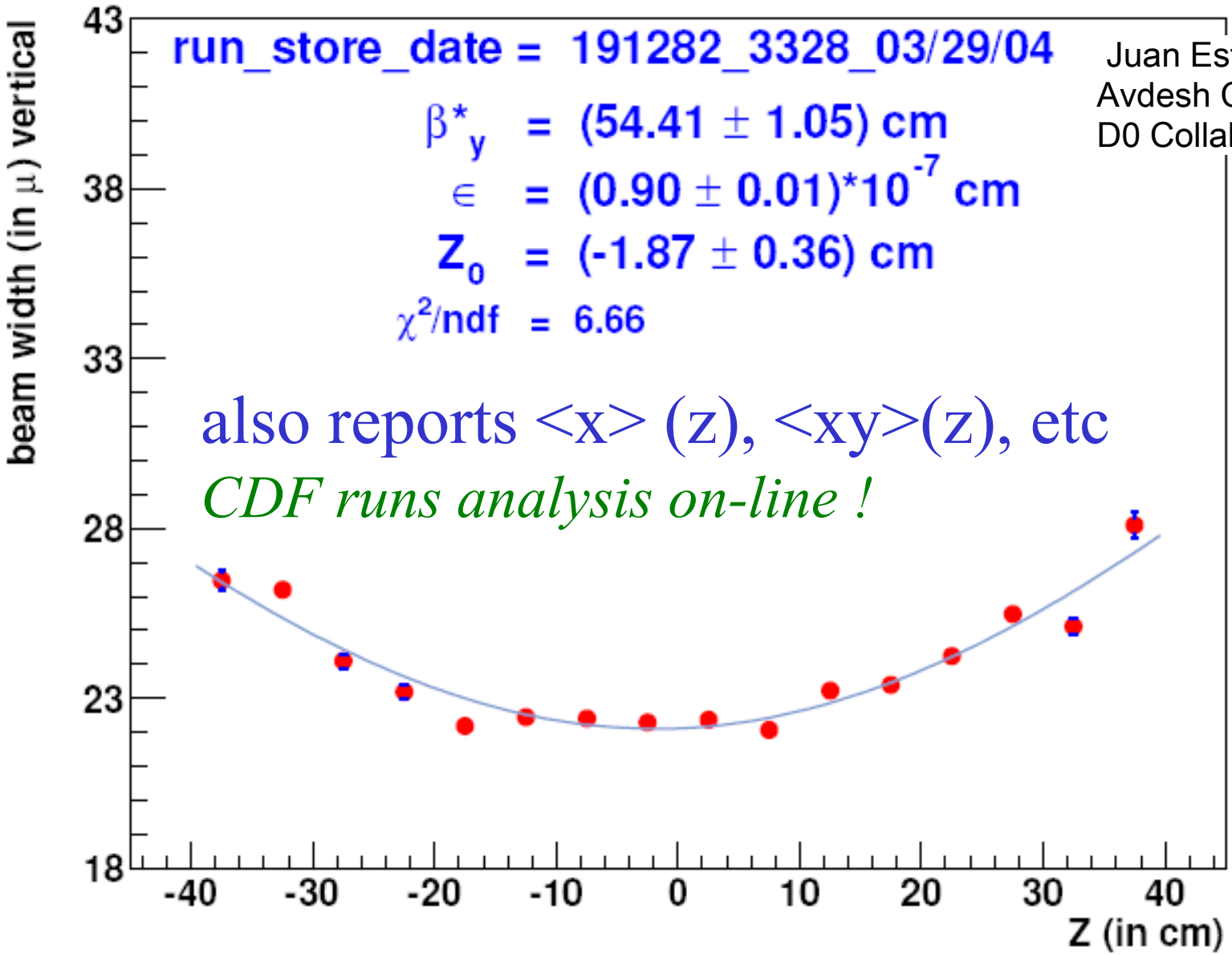
D0 β*38/39 → 33/30 ±2cm

- 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

β* from Luminous Region Analysis

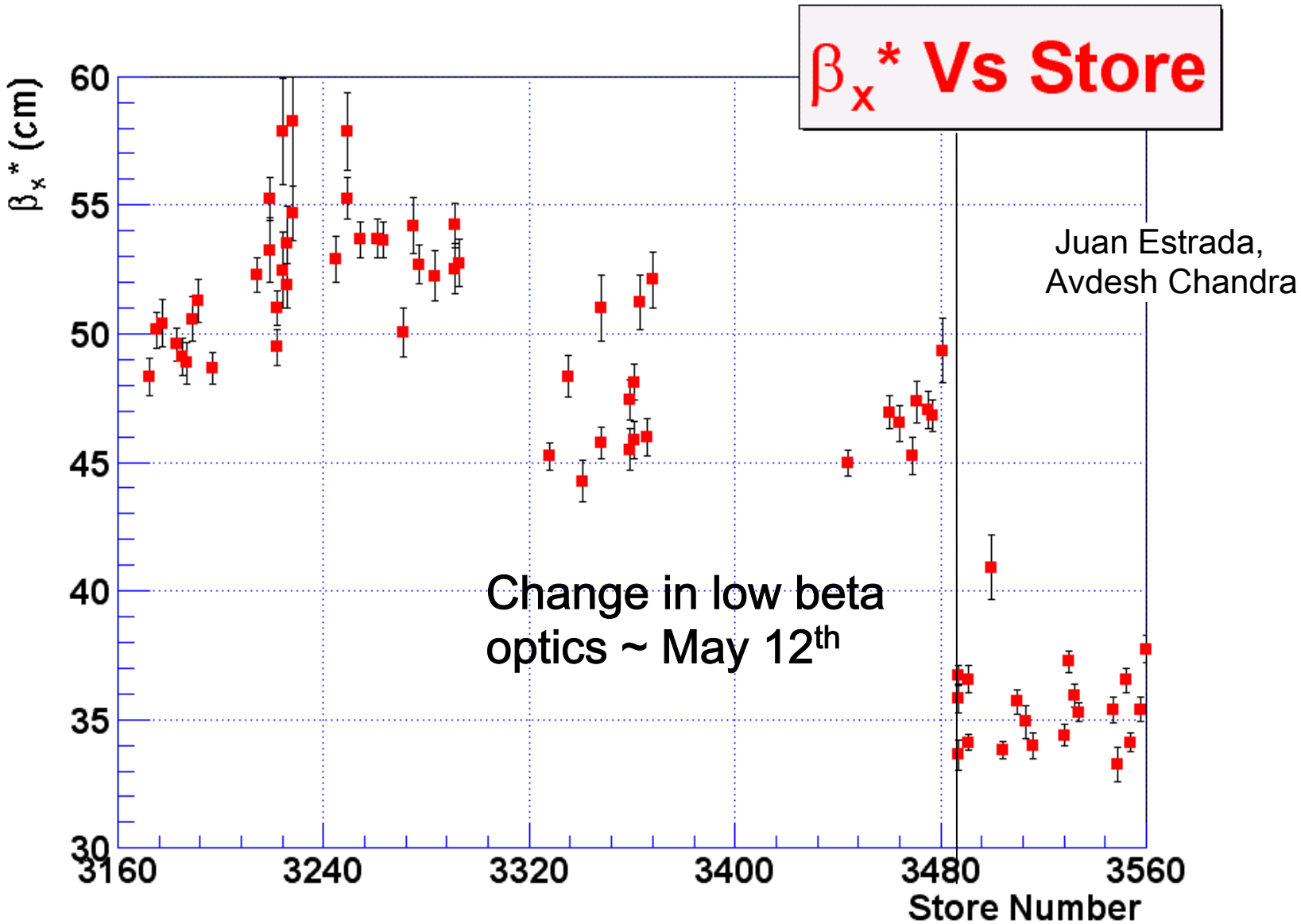


Juan Estrada,
Avdesh Chandra
D0 Collaboration

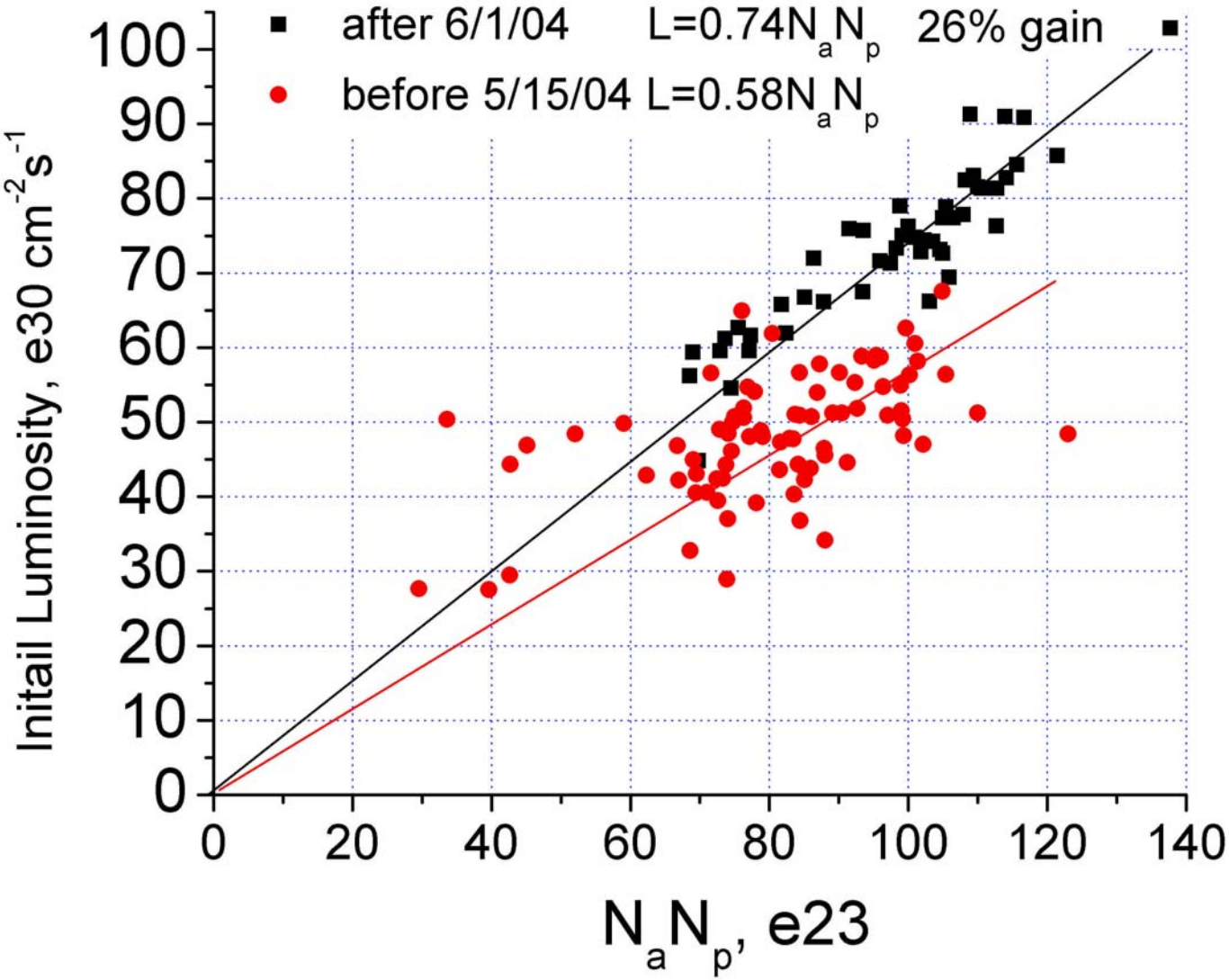
also reports <x> (z), <xy>(z), etc

CDF runs analysis on-line !

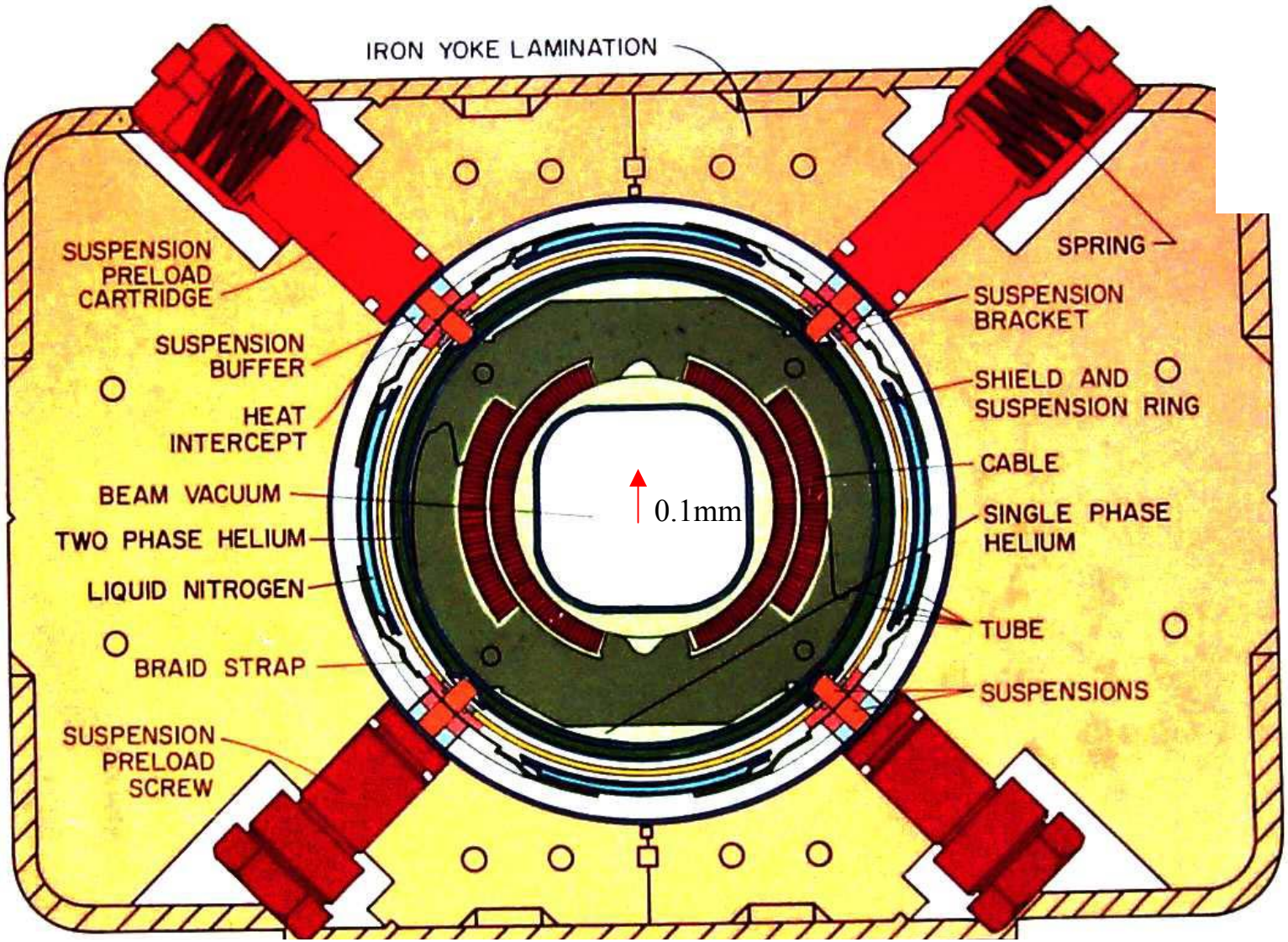
β* Reduction Confirmed by Detectors



…and You Get 26% in Peak Luminosity



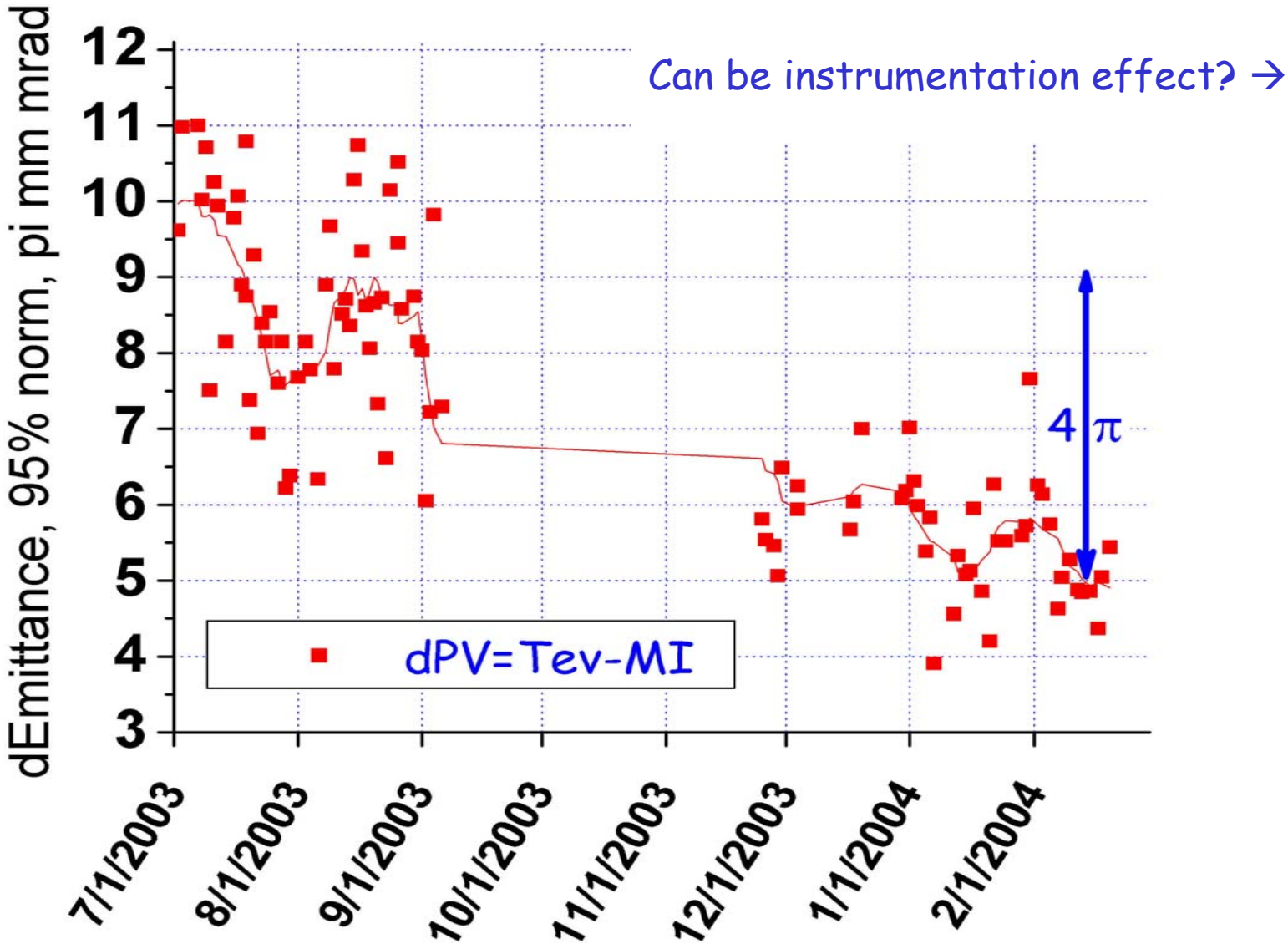
Reshimming=Lifting Up SC Coils



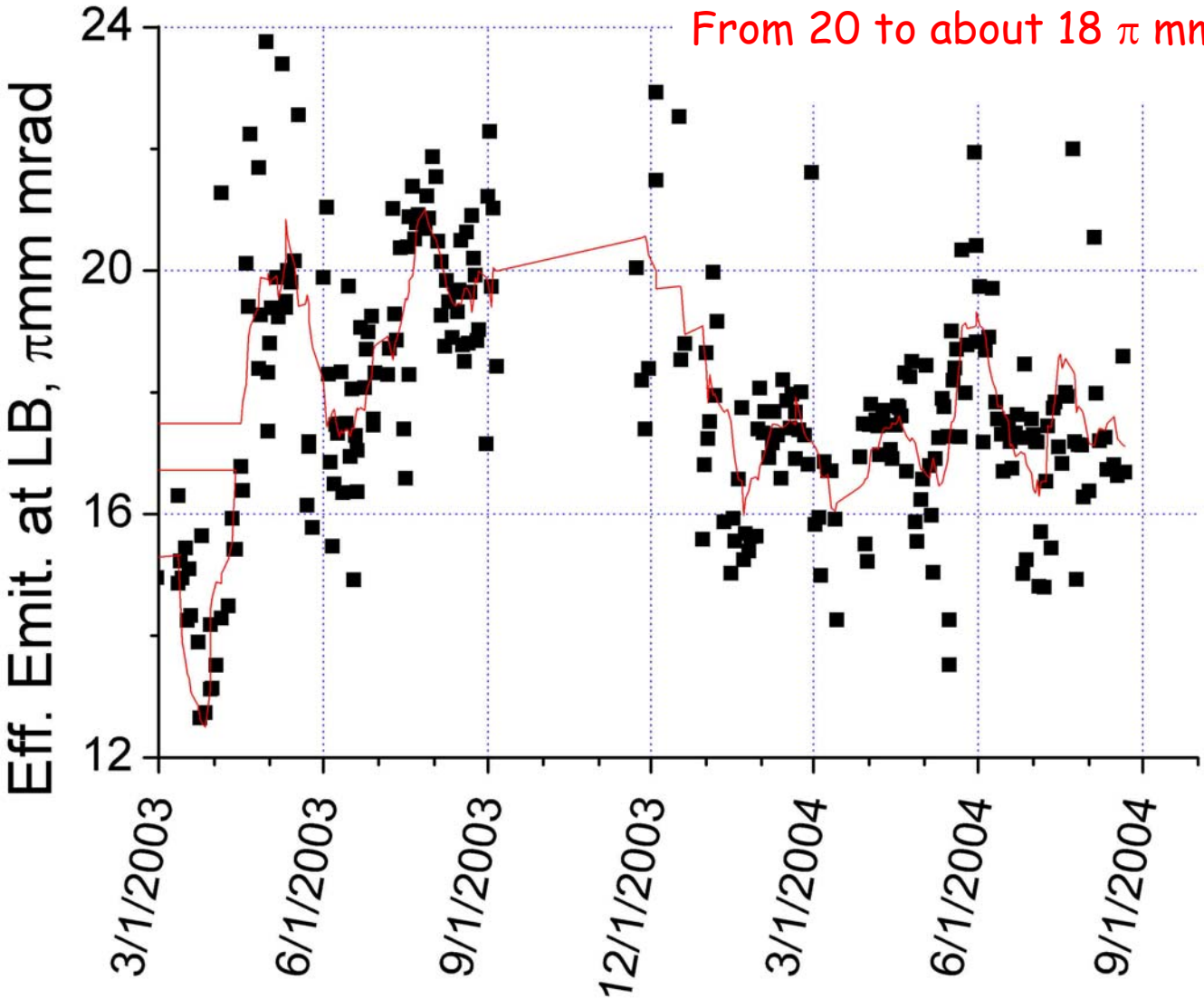
M.Syphers, D.Harding,TD team

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

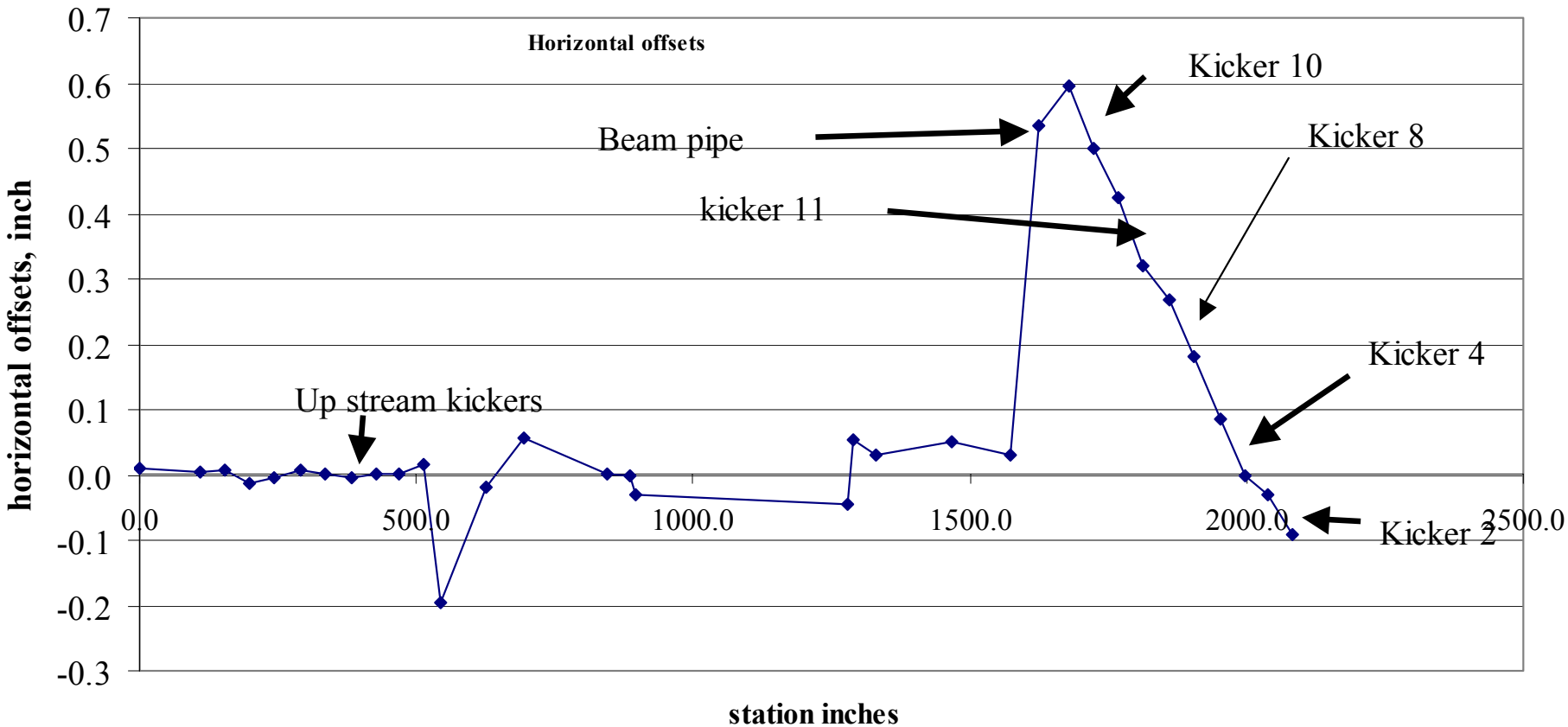
Emittance Dilution in MI→Tev Transfer



Seen Well in Luminosity



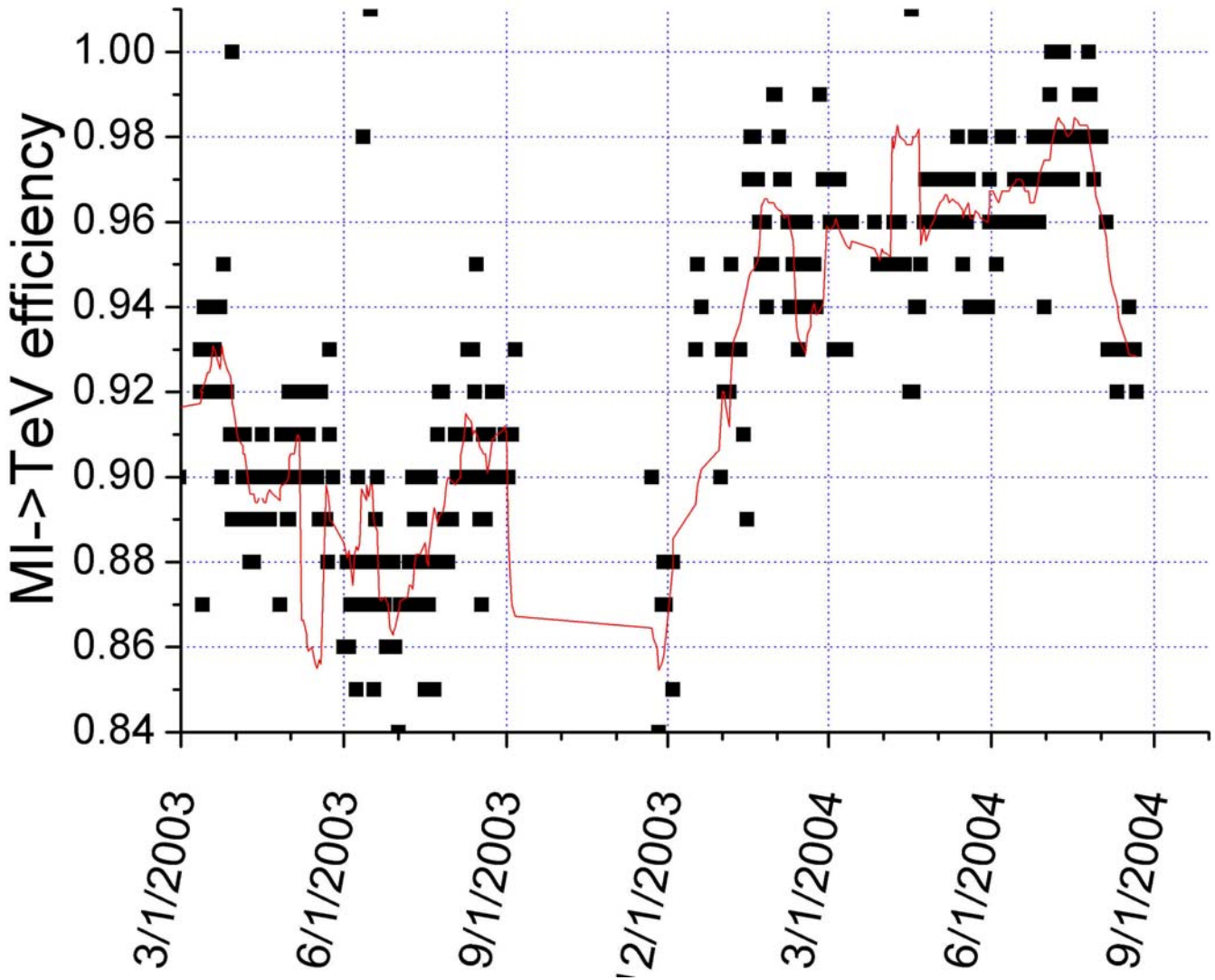
Alignment: Open Apertures



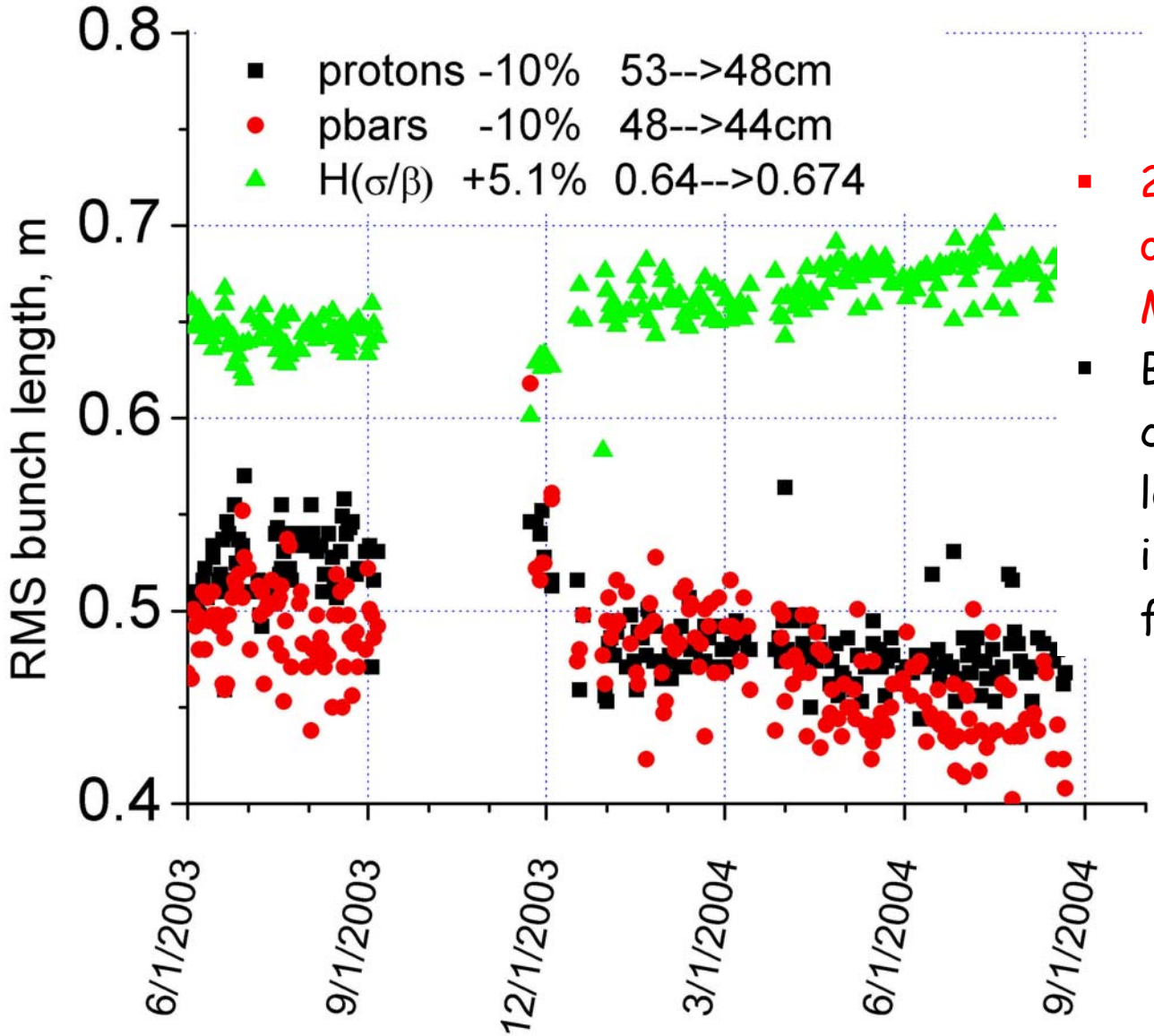
- Another ¼" misalignment fixed at D0
- Rolls >2mrad ~complete
- # of dipole correctors running >35A out of 50A: 26 → 6

Alignment: What it really means…

All That Pays Off in Transfer Efficiency



Hard Work of MI Pays Off, Too!

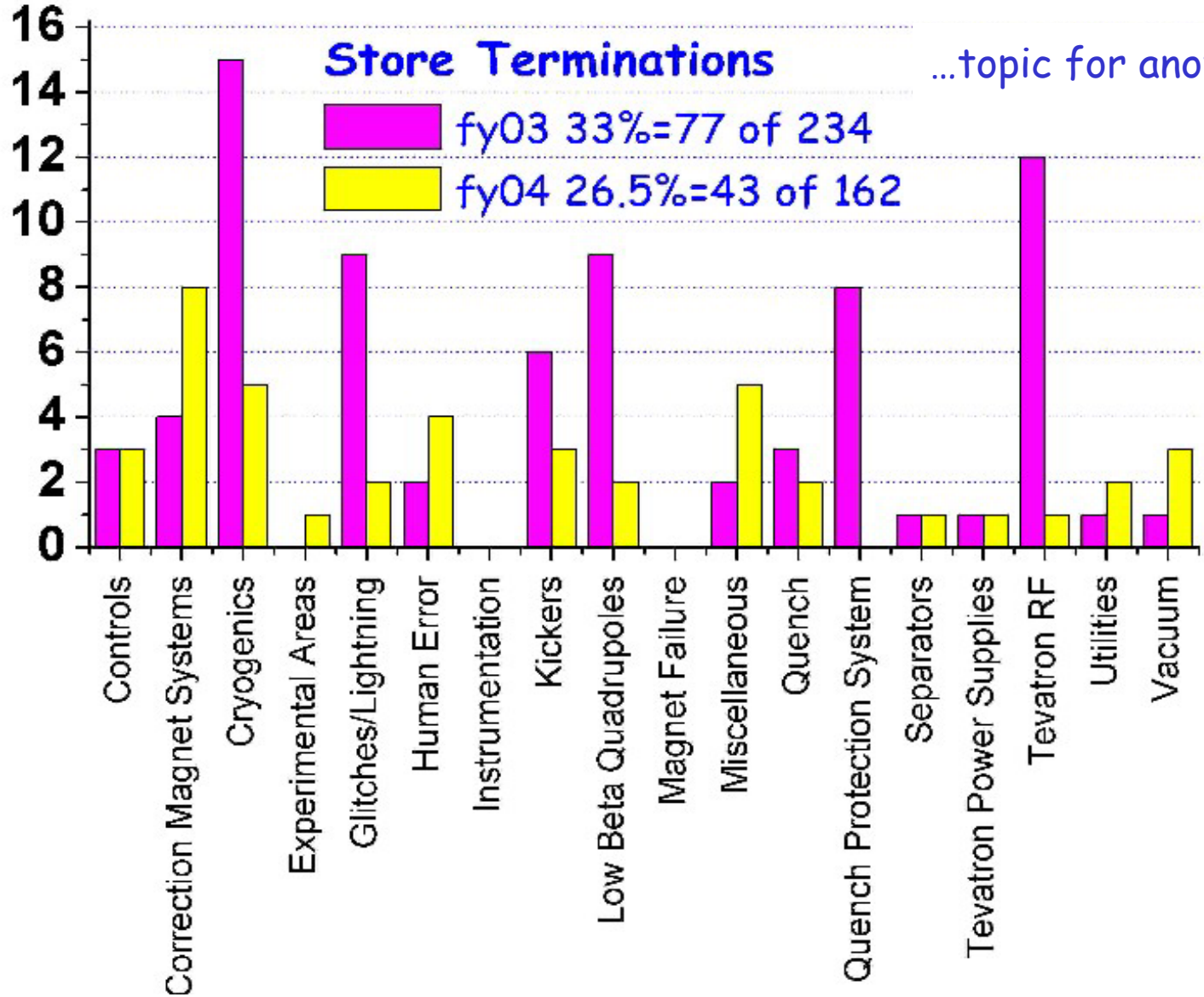


- 2.5 MHz transfers of pbars from AA to MI
- Beam loading compensation and longitudinal instability damper for protons

Another Factor: Machine Availability

- 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

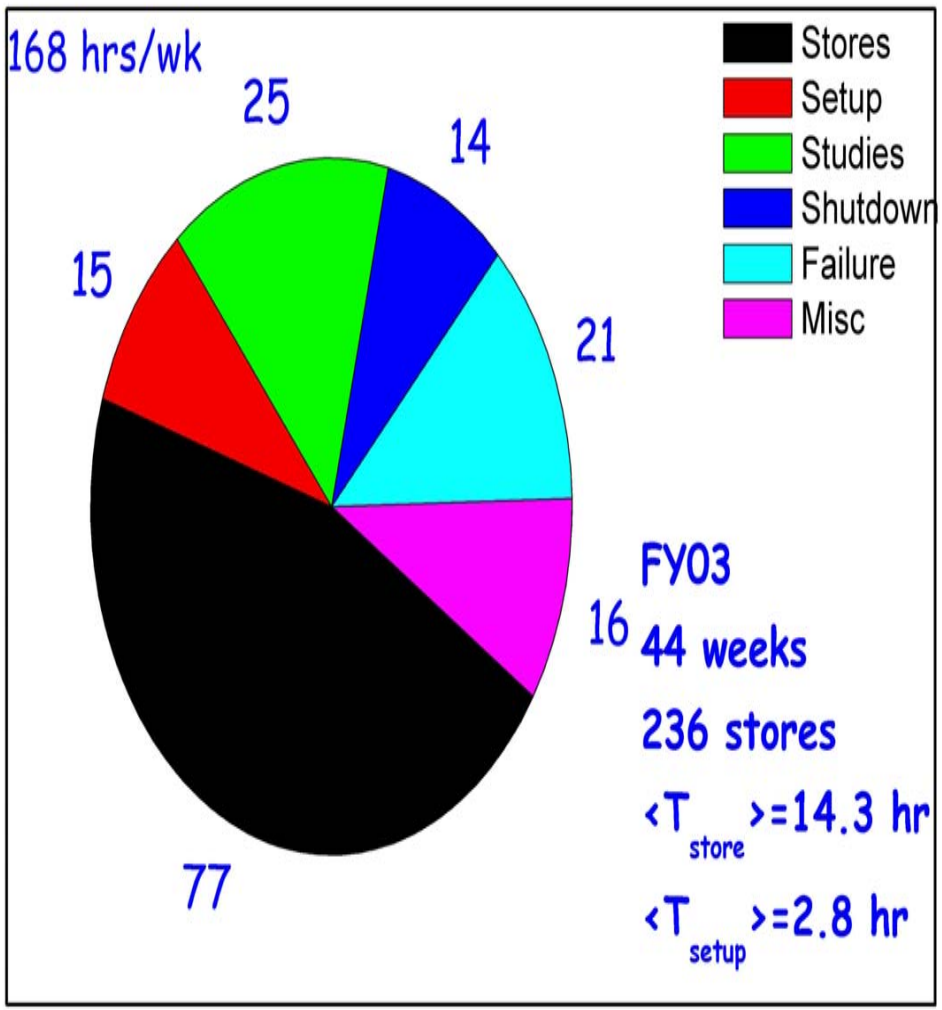
Store Termination Statistics

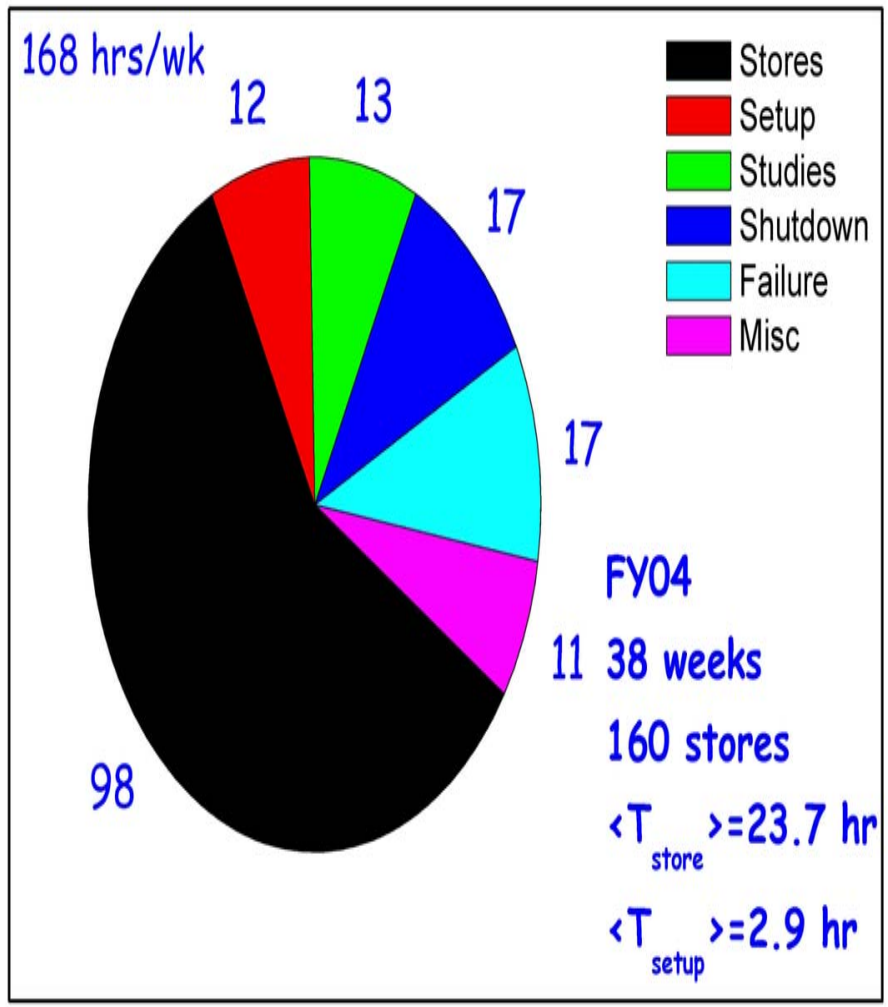


…topic for another seminar

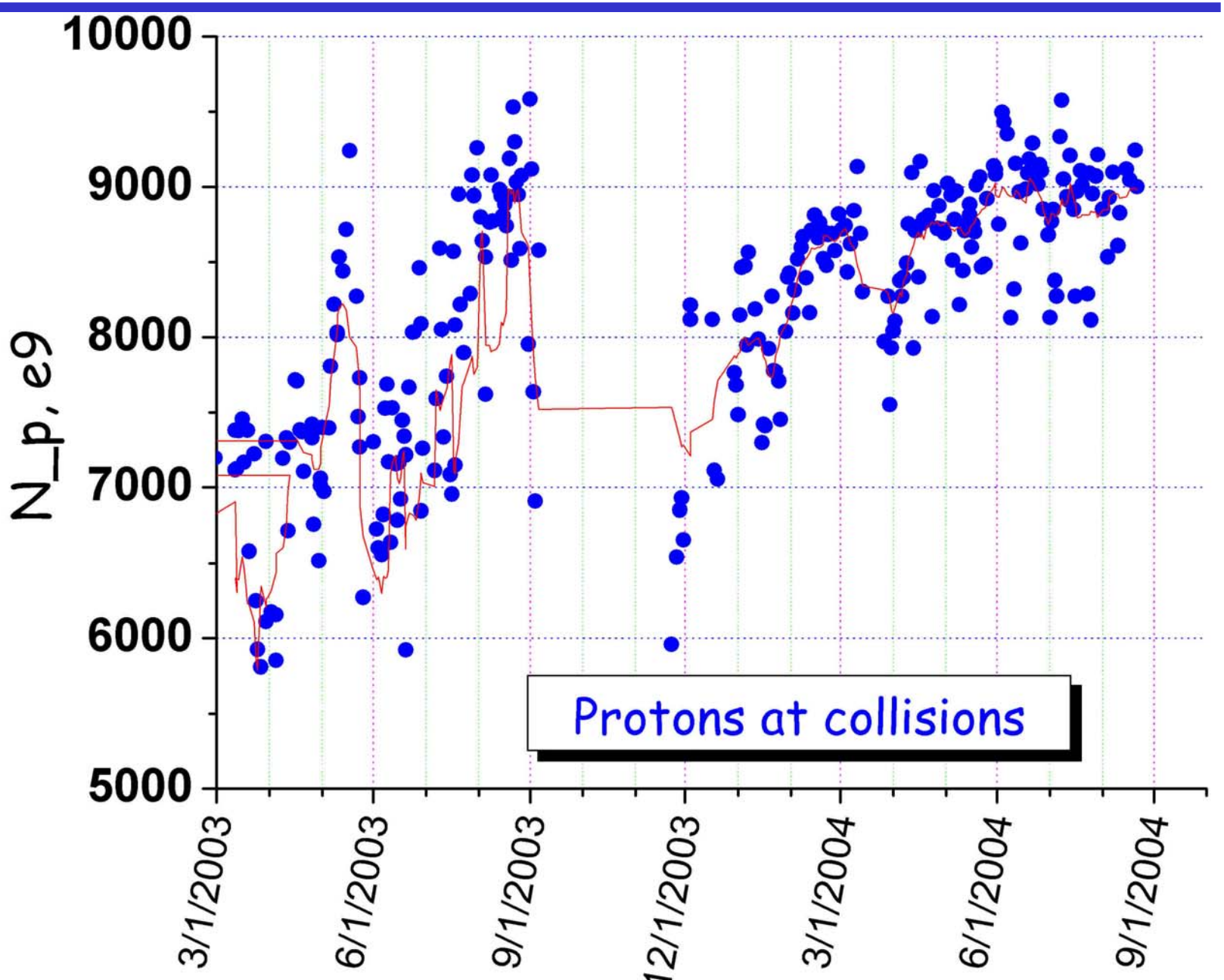
Tevatron Time Breakdown

Courtesy of J.Crawford

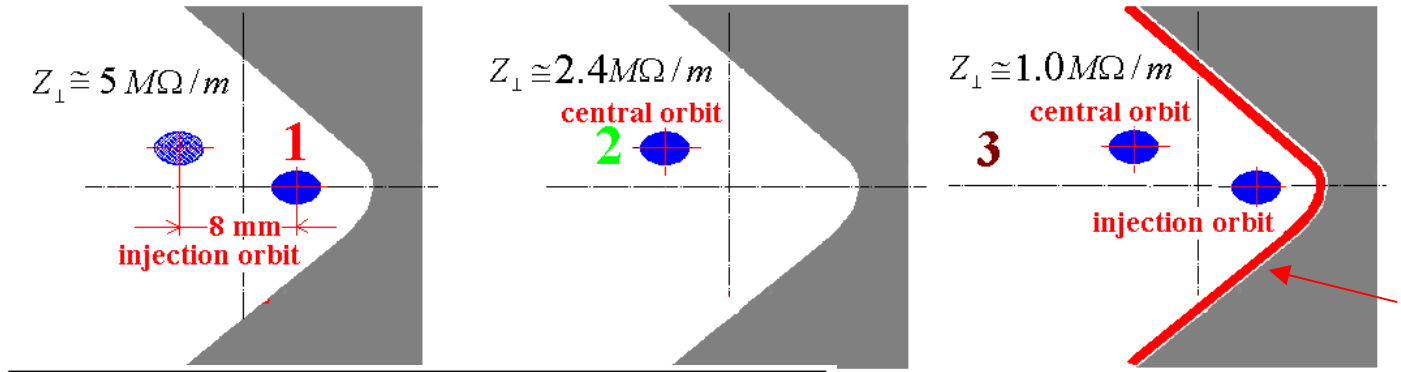




Proton Intensity Stabilized in FY04

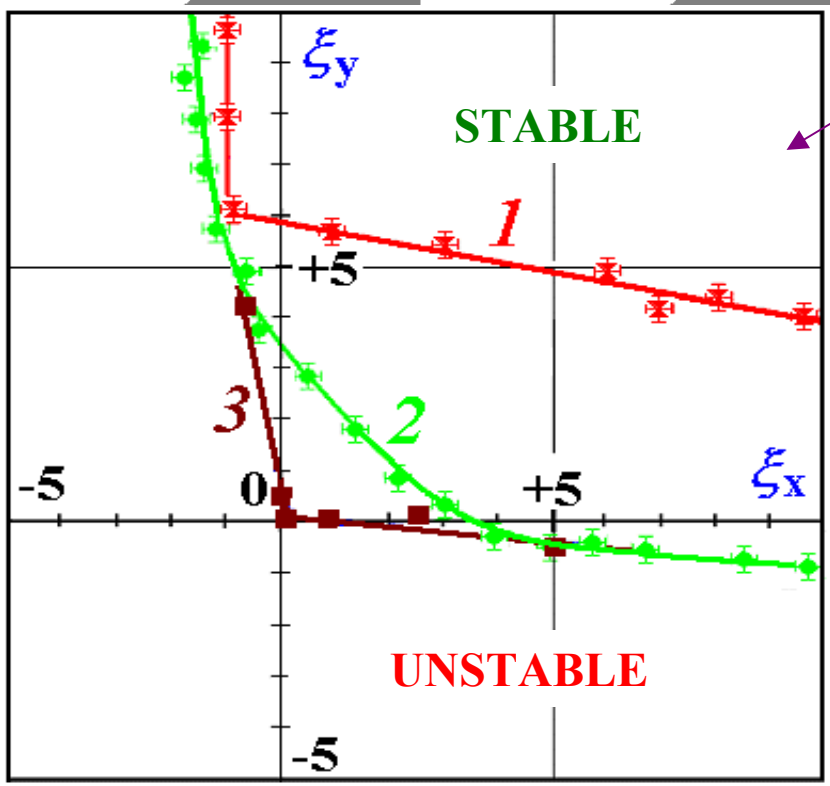


Tevatron Impedance Reduced by Liners



P.Ivanov
A.Burov
A.Chen

0.4 mm liner
CuBe (98+2%)



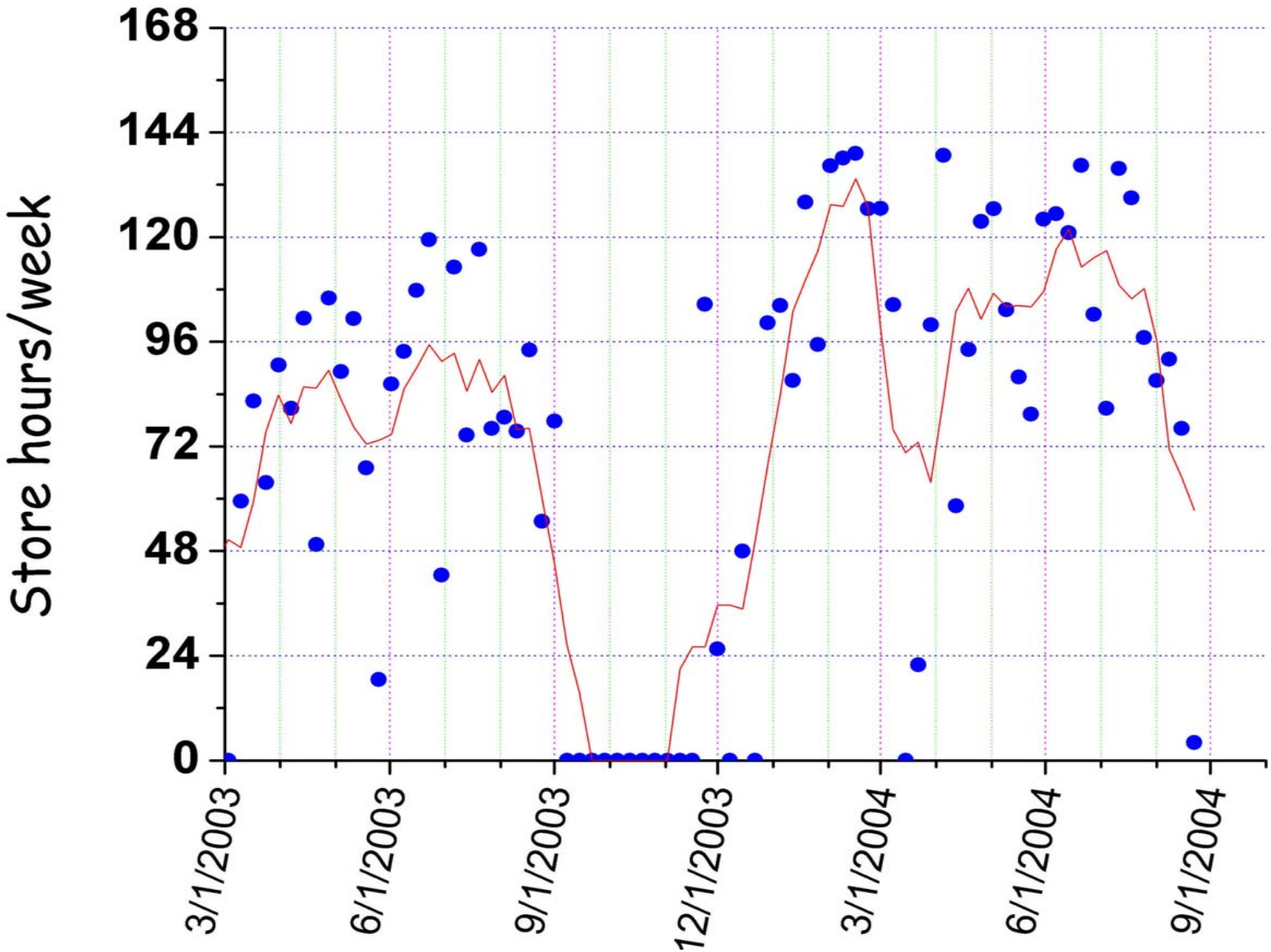
Region of stability of high intensity coalesced bunches (~230e9) on chromaticity plane before (#1 and #2) and after (#3) installation of conducting liner in F0 Lambertson magnets

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

Losses at 150 ~ Chromaticity 4→2

Octupoles for safety at C_vh=0

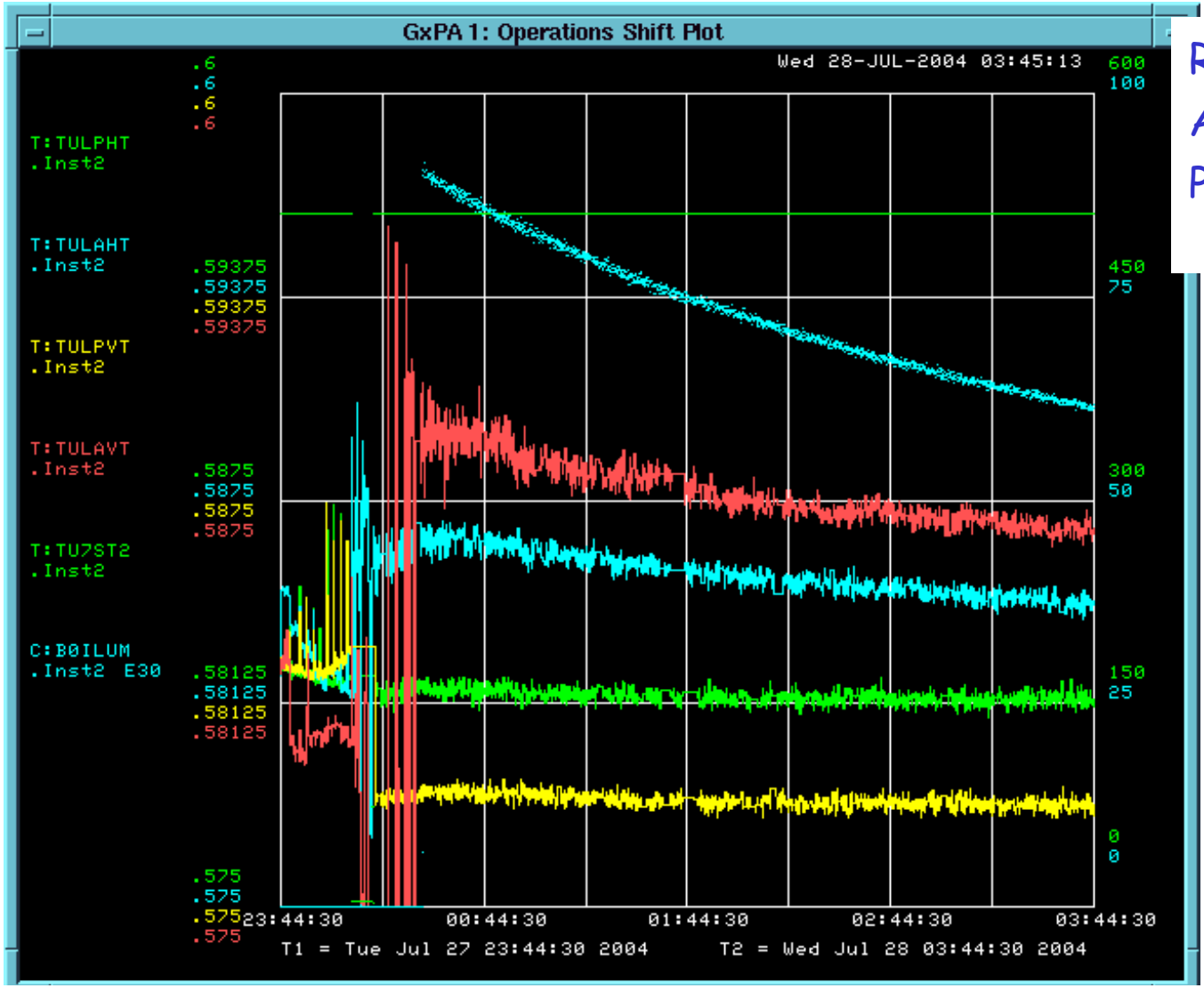
Fantastic! - 140 Store-Hours a Week!



Other Helpful Actions

- 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 slide

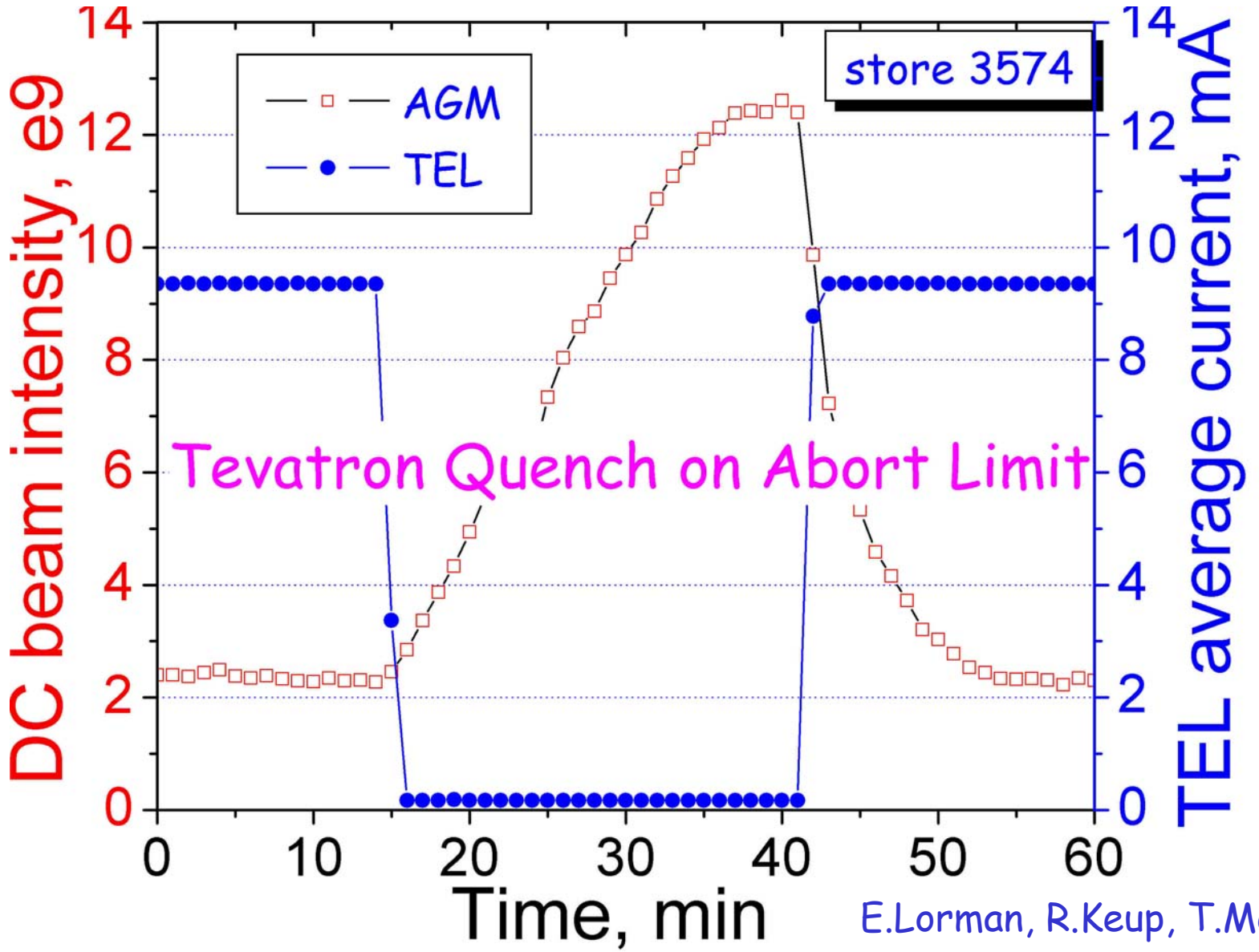
Helpful Diagnostics: 1.7 GHz Schottky



R.Pasquinelli
A.Jansson
P.Lebrun

On-line P and Pbar tune measurements help to reduce tuneup time at LB

Abort Gap Monitor



E.Lorman, R.Keup, T.Meyer

FY04 vs FY03

	L_0	*Integral*
Beta* reduction	26 ±3%	~14 ±3%
Longer stores	~20%	~8 ±3%
Mixed AA+RR shots	18%	~0%
Emittance	11 ±2%	~8%
Tev Inj work	7 ±2 %	~6%
MI work	5.1 ±0.3 %	~3.6%
Total store hours/yr	0%	4.3%
/week	0%	27%
Total /year	x(2.2±0.15)	x 1.5±0.1
/week		x 1.9
BO IP move	0%	~20% (CDF only)

Compare with Other Hadron Colliders

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 II	36 mos	140

1982

…so, Tev is the fastest growing h-machine

Another Look: FY04 vs FY03

+45% in Integrated Luminosity=

18 ±3% from beam studies

14 ±3% from shutdown work

12 ±3% from reliability and up time

"Country Should Know Its Heroes!"

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

DOE/CDF/D0 Goal:

470 pb-1/yr

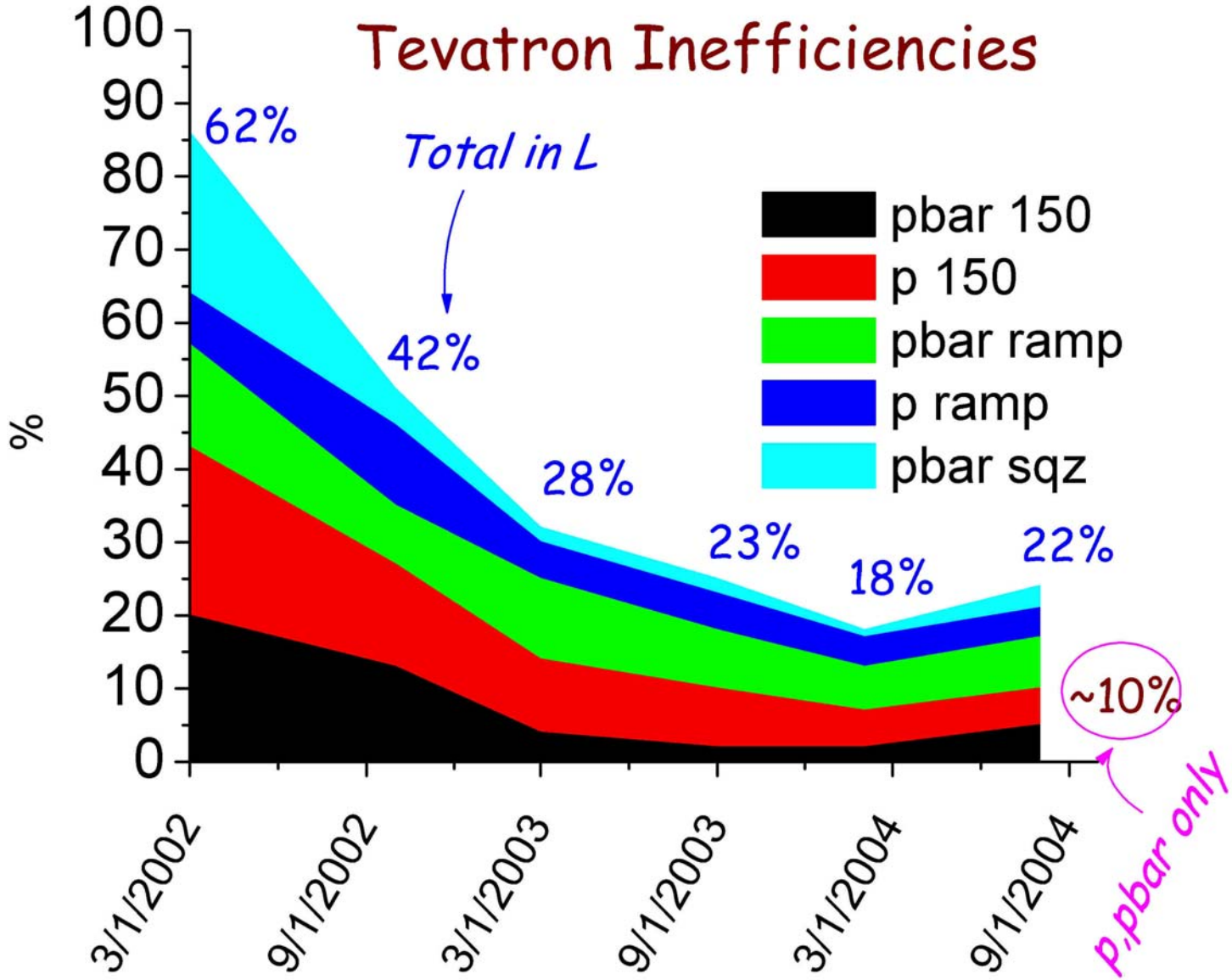
Goal for Tev: break ISR record

140e30 cm-2 s-1

What the Tevatron Can Contribute:

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

Total $N_a N_p$ Inefficiency in Tevatron



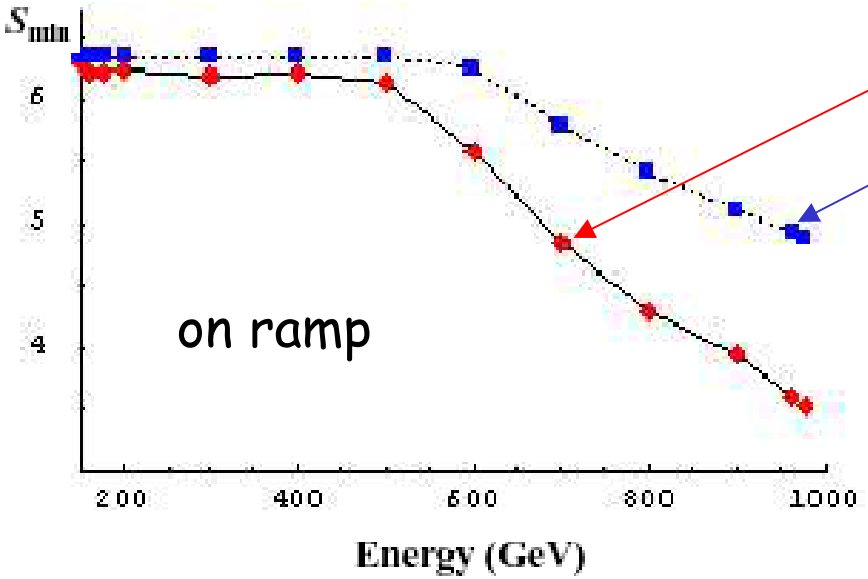
How to Improve Efficiencies

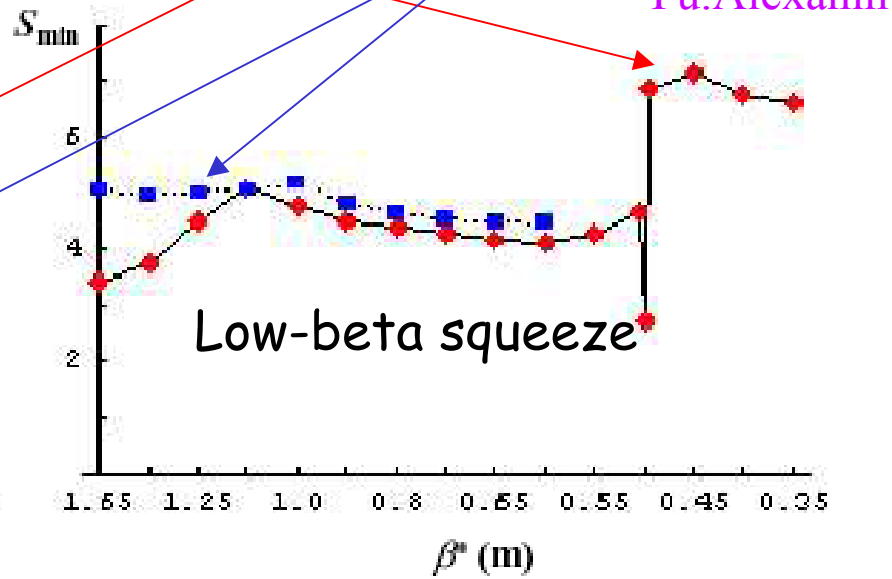
- Drop Chromaticity at 150: Q'=2-4 to 0
  - Use octupoles — pending study time
- Drop Chromaticity on ramp: Q'=8-16 to 0
  - Use transverse dampers — pending study time
  - Or use octupoles — pending study time
  - Proper b2-snapback compensation — almost there
- Larger Separation on Ramp and Squeeze — 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

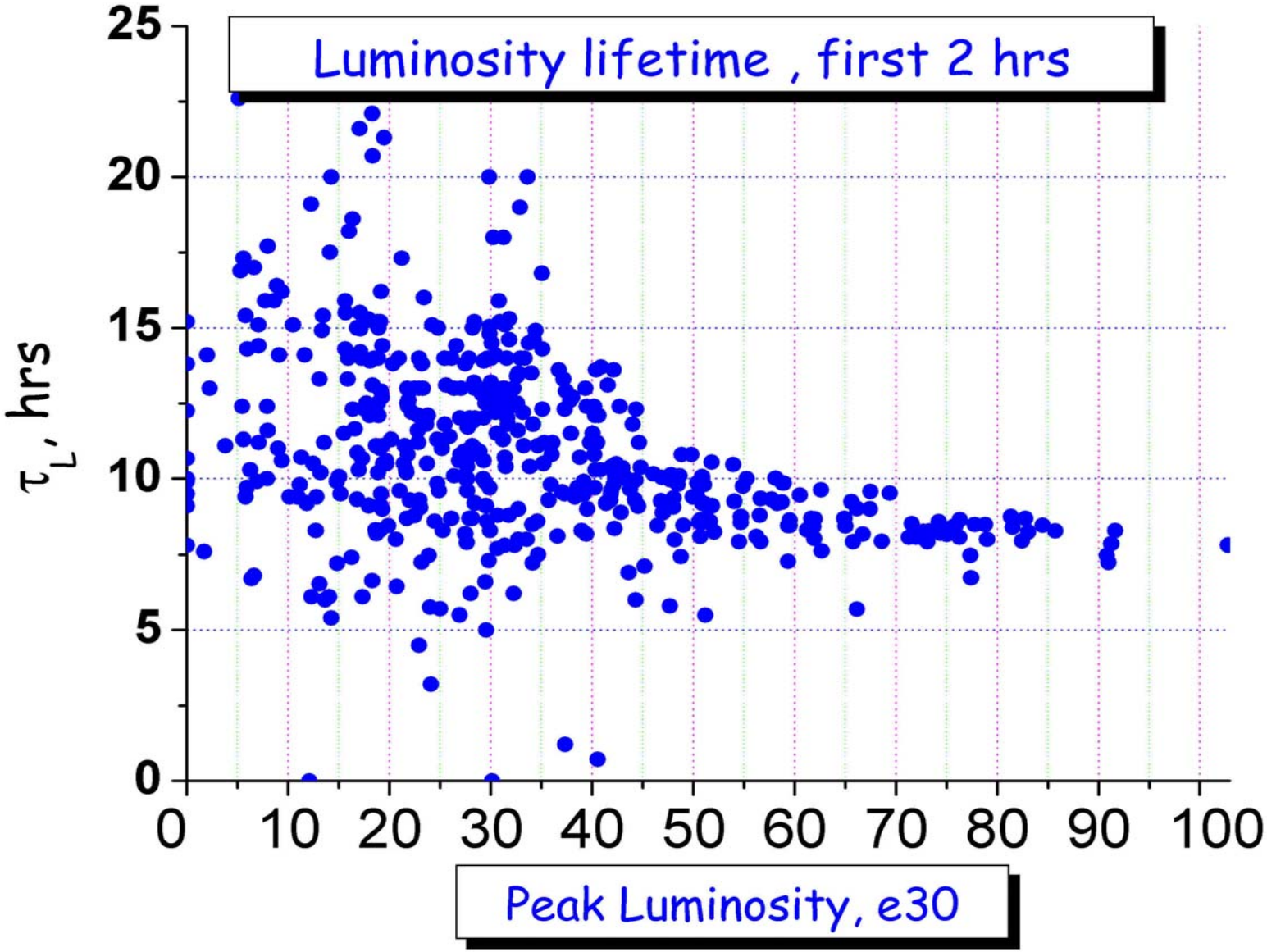
note that $d \propto V/\gamma$ while $\sigma \propto \sqrt{1/\gamma}$

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

Reduce IP Size: β* and Emittances

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

Luminosity Lifetime is a Big Issue



Lifetime Constituents

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

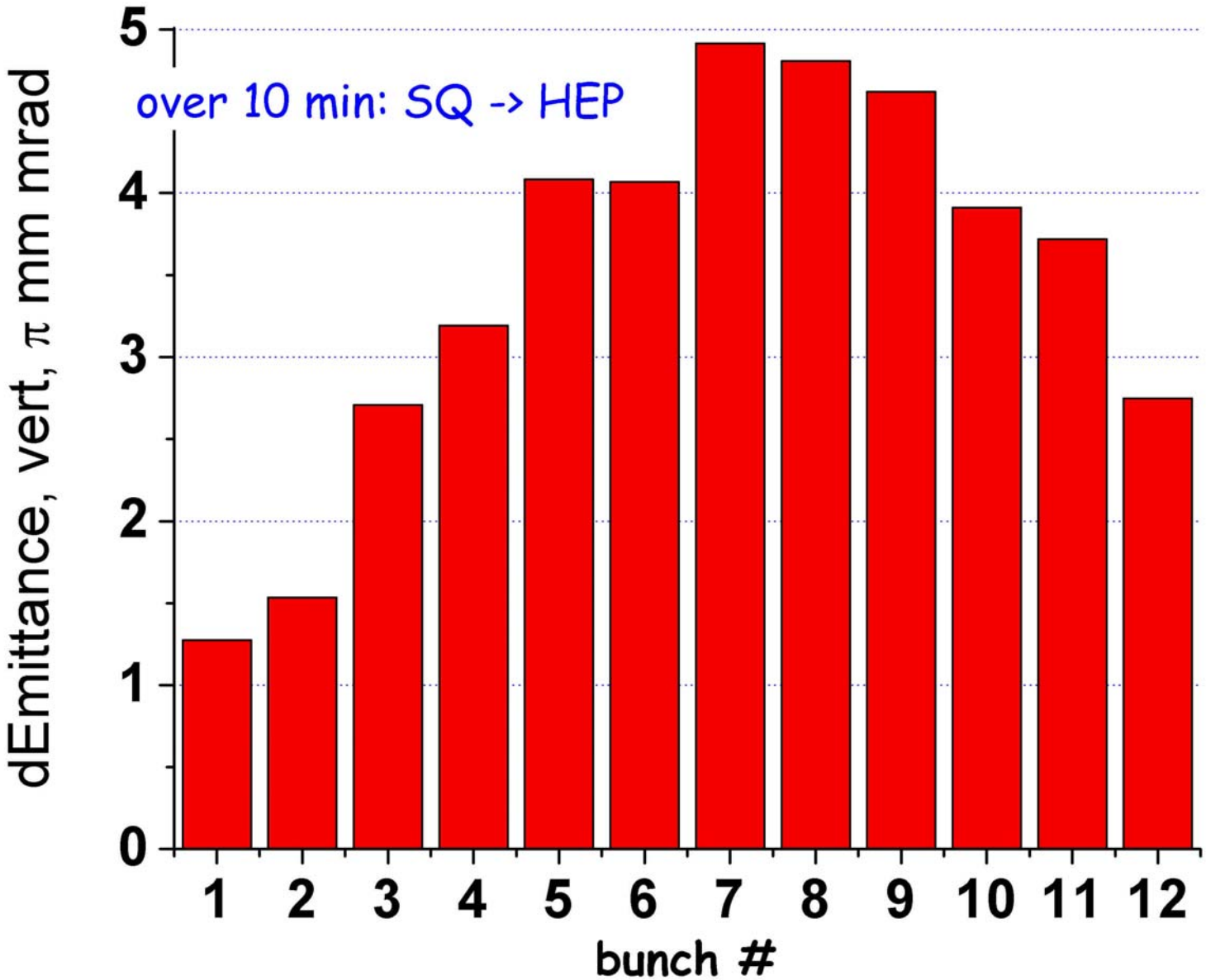
(15-20) + (20-25) +(35-210)+(70-80) =(7.5-9.0)hrs

- 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
- Hougrlass lifetime = 90% IBS + 10 % Beam-Beam

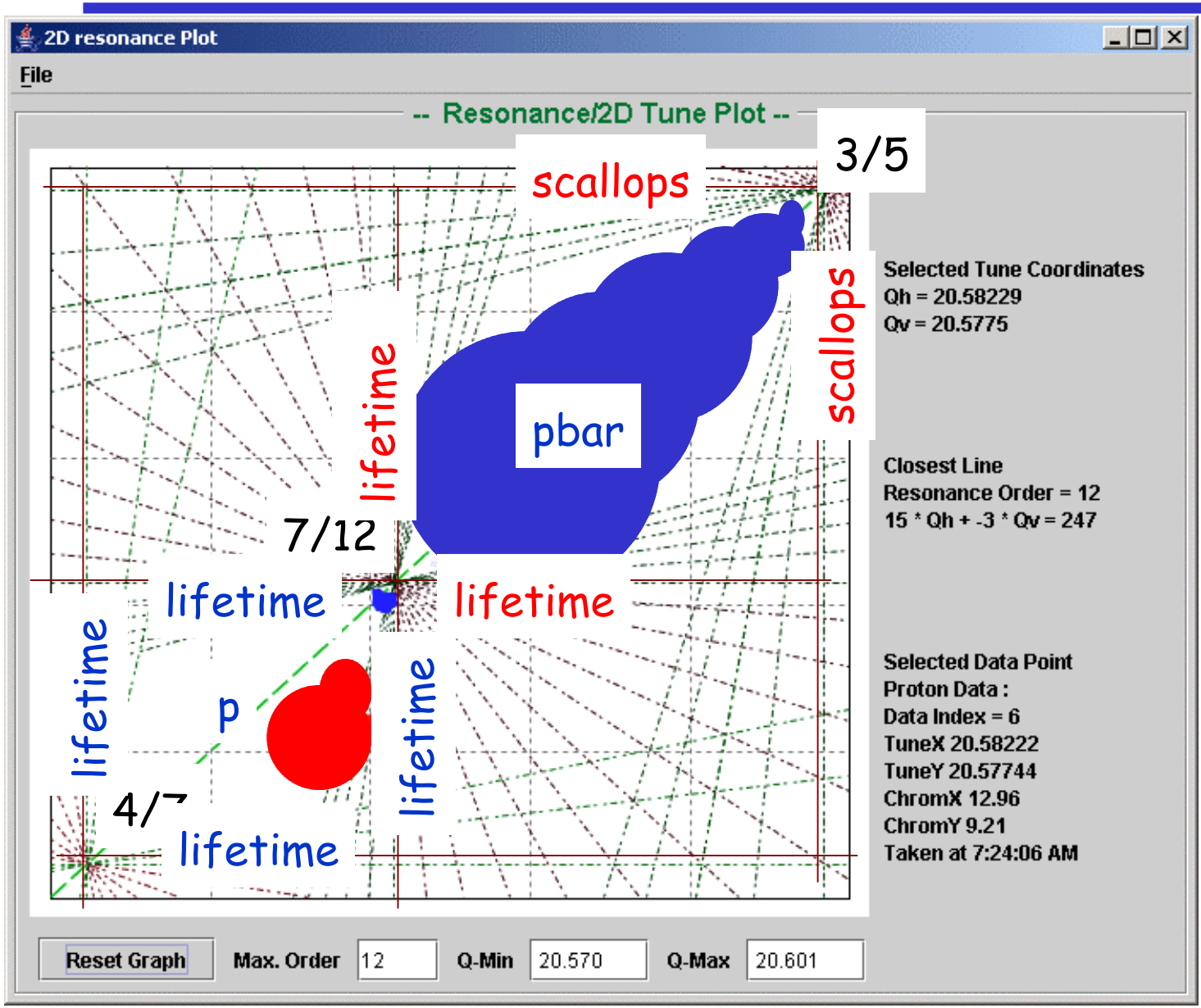
slide

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

Pbar Bunch Emittance Growth



Betatron Tunes (Working Points)

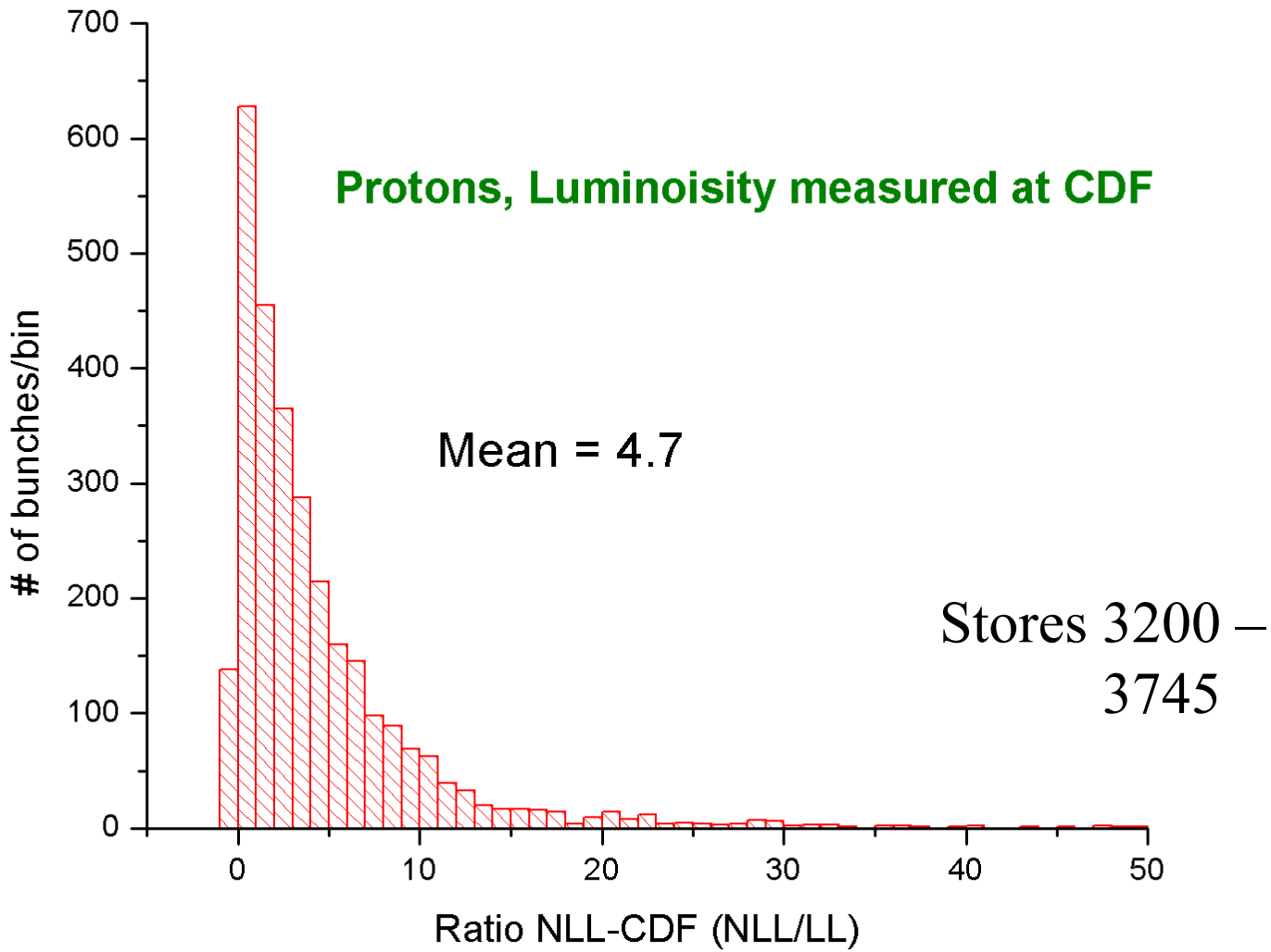


- Balancing btw major resonances

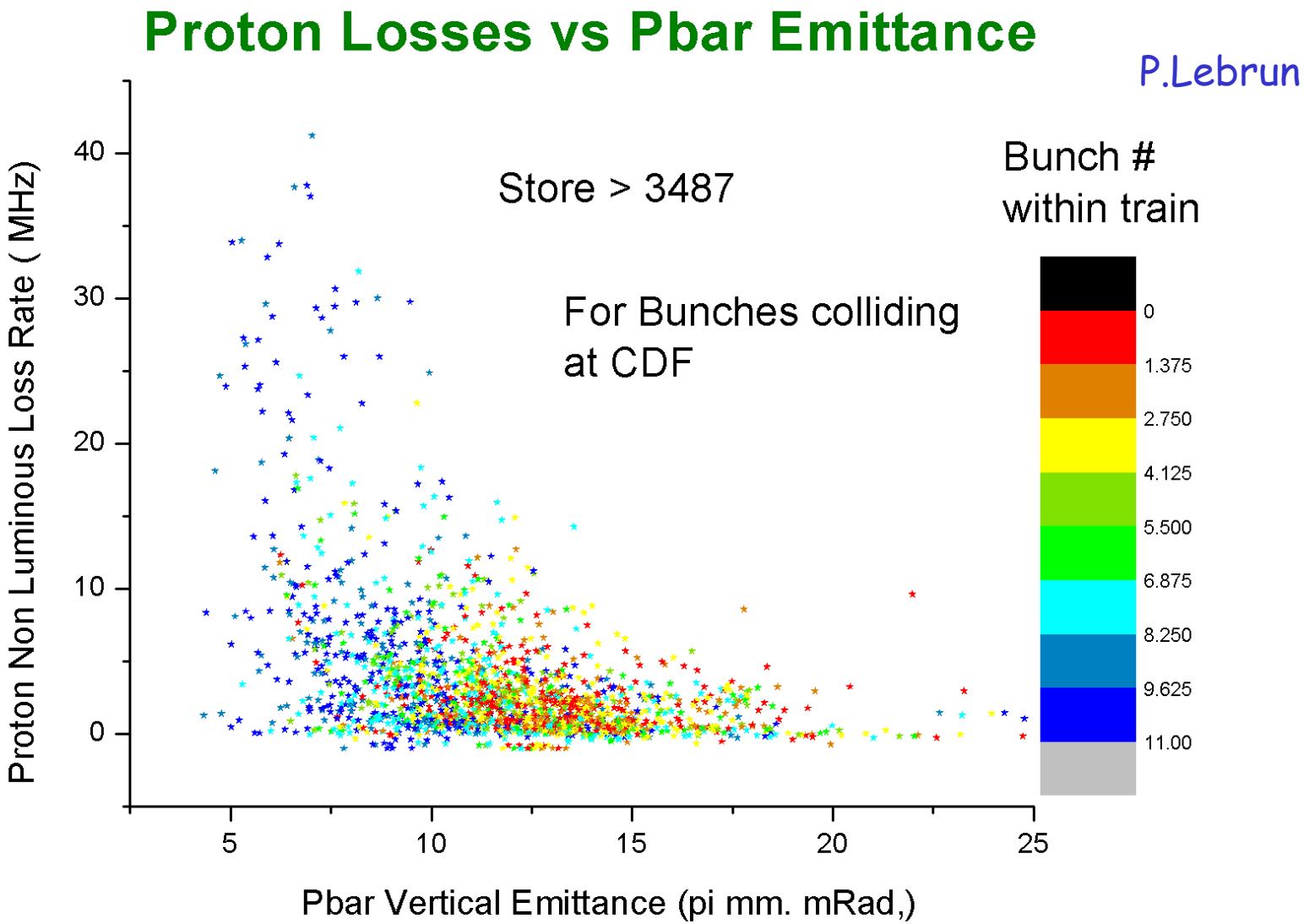
Proton Losses Mostly Induced by Pbars!

Ratio of Non-Luminous Losses over Luminous Losses.

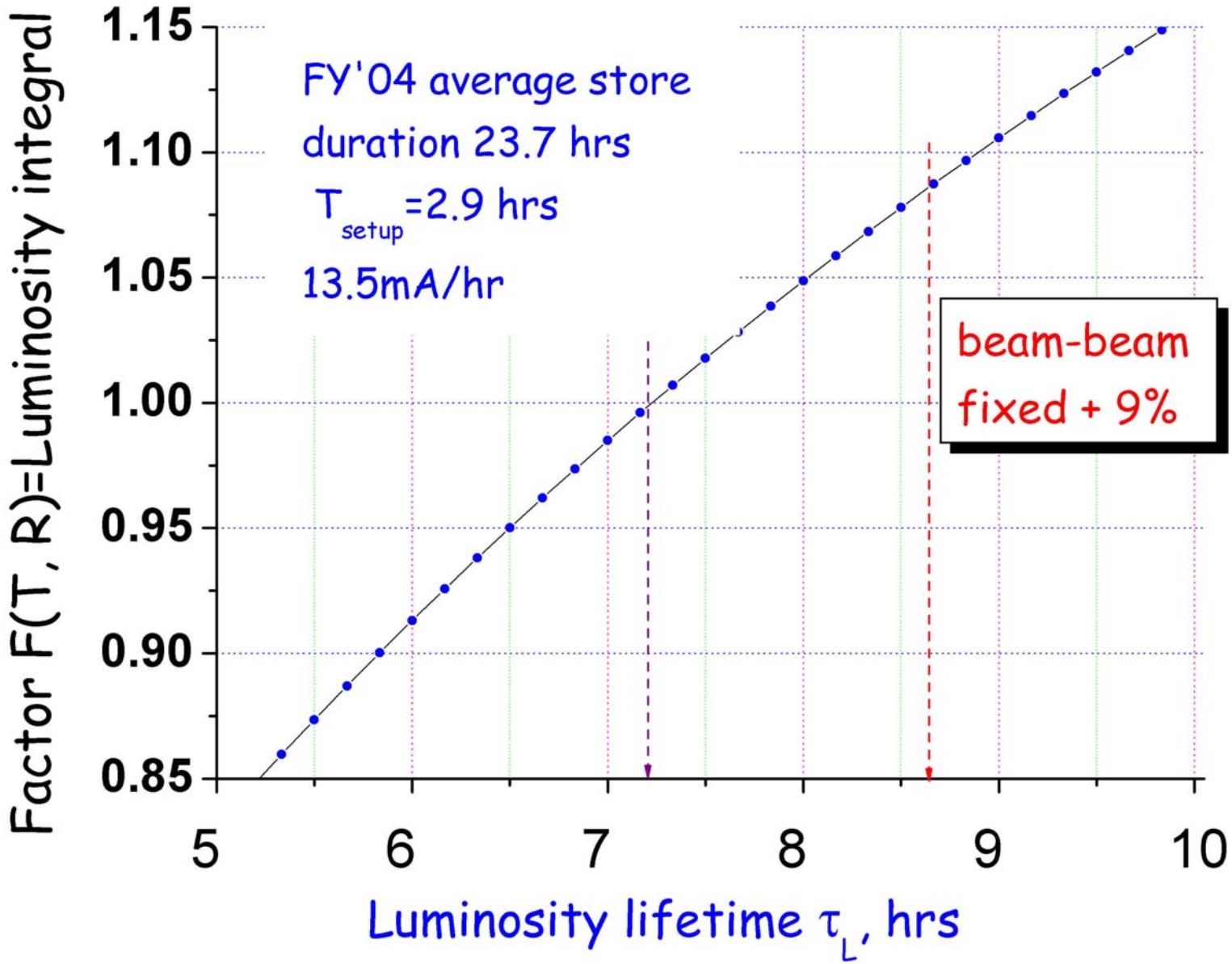
P.Lebrun



P-loss Rate Up for Smaller Pbar-size



Beam-Beam Spoils Lifetime – 9% Effect



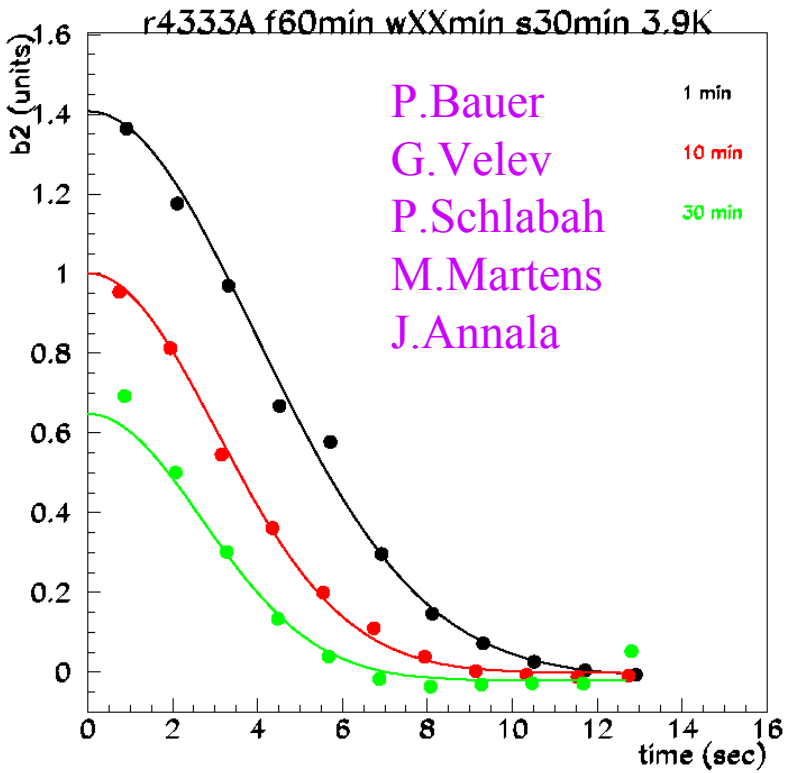
How to Improve *L*-Lifetime

- 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

- Correct b2-snapback compensation saves 2% slide
- 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



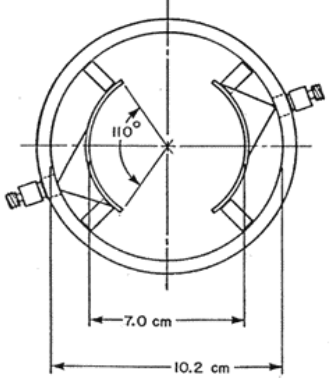
- **Tev dipole b2 snapback meas'ts → recommendations:**
  - Fix back-porch time, it's the most important parameter → fixed **96 sec**
  - Reduce # of beam-less pre-cycles after Tevatron quench from 6 to 1;
  - Improve b2 snapback fit→ Gaussian
  - Saturation of flat-top duration effect on drift amplitude 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**

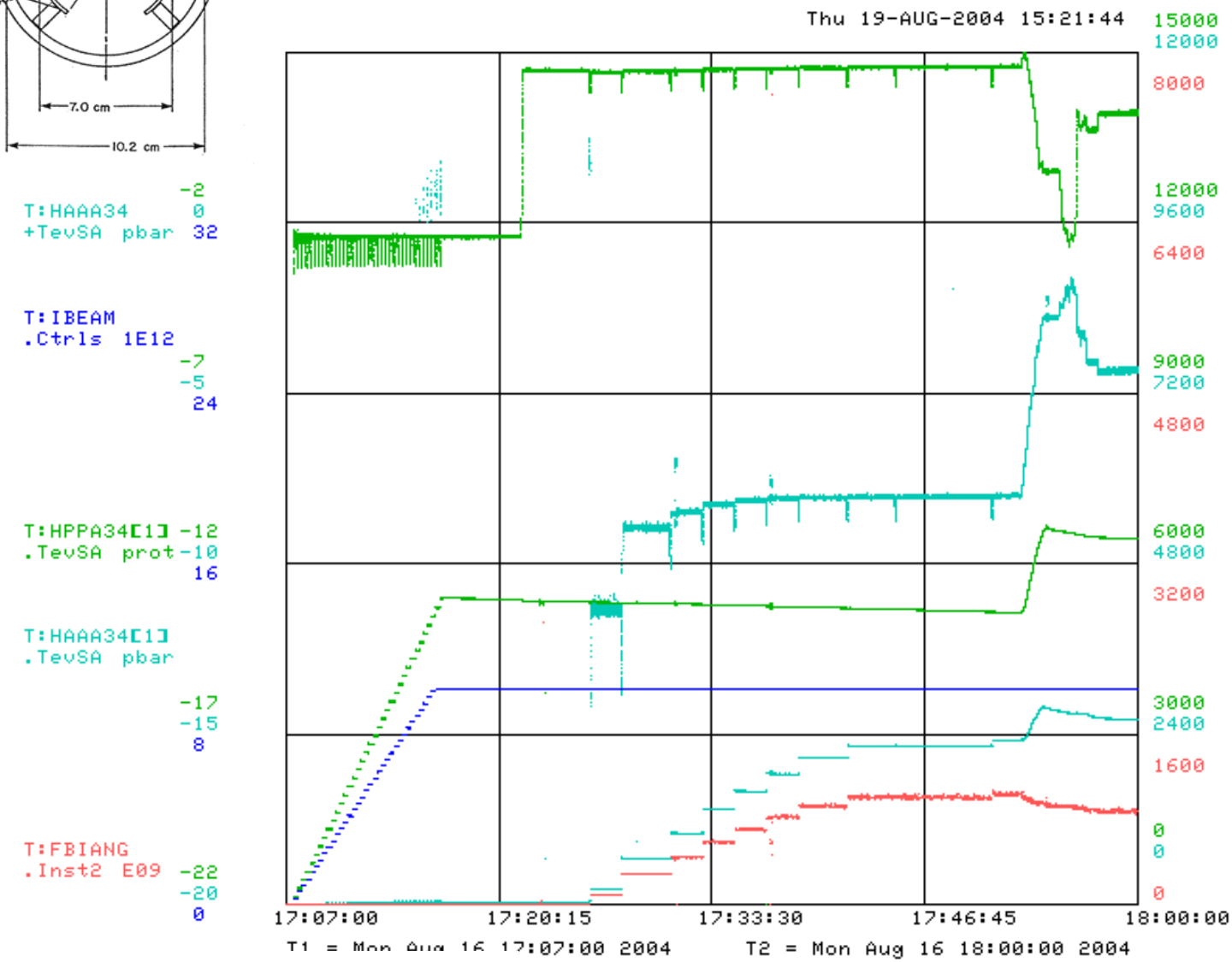
Better Diagnpstics Saves Beam Time

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

Tevatron BPM Upgrade

S.Wolbers
R.Webber
J.Steimel
CD Team





Tested @

HA34, VA34

Orbit resolution

<8 micron p's

<13 micron a's

Turn-by-turn

<50 micron

Be done by April'05

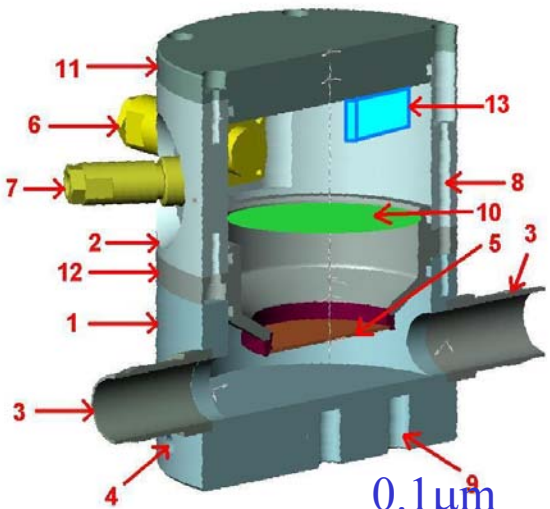
Need 8 MD shifts

beams-doc-1310

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

24 water level sensors every 30m in B-sector

BINP(Novosibirsk), J.Volk



0.1μm resol'n)

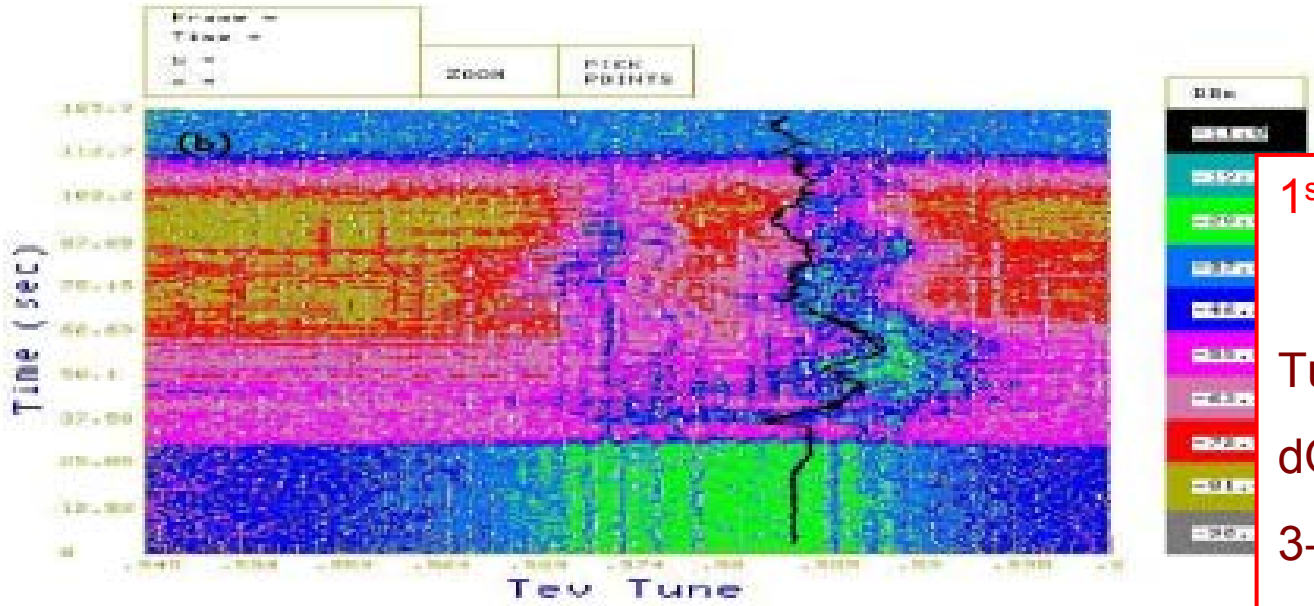
PC

Data Flow

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

TuneTracker: Promising Results

C.Y.Tan



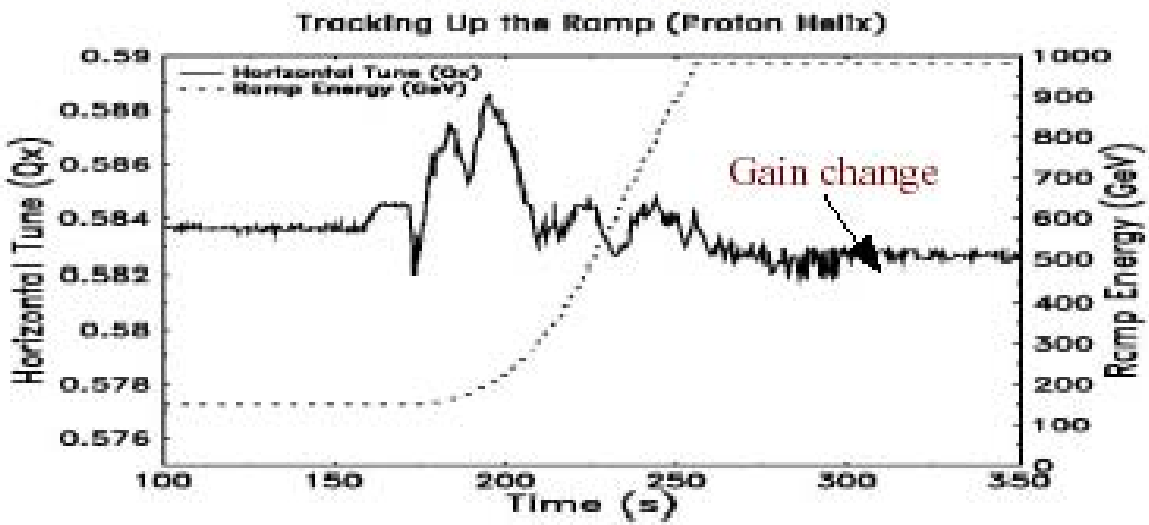
1st Tests in FY04

Tune resolution

dQ ~ 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

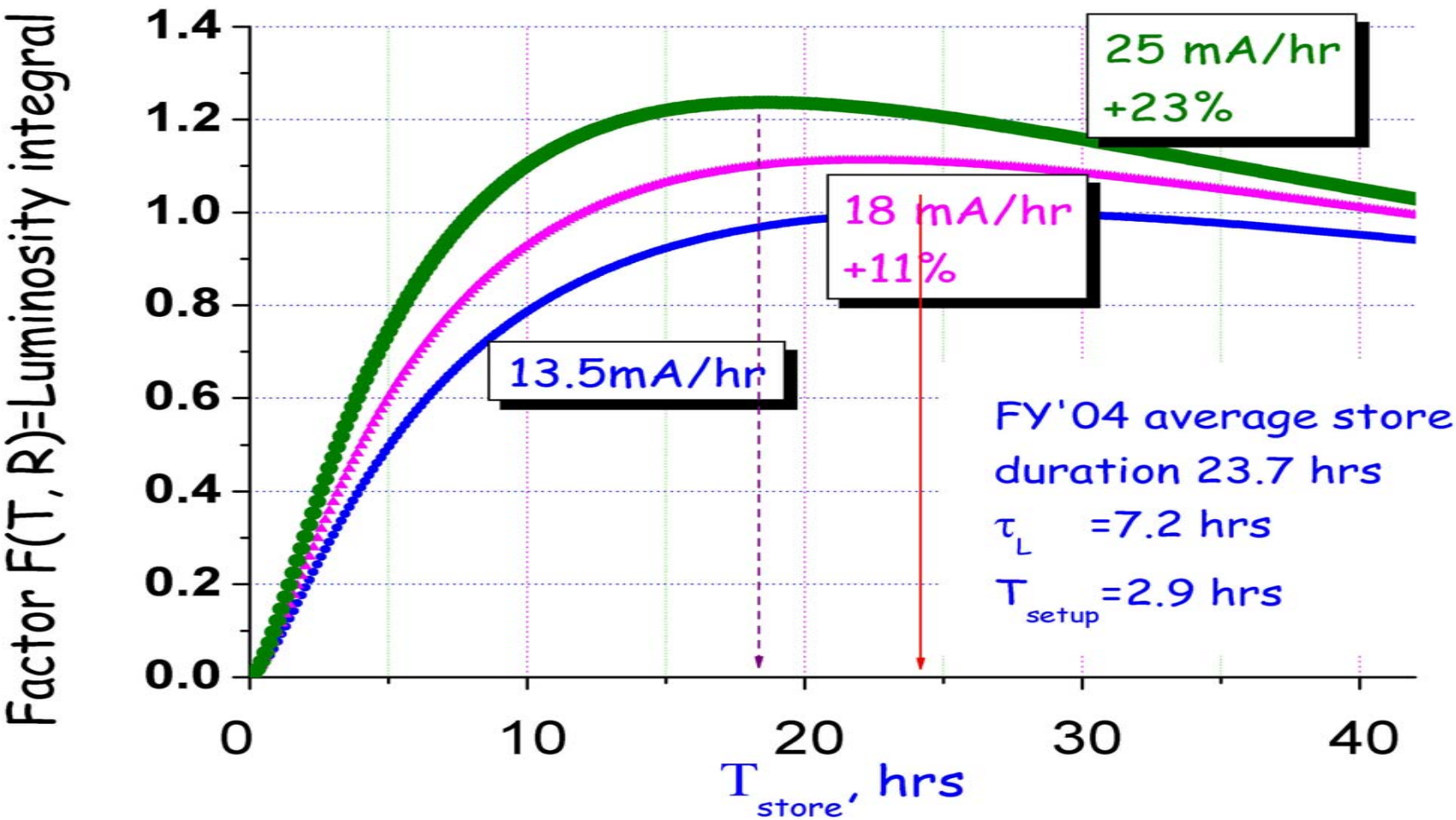
	FY'05 Tev Study Time Estimate	Final
#	Project	MD Shifts
1	New Helix/Separators	5.875
2	New BPMs	7.75
3	Lattice/28 cm beta*	4.5
4	Octupoles/Instabilities	5
5	TEL	2.75
6	Injection Dampers	5
7	Tune Tracker	3
8	Dampers on Ramp	1
9	IPM	0.875
10	Q' x,y /Coupling on Ramp	0.875
11	Orbit Stabilization	2
12	b2 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
	Total shifts	53.875

10 hrs/week – Is That A Lot?

- 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 ?

- 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

- We have everything in place to integrate 470 pb-1 in FY'05
  - 40 weeks x 12 pb-1/wk
- We can break L_{peak} = 140 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^{-1} more