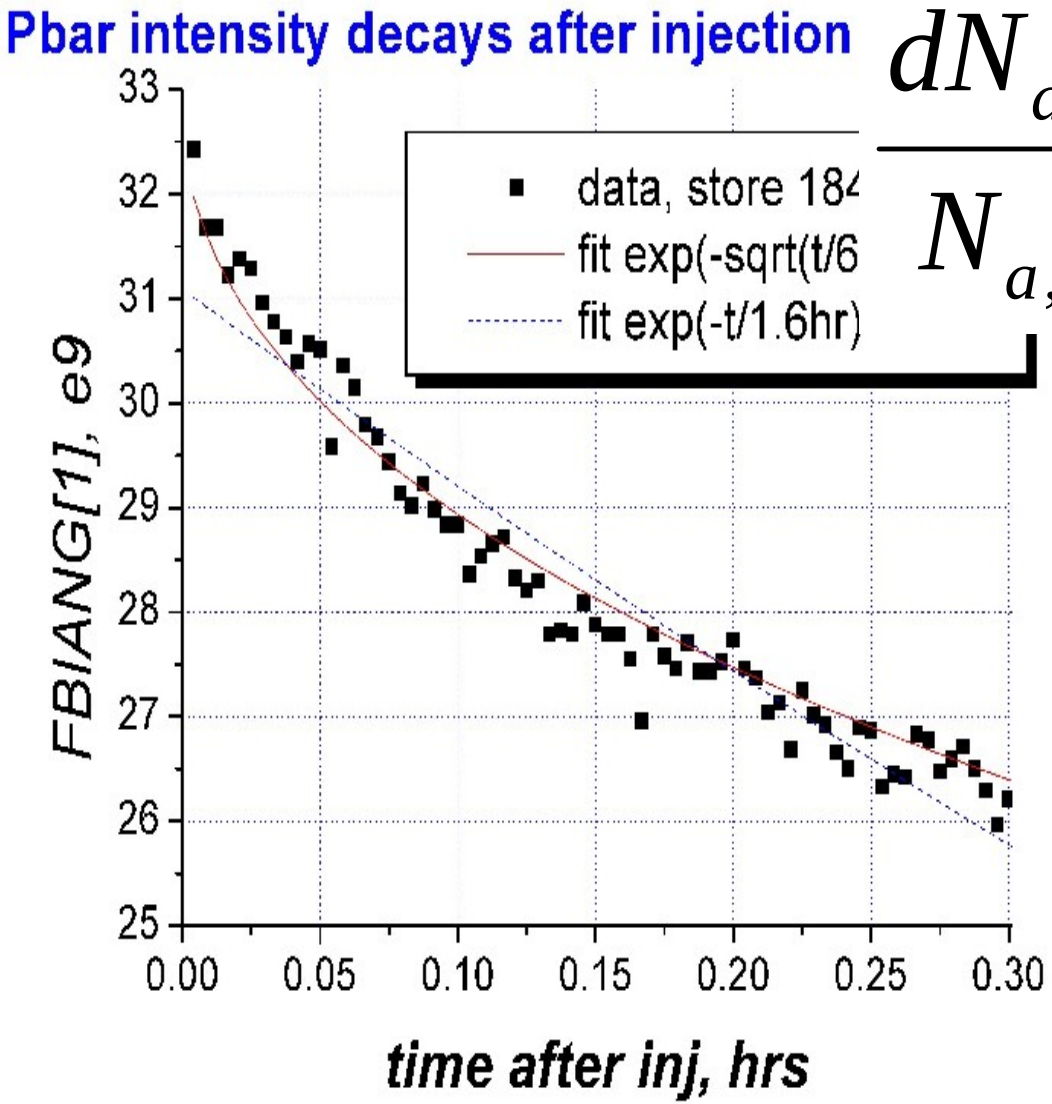
Fermilab

Octupoles in Tevatron Operations: Motivation, Experience and Plans

V.Shiltsev & J.Annala

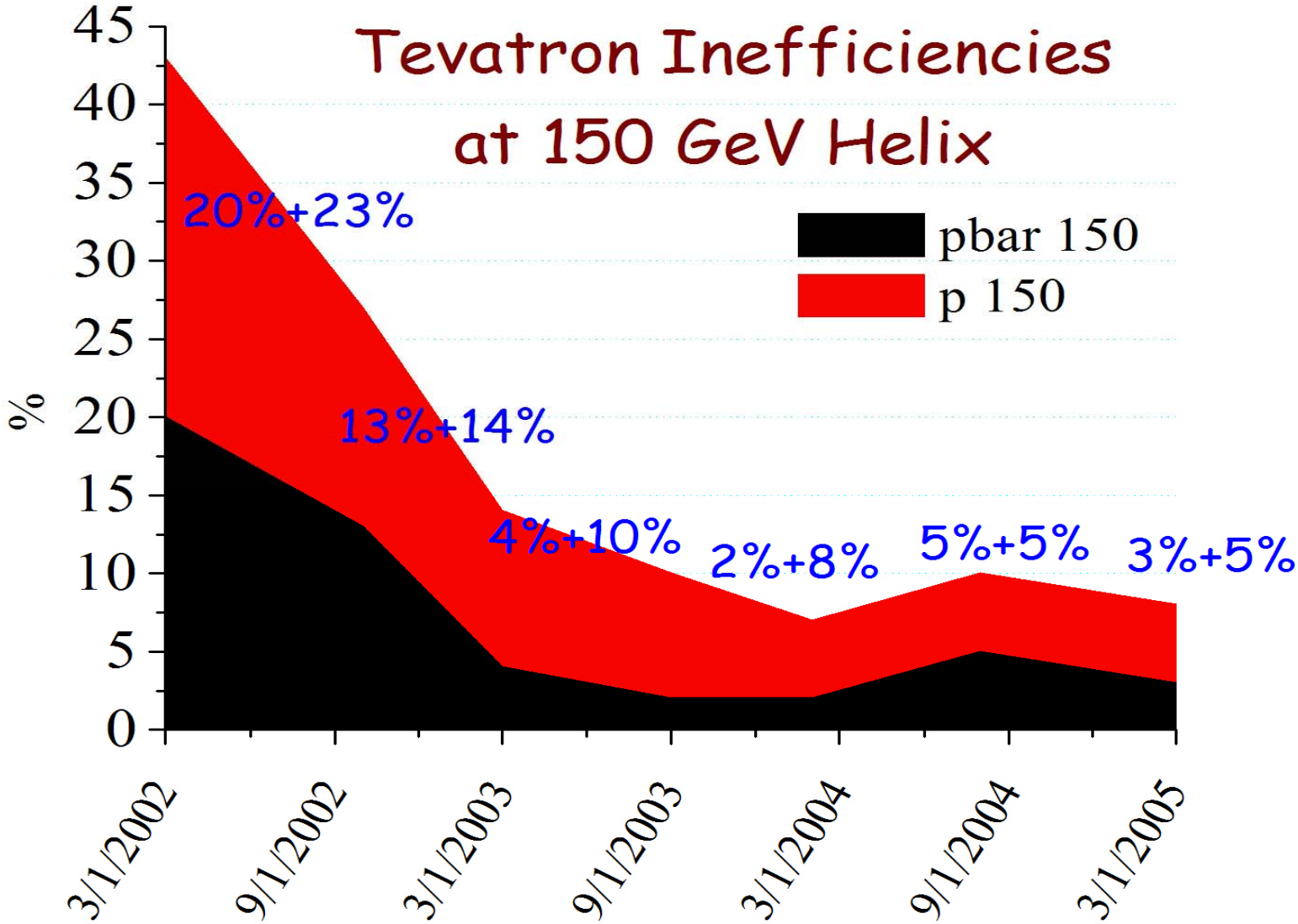
Beam "Shaving" (Longitudinal) after Injection



$$\frac{dN_{a,p}}{N_{a,p}} \propto \sqrt{t} \cdot Q' \cdot \frac{N_{p,a}}{\varepsilon_{a,p}^{2}}$$

- Q'=dQ/(dP/P) - chromaticity
- dN(t) ~ Sqrt(time)
- Larger for larger emittances
- Mostly Beam-beam induced
- Larger for larger dp/p as bunchlength shrinking
- Protons affected as well
- Aperture matters
- Tunes matter (e.g. 4/7)

What's On Stake? – 5-8% in Na*Np



150 GeV Lifetime Improvements (2002-2004)

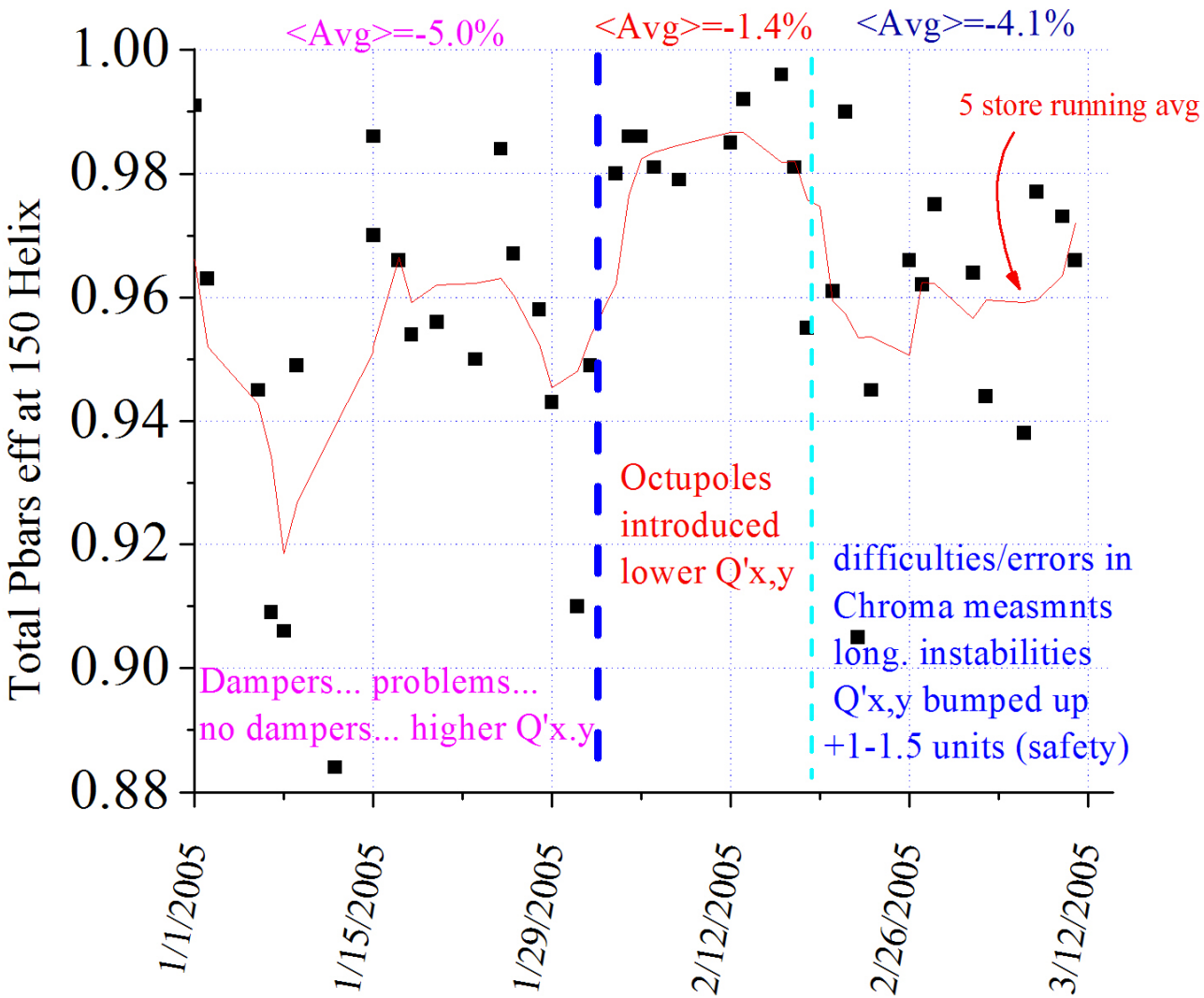
- Things which helped to improve lifetime at 150 GeV
  - Emittances greatly improved since 2002 ← thanks to AA, Booster and MI (recently – RR) in addition to Tev work: better pbar BLT closure; vert dispersion matched at inj after four P1 quads rolled and 100+440 Tev dipoles reshimmed
  - Apertures opened: lambertsons replaced @ C0 – gain 25 mm vertically, kickers, separators, LB quads aligned
  - Original injection helix has been modified, separation increased and optimized to fill the aperture ("new-new helix" "5*" etc)
  - F0 liners and transverse dampers to drop Q' from (8-10)→(4-5)
- Issues
  - Dampers (intrinsically) stabilize mostly mode 0, so chromaticity can not be dropped below 2-3 units in each plane
  - There was no control of differential chromaticity (upto 8 units!)
  - Dampers sensitive to local coupling-> various problems in Jan'05

The Solution We Pursued Was…

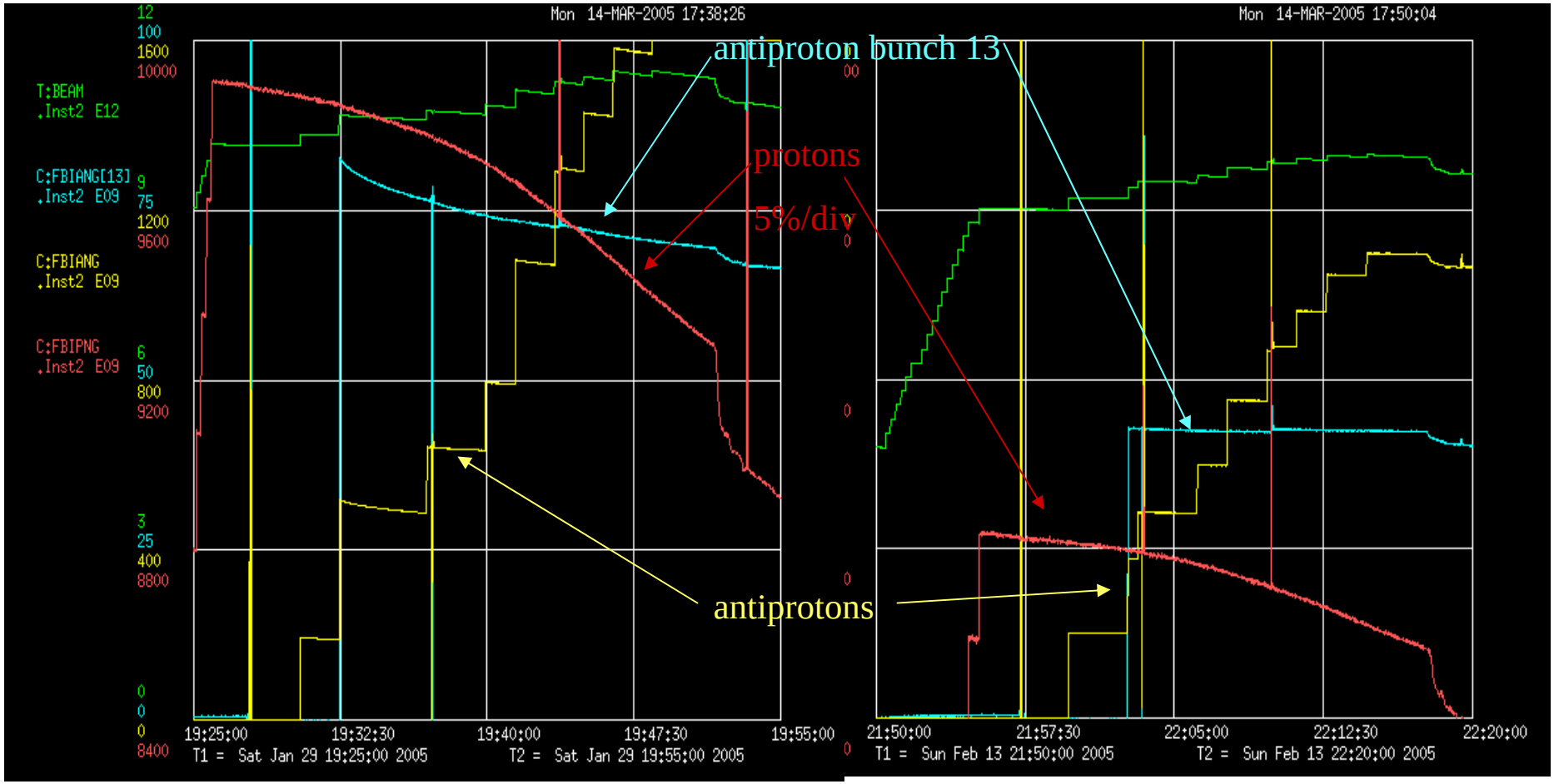
OCTUPOLES !

- First Considered and Used for Operations in 2003 (OZD and OZF families, Yu.Alexahin)
- New Circuits Designed, Reconnected and Commissioned during Fall'03 Shutdown (P.Ivanov, J.Annala, Yu,Alexahin)
  - OD and OF to control tune spread for Landau damping
  - O1 and O2 to control differential p/a chromaticities
  - ~insensitive to orbit drifts (dQ<0.001 dQ'<1 for 1 mm)
- In routine operation since Feb 4, 2005

Pbar Loss at 150



Octupoles → Lower Q'x,y → Better a, p Lifetimes

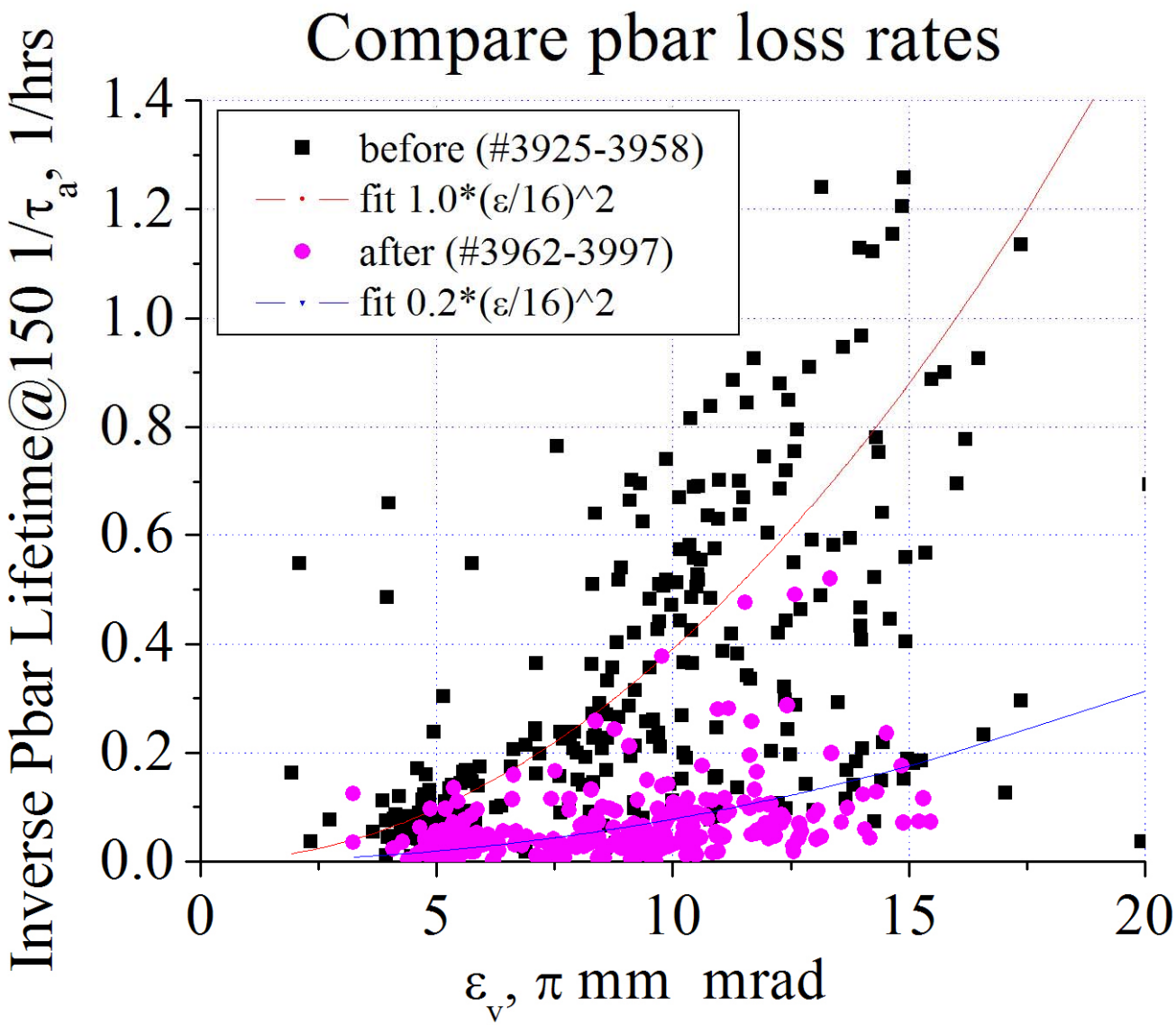


Store 3952: no Octupoles

Store 3980: with Octupoles

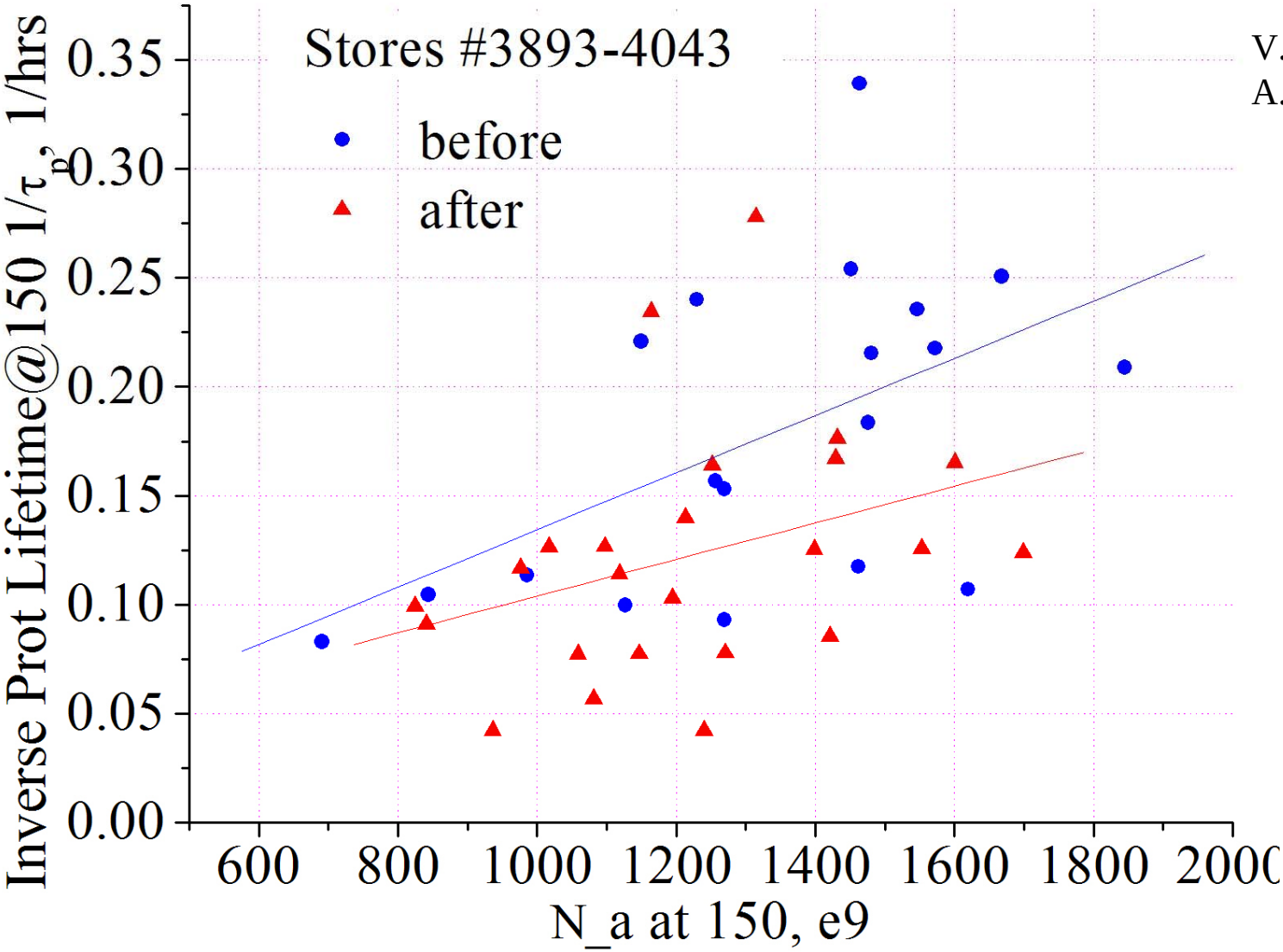
*below: bunch lifetime calc'd for the first 4 min after injection

Comparing "Apples With Apples": 1/τ vs ε

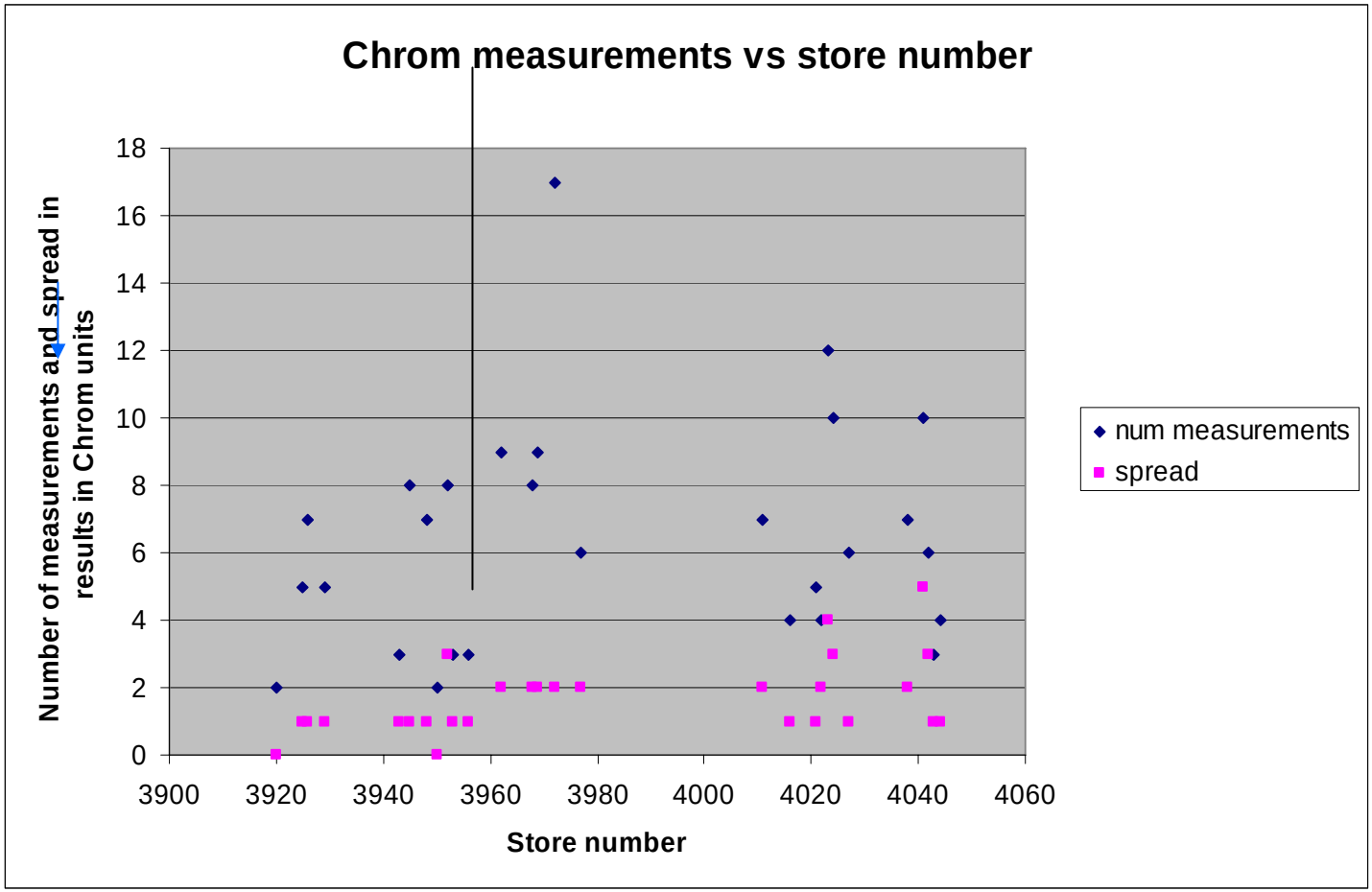


V.S.
A.Xiao

Comparing "Oranges With Oranges": 1/τ vs Na



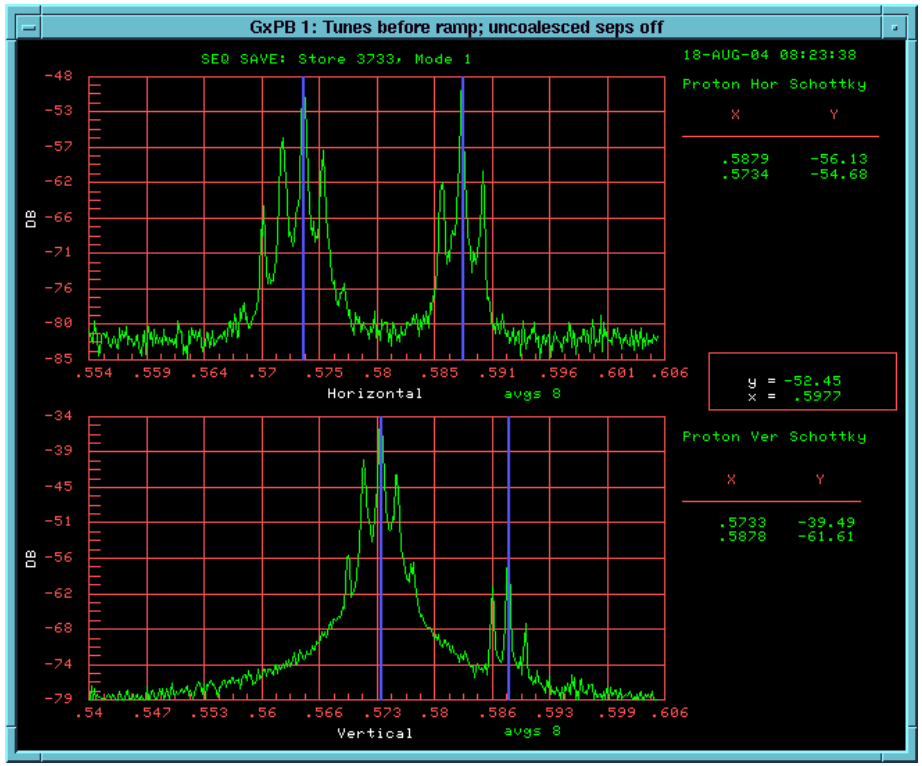
Nothing's For Free…



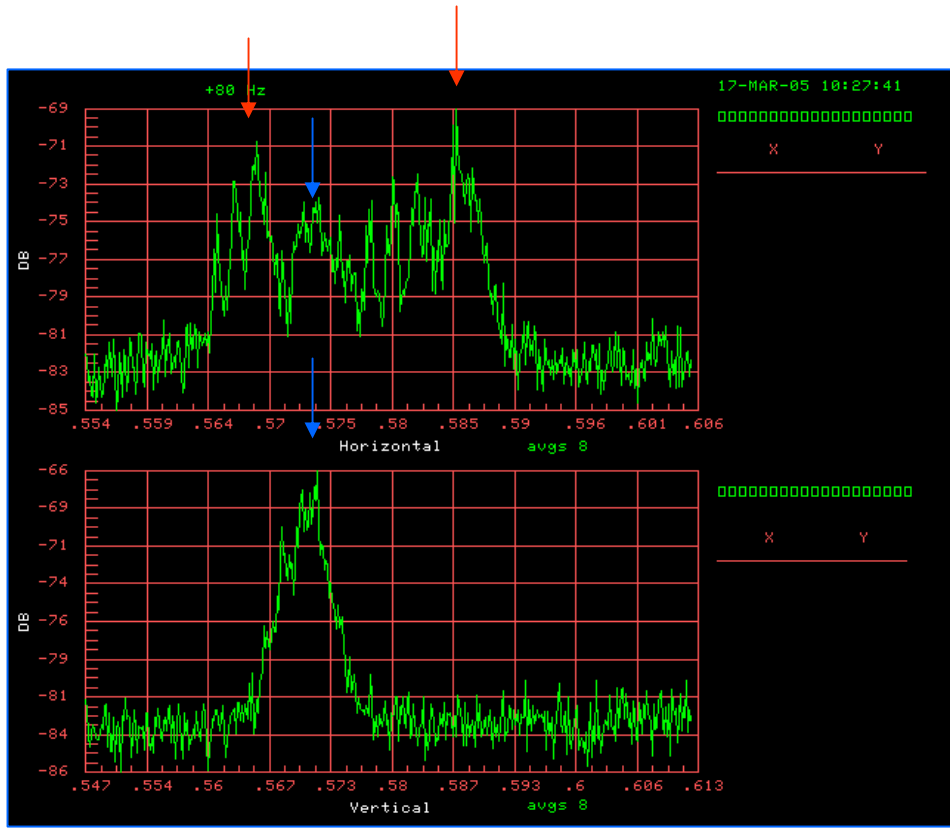
This plot shows the number of measurements made, and the spread of the results during shot setup.

The vertical line indicates where we began using the Octupoles

August 18, 2004

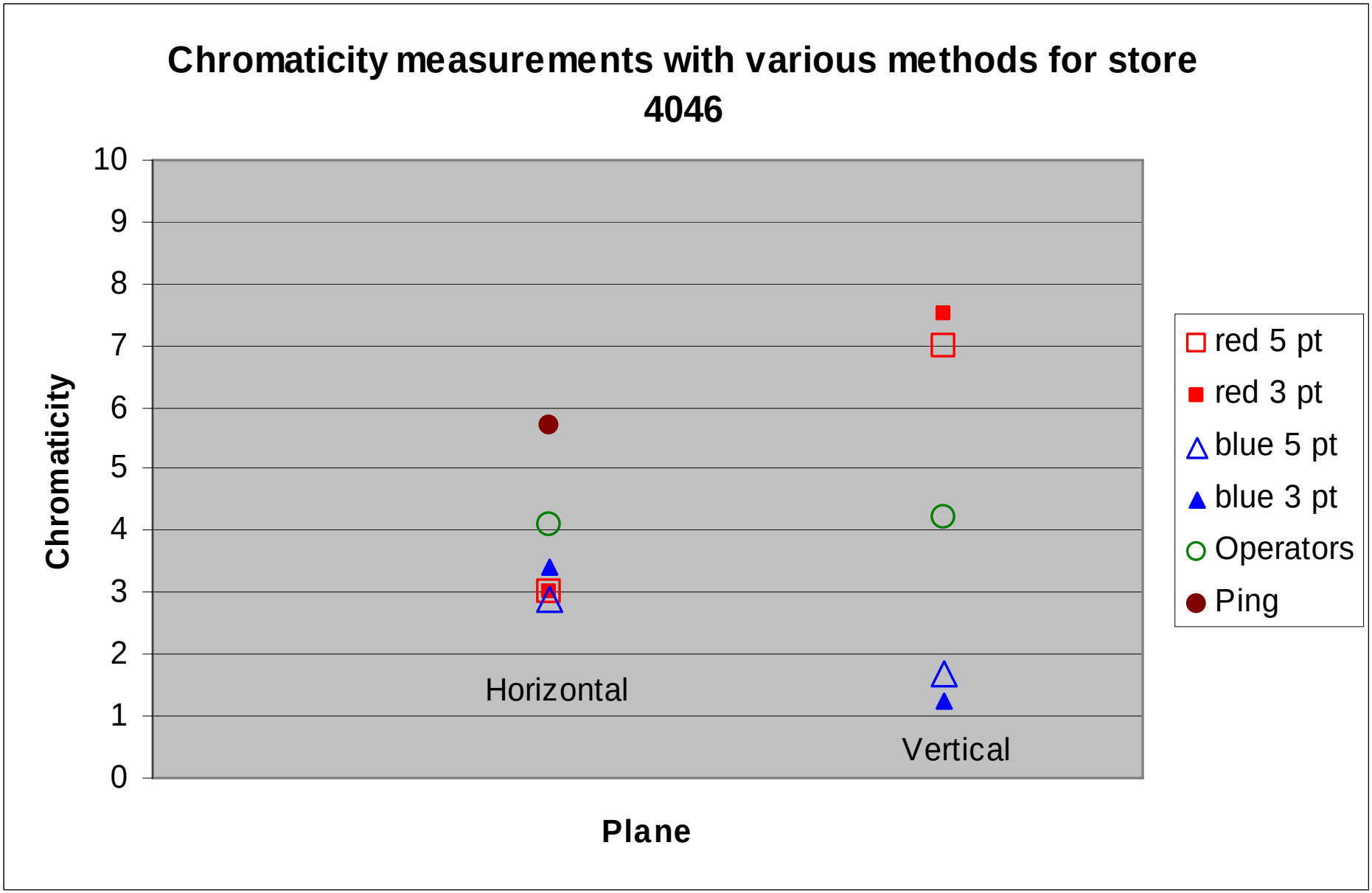


March 17, 2005



both at 150 GeV, uncoalesced beam

The red and blue lines indicate different interpretations of where the tune might be measured.


Chromaticity measurements with various methods for store 4046
Chromaticity
10
9
8
7
6
5
4
3
2
1
0
Horizontal
Vertical
Plane
red 5 pt
red 3 pt
blue 5 pt
blue 3 pt
Operators
Ping

Conclusions

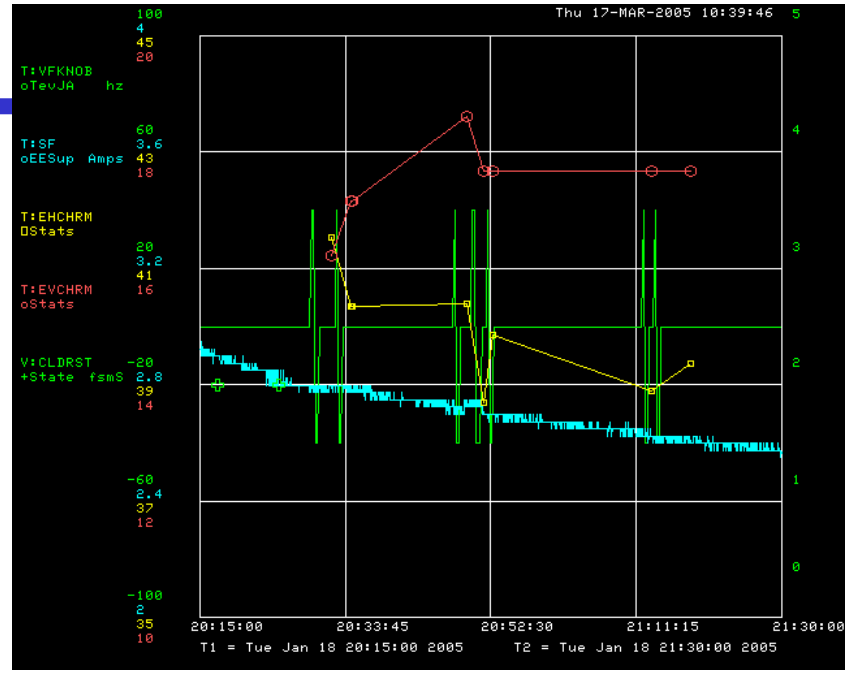
- We have proposed and introduced 4 octupole circuits into routine Tevatron operations with the goal to lower chromaticity and reduce p and pbar losses at 150 GeV helix
  - done timely when problems with dampers occured
  - credit to P.Ivanov, J.Annala, Yu.Alexahin
- Very good results in several weeks of operation
  - Stable operation
  - Overall pbar-loss @150 down -2%, p-loss <-1% → luminosity
  - Initial bunch lifetimes improved 5-6 times for pbars; 30% for p
  - Longitudinal instability can make life worse → to be fixed soon
- A better control of Q' should allow to gain a bit more
- There are potential gains from using octupoles at Low-Beta and on ramp – … and it's in our plans.

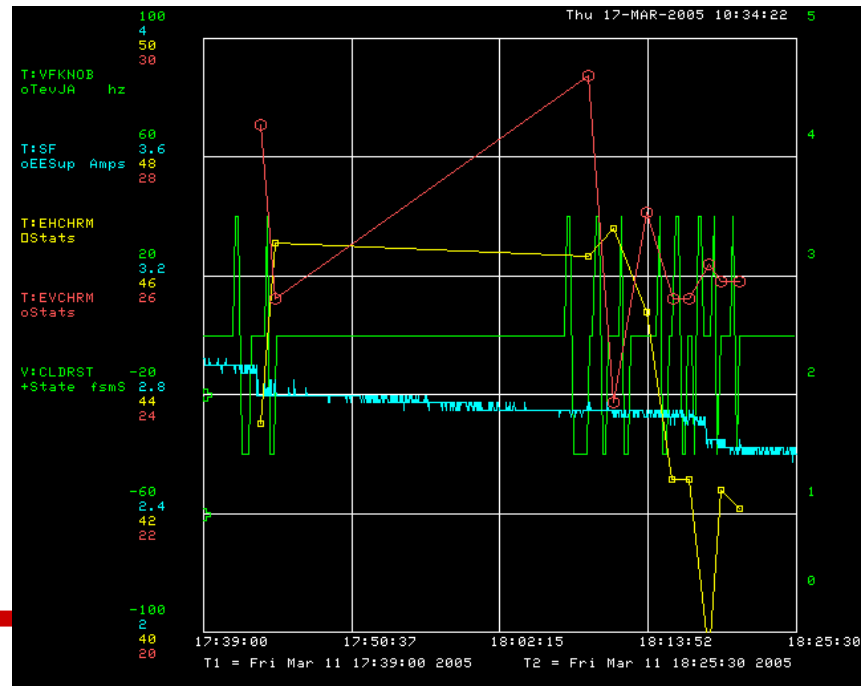
BackUp Slides

Top picture shows number of measurements and scatter of results before we used Octupoles in store 3926

Bottom picture shows number of measurements and scatter of results after turning on Octupoles in store 4041

Changes in settings are being made during these intervals, and that makes this data harder to interpret.





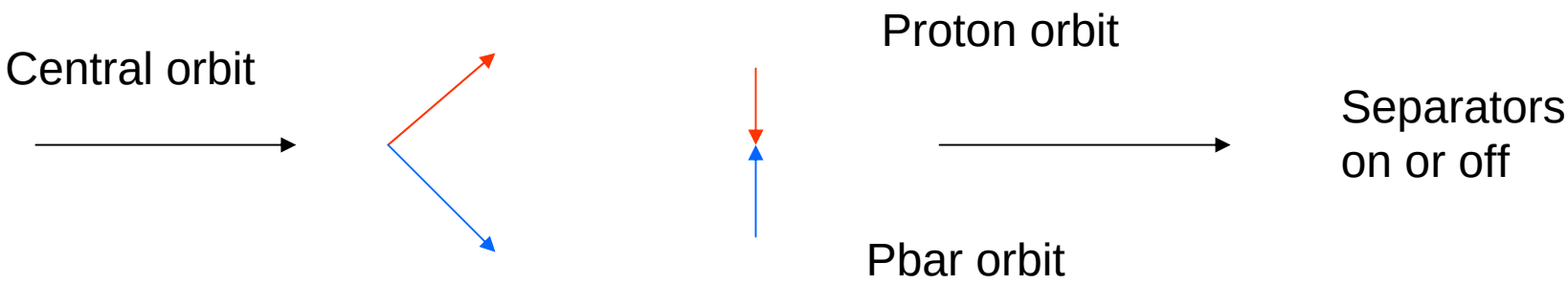
Complications added by Octupoles

Horz tune (example)

No Octupoles

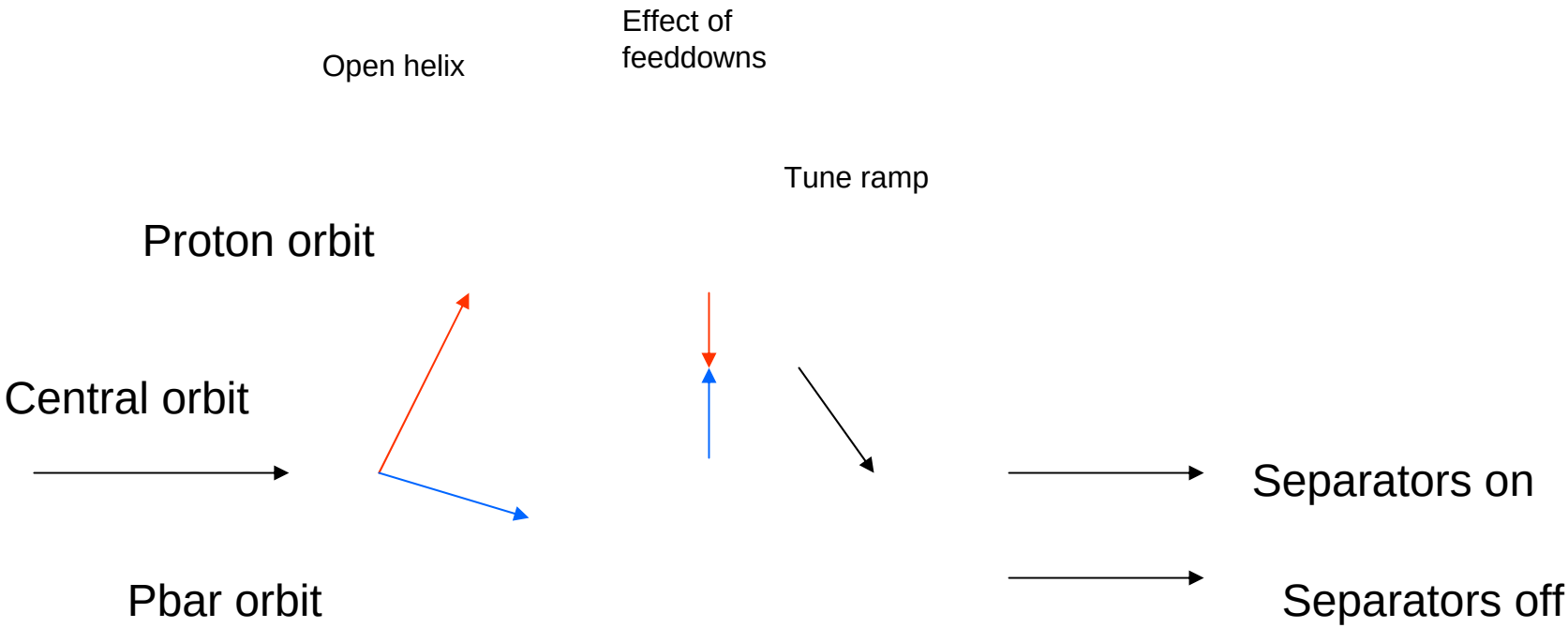
Open helix

Effect of feeddowns



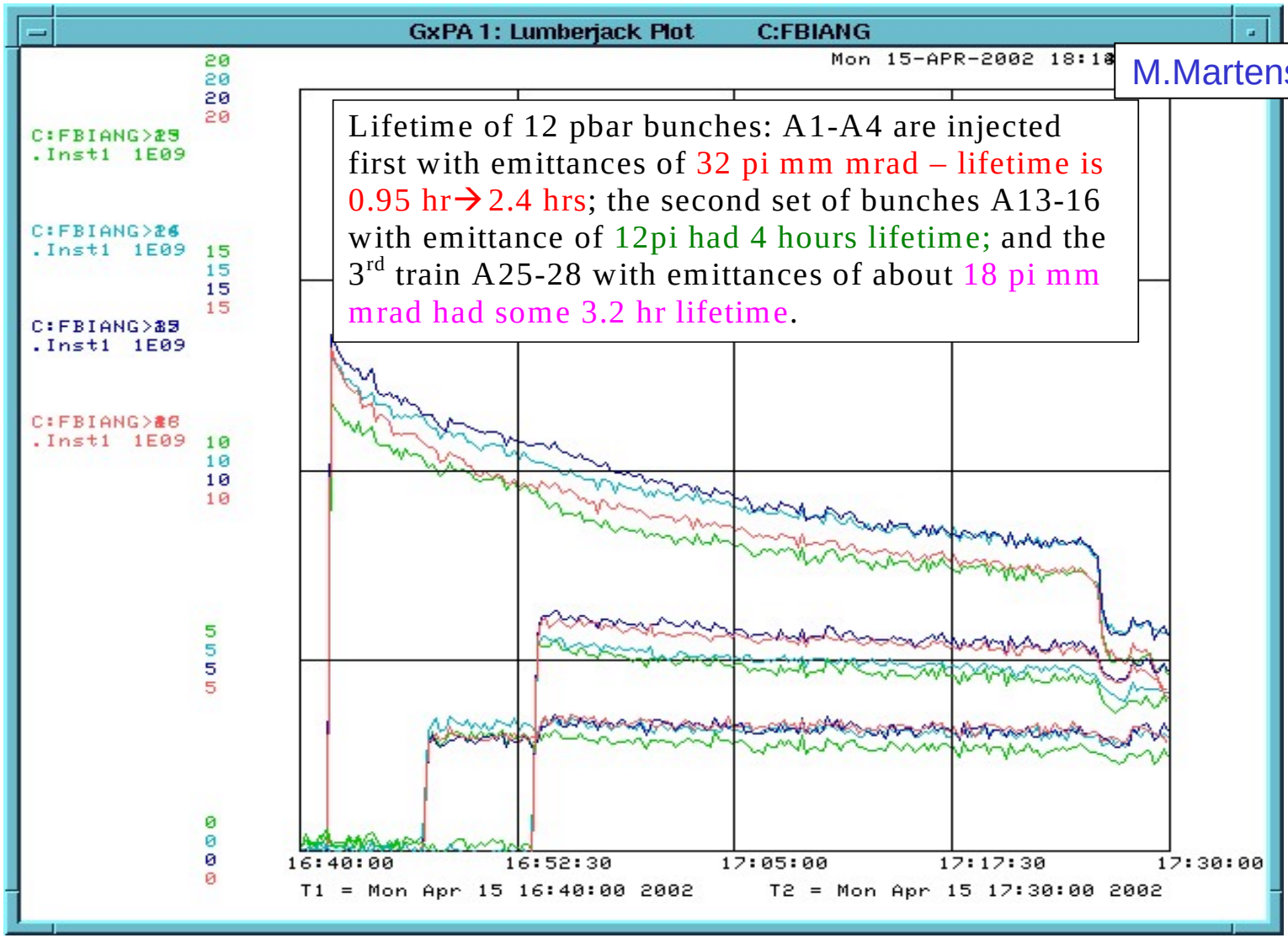
Difference between central orbit and helix is only separator voltage

If Octupoles are on



The same concept holds for Vert tune, chromaticities, coupling.

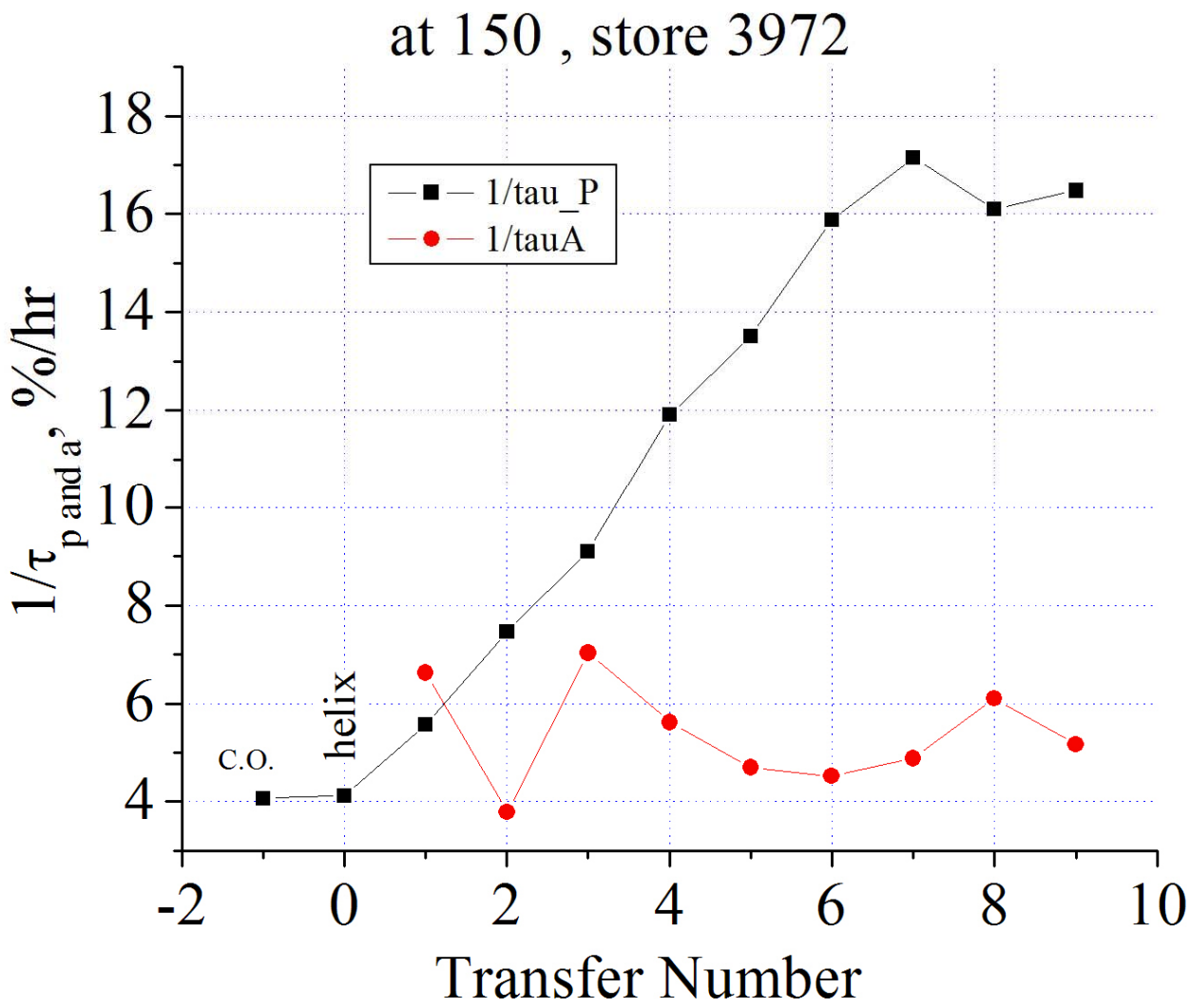
Lifetime Depends on Beam Emittance (2002)



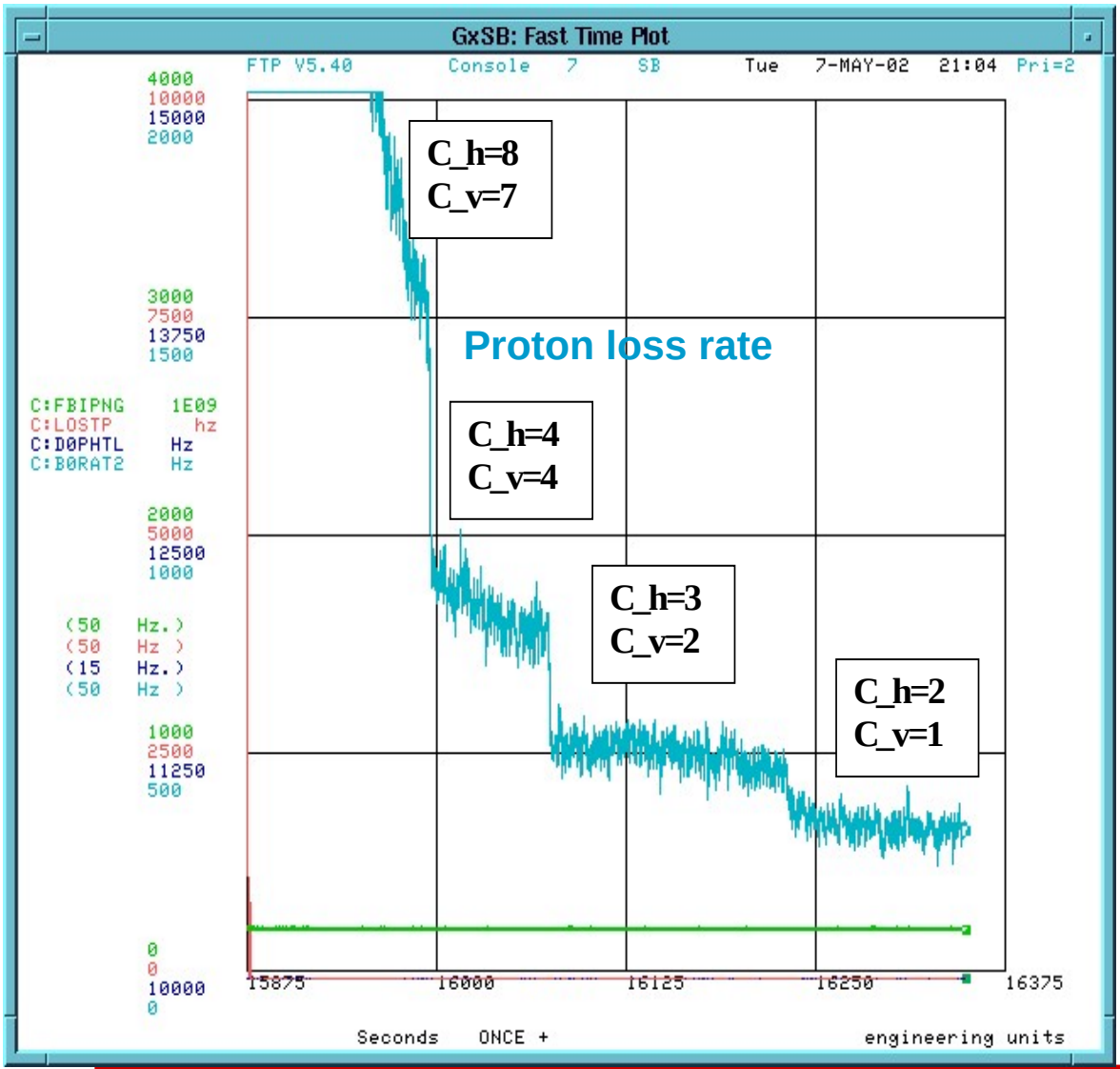
M.Martens

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.

150 Lifetime Depends on Other Beam Intensity



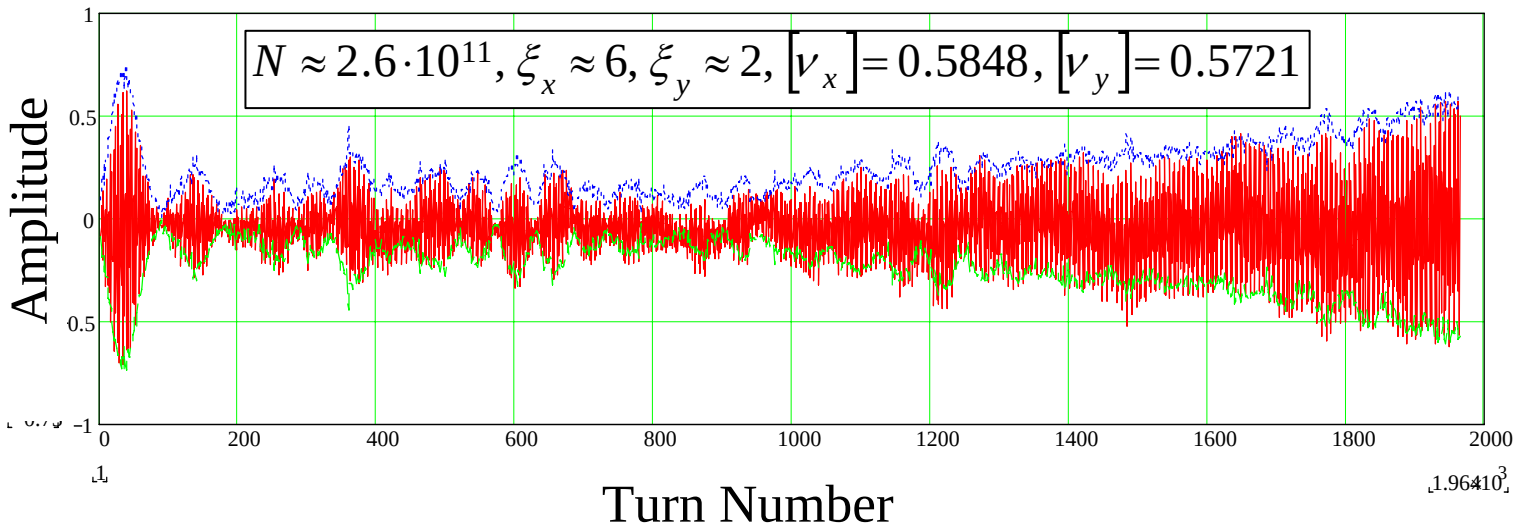
Lifetime Depends on Chromaticity (2002)



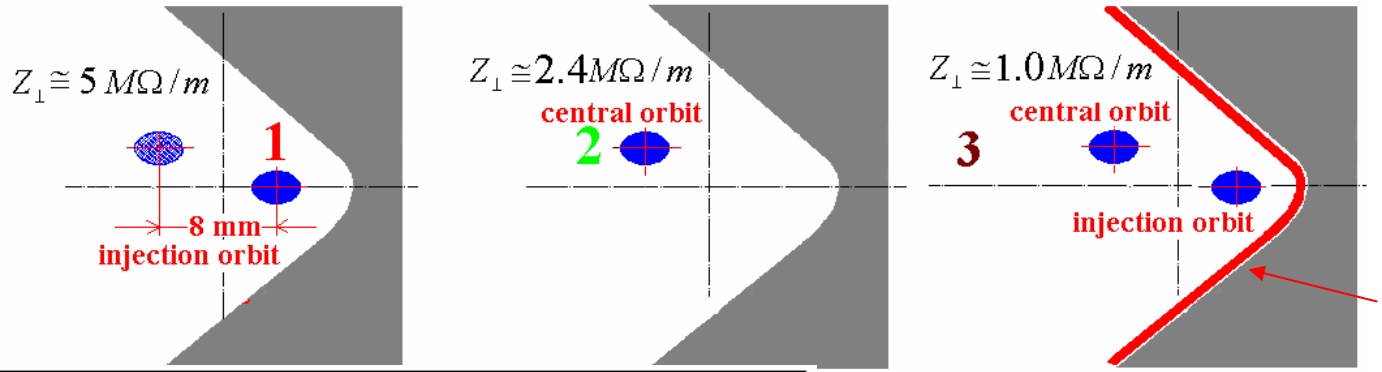
- Large dQ due to chromaticity in limited good working point space (tune aperture)
- p-loss rate (dN/dt) goes down for smaller chromaticities *C*_v,h
- with 36 p-bunches the only way to keep C_v,h=4 is to introduce tune spread by octupoles, or have effective dampers, otherwise beam is unstable (weak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

Head-tail Motion Unstable at Low Q'x,y (2003)

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

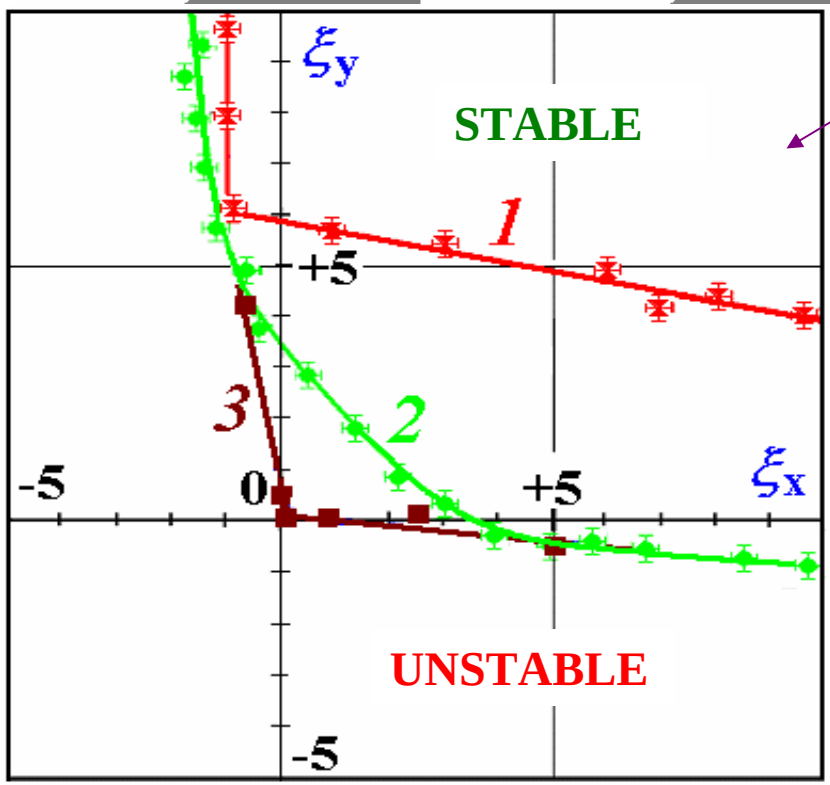


Impedance Reduced by Liners (2003)



P.Ivanov
A.Burov
A.Chen

0.4 mm liner
CuBe (98+2%)



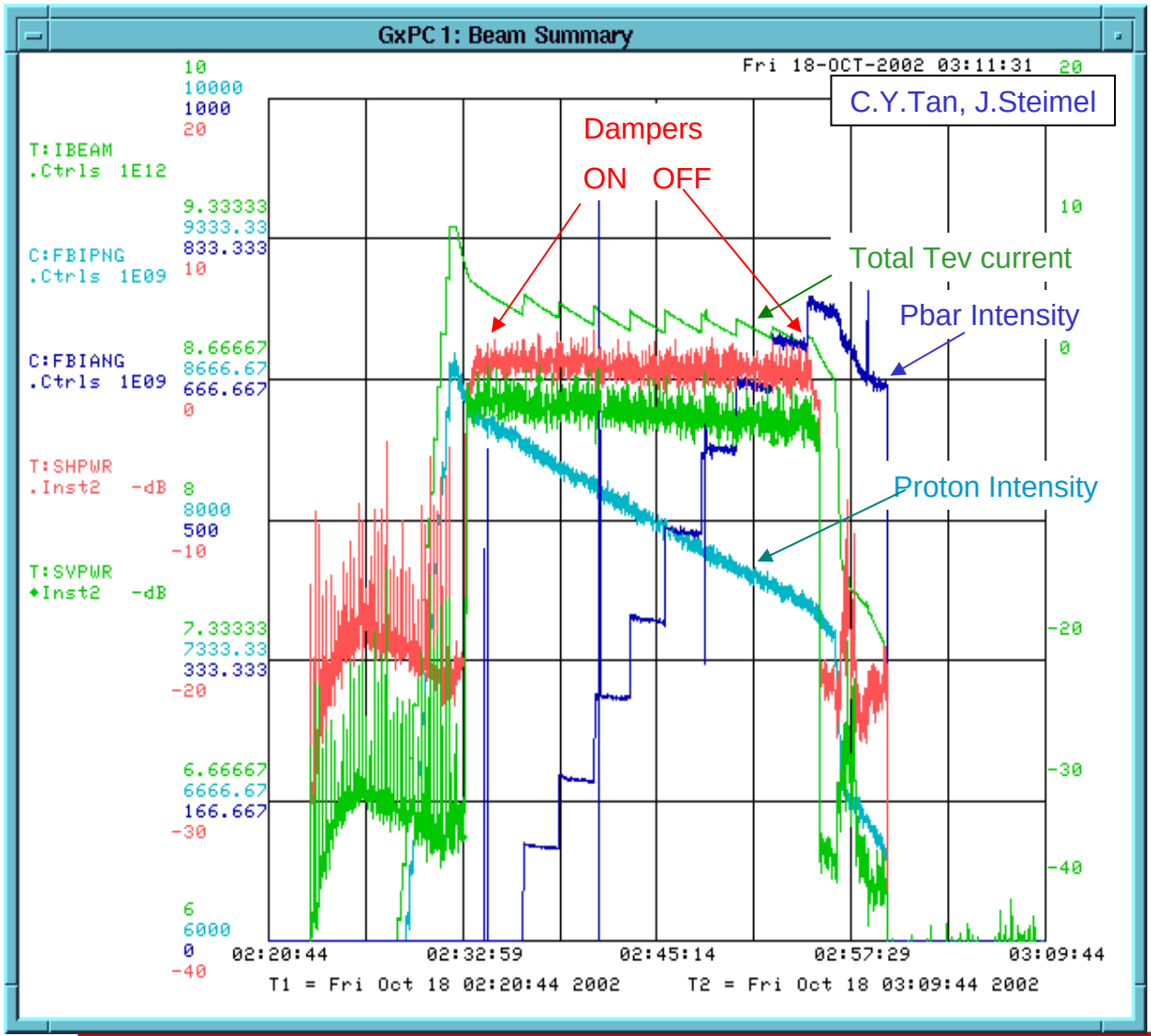
Region of stability of high intensity coalesced bunches (~230e9) on chromaticity plane before (#1 and #2) and after (#3) installation of conducting liner in F0 Lambertson magnets

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

Losses at 150 ~ Chromaticity 4→2

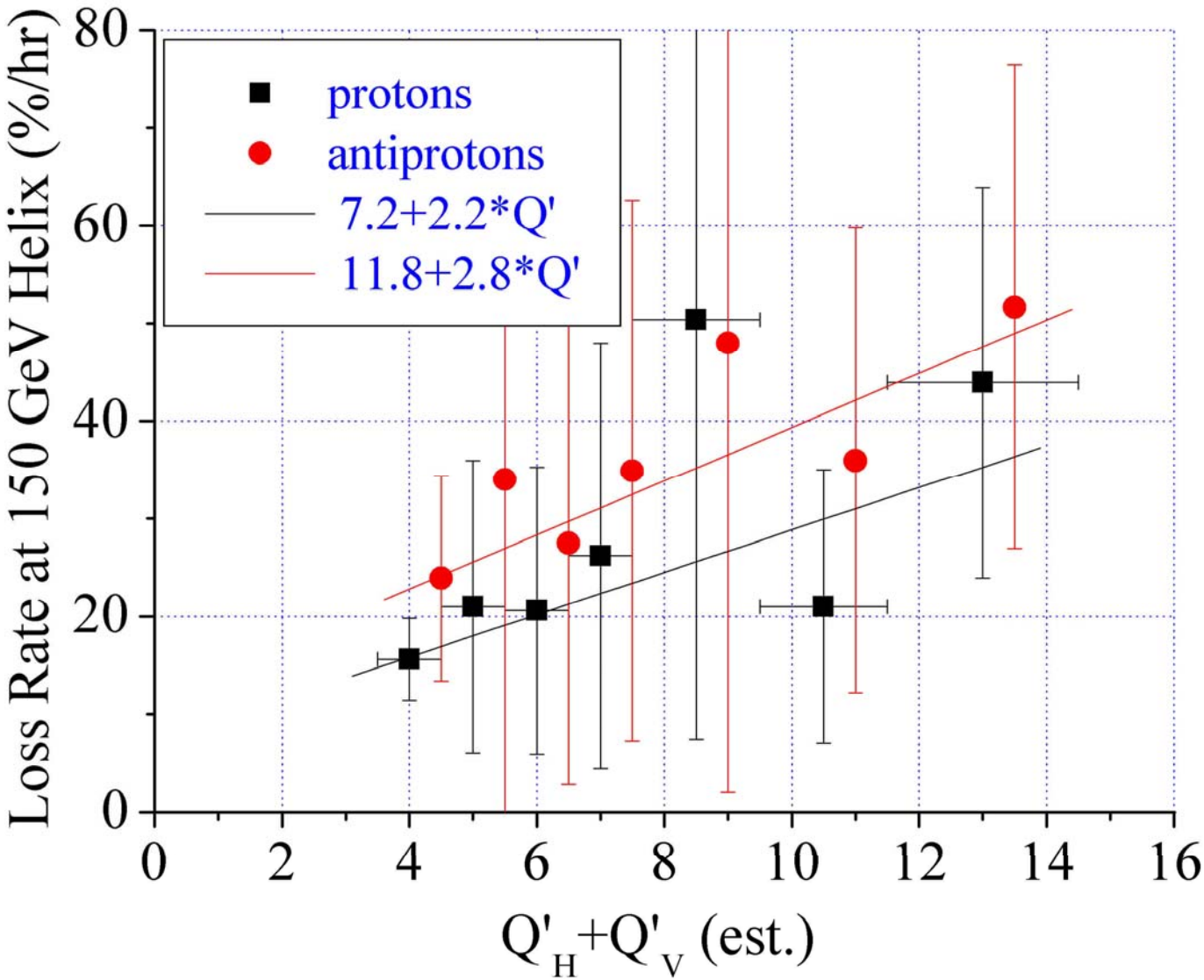
Octupoles for safety at C_vh=0

Transverse Dampers Helpful at 150 GeV (2003-2004)



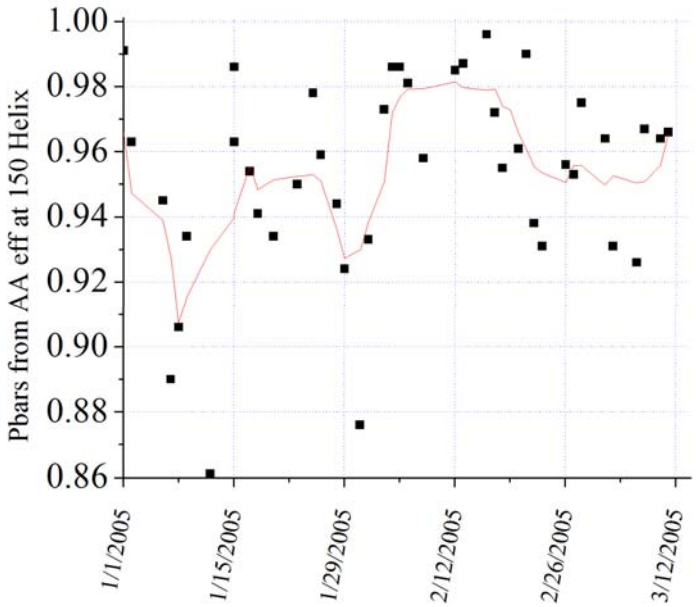
- dampers provide some 3ms damping time in both planes, coherent mode only
- dampers allow to operate high proton intensities with small chromaticities, e.g. C_h=8→3, C_v=8→5 at 150 GeV in #1868
- that resulted in >2 fold lifetime improvement (from 0.5-1 hr to 2.5 hr)
- dampers are proven to allow reduced 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

FY'03+FY'04 Stores: Lifetime vs Q'

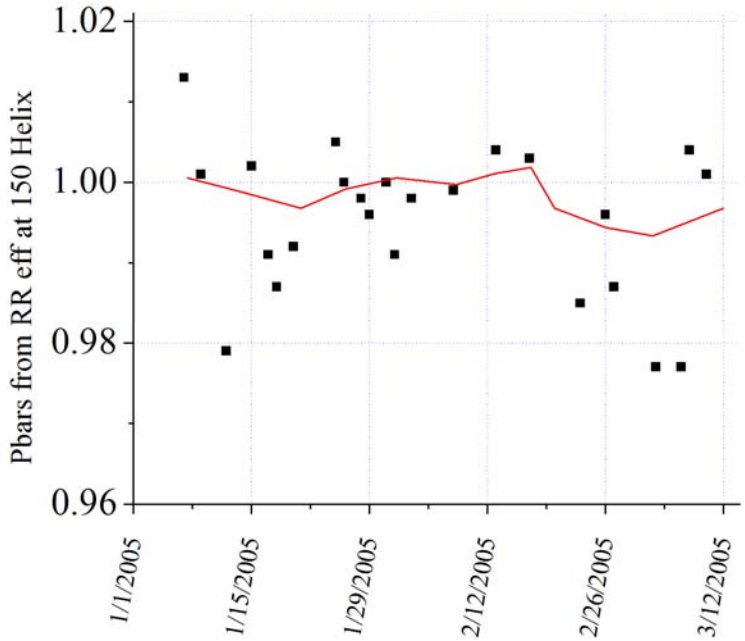


Lifetime of Pbars from AA Affected Most

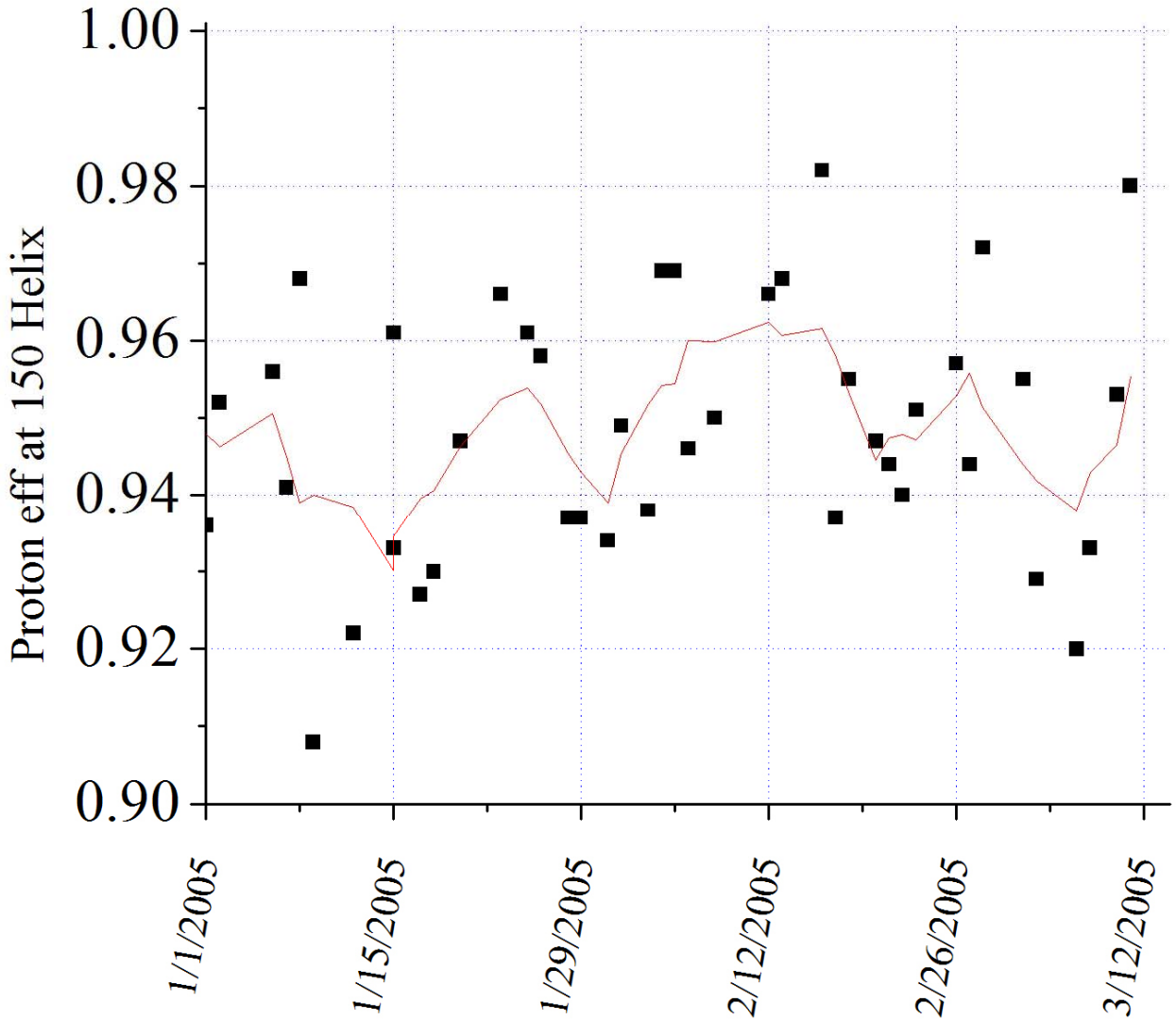
From AA



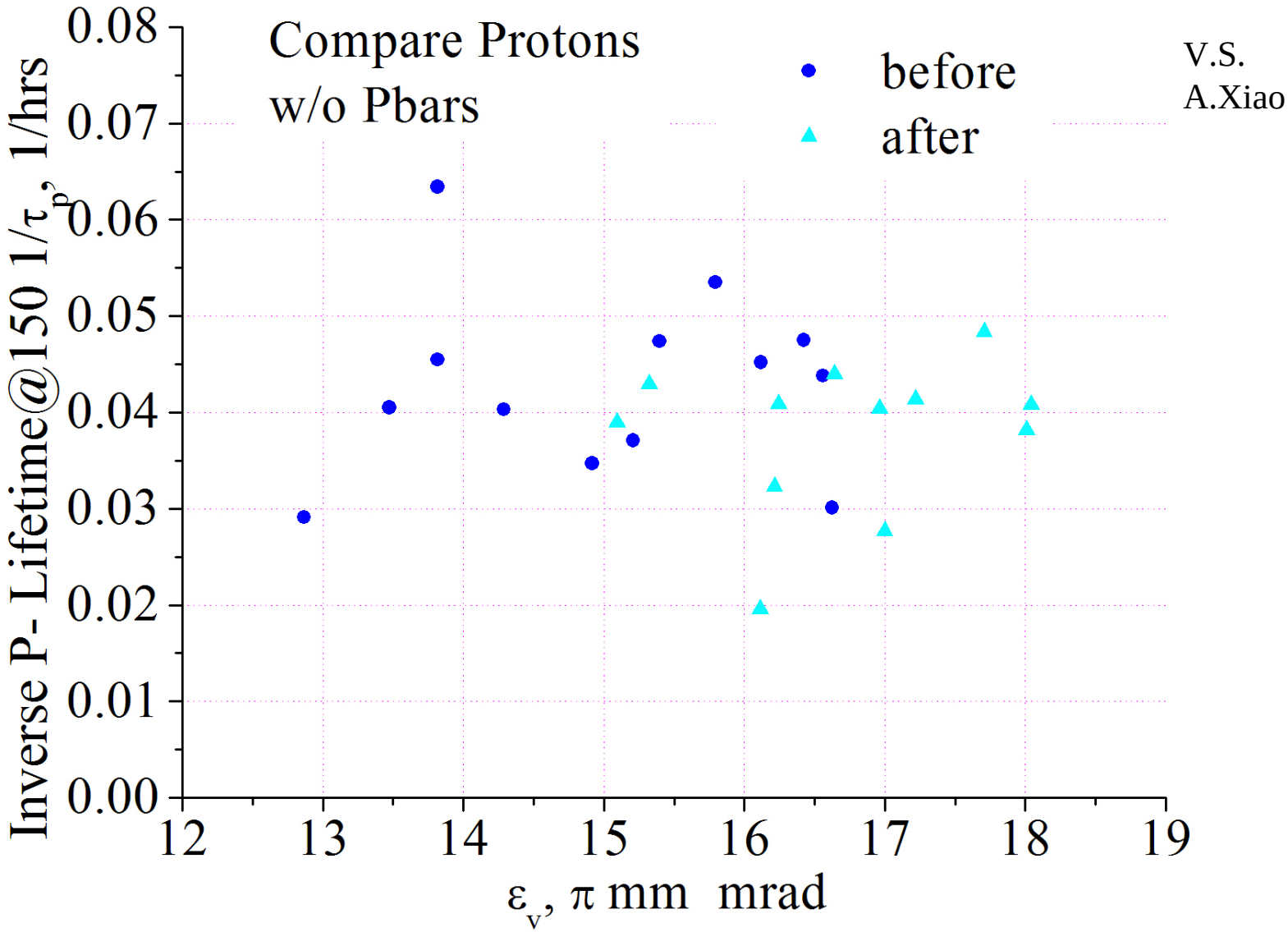
From RR



Slightly Better Proton Lifetime

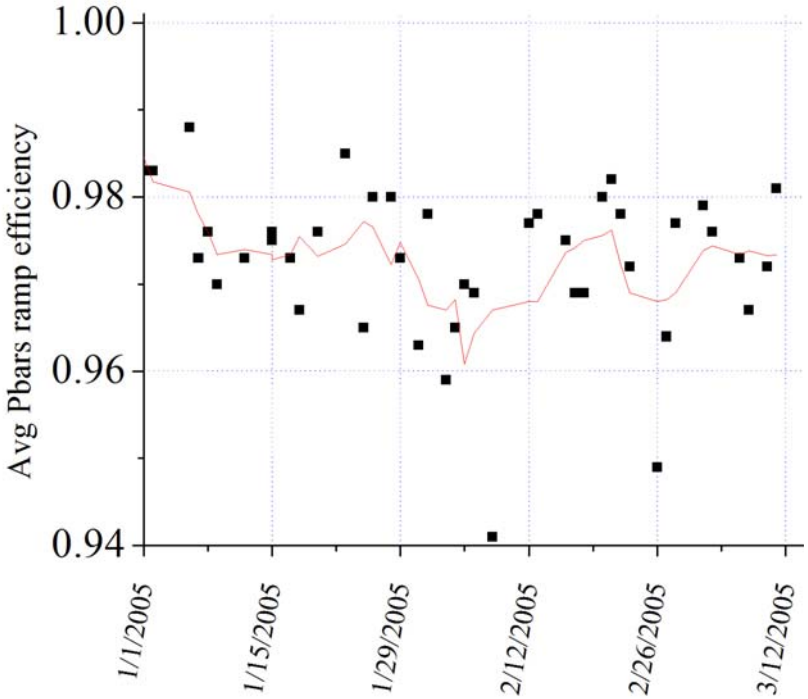


Proton Lifetime w/o Pbars ~ Same (25hrs)

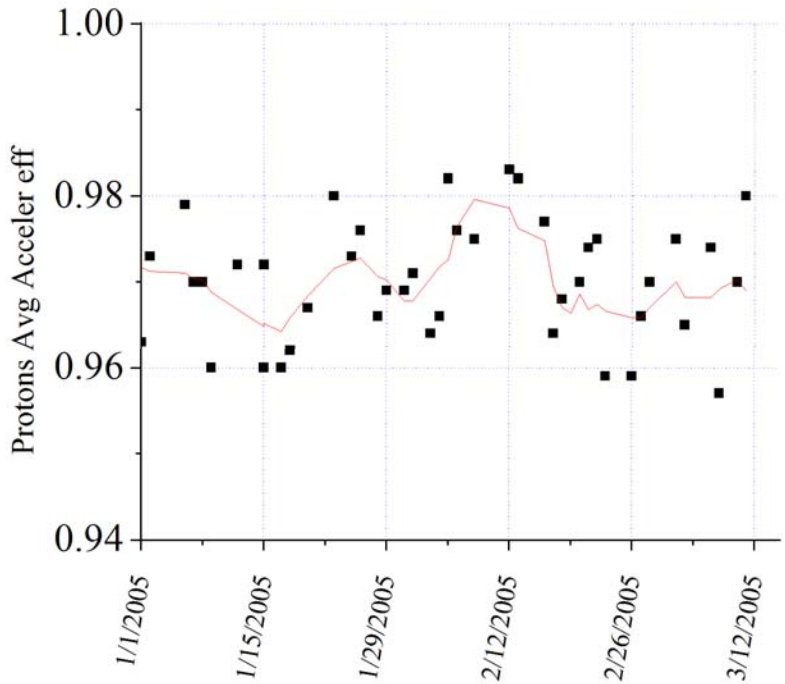


Ramp Efficiencies ~Same within +- 0.5%

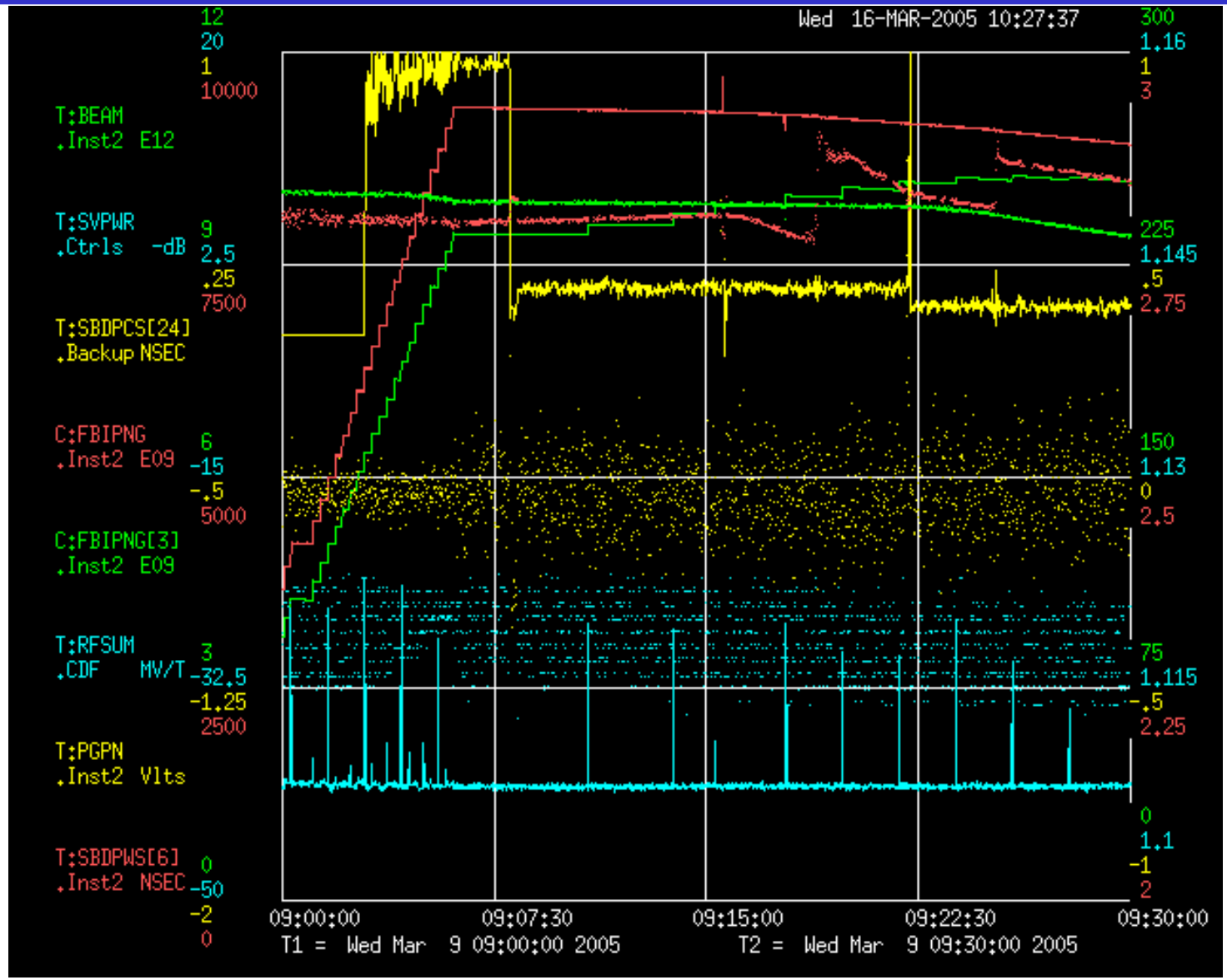
Pbars



Protons



Longitudinal Instability in #4029



Strange Instability in #3989 (Q' +1.5)