

Recent improvements in Antiproton stacking

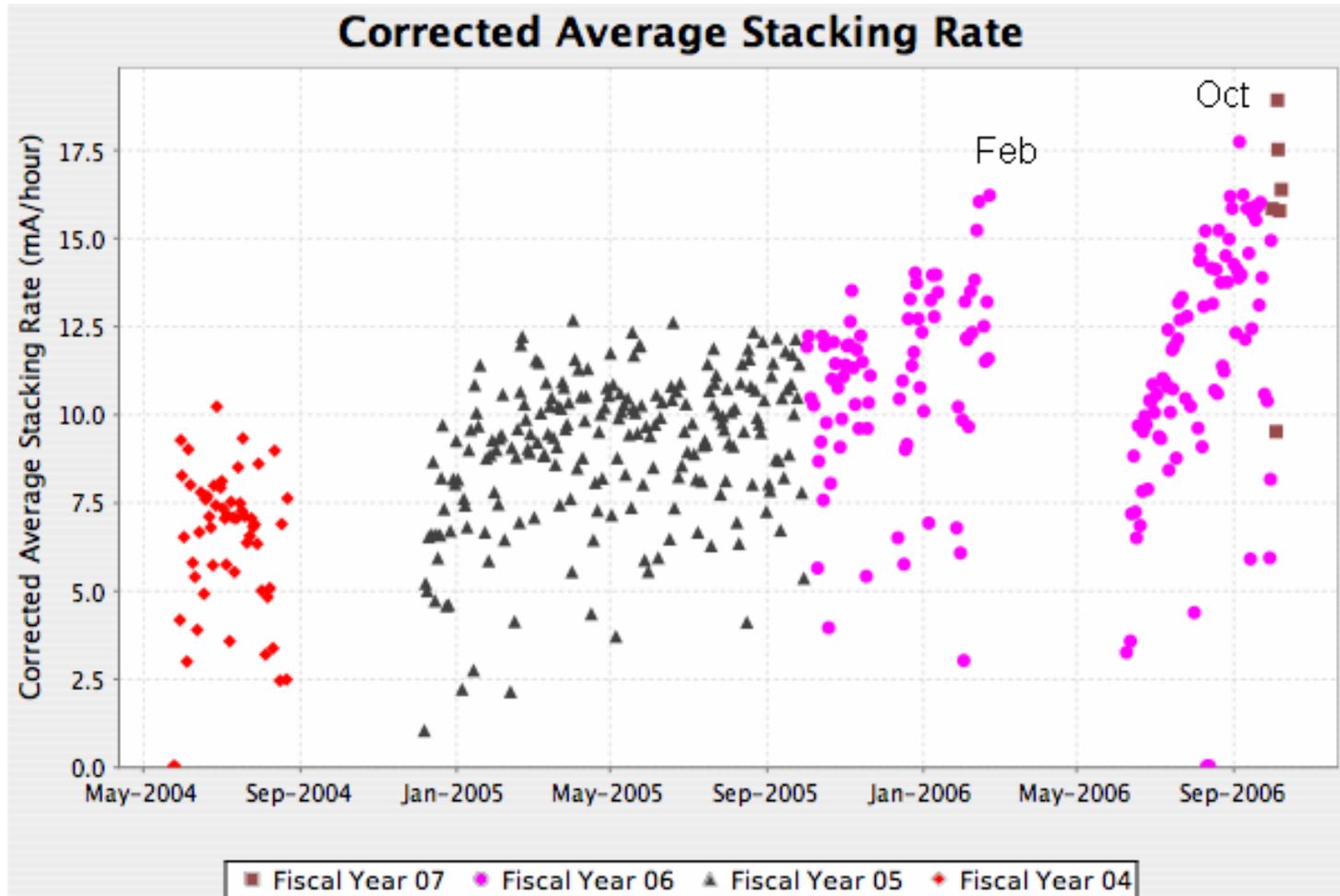
Valeri Lebedev

All Experimenters' Meeting
FNAL
October 23, 2006

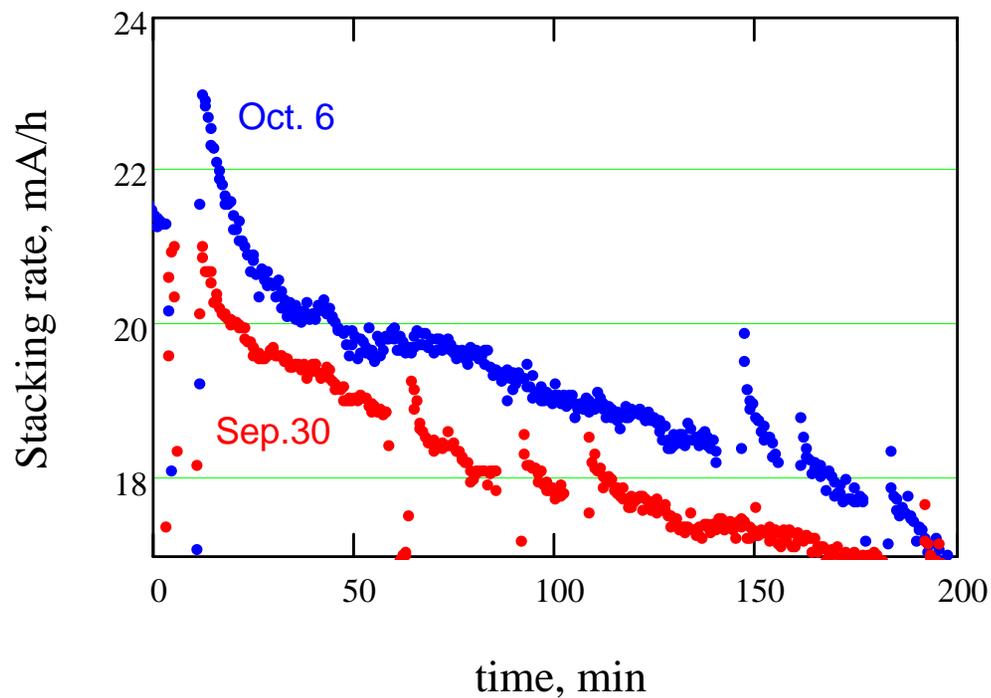
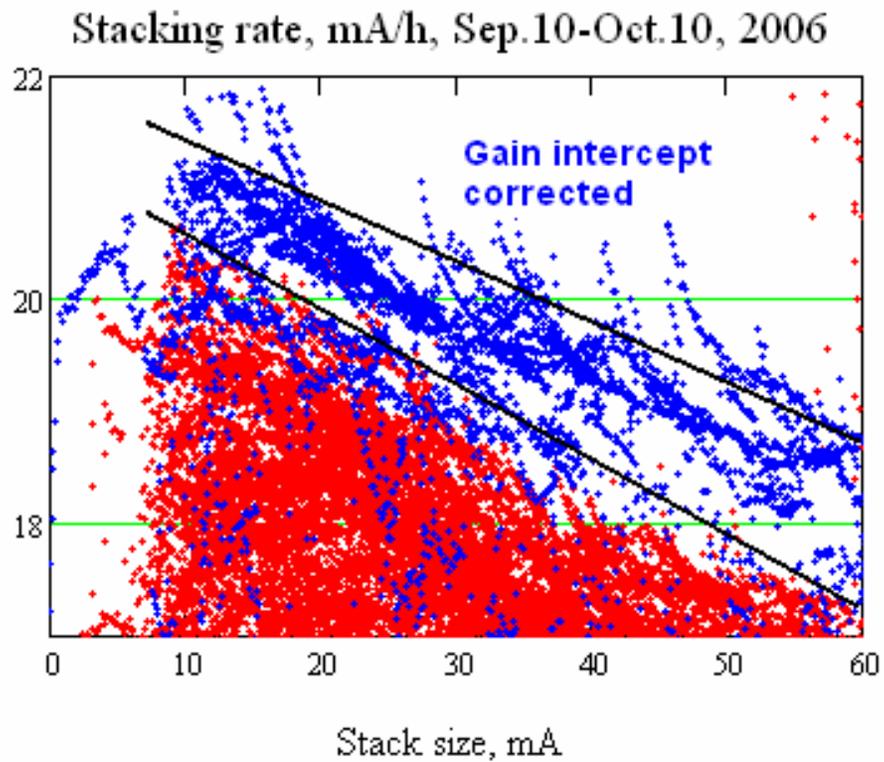
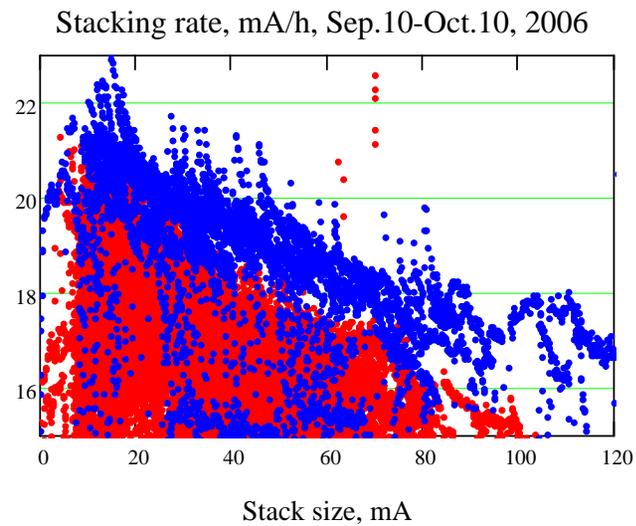
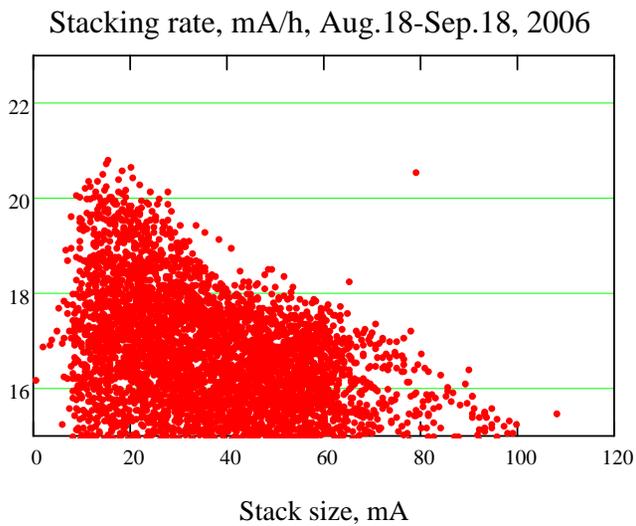
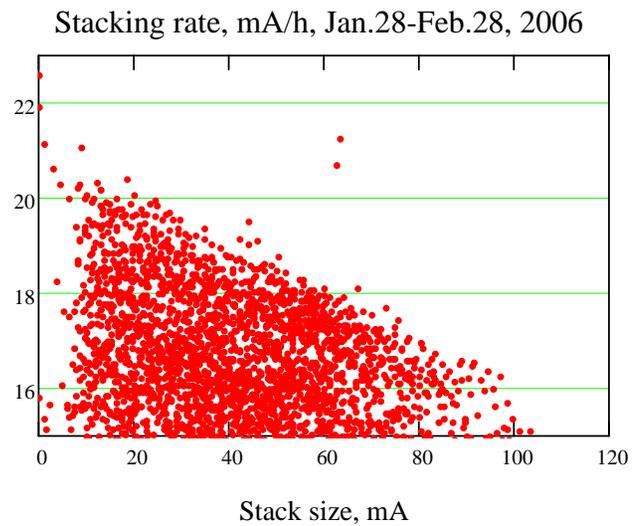
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Improvements of Stacking in Accumulator



- ◆ 2006 Stacking improvements are mainly related to the stack-tail
 - February - increased gain in 4-8 GHz longitudinal core cooling
 - peak rate of 20 mA hour
 - October - Phase intercept correction
 - peak rate of 21.2 mA/hour



Flux limitations for stack tail

- For $G_x(x) = G_0 \exp(-x/x_d)$ one obtains an estimate of maximum flux:

$$J_{\max} = |\eta| x_d T_0 \frac{\left(\int_0^{\infty} \operatorname{Re}(G_{\omega}(2\pi f)) df \right)^2}{\int_0^{\infty} |G_{\omega}(2\pi f)|^2 \frac{df}{f}}$$

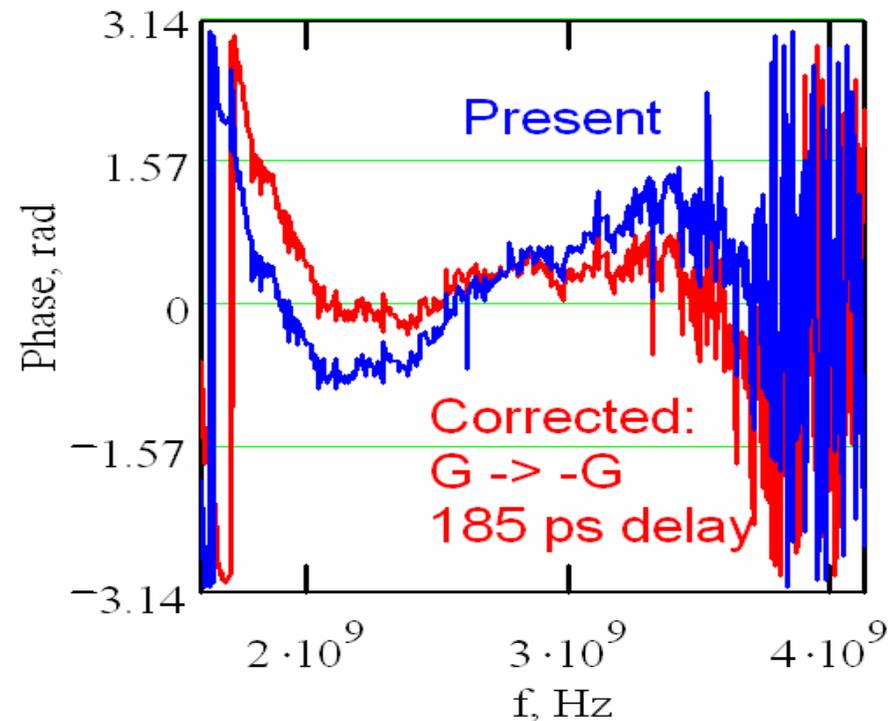
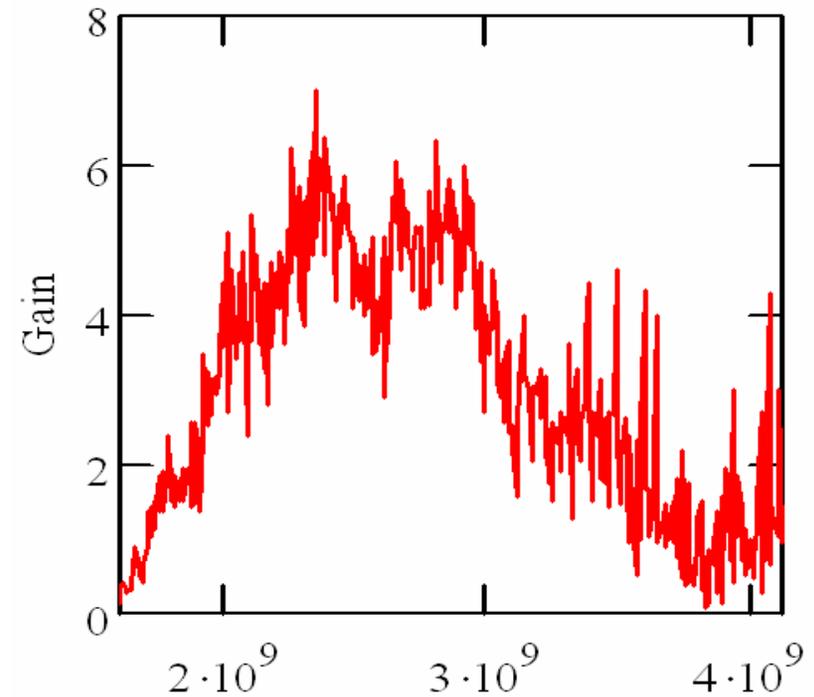
- For the gain measured at Sep. 26, 2006 ($E_d=8.5$ MeV) we obtain:

$J_{\max}=20.4$ mA/hour . This is very close to our peak pre-October performance!!!

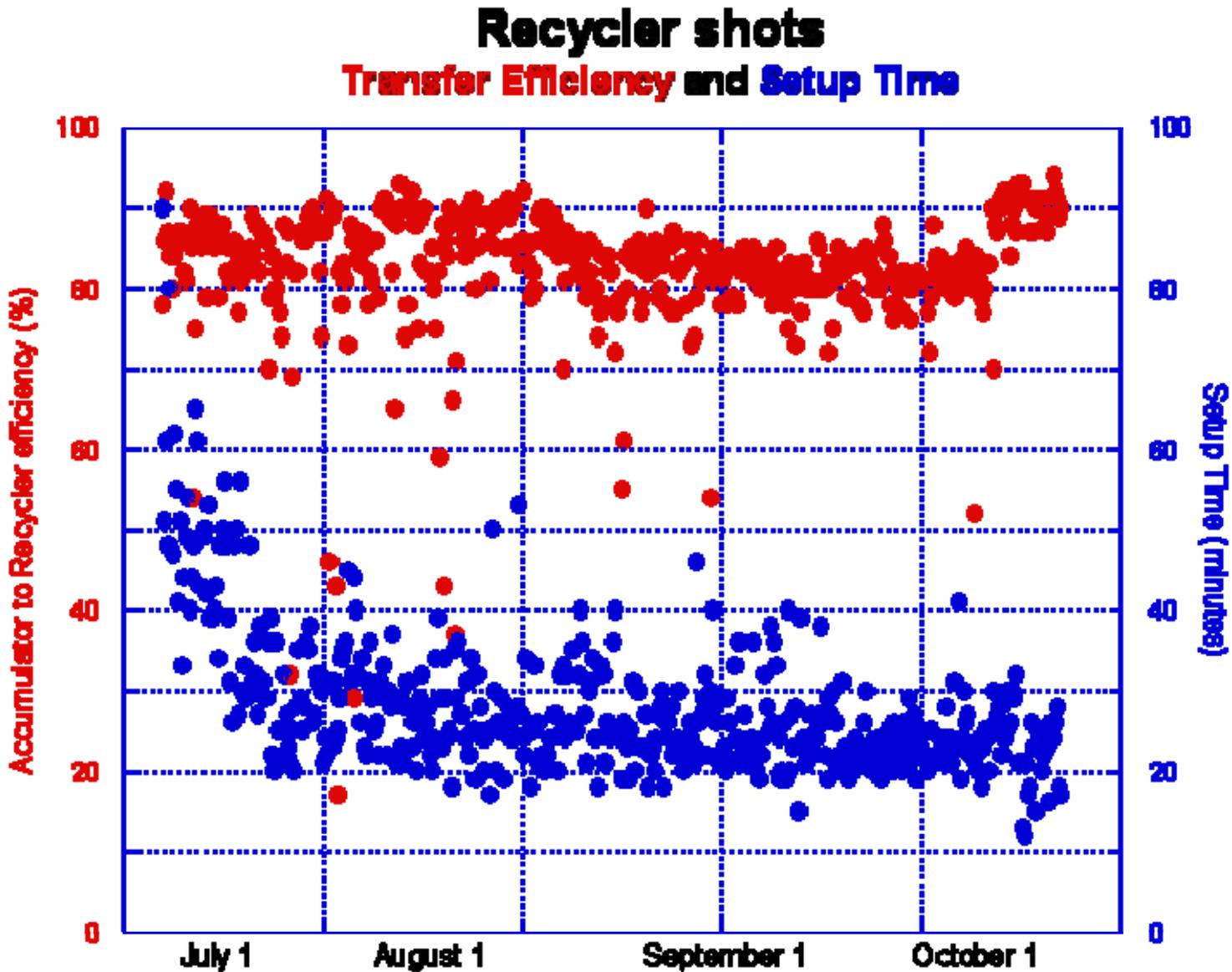
- Flipping the gain polarity and introducing 185 ps delay moves maximum flux to

$J_{\max}=23.4$ mA/hour

- Half of the expected gain was obtained after Oct. 2 polarity flip

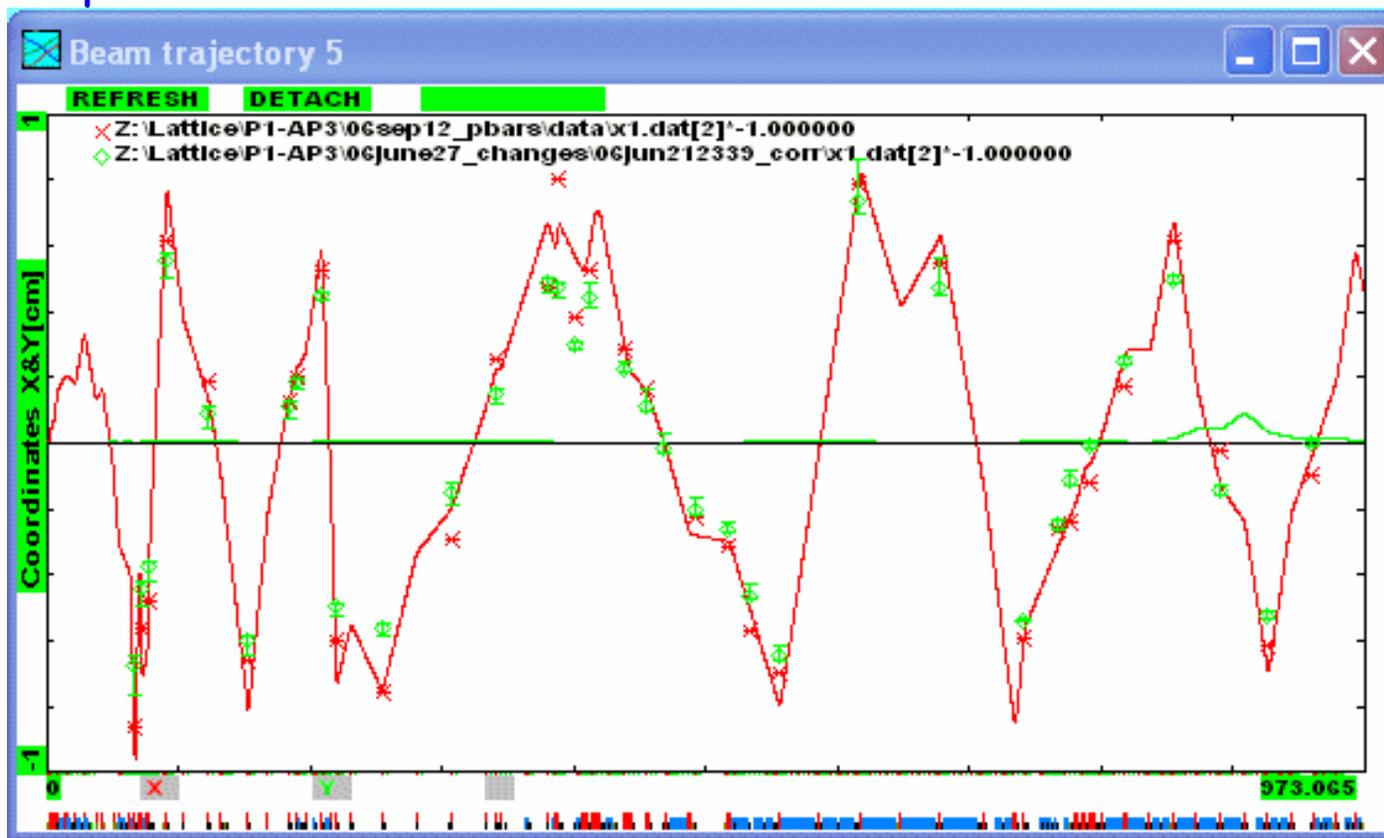


Optics Correction for Accumulator-to-MI Transport



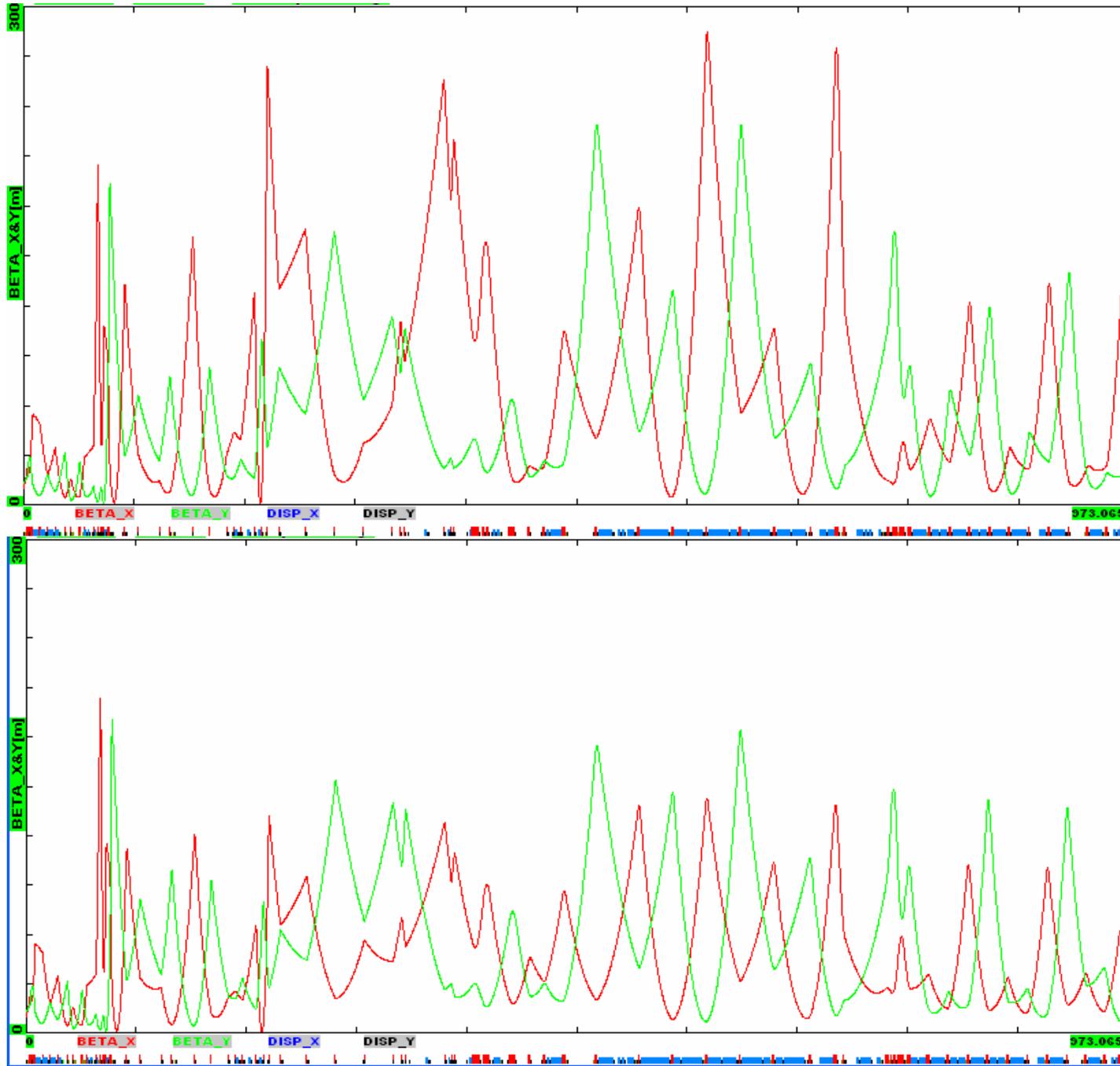
- Optics correction was performed at the beginning of October
- It resulted in ~10% improvement of the transfer efficiency

- Compensation of seasonal optics drifts requires correction each half year
- The first time optics measurements were done with forward pbars instead of reverse protons



One of five differential orbits used for optics reconstruction

Beta functions before and after correction



Quad currents

D:Q901= 374.4-2.6

I:Q701T = 15.70-0.85

I:Q702T =12.77+1.12

I:Q703T = 191.34

I:Q710T =9.99

I:Q711T =16.36-0.84

I:Q712T =19.18-0.96

I:Q713T =16.66-0.83

I:Q714T =7.72+0.21

I:QF11AT = 24.70

I:QF11BT =17.44

I:QF12T =122.526

M:Q201 =7.58

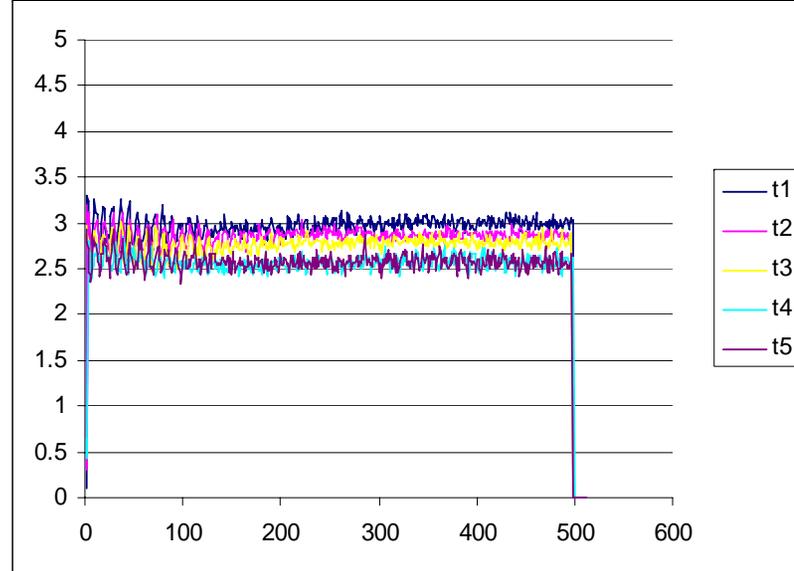
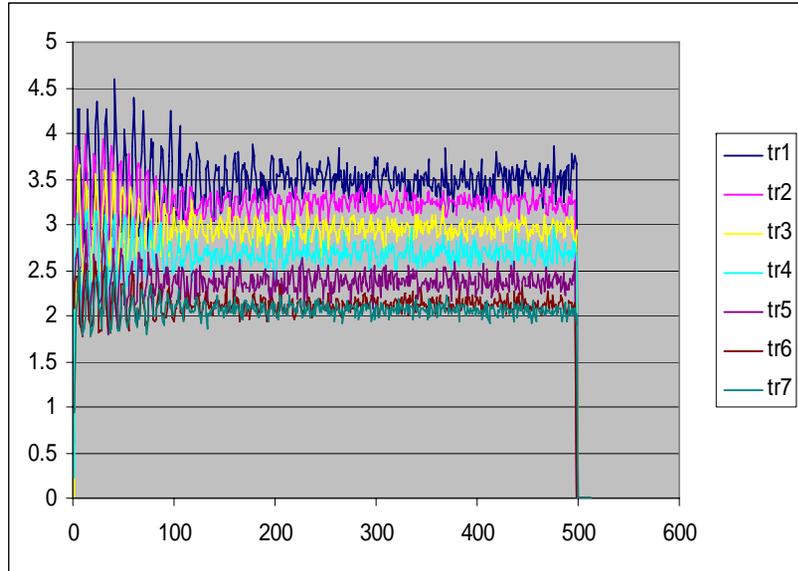
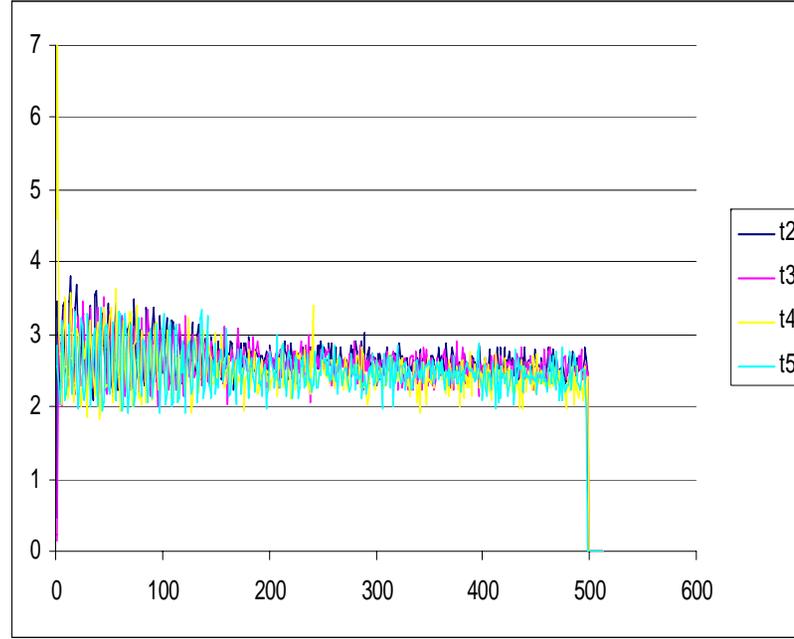
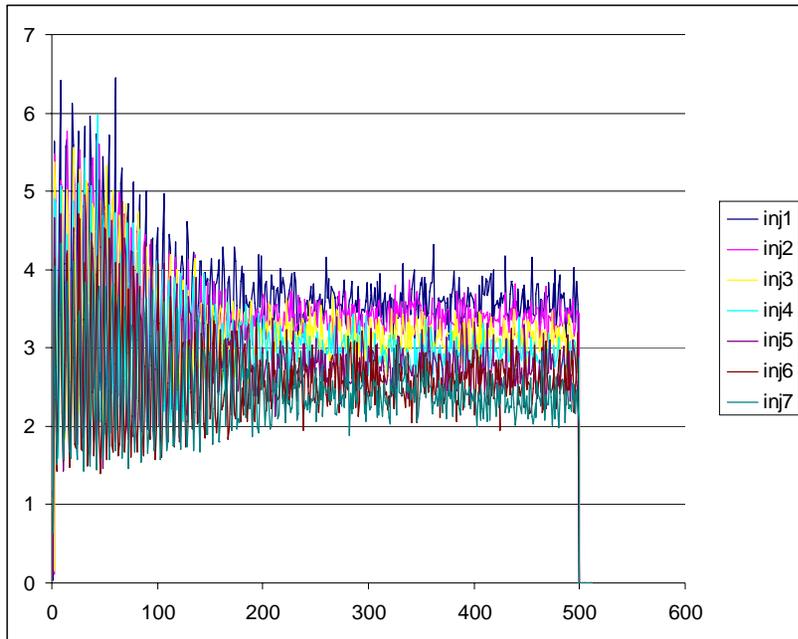
M:Q202 =10

M:Q203 =9.36

M:Q204 =10.65

M:Q205 =5.00

IPM measurements of beam sizes for beam injected to MI



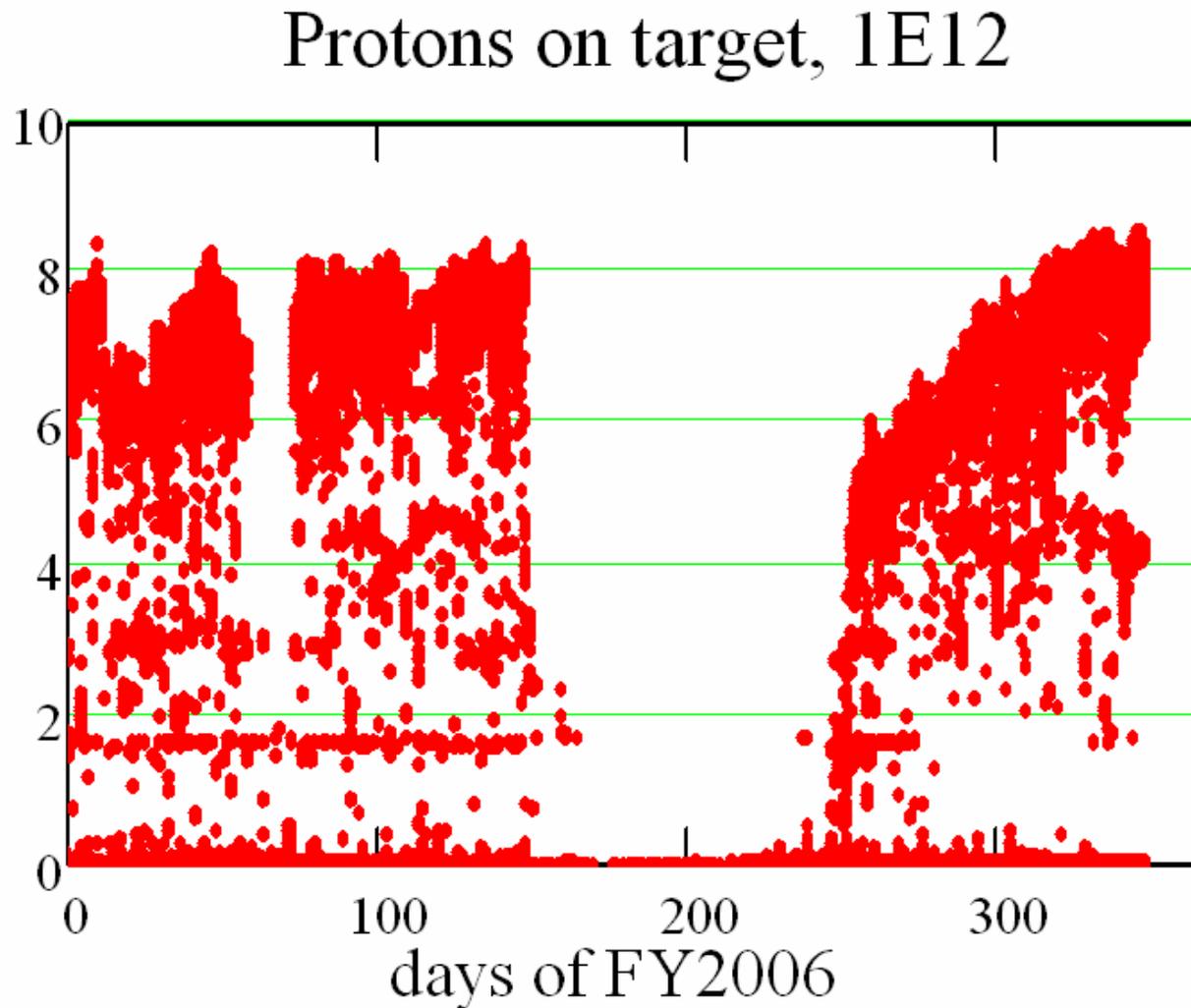
MI Horizontal (top) and Vertical (bottom) IPM σ (mm) vs. turn 9/29/2006 vs. 10/2/2006

Farther Antiproton Production Improvements

- Two task forces are created in AD
- Stacking Task Force
 - ◆ By June 2007
 - Peak stacking rate ≥ 30 mA/hour
 - Average stacking rate ≥ 25 mA/hour
- Fast transfers Task Force
 - ◆ By March of 2007
 - Transfer efficiency better than 95%
 - Transfer time less than 5 min

Injector Chain

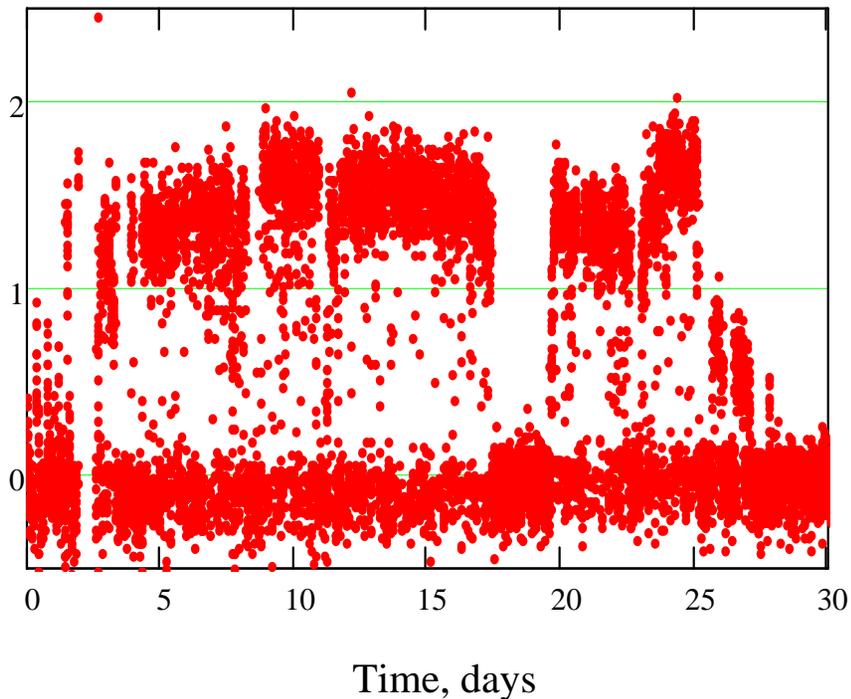
- Performance of the injector chain (Linac - Booster - MI) is restored to the level slightly above pre-shutdown level
- It satisfies present and future Run II requirements
- Further improvements are mostly NUMI driven
- Improvements of pbar-coalescing are expected



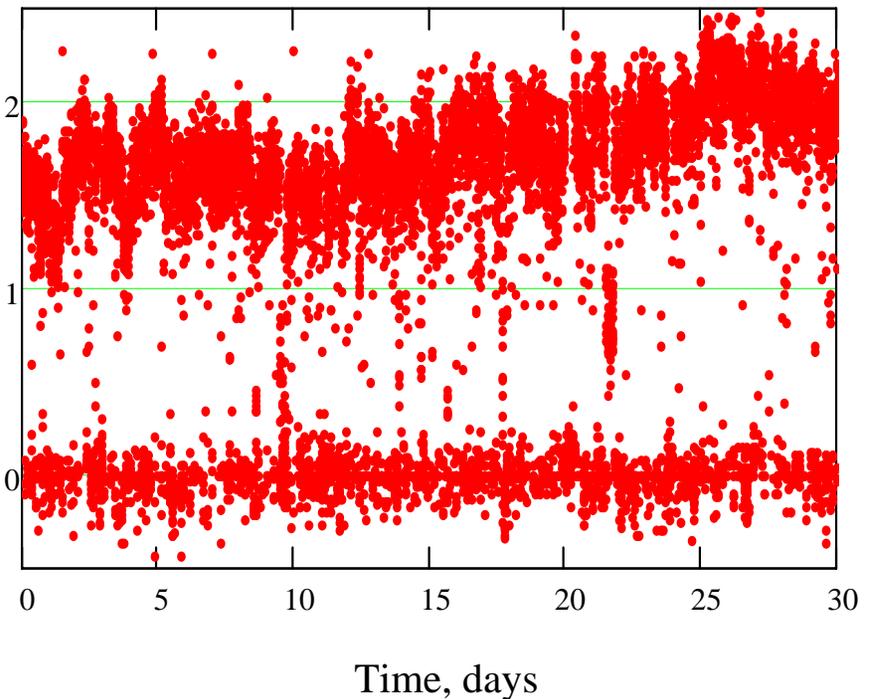
Debuncher and AP-2 transport

- We inject $2 \cdot 10^8$ antiprotons to Debuncher
 - ◆ That corresponds to P-bar yield $25 \cdot 10^{-6}$ pbar/p
 - ◆ If all cooled that would make 30 mA/hour for 2.4 s cycle

Pbars in Debuncher, 1E8, Jan.28-Feb.28, 2006 Pbars in Debuncher, 1E8, Aug.13-Sep.13, 2006



30 days before shutdown

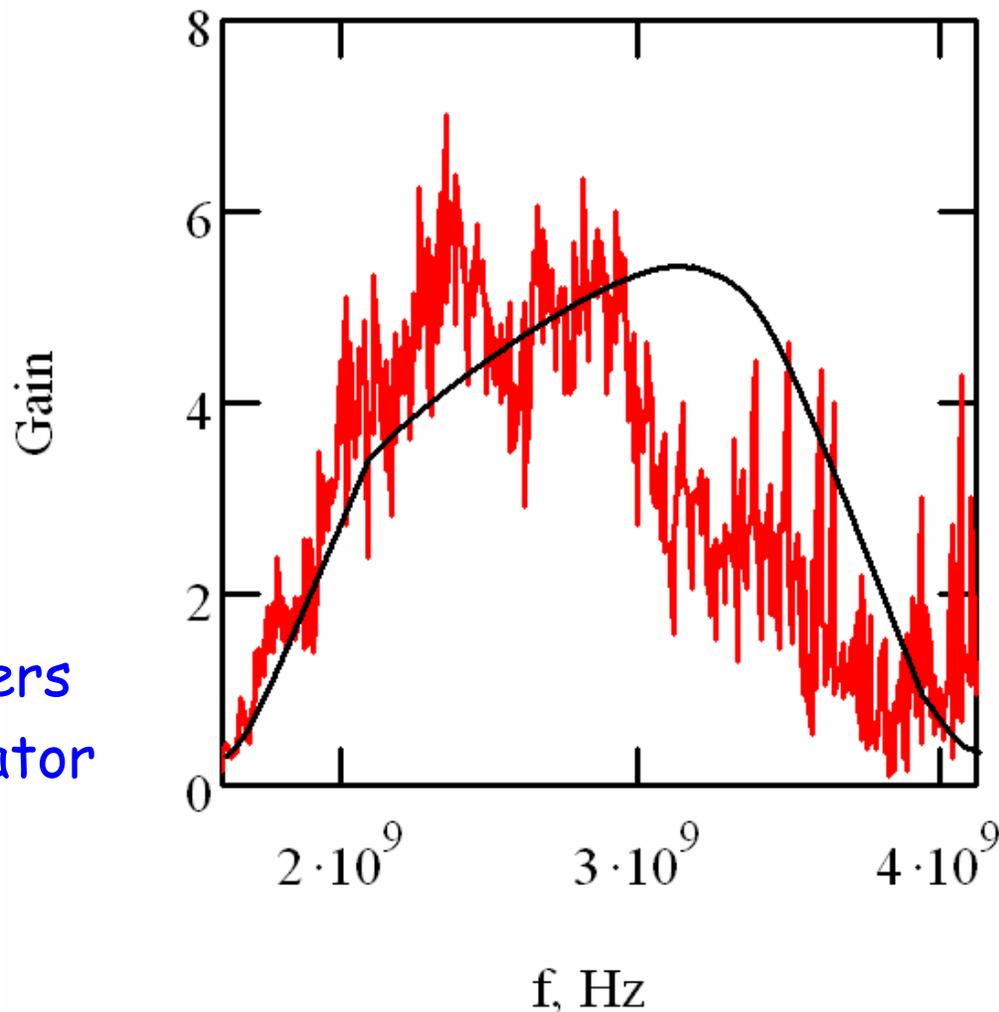


Last 30 days

- Further improvements (15-25%)
 - ◆ Lithium lens
 - ◆ Debuncher and AP-2 acceptances
 - ◆ Transverse cooling in Debuncher (Band 3 and 4 notch filters)

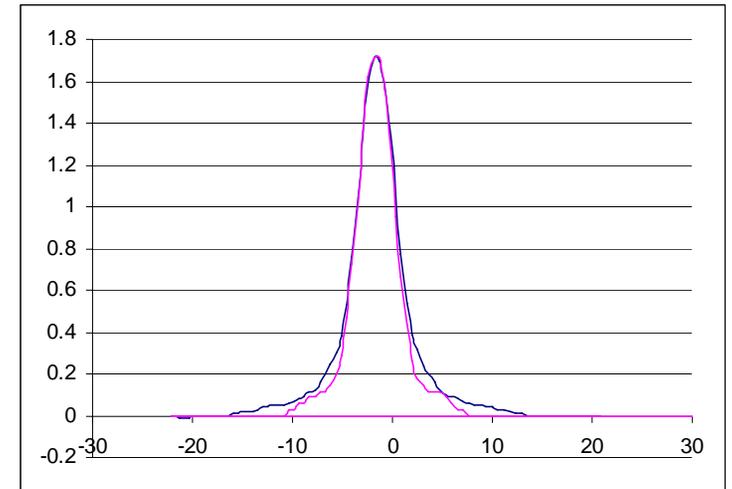
Accumulator improvements

- Stack-tail
 - ◆ Installation of equalizers
 - corrects both phase and amplitude
 - ⇒ 20 mA/hour → 30 mA/hour
 - ◆ E_d increase
 - ⇒ Reduced stack size, has to be supported by fast transfers
- Optics and apertures in Accumulator



Fast transfers

- ◆ Optics and steering improvements in MI-to-Recycler line and Recycler
- ◆ Mitigation of ripple for Accumulator extraction kicker
 - Injection damper for antiprotons incoming to MI
 - Shortening of kicker rise time
- ◆ Global optimization of transfer process
 - How much, How frequent, Gated stochastic cooling in Recycler



*MI HFW 3rd transfers,
9/29/2006 vs. 10/2/2006*

Conclusions

- 15-20% improvements of luminosity are expected after Tevatron recovery
- Factor of 1.5-2 improvement in number of Antiprotons delivered to Tevatron is expected by the end of FY'07

17 steps up in '02-05 → 1.1717 = 15 times (V. Shiltsev)

- | | | |
|--------------------------------------|----------|-------|
| • Optics AA→MI lines fixed | Dec'01 | ~25 % |
| • New LB squeeze helix, TEL-1 abort | Mar'02 | ~40 % |
| • "New-new" injection helix | May'02 | ~15 % |
| • AA Shot lattice vs IBS | July'02 | ~40 % |
| • Tev BLT/inst. dampers at injection | Sep'02 | ~10 % |
| • Pbar coalescing improved in MI | Oct'02 | ~5 % |
| • CO Lambertsons Removed | Feb'03 | ~15 % |
| • S6 cuircuit tuned/SEMs removed | June'03 | ~10 % |
| • "5 star" helix on ramp | Aug'03 | ~2 % |
| • Reshimming/Alignment | Nov'03 | ~12 % |
| • Longer Stores/ MI dampers | Feb'04 | ~19 % |
| • 2.5MHz AA → MI trnsf/Cool shots | April'04 | ~8 % |
| • Reduction of beta* to 35 cm | May'04 | ~26 % |
| • Shots from Recycler | July'04 | ~20% |
| • Slip Stacking in MI | Mar'05 | ~20% |
| • Tev Octupoles at 150 GeV | April'05 | ~5% |

- Reduction of beta* to 28 cm Sep'05 ~8 %

2006 improvements

- Pbar production task force Feb'06 ~10 %
- Tevatron 150 GeV helix → more p's June'06 ~10 %
- Tev collision helix → lifetime July'06 ~15 %
- New RR WP → emittances Sep'06 ~25 %
- Acc.-to-MI optics correction
and stack tail phase intercept Oct'06 ~15 %

What's wrong with Stack-Tail?

- First we do not have sufficiently accurate model to compare
- Let's look in details

$$\frac{\partial \psi}{\partial t} + \frac{\partial}{\partial x} (F(x)\psi) = \frac{1}{2} \frac{\partial}{\partial x} \left(D(x) \frac{\partial \psi}{\partial x} \right)$$

$$F(x) \equiv \frac{dx}{dt} = \frac{1}{T_0} \sum_{n=-\infty}^{\infty} \frac{G(x, \omega_n)}{\varepsilon(\omega_n)} (1 - A(\omega_n) e^{-i\omega_n T_0}) e^{i\omega_n T_2 \eta_2 x}, \quad \omega_n = n\omega_0 (1 - \eta x)$$

$$D(x) = \sum_{n=-\infty}^{\infty} \frac{1}{\varepsilon(\omega_n)^2} \left[\frac{2\pi e^2 P_{\text{Unoise}}(\omega_n)}{T_0^2 (\gamma\beta^2 mc^2)^2} \left| \frac{Z_k(\omega_n)}{Z_{\text{amp}}(\omega_n)} \right|^2 + \frac{N}{T_0} \left| G(x, \omega_n) (1 - A(\omega_n) e^{-i\omega_n T_0}) \right|^2 \sum_{k=-\infty}^{\infty} \frac{1}{|k\eta|} \psi \left(\frac{k - (1 - \eta x)n}{\eta k} \right) \right]$$

- We factorize cooling force and diffusion
- We neglect pickup-to-kicker delay
- We neglect particle screening
- We neglect thermal noise
- ◆ Finally we arrive to

$$F(x) = 2G_x(x) \int_0^{\infty} \text{Re}(G_\omega(2\pi f)) df$$

$$D(x) = \frac{2N\psi(x)G_x(x)^2}{T_0|\eta|} \int_0^{\infty} |G_\omega(2\pi f)|^2 \frac{df}{f}$$

- ◆ Assuming that $G_x(x) = G_0 \exp(-x/x_d)$ we arrive to the maximum flux:

$$J_{\max} = |\eta| x_d T_0 \frac{\left(\int_0^{\infty} \operatorname{Re}(G_{\omega}(2\pi f)) df \right)^2}{\int_0^{\infty} |G_{\omega}(2\pi f)|^2 \frac{df}{f}} \quad (1)$$

- ◆ For rectangular gain function

$$G_{\omega}(2\pi f) = \begin{cases} G_{opt}, & f \in [f_{\min}, f_{\max}] \\ 0, & \text{otherwise} \end{cases}$$

that yields

$$J_{\max} = |\eta| x_d T_0 \frac{(f_{\max} - f_{\min})^2}{\ln(f_{\max} / f_{\min})}$$

- Final tuning is still not finished