Fermilab

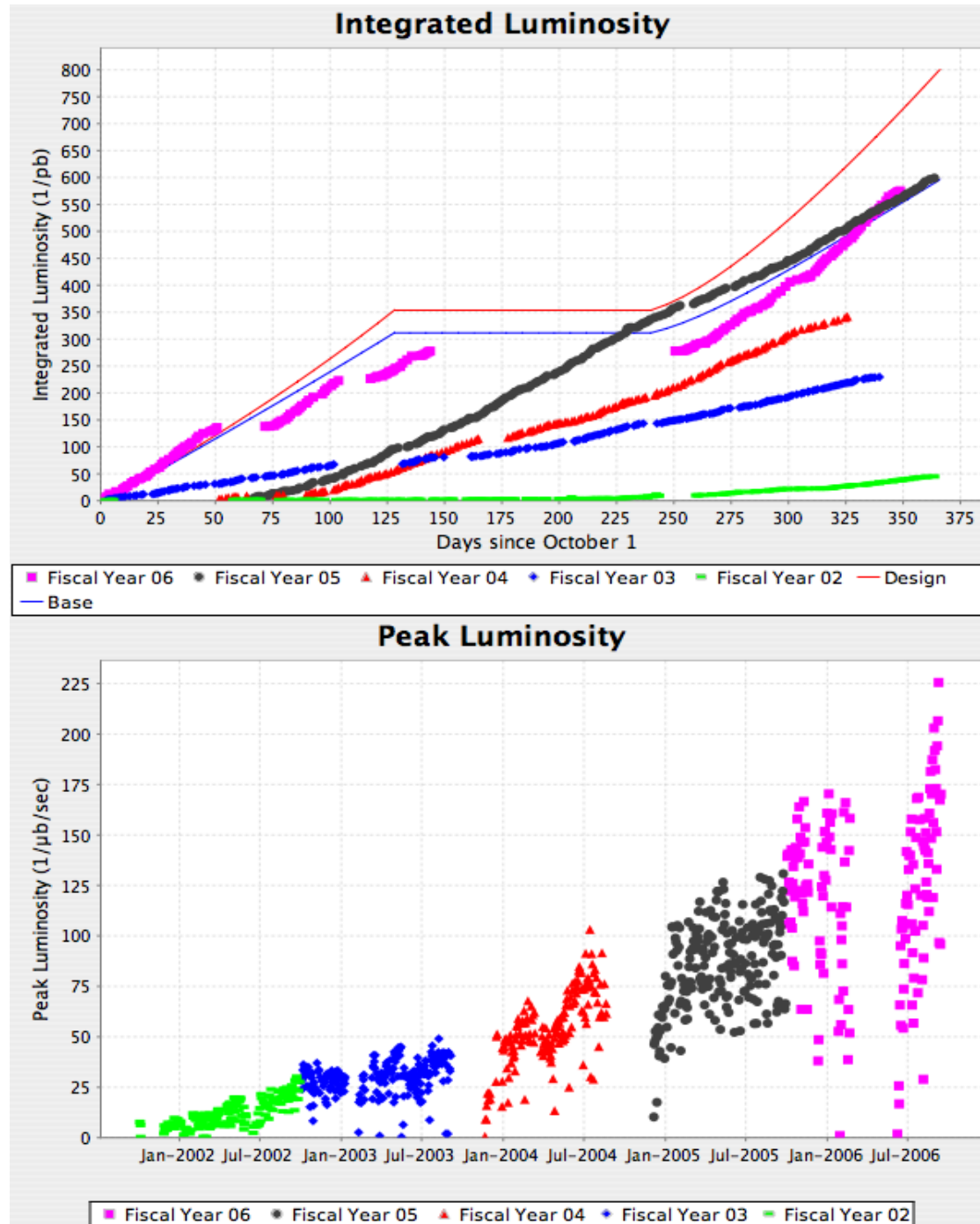# Run II Status and Goals: Can We Achieve 8 fb^{-1}

Valeri Lebedev

FNAL
September, 2006

Contents

- Present collider status
- Objectives for further upgrades
- Present Tevatron performance
- Future Tevatron performance
- Luminosity leveling
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- Antiproton source
- Fast transfers
- Conclusions

Present Collider Status

Integrated Luminosity

Peak Luminosity

- ~30 pb^{-1}/week during last month
- That corresponds to 1300 pb^{-1}/year for 10 months operation
- DoE goal for FY-06 of 545 pb^{-1} is achieved on Sep. 8
- ~630 pb^{-1} is expected for FY-06

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Objectives for further upgrades

1. Major goal – Luminosity integral of 7 fb^{-1} by the end of FY2009

	Lum. integral, fb^{-1}	
	No upgrades	Upgrade path
Total integral by the end of FY 2006	**1.84**	**1.84**
FY 2007	1.2†	1.5
FY 2008	1.2	1.9
FY 2009	1.2	2.2
Total integral by the end of FY 2009	**5.4**	**7.4**

- ♦ We can run 45 weeks in FY 2009 (1 month shutdown)
  - ⇒ 47 pb^{-1}/week
  - • Last month - 30 pb^{-1}/week
- ♦ Upgrade plan requires factor of 1.3 increase for weekly integrated luminosity for next year and factor of 1.7 for last two years
  - • We assume the same reliability (~130 store hours per week)

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† Relative to last month 30 pb^{-1}/week the 10% correction on reliability is taken into account, 4 week shutdown is also assumed

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

2. Major objectives for upgrade

♦ **Peak production rate in Accumulator**

- Maximum gain is expected from

  Lithium lens

  Stochastic cooling !!!

  Optics correction in Accumulator

♦ **Reduce difference between peak production rate (20 mA/hour) and average rate injected to Tevatron (7.5 mA/hour – last month, ~9 mA/hour – last week)**

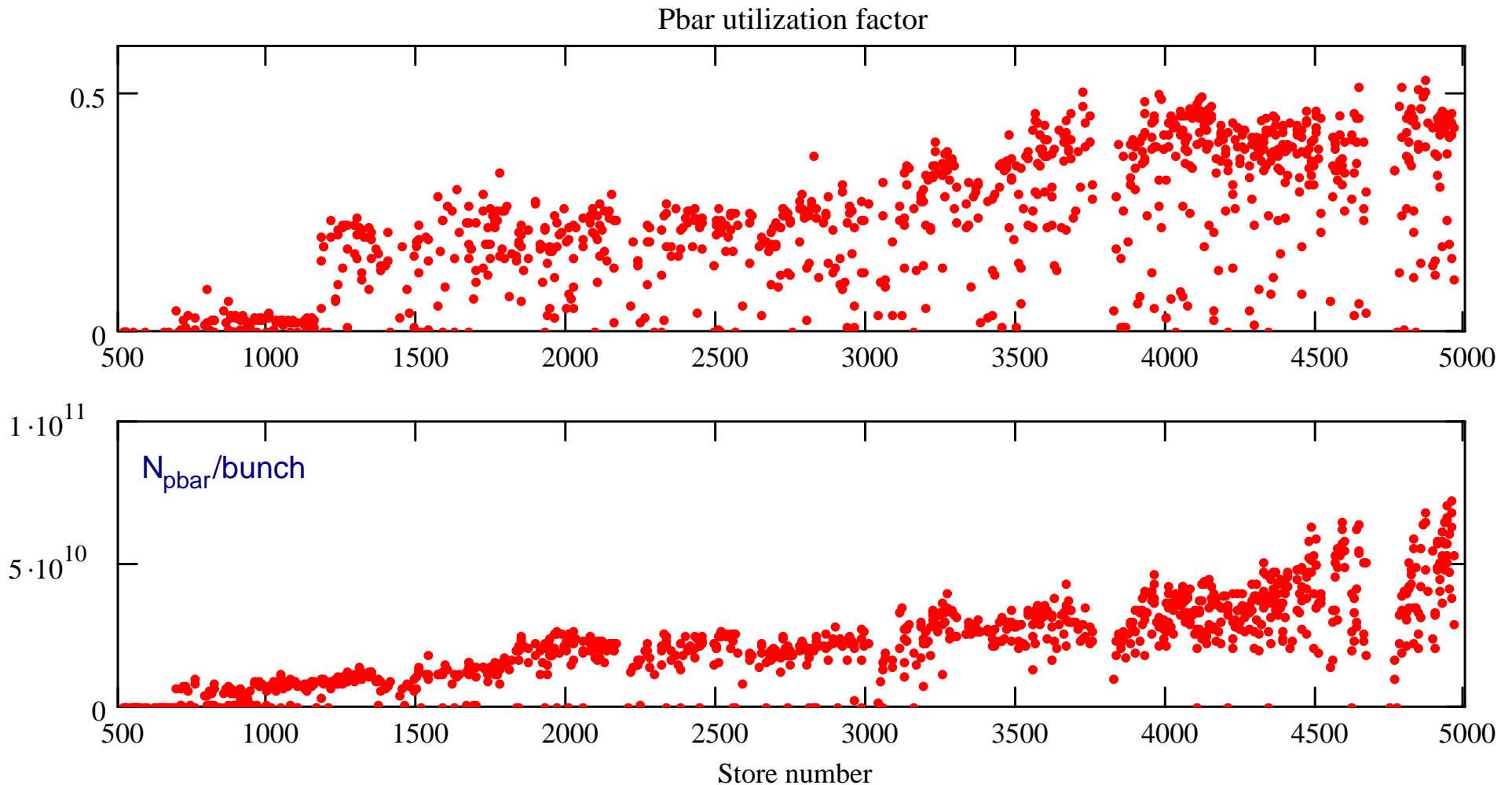⇒ **Fast transfers from Accumulator to MI**

- Maximum gain is expected from

  Smaller antiproton loss at transfers

  Less time spent for transfers

♦ **Tevatron improvements**

  New working point

Present Tevatron performance

## Antiproton utilization factor

Pbar utilization factor

In good (long) stores we burn more than 50% of pbars injected to Tevatron

- Helix improvement in Tevatron resulted in 20% improvement of luminosity integral
  - Better beam separation (near parasitic collisions)
  - Significant reduction of beam-beam effects

Beam separation near IPs (in σ's)

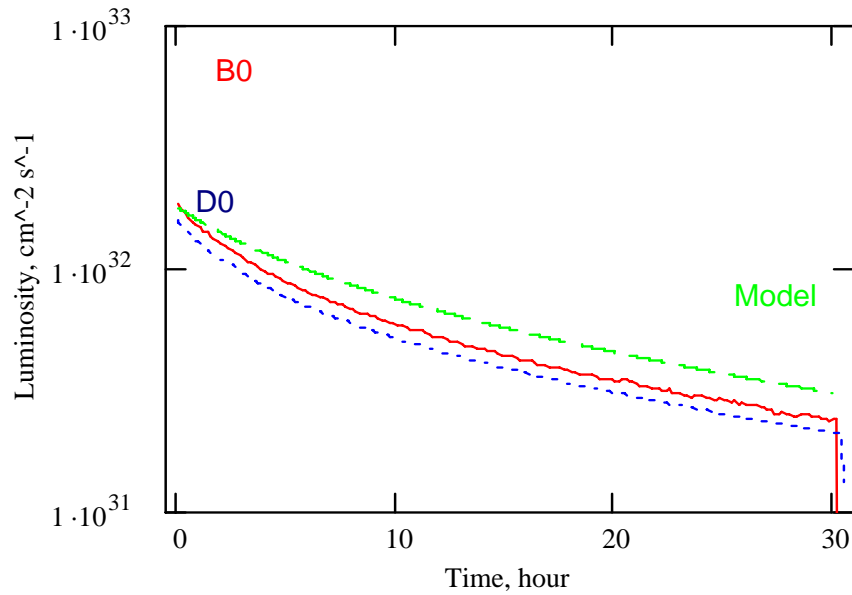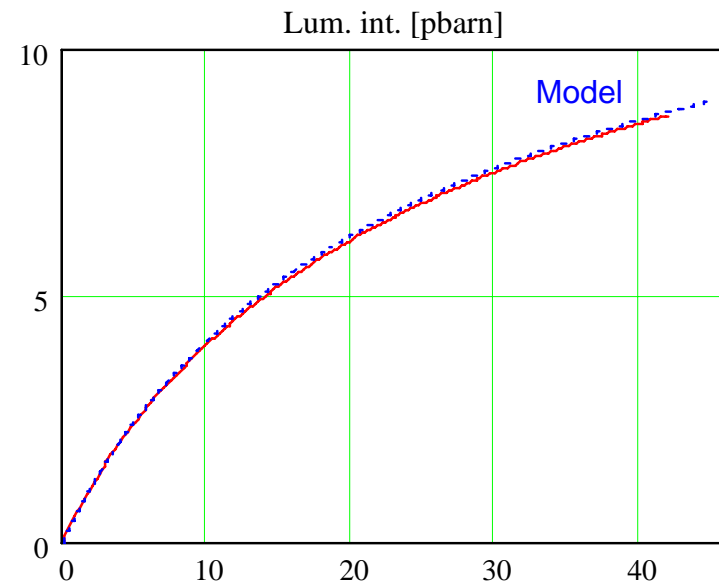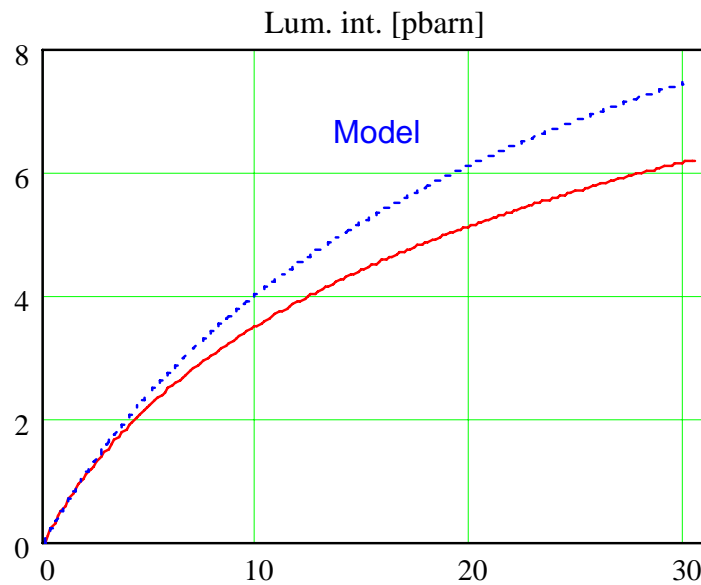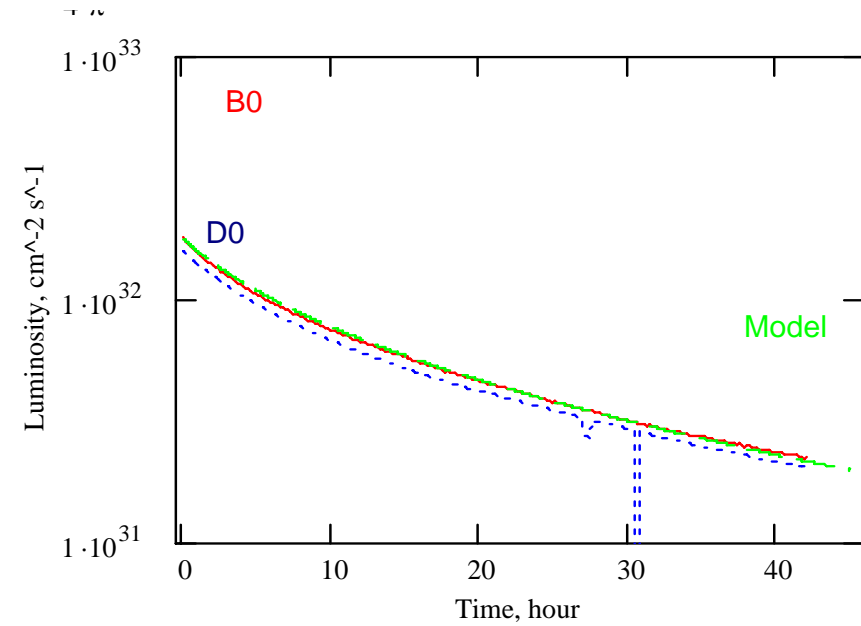|	B0 US	B0 DS	D0 US	D0 DS
Before	5.4	5.6	5.0	5.2
After	6.4	5.8	6.2	5.6
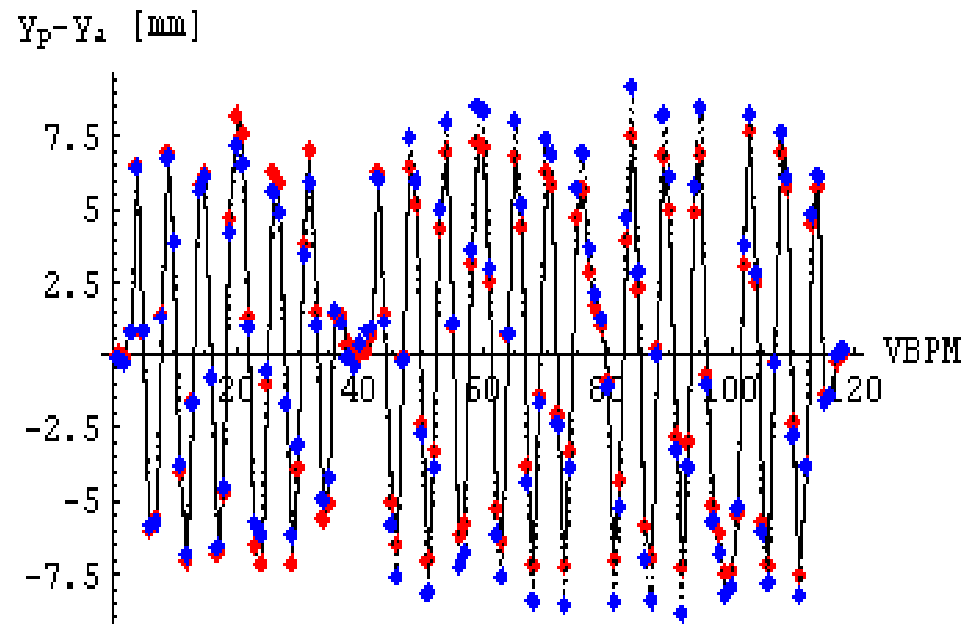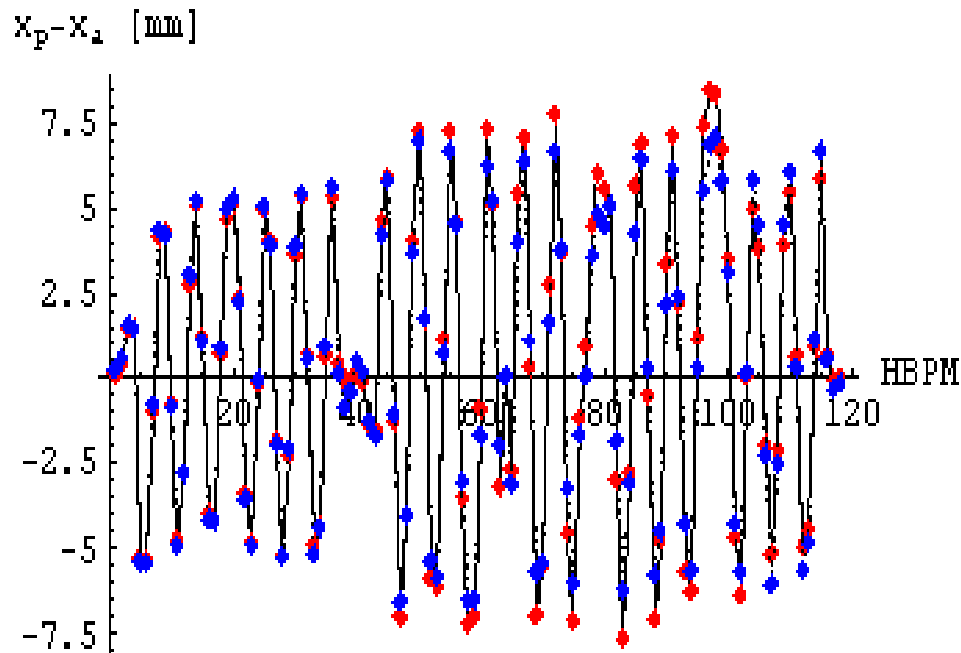
Changes in beam separation-after shutdown[‡]
Red – full separation now (with A17H and B48V separators), blue – before (double the proton helix).

Store 4581

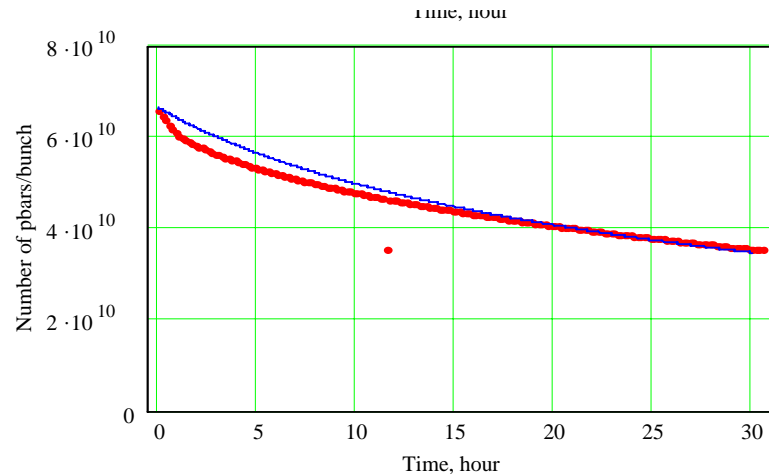# Store 4859

Lum. int. [pbarn]
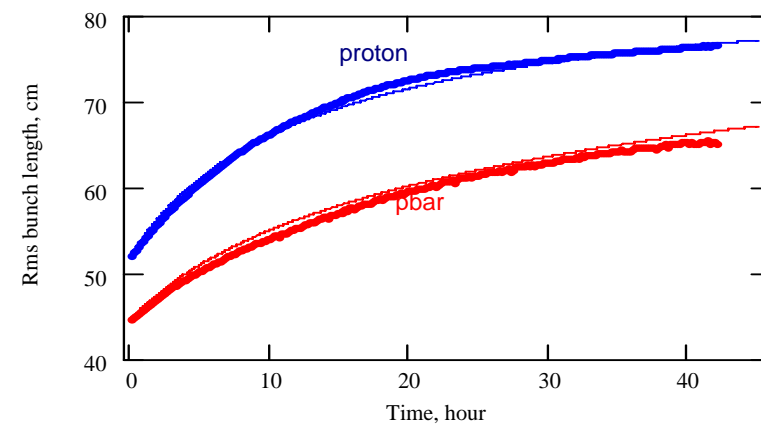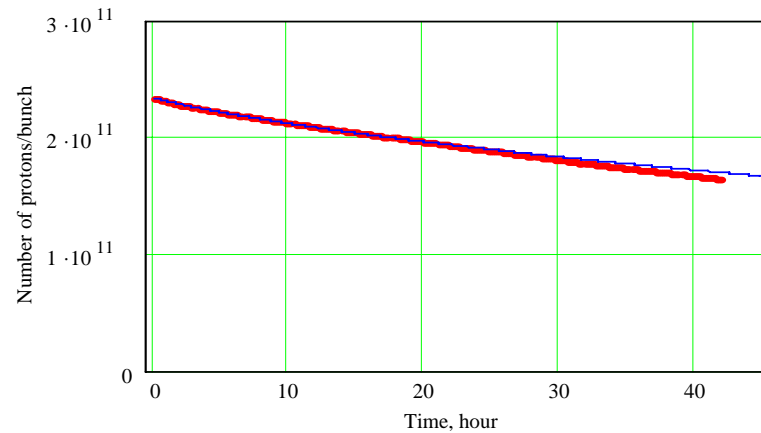

Lum. int. [pbarn]

Before shutdown (Jan. 6, 06)

After shutdown (July. 27, 06)

Store 4581
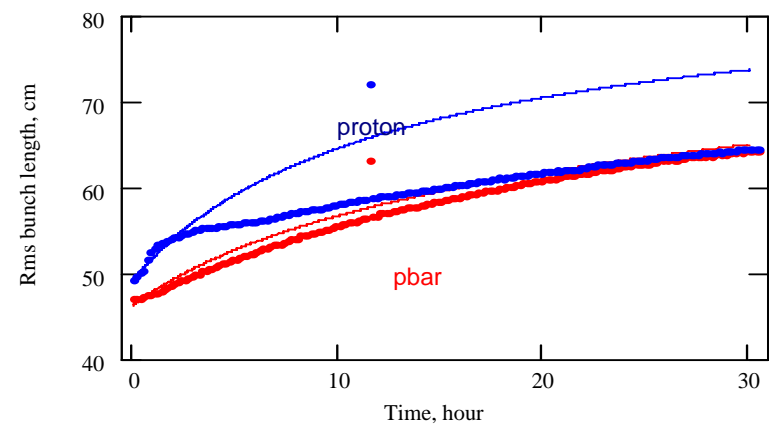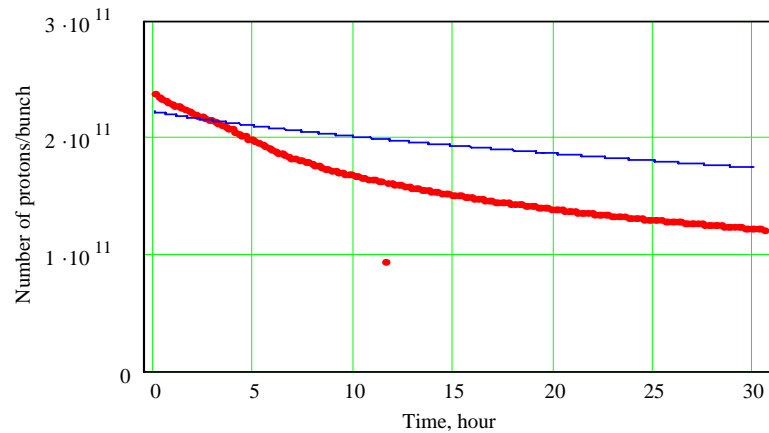
Store 4859
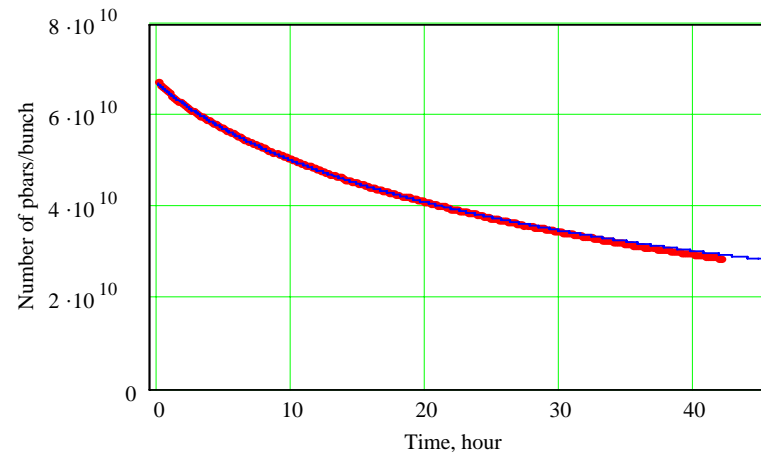
Model parameters

- Cross-section of nuclear interaction in IPs   -   69 mbarn
- Beam life-time due to interaction with res. gas   -   480 hour
- Spectral density of RF phase noise   - $4.2 \cdot 10^{-11}$ rad^2/Hz
- Amplification factor of IBS   -   1.3 (?)

The same parameters are used to estimate the luminosity integral for future (end of upgrade) stores; But

- Beta-function in IP   -   31 => 28 cm
- Number of protons per bunch   - $2.3 \cdot 10^{11}$ => $2.7 \cdot 10^{11}$
  - That implies new working point
- Proton $\perp$ emittance stays the same   -   18 mm·mrad
- Antiproton $\perp$ emittance   -   13 => 15 mm·mrad
- Longitudinal emittances stay the same
  - ♦ Proton rms momentum spread at HEP   - $1.22 \cdot 10^{-4}$
  - ♦ Antiproton rms momentum spread at HEP - $1.07 \cdot 10^{-4}$

- Since end of August this model is applied for analysis of each store and results are available on the web

Why protons experience stronger beam-beam effects

$$\nu_0 = 0.578$$
$$\xi_1 = 0.01$$
$$\xi_2 = 0.01$$
$$\sigma_s = 0$$
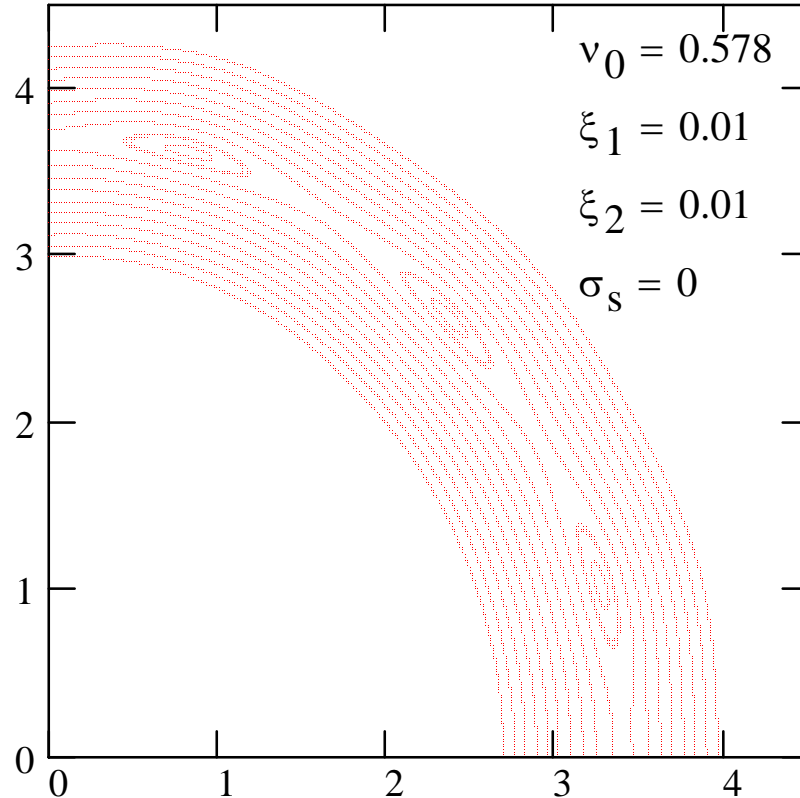
Phase trajectories in vicinity of 12-th order resonance $\nu_x = 7/12$; two Tevatron IPs but zero length of counter-rotating bunch, and zero synchrotron motion amplitude

■ **Resonance overlap strongly amplifies diffusion**

5 E_{pbar}

f_p

E_p

5 f_{pbar}

r / σ_p
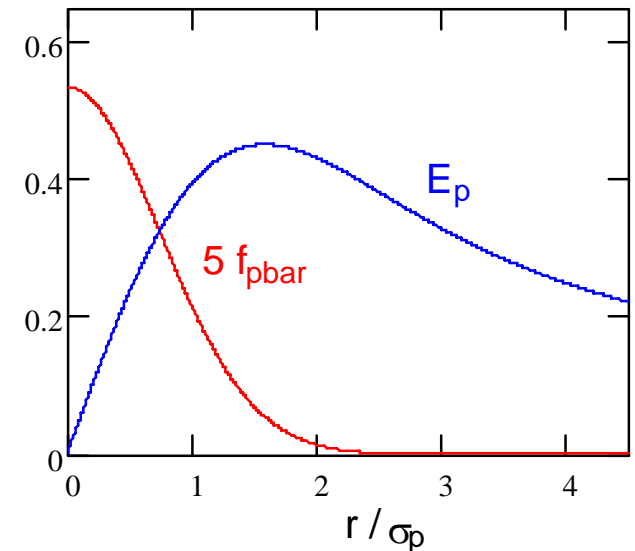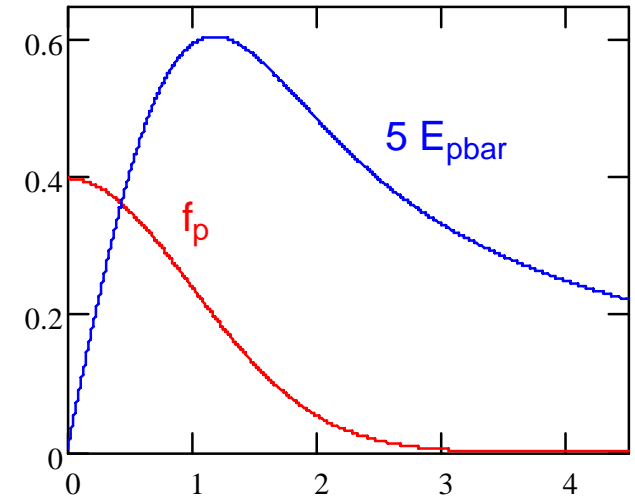
$\varepsilon_p = 18$ mm mrad
$\varepsilon_{pbar} = 10$ mm mrad
$N_p / N_{pbar} = 5$

Tune Diagram[§]

$$\xi = \frac{N_p r_p}{4\pi\varepsilon_p} \approx 0.025$$

pbar

p

5th order resonances:

Q=3/5=0.600 –

EMITTANCE BLOWUP

12th order resonances:

Q=7/12=0.583 –

Bad lifetime

7th order resonances:

Q=4/7=0.571 –

HIGH LOSSES

Qx
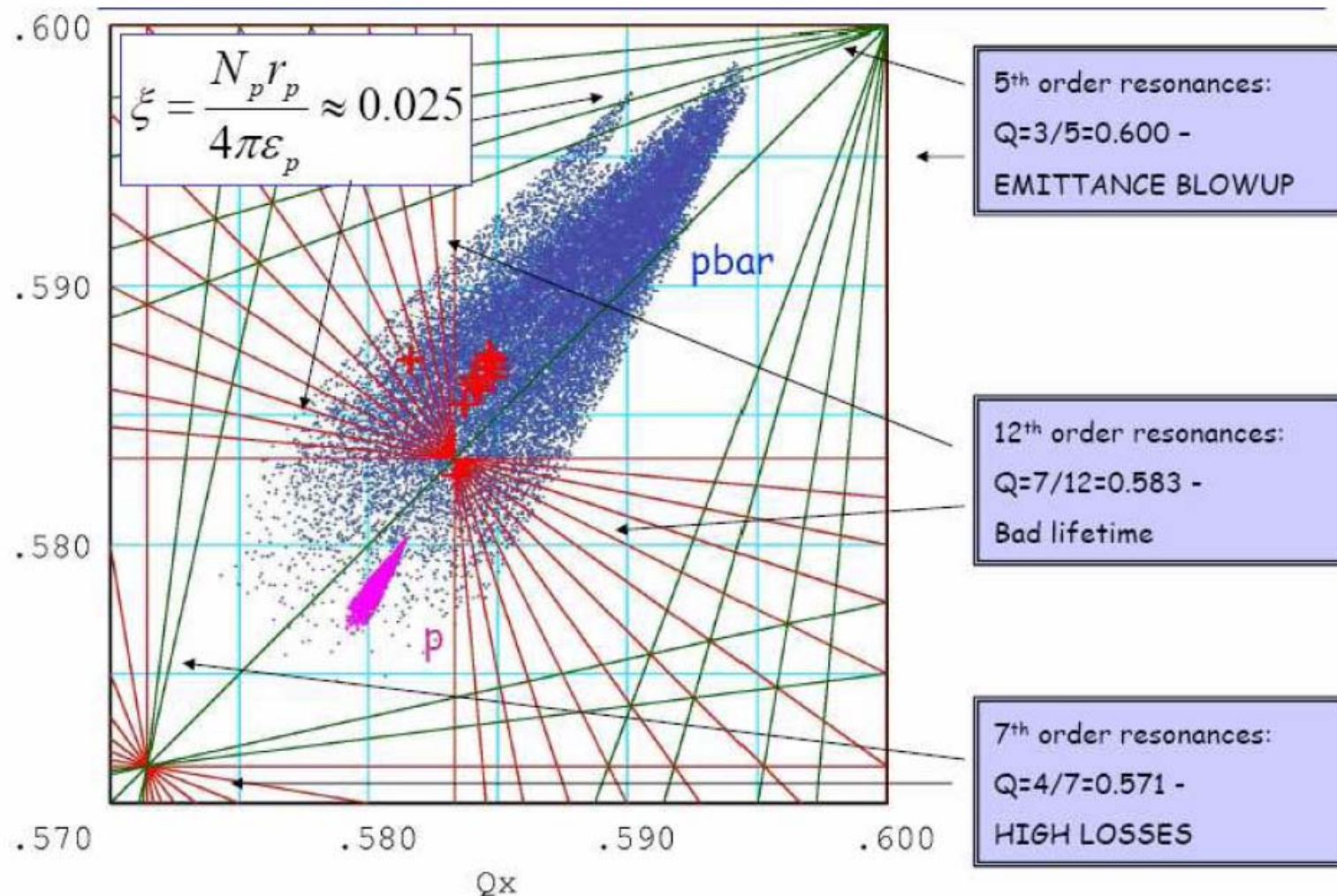
- **New tune monitor should be operational in 2-3 month**
  - ♦ Each proton and pbar bunch
  - ♦ Tickler is planned to be used to improve sensitivity

Long Range collisions[*]
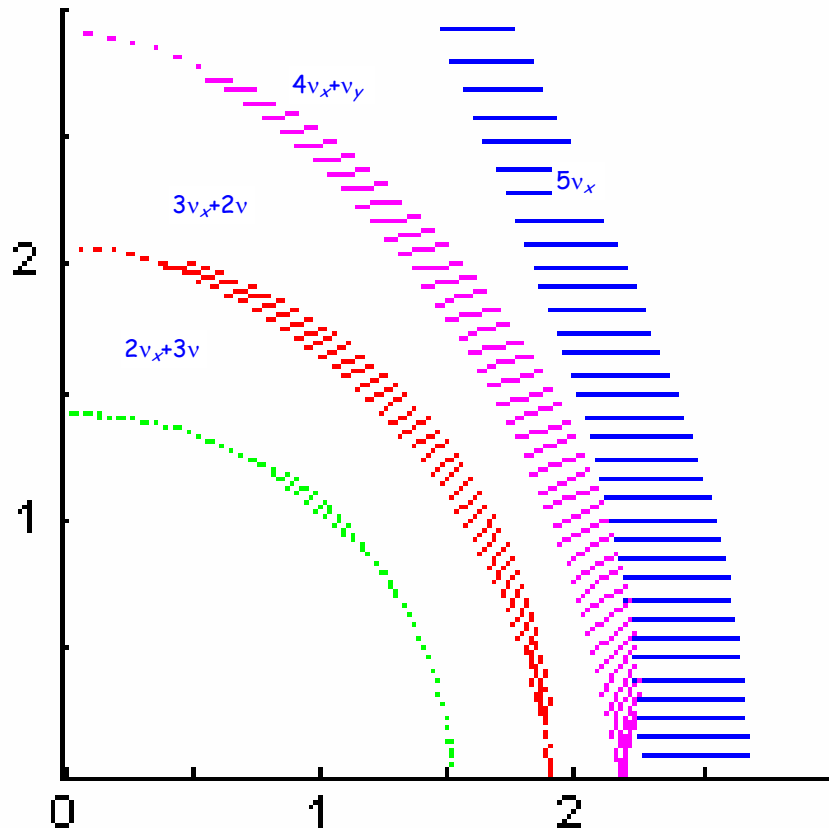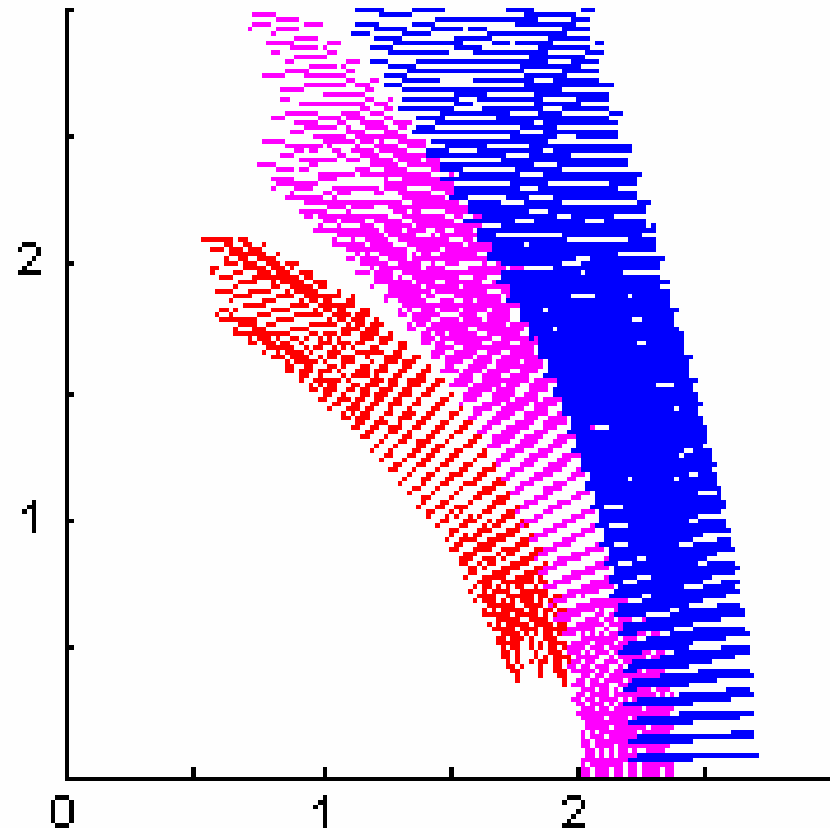
$\delta_p = 0$ $\delta_p = 1.25 \cdot 10^{-4}$

Swing of the normalized transverse amplitudes on the 5th order resonances and their synchrotron satellites at synchrotron amplitude $\delta_p = 0$ (left) and $\delta_p = 1.25 \cdot 10^{-4}$ (right), lattice chromaticity is zero, $\nu_x = 20.585$, $\nu_y = 20.575$.

[*]*Courtesy of Yu. Alexahin, DoE review 2003*

Dependence of luminosity on Store time

Luminosity [e32 /cm^2/s] vs Time of a store

- Average luminosity*3
- Peak luminosity
- 34.5
- 2.3

Np in Recycler [e10] vs Time of a store

- 34.5
- 325
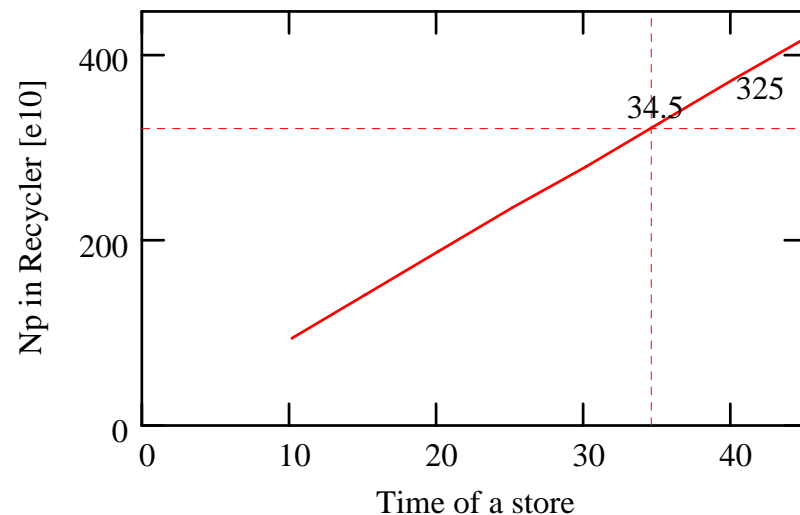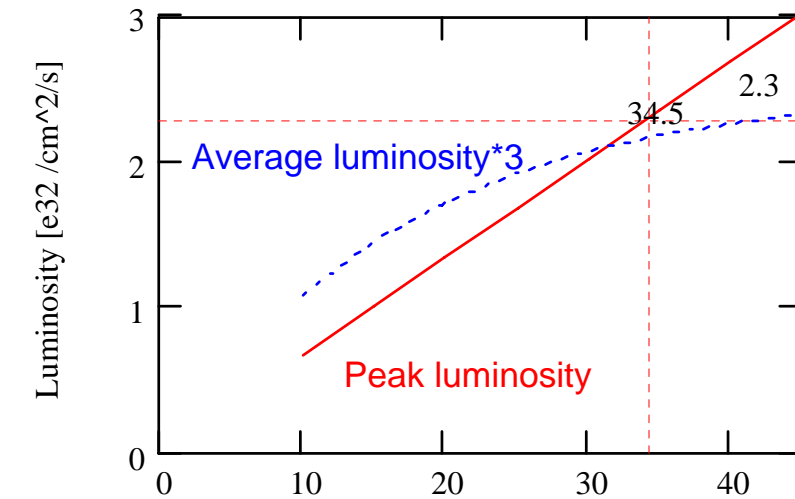
Present pbar production rate of ~7.5 mA/hour (average for Tev. at 150 GeV). Beam-beam effects are not taken into account

Number of protons/bunch vs Time, hour

Number of pbars/bunch vs Time, hour
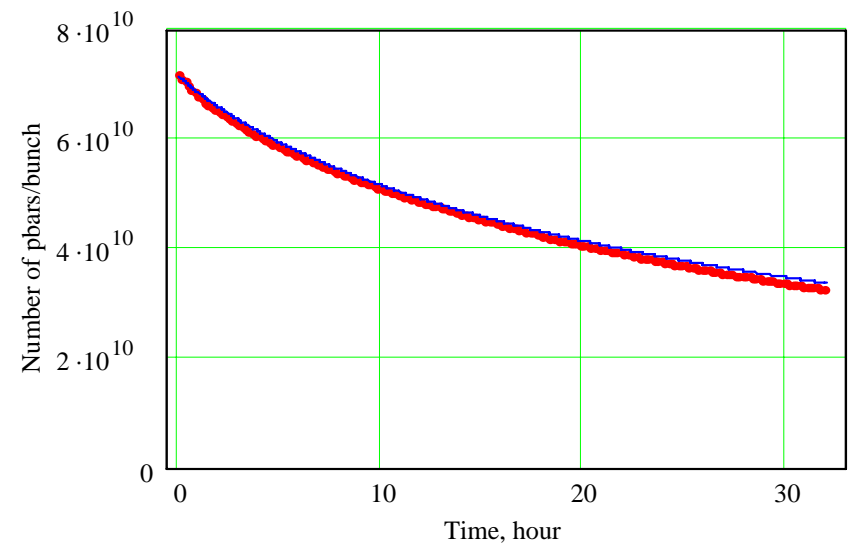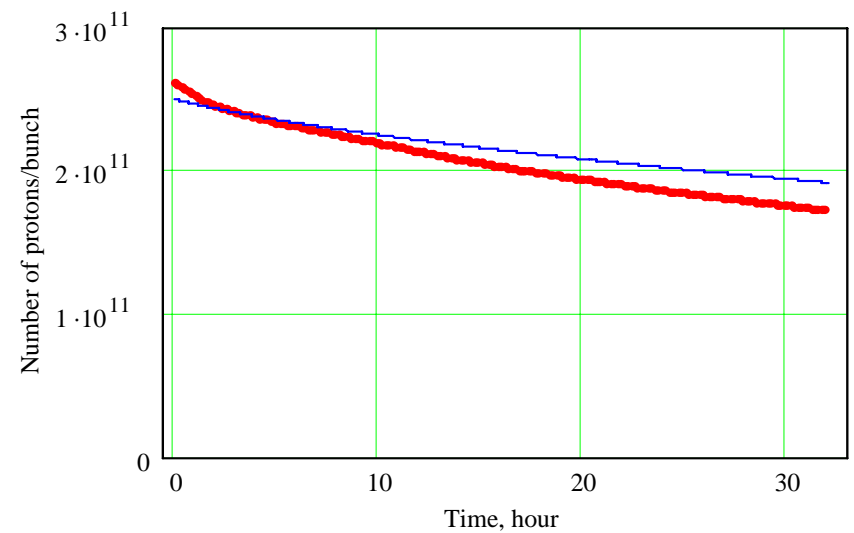
- Beam-beam effects affect protons for store 4949 causing 5% loss of luminosity integral
- 30-35 hour store time looks optimal for present Tevatron performance!!!

Future Tevatron performance

Change of collider tunes

- New working point should allow 40% larger tune spread
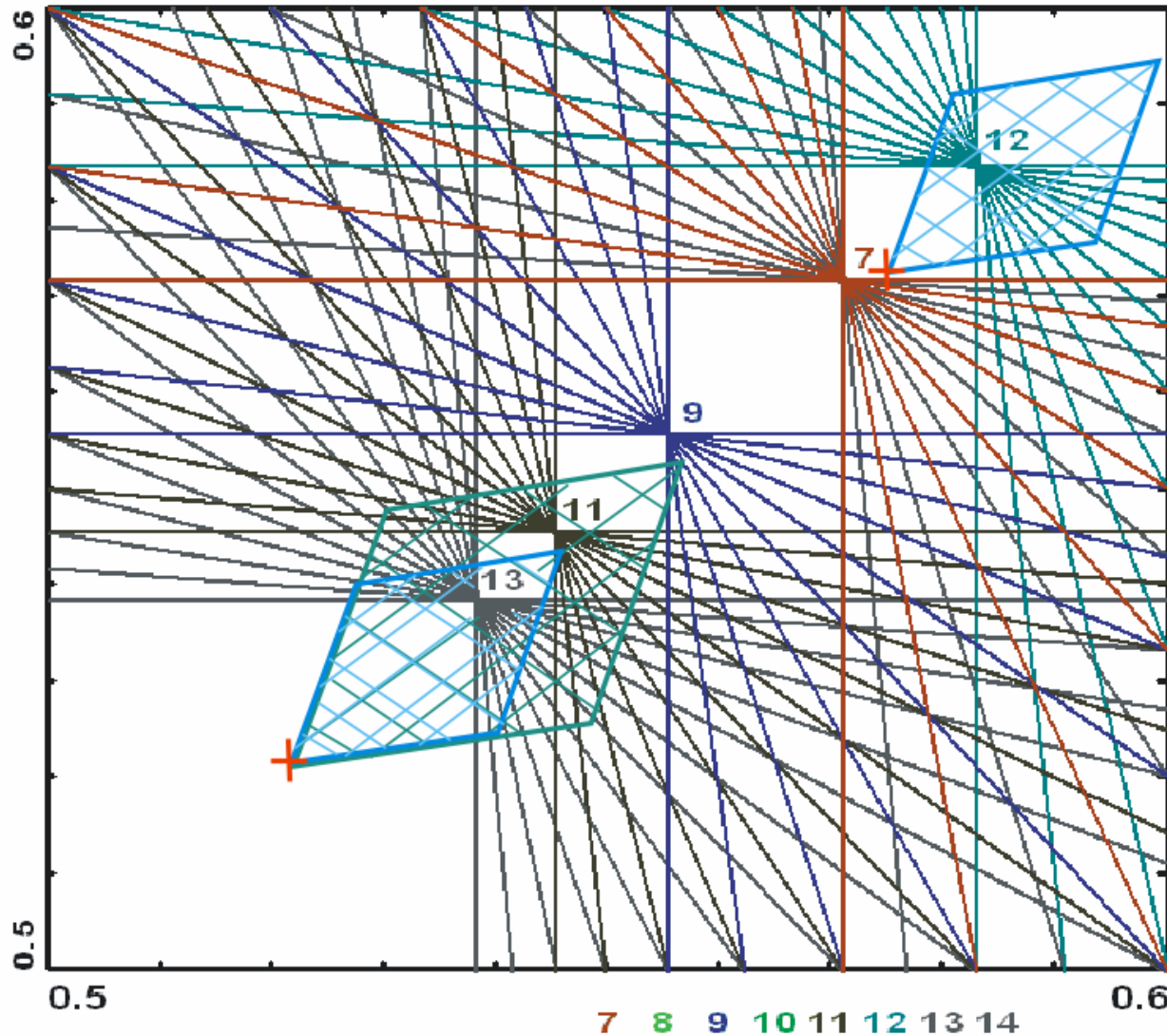
- Higher sensitivity of linear optics to quad strengths and orbit variations (feeddown effect from sextupoles)
- Reconnection of sextupoles to suppress 2-nd order chromaticity!!!
- Further improvements of the model and more detailed simulations are on the way

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

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Chromaticity of beta-functions
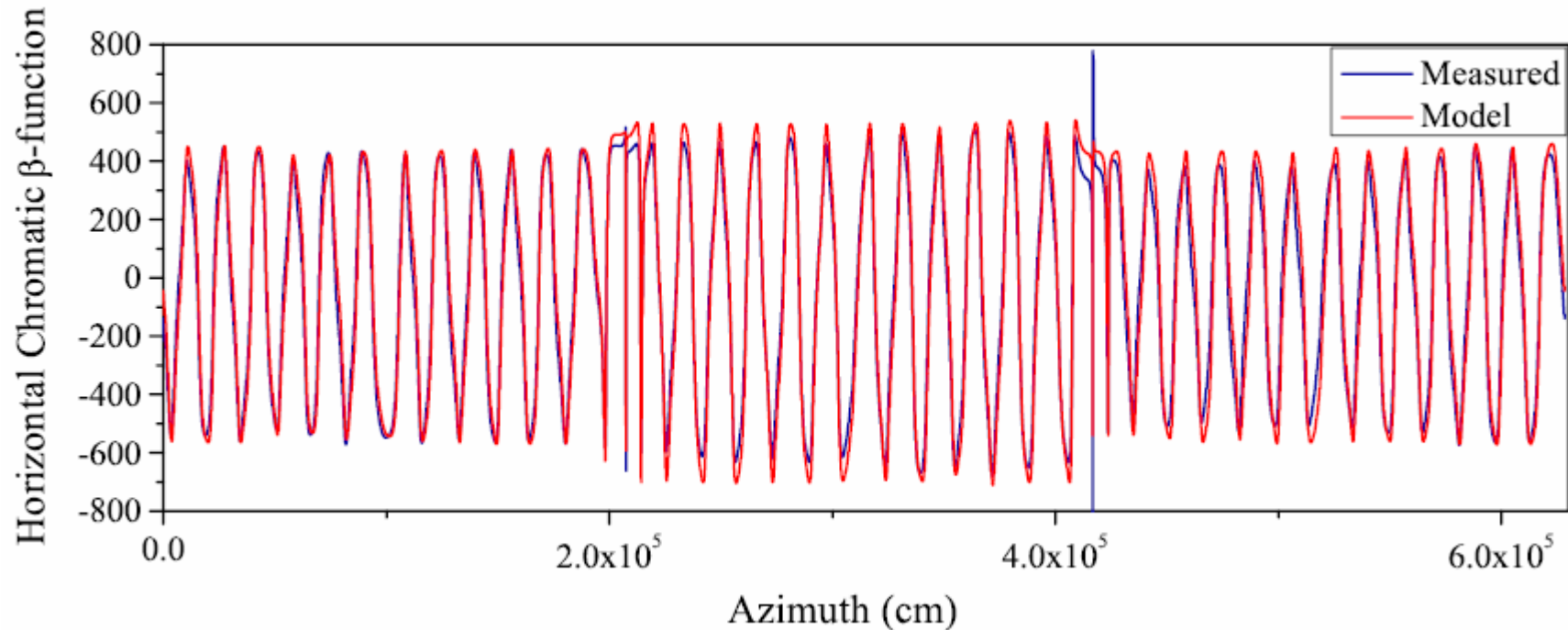
- **Beta-function chromaticity at present tunes**
  - ◆ Present WP
    - • Bucket height – $\Delta p/p = 4.5 \cdot 10^{-4} \Rightarrow \Delta\beta/\beta \sim 600 * 4.5 \cdot 10^{-4} = 0.28$
  - ◆ New WP (if not- compensated)
    - • 0.28*4=1.12 (lost stability)
- **New sextupole circuits will compensate the beta-function chromaticity**
  - ◆ Power supplies will be ready in October
  - ◆ First tests are planned at present tunes

Beam-beam Effects at New and Present Tunes for 30% more p's[**]
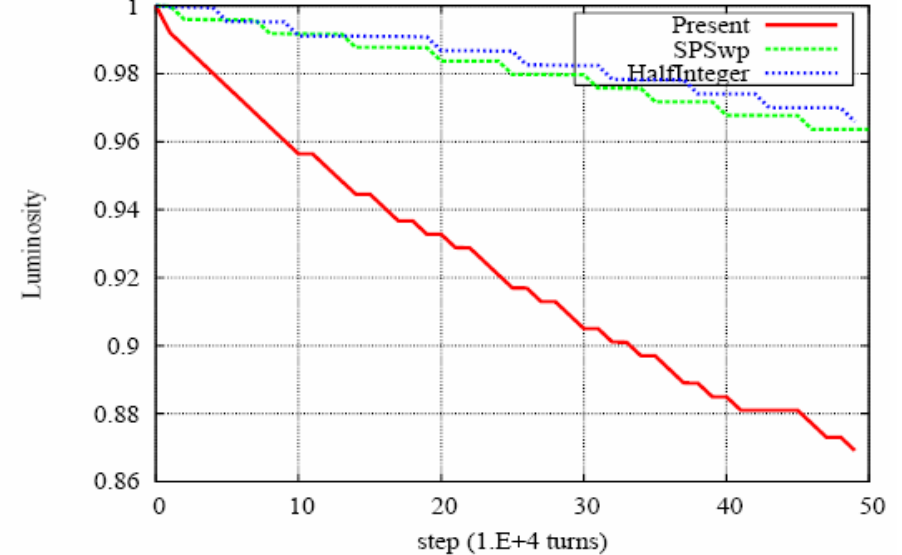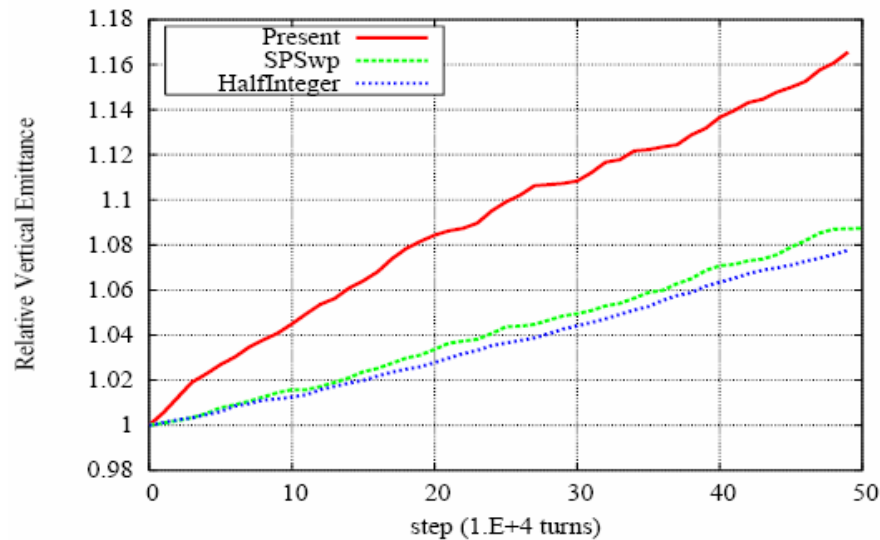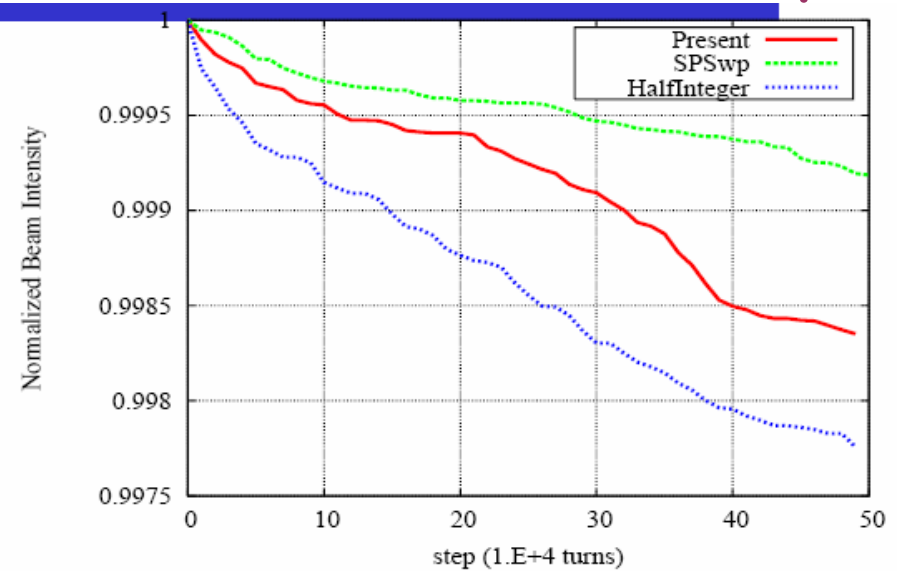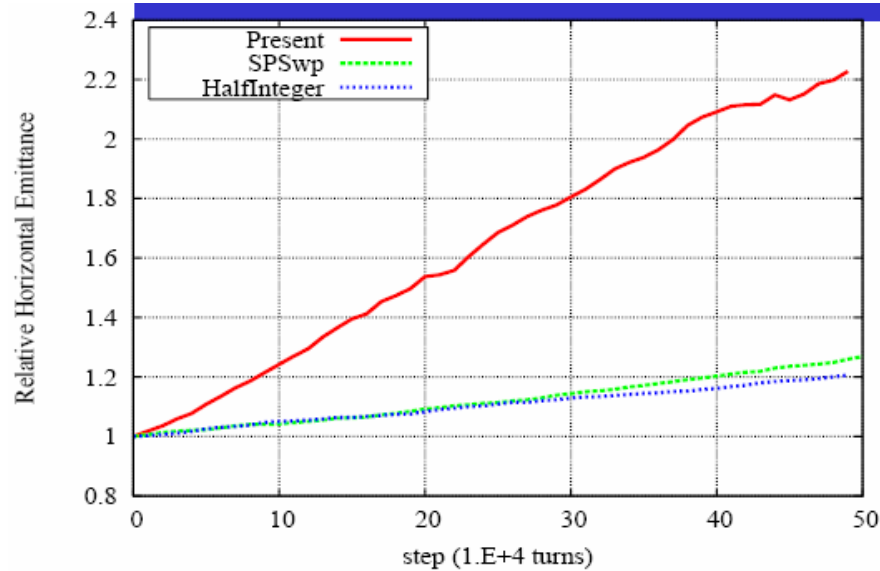
Weak-strong simulations, pbar bunch 6; ε_p=18, ε_{pbar}=12 mm mrad, Np=3·10[11]

♦ **Simulations show little difference for present proton intensities**

Results of Model prediction
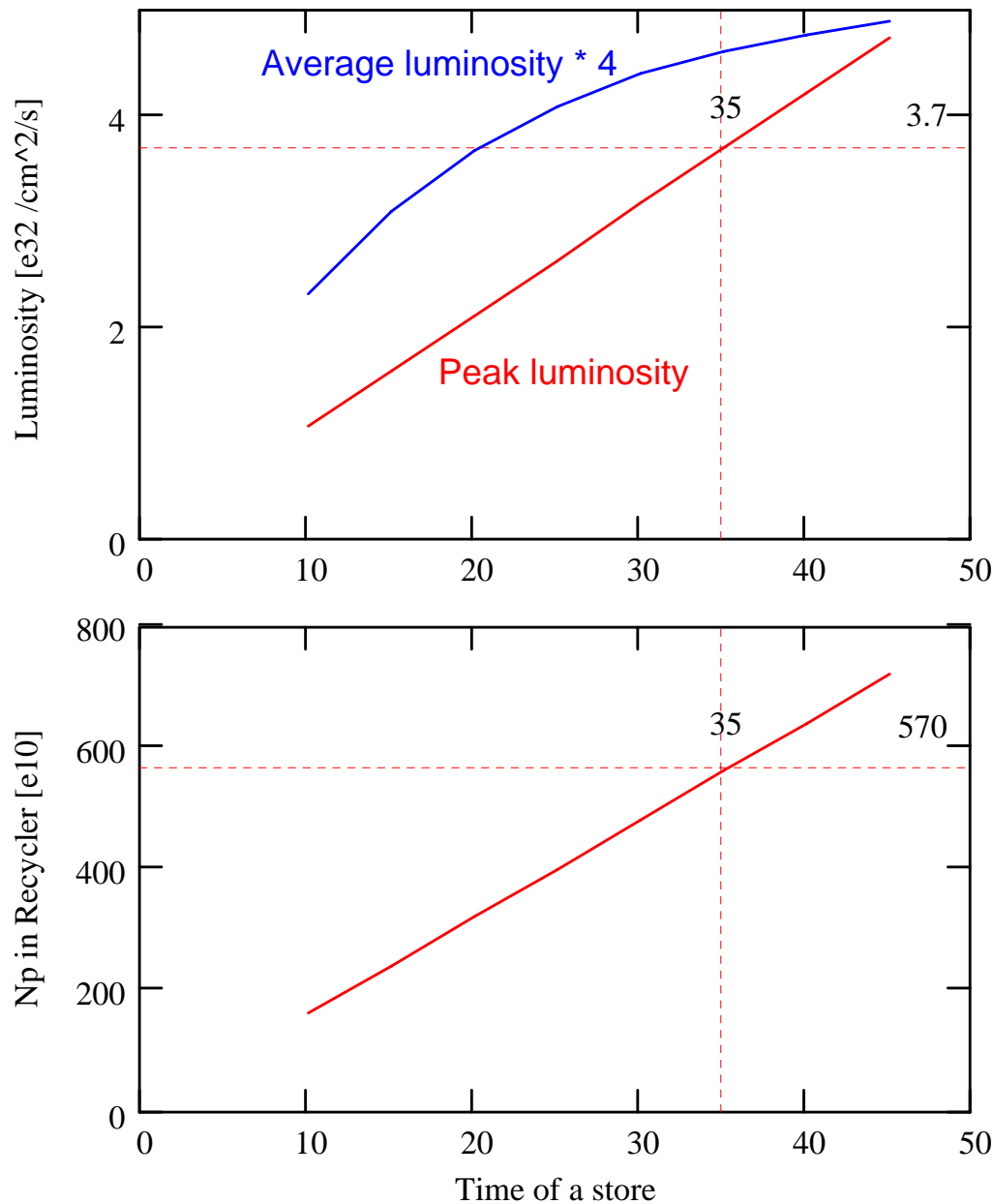
We assume:

- Average pbar product. rate in Recycler – $16 \cdot 10^{10}$ /hour
- Efficiency of Recycler to HEP - 0.8
- 2 hour shot setup
- Store time 35 hour
- 130 hour store time per week

That yields

- Pbars per bunch – $1.25 \cdot 10^{11}$
- Peak luminosity – $3.7 \cdot 10^{32}$
- 15 pb^{-1} per store
- 58 pb^{-1} per week
- 2.3 fb^{-1} per 10 month
  - ◆ Model does not take into account negative effect of prematurely lost stores

Conclusions following from the luminosity evolution model

- **Longer stores are preferable**
  - Limitations come from
    - Recycler (emittance growth and beam loss for large stash)
    - Limitation of pbar intensity in Tevatron are already visible (poor proton lifetime)
    - Operational prudence – if you lose a store you lose a lot of pbars
- **Mitigating of beam-beam effects has profound effect on the luminosity integral**
  - New tune has ~40% larger tune space
  - Protons per bunch should grow up at least 17% ($2.3 \cdot 10^{11}$ => $2.7 \cdot 10^{11}$) that yields the luminosity growth of 11% (35 hour store)

Tevatron plans

- **Increase number of protons**
- **Be ready to accept 2 times more antiprotons**
- **Concerns are**
  - Beam-beam effects (New working point will be pursued?)
  - Beam stability
  - Beam loss

Luminosity Leveling

- Any luminosity leveling results in reduced luminosity integral
- (1) Smooth (multi-step) beta-function changes during the store is close to impossible to implement in operations
- (2) One step beta-function change looks promising
    - Significant time for commissioning
    - More complicated operations – larger probability to lose the store. ~1 min stop for data acquisition beta-function change
- (3) Reduced store duration
    - change Tevatron tunes introduce minor (~2-3%) improvement
        - More protons
        - Less pbars – faster burn rate for the same luminosity
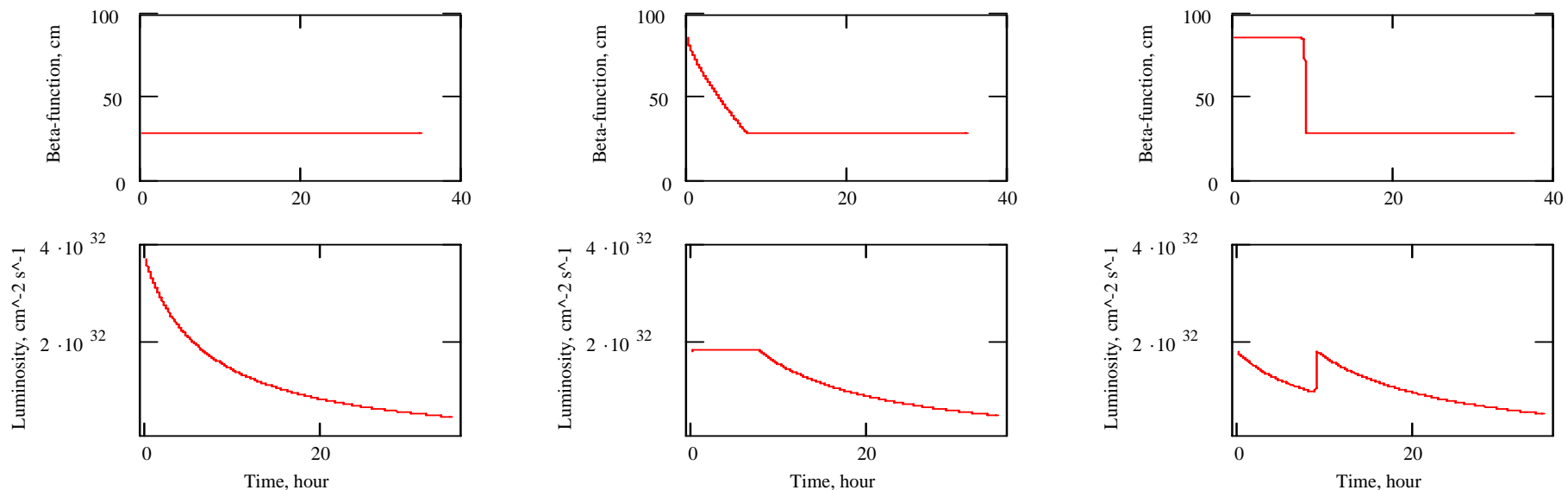
Luminosity leveling (continue)

	Maximum Luminosity scenario	Smooth β-function leveling	2 step β-function leveling	Reduced store time		
				at present WP	at new WP	at new WP + large Np
L_{peak}, 10^{32}	3.68			1.8		
Store time, h	35			15.7	13.5	12.3
$\int Ldt$, fb^{-1}/year	2.35	2.19 -6.5%	2.03 -13.5%	1.67 -29%	1.67 -29%	1.71 -27%
N_p	$2.70 \cdot 10^{11}$			$2.50 \cdot 10^{11}$	$2.70 \cdot 10^{11}$	$3.20 \cdot 10^{11}$?
N_{pbar}	$1.25 \cdot 10^{11}$			$5.58 \cdot 10^{10}$	$4.80 \cdot 10^{10}$	$4.37 \cdot 10^{10}$
ε_p, mm mrad	18			18	18	20
ε_{pbar}, mm mrad	15			10	8	8

We assume:

- ◆ Average pbar production rate in Recycler – $16 \cdot 10^{10}$ /hour
- ◆ Efficiency of Recycler to HEP   -   0.8
- ◆ 2 hour shot setup
- ◆ 130 hour store time per week
- ◆ 10 month operation

For present and near future staking rates the reduced store time can be used for leveling with very little penalty

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 required

Protons on target, 1E12

days of FY2006
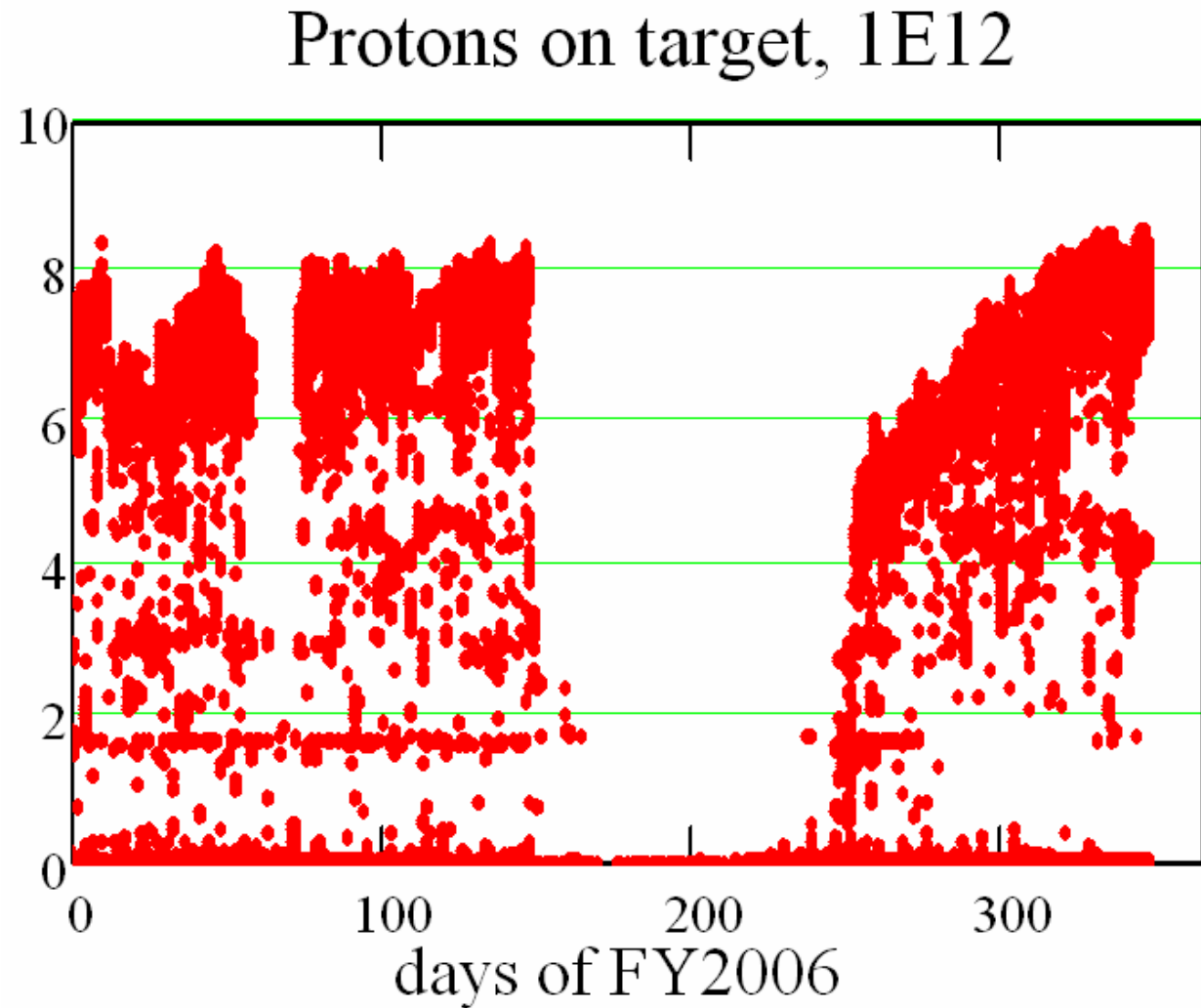
Pbar Coalescing Efficiency and Acceleration in MI and Tevatron

MI and Tevatron antiproton beam loss factors
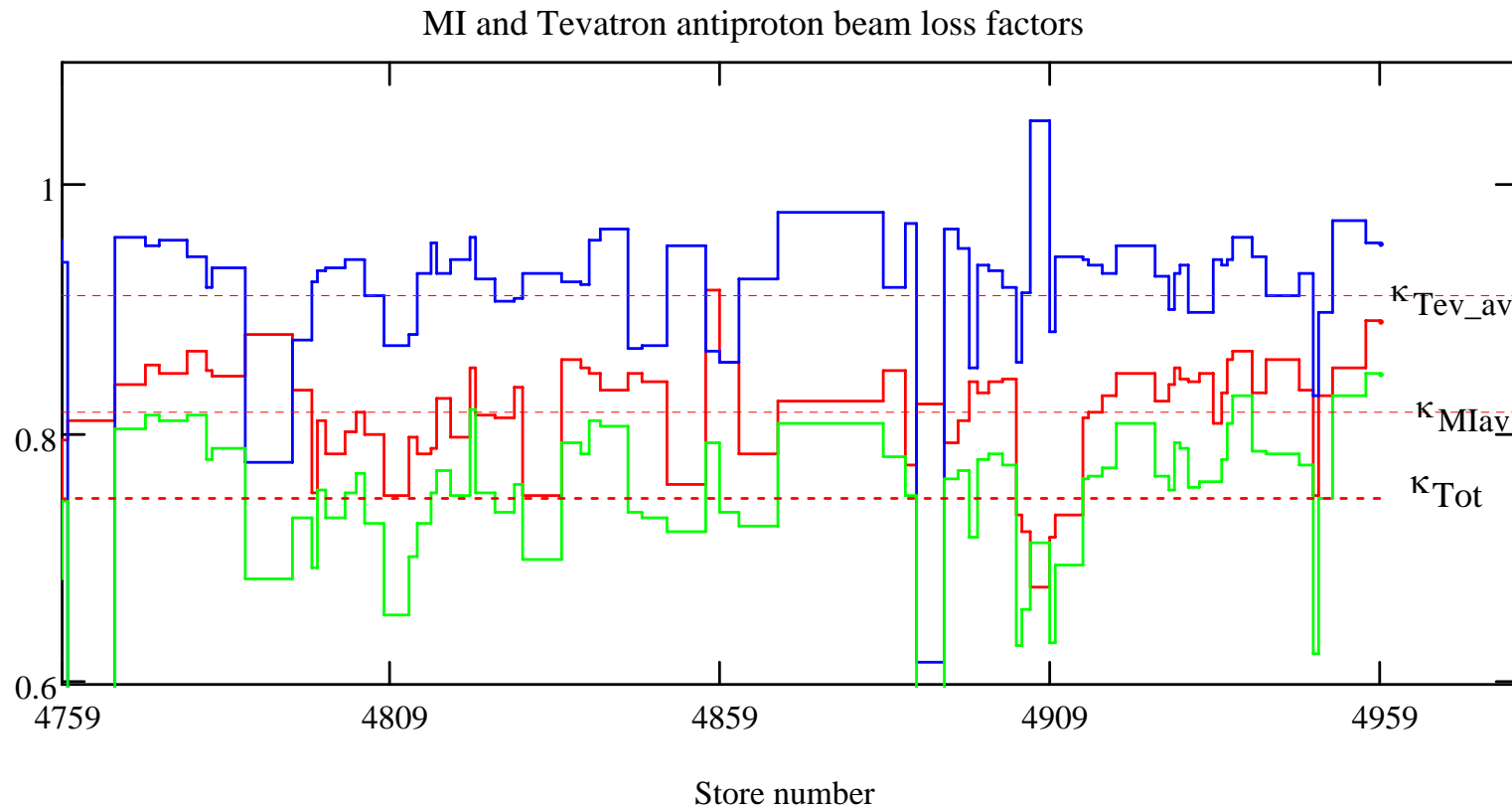
Pbar efficiencies for stores after 2006 shutdown

- There are 25% average pbar beam loss for Recycler-to-980 GeV transport
- Average MI acceleration and coalescing efficiency is ~0.82 while the best one has efficiency of 0.87 with $306 \cdot 10^{10}$ unstacked pbars (store 4859)
    - ♦ We need to understand what need to be done to make acceleration and coalescing more stable
- Improvements in pbar beam loss for Tevatron would be also helpful
    - ♦ Presently the average Tevatron efficiency is ~0.91

Recycler

- Recent improvements in luminosity came
  - New tunes (25.42, 24.425)->(25.455, 24.461)
  - New transverse damper
  - Optimized cooling procedure
- Lower $\perp$ and longit. emittances
- Smaller beam loss
- Present performance is close to the required final Run 2 performance
- Goals
  - Achieve – 600E10
    - Present – 420E10
  - Decrease loss at transfers
  - Smaller longitudinal emittance for better pbar coalescing

Recycler Long Emittance vs Stash Size
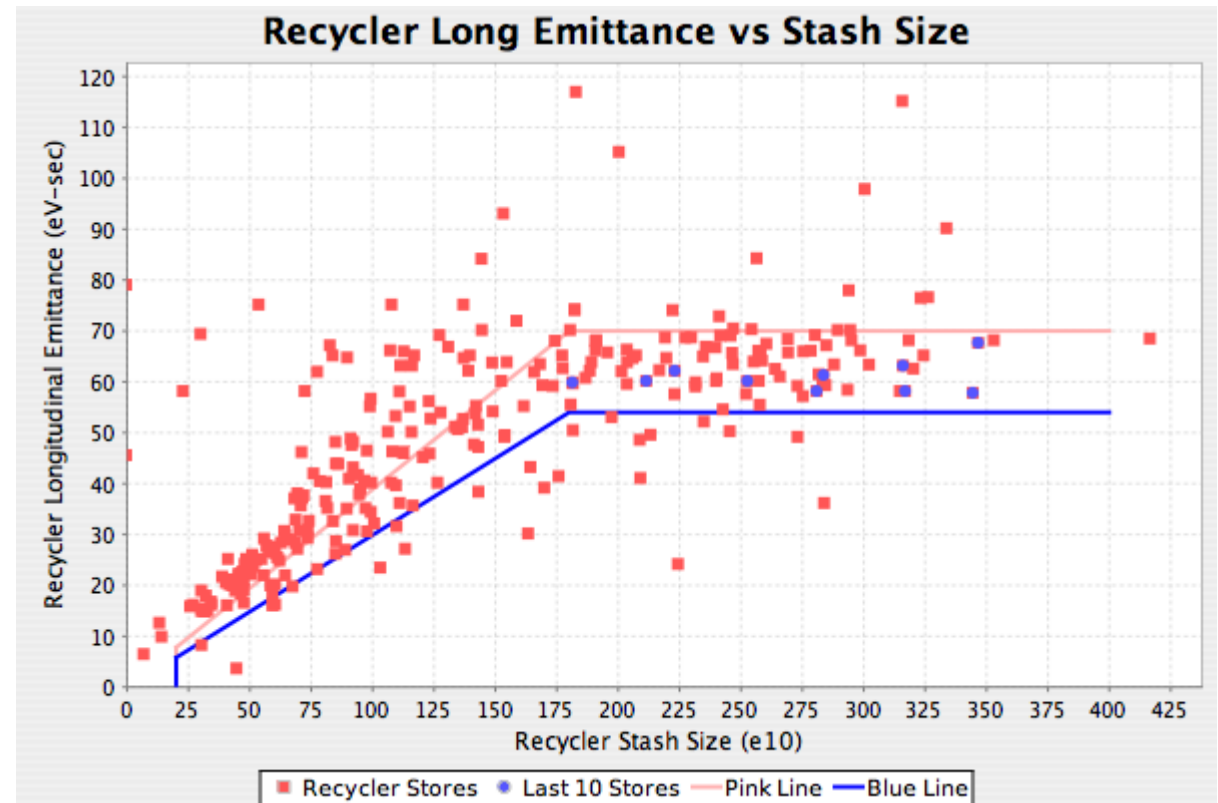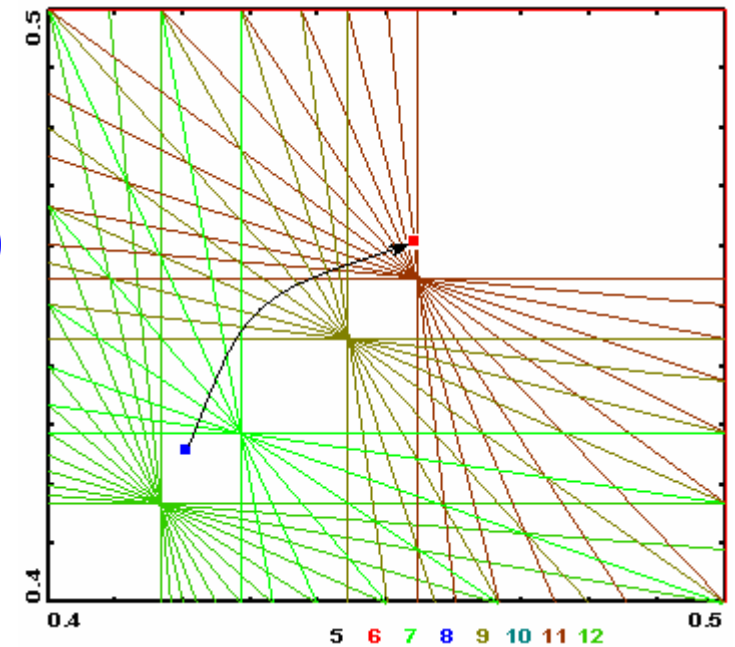
Antiproton source

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, 20
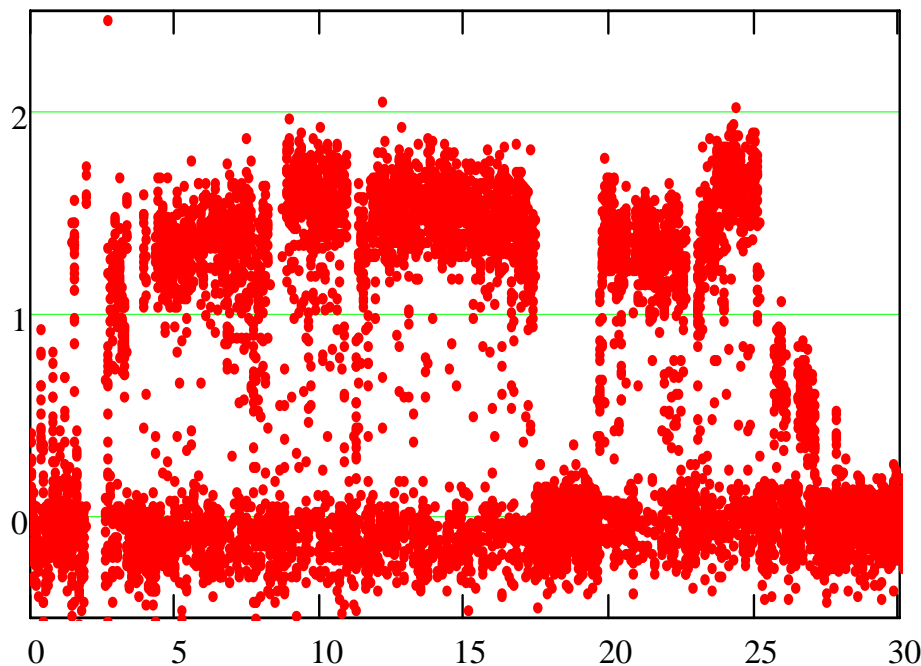
Time, days
30 days before shutdown
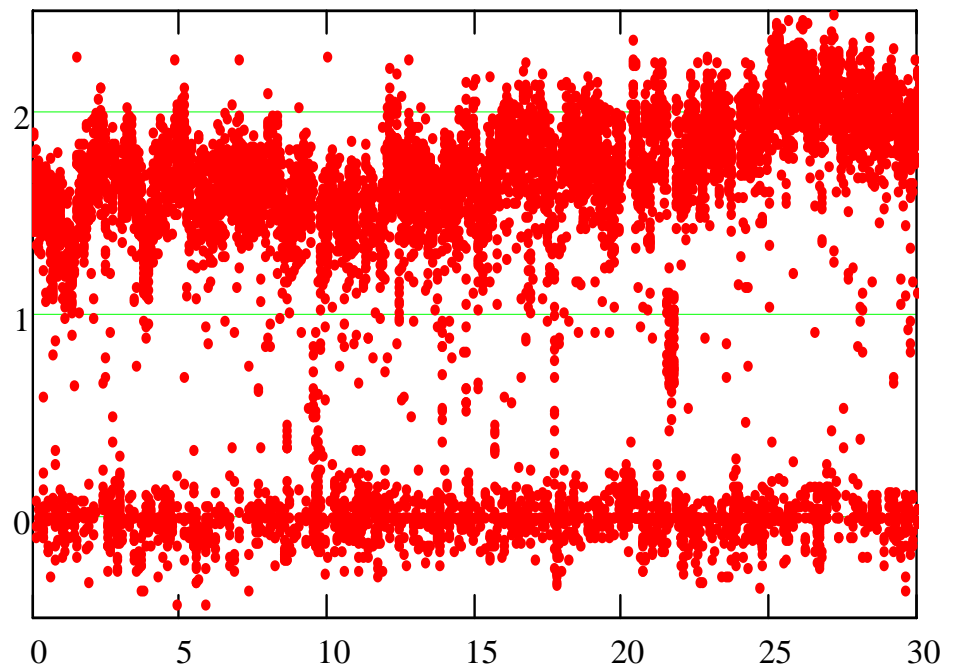
Time, days
Last 30 days

Antiproton yield to Debuncher
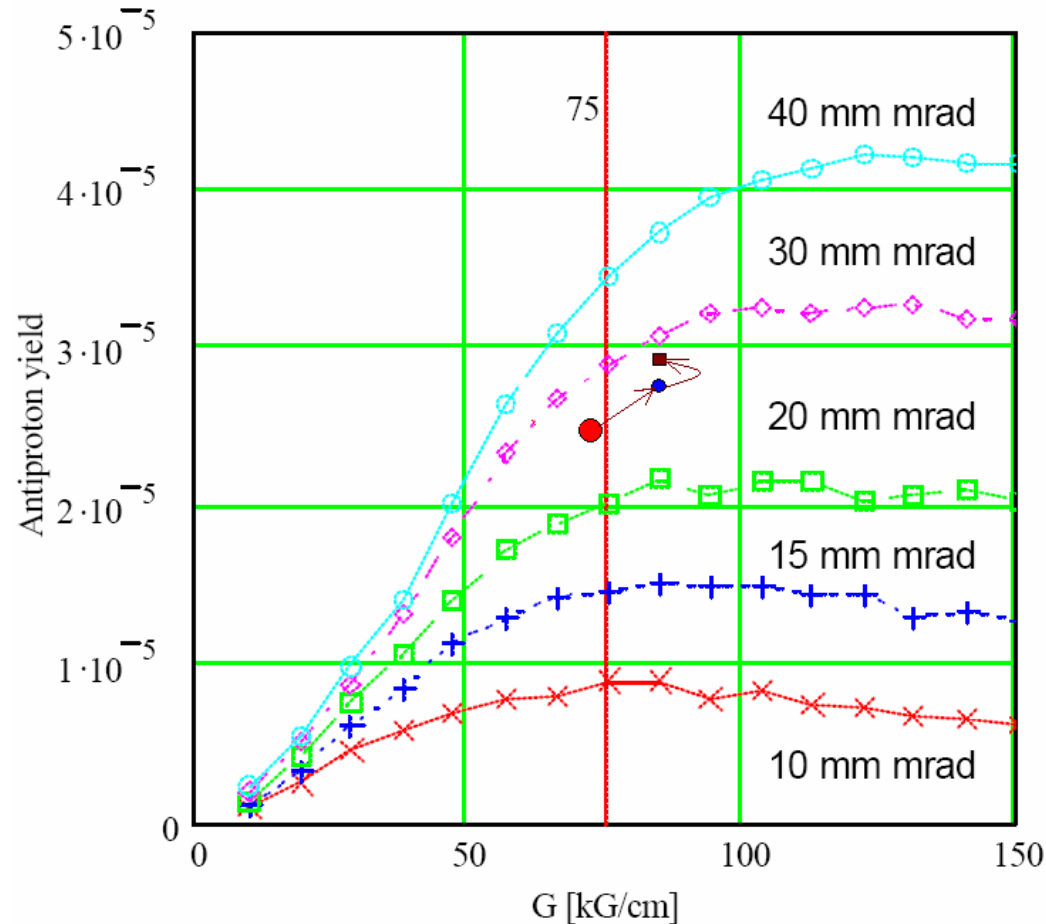
Dependence of Computed Antiproton yield on Debuncher acceptance and lithium lens gradient (2002)

■ For present Debuncher acceptance of ~33 mm mrad and lens gradient the computations yield $30 \cdot 10^{-6}$

■ Achieved stacking rate is 17% below calculated

  ♦ 3% - due to larger spot at target
  ♦ 10% - chromatic effects in AP-2
  ♦ ~4% - unknown (calc. accuracy?)

■ 15% increase in pbar yield is planned ($25 \cdot 10^{-6} \Rightarrow 29 \cdot 10^{-6}$)

  ♦ Lithium lens (up to 15%)
  ♦ AP-2 and Debuncher aperture (up to 10%)
    ● $\varepsilon = 33 \Rightarrow 37$ mm mrad

■ At 2.2 s cycle that would yield stacking rate of 38 mA/hour

Transverse Debuncher cooling

	Initial	Decrement	Base	at 2 sec
X plane:	32.508	0.719	2.06	3.946
Y plane:	40.884	0.811	2.508	5.762
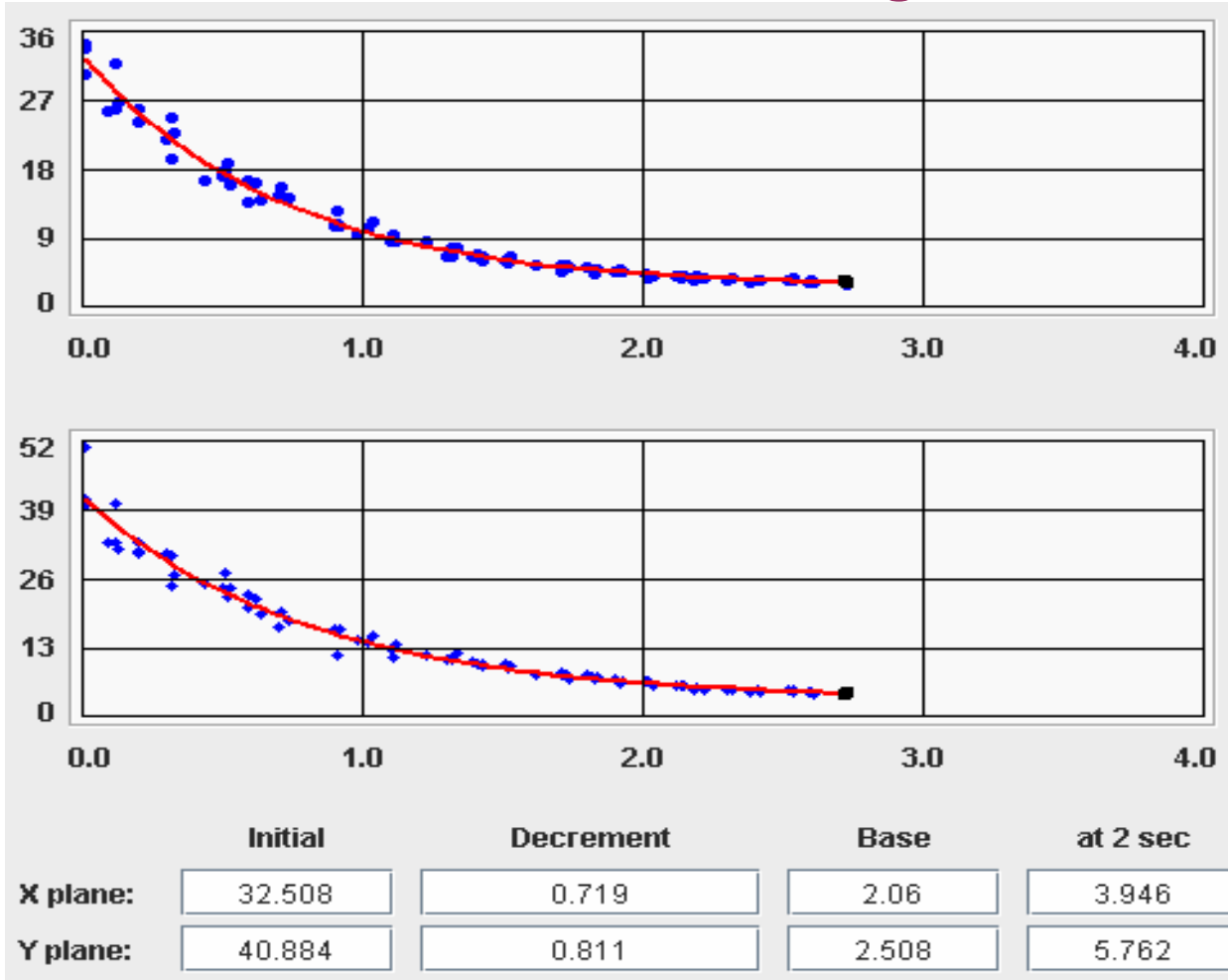
X & Y 95% emittances on time

- During 2 s we cool $2 \cdot 10^8$ pbars
  - ◆ to $\varepsilon_{H95\%}$= 4 mm mrad
  - ◆ and $\varepsilon_{V95\%}$=5.8 mm mrad

- To have negligible loss we need 4s acceptances (0.25% loss in 4D phase space) that would require accumulator acceptances
  - ◆ to $\varepsilon_{H95\%}$= 10.5 mm mrad
  - ◆ and $\varepsilon_{V95\%}$=15 mm mrad

Transverse Debuncher Cooling

- Transverse cooling determines beam loss for Debuncher-to-Accumulator transfers

- For small Accumulator acceptance there is some transfer loss but it is comparatively small (~8% for ε_{acc}=6.9 mm mrad) even for 2 s stacking cycle

- Thus, improvements of D-to-A line and Accumulator acceptances as well as the transverse cooling are desirable but shortening of the cycle to 1.8 – 2 s would be much more effective way to achieve highest stacking rate

Plot 1 (top right): Transfer efficiency vs Stacking cycle time, s
- $\varepsilon_{acp} = 11.7$
- $\varepsilon_{acp} = 6.9$
- $\varepsilon_{acp} = 9$

Plot 2 (bottom right): Stacking rate vs Stacking cycle time, s
- $\varepsilon_{acp} = 11.7$
- $\varepsilon_{acp} = 9$
- $\varepsilon_{acp} = 6.9$
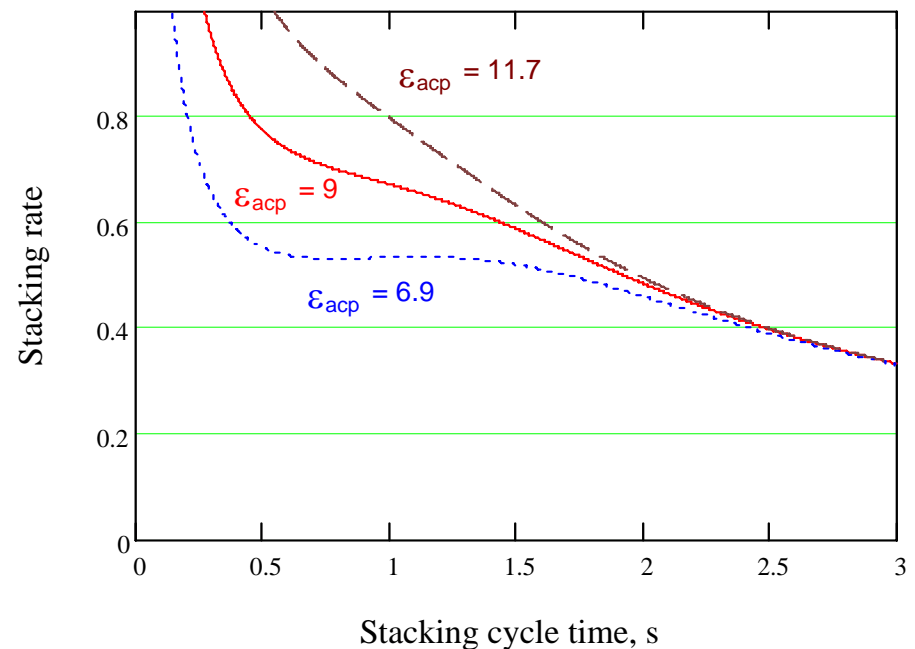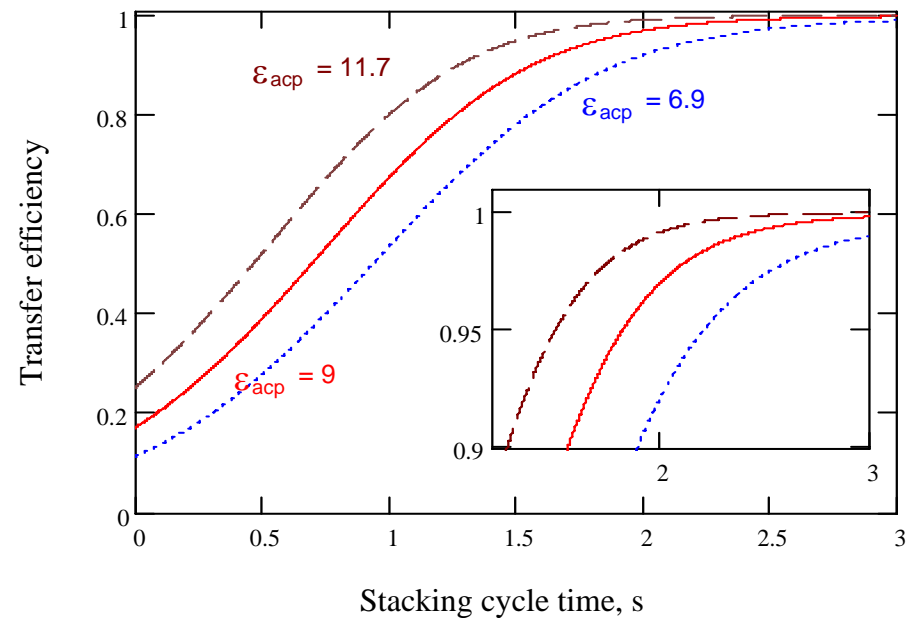
Pictures are built using cooling parameters of previous viewgraph

Longitudinal Debuncher cooling
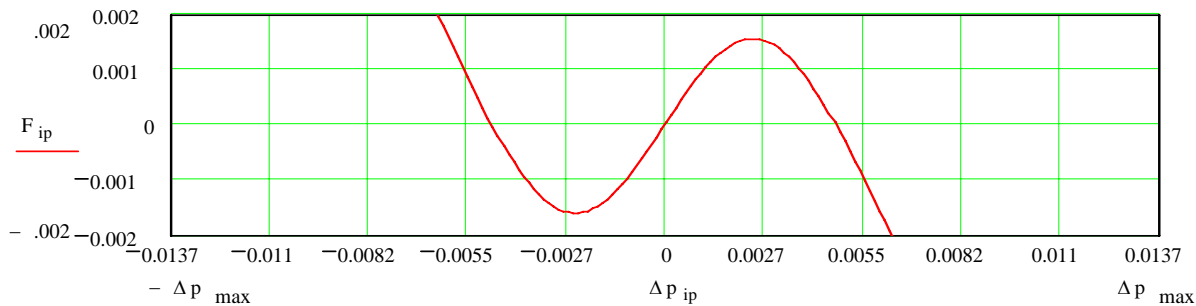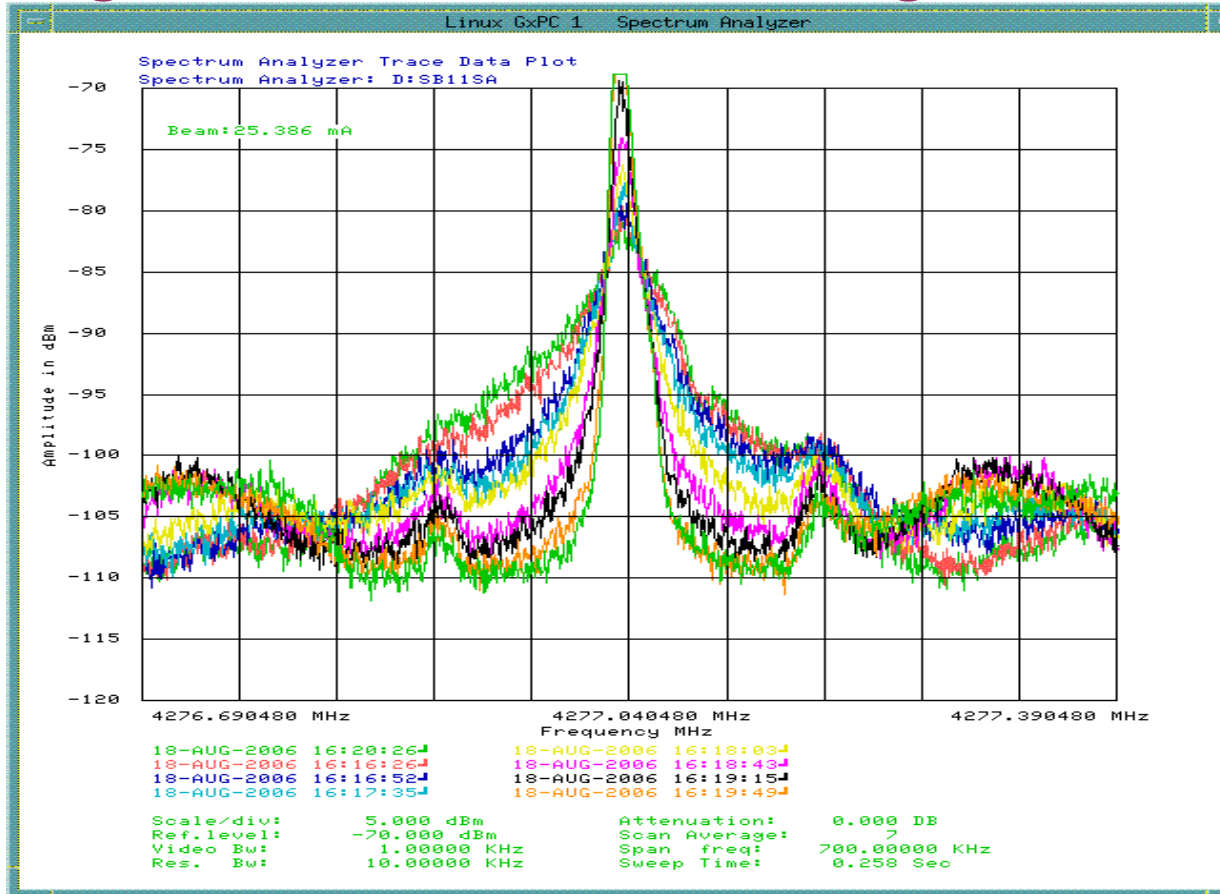
- Measured long. cooling acceptance ($\Delta p/p$) coincides sufficiently well with theory predictions
- Beam is cooled to equilibrium momentum spread of $\sigma_{\Delta p/p}=10^{-4}$ in about 2 s
- There is a number of questions we do not understand but the performance is close to the required one

Top: Longitudinal spectra at 0, 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.6, 2 s
Bottom: Computed dependence of cooling force on momentum

Effective Acceptance of D-to-A line and Accumulator

- Stacking rate was measured as function of cooling time for fixed cycle time of 4.0 s[tt]

    - For 4 s cooling time the difference in production rate between Debuncher and Accumulator is 13%
    - ~4% is left on injection orbit
    - 10% is unaccounted
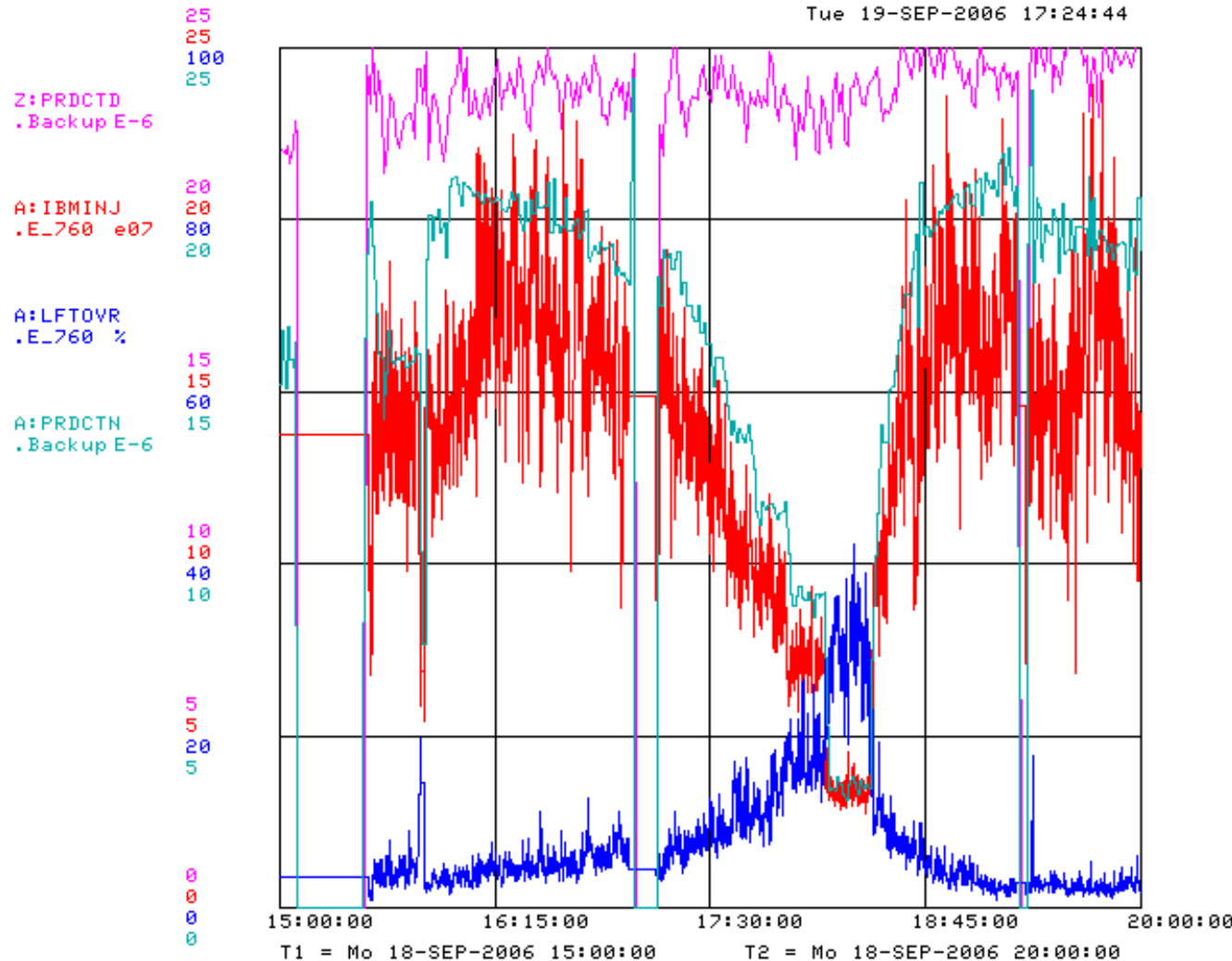
Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

- **Fitting of the measurements yields that effective D-to-A & Accumulator acceptance is > 9 mm mrad**
  - ◆ Very close to the measured Accumulator acceptances
- **For 4 s cycle 1% of unaccounted 10% is lost due to aperture limitation. We need to understand where are other 9%**
  - ◆ Timing
  - ◆ Debuncher bunching (DRF2 barrier bucket)
  - ◆ DCCT miscalibration
- **For 2.4 s cycle aperture limitation yields only ~4% loss**

⇒ ~23 mA/hour antiproton flax incoming to Accumulator for 7.62E12 protons on target used in the experiment

Transfer efficiency vs **Cooling time, s**

Production Corrected by A:LFTOVR   A:PRDCTN / 21.5

Effective Accumulator acseptance - **9 mm mrad**

Stacking rate, mA/hour vs **Stacking cycle time, s**

Rate for Pbars coming into Recycler for Np=7.62E12
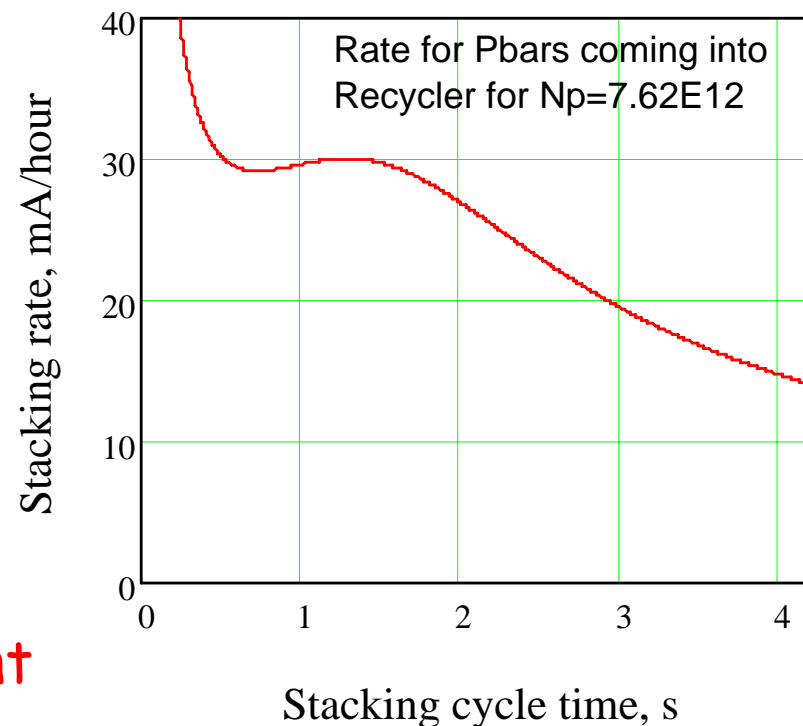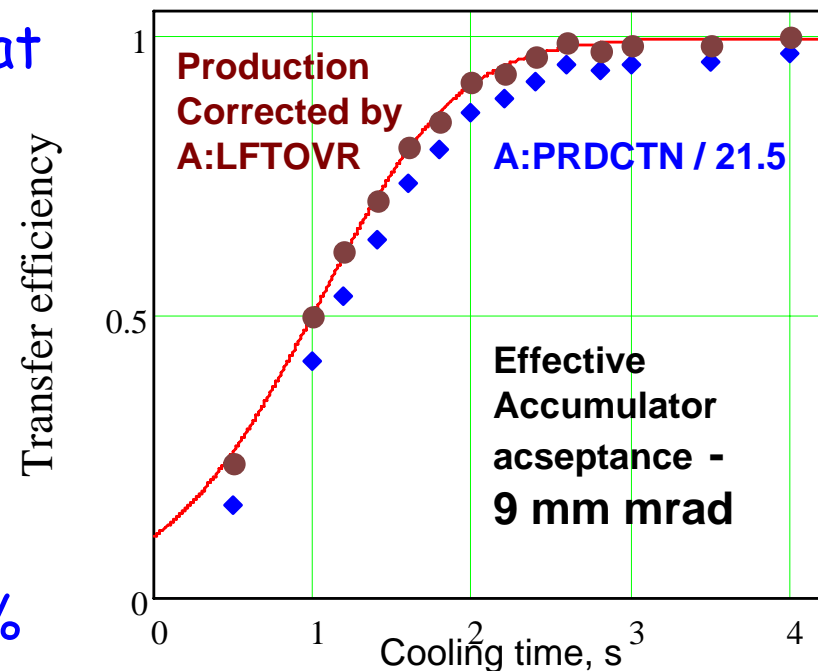
Stacking rate in Accumulator

Stacking rate, mA/h, Jan.28-Feb.28, 2006

Time, days

Stacking rate, mA/h, Aug.18-Sep.183, 2006
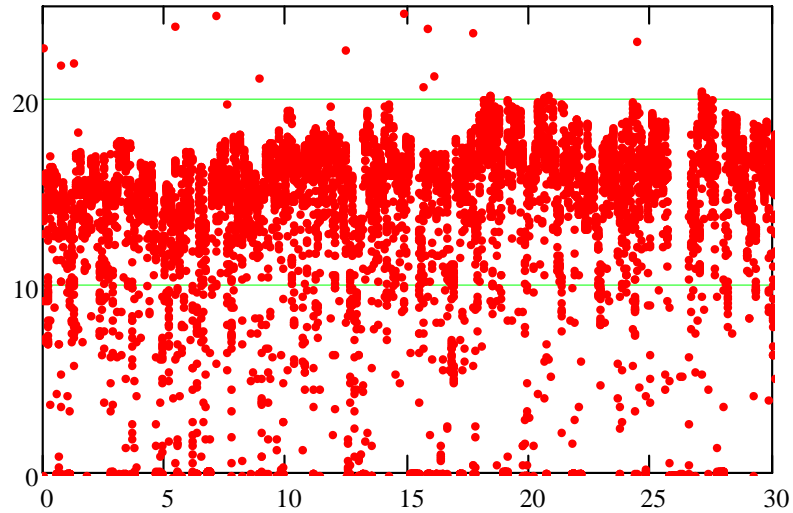
Time, days

Stacking rate, mA/h, Jan.28-Feb.28, 2006

Time, days

Stacking rate, mA/h, Aug.18-Sep.18, 2006

Time, days

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

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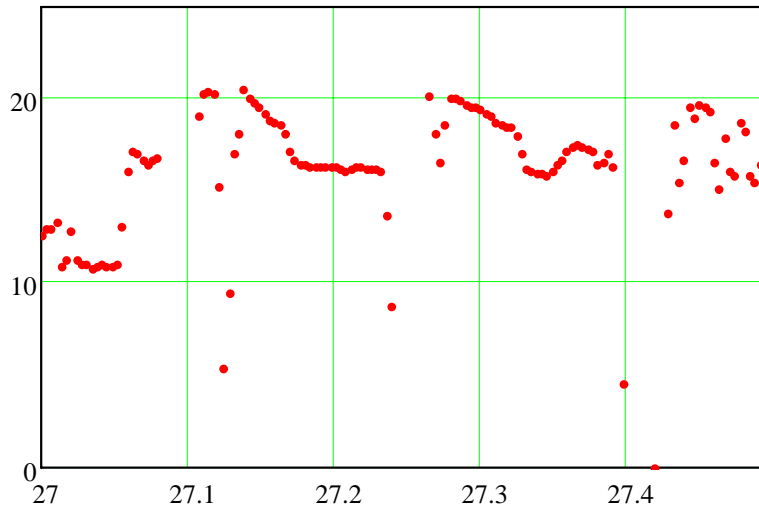
Stacking rate in Accumulator (continue)

Stacking rate, mA/h, Jan.28-Feb.28, 2006
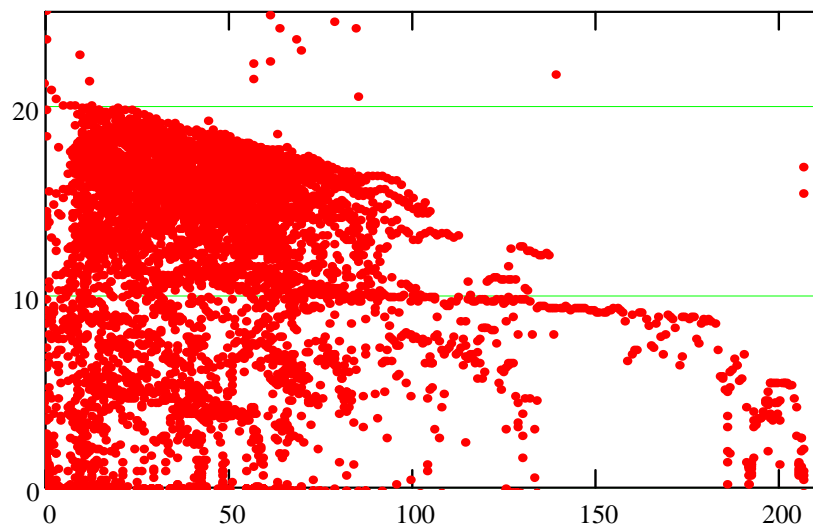
Stacking rate, mA/h, Aug.18-Sep.18, 2006
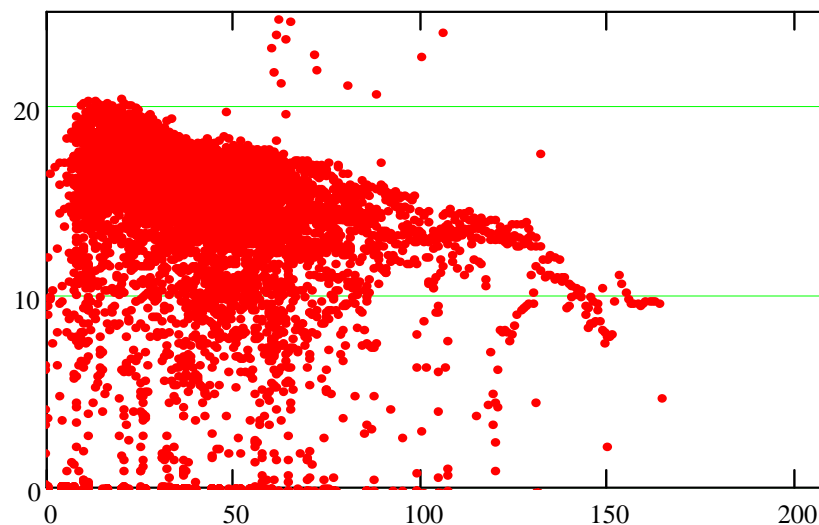
Stack size, mA

Stack size. mA

- We are slightly above the pre-shutdown record peak st. rate
- There are large discrepancy between stacking rate in Debuncher (30 mA/hour) and Stacking rate in Accumulator
  - Debuncher cooling is good up to 2.4 s cycle
  - Stack-tail performance is a major problem to address
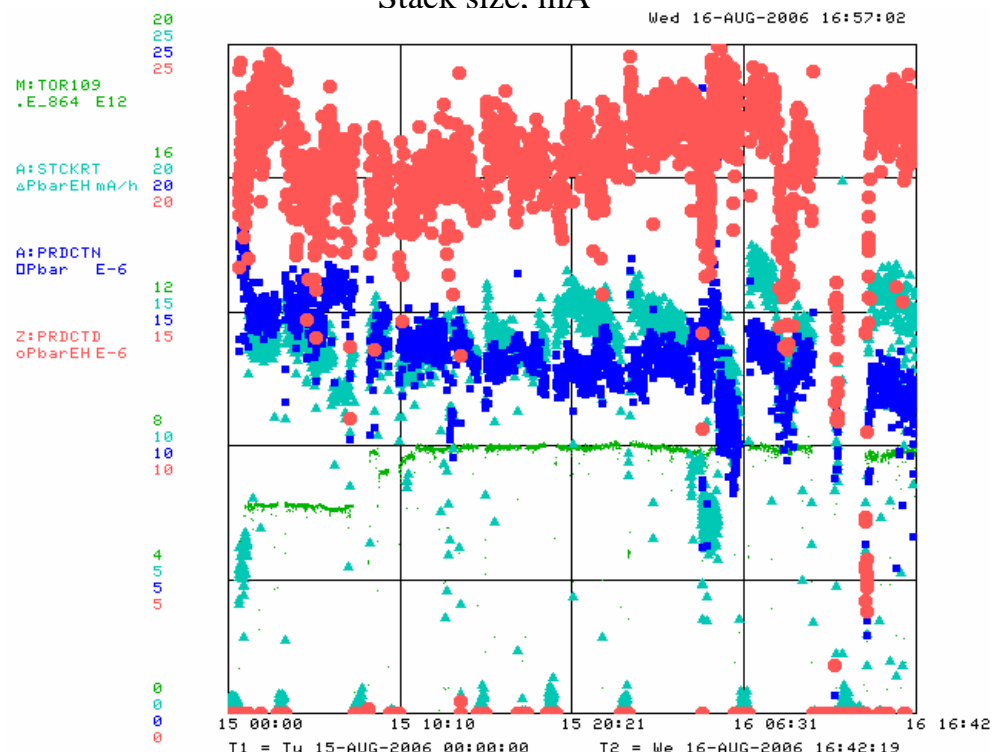
What's wrong with Stack-Tail?

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

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

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

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

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

♦ Finally we arrive to

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

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

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

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

- ♦ For rectangular gain function

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

that yields

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

- ■ For the gain measured in 2004 and E_d=10 MeV we obtain from Eq. (1) [‡‡]:

  J_{max}=29 mA/hour

- ■ For the gain measured at August 21, 2006 (E_d=8.5 MeV) we obtain:

J_{max}=20.7 mA/hour . This is very close to our peak performance!!!
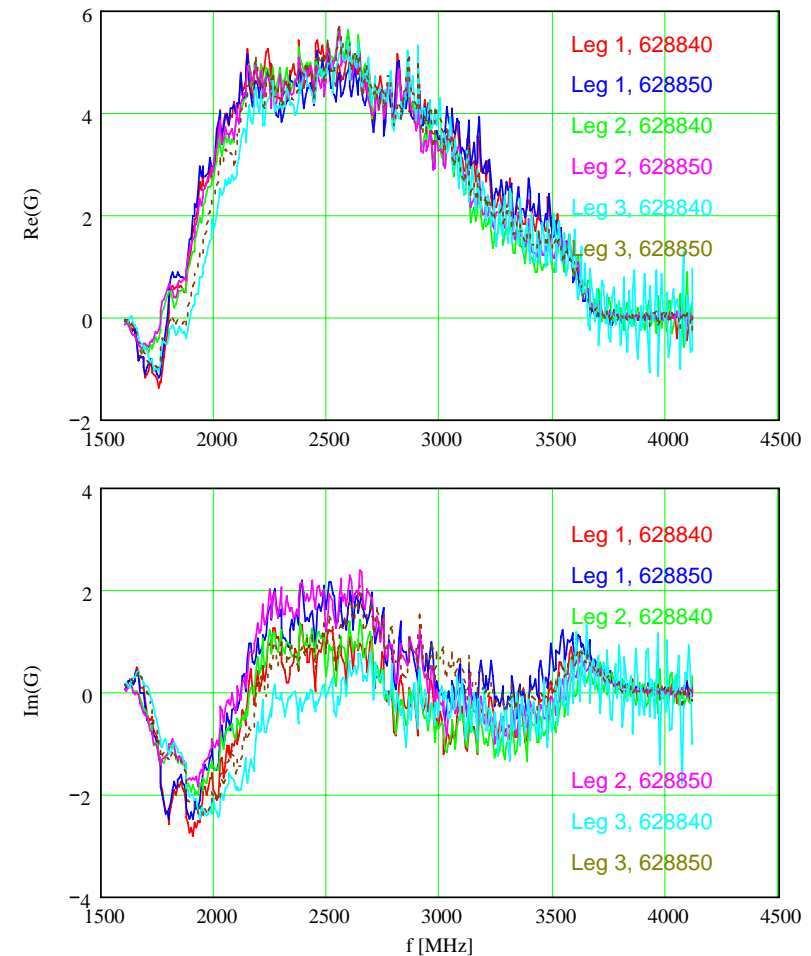
The Real (top) and imaginary (bottom) parts of gain measured in June 2004. All measurements are scaled to present dependence on frequency only.
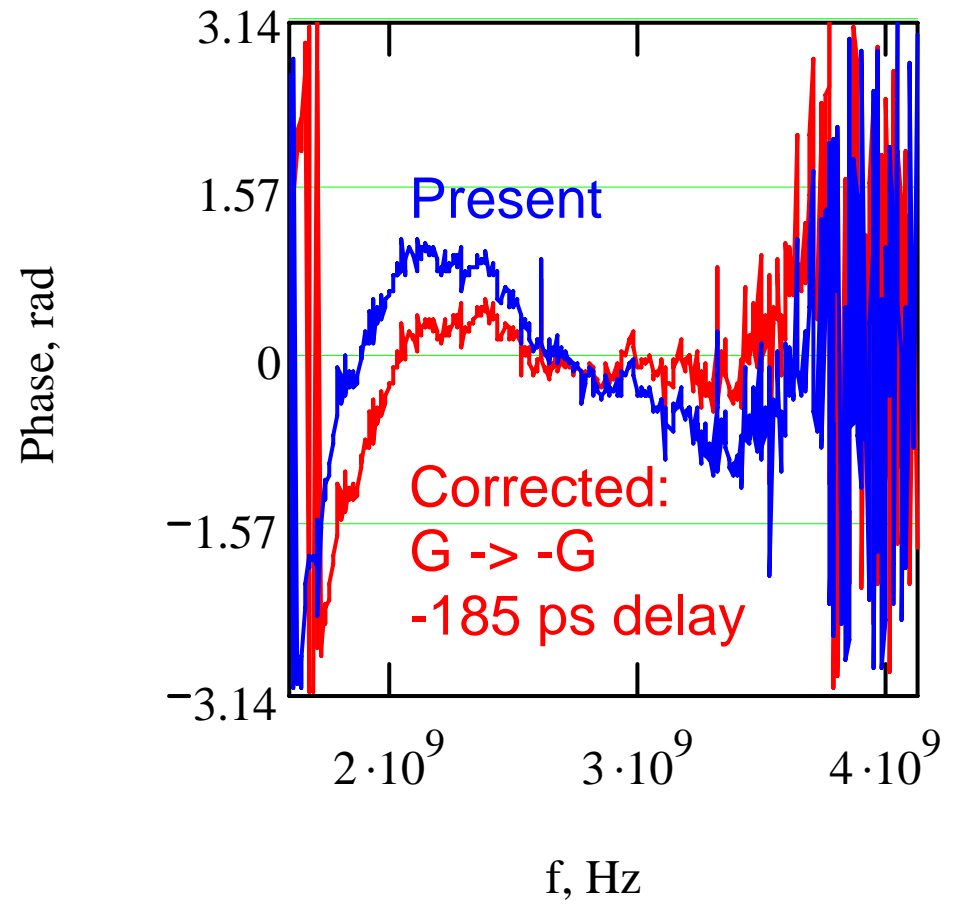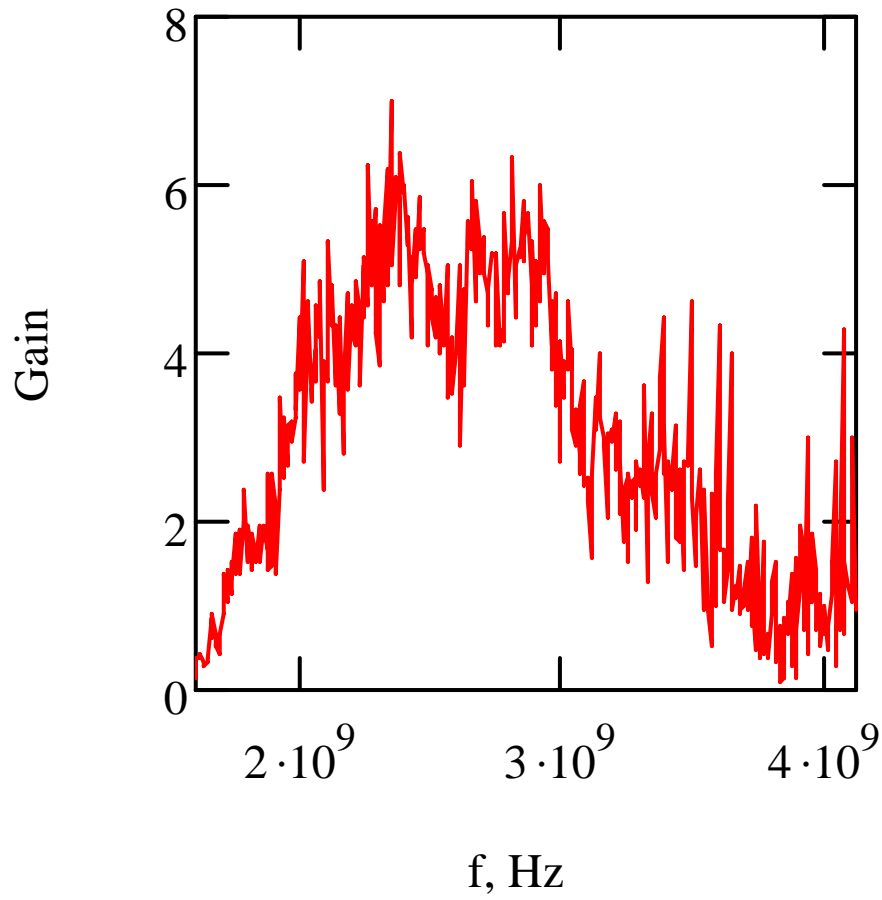
- Flipping the gain polarity and introducing -185 ps delay moves maximum flux to
   J_{max}=25 mA/hour

What else can be done to improve the stack-tail?

- Introducing equalizers
  - we can convert heating to cooling at low frequencies,
  - and make high frequencies contributing more $G(\omega) \propto \omega$

  we can gain factor of ~1.5 in stacking rate
  - 20 mA/hour -> 30 mA/hour
- Upgrading stack-tail to 2-6 GHz band should yield further improvement by ~1.5 times resulting the stacking rate above 45 mA/hour
  - This value is close to the value supported by planned improvements in AP-2, Debuncher and Accumulator optics

Fast transfers

- Peak stacking rate is ~20 mA/hour
- Average rate of pbars delivered to Tevatron(150 GeV) ~7.5 mA/hour
- Fast transfers can improve this by ~20%
- Jim Morgan will lead Fast Transfers Task Force
- Goals
  - ◆ Average transfer efficiency for Accumulator-to-Recycler transfers >95%
  - ◆ Transfer time <5 min

- **<u>Means</u>**
  - ◆ Optics measurements and careful steering through the lines based on aperture centering
  - ◆ Optics adjustments to minimize effect of places with small apertures
    - • AP3-P1 line
    - • MI-to-Recycler
    - • Recycler
    - • If there is not enough knobs we can make optics adjustments in MI
  - ◆ Injection damper for antiprotons incoming to MI
  - ◆ Additional means to be considered
    - • On-line orbit correction in AP3-P1 line
  - ◆ Global optimization of transfer process
    - • How much, How frequent, Additional cooling in Accumulator
  - ◆ Operational improvements
    - • Sequencer aggregate
    - • Timing
    - • Kickers
  - ◆ ...

Conclusions

- Major contributors to Luminosity improvements in 2006
  - Pbar production task force   Feb'06   ~10 %
  - Tevatron helix → more p's, lifetime   July'06   ~25 %
  - New RR WP →emittances, Coalescing   Sep'06   ~25 %
  - D0 luminosity recalibration ~5%
  - After shutdown increase of protons on the target by ~5% will be utilized in the future
- Expected growth of average antiproton production rate
  - Next 2-3 months due to fast transfers improvements ~ 20%
  - In 4-6 months other 30% stack-tail band correction
- By summer
  - Peak production rate ~30 mA/hour
  - Tevatron and Recycler have to be able to operate with antiproton stacks of 450-500 mA
  - Peak luminosity ~$3 \cdot 10^{32}$ cm^{-2}s^{-1}
  - Luminosity integral per week – 40-45 pb^{-1}/week

- We will look into single step luminosity leveling as a low priority task
    - Detector collaborations need to get to consensus on its necessity and level. Sooner is better
    - Reduced store time can be used to avoid excessive luminosities in near future
- Stack-tail upgrade from 2-4 to 2-6 GHz is now discussed. Expected to be carried out at FY'07 shutdown.
    - ~9 – 12 month time to prepare hardware
    - 4 - 6 week shutdown
    - Commissioning and recovery can be painful

Break-down of the luminosity goal

- Increase the peak antiproton production in the antiproton source
  - 20 -> 30 mA/hour (× 1.5)
    - That implies

  Number of protons on target: $8 \cdot 10^{12}$ /pulse (already achieved)
  Antiproton yield: $25 \cdot 10^{-6}$ pbar/p (already achieved in Debuncher)
  Cycle time: 2.4 s

- Increase of average production to Recycler
  - 9 -> 16 mA/hour (1.5×1.05×1.05×1.10 = 1.8)
    - That implies high efficiency Fast transfers (× 1.2)
      - Accumulator-to-MI loss: 90 -> 95% (× 1.05)
      - Transfer time: 20 min -> (<5 min) (× 1.05)
      - Operational improvements(no shot effect on pbar-
      -     production, stability of parameters) should reduce
      -     downtime in Pbar source: 75% -> 82% (× 1.10)
- Tevatron improvements (1.8 × 1.10 = 2)
  - New working point (× 1.1)
    - Number of protons
- This estimate yields 15% larger increase than planned

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 %
- C0 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 %

Shot Summary 4859 07/27/2006 05:42:47 Initial Stack size: No data received! E10 Initial Stash size: 316.06 E10
FBI-based table (Main)

Tevatron Shot Stage	Proton Intensity [E9]	Step Efficiency [%]	Cumulative Efficiency [%]	Pbar Intensity [E9] All		Step Efficiency [%] All		Cumulative Efficiency [%] All	
				Acc	Rec	Acc	Rec	Acc	Rec
Booster	13244	.	.	.		.		.	
Amount unstacked	.	.	.	**3066** ï¿½ 3066		.		.	
MI 8GeV	11225	84.8	84.8	**3171** ï¿½ 3171		**103.4** .0 103.4		**103.4** .0 103.4	
MI 150 GeV	10955	97.6	82.7	**3143** ï¿½ 3143		**99.1** .0 99.1		**102.5** .0 102.5	
MI Coalescing	9479	86.5	71.6	**2782** 0 2782		**88.5** .0 88.5		**90.7** .0 90.7	
Inject Protons	9742	102.8	73.6	.		.		.	
Pbar Injection porch	9585	98.4	72.4	.		.		.	
Inject Pbars	9130	95.3	68.9	**2760** 0 2760		**99.2** .0 99.2		**90.0** .0 90.0	
Before Ramp	9130	100.0	68.9	**2723** 0 2723		**98.6** .0 98.6		**88.8** .0 88.8	
Flattop	8524	93.4	64.4	**2503** 0 2503		**91.9** .0 91.9		**81.6** .0 81.6	
Squeeze	8425	98.8	63.6	**2463** 0 2463		**98.4** .0 98.4		**80.3** .0 80.3	

Initiate Collisions	8402	99.7	63.4	**2436** 0 2436	**98.9** .0 98.9	**79.4** .0 79.4
Remove Halo	8288	98.6	62.6	**2385** 0 2385	**97.9** .0 97.9	**77.8** .0 77.8
Begin HEP	8283	99.9	62.5	**2372** 0 2372	**99.5** .0 99.5	**77.4** .0 77.4
End HEP	5821	70.3	44.0	**1011** 0 1011	**42.6** .0 42.6	**33.0** .0 33.0
Initial Lumosity	179.01	E30, CDF	.	157.58	E30, DZero	.
Shot Setup Time	136.59	min	.	.	.	.

<div align="center">*SBD-based table*</div>

Tevatron Shot Stage	Proton Intensity [E9]	Step Efficiency [%]	Cumulative Efficiency [%]	Pbar Intensity [E9] All Acc Rec	Step Efficiency [%] All Acc Rec	Cumulative Efficiency [%] All Acc Rec
Inject Protons	9484	100.1	71.6	.	.	.
Pbar Injection porch	9581	101.0	72.3	.	.	.
Inject Pbars	9105	95.0	68.7	**2807** 0 2807	**100.9** .0 100.9	**91.5** .0 91.5
Before Ramp	9120	100.2	68.9	**2760** 0 2760	**98.3** .0 98.3	**90.0** .0 90.0
Flattop	8680	95.2	65.5	**2571** 0 2571	**93.1** .0 93.1	**83.8** .0 83.8
Squeeze	8569	98.7	64.7	**2517** 0 2517	**97.9** .0 97.9	**82.1** .0 82.1

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

Initiate Collisions	8555	99.8	64.6	**2493** 0 2493	**99.0** .0 99.0	**81.3** .0 81.3
Remove Halo	8423	98.5	63.6	**2435** 0 2435	**97.6** .0 97.6	**79.4** .0 79.4
Begin HEP	8416	99.9	63.5	**2422** 0 2422	**99.5** .0 99.5	**79.0** .0 79.0
End HEP	5774	68.6	43.6	**982** 0 982	**40.5** .0 40.5	**32.0** .0 32.0

Recomputed Intensities Table

Shot Summary 4959 09/15/2006 20:18:13 Initial Stack size: No data received! E10 Initial Stash size: 227.05 E10

FBI-based table (Main)

Tevatron Shot Stage	Proton Intensity [E9]	Step Efficiency [%]	Cumulative Efficiency [%]	Pbar Intensity [E9] All Acc Rec	Step Efficiency [%] All Acc Rec	Cumulative Efficiency [%] All Acc Rec
Booster	13151	.	.	.	.	.
Amount unstacked	.	.	.	**2239** ï¿½ 2239	.	.
MI 8GeV	11410	86.8	86.8	**2198** ï¿½ 2198	**98.2** .0 98.2	**98.2** .0 98.2
MI 150 GeV	11146	97.7	84.7	**2213** ï¿½ 2213	**100.7** .0 100.7	**98.8** .0 98.8
MI Coalescing	9855	88.4	74.9	**1987** 0 1987	**89.8** .0 89.8	**88.8** .0 88.8
Inject Protons	10127	102.8	77.0	.	.	.
Pbar Injection porch	10007	98.8	76.1	.	.	.

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

Tevatron Shot Stage	Proton Intensity [E9]	Step Efficiency [%]	Cumulative Efficiency [%]	Pbar Intensity [E9] All (Acc / Rec)	Step Efficiency [%] All (Acc / Rec)	Cumulative Efficiency [%] All (Acc / Rec)
Inject Pbars	9805	98.0	74.6	1981 (0 / 1981)	99.7 (.0 / 99.7)	88.5 (.0 / 88.5)
Before Ramp	9794	99.9	74.5	1977 (0 / 1977)	99.8 (.0 / 99.8)	88.3 (.0 / 88.3)
Flattop	9498	97.0	72.2	1940 (0 / 1940)	98.1 (.0 / 98.1)	86.7 (.0 / 86.7)
Squeeze	9369	98.6	71.2	1930 (0 / 1930)	99.5 (.0 / 99.5)	86.2 (.0 / 86.2)
Initiate Collisions	9344	99.7	71.0	1921 (0 / 1921)	99.5 (.0 / 99.5)	85.8 (.0 / 85.8)
Remove Halo	9139	97.8	69.5	1878 (0 / 1878)	97.8 (.0 / 97.8)	83.9 (.0 / 83.9)
Begin HEP	9112	99.7	69.3	1869 (0 / 1869)	99.6 (.0 / 99.6)	83.5 (.0 / 83.5)
End HEP	6714	73.7	51.0	965 (0 / 965)	51.6 (.0 / 51.6)	43.1 (.0 / 43.1)
Initial Lumosity	176.10	E30, CDF	.	163.55	E30, DZero	.
Shot Setup Time	117.84	min	.	.	.	.

SBD-based table

Tevatron Shot Stage	Proton Intensity [E9]	Step Efficiency [%]	Cumulative Efficiency [%]	Pbar Intensity [E9] All (Acc / Rec)	Step Efficiency [%] All (Acc / Rec)	Cumulative Efficiency [%] All (Acc / Rec)
Inject Protons	9855	100.0	74.9	.	.	.
Pbar Injection porch	10019	101.7	76.2	.	.	.
Inject Pbars	9797	97.8	74.5	1993 (0 / 1993)	100.3 (.0 / 100.3)	89.0 (.0 / 89.0)

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

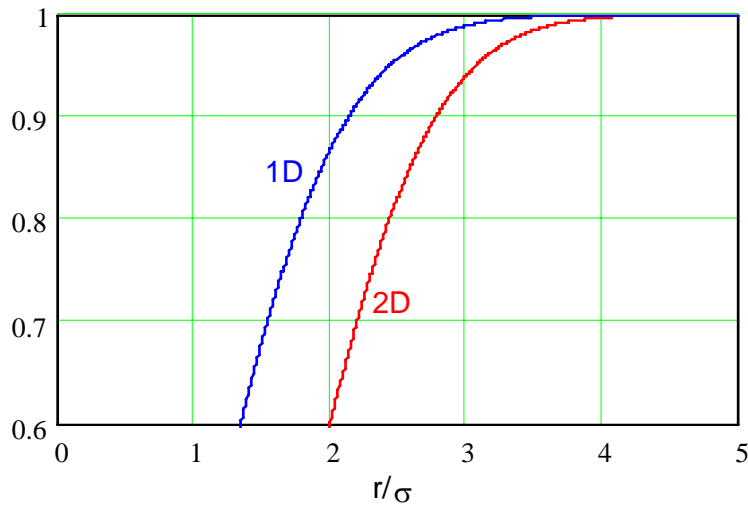|						
Before Ramp	9788	99.9	74.4	**1979** 0 1979	**99.3** .0 99.3	**88.4** .0 88.4
Flattop	9670	98.8	73.5	**1971** 0 1971	**99.6** .0 99.6	**88.0** .0 88.0
Squeeze	9532	98.6	72.5	**1954** 0 1954	**99.1** .0 99.1	**87.3** .0 87.3
Initiate Collisions	9509	99.8	72.3	**1947** 0 1947	**99.7** .0 99.7	**87.0** .0 87.0
Remove Halo	9297	97.8	70.7	**1902** 0 1902	**97.7** .0 97.7	**84.9** .0 84.9
Begin HEP	9259	99.6	70.4	**1894** 0 1894	**99.6** .0 99.6	**84.6** .0 84.6
End HEP	6683	72.2	50.8	**934** 0 934	**49.3** .0 49.3	**41.7** .0 41.7

Debuncher cooling

1D(2D-phase space):

$$f(r) = \frac{1}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) r \;\Rightarrow\; f_\varepsilon(\varepsilon) = \frac{1}{2\varepsilon_\sigma} \exp\left(-\frac{\varepsilon}{2\varepsilon_\sigma}\right) \;\Rightarrow\; F(\varepsilon_\sigma) = \int_0^{\varepsilon_{acc}} f_\varepsilon(\varepsilon) d\varepsilon = 1 - \exp\left(-\frac{\varepsilon_{acc}}{2\varepsilon_\sigma}\right)$$

2D(4D-phase space):

$$f(r) = \frac{1}{\sigma^4} \exp\left(-\frac{r^2}{2\sigma^2}\right) r^3 \;\Rightarrow\; f_\varepsilon(\varepsilon) = \frac{\varepsilon}{4\varepsilon_\sigma^2} \exp\left(-\frac{\varepsilon}{2\varepsilon_\sigma}\right) \;\Rightarrow\; F(\varepsilon_\sigma) = \int_0^{\varepsilon_{acc}} f_\varepsilon(\varepsilon) d\varepsilon = 1 - \exp\left(-\frac{\varepsilon_{acc}}{2\varepsilon_\sigma}\right)\left(1 + \frac{\varepsilon_{acc}}{2\varepsilon_\sigma}\right)$$

Dependance of fraction of survived particles on vacuum chamber size (r/σ)

Longitudinal cooling formulas

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

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

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

Data Logger Plotter

Z:IBMV16   Z:PRDCTD   A:PRDCTN

23.8
20.6

start time: 09/18/06 12:00:00 (000)

Run II status and goals: Can we achieve 8 fb^{-1}, September 2006, FNAL

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