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

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FNAL
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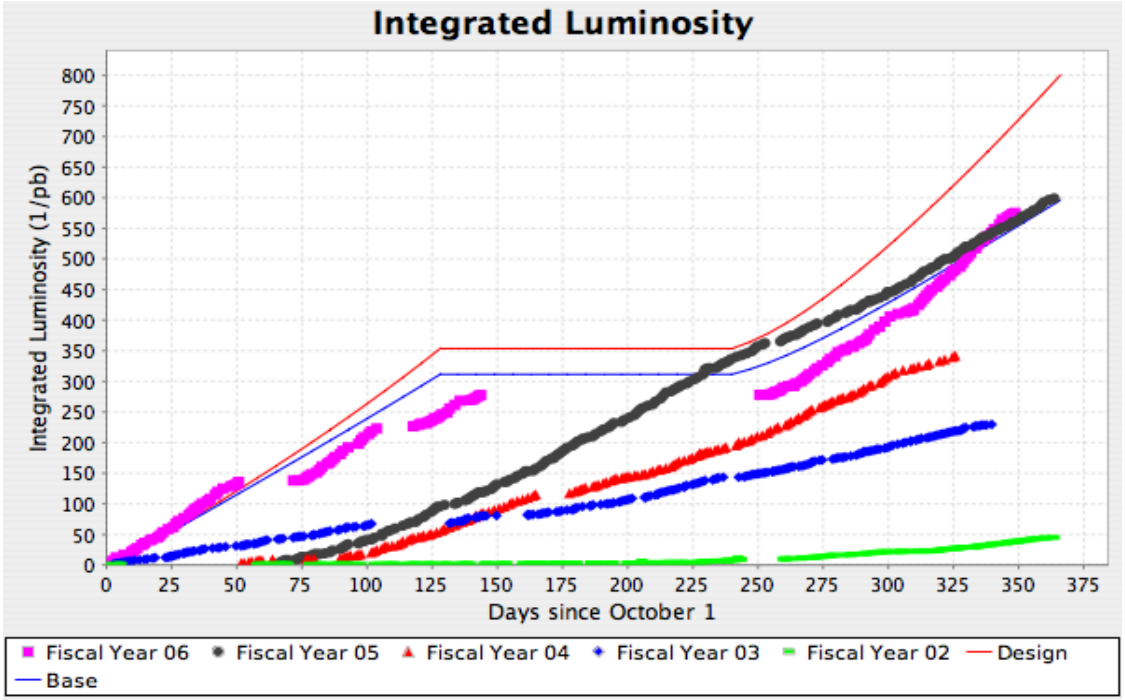
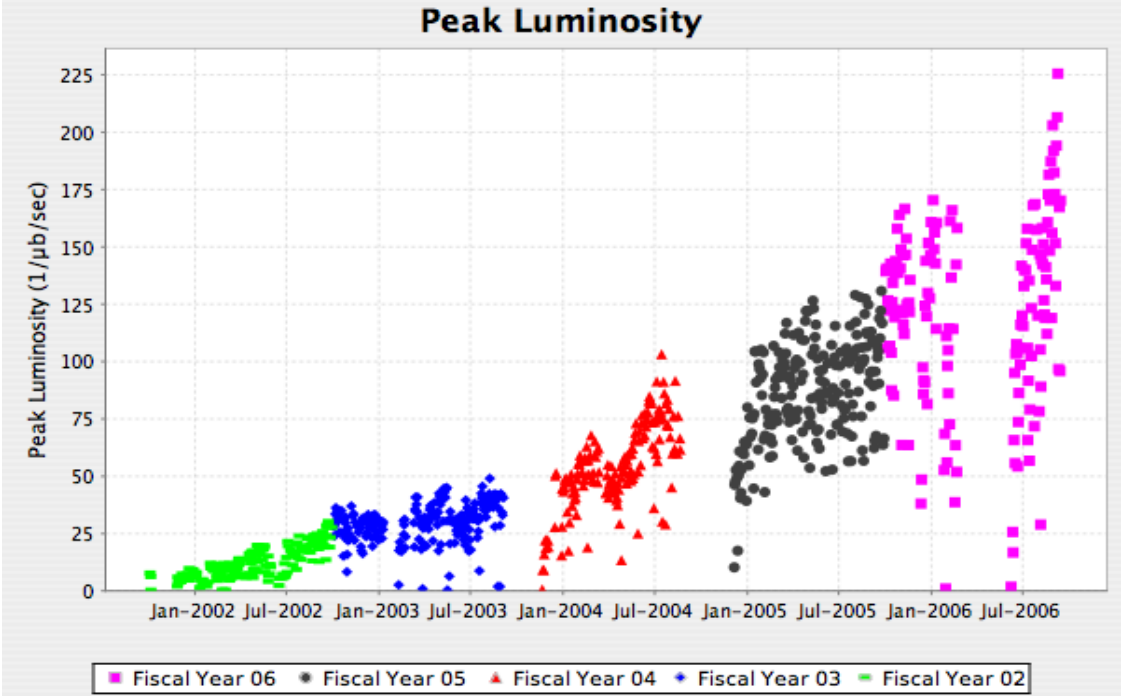
Contents

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

Present Collider Status





- ~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

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)**
  - $\Rightarrow$ **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)**

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

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

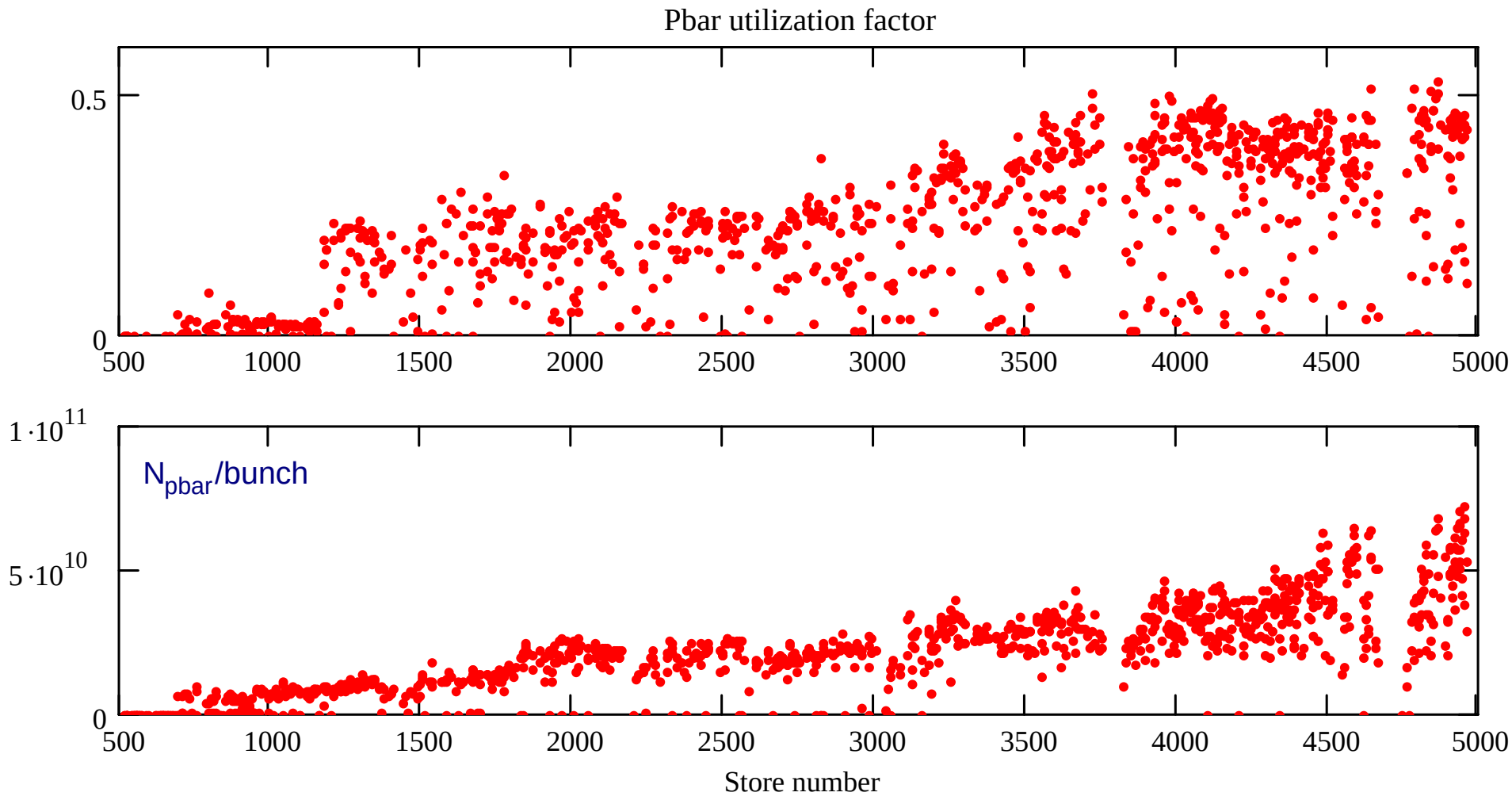
    Smaller antiproton loss at transfers

    Less time spent for transfers
- Tevatron improvements

    New working point

Present Tevatron performance

Antiproton utilization factor

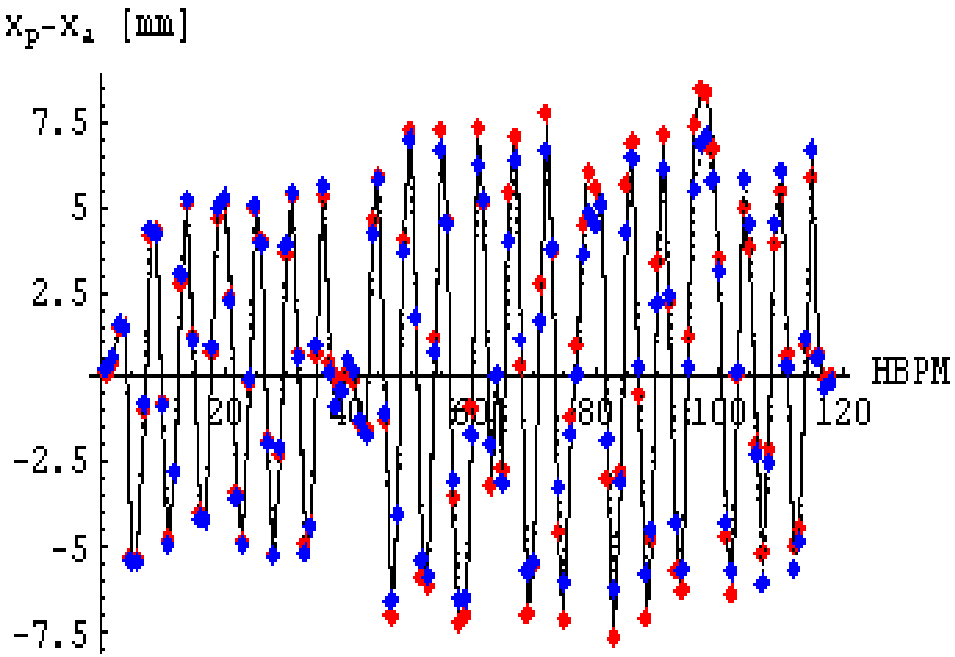


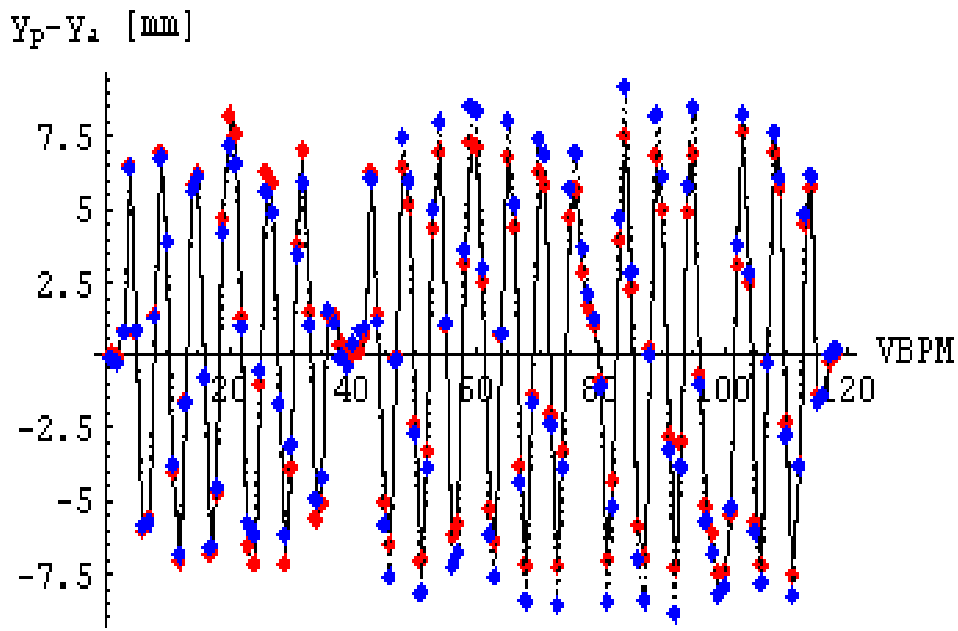
In good (long) stores we burn more than 50% of pbars injected to Tevatron

- 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



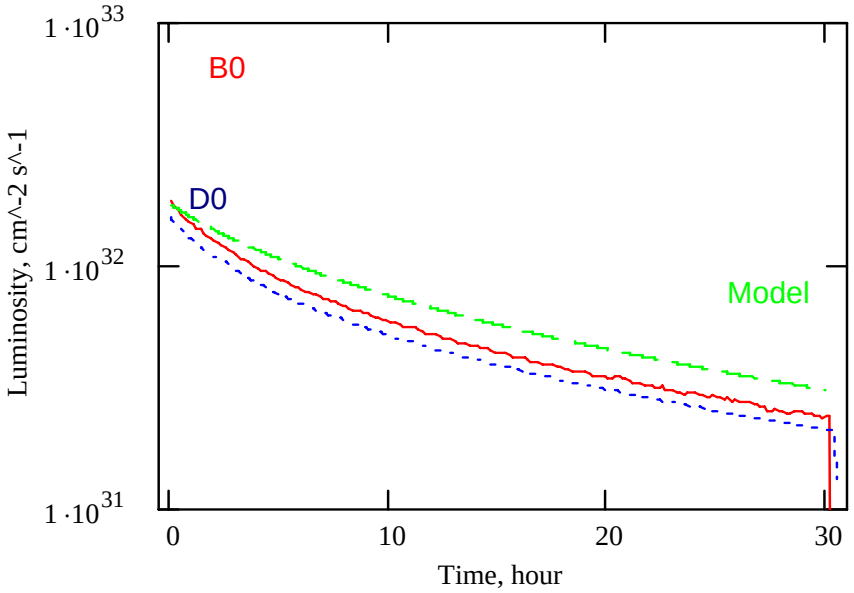


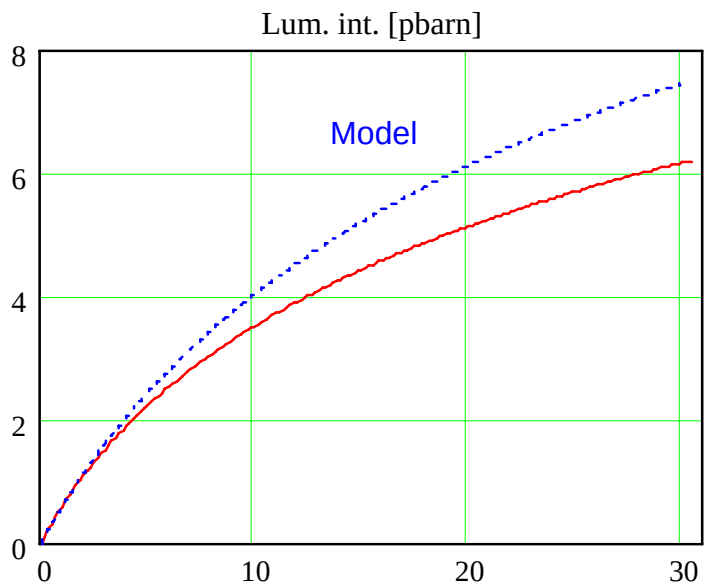
Changes in beam separation-after shutdown‡

Red – full separation now (with A17H and B48V separators), blue – before (double the proton helix).

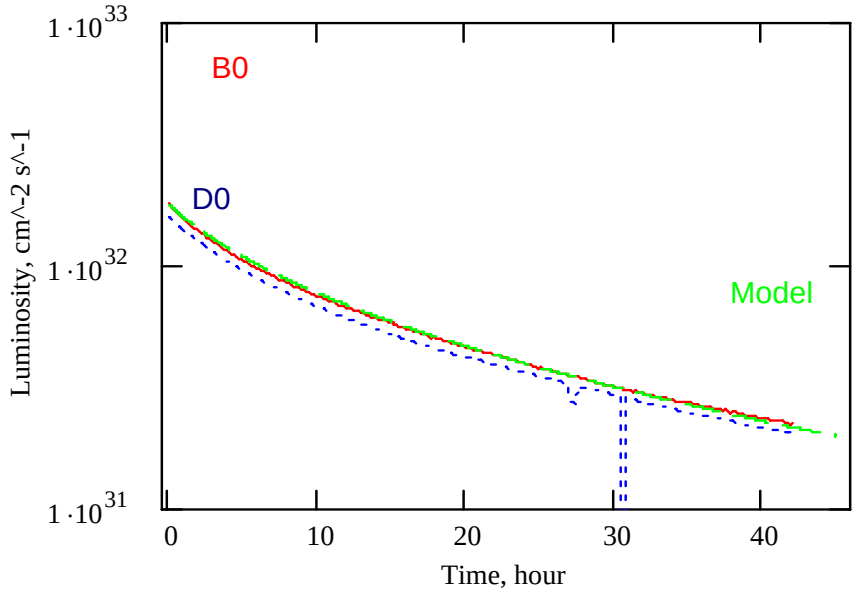
‡ Courtesy of Yuri Alexahin

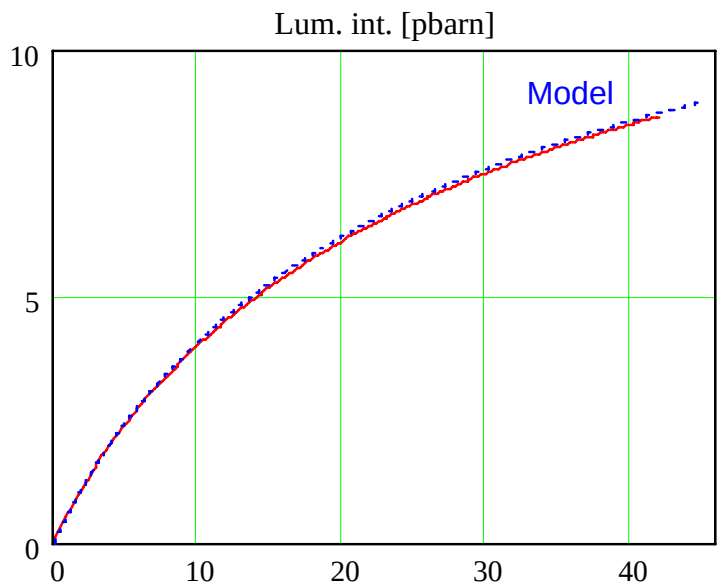
Store 4581





Store 4859

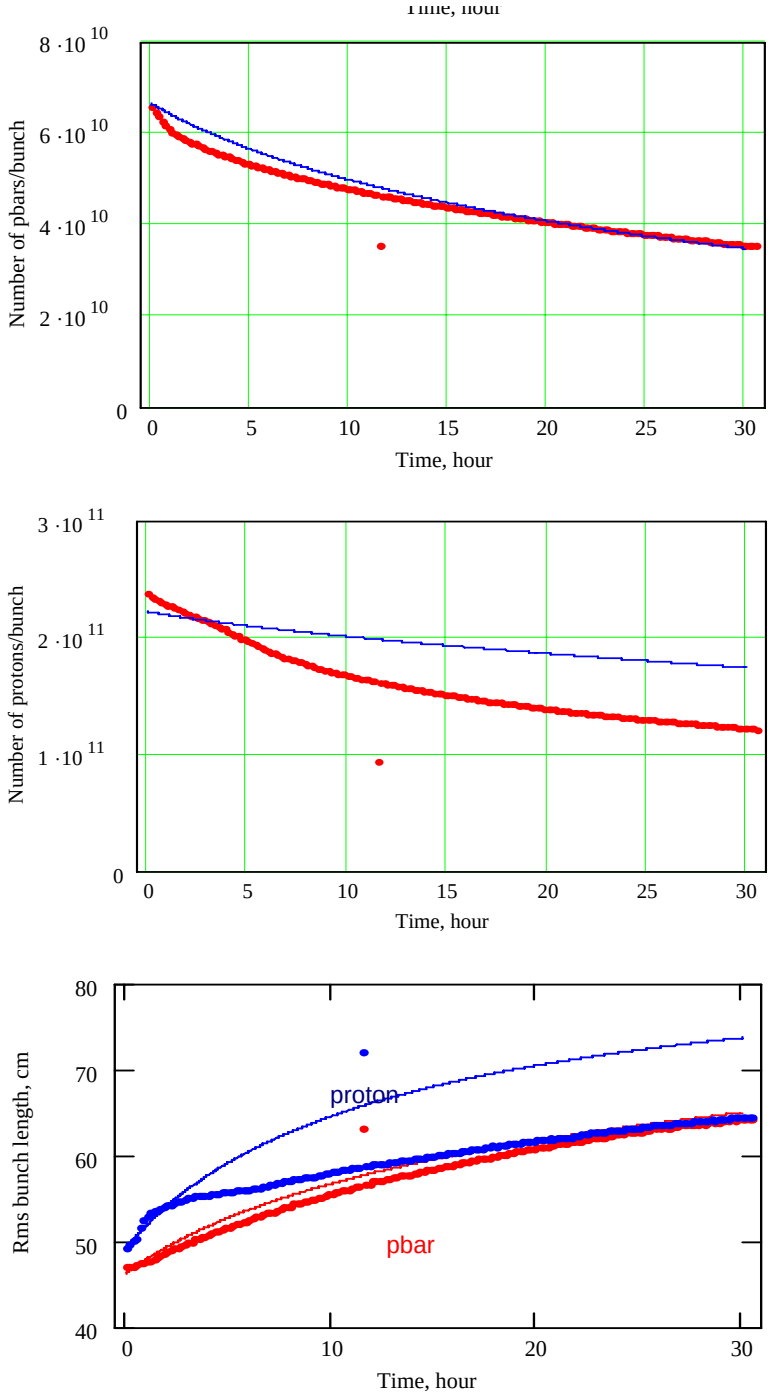




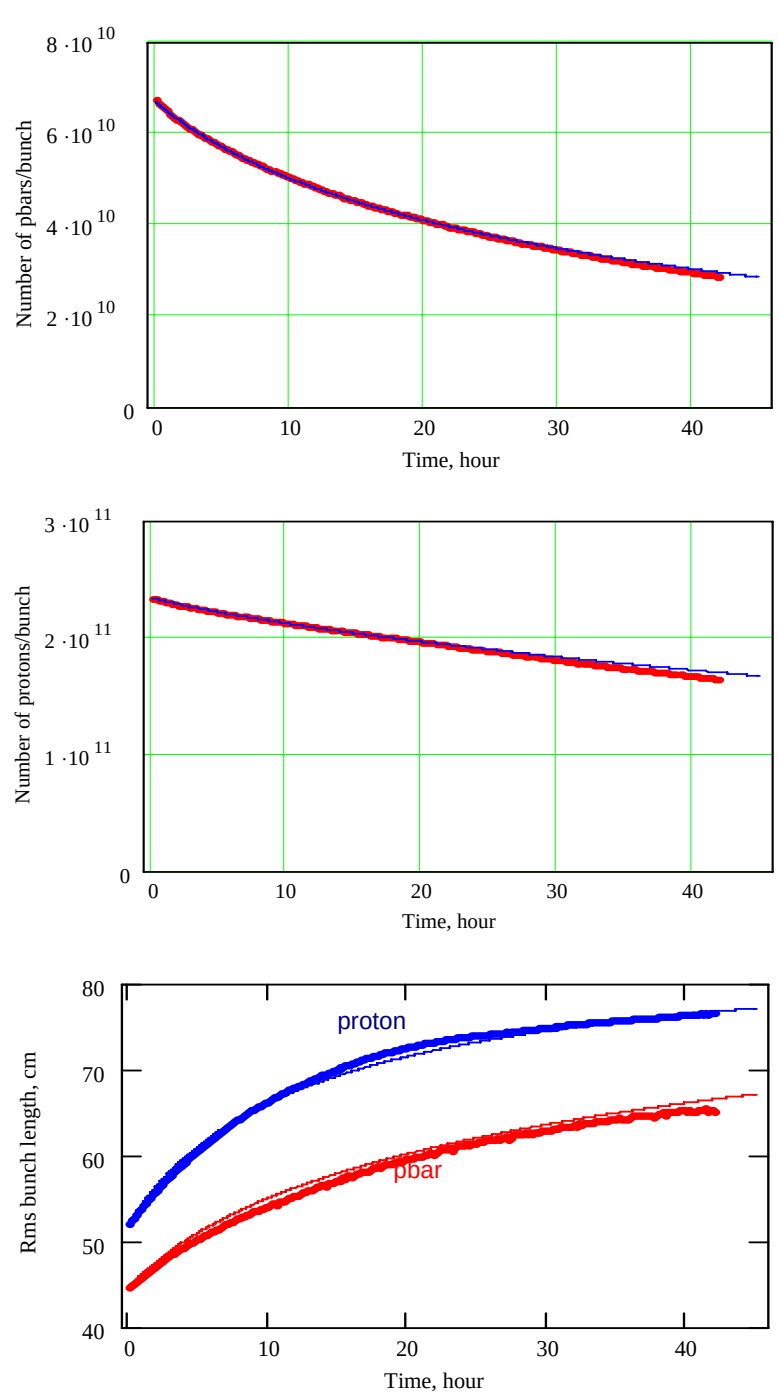
Before shutdown (Jan. 6, 06)

After shutdown (July. 27, 06)

Store 4581



Store 4859



Model parameters

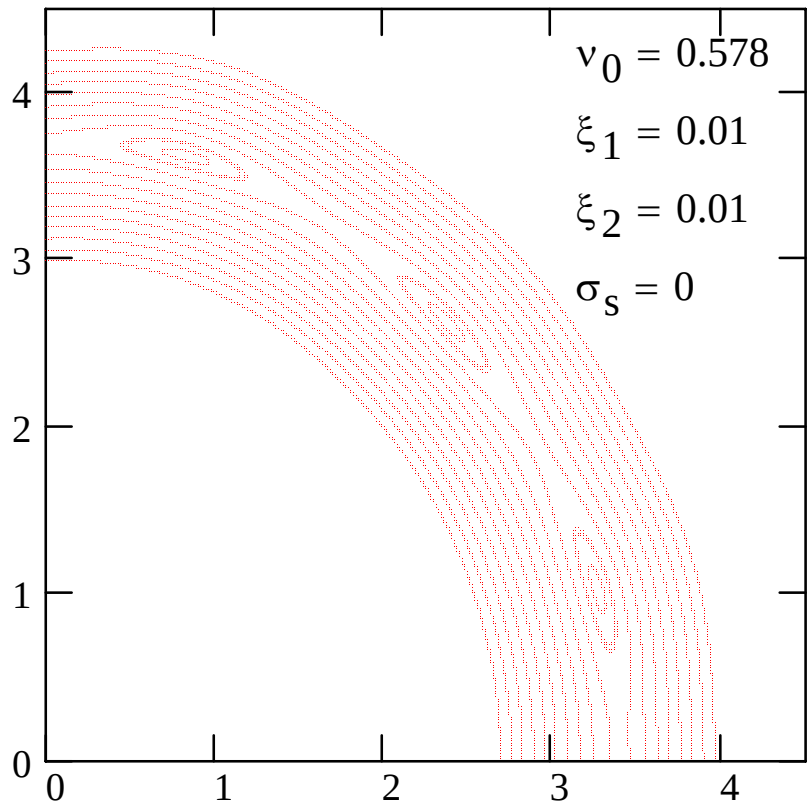
- Cross-section of nuclear interaction in IPs - 69 mbarn
- Beam life-time due to interaction with res. gas - 480 hour
- Spectral density of RF phase noise - $4.2 \cdot 10^{-11}$ rad^2/Hz
- Amplification factor of IBS - 1.3 (?)

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

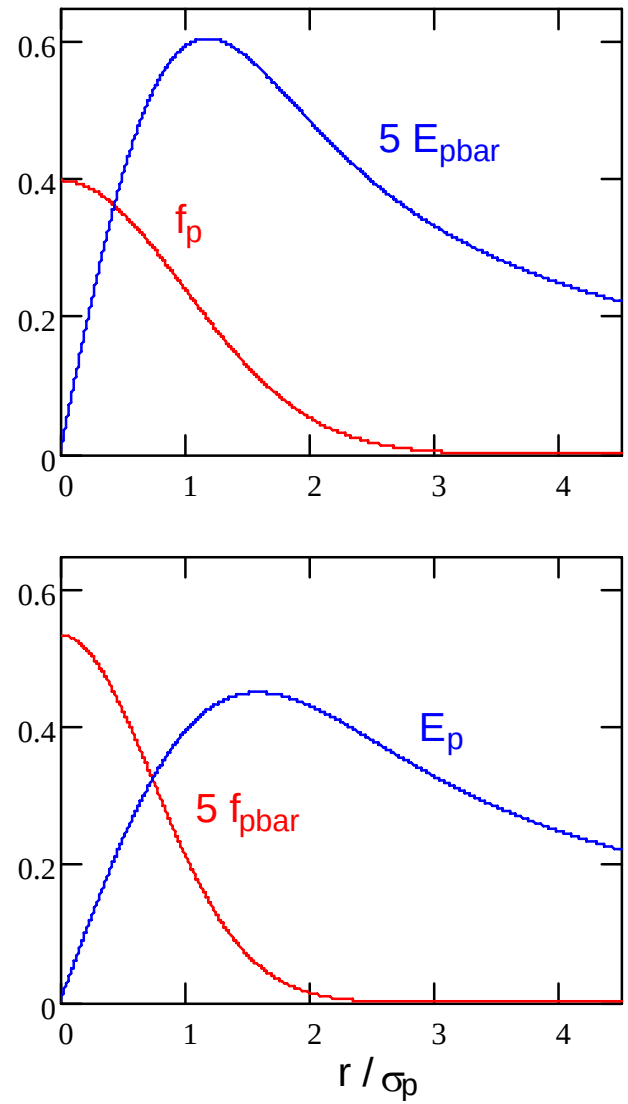
- Beta-function in IP - 31 => 28 cm
- Number of protons per bunch - $2.3 \cdot 10^{11}$ => $2.7 \cdot 10^{11}$
  - That implies new working point
- Proton $\perp$ emittance stays the same - 18 mm·mrad
- Antiproton $\perp$ emittance - 13 => 15 mm·mrad
- Longitudinal emittances stay the same
  - Proton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



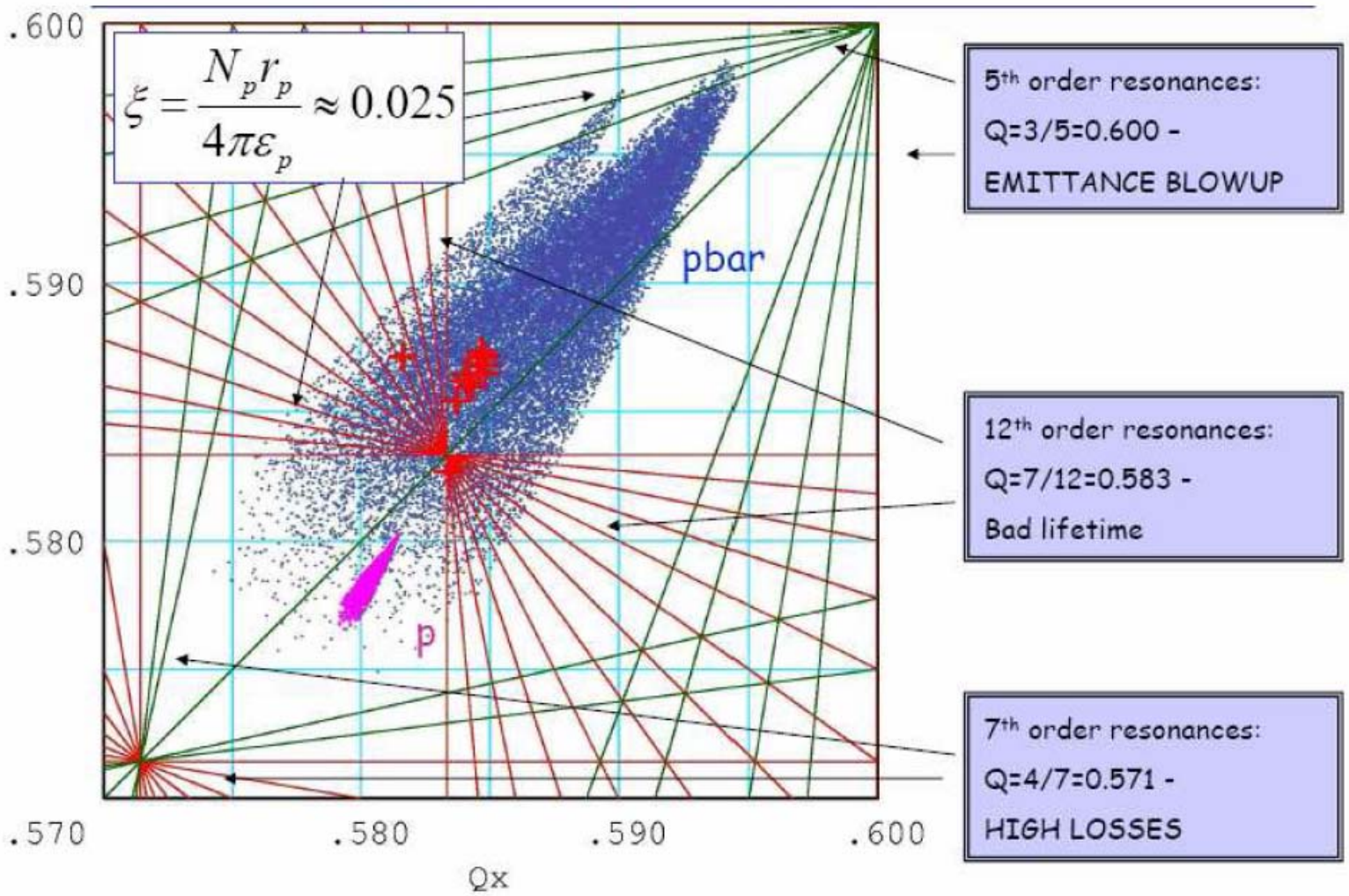
Phase trajectories in vicinity of 12-th order resonance ν_x=7/12; two Tevatron IPs but zero length of counter-rotating bunch, and zero synchrotron motion amplitude



- Resonance overlap strongly amplifies diffusion

ε_p = 18 mm mrad
ε_{pbar} = 10 mm mrad
N_p/N_{pbar} = 5

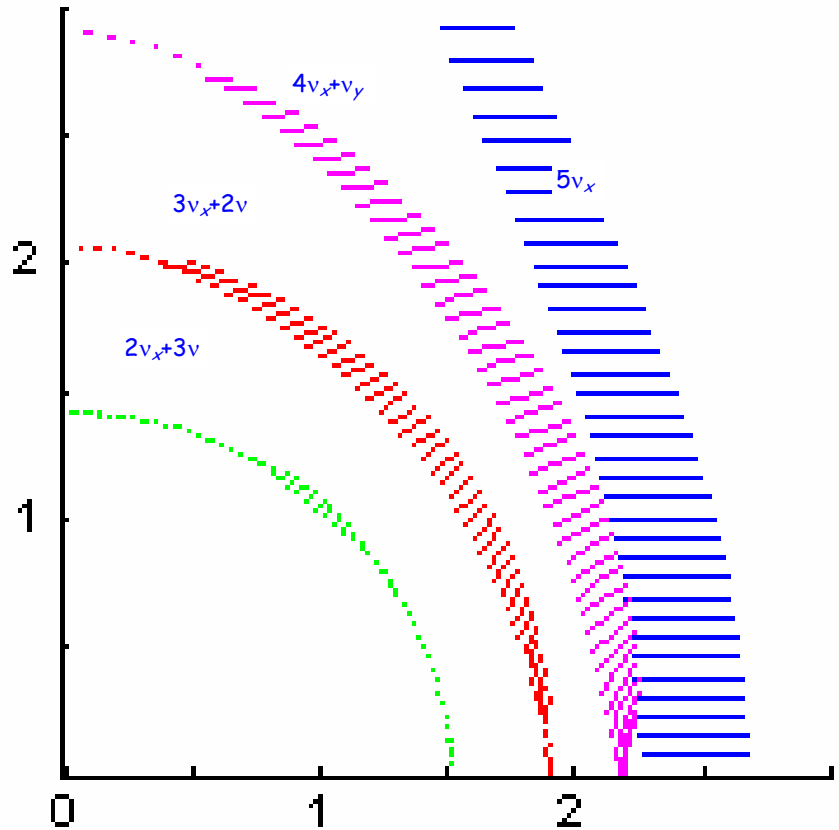
Tune Diagram[§]

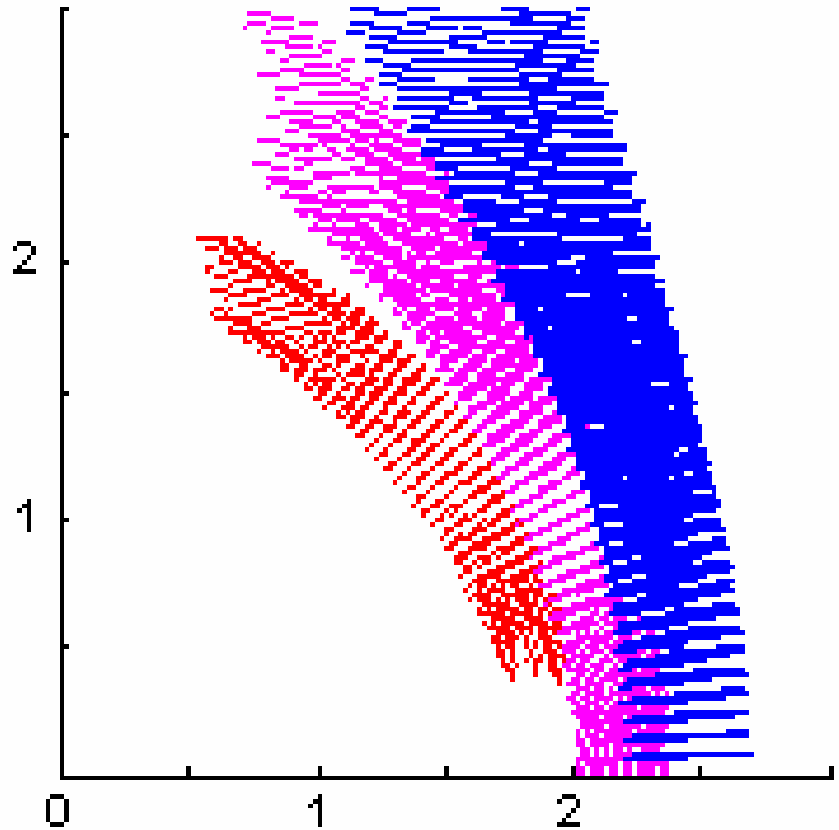


- New tune monitor should be operational in 2-3 month
  - Each proton and pbar bunch
  - Tickler is planned to be used to improve sensitivity

[§] Courtesy of Yu. Alexahin, & V. Shiltsev

Long Range collisions*



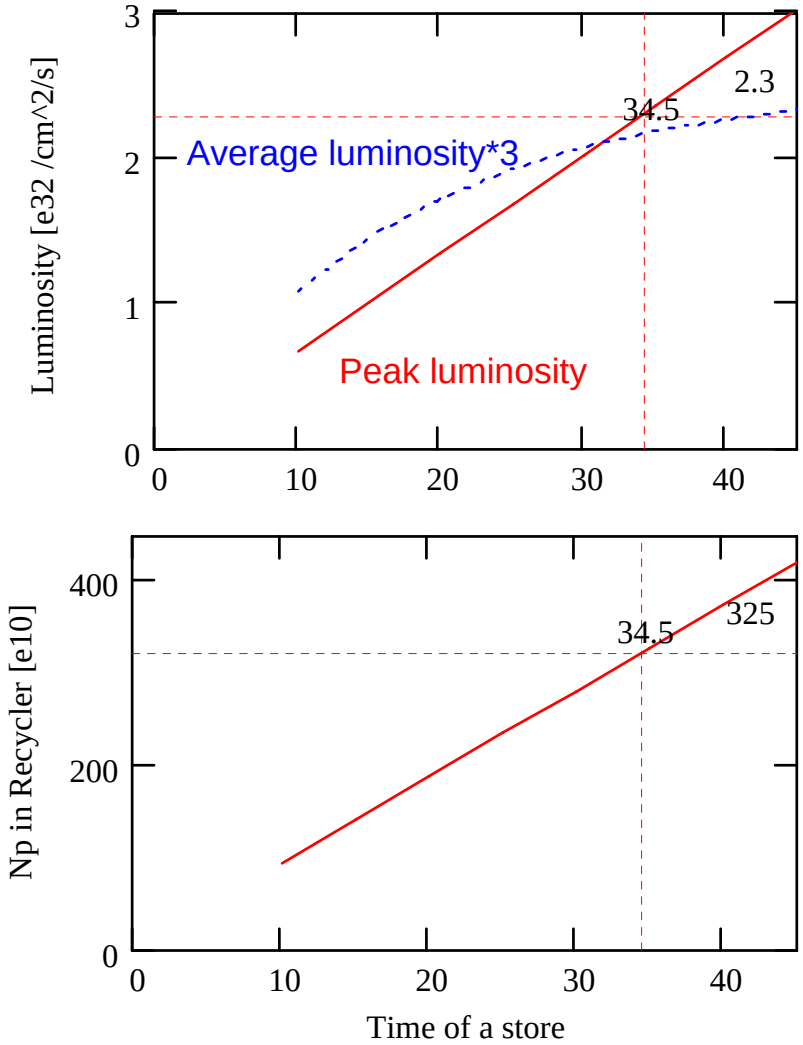


$\delta_p = 0$ $\delta_p = 1.25 \cdot 10^{-4}$

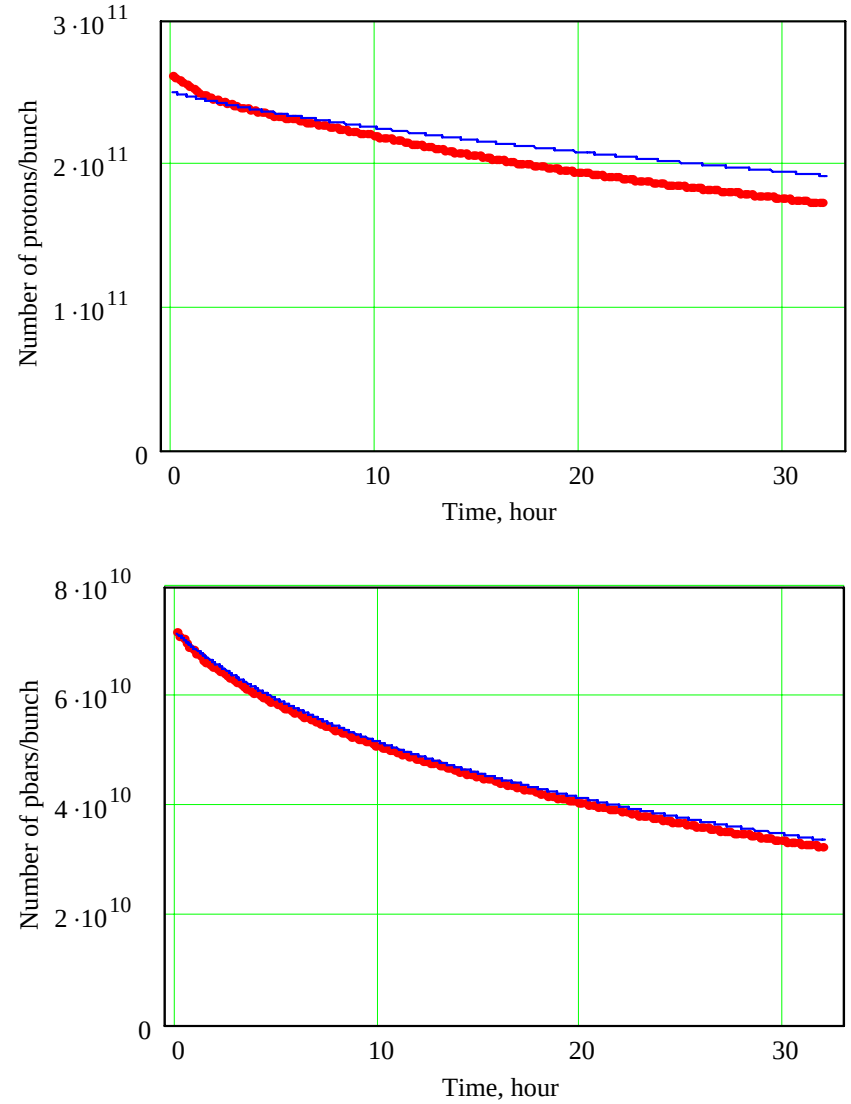
Swing of the normalized transverse amplitudes on the 5th order resonances and their synchrotron satellites at synchrotron amplitude $\delta_p = 0$ (left) and $\delta_p = 1.25 \cdot 10^{-4}$ (right), lattice chromaticity is zero, $\nu_x = 20.585$, $\nu_y = 20.575$.

Courtesy of Yu. Alexahin, DoE review 2003

Dependence of luminosity on Store time



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

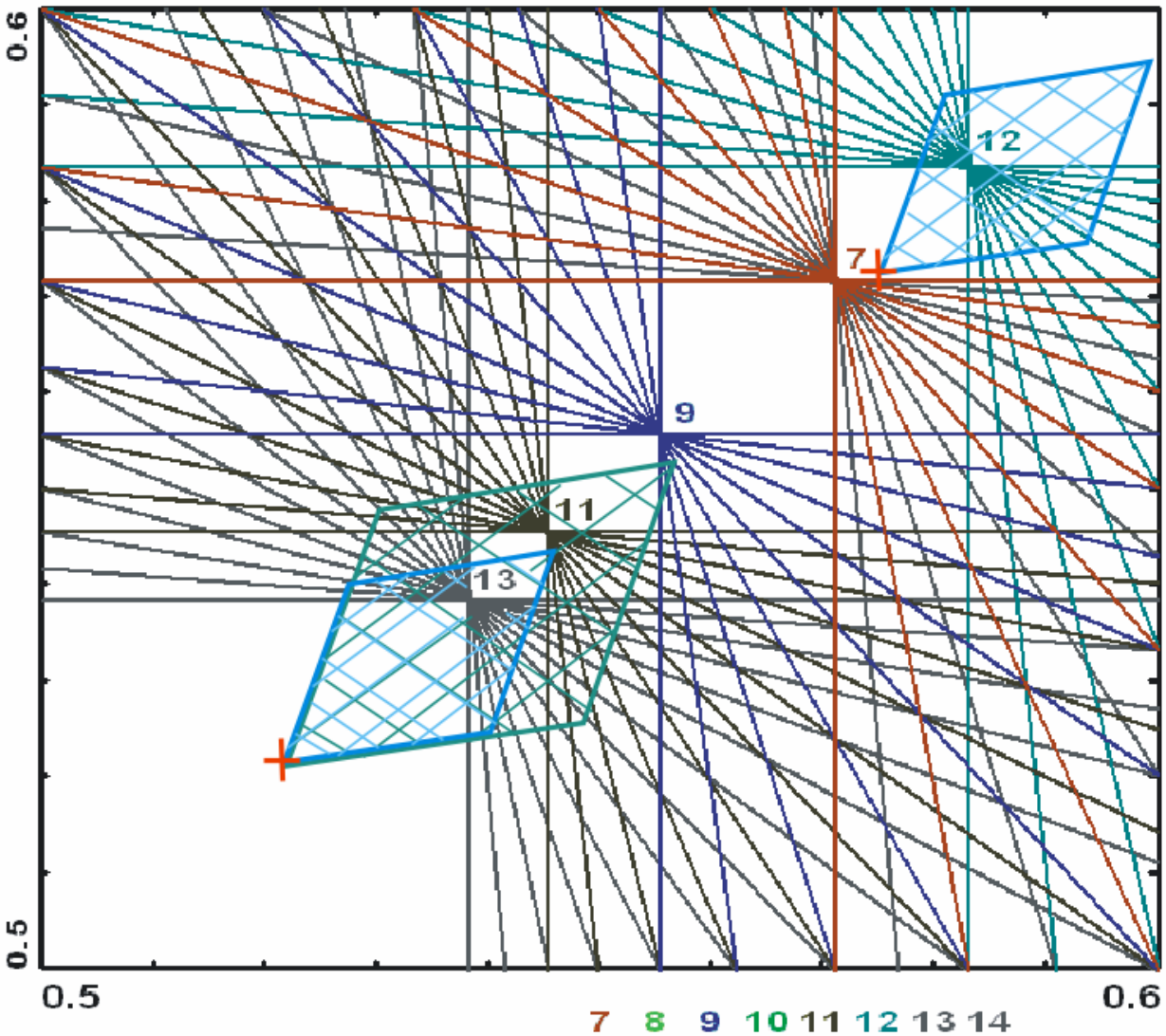


- Beam-beam effects affect protons for store 4949 causing 5% loss of luminosity integral
- 30-35 hour store time looks optimal for present Tevatron performance!!!

Future Tevatron performance

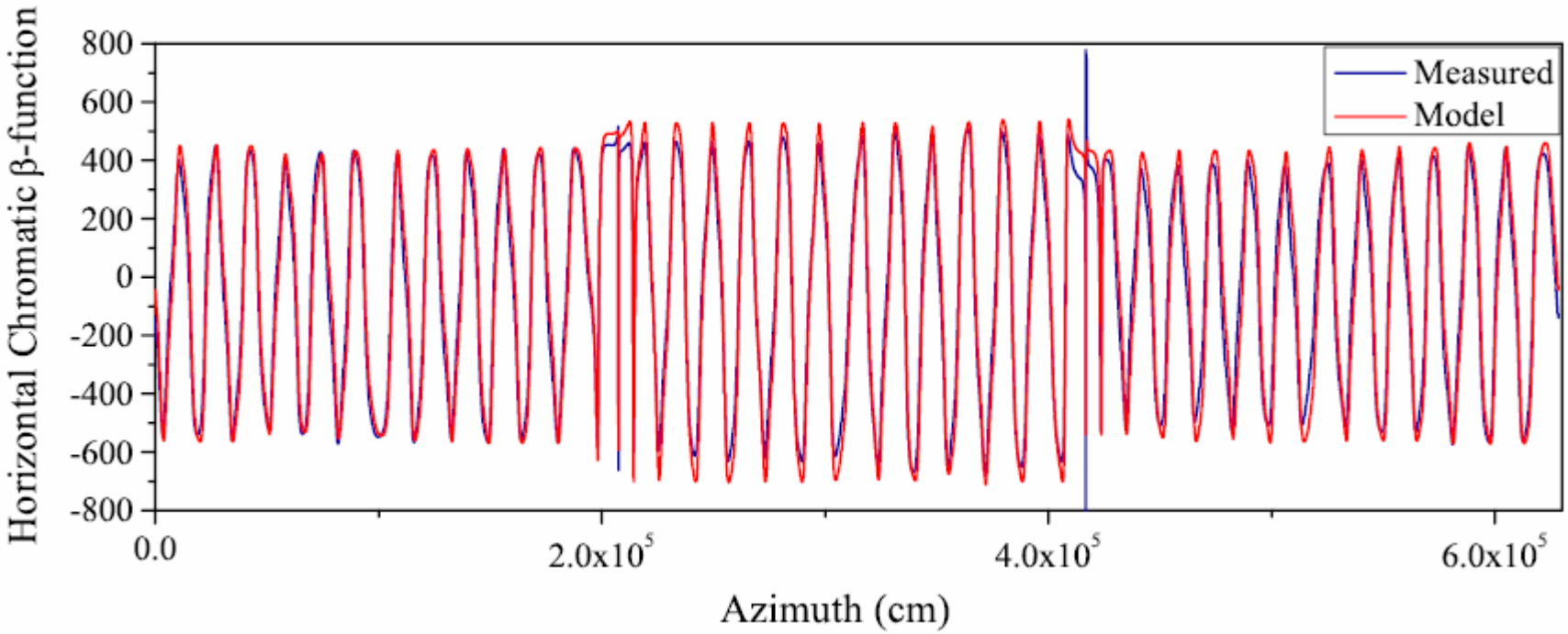
Change of collider tunes

- New working point should allow 40% larger tune spread



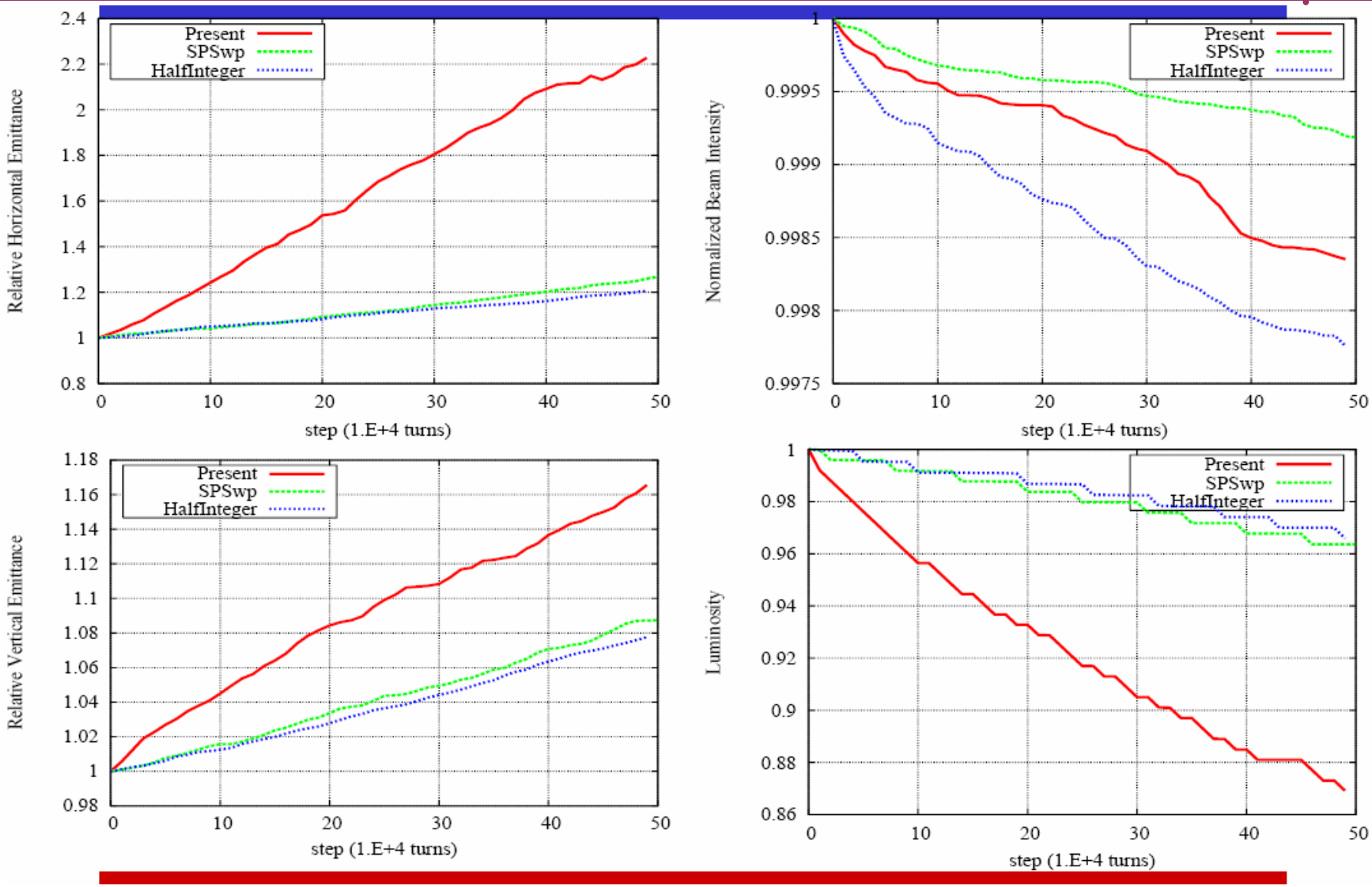
- Higher sensitivity of linear optics to quad strengths and orbit variations (feeddown effect from sextupoles)
- Reconnection of sextupoles to suppress 2-nd order chromaticity!!!
- Further improvements of the model and more detailed simulations are on the way

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**

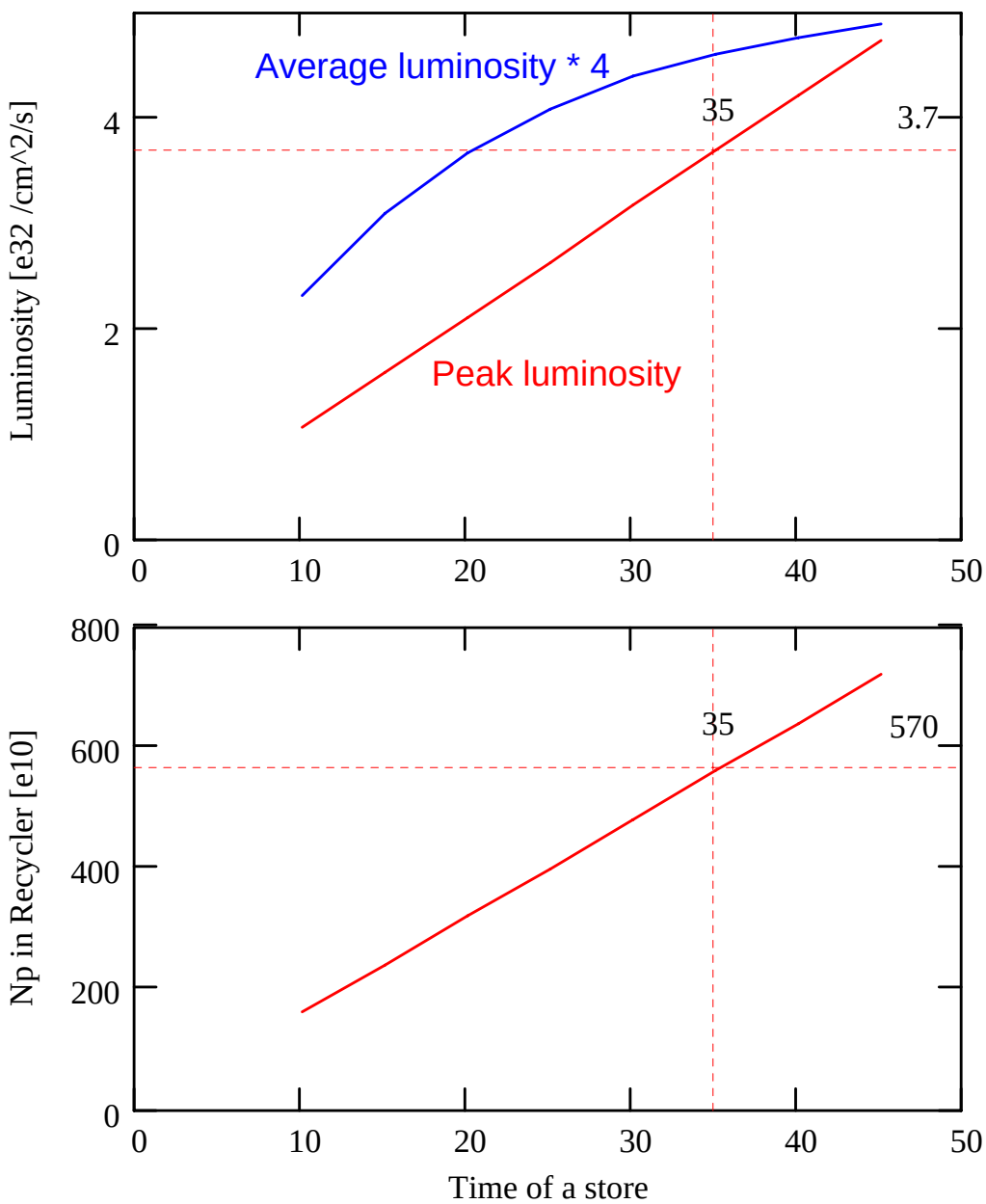


Weak-strong simulations, pbar bunch 6; ε_p=18, ε_{pbar}=12 mm mrad, Np=3·10^{11}

- Simulations show little difference for present proton intensities

** Courtesy of A. Valishev

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

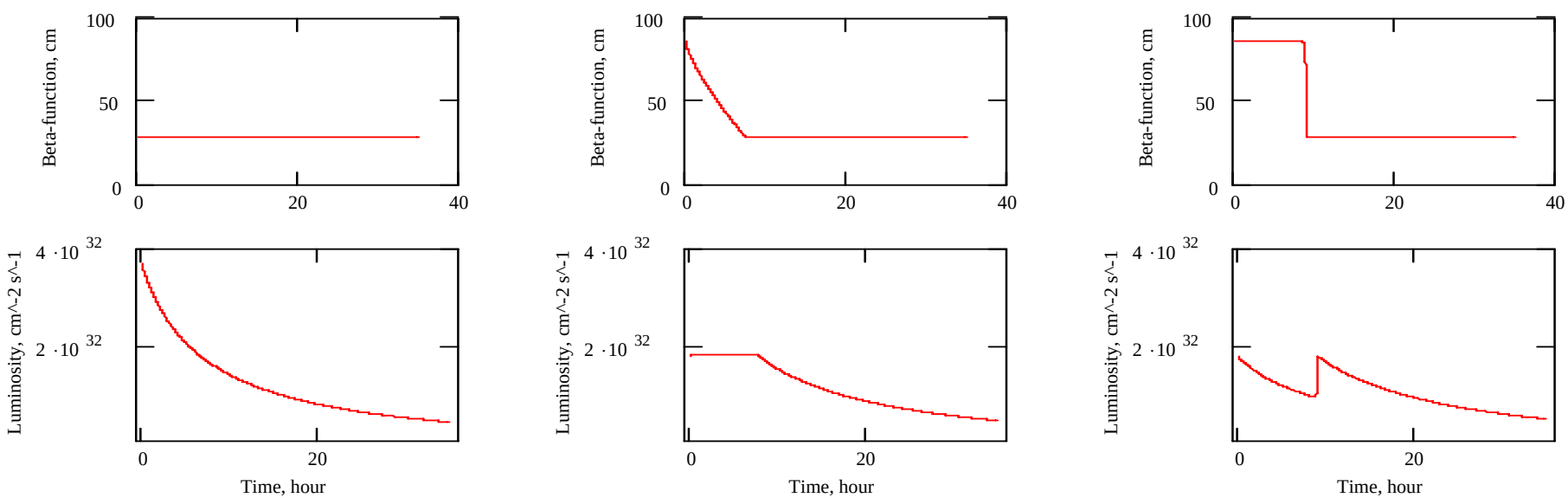
- Longer stores are preferable
  - Limitations come from
    - Recycler (emittance growth and beam loss for large stash)
    - Limitation of pbar intensity in Tevatron are already visible (poor proton lifetime)
    - Operational prudence – if you lose a store you lose a lot of pbars
- Mitigating of beam-beam 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%
Np	$2.70 \cdot 10^{11}$			$2.50 \cdot 10^{11}$	$2.70 \cdot 10^{11}$	$3.20 \cdot 10^{11}$?
Npbar	$1.25 \cdot 10^{11}$			$5.58 \cdot 10^{10}$	$4.80 \cdot 10^{10}$	$4.37 \cdot 10^{10}$
ε_p, mm mrad	18			18	18	20
ε_{pbar}, mm mrad	15			10	8	8

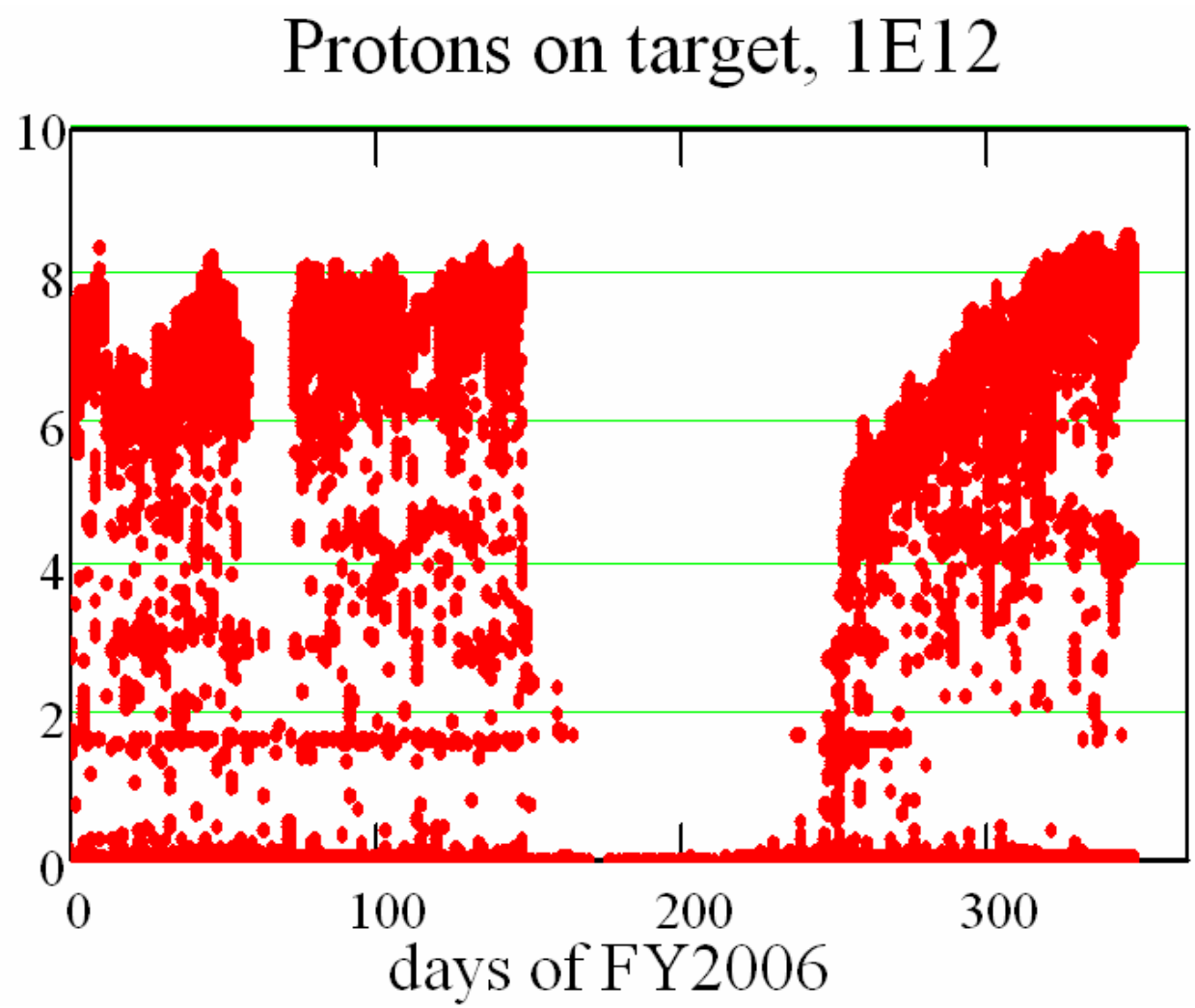
We assume:

- 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

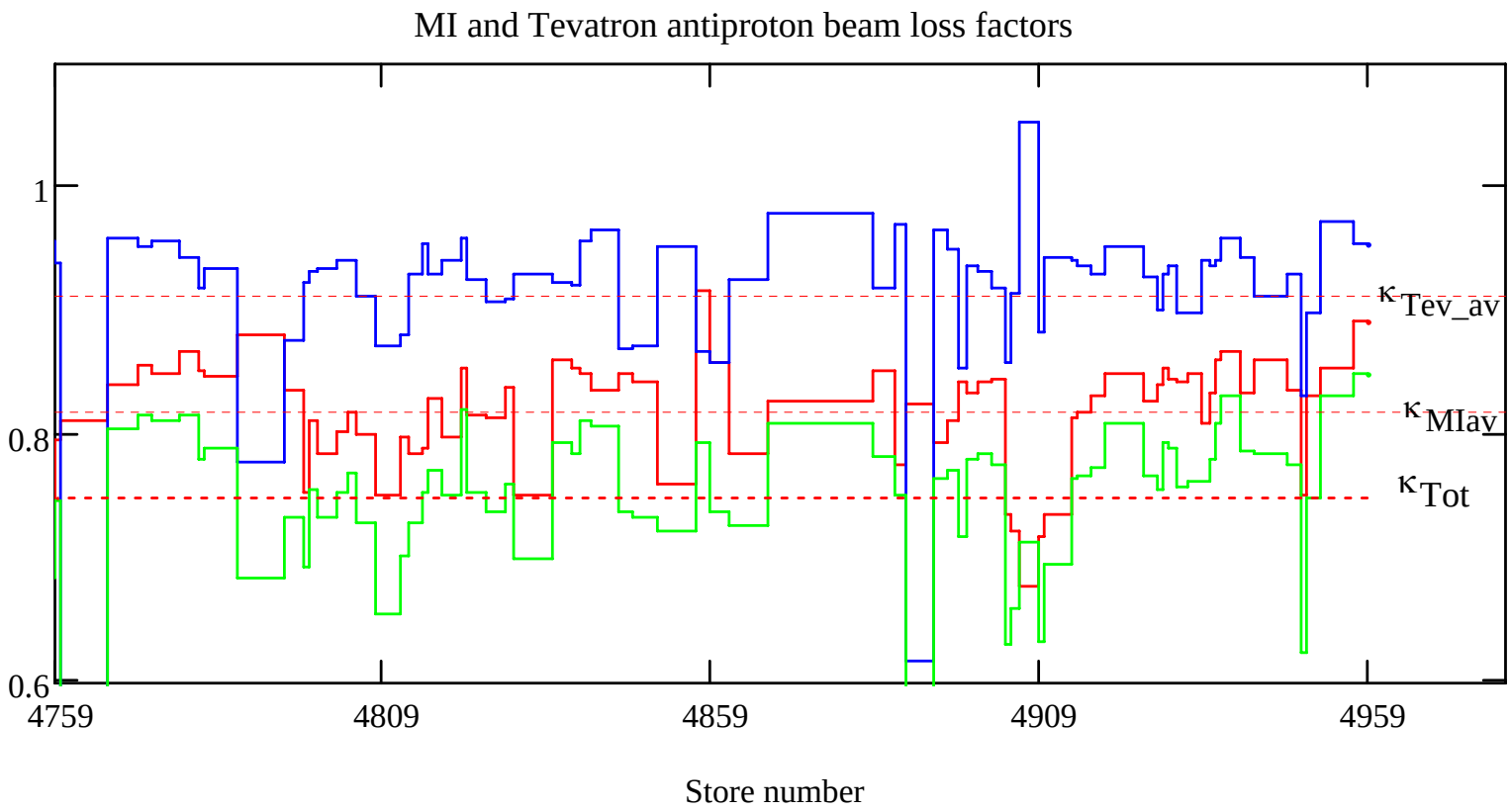
For present and near future staking rates the reduced store time can be used for leveling with very little penalty

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



Pbar Coalescing Efficiency and Acceleration in MI and Tevatron

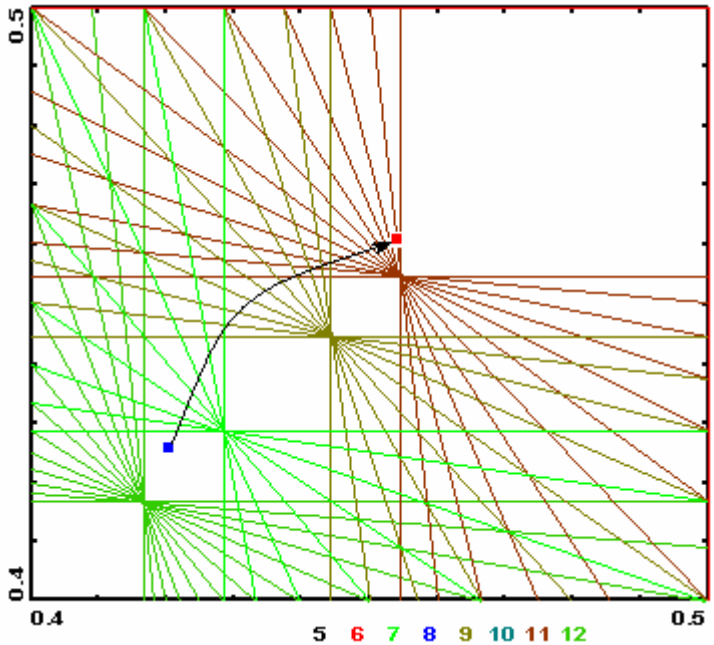


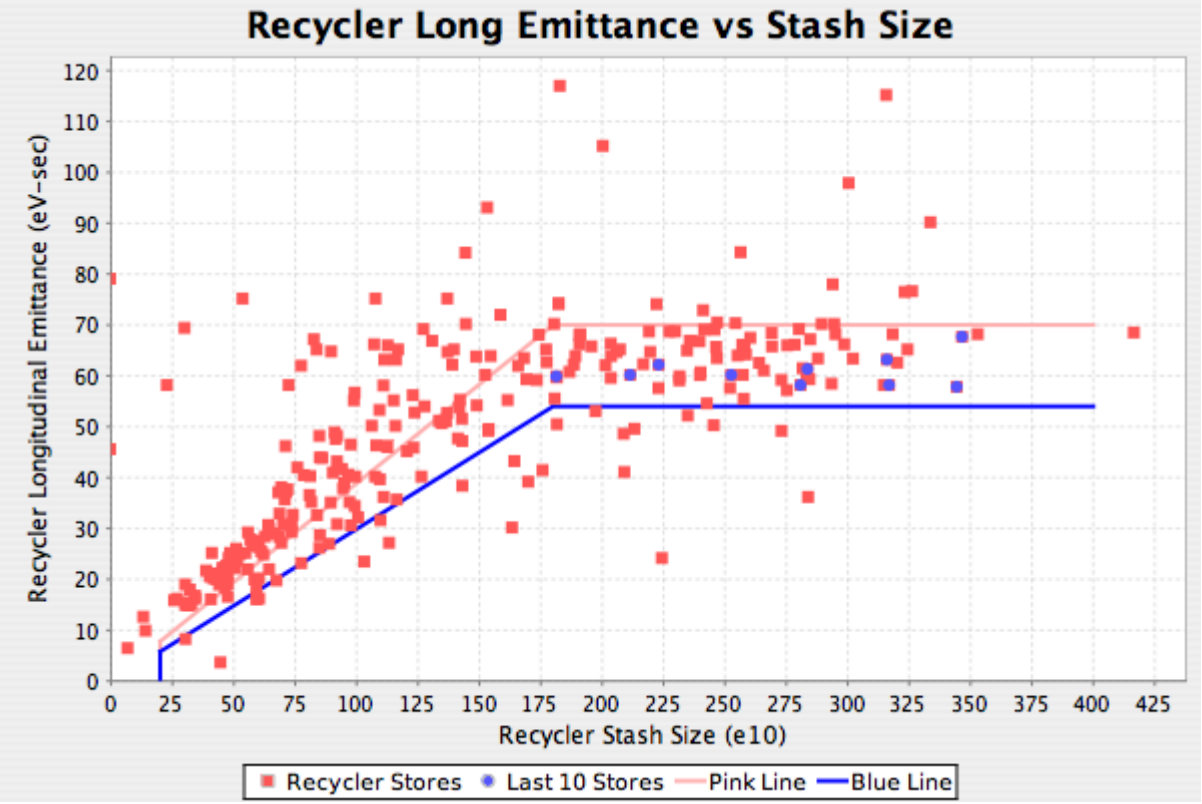
Pbar efficiencies for stores after 2006 shutdown

- 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 ⊥ 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



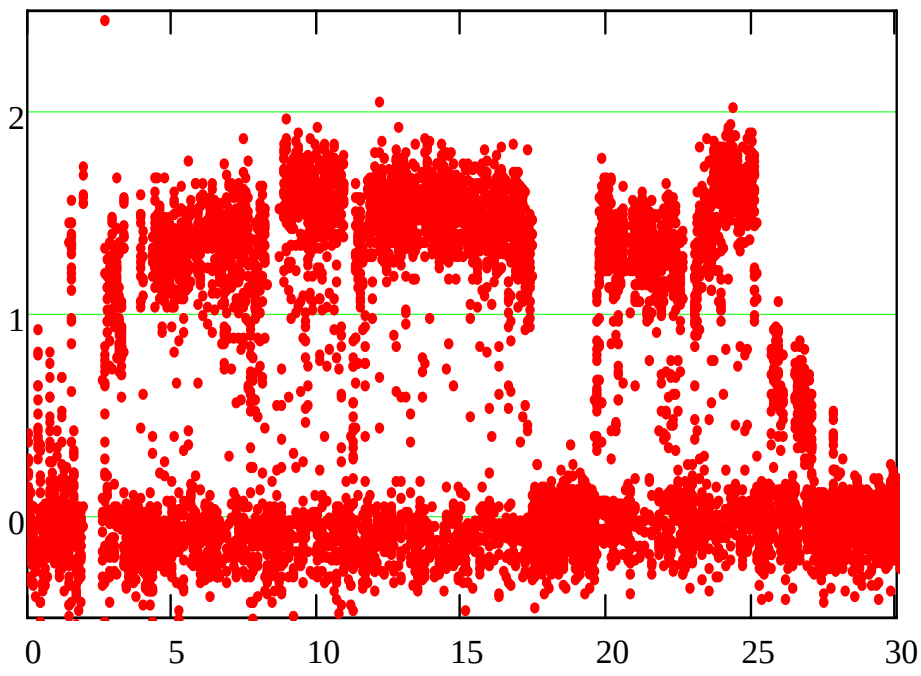


Antiproton source

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

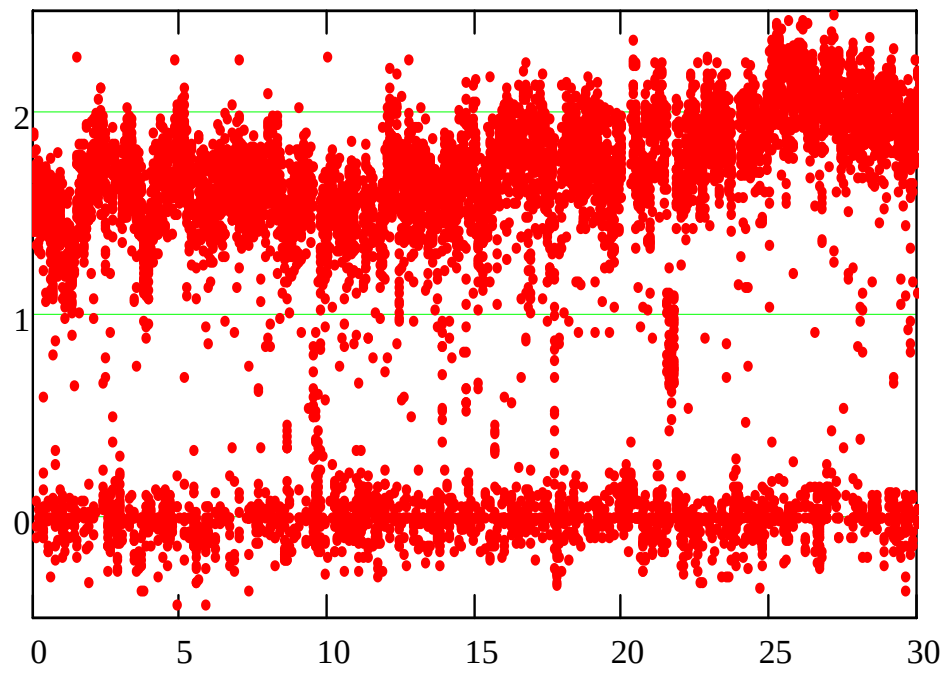
Pbars in Debuncher, 1E8, Jan.28-Feb.28, 2006



Time, days

30 days before shutdown

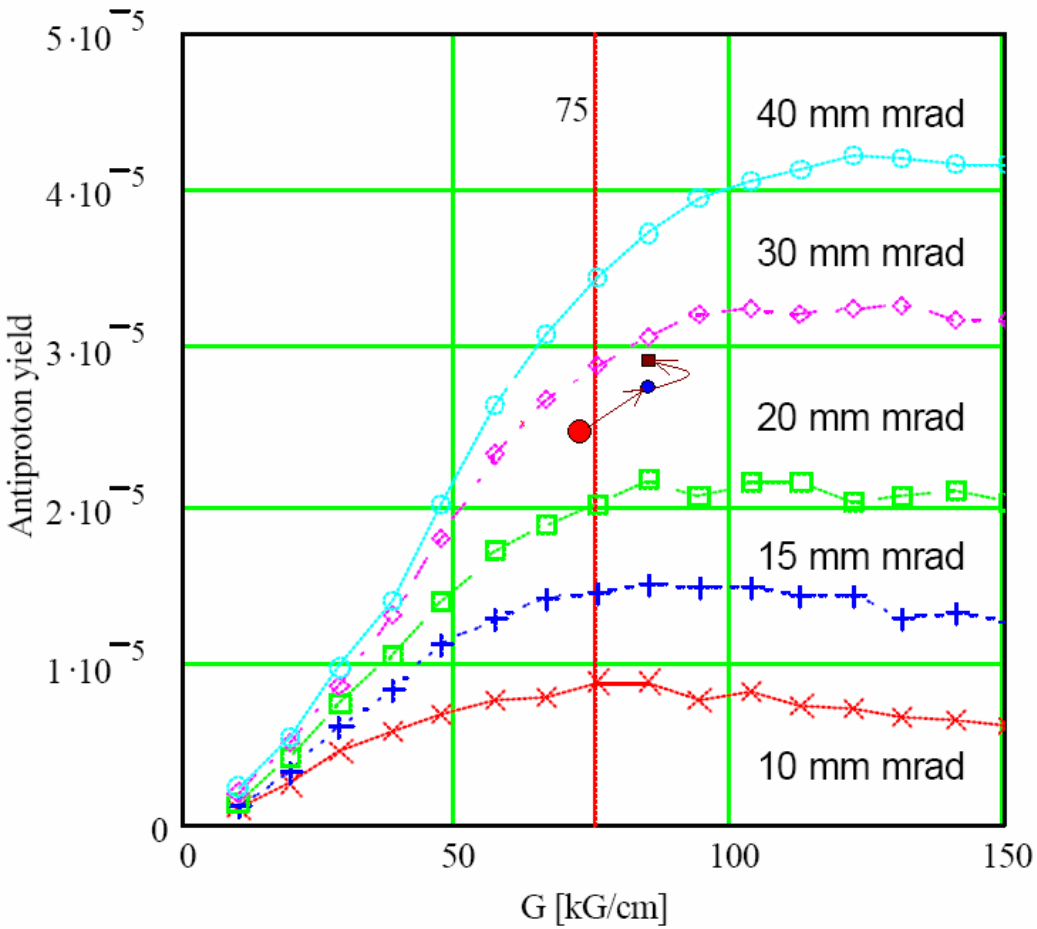
Pbars in Debuncher, 1E8, Aug.13-Sep.13, 20



Time, days

Last 30 days

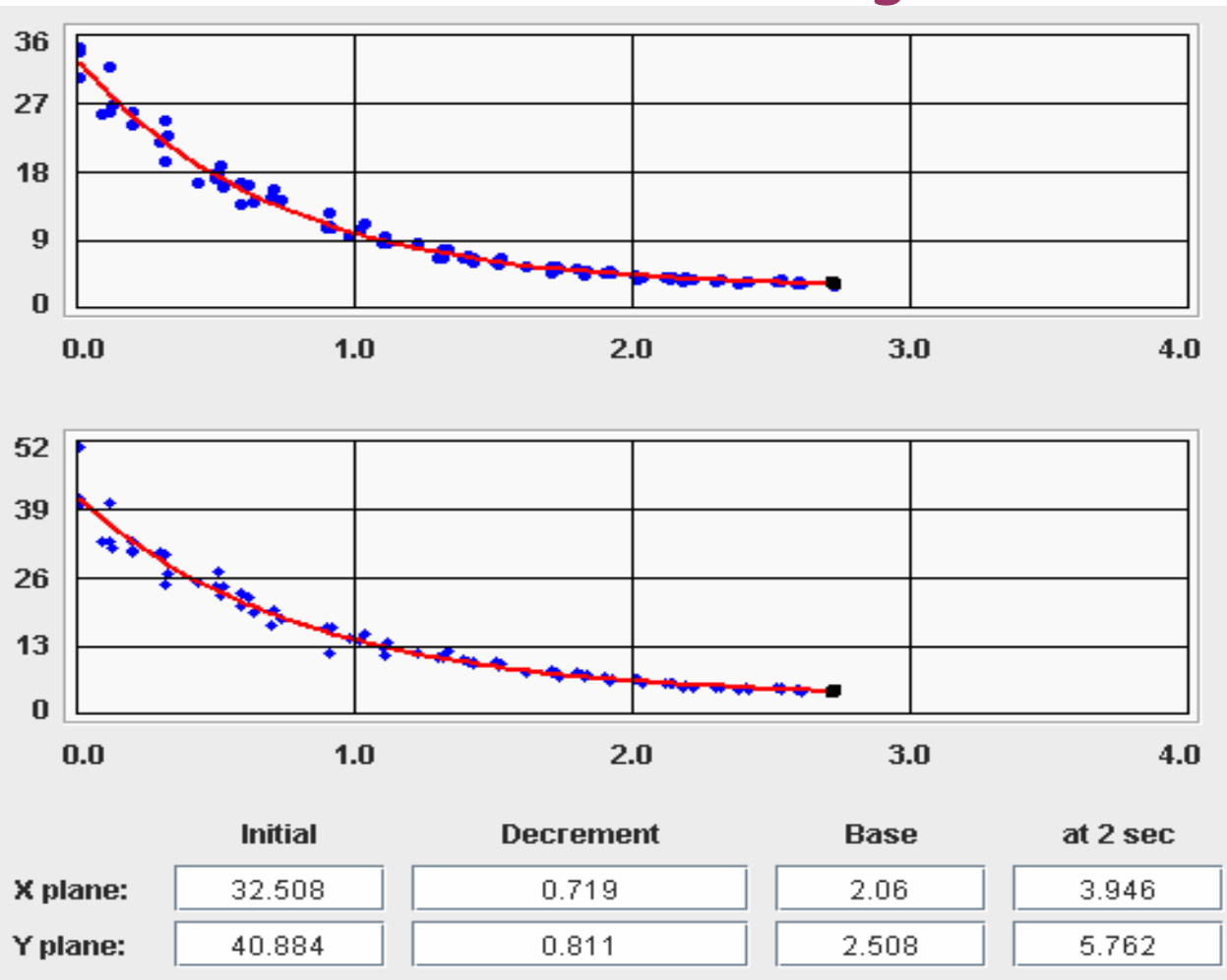
Antiproton yield to Debuncher



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 ($25 \cdot 10^{-6}$ => $29 \cdot 10^{-6}$)
  - 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



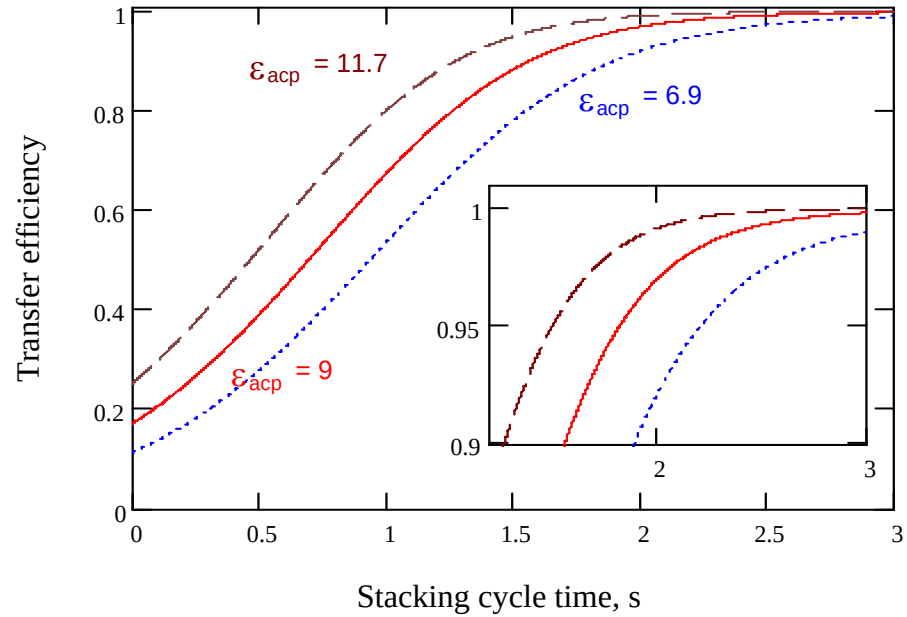
X & Y 95% emittances on time

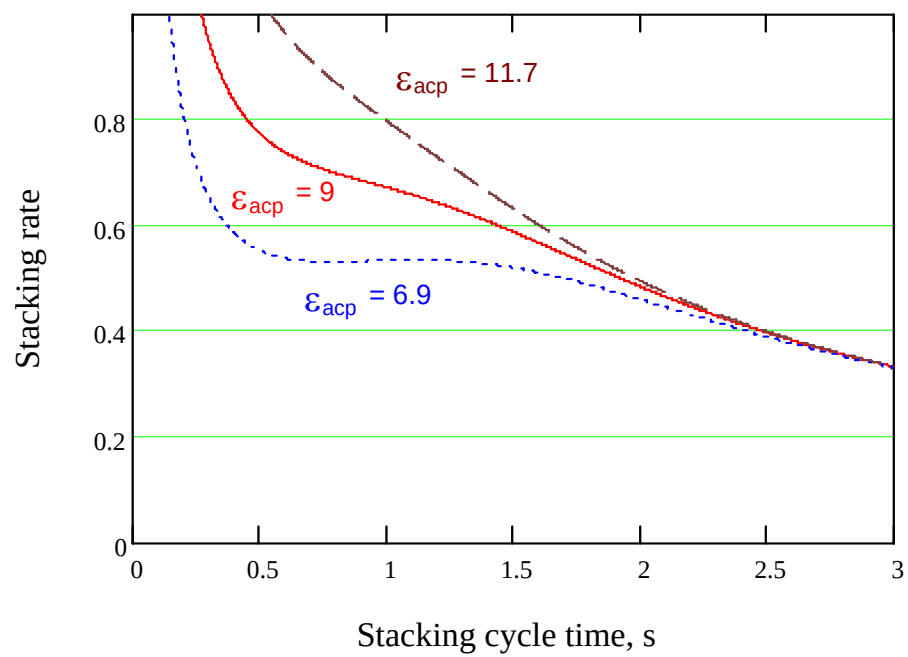
- During 2 s we cool $2 \cdot 10^8$ pbars
  - to $\varepsilon_{H95\%}$= 4 mm mrad
  - and $\varepsilon_{V95\%}$=5.8 mm mrad

- 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

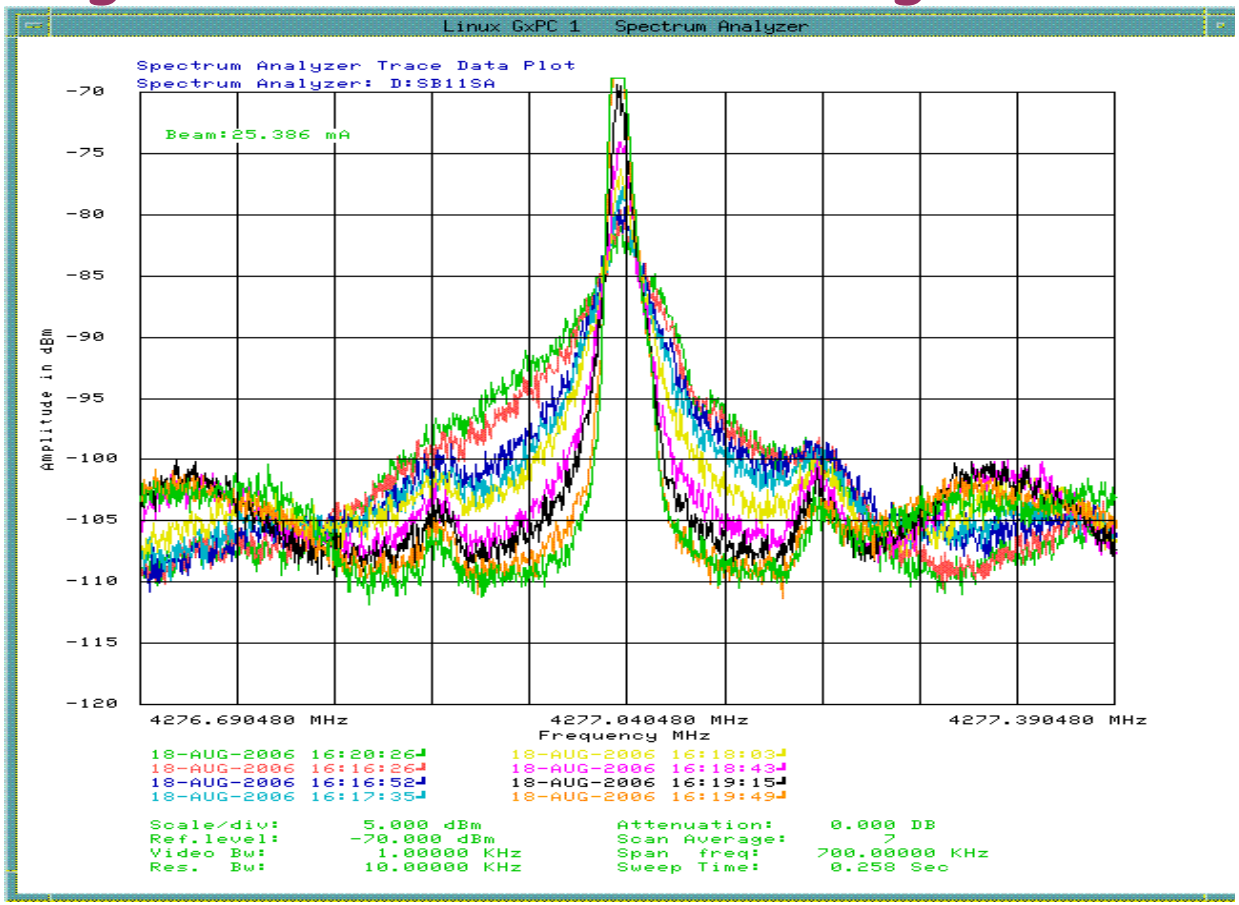
- Transverse cooling determines beam loss for Debuncher-to-Accumulator transfers
- For small Accumulator acceptance there is some transfer loss but it is comparatively small (~8% for ε_{acc}=6.9 mm mrad) even for 2 s stacking cycle
- Thus, improvements of D-to-A line and Accumulator acceptances as well 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

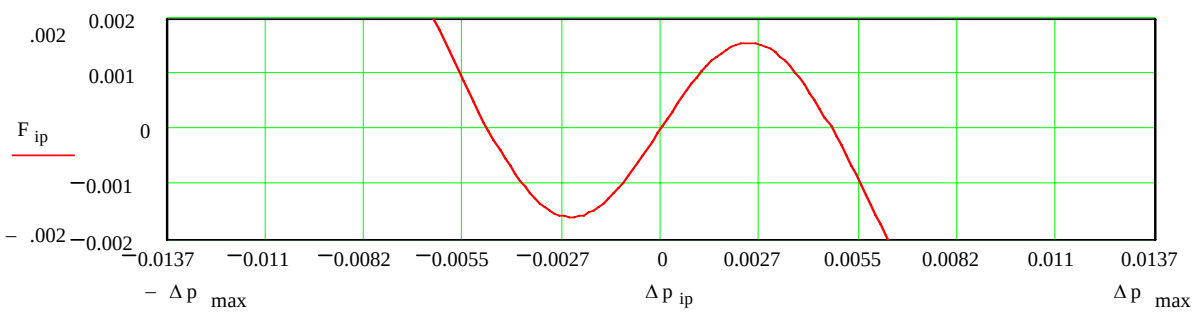




Pictures are built using cooling parameters of previous viewgraph

Longitudinal Debuncher cooling



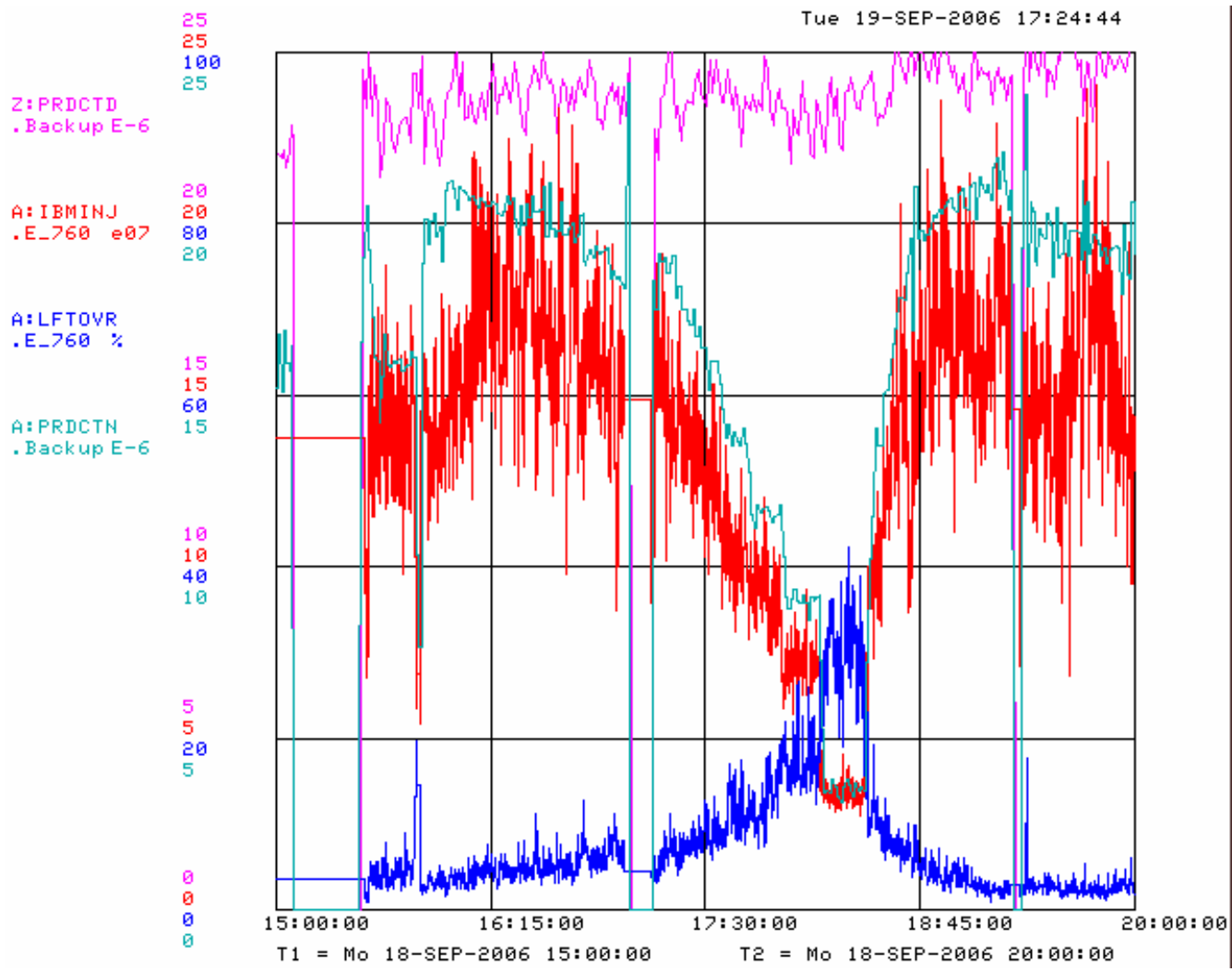


Top: Longitudinal spectra at 0, 0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.6, 2 s
Bottom: Computed dependence of cooling force on momentum

- 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

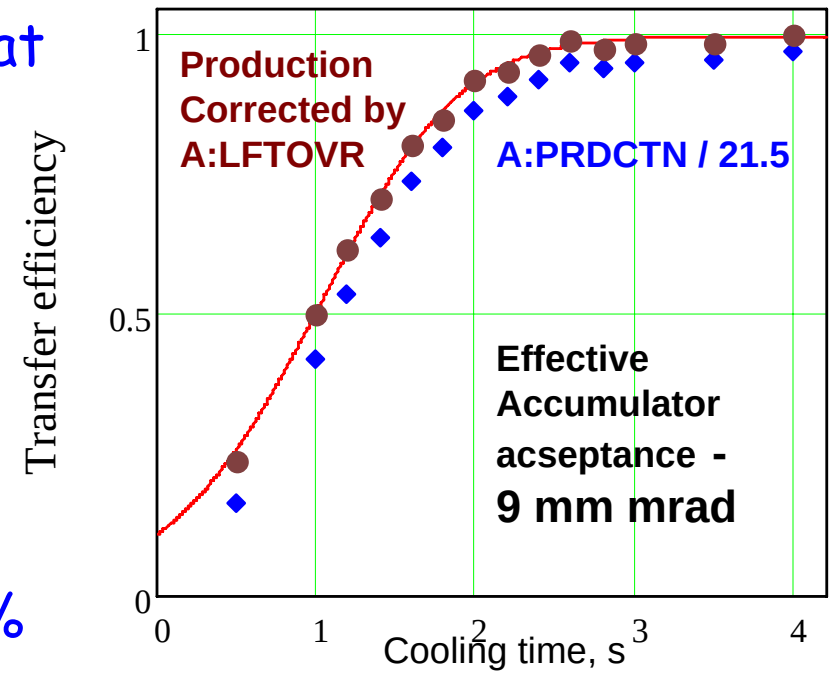
Effective Acceptance of D-to-A line and Accumulator

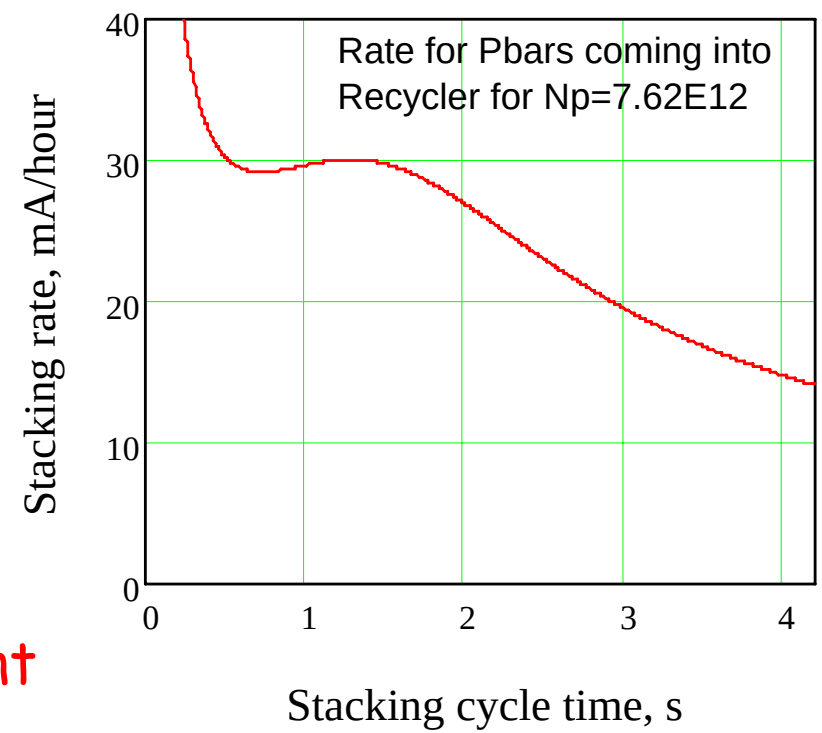
- Stacking rate was measured as function of cooling time for fixed cycle time of 4.0 s[††]
  - For 4 s cooling time the difference in production rate between Debuncher and Accumulator is 13%
  - ~4% is left on injection orbit
  - 10% is unaccounted



[††] Measurements are performed by K, Gollwitzer at Sep.18, 2006

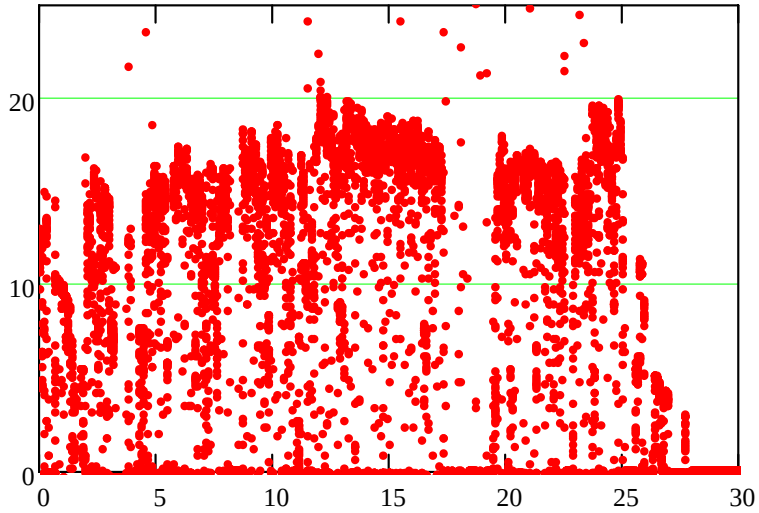
- Fitting of the measurements yields that effective D-to-A & Accumulator acceptance is > 9 mm mrad
  - Very close to the measured Accumulator acceptances
- For 4 s cycle 1% of unaccounted 10% is lost due to aperture limitation. We need to understand where are other 9%
  - Timing
  - Debuncher bunching (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





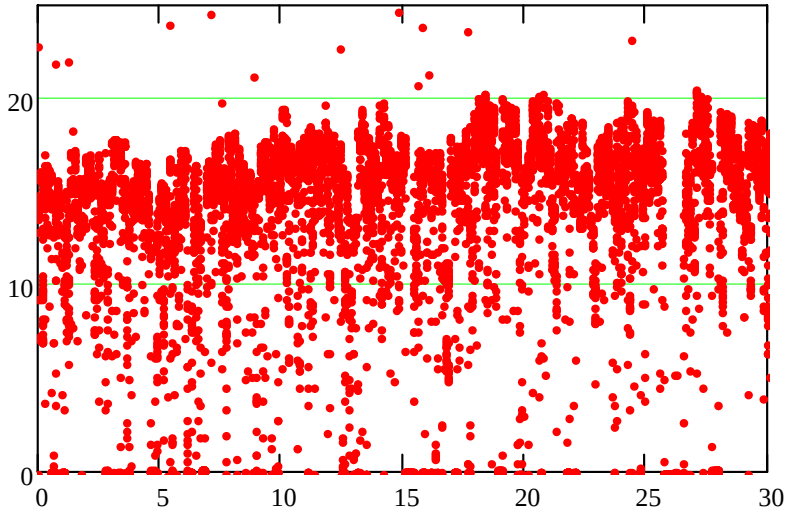
Stacking rate in Accumulator

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



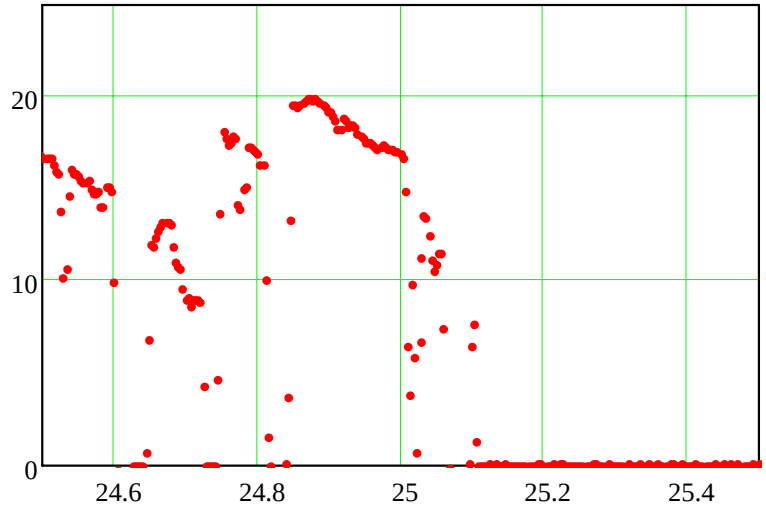
Time, days

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



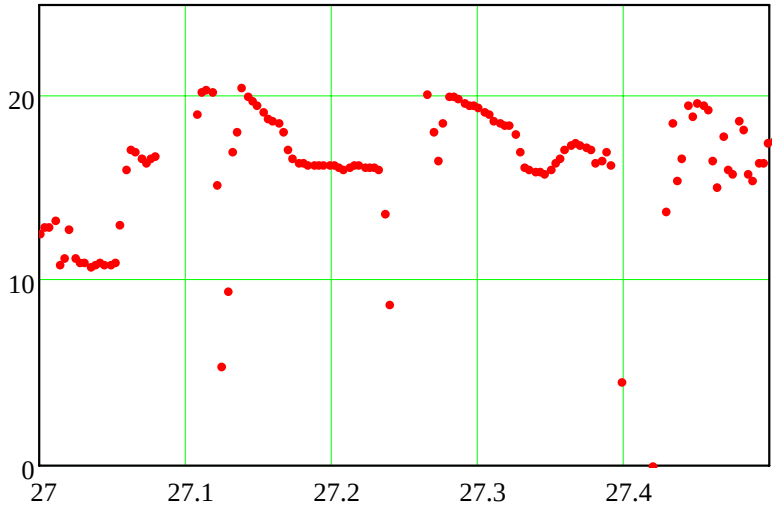
Time, days

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



Time, days

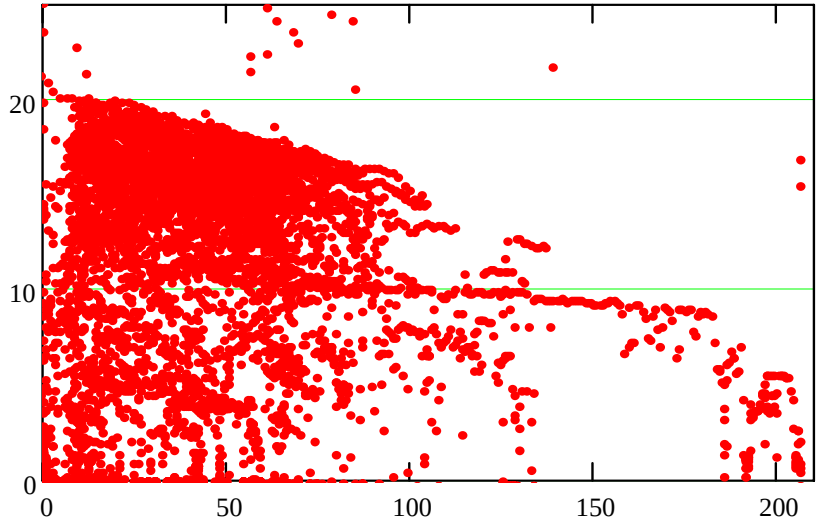
Stacking rate, mA/h, Aug.18-Sep.18, 2006



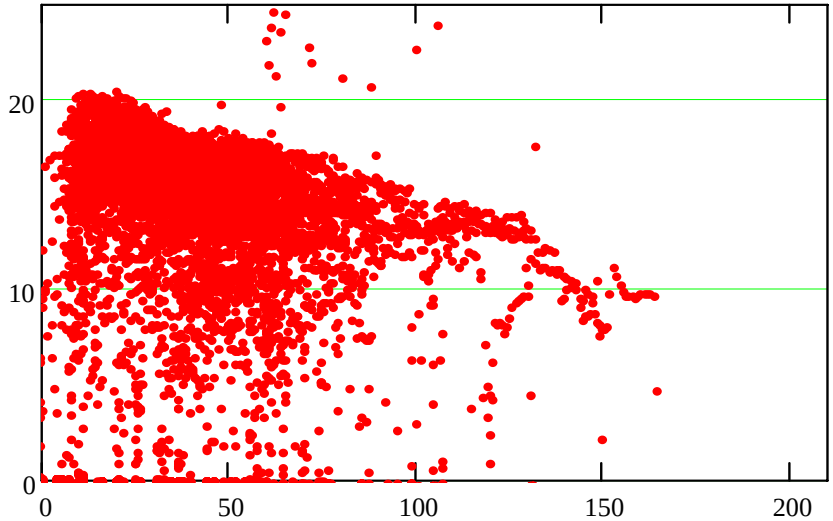
Time, days

Stacking rate in Accumulator (continue)

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

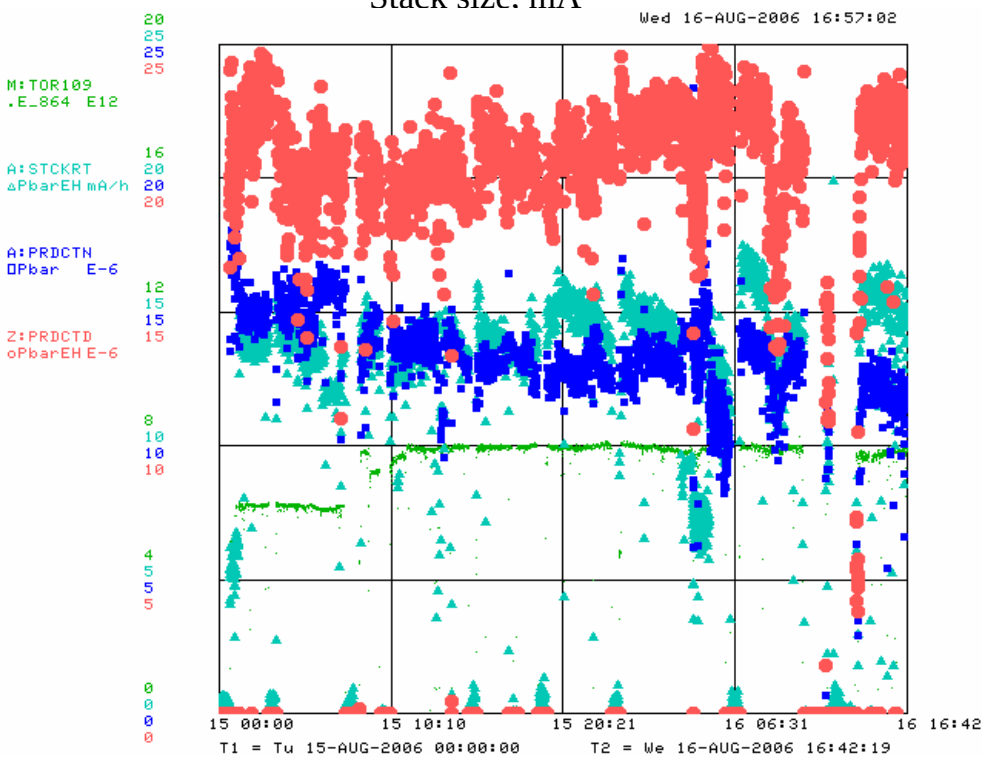


Stacking rate, mA/h, Aug.18-Sep.18, 2006



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

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

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

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

  - 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:

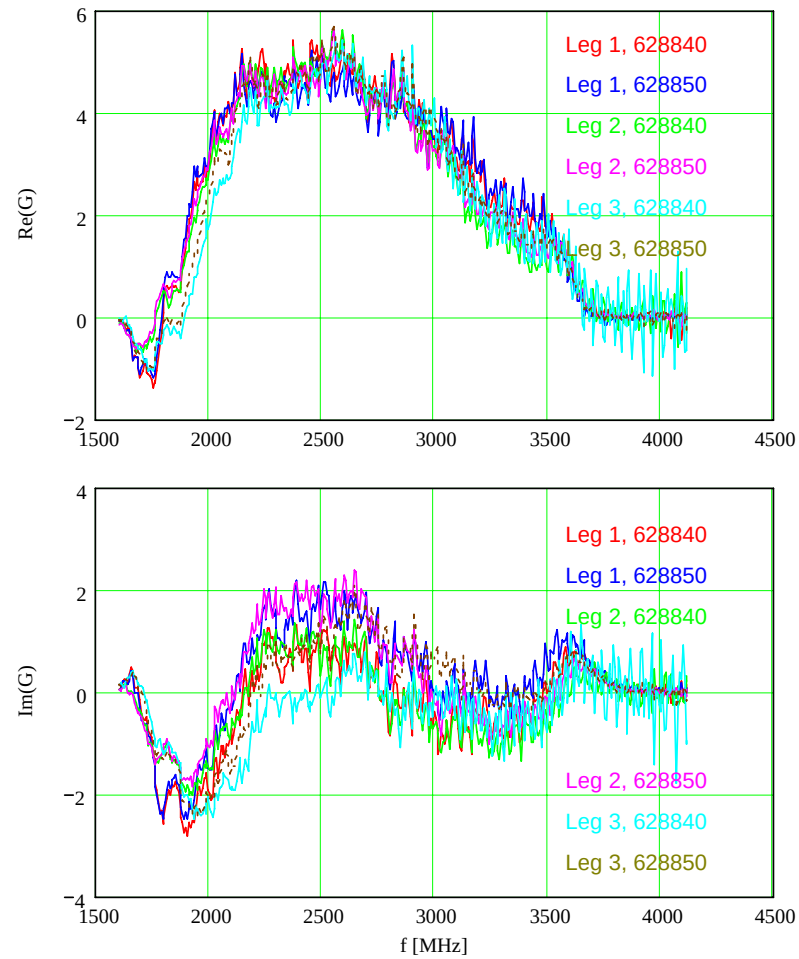
$$J_{\max} = |\eta| x_d T_0 \frac{\left(\int_0^\infty \mathrm{Re}(G_\omega(2\pi f))df\right)^2}{\int_0^\infty |G_\omega(2\pi f)|^2 \frac{df}{f}} \qquad (1)$$

- 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

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



The Real (top) and imaginary (bottom) parts of gain measured in June 2004. All measurements are scaled to present dependence on frequency only.

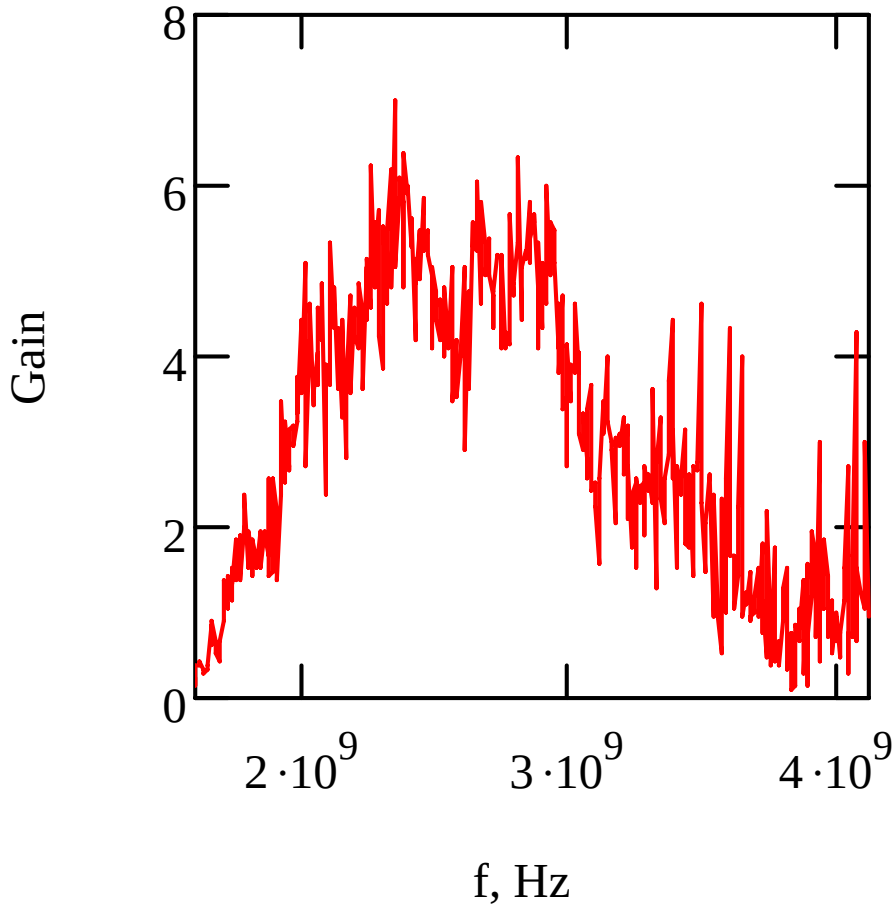
- For the gain measured in 2004 and E_d=10 MeV we obtain from Eq. (1) [‡‡]:

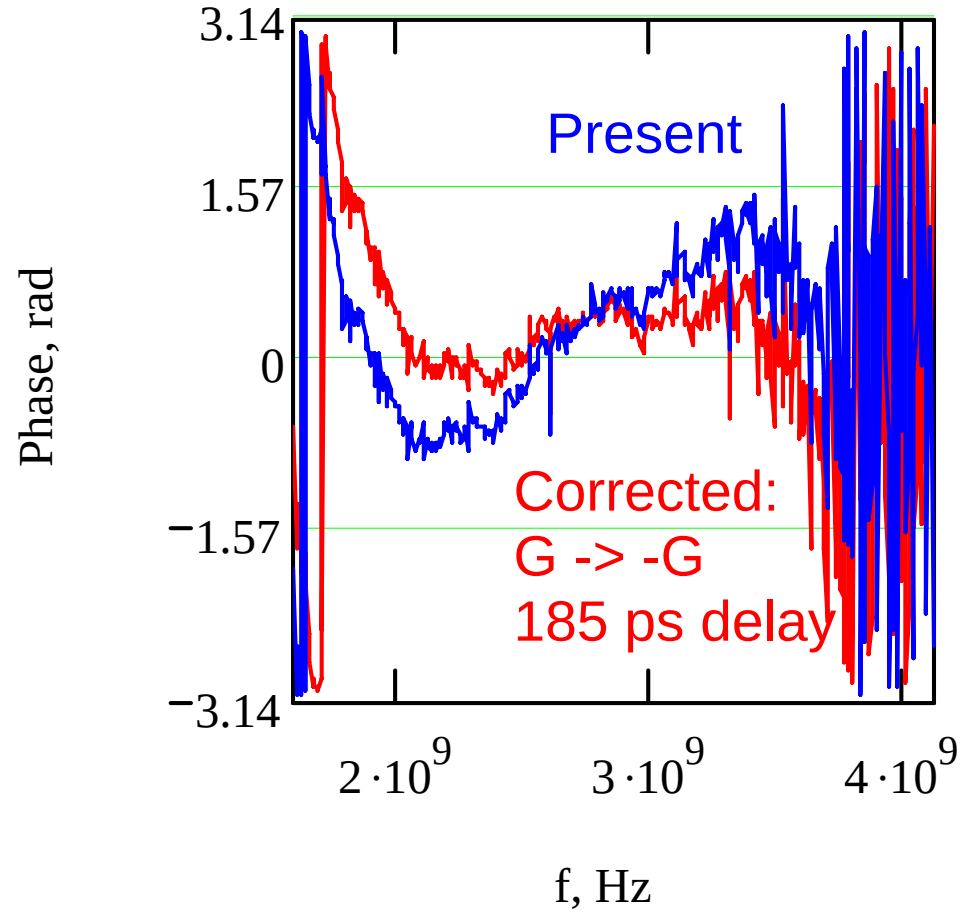
  J_{max}=29 mA/hour

- 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!!!

[‡‡] S. Werkema, Sep. ,2006





- 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

- **Means**
  - 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 Acc Rec	Step Efficiency [%] All Acc Rec	Cumulative Efficiency [%] All Acc Rec
Booster	13244	.	.	.	.	.
Amount unstacked	.	.	.	**3066** ¿½ 3066	.	.
MI 8GeV	11225	84.8	84.8	**3171** ¿½ 3171	**103.4** .0 103.4	**103.4** .0 103.4
MI 150 GeV	10955	97.6	82.7	**3143** ¿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	.	.	.	.

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	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

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	.	.	.

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

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

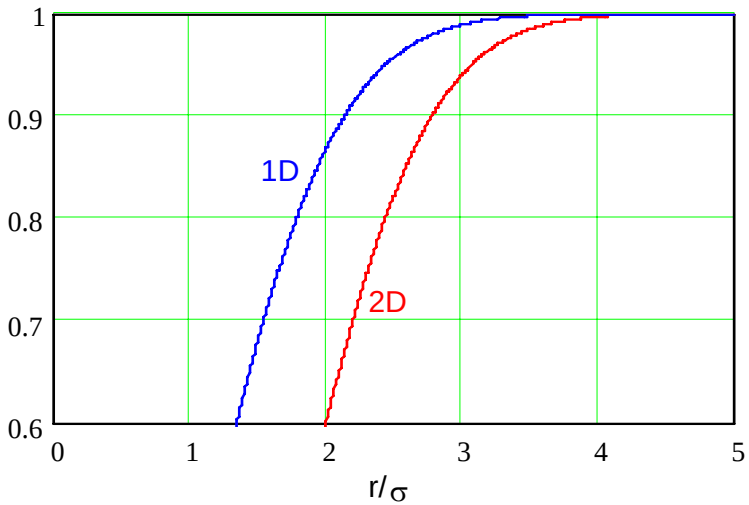
Debuncher cooling

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):

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



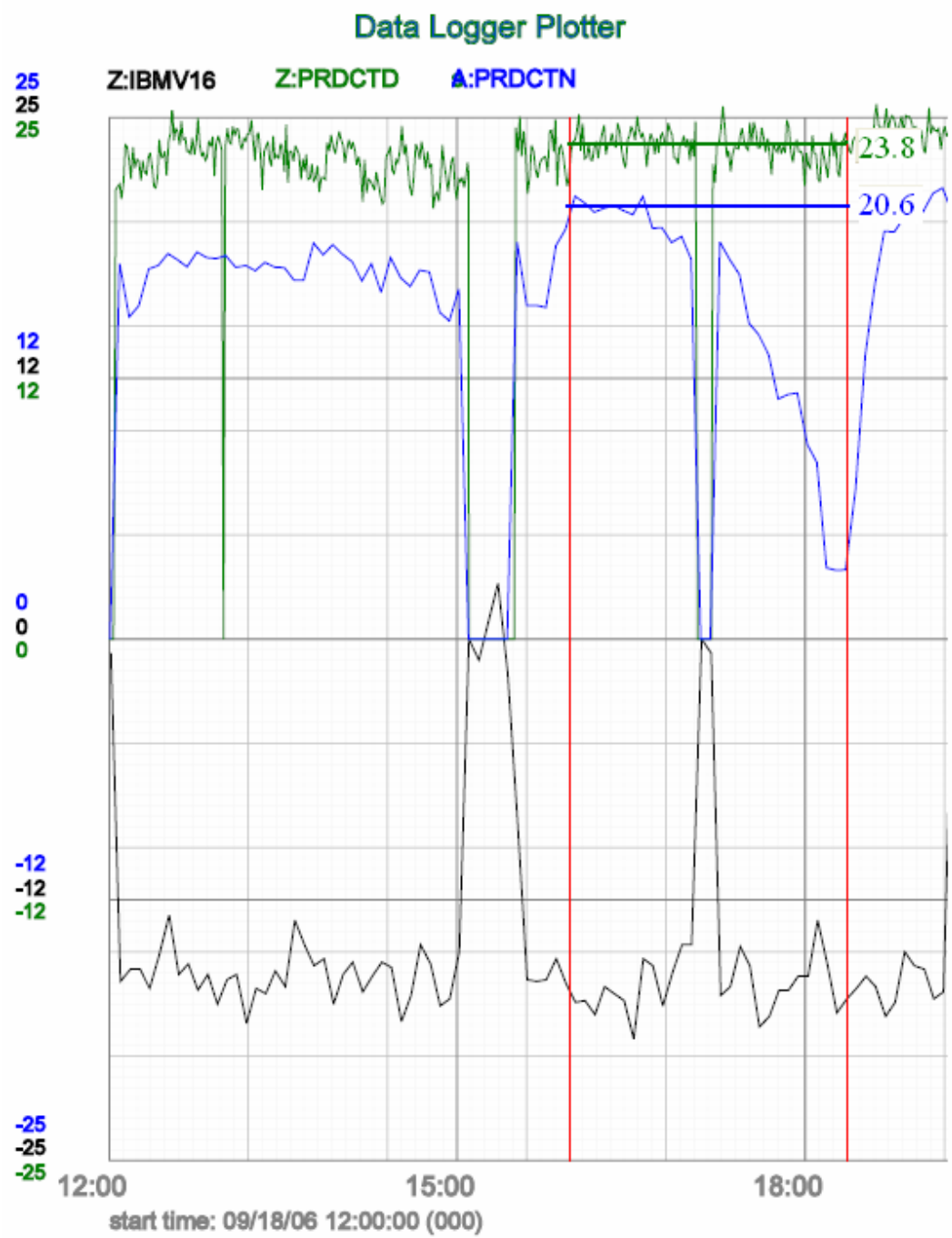
Dependance of fraction of survived particles on vacuum chamber size (r/σ)

Longitudinal cooling formulas

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

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

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


Data Logger Plotter
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