Fermilab

Leveling with β*

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Contents

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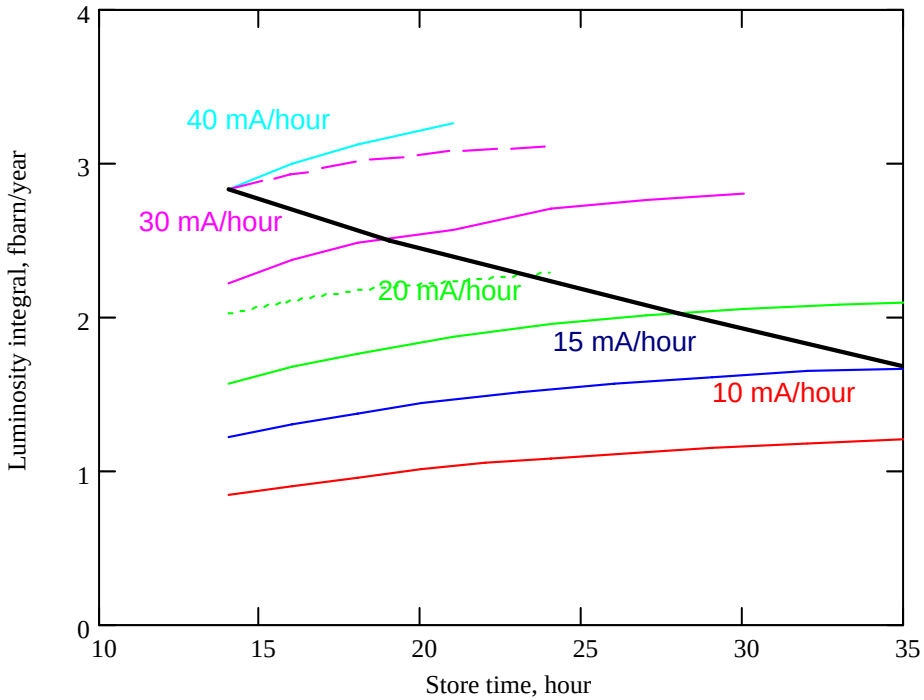
Tevatron Experience

- Three projects which were considered as a high priority at the beginning of Run II were discarded in the course of upgrades
  - Recycling of antiprotons
  - Transition from 36×36 to 103×103 bunches
  - Luminosity leveling
- The last two were aimed at reduction of the peak luminosity per collision
- The first one (Antiproton recycling) was indirectly aimed to the same goal

Tevatron Experience (continue)

Antiproton recycling

- In the case of long stores there is small number of particles left at the store end and they have large emittances. That means there is not much to recycle.
- The expected gain was only 10% versus ~(30-50)% estimated earlier
  - Separate optimization with and without recycling reduced the gain of recycling
  - If one takes into account ~1 hour time for recycling the gain basically disappears
- The recycling project was stopped in 2003
- As result we are running 25 hour stores instead of 12 hour ones
  - That makes large variation of luminosity



Solid lines – no recycling
Dashed lines – with recycling
Solid black line $N_{pbar}=1.35\cdot10^{11}$ /bunch
**FNAL AAC, February 4-6, 2003*

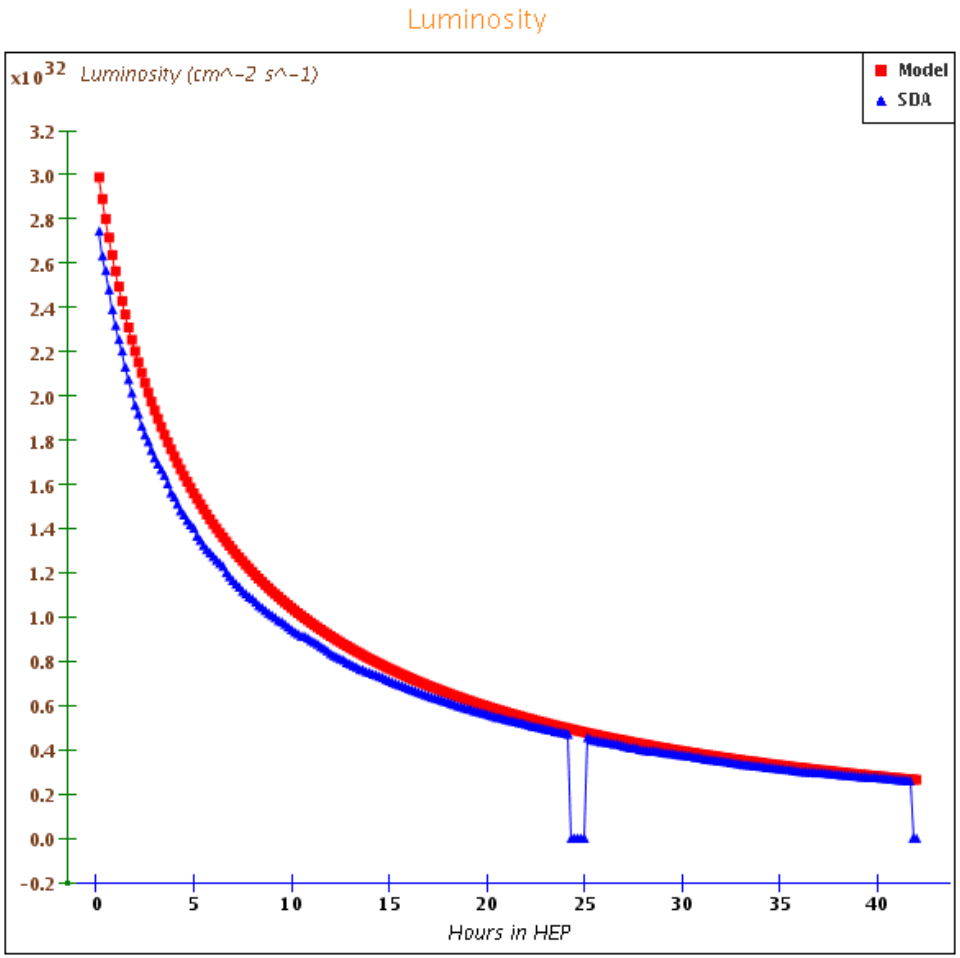
Tevatron Experience (continue)

Transition from 36×36 to 103×103 bunches

- The use of 103 bunches would require 3 times larger number of protons in Tevatron. It would compromise the beam stability
  ⇒ transverse damper ⇒ emittance growth due to damper
- The project was stopped in 2003

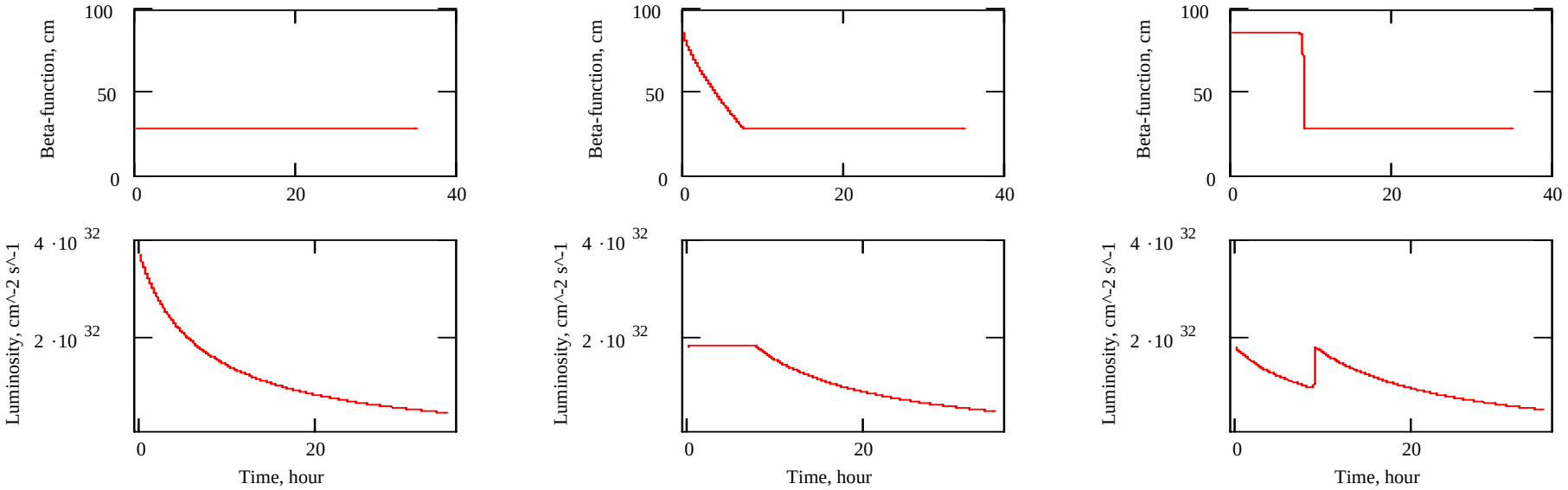
Luminosity leveling

- Project was never discarded but never got sufficiently high priority to be considered seriously
- Typical luminosity variation during store is 5-6 times
- Any luminosity leveling would affect the luminosity integral
- CDF and D0 can operate at present maximum luminosity
  - Maximum number of collisions per crossing ~10 (σ=60 mb, L=2.9·10^{32})



Luminosity Leveling in Tevatron

- Any luminosity leveling results in a reduced luminosity integral
- (1) Smooth (multi-step) beta-function change during the store is close to impossible to implement in operations
- (2) Single step beta-function change looks promising
  - Significant time for commissioning
  - More complicated operations – larger probability to lose the store. ~1-5 min stop for data acquisition during the beta-function change
- (3) Reduced store duration
  - Easy to do. Does not require any praparations



Luminosity leveling (continue)

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

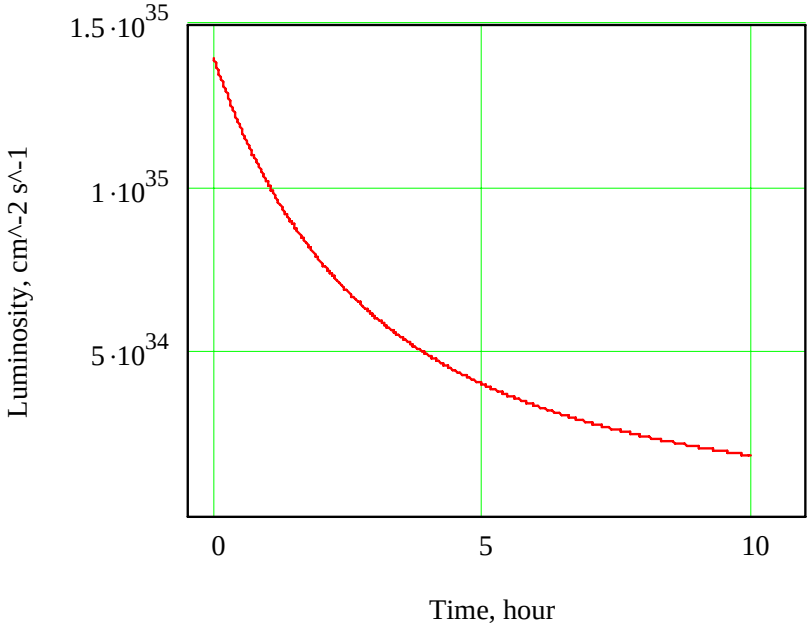
For present and near future staking rates the reduced store time can be used for leveling with very little penalty

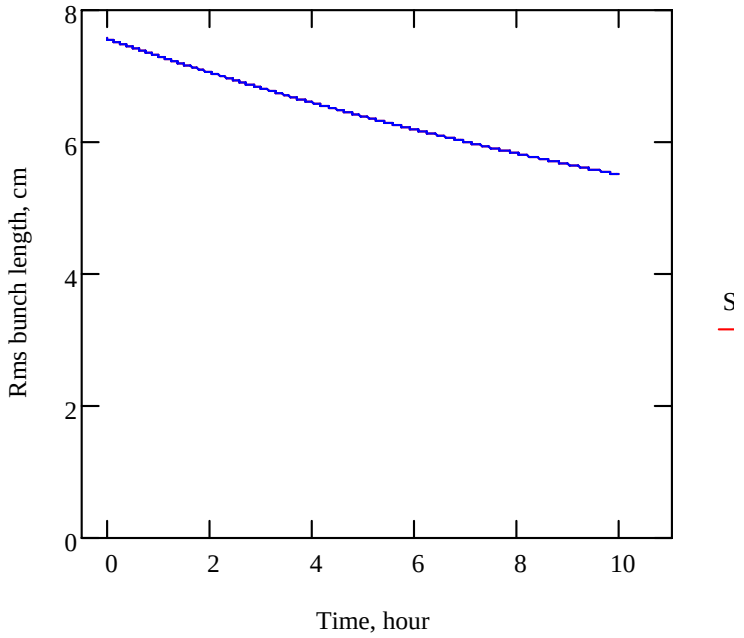
Is Luminosity Leveling going to happen in Tevatron?

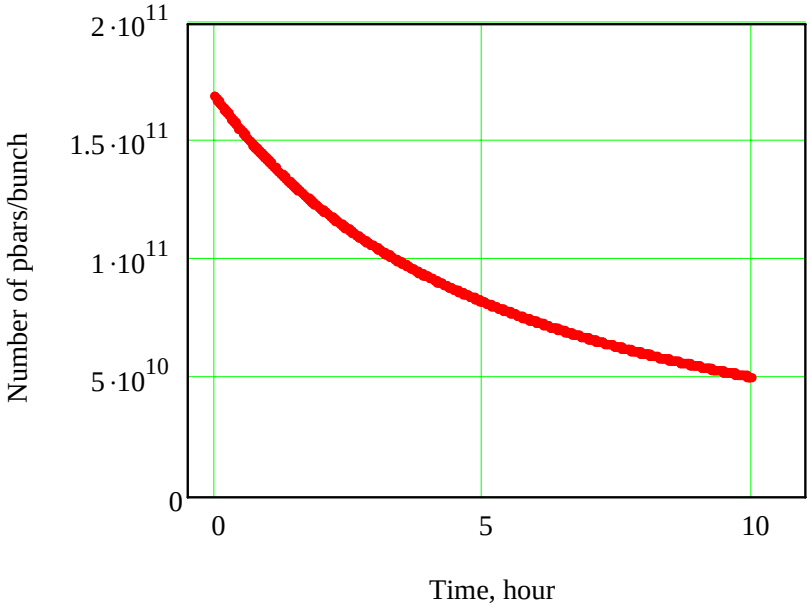
- When in collisions Tevatron is extremely sensitive to any optics change
- Therefore the only scheme which was seriously discussed is the single step beta-function change
- It requires ~5 min to perform the following steps
  - Beam separation in IPs
  - Optics and helix adjustments
  - Bringing beams back to collisions
  - Rescraping
- Implementation of such a scheme would require considerable study time and would result in 10-20% loss of the luminosity integral
- Presently both detector collaborations can operate on the highest luminosities we managed to deliver
  - It is much easier to reduce the store time and, consequently, the number of pbars and the peak luminosity
- It looks like that the luminosity leveling will never be implemented in the course of Tevatron Run II

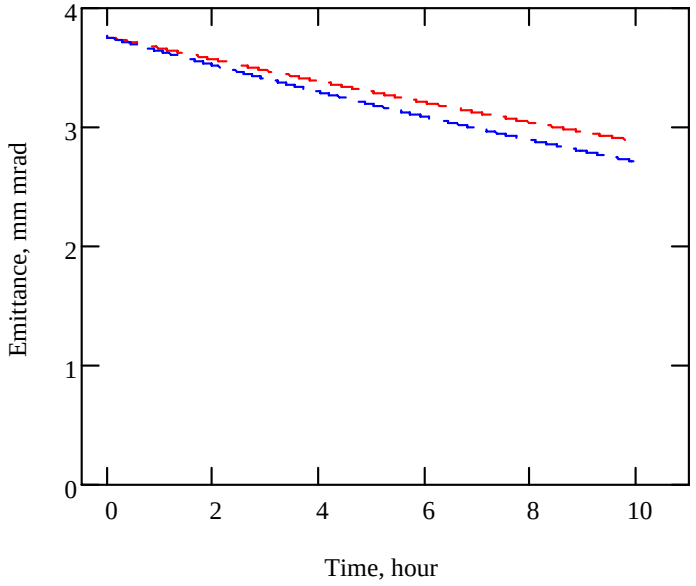
Luminosity leveling for the SLHC

- Luminosity evolution is almost entirely set by particle loss in IP









Luminosity evolution without leveling

- Neglecting other mechanisms one can build a simple model for the luminosity evolution

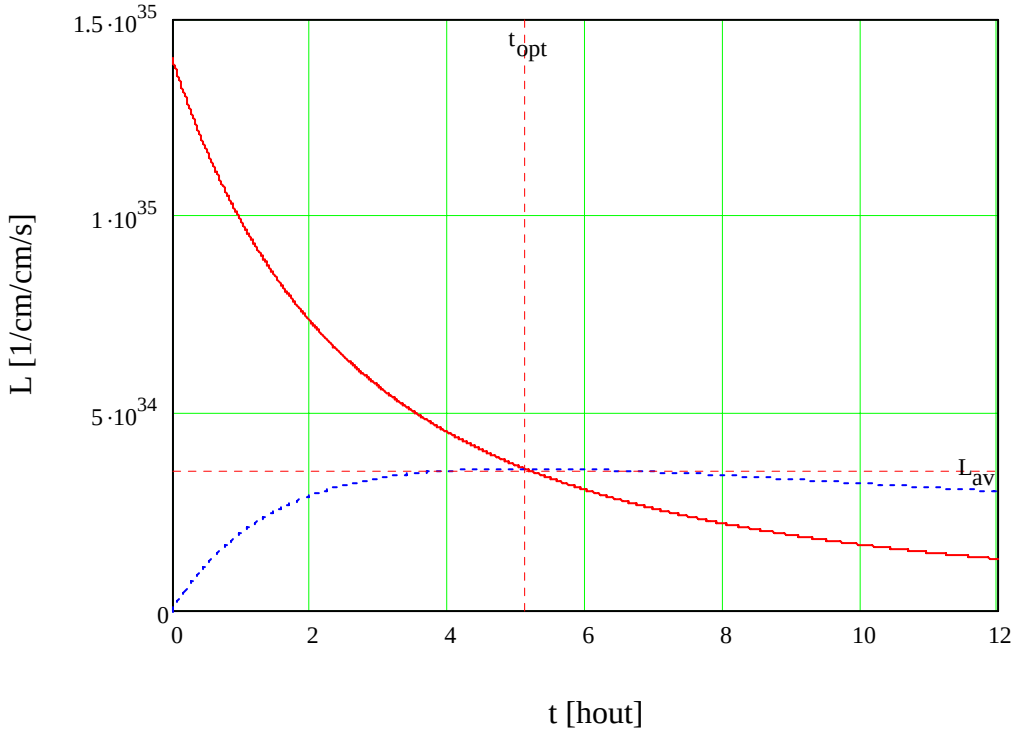
$$L(t) = \frac{L_0}{(1 + t/\tau)^2}, \quad \tau = \frac{N_0}{n_{IP} L_0 \sigma}$$

$\sigma \approx 90$ mb

For Tevatron energy of 1 TeV

$\sigma_{total} \approx 69$ mb, $\sigma_{inelastic} \approx 60$ mb,

$\sigma_{elastic} \approx 15$ mb - about half stays in the aperture after an elastic scattering



$$L_{aver} = \frac{L_0 \tau}{\left(\sqrt{\tau} + \sqrt{T_s}\right)^2} \quad \text{for} \quad t = T_{opt} \equiv \sqrt{T_s \tau}$$

T_s the is the turn around time, ~5 hour

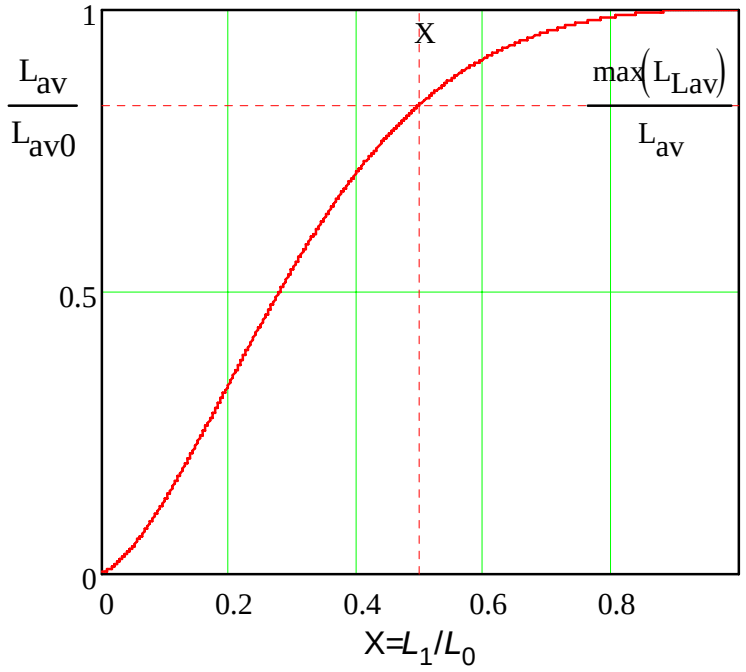
- At optimum, $L_{aver} = L_{min}$, and the peak luminosity exceeds the average one by $\frac{L_0}{L_{aver}} = \left(1 + \sqrt{\frac{T_s}{\tau}}\right)^2$. For ES scenario: $\tau \sim 5.6$ hour, $L_0/L_{aver} \sim 3.9$.

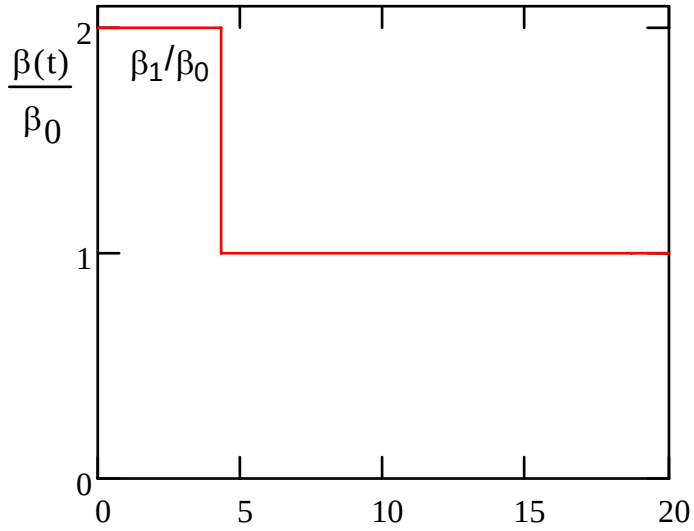
Luminosity evolution with one step β* leveling

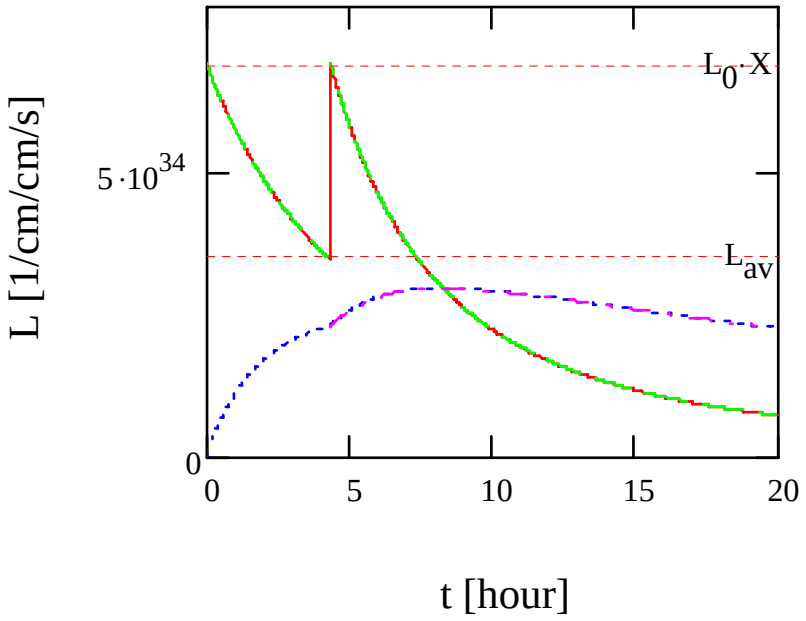
- Luminosity and the IP β-function are directly related

$$X = \frac{L_1}{L_0} = \frac{\beta_0}{\beta_1}$$

- Two times reduction of the peak luminosity results in only 17% average luminosity reduction (relative to the case with no leveling







Luminosity evolution with one step β* leveling (continue)

- Analytical optimization yields
  - Time between the store beginning and the beta-function change

$$T_1 = \frac{\tau}{X}\left(\sqrt{\frac{1}{X}} - 1\right)$$

  - Time between the beta-function change and the store end

$$T_2 = \tau\left(1 - \sqrt{\frac{1}{X}} + \sqrt{\left(1 - \sqrt{\frac{1}{X}}\right)\left(1 - \frac{1}{X}\right) + \frac{T_s}{\tau}}\right)$$

  - Average luminosity as function of $X = L_{init}/L_0 \equiv L_1/L_0$

$$L_{aver} = L_0 \frac{1 + \sqrt{X}\left(T_2/\tau - 1\right)}{1 + \sqrt{X}\,T_2/\tau} \frac{\tau}{T_s + T_1 + T_2}$$

Conclusions

- Leveling with β^* was never tried at Tevatron
  - Nevertheless the accumulated experience supports one or few steps leveling. Time required for beam manipulations is small relative to the store time and will not affect the average luminosity
- Even the single step β^* leveling allows one to reduce the peak luminosity by ~2 times with only ~15-20% loss in the average luminosity
- Tevatron experience does not support continues (smooth) β^* change
  - The main limitation is the required commissioning time