Run II: Current Operations and FY03 Goals

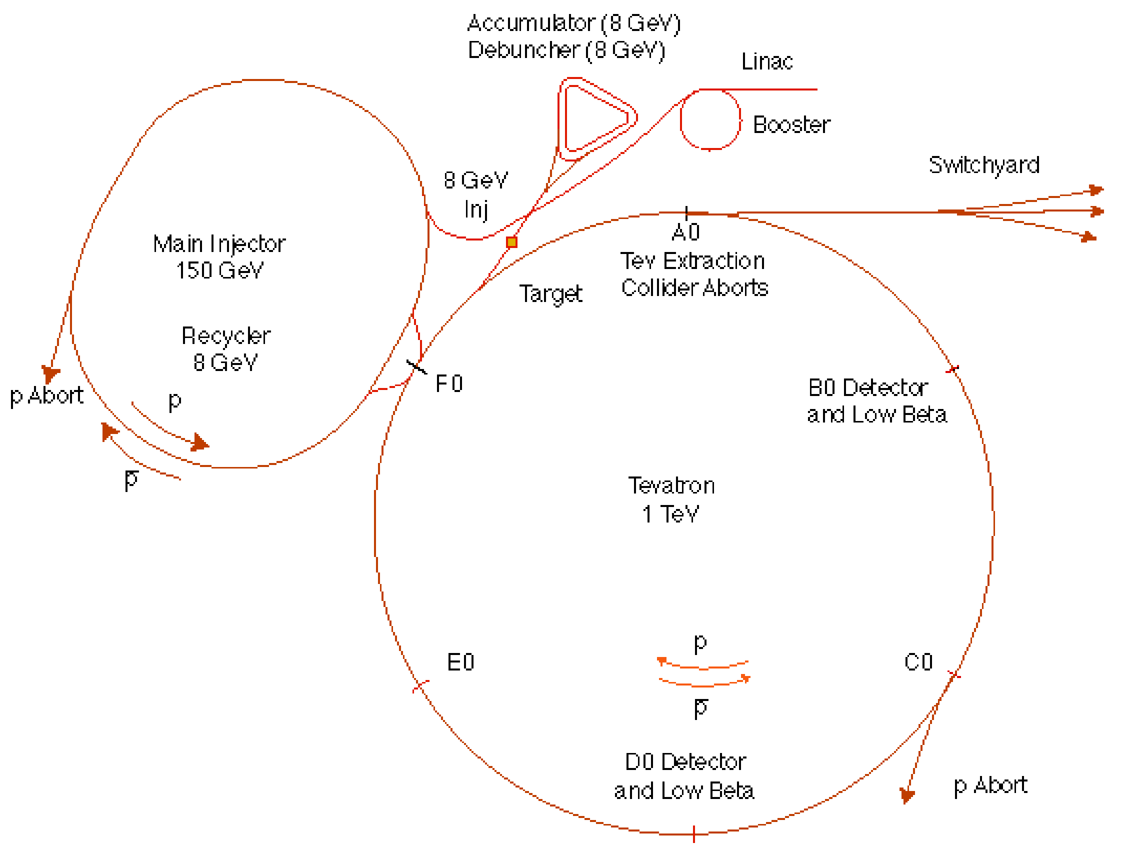
Mike Church

FNAL

3/14/03 URA Visiting Committee Meeting

Accelerator Complex

FermilabTevatron Accelerator With Main Injector

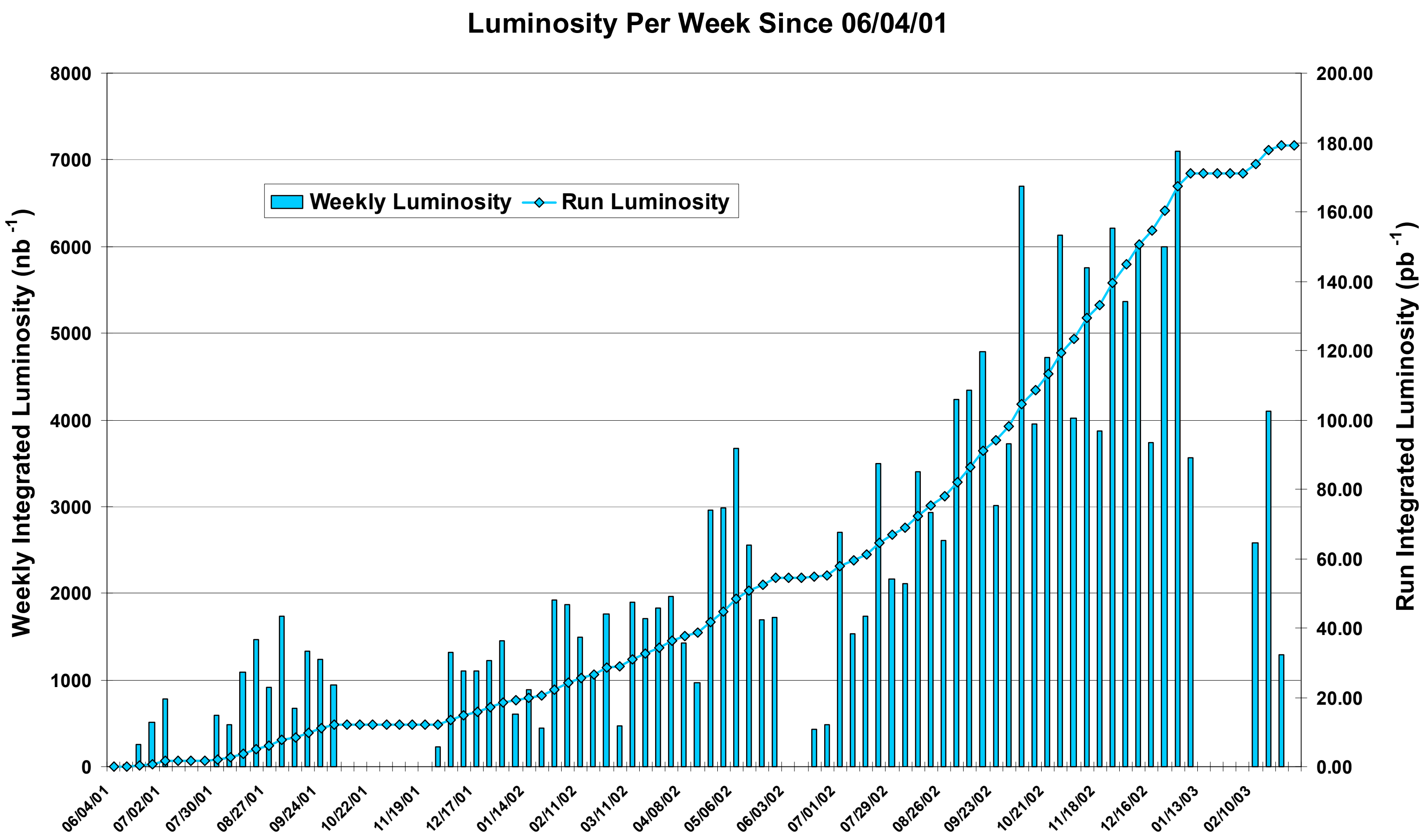


Operating Scenario

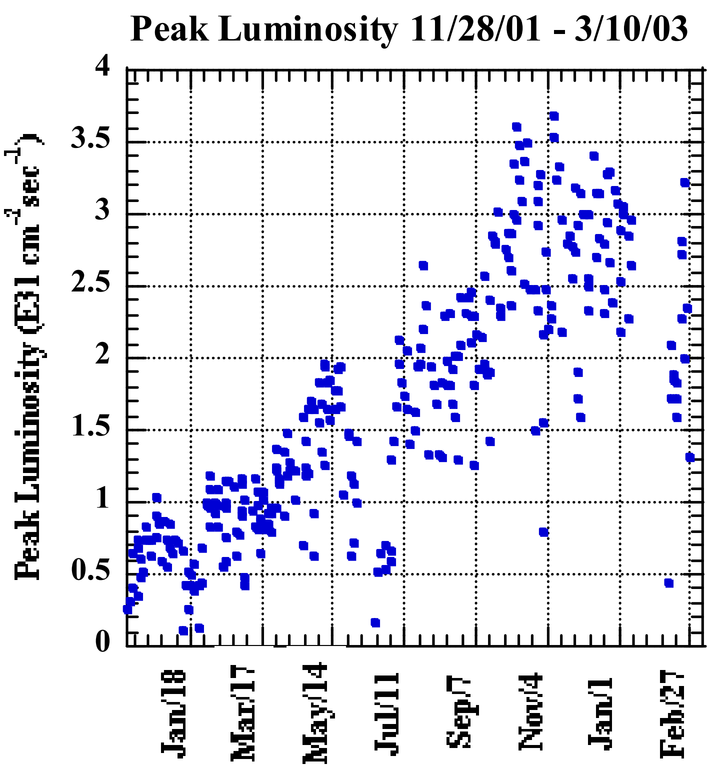
<u>Antiproton Production:</u> Every ~2.2 seconds a single batch of 84 proton bunches is extracted from the Booster and accelerated from 8 GeV to 120 GeV in the Main Injector. This beam is then extracted and targeted on the Antiproton Production Target. 8 GeV antiprotons from the target are collected and cooled in the Debuncher and then stored in the Accumulator stack. Antiproton production takes place continually during Collider stores.

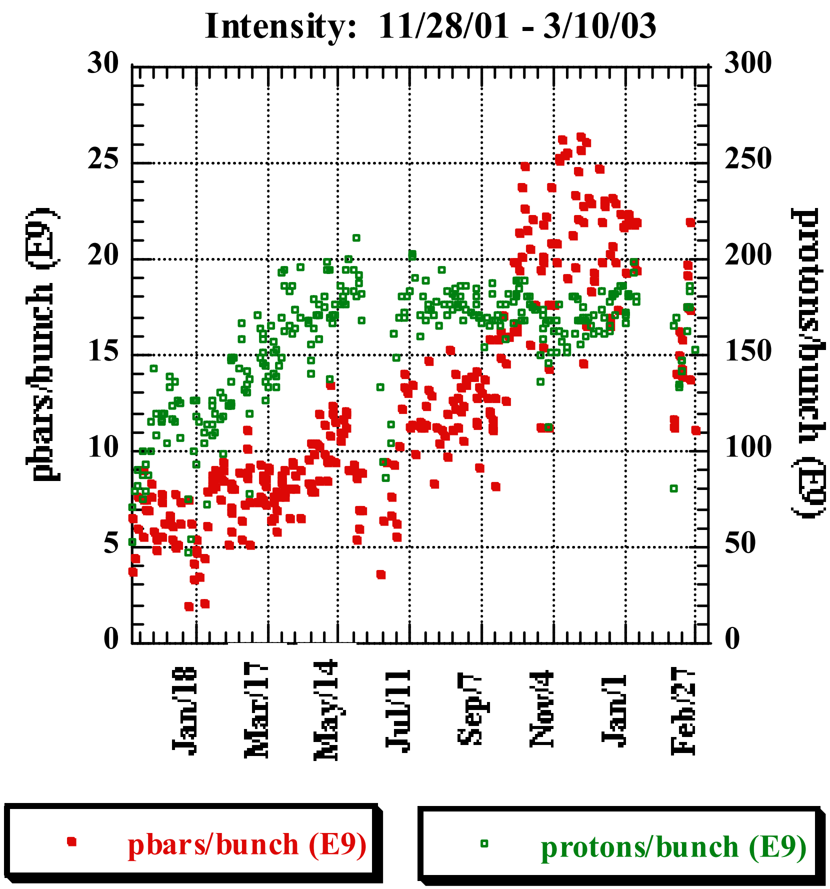
<u>A Collider shot</u> is the process of loading protons and antiprotons into the Tevatron for a store. A batch of 7 proton bunches is injected into the Main Injector and accelerated to 150 GeV. These 7 bunches are then coalesced into a single bunch and injected into the Tevatron. This is repeated 36 times. The helix is opened in the Tevatron so that the protons and antiprotons circulate on separate orbits and do not collide. Then 4 batches of ~5-10 bunches of antiprotons is extracted from the Accumulator stack and injected into the Main Injector. These are accelerated to 150 GeV, coalesced into 4 bunches separated by 396 nsec, and then injected into the Tevatron. This process is repeated 9 times. When all 36 proton and 36 antiproton bunches are loaded into the Tevatron, the beam is accelerated to 980 GeV, and the low beta squeeze is initiated. In the low beta squeeze quadrupole currents and the helical orbits are changed so that the transverse beam size is reduced at the Interaction Regions (D0 and B0) and the protons and antiprotons are brought into collision there. A typical store lasts ~18 hours.

Integrated Luminosity History

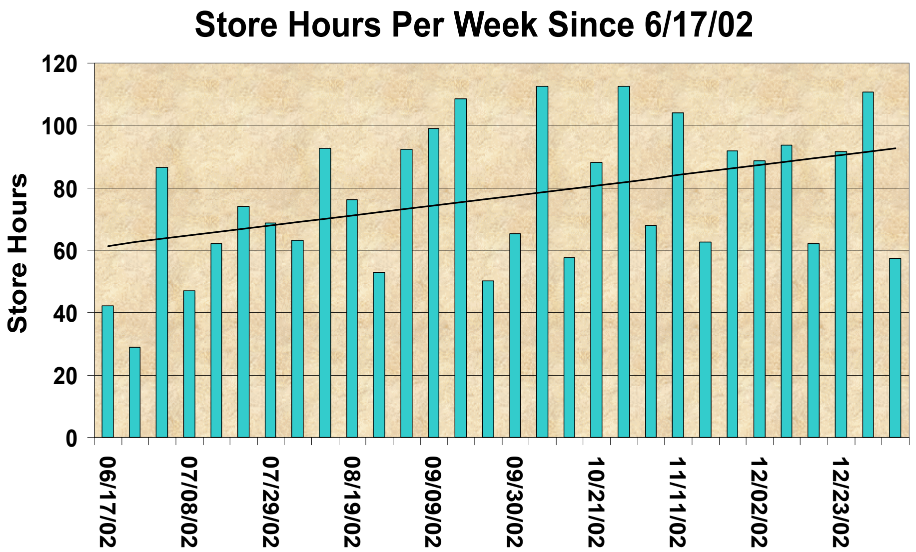


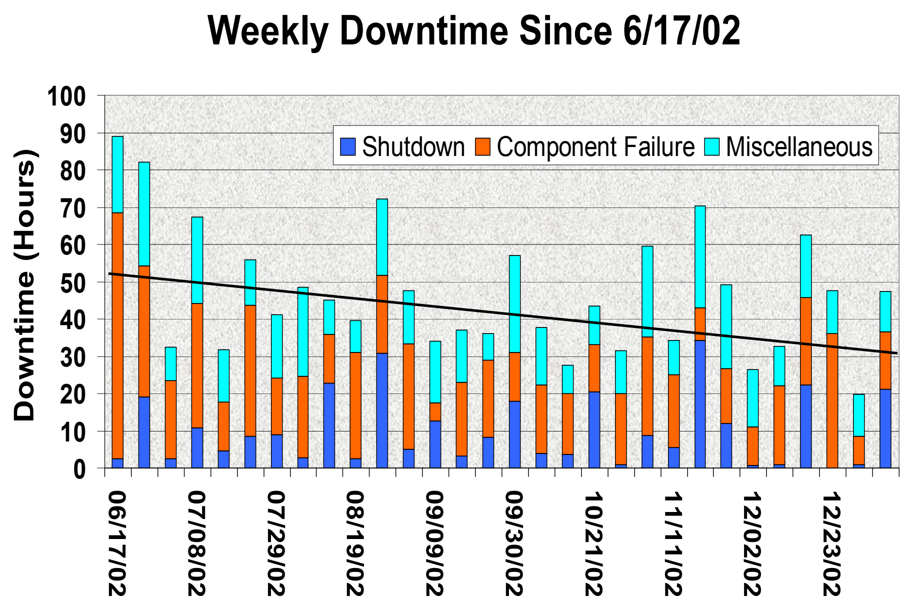
Peak Luminosity and Intensity History





Weekly Performance





(Plots end on 1/13/03, just before shutdown)

Luminosity Recipe

$$L = \frac{10^{-6} fBN_p N_{\bar{p}} (6\beta_r \gamma_r)}{2\pi\beta^* (\varepsilon_p + \varepsilon_{\bar{p}})} H(\sigma_l / \beta^*) \qquad (10^{31}\ cm^{-2}\ sec^{-1})$$

f = revolution frequency = 47.7 KHz

B = # bunches = 36

$\beta_r\gamma_r$ = relativistic beta x gamma = 1045

β^* = beta function at IR = 35 cm

H = hourglass factor = .60 - .75

N_{pbar}, N_p = bunch intensities (E9)

ε_{pbar}, ε_p = transverse emittances (π-mm-mrad)

σ_l = bunch length (cm)

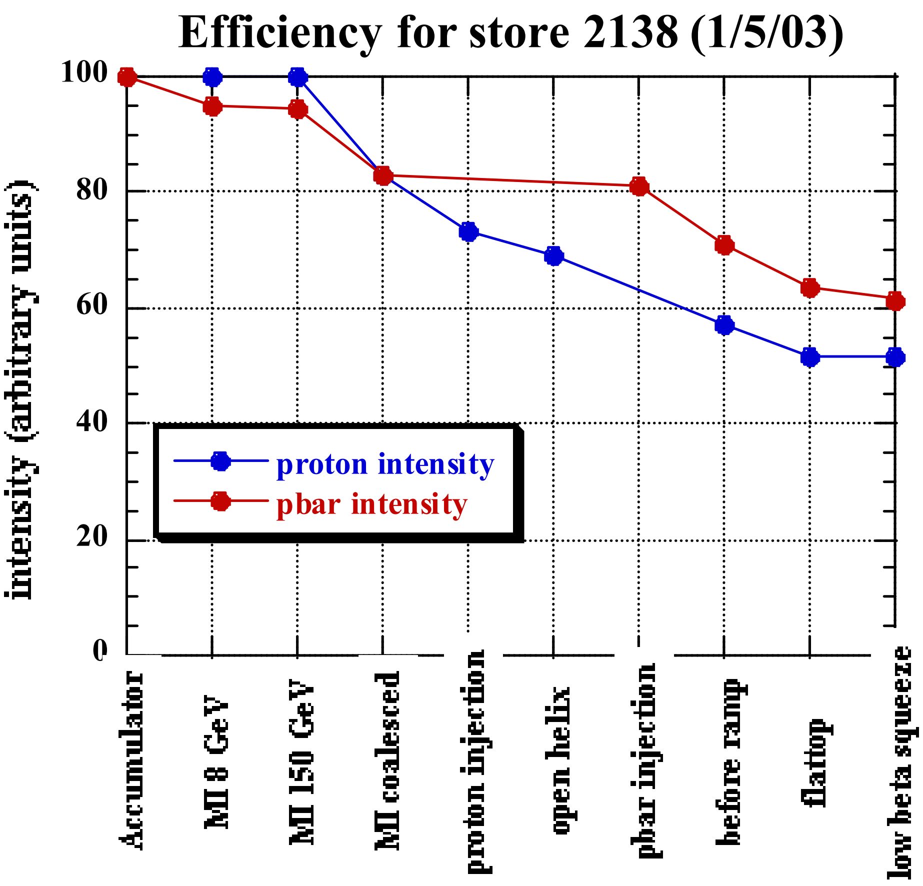
} **"variables"**

Status on Luminosity Parameters

	best luminosity 1 year ago	highest luminosity to date	FY03 stretch goals
max. antiproton stackrate (E10/hr)	10.2		18
max. antiproton stacksize (E10/hr)	100	167	200
pbar xfer eff.	.44	.60	.80
pbars/bunch at low beta (E9)	8.7	25.0	31.0
protons/bunch at low beta (E9)	126	163	240
peak luminosity (E31 $cm^{-2}sec^{-1}$)	1.18	3.7	6.6

Beam Intensity

- **Booster can produce adequate # protons for Tevatron FY03 intensity goals**
- **Accumulator can produce (almost) adequate # antiprotons for FY03 goals**
- **Emittance growth produces poor efficiencies**



Proton Longitudinal Emittance

- Booster can produce <.15 eV-sec bunches at required intensity (6 dipole mode dampers are effective in controlling coupled bunch instabilities).

- <u>However</u>, to control longitudinal instability in the MI the Booster emittance is intentionally blown up to ~.3 eV-sec/bunch (7 bunches)

- After coalescing in the MI this is ~4.0 eV-sec.

  This contributes to poor coalescing, poor MI→Tev transfer efficiency, poor beam lifetime @ 150 GeV in the Tevatron, and poor acceleration efficiency; may contribute to deleterious beam-beam effects.

- At low beta longitudinal emittance is ~4 eV-sec. <u>Goal is 3 eV-sec.</u>

- <u>Longitudinal dampers will be installed in the MI in July.</u>

Antiproton Longitudinal Emittance

- Accumulator core is kept at 25 eV-sec during shots, independent of stack size. This allows for extracting 90% of the core with ….
- extracted emittance of .8 eV-sec – 2.5 eV-sec /bunch with an average of ~1.25 eV-sec @ 8 GeV
- MI measures ~1.5 eV-sec before coalescing (@150 GeV), ~3.0 eV-sec after coalescing
- Tevatron measures ~3.5 eV-sec @ 150 GeV.
- Tevatron measures ~3.5 – 4 eV-sec at low beta. Goal is 3 eV-sec.
- No single cure: Small emittance blowups during unstacking, transfers, acceleration and coalescing:

1) Feedforward beamloading compensation on the ramp on the 53 MHz cavities in the MI should help.
2) Higher voltage on Accumulator unstacking cavity should help.
3) Better energy and phase matching during transfers should help.
4) Long range beam-beam effects in the Tevatron may be contributing to emittance blowup??

Proton Transverse Emittance

- At Booster intensity of 4.2E12/batch, ε_H = 17 π-mm-mrad, ε_V = 14 π-mm-mrad @ 8 GeV
- Coalesced beam @ 150 GeV in MI is ε_H = ~19 π-mm-mrad, ε_V = ?? π-mm-mrad (instrumentation problem)
- Tevatron measures ε_H = ~20-25 π-mm-mrad, ε_V = ~25 π-mm-mrad @ 150 GeV
- Tevatron emittance at low beta is ~24 π-mm-mrad. Goal is 20 π-mm-mrad.

-Again, no single cure:

1) Booster improvements may lower initial transverse emittance.
2) Injection dampers in MI and Tevatron will help.
3) Improved lattice match between MI and Tevatron will help.
4) Better vacuum in Tevatron will help.

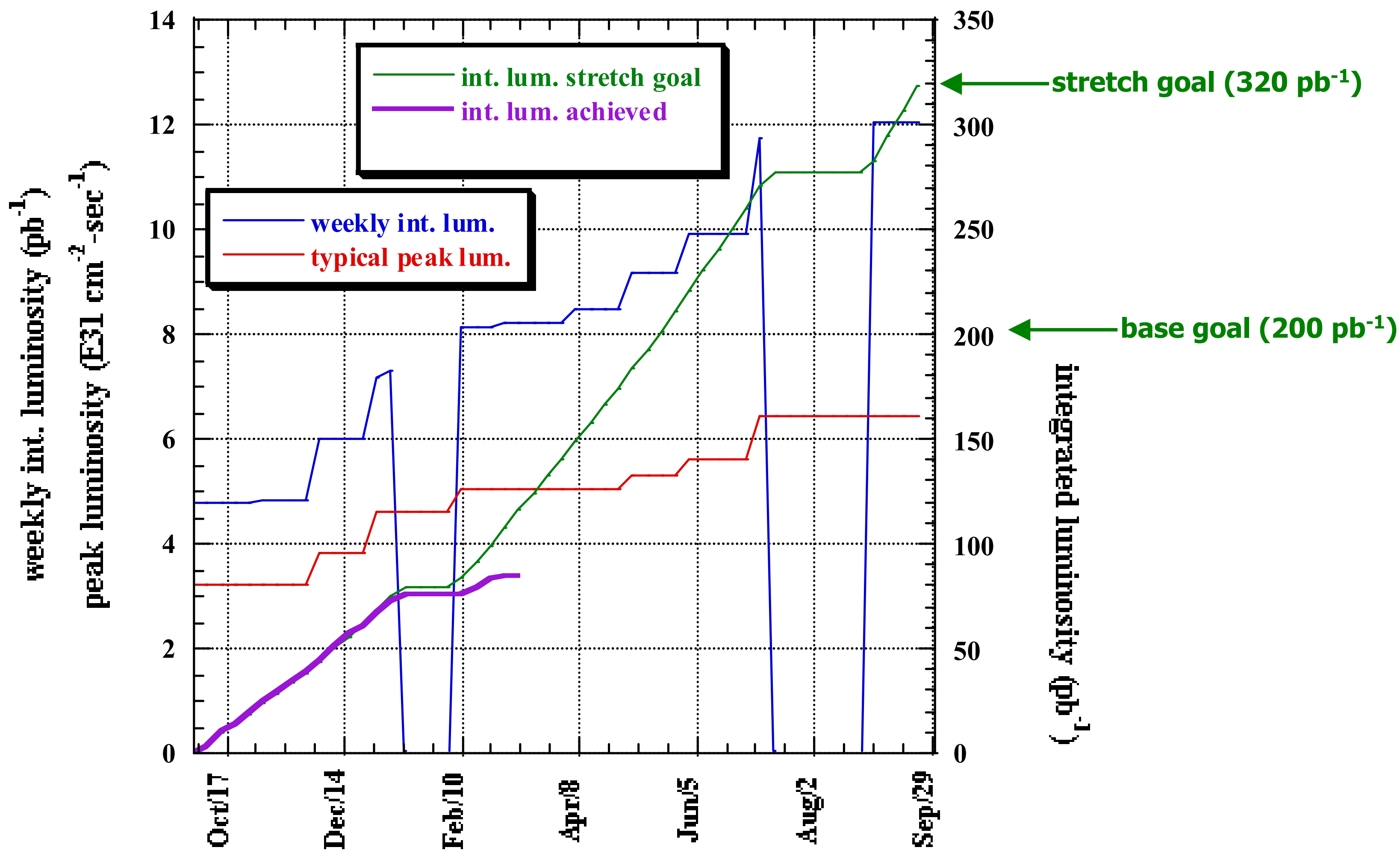
Antiproton Transverse Emittance

- **Core transverse emittance grows linearly with stack size. $\varepsilon_{average}$ = 6 π-mm-mrad @ 140mA (this is the nature of stochastic cooling)**
- **At 8 GeV in MI, ε_H = 8 π-mm-mrad, ε_V = 8 π-mm-mrad, becoming ε_H = 11 π-mm-mrad, ε_V = 9 π-mm-mrad after coalescing**
- **Tevatron measures ε_H ~ 25 π-mm-mrad, ε_V ~ 21 π-mm-mrad @ 150 GeV**
- **Tevatron emittance at low beta is ~ 20 π-mm-mrad (dynamic or physical aperture limit). Goal is 15 π-mm-mrad.**
- **Major problem is the emittance blowup during the MI—>Tev transfer. Not understood, but under investigation.**
- **Improved helix in the Tevatron will also reduce pbar transverse emittance blowup(??)**

Agenda for FY03

- **3 week shutdown in January** (complete)
  - C0 Lambertson removal; Recycler vacuum upgrades; Tevatron vacuum; CDF shielding; ….
- **February to late-July**
  - deliver luminosity; routine pbar shots to Recycler; up to 5 shifts/week dedicated studies; minimize shutdown days; (suffered 2 Tevatron magnet failures since shutdown)
- **6 week shutdown starting late July**
  - Recycler vacuum; e-cooling civil construction; A0 modifications; Tevatron collimators; NUMI installation work; (full scope of work not yet determined)….
- **Continued running in Fall**
  - same as February - July

Integrated Luminosity Performance and "Stretch" Goal for FY03



Critical Projects for Luminosity in FY03

- **A150/P150 beamlines – 20% in peak luminosity by 12/1/02**

- The original scope of the work -- reduction of injection oscillations and matching of beamlines has been completed.

- This was thought to be the major source of the problem (emittance blowup), but this turns out not to be the case.

- Beam studies and calculations underway are aimed at understanding coupling and beam-beam effects in Tevatron as a source of emittance blowup.

- **Tevatron transverse dampers – 20% in peak luminosity by 1/1/03**

- Transverse damper installation is complete: dampers are used at 150 GeV with positive effect (Tevatron can run with lower chromaticity @ 150 GeV).

- Dampers are not used on the ramp and squeeze because excessive coupling causes the dampers to anti-damp out-of-plane motion.

- ➔ proton intensity has not been increased, which was intended to be the source of the 20% improvement in luminosity.

- <u>The removal of the C0 Lambertsons has reduced transverse impedance, and that will make the beam more stable so that the proton intensity can increased after the Jan. shutdown</u>

Critical Projects (continued)

- **C0 Lambertson replacement – 10% in peak luminosity by 3/1/03**

- Completed in January shutdown. Commissioning in progress. New helix commissioning to start soon.

- **Accumulator bands 2&3 equalizers – 5% in peak luminosity by 5/1/03**

- Installed during the January shutdown. Expect 7% decrease in Accumulator core emittances during shots to Tevatron.

- **AP3 beamline – 5% in peak luminosity by 6/1/03**

- Found a plastic magnet cap in the beamline in January shutdown (been there for ~20 years). Should give ~1-2π emittance reduction.

- Future efforts will be directed toward 8 GeV transfer reliability and faster shot setups.

- **MI longitudinal dampers – 15% in peak luminosity by 7/1/03**

- Cavity fabrication and FPGA programming is in progress.

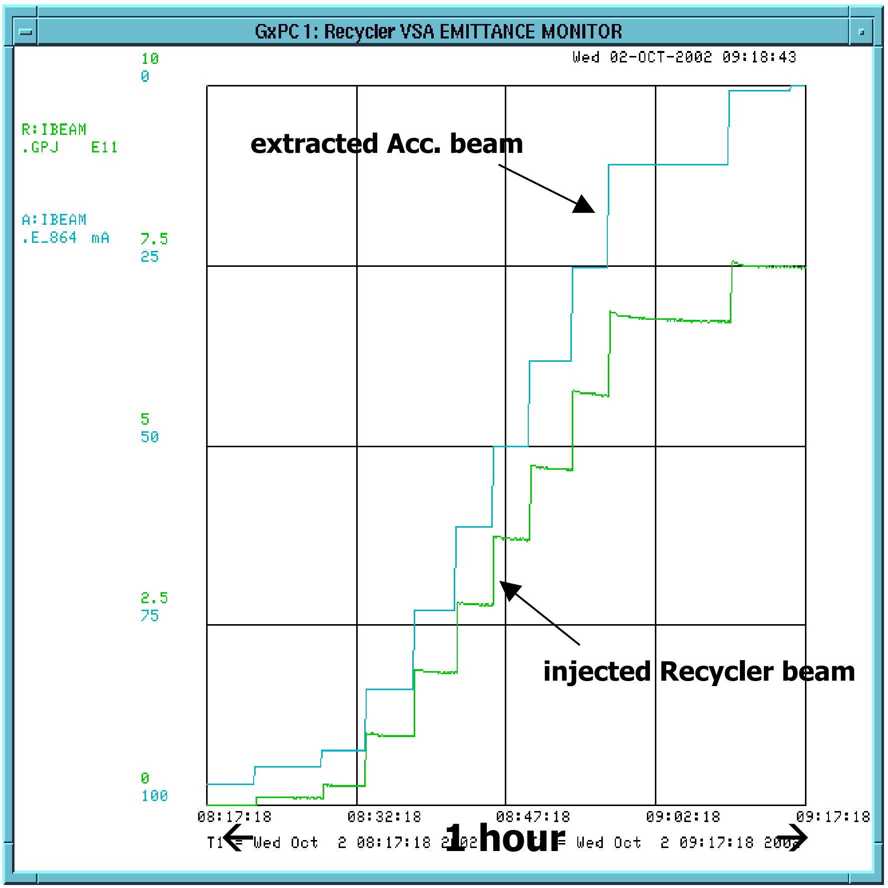
- High power amplifiers have been purchased. Cavity fabrication in progress.

Critical Projects (continued)

- **Reliability – 1.5%/month in <u>integrated luminosity</u> over 9 months**
  - VFC replacement is 70% complete; cryo wet engine rebuild is complete.
  - # store hours/week has been better than anticipated (averaging 86 hrs/week from 10/1/02 to 1/13/03)-- partly because of reduced study shifts, partly from less downtime.
- **Stacking upgrades – 1.5%/month in <u>integrated luminosity</u> over 9 months**
  - Major emphasis has been on Debuncher momentum cooling, stacktail system, and yield into Debuncher (AP2 and target).
  - No real stacking improvements since mid-November when peak stacking rate of 13.1 mA/hr was achieved.
  - Booster/MI are able to deliver 4.5E12 protons/pulse on pbar target, while delivering beam to MiniBooNE.

Recycler Commissioning

Accumulator → Recycler antiproton transfers



•Injection and circulating efficiency for proton and pbar is about 75%

• Emittance growth rate is about a factor of 2-4 larger than the design. Significant fraction of this appears to be vacuum related.

• Recycler performance is adversely affected by the Main Injector ramp.

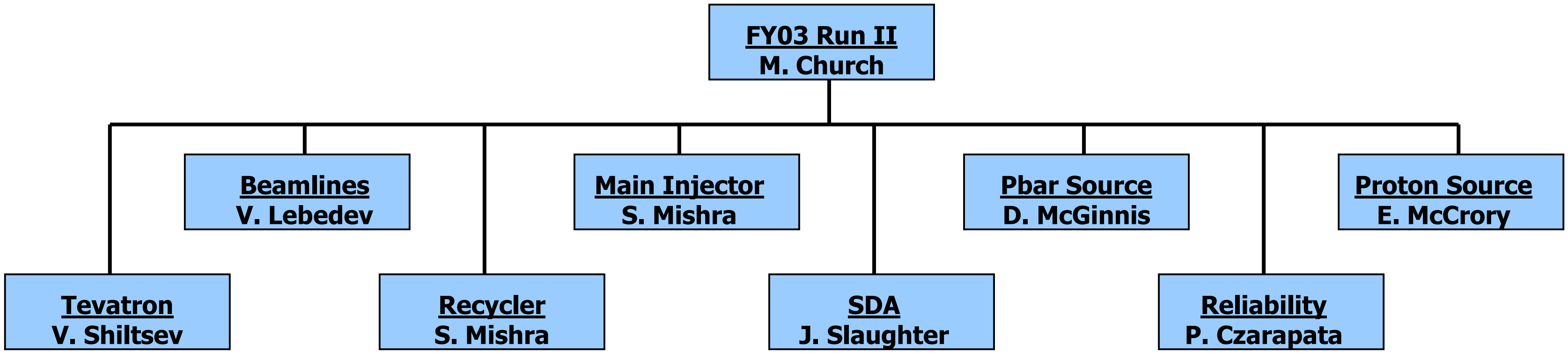
• Circulating and injection lattice and aperture are not understood

• Operating point of the Recycler is very sensitive to the Recycler orbit.

• Stochastic cooling needs further study and optimization.

• RF manipulations need further study and optimization.

FY03 Project Organization



8 Level 2 Projects

~90 Level 3,4,5 Projects

Resource loaded schedule: Resources are $$'s, machine study shifts, personnel

Summary

- **Factor of <u>3.7</u> increase in peak luminosity in CY02**
- **Factor of <u>5-6</u> increase in weekly integrated luminosity in CY02**
- **Increased stacking rate and Accumulator stack size**
- **Significant improvement in Recycler operations**
- **Reduced downtime**
- **Progress on instrumentation**
- **Improvements in theoretical understanding of issues**

- **Plan of action for continuing improvements in luminosity**