



Run II Luminosity Upgrade Plan

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DOE Tevatron Operations Review
March 21, 2006



Luminosity

▪ Limitations to peak luminosity

- Number of pbars (BN_{pbar})
- Proton brightness (N_p/ϵ_p)
 - Beam-Beam effects
- Antiproton emittance
- $F < 1$

$$\mathcal{L} = \frac{3\gamma f_0}{\beta^*} (BN_{\bar{p}}) \left(\frac{N_p}{\epsilon_p} \right) \frac{F(\beta^*, \sigma_\delta)}{\left(1 + \frac{\epsilon_{\bar{p}}}{\epsilon_p} \right)}$$

▪ Pbar Burn Rate (Φ_{pbar}) limits $\int \mathcal{L} dt$

- $n_c = 2$
- $\sigma_a = 70 \text{ mb}$
- $L = 300 \times 10^{30} \text{ cm}^{-2}\text{-sec}^{-1}$
- $\Phi = 15 \times 10^{10} \text{ hr}^{-1}$

$$\Phi_{\text{pbar}}^{(\text{min})} = n_c \sigma_a \mathcal{L}$$



Stacking Rate

$$\Phi = \frac{N_p P}{T_{\text{rep}}}$$

- N_p is the number of protons on target
 - Slip Stacking
- P is the production ratio of the number of antiprotons produced to N_p
 - Typically about $15\text{-}20 \times 10^{-6}$
 - Mostly a function of the collection aperture
- T_{rep} is the cycle time
 - Mostly a function of the cooling rate



Run II Upgrade Project Status

- Run II Upgrade Project began 3 years ago.
 - DOE received Project Plan and Resource-Loaded Schedule on June 15, 2003
- Strategy
 - Protons on Target
 - Slip Stacking in the Main Injector
 - Pbar Production Rate
 - AP2 and Debuncher Aperture
 - Li Lens Upgrade
 - Pbar Cooling Rate
 - E-cooling in the Recycler Ring
 - Rapid Transfers from AA to RR
 - Stacktail Cooling Upgrade
 - Tevatron beam-beam effects
 - Increased Helix Separation in the Tevatron
- The Luminosity Goals have been met for FY03 - FY05
 - Expect to meet goals for FY06.



Run II Upgrade Luminosity Projections

Integrated Luminosity (fb ⁻¹)						
	Design Projection		Base Projection		Delivered	
	Per year	Total	Per year	Total	Per year	Total
FY03	0.22	0.30	0.20	0.28	0.23	0.29
FY04	0.38	0.68	0.31	0.59	0.35	0.62
FY05	0.67	1.36	0.39	0.98	0.61	1.22
FY06	0.89	2.24	0.50	1.48	0.80*	2.02*
FY07	1.53	3.78	0.63	2.11	* Projected for FY06	
FY08	2.37	6.15	1.14	3.25		
FY09	2.42	8.57	1.16	4.41		

Table 8 from “Run II Luminosity Upgrade at the Fermilab Tevatron”,
June 15, 2003



Run II Upgrade Project Status

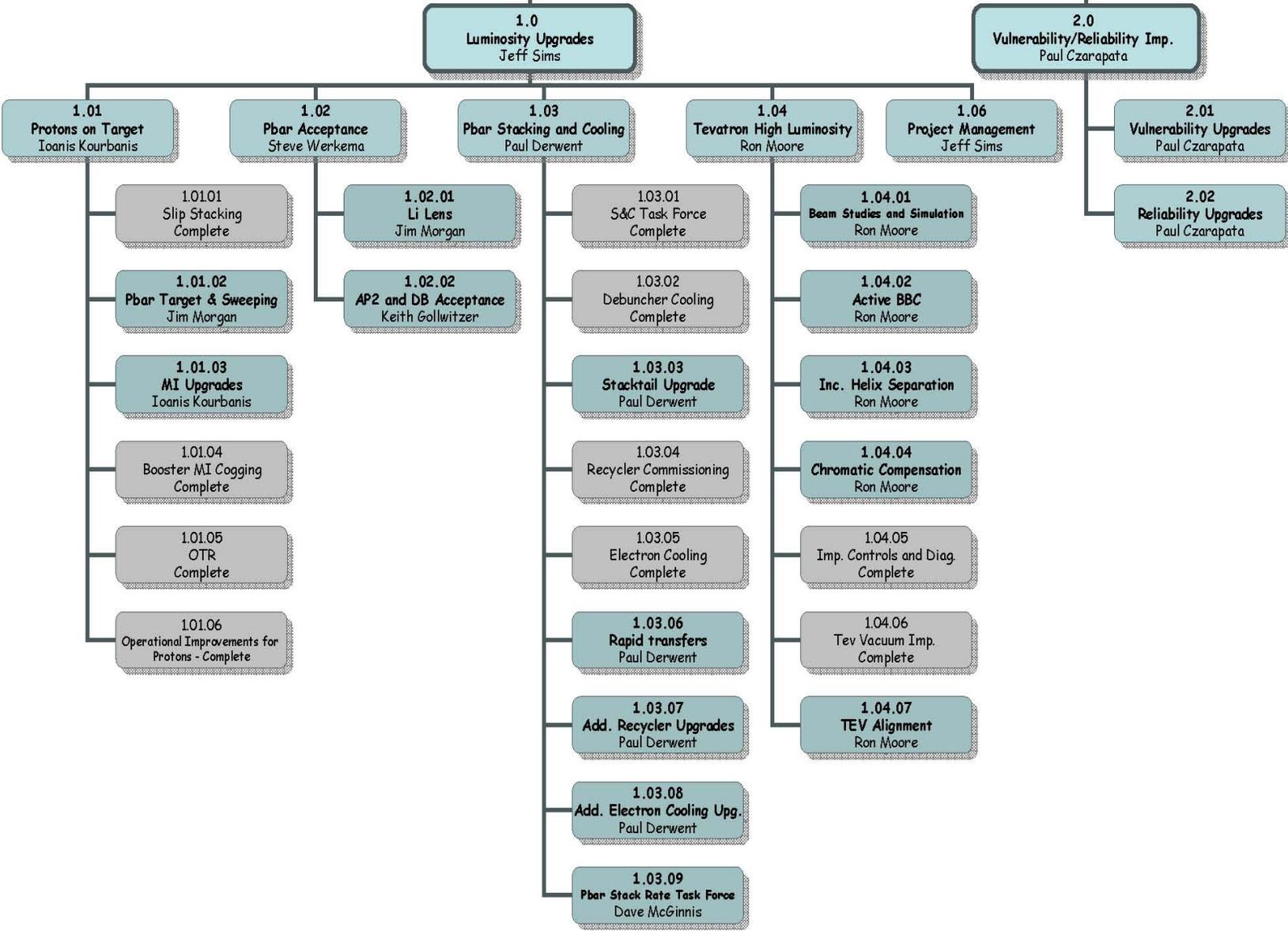
- **Run II Upgrade Project**

- The Project is now 85% complete and scheduled to complete in FY '07
- Almost all projects will be completed during the present shutdown
- Many Successes (See Later Slides)
- M&S and Labor Profiles for the project are winding down

However...

- **The Run II Upgrade Plan continues till FY '09**
 - Deliver Luminosity till FY '09
 - Continue to benefit from the Run II Upgrade Projects
 - Continue to make improvements

Run II Luminosity Upgrades
Jeff Sims, Project Manager
Mike Martens, Technical Lead



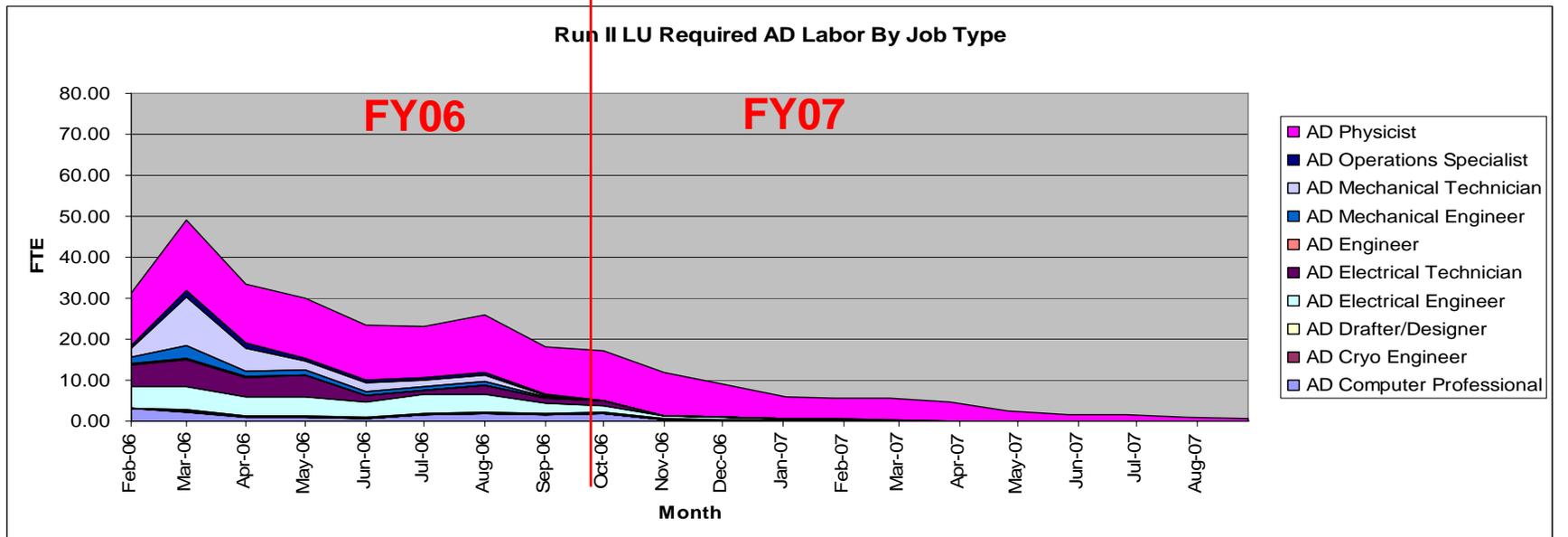
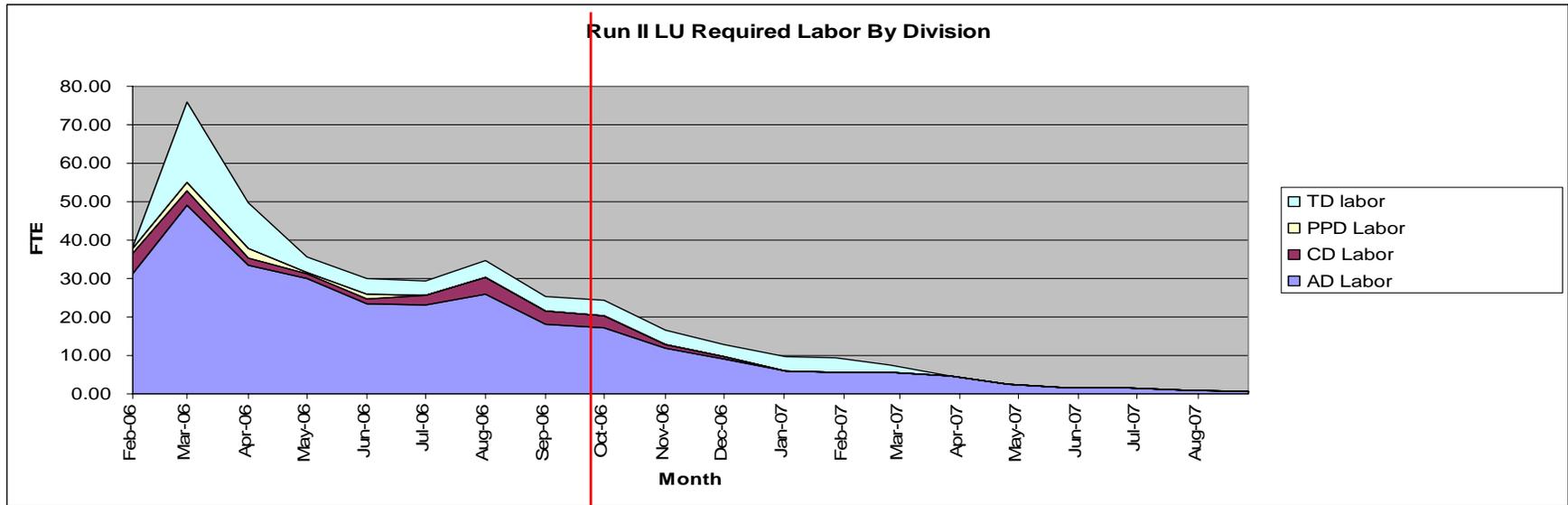


M&S Spending through Feb. '06

M&S Spending	v4 Plan Estimate		FY06	Inception To date Costs			% Plan used	
	(then yr\$)						Obl+RIP	
	FY06	Total	Obl+RIP	Actual	Obligations	Obl+RIP	/Total Est	
0	Run II Upgrades	4,518	18,607	1,354	15,402	15,589	15,656	84%
1	Luminosity Upgrades	3,145	14,346	1,164	12,120	12,091	12,159	85%
1.1	Protons on Target	379	1,859	447	2,119	1,639	1,696	91%
1.2	pbar Acceptance	672	1,433	97	904	940	945	66%
1.3	pbar Stacking and Cooling	1,030	5,678	356	4,243	4,516	4,516	80%
1.4	Tevatron High Luminosity	956	5,175	265	4,752	4,894	4,899	95%
1.6	Management	108	201	0	102	102	102	51%
2	Reliability Upgrades	1,372	4,261	190	3,282	3,498	3,498	82%
2.1	2003 White Paper/Vulnerability R	1,085	2,598	-74	1,964	1,971	1,971	76%
2.2	Reliability Upgrades	287	1,663	264	1,318	1,527	1,527	92%



Run II Labor Profiles





Electron cooling system setup at MI-30/31

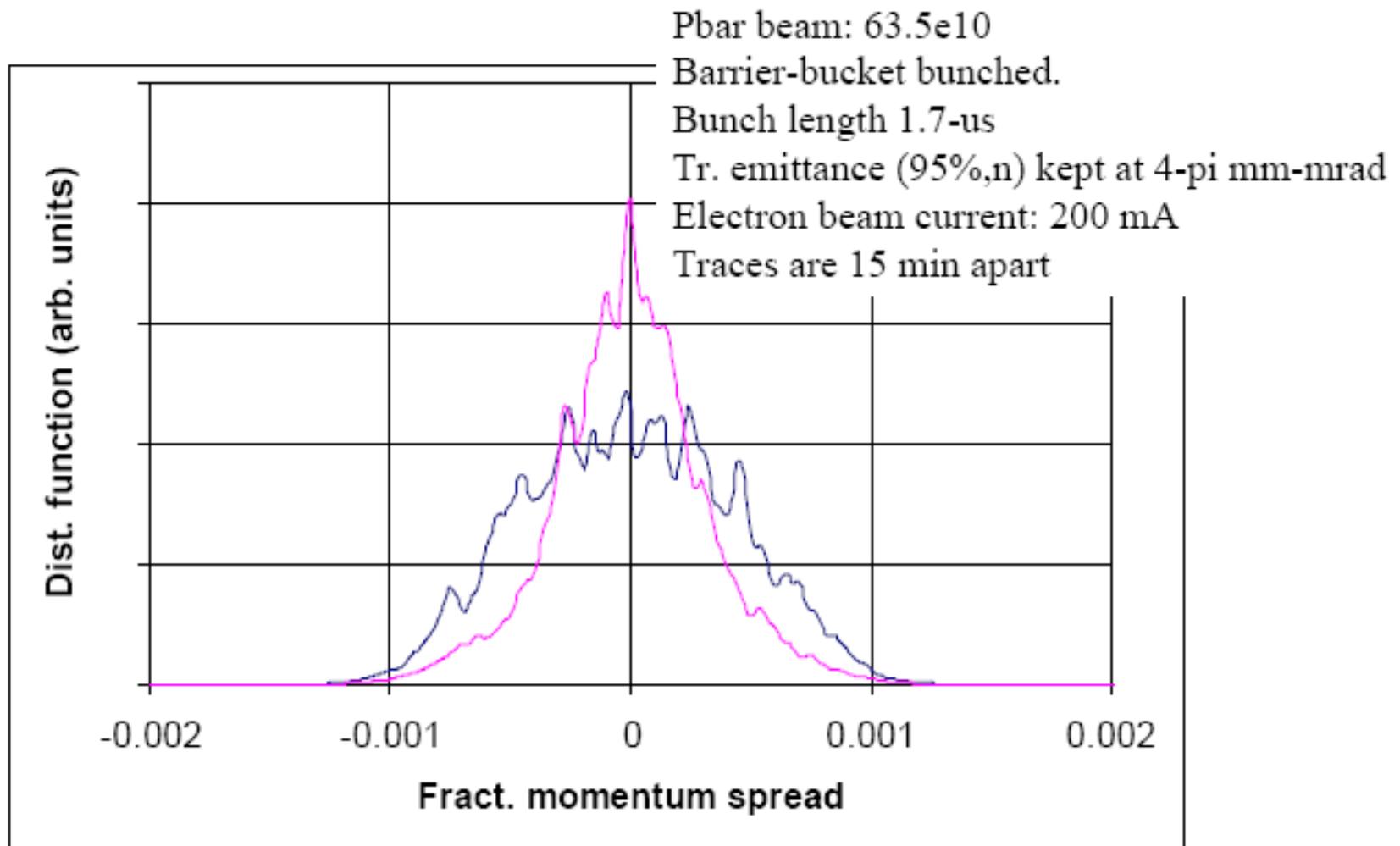
Pelletron
(MI-31 building)

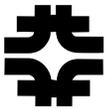


Cooling section
solenoids
(MI-30 straight section)



First e-cooling demonstration - 07/15/05





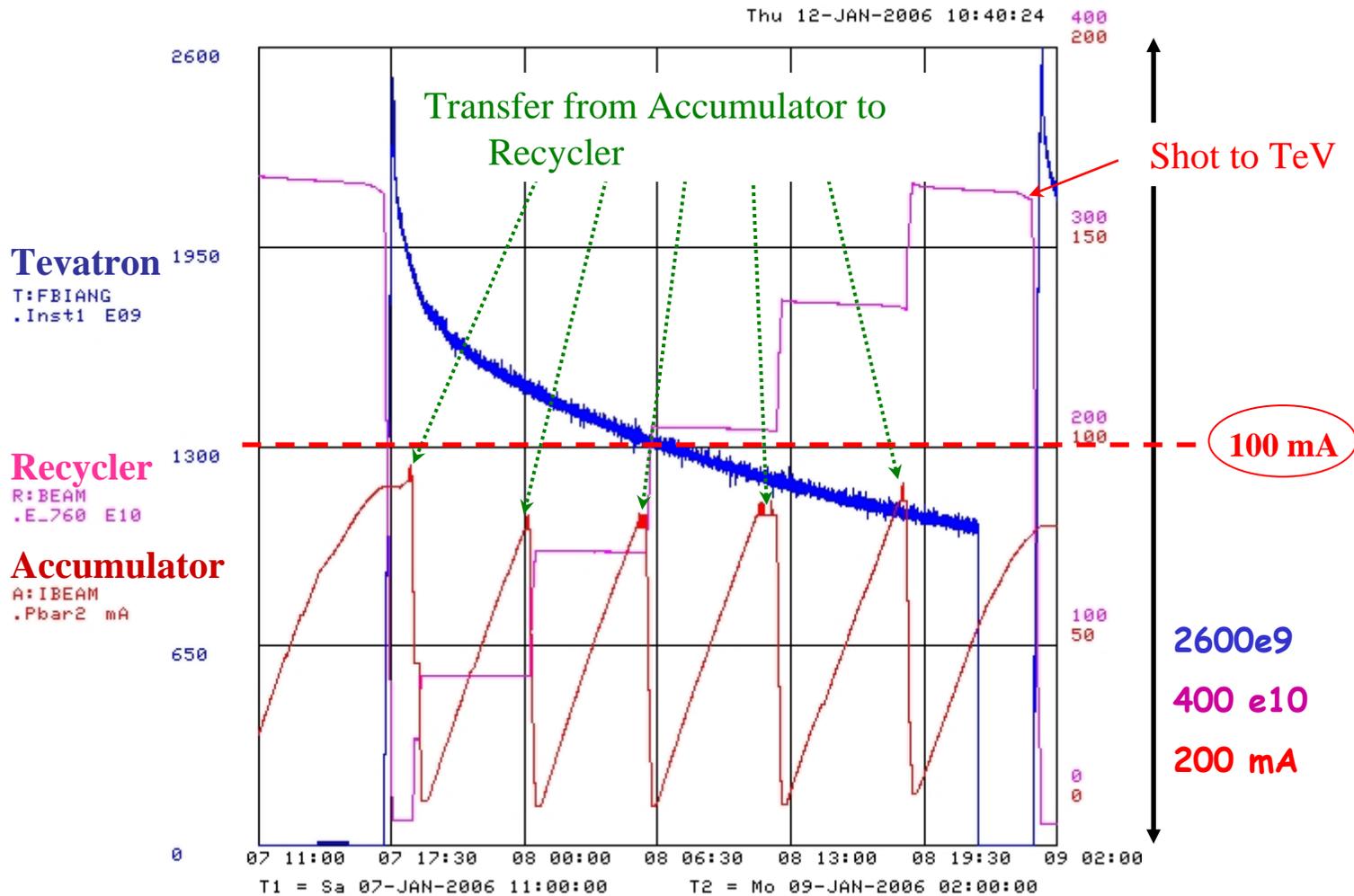
Electron beam design parameters

- Electron kinetic energy 4.34 MeV
- Uncertainty in electron beam energy $\leq 0.3 \%$
- Energy ripple 500 V rms
- Beam current 0.5 A DC
- Duty factor (averaged over 8 h) 95 %
- Electron angles in the cooling section
(averaged over time, beam cross section,
and cooling section length), rms ≤ 0.2 mrad

All design parameters have been met



Antiprotons flow (Recycler only shot)



Keep Accumulator stack <100 mA \Rightarrow Increase stacking rate



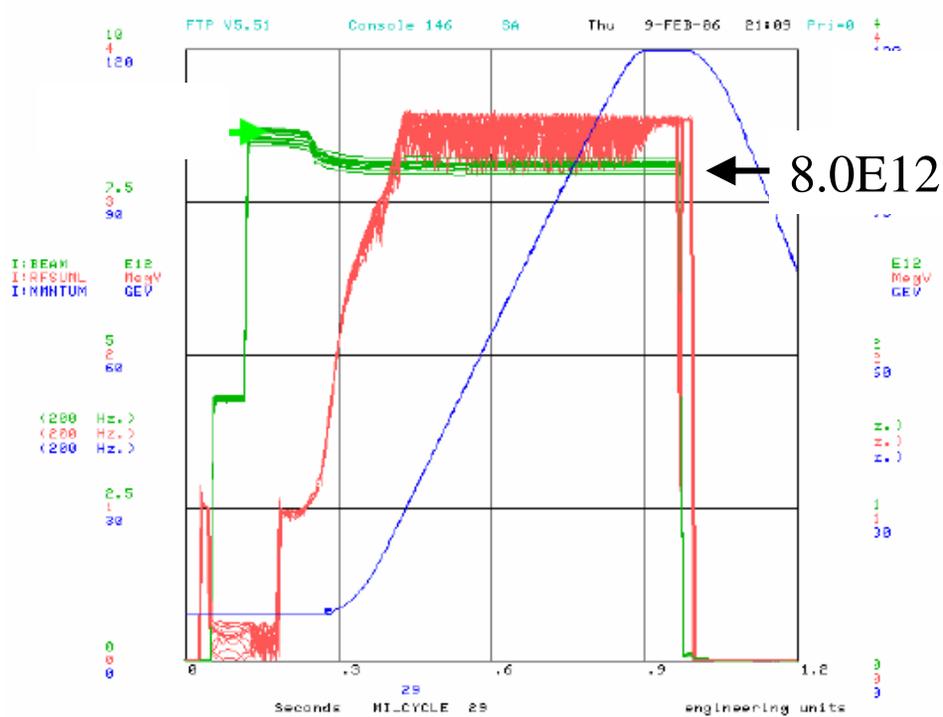
E-cool Conclusion

- Fermilab now has a world-record **operational** electron cooling system
 - Since the end of August 2005, electron cooling is being used on (almost) every Tevatron shot
 - Increases of stash sizes are a direct consequence of the ability to cool the beam efficiently (current record $437e10$)
 - Electron cooling allowed for the latest advances in the TeV peak luminosity (current record $172e30$)
- Lifetime issue now limits the maximum number of anti-protons that the Recycler can stored
 - Primary focus

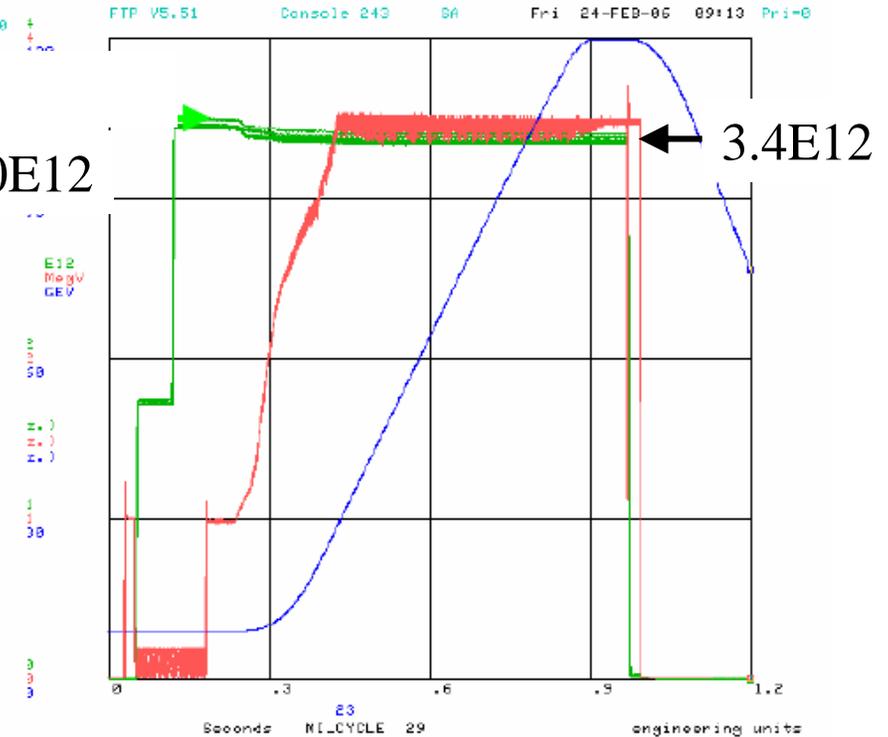


Slip Stacking in MI

High intensity (~6.5% Loss)



Low intensity (~2.5% Loss)



Goal was 8E12 per pulse



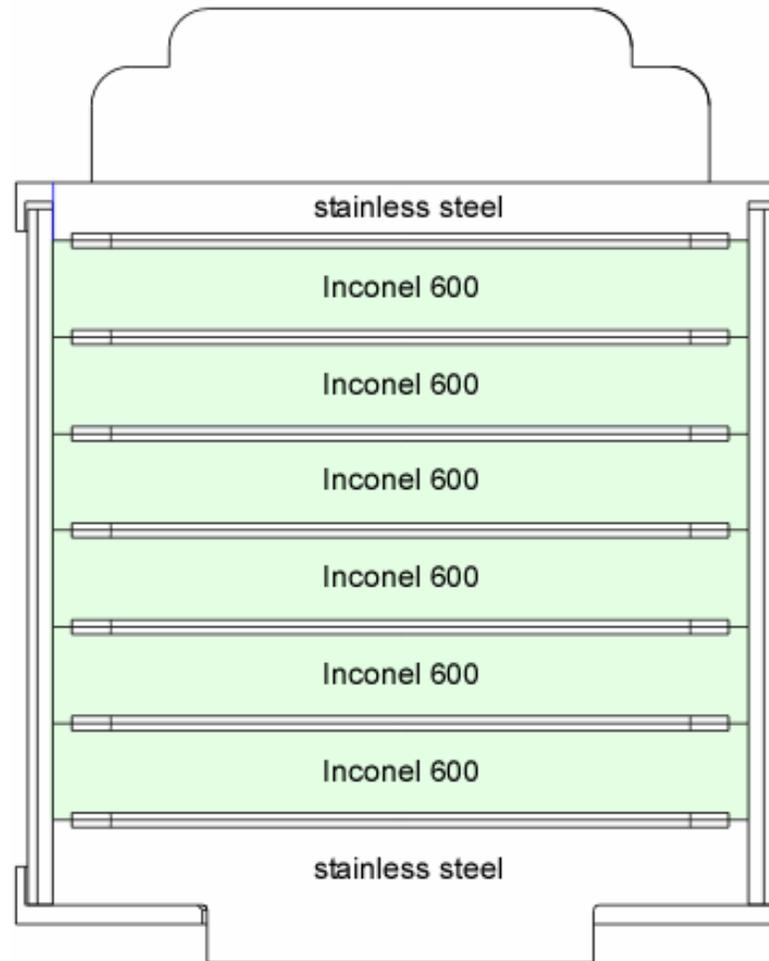
Pbar target and beam sweeping

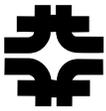
- Pbar Target and Beam Sweeping
 - Inconel 600 used as operational target material
 - 40% higher tensile strength than nickel
 - Yield reduction from target damage has increased as beam intensity has reached 8-8.5E12 ppp
 - Changes to target being implemented to reduce heating
 - Spot size increased from a σ of 0.15mm to 0.20mm to maintain a "reasonable" operational life of 6 months (reduces production rate by only 4%)
 - Faster rotation speed (17° instead of 0.4° degrees per beam pulse to spread heating more evenly on target)
 - Redesigned air cooling with higher air volume and more efficient cooling disks
 - Beam sweeping put on "hold" due to success with Inconel 600 targets at intensities of 6E12 ppp



Pbar target assembly last in use

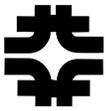
Run 2 Target 4
Installed 8/31/05



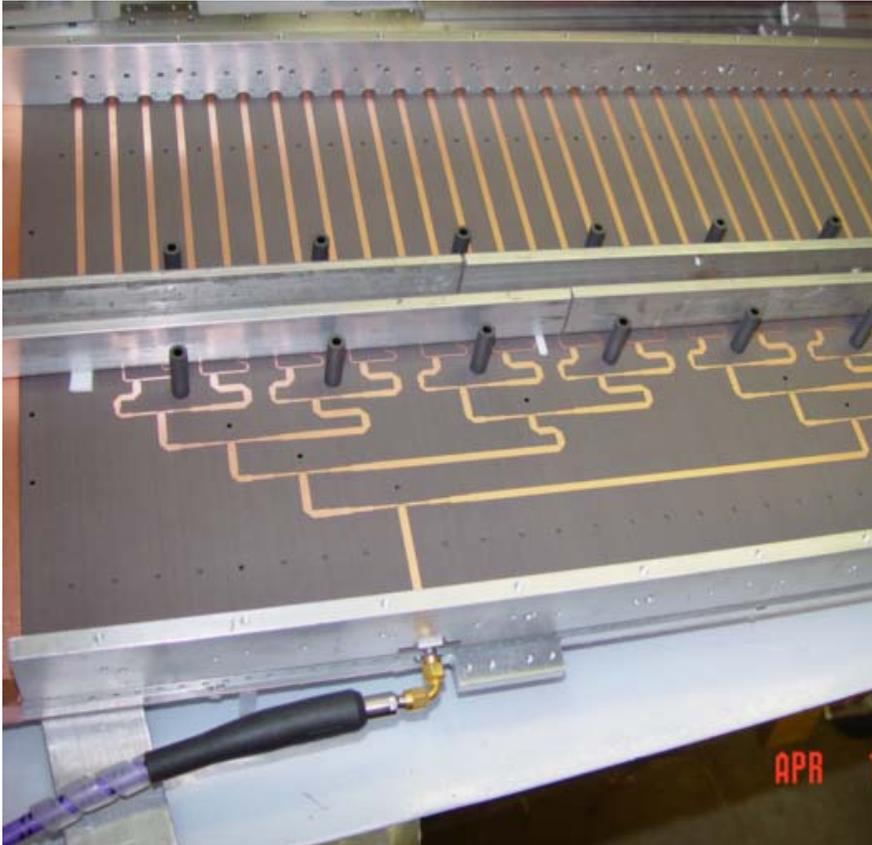


Antiproton Acceptance

- Significant Accomplishments
 - Installation of Debuncher quad stands completed
 - AP2 BPM upgrade completed
 - Substantial beam study time
 - **NET RESULT:**
 - 25% increase in Deb Admittance:
 - $A_x = 32.6 \pi$ mm-mrad, $A_y = 34.6 \pi$ mm-mrad
 - 32% increase in AP2 + Debuncher admittance:
 - $A_x = 33.3 \pi$ mm-mrad, $A_y = 31.2 \pi$ mm-mrad
- Major Work Remaining
 - Debuncher extraction kicker aperture upgrade
 - 53 MHz BPM upgrade in Debuncher
 - Allows orbit measurement during stacking



Stacktail Cooling Upgrade



Prototype tank is vacuum certified at 10^{-8} Torr.

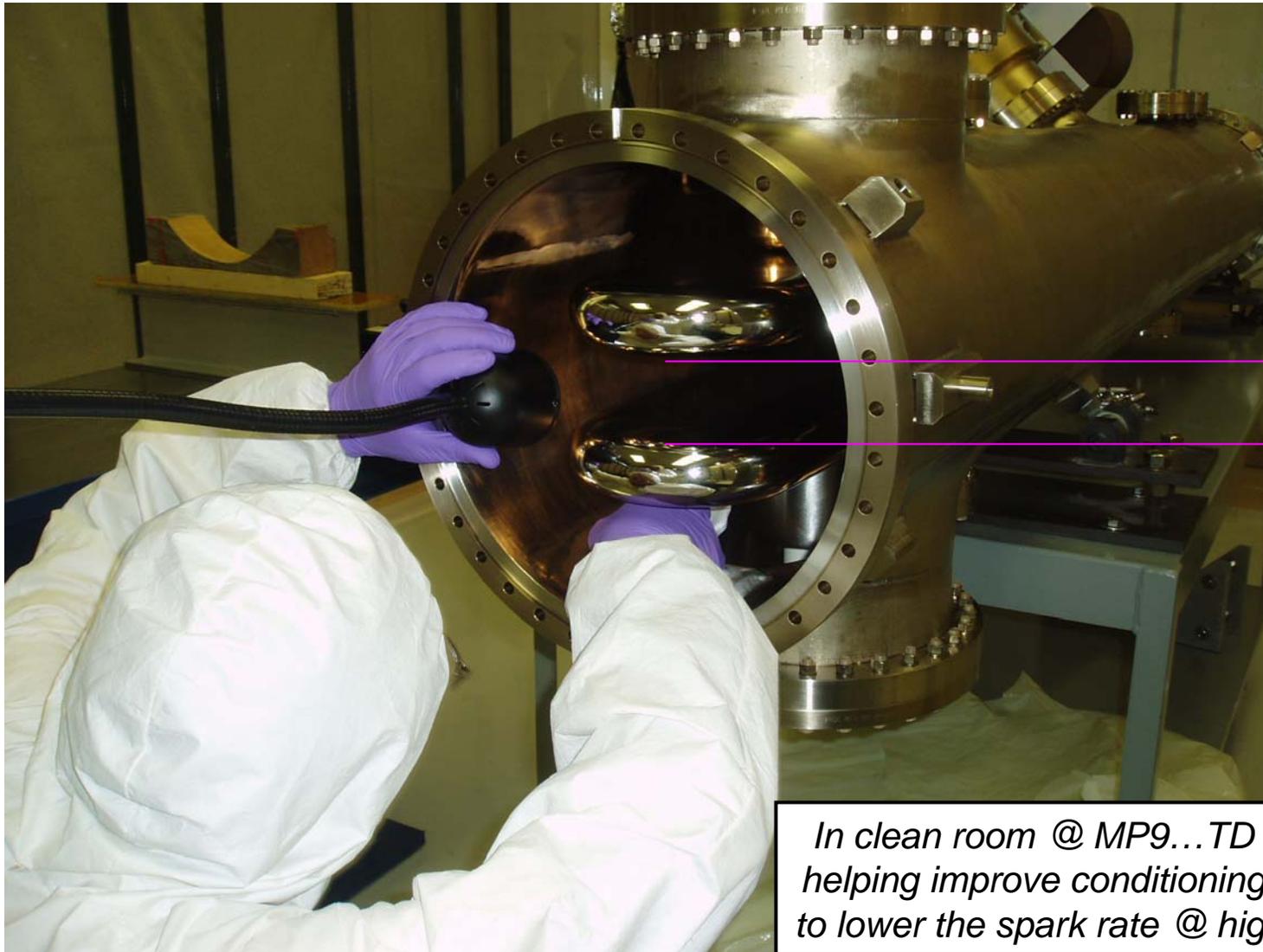
Tank installed this shutdown.

Testing of tank after shutdown.

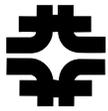
Decision to build remaining tanks depends on test results and pbar production rate.



Looking into a separator



In clean room @ MP9...TD has been helping improve conditioning of spares to lower the spark rate @ high voltages



Tevatron Electrostatic Separators

- In the past year and in 2006 shutdown...
 - 5 separators (re)conditioned/prepared for installation
 - Replace A49 seps (limited voltages due to sparks)
 - 2 new separator installations - horz @ A17, vert @ B48
 - Started testing Ti electrodes in test stand
- Will increase helical separation at collisions
- Will implement new helix "5-star" after shutdown

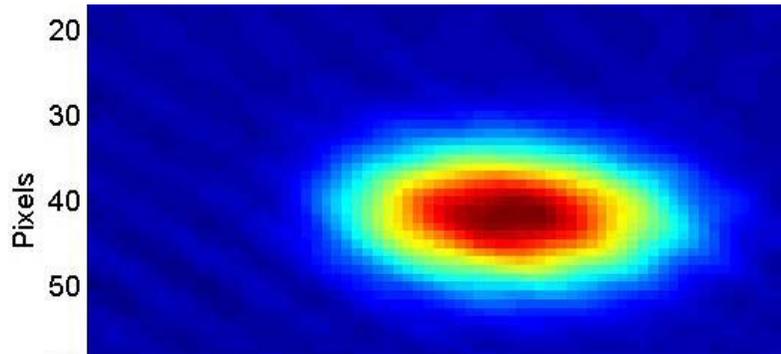
3rd order RDT due to BB at 150 (analytics):

helix	$3Q_x$	$2Q_x + Q_y$	$Q_x + 2Q_y$	$3Q_y$
nominal	4.0	7.7	8.7	3.5
"5-star"	3.7	5.9	7.3	2.3



Instrumentation

- OTR detectors see first images



- IPM installed and begun commissioning
- Tevatron BPMs
 - Used to smooth during a store
 - TBT used to locate coupling sources
- MI BPMs - Installation after shutdown
- Tevatron and MI BLMs - ready in summer



Remaining Milestones

Uniq	WBS	Name	Finish	Base Fin	%	MS Class	2007								
							Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4		
853	1.2.2.11	Intermediate AP2&DB Improvements Complete (Milestone)	5/26/06	6/6/06	0%	(A)	▽								
1527	1.5.6	Finish Summer 06 Shutdown	5/26/06	5/26/06	0%	C	▽								
895	1.3.3.1.2.4	Stacktail Reconfigured (option) (Milestone)	6/5/06	6/13/06	0%	C	▽								
926	1.6.5.6	Start Phase 4 (Milestone)	6/5/06	6/13/06	0%	(A)	▽								
750	1.4.2.1.4	TEL System Operational	8/25/06	8/25/06	0%	A		▽							
866	1.3.6.8	Rapid Transfers Operational (Milestone)	9/1/06	2/24/06	0%	(A)		▽							
2769	2.2.4.4.4.1.6	Tevatron BLM System Operational	9/25/06	8/11/06	0%	B		◇	▽						
2774	2.2.4.4.4.2.4	MI BLM System Operational	9/25/06	8/11/06	0%	B		◇	▽						
2371	1.1.3.2.6	MI BPM system complete	9/26/06	8/18/06	0%	B		◇	▽						
2779	2.2.4.4.4.3.4	Booster BLM System Operational	10/2/06	8/18/06	0%	B		◇	▽						
91	1.5.7	Start Summer 07 Shutdown	7/2/07	7/2/07	0%	C									▽
854	1.2.2.12	Final AP2&DB Improvements Complete (Milestone)	8/24/07	7/27/07	0%	(A)									▽
1778	1.5.8	Finish Summer 07 Shutdown	8/24/07	8/24/07	0%	C									▽
922	1.6.5.7	Start Phase 5 (Milestone)	9/17/07	9/17/07	0%	(A)									▽
1129	1.6.5.8	End Project	9/17/07	9/17/07	0%	(A)									▽

See Note 1 below

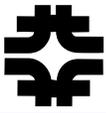
- ◇ Baseline Finish Date
- ◆ Actual Finish Date
- Forecast Date

Note 1: Delayed as a result of moving the fall 2005 shutdown to spring 2006, Part of CR-44.

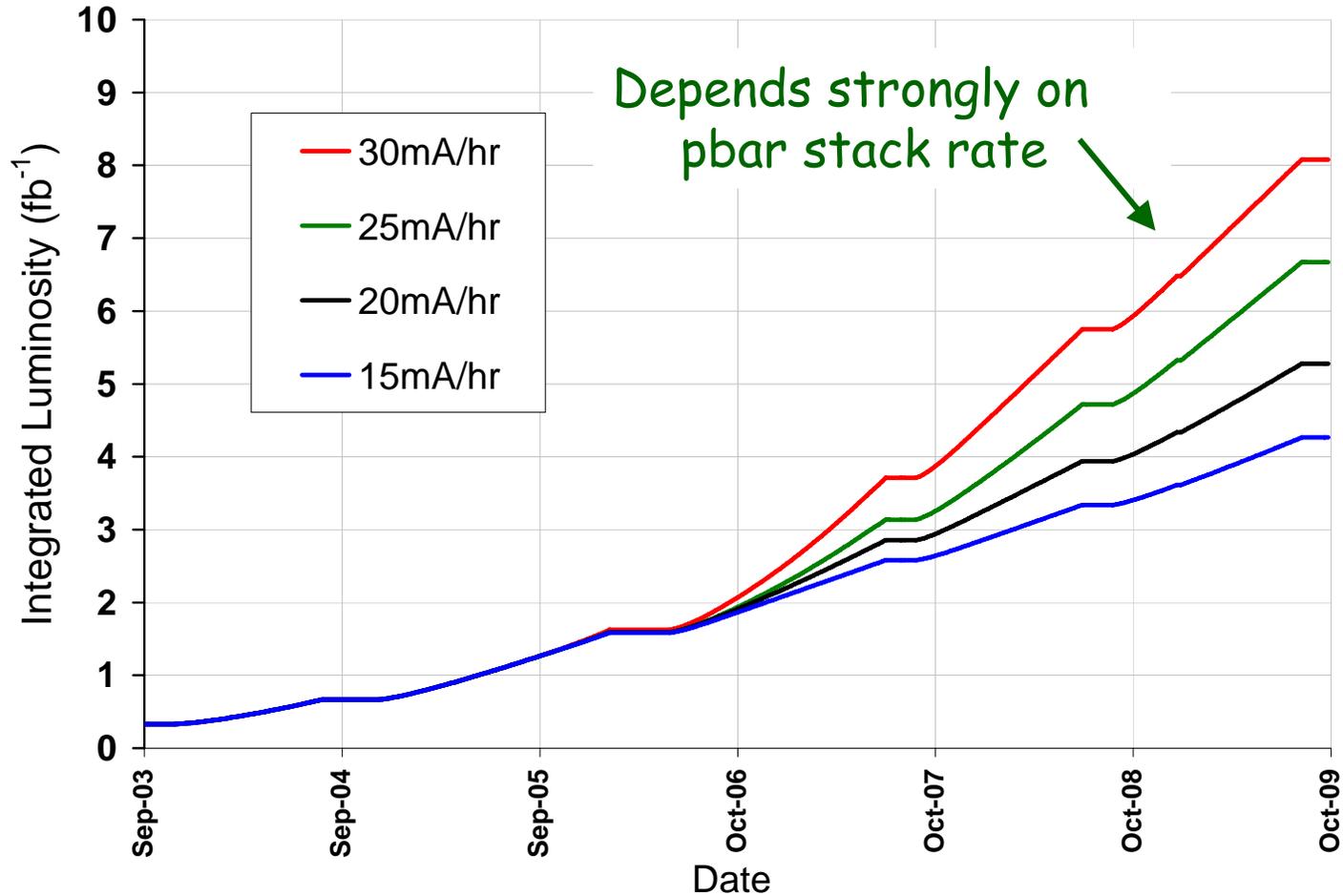


Descoping options

- **Stacktail Cooling**
 - Design work and prototype completed
 - Not needed unless significant gain in stack rate
 - Will decide in Summer '06 if needed.
- **Debuncher Vertical Band 4 Aperture**
 - Design is completed
 - Not a significant gain in aperture
 - Eliminates lots of cryo, vacuum, and mechanical work during an already packed shutdown
- **Pbar Target Sweeping**
 - Design and Hardware completed
 - Will focus on target improvements
 - If needed, the remaining work is mostly commissioning



Luminosity Projection





Projection for 30 mA/hr stack rate

Luminosity Parameters							
Phase	1	2	3	4	5	6	
Initial Luminosity	77.0	97.1	137.2	318.9	331.2	331.2	$\times 10^{30} \text{cm}^{-2} \text{sec}^{-1}$
Average Luminosity	33.8	45.3	64.0	128.0	132.9	132.9	$\times 10^{30} \text{cm}^{-2} \text{sec}^{-1}$
Integrated Luminosity / week	12.1	16.5	23.3	48.2	50.1	50.1	pb^{-1}
Integrated Luminosity / store	3.0	3.6	5.1	10.1	10.5	10.5	pb^{-1}
Number of stores / week	4.0	4.6	4.6	4.8	4.8	4.8	
Average Store Hours / week	100	101	101	105	105	105	Hours
Store Length	25	22	22	22	22	22	Hours
Initial Lifetime	6.4	6.4	6.4	5.0	5.0	5.0	Hours
Average Lifetime	12.8	12.3	12.3	9.9	9.9	9.9	Hours
HEP Up Time / week	110	113	113	117	117	117	Hours
Shot Setup Time	2.6	2.6	2.6	2.6	2.6	2.6	Hours

Now entering phase 4 



Projection for 30 mA/hr stack rate

Antiproton Parameters							
Phase	1	2	3	4	5	6	
Zero Stack Stacking Rate	13.0	16.0	18.9	30.2	30.2	30.2	$\times 10^{10}$ /hour
Average Stacking Rate	6.3	7.4	9.6	21.7	21.7	21.7	$\times 10^{10}$ /hour
Stack Size transferred	158.2	163.8	211.5	476.5	476.5	476.5	$\times 10^{10}$
Stack to Low Beta	117.1	124.5	169.2	381.2	381.2	381.2	$\times 10^{10}$
Pbar Production	16.0	15.0	16.0	21.0	21.0	21.0	$\times 10^{-6}$
Protons on Target	5.4	6.5	7.2	8	8	8	$\times 10^{12}$
Pbar cycle time	2.4	2.2	2.2	2	2	2	Secs.
Pbar up time fraction	0.75	0.75	0.75	0.9	0.9	0.9	
Initial Stack Size	15	15	0	0	0	0	$\times 10^{10}$
Stack Size at 1/2 Stacking Rate	150	150	150	150	150	150	$\times 10^{10}$

Now entering phase 4 



Run II Upgrade Summary

- Run II Project 85% complete
 - Has met Luminosity goals

- Poised to take advantage of Run II Projects
 - E-cooling in Recycler well established
 - Improvements in stack rate continue
 - Tevatron Beam-Beam
 - Separator Upgrades
 - Chromatic Compensation

- Luminosity projections
 - Based on experience with E-cool and Recycler Shots
 - Scenario is stack rate dependent
 - Can reach 8 fb^{-1} with stack rate of 30 mA/hour
 - Fallback is reduced stack rate (5.2 fb^{-1} for 20 mA/hour)