The Run II Upgrade Program

DOE Review
July 21, 2003

Program of upgrade projects in
MI-Accumulator-Recycler-Tevatron and the beam transfers

- Increase pbar production and stack size
- Upgrade Tevatron for higher bunch intensities

Sections

- Introduction
  - Context, project organization and process
- Summary, Resource-loaded schedule
  - Methodology, milestones and phases, roll-ups
- Luminosity projection
  - Parameters, projections
- Technical progress
  - Subprojects
- Conclusion

Context

- History
  - Plans for Run IIb (Dec 01) ← motivation and technical basis
    - includes cost, labor estimates and luminosity projection, but not a "project plan"
    - at that time many of the projects were already well underway
  - DOE Review (Oct 02)
    - technical tasks in the upgrade program are "adequate, reasonable, and in principle achievable" while some of the subprojects "represent significant challenge" and require R&D
    - ACTION ITEM: prepare a "detailed, resource loaded plan for completing the Run II luminosity upgrade"

Process

- Dropped Run IIa / Run IIb distinction
- Established project organization: planning, execution
- Integrated organization for Run II
  - Operations (WBS 1.1)
    - operations, and operational maintenance and improvements (via system and support departments)
  - Reliability/Maintenance Upgrades (WBS 1.2)
    - planned improvements to reliability and mitigation of vulnerabilities
  - Luminosity Upgrades (WBS 1.3)
    - planned system upgrades to increase luminosity

Process

- Developed models for luminosity performance
- Assembled bottom-up WBS for 1.2 and 1.3
- Developed project plan, phases, and luminosity projection
- Now developing project tracking and reporting
  - Tracking – status every month
  - Benchmark – update < quarterly ← Sep and Dec
  - Reporting - quarterly

Upgrade Strategy

- Peak luminosity goal (design) is 2.9×10^{32} $cm^{-2}sec^{-1}$ (x7-8 increase over current typical)
- Luminosity

$$L = \frac{3\gamma f_0}{\beta^*}\left(BN_{\bar{p}}\right)\left(\frac{N_p}{\varepsilon_p}\right)\frac{F\left(\beta^*, \theta_{x,y}, \varepsilon_{p,\bar{p}}, \sigma^L_{p,\bar{p}}\right)}{\left(1+\varepsilon_{\bar{p}}/\varepsilon_p\right)}$$

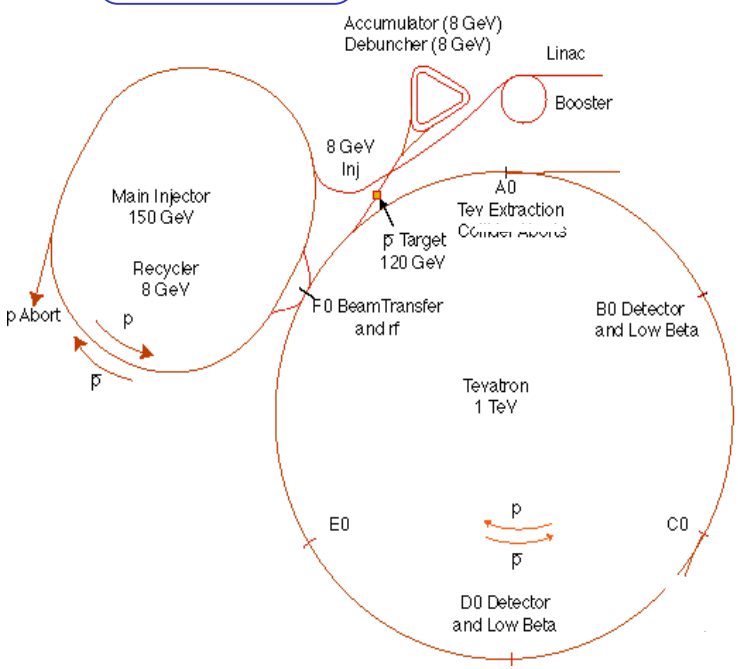
- Primary factors
  - The number of antiprotons = BN_{pbar}
  - The proton beam brightness (N_p/ε_p) (drives the pbar beam-beam tune shift)
  - $\varepsilon_p/(\varepsilon_p + \varepsilon_{pbar})$ and form factor *F*
- The pbar "burn" rate
  - $n_c = 2$
  - σ_a = 70 mb (cross-section for scattering outside Tev acceptance)
  - $L = 2.9\times10^{32}$ cm^{-2} sec^{-1}
  - → $\Phi = 15\times10^{10}$ hr^{-1}

Design/Now

Parameter		May 03 Average	Run II Design	Ratio
Peak Luminosity	$x10^{31}cm^{-2}sec^{-1}$	3.7	29	7.8
Store hours per week		75	97	1.3
Store Duration	hr	15	15	1.0
Integrated Luminosity	pb^{-1}/wk	5.9	55	9.3
Number of Bunches		36	36	1.0
Protons/bunch	$x10^{10}$	22	27	1.2
Antiprotons/bunch	$x10^{10}$	2.2	13	5.9
$\beta*$	cm	35	35	1.0
MI extraction Longitudinal Emittance	eV s	3.5	2.5	0.7
Bunch Length (rms)	m	0.6	0.5	0.9
Proton Transverse Emittance (at collision)	π-mm-mrad	20	18	0.9
Antiproton Transverse Emittance (at collision)	π-mm-mrad	18	18	1.0
Hourglass Form Factor		0.6	0.63	1.1
Pbar Transmission Efficiency	%	60	80	1.3
Stack Used	$x10^{10}$	134	583	4.4
Avg. Antiproton Production Rate	$x10^{10}/hr$	8.3	40	4.8

Luminosity Upgrade Organization

- 1.3 Luminosity Upgrades — J. Spalding Prj Mgr; D McGinnis Tech Coord
  - 1.3.1 Protons on pbar Target — I Kourbanis
    - 1.3.1.1 Slip stacking — R Pasquinelli
    - 1.3.1.2 Pbar Target — J Morgan
    - 1.3.1.3 MI Upgrades — I Kourbanis
  - 1.3.2 Pbar Acceptance — S Werkema
    - 1.3.2.1 Li Lens Upgrade — J Morgan
    - 1.3.2.2 AP2 & Deb Acc — K Gollwitzer
  - 1.3.3 Pbar Stacking & Cooling — P Derwent
    - 1.3.3.1 Integ Task Force — S Nagaitsev
    - 1.3.3.2 Debuncher — P Derwent
    - 1.3.3.3 Stacktail — P Derwent
    - 1.3.3.4 Recycler Comm — S Nagaitsev
    - 1.3.3.5 Electron-Cooling — S Nagaitsev
    - 1.3.3.6 Rapid Transfers — E Harms
  - 1.3.4 Tevatron High Luminosity — V Shiltsev
    - 1.3.4.1 Tevatron Task Force — V Lebedev
    - 1.3.4.2 Beam-beam Studies — T Sen
    - 1.3.4.3 Active B-B Comp — V Shiltsev
    - 1.3.4.4 Helix Separation — R Moore
    - 1.3.4.5 Luminosity Leveling — M Martens
    - 1.3.4.6 Control & Diag — J Steimel
    - 1.3.4.7 Vacu Improvements — B Hanna
    - 1.3.4.8 Tevatron Alignment — R Stefanski



Task Forces: Stacking and Cooling, and Tevatron

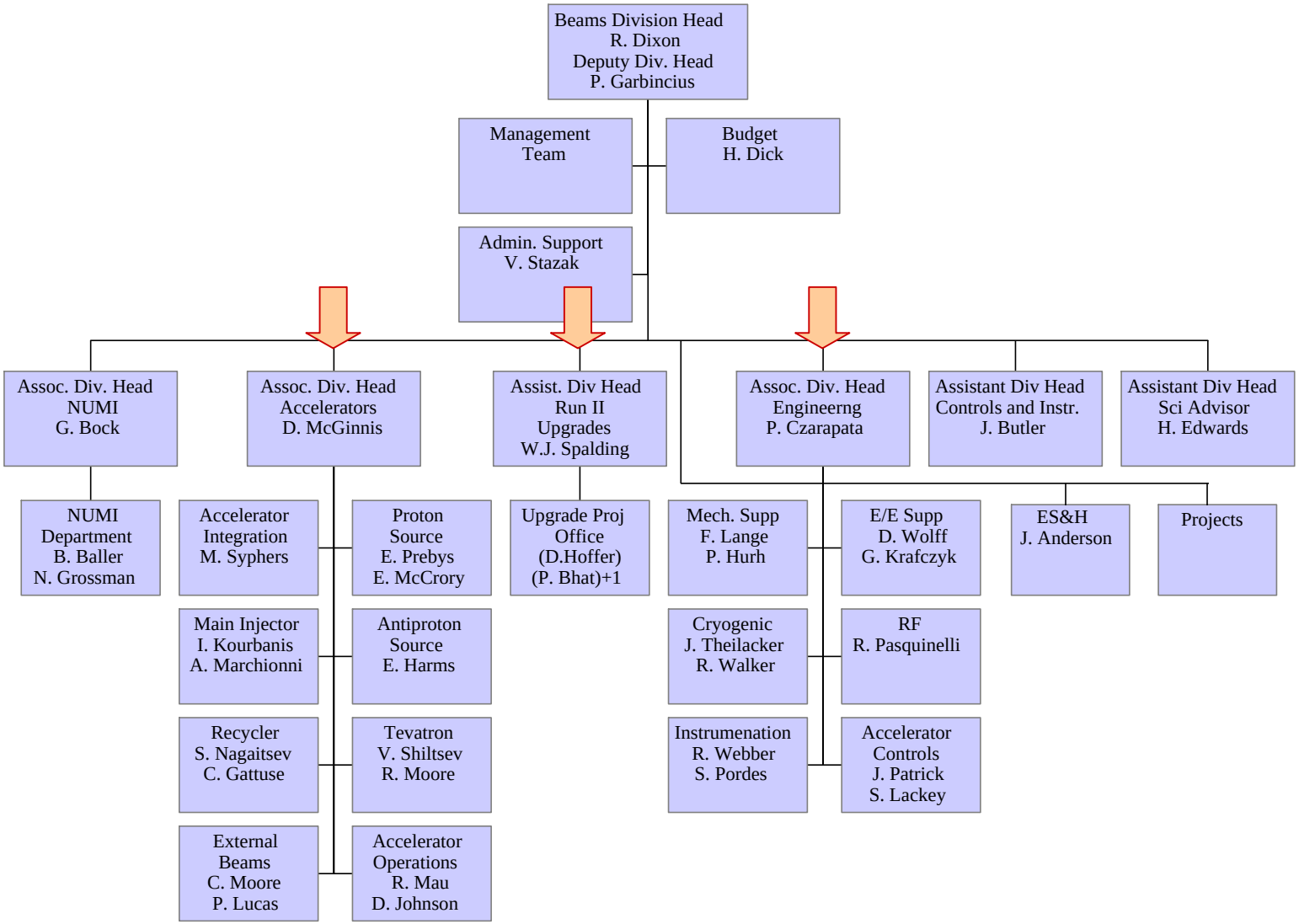
- Developed models for pbar production (integrated across machines) and Tevatron stores
- Benchmarked parametric models to data, calculations and simulation

→Develop project phasing and performance

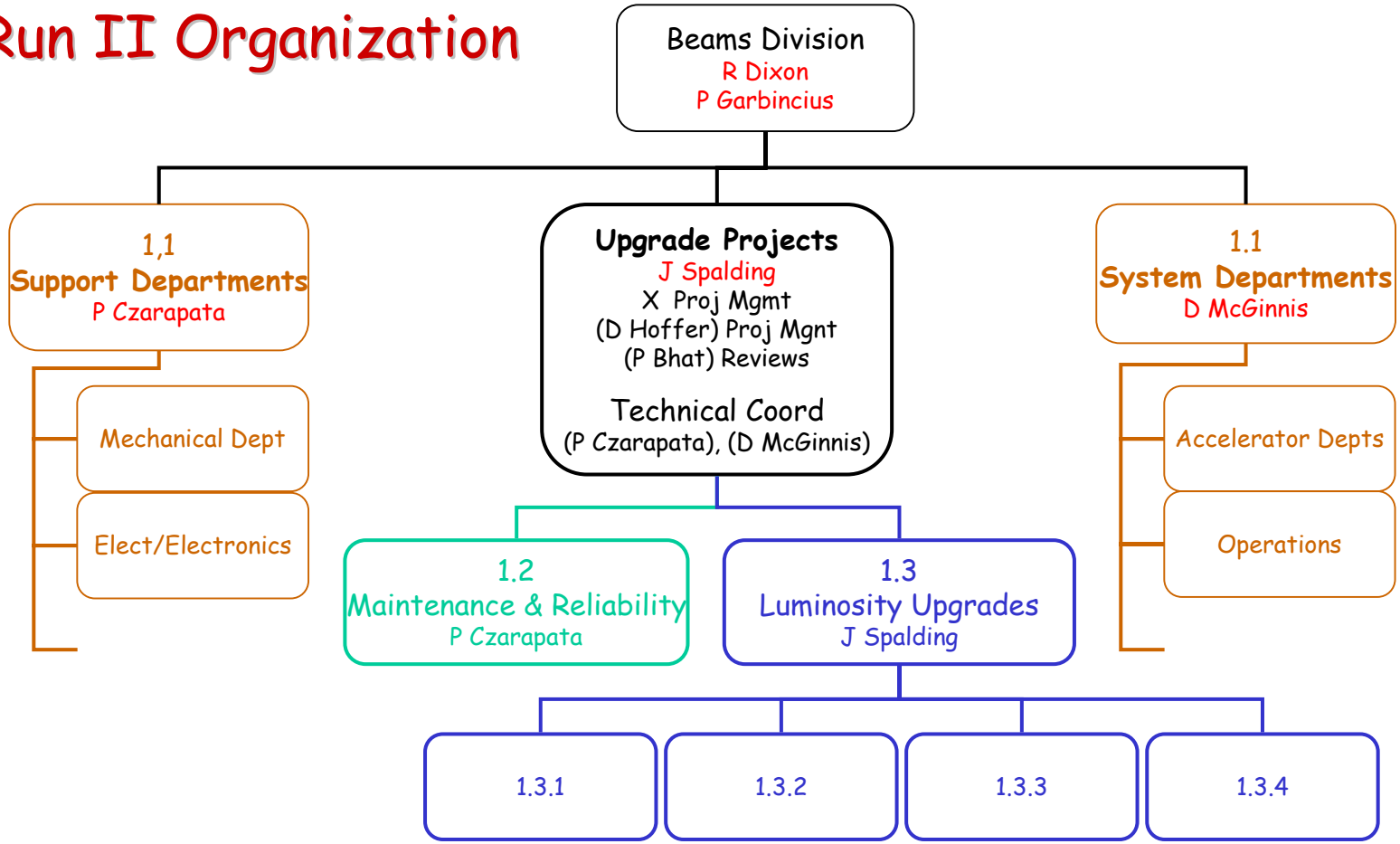
→ Project scope for Tevatron upgrades

→Dependence on key parameters

Beams Division Organization



Run II Organization



WBS 1.1 Operational support, maintenance & improvements - Support and System Departments
WBS 1.2 Longer-term Maintenance and Reliability improvements captured in project WBS
WBS 1.3 Longer-term Luminosity Upgrades captured in project WBS

WBS 1.2 and 1.3 consolidate the upgrade plans across the complex into a programmatic WBS

Management Team – in red

Project Scope

- Project scope is well defined, with estimates based on design concepts or prototypes

…with three exceptions

- AP2&DB acceptance:
  - Identify and mitigate aperture limitations ← representative scope included where unknown, with 100% contingency
- Beam-beam mitigation in the Tevatron
  - Beam-beam compensation (active and helix): studies on-going ← evaluation and decision points included in schedule – estimates assume we go ahead
- Recycler
  - Commissioning plan presently being re-evaluated. This will result in an update to the overall plan - expect to complete by December 2003

Project Scope

- Scope changes since the Oct 02 DOE Review
  - Dropped 132 nsec operation in the Tevatron
    - number of int/crossing: new expt limit = 10 ←$4\times10^{32}cm^{-2}s^{-1}$ @396 ns
    - 132 requires a crossing-angle → ~40% red. in luminosity
    - total protons x3 → long range beam-beam int and instabilities
    - requires large study and simulation effort & work on hardware
    - will develop luminosity leveling (vary β^*) if needed
    - has consequences for cooling in the Recycler, longitudinal emittance 1/3. fully simulated.
  - Dropped work on pbar recycling
    - historically ~30% of stores end prematurely
    - ~75% pbar left, 70% acceptance to Recycler → ~35% pbars return
    - reduce loss of integrated luminosity with longer stores/stacking
    - contribution depends on stacking rate and store length
    - biggest issue - timely removal of protons (without risk to experiments or quenching), followed by pbar deceleration
    - not included in present plan

Project Scope

- Dropped operating phase with Recycler, without electron cooling (stochastic cooling only)
  - no longer fits in project schedule
  - little design margin with stochastic cooling only
- Added emphasis on increasing helix separation in the Tevatron
  - to reduce long range beam-beam effects
- Investigating wire-based active beam-beam compensation
  - study applicability, consider development program
- Added major instrumentation projects and Tev alignment
  - WBS 1.2 and 1.3 capture all long term work for RUN II

Resource-Loaded Schedule

handout includes:

- Labor and M&S costs per FY
- WBS dictionary and Basis of Estimate
- List of milestones
- Gantt chart with dates and resources

RLS Methodology

- Bottom-up – realistic ~ include resource sharing with operations
- Project leaders defined the WBS and estimates for their project (~600 tasks)
- Assigned resources (named where possible), study shifts, duration and links
- Labor calculated in work-days, converted to FTE using 85% availability
- Access to tunnels OK for ~1-day jobs, otherwise <u>constrained by Lab shutdown schedule</u>
  - Shutdowns set by these projects (WBS 1.2 and 1.3), plus maintenance, NuMI, lab budgets…
  - Shutdowns introduce a delay of 1-3 months at various stages (i.e. not optimized)
  - Shutdown schedule is a significant schedule driver

RLS Methodology

- Quality of estimate
  a) an engineered concept, or vendor information – 20% contingency
  b) initial conceptual design, experience with similar projects– 40% contingency
  c) experience with other projects – 60% contingency
  d) R&D or scope not yet fully defined - use an estimate of the cost scale – 100% contingency

Changes since document submitted to DOE

- Cost and Labor estimates updated
- All costs are in FY03 $ in *Microsoft Project*, escalated to then year $ in *Excel*

Cost (Obligation) Summary by FY in FY03 and Actual Year $

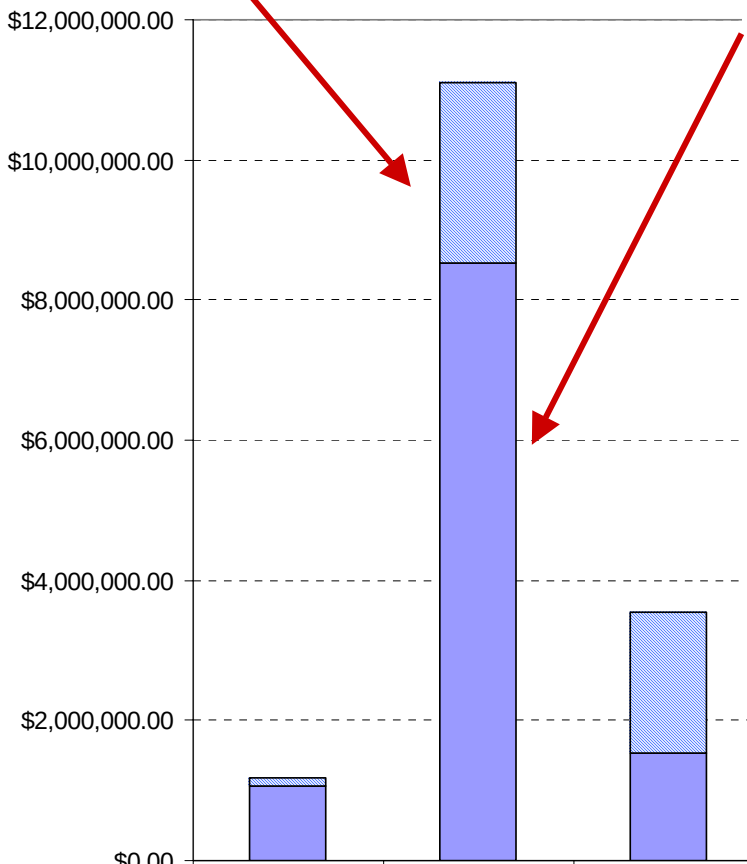
		FY03	FY04	FY05	FY06	FY07	Total	%Cont
WBS 1.2 Maintenance and Reliability								
M&S								
Base Cost	FY03 $K	258	1,288	858	1,000	0	3,404	
Base+ Contingency	FY03 $K	368	1,840	1,225	1,428	0	4,862	43
Base + Contingency	Actual Year $K	368	1,891	1,294	1,547	0	5,100	
(Base + Contingency) + Indirect Costs	Actual Year $K	427	2,194	1,501	1,795	0	5,916	
Labor								
Base Cost	FY03 $K	114	372	403	215	6	1,109	
Base+ Contingency	FY03 $K	184	604	653	349	9	1,799	62
Base + Contingency	Actual Year $K	184	628	706	392	11	1,922	
(Base + Contingency) + Indirect Costs	Actual Year $K	239	817	918	510	14	2,499	
WBS 1.3 Luminosity Upgrades								
M&S								
Base Cost	FY03 $K	1,065	8,307	1,460	730	0	11,561	
Base+ Contingency	FY03 $K	1,171	10,798	3,358	1,460	777	17,565	52
Base + Contingency	Actual Year $K	1,171	11,101	3,545	1,581	863	18,262	
(Base + Contingency) + Indirect Costs	Actual Year $K	1,359	12,877	4,112	1,835	1,001	21,184	
Labor								
Base Cost	FY03 $K	3,386	6,956	4,270	1,886	587	17,085	53
Base+ Contingency	FY03 $K	3,555	9,391	8,540	2,956	1,658	26,101	
Base + Contingency	Actual Year $K	3,555	9,767	9,237	3,326	1,940	27,824	
(Base + Contingency) + Indirect Costs	Actual Year $K	4,622	12,697	12,008	4,323	2,522	36,171	
WBS 1.2+1.3								
Total: M&S + Labor								
Base Cost	FY03 $K	4,822	16,923	6,990	3,831	593	33,159	
Base+ Contingency	FY03 $K	5,279	22,633	13,776	6,194	2,445	50,327	
Base + Contingency	Actual Year $K	5,279	23,387	14,782	6,847	2,814	53,108	
(Base + Contingency) + Indirect Costs	Actual Year $K	6,647	28,584	18,539	8,462	3,537	65,770	

M&S Base Costs for WBS 1.1 ,1.2 & 1.3

Base Costs in Actual Year $K	FY03	FY04	FY05	FY06	FY07	Total		
M&S	**13,247**	**22,207**	**15,223**					
WBS 1.1 Base Cost*	11,924	12,344	12,776				Cont held by B.Div and Directorate	
WBS 1.2 Base Cost	258	1,324	906	1,083	0	3,571	Contingency estimate	43%
WBS 1.3 Base Cost	1,065	8,539	1,541	791	0	11,936	Contingency estimate	52%
Labor	**34,863**	**40,089**	**38,767**					
WBS 1.1 Base Cost*	31,364	32,467	33,713				Cont held by B.Div and Directorate	
WBS 1.2 Base Cost	114	387	435	242	7	1,185	Contingency estimate	62%
WBS 1.3 Base Cost**	3,386	7,235	4,618	2,121	687	18,047	Contingency estimate	53%
* WBS 1.1 is estimated through FY05								
** about 30% of this labor will be non Beams Division								

1.3 M&S Obligations in Actual Year $

52% contingency roll-up is reapplied by FY
(30% in FY04)

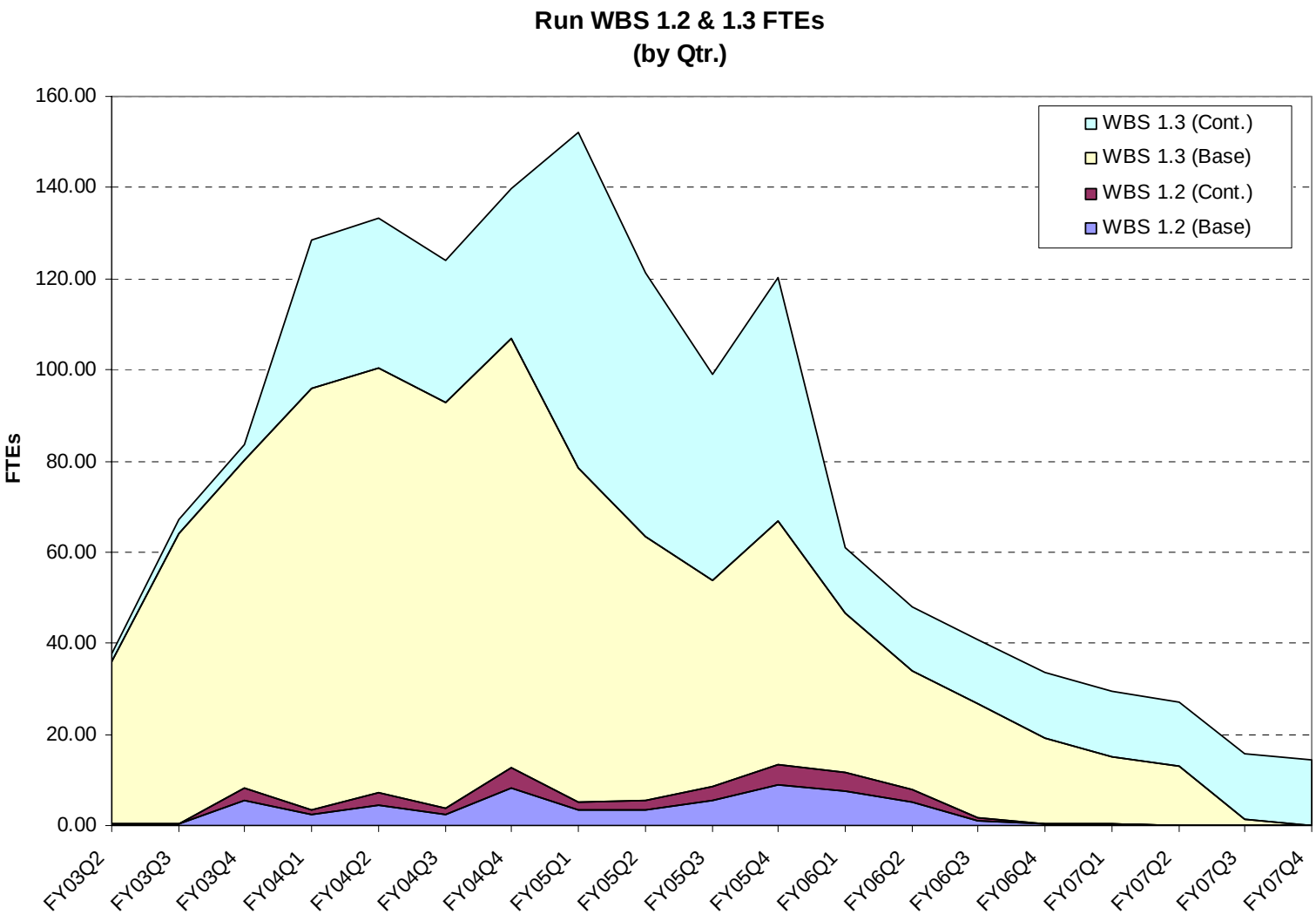


	FY03	FY04	FY05	FY06	FY07
WBS 1.3 M&S - (Cont. + Esc.)	$106,496.00	$2,561,724.60	$2,003,824.89	$790,740.13	$863,178.37
WBS 1.3 M&S - (Base Cost + Esc.)	$1,064,960.00	$8,539,082.00	$1,541,403.76	$790,740.13	$0.00

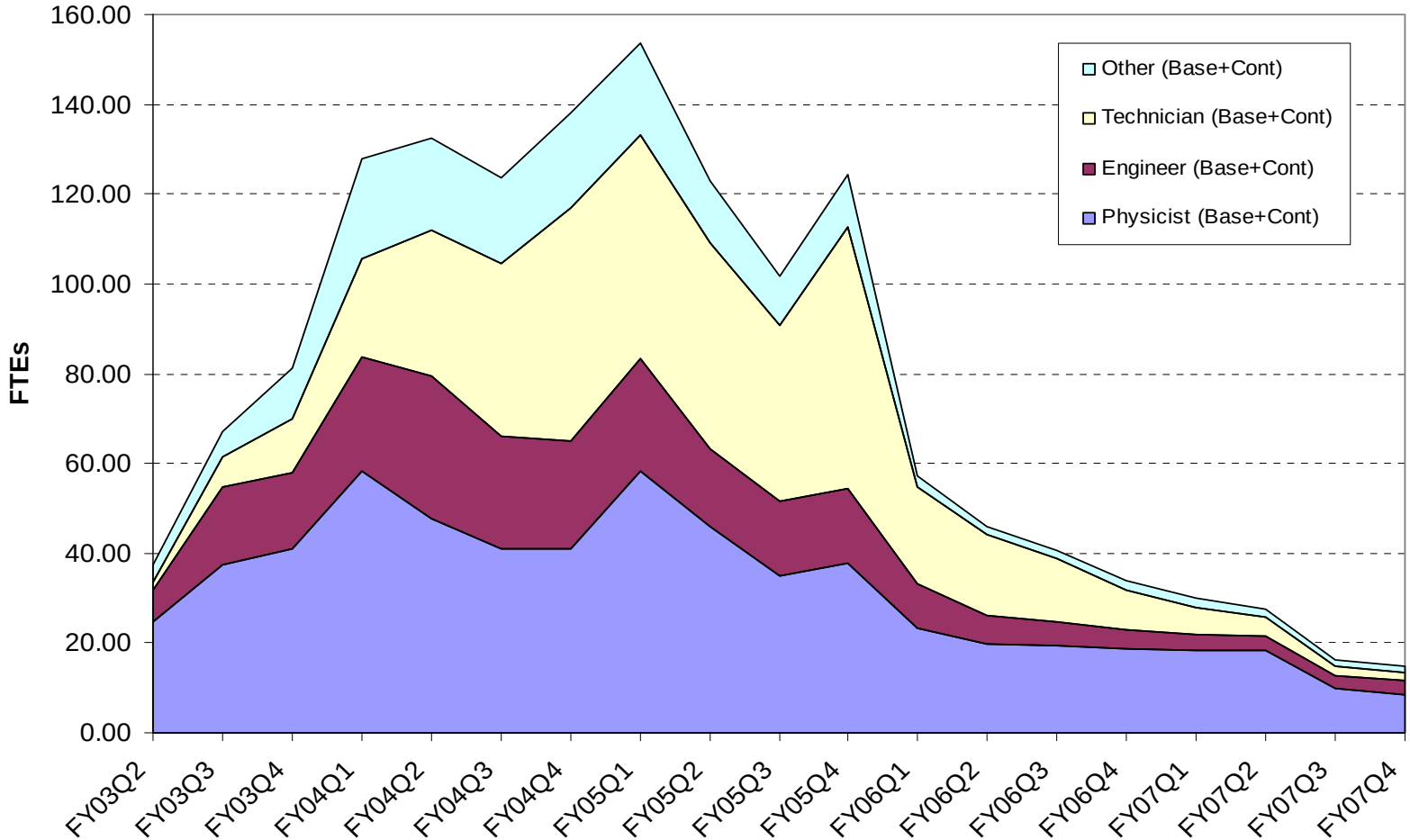
Spending peak in FY04

- FY04 peak $8.5M
- Parallel subprojects advance together
- cost drivers >$5M
  - Separators $1.4M
  - Stacktail (TWTs…) $1.0M
  - TEV BPMs $0.9M
  - MI BPMs $0.9M -
  - Slip stacking amps $0.7M
  - Beamline BPM $0.3M
  - Others <$0.2M

Labor Profile (FTE) for WBS 1.2 and 1.3



WBS 1.2+1.3 Labor Breakdown (w/Contingency)



FY03

- projects ongoing as WBS filled - only ~2/3 of FY03 captured in WBS
- FY03 plan hands over ongoing projects at start FY04
- contingency added for FY04 on

Specific Labor Needs

- Large contribution (>30%) from outside B. Div
  - from other divisions
    - TD, PPD, CD
      - shot data analysis
      - fabrication
      - instrumentation
      - alignment
      - …
  - from other labs, including
    - Tevatron simulation ← SLAC, LBNL
    - Beamline optics, design ← LBNL
    - TEL ← Budker INP

- Specific outstanding needs
  - Electron Cooling: 2 physicists, 1 engineer
  - Recycler: 2 physicists (need updated plan)
  - Tevatron electron lens: 1 physicist, 1 engineer
  - Tevatron Task Force: 1 physicist

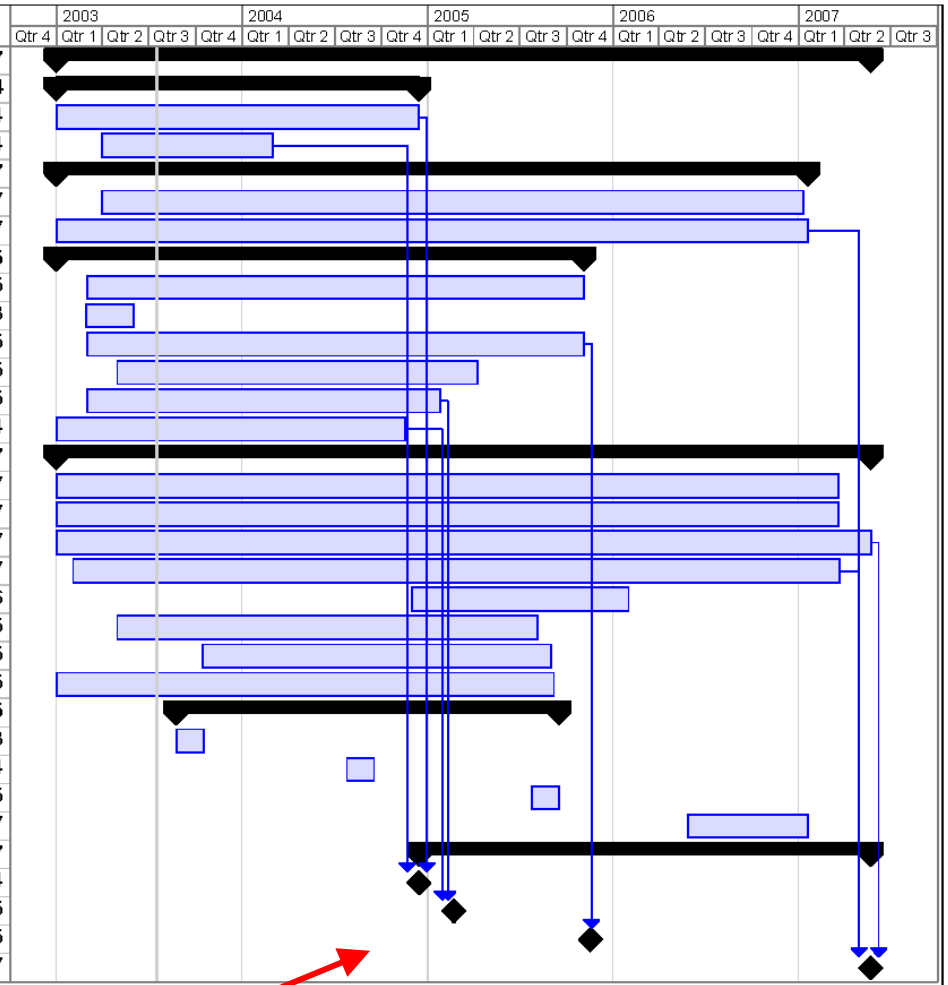
  8 total
  4 identified
  - 3 visitors
  - 1 p-d offer
  4 to find
  - 2 more p-d
  - LBNL?

  - BPM systems: ~6 ← CD, in process

Milestones and Phases

>600 Tasks
~ 50 Project Milestones

ID	WBS	Task Name	Finish
1	**1.3**	**Run II Upgrades**	**Wed 5/23/07**
2	**1.3.1**	**Protons on Pbar Target**	**Tue 12/14/04**
3	1.3.1.1	Slip Stacking	Tue 12/14/04
4	1.3.1.2	Pbar Target and Sweeping	Mon 3/1/04
5	**1.3.2**	**Pbar Acceptance**	**Fri 1/19/07**
6	1.3.2.1	Lithium Lens Upgrades	Wed 1/10/07
7	1.3.2.2	AP2 and Debuncher Acceptance	Fri 1/19/07
8	**1.3.3**	**Pbar Stacking and Cooling**	**Fri 11/4/05**
9	1.3.3.1	Integration	Fri 11/4/05
10	1.3.3.2	Debuncher Cooling	Mon 6/2/03
11	1.3.3.3	Stacktail Cooling	Fri 11/4/05
12	1.3.3.4	Recycler Stacking and Cooling	Fri 4/8/05
13	1.3.3.5	Electron Cooling	Tue 1/25/05
14	1.3.3.6	Rapid Transfers	Thu 11/18/04
15	**1.3.4**	**Tevatron High Luminosity**	**Wed 5/23/07**
16	1.3.4.1	Tevatron Task Force	Tue 3/20/07
17	1.3.4.2	Beam-beam limitations	Tue 3/20/07
18	1.3.4.3	Active Beam-Beam Compensatio	Wed 5/23/07
19	1.3.4.4	Increased Helix Separation	Fri 3/23/07
20	1.3.4.5	Luminosity Leveling	Tue 1/31/06
21	1.3.4.6	Improved Control and Diagnostic:	Fri 8/5/05
22	1.3.4.7	Vacuum Improvements	Thu 9/1/05
23	1.3.4.8	Tevatron Alignment	Tue 9/6/05
24	**1.3.5**	**Shutdowns**	**Fri 9/16/05**
25	1.3.5.1	summer 03	Fri 10/17/03
26	1.5.2	summer 04	Fri 9/17/04
27	1.5.3	summer 05	Fri 9/16/05
28	1.5.4	IIb shutdown	Fri 1/19/07
29	**1.6**	**Operating Phases**	**Wed 5/23/07**
30	1.6.2.4	Start Phase 2	Tue 12/14/04
31	1.6.2.5	Start Phase 3	Tue 2/22/05
32	1.6.2.6	Start Phase 4	Thu 11/17/05
33	1.6.2.7	Start Phase 5	Wed 5/23/07



Start Operating Phases 2,3,4,5

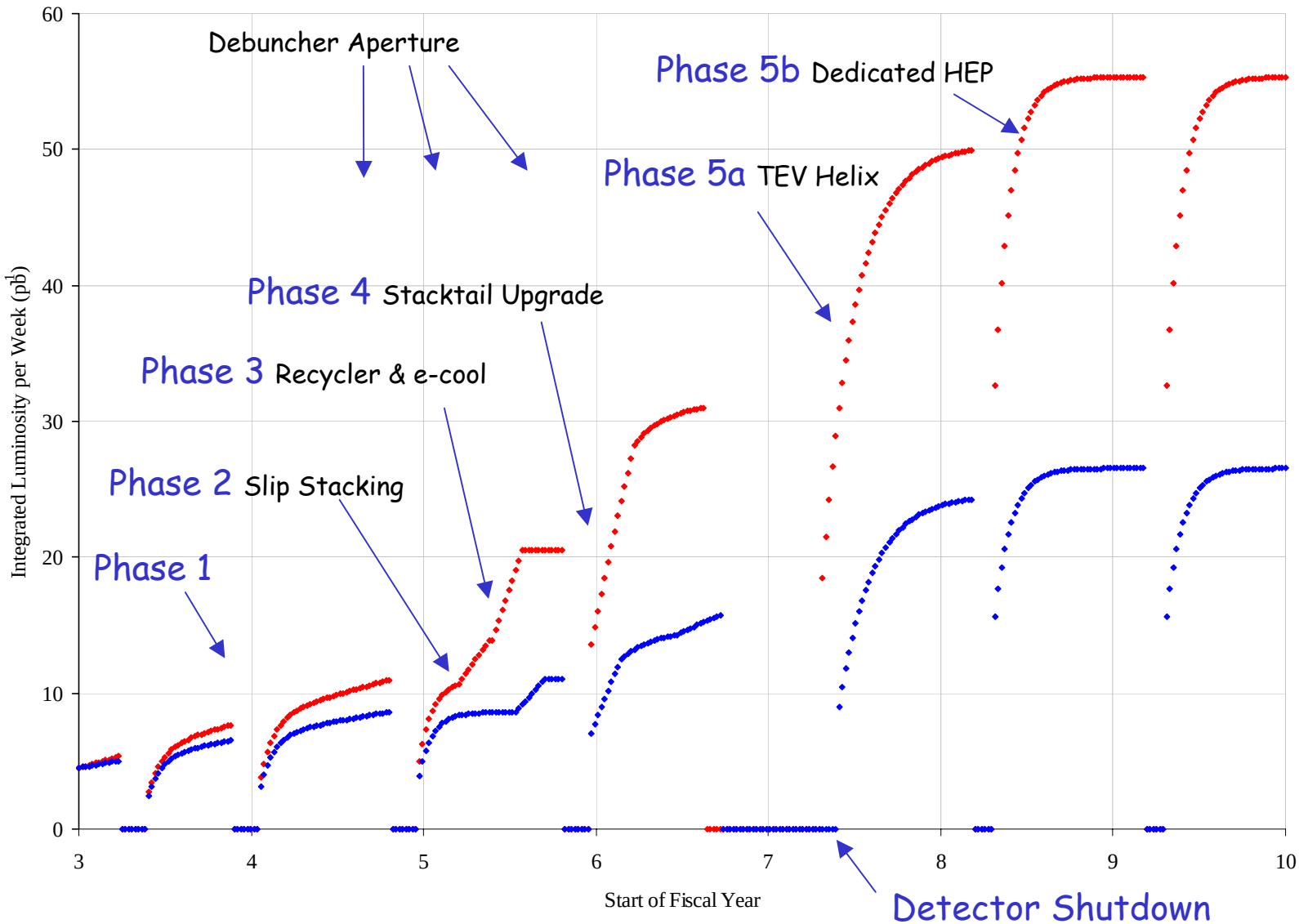
Operating Phases

- phase 1 - present
  - See Dave McGinnis' talk.
    pbar rep rate, emittance blowup, transfer efficiency
- phase 2 – December 2004
  - Slip-stacking and the first part of the AP2 & Debuncher Acceptance upgrade
  - pbar stacking rate and size limited by present Stacktail + Core
  - needs target station upgrade
- phase 3 – February 2005
  - Recycler and electron cooling
  - operating mode is very different
  - initial commissioning HEP supported by the Accumulator, reducing disruption to the program
  - with the stack transferred to the Recycler, larger stack sizes possible, though stacking rate will continue to be limited by the Stacktail cooling in the Accumulator

Operating Phases

- phase 4 – November 2005
  - once HEP is supported from Recycler (large stacks no longer in Accumulator)
  - upgrade the Stacktail cooling system for much higher stacking rates
  - Rapid transfers to Recycler every half hour
- phase 5 – May 2007
  - complete increase in helix separation and active beam-beam compensation → large p and pbar bunch intensities
  - phase 5a includes studies to complete final upgrade commissioning. Phase 5b includes only "maintenance studies" for maximum HEP running
- AP2 and Debuncher acceptance throughout phases

Weekly Luminosity and Phases



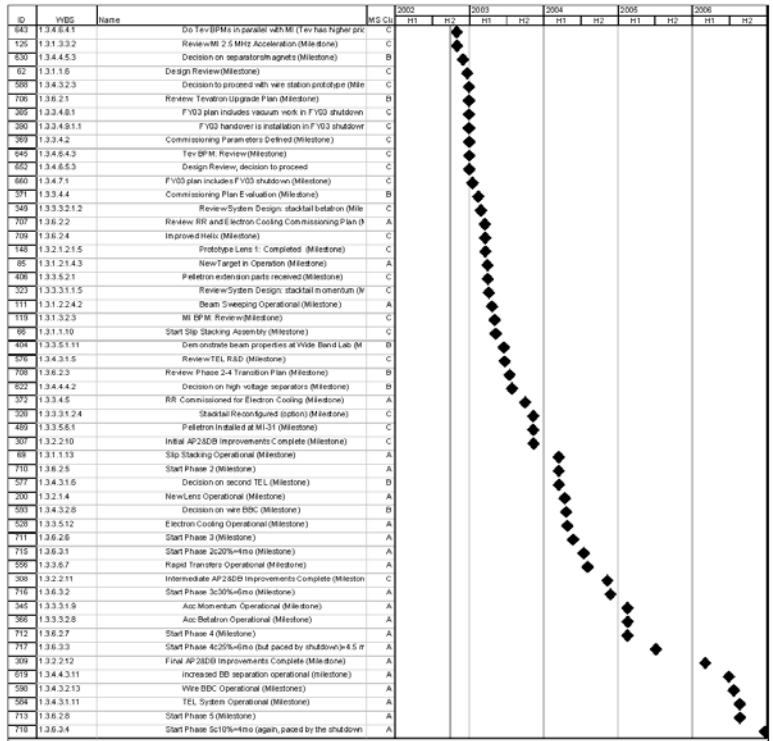
Milestones

Hierarchy

(A) drive the timeline in the luminosity projection
- completion of each subproject
- start of each operating phase

(B) major scope decisions
- review of Recycler plan
- evaluation of e-cooling
- review of Tevatron upgrade plan

(C) internal technical reviews and progress evaluation
- transition from design or R&D to production
- other progress tracking points



ID	WBS	Name	MS Cl
543	1.3.4.5.4.1	Do Tev BPMs in parallel with MI (Tev has higher pric	C
125	1.3.1.3.3.2	Review MI 2.5 MHz Acceleration (Milestone)	C
630	1.3.4.4.5.3	Decision on separators/magnets (Milestone)	B
62	1.3.1.1.6	Design Review (Milestone)	C
588	1.3.4.3.2.3	Decision to proceed with wire station prototype (Mile	C
706	1.3.6.2.1	Review Tevatron Upgrade Plan (Milestone)	B
289	1.3.3.4.8.1	FY03 plan includes vacuum work in FY03 shutdown	C
290	1.3.3.4.9.1.1	FY03 handover is installation in FY03 shutdowr	C
369	1.3.3.4.2	Commissioning Parameters Defined (Milestone)	C
545	1.3.4.5.4.3	Tev BPM: Review (Milestone)	C
652	1.3.4.6.5.3	Design Review, decision to proceed	C
660	1.3.4.7.1	FY03 plan includes FY03 shutdown (Milestone)	C
371	1.3.3.4.4	Commissioning Plan Evaluation (Milestone)	B
349	1.3.3.3.2.1.2	Review/System Design: stacktail betatron (Mile	C
707	1.3.6.2.2	Review RR and Electron Cooling Commissioning Plan (I	A
709	1.3.6.2.4	Improved Helix (Milestone)	C
148	1.3.2.1.2.1.5	Prototype Lens 1: Completed (Milestone)	C
85	1.3.1.2.1.4.3	New Target in Operation (Milestone)	A
406	1.3.3.5.2.1	Pelletron extension parts received (Milestone)	C
323	1.3.3.3.1.1.5	Review/System Design: stacktail momentum (M	C
111	1.3.1.2.2.4.2	Beam Sweeping Operational (Milestone)	A
119	1.3.1.3.2.3	MI BPM: Review (Milestone)	C
66	1.3.1.1.10	Start Slip Stacking Assembly (Milestone)	C
404	1.3.3.5.1.11	Demonstrate beam properties at Wide Band Lab (M	B
576	1.3.4.3.1.5	Review TEL R&D (Milestone)	C
708	1.3.6.2.3	Review: Phase 2-4 Transition Plan (Milestone)	B
622	1.3.4.4.4.2	Decision on high voltage separators (Milestone)	B
372	1.3.3.4.5	RR Commissioned for Electron Cooling (Milestone)	A
326	1.3.3.3.1.2.4	Stacktail Reconfigured (option) (Milestone)	C
489	1.3.3.5.8.1	Pelletron Installed at MI-31 (Milestone)	C
307	1.3.2.2.10	Initial AP2&DIB Improvements Complete (Milestone)	C
69	1.3.1.1.13	Slip Stacking Operational (Milestone)	A
710	1.3.6.2.5	Start Phase 2 (Milestone)	A
577	1.3.4.3.1.6	Decision on second TEL (Milestone)	B
200	1.3.2.1.4	New Lens Operational (Milestone)	A
593	1.3.4.3.2.8	Decision on wire BBC (Milestone)	B
528	1.3.3.5.12	Electron Cooling Operational (Milestone)	A
711	1.3.6.2.6	Start Phase 3 (Milestone)	A
715	1.3.6.3.1	Start Phase 2c20%=4mo (Milestone)	A
556	1.3.3.6.7	Rapid Transfers Operational (Milestone)	A
308	1.3.2.2.11	Intermediate AP2&DIB Improvements Complete (Milestoı	C
716	1.3.6.3.2	Start Phase 3c30%=6mo (Milestone)	A
345	1.3.3.3.1.9	Acc Momentum Operational (Milestone)	A
366	1.3.3.3.2.8	Acc Betatron Operational (Milestone)	A
712	1.3.6.2.7	Start Phase 4 (Milestone)	A
717	1.3.6.3.3	Start Phase 4c25%=4mo (but paced by shutdown)=4.5 m	A
309	1.3.2.2.12	Final AP2&DIB Improvements Complete (Milestone)	A
619	1.3.4.4.3.11	increased BB separation operational (milestone)	A
590	1.3.4.3.2.13	Wire BBC Operational (Milestones)	A
594	1.3.4.3.1.11	TEL System Operational (Milestone)	A
713	1.3.6.2.8	Start Phase 5 (Milestone)	A
718	1.3.6.3.4	Start Phase 5c10%=4mo (again, paced by the shutdown	A

Page 1

Operating Phase Milestones		
1.3.6.2.5	Start Phase 2 Operations	12/14/2004
1.3.6.2.6	Start Phase 3 Operations	2/22/2005
1.3.6.2.7	Start Phase 4 Operations	11/17/2005
1.3.6.2.8	Start Phase 5 Operations	5/23/2007

Project milestones and model milestones differ due to commissioning

Schedule "Contingency"

- "Deliverable" is a luminosity profile – not a completion date (as in a construction project)
  - delivered by WBS 1.1+1.2+1.3
- Schedule risk is in parallel between the projects
- 6 months schedule "contingency" is used to indicate the effect of slippage on the profile (see later discussion)
  - added to the phase milestones
- Shutdowns can drive the schedule
- Slippage >6 months would lead to re-evaluation of scope for Run II, at specific milestones (based on updating the luminosity projection)

Risks and Mitigation: 3 categories

1. Performance Parameters fail to meet design spec:
   - Models→ dependence on parameters

2. Major technical and schedule risk
   - Recycler ← present estimate will be updated Dec 2003
   - Electron-cooling ← perf demonstrated Mar 04, Jan 05

3. Schedule creep
   - bottom-up estimates include most [?] resource sharing
   - evaluate progress monthly, benchmark quarterly

Recycler

- Recycler commissioning was expected to be complete by the end of FY03
- Following Jan shutdown - problems encountered with vacuum system - limited tunnel access hampered repairs

- Recycler needed for electron-cooling by October 2004

- Re-evaluating commissioning plan
  - Task force: revisit specs on engineering parameters
  - Identify technical issues
  - Address key issue (vacuum) in August shutdown
  - Commissioning plans beyond the shutdown
  - Estimate resources, access time and pbar tax

and the effect on HEP luminosity

- update RLS by December 03

Electron Cooling

- Completed Pelletron tests with U-bend
  - Meet specs except for recirculating stability – quick recovery but trips too frequent
  - Additional 1MeV stage for Pelletron ordered to reduce field and improve operating stability

- Current phase: operate full beamline at Wideband
- MI-31 construction started April 03
- Move to MI-31 Spring-Summer 04
- Add 6th stage and recommission with U-bend
- Install beamline in MI tunnel summer shutdown 04
- Commission @Recycler Fall

Cooling section: nine 2m long solenoids supported from the tunnel ceiling

Electron Cooling Milestones

Technical (and schedule) risk limited in 3 stages

- Done
  - operation of Pelletron with U-bend (need extra stage)
- Milestone Mar 04
  - demonstrate electron beam properties in the beamline
- Milestone Jan 05
  - electron beam and pbar beam (alignment in Recycler, MI ramp… cooling)

Luminosity Projection

Luminosity Projection

Developed a realistic model for the luminosity projection

Three classes of parameters

1. Performance parameters determine luminosity performance in a single store (incl pbar stacking rate, transfer efficiencies, bunch intensities) ← from parametric models (benchmarked to data and calculations)

2. Operating scenario parameters define operating up-time (incl time scheduled for HEP rather than studies and maintenance, down time due to quenches, and equipment failure)← from REAL running Feb-June, including good and bad (zero) weeks

3. Learning rates when new upgrades are introduced, and recovery rates after each scheduled shutdown ← est from experience

Class 1 Parameters

- Stacking and Cooling Task Force
  - Integrated model for Accumulator – transfers – Recycler – Tevatron
  - Detailed simulation of Stacktail upgrade at high rates
  - Detailed simulation of Recycler performance with stochastic cooling and with electron cooling

- Tevatron Task Force
  - Parametric model of Tevatron Stores
  - Study beam-beam tune shifts and increasing helix + active beam-beam compensation
  - Extensive document, work continues…

Stacking and Cooling System Parameters

Key Design Parameters: each machine and transfers

Parameter	Value	Unit
Average Stacking rate	40	$x10^{10}$ per hour
Peak Stacking rate	45	$x10^{10}$ per hour
Number of particles injected into the Debuncher	280	$x10^{6}$
Debuncher transverse aperture	35	π-mm-mrad
Antiproton production cycle time	2	Secs
Maximum bunch length on target	1.5	nSecs.
Debuncher momentum aperture	4	%
Debuncher momentum cooling aperture	0.4	%
Debuncher final transverse emittance	5	π-mm-mrad
Debuncher final momentum spread	6	MeV
Debuncher transverse cooling common mode rejection	1.5	mm
Debuncher transverse cooling phase imbalance	3	degrees
Debuncher transverse cooling delay imbalance	1.4	pS
Debuncher momentum notch filter delay tolerance	1	pS
Debuncher momentum cooling notch filter dispersion	2.5	degrees
Debuncher to Accumulator transfer efficiency	95	%
Accumulator Stacktail Momentum bandwidth	2-6	GHz
Accumulator Core Momentum bandwidth	4-8	GHz
Accumulator Stacktail Momentum energy slope	8	MeV
Accumulator Stacktail Power	625	Watts
Accumulator Stacktail 2-6 GHz kicker impedance	6400	Ω
Accumulator Core Momentum energy slope	5	Mev
Accumulator Core Momentum cooling aperture	9.6	MeV
Accumulator Momentum cooling aperture	58	MeV

Parameter	Value	Unit
Accumulator Momentum cooling aperture	58	MeV
Accumulator to Recycler transfer longitudinal emmitance	10	eV-Sec
Accumulator to Recycler transfer interval	30	minutes
Number of particles extracted from the Accumulator per trans	24	$x10^{10}$
Accumulator to Recycler transfer time	1	minutes
Accumulator to Recycler transfer efficiency	95	%
Accumulator core transverse emittance	1	π-mm-mrad
Recycler transverse emittance injection dilution	50	%
Recycler longitudinal emmittance injection dilution	50	%
Recycler transverse Stochastic Cooling Bandwidth	>1	GHz
Recycler Transverse Stochastic cooling Center Frequency	3	GHz
Maximum Recycler Transverse emittance Growth Rate	0.7	π-mm-mrad/hr
Peak Stack in Recycler	620	$x10^{10}$
Transverse emmitance of antiprotons extracted from Recycler	1	π-mm-mrad
Total Longitudinal emmitance of antiprotons extracted from Recycler	50	eV-Sec
Number of bunches extracted from the Recycler	36	
Minimum longitudinal cooling rate of Electron Cooling	55	eV-Sec/hour
Minimum Electron Cooling Current	250	mA
Electron Beam alignment tolerance	0.1	mrad
Transverse electron cooling rate per 100 mA	0.12	π-mm-mrad
Maximum transverse emittance for electron cooling	1.5	π-mm-mrad

Tevatron Stores

Valeri Lebedev

Slide from earlier talk

The model takes into account the major beam heating and particle loss mechanisms

Phenomena taken into account

- Interaction with residual gas
  - Emittance growth due to electromagnetic scattering
  - Particle loss due to nuclear and electromagnetic interaction
- Particle interaction in IPs (proportional to the luminosity)
  - Emittance growth due to electromagnetic scattering
  - Particle loss due to nuclear and electromagnetic interaction
- IBS
  - Energy spread growth and emittance growth due to multiple scattering
- Bunch lengthening due to RF noise
- Particle loss from the bucket due to heating of longitudinal degree of freedom

Phenomena ignored in the model

Beam-beam effects ← under study, ~taken into account here by leaving emittances unchanged with improvements in beam transfers

Non-linearity of the lattice

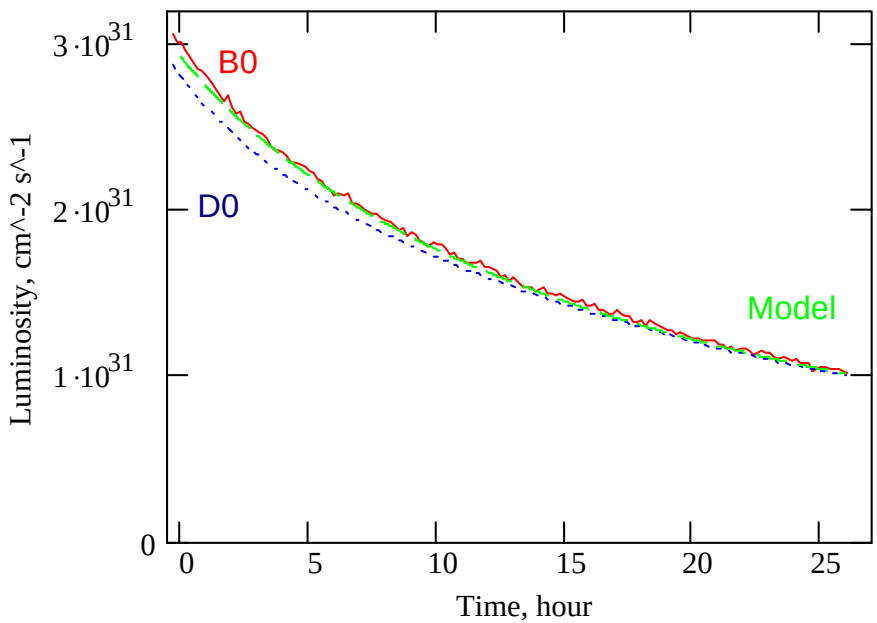
Diffusion amplification by coherent effects

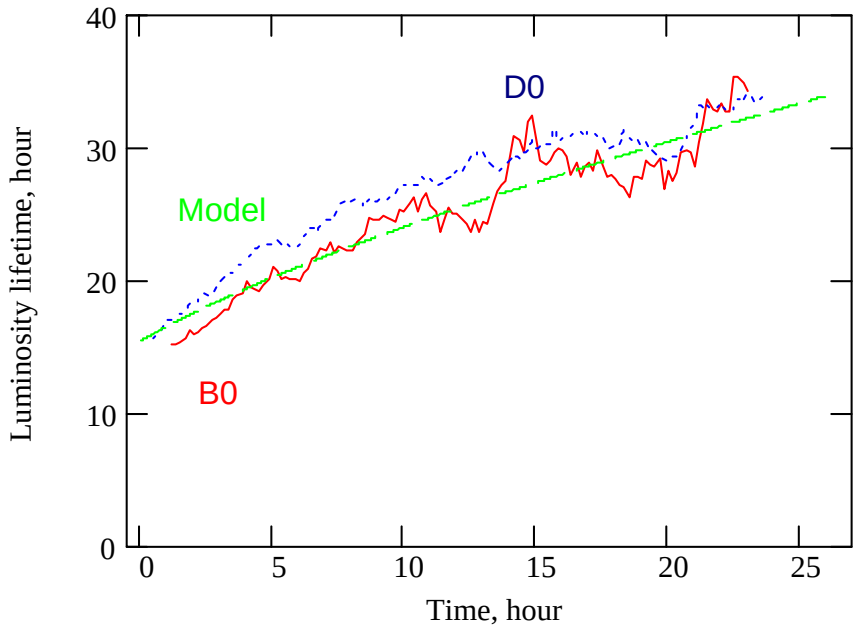
Thus, it can be considered as **the best-case scenario**

It describes well our best present stores

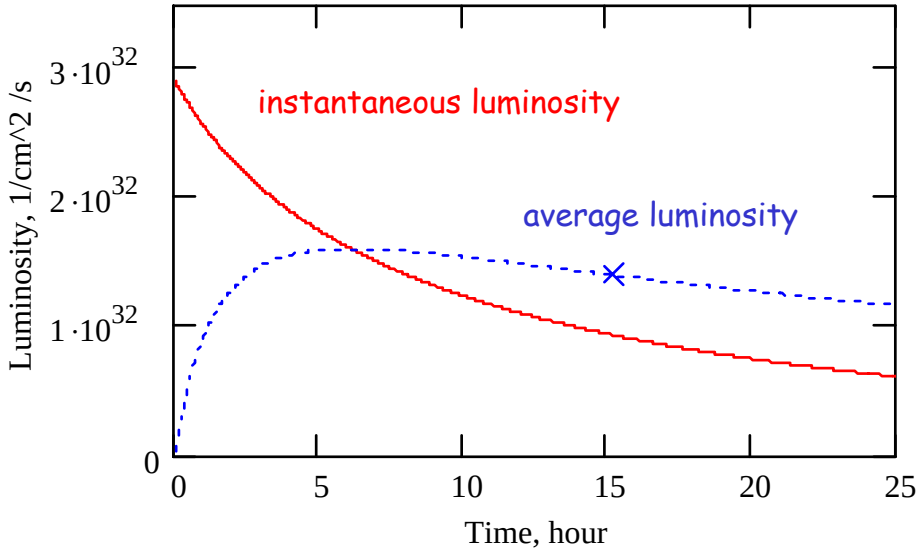
Benchmark to Present Stores

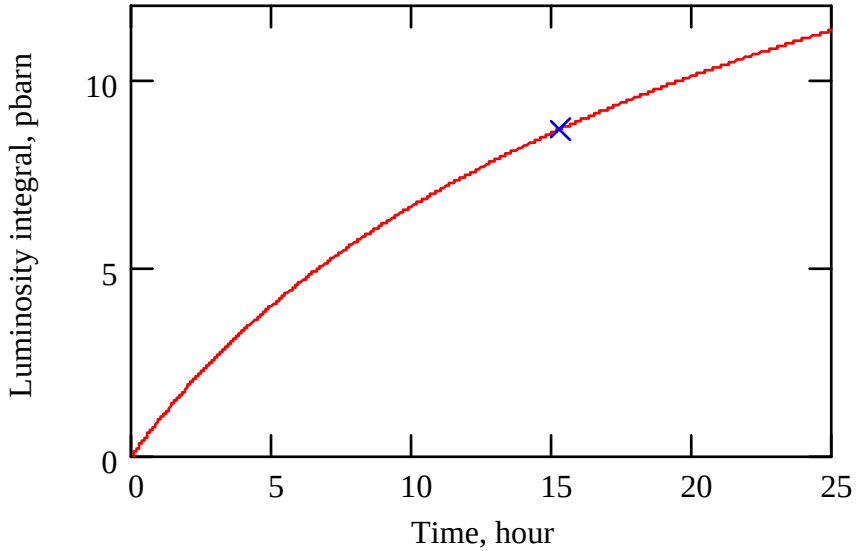
Comparison of the Model Predictions to Store 2138 (Jan.5 2003)





Project to High Luminosity

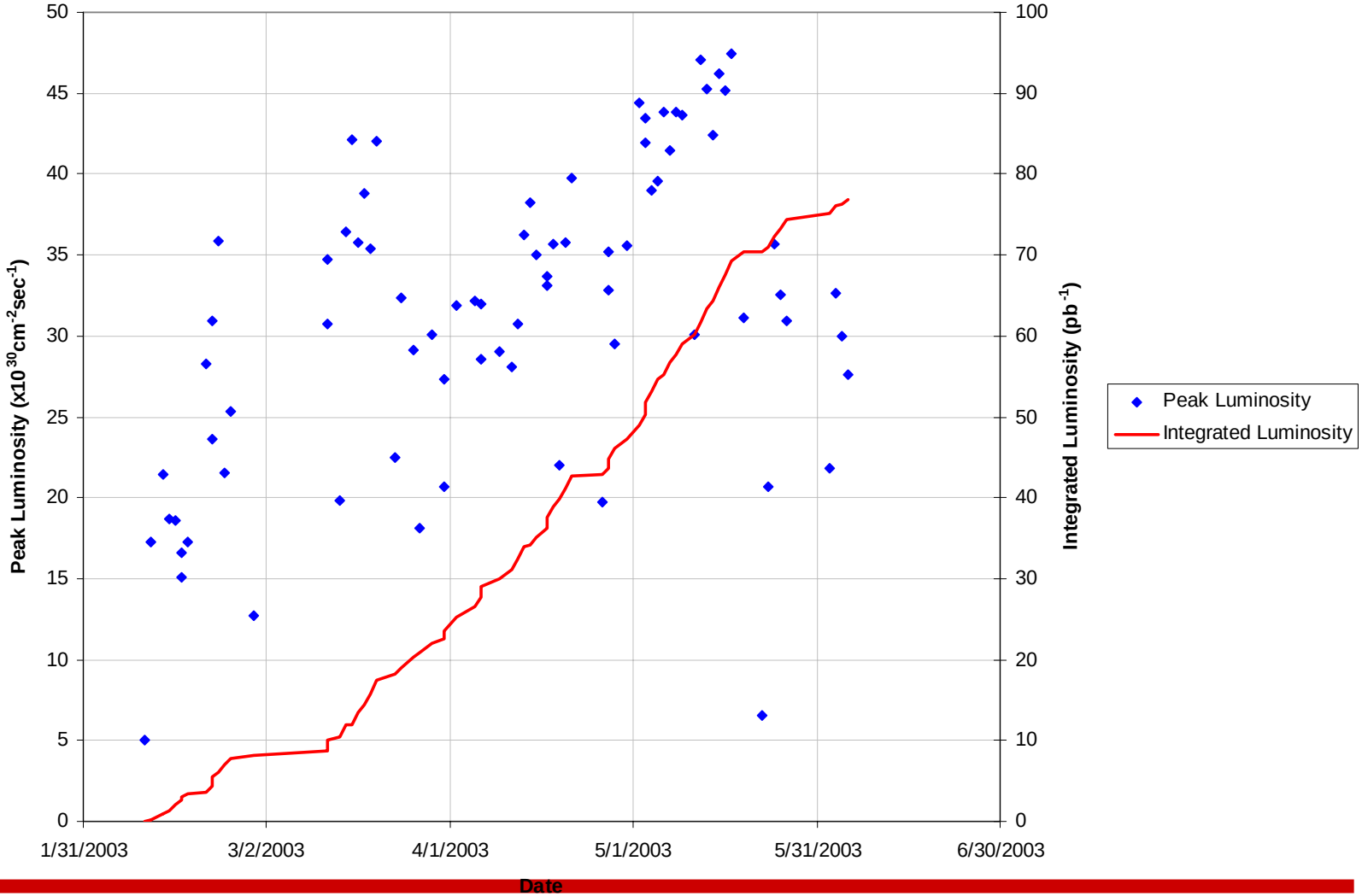




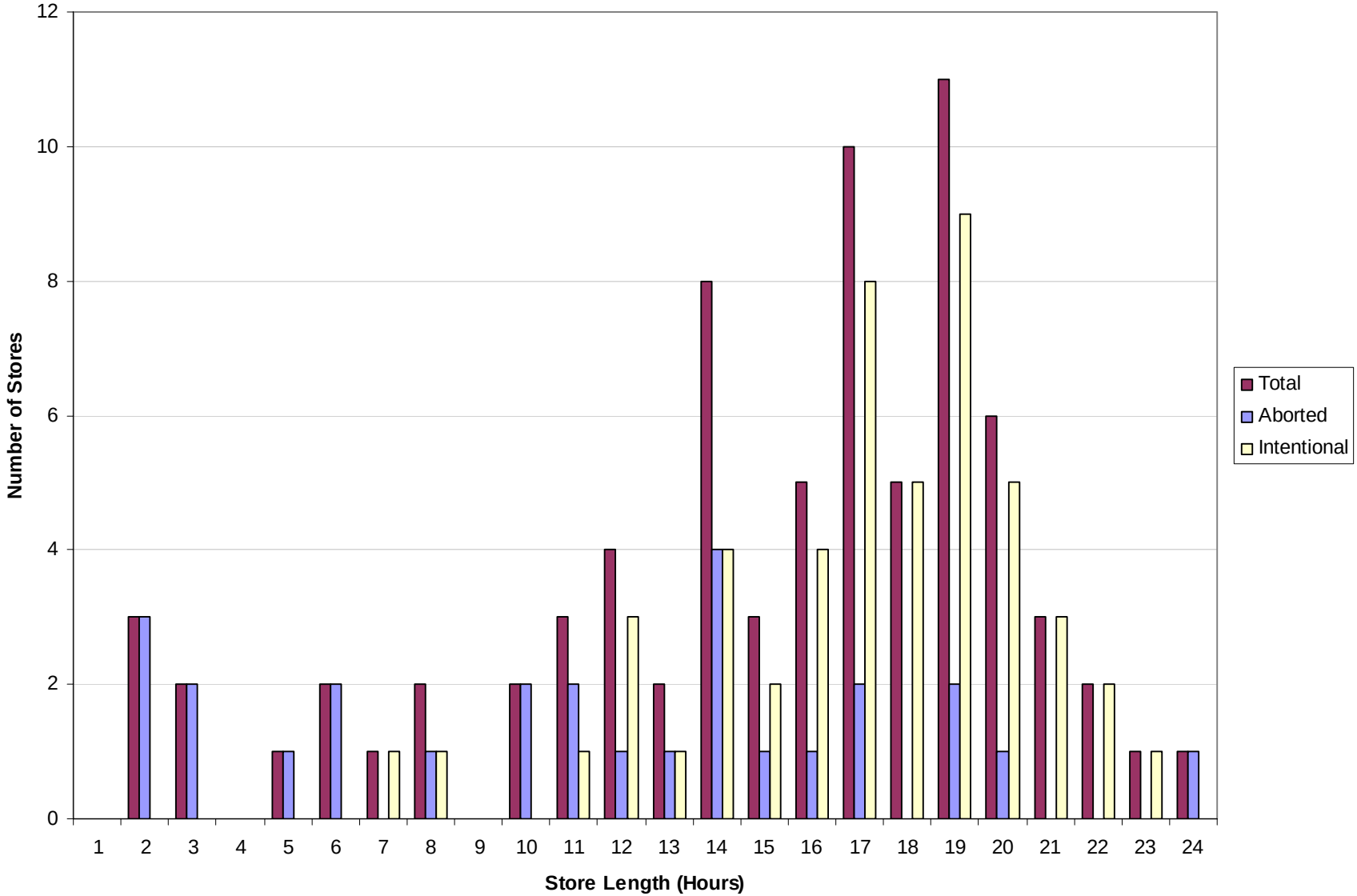
Peak luminosity 2.9×10^{32} $cm^{-2}s^{-1}$
15 hour store length

Class 2 parameters

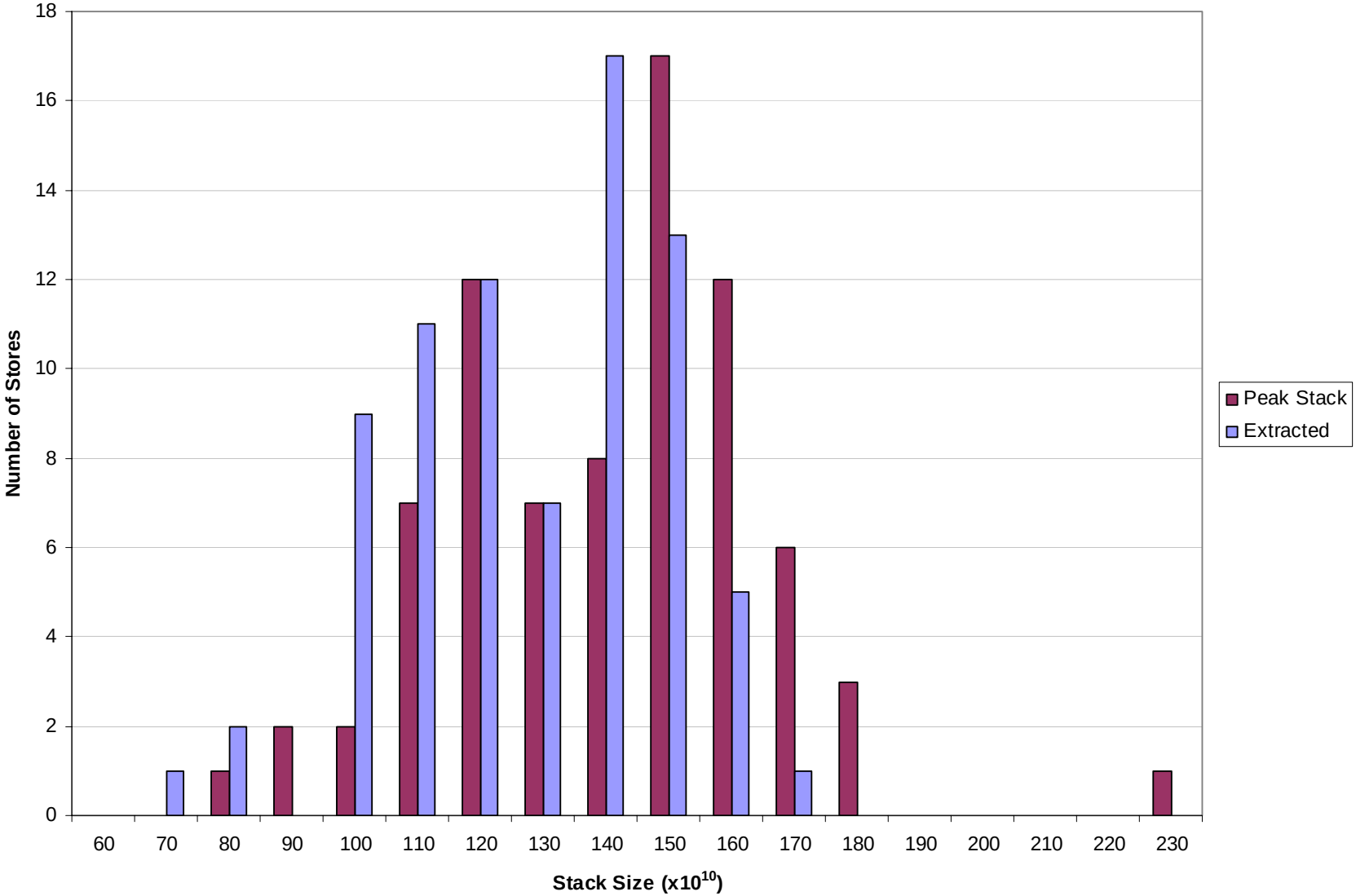
Based on operating experience 2/10/03 – 6/5/03



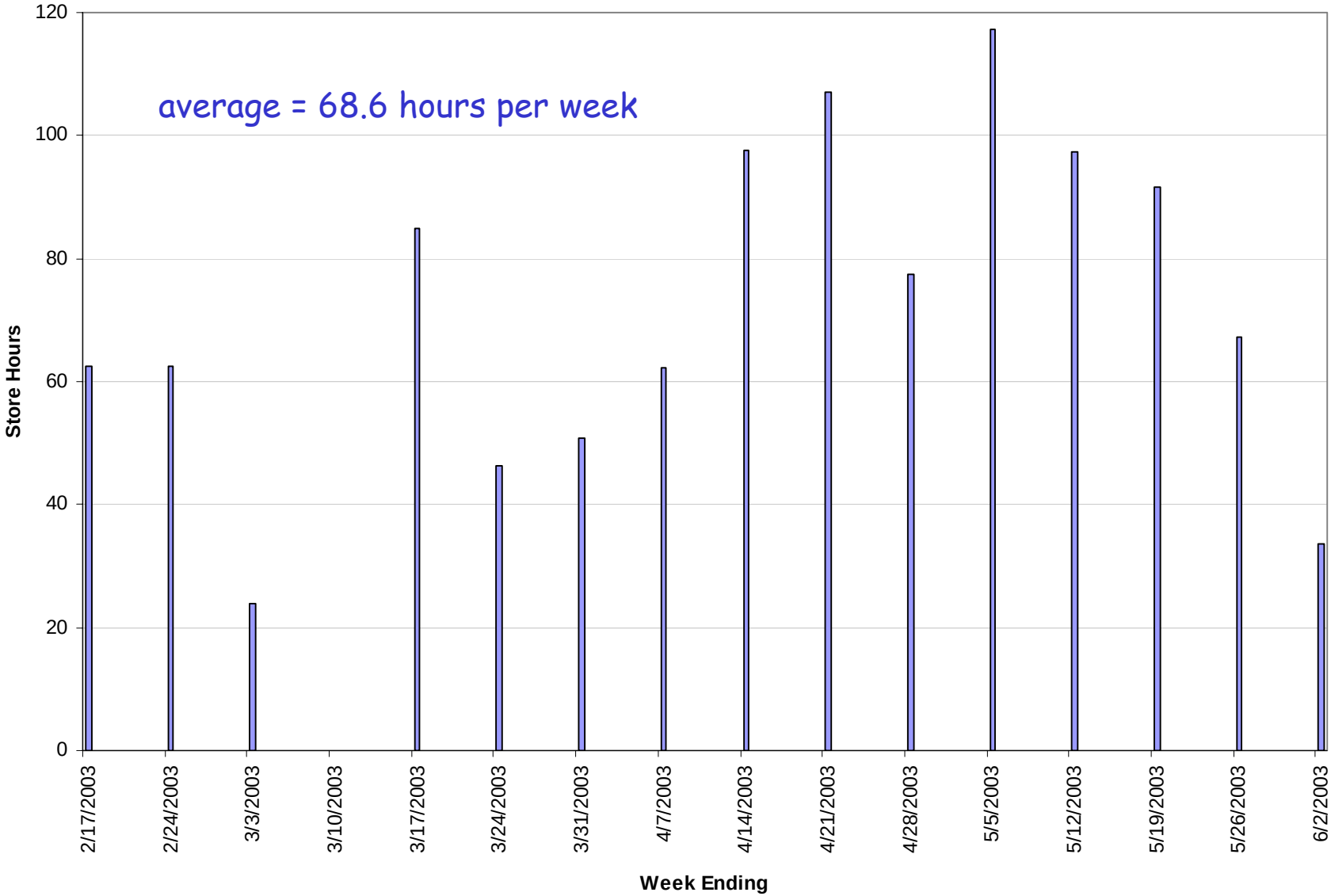
Store Length (Hours)



Antiproton Stack Size



Store Hours per Week

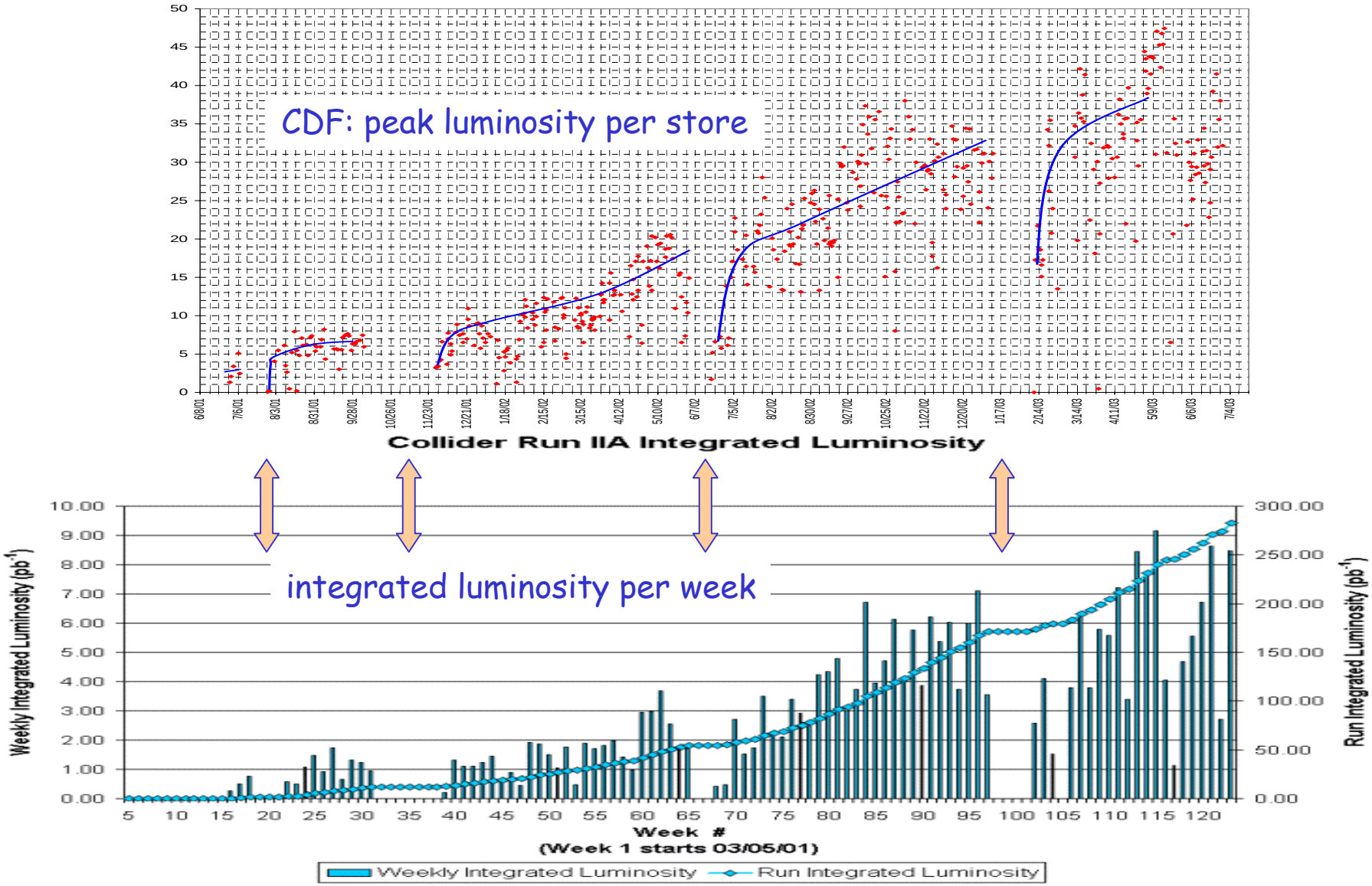


Class 2 parameters

- Summarized by
  - 70 store-hours per week, increased only on completion of the upgrades
  - Average store length less than ideal due to quenches, assume 14.5 hrs

will improve, but take no credit

Class 3 Parameters



Projections

Design Projection

- uses the design performance parameters for the upgrade projects (additional margin is included in subproject specs)
- assumes improvement in the HEP store hours only in the last phase of the upgrades
- does not include schedule contingency

Base Projection

- uses conservative performance parameters that the subprojects are likely to exceed
- does not assume improvements in HEP store hours per week
- includes 6 months schedule slip for bringing upgrades online

Design Projection per Phase

performance parameters at completion of each phase

sustained

Operating Phase	1	2	3	4	5a	5b	
Phase Commissioning Starts	current	12/14/04	2/22/05	9/13/05	1/16/07	12/11/07	
Luminosity Parameters							
Initial Luminosity	68.0	90.5	136.7	218.0	294.0	294.0	$x10^{30}cm^{-2}$ sec^{-1}
Integrated Luminosity per wk	10.9	13.9	20.5	31.4	50.3	55.3	pb^{-1}
Integrated Luminosity per store	2.3	2.9	4.2	6.5	8.3	8.3	pb^{-1}
Number of stores per wk	4.8	4.8	4.8	4.8	6.1	6.7	
Average Store Hours per Wk	70	70	70	70	88	97	Hours
HEP Up Time per Week	80	80	80	80	100	110	Hours
Shot Setup Time	2	2	2	2	2	2	Hours
Tevatron Parameters							
Number of Protons per bunch	240	240	240	240	270	270	$x10^{9}$
Number of Pbars per bunch	36.3	44.9	67.8	108.1	129.6	129.6	$x10^{9}$
Proton Emittance	18	18	18	18	18	18	π-mm-mrad
Pbar Emittance	18	18	18	18	18	18	π-mm-mrad
Transfer Eff. To Low Beta	0.75	0.75	0.75	0.75	0.8	0.8	
Antiproton Parameters							
Zero Stack Stacking Rate	18.0	26.2	26.2	40.3	46.1	46.1	$x10^{10}$/hour
Average Stacking Rate	12.0	14.9	22.4	35.8	40.2	40.2	$x10^{10}$/hour
Stack Size transferred	174.3	215.4	325.4	518.9	583.2	583.2	$x10^{10}$
Protons on Target (PoT)	5	8	8	8	8	8	$x10^{12}$
Pbar Production per PoT	17.0	20.0	20.0	28.0	32.0	32.0	$x10^{-6}$
Pbar cycle time	1.7	2.2	2.2	2	2	2	sec

Design and Base Projections

Comparison at completion of the upgrades

Parameter	Design	Base	
Luminosity			
Initial Luminosity per store	294.0	160.5	$x10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per week	55.3	26.5	pb^{-1}
Integrated Luminosity per store	8.3	4.9	pb^{-1}
Number of stores per week	6.7	5.5	
Average Store Hours per Week	97	79	Hours
HEP Up Time per Week	110	90	Hours
Shot Setup Time	2	2	Hours
Tevatron			
Number of Protons per bunch	270	250	$x10^{9}$
Number of Pbars per bunch	129.6	76.4	$x10^{9}$
Proton Emittance	18	18	π-mm-mrad
Pbar Emittance	18	18	π-mm-mrad
Transfer Eff. To Low Beta	0.8	0.75	
Antiproton			
Zero Stack Stacking Rate	46.1	31.5	$x10^{10}$/hour
Average Stacking Rate	40.2	25.3	$x10^{10}$/hour
Stack Size transferred	583.2	366.7	$x10^{10}$
Protons on Target (PoT)	8	7	$x10^{12}$
Pbar Production per PoT	32.0	25.0	$x10^{-6}$
Pbar cycle time	2	2	sec

reduced parameters in base projection

Design Margin

On Completion of the Upgrades		
Parameter	**Design**	**"Limit"**
Weekly integrated luminosity (pb^{-1})	55	110
Tevatron Parameters		
Store hours per week	97	106
Protons per bunch ($x10^9$)	270	330
Pbars per bunch ($x10^9$)	130	160
Ave Proton/Pbar emittance (π-mm-mrad)	18	13
Ave store length (hrs)	14.5	10
Peak Luminosity ($x10^{32}cm^{-2}s^{-1}$)	2.9	5.6
Stack		
Stack size transferred (10^{10})	583	606
Transfer efficiency (10^{10})	80	95
Pbar Production		
Ave stacking rate (10^{10}/hr)	40	62
Protons on target (10^{12})	8	10
Pbar acceptance (10^{-6})	32	40
Pbar cycler time (sec)	2	2

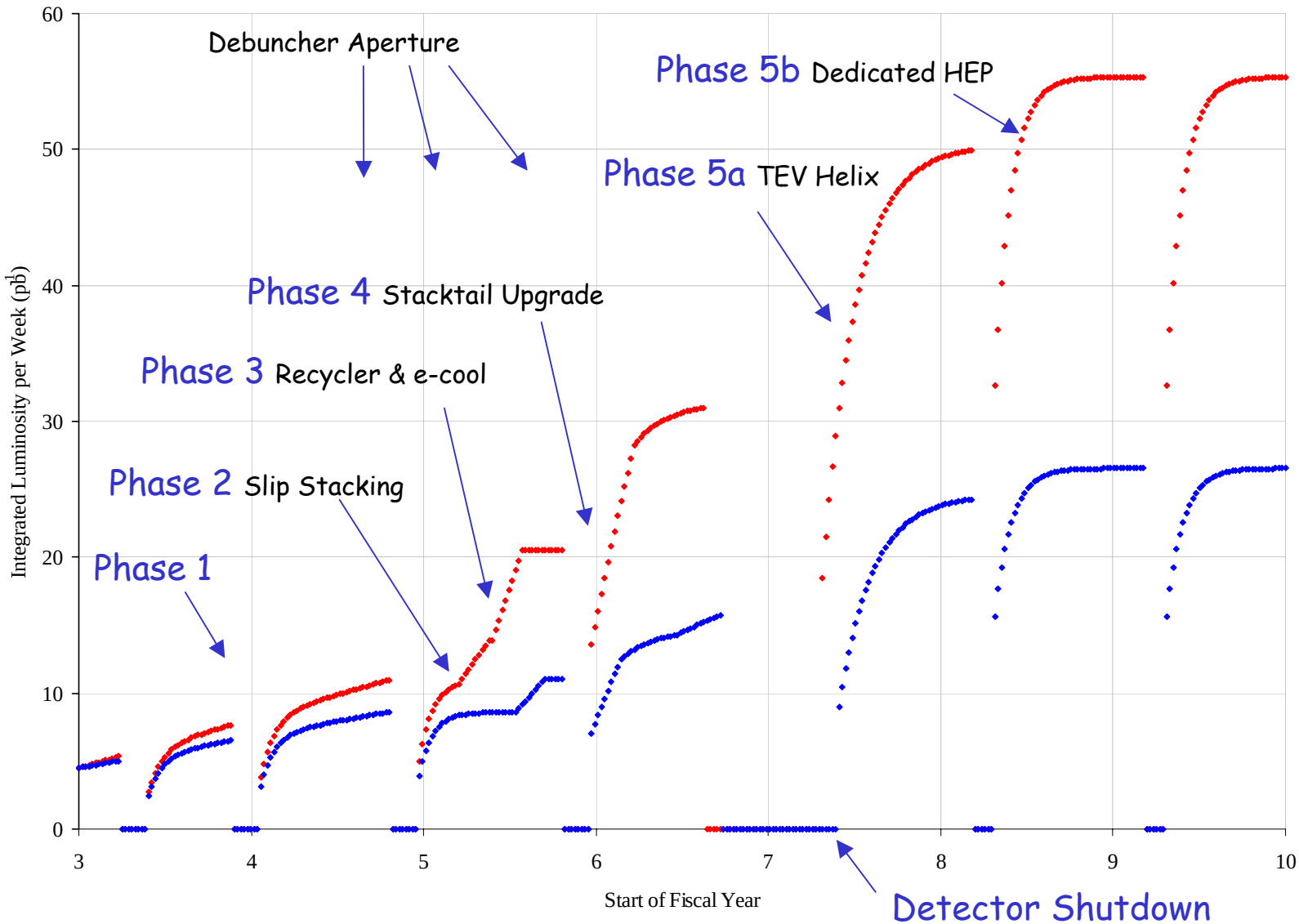
allows 40 hrs down/studies per week (already achieved for good wks)

improved helix separation and beam-beam compensation

within stacktail spec

at "spec"

Weekly Luminosity and Phases



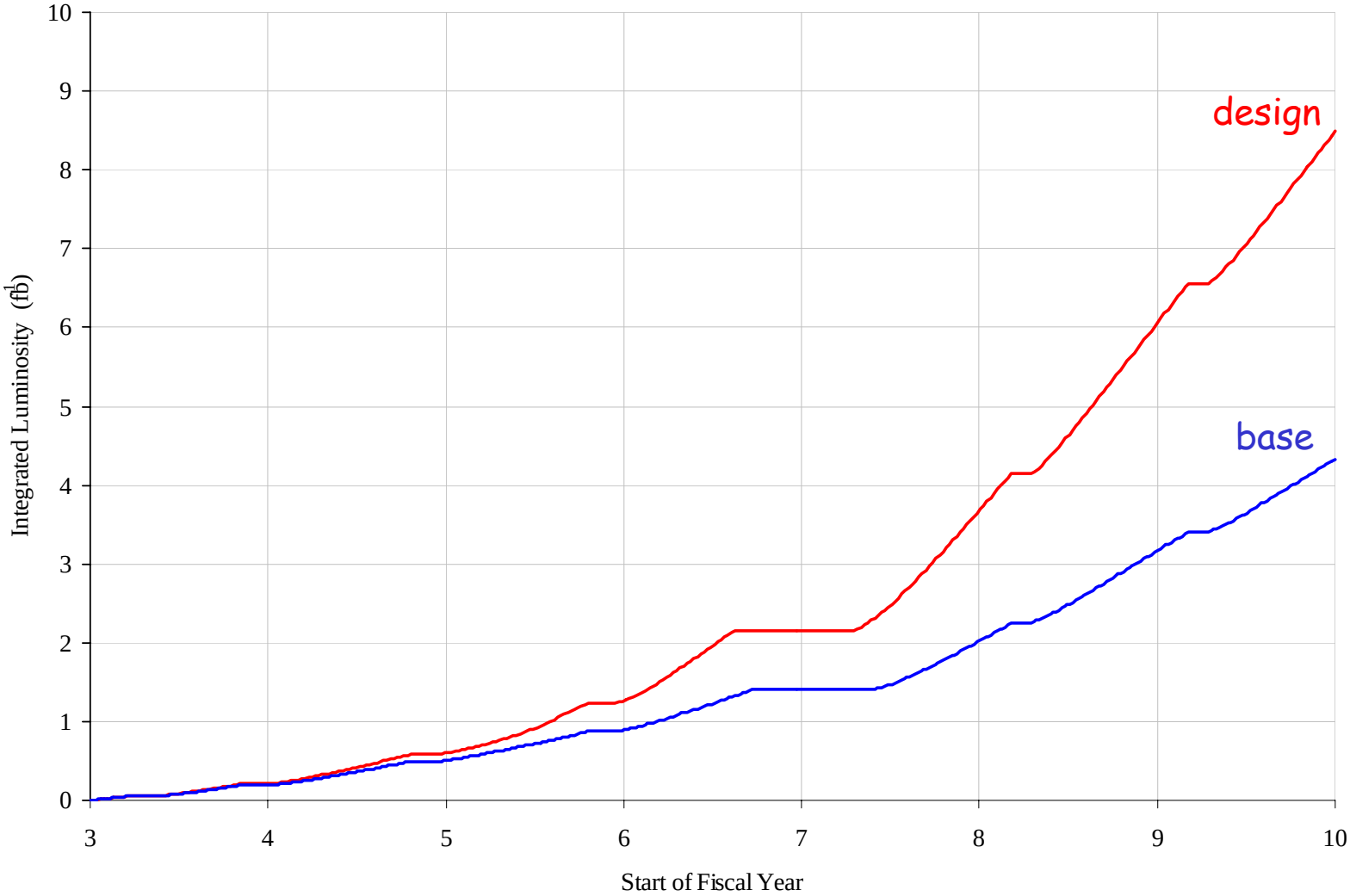
Integrated Luminosity

Integrated Luminosity (fb^{-1})				
	Design Projection		**Base Projection**	
	per year	Accum-ulated	per year	Accum-ulated
FY03	0.22	0.30	0.20	0.28
FY04	0.38	0.68	0.31	0.59
FY05	0.67	1.36	0.39	0.98
FY06	0.89	2.24	0.50	1.48
FY07	1.53	3.78	0.63	2.11
FY08	2.37	6.15	1.14	3.25
FY09	2.42	8.57	1.16	4.41

without "pbar tax" for Reycler commissioning (could be ~0.06fb^{-1} in FY04)

with Recycler and electron cooling

Projected Integrated Luminosity



New Luminosity Projection

- Upon completion of the upgrade plan
  - annual integrated luminosity is 2.4 fb^{-1} for the Design and 1.2fb^{-1} for the Base
  - compare to 3.0 fb^{-1} and 1.8 fb^{-1} for the Stretch and Base goals of Oct 02
  - slower pace of implementing the individual upgrade components
- These changes result from improvements and updates in the projections:
  - inclusion of the Fermilab long-range shutdown schedule to accommodate detector installations
  - improved performance modeling and realistic operating scenario
  - bottom-up resource-loaded schedule
  - removal of 132 nsec, recycling and Recycler (stochastic) from the project scope
  - delays in Recycler commissioning

Conclusion

- realistic modeling of performance
- developed bottom-up resource-loaded plan
- established milestones for tracking progress and decision points

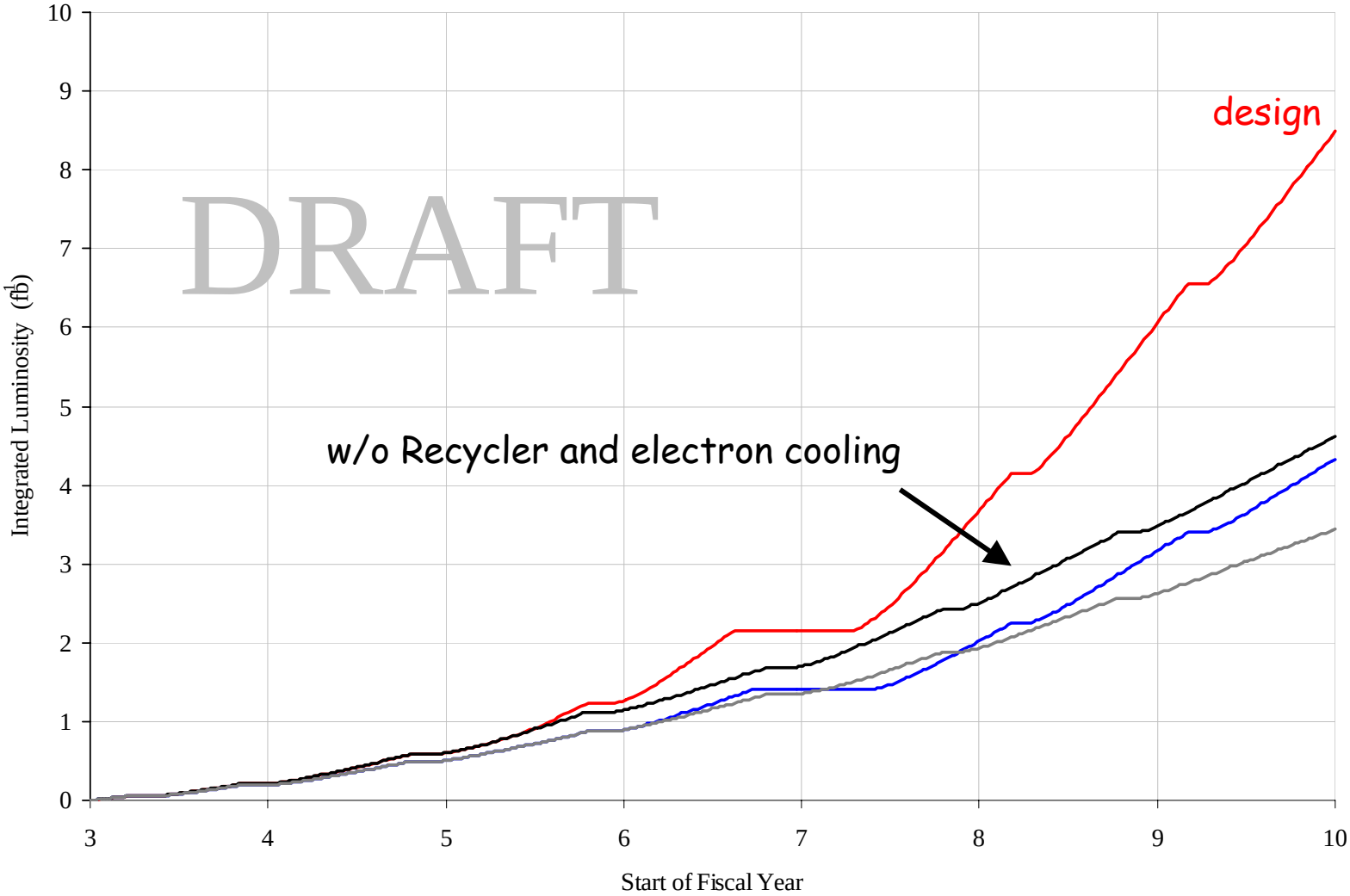
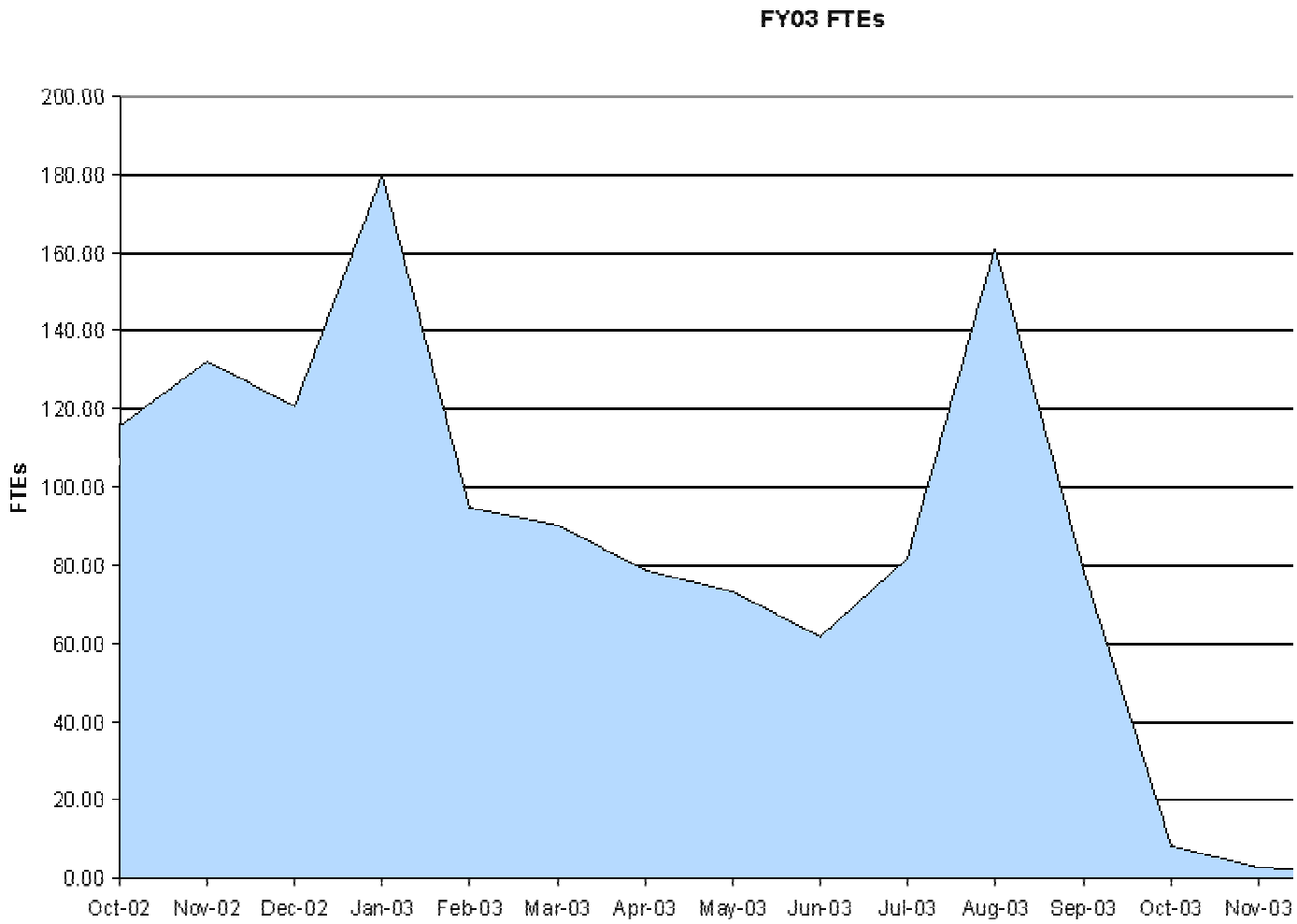
- defined a strategy to maximize the luminosity in Run II

Fall-Back Scenario

What if the Recycler and/or electron cooling will not converge within the schedule for CDF and D0 Run II?

- Fall-back position without Recycler and electron cooling
  - other upgrades proceed → achieve ~1fb^{-1} per year
    - Black curve = "~design-like"
    - Grey curve = "~base-like"

Fall-Back Scenario



Labor Profile for the FY03 Workplan