Performance Goals for the Accelerator Complex

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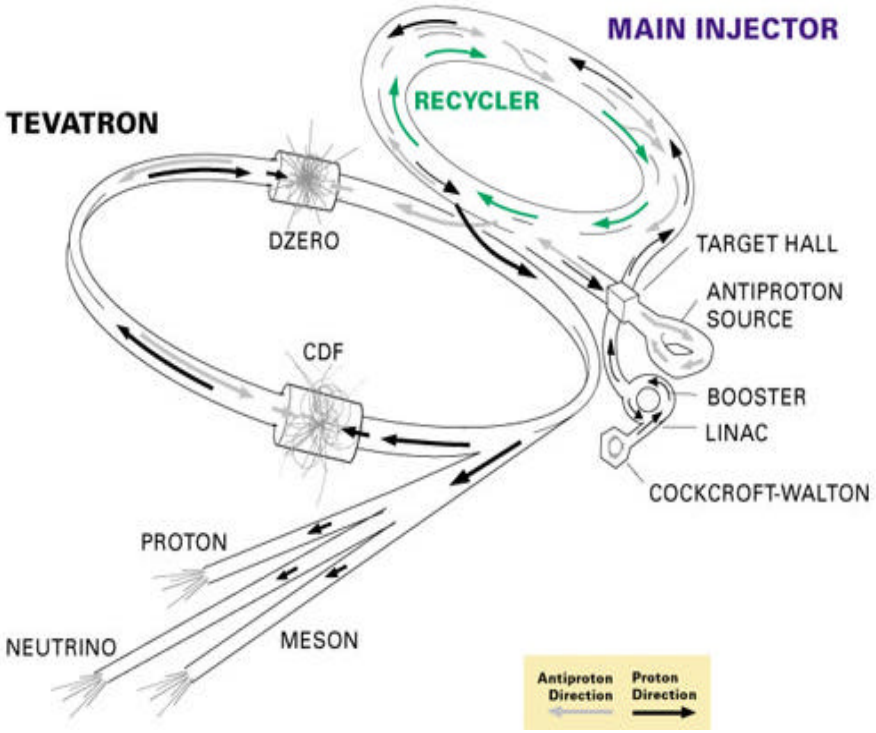
P5 Meeting at Fermilab
March 26, 2003

Outline

- Collider Performance and Planning
  - Current status
  - Beyond 2003
- Collider Support for BTeV
- Accelerator Support for CKM

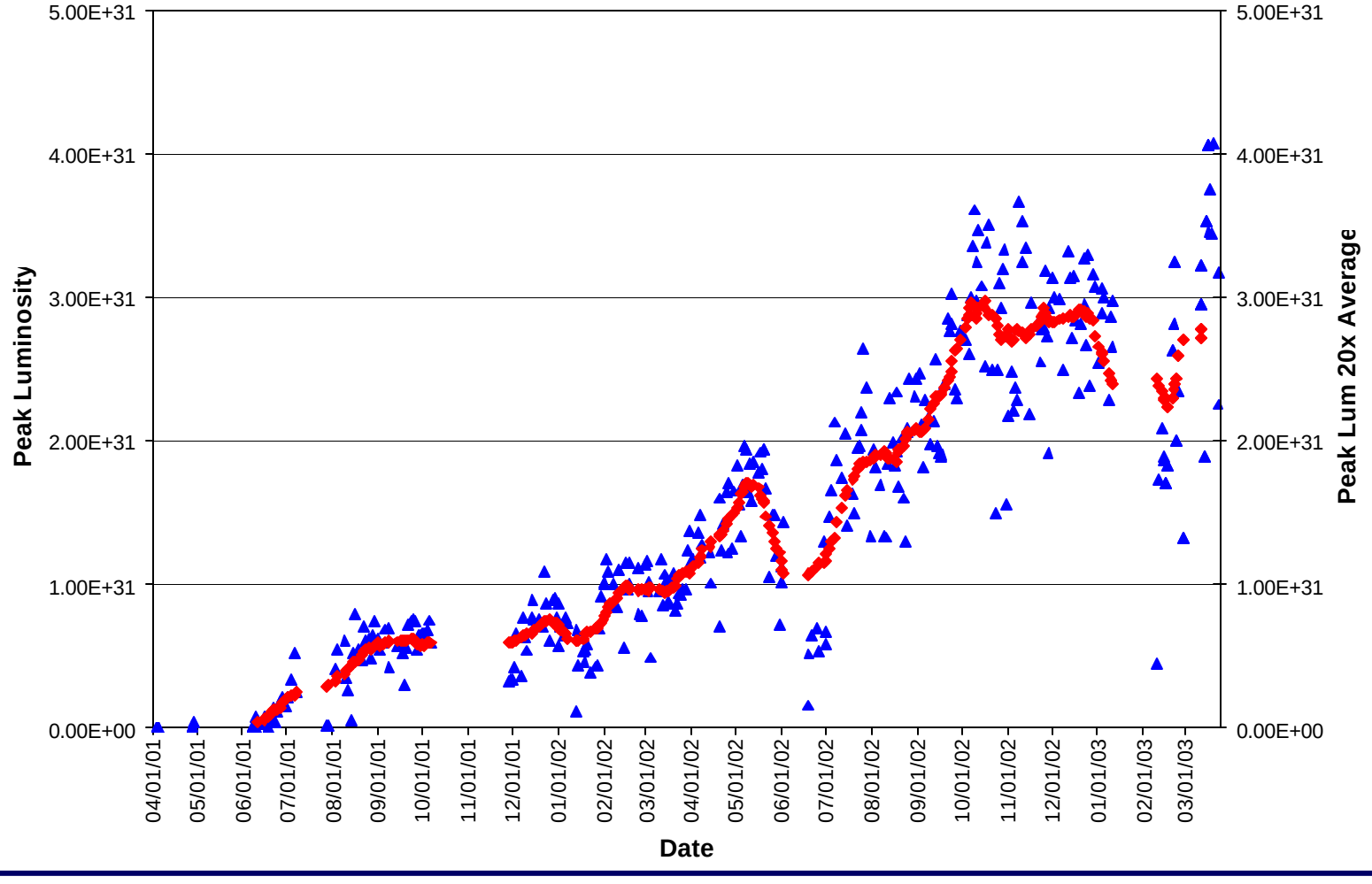
Collider Performance
Current Status

- Current configuration is that envisioned with construction of the Main Injector. It is unchanged since the Run II startup.
- Next major change will be integration of the Recycler, planned for fall 2003.
- Roughly factor of 4.5× performance improvement from January, 2002



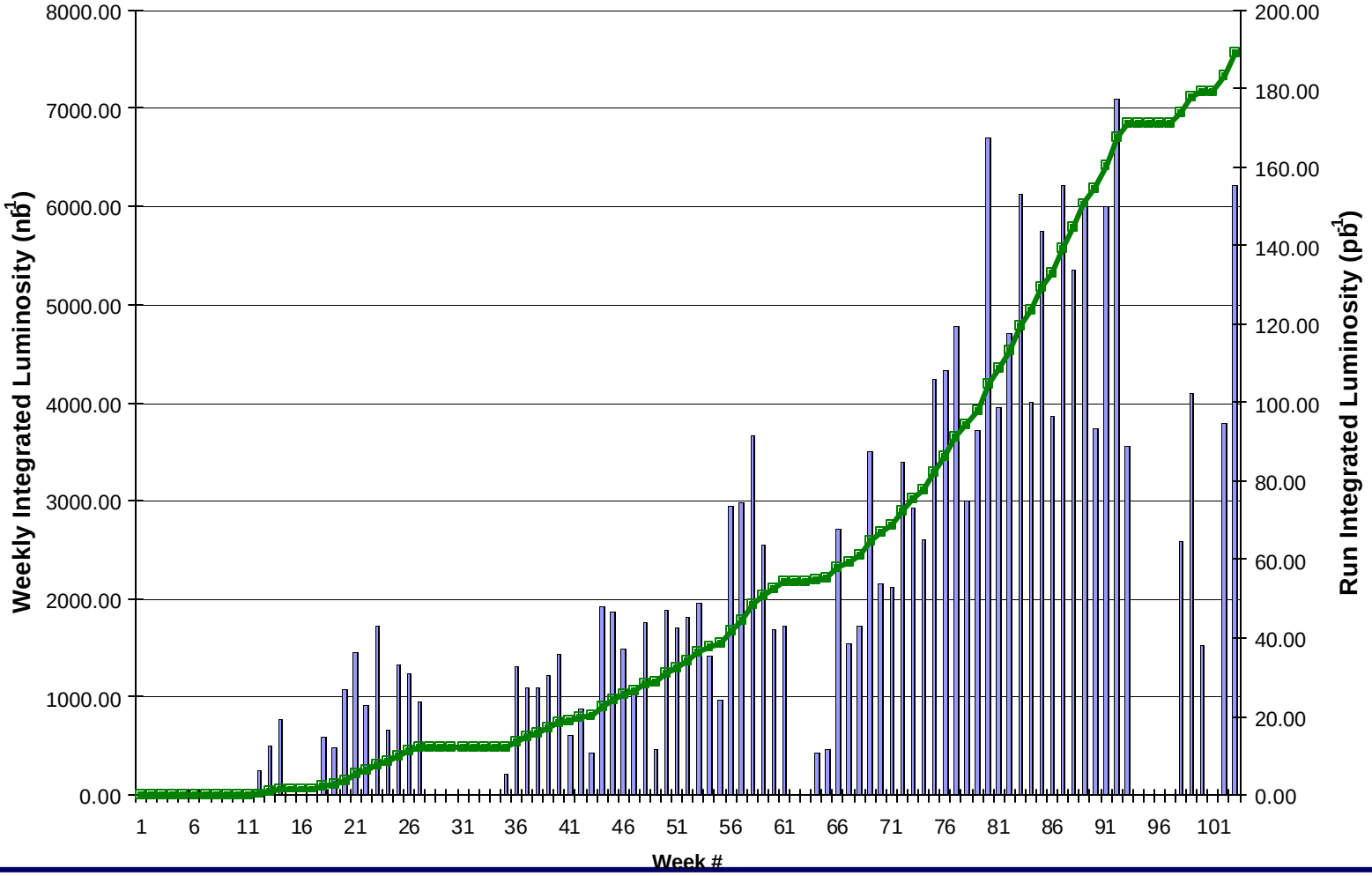
Collider Performance

Initial Luminosity Performance through 3/23/03



Collider Performance

Integrated Luminosity Performance through 3/23/03



Collider Performance
Modifications to the Complex

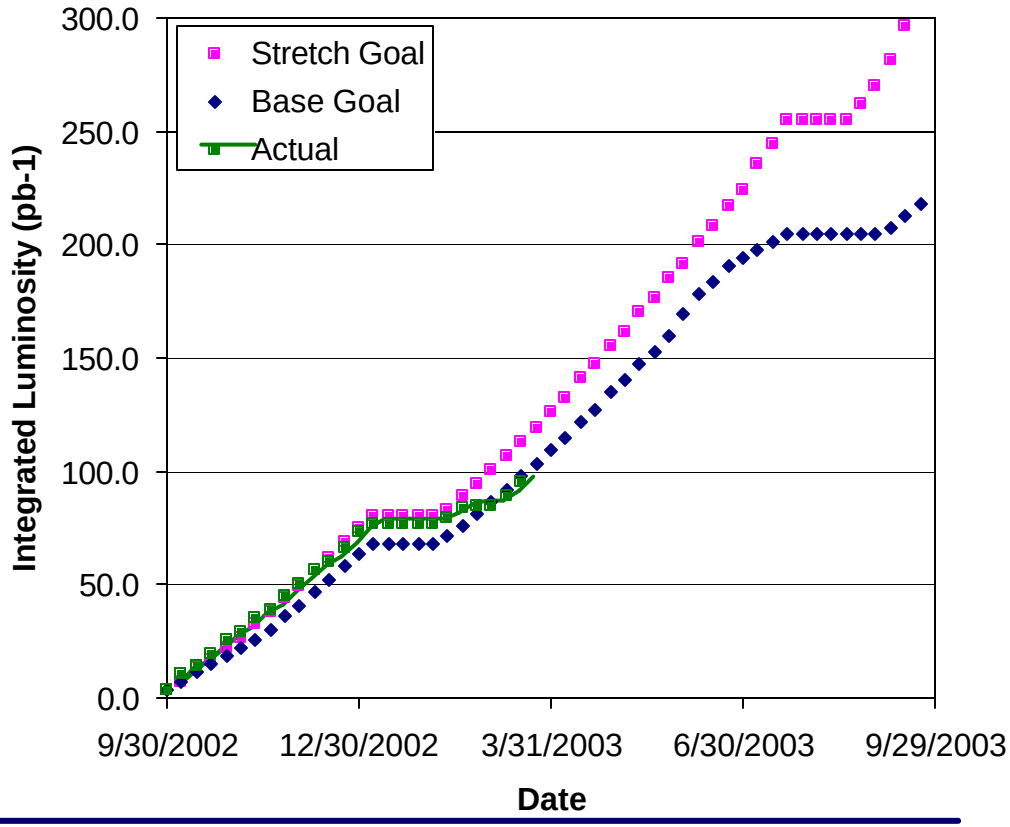
- Every improvement in luminosity performance has been associated with a specific modification to the accelerator complex. Major modifications since January 1, 2002:
  - Accumulator->Main Injector transfer optics
  - Adjustment of tunes and helix during low beta squeeze
  - Modified injection helix
  - Proton beam loading compensation in Main Injector
  - Accumulator (stochastic) cooling upgrade
  - Accumulator shot lattice
  - Antiproton beam loading compensation in Main Injector
  - Tevatron beam line tuner (BLT)
  - Tevatron tune/coupling drift compensation
  - Tevatron dampers
  - C-0 Lambertson magnets removal
- **Note: $(1.15)^{11} = 4.6$**

Collider Performance

FY2003 Plan: Performance through 3/23/03

On October 1, 2002 we submitted to the DOE performance goals for FY2003, based on our plan for accelerator complex improvements.

- Base goals:
  - 200 pb^{-1} for FY2003
  - 10 pb^{-1}/week by the end of the year
- Stretch goals:
  - 320 pb^{-1} for FY2003
  - 15 pb^{-1}/week by the end of the year
- FY2002 comparison:
  - 80 pb^{-1} for the year
  - 6.7 pb^{-1} best week



Collider Performance
Comparison with Year-end Goals

	RunII/FY03 Base	RunII/FY03 Stretch	RunII (achieved*)	
Protons/bunch	2.00E+11	2.15E+11	2.06E+11	
Antiprotons/bunch	2.70E+10	3.60E+10	2.51E+10	
Total Antiprotons	9.8E+11	12.8E+11	9.02E+11	
Antiproton Production Rate	1.5E+11	1.8E+11	1.3E+11	$hour^{-1}$
Accumulator -> low β efficiency	0.64	0.81	0.66	
Proton emittance (95%, norm)	24	24	25	π mm-mr
Pbar emittance (95%, norm)	16	16	21	π mm-mr
Beta @ IP	0.35	0.35	0.35	m
Beam Energy	980	980	980	GeV
Bunches	36	36	36	
Longitudinal Emittance (protons)	3	3	4	eV-sec
Longitudinal Emittance (pbars)	3	3	4	eV-sec
Form Factor (Hourglass)	0.70	0.70	0.65	
Typical Luminosity	5.4E+31	7.6E+31	4.1E+31	$cm^{-2}sec^{-1}$

*"Achieved" refers to (second) best simultaneous performance. Best individual parameters are higher.

Collider Performance
Current Performance Issues

- Current antiproton production rate is sufficient to support a luminosity in the 4-5×10^{31} $cm^{-2}sec^{-1}$ range.
- Protons are roughly 95% of FY2003 stretch goal
- Antiprotons are roughly 70% of FY2003 stretch goal
  - Transfer efficiency accumulator to low beta has improved significantly, 65-70% (depends on stack size), and is approaching the stretch goal of 81%.
- Primary outstanding issues
  - Emittance preservation throughout the complex
  - Proton and antiproton acceleration efficiencies (Tevatron)
  - Tevatron alignment/coupling
- A variety of hardware projects are currently underway dealing with these issue. These are scheduled for implementation over the spring/summer. They are expected to support performance somewhere between the base and stretch levels

Collider Performance
2003 Schedule

- October to mid-January
  - Deliver luminosity with up to 5 shifts/week dedicated studies. Initiate antiproton shots to Recycler in December
- 3 week shutdown in January
  - 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;
- 6 week shutdown starting late July
  - Tevatron alignment; Recycler vacuum; e-cooling civil construction; A0 modifications; Tevatron collimators; NUMI installation work; (full scope of work TBD…)
- Mid-September to …
  - No shutdown yet specified before summer 2004

Run II Beyond 2003

We are developing a plan whose "…**goal is to maximize output of the Tevatron Collider during the period leading up to the initiation of physics results from the Large Hadron Collider at CERN.**"

- Plan includes:
  - Scope of work
  - Resource loaded schedule
  - Flexibility to changing conditions and/or understanding
  - Completion of accelerator upgrades in FY2006
  - To be reviewed by the DOE in July
- Scope
  - Operations
  - Maintenance initiatives
  - Upgrades
  - (Other division activities)

Run II Beyond 2003
Strategy

The evolution of luminosity in Run II will directly track increases in the number of antiprotons in collision. Major strategic/technical elements of the upgrade plan (largely unchanged over last several years):

- More protons on the antiproton production target
  - Proton accumulation in the Main Injector
- Increased antiproton yield per proton on target
  - Lithium lens upgrade
  - AP-2 and Debuncher aperture improvements
- Increased antiproton stacking and storage ability
  - Accumulator stochastic cooling improvements
  - Electron cooling in the Recycler
- Beam dynamics in the Tevatron
  - Active beam-beam compensation and/or
  - Increased beam separation

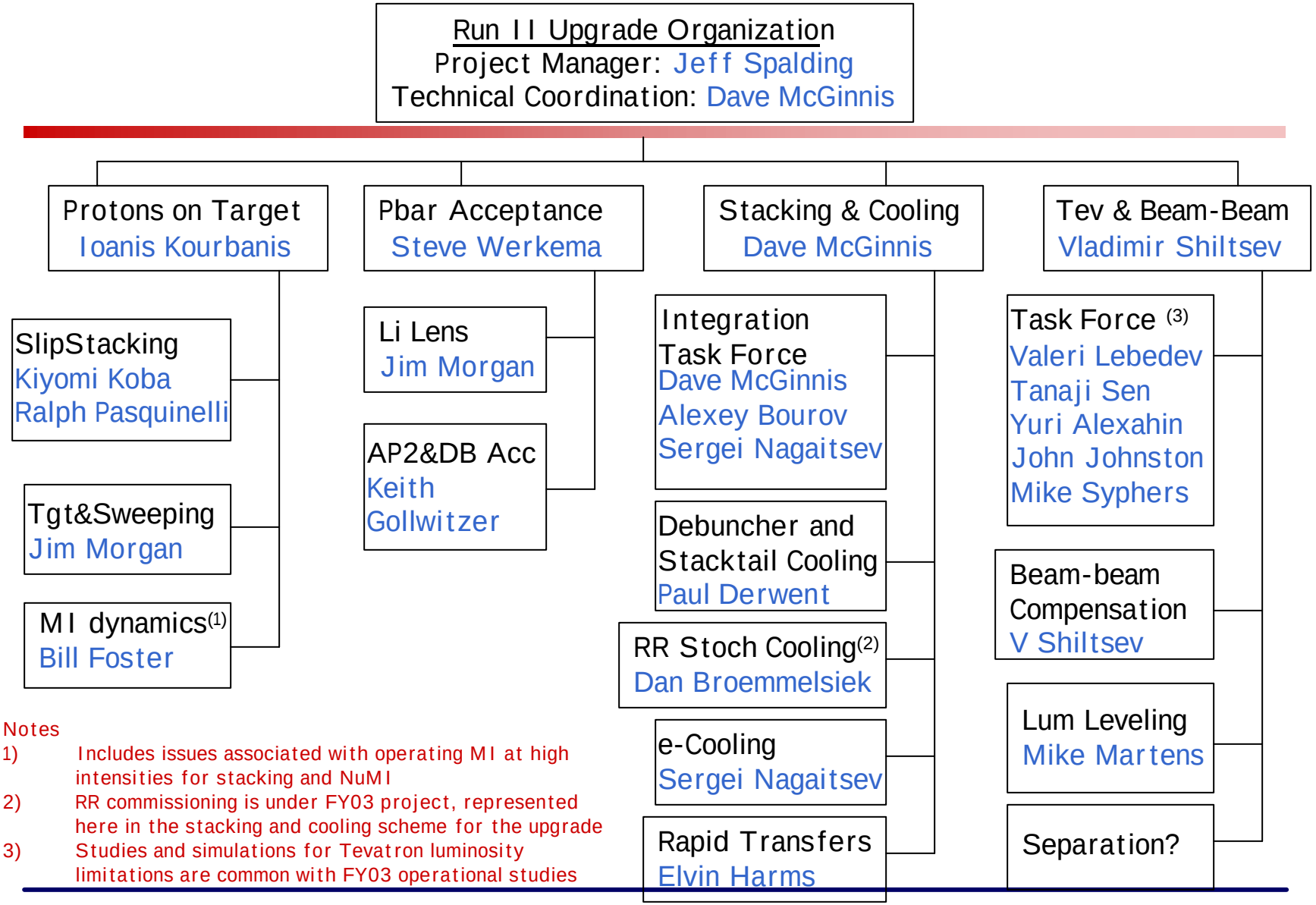
Run II Beyond 2003
Organizational Approach

In parallel with upgrades we need to maintain efficient operations of the collider complex.

⇒ Run II effort is being organized utilizing a project approach within the Beams Division. Responsibility for the execution resides with the Beams Division Head (Roger Dixon). Responsibility for major sub-tasks:

- Operations
  - Deputy Division Head, Mike Church
- Reliability and Maintenance
  - Associate Division Head for Engineering, Paul Czarapata
- Accelerator Upgrades
  - Assistant Division Head for Run II, Jeff Spalding

Matrix organization. The incorporation of Beams Division line management within the project structure assures appropriate priority for integration of work (both from within and outside the division).



Notes

1) Includes issues associated with operating MI at high intensities for stacking and NuMI
2) RR commissioning is under FY03 project, represented here in the stacking and cooling scheme for the upgrade
3) Studies and simulations for Tevatron luminosity limitations are common with FY03 operational studies

Run II Beyond 2003
Preparing the Plan

1. Define and review the subproject scope
   - Done for pbar subprojects, in process for Tevatron
   - AAC Review Feb. 4-6, 2003
2. Develop plan for phasing the upgrades
3. Prepare WBS and Resource Loaded Schedule
   - Director's Review May 5-7
4. Document Scope, Technical Plan, and Resource Loaded Schedule
   → DOE June 1
5. DOE review: week of July 14

- Also! – continue to make technical progress in parallel

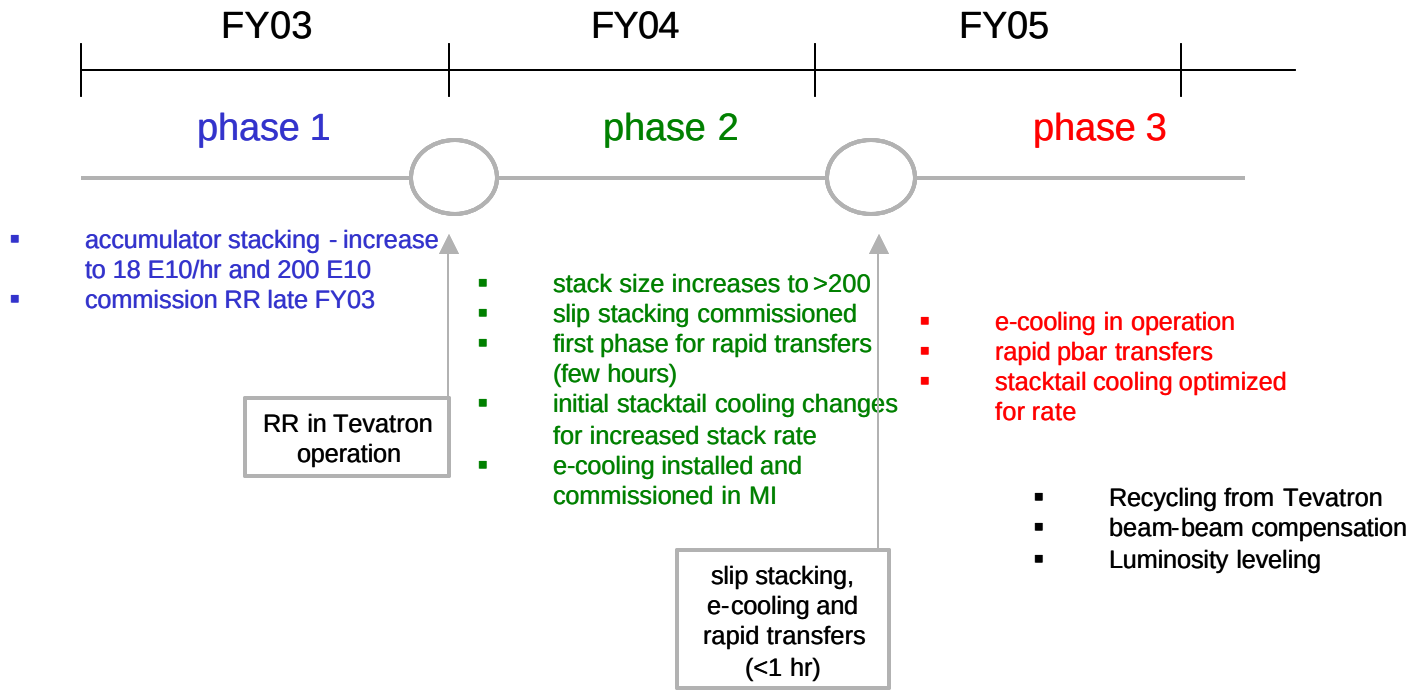
Biggest issue: personnel shared with near-term operations

Run II Beyond 2003
Upgrade Scope of Work

- Essential components:
  - Slip stacking
  - Antiproton targeting improvements
  - AP2 + Debuncher Acceptance
  - Stacktail Cooling
  - Rapid Transfers
  - Electron cooling
- Under consideration (some combination will be essential):
  - Active beam-beam compensation
  - Increased beam separation
- Dropped
  - 132 nsec operation
  - recycling pbars from Tevatron (10% performance hit)
  - position endorsed by AAC at February 2003 meeting

Run II Beyond 2003
Strategic Approach

A preliminary phasing of upgrades was identified at the October DOE review. This remains the context for development of the detailed plan which represents the primary action item emerging from that review.



Run II Beyond 2003
Luminosity Evolution

Goals as presented to the October DOE Review:

"A reasonable range of goals based on our current experience would be:"

FY02	.08	.08	fb^{-1}
FY03	0.2	0.32	
FY04	0.4	0.6	
FY05	1.0	1.5	
FY06	1.5	2.5	
FY07	1.5	3.0	
FY08	1.8	3.0	
TOTAL	6.5	11.0	fb^{-1}

Note: Taking account of a seven month shutdown in FY06 and typical re-start performance experience could decrease these numbers by ~15%. Running beyond FY08 will increase them by ~25%/year.

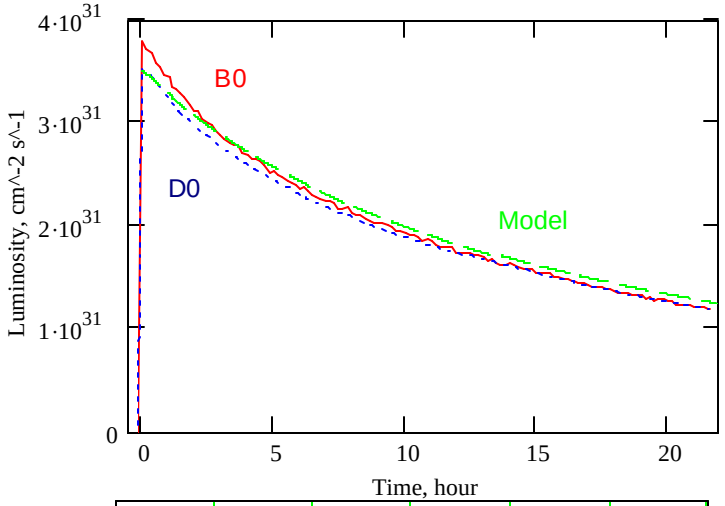
Þ **Bottoms-up projections will be incorporated in the June 1 plan**

Run II Beyond 2003
(Stretch) Goals

	Phase 1	Phase 2	Phase 3	
Protons/bunch	2.15E11	2.70E11	2.70E11	
Antiprotons/bunch	3.6E10	4.8E10	10.9E10	
Bunches	36	36	36	
Antiproton Production	1.5E11	2.8E11	4.0E11	$hour^{-1}$
Luminosity	7.6E31	13E31	30E31	$cm^{-2}sec^{-1}$
Luminosity/week	15	25	60	pb^{-1}

Note: Stretch goals assume essentially everything is funded and works as planned. The DOE Review Committee described the base goal as “a significant challenge” in and of itself, and the stretch goal as “very uncertain”. Nonetheless, **stretch parameters form the basis of our planning.**

Run II Beyond 2003
Parametric (Store) Model



$\varepsilon n_{px} \cdot 10000 = 19$ mm mrad

$\varepsilon n_{py} \cdot 10000 = 19$ mm mrad

$\varepsilon n_{ax} \cdot 10000 = 18$ mm mrad

$\varepsilon n_{ay} \cdot 10000 = 18$ mm mrad

$\kappa = 0.3$

$\frac{\tau_{gas}}{3600} = 300.087$ hour

$d\varepsilon dt_{gas} = 0.168$ mm mrad/hour

$\sqrt{d\phi 2dt_{RF} \cdot 3600} = 0.016$ rad/hour$^{1/2}$

$N_p = 1.6 \times 10^{11}$

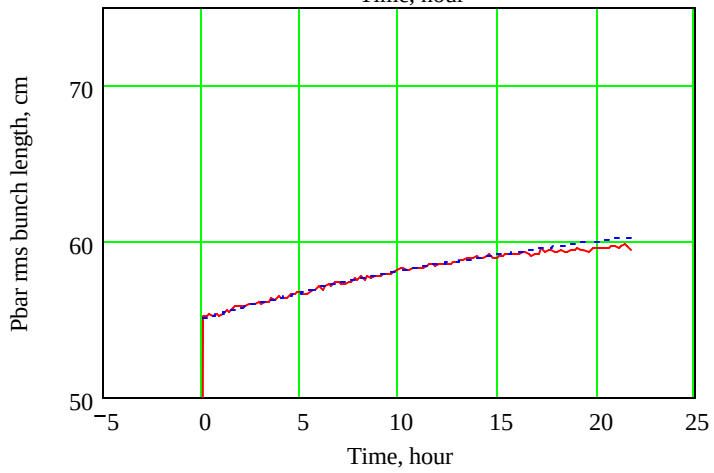
$N_a = 2.72 \times 10^{10}$

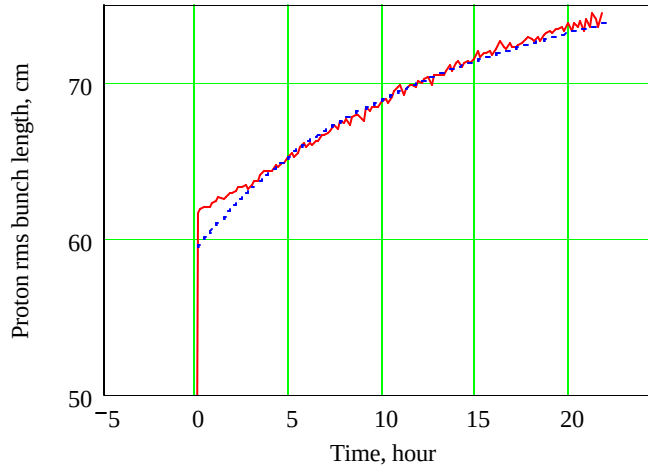
$\sigma s(\sigma_{pp}) = 59.4$ cı

$\sigma s(\sigma_{pa}) = 55.112$ cı

$Lum_0 = 3.513 \times 10^{31}$

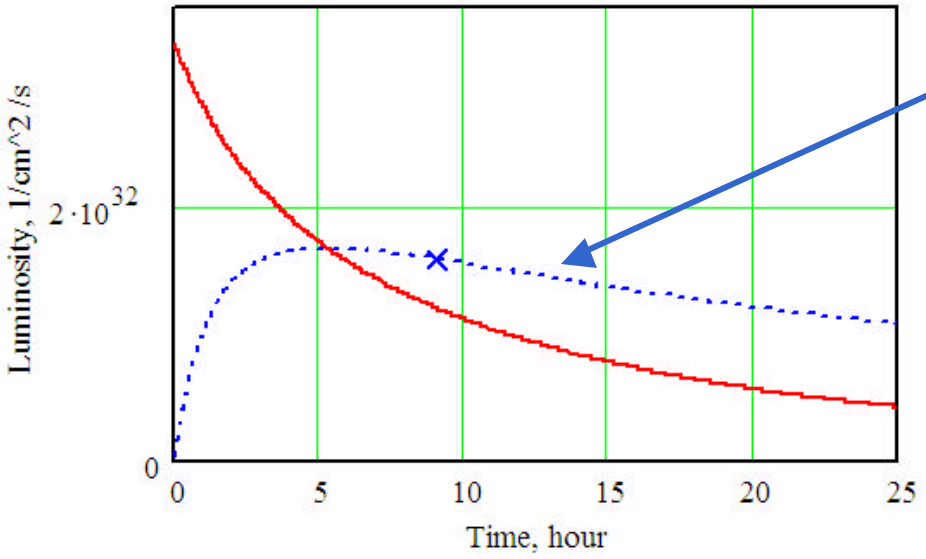
$\tau_{Lum_1} = 13.826$ hı





Run II Beyond 2003
Parameter Sensitivity

- How robust is the integrated luminosity?
  - Leveling @2E32: lose ~12% (if required by experiments)
  - No recycling: lose ~10% (longer stores)
  - Pbar intensity ×80%: lose ~14% (shorter stores)
  - Average stacking = 30E10/hr: lose ~10% (longer stores)



average luminosity (incl shot setup) vs store length

Run II Beyond 2003
Risk Elements

- Technical
  - Tevatron ability to handle large beam intensities
  - Electron cooling in the Recycler
  - Antiproton stacking performance
- Funding
  - Performance goals cannot be achieved independent of resources applied to the effort.
- Reliability
  - Major component of our planning
  - Preparing for Run II operations through end of decade, then BTeV
  - Most of our accelerator complex will be in “middle-age”
- People
  - Lab is trying to shrink staff.
- Proton Economics: See subsequent discussion

Collider Support for BTeV
Requirements

- **BTeV request is 2×10^{32} cm^{-2}sec^{-1}**
- BTeV is slated for the C-0 IR
- Would like to start (low luminosity) commissioning late 2008/early 2009
- Operations (data taking) start in 2009
  - CDF/D-0 operations are not viewed as concurrent with BTeV
- The experiment is compatible with the planned continuation of 36×36 (396 bunch spacing) operations.

Collider Support for BTeV
Accelerator (re)Configuration: Option 1

- Reuse components from the CDF or D-0 IR
  - β*=150 cm Þ **luminosity 32% of Run II (1.0E32)**
    - ➢ (Plus ~15% enhancement in integrated luminosity from single IR operation)
- BTeV commissioning
  - Run at 1-10E29 exclusive of CDF/D-0 operations after C-0 normal straight implemented
- Installation/commissioning requirements
  - ~5 months + commissioning period (~1 month)

Collider Support for BTeV
Accelerator (re)Configuration: Option 2

- Newly constructed components
  - IR quads (10 modified LHC + 6 "tune matching" + spares)
    - LHC quads operate at 4.5 K with 170 T/m gradient
    - Some require new (smaller) cryostats. (Design concept exists)

    β*=50 cm Þ **luminosity 80% of Run II (2.4E32)**
    - β* limited by LHC quad aperture
    - (Plus ~15% enhancement in integrated luminosity from single IR operation)
  - Six new electrostatic separators
- BTeV Commissioning
  - Run at 1-10E29 exclusive of CDF/D-0 operations after C-0 normal straight implemented
- Installation/commissioning requirements
  - ~6 months + commissioning period (~1 month)

Option 1/Option 2 decision in FY2005

Accelerator Support for CKM
Beam Requirements

- Primary Beam
  - 5×10^{12} proton /sec (instantaneous) at 120 GeV
  - Slow spill with macroscopic duty factor of 33%
    - (17% of MI design intensity)
    - Duty factor set by maximum average power dissipation in MI
  - Debunched proton beam (~10%, 53MHz, modulation OK)
- Secondary beam
  - 30 MHz separated K+ beam; 22 GeV/c
- Commission start in 2008
- Operations start in late 2009
- CKM will be located in the Meson area

Accelerator Support for CKM
MI and Proton Economics

- Collider Program and CKM only is pretty straightforward
  - Antiproton production cycles specified at 8E12 every 2 seconds (1.4E16/hour)
  - CKM wants 5E12/second × 1200 seconds/hour (6.0E15/hour)
  - Most straightforward is to run MI in "combined mode":
    - 3 second cycle
    - 8E12 to pbar
    - 5E12 to CKM
    - Stacking rate × 67% => **luminosity ´ 88%**
  - **Of course we should assume that MINOS or its successor will be operational during this time period.**

Accelerator Support for CKM
MI and Proton Economics

- Collider Program, CKM, and NuMI is less straightforward
  - Antiproton production cycles specified at 8E12 every 2 seconds (1.4E16/hour)
  - CKM wants 5E12/second × 1200 seconds/hour (6.0E15/hour)
  - NuMI will want>2.5E13 every 2 seconds (>4.5E16/hour)
  - It is technically challenging to support all three users on a single MI cycle

    => will interleave fast and slow spill cycles.
  - A variety of options exist. A representative example:
    - Eight (2 second) fast spill cycles, followed by one (8 sec.) cycle with a 6 second slow spill:
    - 24 second supercycle
    - Stacking rate × 67% => **luminosity ´ 88%**
    - **NuMI rate ´ 67%**
    - **CKM rate ´ 83%**
  - What about Booster?
    - Total protons/hour = 4.4E16/hour (~ current performance)

Summary

Run II

- We are succeeding in bring collider performance to where it should be.
- A comprehensive plan for maximizing integrated luminosity between now and LHC physics is in preparation for June 1 release.
  - Shooting for 3×10^{32} $cm^{-2}sec^{-1}$ when all upgrades implemented
  - Will include bottoms-up luminosity projection
  - Requires ongoing R&D

BTeV

- Situated in new interaction region at C-0
  - C-0 modification options are understood
  - Need Option 1 vs 2 decision in 2005
- Project delivering 1-2.4$\times10^{32}$ $cm^{-2}sec^{-1}$ starting in 2009

CKM

- Situated in Meson area, based on 120 GeV beams from Main Injector
- RF cavity development and beamline engineering underway
- Operations simultaneous with collider and NuMI with modest cost in performance