# Tevatron Helix Upgrades: Introductory Comments

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# Tevatron in Run II: Goals/Issues

- differences between now ($L$~37e30) and then ($L$=290e30):

| | *L gain* |
|---|---|
| more protons | x 1.2 |
| more pbars | x 5.9 (to $\frac{1}{2}$ of p's) |
| shorter bunches | x 1.1 |
| ~ same transverse emittances | |
| total: | x 7.8 |

- as the result:
  - Stronger beam-beam force on pbars
  - Noticeable beam-beam force on protons
  - Possible coherent beam-beam phenomena
  - Tighter control of tunes, orbit, coupling, chromaticities
  - Tighter tolerances on transfers: intensity and emittances
  - Stability concerns for both beams

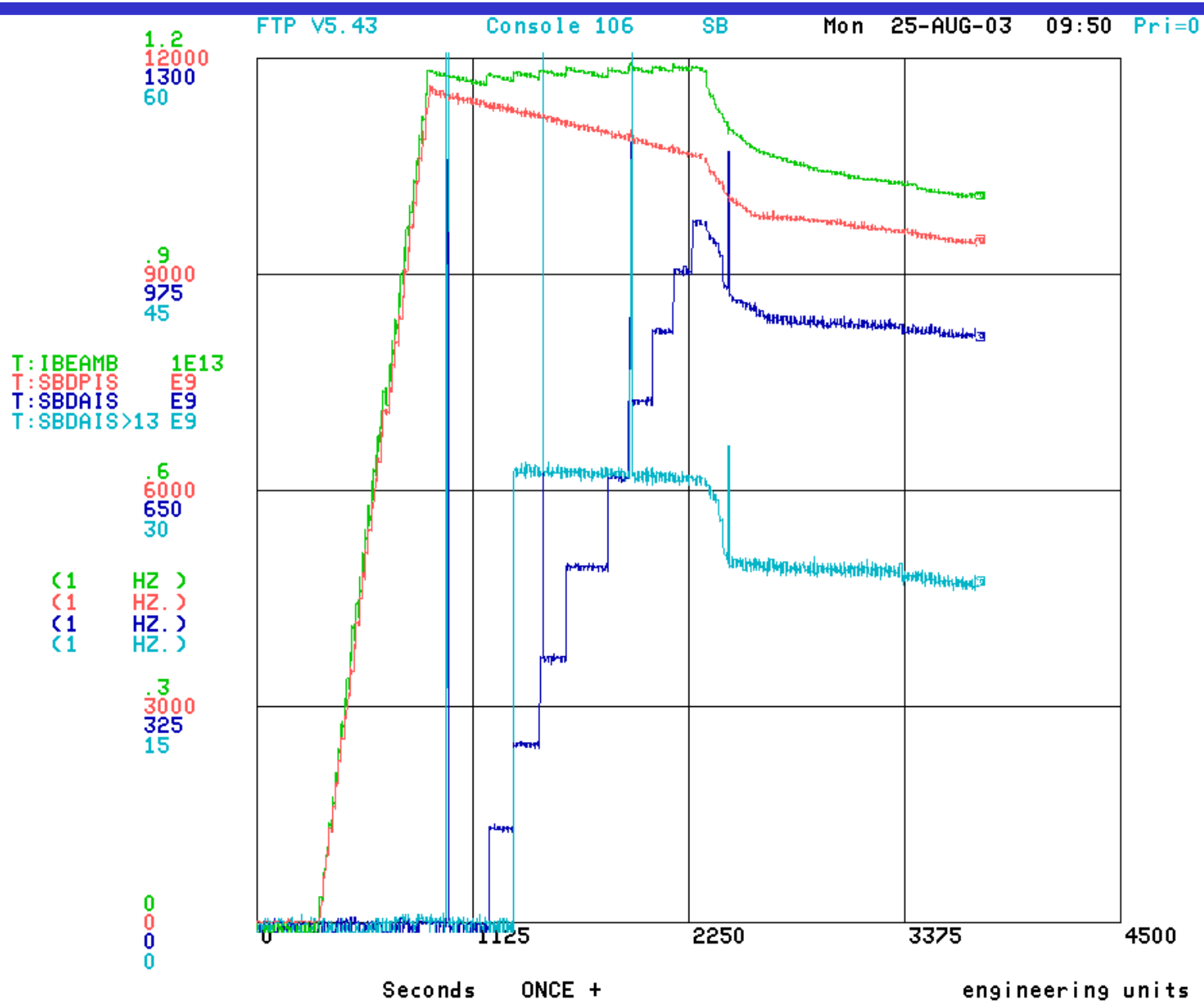
# Tevatron Upgrade Projects

| WBS | Task | In Charge | Labor Est ($K) | Labor Cont | M&S Est ($K) | M&S Cont | Start |
|---|---|---|---|---|---|---|---|
| **1.3.4** | **Tevatron High Luminosity** | **V Shiltsev** | **7,588** | **51%** | **5,103** | **47%** | **1/1/03** |
| 1.3.4.1 | Tevatron Task Force | V. Lebedev | 1,856 | 40% | 0 | 0% | 1/1/03 |
| 1.3.4.2 | Beam-beam Limitations | T. Sen | 453 | 60% | 5 | 40% | 1/1/03 |
| 1.3.4.3 | Active Beam-Beam Compensation | V Shiltsev | 1,400 | 64% | 1,380 | 57% | 1/1/03 |
| 1.3.4.3.1 | BBC: Tevatron Electron Lens | V. Shiltsev | 1,088 | 55% | 1,250 | 53% | 1/1/03 |
| 1.3.4.3.2 | BBC: Wires | T. Sen | 312 | 94% | 130 | 100% | 4/1/03 |
| 1.3.4.4 | Increased Helix Separation | R. Moore | 1,222 | 40% | 1,847 | 27% | 4/1/03 |
| 1.3.4.4.1 | Optimize separation with present Separators | Y. Alexahin | 39 | 60% | 0 | 0% | 5/1/03 |
| 1.3.4.4.2 | Tevatron Polarity Switches for Separators | B. Hanna | 98 | 47% | 237 | 41% | 11/3/03 |
| 1.3.4.4.3 | Long Separators | R. Moore | 735 | 25% | 1,570 | 23% | 9/2/03 |
| 1.3.4.4.4 | Coated Separators | B. Hanna | 222 | 70% | 40 | 100% | 5/1/03 |
| 1.3.4.4.5 | Additional  Seperators | B. Hanna | 128 | 60% | 0 | 0% | 4/1/03 |
| 1.3.4.5 | Luminosity Leveling | M. Martens | 13 | 54% | 0 | 0% | 12/1/04 |
| 1.3.4.6 | Improved Control and Diagnostics | J. Steimel | 1,742 | 55% | 1,500 | 61% | 1/1/03 |
| 1.3.4.6.1 | abort gap monitor | H. Cheung | 31 | 60% | 30 | 60% | 4/1/04 |
| 1.3.4.6.2 | Tev Dampers | J. Steimel | 52 | 60% | 0 | 0% | 12/1/03 |
| 1.3.4.6.3 | p/pbar Tune Tracker | CY Tan | 11 | 60% | 30 | 60% | 11/3/03 |
| 1.3.4.6.4 | Tevatron BPM Upgrade | J. Steimel | 412 | 57% | 900 | 60% | 8/1/03 |
| 1.3.4.6.5 | Tevatron IPM | A. Jansson | 324 | 57% | 300 | 60% | 5/1/03 |
| 1.3.4.6.6 | B-field diagnostics | P. Bauer | 846 | 52% | 160 | 53% | 1/1/03 |
| 1.3.4.6.7 | 1.7 GHz Schottky Detector | A. Jansson | 65 | 60% | 30 | 60% | 3/3/03 |
| 1.3.4.6.8 | Head-tail Monitor | V. Ranjbar | 0 | 0% | 50 | 100% | 11/1/04 |
| 1.3.4.7 | Tevatron Vacuum Improvements | B. Hanna | 12 | 40% | 90 | 40% | 10/17/03 |
| 1.3.4.8 | Tevatron Alignment | R. Stefanski | 891 | 60% | 281 | 60% | 1/1/03 |
| 1.3.4.8.2 | Orbit/aperture optimization | J. Annala | 314 | 60% | 0 | 0% | 1/1/03 |
| 1.3.4.8.3 | Tevatron On-line Level System | J. Volk | 291 | 60% | 181 | 60% | 3/3/03 |
| 1.3.4.8.4 | Magnet Alignment | R. Stefanski | 118 | 60% | 100 | 60% | 8/25/03 |
| 1.3.4.8.5 | SC Coil Realignment/Smart Bolts | D. Harding | 168 | 60% | 0 | 0% | 8/25/03 |

# Increased Helix Separations

- Goal of the project is to reduce strength of beam-beam resonances by increasing beam separation
  - Will not reduce head-on beam-beam interaction
  - Will not help much at 150 GeV (aperture limited)
- Status/plans:
  - New helix at 150, ramp, squeeze: FY'03 → FY'04
  - Aperture studies ~complete
  - Need study time to implement (before Sept '03)
  - More separators
  - Stronger "coated" electrode R&D started (TD)
- Optimal helix solutions come from the Tev Task Force
- TD to make essential contribution to design and fabrication

# Tevatron Inefficiencies



# Inefficiencies and key paramters

| | 03/02 | 10/02 | 01/03 | 03/03 | #2555 | #2943 |
|---|---|---|---|---|---|---|
| Protons/bunch | 140e9 | 170e9 | 180e9 | 205e9 | 243e9 | 248e9 |
| Pbars/bunch | 7.5e9 | 22e9 | 20e9 | 23e9 | 26e9 | 23e9 |
| P-loss at 150 GeV | 23% | 14% | 16% | 10% | 11% | 7.6% |
| Pbar-loss at 150 | 20% | 9% | 4% | 4% | 4% | 1.1% |
| P-loss on ramp | 7% | 6% | 9% | 5% | 6% | 5.1% |
| Pbar-loss on ramp | 14% | 8% | 12% | 11% | 16% | 7.8% |
| Pbar-loss in squeeze | 25% | 5% | 3% | 2% | 5% | 2.8% |

**Key Parameters ( ~in order)**

| | | | | | |
|---|---|---|---|---|---|
| P-loss at 150 GeV | C_v,h | Apert | Emm_x,y | dP/P | helix |
| Pbar-loss at 150 | C_v,h | Apert | Emm_x,y | helix | dP/P |
| P-loss on ramp | Emm_y,x | dP/P | tunes | Apert | C_v,h |
| Pbar-loss on ramp | Emm_x,y | Tunes | dP/P | C_v,h | N_p |
| Pabr-loss in squeeze | Helix | Tunes | N_p | Emm_x,y | |
| Scallops | Tunes | N_p | | | |

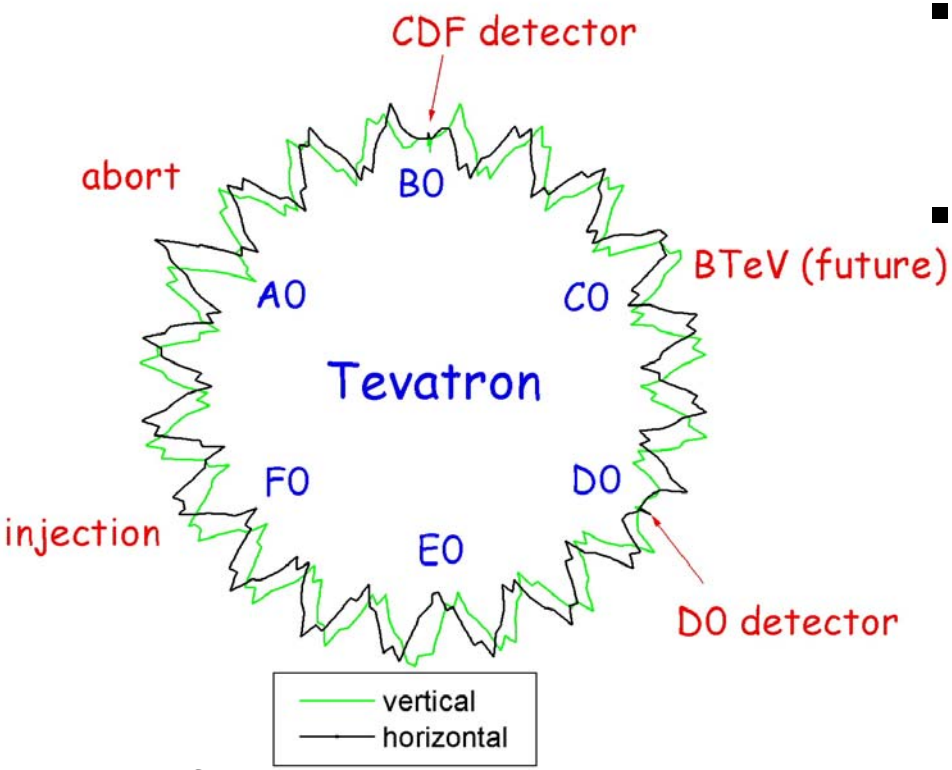
# Ultimate Expectations

- Improve pbar ramp and squeeze efficiency by 5-10%
  - Same gain in luminosity 5-10%
  - Keep the losses low at larger pbar stack size and large emittances
  - keep the losses low at higher proton intensity 270e9/bunch

    ? → 300e9/bunch ?→330e9/bunch at LB (another 10-20% in L)
- Reduce pbar emittance growth rate at HEP:
  - Gain in L not yet clear as scallops do not always occur now
- Reduce proton (and pbar) losses on ramp, squeeze, LB
  - Fewer quenches → some 5% gain in integrated Luminosity
  - Better p/pbar lifetime at LB → 5-10% in integrated Luminosity
- Reduce separator sparking rate (?) → 2-4% in integr Lumi

TOTAL: 12 – 44%

# Helix Improvements




- Quantative improvement:
  - Increase minimum separation in s's
- Qualitative improvements:
  - Decrease strength of resonances
  - Decrease maximum separation in mm

| Modification | near-misses gain % | Ringwide gain% |
|---|---|---|
| 10% separator voltage increase | 10 | 10 |
| 50mrad half-crossing angle | 21.5 | ~0 |
| Additional arc modules | 7.7 | 15 |
| Increase IR separator strength | 19 | 19 |
| TOTAL GAIN | 71 | 50 |

# Back-up Slides

- Run II vs Run Ib
- FY'04 vs FY'03
- Upgrade vs Now
- Separators cost breakout
- Longer separators

# Run II (without the Recycler) and Run Ib

- Projected - 5.3x ($8.5\times10^{30}cm^{-2}\ sec^{-1}$ / $1.6\times10^{30}cm^{-2}\ sec^{-1}$)
- Delivered* – 1.94x ($3.1\times10^{30}cm^{-2}\ sec^{-1}$ / $1.6\times10^{30}cm^{-2}\ sec^{-1}$)
- More Pbars
  - projected - 3.3x
    - More protons on target - 2x ($5\times10^{12}/2.5\times10^{12}$)
    - Faster Pbar cycle rate - 1.6x (2.4sec/1.5sec)
  - delivered* - 1.9x
    - More protons on target - 1.9x ($4.7\times10^{12}/2.5\times10^{12}$)
    - Faster Pbar cycle rate - 1x (2.4sec/2.4sec)
- More Protons
  - projected - 1.17x ($270\times10^{9}/230\times10^{9}$)
  - delivered* - 0.83x ($192\times10^{9}/230\times10^{9}$)
- Shorter Bunch lengths
  - projected - 1.25x (0.37m <- 0.6 m)
  - delivered* – 1x (0.6m <- 0.6 m)
- Higher Energy
  - projected – 1.11x (1000 GeV/ 900 GeV )
  - delivered* – 1.09x (980 GeV/ 900 GeV )

*Based on 75 Stores between 2/10/03 – 6/5/03

# FY03 - FY04 Collider Parameters

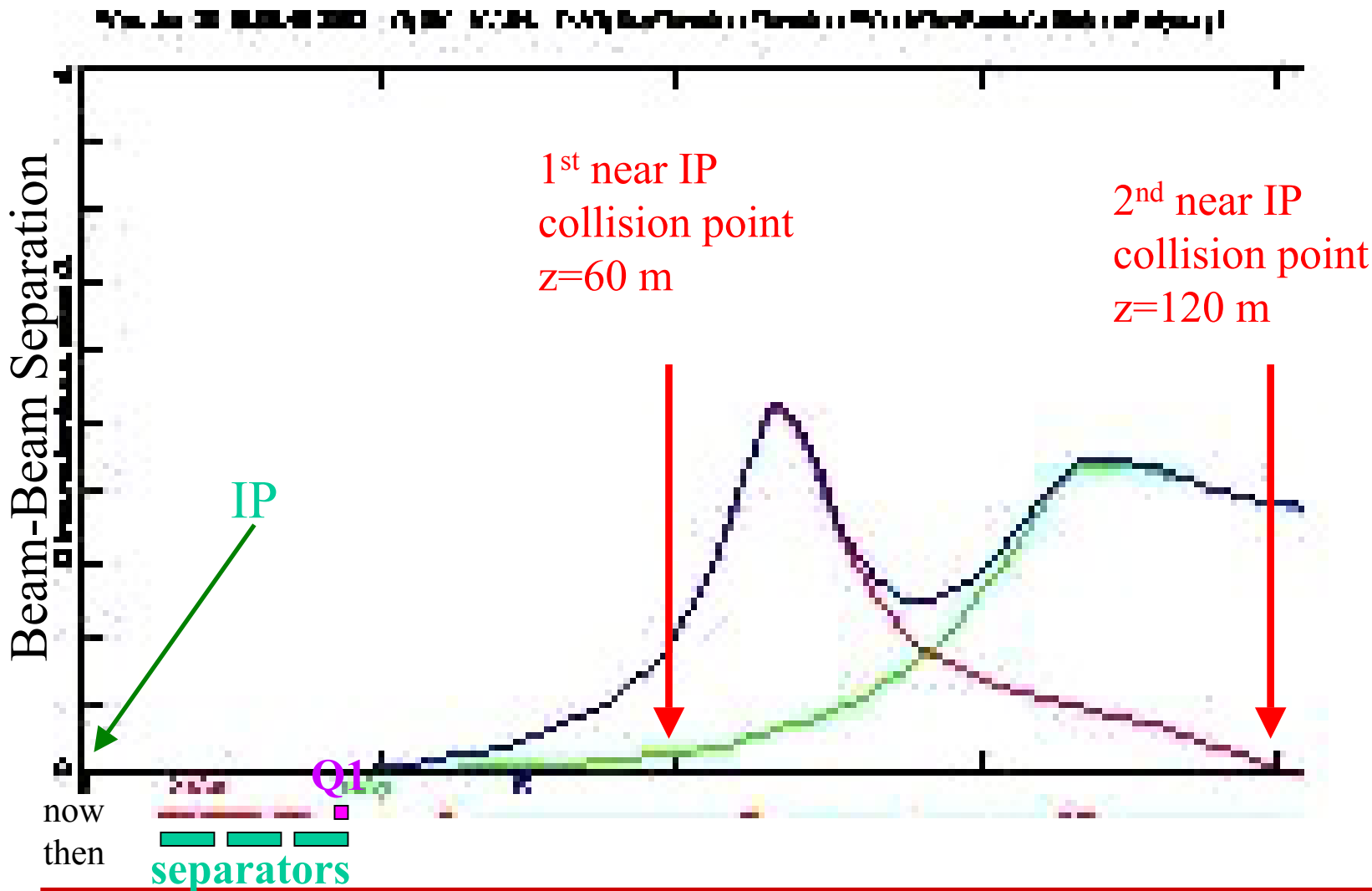
| Parameter | Average* | St. Dev.* | Best Integrated | Best Peak | Phase 1 | |
|---|---|---|---|---|---|---|
| Initial Luminosity (CDF) | 31.2 | 9.6 | 42.0 | 47.4 | 68.0 | $x10^{30} cm^{-2} sec^{-1}$ |
| Average Instantaneous Luminosity (CDF) | 19.4 | 6.8 | 22.3 | 27.0 | 37.9 | $x10^{30} cm^{-2} sec^{-1}$ |
| Integrated Luminosity per Store (CDF) | 985.7 | 450.5 | 1713.0 | 1650.0 | 2251.3 | $nb^{-1}$ |
| Luminosity per week (CDF) | 4.7 | 2.6 | 4.6 | 7.0 | 10.9 | $pb^{-1}$ |
| Number of Stores per Week | 4.7 | - | - | - | 4.8 | |
| Store Length | 14.4 | 5.5 | 21.3 | 17.0 | 14.5 | Hours |
| Intentional Store Length | 16.6 | 3.4 | 21.3 | 17.0 | 14.5 | Hours |
| Aborted Store Length | 10.6 | 6.4 | - | - | - | Hours |
| Store Hours per week | 68.6 | 31.9 | 46.3 | 91.6 | 70.3 | Hours |
| Time spent stacking per store | 14.6 | 3.4 | 19.5 | 20.9 | 14.5 | Hours |
| Shot Setup Time | 2.8 | 2.6 | 1.8 | 2.0 | 2.0 | Hours |
| Store Lifetime | 13.6 | 3.8 | 14.9 | 13.6 | 10.8 | Hours |
| Protons per bunch | 192.1 | 29.0 | 203.8 | 242.0 | 240.0 | $x10^{9}$ |
| Start Stack | 135.3 | 25.1 | 166.0 | 173.0 | 174.3 | $x10^{10}$ |
| End Stack | 11.2 | 13.6 | 12.0 | 11.0 | 0.0 | $x10^{10}$ |
| Zero Stack Stack Rate | 11.7 | 1.6 | 11.7 | 11.7 | 18.0 | $x10^{10}$/Hour |
| Zero Stacking Rate Stack Size | 303.7 | 1.7 | 303.7 | 303.7 | 300.0 | $x10^{10}$ |
| Pbar Transfer efficiency to Low Beta | 57.9 | 7.5 | 57.7 | 56.7 | 75.0 | % |
| HourGlass Factor | 0.64 | 0.03 | - | 0.65 | 0.65 | |

*Based on 75 Stores between 2/10/03 – 6/5/03

# Run II: 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) | $\pi$-mm-mrad | 20 | 18 | 0.9 |
| Antiproton Transverse Emittance (at collision) | $\pi$-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 |

# Increased Helix Separation

| | | | | |
|---|---|---|---|---|
| **1.3.4.4** | **Increased Helix Separation** | **$0.00** | | **4/1/2003 8:00** | **1044 days** |
| **1.3.4.4.1** | **Optimize separation with present Sepa** | **$0.00** | | **5/1/2003 8:00** | **166 days** |
| 1.3.4.4.1.1 | Design new Helix and investigate Separato | $0.00 | C | 5/1/2003 8:00 | 66 days |
| 1.3.4.4.1.2 | Implement new separator Protocol | $0.00 | C | 11/19/2003 8:00 | 22 days |
| **1.3.4.4.2** | **Tevatron Polarity Switches for Separat** | **$0.00** | | **11/3/2003 8:00** | **209 days** |
| 1.3.4.4.2.1 | Purchase parts | $165,000.00 | B | 11/3/2003 8:00 | 1 day |
| 1.3.4.4.2.2 | Assemble and test switches | $64,000.00 | B | 1/5/2004 8:00 | 88 days |
| 1.3.4.4.2.3 | Install switches in service buildings | $8,000.00 | C | 5/6/2004 8:00 | 66 days |
| 1.3.4.4.2.4 | Commission with beam | $0.00 | C | 8/5/2004 17:00 | 10 days |
| **1.3.4.4.3** | **Seperator Upgrade** | **$0.00** | | **5/1/2003 8:00** | **956 days** |
| 1.3.4.4.3.1 | R&D on high voltage separator design | $40,000.00 | C | 5/1/2003 8:00 | 260 days |
| 1.3.4.4.3.2 | Decision on high voltage separators (Milest | $0.00 | | 4/28/2004 17:00 | 0 days |
| 1.3.4.4.3.3 | retrofit spare separators | $0.00 | C | 4/29/2004 8:00 | 130 days |
| 1.3.4.4.3.4 | replace separators -1 | $0.00 | C | 5/29/2006 8:00 | 33 days |
| 1.3.4.4.3.5 | retrofit separators | $0.00 | C | 7/13/2006 8:00 | 88 days |
| 1.3.4.4.3.6 | replace separators -2 | $0.00 | C | 11/14/2006 8:00 | 33 days |
| **1.3.4.4.4** | **Additional Seperators** | **$0.00** | | **4/1/2003 8:00** | **1044 days** |
| 1.3.4.4.4.1 | develop lattice/helix concept | $0.00 | C | 4/1/2003 8:00 | 66 days |
| 1.3.4.4.4.2 | develop magnet/separator concept | $0.00 | C | 4/1/2003 8:00 | 88 days |
| 1.3.4.4.4.3 | Decision on separators/magnets (Milestone | $0.00 | | 7/31/2003 17:00 | 0 days |
| **1.3.4.4.4.4** | **Long Separators** | **$0.00** | | **8/1/2003 8:00** | **780 days** |
| 1.3.4.4.4.4.1 | design long separators | $0.00 | A | 8/1/2003 8:00 | 66 days |
| 1.3.4.4.4.4.2 | procurement 14 long separators | $1,300,000.00 | A | 11/3/2003 8:00 | 132 days |
| 1.3.4.4.4.4.3 | setup separator production | $100,000.00 | B | 2/3/2004 8:00 | 22 days |
| 1.3.4.4.4.4.4 | fabrication+testing first long separator | $0.00 | A | 5/5/2004 8:00 | 88 days |
| 1.3.4.4.4.4.5 | fabrication+testing 12 long separators | $0.00 | A | 9/6/2004 8:00 | 440 days |
| 1.3.4.4.4.4.6 | installation design | $0.00 | B | 11/3/2003 8:00 | 132 days |
| 1.3.4.4.4.4.7 | installation fabrication | $50,000.00 | C | 5/5/2004 8:00 | 44 days |
| 1.3.4.4.4.4.8 | long separator installation | $0.00 | B | 5/29/2006 8:00 | 44 days |
| 1.3.4.4.4.5 | commission high voltage separators | $20,000.00 | C | 12/29/2006 8:00 | 22 days |
| 1.3.4.4.4.6 | new helix commissioning | $0.00 | B | 1/29/2007 17:00 | 44 days |
| 1.3.4.4.4.7 | increased BB separation operational (miles | $0.00 | | 3/30/2007 17:00 | 0 days |

# Longer Separators