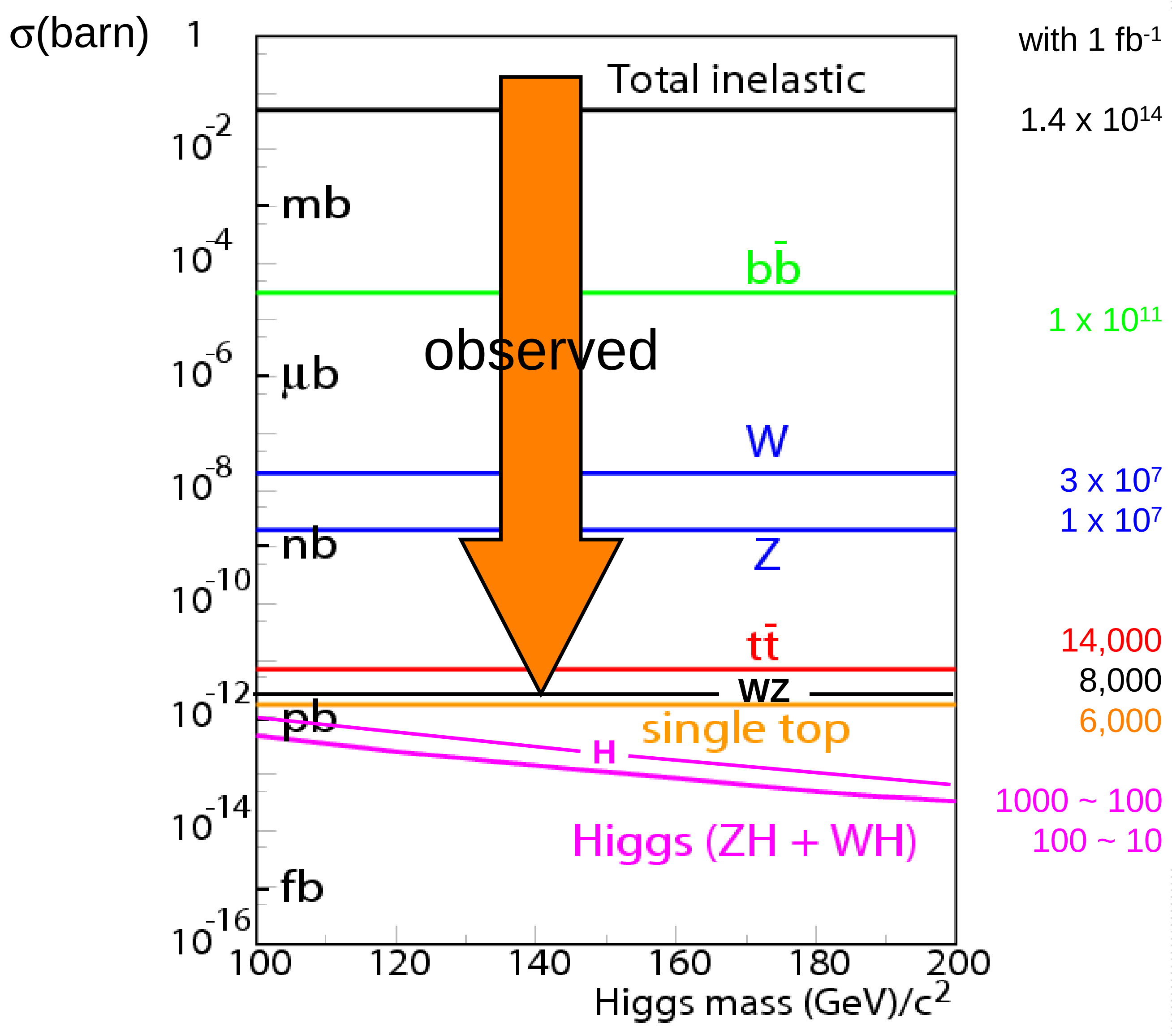
The Tevatron

HEPAP Meeting, October 12-13, 2006, Young-Kee Kim

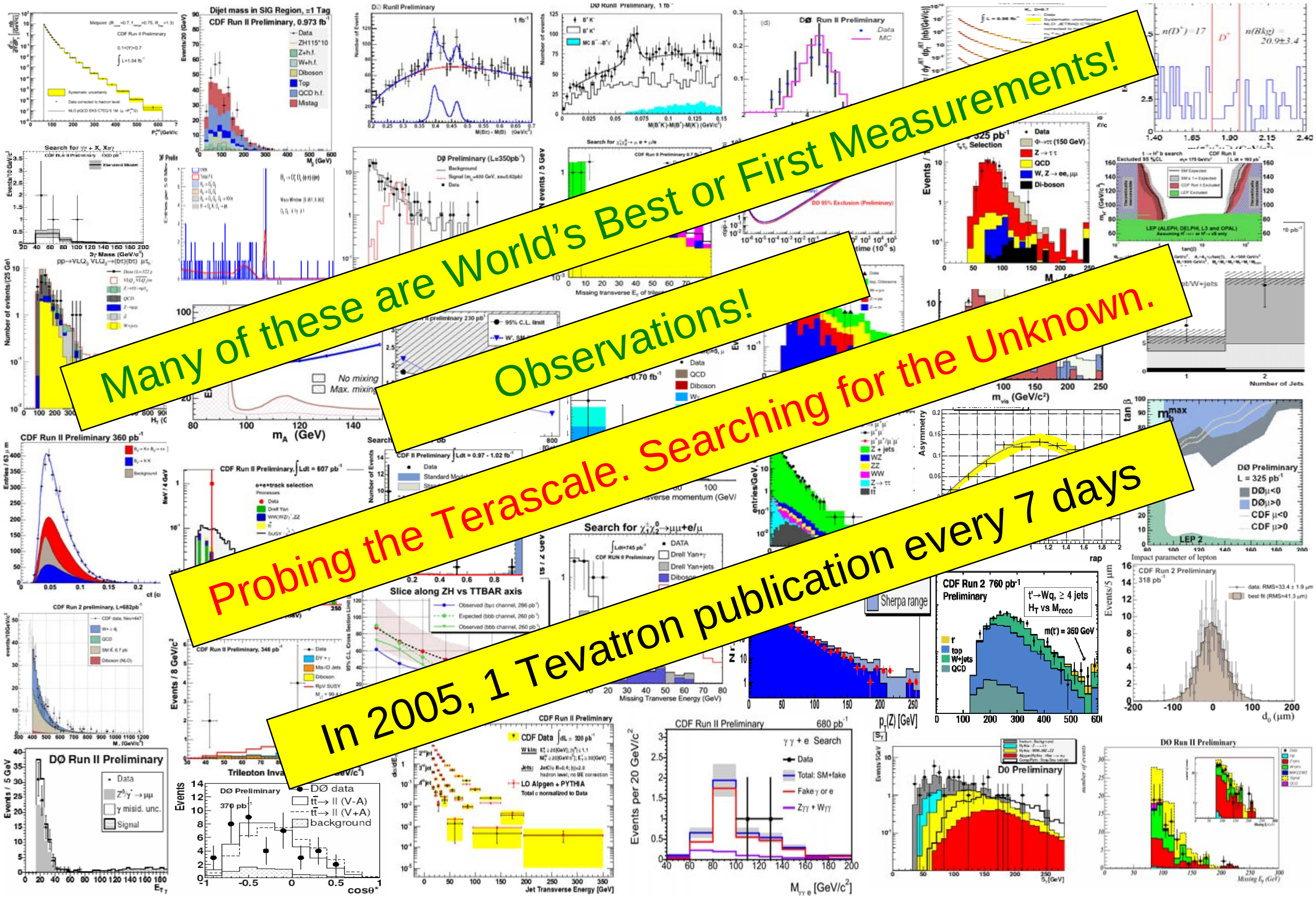
1. Physics Highlights with Data through Feb. 2006 (~1 fb^{-1})
   - B_s Oscillation, M_{top}, Higgs, ...
2. Achievements during the Shutdown (March - mid June 2006)
3. Tevatron Performance since the Shutdown
4. Challenges and Excitements Ahead

Entry to Tevatron Luminosity: www-bdnew.fnal.gov/operations/lum/lum.html
Entry to Tevatron Physics: www-d0.fnal.gov/Run2Physics/WWW/results.htm
www-cdf.fnal.gov/physics/physics.html

Physics at the Tevatron

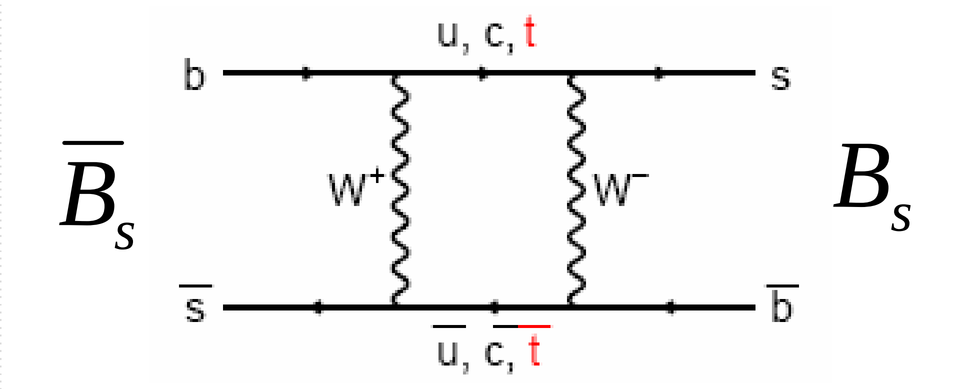


Many many measurements and searches at Tevatron



B_s Oscillation (B_s Mixing)

- B_s particles can change into their anti-particles.



- The rate at which $B_s \longleftrightarrow \overline{B}_s$ oscillate = Δm_s

- Important consistency check of CKM quark-mixing Matrix in the standard model.

$$\left|\frac{V_{td}}{V_{ts}}\right| = \xi \sqrt{\frac{\Delta m_d}{\Delta m_s} \frac{m_{B_s}}{m_{B_d}}}$$

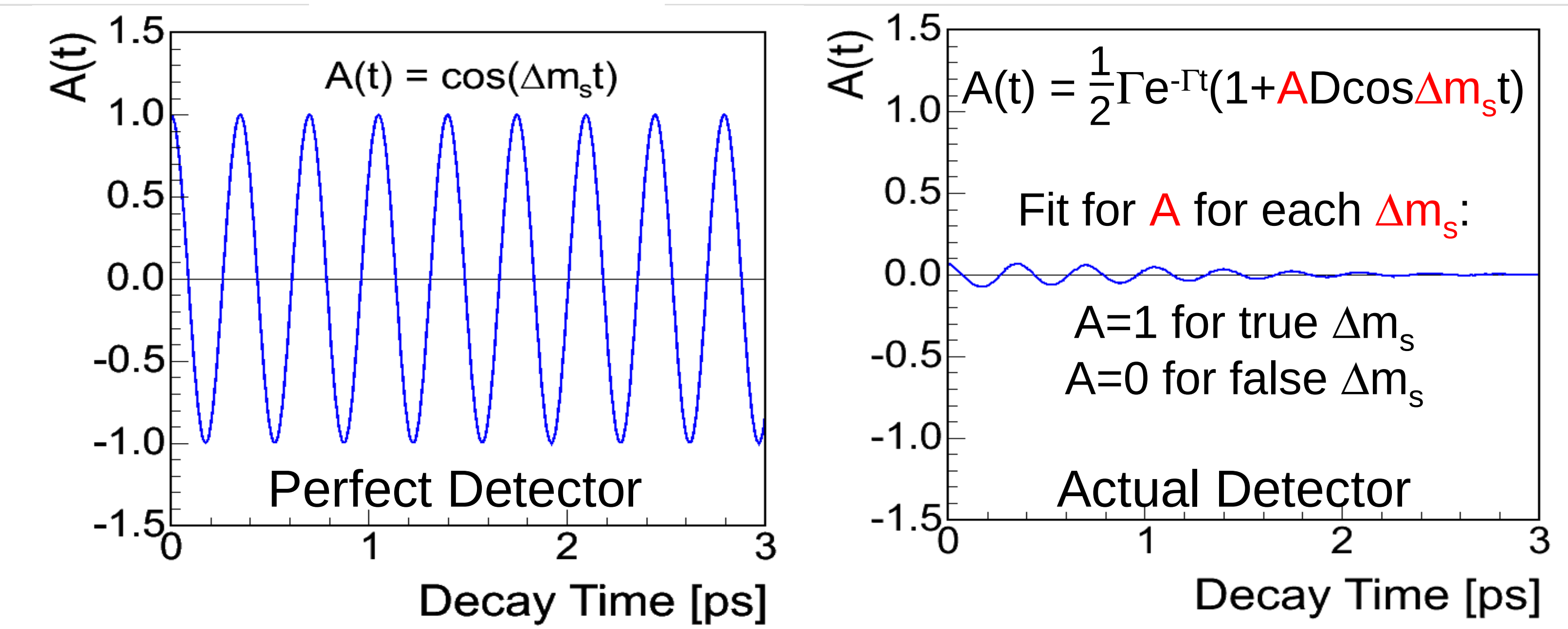
B_s Oscillation

- Probability that B_s at t=0 decays as $\overline{B}_s$ at time t

$$P(\text{mixed}) = \frac{1}{2\tau} e^{-\frac{t}{\tau}} (1 - \cos \Delta m_s t)$$

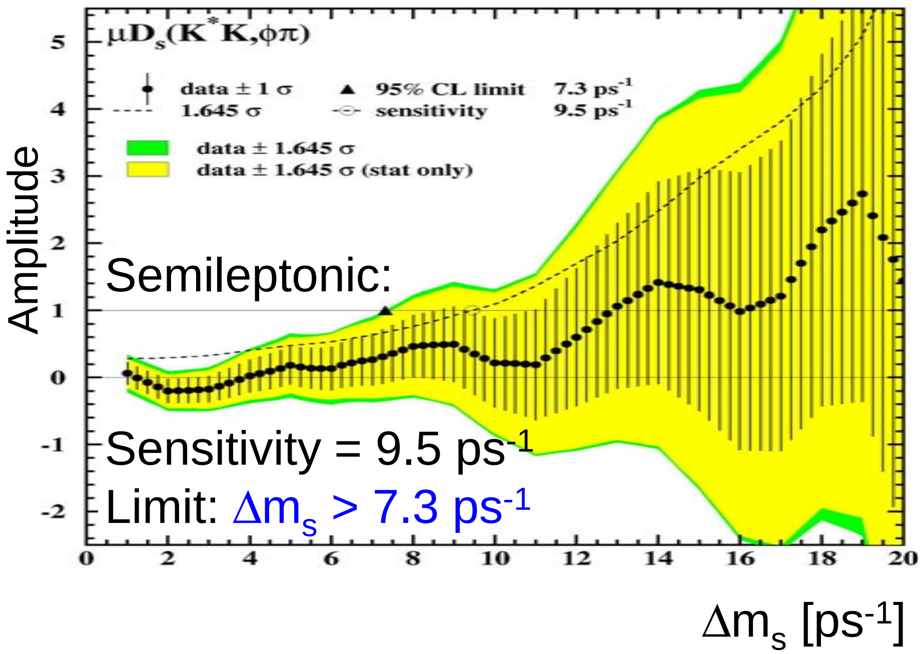
- Experimentally, measure Asymmetry as a function of proper decay time

$$A(t) = \frac{\#\text{unmixed}(t) \ - \ \#\text{mixed}(t)}{\#\text{unmixed}(t) \ + \ \#\text{mixed}(t)}$$

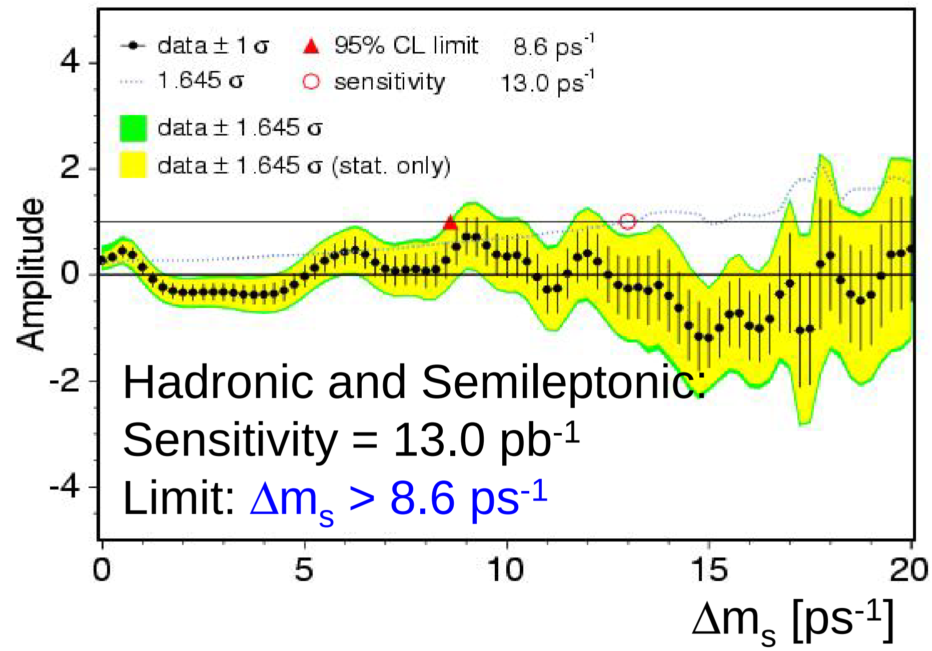


B_s Oscillation: Fall 2005

DØ Preliminary 610 pb^{-1}



CDF Preliminary 355 pb^{-1}

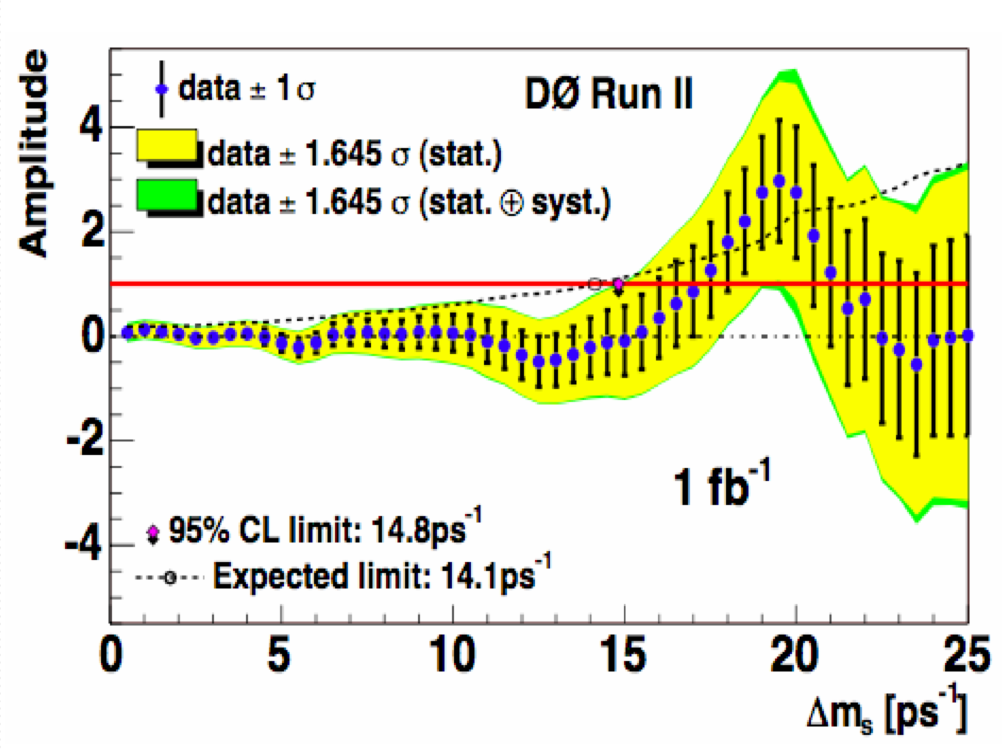


These results improved world limit
from $\Delta m_s > 14.5\ ps^{-1}$ to $\Delta m_s > 16.6\ ps^{-1}$ @95%CL.

Summer 2005 CKM Fit Result: $\Delta m_s = 18.3\ ^{+6.5}_{-1.5}\ ps^{-1}$

B_s Oscillation: DØ 1 fb^{-1} March 2006

- Two-side limits:
  - $17 < \Delta m_s < 21\ ps^{-1}$ at 90% CL
  - 8% probability random fluctuation would look like a signal

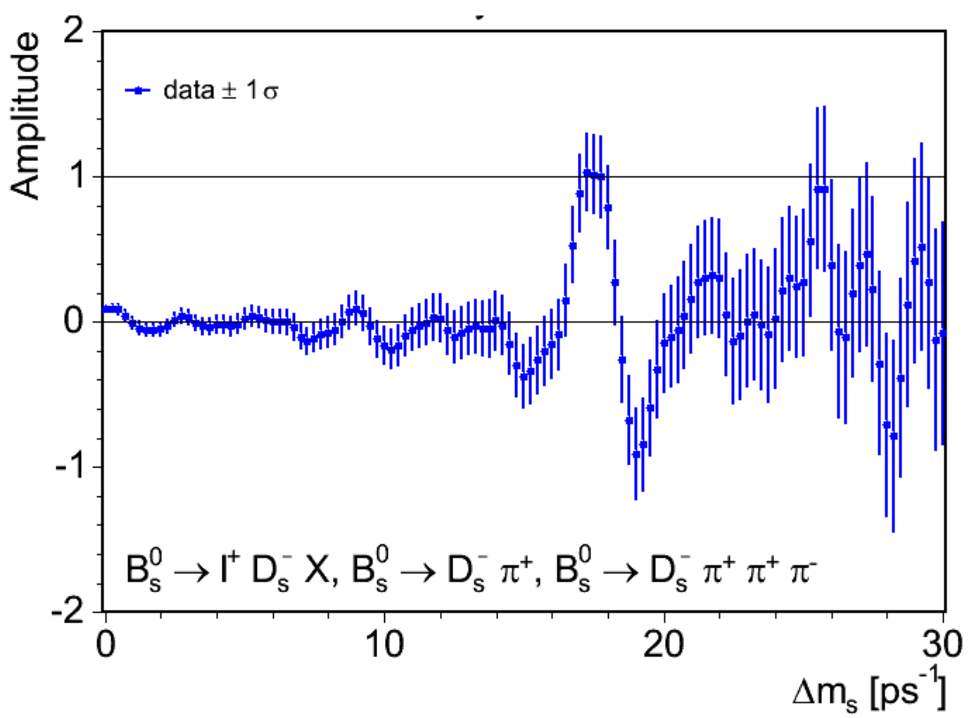


Lab Press Release on March 22:
What happened to the Antimatter? Fermilab's DØ Experiment Finds Clues in Quick-Change Meson.

PRL 97, 021802 (2006)
hep-ex/0603029

B_s Oscillation: CDF 1 fb^{-1} April 2006

- Evidence:
  - 0.2% probability (> 3σ) random fluctuation would look like a signal
  - $\Delta m_s = 17.31\ ^{+0.33}_{-0.18} \pm 0.07\ ps^{-1}$
  - $|V_{td} / V_{ts}| = 0.208\ ^{+0.001}_{-0.002}$ (expt.) $^{+0.008}_{-0.006}$ (theo.)

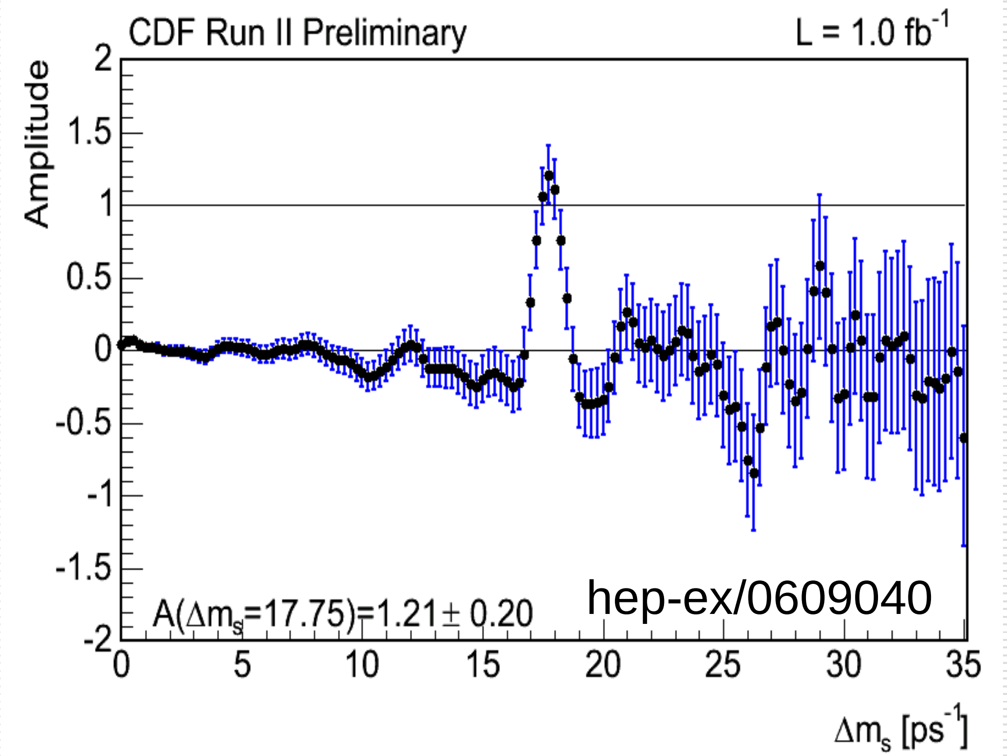


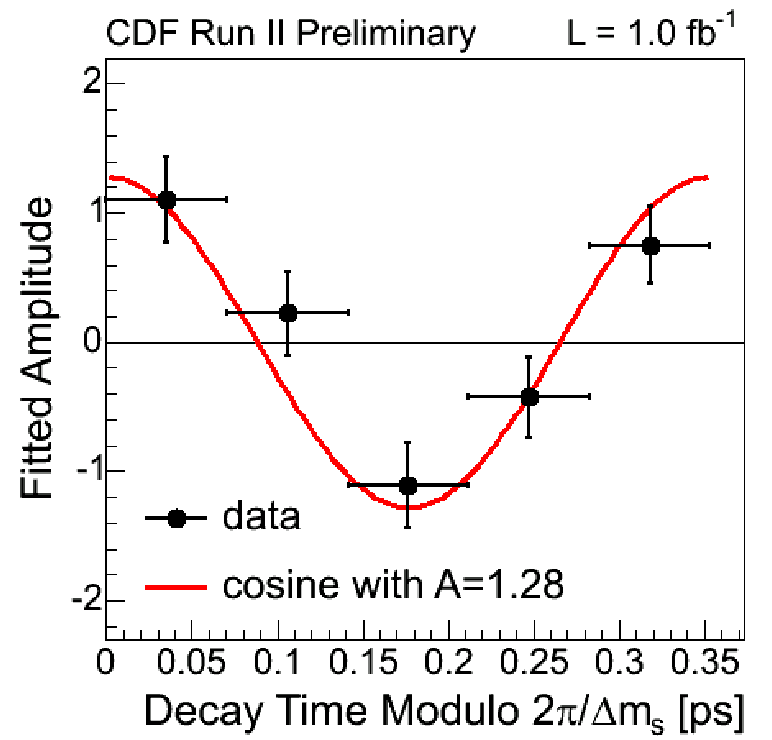
Lab Press Release on April 11:
Fermilab CDF scientists present a precision measurement of a subtle dance between matter and antimatter.

PRL 97, 062003 (2006)
hep-ex/0606027

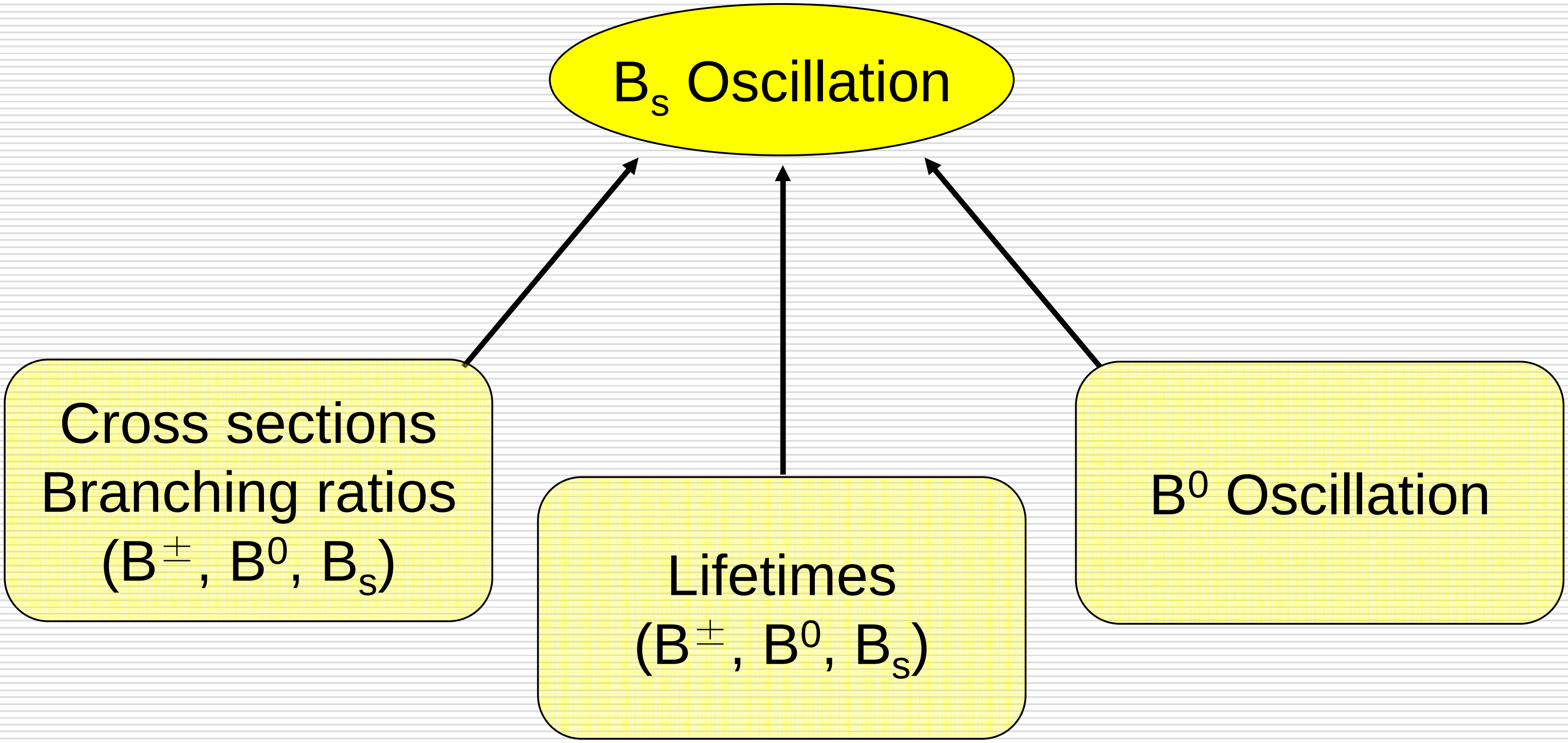
B_s Oscillation: CDF 1 fb^{-1} September 2006

- Observation: Reanalyzed the same dataset used for Evidence.
  - 8×10^{-8} probability (> 5σ) random fluctuation would look like a signal
  - Effective statistics a factor of 2.5: Evidence became Observation.
  - $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ ps^{-1}$
  - $|V_{td} / V_{ts}| = 0.2060 \pm 0.0007\ (expt.)\ ^{+0.0081}_{-0.0060}\ (theo.)$





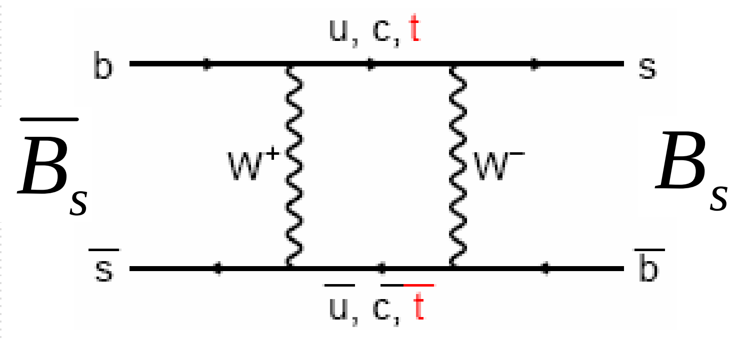
B_s Oscillation is not "ONE" analysis!



21 Ph.D.s in the course of the analysis

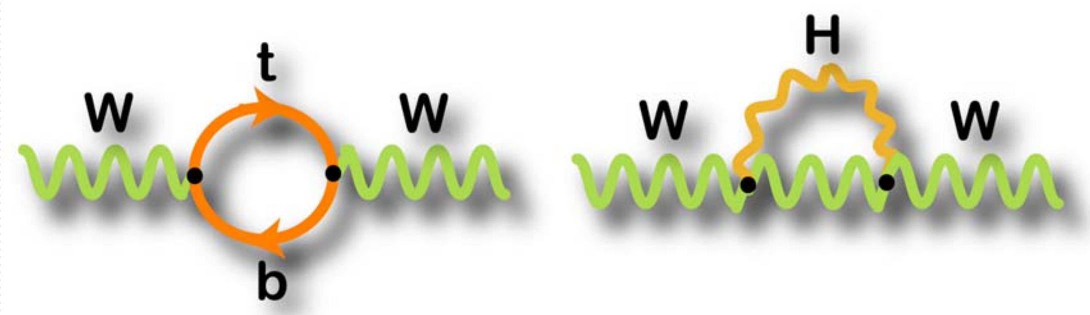
Constraining New Physics with B_s

- Measurements in B_s section constrain new physics.
  - B_s sector largely unexplored
- New physics can affect
  - $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ ps^{-1}$
  - $\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.03\ pb^{-1}$
  - $Br(B_s \rightarrow \mu\mu) < 1.0 \times 10^{-7}$
  - CP violation
    - CPV phase $\delta\phi = -0.79 \pm 0.56 \pm 0.01$
    - CPV parameter $Re(\varepsilon_b) / (1 + |\varepsilon_b|^2) = -1.1 \pm 1.0 \pm 0.7$
    - $A_{CP} (B_s \rightarrow K\pi) = + 0.39 \pm 0.15 \pm 0.08$
  - …
- e.g. SUSY: already puts stringent limits.
  - There is little room left for generic SUSY that produce large new flavor-changing effects.



Understanding the Origin of Mass

There might be something (Higgs) in the universe
that gives mass to particles.



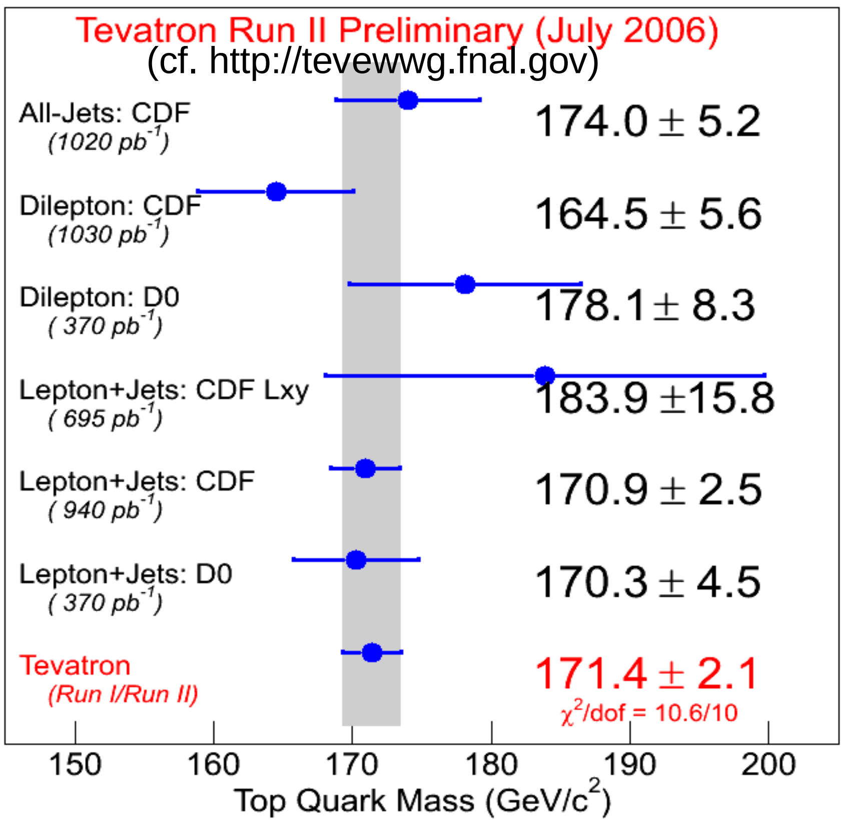
M_W - M_{top} - M_{Higgs} Relation:
M_W, M_{top} measurements predict M_{Higgs}.

M_{top} is an important input for new physics models.
e.g. MSSM:

$M_{Higgs} < M_Z$ at tree level, and
$M_{Higgs} <$ 135 GeV with top quantum corrections (M_{top}).

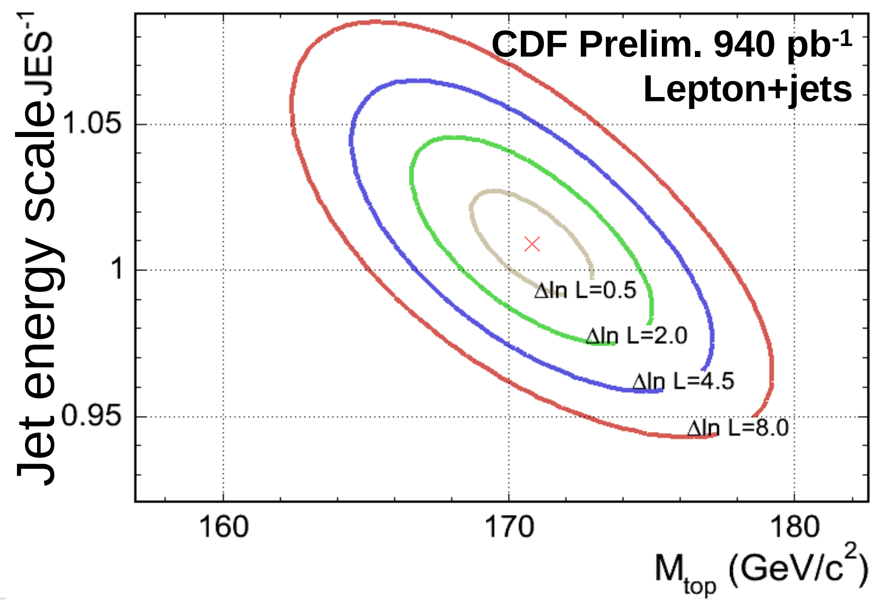
Top Quark Mass

- δM_{top} = 2.1 GeV (1.2%), L < 1fb^{-1}
  - δM_{top} (stat.) = ± 1.2 GeV
  - δM_{top} (Jet E) = ± 1.4 GeV
  - δM_{top} (syst.) = ± 1.0 GeV
- Surpassed 2 fb^{-1} Goal!
  - Results of improvements through creativity, boldness
  - e.g.: Jet Energy Scale
    - 3 GeV → 1.4 GeV



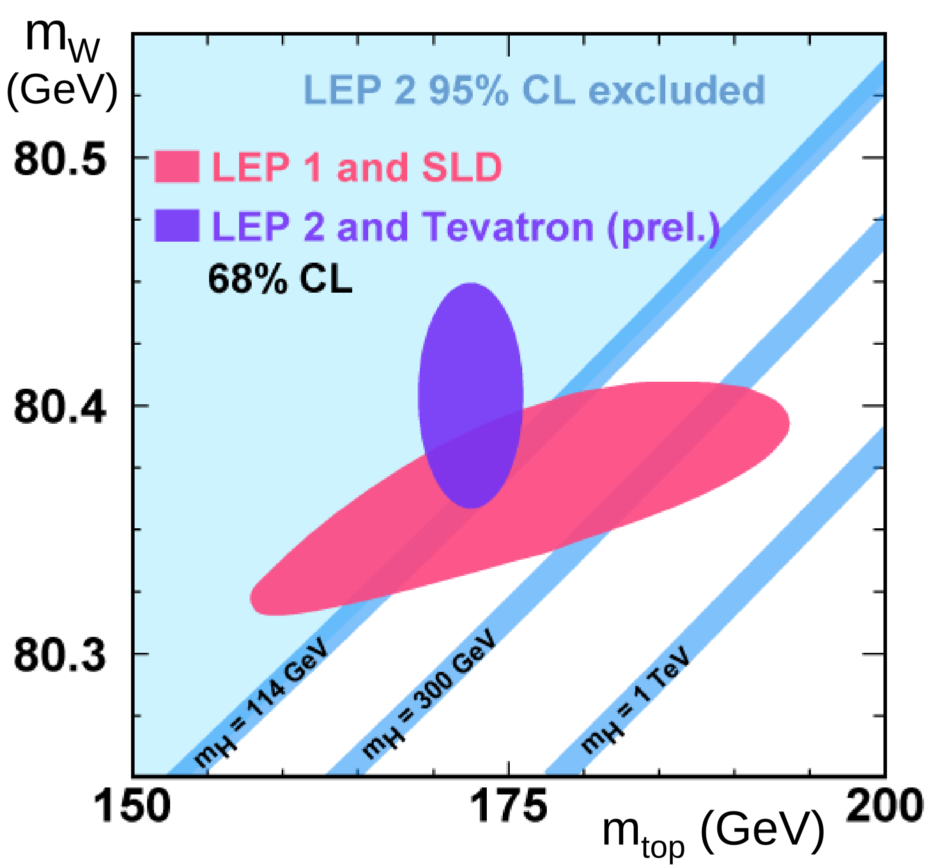
$t \to W^+ b \to e/\mu\ \nu$ b-jet

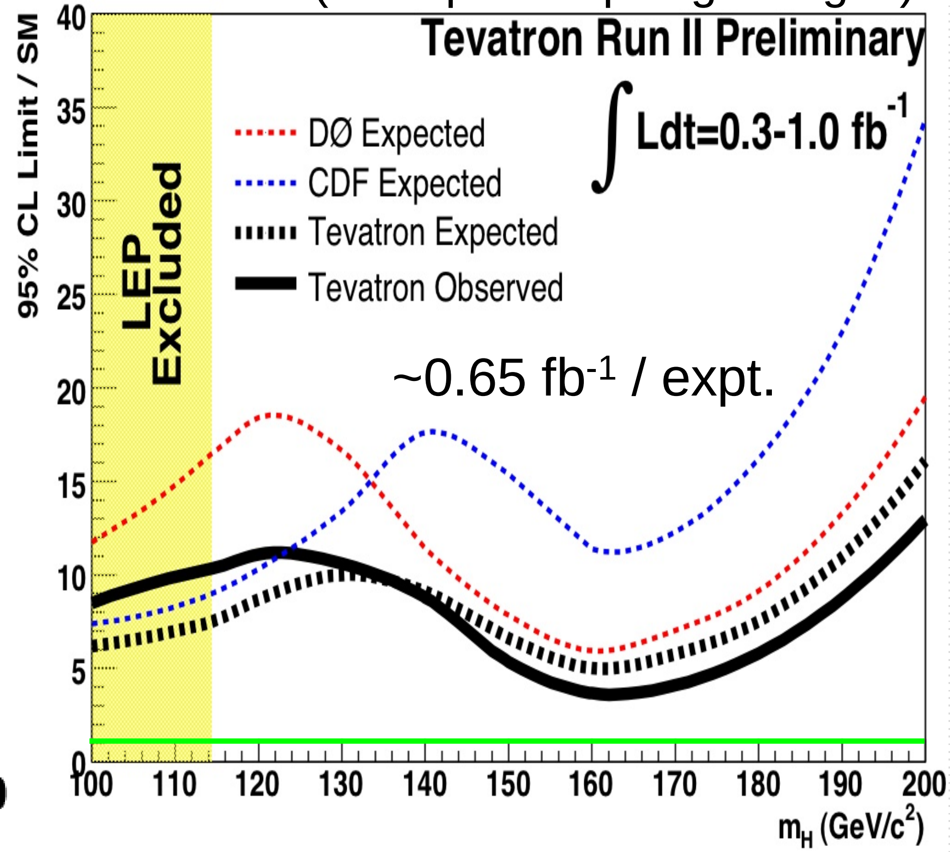
$\bar{t} \to W^- \bar{b} \to$ jet jet b-jet



Top Quark Mass and Higgs Searches

(cf. http://tevnphwg.fnal.gov)





Indicates Higgs is light
(M_{higgs} < 166 GeV at 95% CL)
Where Tevatron sensitivity is best!

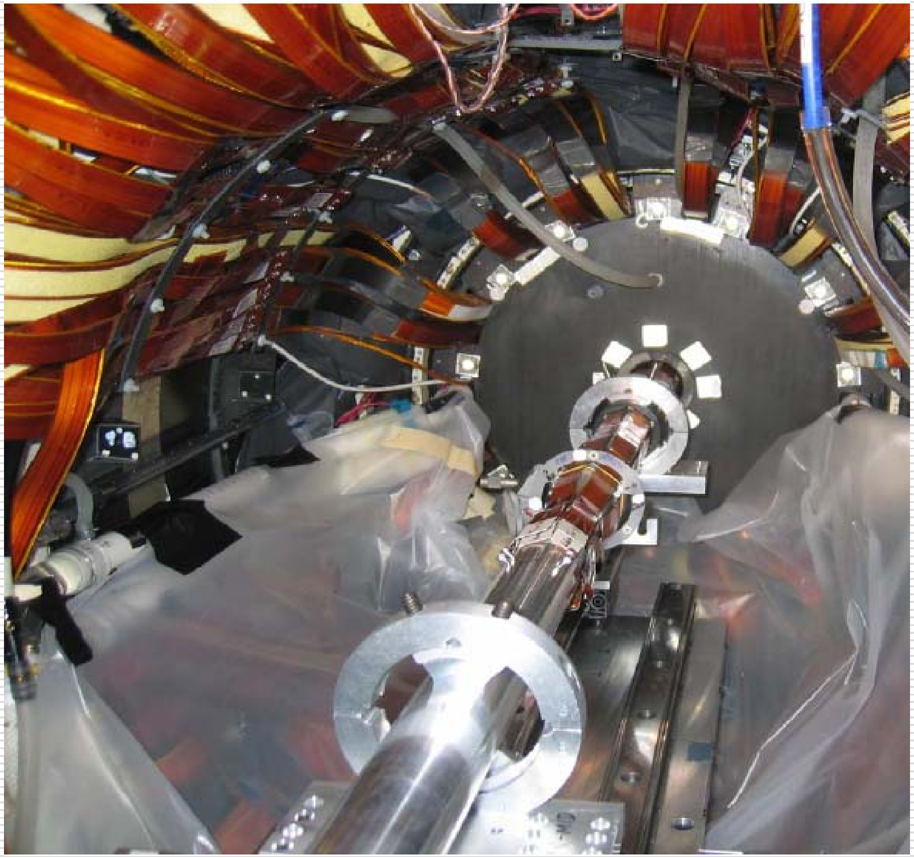
~15 CDF + DØ Results combined.
SM Sensitivity within a factor of
5-10 for 110 < M_{higgs} < 200 GeV

Shutdown: March - Mid June, 2006

- Completion of Run IIb Detector Upgrades!
  - DØ Layer-0 Silicon (new)
  - DØ Level-1 Calorimeter and Tracking Trigger Upgrades
  - CDF Level-1 Tracking Trigger Upgrade

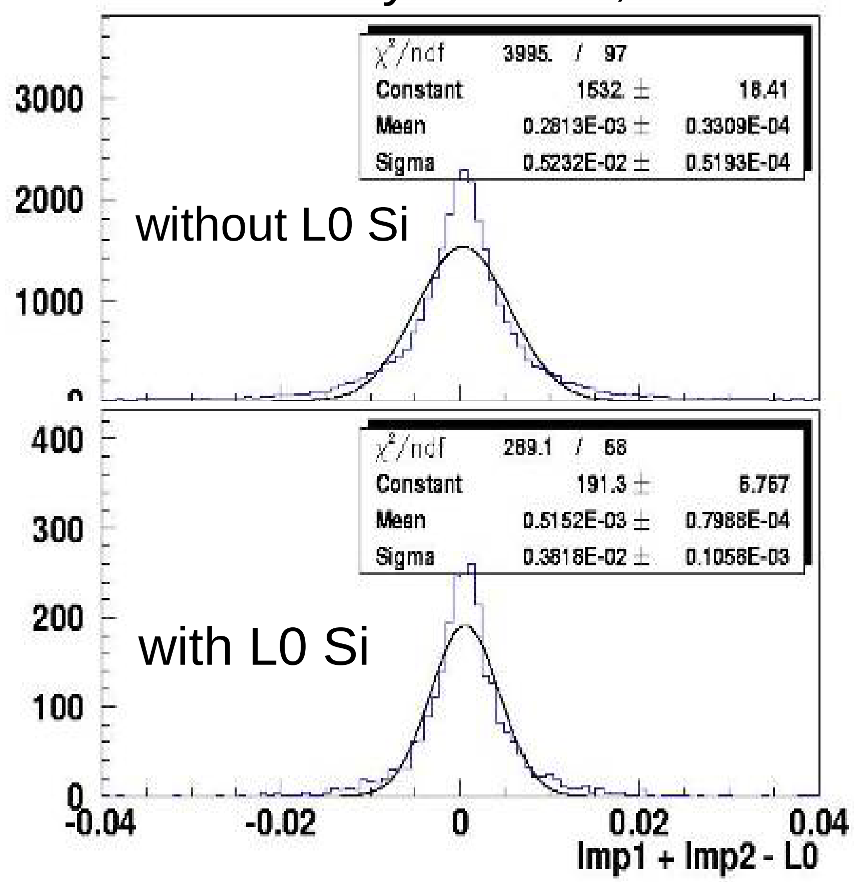
- Accelerator Improvements and Maintenance
  - Booster: rebuilt booster injection system
  - Main injector: installed large aperture quadruples at injection and extraction points
  - Tevatron: new separators, better magnet alignment
  - More protons
  - Antiprotons with less emittances
  - Longer collision lifetime

DØ Layer-0 Silicon Installed!



All went extremely well!

Cosmic ray June 18, 2006

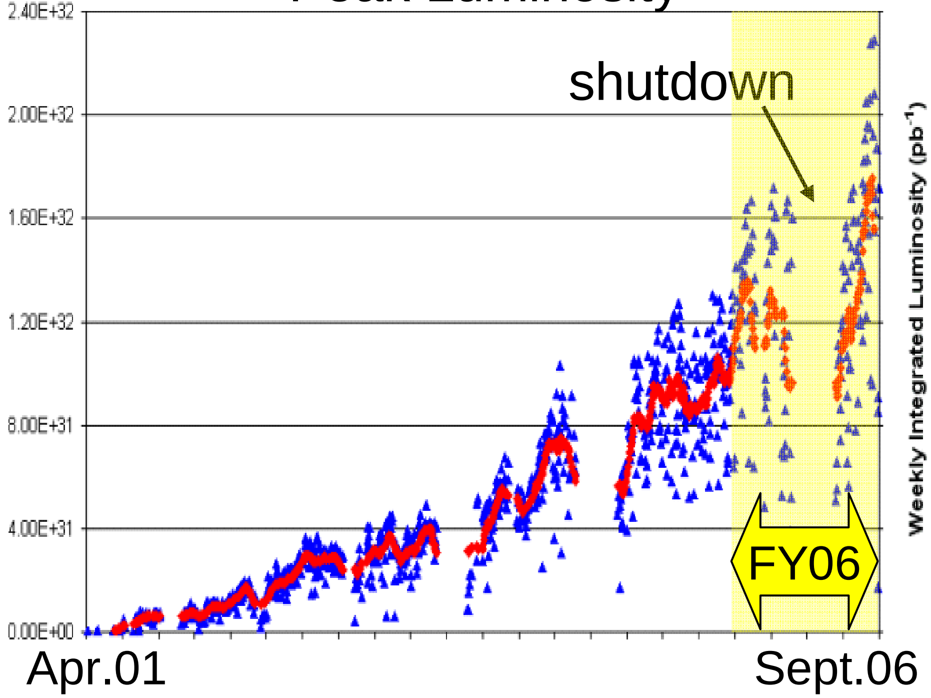


~30% Improvement!
even before final alignment

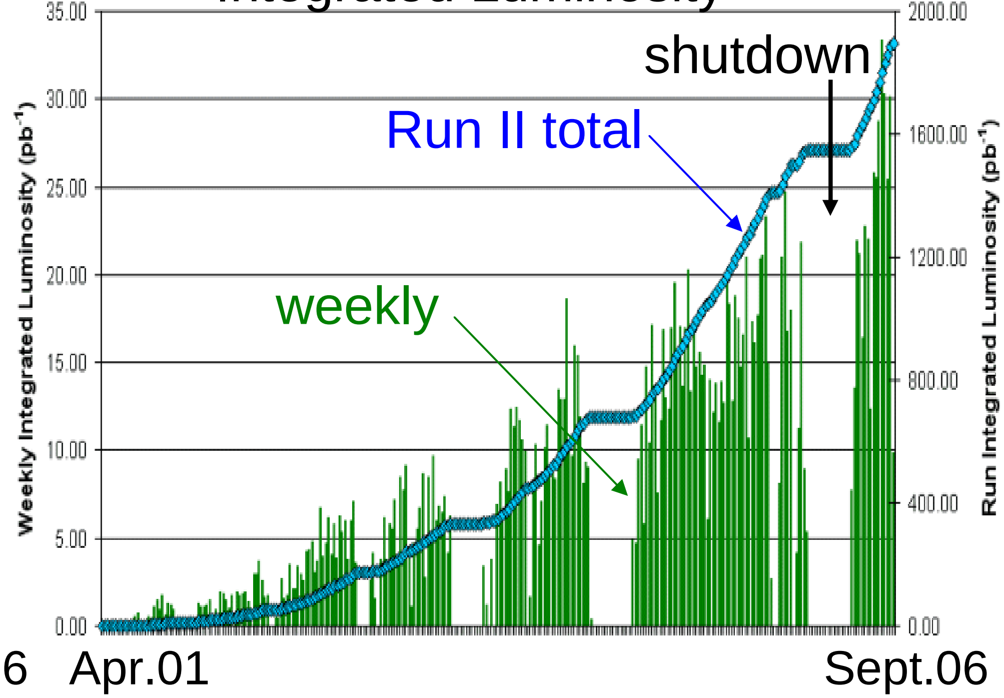
Expect 15% gain in b-tagging efficiency

Tevatron performs extremely well!

Peak Luminosity

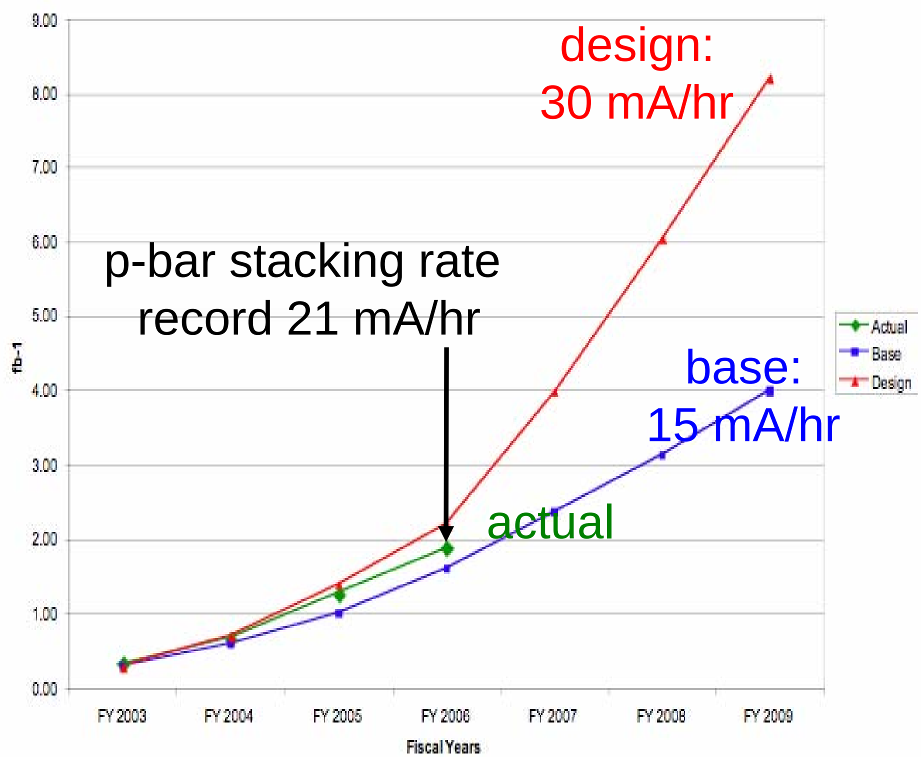


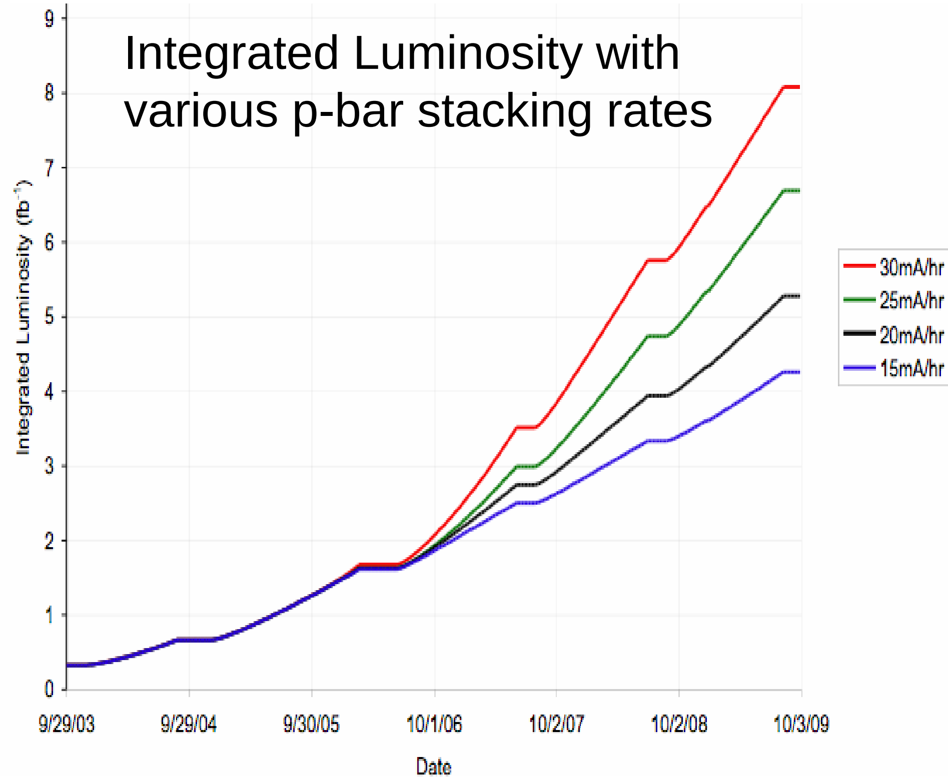
Integrated Luminosity



- Peak luminosity record: 2.3×10^{32} cm^{-2} s^{-1}
- Weekly Integrated luminosity record: 33 pb^{-1} / week / expt
- total delivered: 1.8 fb^{-1} / expt, total recorded: 1.5 fb^{-1} / expt
- Doubling time: ~1 year
- FY06: 620 pb^{-1} (664 pb^{-1} with final corrections)

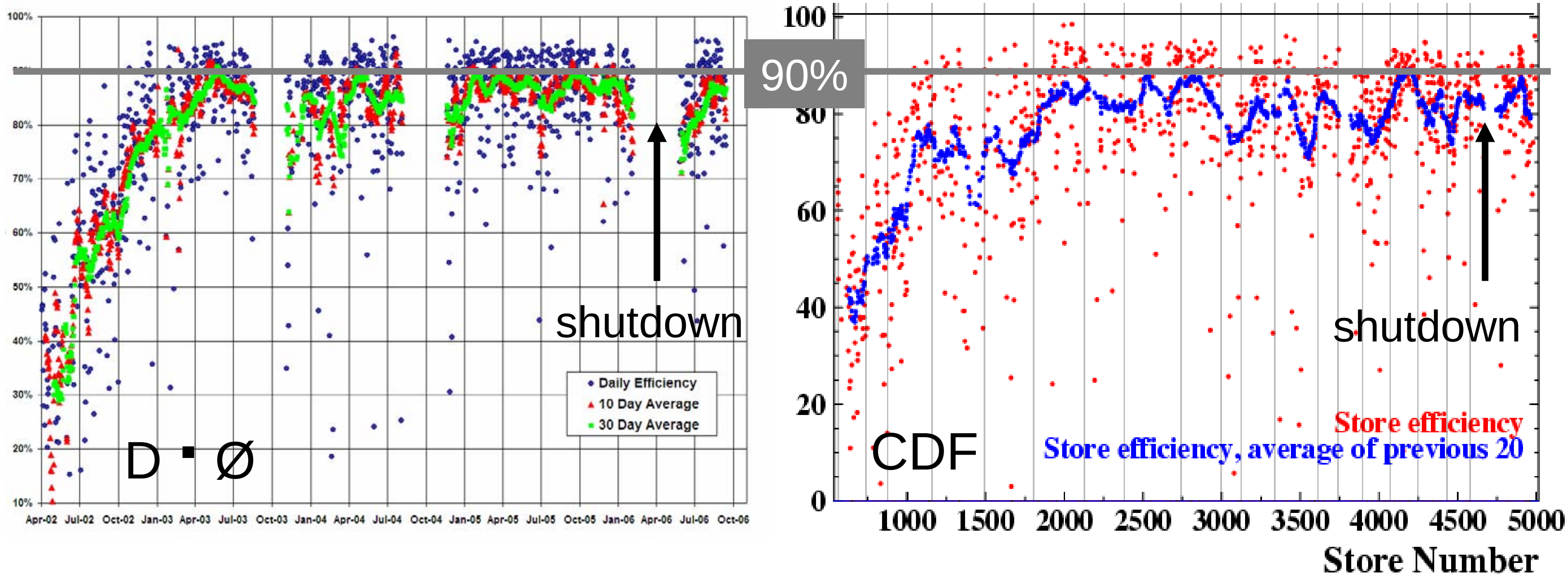
Tevatron Luminosity Projection





- Given the current p-bar stacking rate, doing better than expected
  - Results of many people's hard work
- Primary goal now is to reach 30 mA/hr

Data Taking Efficiencies



- Challenges with rapidly improving instantaneous luminosity
  - Over 100 trigger paths per each experiment - richness of physics
  - Trigger rates increase much faster than inst. luminosity.
  - Not all of them can be estimated reliably by Monte Carlo.
  - Re-optimize triggers with real data

Tevatron Accomplishments and Prospects

Tevatron Accelerator and DØ and CDF Experiments have been performing well. Better than ever!

- We are confident that we will get 8 fb^{-1}!
- B_s oscillation observed
  - $\delta(\Delta m_s^{Tevatron}) = 0.1 \times \delta(\Delta m_s^{theory})$
- Top and W mass
  - $\delta M_{top} = 2.1$ GeV - with <1 fb^{-1}, surpassed 2 fb^{-1} goal
  - Reaching $\delta M_{top} = 1\text{-}1.5$ GeV, $\delta M_W = 20\text{-}30$ MeV is critical!
- We are now measuring processes with a few pb's.
  - $\sigma_{WZ} = 3.98\ ^{+1.91}_{-1.53}$ ps
  - Close to low mass SUSY cross sections
  - An important stepping stone for the Higgs search
- What is the next biggest challenge?

Tevatron Sensitivity to Higgs

- Primary goal is to reach SM Higgs sensitivity.
  - Improvements
    - Statistics (so far 0.65 fb^{-1} / expt on average)
    - Triggers, Acceptance, Efficiency, Jet Resolutions, Analysis techniques, …
  - Complex and challenging
    - even more than B_s oscillation and M_{top}
    - Many final states, Small cross sections, large backgrounds
  - Many other high profile analyses will benefit from this.
    - Examples:
      - "Single top observation"
        - another important stepping stone towards Higgs
      - Low mass SUSY searches

- Achievable by coordinated effort, focus, and determination as demonstrated in success in B_s oscillation, M_{top} ...

Our Goal:

be prepared…

Then let Nature decide
whether we see the Higgs or see a hint of it!

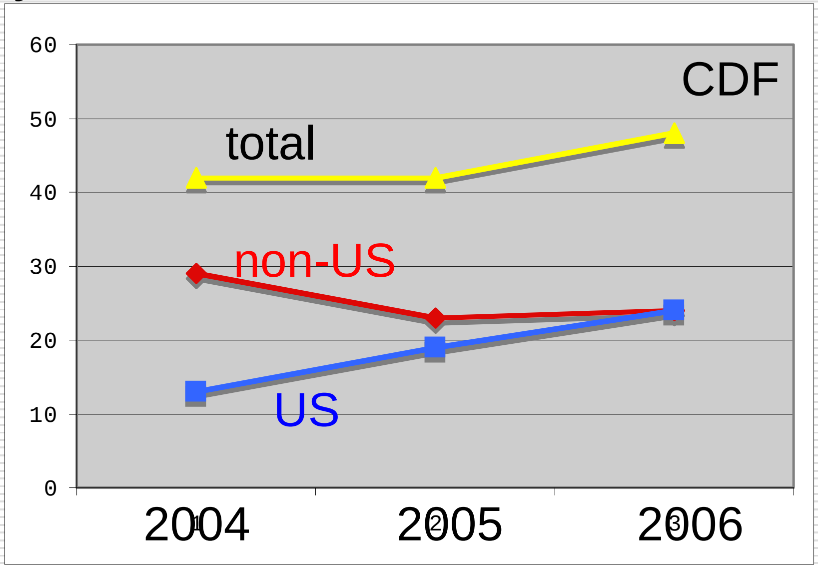
Concerns: Physicist Resources

- Progress made from CDF and DØ Collaborations
  - Stream-lined operations
  - Adopting common solutions in computing
  - Focusing on “high impact” physics analyses
- Progress made from Fermilab
  - Visitors budget: ~12% increase for DØ
  - Added 4 postdoc positions (2 to CDF, 2 to DØ)
  - Initiated International Fellowship Program
    - 2 to CDF, 2 to DØ (1 student from UK, 1 postdoc from Mexico, 2 faculty members from China and Cyprus)
  - Slowed down physicists transition from the Tevatron to the CMS
  - Provided further Fermilab staff support to the DØ operations
  - Inviting theorists to Fermilab, sponsoring mini workshops

- Current “Concerns”: loosing detector/offline experts (university groups)
  - Modest help from funding agencies could make a big difference
    - Supporting Ph.D. students
    - Supporting key personal (experts) from university groups

Participation of New Students

- Survey on new students in this coming year
  - CDF: 45 out of 55 universities responded



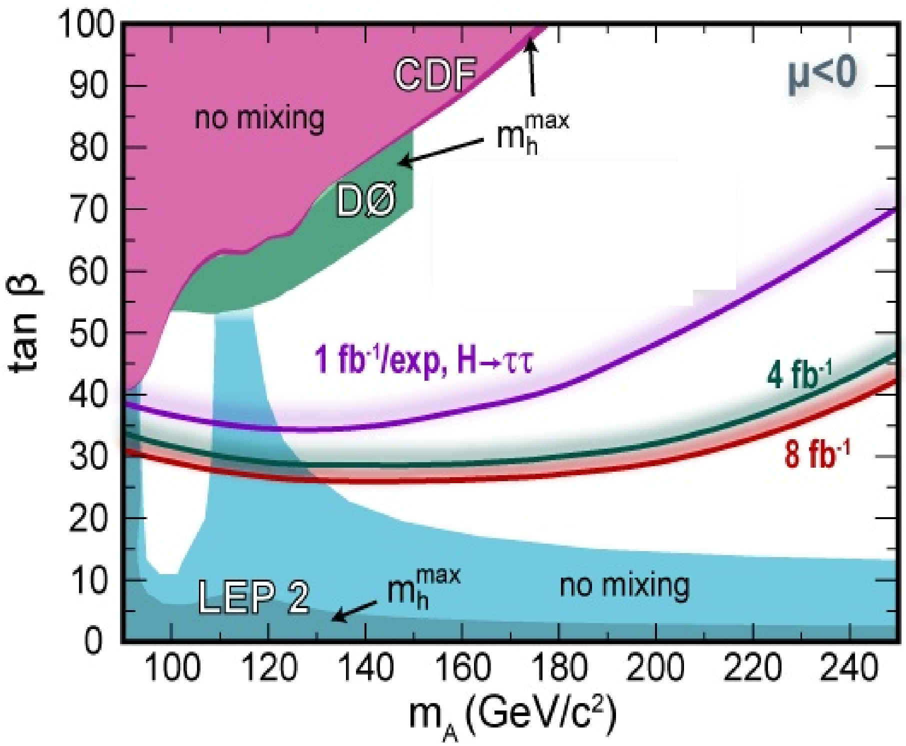
  - DØ: 49 out of ~85 institutions responded
    - New Students = 30^{+2}_{-5}, New U.S. Students = 15 ± 2
- More than 80 new Ph.D. Students
- Tevatron is a great place for Ph.D. students
  - Excellent physics
  - Educating and training - analyses, hands-on operational experience.
- A few new institutions joining the Tevatron experiments.

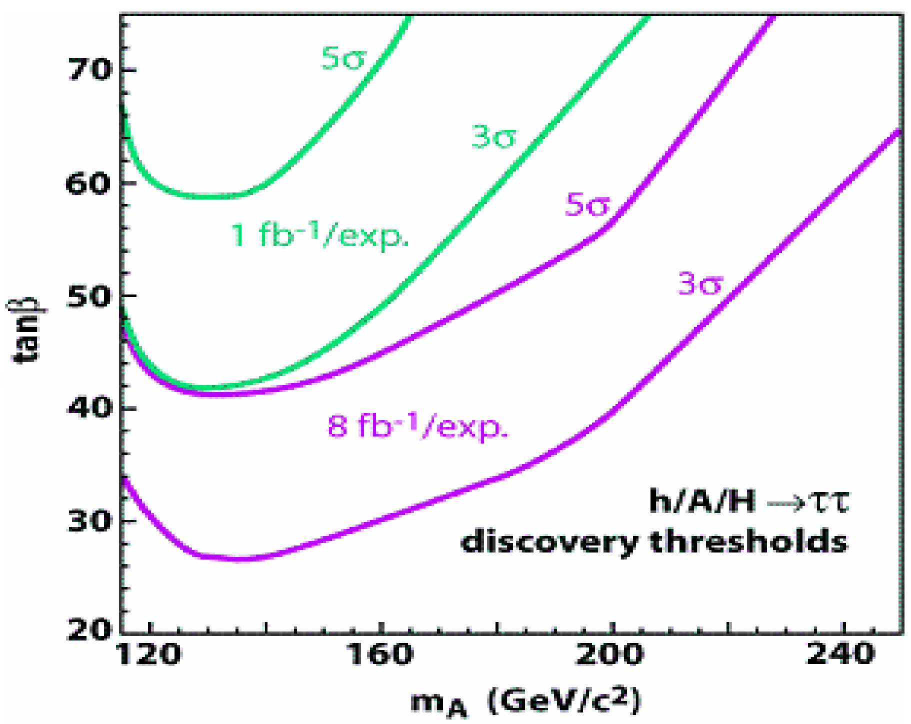
Backup Slides

Tevatron Lum Progress since the Shutdown

- More protons
  - New 150 GeV helix
    - Less proton loss during p-bar loading
    - Improved proton lifetime
  - New booster injection system and removal of L13 extraction system
    - Booster performance is better
  - 5-10% more protons in collision
- Antiprotons with low emittances
  - Accumulator to Recycler transfers shortened significantly (45’→ 25’)
    - 5-10% higher stacking rate
  - Changed recycler tune point
    - Transverse emittances in Recycler is preserved better.
    - 5-10% higher luminosity per antiproton
- Improved luminosity lifetime
  - 10% higher integrated luminosity for the same initial luminosity.

MSSM Higgs Sensitivities





Tevatron will have sensitivity to MSSM Higgs
for all tanβ > 30 and M_A < 200 GeV/c^2