Fermilab Users' Meeting

June 12, 2012

Top and flavor physics at the Tevatron

- b-physics recent results
  - Λ_b studies
  - $B_s \rightarrow \mu\mu$
  - $B_s \rightarrow J/\psi\ f_2'(1525) \rightarrow \mu^+\mu^-K^+K^-$
  - CP violating B_s mixing phase in $J/\psi\phi$ decays
- Top physics recent results
  - Top mass and Δm_t
  - Evidence for spin correlations
  - Top charge asymmetry
  - Single top cross sections, top width
- Conclusions

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On behalf of CDF and DØ

b/t results since last year

CDF b-physics

- Observation of Ξ_b^0
- FCNC and angular observables in B→K(*)μμ
- Measurement of B_c lifetime in $B_c \to J/\psi\pi$
- First 3d measurement of ϒ(nS) spin alignment
- Measurement of $B_s \to \mu\mu$ decay BFs and asymmetries
- Measurement of B($\Lambda_b \to \Lambda_c \pi\pi\pi$)
- Search for CP violation in $D^0 \to K_S \pi+\pi-$
- Fragmentation study of D_s^+/D^+ and K correlations
- Measurement of $B_s \to D_s^{(*)} D_s^{(*)}$ branching fractions
- Measurement of $B_s \to J/\psi\phi$ CP violating phase
- Measurement of ΔA_{CP} between $D^0 \to KK$ and $D^0 \to \pi\pi$
- Measurement of $(f_s/f_d)*Br(B_s \to J/\psi\phi)$

CDF top physics

- Charge asymmetry A_{FB} in ℓ+jets
- Spin correlation coefficient
- Combined charged asymmetry
- W helicity from cosθ*
- Cross section and Mt in τ_{had}+jets
- Cross section combination
- Template Mtop with insitu JES calibration
- ME Mtop with insitu JES calibration
- Mass difference
- Dilepton mass using Daliz-Goldstein
- Singletop and |Vtb|
- Z' search in ttj
- Dark matter and singletop
- t' in MET+jets
- Tevatron m_t combination

D0 top physics

- Top quark mass in dilepton channel
- Combination of searches for anomalous top quark couplings with 5.4 fb^{-1}
- Search for violation of Lorentz invariance
- Improved determination of the top width
- CDF and DØ measurements of the W helicity
- Search for a narrow tt resonance
- Evidence for spin correlation in tt production
- Search for anomalous Wtb couplings
- Forward-Backward asymmetry
- Single top quark cross sections and |Vtb|
- Model-independent measurement of t-channel
- Cross section using dilepton events

D0 b-physics publications

- Study of $B_s^0 \to J/\psi f_2'(1525)$ in $\mu^+\mu^-K^+K^-$
- Observation of a narrow state decaying into Υ(1S) + γ
- Measurement of the Λ_b^0 lifetime in the exclusive decay $\Lambda_b^0 \to J/\psi\Lambda^0$
- Measurement of the CP-violating phase $\varphi_s^{J/\psi\varphi}$ in $B_s^0 \to J/\psi\varphi$ in 8 fb^{-1}
- Measurement of the relative branching ratio of $B_s^0 \to J/\psi f_0(980)$ to $B_s^0 \to J/\psi\varphi$

Flavor physics

Motivation:

- Why the huge matter-antimatter asymmetry in the Universe?
- Understand QCD: production, masses, lifetimes, decays
- Determine flavor structure: CKM matrix, CP violation, FCNC's
- Search for new physics

Why at the Tevatron?

- Produce heavier states not accessible at b-factories (now also at LHC)

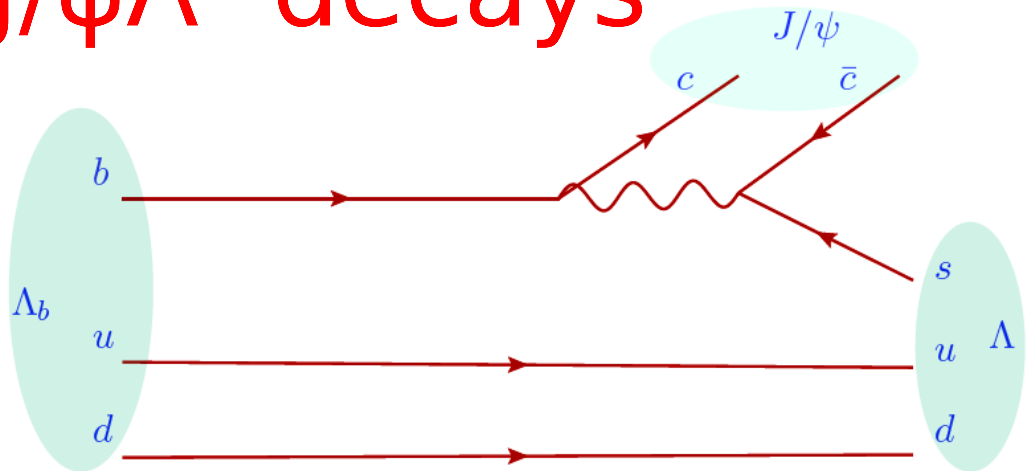
$\bar{b}s$	$\bar{b}c$	bud	buu	bsd	bss
$\mathbf{B_s}$	$\mathbf{B_c}$	$\mathbf{\Lambda_b}$	$\mathbf{\Sigma_b}$	$\mathbf{\Xi_b}$	$\mathbf{\Omega_b}$

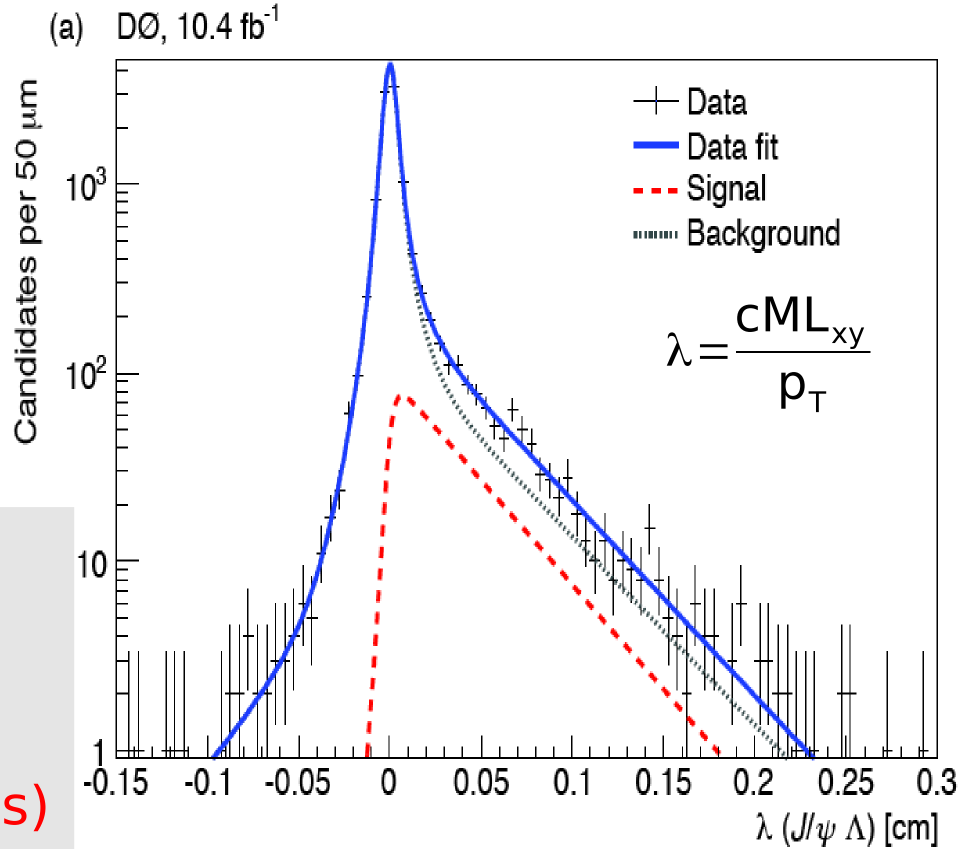
- Complementary to b-factories $\Upsilon(4S)$
- Huge production rate: rare decays, precision measurements
  - Can compete with b-factories in some B_d^0 and B^+ decays

$\bar{b}d$	$\bar{b}u$
$\mathbf{B_d^0}$	$\mathbf{B^+}$

Λ_b^0 lifetime in $J/\psi\Lambda^0$ decays

- Measurements of b-hadron lifetimes help determine the importance from non-spectator contributions in the decay
- Experimental resolution similar to theory calculations in $\tau(\Lambda_b)/\tau(B_d)$
- Method tested in $B_d \rightarrow J/\psi K_s$ decays
- Reconstruct J/ψ and two tracks with significant IP forming a good vertex (Λ or K_s candidate)
- Parametrize signal and background and fit M, proper decay length, and its error





$\tau(\Lambda_b)$ = 1.30 ± 0.08(stat) ± 0.04(sys) ps

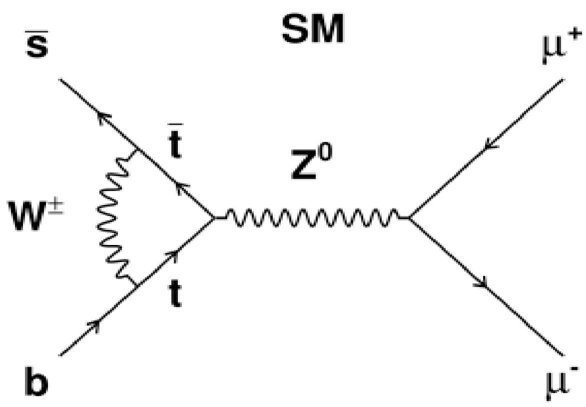
consistent with W.A. (1.45 ± 0.03) ps

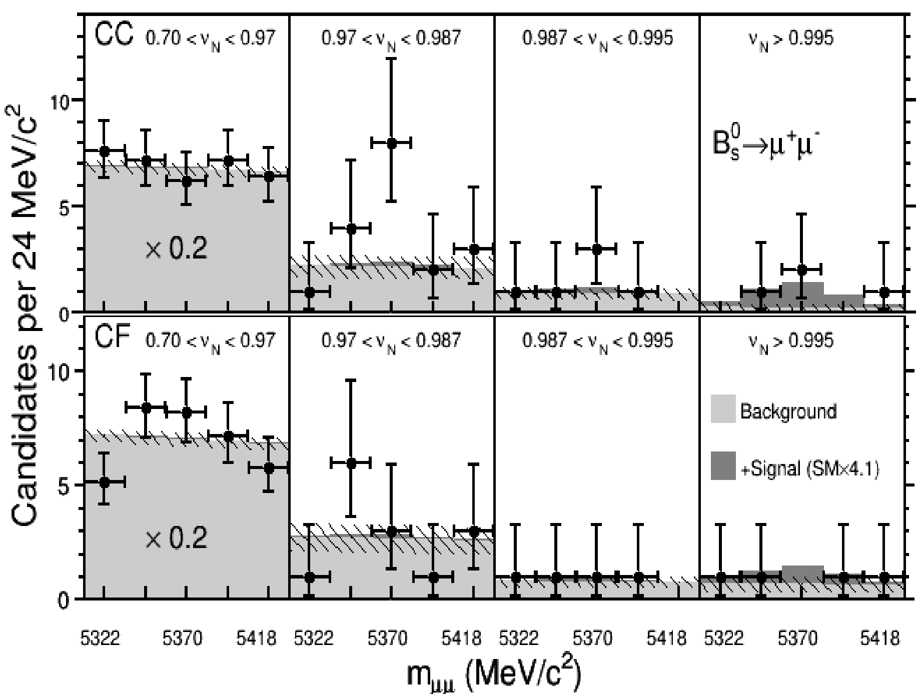
$\tau(B_d)$ = 1.51 ± 0.03(stat) ± 0.04(sys) ps

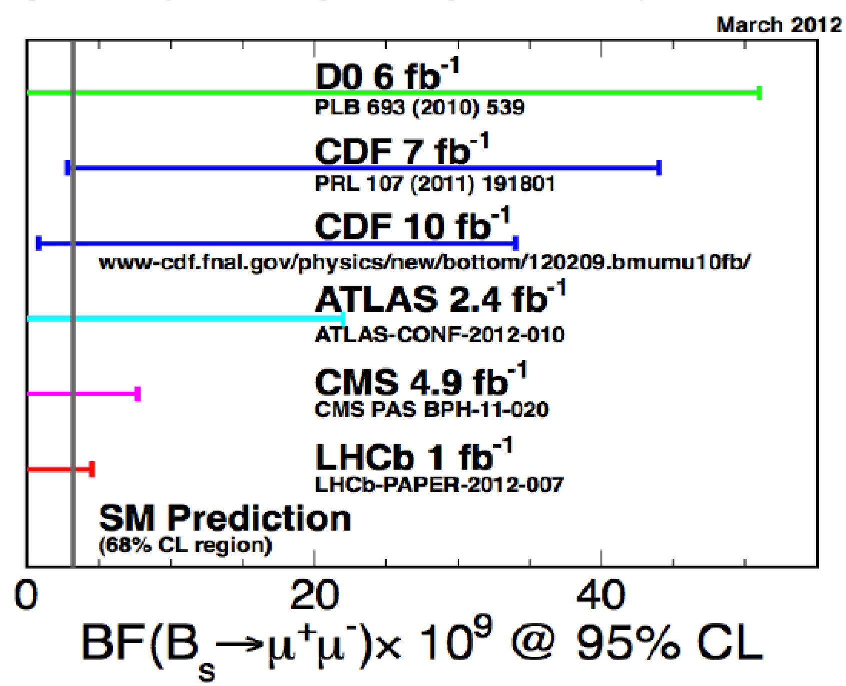
$\tau(\Lambda_b)/\tau(B_d)$ = 0.86 ± 0.05(stat) ± 0.03(sys)

$B_s \to \mu\mu$

- This decay is highly suppressed in the SM
  $BR(B_s^0 \to \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$; $BR(B^0 \to \mu\mu) = (1.0 \pm 0.1) \times 10^{-10}$
- Golden channel for FCNC and NP
- CDF uses full dataset (same analysis as 7 fb^{-1})
  - Need to reject 10^6 larger background
  - Use Neural Network with 14 variables
  - Combinatorial background from mass sidebands



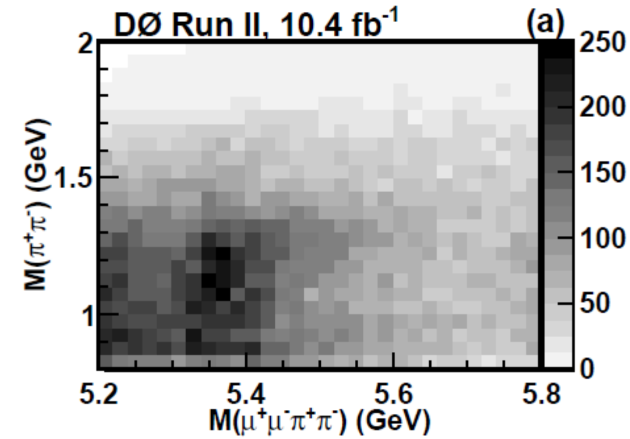


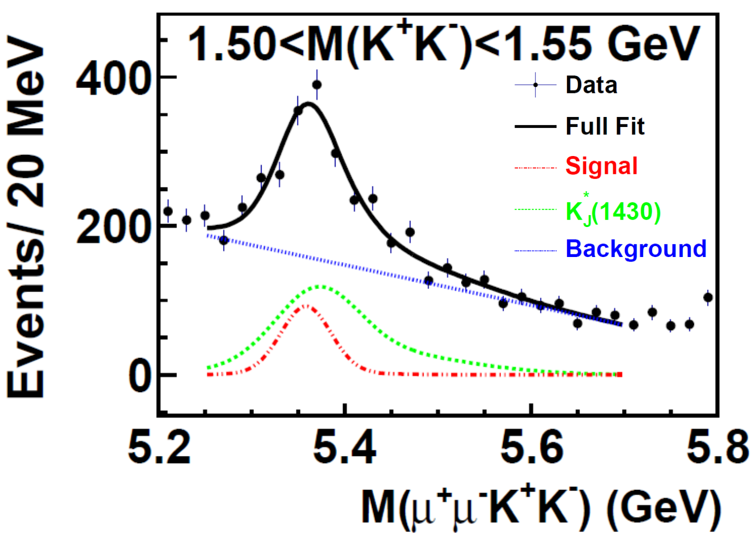


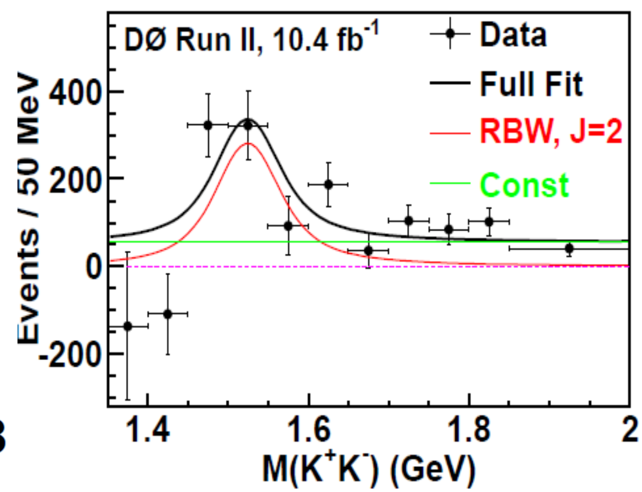
$0.8 \times 10^{-9} < BR(B_s^0 \to \mu\mu) < 3.4 \times 10^{-8}$ @ 95% CL [still >2σ over background]

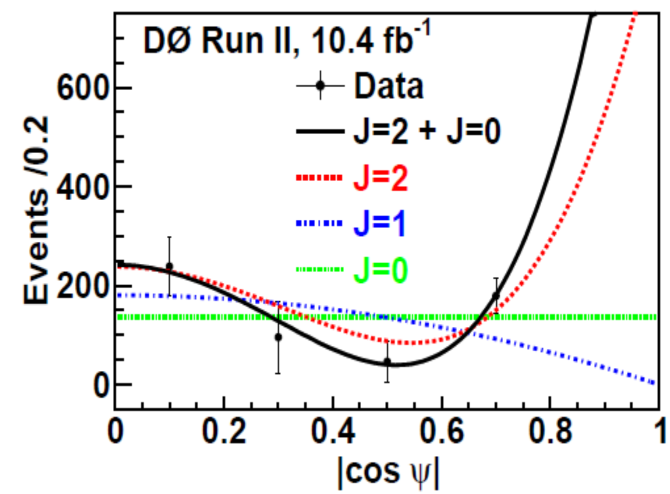
Study of $B_s \to J/\psi\ f_2'(1525) \to \mu^+\mu^- K^+K^-$

- Confirmed observation by LHCb
- $f_2'(1525)$ and not $f_0(1500)$, which decays predominantly to $\pi\pi$
- Main bkgd:
  - $B_d^0 \to J/\psi\ K_2^*(1430)$ or $K_0^*(1430)$, combinatorial
- Can fit total yield with signal+constant S-wave
  - 669 ± 158 $f_2'(1525)$ candidates









$BR[B_s \to J/\psi\ f_2'(1525)] / BR[B_s \to J/\psi\phi] = 0.22 \pm 0.05(stat) \pm 0.04(sys)$

Spin of KK resonance is consistent with J=2 (and a coherent admixture of J=0). Inconsitent with pure J=0 or J=1.

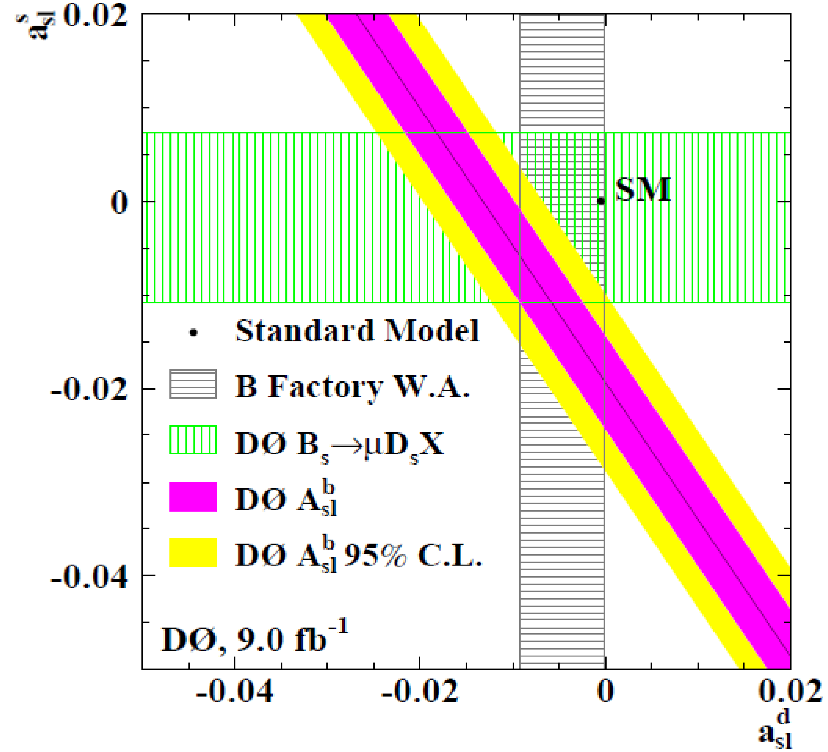
CP violating B_s mixing phase

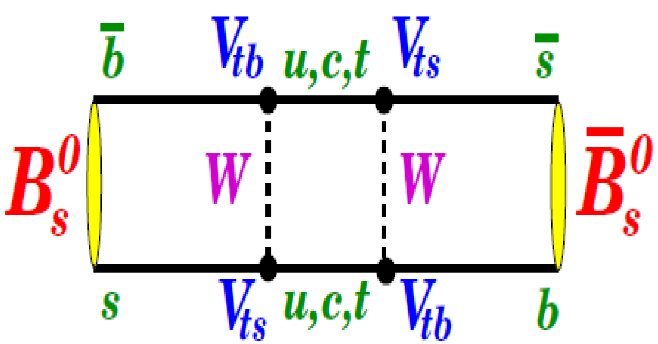
- DØ measures deviation in semileptonic b asymmetry (A_{sl}^{b}): 3.9σ away from SM
- Important to cross check independently

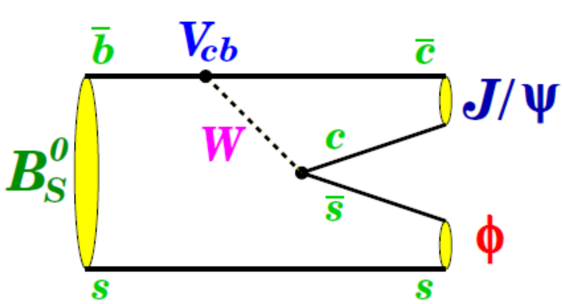
$$a_{sl}^{s} \equiv \frac{N(\bar{B}_s \to f) - N(B_s \to \bar{f})}{N(\bar{B}_s \to f) + N(B_s \to \bar{f})}$$

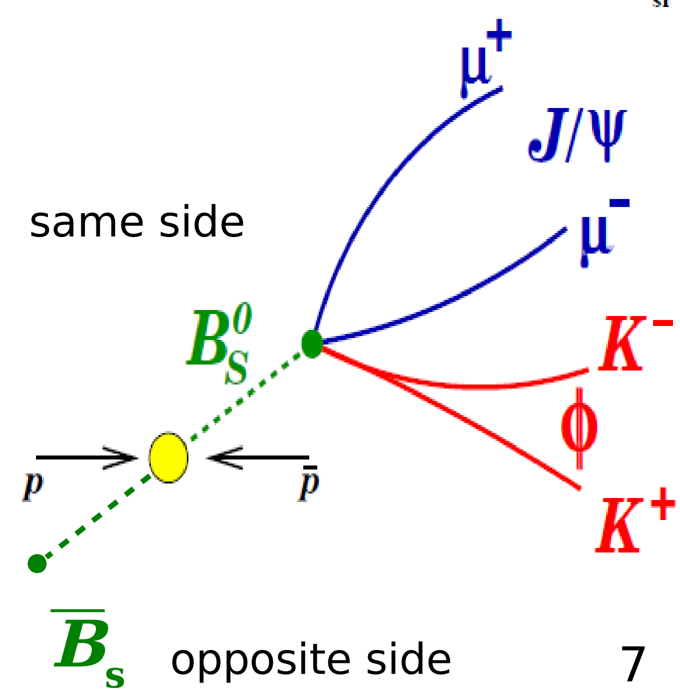
$$a_{sl}^{s} \approx \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$

- Interference in $B_s \to J/\psi\phi$ decay with or without B_s-$\bar{B}_s$ oscillation gives rise to CP violating phase ϕ_s (~0 in SM)
- Very sensitive channel to NP in B_s decay



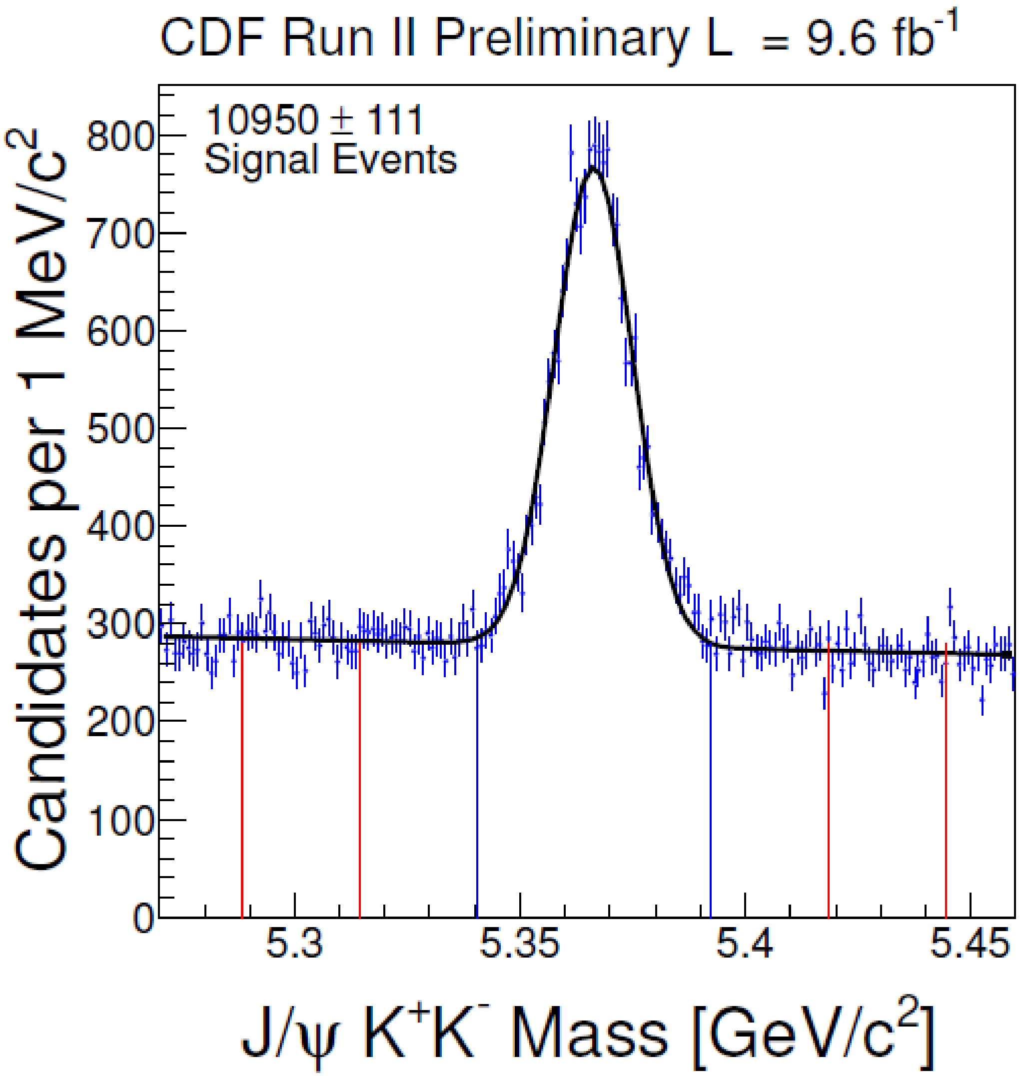


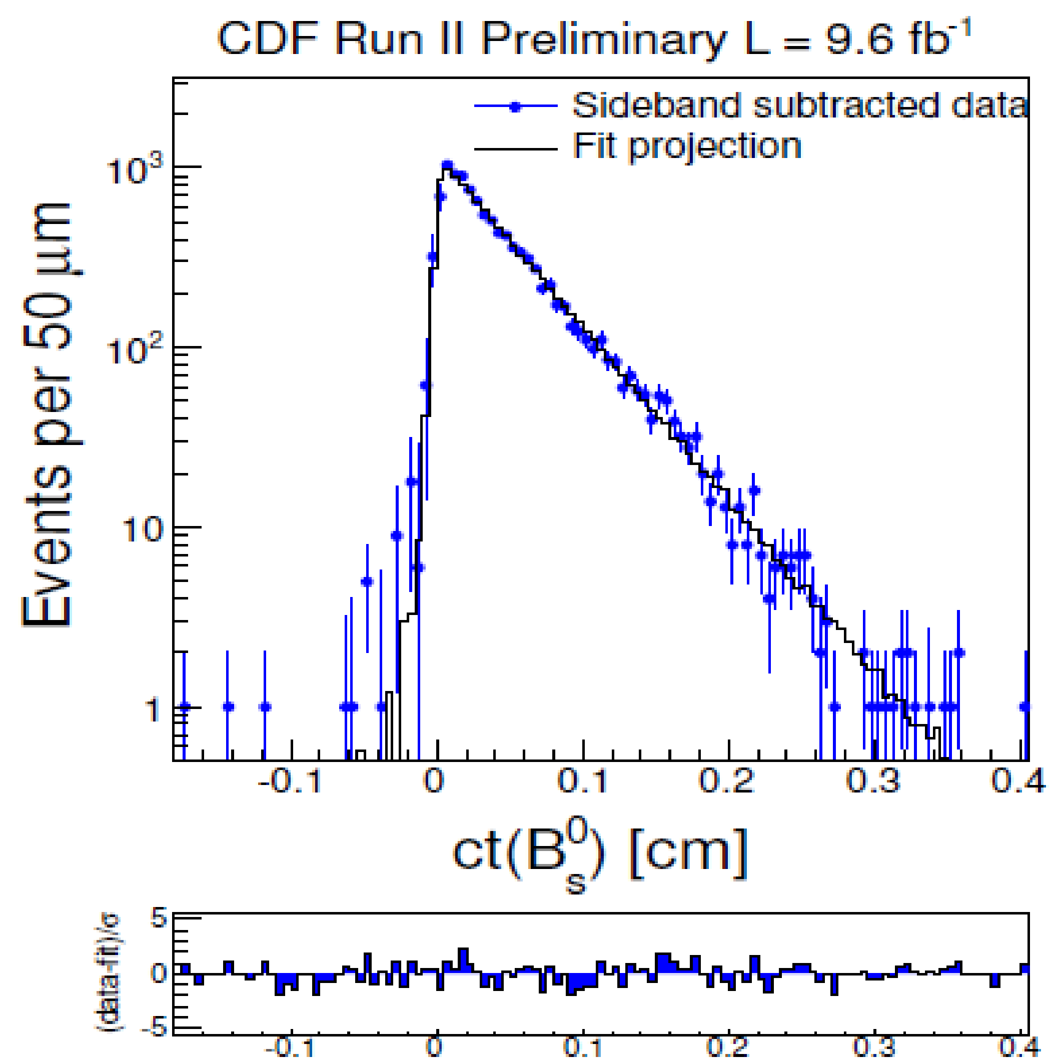




- Tag other B: jet charge $\varepsilon D^2 \sim 1.4\%$
- Look at same side K: $\varepsilon D^2 \sim 3\%$

B_s mixing phase in $J/\psi\phi$

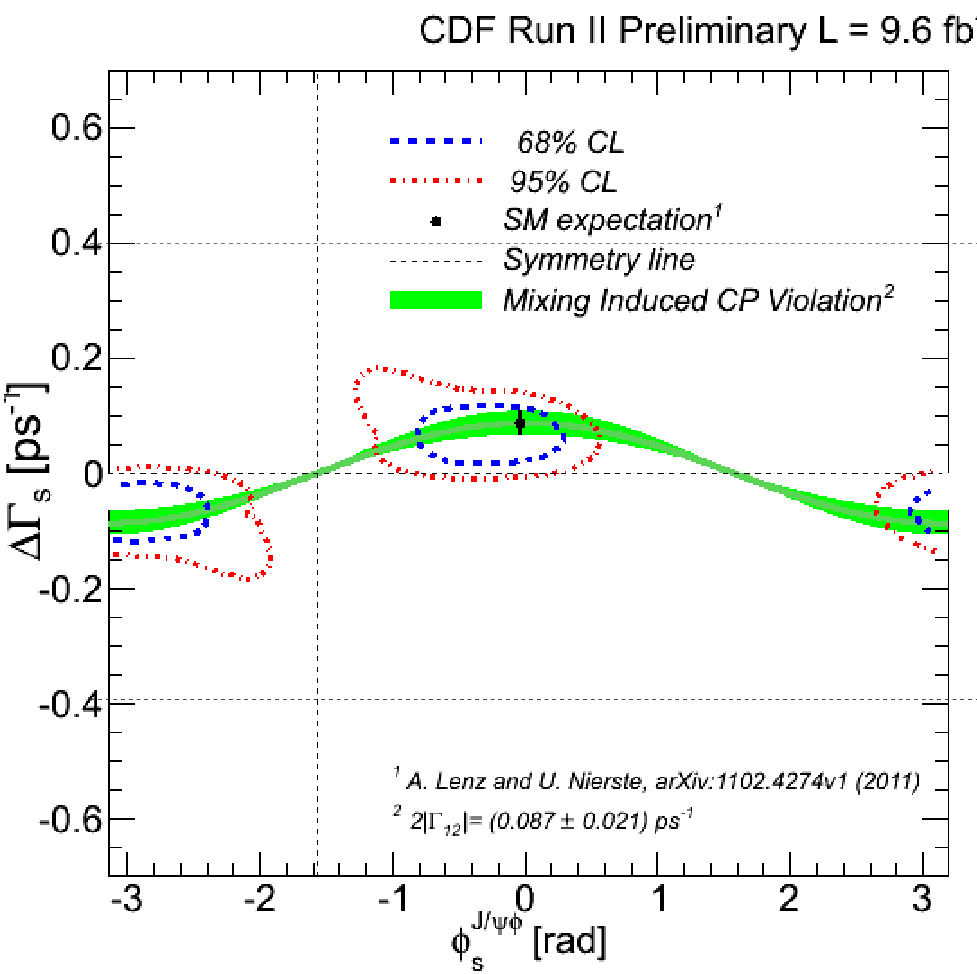


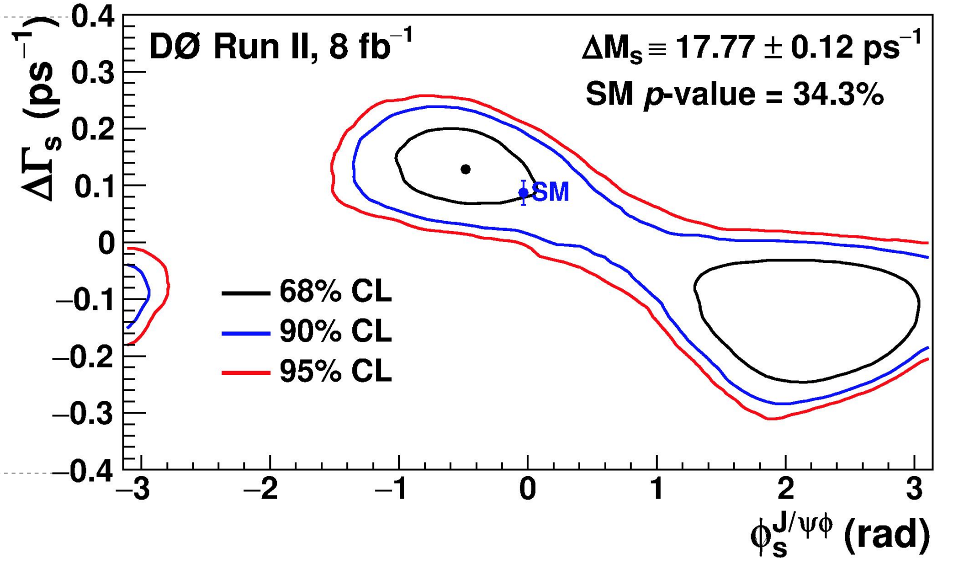


- Joint fit of mass, production flavor, decay time, and decay angles

$$\frac{d^4\Gamma(B_s^0 \to J/\psi\phi)}{dt d cos\theta d\phi d cos\psi} = f(\phi_s, \Delta\Gamma_s, \Delta m_s, \tau_{B_s^0}, M_{B_s^0}, |A_0|, |A_\perp|, \delta_\perp, \delta_\parallel, f_{SW}, \delta_{SW})$$

B_s mixing phase in $J/\psi\phi$





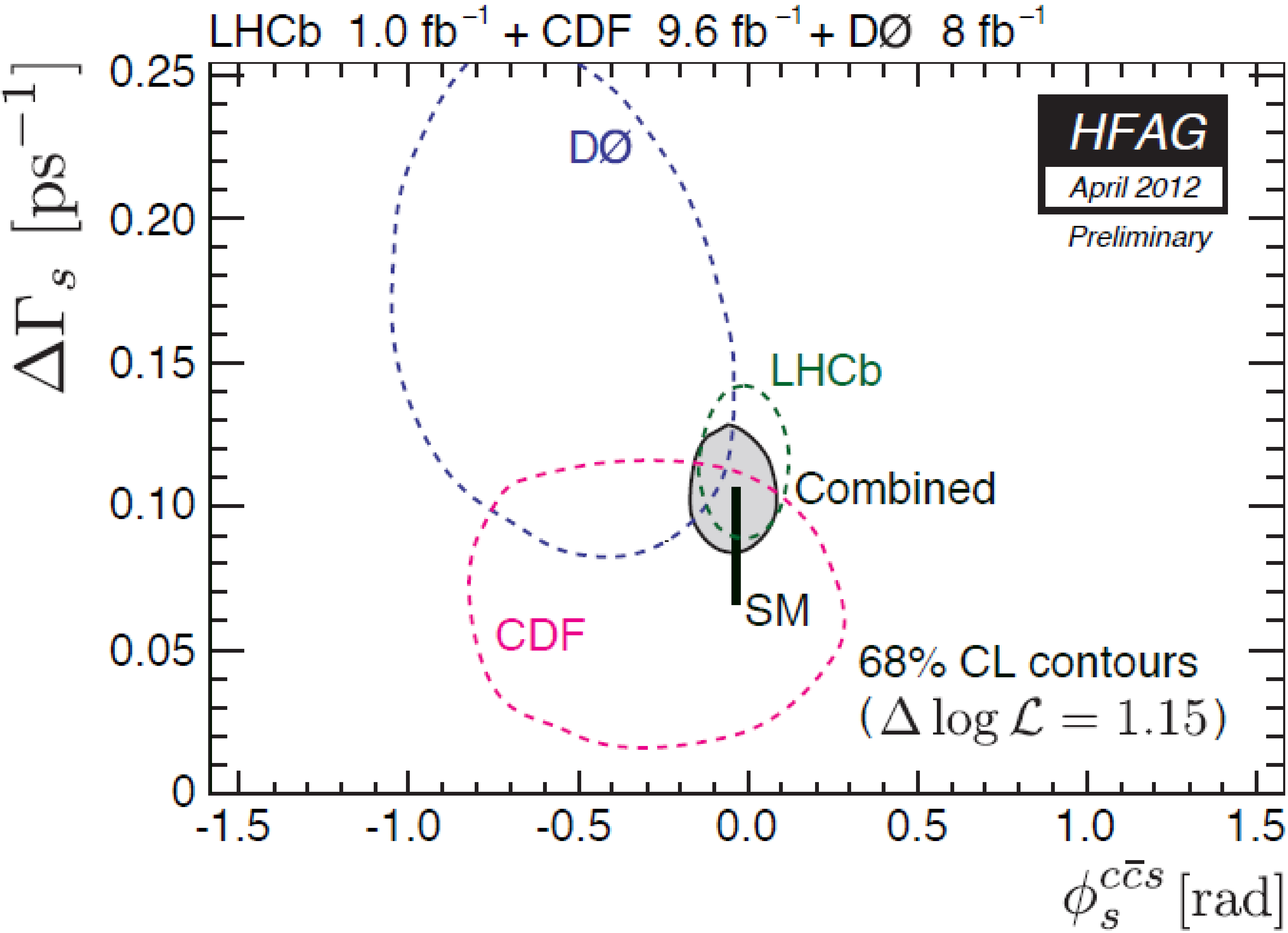
Both experiments consistent with SM

ϕ_s in [-0.60,0.12] rad @ 68% CL

$\Delta\Gamma_s = 0.068 \pm 0.027\ ps^{-1}$

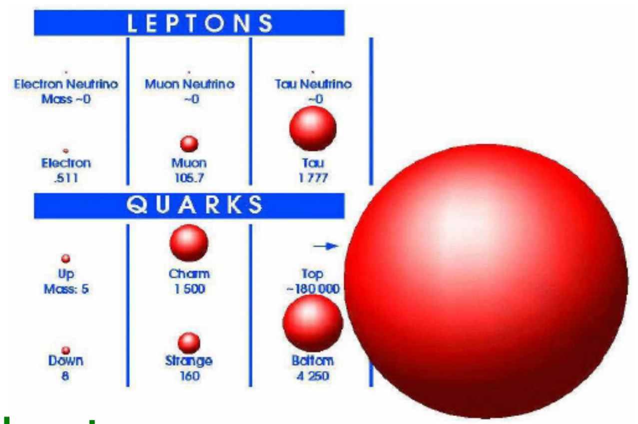
$\phi_s = -0.55 \pm 0.38$ rad

$\Delta\Gamma_s = 0.163 \pm 0.065\ ps^{-1}$

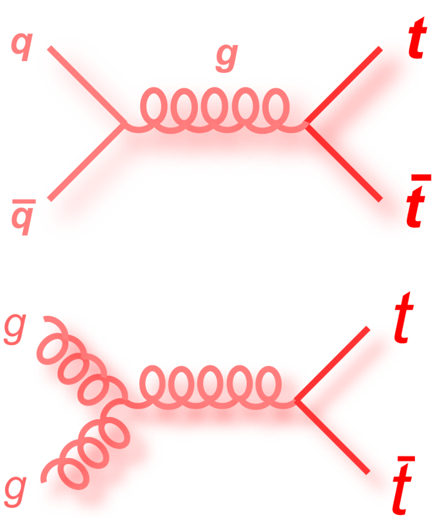


LHCb 1.0 fb^{-1} + CDF 9.6 fb^{-1} + DØ 8 fb^{-1}
$\Delta\Gamma_s$ [ps^{-1}]
0.25
0.20
0.15
0.10
0.05
0
HFAG
April 2012
Preliminary
DØ
LHCb
Combined
SM
CDF
68% CL contours
$(\Delta \log \mathcal{L} = 1.15)$
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
$\phi_s^{c\bar{c}s}$ [rad]

Top quark physics

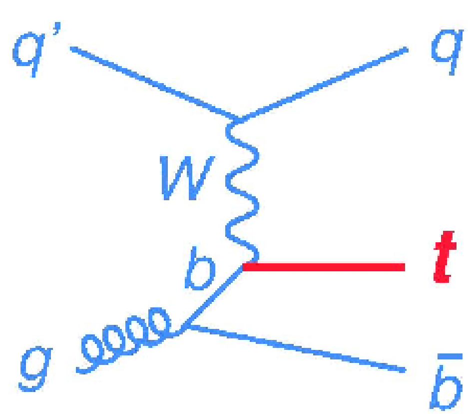


- Heaviest known particle
  - $m_t \sim v/\sqrt{2} \rightarrow \lambda_t \sim 1$ Why so massive?
  - Sensitive probe for new physics
- Decays as a free quark $\tau_t \sim 5\cdot10^{-25}$ s $\ll \Lambda_{QCD}^{-1}$
  - Spin information is passed to its decay products
  - Test V-A structure of the SM
- Production modes at the Tevatron:



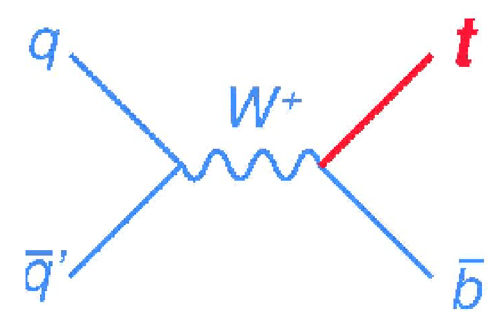
7.1±0.4 pb

t-channel



2.1±0.1 pb

s-channel

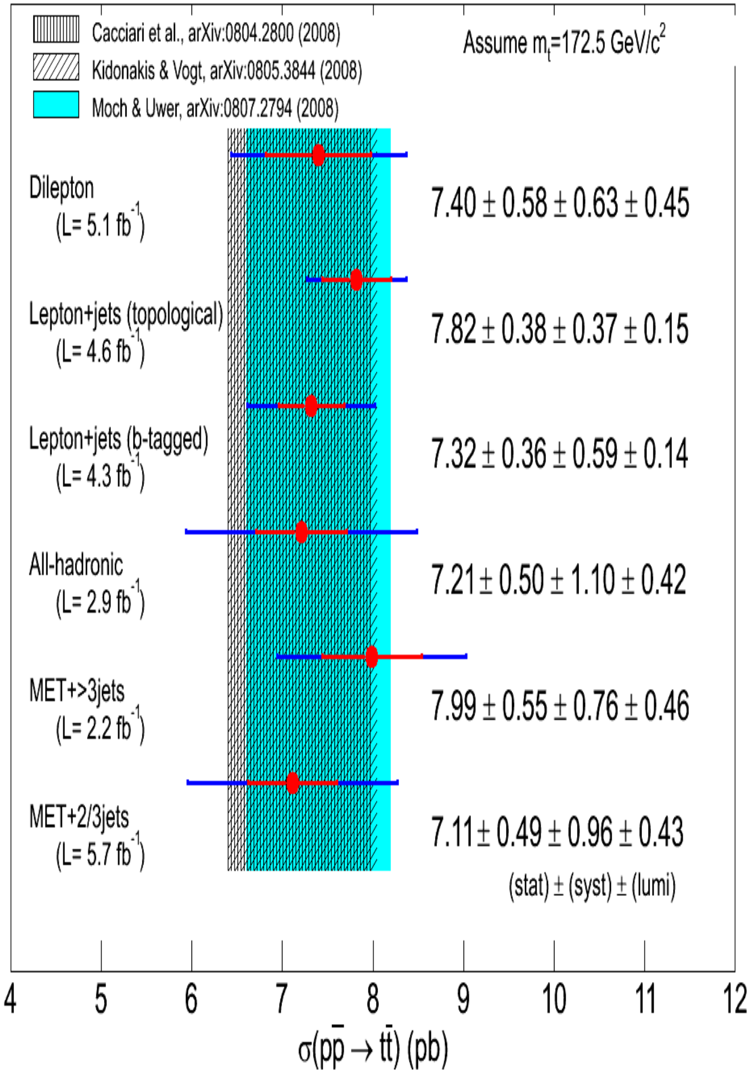


1.1±0.1 pb

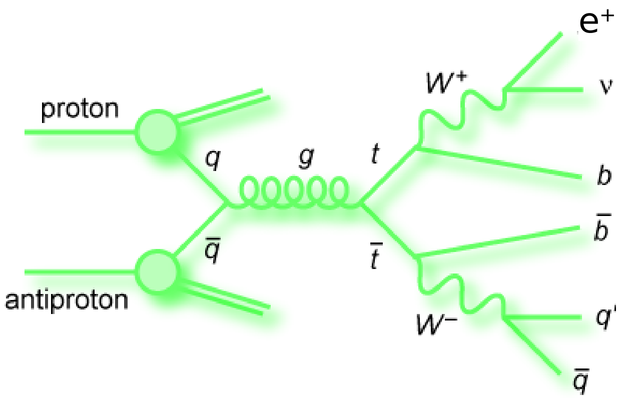
Kidonakis NNLL m_t = 173 GeV with MSTW 2008 PDFs

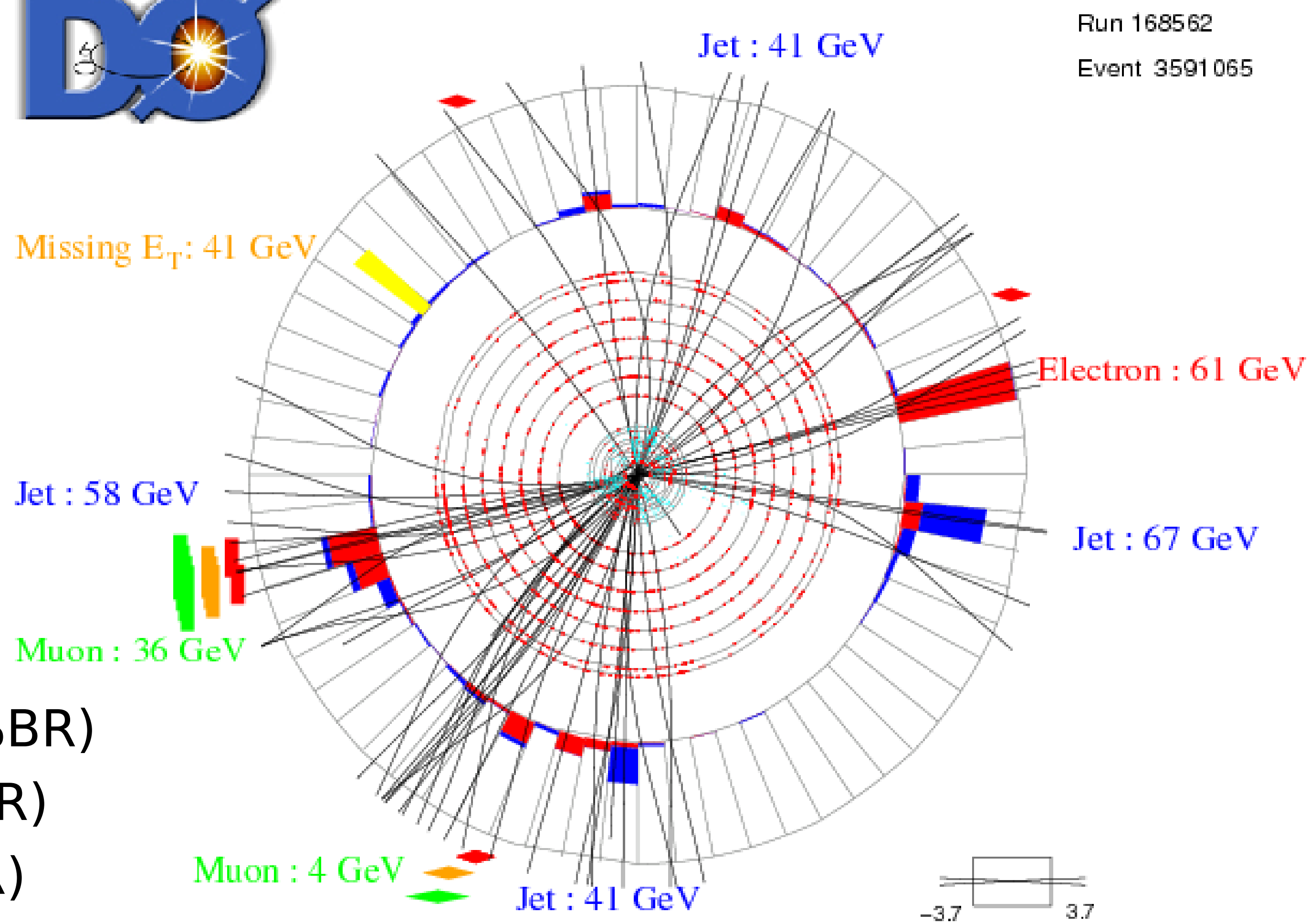
After 17 years of studies

- Tevatron program: study its production, decay properties, and search for new physics
- We have measured:
  - M_t = 173.2 ± 0.9 GeV
  - $\sigma(tt)$ = 7.6 ± 0.6 pb for m_t=172.5 GeV
  - $\sigma(t)$ = 3.0 ± 0.6 pb for m_t = 172.5 GeV
  - $|V_{tb}|$ = 0.96 ± 0.09(exp.) ± 0.05(theory)
  - BR(t→Wb)/BR(t→Wq) = 0.90 ± 0.04
  - Charge: exclude 4e/3 @ 99% CL
  - Longitudinally polarized W:
    f_0 = 0.72 ± 0.08 [f_0(SM)=0.7]
  - $\Delta m = m_t - m_{\bar{t}}$ = -2.0 ± 1.6 GeV
  - Γ_t = 2.0 ± 0.5 [Γ_t(SM) = 1.4 GeV]
  - $c\tau$ < 52.2 μm @ 95% CL
  - … and many more limits on new physics



$t\bar{t}$ decays





- Dilepton: $\ell\ell\nu\nu$bb (~8%BR)
- ℓ+jets: $\ell\nu$jjbb (~30%BR)
- Alljets: jjjjbb (~44%BR)

- Main backgrounds: W+jets and multijets; Z/γ for dilepton
- All subdetectors are involved: MET (ν), leptons, jets, and b-identification
- b-tag efficiency: ~45 - 55% ; Mistag rate: ~0.5 - 1.5%

Top mass and m_t-$m_{\bar{t}}$ difference

Top mass with template method with full CDF dataset 8.7 fb^{-1}

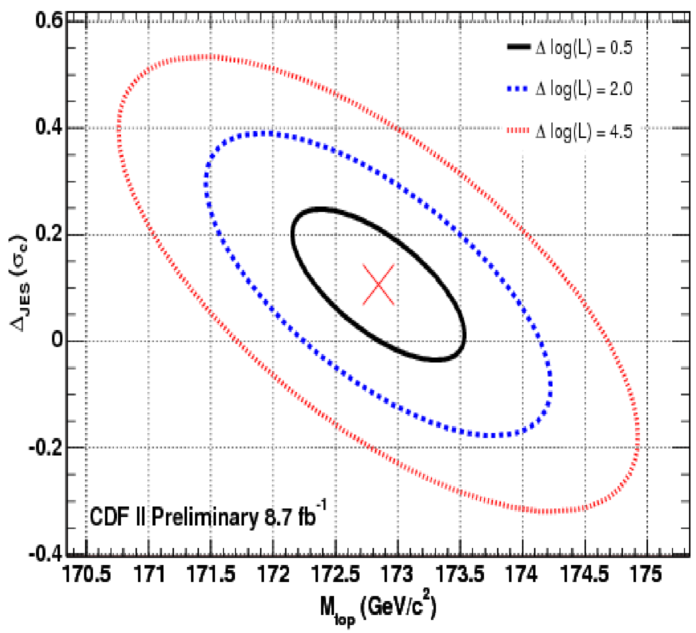
- Kinematic fitter to reconstruct $t\bar{t}$ system (assign partons-jets)
- Templates on (m_t^{reco},m_t^{reco2},m_{jj}) for each generated m_t, JES
- Apriori JES determination for b-jets uses NN including tracker info
- Likelihood fit for m_t and JES

m_t = 172.9±0.7(stat)±0.8(sys) GeV

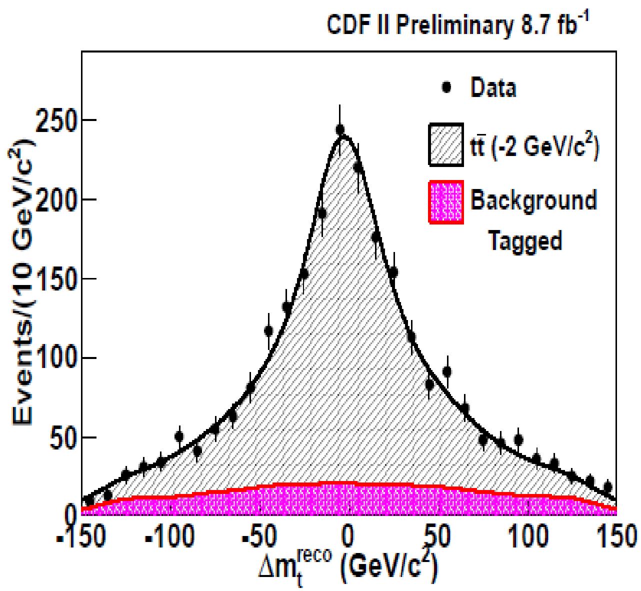
±0.6%

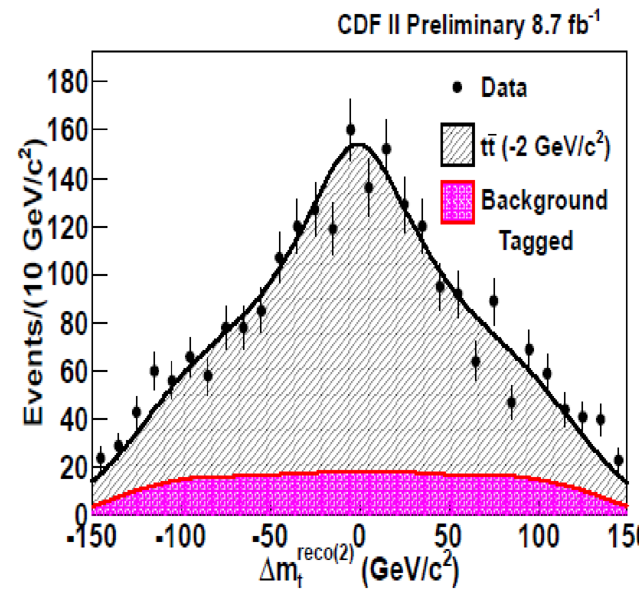
Top-antitop mass difference with full CDF dataset

- m_q and $m_{\bar{q}}$ should be equal: Δm_t=m_t-$m_{\bar{t}}$ tests CPT invariance
- Same technique as above, 2D templates on Δm_t^{reco} and Δm_t^{reco2}

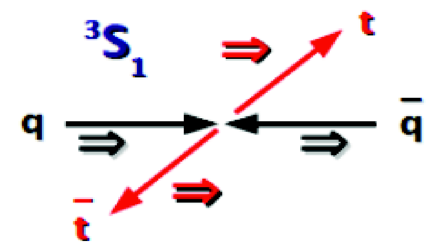


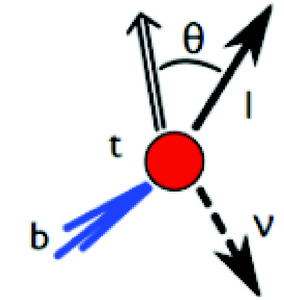
Δm_t= -2.0±1.1(stat)±0.6(syst) GeV





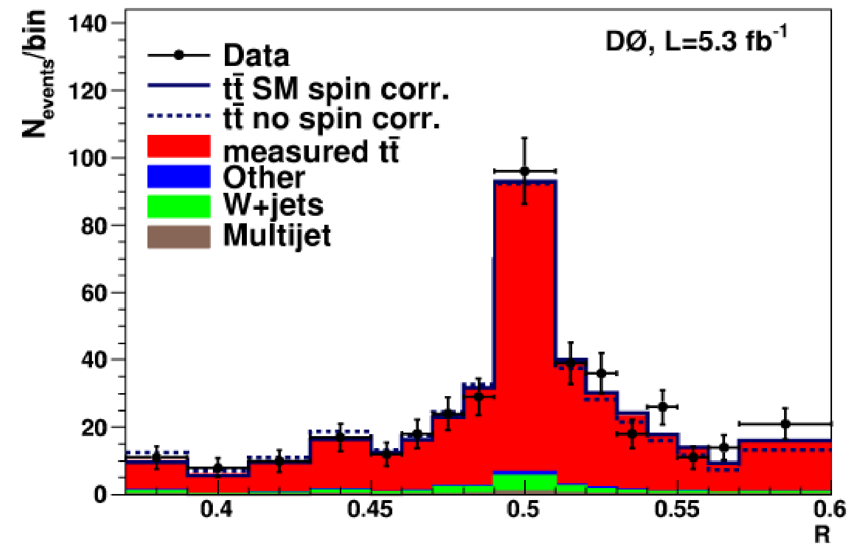
Evidence for spin correlations





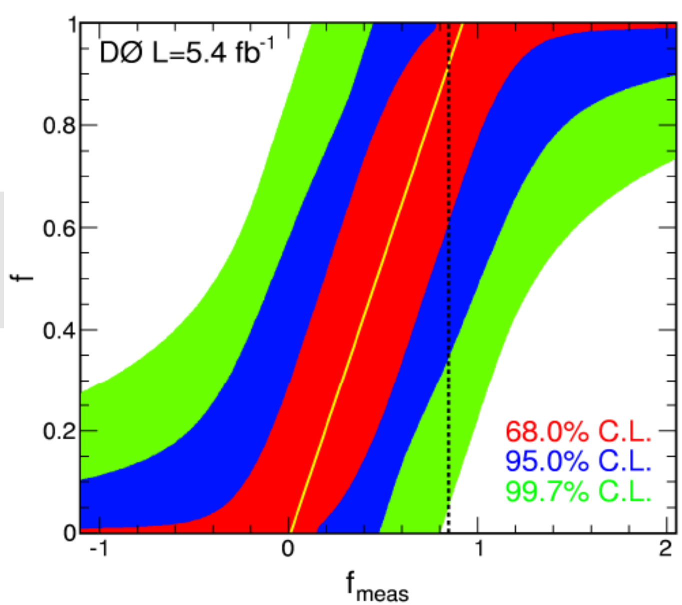
- Pair production: top quarks are unpolarized, but spins are correlated
- Flight directions of top decay products carry information about top polarization
- Matrix Element analysis (30% improvement over single variable)

$$R = \frac{P_{\rm sgn}(H=1)}{P_{\rm sgn}(H=0) + P_{\rm sgn}(H=1)}$$



- Test hypothesis of correlated (c) or uncorrelated (u) t and $\bar{t}$ spins
- Build templates in R
- Extract f = $N_{t\bar{t}}$(with spin)/$N_{t\bar{t}}$(total)
- Use ℓ+jets and dilepton samples

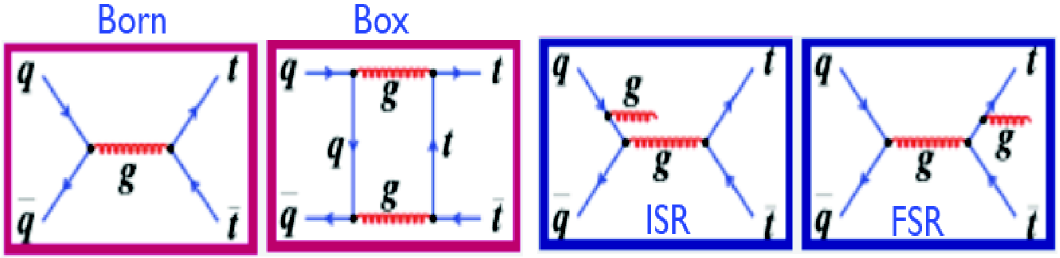
C_{obs} = 0.66±0.23 ; f_{obs} = 0.85 ± 0.29
Exclude f=0 @ 3.1σ

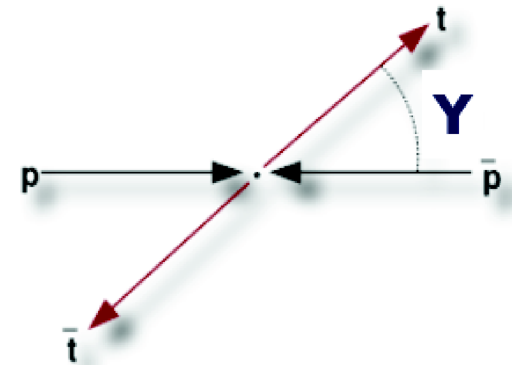


- C_{NLO} = 0.78 ± 0.04 ; f_{SM} = 1
- ATLAS has confirmed with 5.1σ

Charge asymmetry

- LO: top quark production angle is symmetric wrt beam direction

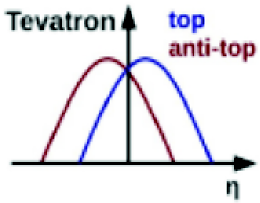


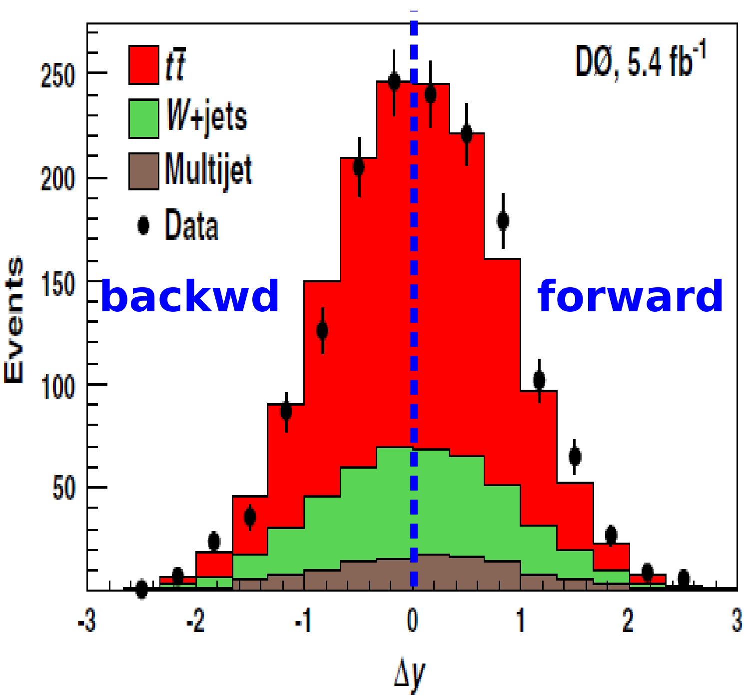


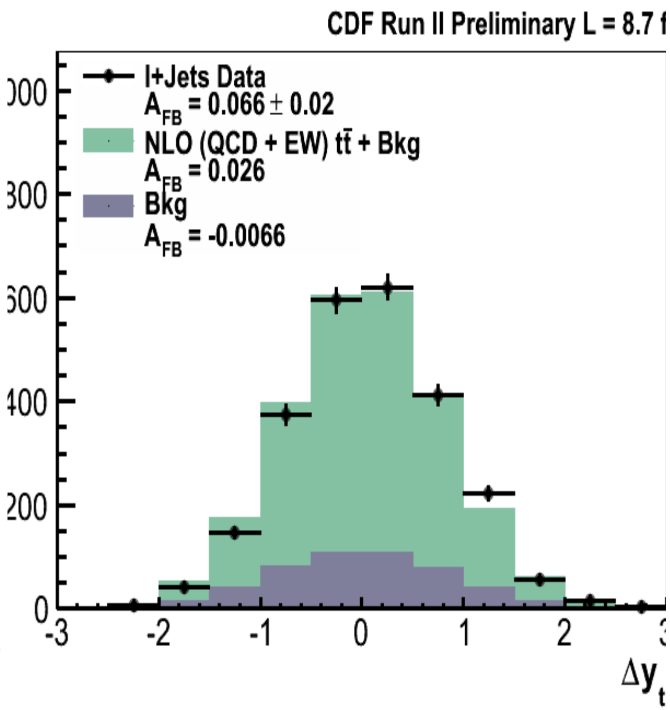
$\Delta y = y_t - y_{\bar{t}}$

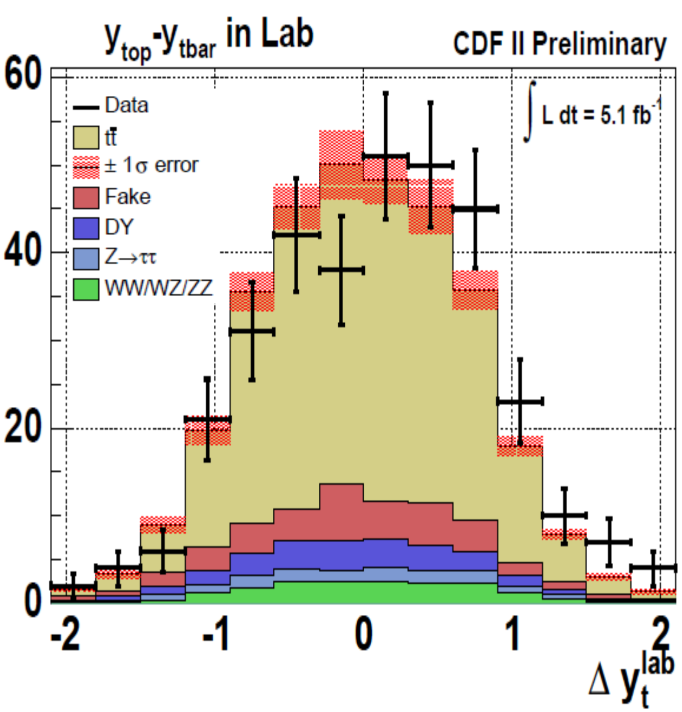
- NLO: forward-backward asymmetry A_{fb}~5% due to interference effects

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$





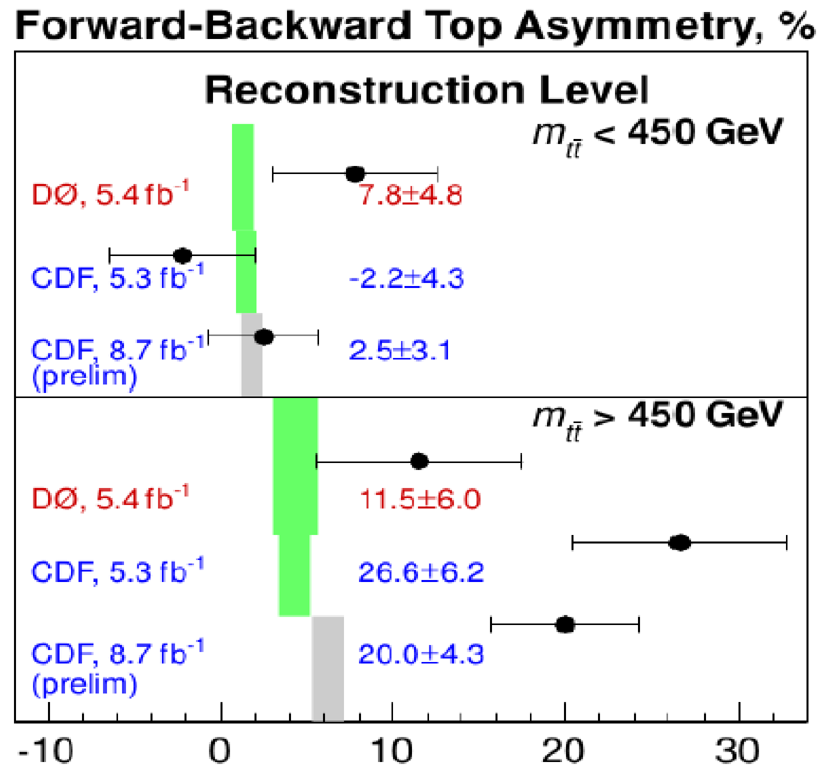


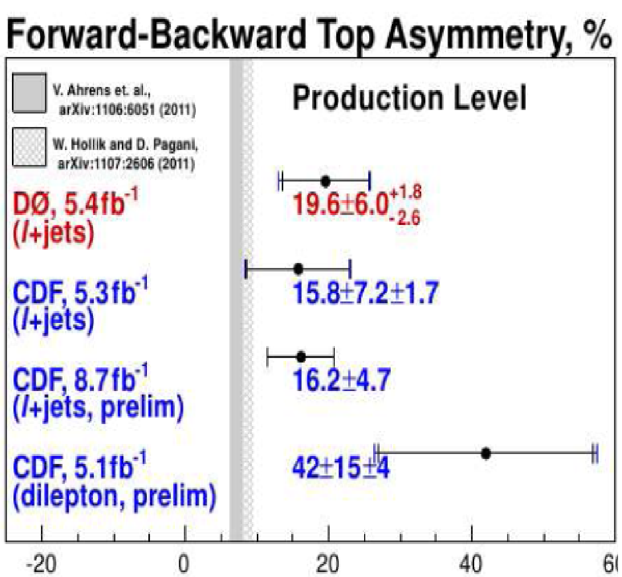


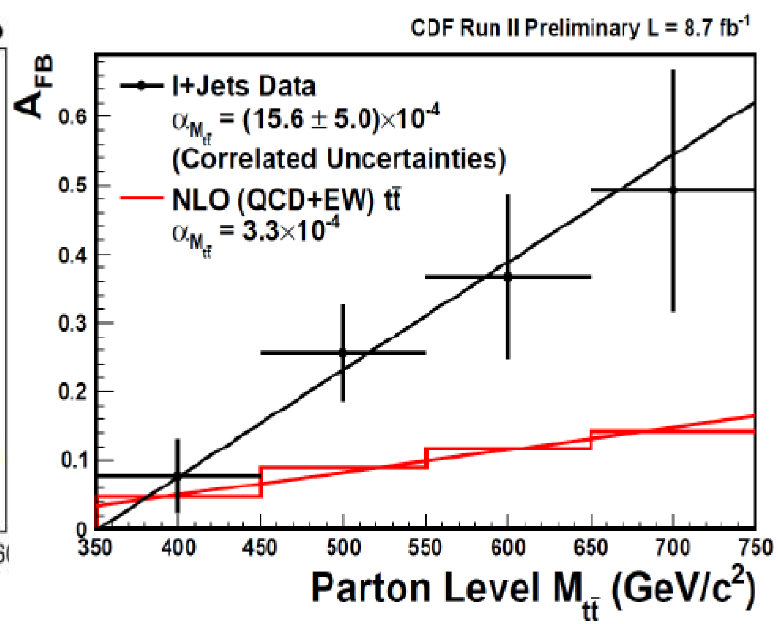
Charge asymmetry: results

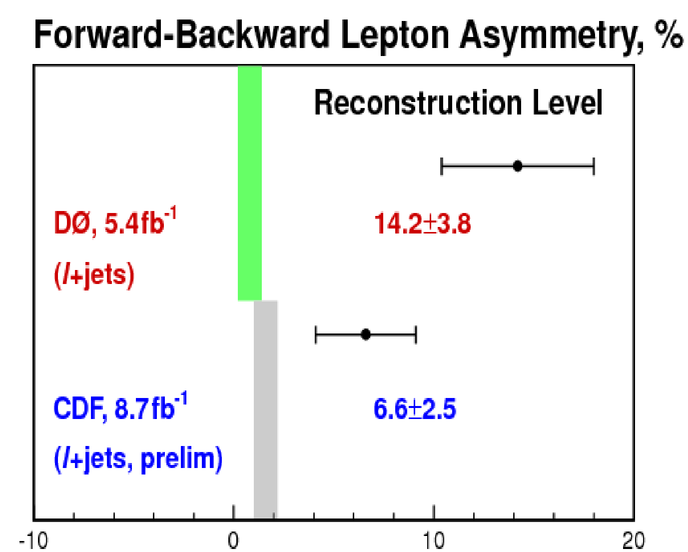
- CDF sees larger effect (>2σ) for $m_{t\bar{t}} > 450$ GeV and $|\Delta y|>1$
- To compare to theory (parton level), data is corrected for background, acceptance and resolution effects
- NLO A_{fb} dependence on $m_{t\bar{t}}$ is shallower than data
- D0 sees 3σ discrepancy in lepton-based asymmetry

$$A_{fb}^{\ell} = \frac{N^{q_\ell y_\ell>0} - N^{q_\ell y_\ell<0}}{N^{q_\ell y_\ell>0} + N^{q_\ell y_\ell<0}}$$





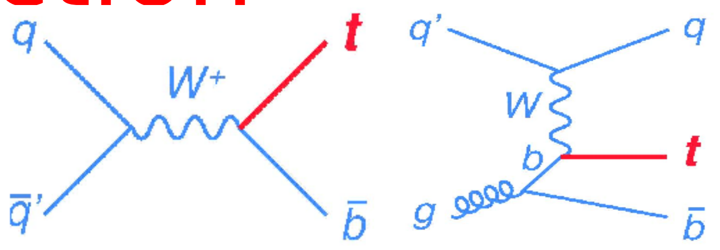


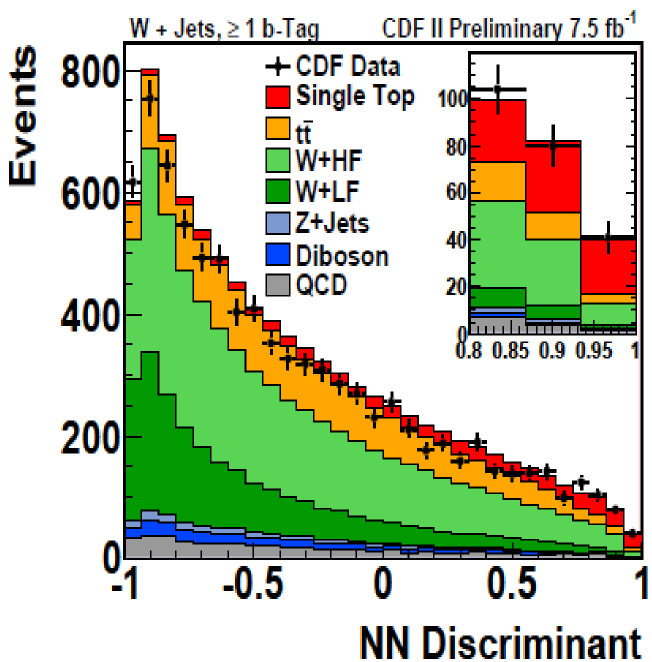


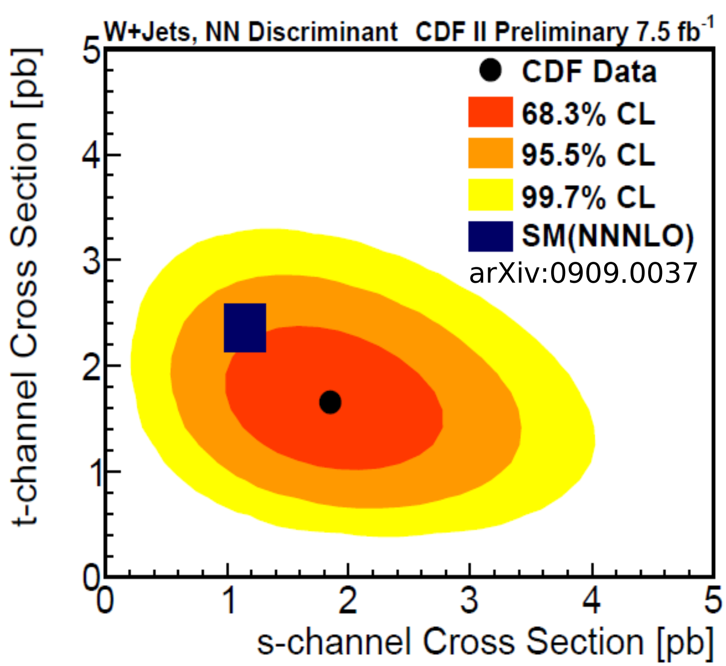
Single top production

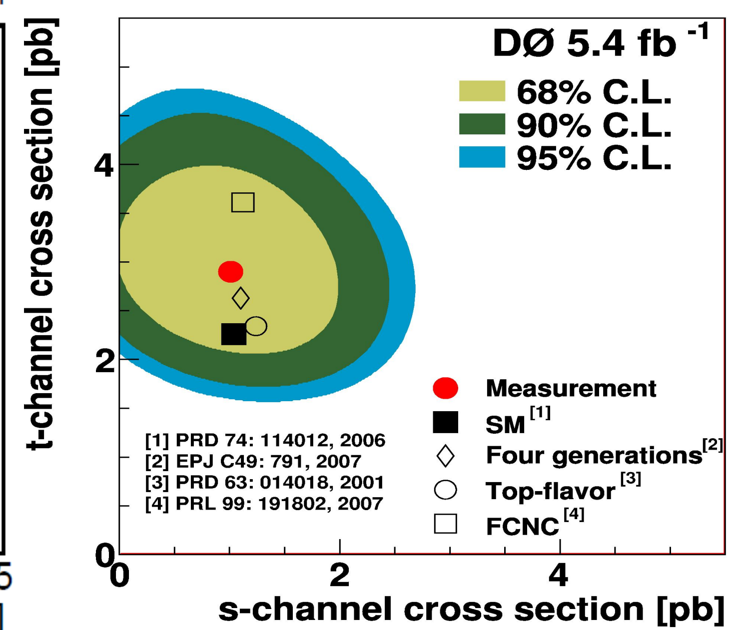
- Took 14 years to observe after top discovery!
  - Large backgrounds with large uncertainties
  - Smaller cross section, less energetic
  - Developed and tested sophisticated multivariate techniques
- TeV (3.2 fb^{-1}): **$|V_{tb}|$ = 0.91 ± 0.08**
- D0 observed t-channel alone with 5.4 fb^{-1}
- Several searches for new physics: W', FCNC, anomalous couplings
- CDF new result with 7.5 fb^{-1}

σ_{s+t} = 3.0 $^{+0.5}_{-0.4}$ pb @ m_t=172.5 GeV
$|V_{tb}|$ = 0.96±0.10(stat+sys)± 0.05(th)

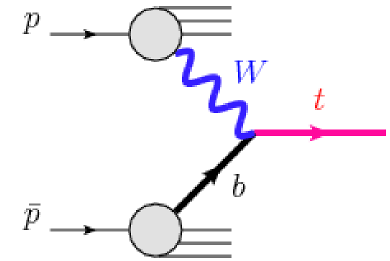








Top quark width



- Direct measurement on m_t distribution is limited by detector resolution

$0.3 < \Gamma_t < 4.4$ GeV @ 68% CL

- D0 performs an indirect measurement:

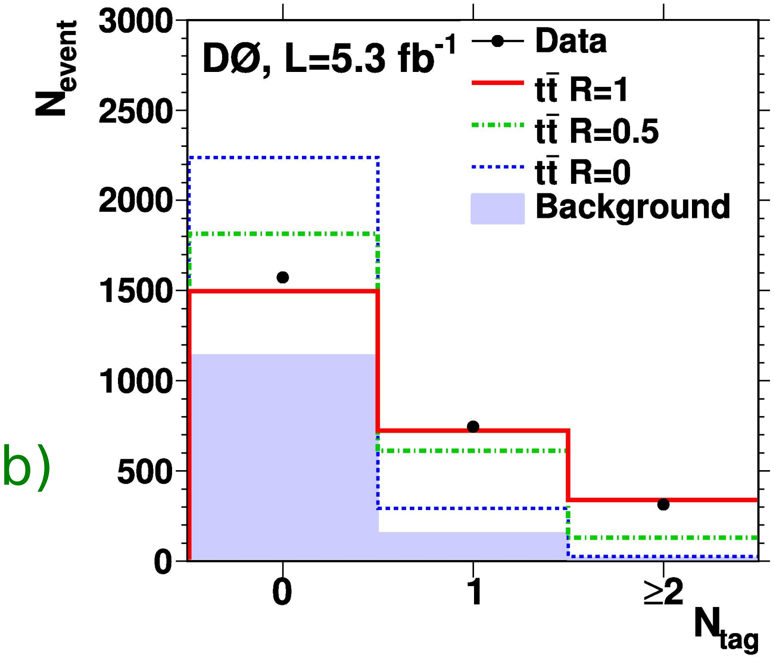
$$\Gamma_t = \frac{\Gamma(t \to Wb)}{B(t \to Wb)}$$

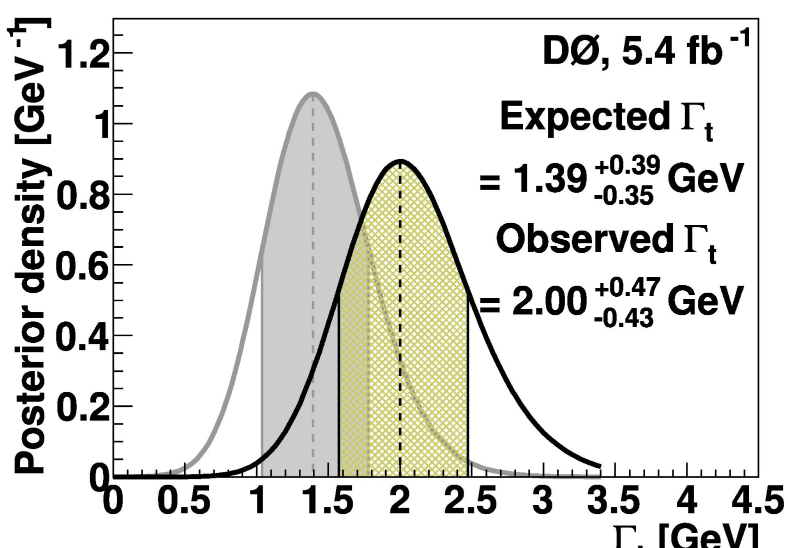
$$\sigma(tqb)\frac{\Gamma(t \to Wb)_{SM}}{\sigma(tqb)_{SM}}$$

t-channel cross section: σ(tqb) is proportional to Γ(t→Wb)

$$R = \frac{B(t \to Wb)}{B(t \to Wq)}$$

B(t→Wb) from $t\bar{t}$ decays





- NLO: Γ_t=1.33 GeV for m_t=172.5 GeV

$\Gamma_t = 2.0^{+0.5}_{-0.4}$ GeV

$\tau_t = (3.3^{+0.9}_{-0.6})\ 10^{-25}$ s

$|V_{tb'}| < 0.59$

Conclusions

B-physics program: competitive and complementary to b-factories

- Broad range of discoveries and analyses
- Spectroscopy: flood of new states
- Still pushing searches in rare decays
- Discrepancy in like-sign dimuon asymmetry: new phenomena?

Top physics program: from discovery to precision

- 0.6% uncertainty on m_t (single measurement)
- 6% uncertainty on cross section (theory limited)
- Pinned down properties, many searches for new physics
- Now focus on complementary analyses to LHC
- Discrepancy in A_{fb} remains exciting: more studies under way

http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
http://www-d0.fnal.gov/Run2Physics/ckm/
http://www-cdf.fnal.gov/physics/new/top/top.html
http://www-d0.fnal.gov/Run2Physics/top/