Review of Tevatron Summer 2012 Results: Part I

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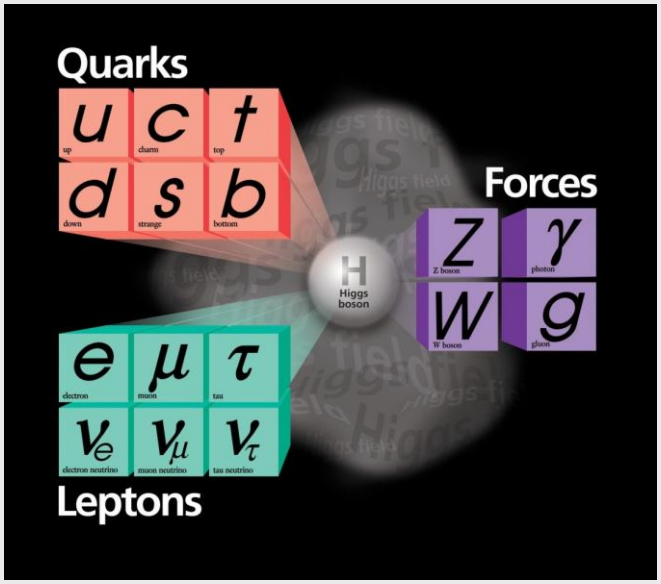
Fermi National Accelerator Laboratory and

Hampton University

Joint Experimental-Theoretical Seminar

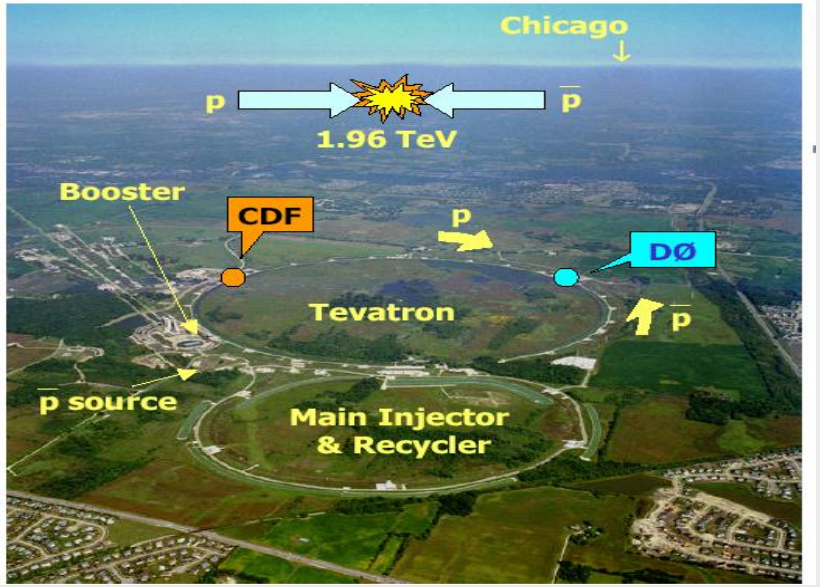
Fermilab, August 10, 2012

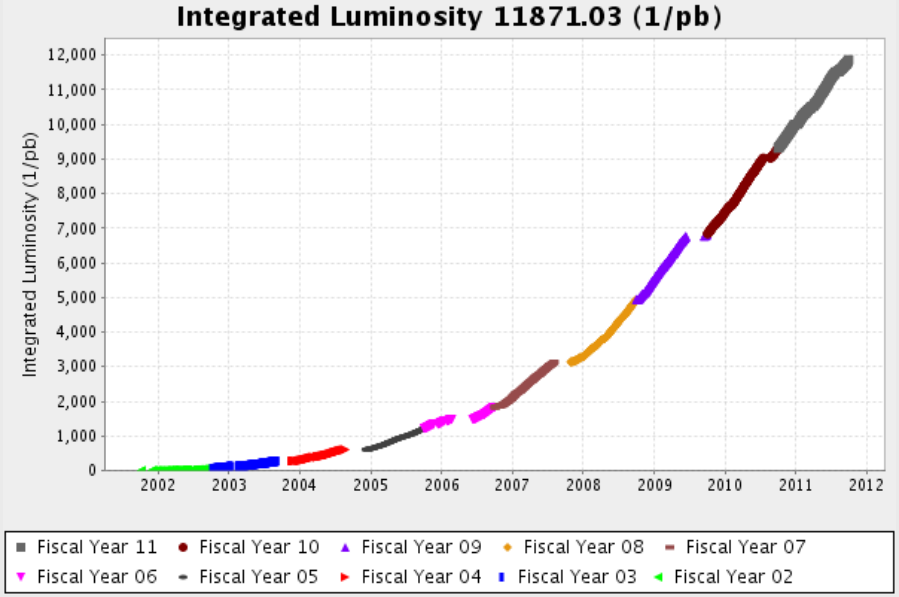
Outline



- Overview of Tevatron physics program
- Recent results from CDF and D0
- Part I : My talk will cover
  - Quantum chromodynamics (QCD)
  - Flavor physics
  - Top-quark physics
- Part II : Marco Verzocchi will cover Higgs searches and the related measurements
- Mostly showing the results presented at ICHEP 2012
  - In the context of the HCP Summer School
  - More extensive presentations by H. Wolfe and R. Hirosky on July 12 at the special Joint Experimental-Theoretical Seminar

Tevatron Run II



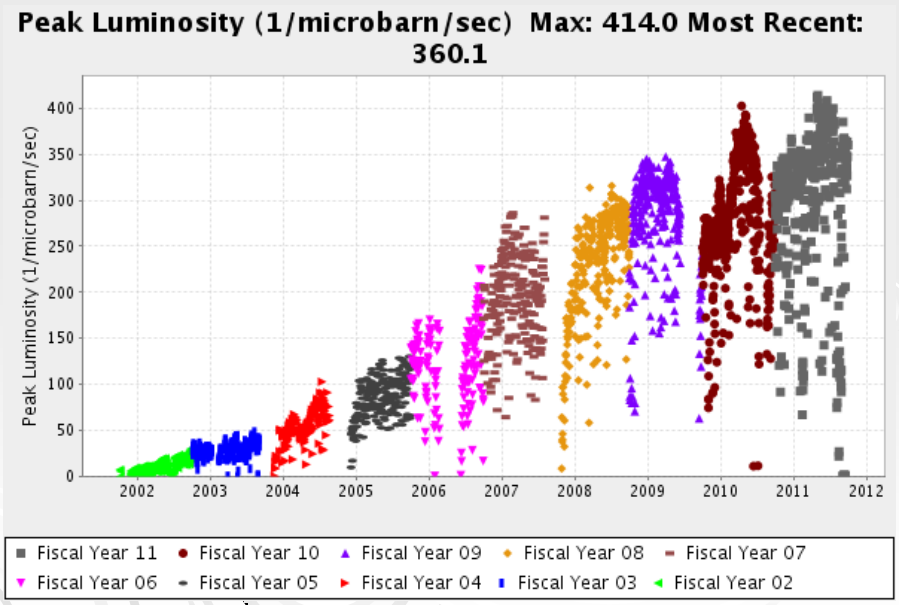


Proton-antiproton collider (2001-2011)

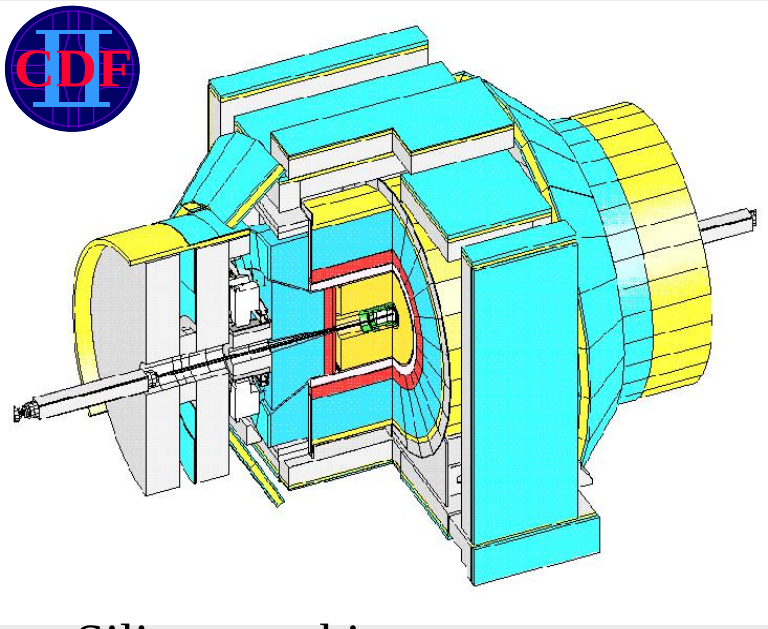
$\sqrt{s}$ = 1.96 TeV (300 GeV, 900 GeV)

- Peak Luminosity record : $4.14 \cdot 10^{32}$ cm^{-2}sec
- Total integrated luminosity delivered : ~12 fb^{-1}
  - ~10 fb^{-1} recorded per experiment
- Tevatron substantially exceeded its design parameters

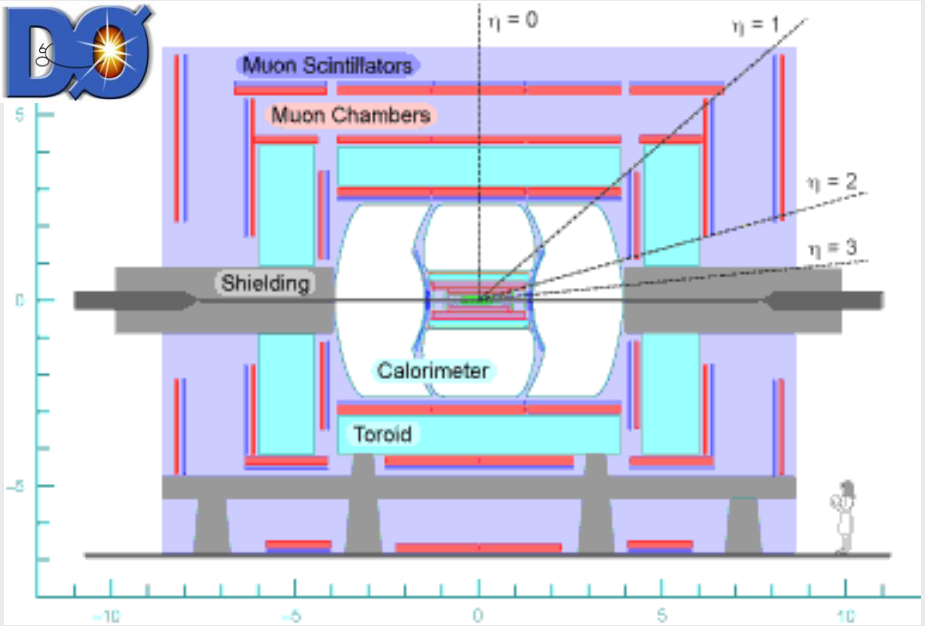
Thanks to the FNAL Accelerator Division!



The CDF and D0 Detectors



- Silicon tracking
- Large radius drift chamber (r=1.4m)
- 1.4 T solenoid
- Projective calorimetry ($|\eta| < 3.5$) (pseudorapidity $\eta = -\ln \tan(\theta/2)$)
- Muon chambers ($|\eta| < 1.0$)
- Particle identification
- Silicon Vertex Trigger



- Silicon tracking
- Outer fiber tracker (r=0.5m)
- 2.0 T solenoid
- Hermetic calorimetry ($|\eta| < 4$)
- Muon chambers ($|\eta| < 2.0$)
- New trigger and more silicon in Summer 2006 (Run2b)

Suitable for a wide range of physics topics!

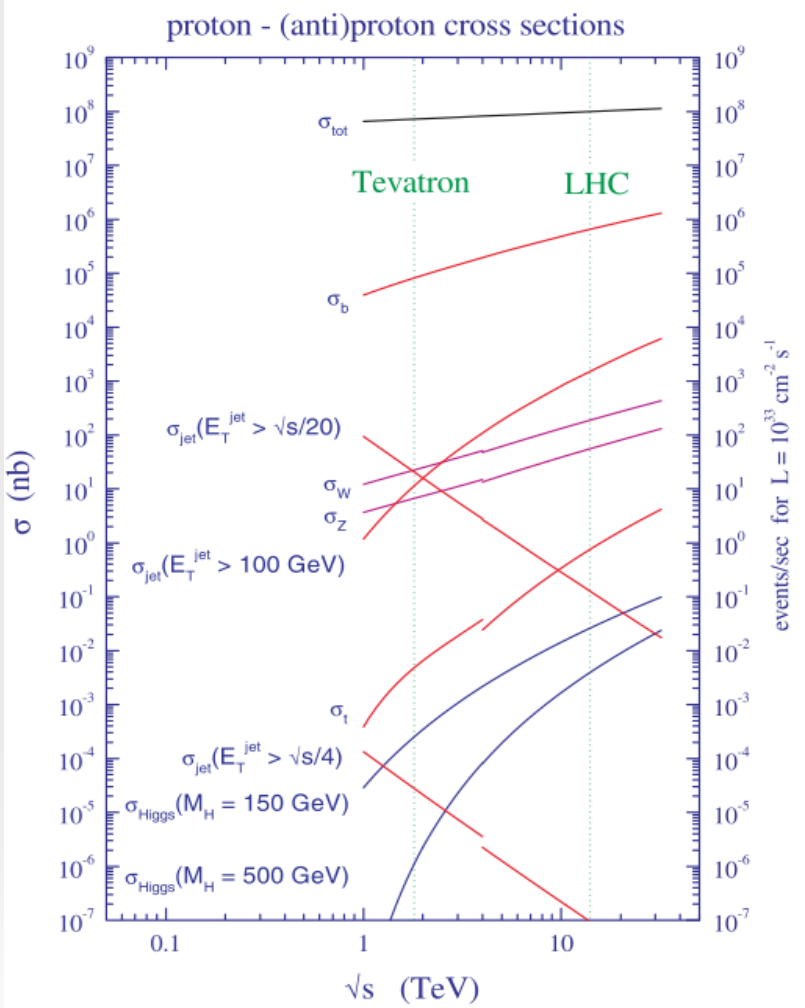
The CDF and D0 Collaborations

Taken during the last hour of Run II!

CDF: 474 authors in 57 institutions from14 countries

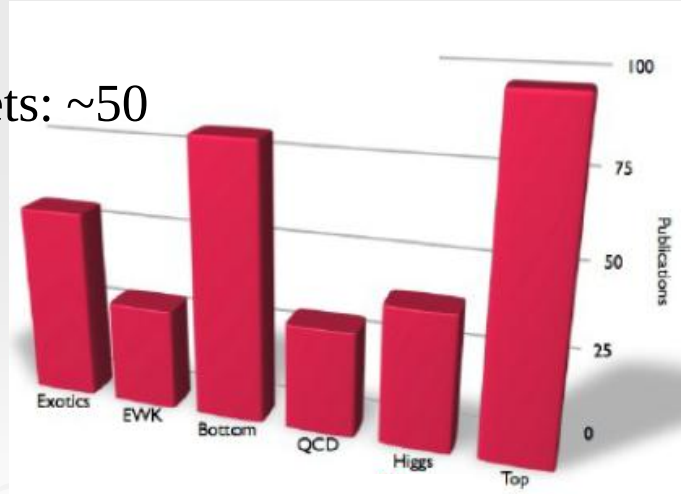
D0: 446 authors from in 82 institutions from 18 countries

Physics Program



Reconstructed candidates in ~10 fb^{-1} per experiment

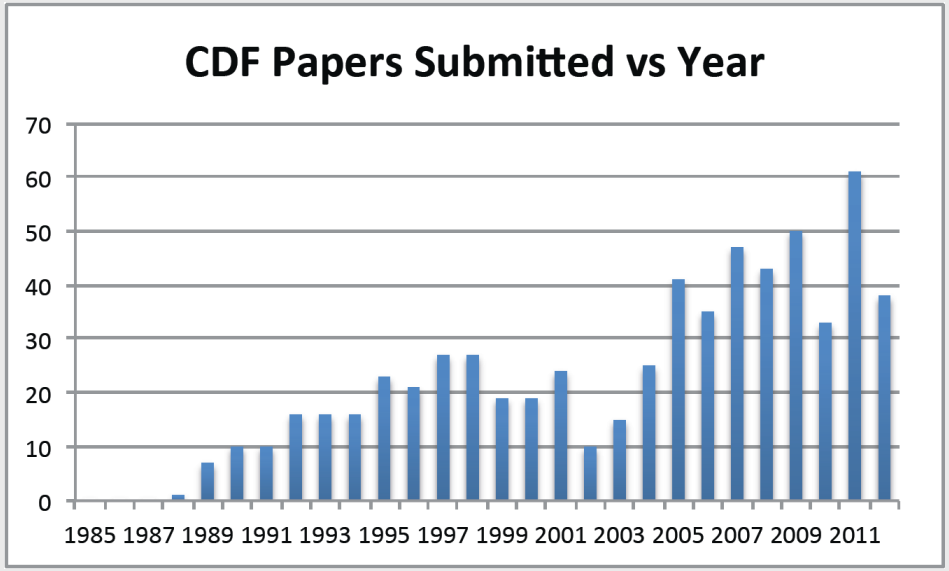
- $B_s^0 \rightarrow J/\psi\varphi$: ~10K-20K
- tt→ (e/μ and >=1 b-jet) : ~2000
- >30 GeV photons : ~20M
- Z→ee/μμ : ~600K
- (W→e/μ)+dijet : ~100K
- ZZ→4l: ~10
- tt+γ→γ+l+jets: ~50

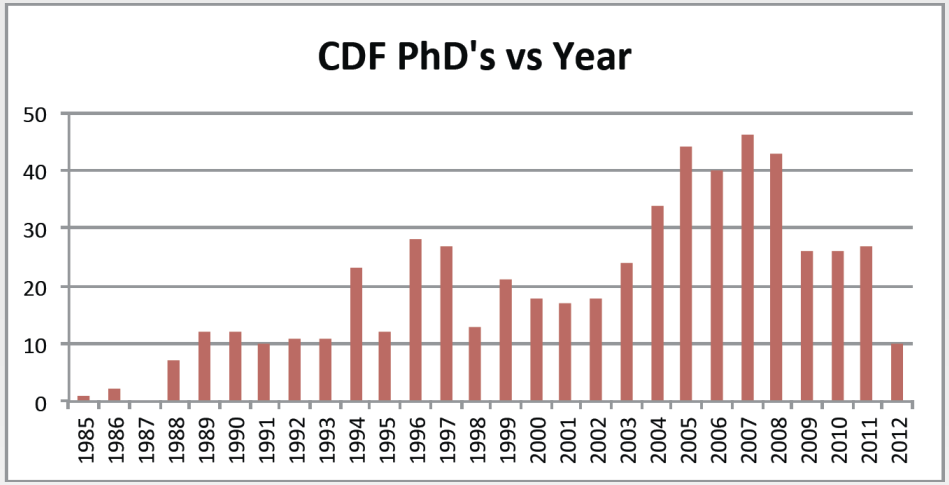


CDF publications (as of July 2012)

Covering wide range of physics analysis topics

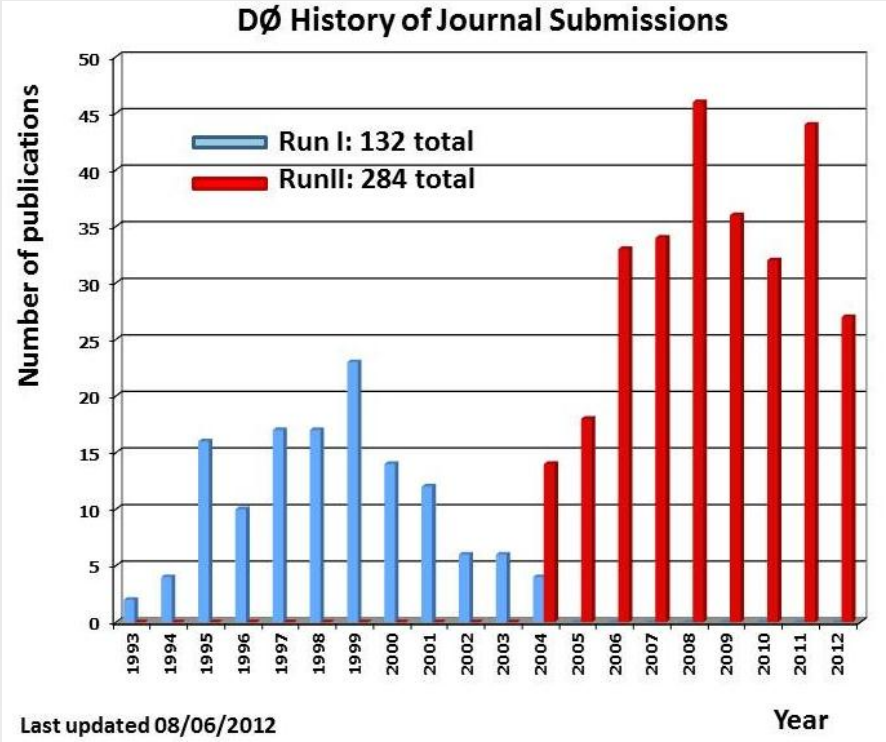
Publication History





CDF

- 596 Published. Over 350 on RunII
- Over 550 Ph.D. Theses

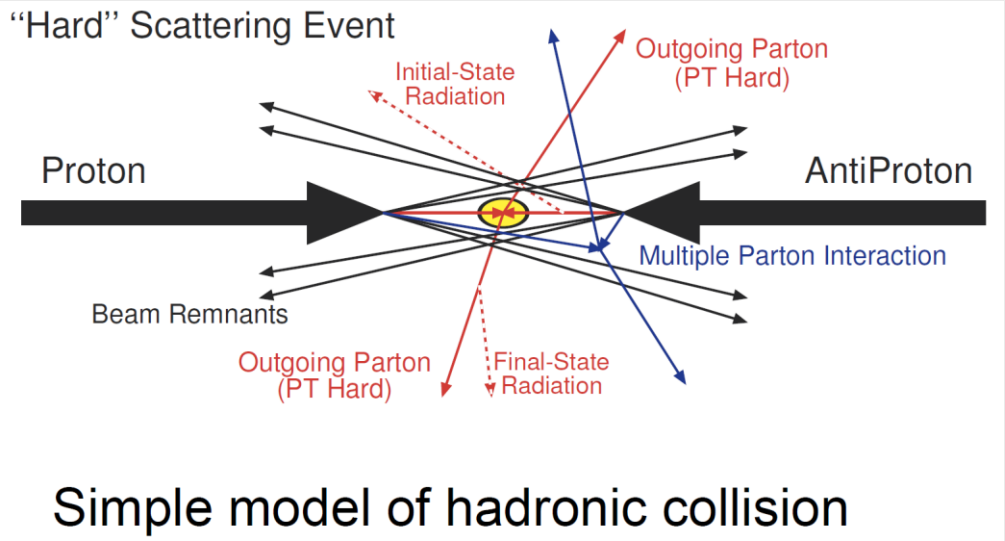


D0

- Publications : 284 from Run II + 132 from Run I
- ~330 Ph.D. thesis, another 50 in the pipeline

QCD

- Test of pQCD
- Constraints on PDFs
- Precision determination of SM parameters are limited by understanding of QCD processes
- Sensitivity to new physics
  - Produced in QCD processes
  - Background to new physics

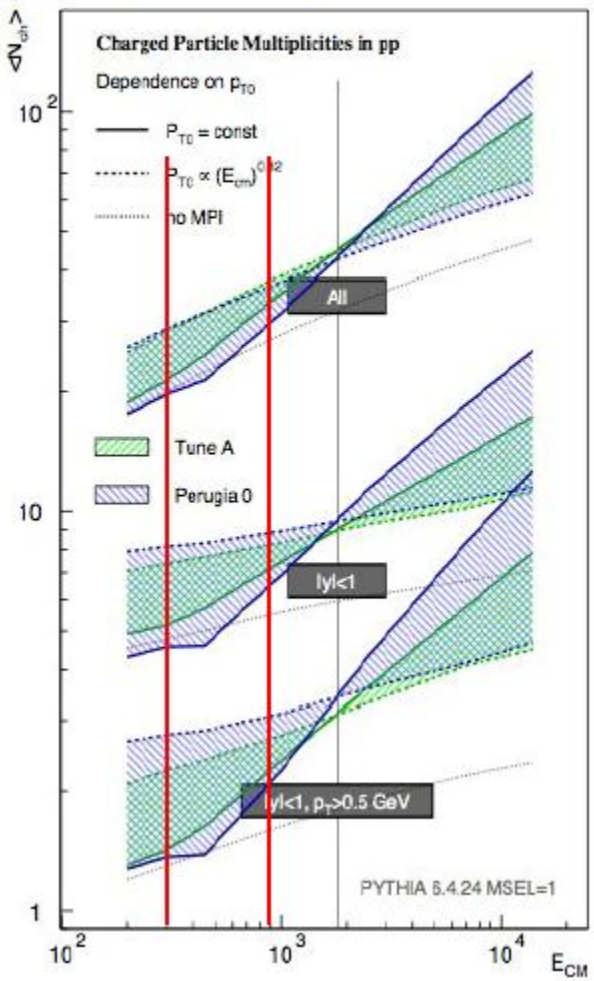


- Hard QCD (large-Q^2 transfers) :
  - Perturbative components, "hard" scattering", initial and final state radiation
  - Jets, heavy flavor, γ, W, Z … studies. Test of pQCD
- Soft QCD (low-Q^2 transfers) :
  - Fragmentation, underlying event, multiple parton interaction, hadronization, difractive physics.
  - Tuning MC, develop phenomenological models

Tevatron Low Energy Scan

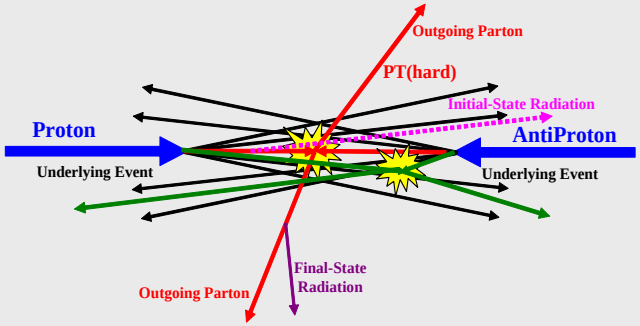
- Tevatron Low Energy Scan:
  - Sept 8th–Sept 16th 2011
  - 3x3 bunches, no low-β, minimal pileup
  - 300 GeV: 12.1 M Events (10h)
  - 900 GeV: 54.3 M Events (39h)
- Unique opportunity for better understanding
  - Min-bias events
  - Underlying events
  - Events with rapidity gaps
  - Compare between 900 GeV data from Tevatron and LHC
  - Can be used to better predict future high energy LHC data

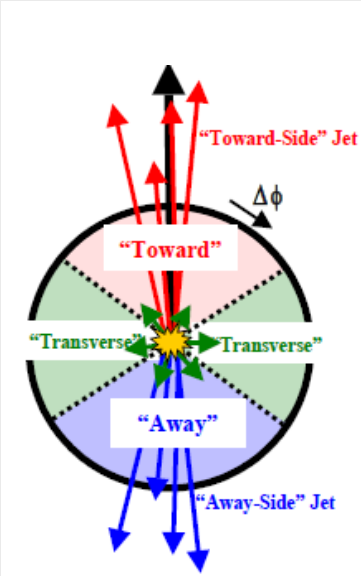
Peter Skands:
"Energy Scaling of Min-Bias Tunes"
arXiv:1103.3649,



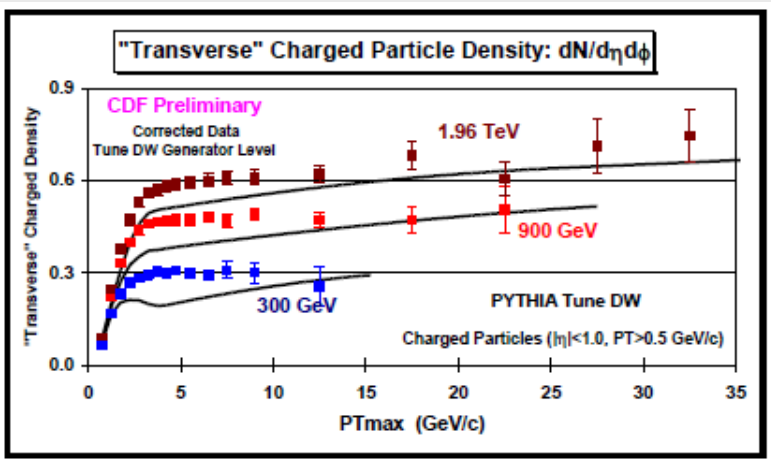
Underlying Event Studies

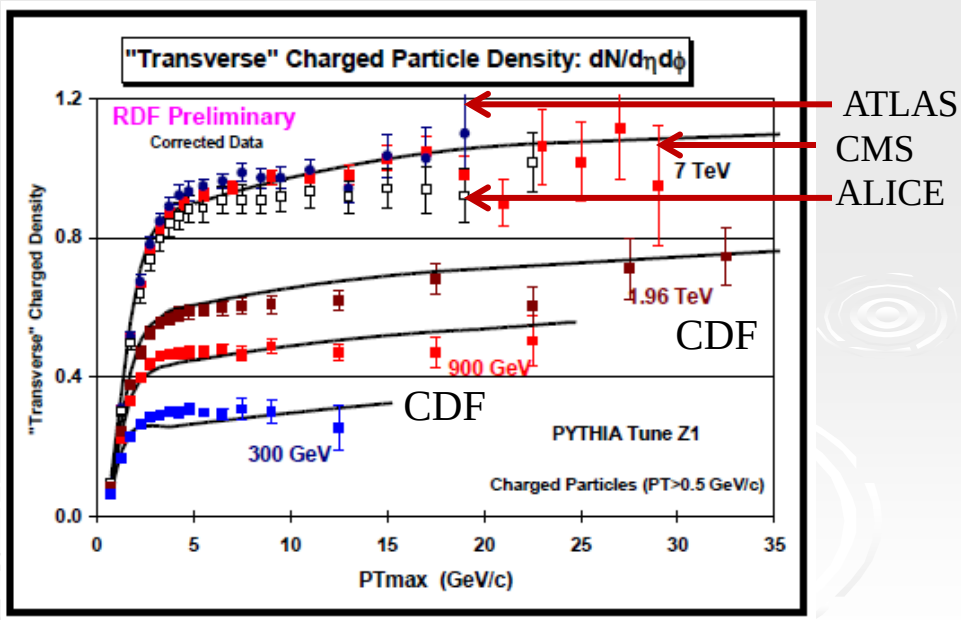
The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).





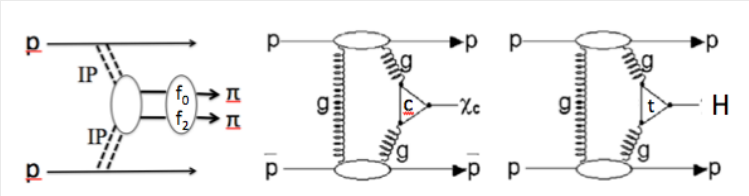
- Compare PYTHIA Tunes *(from Rick Field's talk at ICHEP 2012)*
  - CDF PYTHIA 6.2 Tevatron Tune DW (Q^2 ordered)
  - CMS PYTHIA 6.4 LHC Tune Z1 (P_T ordered)
- CDF low-energy UE better described by Z1

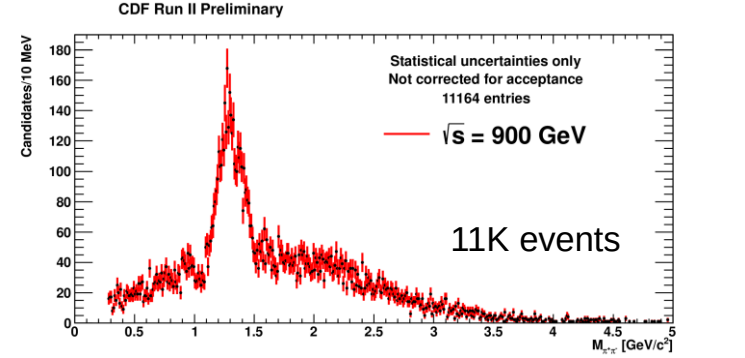


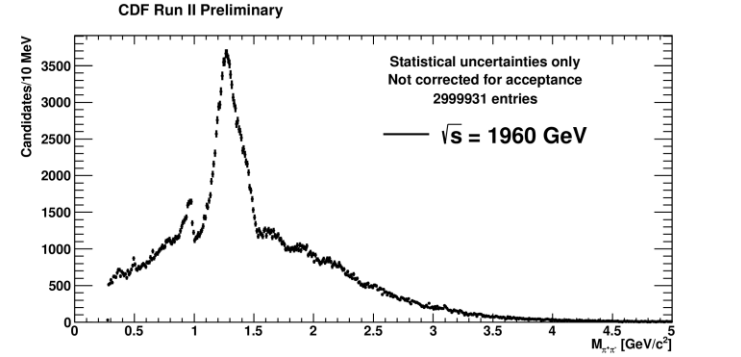


Exclusive Central Hadron Pair Production

- Study $p\bar{p} \rightarrow p\bar{p}$ X, X$\rightarrow\pi^+\pi^-$. Hadron pairs in central y≈0, and between Δy≈4
- Dominated by double pomeron exchange
- Test of of non-perturbative QCD
- Explore hadron spectroscopy and diffraction mechanism
  - Exclusive χ_c production seen in CDF and LHC
  - Test the theory of exclusive Higgs production at LHC
- Study 2-track mass spectra between rapidity gaps from |η|=1.32 to 5.9 at √s = 1960 and 900 GeV
  - Resonant structure attributed to $f_0(980)$ and f_2 (1270) states





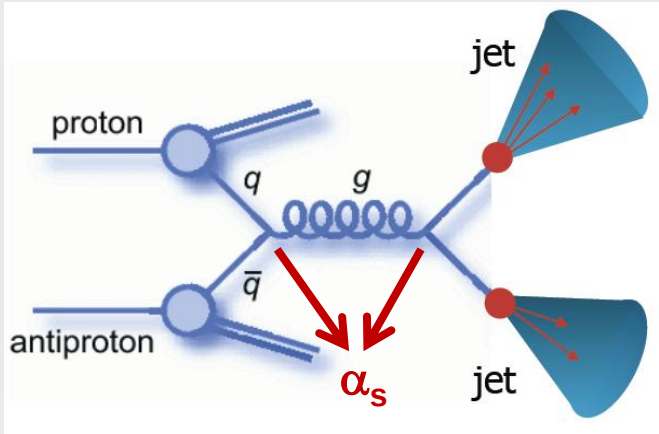


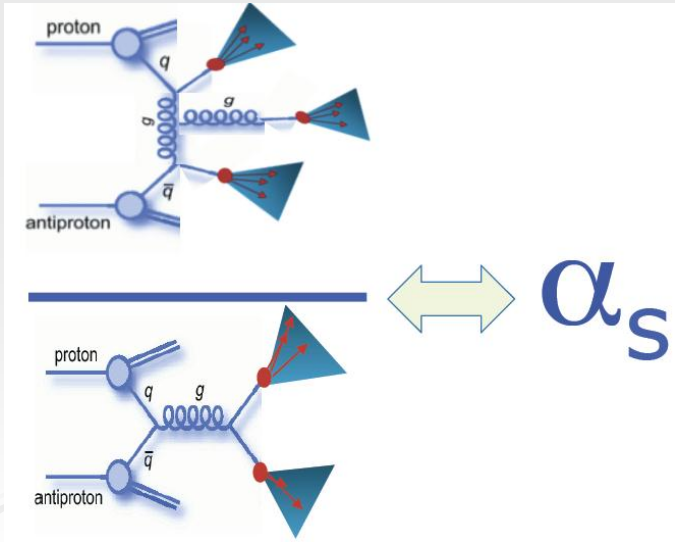
Measuring α_s from Multijet Events

- Renormalization group equation (RGE) describes the dependence of strong coupling α_s on renormalization scale μ_R
- Test validity of RGE:
  - Observables use parton distribution functions (PDFs) of the proton at large scales as input $\Rightarrow$ depends on assumption of the validity of RGE
- Use $R_{\Delta R}$ observable : average number of neighboring jets per jet (New Method)

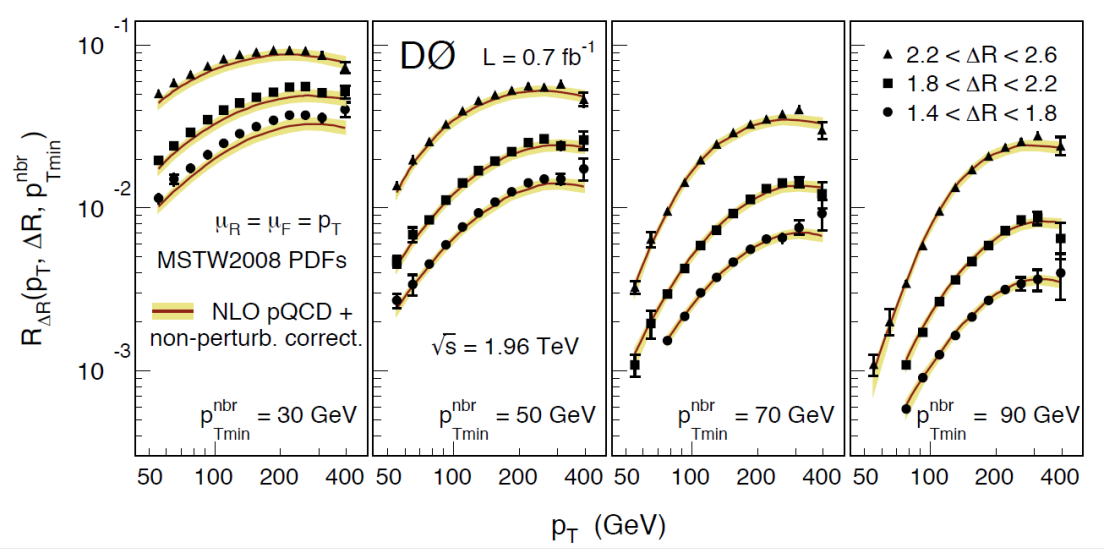
$$R_{\Delta R}(p_T, \Delta R, p_{T\min}^{\mathrm{nbr}}) = \frac{\sum_{i=1}^{N_{\mathrm{jet}}(p_T)} N_{\mathrm{nbr}}^{(i)}(\Delta R, p_{T\min}^{\mathrm{nbr}})}{N_{\mathrm{jet}}(p_T)}$$

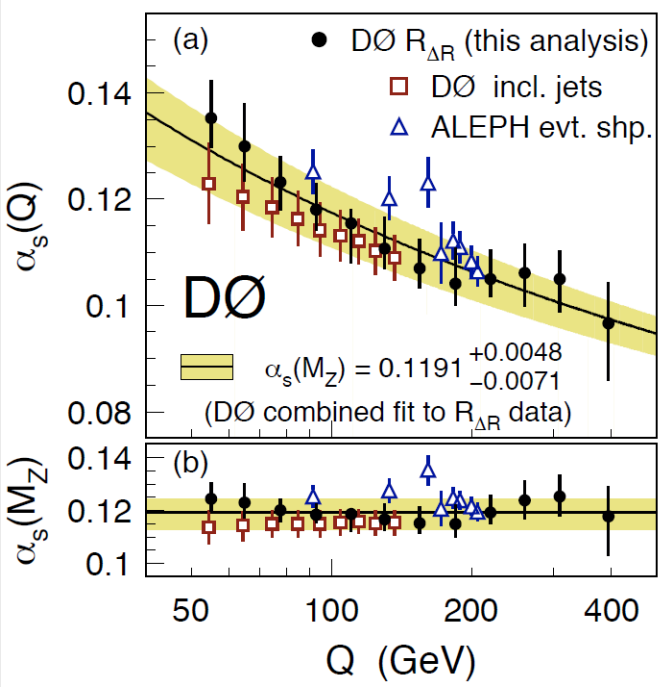
  - Depends on inclusive jet p_T, distance ΔR to neighbor jet in ($\Delta\varphi$, Δy), # of neighboring jets with $P_T > p_T$-nbr requirement
  - This ratio of jet cross sections is proportional to α_s. PDF dependencies almost cancel in the ratio





Measuring α_s (Cont')



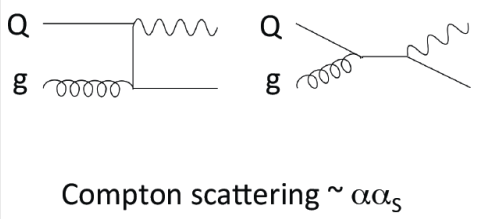


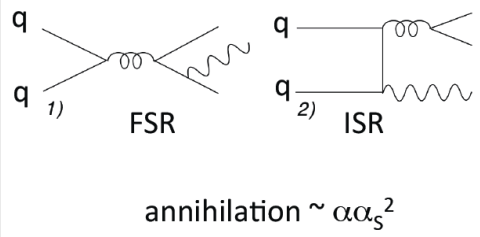
- Measurement of $R_{\Delta R}$ as a function of inclusive jet P_T
  - Dependence of $R_{\Delta R}$ on (p_T , p_T-nbr , ΔR) described by pQCD
- Study dependence of α_S on momentum transfer Q, $\alpha_S(Q)$
  - $\alpha_s(p_T)$ results up to 400 GeV
  - $\alpha_s(p_T)$ decreases with p_T as predicted by the RGE

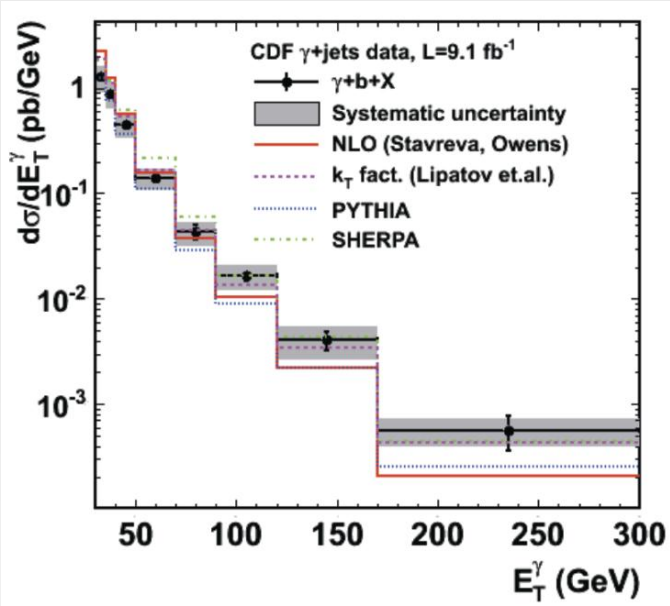
$$\alpha_s(M_Z) = 0.1191^{+0.0048}_{-0.0071}$$

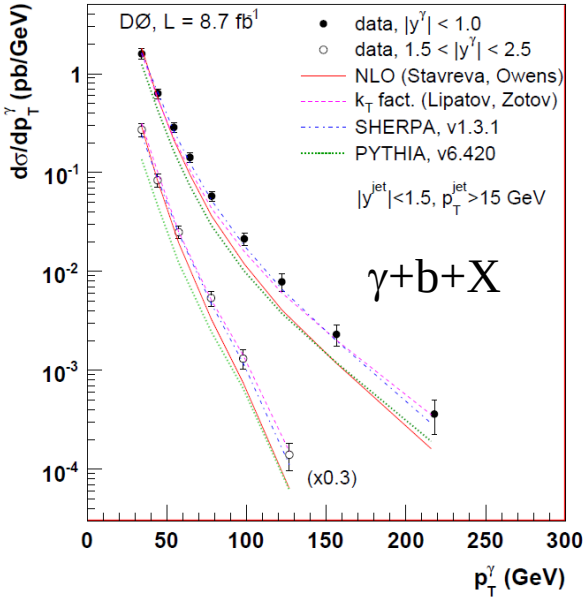
γ+b/c Production Cross Section

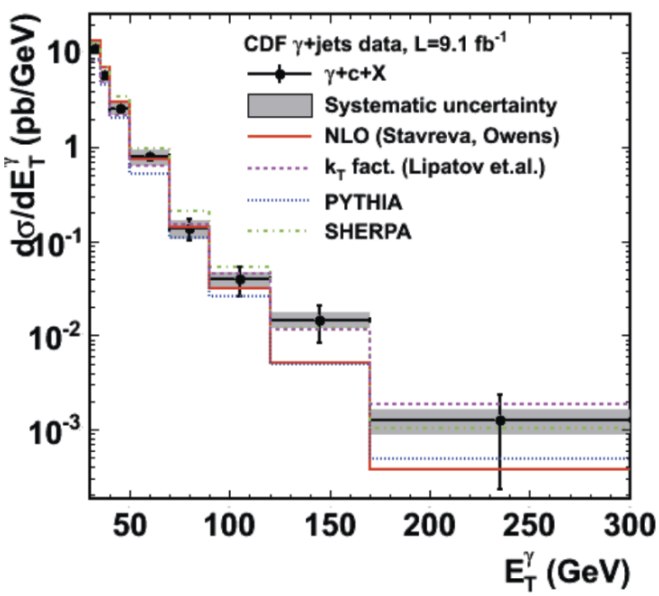
- Probe heavy flavor content in hadrons
- For photons with E_T > 30 GeV
  - Fit b/c/light flavor fractions using secondary vertex mass distribution
- Compare data and predictions: k_T factorization calculation achieves the best agreement with data
  - Similar disagreement with Pythia and NLO
  - CDF Ratio γ+b/γ+c agrees somewhat better



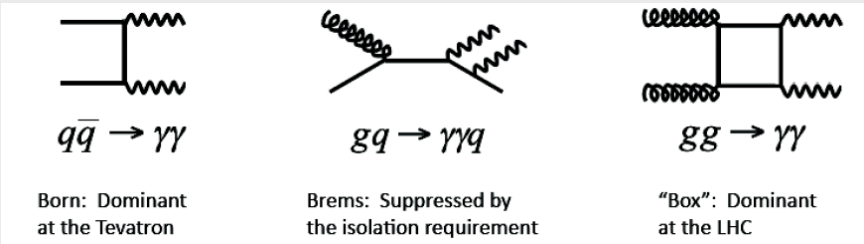


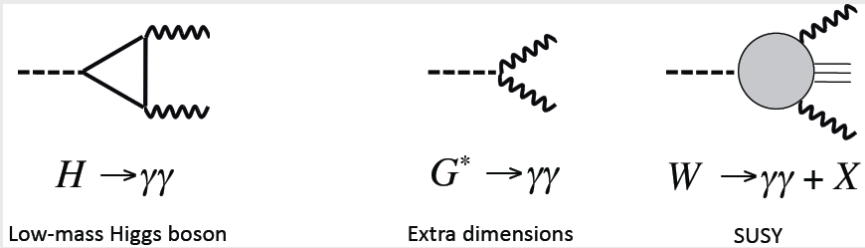




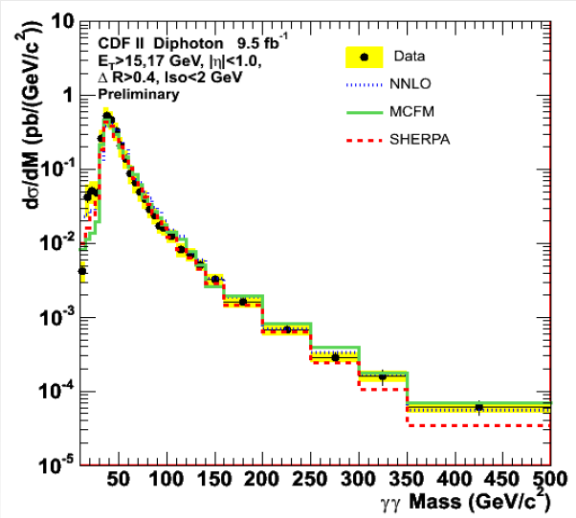


Prompt Isolated γγ Cross Sections





- Sensitive to QCD calculation, as well as a wide variety of BSM models
- Compare data distributions and model predictions of differential cross sections for di-photon distributions: invariant mass, P_T, $\Delta\phi$

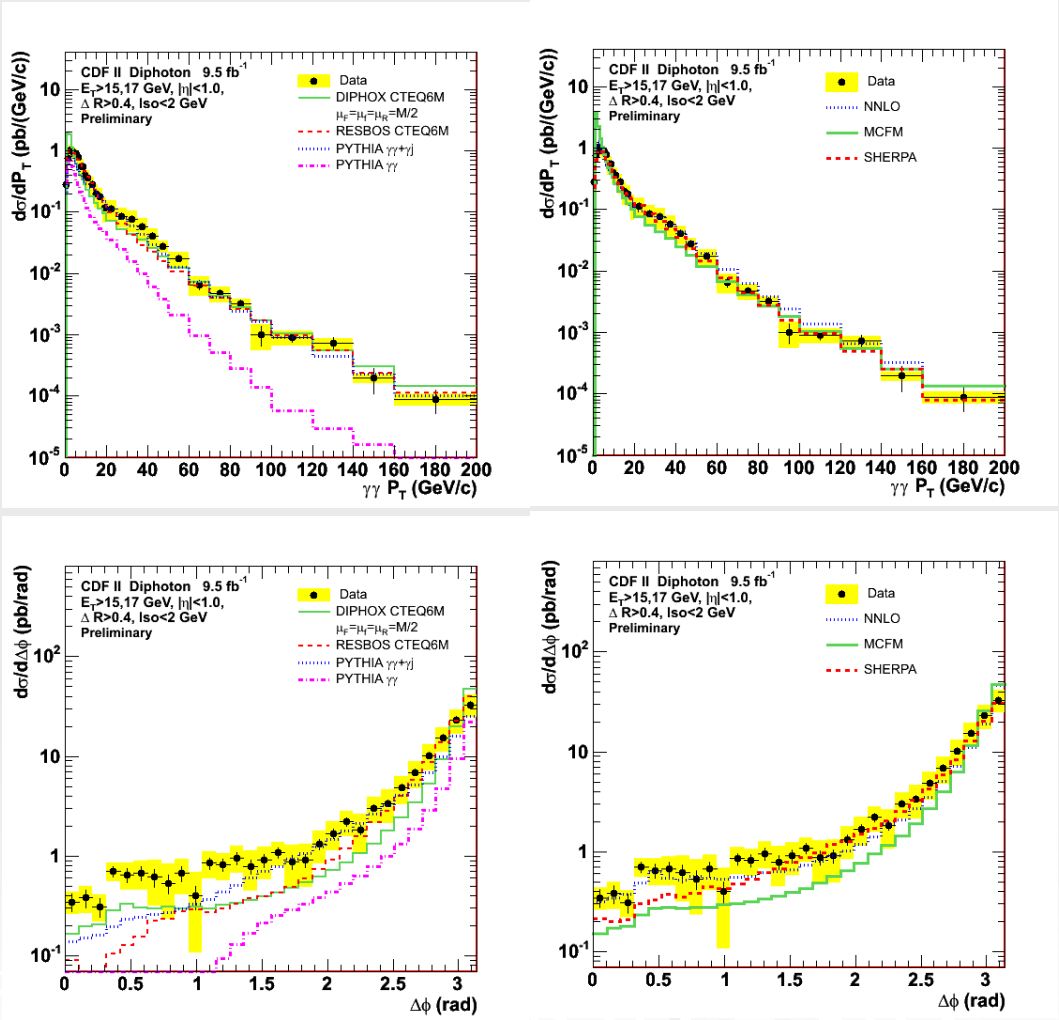


	Total cross section (pb)
Data	$12.3 \pm 0.2_{stat} \pm 3.5_{syst}$
RESBOS	11.3 ± 2.4
DIPHOX	10.6 ± 0.6
MCFM	11.6 ± 0.3
SHERPA	10.9
PYTHIA γγ+γj	9.2
PYTHIA γγ	5.0
NNLO	11.8 + 1.7 – 0.6

- Reasonable agreement for mass distributions above the peak at 30 GeV/c^2
  - 80 <$M_{\gamma\gamma}$<150 GeV/c^2 relevant to Higgs searches

γγ Differential Cross Sections (Cont')

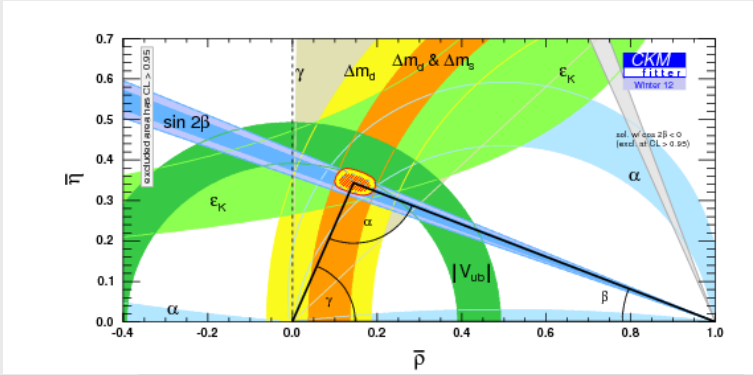
- Pythia direct calculation : fails to describe scale and shape
  - Fixed by including radiation
- The SHERPA calculation overall provides a very good description
  - Somewhat low in regions sensitive to fragmentation (very low mass, very low $\Delta\phi$, large $|\cos\theta|$).
- The RESBOS calculation provides the best description at low P_T, where resummation is important
  - Fails in regions sensitive to fragmentation.



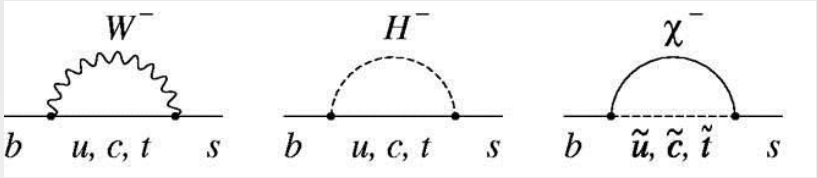
Flavor Physics

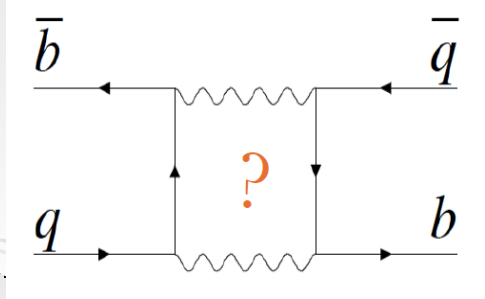
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- Powerful tool to test the SM and probe new physics
  - Flavor problem: Why 3 replications of quarks & leptons?
  - Measure CKM parameters
  - Study CP violation (CPV)
  - Study properties of meson/baryons : mass, lifetime, branching ratios
  - Mass spectroscopy ….
- Probe new physics and large mass scale in loops



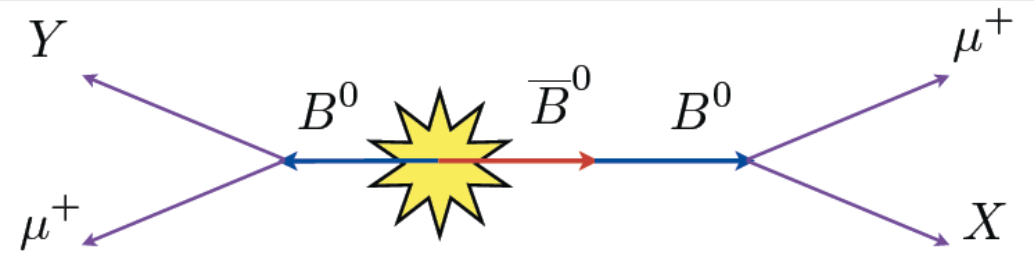
$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$





- Different rates/properties compared to the SM
- Different CPV compared to the SM

Anomalous Like-sign Dimuon Asymmetry



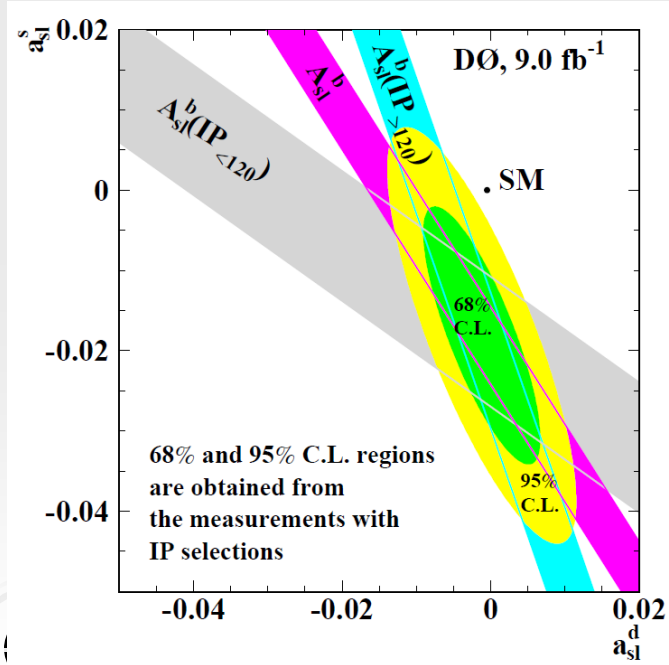
$$A^b_{sl} = (-0.787 \pm 0.172\ (\text{stat}) \pm 0.093\ (\text{syst}))\%$$

$$A^b_{sl}(\text{SM}) = (-0.028^{+0.005}_{-0.006})\%$$

$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = C_d a^d_{sl} + C_s a^s_{sl}$$

$$a^q_{sl} = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q$$

PRD 84, 052007 (2011)



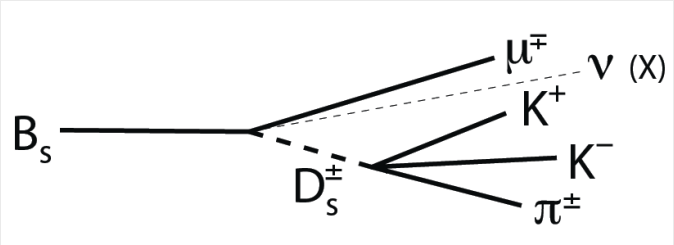
- 3.9σ deviation from SM expectation
- Separate dimuons into B_d and B_s samples using muon impact parameter

$$a^d_{sl} = (-0.12 \pm 0.52)\%$$
$$a^s_{sl} = (-1.81 \pm 1.06)\%$$

  - Uncertainties do not allow for definitive conclusion that a^s_{sl} dominates

Semileptonic Charge Asymmetry Using $B_s^0 \to D_s \mu X$ Decays

- Independent measurement of asymmetry for B_s^0
- SM expected asymmetry $O(10^{-4}\text{-}10^{-5})$
- Flavor of B_s^0 at decay time obtained from the muon charge



$$a_{\rm sl}^s = \frac{\Gamma\left(\bar{B}_s^0 \to B_s^0 \to \ell^+\nu X\right) - \Gamma\left(B_s^0 \to \bar{B}_s^0 \to \ell^-\bar{\nu}\bar{X}\right)}{\Gamma\left(\bar{B}_s^0 \to B_s^0 \to \ell^+\nu X\right) + \Gamma\left(B_s^0 \to \bar{B}_s^0 \to \ell^-\bar{\nu}\bar{X}\right)}$$

$$\ell = \mu \text{ and } X = D_s^{(*)-}$$

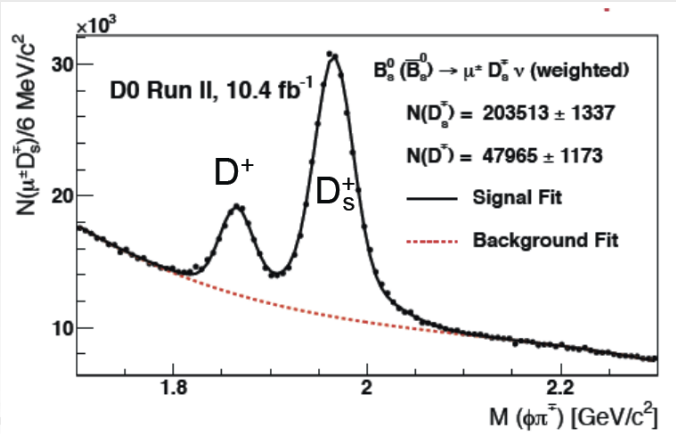
$$D_s^- \to \phi\pi^- \quad \phi \to K^+K^-$$

$$A = \frac{N_{\mu^+D_s^-} - N_{\mu^-D_s^+}}{N_{\mu^+D_s^-} + N_{\mu^-D_s^+}} \qquad a_{\rm sl}^s = \frac{A - A_\mu - A_{\rm track}}{F_{B_s^0}^{\rm osc}}$$

- Correct raw asymmetry A for positively and negatively signed muon and (pion) track asymmetries, B_s^0 oscillation probabilities

$$a_{\rm sl}^s = [-1.08 \pm 0.72\,({\rm stat}) \pm 0.17\,({\rm syst})]\,\%$$

Consistent with SM



Semileptonic Charge Asymmetry Using $B_s^0 \rightarrow D_s \mu X$ Decays (Cont')

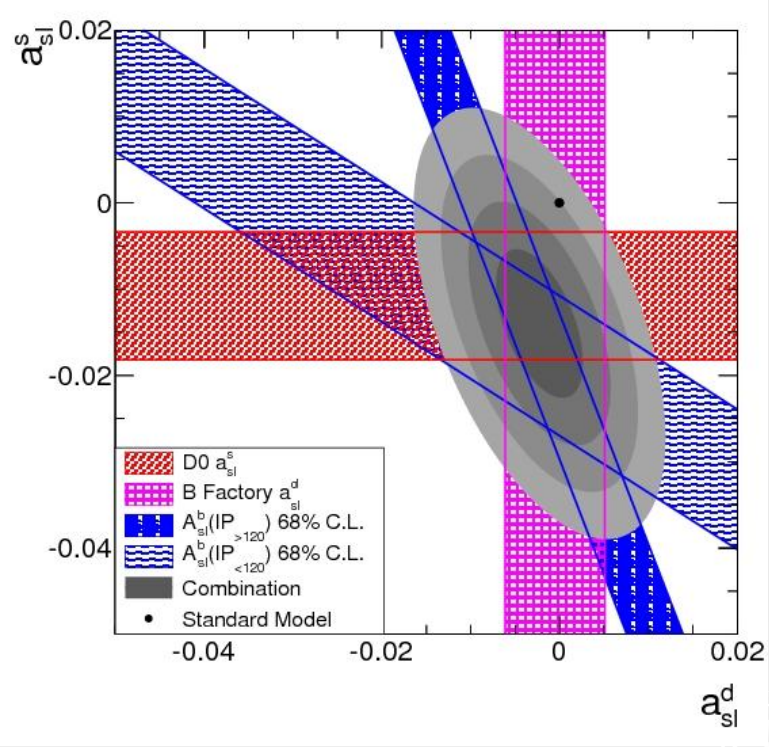
- Combination with D0 like-sign dimuon and B-factory results

$$a_{sl}^s = (-1.40 \pm 0.57)\%$$
$$a_{sl}^d = (-0.22 \pm 0.32)\%$$

  - 2.5σ deviation from the SM

- Also measure a_{sl}^d using $D^+\mu^-\nu$, $D^+ \rightarrow K^+\pi^+\pi^-$

$$a_{sl}^d = (0.93 \pm 0.45 \pm 0.14)\%$$

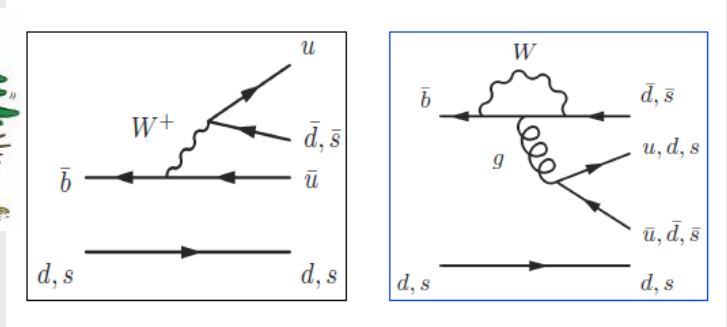


LHCb : $a_{sl}^s = (-0.24 \pm 0.54 \pm 0.33)\%$

B-Factory : $a_{sl}^d = (-0.05 \pm 0.56)\%$

Direct CPV in Charmless B Decays

- Direct CPV asymmetries require at least two (SM or NP) amplitudes with different strong and weak phases:



$$a_f = a_1 e^{i(\delta_1+\phi_1)} + a_2 e^{i(\delta_2+\phi_2)} \qquad \bar{a}_{\bar{f}} = a_1 e^{i(\delta_1-\phi_1)} + a_2 e^{i(\delta_2-\phi_2)}$$

$$A_{CP} = \frac{\left|\bar{a}_{\bar{f}}\right|^2 - \left|a_f\right|^2}{\left|\bar{a}_{\bar{f}}\right|^2 + \left|a_f\right|^2} = \frac{2a_1a_2\sin(\delta_2-\delta_1)\sin(\phi_2-\phi_1)}{a_1^2+a_2^2+2a_1a_2\cos(\delta_2-\delta_1)\cos(\phi_2-\phi_1)}$$

- Penguin-dominated decays sensitive to extra CP-violating phases due to NP

- Look at charmless decays $B^0 \to K^+\pi^-$, $B_s^0 \to K^-\pi^+$, $\Lambda_b^0 \to pK^-$, $\Lambda_b^0 \to p\pi^-$

$$A_{CP} = \frac{N(b \to f) - c_f N(\bar{b} \to \bar{f})}{N(b \to f) + c_f N(\bar{b} \to \bar{f})}$$

Count and correct for detector induced charge asymmetries

Direct CPV in Charmless B Decays (Cont')

- Determine fraction of individual modes and charge asymmetries, using an unbinned LH fit incorporating kinematic and PID information
- $\mathbf{A_{CP}(B^0 \to K^+\pi^-) = -0.083 \pm 0.013 \pm 0.003}$

  Significance > 5σ
- $\mathbf{A_{CP}(B_s^0 \to K^-\pi^+) = +0.22 \pm 0.07 \pm 0.02}$

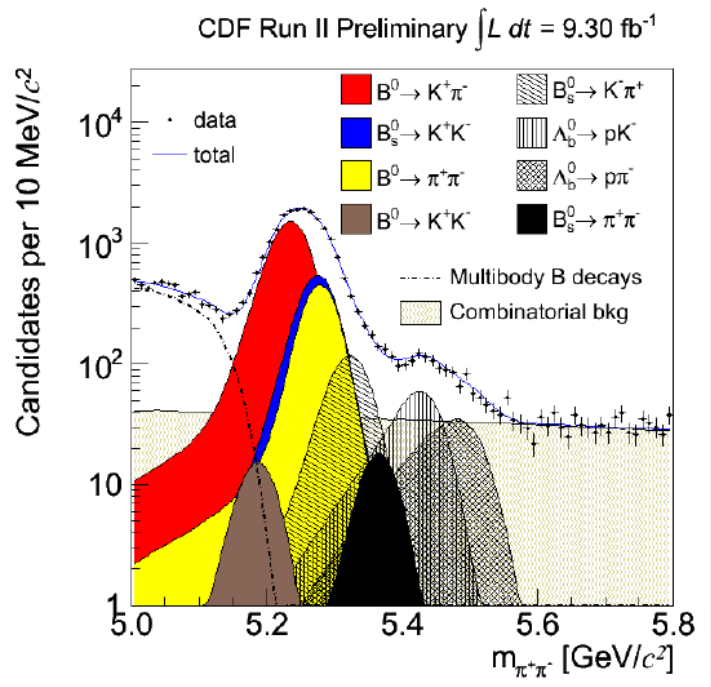
  2.9σ significance.

  LHCb $A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.08 \pm 0.02 \Rightarrow 3.3\sigma$

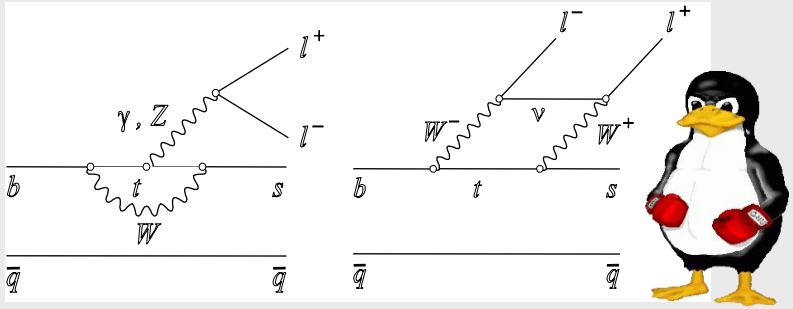
  CDF and LHCb average ⇒ 4.5σ

  SM prediction ~30% asymmetry
- $\mathbf{A_{CP}(\Lambda_b^0 \to p\pi^-) = +0.07 \pm 0.07 \pm 0.03}$
  $\mathbf{A_{CP}(\Lambda_b^0 \to pK^-) = -0.09 \pm 0.08 \pm 0.04}$

  SM predicts upto ~10% asymmetry
- Consistent with SM and other experiments



Exclusive $b \to s\mu^+\mu^-$ Measurements



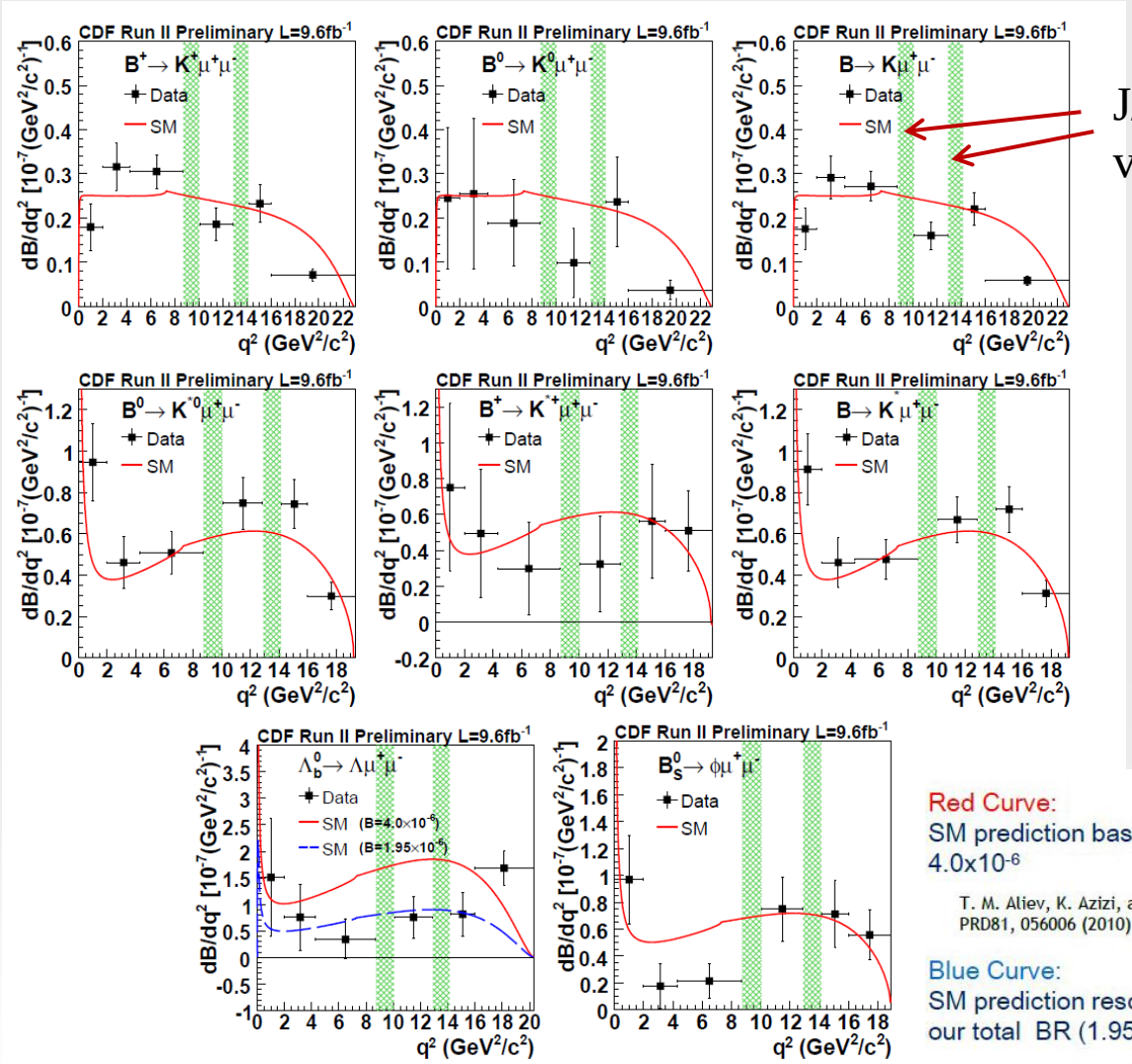
- Flavor Changing Neutral Current (FCNC)
  - SM predicted rates $O(10^{-6})$
- Reconstruct decays:

$$B^+ \to K^+\mu^+\mu^-,\ B^0 \to K^*(892)^0\ \mu^+\mu^-,\ B_s^0 \to \phi(1020)\ \mu^+\mu^-,$$

$$B^0 \to K_s^0\ \mu^+\mu^-,\ B^+ \to K^*(892)^+\mu^+\mu^-,\ \Lambda_b^0 \to \Lambda\mu^+\mu^-$$

- Study distributions as a function of di-muon invariant mass $q^2 = M^2_{\mu\mu}c^2$
  - In the SM framework theory calculations of the angular observables at different q^2 ranges are described in terms of short term Wilson coefficient $C^{eff}_{7,9,10}$ $\Rightarrow$ modified in various BSM physics scenario
- To cancel dominant systematic uncertainties use the corresponding resonant channel $Hb \to J/\psi h$
  - Where ($H = B^+, B^0, B_s^0, \Lambda_b^0$) and ($h = K^+, K^{*0}, \phi, K_s^0, K^{*+}$ and Λ)

Differential Branching Ratio



J/ψ and ψ′ veto

Red Curve:
SM prediction based on 4.0×10^{-6}

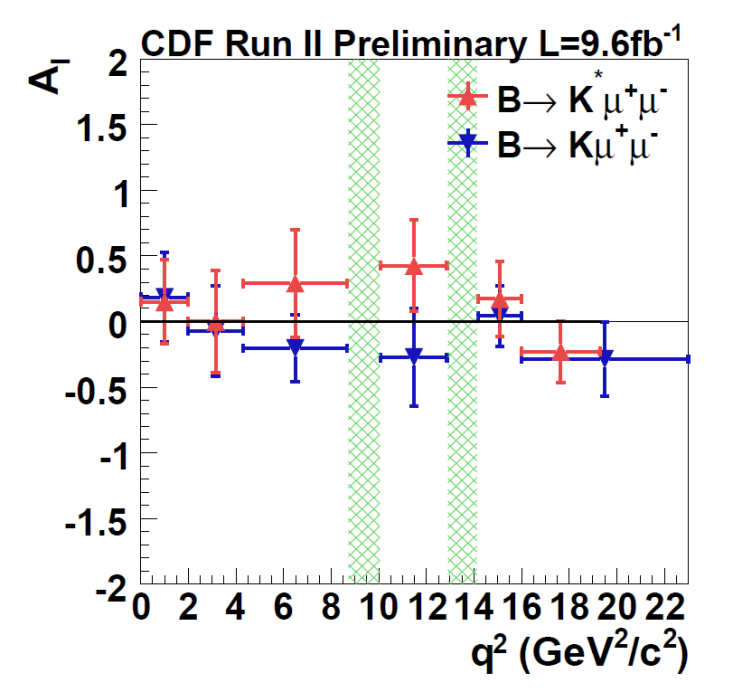
T. M. Aliev, K. Azizi, and M. Savci, PRD81, 056006 (2010)

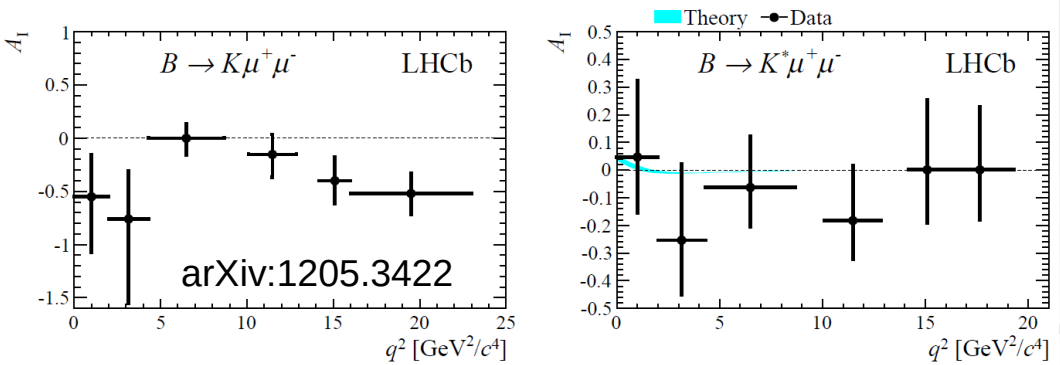
Blue Curve:
SM prediction rescaled to our total BR (1.95/4.0)

Isospin Asymmetry

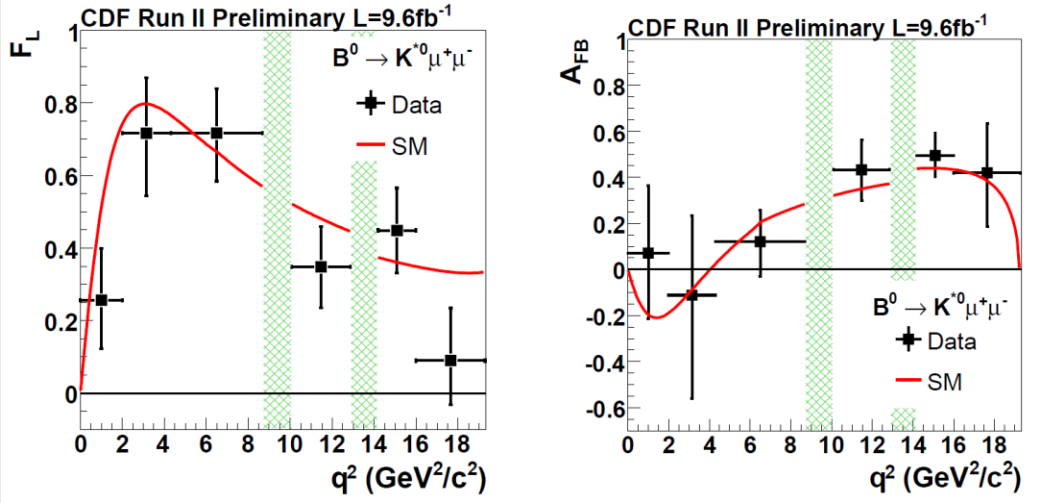
$$A_I^{(*)} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

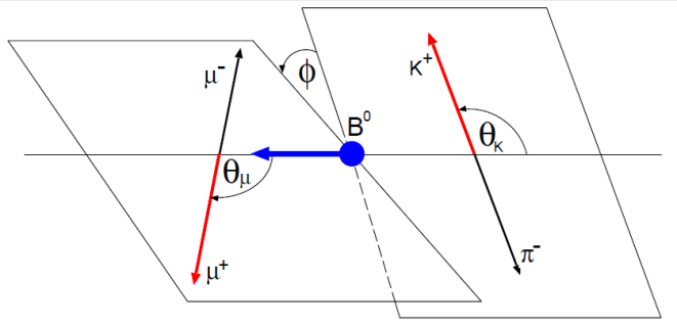
- Differential results compatible with zero
- Previous LHCb, BaBar results showed A_I~4 sigma below zero!
- New BaBar result consistent with zero (arXiv:1204.3933)
- CDF result competitive with LHCb





Angular Analysis on $B \to K^{(*)}\mu^+\mu^-$





- A_{FB} : Muon forward backward asymmetry
- F_L : K* longitudinal polarization

$$\frac{1}{\Gamma}\frac{d\Gamma(B \to K^*\mu^+\mu^-)}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

$$\frac{1}{\Gamma}\frac{d\Gamma(B \to K^*\mu^+\mu^-)}{d\cos\theta_\mu} = \frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu$$

Results consistent with the SM prediction

Evidence of the Bottom Baryon Resonance Λ_b^{*0}

- Baryon with heavy quark Q can be used to test non-perturbative QCD
  - Modeled in a framework of heavy quark effective theories (HQET)
- Search for resonance state Λ_b^{*0} in the decay mode:

$$\Lambda_b^{*0} \rightarrow \Lambda_b^0 \pi^- \pi^+ \text{ where } \Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-, \Lambda_c^+ \rightarrow p\, K^- \pi^+$$

- Λ_b^{*0} mass distribution analyzed using Q-value

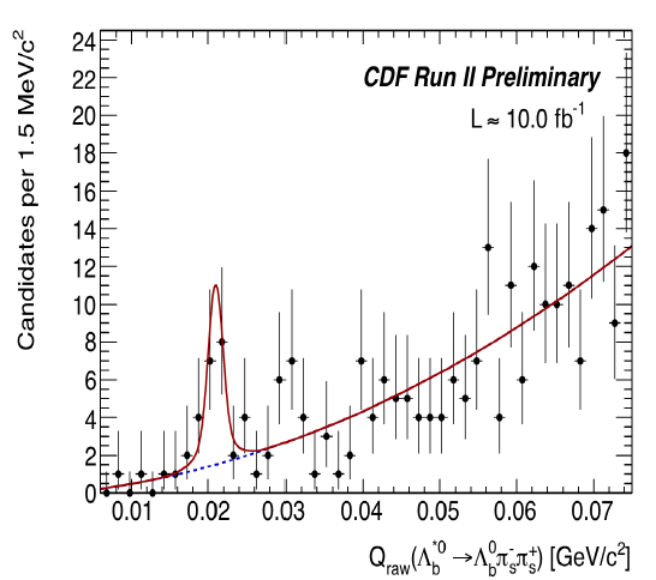
$$Q = m(\Lambda_b^0 \pi^- \pi^+) - m(\Lambda_b^0) - 2m_\pi$$

- The significance of signal is 3.5 σ
- Mass of observed state:

$$5919.5 \pm 0.35\ (\text{stat}) \pm 1.72\ (\text{syst})\ \text{MeV}/c^2$$

(Syst includes Λ_b^0-mass uncertainty of 0.7 MeV/c^2)

- *Confirms one of two LHCb observed resonances $\Lambda_b^{*0}(5920)$*



$$M_{\Lambda_b^{*0}(5920)} = 5919.76 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}) \pm 0.66\ (\Lambda_b^0\text{-mass uncertainty})\ \text{MeV}/c^2$$

The Top Quark

- Existence required by the SM
  - Spin 1/2, charge +2/3, weak-isospin partner of the bottom quark
- Discovered in 1995 at Tevatron
- Mass ~173.3 GeV/c^2
  - Only SM fermion with mass at the EW scale
- Top decays before hadronization: $\Gamma \sim 1.4$ GeV $\gg \Lambda_{QCD}$
  - Provide an unique opportunity to study a "bare" quark

Trying to address some of the questions:

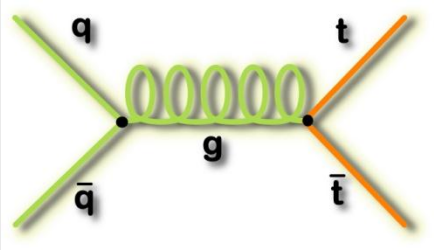
- Why is top so heavy ? Is top related to the EWSB mechanism?
- Is it the SM top?
- Search for beyond SM physics : decay into new particles, non-SM couplings

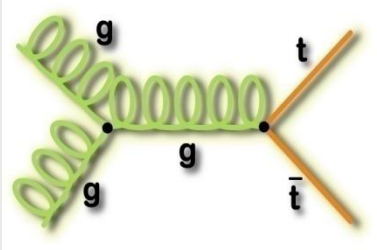
Top Quark Pair at Tevatron

- Predominantly pair produced via strong interaction
  - $\sigma_{tt} = 7.45^{+0.72}_{-0.63}$ pb

  for m_{top}=172.5 GeV/c^2

  (Nucl. Phys. Proc. Suppl. 183, 75 (2008))



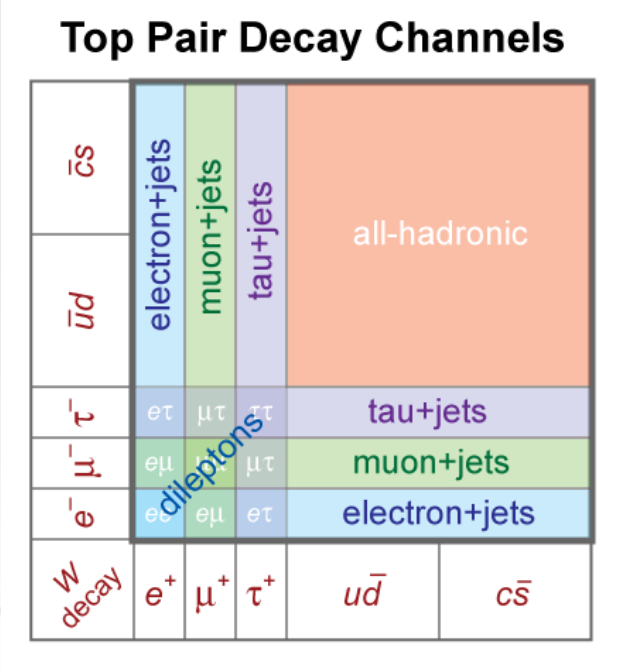


~85% from qq→ttbar ~15% from gg→ttbar

Top Quark Pair Production

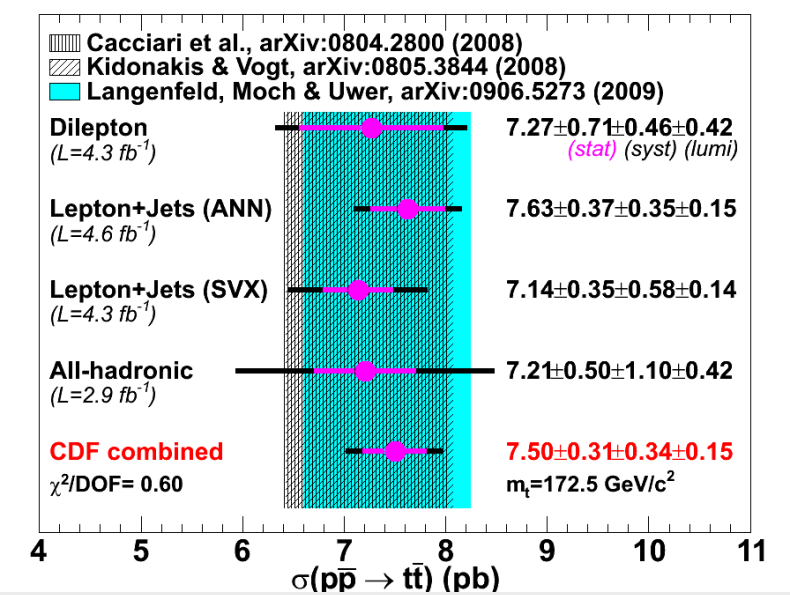
In the SM Br(t →Wb) ~ 100%

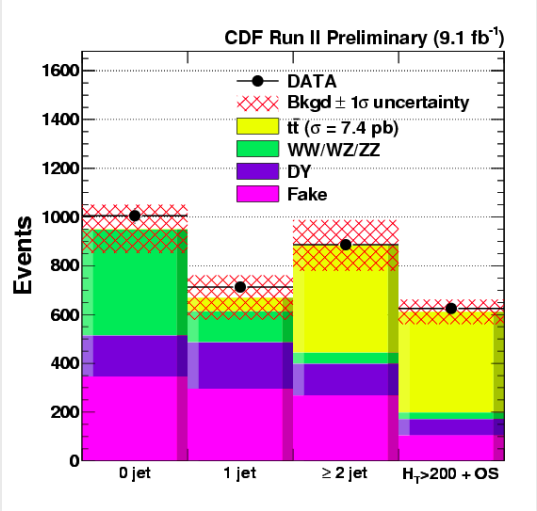
- Top pair decay channels
  - Dilepton : $l\nu l\nu bb$
  - Lepton+jets : $l\nu qqbb$
  - All-hadronic: $qqqqbb$

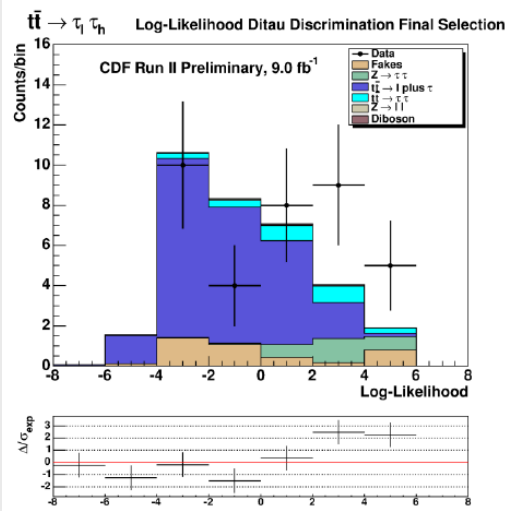


Top Pair Production Cross-Section

- Tests QCD in very high Q^2 regime. Compare measured cross sections among various ttbar final states. ⇒ Anomalies would indicate the presence of non-QCD production







CDF combination (up to 4.6 fb^{-1}) : $\sigma = 7.5 \pm 0.31_{stat} \pm 0.34_{syst} \pm 0.15_{Z\text{-theory}}$ pb

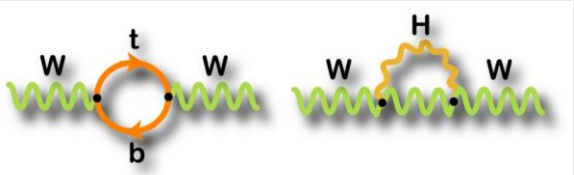
Dilepton (l = e, μ): $\sigma(\text{Pretagged}) = 7.66 \pm 0.46_{stat} \pm 0.66_{syst} \pm 0.47_{lumi}$ pb

$\sigma(\text{b-tagged}) = 7.47 \pm 0.50_{stat} \pm 0\ 53_{syst} \pm 0.46_{lumi}$ pb

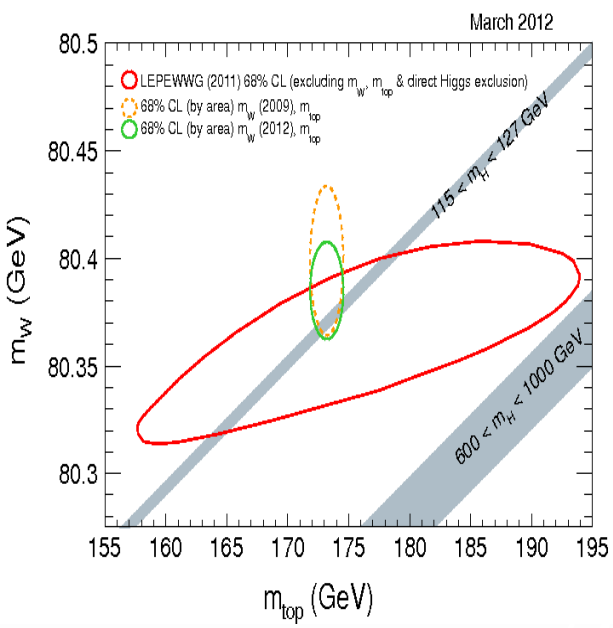
Dilepton (with τ) : $\sigma = 8.2 \pm 2.3_{stat} \pm 1.2_{syst} \pm 0.5_{lumi}$ pb

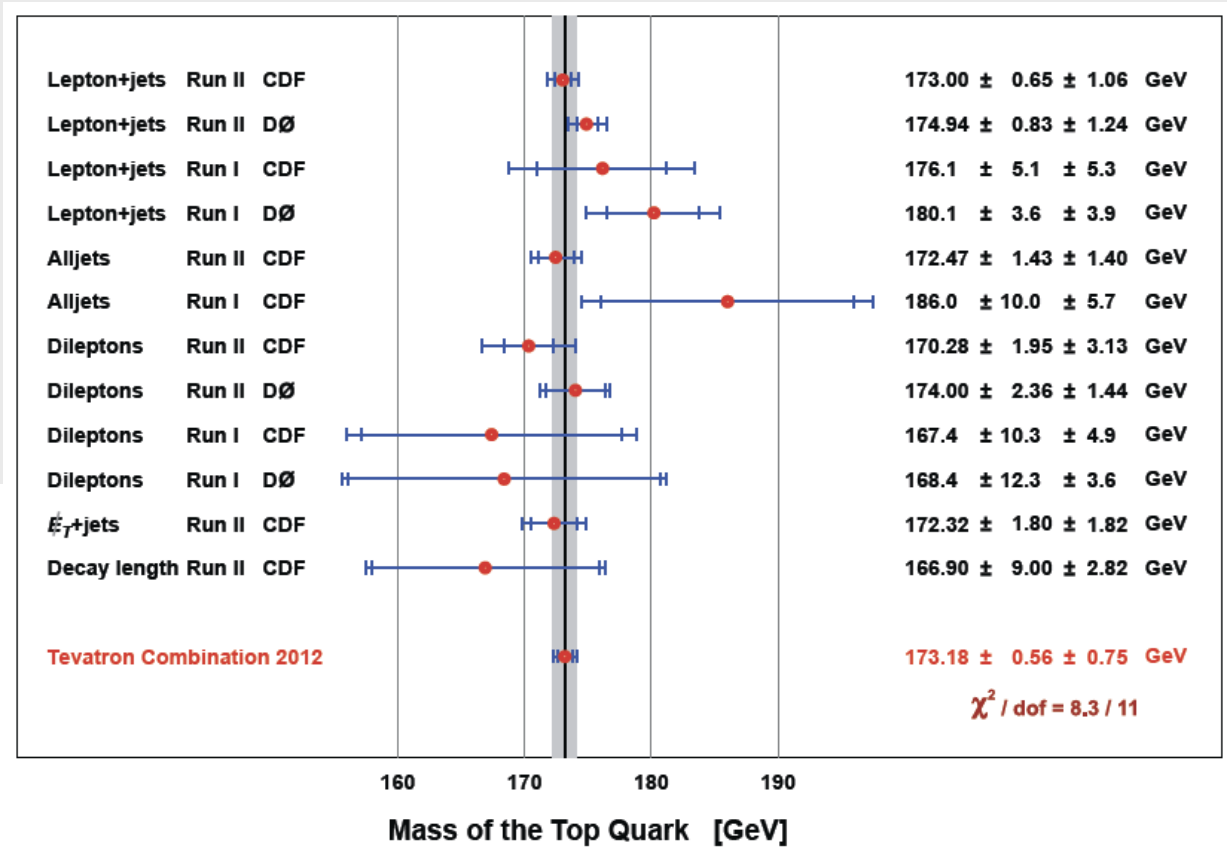
Top Quark Mass

- Related to SM observables through loop diagrams
- Consistency checks of SM parameters



$\Delta m_W \propto m_t^2$ $\Delta m_W \propto \ln m_H$



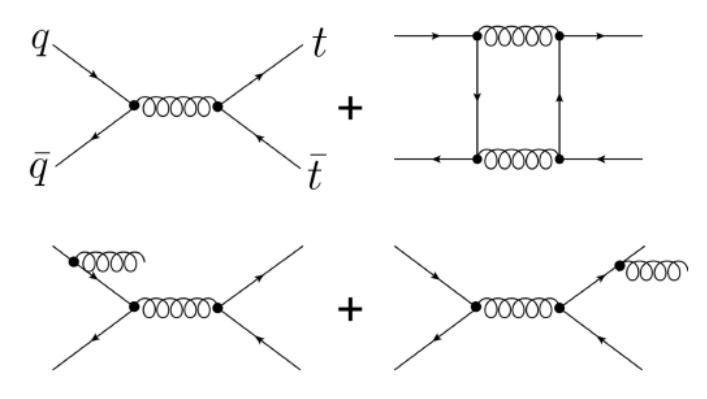


Tevatron Combination
$m_t = 173.18 \pm 0.94$ GeV/c^2
Precision 0.54% with upto 5.8 fb^{-1} data

Forward Backward Asymmetry in Top Pair Production

- Asymmetry caused by interference of ME amplitudes for same final state
- Significantly enhanced in BSM models: Z'-like states with parity violating coupling , theories with chiral color
- The SM prediction (QCD at NLO) :

$$A^{ttbar} = 0.058 \pm 0.009$$



$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

Δy $t\bar{t}$ rapidity difference: $y_t - y_{\bar{t}}$

- Look at A^{ttbar} dependence on the invariant mass of ttbar
  - Sensitive to new physics effect

A^{ttbar} (cont')

- Corrects for acceptance and smearing effects
- CDF Lepton+Jets (8.7 fb^{-1}):

Inclusive parton-level

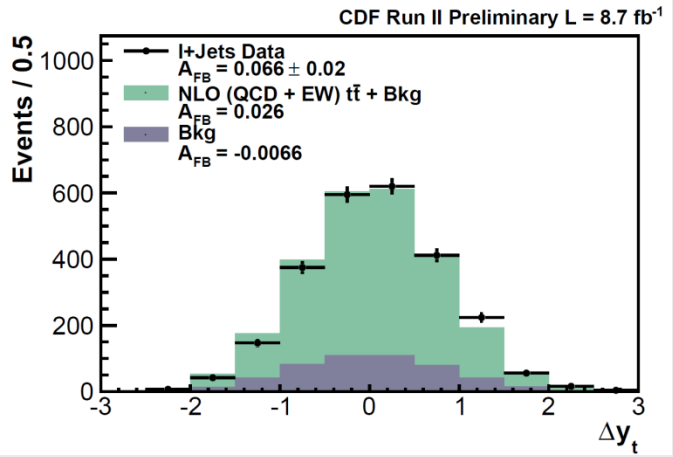
$A^{ttbar} = (16.2 \pm 4.7_{stat})\%$

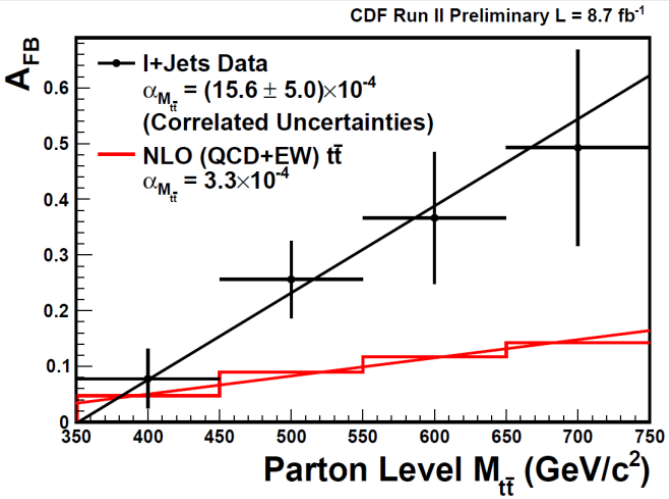
3.4σ from no asymmetry, 2σ from NLO SM

Parton-level $A^{ttbar}(M_{tt})$ slope

$(15.6 \pm 5.0) \times 10^{-4}$.

Compare to 3.3×10^{-4} from NLO SM.





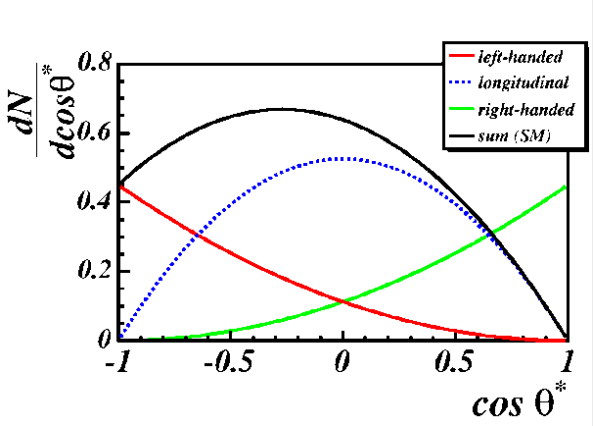
- D0 lepton+jets and dilepton channel combinaiton (5.4 fb^{-1}):

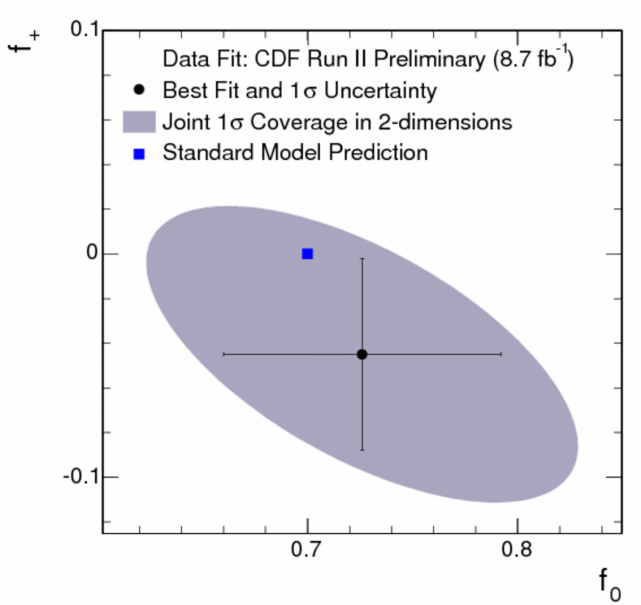
$A^{ttbar} = (11.8 \pm 3.2)\%$

2.2 σ above higher order QCD+EW prediction

Polarization of W from Top Decay

- V-A coupling in the SM
  - longitudinal fraction f_0 ~70%
  - left-handed fraction f_- ~30%
  - right-handed fraction f_+ ~0%
- Sensitive to non-SM tWb coupling
- Use θ*: Angle between lepton (down-type quark) in W rest frame and the momentum of the W in the top rest frame





Simultaneous measurement of f_0 and f_+

- **CDF (lepton+jets, 8.7 fb^{-1}):**

  $f_0 = 0.726 \pm 0.066\ (\text{stat}) \pm 0.067\ (\text{syst})$

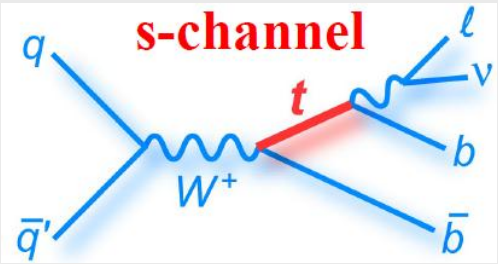
  $f_+ = -0.045 \pm 0.043\ (\text{stat}) \pm 0.058\ (\text{syst})$
- **Tevatron Combination (lepton+jets and dilepton, 2.7-5.4 fb^{-1})**

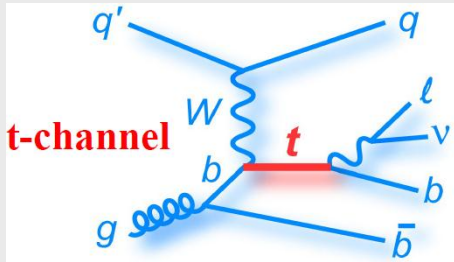
  $f_0 = 0.722 \pm 0.062\ (\text{stat}) \pm 0.052\ (\text{syst})$

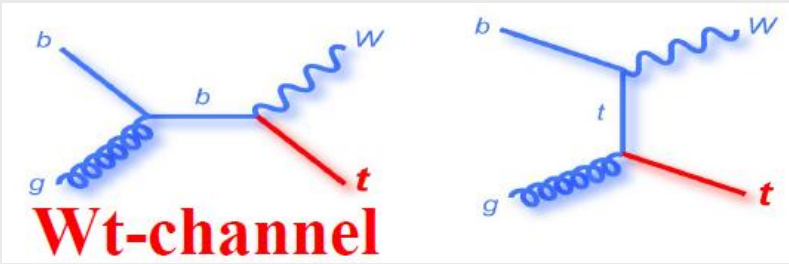
  $f_+ = -0.033 \pm 0.034\ (\text{stat}) \pm 0.031\ (\text{syst})$

LHC measurements already have a smaller statistical uncertainty. Systematic uncertainties are comparable

EW Single Top Production

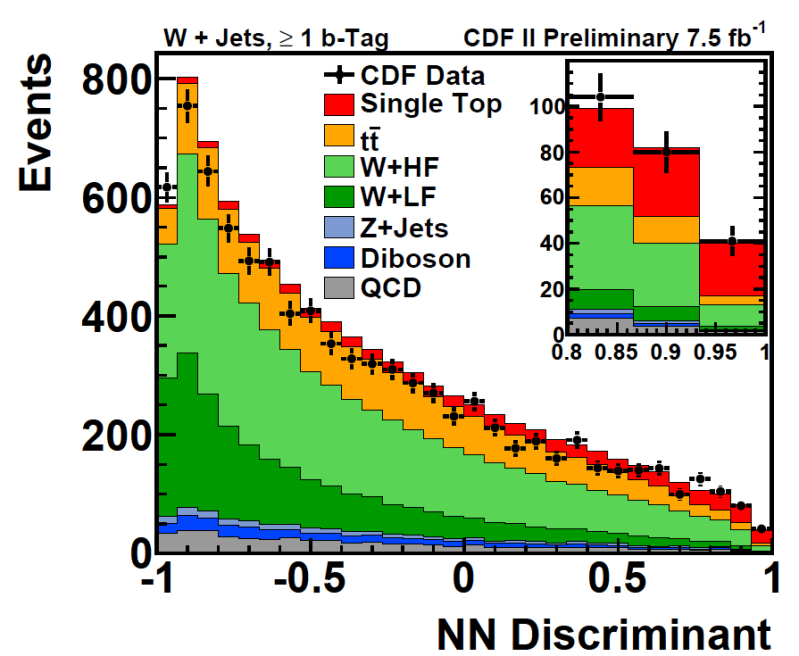




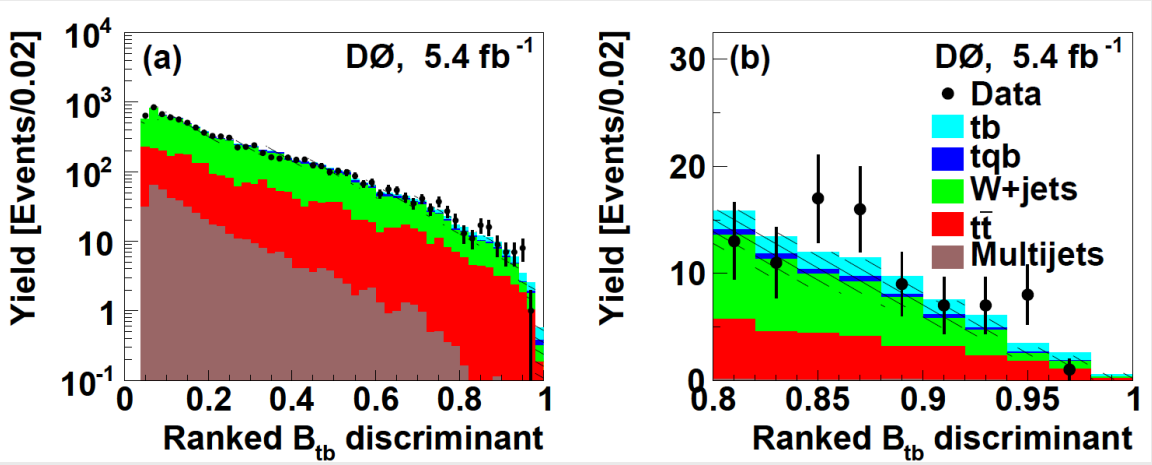


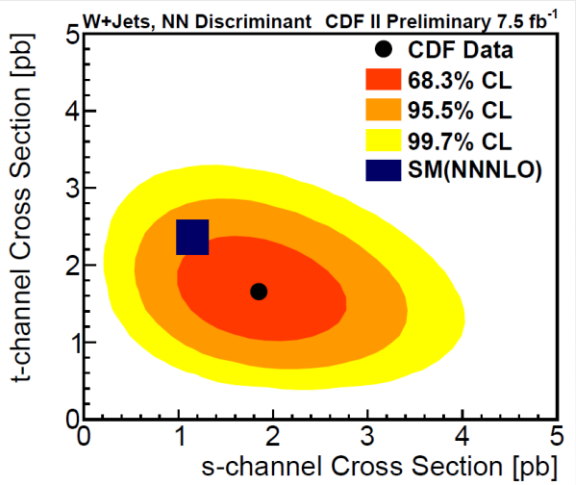
Collider	s-channel: σ_{tb}	t-channel: σ_{tqb}	Wt-channel: σ_{tW}
Tevatron: $p\bar{p}$ (1.96 TeV)	1.04 pb	2.26 pb	0.28 pb
LHC: pp (7 TeV)	4.6 pb	64.6 pb	15.7 pb

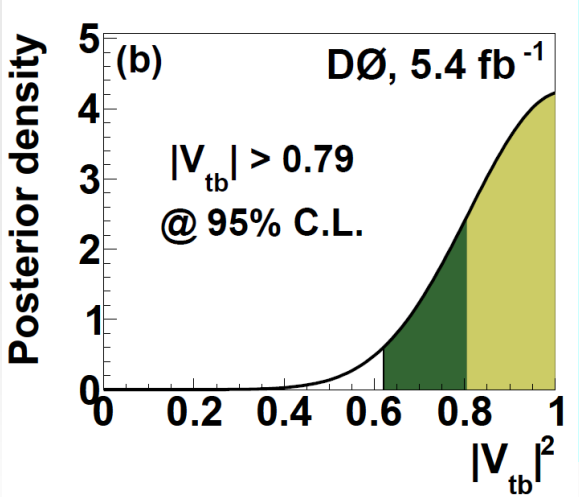
- First observation by CDF and D0 in March 2009
- Direct measurement of V_{tb}
- Produced ~100% polarized top
  - Test of the V-A structure of the top EW interaction
- Sensitive to beyond SM physics
  - t-channel: 4th family, FCNC
  - s-channel: W', H^+
- Large amount of W+jets backgrounds
  - After requiring ≥1 b-tag S:B ~ 1:20
  - Multivariate discriminant techniques applied for signal-background separation



EW Single Top Production







- **CDF (7.5 fb^{-1})**

  $\sigma_{s+t} = 3.05^{+0.57}_{-0.53}$ pb

  $|V_{tb}| > 0.78$ at 95% CL

  From 2D fit :

  $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb

  $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb

- **D0 (5.4 fb^{-1})**

  $\sigma_{s+t} = 3.43^{+0.73}_{-0.74}$ pb

  $0.79 \leq |V_{tb}| \leq 1$ at 95% CL

  From 2D fit

  $\sigma_s = 0.68^{+0.38}_{-0.35}$pb

  $\sigma_t = 2.86^{+0.69}_{-0.63}$pb

More Physics Results From Tevatron

Apologies for my many omissions.

For a full listing of results go to:

- http://www-cdf.fnal.gov/physics/new/qcd/QCD.html
- http://www-cdf.fnal.gov/internal/physics/bottom/bottom.html
- http://www-cdf.fnal.gov/physics/new/top/top.html
- http://www-d0.fnal.gov/Run2Physics/D0Summer2012.html

Summary

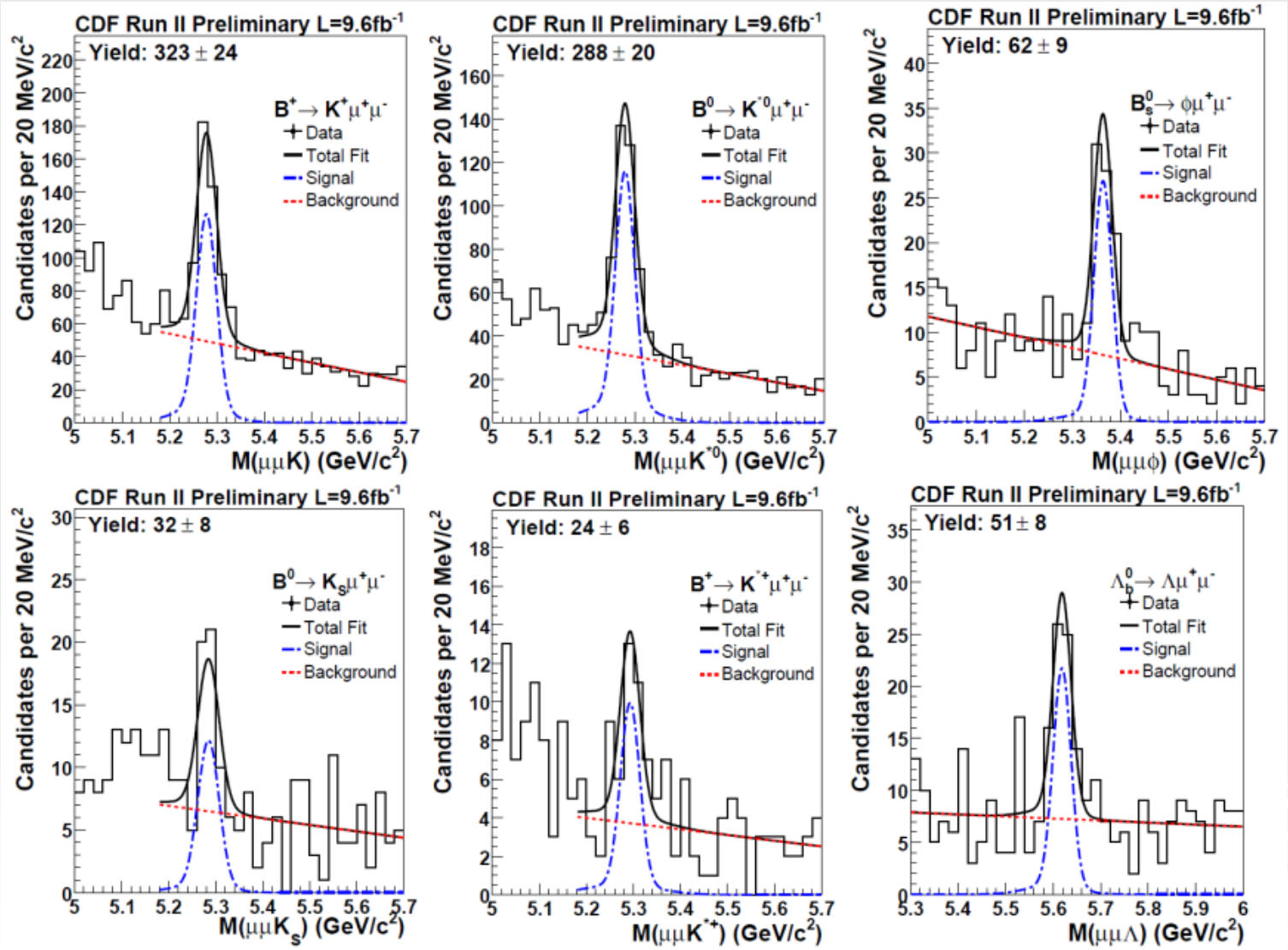
CDF and D0 experiments are producing a breadth of results using the full RunII dataset

- These are the legacy measurements of Tevatron RunII
- Many offer world class sensitivity
- Some are complementary to future results due to differences in production mechanisms (e.g. QCD, s-channel single top, A^{ttbar})
- Most of the results agree with the SM predictions
  - A few intriguing discrepancies persist: A^{ttbar}, like-sign di-muon asymmetry
- Most of the results are in agreement with results form LHC, LHCb, and B-factories

Next talk by Marco Verzocchi will cover Higgs searches and related topics

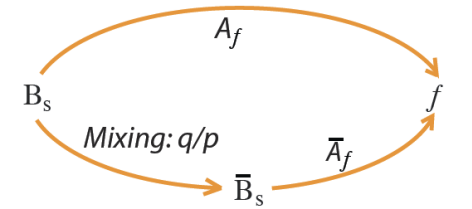
BACKUP SLIDES

Exclusive $b \to s\mu^+\mu^-$ Measurements



$B_s^0 \to J/\psi f_2'(1525)$ in $\mu^+\mu^- K^+K^-$

- Final states common to both mesons and anti-mesons
  - CPV from interference in mixing and decay
  - SM predicts small CPV for $B_s^0 \to J/\psi X$ decays $(X = K^+K^-, \pi^+\pi^-)$
  - Sensitive to new phenomena

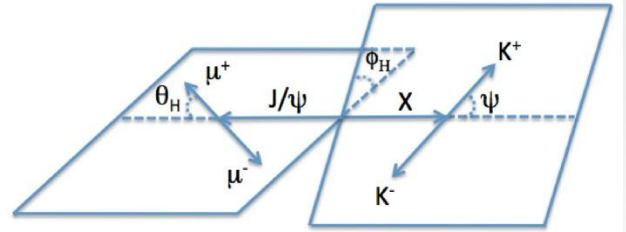


- Measure ratio of branching fractions $B_s^0 \to J/\psi\, f'_2$ and $B_s^0 \to J/\psi\, \phi$:

  $0.22 \pm 0.05\,(\text{stat}) \pm 0.04\,(\text{syst})$

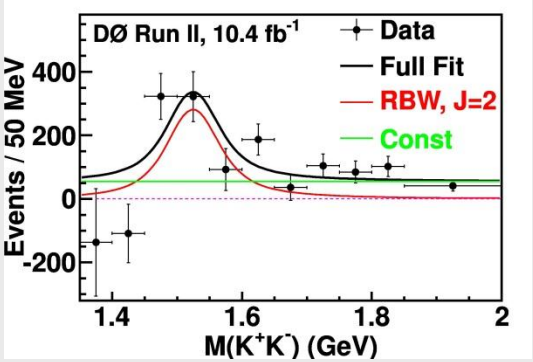
- Fit helicity angle ψ in the K^+K^- rest frame

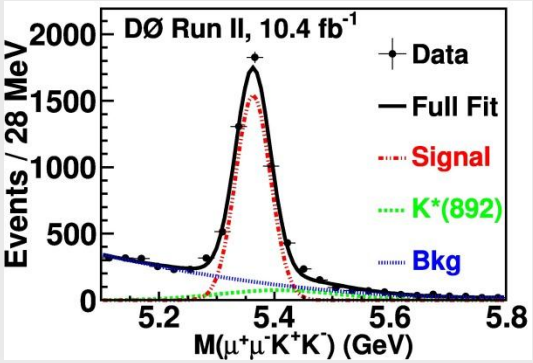
  Consistent with J=2 with Prob=0.3 and incompatible with J=0 or 1

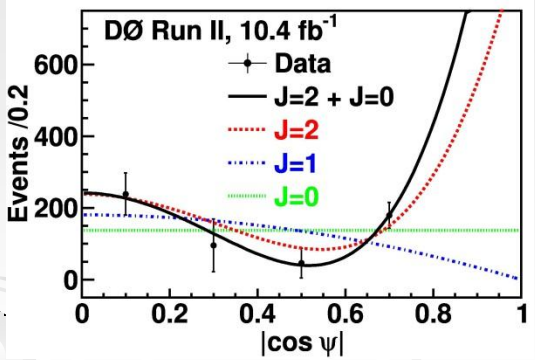


- *Confirm recent LHCb observations*

  $BR(B_s^0 \to J/\psi\, f'_2)/BR(B_s^0 \to J/\psi\, \phi) = (26.4 \pm 2.7 \pm 2.4)\%$







Measurement of the ratio $R = B(t \to Wb)/B(t \to Wq)$

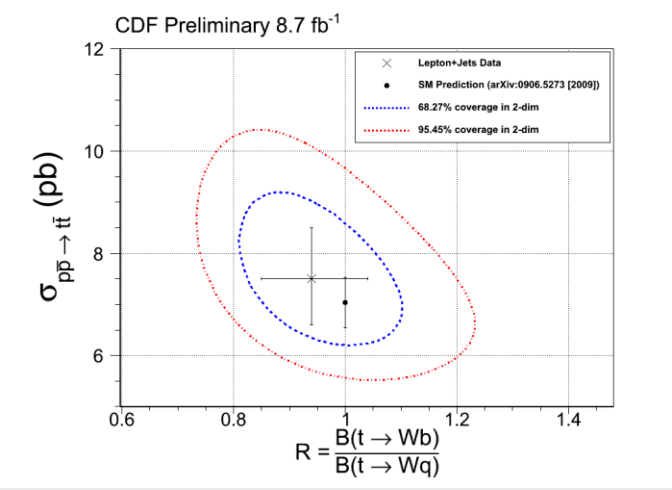
- CDF analysis using lepton+jets channel using 8.7 fb^{-1} simultaneously measure R and $\sigma_{pp \to tt}$

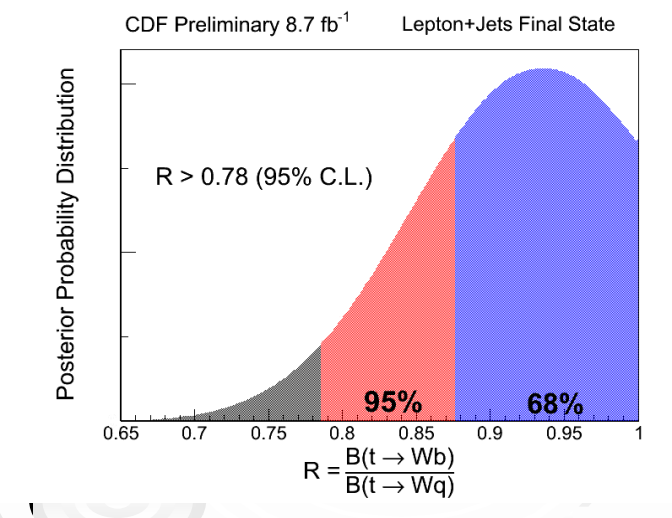
  $R = 0.94 \pm 0.04\ (stat) \pm 0.09\ (syst)$

  $\sigma_{pp \to tt} = 7.5 \pm 0.3\ (stat) \pm 0.9\ (syst)\ pb$

- $|V_{tb}|>0.89$ at 95% CL, assuming unitarity of the 3x3 CKM matrix
  - $|V_{tb}| > 0.08$ at 95% CL, without unitarity constraint on the CKM matrix and using the measured values of $|V_{ts}|$ and $|V_{td}|$

- Consistent with D0 results in 5.4 fb^{-1}, using l+jets and dilepton channels
  - $R= 0.90\pm0.04$ and $|V_{tb}| =0.95\pm0.02$

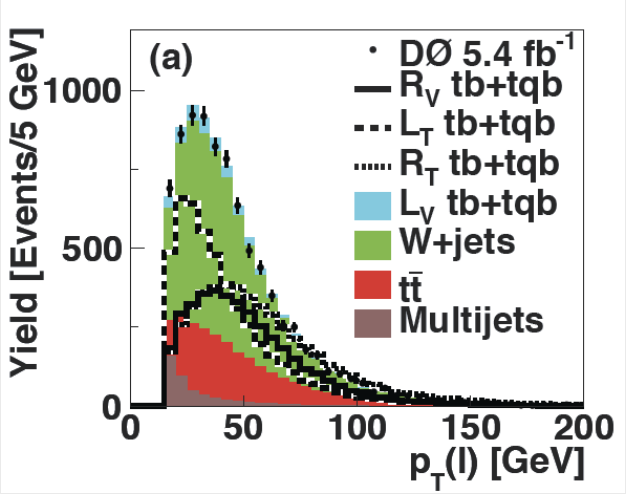
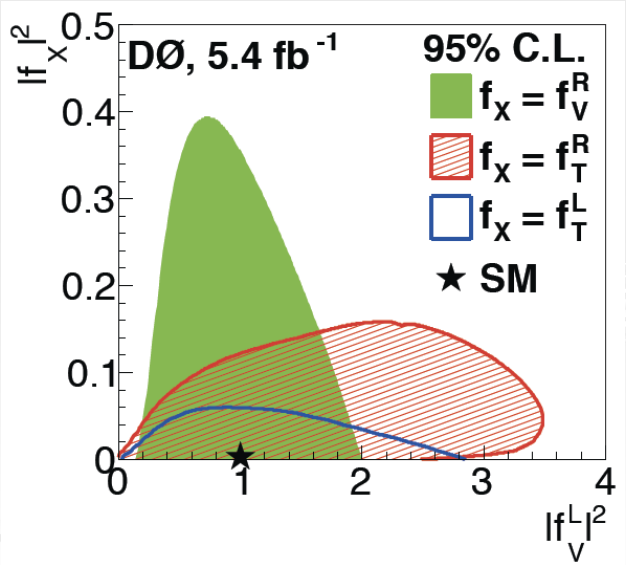




Anomalous Wtb Couplings

- Lagrangian at the tWb vertex

$$\mathcal{L} = \frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}(f_V^L P_L + f_V^R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}V_{tb}}{M_W}(f_T^L P_L + f_T^R P_R)tW_{\mu}^{-}$$

- In the SM, coupling form factors $f_V^L = 1$ and $f_V^R = f_T^L = f_T^R = 0$
- Use W helicity in top-pair decays, and of single-top production rate and kinematics to probe anomalous Wtb couplings

Scenario	only W helicity	only single top	combination
$\lvert f_V^R\rvert^2$	0.62	0.89	0.30
$\lvert f_T^L\rvert^2$	0.14	0.07	0.05
$\lvert f_T^R\rvert^2$	0.18	0.18	0.12