Tevatron Physics

Fermilab Users Meeting

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Overview

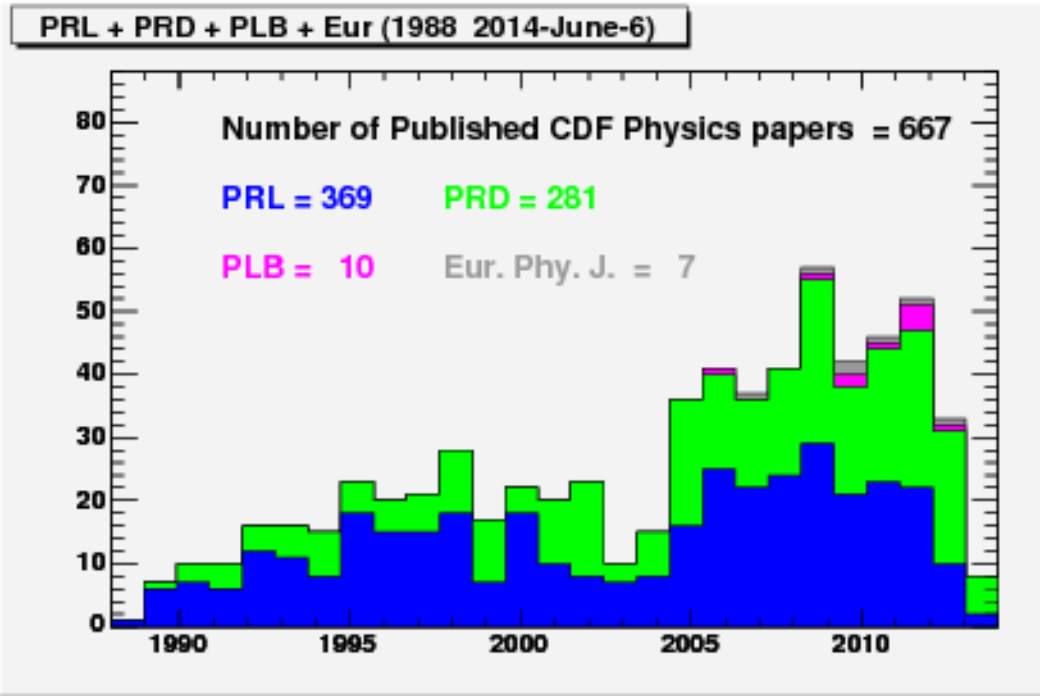
- **The CDF and DZero collaborations are still doing exciting physics and publishing at a strong rate**
- **Focusing on legacy results that are competitive and complementary to the LHC**
- **In a phrase, our motto is "*get the papers out!*"**

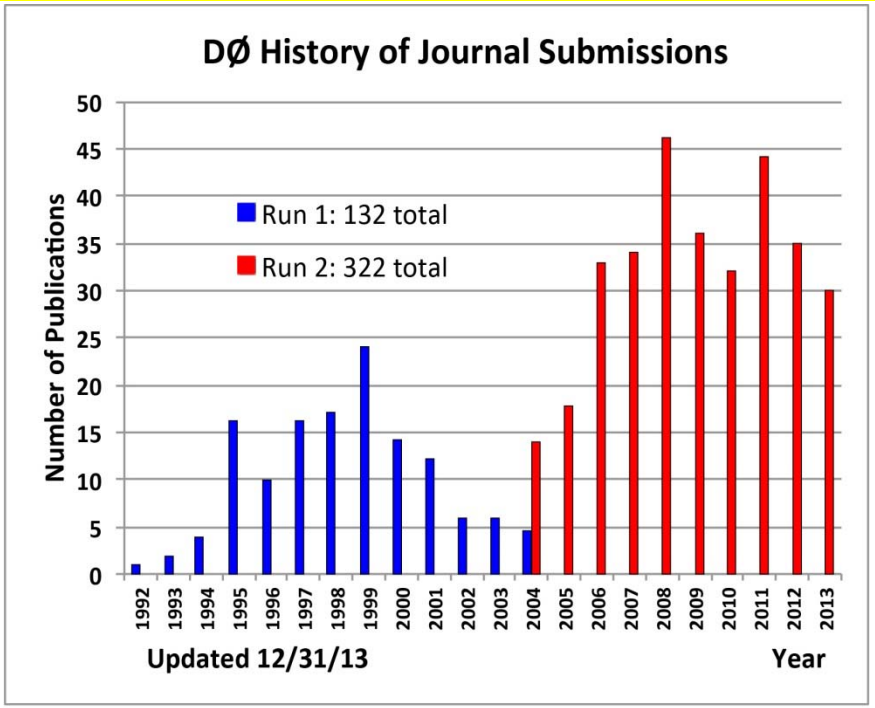
Publication History

CDF and DZero: ~30 paper each in 2013

Excellent results in all physics groups

Tevatron Legacy: Over 1,000 papers published and 1,000 PhD's granted





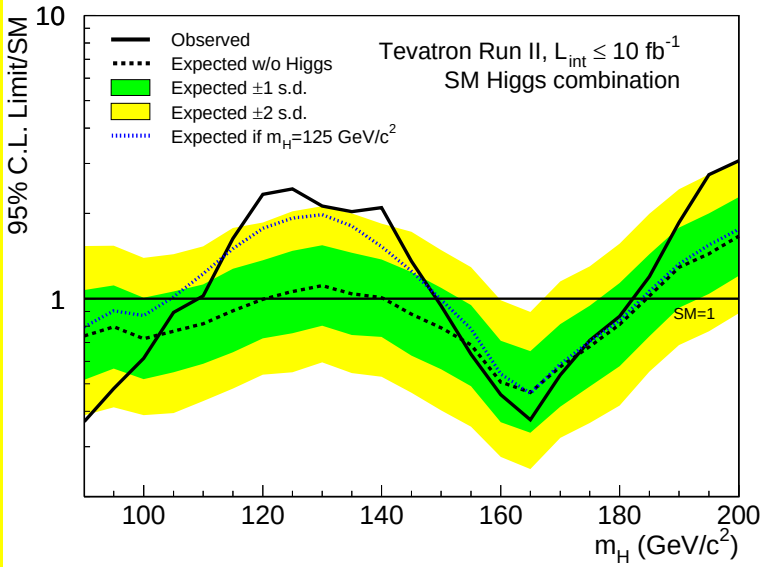
Rich Program

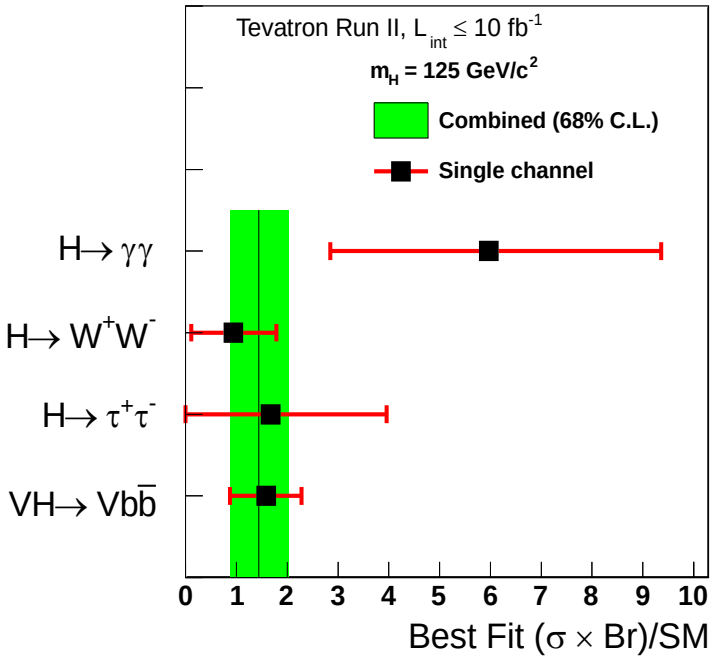
Selected Results

- **Higgs**
  - **Final Higgs Combination**
  - **Higgs Couplings**
- **Exotics/New Phenomena**
  - **Search for Heavy Vector Bosons**
- **QCD**
  - **Exclusive production**
  - **Double parton Interactions**
  - **W/Z + Jets**
  - **Vector Boson +HF**
- **Heavy Flavor**
  - **CP Violation $B^{\pm}$ decays**
  - **Excited B-mesons**
  - ***b*-Baryon properties**
  - **Di-muon charge asymmetry**
- **EWK**
  - **A_{FB}: $Sin^2\theta_{eff}$ and M_W**
  - **WW and ZZ Results**
  - **W Mass**
- **Top**
  - **Top Pair-Production Cross section**
  - **Top Mass**
  - **Single Top s+t**
  - **Single Top in s-only**
  - **A_{FB} in tt**
  - **A_{FB} in bb**

Final Higgs Combination

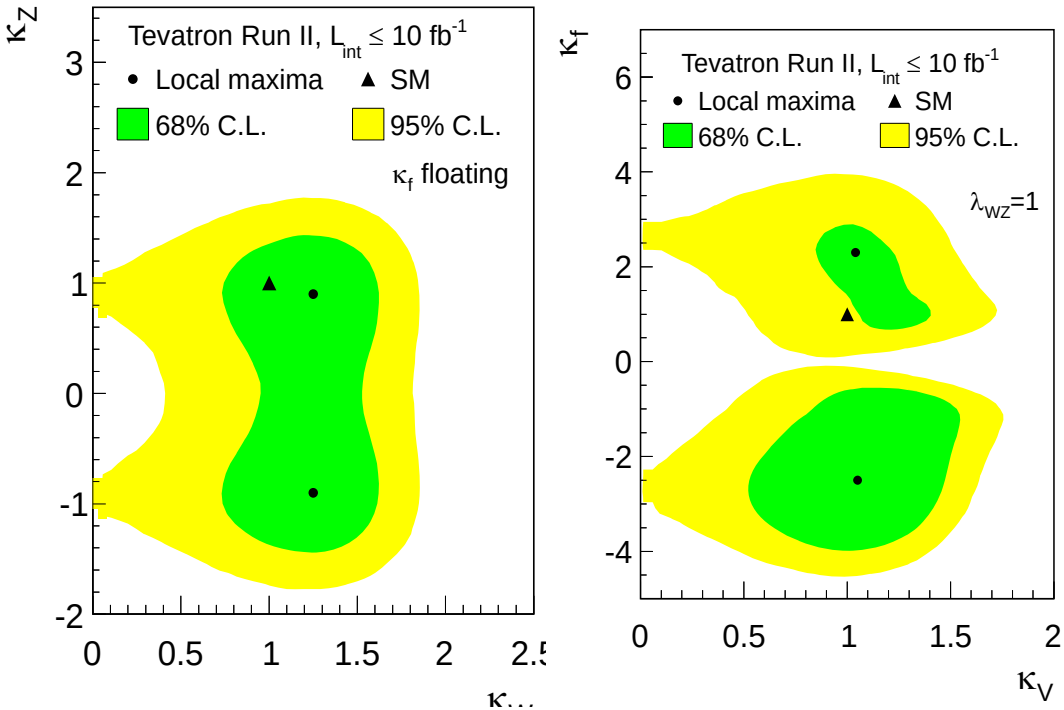
- **The Higgs groups at both CDF and DZero have completed their search work**
- **Powerful results in bb are complementary to the final states from the LHC**
- **Observed significance is 3.0σ at a Higgs mass of 125 GeV**
- **Tevatron combination published**
  - **PRD 88, 052014 (2013)**

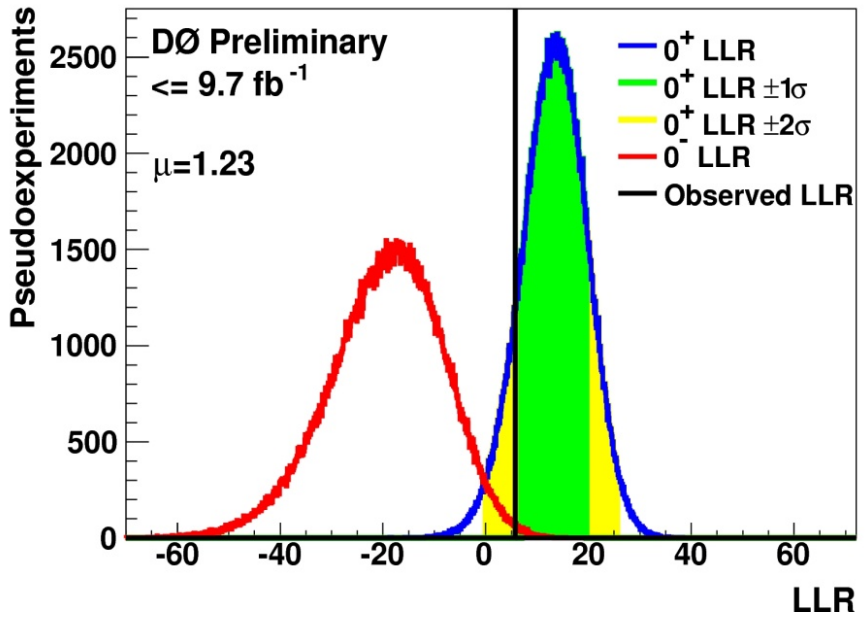




Higgs Couplings

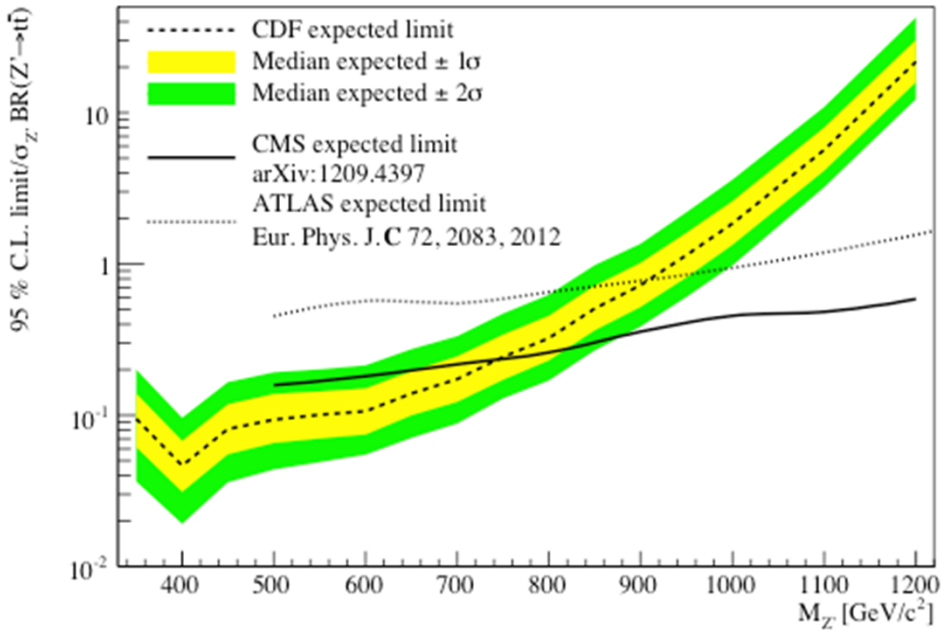
- **The world-wide emphasis has shifted to property measurements**
- **Combination of CDF and DZero results on Higgs Spin-parity is in progress**
  - **DZero results are public (Conf Notes 6387 and 6404)**
  - **CDF results are nearing completion**
- **All results are currently consistent with the SM**

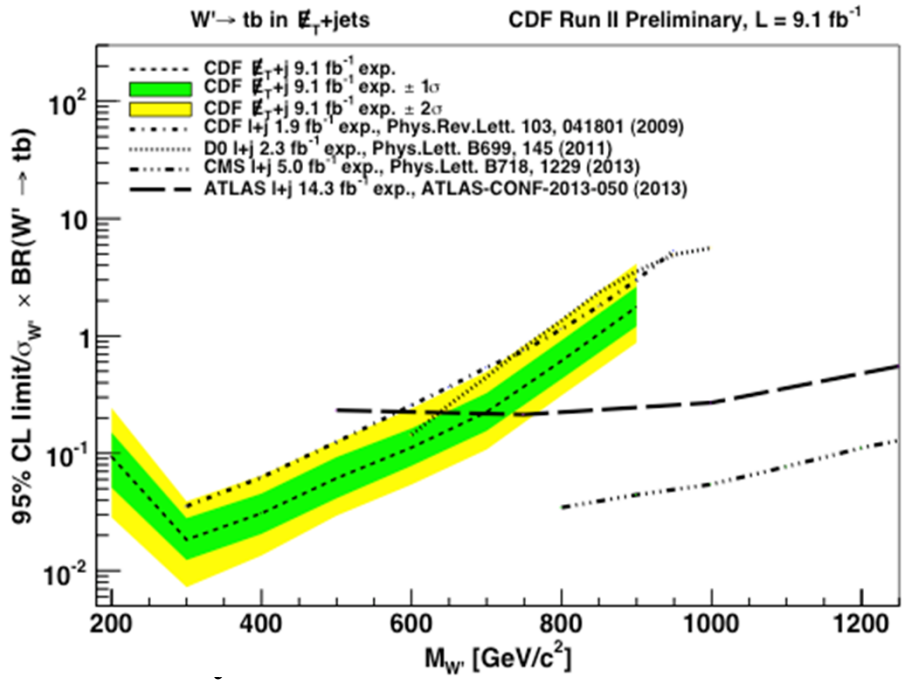




Search for Heavy Vector Bosons
Exotics/New Phenomena

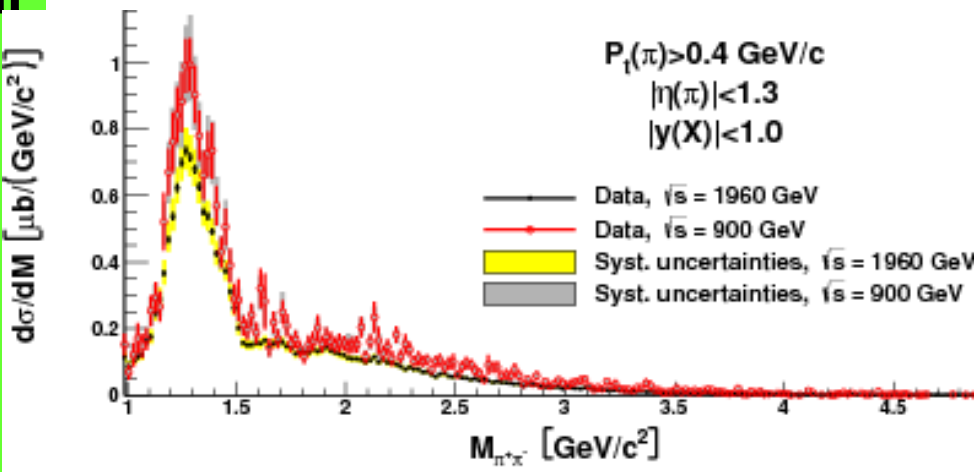
- **While the Tevatron isn't competitive for the high mass searches any more, there are still a number of places where it has advantages**
  - **PPbar vs. PP**
  - **Low number of interactions per crossing**
- **New limits on W'→tb and Z'→tt are the world's best at intermediate masses**
  - **PRL 110, 121802 (2013)**
  - **CDF Public note 11079**
- **A few more results to come in the next year**
  - **Delayed photons**
  - **Monopoles**
  - **Others**

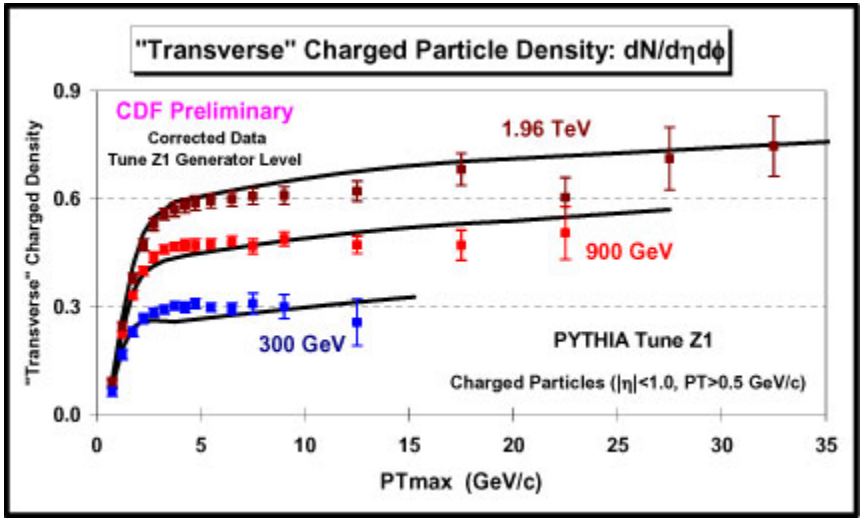




QCD: Exclusive Production

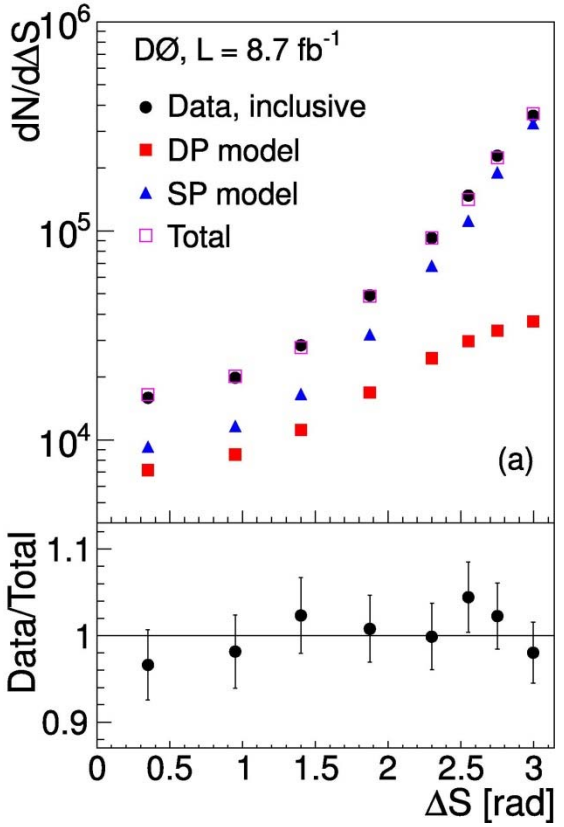
- Measurements of Exclusive Production are important in their own right as well as for input in our Monte Carlos (Pythia, Herwig++ etc.)
- Central Exclusive Hadron Pair Production
  - CDF Public Note 10841
- Many other exclusive results
  - High mass di-jet production
  - Exclusive di-jet production,
  - exclusive di-photon
  - exclusive χ_c production
- Measurements at multiple Tevatron energies
  - 300, 900 and 1960 GeV
  - CDF Pub Note 10841 and 10874

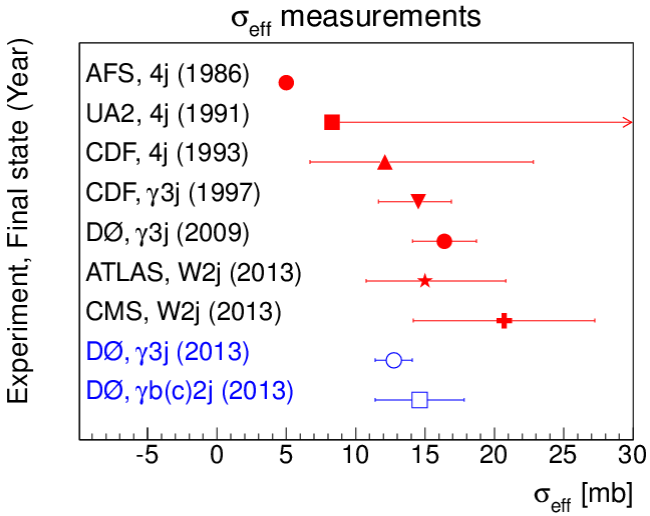




Double Parton Interactions

- **Ability to separate single and double parton interactions**
- **Measurements in both γ + 3 jets and γ + b/c + 2 jets events**
  - **DZero: PRD 89, 072006 (2014)**
- **In agreement with the SM**



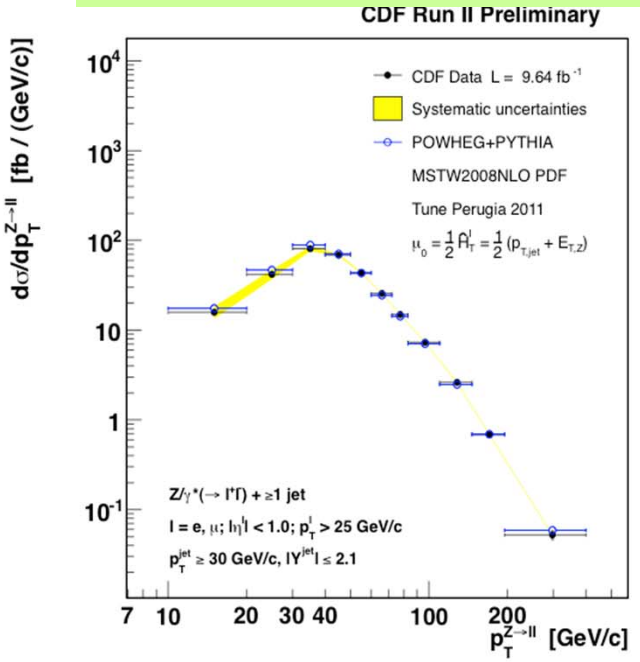


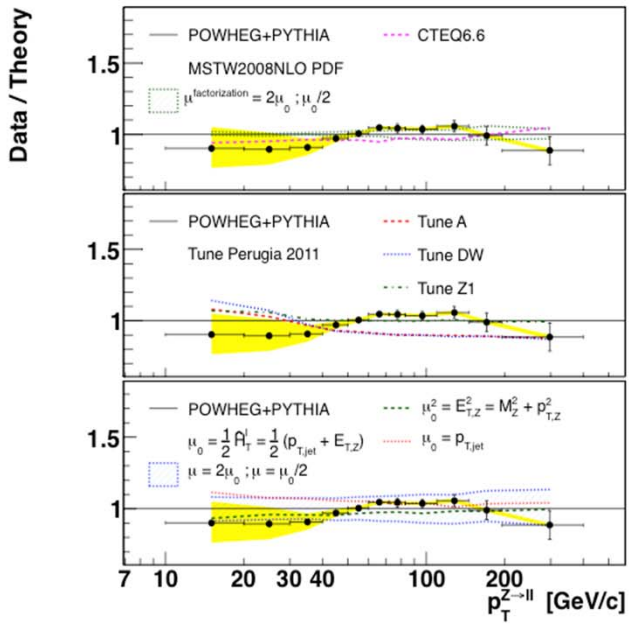
W/Z+Jets

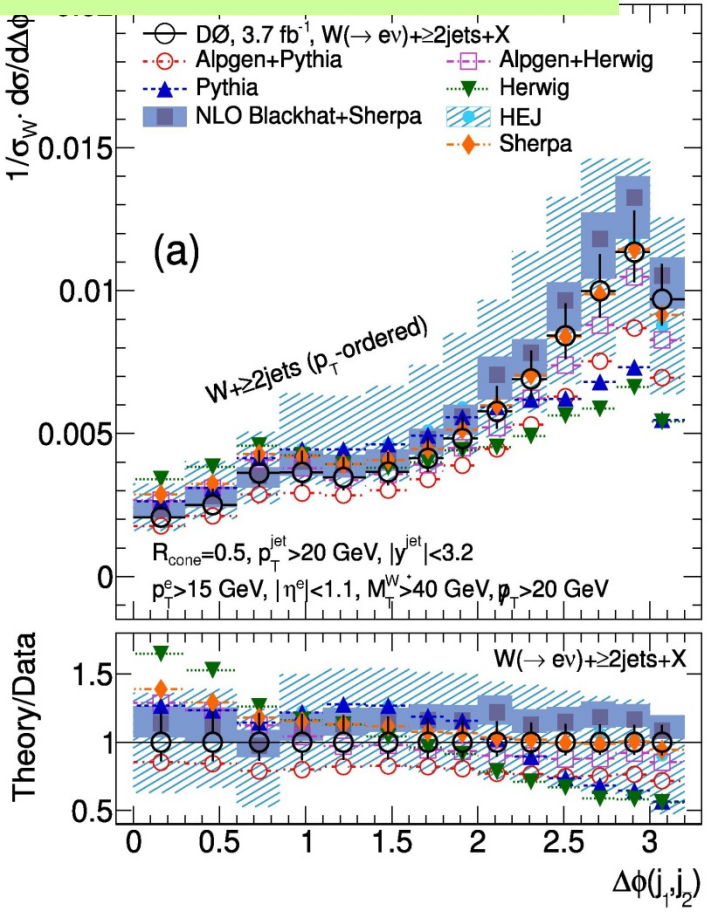
Z+jets & W+jets Cross Section Measurements

CDF: Public Note 10216

DZero: PRD 88, 092001 (2013)





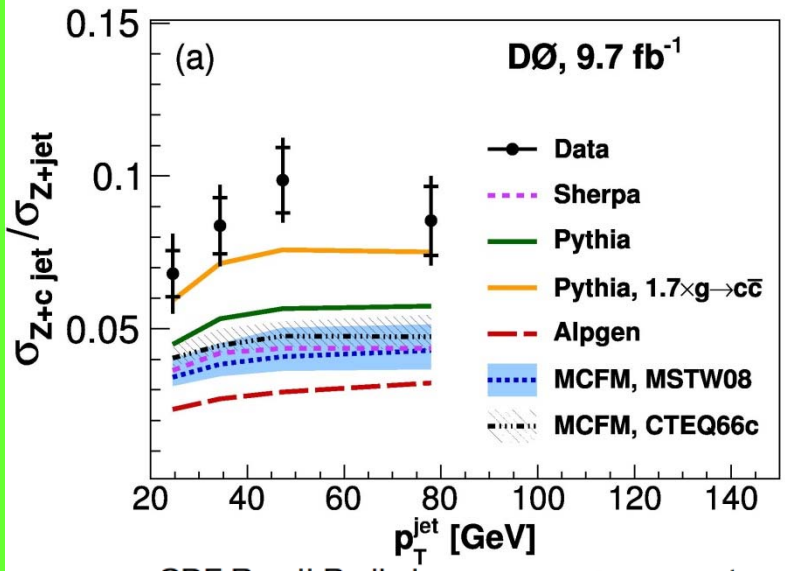


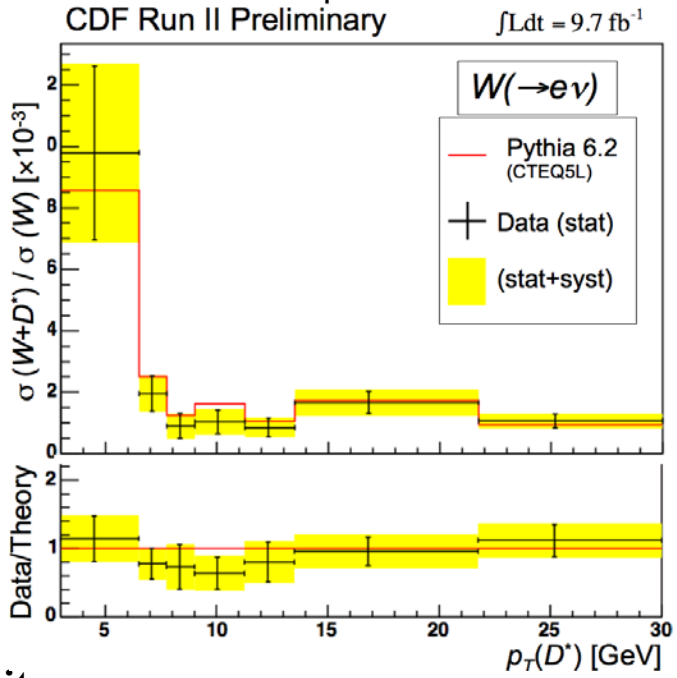
QCD@NLO works reasonably well and is very useful for model builders

Vector Boson + HF

- Using the low pileup environment to pushing down to low rate and/or soft production
- V+Charm jet
  - DZero: PRL 112, 042001 (2014)
- V+D*
  - New method allows for lower P_T Charm
  - CDF Public Note 11087
- W/Z+Upsilon
  - No observation, new limits
  - CDF Public Note 11099

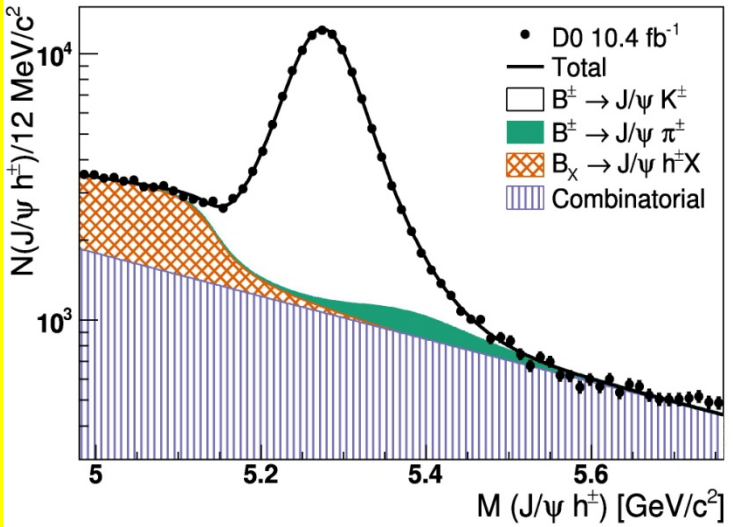
	$\Upsilon + W$	$\Upsilon + Z$
expected limit (pb)	5.5	13
observed limit (pb)	5.5	20

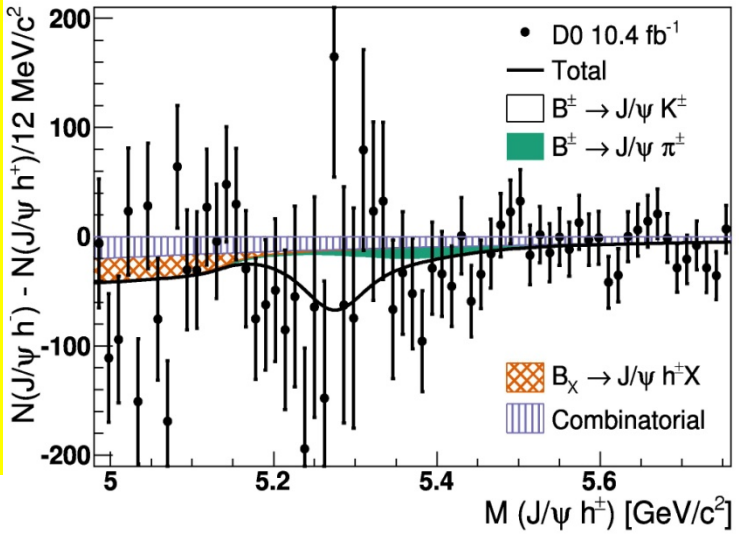




CP violation in $B^{\pm}$ decays

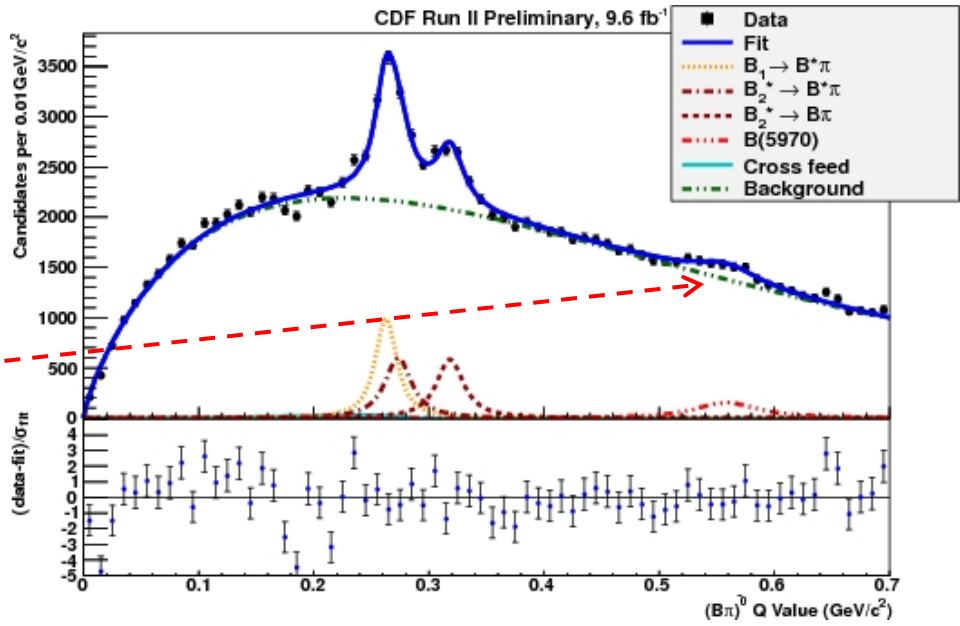
- Analyzed decay multiple modes of $B^{\pm}$ for CP violation
  - $B^{\pm} \rightarrow J/\psi K^{\pm} \rightarrow \mu^{+}\mu^{-}K^{\pm}$
  - $B^{\pm} \rightarrow J/\psi \pi^{\pm} \rightarrow \mu^{+}\mu^{-}\pi^{\pm}$
- World's most precise measurement
  - $A^{J/\psi K} = (0.59 \pm 0.36)\%$
  - $A^{J/\psi \pi} = (-4.2 \pm 4.8)\%$
- Consistent with SM expectations
  - DZero: PRL 110, 241801 (2013)





Excited B-mesons

- First evidence of resonances (4.4σ) consistent with two states of orbitally excited (L=1) B^+-mesons
  - In both $B^0\pi^+$ and a $B^+\pi$ samples
- Measured masses and widths of all states, as well as the relative production rates
  - CDF: arXiv:1309.5961



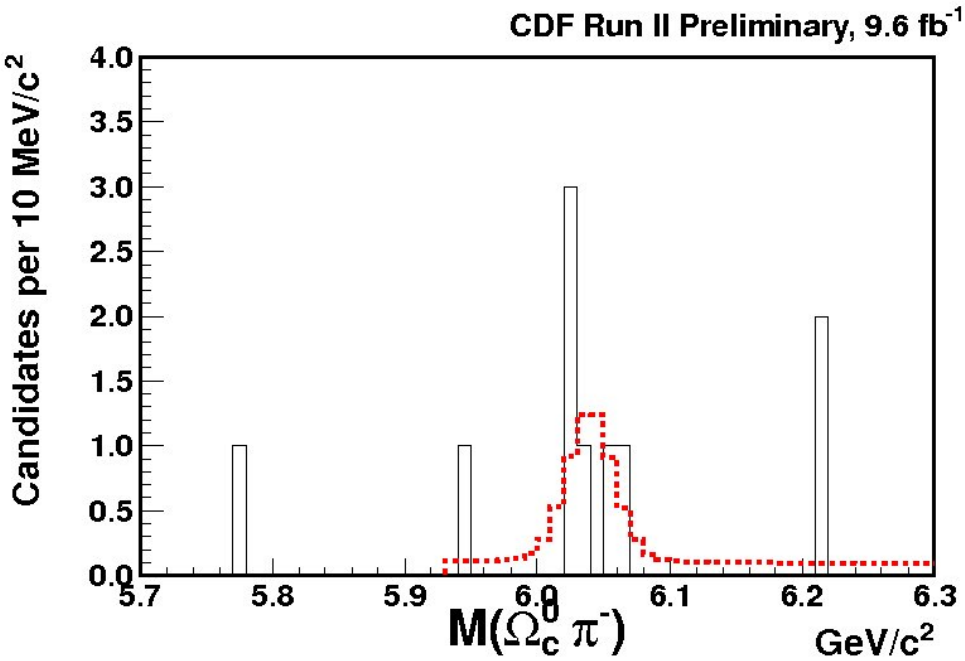
Quantity MeV/c^2	Value MeV/c^2	Stat. uncert. MeV/c^2	Syst. uncert. MeV/c^2
$Q(B(5970)^0)$	558	5	12
$Q(B(5970)^+)$	541	5	3
$m(B(5970)^0)$	5978	5	12
$m(B(5970)^+)$	5961	5	3
$\Gamma(B(5970)^0)$	70	18	31
$\Gamma(B(5970)^+)$	60	20	40

Masses are calculated assuming the state decays to $B\pi$.

b-Baryon Properties

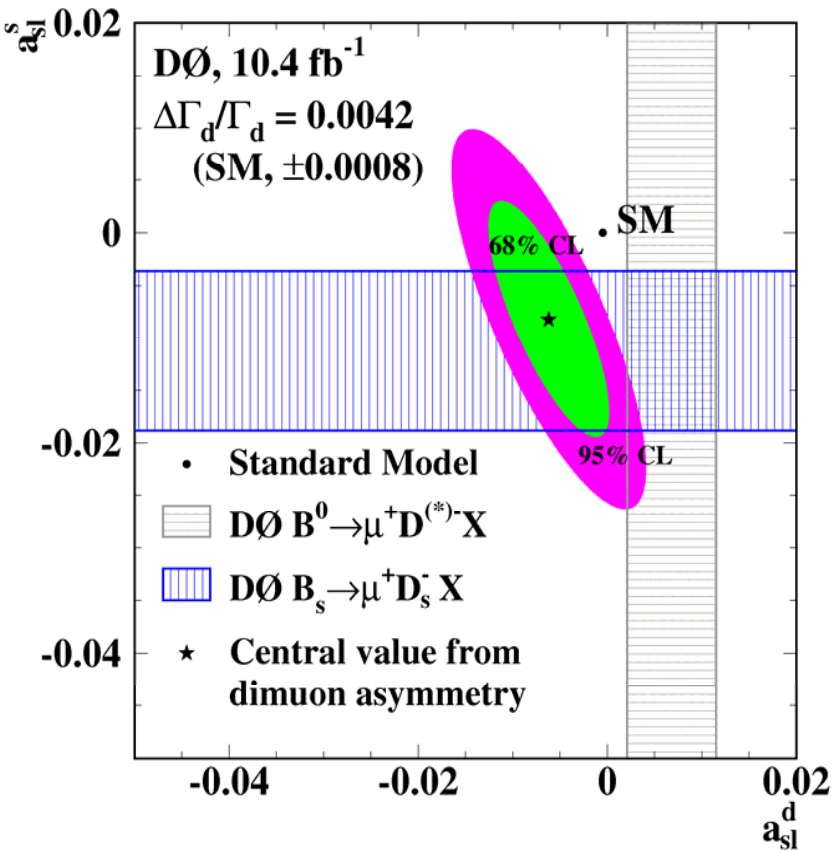
- **Best measurements of the masses and lifetimes of Ξ_c and *b*-baryons**
- **First observations of $\Omega_b^- \rightarrow \Omega_c^0 \pi^-$ and $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$**
  - **CDF: PRD 89 072014 (2014)**
  - **Not yet seen at LHC**

Baryon	Mass (MeV/c^2)
Ξ_c^0	$2470.85 \pm 0.24 \pm 0.55$
Ξ_c^+	$2468.00 \pm 0.18 \pm 0.51$
Λ_b	$5620.15 \pm 0.31 \pm 0.47$
Ξ_b^-	$5793.4 \pm 1.8 \pm 0.7$
Ξ_b^0	$5788.7 \pm 4.3 \pm 1.4$
Ω_b^-	$6047.5 \pm 3.8 \pm 0.6$
$M(\Xi_c^0) - M(\Xi_c^+)$	$2.85 \pm 0.30 \pm 0.04$
$M(\Xi_b^-) - M(\Xi_b^0)$	$4.7 \pm 4.7 \pm 0.7$



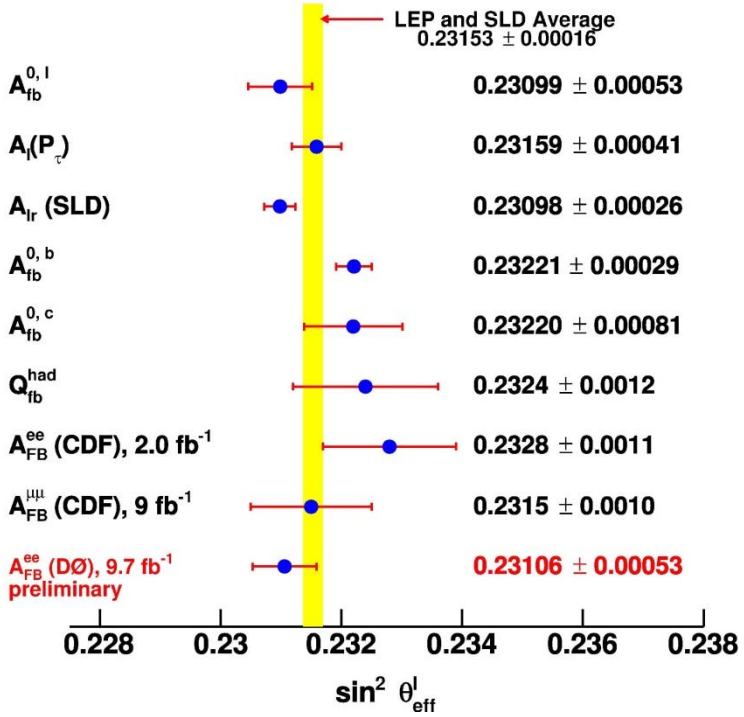
Like-sign di-muon charge asymmetry

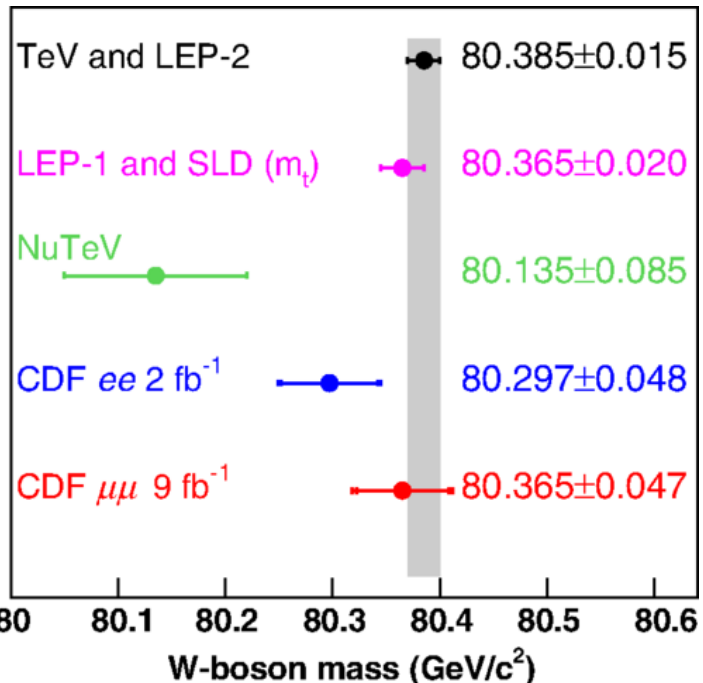
- **Current result deviates from the SM prediction by 3.0σ**
  - **DZero: PRD 89, 012002 (2014)**
- **Result is consistent with independent DZero measurements**
  - **Semi-leptonic asymmetry in B^0 (a^d_{sl}): PRD 86, 072009 (2012)**
  - **Semi-leptonic asymmetry in B_s (a^s_{sl}): PRL 110, 011801 (2013)**
- **This effect is one of a few remaining puzzles from the Tevatron program which might indicate physics beyond standard model**



Precision EWK: A_{FB} from leptons $\sin^2\theta_{eff}$ and W-mass

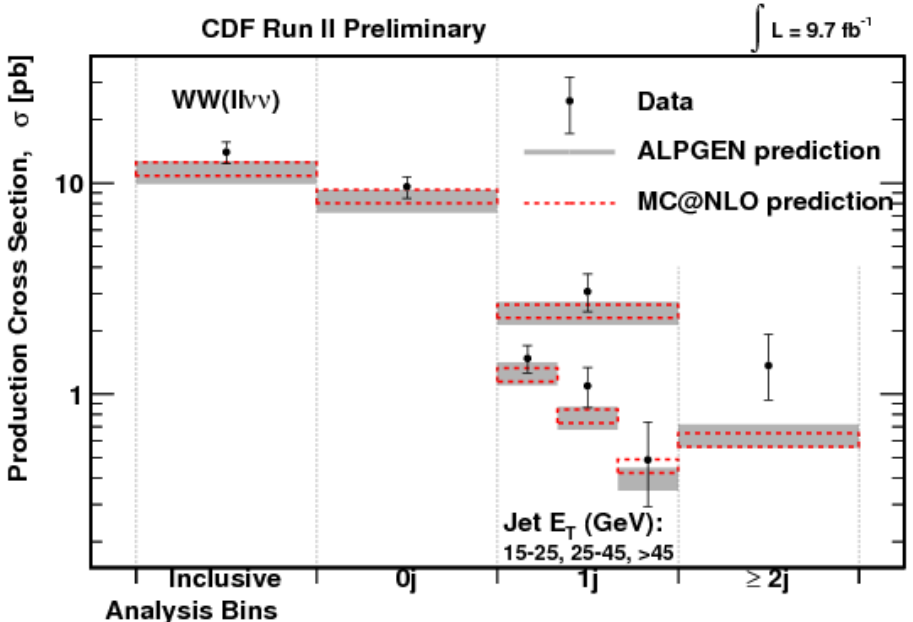
- A_{FB} from leptons provides a powerful way to measure $\sin^2\theta_{eff}$
- CDF:
  - Interpret the results as an indirect W mass measurement → quite competitive
  - New μμ measurement in PRD 89, 072005 (2014)
  - Result for *ee* in progress
- DZero:
  - Single most precise $\sin^2\theta_{eff}$ measurement is in *ee* final state
  - Public Note 6426





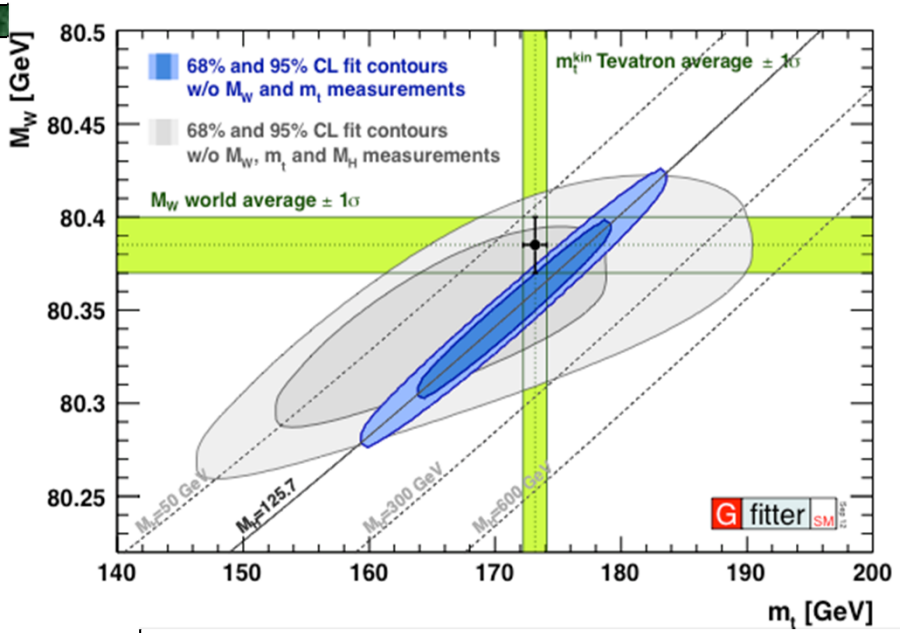
WW and ZZ Results

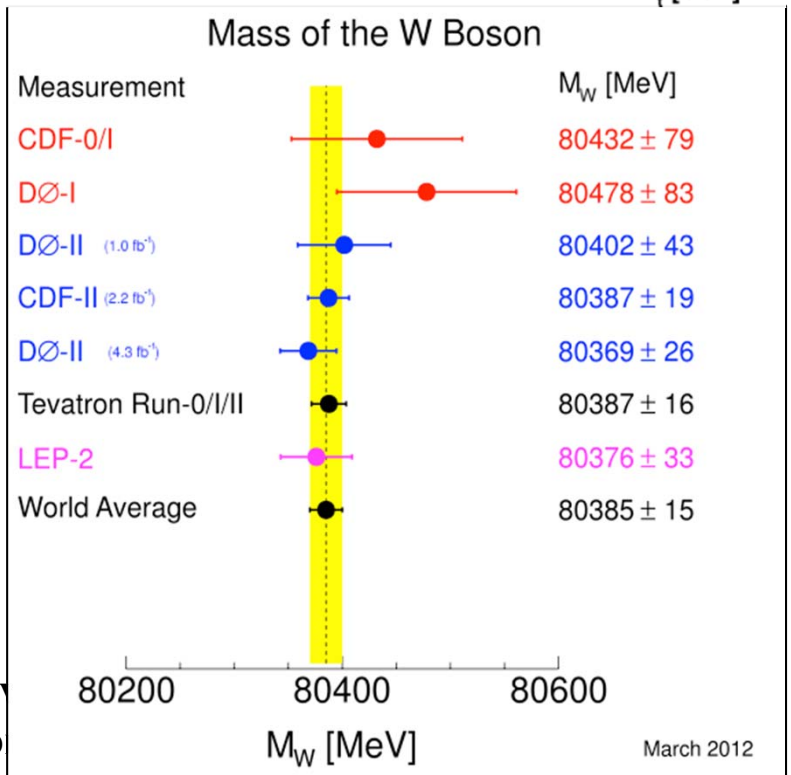
- **WW cross section**
  - **New full data set results as a function of N_{jet} and Jet E_T**
    - **CDF Public note 11098**
  - **Dzero: PRD 88, 112005 (2012)**
- **ZZ Cross Section**
  - **$\sigma_{zz}=1.04^{+0.32}_{-0.25}$ pb**
  - **CDF: PRD 89, 112001 (2014)**
  - **DZero: PRD 88, 0230080 (2013)**
- **All in agreement with the SM**



W Mass Measurement

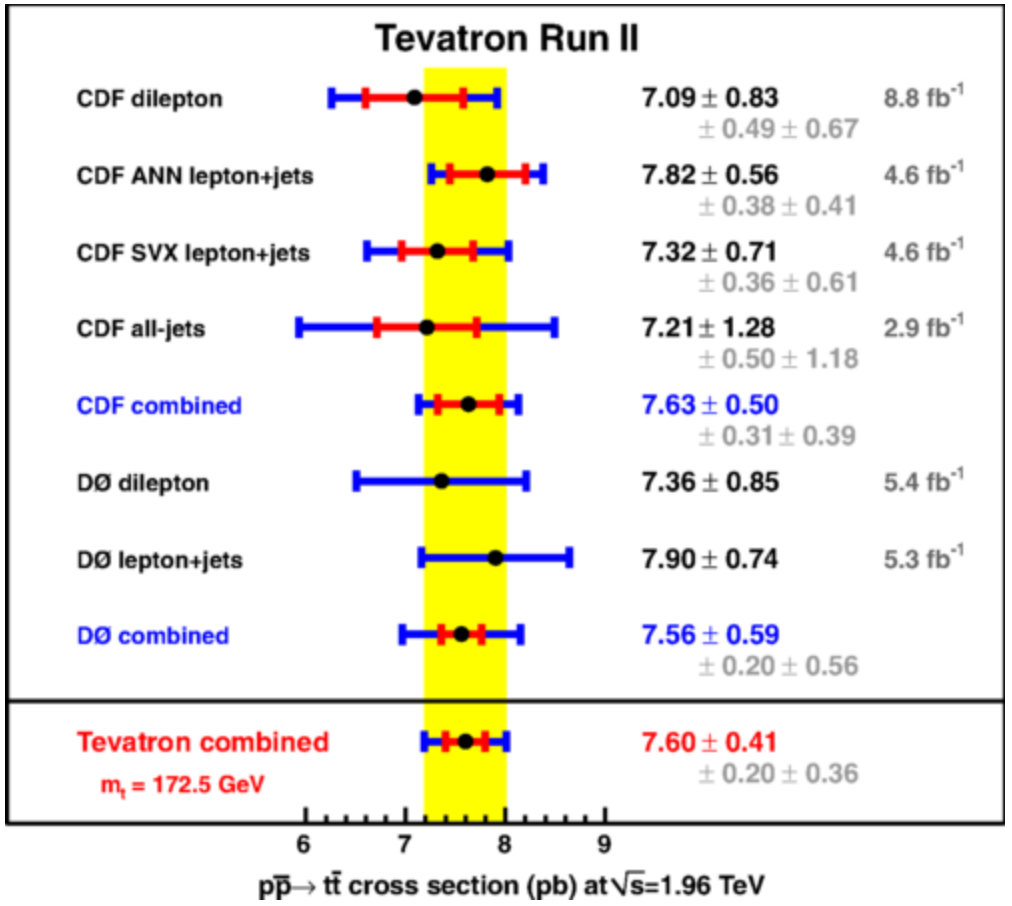
- **Tevatron Combination**
  - **PRD 88, 052018 (2013)**
    - **CDF: PRD 89, 072003 (2014)**
    - **DZero: PRD 89, 012005 (2014)**
  - **$M_W = (80387 \pm 16)$ MeV/c^2**
  - **0.02% precision!**
- **Further reduction of uncertainties are difficult and time consuming**
  - **Full-data results from both CDF and DZero in progress**





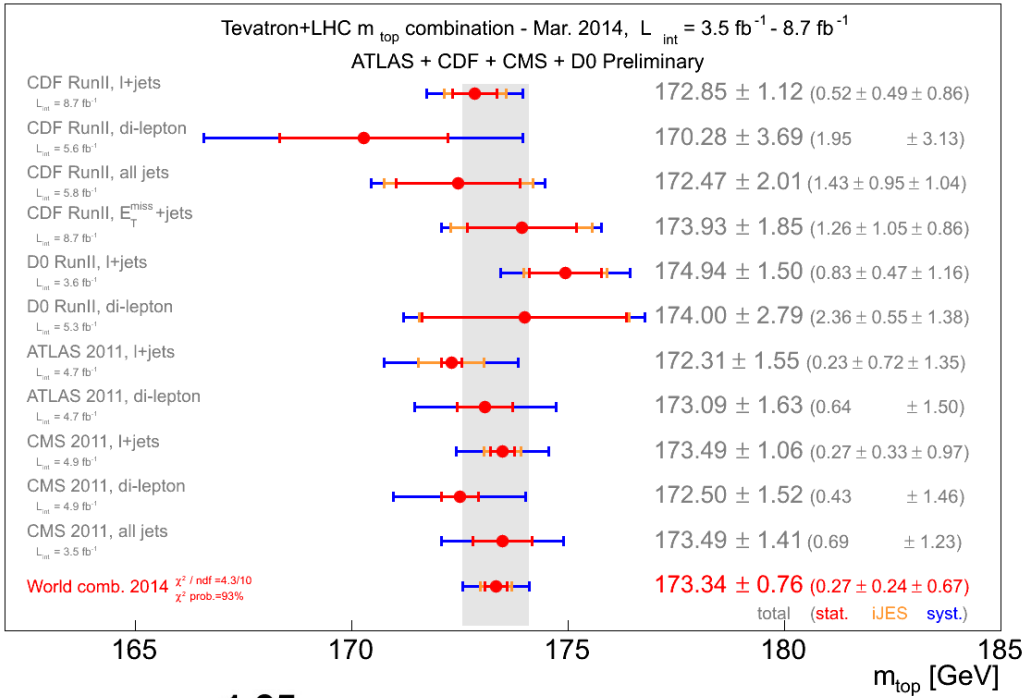
Top Pair-Production Cross Section

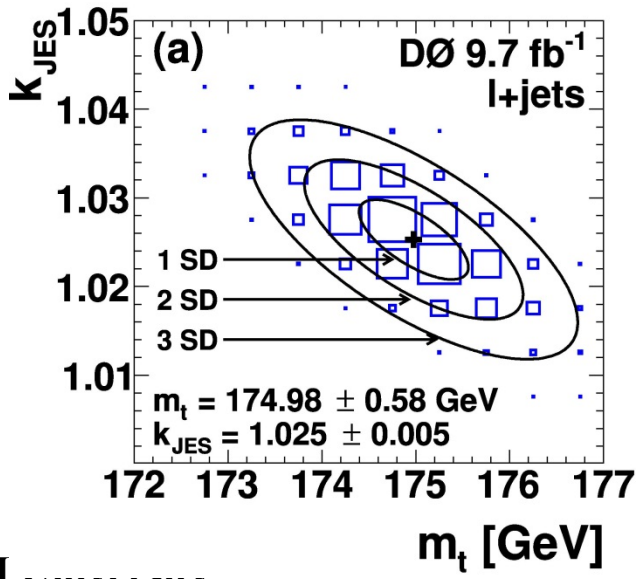
- Combined CDF/DZero results from ~8.8 fb^{-1} published
  - PRD 89, 072001 (2014)
- Result is 7.60±0.41 pb
- CDF version in lep+jets with the full dataset nearing release



Top Mass

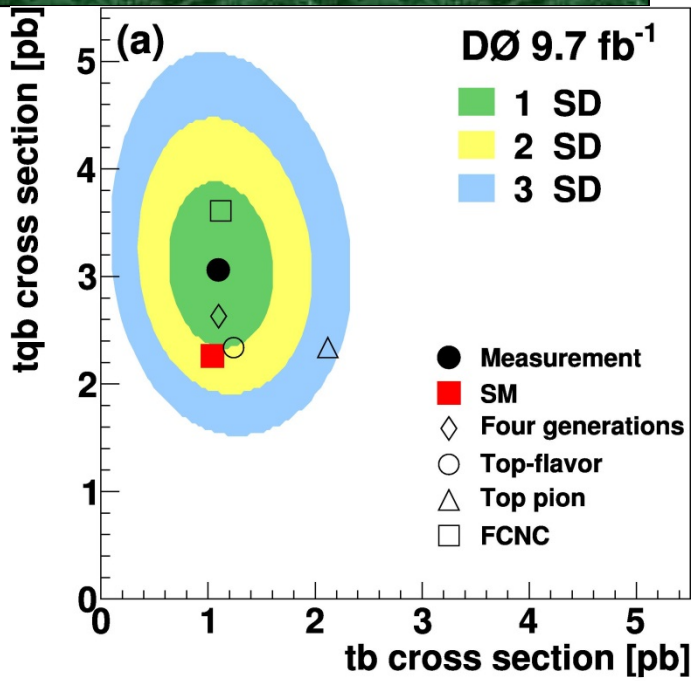
- CDF Combination now complete in all channels
  - Public Note 11080
- Tevatron Combination
  - arXiv:1305.3939
- Strong impact on World combination
  - arXiv:1403.4427
- New DZero results in lepton+jets
  - Very small uncertainties: $M_{top} = 174.98 \pm 0.76$
  - arXiv:1405.1756

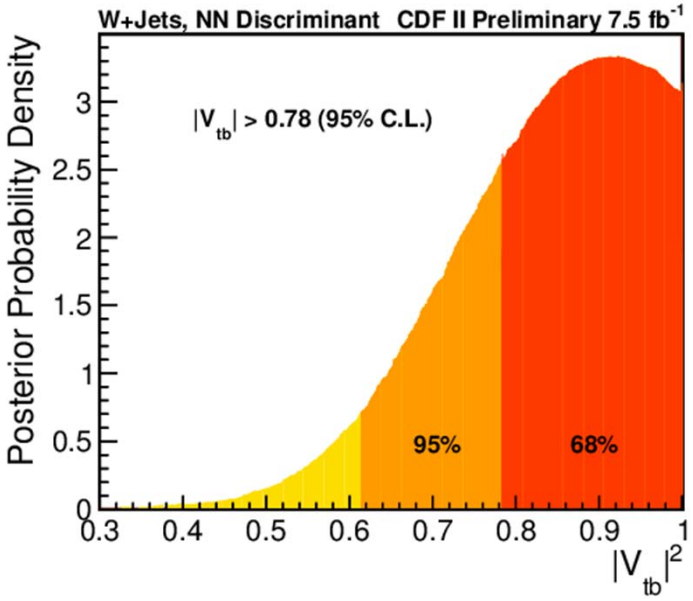




Single Top s+t

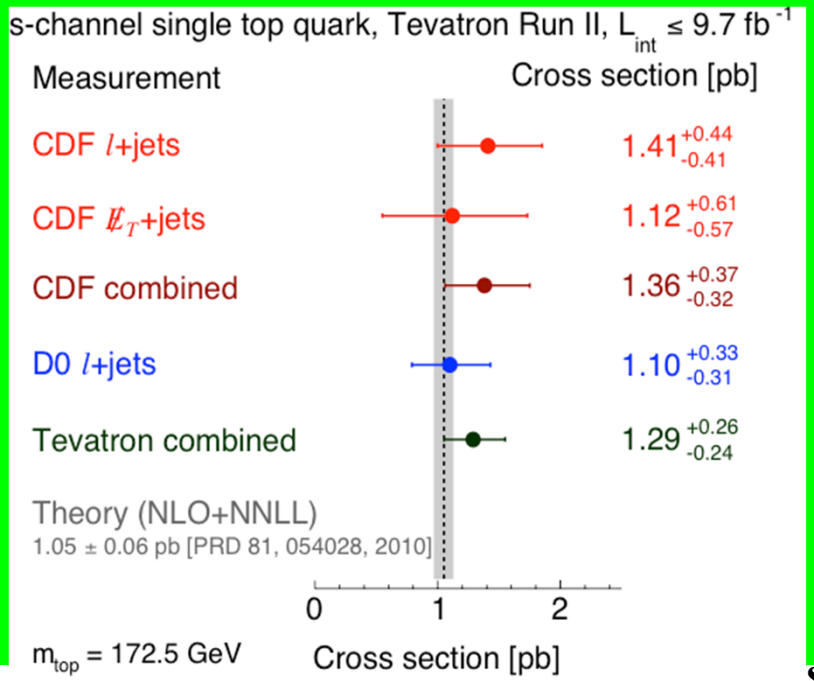
- **CDF Results in Met+Jets and Lep+Jets**
  - **Public Notes 10793 and 10926**
  - **Combined results coming soon**
- **DZero Result**
  - **Phys. Lett. B 726, 656 (2013)**
- **Tevatron Combination is well underway, results expected soon**

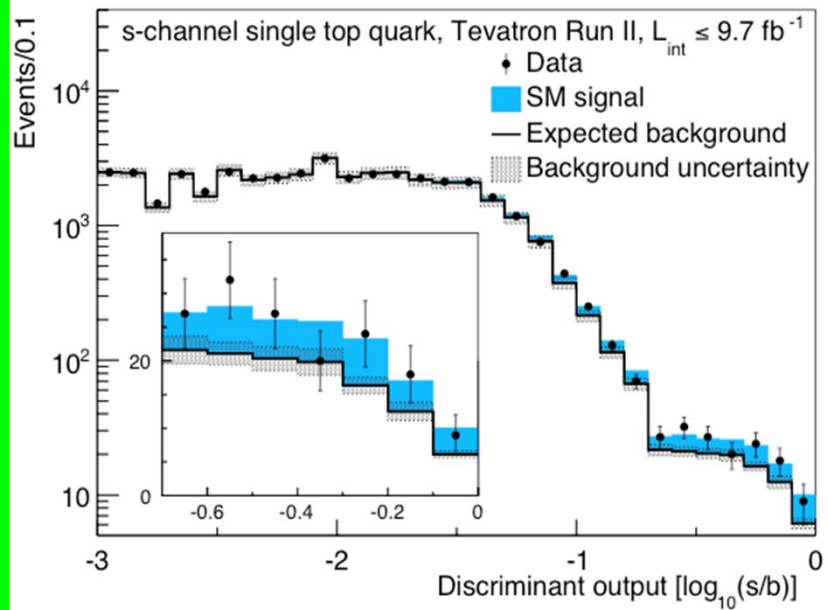


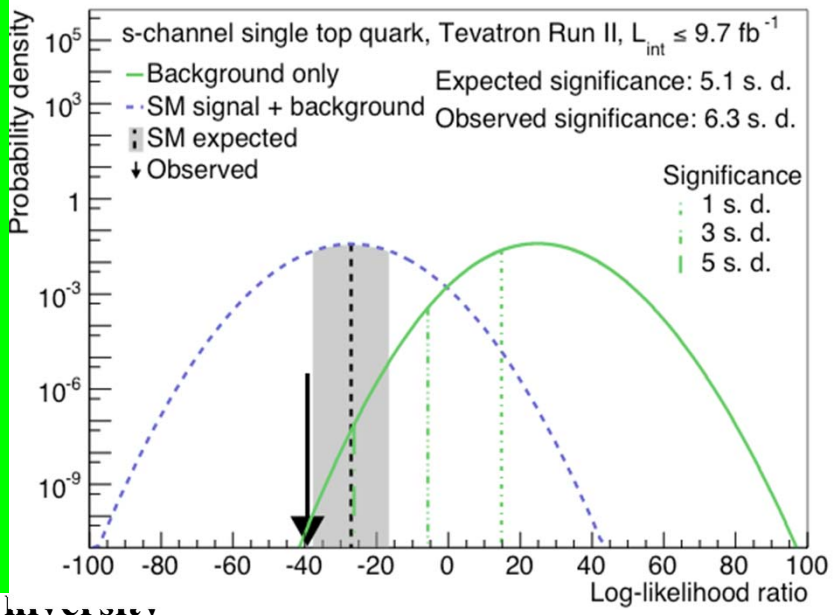


Observation of Single Top in the S-Channel

- **Single top production in the S-only Channel has now been observed**
  - **Combination complete**
  - **PRL 112, 231802 (2014)**
- **Observed significance 6.3σ**

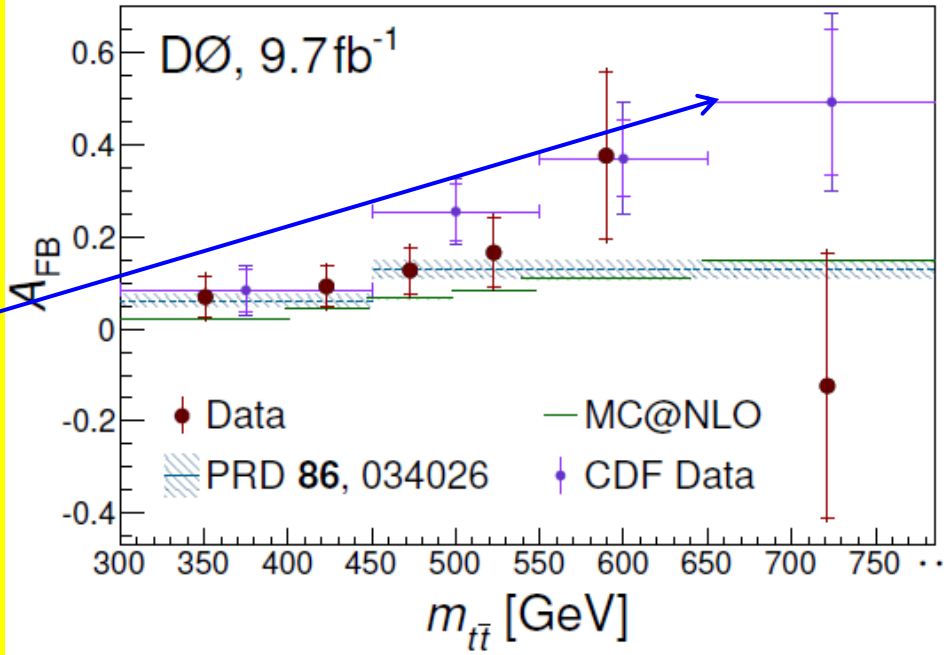


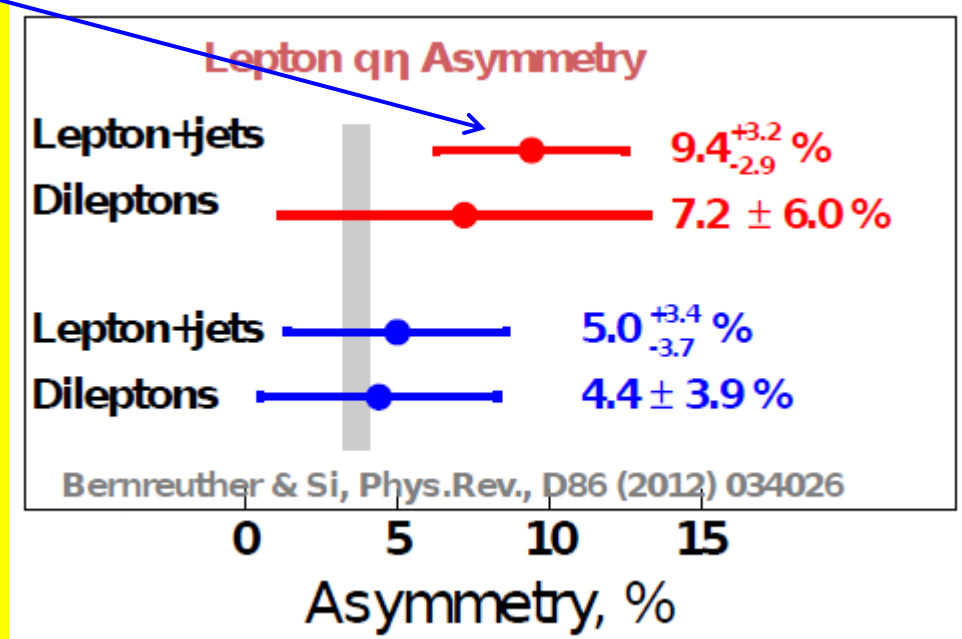




Forward-Backward Asymmetry in ttbar

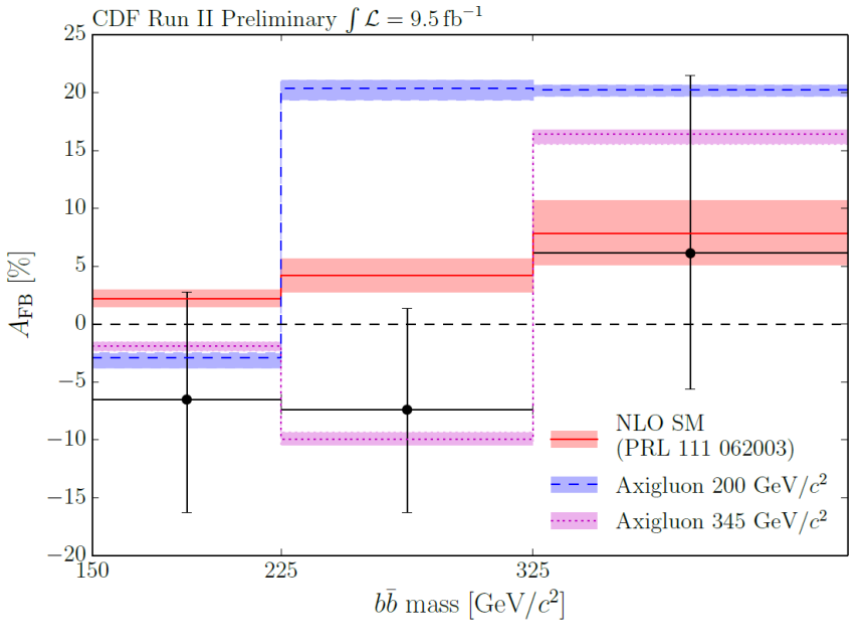
- Hot topic for a number of years
- CDF Lep+Jets results shows anomalies
  - In total reconstructed asymmetry
    - CDF: PRD 87, 092002(2013)
    - Most pronounced as a function of mass
  - In $d\sigma/d\cos\theta_t$ in l+jets
    - CDF: PRD 88, 072003(2013)
  - In lepton asymmetry
    - CDF: PRL 111, 182002(2013)
- Full suite of CDF and DZero results since in then
  - Leptonic: l+jets & dileptons
  - Full Reconstruction: Lep+Jets only
- Recent results from CDF and DZero are more consistent with SM
  - DZero leptonic Asy: PRD 88, 112002 (2013)
  - DZero Reconstructed: arXiv:1403.1294
  - CDF leptonic Asym: arXiv:1404.3698
- Not sure what the final conclusion is: working to finish results, reconcile them all and combine

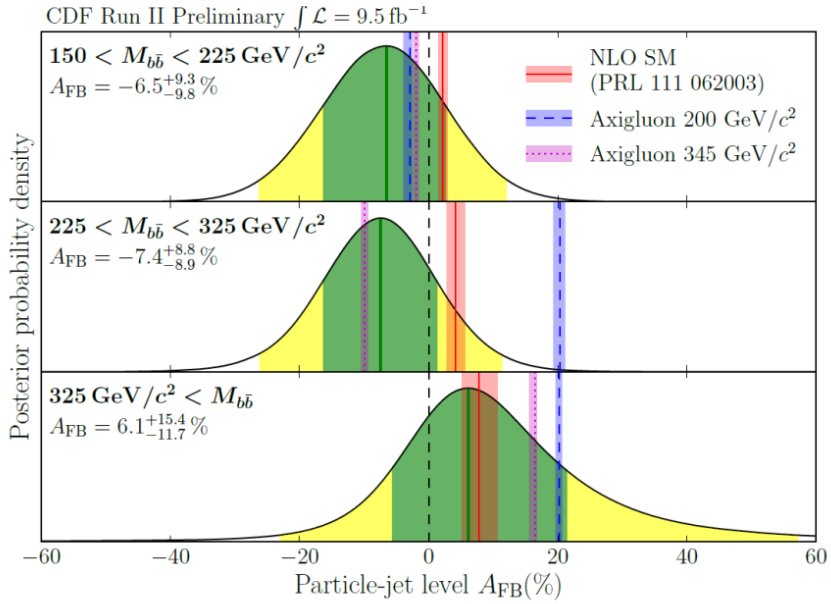




A_{FB} in High Mass bb

- The A_{FB} in tt suggests that looking in the lower mass bb state is useful at large bb invariant masses
- New results consistent with SM
  - CDF Public note 11092
- DZero and CDF low mass results in the works





Future Publication Plans

CDF

- Expect ~30 papers in 2014
- Expect ~15 in 2015

DZero:

- Expect ~25 papers in 2014
- Expect ~15 papers in 2015

CDF		
Topic	2014	2015
BSM	3	3
Higgs	1	0
Top	11	2
SM (EWK+QCD)	8	6
Heavy Flavor	6	4
Combinations	4	3
Total	34	18

DZero		
Topic	By summer 2014	Beyond summer 2014
EWK	4	5
Higgs	1	1
Top	3	5
QCD	3	5
Heavy Flavor	2	3
Combinations	3	4
NIM	-	1
Total	16	24

Conclusions

- The CDF and DZero collaborations are still doing exciting physics and publishing at a strong rate
- The Tevatron has now published over 1,000 papers and graduated over 1,000 PhD students
- The last year(s) have had many successes by focusing on legacy results that are competitive and complementary to the LHC
  - Single Top, W Mass, Top Mass, A_{FB} in tt, Higgs(bb)
- Modest support from the laboratory and funding agencies around the world is well leveraged and will assure many more important results to come based on the Tevatron data
- In the next year or so we expect many exciting results including the final Tevatron word on the Higgs Spin-parity in VHiggs(bb) Top mass, A_{FB} in tt and bb, W charge asymmetry and a W Mass measurement in the 10-15 MeV range