# CDF Legacy Results

## *2014 and Future*

**Fermilab Wine & Cheese**


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**December 2014**

# Prelude

- **The CDF collaboration continues to do exciting physics and publish 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!*"**

# Overview

- Big picture of the science in 2014, and CDF's role in it
- Some fun numbers for those keeping track
- The CDF Legacy Program
  - Higgs
  - Searches
  - Top
  - Heavy Flavor
  - QCD
  - EWK
- Looking Forward & Conclusions

# The Big Picture in 2014

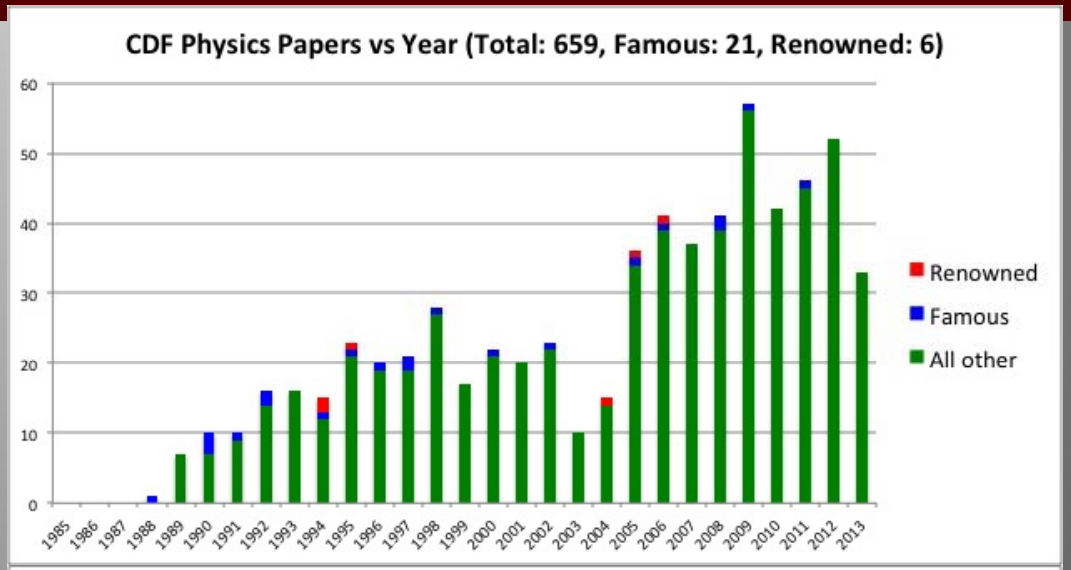
- **There are many BIG questions in 2014, many of which were not on our radar screen in the early 1980's when CDF started**
- ***Why is the top mass so much bigger than all the others?***
  - ***Why is the top coupling to the Higgs so large?***
- ***What protects the Higgs mass?***
- ***Is Supersymmetry a correct description of nature?***
- ***Are there extra dimensions of nature?***
- ***What is the mechanism that gives neutrinos mass?***
- ***What is the dark matter that fills the universe?***
- ***What is the dark energy that is causing the universe to accelerate?***
- ***Why so much matter in the universe and so little anti-matter?***
- ***What bigger theory does the SM approximate so well?***

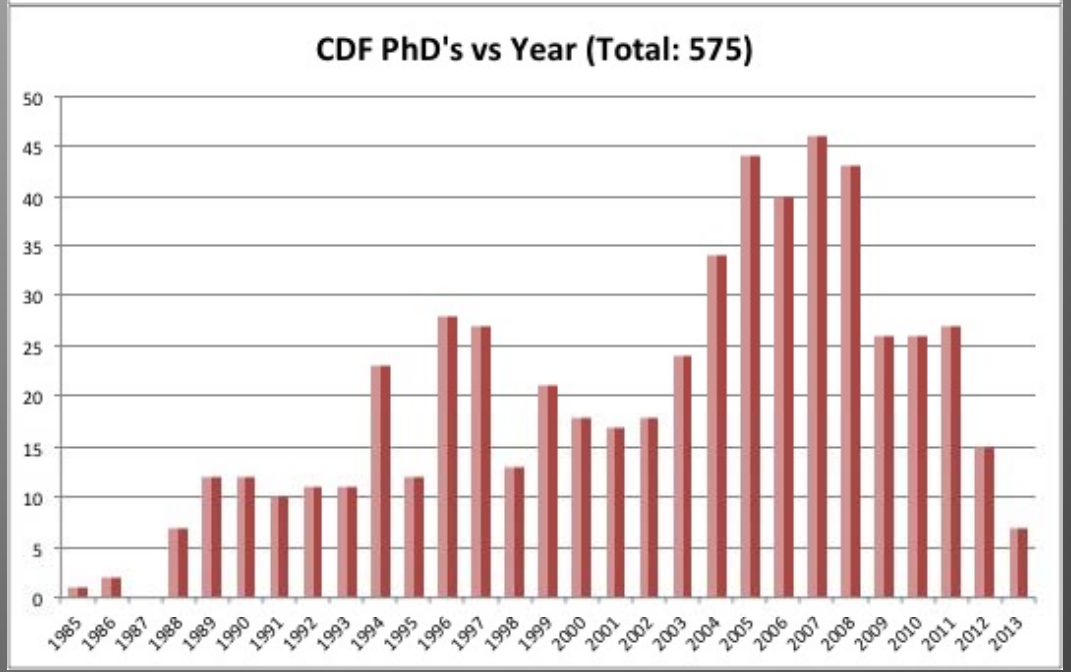
# The Collider Program

- **The Collider Program, Tevatron and LHC, try to address many of these questions**
- **LHC has taken over in many ways, especially for interactions which are only probed at the highest energies**
- **Tevatron is completing its studies in a number of competitive areas**
  - **Typically complementary to the LHC and other experiments**

# History

- The numbers leading up to 2014 were large and impressive
- Continue to have excellent results in all physics groups
- Already have 20 papers this year



# Tevatron Legacy Review Papers

**CDF and Dzero Recently came together to do a set of Review Papers that nicely summarize both Run I and Run II results**

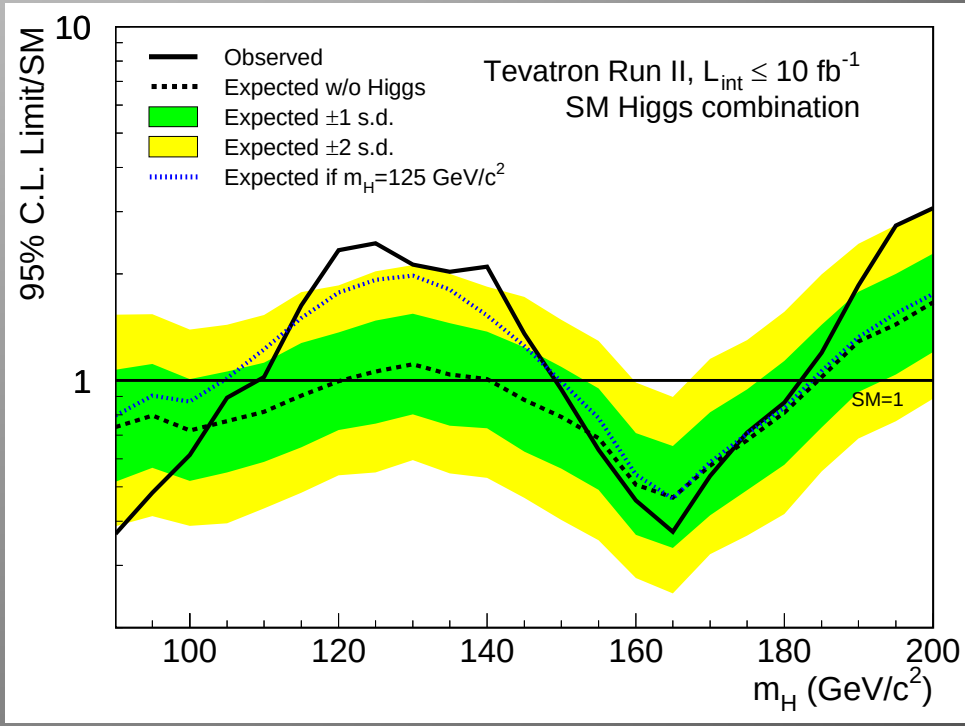
- **Overview: 1409.4861**
- **Higgs: 1409.5043**
- **New particles: 1409.4910**
- **Top: 1409.5038**
- **Heavy Flavor: 1412.5211**
- **QCD: 1409.5639**
- **EWK: 1409.5163**

# Higgs Physics

- **Tevatron has the advantage in the Higgs → bb final state**
- **LHC has done an excellent job in the other modes, giving strong evidence that it behaves like a SM Higgs**
- **CDF Legacy program is about finishing our statements about the bb final state, and contributing to the understanding of the story by testing the spin/parity of the Higgs**

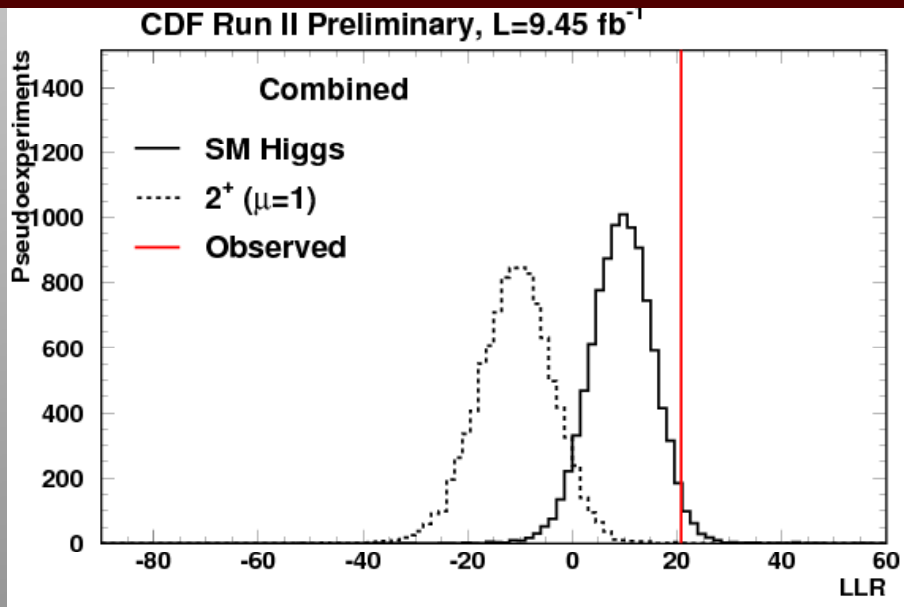
# Final Higgs Combination

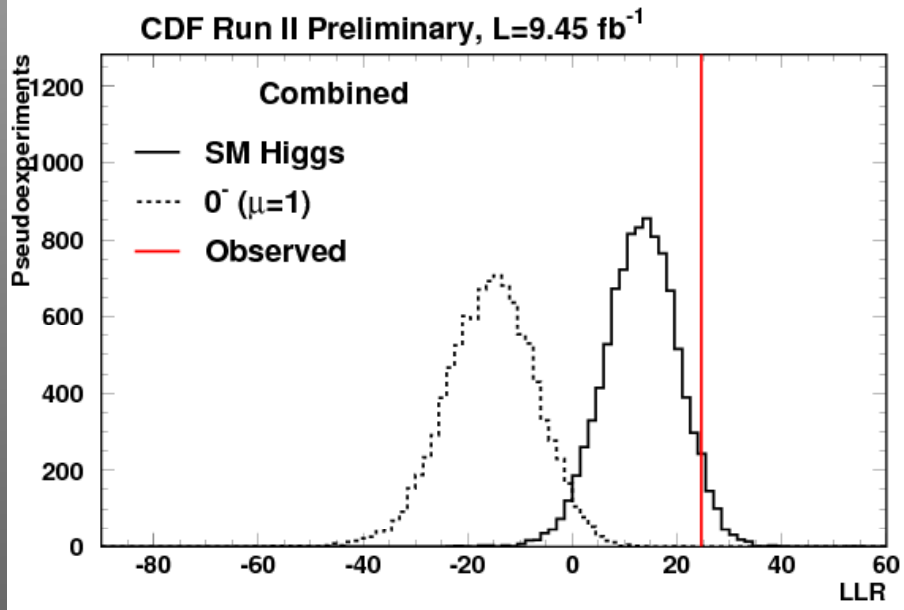
- **Both CDF and DZero have completed their searches**
- **Powerful results in bb are complementary to the final states from the LHC**
- **Observed significance is 3.0σ at a Higgs mass of 125 GeV**
- **Tevatron combination published in PRD 88, 052014 (2013)**



# Higgs Couplings

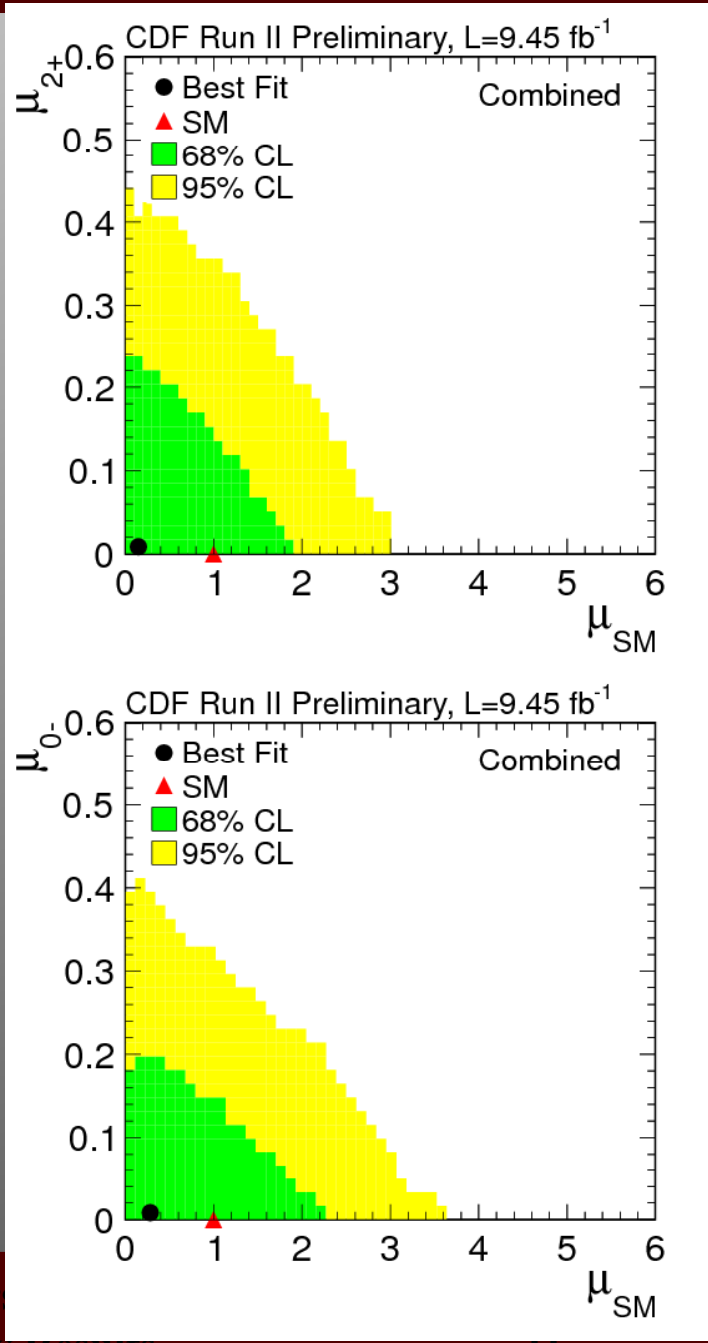
- Emphasis has shifted to property measurements
- Compare data in VX with X→bb to predictions of exotic Spin and Parity combinations
  - Pseudoscalar Higgs with $J^P=0^-$
  - Graviton-like state with $J^P=2^+$
  - Kinematics are very different than in SM (which has $J^P=0^+$)
- Data is much more like SM than either of the two other hypotheses (exclude at better than 95% C.L.)



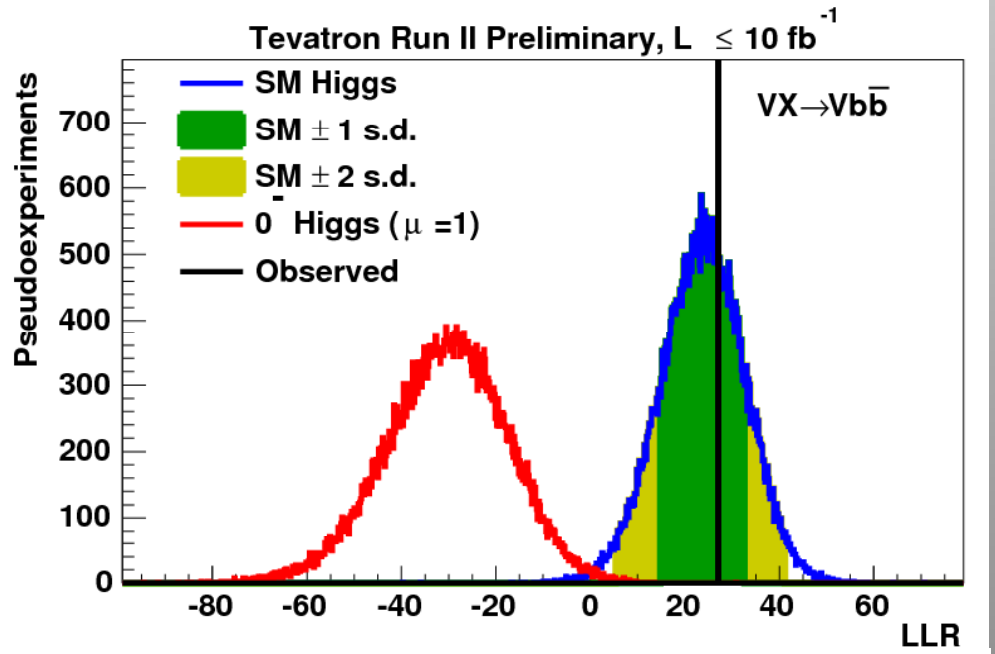



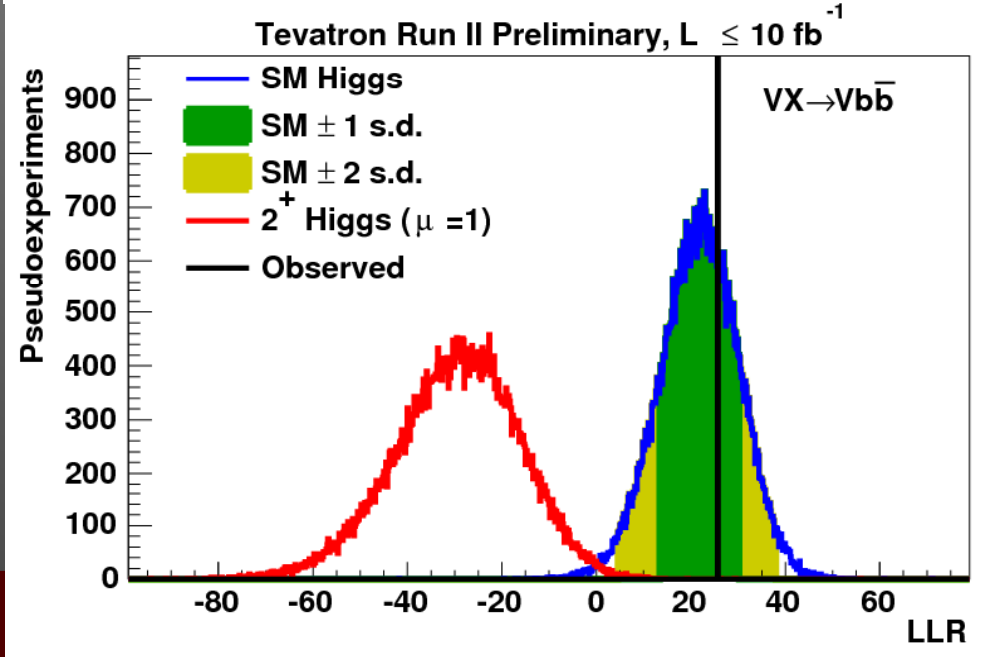
# Higgs Couplings Continued

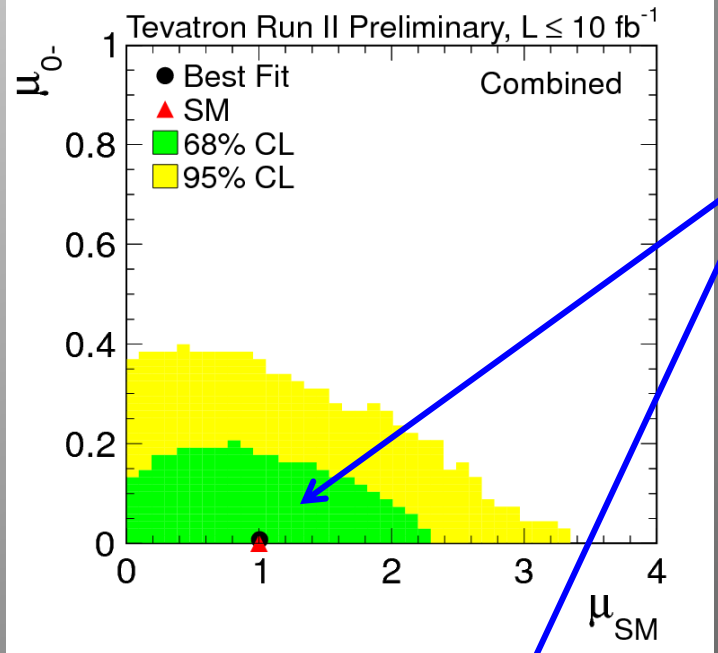
- Can also test the amount of strength of the two hypotheses simultaneously
- Data favors SM at its expected rate and no contribution from exotic states

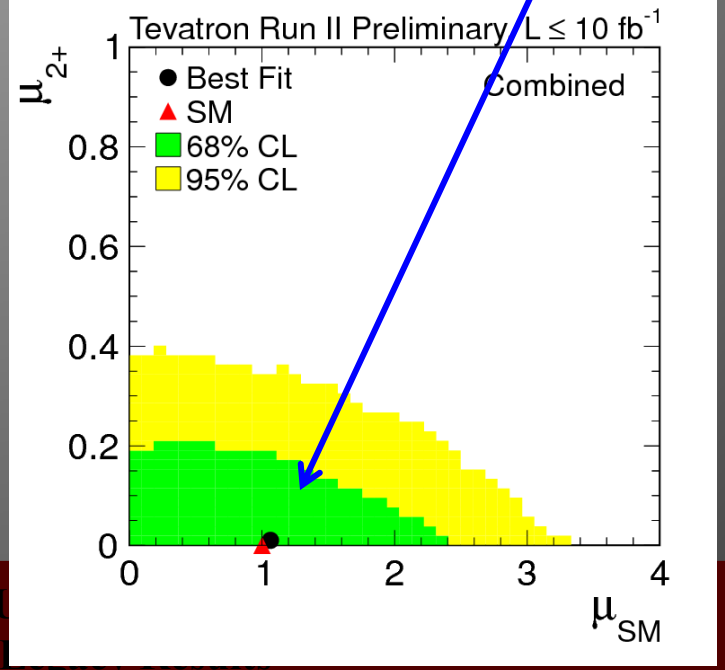


# Tevatron Combination to be Submitted by the End of the Year



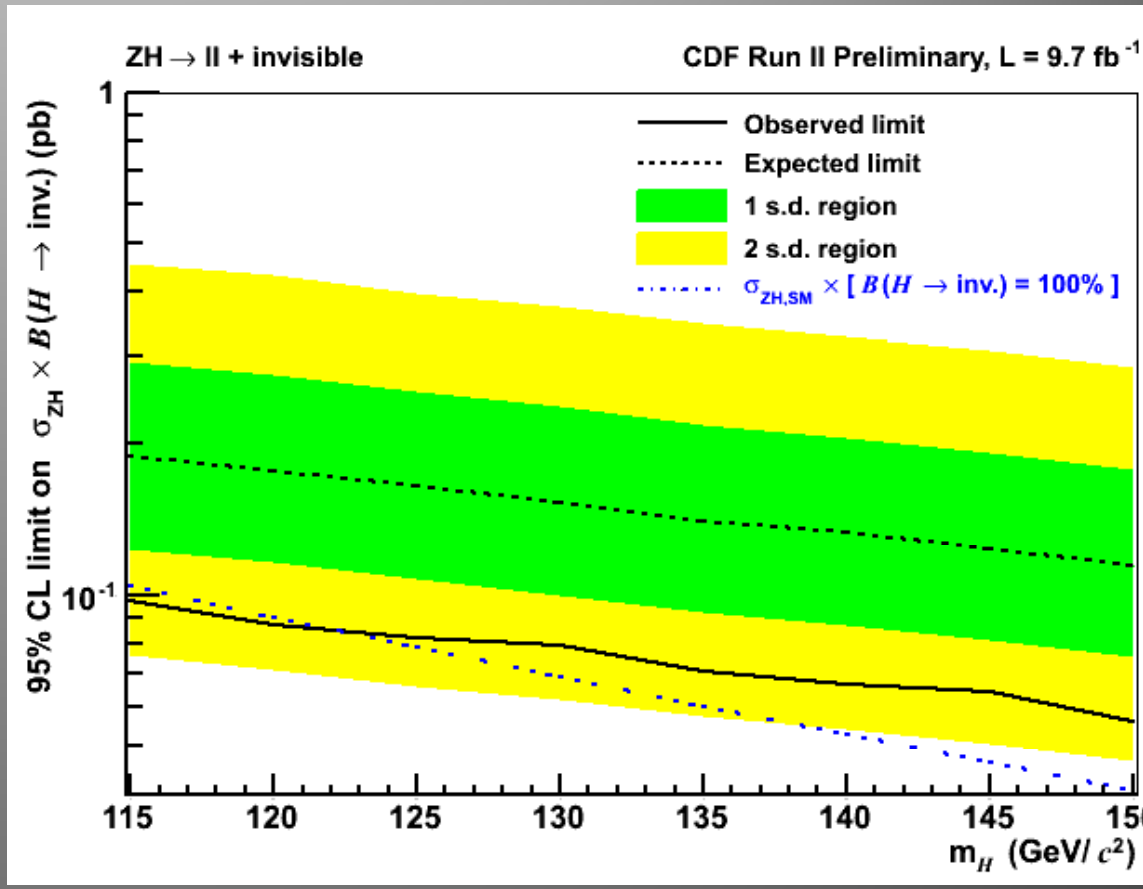



# Invisible Higgs

- Search for ZH→ll+Invisible is recently completed
  - CDFNote 11068
- Working on new interpretation of this result in dark matter scenarios

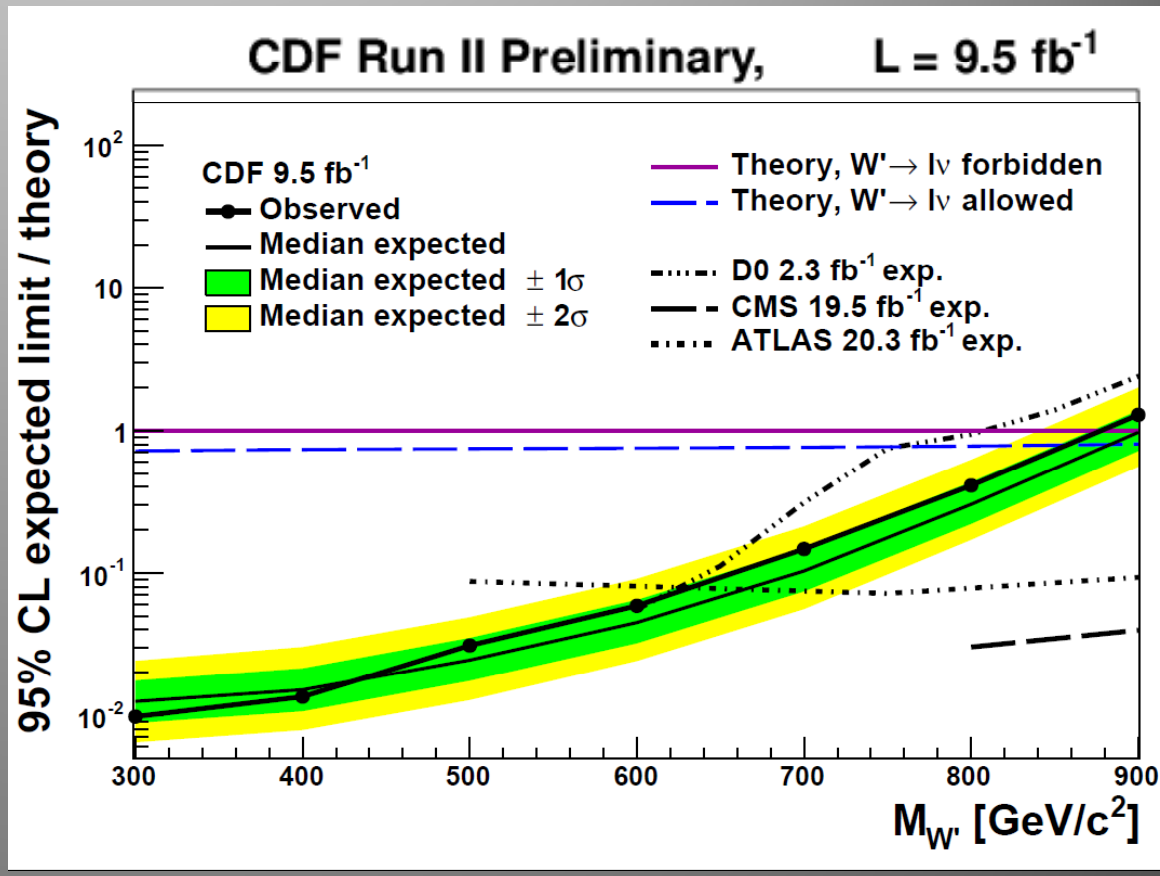


# New Particle Searches

- **Long history of searches at CDF for established models like Supersymmetry, heavy vector bosons, or extra dimensions**
- **Try different models of each, but also in many different variations**
- **Any indication of a deviation from the SM could help point the way to an understanding of what protects the Higgs mechanism, gives neutrinos their mass, tell us if the world is Supersymmetric in nature, or perhaps even give us a dark matter candidate**

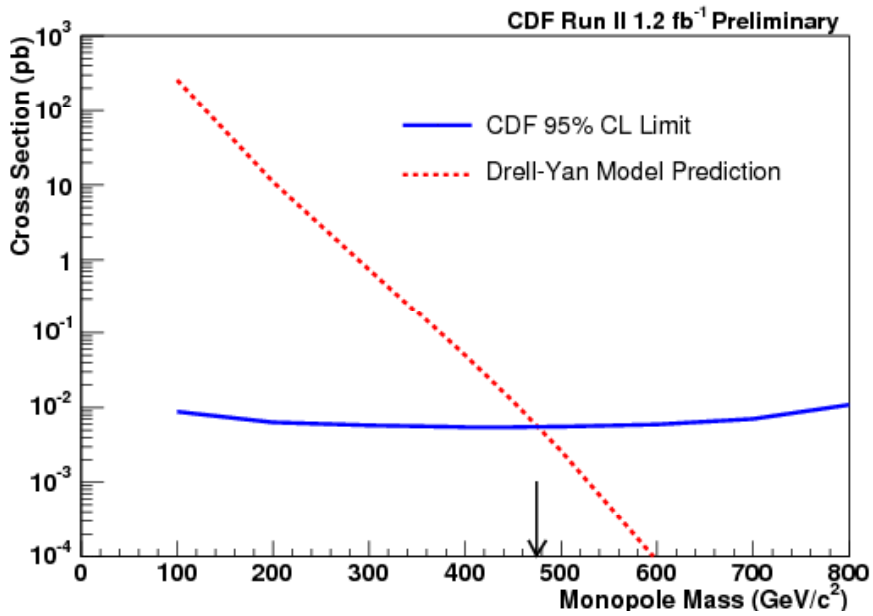
# Search for Heavy Vector Bosons

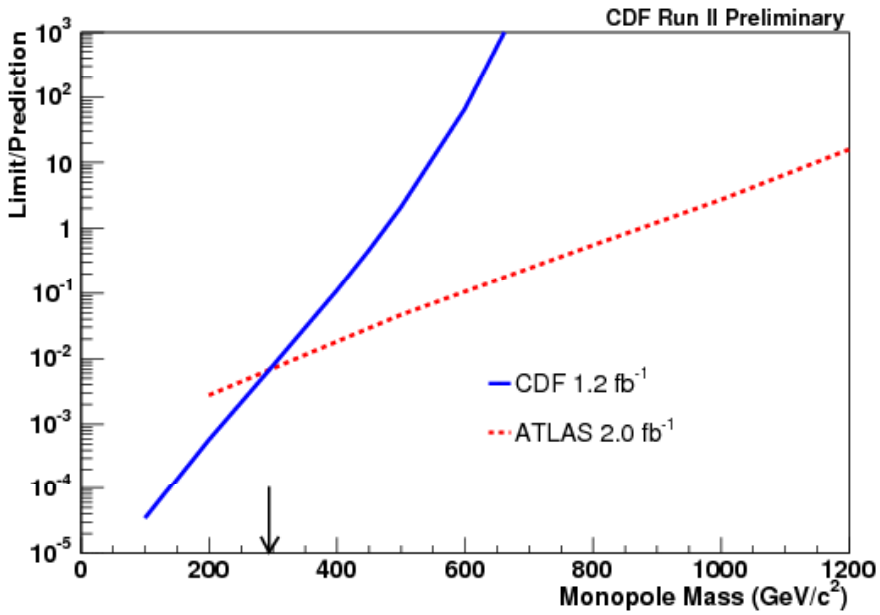
- Tevatron still has advantages for intermediate-mass searches
  - PPbar vs. PP (backgrounds)
  - Low number of interactions per crossing (triggers)
- Recent limits on W'→tb are the world's best at intermediate masses
  - Same for Z' → tt



# Monopoles

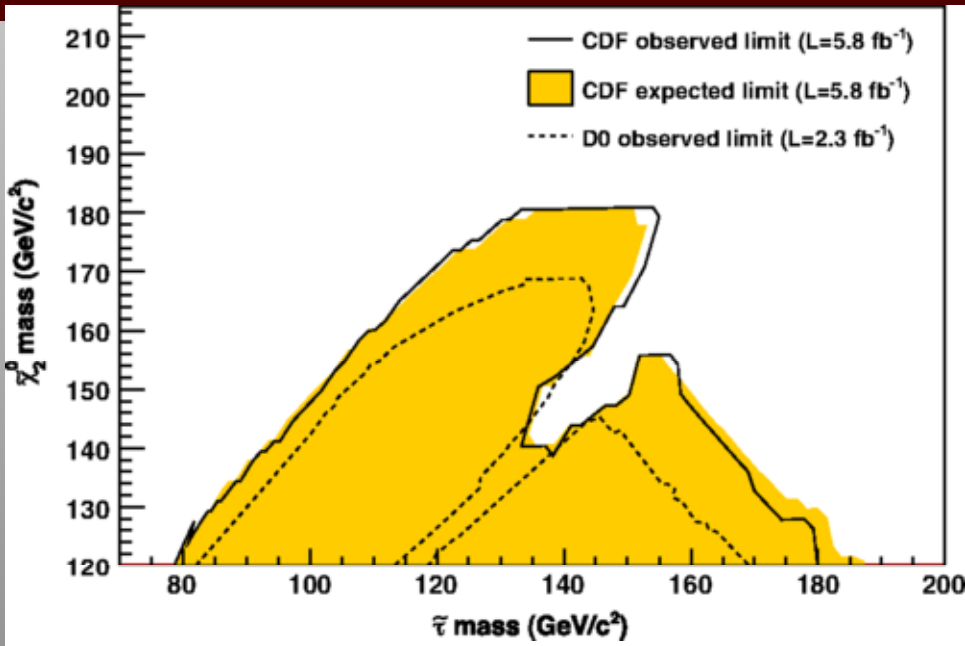
- Use the detector in fun new ways (straight tracks, very high ionization, time-of-flight) to expand our sensitivity to magnetic monopoles
- World's most sensitive limits for intermediate masses
  - Public Note 11102

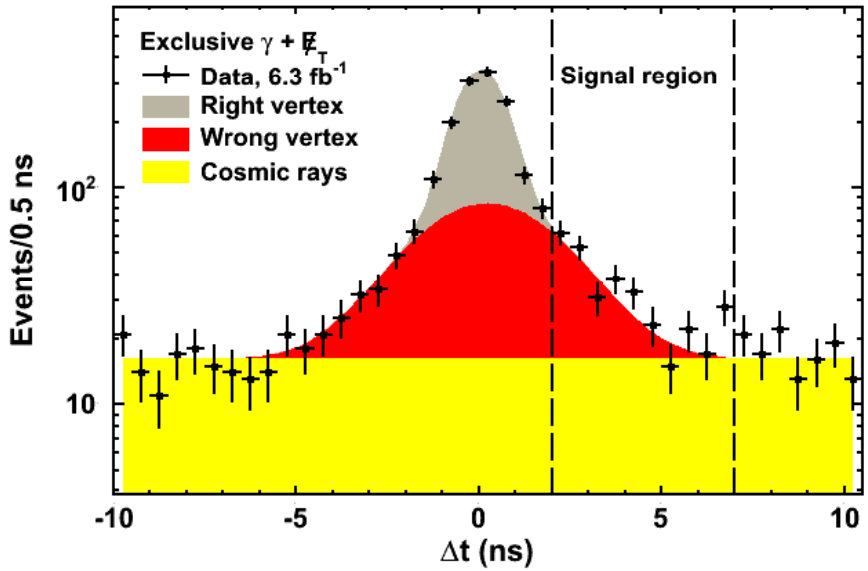


# Supersymmetry

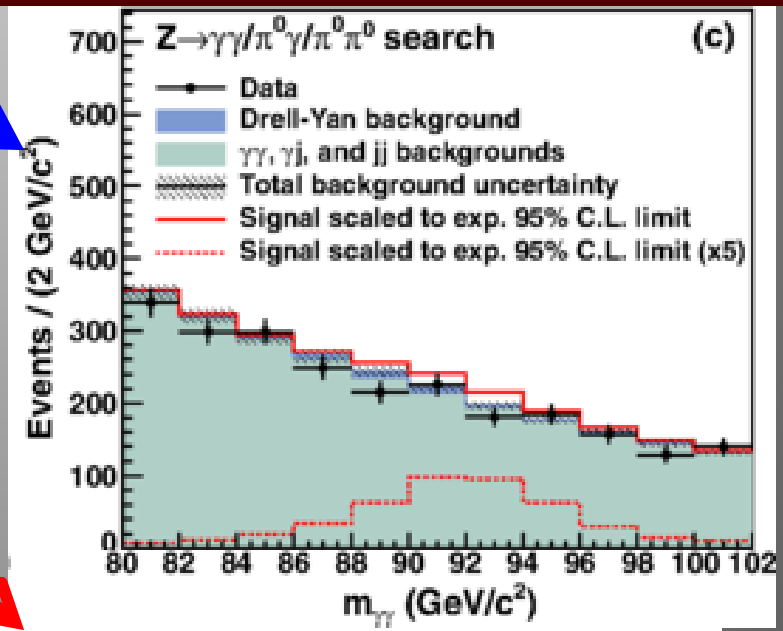
- Long history of searches for SUSY, including models with mSUGRA, GMSB, and Large tanBeta versions of both
- Important results in τ and photon final states, including the EMTiming system to search for Delayed Photons
  - mSUGRA program finished
  - Last GMSB results with delayed photons expected soon

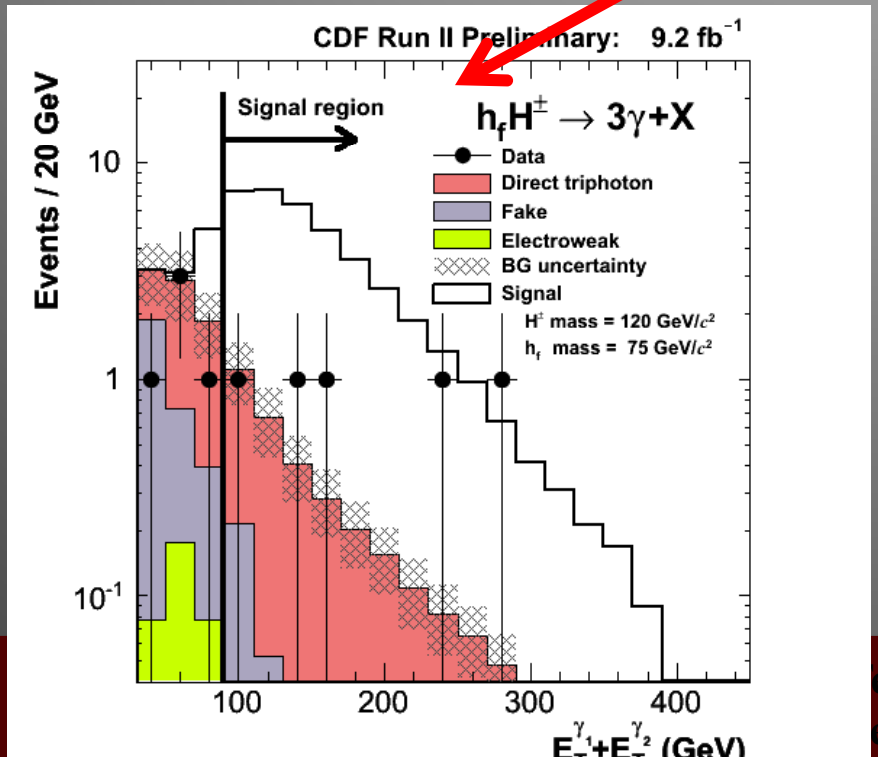


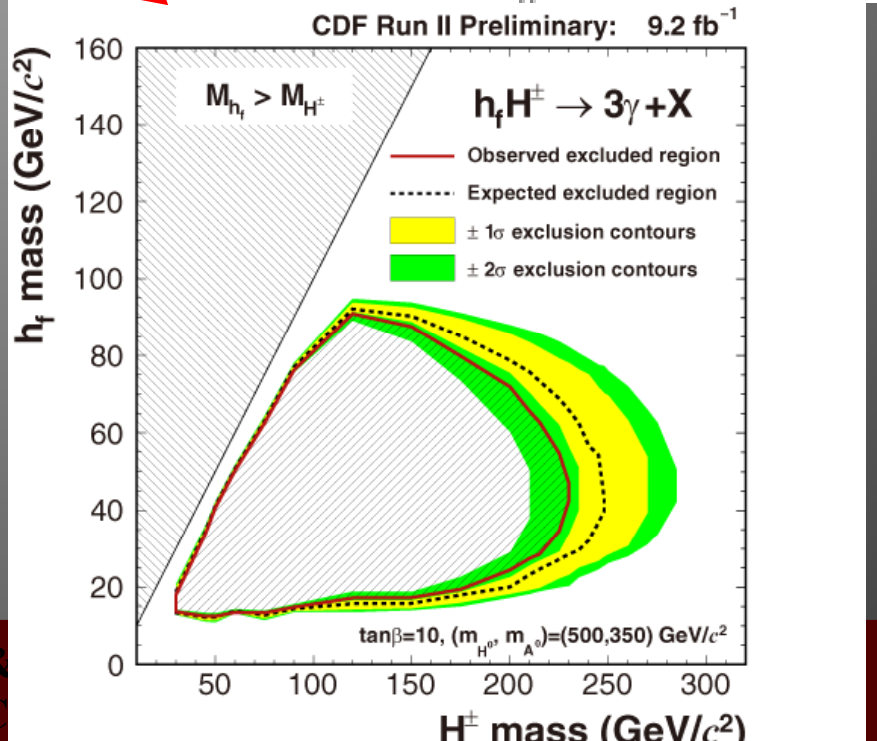



# Diphotons and Triphotons

- Search for forbidden Z→γγ decay (PRL 112, 111803 (2014))
- First tri-photon results which can be interpreted in Higgs models (CDFNote 11116)



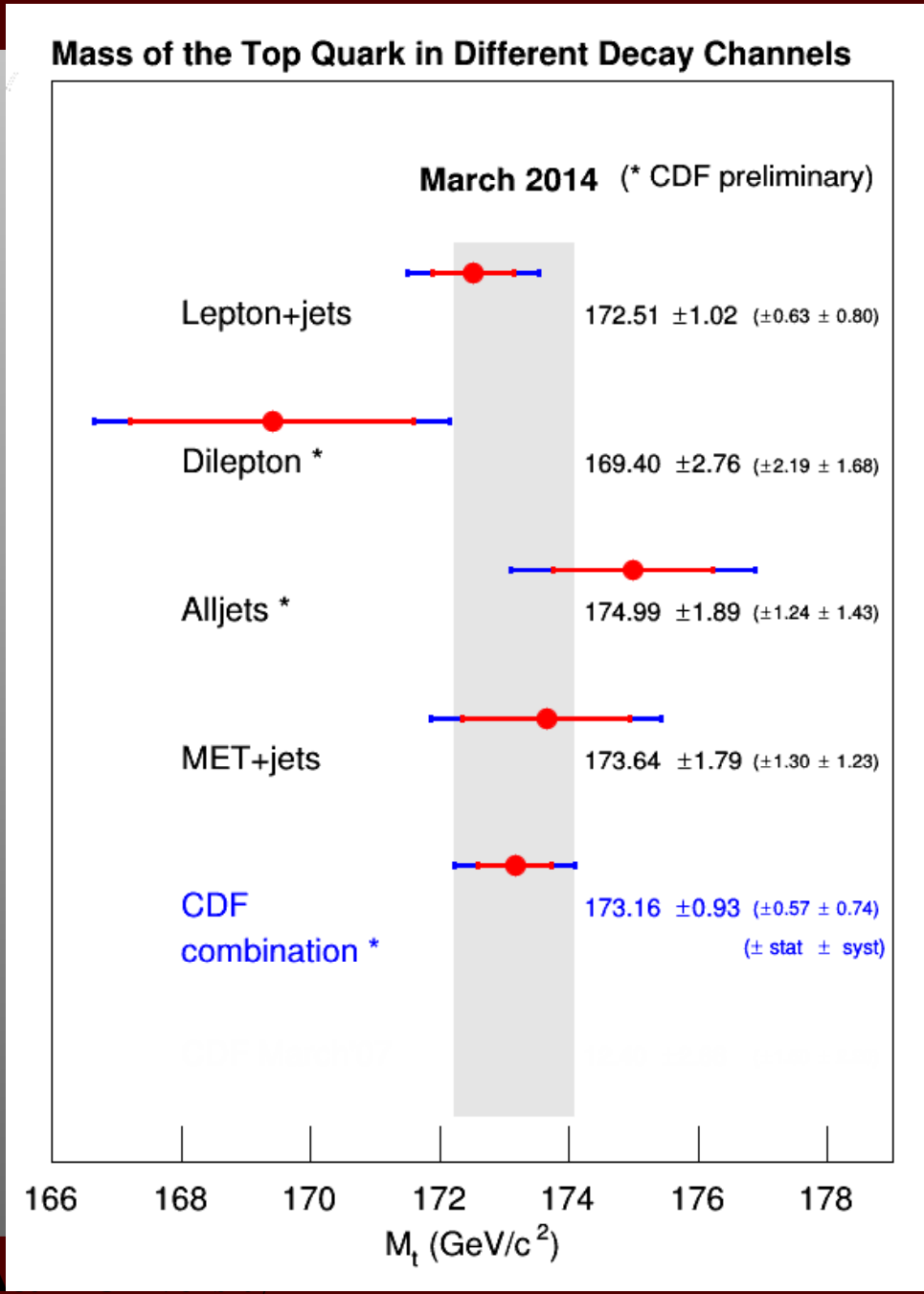



# Top Quarks

- Top quark is a unique probe of particles and their interactions
- Precision measurements are important in their own right, as well as completing the EWK model with the Higgs
- Cross sections (single top and pair production) are the last of their kind for the foreseeable future
- Property measurements are still competitive with LHC
- The forward-backward asymmetry has been anomalous for years, and it may well be that it tells us that NNLO understanding of top quark production is necessary

# Top Mass

- CDF Combination now complete in all channels
  - Public Note 11080
- Updating Lepton+Jets analysis for Matrix Element Methods



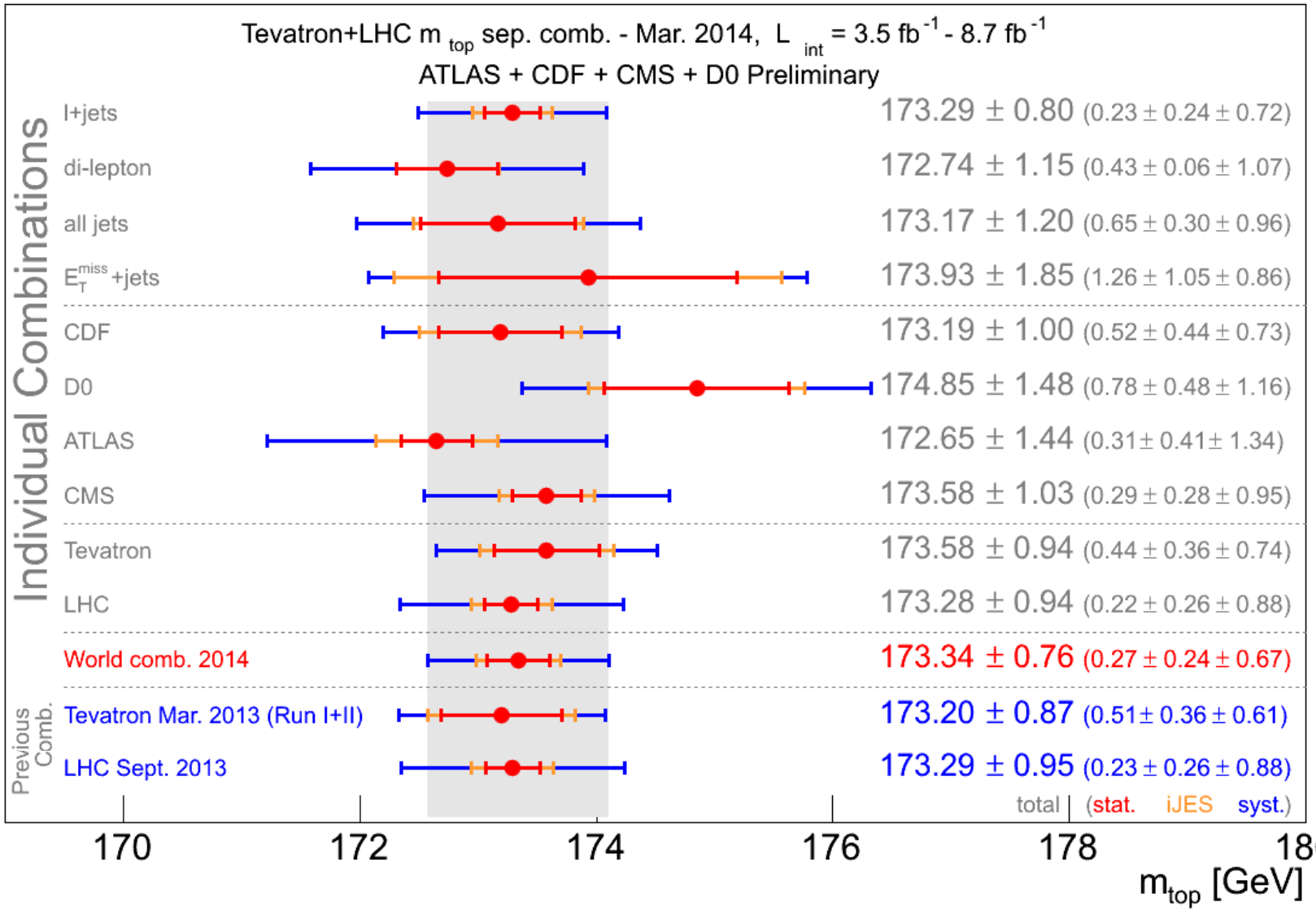
# Top Mass Combinations

## Tevatron Combination

arXiv:1305.3939

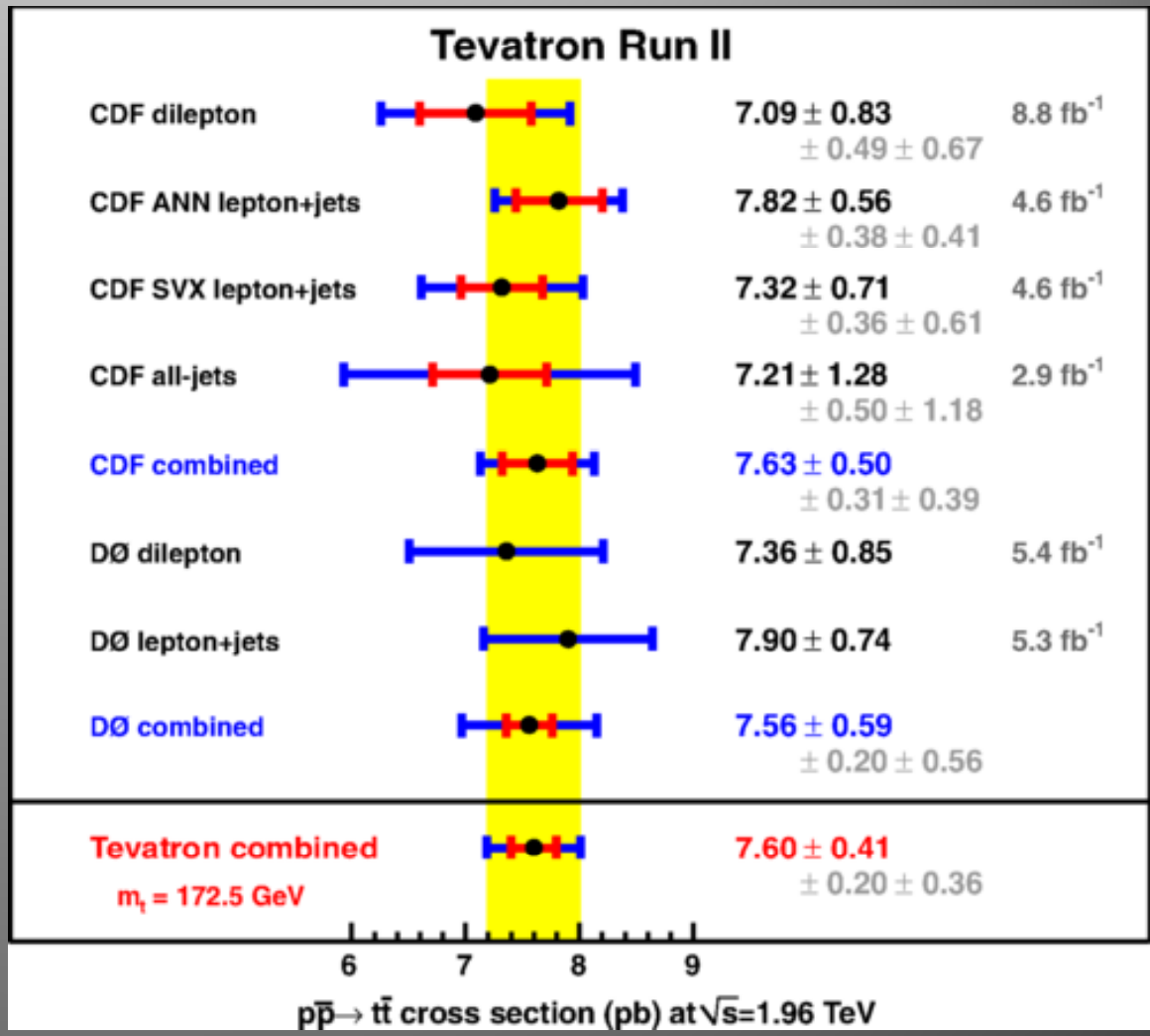
## World combination

arXiv:1403.4427



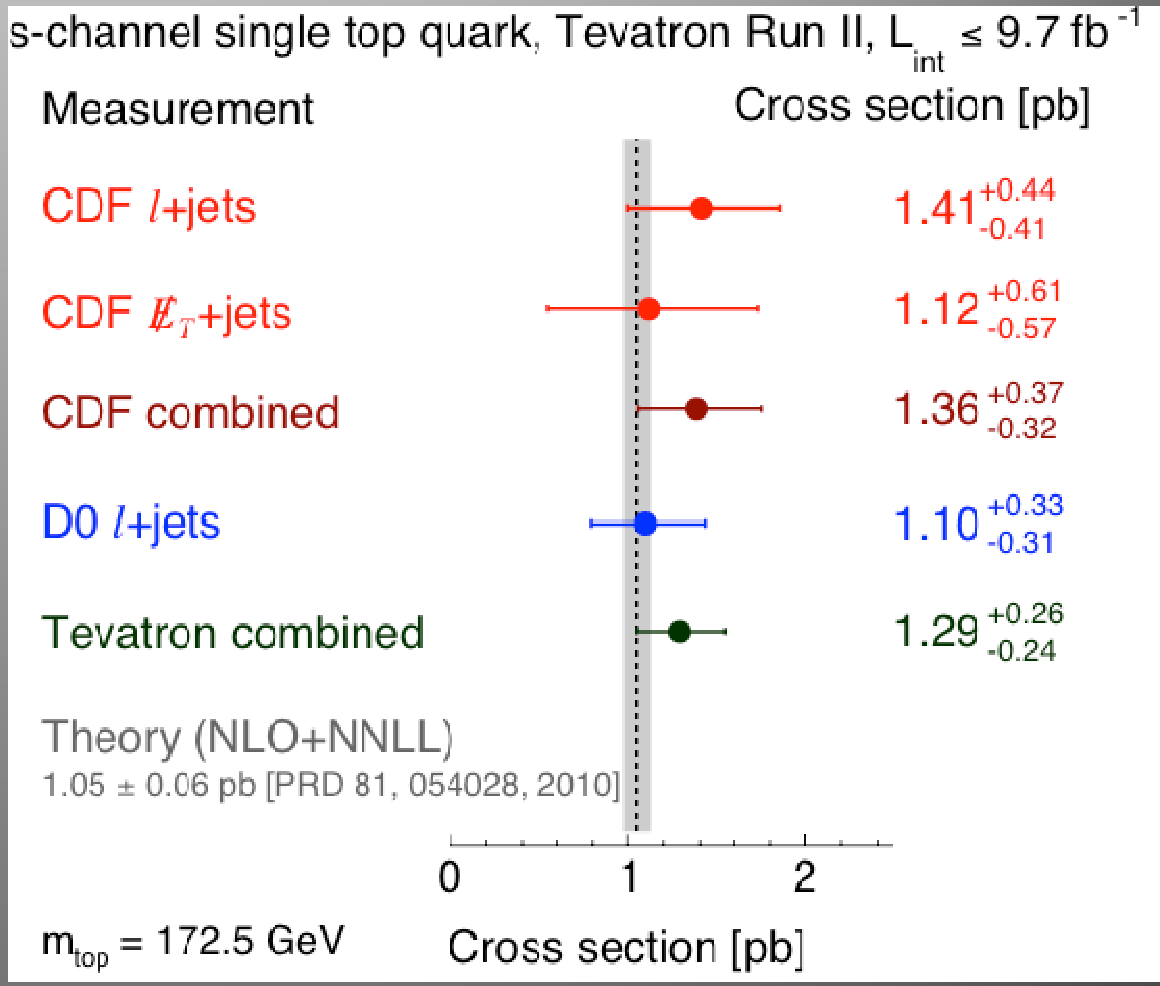
# Top Pair-Production Cross Section

- Combination from ~8.8 $fb^{-1}$ published
  - Phys. Rev. D 89, 072001 (2014)
  - 7.60±0.41 pb
- CDF version in lep+jets with the full dataset in progress



# Observation of Single Top in the s-Channel

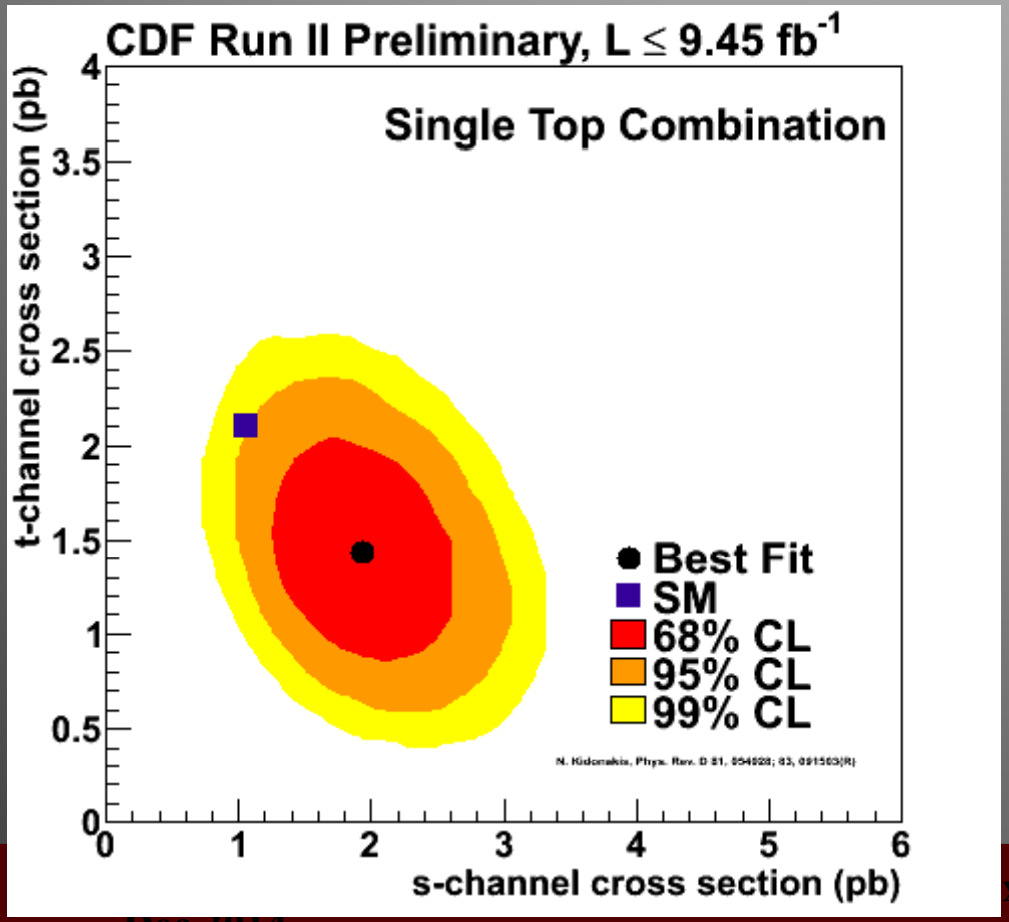
- CDF 4.2σ evidence in the combined Met+Jets and Lepton+Jets
  - PRL 112, 231803 (2014)
  - PRL 112, 231805 (2014)
- Tevatron Combination at 6.3σ
  - PRL 112, 231802 (2014)

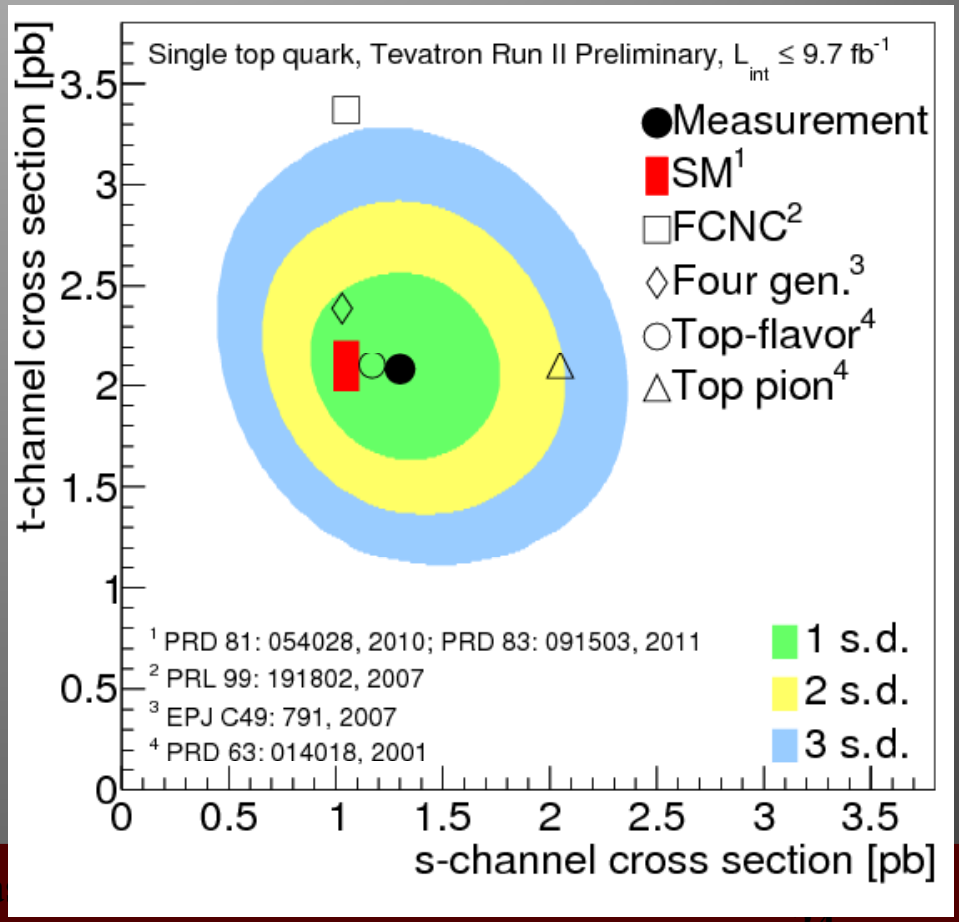


# Single Top: s vs. t

**CDF Result and Tevatron combination for s and t channels separately are complete**

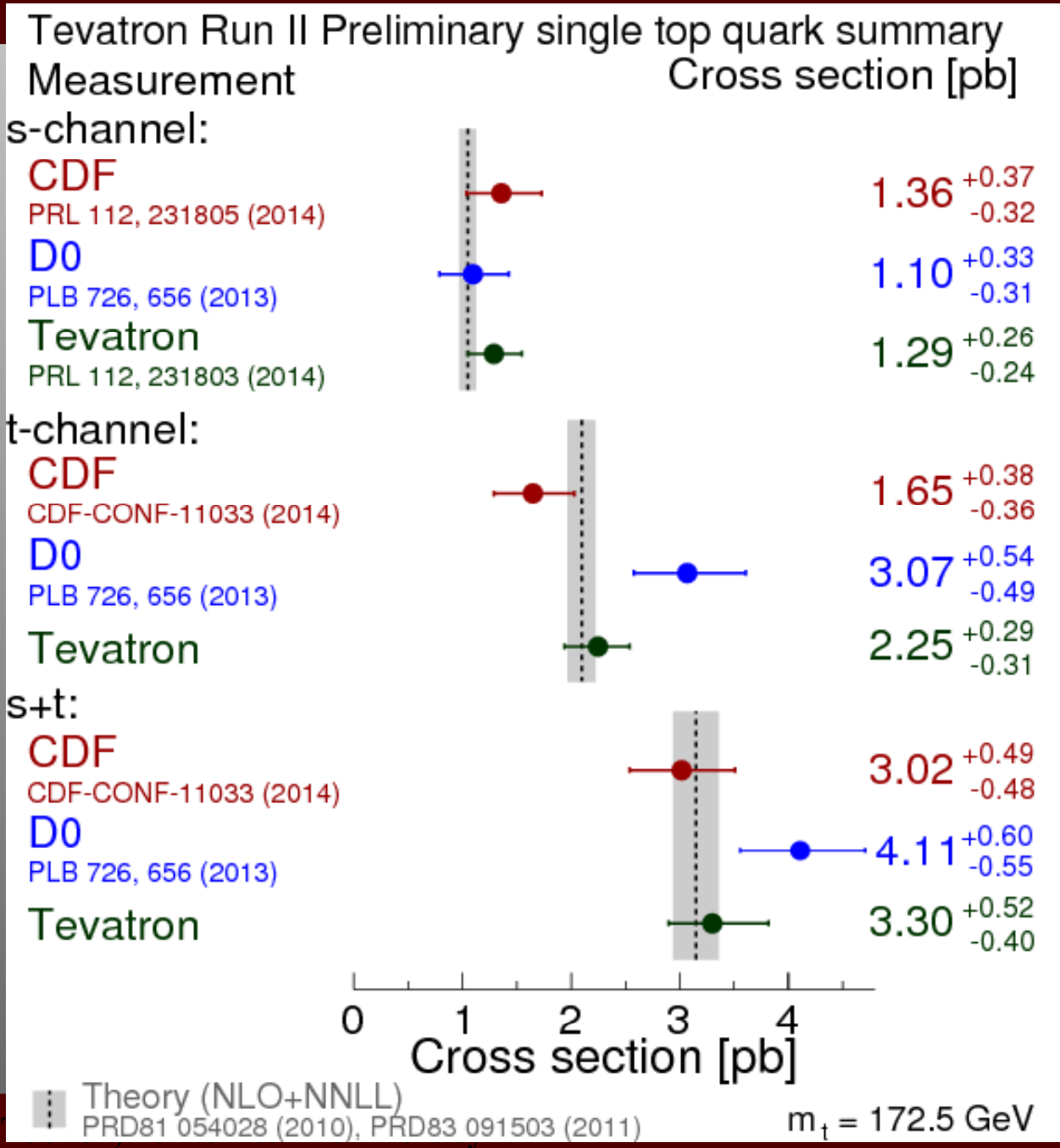
**Nearing publication**



# Cross Sections and Extracting $|V_{tb}|$

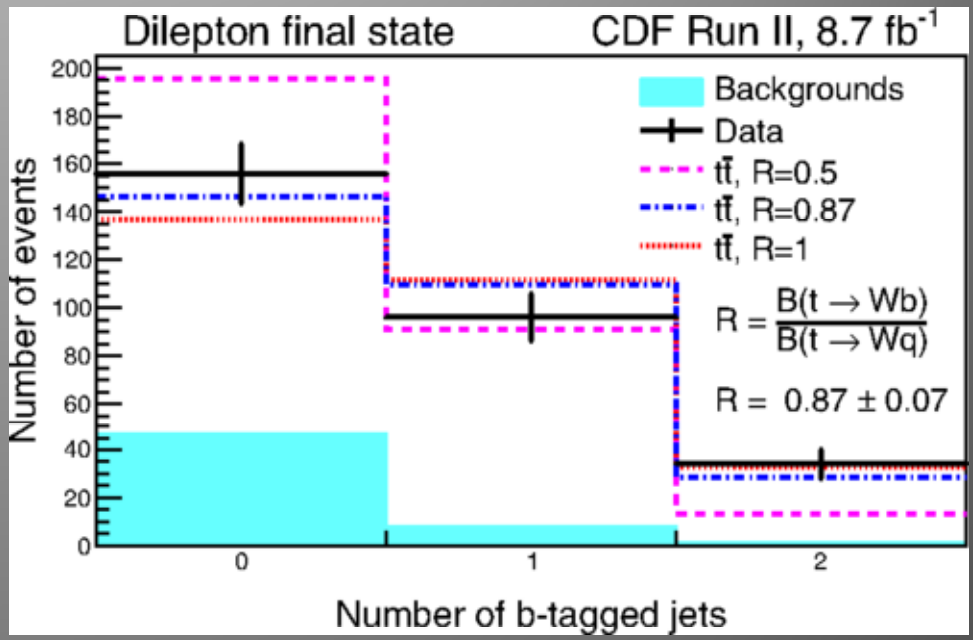
- All single-top cross sections are consistent with SM
- CDF Combined
  - $|V_{tb}|>0.84$
- Tevatron
  - $|V_{tb}|>0.92$



# $|V_{tb}|$ from Top Branching Fractions

- **Can also measure $|V_{tb}|$ from the ratio of t→Wb to t→Wq**
  - **Use Lepton+Jets and Dilepton final state**
- **Measure:**
  - **R=0.87±0.07**
  - **$|V_{tb}|$=0.93±0.04**
  - **$|V_{tb}|$>0.85 at 95% CL**

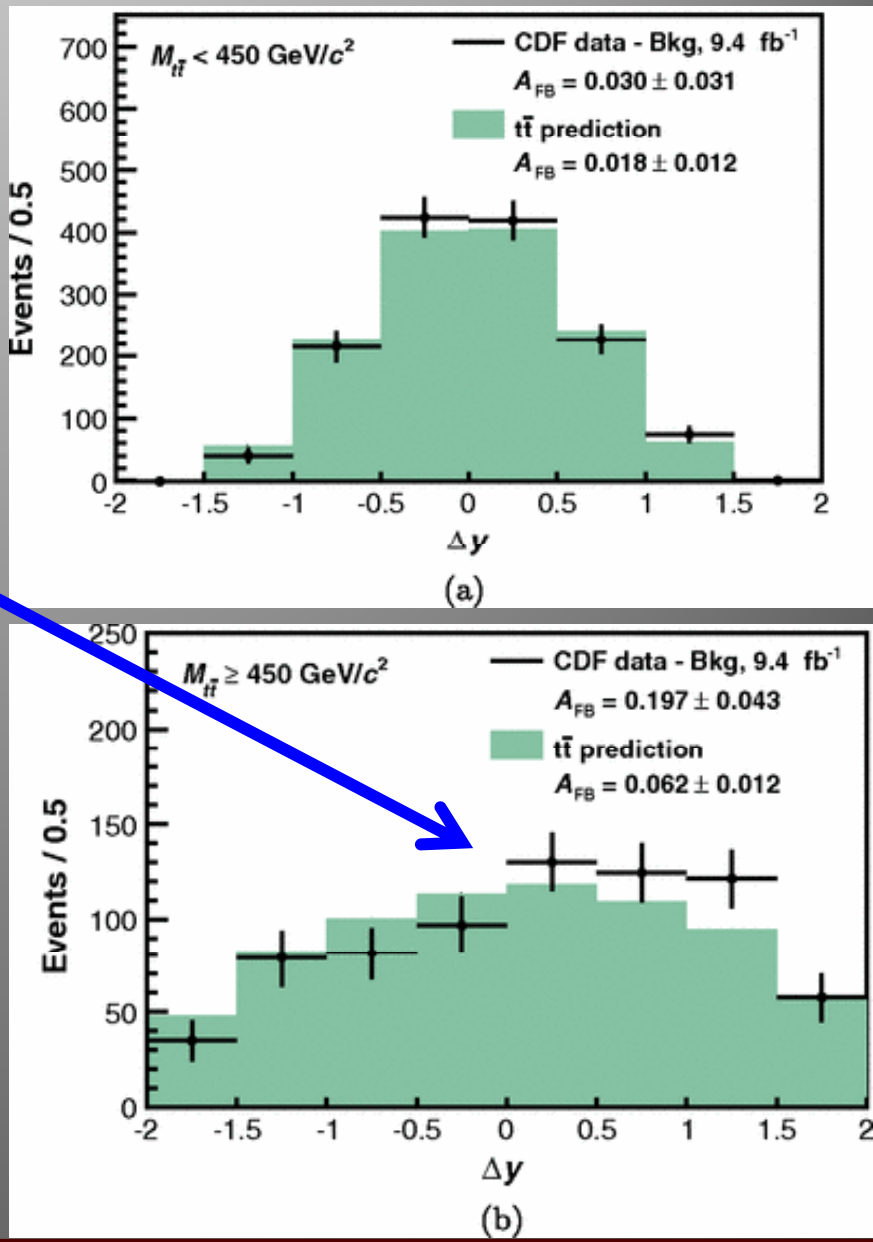
$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$




**Phys. Rev. Lett. 112, 221801 (2014)**

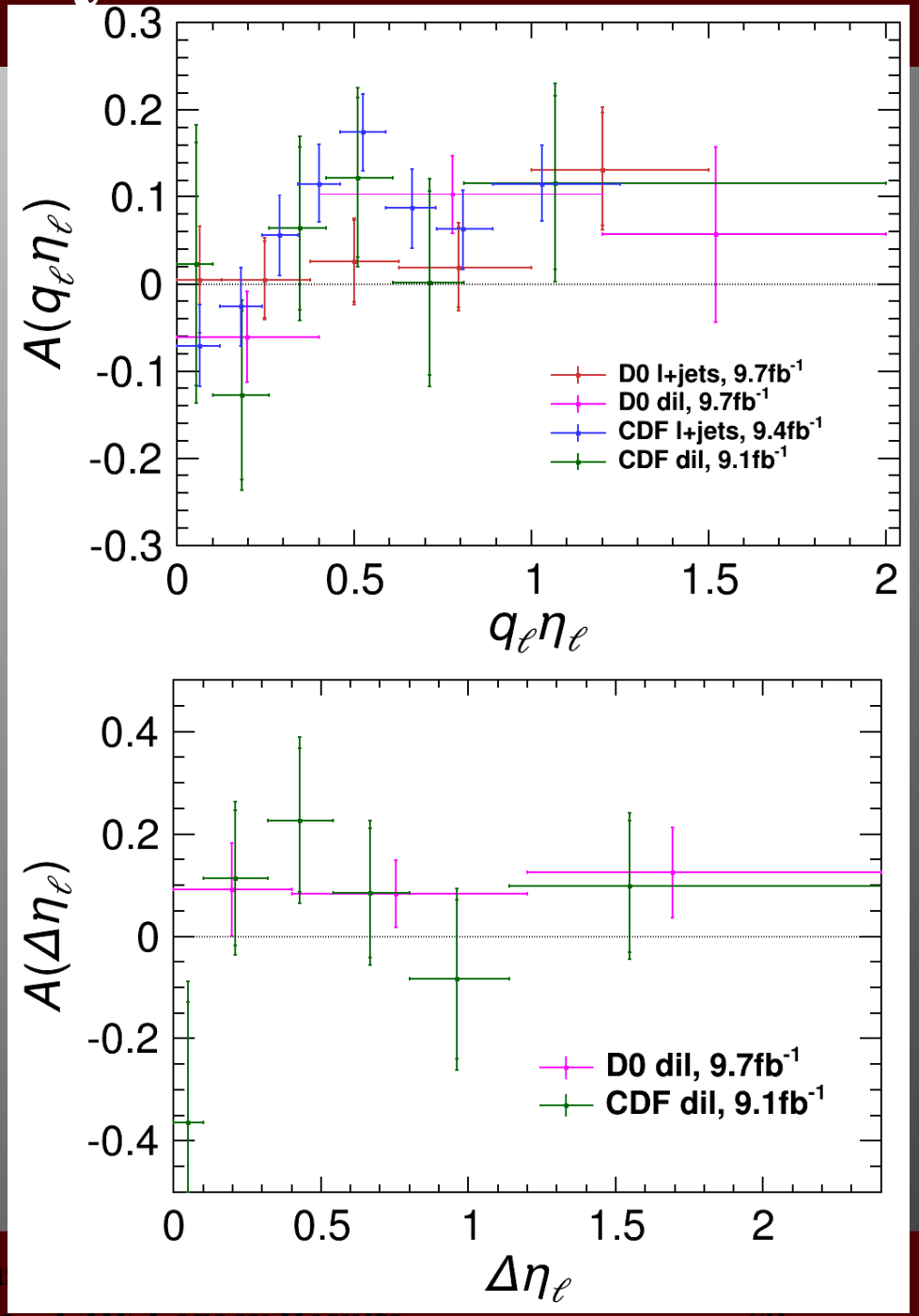
# Forward-Backward Asymmetry in ttbar

- Hot topic for a number of years/Theory-Experiment doesn't hang together well
- Focus on gathering facts to improve methods and theory
- CDF Lep+Jets results shows many more forward events than backward events (when compared to predictions) at large $m_{tt}$
- Large amounts of follow up
  - Lepton+Jets and Dilepton
  - Both Full-reconstruction asymmetry and the leptonic-asymmetry
  - NLO simulations and recently a NNLO calculation



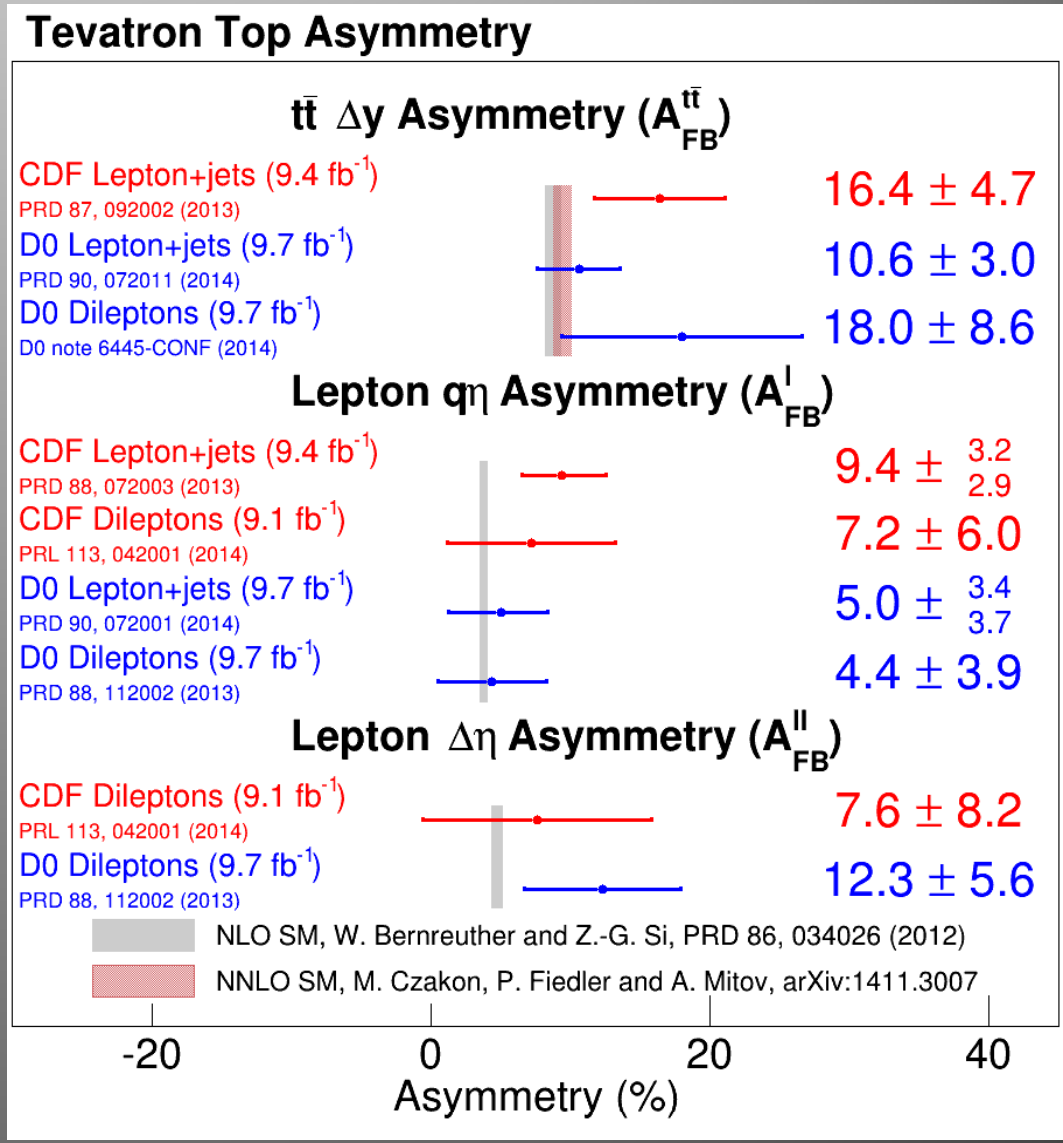
# Differential Asymmetries

- Get leptonic asymmetries with negligible reconstruction uncertainties
- Extrapolate the inclusive asymmetry from the differential distributions
- For dilepton events, can get the $\Delta\eta$ asymmetry
- Individual results published, Tevatron combination results in progress



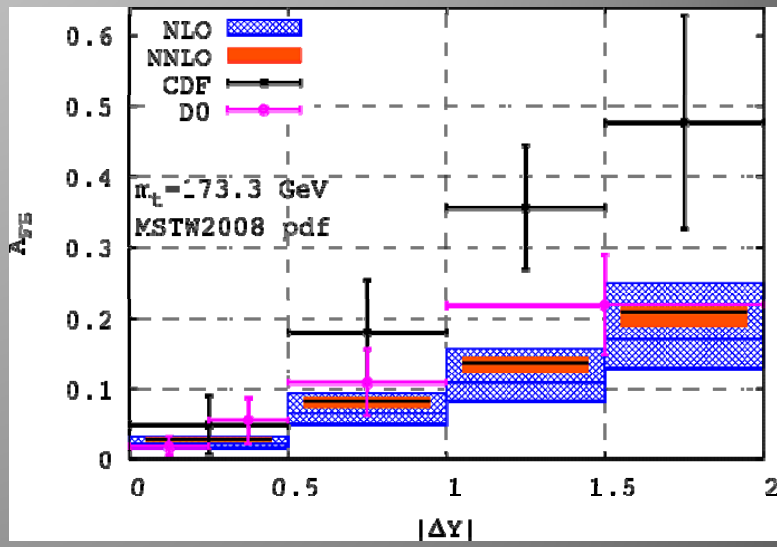
# Integrated Asymmetries

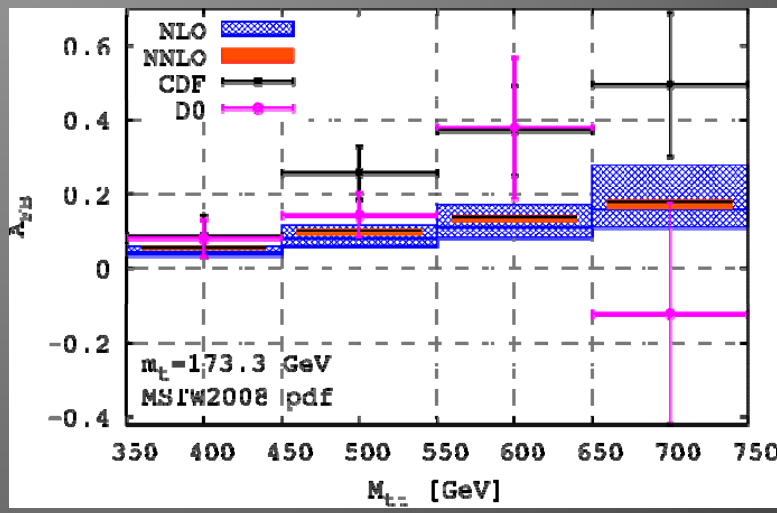
- New NNLO measurement for tt asymmetry (slight increase)
- The "by eye" $\chi^2$ is small, but 9 out of 9 are above predictions
- CDF full reconstruction in dileptons nearing completion, final combination in progress



# What remains? Differential Distributions

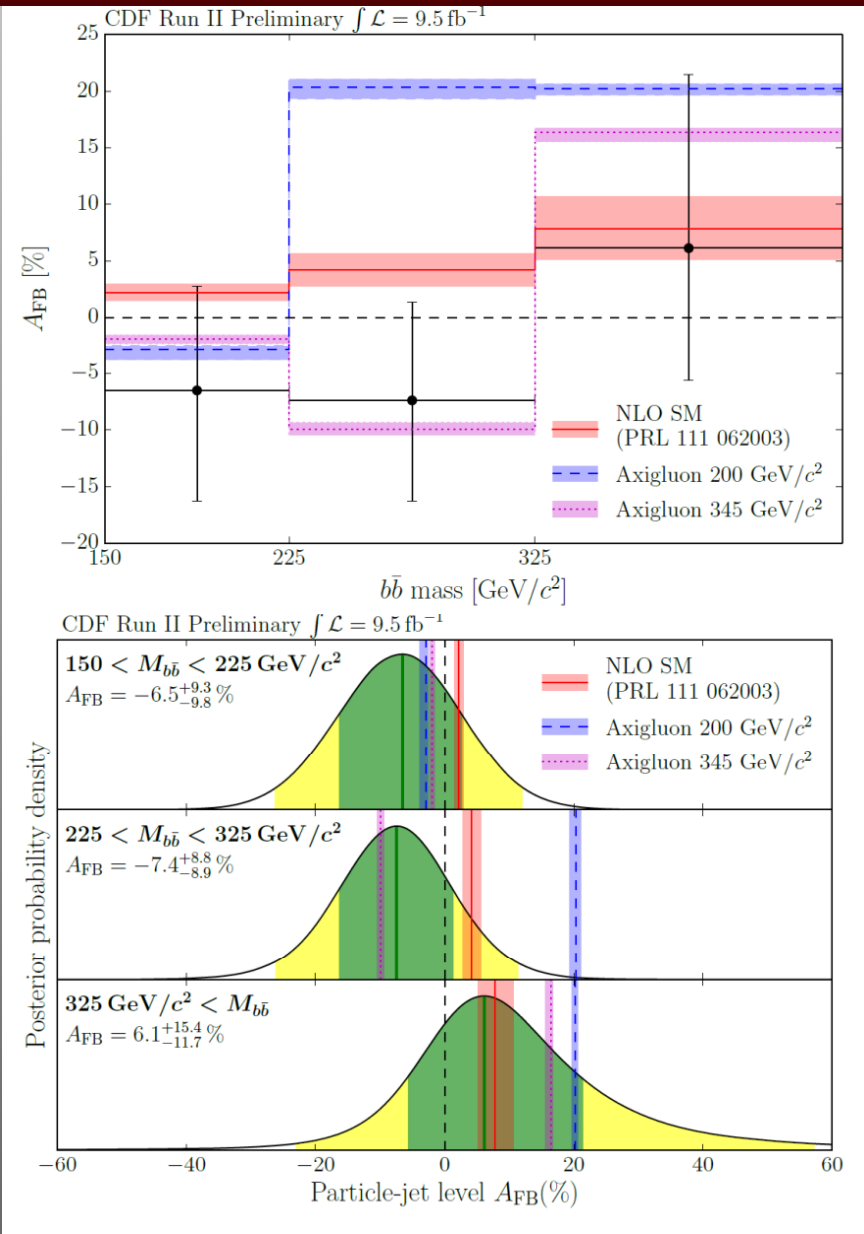
- Differential distributions agree with NNLO? Not as clear at large $\Delta Y$ and $M_{tt}$
- Modest discrepancies between CDF and Dzero at large $\Delta Y$ and $M_{tt}$
- Working on combination for final Tevatron Legacy numbers



# $A_{FB}$ in bb

- The $A_{FB}$ in tt makes it compelling to look at the same measurement in the bb final state
- New results consistent with SM
  - Public note 11092
- Measurement at lower masses of bb in the works



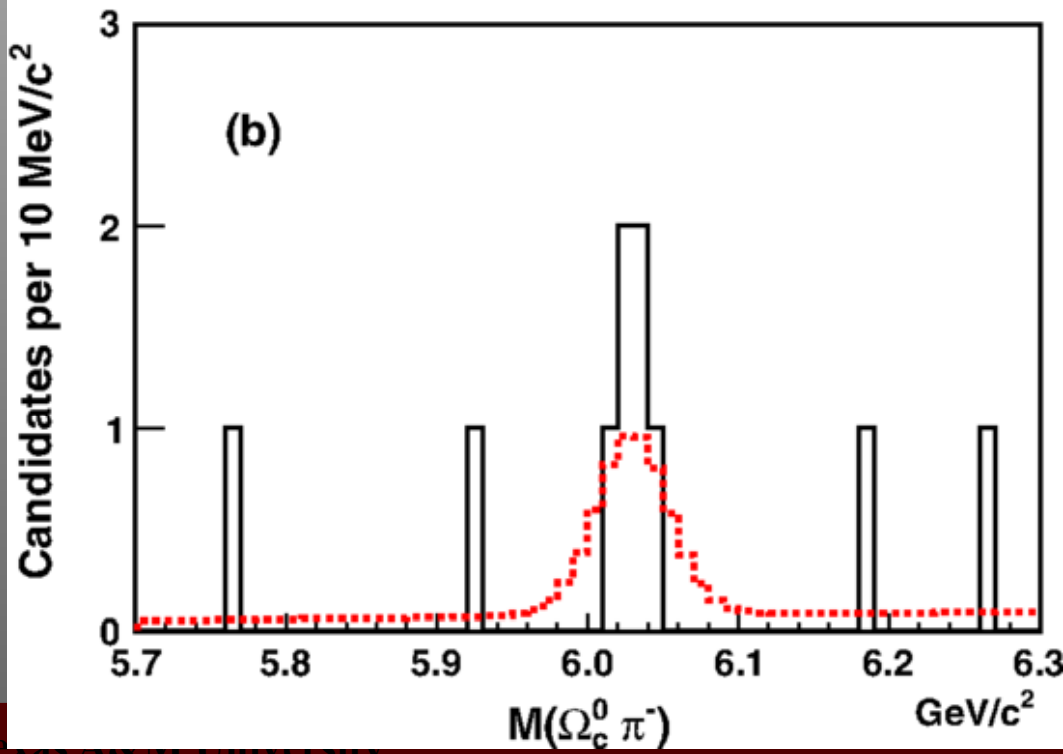
# Heavy Flavor

- **The CDF Heavy Flavor program has been powerful for many years and is rich and broad in measurements and searches for both bottom and charm states**
- **Probe of strong production, meson and baryon states, and EWK decays**
- **CP violation could tell us about the matter anti-matter asymmetry in the universe**

# *b*-Baryon Properties

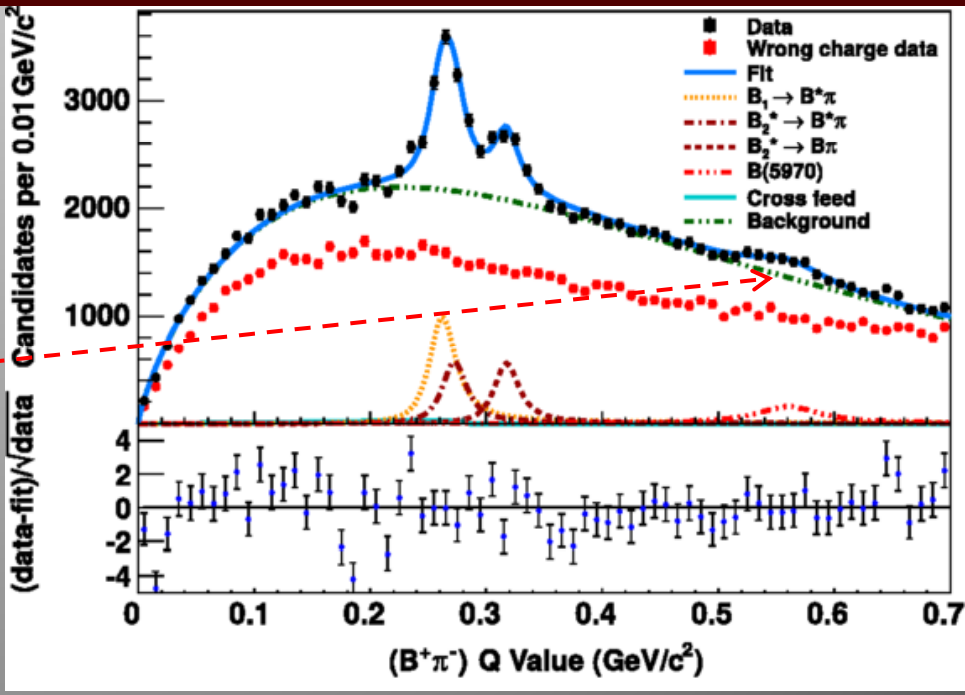
- **Full dataset measurement of the masses and lifetimes of $\Xi_c$ and *b*-baryons**
- **First observations of**
  **$\Omega_b^- \rightarrow \Omega_c^0 \pi^-$ and**
  **$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$**
  - **PRD 89, 072014 (2014)**

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



# 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
  - PRD 90, 012013 (2014)

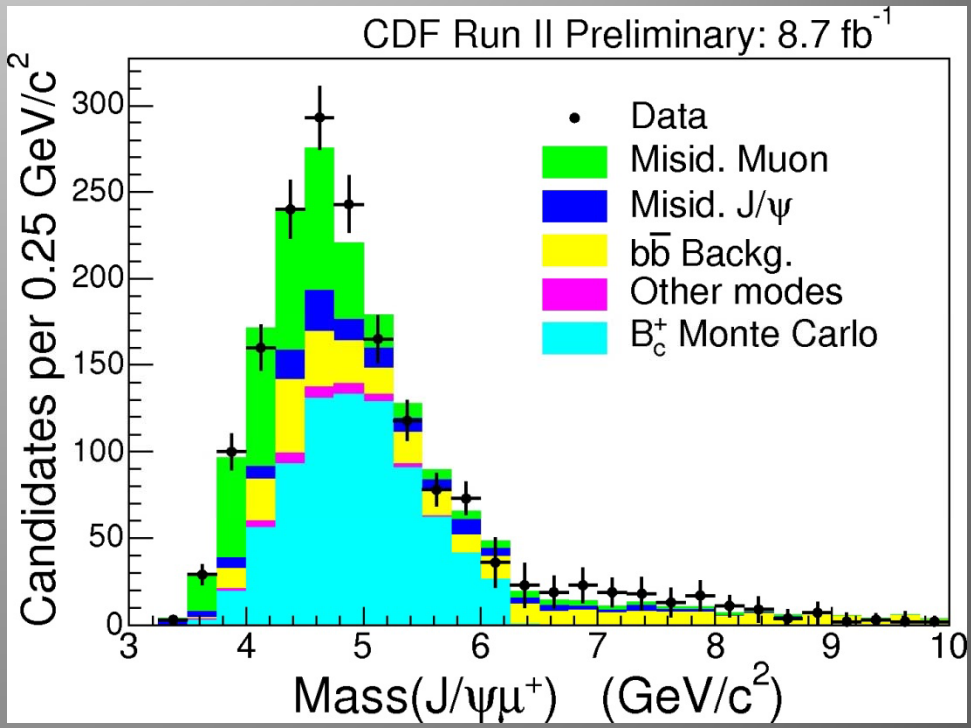



| Quantity MeV/$c^2$ | Value MeV/$c^2$ | Stat. uncert. MeV/$c^2$ | Syst. uncert. MeV/$c^2$ |
|---|---|---|---|
| $Q(B(5970)^0)$ | 558 | 5 | 12 |
| $Q(B(5970)^+)$ | 541 | 5 | 3 |
| $m(B(5970)^0)$ | 5978 | 5 | 12 |
| $m(B(5970)^+)$ | 5961 | 5 | 3 |
| $\Gamma(B(5970)^0)$ | 70 | 18 | 31 |
| $\Gamma(B(5970)^+)$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

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

# Measurement of $B_c$ Production

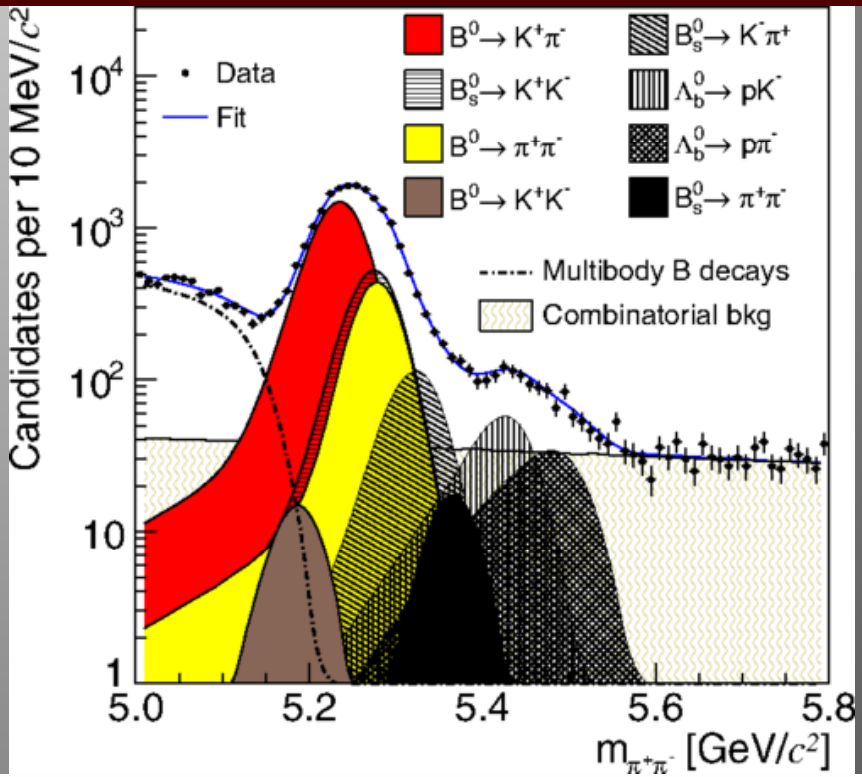
- Important to learn more about $B_c$, do what we can at the Tevatron
- Measure the ratio of the production cross section times branching fraction of $B_c^+ \rightarrow J/\psi\, \mu^+\nu$ relative to $B^+ \rightarrow J/\psi K^+$
- CDFNote 11083




| Quantity | Value |
|---|---|
| $N(B_c^+ \rightarrow J/\psi\mu^+\nu)$ | $739.5 \pm 39.6(\text{stat})\ ^{+19.8}_{-23.9}(\text{sys})$ |
| $N(B^+ \rightarrow J/\psi K^+)$ | $14338 \pm 125$ (stat) |
| $\epsilon_{rel}$ | $4.093 \pm 0.038(\text{stat})^{+0.401}_{-0.359}(\text{sys})$ |
| $\frac{\sigma(B_c^+)BR(B_c^+\rightarrow J/\psi\mu^+\nu)}{\sigma(B^+)BR(B^+\rightarrow J/\psi K^+)}$ | $0.211 \pm 0.012$ (stat) $^{+0.021}_{-0.020}$ (sys) |

# Direct CP Violating Asymmetries in Charmless Decays of Strange Bottom Mesons and Bottom Baryons

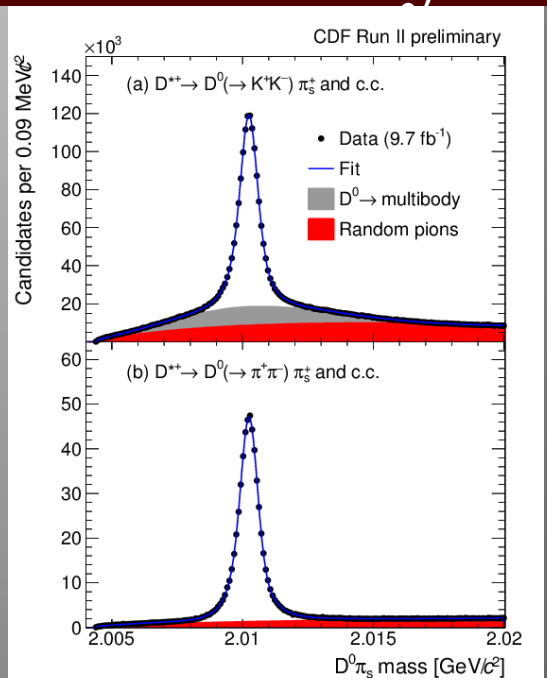
- Direct CP violation in charmless decays of B mesons have shown discrepancies from expectations
- Follow up on with $B^0 \to K^+ \pi^-$, $B^0_s \to \pi^+ K^-$ as well as Lambdas
- Results are compatible with and have comparable accuracy with current results from B-Factories and LHCb
  - PRL 113, 242001 (2014)

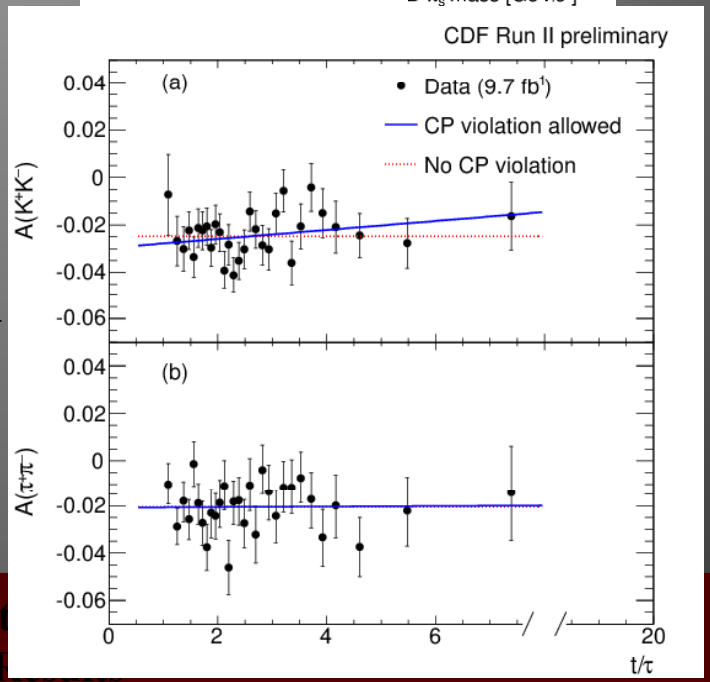



| Quantity | Measurement |
|---|---|
| $\frac{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)}$ | $\mathcal{A}_{CP}(B^0 \to K^+\pi^-) = -0.083 \pm 0.013 \pm 0.003$ |
| $\frac{\mathcal{B}(\overline{B}^0_s \to K^+\pi^-) - \mathcal{B}(B^0_s \to K^-\pi^+)}{\mathcal{B}(\overline{B}^0_s \to K^+\pi^-) + \mathcal{B}(B^0_s \to K^-\pi^+)}$ | $\mathcal{A}_{CP}(B^0_s \to K^-\pi^+) = +0.22 \pm 0.07 \pm 0.02$ |
| $\frac{\mathcal{B}(\Lambda^0_b \to p\pi^-) - \mathcal{B}(\overline{\Lambda}^0_b \to \overline{p}\pi^+)}{\mathcal{B}(\Lambda^0_b \to p\pi^-) + \mathcal{B}(\overline{\Lambda}^0_b \to \overline{p}\pi^+)}$ | $\mathcal{A}_{CP}(\Lambda^0_b \to p\pi^-) = +0.07 \pm 0.07 \pm 0.03$ |
| $\frac{\mathcal{B}(\Lambda^0_b \to pK^-) - \mathcal{B}(\overline{\Lambda}^0_b \to \overline{p}K^+)}{\mathcal{B}(\Lambda^0_b \to pK^-) + \mathcal{B}(\overline{\Lambda}^0_b \to \overline{p}K^+)}$ | $\mathcal{A}_{CP}(\Lambda^0_b \to pK^-) = -0.09 \pm 0.08 \pm 0.04$ |

# Indirect CP-violating asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays

- Use $D^{*+} \to D^0 \pi^+$ decays to identify the flavor of the neutral charmed meson at production
- Allows a measurement of the effective-lifetime asymmetry, $A_\Gamma$
  - $A_\Gamma (\pi^+\pi^-) = [-0.1 \pm 1.8 \text{ (stat.)} \pm 0.3 \text{ (syst.)}] \times 10^{-3}$
  - $A_\Gamma(K^+K^-) = [-1.9 \pm 1.5 \text{ (stat.)} \pm 0.4 \text{ (syst.)}] \times 10^{-3}$
- CDF Public Note 11117, accepted for publication in PRD-RC



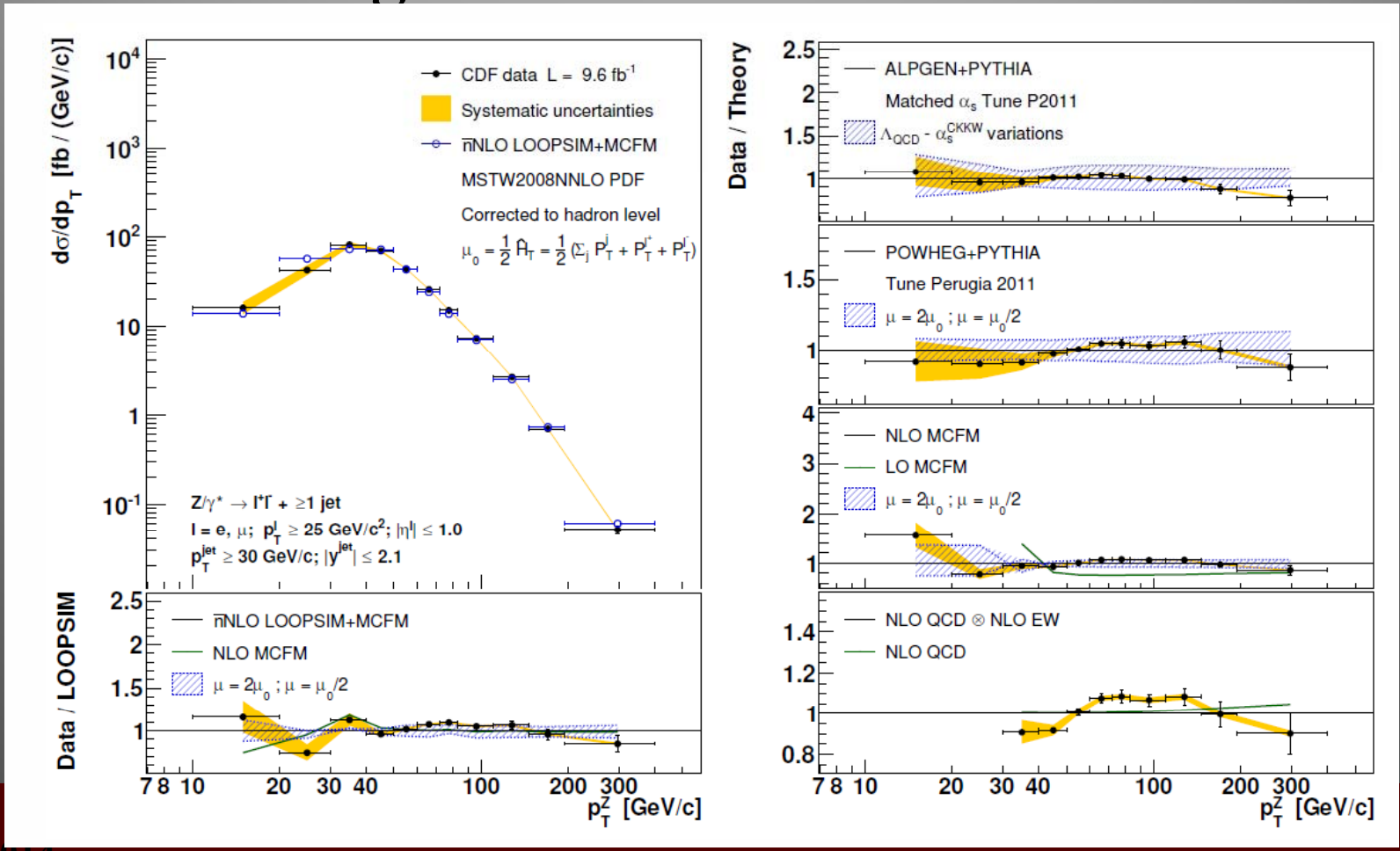



# QCD

- **The strong interaction is one of the most difficult to probe in any experiment**
- **Many studies which look for deviations of the Standard Model as well as to improve future experiments**

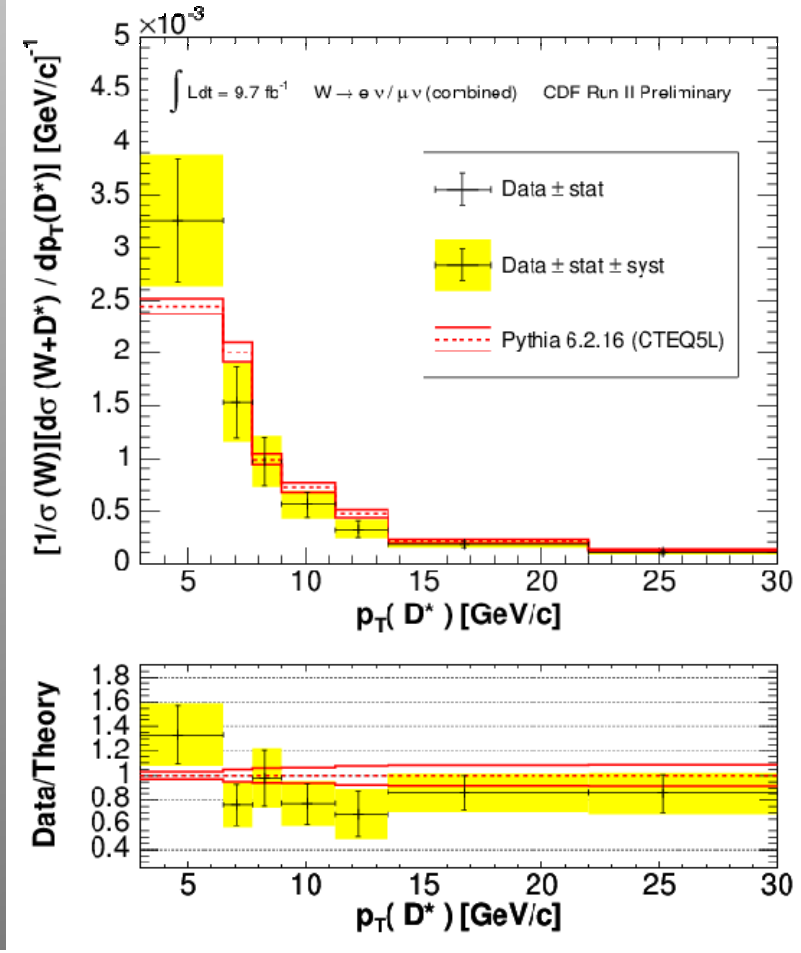
# W/Z+Jets

- Z+jets Production well described by QCD@NLO
  - arXiv:1409.4359, Accepted to PRD
- W+Jets coming soon



# Vector Boson + Heavy Flavor Production

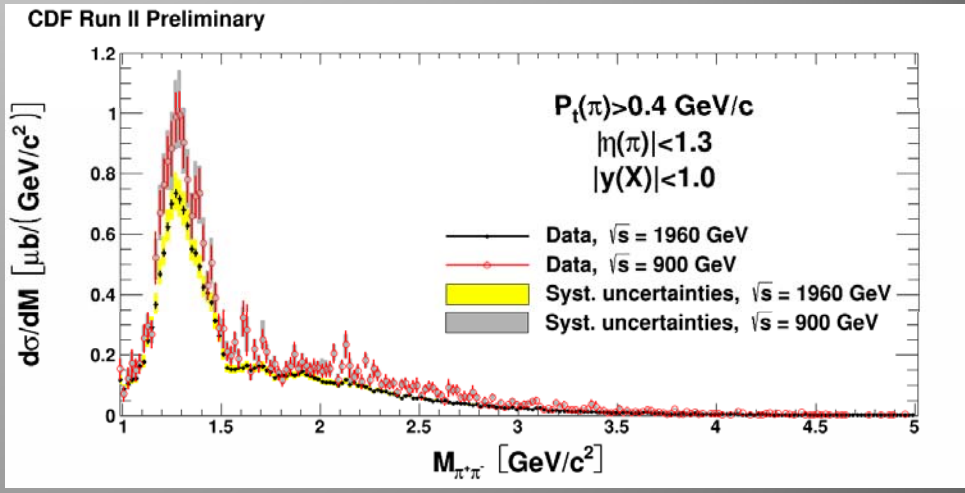
- **Measurements of $\sigma(W+D^*)/\sigma(W)$ and $\sigma(Z+D^*)/\sigma(Z)$ in the W/Z leptonic decay channels using full $D^*$ reconstruction**
  - **First measurement of W/Z+$D^*$ production with $p_T(c) < 15$ GeV at the Tevatron**
  - **CDF Public Note 11087**
- **W/Z+Upsilon**
  - **No observation, new limits**
  - **arXiv:1412.4827 Submitted to PRD**

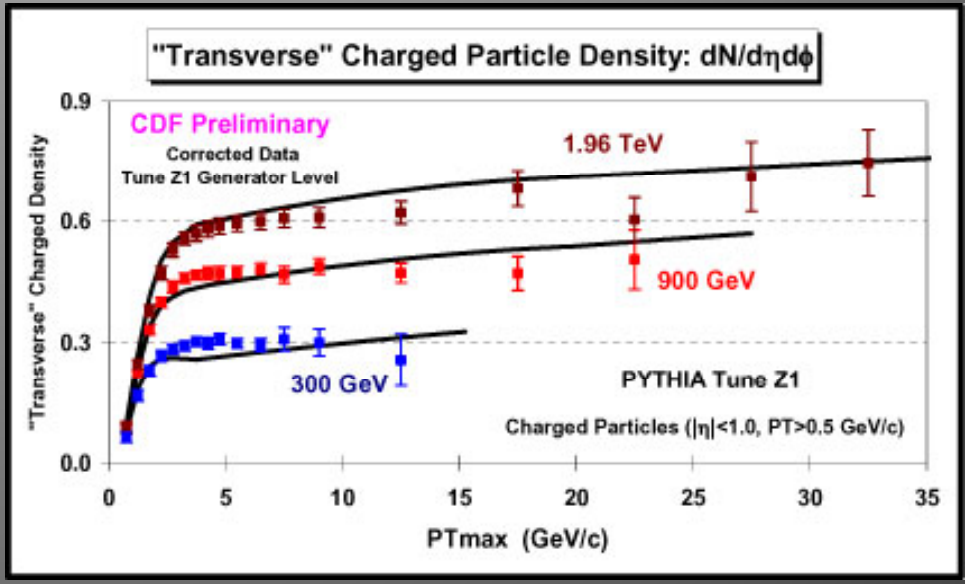



| | $\Upsilon W$ | $\Upsilon Z$ |
|---|---|---|
| 90% C.L. expected limit (pb) | 4.4 | 9.9 |
| 90% C.L. observed limit (pb) | 4.4 | 16 |
| 95% C.L. expected limit (pb) | 5.6 | 13 |
| 95% C.L. observed limit (pb) | 5.6 | 21 |
| Run I 95% C.L. observed limit (pb) | 93 | 101 |

# QCD: Exclusive Production

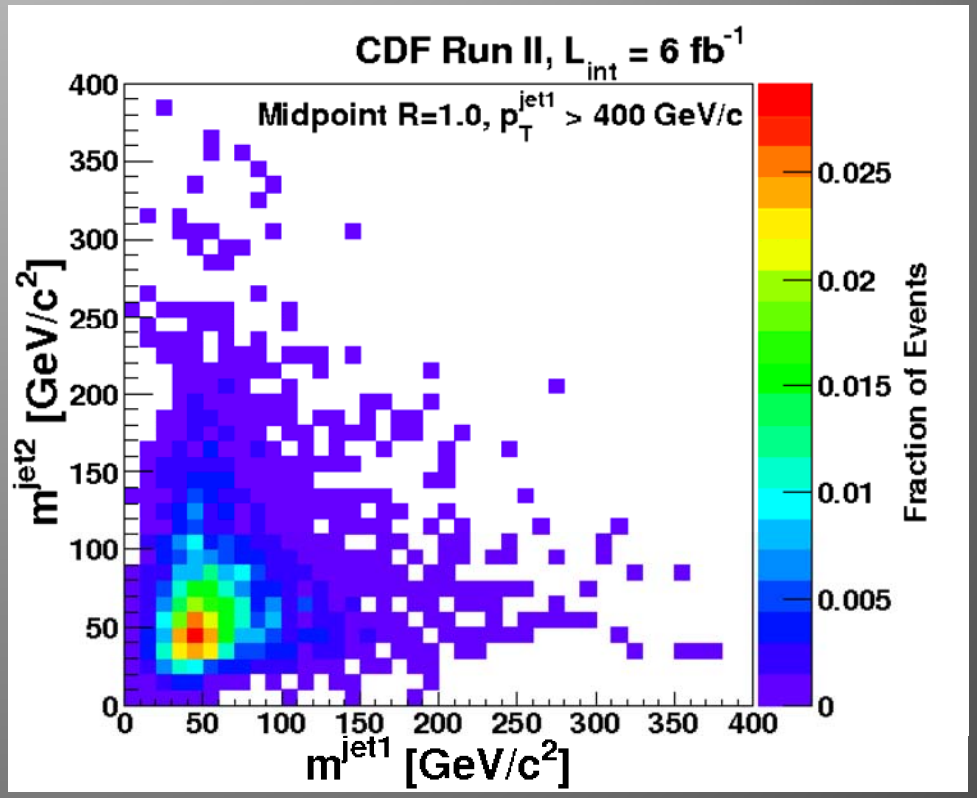
- Central Exclusive Hadron Pair Production
  - CDF Public Note 10841
- Measurements at multiple Tevatron energies
  - 300, 900 and 1960 GeV
  - CDF Public Notes 10841 and 10874
- Important in its own right as well as for confidence in our Monte Carlos (Pythia, Herwig++ etc.)



# Jet Substructure and Boosted Tops

- Studied inclusive jets with $p_T$>400 GeV/c for large mass objects and deviations from expectations
- Search for boosted top quark production in events with 2 massive jets, or 1 massive jet with MET
  - $\sigma_{95\%}$ < 38 fb @ 95% CL
    - arXiv:1407.3484
- Powerful tool now in regular use by the LHC for top-tagging

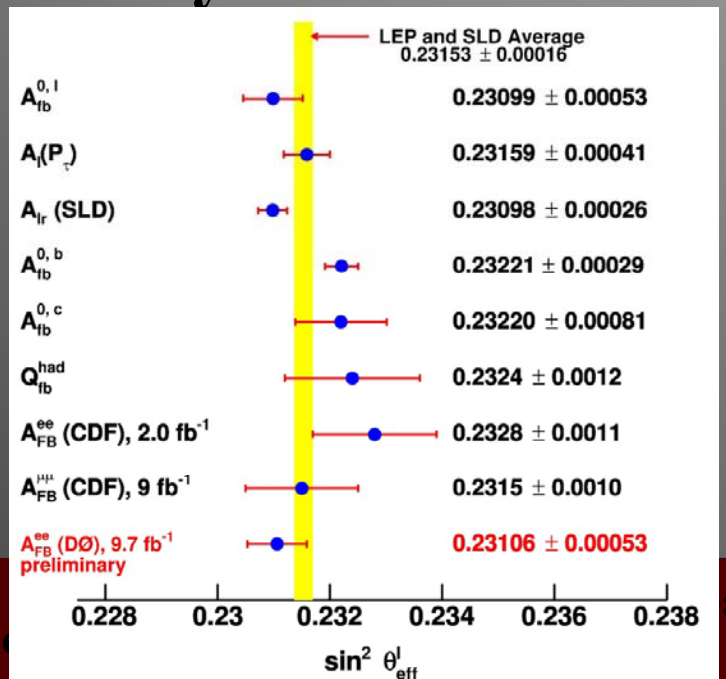


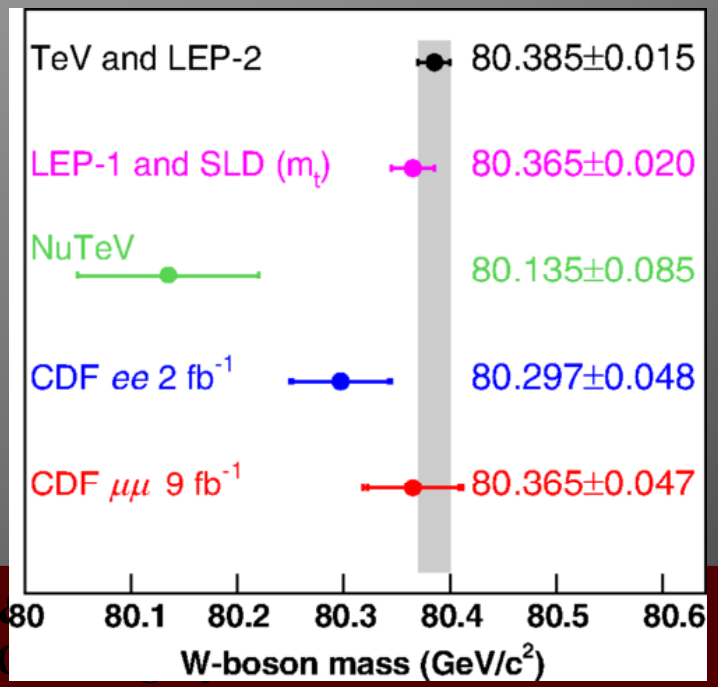
# Electroweak

- The study of the electroweak sector has a long history at CDF and been invaluable to the field
- Measurement of the W mass
- Measurement of the $A_{FB}$ of the $Z/\gamma^*$ system as a measurement of the Weinberg angle, as well as an indirect measurement of the W mass
- W asymmetry has played an important role in understanding the PDFs
- Full set of diboson measurements are an excellent probe of the SM and were invaluable in the Higgs searches

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

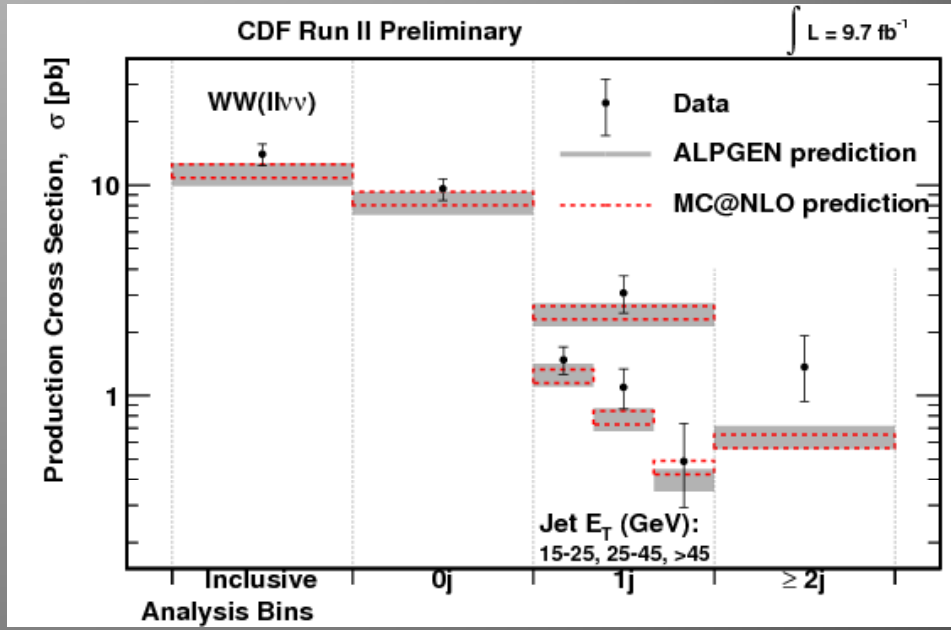
- $A_{FB}$ above and below the Z pole probes the SM
- Measure the Weinberg angle and an indirect W mass measurement - Competitive results in both areas
- Just published the μμ result, with *ee* in progress. Discussions for a Tevatron combination have started
- Plans for a W Asymmetry measurement to come shortly after



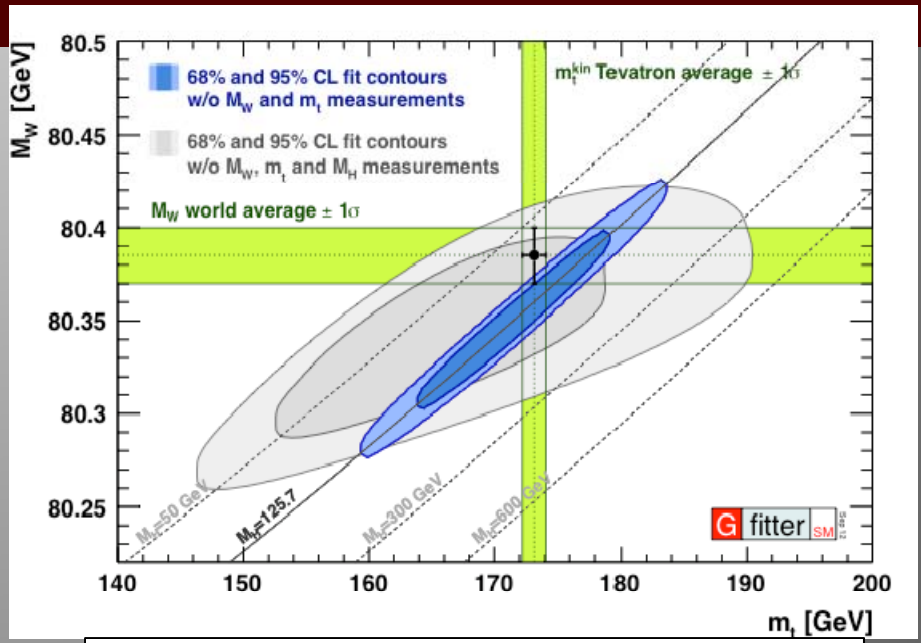
# Dibosons: WW, WZ, ZZ, Wγ, Zγ and γγ

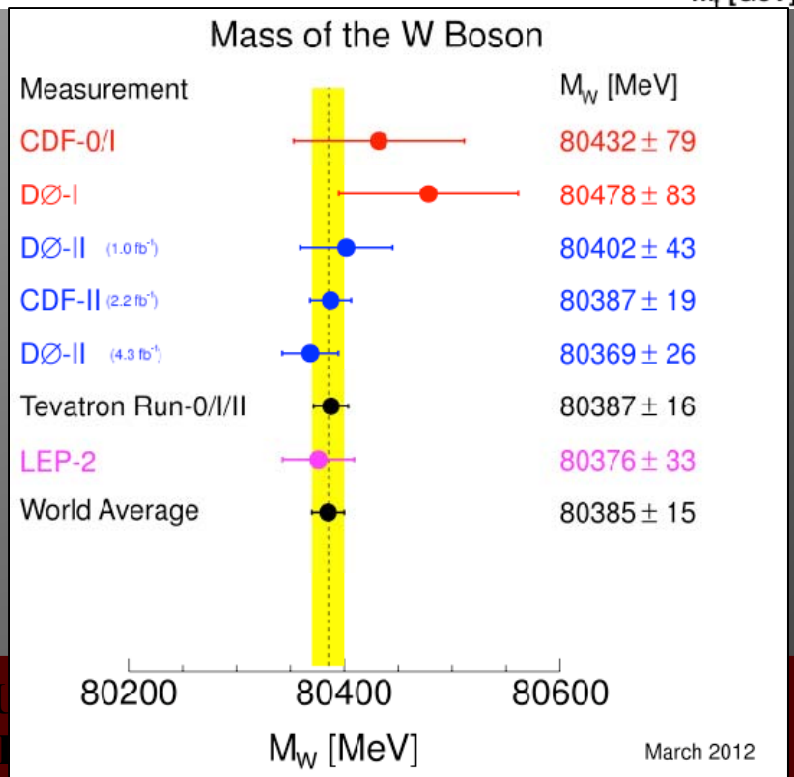
- Dibosons provide an important test of the SM, and are vital to measurements of Top, Higgs and other Searches
- Powerful new differential measurements of the WW cross section recently released
  - WW+Jets may well be impossible at LHC
- Full suite of measurements done, all consistent with the SM



# 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



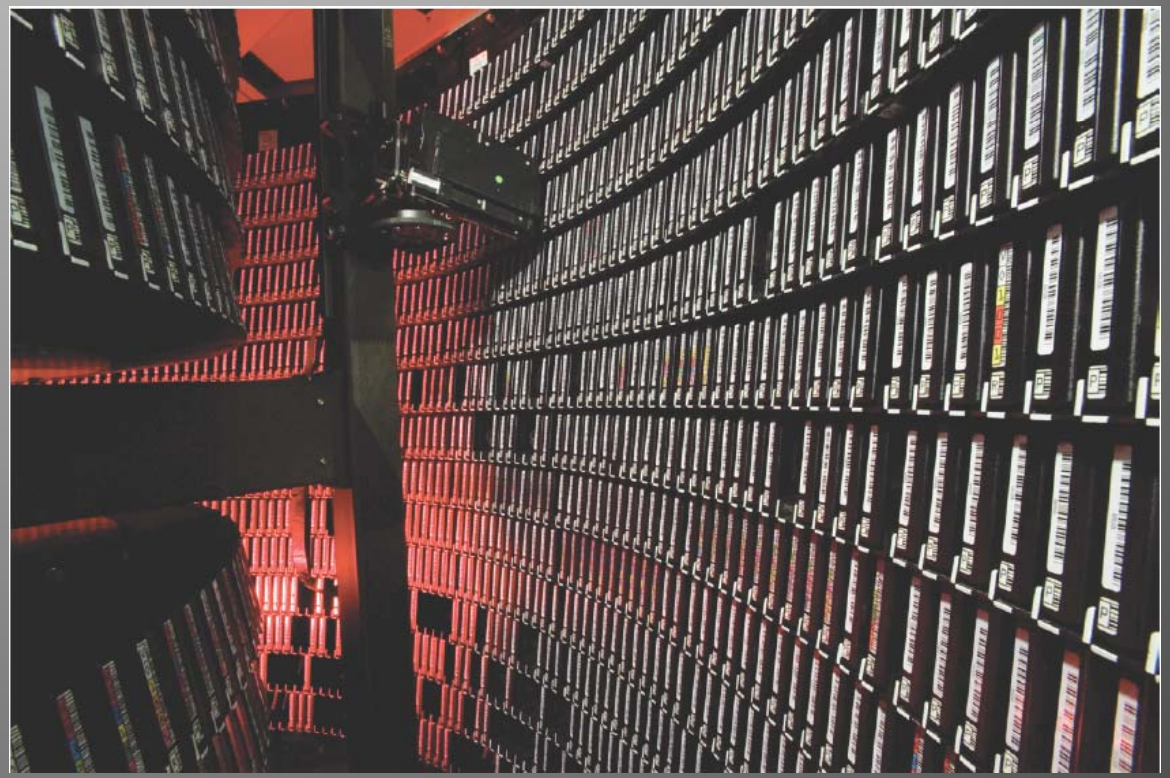
# Legacy: Publications
# *This Year and Looking Forward*

**Over 675 papers published with a good chance of topping 700 by the time we're done**

| Topic | Published or Accepted in 2014 | Submitted but not yet Accepted | Blessed but not yet Submitted |
|---|---|---|---|
| BSM | 2 | 0 | 3 |
| Higgs | 1 | 0 | 1 |
| Top | 8 | 2 | 4 |
| SM (EWK+QCD) | 4 | 1 | 3 |
| Heavy Flavor | 4 | 0 | 1 |
| Combinations | 1 | 0 | 4 |
| Total | 20 | 3 | 16 |

# Data Preservation

- **Hypothetical: Discovery at LHC which could be further studied from archived Tevatron data**
- **Need to do preparations now so we have moved to SL6 and made all data available on tape in a current format**
- **Should be able to act through 2020**
- **Have moved to archive all of CDF's documentation (including CDF notes that were only on paper).**



# Conclusions

- **The CDF collaboration is still doing exciting physics and publishing at a strong rate**
- **In the last year(s) we have had many successes by focusing on legacy results that are competitive and complementary to the LHC**
- **We have published almost 700 papers and graduated more than 575 PhD students**
- **Soon expect publication of some our most important results including final words on the combined top mass, Higgs Spin-parity in VHiggs(bb), $A_{FB}$ in tt and bb, and new results in W charge asymmetry and the much anticipated Wmass measurement in the 10-15 MeV range**
- **Stay tuned… we're not done quite yet**

*http://www-cdf.fnal.gov/physics/S14CDFResults.html*

# Backups

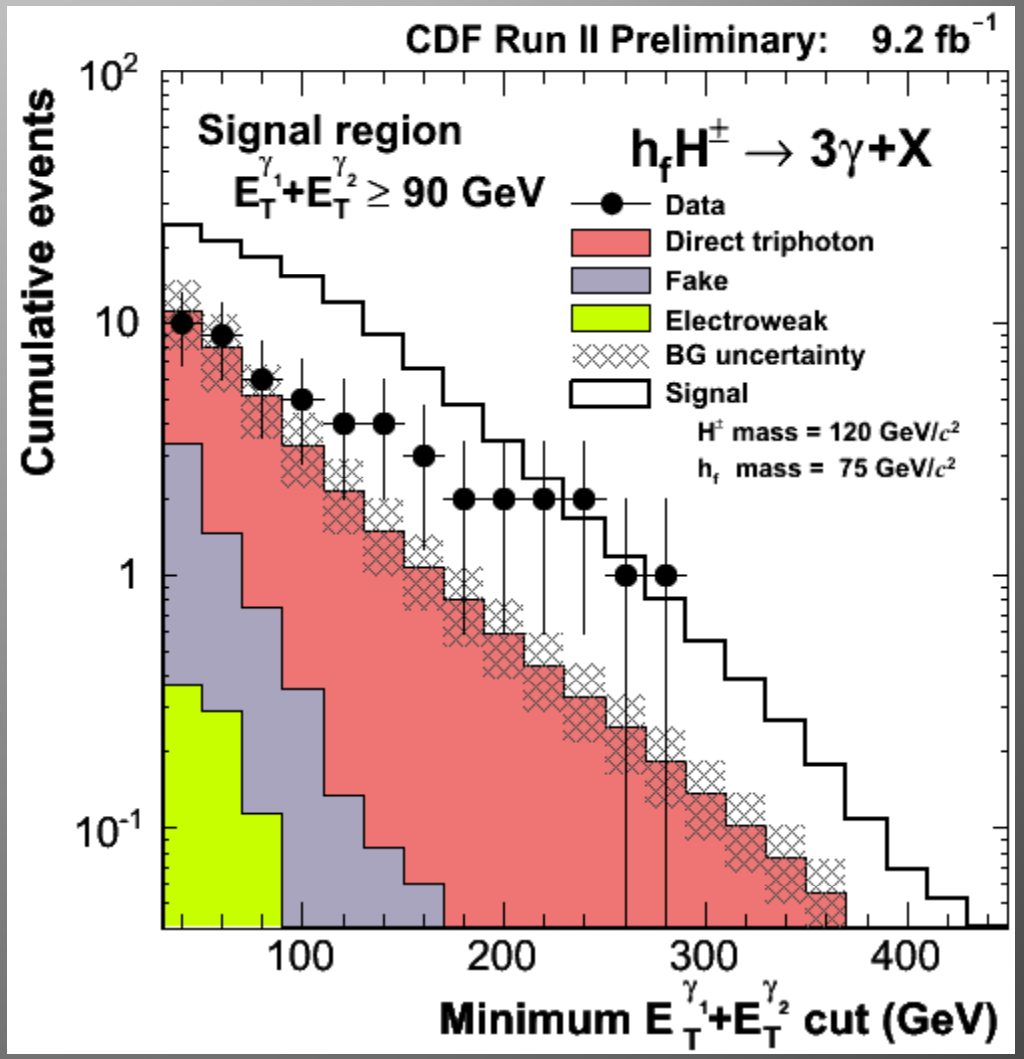
**"*Something, something, something,* Legacy Program. *Something, something, something,* Complete"**

# http://www-cdf.fnal.gov/physics/S14CDFResults.html

- Higgs Spin/Parity Limits (Tevatron Combination)Higgs7/24/2014Note 11104
- CP Violation in $D^0$Heavy Flavor8/21/2014Note 111171410.5435Submitted to PRL
- Fermiophobic Higgs in the 3γ+X ChannelExotics8/7/2014Note 11116
- Search for W'→tbTop/Exotics8/7/2014Note 11100
- Higgs Spin/Parity LimitsHiggs7/21/2014Note 11103
- Central Exclusive Production of Pion PairsQCD7/8/2014Note 11034
- Top Mass Tevatron Combination (2014 combination)Top7/2/2014Note 111051407.2682(NA)
- W/Z + D*QCD6/21/2014Note 11087
- MonopolesExotics6/19/2014Note 11102
- Measurement of Orbitally Excited B Mesons and First Evidence for a New Bπ ResonanceHeavy Flavor6/13/2014Note 110221309.5961PRD 90 012013 (2014)
- Single Top in S+T Channel (Met+Jets and CDF Combination)Top6/13/2014 MET+Jets ComboNote 110331410.4909Submitted to PRL
- $A_{FB}$ of $b\bar{b}$Top6/11/2014Note 11092
- WW+Jets Cross SectionEWK6/10/2014Note 11098
- CDF Top Mass CombinationTop3/21/2014Note 11080
- World (TeV+LHC) Top Mass CombinationTop3/17/2014Note 110711403.4427(NA)
- Top Mass in the all hadronic final stateTop3/7/2014Note 110841409.4906PRD 90, 091101(R) (2014)
- $B_c^+ \rightarrow J/\psi\mu^+\nu$ relative cross sectionHeavy Flavor2/28/2014Note 11083
- Single top (S Channel) Tevatron Combination/ObservationTop2/22/2014Note 110731402.5126PRL 112, 231803 (2014)
- Search for Invisible Higgs Boson Decays in Dilepton EventsExotics2/10/2014Note 11068
- Top Mass in DileptonsTop1/10/2014Note 11072
- Z+Jets Cross Section MeasurementQCD3/22/2012Note 110811409.4359Submitted to PRD
- Single Top (S+T Channel) in the Lep+Jets Final StateTop2/27/2012Note 107931407.4031Accepted to PRL
- Studies of high-transverse momentum jet substructure and top quarksQCD/Top5-26-2011 Boosted Jets Boosted Tops Note 10199 Note 102341407.3484Submitted to PRD
- Leptonic $A_{FB}$ of $t\bar{t}$ in Dilepton Final State + CDF CombinationTop9/19/2013 and 10/25/2013Note 110351404.3698PRL 113, 042001 (2014)
- BR(t→ Wb)/BR(t→ Wq) in dileptonsTop10/25/2013Note 110481404.3392PRL 112, 221801 (2014)
- Measurement of B Baryon PropertiesHeavy Flavor8/1/2013Note1403.8126PRD 89, 072014 (2014)
- $A_{CP}$ measurements in B→hh' decay modesHeavy Flavor6/28/2012Note 107261403.5586Accepted to PRL
- ZZ production cross section measurement in lll'l' and llνν final statesEWK6/20/2013Note 109571403.2300PRD 89, 112001 (2014)
- Search for Dijet Resonance in lνjj Final StateHiggs2/22/2013Note 109731402.7044PRD 89 092001 (2014)
- Measurement of Top Production and Decay into Tau and Limit on Charged HiggsTop9/6/2012Note 109151402.6728PRD 89, 091101 (2014)
- Single Top (S Channel) in the Met+Jets and CDF CombinationTop7/11/2013 and 10/25/2013Note 11076 and Note 110451402.3756PRL 112, 231805 (2014)
- Measurement of $\sin^2\theta_W$ using $\mu^+\mu^-$ pairsEWK2/24/2014Note 110311402.2239PRD 89, 072005 (2014)
- Single Top (S Channel) in the Lep+Jets Final StateTop8/8/2013Note 110251402.0484PRL 112, 231804 (2014)
- Search for Rare Z Decays into Two Reconstructed PhotonsExotics3/8/2013Note 109781311.3282PRL 112, 111803 (2014)
- W Boson Mass MeasurementEWK10/2012Note 107751311.0894PRD 89 072003 (2014)
- Tevatron Combined $t\bar{t}$ Cross Section MeasurementTop7/1/2012Note 109261309.7570PRD 89 072001 (2014)
- Search for Trilepton New Physics and Chargino-Neutralino ProductionExotics8/25/2011Note 106361309.7509PRD 90, 012011 (2014)

# Triphoton Details

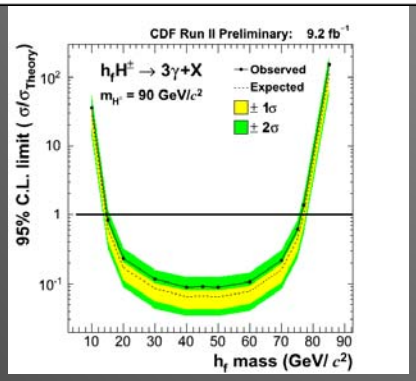
- **Background dominated by Direct TriPhoton**
  - **Estimated using MadGraph/MadEvent +Pythia**
- **Optimization for Higgs is at 90 GeV**
  - **5 observed events, on a background of 2.96±0.94**

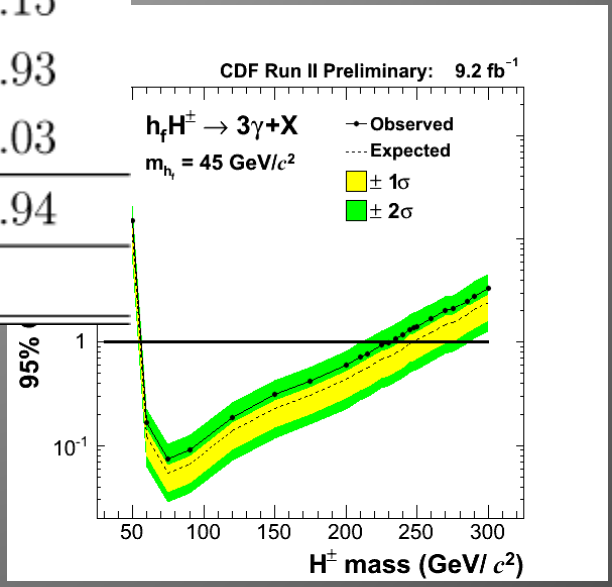


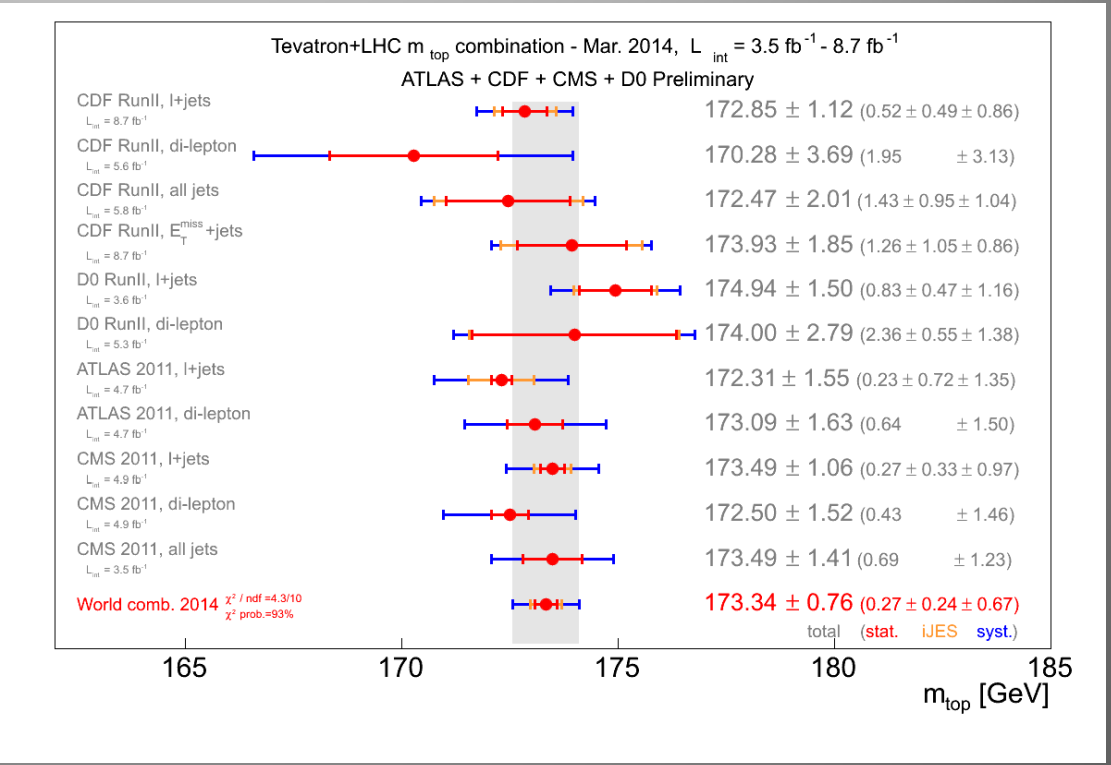
# Fermiphobic Higgs

- **CDFNote 11116**

| $h_f H^\pm \to 3\gamma + X$ | CDF Run II Preliminary: 9.2 fb$^{-1}$ | | | | |
|---|---|---|---|---|---|
| | Events ($E_T^{\gamma 1} + E_T^{\gamma 2} > 90$ GeV: signal region) | | | | |
| | | | (stat) | | (syst) |
| Fake | 0.32 | $\pm$ | 0.07 | $\pm$ | 0.15 |
| Direct triphoton | 2.60 | $\pm$ | 0.04 | $\pm$ | 0.93 |
| Electroweak | 0.04 | $\pm$ | 0.01 | $\pm$ | 0.03 |
| Total | 2.96 | $\pm$ | 0.08 | $\pm$ | 0.94 |
| Data | 5 | | | | |

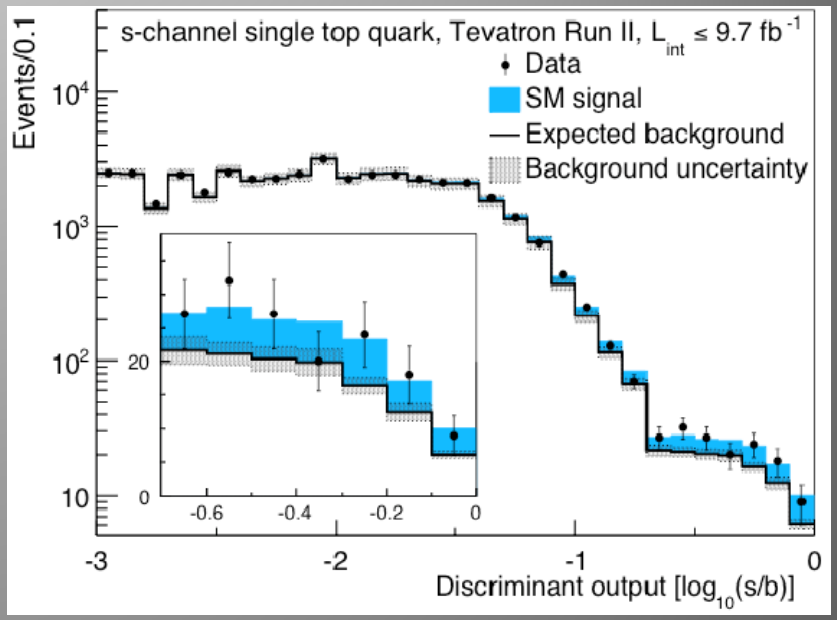


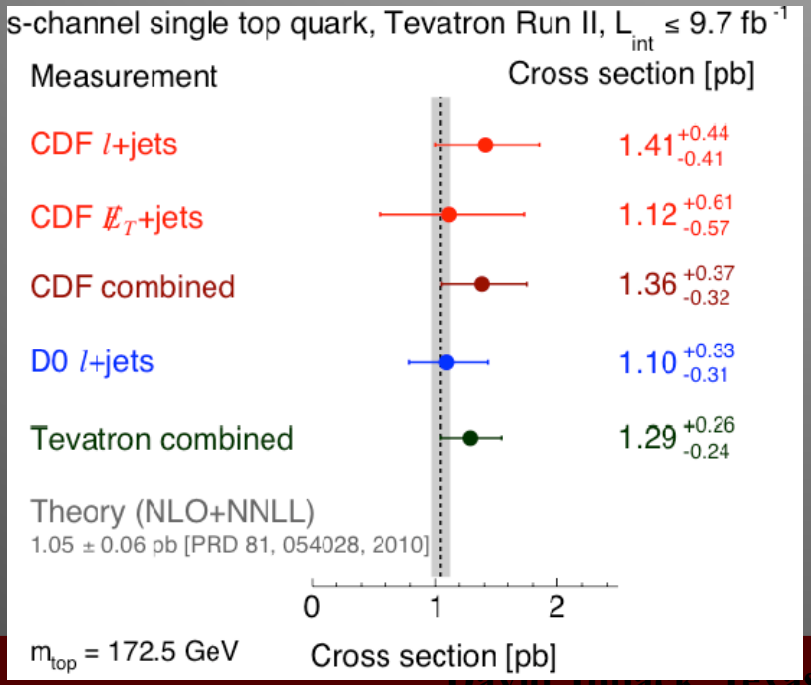



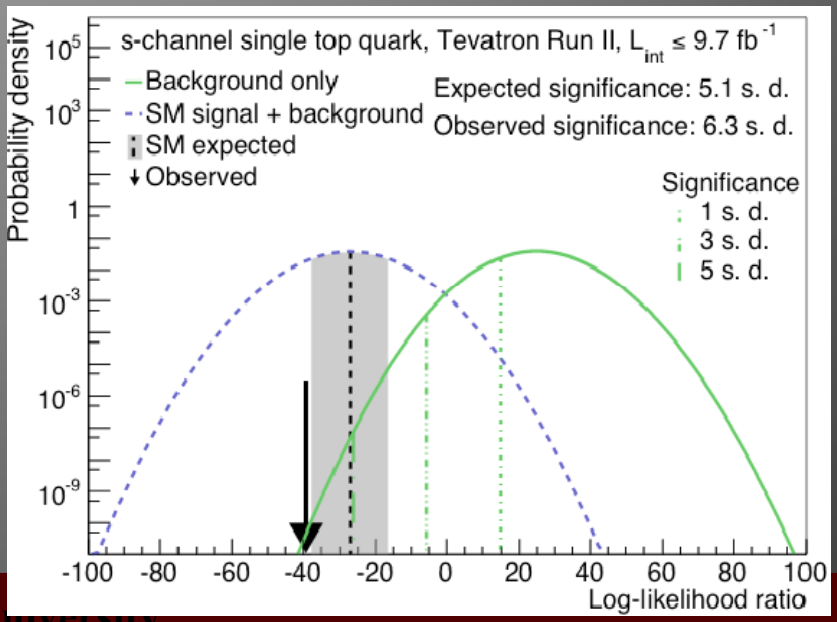

Tevatron+LHC m top combination - Mar. 2014, L int = 3.5 fb-1 - 8.7 fb-1
ATLAS + CDF + CMS + D0 Preliminary
CDF RunII, l+jets
CDF RunII, di-lepton
CDF RunII, all jets
CDF RunII, E_T^miss +jets
D0 RunII, l+jets
D0 RunII, di-lepton
ATLAS 2011, l+jets
ATLAS 2011, di-lepton
CMS 2011, l+jets
CMS 2011, di-lepton
CMS 2011, all jets
World comb. 2014 χ² / ndf =4.3/10
χ² prob.=93%
172.85 ± 1.12 (0.52 ± 0.49 ± 0.86)
170.28 ± 3.69 (1.95 ± 3.13)
172.47 ± 2.01 (1.43 ± 0.95 ± 1.04)
173.93 ± 1.85 (1.26 ± 1.05 ± 0.86)
174.94 ± 1.50 (0.83 ± 0.47 ± 1.16)
174.00 ± 2.79 (2.36 ± 0.55 ± 1.38)
172.31 ± 1.55 (0.23 ± 0.72 ± 1.35)
173.09 ± 1.63 (0.64 ± 1.50)
173.49 ± 1.06 (0.27 ± 0.33 ± 0.97)
172.50 ± 1.52 (0.43 ± 1.46)
173.49 ± 1.41 (0.69 ± 1.23)
173.34 ± 0.76 (0.27 ± 0.24 ± 0.67)
total (stat. iJES syst.)
165
170
175
180
185
m_top [GeV]

# Observation of Single Top in the S-Channel

- **Tevatron Combination of Single top production in the S-Channel shows observation with 6.3σ significance**
- **PRL 112, 231802 (2014)**

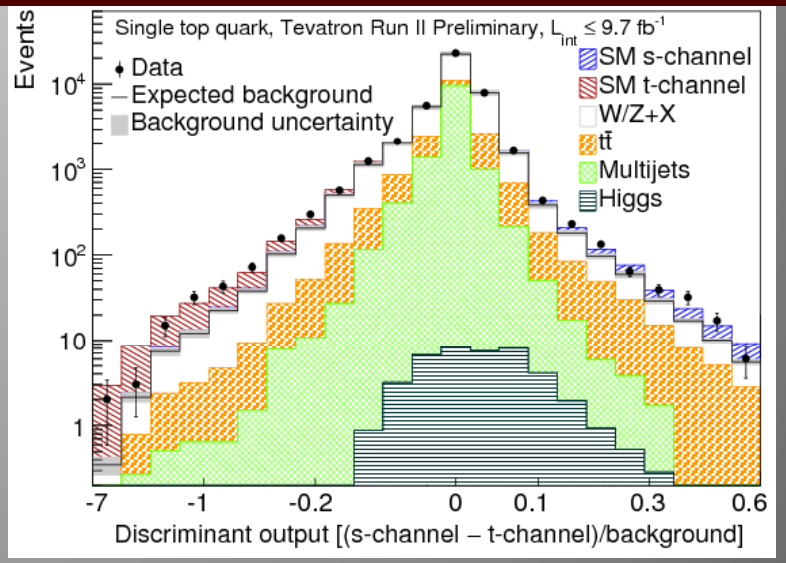


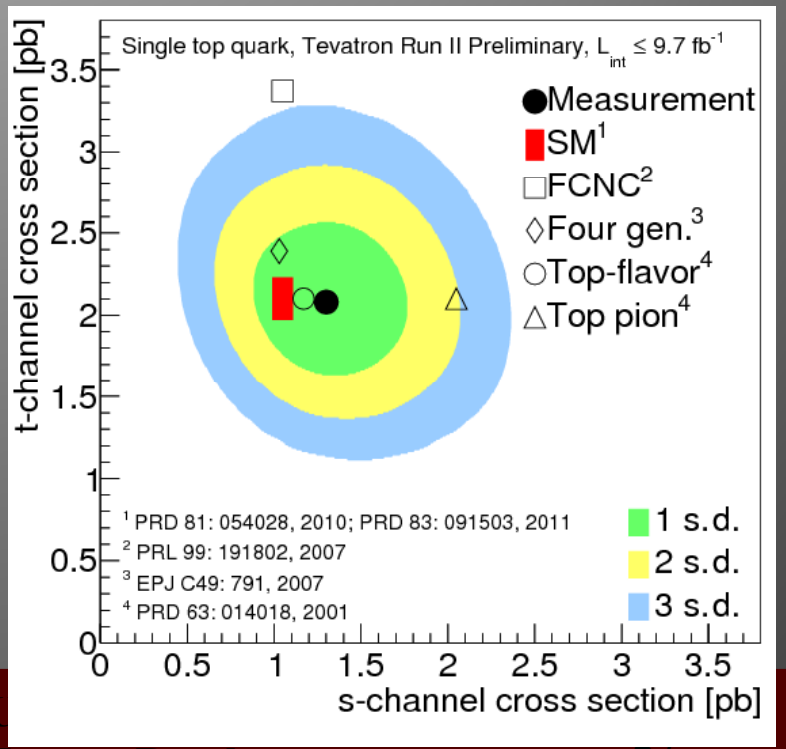



# Single Top: S, T, S+T and S vs. T

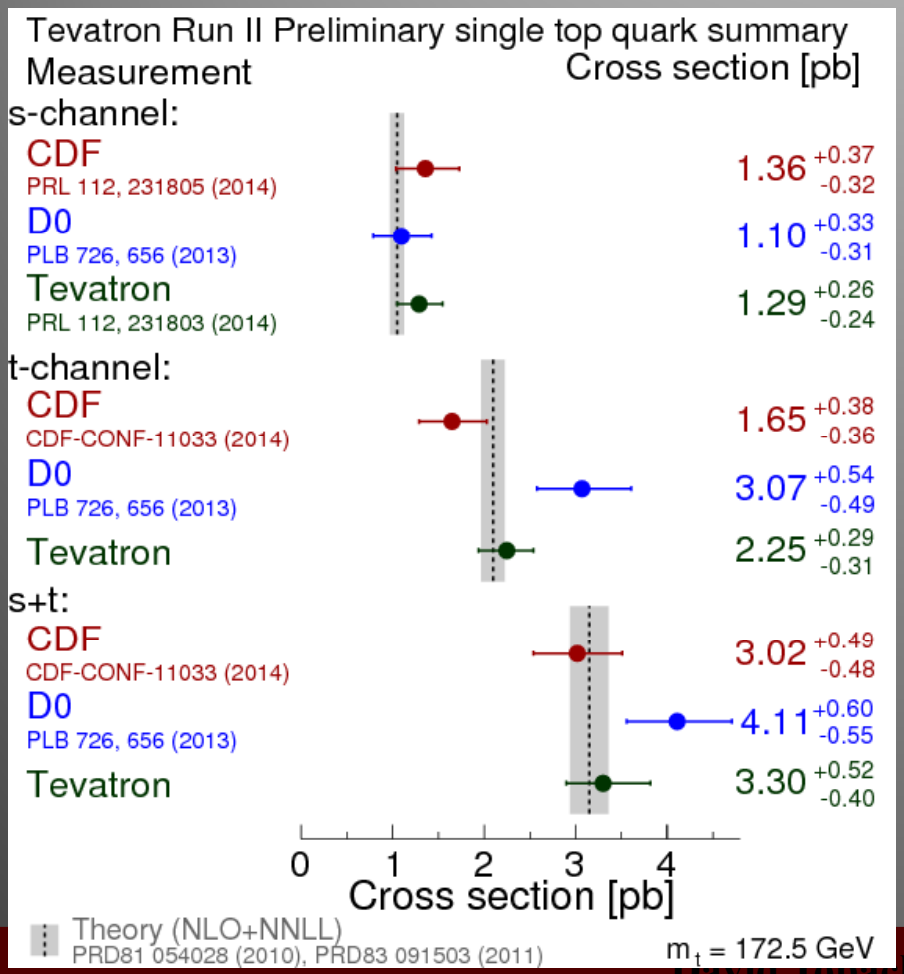
**Tevatron combination for S and T channels separately is complete and nearing publication**

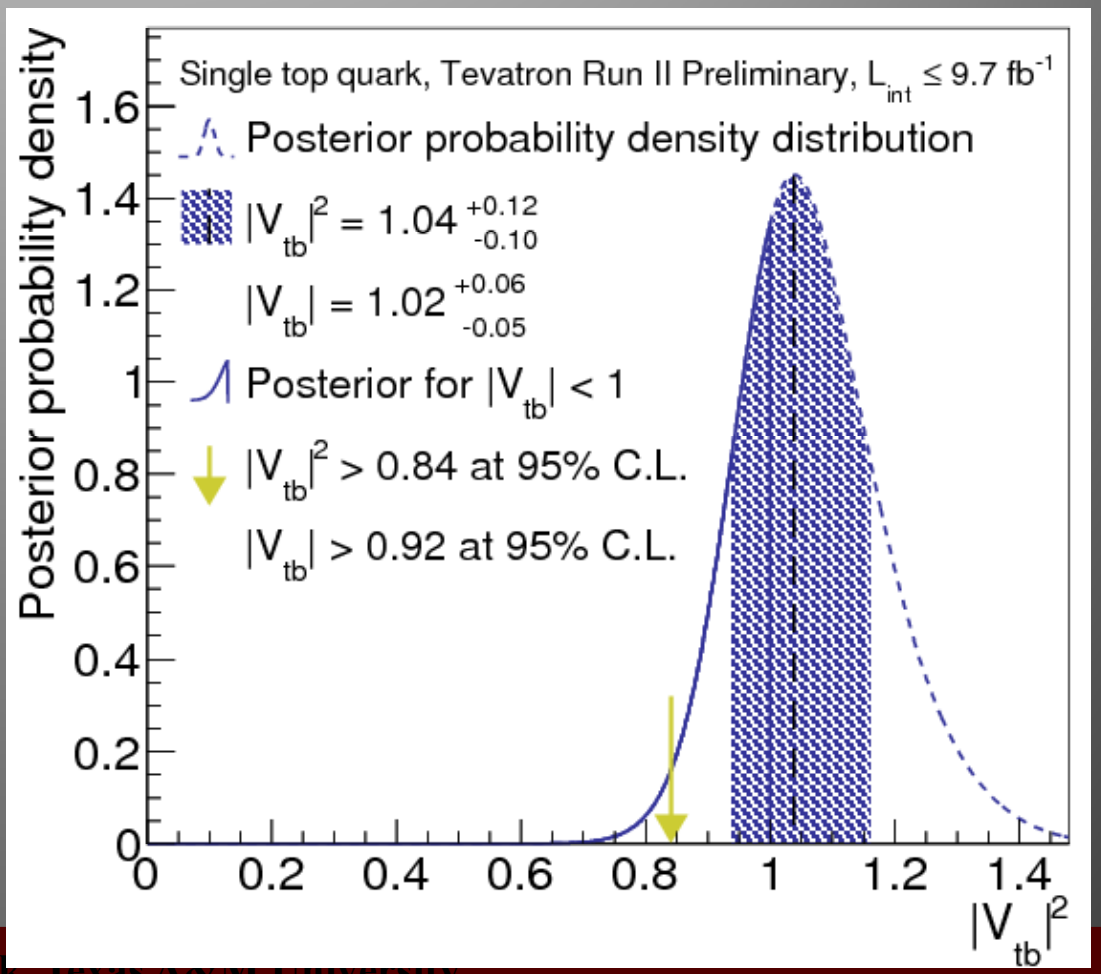


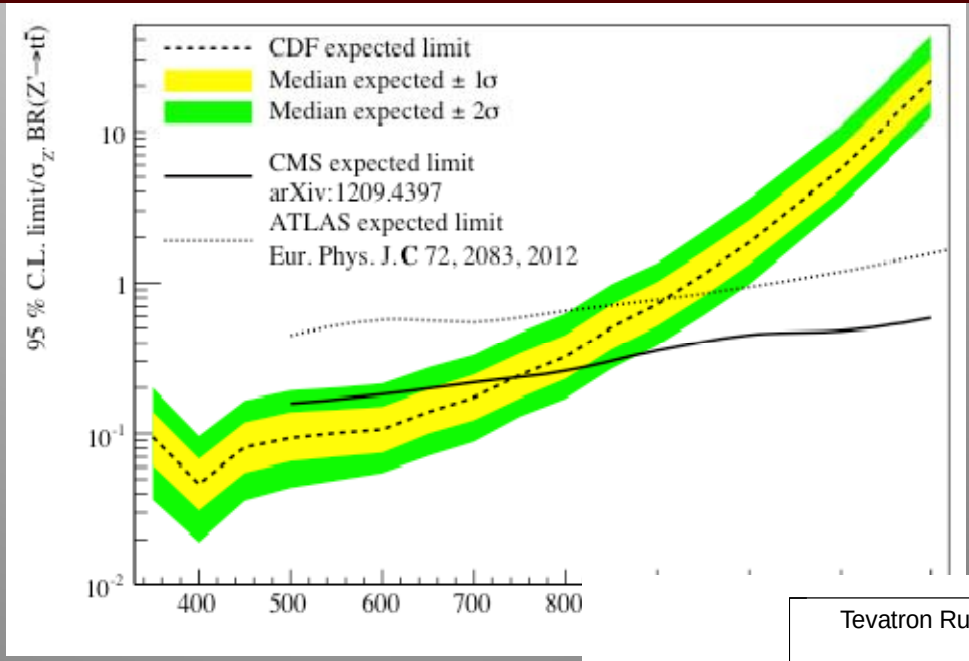



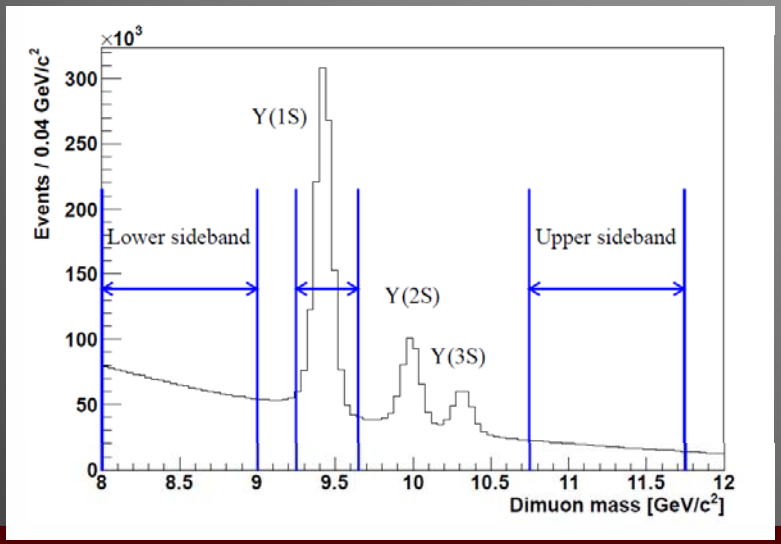
# Cross Sections and Extracting $|V_{tb}|$

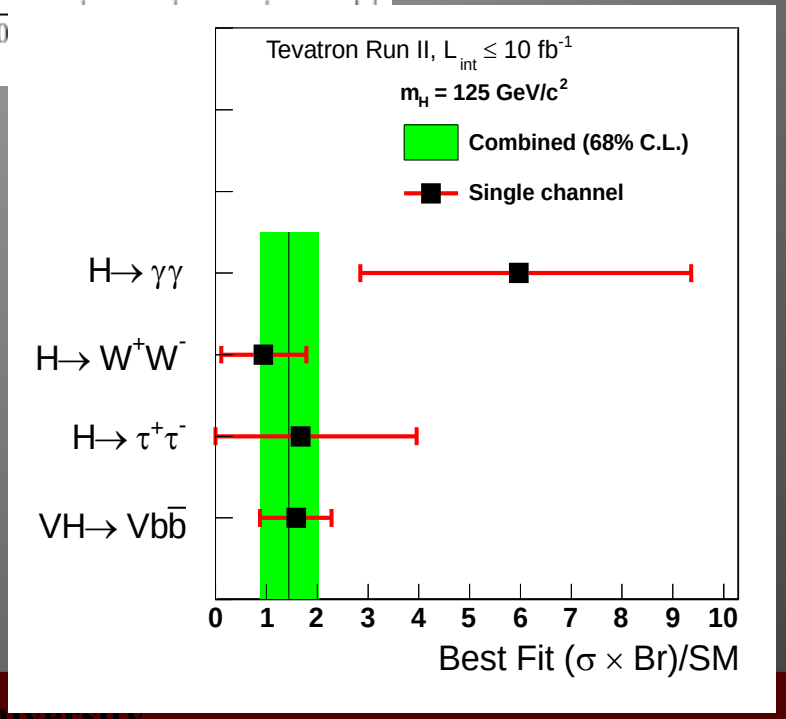
- **Cross Sections are consistent with SM**
- **Powerful method of extracting $V_{tb}$**




95 % C.L. limit/σ_Z'.BR(Z'→tt̄)
CDF expected limit
Median expected ± 1σ
Median expected ± 2σ
CMS expected limit
arXiv:1209.4397
ATLAS expected limit
Eur. Phys. J. C 72, 2083, 2012
10
1
10^-1
10^-2
400
500
600
700
800


×10^3
Events / 0.04 GeV/c^2
300
250
200
150
100
50
0
Y(1S)
Lower sideband
Upper sideband
Y(2S)
Y(3S)
8
8.5
9
9.5
10
10.5
11
11.5
12
Dimuon mass [GeV/c^2]


Tevatron Run II, L_int ≤ 10 fb^-1
m_H = 125 GeV/c^2
Combined (68% C.L.)
Single channel
H→ γγ
H→ W^+W^-
H→ τ^+τ^-
VH→ Vbb̄
0
1
2
3
4
5
6
7
8
9
10
Best Fit (σ × Br)/SM