# Top physics results from the Tevatron

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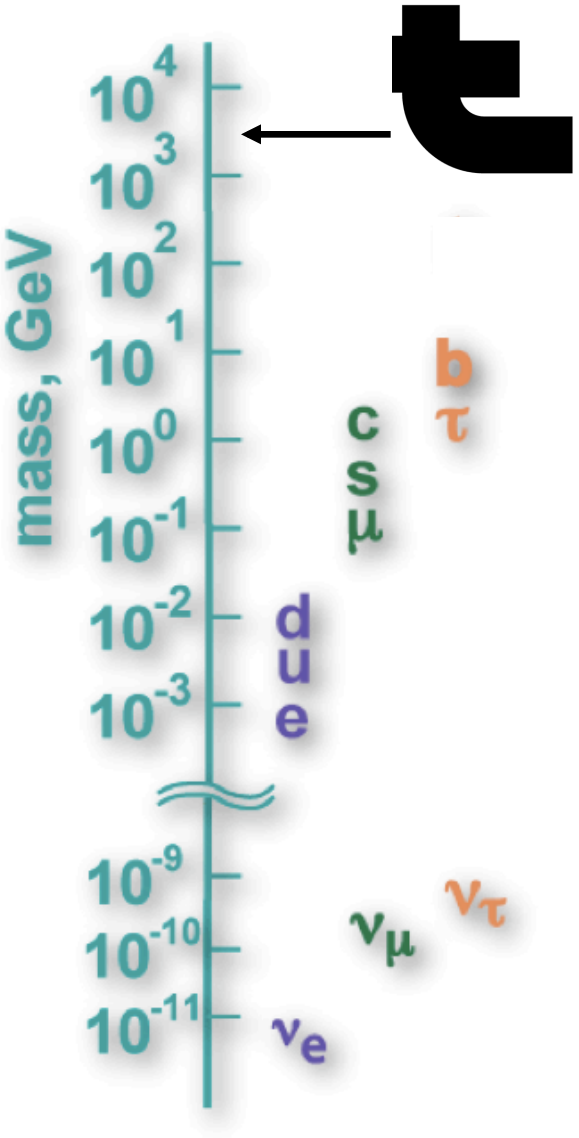
**On behalf of the CDF and D0 Collaborations**

# The top quark is special

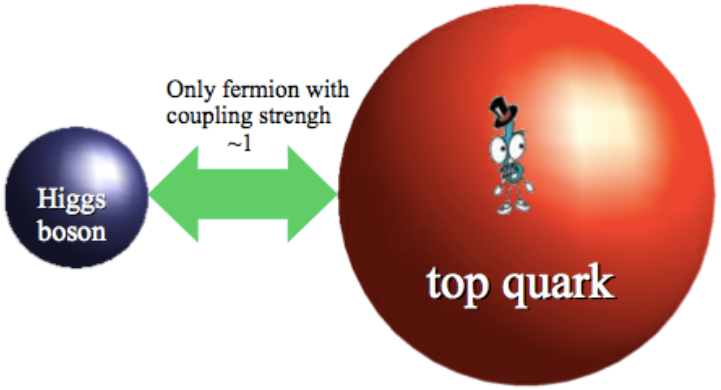
- Top was discovered at Fermilab in 1995
- Its mass much larger than any other fermion
- Lifetime shorter than hadronization time -> only quark that decays before hadronizing


O($10^4$) of top quarks analyzed by Tevatron collaborations

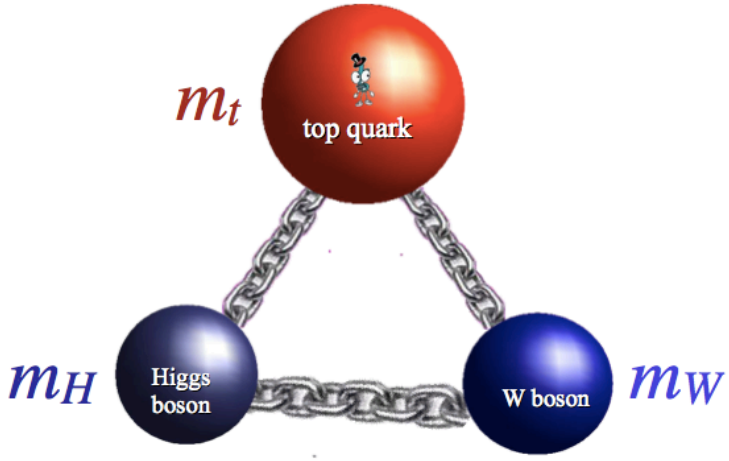


# The top beyond the top

- Coupling to the Higgs -> top mass biggest coupling
  - Using the latest Tevatron-averaged $M_{top}$
  - Yukawa coupling = 0.996±0.006
  - Only quark with large coupling to Higgs




- In most natural modes top is linked to EW symmetry breaking
  - Indirect contraint on Higgs mass
  - Direct searches for t-partners (SUSY, composite Higgs)



# The Tevatron (RIP)

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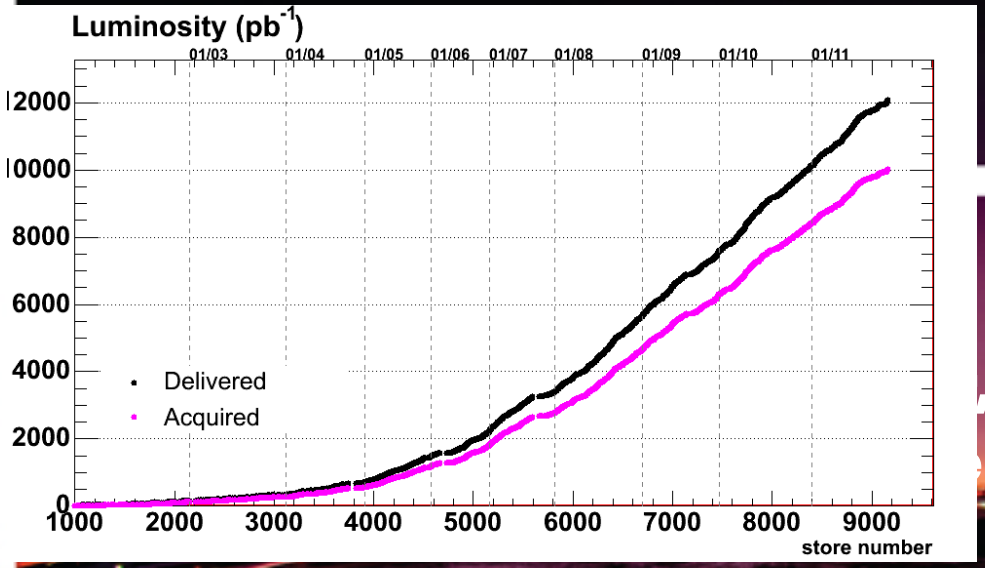

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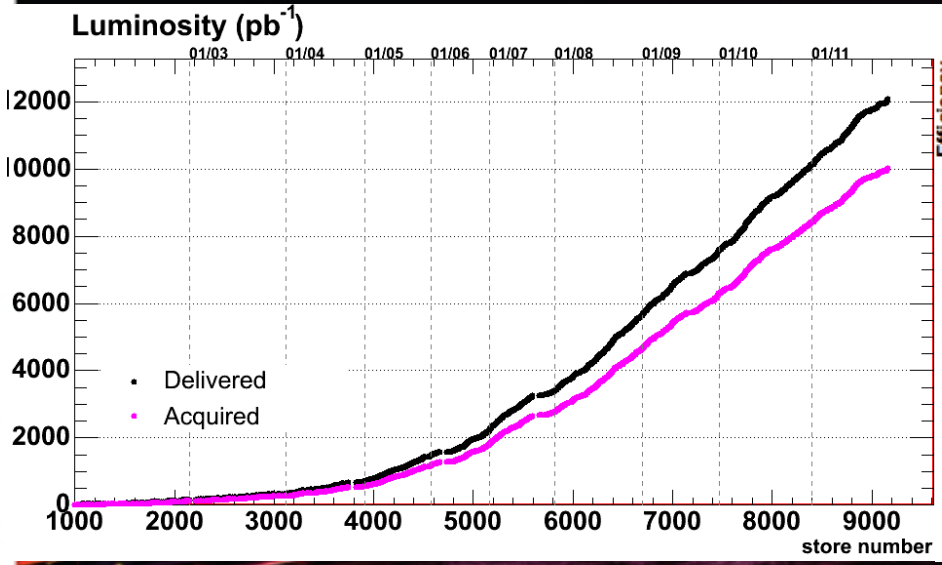
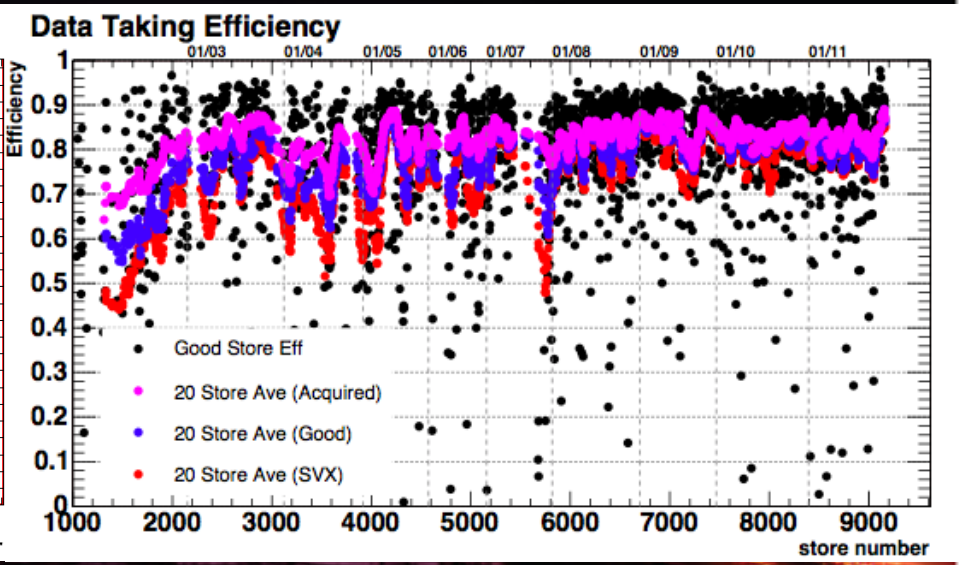
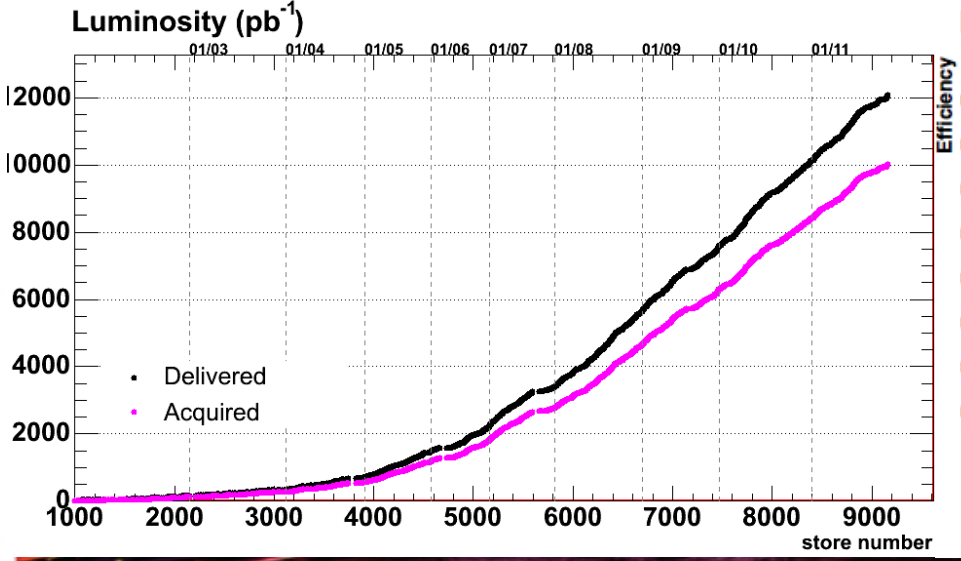
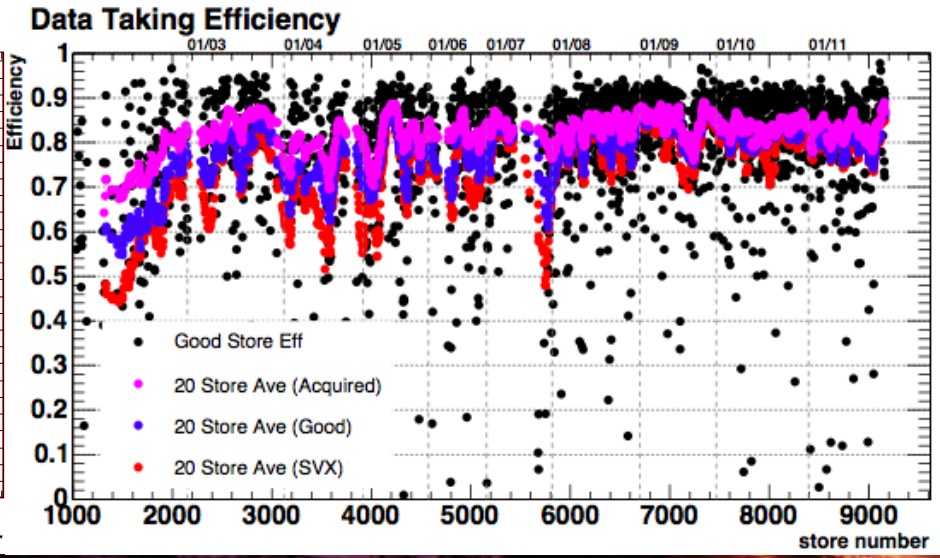


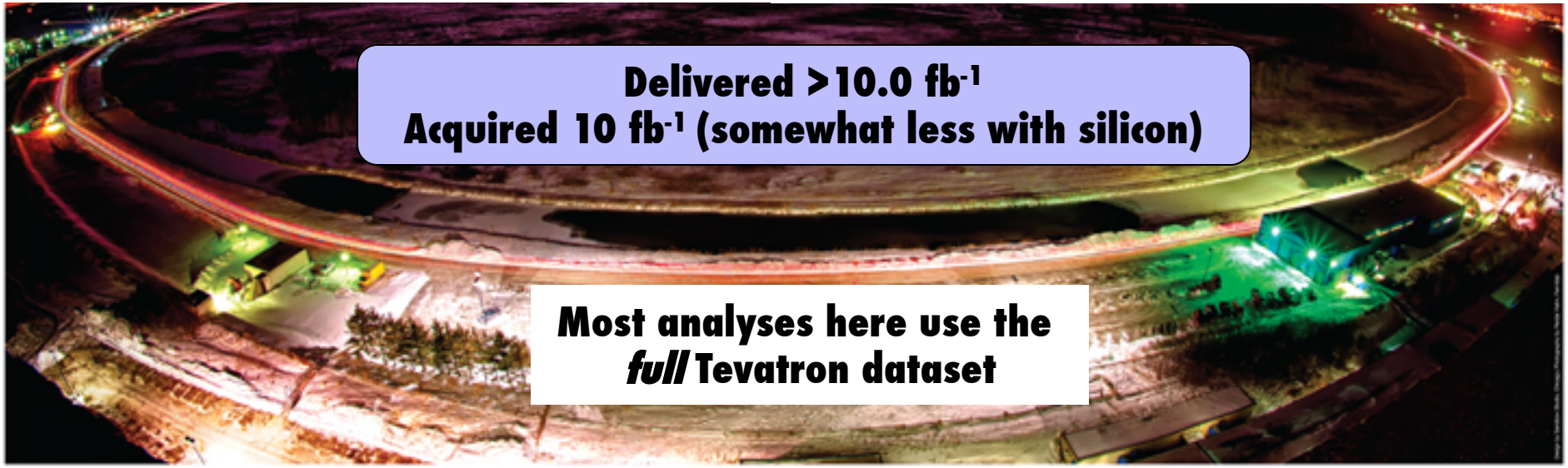




**Delivered >10.0 fb$^{-1}$**
**Acquired 10 fb$^{-1}$ (somewhat less with silicon)**

# The Tevatron (RIP)



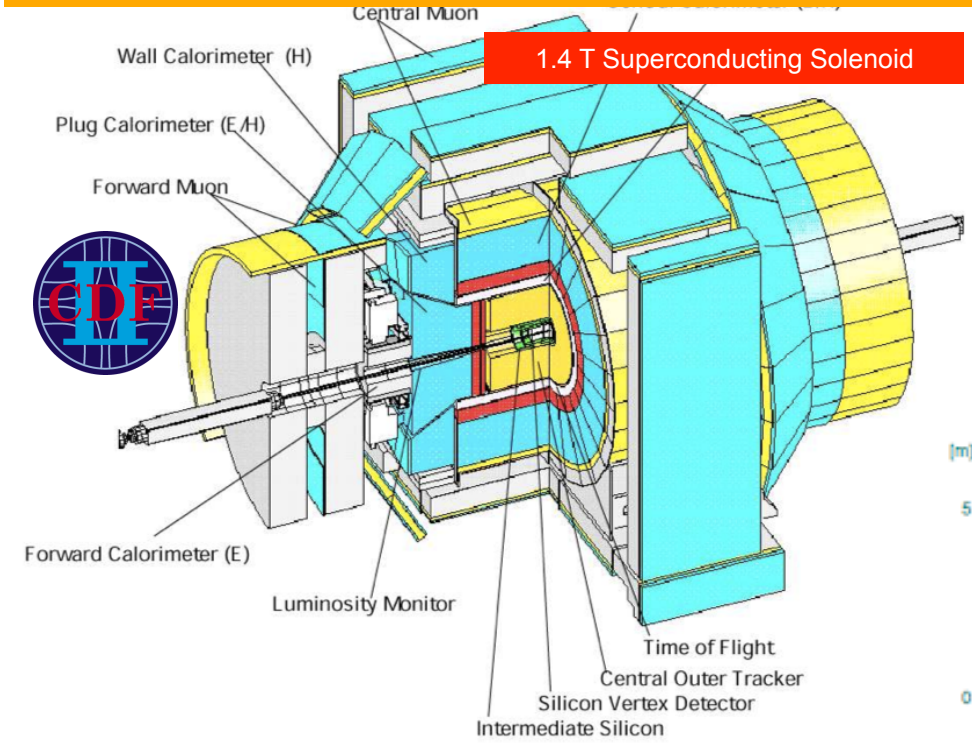



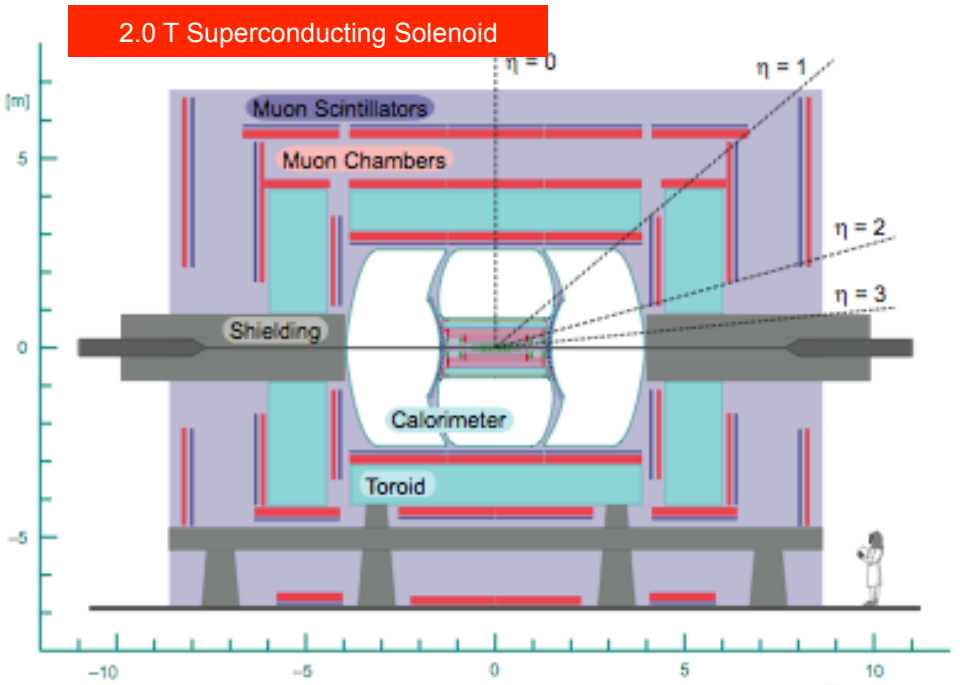
**Delivered >10.0 fb$^{-1}$**
**Acquired 10 fb$^{-1}$ (somewhat less with silicon)**

**Most analyses here use the *full* Tevatron dataset**

# Its detectors



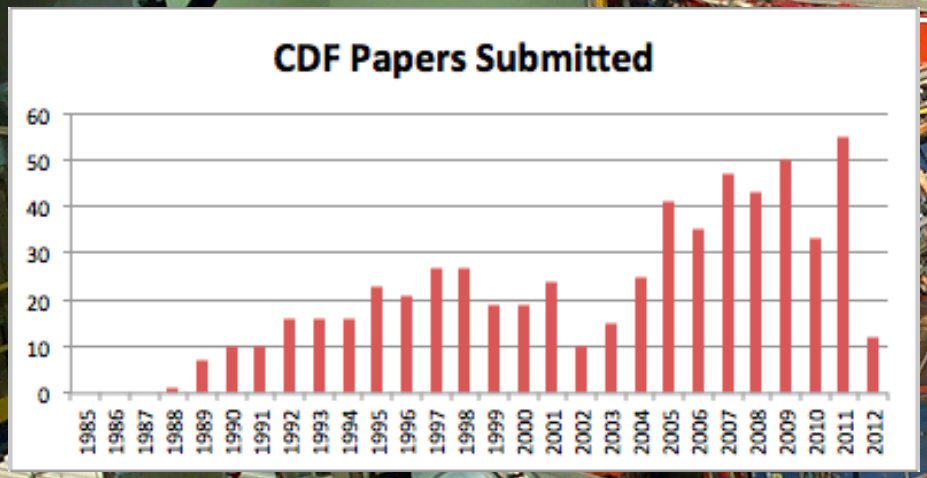

**Calorimeter (EM+HAD)**
**Shower maximum detector in EM**
**Cal coverage: |eta|<3.6 CDF**
**|eta|<4.2 D0**

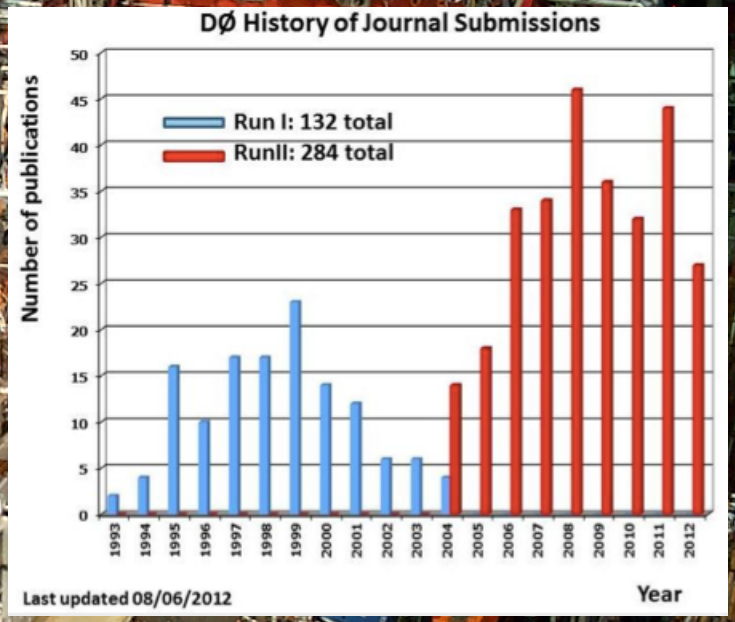



✓ **Tracking: silicon tracker allows precision vertex detection |eta|<2 (2.5) for CDF (D0) and spectrometer up to |eta|<1.5 (3) for CDF (D0)**

✓ **Muon chamber outside calorimeter coverage |eta|<1.5 (2.0) for CDF (D0)**

# Top at the Tevatron

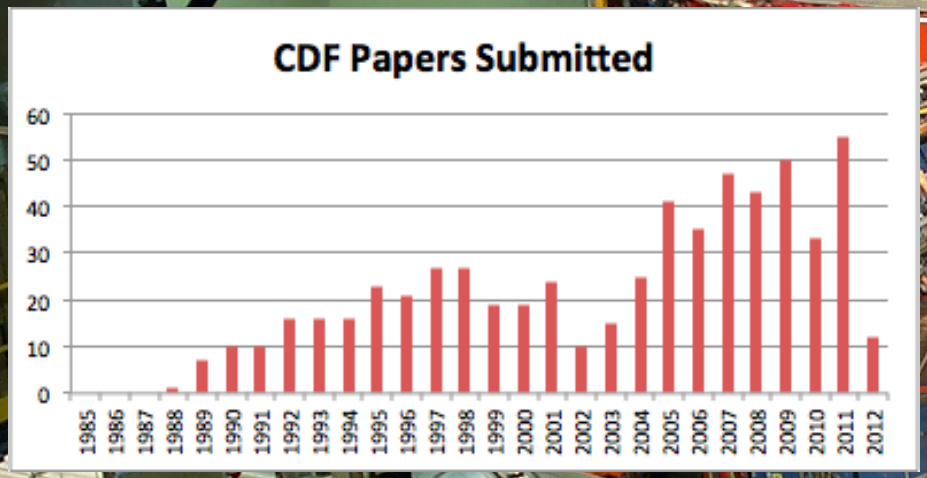


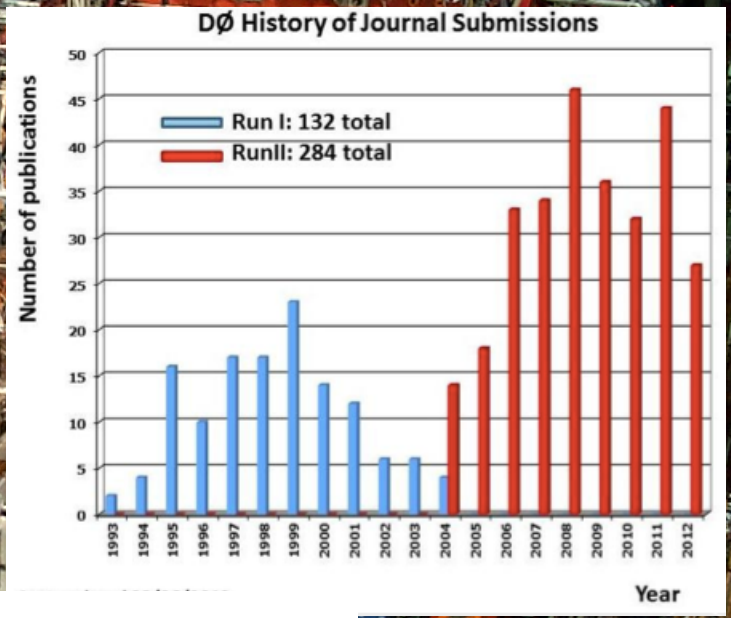




**Over 1000 papers total**

**Over 600 RunII papers**

# Top at the Tevatron

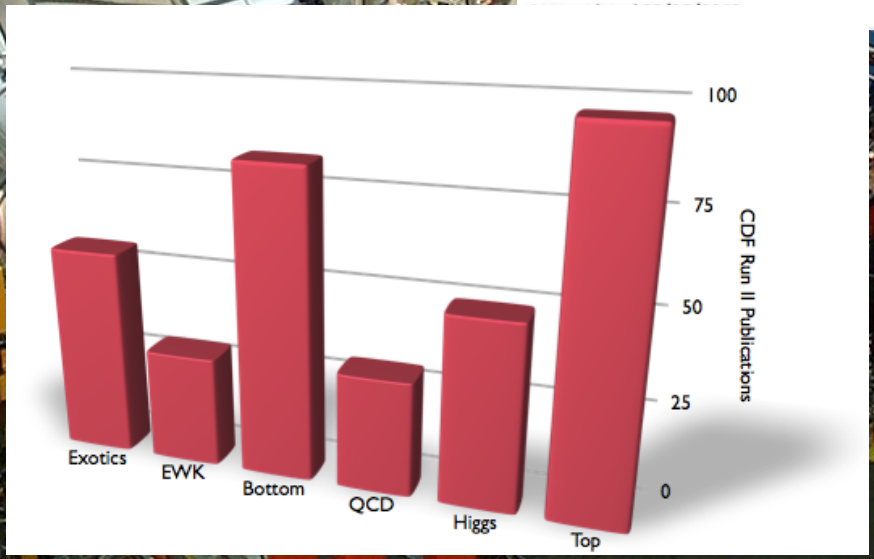



**Over 1000 papers total**

**Over 600 RunII papers**

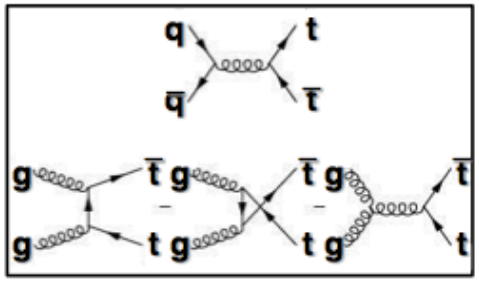
**More than a quarter are top results**



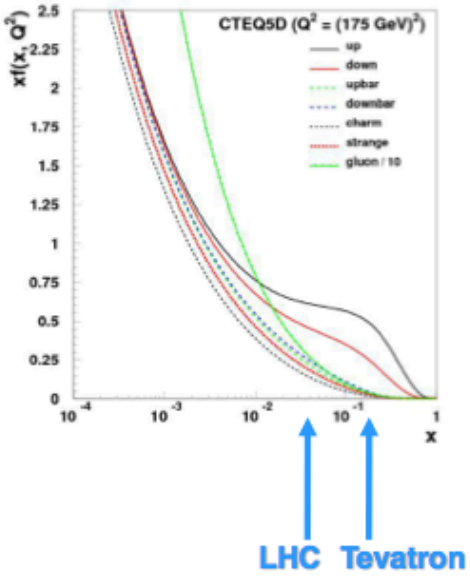

**CDF histo.Similar numbers for DO**

# Top production at Tevatron

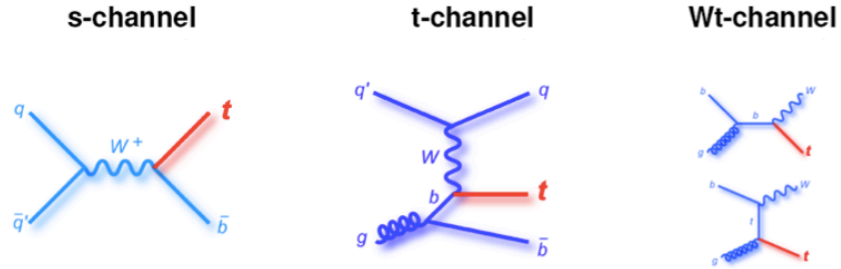
**Tops mainly produced through QCD: Sigma(ttbar) about 7pb, or about 1 in $10^{10}$ collisions**




| | TEV | LHC |
|---|---|---|
| ← | ~85% | ~15% |
| ← | ~15% | ~85% |



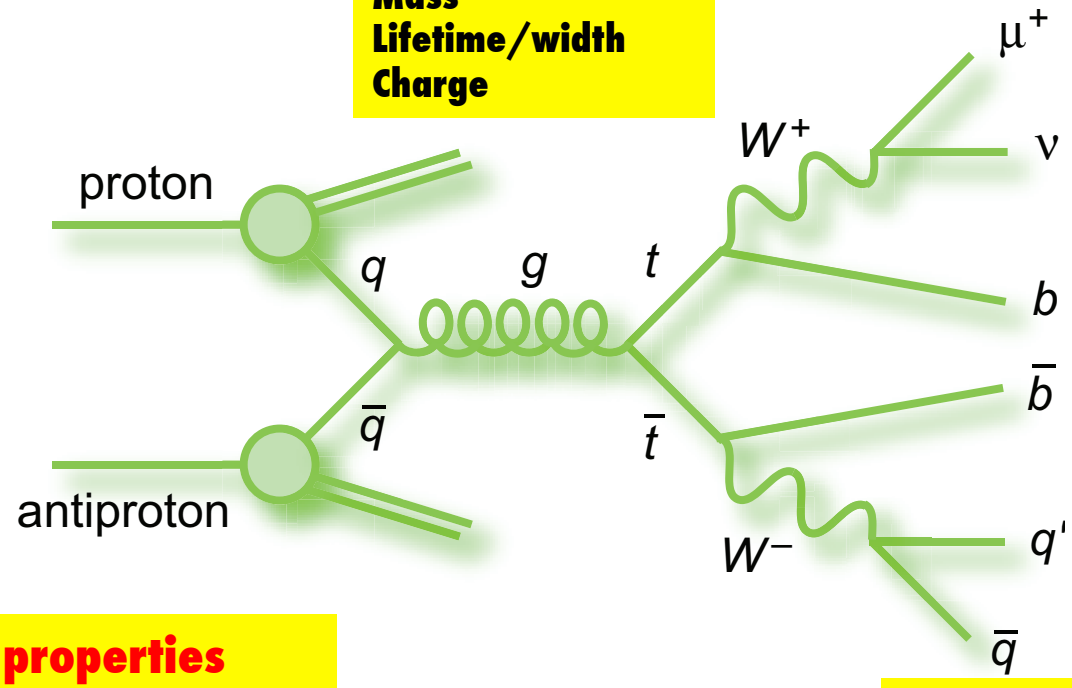

**EWK single top production also possible, and interesting in its own way**
**Cross section about half as for pairs, less striking signature**




**Crucial to study both processes, at different sqrt(s), at different colliders!**

# Is it really the SM top?

**Intrinsic properties**
- Properties
- Mass
- Lifetime/width
- Charge




**Production properties**
- Cross sections
- Spin correlations
- Production asymmetries
- Resonances: X->tt, Y->tb(or q, or X)
- Fourth generation

**Decay properties**
- W helicity
- CKM matrix elements
- Anomalous couplings
- Charged Higgs

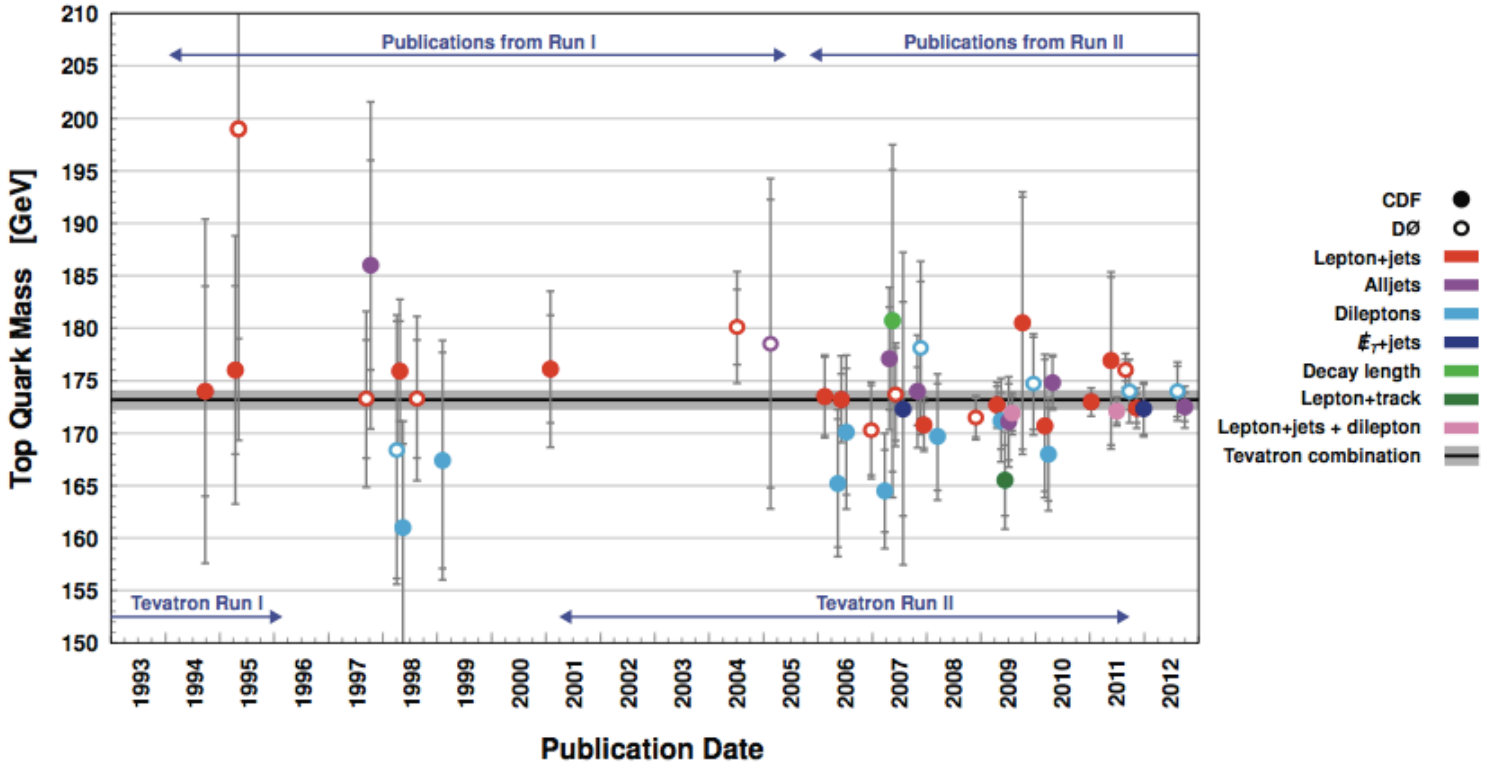
# Intrinsic properties

# The top quark mass

- **The measurement of the top quark mass is a difficult business as it involves a 6 particle final states, with all sort of ambiguities**
- **A plot below to summarize almost two decades of measurements**

A review:
Galtieri Volobuev & myself
Rept.Prog.Phys. 75 056201

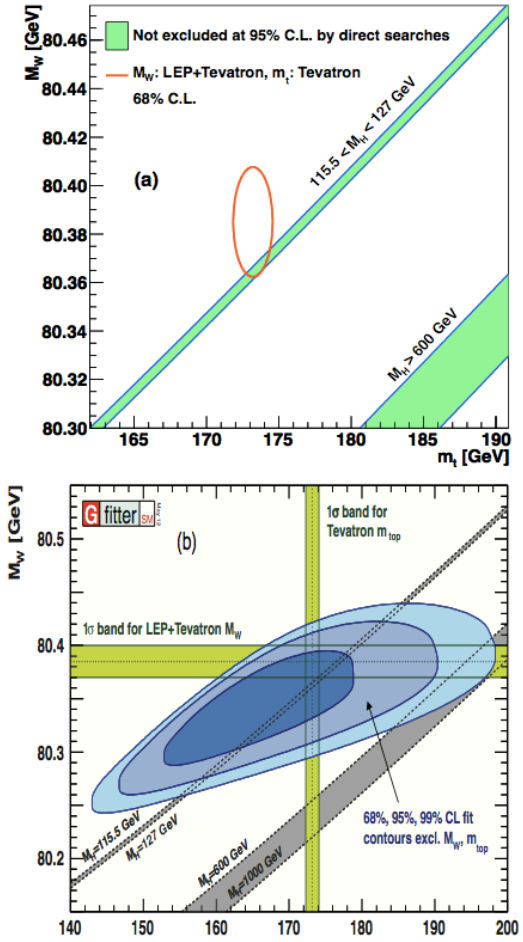
This result:
CDF and D0 coll.
arxiv:1207.1069




- **A combination of the single most precise results from all final states with different techinques gives you 173.2 with 0.6% precision**

# Some considerations

- No other quark mass is known so precisely
- Relation among Mtop and Mhiggs in SM (LEPEWWG) and BSM (GFITTER)




Precision measurements of several EWK observables plus Mtop give predicted Higgs mass in March 2012 was approx 90+-30 (68%CL)

Adding the LEP direct exclusion, little room to hide LHC discovered it at about plus 1 SD edge.

No need to think it's necessarily the SM Higgs: BSM Higgses are still possible

# Production properties

# Total cross sections New

**NP could appear as modifications to observed differences in different top-quark final states**

**Updated result in dilepton channel:**

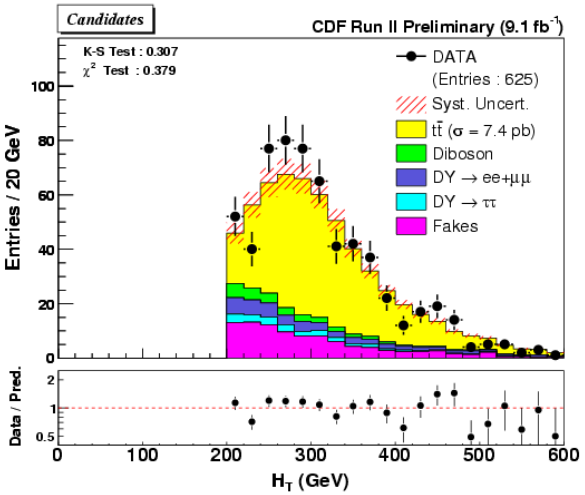
**$\sigma$ (pretag) = 7.66 ± 0.46(stat) ± 0.66(syst) ± 0.47(lumi) pb**

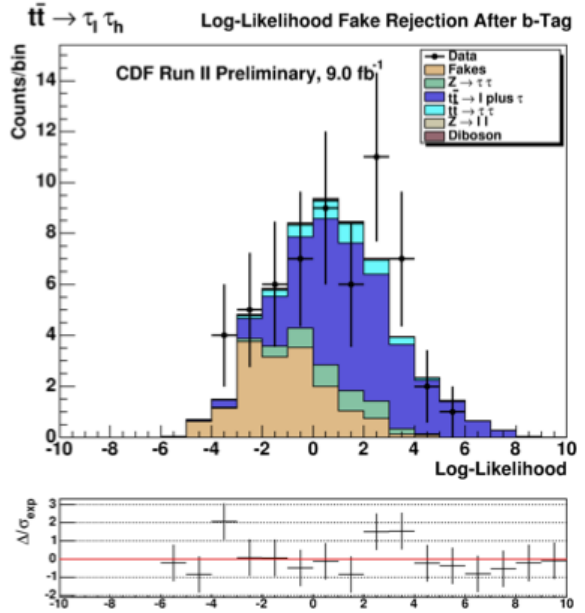
**$\sigma$ (btag) = 7.47 ± 0.50(stat) ± 0.53(syst) ± 0.46(lumi) pb**

**New result in tau channel (1tau and 2tau) sensitive to MSSM Higgs**

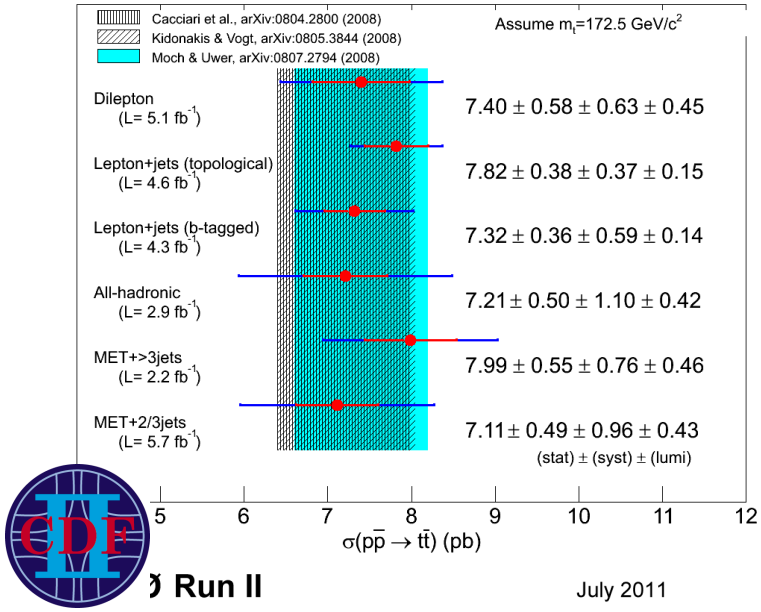
**$\sigma$ (tag) = 8.2 ± 2.3(stat) ± 1.1(syst) ± 0.5(lumi) pb**

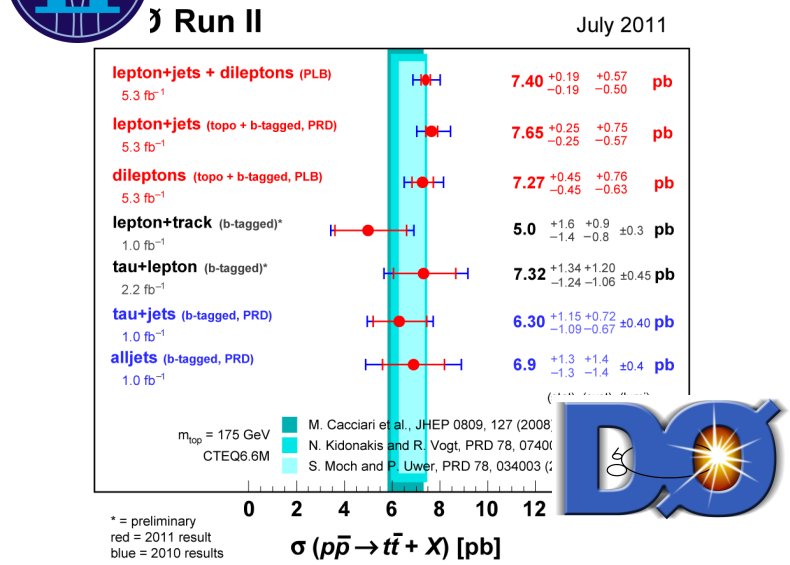
**BR(t->tau nu b) = 0.098 ± 0.022(stat) ± 0.014(syst)**



# Any SUSY hint from $\sigma(t\bar{t})$?



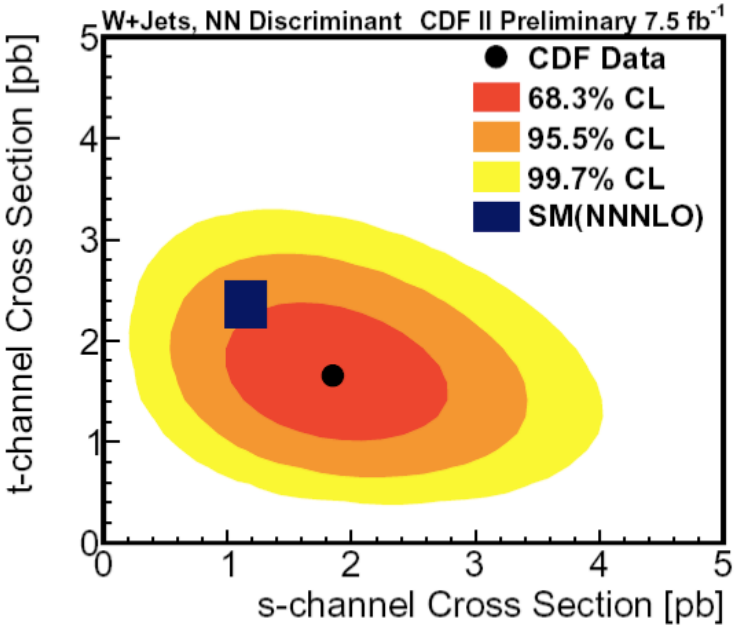

- **Measurements in good agreement with theory**
- **Most precise determinations in leptonic channels**
- **NNLO predictions (Bernreuter, Czakon, Mitov, arXiv:1204.5201) 7.1+-0.3pb**
- **Leptonic channel measurements slightly above (1 sigma)**

**Combination of the all of the above will provide the reference sigma(ttbar) at Tevatron**

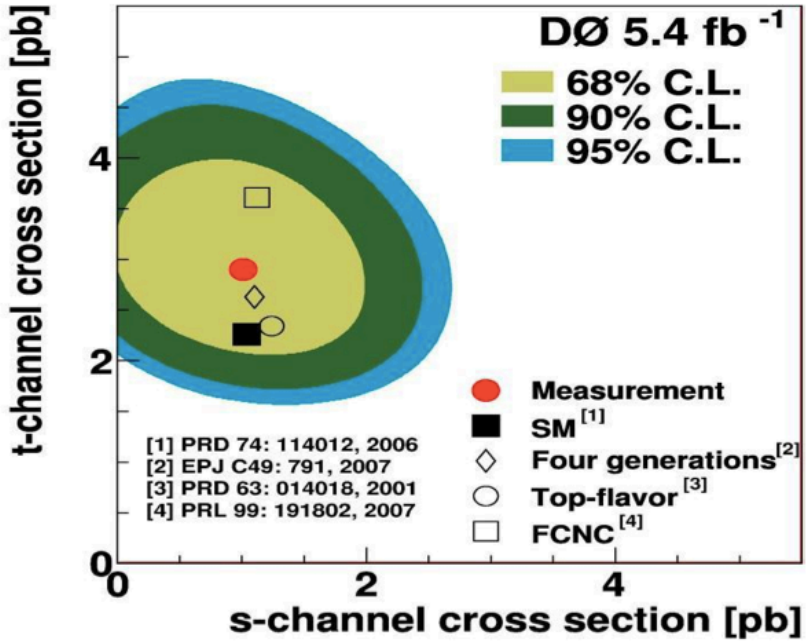
# Single top cross sections

- **Reminders:**
  - **single top first observed in 09 by CDF and D0 simultaneously**
  - **LHC sensitive mostly to t-channel and Wt channel**
  - **At Tevatron s- and t-channels are comparable (and Wt almost negligible)**
  - **s- and t-channels have sensitivity to different NP scenarios**

**CDF Note 10878**




**PLB 705, 313 (2011)**




*World best determination of s-channel cross section*

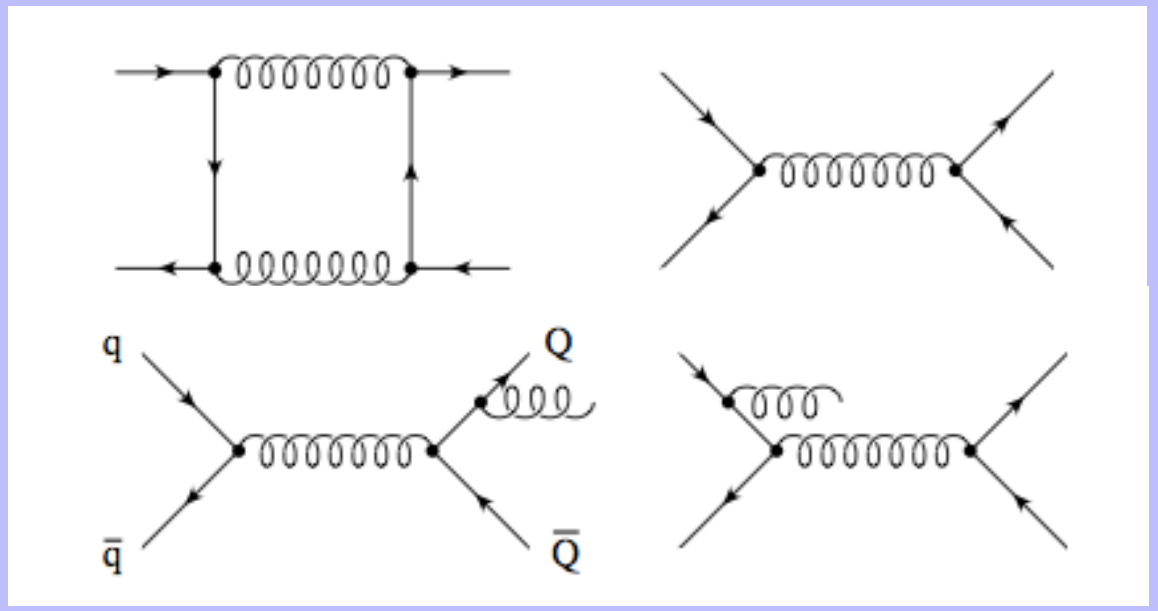
*Similarly, low mass W'->tb searches at Tevatron competitive with LHC*

# C asymmetry in ttbar production

- LO collision is charge-symmetric
- NLO produces asymmetry through interference:

between box and Born diagram

between ttj states



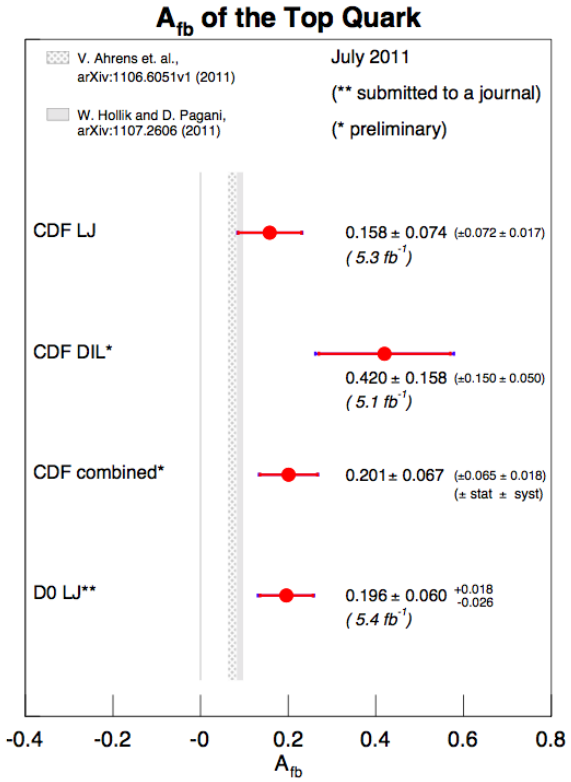

- Net result is a positive asymmetry of about 5%
- Several exotic ttbar production modes generate at tree-level a larger asymmetry through the interference with SM qq->tt

# A sizeable deviation

**Top quark at the Tevatron are produced mostly along the proton direction.**
**NLO QCD predicts AFB about 5%, CDF and D0 traditionally measured larger values, albeit with low significance**

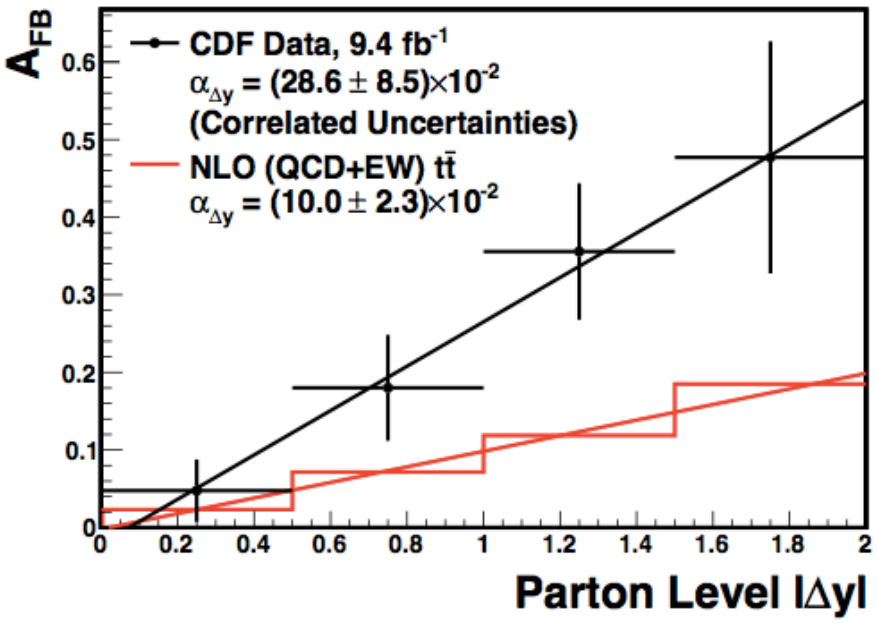
- **First breakthrough(>3σ) one year ago with large m(ttbar) dependence observed by CDF**
- **Then (CDF+D0) finding large inclusive asymmetries**
- **Then improved theory computation enhanced the central value by 20%**
- **Topic gave rise to lots of discussions: hundreds of NP and SM possible explanations, dedicated workshop on spring at CERN**

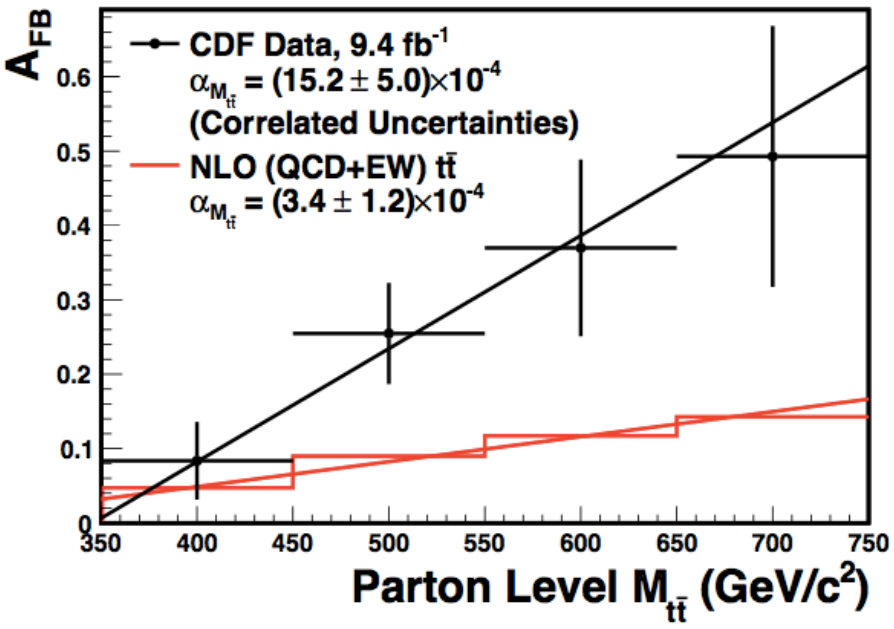
http://indico.cern.ch/conferenceDisplay.py?confId=175916



# Most recent CDF result New

- Recovery of previously discarded data: L=8.7fb-1 -> 9.4fb-1
- Better QCD background model – better description of Pt(ttbar)
- Additional charge asymmetry measurement test in $10^6$ W+1 jet events



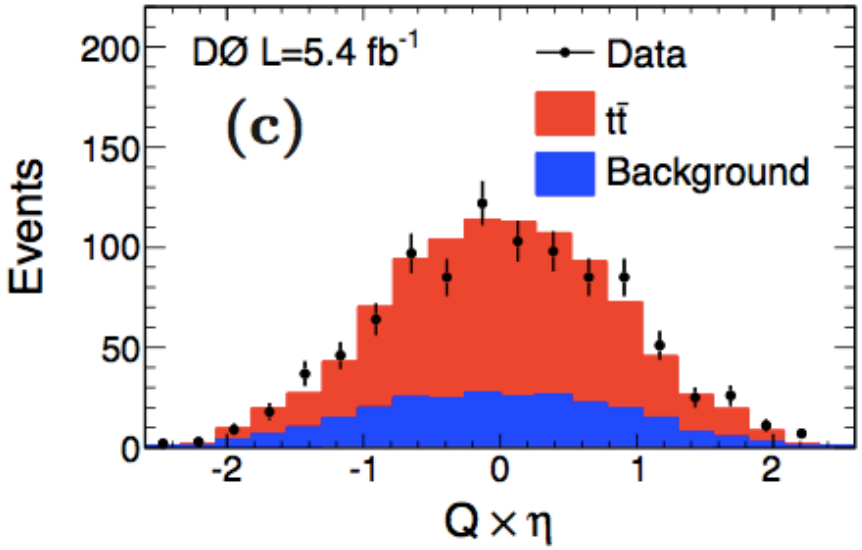



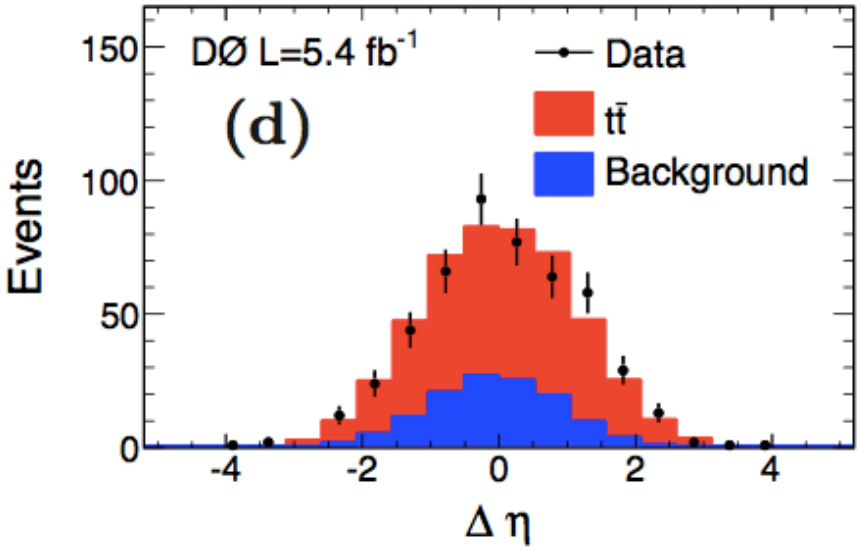

- Now experiment a little closer to theory, still large dependence

# Most recent D0 result New

- **D0 observed no significant mass dependence, but large (3SD) asymmetry in leptons. Dilepton channel provides an orthogonal dataset to study this**
- **Using half the currently available dataset, study several observables**

arxiv:1207.0364




***A l*** **= 5.8 ± 5.1(stat) ± 1.3(syst) %** ***FB***

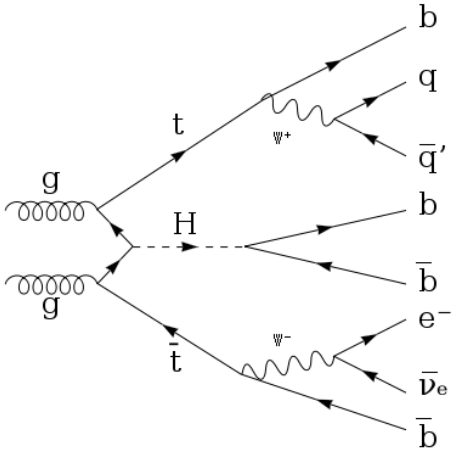
**l+jets (arXiv:1107.4995) and dilepton (this) results consistent within 68%**

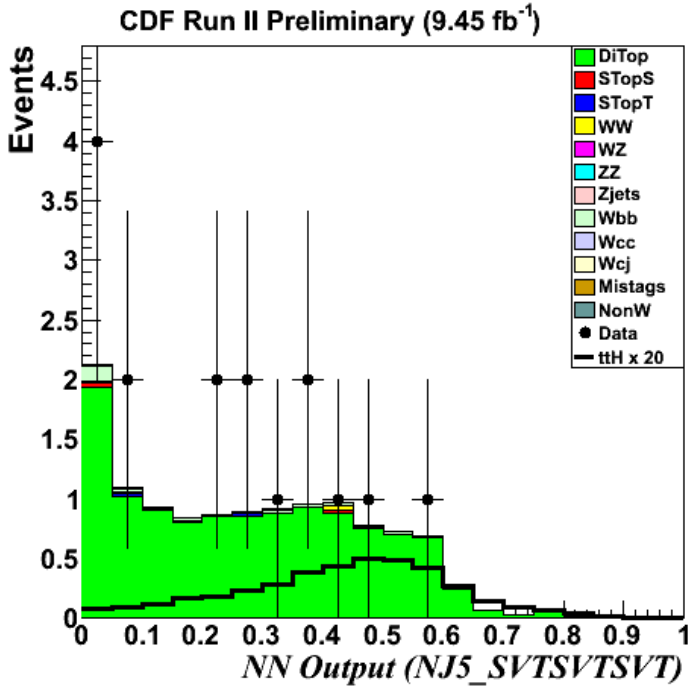
**Combination:** ***A l*** **= (11.8 ± 3.2) %** ***FB***

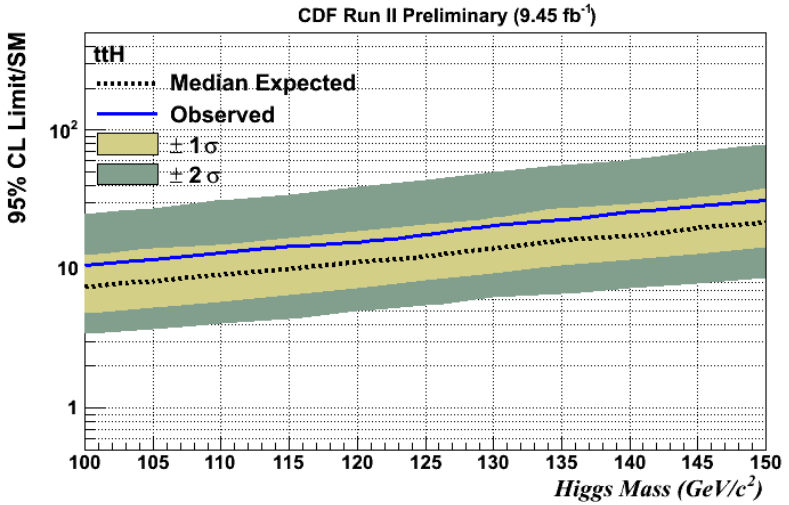
**Within 2.2 SD with MC@NLO prediction of 4.7%**

# Top and Higgs New

- After the discovery of a new state, crucial to understand its couplings to SM particles. Measuring top-Higgs coupling crucial to determine what Higgs is the one we're seeing.
- CDF and D0 pioneered the searches for tth production
- Sensitive to top-H and bottom-H couplings
- Here is the last update to CDF ttH search

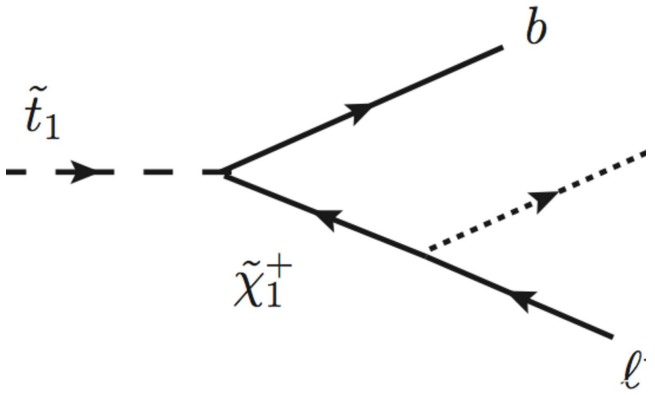


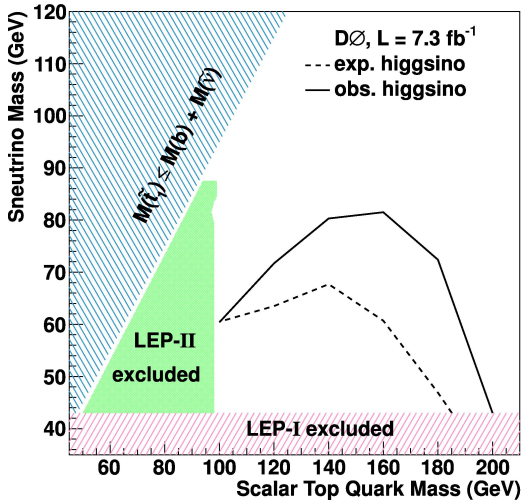



# SUSY and top New

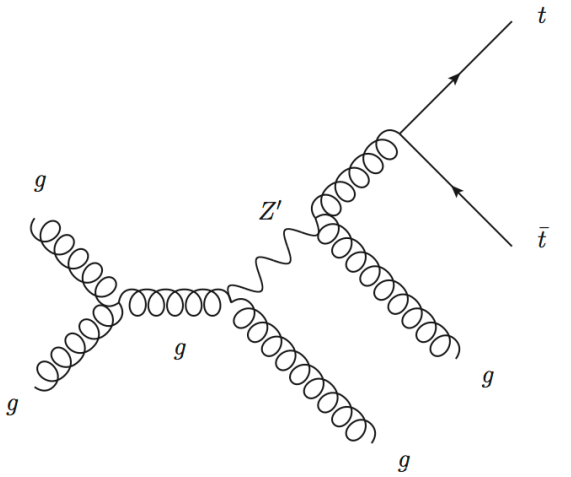
- There exists a multitidue of stop decay modes, depending on the masses of SUSY particles some are not allowerd
- Looking here at chargino to l snu decays.
- Snu assumed to be LSP
- Chargino is superposition of Wino and Higgsinos. If Higgsino like, tau final states are most important
- Select muon+tau+jets with NN tau ID to suppress backgrounds
- Sets limits to both Wino and Higgsino-like hypotheses

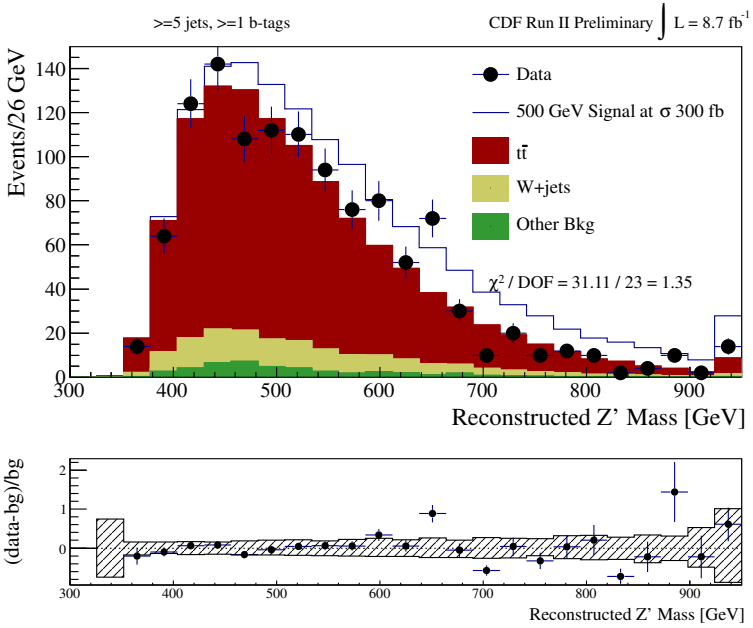


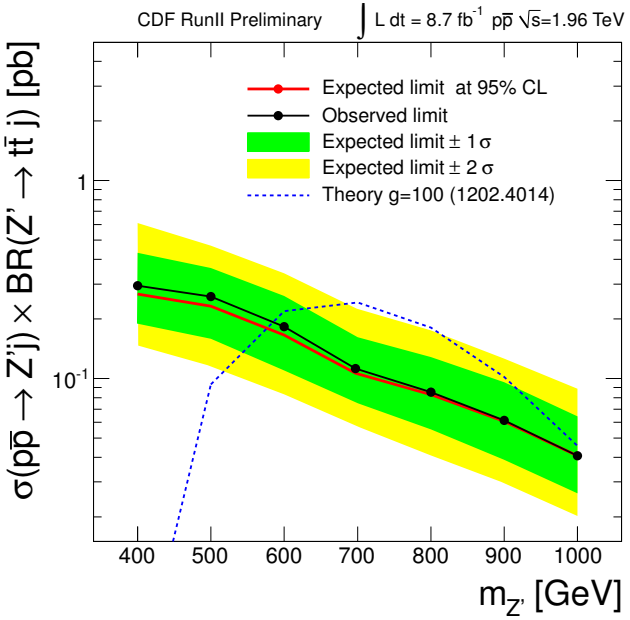



# Search for chromophilic Z' New

- **Z′ bosons expected in a multitude of SM extension.**
- **Strong bounds on Z′ with coupling to fermions from Tevatron and LHC**
- **Z′ with couplings only to gluons still unexplored. Z′ decays to g*g->qqg** arxiv:1202.4014
- **Use qq=tt to suppress backgrounds**



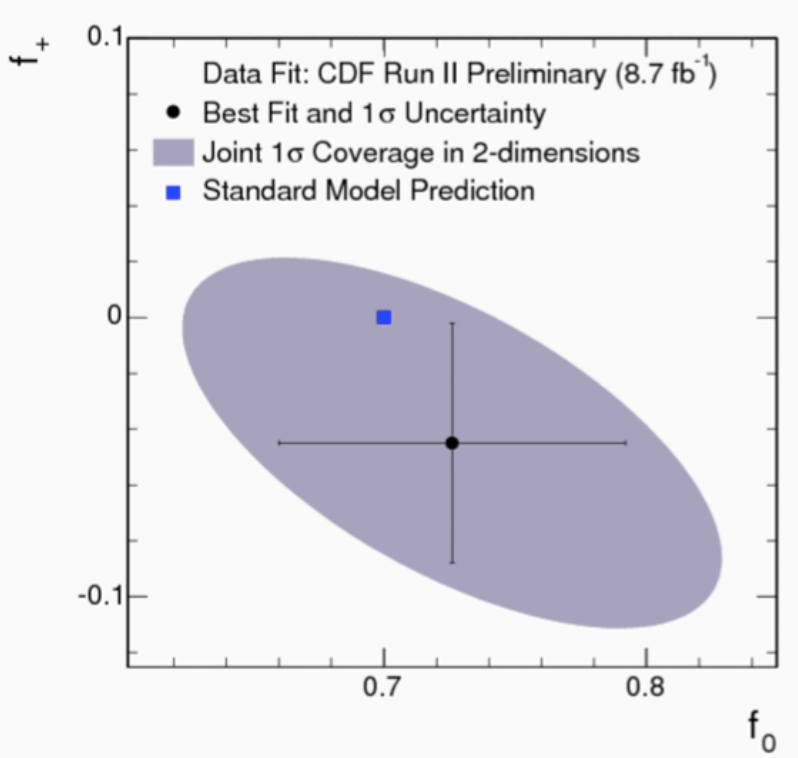



# Decay properties

# W helicity New

**With three helicity orientations, there are two independent quantities to measure (3rd fraction is fixed since $\sum f = 1$)**

- **We choose to measure f0 and f+**
- **Can either measure both fractions simultaneously (2D fit)**
- **or fix one fraction to its SM value and measure the other (1D fit)**




**Simultaneous measurement of f0 and f+**

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

- **f0 = 0.726 ± 0.066 (stat) ± 0.067 (syst)**
- **f+ = -0.045 ± 0.043 (stat) ± 0.058 (syst)**

**CDF+D0 (lepton+jets and dilepton, 2.7-5.4 fb-1)**

- **f0 = 0.722 ± 0.062 (stat) ± 0.052 (syst)**
- **f+ = -0.033 ± 0.034 (stat) ± 0.031 (syst)**

*Statistical uncertainty smaller at LHC, systematic uncertainties smaller at Tevatron*

# BR(t->Wb/t->Wq) New

- This ratio is sensitive to NP (think about 4th generation)

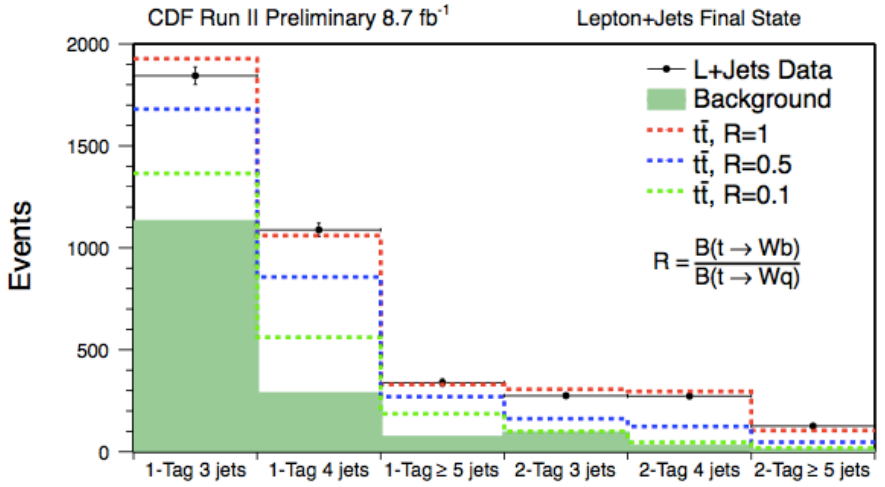
$$R_{SM} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2 = 1$$

unitarity of CKM matrix

- D0 measured R 2.5SD away from SM
- CMS in better agreement with SM
- CDF measures the same observable in the "lepton+jets" events
  - It's basically about how many b-tagged jets you see, vs how many you expected to see

R = 0.94 ± 0.10 (stat+syst)

  - Now systematically limited



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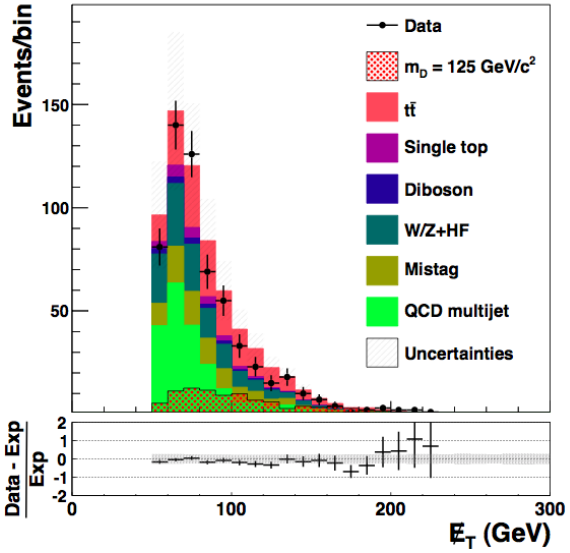
**Exciting times are awaiting us!**

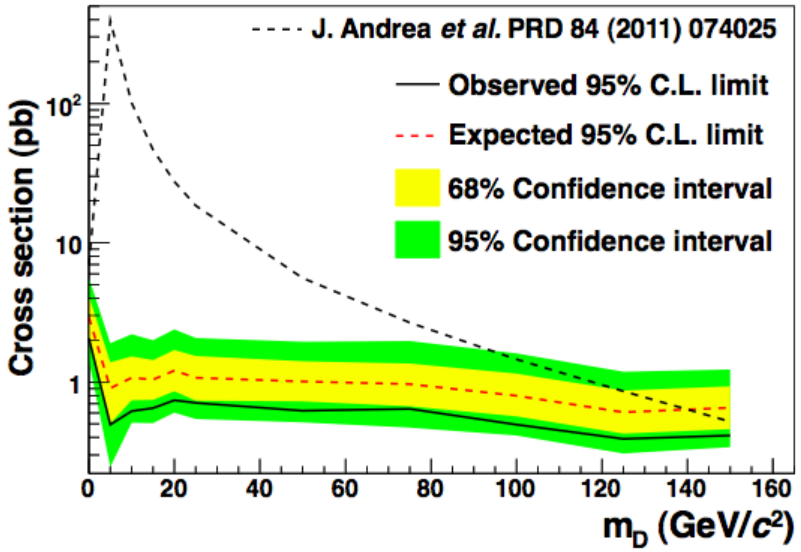
# The end..?

# …and monotop

**One more signature that has been investigated here for the first time.**

- **Study events with a single top quark plus large MET.**
  - **Can arise from FV models, SUSY etc.**



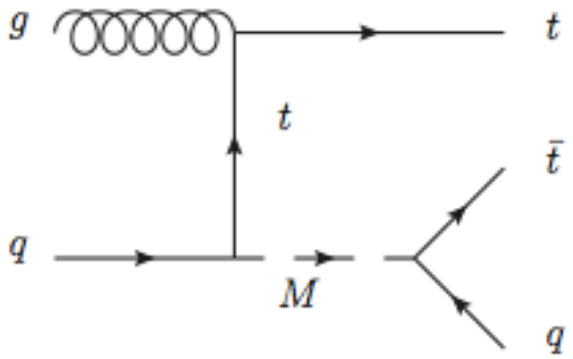



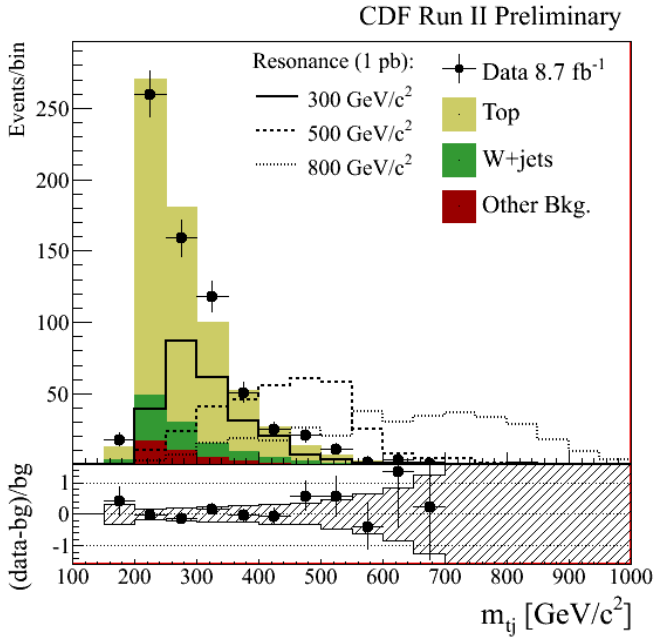

**No signal seen, set limits on cross section in a model with mediator D**

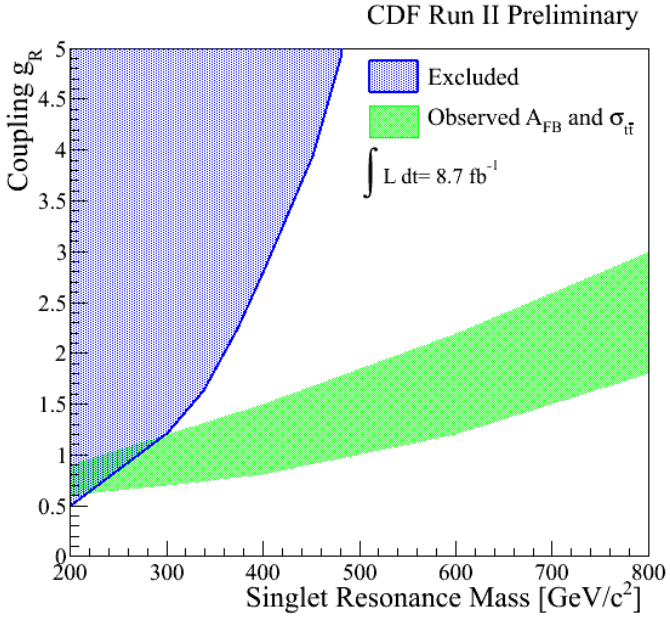
**arXiv:1202.5653, submitted to PRL**

# Possible AFB explanation?

- **Anomalous top AFB could be explained by a new particle Z' with uZ' t coupling. Would give rise to**
  - **Same sign top production (already investigated)**
  - **Search tZ' → ttj events for resonant top +jet production**



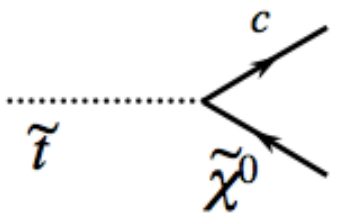



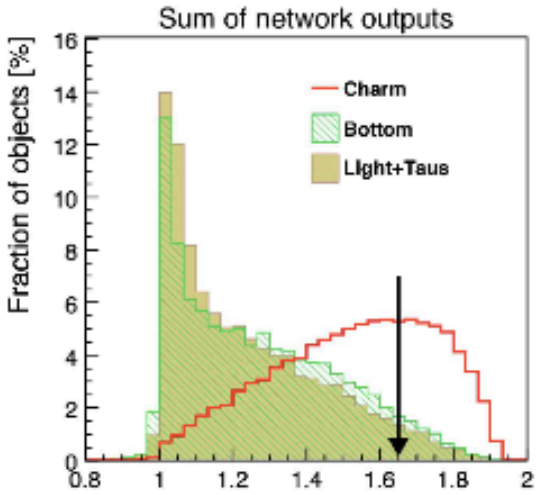



# $\tilde{t}$->c$\tilde{X}$

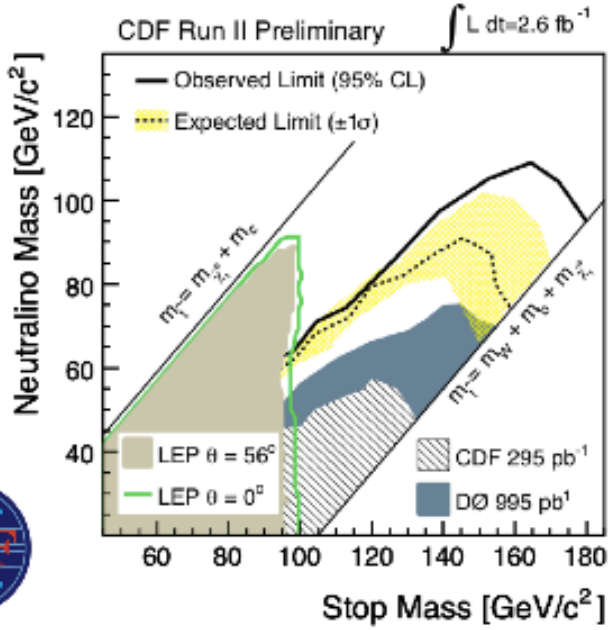
## *Charm is hard to find with just vertex detectors*

**Typically τ(*b* hadrons) > τ(*c* hadrons)**
**⇒ no high-purity selection**



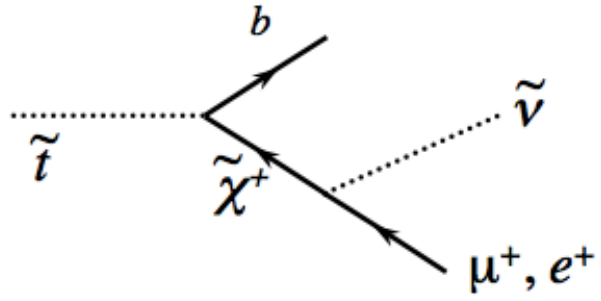

**2 output, 22 input Neural Net**

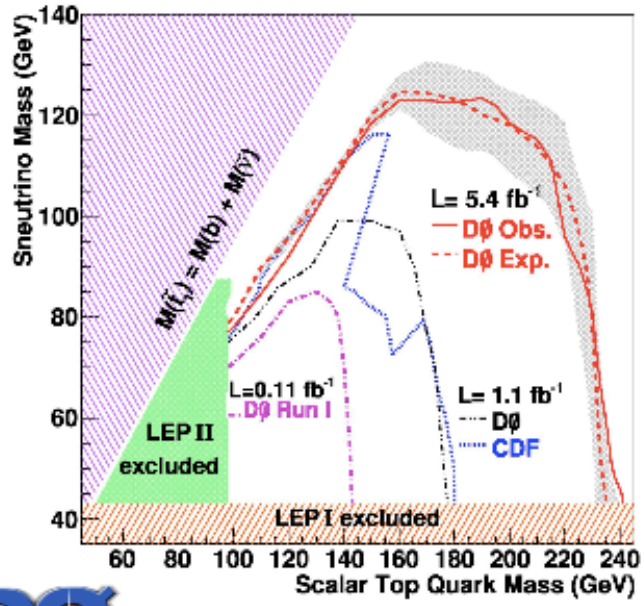



**CDF CONF Note 9834**

# $\tilde{T}$->b$\tilde{X}$->bnu$\tilde{l}$

## $\tilde{t}$ pairs in $e\,\mu\,\not\!\!E_T$




*Backgrounds are*

$p\bar{p} \to Z/\gamma^* \to \tau^+\tau^- \to e^+\mu^- 4\nu$
occurs at relatively low $\not\!\!E_T$, $p_T(\ell^\pm)$ (< 20 GeV) and large opening angle ($\Delta\phi > 2.8$) in the transverse plane

$p\bar{p} \to t\bar{t}$ is basically the same thing without the SUSY; it can be suppressed with MVA methods

*WW* likewise

*Abazov et.al., Phys.Lett. B696,321(2011)*

*Aaltonen et al. Phys. Rev. D82, 092001 (2010)*

Other stop searches:
- top-like $\ell\ell$
  Aaltonen etal, Phys.Rev.Lett. 104,251801(2010)
  Abazov etal, Phys.Lett. B675,289 (2009)
- top-like $\ell$+*jet* Abazov Phys.Lett.B674,4(2009)

# T->bX+->bW0l

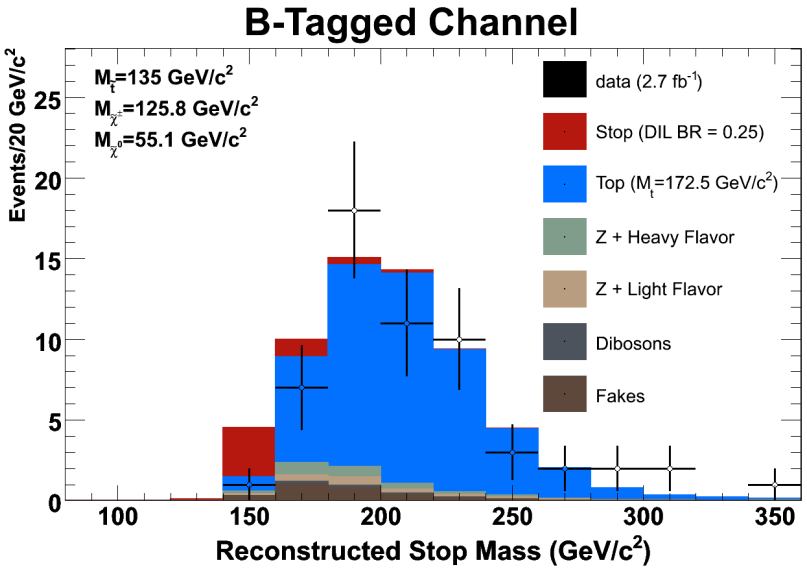
**Event kinematics determined by stop, chargino, & neutralino masses**

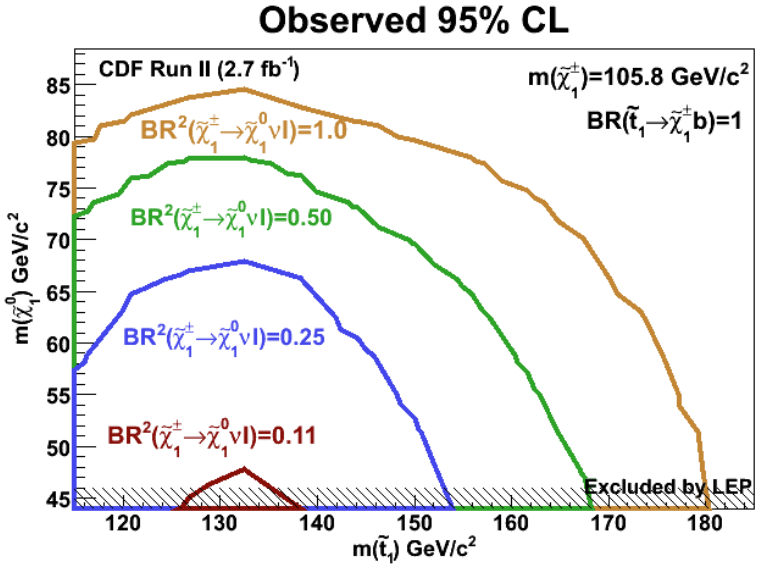
- **Dilepton branching ratio determined by SUSY parameters**
- **Reconstruct event under stop hypothesis**
- **Use reconstructed stop mass to discriminate stop from SM**

$\tilde{\chi}_1^0$ is the LSP, and $\tilde{q}, \tilde{\ell}, \tilde{\nu}$ are heavy

$m_{\tilde{t}_1} \lesssim m_t$

$m_{\tilde{\chi}_1^+} < m_{\tilde{t}_1} - m_b$



# Jets at the Tevatron

- Use cone based jet reconstruction algorithm
  - energy resolution driven by HAD cal resolution $80\%/\sqrt{E_T}$
  - Non-instrumented regions in calorimetry+resolution effects lead to mismeasurement of jet $E_T$ source of apparent MET

- Typical b-tagging id numbers at CDF/ D0:
  - b-tag eff ~40%
  - fake rate~0.5%