Top Quark Properties and searches for the Higgs Boson at CDF

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Fundamental Questions

- **Fundamental questions of Contemporary Physics**
  - What is dark energy ? Dark matter ?
  - What's the deal with neutrinos ?
  - Why so many particles ? What's the reason for their masses ?
  - Are there other symmetries ?
  - Are all the forces related at some high energy ?

- **Standard Model of particles and fields (SM)**
  - Electroweak symmetry (EWS). Massless particles predicted.
  - The Higgs field breaks symmetry (EWSB) generating mass. Predicts $h^{0(SM)}$.
  - But we can't find the h^0. Maybe another mechanism in place ? New particles ?

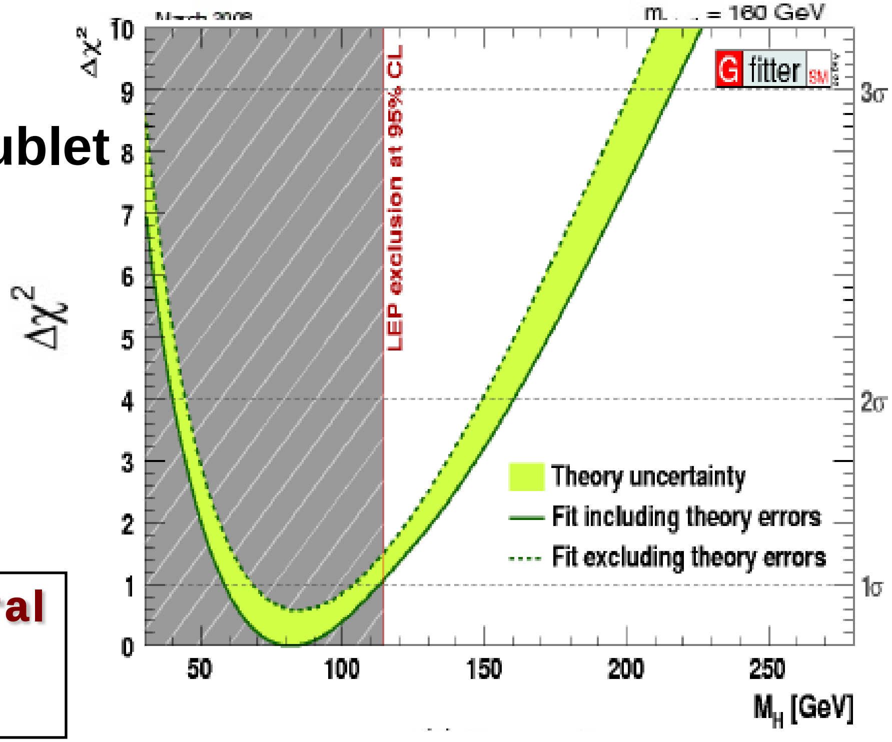
The unknown mechanism of EWSB is a key aspect to help answer some of the fundamental questions of the Universe.

Electroweak Symmetry Breaking

- **Top quark**
  - Large mass suggest it plays an important role
  - Fermion to which coupling to Higgs is most important, $y_t = M_t/v \approx 1$.

New physics related to EWSB and thus likely to couple to top

- **Standard Model (SM) : 1 Higgs doublet**
  - EWSB → One Higgs boson, $h^{0(SM)}$
  - Decays to bb , $\tau\tau$, etc.
  - Excluded by LEP up to ~114 GeV
  - **Plenty of room to be hiding**



Top and Higgs datasets are the natural samples to look for physics beyond the SM

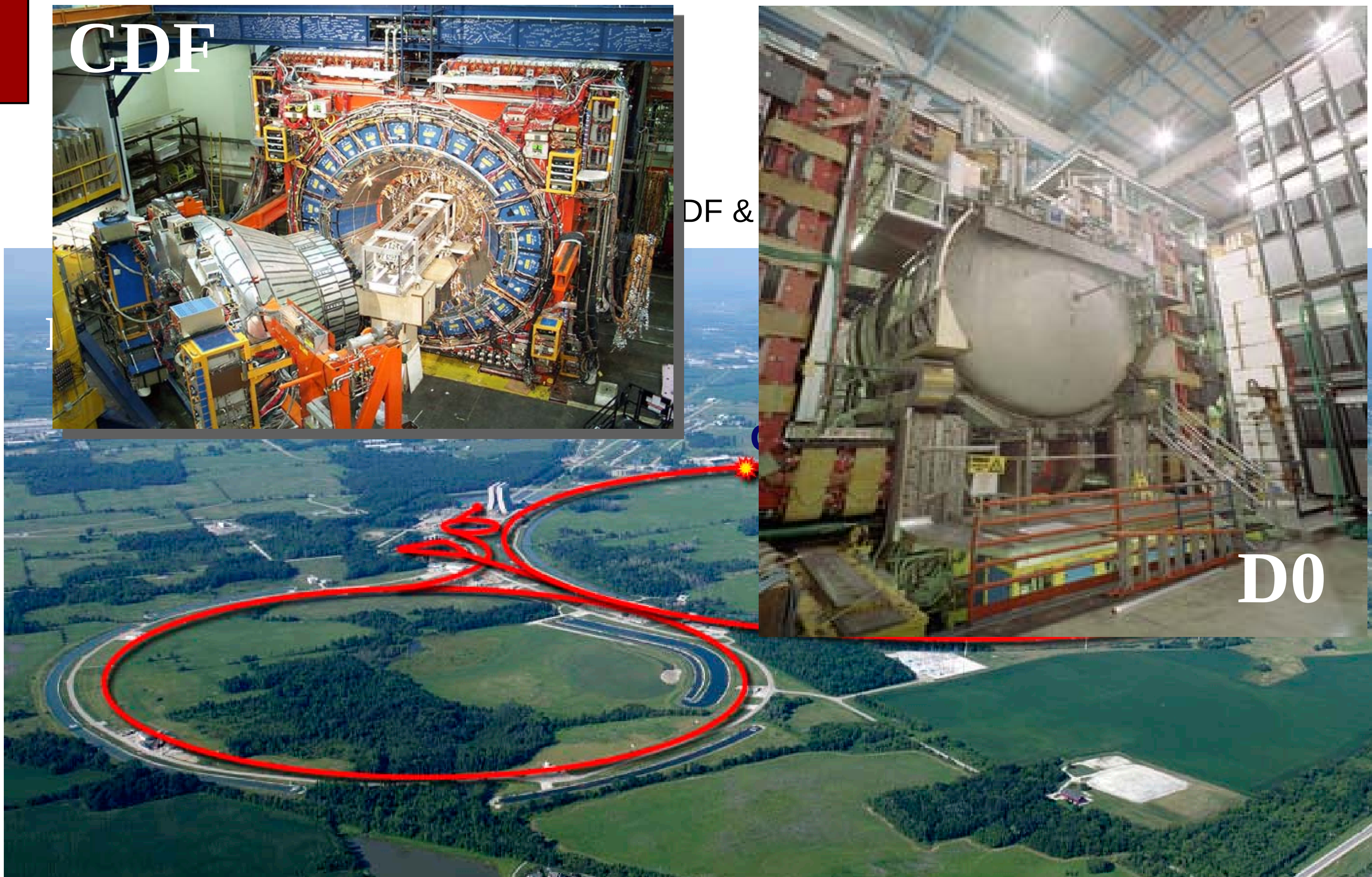
Chapters

- Motivation: Fundamental Questions
- Fermilab, the Tevatron, and CDF
- Producing and Finding Top Quarks
- Top Properties
- Searching for the Higgs Boson
- Summary

Chapter

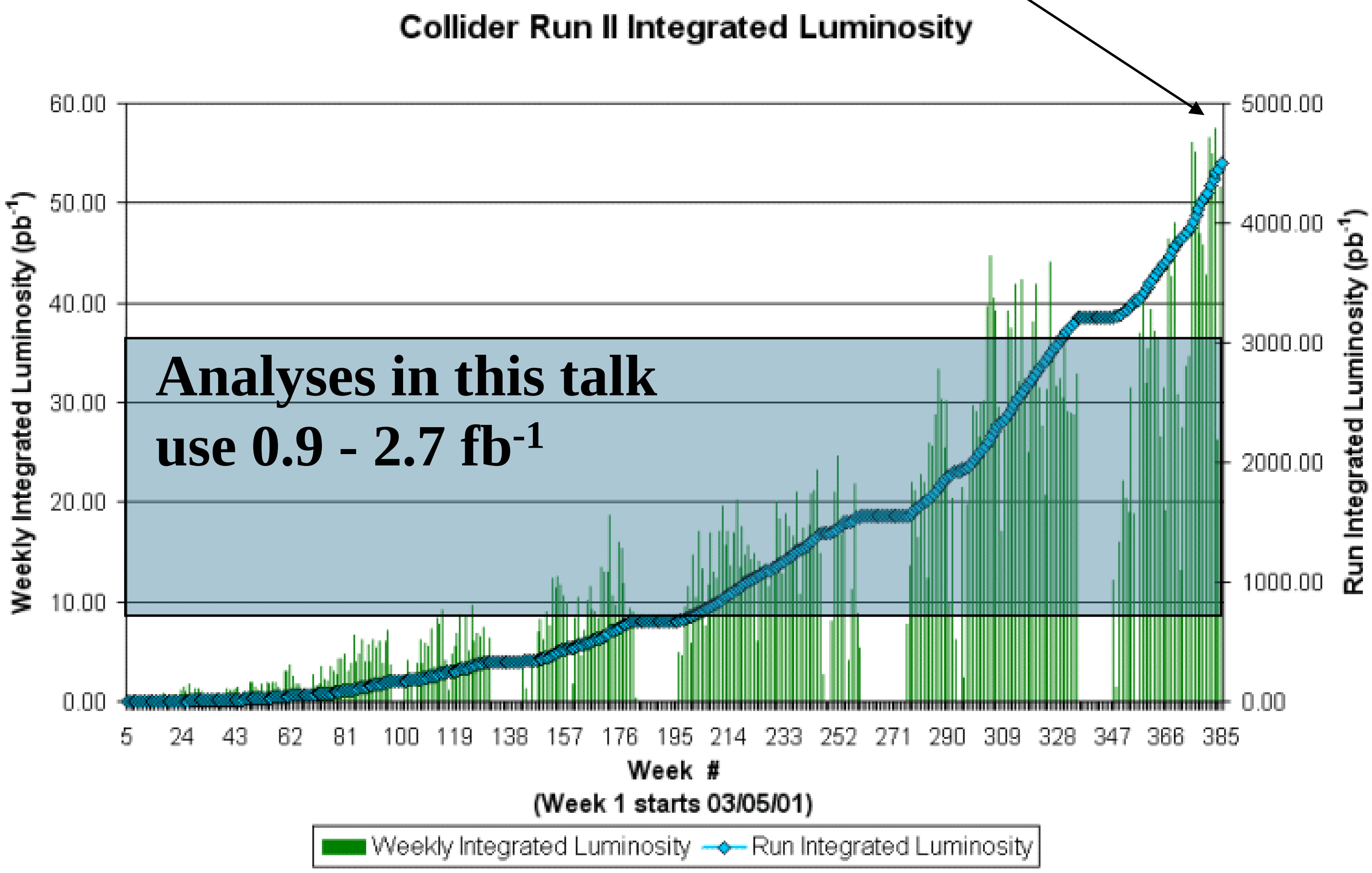
Fermilab, the Tevatron and CDF

Tevatron Experiments



Tevatron Integrated Luminosity

- Tevatron is performing extremely well ~58 pb^{-1} / week!



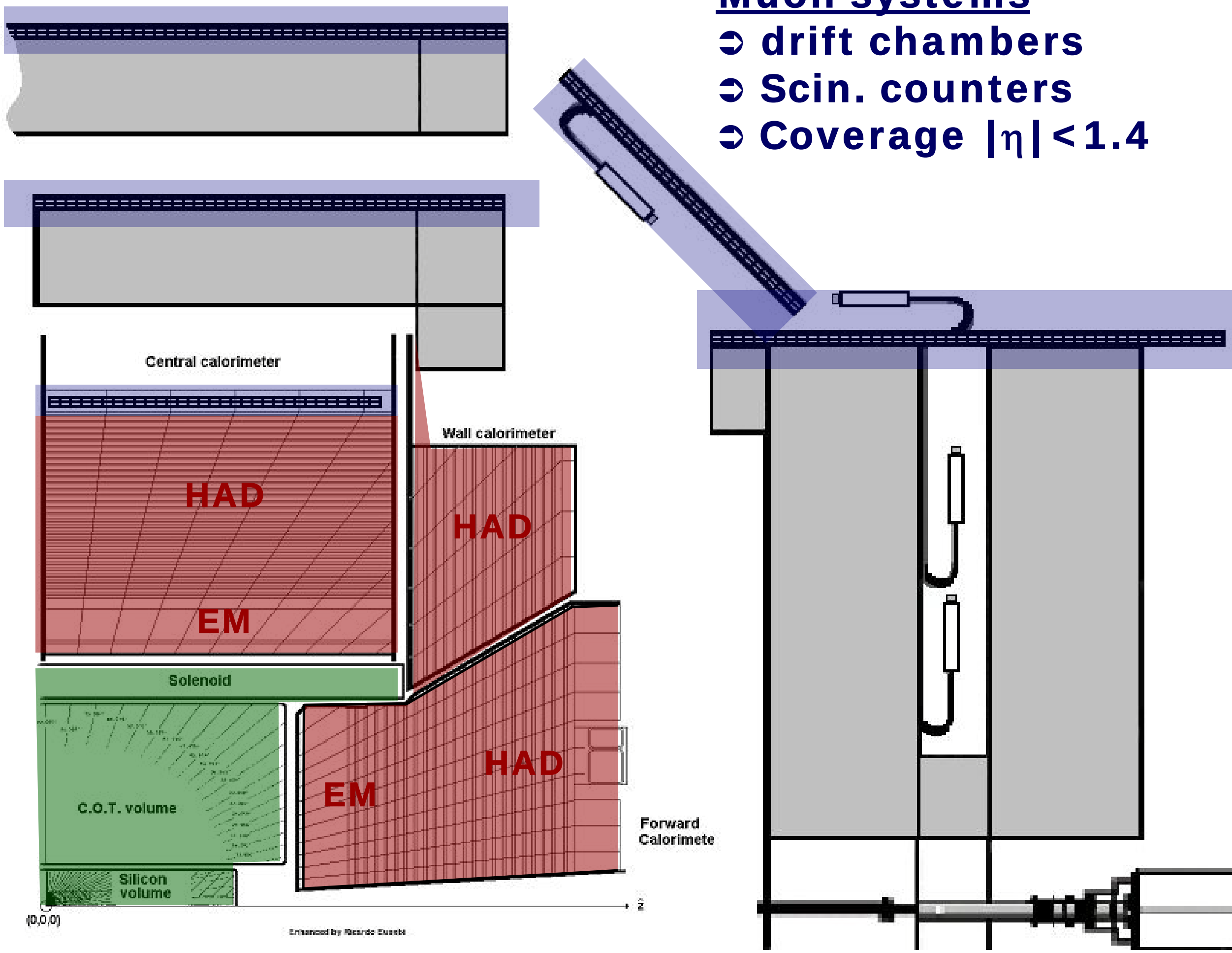
- Expect 6-8 fb^{-1} datasets by end of 2009

The CDF II Detector at the Tevatron

Quadrant of the CDF II detector section view

Sampling Calorimeters
- Iron/scin (HAD)
- Pb/scin (EM)
- Coverage $|\eta|<3.6$
- $\frac{\Delta E_{Had}}{E_{Had}} = \frac{0.80 GeV^{1/2}}{\sqrt{E_{Had}}}$
- $\frac{\Delta E_{em}}{E_{em}} = \frac{0.13 GeV^{1/2}}{\sqrt{E_{em}}}$

Muon systems
- drift chambers
- Scin. counters
- Coverage $|\eta|<1.4$



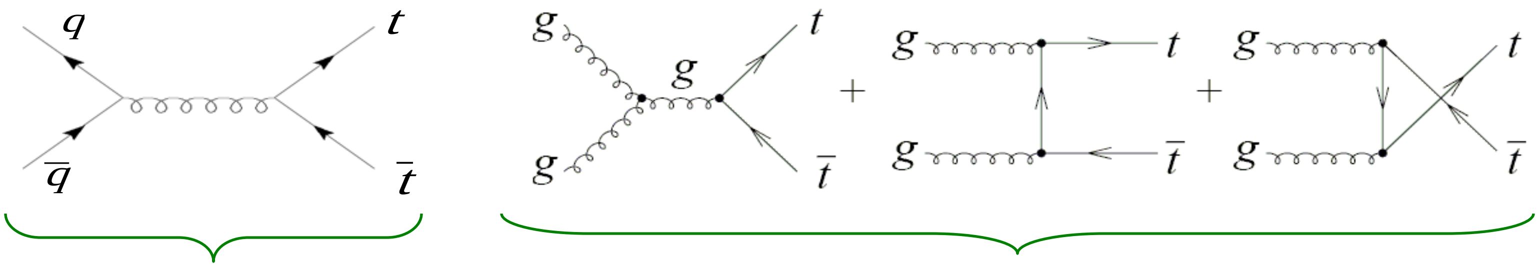
Tracking system
- Solenoid 1.4 Tesla
- Central Outer Tracker Drift chambers
- $\Delta P_T / P_T = 0.15\% P_T GeV^{-1}$
- Silicon Detectors
  - determination of secondary vertexes
  - $40\mu m$ resolution

Chapter

Producing and Finding Top Quarks

Top Quark Production at the Tevatron

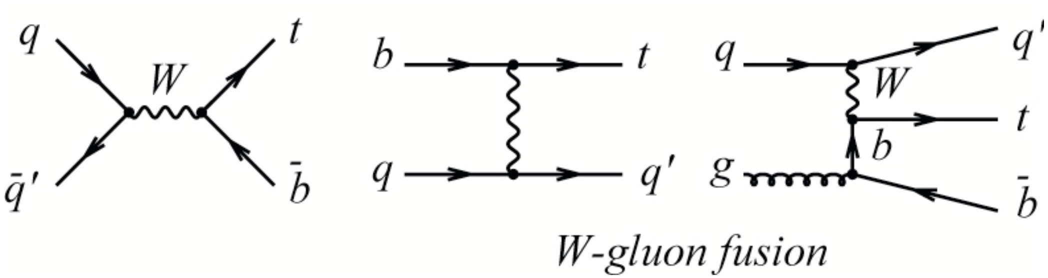
- produced in pairs **via the strong interactions.**



$$\sigma(\bar{p}p \to t\bar{t} \ @\ M_{top} = 172 GeV) \approx 7.3 \pm 0.9 \text{ pb}$$

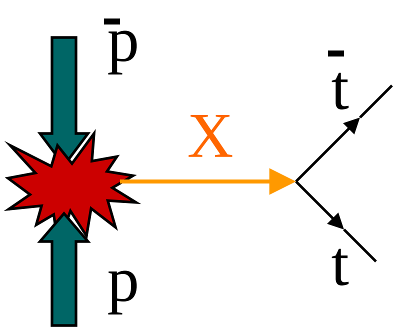
one top pair event every 10^{10} inelastic collisions

- single produced, **in association with other particles**



$$\sigma(\bar{p}p \to t + X \ @\ M_{top} = 172 GeV) \approx 2.0 \text{ pb}$$

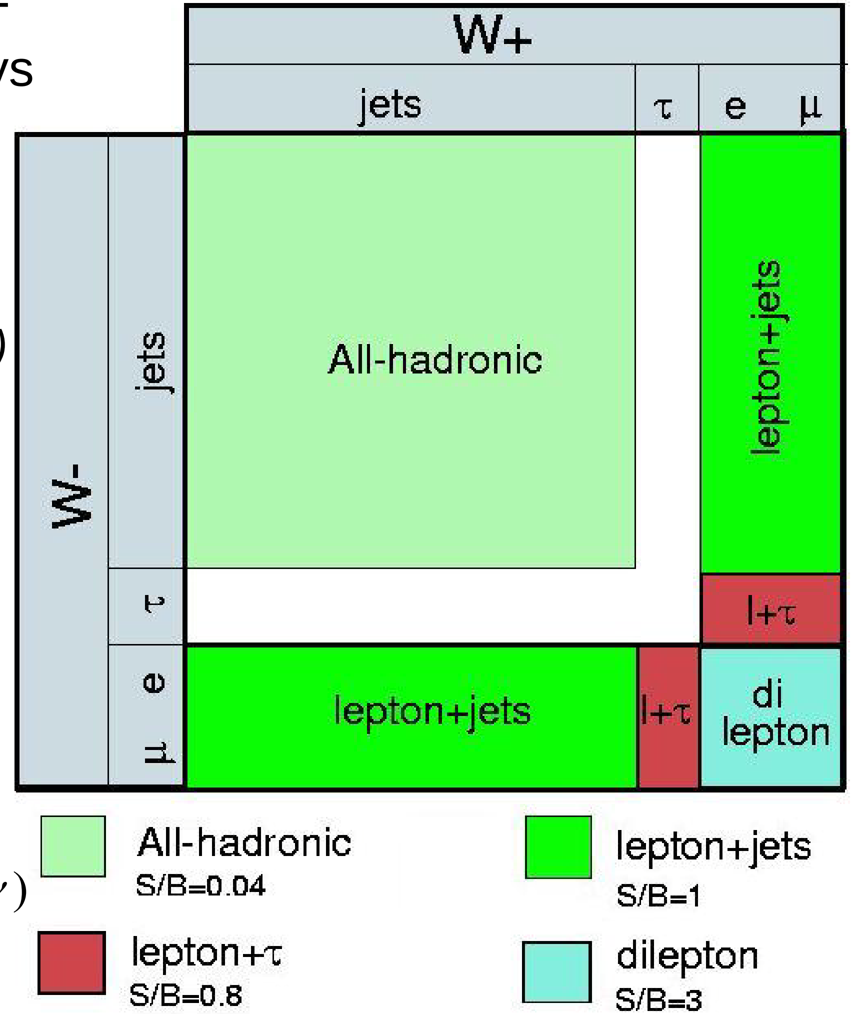
- Through resonances ??



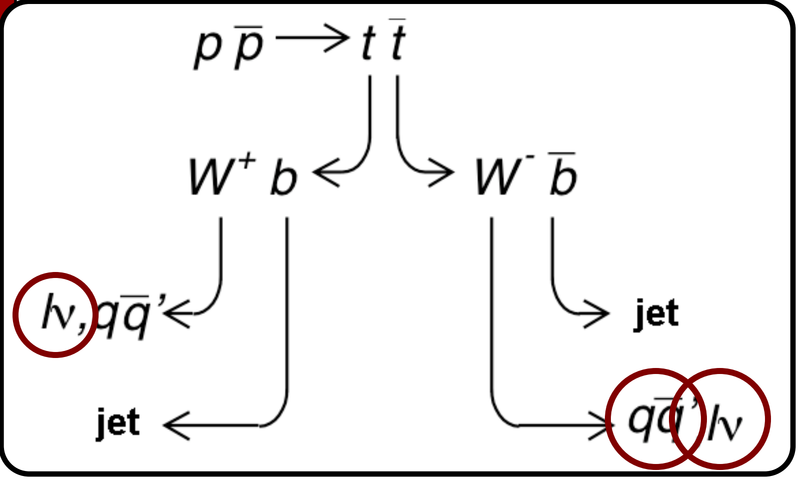
- **Topcolor-assisted Technicolor**

Top Pair SM Signatures

- In the SM, BR($t \rightarrow W^{+}b$) >0.99 @95%CL
- Final state is given by W^{+} and W^{-} decays
  - All Hadronic channel ($tt \rightarrow bqq'bqq$)
    - Large BR
    - Small S/B
  - Lepton (e,μ)+Jets channel ($tt \rightarrow bl\nu bqq'$)
    - Second large BR
    - Good S/B
    - overconstrained kinematics
  - Dilepton channel : ($tt \rightarrow bl\nu bl\nu$)
    - BR is ¼ of L+Jets
    - cleanest channel
    - underconstrained kinematics
  - Lepton + Had. Tau channel($tt \rightarrow bl\nu b\tau_h \nu$)
    - Very small BR
    - S/B~1



Typical Selection Criteria



- Cylindrical coordinate system:
- θ: polar angle w.r.t. to proton direction
- ϕ: azimuthal angle
- Pseudorapidity: $\eta = -\ln\tan(\theta/2)$
- Transverse energy:

$$\vec{E}_T = \sum_{\text{cal towers}} E_i(\sin\theta_i, \phi_i)$$

- Missing transverse energy ("MET"):

$$\vec{\not{E}}_T = -\sum_{\text{jets}} \vec{E}_T - \sum_{\text{leptons}} \vec{p}_T$$

- Lepton + Jets: tt → Wb Wb → lvb qq'b
  - Isolated lepton with p_T > 20 GeV/c
  - Neutrino: missing E_T ("ME_T") > 20 GeV
  - 3 jets within |η| < 2 with E_T > 15 GeV, 4th jet: E_T > 8 GeV
  - 0, 1, ≥ 2 identified jets from b quarks ("b-tags")
- Dilepton: tt → Wb Wb → lvb lvb
  - Two oppositely charged leptons with p_T > 20 GeV/c
  - Two neutrinos: ME_T > 25 GeV
  - ≥ 2 jets within |η| < 2.5 with E_T > 15 GeV
  - Scalar sum of lepton p_T's, jet E_T's and ME_T: H_T > 200 GeV
  - 0, 1, ≥ 2 b-tags

Understanding the sample composition

- **Cross section requires understanding of all processes in sample**

- **Sample-composition estimator**
  - Performed in a jet-bin basis
  - Based on the pretag data
  - Predicts sample composition in the tagged sample

- **Components in pretag data:**
  - $t\bar{t}$
  - WW,WZ,ZZ,Z/$\gamma \rightarrow \tau\tau$
  - single top

  } Production cross section relatively well known

  - non-W

  } Handle on these processes: MET

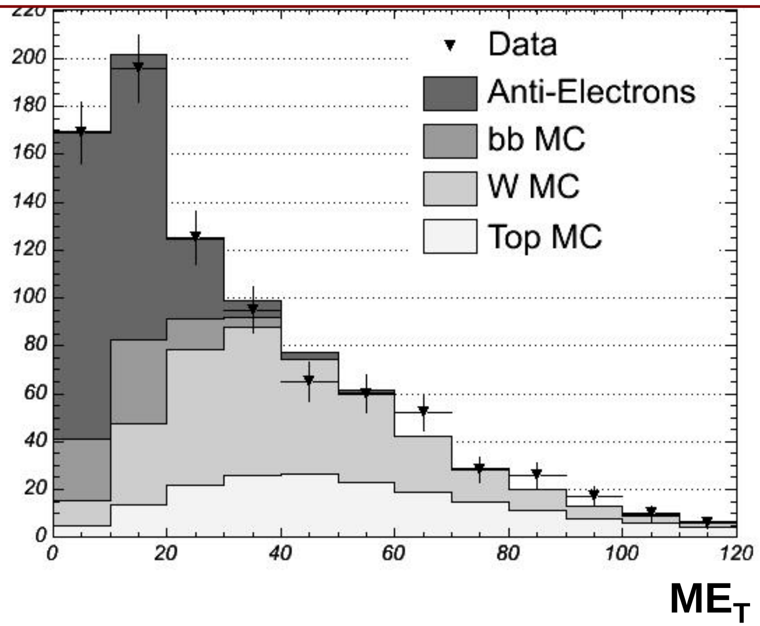
  - W+jets (W+HF, W+LF)

  } Theoretical cross section with large corrections

Non-W component

- **Non-W processes :**
  - have low missing E_T → use ME_T shape to estimate it
  - estimate as a fraction of total pretag events, $\mathbf{F^{non\text{-}W}}$
    - for each jet-bin, in each tagged bin
    - ttbar cross section fixed to SM expectation
    - Normalization of other processes left floating

Example: in 3-jet bin, ≥1 Loose



	1-jet	2-jet	3-jet	≥4-jet
F^{pre}_{non-W} (%)	9.7 ±0.1	16.2 ±0.1	20.1 ±0.3	20.8 ±0.9
Loose				
F^{tag}_{non-W} (%)	0.25 ± 0.01	1.2 ± 0.1	1.9 ± 0.1	2.3 ± 0.3
F^{2tag}_{non-W} (%)	-	0.05 ± 0.01	0.21 ± 0.05	0.38 ± 0.17
Tight				
F^{tag}_{non-W} (%)	0.19 ± 0.01	0.80 ± 0.02	1.4 ± 0.1	1.8 ± 0.3
F^{2tag}_{non-W} (%)	-	0.03 ± 0.01	0.09 ± 0.03	0.31 ± 0.12

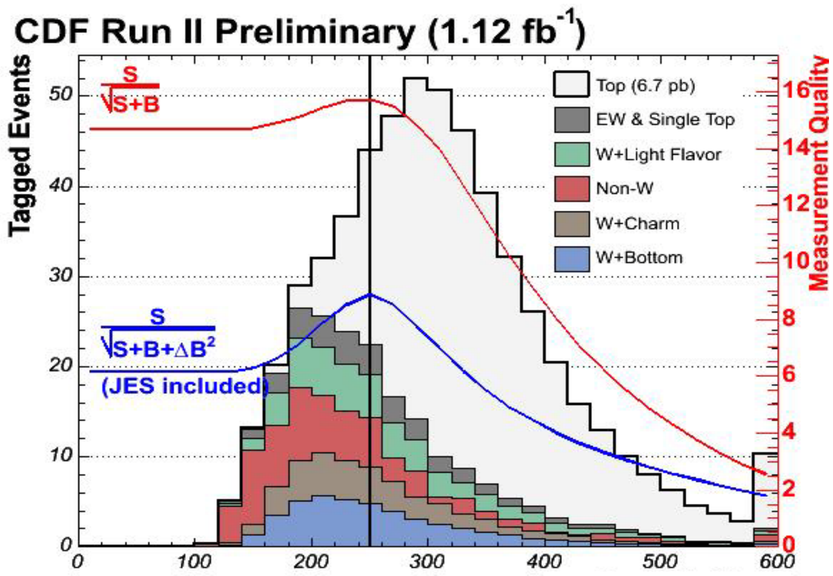
Chapter

Top Quark Properties

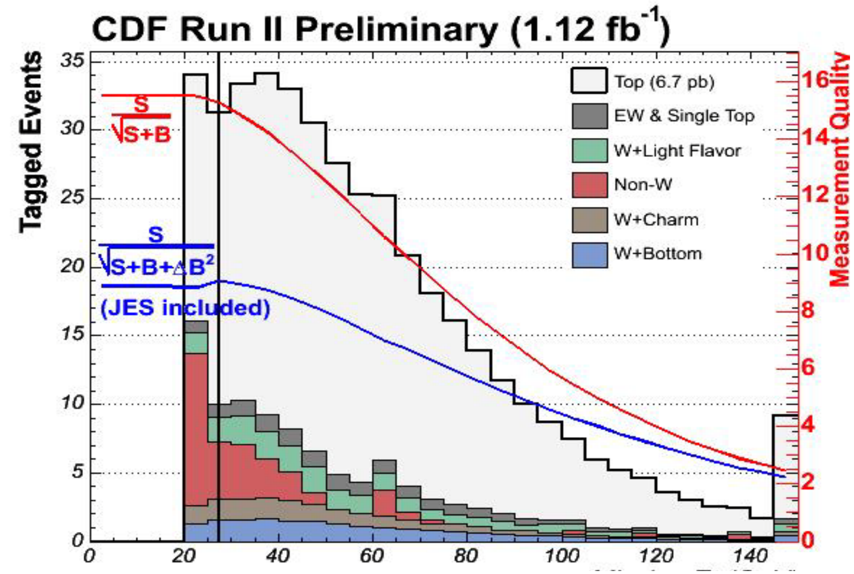
- **Production properties**
- **Intrinsic properties**
- **Decay properties**

Measuring the cross section

- First optimize cuts: example for ≥ secVtx tags.



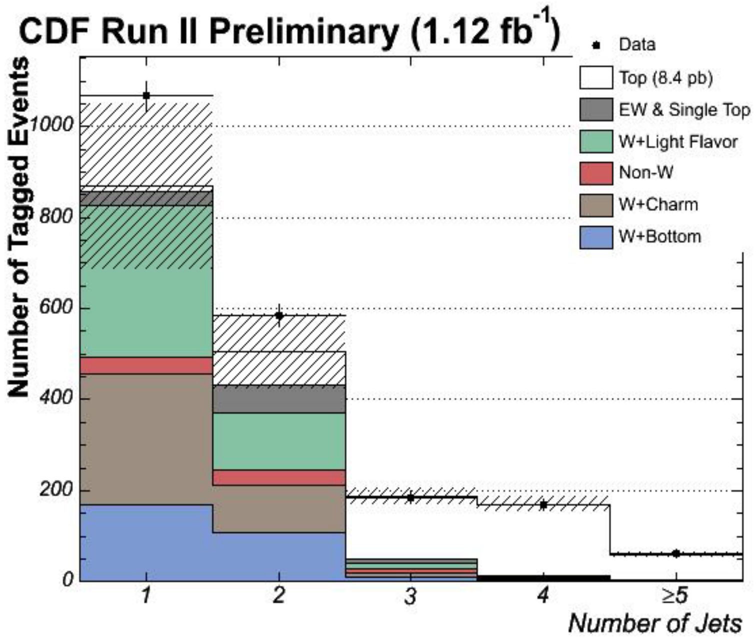
H_T

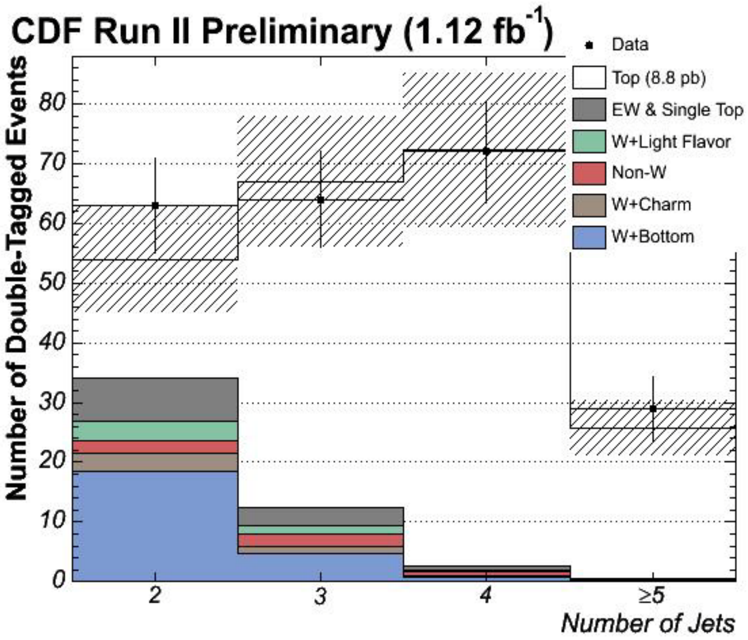


ME_T

- Measure the cross section
  - Assume $t\bar{t}$ production cross section, $\sigma_{t\bar{t}}$
  - Get backgrounds assuming $\sigma_{t\bar{t}}$
  - Measure a new $\sigma_{t\bar{t}}$ and iterate until convergence

Top Cross Section Results





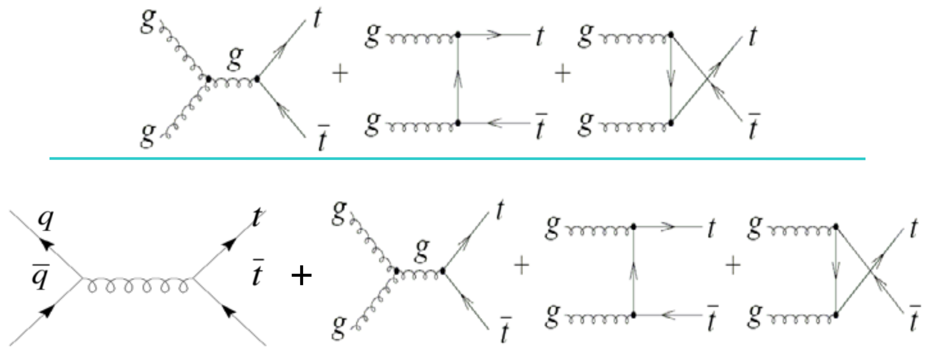
- **After statistical treatment to consider the iterative process**
  - ≥1 tight tag: σ=8.4 ± 0.6(stat) ± 0.9(syst) pb,
  - ≥2 tight tag: σ=8.8 ± 0.8(stat) ± 0.8(syst) pb,

Results obtained for a variety of cuts. i.e. with and without Ht, using secvtx or loose tags,etc.

$t\bar{t}$ Fraction Production Cross Section

- **Fraction of $t\bar{t}$ produced via gluon fusion to the total production**

$$G_f = \frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} =$$



- **SM expectations**

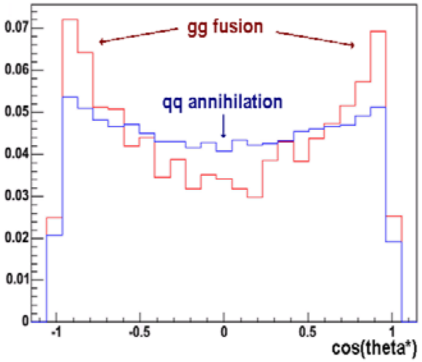
$$G_f = \frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} = 0.15 \pm 0.05, \qquad \frac{\sigma(qq \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} = 0.85 \mp 0.05$$

  - With large errors due to parton density functions (PRD 68, 114014 & J. High Energy Phys. 0404, 068)
  - Processes with <u>different kinematic characteristics.</u>

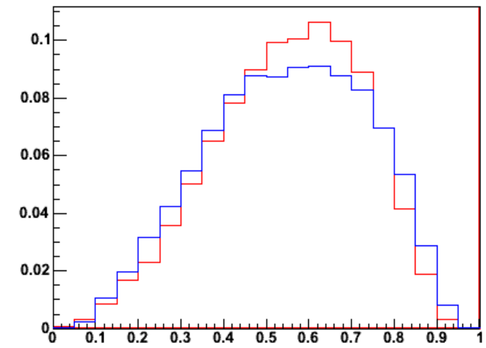
Kinematic properties

- **Production in $t\bar{t}$ rest frame depends only on:**
  - β: the top velocity relative to c.
  - cos(θ*): angle between the top and the right incoming parton.

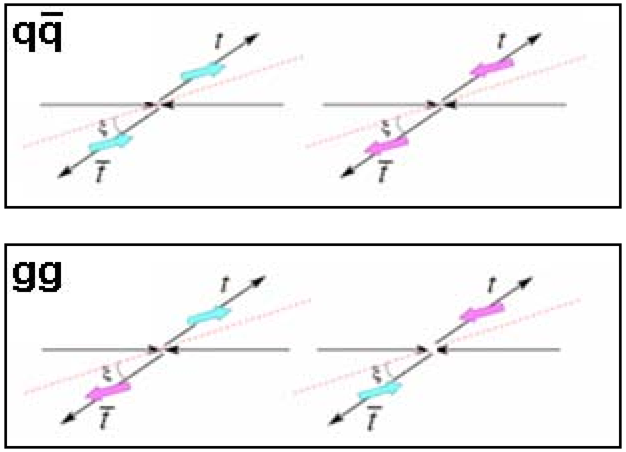
cos(Θ*)



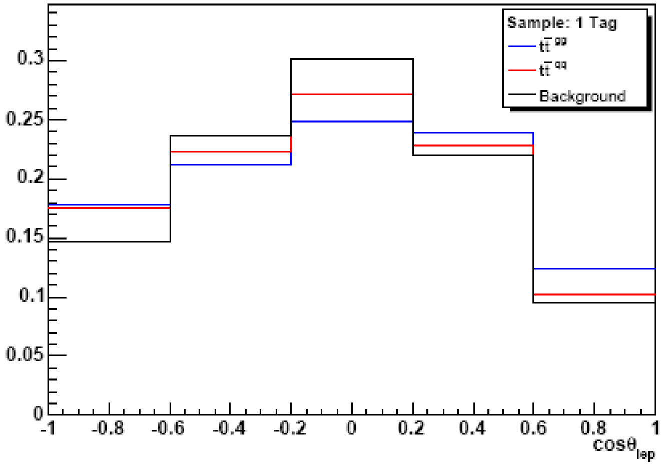
β



- **Decay includes spin correlations**
  - Define off-diagonal basis (Phys. Lett. B 387,199 & Phys. Lett. B 411,173)
  - Many discriminators: e.g. angle between lepton and off-dia axis in top r.f

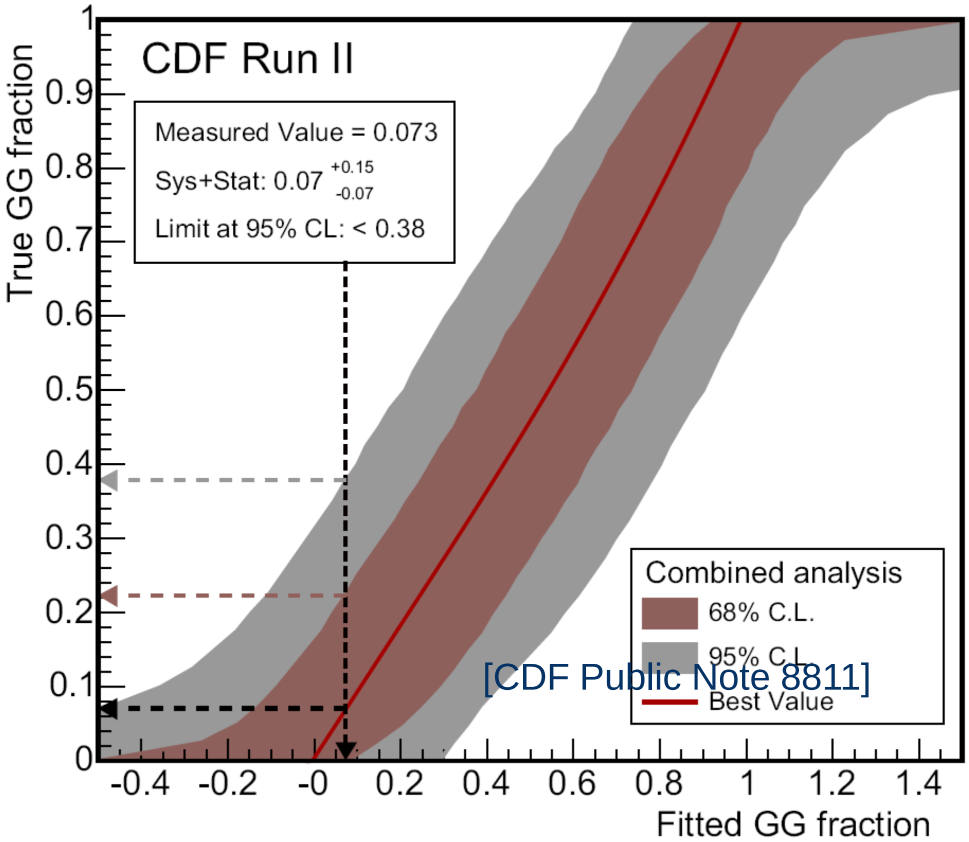


cos(Θ_{lep}*)



Top Production: Results

- **Results**
  - Find the ratio of the gg-produced to the total tt events $F_{GG} = \frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})}$



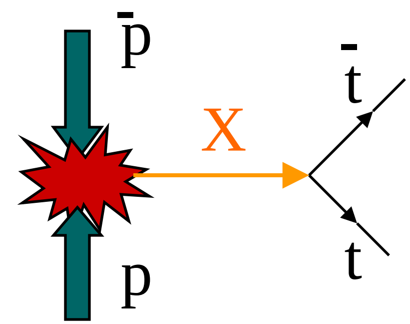
[CDF Public Note 8811]

F_{GG} < 0.07+0.15-0.07

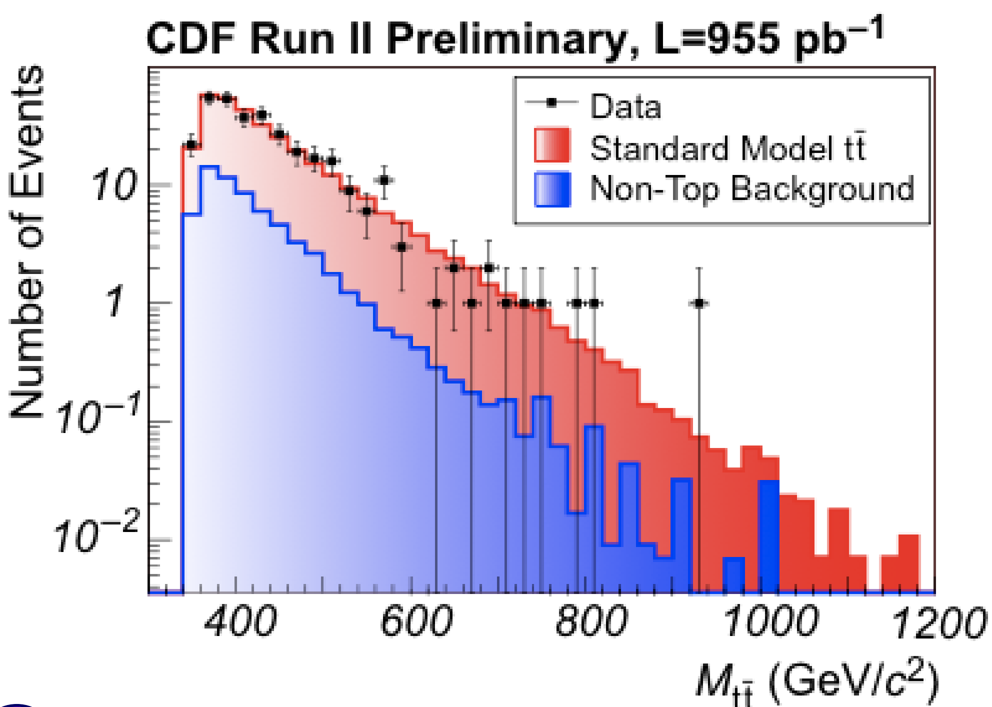
F_{GG} < 0.38 @ 95% C.L.

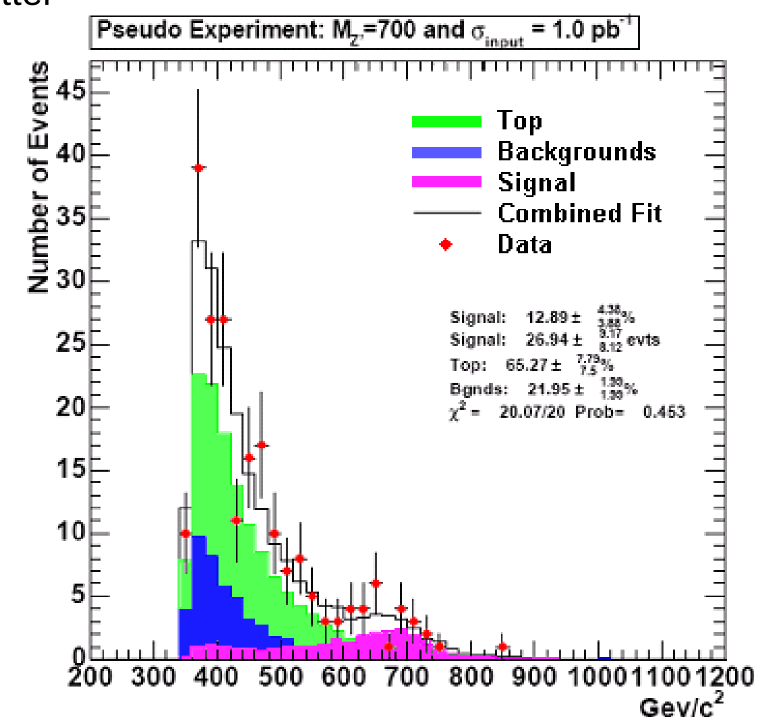
Search for $t\bar{t}$ resonances

- **Production**
  - top quark pairs can be produced by decays of heavy particles.
  - Possible in Topcolor-assisted technicolor
    - Heavy particle (Z') couples strongly to 3rd generation,
    - Heavy particle does not couple to leptons



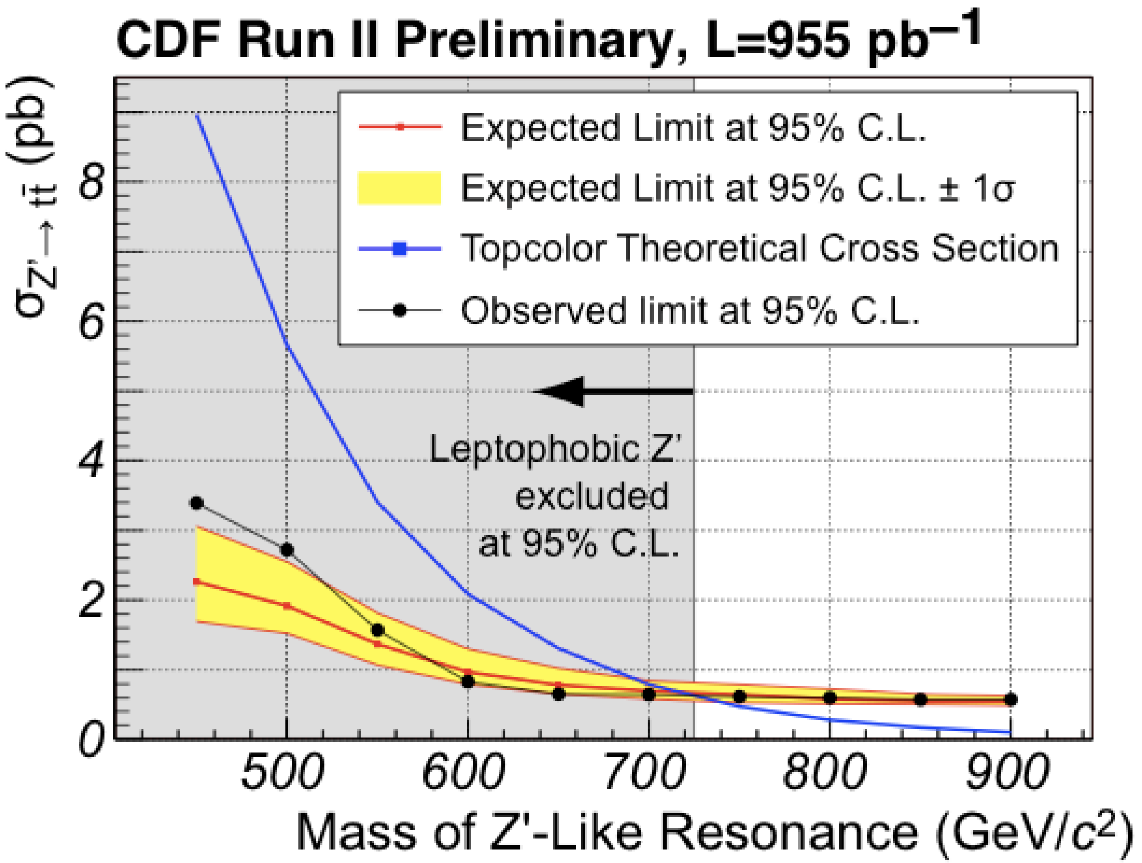
- **Analysis** [CDF Public Note 8675]
  - Reconstruct mass of $t\bar{t}$ system using kinematic fitter





Search for $t\bar{t}$ resonances:Results

- Set limits on leptophobic Z' mass



$M_{Z'}$>725 GeV @ 95% C.L.

Top Quark Properties

- Production properties
- Intrinsic properties
- Decay properties

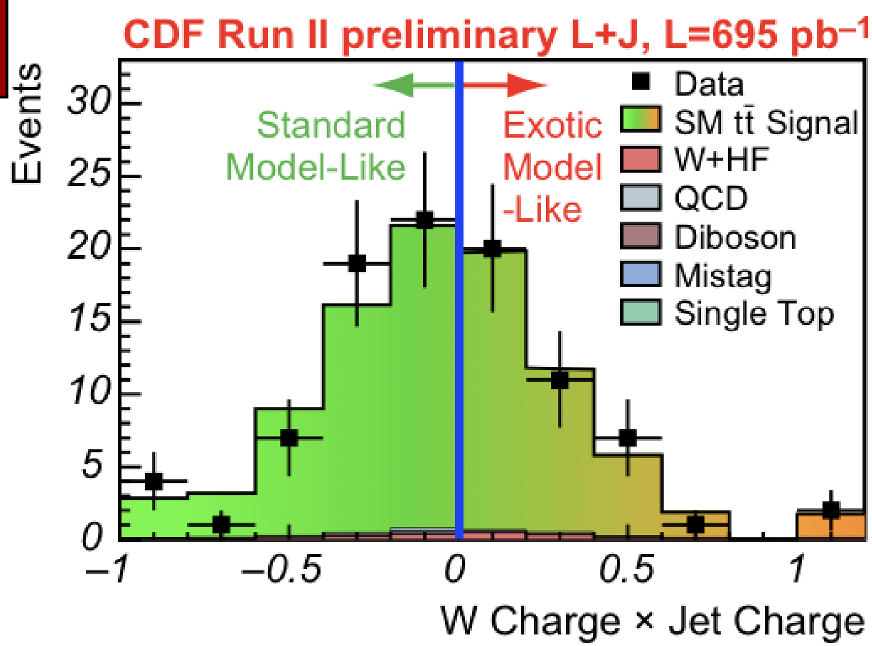
Top Charge measurement

- **Standard Model**
  - predicts Q_{top} = 2/3 e
- **Exotic model:**
  - Observed “top” could be part of exotic quark doublet with charge (–1/3e,–4/3e)
  - Predicts true top mass: 258 GeV/c2
  - Assuming exotic model improves electroweak fits

  See [D. Chang et al., Phys. Rev. D59 (1999) 091503] for details

Top Charge Measurement: distinguish Q_{top} between 2/3e and -4/3e

Top Charge: 2/3e or –4/3e?



- **Counting experiment:**
  - Both Lepton+Jets & Dilepton datasets
  - 62 Standard Model-like events
  - 48 exotic model-like events

Statistical Treatment: Hypothesis Test

- Null hypothesis: SM is correct
- Decide *a priori*: probability of incorrectly rejecting SM: $\alpha = 0.01$
- If nature followed exotic model: 81% of all measurements would return p-values below 0.01 under SM hypothesis
- Measured p-value: 0.35, i.e. larger than α

→ data consistent with SM

→ exotic model excluded at 81% C.L.

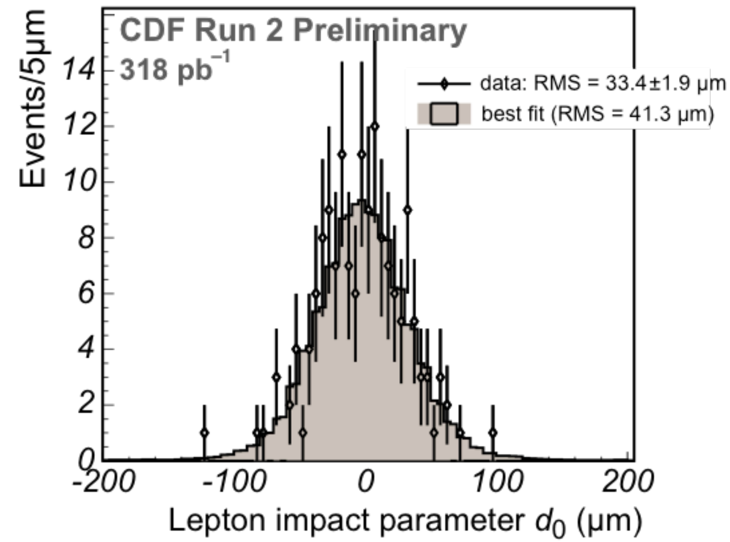
P-value: Probability that measurement results in the measured value or worse, given a hypothesis.

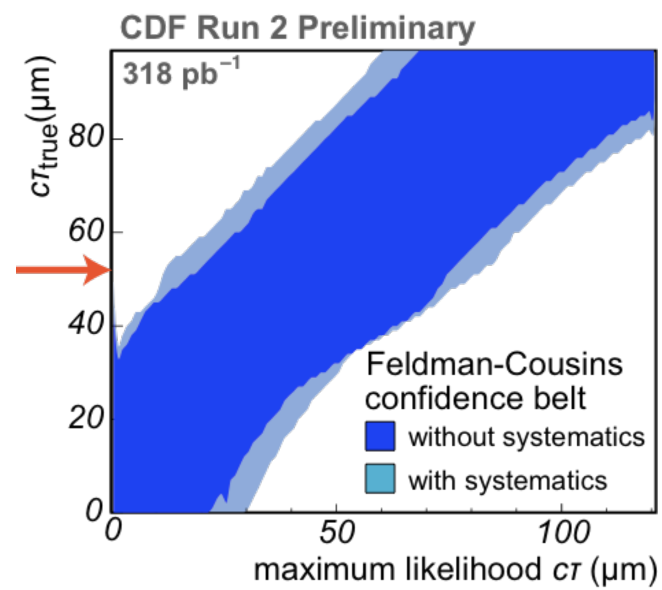
Top Lifetime

- **Top lifetime in the Standard Model**
  - Expected lifetime: < 10^{-24} s
  - Constrained by unitarity of CKM matrix, but no direct measurements so far
- **First direct measurement at CDF**
  - 318 pb^{-1}, Lepton+Jets sample
  - Measure lepton impact parameter d0
  - Calibrate impact parameter resolution in data with leptons from γ*/Z decays
  - Create templates for signal & background
- **Results:**
  - Maximum likelihood: cτ = 0 μm
  - Feldman-Cousins limit including systematics:

cτ < 52.5 μm at 95%C.L.

[CDF Public Note 8104]



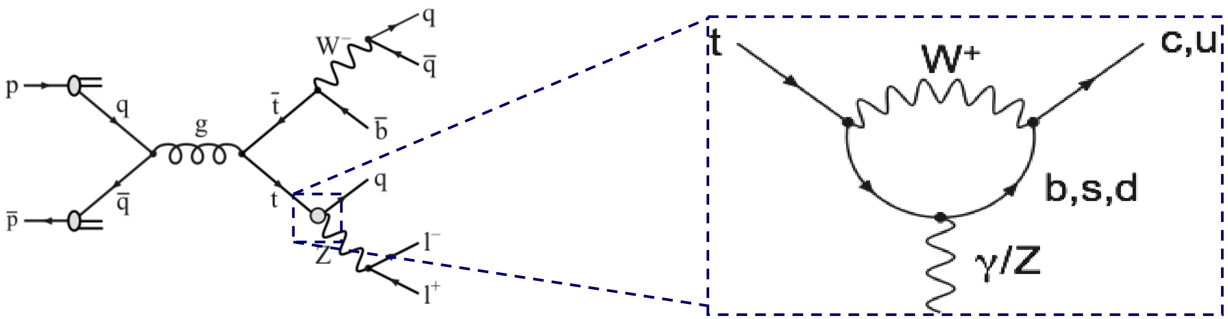


Top Quark Properties

- Production properties
- Intrinsic properties
- Decay properties

Flavor Changing Neutral Currents

- No Flavor Changing Neutral Currents (FCNC) at tree level in the SM.



- **FCNC are allowed at higher orders, but heavily suppressed**
  - Suppression by GIM mechanism
    - Penguin matrix element depends on universal functions of single parameter $x_i = m_i^2/m_W^2$

$$\mathcal{M} \propto F(x_d)\, V_{cd}^* V_{td} + F(x_s)\, V_{cs}^* V_{ts} + F(x_b)\, V_{cb}^* V_{tb},$$

    - Exact cancellation if masses of b, s, and d quarks were the same
    - Top FCNC more strongly suppressed than bottom FCNC: BR($t \to Zq$) ≈ 10^{-14} Vs. BR($b \to s\gamma$) ≈ 10^{-4}
  - Suppression by CKM elements:

$$|V_{cd}^* V_{td}| \approx 0.002,\ |V_{cs}^* V_{ts}| \approx 0.04,\ |V_{cb}^* V_{tb}| \approx 0.04$$

- **Expected Signature : l^+l^- + 4 jets**

Beyond SM models predict branching ratios up to $O(10^{-2})$…

Kinematic Constraints: Optimization

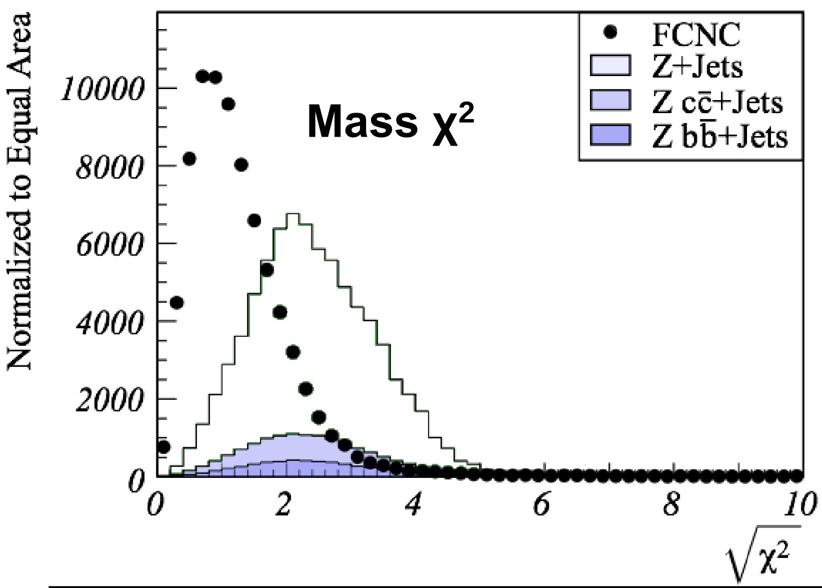
- **Kinematic χ2: combination of mass constraints – best discriminator**

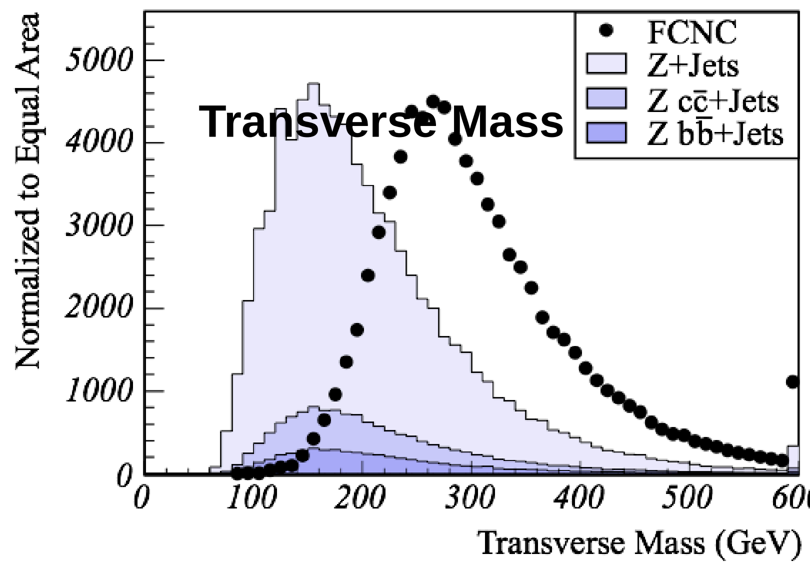
$$\chi^2 = \left(\frac{m_{W,rec} - m_{W,PDG}}{\sigma_{W,rec}}\right)^2 + \left(\frac{m_{t\to Wb,rec} - m_{t,PDG}}{\sigma_{t\to Wb}}\right)^2 + \left(\frac{m_{t\to Zq,rec} - m_{t,PDG}}{\sigma_{t\to Zq}}\right)^2$$

- **Transverse mass: FCNC top decays are more central than Z+jets**

$$M_T = \sqrt{\left(\sum E_T\right)^2 - \left(\sum \vec{p}_T\right)^2}$$

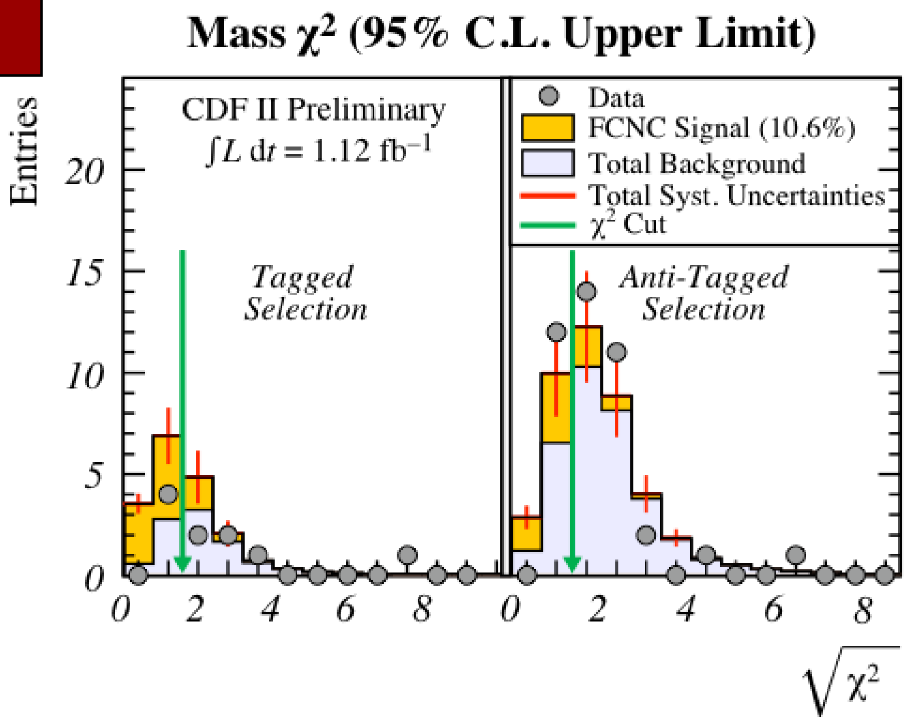
- **Jet transverse energies: FCNC signal has four "hard" jets, background processes: jets have to come from gluon radiation**





Optimization in (anti) tag sample: X^2<1.35 (<1.6), M_T>200 GeV

Top FCNC Search: Results



Mass χ^2 distributions for the two signal regions. The arrows indicate the optimal cuts on χ^2. The expected FCNC signal at the measured upper limit is overlaid.

- **Unblinding after optimization: observed numbers events consistent with background**

Selection	Observed	Expected
Base Selection	141	130±28
Base Selection (Tagged)	17	20±6
Anti-Tagged Selection	12	7.7±1.8
Tagged Selection	4	3.2±1.1

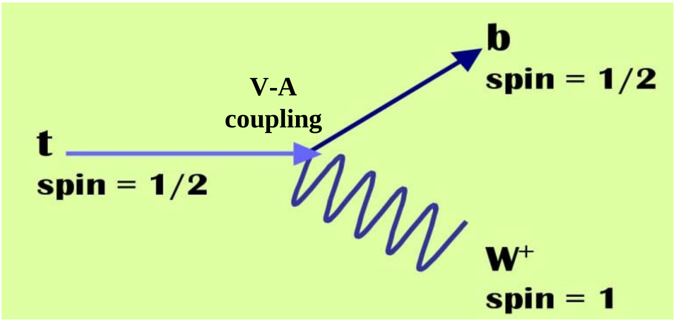
- **Feldman-Cousins upper limit for two signal regions including systematics:**

B(t→Zq) < 10.6% @ 95% C.L.

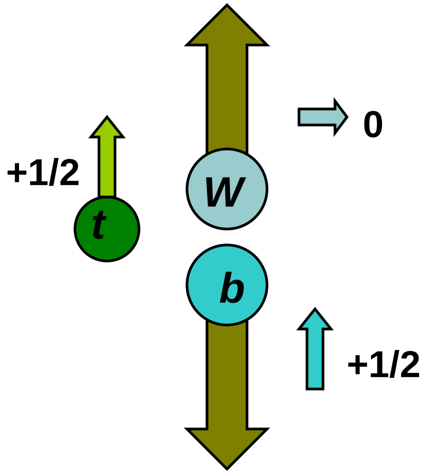
- **New world's best limit, improves previous limit (13.7% @ L3) by 25%**

W helicity from t→Wb decays

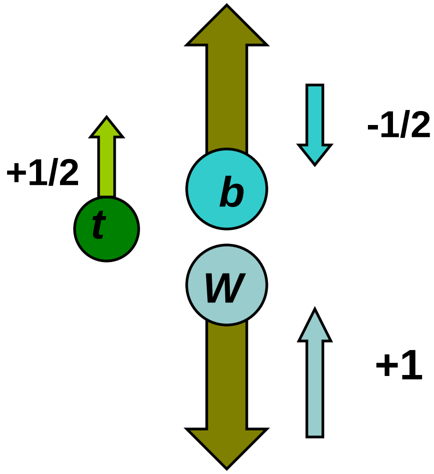
- Examines the nature of the tWb vertex, **probing the structure of weak interactions at energy scales near EWSB**
- **Stringent test of Standard Model and its** V-A **type of interaction.**



W_0 Longitudinal fraction F_0

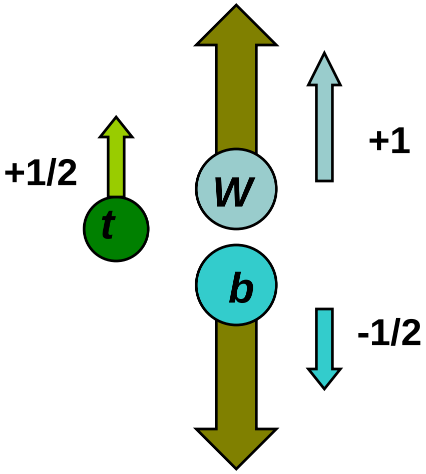


W_- Left-Handed fraction F_-



Suppressed

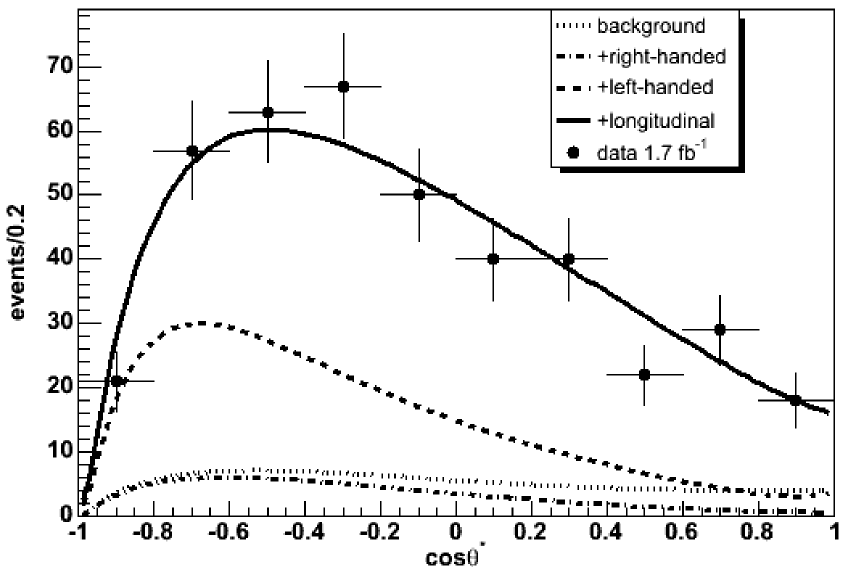
W_+ Right-Handed fraction F_+

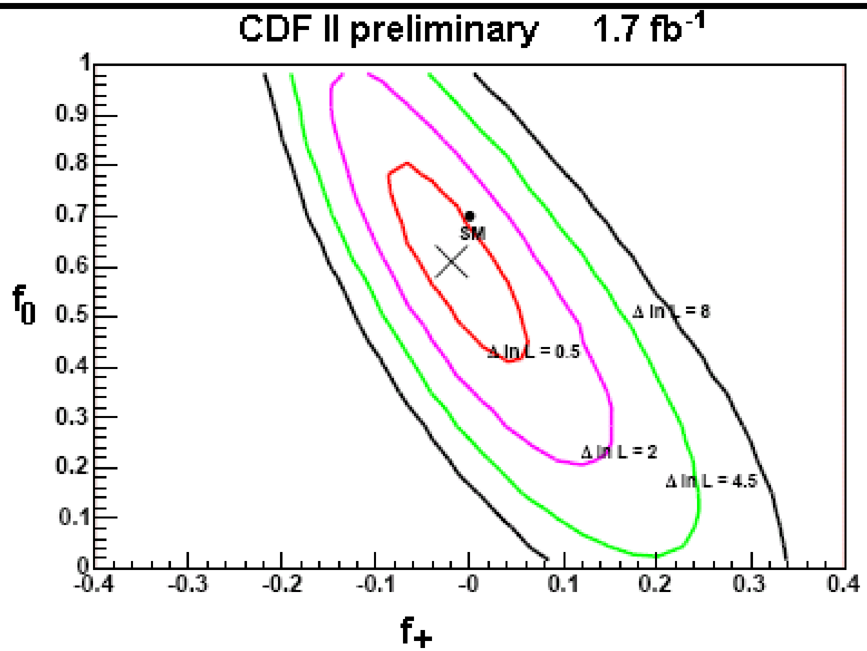


W helicity : Longitudinal Fraction

- **Template fits for f_0, $f_{+.}$ Lepton+jet channel: 407 events, 1.7 fb^{-1}**

CDF II preliminary. 1.7 fb^{-1}





$f_0 = 0.57 \pm 0.11(stat) \pm 0.04(syst)$

$f_+ = -0.04 \pm 0.04(stat) \pm 0.03(syst)$

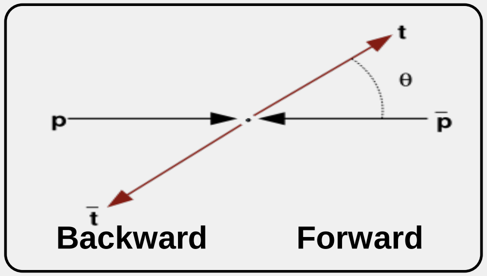
$f_0 = 0.61 \pm 0.20(stat) \pm 0.03(syst)$

$f_+ = -0.02 \pm 0.08(stat) \pm 0.03(syst)$

Top Properties: Other Measurements

Forward–Backward asymmetry

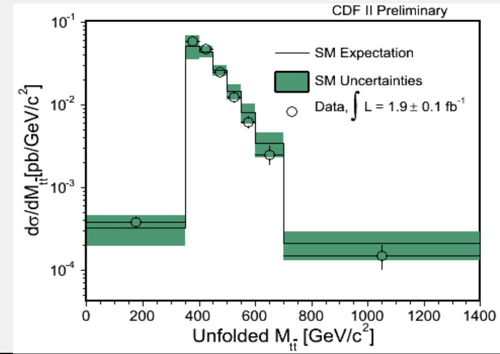
$$A_{fb} = \frac{N_{(-Q_\ell)\cdot Cos\Theta>0} - N_{(-Q_\ell)\cdot Cos\Theta<0}}{N_{(-Q_\ell)\cdot Cos\Theta>0} + N_{(-Q_\ell)\cdot Cos\Theta<0}}$$



Is the Top really the Standard Model Top?

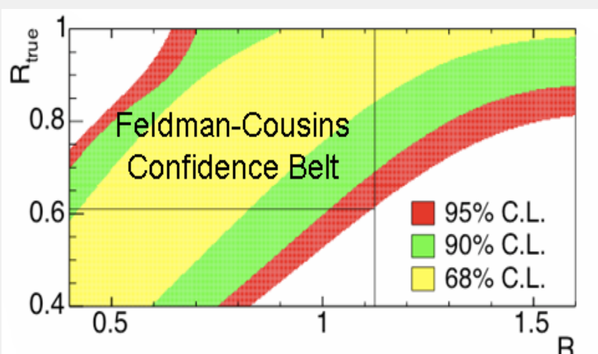
Differential cross section

$$\frac{d\sigma^i}{dM_{t\bar{t}}} = \frac{N_i - N_i^{bkg}}{\mathcal{A}_i \int \mathcal{L}\Delta^i_{M_{t\bar{t}}}}$$

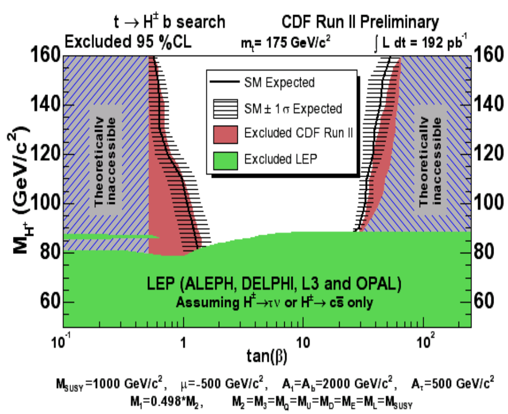


Measurement of |Vtb|

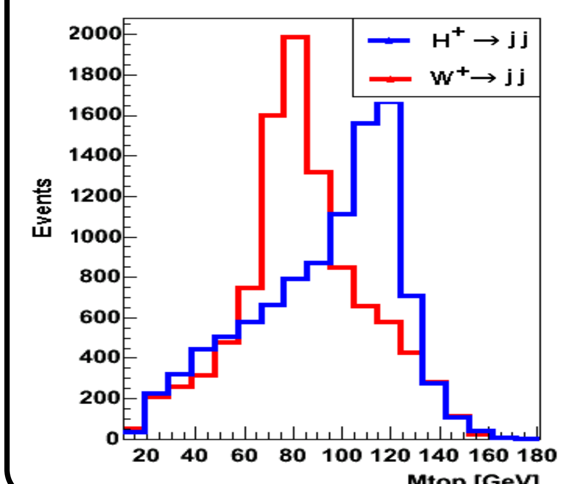
$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$



Search for Charged Higgs Limits on B(t→H⁺b)



Limits on BR(t→H⁺b), H⁺→cs̄



Chapter

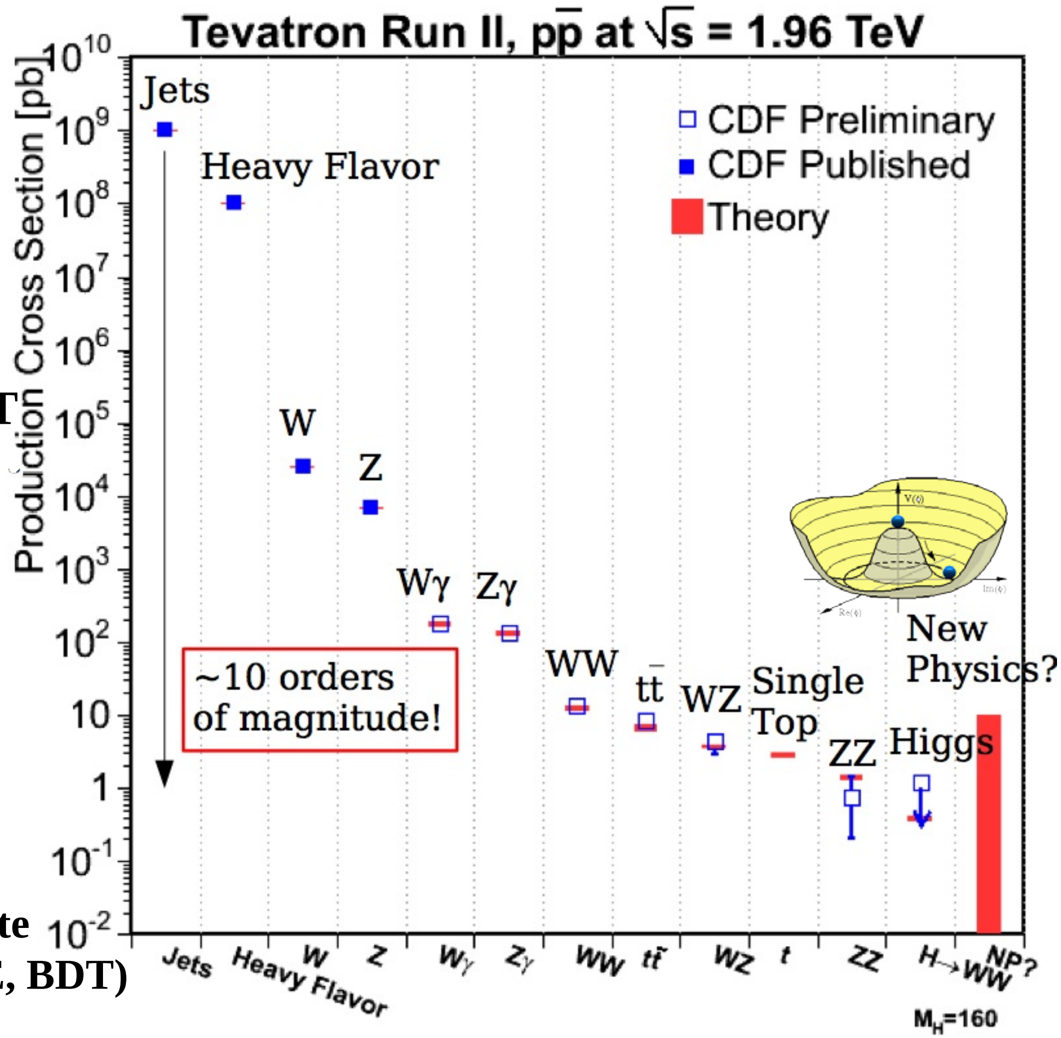
Searching for the Higgs boson at CDF

The Challenge

- Higgs production is a very rare process at the Tevatron
- Before doing anything S:B ~ 1:10^{10}
- *First step:*
  Trigger and ID clean leptons/MET
  Improves S:B by ~ 10^6

  High p_T e,μ triggers
  MET + Jets triggers
  Track + MET + Ecal τ-trigger

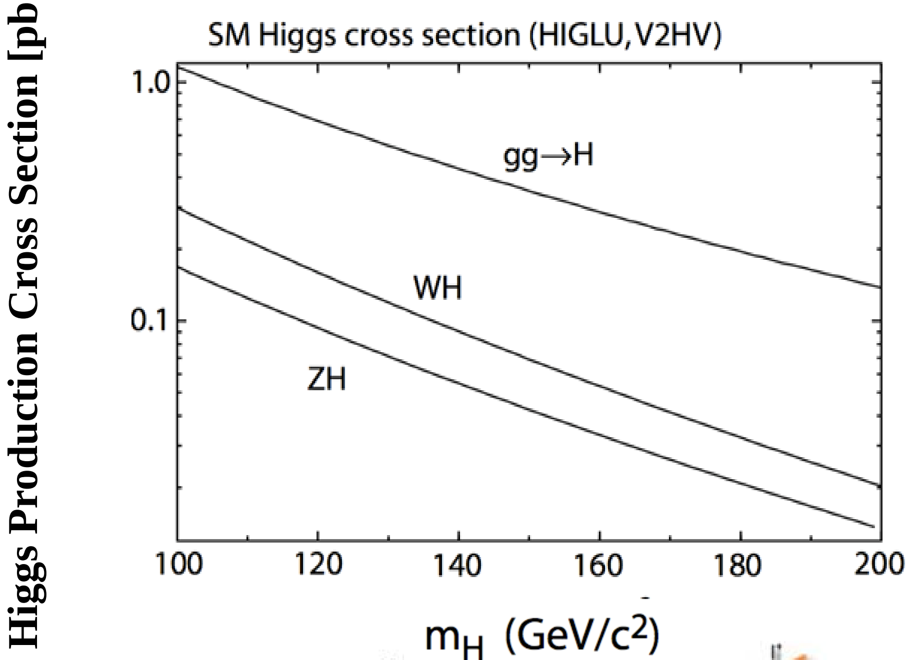
- *Second step:*
  - -Efficient b-tagging
  - -Careful background estimates
  - -Advanced analysis tools to separate signal from background (NN, ME, BDT)



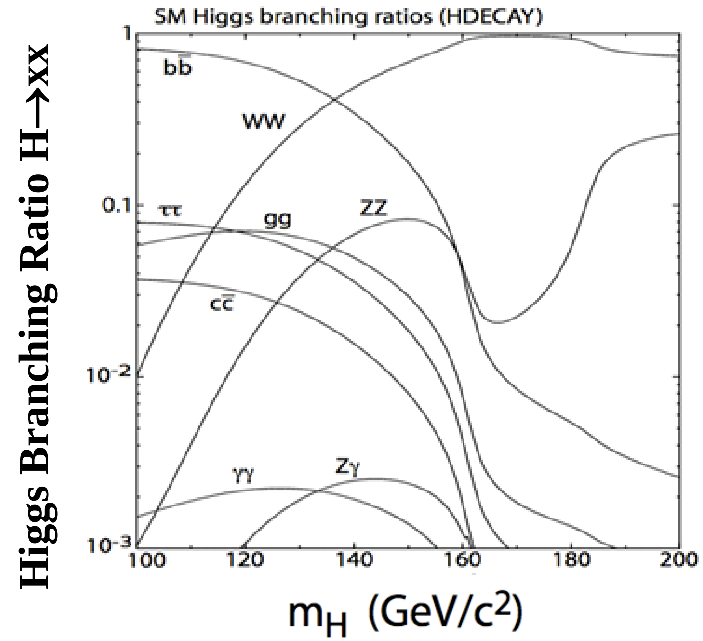
Other rare processes (dibosons, single top) are being measured at CDF and D0 and serve as excellent testing ground for new analysis techniques

Higgs Production and Decay

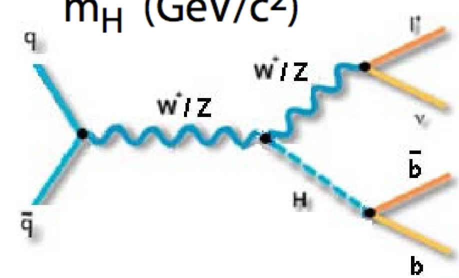
Production



Decay

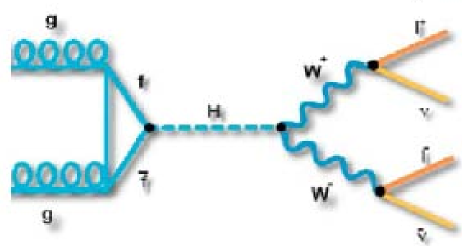


Low mass Higgs:
(m_H < 135 GeV/c²)



- Higgs goes mostly to b's
- Identification of b-jets (or τ's)
- gg→H→bb̄ swamped by background
- detect associated W or Z: leptons, MET

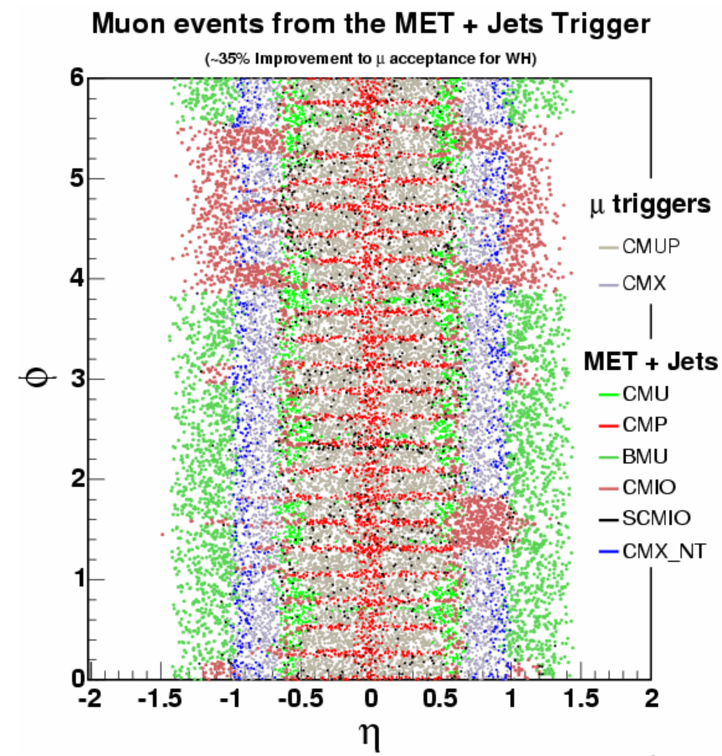
High Mass Higgs:
(m_H > 135 GeV/c²)



- H→WW→llbb̄
- backgrounds low enough to use gg->H
- signature: leptons and MET

$WH \rightarrow l\, \nu\, b\, b$

- **Using multivariate techiques**
  - Used in all CDF analyses
- **Functions which transform multiple inputs into single discriminant , tuned for identifying a single process**
  - NN = Neural Net
  - ME = Matrix Element
  - BDT = Boosted Decision Trees



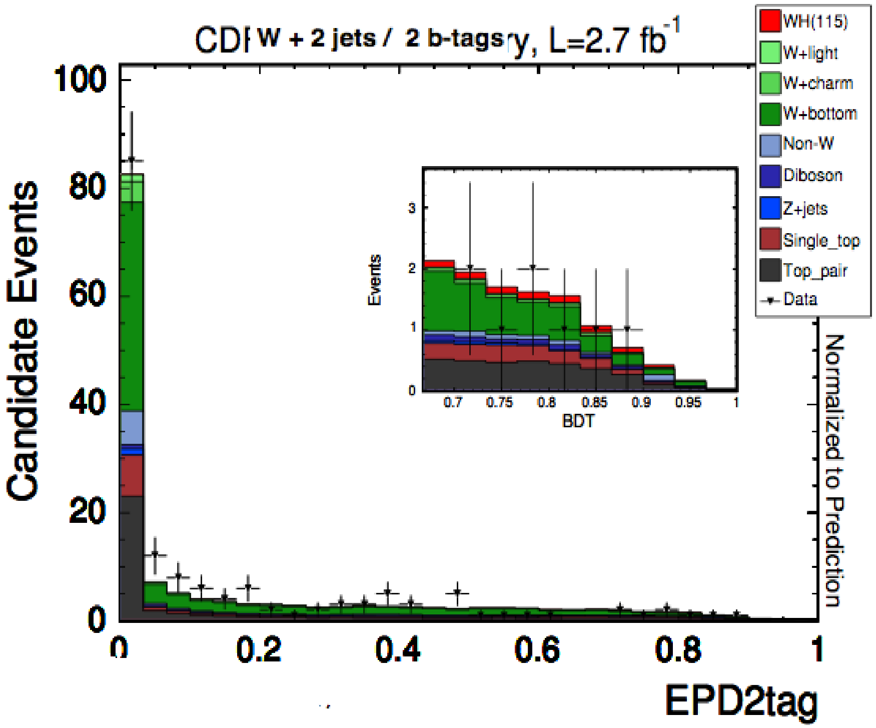
- Highlights

-

- **Loose double tagging**
- **Lepton ID with isolated tracks/extended muons**
- **NN discriminator**
- **ME+BDT (LO+NLO)**

$WH \rightarrow l\ \nu\ b\ b$

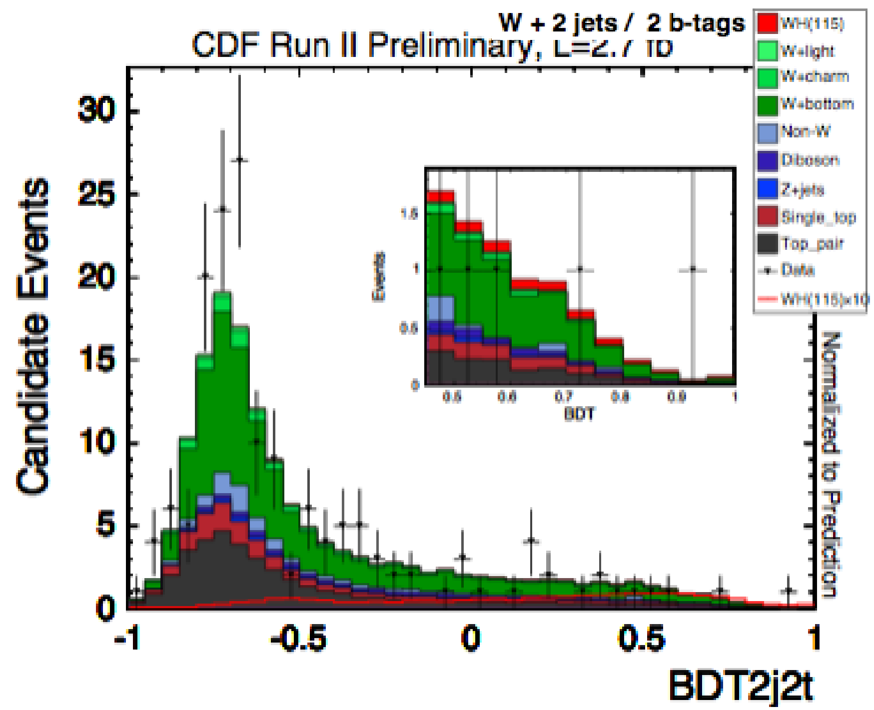
Matrix Element (ME) discriminant



background ← → signal

ME approach good in capturing Leading Order discrimination

ME + Boosted Decision Trees (ME+BDT)



background ← → signal

Add other kinematic event variables to ME in a BDT to capture Next to Leading Order effects

Summary of low-mass analyses

- **Observed (and expected) limits for $m_H = 115\ GeV/c^2$**

Channel	CDF 95% C.L. Limits $\sigma \cdot BR/SM$ obs (exp)
$WH \to l\nu bb$ (NN)	5.0 (5.8) $2.7 fb^{-1}$
$WH \to l\nu bb$ (ME+BDT)	5.7 (5.6) $2.7 fb^{-1}$
$WH \to qqbb$ (ME)	37.0 (36.6) $2.0 fb^{-1}$
$ZH \to llbb$ (NN)	11.6 (11.8) $2.7 fb^{-1}$
$ZH \to llbb$ (ME)	14.2 (15.0) $2.7 fb^{-1}$
$VH \to \nu\nu/(l)bb$ (NN)	7.9 (6.3) $2.7 fb^{-1}$
$H \to \tau\tau$	30.5 (24.8) $2.2 fb^{-1}$

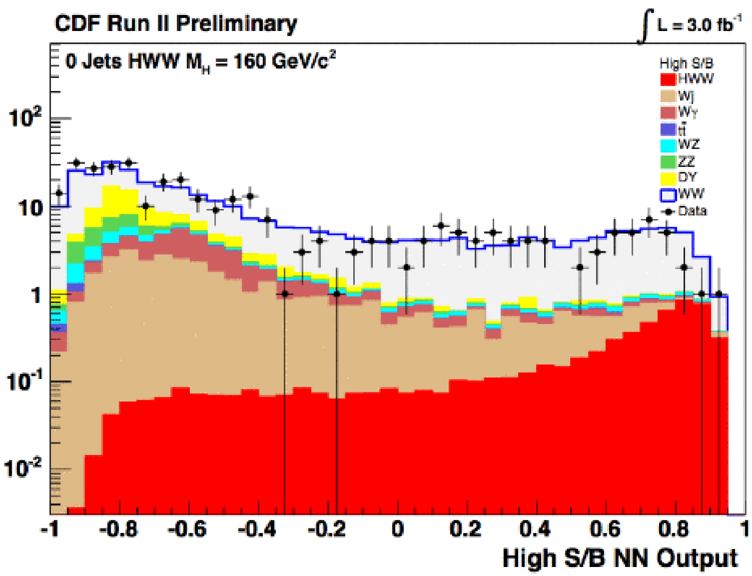
High Mass: H→WW

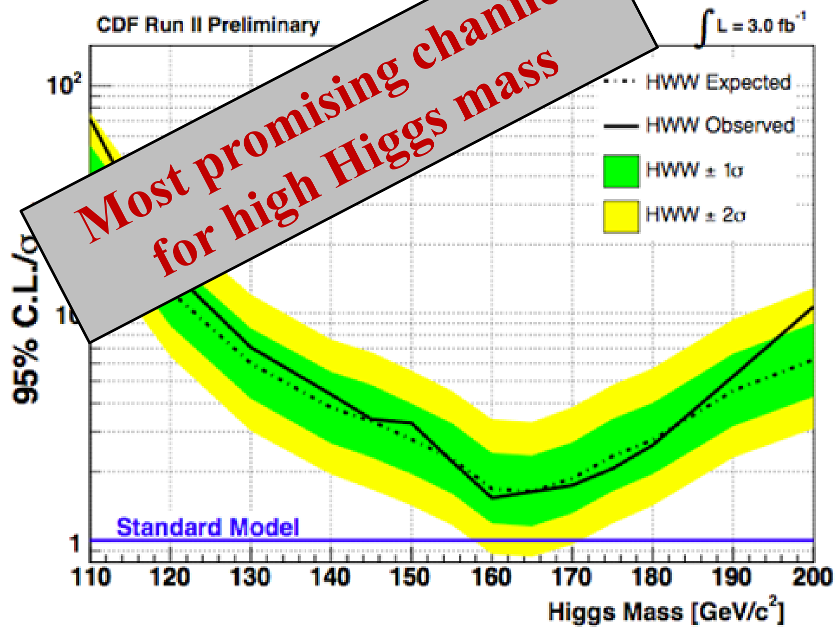
- Background composition strongly depend on the jet- bin

# jets	H→WW events	Total Bkg events	% WW	% Drell-Yan	% tt	% fakes & conversions
0	8	540	52	12	0.2	30
1	5	230	32	31	11	16
2	4	130	12	22	54	8

- Gain sensitivity by using three analyses optimized fo[...] bin

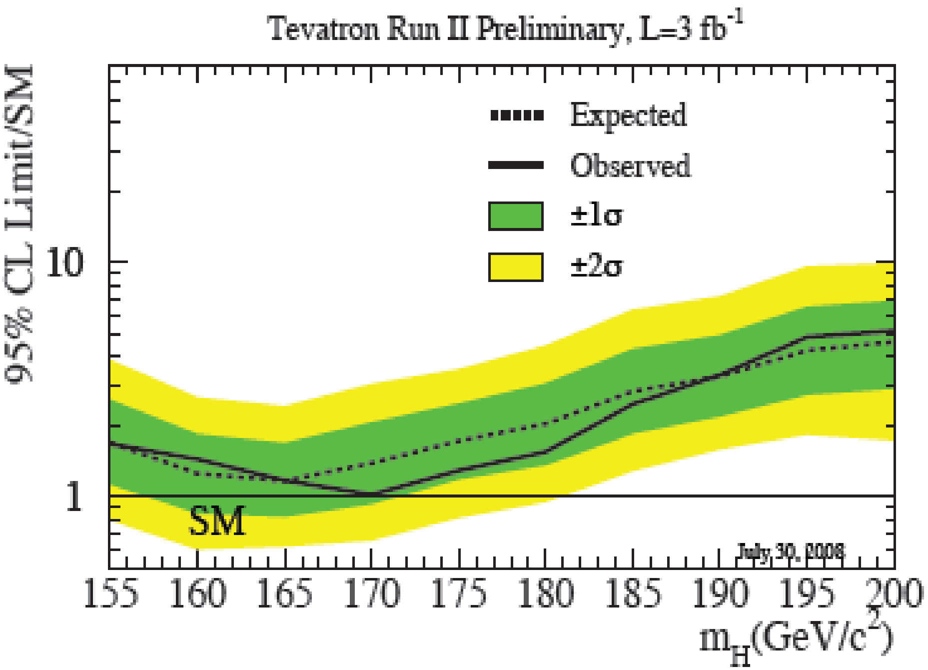
Most promising channel for high Higgs mass

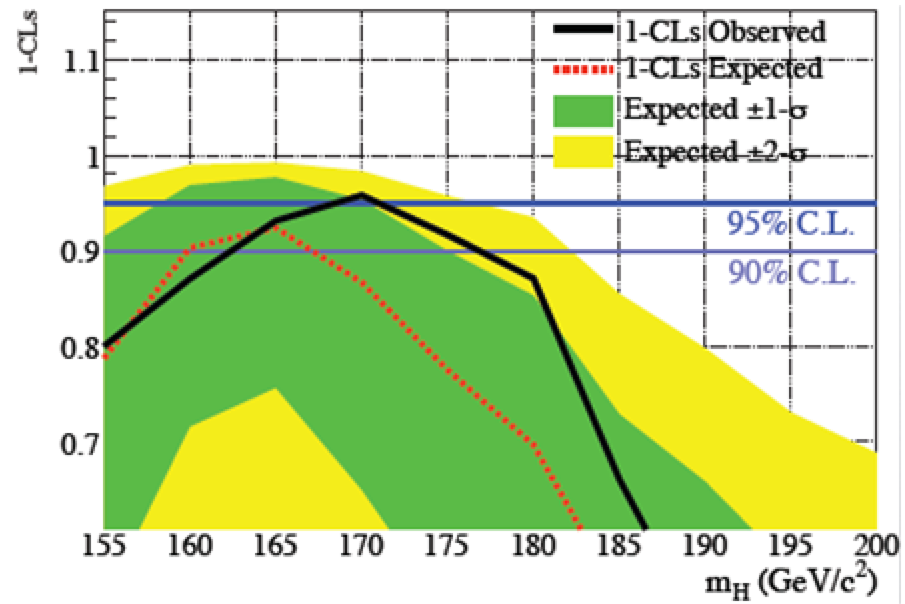




Combine CDF and D0 's results

- **Use two different methods to verify accuracy**
  - Method 1 : CLs by D0
  - Method 2 : Bayesian by CDF - expected to be more conservative.





- **Results are consistent :**

mH at 170 GeV ruled out at 95% CL

Chapter

Summary

Summary

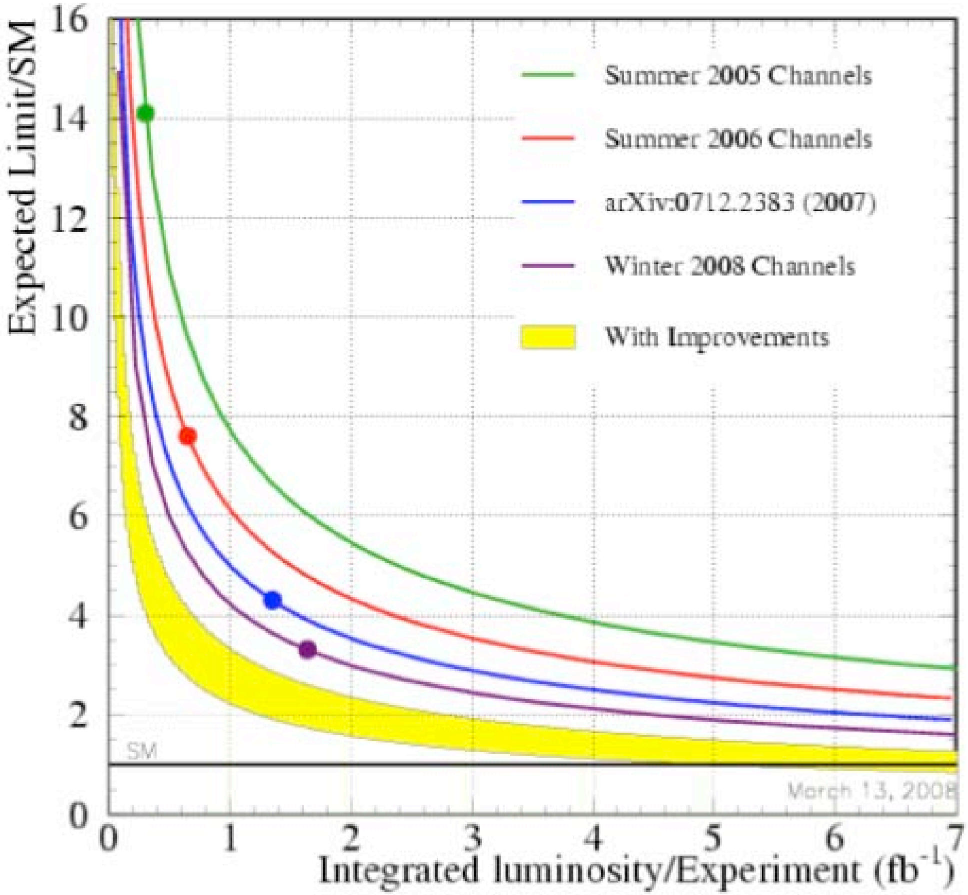
- **CDF is seriously focused on exhaustive measurements of top properties and Higgs bosons.**
- **Many more analyses ongoing**
  - $B(t \rightarrow H^+b)$, with H^+ decaying to specific channels.
  - Top Spin correlations, searches for $t' \rightarrow Wq$

So far, no departure from SM expectations in the top sample

- **Higgs searches, exciting times :**
  - Starting to rule out high Higgs masses
  - Higgs analyses are very mature
  - Much more data on tape
- **Uncertainties are beginning to shrink…**

More and more we are putting the SM to the test!

Projections



- **Details on each Higgs analysis is available at:**
  - **CDF: http://www-cdf.fnal.gov/physics/new/hdg/hdg.html**
  - **D0: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm**

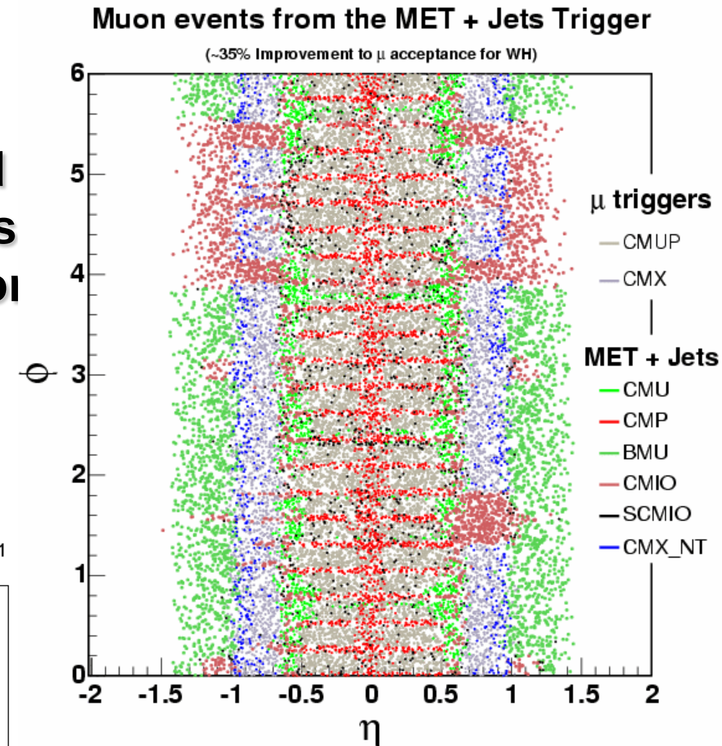
Backup slides

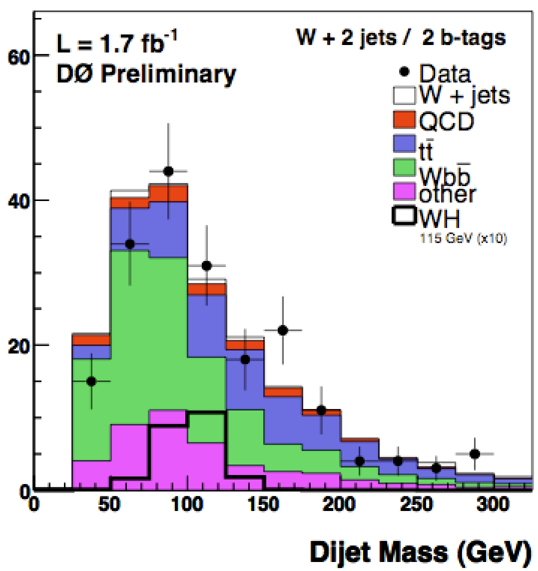
$WH \rightarrow l\,\nu\,b\,b$

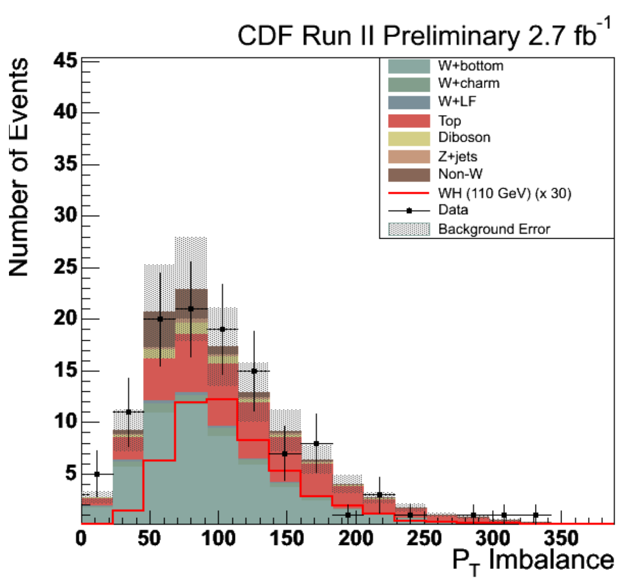
- 1 lepton+MET+ 2 b jets
- About 3-4 evts / $1fb^{-1}$
- ***Most sensitive channel***

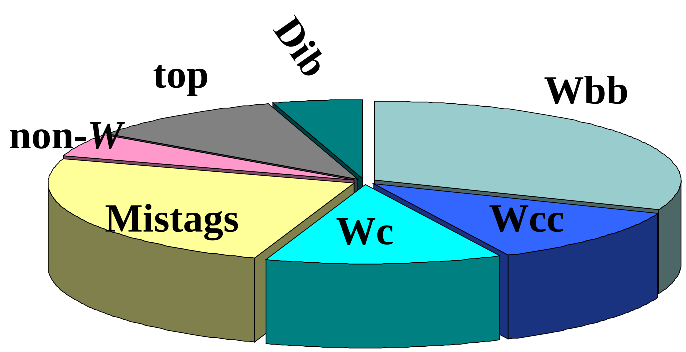
- Highlights -

- Loose double tagging
- Lepton ID with isolated tracks/extended muons
- NN Jet Flavor Separator for single tag events
- NN discriminator
- ME+BDT (LO+NLO)









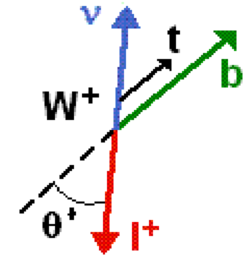
W helicity from t→Wb decays

- **In general, the θ^* distribution of top decays in the W rest frame is**

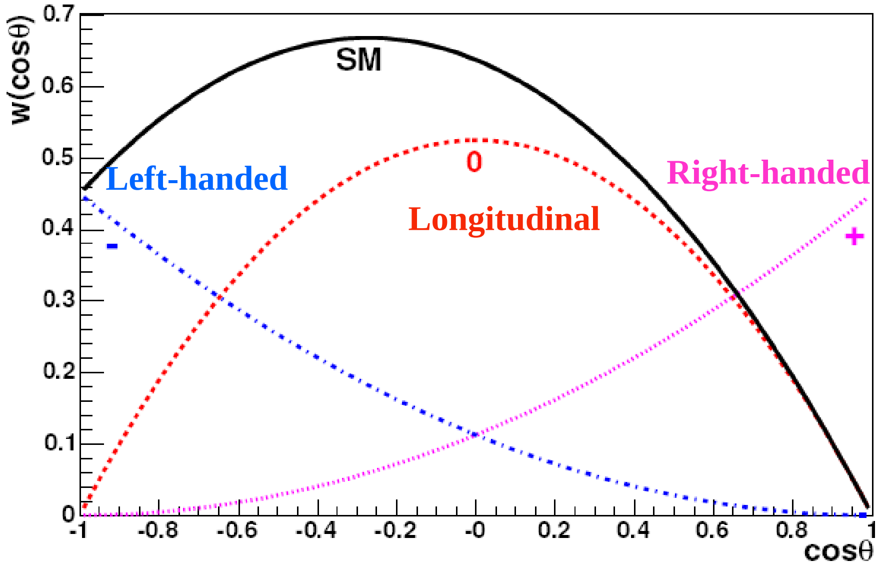
$$w(\cos\theta^*) = F_- \cdot \frac{3}{8}(1-\cos\theta^*)^2 + F_0 \cdot \frac{3}{4}(1-\cos^2\theta^*) + F_+ \cdot \frac{3}{8}(1+\cos\theta^*)^2$$

where $F_-+F_0+F_+\equiv 1$

W rest frame



- **In the Standard Model** : $F_-= 0.3$ $F_0= 0.7$ $F_+\approx 0$ ***(exact when m_b=0)***

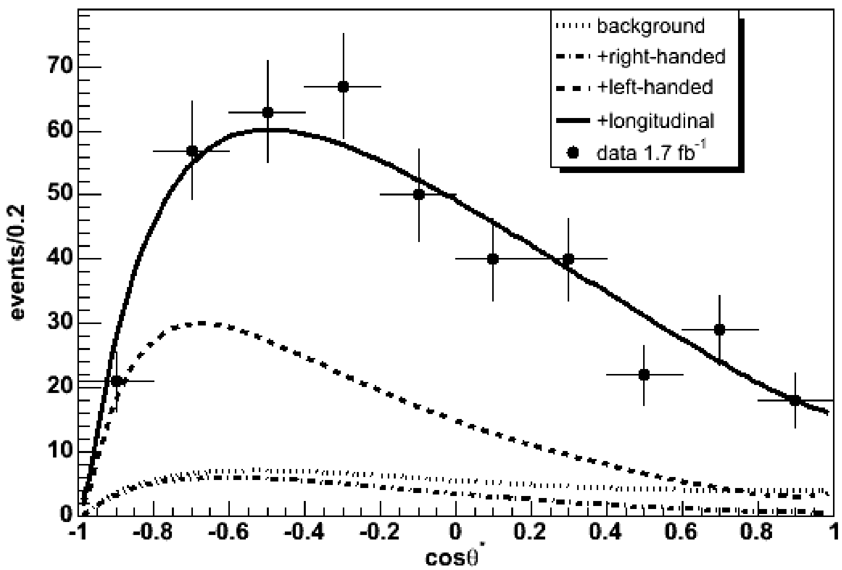


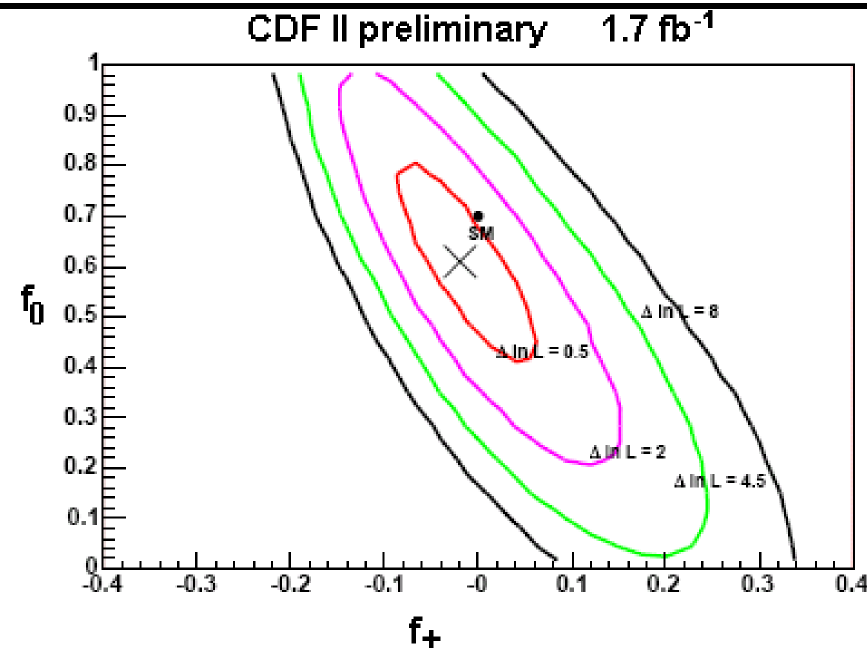
- **The different W helicities result in different P_T spectrums**
  - **left-handed**: leptons are emitted opposite to W boson (**softer lepton P_T**)
  - **longitudinal**: leptons are emitted perpendicular to the W (**harder lepton P_T**)
  - **right-handed**: leptons are emitted parallel to W boson (**hardest lepton P_T**)

W helicity : Longitudinal Fraction

- Template fits for f_0, f_+. Lepton+jet channel: 407 events, 1.7 fb^{-1}

CDF II preliminary. 1.7 fb^{-1}





$f_0 = 0.57 \pm 0.11(stat) \pm 0.04(syst)$

$f_+ = -0.04 \pm 0.04(stat) \pm 0.03(syst)$

$f_0 = 0.61 \pm 0.20(stat) \pm 0.03(syst)$

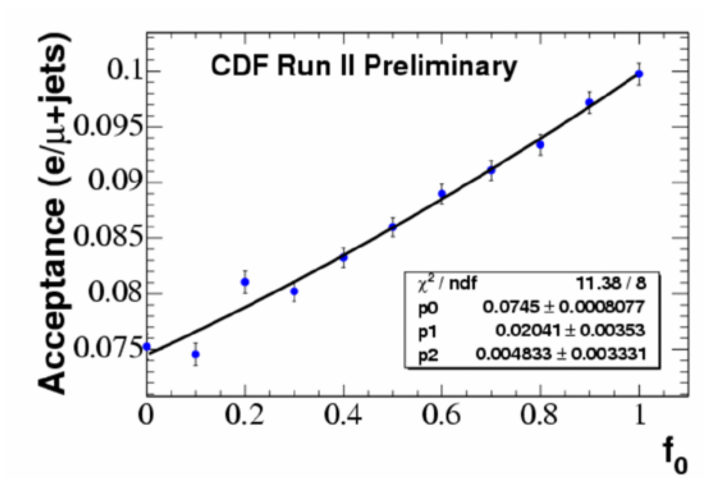
$f_+ = -0.02 \pm 0.08(stat) \pm 0.03(syst)$

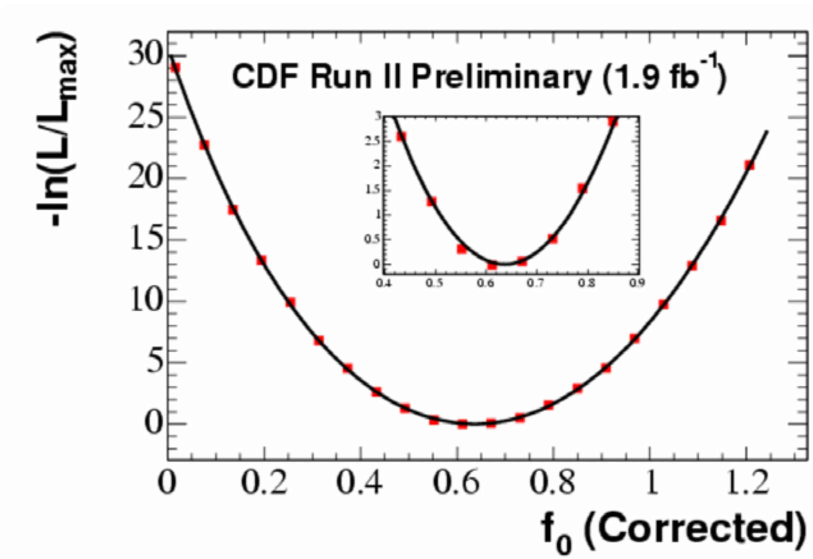
W helicity : ME measurement

- **Template Probability:**
  - Compute Probabilities per event
    - Ptt(f_0,f_+) as expected from SM
    - P_{W+jets}() from Vecbos
    - Create total event probability
  - Evaluate L(f_0) for full set of events
    - Includes acceptance corrections

$$P_{evt,i}(X; C_s, f_0) = C_s\, P_{ttbar,i}(X; f_0) + (1 - C_s)\, P_{W+jets,\, i}(X)$$

$$L(X; C_s, f_0) = \Pi_{i=1}^{Nevents} P_{evt,i}(X; C_s, f_0)$$





f_0 = 0.637 ± 0.084 ± 0.069 for m_T=175 GeV && f_+=0

Statistical limited. Working on obtain simultaneously f_0 and f_+

Measurement of $BR(t \to Wb)/BR(t \to Wq)$

- Indirect measurement using the CKM matrix :
  - Elements $|V_{ub}|$ and $|V_{cb}|$ are measured from the decay of B mesons to be very small.
  - Assuming unitarity and only three generations $|V_{tb}|$ is expected to be 0.998@90 %CL
- With top quarks at hand we can measure it directly :
  - we measure R, defined as

$$R \equiv \frac{BR(t \to Wb)}{BR(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} \quad \text{where } q = \{d, s, b\}$$

  - Use the ability to identify jets with a distinguished secondary vertex associated with the b parton .
    - **The number of b-tagged jets depends strongly on R and ε_b**
  - We classify the ttbar sample based on the number of b-tagged jets
    - **The relative rates of events with 0/1/2 b-tags is very sensitive to R**

Measurement of BR(t→Wb)/BR(t→Wq)

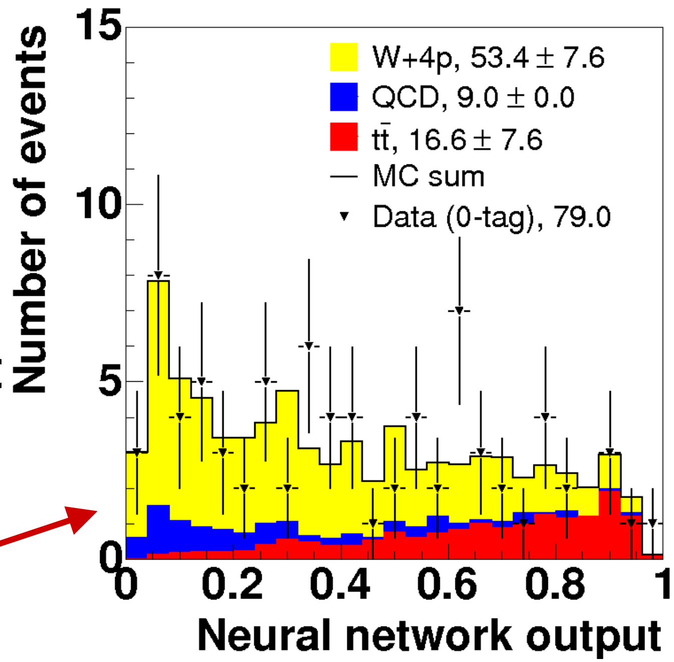
- **Use the** Lepton+Jets **and** Dilepton **samples.**
  - Total integrated luminosity of 162 pb^{-1}

- Lepton+Jets **sample requires:**
  - Isolated lepton (e,μ) with E_T>20 GeV
  - ME_T>20 GeV
  - at least 4 jets with E_T>15 GeV

- Dilepton **sample requires :**
  - At least two leptons (ee, μμ, eμ) E_T>20 Ge
  - ME_T>20 GeV
  - at least two jets with E_T>15 GeV.

- **Classify** both **samples based on the number of b-tagged jets**

- **Estimate the background contributio to each of the six sub-samples**
  - MC and data driven
  - Background in the Lepton+Jet with 0-tags obtained using NN techniques.

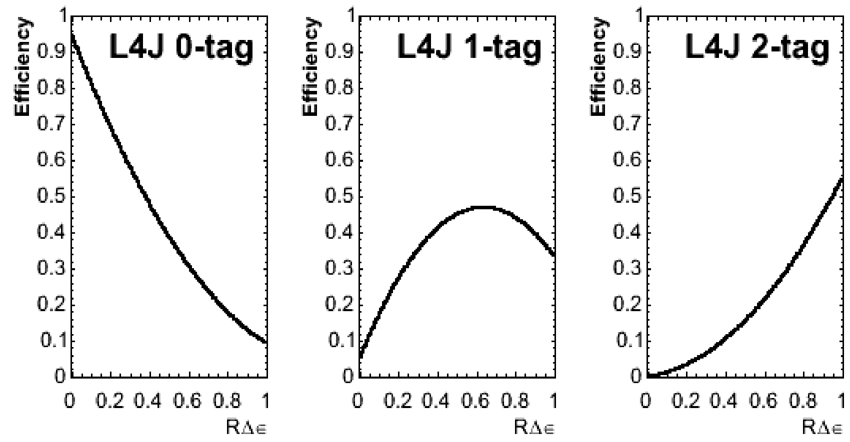


Measurement of BR(t→Wb)/BR(t→Wq)

- In the Dilepton and Lepton+Jets samples analyze the relative number of events with different multiplicity of secondary vertexes, *i* .

$$N_i^{exp} = N_{inc}^{t\bar{t}} \cdot \varepsilon_i(R) + N_i^b$$

$\varepsilon_i(R\Delta\varepsilon)=\varepsilon_i(R(\varepsilon_b-\varepsilon_q))$



- We could assume the productio[n]
  cross section to estimate $N_{inc}^{t\bar{t}}$ a[...]
  compare different tag bins.

- *Instead,* we take the different approach of using

$$N_{inc}^{t\bar{t}} = \sum_i N_i^{obs} - N_i^b$$

→result independent of the ttbar production cross section

Measurement of BR(t→Wb)/BR(t→Wq)

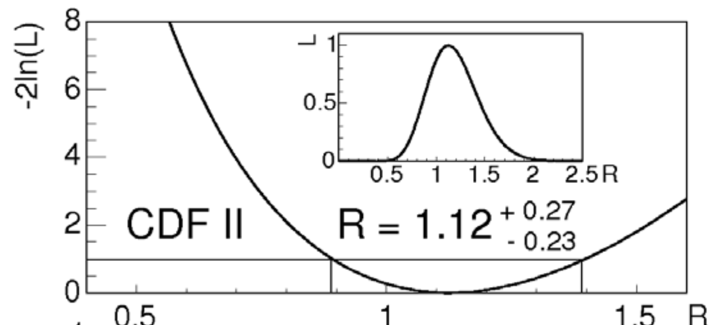
Lepton + Jets (L+J)	0-tag	1-tag	2-tag
ϵ_i $(R=1)$	0.45 ± 0.03	0.43 ± 0.02	0.12 ± 0.02
ANN background	62.4 ± 9.0	5.8 ± 5.2	$0.1^{+1.0}_{-0.1}$
a priori background		4.2 ± 0.7	0.2 ± 0.1
Total expected	80.4 ± 5.2	21.5 ± 4.1	5.0 ± 1.4
Observed	79	23	5
Dileptons (DIL)	**0-tag**	**1-tag**	**2-tag**
ϵ_i $(R=1)$	0.47 ± 0.03	0.43 ± 0.02	0.10 ± 0.02
a priori background	2.0 ± 0.6	0.2 ± 0.1	< 0.01
Total expected	6.1 ± 0.4	4.0 ± 0.2	0.9 ± 0.2
Observed	5	4	2

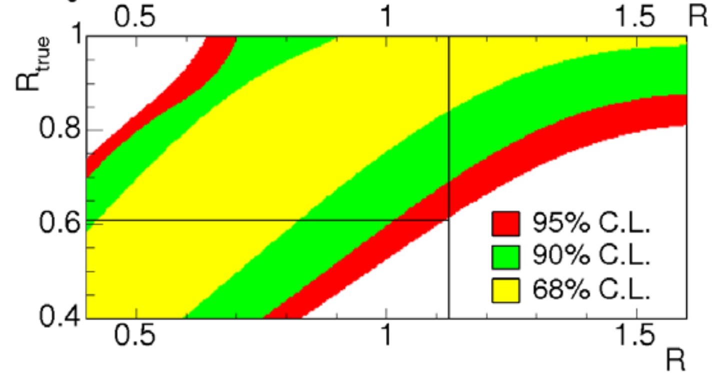
Obtain expected events as a function of R

$$N_i^{exp} = N_{inc}^{t\bar{t}} \cdot \epsilon_i(R) + N_i^b$$

$$N_{inc}^{t\bar{t}} = \sum_i (N_i^{obs} - N_i^b)$$

Compare to observed and Maximize the likelihood





Measure R :

$$R = 1.12^{+0.21+0.17}_{-0.19-0.13} \quad (\text{stat} + \text{syst})$$

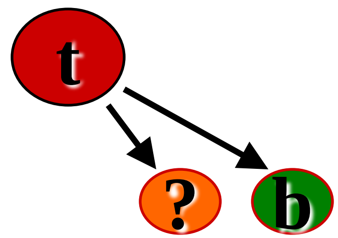
Set F-C lower limit :

R>0.61 at 95%CL

|Vtb| > 0.79 at 95%CL
(assuming unitarity)

What the results of R implies ?

- The R result is consistent with the SM.
- This means that the top decays to a b quark most of the time, as expected.



But, is ? always a W+ ?

Could ? be sometimes an H^+ ?

Measurement of BR($t \rightarrow H^{\pm}b$)

Charged Higgs bosons appear in the context of 2HDM's, like MSSM.

- **E.S.B ➔ 5 Higgs bosons; 3 neutral (h^0, H^0, A^0) and 2 charged ($H^{\pm}$)**

  Myriad of new decay channels :

  - h^0, $H^0 \rightarrow$ bb, $\tau\tau$, gg, W^+W^-, ZZ, cc
  - $A \rightarrow$ bb, $\tau\tau$, gg, Zh^0
  - $H^+ \rightarrow t^*b$, $\tau+\nu$, cs, W^+h^0, W^+A, etc

  Assume H+ may decay to any of these

- **The presence of an H+ would affect the relative number of events in each top decay channel, according to its decay. For example :**
  - If **$H+ \rightarrow \tau\nu$**, number of events in the **Lepton+Tau** sample would show an excess.
  - If **$H+ \rightarrow cs$,** number of events in the **Dilepton** and **Lepton+Jets** would show a deficit.

- **Top and Higgs BR's can be predicted by MSSM for specific benchmark parameters.**

Measurement of BR(t→H±b)

- **For each top quark we have 5 possible decay modes**
  - **t→Wb**
  - **t→Hb→t*bb→Wbbb**
  - **t→Hb→csb**
  - **t→Hb→τνb**
  - **t→Hb→Wh⁰b→WbBb**

- **Use the** Dilepton, Lepton+Jets **(1 and 2 or more tags) and** Lepton+TauH **(generically called XSA)**
- **The number of expected candidates N^{exp} is**

$$N_{XSA}^{\exp} = N_{XSA}^{back} + \sigma\, \varepsilon_{tt,XSA} \int Ldt$$

N_{XSA}^{back}: from XS meas.

σ^{theo}=(6.7±0.7)pb (hep-ph 0303085)

$\int Ldt$ → ~193 pb^{-1}

$$\varepsilon_{tt,XSA} = \sum_{i,j=1}^{5} B_i B_j\ \varepsilon_{i,j\ XSA}\left(wTop, wHiggs, m_{H^\pm}, m_{h^0}\right)$$

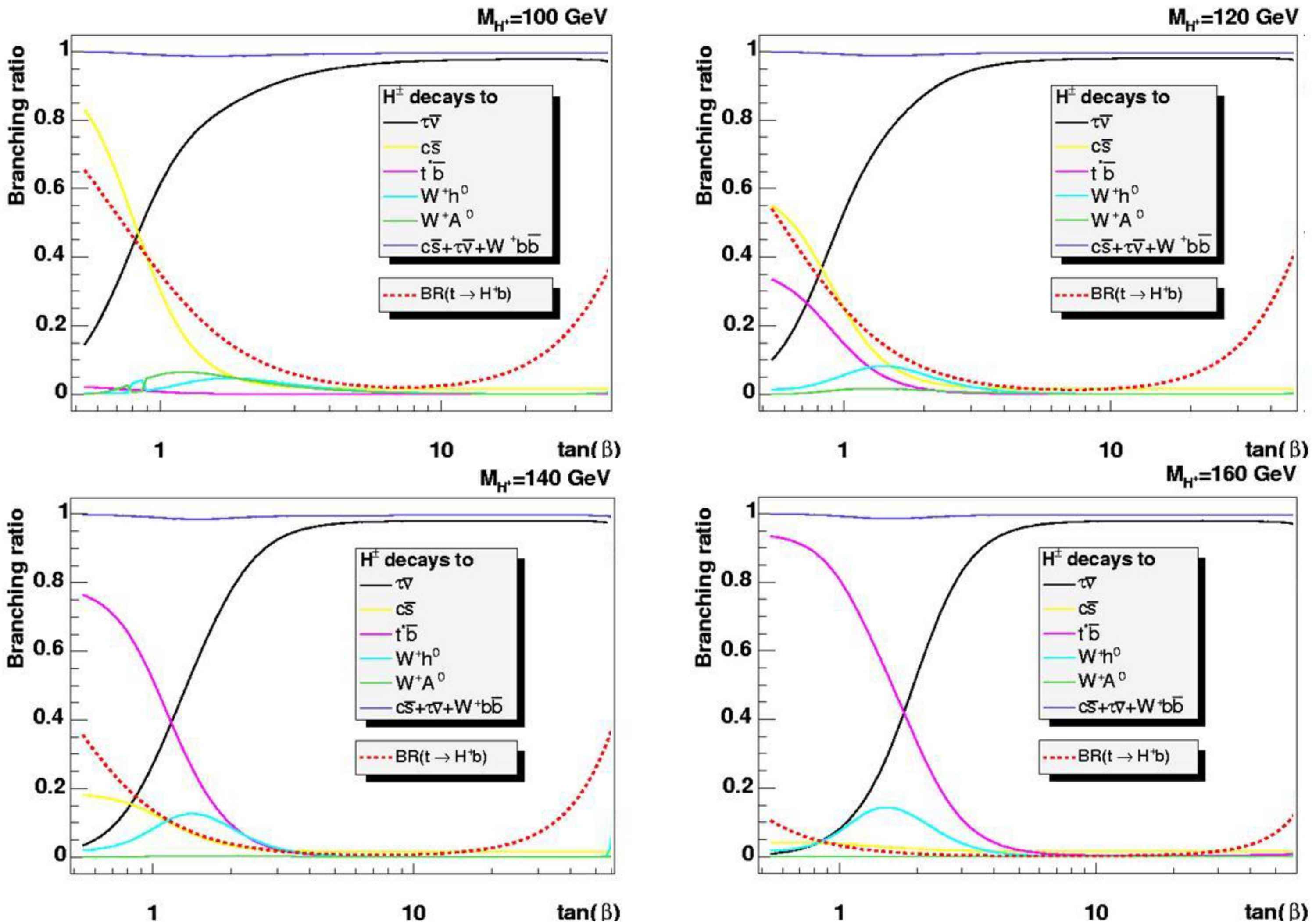
$\varepsilon_{i,j\ XSA}$: from MC

$B_i B_j$: Branching fractions of each decay mode

  - **Need to know the BR's to compute the efficiency**
- **Given {BR's} compare N^{obs} to N^{exp} for each cross section measurement**
  - Use a likelihood in the parameter of interest

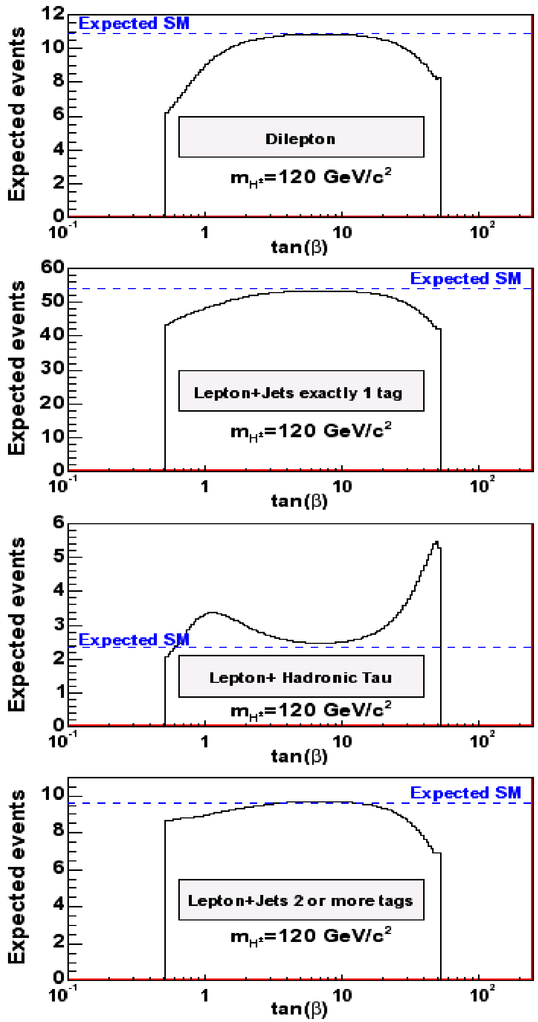
Measurement of BR(t→H±b)

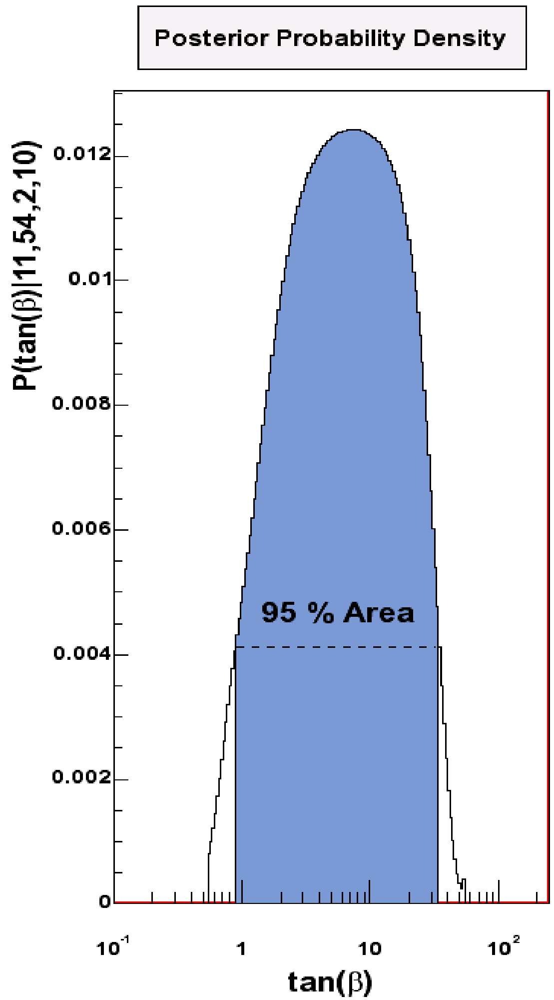
- Using CPsuperH (hep-ph/0307373) to predict the BRs
  - **Full QCD, SUSY-EW and SUSY-QCD corrections included**



Measurement of BR(t→H±b)

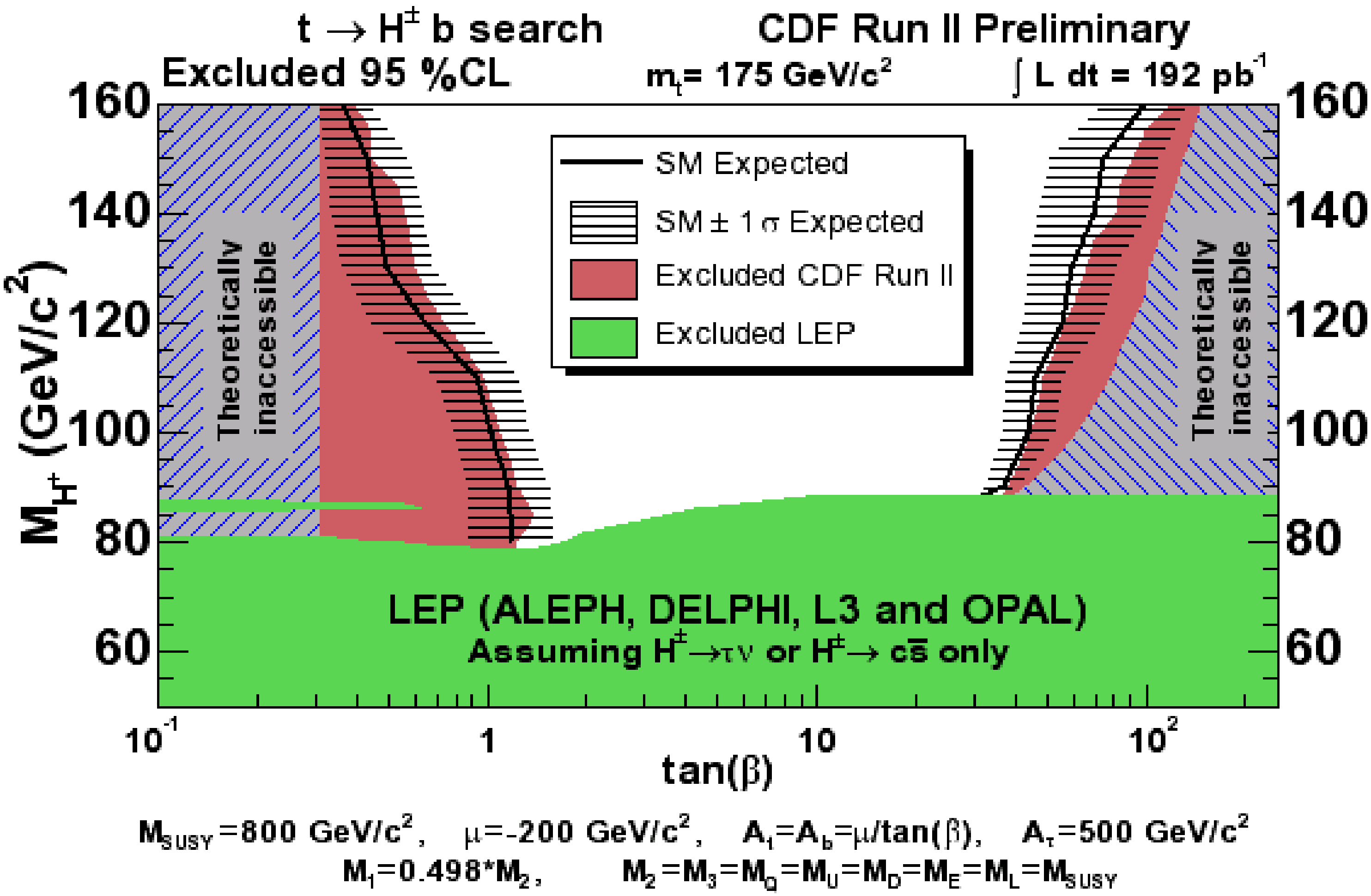
- Expected Events as a function of tan(β) . Integrated luminosity 191 pb^{-1}





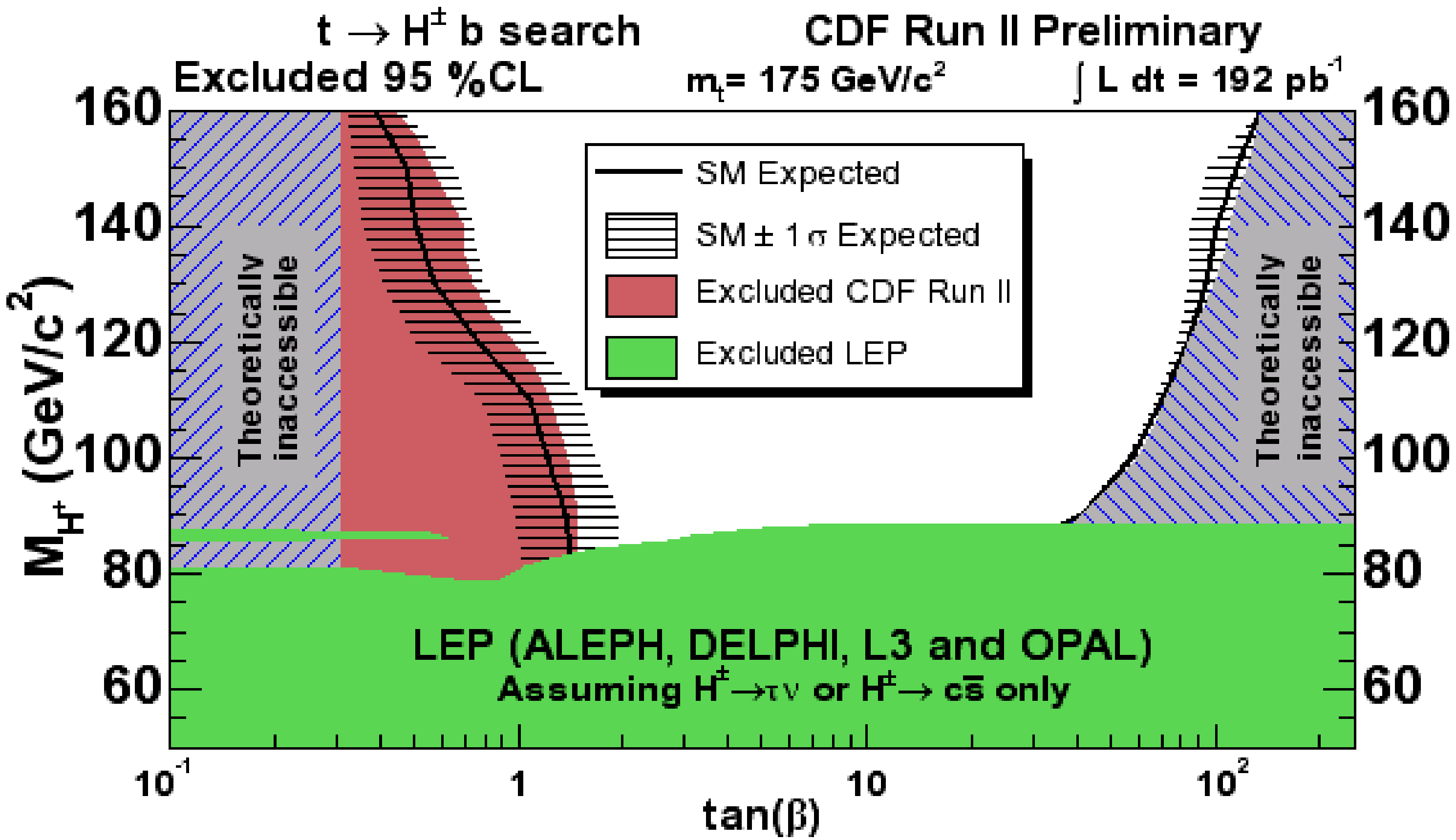
Measurement of BR(t→H±b)

➲ BR's predicted by MSSM in Minimal Stop Mixing scenario



Measurement of BR(t→H±b)

➲ BR's predicted by MSSM in another benchmark scenario

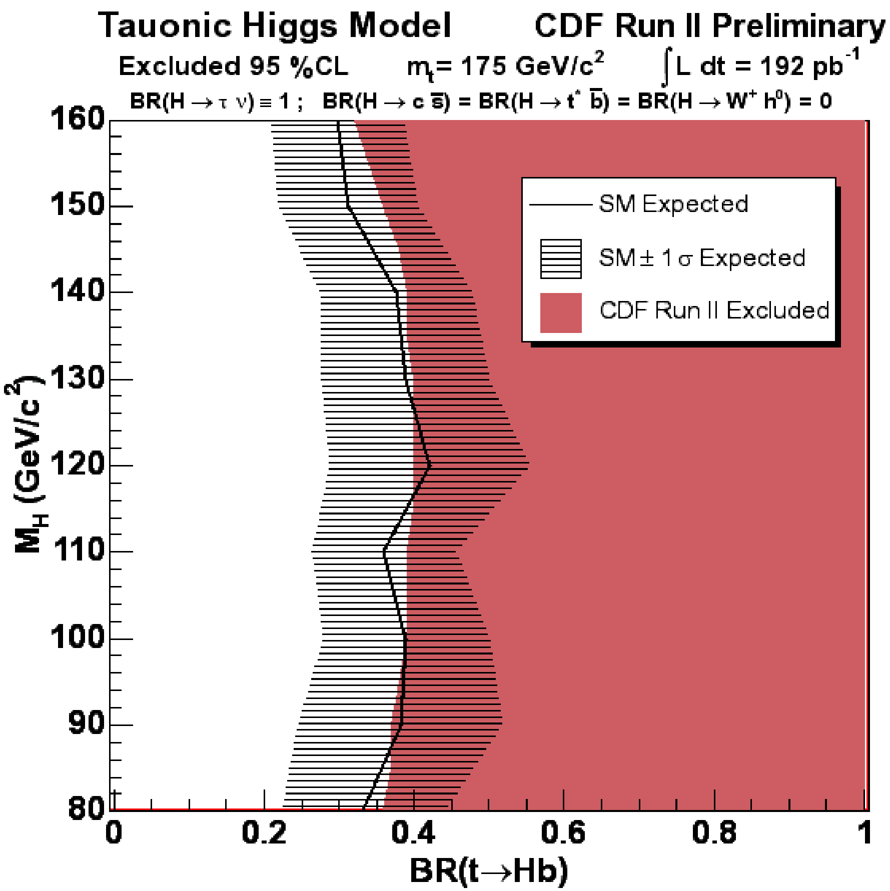


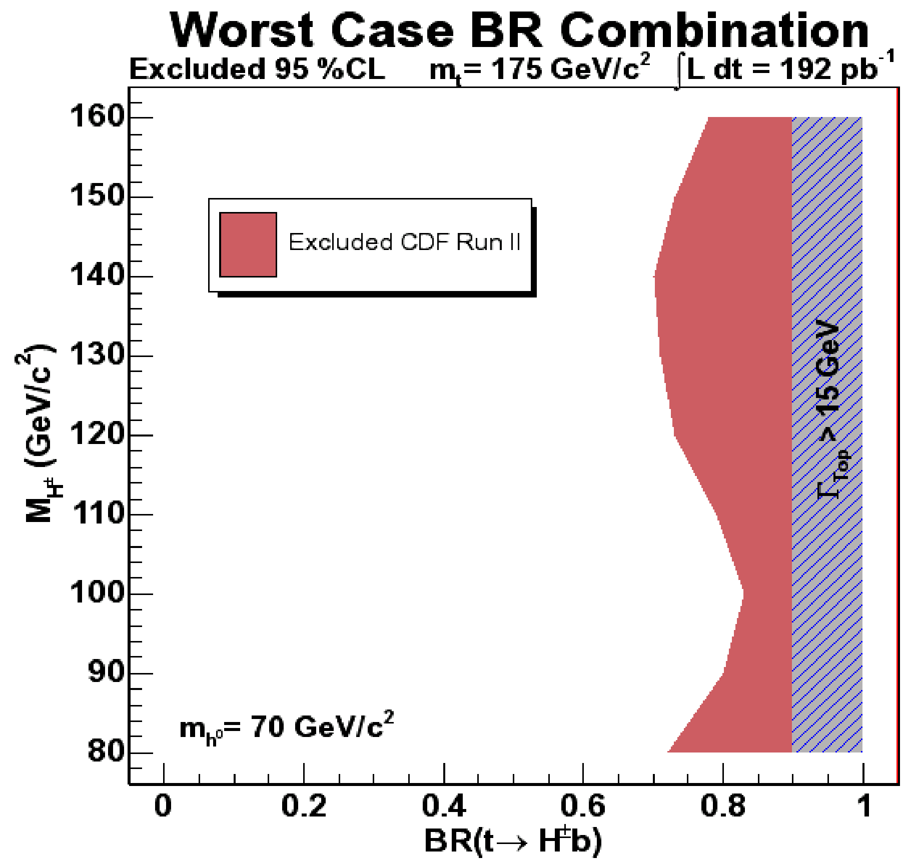
M_{SUSY}=1000 GeV/c², μ=500 GeV/c², $A_t=A_b$=2800 GeV/c², A_τ=500 GeV/c²

$M_1=0.498*M_2$, $M_2=M_3=M_Q=M_U=M_D=M_E=M_L=M_{SUSY}$

Measurement of BR(t→H±b)

- Assuming $H^+ \to \tau\nu$ only.
- Worst case of all possible BR's combinations



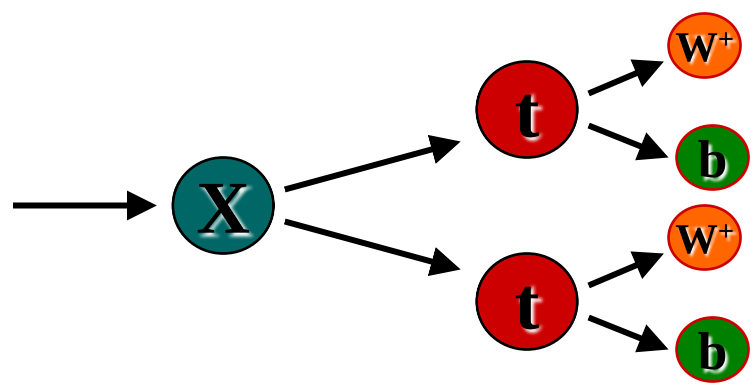


$BR(t \to H^+ b) < 0.4$ @95%CL for 80<mH<160 GeV

$BR(t \to H^+ b) < 0.85$ @95%CL for 80<mH<160 GeV

What about production ?

- We know that, within errors,:
  - **The top decays mostly to b**
  - **The top decays mostly to W+**
  - **The nature of the tWb vertex is what's expected.**



Are some top pairs coming from a resonance?

What else ?

- We know that:
  - **Top is produced in ttbar pairs (and possible singly too)**
  - **The top decays mostly to b**
  - **The top decays mostly to W+**
  - **The nature of the tWb vertex is what's expected.**

- **Is anything beyond SM in our top sample?**

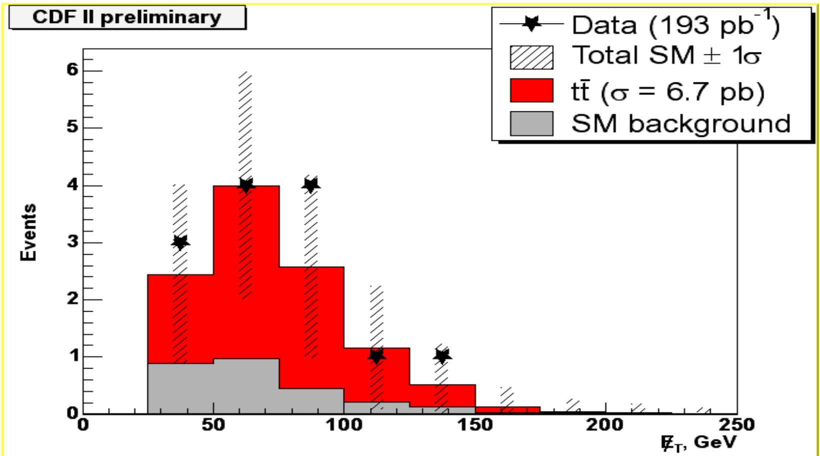
SM Kinematic Test

- **Work in the** Dilepton **sample**
- **Choose** *a priori* **a set of variables with potential sensitivity to new physics**
  - ME_T
  - Angle(ME_T, Leading Lepton)
  - Leading lepton P_T
  - "Topness" (based on kinematical fit)
- **Perform Kolmogorov-Smirnov consistency test between data and MC**
- **Select the subset of events with the most non-SM features**
- **Run 1 saw an excess of large ME_T and lepton P_T**
  - PRL **77** 3506 (1996) proposed that squarks around 300 GeV show better agreement to data
  - Expected sensitivity of **current analysis** for that model, given 13 events :

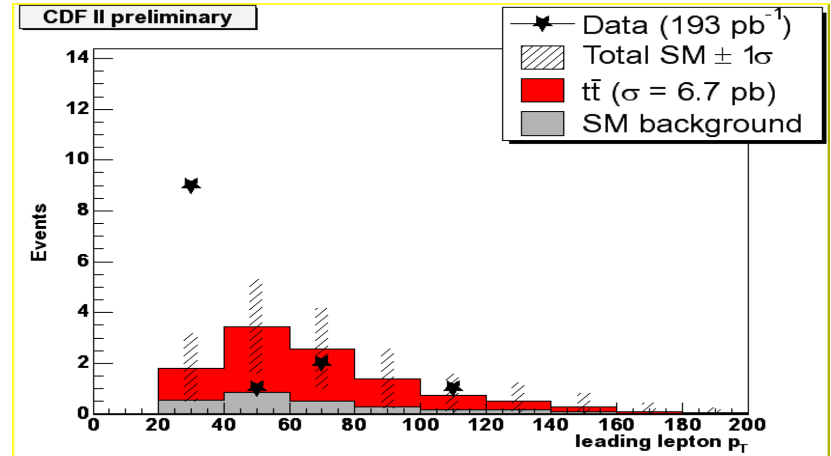
SUSY fraction	Chance to find 3σ evidence
50%	**50%**
30%	**25%**
10%	**7 %**

SM Kinematic Test

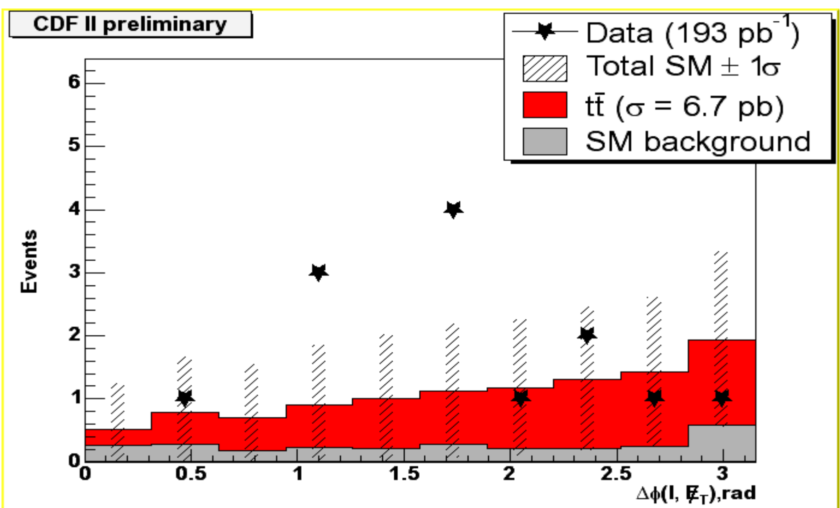
Missing E_T



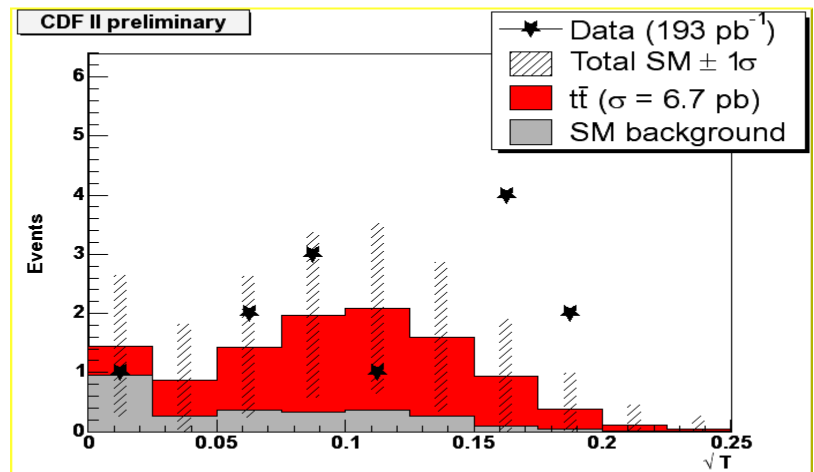
Leading lepton p_T



$\Delta\phi$ (leading lepton, met)



"topness" = ttbar decay goodness-of-fit



t→Zc: Signature and Backgrounds

- **Signature:**
  - Z → e+e–,μ+μ–
    76 GeV < M_{ll} <106 GeV
    opposite charge.
  - 4 jets, with E_T>15 GeV
  - Two separate signal regions: zero b-tags, and one or more b-tags.

- **Background:**
  - Z+Jets: dominant background for top FCNC search.
    Most difficult to estimate
  - Standard model tt production → small background
  - Dibosons: WZ and ZZ diboson production → small background
  - W+Jets, WW: negligible

Diboson Production: WZ, ZZ

- Small background (similar in size to standard model $t\bar{t}$ production)
- Small cross section but real Z
- Need extra jets from gluon radiationZZ: Heavy flavor contribution from Z→$b\bar{b}$ decay
- Estimated from MC simulation