The "truth" about the "top" quark from CDF

Véronique Boisvert
University of Rochester
Royal Holloway University of London

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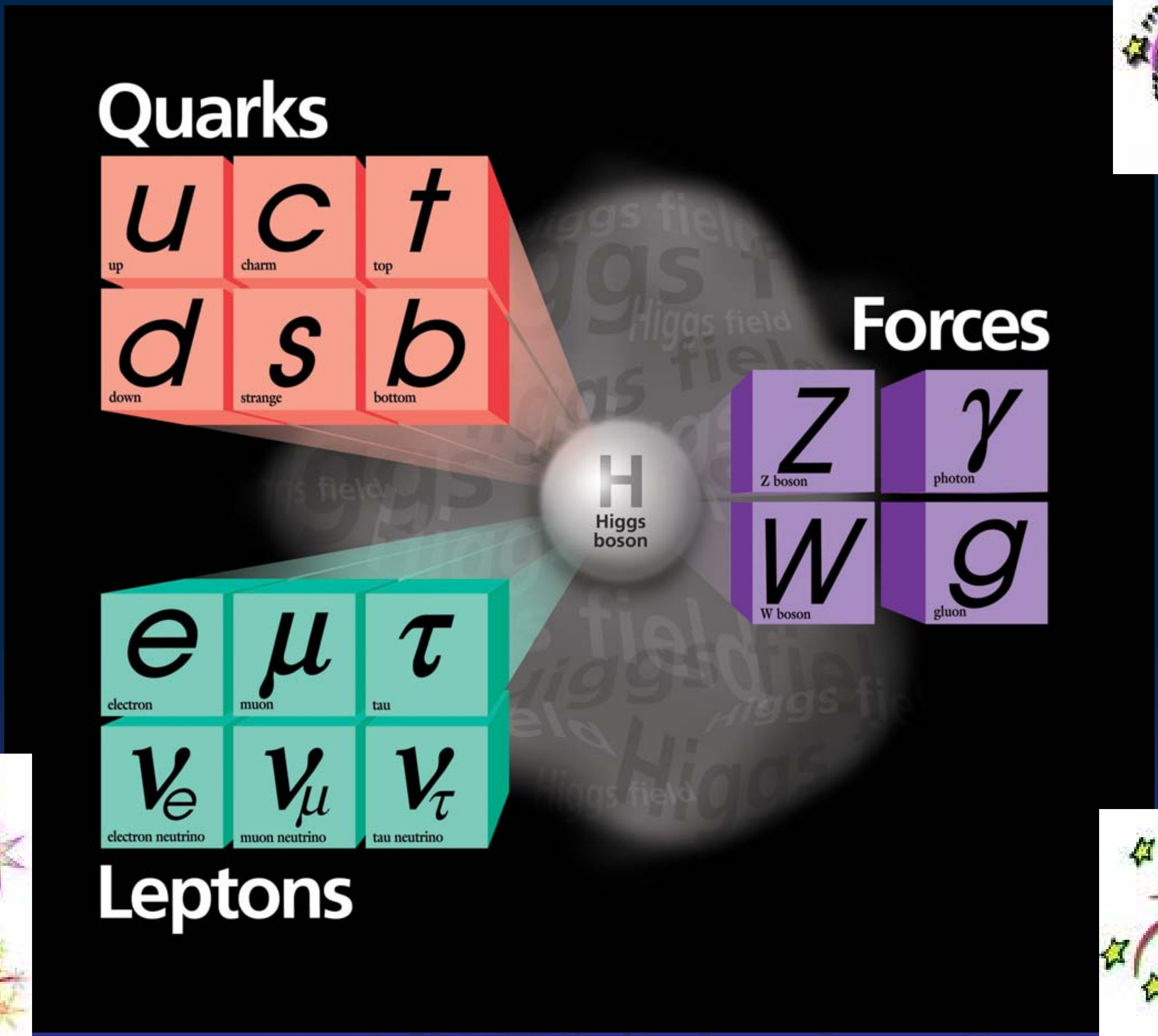
The Standard Model



What we don't know…

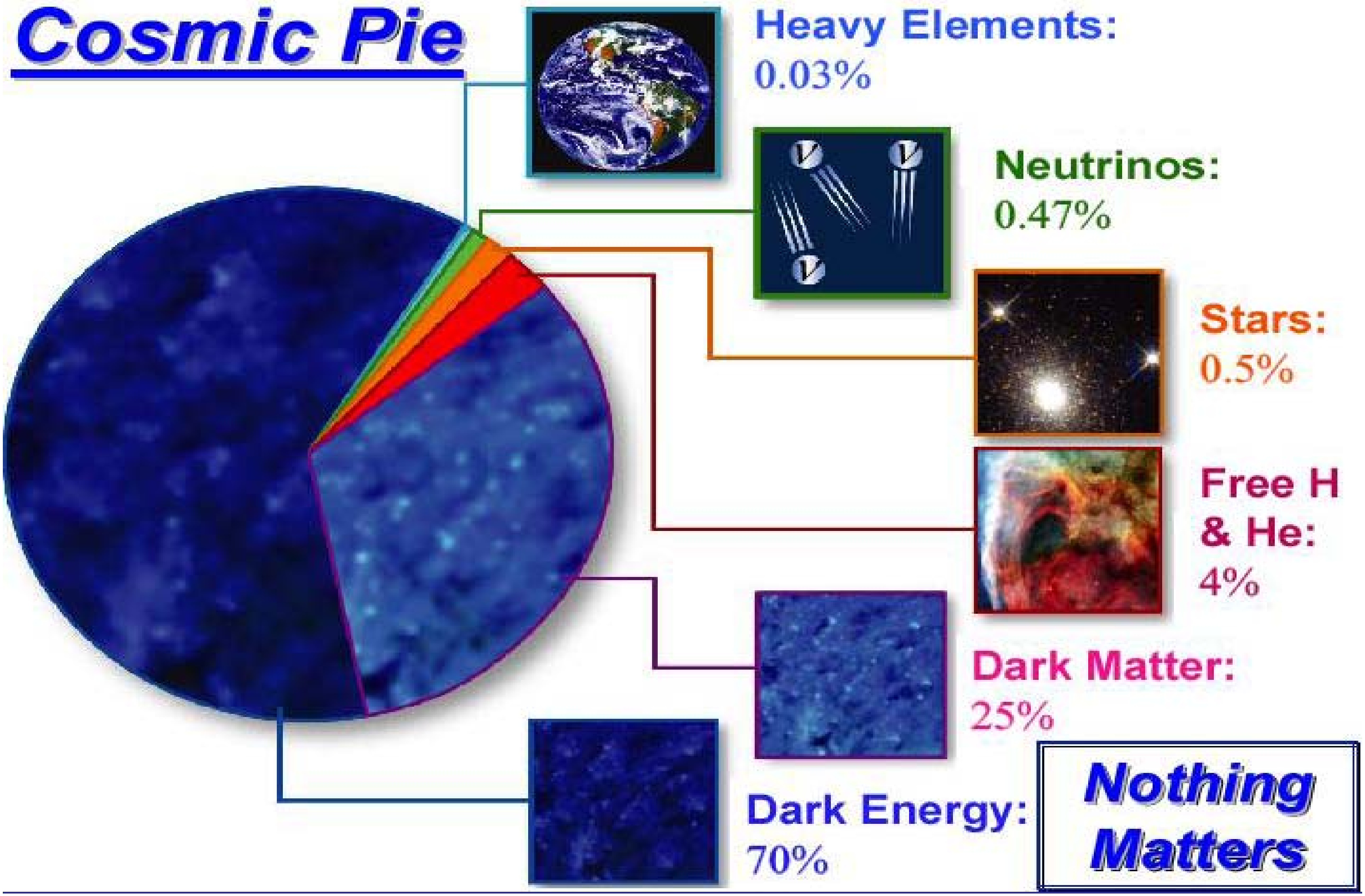
- Incorporate neutrino mass in the SM in a natural way

- Strong CP problem: Why QCD does not break CP?
  - Electric dipole of the neutron: $d_N \sim 5\times10^{-16}\ \theta_{QCD}$ e cm
    - $d_N < 3.0\times10^{-26}$ e cm so $\theta_{QCD} < 10^{-10}$
    - naturalness: $\theta_{QCD} \propto O(1)$ so fine tuning

- Higgs mass should be around 10^{16} GeV, not O(100GeV)
- Planck scale so different from the Electroweak scale

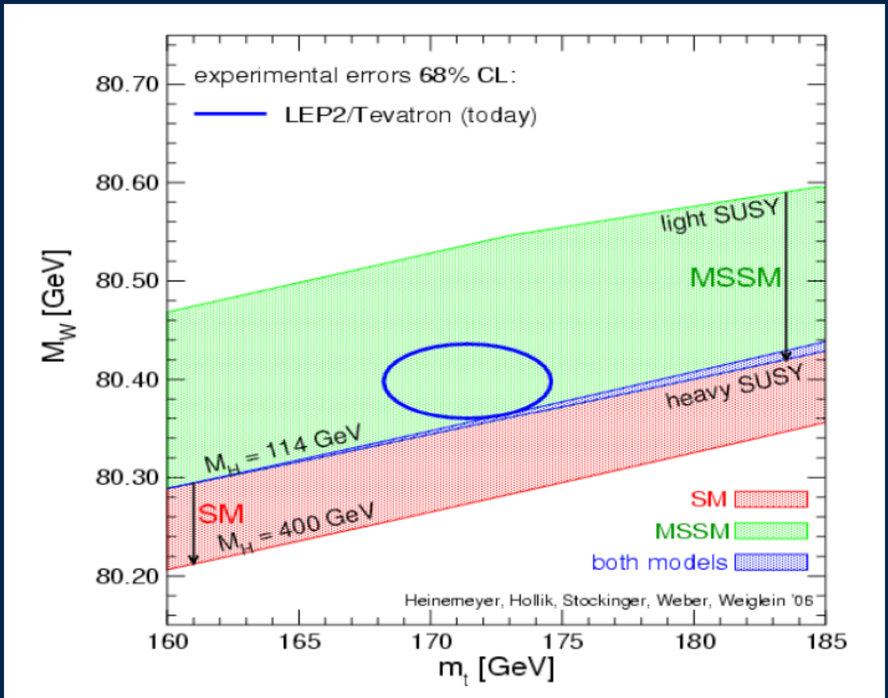
} Hierarchy Problem

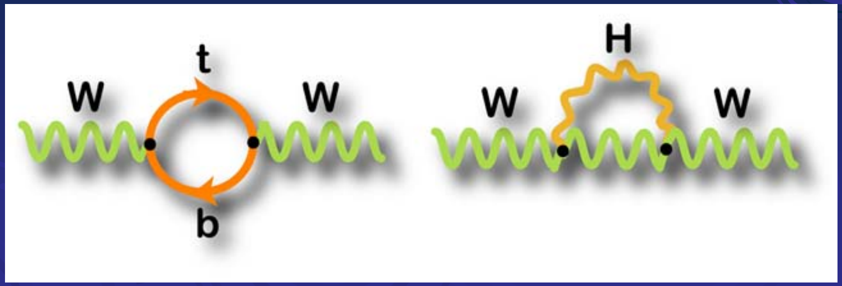
What we don't know…

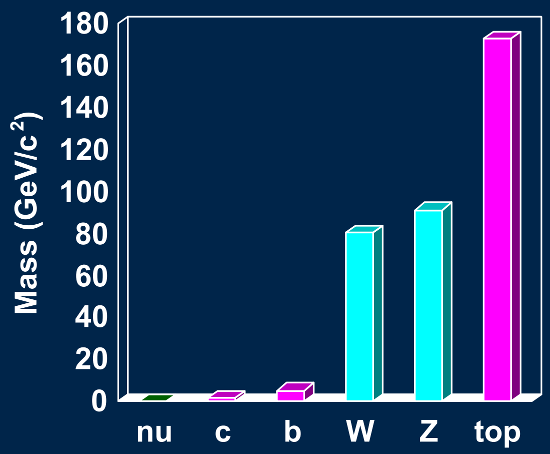


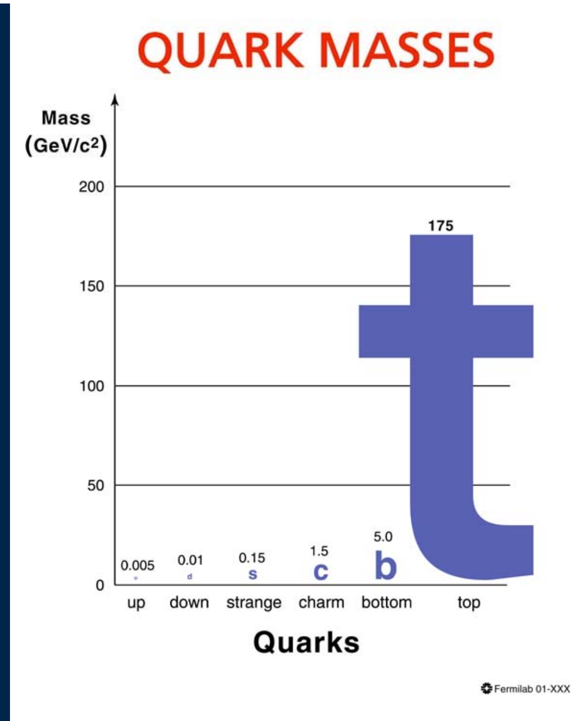
Higgs Mass

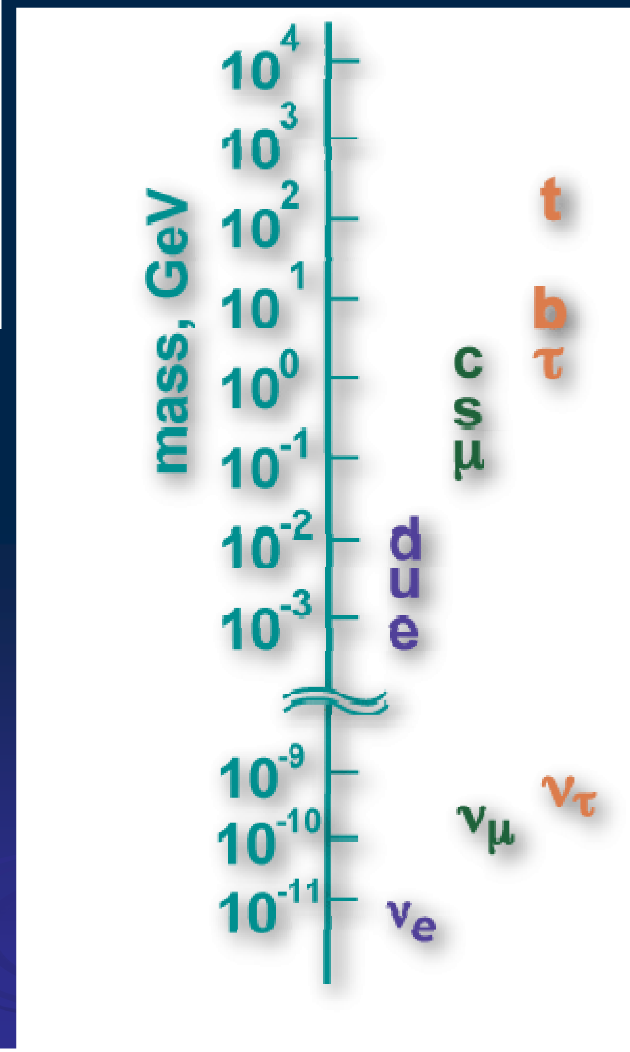
- Electroweak observables put strong constraints on the Higgs mass
- Higgs enters into radiative corrections of EW boson
  - Only logarithmically
  - Top mass enters quadratically…
- Higgs largest coupling is to the top quark







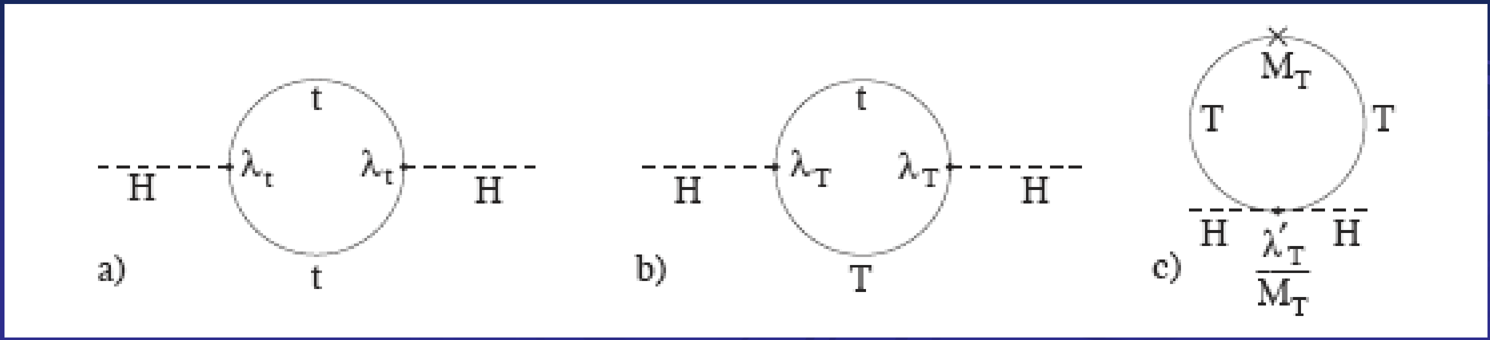




- … Top mass is so large…Maybe the Top quark is not just a normal quark… maybe it's involved more directly in the electroweak symmetry breaking mechanism!

An Example of this…

- "Little Higgs" models
  - Similarly to SUSY predict new particles to cancel Higgs mass divergences
    - Fermions cancel fermions and bosons cancel bosons
    - "nonlinearly realized symmetry"
  - Predictions:
    - One or several Higgs with relatively small masses
    - At least one heavy fermion (T) m < 2 TeV to cancel the top
    - New heavy gauge bosons (Z')
  - Signatures in Tevatron top quark sector:
    - Z' forward-backward asymmetry to tt̲ pair



So far…

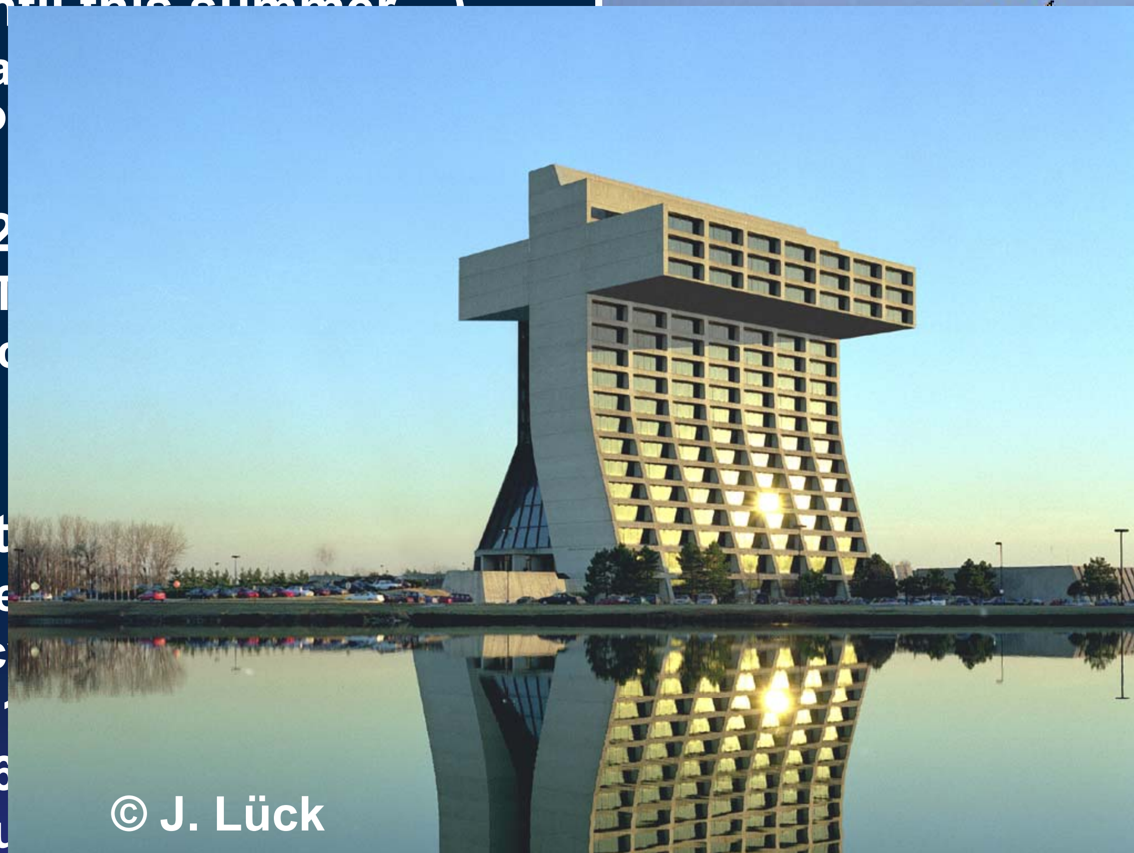
- Looked at Standard Model
  - Hierarchy problem
    - Electroweak symmetry breaking mechanism is involved
    - Top quark seems to be an important player and could give us clues

Next…

- Top Physics:
  - Top Factory: Tevatron
  - Top Production
  - Top measurements

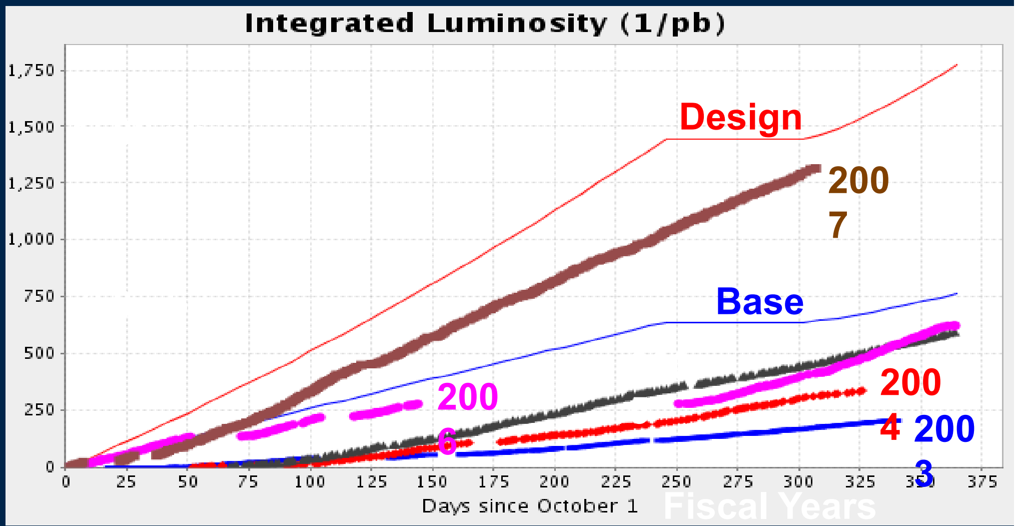
Current Top Factory: Tevatron

- World's highest energy collider (until this summer…)
  - Proton-a
    Synchro
- Run I (1992
  - √s = 1.8T
  - 6x6 bunc
  - 100 pb^{-1}
- Upgrades t
  - Main inje
  - Pbar rec
- Run II (200
  - √s = 1.96
  - 36x36 bu

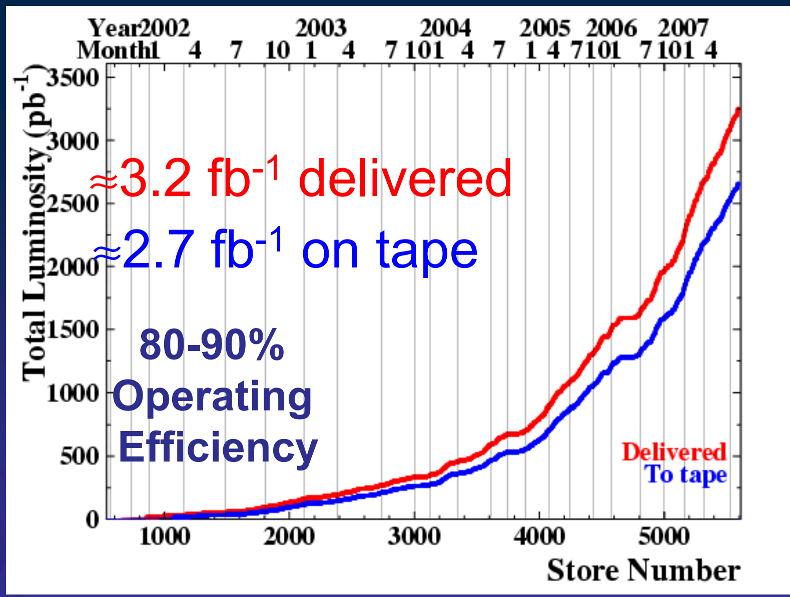


Tevatron Performance

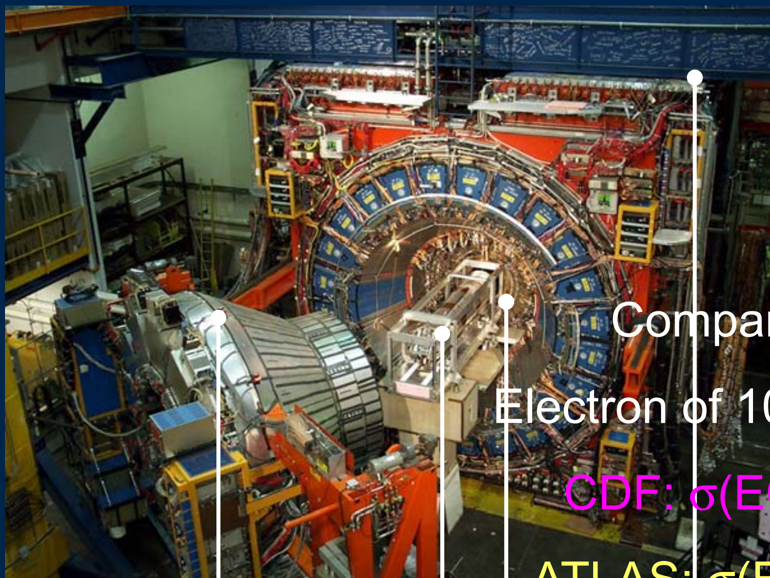
- Record Luminosity achieved for a hadron collider:
  - ~2.86E32 $cm^{-2}\ s^{-1}$
- Expect 6-7 fb^{-1} by October 2009

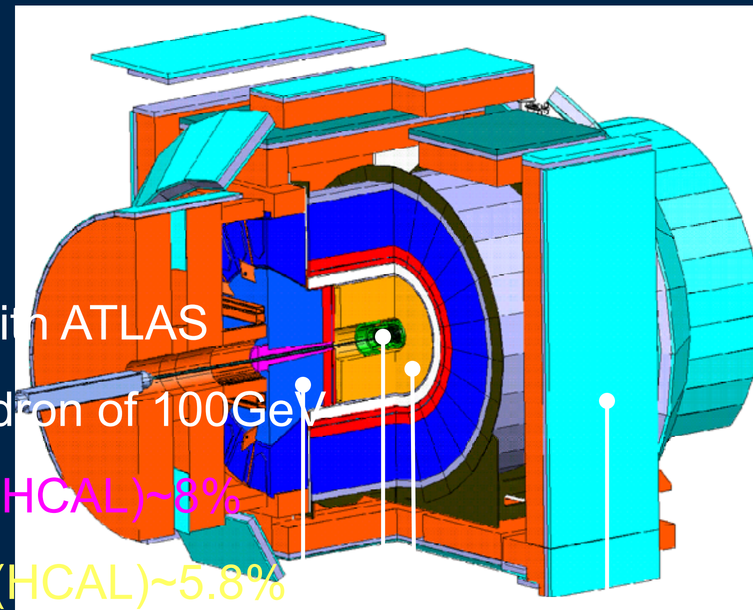


Process	Events/week/exp. (before trigger & cuts)
$t\bar{t}$	150
$W\rightarrow e\nu_e$	54,000
$Z\rightarrow ee$	5100
WW	270
$gg\rightarrow H$ (M_H=115GeV/c^2)	18



Collider Detector at Fermilab





Comparison of CDF with ATLAS

Electron of 100GeV and hadron of 100GeV

CDF: σ(ECAL)~ 2.0% σ(HCAL)~8%

ATLAS: σ(ECAL)~1.2% σ(HCAL)~5.8%

Calorimeter showers much better defined with ATLAS

Example of consequence for top physics:

Probability of jet faking an electron is much reduced at ATLAS

less QCD background – reason 1

Drift chamber outer tracker:

$$\delta p_T / p_T \approx 0.0005 \times p_T \quad [\text{GeV/c; beam constrained}]; |\eta| < 1$$

Silicon vertex detector:

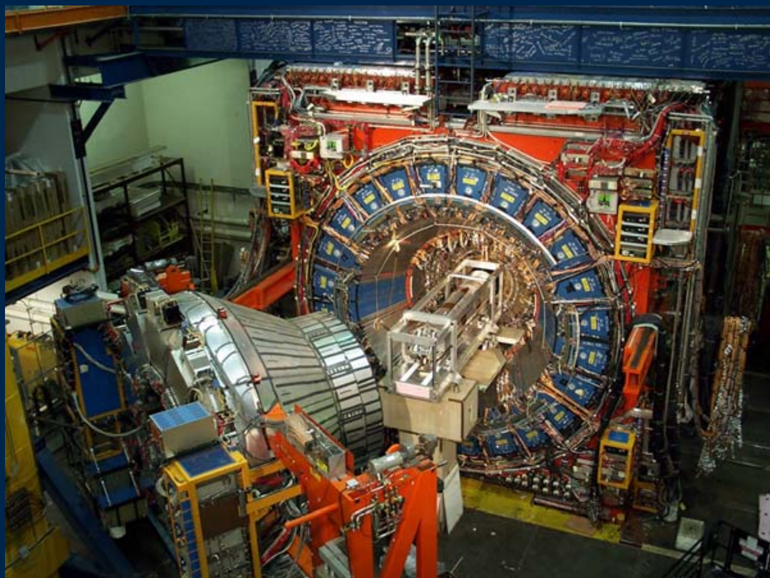
σ(IP)~40μm, σ(z_0)~70μm, tracking coverage out to |η|<2.8)

Central calorimeter: $\delta E_T / E_T \approx 13.5\%/\sqrt{E_T} \oplus 1.5\% \quad |\eta| < 1.1$

Plug calorimeter: coverage out to |η|<3.0

Muon chambers: coverage out to |η|<1.0

Collider Detector at Fermilab



2.5 MHz → L1 Trigger

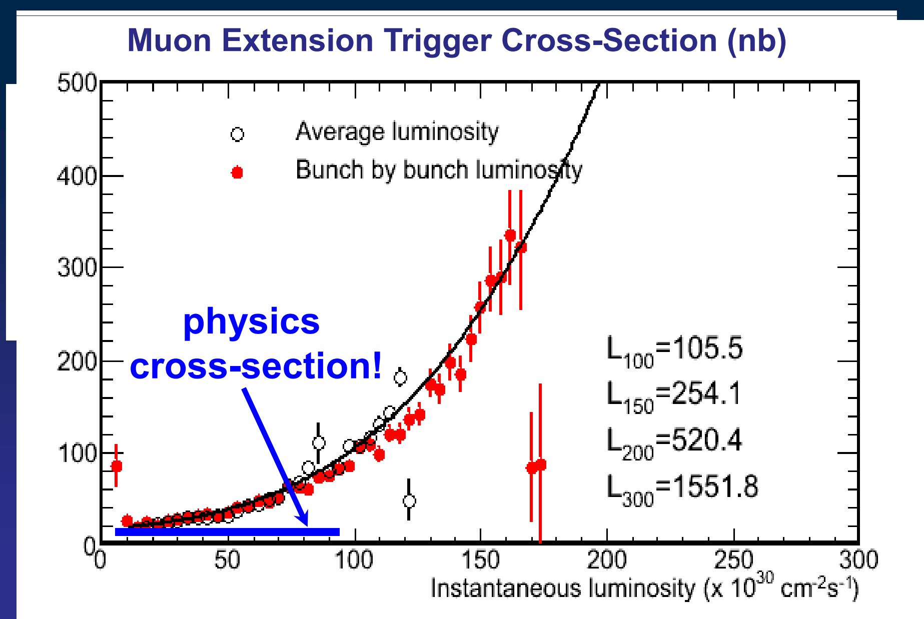
~20 kHz → L2 Trigger

~600 Hz → L3 Trigger

~90 Hz ~20 MB/s → Offline Reconstruction ← Simulation

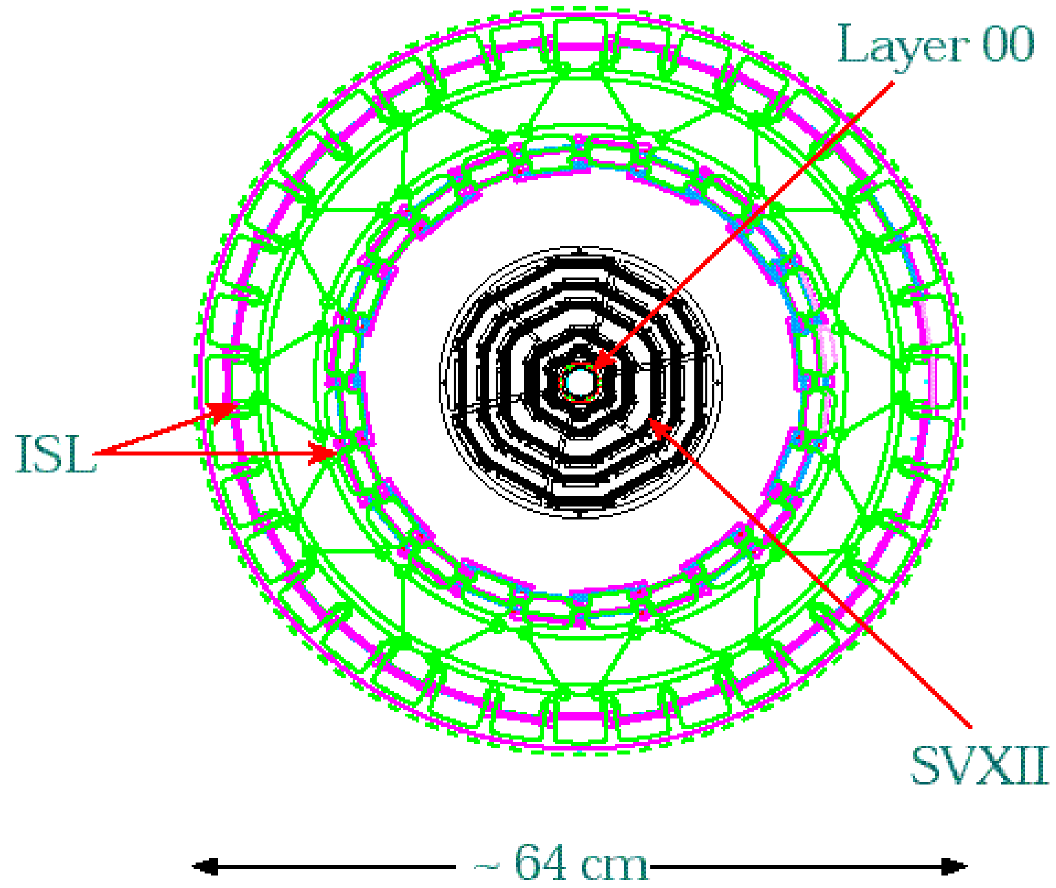
~1 PB/yr → Data Handling

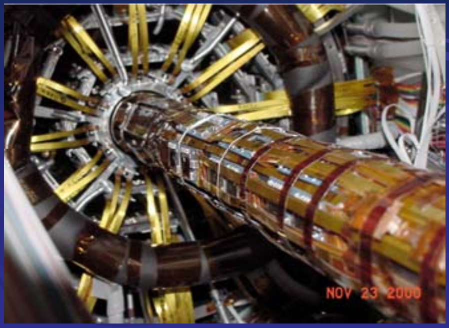
- Challenges at high L:
  - Trigger rates out of control (L1, L2)
  - So high dead time
  - Processing time (L3)
  - Data size & transport



Silicon detector

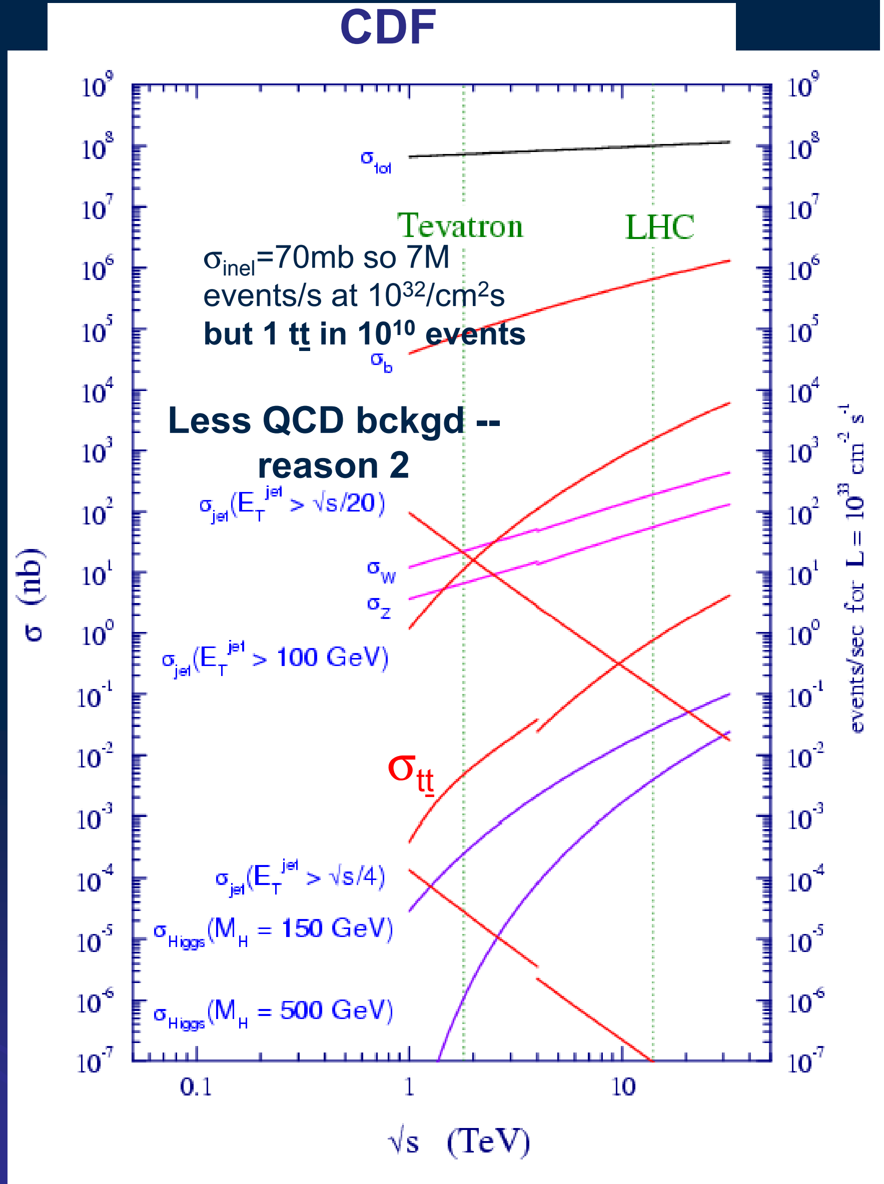
- One of the biggest silicon detectors currently online
  - (722K channels, 6.2 m^2)
- Cannot be accessed for maintenance
  - 'space probe' engineering and operation
  - Needs to 'live' longer than designed for
  - 1.35cm away from the beam
    - improved performance
    - a dangerous place to be
- Silicon hits-on-track efficiency 94.8% if requiring 3 r-ϕ layer hits
- 9 μm resolution for residuals
- The key to top and B physics





The Standard Model Top

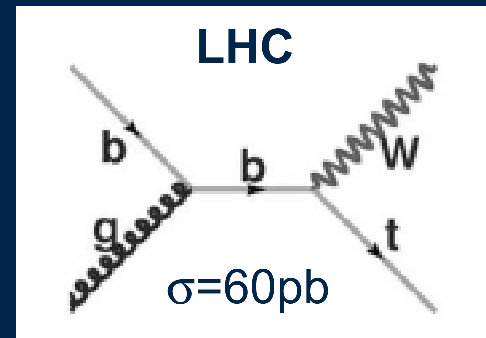
- Top quark is isospin partner of b quark:
  - Charge = +2/3
  - Spin = 1/2
  - Mass = ???
- How is top produced:
  - Tevatron:
    - qq̲ vs gg is 85% vs 15%
    - For m_t=175GeV/c^2:
      - $\sigma_{t\bar{t}}$ (theo) ≅ 6.7± 0.8 pb
    - top are nearly at rest
  - LHC:
    - qq̲ vs gg is ~10% vs 90%
    - For m_t=175GeV/c^2:
      - NLO $\sigma_{t\bar{t}}$ (theo) ≅ 830± 100 pb
    - more momentum available

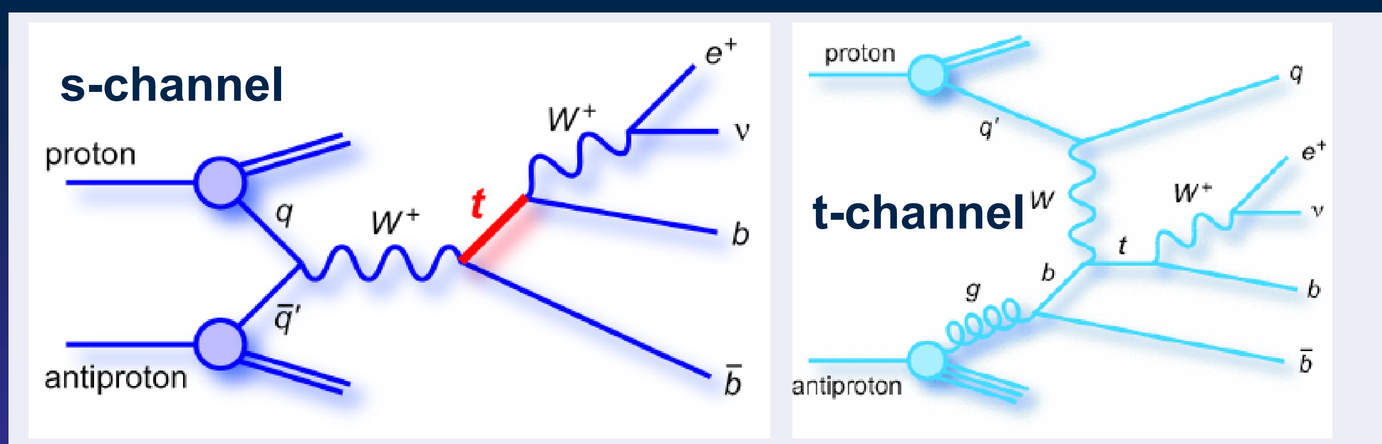


Single Top Production

- Electroweak production:
  - Different New Physics
    - s-channel: New resonances
    - t-channel: FCNC
  - Measurement of $|V_{tb}|$ if assume SM
  - Anomalous Wtb coupling
  - CP violation:

$$A = \frac{\sigma(p\bar{p} \to t) - \sigma(p\bar{p} \to \bar{t})}{\sigma(p\bar{p} \to t) + \sigma(p\bar{p} \to \bar{t})}$$

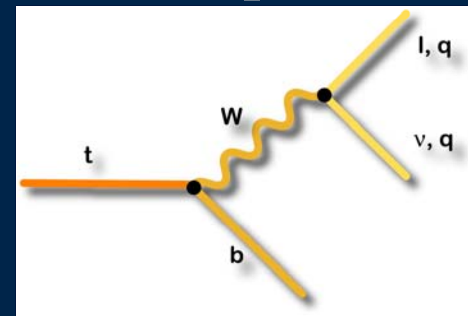




$\sigma_s=0.88\pm0.07$pb   LHC $\sigma_s=10$pb

$\sigma_t=1.98\pm0.21$pb   LHC $\sigma_s=250$pb

Standard Model Top



- $m_t > m_W + m_b$ so dominant decay $t \rightarrow Wb$
- If assume unitarity $B(t \rightarrow Wb) \sim 100\%$

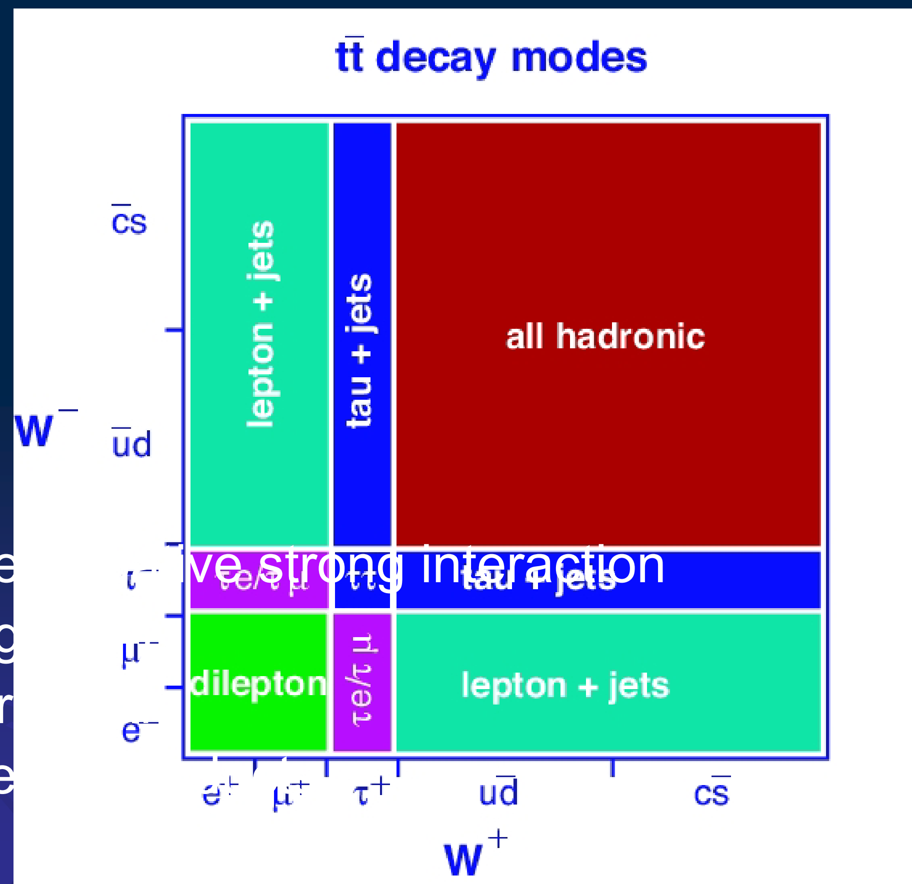
$$\Gamma_t \sim 1.6 GeV \left(\frac{m_t}{180}\right)^3$$

$$\tau_t = \frac{1}{\Gamma_t} \sim 4.4 \times 10^{-25} \left(\frac{m_t}{180}\right)^3 \text{ sec}$$

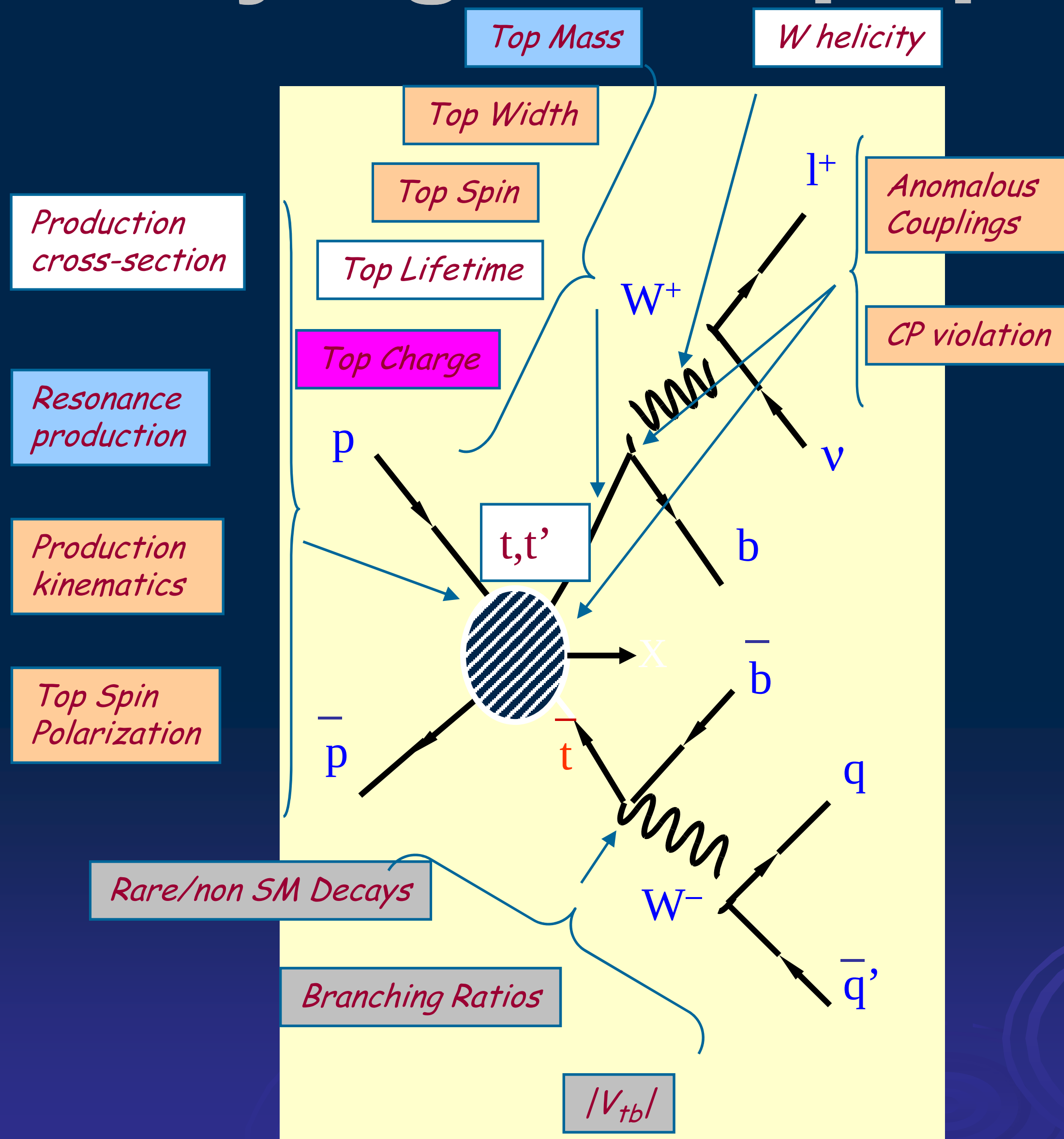
$$\frac{1}{\Lambda_{QCD}} \sim \frac{1}{0.2\text{GeV}} \sim 3.3 \times 10^{-24} \text{ sec}$$

- Top decays before it feels non-pe... ve strong interaction
- ... eg
- ... ar
- → Top spin transferred to de...

(not inc. τ)	BR	background
dilepton	~5%	low
lepton + jets	~30%	moderate
all hadronic	~44%	high



Studying the top quark



Next

- Top pair cross section measurements
  - Dilepton
  - Lepton + Jets
  - All hadronic

- Measuring $\sigma_{t\bar{t}}$ is crucial:
  - Window to NP
  - Look at all possible channels
  - Starting point for most properties analysis
    - Literally… selection is the same so can use same acceptance scale factors and same background predictions
  - $t\bar{t}$ is background for searches

Triggers used by Top group

- Physics triggers

ELECTRON_CENTRAL_18
- L1_CEM8_PT8
- L2_CEM16_PT8
- L3_ELECTRON_CENTRAL_18

MUON_CMUP18_L2_PT15
- L1_CMUP6_PT4
- L2_CMUP6_PT15
(was L2_CMUP6_PT8)
- L3_MUON_CMUP_18

Analysis requirements

For lepton p_T: > 20GeV

MUON_CMX18_L2_PT15
- L1_CMX6_PT8_CSX

← Recently prescaled

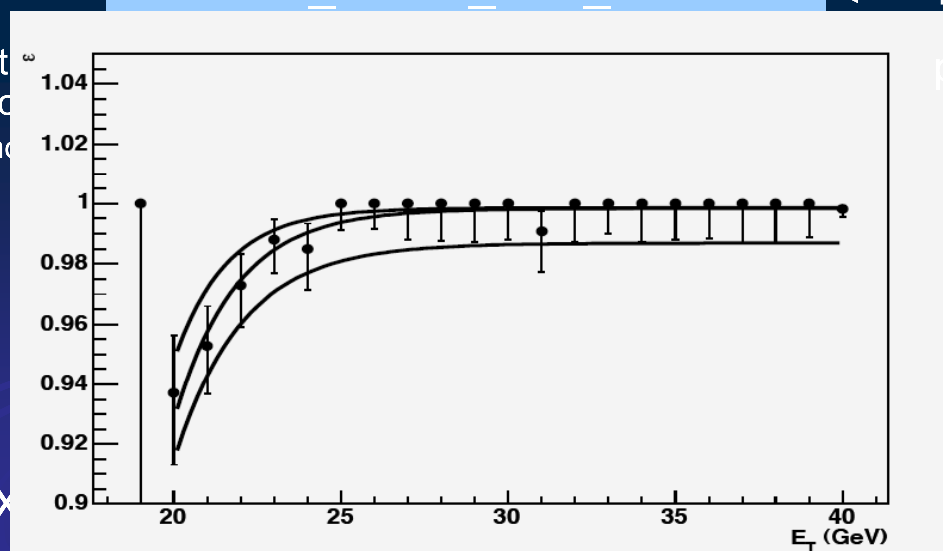
UMET175

- Calibration triggers (prescaled!!):
  - T4
  - Monitoring
  - b-tagging:
    - Prescaling is part of the stat
    - uncertainty of b-tagging effic
    - b-tagging efficiency is am dominant systematics of analyses using b-tagging

all hadronic channel

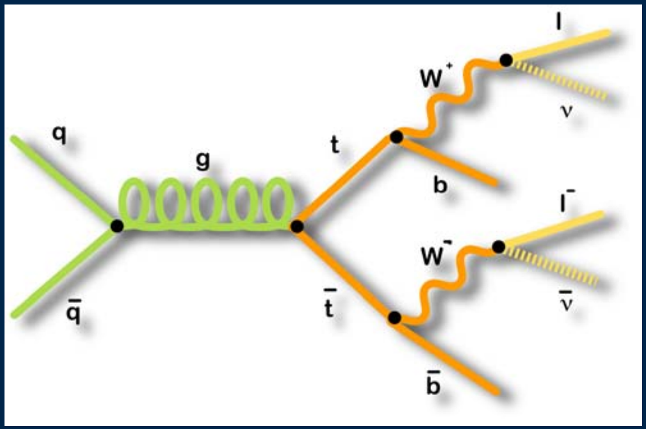
b tagging mistag matrix

- Example of trigger efficiencies:
  - Tag & Probe using Z's
  - Tracking:
    - L1: 0.9838(3) (η dep.)
    - L2: 0.9993(1)
    - L3: 0.9986(2)
  - Calorimetry:
    - L1: 100%
    - L2: E_T dep.
    - L3: 100%
  - Total for top analyses:
    - Dilepton: 0.9792(44)
    - L+J: 0.9755(55)

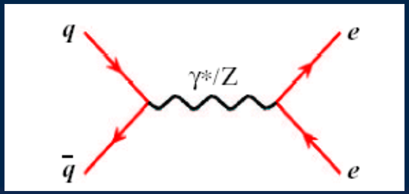


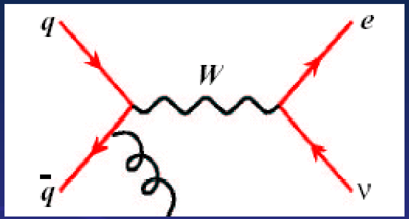
Cross section in dilepton channel

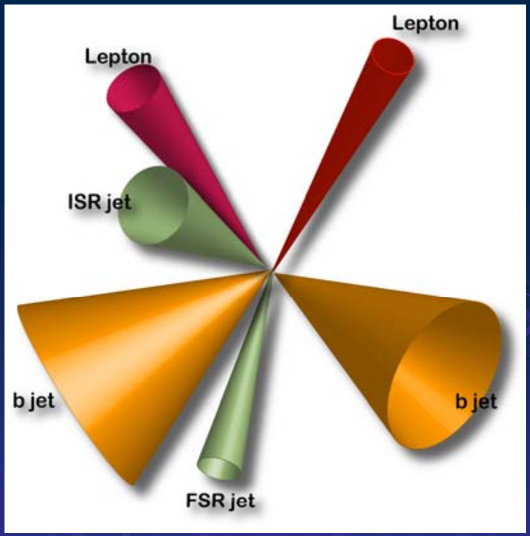
- Event Selection:
  - 2 leptons E_T>20GeV with opposite sign
  - ≥2 jets E_T>15GeV
  - Missing E_T >25GeV (and away from any jet)
  - $H_T=p_{Tlep}+E_{Tjets}+ME_T$>200GeV



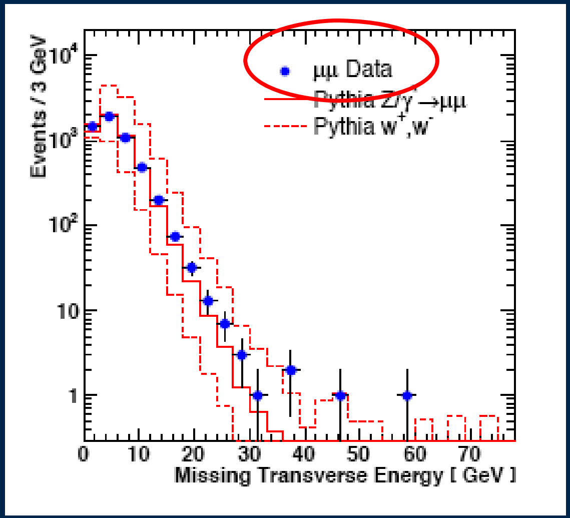
- Backrounds:
  - Drell-Yan:
    - Large
    - Must have “fake” ME_T
    - Estimate from **data**
  - W+jets:
    - Large
    - Must have jet faking lepton
    - Estimate from **data**
  - Diboson (WW, ZZ,…)
    - Small
    - Estimate from MC



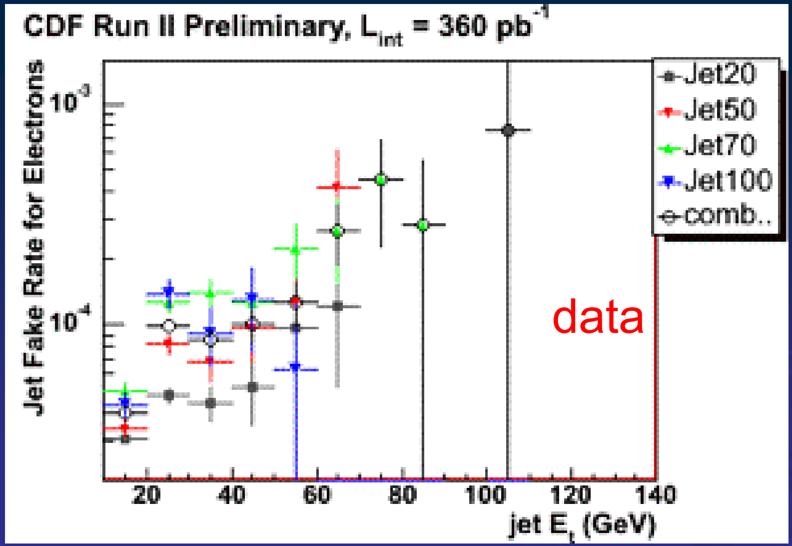




Cross section in dilepton channel



$$\times \left[R\left(\frac{\text{outside Z window}}{\text{inside Z window}}\right) R(N_{jet}) \right]_{MC} = \text{DY prediction}$$

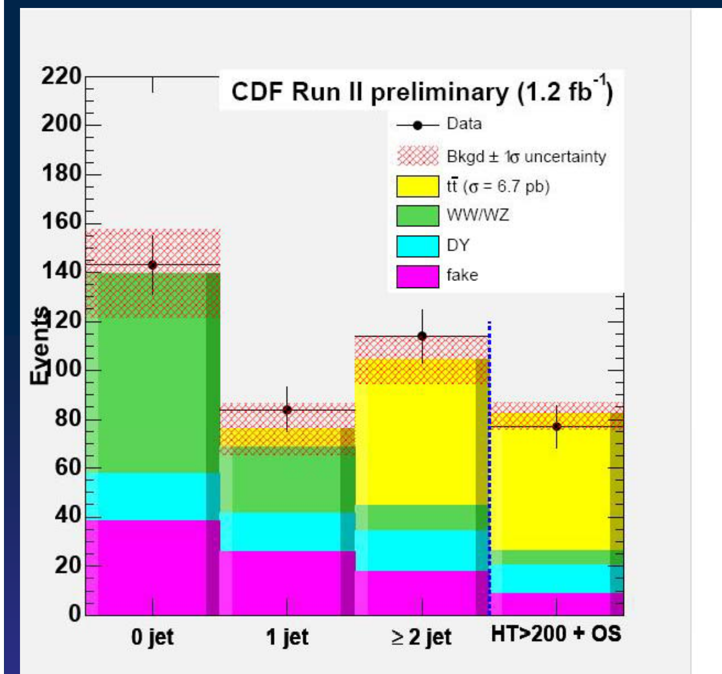


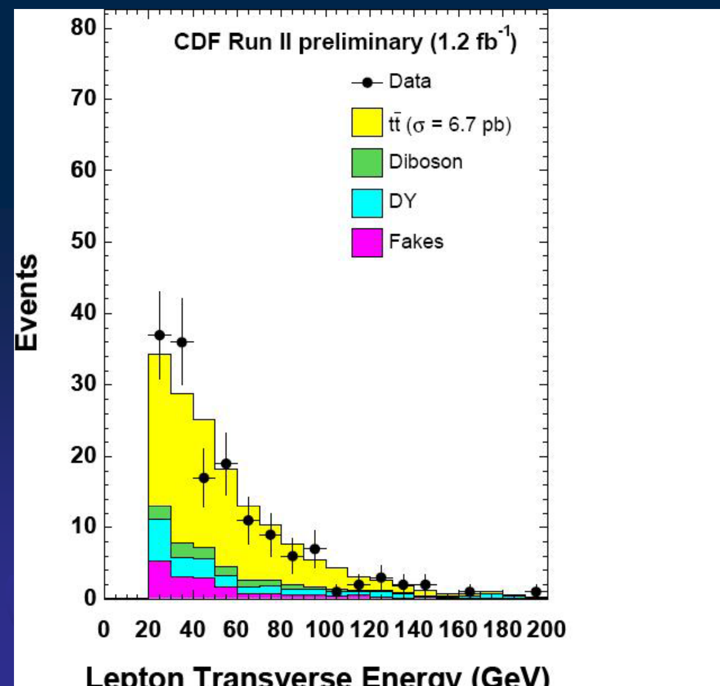
$$\times\ N(W+jets)_{data} = \text{Fakes prediction}$$

Cross section in dilepton channel

$$\sigma = \frac{N_{obs} - N_{backg}}{A \cdot L \cdot \varepsilon}$$

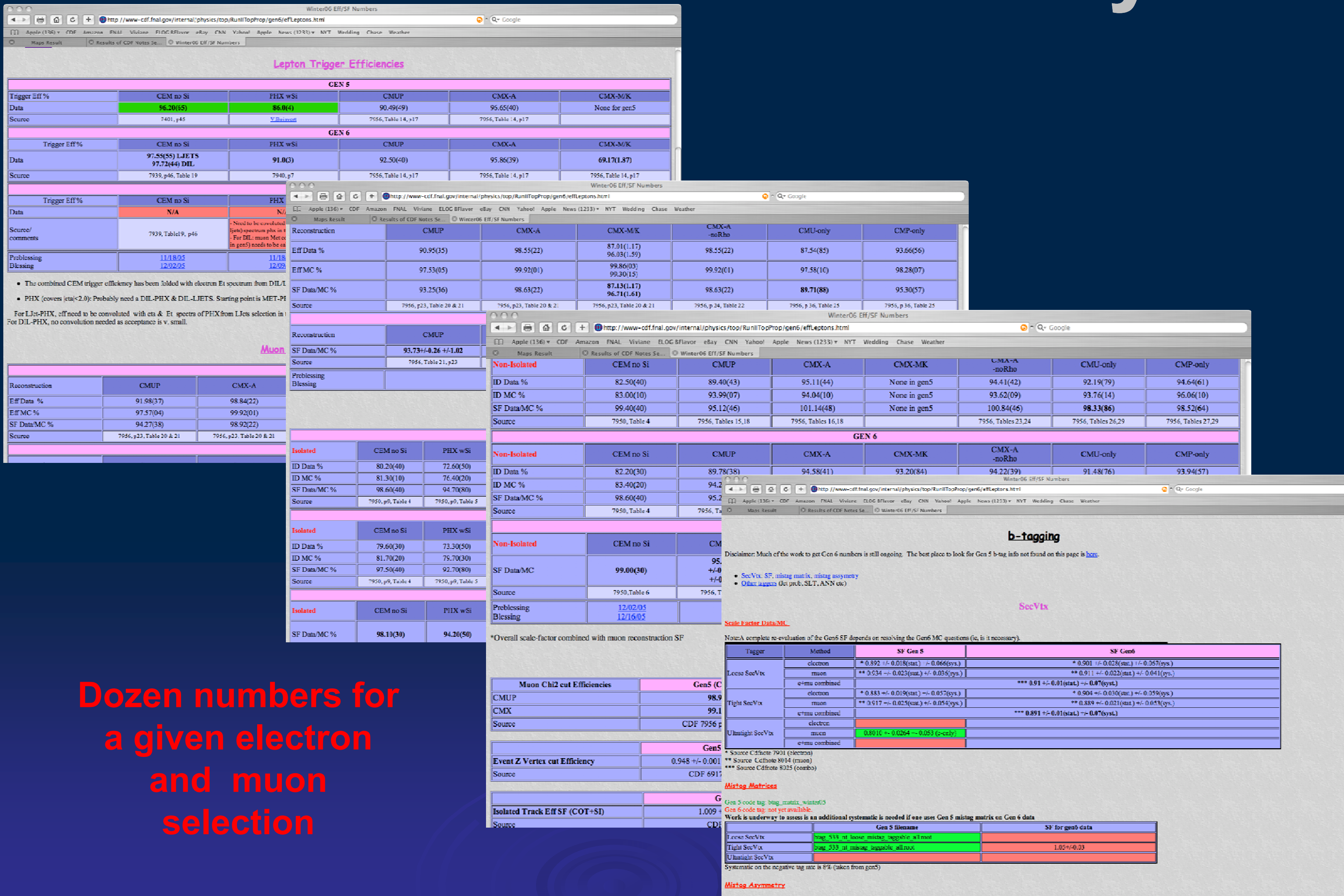
Events per 1200 pb^{-1} after all cuts				
Source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
WW	1.01±0.19	1.04±0.19	2.14±0.37	4.19±0.71
WZ	0.40±0.07	0.30±0.05	0.25±0.05	0.95±0.15
ZZ	0.28±0.22	0.28±0.22	0.10±0.08	0.65±0.51
Wγ	0.11±0.11	0.00±0.00	0.00±0.00	0.11±0.11
DY$\to \tau\tau$	0.48±0.23	0.87±0.33	1.61±0.54	2.97±0.89
DY$\to ee + \mu\mu$	2.46±0.88	4.89±1.25	0.54±0.27	7.89±2.14
Fakes	2.12±1.25	3.10±1.36	3.58±2.02	8.80±3.86
Total background	6.86±1.70	10.47±2.06	8.23±2.30	25.56±5.54
$t\bar{t}$ ($\sigma = 6.7$ pb)	12.18±0.94	13.60±1.04	30.17±2.30	55.95±4.26
Total SM expectation	19.04±2.26	24.08±2.68	38.40±3.90	81.52±8.92
GEN6 DATA	16	26	35	77





$\sigma(t\bar{t})$ = 6.2 ± 1.1 (stat) ± 0.7 (syst) ± 0.4 (lumi) pb

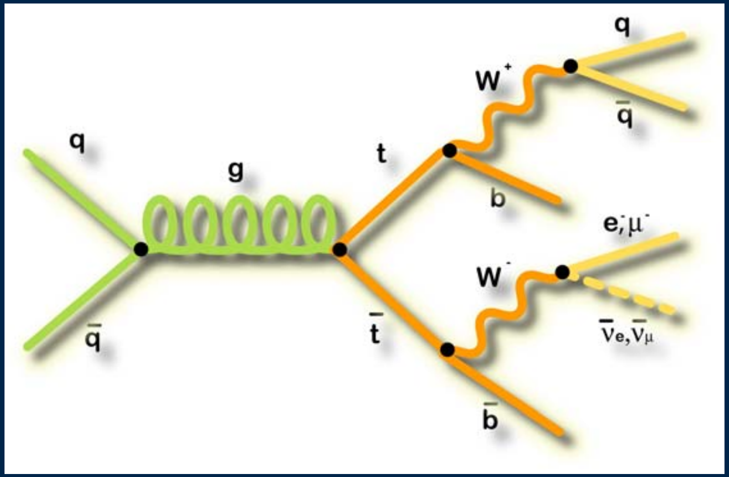
That ε number is actually…

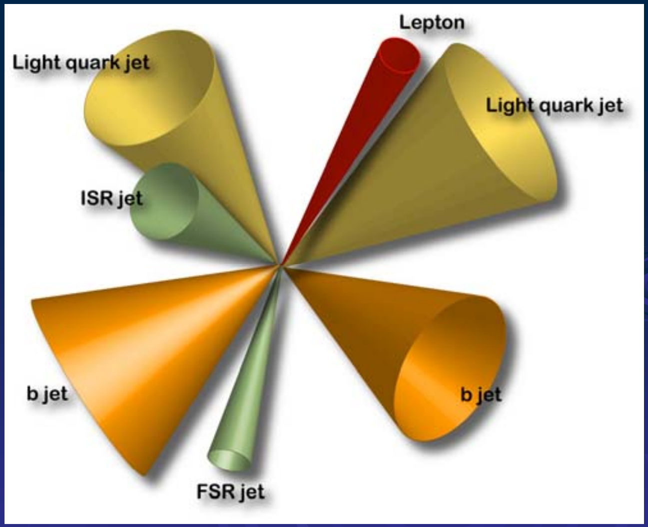


Dozen numbers for a given electron and muon selection

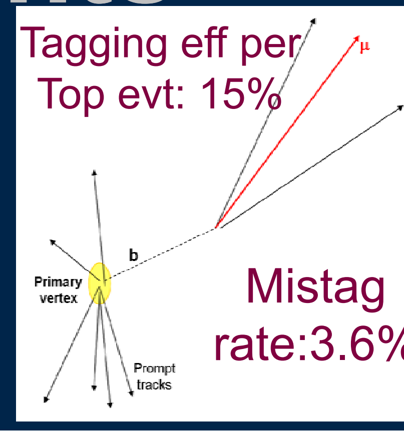
Cross section in L+J channel

- Event selection:
  - 1 lepton E_T>20GeV
  - ≥3 jets E_T>15GeV
  - Missing E_T >20GeV
  - $H_T=p_{Tlep}+E_{Tjets}+ME_T$>200GeV
  - ≥1 jet: secondary vertex tag with significant positive decay length
- Backgrounds:
  - W+jets
    - Use data and MC
  - QCD
    - Use data

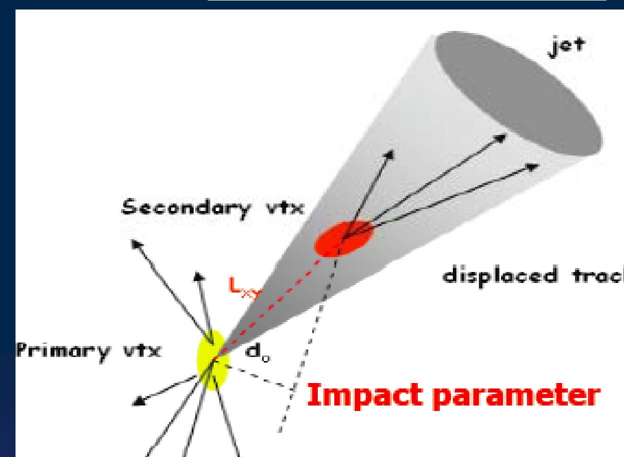




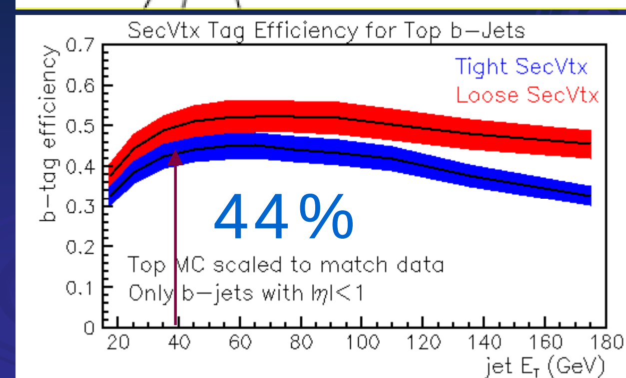
b tagging in top events



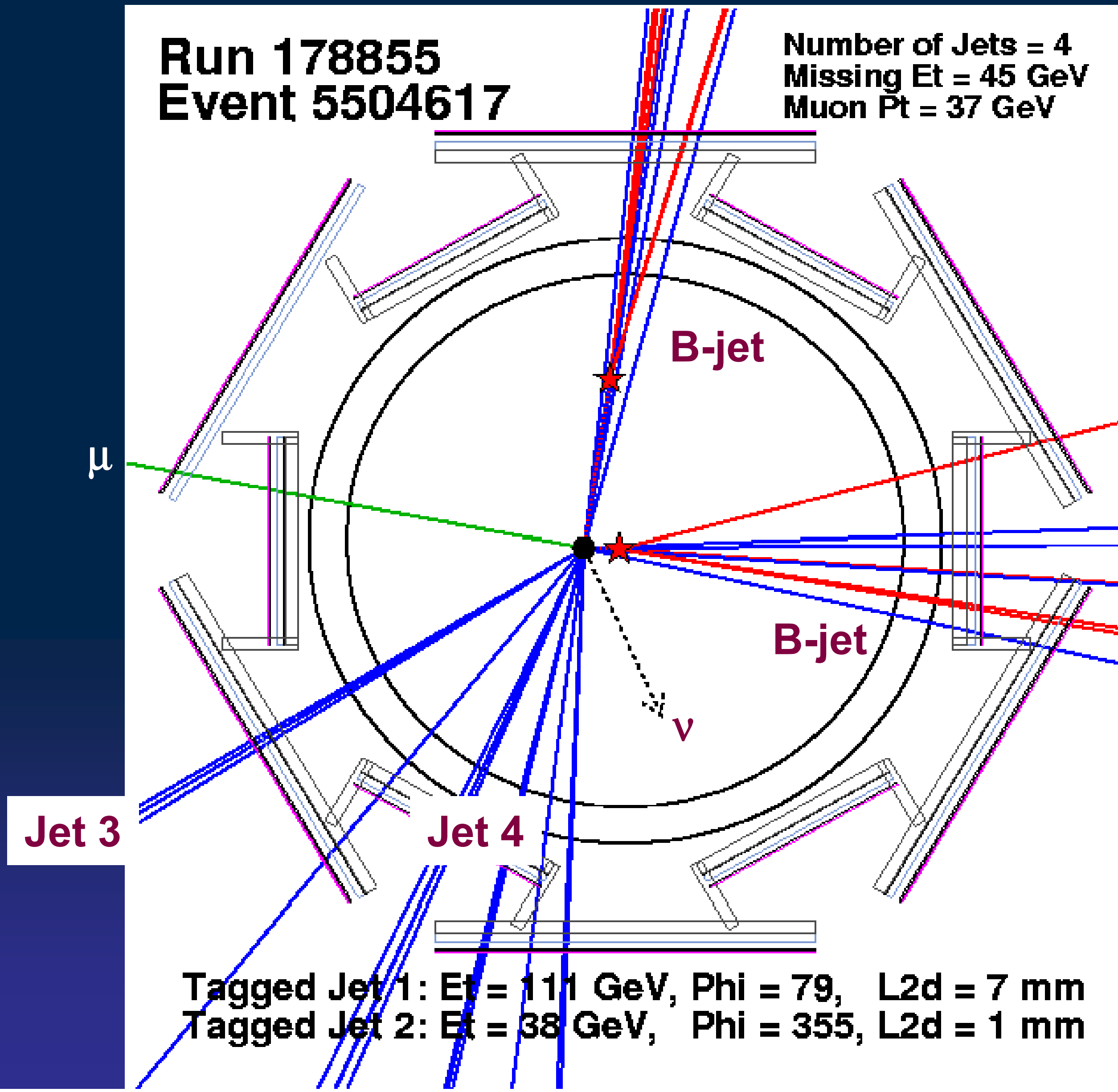
- b hadrons are massive:
  - Transition into lighter flavors
  - Semileptonic decay: 20%
    - Soft Lepton Tag
- b hadrons have life time:
  - $c\tau \sim 460\mu m$, travel few mm
  - Make secondary vertex
    - SecVtx tagger



	Tight SecVtx	Loose SecVtx
Efficiency per b-jet	40±3%	48±4%
Efficiency per c-jet	9±2%	13±2%
Mistag per jet	0.48±0.04%	1.20±0.07%
Tagging efficiency per Top evt		
³1	60±3%	69±5%
³2	16±3%	23±3%



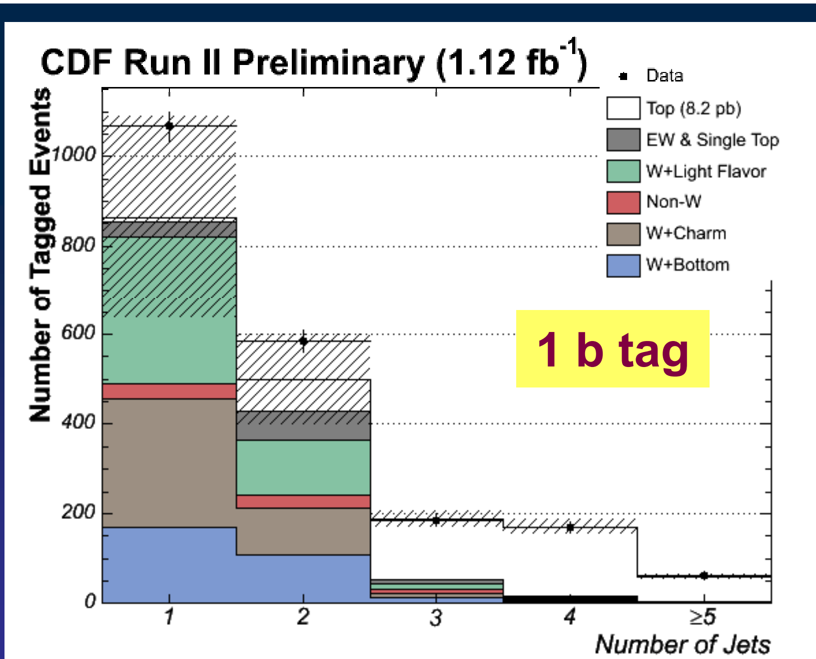
b tagging in Top events

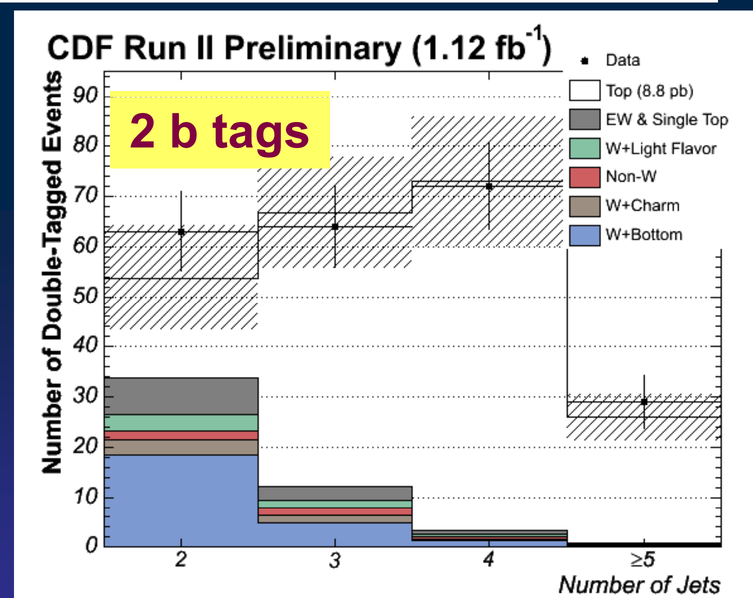


Cross section in L+J channel

Systematic	Inclusive (Tight)	Double (Loose)
Lepton ID	1.8	
ISR	0.5	0.2
FSR	0.6	0.6
PDFs	0.9	
Pythia vs. Herwig	2.2	1.1
Luminosity	6.2	
JES	6.1	4.1
b-Tagging	5.8	12.1
c-Tagging	1.1	2.1
l-Tagging	0.3	0.7
Non-W	1.7	1.3
W+HF Fractions	3.3	2.0
Mistag Matrix	1.0	0.3
Total	11.5	14.8

$\sigma(t\bar{t})$ = 8.2 ± 0.5 (stat) ± 0.8 (syst) ± 0.5 (lum) pb

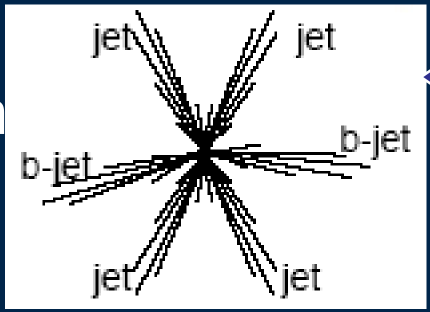




$\sigma(t\bar{t})$ = 8.8 ± 0.8 (stat) ± 1.2 (syst) ± 0.5 (lum) pb

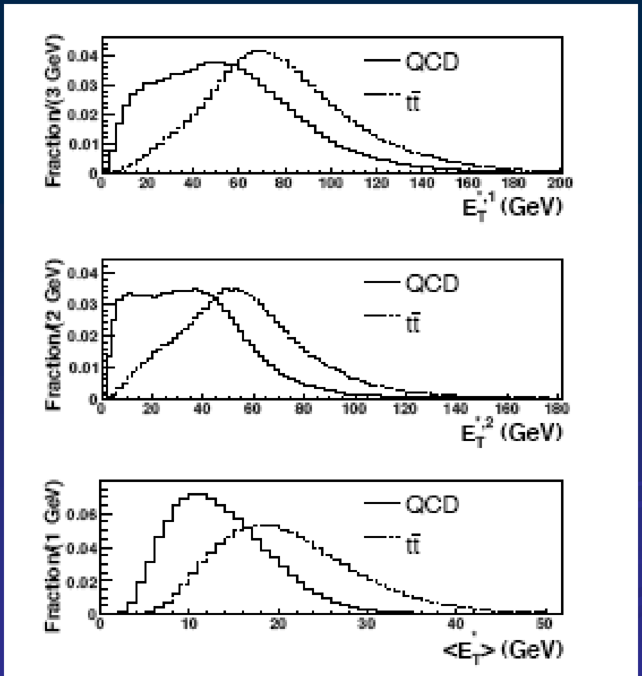
Cross section in all hadronic

- Selection:
  - $6 \leq N$ jets ≤ 8 with $p_T > 15GeV/c$
  - $\Delta R_{min} \geq 0.5$
  - ≥ 1 b tagged
  - NN discriminant > 0.94

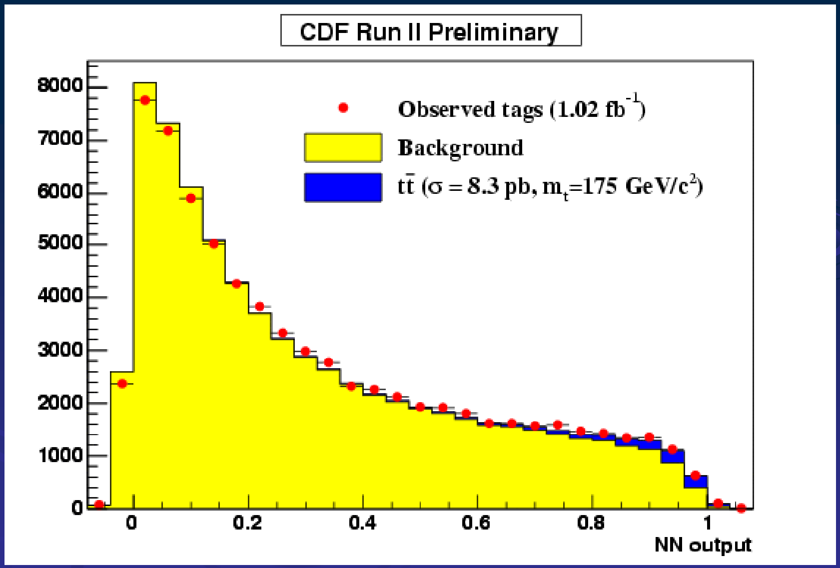


discriminate ⟷ Huge QCD background !

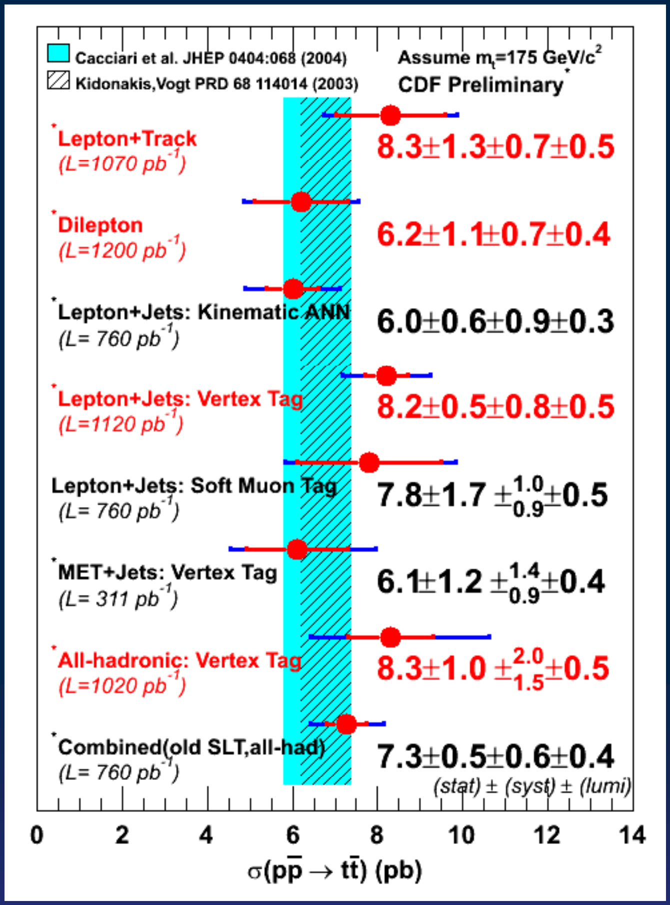
11 kinematic variables in neural net



$$\sigma(t\bar{t}) = 8.3 \pm 1.0(\text{stat}) \pm 0.5(\text{lum})^{+2.0}_{-1.5}(\text{syst})\text{pb}$$



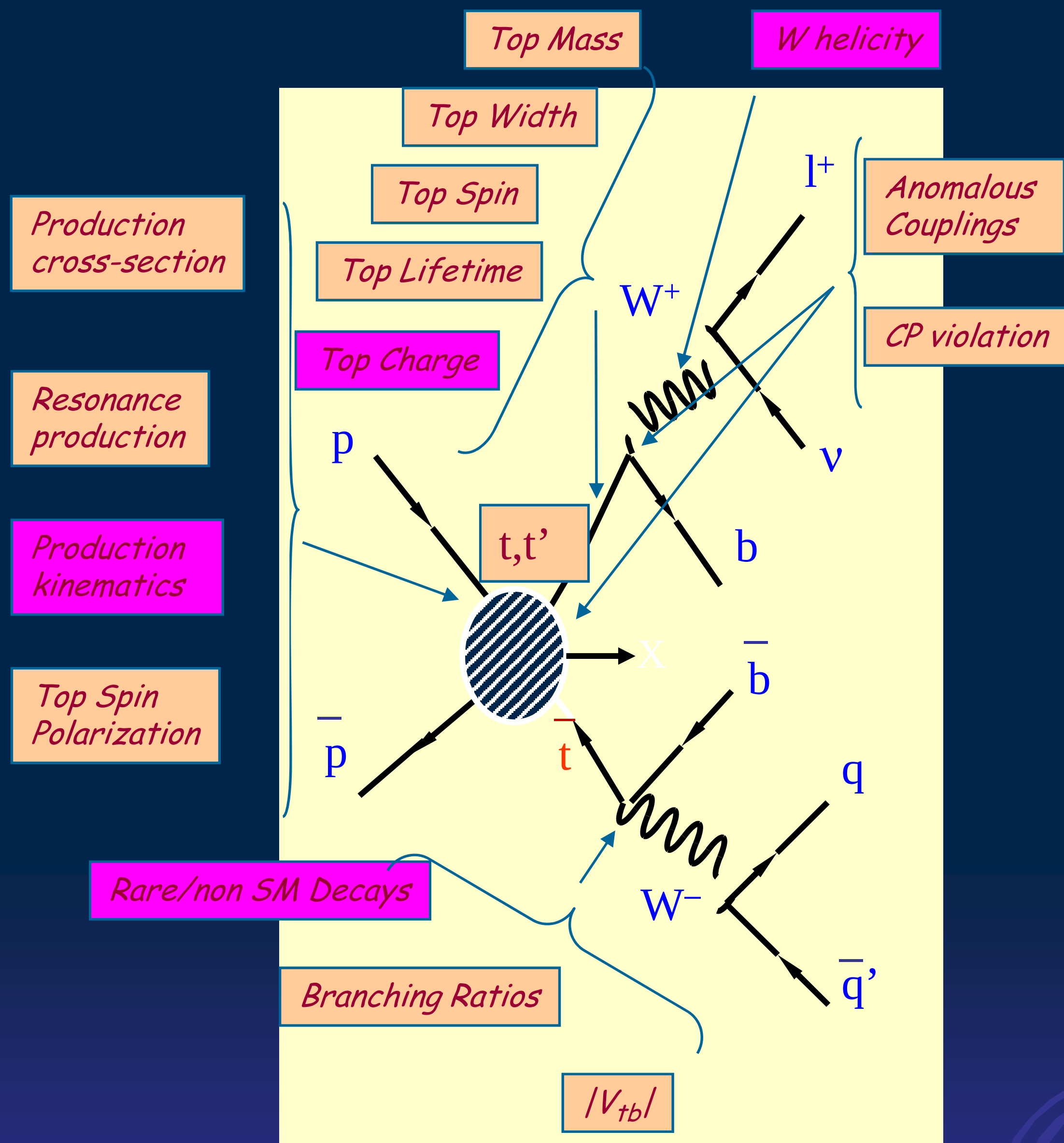
Summary of Top cross sections



- Can already test theory estimate
- Soon can test among different channels

So far…

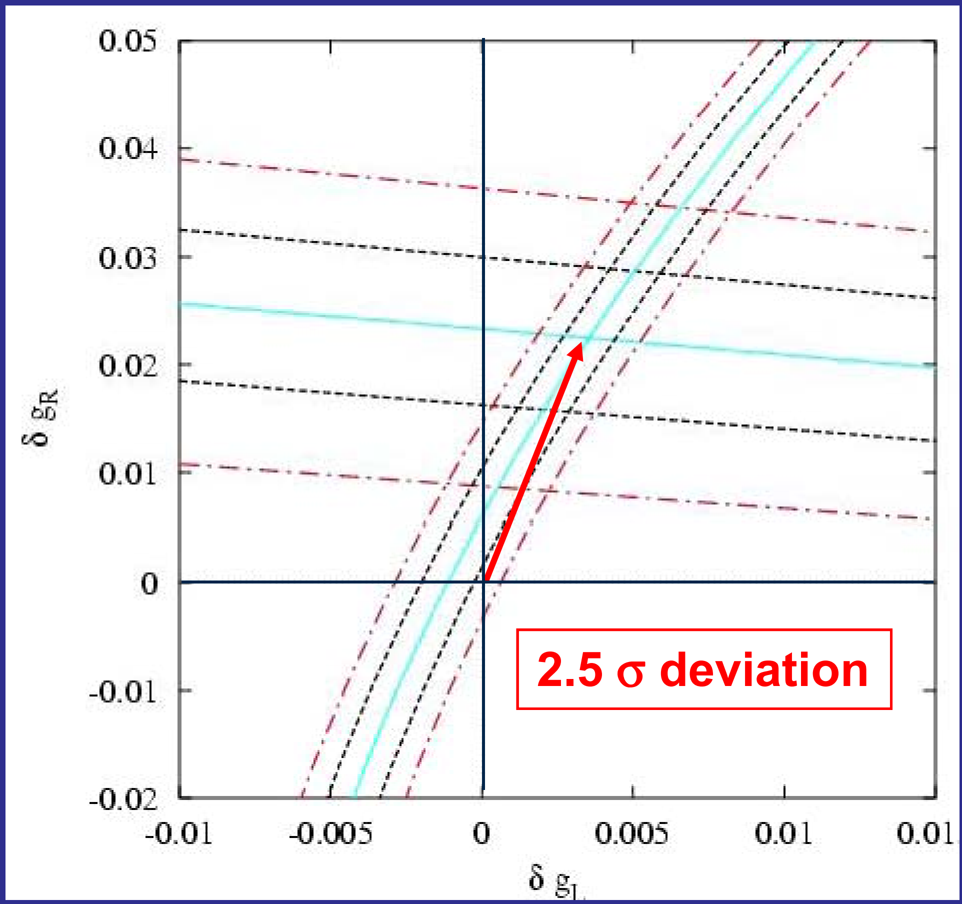
- Looked at Standard Model
  - Hierarchy problem
    - Electroweak symmetry breaking mechanism is involved
    - Top quark seems to be an important player and could give us clues
- Top Physics:
  - Top Factory: Tevatron
  - Top Production
  - Top cross section measurement
  - Top properties measurements



All CDF Top results: http://www-cdf.fnal.gov/physics/new/top/top.html

Why Measure Top Charge

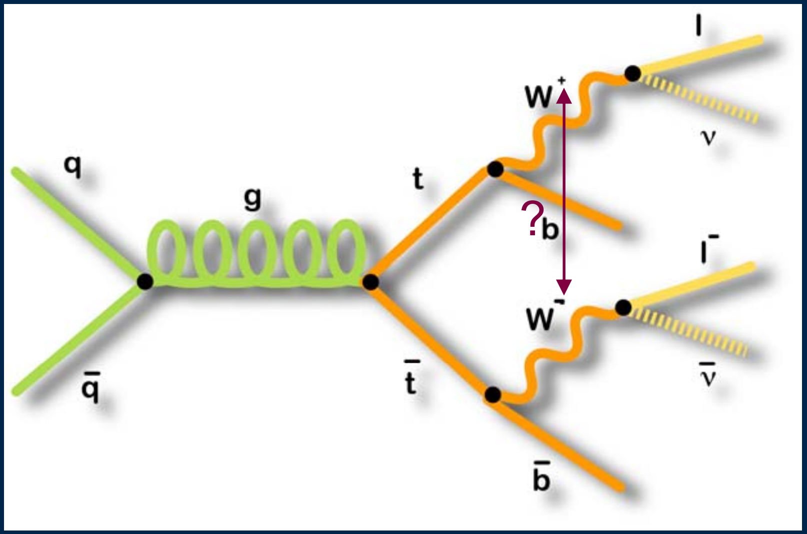
- "Top" is SM Top (Q=+2/3) or something more exotic related with EWSB?
- Alternative to +2/3
  - $(Q_1,Q_4)_R$ Q_4q=-4/3
  - Better global EW fit
    - g_{bL} shift: larger m_t
    - g_{bR} shift: mixing of b_R with $(Q_1,Q_4)_R$
  - m_t~274GeV/c^2
  - Higgs triplet
  - D. Chang et. al. Phys. Rev. D (59) 1999 091503

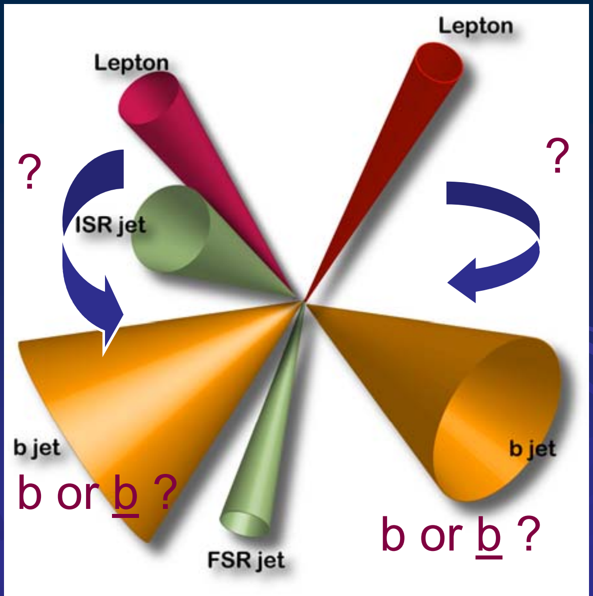


Choudhury, Tait, Wagner, PRD65, 053002 (2002)

How to measure the |charge|

- $X \rightarrow W^{+}b$ or $W^{-}b$ (and cc)?
- Ingredients:
  - 1) Charge of W
    - Charge of lepton
  - 2) Pairing between W and b
  - 3) Flavor of b jet
- Datasets:
  - Use cross section meas.
    - Dilepton (single tagged)
    - Lepton+Jets (double tagged)

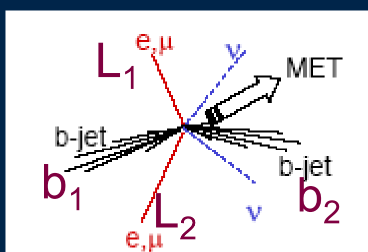




Wb pairing

- Dilepton Channel:
  - Calculate M_{lb}^2, order 4 values in ascending order
  - $M_{lbmax}^2 > 21{,}000\ \mathrm{GeV}^2/c^4$
  - Choose combination without M_{lbmax}^2

$$M_{lb}^2 = (E_l + E_b)^2 - (\vec{p}_l + \vec{p}_b)^2$$

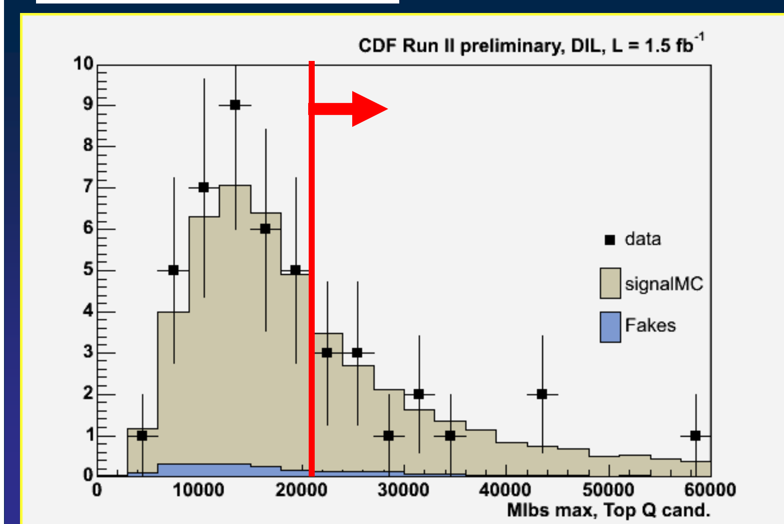


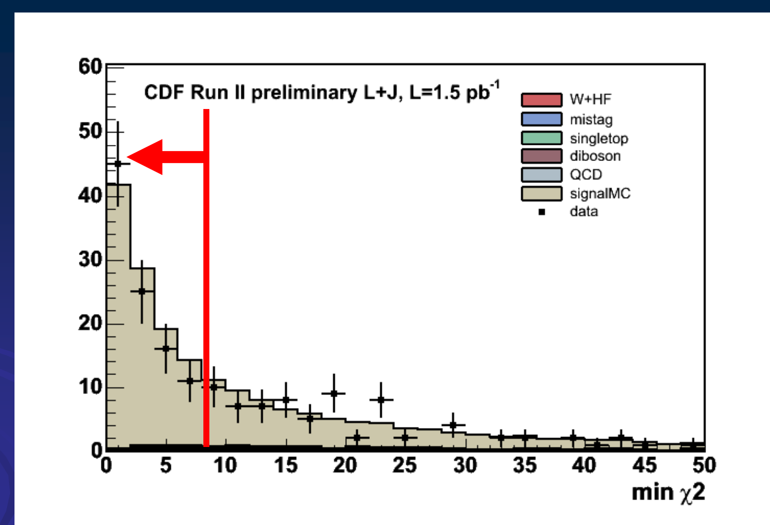
ε=39% P=95% εD²=0.32

D=2P-1

- Lepton+Jets Channel:
  - Constraints: W mass, top mass, etc.
  - Same χ^2 as in top mass analyses
  - 12 combinations x 2 (p_z neutrino)
    - Double tagged events:
      - 4 combinations
  - Take min χ^2 combination and require < 9

ε=53% P=86% εD²=0.27





Top Mass χ^2

$$\chi^2 = \sum_{i=l,\,jets} \frac{(p_t^{i,meas} - p_t^{i,fit})^2}{\sigma_i^2} + \sum_{i=x,y} \frac{(p_i^{UE,meas} - p_i^{UE,fit})^2}{\sigma_i^2}$$

$$+ \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{l\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - M_{fit})^2}{\Gamma_t^2} + \frac{(M_{bl\nu} - M_{fit})^2}{\Gamma_t^2}$$

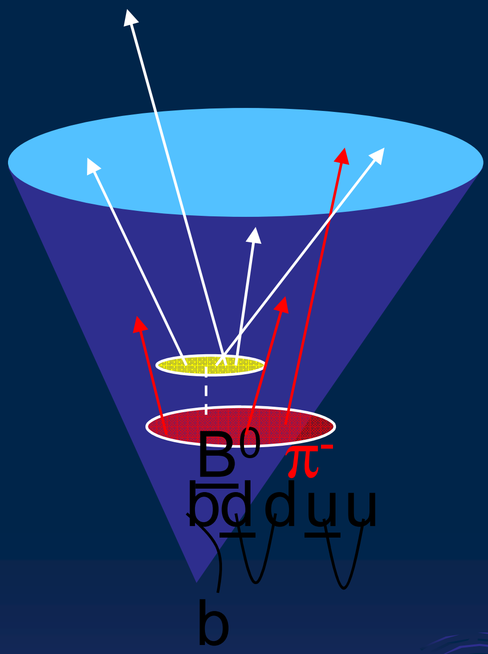
- UE=Unconstrained Energy (energy outside $t\bar{t}$ interaction)
- Fit modifies p_t of leptons and jets
  - Improves resolution
  - Improves probability of correct assignment
- Constrained or unconstrained fit
- 24 possible combinations (2 $p_{z\nu}$ possible)
- Performance of correct b assignment: (take lowest χ^2 combination)
  - 1 “tight” b-tag constrained fit: 60%
  - 2 “loose” b-tag constrained fit require lowest $\chi^2 < 9$: 84%

b flavor tagging

$$\text{JetQ} = \frac{\sum (\vec{p}_{track} \bullet \vec{p}_{jet})^x \cdot Q_{track}}{\sum (\vec{p}_{track} \bullet \vec{p}_{jet})^x}$$

Dil: ε=87% P=61% εD^2=0.10

L+J: ε=98% P=61% εD^2=0.13



- Need to calibrate in data!

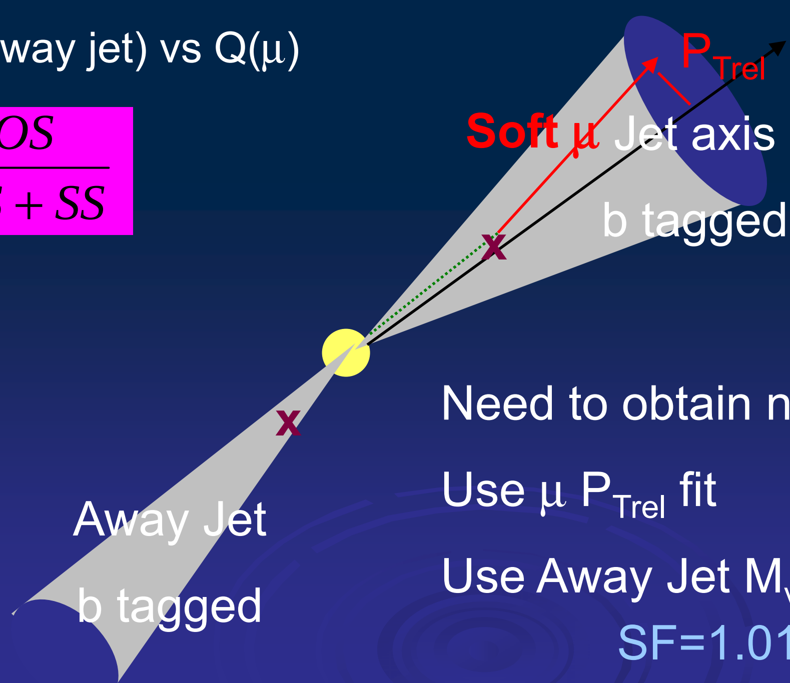
Compare: JetQ(away jet) vs Q(μ)

$$P = \frac{OS}{OS + SS}$$

Correct for:

$b \to c \to \mu$

Mixing



Need to obtain non-b fraction:

Use μ P_{Trel} fit

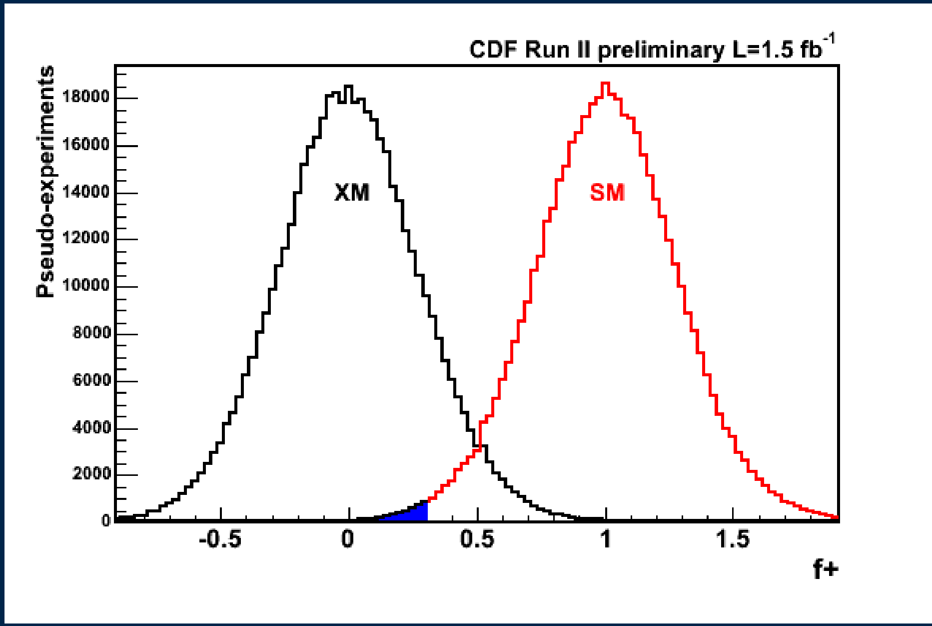
Use Away Jet M_{vtx}

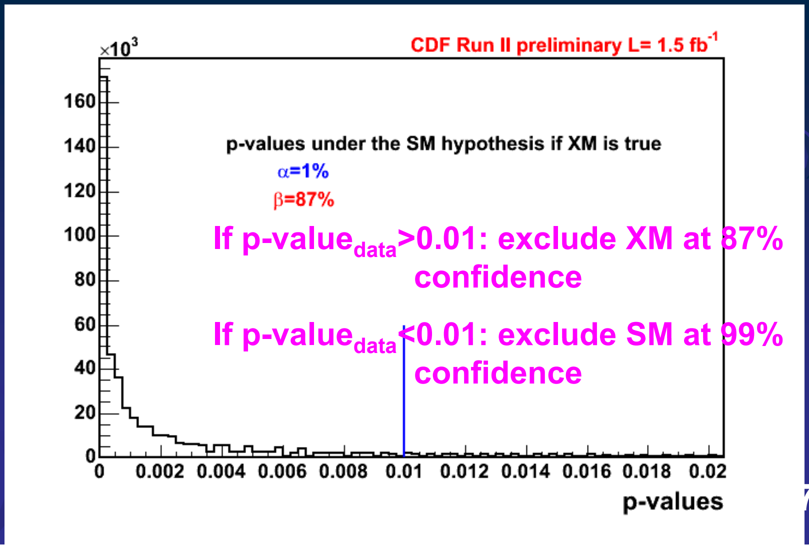
Extrapolate to high p_T, η

SF=1.01 ±0.01(stat) ±0.02(syst)

Statistical treatment

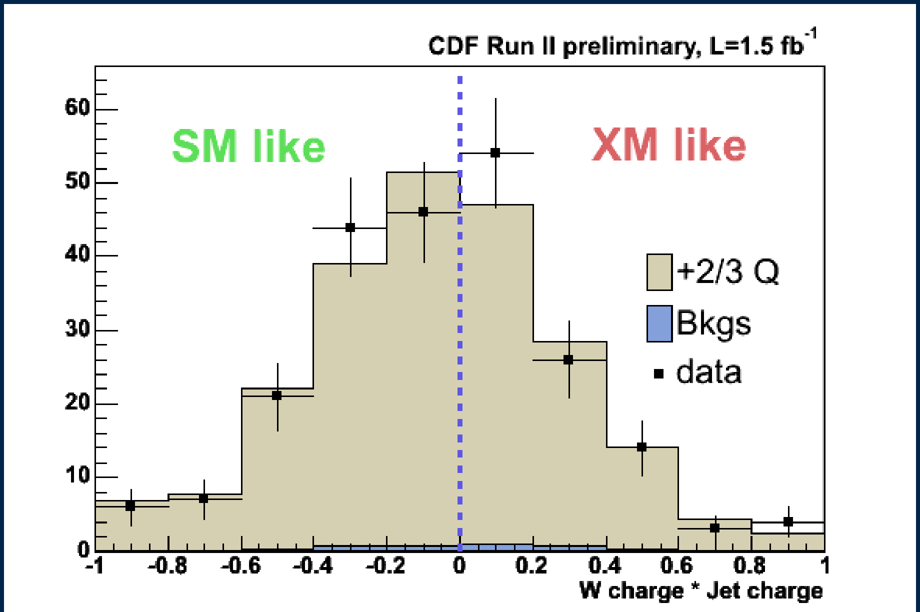
- From Data N(SM), N(XM) then what?
- Use Profile Likelihood method where f^+ is parameter of interest
  - Get p-value according to SM
    - Prob of measuring f_+ <= value
  - Decide before looking at the data a value of α=1%
    - α=Prob of incorrectly rejecting the SM
    - β=sensitivity= prob of rejecting the SM if XM is true = 87%
- Since comparing 2 hypothesis (SM vs XM) compute a Bayes Factor:
  - Likelihood ratio and integrate over the nuisance parameters
  - If use expectations get x+=102 out of 179 : 2Ln(BF)=13.1 ~ 3.6σ
- Also provide Feldman-Cousins bands for f^+



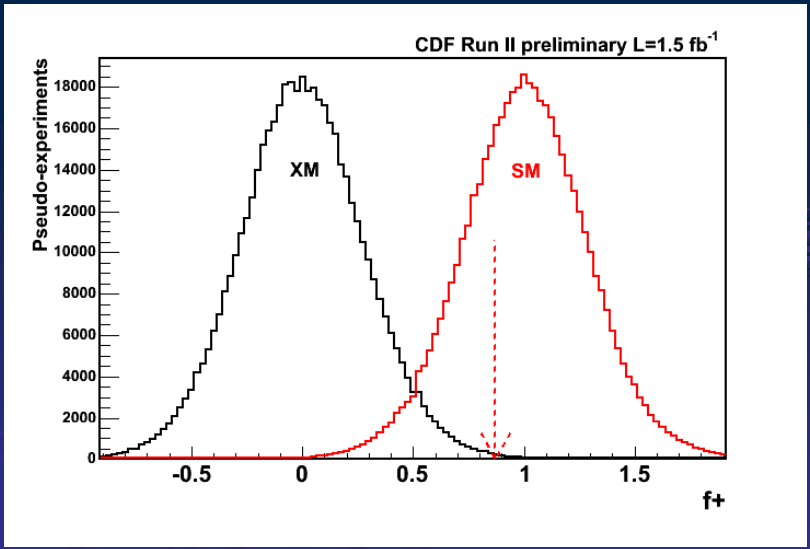


Data Results

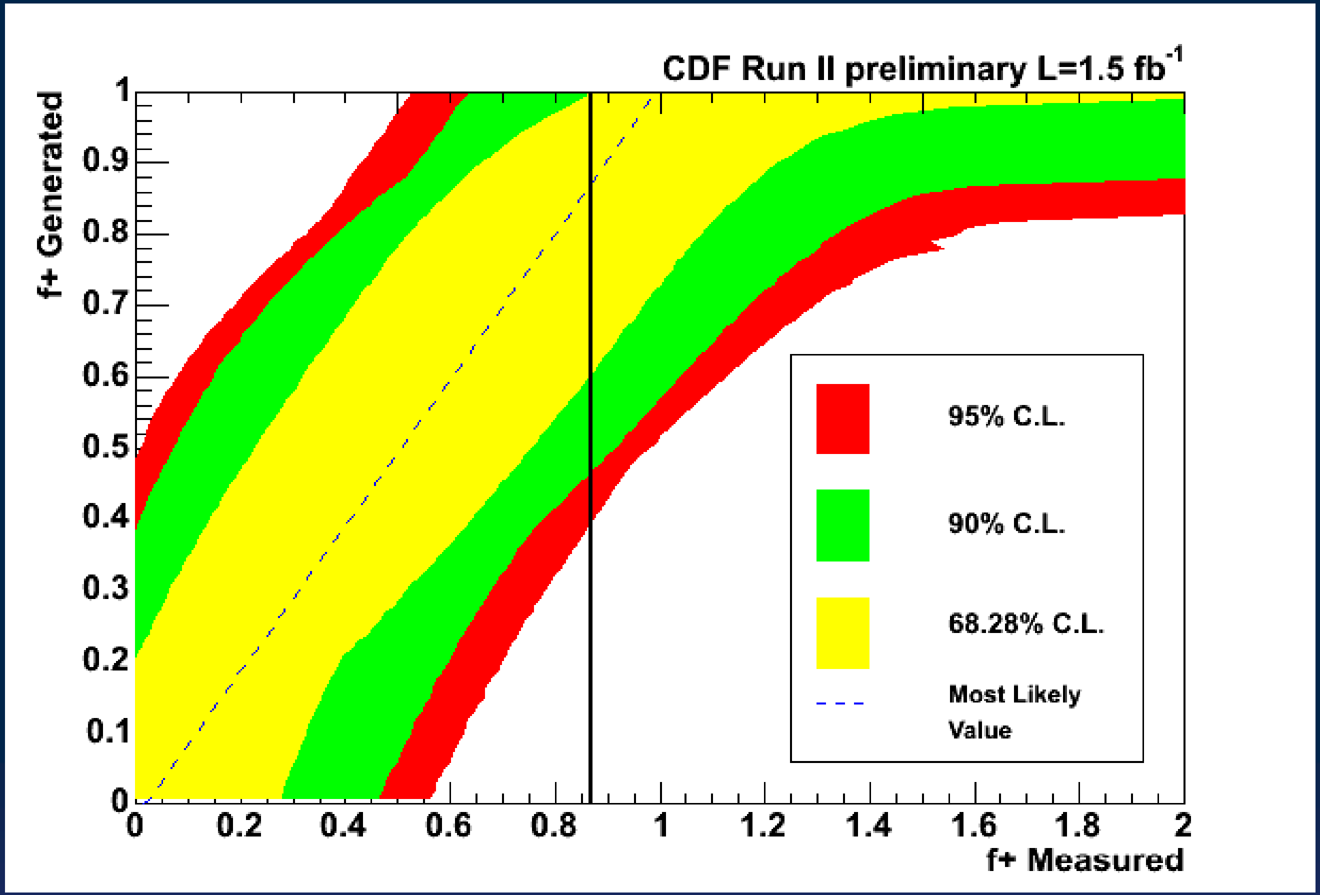
- Using 124 SM and 101 XM
- Get f_+ = 0.87
- p-value=0.31
- Since this is >0.01
  - We exclude the XM with 87% confidence



- Bayes Factor is 12.01~3.4σ
  - The data favors “very strongly” the SM over the XM



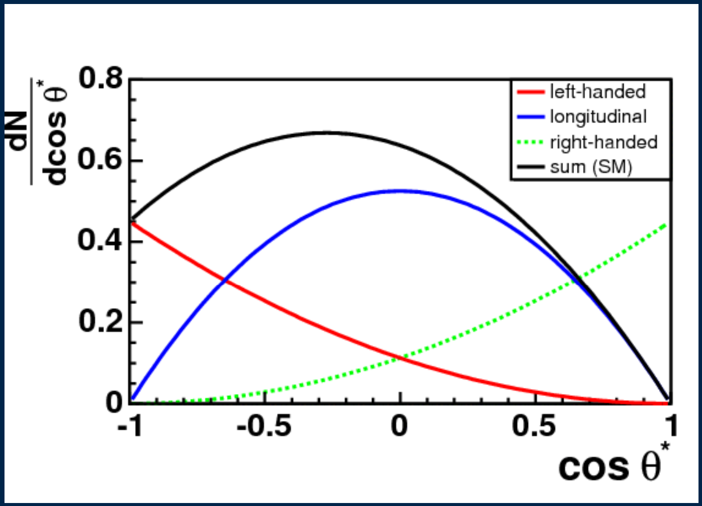
Feldman-Cousins band

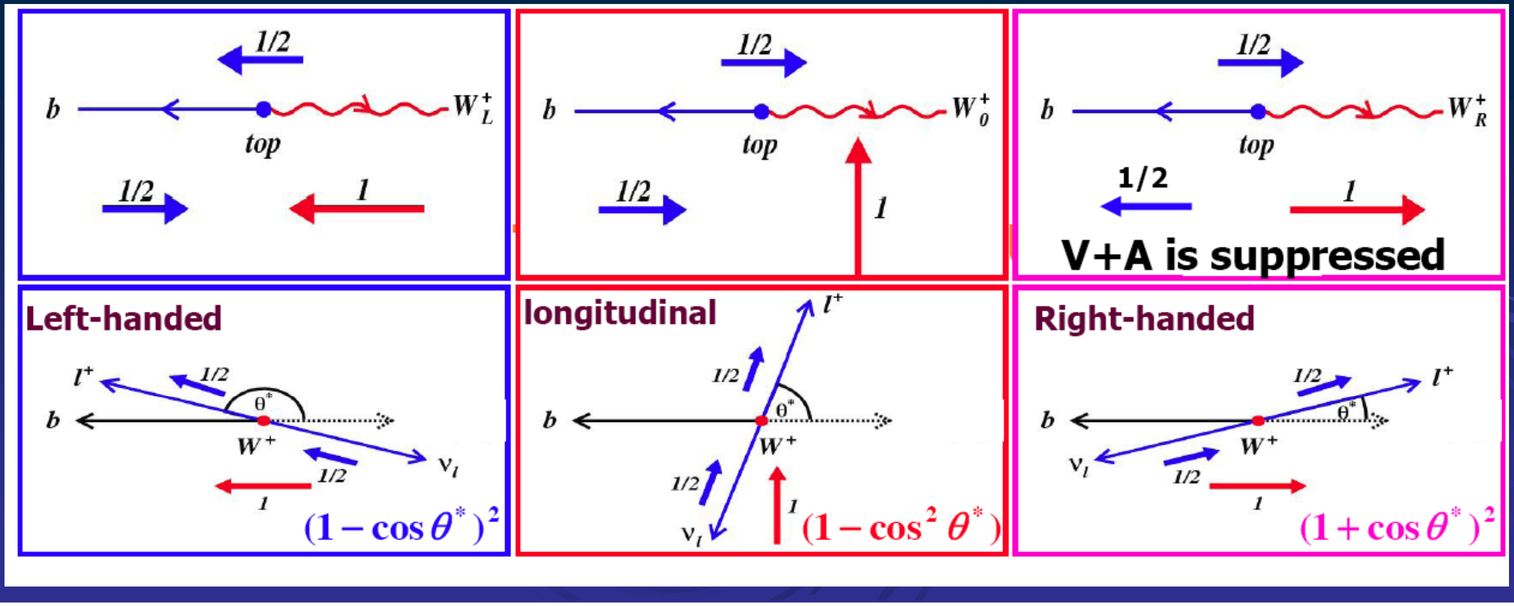


- $f_+ > 0.40$ at 95%CL
- $f_+ > 0.46$ at 90%CL
- $f_+ > 0.60$ at 68%CL

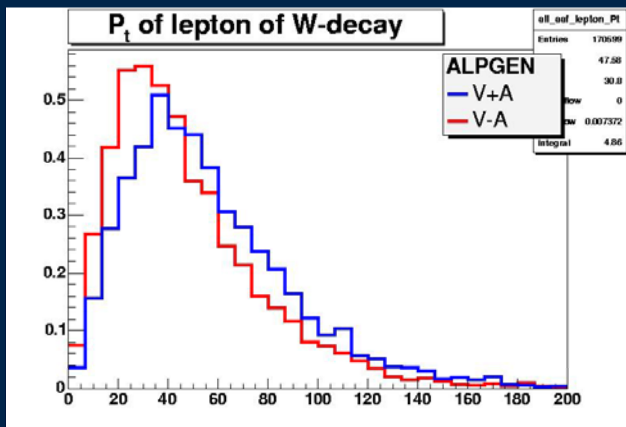
W helicity measurement

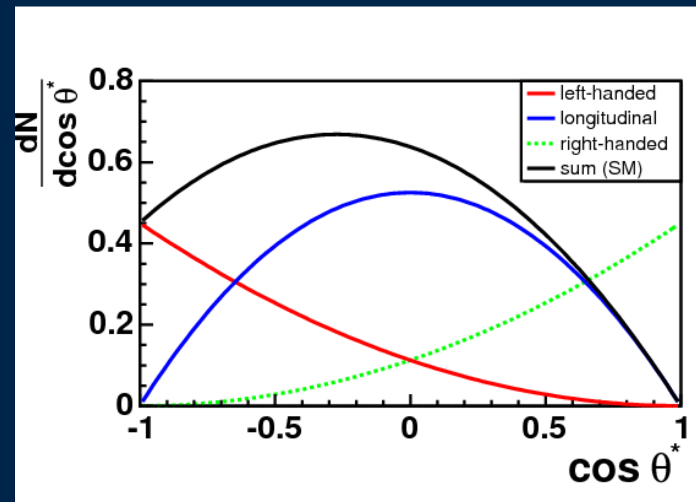
- Measurement possible because of large Top mass
  - Top spin transferred to decay products
- Test V-A structure of the tWb vertex
  - EWSB predicts large longitudinal component:
    - At LO: $f_- = 0.3 \;\; f_0 = 0.7 \;\; f_+ = 0$



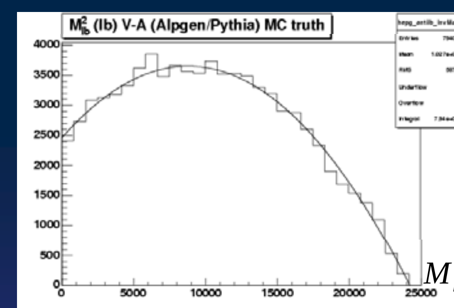


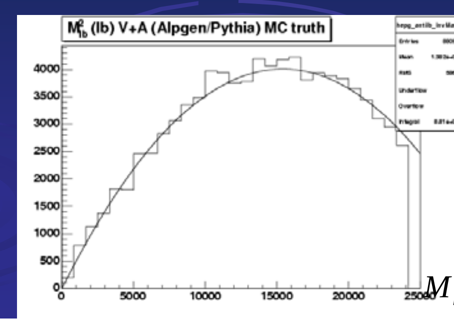
W helicity measurement





$$M_{lb}^2 = \frac{1}{2}(\cos\theta^* + 1)(m_t^2 - M_W^2)$$





Need to correct for acceptance effects!

- Choose 3 analyses:
  - 2 involving cosθ*
    - Unfolding method
    - Template method
  - 1 making use of Matrix Element

Unfolding method results

Unfolding method

Fully reconstruct the tt event

Calculate cosθ*

Construct efficiency and migration matrix

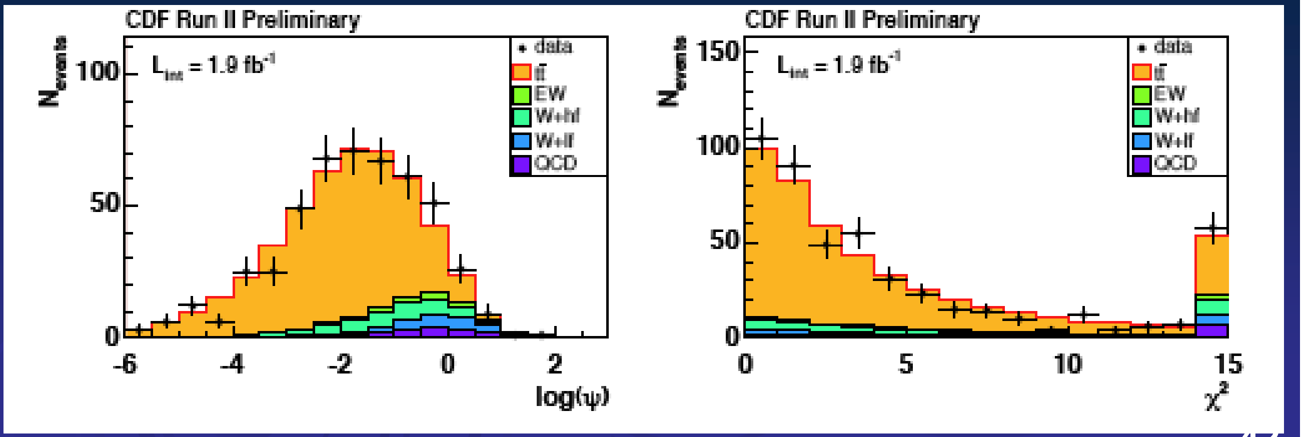
Fit helicity fractions using binned likelihood fitter

Unfold cosθ* distribution

- Use ME_T for the neutrino four-momentum
  - Ambiguity for p_z
- Try all possible hypothesis of assigning jets to partons
  - Build a quantity Ψ for each hypothesis:

$$\Psi = P_{\nu} \cdot P_{b-light} \cdot \chi^2$$

  - $$\cos\theta^* = \frac{p_l \cdot p_b - E_l \cdot E_b}{|p_l||p_b|}$$ he chosen z component solution of the
  - $P_{b\text{-light}}$ is measure of light quark likeness
  - χ^2 is constraint on mass of W, top and total transverse energy of the event



Unfolding method results

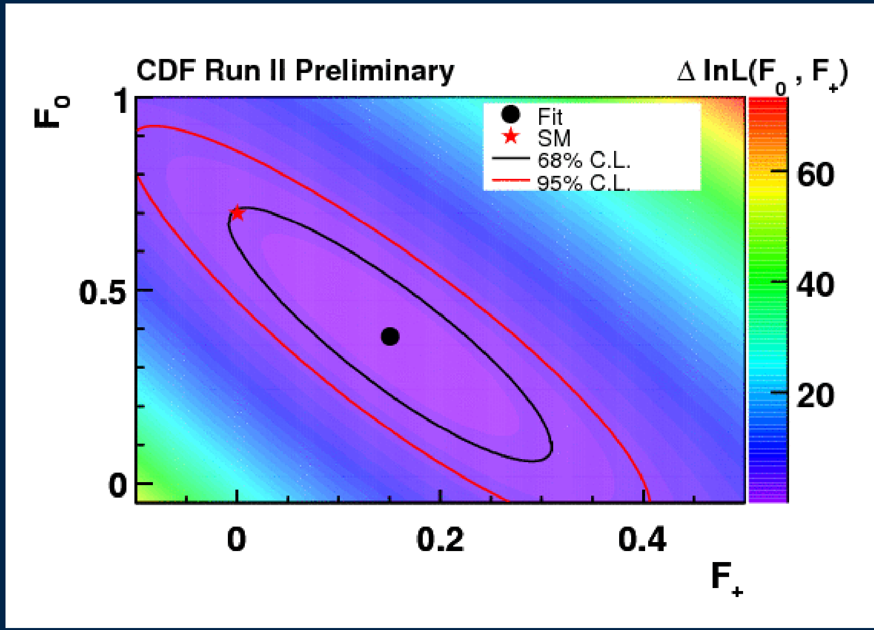
Unfolding method

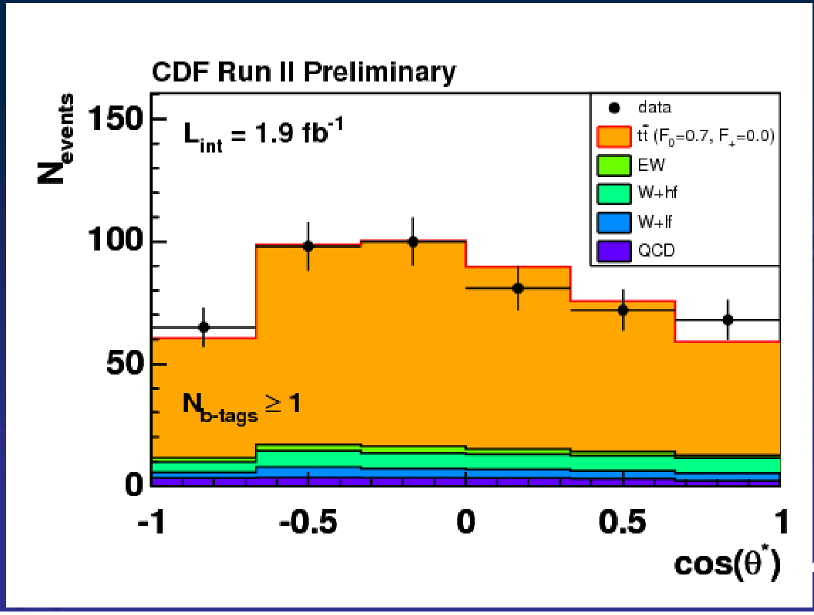
Fully reconstruct the $t\bar{t}$ event

Calculate cosθ*

Construct efficiency and migration matrix

Fit helicity fractions using binned likelihood fitter





2-D fit:

$f_0 = 0.38 \pm 0.21(\text{stat}) \pm 0.07(\text{syst})\ f_+ = 0.15 \pm 0.1 \pm 0.05$

1-D fits:

$f_0 = 0.66 \pm 0.10 \pm 0.06 \quad f_+ = 0.01 \pm 0.05 \pm 0.03$

$f_+ < 0.12$ at 95%CL

Unfolding method results

Unfolding method

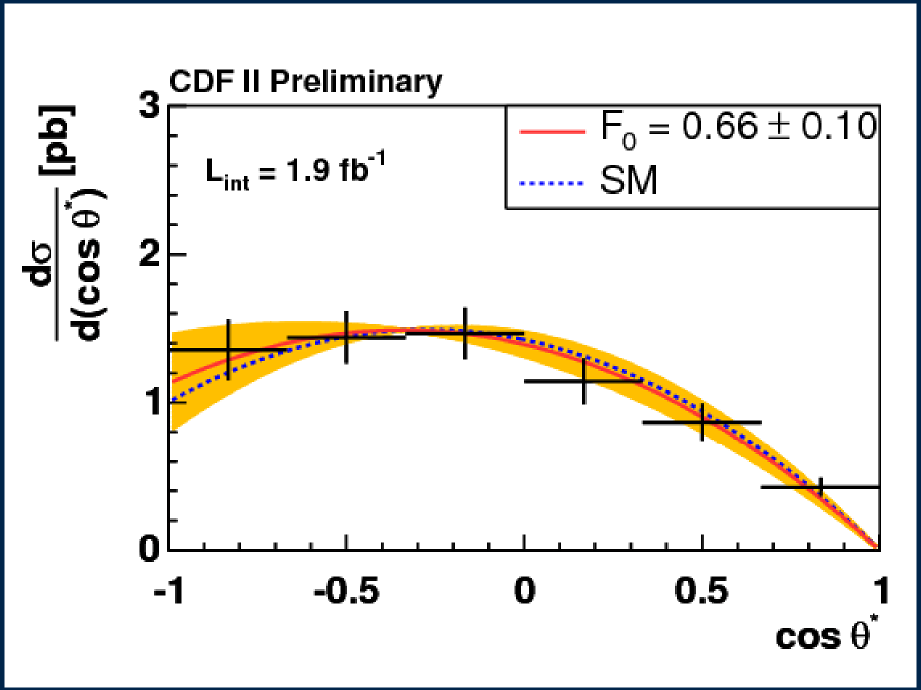
Fully reconstruct the $t\bar{t}$ event

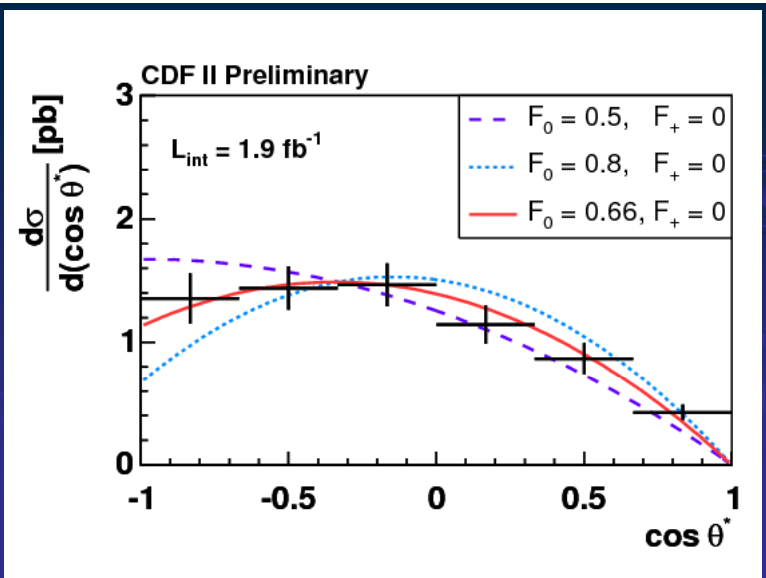
Calculate cosθ*

Construct efficiency and migration matrix

Fit helicity fractions using binned likelihood fitter

Unfold cosθ* distribution





Template method results

Template method

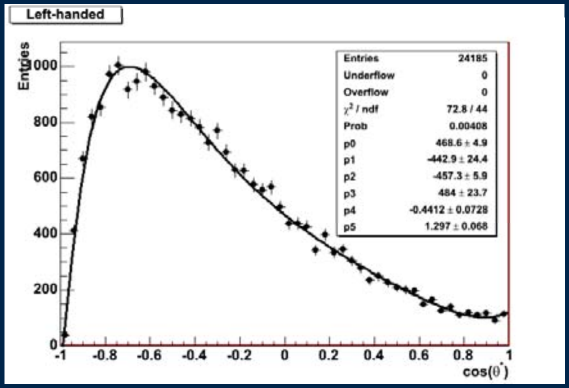
Fully reconstruct the $t\bar{t}$ event

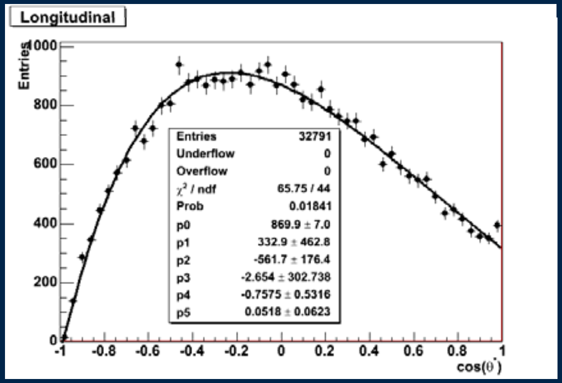
Calculate cosθ*

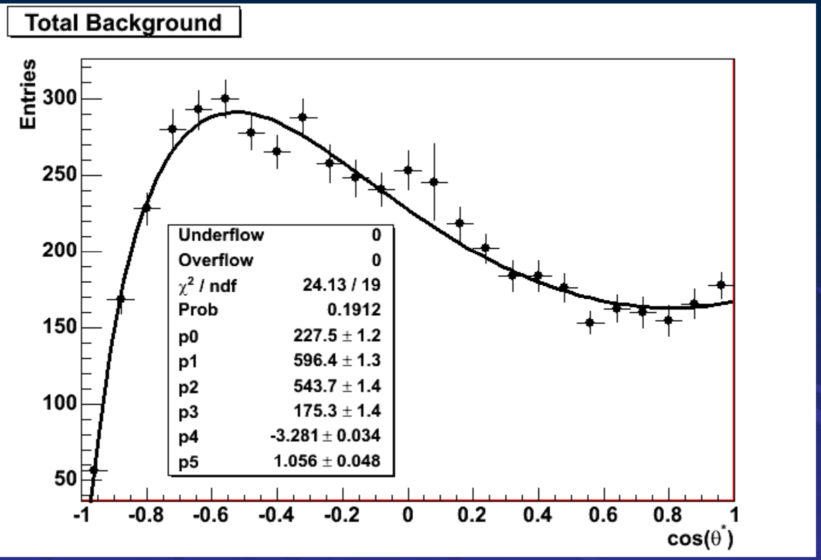
Construct templates for +,-,0 W's and background

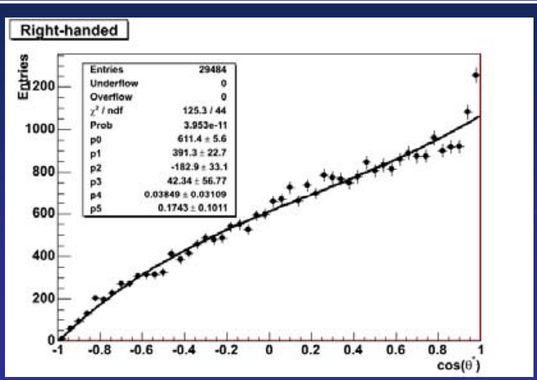
Fit helicity fractions using unbinned likelihood fitter

Correct for acceptance effects









Template method results

Template method

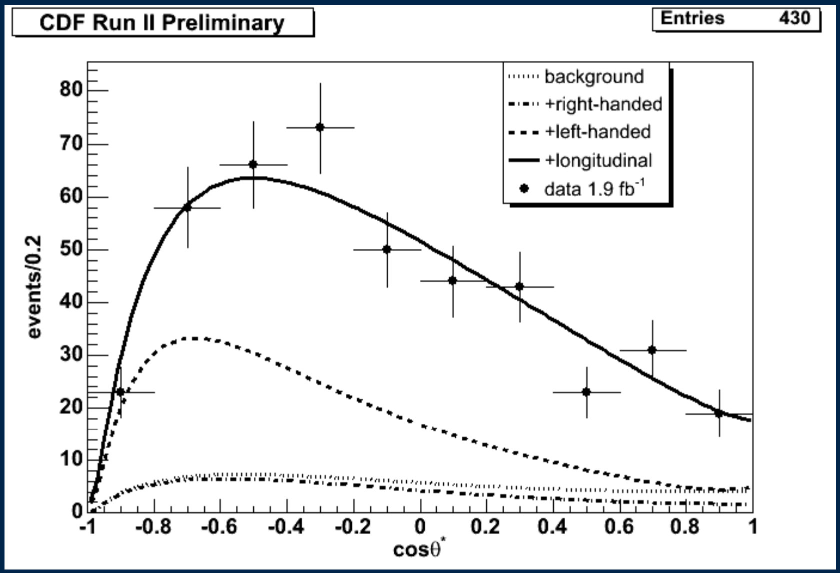
Fully reconstruct the tt event

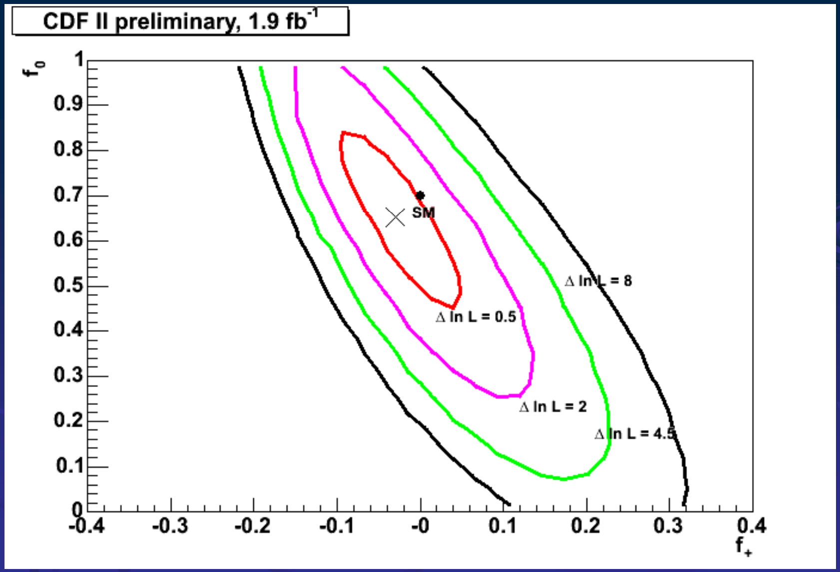
Calculate cosθ*

Construct templates for +,-,0 W's and background

Fit helicity fractions using unbinned likelihood fitter

Correct for acceptance effects





Template method results

Template method

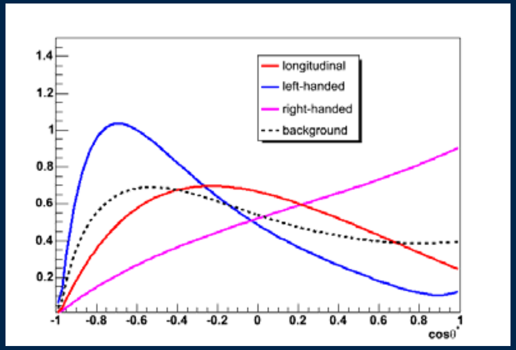
Fully reconstruct the tt event

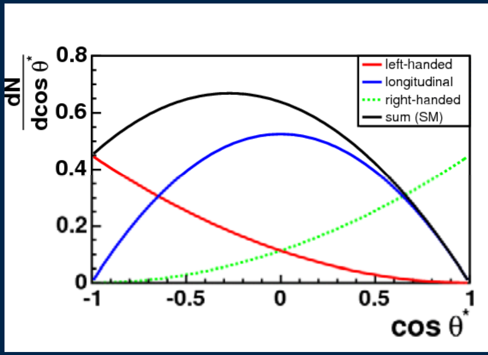
Calculate cosθ*

Construct templates for +,-,0 W's and background

Fit helicity fractions using unbinned likelihood fitter

Correct for acceptance effects





Invert :

$$f_i^{reco} = \frac{\sum_{j=1}^{3} f_i^{true} f_j^{true} A_{ij}}{\sum_{i,j=1}^{3} f_i^{true} f_j^{true} A_{ij}}$$

2-D fit:

$f_0 = 0.65 \pm 0.19(\text{stat}) \pm 0.03(\text{syst})$ $f_+ = -0.03 \pm 0.07 \pm 0.03$

1-D fits:

$f_0 = 0.59 \pm 0.11 \pm 0.04 \quad f_+ = -0.04 \pm 0.04 \pm 0.03$

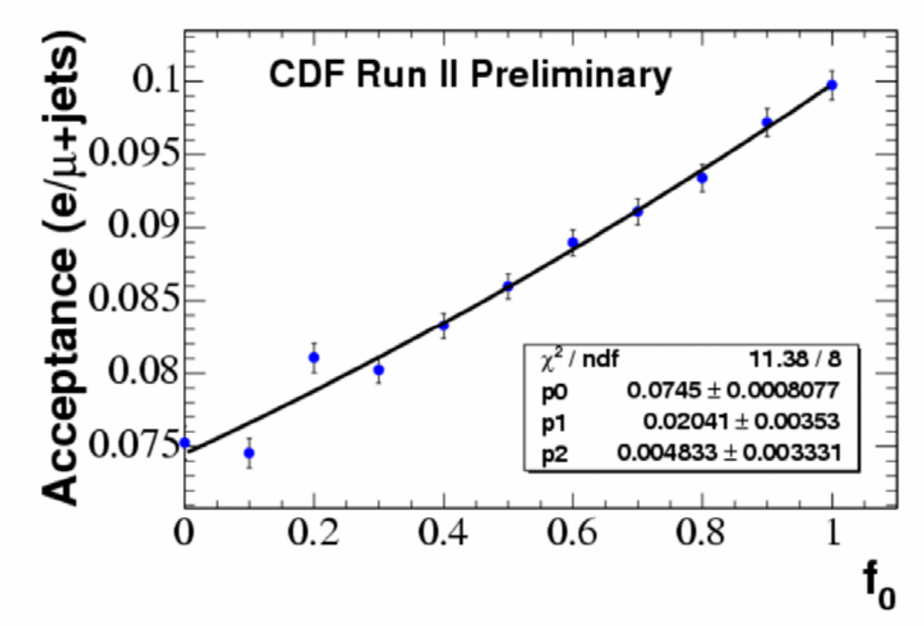
$f_+ < 0.07$ at 95%CL

Matrix Element method

- Obtain Likelihood for N events:

$$L(X;C_S,f_0) = \Pi_{i=1}^{N} P_i(X;C_s,f_0)$$
$$P_i(X;C_s,f_0) = C_s P_{tt,i}(X;f_0) + (1-C_s) P_{W+jets,i}(X)$$

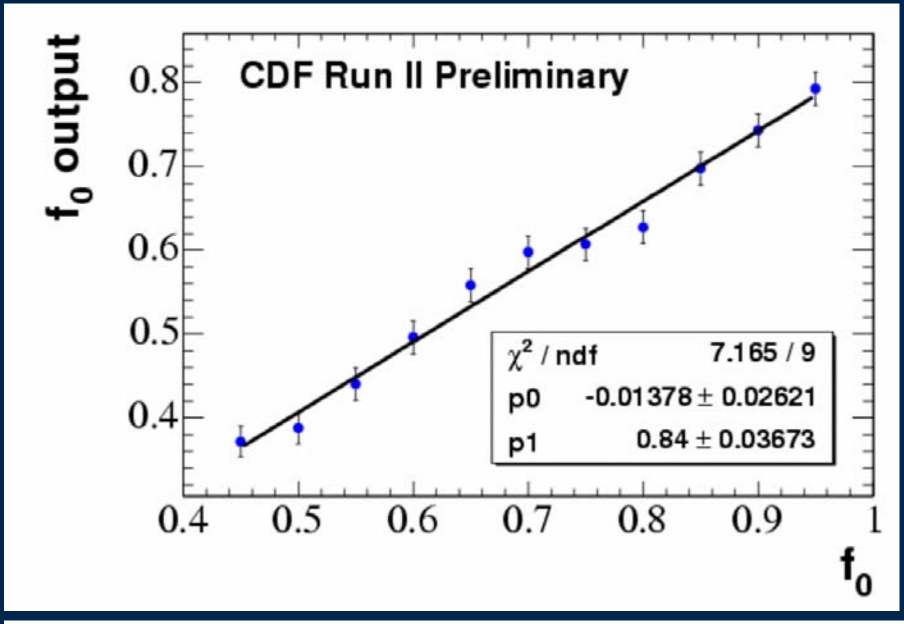
- Minimize C_s ($t\bar{t}$ fraction) using Minuit at each f_0, obtain: -lnL(X; f_0) curve
- Signal acceptance vs f_0
  - Analytical parameterization

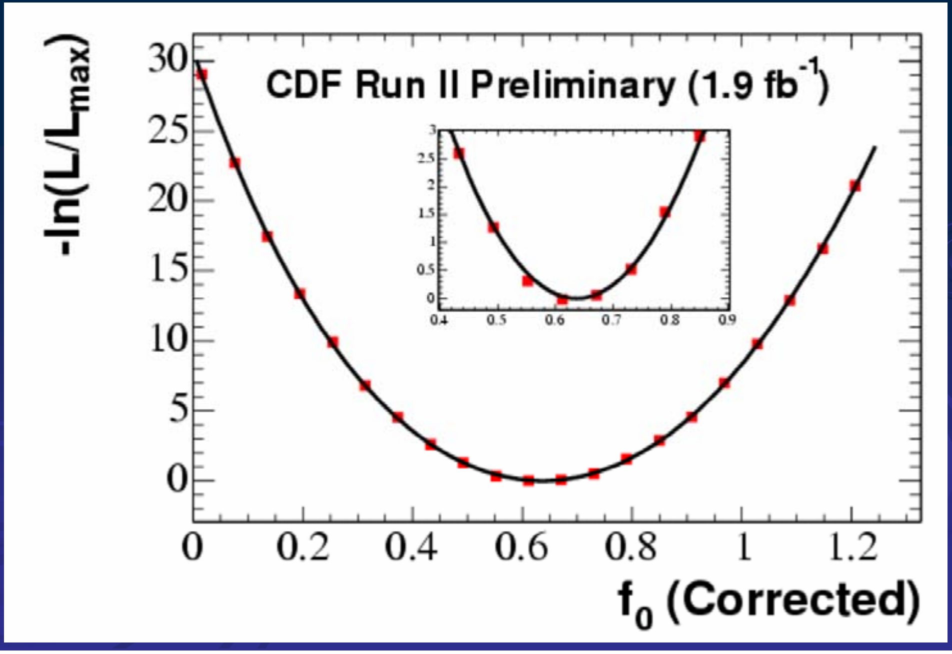


Matrix Element Method

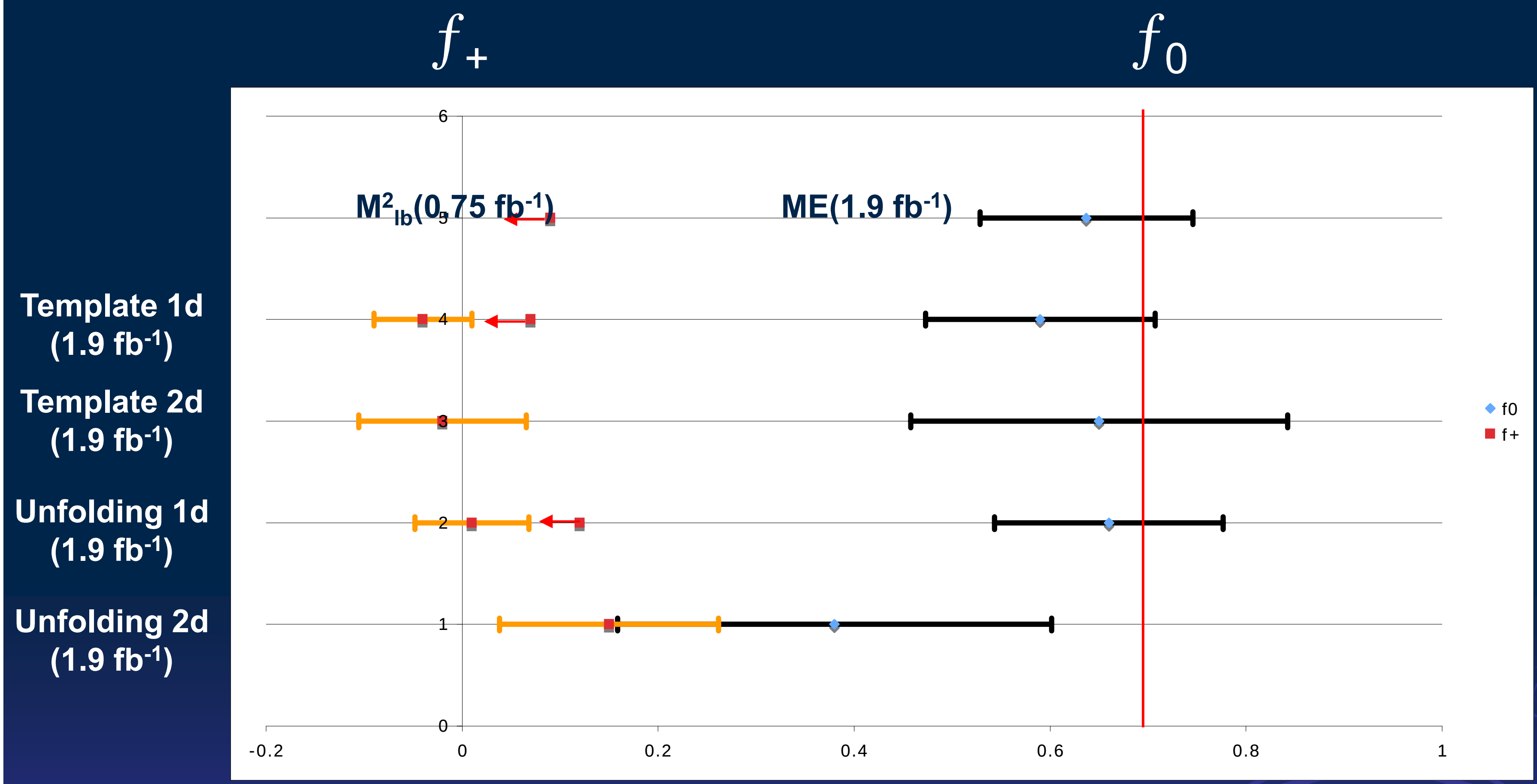
- Calibration: Pseudo-exp and input vs f_0 output
  - Slope < 1:
    - Eg NLO effects
  - Pull width vs f_0
    - Average is 0.93
    - Independent of f_0
    - Scale statistical uncertainty by 0.93
- Results:

$$m_t = 175 GeV/c^2 \text{ and } f_+ = 0$$
$$f_0 = 0.637 \pm 0.084(\text{stat}) \pm 0.069(\text{syst})$$



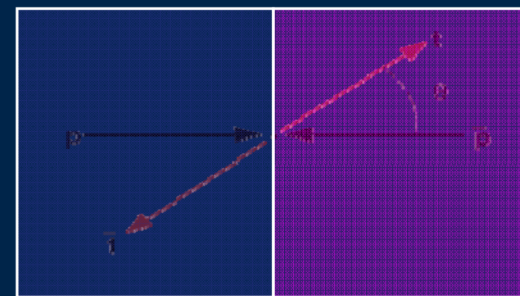


Summary of W helicity results



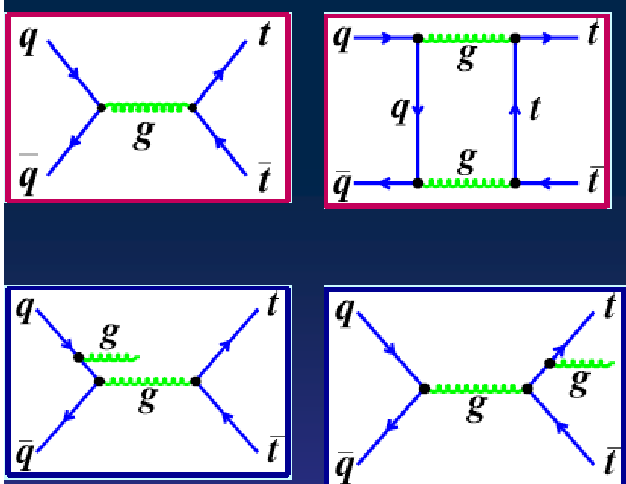
$t\bar{t}$ Front Back Asymmetry

- First measurement of discrete symmetries of the strong interaction at high energies!
  - Tevatron favored over LHC for this ($q\bar{q}$ vs gg production)



$$A_C = \frac{N_t(p) - N_{\bar{t}}(p)}{N_t(p) + N_{\bar{t}}(p)}$$

$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})} = \frac{N_{-Q_l Cos\theta>0} - N_{-Q_l Cos\theta<0}}{N_{-Q_l Cos\theta>0} + N_{-Q_l Cos\theta<0}}$$



NLO QCD predicts overall charge asymmetry

4-5% Kuhn-Rodrigo, 3.8% MC@NLO

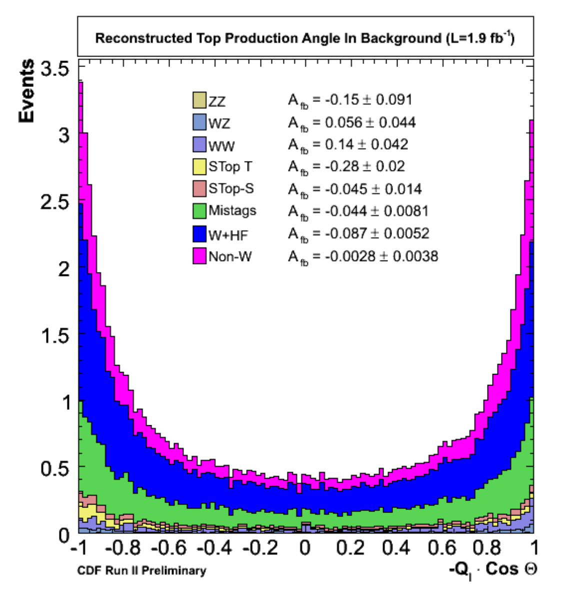
Not expected for strong interactions

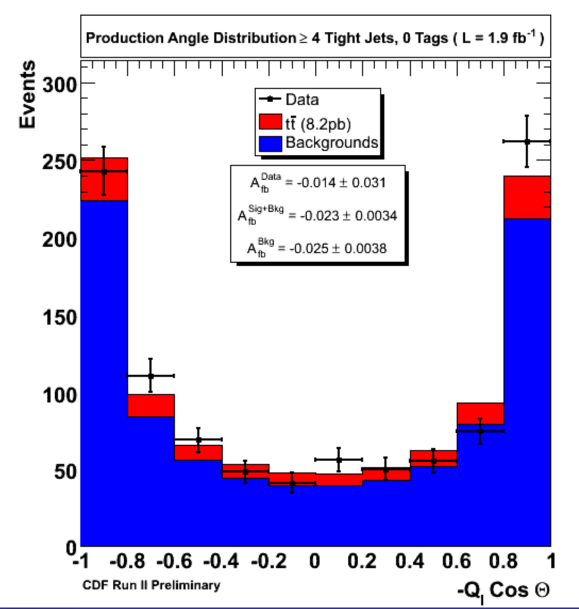
But new productions mechanisms (Z', top color) could appear as front back A

Assume CP is conserved $\rightarrow$ $N_{\bar{t}}(p) = N_t(\bar{p})$ $\rightarrow$ $A_C = A_{fb}$

$t\bar{t}$ Front Back Asymmetry

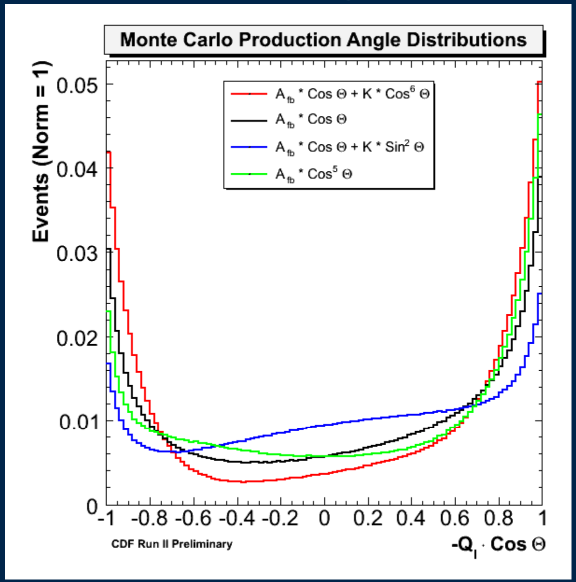
- Reconstruct production angle:
  - Assign parton to jets using the top mass χ^2
- Need to correct for:
  - Backgrounds:
    - Subtract bin by bin
      - Check shape running on data anti-tag sample
    - A_{fb}^{bckd}=-0.5±0.01 (W+jets)
  - Reconstruction (mismeasured jet E, etc.) and Acceptance (detection efficiencies)
    - Matrix inversion using MC

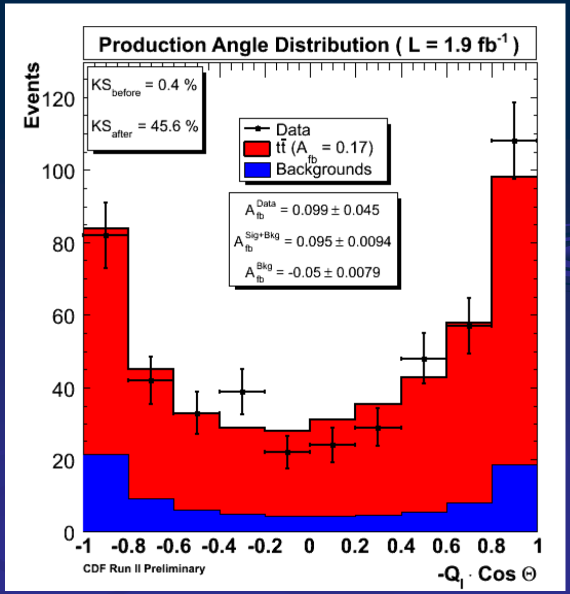




$t\bar{t}$ Front Back Asymmetry

- Underlying distribution might look different from MC
  - High number of bins (4) in matrix inversion take care of this
- Corrected Result:
  - A_{fb}=0.17±0.07(stat)±0.04(syst)
  - vs A_{fb}^{Theo}=0.04±0.01





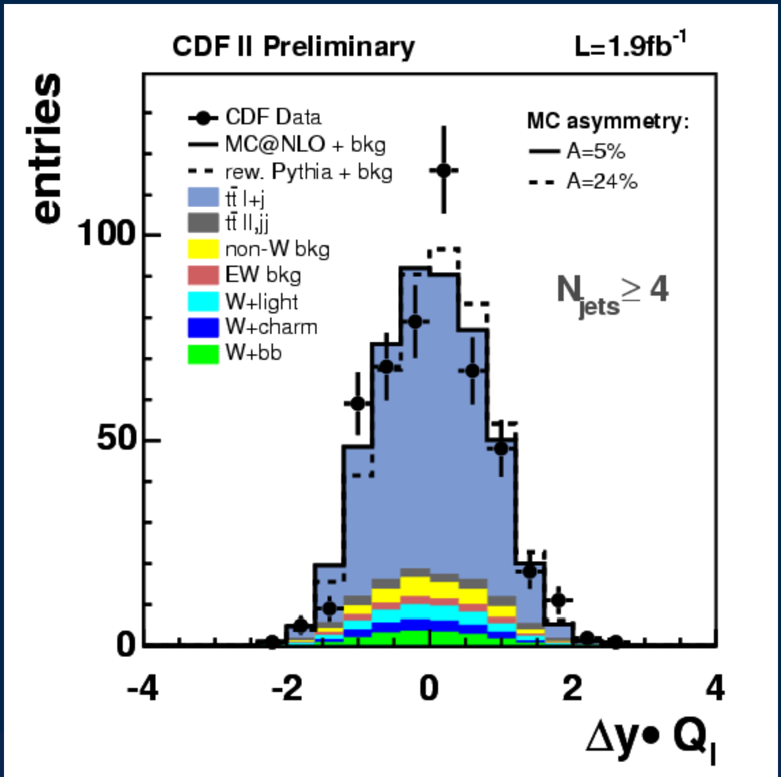
$t\bar{t}$ Front Back Asymmetry

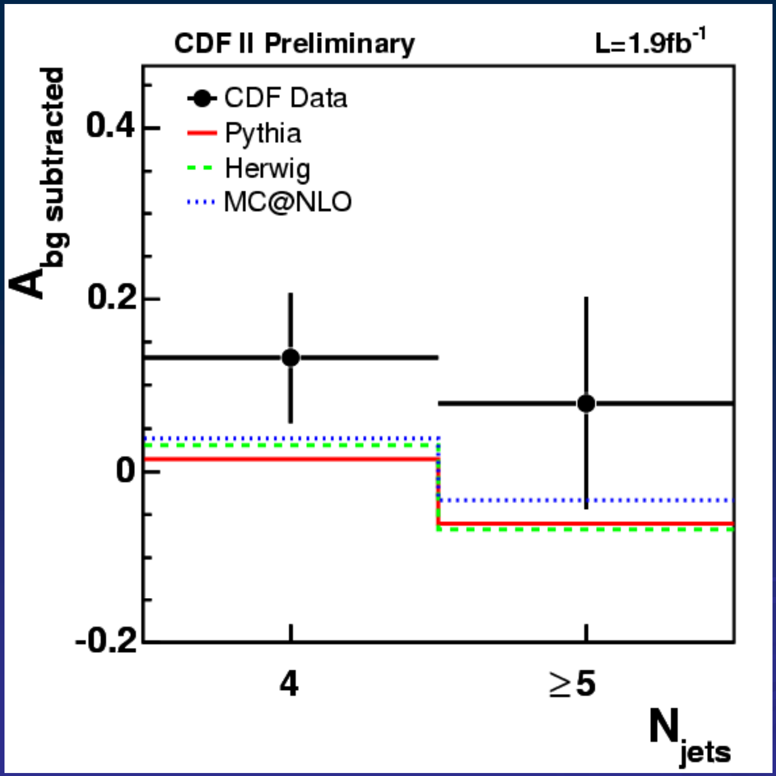
- 2nd analysis:
  - Parton rest frame using

$$y_t - y_{\bar{t}} = \Delta y \cdot Q_l$$

$$\Delta y = y_{t_{lep}} - y_{t_{had}}$$

  - A(parton rest frame) = 1.3A(lab frame)

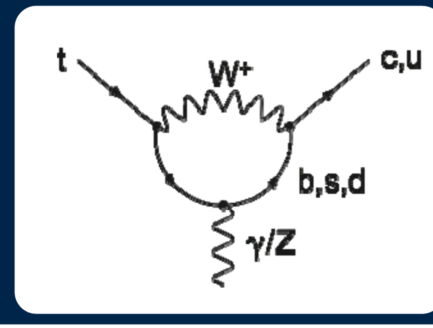




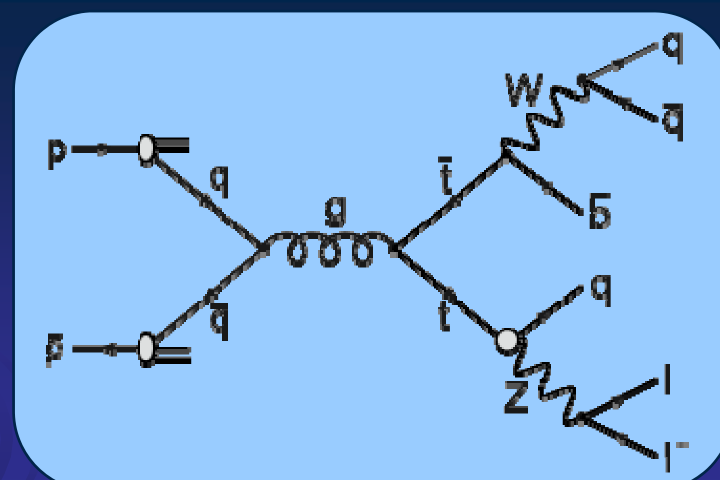
- Corrected Inclusive result:
  - A_{fb}=0.24±0.13(stat)±0.04(syst)
  - vs A^{theo}_{fb}=0.06±0.01

Flavor Changing Neutral Currents

- In the SM no FCNC at tree level
  - Need loop diagrams
    - $B(t \to Zq) = O(10^{-14})$
- New Physics enhances that BF
  - $\Rightarrow$ Observation = New Physics!
- Previous searches:
  - CDF Run I: $B(t \to Zq) < 33\%$ at 95%CL
  - L3: $B(t \to Zq) < 13.7\%$ at 95%CL
  - (HERA most sensitive to $t\gamma(u,c)$ vertex)
- Perform analysis using 1.9 fb^{-1} $t\bar{t} \to Wb\ Zq$
  - $W \to qq$ and $Z \to ll$ (4%) (Z+4jets)
  - Background is mostly Z+jets!

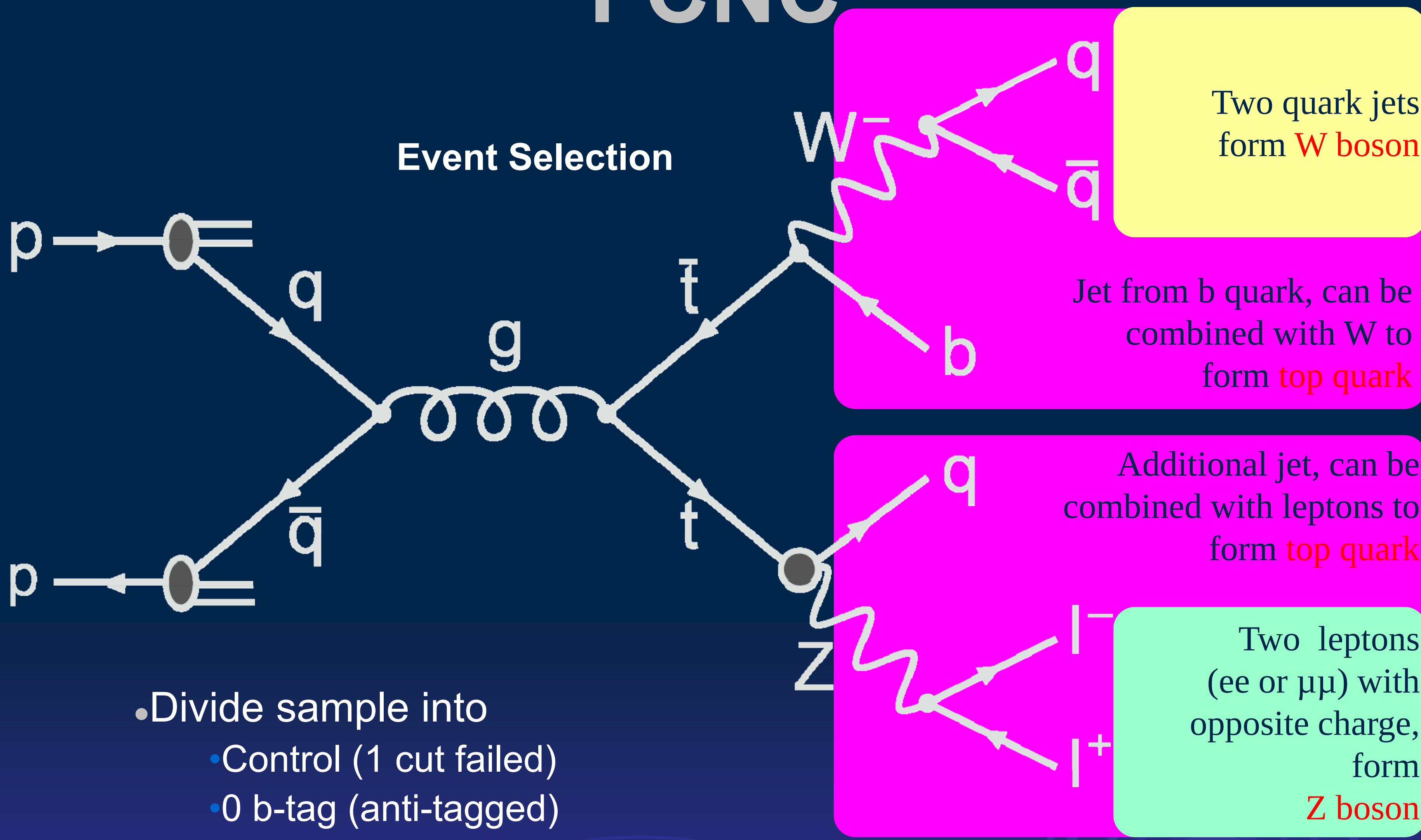


Model	BR($t \to Zq$)
Standard Model	$\mathcal{O}(10^{-14})$
$q = 2/3$ Quark Singlet	$\mathcal{O}(10^{-4})$
Two Higgs Doublets	$\mathcal{O}(10^{-7})$
MSSM	$\mathcal{O}(10^{-6})$
R-Parity violating SUSY	$\mathcal{O}(10^{-5})$



FCNC

Event Selection



- Divide sample into
  - Control (1 cut failed)
  - 0 b-tag (anti-tagged)
  - ≥1 loose b-tag (tagged)

FCNC

- Event selection:
  - Transverse mass: top more central than Z+jets

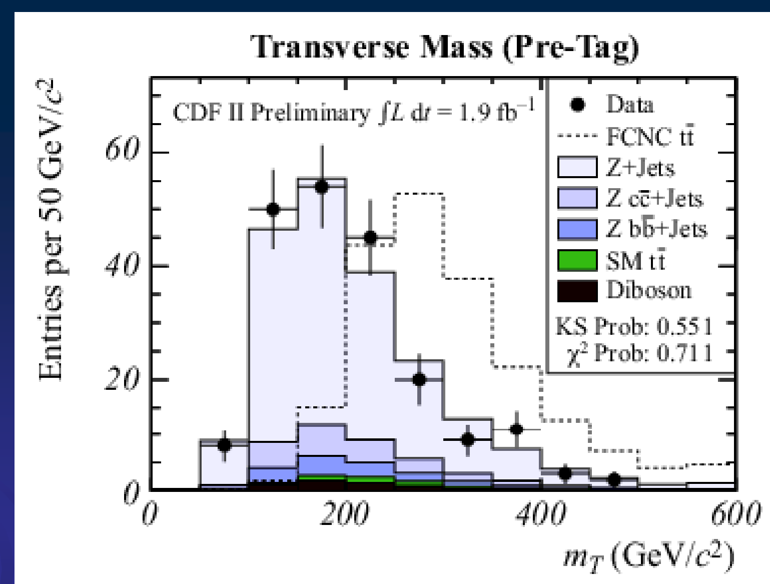
$$m_T = \sqrt{\left(\sum E_T\right)^2 - \left(\sum \vec{p}_T\right)^2}$$

  - Strongest discriminant:

Kinematic Variable	Optimized Cut
Transverse Mass	$\geq 200\,\text{GeV}$
Leading Jet	$\geq 40\,\text{GeV}$
Second Jet	$\geq 30\,\text{GeV}$
Third Jet	$\geq 20\,\text{GeV}$
Fourth Jet	$\geq 15\,\text{GeV}$

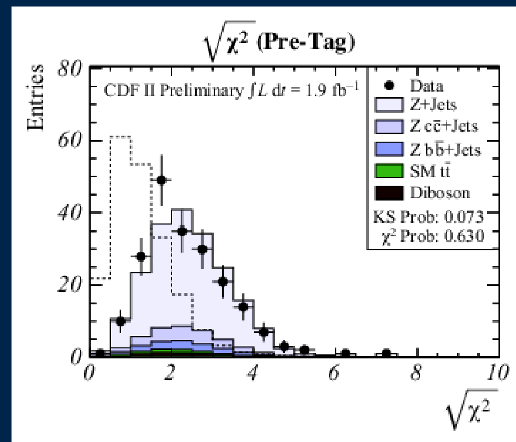
$$\chi^2_{\text{mass reconstruction}} = \left(\frac{m_{tWb\ \text{recon}} - m_t}{\sigma_{tWb}}\right)^2 + \left(\frac{m_{tZc\ \text{recon}} - m_t}{\sigma_{tZc}}\right)^2 + \left(\frac{m_{W\ \text{recon}} - m_W}{\sigma_W}\right)^2$$

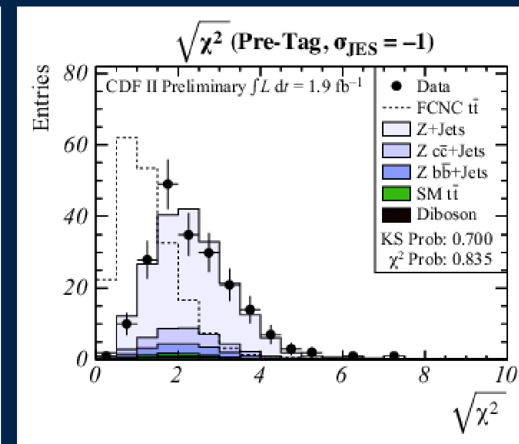
- It's all about backgrounds:
  - Z+jets: data and MC
  - $t\bar{t}$: rely on pythia and measured σ
  - WZ, ZZ: rely on pythia

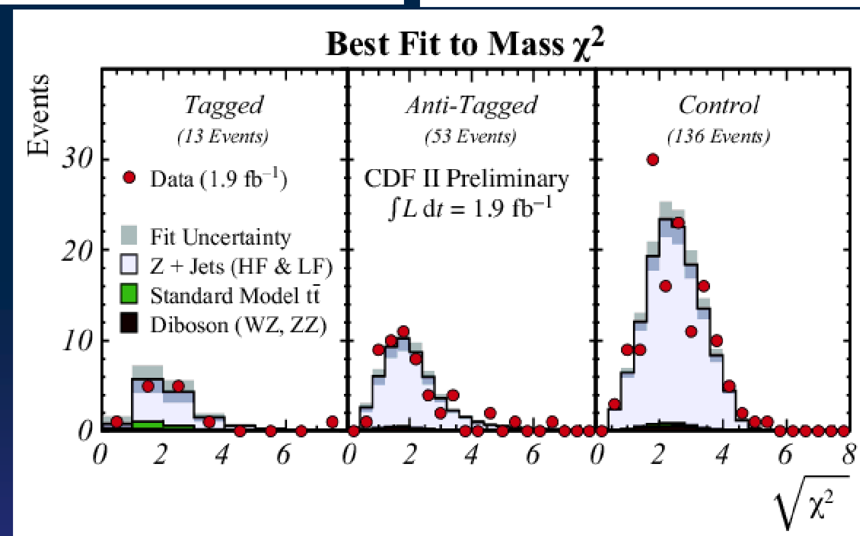


FCNC

- Z+jets: template fit to the data in control region and 2 signal regions
- Diboson and tt are fixed (small)
- Fit returns
  - Z+jet and signal amounts
    - Shape is changed according to best fit of Jet Energy Scale
  - Tagging rate
- Use MC for estimate of fraction of Z+jets in control region vs in signal regions
  - 20% uncertainty



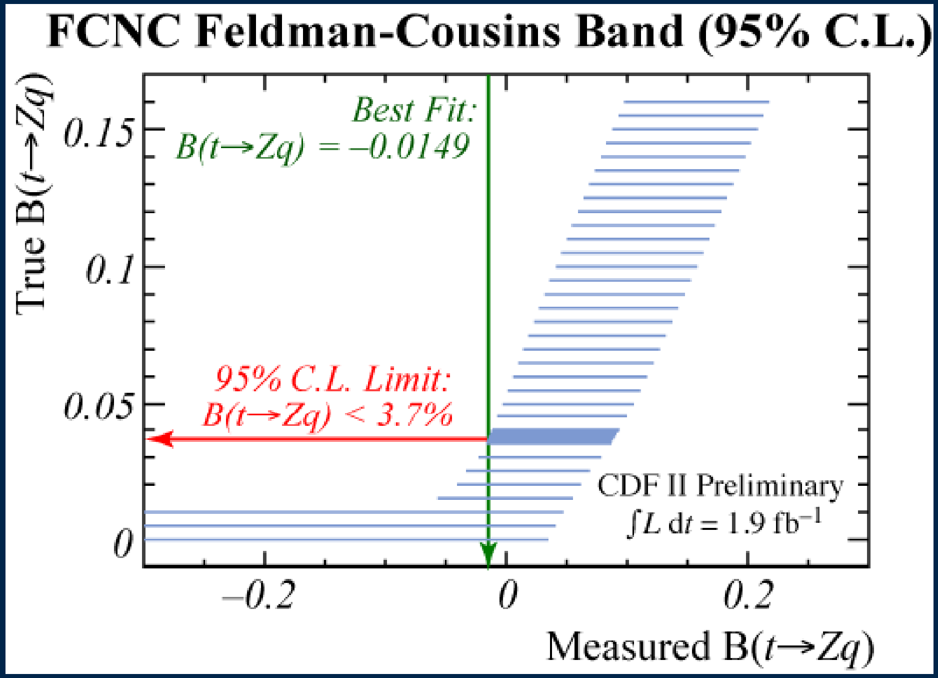


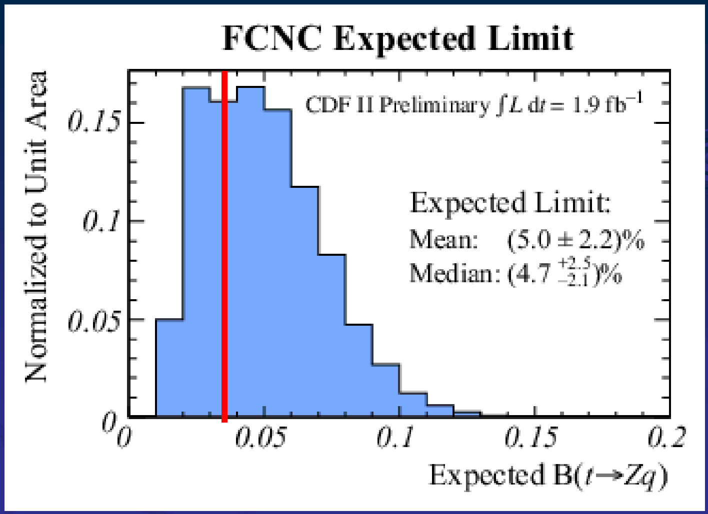


Fit Parameter $\left(\int L\,dt = 1.9\ \text{fb}^{-1}\right)$	Value		
Branching Fraction, $\mathscr{B}(t \to Zq)$ (%)	-1.49	$\pm$	1.52
Z+Jets Events in Control Region, Z_{control}	129.0	$\pm$	11.1
Shift in Ratio Signal/Control Region, $\sigma_{\mathscr{R}_{\text{sig}}}$	-0.61	$\pm$	0.60
Tagging Fraction, f_{tag} (%)	20.0	$\pm$	5.9
Jet Energy Scale Shift, σ_{JES}	-0.74	$\pm$	0.43

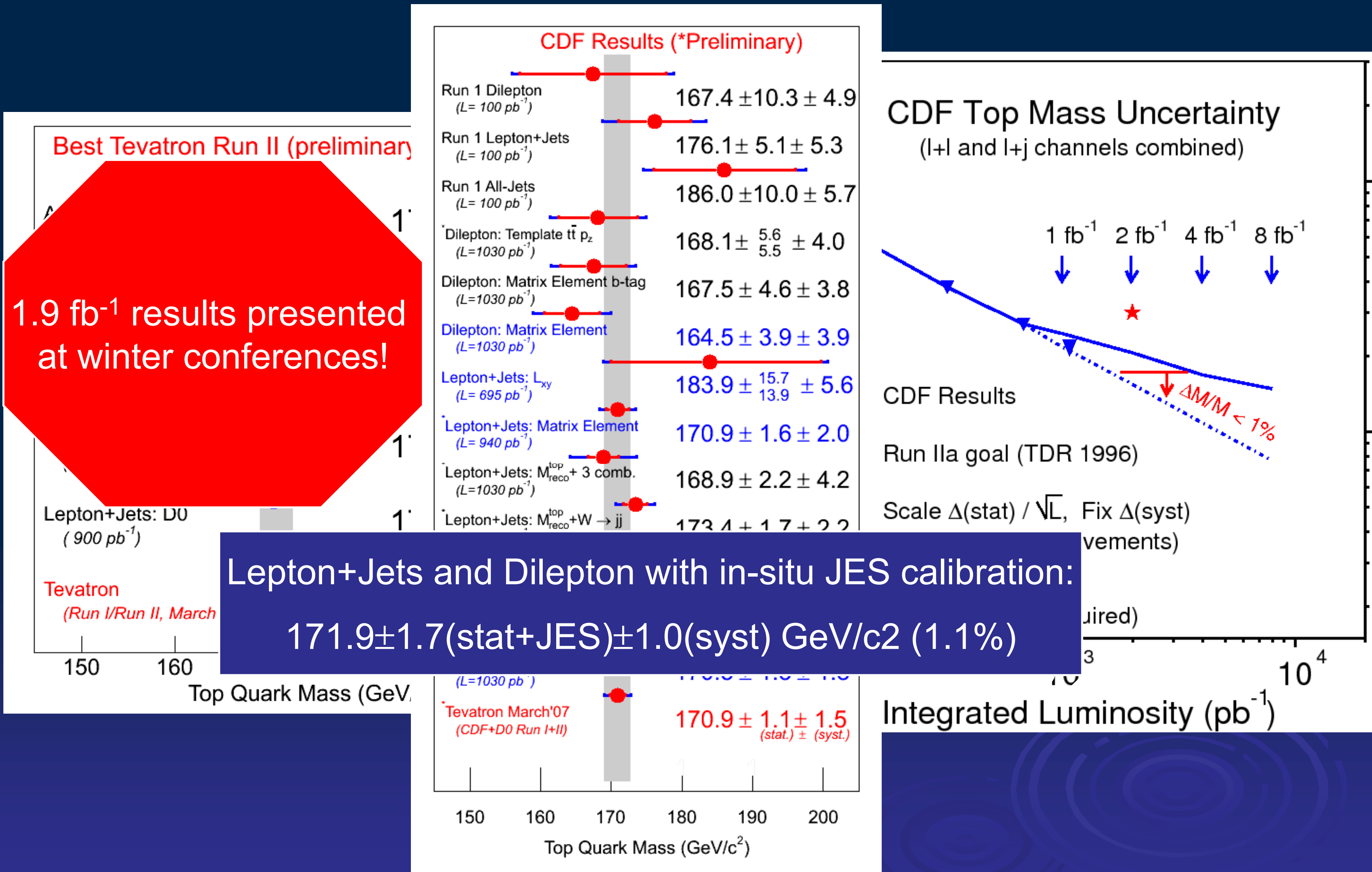
FCNC

- Feldman-Cousins limit obtained using full systematic studies
  - *B*(t→Zq)< 3.7% at 95%CL
  - 3.5 times better than published best limit from L3 (~10x better than Run 1 results)





Top mass results



$1.9\ fb^{-1}$ results presented at winter conferences!

Lepton+Jets and Dilepton with in-situ JES calibration:

171.9±1.7(stat+JES)±1.0(syst) GeV/c2 (1.1%)

Single top results

CDF Top Physics Group Public Results

http://www-cdf.fnal.gov/physics/new/top/public_singletop.html

CDF Top Quark Physics Public Results

Home | Mass | Cross Sections | Properties | Single top

Single top production

Color code :	< 1 fb^{-1}	1-1.9 fb^{-1}	>1.9 fb^{-1}

Channel	Description (Link to web-page)	Measurement	Integrated Luminosity (pb^{-1})	Publication
Lepton+jets	**Neural Network**	s+t channel <2.6 pb @ 95% C.L. t-channel = 0.2 +1.1 -0.2 pb s-channel = 0.7 +1.5 -0.7 pb (2-d most probable values)	1 fb^{-1}	12/14/2006 **Conf. Note 8677** 695 pb^{-1} **Conf. Note 8185**
Lepton+jets	**Multivariate Likelihood Function**	s+t channel = 2.7 +1.3 -1.1 pb t-channel = 1.3 +1.2 -1.0 pb s-channel = 1.1 +1.4 -1.1 pb Obs p-value = 0.3% (2.7 sigma) |Vtb| = 0.97 +0.21 -0.19(exp) +/- 0.07(theory)	1.5 fb^{-1}	08/09/2007 **Conf. Note 8964** 1 fb^{-1} **Conf. Note 8585** 695 pb^{-1} **Conf. Note 8185**
Lepton+jets	**Matrix Element Discriminant**	s+t channel = 3.0 +1.2 -1.1 pb Obs p-value(1-CL_b)=0.09% (3.1 sigma) |Vtb| = 1.02 +/- 0.18(exp) +/- 0.07(theory)	1.5 fb^{-1}	08/09/2007 **Conf. Note 8968** 1 fb^{-1} **Conf. Note 8588**
Lepton+jets	**H_T**	t-channel < 10.1 pb s-channel < 13.6 pb	160 pb^{-1}	01/28/2005 **PRD 71 012005**
Lepton+jets *New!*	**Search for W'->tb using single top sample**	$M_{W'}$>800 GeV/c^2 for $M_{W'}$ > M_{ν_R} and $M_{W'}$>825 GeV/c^2 for $M_{W'}$ < M_{ν_R} at 95% CL	1.9 fb^{-1}	12/20/2007 **Conf. Note 9150** 1 fb^{-1} **Conf. Note 8747**

D0 paper: "Evidence for production of single top quarks": PRL 98 181802 (2007)

http://www-cdf.fnal.gov/physics/new/top/public_singletop.html

The "truth" about the Top

$\sigma_{t\bar{t}}$ measurements consistent with SM

A_{FB} within 2σ of SM value

f_0 consistent with 0.7
f_+ consistent with 0

- No hints of New Physics in the top quark sector… yet!
  - Only analyzed less than a third of final dataset!

No hints of Flavor Changing Neutral Currents