A Search For Right Handed W Bosons in Top Quark Decays

Bryan Gmyrek, Kenneth Johns, Jessica Leveque, Erich Varnes

University of Arizona

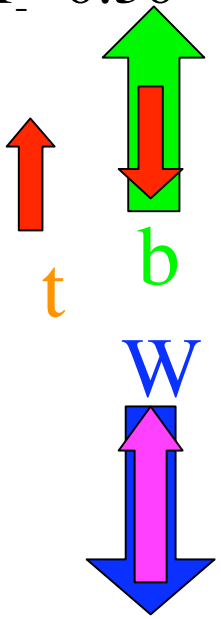
For the DØ Collaboration

gmyrek@fnal.gov

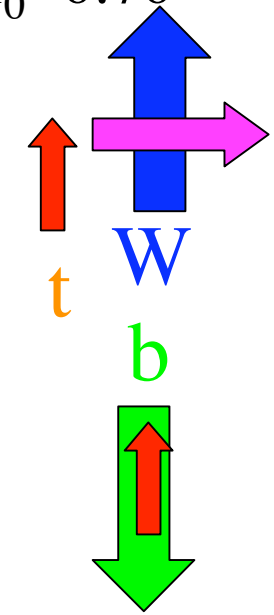
W Boson Helicity

- Helicity is the projection of a particle's spin onto it's direction of motion
- In the standard model the top quark decays to a W boson and b quark via V-A interaction
- There are the three possible W boson helicity states

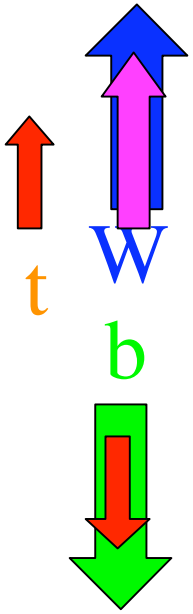
Negative Helicity
$f_- = 0.30$



Longitudinal Helicity
$f_0 = 0.70$

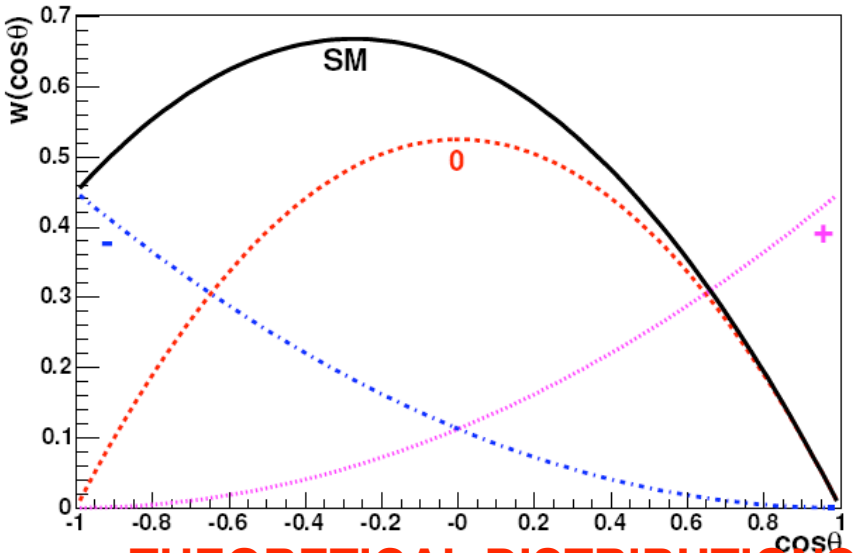


Positive Helicity
$f_+ = 3.6 \times 10^{-4}$

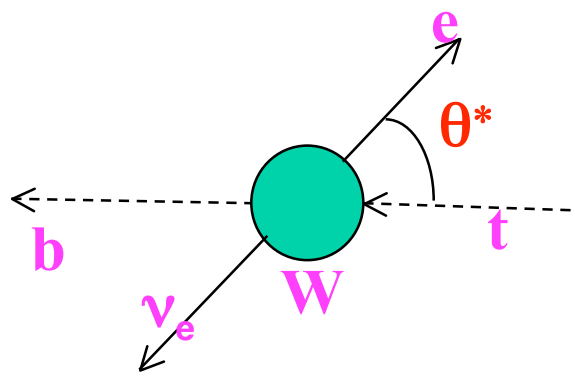


Motivation & Observables

- Top quark is probe of new physics at the electroweak symmetry breaking scale because of large mass (e.g. possible V+A contribution to tWb)
- Measure f_+ holding f_0 constant
  - Lepton+jets channel and di-lepton channel
- Measurement of f_+ which differs from the predicted value means:
  - There is a V+A contribution
  - There are non-standard model events in our signal sample
- The helicity can be found from the distribution of $\cos\theta^*$
  - θ^* is measured in the W rest frame
  - θ^* is the angle between the charged lepton and the top quark direction



THEORETICAL DISTRIBUTIONS



Outline of the Analysis

- Two channels
  - Lepton plus jets (e+jets, μ+jets) and dilepton (ee, μ μ,e μ)
- Analysis Method:

1. Select a sample rich in ttbar events
2. Reconstruct the 4-vectors of the two top quarks and their decay products with a kinematic fit
   - Use t and W mass as constraints
3. Calculate $\cos\theta^*$ for each event in the sample
4. Run Monte Carlo simulation to find expected $\cos\theta^*$ distributions for various right-handed fractions (f+) from 0.0 to 0.30
5. Apply a binned maximum likelihood fit to the $\cos\theta^*$ distribution in the data using signal and background models to determine the most likely value of f+ (minimum of -ln(L) curve)
6. Use ensemble testing to estimate the expected sensitivity and systematic errors
7. Combine lepton+jets and dilepton results

Event Selection

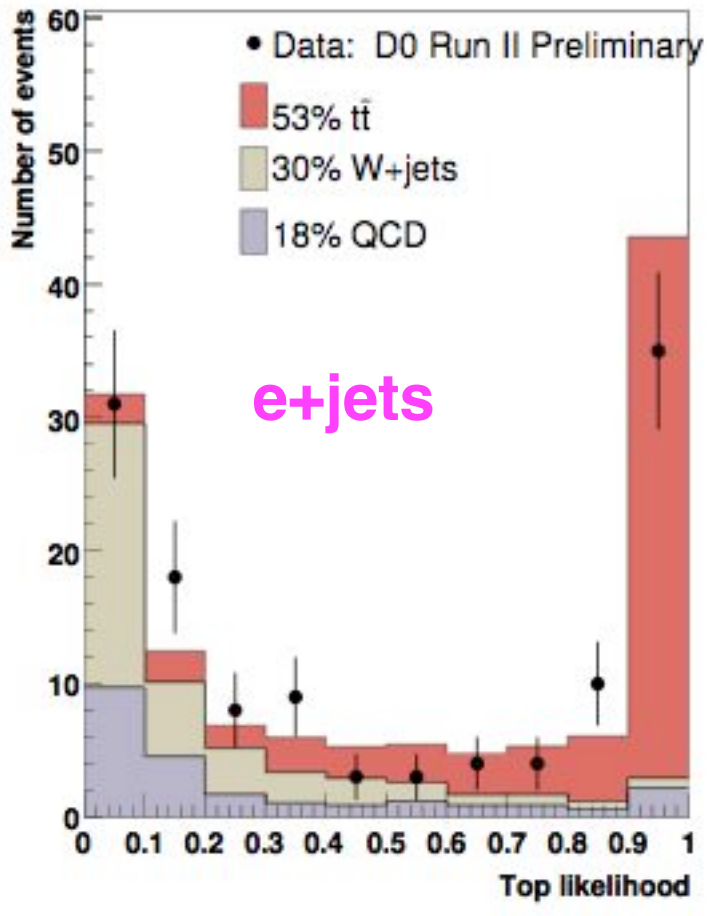
- Integrated Luminosity = 370pb^{-1}
- Dilepton selection cuts overview:
  - ALL: 2 of the appropriate leptons
    - with opposite sign
    - P_T > 15 GeV
  - ALL: >= 2 jets with P_T > 20GeV and leta_detl < 2.5
  - All: cuts to supress Z->ll
  - $\mu\,\mu$ channel
    - veto events with electrons
  - ee channel
    - Sphericity > 0.15
  - e μ channel
    - At least one muon with P_T>15GeV and $|\eta_{det}|$<2

Event Selection

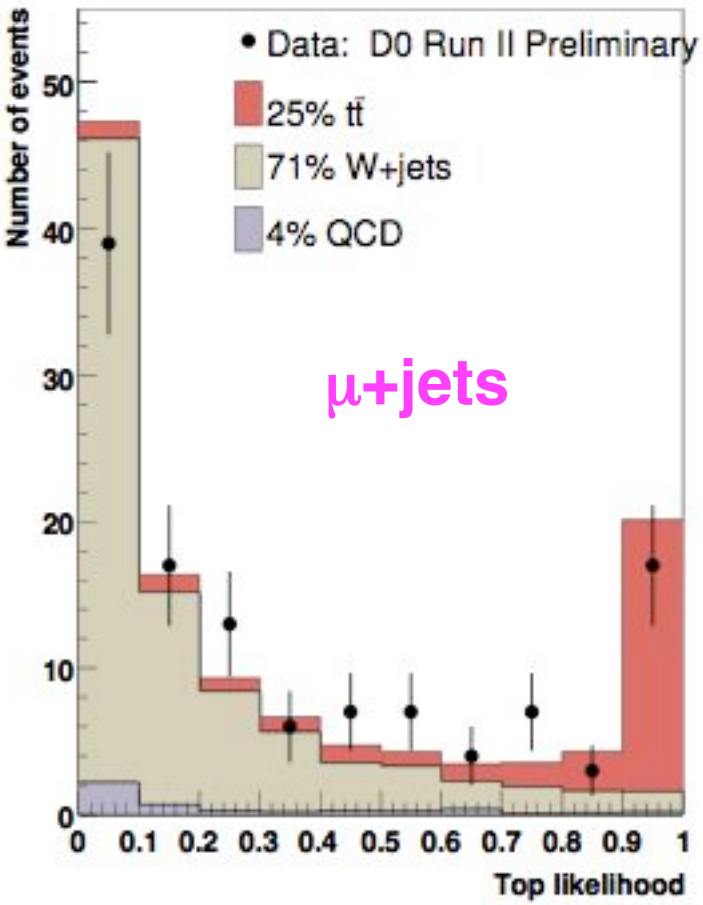
- Integrated Luminosities
  - 370pb^{-1} of lepton+jets channel data
- l+jets events selection cuts overview
  - An isolated lepton, at least 4 jets
  - $p_{T,lepton} > 15$ GeV, missing $E_T > 20$ GeV
  - $p_{T,jet} > 20$, rapidity $|y^j|<2.5$
- Form a discriminant, D, based on topological variables and vertex information (for b quark identification)
  - Aplanarity, Sphericity,…
  - Impact parameters of all tracks (used to find events with b's)
- Consider all possible combinations of variables for D
  - Choose variables and cut that gives best $N_s/\sqrt{(N_s+N_b)}$
    - N_s=expected signal yield, N_b=expected background yield
- Do the above seperately in e+jets and μ+jets channels
  - e+jets D = D(S, Ht, Ktminp, $<P_{PV}>$, and hitfit χ^2) > 0.35
  - μ+jets D = D(A,C,m_jjmain,$<P_{PV}>$, and hitfit χ^2) > 0.70

Likelihood Discriminant (D)

- W+jets background is signifigantly higher in μ+jets



S/B=1.1



S/B=0.33

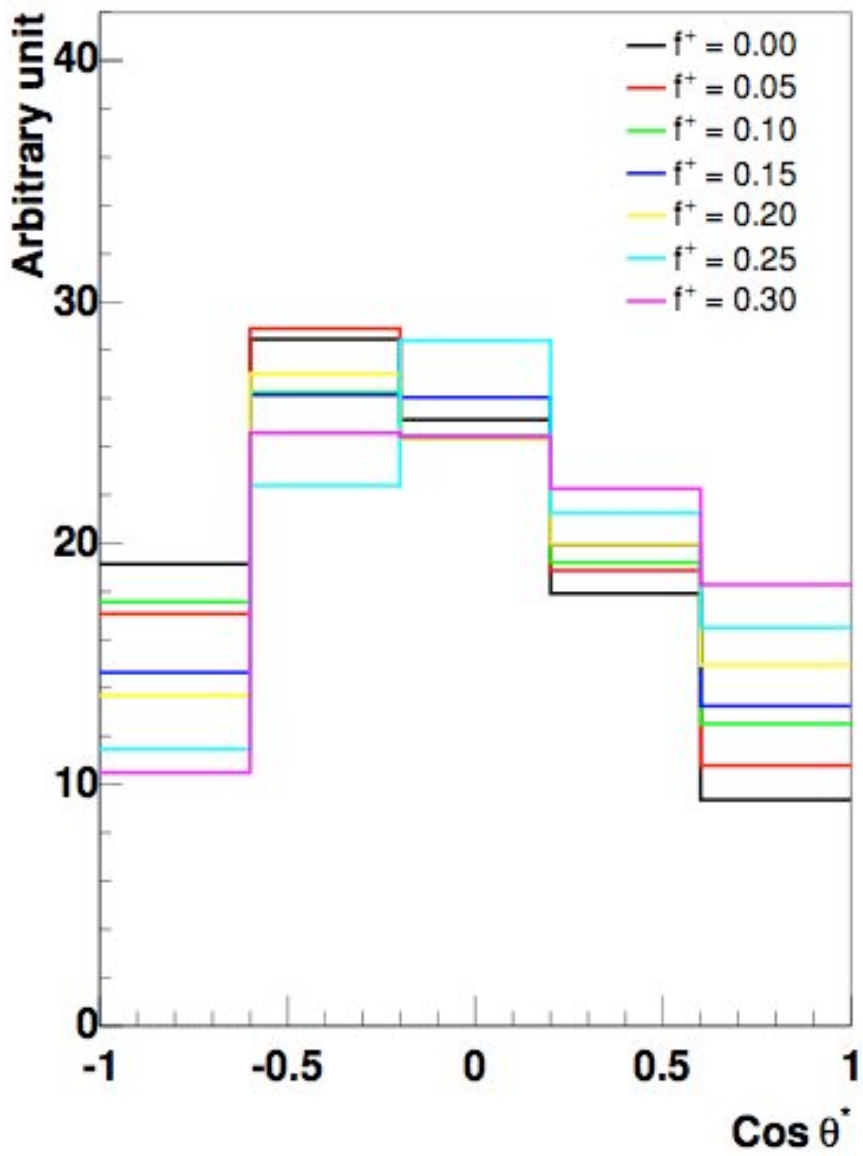
Background Determination

- Backgrounds are
  - Lepton+jets channel: W+jets and multijet
  - Dilepton channel: WW+jets, Z->ll or tau tau
- Compare D distribution in data to sum of signal and background distributions
- Extract numbers of expected signal and background:

	Observed	Background
e + jets	64	13.9 ± 7.4
μ + jets	27	5.0 ± 0.7
$e\mu$	15	2.2 ± 0.6
ee	4	0.8 ± 0.2
$\mu\mu$	1	0.4 ± 0.1

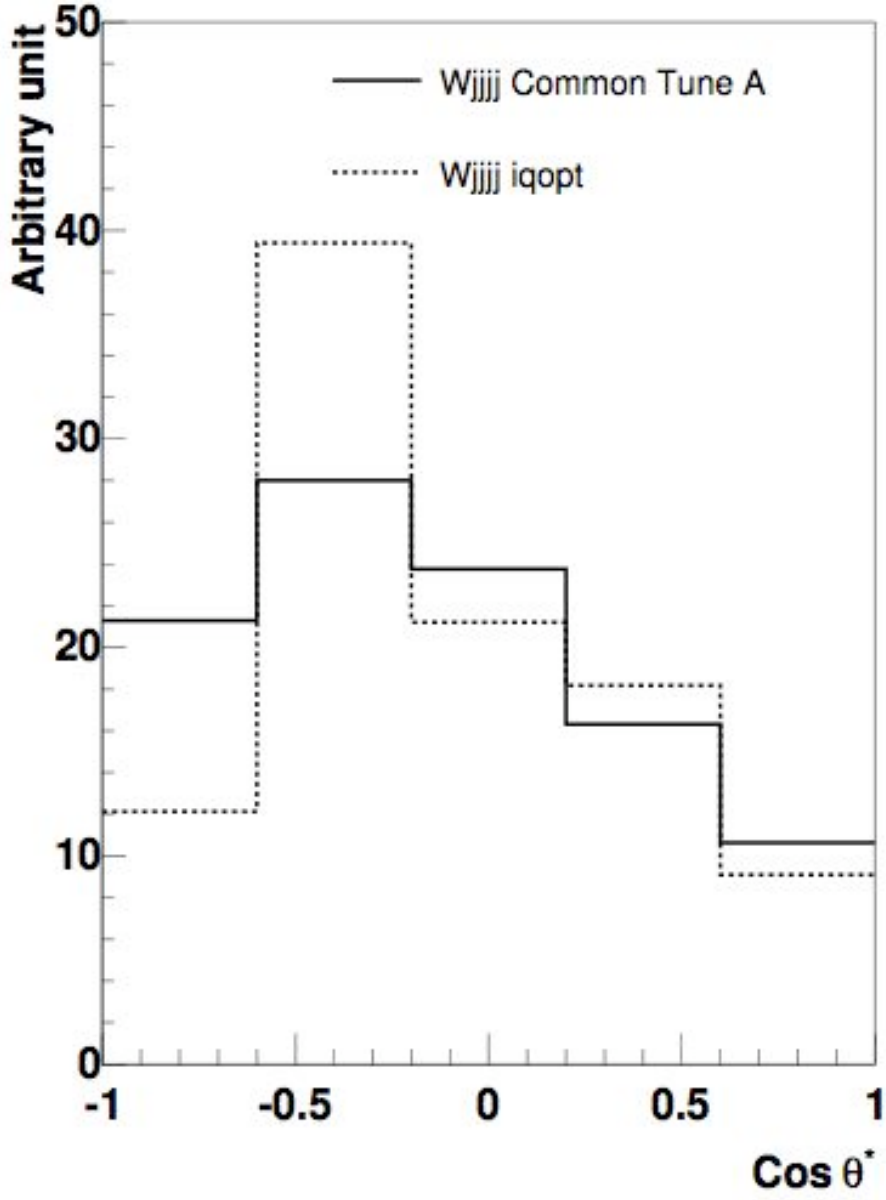
cosθ* Templates

- Signal templates
  - ALPGEN allows the tWb coupling to have a V+A component (in addition to SM V-A)
  - f+ = 0.0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30



cosθ* Templates

- Background templates
  - ALPGEN Monte Carlo for W+jets
  - Data for multijet
  - Use iqopt to estimate systematic error



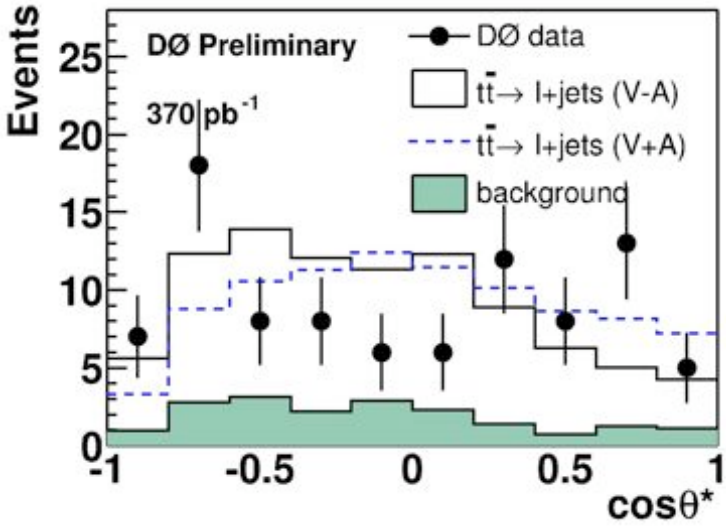
Systematic Uncertanties

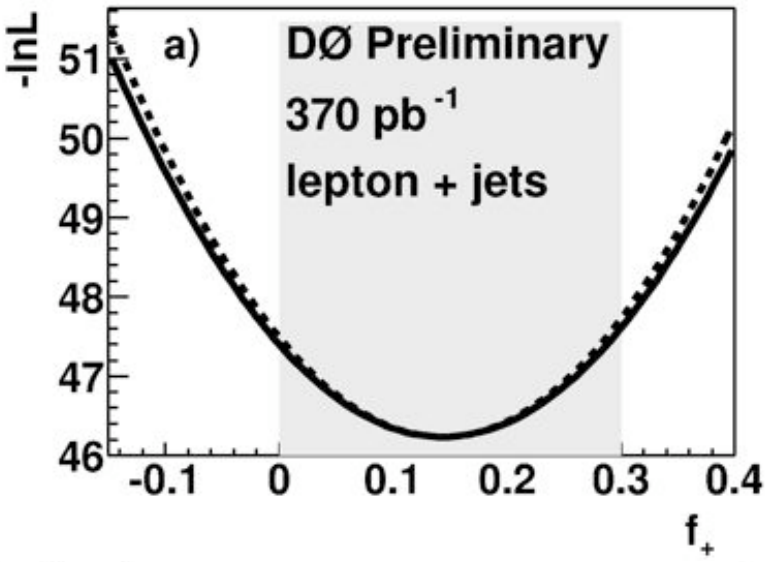
- **Procedure:**
  - **Use standard templates**
  - **Perform ensemble tests where parameter (e.g. top mass) is varied**
  - **Observe shift in average f_+ value of maximum likelihood**

Source	δ in dilepton analysis	δ in ℓ+jets analysis	Correlation coeff.	Combined δ
Jet energy scale	0.039	0.023	1	0.027
Top quark mass	0.070	0.033	1	0.042
Analysis self-consistency	0.010	0.010	0	0.008
Bkg. model	0.007	0.014	0	0.011
$t\bar{t}$ model	0.010	0.018	1	0.012
Template statistics	0.030	0.024	0	0.019
Lepton p_T resolution	0.005	0	1	0.005
Trigger turn-on	0.012	0	1	0.012
Total				0.058

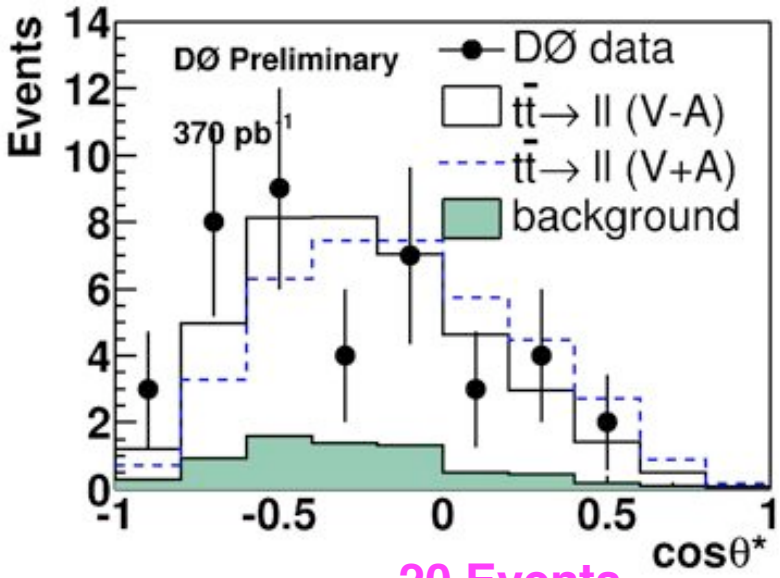
Data Results

91 Events

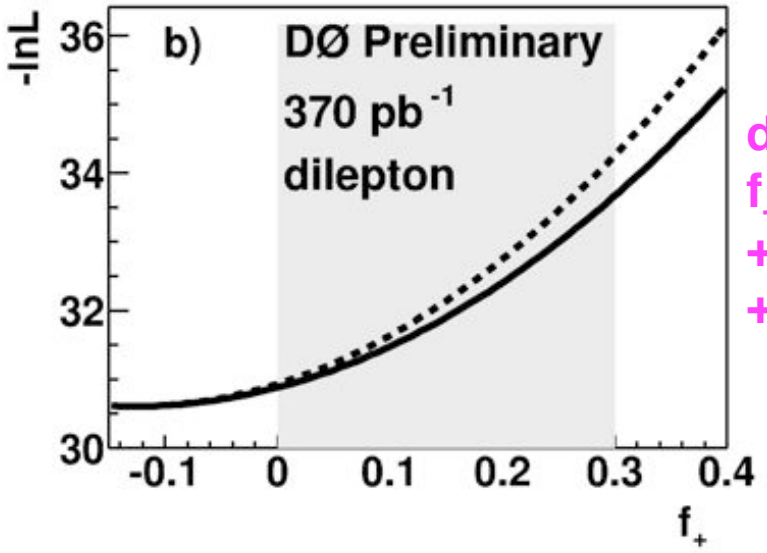




Lepton+jets:
f_+=0.14
+- 0.09 (stat)
+-0.05 (syst)

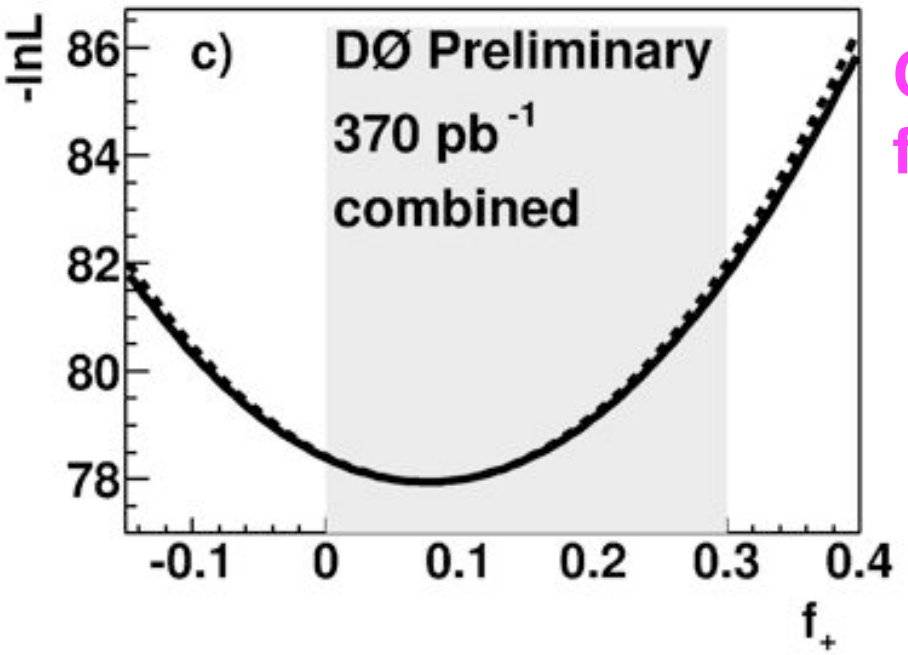


20 Events



dilepton:
f_+= -0.12
+- 0.16 (stat)
+- 0.09 (syst)

Data Results



Combined:
f_+=0.08+-0.08(stat)+-0.06 (syst)

- **Combined result: $f_+ < 0.24$ @ 95% Bayesian Confidence Level**
  - **Flat Bayesian prior in physical region of 0.00 to 0.03**
- **Performed measurements of V+A component in tWb vertex by analyzing the helicity angle distribution**
- **About 370pb-1 of data analyzed**
- **Our measurements are consistent with the SM prediction (no V+A component)**
- **References:** http://link.aps.org/abstract/PRD/v72/e011104

EXTRA SLIDES

- **EXTRA SLIDES follow**

Kinematic Fitter (HITFIT)

- For events passing all selection criteria we perform a kinematic fit using the HITFIT* package to select the b-jet associated with the leptonic W. We use the term “leptonic W” as shorthand notation for the phrase “W that decays leptonically”.

- *Algorithm is detailed in Scott Snyder’s Ph.D. thesis:
- http://www-d0.fnal.gov/results/publications_talks/thesis/snyder/thesis.html

Kinematic Fit

- Q: How do you reconstruct the top quark and W boson 4 vectors?
- Require:
  - Two jets form invariant mass of W boson
  - Lepton, MET, and neutrino Pz must form mass of W boson
  - Masses of 2 reconstructed top quarks must be 175
  - Reconstruct neutrino Pz by requiring equal t quark masses
    - Gives a quadratic equation for Pz. If the solutions lead to different fit results, keep lowest (fit) chi^2 solution.
  - 12 possible jet combinations
    - Choose combination that gives minimal chi^2 from kinematic fit result.
    - MC studies show this gives correct result 60% of time.

Likelihood Discriminant

- D is based on 6 (4 for b-tagged) variables
  - E+jets:
    - Sphericity, H_T , Ktminp, <Ppv>, χ^2 ; D > 0.35
  - μ+jets:
    - Aplanarity, Centrality, minimum dijet mass, <Ppv>, χ^2 ; D > 0.70

- Aplanarity: measure of deviation from flatness of the event, A is larger for signal events
- Sphericity is similar to A
- Ht is the scalar sum of jet pt values > 15GeV, jets from gluon radiation have lower Pt so background events will have a lower Ht value
- Centrality is similar to Ht but normalized to the sum of jet energies greater than 15GeV to reduce dependence on top quark mass
- Minimum dijet mass is the minimum dijet mass of all jet pairs. Tends to be lower for background.
- X^2_{hitfit} x^2 associated with the kinematic fit(HITFIT) to the hypothesis of ttbar decays in the l+jets channel. Signal events have a lower x^2 value.
- Ktminp: distance in eta-phi space where phi is the azimuth between the closest pair of jets multiplied by the pt of the lowest pt jet in the pair and divided by the transverse energy of the reconstructed W boson
- <Ppv>: Ppv is based on the impact parameters of all tracks in the jet cone w.r.t. the primary vertex. Then average the two lowest Ppv to get the continuous variable <Ppv>. Tends to be small for ttbar.