Helicity of the W Boson in Lepton+Jets $t\bar{t}$ Events

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- Introduction
- The new approach for measuring top quark properties
- Monte Carlo tests with the new approach
- F_0 measurement using Run I DØ data
- Systematic uncertainties
- Conclusions

Event Topology and Selection Criteria

- **DØ Statistics Run I (125 pb^{-1})**
  - In proton antiprotons collisions @ $\sqrt{s}$ =1.8TeV top quarks are primarily **produced in pairs**
  - **90% qqbar ->ttbar, 10% gg-.ttbar**
  - Each top quark decays weakly: **BR(t→ Wb) @ 100%**
  - There are 3 main experimental ttbar signatures depending on the decay of the *W* bosons:
    - Dilepton BR(ee+μμ+eμ) ~ 5%
    - All-Hadronic BR(quarks) ~ 44%
    - Lepton +Jets BR(e+jets,μ+quarks) ~ 30%

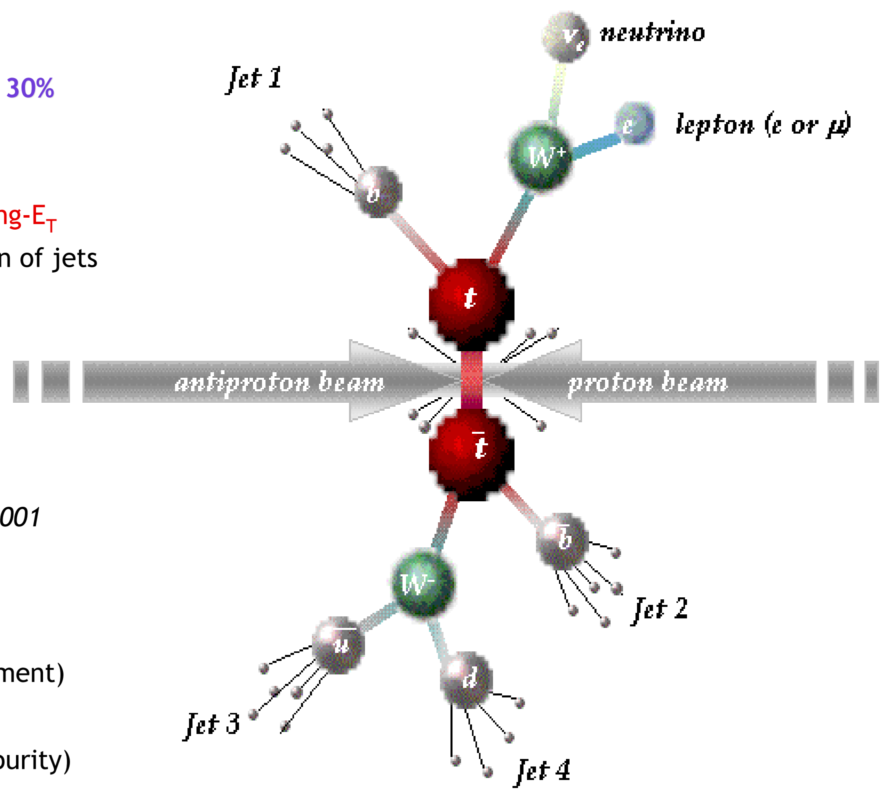
- **Lepton+Jets**
  - **Signal:** 1 high-P_T lepton, 4 jets, large missing-E_T
  - **Background:** *W* with associated production of jets
  - Standard Selection:
    - **Lepton:** E_T>20GeV, $|\eta^e|<2$, $|\eta^\mu|<1.7$
    - **Jets:** ≥4, E_T>15 GeV, $|\eta|<2$
    - **Missing E_T** > 20 GeV
    - "E_T^W" > 60 GeV ; $|\eta_W|<2$

    91 events *Ref. PRD 58 (1998), 052001*

    After χ^2 cut 40% signal
  - Additional cuts for this analysis :
    - 4 Jets only (Leading Order Matrix Element)

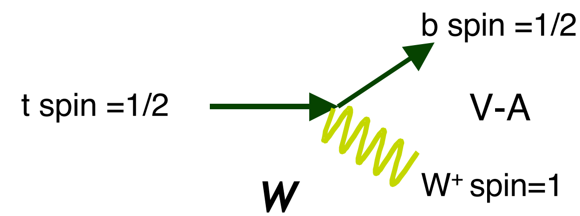
    71 events
    - Background probability (to improve purity)

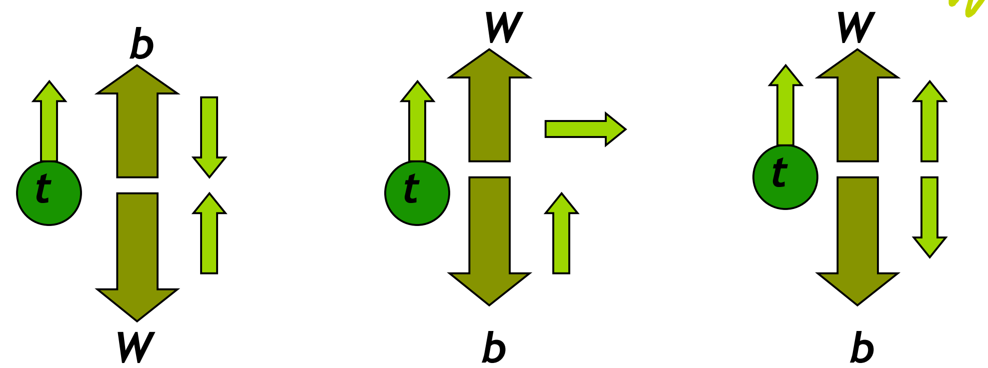
    22 events => 12 signal + 10 background



Helicity of the W *in* ttbar *events*

- Top Standard Model weak decay ->
  V-A coupling as it is for all the other fermions





Suppressed by the V-A coupling

W_- Left-Handed fraction **F_-**

W_0 Longitudinal fraction **F_0**

W_+ Right-Handed fraction **F_+**

$$w(\cos\theta_{l\bar{b}}) = F_- \cdot \frac{3}{8}(1-\cos\theta_{l\bar{b}})^2 + F_0 \cdot \frac{3}{8}(1-\cos^2\theta_{l\bar{b}}) + F_+ \cdot \frac{3}{8}(1+\cos\theta_{l\bar{b}})^2$$

In SM (with m_b=0, M_{top} = 175 GeV and m_W = 80.4 GeV),

$$F_- = \frac{2\frac{m_W^2}{M_{top}^2}}{1+2\frac{m_W^2}{M_{top}^2}} \approx 0.30$$

We want to extract

$$F_0 = \frac{1}{1+2\frac{m_W^2}{M_{top}^2}} \approx 0.70$$

$$F_+ = 0$$

The General Method

- We want to find the value of a parameter α

In our case α = F_0

- The best estimate of a **parameter (α)** is achieved comparing the events with the probability from the theory with the data. This is done by maximizing a likelihood:

$$L(\alpha) = e^{-N\int \bar{P}(x;\alpha)dx} \prod_{i=1}^{N} \bar{P}(x_i;\alpha)$$

where x is a set of measured variables

- **Probability.** Sum over all the possible parton variables *y* leading to the observed set of variables *x*

$d^n\sigma$ is the differential cross section.
ME: F_0 in leptonic and hadronic decays

W(y,x) is the probability that a parton level set of variables ***y*** will be measured as a set of variables ***x***

$$\bar{P}(x;\alpha) = \frac{1}{\sigma}\int d^n\sigma(y;\alpha)\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(x,y)$$

f(q) is the probability distribution than a parton will have a momentum ***q***

- **Detector effects**

$$\bar{P}_{measured}(x;\alpha) = Acc(x)\bar{P}_{production}(x;\alpha)$$

where ***Acc(x)*** include all conditions for accepting or rejecting an event

- **Background** events with weights c_i

$$\bar{P}(x;c_1,\ldots,c_K,\alpha) = \sum_{i=1}^{K} c_i\bar{P}_i(x;\alpha)$$

Transfer Function W(x,y)

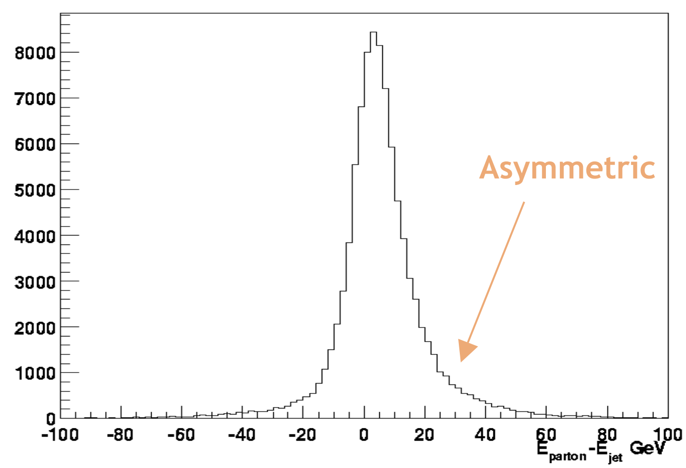
- ***W(x,y)*** probability of measuring ***x*** when ***y*** was produced (***x*** jet variables, ***y*** parton variables):

Energy of **electrons** is considered well measured

$$W(x,y) = \delta^3(p_e^y - p_e^x) \prod_{j=1}^{4} W_{jet}(E_j^y, E_j^x) \prod_{i=1}^{4} \delta^2(\Omega_i^y - \Omega_i^x)$$

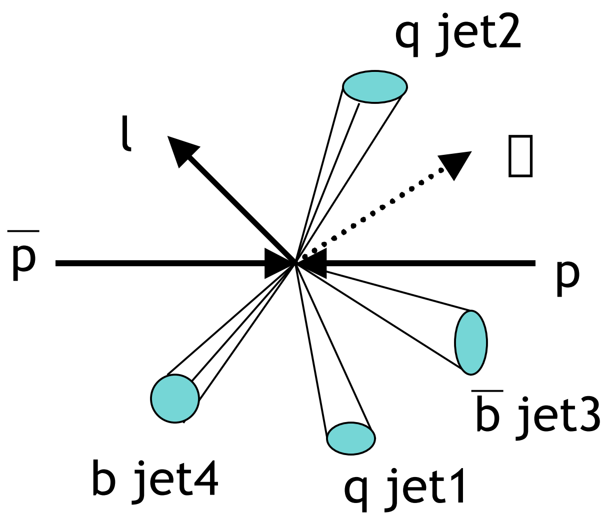
And due to the excellent granularity of the D∅ calorimeter, **angles** are also considered well measured

- ***W_{jet}(x,y)*** model the smearing in jet energies from effects of **radiation, hadronization, measurement resolution, and jet reconstruction algorithm**
  - o Use 2 gaussians, one to account for the peak and the other to fit the asymmetric tails
  - o Correcting on average, and considering these distributions to be Gaussian can underestimate the jet energy
  - o *b* and light quarks parameterizations



- Events with muons are integrated over their resolution

Probability for Signal Events



- 2(*in*) + 18(*final*) = **20 degrees of freedom**
- 3(*e*)+8($\delta_1..\delta_4$)+3($P_{in}=P_{final}$)+1($E_{in}=E_{final}$) = **15 constraints**

⇒20 – 15 = **5 integrals** => we choose M_{top}, m_W and jet energy of one of the jets because $|M|^2$ is almost negligible, except near the four peaks of the Breit-Wigners within $|M|^2$

- All the neutrino all possible solutions are considered
- Sum over 12 combinations of jets

$$P_{t\bar t}(x,\alpha) = \frac{1}{12\sigma_{t\bar t}} \int d\rho_1 dm_1^2 dM_1^2 dm_2^2 dM_2^2 \sum_{comb,\nu} |M_{t\bar t}(\alpha)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} \Phi_6 W_{jet}(x,y)$$

ρ_1 momentum of one of the jets
m_1,m_2 top mass in the event
M_1,M_2 *W* mass in the event
$f(q_1),f(q_2)$ parton distribution function (CTEQ4) for incident partons
q_1,q_2 initial parton momentum
Φ_6 six particle phase space
$W_{jet}(x,y)$ probability of measuring x when y was produced in the collision
$|M_{ttbar}|^2$ ttbar->lepton_jets matrix element (only qqbar)

Approximations in the probabilities definitions (things to do better with more statistics)

- **Only *ttbar* from *qqbar* production:** it does not include 10% of ttbar events that are produced by gluon fusion

- **Only *W*+jets background:** that is ~85% only of the background
  - The background probability is defined only in terms of the main background (*W*+jets, 85%) which proves to be an adequate representation for multijet background
  - The background probability for each event is calculated using VECBOS subroutines for *W*+jets
  - Similar procedure than for *ttbar* events

- **Leading-Order ttbar matrix element:** no extra jets, constrains our sample to have only 4 jets

$$P_0(x;c_1,c_2,\alpha) = c_1 P_{ttbar}(x;\alpha) + c_2 P_{W+jets}(x)$$

After these approximations, the likelihood function used is

$$-\ln L(\alpha) = -\sum_{i=1}^{N} \ln\left[c_1 P_{ttbar}(x_i;\alpha) + c_2 P_{W+jets}(x_i)\right] + N\int A(x)\left[c_1 P_{ttbar}(x;\alpha) + c_2 P_{W+jets}(x)\right]dx$$

The values of **c_1 and c_2 are optimized,** and the likelihood is normalized automatically at each value of α

Depends on α → Calculated in two different ways using Monte Carlo method of integration

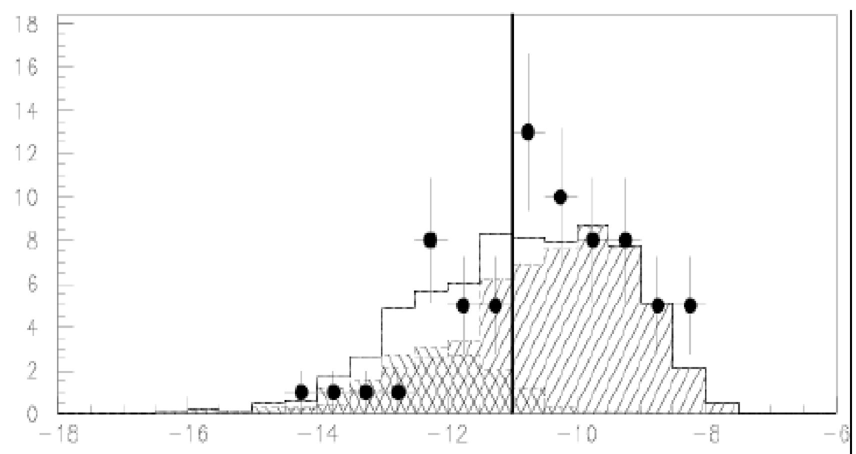
Constant

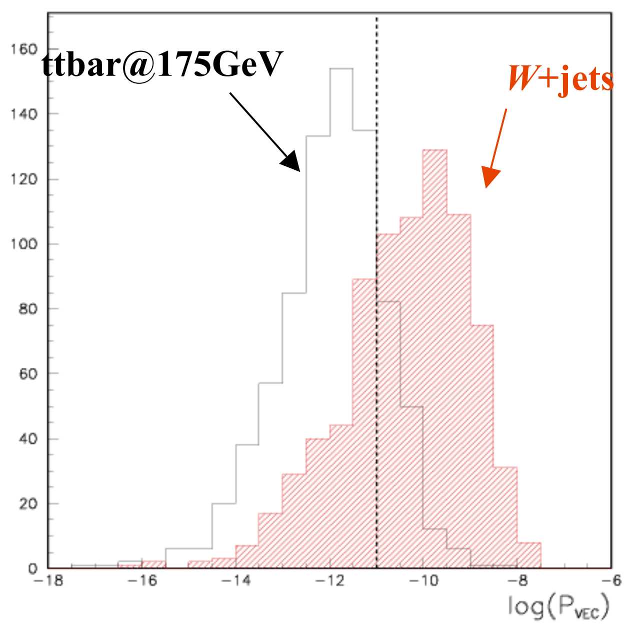
Extra Selection in P_{bkg}

- In order to increase the purity of signal another selection is applied on P_{bkg}, with efficiencies:

  ϵ_{ttbar} = 0.70,
  ϵ_{W+jets} = 0.30

- We select on $P_{bkg}<10^{-11}$, according to a previous analysis done with this method to measure the top mass



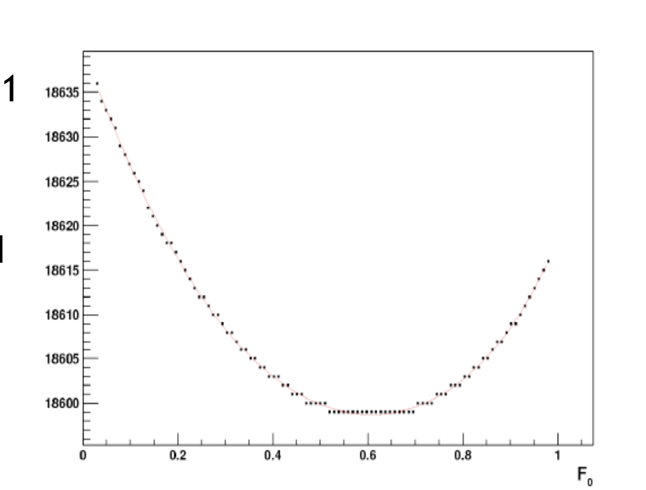


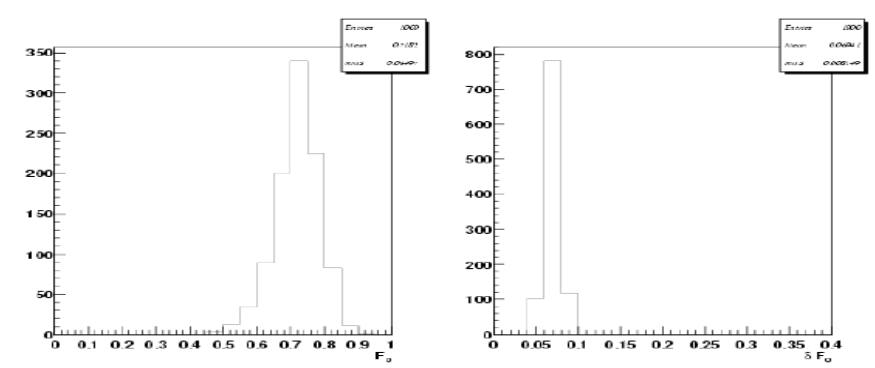
- Comparison of (16 Signal + 55 Background) MC and data sample. Background probability comparison between data (dots) and MC (histogram)

Example using Monte Carlo Events

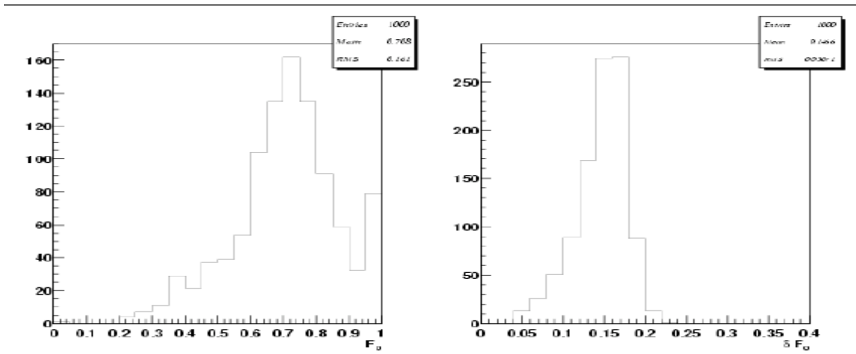
- Likelihood is calculated in the physical region, 0 to 1

- Since we are dealing with low statistics, we choose to extract the most probable value and its error defined as the _ 68.27% region around it





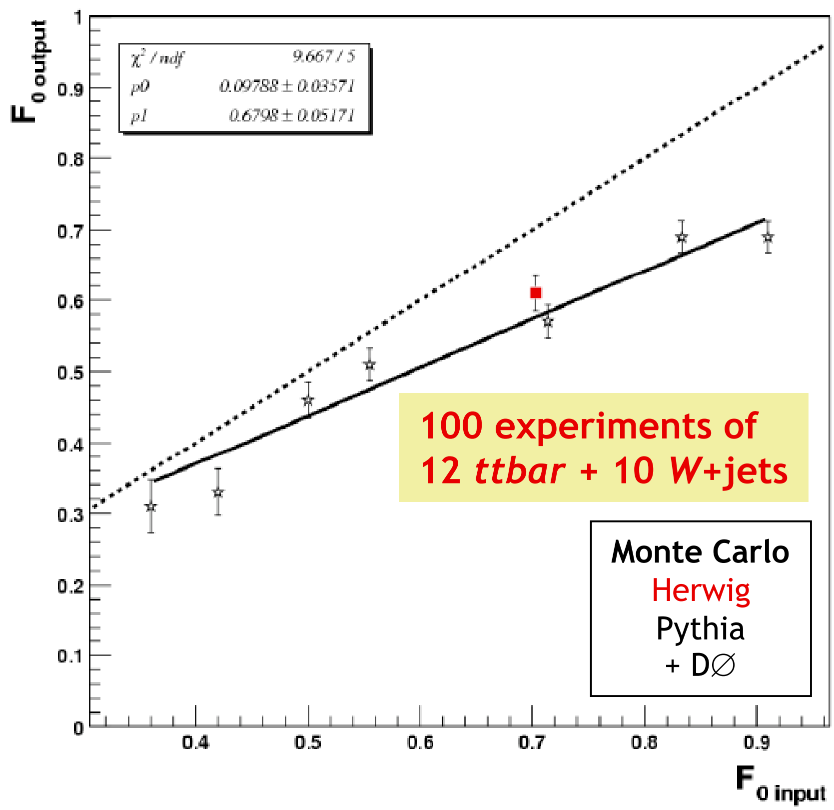
100 events per experiment



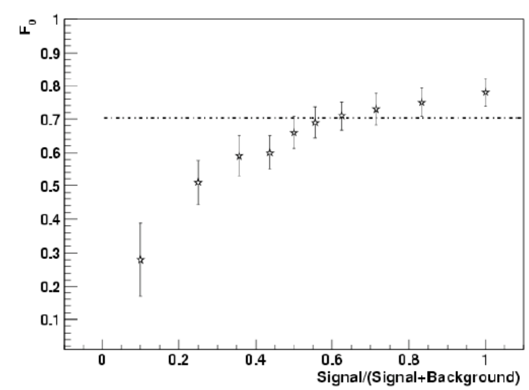
20 events per experiment

Linearity of Response for F_0

- Using different input values of F_0, experiments are used to determine output values of F_0
- A response correction needs to be applied to the data



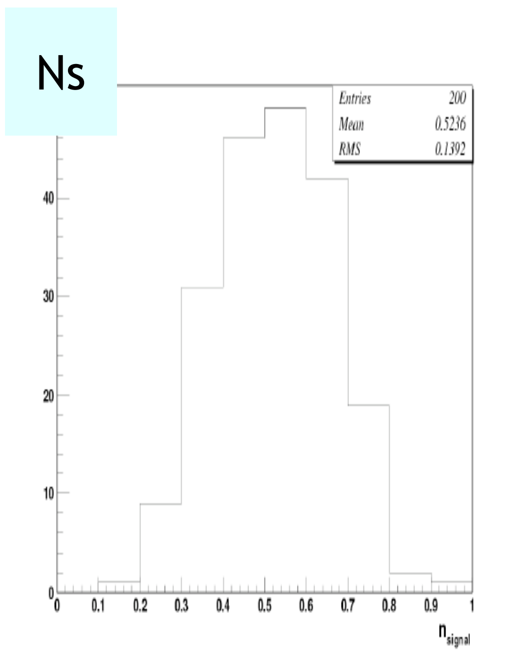
- Output F_0 is biased towards smaller values as more background is introduced
- There is no bias when using parton level *ttbar* and *W*+jets Monte Carlo events
  - Effect may come from radiation

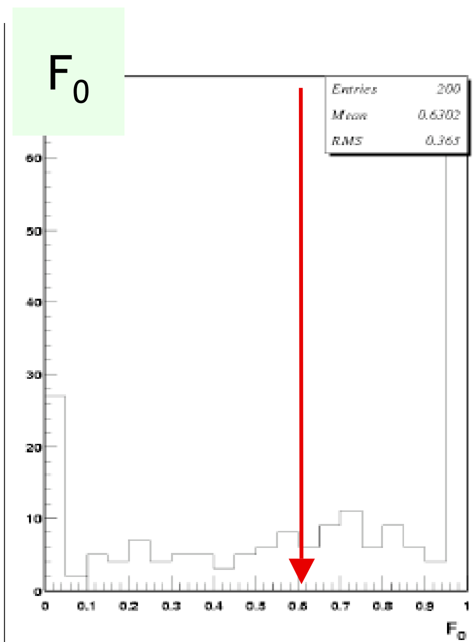


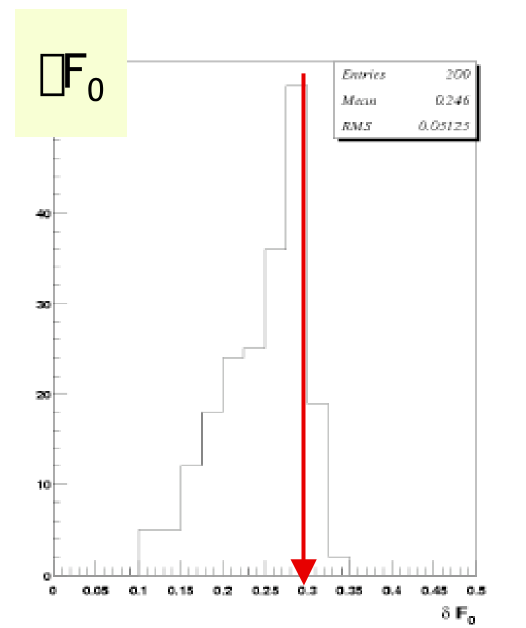
Full MC Simulation

Ensemble Tests (12 Signal +10 Background)

- 200 experiments of 12 *ttbar* (F_0=0.7) + 10 *W*+jets events
- Input F_0 is within 68.27% interval of the likelihood in 67% of the experiments
  - reasonable definition for the uncertainty on F_0
- Distributions show most probable F_0, uncertainty in F_0, and number of signal events
- **Arrows show Run I data**



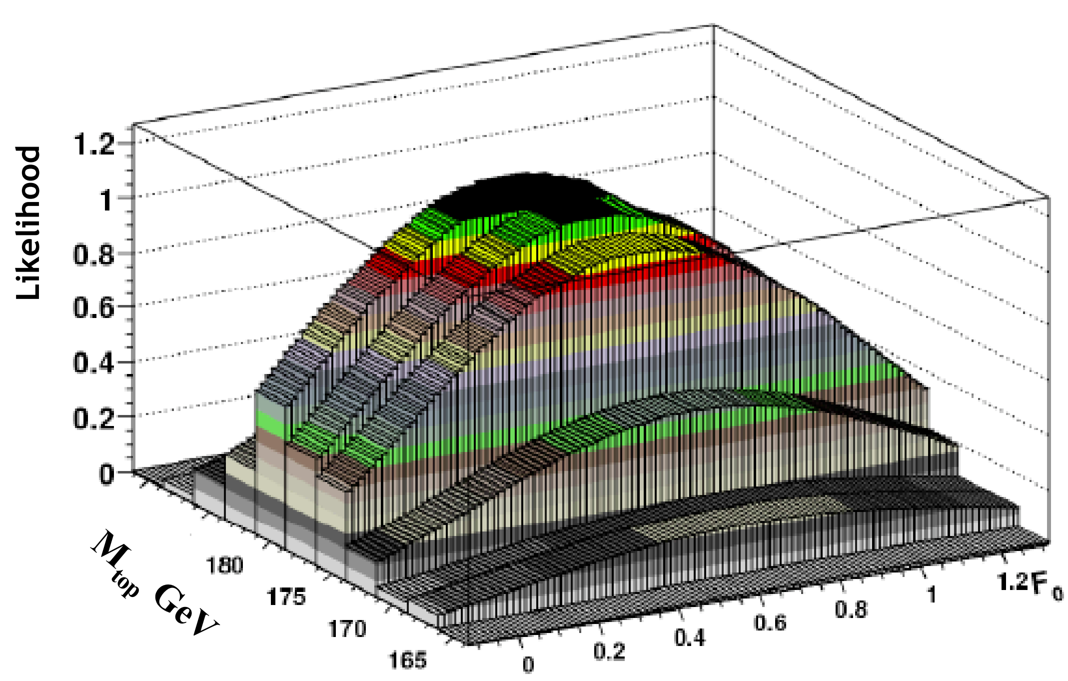




Two-dimensional Probability - M_{top}, F_0

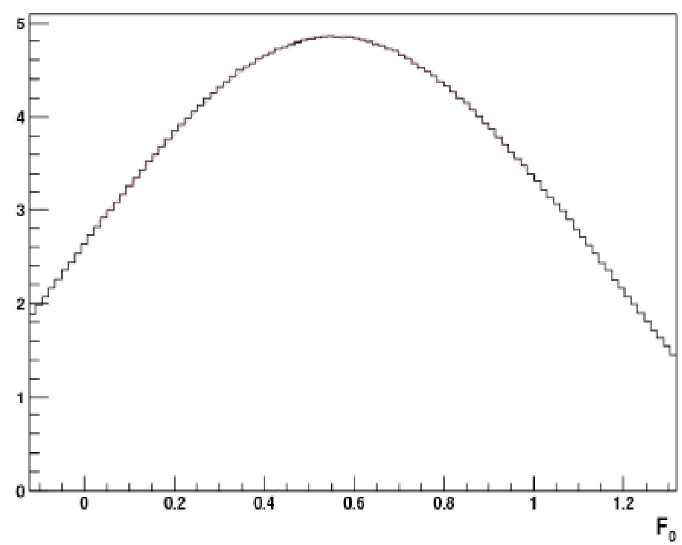
- Assuming F_0= 0.7 (SM), **M_{top} is measured** to be 180.1 ± 3.6 GeV (shift of 0.5 GeV applied)

- Assuming M_{top}=175 GeV, **F_0 is measured** to be 0.599 ± 0.302 (linearity response applied)



Preliminary Measurement of F_0 with DØ Run I Data

- Uncertainty on the top mass translates into a systematic error on the measurement of F_0
- Integrate over M_{top} $L(F_0) = \int L(M_{top}, F_0) dM_t$
- Most probable value and 68.27% interval using M_{top}=175 GeV
- 22 events pass our cuts => from fit, **12 signal + 10 background events**



$F_0 \pm \Delta F_0(\text{Stat+ } M_{top}) = 0.558 \pm 0.306$

	Statistics + M_{top} uncertainty	0.306
From data	Jet Energy Scale	0.014
From data	Parton Distribution Function	0.007
From data	Acceptance-Linearity Correction	0.021
From Monte Carlo	Background	0.010
From Monte Carlo	Signal Model	0.020
From Monte Carlo	Multiple Interactions	0.009
From Monte Carlo	ttbar Spin Correlations	0.008

Conclusions

- The helicity of the *W* boson offers a way to learn about the decay coupling of the top quark

- Using LO approximation and parameterized showering, we calculated the event probabilities, and measured:

  F_0 (preliminary)= 0.56 ± 0.31

  First F_0 measurement done at **DØ** using **22 events** (~50% signal)

  CDF measurement using **108 leptons** (~70% signal) **0.91 ± 0.39**

- This method was first applied to the re-measurement of the top quark mass, and now applied to measure angular distributions

- We have a method that allows us to extract F_0 using the maximal information in the event:
  - ✓ Correct permutation is always considered (along with the other eleven)
  - ✓ All features of individual events are included, thereby well measured events contribute more information than poorly measured events
  - ✓ This method offers the possibility of increasing the statistics using **both W decay branches**
  - ✓ For higher statistics, one clearly needs to improve the calculation of the probabilities, but this method is a **better way** to do the analysis