Measurement of W Boson Helicity in Top Quark Decay

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OUTLINE

- **Introduction**
- **Analysis**
- **Conclusion**

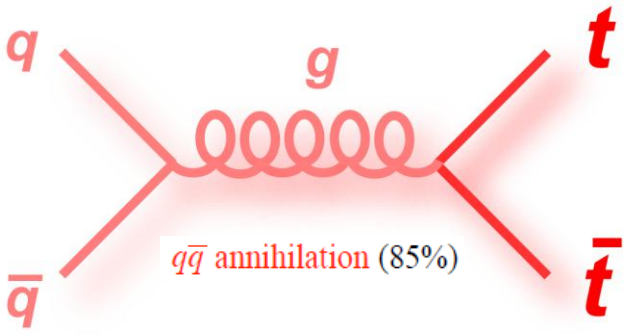
Start with answering some basic questions

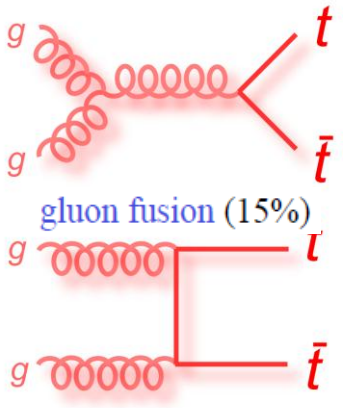
- What is W boson helicity?
- Why in top quark decay?
- How do we measure that?

Top quark at Tevatron

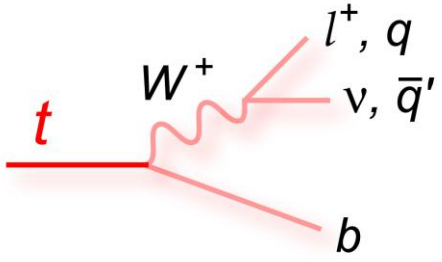
- The top quark is the most recently discovered quark , discovered at Fermilab in 1995

Top quark pair production at Tevatron



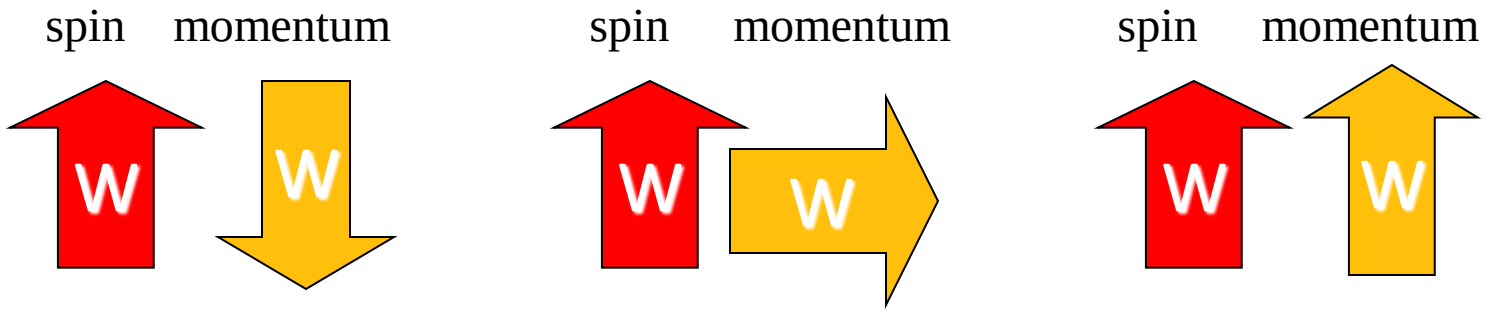


Top quark decays ~100% to W and b quark



What is W boson Helicity ?

The *W* boson from top quark decay is produced in one of three polarization states



In Standard Model :

Negative helicity $f_- \sim 30\%$ (left handed, W_-)

Zero helicity $f_0 \sim 70\%$ (longitudinal, W_0)

Positive helicity $f_+ \sim 0\%$ (right handed, W_+)

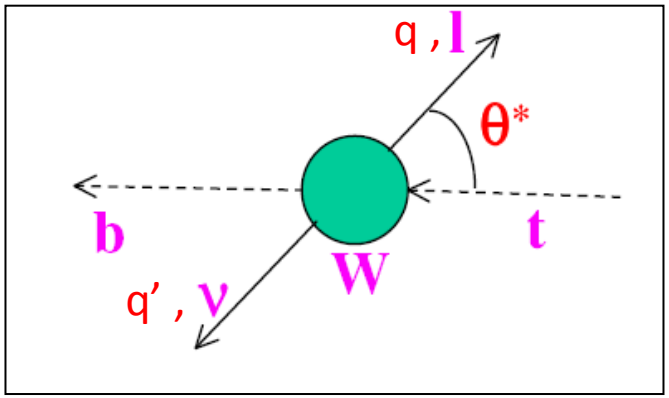
The uncertainties in the Standard Model prediction are far smaller than the precision we can achieve experimentally.

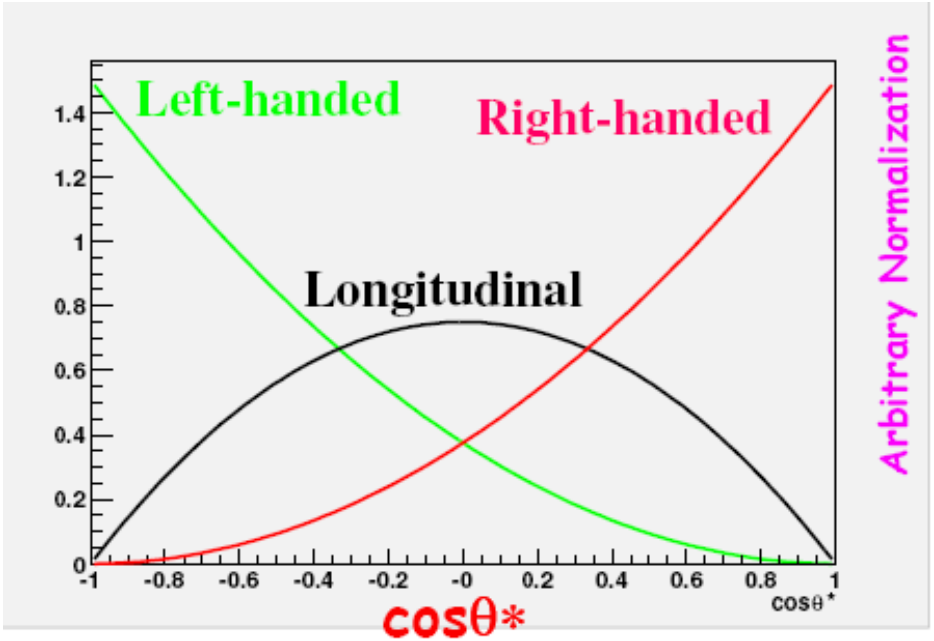
Any significant deviation from the SM values would be a clear signature of new physics.

How do we measure *W* Helicity

We can get *W* helicity fractions (f_0 and f_+) from the cosθ* distribution in *W* rest frame

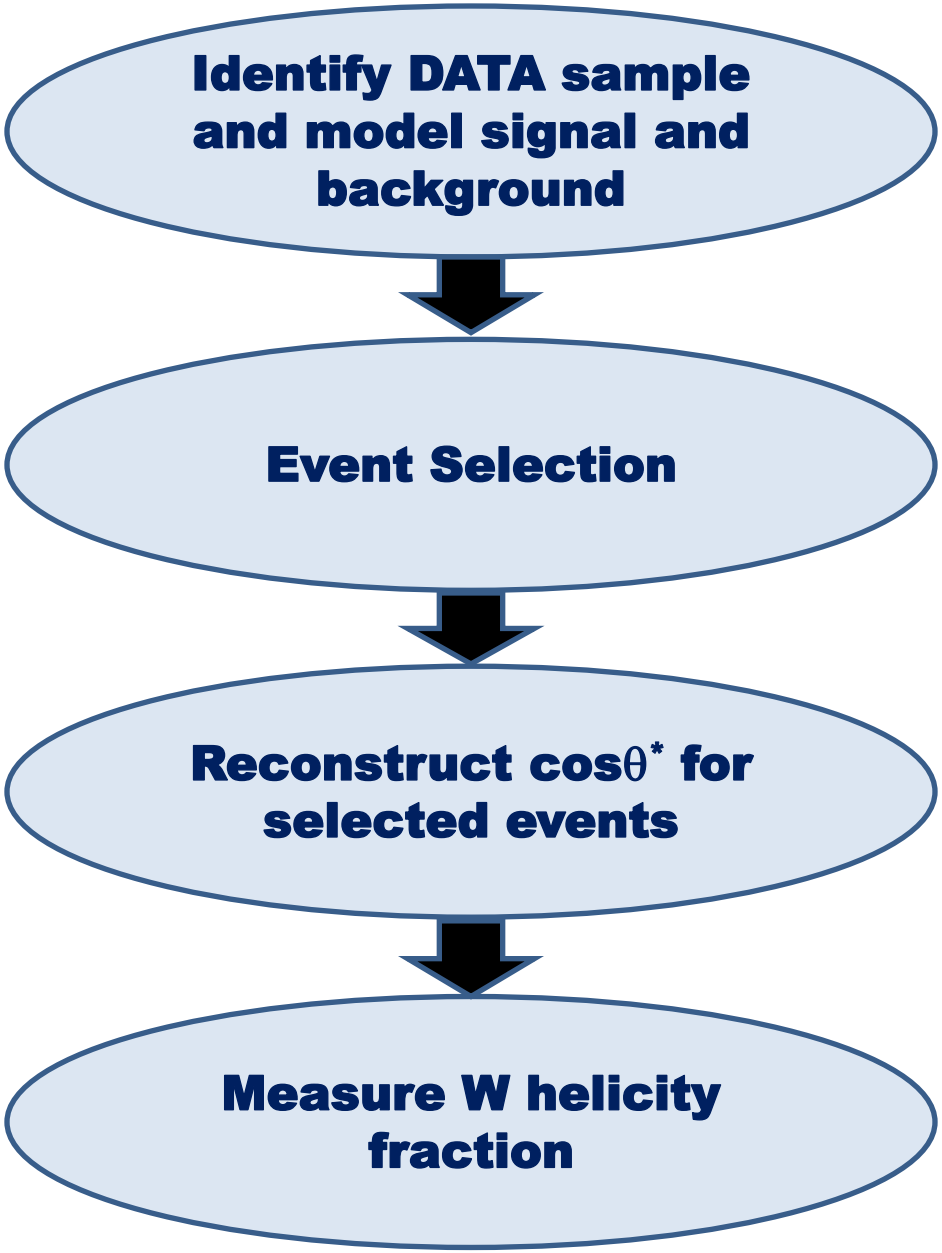
$$c = \cos\theta^* = \frac{-(\vec{l}\,.\vec{b})}{|\vec{l}\,||\vec{b}\,|}$$

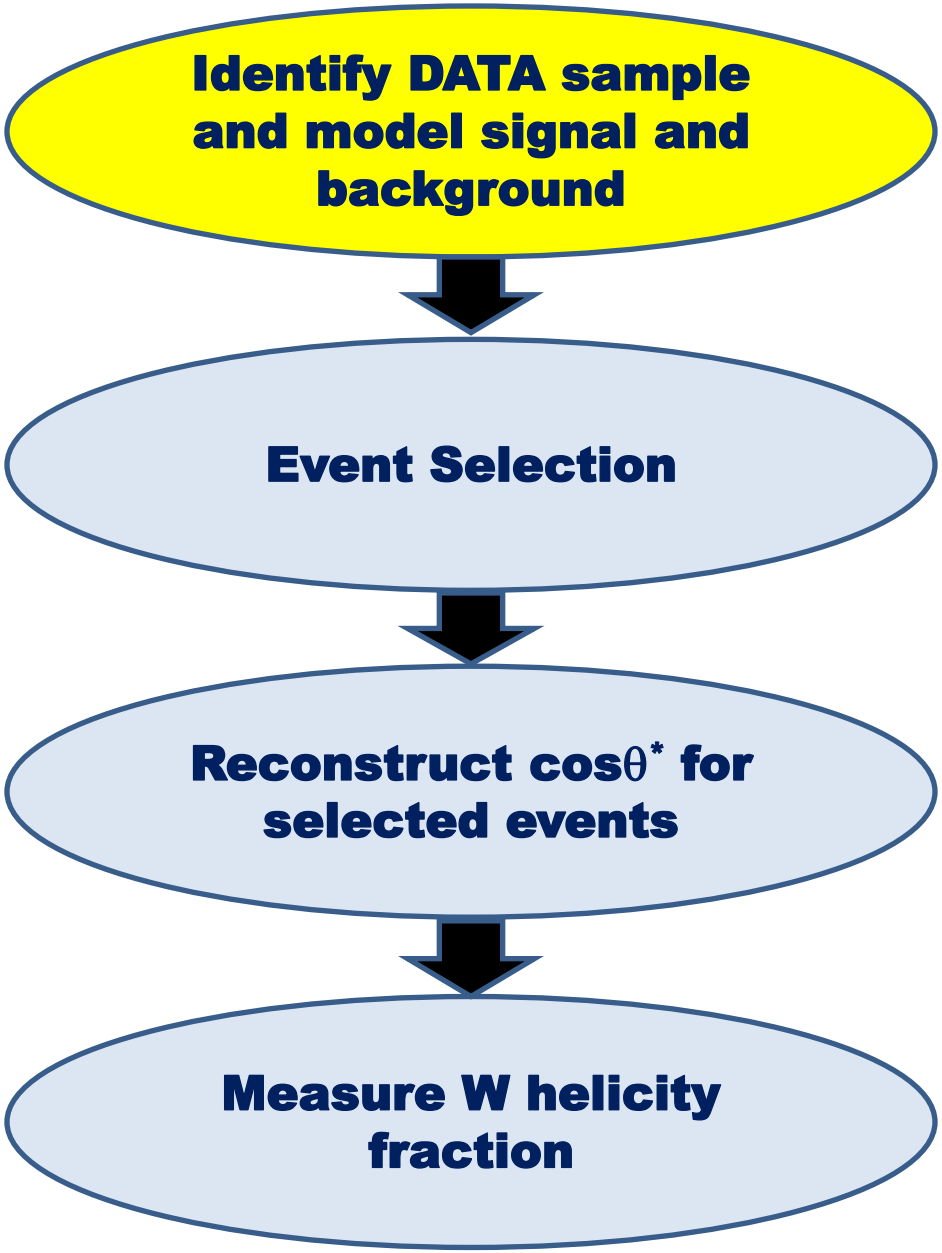




$$\omega(c) \propto 2(1-c^2)f_0 + (1-c)^2 f_- + (1+c)^2 f_+$$

This is the basis of this measurement.


Identify DATA sample and model signal and background
Event Selection
Reconstruct cosθ* for selected events
Measure W helicity fraction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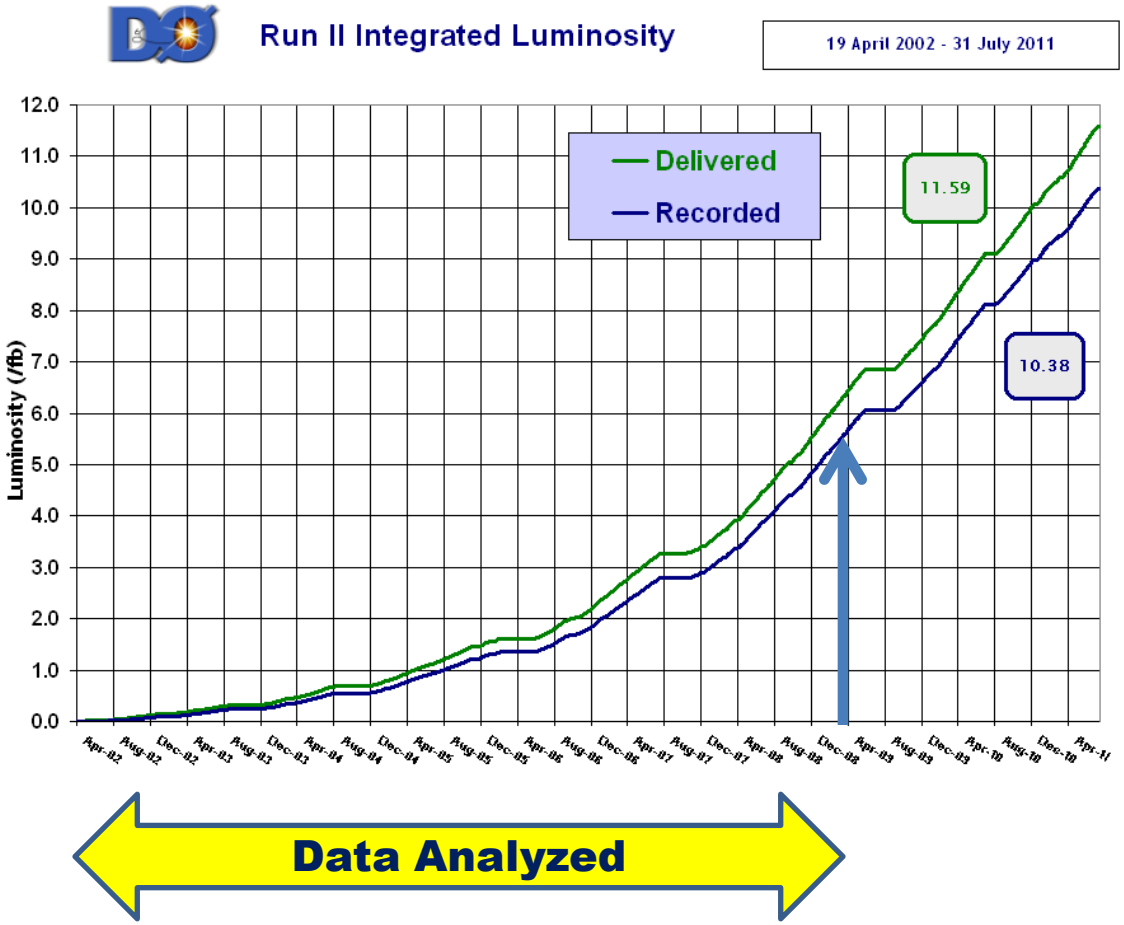
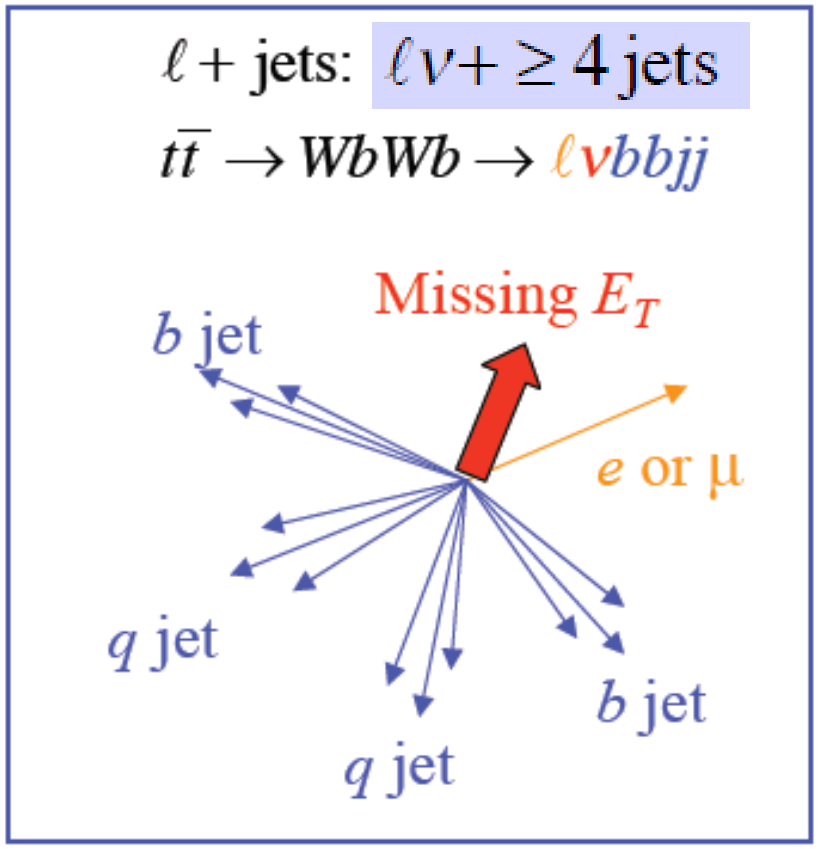
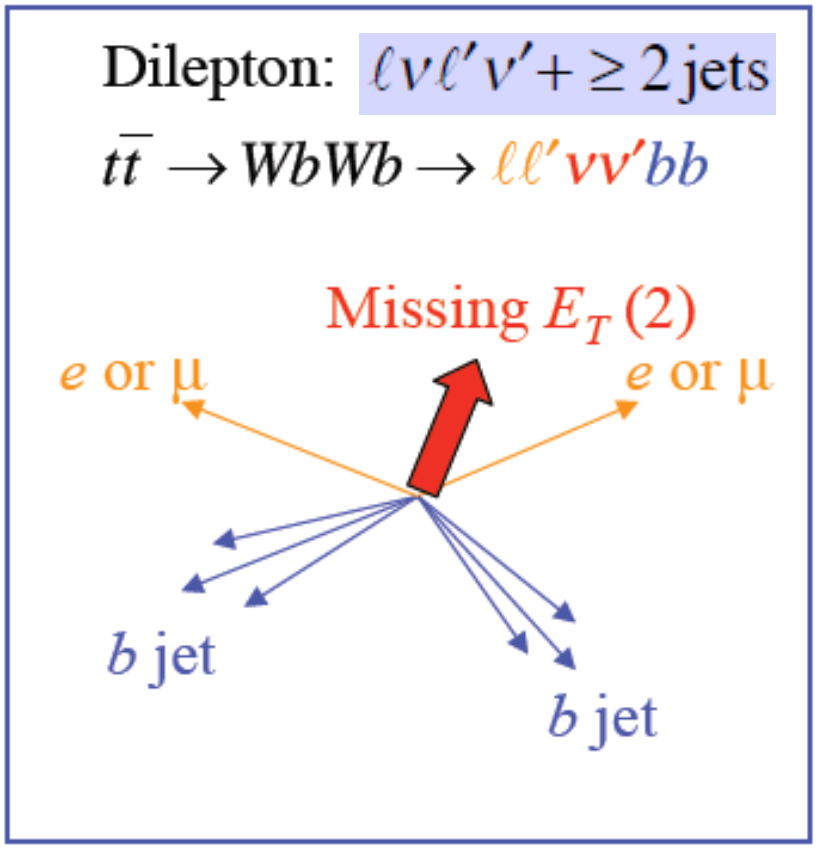


Integrated Luminosity x Cross-section = Number of events

- Data used for this analysis was collected between April 2002 and June 2009 which corresponds to a total integrated luminosity of 5.4 fb^{-1}.
- Simulated samples (Monte Carlo) were used to model the data.

Signal Events for this analysis



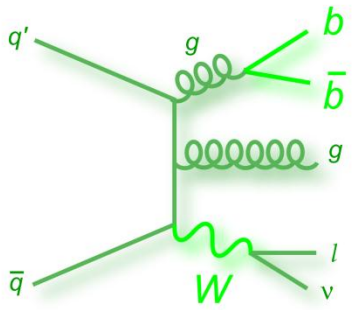


Background events for this analysis

There are two categories of background

1. Inherent background from standard model physics process having similar final state as from top pair, e.g.

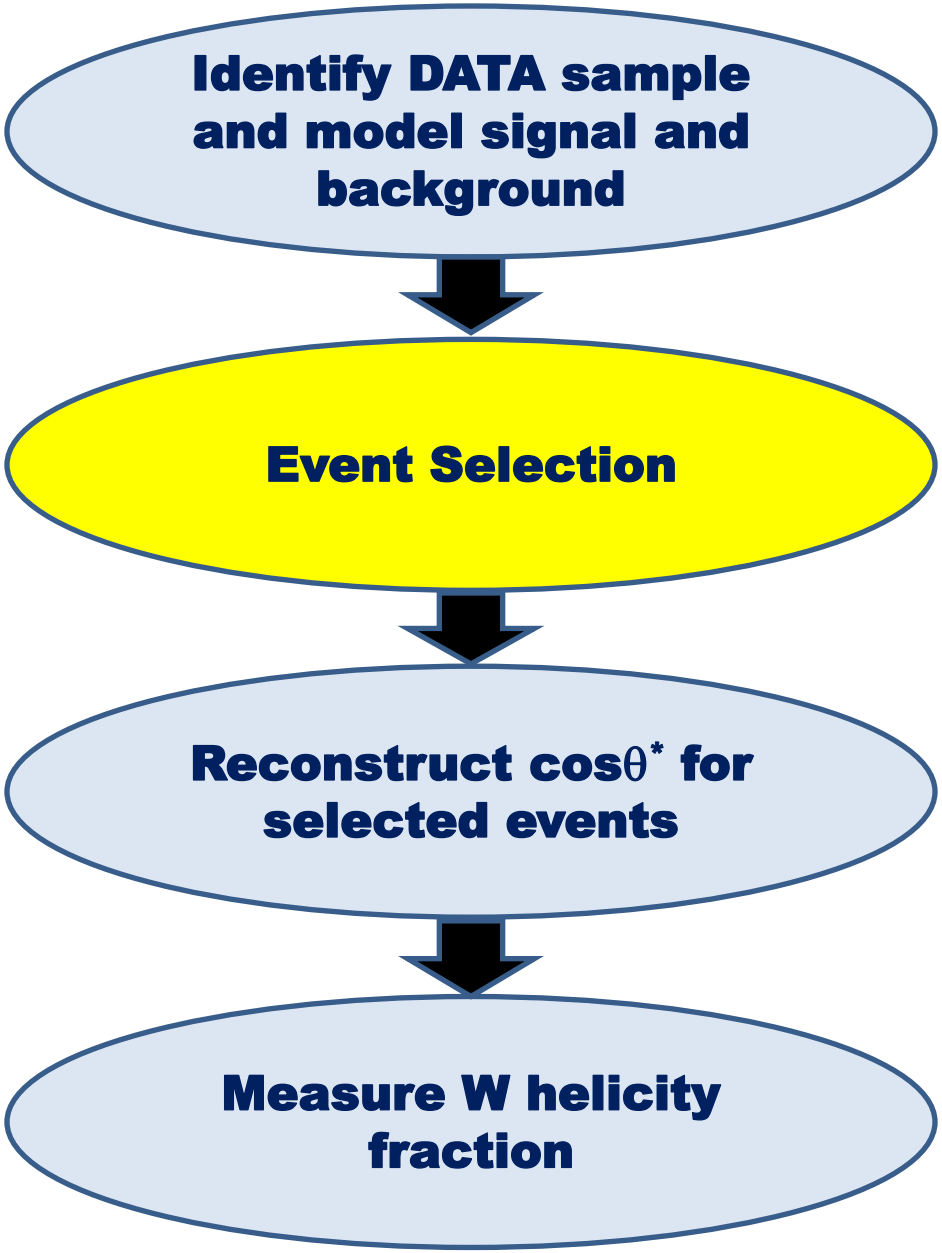
$$W + \geq 4\,\text{jets} \rightarrow \ell\nu + \geq 4\,\text{jets}$$



Simulated sample (MC) used to model the inherent background

2. Instrumental background where a final state object is misidentified, e.g. a jet misidentified as an electron.

Data control sample is used to model the instrumental background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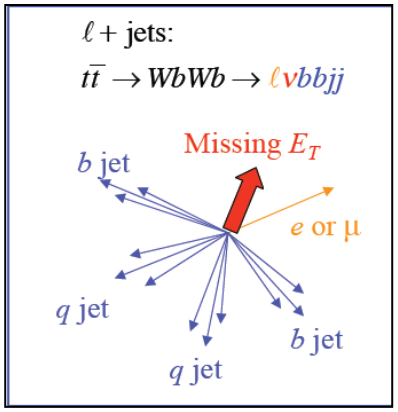
The event selection is done in two steps

Pre-selection

Apply well understood selection criteria to identify each object expected in the final state of an event with top pair.

Example : for lepton+jet final state, we select events with

- At least 4 or more jets with a minimum transverse momentum
- 1 well identified lepton (electron or muon)
- Missing energy to account for the neutrino

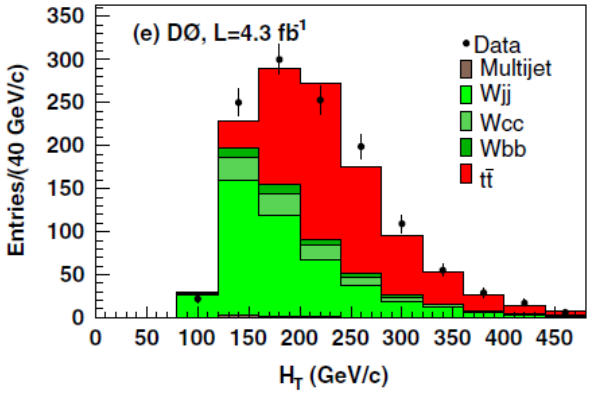


Final Selection

- Use a multivariate discriminant to separate background from signal events and apply a cut to get a sample enriched with top quarks.

- We develop a **classical likelihood** (L_t) based on simulated events that combines all the information we have in terms of several variables. An example of one such variable:

H_T – Scalar sum of the pre-selected jet transverse momentum. Jets originating from background are less energetic than those originating from top pair decay.



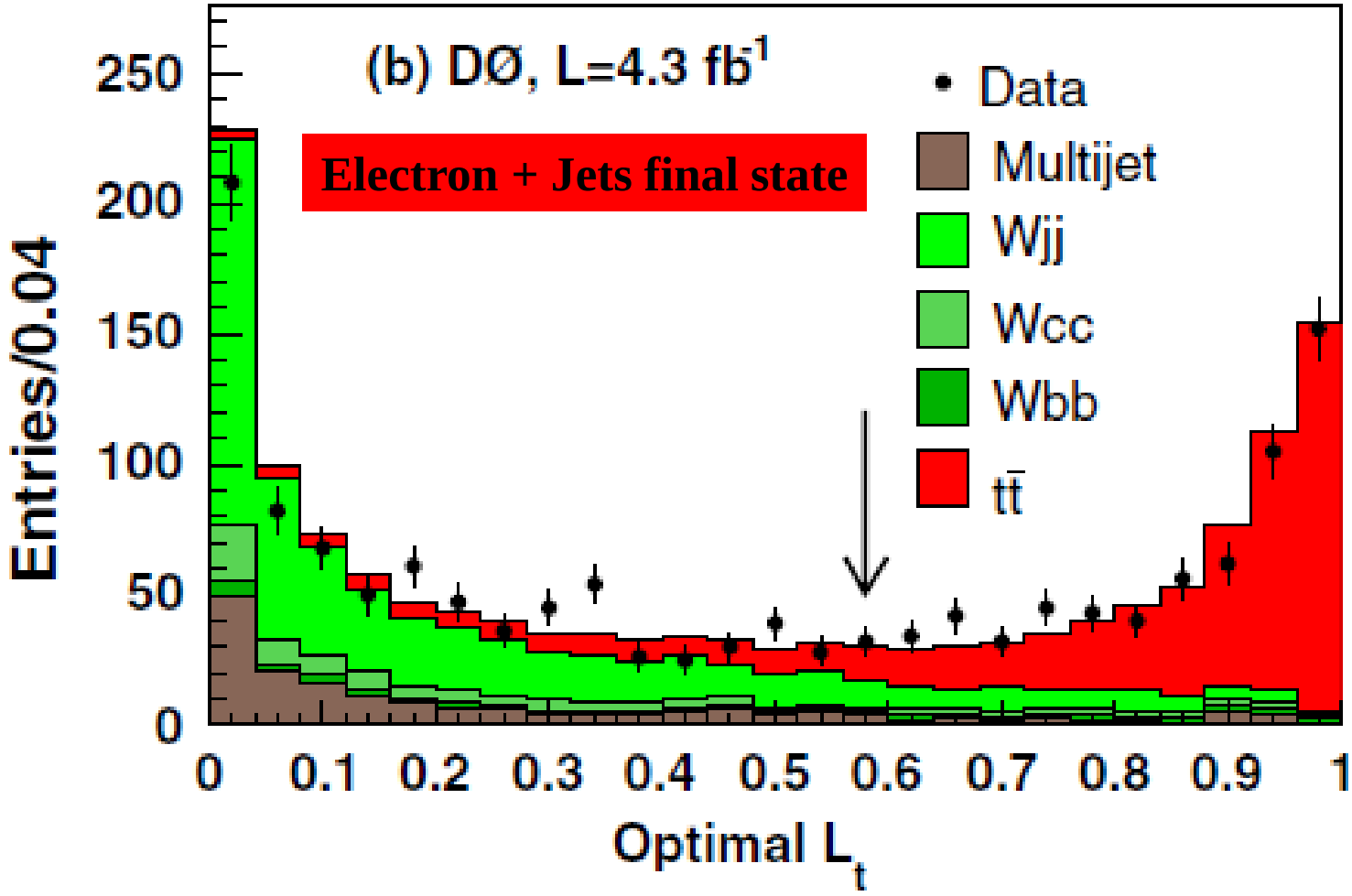
H_T distribution of signal (red), background and data (points) after pre-selection.

Optimization of final selection

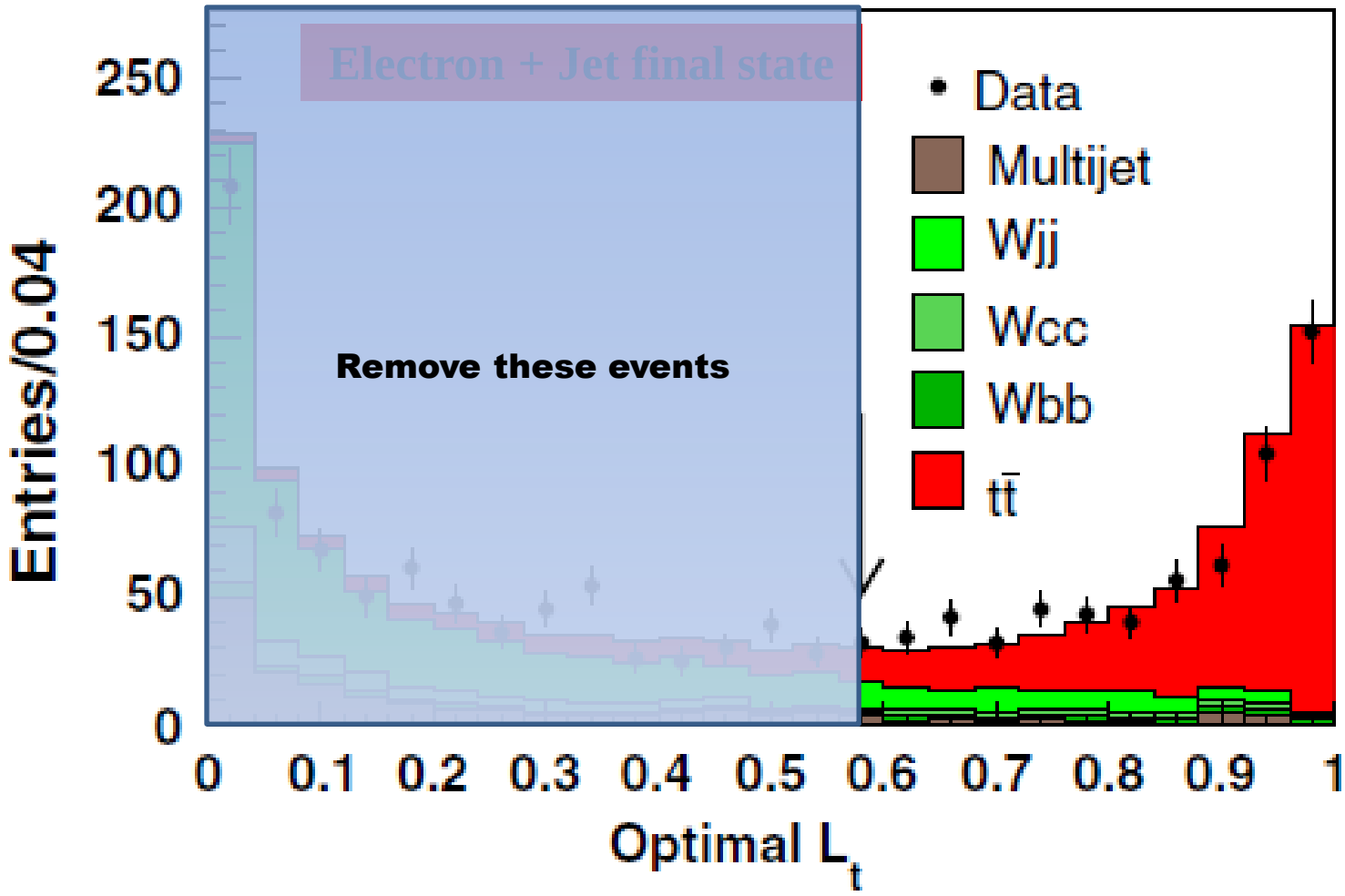
- Over 10 such variables are used to train the classical likelihood where different combinations of these variables return one classical likelihood.

- Optimization is done by trying all possible combinations of variables, and all possible cut points on the likelihood, to find the one that maximizes the figure of merit (Signal/Background).

One Example ……


(b) DØ, L=4.3 fb^{-1}
Electron + Jets final state
Data
Multijet
Wjj
Wcc
Wbb
$t\bar{t}$
Entries/0.04
Optimal L_t
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

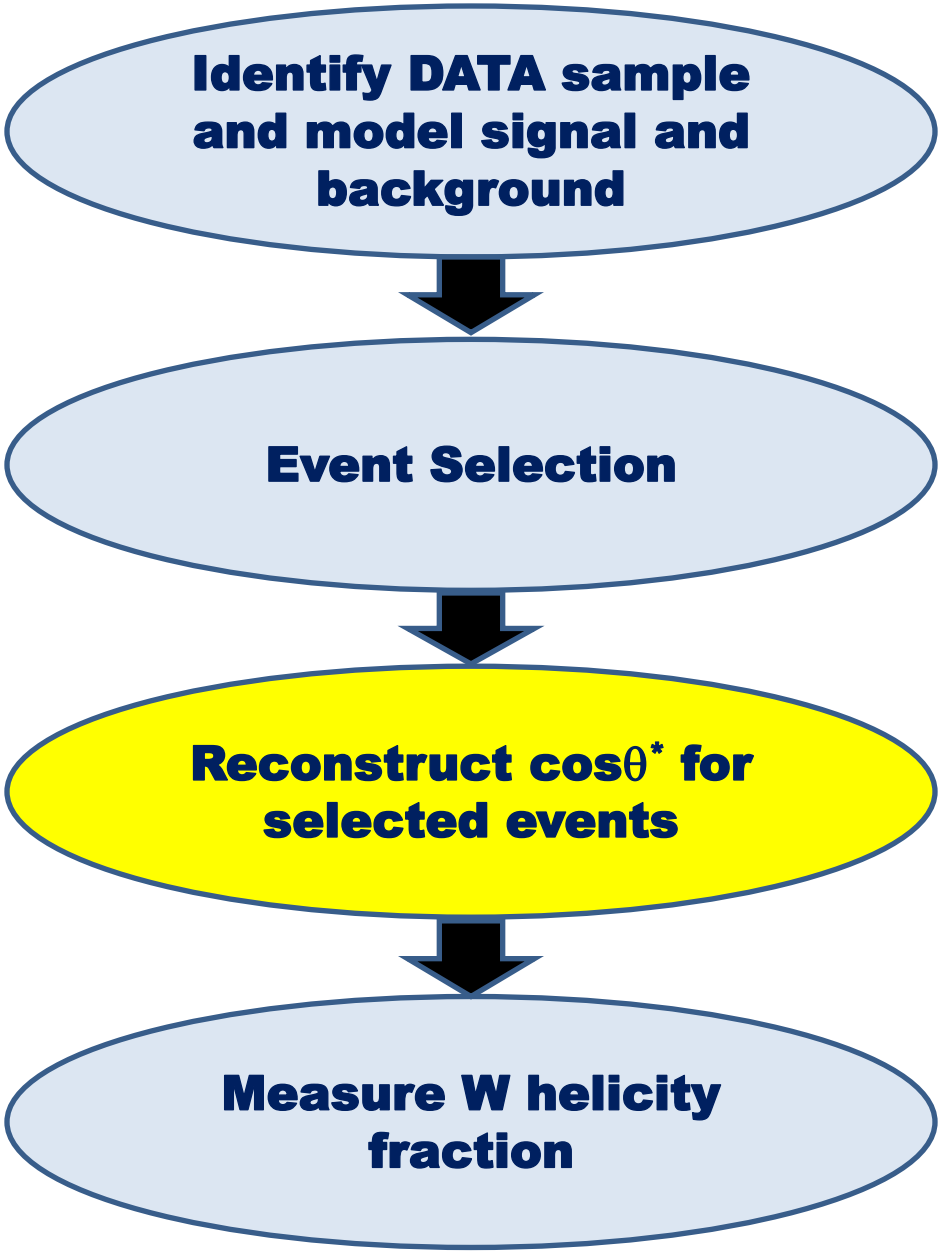
One Example ……


Electron + Jet final state
Remove these events
Data
Multijet
Wjj
Wcc
Wbb
$t\bar{t}$
Entries/0.04
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Optimal L_t

- For each of the 5 channels, we get one such optimized likelihood
- We apply the optimized selection criteria

Final State	Electron + JETS	Muon + JETS	Electron + Electron	Muon + Muon	Electron + Muon
Signal purity before L_t cut (PRE-SELECTED SAMPLE)	41%	49%	2%	2%	55%
Signal Purity after L_t cut (FINAL SAMPLE)	73%	71%	83%	65%	82%

This defines the top quark sample used for our measurement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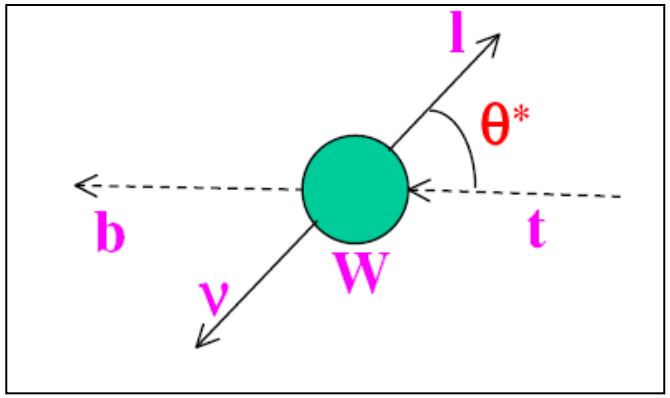


$$c = \cos\theta^* = \frac{-(\vec{l}\,.\vec{b})}{|\vec{l}\,||\vec{b}\,|}$$

❑ For each event in the final sample we reconstruct the four-momenta of the top quark and the W boson. For each event, we calculate 2 cos θ* (one for each tWb vertex).

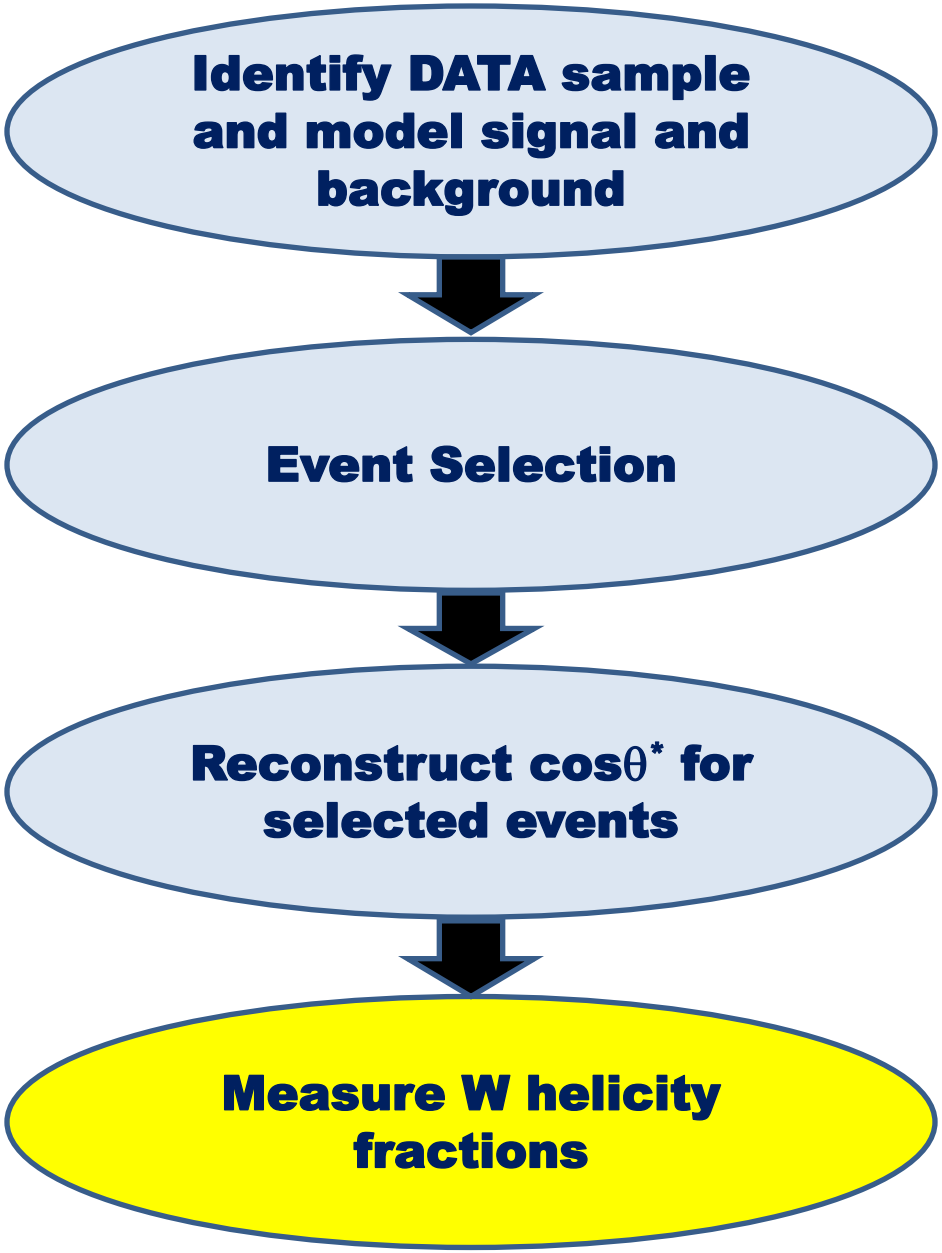
❑ This is done using the following constraints :

✓ The invariant mass of the lepton and neutrino is the *W* mass

✓ In lepton+jet events, the invariant mass of the two jets is the *W* mass

✓ The top mass is 172.5 GeV

❑ Using these four-momenta, cos θ* is calculated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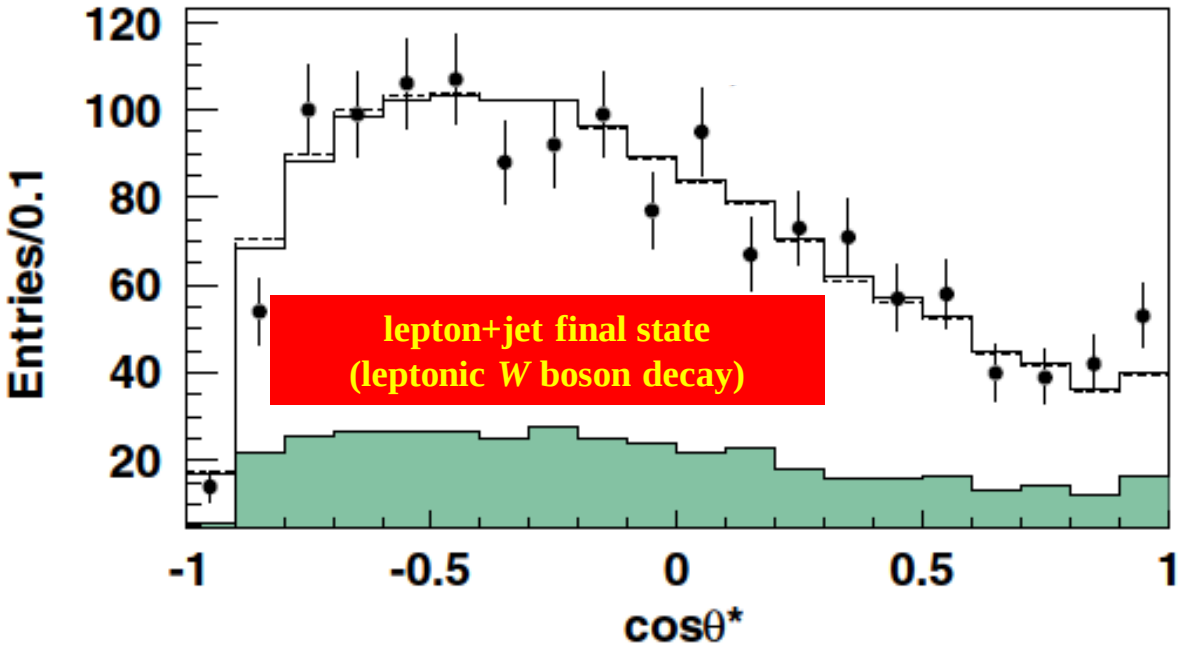
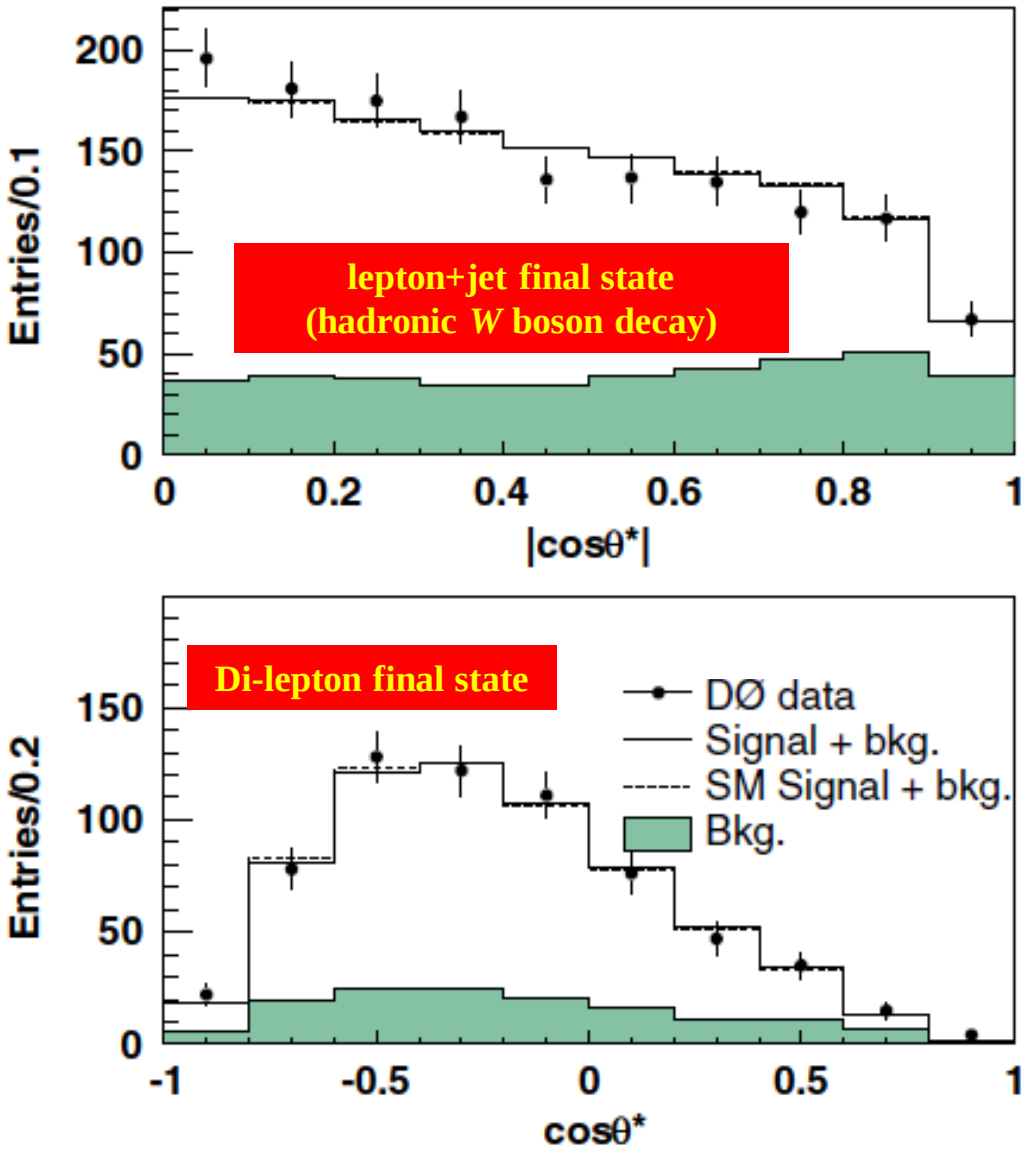
❑ Starting with the simulated signal samples (top pair sample), we model the expected distributions of cosθ* for left-handed, longitudinal and right-handed *W*s.

❑ Once we have the cosθ* distributions for signal, background and data, we use a maximum likelihood fit, for the data to be consistent with the sum of signal and background in the cosθ* distribution.



The fit parameters include the *W* helicity fractions f_0 and f_+


lepton+jet final state
(hadronic W boson decay)
Entries/0.1
|cosθ*|
Di-lepton final state
DØ data
Signal + bkg.
SM Signal + bkg.
Bkg.
Entries/0.2
cosθ*

RESULT

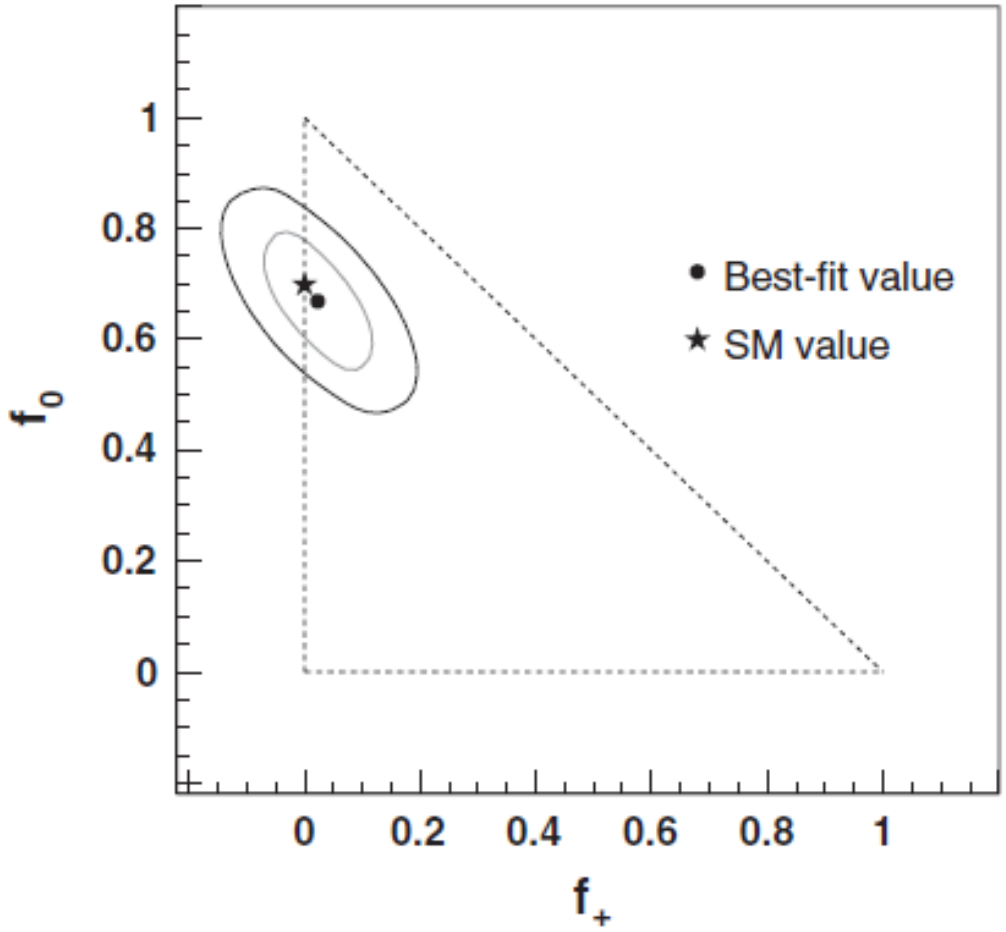
Analyzing a data sample corresponding to 5.4 fb^{-1} of proton-antiproton collisions collected by the D0 detector at Fermilab

$$f_0 = 0.669 \pm 0.102[\pm 0.078(stat.) \pm 0.065(syst.)]$$

$$f_+ = 0.023 \pm 0.053[\pm 0.041(stat.) \pm 0.034(syst.)]$$

Compare to SM values : $f_0 = 0.698$ & $f_+ = 4.1 \times 10^{-4}$

The consistency of this result with the standard model value is 98%



The ellipses are the 68% and 95% C.L. contours, the triangle borders the physically allowed region where f_0 and f_+ sum to one or less, and the star denotes the SM values.

CONCLUSION

After analyzing 5.4 fb^{-1} of data collected with the D0 detector, we find the measured values of the W helicity fractions consistent with the standard model value.

Hence we state that we found no evidence of new physics at the tWb decay vertex.

This is the world's most precise measurement of W boson helicity

published in PRD [Phys. Rev. D 83, 032009 (2011)]

THANK YOU