W-polarization from top decays

Muhammad Irfan Asghar
Deptt. Of Physics & NCP
QAU
Introduction to LHC

- Proton-proton collider
- Proton beam energy is 7 TeV
- Luminosity ~ $10^{34}$ cm$^{-2}$ sec$^{-1}$
- Number of bunches 2808
- Number of particles in one bunch $1.15 \times 10^{11}$
- Four detectors
New schedule of LHC operation

- Beam energy 3.5 TeV, CME = 7 TeV
- Start of March 2010
- 18-24 months of continuous collisions
- Long shutdown
- Preparation for designed collision energy of 14 TeV
Pakistani RPC’s
Tools for analysis

Analyze the data, which is recorded

Real data
- Proton-proton collision
- Detector geometry and interaction
- Inclusion of electronics
- Local reconstruction
- Global reconstruction

Simulated data
- Event generator
- Detector simulation (GEANT)
- Digitization
- Reconstruction
Stable objects
- Electrons
- Photons
- Muons
- Protons, etc

Tracks
- Jets
- Missing energy
- Muons, photon, electron

Reconstruction of all objects is performed by using these objects
Introduction

- Top quark was discovered at Tevatron
- Iso-spin partner of b-quark, spin 1/2
- Heavy mass of top
- Short lifetime
- Decay before hadronization
- Top polarization predicted by SM
- Reflect fundamental interaction involved
- W-polarization predicted by SM
- W-polarization complements top spin studies

\[
\frac{1}{N} \frac{dN}{d \cos \Psi} = \frac{3}{2} \left( F_0 \left( \frac{\sin \Psi}{\sqrt{2}} \right)^2 + F_L \left( \frac{1 - \cos \Psi}{2} \right)^2 + \left( \frac{1 + \cos \Psi}{2} \right)^2 \right)
\]
Introduction

- Understand the t-W-b vertex
- Particularly its V-A structure
- Good tool to test SM predictions $t \rightarrow bW$ 99.9 %.
- Signatures of new physics
- V+A component
- Sensitive probe of new physics in top production and decay.
Introduction

- LHC $\sigma \sim 883 \pm 45$ pb (NNLO), 10% qq, 90% gg.
- BR ($t \rightarrow bW$) $\sim 100\%$ in SM
- 1 tt/sec@ $L = 10^{33}$
- LHC will be a top factory
**W-helicity States**

- Top rest frame
- Angular momentum conservation
- Massless b left-handed
- Right most forbidden at tree level
Leptons from LH W have less boost
Leptons from RH W have more boost
Generator Level Results
Measurement Method

- 50,000 $\text{ttbar} \approx 0.05 \text{ fb}$ at luminosity of $10^{33}$
- NLO Event Generator (TopRex) 4.21 (CMSSW_1_2_3)
- Top quarks and its decay products were selected
- Mother and daughter relationship was ensured
- Leptons from longitudinal W have harder $p_T$ spectrum
- Leptons from left-handed W have softer $p_T$ spectrum
Measurement Method (continued)

- W-polarization is measured in semi-leptonic $t\bar{t}$ channel through the distribution of the $\psi$ angle.
- $\psi$ is defined as the angle between the charged lepton direction in $W$ rest frame and the $W$ direction in the top rest frame.
- No cuts used.
- Distribution fitted with eqn below.
- Constraint used $F_0 + F_L + F_R = 1$

Fitting function

$$\cos \psi = x$$

$$\frac{3}{2} F_0 \cdot \left( \frac{1 - x^2}{2} \right) + F_L \cdot \left( \frac{1 - x}{2} \right)^2 + F_R \cdot \left( \frac{1 + x}{2} \right)^2$$
Generator Level Results

<table>
<thead>
<tr>
<th>top pT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>RMS</td>
</tr>
</tbody>
</table>

$pT$ of top
Generator Level Results (continued)

![Histogram of muon pT]

- **Entries**: 50000
- **Mean**: 52.15
- **RMS**: 37.73

**pT of muon**

```
-100  -50   0   50  100  150  200  250  300  350
```
Generator Level Helicity plot

\[ F_0 = 0.7039 \pm 0.2580 \]
\[ F_L = 0.2952 \pm 0.1937 \]
\[ F_R = 0.0005 \pm 0.0782 \]
F0  Longitudinal Polarization = 0.703
FL  Left-handed Polarization = 0.295
FR  Right-handed polarization = 0.000

these values match with the standard model predicted values.
With lepton pt-cut of 30 GeV
Comparison before and after cut

- Only a pt-cut of 30 GeV on lepton changes the whole distribution.

- e.g. F0, $0.703 \pm 0.2580$ before cut
- F0, $0.950 \pm 0.2576$ after cut

- FL, $0.295 \pm 0.2952$ before cut
- FL, $0.045 \pm 0.1323$ after cut

- FR, $0.000 \pm 0.0782$ before cut
- FR, $0.001 \pm 0.090$ after cut
Reconstruction Level Results
Reasons to choose semi-leptonic channel

- $\text{Br}(t \to Wb) \sim 1$
- $\text{Br}(W \to lv) \sim 1/3, \ l = e, \mu, \tau$
- $t, \bar{t}$ preferentially produced in central region $|\eta| < 2.5$
- Back to back in transverse plane
- $t, \bar{t}$ are naturally well separated
- Less missing energy
- Easy to reconstruct the event

Semi-leptonic $t\bar{t}$ channel
Data formats

- Analysis was performed using CMSSW_1_3_1 and TQAF_131_070822
- Top Quark Analysis Framework
- An additional layer on RECO data formats
- Further manipulates RECO data and divide into
  - GENerated
  - REConstruceted
  - CALibrated
  - FITted
- All above data formats are like RECO in nature
Data

- Present results 97248 (0.097M ~ 0.1/fb at low luminosity) inclusive tt-bar events.
- There are ~ 2.7M tt-bar events, due to problems in:
  - job submission
  - job not finished successfully
  - ended with some certain exit code
  - Corrupt root files
- In CRAB (version 1_5_2) we got 36% of data.
- For data production:
  - Gen+Sim with CMSSW_1_2_3 using TopREX.
  - Digi+Reco with CMSSW_1_3_1.
Procedure

- In the first Pass of our analysis:
- Make helicity plot at generator level without any cuts
- Make helicity plots after selection cut for generator, reconstruction, calibration and fitted level
- Using after cut plots as Numerator and generator level plot as denominator find a ratio (correction/weighting function w)
- Fit this ratio with a 3rd order polynomial
- Run on the same set of data in the 2nd loop.
- Fill all histograms after cut at generator, reconstruction, calibration and fitted level, weighted with 1/w.
Selection Criteria

- Cuts used are
  - 2b Jets, with $\text{Pt}_{\text{jets}} > 30$ GeV, $|\eta| < 2.5$
  - 2 light jets, with $\text{Pt}_{\text{jets}} > 30$ GeV, $|\eta| < 2.5$
  - 1 lepton, with $\text{Pt}_{\text{lepton}} > 20$ GeV, $|\eta| < 2.5$
  - $E_T$ (missing) > 20 GeV
  - $|M_t - M_t^{PDG}| < 35$ GeV both for leptonic and hadronic side
  - $|M_w - M_w^{PDG}| < 20$ GeV hadronic side only
- Advantage of using this variable is to enhance selection efficiency.
Generator level

- $F_0 = 0.6759 \pm 0.3558$, $F_L = 0.3269 \pm 0.2624$
- $F_R = 0.04919 \pm 0.19159$
Reconstruction level

- $F_0 = 0.5744 \pm 0.3605$, $F_L = 0.2772 \pm 0.2546$
- $F_R = 0.04418 \pm 0.20102$
Calibration level

- $F_0 = 0.6789 \pm 0.3623$, $F_L = 0.3267 \pm 0.2652$
- $F_R = 0.04773 \pm 0.19594$
Fitted level

- $F_0 = 0.6762 \pm 0.3629, F_L = 0.3258 \pm 0.2656$
- $F_R = 0.04817 \pm 0.19621$
Effect on F0, FL, FR

1- Gen No Cut
2- Gen
3- Rec
4- Cal
5- Fit
Helicity plot from Mlb

- Again with the same cuts i.e
  - 2b Jets, with $\text{Pt}_{\text{jets}} > 30 \text{ GeV, } |\eta| < 2.5$
  - 2 light jets, with $\text{Pt}_{\text{jets}} > 30 \text{ GeV, } |\eta| < 2.5$
  - 1 lepton, with $\text{Pt}_{\text{lepton}} > 20 \text{ GeV, } |\eta| < 2.5$
  - $\text{Et}_n > 20 \text{ GeV}$
  - $|M_t - M_t^{\text{PDG}}| < 35 \text{ GeV}$ both for leptonic and hadronic side
  - $|M_w - M_w^{\text{PDG}}| < 20 \text{ GeV}$ hadronic side only

- Advantage of using this variable
  - No neutrino missing $\text{Et}$ uncertainties

\[
\cos \psi \sim \frac{2 \left( p_l + p_b \right)^2}{M_t^2 + M_w^2} - 1 \]

$M_b \sim 0$ for above relation
- $F_0 = 0.7743 \pm 0.3408$, $F_L = 0.2751 \pm 0.2524$
- $F_R = -0.01578 \pm 0.16561$
Reconstruction level

- $F_0 = 1.872 \pm 1.085$, $F_L = 0.6423 \pm 0.6179$
- $F_R = -0.077 \pm 0.777$
Calibration level

- $F_0 = 0.7459 \pm 0.3737$, $F_L = 0.2609 \pm 0.2612$
- $F_R = -0.01649 \pm 0.20557$
Fitted level

- $F_0 = 0.7317 \pm 0.3569$, $F_L = 0.2638 \pm 0.2571$
- $F_R = -0.0139 \pm 0.1812$
Effect on F0, FL, FR Again

1- Gen No Cut
2- Gen
3- Rec
4- Cal
5- Fit
Conclusions

\[ F_0 = 0.7039 \pm 0.2580, \quad F_L = 0.2952 \pm 0.1937, \quad F_R = 0.00058 \pm 0.07828 \]

- Successfully extracted SM predicted values
- Generator level results gave correct path to extract the helicity probabilities.
- Obtained results at reconstruction level by using two different definitions of W-helicity
- The data used has the format as the REAL DATA will have.
- Ready to extract W-helicity from real data
Back up slides

\[ L = \frac{g}{\sqrt{2}} \left\{ W^-_\mu \bar{b} \gamma^\mu (f_1^L P^- + f_1^R P^+) t - \frac{1}{M_W} \partial_\nu W^-_\mu \bar{b} \sigma^{\mu\nu} (f_2^L P^- + f_2^R P^+) t \right\} \\
+ \frac{g}{\sqrt{2}} \left\{ W^+_\mu \bar{f} \gamma^\mu (f_1^L* P^- + f_1^R* P^+) b - \frac{1}{M_W} \partial_\nu W^+_\mu \bar{f} \sigma^{\mu\nu} (f_2^R* P^- + f_2^L* P^+) b \right\}, \]
The number of ion pairs produced in the avalanche is

\[ n_{ip}(x) = n_j e^{\eta(x-x_j)} \]

The charge of free electrons is

\[ Q_e(x) = Q_j e^{\eta(x-x_j)} \]

being \( Q_j = q_{el} n_j \) (\( q_{el} \) is the electron charge). The charge of negative ions is:

\[ Q_i^-(x) \simeq \frac{\beta}{\eta} Q_e(x) \]

and that of positive ions

\[ Q_i^+(x) \simeq \frac{\alpha}{\eta} Q_e(x) \]

The average charges for the j-th cluster can be computed as:

\[ < Q_e(x) > = q_{el} \mu e^{\eta x} \left( \frac{\lambda}{\eta + \lambda} \right)^3 \]

\[ < Q_i^-(x) > = \frac{\beta}{\eta} < Q_e(x) > \]

\[ < Q_i^+(x) > = \frac{\alpha}{\eta} < Q_e(x) > \]
As known, a point-like charge \( Q(P) \) moving in an electric field \( \mathbf{E}(P) \), inside a multi-electrode detector, induces on a pick-up electrode a short circuit current signal given by the generalized Ramo’s theorem [4], expressed as

\[
\dot{i}(t) = -\int_{-\infty}^{t} Q(P(\tau)) \Phi_w(P(t - \tau)) \times \mathbf{v}_d(P(\tau)) d\tau
\]  

(10)

\[
C_g = \varepsilon_0 A/d, \quad C_b = \varepsilon_r \varepsilon_0 A/s, \quad R_b = \rho s/A
\]

\[
\Phi_w(t) = -\nabla V_g = \delta(t) \Phi_w
\]

\[
\Phi_w = k/d
\]

\[
k = \frac{C_b}{C_b + 2C_g} = \frac{\varepsilon_r d/s}{\varepsilon_r d/s + 2} = \text{const}
\]

\[
i(t) = -Q(x) \Phi_w \times \mathbf{v}_d = kQ(x) \frac{v_d}{d}
\]

\[
q_e \approx \frac{k}{\eta d} < Q_e(d) >
\]
Back up slides

- Time constant of RPC cell $\tau = \varepsilon_0 (\varepsilon_r + 2) \rho$
- Voltage drop $V_d = 2 Q_e r s \rho$

$Q q_e = k/\eta d$ 
$Q_e = q_{eln_0} k/\eta d$ 
$\lambda/\lambda + \eta e^{\eta d}$
Fig. 5.1.2: Dependence of the trigger efficiency on the RPC time resolution (a) and on the RPC efficiency (b) for muons generated in the region $-0.09 < \eta < 0.09$ with $50 < p_T < 70$ GeV/c and subject to a $p_T$ cut of 5 GeV/c.