Top-quark Polarization and the Chiral Couplings of a W′ at the LHC

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Outline

- Motivation
- Theoretical Framework
- Reconstruction of Events at LHC
- Angular Distributions
- Conclusions

Motivation

- New heavy gauge bosons in many extensions of the Standard Model
- Large Hadron Collider (LHC) has potential to find such a vector state
- Once discovered, need to measure properties of new gauge boson
- An important quantity is the chiral couplings of the new gauge boson to standard model (SM) fermions
- Will focus on measuring chiral couplings of a new charged vector boson (W′) with the process

$$pp \to W' \to t\bar{b} \to \ell^+ \nu b\bar{b}, \qquad (\ell = e,\ \mu)$$

Theoretical Framework

- Motivated by SM interactions, we use the interaction Lagrangian

$$\mathcal{L} = \frac{g_2}{\sqrt{2}} \bar{\psi}_u^i \gamma_\mu \sum_{\tau=L,R} g_\tau V_\tau'^{ij} P_\tau \psi_d^j W_\tau'^{\mu +} + \text{h.c.}$$

- The model specification is parameterized by

$$g_{L,R}^{ij} \equiv g_{L,R} V_{L,R}'^{ij} \ , \quad \begin{cases} g_L = 1, \quad g_R = 0, \quad \text{pure left} - \text{handed theory } W_L', \\ g_L = 0, \quad g_R = 1, \quad \text{pure right} - \text{handed theory } W_R', \\ g_L = g_R = 1, \quad \text{left} - \text{right symmetric theory.} \end{cases}$$

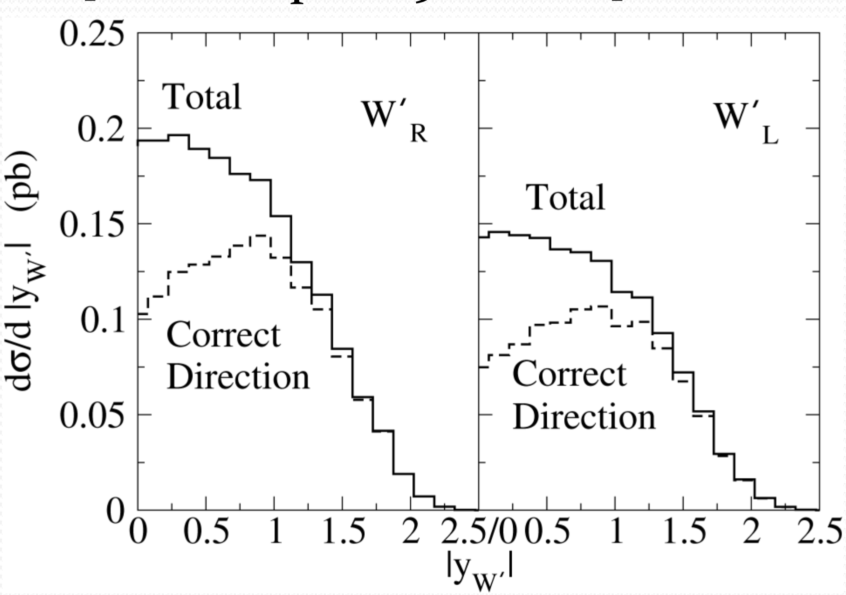
- For our study, use a W′ mass of 1 TeV and SM strength couplings

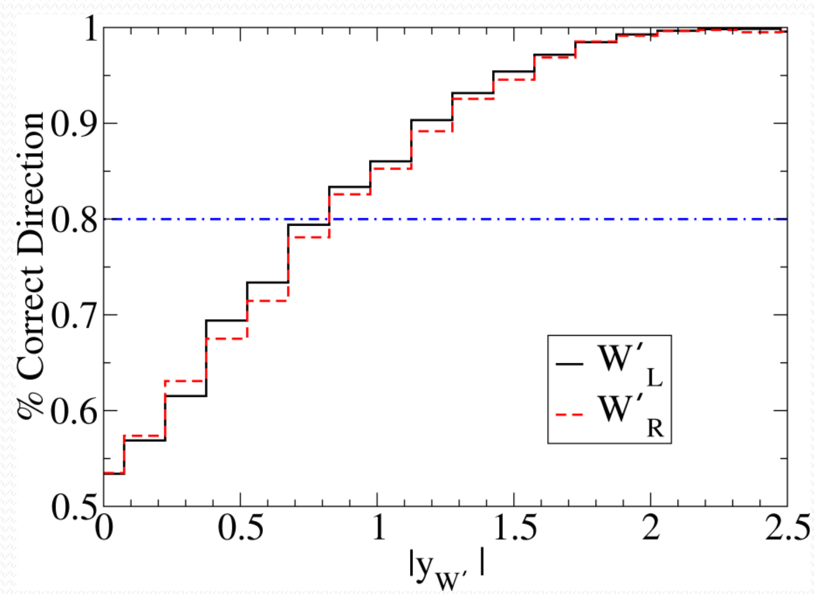
Reconstruction of Events

- To study angular correlations, need to completely reconstruct event, i.e., neutrino momentum and which b jet comes from the top decay
- Conservation of momentum for transverse component: $\mathbf{p}_{\nu T} = -(\mathbf{p}_{\ell T} + \mathbf{p}_{bT} + \mathbf{p}_{\bar{b}T})$
- Solve for neutrino longitudinal momentum and identify which b-jet results from top decay:
  - Impose W-mass: $M_W^2 = (p_\nu + p_\ell)^2$
  - Impose top mass: $m_t^2 = (p_\nu + p_\ell + p_b)^2$

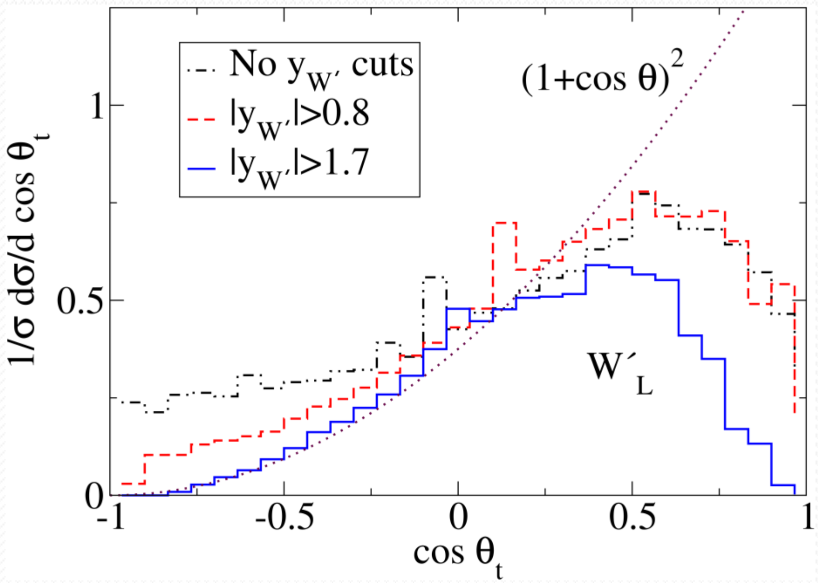
Top quark angular distribution

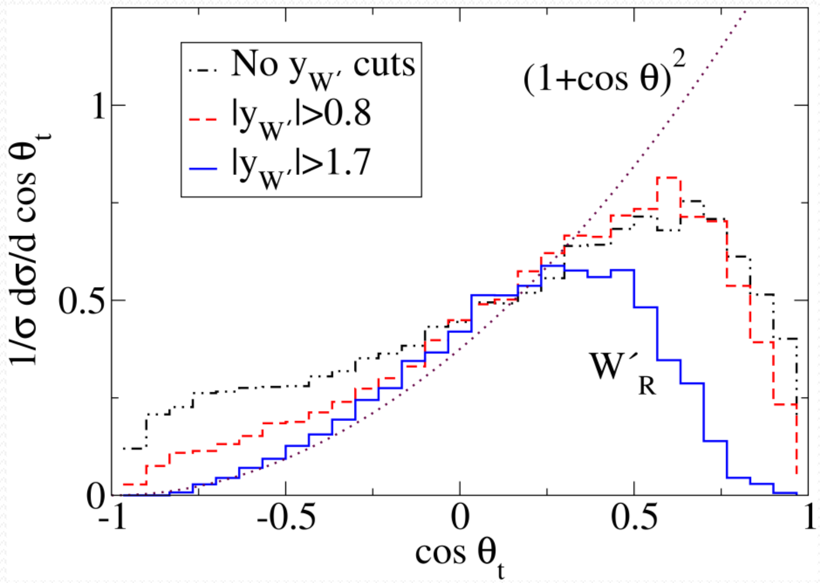
- Top quark angular distribution defined with respect to initial state quark direction.
- At hadron colliders, don't know the initial state quark direction.
- [arXiv:hep-ex/9606002]





Top quark angular distribution



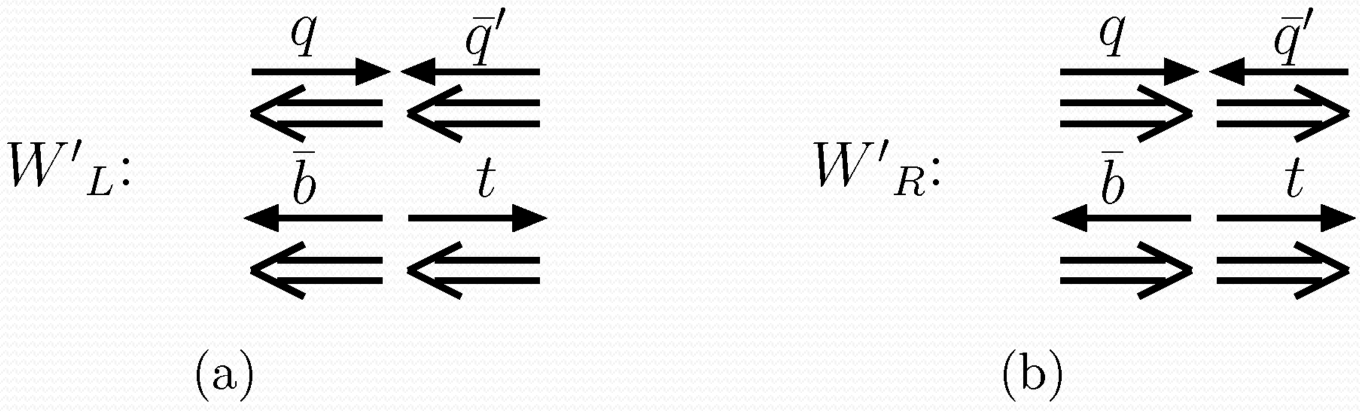


$$A_{FB} = \frac{3}{4}\frac{\left(g_R^{tb^2} - g_L^{tb^2}\right)}{\left(g_R^{tb^2} + g_L^{tb^2}\right)} \frac{\sum_{qq'}\left(g_R^{qq'^2} - g_L^{qq'^2}\right)(q\otimes q')(\tau_0)}{\sum_{qq'}\left(g_R^{qq'^2} + g_L^{qq'^2}\right)(q\otimes q')(\tau_0)},$$

- Unable to distinguish left and right handed cases.

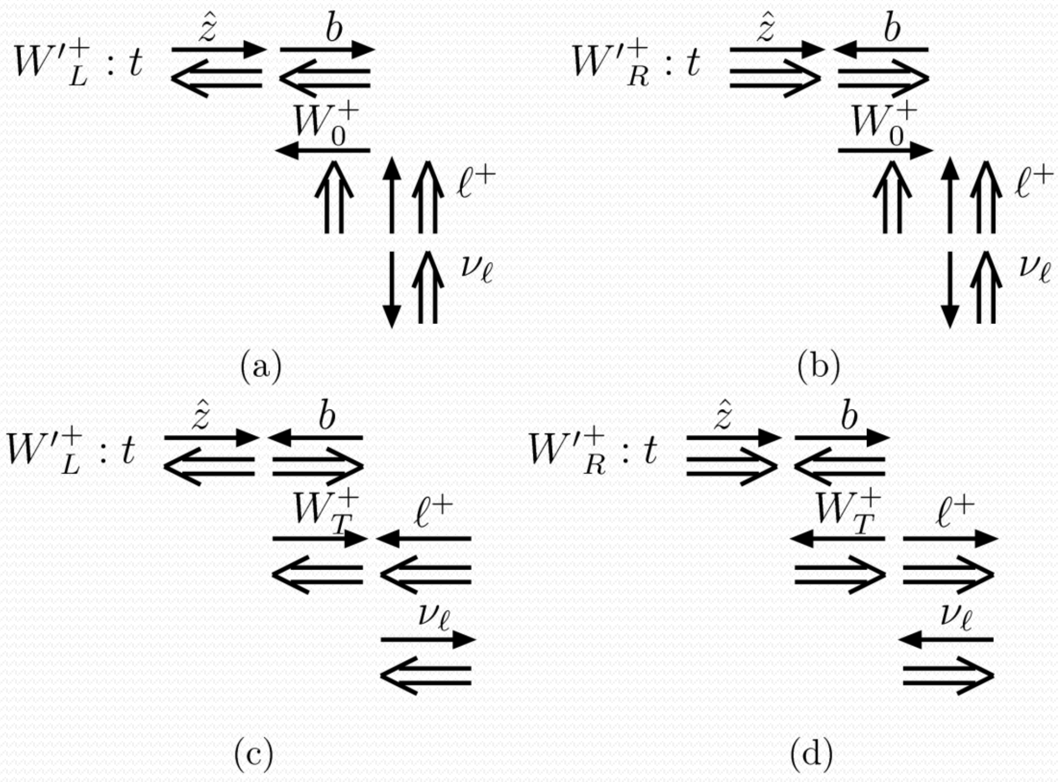
Spin Correlations

- Look at spin correlations to understand why left and right handed cases indistinguishable
- Single arrow lines are momenta
- Double lines are spin



Spin Correlations (ct'd)

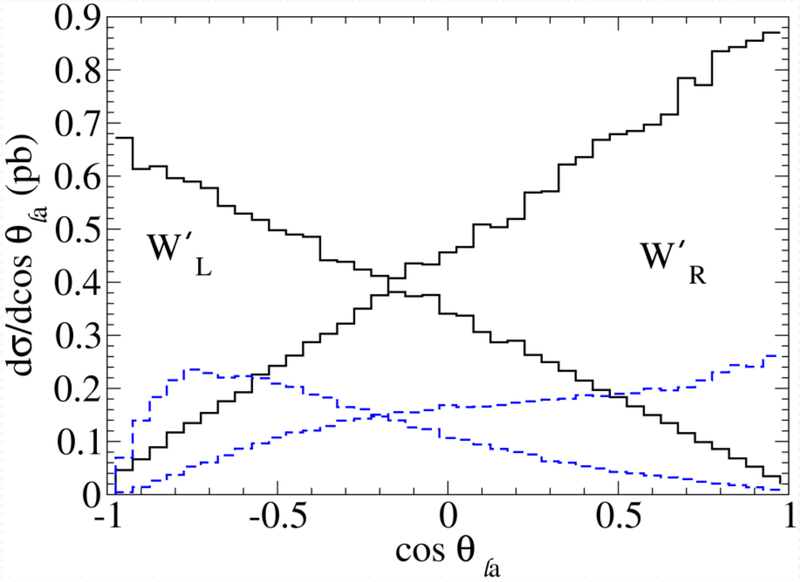
- Chirality of couplings reflected in top quark spin.
- Define the z direction to be top quark direction in the partonic CM
- Lepton angular distribution is a good diagnostic for the top quark spin
- [arXiv:hep-ph/0007298]



Lepton Angular Distribution

$$\frac{d\sigma}{d\cos\theta_\ell} = \frac{1}{2}\sigma\left\{1 + 2\,A\,\cos\theta_\ell\right\},$$

$$A = \frac{1}{2}\left(\frac{g_R^{tb^2} - g_L^{tb^2}}{g_R^{tb^2} + g_L^{tb^2}}\right)\left(\frac{M_{W'}^2 - m_t^2/2}{M_{W'}^2 + m_t^2/2}\right).$$



- Clearly distinguish between the left-handed and right-handed cases.

Conclusions

- If new charged gauge boson discovered, need to measure chiral couplings to distinguish between proposed theories.
- Angular distributions traditionally used to measure chiral coupling to SM fermions.
- Proposed a method to reconstruct events of the form

$$pp \to W' \to t\bar{b} \to \ell^+ \nu b\bar{b}, \qquad (\ell = e,\ \mu)$$

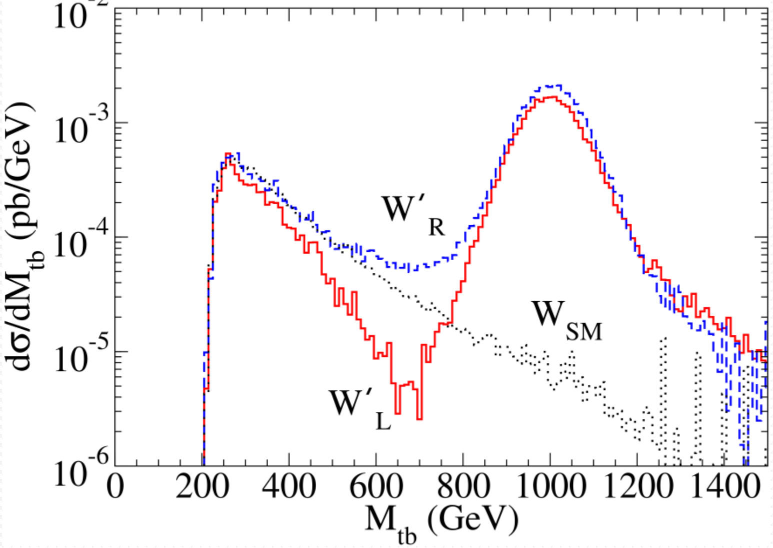
- Reconstructed top quark angular distribution, but unable to distinguish between left and right handed cases.
- Showed that the lepton angular distribution in the top quark rest frame clearly distinguishes these two cases.

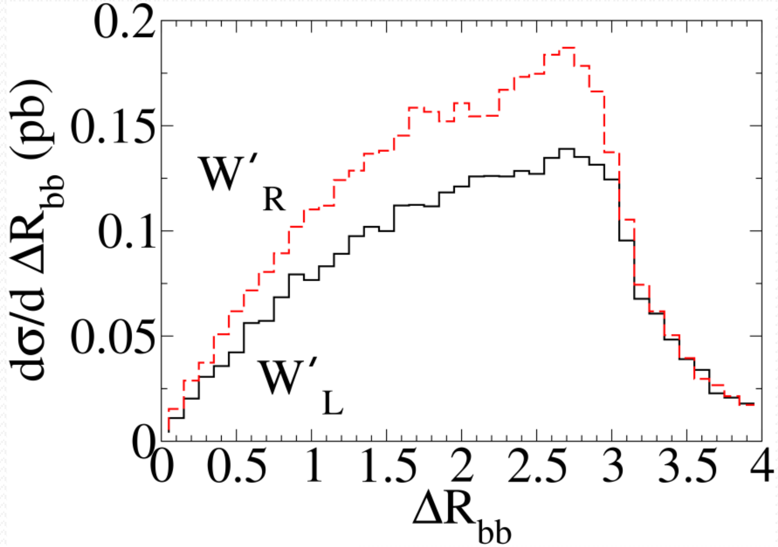
Extra Slides

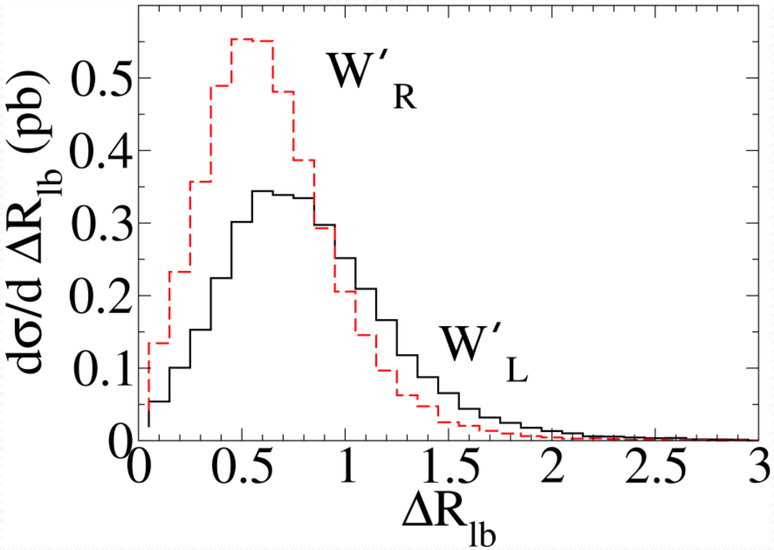
Energy resolution and cuts

- Energy Resolution: $$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b$$
  - Leptons: a = 5 %, b = 0.55 %
  - Jets: a = 100 %, b= 5 %
  - (arXiv:0901.0512 [hep-ex], J. Phys. G 34, 995)
- Acceptance cuts: $$\begin{aligned} p_T(\ell) &> 20\ \text{GeV}, & \eta(\ell) &< 2.5, \\ p_T(j) &> 50\ \text{GeV}, & \eta(j) &< 3.0, \\ & & E_{T,\text{miss}} &> 25\ \text{GeV}. \end{aligned}$$
- Isolation cuts: $\Delta R_{\ell b} > 0.3, \quad \Delta R_{bb} > 0.4$

Distributions







Mass Cuts and Efficiencies

- Invariant Mass Cuts:

$$\begin{aligned} M_{W'} - 100\,\mathrm{GeV} &\leq M_{t\bar{b}} \leq M_{W'} + 100\,\mathrm{GeV}, \\ m_t - 20\,\mathrm{GeV} &\leq m_t^{rec} \leq m_t + 20\,\mathrm{GeV}\ . \end{aligned}$$

- 60 % b-tagging efficiency
- Light jet mistagging efficiency:

$$\varepsilon_\ell = \begin{cases} \frac{1}{100} & p_T < 100\ \mathrm{GeV} \\ \frac{1}{450}\left(\frac{p_T}{25\ \mathrm{GeV}} - 1\right) & 100\ \mathrm{GeV} < \mathrm{p_T} < 150\ \mathrm{GeV} \\ \frac{1}{50} & p_T > 250\ \mathrm{GeV} \end{cases}$$

(arXiv:0901.0512 [hep-ex], J. Phys. G 34, 995)

Cross Sections

- Signal:

σ(pb)	$W + W'_L$	$W + W'_R$	W'_L	W'_R
No cuts or smearing	1.1	1.4	0.67	0.90
No Cuts	0.92	1.2	0.57	0.75
Cuts Acceptance	0.38	0.51	0.32	0.42
+Isolation	0.35	0.46	0.30	0.37
+Invariant Mass	0.22	0.29	0.22	0.29
+Tagging Efficiencies	0.070	0.10	0.070	0.10

- Background:

σ (pb)	$gW^+ \to t\bar{b}$	jjW^+	$b\bar{b}W^+$
Cuts Acceptance + Isolation	0.56	86	0.17
+Invariant mass	3.7×10^{-3}	1.1	2.6×10^{-4}
+Tagging Efficiencies	1.3×10^{-3}	9.8×10^{-5}	9.5×10^{-5}