



Vrije Universiteit Brussel



Master thesis defense: Measurement of the W helicities in top quark events with CMS at the LHC

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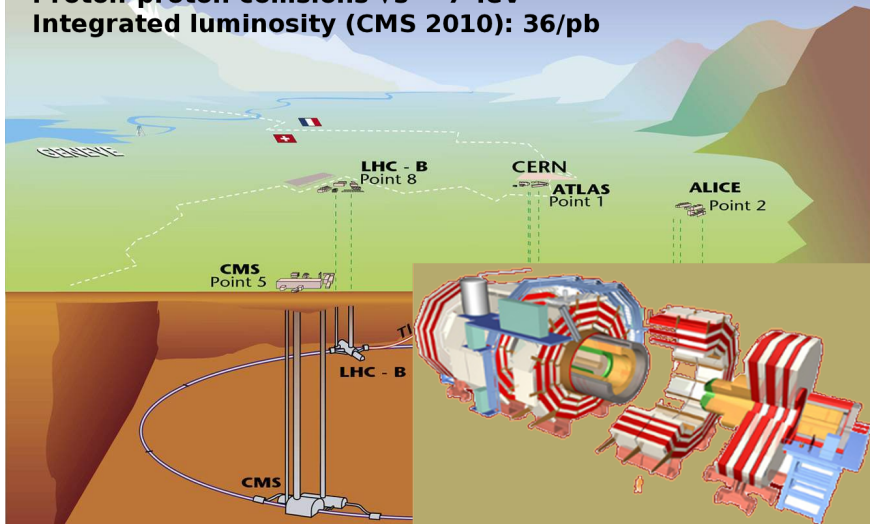
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27 June 2011

Overall view of the LHC experiments.

Proton-proton collisions $\sqrt{s} = 7 \text{ TeV}$

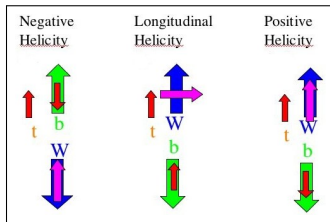
Integrated luminosity (CMS 2010): 36/pb



$\sigma_{\text{NLO}}(\text{pp} \rightarrow \text{tt}) \approx 163 \text{ pb} \rightarrow 5\,868 \text{ top pair events expected}$
 $\text{BR}(\text{tt} \rightarrow \text{b}\mu\nu\text{bqq}) = 4/27$

Weak V-A interaction for top physics

- ▶ Top quark decays almost exclusively in W-boson and bottom quark ($V_{tb} \approx 1$)
- ▶ Spin information of top quark restricts possible decay configurations:

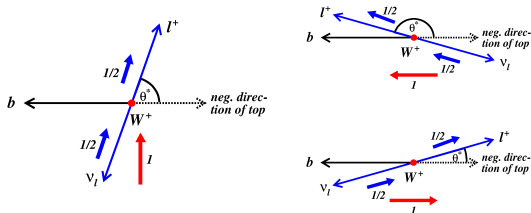
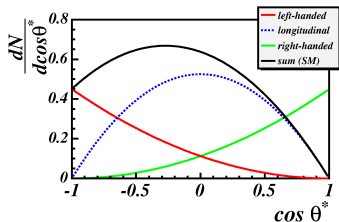


- ▶ Left-handed $f_- = 0.301$
- ▶ Longitudinal $f_0 = 0.698$
- ▶ Right-handed $f_+ = 4.1 \times 10^{-4}$

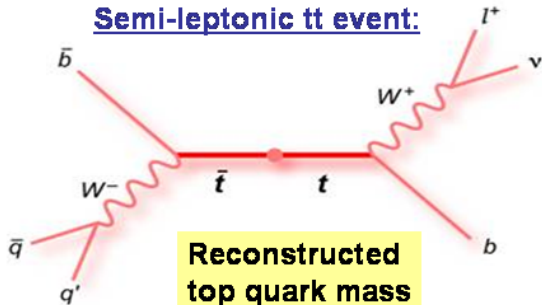
⇒ Right-handed helicity suppressed

SM relation: $f_- + f_0 + f_+ = 1$

- ▶ W boson helicity restricts angular distribution of decay products:



$\theta^* \equiv$ Angle between μ in W-boson restframe and W-boson in top quark restframe

Semi-leptonic tt event:Selection requirements:

- 4jets, $p_T > 30 \text{ GeV}/c$
- 1muon, $p_T > 20 \text{ GeV}/c$
- Isolated muon

Reconstructed top quark mass

Jet $p_T = 56.6 \text{ GeV}/c$, $\eta = 0.389$, $\varphi = 2.38$

Jet-quark matching

b tagged Jet

$p_T = 82.2 \text{ GeV}/c$, $\eta = -1.79$, $\varphi = 1.03$

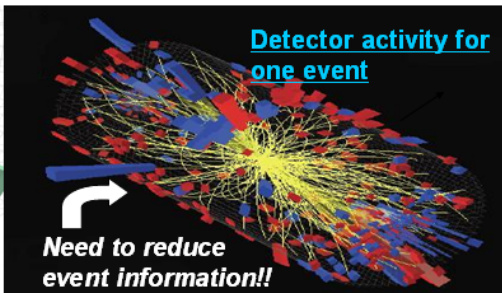
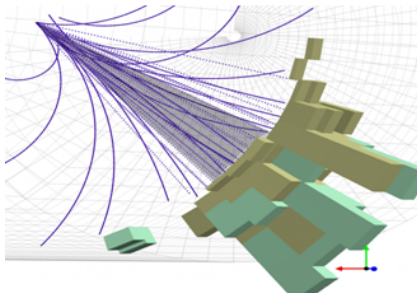
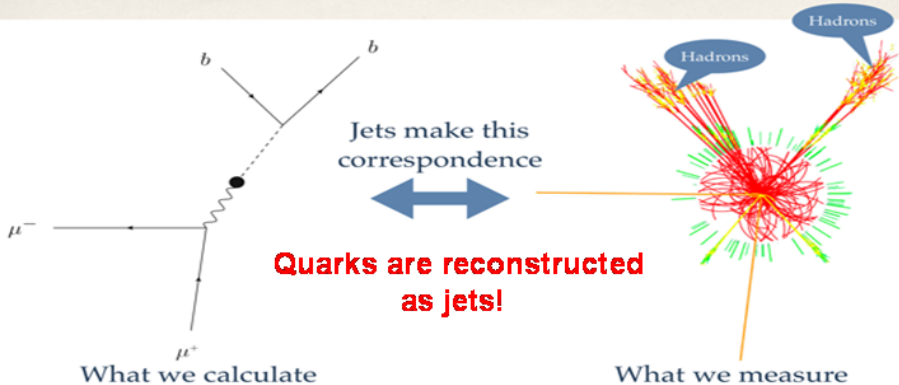
Reconstructed W-boson mass

Jet $p_T = 152.2 \text{ GeV}/c$, $\eta = 0.354$, $\varphi = -2.75$

$\cancel{E}_T = 119.0 \text{ GeV}$, $\varphi = 0.010$

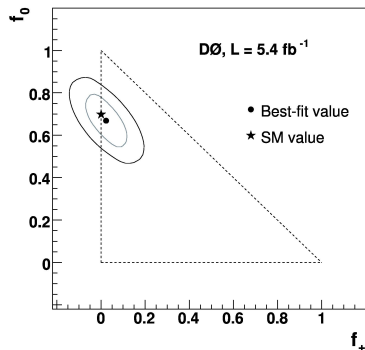
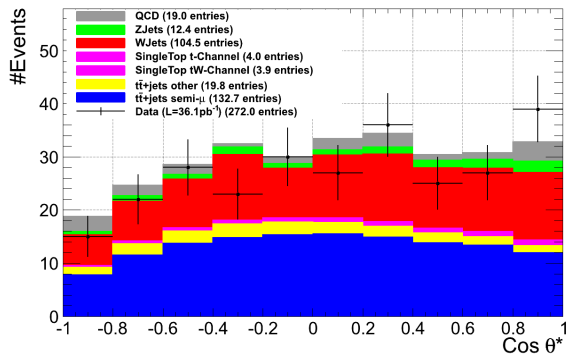
Jet $p_T = 43.4 \text{ GeV}/c$, $\eta = 0.827$, $\varphi = -0.587$

muon $p_T = 30.6 \text{ GeV}/c$, $\eta = -1.67$, $\varphi = -2.06$



Aim of analysis

- ▶ Compare helicity distribution for data with alternative helicities
- ▶ Best-fit χ^2 value represents data helicity
- ▶ Result presented in helicity (f_+ , f_0) plane

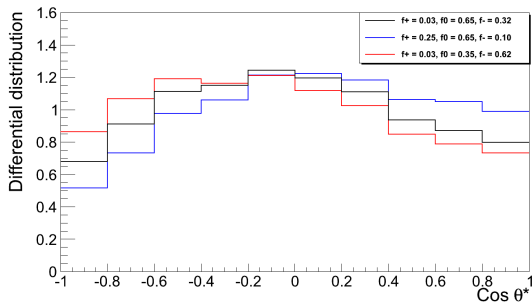


Reweighting helicity distribution

- ▶ No Monte Carlo simulation samples for different helicity values
 \Rightarrow Reweighting applied on simulated semi-muonic $t\bar{t}$ sample
- ▶ Distribution for SM compared with alternative helicity for each event:

$$\frac{d\sigma}{d\cos\theta^*} = f_- \frac{3(1 - \cos\theta^*)^2}{8} + f_0 \frac{3(1 - \cos^2\theta^*)}{4} + f_+ \frac{3(1 + \cos\theta^*)^2}{8}$$

- ▶ Comparison performed on generator level

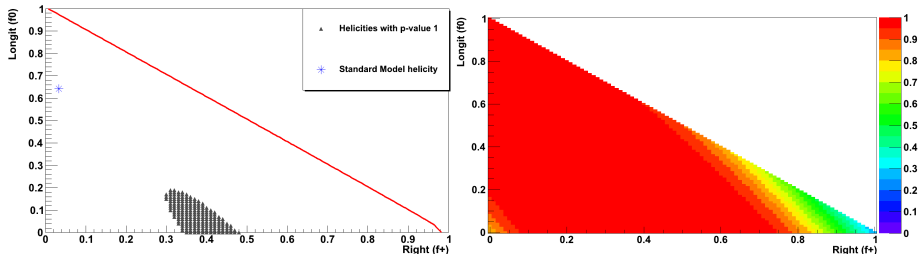


$$weight = \frac{g(\cos\theta_{gen}^* | \vec{f}_{alt})}{g(\cos\theta_{gen}^* | \vec{f}_{SM})}$$

Measurement of W boson helicity

Compare Standard Model helicity distribution with alternative helicity distributions with $\Delta\chi^2$ method:

$$\chi^2(f_+, f_0) = \sum_{i=1}^{bins} \left(\frac{y_{alt,i} - y_{Data,i}}{\sqrt{y_{Data,i}}} \right)^2$$

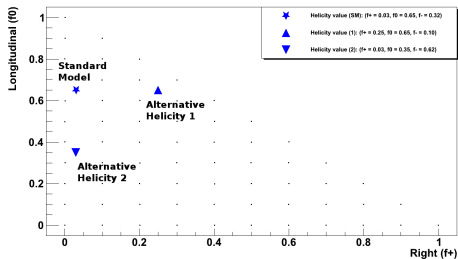


Conclusion:

- ▶ Result is in agreement with the Standard Model
- ▶ Best-fitted result position can be enhanced with extra selection criteria

Extra selection criteria: b-flavour identification

The impact of b-tagging is determined by testing whether the relative difference in the $\cos\theta_{reco}$ distribution between points in the (f^+, f_0) plane is enhanced or not.



$$\chi^2 = \sum_{i=1}^{bins} \left(\frac{y_{SM,i} - y_{Alt,i}}{\sqrt{y_{SM,i}}} \right)^2$$

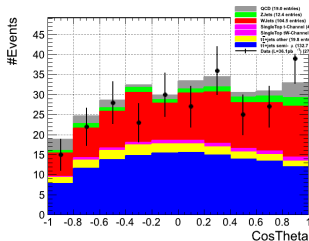
	$\chi_{SM,1}^2$	$\chi_{SM,2}^2$	# events
No bTag	1.59	1.68	274
Loose bTag	2.46	2.75	103
Medium bTag	2.66	2.78	59

Conclusion:

Loose bTag has the best balance between high χ^2 and results in enough selected events

B-Tag effect

No bTag

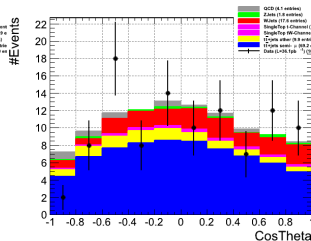


- QCD (19.0 entries)
- ZJets (12.4 entries)
- WJets (104.5 entries)
- SingleTop t-Channel (4.0 entries)
- SingleTop tW-Channel (3.9 entries)
- tt+jets other (19.8 entries)
- tt+jets semi- μ (132.7 entries)
- Data (L=36.1pb⁻¹) (272.0 entries)

$$S/B = 132.7/163.6$$

$$= 0.811$$

Low bTag

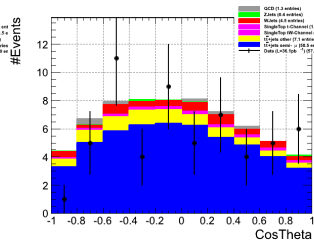


- QCD (4.1 entries)
- ZJets (1.8 entries)
- WJets (17.6 entries)
- SingleTop t-Channel (1.5 entries)
- SingleTop tW-Channel (1.5 entries)
- tt+jets other (9.9 entries)
- tt+jets semi- μ (69.2 entries)
- Data (L=36.1pb⁻¹) (101.0 entries)

$$S/B = 69.2/36.4$$

$$= 1.901$$

Medium bTag



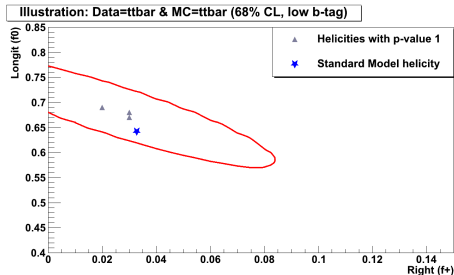
- QCD (1.3 entries)
- ZJets (0.4 entries)
- WJets (4.5 entries)
- SingleTop t-Channel (1.0 entries)
- SingleTop tW-Channel (1.0 entries)
- tt+jets other (7.1 entries)
- tt+jets semi- μ (50.5 entries)
- Data (L=36.1pb⁻¹) (57.0 entries)

$$S/B = 50.5/15.3$$

$$= 3.301$$

Systematic uncertainty

To enhance statistics simulated sample is compared against slightly adapted simulated sample



Conclusion:

Small systematics with respect to statistical uncertainty on 2010 data

Effect of JES on $t\bar{t}$:

	Δf_+	Δf_0
$\pm 5\%$ JES	0.5%	8.5%
$\pm 2\%$ JES	0.2%	3.4%

Effect of W XSection on $t\bar{t}$ & W:

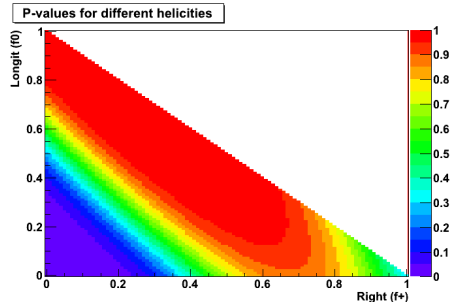
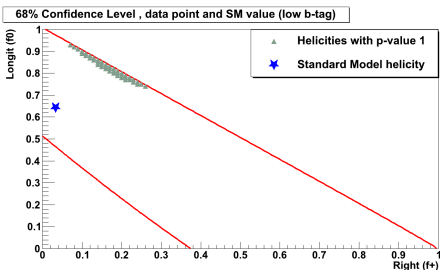
	Δf_+	Δf_0
$\pm 30\%$ XSection	1%	4.5%

Effect of background on $t\bar{t}$:

	Δf_+	Δf_0
Background	0.5%	0%

First measurement of W helicities with CMS at LHC

Standard Model relation constraint: $f_{-} + f_{0} + f_{+} = 1$



→ Preliminary 68% Confidence Level is in agreement with Standard Model value

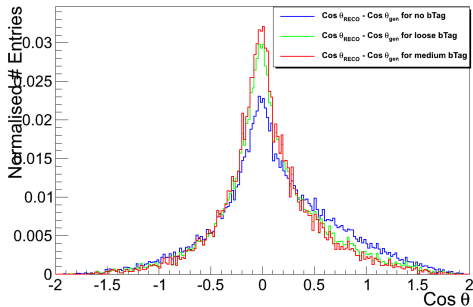
Outlook

This analysis on the 2010 data is the basis of my Master thesis, but I will repeat this on the 2011 data during the summer and study more detailed the systematics.

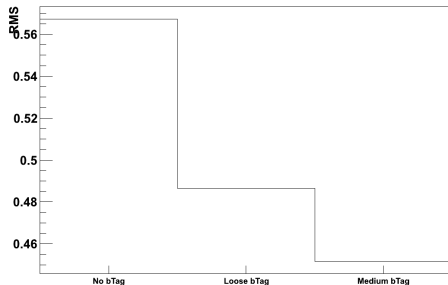
Back-up

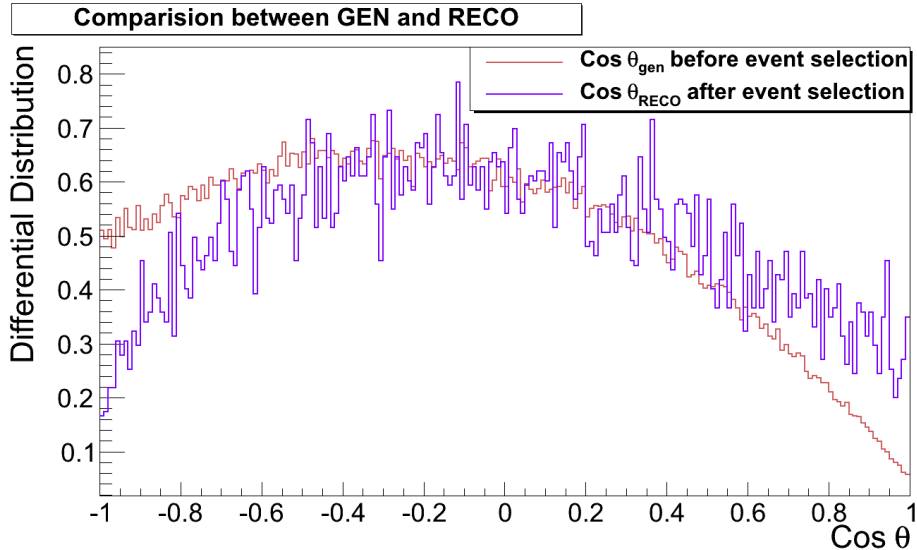
Effect of bTag on RECO vs GEN

Difference of $\text{Cos } \theta$ on GEN and RECO level



RMSCosThetaDiffHisto





Samples

- ▶ SM Monte Carlo samples: 38X Fall10, PAT-ified in CMSSW_3.8.5_patch3:

Process	σ_{eff} (NLO) (pb)	Sample
TTJets	157.5	/TTJets_TuneD6T_7TeV-madgraph-tauola/Fall10-START38_V12-v2/AODSIM
WJets	31314	/WJetsToLNu_TuneD6T_7TeV-madgraph-tauola/Fall10-START38_V12-v1/AODSIM
ZJets	3048	/DYJetsToLL_TuneD6T_M-50_7TeV-madgraph-tauola/Fall10-START38_V12-v2/AODSIM
Single top (t)	20.93	/TToBLNu_TuneZ2_t-channel_7TeV-madgraph/Fall10-START38_V12-v2/AODSIM
Single top (tW)	10.6	/TToBLNu_TuneZ2_tW-channel_7TeV-madgraph/Fall10-START38_V12-v2/AODSIM
QCD (mu+jets)	84679.3 (LO)	/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6/Fall10-START38_V12-v1/AODSIM

- ▶ Data: Full 2010 /Mu dataset: $L_{int} = 36.1 \text{ pb}^{-1}$
 - Nov4 ReReco of Run2010A and Run2010B, PAT-ified in CMSSW_3.8.6_patch1

MC corrections and event selection

- ▶ The **lepton + jets (mu channel)** topology
 TopLeptonPlusJets group twiki (mu):
https://twiki.cern.ch/twiki/bin/view/CMS/TopLeptonPlusJetsRefSel_mu
- ▶ **Corrections and scale factors** applied to the MC [according to recipe on twiki]
 - ▶ Jet Energy Resolution
 - ▶ Leptonic branching ratio correction
 - ▶ Trigger- and lepton efficiencies

Data-driven factors to scale the SM Monte Carlo (to be multiplied with cross section):

$$\beta_{t\bar{t}} = 1.06, \beta_{W\text{Jets}} = 1.34, \beta_{Z\text{Jets}} = 1.32, \beta_{\text{single top}} = 1.0, \beta_{QCD} = 2.09$$

- ▶ **Analysis selection:**
 - ▶ Reference selection **SelV4** of the TopLeptonPlusJets group (in sync)
 "exactly 1 isolated muon with $p_T > 20$ GeV/c, and at least 4 jets with $p_T > 30$ GeV/c"
 - ▶ In following: Particle Flow jets (MC: L2L3 corrections START38_V14, data: L1OffsetL2L3 and L2L3Residual GR_R_38X_V15)