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Combination of the ATLAS and CMS measurements of the *W*-boson polarization in top-quark decays

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Overview

- Physics case
- Combination of ATLAS and CMS results:
  - BLUE
  - Input measurements
  - Categories of correlation
  - Systematic uncertainties
  - Results
  - Interpretation
- Conclusions

Overview

TOPLHC NOTE

ATLAS-CONF-2013-033
CMS PAS TOP-12-025

March 13, 2013

Combination of the ATLAS and CMS measurements of the W-boson polarization in top-quark decays

The ATLAS and CMS Collaborations

Abstract

This note describes the combination of measurements of the W-boson polarization in top-quark decays performed by the ATLAS and CMS Collaborations. The measurements are based on proton-proton collision data corresponding to integrated luminosities ranging from 35 pb^{-1} to 2.2 fb^{-1} produced at the LHC at a center-of-mass energy of $\sqrt{s} = 7$ TeV. The results are quoted as helicity fractions, i.e. the fractions of events which contain W bosons with longitudinal and left-handed polarization.

The combined helicity fractions are

$$F_0 = 0.626 \pm 0.034\,(\text{stat.}) \pm 0.048\,(\text{syst.}),$$
$$F_L = 0.359 \pm 0.021\,(\text{stat.}) \pm 0.028\,(\text{syst.}),$$

which are in agreement with predictions from NNLO QCD. The fraction of W bosons with right-handed polarization is calculated assuming the sum of all fractions to be unity:

$$F_R = 0.015 \pm 0.034,$$

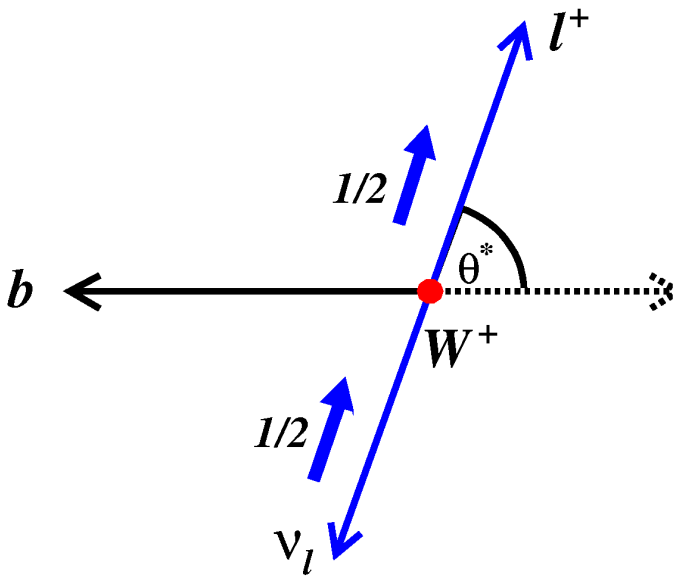
where the uncertainty includes the statistical and systematic uncertainties. Exclusion limits on anomalous Wtb couplings are derived from these results.

W-boson polarization

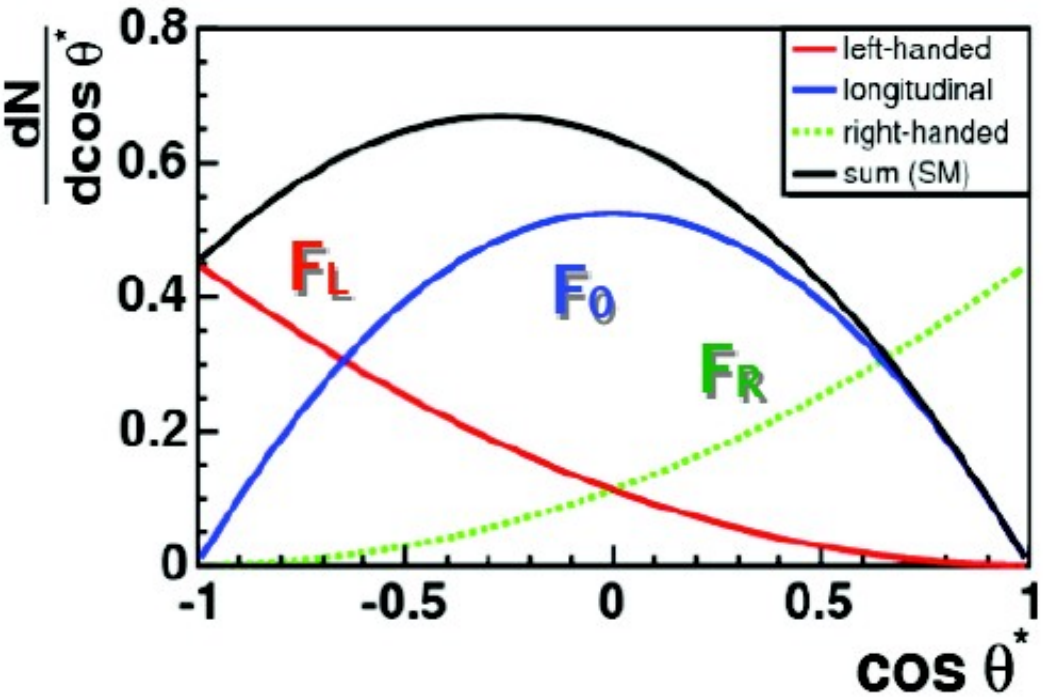
W bosons produced in top-quark decays are polarized

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2 F_R + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{4}\sin^2\theta^* F_0$$

SM: ~0% ~30% ~70%

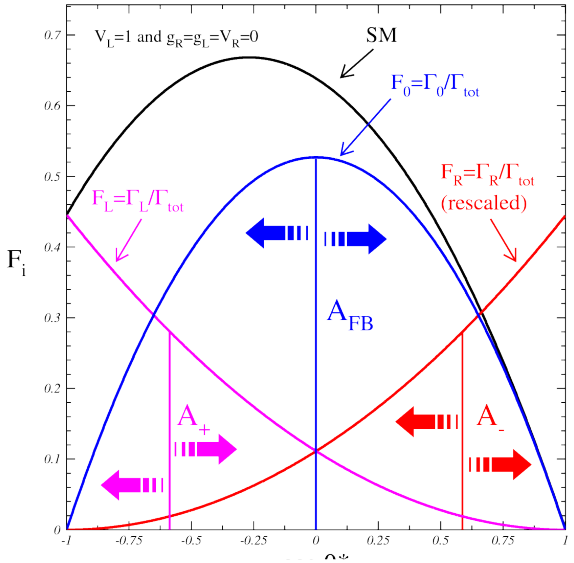


Reverse momentum of top quark

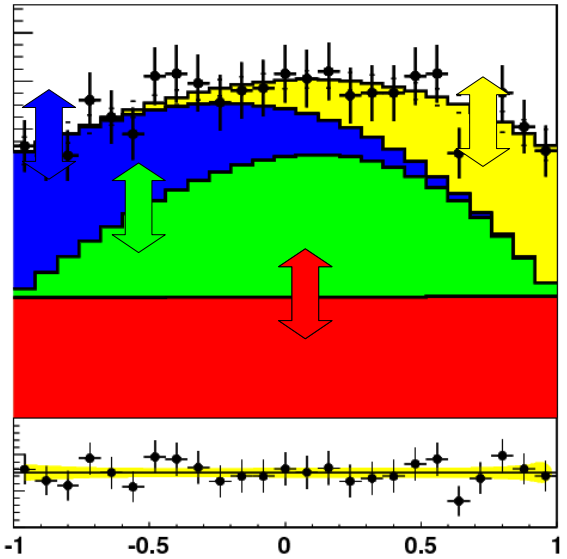


Methods

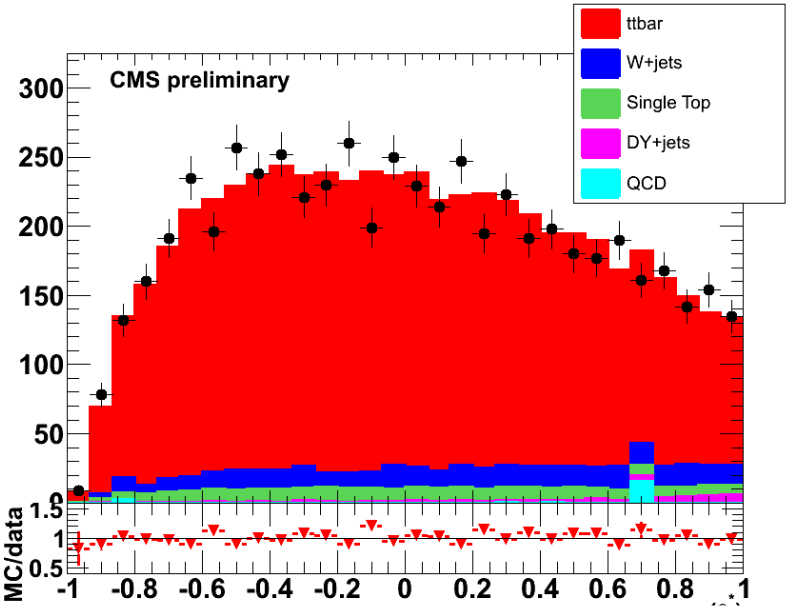
Angular asymmetries



Templates



Reweighting



Strategy and inputs

- Aim: Combination of ATLAS and CMS *W*-helicity measurements
- Method: BLUE with two observables (F_0 and F_L)
  - Measured central values
  - Statistical and systematic uncertainties
  - Correlation among measurements
- Input for LHC combination:

Measurem.	Channel	Method	Int. lum.	Ref.
ATLAS 2010	Single lepton	Template	35 pb^{-1}	ATLAS-CONF-2011-037
ATLAS 2011	Single lepton Dilepton	Template/ Asymmetries	1.04 fb^{-1}	JHEP 1206 (2012) 088
CMS 2011	Single muon	Reweighing	2.2 fb^{-1}	CMS PAS TOP-11-020

Modifications to the original measurements

- Categories of systematic uncertainties (ATLAS and CMS)
  - Inspired by former LHC combinations
  - Merge several sources of uncertainties
- New estimates of correlations (ATLAS)
  - Update estimate of correlations
  - Most important modification
- Uncertainty on top mass (ATLAS and CMS)
  - Changed to 1.4 GeV (instead of 0.9 GeV)
- Pre-combinations (ATLAS)
  - BLUE implementation handels up to 20 measurements
  - Combine ATLAS single lepton 2011 and ATLAS dilepton 2011

Detector modeling
Detector model
Jet energy scale
Luminosity and pile-up
Signal and background modeli
Monte Carlo
Radiation
Top-quark mass
PDF
Background (MC QCD)
Background (MC W + jets)
Background (MC other)
Background (data-driven)
Method-specific uncertainties
Method

Input to BLUE: Central values (and total uncertainties)

Measurement	F_0	F_L	F_R
ATLAS 2010 (single lepton) [Alj2010]	$0.652 \pm 0.134 \pm 0.092$	$0.359 \pm 0.088 \pm 0.056$	$-0.011 \pm 0.060 \pm 0.046$
ATLAS 2011 (single lepton) [Alj2011]	$0.642 \pm 0.030 \pm 0.071$	$0.344 \pm 0.020 \pm 0.042$	$0.014 \pm 0.014 \pm 0.055$
ATLAS 2011 (dilepton) [Adil2011]	$0.744 \pm 0.050 \pm 0.087$	$0.276 \pm 0.031 \pm 0.051$	$-0.020 \pm 0.026 \pm 0.065$
CMS 2011 (single lepton) [Clj2011]	$0.567 \pm 0.074 \pm 0.048$	$0.393 \pm 0.045 \pm 0.024$	$0.040 \pm 0.035 \pm 0.043$

Input to BLUE: Categories of correlation

- **Category "CMS":**
  - F_0 vs. F_L for a single measurement
  - Calculated from propagation of uncertainty

$$\rho_{\mathrm{CMS}}(F_0, F_L) = \frac{\sigma^2[F_R] - \sigma^2[F_0] - \sigma^2[F_L]}{2\sigma[F_0]\sigma[F_L]}$$

- **Category "ATLAS":**
  - F_0 vs. F_L for a single measurement
  - BLUE does not return correlation coefficients for each category of uncertainty
  - Use arithmetic mean of correlation coefficients (average over 2, 4, 6 measurements)

Input to BLUE: Categories of correlation

- **Category "exp":**
  - F_0s of different ATLAS measurements
  - Stat. uncertainties, DD estimates, and method specific unc. uncorrelated
  - Everything else fully correlated

$$\rho_{\text{exp}}(F_0, F_0) = \rho_{\text{exp}}(F_L, F_L)$$

$$\rho_{\text{exp}}(F_0, F_L) = -\rho_{\text{exp}}(F_0, F_0)$$

- **Category "LHC":**
  - F_0s of different measurements performed ATLAS and CMS
  - Stat. uncertainty, DD estimates, and method specific unc. uncorrelated
  - Radiation partially correlated (0.5)
  - Everything else fully correlated

$$\rho_{\text{LHC}}(F_0, F_0) = \rho_{\text{LHC}}(F_L, F_L)$$

$$\rho_{\text{LHC}}(F_0, F_L) = -\rho_{\text{LHC}}(F_0, F_0)$$

Input to BLUE: Categories of correlation

Measurement	Fraction	Alj2010 F_0	Alj2011 F_0	Adil2011 F_0	Clj2011 F_0
Alj2010	F_0	$+1$	$\rho_{\text{exp}}(F_0, F_0)$	$\rho_{\text{exp}}(F_0, F_0)$	$\rho_{\text{LHC}}(F_0, F_0)$
Alj2011	F_0	$\rho_{\text{exp}}(F_0, F_0)$	$+1$	$\rho_{\text{exp}}(F_0, F_0)$	$\rho_{\text{LHC}}(F_0, F_0)$
Adil2011	F_0	$\rho_{\text{exp}}(F_0, F_0)$	$\rho_{\text{exp}}(F_0, F_0)$	$+1$	$\rho_{\text{LHC}}(F_0, F_0)$
Clj2011	F_0	$\rho_{\text{LHC}}(F_0, F_0)$	$\rho_{\text{LHC}}(F_0, F_0)$	$\rho_{\text{LHC}}(F_0, F_0)$	$+1$
Alj2010	F_L	$\rho_{\text{ATLAS}}(F_0, F_L)$	$-\rho_{\text{exp}}(F_0, F_0)$	$-\rho_{\text{exp}}(F_0, F_0)$	$-\rho_{\text{LHC}}(F_0, F_0)$
Alj2011	F_L	$-\rho_{\text{exp}}(F_0, F_0)$	$\rho_{\text{ATLAS}}(F_0, F_L)$	$-\rho_{\text{exp}}(F_0, F_0)$	$-\rho_{\text{LHC}}(F_0, F_0)$
Adil2011	F_L	$-\rho_{\text{exp}}(F_0, F_0)$	$-\rho_{\text{exp}}(F_0, F_0)$	$\rho_{\text{ATLAS}}(F_0, F_L)$	$-\rho_{\text{LHC}}(F_0, F_0)$
Clj2011	F_L	$-\rho_{\text{LHC}}(F_0, F_0)$	$-\rho_{\text{LHC}}(F_0, F_0)$	$-\rho_{\text{LHC}}(F_0, F_0)$	$\rho_{\text{CMS}}(F_0, F_L)$

Results

$$F_0 = 0.626 \pm 0.034\,(\text{stat.}) \pm 0.048\,(\text{syst.})$$
$$F_L = 0.359 \pm 0.021\,(\text{stat.}) \pm 0.028\,(\text{syst.})$$
$$F_R = 0.015 \pm 0.034$$

$$\rho = -0.86$$

$$\chi^2 = 3.3$$ (8 correlated measurements)

Measurement	Coefficient [%] w_{F_0}	w_{F_L}
F_0 ATLAS 2010 (single lepton)	12.2	7.4
F_L ATLAS 2010 (single lepton)	19.0	11.6
F_0 ATLAS 2011 (single lepton)	39.5	- 8.4
F_L ATLAS 2011 (single lepton)	-16.0	35.4
F_0 ATLAS 2011 (dilepton)	13.0	2.8
F_L ATLAS 2011 (dilepton)	4.9	15.2
F_0 CMS 2011 (single lepton)	35.4	- 1.8
F_L CMS 2011 (single lepton)	- 7.9	37.8
Total weight:	100.0	100.0

largest weight

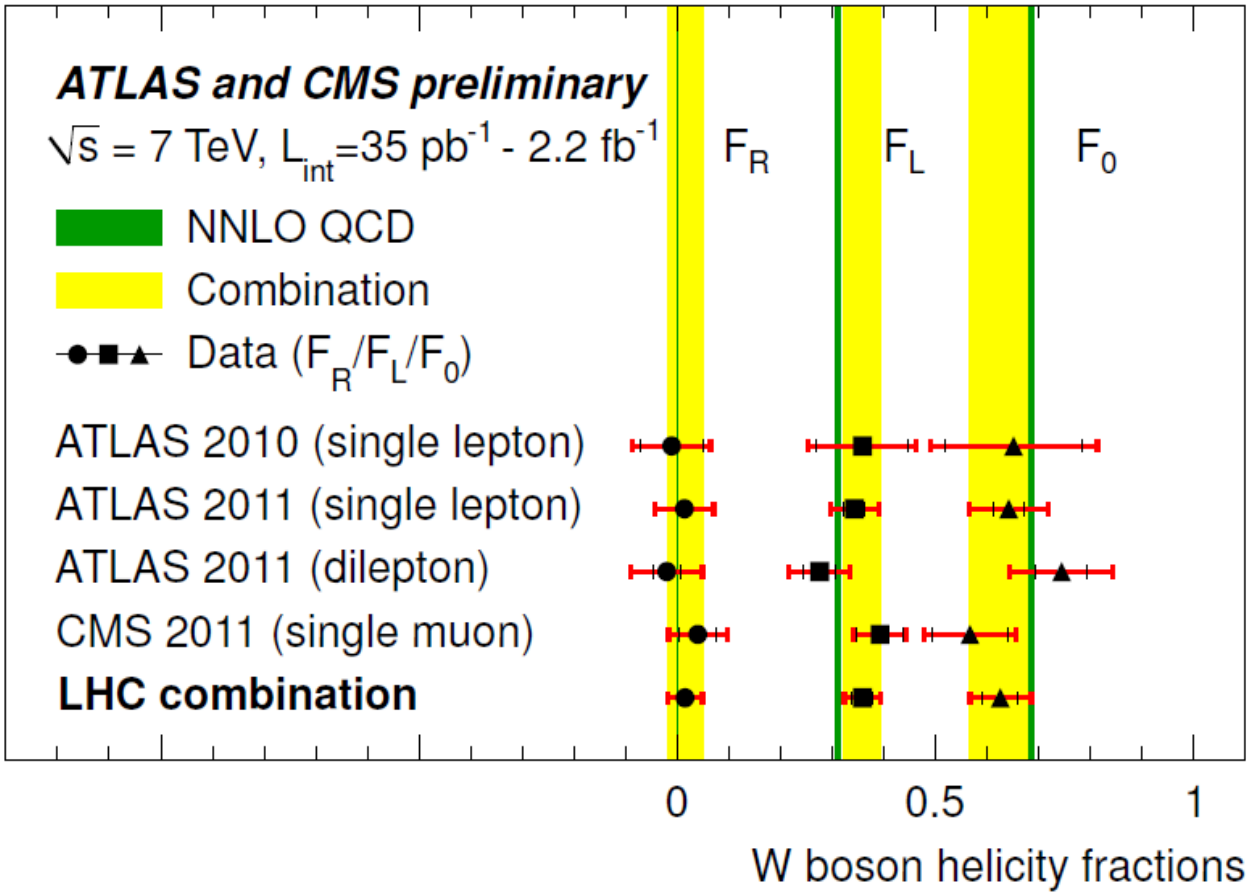
smallest weight

Combination

Results

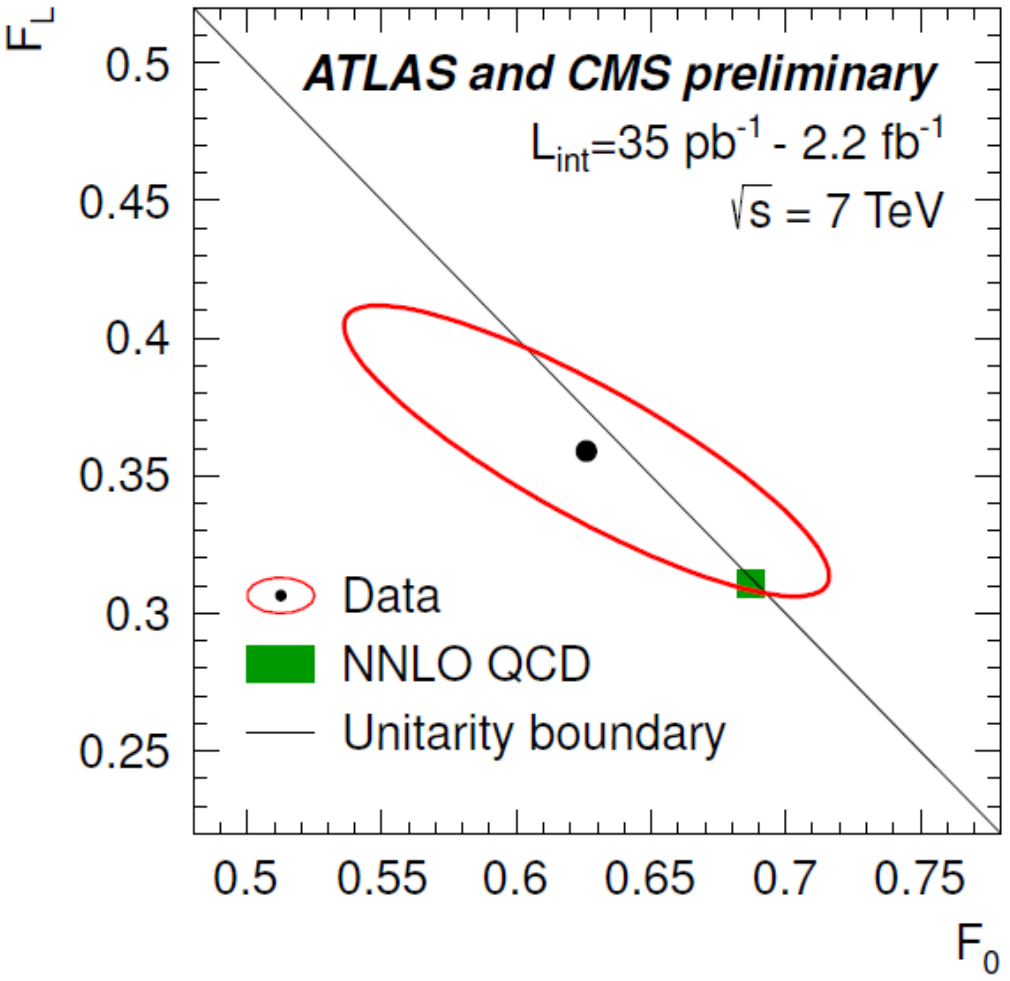
Category	LHC combination F_0	LHC combination F_L
Detector modeling		
Detector model	0.019	0.011
Jet energy scale	0.020	0.012
Luminosity and pile-up	0.006	0.003
Signal and background modeling		
Monte Carlo	0.012	0.008
Radiation	0.024	0.012
Top-quark mass	0.019	0.012
PDF	0.008	0.004
Background (MC QCD)	0.003	0.001
Background (MC W + jets)	0.007	0.002
Background (MC other)	0.011	0.006
Background (data-driven)	0.013	0.008
Method-specific uncertainties		
Method	0.008	0.005
Total uncertainties		
Total systematic uncertainty	0.048	0.028
Statistical uncertainty	0.034	0.021
Total uncertainty	0.059	0.035

Results



All measurements consistent “by eye”

Results

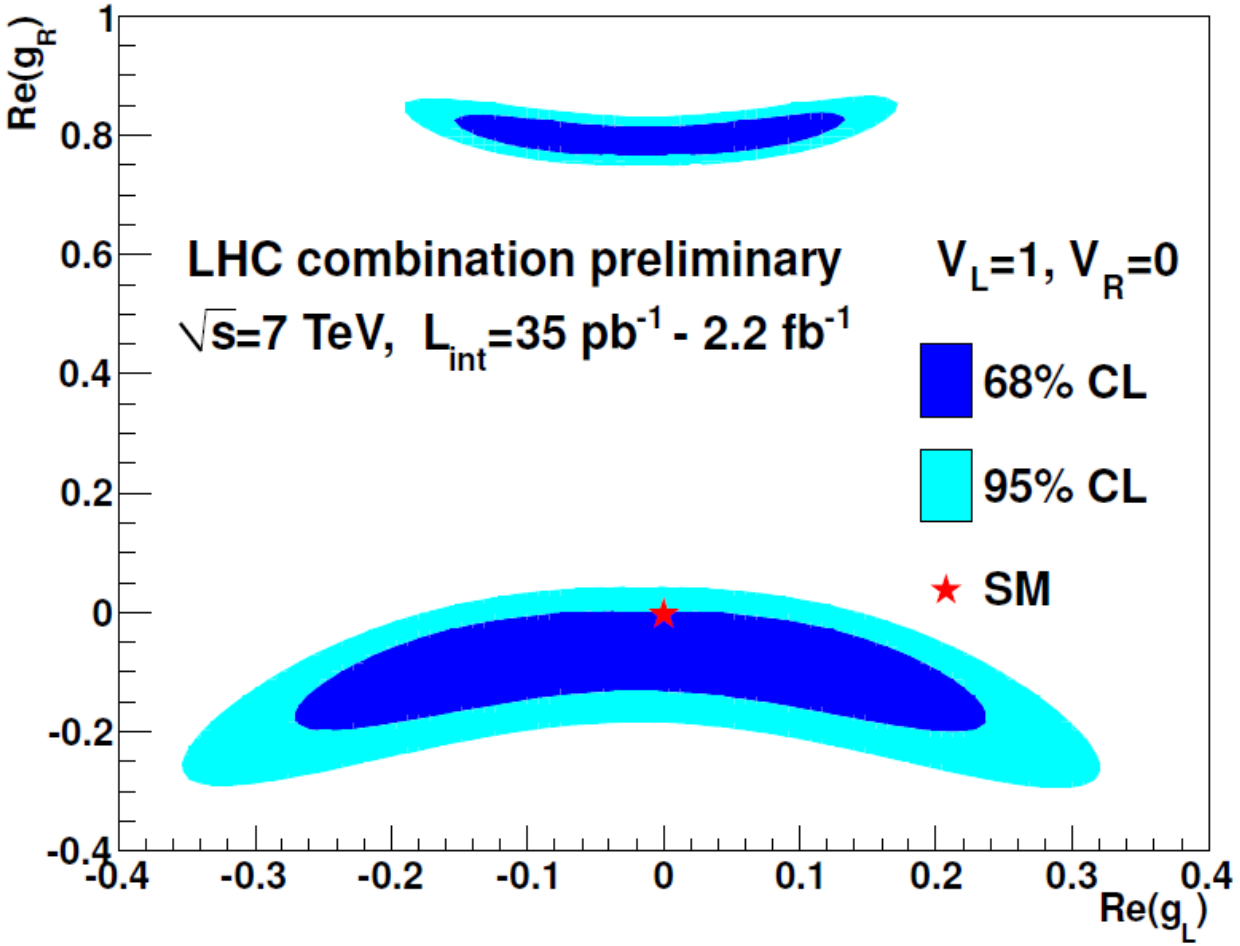


No physical constraints on the fractions

Interpretation

Interpretation

$V_L=1$, $V_R=0$
all coupling real



$V_L=1$, $V_R=0$, $g_L = 0$
all coupling real

$$\mathrm{Re}(g_R) = -0.10 \pm 0.06\ (\mathrm{stat.})\ ^{+0.07}_{-0.08}\ (\mathrm{syst.})$$

$$\frac{\mathrm{Re}(C_{uW}^{33})}{\Lambda^2} = -1.1 \pm 0.6\ (\mathrm{stat.})\ ^{+0.9}_{-1.0}\ (\mathrm{syst.})\ \mathrm{TeV}^{-2}$$

Conclusions

- First approach of combining ATLAS and CMS results on *W*-boson polarization
- Pre-combined ATLAS results (INT note) and modified original measurements (categories of systematic uncertainty, correlations, top mass uncertainty)
- All measurements are consistent with one another and the combination within their 2-sigma uncertainty intervals
- Results are in good agreement with SM predictions
- Dominating uncertainties: statistical uncertainty and radiation, detector-related and JES uncertainty, top-quark mass uncertainty
- New BAT-tool overcomes technical difficulties (see talk on BLUE)
- Next: include at least two new measurements
  - CMS-PAS-TOP-12-015 (dilepton ttbar)
  - CMS-PAS-TOP-12-020 (single top)

Backup

Input to BLUE: Statistical and systematic uncertainties

Category	ATLAS 2010 (single lepton)			
	F_0	F_L	$\rho_{\text{ATLAS}}(F_0, F_L)$	F_R
Detector modeling				
Detector model	0.047	0.029	-0.905	0.024
Jet energy scale	0.043	0.027	-0.924	0.021
Luminosity and pile-up	0.013	0.006	-0.861	0.008
Signal and background modeling				
Monte Carlo	0.020	0.012	-0.887	0.011
Radiation	0.033	0.016	-0.882	0.020
Top-quark mass	0.018	0.012	-0.920	0.008
PDF	0.004	0.002	-0.924	0.002
Background (MC QCD)	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Background (MC W + jets)	0.023	0.013	-0.908	0.012
Background (MC other)	0.005	0.003	-0.947	0.002
Background (data-driven)	0.035	0.023	-0.934	0.016
Method-specific uncertainties				
Method	0.026	0.017	-0.962	0.010
Total uncertainties				
Total systematic uncertainty	0.092	0.056	-0.912	0.046
Statistical uncertainty	0.134	0.088	-0.937	0.060
Total uncertainty	0.162	0.105	-0.925	0.076

Input to BLUE: Statistical and systematic uncertainties

Category	ATLAS 2011 (single lepton)				ATLAS 2011 (dilepton)			
	F_0	F_L	$\rho_{\text{ATLAS}}(F_0, F_L)$	F_R	F_0	F_L	$\rho_{\text{ATLAS}}(F_0, F_L)$	F_R
Detector modeling								
Detector model	0.032	0.019	-0.778	0.021	0.012	0.005	-0.887	0.008
Jet energy scale	0.027	0.014	-0.310	0.026	0.056	0.036	-0.485	0.050
Luminosity and pile-up	0.012	0.005	-0.862	0.008	0.002	0.001	-0.940	0.001
Signal and background modeling								
Monte Carlo	0.019	0.014	-0.915	0.008	0.023	0.015	-0.917	0.011
Radiation	0.030	0.019	-0.579	0.025	0.028	0.014	-0.854	0.017
Top-quark mass	0.027	0.014	-0.090	0.029	0.028	0.016	-0.436	0.025
PDF	0.009	0.005	-0.875	0.005	0.028	0.015	-0.875	0.017
Background (MC QCD)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Background (MC W + jets)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Background (MC other)	0.008	0.005	-0.891	0.004	0.006	0.004	-0.913	0.003
Background (data-driven)	0.027	0.017	-0.929	0.013	0.018	0.011	-0.997	0.007
Method-specific uncertainties								
Method	0.015	0.011	-0.779	0.009	0.032	0.016	-0.945	0.018
Total uncertainties								
Total systematic uncertainty	0.071	0.042	-0.627	0.055	0.087	0.051	-0.664	0.065
Statistical uncertainty	0.030	0.020	-0.910	0.014	0.050	0.031	-0.913	0.026
Total uncertainty	0.076	0.046	-0.673	0.057	0.100	0.059	-0.729	0.070

Input to BLUE: Statistical and systematic uncertainties

Category	CMS 2011 (single lepton)			
	F_0	F_L	$\rho_{CMS}(F_0, F_L)$	F_R
Detector modeling				
Detector model	0.020	0.015	-0.95	0.007
Jet energy scale	0.018	0.011	-0.99	0.007
Luminosity and pile-up	–	–	–	–
Signal and background modeling				
Monte Carlo	–	–	–	–
Radiation	0.026	0.008	+0.21	0.028
Top-quark mass	0.009	0.010	-0.87	0.005
PDF	0.001	0.001	-1.00	$< 10^{-4}$
Background (MC QCD)	0.007	0.002	-1.00	0.005
Background (MC W + jets)	0.020	0.006	+1.00	0.026
Background (MC other)	0.019	0.007	-0.59	0.015
Background (data-driven)	–	–	–	–
Method-specific uncertainties				
Method	–	–	–	–
Total uncertainties				
Total systematic uncertainty	0.048	0.024	-0.43	0.043
Statistical uncertainty	0.074	0.045	-0.94	0.035
Total uncertainty	0.088	0.051	-0.81	0.056