Measurement of the Polarisation of high-P_T(W) Bosons in W+Jets Events at the LHC

Jad Marrouche

on behalf of the **CMS collaboration**

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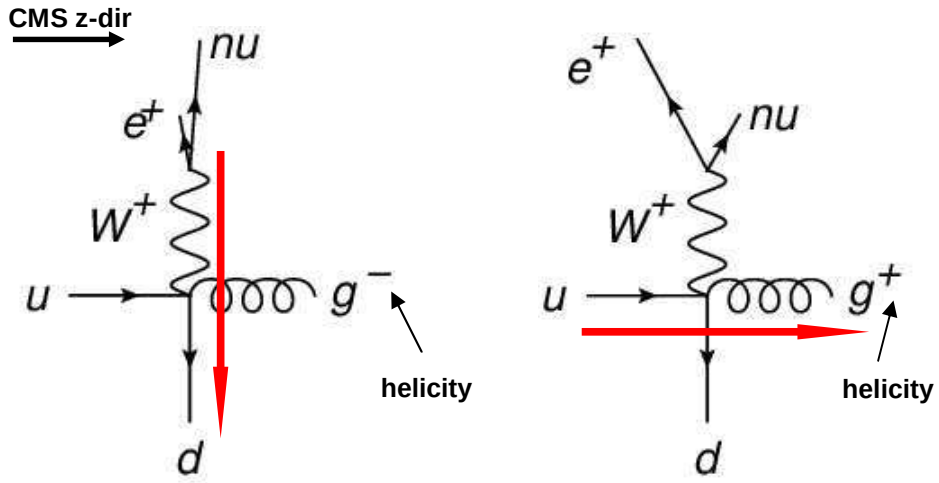
pp versus $p\bar{p}$

- Valence quark content differs, leading to two distinct effects which scale with increasing $P_T(W)$
  - Charge Asymmetry, since $N(q^+) > N(q^-)$
  - Transverse Polarisation, since $N(q_L) > N(q_R)$. Dominant production mechanism at high $P_T(W)$ involves quark-gluon vertex at LHC:

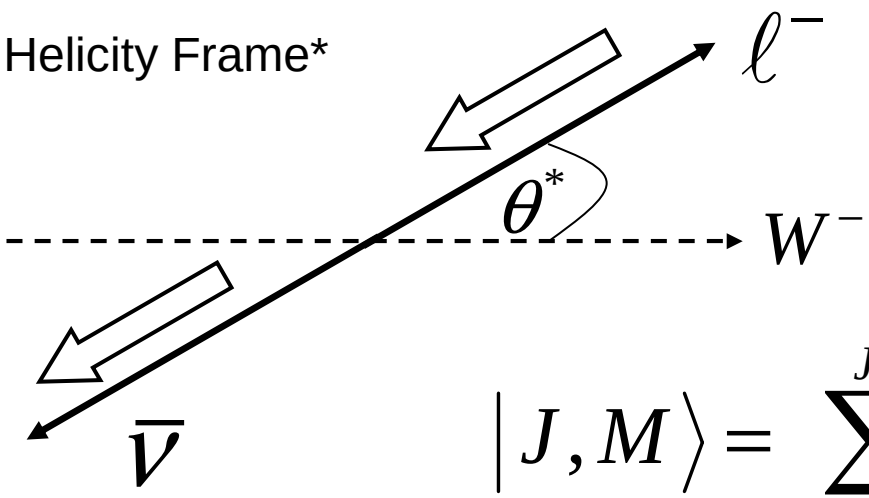


W+1jet dominant production mechanism at LHC (not a Feynman diagram)

Expect predominantly left-handed W-bosons at the LHC

Parameterising Polarisation

Helicity Frame*



$$d^1_{1,1} = \frac{1+\cos\theta}{2}$$
$$d^1_{1,0} = -\frac{\sin\theta}{\sqrt{2}}$$
$$d^1_{1,-1} = \frac{1-\cos\theta}{2}$$

$$\left|J,M\right\rangle = \sum_{M'=-J}^{J} d^J_{M,M'} \left|J,M'\right\rangle$$

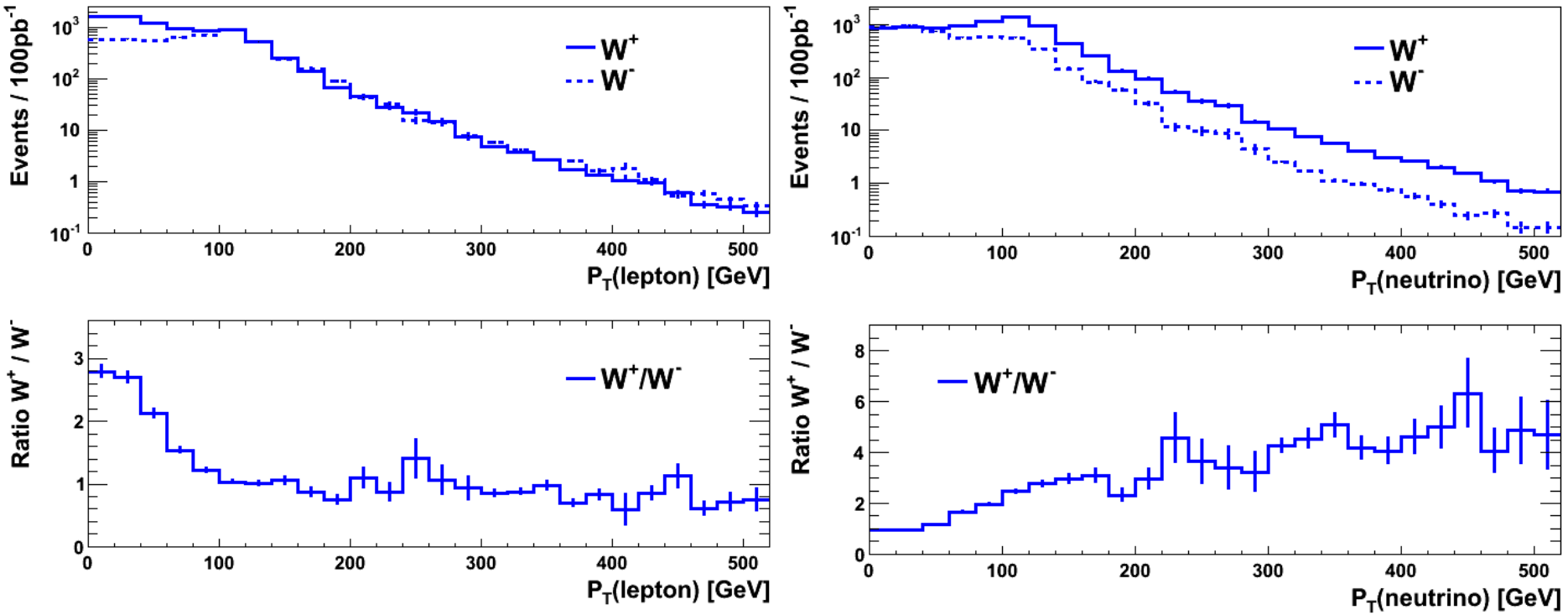
W^+: $$\sigma(\theta^*) \sim f_L \frac{(1-\cos\theta^*)^2}{4} + f_0 \frac{\sin^2\theta^*}{2} + f_R \frac{(1+\cos\theta^*)^2}{4}$$

W^-: $$\sigma(\theta^*) \sim f_L \frac{(1+\cos\theta^*)^2}{4} + f_0 \frac{\sin^2\theta^*}{2} + f_R \frac{(1-\cos\theta^*)^2}{4}$$

* W-boson rest frame, z-axis aligned with W flight direction.

Lepton P_T distributions

Leading Order generator level expectations for $P_T(W)>100$ GeV:



Polarisation effects contribute to e.g. more E_T^{miss} from W^+ decays than W^- decays

Important to establish and quantify this effect (New Physics searches)

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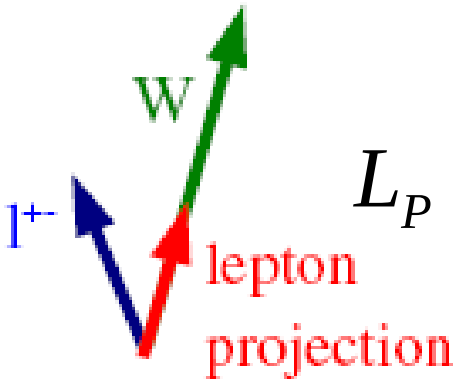
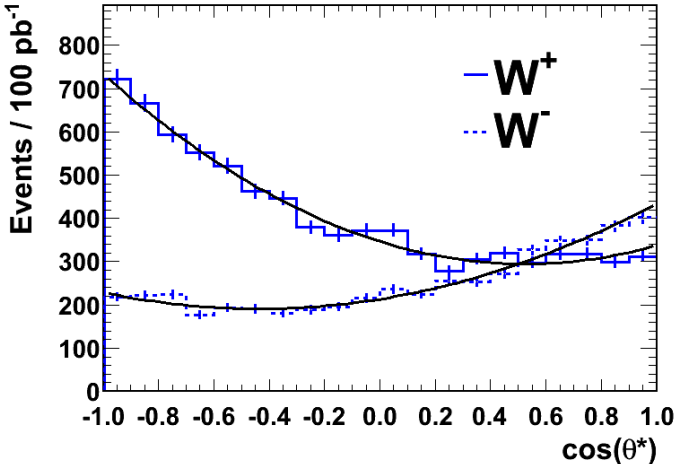
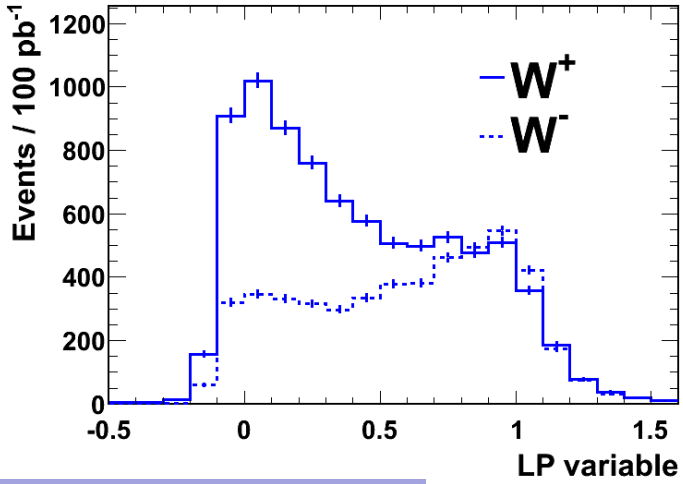
Detector Observable: L_P

Define a transverse variable highly correlated to cos θ* (which determines the Lorentz boost)



$$L_P = \frac{\vec{p}_T(\ell)\cdot\vec{p}_T(W)}{\left|\vec{p}_T(W)\right|^2}$$





Use LP to measure W polarisation at large $P_T(W)$

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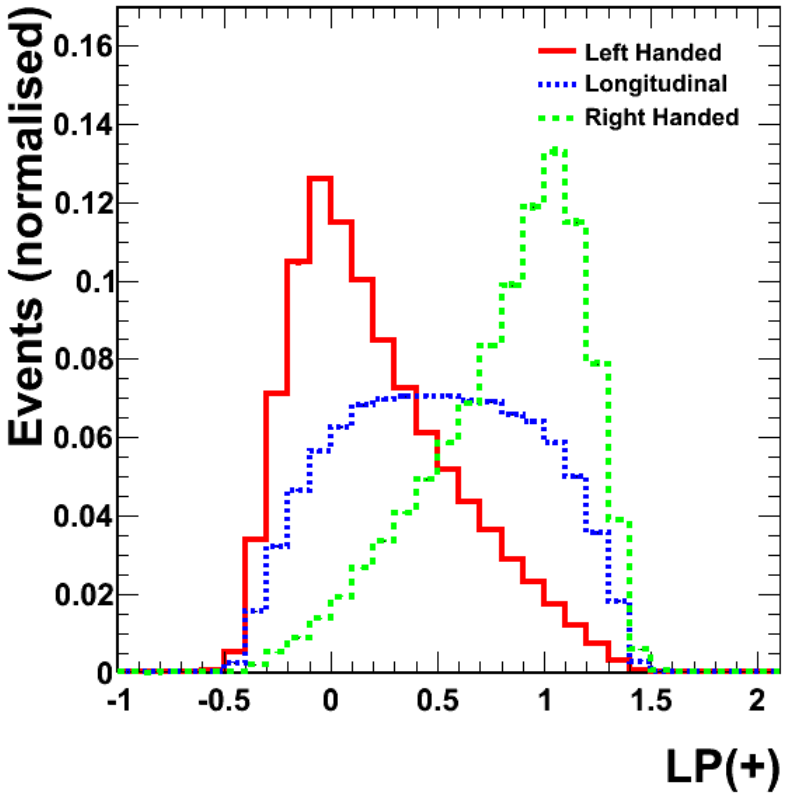
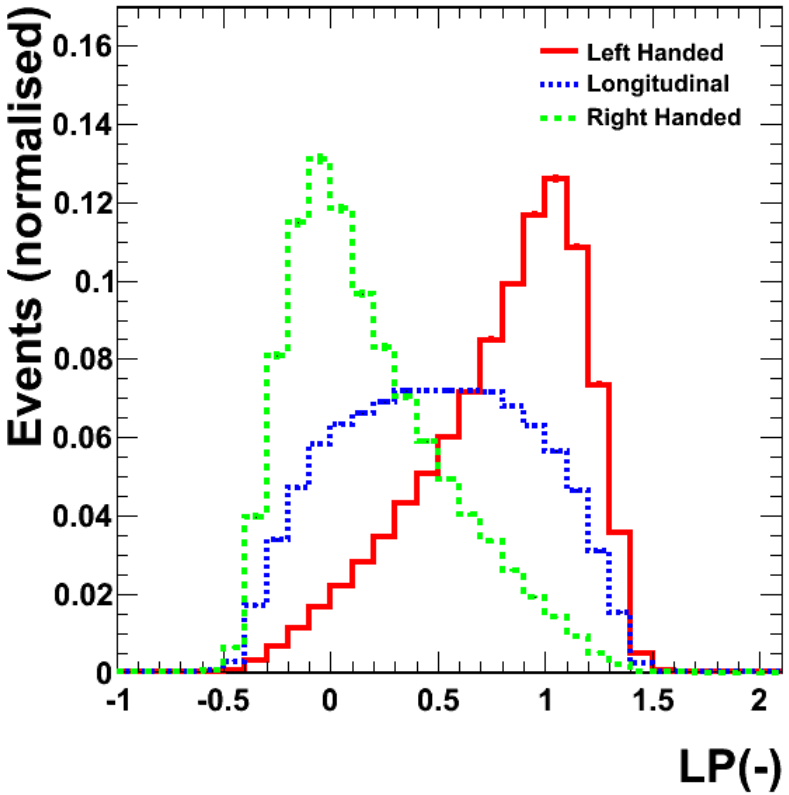
Procedure

- Idea is to generate templates of 100% polarised states in L_P, via a reweighting of the Monte Carlo information, and fit these templates to the data observed. Generator Level Example:





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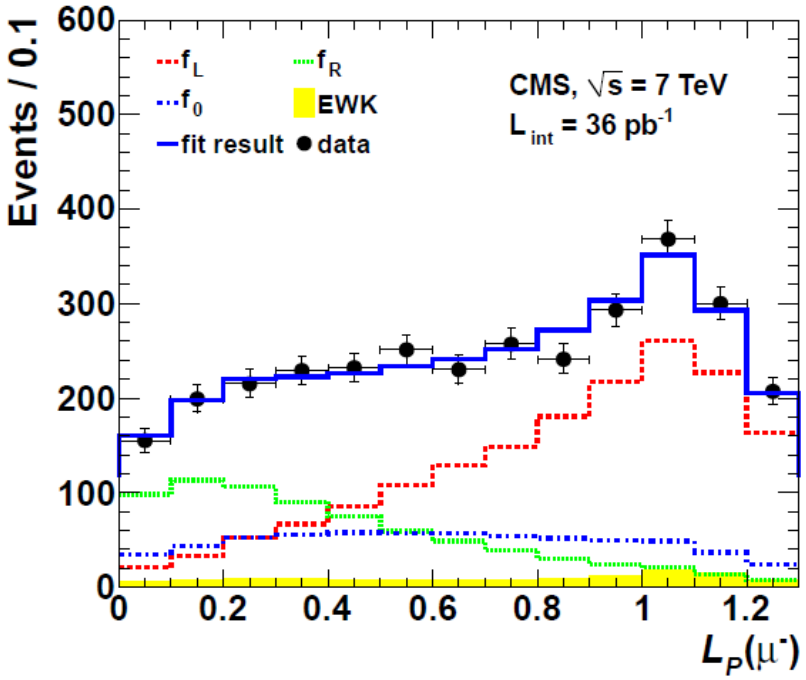
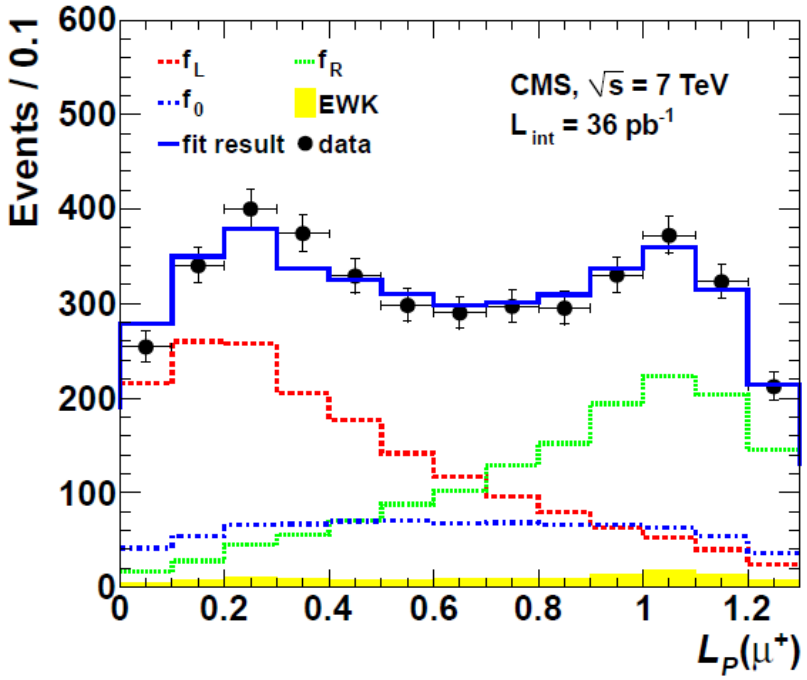
Muon Channel Measurement

- Selection Criteria:
  - Single muon trigger
  - One isolated muon with $P_T > 20$ GeV
    - Veto events with second muon > 10 GeV (to suppress Z+Jets events)
  - No isolated electrons with $P_T > 20$ GeV
  - $M_T > 30$ GeV (to suppress QCD events)
    - Do not want to place any requirements on E_T^{miss} i.e. neutrino (correlated to polarisation)
  - Require < 4 Jets, $P_T^{jet} > 20$ GeV (to suppress ttbar+Jets events)
  - $P_T(W) > 50$ GeV (to enhance polarisation effects)
- After all selection criteria, find 8626 events in 36 pb^{-1} of data
- QCD negligible, use background template from MC for Z,ttbar+jets contributions, fixing ratio to W+Jets (S/B expected ~ 26)
- 2 fit parameters: $(f_L - f_R)$ and f_0
  - Fit range optimised with respect to leading systematic uncertainties

Muon Channel Result



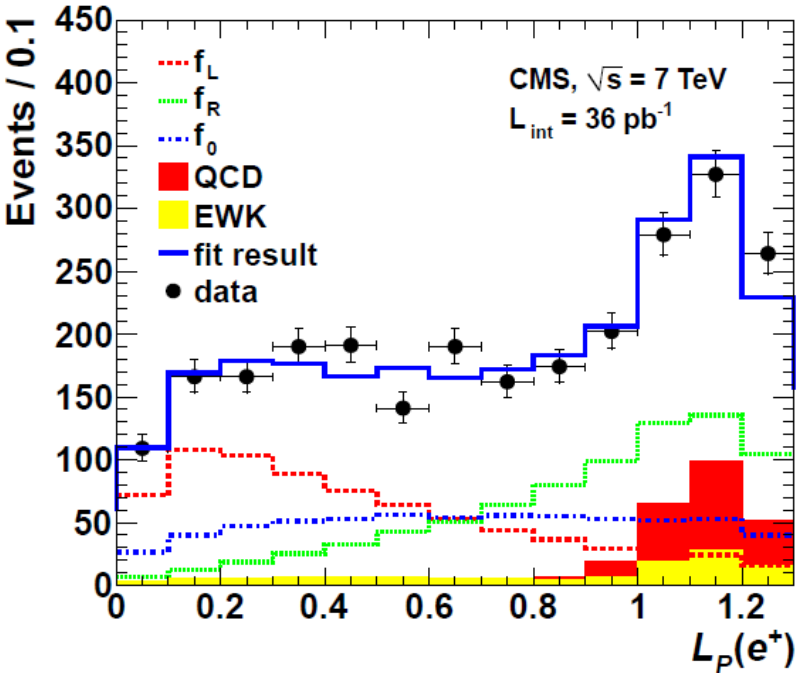


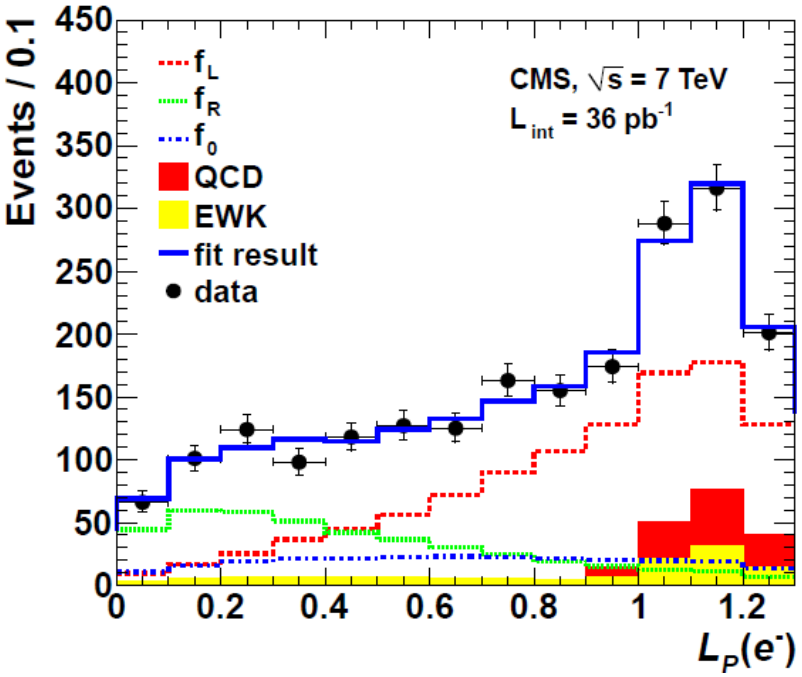
$\mu : (f_L - f_R)^-$	0.240 ± 0.036 (stat.) ± 0.031 (syst.)
$\mu : f_0^-$	0.183 ± 0.087 (stat.) ± 0.123 (syst.)
Correlation	0.395 (stat.), -0.308 (stat. + syst.)
$\mu : (f_L - f_R)^+$	0.310 ± 0.036 (stat.) ± 0.017 (syst.)
$\mu : f_0^+$	0.171 ± 0.085 (stat.) ± 0.099 (syst.)
Correlation	-0.721 (stat.), -0.269 (stat. + syst.)

Electron Channel Measurement

- Selection Criteria:
  - Single electron trigger
  - One isolated electron with P_T > 25 GeV
    - Veto events with second electron > 15 GeV (to suppress Z+Jets events)
  - No isolated muons with P_T > 20 GeV
  - M_T > 50 GeV (to suppress QCD events)
    - Do not want to place any requirements on E_T^{miss} i.e. neutrino (correlated to polarisation)
  - Require < 4 Jets, P_T^{jet} > 20 GeV (to suppress ttbar+Jets events)
  - $P_T(W)$ > 50 GeV (to enhance polarisation effects)
- After all selection criteria, find 5485 events in 36 pb^{-1} of data
- Same strategy, except QCD non-negligible (S/B ~ 10). Generate data-driven template for QCD L_P shape via cut-inversion and include normalisation as extra fit parameter

Electron Channel Result





$e : (f_L - f_R)^-$	0.187 ± 0.069 (stat.) ± 0.066 (syst.)
$e : f_0^-$	0.130 ± 0.200 (stat.) ± 0.174 (syst.)
Correlation	-0.204 (stat.), -0.283 (stat. + syst.)
$e : (f_L - f_R)^+$	0.277 ± 0.060 (stat.) ± 0.050 (syst.)
$e : f_0^+$	0.240 ± 0.190 (stat.) ± 0.090 (syst.)
Correlation	-0.295 (stat.), 0.001 (stat. + syst.)

QCD events at L_P~1 for both charges (low E_T^{miss} events)

Results between channels agree well

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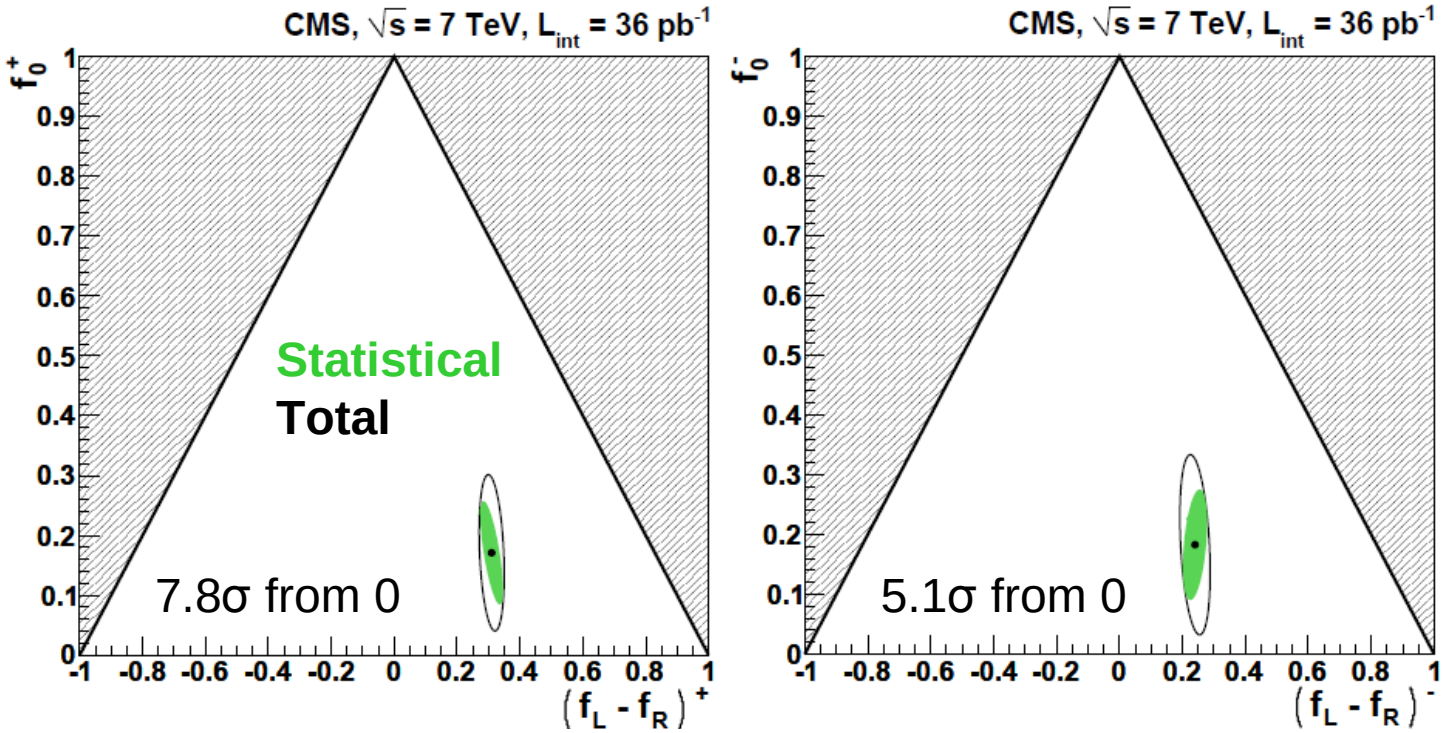
Systematic Uncertainties

- Leading systematic uncertainties stem from the W+Jets recoil energy scale and resolution uncertainties (by construction of L_P)
  - Uncertainties larger in the electron channel, carry forward when combining channels
  - Most precise measurement is that of the muon channel only

Uncertainty	$(f_L - f_R)^-$	f_0^-	$(f_L - f_R)^+$	f_0^+
	Electron channel			
Recoil energy scale	±0.042	±0.150	±0.027	±0.078
Recoil resolution	±0.046	±0.047	±0.037	±0.039
Electron scale	±0.017	±0.014	±0.019	±0.016
Total uncertainty	±0.066	±0.174	±0.050	±0.090
	Muon channel			
Recoil energy scale	±0.029	±0.123	±0.011	±0.092
Recoil resolution	±0.012	±0.006	±0.012	±0.004
Muon scale	±0.002	±0.007	±0.004	±0.008
Total uncertainty	±0.031	±0.123	±0.017	±0.099

Contour Representation

- Results in $(f_L\text{-}f_R)$ vs f_0 plane for muon channel result:



Measurement shows, for the first time, that in both the electron and muon channels, W-bosons produced in pp collisions are predominantly left-handed

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Theoretical Expectations

- A comparison of the CMS results with theoretical predictions (Blackhat collaboration, arXiv:1103.5545)

	Muon Fit Result	NLO	ME+PS	LO
$(f_L-f_R)^-$	0.240 ± 0.036 ± 0.031	0.248	0.222	0.235
f_0^-	0.183 ± 0.087 ± 0.123	0.193	0.179	0.190
$(f_L-f_R)^+$	0.310 ± 0.036 ± 0.017	0.308	0.283	0.309
f_0^+	0.171 ± 0.085 ± 0.099	0.200	0.187	0.198

Measurement shows, for the first time, that in both the electron and muon channels, W-bosons produced in pp collisions are predominantly left-handed as expected in the Standard Model

Conclusions

- W boson polarization properties unique in the LHC environment
- Predominant left-handedness expected which dictate the W-decay lepton kinematic properties
- First measurement using LHC data performed and establishes the effect to high precision

Appendix

- Combined Fit Systematic uncertainties:
  - Correlations taken into account for the energy scale and resolution

	Combined measurement			
Recoil energy scale	±0.033	±0.133	±0.016	±0.087
Recoil resolution	±0.035	±0.023	±0.027	±0.015
Electron scale	±0.013	±0.011	±0.012	±0.008
Muon scale	±0.002	±0.004	±0.004	±0.004
Total uncertainty	±0.050	±0.136	±0.034	±0.089

- Combined Fit Results:

Combined: $(f_L - f_R)^-$	0.226 ± 0.031 (stat.) ± 0.050 (syst.)
Combined: f_0^-	0.162 ± 0.078 (stat.) ± 0.136 (syst.)
Correlation	0.304 (stat.), −0.326 (stat. + syst.)
Combined: $(f_L - f_R)^+$	0.300 ± 0.031 (stat.) ± 0.034 (syst.)
Combined: f_0^+	0.192 ± 0.075 (stat.) ± 0.089 (syst.)
Correlation	−0.660 (stat.), −0.121 (stat. + syst.)