W-boson polarization at high $P_T(\boldsymbol{W})$ at LHC

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On behalf of the **CMS** collaboration

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Introduction & Motivation

Introduction

High $P_T(W)$ (a)symmetries

TEVATRON (p-$\bar{p}$)	**LHC (p-p)**
Dominance production:	Dominance production:
• $q\bar{q}$ and qg (increasing with $P_T(W)$)	• qg (g larger x than sea quark)
Symmetries (initial states):	Symmetries (initial states):
• Helicity: $N(q_L)=N(q_R)$ ➔ net polarization symmetry	• Helicity: $N(q_L)>N(q_R)$ ➔ net polarization asymmetry ?
• Charge: $N(+)=N(-)$ ➔ net charge symmetry	• Charge: $N(+)>N(-)$ ➔ net charge asymmetry!

effects grow with $P_T(W)$

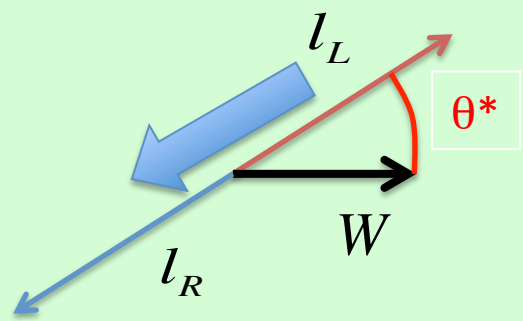
- LHC has strong overall C and P asymmetries
- LHC and Tevatron (Lep) are very different in polarizations

Polarization reminder

W restframe:
z': W "flight" direction
z : l_L flight direction

$$(l_L + l_R): J = 1; Jz = 1$$

$$W_X : J = 1; Jz' = X$$



Rotate spin via Wigner D-matrices to W direction.

$$d^J_{Jz,Jz'}$$

f_L, f_R and f_0 : left-handed, longitudinal and right-handed fraction of Ws.

W x-section: $$\frac{d\sigma}{d\theta^*} \sim f_L\,(d^1_{-1,-1})^2 + f_0\,(d^1_{0,-1})^2 + f_R\,(d^1_{1,-1})^2$$

$$\Updownarrow$$

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

θ* required to determine W helicity

W Polarization (1jet) at LHC

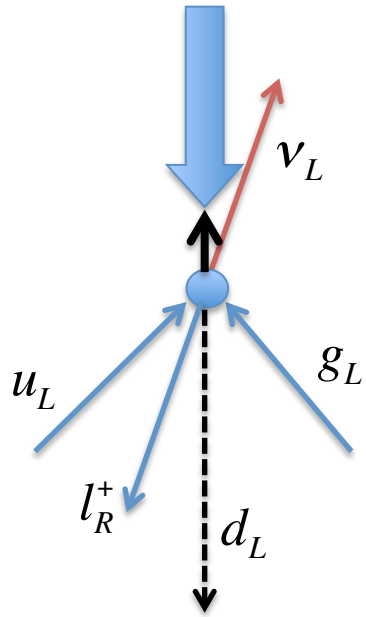
Illustrations in W restframe

W Spin

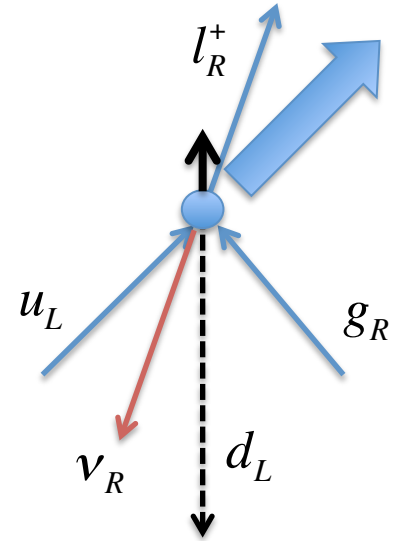
W flight direction

$u_L g$: incoming particles

$\upsilon_R d_L l_R^+$: outgoing particles



a) u, gluon left-handed:
W spin in d quark direction
W_L 100%



b) u, gluon right-handed:
W spin opposite to u quark
W_R preferred: 100% at infinite $P_T(W)$

(amplitude a)^2/(amplitude b)^2 = 4/1 at infinite $P_T(W)$

Predominantly left-handed Ws (W_L) expected at the LHC

Polarization observable LP

Lorentz-boost from W rest to CMS (M_W<<P(W)):

$$P_{\parallel}^{l} = \frac{P(W)}{2}(\cos(\theta^*)+1)$$

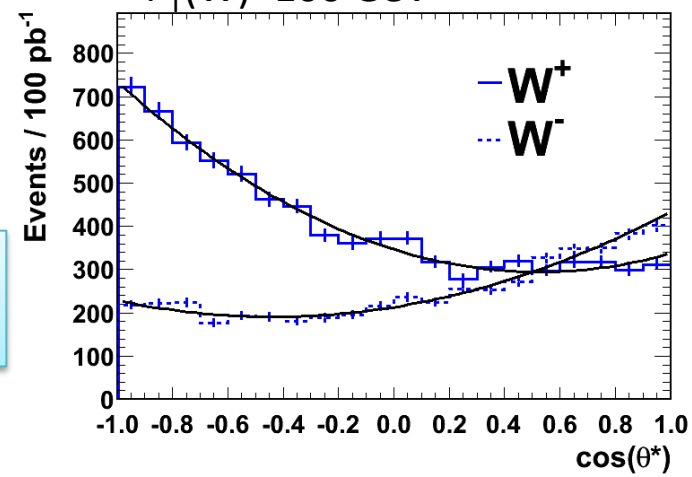
Left-handed W gives most momentum to left-handed lepton!

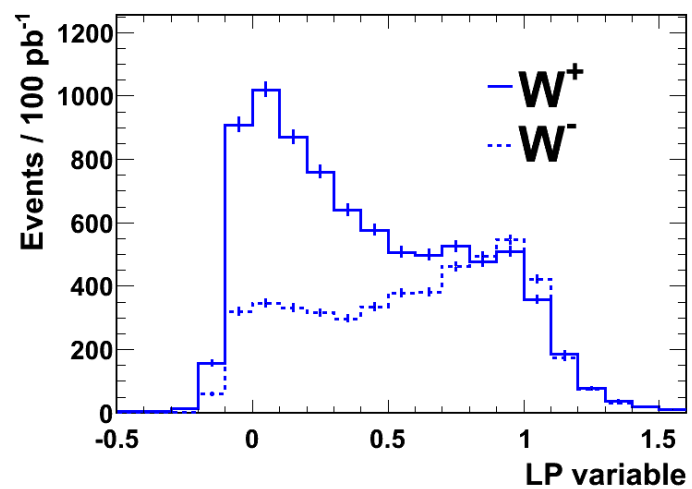
- Define a variable using this fact (**L**epton **P**rojection)
- Only PT(W), not P(W) measured: use P_T not P

$$\mathrm{LP} = \frac{\vec{P}_T(\ell)\cdot\vec{P}_T(W)}{\left|\vec{P}_T(W)\right|^2}$$

LP highly is correlated to cos(θ*)

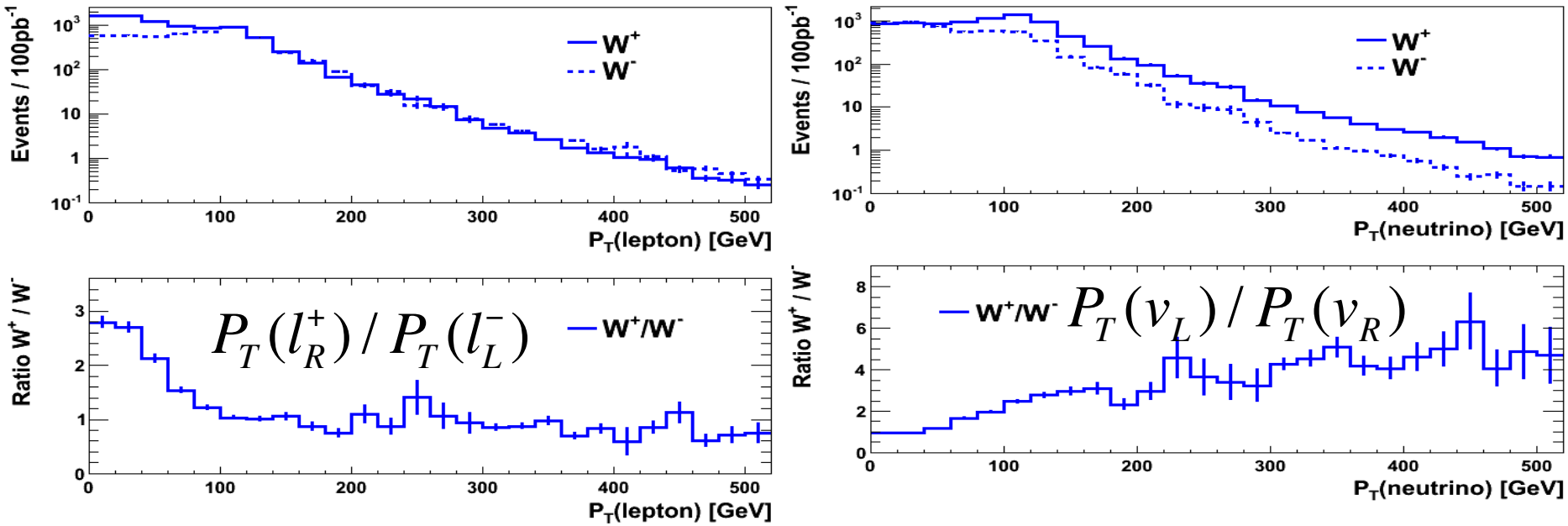
Madgraph W+jet Gen-level: P_T(W)>100 GeV





Kinematic effects & applications

Madgraph W+jet Gen-level: $P_T(W)>100$ GeV



- Strong charge asymmetry in MET produced (4:1)
- W acceptance affected by polarization

Kinematic effects from polarization are strong!

Application

RPC SUSY: lepton PT << MET

- e.g. CMS one leptonic SUSY search

gluon fusion processes (i.e. LQ,tt)

- fully CP symmetric
- tt/W+jet separation

....

The Measurement

Muons

Strategy

Extract polarization:

- Use **LP** variable
- MC-templates of LP for 100% f_L, f_R, f_0
- Fit templates to data

Backgrounds:

- EWK (Z^0,$t\bar{t}$):
  - MC-templates of LP
  - EWK/W+jets ratio fixed in fit
- QCD:
  - Cuts make QCD neglectable

Selection

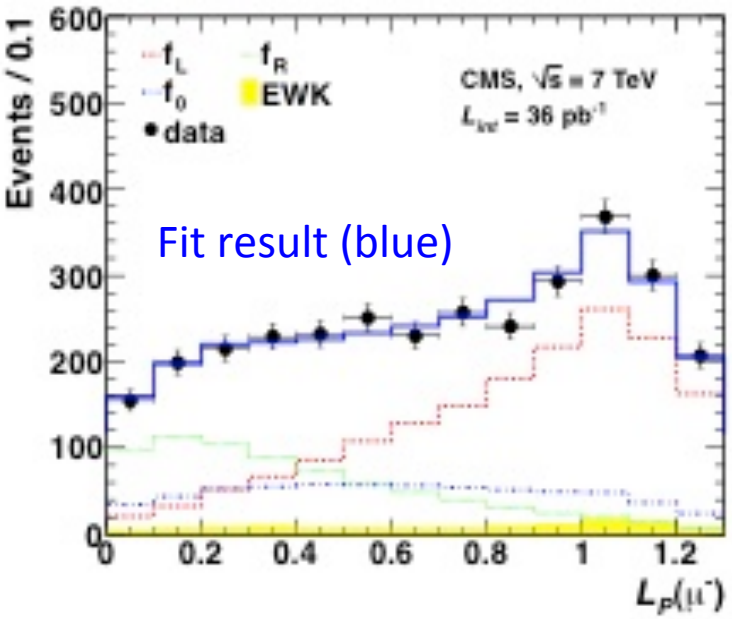
- Single muon trigger
- 1 isolated muon, P_T>20 GeV $|\eta|$<2.1
- 0 isolated electron (P_T>20 GeV, $|\eta|$<2.5)
- < 4 Jets (P_T^{jet} > 20 GeV) (reject tt)
- $\Delta R_{min}(\mu, jet) > 0.5$
- Veto 2nd muon with p_T>10 GeV (reject Z^0)
- M_T > 30 GeV (reject QCD)
- $P_T(W)$ > 50 GeV

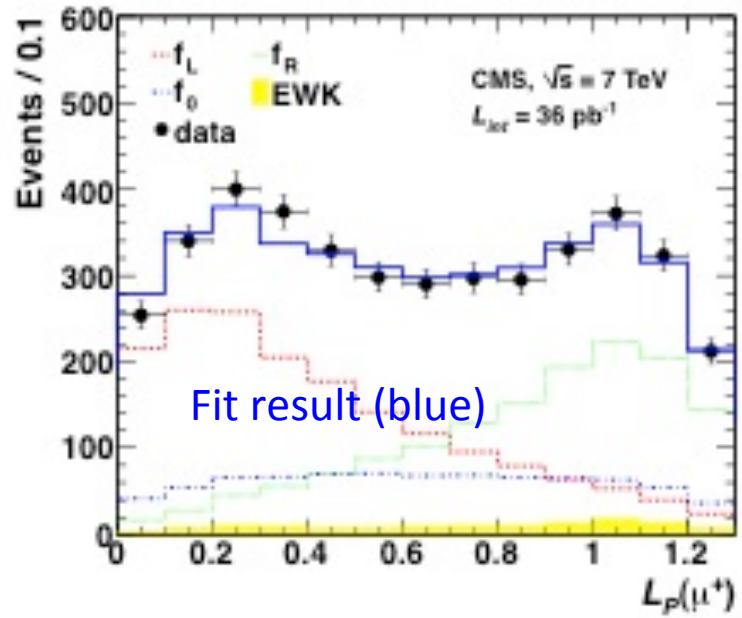
- Event yields per pb^{-1} from the MC:

	W+Jets	QCD	Z+Jets	$t\bar{t}$	S/B
$P_T(W) > 50$GeV	264	21.3	14.6	3.1	6.8
$M_T > 30$GeV	218	0.0	5.4	2.0	26.0

Template fits to extract polarization of Ws with > P_T 50 GeV

Muon fit





- Templates clearly distinct also in RECO level
- "Medium" W P_T and RECO effects smears peaks at 0,0.5 and 1
- Fit parameters are f_L-f_R and f_0 (fs have add up to one)

- Final fit agrees well to data

Electrons

Strategy (changes w.r.t. muon)

Backgrounds:

- QCD:
  - Cut harder on MT
  - Data-driven templates via cut-inversion (track-cluster matching inverted)
  - Keep QCD fraction an open parameter in the fit

Selection

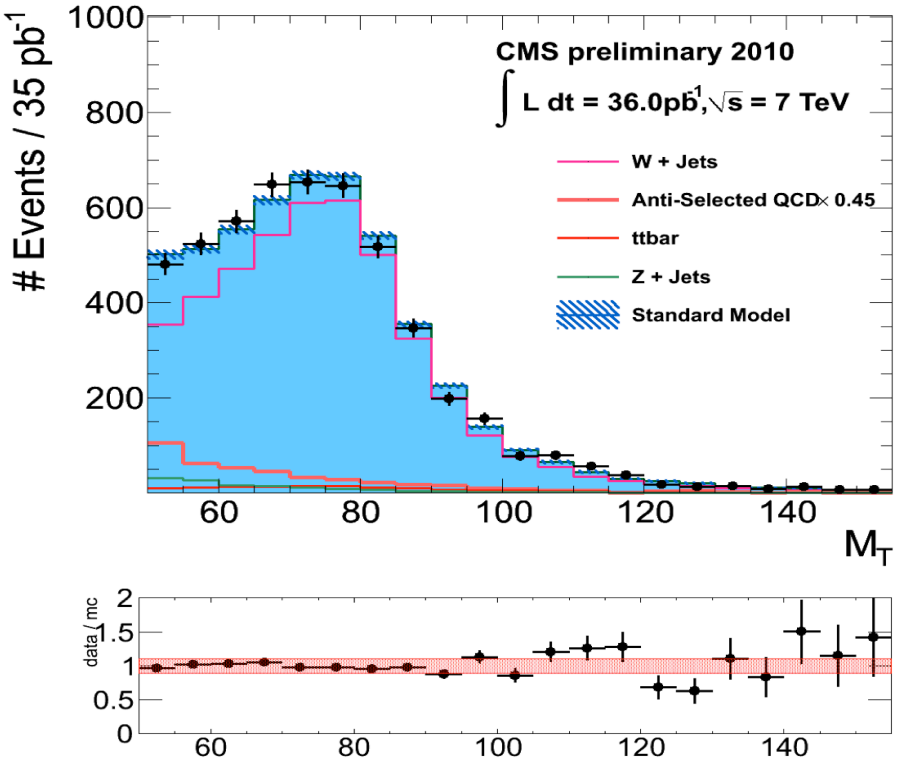
- Single electron trigger
- 1 isolated electron, P_T>25 GeV $|\eta|$<2.5
- 0 isolated emuon (P_T>10 GeV)
- < 4 Jets (P_T^{jet} > 20 GeV) (reject tt)
- Veto on 2nd electron with p_T>15 GeV
- M_T > 50 GeV (reject QCD)
- P_T(W) > 50 GeV

- Event yields expected per pb^{-1} from the MC:

Cut	W+Jets	QCD	Z+Jets	γ+jets	$t\bar{t}$	S/B
W boson $P_T > 50$ GeV	182.2	17.2	28.4	15.9	5.0	2.7
$M_T > 50$ GeV	122.8	2.7	3.7	3.1	3.3	9.6

Use data-driven templates for QCD and fit QCD fraction

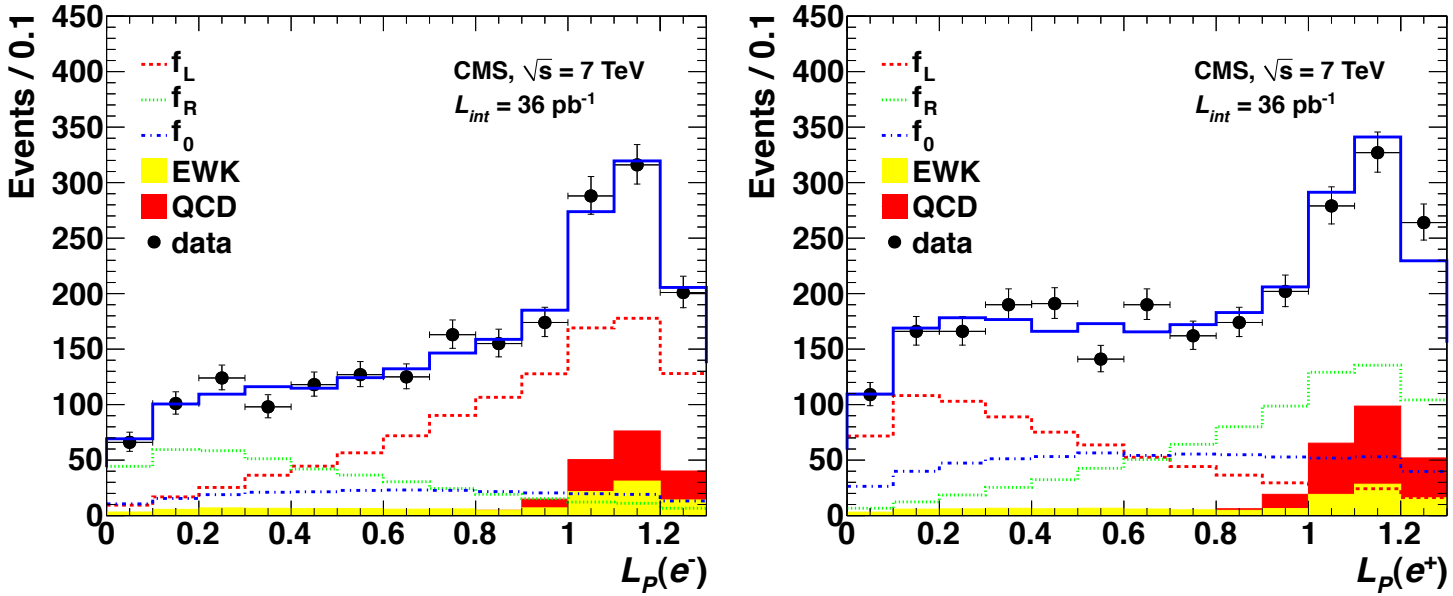
Anti-selection x-check



- QCD anti-selection used for QCD shape
- QCD normalization fitted to data
- Same anti-selection for control sample as in CMS's W x-section measurement

Anti-selected QCD describes data well

Electron Fit



- "Fake" isolated electrons in QCD have few MET ➔ QCD peaks at LP~1
- QCD peak close to other template peaks ➔ correlations in fit increase

➢ Electron fit more sensitive to systematics and less statistical precision than muon

- Electrons important test of muon result
- Final fit agrees well to data

Leading Systematics

Muons:

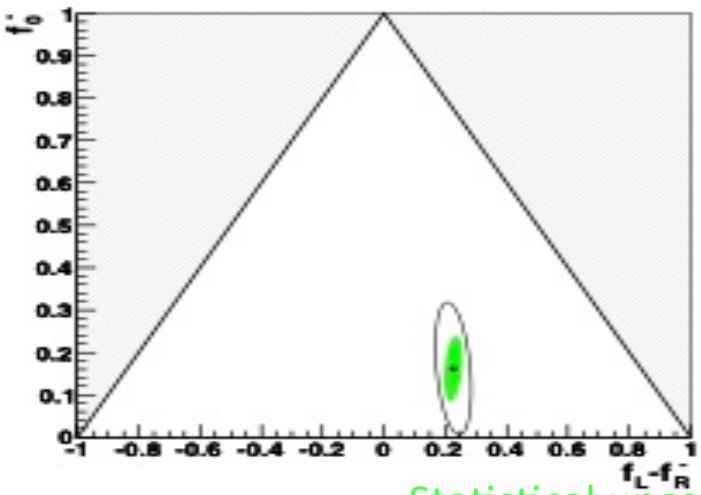
		$(f_L - f_R)^-$	f_0^-	$(f_L - f_R)^+$	f_0^+
$P_T(W)$ {	recoil energy scale	± 0.029	± 0.123	± 0.011	± 0.092
	recoil resolution	± 0.012	± 0.006	± 0.012	± 0.004
	muon scale	± 0.002	± 0.004	± 0.004	± 0.036
	total uncertainty	± 0.031	± 0.123	± 0.017	± 0.099

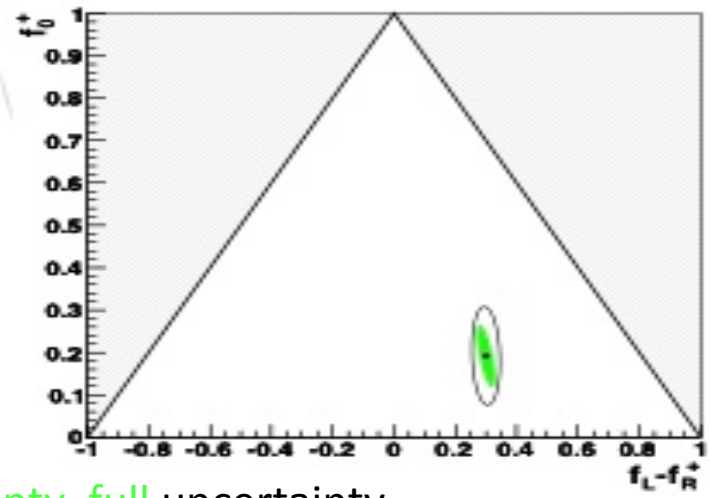
Electrons:

$P_T(W)$ {	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

- $P_T(W)$ related uncertainties directly affect measurement:
  - ➢ Dominating uncertainty
- The electron channel is more sensitive to systematics

Results: Muon&electron combined





Statistical uncertainty, full uncertainty

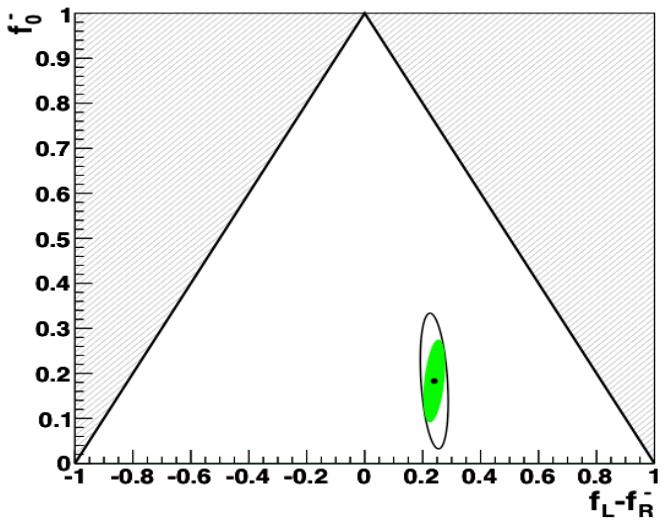
Combined fit takes correlations of systematics into account

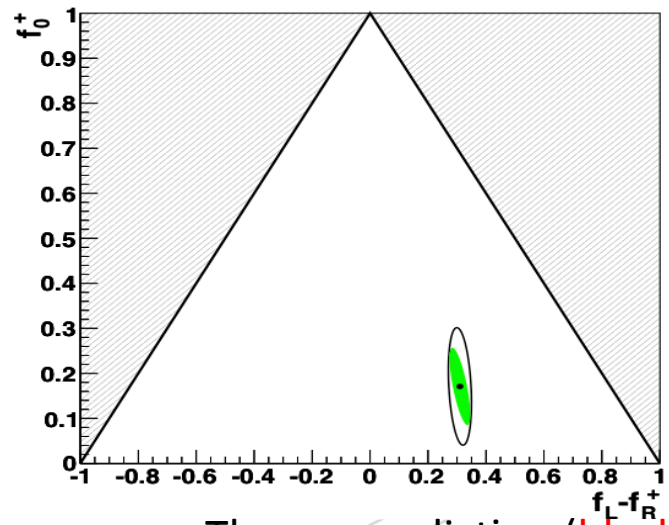
comb: $(f_L - f_R)^-$	0.226 ± 0.031 (stat.) ± 0.050 (syst.)
comb: f_0^-	0.162 ± 0.078 (stat.) ± 0.136 (syst.)
Correlation (stat)	0.304 (stat.)

comb: $(f_L - f_R)^+$	0.300 ± 0.031 (stat.) ± 0.034 (syst.)
comb: f_0^+	0.192 ± 0.075 (stat.) ± 0.089 (syst.)
Correlation (stat)	-0.660 (stat.)

Results from muon and electron fits agree

Results: Muons





	Data Fit Result
$\mu : (f_L - f_R)^-$	0.240 ± 0.036 (stat.) ± 0.031 (syst.)
$\mu : f_0^-$	$0.183 \pm 0.087 \pm 0.123$
Correlation	0.395 (stat.)
χ^2/ndof (stat)	0.767
$\mu : (f_L - f_R)^+$	$0.310 \pm 0.036 \pm 0.017$
$\mu : f_0^+$	$0.171 \pm 0.085 \pm 0.099$
Correlation	-0.721 (stat.)
χ^2/ndof (stat)	0.967

Theory prediction (blackhat):
arXiv:1103.5445

	NLO	ME+PS	LO
(fL-fR)-	0.249	0.221	0.236
f0-	0.193	0.179	0.19
(fL-fR)+	0.308	0.302	0.31
f0+	0.2	0.187	0.198

Prediction and measurement agree

Precision on (f_L-f_R): < 5%

Summary

- W polarization at LHC distinct to particle-antiparticle colliders
- W polarization strongly affects kinematics at high $P_T(W)$
- Standard Model expectation and data agree
- Polarization (f_L- f_R) measured up to few %