First Measurement of Polarization of High Transverse Momentum W Bosons in W +jets Events at a pp Collider

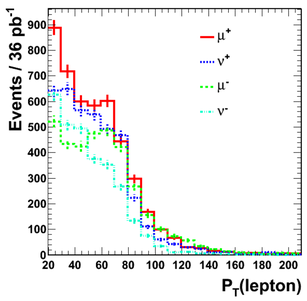
O. Buchmuller[a], G. Karapostoli[a], J. Marrouche[a], A. Sparrow[a], P. Sphicas[b, c], M. Stoye[b], M. Peruzzi[d]

[a]Imperial College London, UK – [b]CERN, Geneva, Switzerland – [c]University of Athens, Greece – [d]University of Pisa, Pisa, Italy

Introduction

At the LHC, production of W bosons in association with jets is an important probe of both QCD and electroweak interactions. This is particularly interesting in light of potential applications to New Physics searches.

The proton-proton environment at the LHC leads to a dominance of quark-gluon initial states in W+jets production. When taken together with the V-A nature of the weak interaction, this causes W bosons to be produced with a sizable transverse polarization. This effect manifests itself as an asymmetry in the transverse momenta spectra of the neutrino and the charged lepton (Fig 1).



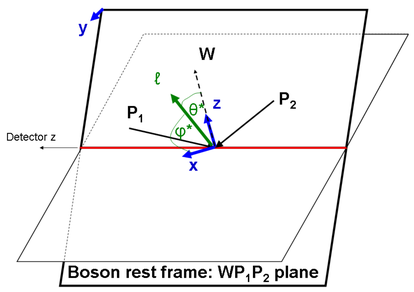


Fig 1 (Left) Lepton momentum spectra in data.
Fig 2 (Right) Illustration of the W boson helicity frame

Helicity Frame

The polarization of the W boson is measured in the helicity frame, in which the polar angle (θ*) is measured with respect to the boson flight direction in the laboratory frame, and the azimuthal angle (φ*) is defined to be zero for the proton which has the smaller φ* in the boson rest frame.

The differential angular cross-section has the form:

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega} \sim (1+\cos^2\theta^*) + \frac{1}{2}A_0(1-3\cos^2\theta^*) + A_1\sin 2\theta^*\cos\phi^* + \frac{1}{2}A_2\sin^2\theta^*\cos 2\phi^* + A_3\sin\theta^*\cos\phi^* + A_4\cos\theta^*$$

where the θ* and φ* represent the azimuthal and polar angles of the decay lepton in the helicity frame. The A_i are the ratios of the polarized cross-section to the total unpolarized cross-section. Integrating over φ*, a measurement of cos(θ*) allows determination of the parameters A_0 and A_4. These correspond to the longitudinally polarized fraction ($f_0 \sim A_0$) and the difference between the left-handed and right handed fractions ((f_L-f_R) ~ A_4).

Method

Since it is not possible to measure the momentum of the neutrino parallel to the beam line, there is a two-fold ambiguity in the determination of the W boson momentum. It is therefore not possible to extract the decay angle θ* directly. A variable found to be highly correlated with cos(θ*) at high transverse momentum (see Fig 3), the lepton projection (L_P) is therefore used instead:

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

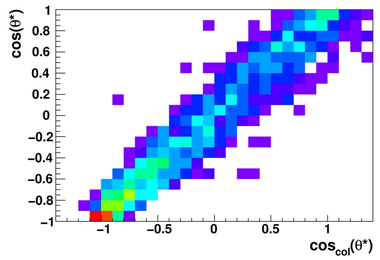


Fig 3 The correlation of (2LP – 0.5) with cos(θ*) for W bosons with $P_T(W) > 200$ GeV

L_P distributions corresponding to 100% left-handed, right-handed and longitudinally polarized W bosons are generated via a reweighting of a simulated W+Jets sample. These are produced separately for each charge and lepton flavour and account for all detector and acceptance effects. A binned maximum likelihood fit is performed with templates included for surviving backgrounds (see below).

Selection & Backgrounds

The selection is as follows:

- One muon (electron) $p_T > 20$ (25) GeV
- Veto events with 2nd muon (electron) $p_T > 10$ (15) GeV
  To suppress background from Z+jets
- < 4 jets To suppress background from $t\bar{t}$
- $P_T(W) > 50$ GeV To enhance polarization effect
- $M_T > 30$ (50) GeV To suppress QCD multijet background

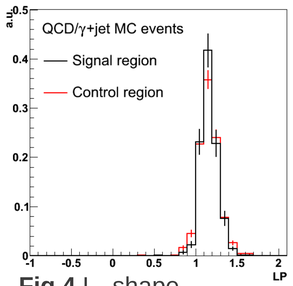


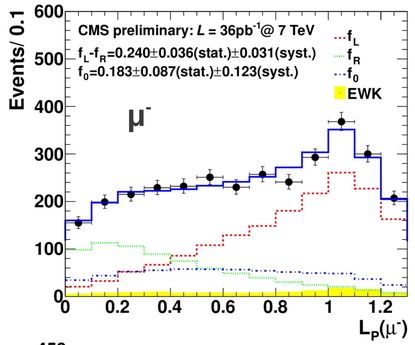
Fig 4 L_P shape comparison between selected and anti-selected simulated QCD samples.

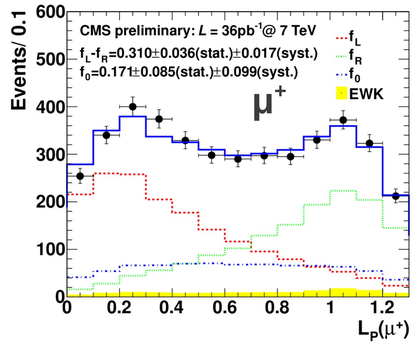
The remaining backgrounds are:

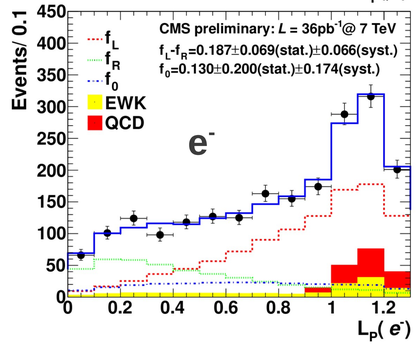
• Z & tt (EWK)
Included in the fit with templates taken from simulation. Normalization is fixed to the MC expectation.

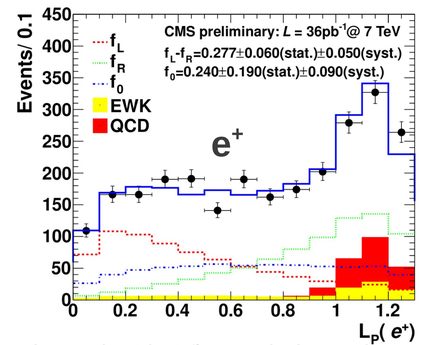
• QCD multijet (electron channel only)
This background is expected to be poorly modelled by simulation. A data-driven template is constructed from a sample formed by anti-selecting on a subset of the electron ID criteria (Fig 4).

Results

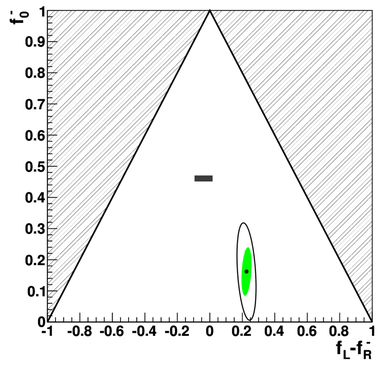


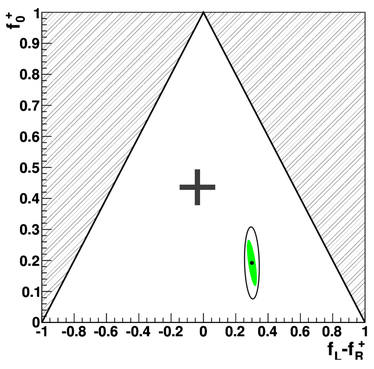






The values of f_0 and (f_L-f_R) are charge dependent but flavour independent
A combined fit is performed (see below).





Combined fit error ellipses for negative charge (left) and positive charge (right). The black point represents the measured value, the green ellipse statistical uncertainty and the black ellipse combined statistical and systematic uncertainties.

This measurement demonstrates for the first time that high p_T W bosons produced in association with jets at a pp collider exhibit a significant left-handed polarization!