Towards a measurement of W-boson polarisation using jets and leptons with the CMS detector at the LHC

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Why study *W*-bosons?

W-boson helicity and charge asymmetry effects at the energies of the LHC, and in the proton-proton environment of the LHC, have not been previously studied or discussed. There are key differences to both LEP and Tevatron

Early LHC Data

Helicity arguments give a well defined relationship between neutrinos and charged leptons from *W*-boson decays, and these can be used to test SM compatibility.

Explicit knowledge of the ratio between *W*+jets and ttbar events is required for particular background estimation methods.

Later

W-bosons in *W*+jets events are an important background for many new physics searches.

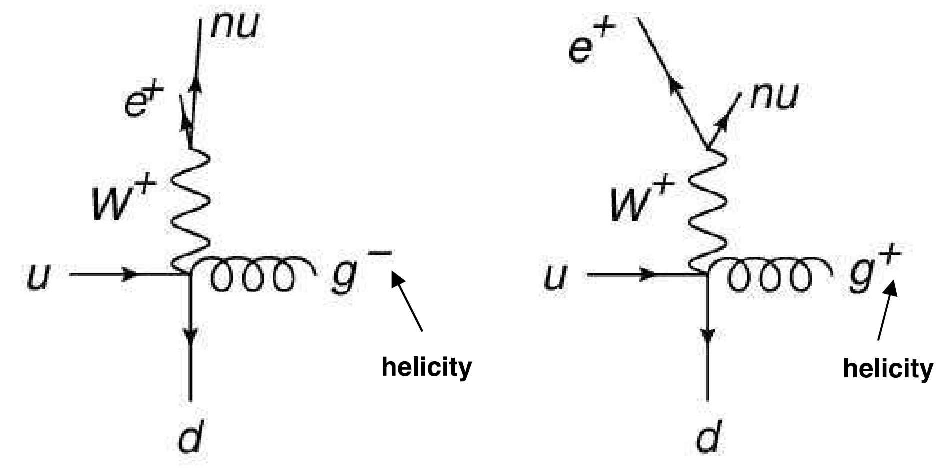
Explicit knowledge of charge asymmetry and polarisation effects are critical for acceptance adjustments.

W-boson helicity can be part of a search strategy in the one-lepton channel for e.g. SUSY

Differences to Tevatron

Production of high Pt (>100 GeV) W-bosons will involve a large fraction of a proton's energy i.e. valence quarks. **No valence anti-quarks at the LHC**

Valence quark dominance leads to a factor of approximately **2:1** between W+:W- boson production.



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

Dominant production mechanism involves valence quark-gluon.

Replacing u-quark with d-quark flips charge but not helicity i.e. initial states and CP counterparts not present in equal amounts!

Quantifying polarisation

The polarisation of bosons affects the angular distribution of their decay products. This is totally encompassed in the production cross section. e.g. at UA1:

$$\sigma_{W^{\mp}} \sim (1 \pm \cos\theta)^2$$

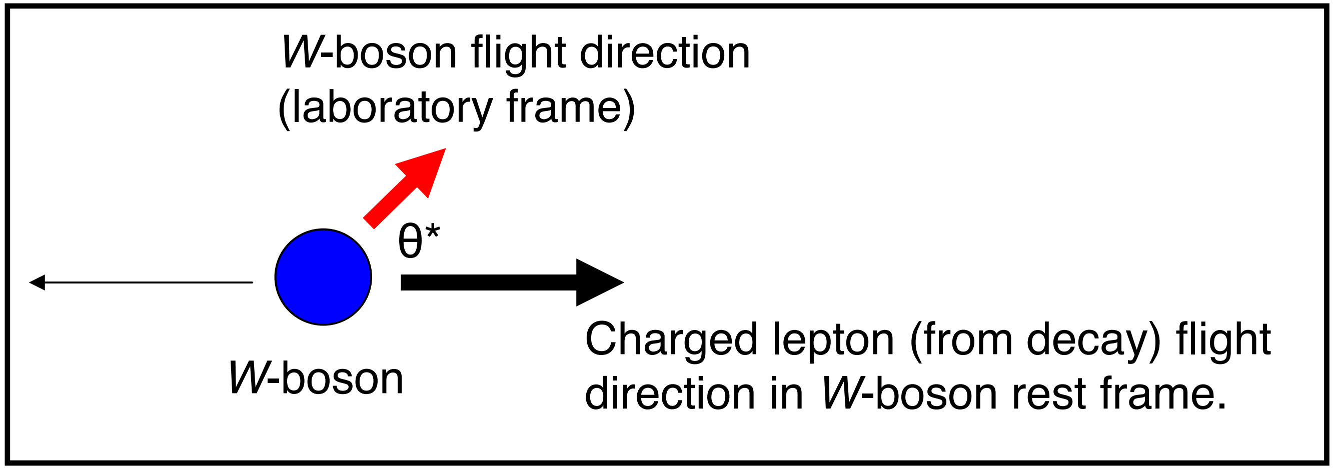
However, for production of boosted W-bosons (i.e. with some P_T) and hence with additional gluons and quarks, at LO QCD:

$$\sigma \sim \left(1+\cos^2\theta\right)+\frac{1}{2}A_0\left(1-3\cos^2\theta\right)+A_1\sin 2\theta\cos\phi + \frac{1}{2}A_2\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi + A_4\cos\theta$$

A convenient frame to study these distributions is in the plane spanned by the beam and the boson direction (the Collins-Soper frame).

However experimentally the boson rest frame can provide a more physical parameterisation

Parameterising Polarisation



W-boson flight direction
(laboratory frame)

θ*

W-boson

Charged lepton (from decay) flight
direction in *W*-boson rest frame.

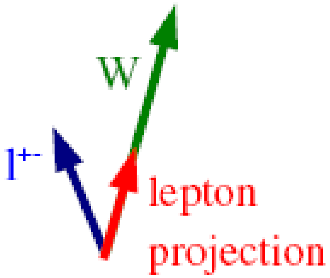
The cross-section can be parameterised as a function of left-handed (f_l), right-handed (f_r), and longitudinal (f_0) helicity components (as the W-boson is massive):

$$\sigma(\theta^*_{l+}) \sim f_l \frac{(1-\cos(\theta^*_{l+}))^2}{4} + f_0 \frac{\sin(\theta^*_{l+})^2}{2} + f_r \frac{(1+\cos(\theta^*_{l+}))^2}{4}$$

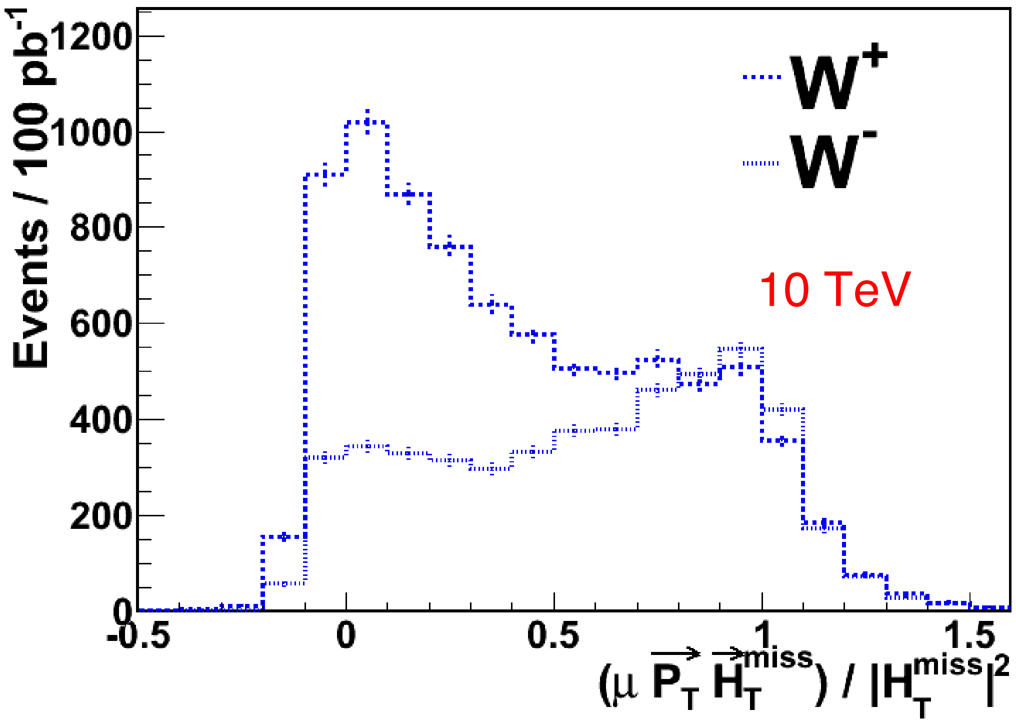
$$\sigma(\theta^*_{l-}) \sim f_l \frac{(1+\cos(\theta^*_{l-}))^2}{4} + f_0 \frac{\sin(\theta^*_{l-})^2}{2} + f_r \frac{(1-\cos(\theta^*_{l-}))^2}{4}$$

Aim to measure both sets of components at the LHC

Lepton Projection variable



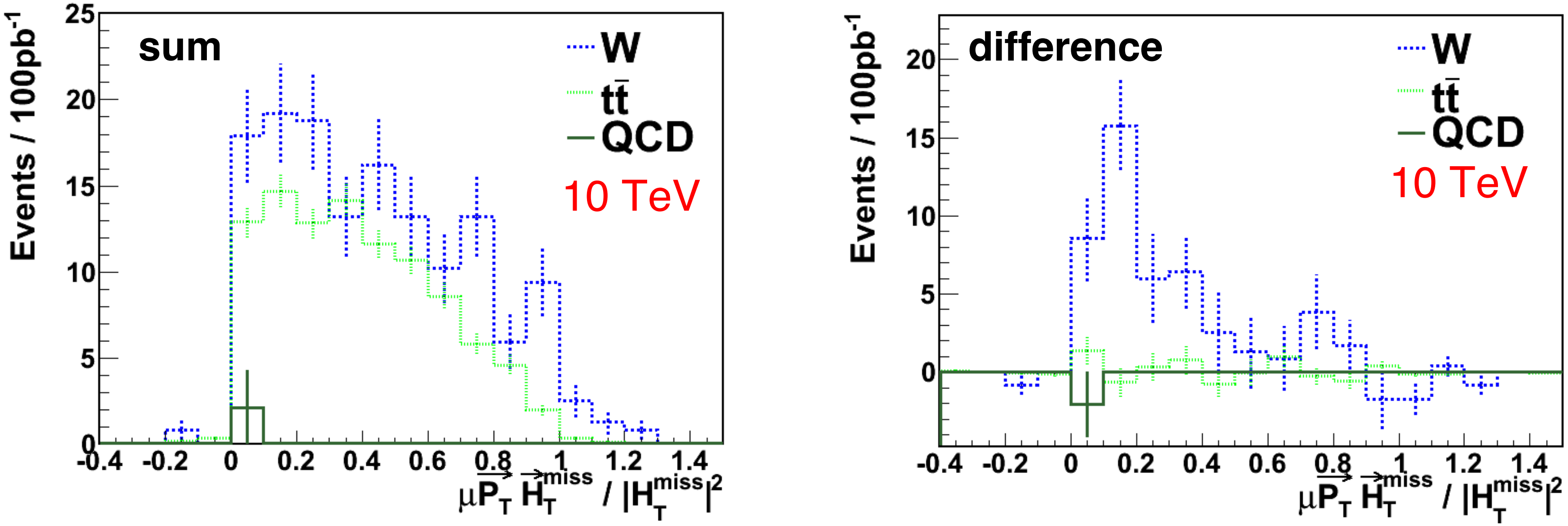
The LPV is defined as the projection of the charged lepton Pt (from the *W*-boson decay) onto the normalised W-boson Pt



1. Similar behaviour to cos(θ*)
2. *W*-boson recoils jets – can replace with H_T^{miss}
3. Values outside (0,1) due to mass effects
4. Can make unambiguously with detector quantities

Measuring ttbar:W

Select a sample rich with W+jets and ttbar+jets events and use this to estimate individual contributions



Notice the similar shapes when both muon charges are combined, and the expected zero difference for ttbar when subtracted

Measuring ttbar:W

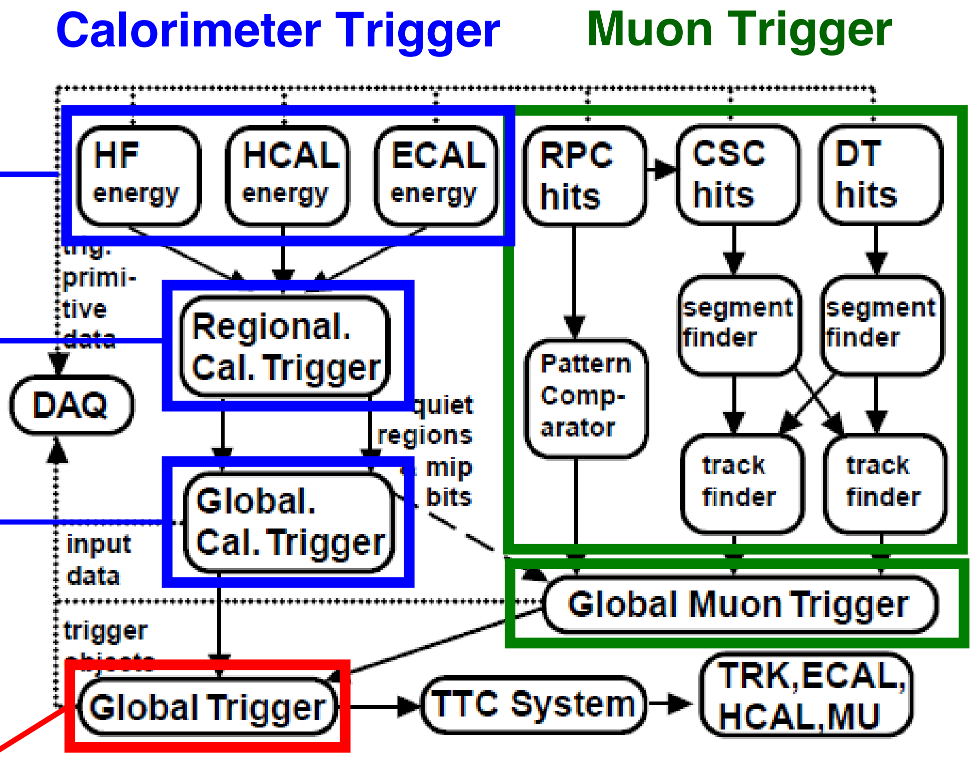
- Use the ratio r = N+/N- from generator level (1.93 +/- 0.17). (This number excludes muon reconstruction efficiency and resolution effects)
- Multiply (r+1)/(r-1) with N(+) – N(-) at reconstruction level to estimate the total *W*+jets contribution (this will include any asymmetries from SM processes)
- The difference between this estimate and N(+) + N(-) is the ttbar estimate
- Shown are the results of applying such a procedure:

datasets	predicted number of events	measured number of events
W+jets	130 ± 24	143 ± 7.8
$t\bar{t}$	115 ± 24	99 ± 2.5

- Overall such helicity and charge asymmetry effects will allow many opportunities to test various aspects of a *W*+jets and ttbar sample selection

The CMS Level 1 Trigger

Reduces the event rate from 40MHz to 100kHz
A Level 1 Accept (L1A) decision must come within 3.6μs



Trigger tower energy sums formed by ECAL, HCAL and HF

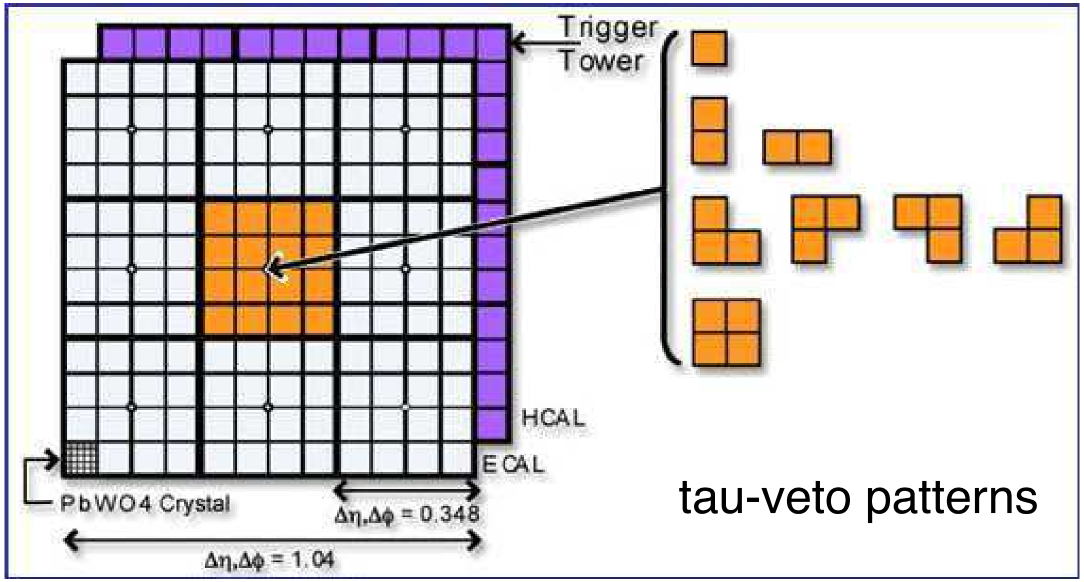
RCT finds e/γ candidates and combines E_T sums into calorimeter regions

GCT sorts e/γ candidates, finds and sorts jets and tau candidates, and calculates total and missing E_T

The **L1A decision** is transmitted by the Global Trigger via the Trigger Timing and Control (TTC) to all sub-detectors.

The CMS Level 1 Jet Trigger

Level 1 Jets are found in 600ns based on a 3x3 sliding window of calorimeter regions. The input data rate is ~300Gb/s



tau-veto patterns

If the E_T of the central region is larger than its 8 neighbours, a jet candidate is formed at that region, with the energies of the 9 regions summed into it.

The jet type (tau, central, forward) is identified based on physical location, and on the existence of tau-veto bits, which are set based on the energy deposition patterns shown in the figure.

The Level 1 H_T^{miss} trigger

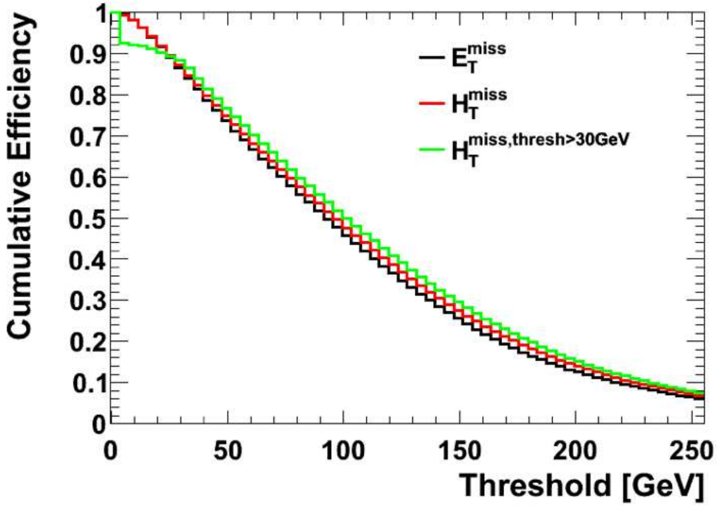
What is H_T^{miss}?

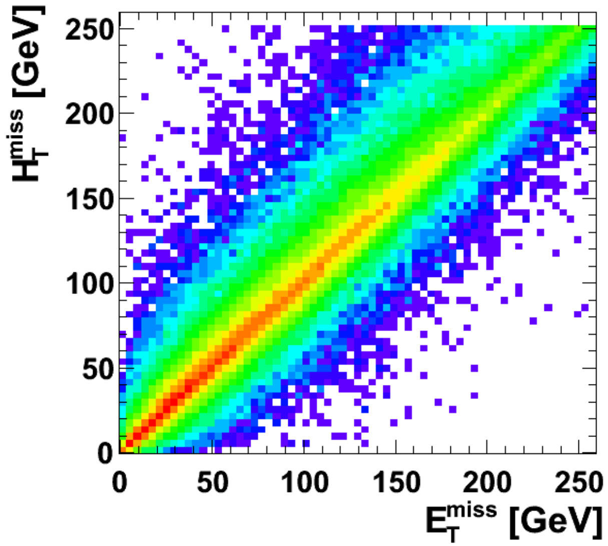
H_T^{miss} and E_T^{miss} are extremely similar in their calculation; the former uses clustered jets, whilst the latter uses calorimeter E_T deposits.

Why H_T^{miss}?

Effects such as detector noise, pile-up, hot channels etc will affect missing energy calculations. H_T^{miss} provides a configurable jet threshold which may make it a more robust trigger in the search for new physics. Studies at Level 1 show performance of these triggers is very similar

H_T^{miss} useful for many analyses e.g. using a SuperSymmetry Monte Carlo sample, high efficiency can be kept with an $E_T > 30$ GeV jet cut





Conclusions

- The LHC environment makes studies of *W*-boson polarisation unique.

- *W*-boson polarisation and charge asymmetry effects shown in this talk can be utilised for several purposes, namely background estimations and new physics discoveries.

- A Level 1 H_T^{miss} trigger has been developed and will be useful to many physics analyses, as a potentially more robust trigger than its E_T^{miss} counterpart.