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Precision measurement of W mass at LHC

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The W mass allows for a precise cross check of the Standard Model (SM), and its uncertainty is the limiting factor for sensitivity to the SM Higgs mass and what may lie beyond. A precise W mass measurement is feasible at the LHC due to large number of events, not only for W decays, but also corresponding Z decays, which will be the key ingredients for precision calibration and understanding of systematic errors. Using statistics corresponding to 10 fb^{-1} of data at the LHC, we have investigated strategies for improving the uncertainty on the mass measurement beyond 15 MeV, including both theoretical and experimental effects. No single source of uncertainty necessarily contribute more than 5 MeV to the overall uncertainty.

1. Introduction and Motivation

In the Standard Model (SM), the W mass can be predicted very precisely. At tree level, only three input parameters are required, usually taken to be the very precisely measured α_{QED}, G_μ, and m_Z. Beyond tree level, other parameters are involved, most notably the square of the top quark mass and the logarithm of the SM Higgs mass. These can in turn can be predicted from measurements of the W mass, and given the top quark mass, this becomes an indirect measurement of the SM Higgs boson mass. However, given the weak Higgs mass dependence, a very accurate W mass measurement is required to reach any meaningful precision.

Currently, the W boson and top quark masses are measured to be $m_W = 80.425 \pm 0.025$ GeV [1] and $m_t = 170.9 \pm 1.8$ GeV [2]. Given these measurements, the Higgs mass is predicted to be $m_H = 76^{+33}_{-24}$ GeV [3]. The uncertainty comes from propagating the uncertainty in the input parameters, and the largest source of error is from the W mass measurement.

At the ATLAS and CMS experiments, the large statistics and the good detector capabilities will provide a good opportunity to increase the precision. We have investigated these possibilities, and designed analyses to measure the W mass with the greatest possible precision during the first year(s) of low luminosity running.

2. Analysis overview

At hadron colliders only the leptonic decay of single vector bosons can be reconstructed. However, the large W cross section assures ample statistics in the leptonic decay channels ($W \rightarrow e\nu, \mu\nu$), and the statistical error is almost negligible. The systematic errors are controlled by using the Z boson decays, which apart from a known phase space difference, are very alike to the W boson decays. The cross section multiplied by the leptonic branching fractions of the Z are an order of magnitude smaller than that of the W, but still very significant, see Table 1.

Channel	$We\nu$	$W\mu\nu$	Zee	$Z\mu\mu$
Xsec (nb)	190.1	190.1	55.4	55.4
Bf (%)	10.72	10.57	3.363	3.366
Acc. (%)	37.6	44.3	64.5	74.9
Eff. (%)	60.0	70.0	36.0	49.0
Stat. (10^6)	46.0	62.3	4.3	6.8
$\sigma(m)$ (MeV)	5.1	4.5	2.3	1.9

Table 1
Cross sections [4] (Xsec), branching fractions (Bf) [1], acceptances (Acc.), reconstruction efficiency (Eff.), resulting statistics for 10 fb^{-1} of data (Stat.), and statistical error on mass fit ($\sigma(m)$) for leptonic decays of W and Z bosons.

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Since both the Z mass and width are measured with a precision of 2 MeV, it is ideal for calibration. First, the energy/momentum scale and resolution can be established, not only at the Z peak, but also as a function of energy, by using the energy distribution of the decay leptons (caused by the non-zero p_t of the Z). Next, the p_t distribution of the Z can be determined, and the recoil scale thus set, which together with the lepton momentum scale yields the missing transverse energy (MET) scale. Finally, the Z provides a mean to measure the lepton efficiency, by triggering on one lepton, and then investigating, if the other passed the trigger and identification cuts ("tag and probe" method).

As the Z boson provides the mass scale, one is effectively measuring m_W/m_Z. This is a convenient necessity, as one is then only sensitive to effects, which affect W and Z bosons differently. In this way, many theoretical as well as experimental effects diminish or completely cancel.

A sample of leptonic W boson decays is obtained with the following selection:

- High p_t isolated lepton, $p_t > 25$ GeV.
- Missing transverse energy, $\not{E}_T > 25$ GeV.
- Hadronic recoil, $u < 20$ GeV.
- No high p_t jets, $p_t(jet) < 30$ GeV.

These cuts ensure a clean lepton with neutrino signature with no other hard processes, reducing smearing of p_t^l edge. The event selection for the Z bosons is similar, except for an extra lepton instead of a neutrino.

Unlike Z bosons, W bosons can not be fully reconstructed, due to the lacking knowledge of the longitudinal neutrino momentum. The observables most sensitive W mass are the Jacobian edges of the following distributions:

- The lepton transverse momentum, p_t^ℓ.
- The transverse W mass, $M_T^W \equiv \sqrt{2p_T^l p_T^\nu(1-\cos(\phi^l-\phi^\nu))}$.

The distribution of these (correlated) variables can be seen in figure 1. The M_T^W resolution is limited by the MET resolution, while the p_t^ℓ sensitivity is limited by the non-zero p_t^W, which in turn also relies on the MET.

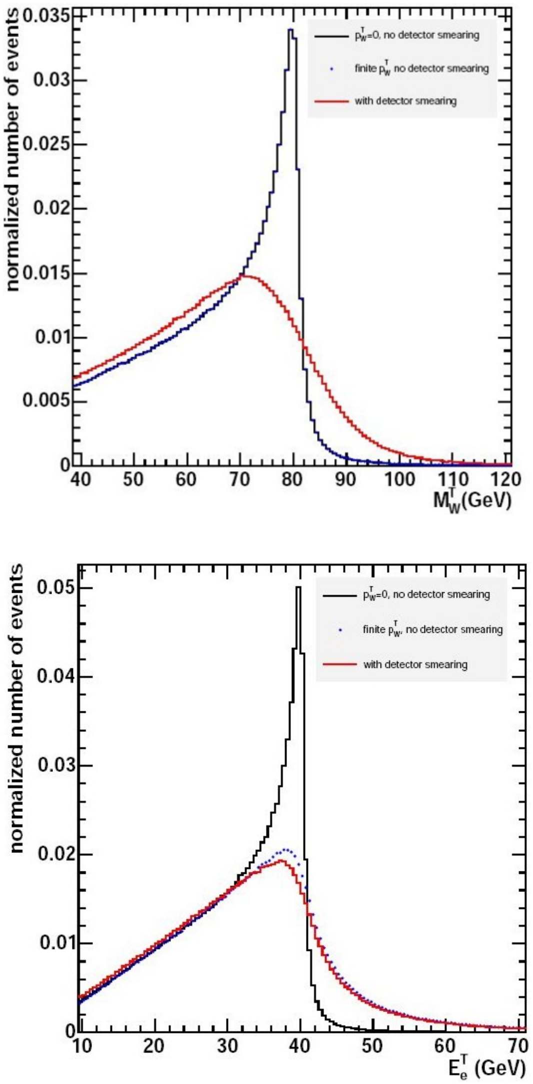

Figure 1. Distribution of M_T^W (top) and p_t^ℓ (bottom) before and after detector resolution and non-zero p_t^W (figure from [5]).