PROCEEDINGS OF SCIENCE

Inclusive vector boson measurements at CMS

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Recent results are presented of inclusive W and Z boson production measurements obtained using CMS proton-proton collision data at 13 TeV. The results include total cross sections and decay properties of W and Z bosons. Recent differential results on Drell-Yan dilepton production in a wide range of invariant masses are also included.

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1. Introduction

The large amount of proton-proton collision data collected by the CMS experiment [1] in 2016 at a center-of-mass energy $\sqrt{s} = 13\,\text{TeV}$, corresponding to an integrated luminosity of $36.3\,\text{fb}^{-1}$, allow precision measurements of Standard Model processes. In particular, the combination of the large number of recorded events in which an electroweak vector boson (W or Z/γ^*) was produced and the excellent performance of the detector allows detailed studies of the properties and production modes of the vector bosons. This is probed in CMS by an extensive physics programme; the present report focuses on the latest results related to the branching fractions of the W boson and cross section measurements for the Drell-Yan process.

2. Measurement of the branching fractions of the W boson

The CMS Collaboration has performed a measurement of the branching fractions of the W boson [2]: $\mathcal{B}(\text{W} \to \ell\bar{\nu})$ for $\ell = \text{e}, \mu, \tau$ and $\mathcal{B}(\text{W} \to \text{hadrons})$. The analysis mainly uses events with two W bosons, with at least one of them decaying leptonically. The main process in which two W bosons are produced is the decay of pairs of top quarks, which are further selected by categorizing events in the number of jets and b-tagged jets. In addition, the events are categorized based on the presence of a second electron or muon, or identified τ lepton decaying hadronically. A total of 32 event categories are defined, six of which are used to constrain the tagging efficiency for hadronic τ decays from $\text{Z} \to \tau(\to \ell\nu\nu_\tau)\,\tau(\to \text{hadrons})$ events.

In each event category, a differential distribution in the transverse momentum p_T of one of the particles is considered. This allows a separation between W boson decays to electrons or muons and W boson decays to τ, with the τ lepton decaying leptonically: due to the presence of two additional neutrinos, τ events appear at smaller p_T. Four such distributions are shown in figure 1, illustrating the main processes contributing to the signal regions as well as the separation power of the differential distributions.

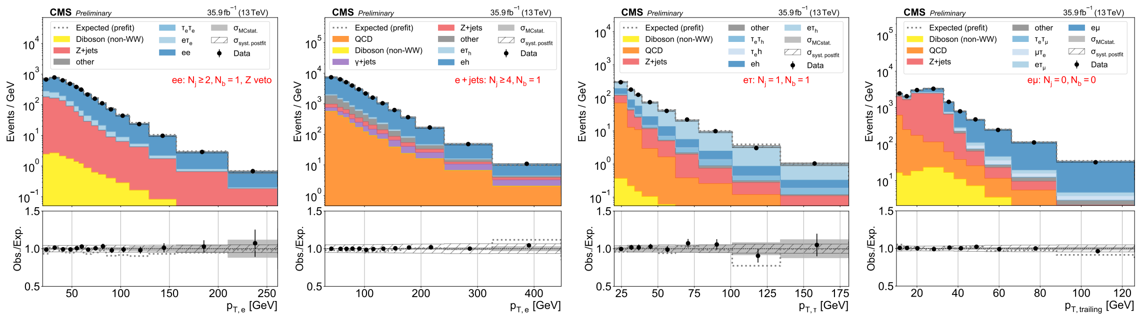

Figure 1: Transverse momentum distributions used in four of the categories. From left to right: ee events with at least two jets and exactly one b-tagged jet, e + jets events with at least four jets and exactly one b-tagged jet, eτ events with exactly one b-tagged jet, and eμ events without jets [2].

The branching fractions are extracted using a simultaneous binned likelihood fit to the distributions in all categories. The efficiency for the reconstruction of hadronic τ decays is included in the fit as a set of free parameters and constrained from data. The fit is performed twice, once with the three leptonic branching fractions $\mathcal{B}(\mathrm{W} \to \ell\bar{\nu})$ allowed to vary independently and once with the additional constrain that they must be identical ("lepton flavor universality"). The results of the fit are shown in figure 2, where it is also compared to combination of the four LEP experiments [3]. The measured values are compatible between the channels, supporting lepton flavor universality. For the electron and muon decay channels, they are also more precise than the LEP average.

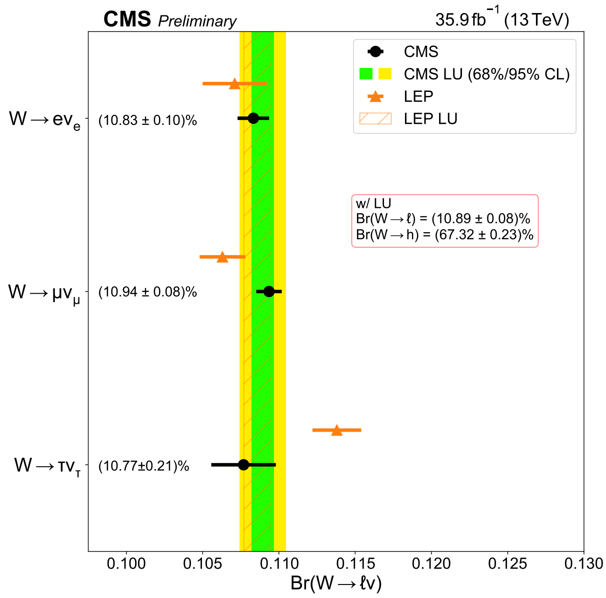

Figure 2: Measured branching fractions of the W boson to leptons [2].

By measuring $\mathcal{B}(\mathrm{W} \to \mathrm{hadrons})$, the analysis is also sensitive to elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. In particular, the square sum of the first two rows of the CKM matrix is found to be $\sum_{ij} |V_{ij}|^2 = 1.989 \pm 0.021$ (under the assumption of lepton flavor universality). This can in turn be used to obtain $|V_{\mathrm{cs}}|$ by using the measured values of the other elements, which yields a value of $|V_{\mathrm{cs}}| = 0.969 \pm 0.011$ as precise as the current world average obtained from D meson decays.

3. Drell-Yan p_{T} over a wide mass range

The production of a virtual Z/γ^* boson decaying to a pair of charged leptons, or Drell-Yan process, is of particular interest to study the dynamics of quarks in the initial state. Indeed, the transverse momentum $p_{\mathrm{T}}(\ell\ell)$ of the produced lepton pair is sensitive to the emission of gluons by the interacting quarks. By measuring differential cross sections with respect to p_{T} in several windows in the dilepton invariant mass $m_{\ell\ell}$, the analysis of Ref. [4] probe the scale dependence of initial-state radiation.

The analysis combines measurements in the dielectron and dimuon channels, with lepton $p_{\mathrm{T}} > 25$ and 20 GeV for the leading and subleading lepton, respectively. This selection leads to a high-purity sample of Drell-Yan events, as shown in Fig. 3. The remaining background processes are estimated using Monte-Carlo simulations, except for a minor one.

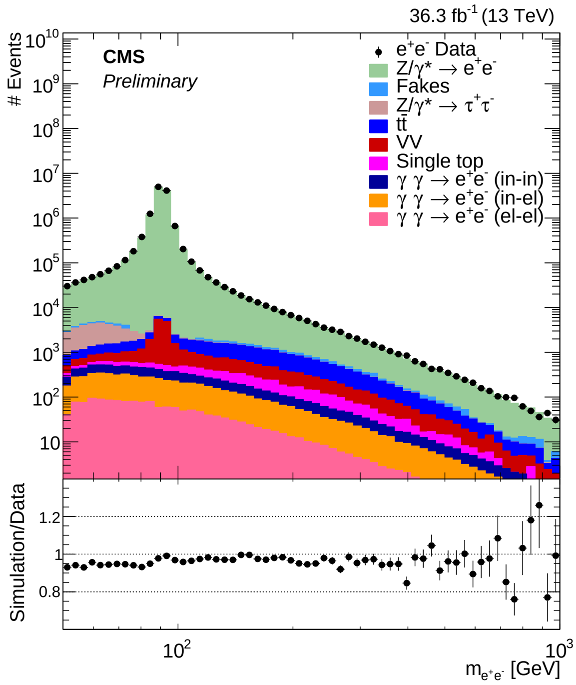

Figure 3: Invariant mass distribution of electron pairs from 50 to 1000 GeV [4].

The measurement of the cross section differential in $p_{\mathrm{T}}(\ell\ell)$ is performed in five $m_{\ell\ell}$ windows: between 50 and 76 GeV, between 76 and 106 GeV, between 106 and 170 GeV, between 170 and 350 GeV, and between 350 and 1000 GeV. The observed distributions are corrected for detector effects by unfolding them to the generator level phase space described in Ref. [4]. They are shown in figure 4, where they are also compared to predictions using four different approaches for the description of soft gluon emissions:

- A Monte-Carlo sample representative of the setup commonly used by LHC experiments to predict the Drell-Yan process (in blue).
- Two predictions using transverse-momentum-dependent (TMD) parton density functions (in green and red).
- A prediction at next-to-next-to-leading order (NNLO) with next-to-next-to-leading logarithm resummation in the event thrust.

When comparing the measurement and the predictions in the “traditional” approach (blue), one can see that the latter underestimates the cross section at low p_{T} and that the agreement degrades with larger invariant masses. In contrast, the two predictions using TMD distribution functions provide a consistently better description of the observed spectrum at low p_{T}.

The total uncertainty in the measured distributions is around 2% for the mass windows around the Z boson peak region, as is shown in Fig. 5. In this part of the phase space, the dominant contribution to the uncertainty arises from the measurement of the integrated luminosity. The

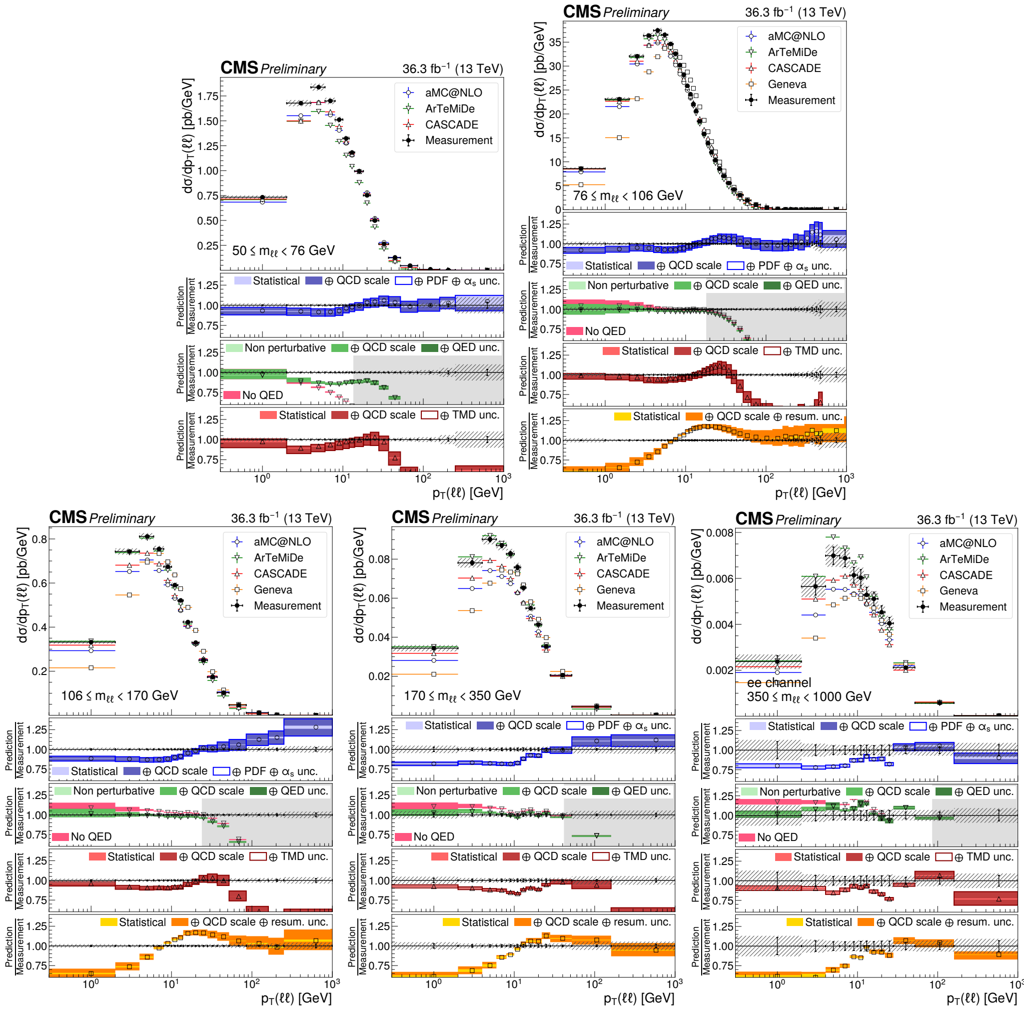

Figure 4: Measured differential cross sections in the transverse momentum of the lepton pairs, for five mass windows between 50 and 1000 GeV [4].

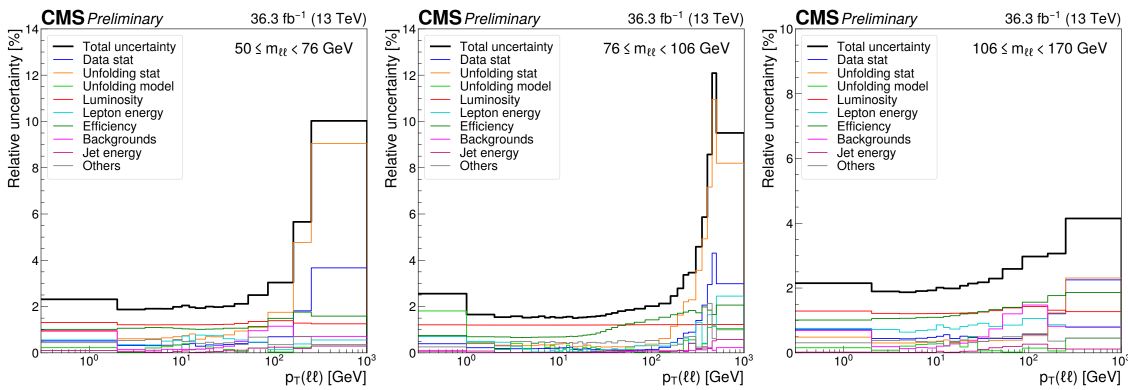

Figure 5: Uncertainty breakdown of the measured $p_T(\ell\ell)$ distributions in the lower three mass windows [4].

second largest uncertainty comes from the determination of the efficiency. The total uncertainty is larger for higher invariant masses, mainly because of the growing statistical uncertainty.

4. Drell-Yan p_{T} and rapidity in $\mathrm{Z}+1$ jet events

The rise of NNLO event generators matched to parton showers prompts the question of how well they perform for the description of the leading jets. Instead of measuring the jets directly, one can measure the kinematic distributions of Z/γ^* bosons in the presence of at least one high-p_{T} jet. The CMS Collaboration has measured single- and double-differential distributions in the rapidity, invariant mass and transverse momentum of Z/γ^* bosons [4, 5]. The results are shown in figures 6 and 7.

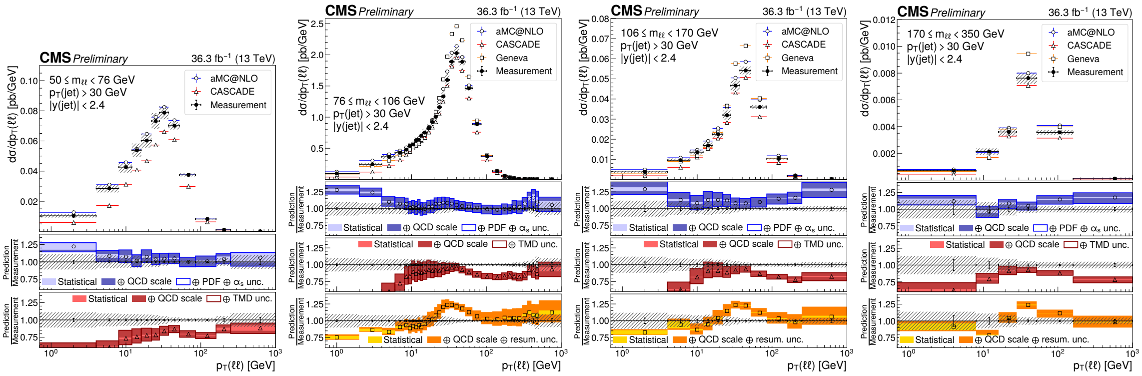

Figure 6: Measured differential cross sections in the transverse momentum of the lepton pairs, for four mass windows between 50 and 350 GeV [4].

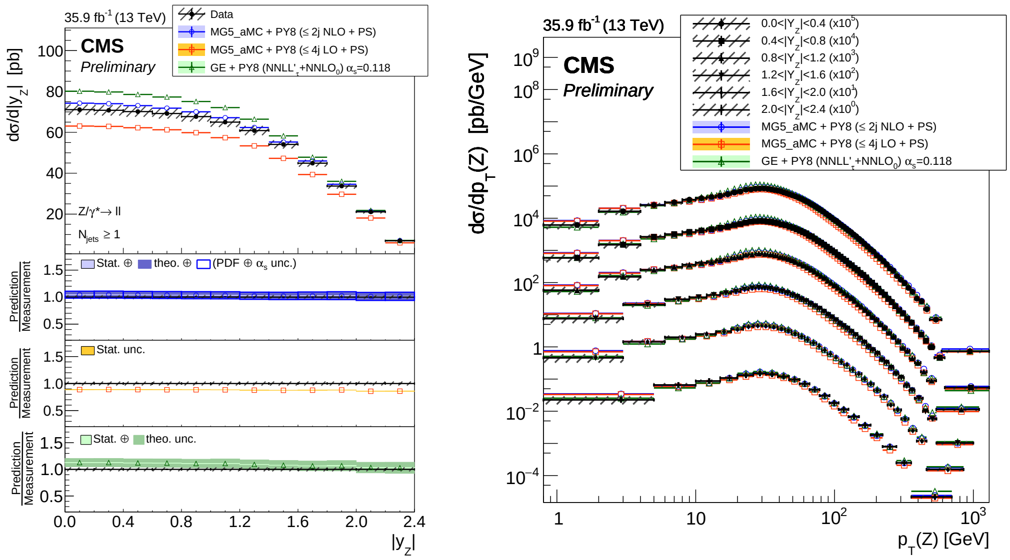

Figure 7: Differential cross sections in the rapidity (left) and the rapidity and transverse momentum (right) of the lepton pairs, for events with at least one jet [5].

5. Summary

Several precision measurements of vector boson production carried out by the CMS Collaboration at the LHC have been reported. Firstly, a measurement of the branching fractions of the W boson to electrons, muons, τ leptons, and hadrons was described, using top quark production as a "W factory". The results support lepton universality and are compatible with the Standard Model, with a precision competitive with the combination of the LEP results.

Secondly, a measurement of the transverse momentum of Drell-Yan lepton pairs was reported, that probes the kinematics of quarks in the initial state for scales of the hard process between 50 and 1000 GeV. An accuracy of 2% is achieved for masses around the Z peak, which provides stringent constrains for predictions. It is found that predictions including transverse momentum-dependent parton density functions provide a better description of the data for small transverse momenta.

Thirdly, measurements of the kinematics of Drell-Yan lepton pairs in events with at least one hard hadronic jet have been reported. Differential cross sections are available as a function of the rapidity of the pair, as well as as a function of its transverse momentum for different rapidity and invariant mass ranges. These results will be essential for the validation of new event generators at NNLO.

References

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