Measurement of the ratio of $Z/\gamma^* +$ jets to $\gamma +$ jets cross sections in pp collisions at $\sqrt{s}$ = 8 TeV

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Abstract

We present the ratio of the transverse momentum of Z/γ^* plus jets and γ plus jets in proton-proton collisions. We also present the measurement of the differential transverse momenta cross-sections separately. The data were collected with the CMS detector at $\sqrt{s} = 8$ TeV, corresponding to an integrated luminosity of 19.7 fb^{-1}. A precise measurement of the individual cross-sections allows for a stringent test of high multiplicity NLO perturbative QCD calculations from BlackHat and other multi-purpose Monte Carlo generators in several phase space selections. It also acts as a test to validate a commonly used method to estimate backgrounds arising from Z to invisible decays in BSM searches with CMS-collected data.

Event Selection

Leptons $p_T > 20$ GeV, $|\eta| < 2.4$
Z boson $p_T^Z > 40$ GeV [p_T^Z spectra], $p_T^Z > 100$ GeV [p_T^Z over p_T^γ ratio], $71 < m_{ll} < 111$ GeV for same flavor, opposite sign dileptons
Jets $p_T > 30$ GeV, $|\eta| < 2.4$, $\Delta R(j,l) \geq 0.5$, reject jets from pileup and $n_{jets} \geq 1$
Photons Isolated photons ($<$ 10 GeV within a cone of radius 0.3), $|y^\gamma| < 1.4$, $p_T^\gamma > 100$ GeV

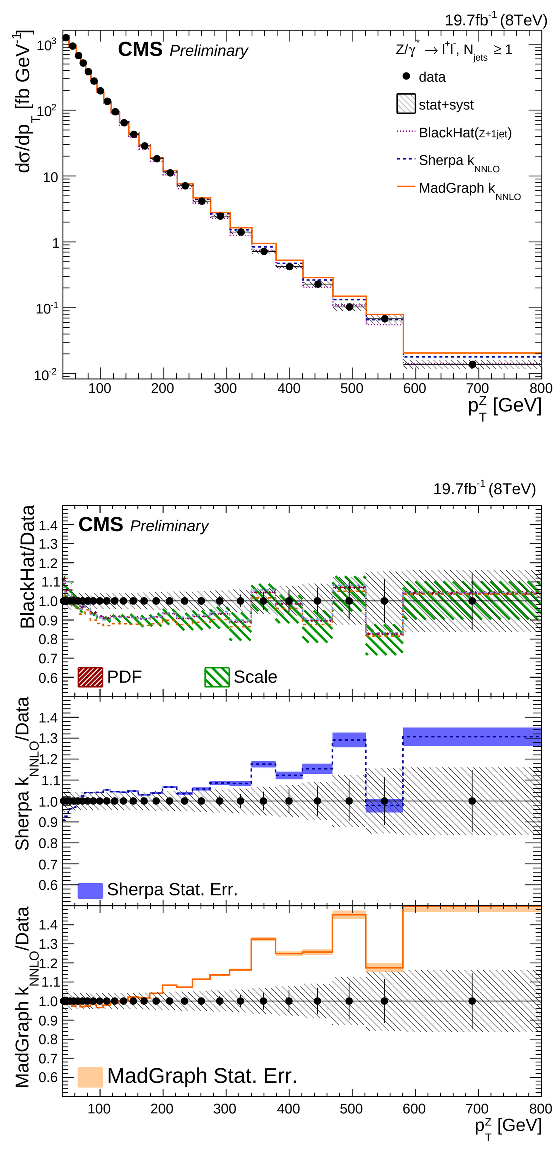
Systematics

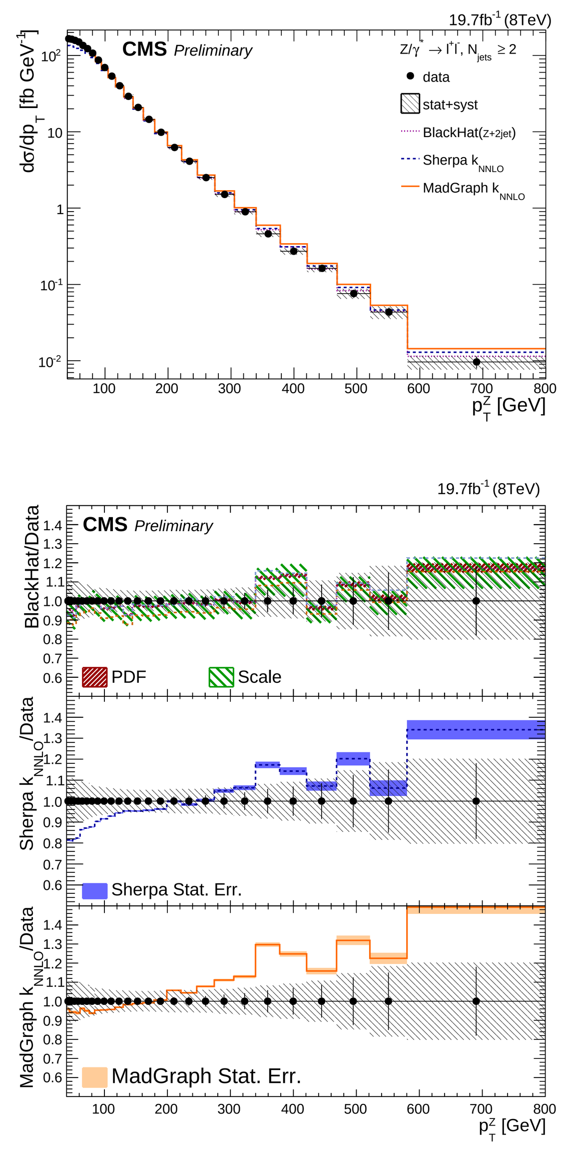
The largest systematic errors considered are:

- Jet Energy Scale - negligible for the $n_{jets} \geq 1$ selection, dominant at low p_T otherwise (up to 10%)
- Scale Factor Uncertainty - 3-5%, largest in $n_{jets} \geq 1$
- Luminosity Uncertainty - flat 2.6% effect

The remaining errors considered (Lepton Scale, Pileup, Background, Jet Energy Resolution, Lepton Resolution, and Unfolding) were minor, all separately less than 0.5%. The background-subtracted detector level distributions from data are unfolded to the particle level which accounts for detector resolution effects and efficiencies.

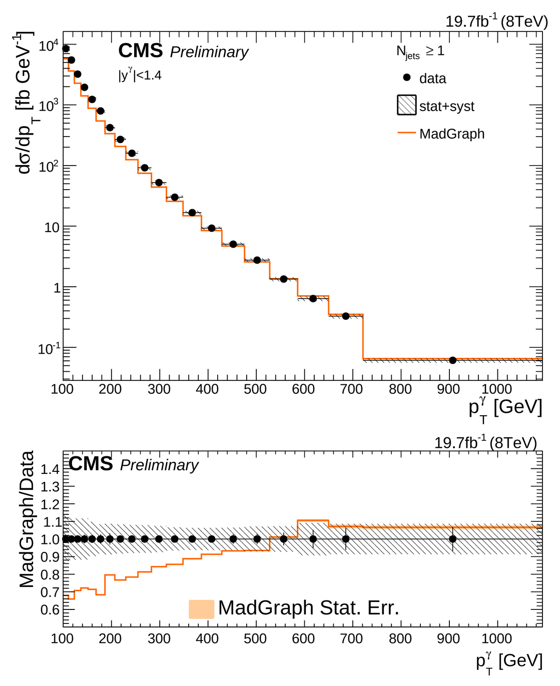
p_T^Z Spectrum, $n_{jets} \geq 1$, $n_{jets} \geq 2$

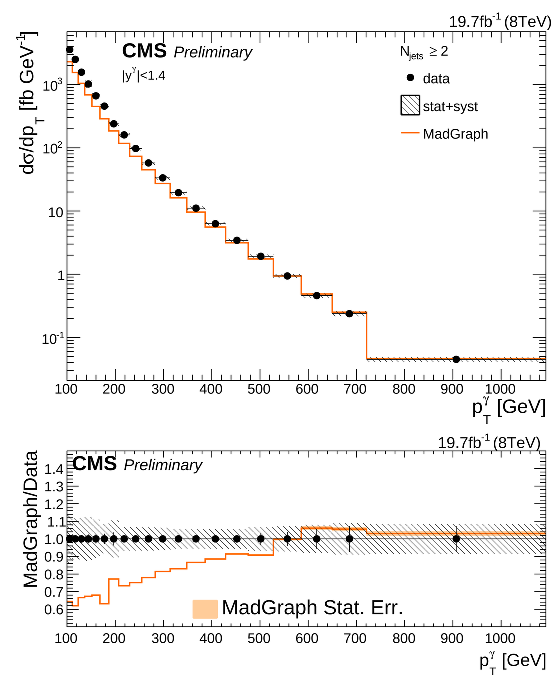




The p_T^Z spectrum in the $n_{jets} \geq 1$ selection (left) and the $n_{jets} \geq 2$ (right). MadGraph and Sherpa (scaled to NNLO) overestimate data in the high p_T^Z end in both jet selections. In the $n_{jets} \geq 1$ selection, BlackHat underestimates the cross section in the lower end tail but performs well in the $n_{jets} \geq 2$ selection.

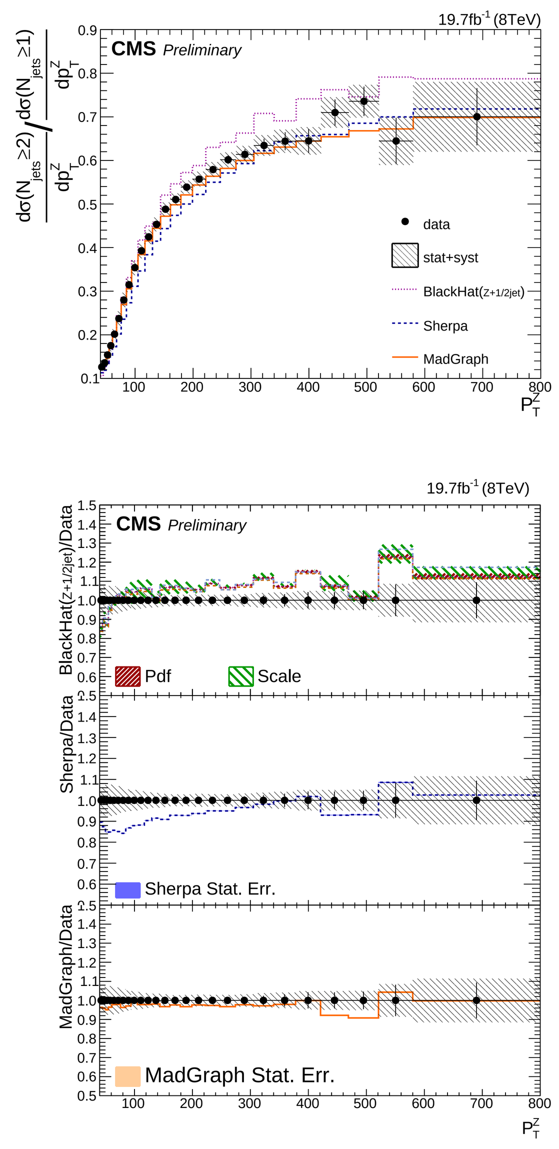
p_T^γ Spectrum, $n_{jets} \geq 1$, $n_{jets} \geq 2$

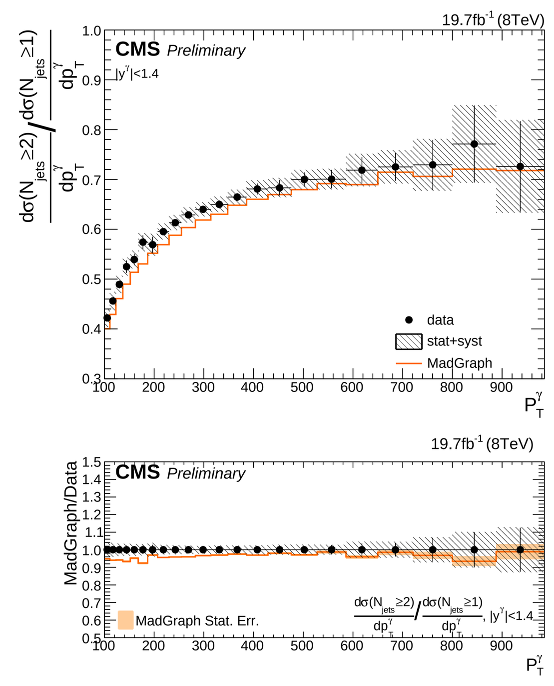




The p_T^γ spectrum in the $n_{jets} \geq 1$ selection (left) and the $n_{jets} \geq 2$ (right). MadGraph underestimates the rate at lower p_T^γ, but increases and matches the data in the higher end.

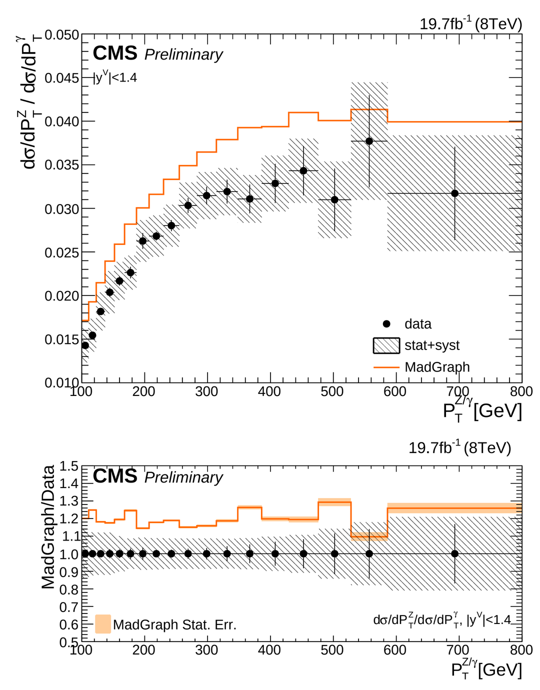
$n_{jets} \geq 2/1$ Cross Section Ratios for p_T^Z and p_T^γ

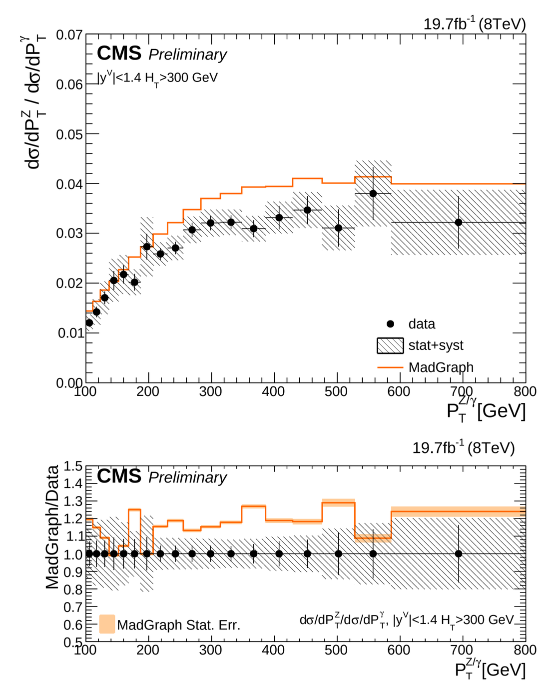




Cross section ratio of $n_{jets} \geq 2$ to $n_{jets} \geq 1$ in $Z/\gamma^* +$ jets (left) and $\gamma +$ jets (right). MadGraph reproduces the cross section ratio well in both $Z/\gamma^* +$ jets and $\gamma +$ jets cases. Sherpa underestimates the rate for low p_T^Z. BlackHat reproduces the shape well in the p_T^Z spectrum, but overestimates the rate by approximately 10%.

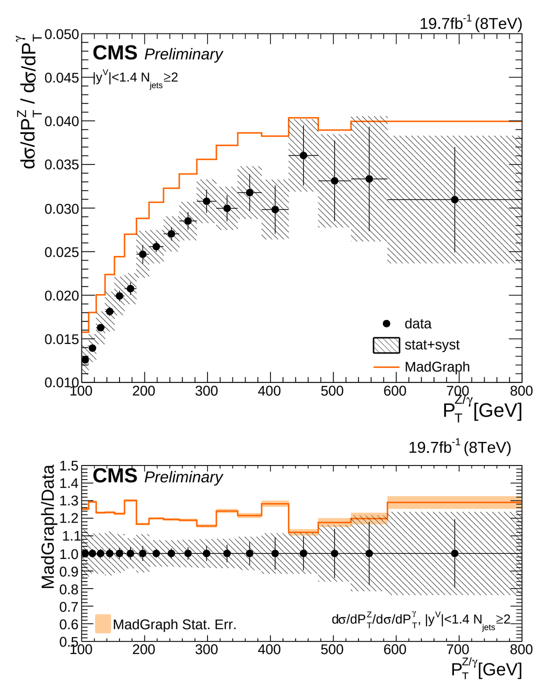
p_T^Z/p_T^γ Cross Section Ratios, $n_{jets} \geq 1$, $H_T > 300$ GeV

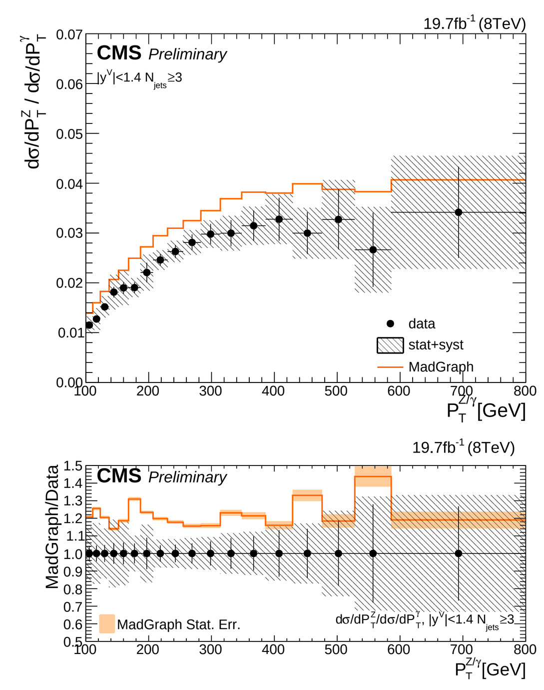




Cross section ratio of p_T^Z to p_T^γ in the $n_{jets} \geq 1$ case (left) and in the $H_T > 300$ GeV case (right). The rapidity range on the bosons is restricted to $|y^V| < 1.4$. MadGraph overestimates the rate by approximately 20% in both the $n_{jets} \geq 1$ case and in the $H_T > 300$ GeV case.

p_T^Z/p_T^γ Cross Section Ratios, $n_{jets} \geq 2$, $n_{jets} \geq 3$





Cross section ratio of p_T^Z to p_T^γ in the $n_{jets} \geq 2$ case (left) and in the $n_{jets} \geq 3$ case (right). The rapidity range on the bosons is restricted to $|y^V| < 1.4$. MadGraph again overestimates the rate by approximately 20% in both the $n_{jets} \geq 2$ case and in the $n_{jets} \geq 3$ case.

Conclusions

We find that the ratio of data to MC for $Z/\gamma^* +$ jets and $\gamma +$ jets is not well reproduced for LO ME+PS Monte Carlos. We observe a linear increase with increasing vector boson p_T for MadGraph+Pythia6 and Sherpa. At NLO (BlackHat), we find a reduction in the discrepancy in shape between data and MC for $Z/\gamma^* +$ jets, indicating that it is likely related to missing higher-order effects.
In all cases, we observe that the ratio of p_T^Z to p_T^γ saturates at $p_T \simeq 314$ GeV. This agrees with the LO predictions that state that the mass difference is the only distinction between the two processes. In the $n_{jets} \geq 1$ selection, the plateau is $R_{dilep} = \frac{\sigma_{Z\to l^+l^-}(p_T^Z > 314\text{ GeV})}{\sigma_\gamma(p_T^\gamma > 314\text{ GeV})} = 0.0322 \pm 0.0008(\text{stat}) \pm 0.0020(\text{syst})$. This translates into the ratio of $R_{tot} = 0.957 \pm 0.066$ when divided by the average leptonic branching fraction $(3.3658 \pm 0.0023\%)$.
MadGraph+Pythia6 predicts the ratio with a value of $R_{MG} = 0.0391$, which is higher than that observed in data by 21% $\pm$ 8% (stat+syst). Higher-order effects beyond LO are smaller than the experimental uncertainties.

References

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