Electroweak and QCD aspects in V+jets

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On behalf of the CMS collaboration

EPS HEP, Venice

05-12 July, 2017

Outline

Phys. Rev. D 95.052002

★ Differential cross section of W+jets — CMS SMP-16-005

JHEP04(2017)022

★ Differential cross section of Z+jets — CMS SMP-15-010

- Provides stringent tests of pQCD and corresponding MC simulations
- Important BG for many SM and BSM processes. It is therefore crucial to measure it with highest possible precision

★ Electroweak production of Z in association with 2 jets[NEW] — CMS SMP-16-018

- Study of EWK Z+jets processes is part of a more general investigation of SM VBF processes
- Study of additional hadronic activity in a signal-enriched sample provides tests of soft QCD modelling

W+jets, 13 TeV

W + jets : 8 TeV & 13 TeV

13 TeV

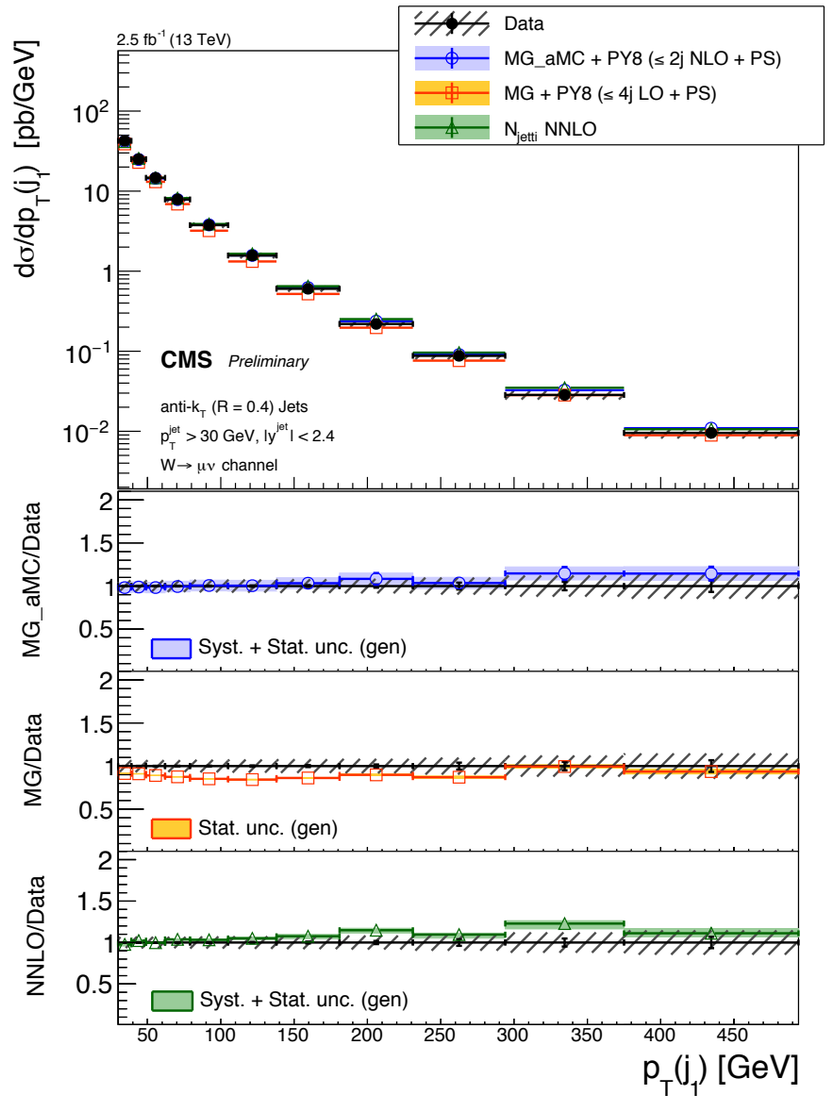
CMS SMP-16-005

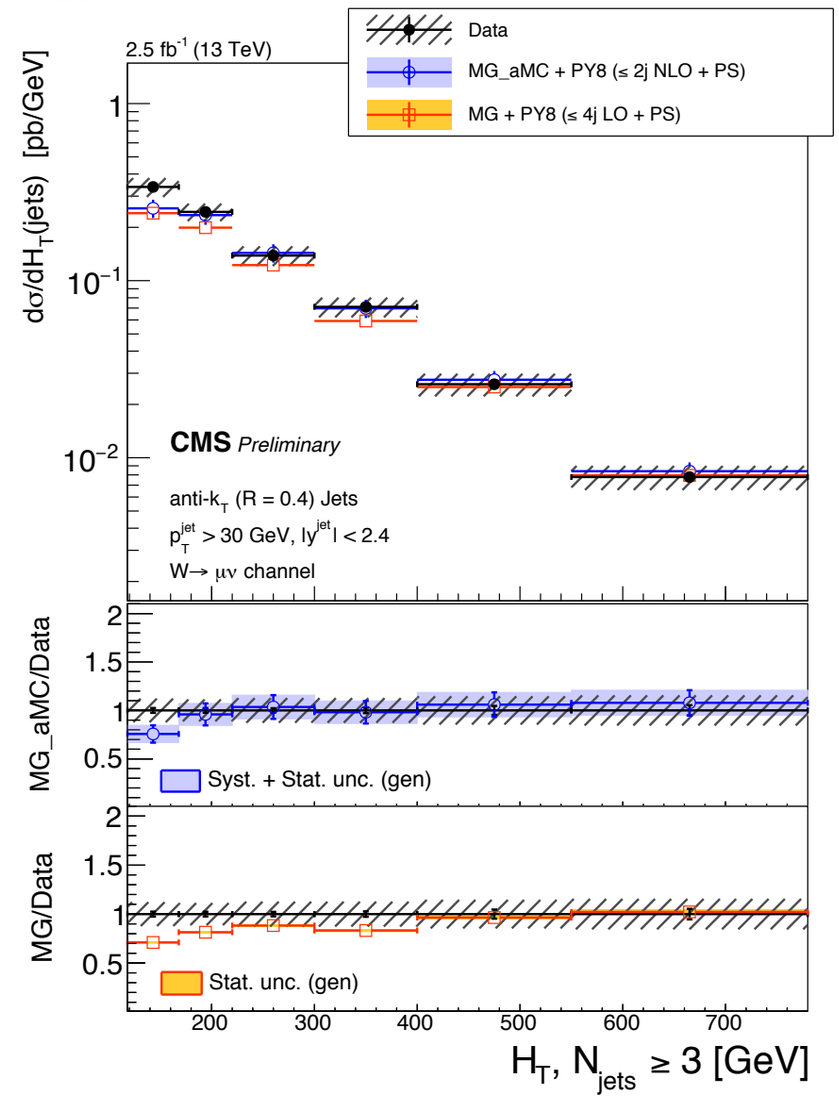
Event selection(8/13 TeV):

- 1 μ, $p_T > 25$ GeV
- $|\eta_\mu| < 2.4$
- $p_{T\,jet} > 30$ GeV
- $|y_{jet}| < 2.4$
- $\Delta R(\mu, jet) > 0.4$
- $M_T > 50$ GeV

BG:

- QCD - data-driven
- tt dominant BG, larger at high jet multiplicities
- Iterative d'Agostini unfolding





- Compared to predictions: LO(≤4j) and NLO(≤2j) MadGraph5_aMC@NLO; NNLO for one inclusive jet
- Measured : Excl./Incl. jet multiplicities, jet p_T, jet η, and H_T up to ≥ 3 jets
- Good agreement with predictions, but overall LO MaGgraph5_aMC@NLO slightly underestimates data on the observables

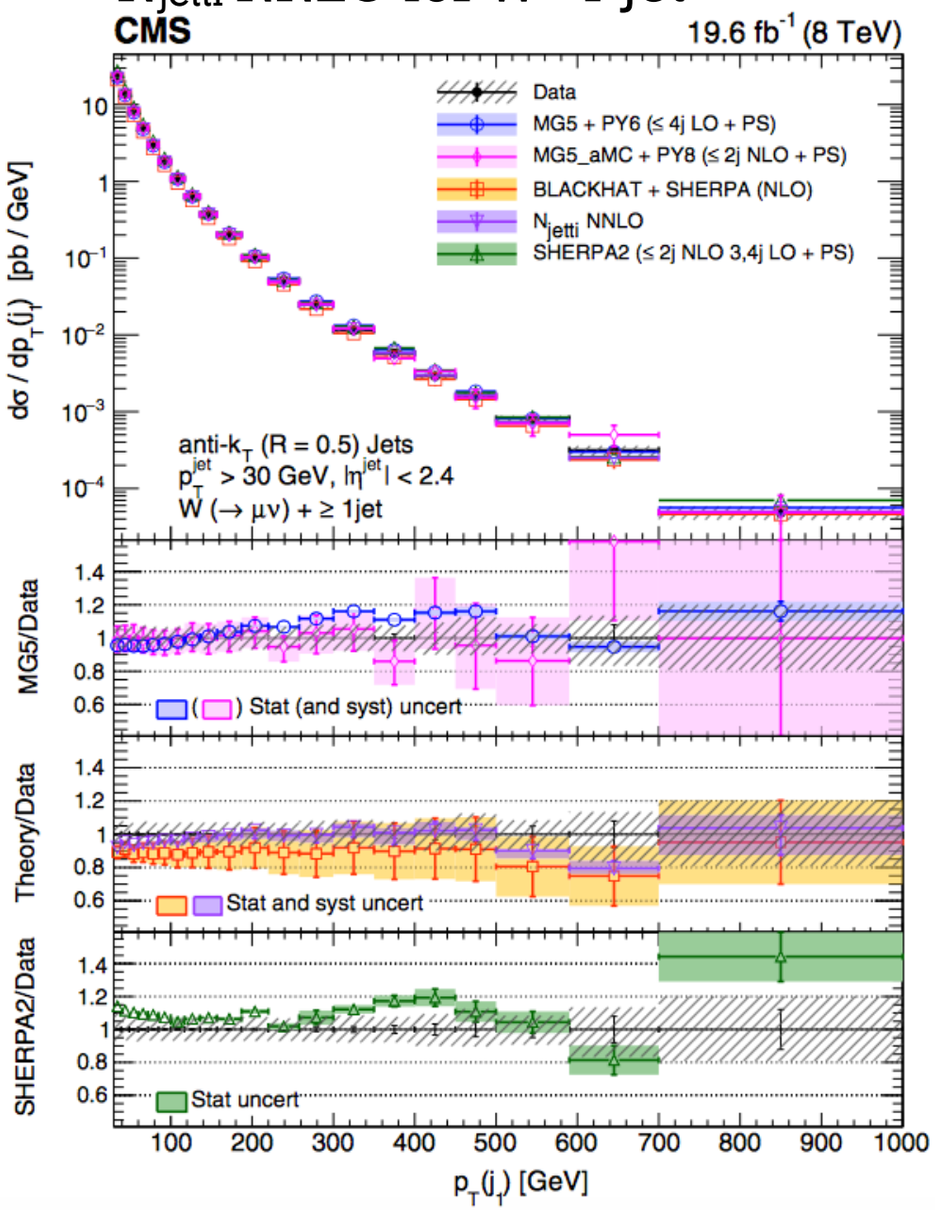
W+jets, 8 TeV

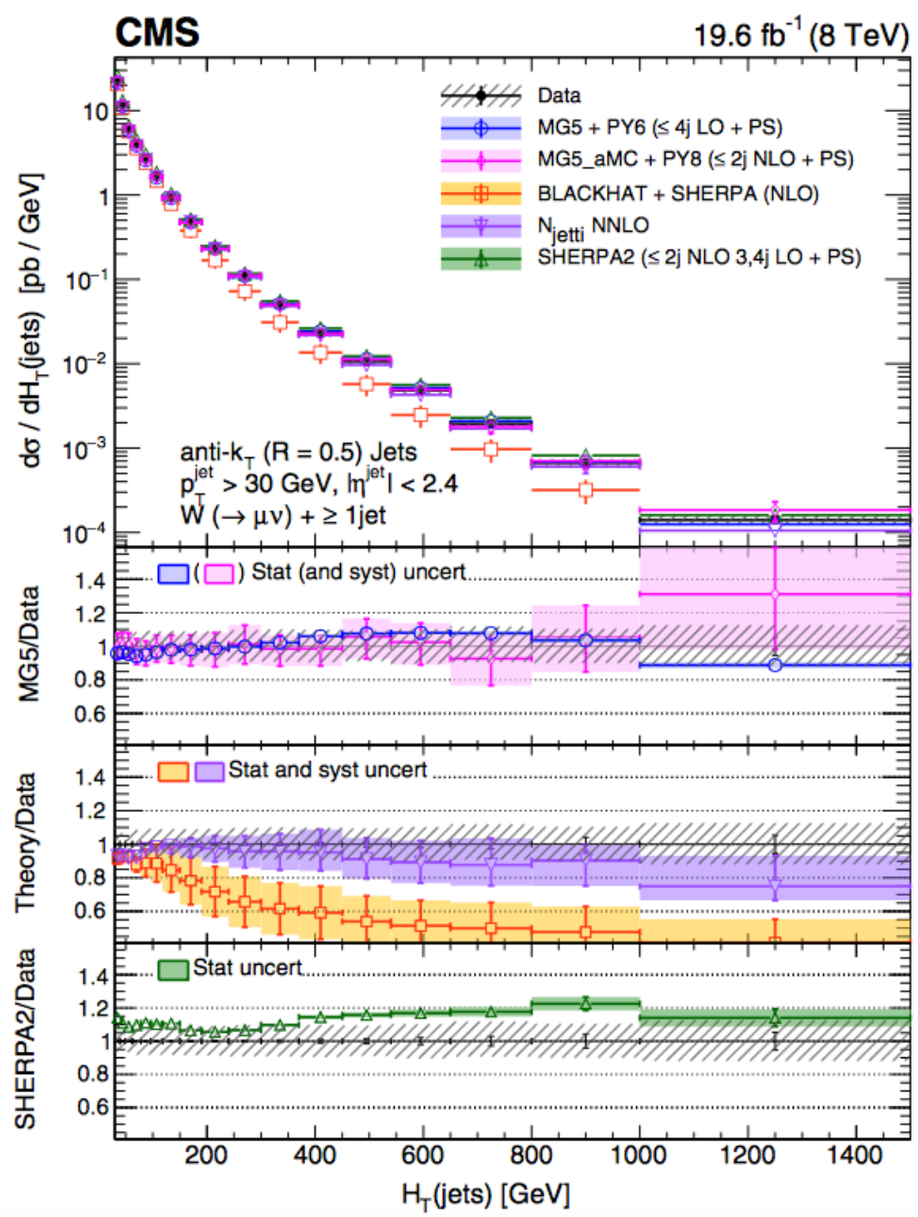
Data compared to :

- MadGraph5+Pythia6 kt MLM (LO <= 4 jets)
- MadGraph5_aMC@NLO+Pythia8 FxFx (NLO <= 2jets; 3 LO)
- Sherpa+Blackhat (v2) (NLO <= 2 jets, LO <= 4 jets)
- BlackHat fixed order at NLO
- N_{jetti} NNLO for W+1 jet

Phys. Rev. D 95.052002

8 TeV





- Good agreement with NLO 0, 1, 2 jets FxFx and NNLO 1 jet
- Sherpa 2 overestimate the cross section at high H_T

Z+jets, 13 TeV

Z + jets : 8 TeV & 13 TeV

13 TeV

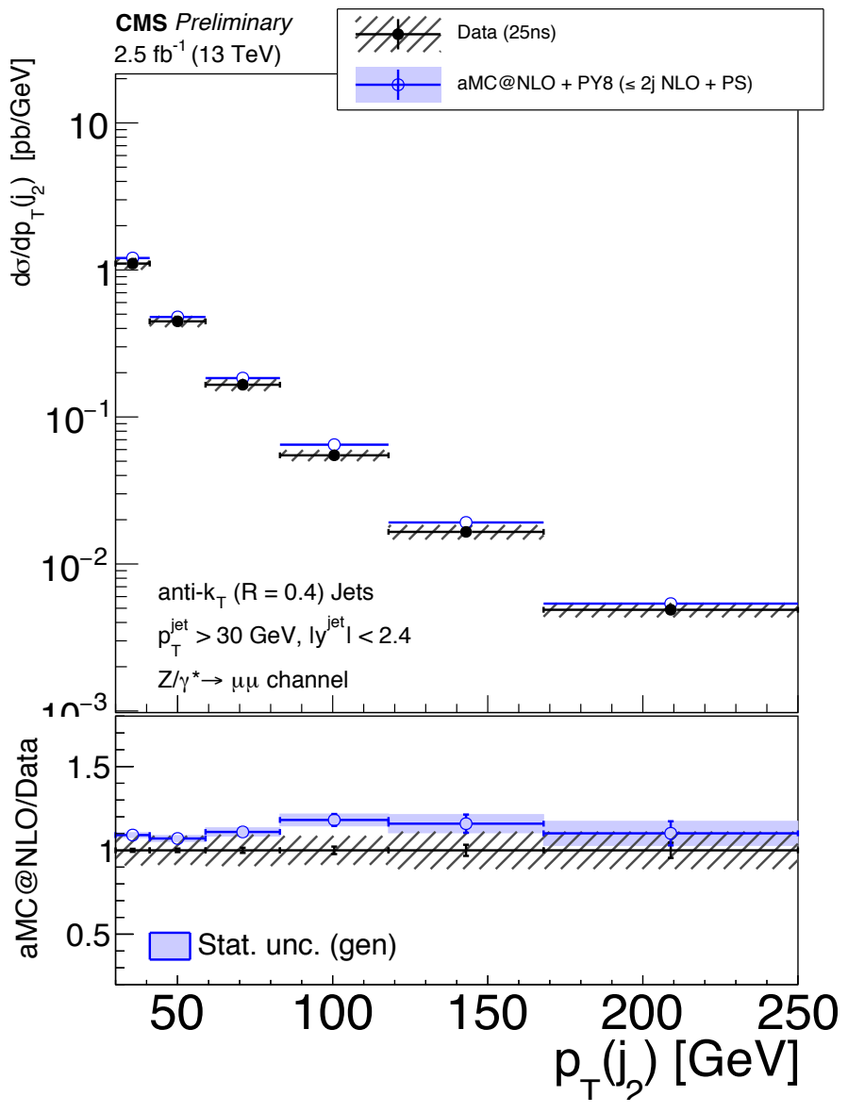
CMS SMP-15-010

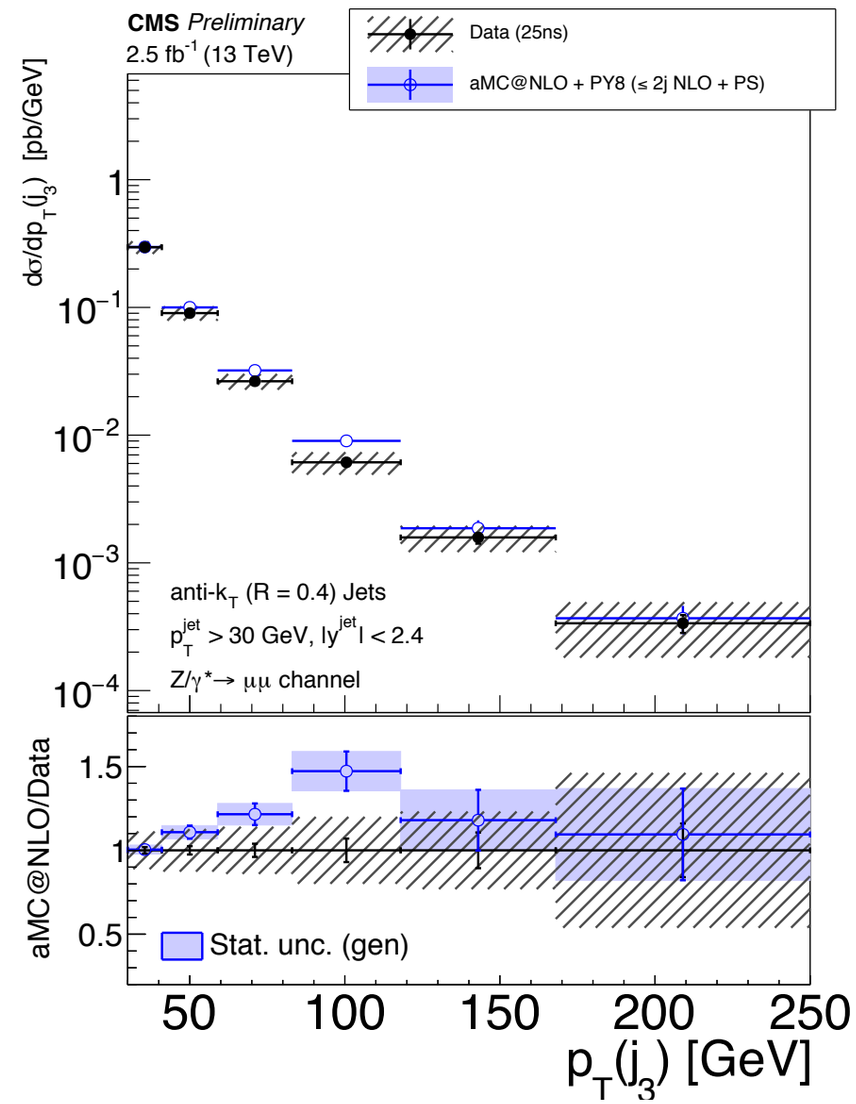
Event selection(8/13 TeV):

- 2 e/μ, p_T > 20 GeV
- $|\eta_l| < 2.4$
- $p_{T\,jet}$ > 30 GeV
- $|y_{jet}| < 2.4$
- ΔR(l, jet) > 0.4
- $|m_{ll}-m_Z| < 20$ GeV

BG:

- BG is estimated from MC
- tt dominant BG at large jet multiplicities(15%)
- Z->ττ subtracted
- Iterative Bayesian unfolding





- Compared to predictions : MadGraph5_aMC@NLO with NLO for 0, 1 and 2 jets
- Good agreement although the third jet p_T is decreasing more rapidly in simulation than data

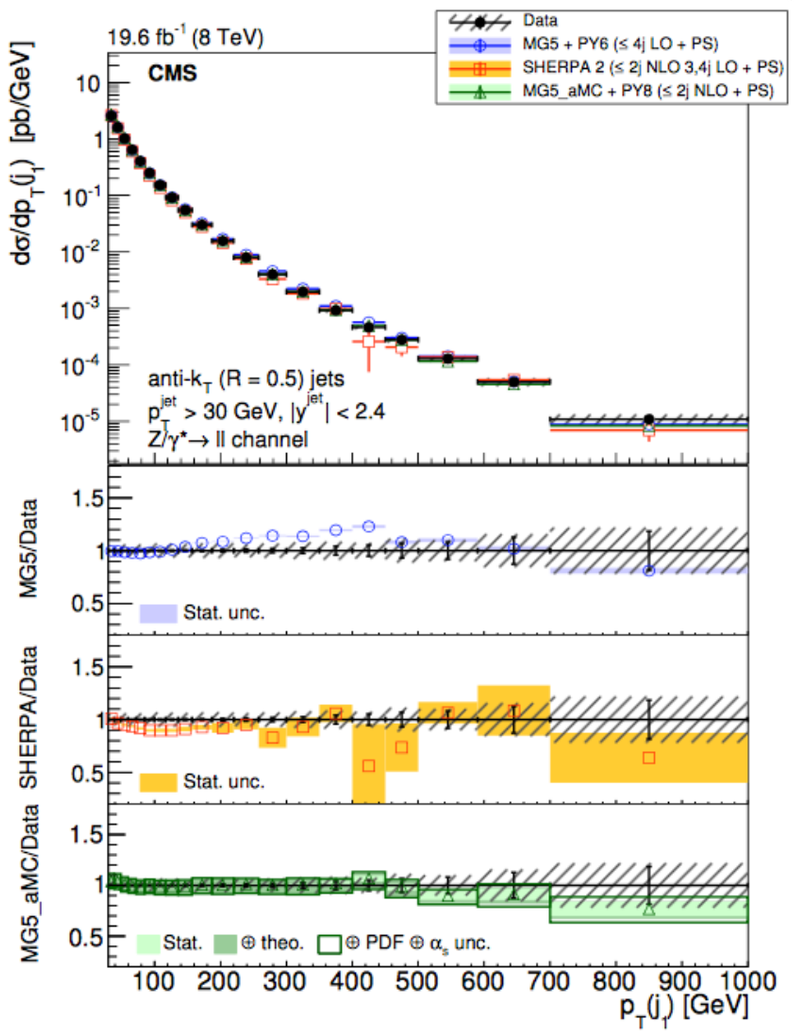
Z+jets, 8 TeV

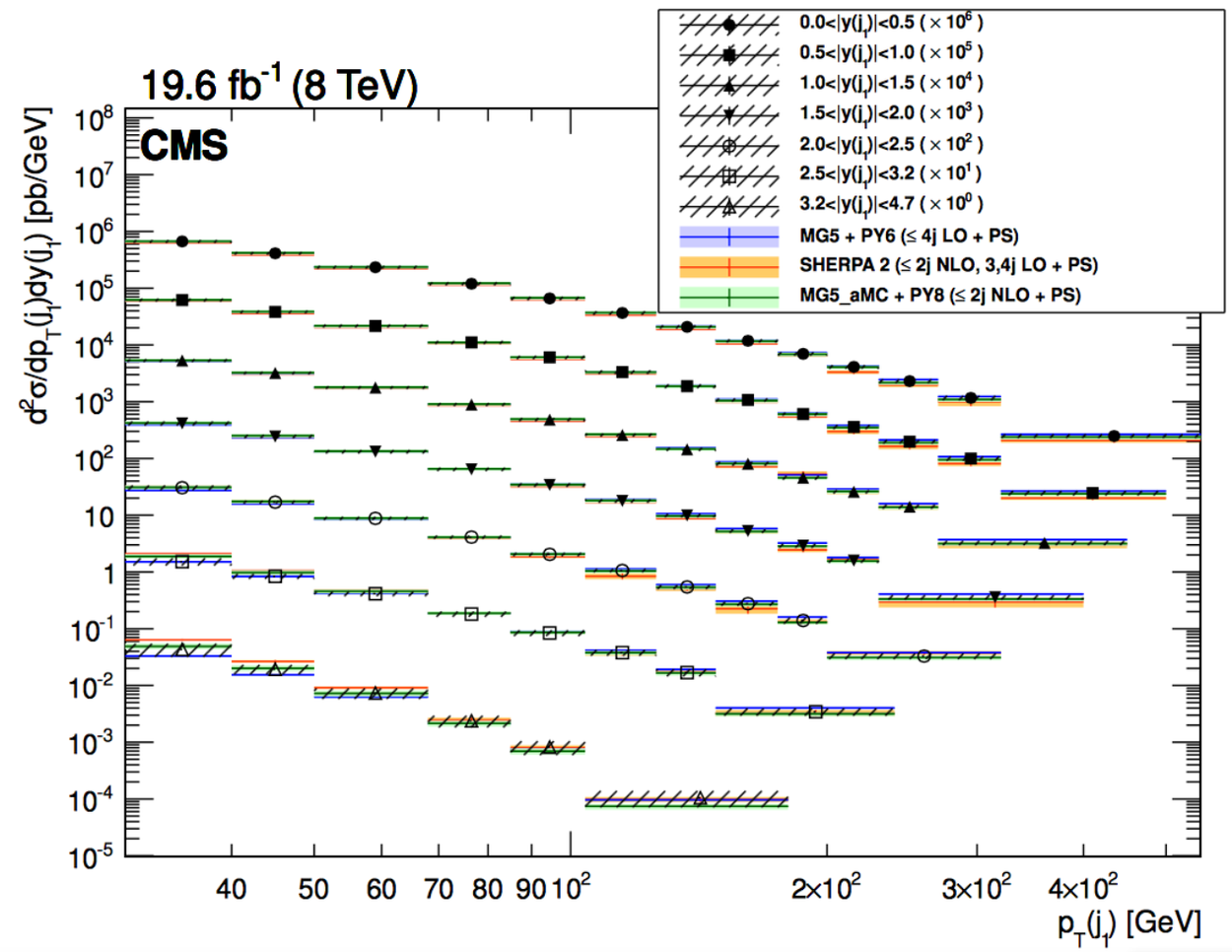
JHEP04(2017)022

8 TeV

Data compared to :

- MadGraph5+Pythia6 kt MLM (LO <= 4 jets)
- MadGraph5_aMC@NLO+Pythia8 FxFx (NLO <= 2jets; 3 LO)
- Sherpa+Blackhat (v2) (NLO <= 2 jets, LO <= 4 jets)

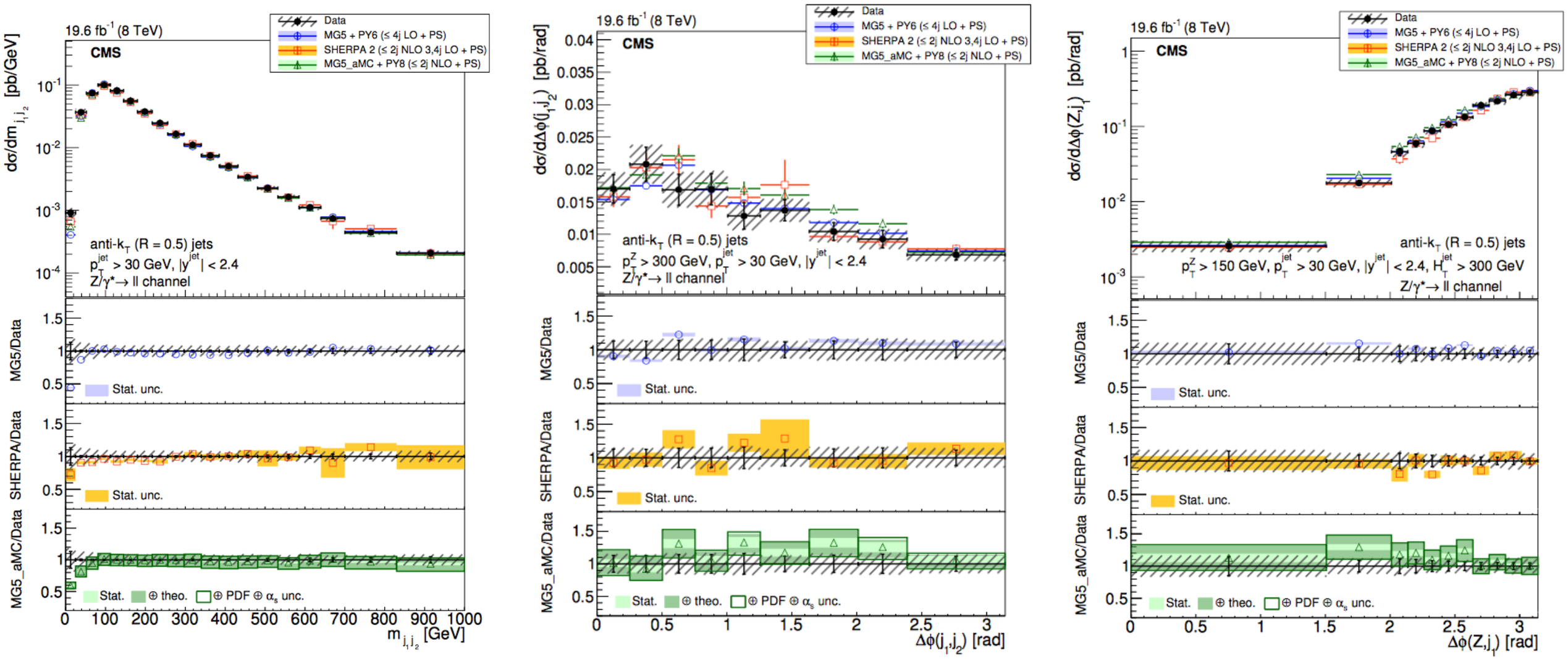




- Very good agreement with the considered NLO multileg predictions
- Essential to include a large number of FS partons in ME to correctly describe the kinematics of the leading jets

Z+jets, 8 TeV

JHEP04(2017)022 **8 TeV**

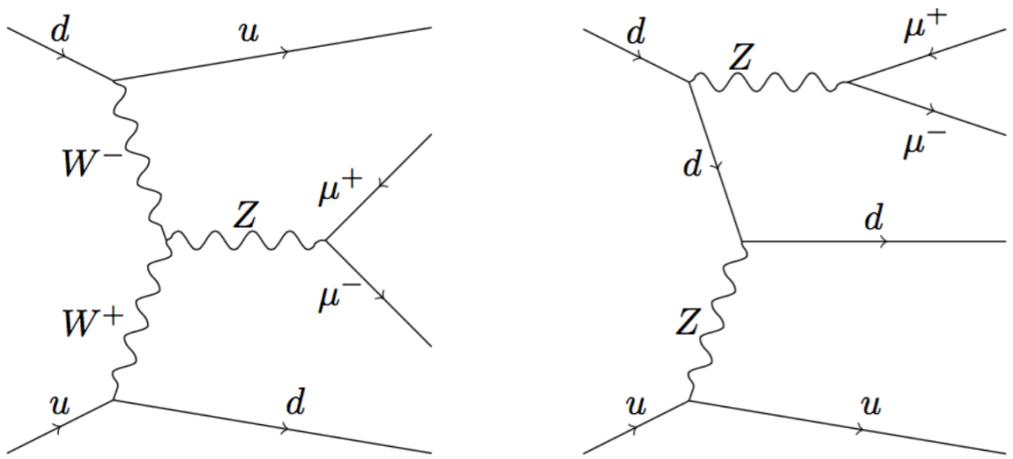


- Dijet mass spectrum : discrepancies with LO and NLO predictions at low mass(region where the angle between the two jet directions is smaller than π/2)
- Azimuthal angles (Z,jet) and (j,j) : very well reproduced by both LO and NLO predictions

EWK Z+jets, 13 TeV

CMS SMP-16-018

Signal is defined as : lljj final state with $p_T(j)>25$ GeV, m(jj)>120 GeV, m(ll)>50 GeV. $\sigma_{LO}(EW\ lljj) = 543^{+7}_{-9}(QCDscale)^{+22}_{-22}(PDF)$



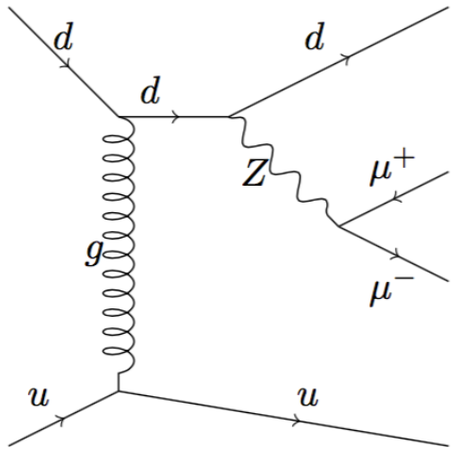
pure EWK

- non- VBF diagrams that lead to identical final states and cannot be neglected
- these diagrams have important negative interferences with the VBF productions

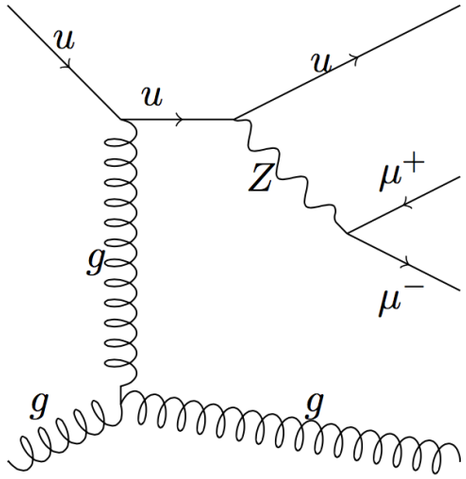
Event selection:

- ≥ 2 e/μ, p_T > 30,20 GeV, |η| < 2.4
- |m(ll)-m(Z)|<15 GeV
- ≥2 jets p_T >50,30 GeV, |η| < 4.7
- *Mjj* > 200 GeV

Small interference with the DY bg: generated with MG5_amc in the signal definition phase space



background
DY + 2 (QCD) jets



EWK Z+jets, 13 TeV

CMS SMP-16-018

S/BG separation :

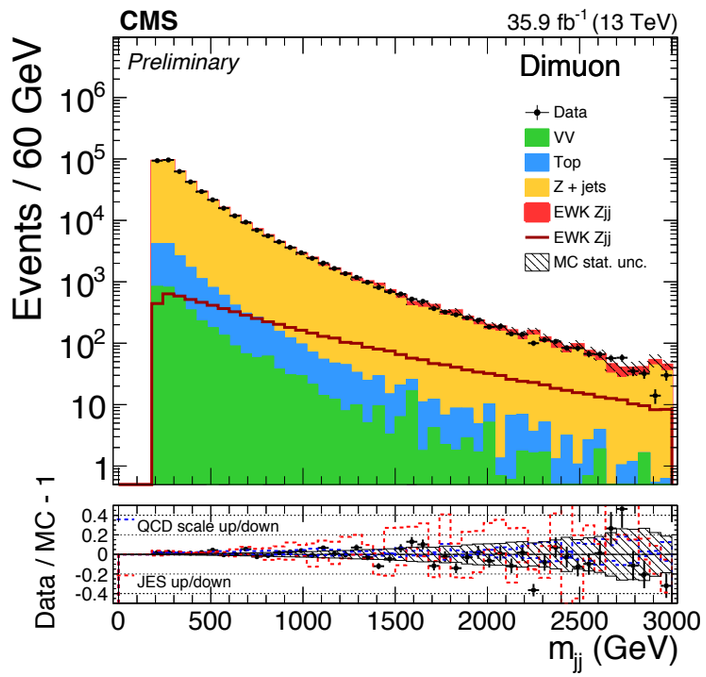
- m(qq), Δη(qq)
- qgl(1st/2nd jets)
- p_T(qq)
- R(p_T^{hard}), z^*_{ll}

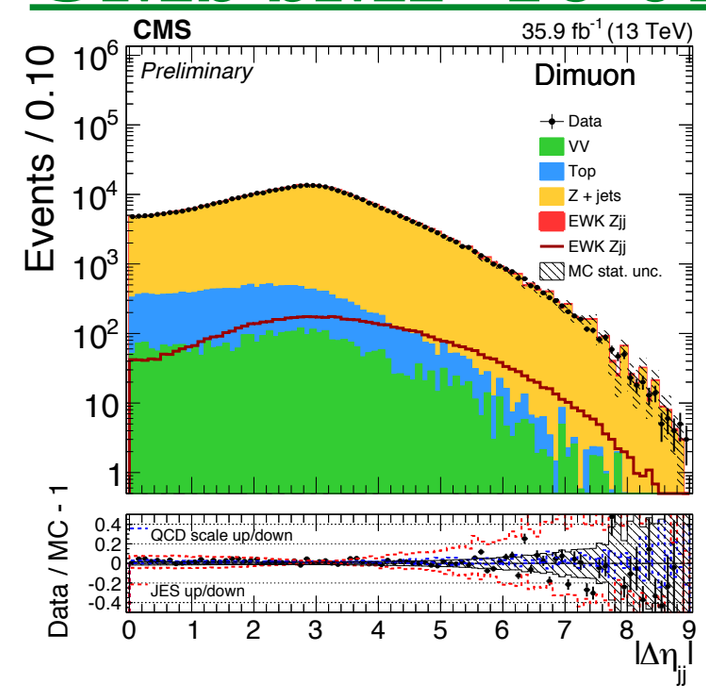
$$y^* = y(Z) - \frac{y(j_1)+y(j_2)}{2}$$

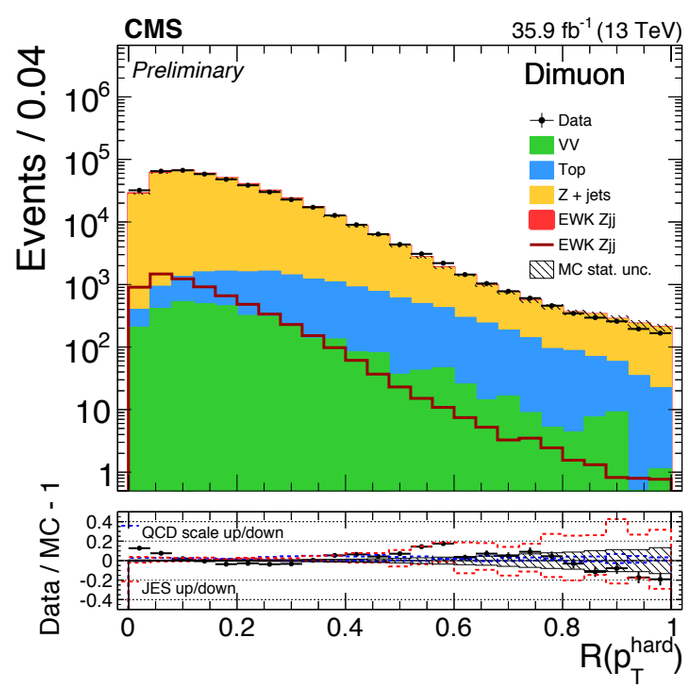
$$z^* = \frac{y^*}{\Delta y_{jj}}$$

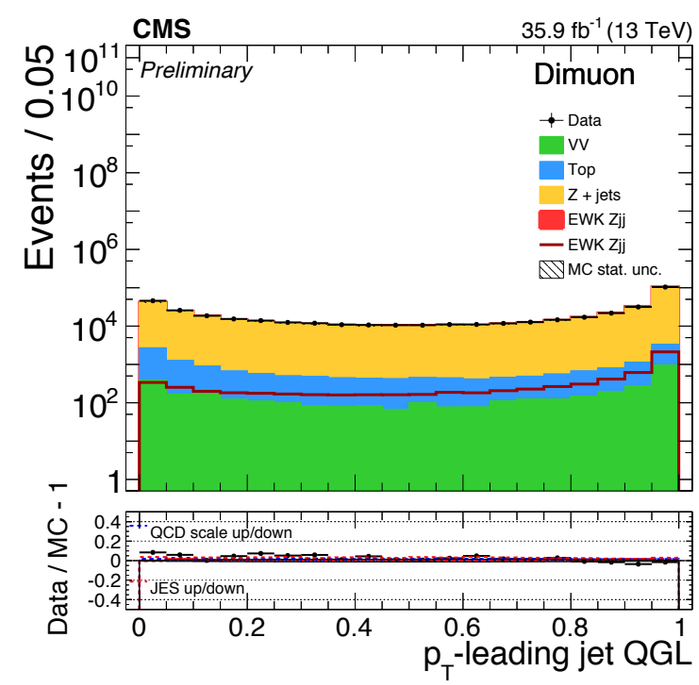
Nice data/MC agreement

$$R\left(p_T^{hard}\right) = \frac{\left|\vec{p}_T(j_1)+\vec{p}_T(j_2)+\vec{p}_T(Z)\right|}{p_T(j_1)+p_T(j_1)+p_T(Z)}$$





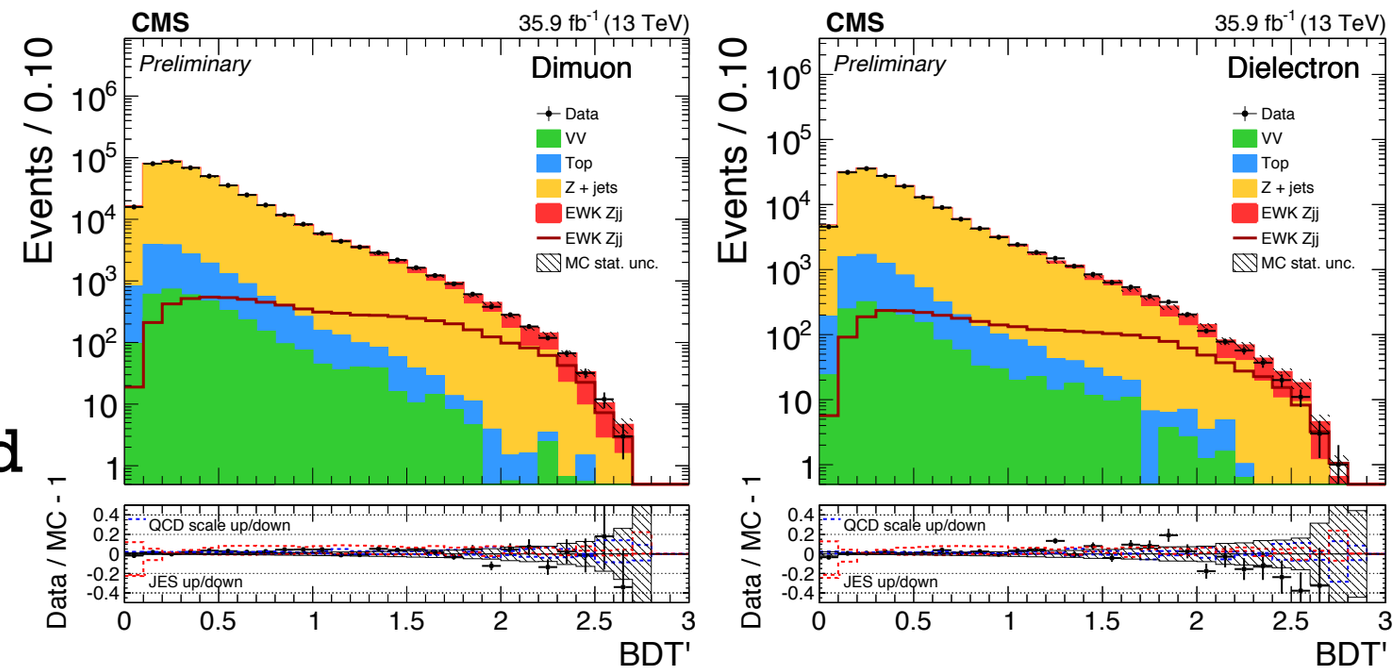




EWK Z+jets, 13 TeV

CMS SMP-16-018

- Multivariate analysis techniques are used to discriminate S/B
- Rapidity gap observables are **not** used for signal extraction
- Binned maximum likelihood fit with strength modifiers for all MC components. Nuisance parameters used to constrain the bkg variation and introduce other systematics unc.



dielectron :

$$\sigma(EW\ lljj) = 554 \pm 34(stat) \pm 70(syst) = 554 \pm 78(total)fb$$

dimuon :

$$\sigma(EW\ lljj) = 540 \pm 23(stat) \pm 56(syst) = 540 \pm 61(total)fb$$

combined :

$$\sigma(EW\ lljj) = 552 \pm 19(stat) \pm 55(syst) = 552 \pm 58(total)fb$$

dominant systematic effects: 10% precision

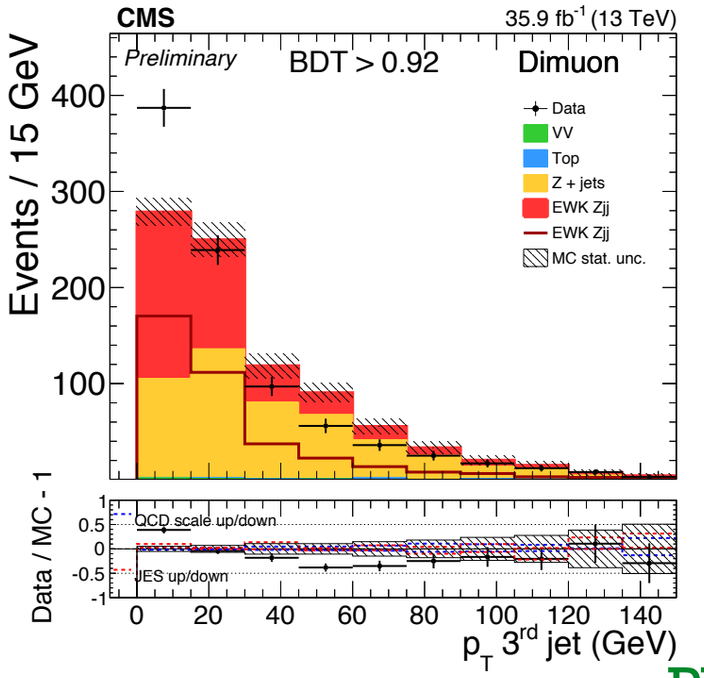
experimental : JES/JER, MC stats, lepton trigger & selection, QGL, luminosity, pileup

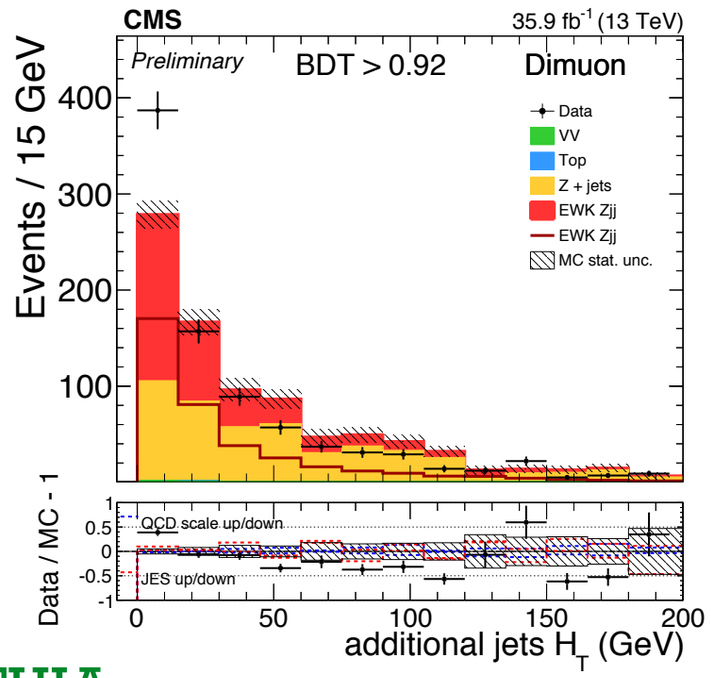
theoretical : QCD scales, S/B interference, PDF, PS model

EWK Z+jets, 13 TeV

CMS SMP-16-018

- Signal enriched sample selected with BDT>0.92 -> S/B ~ 1
- Study additional hadronic activity in region between the VBF tagging jets
- H_T of additional (p_T>15 GeV) jets in the gap. First bin are events with no jets
- H_T of (PU-transparent) soft track-jets in gap with p_T >1 GeV

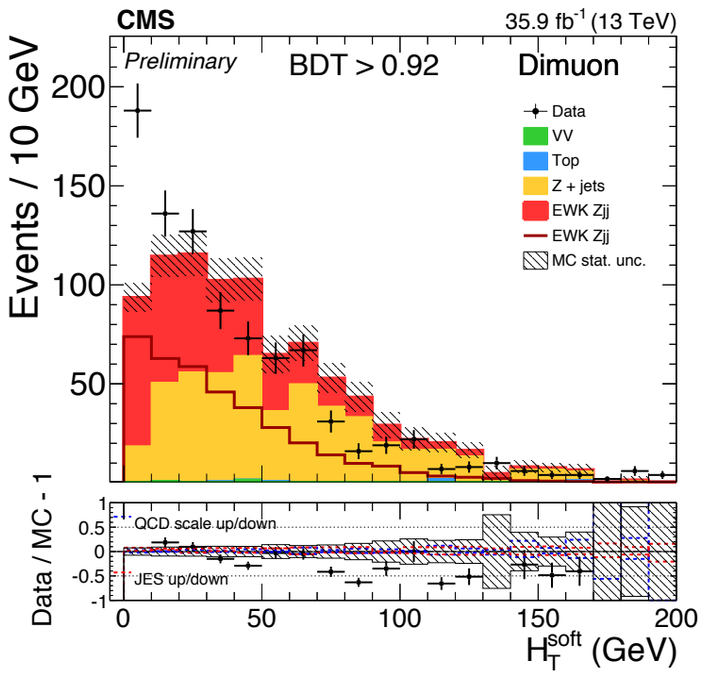




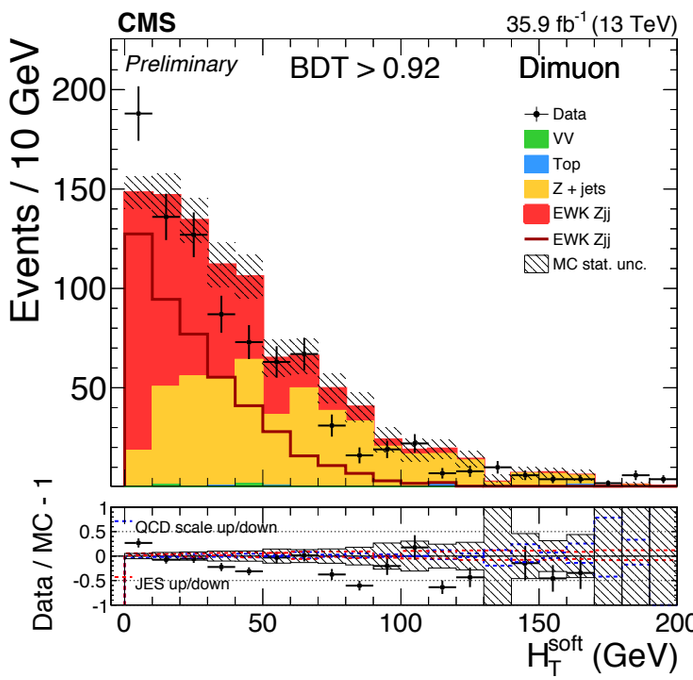
PYTHIA

Herwig predicts more signal events with lowest gap activity, in better agreement with data

PYTHIA



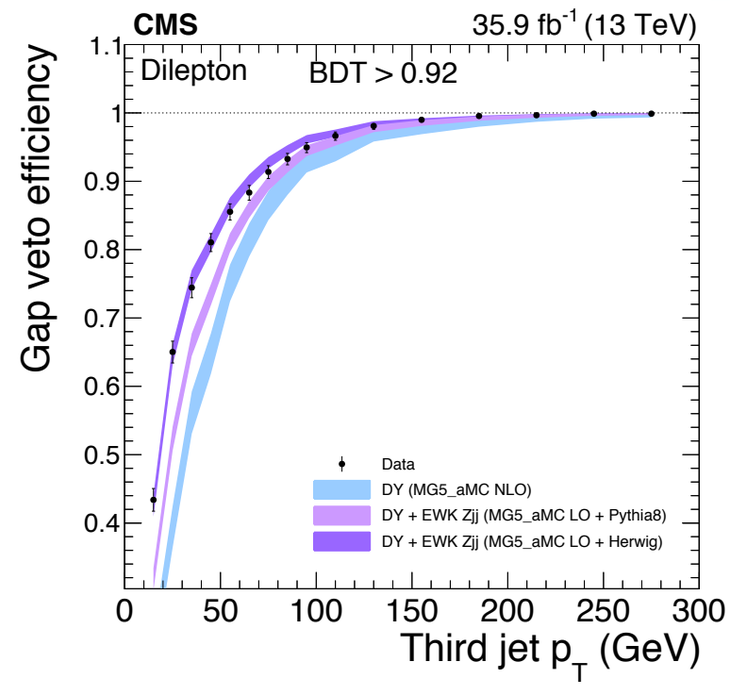
HERWIG

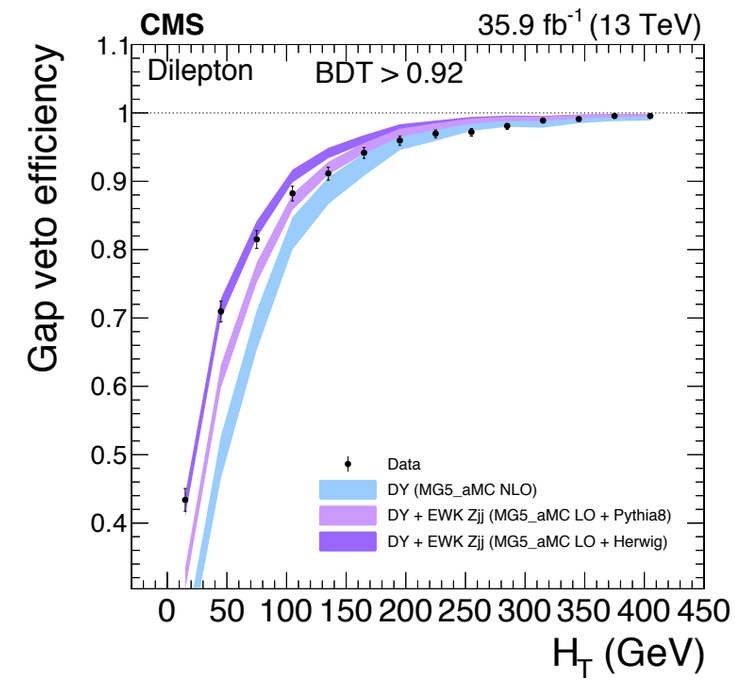


EWK Z+jets, 13 TeV

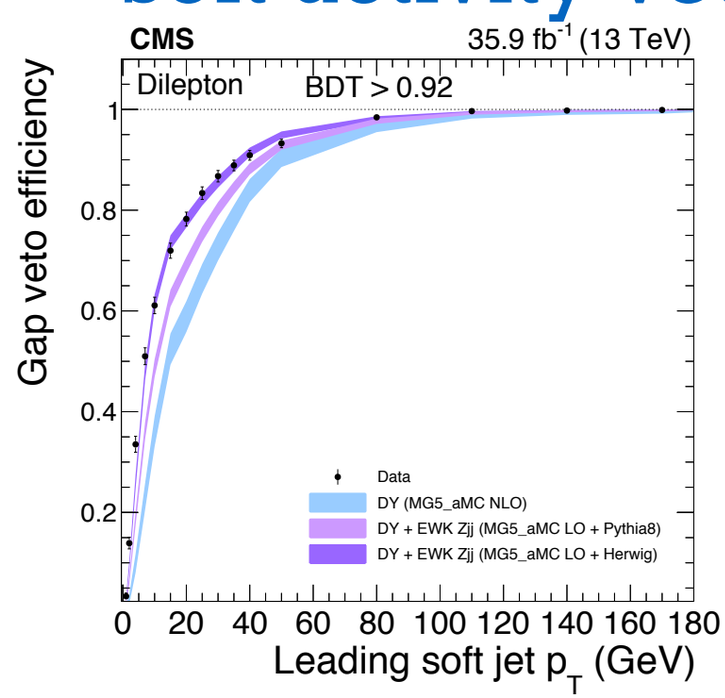
CMS SMP-16-018

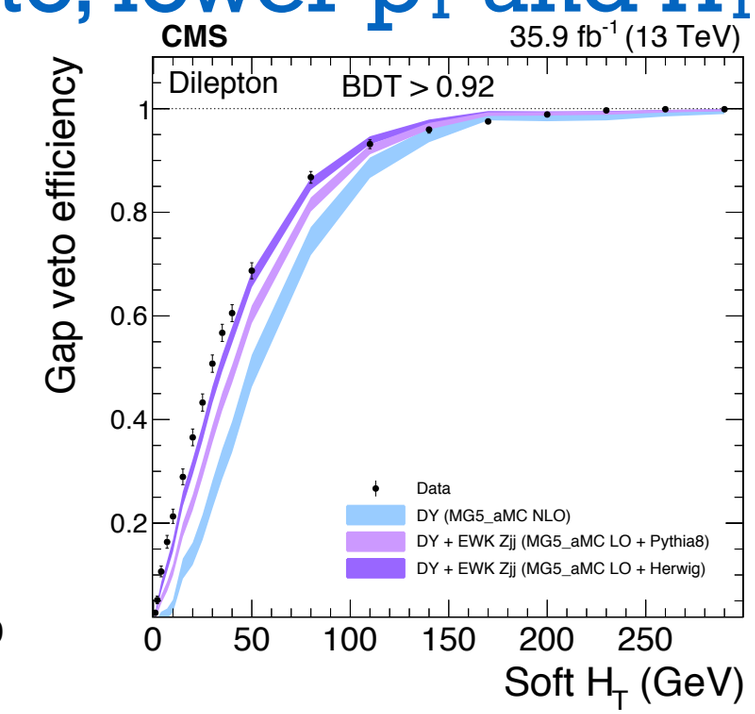
- It is interesting to look at gap activity fraction - fraction of events which do not have a rapidity gap activity above a given threshold
- Measurements of veto efficiency in VBF-like topologies can quantify how reliable the modelling is in particular in a signal-enriched region





soft activity veto, lower p_T and H_T





Data seem to prefer the signal model with HERWIG PS at low gap activity and maybe PYTHIA8 PS for larger gap activities

Summary

★ 8 TeV & 13 TeV results on Z/W+jets productions

- Data is in good agreement with NLO and NNLO predictions

★ New 13 TeV results for EWK Z+jets (VBF Z) with 10% precision and in agreement with SM prediction

- Validation of rapidity gap activity modelling in VBF signal pure samples

Thank you!

Additional Material

EWK Z+jets, 13 TeV

CMS SMP-16-018

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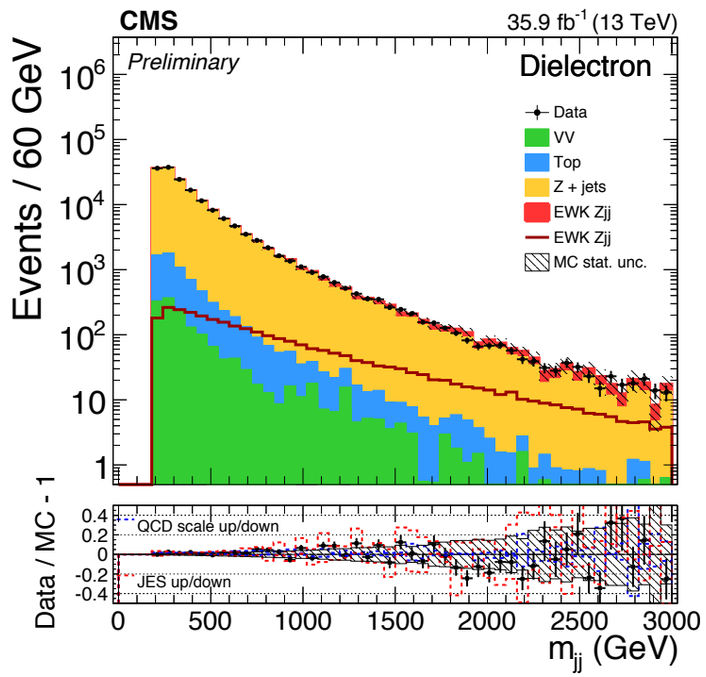

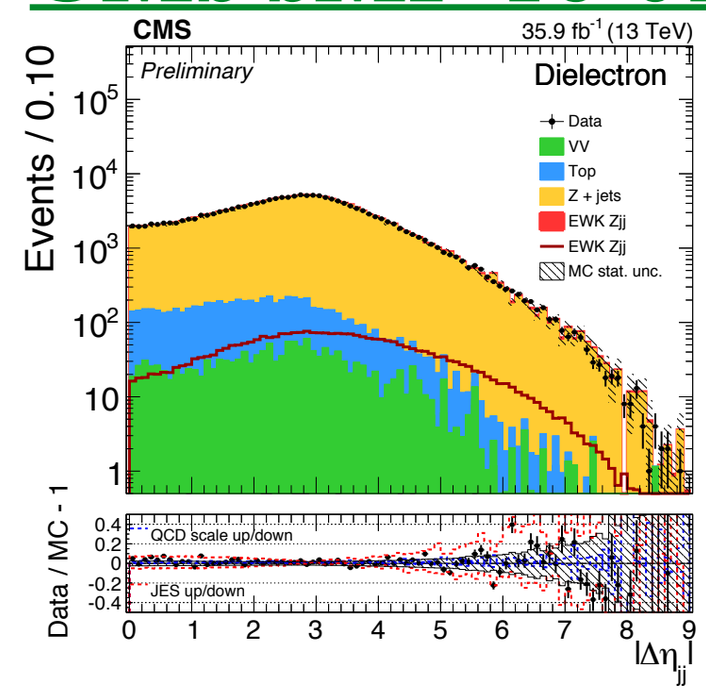

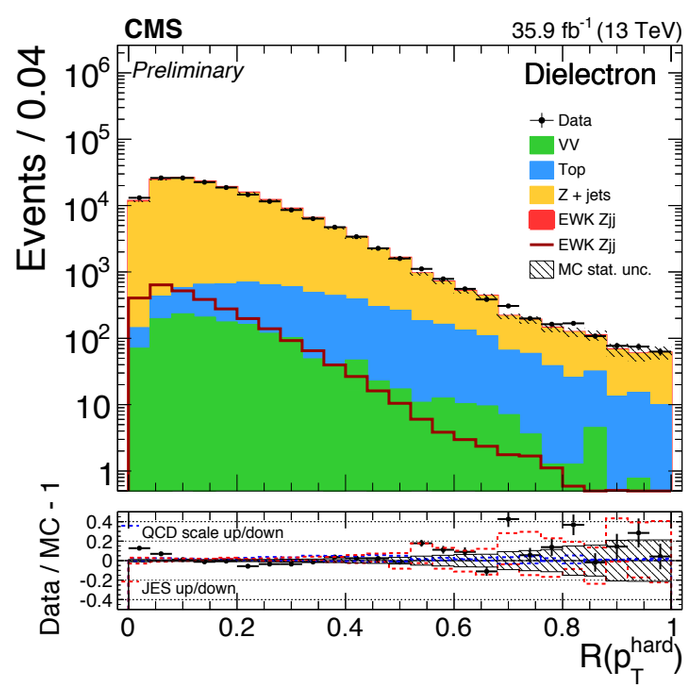

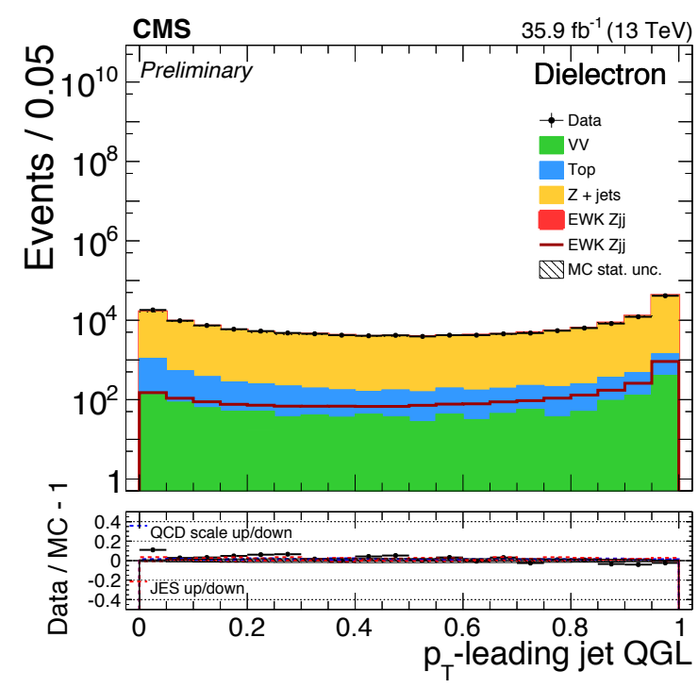

EWK Z+jets, 13 TeV

CMS SMP-16-018

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Nice data/MC agreement

$$R\left(p_T^{hard}\right) = \frac{\left|\vec{p}_T(j_1) + \vec{p}_T(j_2) + \vec{p}_T(Z)\right|}{p_T(j_1) + p_T(j_1) + p_T(Z)}$$