IIHE seminar

Measurement of differential production cross sections for a Z boson in association with jets in pp collisions at $\sqrt{s} = 13$ TeV

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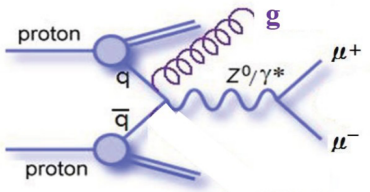
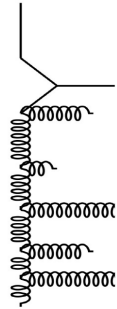
Motivation

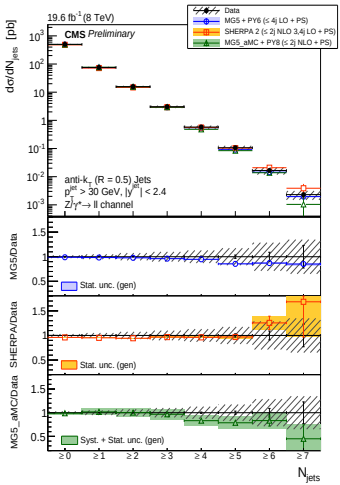
- This process is a standard candle at LHC:
  - High cross section
  - Almost background free
  - Clean signature due to decay of Z boson to two oppositely charged leptons with high reconstruction efficiency
- It is an ideal laboratory for jet production study
- It gives stringent tests on perturbative QCD computations
- It is a significant background in many SM processes, such as single top, ttbar, vector boson fusion, WW scattering, Higgs production, and for SUSY searches
- Measurement on the cross section of Z+jets as a function of different kinematical observables is crucial with highest possible precision
- Precision test on theoretical predictions

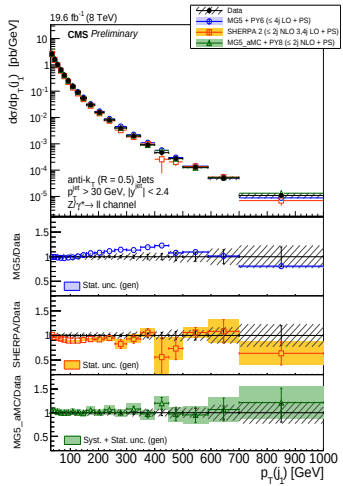
Z+jets: from 8 to 13 TeV





$\rightarrow$ high multiplicity events

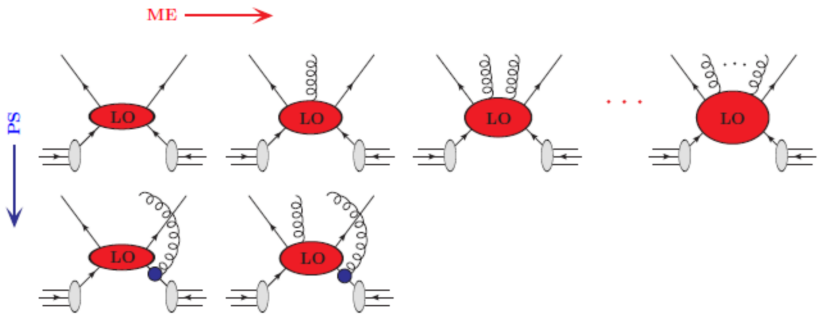




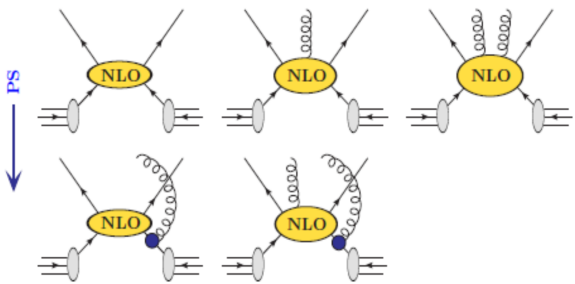
- Recent Z+jets measurements at 8 TeV go up to 7 jets! (CMS-PAS-SMP-14-013)
- Need of higher order Monte Carlo generators to describe the measurements

Z+jets predictions

Madgraph: Multi-parton LO ME +PS (reference MC for 8 TeV data)



aMC@NLO: NLO for higher parton multiplicity ME + PS (reference MC for 13 TeV)



- we now test aMC@NLO computed for 2 legs at NLO:

  Z+0/1/2 partons at NLO + PS
  Z+3 partons at LO + PS
  Z+(> 3) partons purely PS

Data and Simulation Samples

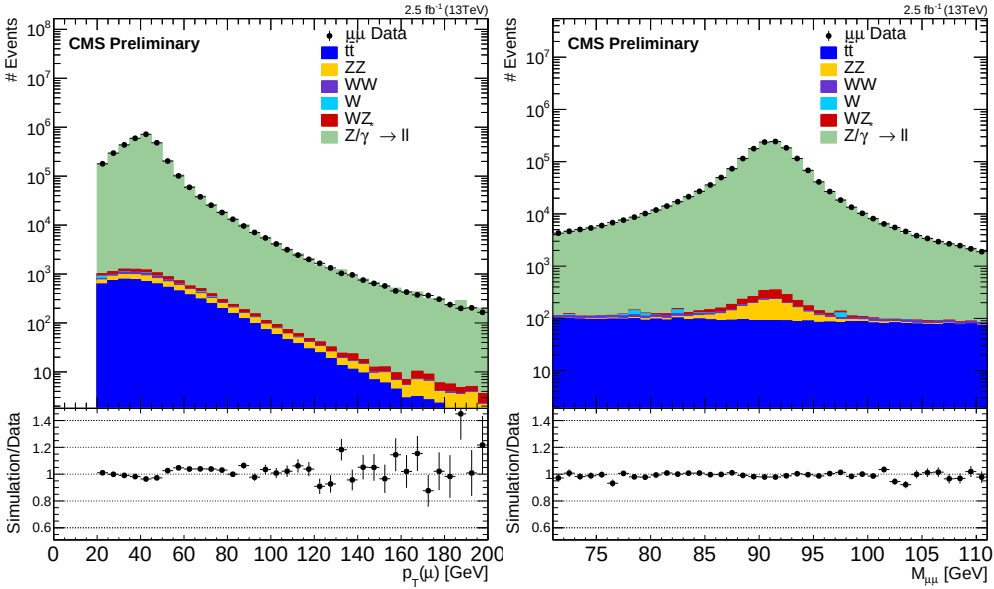
- Data: 2015 RunD with 25ns of bunch spacing
- Integrated luminosity of 2.5 fb^{-1}
- Signal is generated by MG5_aMC@NLO using FxFx merging scheme, with di-lepton mass larger than 50 GeV
  - The matrix elements include Z+0/1/2 partons NLO computation; Z+($\geq$ 3) partons LO approximation
  - The parton shower and hadronization are held by PYTHIA8 using CUETP8M1 tune
  - The total cross section is normalised to the NNLO calculation by FEWZ (2008.4 pb for one decay leptonic channel)
- $t\bar{t}$ background and single top modelled with POWHEG interfaced with PYTHIA 8
- Double vector boson BKG:
  - WW: generated by POWHEG
  - WZ: generated by aMC@NLO, interfaced with PYTHIA 8
  - ZZ: generated by PYTHIA 8
- Wjets sample is generated by aMC@NLO, interfaced with PYTHIA 8

Selection

Cuts:

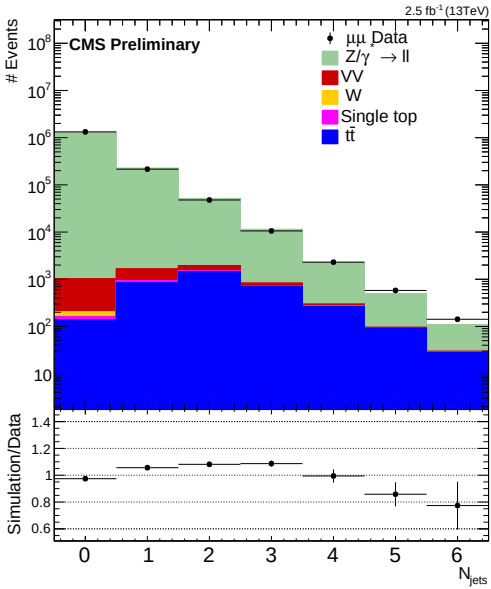
- two well identified oppositely charged muons
- $p_{\mathrm{T}}(\mu) \geq 20$ GeV
- $|\eta(\mu)| \leq 2.4$
- $71 \leq M_{\mu\mu} \leq 111$ GeV,
- Anti-k_t ($\Delta R = 0.4$) jets with $p_{\mathrm{T}}(j) \geq 30$ GeV and $|y(j)| \leq 2.4$

Detector Level Results: Muon's p_T and dimuon mass for $N_{jets} \geq 0$ scenario



Detector Level Results: Jet Multiplicity

Exclusive



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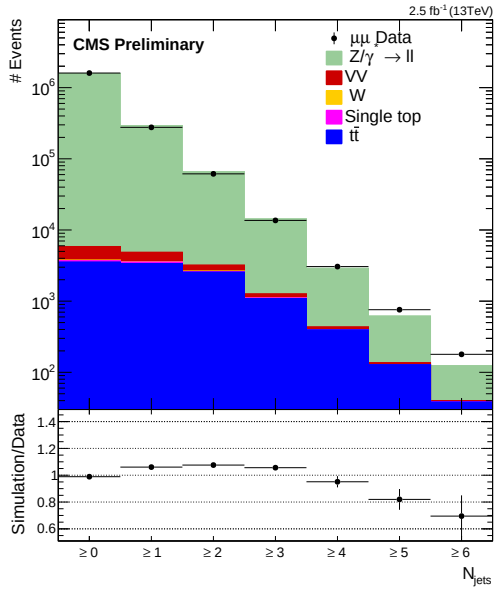
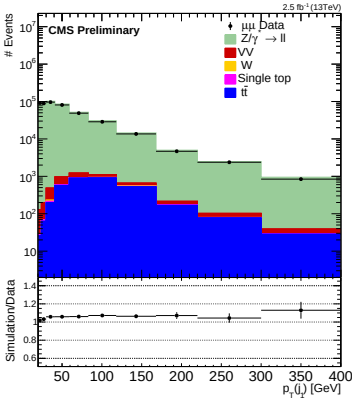
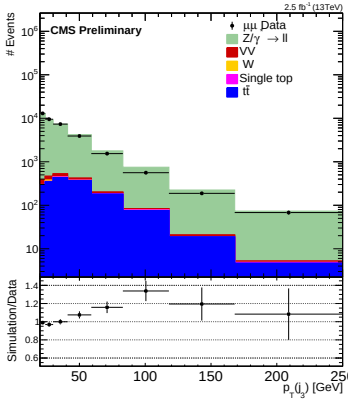
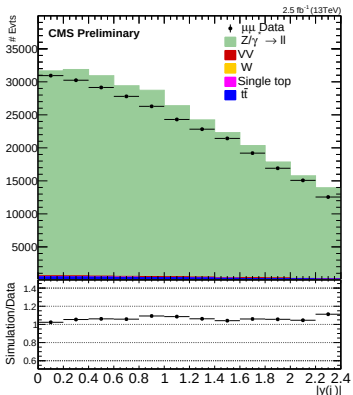


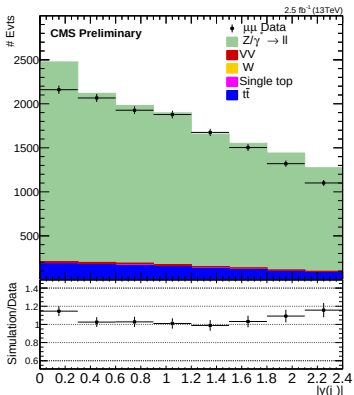
- Good Data/MC description for $N_{jets} < 5$ jet bins

Transverse momentum and absolute rapidity of jet









From Reco Distribution to Cross Sections

- To correct for the detector effects the data are unfolded to the generator level using the iterative D'Agostini method
- Background is subtracted from the data before the unfolding

Phase Space at Generator Level:

- generated muons after EWK FSR are "dressed" with photons:

$$p^{\mu}_{\text{corr.}} = p^{\mu} + \sum_{\gamma}^{\Delta R \leq 0.1} p^{\gamma}$$

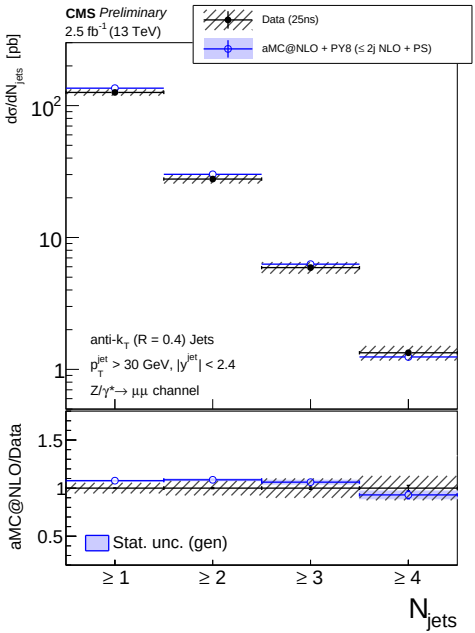
- two opposite charge muons,
- $p_{\mathrm{T}}(\mu) \geq 20$ GeV, $|\eta(\mu)| \leq 2.4$ and $71 \leq M_{\mu\mu} \leq 111$ GeV,
- jets clustered using anti-k_t clustering algorithm with cone size of $R = 0.4$ from MC stable particles after hadronisation and removal of neutrinos.
- $p_{\mathrm{T}}(j) \geq 30$ GeV, $|y(j)| \leq 2.4$, $\Delta R(j, \mu) > 0.4$

Systematic Uncertainties

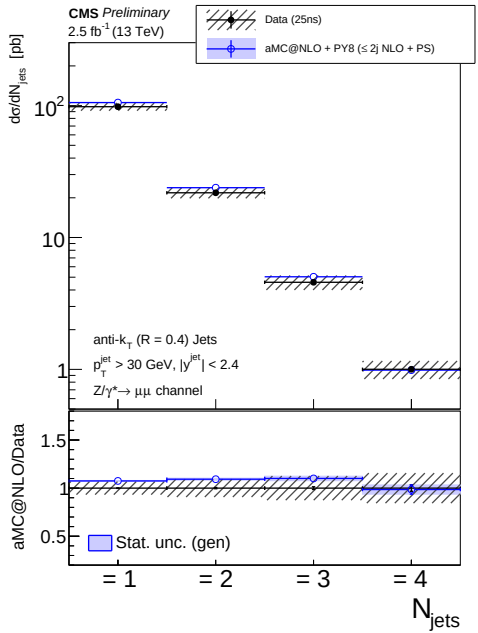
- **Jet energy correction (JEC) uncertainty**
  Varying the JEC by plus and minus by the values provided by JETMET POG
- **Background estimation (Bgnd)**
  Estimated using simulated events by varying the cross section of 10% for $t\bar{t}$. The cross section uncertainties of other backgrounds are negligible.
- **Pile-up (PU)**
  Varying the minimum bias cross section by $\pm 5\%$.
- **Unfolding**
  Estimated by reweighting MC with ratio data/simulation of fine binning reco-level histogram: introduced difference on unfolding results taken as uncertainties
- **Luminosity (Lumi)**
  Total integrated luminosity uncertainty of 4.6% is considered.

Jet multiplicity

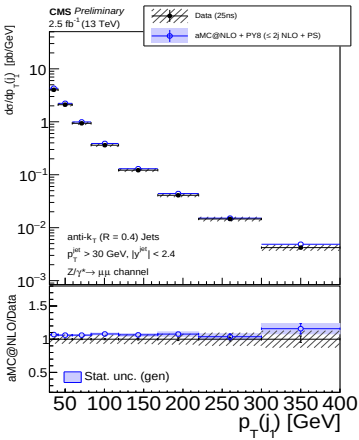
Inclusive:

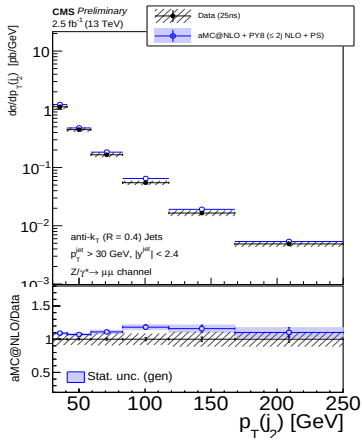


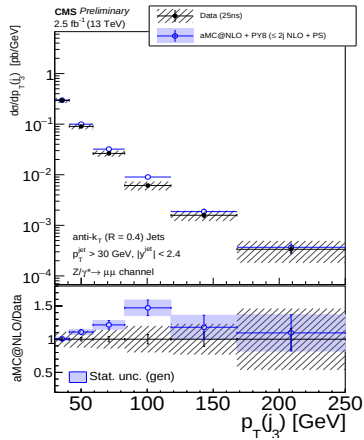
Exclusive:



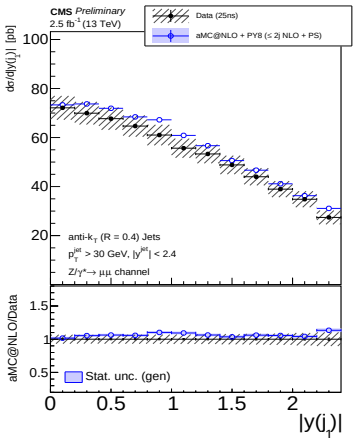
Jet Transverse Momenta

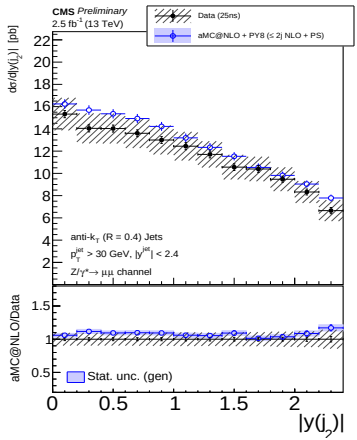


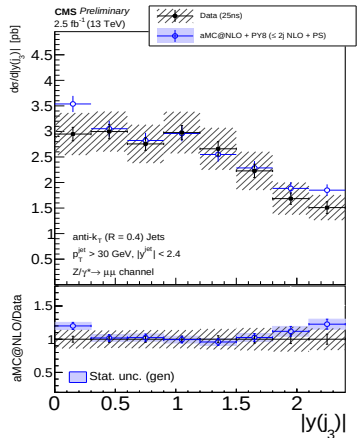




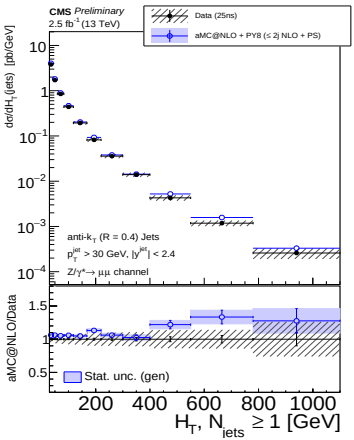
Jet absolute rapidity

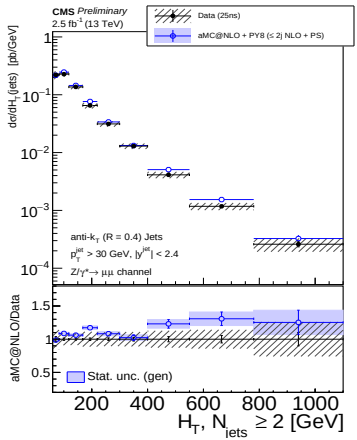






Jet HT


CMS Preliminary
2.5 fb-1 (13 TeV)
Data (25ns)
aMC@NLO + PY8 (≤ 2j) NLO + PS)
dσ/dH_T(jets) [pb/GeV]
anti-k_T (R = 0.4) Jets
p_T^jet > 30 GeV, |y^jet| < 2.4
Z/γ*→ μμ channel
aMC@NLO/Data
Stat. unc. (gen)
H_T, N_jets ≥ 1 [GeV]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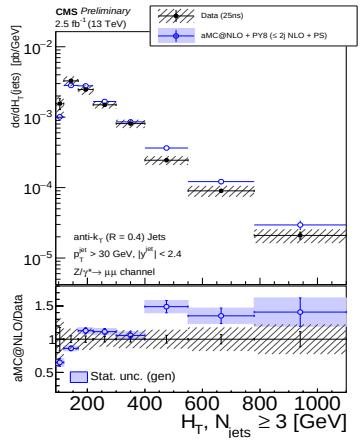
dσ/dH_T(jets) [pb/GeV]
anti-k_T (R = 0.4) Jets
p_T^jet > 30 GeV, |y^jet| < 2.4
Z/γ*→ μμ channel
aMC@NLO/Data
Stat. unc. (gen)
H_T, N_jets ≥ 2 [GeV]


CMS Preliminary
2.5 fb-1 (13 TeV)
Data (25ns)
aMC@NLO + PY8 (≤ 2j) NLO + PS)
dσ/dH_T(jets) [pb/GeV]
anti-k_T (R = 0.4) Jets
p_T^jet > 30 GeV, |y^jet| < 2.4
Z/γ*→ μμ channel
aMC@NLO/Data
Stat. unc. (gen)
H_T, N_jets ≥ 3 [GeV]

Conclusion

- The fiducial cross section of Z boson associated with jets in pp collisions at a central energy of 13 TeV has been measured with the phase space:
  - $p_{\mathrm{T}}(\mu) \geq 20$ GeV, $|\eta(\mu)| \leq 2.4$ and $71 \leq M_{\mu\mu} \leq 111$ GeV,
  - $p_{\mathrm{T}}(j) \geq 30$ GeV, $|y(j)| \leq 2.4$, $\Delta R(j, \mu) > 0.4$
- The full data set, which correspond to the tntegrated luminosity of 2.5 fb^{-1}, is analysed.
- The differential cross section is measured as a function of jet multiplicity, jet transverse momentum, jet rapidity, and scalar sum of jet transverse momenta up to three jets
- The measurements are compared to multi-legs NLO theoretical prediction, and they are consistent within systematical and statistical uncertainties.