THE ROYAL SOCIETY

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Differential measurement of the Z/γ ratio with the CMS experiment in pp collisions at 13 TeV

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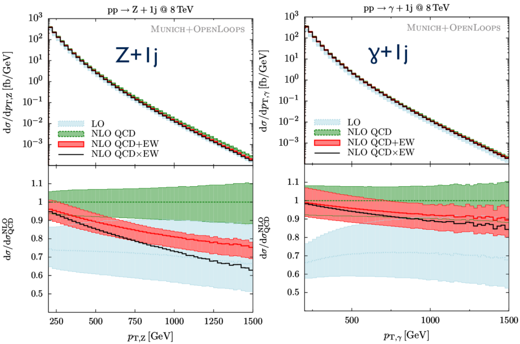
Motivation

- With the large LHC Run2 dataset, precision measurements of V+jets processes are becoming valuable tools to probe several SM features:
  - perturbative QCD
  - higher order QCD and EWK effects
  - PDFs
  - ...
- Active theoretical developments in providing (N)NLO QCD and NLO EWK corrections for V+jets processes. Need data measurements to validate these predictions.
- Differential cross-section ratios are particularly sensitive due to (partial)uncertainty cancellation
- V+Jets are also crucial processes to control backgrounds to BSM searches

Motivation - Z+Jets/γ+Jets

- Z/γ ratio is sensitive to higher order electroweak corrections that increase with p_T due to large Sudakov logarithms



QCD corrections

- Mostly moderate and stable QCD corrections
- Small p_T dependence

EW corrections

- Different corrections for Z and γ
- $-20\%/-8\%$ EW for Z / γ
- EW corrections are growing with p_T

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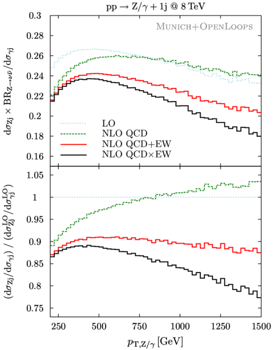

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Z/γ analysis

Event selection

Data

- Using the full 2016 dataset corresponding to an integrated luminosity of 35.9$\pm$0.9 fb^{-1}
- Single muon and single photon datasets used respectively for Z+jets, γ+jet.

MC

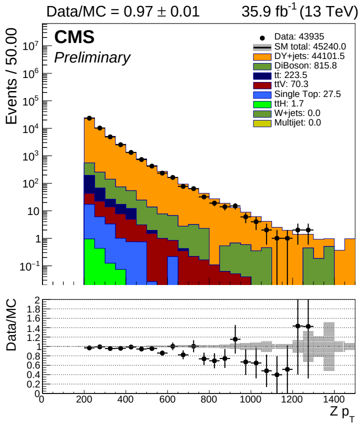
- Signal from Drell-Yan to $\ell\ell$ and γ+jets samples
- Background: W+Jets, $t\bar{t}$, Single top, ttV, VBF W/Z + Jets,Diboson ttγ, QCD multijet

- For **Z+jet**:
  - Require 2 tight muons with $p_{\mathrm{T}} > 30$ GeV, $|\eta| < 2.4$, opposite charge.
  - $71 < m_{ll} < 111$ GeV.
  - p_{T} of dimuon pair > 200 GeV
- For **γ+jet**:
  - Require 1 photon with $p_{\mathrm{T}} > 200$ GeV, $|\eta| < 1.4$.

- Jets with $p_{\mathrm{T}} > 40$ GeV, $|\eta| < 2.4$
- p_{T} of leading jet > 100 GeV
- $N_{jet} \geq 1$

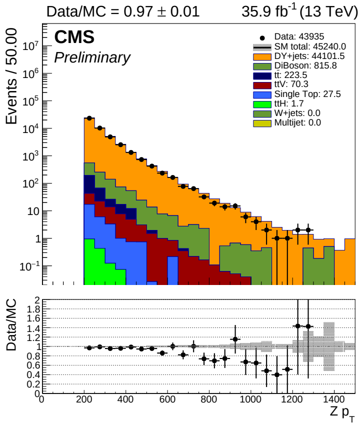
Z+Jets

Extracting the cross section

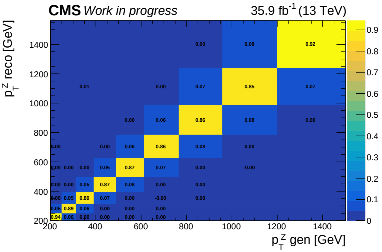


- Good agreement between Data-MC
- Background at 3%, mainly from Diboson and $t\bar{t}$
- MC background subtraction

Extracting the cross section



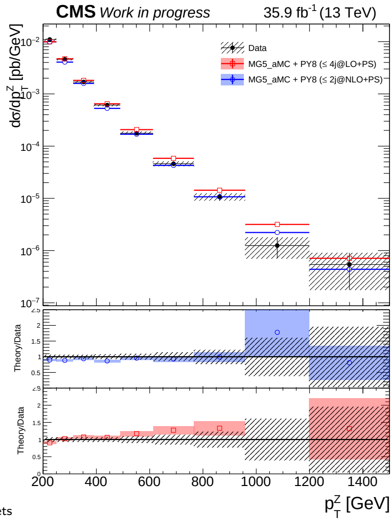
- We unfold the reconstructed events to extract the particle level distribution
- Unfolding is performed using a least square method with Tikhonov regularisation



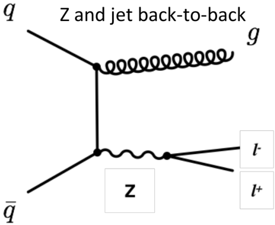
Results

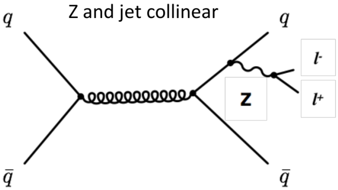
We unfolded the data distribution to particle level, now we can test it against different predictions

- Madgraph DYJets LO
  - up to 4 hard jets
- Madgraph DYJets NLO
  - up to 2 hard jets



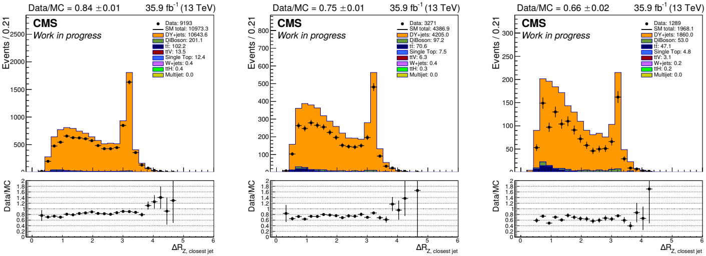
Collinear Z emission





- Studying the angular separation between Z (or its decay products) and closest jet allows to probe configuration where real Z emitted from dijet final state
- At LO in Z+1 jet, Z and jet are back-to-back
- At NLO, Z+1 jet process has QCD and EWK corrections, from real and virtual contributions
- For real Z emission, contribution scales as $O(\alpha ln^2(p_{\mathrm{T},j}/m_Z) \rightarrow$ gives collinear enhancement in angular separation between Z and closest jet.

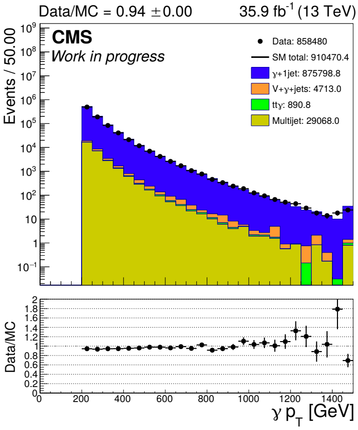
Collinear Z emission



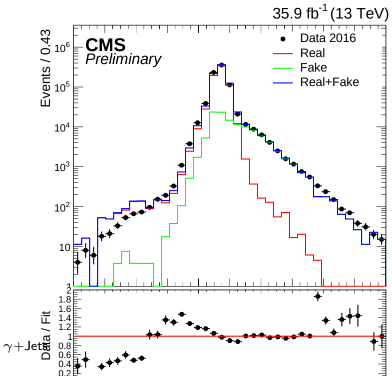
- Small ΔR : Negative correction from real EW emission
- Negative QCD correction in the peak

γ+Jets

extraction of cross section

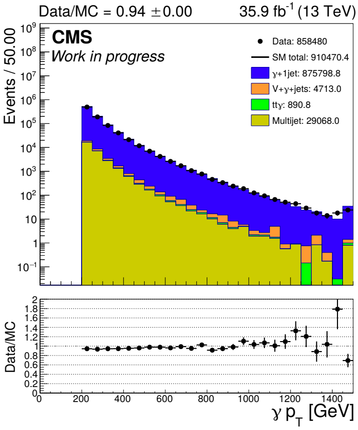


- **Isolation template fit**: fit to shower shape variable $\sigma_{i\eta i\eta}$ using as pdfs:
  - Real template from γ+jets MC
  - Fake template from isolation sideband



- Good Data-MC agreement
- Main background from QCD

extraction of cross section



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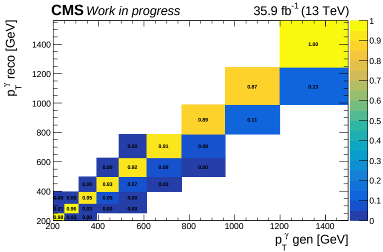


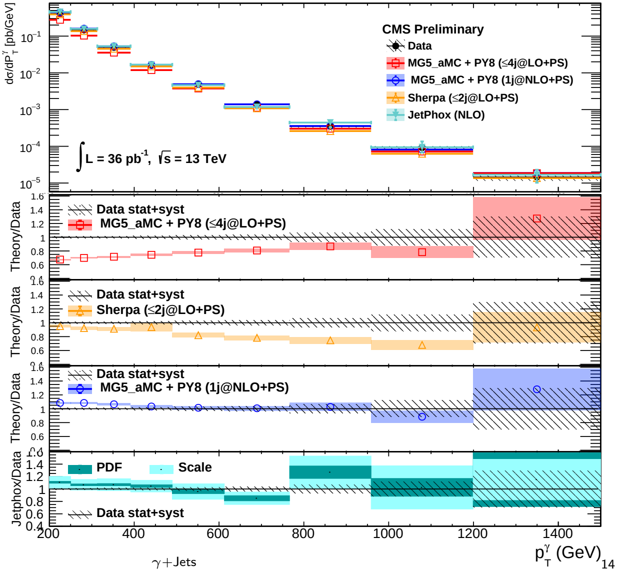
Results

Comparison to 4 theoretical predictions:

MG5_aMC@LO
Sherpa@LO

MG5_aMC@NLO

JetPhox@NLO



A.G. Zecchinelli

Conclusion

- With the Run 2 data we have moved into the precision era of LHC physics
- Z/γ + jets measurement will increase the sensitivity of BSM searches as well as constrain EWK and QCD effects at unprecedented energies
- The γ+jets and Z+jets analysis have been completed, in the internal review process
- Unfolded data to be compared with latast and greatest theoretical predictions

Thank you for your attention

Backup

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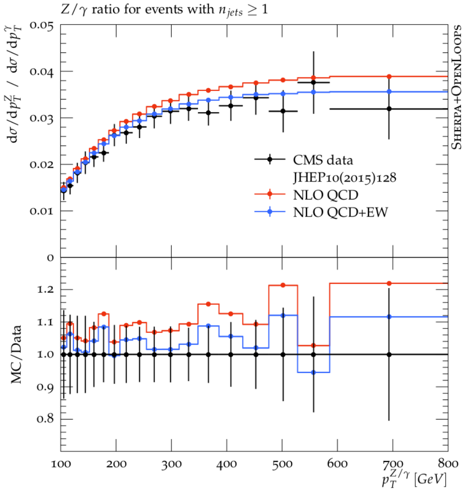
Z+Jets/γ+Jets in Run1

- **Run1** CMS analysis ($19.7\ \text{fb}^{-1}$)
- Data is compared to NLO QCD and NLO QCD+EW
- Better agreement observed when including EW corrections
- Low statistics at high p_T



$\rightarrow$ With Run2 data we can constrain effects from higher order EWK corrections

BSM motivation - The Z $\to \nu\nu$ background

- γ+jets process is a key control sample for BSM in the jets plus missing transverse momentum channel
- The Z/γ ratio is also a crucial theoretical input for new physics searches
- Used for determination of SM $Z \to \nu\nu$ + jets background

To constrain the background 3 control samples are defined

- $Z(\ell\ell)$ + jets
  - Good theoretical knowledge
  - Low statistics
- $W(\ell\nu)$ + jets
  - Good statistics
  - Theoretical uncertainty from W/Z
  - Affected by $t\bar{t}$ background
- $\boldsymbol{\gamma}$ **+ jets**
  - Good statistics
  - Large theoretical uncertainty

$\to$ Precision V+jets measurements can increase the sensitivity to new physics

Transfer Factors

- The number of $Z \to \nu\nu$ events in the region of interest is predicted from the control samples, using the **Transfer Factor** method

$$N^{signal}_{predicted} = \frac{N^{signal}_{simulation}}{N^{control}_{simulation}} \times N^{control}_{observed}$$

Most of the systematic effects are expected to cancel in the ratio

Nevertheless it is necessary to have:

- good statistic in the control sample
- good knowledge of simulations

Object definition - **Jets**

- Use PF jets with anti-kt clustering algorithm and distance parameter of 0.4.
- Jet energy corrections applied : L1FastJet, L2Relative, L3Absolute, Charged Hadron Subtraction
- *Loose* working point Jet ID

Selection variable	value	notes
	$-3.0 < \eta_{\mathrm{jet}} < 3.0$	
Neutral Hadron Fraction	< 0.99	-
Neutral EM Fraction	< 0.99	-
Number of constituents	> 1	-
Charged Hadron Fraction	> 0	only for $\lvert\eta_{\mathrm{jet}}\rvert < 2.4$
Charged Multiplicity	> 0	only for $\lvert\eta_{\mathrm{jet}}\rvert < 2.4$
Charged EM Fraction	< 0.99	only for $\lvert\eta_{\mathrm{jet}}\rvert < 2.4$
	$\lvert\eta_{\mathrm{jet}}\rvert > 3.0$	
Neutral EM Fraction	< 0.90	-
Number of Neutral Particles	> 10	-

Object definition - **Muons**

- Use PF Muons with the *Tight* working point definition.
- relative combined isolation $I^{rel}_{comb} < 0.15$ with $\Delta R = 0.3$
- $\rho \times A_{eff}$ corrections are applied to remove the effects of pileup

Selection variable	value
Reconstructed as Global Muon	True
Particle-Flow muon	True
χ^2/ndof of global muon track fit	< 10
No. of Matched Stations	> 1
No. of muon chamber hits in global-muon track fit	> 0
Transverse Impact parameter w.r.t primary vertex d_{xy} (cm)	< 0.2
Longitudinal distance of tracker track w.r.t primary vertex d_Z (cm)	< 0.55
Number of pixel hits	> 0
Number of tracker layers with hits	> 5
Combined relative isolation I^{rel}_{comb}	< 0.15

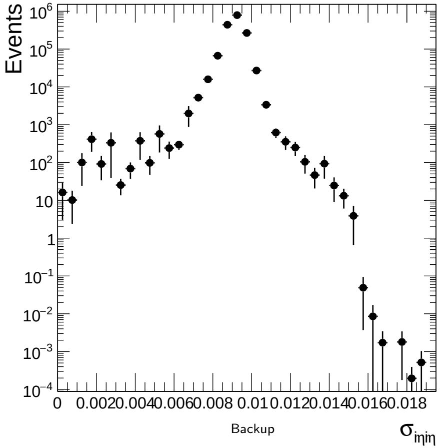
Object definition - **Photons**

- Use cut based *Tight* Photon ID definition.
- PF isolation $\Delta R = 0.3$ and $\rho \times A_{eff}$ corrections are applied to remove the effects of pileup

Selection variable	Barrel	Endcap
Conversion safe electron veto	Yes	Yes
Single Tower H/E	0.05	0.05
$\sigma_{i\eta i\eta}$	0.0100	0.0268
PF charged hadron isolation	0.76	0.556
PF neutral hadron isolation	$0.97 + 0.014 \times p_{\mathrm{T},\gamma} + 0.000019 \times p^2_{\mathrm{T},\gamma}$	$2.09 + 0.014 \times p_{\mathrm{T},\gamma} + 0.000025 \times p^2_{\mathrm{T},\gamma}$
PF photon isolation	$0.08 + 0.0053 \times p_{\mathrm{T},\gamma}$	$0.16 + 0.0034 \times p_{\mathrm{T},\gamma}$

Signal template

- The signal template is taken from the GJets MC, with nominal cuts.
- The photons has to be matched to gen level prompt photons.
- Photons cuts: $p_{\mathrm{T}} > 200$, $|\eta| < 1.4$, tight ID



SideBand template

- The sideband template is taken from Data with no cuts on sigma Ietaleta and ChHadIso $\in [5.0, 8.0]$ GeV
- Photons cuts: $p_{\mathrm{T}} > 200$, $|\eta| < 1.4$