Resent Results from ATLAS and CMS on the Production of Diboson States Associated with Jets

Kenneth Long

University of Wisconsin — Madison

for the ATLAS and CMS Collaborations

Outline

- Introduction and Motivation
- Differential results from ATLAS and CMS
  - ZZ at 8 TeV from CMS
  - WZ at 8 TeV from ATLAS
  - WZ at 13 TeV
  - γγ at 7 TeV from CMS
- Exclusive Results and Jet Vetos from ATLAS and CMS
  - WW at 8 TeV
  - WW at 13 TeV
- Conclusions
- Questions and Discussion

Outline

- **Introduction and Motivation**
- Differential results from ATLAS and CMS
  - ZZ at 8 TeV from CMS
  - WZ at 8 TeV from ATLAS
  - WZ at 13 TeV
  - $\gamma\gamma$ at 7 TeV from CMS
- Exclusive Results and Jet Vetos from ATLAS and CMS
  - WW at 8 TeV
  - WW at 13 TeV
- Conclusions
- Questions and Discussion

Motivation

- Important test of theoretical predictions
  - Direct test of pQCD
    - Jet related observables allow direct probe of higher order corrections
      - LO —> NNLO can increase cross section by ~100%
      - ~40% effects in distributions (pT(V), m(VV), mjj, …)
  - Tests of MC+PS techniques
- Important background: new physics searches, SM measurements
  - New resonances with decays to VV
  - VV+≥2 jets from QCD radiation
    - background to VV VBS and VBF Higgs with diboson decays
- Interplay of theory+experiment
  - Jet vetos or requirements for background rejection in many experimental measurements and searches
    - Large theoretical uncertainty!
  - Experimental constraints improve theory
    - ➡ Improved theory improves experimental reach

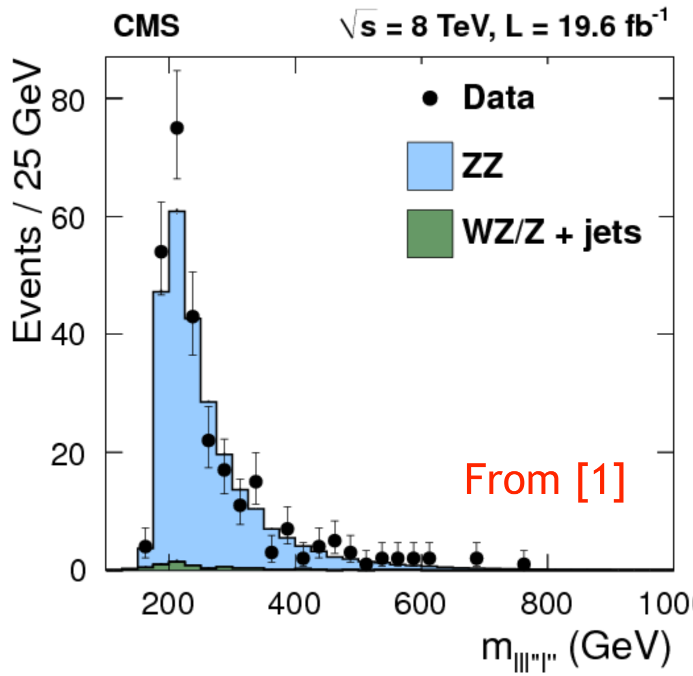
Outline

- Introduction and Motivation
- **Differential results from ATLAS and CMS**
  - ZZ at 8 TeV from CMS
  - WZ at 8 TeV from ATLAS
  - WZ at 13 TeV
  - γγ at 7 TeV from CMS
- Exclusive Results and Jet Vetos from ATLAS and CMS
  - WW at 8 TeV
  - WW at 13 TeV
- Conclusions
- Questions and Discussion

CMS ZZ @ 8 TeV — Overview

CMS-PAS-SMP-15-012

- ZZ $\longrightarrow 4\ell$ (ℓ = e, μ) channel promising for precision VV+jets
  - Very little background
  - ZZ fully reconstructed
  - Currently suffers from low statistics
    - ➡13 TeV data are coming fast!
- New extension of published 8 TeV analysis [1] with jet-related distributions
- Analysis Selection
  - 4 leptons, $p_T^{e\,(\mu)} > 7\ (5)$ GeV
  - $|\eta^{e\,(\mu)}| < 2.5\ (2.4)$
  - $m_{\ell^+\ell^-} \in [60, 120]$ GeV for each Z cand.
- Background
  - Prompt leptons (ttV, VVV, ttVV) — from MC
  - Non-prompt leptons (Z+jets, tt, WZ) — from data
    - "Tight-to-loose" method described in [1]



[1] Physics Letters B 740 (2015) 250-272

CMS ZZ @ 8 TeV — Setup

CMS-PAS-SMP-15-012

- Dominant uncertainties
  - Stats!
  - Systematics
    - Jet Energy Scale, background estimation
- Unfolding via D'Agostini's method
  - MadGraph+MCFM+PHANTOM to build response matrix
  - Response matrix with POWHEG for validation and uncertainty

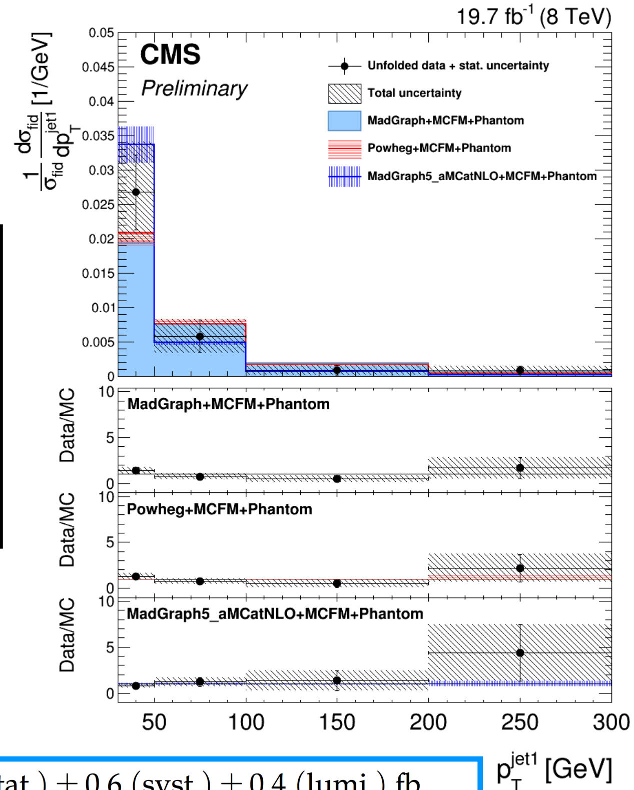
<u>Overview of Signal Monte Carlo</u>

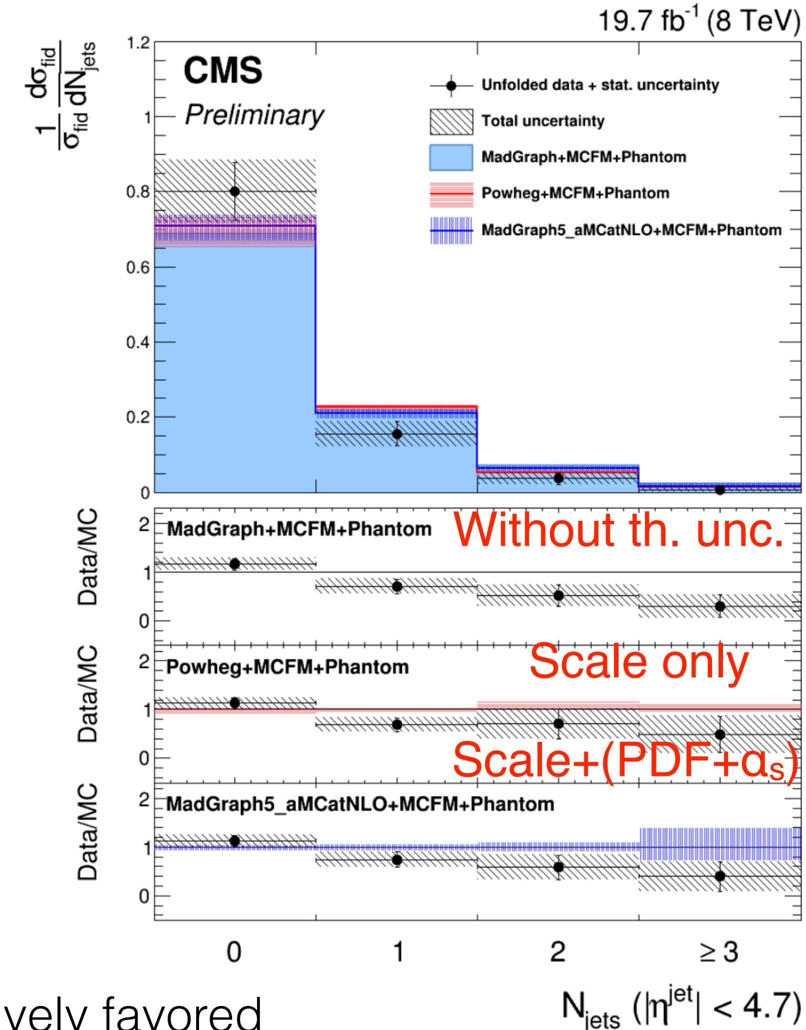
Process	ME Generator	Order / Merging	PS+Had+UE
qq/qg/gg $\longrightarrow$ 4ℓ+nj	POWHEG v2	NLO inc.	PYTHIA 6
	MG5_aMC@NLO	≤1j@NLO FxFx	PYTHIA 8
	MadGraph 5.1	≤2j@LO MLM	PYTHIA 6
gg $\longrightarrow$ 4ℓ	MCFM 6.7	LO inc.	PYTHIA 6
qq/qg/gg $\longrightarrow$ 4ℓ+2j (EWK)	PHANTOM	LO inc.	PYTHIA 6

CMS ZZ @ 8 TeV — Results

CMS-PAS-SMP-15-012

via FASTJET
- anti-k_t R=0.5
- p_T > 30 GeV
- η < 4.7
- $\Delta R(j,\ell)$ > 0.5





$$\sigma_{0\text{ jet}} = 16.3 \pm 1.2\ (\text{stat.}) \pm 0.6\ (\text{syst.}) \pm 0.4\ (\text{lumi.})\ \text{fb}$$
$$\sigma_{1\text{ jet}} = 3.17 \pm 0.62\ (\text{stat.}) \pm 0.38\ (\text{syst.}) \pm 0.08\ (\text{lumi.})\ \text{fb}$$
$$\sigma_{2\text{ jet}} = 0.75 \pm 0.32\ (\text{stat.}) \pm 0.14\ (\text{syst.}) \pm 0.02\ (\text{lumi.})\ \text{fb}$$
$$\sigma_{\geq 3\text{ jet}} = 0.135 \pm 0.104\ (\text{stat.}) \pm 0.045\ (\text{syst.}) \pm 0.004\ (\text{lumi.})\ \text{fb}$$

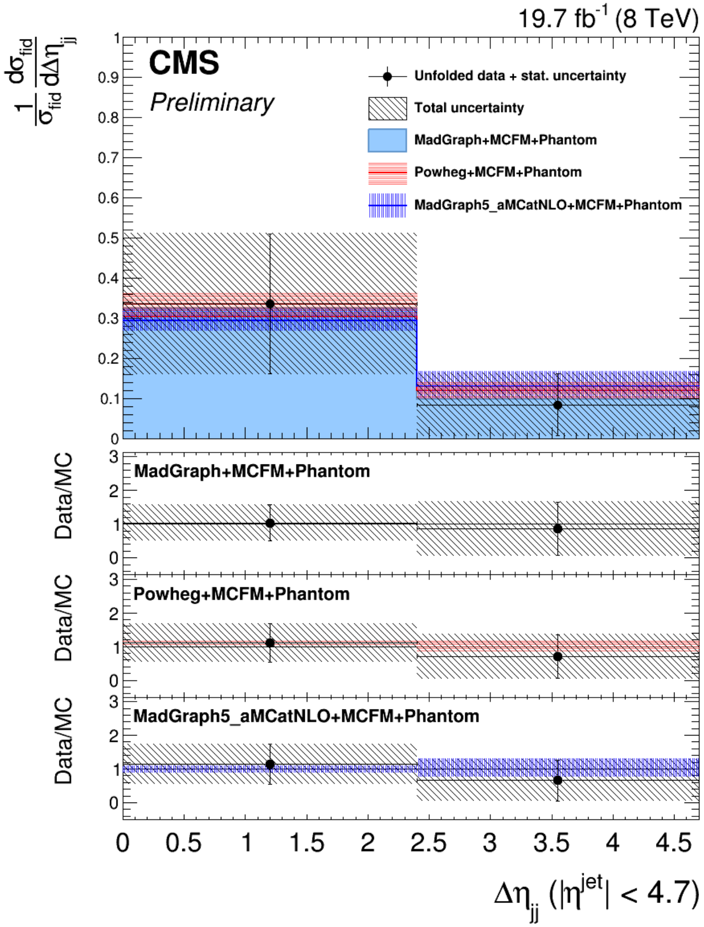
- Conclusions limited by statistics
  - Jet distributions softer in data than MC
  - Modeling differences, but none conclusively favored

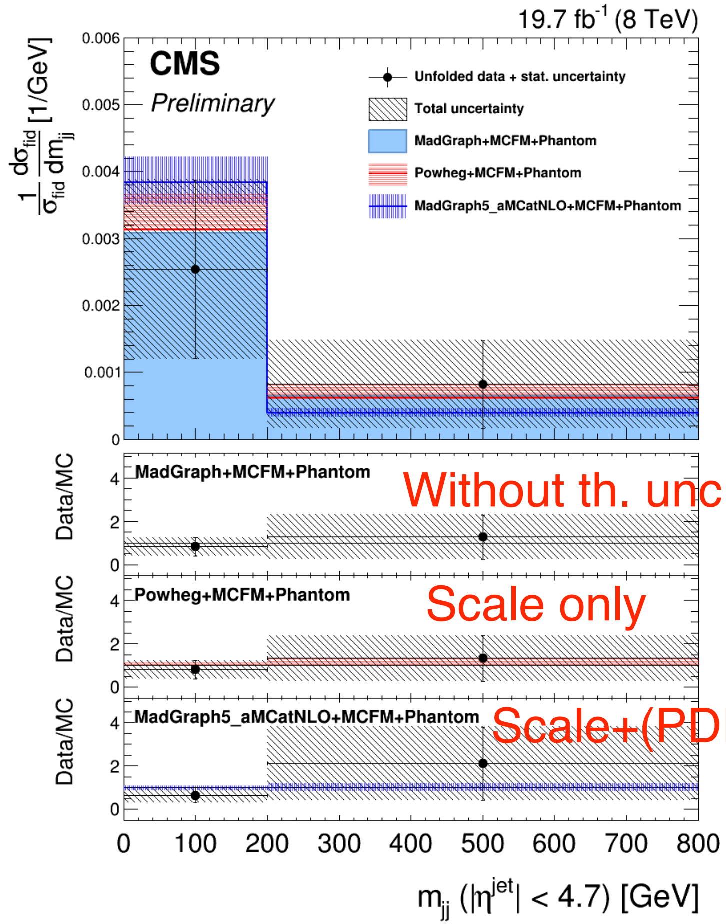
CMS ZZ @ 8 TeV — Results (2)

- Differences in modeling of important VBS variables, none favored by limited data

CMS-PAS-SMP-15-012

via FASTJET
- anti-k_t R=0.5
- p_T > 30 GeV
- η < 4.7
- $\Delta R(j,\ell)$ > 0.5





Without th. unc.

Scale only

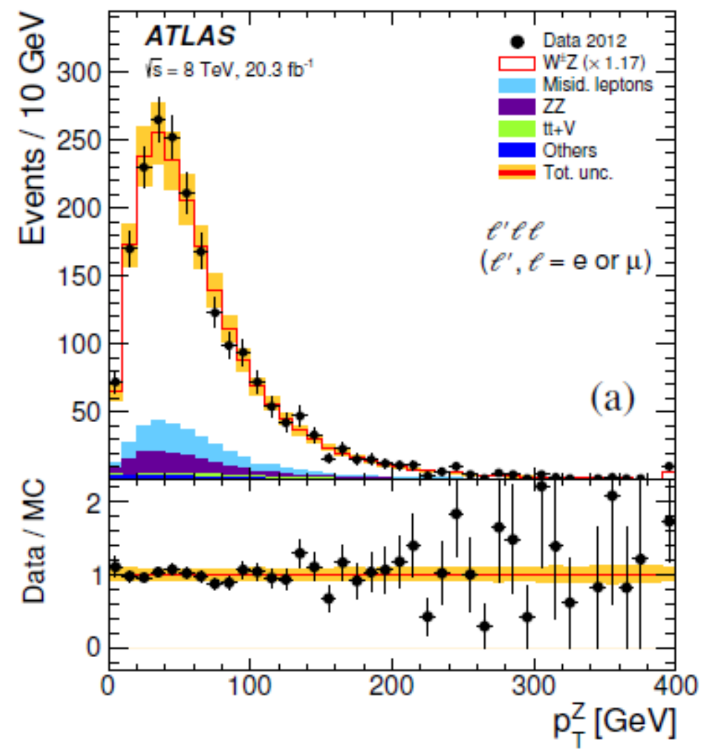
Scale+(PDF+α_s)

- Analysis has exciting potential moving forward in Run II

ATLAS WZ @ 8 TeV — Overview

Phys. Rev. D 93, 092004 (2016)

- WZ ⟶ 3ℓν (ℓ = e, μ) excellent channel for precision VV+jets
  - Less background than WW, Vγ
  - Better statistics than ZZ
  - WZ almost fully reconstructed
- Analysis selection
  - Exactly 3 leptons
  - 2 opposite charge same flavor (OSSF) leptons with $|m_{\ell^+\ell^-} - m_Z^{PDG}| < 10$ GeV
    - Pair closest to m_Z^{PDG} associated with Z
  - Additional lepton $p_T > 20$ GeV
  - $E_T^{miss} > 30$ GeV
- Background
  - Prompt leptons (ZZ (~25%), ttV, tZ, VVV) — from MC
  - Non-prompt leptons (Z+jets, Vγ, tt) — from data (> 50%)
    - "Matrix method" — inversion of matrix of efficiencies and the misidentification probabilities for prompt and fake leptons



ATLAS WZ @ 8 TeV — Setup

Phys. Rev. D 93, 092004 (2016)

- Dominant uncertainties
  - Electron and muon ID efficiencies
  - Mis-ID background — evaluated with comparison to alternative fake rate estimation
- Unfolding via D'Agostini's method
  - Response matrices built from SHERPA and POWHEG+PYTHIA
  - SHERPA (≤3j@LO) used for VBS analysis and jet multiplicity measurement

	eee	μee	$e\mu\mu$	$\mu\mu\mu$	combined
Source	Relative uncertainties [%]				
e energy scale	0.8	0.4	0.4	0.0	0.3
e id. efficiency	2.9	1.8	1.0	0.0	1.0
μ momentum scale	0.0	0.1	0.1	0.1	0.1
μ id. efficiency	0.0	0.7	1.3	2.0	1.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ and jets	0.3	0.2	0.2	0.1	0.3
Trigger	0.1	0.1	0.2	0.3	0.2
Pileup	0.3	0.2	0.2	0.1	0.2
Misid. leptons background	2.9	0.9	3.1	0.9	1.3
ZZ background	0.6	0.5	0.6	0.5	0.5
Other backgrounds	0.7	0.7	0.7	0.7	0.7
Uncorrelated	0.7	0.6	0.5	0.5	0.3
Total systematics	4.5	2.6	3.7	2.5	2.4
Luminosity	2.2	2.2	2.2	2.2	2.2
Statistics	6.2	5.4	5.3	4.7	2.7
Total	8.0	6.3	6.8	5.7	4.2

Overview of Signal Monte Carlo

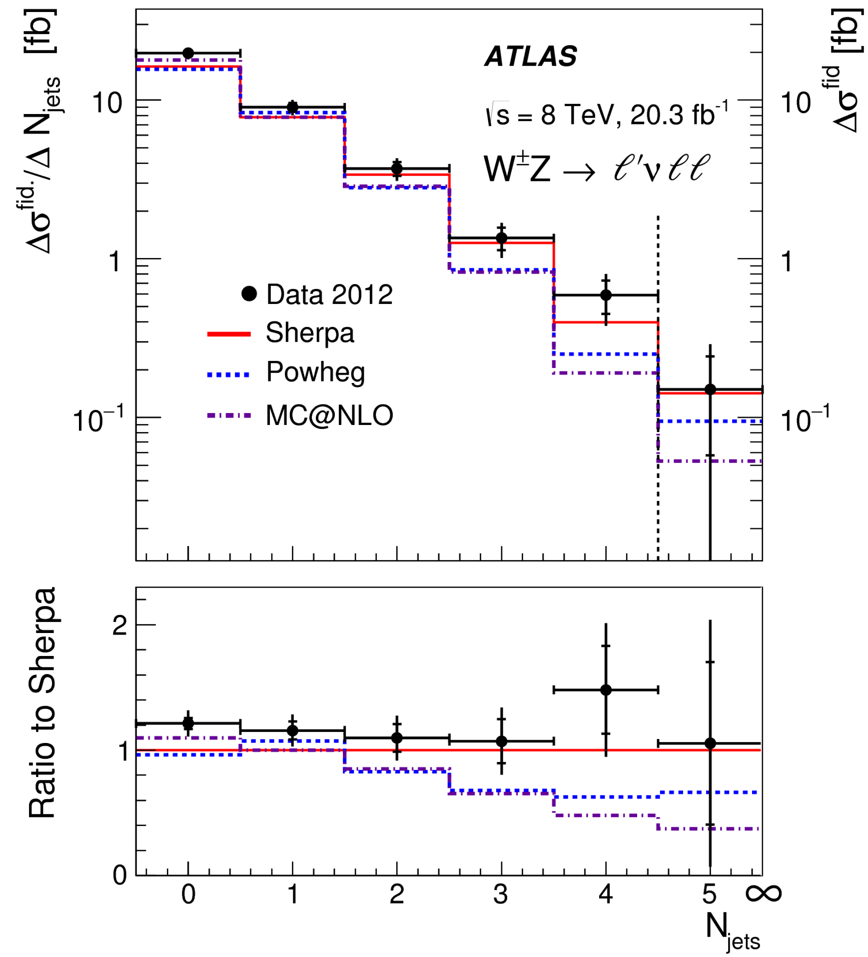
Process	ME Generator	Order / Merging	PS+Had+UE
qq/qg/gg ⟶ 3ℓν+nj	POWHEG	NLO inc.	PYTHIA 8.175
	aMC@NLO 4.0	NLO inc.	HERWIG+JIMMY
	SHERPA 1.4.1	≤3j@LO CKKW	SHERPA

ATLAS WZ @ 8 TeV — Results

- Low systematics allow precise comparisons
- Harder jet spectrum predicted by merged ME predictions via Sherpa favored
- Expected softer jet spectrum from MC@NLO and POWHEG for $n_j > 1$

Phys. Rev. D 93, 092004 (2016)

$N_{\rm jets}$	0	1	2	3	4	≥ 5
$\Delta\sigma^{\rm fid.}_{W^\pm Z}$ [fb]	19.7	9.0	3.7	1.3	0.6	0.15
Relative Uncertainties [%]						
Statistics	3.8	6.3	10.0	16.3	23.6	61.4
All systematics	7.7	8.8	12.8	18.7	27.0	70.4
Luminosity	2.1	2.3	2.5	2.7	3.0	4.8
Total	8.6	10.8	16.3	24.8	35.9	93.4

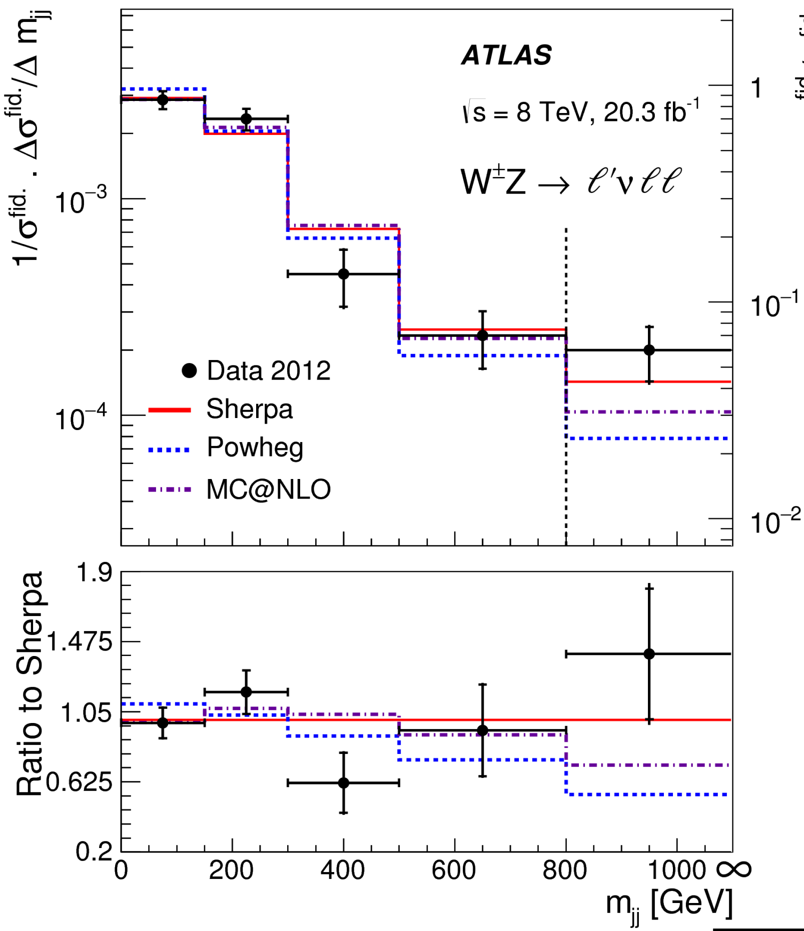


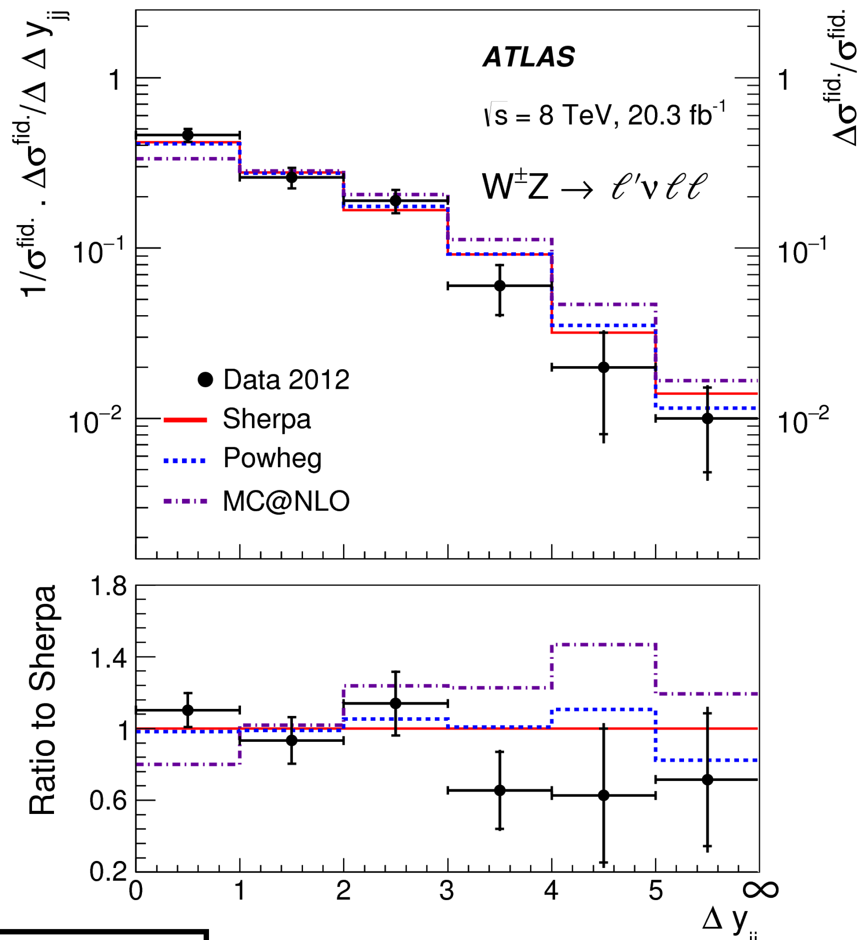
via FASTJET
- anti-k_t R=0.4
- p_T > 25 GeV
- η < 4.5
- $\Delta R(j,\ell)$ > 0.3

ATLAS WZ @ 8 TeV — Results

Phys. Rev. D 93, 092004 (2016)

- Merged LO jet calculations describe data well, but (not shown) theoretical uncertainty still large.
- Merged jets @NLO is here but not yet studied in detail for VV+jets



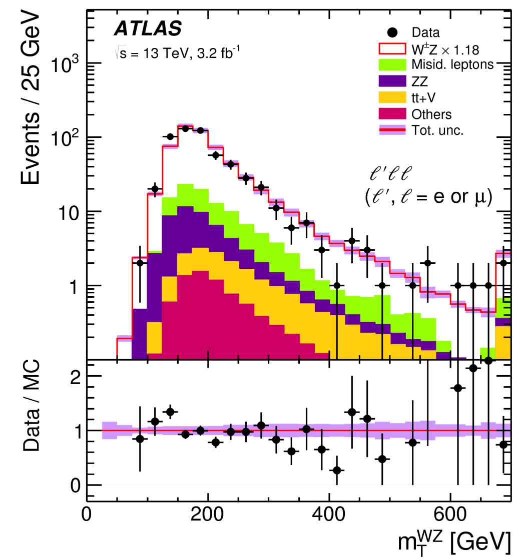


$p_T(j) > 30$ GeV

WZ @ 13 TeV — Overview

- WZ cross section and distributions from CMS and ATLAS with 2.3 fb^{-1} (CMS) and 3.2 fb^{-1} and 13.1 fb^{-1} (ATLAS) with small differences from 8 TeV analyses
- Dominant uncertainties
  - Statistics (better for 13.1 fb^{-1} analysis)
  - Mis-ID background
- Unfolded jet distributions presented by ATLAS with 3.2 fb^{-1}
  - Response matrices built from POWHEG +PYTHIA
- No unfolded distributions from CMS

arXiv:1606.04017
arXiv:1607.06943
ATLAS-CONF-2016-043

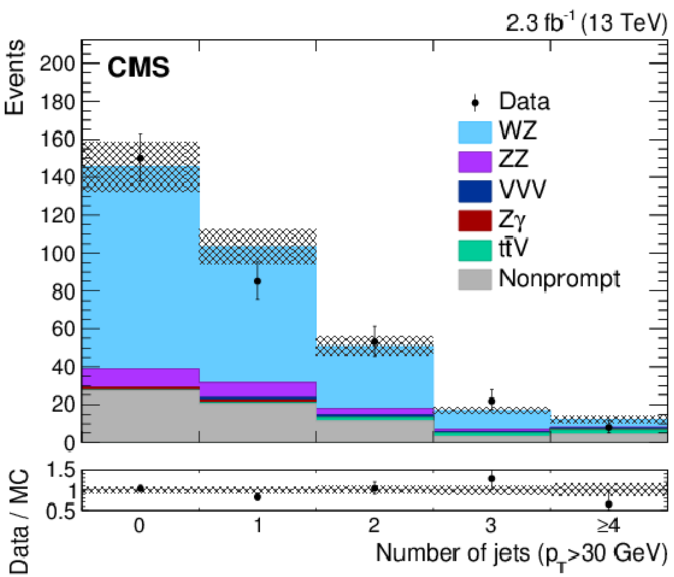


Experiment	ME Generator	Order / Merging	PS+Had+UE
CMS	POWHEG v2	NLO inc.	PYTHIA 8
ATLAS	SHERPA 2.1.1	NLO+≤3j@LO	SHERPA
	POWHEG v2	NLO inc.	PYTHIA 8.210

WZ @ 13 TeV — Results

- Merged prediction from SHERPA convincingly favored
  - Theory uncertainty not shown, but reduced with merged NLO predictions
- 20 fb^{-1} @ 8 TeV ~ 13 fb^{-1} @ 13 TeV
  - Better comparisons coming soon!

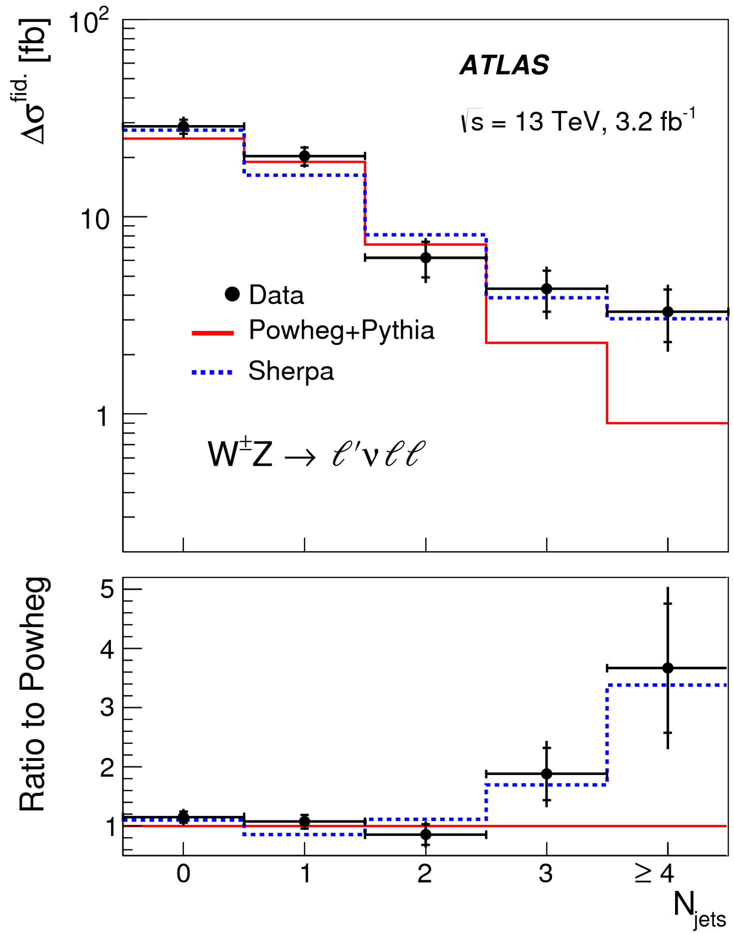
arXiv:1606.04017
arXiv:1607.06943



via FASTJET
- anti-k_t R=0.4

ATLAS
- p_T > 25 GeV
- η < 4.5

CMS
- p_T > 30 GeV
- η < 4.7



CMS γγ @ 7 TeV — Overview

CMS-PAS-SMP-14-021

- Highest statistics test of many aspects of modeling pp collisions
  - Significant contributions from higher pQCD orders (gq channel enters at NLO, strong contribution from gg box diagram at NNLO)
  - Contributions from QED radiation and non-perturbative q/g photon fragmentation functions
- Major background to Higgs discovery channel and searches in γγ channel
- Analysis Selection: $p_T(\gamma) > 40, 25$ GeV; $\Delta R(\gamma_1,\gamma_2) > 0.45$
- Background:
  - "Non-prompt" photons: decays of natural mesons (π_0, η) inside jets (primarily from γ+jets and Z(ee)+jets, and QCD)
    - Distinguished via shower shape in EM calorimeter and isolation
  - Background vs. signal categorization via 2D binned maximum likelihood fit using isolation

CMS γγ @ 7 TeV — Setup

CMS-PAS-SMP-14-021

- Dominant uncertainties
  - Modeling of template variable
    - Evaluated using comparison with isolation templates from simulated events
    - 3% and 4% (barrel, endcap) for prompt, 6% and 9 % non-prompt
- Unfolding via D'Agostini's method
  - Response matrix constructed with SHERPA

Overview of Signal Monte Carlo

ME Generator	PDF Set	Order/Merging	PS+Had+UE
SHERPA[1]	CT10	≤3j@LO CKKW+gg	PYTHIA 6
MG5_aMC@NLO[1]	NNPDF3.0	≤1j@NLO FxFx	PYTHIA 8
PRL111 (2013) 222002[2]		gg+NLO $n_j \geq 1$	None*
PRL 111, 222002[2]		gg+NLO $n_j \geq 2$	None*
PYTHIA 8	NNPDF3.0	gg	PYTHIA 8

[1] Scaled to $\sigma_{\gamma\gamma}$ calculated at NNLO with 2γNNLO [2] Labeled GoSam in plots

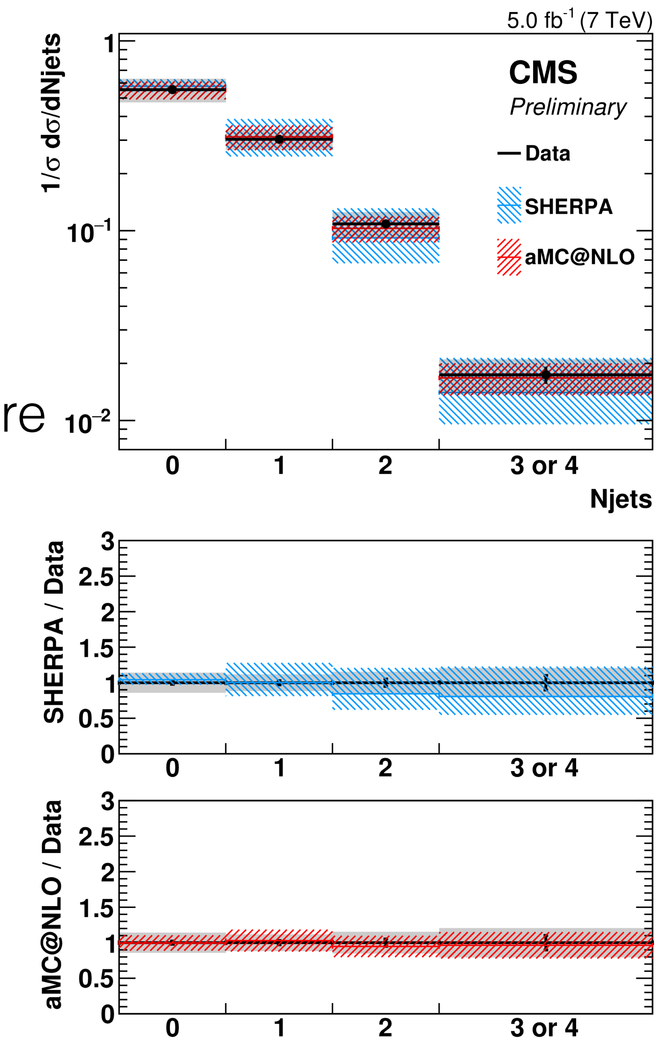
*Correction factor 0.95±0.5 applied to account for PS/Had/UE. Evaluated with PYTHIA 8

CMS γγ @ 8 TeV — Results

- Jet binned cross sections well modeled by gg+LO merged predictions from SHERPA and gg+NLO merged predictions from MG5_aMC@NLO+PYTHIA8
  - ➡ NLO predictions significantly more precise
- Cross section predictions from all generators are consistent and agree with data

via FASTJET
- anti-k_t R=0.5
- p_T > 25 GeV
- η < 4.7
- ΔR(j,γ) > 1.0

CMS-PAS-SMP-14-021



$$\sigma^{1-jet}_{data} = 7.4 \pm 0.2\,(\text{stat.}) \pm 1.0\,(\text{syst.}) \pm 0.2\,(\text{lumi})\ \text{pb}$$

$$\sigma^{2-jet}_{data} = 2.3 \pm 0.1\,(\text{stat.}) \pm 0.4\,(\text{syst.}) \pm 0.1\,(\text{lumi})\ \text{pb}$$

$$\sigma^{1-jet}_{\text{SHERPA}} = 5.9^{+1.9}_{-1.3}\,(\text{scale+stat.})\ \text{pb} \qquad \sigma^{2-jet}_{\text{SHERPA}} = 1.7^{+0.8}_{-0.5}\,(\text{scale+stat.})\ \text{pb}$$

$$\sigma^{1-jet}_{\text{aMC@NLO}} = 8.3^{+1.2}_{-1.2}\,(\text{scale+pdf+stat.})\ \text{pb} \qquad \sigma^{2-jet}_{\text{aMC@NLO}} = 2.5^{+0.4}_{-0.4}\,(\text{scale+pdf+stat.})\ \text{pb}$$

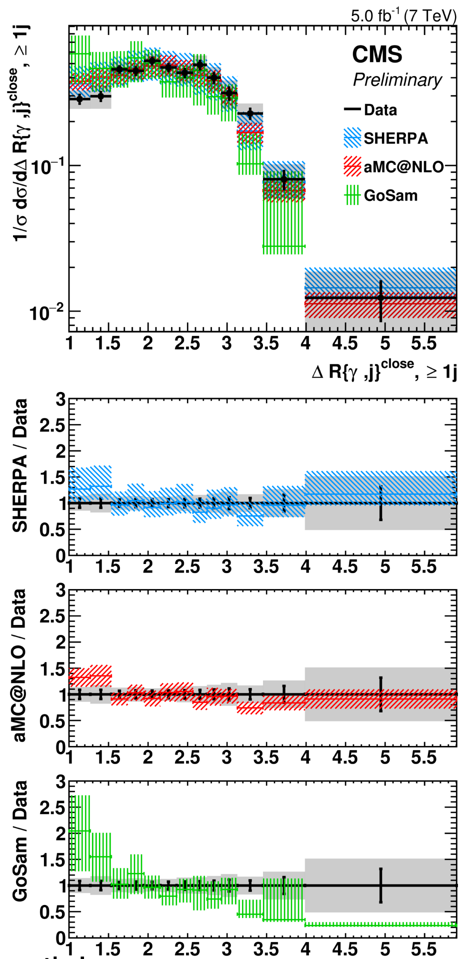
$$\sigma^{1-jet}_{\text{GoSAM}} = 5.8^{+0.9}_{-0.8}\,(\text{scale+stat.})\ \text{pb} \qquad \sigma^{2-jet}_{\text{GoSAM}} = 1.9^{+0.4}_{-0.4}\,(\text{scale+stat.})\ \text{pb}$$

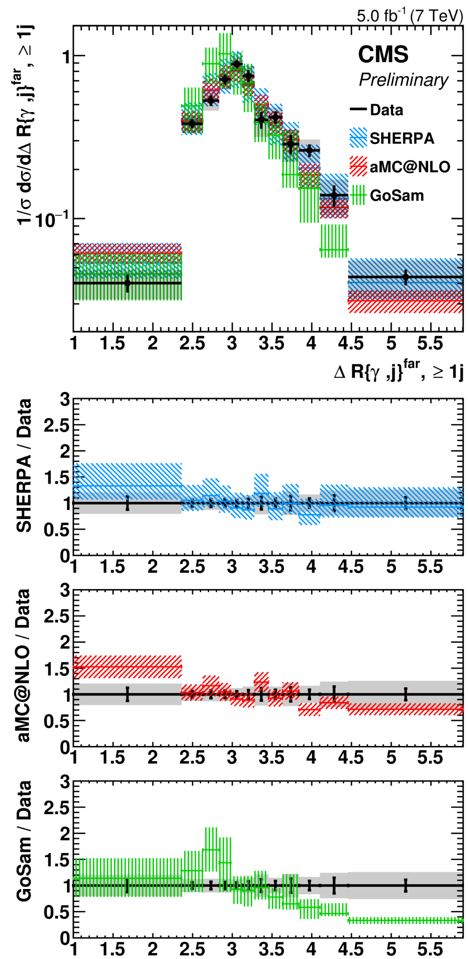
Sherpa and MG5_aMC@NLO+PYTHIA scaled to $\sigma_{\gamma\gamma}$ calculated at NNLO with 2γNNLO

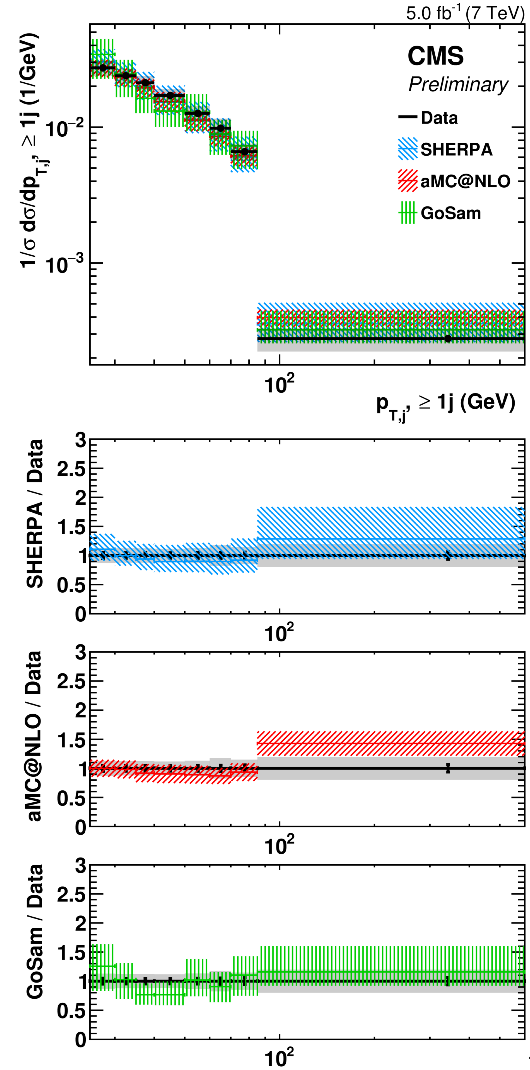
CMS γγ @ 8 TeV — Results

- Fixed order calculation without merging (GoSam) best models $p_T(j)$ but struggles with some topological variables
- ➡ Best results from NLO merged (MG5_aMC@NLO)

CMS-PAS-SMP-14-021





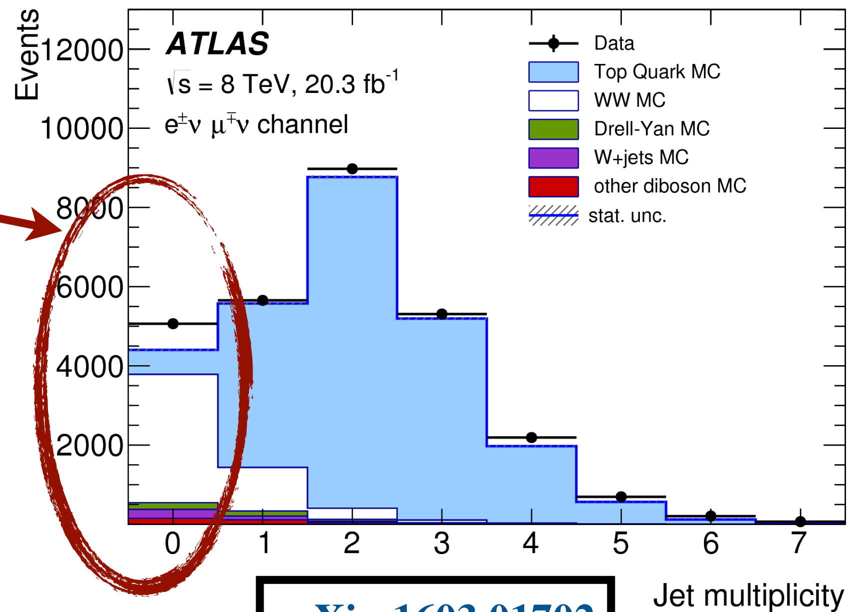


Outline

- Introduction and Motivation
- Differential results from ATLAS and CMS
  - ZZ at 8 TeV from CMS
  - WZ at 8 TeV from ATLAS
  - WZ at 13 TeV
  - γγ at 7 TeV from CMS
- **Exclusive Results and Jet Vetos from ATLAS and CMS**
  - WW at 8 TeV
  - WW at 13 TeV
- Conclusions
- Questions and Discussion

Jet Vetos in Diboson Analyses

- Why apply jet vetos?
  - Suppress background from colored particles
  - Straightforward experimentally...
  - ★ Non-trivial theoretically
    - introduction of a new energy scale, $p_{T,j}^{veto}$
    - partially spoils the cancelation between real and virtual
    - ➡ Large logarithms, need for resummation?
    - Scale variation can underestimate theoretical uncertainty
- Strong interplay between experiment and theory
  - Intense study of resummation in WW motivated by high measurements at 7 TeV
  - Experiment eager to adopt latest results to reduce theoretical uncertainty from jet counting



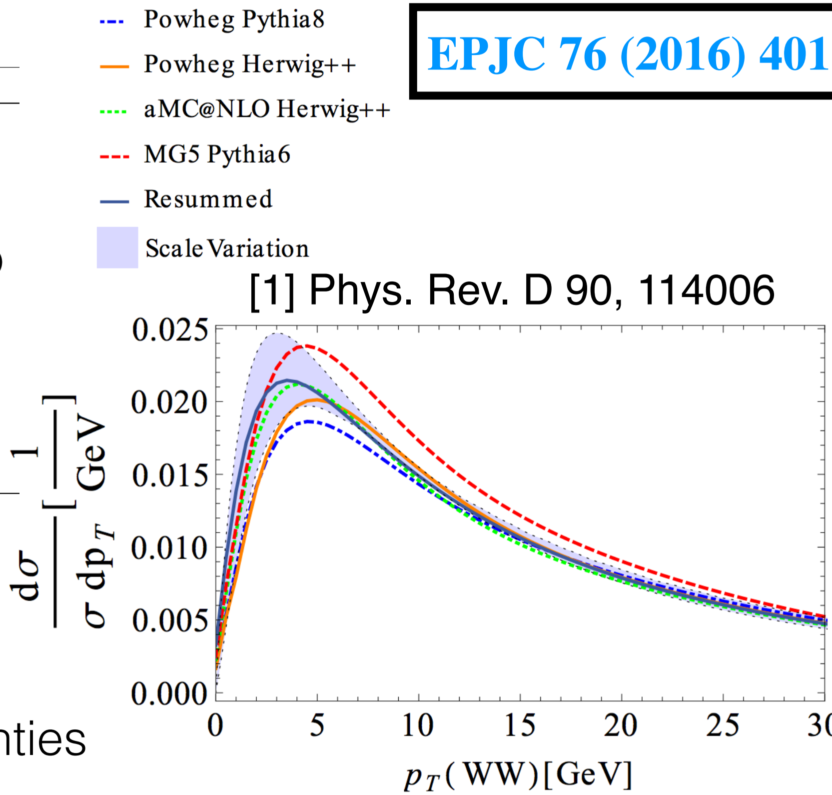
arXiv:1603.01702

Measurements ⇆ Predictions

EPJC 76 (2016) 401

Analysis Selection

Variable	Different-flavor	Same-flavor
Opposite-sign charge requirement	Applied	Applied
p_T^ℓ [GeV]	>20	>20
min(proj. E_T^{miss}, proj. track E_T^{miss})[GeV]	>20	>20
DY MVA	—	>0.88 in zero-jet (>0.84 in one-jet)
$\|m_{\ell\ell} - m_Z\|$ [GeV]	—	>15
$p_T^{\ell\ell}$ [GeV]	>30	>45
$m_{\ell\ell}$ [GeV]	>12	>12
Additional leptons ($p_T^\ell > 10$ GeV)	veto	veto
Top-quark veto	applied	applied
Number of reconstructed jets	<2	<2



[1] Phys. Rev. D 90, 114006

- p_T(WW) distribution reweighted to NLO+NNLL calculation from [1]
  - Jet p_T strongly correlated with p_T(WW)
  - Reduces jet counting and veto uncertainties
- Background
  - Higgs contribution removed using simulation (~4% of final yield)
  - VV and VVV — from MC
  - Top (mostly ttbar and tW) — inverting jet vetos
  - Drell-Yan (inverting mass and MVA vetoes)
  - Non-prompt background from (mis-ID in W+jets) — "Tight-to-loose" method

WW @ 8 TeV — CMS: Results

- Comparison with predictions from POWHEG reweighted to p_T(WW) spectrum from NLO +NNLL
  - allows study of jet veto behavior
  - Only statistical error on POWHEG predictions
- Theoretical error small in total cross section, very small in fiducial region
  - fiducial definition: $n_j = 0$ and $p_T^{veto}(j)$)

EPJC 76 (2016) 401

σ_{W+W-} = 60.1 ± 0.9 (stat) ± 3.2 (exp) ± 3.1 (theo) ±1.6 (lumi) pb

$$\sigma_{NNLO} = 59.8^{+1.3}_{-1.1} \text{ pb}$$

via Phys. Rev. Lett. 113, 212001

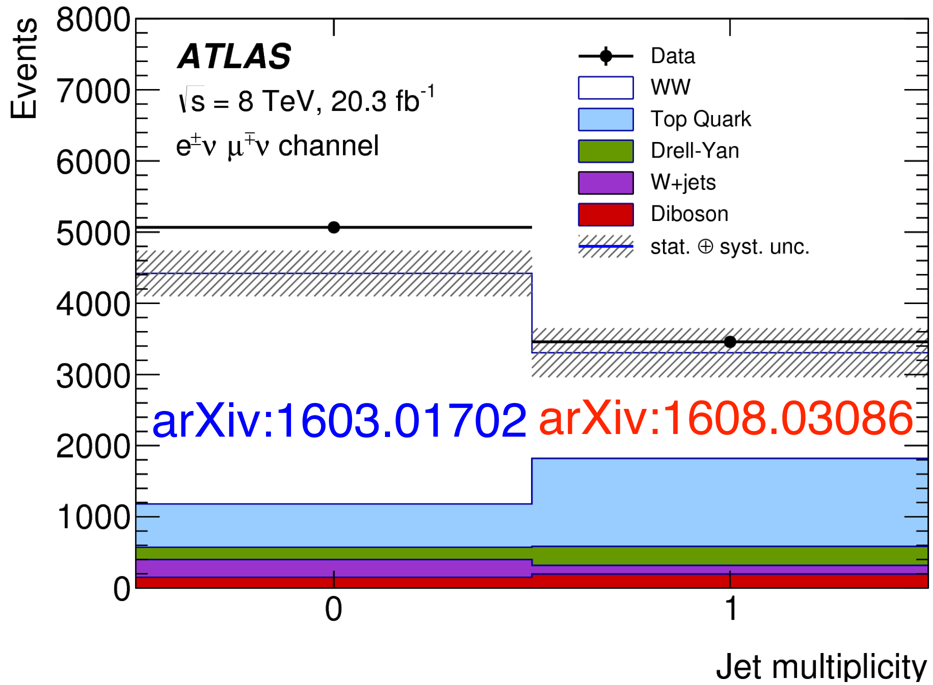
Uncertainty on σ_{tot}

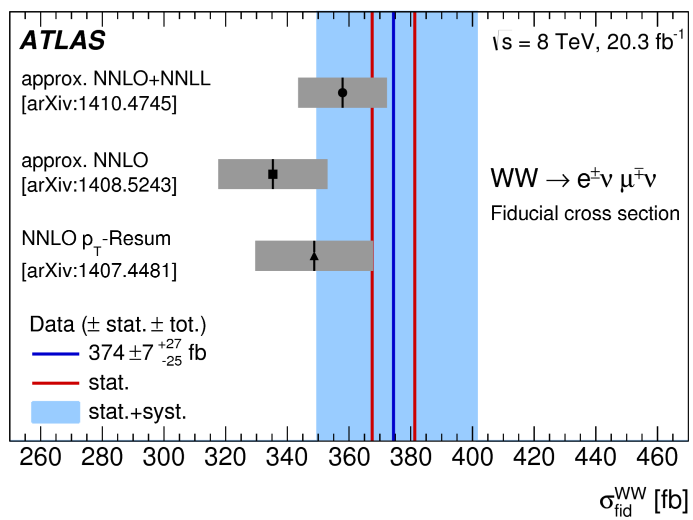
Source	Uncertainty (%)
Statistical uncertainty	1.5
Lepton efficiency	3.8
Lepton momentum scale	0.5
Jet energy scale	1.7
E_T^{miss} resolution	0.7
$t\bar{t}$+tW normalization	2.2
W +jets normalization	1.3
$Z/\gamma^* \to \ell^+\ell^-$ normalization	0.6
$Z/\gamma^* \to \tau^+\tau^-$ normalization	0.2
$W\gamma$ normalization	0.3
$W\gamma^*$ normalization	0.4
VV normalization	3.0
$H \to W^+W^-$ normalization	0.8
Jet counting theory model	4.3
PDFs	1.2
MC statistical uncertainty	0.9
Integrated luminosity	2.6
Total uncertainty	7.9

p_T^{jet} (GeV)	$\sigma_{zero\text{-}jet}$ measured (pb)	$\sigma_{zero\text{-}jet}$ predicted (pb)
>20	36.2 ± 0.6 (stat) ± 2.1 (exp) ± 1.1 (theo) ± 0.9 (lumi)	36.7 ± 0.1 (stat)
>25	40.8 ± 0.7 (stat) ± 2.3 (exp) ± 1.3 (theo) ± 1.1 (lumi)	40.9 ± 0.1 (stat)
>30	44.0 ± 0.7 (stat) ± 2.5 (exp) ± 1.4 (theo) ± 1.1 (lumi)	43.9 ± 0.1 (stat)

includes μ_R, μ_F, resummation, and underlying event uncertainties

- 0 and 1 jet channels separate analyses
  - WW+1j analysis considers only eμ channel
- 0 jet
  - Reject top background
  - No b-tagging uncertainty
  - ➡ Increased theory uncertainty extrapolation to σ_{tot}
- Fiducial cross section (eμ channel)
  - ➡ Total uncertainty ~7%
  - Jet Energy Scale — 4%
  - W+jets background — 3%
  - Luminosity — 2%
  - Theory — < 1%
- Total cross section — 8.6% uncertainty
  - jet veto (3.4%), PS+hadronization +UE (2.5%)

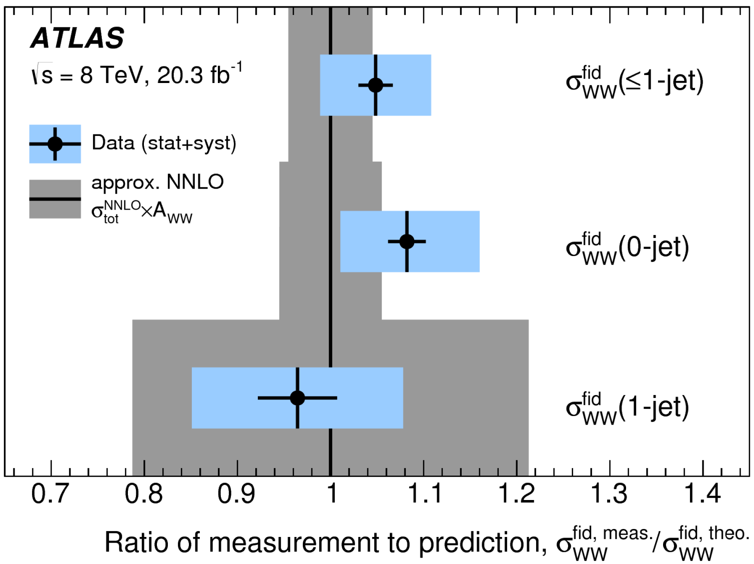


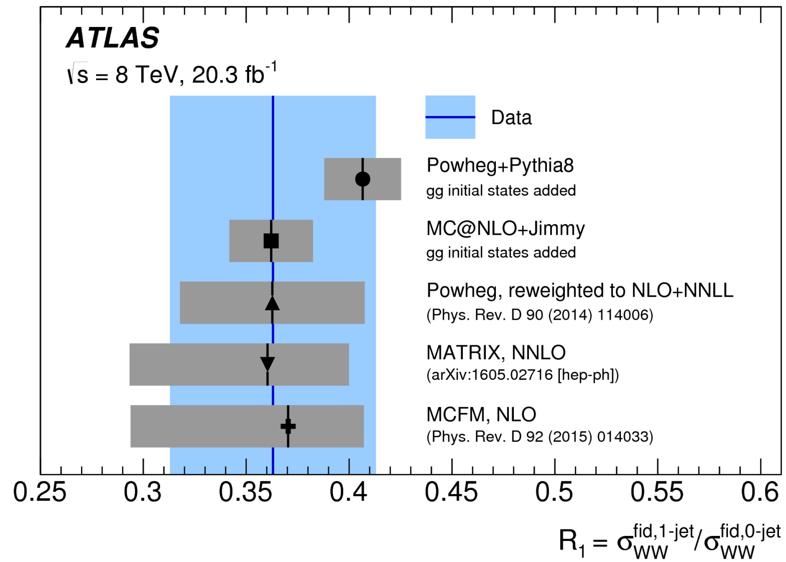


WW @ 8 TeV — ATLAS: 1 jet

arXiv:1603.01702

- Extend previous analysis, decreasing dependence on jet veto — Add tight b-jet veto
  - Reduces theoretical uncertainty
  - Reduces uncertainty in fiducial and total cross section
  - Improves agreement with NNLO prediction





0 jet only: $\sigma_{tot} = 71.1 \pm 1.1(\text{stat})^{+5.7}_{-5.0}(\text{syst}) \pm 1.4(\text{lumi})$ pb

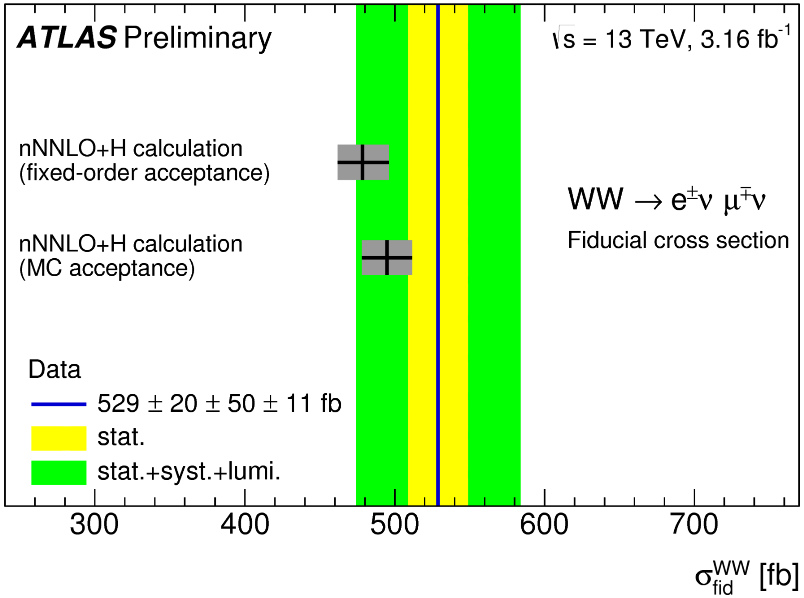
0+1 jet $\boxed{\sigma_{tot} = 68.2 \pm 1.2(\text{stat}) \pm 3.4(\text{syst}) \pm 2.8(\text{theo}) \pm 1.4(\text{lumi}) \text{ pb}}$

$\sigma_{NNLO} : = 65.0^{+1.2}_{-1.1}$ pb

WW @ 13 TeV — Results

- Small differences from 8 TeV measurements
  - Only eμ channel
  - CMS: 0,1 j bins; simplify b-jet veto
  - ATLAS: Only 0 j bin, add b-jet veto
- Data well described by best available calculations
  - ➡Era of precision 13 TeV measurements still to come

CMS-PAS-SMP-16-006
ATLAS-CONF-2016-090



$$\sigma_{\text{NNLO+NNLL}} = 120.3 \pm 3.0 \text{ pb}$$

via Phys. Lett. B754 (2016) 275-280

CMS

Category	Value ± stat. ± exp. syst. ± theo. syst. ± lumi. [pb]
0-jet	$113.6 \pm 6.3 \pm 5.1 \pm 6.5 \pm 3.3$
1-jet	$135.3 \pm 15.4 \pm 34.0 \pm 14.4 \pm 6.0$
Combination	$115.3 \pm 5.8 \pm 5.7 \pm 6.4 \pm 3.6$

Conclusions

- Measurements of dibosons associated with jets have potential to test many aspects of predictions for LHC collisions
  - A variety analyses with Run I data have controlled systematics to allow detailed comparisons
  - Cross sections and more already measured at 13 TeV in WW, WZ, ZZ, Zγ etc.
    - Expanded analyses coming soon
- Strong interplay between theory and experiment
  - Run I diboson results pushing theory
    - NNLO revolution
    - Studies of resummation pushed by WW measurements
  - Experiment quick to adopt new theory developments for comparisons, background modeling, and phase space extrapolation
- With the LHC accumulating 13 TeV data rapidly, precise measurements in a new regime are on the way!

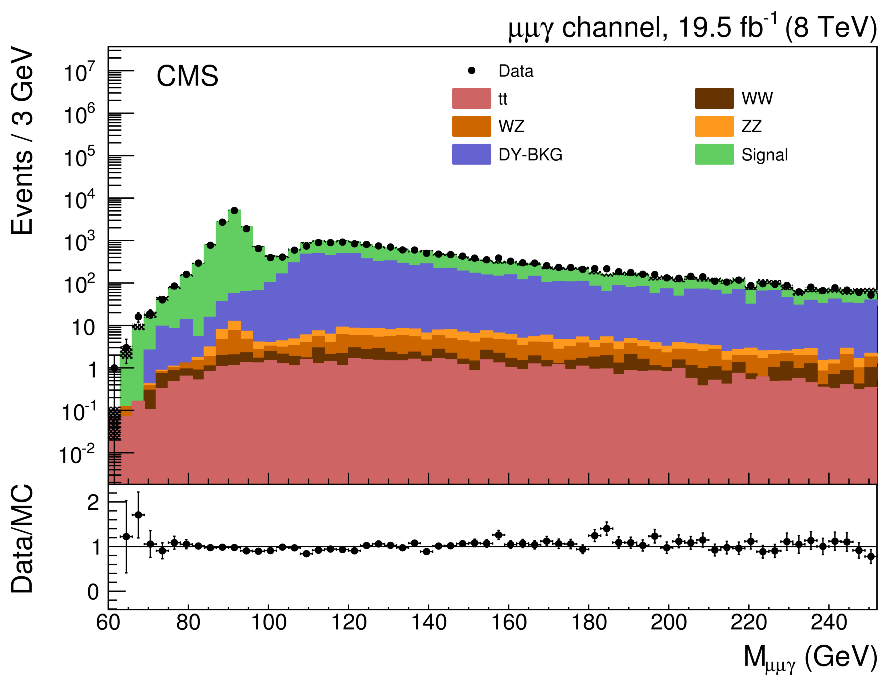
Backup

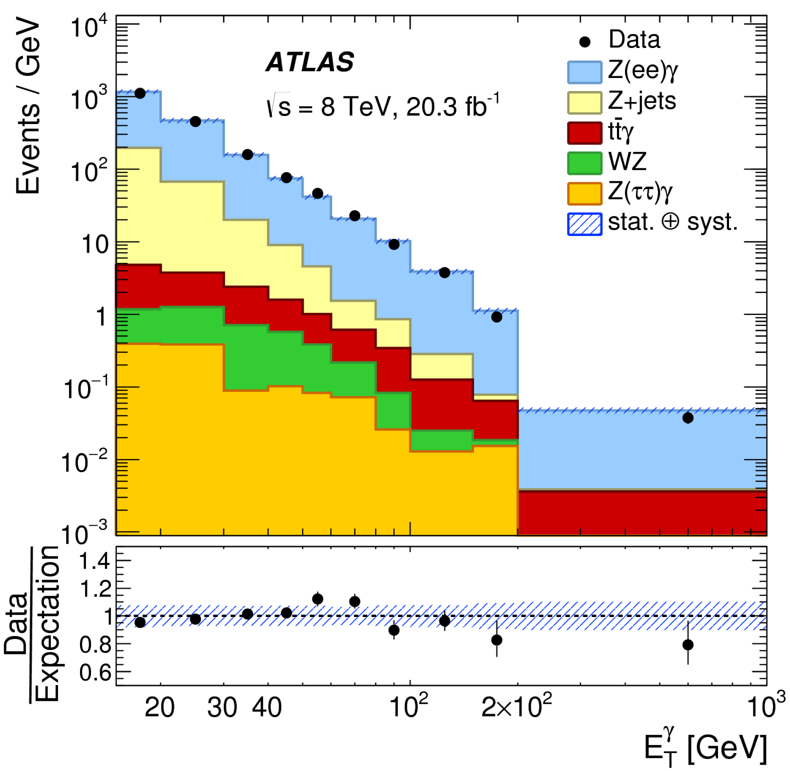
Zγ @ 8 TeV — Overview

- $E_T(\gamma) > 15$ GeV and $\Delta R(l, \gamma) > 0.7$
- Two good OSSF leptons, (ℓ = e, μ)
  - ATLAS: $p_T(\ell) > 25$ GeV; $m_{\ell\ell} > 40$ GeV
  - CMS: $p_T(\ell) > 30$ GeV; $m_{\ell\ell} > 50$ GeV

Phys. Rev. D 93, 112002 (2016)

JHEP 04 (2015) 164

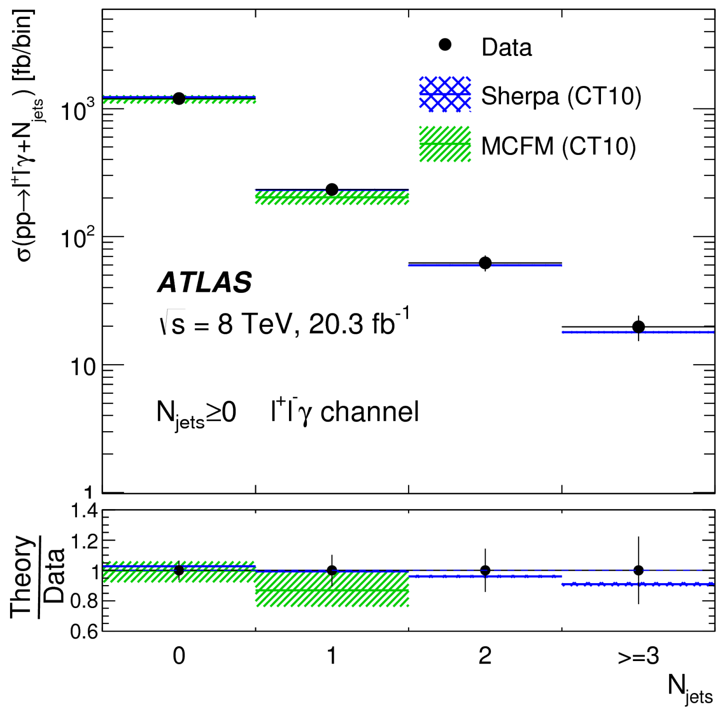




ATLAS Zγ @ 8 TeV — Results

Phys. Rev. D 93, 112002 (2016)

- Compare to fixed-order NLO calculation from MCFM (max 1 jet) and LO merged from Sherpa (≤3j@LO CKKW)
- Sherpa models data well
  - Scale variations large at LO, only statistical error shown



Channel	Measurement [fb]	MCFM Prediction [fb]	NNLO Prediction [fb]
	$N_{\text{jets}} \geq 0$		
$e^+e^-\gamma$	$1510 \pm 15(\text{stat.})^{+91}_{-84}(\text{syst.})^{+30}_{-28}(\text{lumi.})$	1345^{+66}_{-82}	1483^{+19}_{-37}
$\mu^+\mu^-\gamma$	$1507 \pm 13(\text{stat.})^{+78}_{-73}(\text{syst.})^{+29}_{-28}(\text{lumi.})$		
$\ell^+\ell^-\gamma$	$1507 \pm 10(\text{stat.})^{+78}_{-73}(\text{syst.})^{+29}_{-28}(\text{lumi.})$		
$\nu\bar{\nu}\gamma$	$68 \pm 4(\text{stat.})^{+33}_{-32}(\text{syst.}) \pm 1(\text{lumi.})$	68.2 ± 2.2	$81.4^{+2.4}_{-2.2}$
	$N_{\text{jets}} = 0$		
$e^+e^-\gamma$	$1205 \pm 14(\text{stat.})^{+84}_{-75}(\text{syst.}) \pm 23(\text{lumi.})$	1191^{+71}_{-89}	1230^{+10}_{-18}
$\mu^+\mu^-\gamma$	$1188 \pm 12(\text{stat.})^{+68}_{-63}(\text{syst.})^{+23}_{-22}(\text{lumi.})$		
$\ell^+\ell^-\gamma$	$1189 \pm 9(\text{stat.})^{+69}_{-63}(\text{syst.})^{+23}_{-22}(\text{lumi.})$		
$\nu\bar{\nu}\gamma$	$43 \pm 2(\text{stat.}) \pm 10(\text{syst.}) \pm 1(\text{lumi.})$	$51.0^{+2.1}_{-2.3}$	$49.21^{+0.61}_{-0.52}$

$p_T(\gamma) > 15$

JHEP 04 (2015) 164

Measured Cross Section

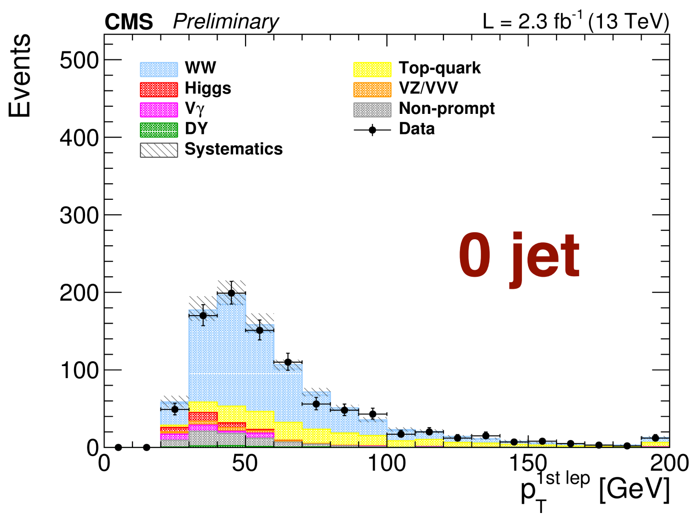
$$\sigma_{\text{incl}} = 2063 \pm 19\,(\text{stat}) \pm 98\,(\text{syst}) \pm 54\,(\text{lumi})\,\text{fb},$$
$$\sigma_{\text{excl}} = 1770 \pm 18\,(\text{stat}) \pm 115\,(\text{syst}) \pm 46\,(\text{lumi})\,\text{fb}.$$

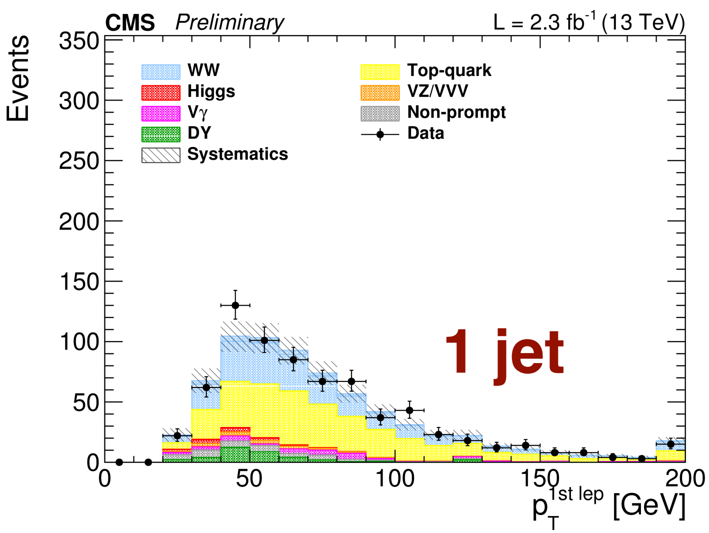
Monte Carlo	Order	σ_{incl} (fb)	σ_{excl} (fb)
MCFM	NLO	2100 ± 120	1800 ± 120
Phys. Lett. B 731 (2014) 204	NNLO	2241 ± 22	—

WW @ 13 TeV — Overview

- Small differences from 8 TeV measurement
  - Only eμ channel
  - Simplify b-jet veto
  - Background method identical to 8 TeV

CMS-PAS-SMP-16-006
ATLAS-CONF-2016-090

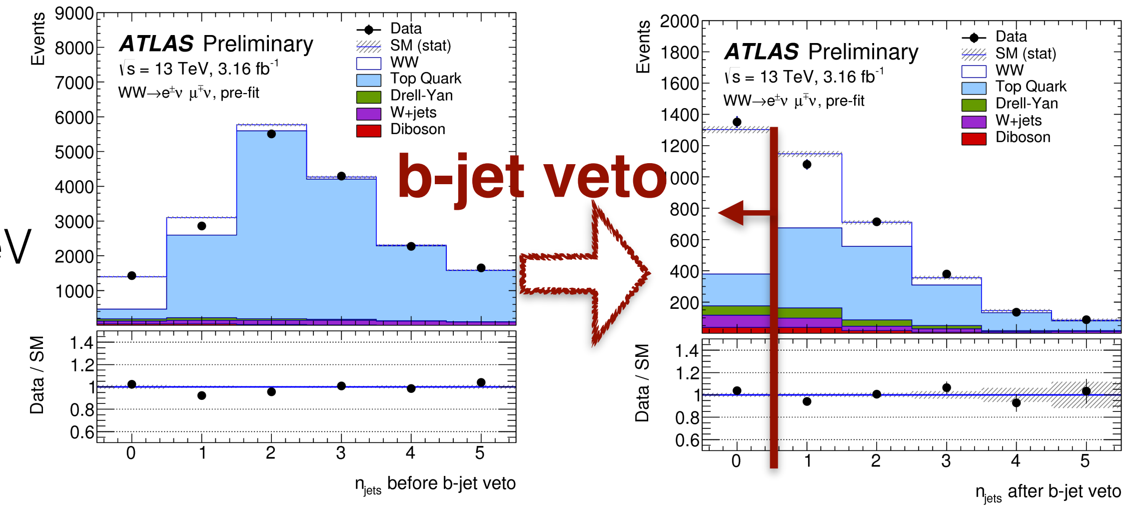




ATLAS WW @ 13 TeV — Details

ATLAS-CONF-2016-090

- Small differences from 8 TeV measurement
  - Only eμ channel
  - Lepton p_T cut moved to 25/25 GeV (from of 25/20 GeV)
  - Veto b-jets with $p_T > 20$ GeV $|\eta| < 2.4$, all jets $p_T > 25$)
- Extract σ_{fid} via simultaneous fit of signal +control regions



$$\sigma_{WW} = 142 \pm 5\,(\text{stat}) \pm 13\,(\text{syst}) \pm 3.0\,(\text{lumi})\ \text{pb}$$

$$\text{NNLO qq + NLO gg + N}^3\text{LO ggH: } \sigma_{WW} = 128.4^{+3.5}_{-3.8}\ \text{pb}$$