(V+)jets measurements with ATLAS and CMS

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Introduction

- We present latest Run-1 results at $\sqrt{s} = 8$ TeV and recent Run-2 results at $\sqrt{s} = 13$ TeV
- Measurements are unfolded to particle-level and compared to the state-fo-the-art theory predictions
- Jet production studies are presented in the first part
  - Inclusive jets and dijets
  - Cross section dependence on the jet radius
  - Azimuthal correlations in multi-jet event topologies
  - Strong coupling extraction
- Second part is devoted to the V+jets ($\gamma/W/Z$ +jet) cross sections measurements

Results shown are selected according to our preference for all jet measurements from ATLAS and CMS.

More Standard Model results:
CMS ATLAS

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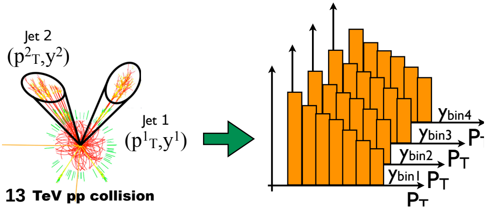
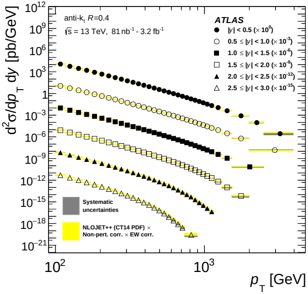
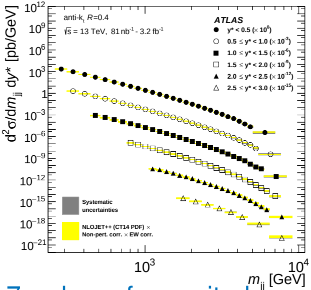
Inclusive jet and dijet cross sections at 13 TeV







- $p_T > 100$ GeV, binned according to resolution
- $|y| < 3$, six rapidity bins, in steps of 0.5
- Theory: NLOJET++ × NPC × EW
- non-pert. correction : Pythia/Herwig with various tunes
- theory is corrected for EW effects

Good agreement between data and theory over 7 orders of magnitude

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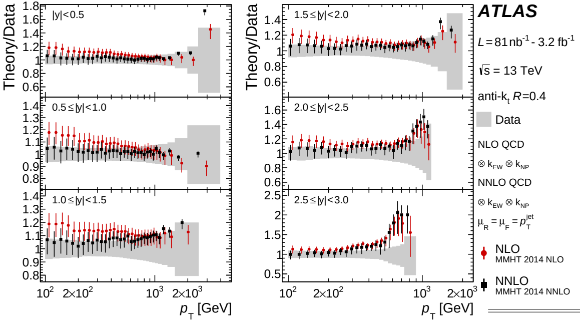
Inclusive jet and dijet cross sections at 13 TeV



- Compared to both NLO and NNLO calculations
- Reasonable p-values in individual y-bins

χ^2/dof all $\lvert y\rvert$ bins	CT14	MMHT 2014	NNPDF 3.0	HERAPDF 2.0	ABMP16
p_T^{max}	419/177	431/177	404/177	432/177	475/177
p_T^{jet}	399/177	405/177	384/177	428/177	455/177

- Very large χ^2 values for the combined fit

Rapidity ranges	P_{obs} CT14	MMHT 2014	NNPDF 3.0	HERAPDF 2.0	ABMP16
p_T^{max}					
$\lvert y\rvert < 0.5$	67%	65%	62%	31%	50%
$0.5 \le \lvert y\rvert < 1.0$	5.8%	6.3%	6.0%	3.0%	2.0%
$1.0 \le \lvert y\rvert < 1.5$	65%	61%	67%	50%	55%
$1.5 \le \lvert y\rvert < 2.0$	0.7%	0.8%	0.8%	0.1%	0.4%
$2.0 \le \lvert y\rvert < 2.5$	2.3%	2.3%	2.8%	0.7%	1.5%
$2.5 \le \lvert y\rvert < 3.0$	62%	71%	69%	25%	55%
p_T^{jet}					
$\lvert y\rvert < 0.5$	69%	67%	66%	30%	46%
$0.5 \le \lvert y\rvert < 1.0$	7.4%	8.9%	8.6%	3.4%	2.0%
$1.0 \le \lvert y\rvert < 1.5$	69%	62%	68%	45%	54%
$1.5 \le \lvert y\rvert < 2.0$	1.3%	1.6%	1.4%	0.1%	0.5%
$2.0 \le \lvert y\rvert < 2.5$	8.7%	6.6%	7.4%	1.0%	3.6%
$2.5 \le \lvert y\rvert < 3.0$	65%	72%	72%	28%	59%

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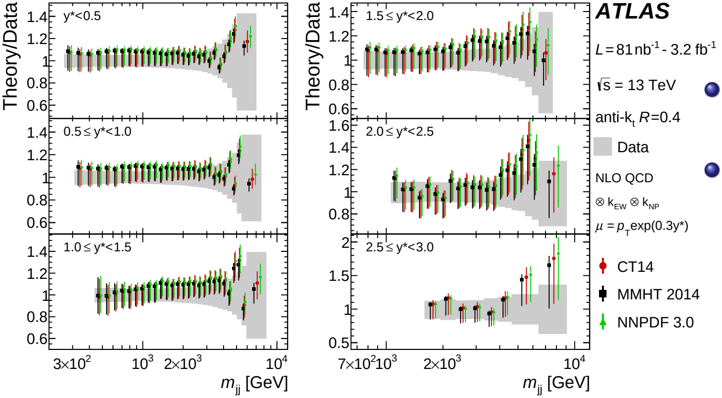
Inclusive jet and dijet cross sections at 13 TeV



- Dijet mass distribution
- Very good p-values in individual y^*-bins.

- Reasonable numbers for the combined fit

y^* ranges	CT14	MMHT 2014	NNPDF 3.0	HERAPDF 2.0	ABMP16
	P_{obs}				
$y^* < 0.5$	79%	59%	50%	71%	71%
$0.5 \le y^* < 1.0$	27%	23%	19%	32%	31%
$1.0 \le y^* < 1.5$	66%	55%	48%	66%	69%
$1.5 \le y^* < 2.0$	26%	26%	28%	9.9%	25%
$2.0 \le y^* < 2.5$	41%	34%	29%	3.6%	20%
$2.5 \le y^* < 3.0$	45%	46%	40%	25%	38%
all y^* bins	9.4%	6.5%	11%	0.1%	5.1%

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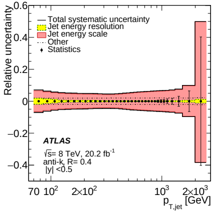
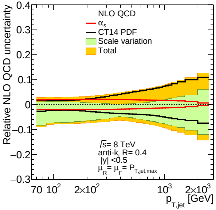
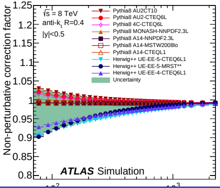
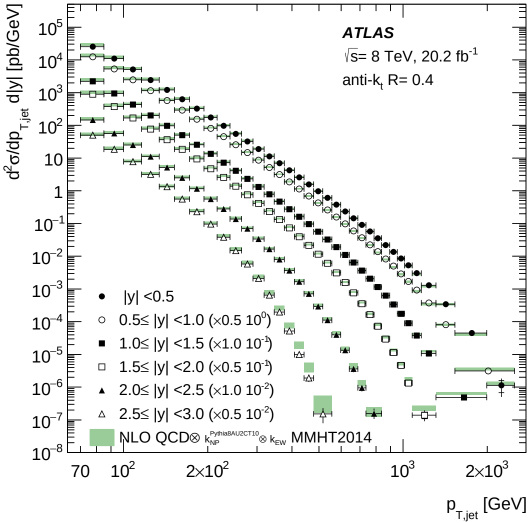
Inclusive jet cross sections at 8 TeV









- two jet sizes are studied : R=0.4 and R=0.6

Inclusive jet cross sections at 8 TeV

χ^2/ndf	$p_{\text{T}}^{\text{jet,max}}$ $R=0.4$	$R=0.6$	$p_{\text{T}}^{\text{jet}}$ $R=0.4$	$R=0.6$
$p_{\text{T}} > 70$ GeV				
CT14	349/171	398/171	340/171	392/171
HERAPDF2.0	415/171	424/171	405/171	418/171
NNPDF3.0	351/171	393/171	350/171	393/171
MMHT2014	356/171	400/171	354/171	399/171
$p_{\text{T}} > 100$ GeV				
CT14	321/159	360/159	313/159	356/159
HERAPDF2.0	385/159	374/159	377/159	370/159
NNPDF3.0	333/159	356/159	331/159	356/159
MMHT2014	335/159	364/159	333/159	362/159
100 ¡ $p_{\text{T}} < 900$ GeV				
CT14	272/134	306/134	262/134	301/134
HERAPDF2.0	350/134	331/134	340/134	326/134
NNPDF3.0	289/134	300/134	285/134	299/134
MMHT2014	292/134	311/134	284/134	308/134
100 ¡ $p_{\text{T}} < 400$ GeV				
CT14	128/72	149/72	118/72	145/72
HERAPDF2.0	148/72	175/72	141/72	170/72
NNPDF3.0	119/72	141/72	115/72	139/72
MMHT2014	132/72	143/72	122/72	140/72

- Compared to NLO calculations
- Reasonable p-values in individual y-bins
- Very large χ^2 values for the combined fit

$p_{\text{T}} > 100$ GeV

$\Downarrow$

Rapidity ranges	P_{obs} CT14	MMHT2014	NNPDF3.0	HERAPDF2.0
Anti-k_t jets $R = 0.4$				
$\lvert y\rvert < 0.5$	44%	28%	25%	16%
$0.5 \leq \lvert y\rvert < 1.0$	43%	29%	18%	18%
$1.0 \leq \lvert y\rvert < 1.5$	44%	47%	46%	69%
$1.5 \leq \lvert y\rvert < 2.0$	3.7%	4.6%	7.7%	7.0%
$2.0 \leq \lvert y\rvert < 2.5$	92%	89%	89%	35%
$2.5 \leq \lvert y\rvert < 3.0$	4.5%	6.2%	16%	9.6%
Anti-k_t jets $R = 0.6$				
$\lvert y\rvert < 0.5$	6.7%	4.9%	4.6%	1.1%
$0.5 \leq \lvert y\rvert < 1.0$	1.3%	0.7%	0.4%	0.2%
$1.0 \leq \lvert y\rvert < 1.5$	30%	33%	47%	67%
$1.5 \leq \lvert y\rvert < 2.0$	12%	16%	15%	3.1%
$2.0 \leq \lvert y\rvert < 2.5$	94%	94%	91%	38%
$2.5 \leq \lvert y\rvert < 3.0$	13%	15%	20%	8.6%

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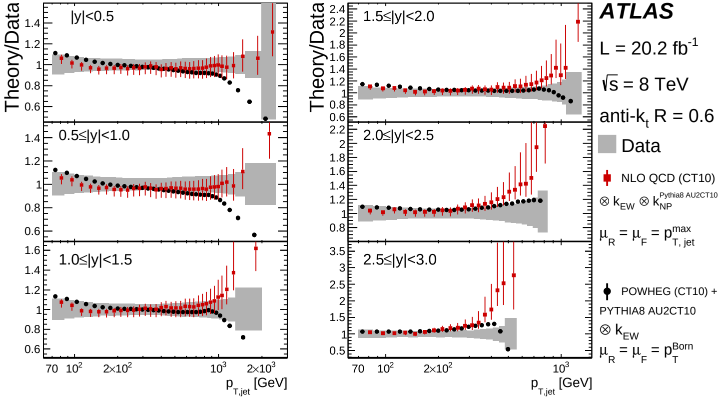
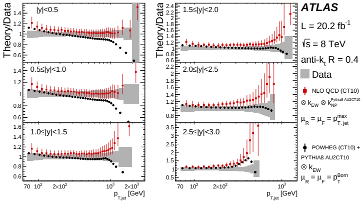
Inclusive jet cross sections at 8 TeV



⇐ R=0.6

R=0.4 ⇓

- Large difference between NLO and PH in the high p_T range
- For both jet sizes



Measurement of the $|y^{\mathrm{jet}}|$ and $p_{\mathrm{T}}^{\mathrm{jet}}$ dependence of dijet azimuthal decorrelations

- 2012 dataset $\sqrt{s} = 8$ TeV
- $\mathcal{L}_{\mathrm{int}} = 20.1$ fb^{-1}
- anti-k_T R=0.6 jets
- $|\eta^{\mathrm{jet}}| < 4.9$

Variable	Value
p_{Tmin}	100 GeV
$y_{\mathrm{boost}}^{\mathrm{max}}$	0.5
y_{max}^{*}	2.0
$p_{\mathrm{T1}}/H_{\mathrm{T}}$	$> 1/3$

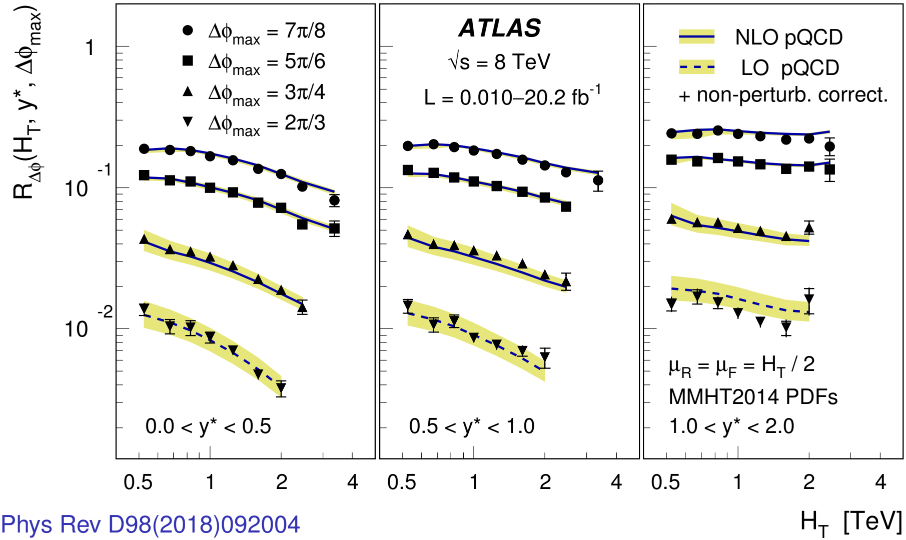
Quantity	Value
H_{T} bin boundaries (in TeV)	0.45, 0.6, 0.75, 0.9, 1.1, 1.4, 1.8, 2.2, 2.7, 4.0
y^* regions	0.0–0.5, 0.5–1.0, 1.0–2.0
$\Delta\phi_{\mathrm{max}}$ values	$7\pi/8$, $5\pi/6$, $3\pi/4$, $2\pi/3$

$$R_{\Delta\phi}\left(H_T, y^*, \Delta\phi_{\mathrm{max}}\right) = \frac{\dfrac{d^2\sigma_{\mathrm{jj}}(\Delta\phi_{\mathrm{jj}}<\Delta\phi_{\mathrm{max}})}{dH_T dy^*}}{\dfrac{d^2\sigma_{\mathrm{jj}}(\mathrm{inclusive})}{dH_T dy^*}}$$

H_{T} range [GeV]	Trigger type	Integrated luminosity [pb^{-1}]
450–600	single-jet	9.6 ± 0.2
600–750	single-jet	36 ± 1
750–900	multi-jet	546 ± 11
>900	multi-jet	$(20.2 \pm 0.4) \cdot 10^3$

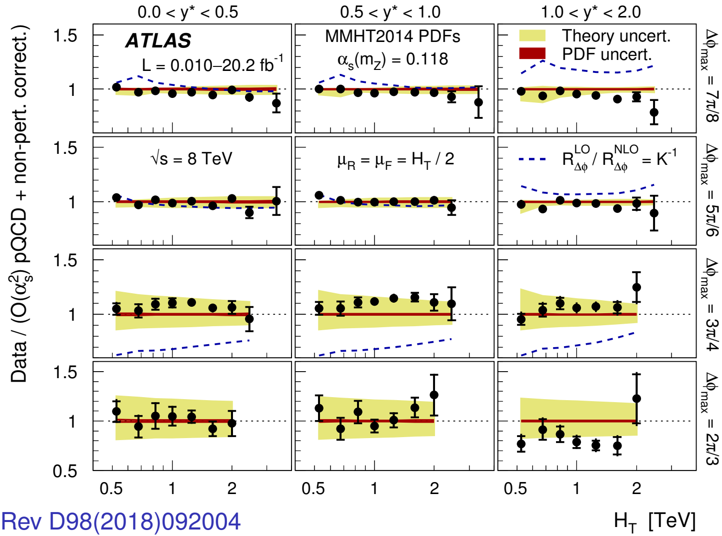
Phys Rev D98(2018)092004

Measurement of the $|y^{jet}|$ and p_T^{jet} dependence of dijet azimuthal decorrelations



Phys Rev D98(2018)092004

Measurement of the $|y^{\mathrm{jet}}|$ and p_T^{jet} dependence of dijet azimuthal decorrelations



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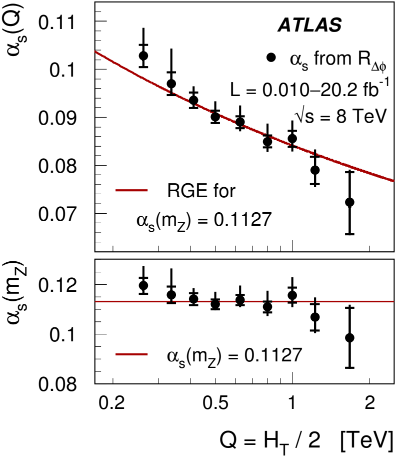
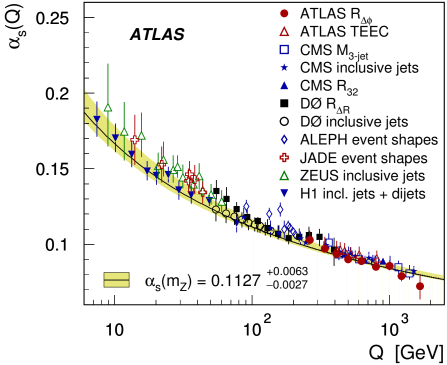




Phys Rev D98(2018)092004

$\alpha_S(m_Z)$	Total uncert.	Statistical	Experimental correlated	Non-perturb. corrections	MMHT2014 uncertainty	PDF set	$\mu_{R,F}$ variation
0.1127	$^{+6.3}_{-2.7}$	± 0.5	$^{+1.8}_{-1.7}$	$^{+0.3}_{-0.1}$	$^{+0.6}_{-0.6}$	$^{+2.9}_{-0.0}$	$^{+5.2}_{-1.9}$

uncertainties $\times 10^3$

Transverse energy-energy correlation at 13 TeV

ATLAS-CONF-2020-025

Measurements of new event shape taken from the e^+e^- annihilation and extended to hadron-hadron colliders

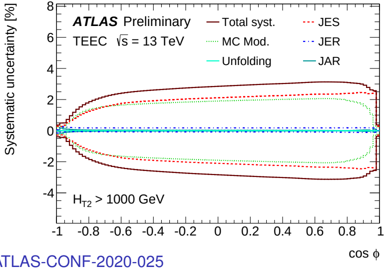
$$\frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi} = \frac{1}{N}\sum_{A=1}^{N}\sum_{ij}\frac{E_{T_i}^{A}E_{T_j}^{A}}{\left(\sum_k E_{T_k}^{A}\right)^2}\delta\left(\cos\phi - \cos\phi_{ij}\right)$$

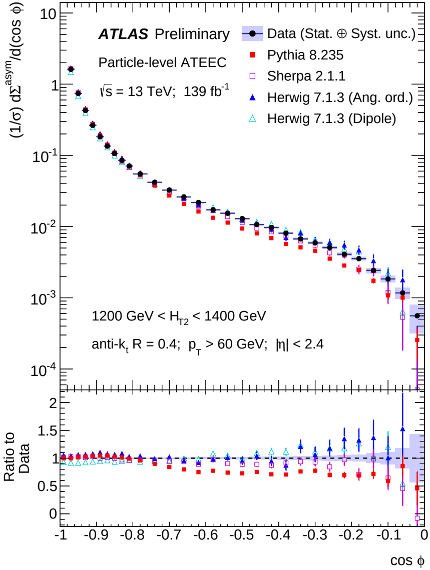
- anti-k_t R=0.4 jets
- ϕ_{ij} azimuthal angle between jets

- Full Run-2 measurement
- $\mathcal{L} = 139\ \mathrm{fb}^{-1}$
- High H_T reach

Transverse energy-energy correlation at 13 TeV

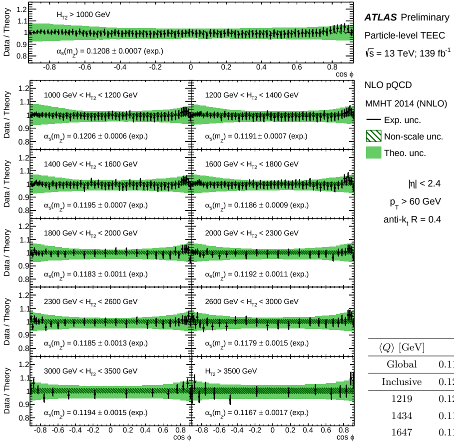
- Percent-level uncertainties in the JES/JER are translated into $\sim 2\%$ uncertainty at the final observable
- Modelling is one of the dominant source of uncertainty



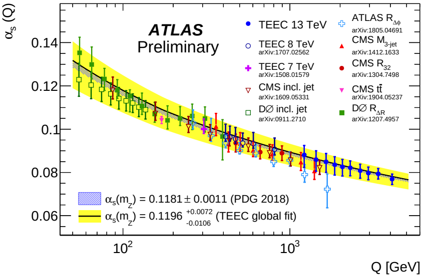


ATLAS-CONF-2020-025

Transverse energy-energy correlation at 13 TeV



$\alpha_s(m_Z)$=0.1196±0.0004(exp.) $^{+0.0072}_{-0.0105}$(theo.)



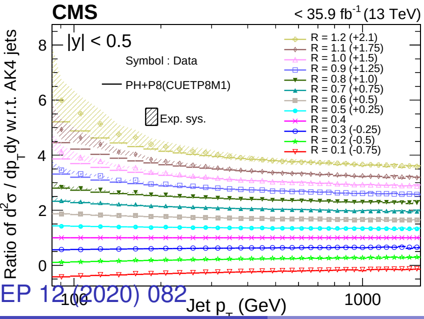
$\langle Q \rangle$ [GeV]	$\alpha_s(m_Z)$ value (MMHT 2014)	χ^2/N_{dof}
Global	0.1196 ± 0.0001 (stat.) ± 0.0004 (syst.) $^{+0.0071}_{-0.0104}$ (scale) ± 0.0011 (PDF) ± 0.0002 (NP)	235.8 / 347
Inclusive	0.1208 ± 0.0002 (stat.) ± 0.0006 (syst.) $^{+0.0081}_{-0.0101}$ (scale) ± 0.0009 (PDF) ± 0.0002 (NP)	42.7 / 91
1219	0.1206 ± 0.0002 (stat.) ± 0.0006 (syst.) $^{+0.0083}_{-0.0105}$ (scale) ± 0.0009 (PDF) ± 0.0003 (NP)	18.6 / 51
1434	0.1191 ± 0.0003 (stat.) ± 0.0007 (syst.) $^{+0.0080}_{-0.0101}$ (scale) ± 0.0010 (PDF) ± 0.0002 (NP)	18.0 / 51
1647	0.1195 ± 0.0002 (stat.) ± 0.0007 (syst.) $^{+0.0077}_{-0.0094}$ (scale) ± 0.0011 (PDF) ± 0.0002 (NP)	38.2 / 51
1856	0.1186 ± 0.0003 (stat.) ± 0.0008 (syst.) $^{+0.0076}_{-0.0094}$ (scale) ± 0.0011 (PDF) ± 0.0004 (NP)	25.9 / 51
2064	0.1183 ± 0.0004 (stat.) ± 0.0010 (syst.) $^{+0.0071}_{-0.0084}$ (scale) ± 0.0012 (PDF) ± 0.0005 (NP)	22.4 / 27
2300	0.1192 ± 0.0004 (stat.) ± 0.0011 (syst.) $^{+0.0066}_{-0.0075}$ (scale) ± 0.0012 (PDF) ± 0.0004 (NP)	21.3 / 27
2636	0.1185 ± 0.0004 (stat.) ± 0.0012 (syst.) $^{+0.0064}_{-0.0072}$ (scale) ± 0.0012 (PDF) ± 0.0001 (NP)	22.0 / 27
2952	0.1179 ± 0.0005 (stat.) ± 0.0014 (syst.) $^{+0.0059}_{-0.0064}$ (scale) ± 0.0013 (PDF) ± 0.0003 (NP)	25.0 / 27
3383	0.1194 ± 0.0007 (stat.) ± 0.0014 (syst.) $^{+0.0052}_{-0.0052}$ (scale) ± 0.0013 (PDF) ± 0.0002 (NP)	15.3 / 13
4095	0.1167 ± 0.0010 (stat.) ± 0.0014 (syst.) $^{+0.0050}_{-0.0053}$ (scale) ± 0.0015 (PDF) ± 0.0003 (NP)	13.5 / 13

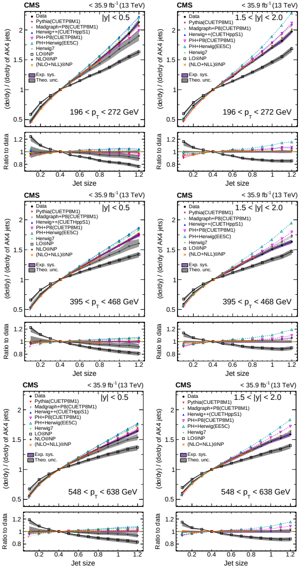
- Precision in α_s is dominated by the scale uncertainty in NLO calculations

ATLAS-CONF-2020-025

Dependence of inclusive jet production on the anti-k_T distance parameter

- 2016 data, $\mathcal{L} = 35.9\ \mathrm{fb}^{-1}$
- jet sizes : from R=0.1 to R=1.2
- dedicated JES calibration
- Cross sections and cross section ratios wrt R=0.4 are measured





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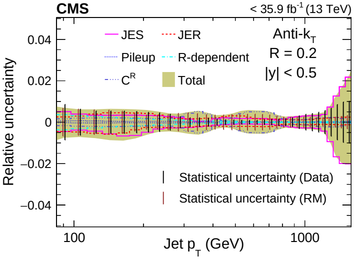
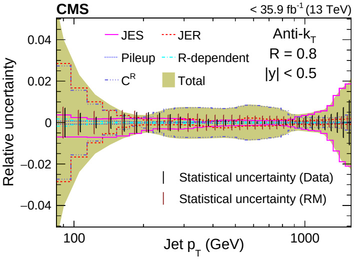
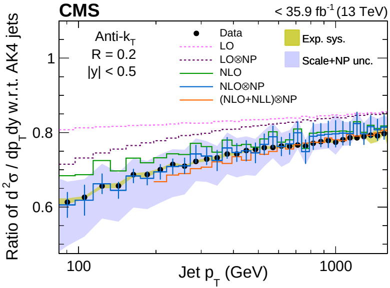
Dependence of inclusive jet production on the anti-k_T distance parameter

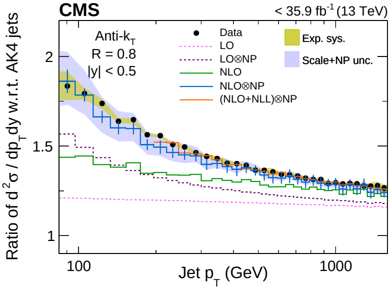




small experimental uncertainties in the ratio

NLO+NLL+NP provides bets description





Large Scale+NP uncertainties in the ratio

scale uncert. is fully correlated in the ratio

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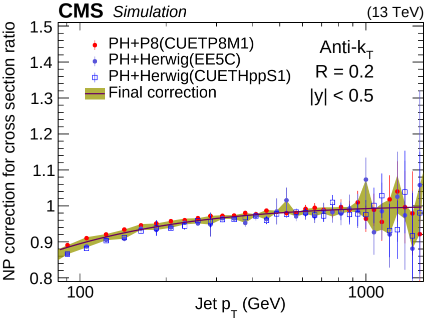
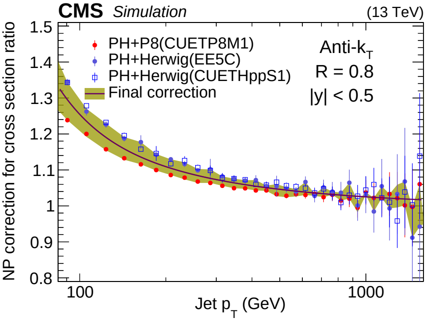
Dependence of inclusive jet production on the anti-k_T distance parameter

- Non-perturbative corrections : ratio of predictions with hadronisation and MPI ON/OFF
- NP uncertainties : envelope of tunes and generators. Cancels to a large extend in the ratio.





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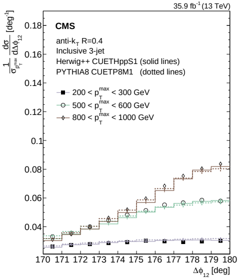
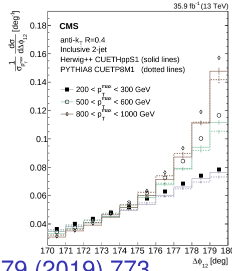
Azimuthal separation in nearly back-to-back jet topologies in inclusive 2- and 3-jet events

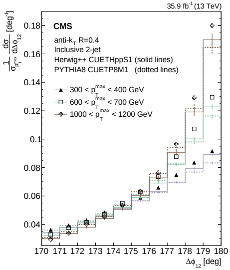
- $\sqrt{s} = 13$ TeV, $\mathcal{L} = 35.9\ \text{fb}^{-1}$

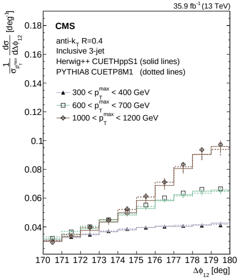
HLT p_T threshold (GeV)	140	200	320	400	450
$\mathcal{L}$ (fb^{-1})	0.024	0.11	1.77	5.2	36
p_T^{max} region (GeV)	200–300	300–400	400–500	500–600	>600

- $170^\circ < \Delta\phi_{12} < 180^\circ$ in bins of the leading jet p_T.
- Compared to LO and NLO predictions with parton showers and hadronisation



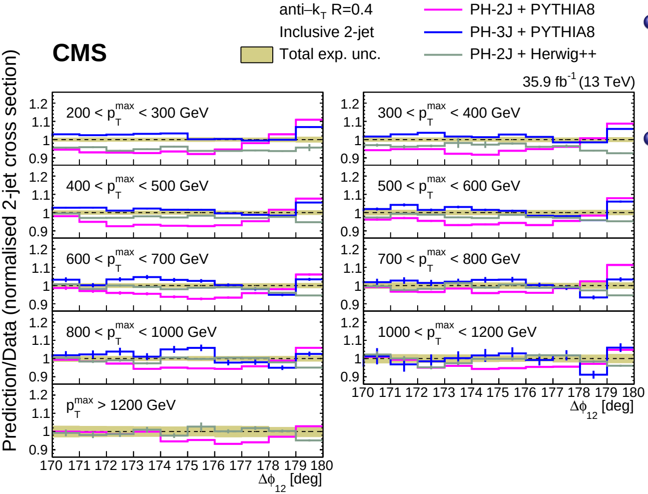






EPJC 79 (2019) 773

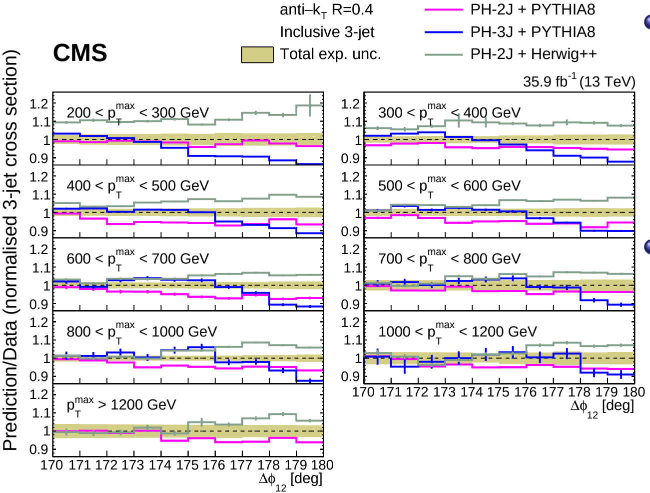
Azimuthal separation in nearly back-to-back jet topologies in inclusive 2- and 3-jet events



- PH-3j+Pythia 8 agrees better with the data
- PH-2j+Herwig++ prediction is similar to PH-3j+Pythia 8, except for the lowest p_T^{max} region.

EPJC 79 (2019) 773

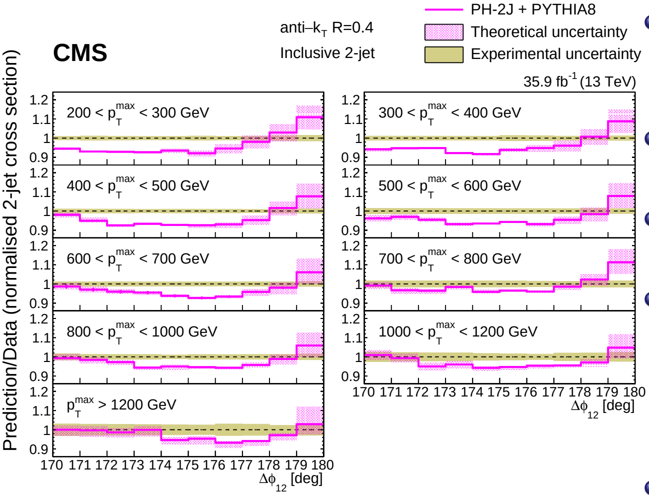
Azimuthal separation in nearly back-to-back jet topologies in inclusive 2- and 3-jet events



- All the considered NLO+PS predictions fail to describe the measurements close to 180°
- PH-3j+Pythia 8 behaves very differently compared to the 2-jet case

EPJC 79 (2019) 773

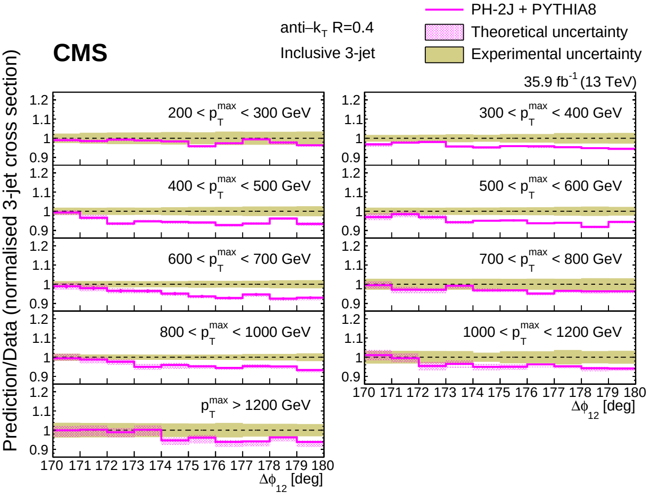
Azimuthal separation in nearly back-to-back jet topologies in inclusive 2- and 3-jet events



- Renorm. and fact. scale uncert. (factor of two)
- PDF (NNPDF 3.0 replicas)
- strong coupling ± 0.001
- parton shower: Pythia 8 scale in ISR and FSR is varied by a factor o two.
- NP uncert. are negligible

EPJC 79 (2019) 773

Azimuthal separation in nearly back-to-back jet topologies in inclusive 2- and 3-jet events



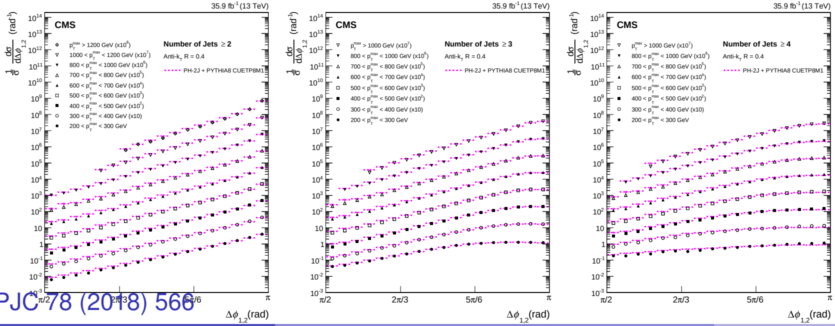
EPJC 79 (2019) 773

Azimuthal correlations for inclusive 2-jet, 3-jet, and 4-jet events

- 2016 data $\sqrt{s} = 13$ TeV, $\mathcal{L} = 35.9\ \mathrm{fb}^{-1}$

HLT p_T threshold (GeV)	140	200	320	400	450
p_T^{max} region (GeV)	200–300	300–400	400–500	500–600	>600
$\mathcal{L}$ (fb^{-1})	0.024	0.11	1.77	5.2	36

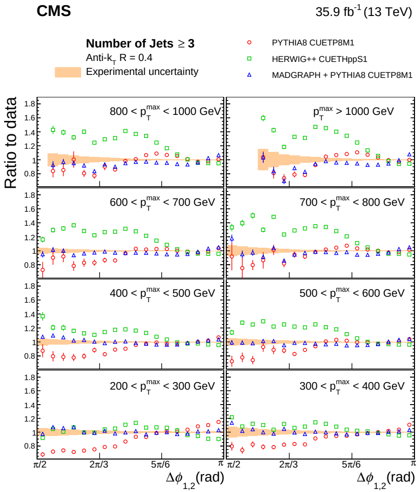
- in the $\pi/2 < \Delta\phi_{12} < \pi$ range in bins of p_T lead.jet
- central jets $|y| < 2.5$
- Data are compared to Pythia 8, Herwig++, MadGraph+Pythia 8, PH-2j matched to Pythia 8 and Herwig++, PH-3j+pythia 8, and Herwig 7 .

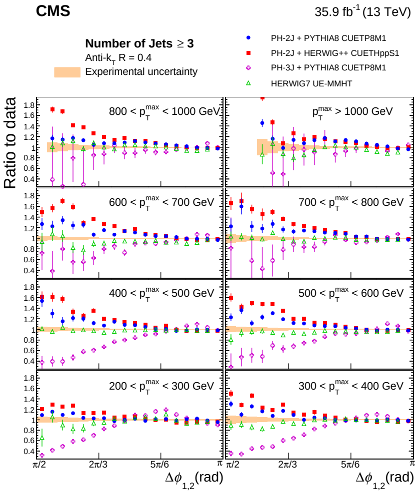


EPJC 78 (2018) 566

Azimuthal correlations for inclusive 2-jet, 3-jet, and 4-jet events

LO : Herwig deviates most; Madgraph (up to 4 partons) - best



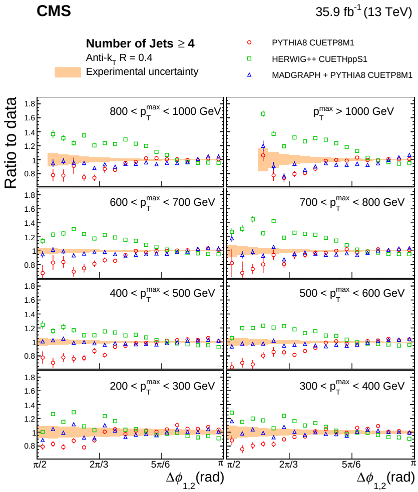


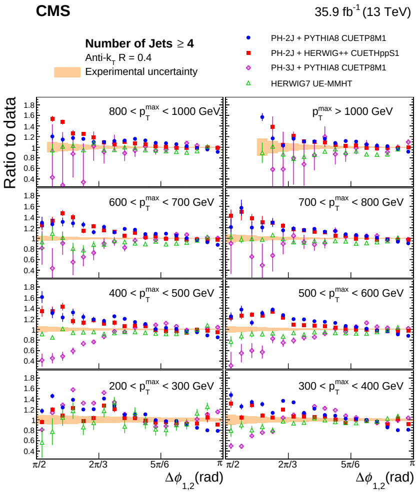
NLO : PH+Pythia describes better than PH+Herwig

Herwig 7 does the best job

EPJC 78 (2018) 566

Azimuthal correlations for inclusive 2-jet, 3-jet, and 4-jet events





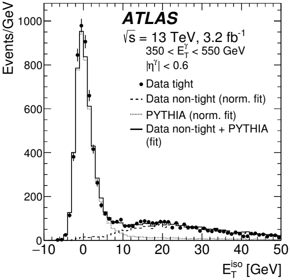
EPJC 78 (2018) 566

Measurement of the cross section for isolated-photon plus jet production

Phys. Lett. B 780 (2018) 578

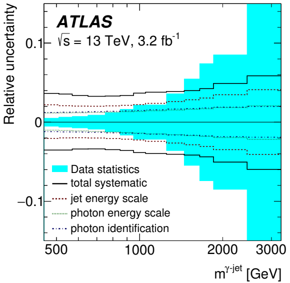
- 2015 data 3.2 $\text{fb}^{-1} \sim 896k$ events
- E_γ; p_T^{jet1}, $\Delta\phi_{\gamma-\text{jet}}$, $m_{\gamma-\text{jet}}$, $\cos\theta^*$

Requirements on photons
$E_T^\gamma > 125$ GeV, $\lvert\eta^\gamma\rvert < 2.37$ (excluding $1.37 < \lvert\eta^\gamma\rvert < 1.56$)
$E_T^{\text{iso}} < 4.2 \cdot 10^{-3} \cdot E_T^\gamma + 10$ GeV
Requirements on jets
anti-k_t algorithm with $R = 0.4$
the leading jet within $\lvert y^{\text{jet}}\rvert < 2.37$ and $\Delta R^{\gamma-\text{jet}} > 0.8$ is selected
$p_T^{\text{jet-lead}} > 100$ GeV
UE subtraction using $k_\perp$ algorithm with $R = 0.5$ (cf. Section ??)
Additional requirements for $d\sigma/dm^{\gamma-\text{jet}}$ and $d\sigma/d\lvert\cos\theta^*\rvert$
$\lvert\eta^\gamma + y^{\text{jet-lead}}\rvert < 2.37$, $\lvert\cos\theta^*\rvert < 0.83$ and $m^{\gamma-\text{jet}} > 450$ GeV



Exp. uncertainties:

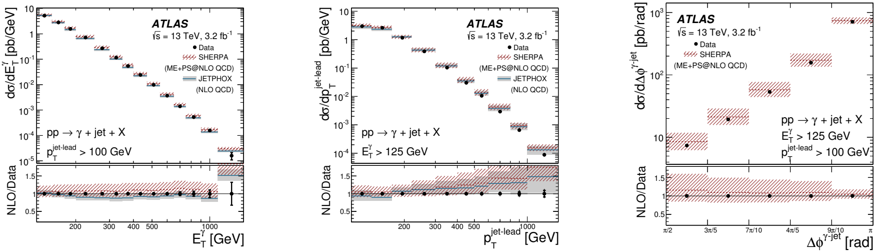
- PES (1–4 .5%)
- JES (2–7.5%)
- Showering $< 2\%$
- Other (P_{ID}, P_{iso},pileup,bkg) $\leq 1\%$



Measurement of the cross section for isolated-photon plus jet production

Phys. Lett. B 780 (2018) 578

- JETPHOX (full NLO pQCD for both direct and fragmentation contributions) +NP corrections
- Sherpa ($\gamma + (1,2)-\mathrm{jet}$ at NLO and $\gamma + (3,4)-\mathrm{jet}$ at LO + PS)
- uncert.: scales (ren,fact.,frag.) and PDF



- Good description by both calculations
- theory is almost always higher than data

Measurement of the cross section for isolated-photon plus two-jet production

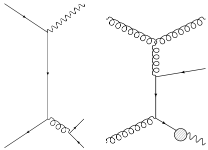
JHEP 03 (2020) 179

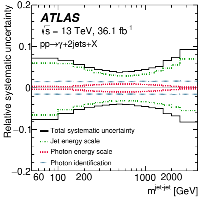
- Run-2 data $\mathcal{L} = 36.6\ \text{fb}^{-1}$
- E_γ; p_T^{jet}, $\Delta y_{\gamma-\text{jet}}$, $\Delta y_{\text{jet}-\text{jet}}$, $\Delta\phi_{\gamma-\text{jet}}$, $\Delta\phi_{\text{jet}-\text{jet}}$, $m_{\text{jet}-\text{jet}}$, $m_{\gamma-\text{jet}-\text{jet}}$

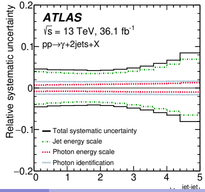
Requirements on photon	$E_T^\gamma > 150$ GeV, $\lvert\eta^\gamma\rvert < 2.37$ (excluding $1.37 < \lvert\eta^\gamma\rvert < 1.56$) $E_T^{\text{iso}} < 0.0042 E_T^\gamma + 4.8$ GeV (reconstruction level) $E_T^{\text{iso}} < 0.0042 E_T^\gamma + 10$ GeV (particle level)		
Requirements on jets	at least two jets using anti-k_t algorithm with $R = 0.4$ $p_T^{\text{jet}} > 100$ GeV, $\lvert y^{\text{jet}}\rvert < 2.5$, $\Delta R^{\gamma-\text{jet}} > 0.8$		
Phase space	**total**	**fragmentation enriched** $E_T^\gamma < p_T^{\text{jet2}}$	**direct enriched** $E_T^\gamma > p_T^{\text{jet1}}$
Number of events	755 270	111 666	386 846

Exp. uncertainties:

Range of the relative uncertainty (in %) for each variable								
E_T^γ	p_T^{jet}	$\lvert y^{\text{jet}}\rvert$	$\lvert\Delta y^{\gamma-\text{jet}}\rvert$	$\Delta\phi^{\gamma-\text{jet}}$	$\lvert\Delta y^{\text{jet}-\text{jet}}\rvert$	$\Delta\phi^{\text{jet}-\text{jet}}$	$m^{\text{jet}-\text{jet}}$	$m^{\gamma-\text{jet}-\text{jet}}$
3.5%–6.5%	4%–15%	4%–6%	4%–9%	3.5%–6%	4%–8%	3%–7%	4%–9%	4%–11%

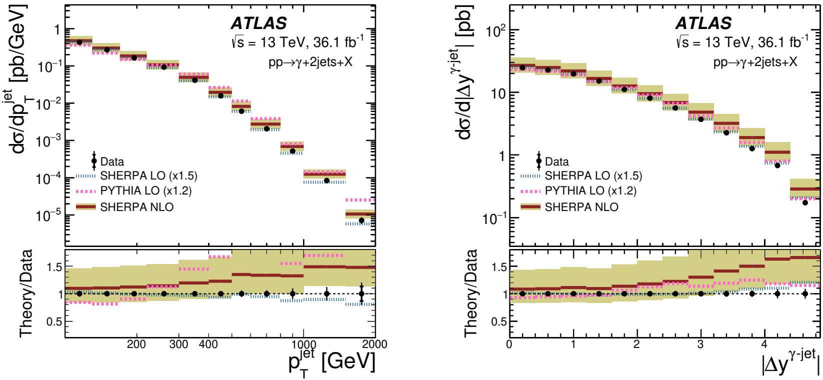






Measurement of the cross section for isolated-photon plus two-jet production

JHEP 03 (2020) 179



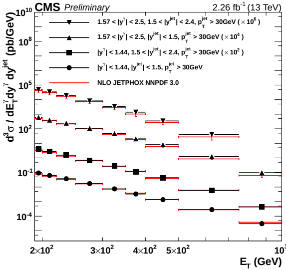
Dedicated studies in the fragmentation and direct regions are performed

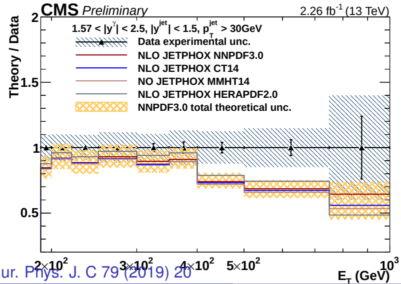
- LO predictions are normalised to data in each phase-space
- Pythia, in general, fail to describe the shape of the data.
- Sherpa LO ($2 \to n$) provides a good description
- NLO Sherpa predictions describe the data adequately in shape and normalisation

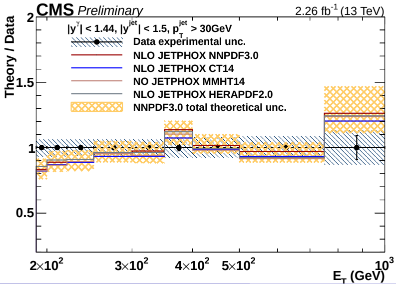
Measurement of the cross section for inclusive isolated-photon and photon+jets production

- 2015 data 2.26 fb^{-1}
- σ as a function of the photon E_T, photon rapidity and the rapidity of the jet

Source	$\lvert y^\gamma \rvert < 0.8$	$0.8 < \lvert y^\gamma \rvert < 1.44$	$1.57 < \lvert y^\gamma \rvert < 2.1$	$2.1 < \lvert y^\gamma \rvert < 2.5$
Trigger efficiency	0.7–8.5	0.2–13.4	0.6–20.5	0.3–7.8
Selection efficiency	0.1–1.3	0.1–1.3	0.1–5.3	0.1–1.1
Data-to-MC scale factor	3.7	3.7	7.1	7.1
Template shape	0.6–5.0	0.1–10.2	0.5–4.9	0.6–16.2
Unfolding	3.8–5.5	1.2–4.1	2.0–8.5	2.3–10.3
Total w/o luminosity	5.4–12.0	5.9–18.2	8.2–26.9	8.6–21.7
Integrated luminosity		2.3		







Eur. Phys. J. C 79 (2019) 20

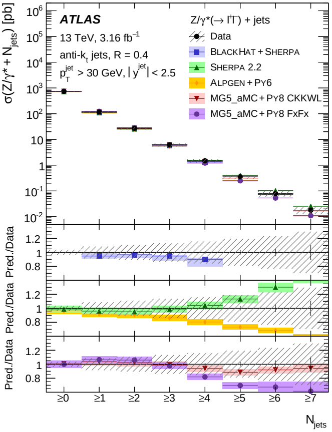
Event shapes using hadronic jets by ATLAS and CMS

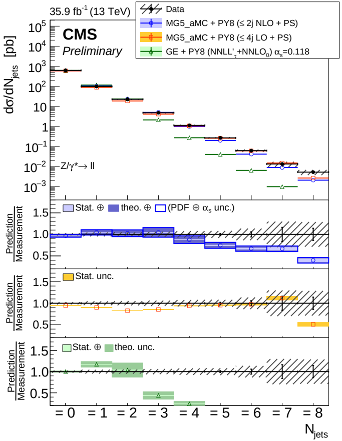
- Measurement of hadronic event shapes in high-p_{T} multijet final states at $\sqrt{s} = 13$ with the ATLAS detector : JHEP 01 (2021) 188 (ATLAS)
  - Full Run-2
  - Six event-shape variables calculated using hadronic jets. Measurements are performed in bins of jet multiplicity and in different ranges of the scalar sum of the transverse momenta of the two leading jets, reaching scales beyond 2 TeV.
- Event shape variables measured using multijet final states in proton-proton collisions at $\sqrt{s} = 13$ TeV : JHEP 12 (2018) 117 (CMS)
  - 2015 data
  - several event shape variables calculated using jet four momenta are measured and compared to theory. The agreement generally improves as the energy, represented by the average transverse momentum of the two leading jets, increases.

Motivation: V + jets

- Processes involving W & Z boson production are one of the best understood processes at hadron colliders
  - $W^{\pm} \rightarrow \ell^{\pm}\nu$, $Z \rightarrow \ell^{\pm}\ell^{\mp}$, ($\ell = e, \mu$) are among the cleanest final states experimentally
    - ★ To test pQCD and validate our modelling of it in MC.
    - ★ Probe/measure EW production cross sections.
    - ★ V+jets provide backgrounds to other measurements and BSM searches.
- Various kinematic properties of jets produced with W and Z boson production are studied.
- Measurements carried out in fiducial phase space.

Z+jet x-sec measurements: Njet 13 TeV, 3.16 fb^{-1} & 35.9 fb^{-1}



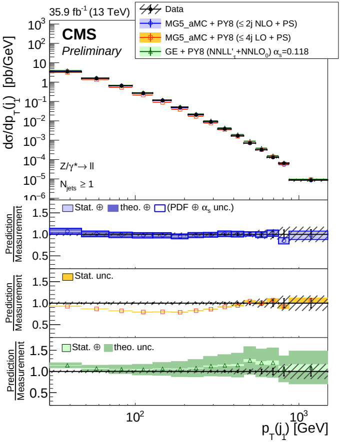


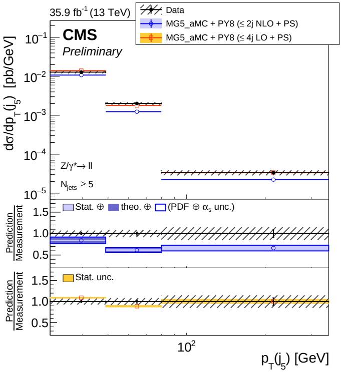
- Measurements carried out in fiducial phase-space.
- Corrected for detector effects via unfolding.
- Measured jet multiplicity up to 7 (8) jets.
- Comparisons with state-of-the art generators at different orders in QCD.

Eur. Phys. J. C77 (2017) 361, CMS-SMP-19-009

Z+jet x-sec measurements: Jet p_T

13 TeV, 35.9 fb^{-1}



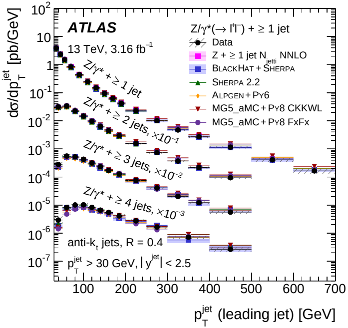


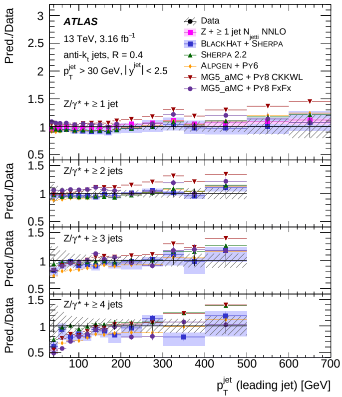
- Measured differential kinematics up to 5 jets.
- Good description with MG5_aMC@NLO (NLO $\leq 2p$) and GENEVA (NNLO + NNLL'$_{\tau_0}$).

CMS-SMP-19-009

Z+jet x-sec measurements: Jet p_T

13 TeV, 3.16 fb^{-1}



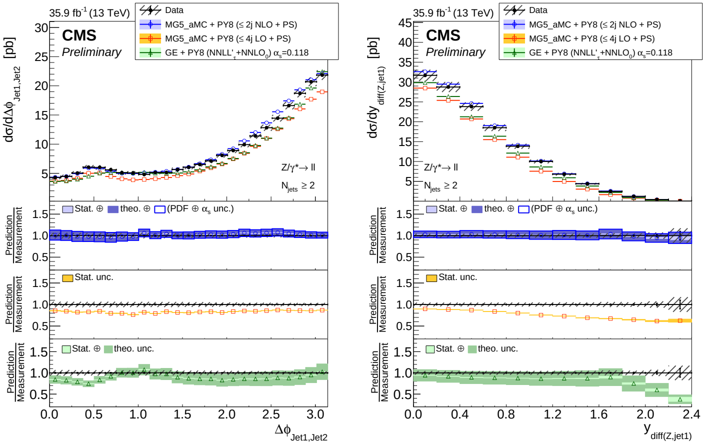


- Measured differential kinematics up to 4 jets.
- All models give an overall good description of the measurements.
- MG5_aMC@NLO + PYTHIA 8 CKKWL predicts a harder spectrum than FxFx.

Eur. Phys. J. C77 (2017) 361

Z+jet x-sec measurements: Angular variables

13 TeV, 35.9 fb^{-1}

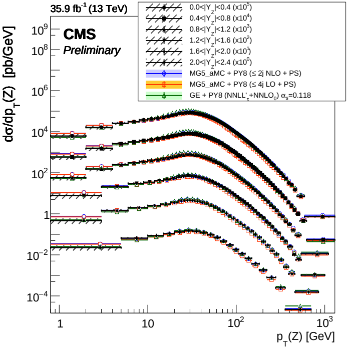


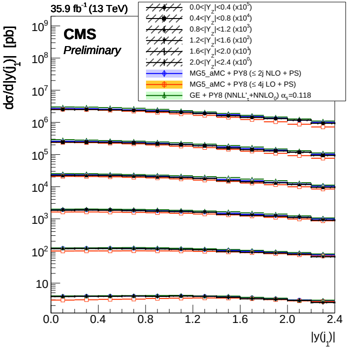
- Measured $\Delta\phi$ and y_{diff} between jets and also Z.
- Differences wrt GENEVA predictions at high y_{diff}

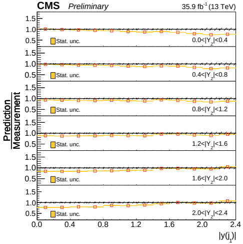
CMS-SMP-19-009

Z+jet multi-d x-sec measurements

13 TeV, 35.9 fb^{-1}





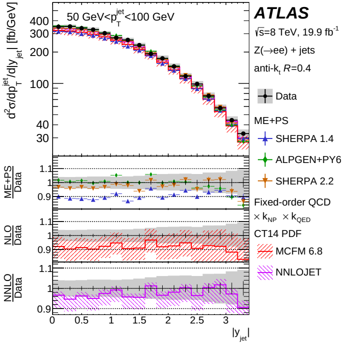


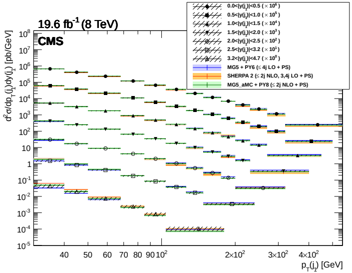
- Double-differential cross sections are measured wrt jet and Z p_T, y.
- LO MG5_aMC@NLO + Pythia 8 (MLM) fails at high y(Z) low y(j).

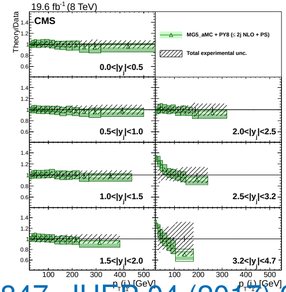
CMS-SMP-19-009

Z + jets: Forward jets

8 TeV, 19.9 fb^{-1} & 19.6 fb^{-1}





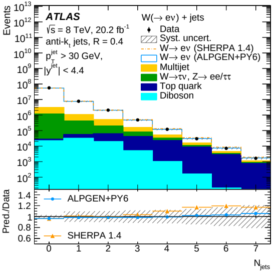


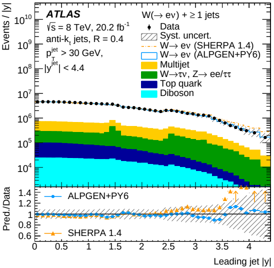
- Multi-d cross sections measured wrt jet and Z p_T, y.
- Extended to forward jets up to 3.5 (4.7)
- Beyond tracker acceptance JES unc dominates

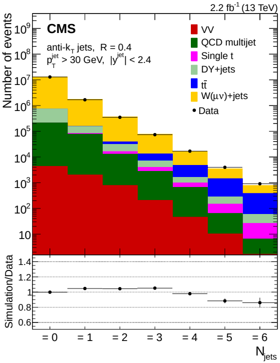
Eur. Phys. J. C 79 (2019) 847, JHEP 04 (2017) 022

W + jets

8 & 13 TeV, 19.9 fb^{-1} & 2.2 fb^{-1}





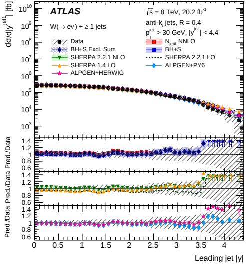


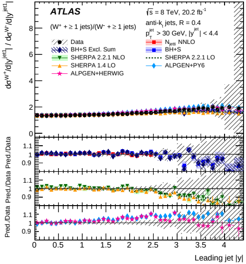
- Measurements carried out in fiducial phase-space.
- Corrected for detector effects via unfolding.
- b-tag veto to supress $t\bar{t}$ contribution.
- Data-driven estimate of QCD background.
- Measured jet multiplicity up to 7 (6) jets.

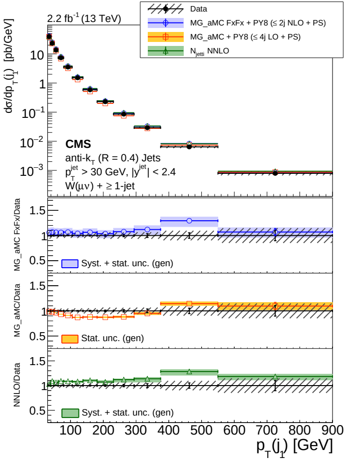
JHEP 05 (2018) 077, Phys. Rev. D 96 (2017) 072005

W + jets

8 & 13 TeV, 19.9 fb^{-1} & 2.2 fb^{-1}





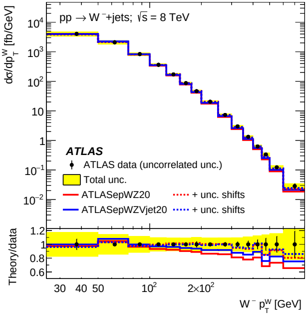


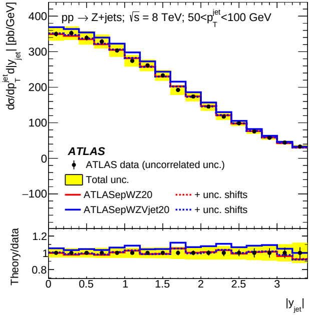
- Comparison to various models, including NNLO W+1j prediction.
- All models give overall good description of the data.
- Forward jets included in ATLAS measurement.
- Beyond tracker acceptance JES unc dominates.

JHEP 05 (2018) 077, Phys. Rev. D 96 (2017) 072005

W/Z+jets, PDF fits

- Carried out a QCD analysis at NNLO (ATLASepWZVjet20)
- Using W/Z (+ jets) at 8 TeV as well as W/Z measurements at 7 TeV.
- Compared to the previous fit, ATLASepWZ20 w/o W/Z+jets.
- Both fits include previous HERA data.



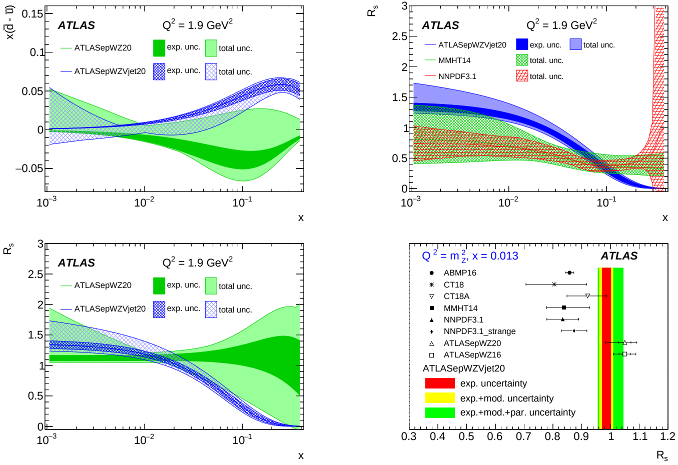


- Compared the predictions to the input distributions.
- Improved description of W p_{T} with better PDF uncertainties wrt previous fit.

arXiv:2101.05095

W/Z+jets, PDF fits

NNLO QCD Analysis

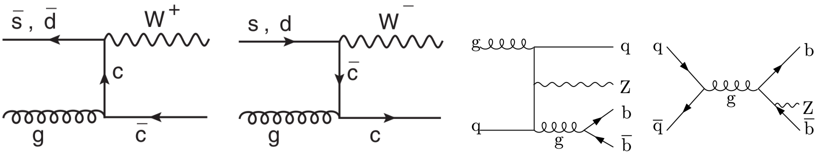


- Improves the PDFs mainly for $\bar{d} - u$.
- More precise estimate for strange supression factor (R_s), closer to other PDF sets wrt previous ATLAS fits.
  - It is better constrained and falls more steeply at high x.
  - At low x confirmed unsuppressed strange PDF as observed in previous ATLAS fit.

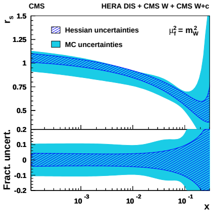
arXiv:2101.05095

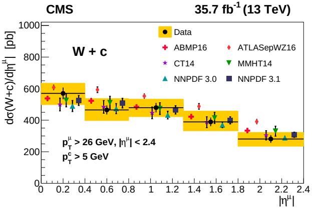
V + HF measurements

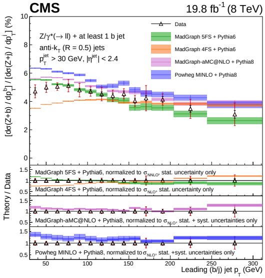
8 &13 TeV, 19.6 & 35.7 fb^{-1}



- Important to study V+ HF production at the LHC
  - Probe HF PDFs
  - Collinear production of b quarks (gluon splitting)







- More details at the Heavy Flavor session tomorrow.

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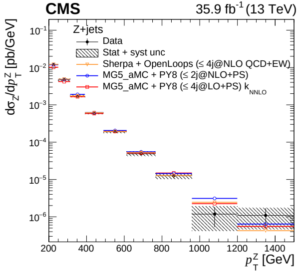
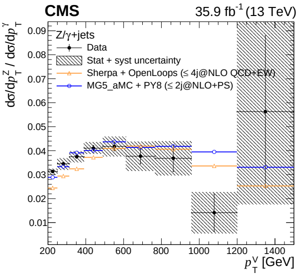
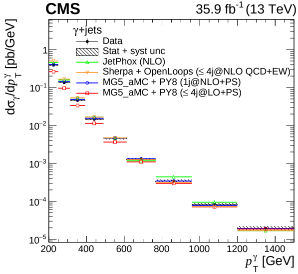
Z/γ + jet p_T ratio measurement

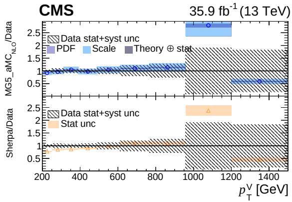
13 TeV, 35.9 fb^{-1}

- Mesurements of Z + jets and γ + jets wrt boson p_T as well as their ratios have been carried out.









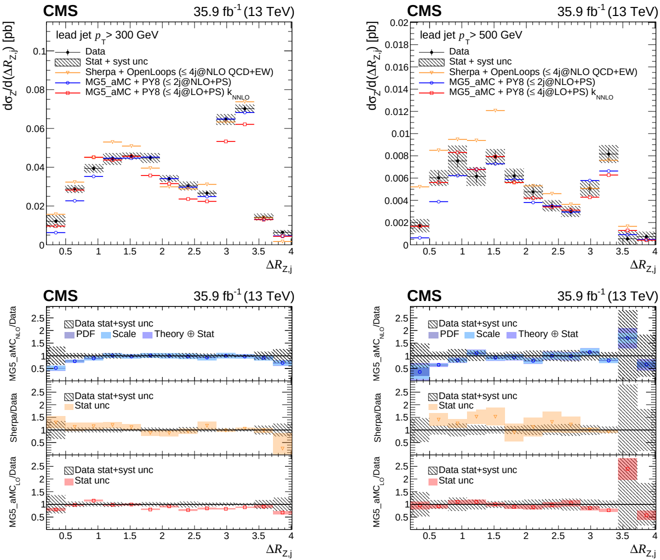
- Low p_T boson part is described well except LO MG5_aMC@NLO prediction normalized to NNLO x-sec.
- Good description of the ratio measurement by both Sherpa and MG5_aMC@NLO

:arXiv:2102.02238

Z boson emission collinear with a jet

13 TeV, 35.9 fb^{-1}

- Measured the $\Delta(R)$ between Z and the closest jet.



- Good description by both Sherpa and MG5_aMC@NLO

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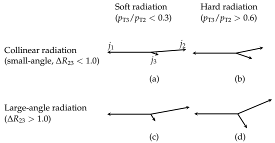
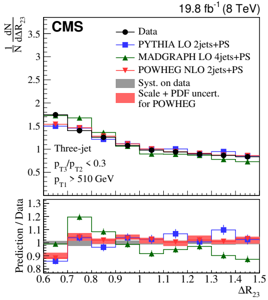
arXiv:2102.02238

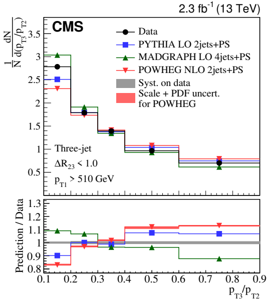
3j & Z+2j Angular distance and momentum ratios

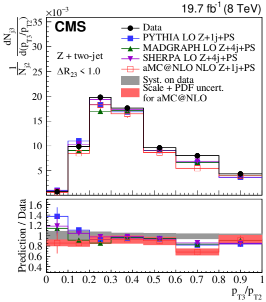
8 &13 TeV, 19.8 & 2.3 fb^{-1}



- Small- & large-angle, soft & hard radiations are investigated in 3 j and Z + 2 j events

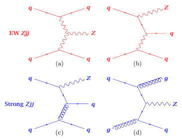


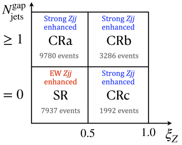




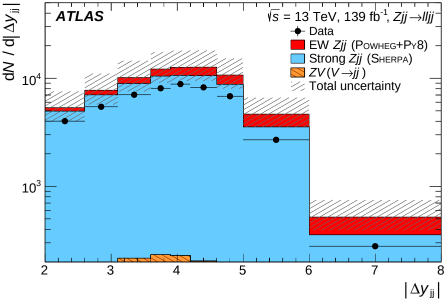
arXiv:2102.08816

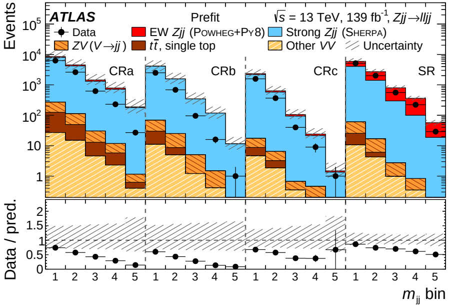
Electroweak production of Z + 2j





- Measurements of EWK production of Z + 2j have been carried out.
- ATLAS measurement carried out in 4 regions.

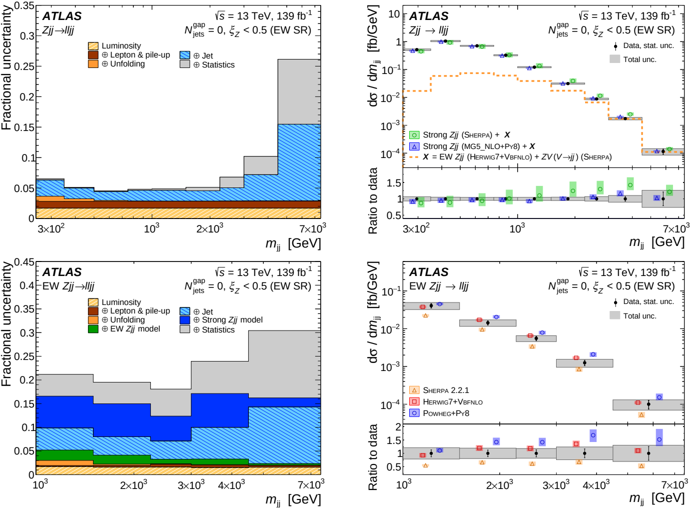




arXiv:2006.15458

Electroweak production of Z + 2j

13 TeV,139 fb^{-1}

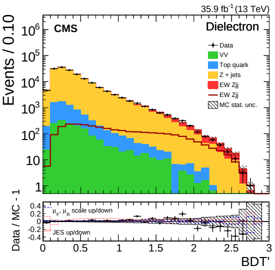


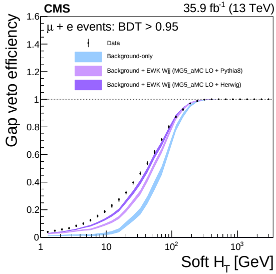
- Measured the differential cross section in the EW SR.
  - Both inclusive and σ_{EW}.
  - JES unc dominates for inclusive, modeling uncertainty for σ_{EW}.

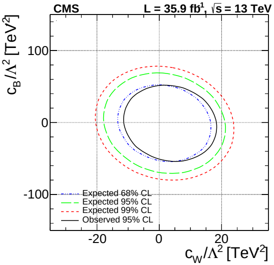
arXiv:2006.15458

Electroweak production of W/Z + 2j

13 TeV 35.9 fb^{-1}







$\sigma_{\mathrm{EW}}(\ell\nu\mathrm{jj})[\mathrm{pb}] = 6.23 \pm 0.12(\mathrm{stat}) \pm 0.61(\mathrm{syst})$

$\sigma_{\mathrm{EW}}(\ell\ell\mathrm{jj})[\mathrm{pb}] = 0.552 \pm 0.019(\mathrm{stat}) \pm 0.055(\mathrm{syst})$

- Measured the EWK production cross section of W+2j and Z+2j with CMS.
- BDT trained to discriminate the EWK signal from DY.
  - Using several kinematic variables that are sensitive, m_{jj}, $\Delta\eta_{jj}$.
- Measured the gap activity veto efficiency.
- Measurement in agreement with the SM expectations, no evidence for ATGCs following an EFT search.
  - Limits on ATGCs associated with dim-six operators.

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Summary

- A large set of jet and V+jet measurements at 8 and 13 TeV is presented
- State-of-the-art predicitons are used for the data interpretation
- Experiments provide precision of a percent level for most of the observable
  - Measurements provide stringent test of our modeling of the SM.
- Theoretical uncertainties, in general, are larger compared to the experimental ones.
  - Mainly for scale uncertainties, also modeling uncertainties in several cases.
  - Possibility to constrain/improve PDFs and α_s.