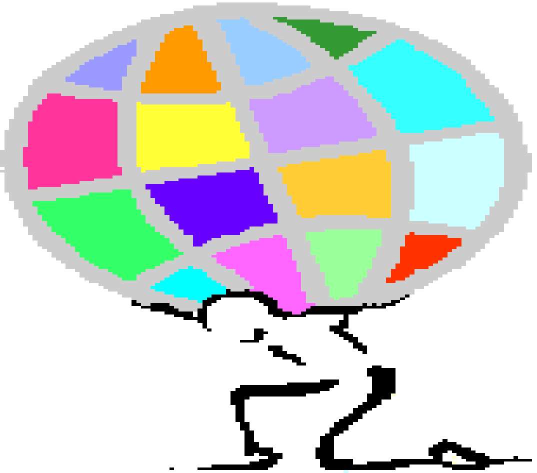
Monte Carlo generators for the modelling of multijet processes in ATLAS at 13 TeV

Evelin Meoni
(Università della Calabria & INFN)

on behalf of the **ATLAS Collaboration**



Introduction

Why is MC modelling of paramount importance at LHC?

In cross-section measurements, MC used to **unfold detector level results** correcting for efficiencies, resolutions and acceptances and used **to correct fixed-order calculations for non-perturbative effects** in order to allow comparisons with data

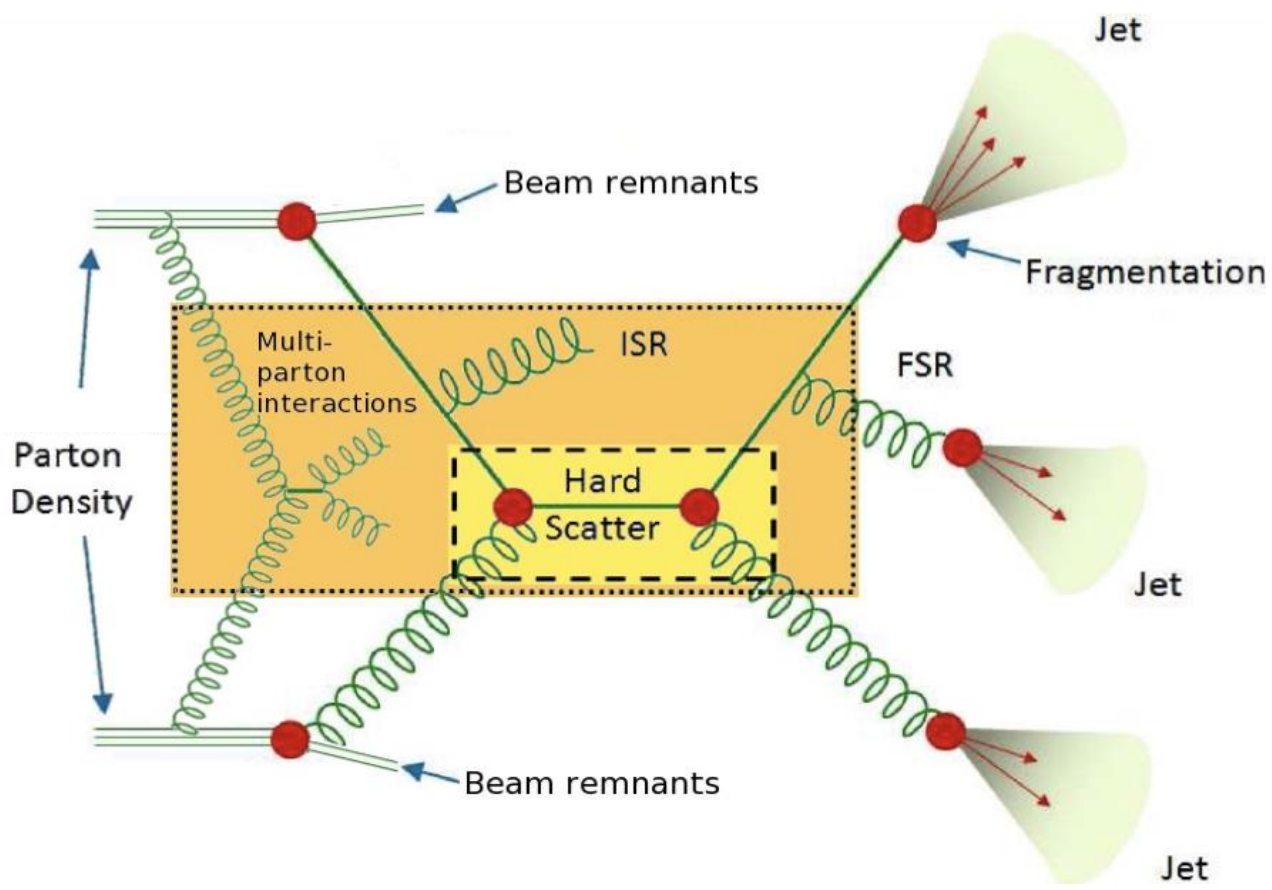
In precision measurements of SM parameters, MC used to **build templates** of the sensitive observables

In measurements and searches, **estimation of backgrounds** often fully MC-based (small background) or based on a mixture of MC and data-driven techniques

MC used to assess **signal and background systematics**

Our ability to constrain and discover New Physics depends on having reliable MC predictions with well understood systematic uncertainties!

MCs



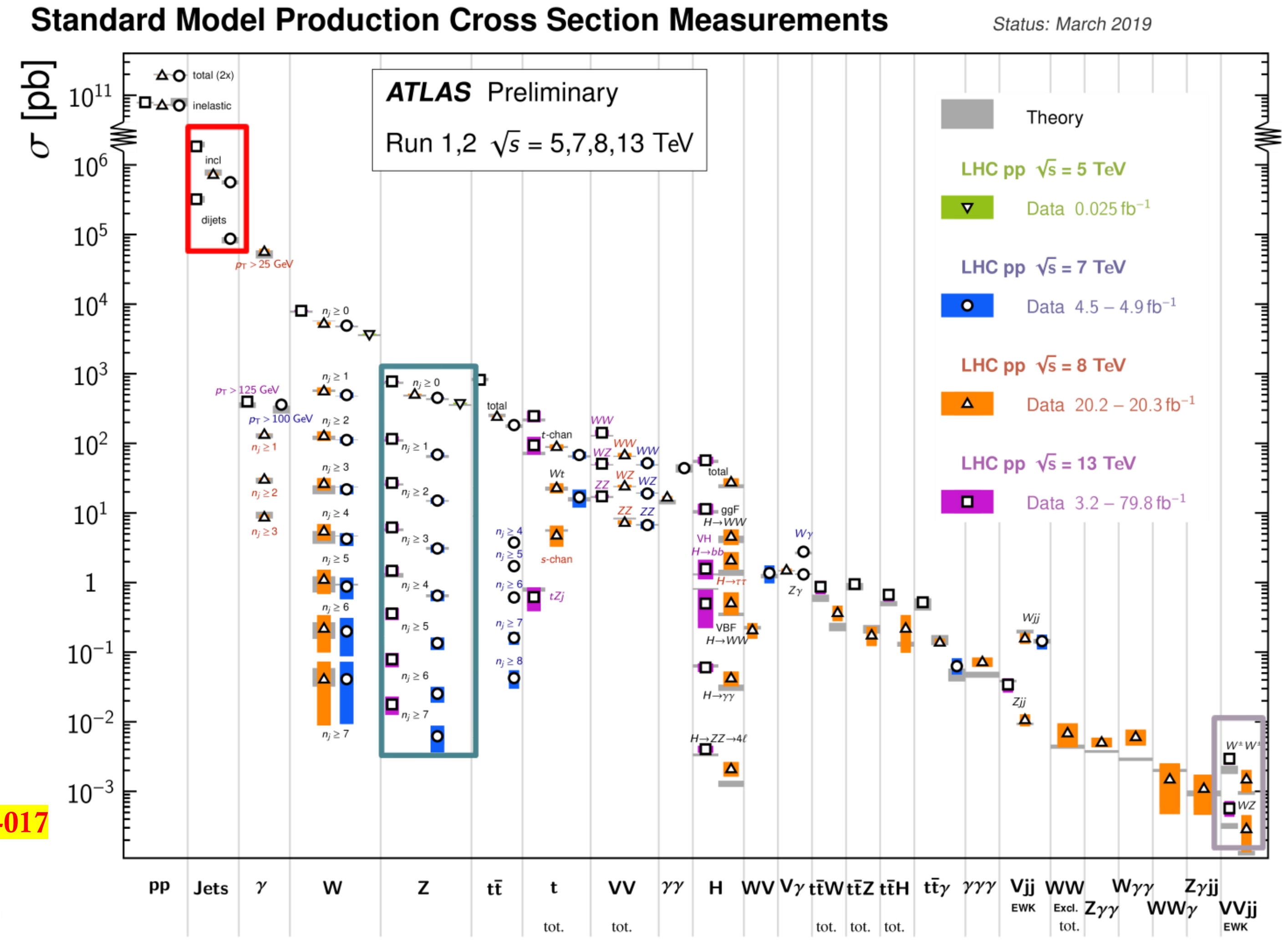
Description of pp collisions in MC via "factorisation":

- ✓ **Hard Scattering (& Resonance decay)** via Matrix Element
- ✓ **Initial and State Radiation** via Parton Shower (PS)
- ✓ **Parton density** via PDFs
- ✓ **Underlying Event (UE):** everything in a pp collisions expect the hard scattering via phenomenological models
  - *Multi-Parton Interactions (MPI):* additional parton-parton scatterings between other partons from the same protons
  - *Beam remnants*
- ✓ **Fragmentation and Hadronisation** via non-perturbative models of color-singlet parton systems

Why does MC modelling of jet processes play a leading role in this effort?

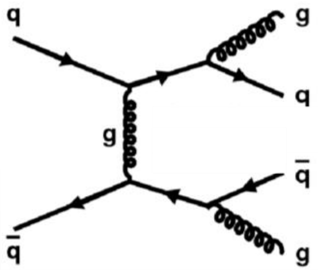
LHC is a jet factory, processes involving jets are crucial inputs for the **understanding of basic physics modelling features**

Outline

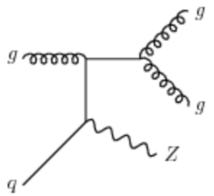


Talk on MC modelling of Multijets & X+jets!

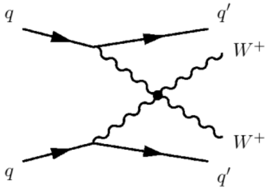
Multijets
ATL-PHYS-PUB-2019-017
JHEP 05 (2018) 195



Z+jets
ATL-PHYS-PUB-2017-006
Eur. Phys. J. C77 (2017) 361



WW+jets (VBS)
ATL-PHYS-PUB-2019-004
ATLAS-CONF-2018-030



Multijet MC configuration

Detailed study performed recently on several MC configurations simulating inclusive jet production:

MC	ME order	PDFs of ME	PS & UE & Had Models	PS &UE tunes
Pythia 8.230	LO 2→2	NNPDF23LO	**p_T-ordered PS** **Lund string model for Had**	A14 tune
Sherpa 2.2.5	LO 2→2	CT14NNLO	**p_T-ordered PS (CSS Sherpa)** **Sherpa AHADIC model for Had (based on Cluster Fragm)**	Sherpa tune (CT10)
			p_T-ordered PS (CSS Sherpa) **Lund string model for Had (Pythia6.4)**	
MadGraph+Pythia8 (MadGraph5_aMC@NLO 2.3.3.1)	LO up to 4 part	NNPDF30NLO	**PS&Had: Pythia 8.212**	A14 tune (NNPDF23LO)
Powheg+Pythia8 (Powheg-Box V2)	**NLO dijets**	NNPDF30NLO	**PS&Had: Pythia 8.230**	A14 tune (NNPDF23LO)
Herwig 7.1.3	**NLO dijets**	MMHT2014NLO	**Angular ordered PS** **Cluster model for Had**	Dedicated tune
			Dipole PS **Cluster model for Had**	Dedicate tune

Explored impact of different aspects:

- **QCD orders of ME** (LO vs NLO)
- **PS models** (p_T ordered vs angular ordered)
- **Factorisation and Hadronisation models** (Lund vs cluster models)

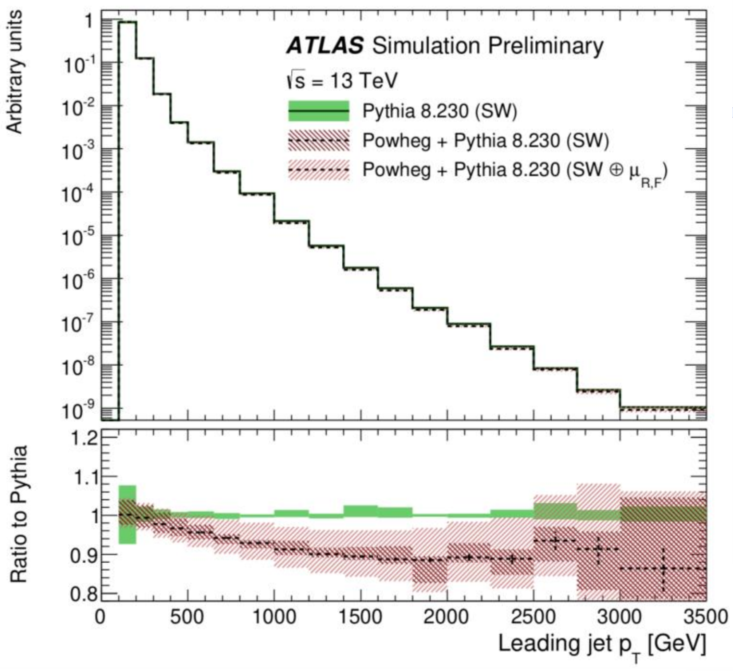
Multijet MC configuration

ME order impact:

MC	ME order	PDFs of ME	PS & UE & Hadr Models	PS &UE tunes
Pythia 8.230	**LO 2→2**	NNPDF23LO	**p_T-ordered PS** **Lund model for Had**	ATLAS A14
Powheg+Pythia8	**NLO**	NNPDF30NLO	**PS: Pythia 8.230**	A14 tune

Large uncertainty at low p_T in **LO Pythia8** (PS unc only), PDFs uncertainties play a role at higher p_T in **NLO Powheg+Pythia8** (PS+scale+PDF unc)

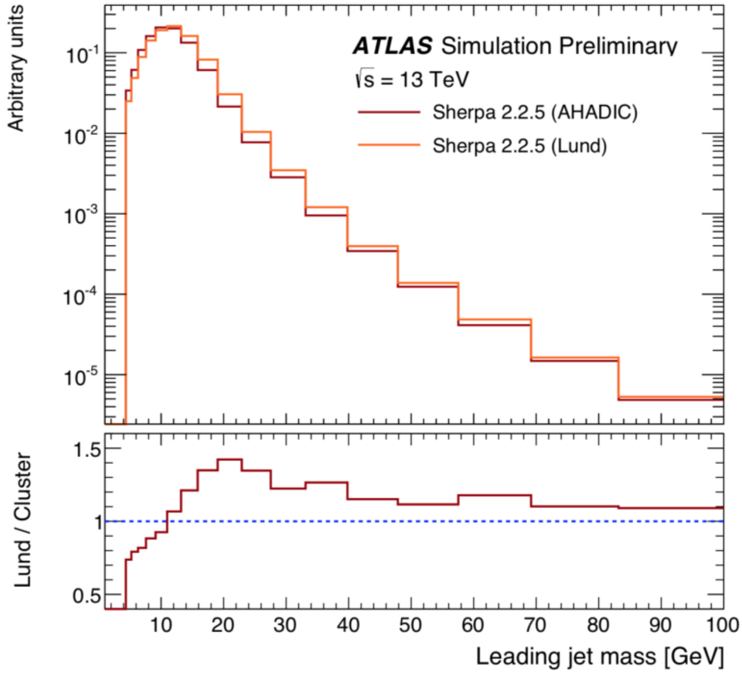
- *employed per-event weight functionality newly implemented in both MCs*



Hadronisation model impact:

MC	ME order	PDFs of ME	PS & UE & Hadr Models
Sherpa 2.2.5	**LO 2→2**	CT14NNLO	p_T-ordered PS (CSS Sherpa) **Sherpa AHADIC model for Had based on Cluster Fragm**
			p_T-ordered PS (CSS Sherpa) **Lund model for Had with Pythia6.4**

Impact of 2 hadronization models in Sherpa reaches the level of 45% at low jet mass

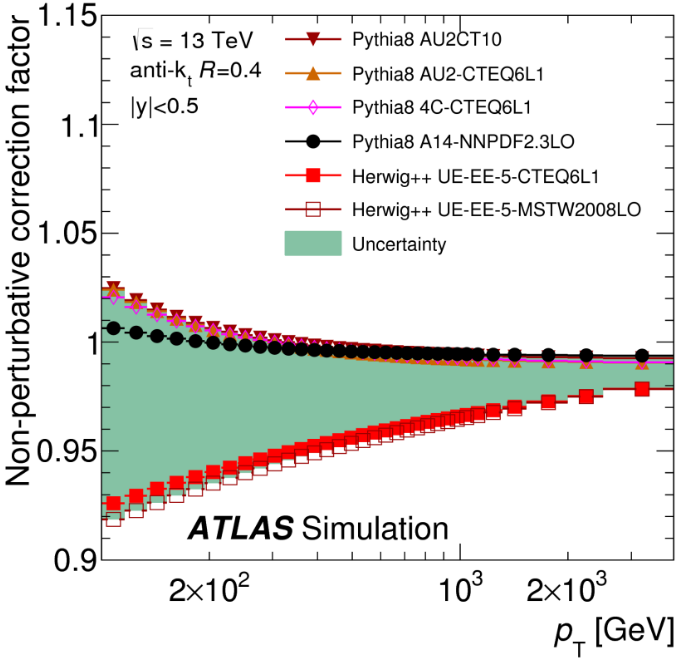


Inclusive jet cross-section

First ATLAS measurement of inclusive jet and dijet cross-section @13 TeV: p_T measured up to 3.5 TeV and m_{jj} up to 9 TeV

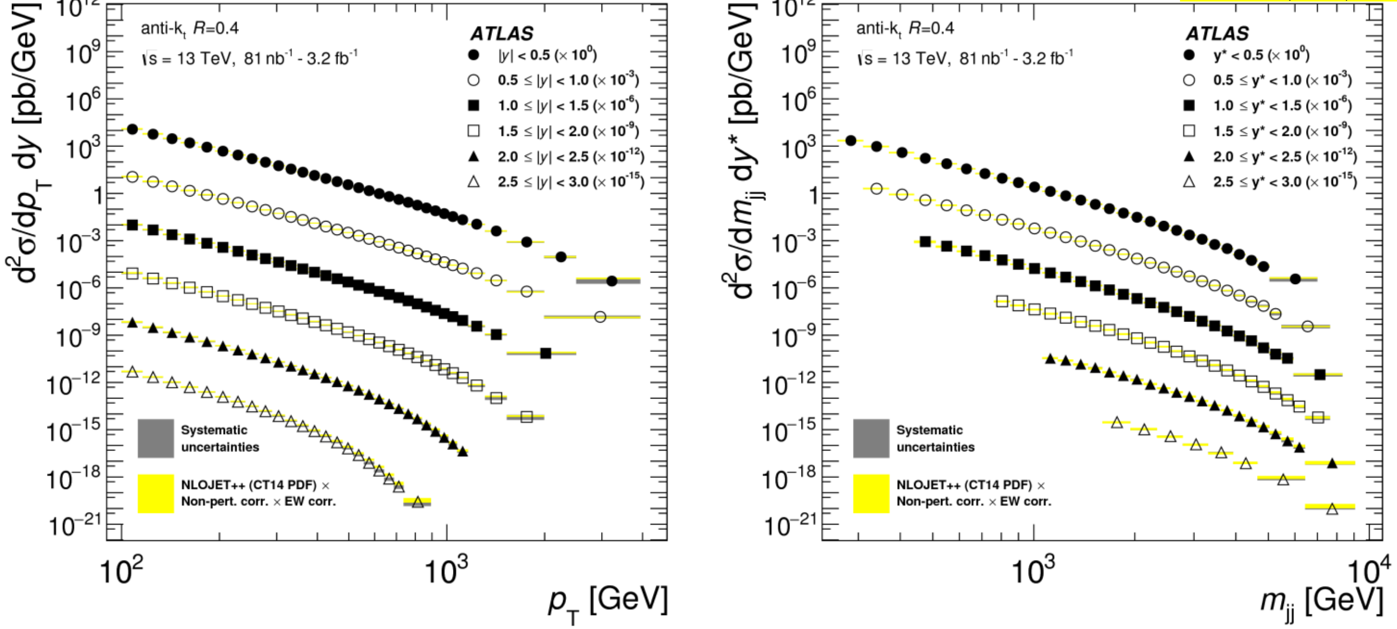
More info in the talk of C. Young (Wednesday)

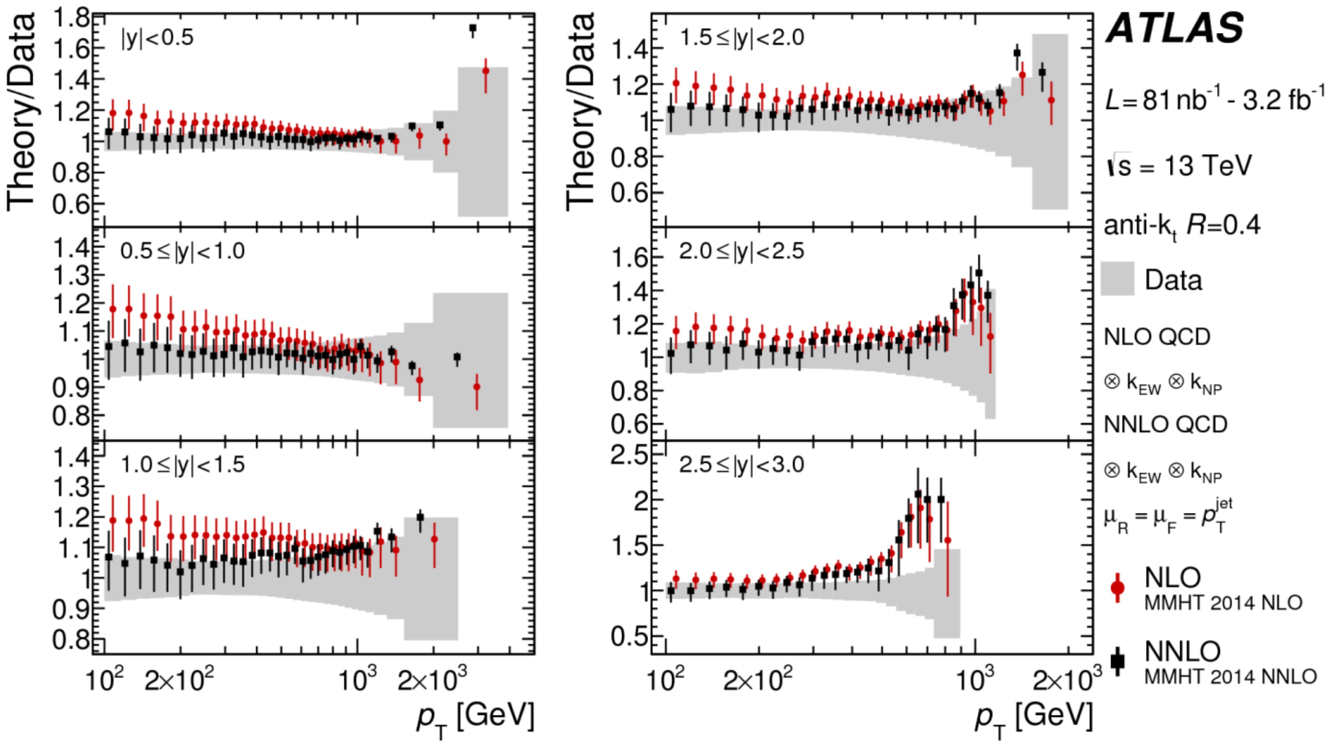
Fair agreement of **NLO prediction** (corrected for non-perturbative and EW effects) with data



No significative difference between NLO and **NNLO** when p_T is used as QCD scale

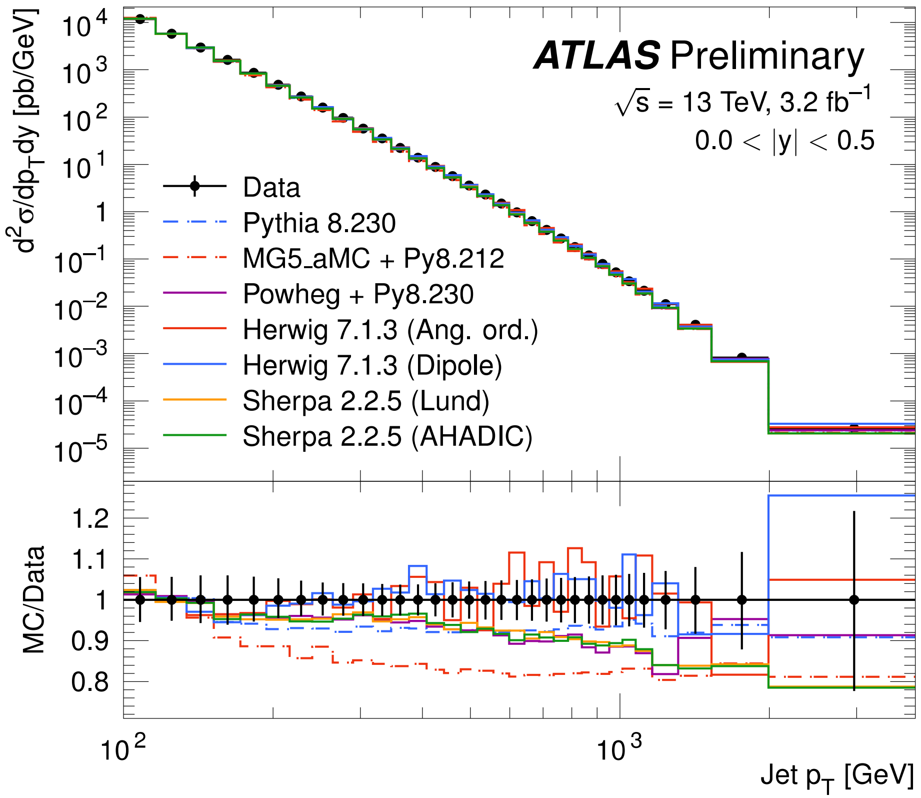
JHEP 05(2018) 195



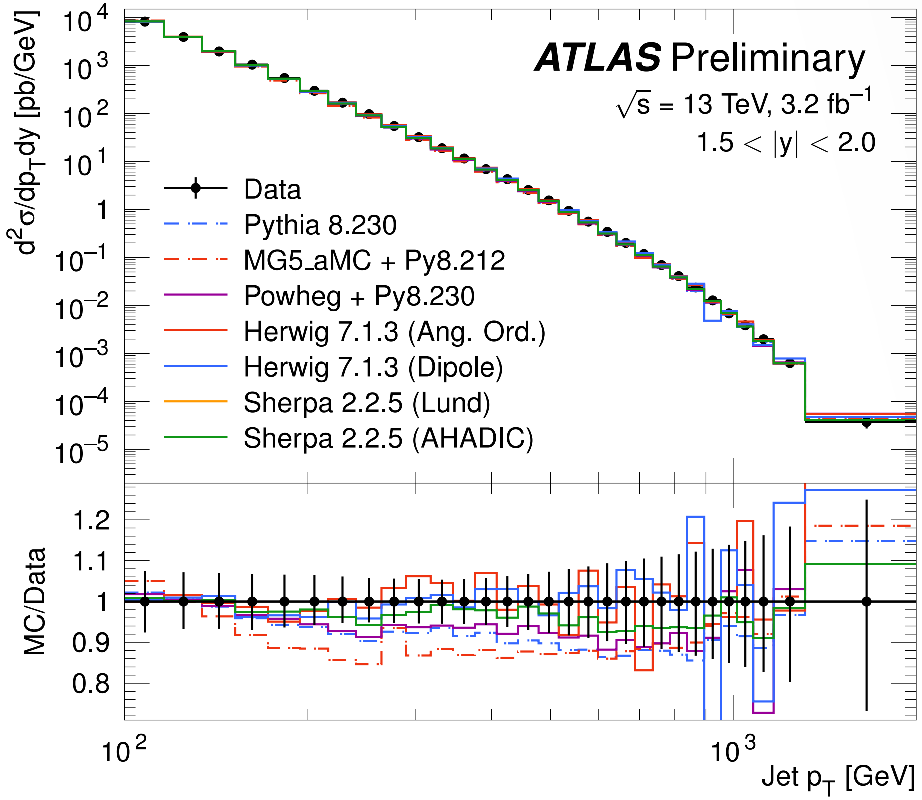


Inclusive jet cross-section

Central rapidities



Forward rapidities



Predictions normalised to data
Shape comparison

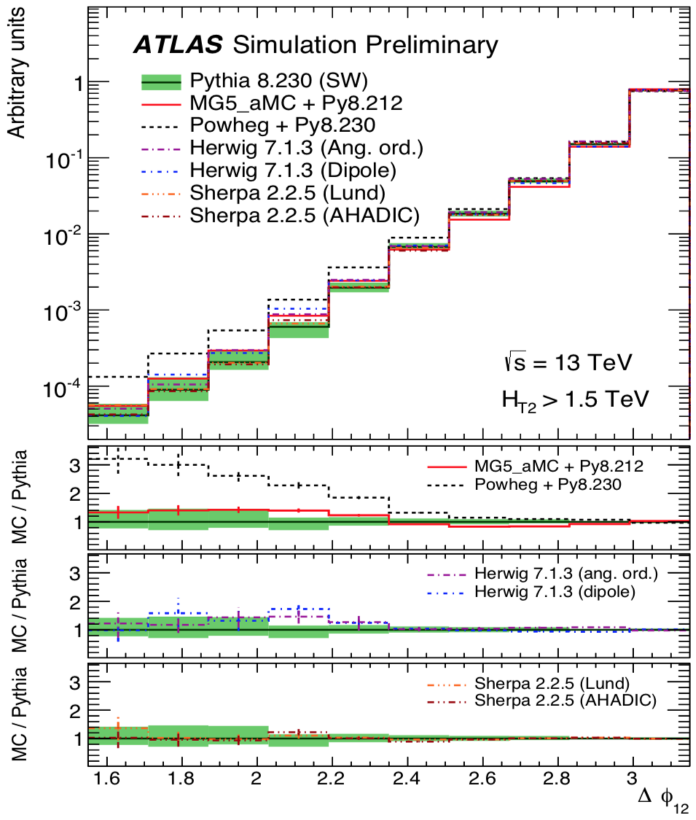
NLO Herwig7 with angular-ordered PS provides the best description of the data for all rapidity ranges,
LO Sherpa matches very well the data for forward rapidities

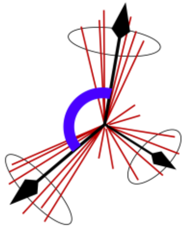
PS model impact:
Different PS models in Herwig7 (**angular-ordered PS** vs **dipole PS**) give small differences in the description of the data

Multijet Event Topology

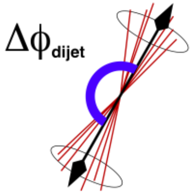
Azimuthal decorrelation between leading jets allows to test additional radiation emission:
3rd jets from PS in Pythia8 and Sherpa (LO 2→2), from ME in MadGraph+Pythia8 (LO up to 4p), Herwig and Powheg+Pyhia8 (NLO)

$\Delta\phi_{12}$



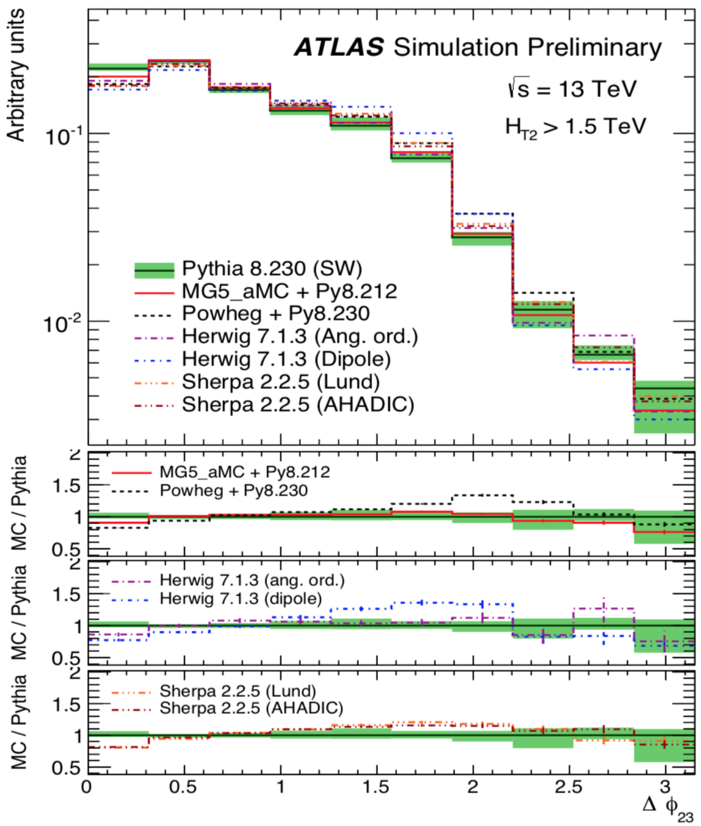


$\Delta\phi$ small (extra jets)



$\Delta\phi = \pi$ (pure dijet)

$\Delta\phi_{23}$



anti-k_t R=0.4 jets with p_T>100 GeV $|\eta|$<2.5 and $H_{T2} = p_{T1} + p_{T2}$ >1.5TeV

Sherpa and **MadGraph+Pythia8** give a similar description as the one of **Pythia8**.

Powheg+Pythia8 shows a much stronger decorrelation

$\Delta\phi_{23}$ sensitive to the color coherence:
Powheg+Pythia8 and **Herwig7 with dipole PS** show the larger differences with respect to Pythia8

Multijet Event Shape

Event shapes sensitive to hard gluon radiation

Transverse Energy-Energy Correlation (TEEC) = transverse energy-weighted distribution of azimuthal difference between jet pairs

$$\frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi} = \frac{1}{N}\sum_{A=1}^{N}\sum_{ij}\frac{E_{\mathrm{T}i}^{A}E_{\mathrm{T}j}^{A}}{\left(\sum_k E_{\mathrm{T}k}^{A}\right)^2}\delta(\cos\phi - \cos\phi_{ij})$$

TEEC used to get α_s at various Q-scale

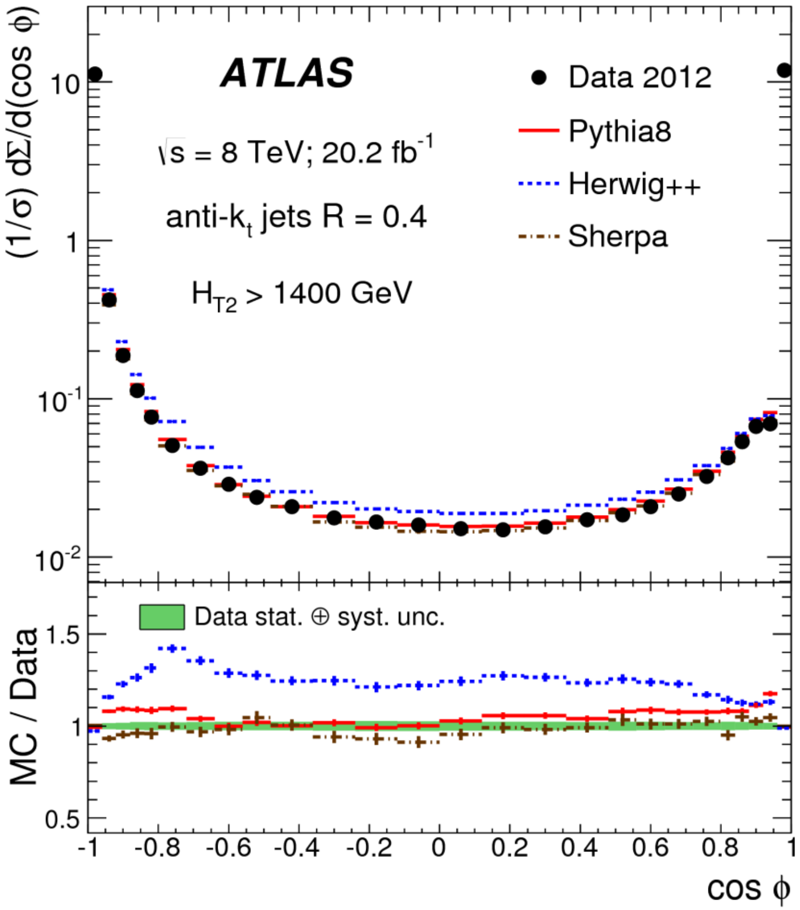
Data-MC@8TeV:

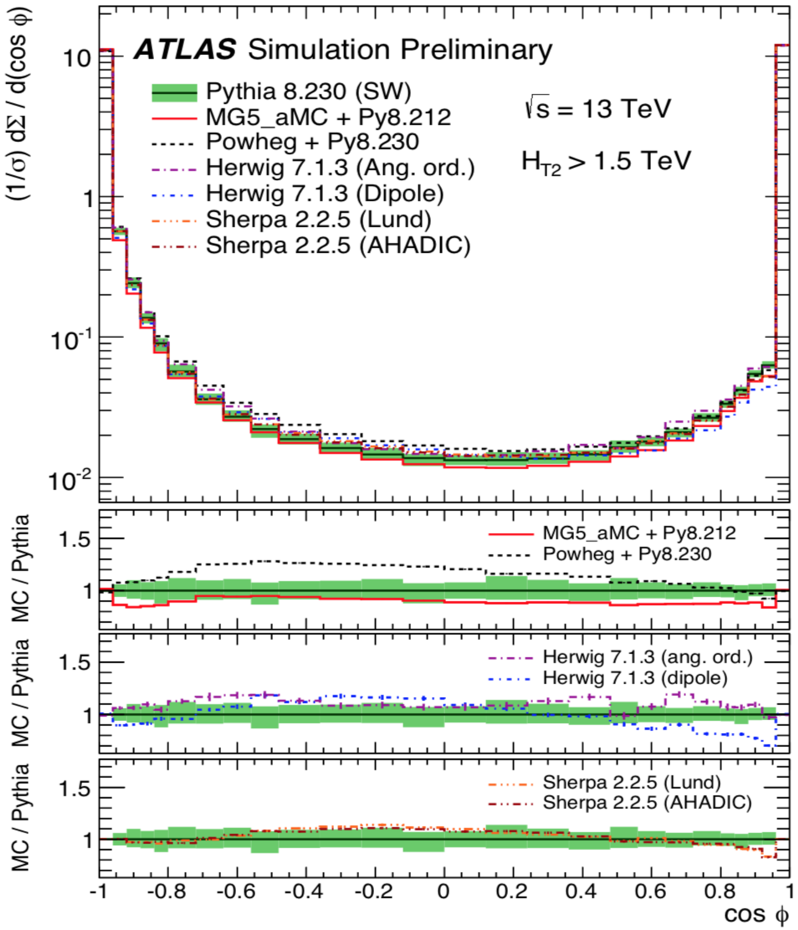
Pythia8 (LO 2→2) and **Sherpa 1.4** (LO up to 3 p) sufficient to provide a good description of the data, much better than **LO Herwig with angular-ordered PS (v2.5.1)**

Latest MC@13TeV

MadGraph+Pythia8 (LO up to 4 p) shows less activity in the central region than **Pythia8**, all other MCs predict slightly more large-angle radiation

Eur. Phys. J. 77 (2017) 872



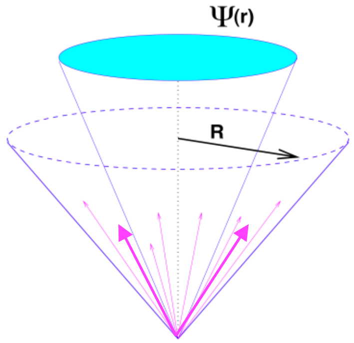


anti-k_t R=0.4 jets with p_T>100 GeV |η|<2.5 and $H_{T2} = p_{T1} + p_{T2}$ >1.5TeV

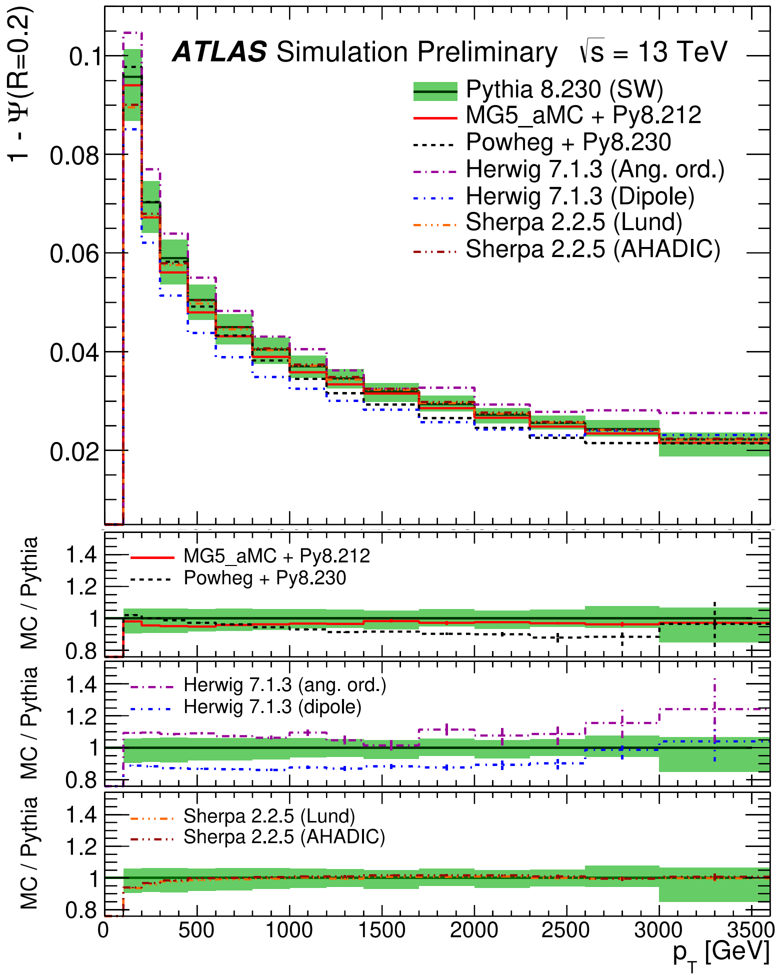
Multijet Jet Shape

Jet shapes sensitive to soft radiation

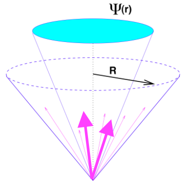
Integral Jet Shape Ψ(r) = fraction of jet p_T inside a cone of radius r



Fraction of the jet p_T outside a cone of 0.2 as a function of the jet p_T



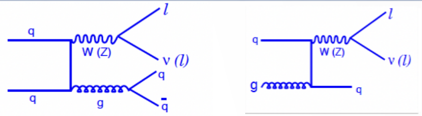
Radiation around the original parton becomes more collimated when increasing the jet p_T



anti-k_t R=0.4 jets with p_T>100 GeV |η|<2.5

Pythia8 (p_T ordered PS) and Herwig7 show significant differences: **dipole PS** predicts systematically narrower jets than Pythia8, while the **angular-ordered PS** gives wider energy distributions inside the jet cone.

Z+jets

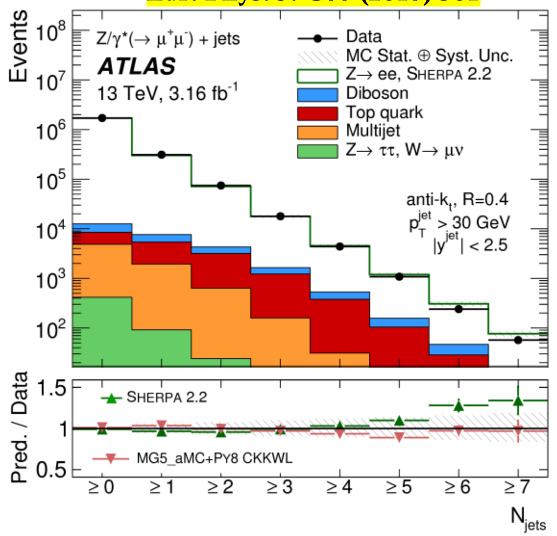


Look at leptonic decays Z→μμ/ee (very clear probe)

Kinematic region with high efficiencies, good detector performances and low backgrounds

Leptons: p_T>25 GeV, |η|<2.4 (μ) - 2.47 (e)
Z: 71 GeV <m_{ll}<111 GeV
Jets: anti-k_t R=0.4, p_T>30 GeV, |y|<2.5, ΔR_{lj}>0.4

Eur. Phys. J. C77 (2017) 361



Comparisons : Data unfolded – MCs
Data unfolded – Fixed order calculations corrected for non perturbative effects

ATL-PHYS-PUB-2017-006

MC	ME order (V+N partons)	PDFs of ME	PS & UE
Sherpa v2.2	NLO up to 2 p +LO up to 4 p	NNPDF3.0nnlo	PS&UE: Sherpa MEPS@NLO merging
MadGraph CKKW-L (MadGraph5_aMC@NLO v2.2.2)	LO up to 4 p	NNPDF3.0nlo	PS&UE: Pythia v8.186 CKKW-L matching and merging
MadGraph FxFx (MadGraph5_aMC@NLO v2.3.3)	NLO up to 2 p	NNPDF2.3lo	PS&UE: Pythia v8.210 Merging with FxFx prescription
Powheg MiNLO	NLO up to 1 p	CT14nnlo	PS&UE: Pythia v8.186
Alpgen	LO up to 5 p	CTEQ6L1	PS&UE: Pythia v6.426 MLM matching and merging

Eur. Phys. J. C77 (2017) 361

Fixed Order Calc	ME order	PDFs
BlackHat+Sherpa	NLO up to 4p	CT14
N_{jetti}NNLO	NNLO	CT14

Z+jets: jet multiplicity

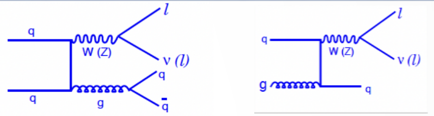
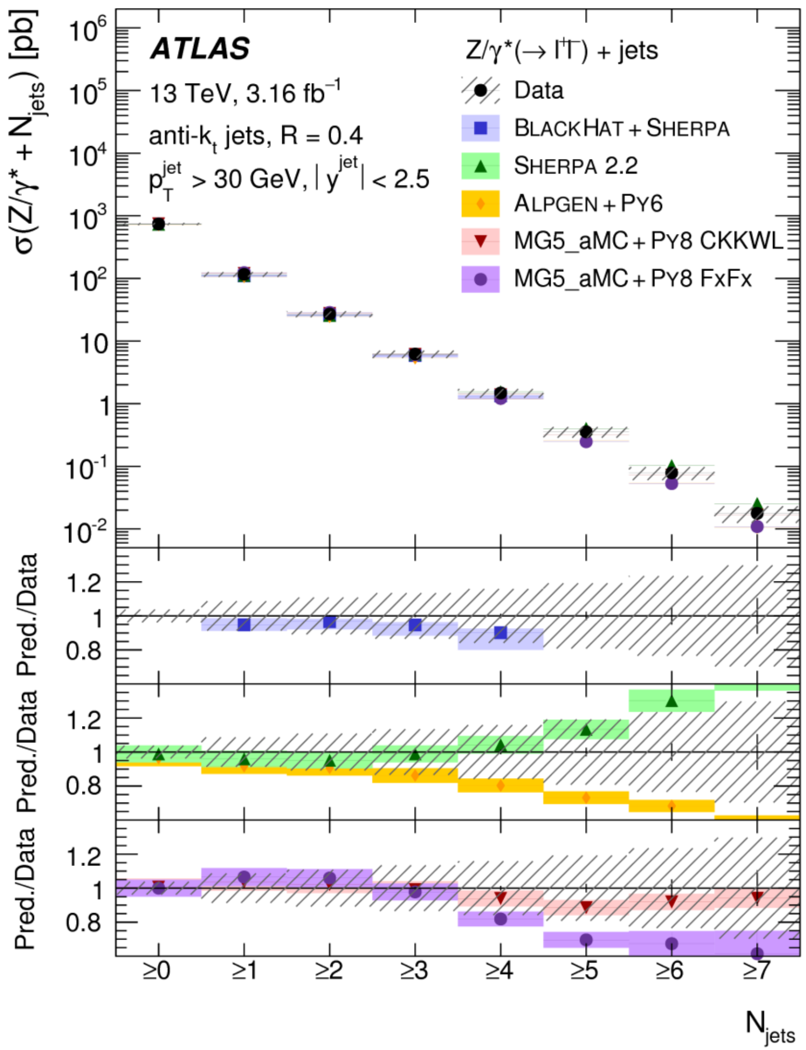


Figure of merit of goodness of QCD predictions and important discriminator with respect to the background in Higgs and searches

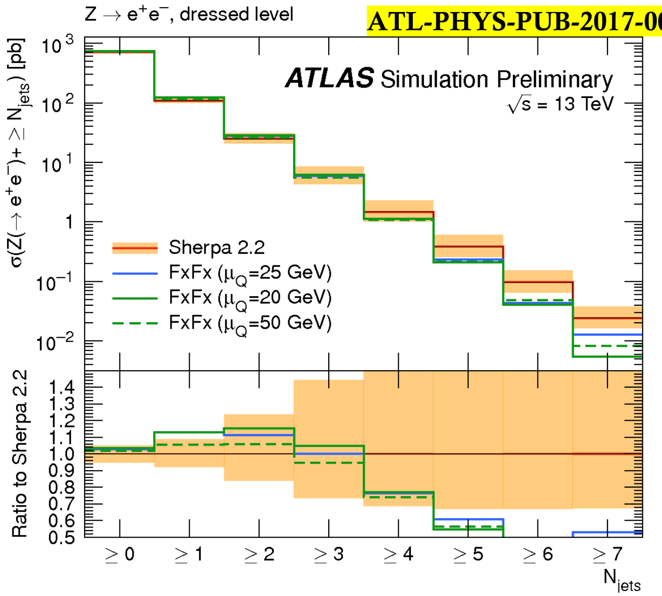
MadGraph+Pythia8 CKKWL (LO up to 4p) shows good agreement with data, while **Alpgen** (LO up to 5p) , **Sherpa** (NLO up to 2 and LO up to 4p) and **NLO MadGraph+Pythia8 FxFx** (NLO up to 2 p) show a systematic trend deviating from data at high jet multiplicities

Eur. Phys. J. C77 (2017) 361



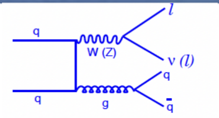
What about MC uncertainty?

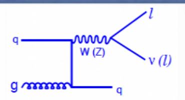
ATL-PHYS-PUB-2017-006



Sherpa uncertainty band (PDF +scale+ statistical unc) quite large at high jet multiplicity

Z+jets: H_T

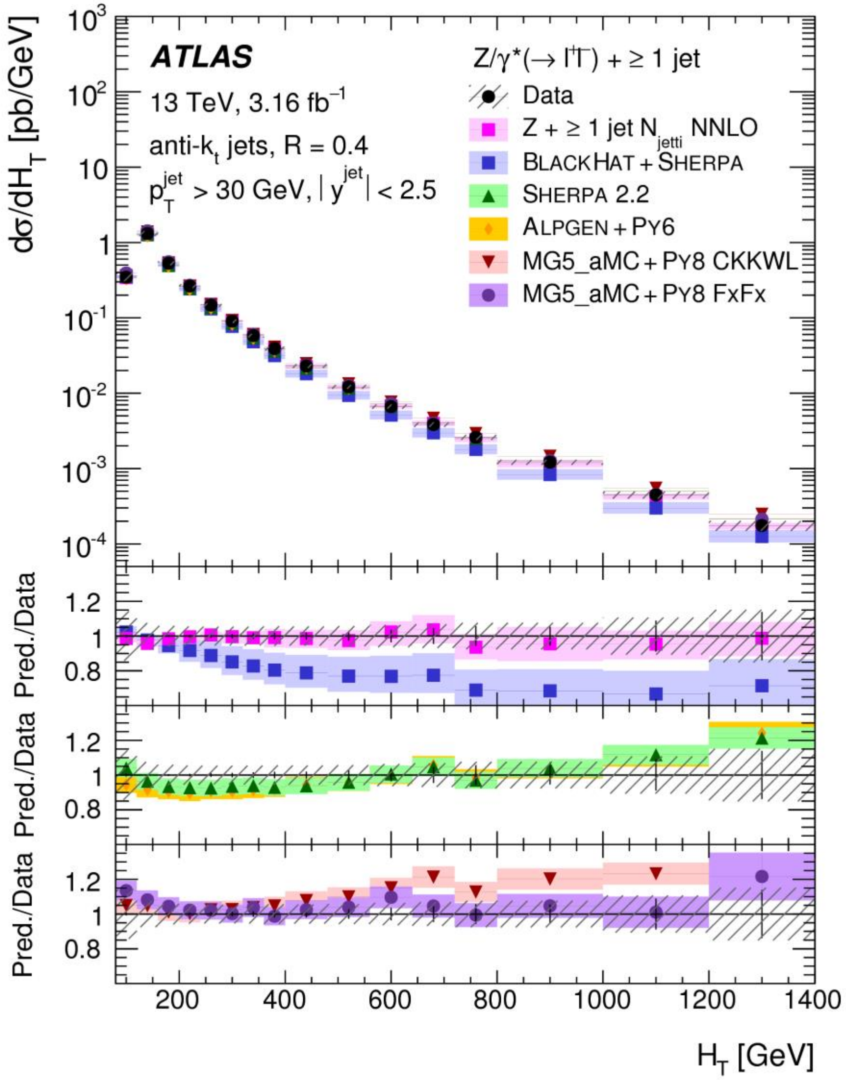




- Important for searches: signal topologies with large jet activity (discriminant with respect to SM background)

$$H_T = \sum_{leptons, jets} |p_T|$$

Eur. Phys. J. C77 (2017) 361



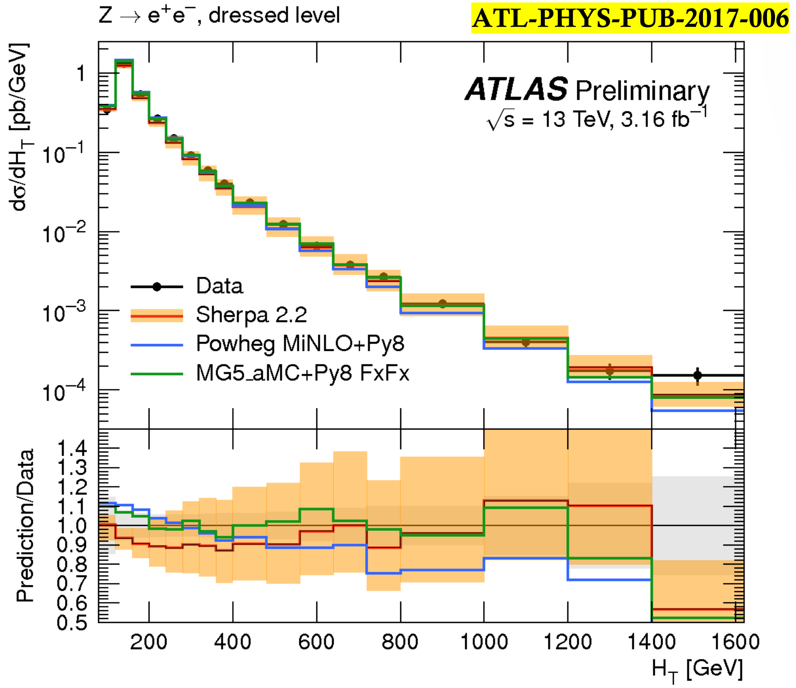
NLO calculations from BlackHat+Sherpa underestimate data

N_{jetti}NNLO recovers agreement by adding higher orders in pQCD

LO MadGraph+Pythia8 CKKWL over-predicts large H_T

What about MC uncertainty?

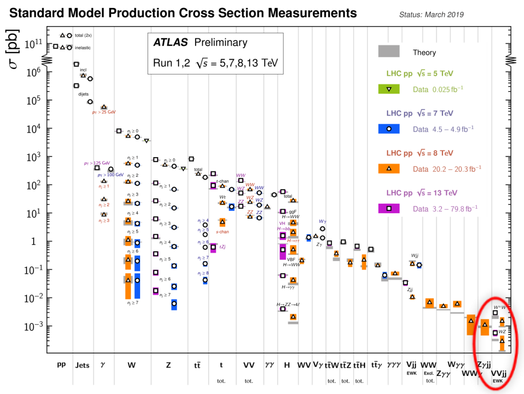
ATL-PHYS-PUB-2017-006



From 5% up to 50% using **Sherpa** (NLO up 2p and LO up to 4)

Other NLO MCs contained within Sherpa uncertainty band, expect at low H_T

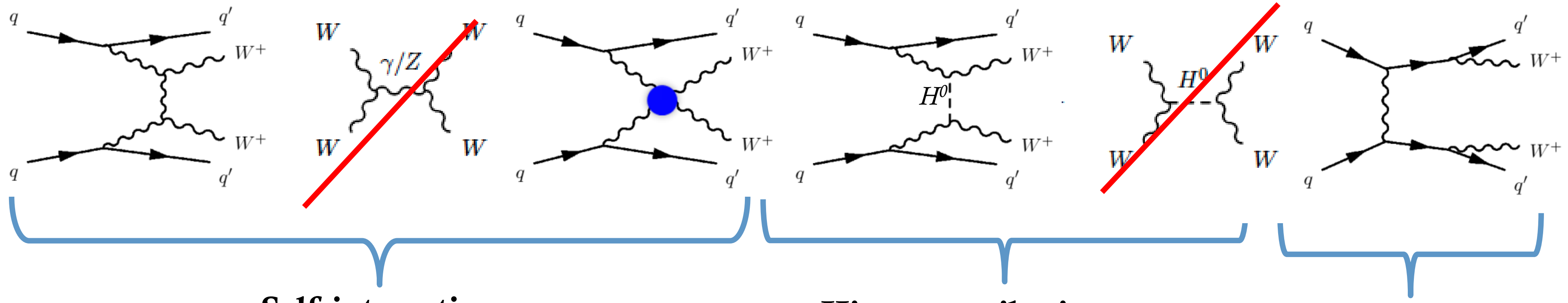
$W^{\pm}W^{\pm}$+jets



Final states sensitive to Vector Boson Scattering (VBS) allow to:
-Test the electroweak breaking symmetry (Higgs contribution)
- Study triple and quadratic gauge coupling

More info in the talk of Francesco Conventi (Tuesday)

EW processes:

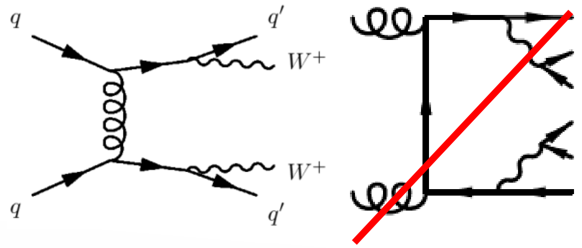


Self-interactions

Higgs contributions

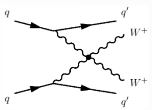
Non resonant

QCD processes:



In $W^{\pm}W^{\pm}$jj (same sign) production
some diagrams do not contribute:
smaller cross-section than $W^{+}W^{-}$jj (opposite sign),
but also large suppression of QCD processes
→ **Golden channel to study VBS**

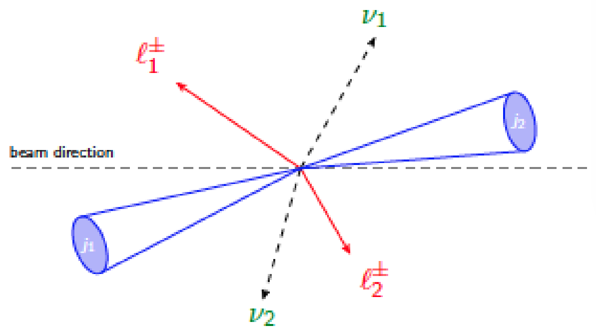
$W^{\pm}W^{\pm}$+jets: measurement



Fiducial phase-space of cross-section measurement:

-2 isolated same-sign leptons ($e^{\pm}e^{\pm}, \mu^{\pm}\mu^{\pm}, e^{\pm}\mu^{\pm}$) central and $p_T >$ 27 GeV, m_{ll}>20 GeV, $\Delta R_{ll} > 0.3$
- Missing $E_T >$ 30 GeV
- >=2 jets with $p_T^{j1} >$ 65 GeV , p_T^{j2} >35 GeV, $\Delta R_{lj} > 0.3$
- $|\Delta y_{jj}|>2$
- m_{jj}> 500 GeV

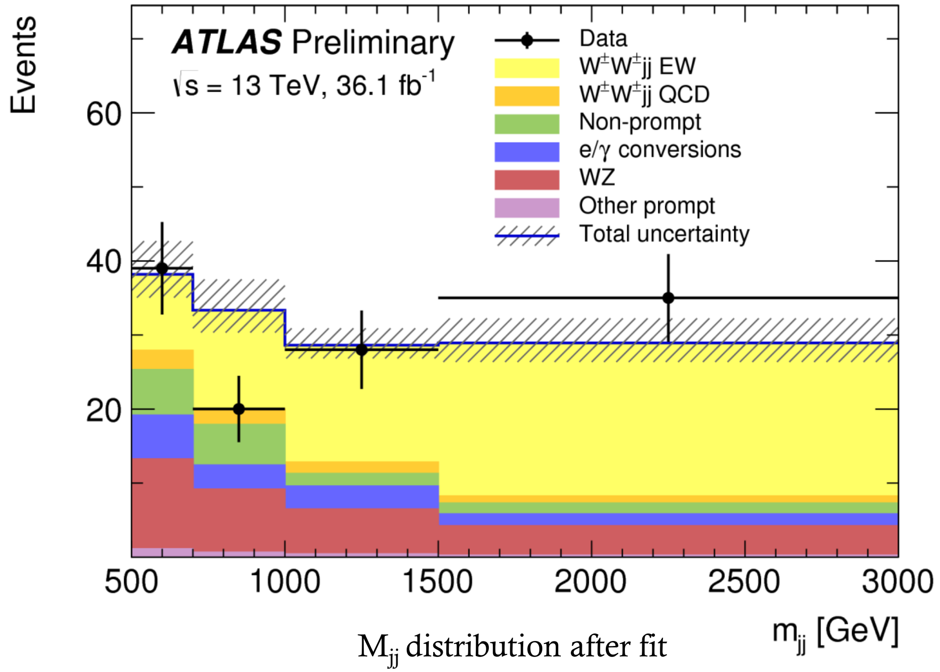
More info in the talk of Francesco Conventi (Tuesday)



Detector level selection very close to fiducial phase-space plus additional cuts to further reject background

EW signal extracted with fit on m_{jj} distribution

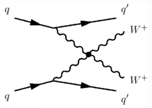
ATLAS-CONF-2018-030



M_{jj} distribution after fit

<u>**Observation of EW $W^{\pm}W^{\pm}$+jets by ATLAS@13 TeV**</u>
background-only hypothesis rejected with an observed significance of 6.9σ

$W^{\pm}W^{\pm}$+jets: MC configuration



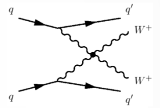
Detailed study performed recently on several MC configurations - **electroweak same-sign WWjj production**

ATL-PHYS-PUB-2019-004

MC	ME order	PDFs of ME	PS & UE &Hadr Models
MadGraph (MadGraph5_aMC@NLO 2.6.2)	LO	NNPDF30nlo	**Pythia8**
	NLO		
	LO		**Pythia 8, Dipole Recoil**
	LO		**Herwig7**
	NLO		
Powheg	**NLO**	NNPDF30nlo	**Pythia8**
			Pythia 8, Dipole Recoil
			Herwig7
			Herwig7, Dipole Shower
Sherpa	LO (2 samples with different scales)	NNPDF30nnlo	**Sherpa PS**
	LO up to 1 additional parton		

Tested impact on different **ME orders** and **PS schemes**

$W^{\pm}W^{\pm}$+jets: cross-section



MC

ATL-PHYS-PUB-2019-004

Leading-Order Configurations	
Sample name	σ [fb]
MG5_AMC _LO+PY8	3.106 ± 0.015
MG5_AMC _LO+PY8,Dipole Recoil	3.104 ± 0.015
MG5_AMC _LO+H7	3.016 ± 0.020
MG5_AMC _LO+H7,Dipole Shower	3.022 ± 0.017
SHERPA_LO-0	2.615 ± 0.011
SHERPA_LO-1	2.806 ± 0.046

Leading-Order Multileg Configurations (0,1 additional parton)	
Sample name	σ [fb]
SHERPA_CKKW	2.048 ± 0.013

Next-to-Leading-Order Configurations	
Sample name	σ [fb]
POWHEG +PY8	$3.122 \pm 0.023^{+0.050}_{-0.040}$ (scale) ± 0.010 (pdf)
POWHEG +PY8,Dipole Recoil	3.082 ± 0.023
POWHEG +H7	2.992 ± 0.026
POWHEG +H7,Dipole Shower	3.004 ± 0.026
MG5_AMC _NLO+H7, Γ_{resc}	$3.304 \pm 0.033^{+0.050}_{-0.040}$ (scale) ± 0.010 (pdf)
MG5_AMC _NLO+PY8, Γ_{resc}	3.345 ± 0.033

ATLAS-CONF-2018-030

Data

$$\sigma_{fid} = 2.91^{+0.51}_{-0.47}(\text{stat.}) \pm 0.27(\text{syst.})\ \text{fb}$$

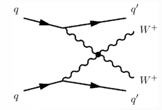
Powheg (NLO) and all **MadGraph** (LO and NLO) configurations agree within 10% while **Sherpa** (LO and LO up to 1 additional p) predicts lower cross-sections

Difference of NLO calculations (**MadGraph** and **Powheg**) of ~10%, larger than their own ±2% uncertainty (scale+PDF+ statistical unc), absence of the s-channel diagrams in the Powheg configuration

Impact of changes in the PS (Pythia8 vs Herwig7) is at most of 5%

Data in agreement with **Powheg** and **MadGraph** and about 1σ higher than **Sherpa**

$W^{\pm}W^{\pm}$+jets: differential distributions



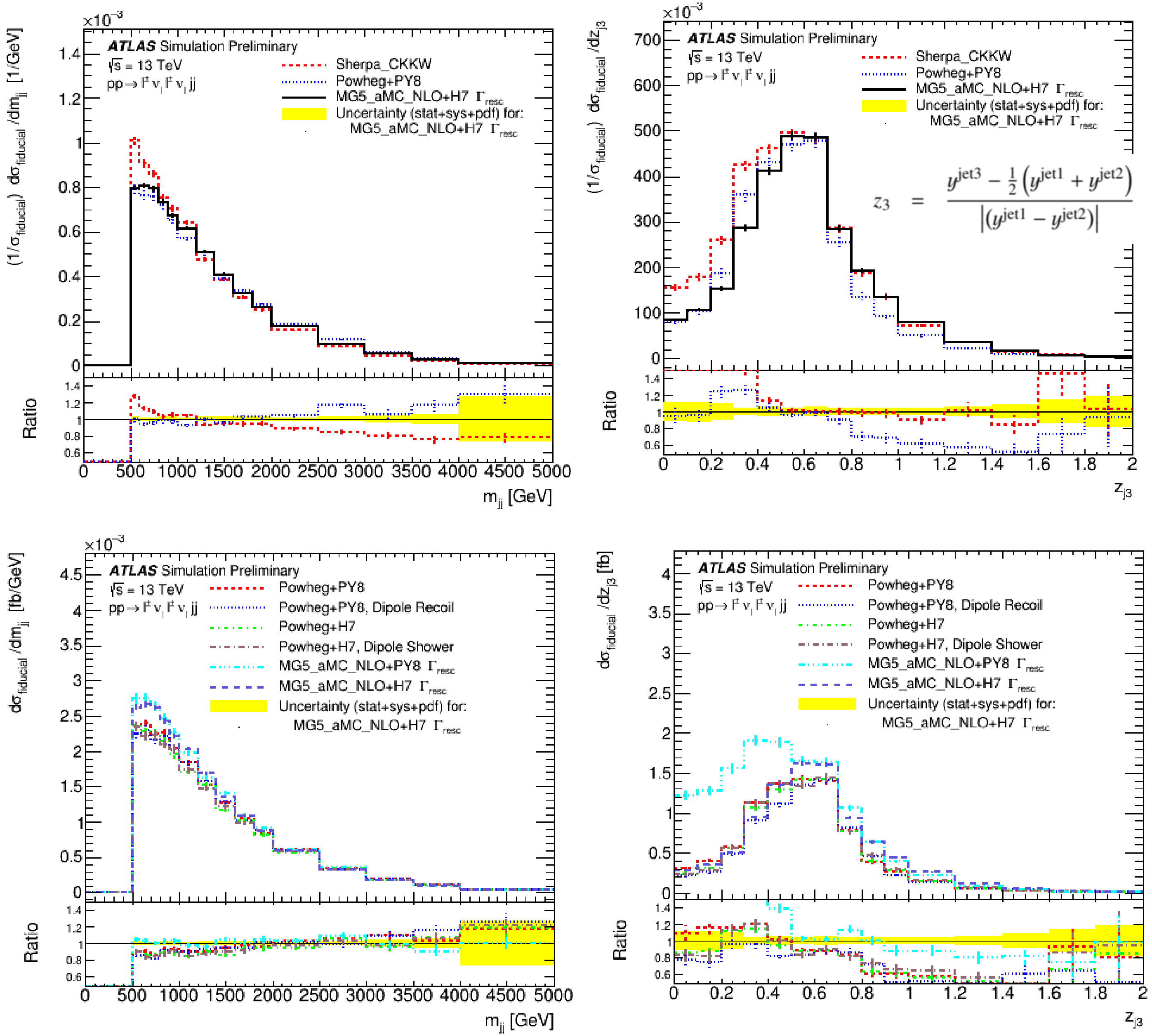
ATL-PHYS-PUB-2019-004

NLO MCs (**Powheg** and **Madgraph**)
produce harder m_{jj} *spectra* than LO MCs (**Sherpa**)

Differences between Sherpa and Powheg
up to 40% at high m_{jj}

Zeppenfeld variable of 3rd jet
found important difference among generators

Impact on PS choice studied for NLO Powheg and Madgraph:
small effects for m_{jj}, while large effects for z_{j3}



Conclusions

Good **MC modelling** is central for producing **high-profile physics results at LHC**

ATLAS Collaboration is investing a **huge effort** in studying several MC configurations for several physics processes, testing impact of several aspects: ME+PS matching , PS modelling, hadronisation modelling, with the aim of identifying **a baseline MC modelling as-good-as-possible and with a reasonable uncertainty**

→ Best approach to push on new improvements on MC market (all our publications come with a Rivet routines to facilitate comparison of our measurements with latest MC setups)

Shown today 3 cases focused on jet modelling: **multijets, V+jets in QCD domain and VV+jets in EW-dominated regions**

In general found good agreement data-MC and among different MCs in intermediate phase-space regions, while in some cases important differences found in extreme phase-space regions (i.e. high m_{jj} and H_T) or in cases dominated by additional radiation (i.e. modelling of z_{j3} or high jet multiplicity)

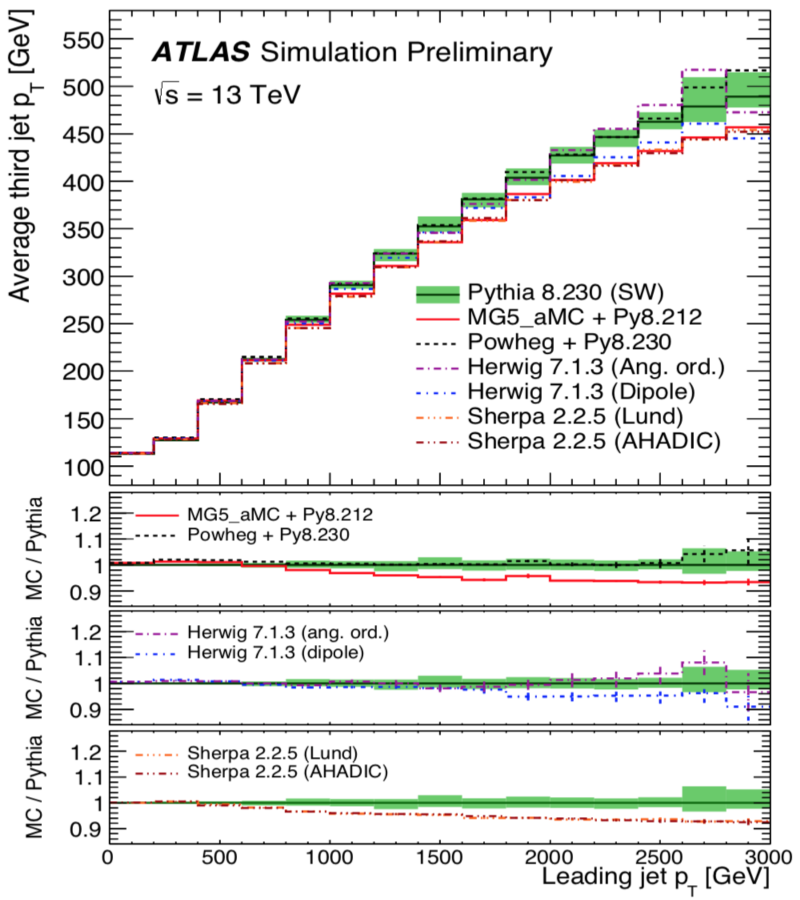
BACKUP

Multijet MC configuration

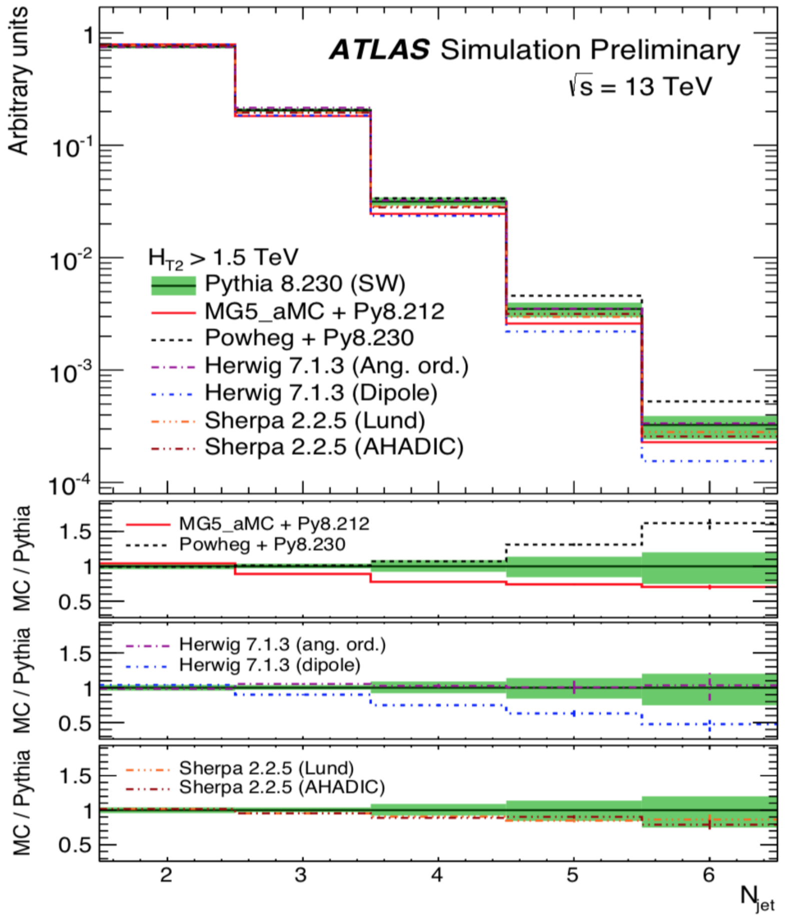
MC	ME order	PS & UE &Hadr Models	PDFs of ME	μ_R μ_F	PS&MPI tunes
Pythia 8.230	LO 2→2	p_T-ordered PS Lund model for Hadr	NNPDF23LO	$m_{T_3} \cdot m_{T_4} = \sqrt{(p_T^2 + m_3^2)(p_T^2 + m_4^2)}$	A14 tune
MG5_aMC@NLO+Pythia8 (MadGraph5_aMC@NLO 2.3.3.1)	LO up to 4 part	PS&Hadr: Pythia8.212 Merging with CKKW-L prescriptions, merging scale=30 GeV	NNPDF30NLO	m_T of 2→2 process	ATLAS A14 (NNPDF23LO)
Herwig 7.1.3	NLO dijets (Matchbox)	Angular-ordered PS Matching with MC@NLO-like algorithm Cluster model for Had	MMHT2014NLO	p_T leading jet	Dedicated tune
		Dipole PS Matching with MC@NLO-like algorithm Cluster model for Had		p_T leading jet	Dedicated tune
Sherpa 2.2.5	LO 2→2	p_T-ordered PS with CSS Sherpa Sherpa AHADIC model for Hadr based on cluster fragm	CT14NNLO		Dedicate tune CT10 for MPI
		p_T-ordered PS with CSS Sherpa **Lund model for had with Pythia6.4**			
Powheg-Box V2 r3480	NLO dijets	PS&MPI: Pythia 8.230	NNPDF30NLO	p_T of Born configuration	A14 tune (NNPDF23LO)

Multijet Event Topology

3^{rd} jets from PS in Pythia8 and Sherpa (LO 2→2), from ME in Madgraph+Pythia8 (LO up to 4p), Herwig and Powheg+Pyhia8 (NLO)



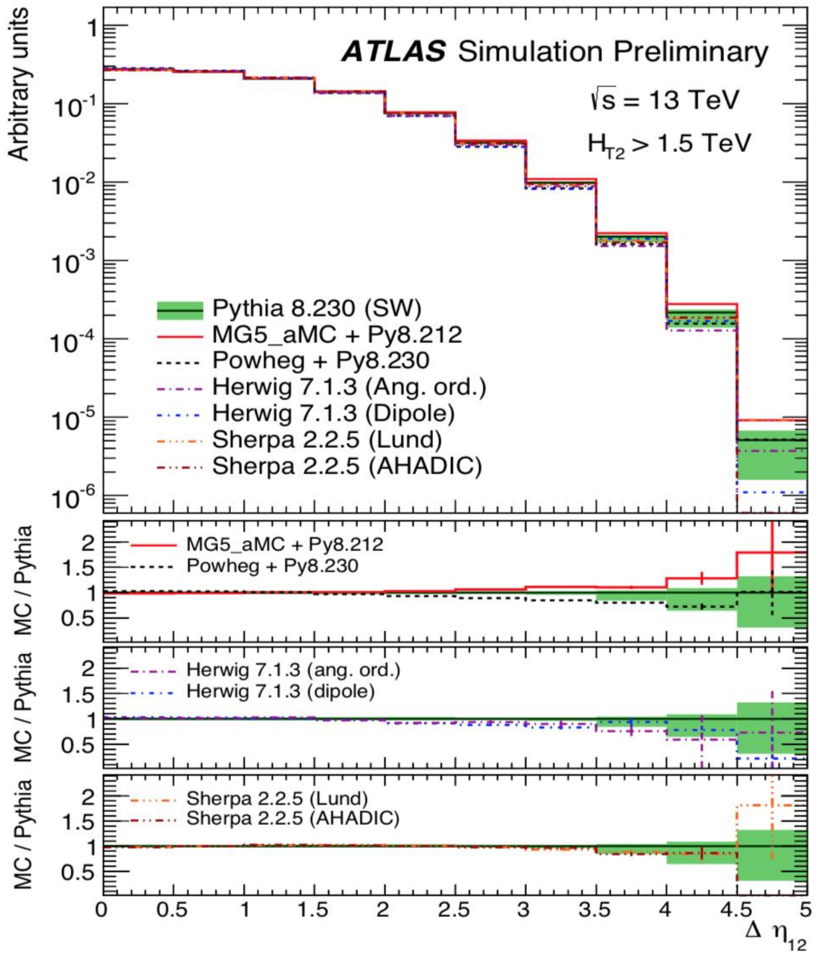
anti-k_t R=0.4 jets with p_T>100 GeV |η|<2.5 and $H_{T2} = p_{T1} + p_{T2}$ >1.5TeV



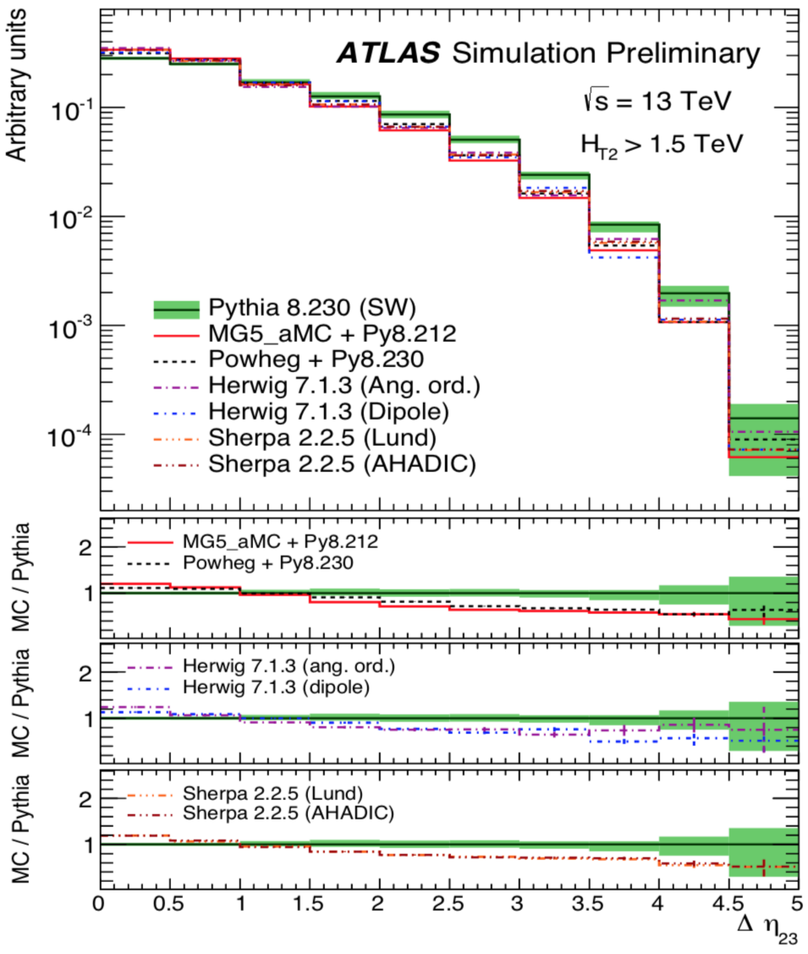
MadGraph+Pythia8 and **Sherpa** predict softer emissions than **Pythia8**

Herwig7 with dipole PS predicts a smaller N_{jet} than **Pythia8**, **angular-ordered PS** and **Sherpa** in agreement with Pythia8 within PS unc. **MadGraph+Pythia8** in the middle between Pythia8 and **Herwig7 dipole PS**. **Powheg** predicts larger N_{jet}

Multijet Event Topology



anti-k_t R=0.4 jets with p_T>100 GeV |η|<2.5



All MCs show a quite similar behaviour

$\Delta\eta_{23}$ shows significant differences among generators: **Pythia8** predicts systematically larger $\Delta\eta_{23}$ than others, differences of up to 50%.

Multijet Event Shape

Event shapes sensitive to hard gluon radiation

Transverse Energy-Energy Correlation (TEEC) = transverse energy-weighted distribution of azimuthal difference between jet pairs

$$\frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi} = \frac{1}{N}\sum_{A=1}^{N}\sum_{ij}\frac{E^A_{\mathrm{T}i}E^A_{\mathrm{T}j}}{\left(\sum_k E^A_{\mathrm{T}k}\right)^2}\delta(\cos\phi - \cos\phi_{ij})$$

Asymmetry between the forward and backward part of TEEC **(ATEEC)**

$$\frac{1}{\sigma}\frac{d\Sigma^{asym}}{d\cos\phi} \equiv \frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi}\bigg|_{\phi} - \frac{1}{\sigma}\frac{d\Sigma}{d\cos\phi}\bigg|_{\pi-\phi}$$

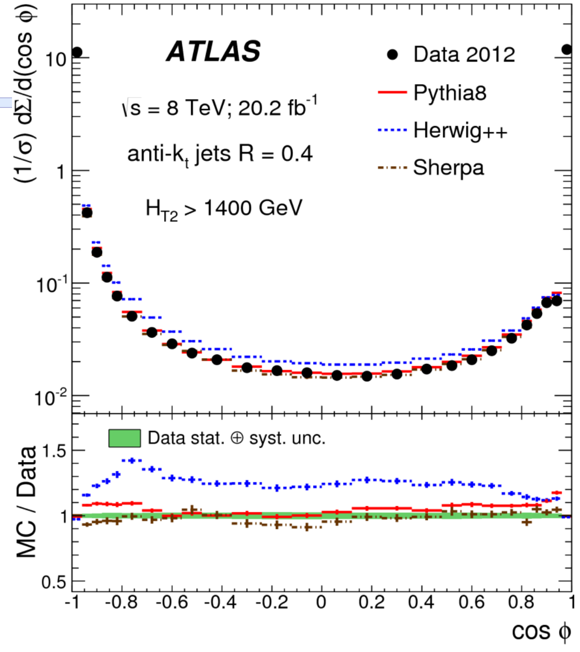
TEEC and ATEEC used to get α_s at various Q-scale

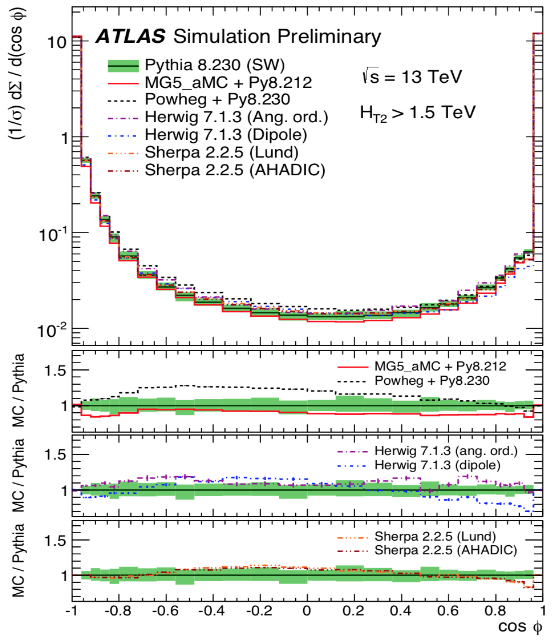
Data-MC@8TeV:

Pythia8 (LO 2→2) and **Sherpa 1.4** (LO up to 3 p) sufficient to provide a good description of the data, much better than **LO Herwig with angular-ordered PS (v2.5.1)**

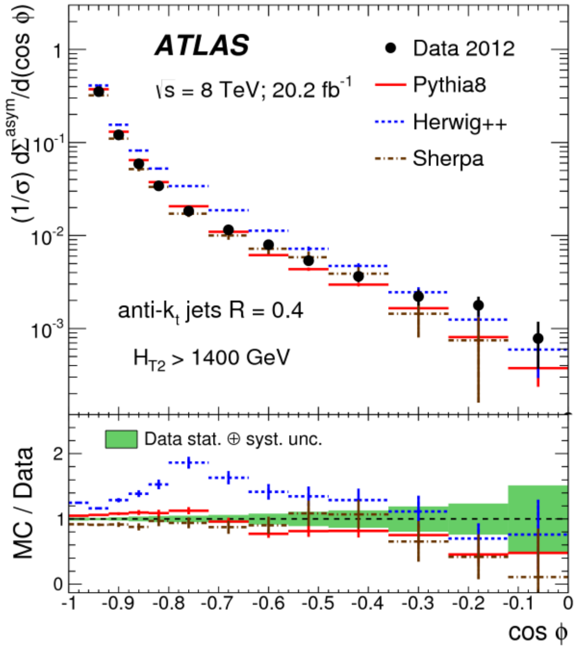
Latest MC@13TeV

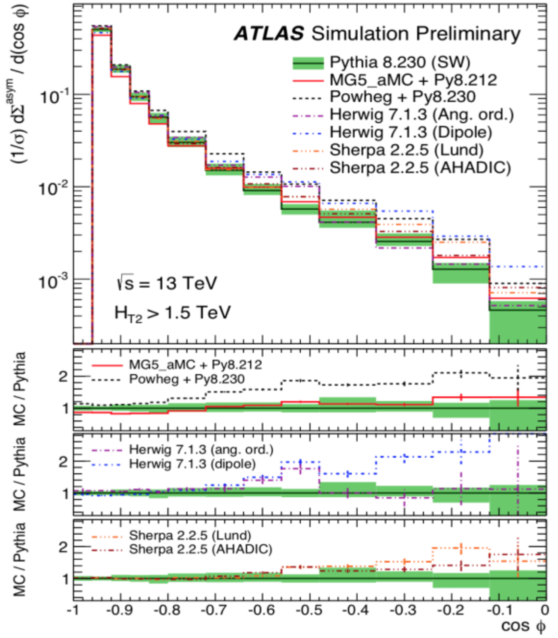
Herwig7 (NLO), **Powheg+Pythia8 (NLO)** and **Sherpa** (LO 2→2) predict more large-angle radiation than **Pythia8** (LO 2→2), **MadGraph+Pythia8** (LO up to 4 p) shows less activity in the central region





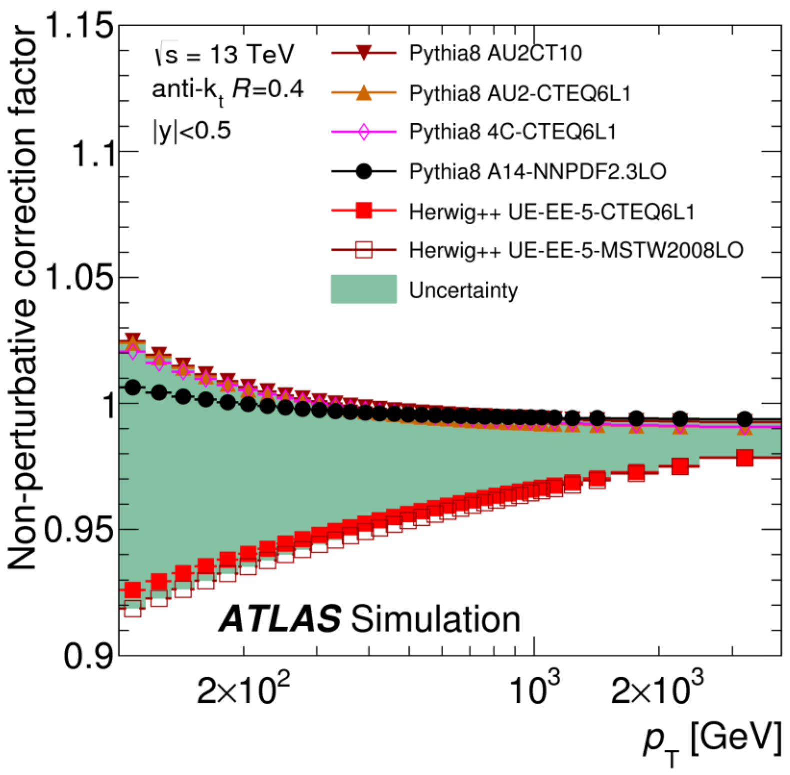
Eur. Phys. J. 77 (2017) 872

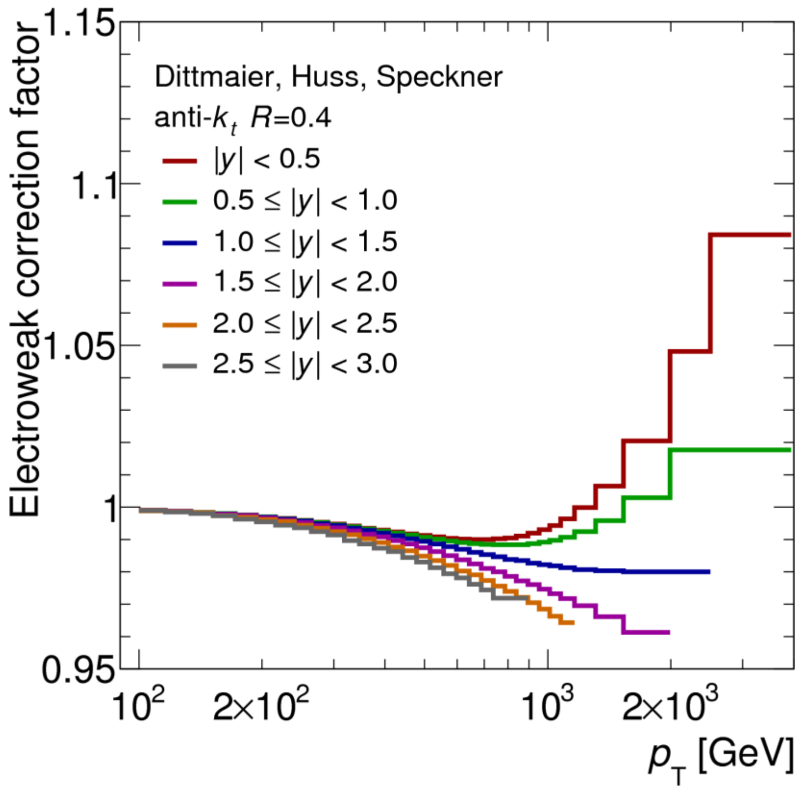




anti-k_t R=0.4 jets with p_T>100 GeV |η|<2.5 and $H_{T2} = p_{T1} + p_{T2}$ >1.5TeV

Inclusive jet cross-section





	CTEQ6L1 [67]	CTEQ6L1 [67]	MSTW2008LO [68]	CT10	NNPDF2.3LO	NNPDF2.3LO	CTEQ6L1 [67]
Pythia 8	4C [69]	AU2 [70]	A14 [30]	AU2 [70]	MONASH [71]	A14 [30]	A14 [30]
Herwig++	UE-EE-5 [72, 73]	UE-EE-4 [72, 73]	UE-EE-5 [72, 73]				

Default

Z+jets

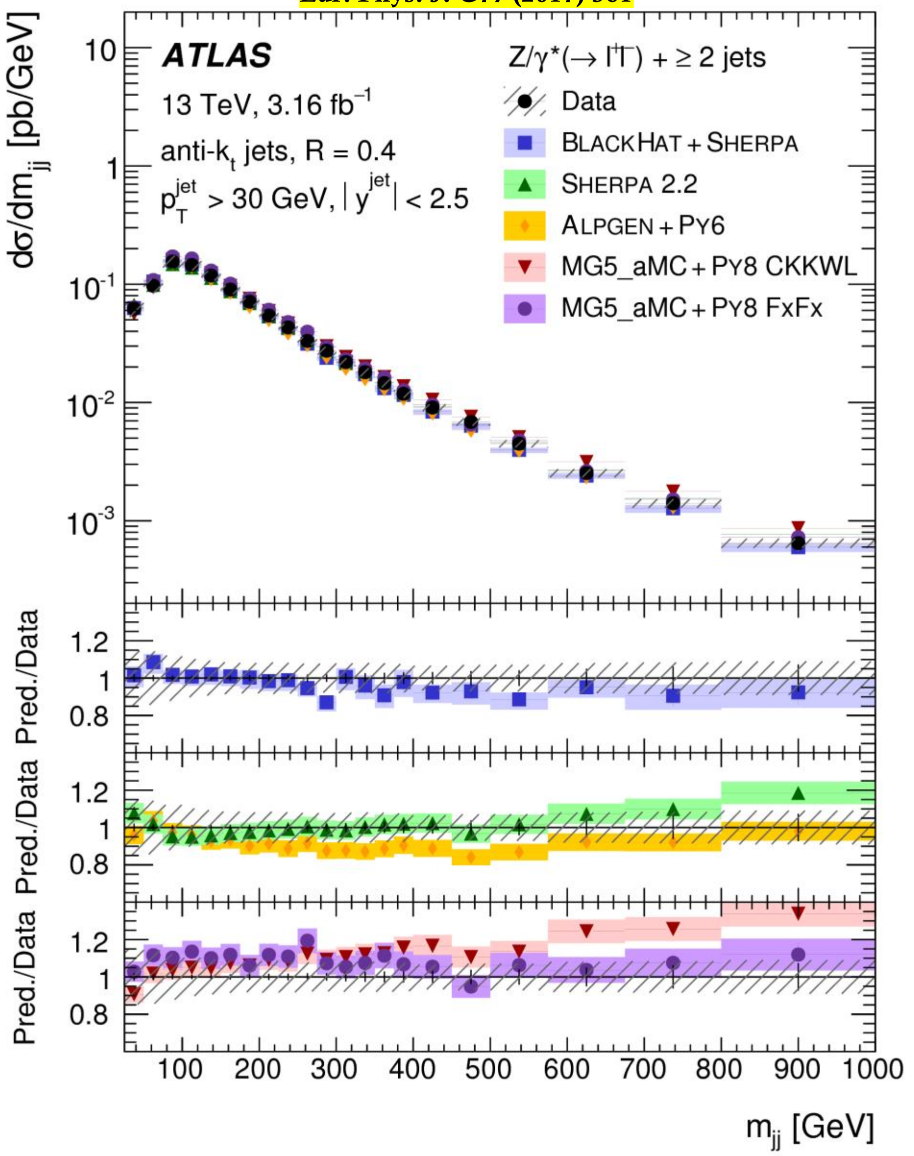
MC	ME order (V+N partons)	PDFs of ME	PS & UE	PS &UE tunes
Sherpa v2.2	**NLO up to 2 p +LO up to 4 p**	NNPDF3.0nnlo	**PS&UE: Sherpa** **MEPS@NLO merging** **Matching scale= 20 GeV**	Dedicated Sherpa tune
MadGraph CKKW-L (MadGraph5_aMC@NLO v2.2.2)	**LO up to 4 p**	NNPDF3.0nlo	**PS&UE: Pythia v8.186** **CKKW-L matching and merging** **Merging scale= 30 GeV**	A14 tune (NNPDF23lo)
MadGraph FxFx (MadGraph5_aMC@NLO v2.3.3)	**NLO up to 2 p**	NNPDF2.3lo	**PS&UE: Pythia v8.210** **Merging with FxFx prescription** **Merging scale = 25 GeV**	A14 tune (NNPDF2.3lo)
Powheg MiNLO	**NLO up to 1 p**	CT14nnlo	**PS&UE: Pythia v8.186**	AZNLO tune (CTEQ6 L1)
Alpgen	**LO up to 5 p**	CTEQ6L1	**PS&UE: Pythia v6.426** **MLM matching and merging** **Matching scale= 20 GeV**	Perugia2011C

Z+jets: m_{jj}

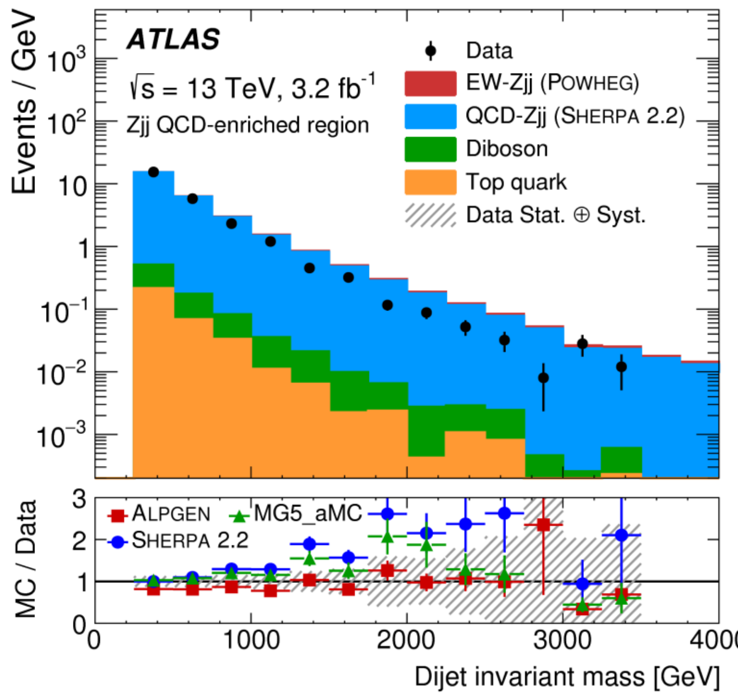
Quite good modelling at low values, in the high mass range **LO MadGraph+Pythia8 CKKWL** predicts an harder m_{jj}

Similar trend also for **NLO Sherpa** exploring up to very high mass range and up to large rapidity separation

Eur. Phys. J. C77 (2017) 361



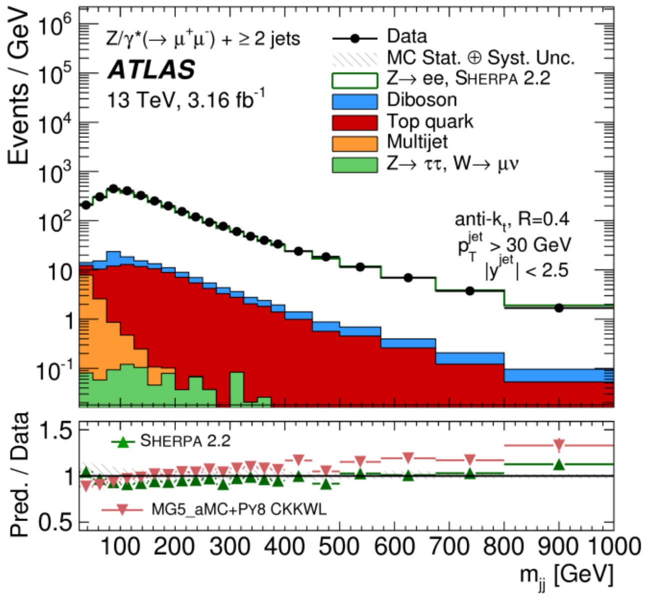
Phys Lett B 775 (2017) 206

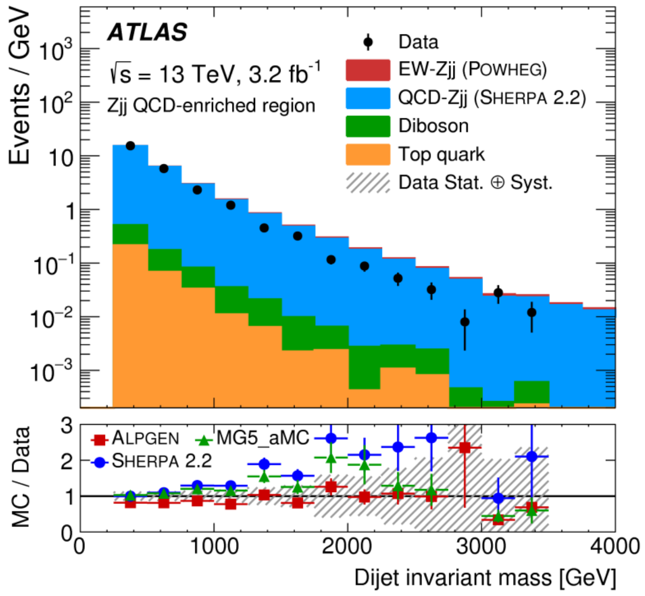


Events with at least 2 jets with p_T>55, 45 GeV |y|<4.4 M_{jj}>250 GeV and at least 1 additional jet in the gap

Z+jets: m_{jj}

Detector level

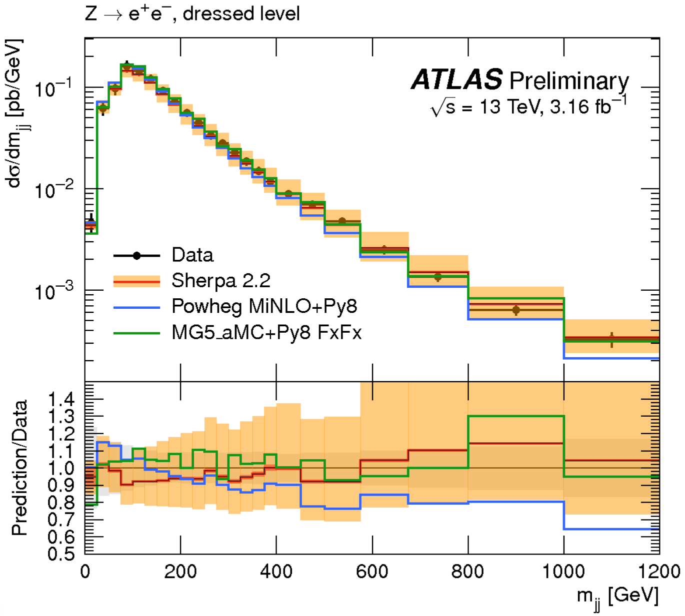




Events with at least 2 jets with p_T>55, 45 GeV |y|<4.4 M_{jj}>250 GeV and at least 1 additional jet in

Particle level

Sherpa uncertainty band shown



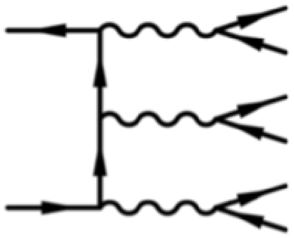
$W^{\pm} W^{\pm}$ +jets

Leading-Order Configurations				
Sample name	Contributions	μ-scale	Shower	Tune
MG5_AMC _LO+PY8	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	PYTHIA 8.235	A14
MG5_AMC _LO+PY8, Dipole Recoil	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	PYTHIA 8.235	A14, Dipole Recoil
MG5_AMC _LO+H7	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	HERWIG 7.1.3	H7.1-Default
MG5_AMC _LO+H7, Dipole Shower	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	HERWIG 7.1.3	H7.1-Default, Dipole Shower
SHERPA_LO-0	s, t, u	dynamic scale = diboson invariant mass	SHERPA v2.2.2	default
SHERPA_LO-1	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	SHERPA v2.2.2	default

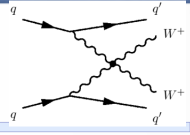
Leading-Order Multileg Configurations (0,1 additional parton)				
Sample name	Contributions	μ-scale	Shower	Tune
SHERPA_CKKW	s, t, u	dynamic scale = diboson invariant mass	SHERPA v2.2.2	default

Next-to-Leading-Order Configurations				
Sample name	Contributions	μ-scale	Shower	Tune
POWHEG +PY8	t, u	fixed scale= m_W	PYTHIA 8.212	AZNLO
POWHEG +PY8, Dipole Recoil	t, u	fixed scale= m_W	PYTHIA 8.235	AZNLO, Dipole Recoil
POWHEG +H7	t, u	fixed scale= m_W	HERWIG 7.1.3	H7.1-Default
POWHEG +H7, Dipole Shower	t, u	fixed scale= m_W	HERWIG 7.1.3	H7.1-Default, Dipole Shower
MG5_AMC _NLO+H7, Γ_{resc}	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	HERWIG 7.1.3	H7.1-Default
MG5_AMC _NLO+PY8, Γ_{resc}	s, t, u	dynamic scale= $\sqrt{p_T^{jet1}\ p_T^{jet2}}$	PYTHIA 8.235	A14

Example of missing processes in Powheg:



$W^{\pm}W^{\pm}$+jets: cross-section



MC

ATL-PHYS-PUB-2019-004

Leading-Order Configurations	
Sample name	σ [fb]
MG5_AMC _LO+PY8	3.106 ± 0.015
MG5_AMC _LO+PY8,Dipole Recoil	3.104 ± 0.015
MG5_AMC _LO+H7	3.016 ± 0.020
MG5_AMC _LO+H7,Dipole Shower	3.022 ± 0.017
SHERPA_LO-0	2.615 ± 0.011
SHERPA_LO-1	2.806 ± 0.046

Leading-Order Multileg Configurations (0,1 additional parton)	
Sample name	σ [fb]
SHERPA_CKKW	2.048 ± 0.013

Next-to-Leading-Order Configurations	
Sample name	σ [fb]
POWHEG +PY8	$3.122 \pm 0.023^{+0.050}_{-0.040}$ (scale) ± 0.010 (pdf)
POWHEG +PY8,Dipole Recoil	3.082 ± 0.023
POWHEG +H7	2.992 ± 0.026
POWHEG +H7,Dipole Shower	3.004 ± 0.026
MG5_AMC _NLO+H7, Γ_{resc}	$3.304 \pm 0.033^{+0.050}_{-0.040}$ (scale) ± 0.010 (pdf)
MG5_AMC _NLO+PY8, Γ_{resc}	3.345 ± 0.033

ATLAS-CONF-2018-030

Data

$$\sigma_{fid} = 2.91^{+0.51}_{-0.47}(\text{stat.}) \pm 0.27(\text{syst.})\ \text{fb}$$

Powheg (NLO) and all **MadGraph (LO and NLO)** configurations agree within 10% while **Sherpa (LO and LO up to 1 additional p.)** predicts lower cross-sections.

Sherpa LO: central emission excess from PS due to not optimal color flow setup; Sherpa LO up to 1 add. part. (CKKW): fixed central emission, but cross-section reduction from suppression of spuriously large Sudakov factors

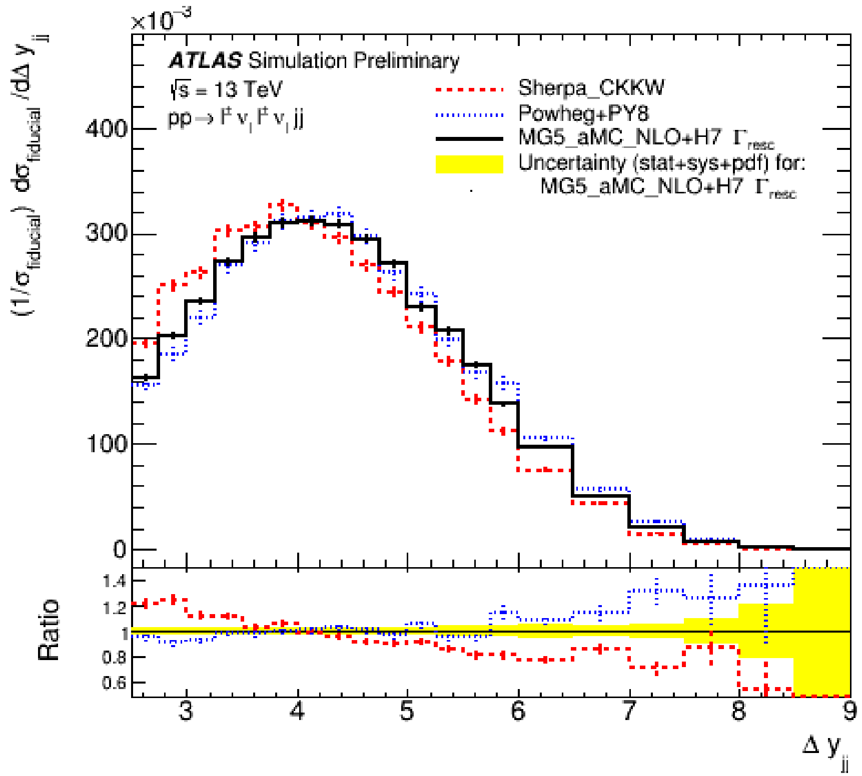
Difference of NLO calculations (**MadGraph** and **Powheg**) of ~10%, larger than their own ±2% uncertainty (scale+PDF+ statistical unc), absence of the s-channel diagrams in the Powheg configuration.

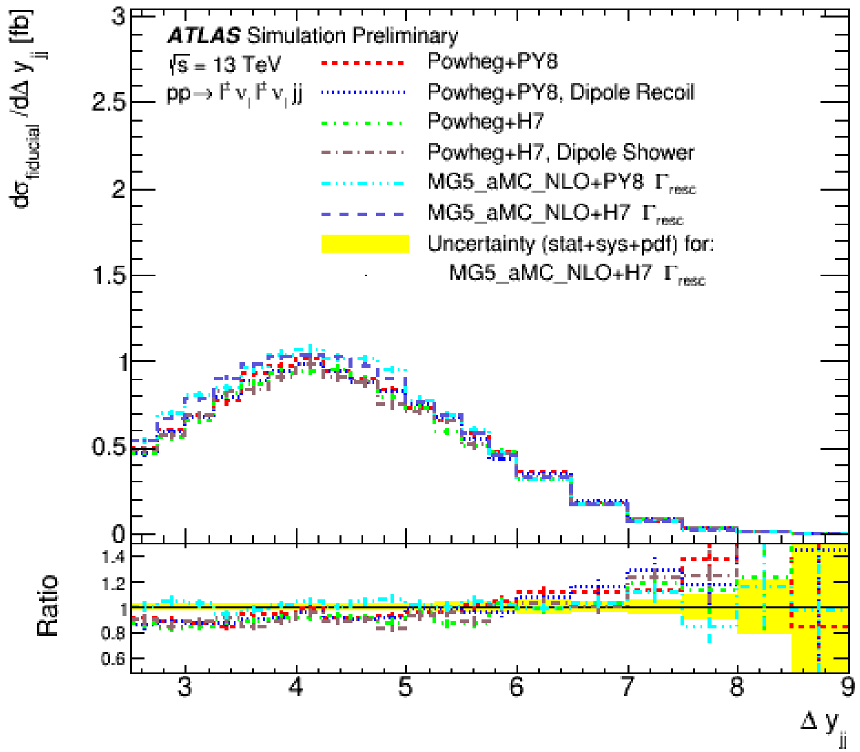
Impact of changes in the PS (Pythia8 vs Herwig7) is at most of 5%.

Data includes $W^{\pm}W^{\pm}jj$ electroweak plus interference with $W^{\pm}W^{\pm}jj$ strong , predictions not include interference with the strong production (+6%) and NLO EW corrections (-16%)

Data in agreement with **Powheg** and **MadGraph** and about 1σ higher than **Sherpa**

$W^{\pm}W^{\pm}$+jets: Δy_{jj}





Sherpa predicts a slightly narrower Δy_{jj} distribution difference up to 20% around $\Delta y_{jj} = 2.0$ (fiducial cut)

$W^{\pm}W^{\pm}jj$: Signal & Background

Further background reduction (applied only at detector level):
-additional leptons veto events → reduce background with prompt leptons
-Z veto in ee final state → reduce Z+jets background from charge mis-ID
-veto events containing b-jets → reduce ttbar

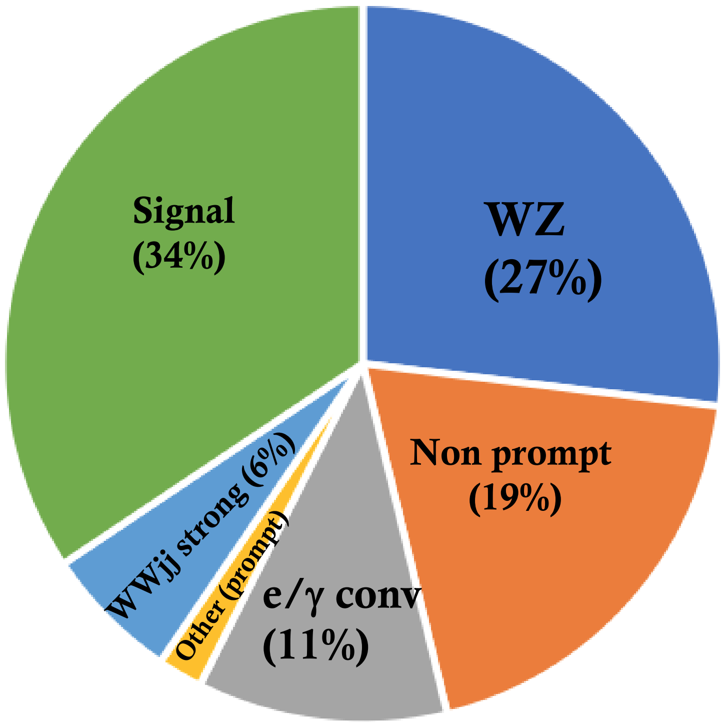
Non-prompt lepton backgrounds (W+jets, ttbar (semi-leptonic), dijet) with data-driven technique in control region with a 50-90% uncertainty, dominant one pre-fit

Electron charge mis-identification & prompt photon conversions:
- Electron charge mis-ID (Z+jets, W^+W^-, ttbar (di-leptonic)) with data-driven technique
- Prompt photon conversion: Wγ from MC with normalization from control region

Prompt backgrounds:
WZ from MC with normalization from a trilepton control region
strong **$W^{\pm}W^{\pm}jj$** **subtracted as background**.

A total of 122 candidate events is observed for a background expectation of 78 ± 15 events before the fit

ATLAS-CONF-2018-030



Expected Signal and background composition before fit

$W^{\pm}W^{\pm}jj$: the observation

ATLAS-CONF-2018-030

Analysis performed in **six channels:**
e^+e^+, $\mu^+\mu^+$, $e^+\mu^+$ and e^-e^-, $\mu^-\mu^-$, $e^-\mu^-$

Signal extracted in a **binned fit** to $\mathbf{m_{jj}}$ distributions (4 bins) in signal region (m_{jj} > 500GeV) and control regions (200 < m_{jj} < 500GeV) dominated by WZ and non-prompt lepton background

The background-only hypothesis is rejected with an observedsignificance of 6.9σ

Measured signal strength parameter:

$$\mu = 1.45^{+0.25}_{-0.24}(\text{stat.})^{+0.13}_{-0.14}(\text{sys.})$$