

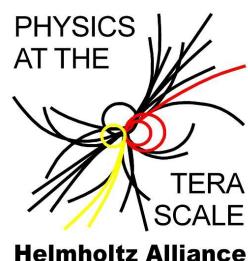
Z($\rightarrow ee$) + jets cross section measurement on hadron level with the ATLAS experiment at the LHC

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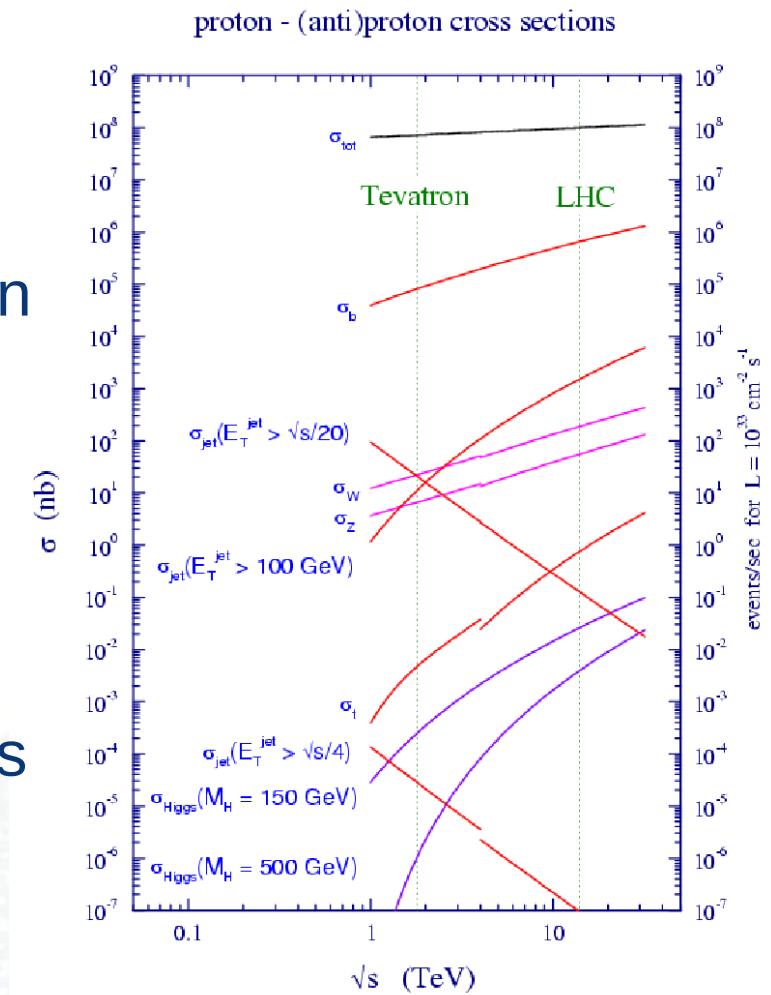
Bundesministerium
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- Analysis:

- Measurement of the inclusive and differential $Z(\rightarrow ee) + \text{jets}$ cross section on hadron level

- Motivation:

- Test of perturbative QCD predictions at the Z scale
 - Background for searches of the Higgs Boson and new physics

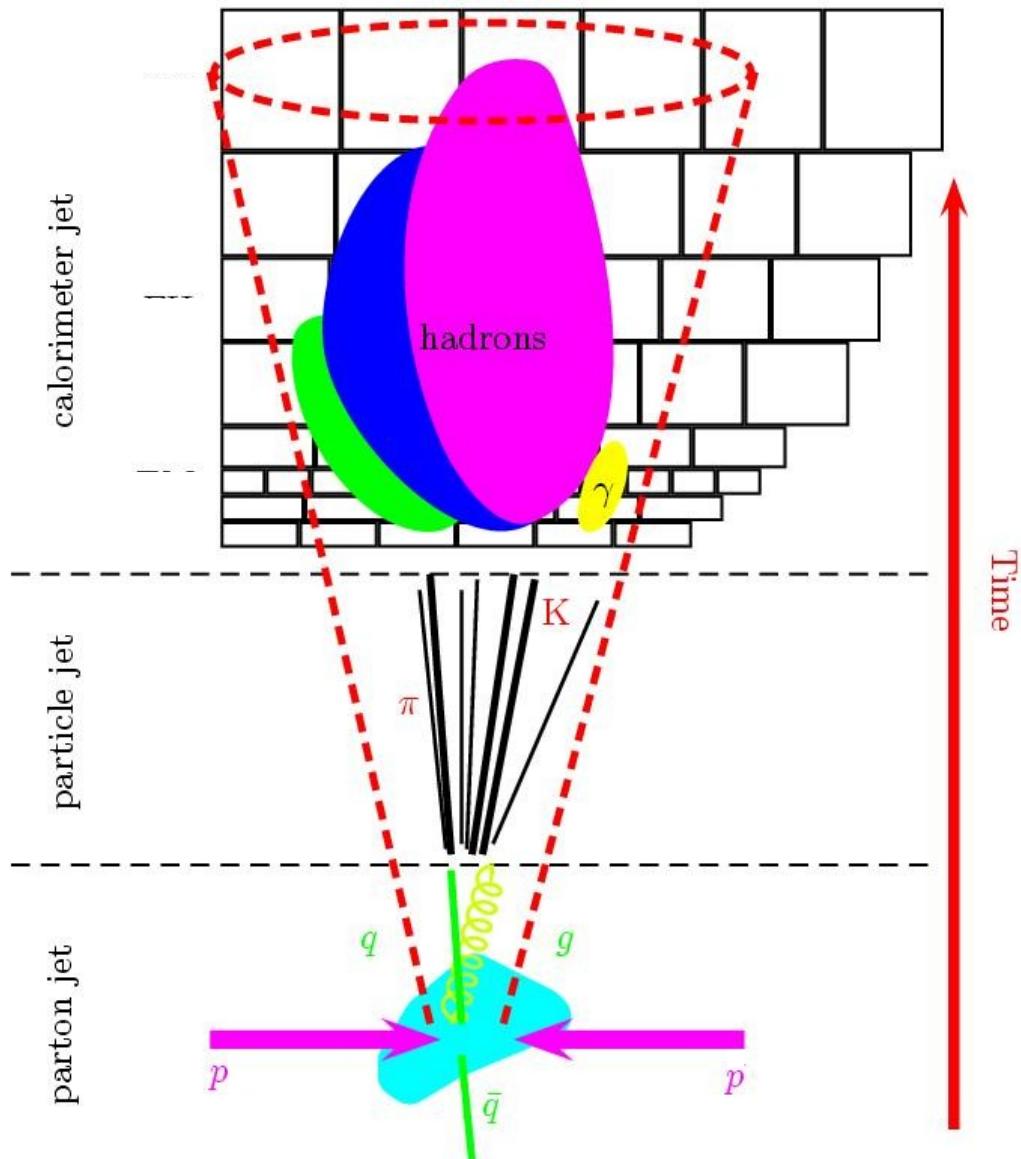
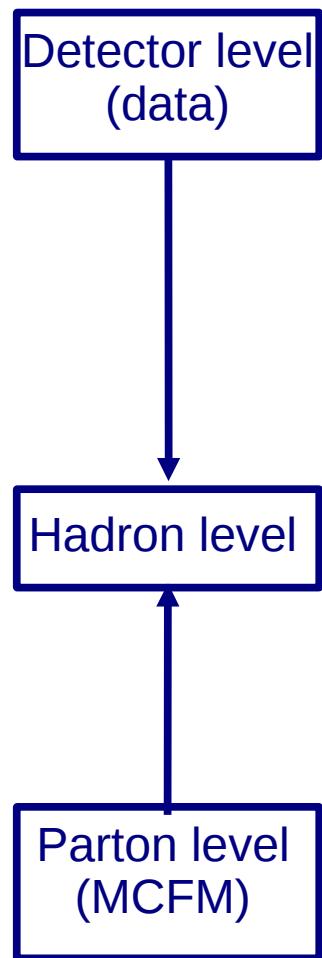


- Data:
 - pp-collisions at 7 TeV
 - Integrated luminosity of 1.3 pb^{-1}
- Monte Carlo (fully simulated):
 - **Z($\rightarrow ee$) + jets:**
 - Alpgen + Herwig
 - Pythia
 - Sherpa
 - **QCD:** Pythia
 - **Ttbar:** MC@NLO + Herwig
 - **Z($\rightarrow \tau\tau$) + jets:** Alpgen + Herwig
 - **W($\rightarrow ee$) + jets:** Alpgen + Herwig
 - **Diboson:** Alpgen + Herwig
- For comparison pQCD (MCFM):
 - NLO for $N_{\text{partons}} = 0, 1, 2$

- Good vertex: $N_{\text{tracks}} \geq 3$, $|z| < 150 \text{ mm}$
- Trigger: L1 EM cluster 14 GeV
- Electrons:
 - Calorimeter cluster + matched track
 - ID: robust medium (shower shape, track quality, track match, pattern in first calo layer)
 - $E_T(\text{cluster}) > 20 \text{ GeV}$, $|\eta(\text{cluster})| < 2.47$, excluding cracks (1.37-1.52)
- Jets:
 - Jet clustered from topological calorimeter clusters
 - anti- k_T jets, $R=0.4$
 - $p_T > 20 \text{ GeV}$, $|\eta| < 2.8$
 - anti pile-up cut: fraction of tracks associated to the vertex > 0.75
- Overlap removal:
 - Electron-jet: remove all jets with $dR < 0.5$
- Event selection:
 - $N(\text{electrons}) = 2$
 - Opposite sign electron pair
 - $71 \text{ GeV}/c^2 < M_{ee} < 111 \text{ GeV}/c^2$

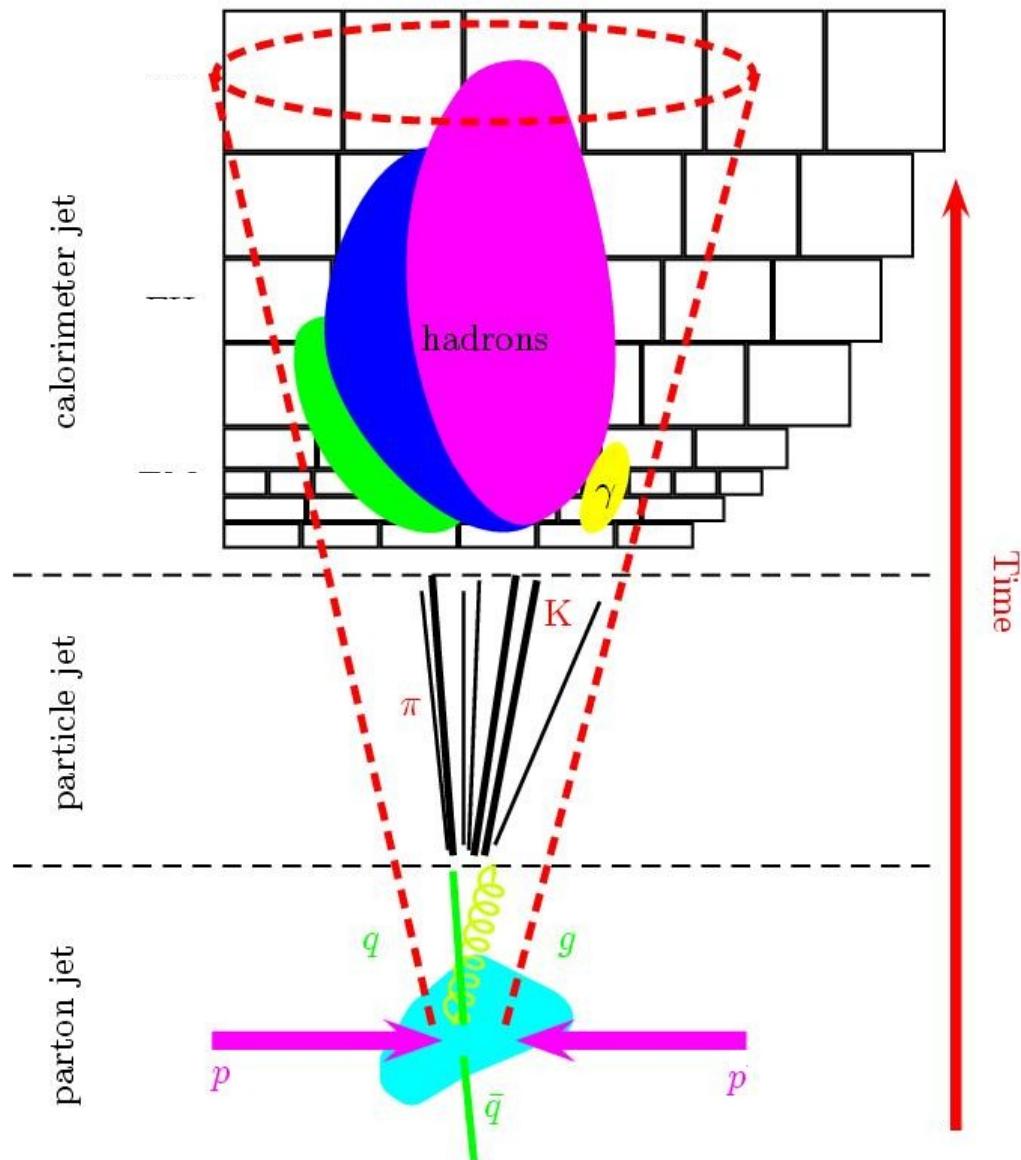
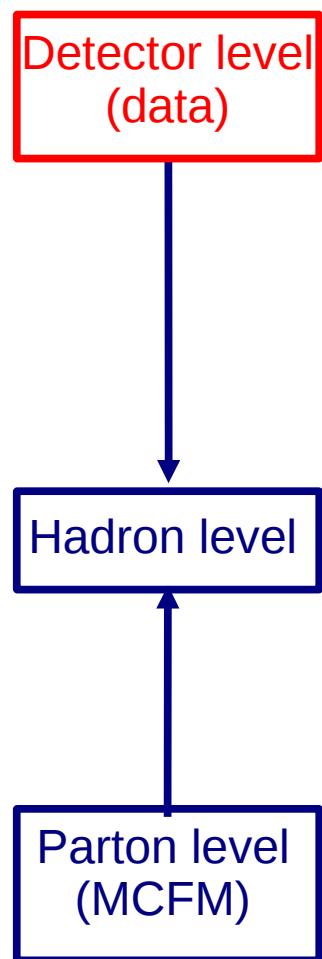
Uncertainties

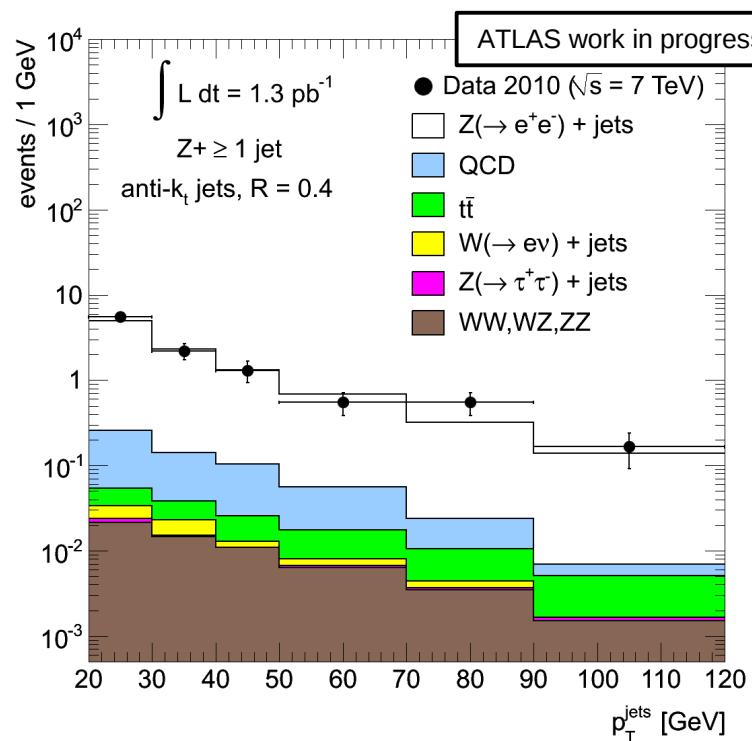
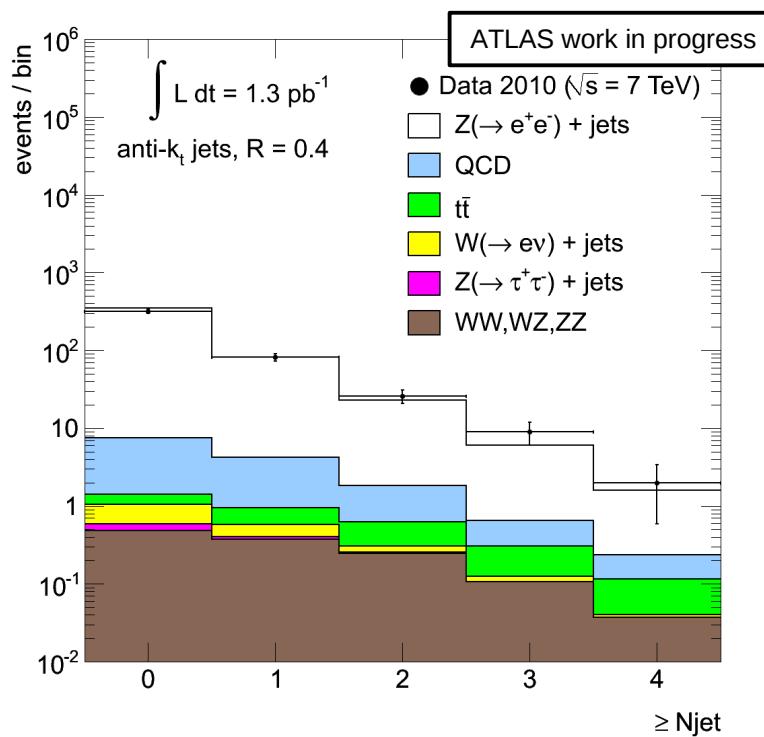
Statistics

JES, JER,
lepton reco & ID + triggerNon-perturbative effects
(UE, fragmentation)PDF, α_s 

Uncertainties

Statistics

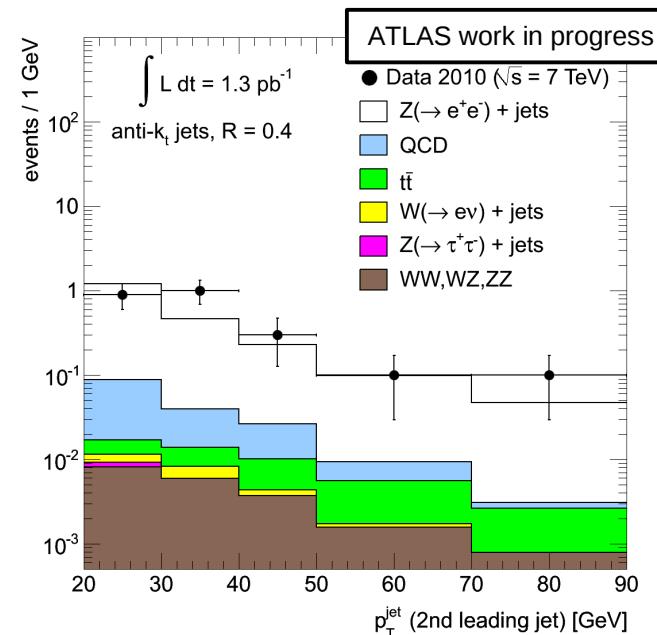
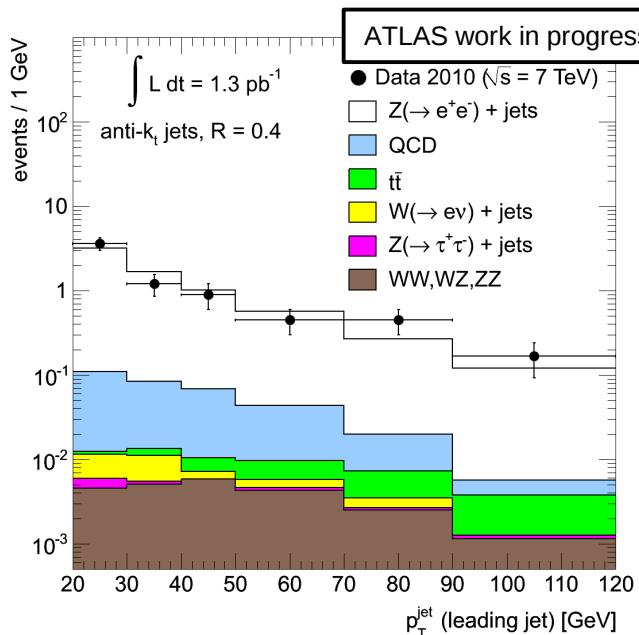
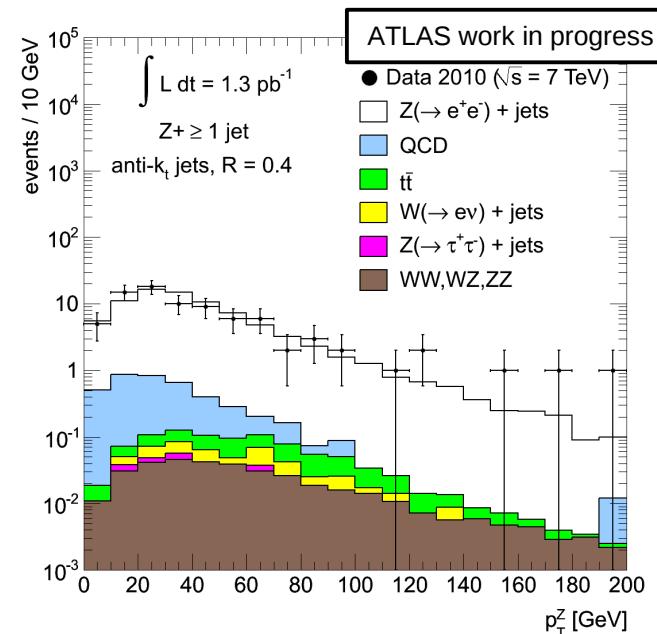
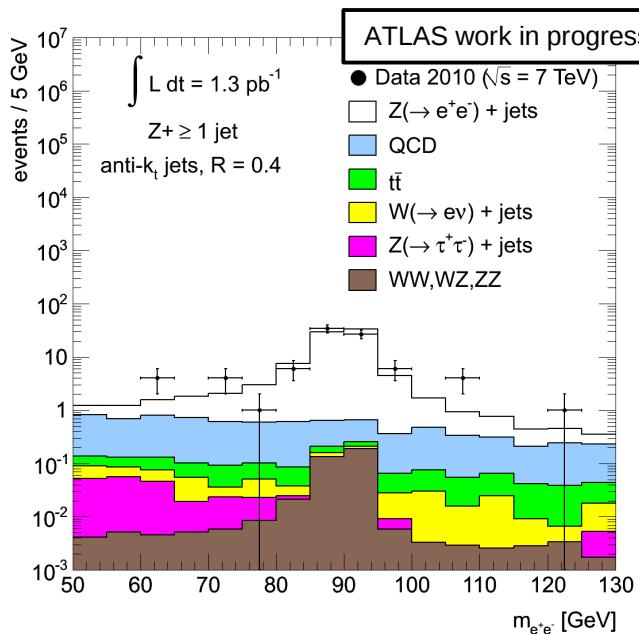
JES, JER,
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- MC is scaled to integrated luminosity in data
- QCD is derived from MC with relaxed ID cuts, but cross checked with data driven methods

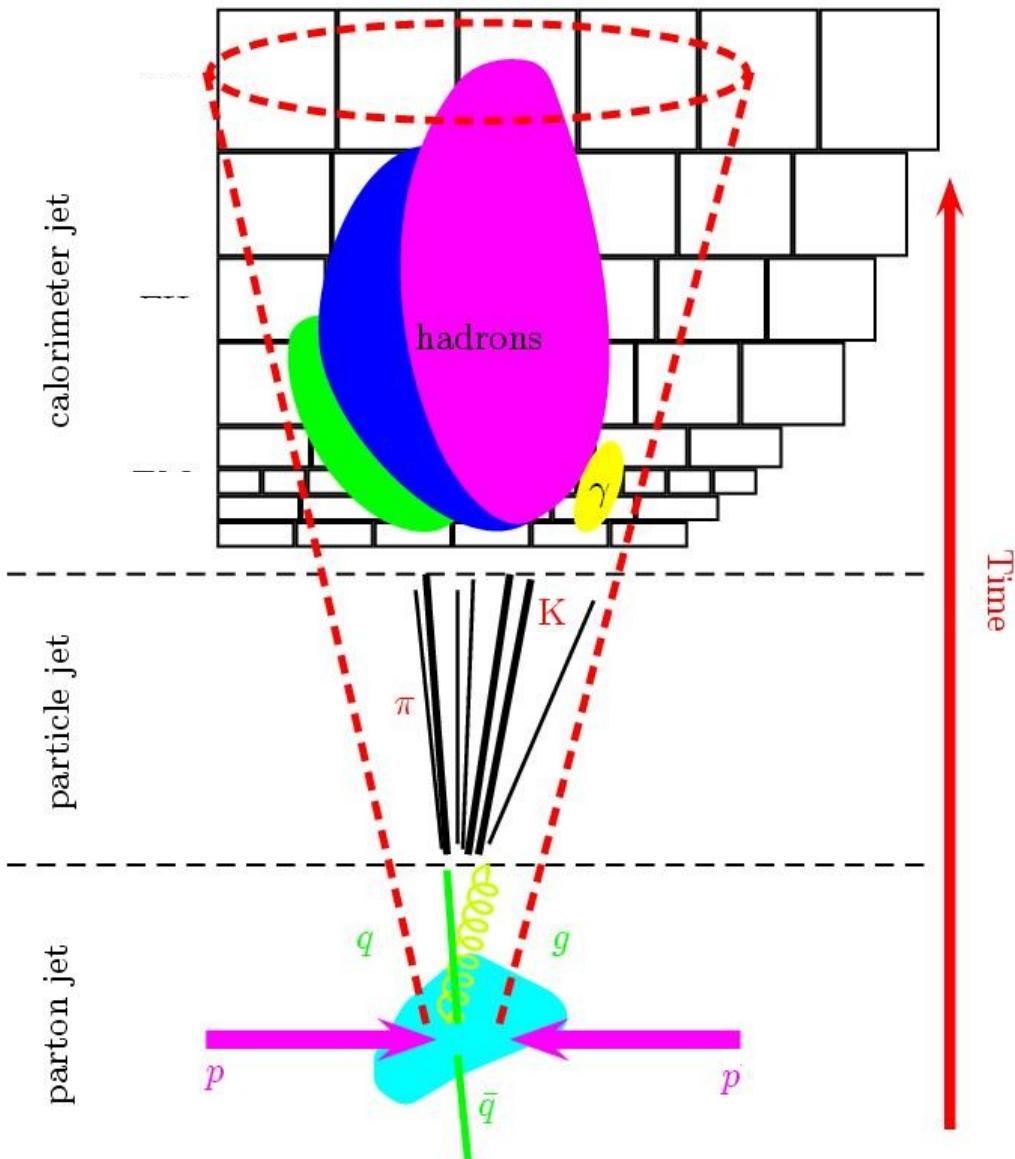
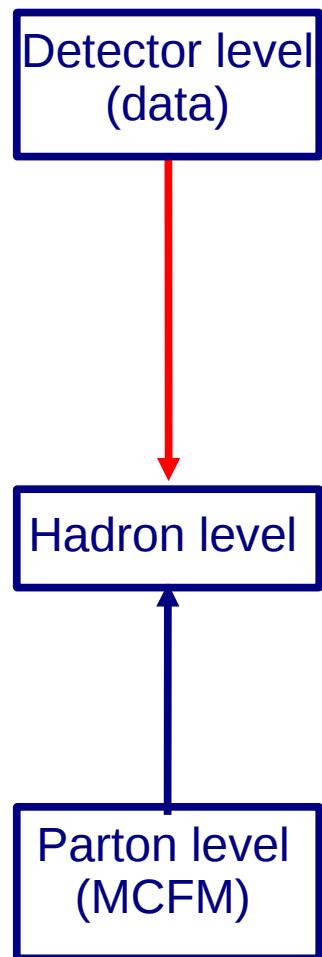
ATLAS work in progress

	$Z \rightarrow \ell\ell$	$Z+ \geq 1 \text{ jet}$	$Z+ \geq 2 \text{ jets}$	$Z+ \geq 3 \text{ jets}$	$Z+ \geq 4 \text{ jets}$
$Z \rightarrow ee$	340.61 ± 1.11	78.57 ± 0.52	20.89 ± 0.27	5.38 ± 0.13	1.35 ± 0.07
$W \rightarrow ee$	0.47 ± 0.05	0.17 ± 0.02	0.05 ± 0.01	0.02 ± 0.01	< 0.01
$Z \rightarrow \tau\tau$	0.10 ± 0.02	0.03 ± 0.01	0.01 ± 0.01	< 0.01	< 0.01
WW, WZ, ZZ	0.49 ± 0.01	0.37 ± 0.01	0.24 ± 0.00	0.11 ± 0.00	0.04 ± 0.00
$t\bar{t}$	0.37 ± 0.01	0.37 ± 0.01	0.32 ± 0.01	0.18 ± 0.01	0.08 ± 0.00
QCD	4.30 ± 0.20	2.11 ± 0.14	0.75 ± 0.08	0.20 ± 0.04	0.06 ± 0.02
Total predicted	346.34 ± 1.13	81.62 ± 0.54	22.27 ± 0.28	5.89 ± 0.15	1.53 ± 0.07
Data observed	316 ± 17.8	82 ± 9.1	26 ± 5.1	9 ± 3.0	2 ± 1.4



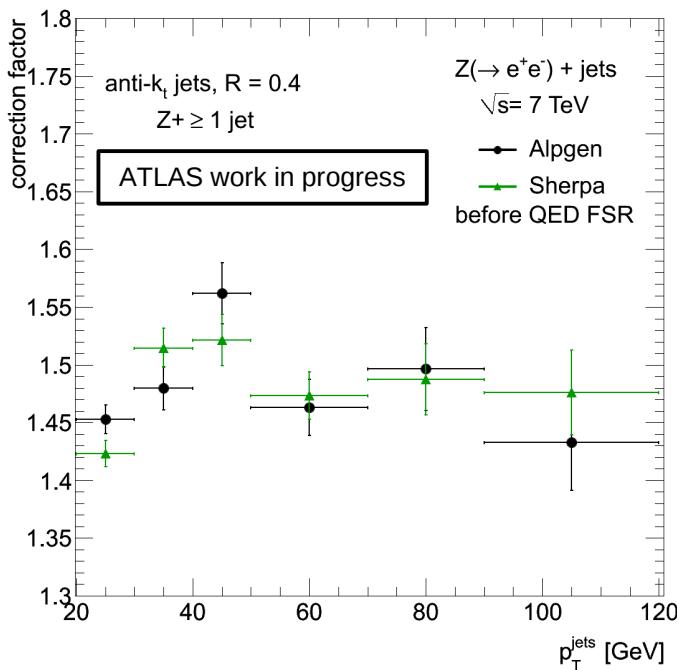
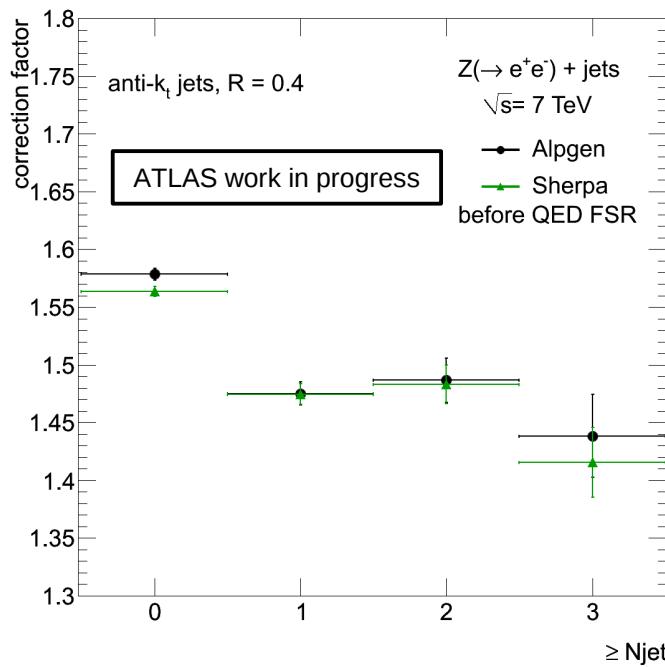
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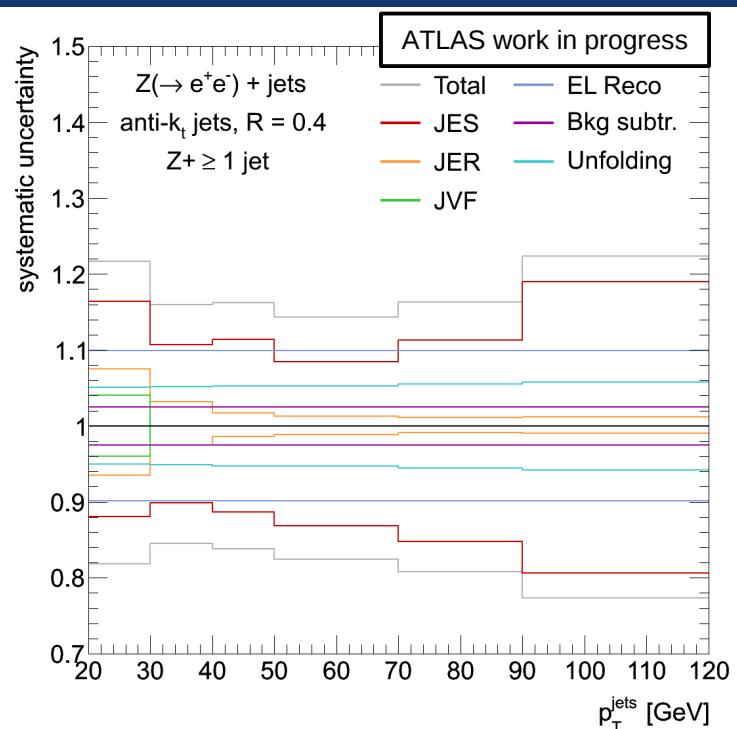
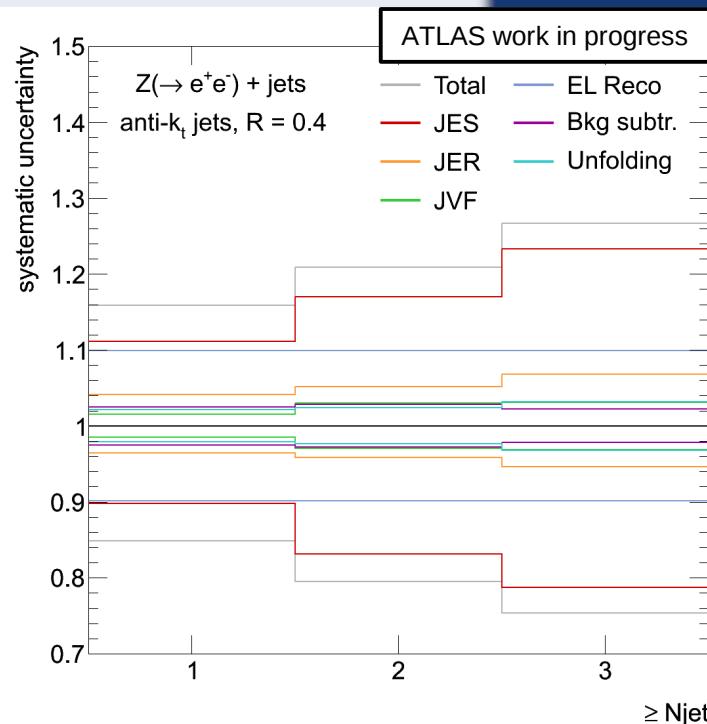
Bin-by-Bin Method:

- Only needs the reconstructed and the truth distribution as input
- Migration is only described to the extend by which the generator models the jet kinematics correctly



- Sherpa shows a slightly different unfolding factor compare to Alpgen → jet kinematics and composition (parton shower, fragmentation, ...) dependence
- Use improved iterative (Bayes) Method in the future (nearly independent of jet kinematics)

Systematic uncertainties



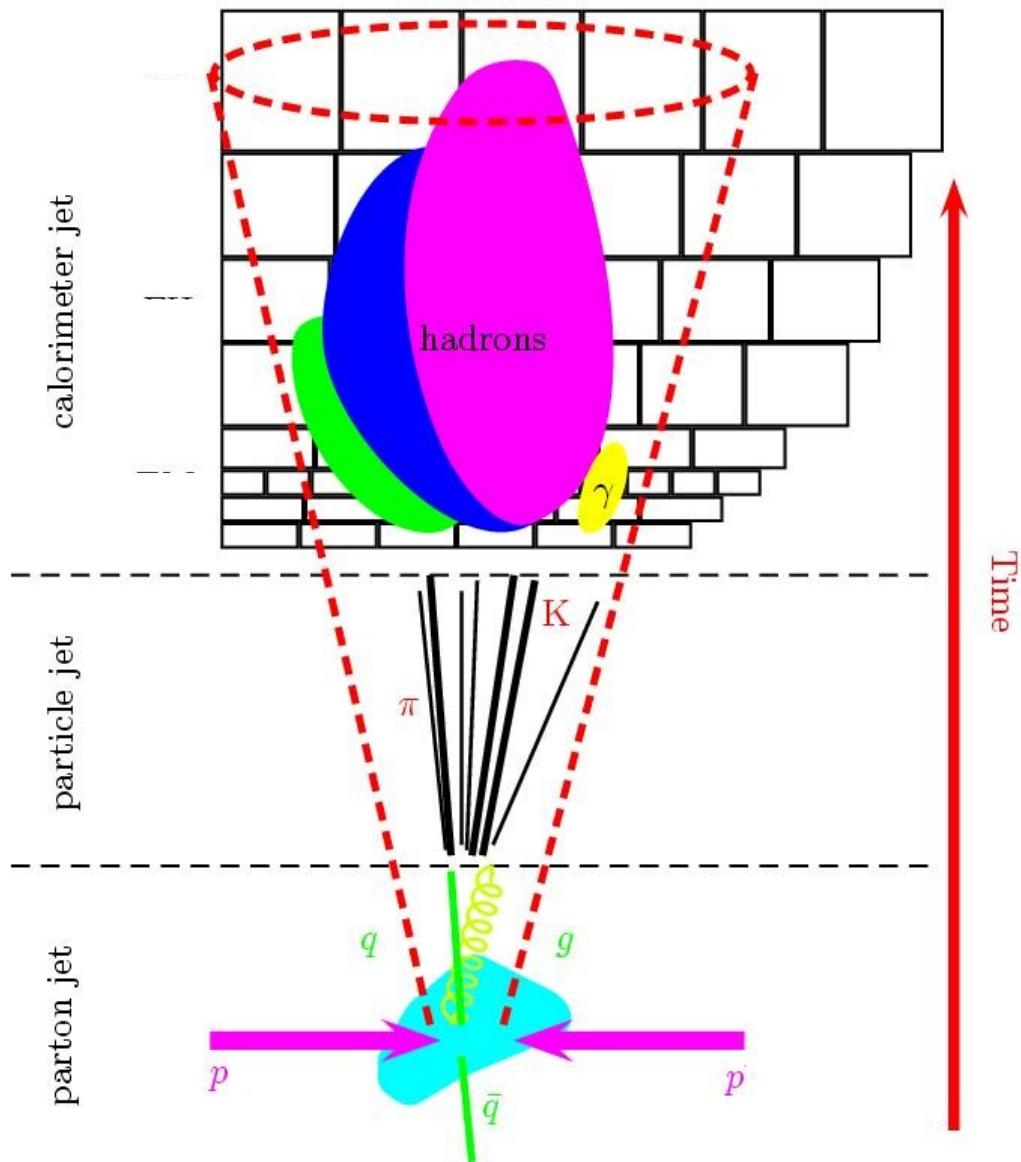
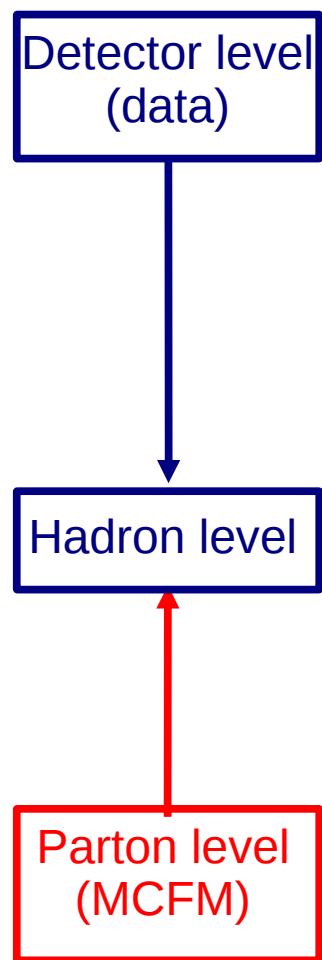
ATLAS work in progress

	Inclusive	$Z+ \geq 1 \text{ jet}$	$Z+ \geq 2 \text{ jets}$	$Z+ \geq 3 \text{ jets}$
Electron trigger	$\pm 0.01\%$	$\pm 0.01\%$	$\pm 0.01\%$	$\pm 0.01\%$
Electron reconstruction	$\pm 9.9\%$	$\pm 9.9\%$	$\pm 9.9\%$	$\pm 9.9\%$
Jet energy scale		$+11.8\% / 9.5\%$	$+18.3\% / -15.4\%$	$+24.3\% / -20.2\%$
Jet energy resolution	-	$+4.1\% / -3.6\%$	$+5.2\% / -4.2\%$	$+6.8\% / -5.4\%$
QCD subtraction	$\pm 1.2\%$	$\pm 2.5\%$	$\pm 3.4\%$	$\pm 3.4\%$
EW background	$\pm 0.02\%$	$\pm 0.06\%$	$\pm 0.13\%$	$\pm 0.18\%$
JVF cut		$\pm 1.5\%$	$\pm 3.0\%$	$\pm 3.1\%$
Unfolding (generator+stat)	$\pm 2.0\%$	$\pm 2.1\%$	$\pm 2.4\%$	$\pm 3.2\%$

- The dominating systematic uncertainty comes from the JES followed by the electron reconstruction

Uncertainties

Statistics

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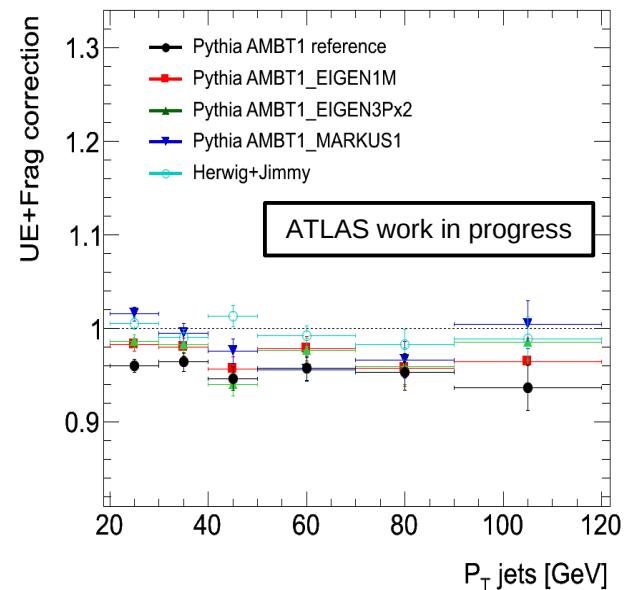
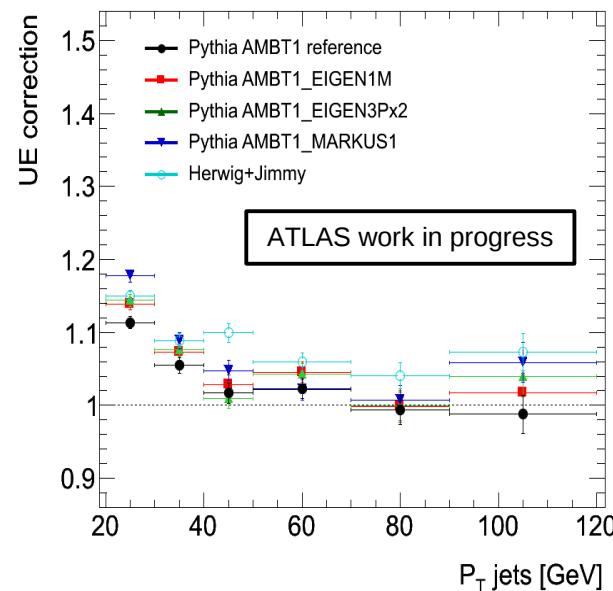
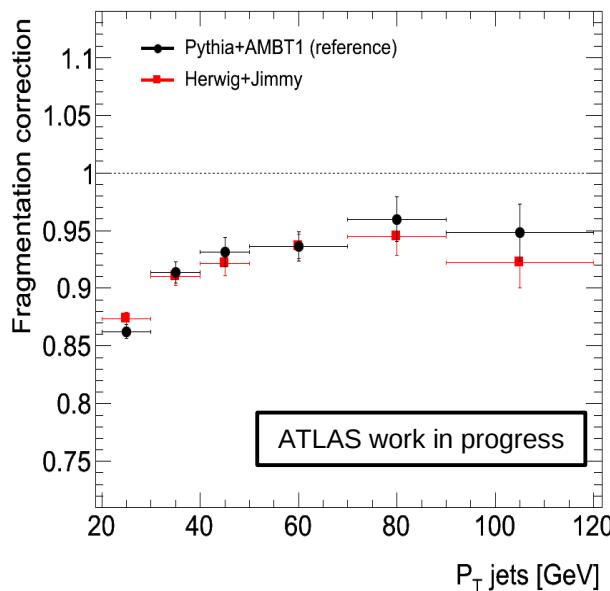
- MCFM version 5.8, Z+0,1,2 jets NL0, Z+1,2,3 jets L0
- Scale:
 - Hadronization and factorization scale: $H_T/2$
 - Systematic uncertainty is calculated by varying both scales simultaneously by factor of 2
- PDF:
 - CTEQ6.6 (NLO), CTEQL1 (LO)
 - Systematic uncertainty: complete PDF CTEQ6.6 error set

$$(\Delta X)_+ = \sqrt{\sum_{i=1}^{22} \max(X(S_i^+) - X(S_0), X(S_i^-) - X(S_0), 0)^2}$$
$$(\Delta X)_- = \sqrt{\sum_{i=1}^{22} \max(X(S_0) - X(S_i^+), X(S_0) - X(S_i^-), 0)^2}$$

- α_s uncertainty:
 - varying the input α_s at the Z scale by +/- 0.002

Corrections parton → hadron level

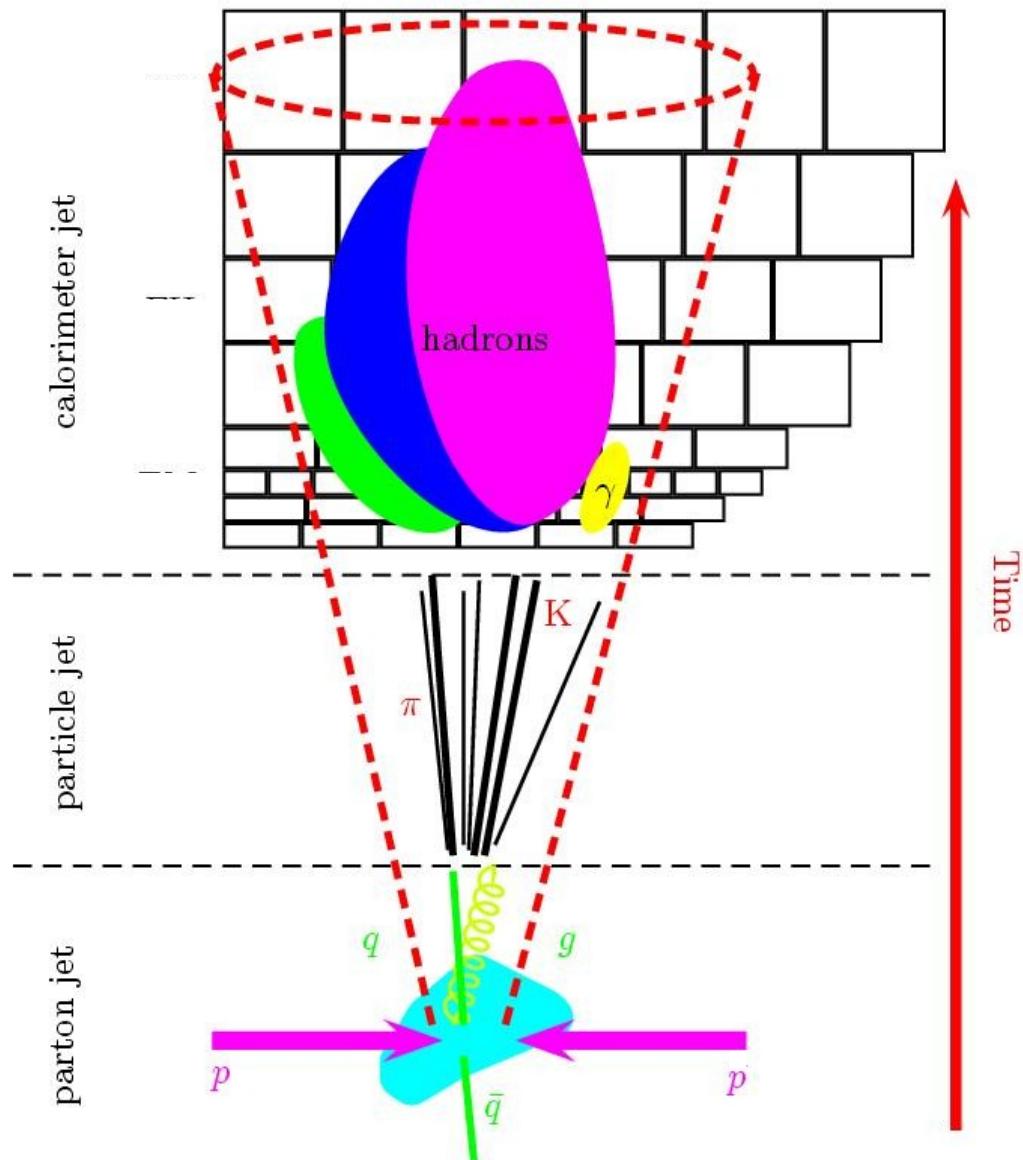
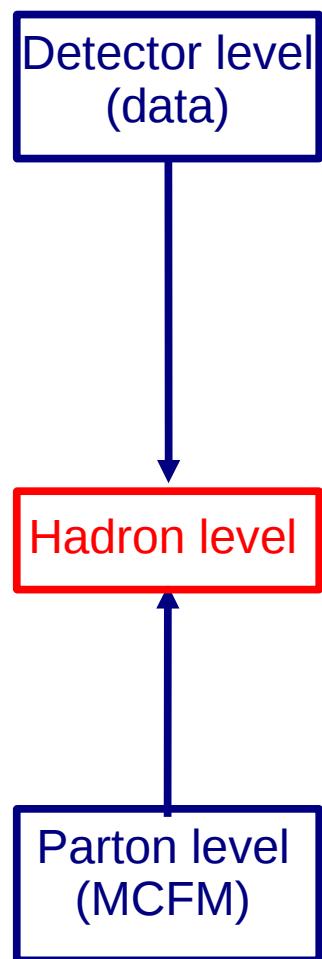
- Use Pythia Z + jets for correction of non-perturbative QCD effects:
 - With current UE tune
 - Without fragmentation
 - Without fragmentation and UE → final correction
- Compare distributions #jets (standard) / #jets (modified)

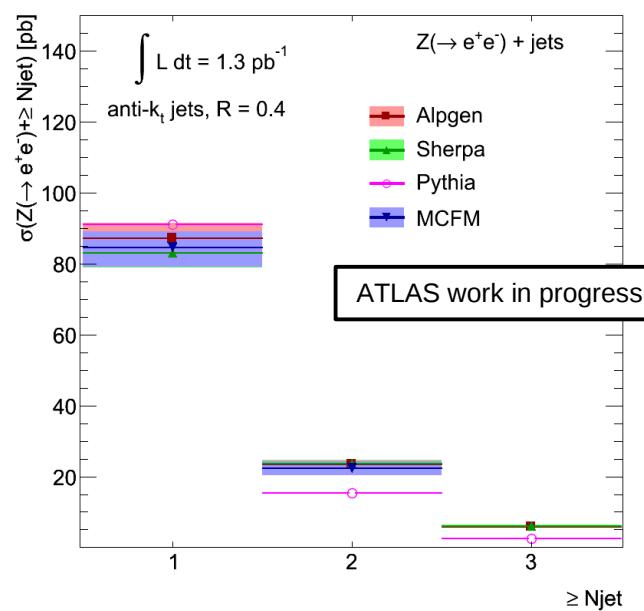
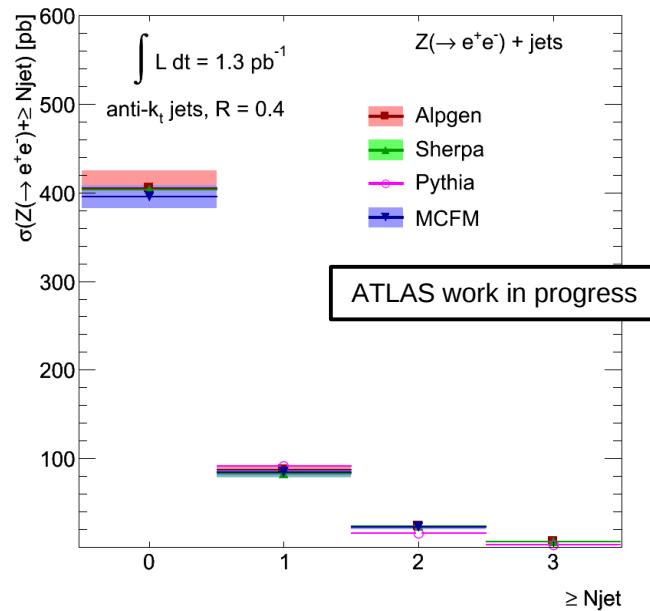


- Fragmentation → energy loss at low p_T
- UE → migration to higher p_T → more jets at low p_T
- Resulting correction < 1 for anti- k_T jets ($R=0.4$) but > 1 for anti- k_T jets ($R=0.6$)
- The systematic uncertainty is taken from the maximum variation of the different tunes to the reference tune

Uncertainties

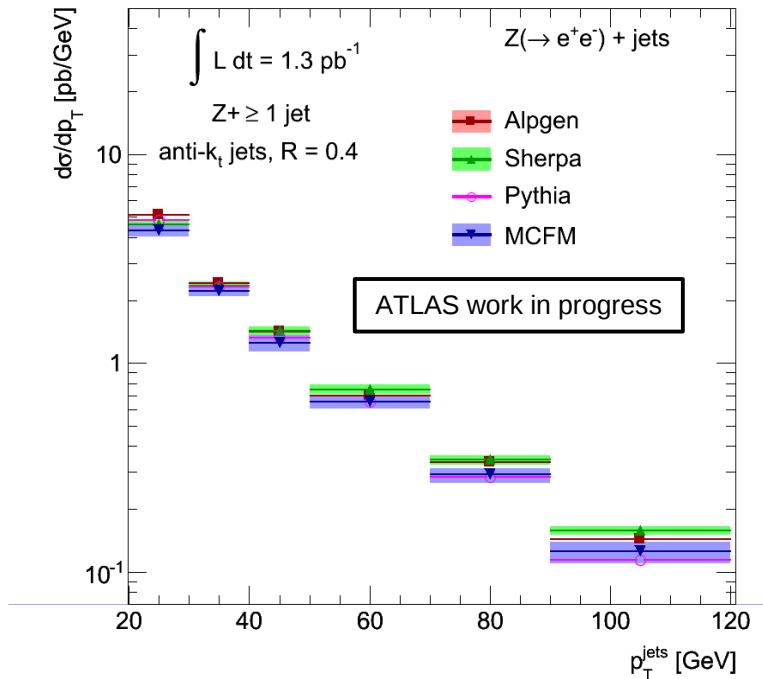
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Jet Multiplicity	Data cross-section (pb)	NLO MCFM cross section (pb)
$Z \rightarrow ee$		
$\geq 0 \text{ jets}$	$[395.1] \pm [13.7] \text{ (stat)} \pm [12.7] \text{ (syst)} \pm [lumi]$	$395.1^{+13.7}_{-12.7} \text{ (scale+pdf)}$
$\geq 1 \text{ jets}$	$[84.5] \pm [3.3] \text{ (stat)} \pm [4.3] \text{ (syst)} \pm [lumi]$	$84.5^{+3.3}_{-4.3} \text{ (scale+pdf)} \pm 3.1 \text{ (UE+frag)}$
$\geq 2 \text{ jets}$	$[22.4] \pm [0.9] \text{ (stat)} \pm [1.0] \text{ (syst)} \pm [lumi]$	$22.4^{+0.9}_{-1.0} \text{ (scale+pdf)} \pm 1.8 \text{ (UE+frag)}$
$\geq 3 \text{ jets}$	$[ATLAS work in progress]$	

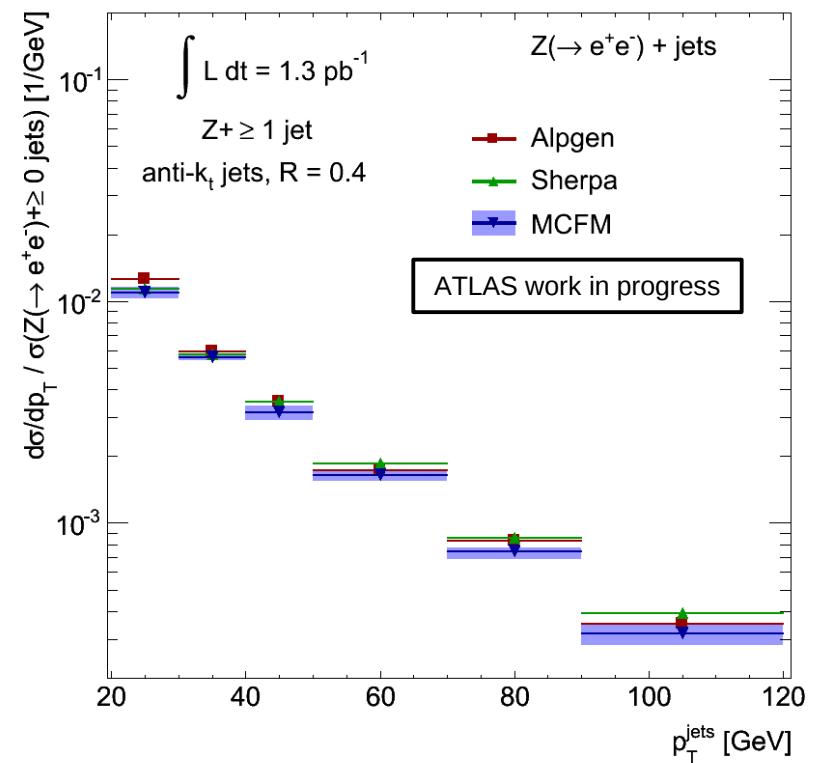
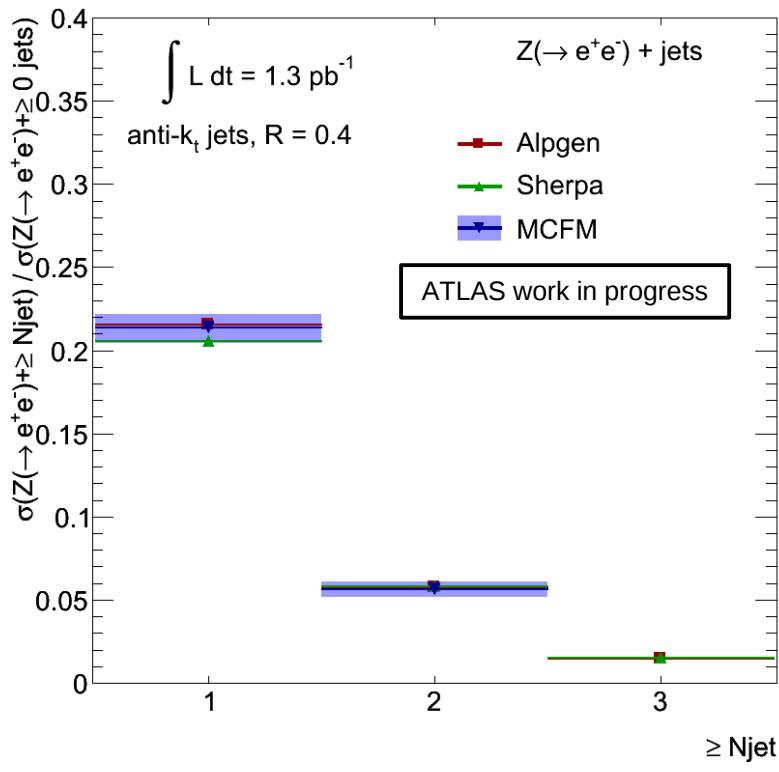
- MC is normalized to the inclusive NNLO cross section
- Good agreement within uncertainties between generator predictions and MCFM in the **fiducial region**
- Inclusive 1 jet and 2 jets cross section measurement is limited by systematics
- Inclusive 3 jets cross section measurement is limited by statistics



- Differential cross section measurement with respect to p_T
 - Measurement is limited by systematics
 - Suffer from statistical fluctuations for large p_T

p_T jets	Data: Cross-section (pb)	MCFM cross section (pb)
$Z \rightarrow ee$		
20-30 GeV	█ \pm █ (stat) \pm █ (syst) \pm █ (lumi)	$4.31^{+0.14}_{-0.14}$ (scale+pdf) ± 0.25 (UE+frag)
30-40 GeV	█ \pm █ (stat) \pm █ (syst) \pm █ (lumi)	$2.21^{+0.07}_{-0.09}$ (scale+pdf) ± 0.07 (UE+frag)
40-50 GeV	█ \pm █ (stat) \pm █ (syst) \pm █ (lumi)	$1.24^{+0.06}_{-0.08}$ (scale+pdf) ± 0.09 (UE+frag)
50-70 GeV	█ \pm █ (stat) \pm █ (syst) \pm █ (lumi)	$0.65^{+0.04}_{-0.04}$ (scale+pdf) ± 0.02 (UE+frag)
70-90 GeV	█ \pm █ (stat) \pm █ (syst) \pm █ (lumi)	$0.29^{+0.02}_{-0.03}$ (scale+pdf) ± 0.01 (UE+frag)
90-120 GeV	█ \pm █ (stat) \pm █ (syst) \pm █ (lumi)	$0.13^{+0.01}_{-0.01}$ (scale+pdf) ± 0.01 (UE+frag)

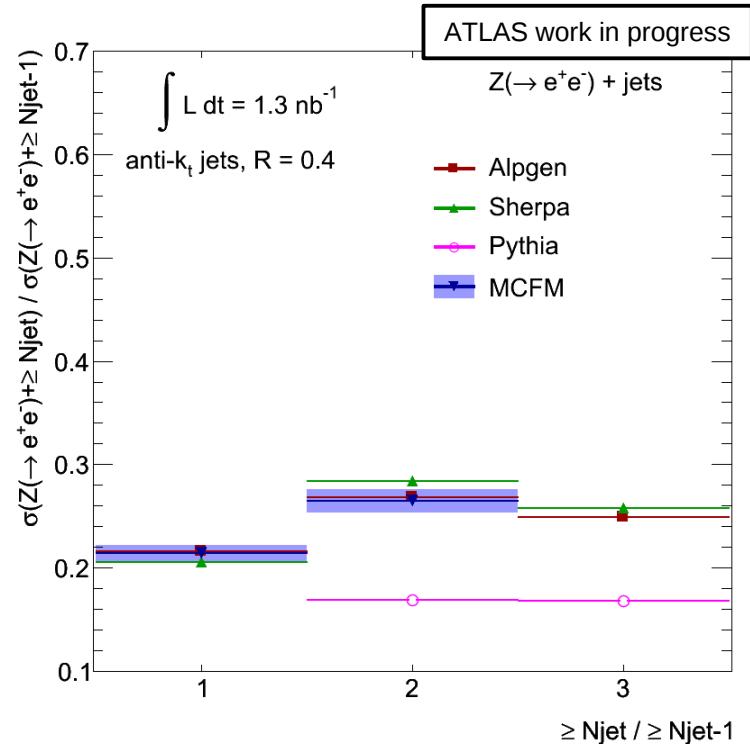
- Cross section normalized to inclusive cross section
 - Some systematics cancel out:
 - Uncertainty on the luminosity measurement
 - Uncertainty on the electron reconstruction efficiency



- Relative uncertainty clearly reduced
- Ratio nearly independent of the lepton fiducial region
- Allows a direct comparison with muon channel

Results on hadron level

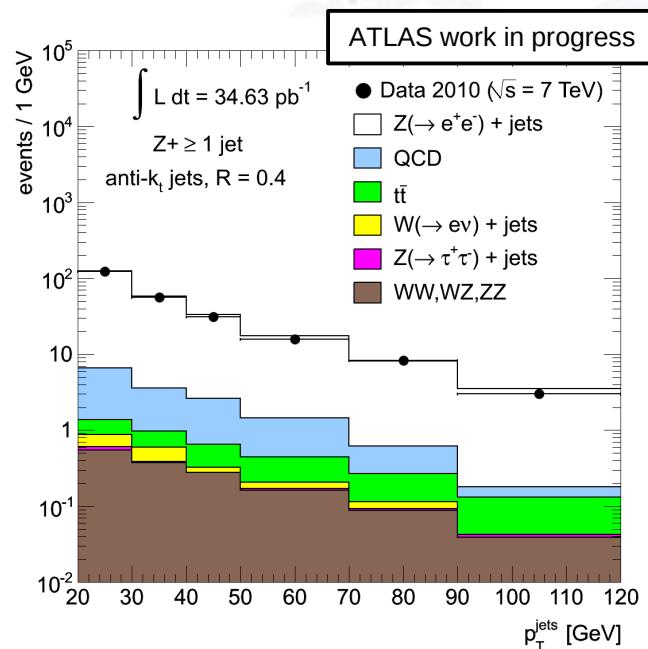
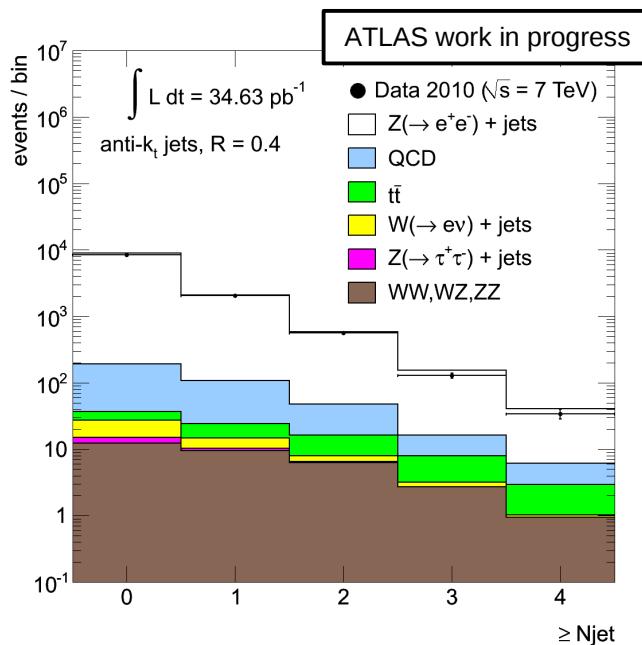
- Ratios of inclusive jet cross section:
 - Some systematics cancel out again
 - Alpgen, Sherpa and pQCD predictions agree well
 - Pythia fails to describe the cross section ratios
 - Pythia parton shower does not model jet kinematics correctly



$\sigma(Z + \geq N+1 \text{ jets}) / \sigma(Z + \geq N \text{ jets})$	data cross section ratio	MCFM cross section ratio
$Z \rightarrow ee$		
$\sigma(\geq 1 \text{ jets}) / \sigma(\geq 0 \text{ jets})$	\pm (stat) (syst)	$0.21^{+0.01}_{-0.01}$ (syst)
$\sigma(\geq 2 \text{ jets}) / \sigma(\geq 1 \text{ jets})$	\pm (stat) (syst)	$0.26^{+0.01}_{-0.04}$ (syst)
$\sigma(\geq 3 \text{ jets}) / \sigma(\geq 2 \text{ jets})$	\pm (stat) (syst)	

ATLAS work in progress

- Inclusive and differential $Z(\rightarrow ee) + \text{jets}$ cross section measurement with an integrated luminosity of 1.3 pb^{-1} on hadron level
- Systematic and statistical uncertainties were evaluated
- Systematics are reduced by normalizing to the inclusive cross section
- pQCD calculations and predictions by Alpgen and Sherpa agree well with data within uncertainties
- Outlook:
 - Update the measurement to the complete 7 TeV data of 2010



- Use improved iterative (Bayes) Method for correction of detector effects

Appendix

