Multi-jet production in association with an electroweak vector boson

Andreas Papaefstathiou

[based on Frederix, Frixione, AP, Prestel, Torrielli, 1511.00847]

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Nikhef

Deep Inelastic Scattering 2017,
Birmingham, UK,
4th April 2017.

or: NLO-merging in V+jets

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merging in 2017

merging in 2017

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Technology

Nokia 3310 mobile phone resurrected at MWC 2017

By Leo Kelion
Technology desk editor

26 February 2017 | Technology

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WATCH: Rory Cellan-Jones tries out the new Nokia 3310

Nokia's 3310 phone has been relaunched nearly 17 years after its debut.

merging in 2017

- merging of multi-jet NLO+parton shower calculations very relevant:
- achieve the “best of both worlds”.
- for many processes: the state-of-the-art in Monte Carlo simulation.

contents:

- multi-jet merging @NLO,
- results,
- conclusions & outlook.

matching to NLO

- consistently **match** NLO Matrix Elements and parton showers.

- e.g.: MC@NLO, POWHEG, KrKNLO.

- **MC@NLO**: remove double-counting with the parton shower by subtraction of the PS contributions in the NLO.

multi-jet merging @ NLO

- the aim: consistently **merge** NLO Matrix Elements and parton showers.
- extend the scope of matched results to many, well-separated jets.
- several approaches exist, mostly developed in the 2010s, e.g.:
  - MiNLO, [Hamilton, Nason, Zanderighi, 1206.3572, Frederix, Hamilton, 1512.0266]
  - MEPS@NLO (Sherpa), [Gehrmann, Hoche, Krauss, Schönherr, Siegert, 1207.5031, Hoeche, Krauss, Schönherr, Siegert, 1207.5030]
  - UNLOPS (Pythia 8), [Lönnblad, Prestel, 1211.7278]
  - Herwig 7 merging (similar to UNLOPS), [Plätzer, 1211.5467, Bellm, PhD thesis + upcoming Herwig 7.1]
  - FxFx (MG5_aMC@NLO + Pythia/Herwig).

[Frederix, Frixione, 1209.6215, Frederix, Frixione, AP, Prestel, Torrielli, 1511.00847]

multi-jet merging @ NLO

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the "FxFx" approach

[Frederix, Frixione, 1209.6215, Frederix, Frixione, AP, Prestel, Torrielli, 1511.00847]

- in a nutshell: 
  - construct MC@NLO samples (MG5_aMC@NLO),
  - suppress hard emissions by means of a function (at ME level),
  - MEs also multiplied by appropriate Sudakov factors (à la CKKW),
  - showered Les Houches events get MLM-type rejection (Pythia/Herwig).

technical aspects:

1. generate a single Les Houches file with “FxFx” events in MG5_aMC@NLO: contains all multiplicities

   [+ multiple weights for each event].

2. Herwig 7* or Pythia 8 read files: shower, vetoing procedure + hadronization, multi-parton interactions, etc..

3. can use, e.g., Rivet for analysis.

* formerly known as Herwig++.

V+jets

- important as backgrounds (e.g. to Higgs, top, new physics).
- interesting in their own right:
  - high-stats at experiments,
  - theoretically simple,
  - allows to probe regions affected both by Monte Carlo & Fixed Order.
- **here**: use for pheno. validation of FxFx NLO-merging formalism.

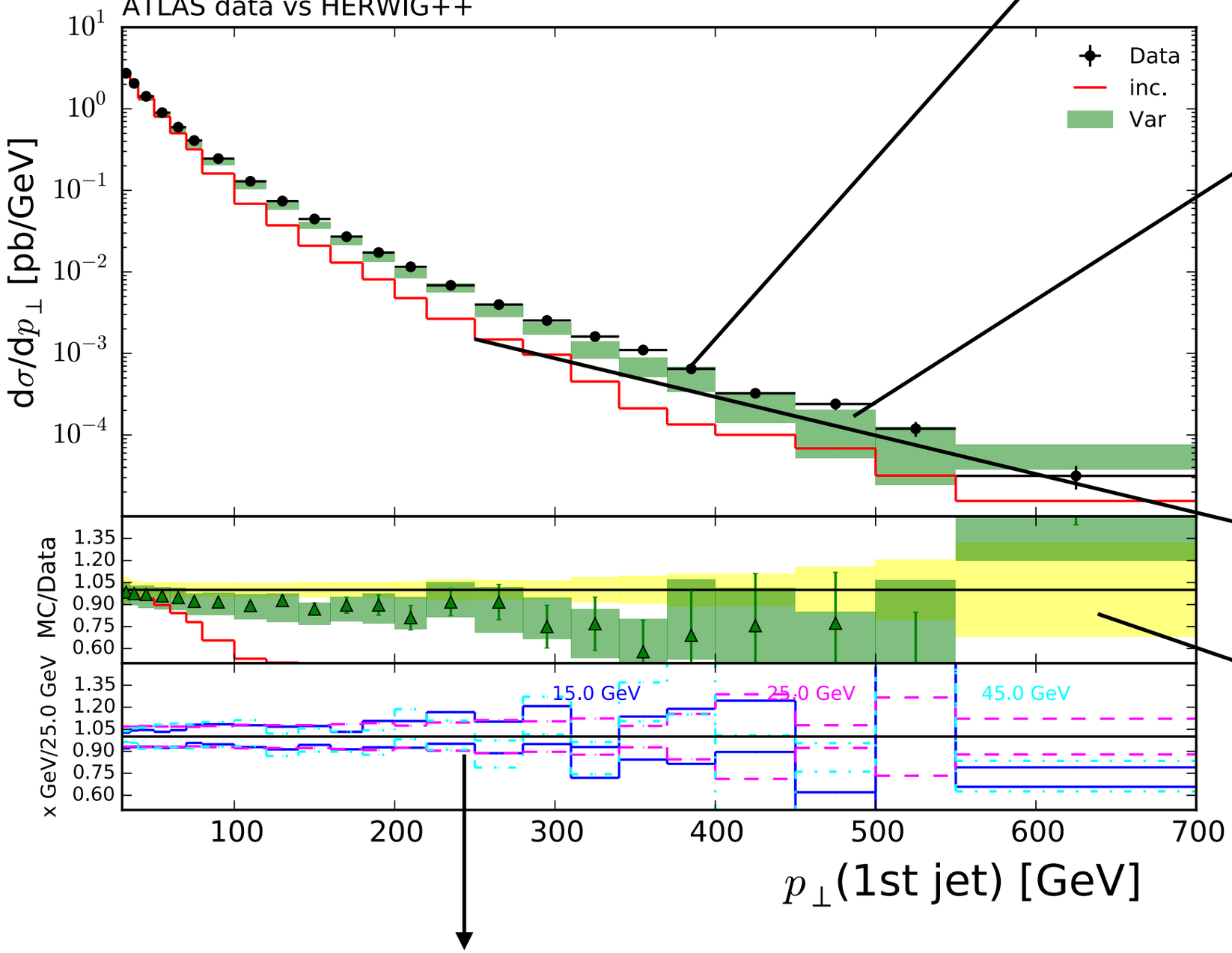
results

[based on Frederix, Frixione, AP, Prestel, Torrielli, 1511.00847]

Monte Carlo simulation details

- V+0, 1, 2 jets in FxFx-merged samples.
- used Herwig++ 2.7.1 or Pythia 8.210,
- NNPDF 2.3 NLO,
- pre-existing Monte Carlo tunes, not tuned for this PDF,
- $\alpha_S(m_Z)$ as in the MC tunes,
- all results shown here straight out of MCs, **no** rescaling applied.

"legend" for plots



data points: ATLAS or CMS data.

green band, "Var": FxFx, envelope of variations:

- hard process scale,
- PDF,
- merging scale,

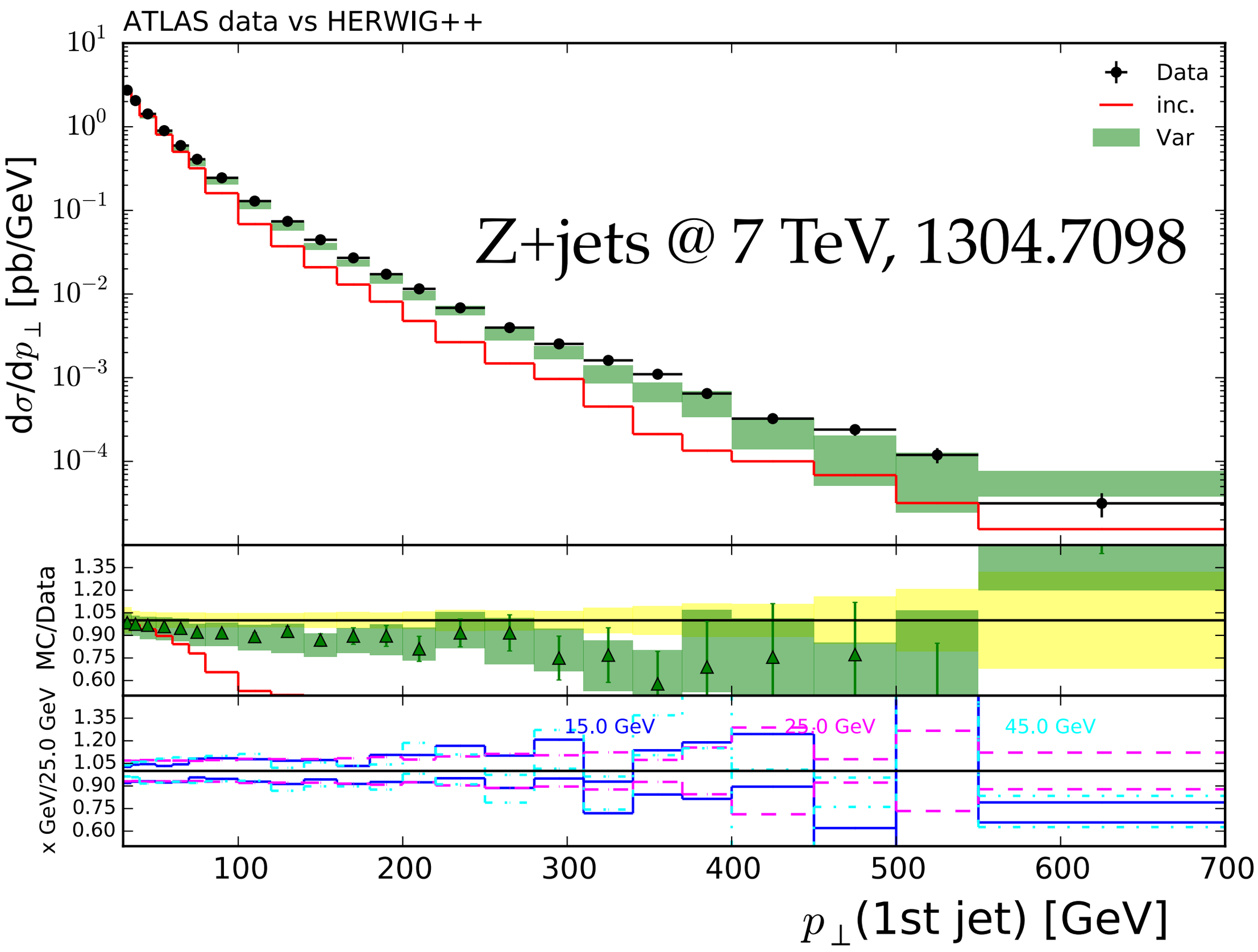
red line, ".inc": MC@NLO inclusive.

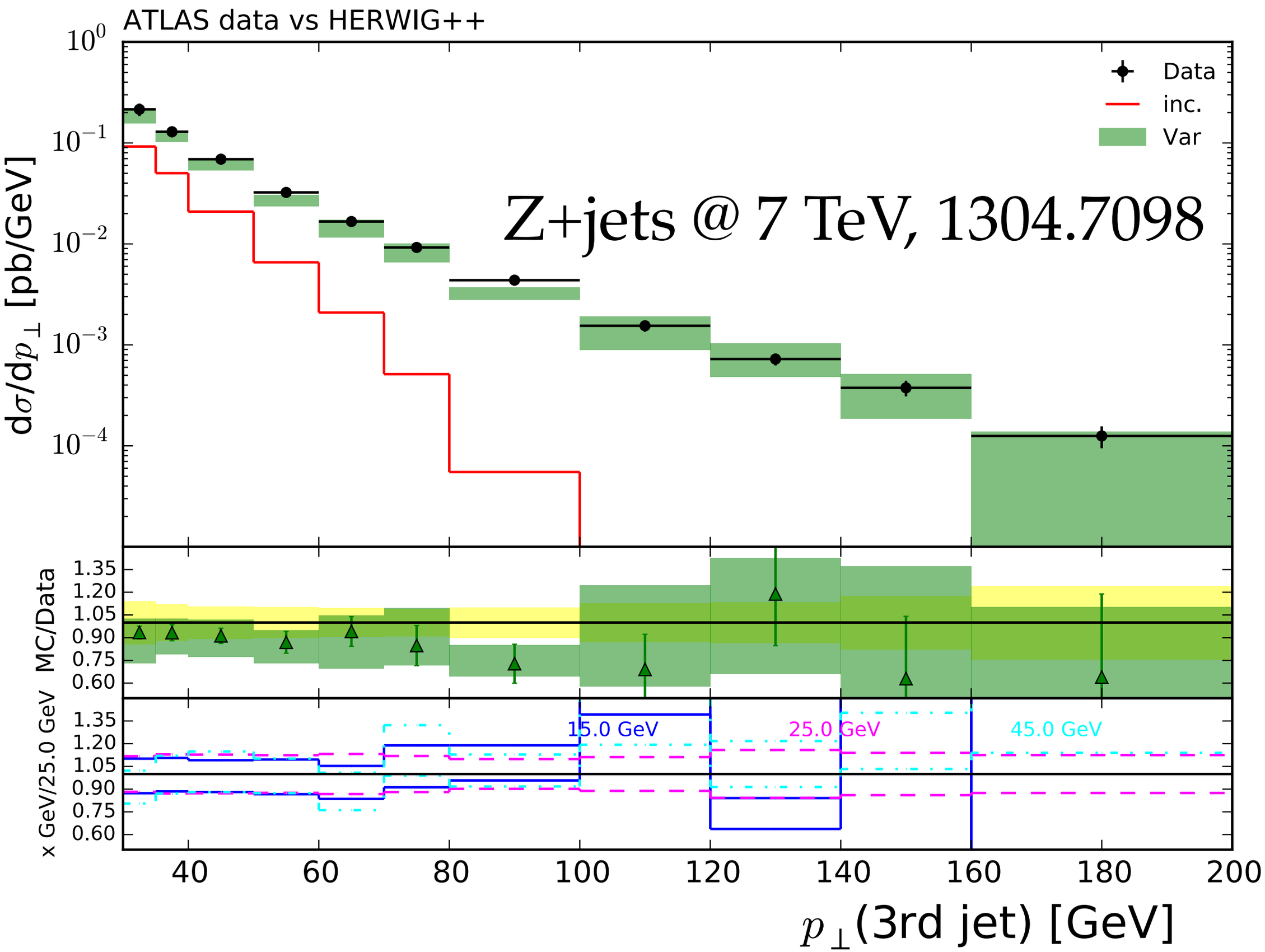
ratio of MC to data.

purple, pink, cyan lines: results for specific merging scales (**15**, **25**, **45** GeV).

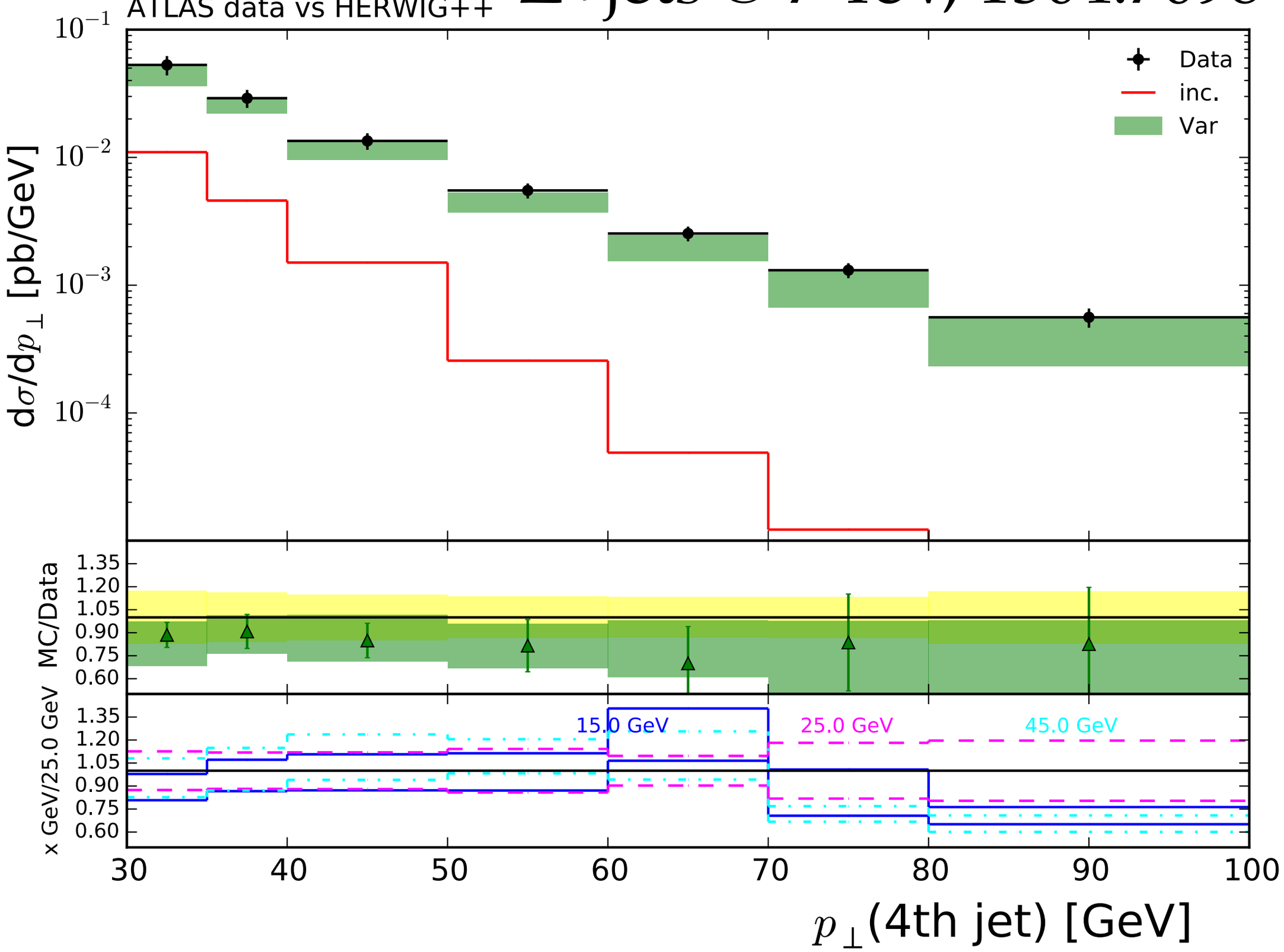
ATLAS Z+jets @ 7 TeV, 1304.7098

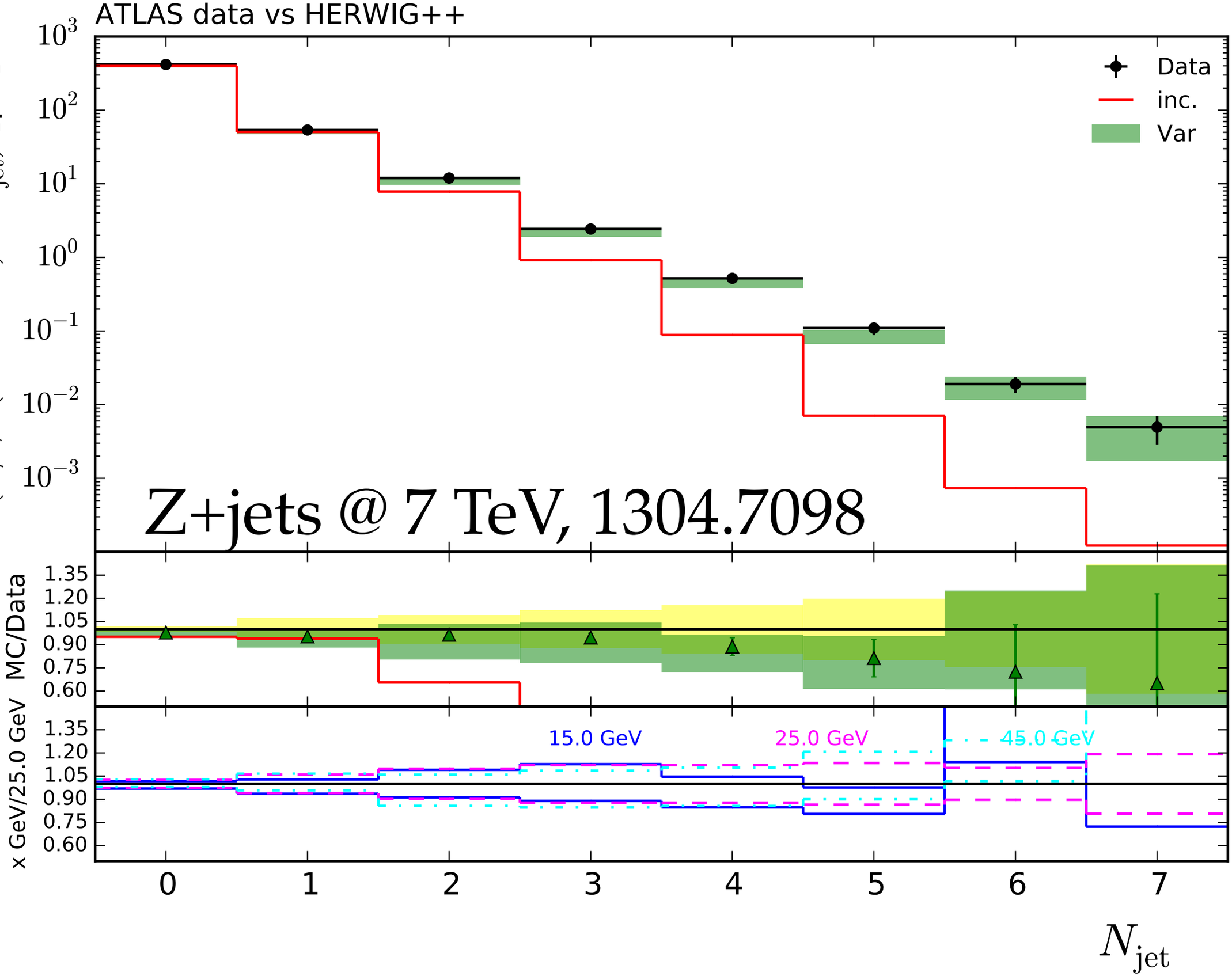
- study of jet, Z, inclusive properties,
- based on an integrated luminosity of 4.6 fb^{-1},
- using both e^+e^- and $\mu^+\mu^-$ pairs,
- with $R = 0.4$ anti-k_T jets, p_T (j) > 30 GeV and $|y(j)| < 4.4$,
- further cuts: $p_T(l) \geq 20$ GeV, $66 \leq M(ll) \leq 116$ GeV, $\Delta R(jl) \geq 0.5$, $\Delta R(ll) \geq 0.2$, $|\eta(\mu)| \leq 2.4$, $|\eta(e)| \leq 1.37$ and $1.52 \leq |\eta(e)| \leq 2.47$.


ATLAS data vs HERWIG++
Data
inc.
Var
Z+jets @ 7 TeV, 1304.7098
dσ/dp⊥ [pb/GeV]
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
p⊥(1st jet) [GeV]


ATLAS data vs HERWIG++
Data
inc.
Var
Z+jets @ 7 TeV, 1304.7098
$d\sigma/dp_\perp$ [pb/GeV]
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
$p_\perp$(3rd jet) [GeV]

Z+jets @ 7 TeV, 1304.7098

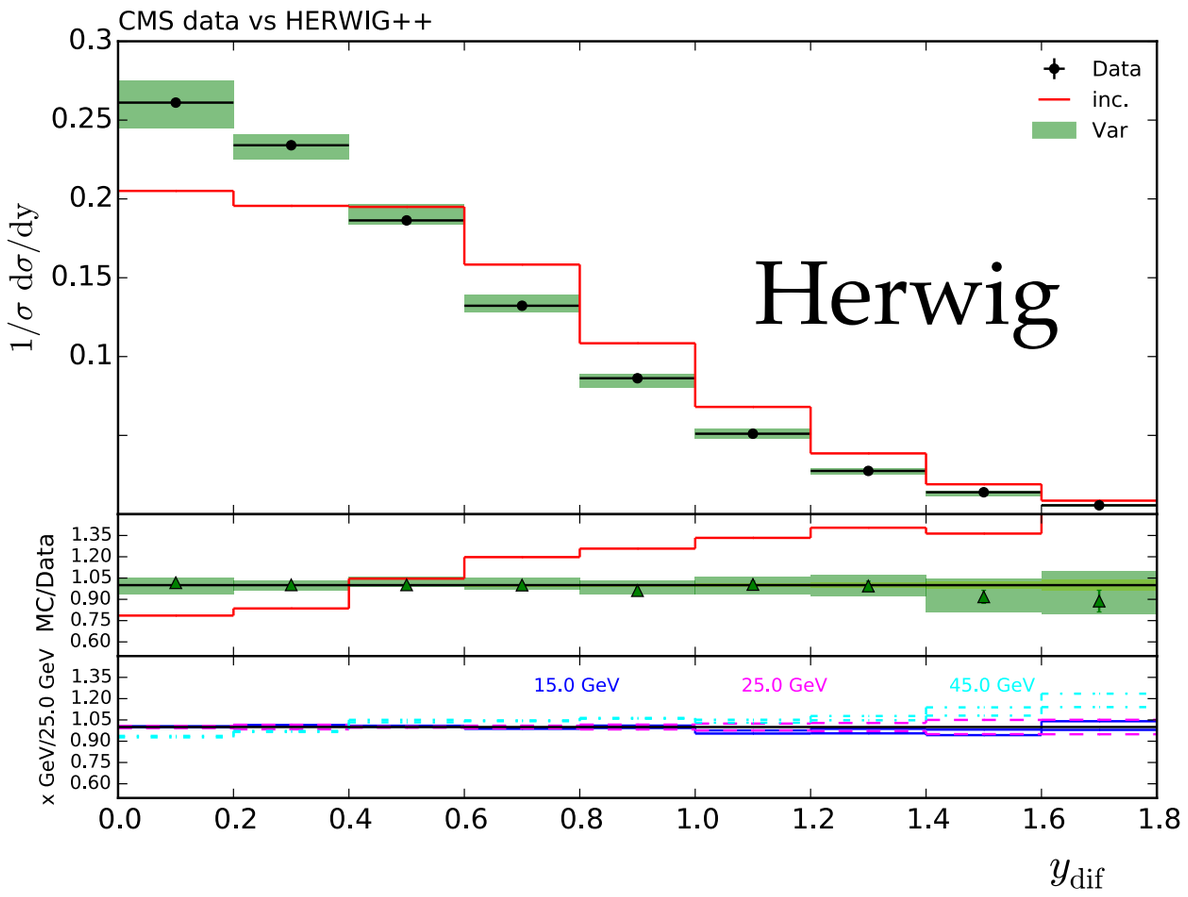


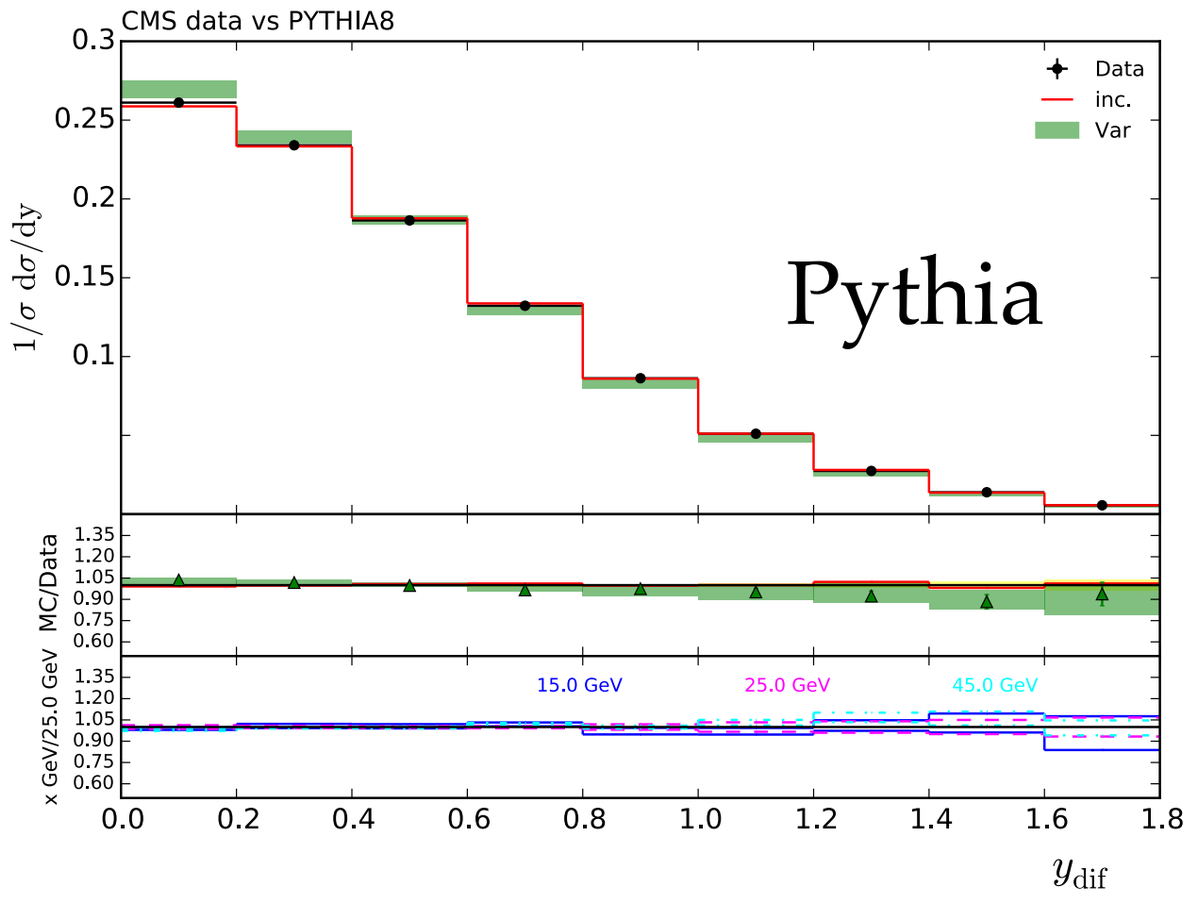

ATLAS data vs HERWIG++
$\sigma(Z/\gamma^*(\rightarrow\ell^+\ell^-)+N_{\rm jet})$ [pb]
Data
inc.
Var
Z+jets @ 7 TeV, 1304.7098
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
$N_{\rm jet}$

CMS Z+jets @ 7 TeV, 1310.3082

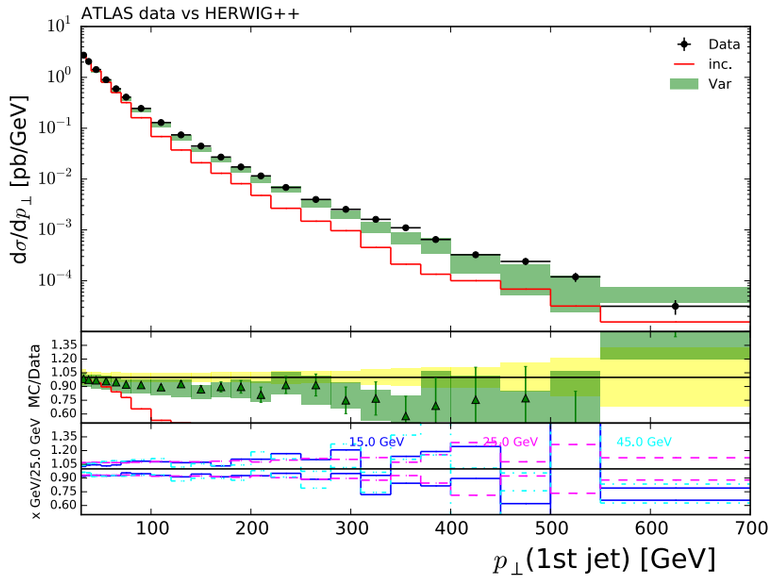
- study of rapidity distributions in Z+1 jet events (i.e. exactly one jet),
- based on an integrated luminosity of 5 fb^{-1},
- using both e^+e^- and $\mu^+\mu^-$ pairs,
- with $R = 0.5$ anti-k_T jets, within p_T (j) > 30 GeV and $|\eta(j)| < 2.4$,
- further cuts: p_T (l) $\geq$ 20 GeV, $76 \leq M(ll) \leq 106$ GeV, $|\eta(l)| \leq 2.1$, p_T (ll) $\geq$ 40 GeV, $\Delta R(jl) \geq 0.5$.

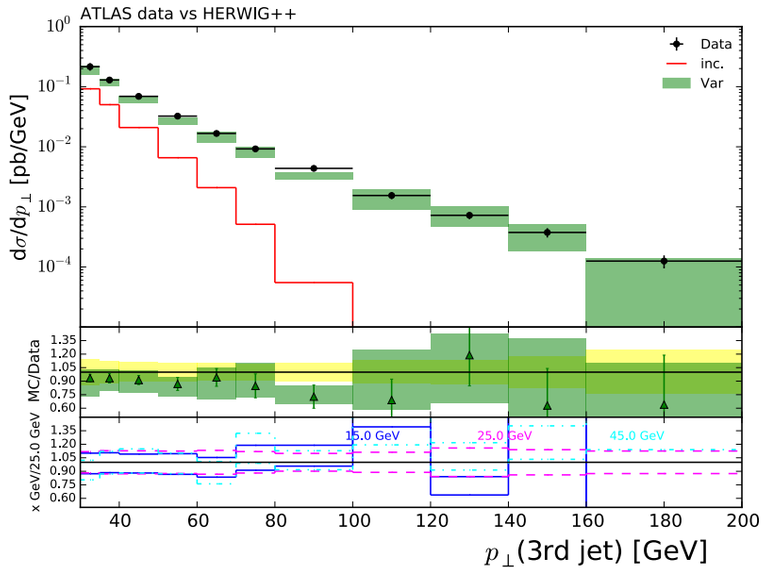
CMS Z+jets @ 7 TeV, 1310.3082

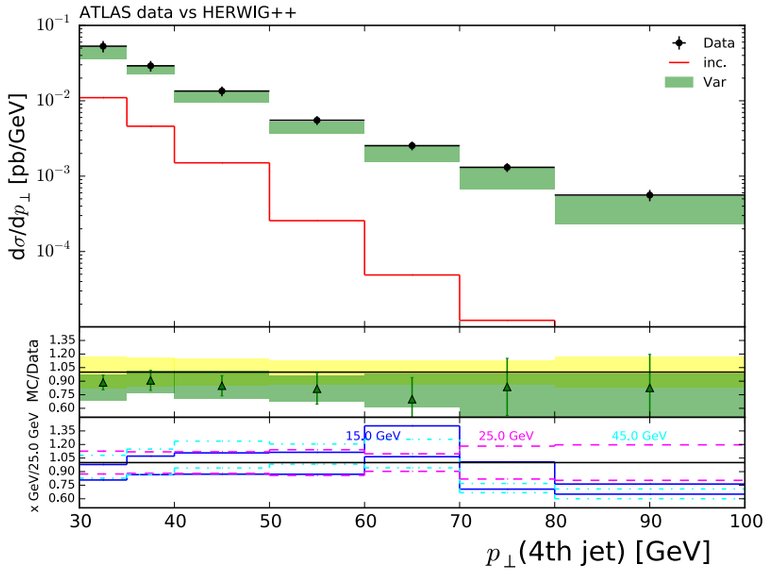


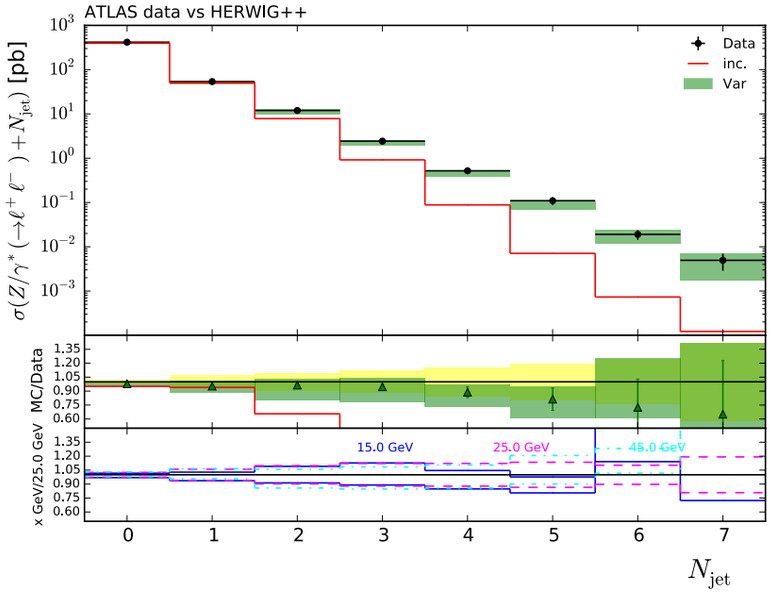


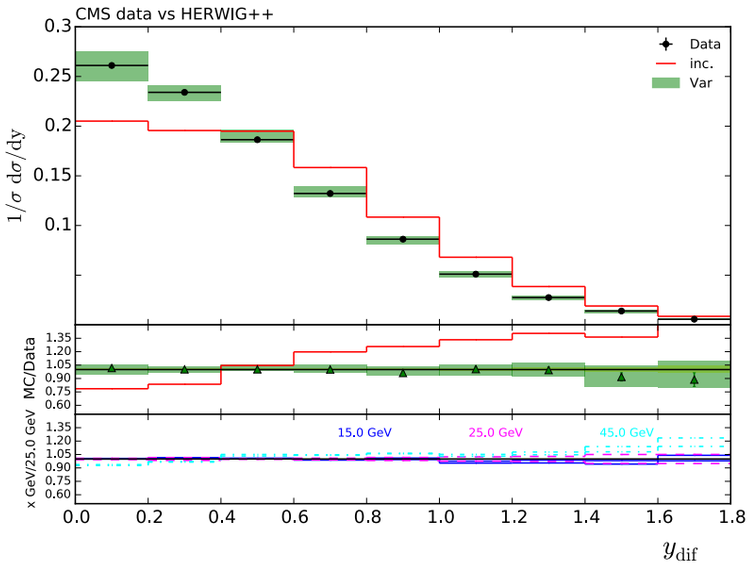
- inclusive MC@NLO (red): substantial differences between MCs!
- FxFx (green): good agreement, similar predictions by both.

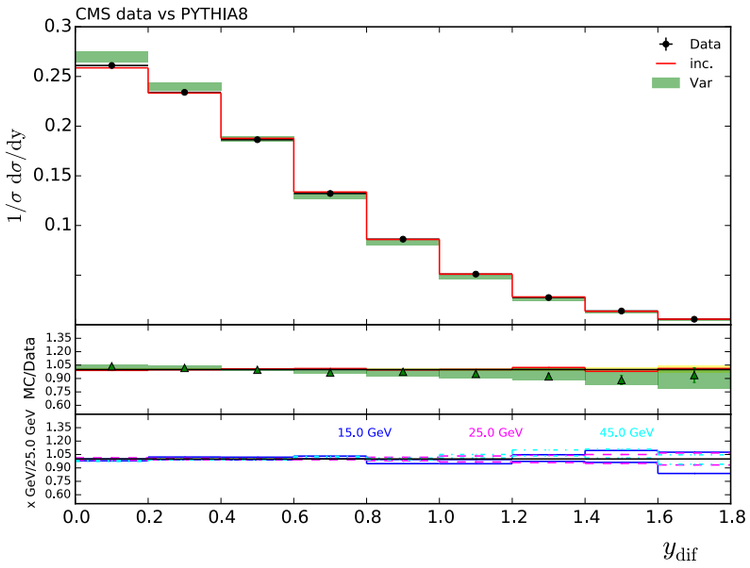








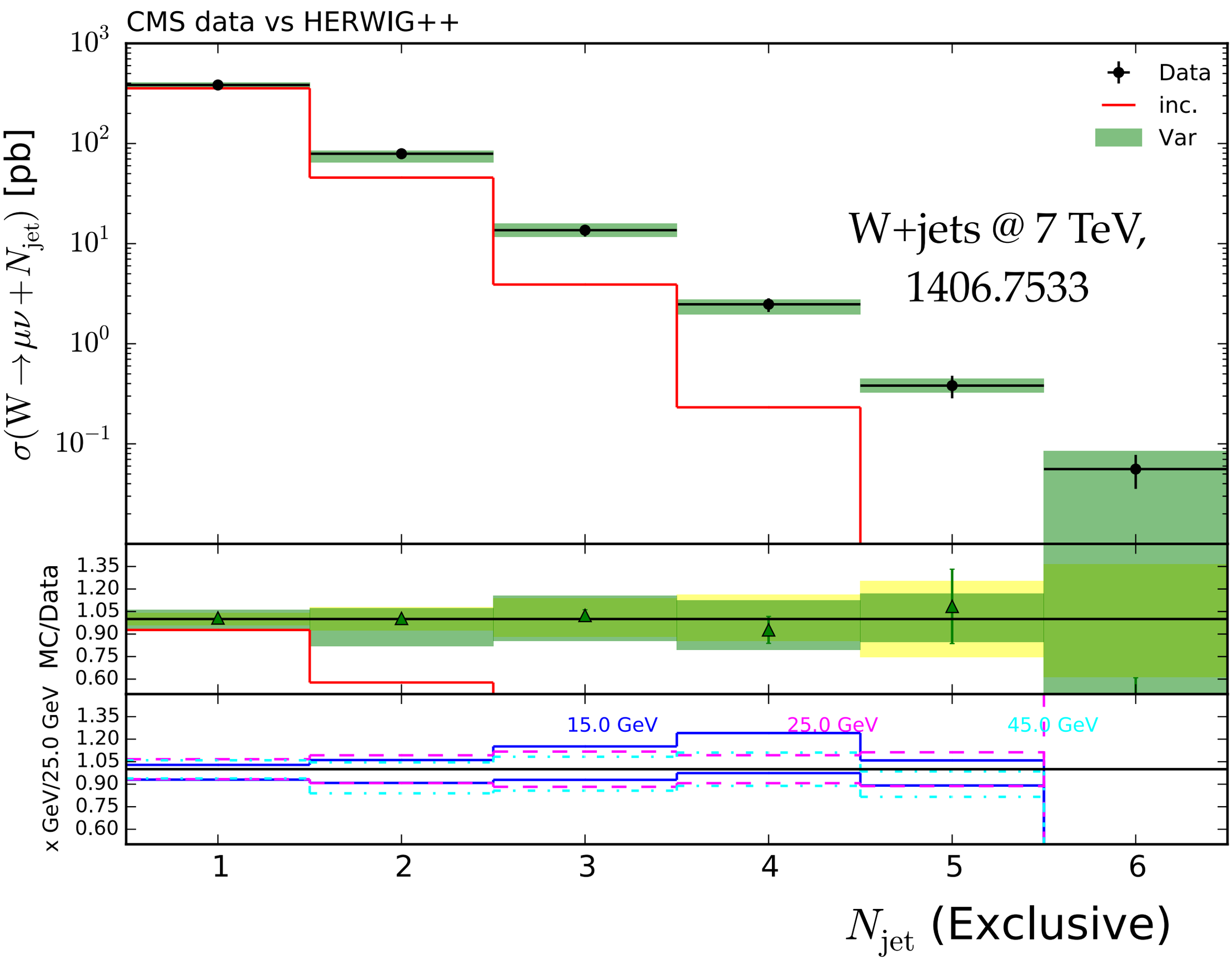


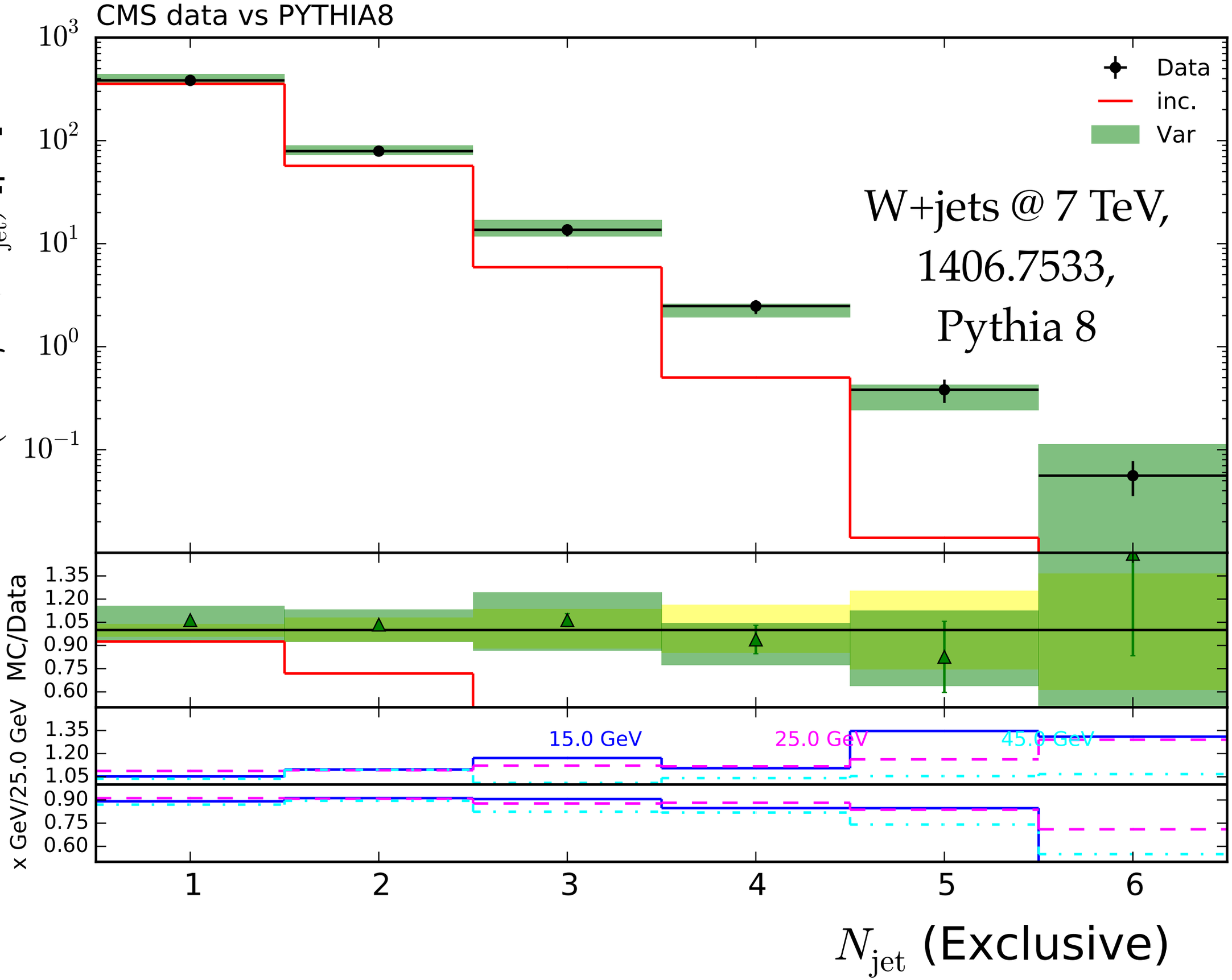


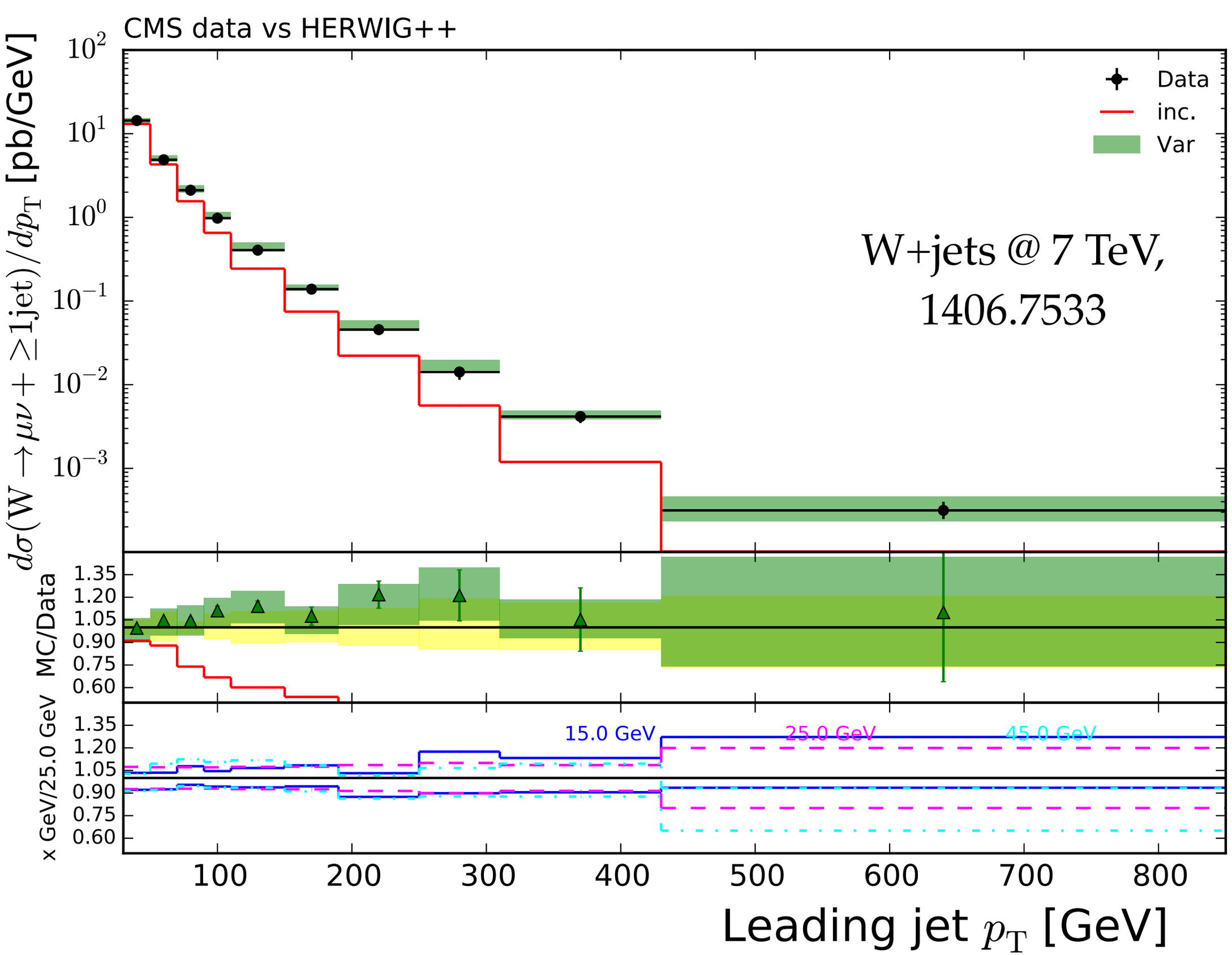
- **<u>Z+jets summary</u>:** good agreement with data!
- presence of few hard partons: allows Monte Carlos to stay within natural range of validity.
- no evidence for necessity of including Z+3 j.

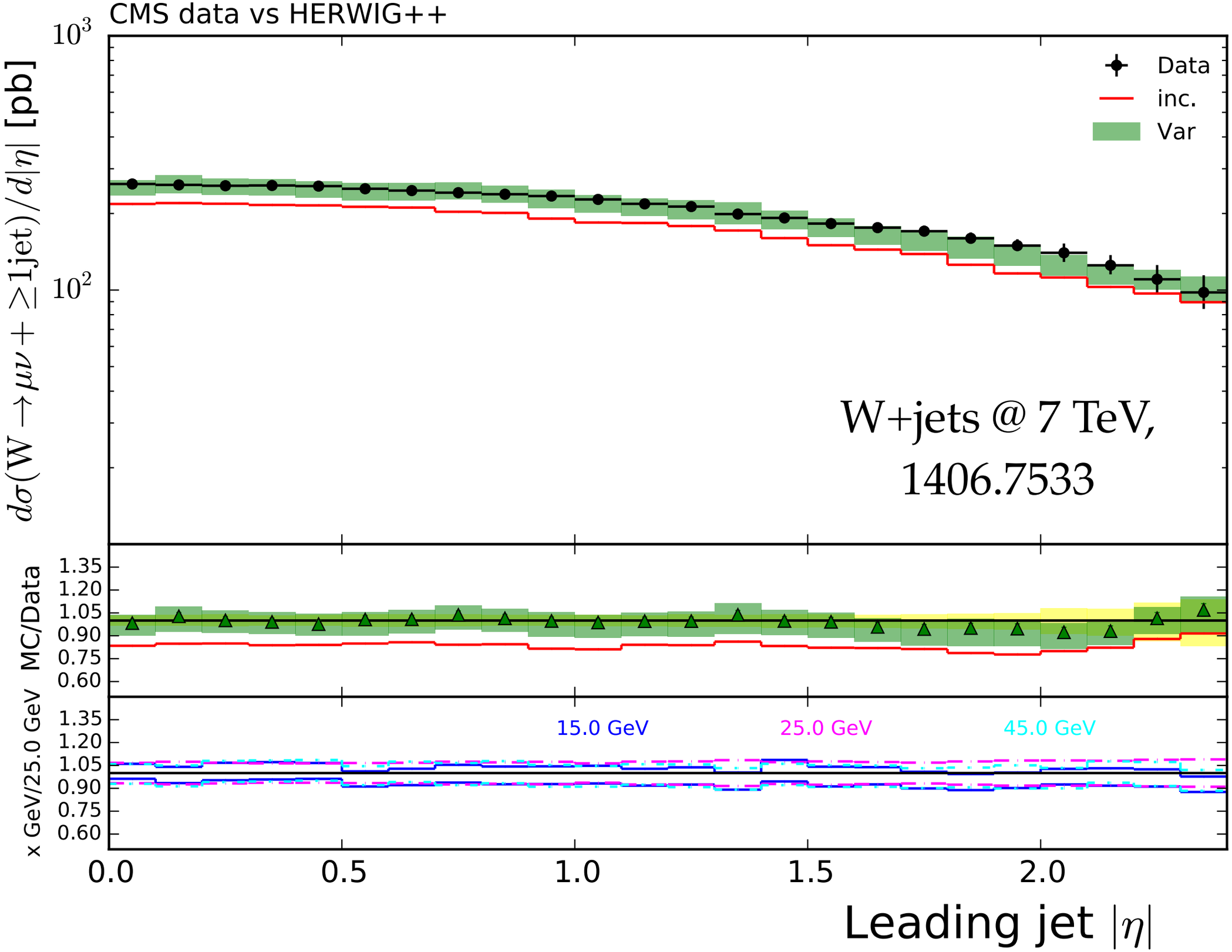
CMS, W+jets @ 7 TeV, 1406.7533

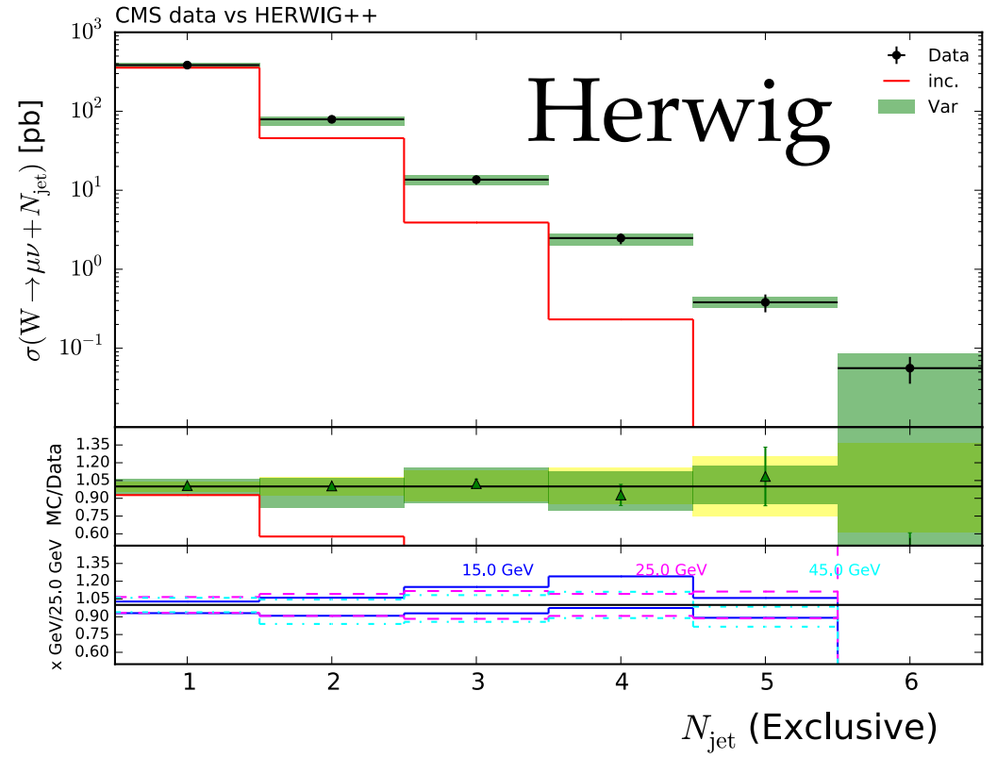
- study of jet, W, inclusive properties,
- based on an integrated luminosity of 5 fb^{-1},
- using muon channel,
- with R = 0.5 anti-kT jets, p_T (j) > 30 GeV and $|y(j)| < 2.4$,
- further cuts: $p_T(\mu) > 24$ GeV, $|\eta(\mu)| < 2.1$, $\Delta R(j\mu) \geq 0.5$, $m_T(\mu\nu) > 50$ GeV.

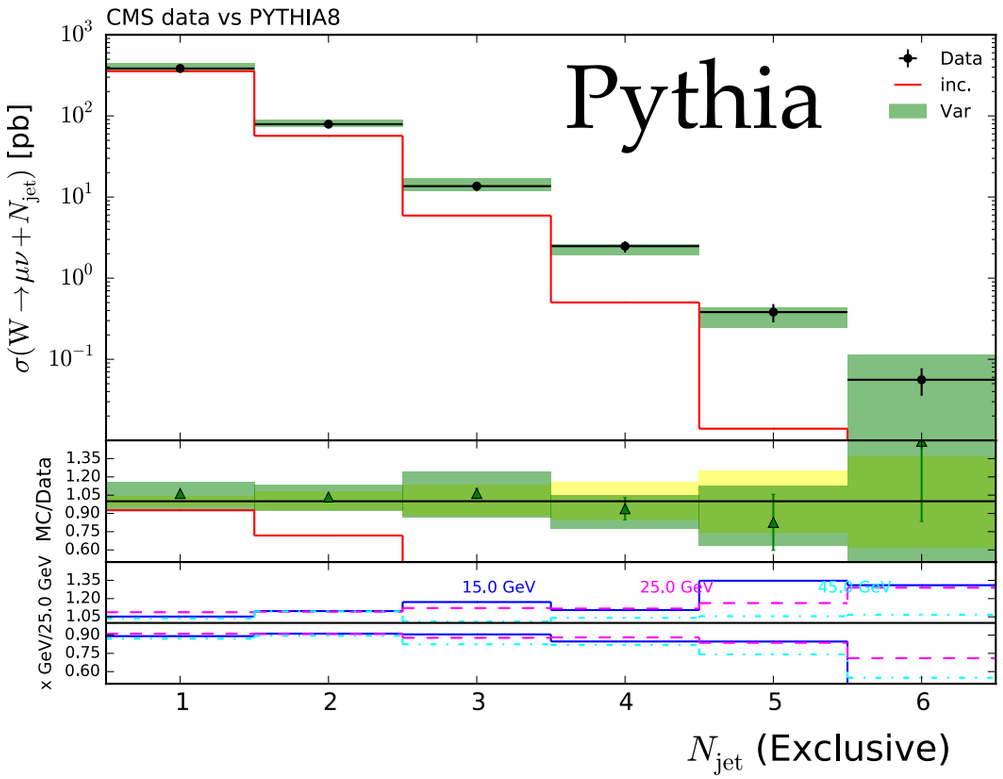

CMS data vs HERWIG++
Data
inc.
Var
W+jets @ 7 TeV,
1406.7533
$\sigma(W \rightarrow \mu\nu + N_{jet})$ [pb]
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
N_{jet} (Exclusive)

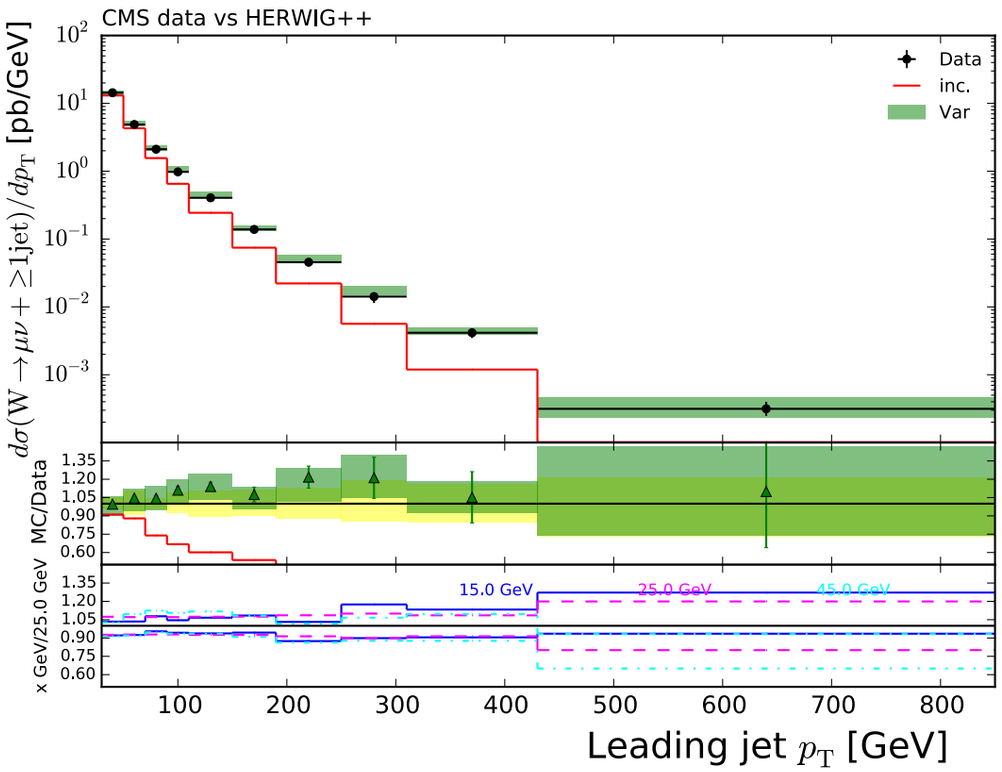

CMS data vs PYTHIA8
Data
inc.
Var
W+jets @ 7 TeV,
1406.7533,
Pythia 8
$\sigma(W \to \mu\nu + N_{jet})$ [pb]
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
N_{jet} (Exclusive)

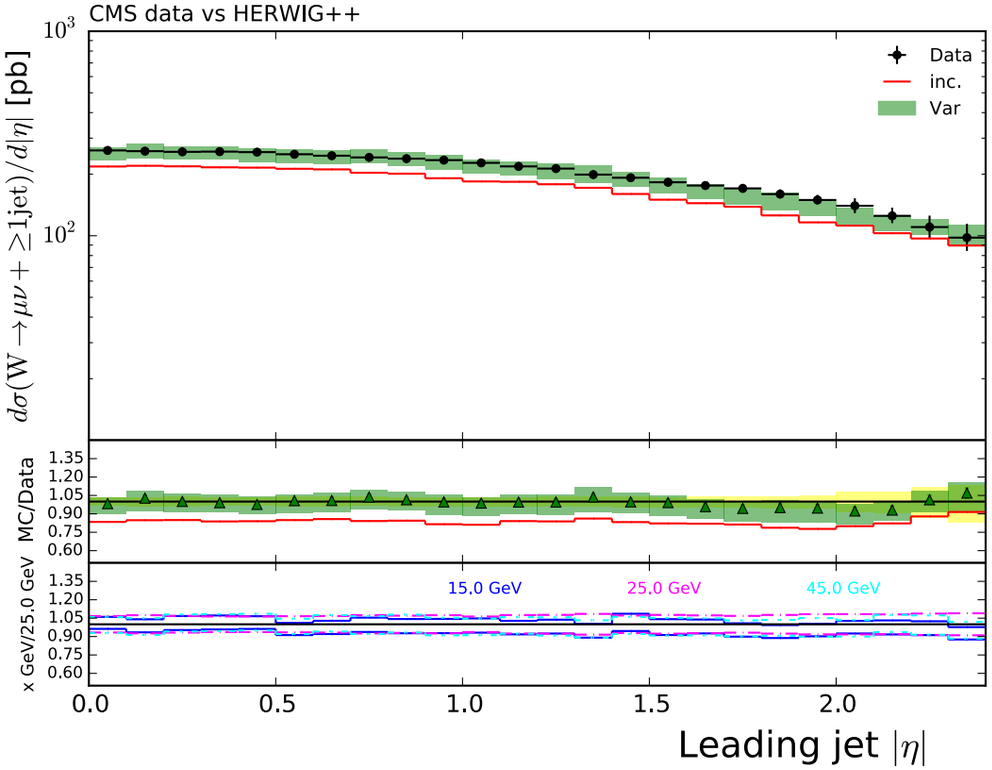

CMS data vs HERWIG++
$d\sigma(\mathrm{W}\to\mu\nu+\geq 1\mathrm{jet})/dp_{\mathrm{T}}$ [pb/GeV]
Data
inc.
Var
W+jets @ 7 TeV,
1406.7533
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
Leading jet p_{T} [GeV]


CMS data vs HERWIG++
$d\sigma(W \to \mu\nu + \geq 1\text{jet})/d|\eta|$ [pb]
Data
inc.
Var
W+jets @ 7 TeV,
1406.7533
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
Leading jet $|\eta|$









➡ **<u>W+jets summary</u>:** good agreement with data, similar trend as in Z+jets.

conclusions & outlook

- **samples constructed using the FxFx method describe a wide range of observables very well.**

- **it has been fully validated using Herwig(++) 7 and Pythia 8, in:**

  - **Z/W+jets,**

  - **as well as V+Higgs [see: Yellow Report 4, 1610.07922].**

- **future work:**

  - **examine top-anti-top/Higgs & comparison to 13 TeV data.**

thanks for your attention!

[pictured: “merging” in the 1980s.]

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appendix

further misc. MC details (I)

- **hard scale:** $\mu_0 = H_T/2$, (scalar sum of the transverse masses $p_T^2 + m^2$ of all final state particles),

- variations between $2\mu_0$ and $\mu_0/2$.

- cut on invariant mass of opposite sign leptons: $M(ll) > 40$ GeV.

- consider only “dressed” leptons + enable QED radiation in MCs.

- 15 million events at LHE level.

further misc. MC details (II)

- negative weights: inclusive MC@NLO ~ 10%, FxFx ~ 25%.

- cross sections:

	$\mu_Q = 15$ GeV	$\mu_Q = 25$ GeV	$\mu_Q = 45$ GeV	inclusive	
Z+jets	2.055(−0.9%)	2.074	2.085(+0.5%)	2.012(−3.0%)	HW++
	2.168(+0.8%)	2.150	2.117(−1.5%)	2.011(−6.5%)	PY8
W+jets	20.60(−0.9%)	20.78	20.87(+0.4%)	19.96(−3.9%)	HW++
	21.71(+1.0%)	21.50	21.18(−1.5%)	19.97(−7.1%)	PY8

Table 2: Total rates (in nb) for the three different choices of the FxFx merging scale, as well as those for the inclusive (i.e. non-merged) samples, obtained with HERWIG++ (upper rows) and PYTHIA8 (lower rows). Relative differences w.r.t. the FxFx results obtained with the central merging scale are also reported in brackets.

further misc. MC details (III)

- vetoing efficiencies:

	$\mu_Q = 15$ GeV	$\mu_Q = 25$ GeV	$\mu_Q = 45$ GeV
Herwig++	44%(2.7)	38%(3.2)	35%(3.5)
Pythia8	45%(4)	37%(4)	32%(4)

Table 1: Efficiencies of the MLM-type rejection in FxFx merging, rounded to the percent; in brackets, we report the corresponding oversampling factors (see the text for details).

further misc. MC details: MC tunes and α_S

- MC tunes used: Pythia 8: Monash 2013, Herwig++: UE-EE-3-CTEQ6L1.

- we used the α_S as it was given in the respective MC tunes:

  - Herwig++: $\alpha_S = 0.118$, Pythia 8: $\alpha_S = 0.1365$ for ISR/FSR, $\alpha_S = 0.130$ for multi-parton interactions.

  - compare to "NNPDF2.3 NLO" $\alpha_S = 0.119$.

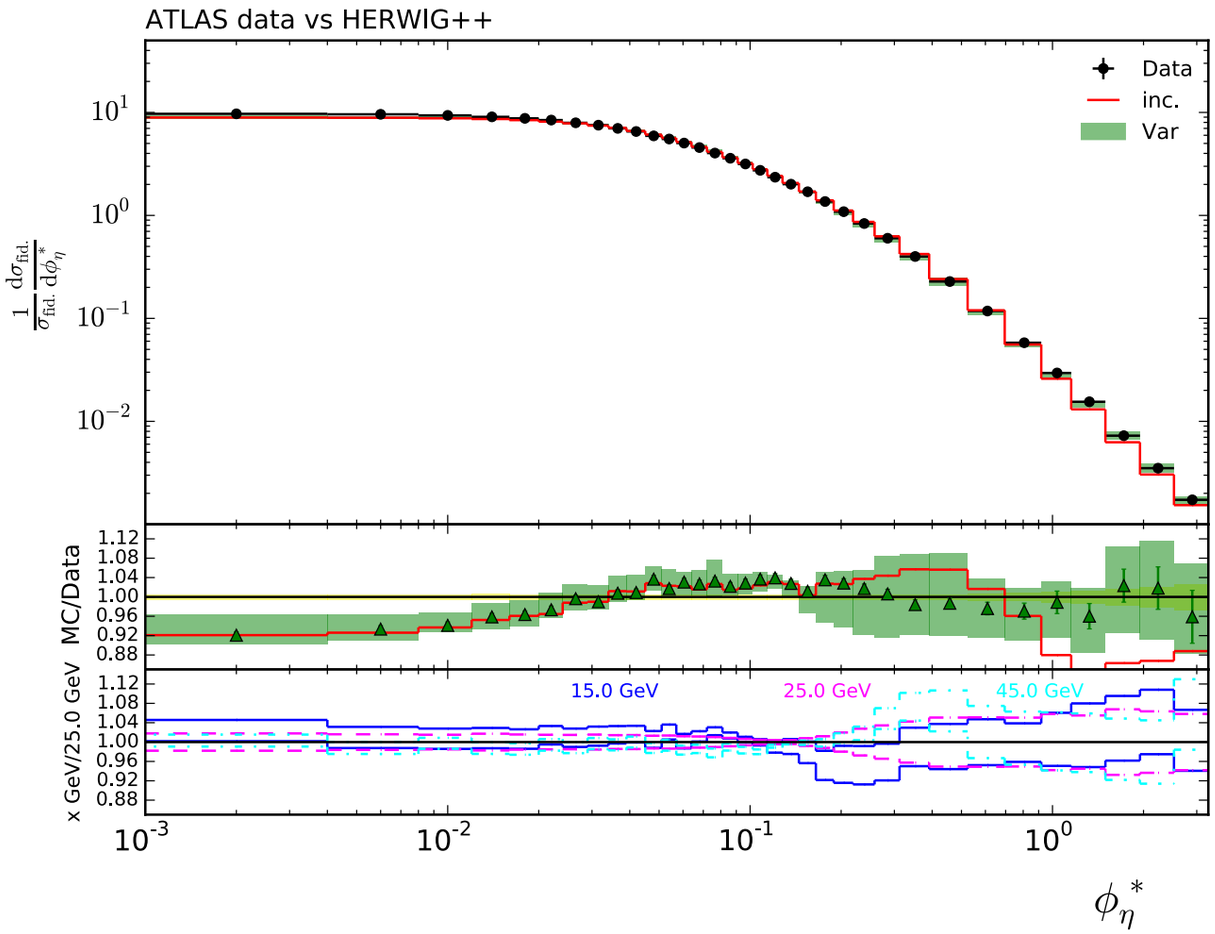
- we attempted: $\alpha_S = 0.130$ in Herwig++, $\alpha_S = 0.119$: generally worsens agreement.

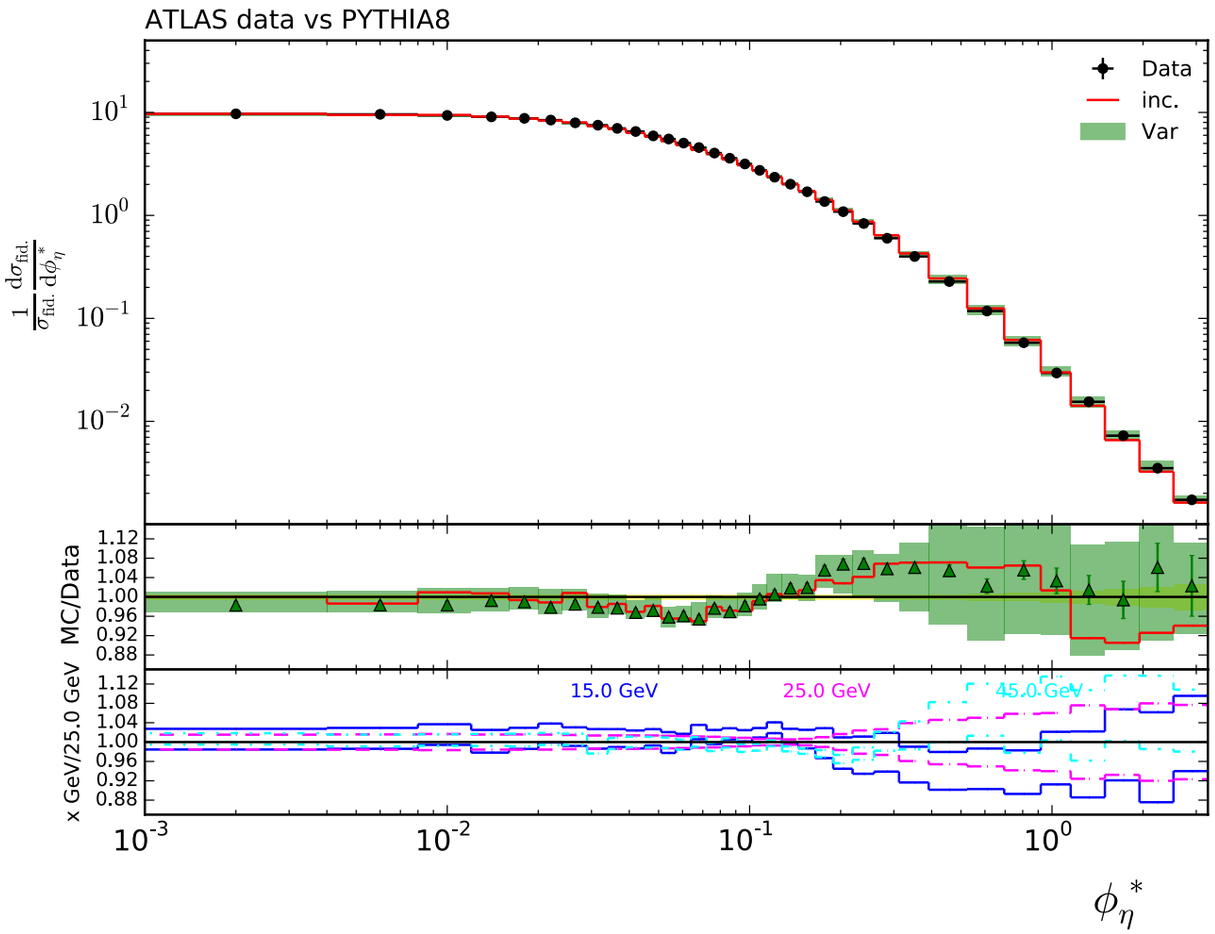
➡ use the α_S values as they were in the tunes.

tuning and soft effects (I)

- ATLAS Z+jets @ 7 TeV, 1211.6899,
- measurement of the $\phi_\eta{}^\star$ angular correlation in e^+e^- and $\mu^+\mu^-$ production, [1009.1580 for definition of $\phi_\eta{}^\star$].
- based on an integrated luminosity of 4.6 fb^{-1},
- within p_T (l) $\geq$ 20 GeV, 66 $\leq M(ll) \leq$ 116 GeV, and $|\eta(l)| \leq$ 2.4.

tuning and soft effects (II)





- ➡ at small $\phi_\eta{}^\star$ (~low pT): merged and inclusive coincide,
- ➡ at small $\phi_\eta{}^\star$ driven by MC, i.e. controlled by tune,
- ➡ at large $\phi_\eta{}^\star$: predictions coincide: driven by MEs.