Merging and Matching with MG5_aMC and Herwig 7

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introduction

why merging in 2017?

why 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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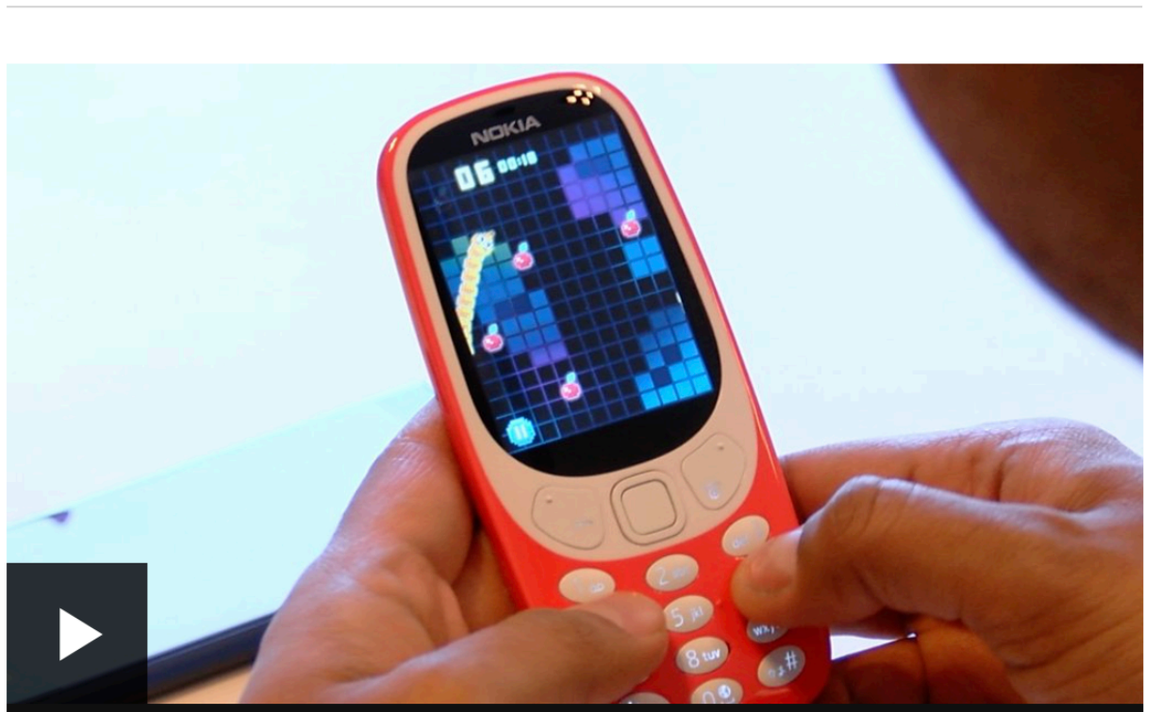

WATCH: Rory Cellan-Jones tries out the new Nokia 3310

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

why merging in 2017?

- merging of **multiple NLO**+parton shower calculations: "best of both worlds".

- merging of high-multiplicity (coloured) final states: technically difficult to get NLO+PS:

  - e.g.:

$$pp \to b\bar{b}b\bar{b} + \text{ jets}$$

$$pp \to b\bar{b}\gamma\gamma + \text{ jets}$$

etc.

contents:

- a brief introduction to multi-jet merging,
- results with Herwig 7,*
- some technical aspects,
- conclusions & outlook.

* formerly known as Herwig++.

multi-jet merging @ LO & NLO

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multi-jet merging @ LO

- the aim: consistently **merge** tree-level Matrix Elements and parton showers.

- several approaches exist, mostly developed in the early 2000s, e.g. CKKW(-L), MLM.

- remove double-counting with the parton shower by vetoing.

- (combine with α_s/PDF/Sudakov reweighing).

- result: description of multi-jet processes @ tree level.

matching to NLO

- the aim: consistently **match** NLO Matrix Elements and parton showers.

- several approaches exist, mostly developed in the mid-2000/10s, 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.

- 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 + Pythia X/Herwig X). [Frederix, Frixione, 1209.6215, Frederix, Frixione, AP, Prestel, Torrielli, 1511.00847]

multi-jet merging @ NLO

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

the "FxFx" approach

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

- in a nutshell:
  - construct MC@NLO samples (MG5_aMC),
  - 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 X/Herwig X).

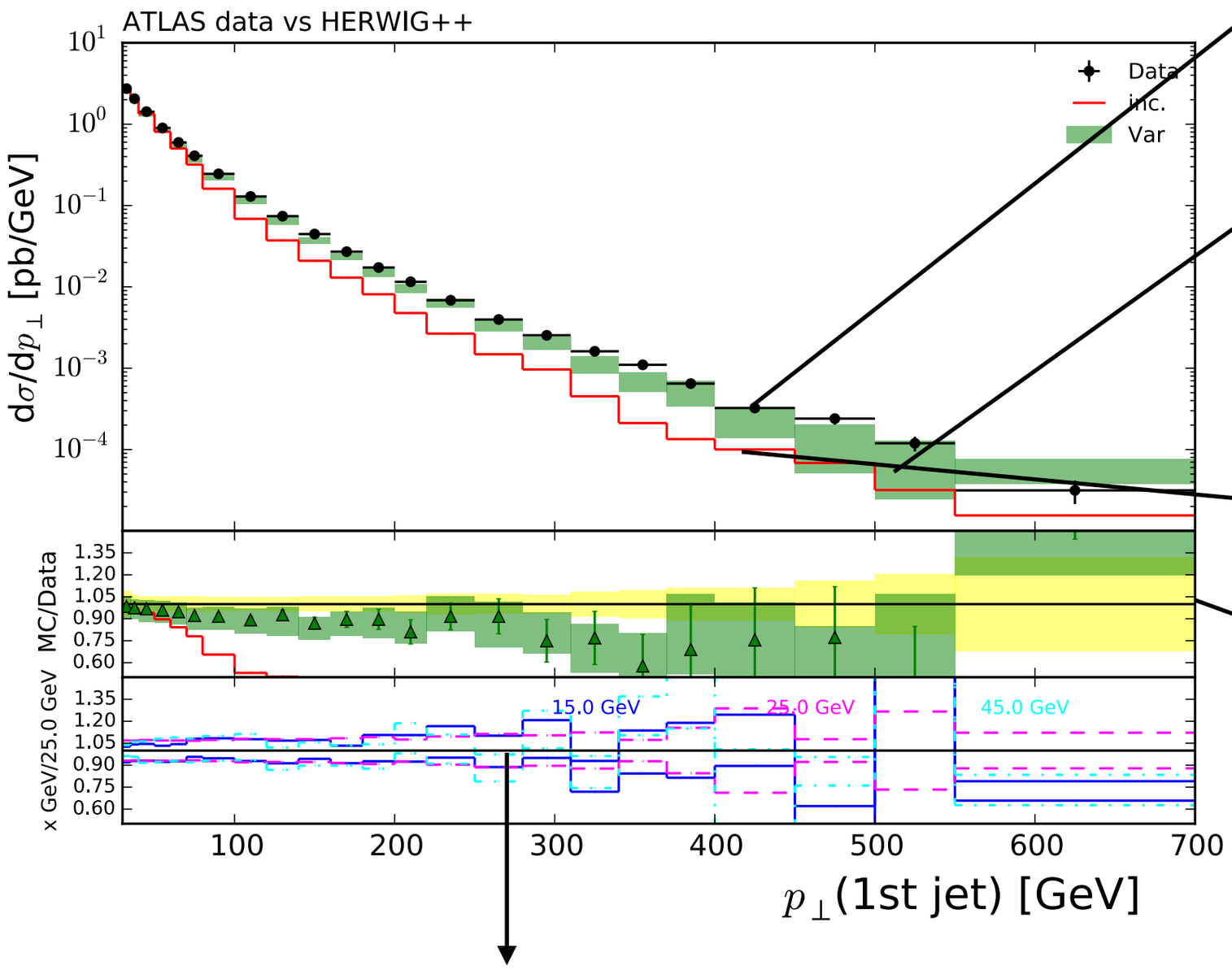
results

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

Z+jets, W+jets, ATLAS & CMS analyses at 7 TeV [using Rivet analyses]

- **FxFx multiplicities: V+0, 1, 2,**
- **MC@NLO: V+0 inclusive,**

"legend" for plots



points: ATLAS or CMS data.

green band: **FxFx,** envelope of variations:

- hard process scale
- PDF
- merging scale

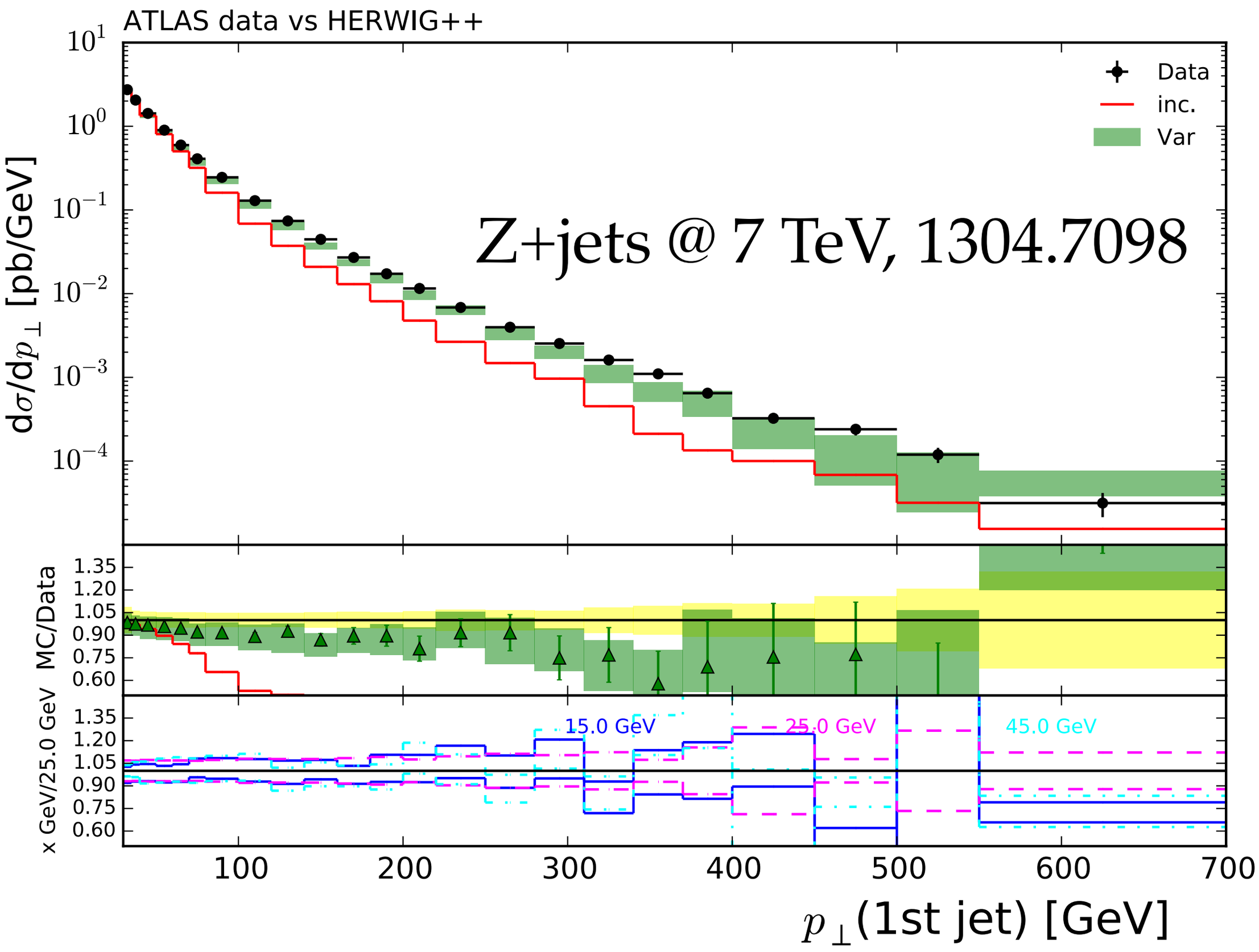
red line: MC@NLO inclusive.

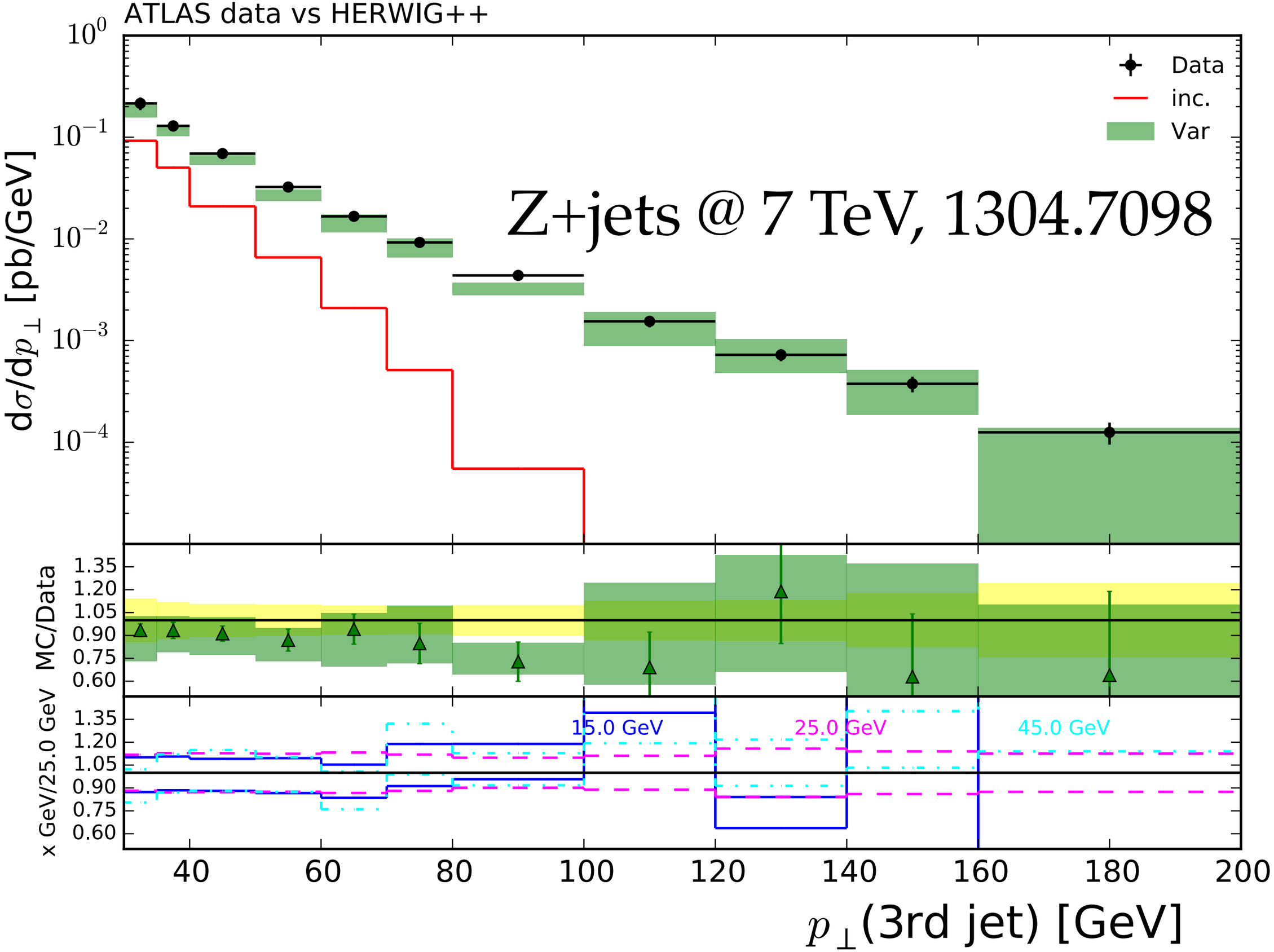
ratio of MC to data.

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

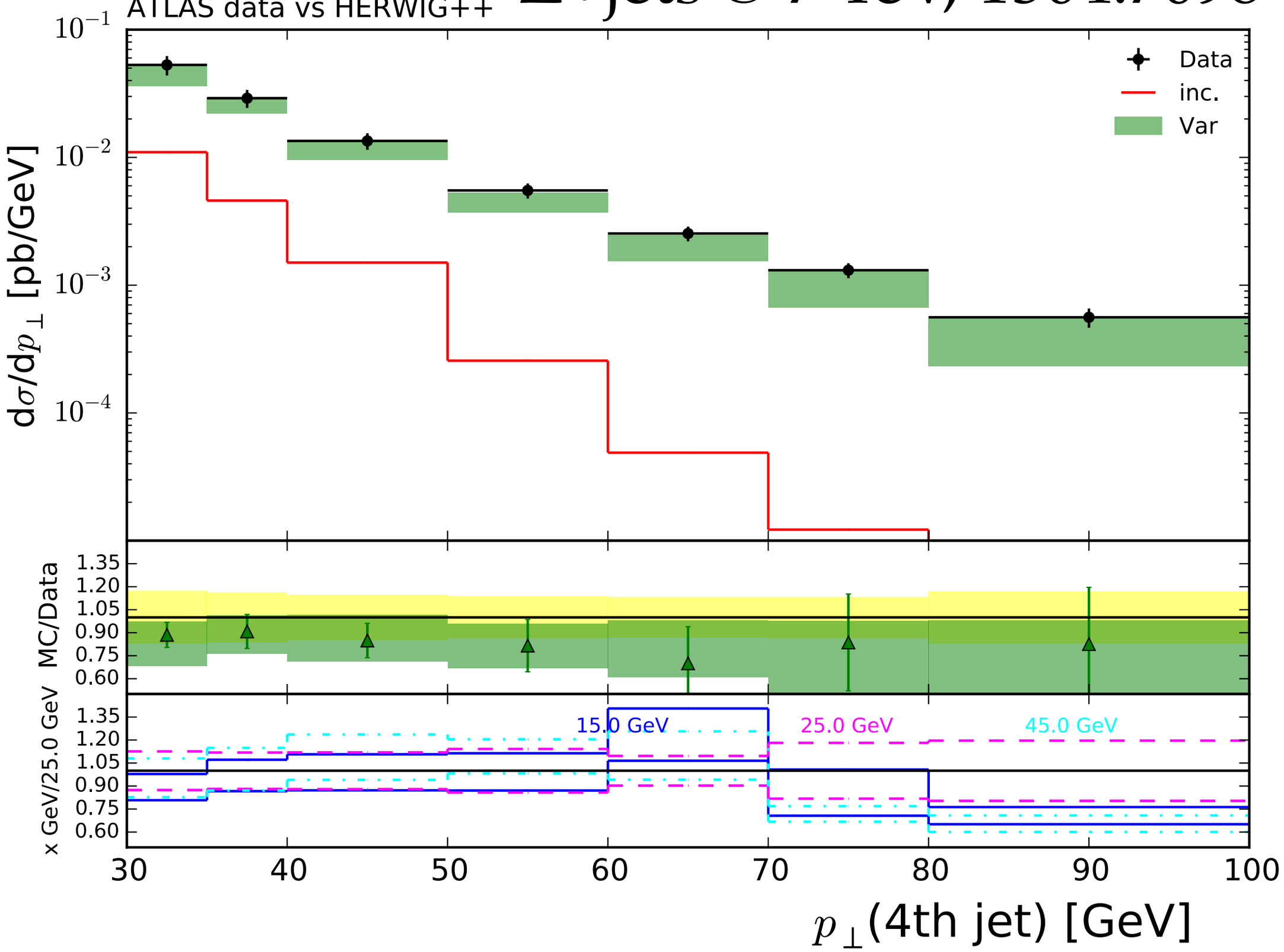
ATLAS Z+jets @ 7 TeV, 1304.7098

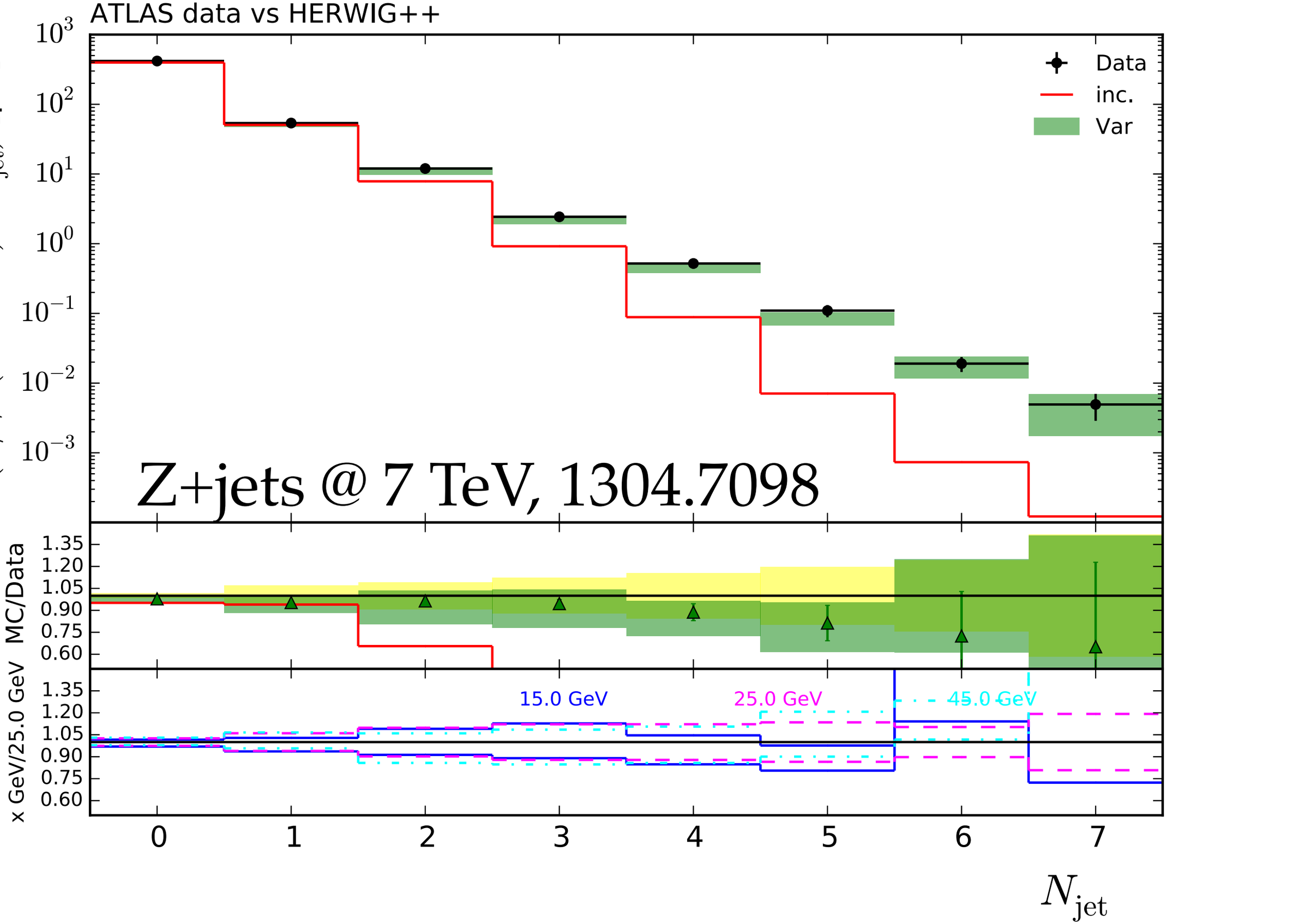
- study of jet, Z, inclusive properties,
- based on an integrated luminosity of 4.6 fb^{-1},
- using both e^+e^- and $\mu^+\mu^-$ pairs,
- with R = 0.4 anti-k_T jets, p_T (j) > 30 GeV and $|y(j)| < 4.4$,
- further cuts: $p_T(l) \geq 20$ GeV, $66 \leq M(ll) \leq 116$ GeV, $\Delta R(jl) \geq 0.5$, $\Delta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

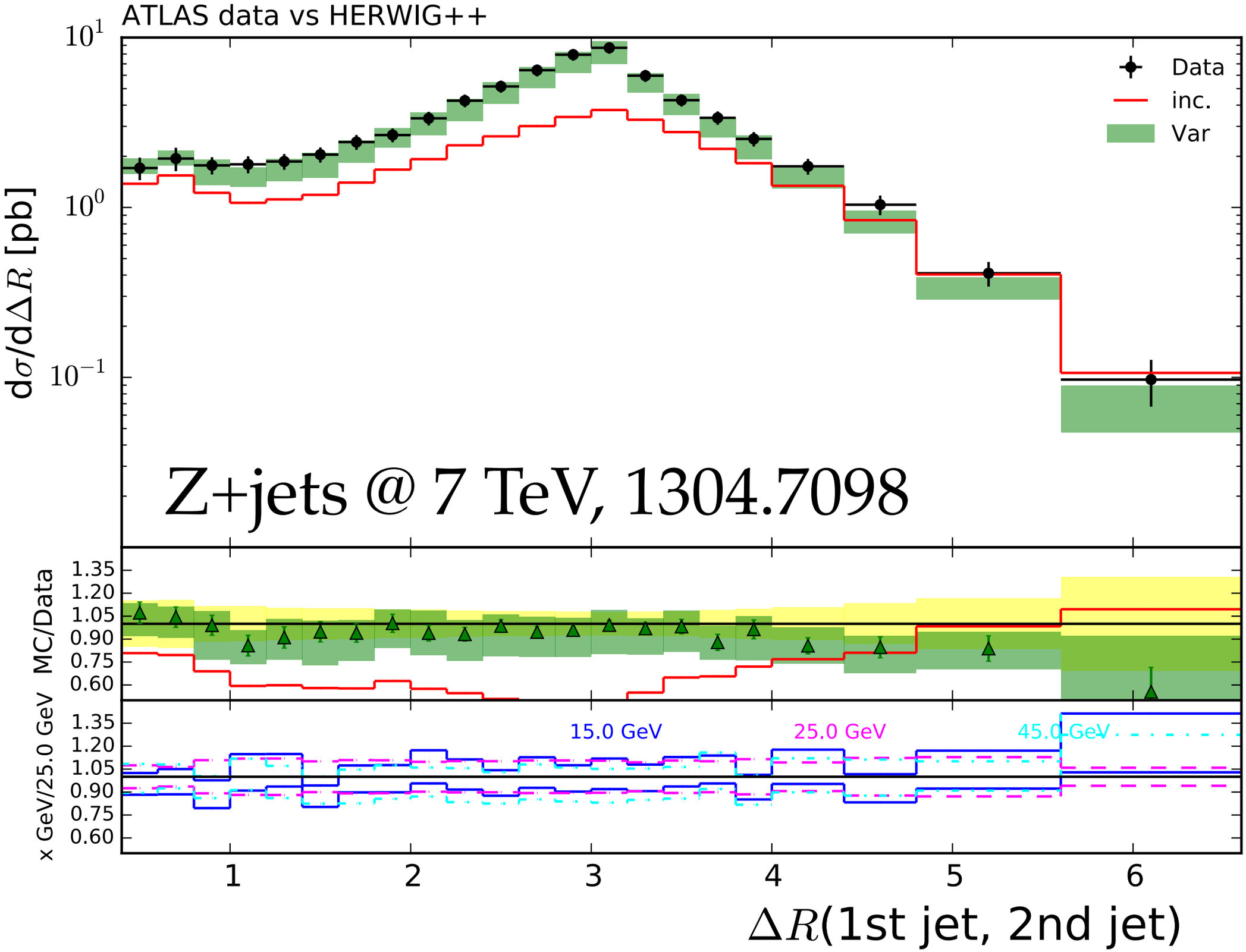

ATLAS data vs HERWIG++
Data
inc.
Var
Z+jets @ 7 TeV, 1304.7098
$d\sigma/dp_\perp$ [pb/GeV]
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
$p_\perp$(1st jet) [GeV]


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

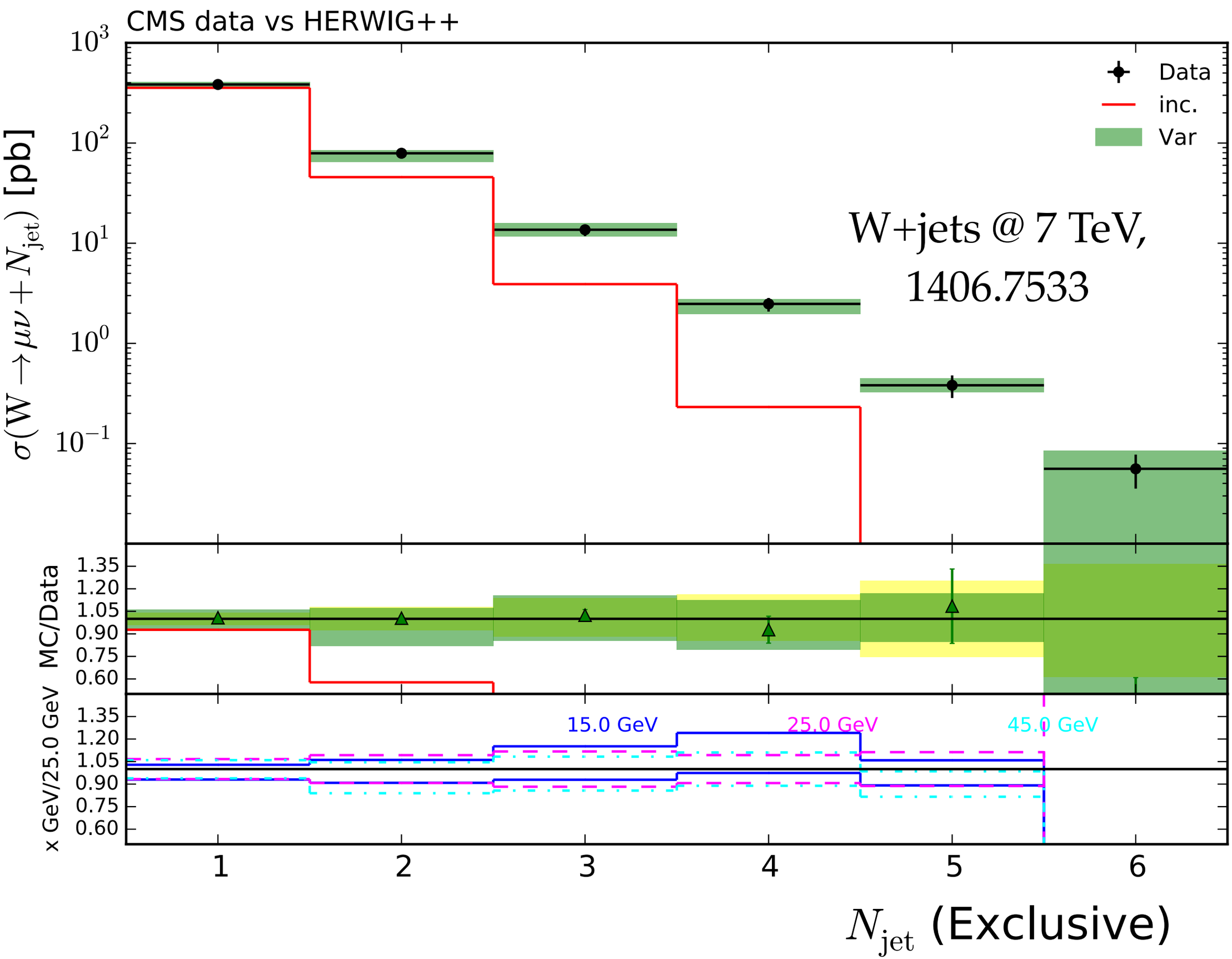


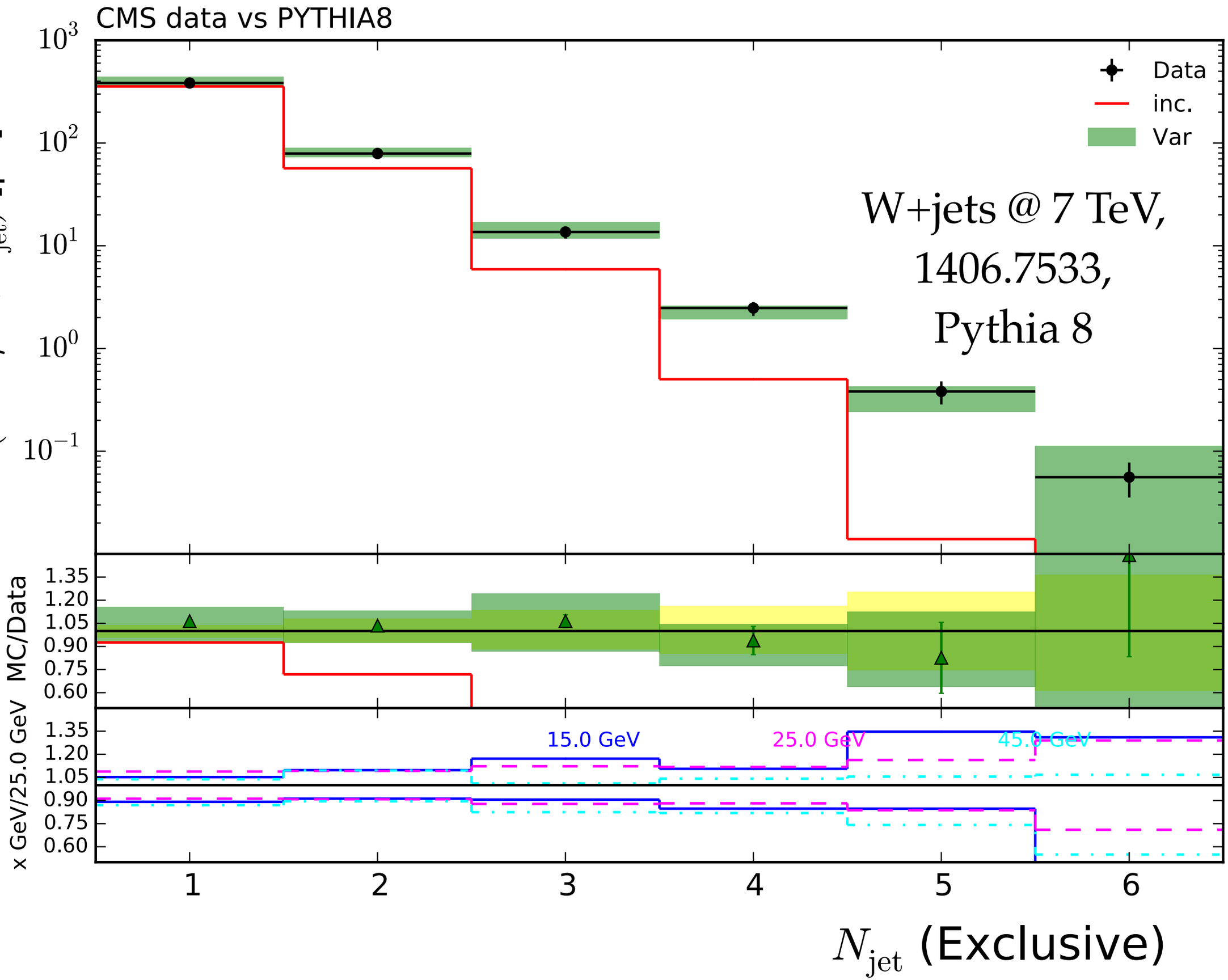

ATLAS data vs HERWIG++
$\sigma(Z/\gamma^*(\rightarrow\ell^+\ell^-)+N_{\rm jet})$ [pb]
Data
inc.
Var
Z+jets @ 7 TeV, 1304.7098
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
$N_{\rm jet}$

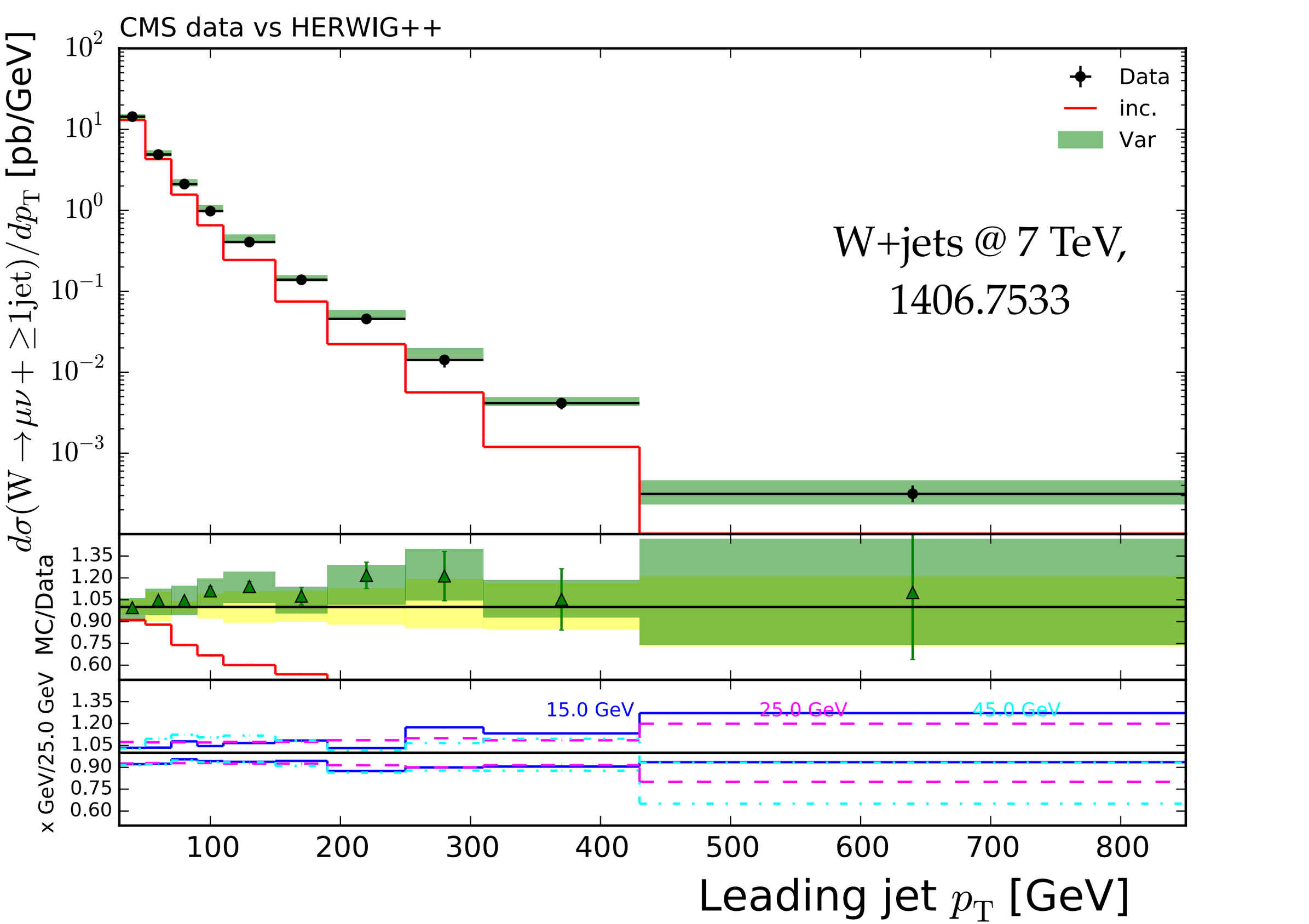

ATLAS data vs HERWIG++
Data
inc.
Var
$d\sigma/d\Delta R$ [pb]
Z+jets @ 7 TeV, 1304.7098
MC/Data
x GeV/25.0 GeV
15.0 GeV
25.0 GeV
45.0 GeV
ΔR(1st jet, 2nd jet)

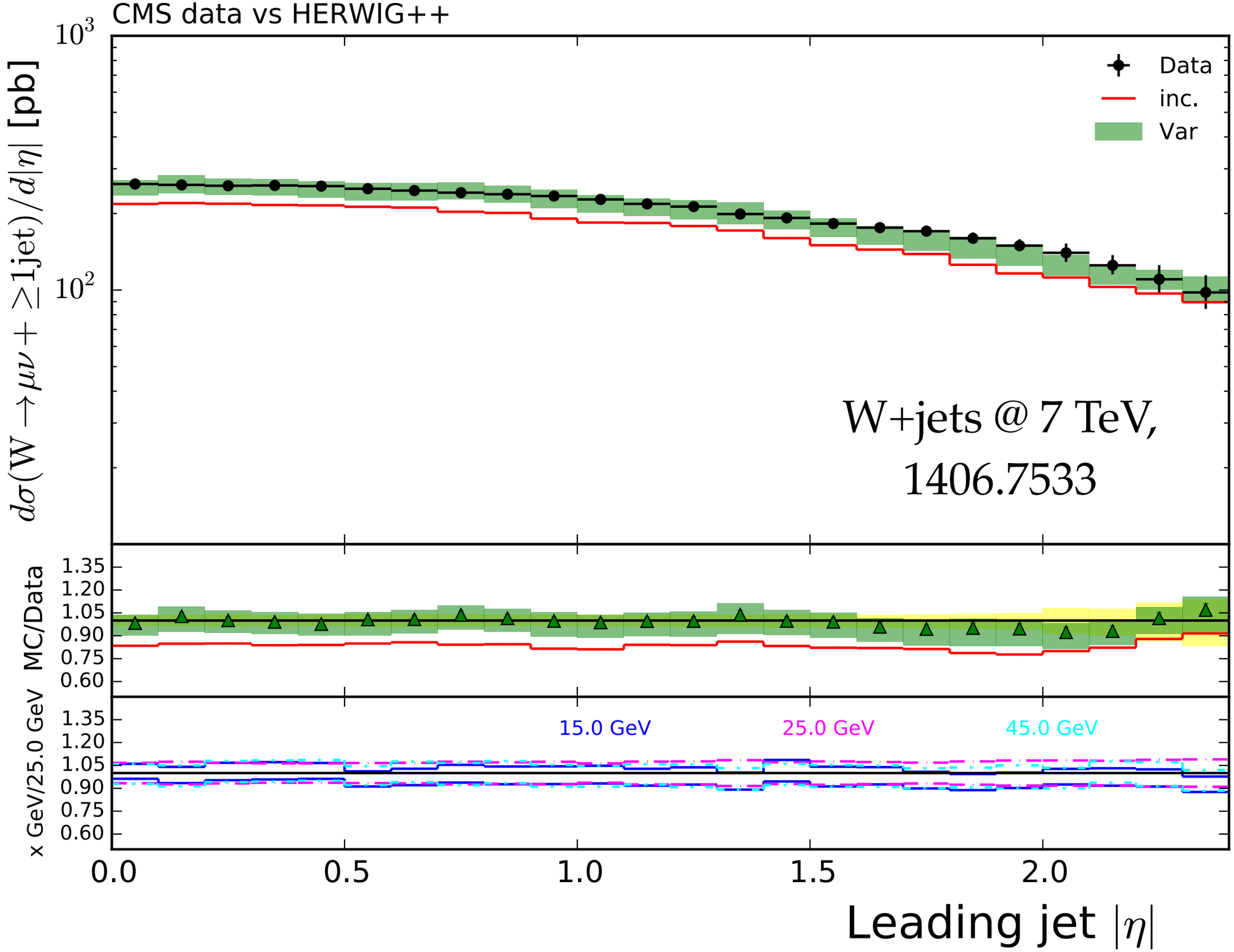
CMS, W+jets @ 7 TeV, 1406.7533

- 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 $|\eta|$

more results

(Z+jets: additional preliminary studies with Herwig 7)

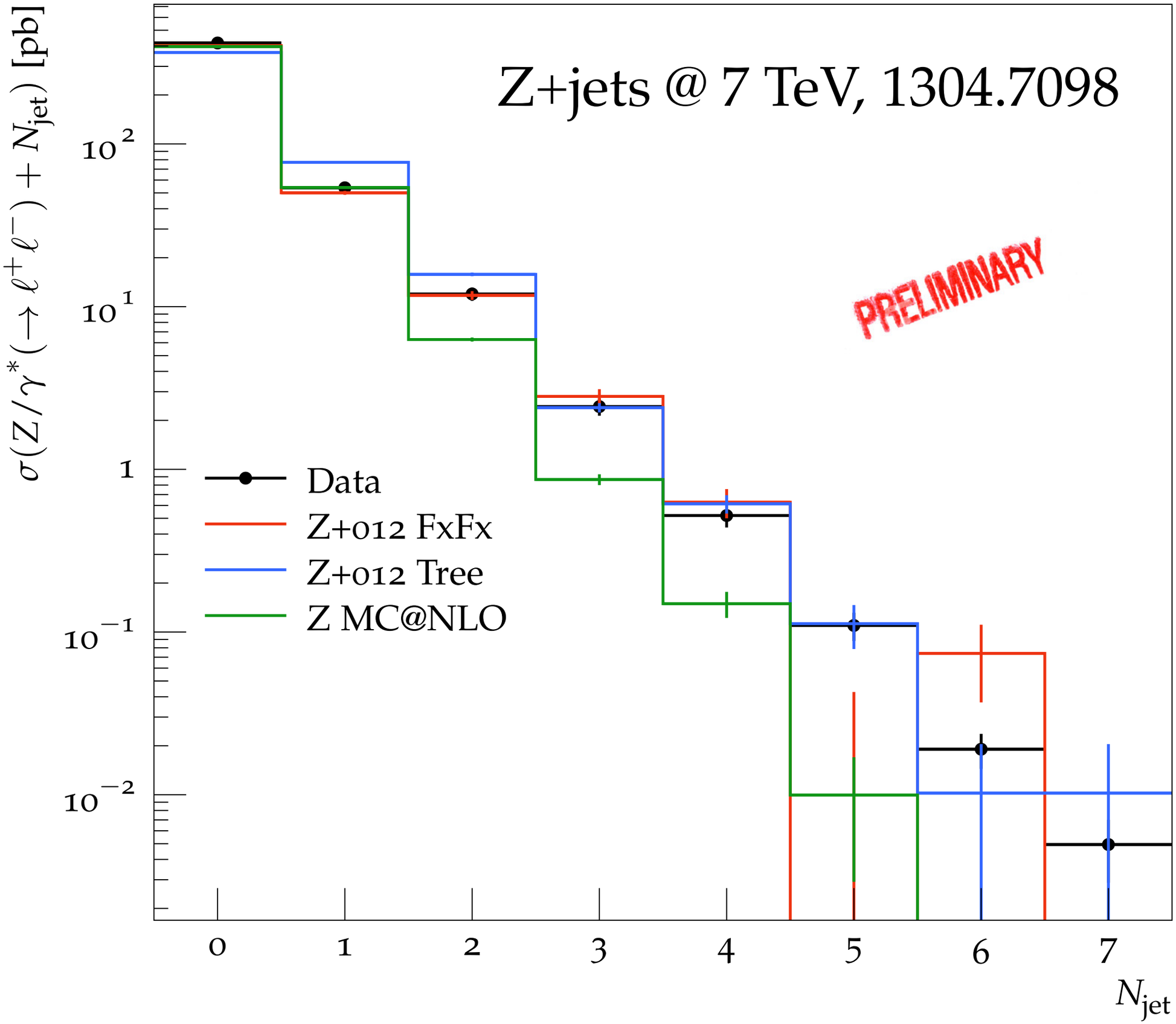
include results for LO multi-jet merging via MLM-type rejection with Herwig 7 for validation.

some comments

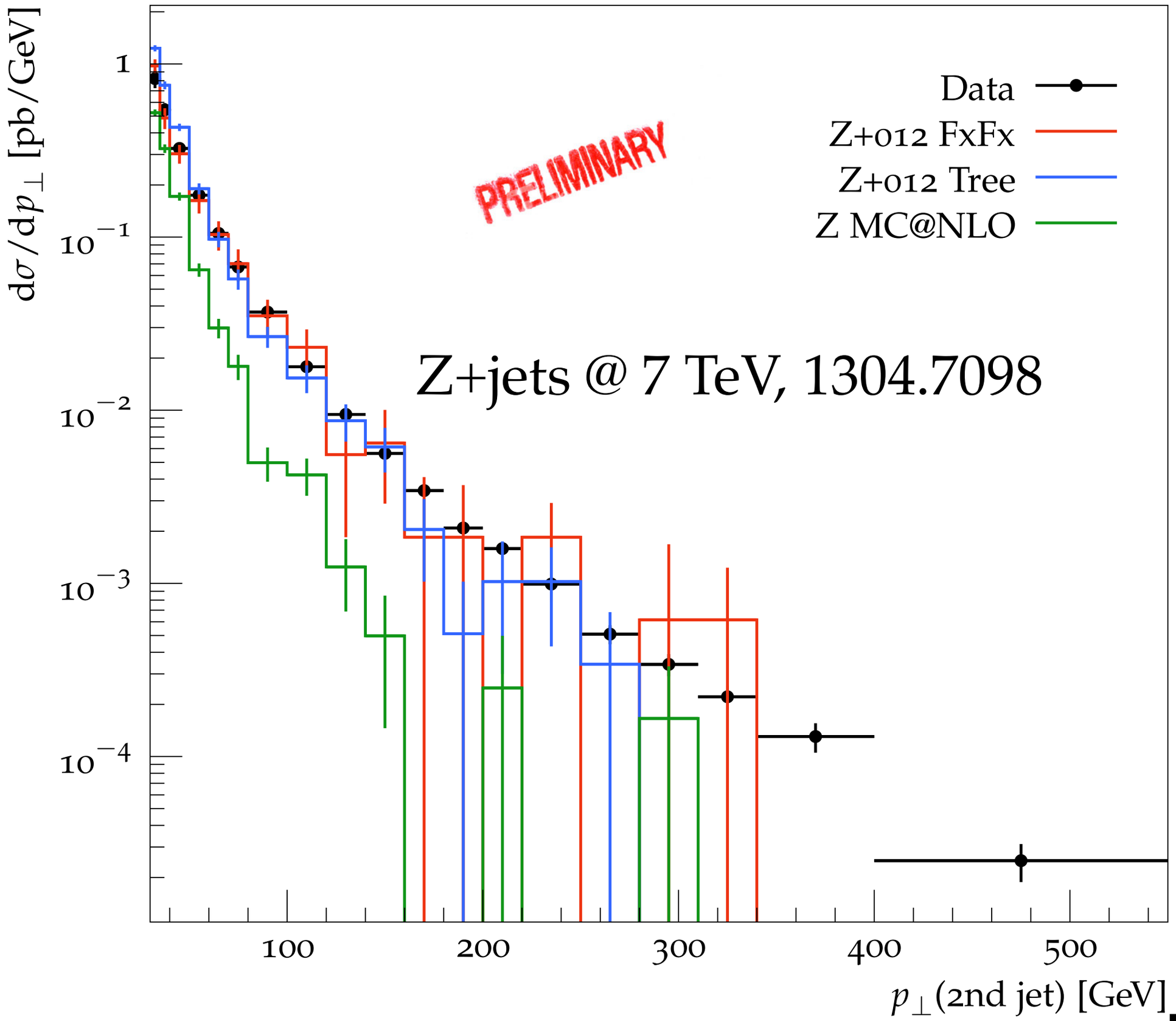
- same ATLAS **Z+jets** analysis as shown earlier (7 TeV, 1304.7098),
- low MC statistics,
- with **merging scale = 25 GeV,**
- includes MC@NLO curve as before.
- total cross sections after merging/matching:

sample	σ(7 TeV) [nb]
tree-level (0+1+2)	2.047(6)
FxFx (0+1+2)	2.04(2)
MC@NLO incl.	2.014(2)

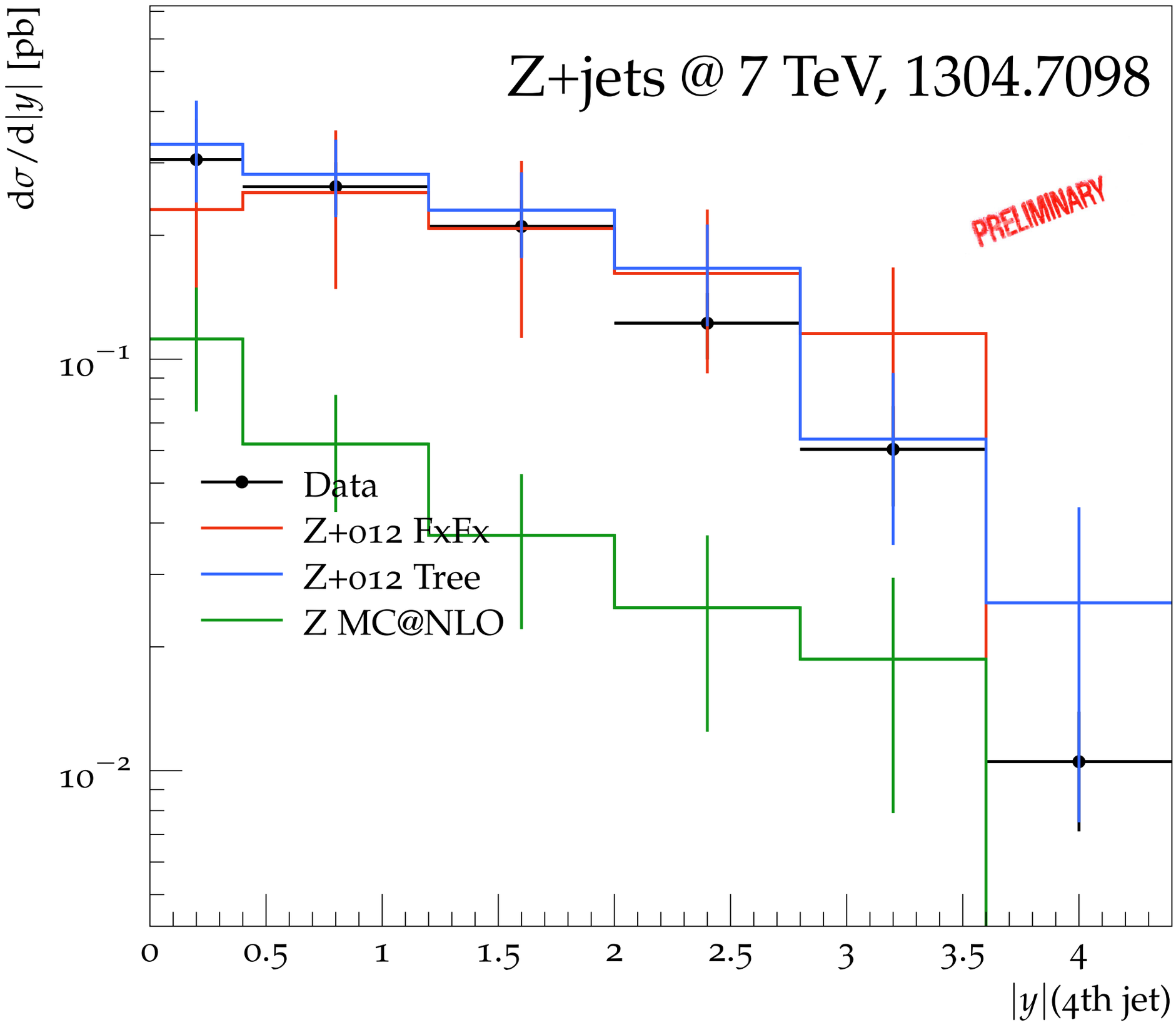
Exclusive jet multiplicity

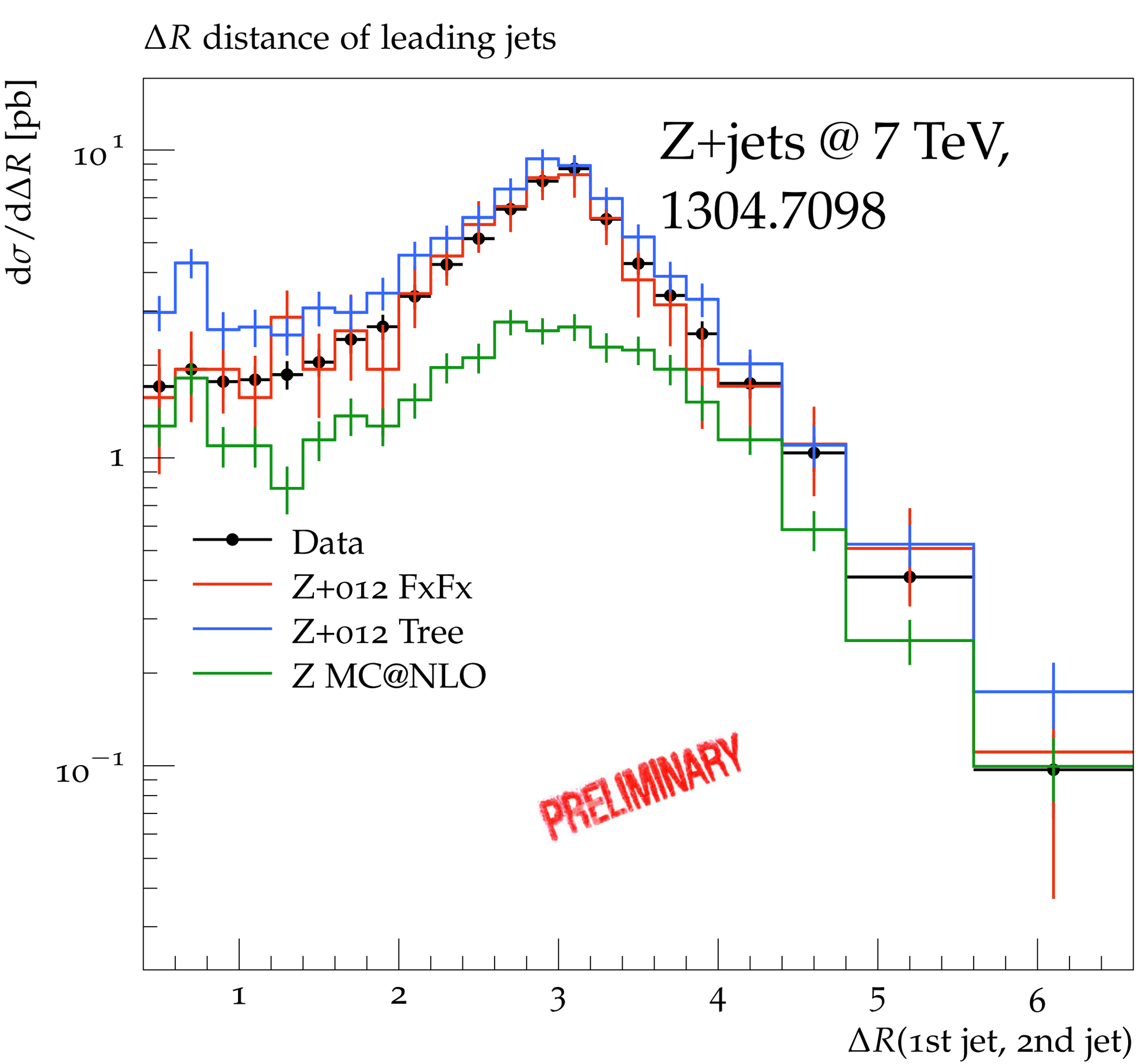


Transverse momentum of 2nd jet



Rapidity of 4th jet




ΔR distance of leading jets
dσ/dΔR [pb]
Z+jets @ 7 TeV,
1304.7098
Data
Z+012 FxFx
Z+012 Tree
Z MC@NLO
PRELIMINARY
ΔR(1st jet, 2nd jet)

technical aspects

- **LO and FxFx merging contained in a single library add-on to Herwig 7: "ExternMerge".**

  - **currently available at:**

https://bitbucket.org/andreasp/externmerge

- **straightforward to compile,**

- **use via standard-type Heriwg 7 input files.**

technical aspects

- **ExternMerge** handles MG5_aMC MLM and FxFx merging.

- [as well as AlpGen (this part: with K. Hamilton).]

- **MG5_aMC LO merging:** uses Les Houches file information on which partons to include in the merging.

- **FxFx:** detects heavy resonances (e.g. Z/W/H/top) and excludes their decay products from merging procedure (special treatment for ***b***s from tops available).

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:**

  - **automate the MG5_aMC interface with Herwig 7,**

  - **complement NLO merging with higher multiplicities.**

  - **further validation: examine top-anti-top/Higgs + comparison to 13 TeV data.**

thanks!

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