

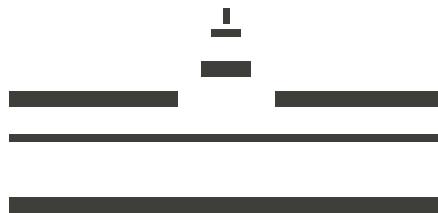
Hadronic W decays in off-shell $t\bar{t}$ production

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based on: [TJ, Nason '15], [TJ, Lindert, Nason, Oleari, Pozzorini '16],
[Ferrario Ravasio, TJ, Nason, Oleari '18], [Ferrario Ravasio, TJ, Nason,
Oleari '19], [Herwig, TJ, Nachman '19], [Ferrario Ravasio, TJ '21], [TJ,
Lindert, Pozzorini 'XY]



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MÜNSTER

Hadronic W decays in off-shell $t\bar{t}$ production

- Motivations:
 - ▶ Why top quark? Because it's a versatile probe of the SM and a window to NP.
 - ▷ a.) Coloured object that b.) decays electroweakly and c.) couples strongly to the Higgs boson
 - ▶ Why top quark at LHC? Because “several hundred million tops produced” ...
 - ▷ ...implies theory will soon lag behind the experiment.
 - ▷ ...means it is major background in many other LHC analyses.

Precise simulation of top quark production and decay at LHC imperative!

Correspondingly we have: NLO QCD, NNLO QCD, NLO EW, NNLO QCD+NLO EW, analytic resummations, NLO QCD+PS and NNLO QCD+PS

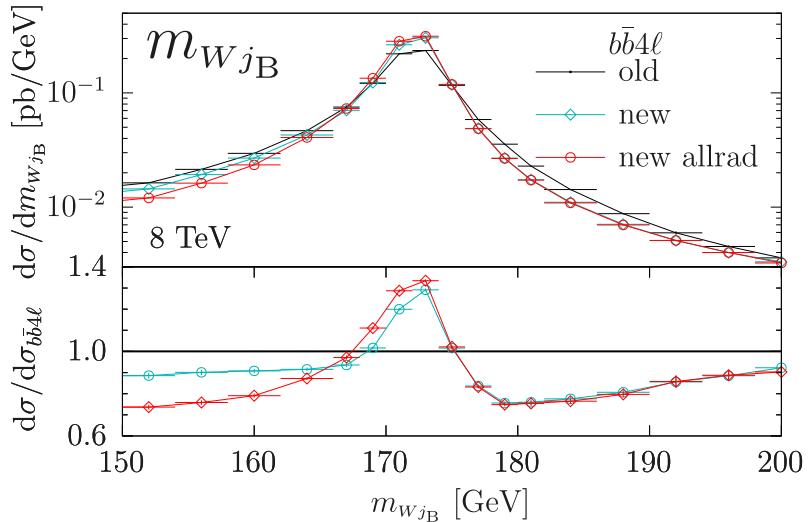
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 - ▷ ...implies theory will soon lag behind the experiment.
 - ▷ ...means it is major background in many other LHC analyses.
 - ▶ But do we also need off-shell effects?
 - ▷ They modify shapes of spectra used for measurements of top properties,
 - ▷ and allow the inclusion of quantum interferences between different production modes and radiation from production and decay

There is: NLO QCD, NLO EW and NLO QCD+PS in the dileptonic channel

Off-shell effects in $t\bar{t}$: bb41

- Off-shell effects distort the top mass shape and other distributions

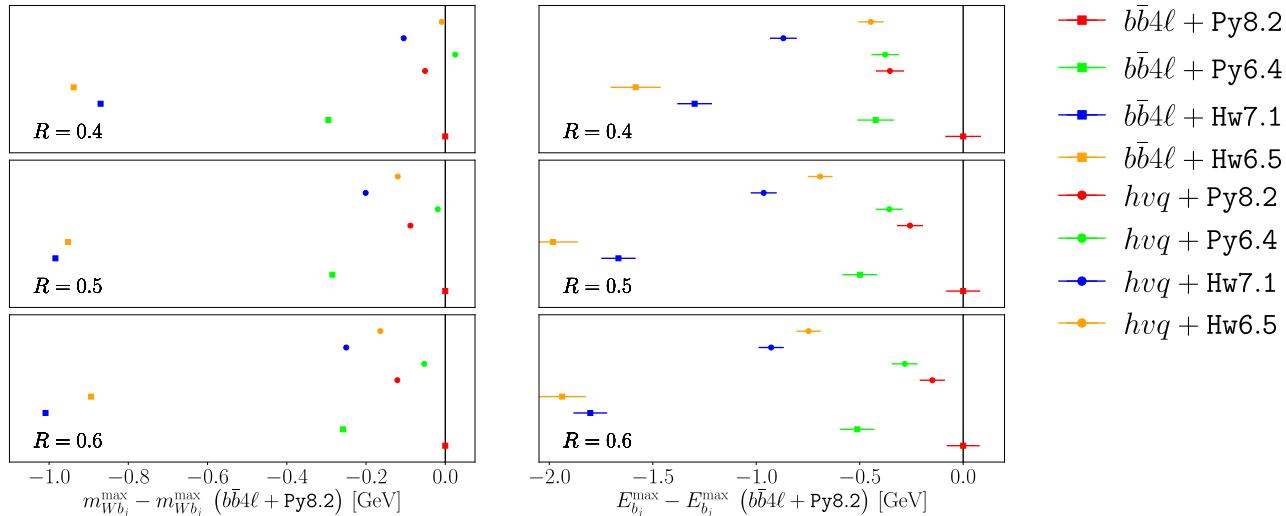


[TJ, Nason '15],
[TJ, Lindert, Nason,
Oleari, Pozzorini '16]

- ▶ Potentially affecting m_t and y_t measurements
- Proper treatment of interference required
 - ▶ To describe the data
 - ▶ And if you have it, you can try measuring Γ_t in tails

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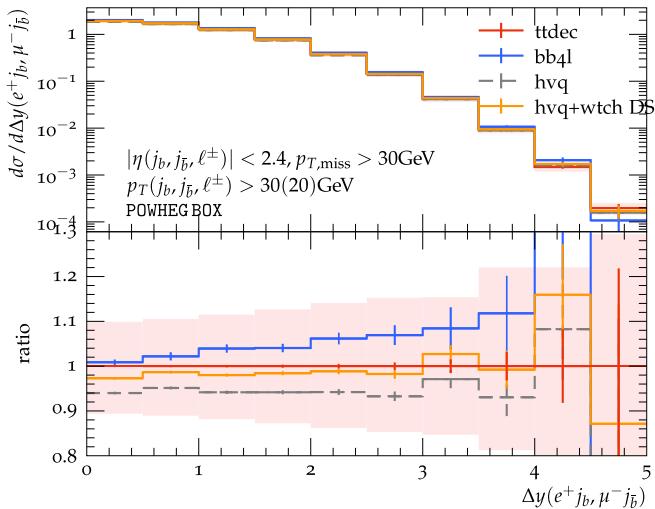


[Ferrario Ravasio,
TJ, Nason,
Oleari '18, '19],
[ATL-PHYS-PUB
-2021-042]

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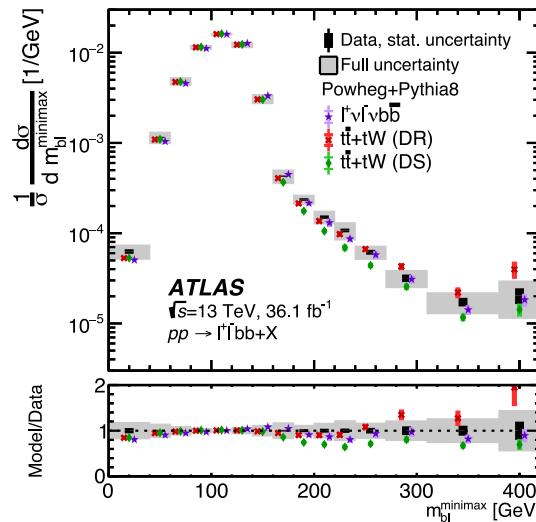


[Ferrario Ravasio, TJ '21]

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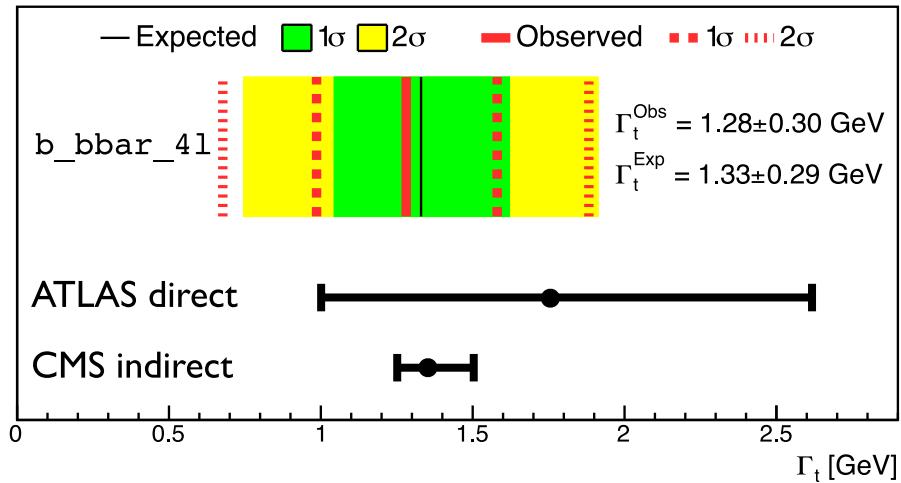


[PRL 121, 152002]

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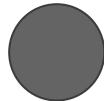


[Herwig, TJ, Nachman '19]

Semileptonic $t\bar{t}$

- Consider the signature $pp \rightarrow \ell^\pm \nu jj b\bar{b}$ at LO

$$\alpha_S^4 \alpha^2$$

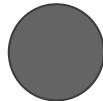


$V+HF$

$$\alpha_S^3 \alpha^3$$



$$\alpha_S^2 \alpha^4$$



$t\bar{t}$

$$\alpha_S \alpha^5$$



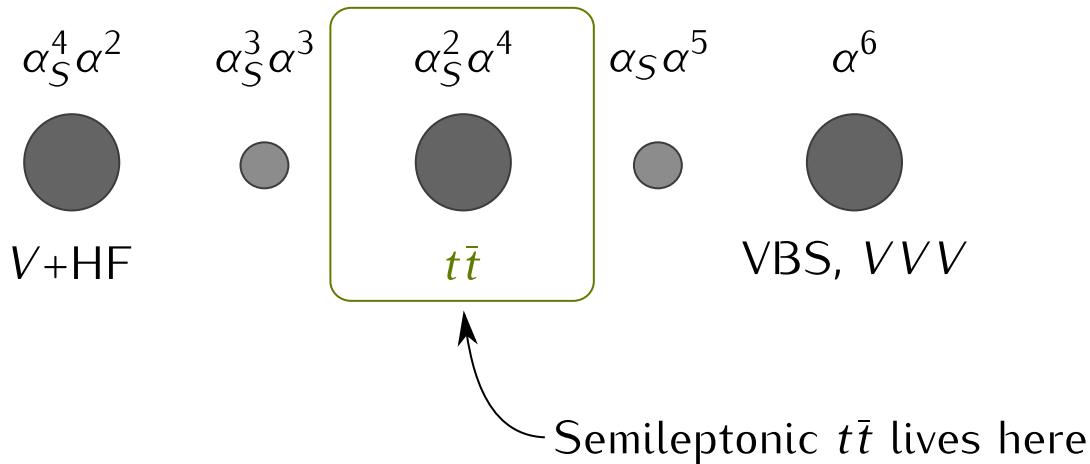
$$\alpha^6$$



VBS, VVV

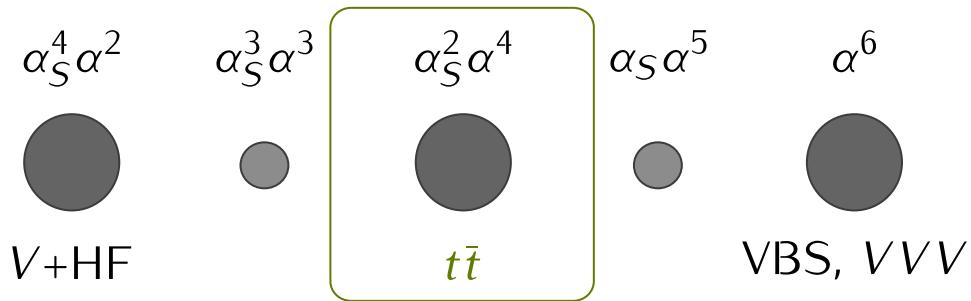
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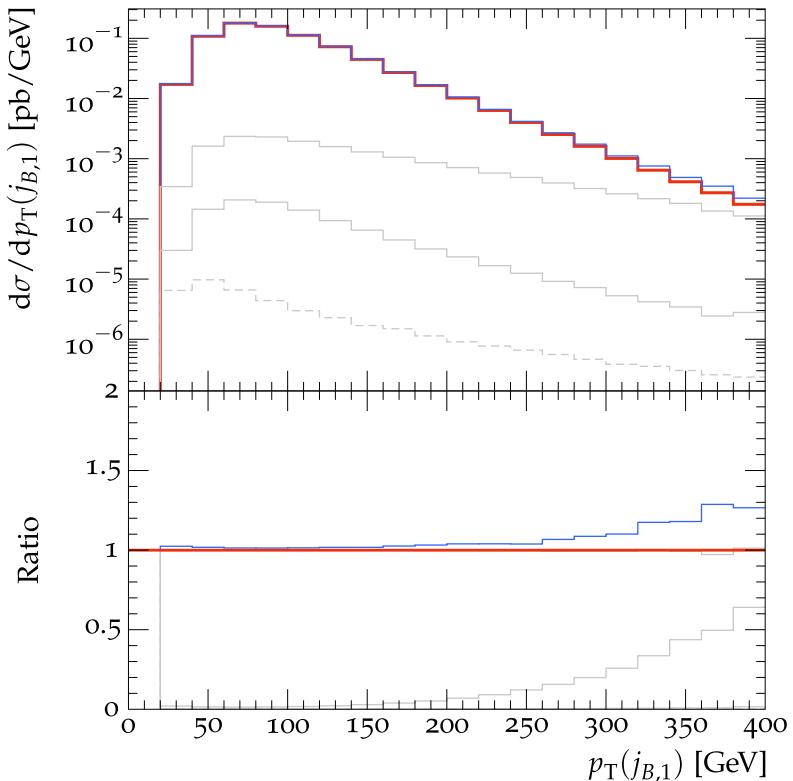
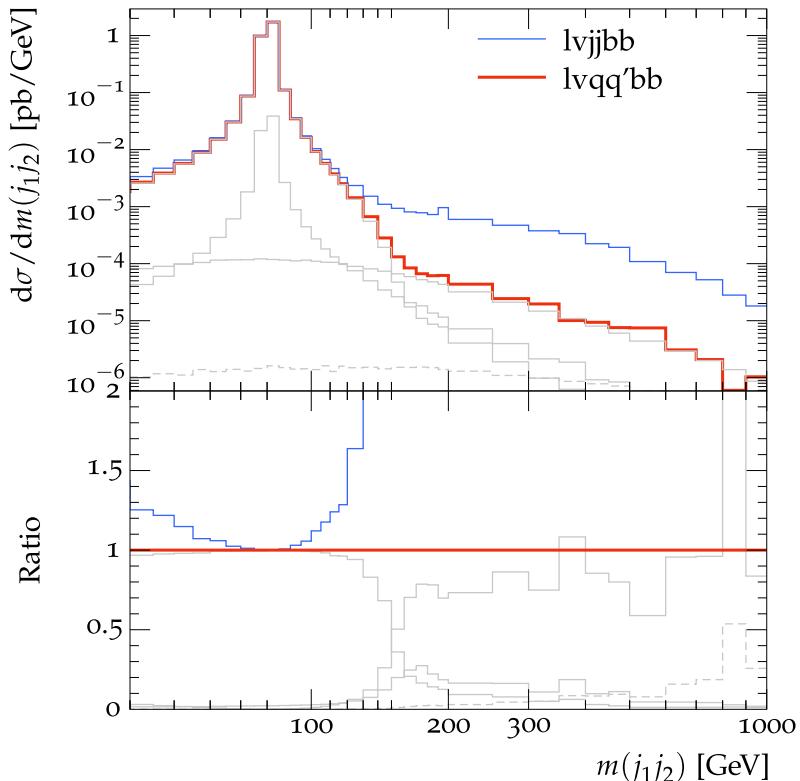
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- Dominant contribution: semileptonic $t\bar{t}$ (with tops and W s on-shell)
 - $pp \rightarrow \ell^\pm \nu q\bar{q}' b\bar{b}$ with $q\bar{q}' = \{u\bar{d}, c\bar{s}\}$ or $q\bar{q}' = \{d\bar{u}, s\bar{c}\}$
 - Also includes: tW , t - and s -channel $t+jets$, VBF- $W+jets$

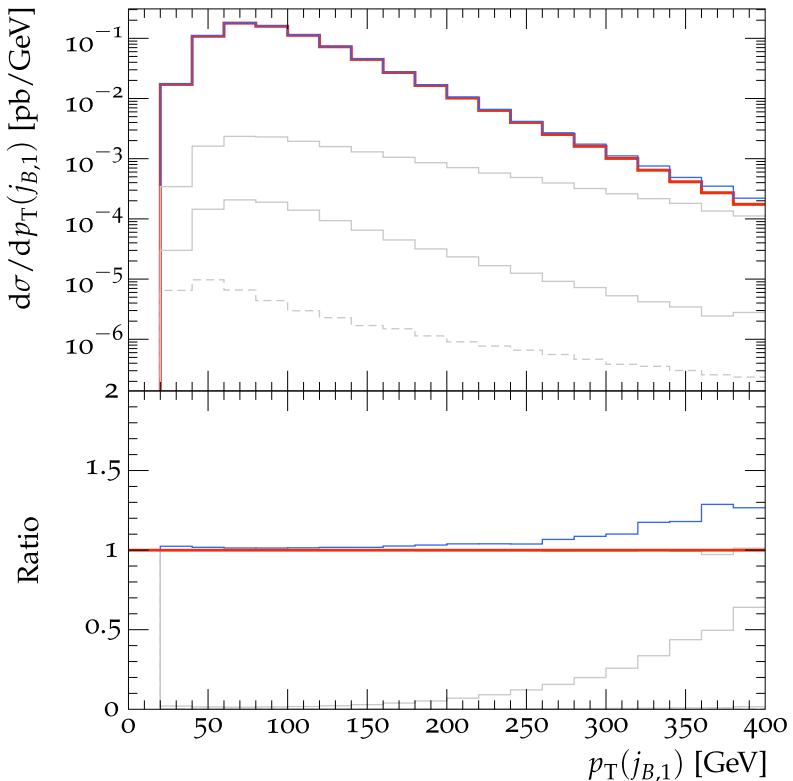
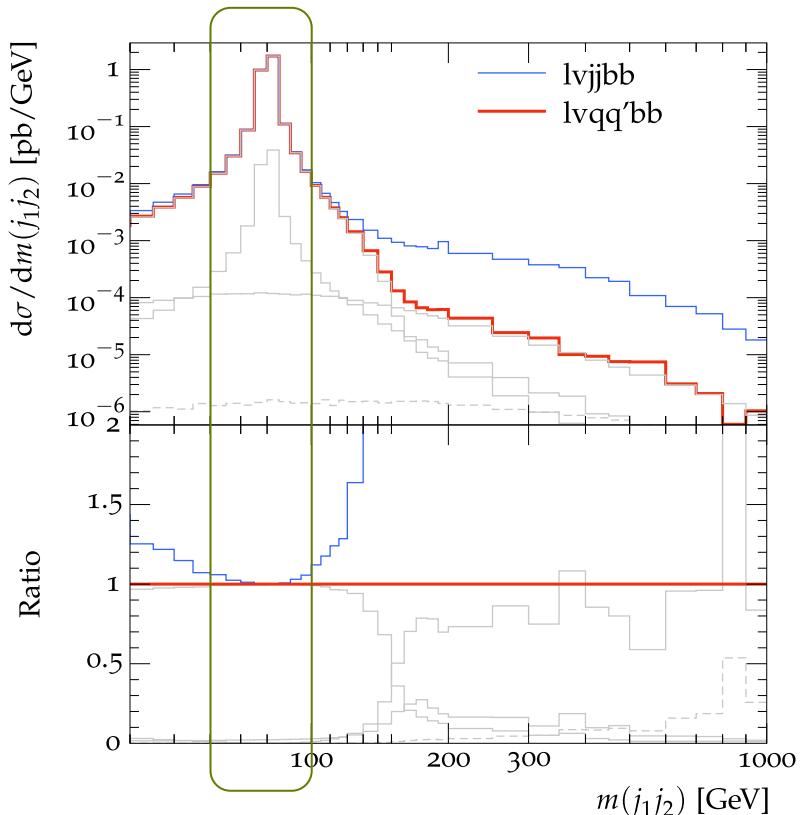
Semileptonic $t\bar{t}$

- leading order, 13 TeV LHC, results from Sherpa/OpenLoops



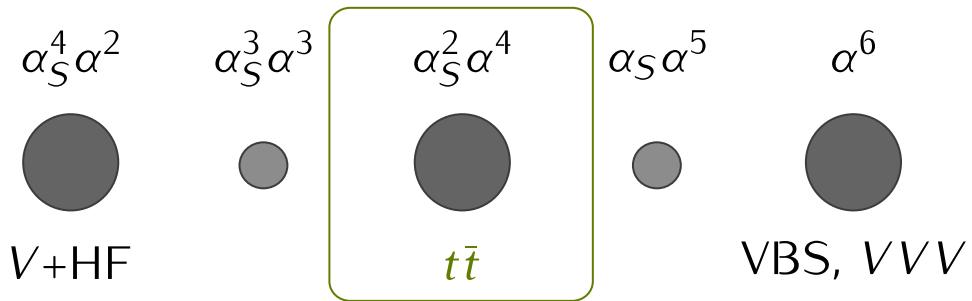
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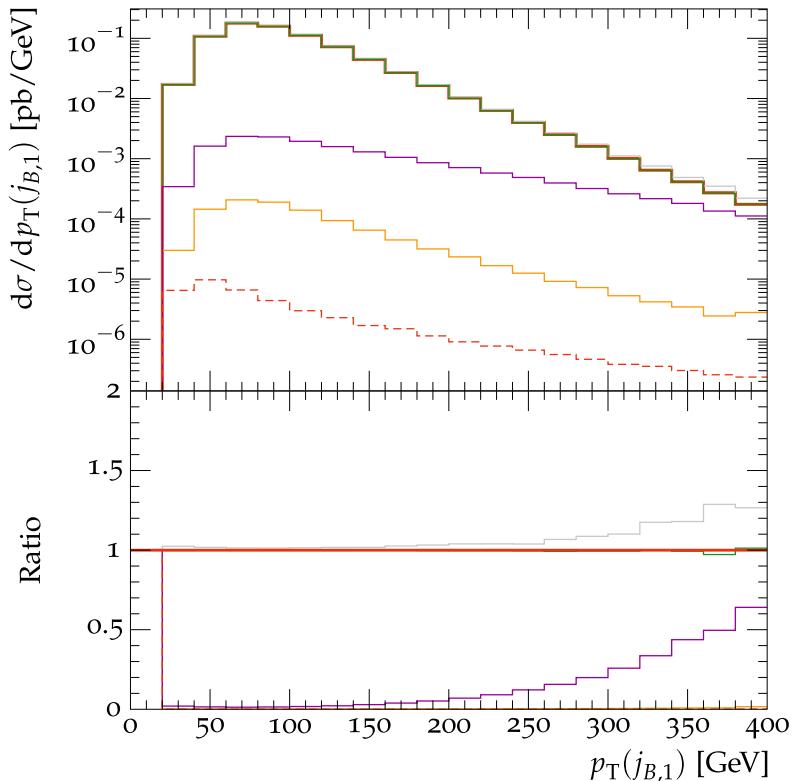
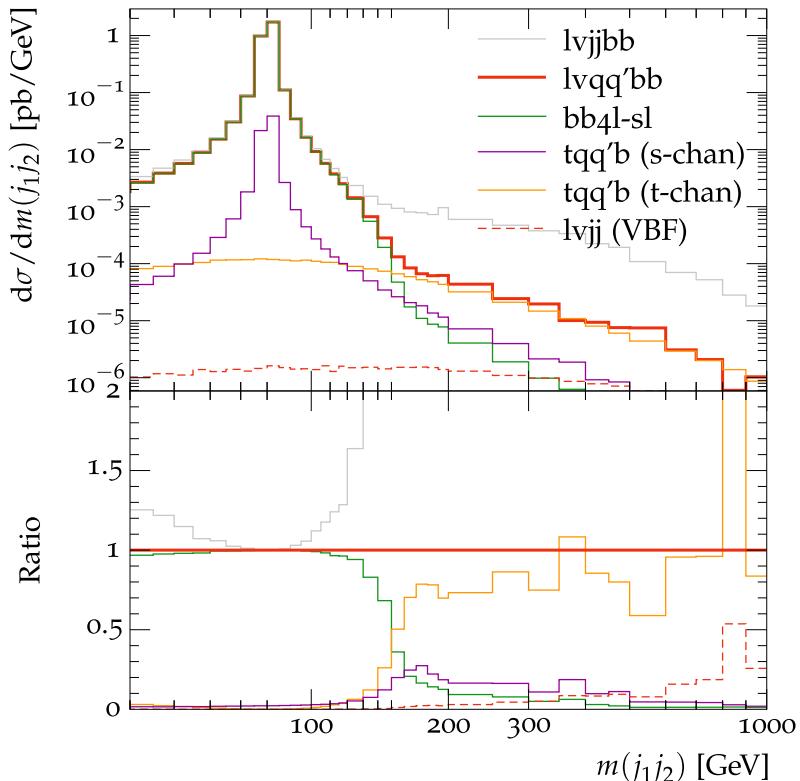
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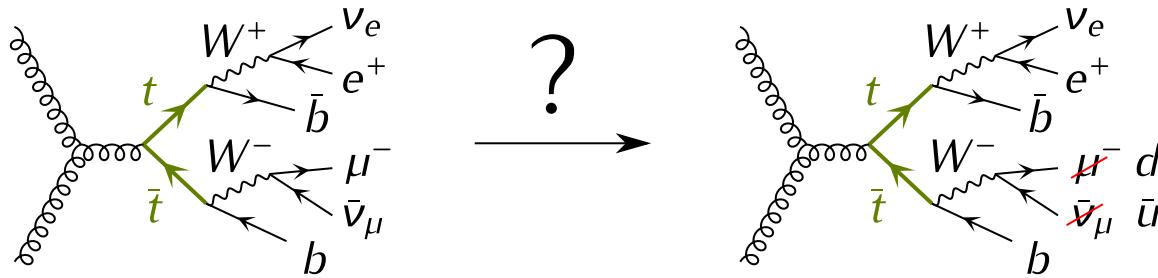
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Semileptonic $t\bar{t}$ from dileptonic $t\bar{t}$?

- Semileptonic channel: **eight legs, six coloured** = very high complexity at NLO QCD
- Leptonic ($pp \rightarrow \ell^\pm \nu_\ell l^\mp \nu_l b\bar{b}$) vs. semileptonic ($pp \rightarrow \ell^\pm \nu_\ell q\bar{q}' b\bar{b}$)

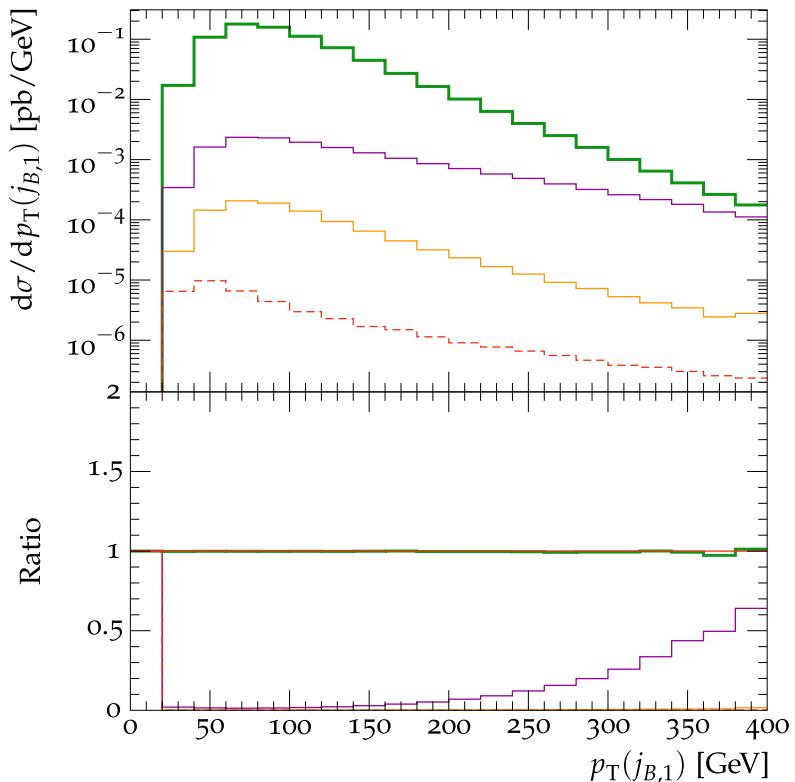
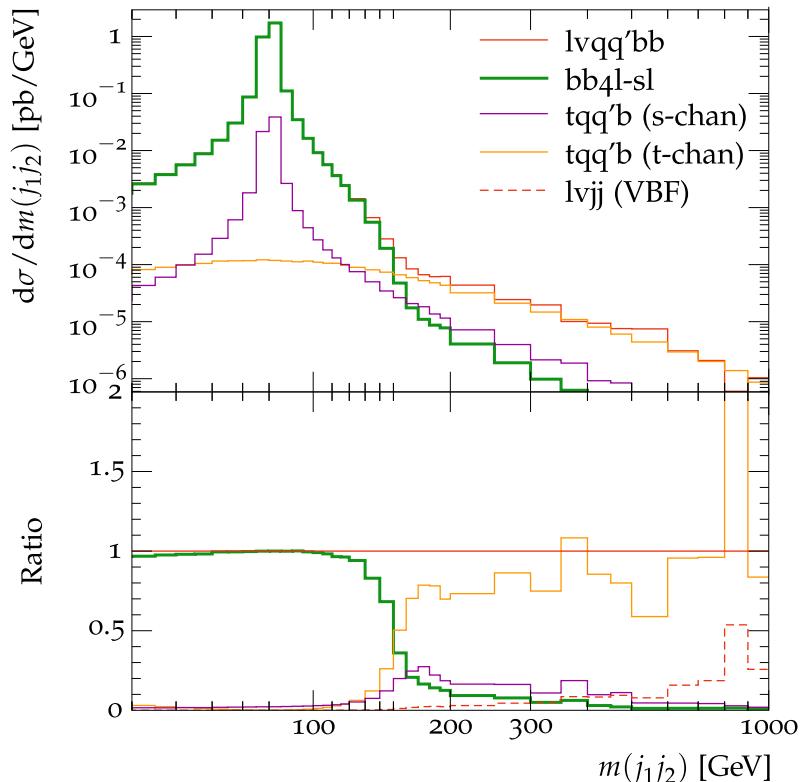


$$d\sigma("bb4l - sl") = d\sigma(bb4l) \frac{BR(SL)}{BR(DL)}$$

- Only leptonic topologies in semileptonic channel \equiv dropping some off-shell effects
 - ▶ tW and the $t\bar{t} - tW$ interference is still included, but not $t+jets$

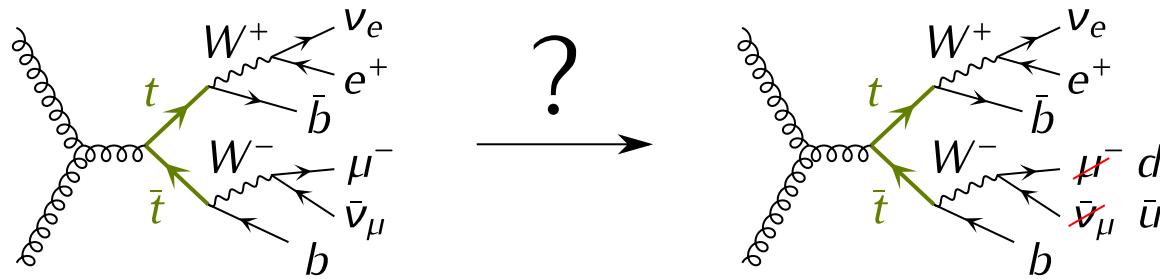
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- Semileptonic $t\bar{t}$ NLO+PS predictions from bb4l:
 - ▶ Read in bb4l LHE files with `allrad`
 - ▶ Relabel W^+ or W^- decay products and attach an emission

$$\begin{aligned} d\sigma = \bar{B}_{\text{bb4l-sl}}(\Phi_B) d\Phi_B \prod_{\alpha=\alpha_b, \alpha_{\bar{b}}, \alpha_{\text{ISR}}} & \left[\Delta_\alpha^{\text{bb4l}}(q_{\text{cut}}) + \Delta_\alpha^{\text{bb4l}}(k_T^\alpha) \frac{R_\alpha^{\text{bb4l}}(\Phi_\alpha(\Phi_B, \Phi_{\text{rad}}^\alpha))}{B^{\text{bb4l}}(\Phi_B)} d\Phi_{\text{rad}}^\alpha \right] \\ & \times \left[\Delta_{\alpha_W}^{pp \rightarrow \ell\nu_l q\bar{q}b\bar{b}}(q_{\text{cut}}) + \Delta_{\alpha_W}^{pp \rightarrow \ell\nu_l q\bar{q}b\bar{b}}(k_T^{\alpha_W}) \frac{R_{\alpha_W}^{pp \rightarrow \ell\nu_l q\bar{q}b\bar{b}}(\Phi_{\alpha_W}(\Phi_B, \Phi_{\text{rad}}^{\alpha_W}))}{B^{pp \rightarrow \ell\nu_l q\bar{q}b\bar{b}}(\Phi_B)} d\Phi_{\text{rad}}^{\alpha_W} \right] \end{aligned}$$

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bb4l-sl

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emission from W^- or W^+

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bb4l-s1

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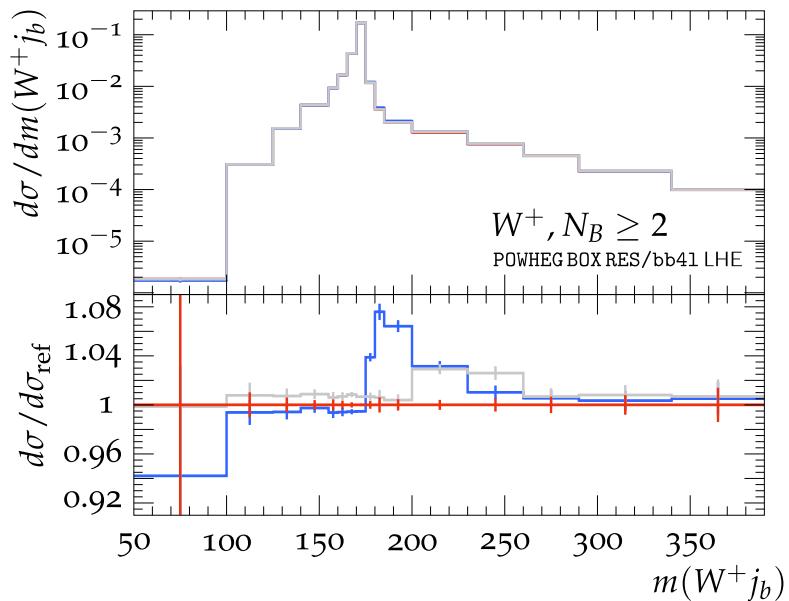
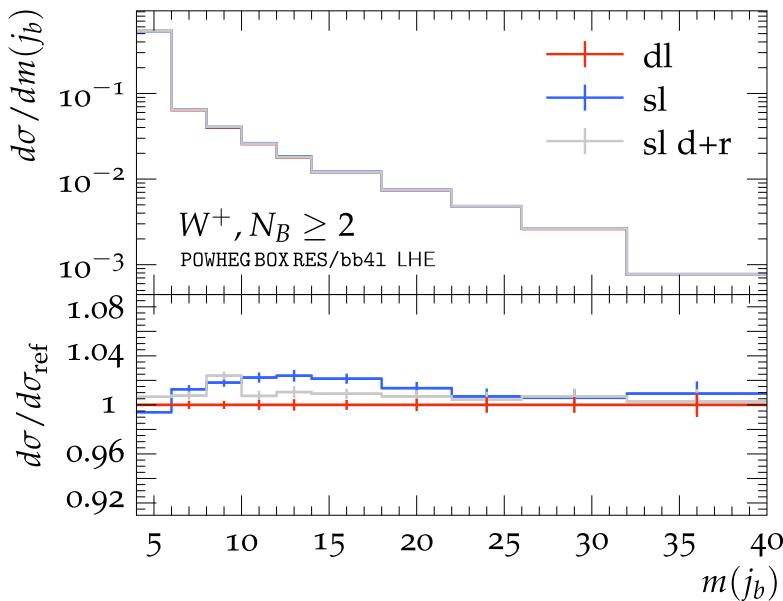
Numerical results

- Our setup:
 - ▶ LHC 13 TeV, NNPDF31_nlo_as_0118, $m_t = 172.5$ GeV, $m_b = 4.75$ GeV
 - ▶ $hdamp = m_t$, $\mu_r = \mu_f = m_t^\dagger$
 - ▶ $R = 0.5$ anti- k_T jets, $p_T > 25$ GeV, $|\eta| < 2.5$
 - ▶ W^+ leptonic, W^- hadronic
 - ▶ Compare bb4l vs bb4l-s1 and for an adequate comparison we need to:
 - ▶ distinguish \bar{u} , d and b , \bar{b} jets (using MC truth partonic content)
 - ▶ require that all tagged top decay products be separated by $\Delta R = 0.5$
 - ▶ construct correctly flavour-matched objects (MC truth)
 - ▶ Employ 2×2 different selection criteria
 - ▶ W^- : $W^- \equiv j_{\bar{u}} + j_d$, W^+ : $W^+ \equiv e^+ + \bar{\nu}_e$
 - ▶ $N_b = 1$, $N_b \leq 2$

[†] not an optimal scale choice, we use it for technical reasons

Numerical results

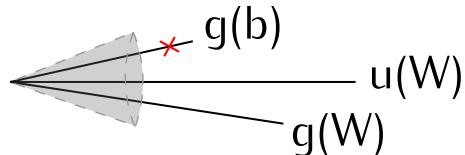
- However, it is not enough to:
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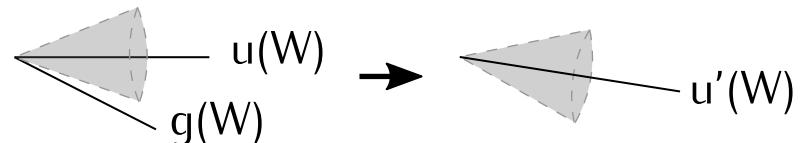
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- We also introduce decontamination and recombination prescriptions:

decontamination = parton removal

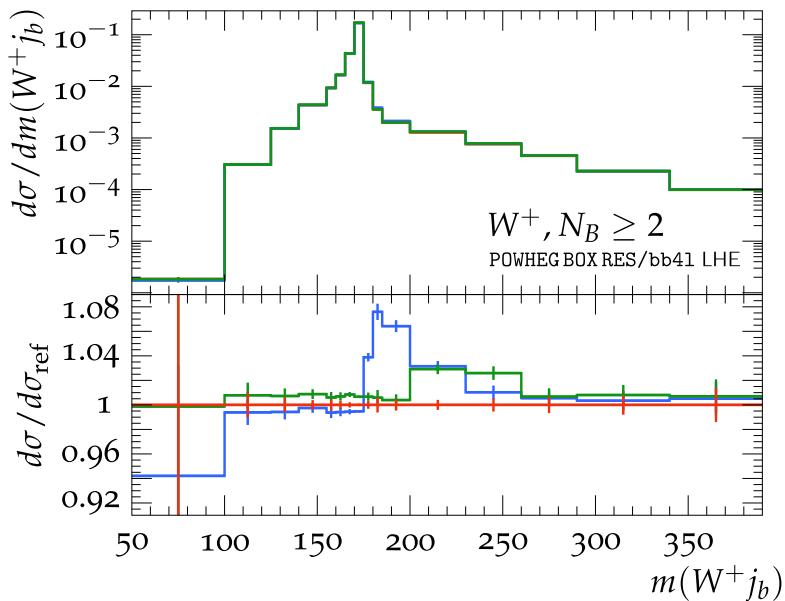
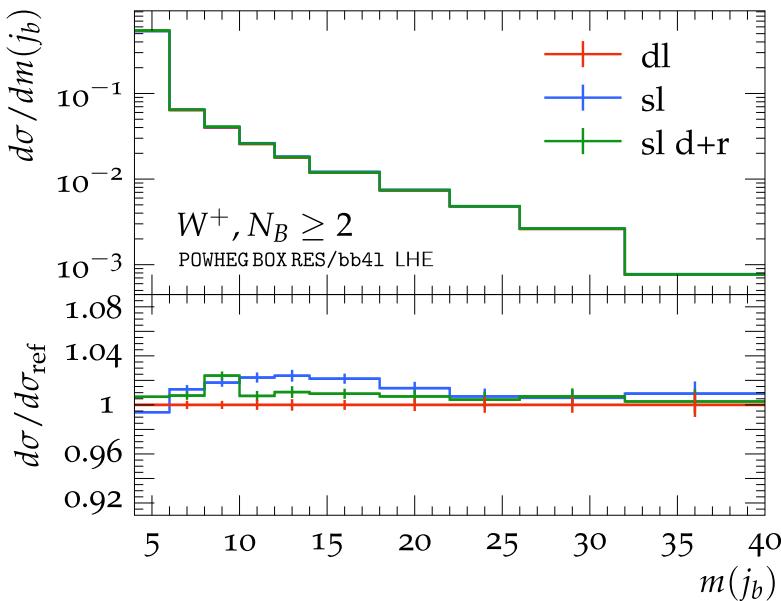


recombination = merging of partons



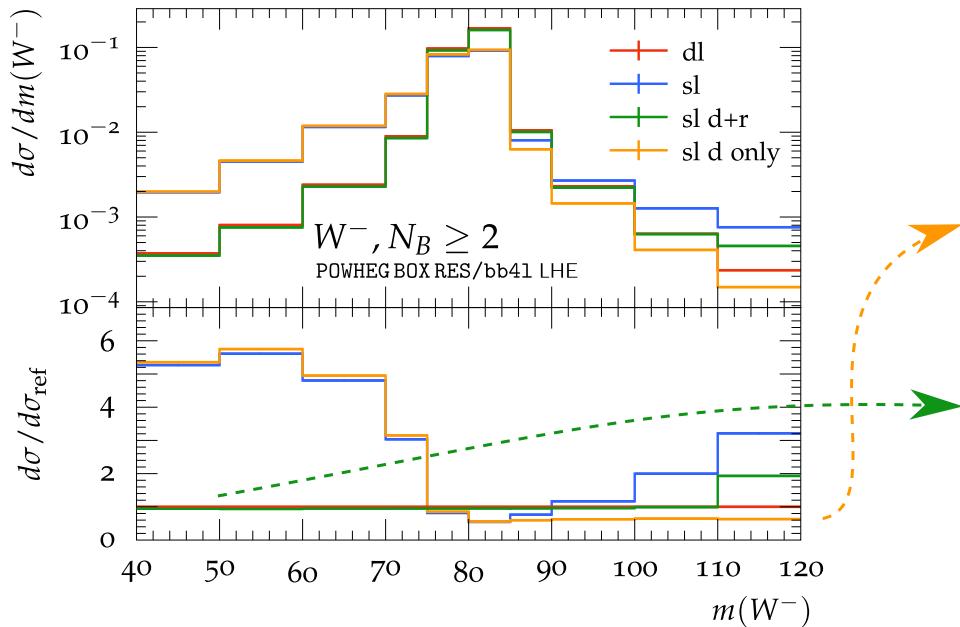
Numerical results

- Legend:
 - **dl**: dileptonic channel; **sl**: semileptonic channel
 - **d only**: only W and b jet decontamination
 - **d+r**: both W and b jet decontamination and recombination



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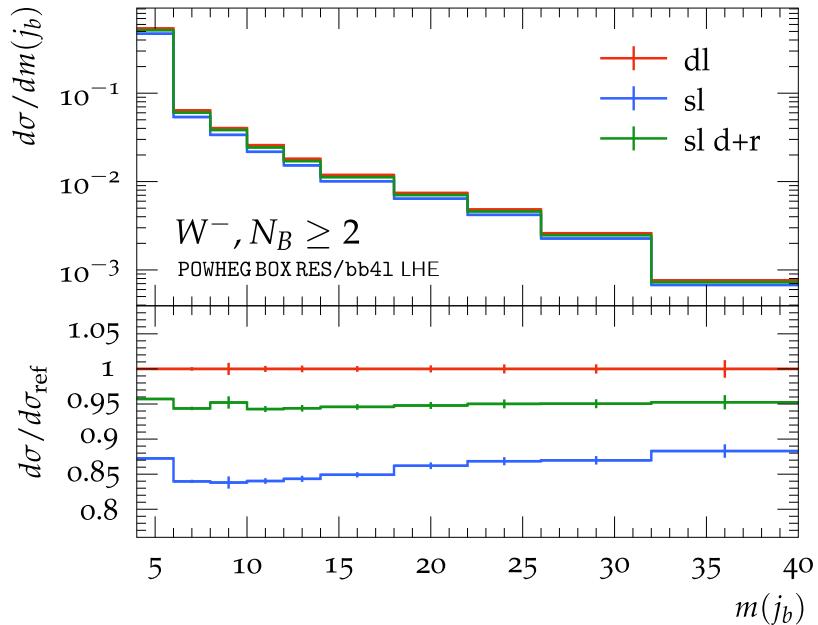
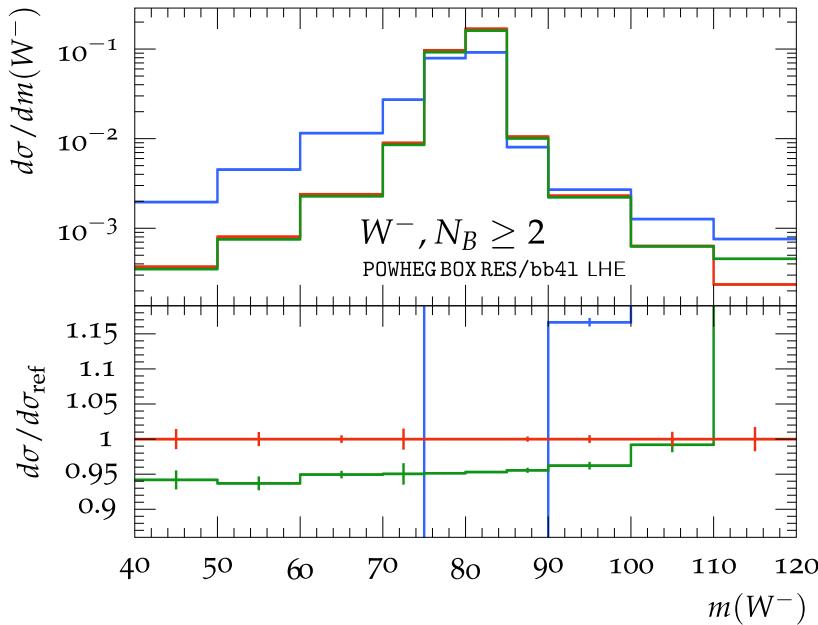


decontamination helps above
the peak

recombination below it

Numerical results

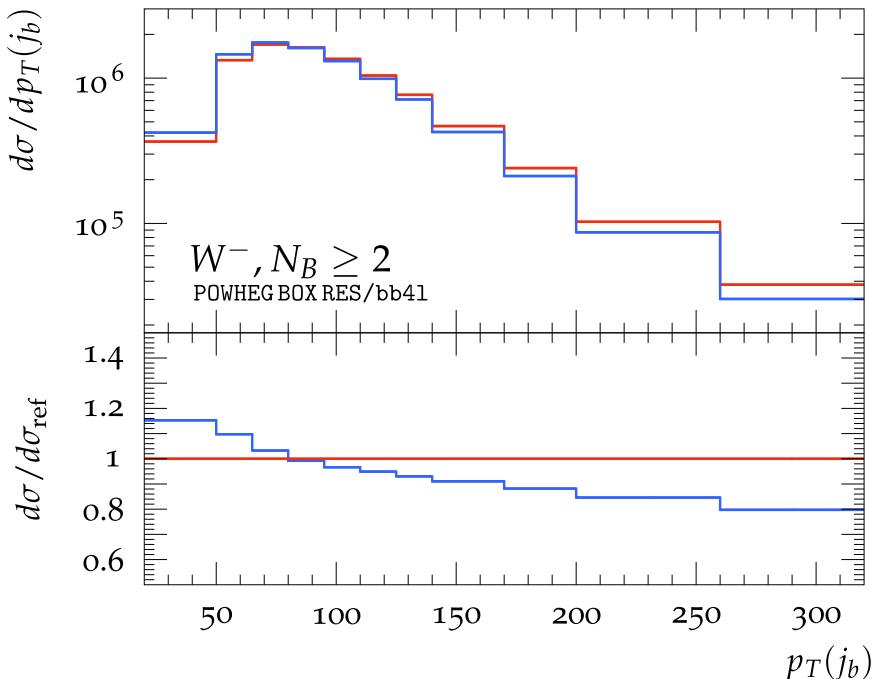
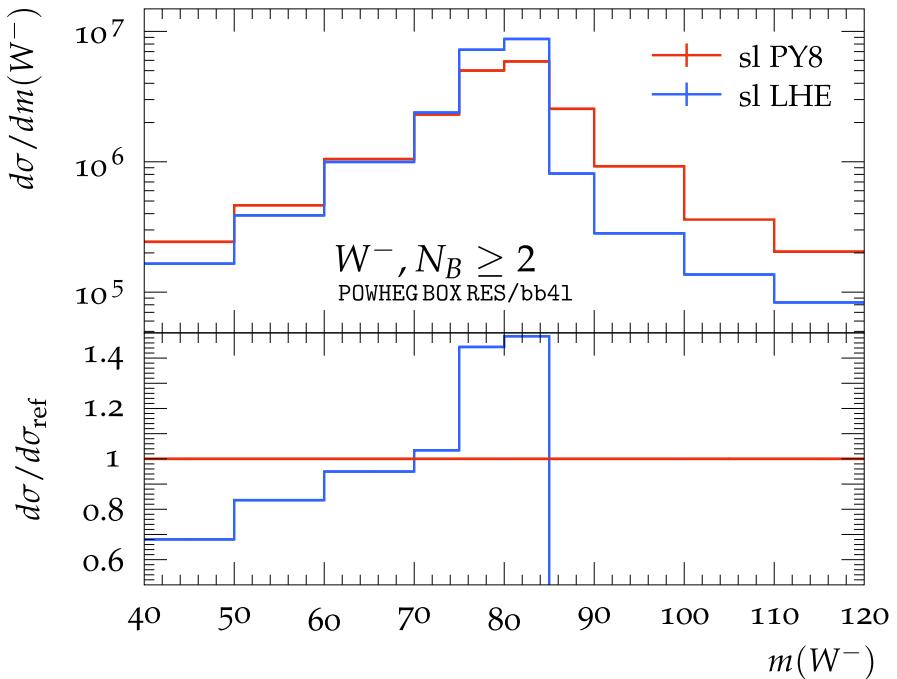
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Numerical results

- Shower effects:

- ▶ bb4l-sl+Pythia8.2 (with PowhegHooks and PowhegHooksBB4L-SL)



Summary and outlook

- Top quark plays a prominent role in the LHC physics program
- Experimental precision now sufficient to resolve off-shell effects in $t\bar{t}$ production
- **Leptonic channel:** available for a long time in bb4l
- **Semileptonic channel**
 - ▶ Now implemented in an approximation as a plugin to bb4l, publicaly available soon.
 - ▶ Still TODO: We're finalizing comparisons against hvq.
- Other developments:
 - ▶ Matching uncertainties due to the choice of resonance history projectors
- **Hadronic channel?**
 - ▶ The algorithm in bb4l-s1 can redecay both W s, but we still need to check whether this approximation is suitable