NLO+PS matching for loop-induced processes in SHERPA

Presented by
Simon Luca Villani

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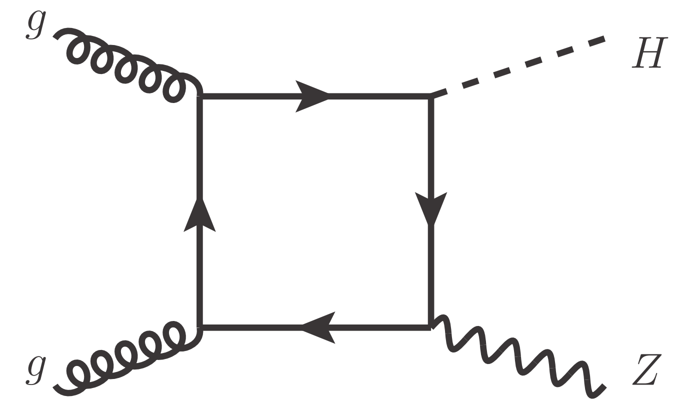
Internet
MCnet Meeting

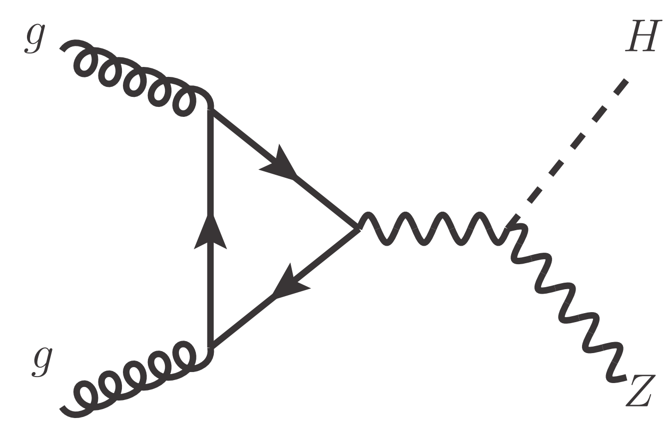
Introduction

- Loop-induced processes feature first non-trivial contribution at loop-level only

$gg \to ZH$ process:



Formally NNLO



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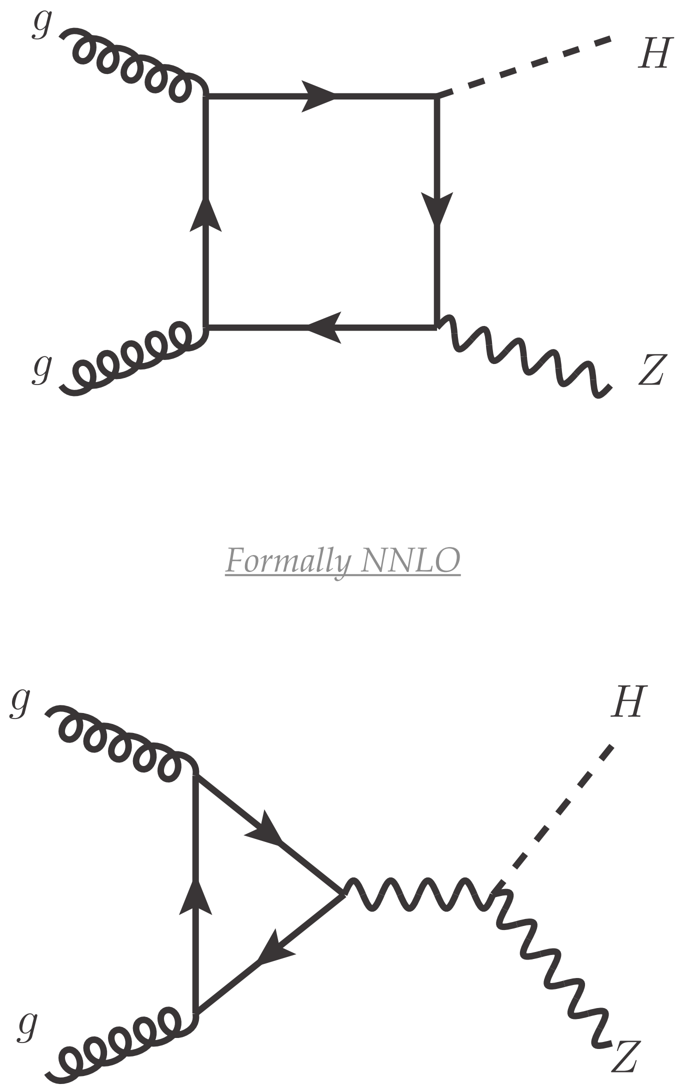

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Peculiarities:

- Ren/fac uncertainty rather big
- NLO very challenging due to the presence of massive multi-scale double box integrals
- Sensitive to theory parameters variation

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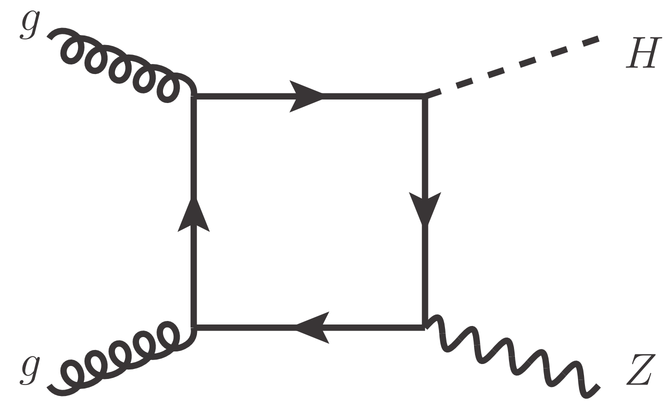

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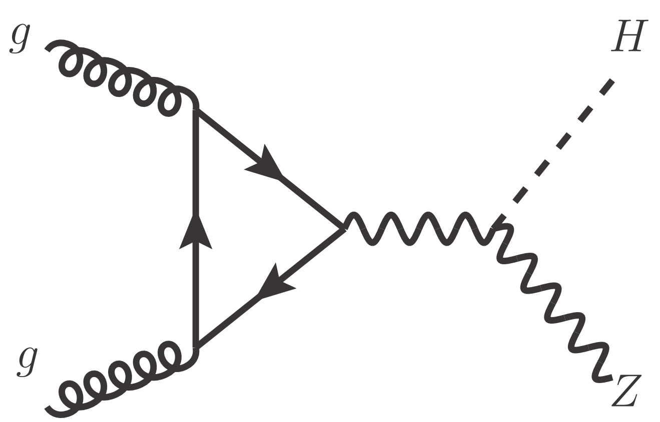

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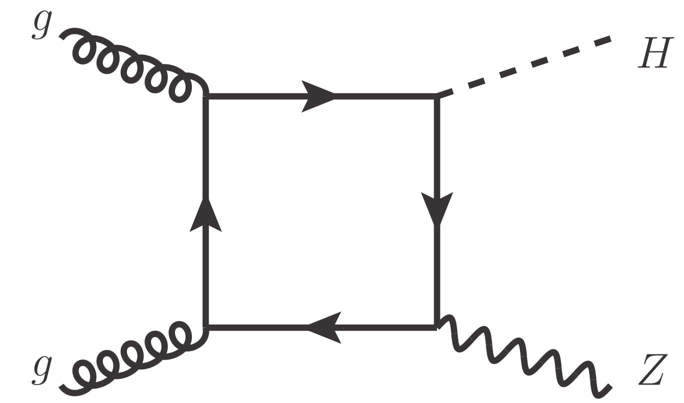

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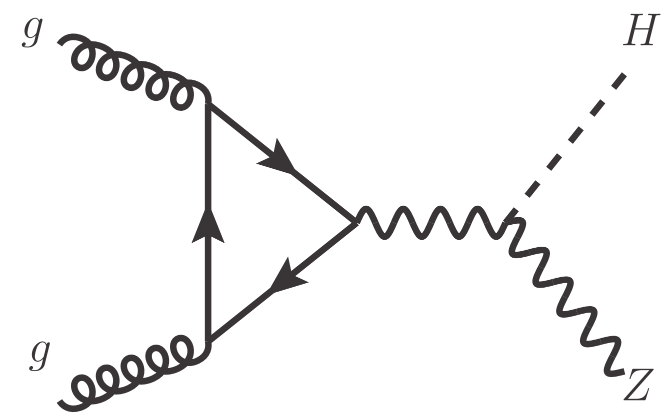

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↓

Particularly suitable for BSM studies and SM precision studies

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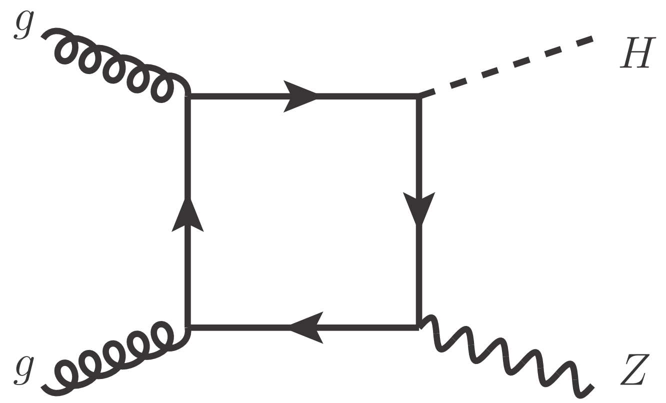

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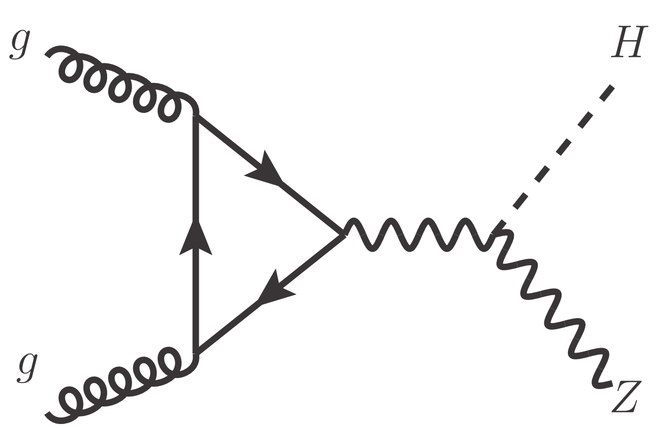

Introduction: impact on a full simulation

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$gg \to ZZ$ case:

[Grazzini, M. et al: JHEP03(2019)070]

$\sqrt{s}$	8 TeV	13 TeV	8 TeV	13 TeV
	σ [fb]		$\sigma/\sigma_{\mathrm{NLO}} - 1$	
LO	$8.1881(8)^{+2.4\%}_{-3.2\%}$	$13.933(1)^{+5.5\%}_{-6.4\%}$	-27.5%	-29.8%
NLO	$11.2958(4)^{+2.5\%}_{-2.0\%}$	$19.8454(7)^{+2.5\%}_{-2.1\%}$	0%	0%
$q\bar{q}$NNLO	$12.09(2)^{+1.1\%}_{-1.1\%}$	$21.54(2)^{+1.1\%}_{-1.2\%}$	$+7.0\%$	$+8.6\%$
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[Astill, W. et al.: 1804.08141]

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~11%

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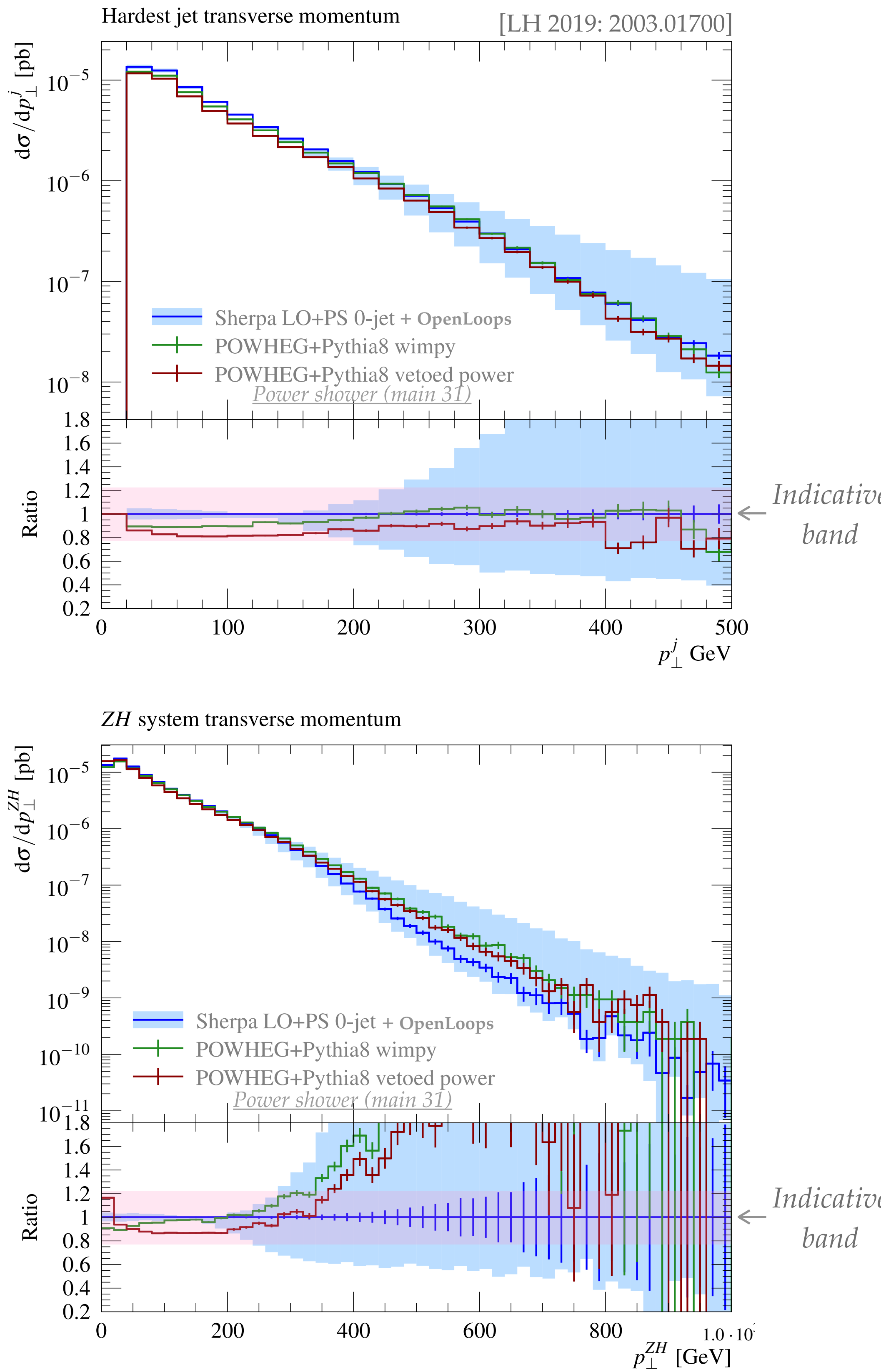

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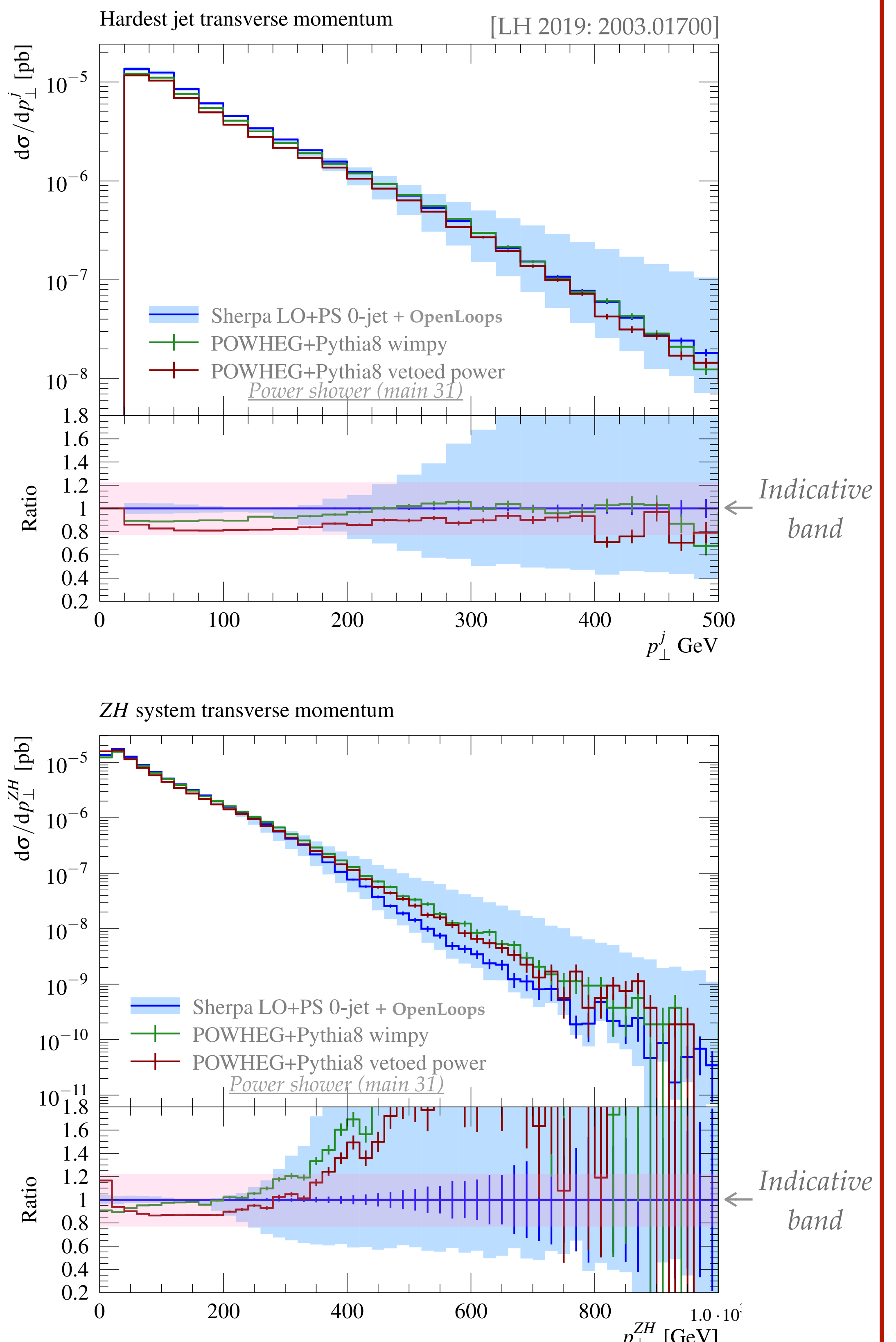

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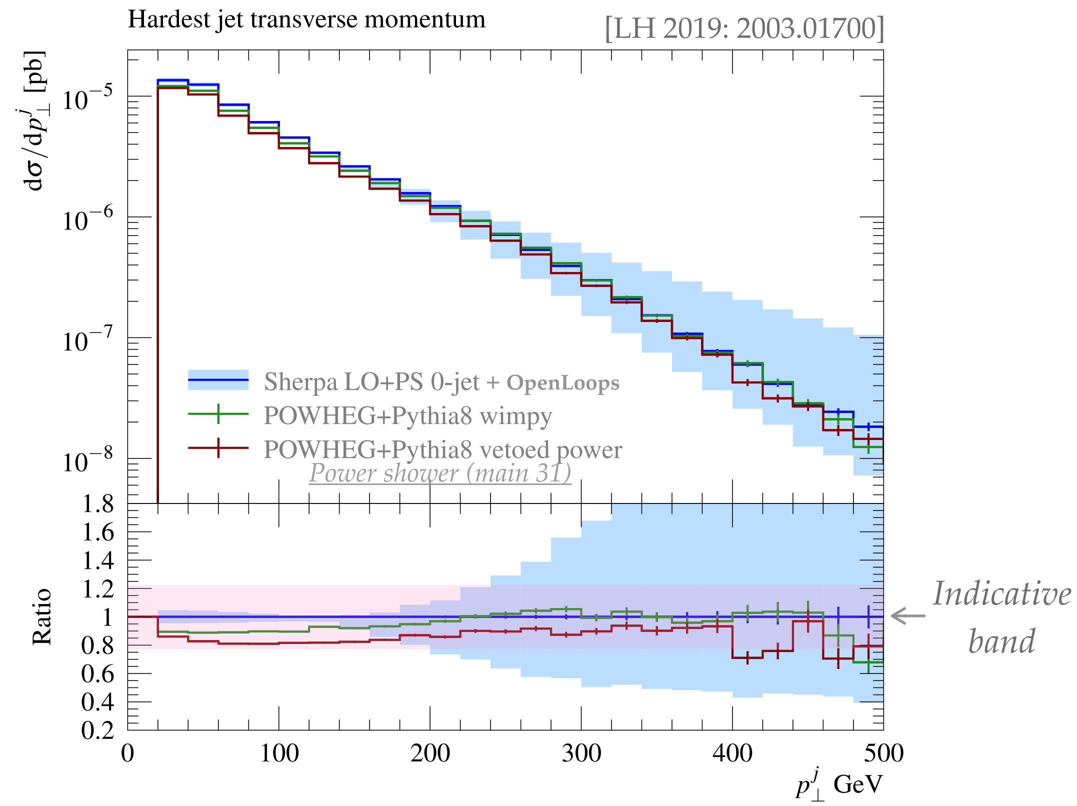

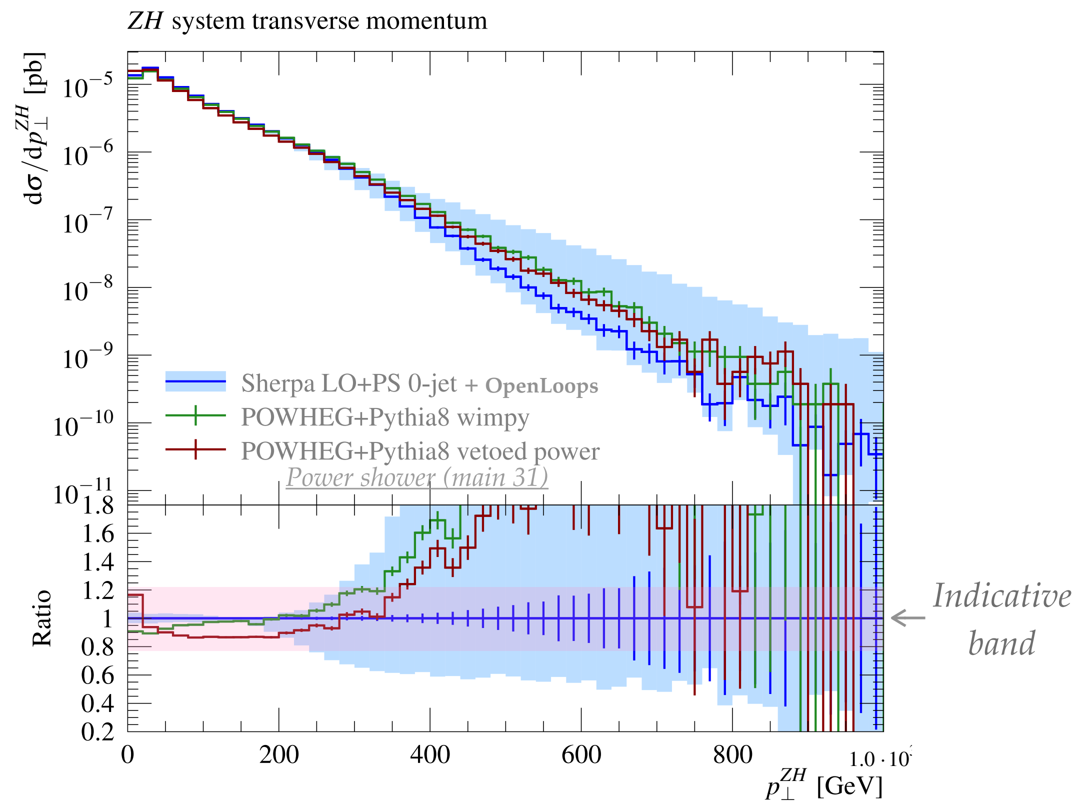

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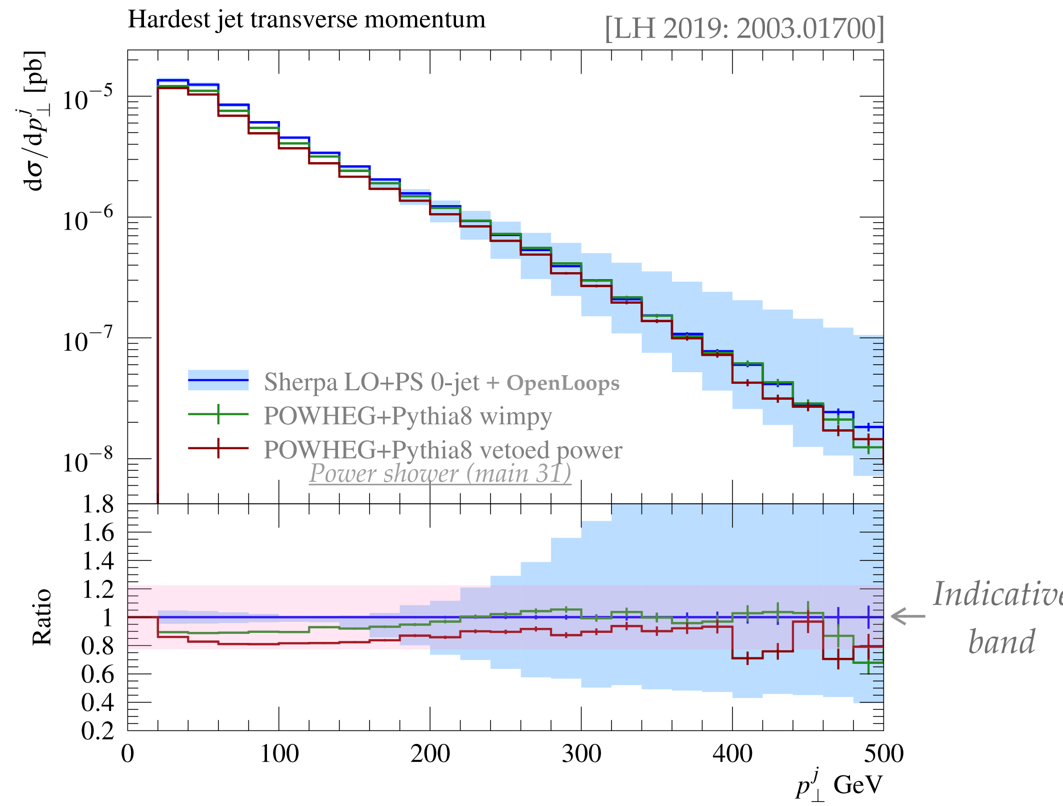

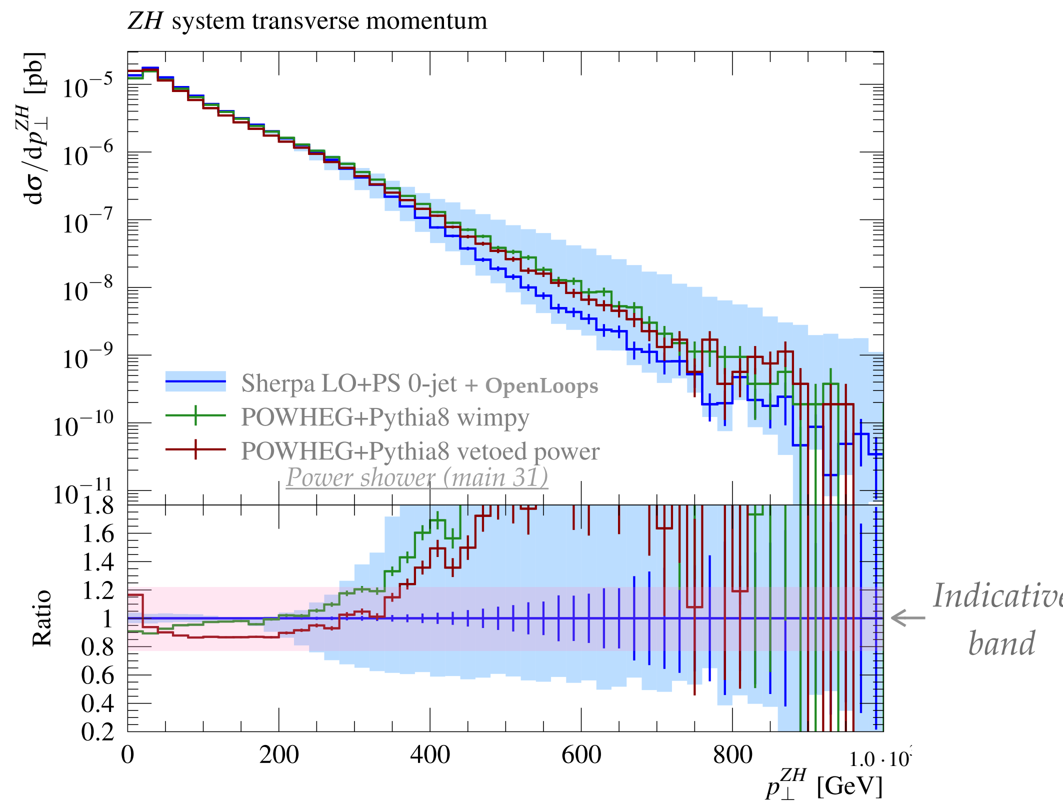

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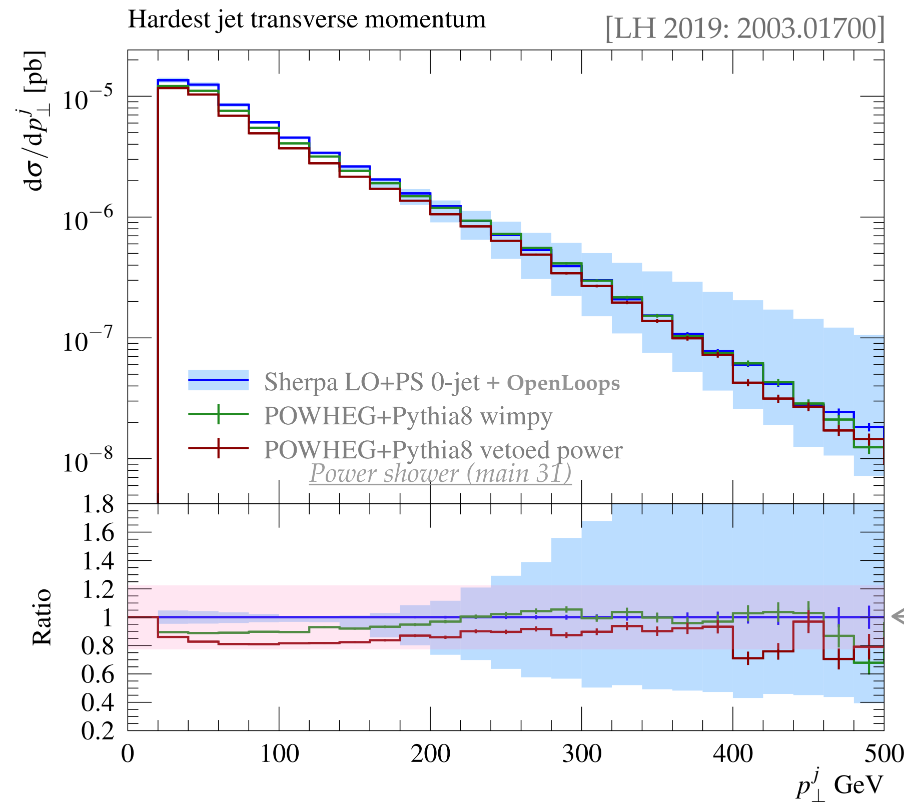
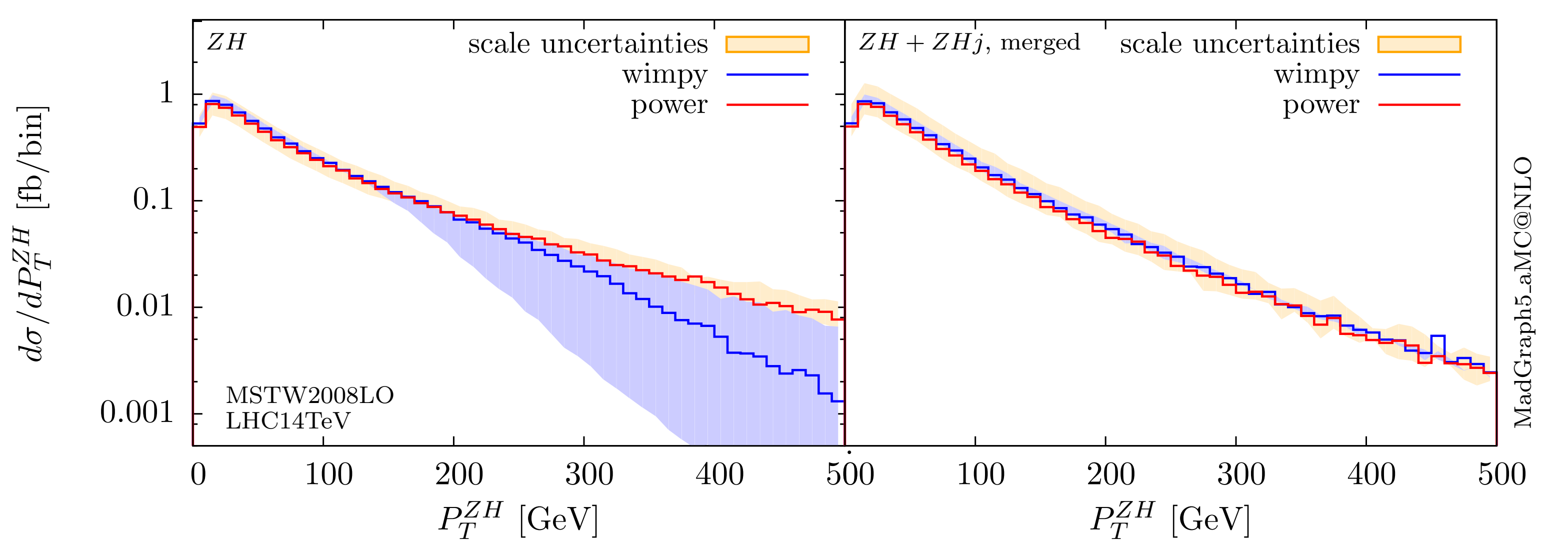
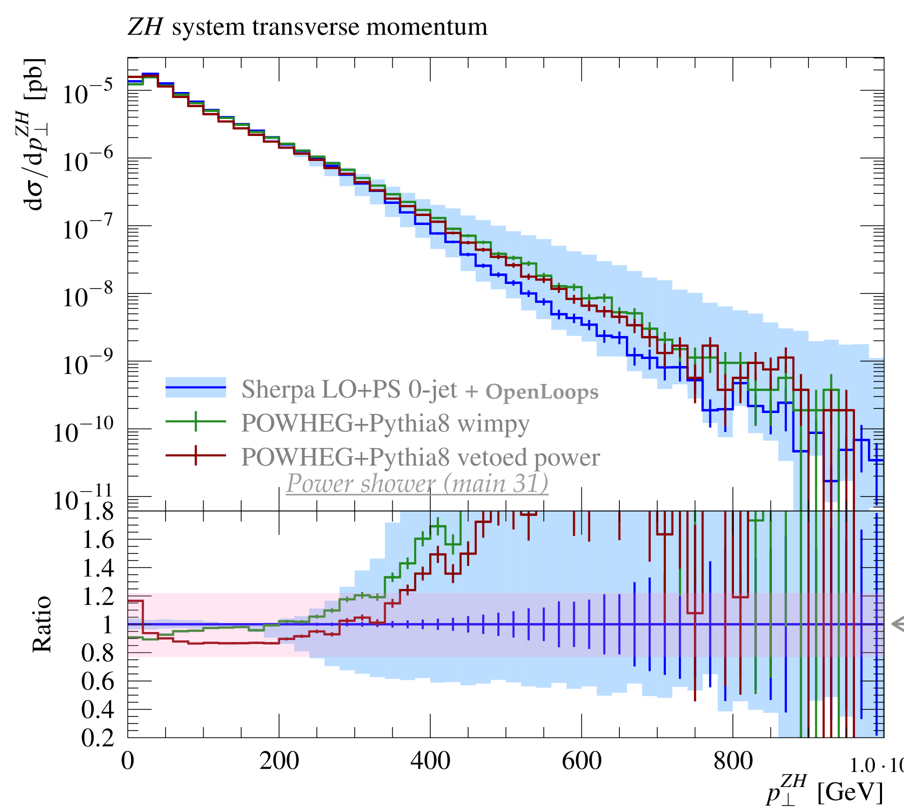


Indicative band

[Hespel, B. et al.: 1503.01656]



Parton shower starting scale variation pushed to zero



Indicative band

NLO matched to parton shower

In Sherpa 3.0.0 $gg \to HH$ is available at full Standard Model only for on-shell final states and can thus be used as test case

Run card configuration example:

```
ME_GENERATORS:
- External
- OpenLoops

BEAMS: 2212
BEAM_ENERGIES: 6500

PROCESSES:
- "21 21 -> 25 25":
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    NLO_Mode: MC@NLO
    NLO_Order: {QCD: 1, EW: 0}
    Loop_Generator: DiHiggsNLO
    Integrator: Rambo
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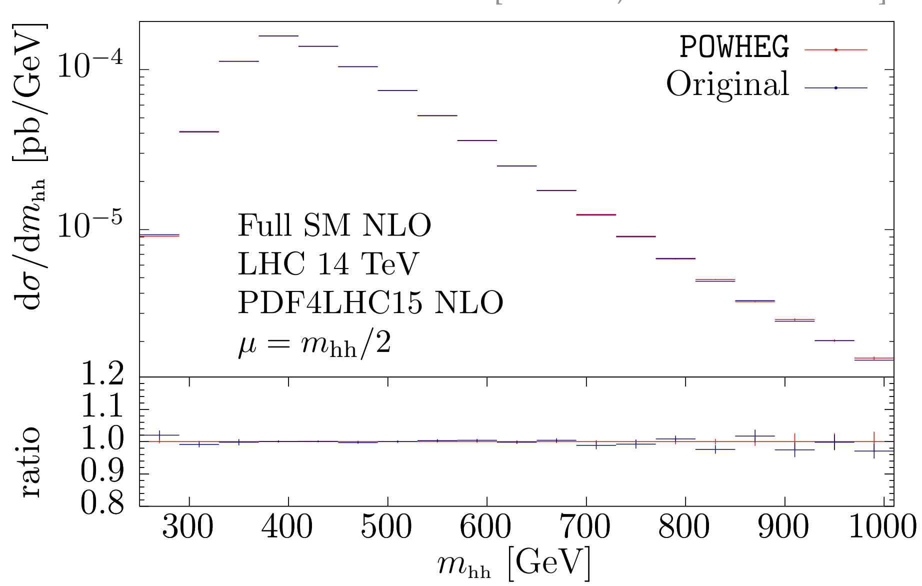
← From interpolation

[Heinrich, G. et al: 1703.09252]



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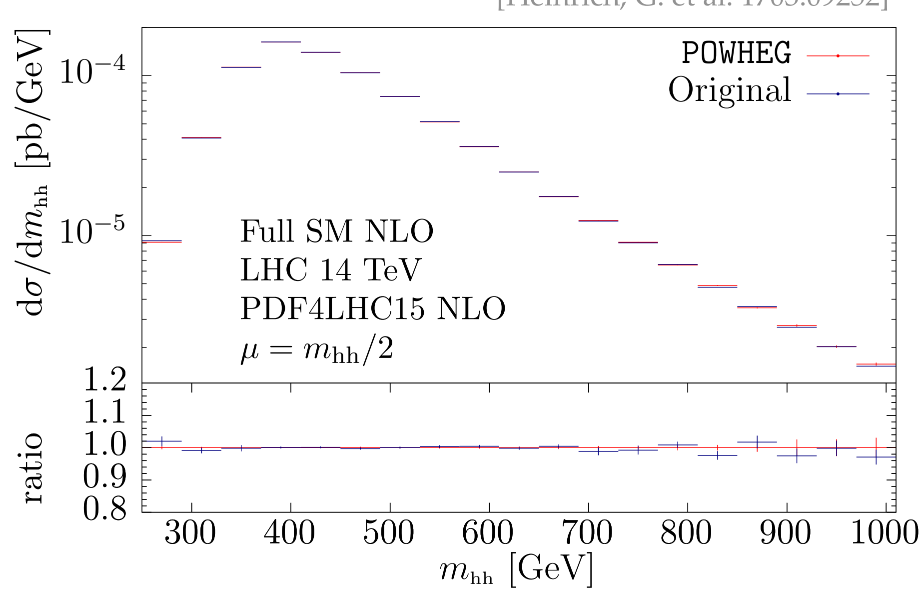
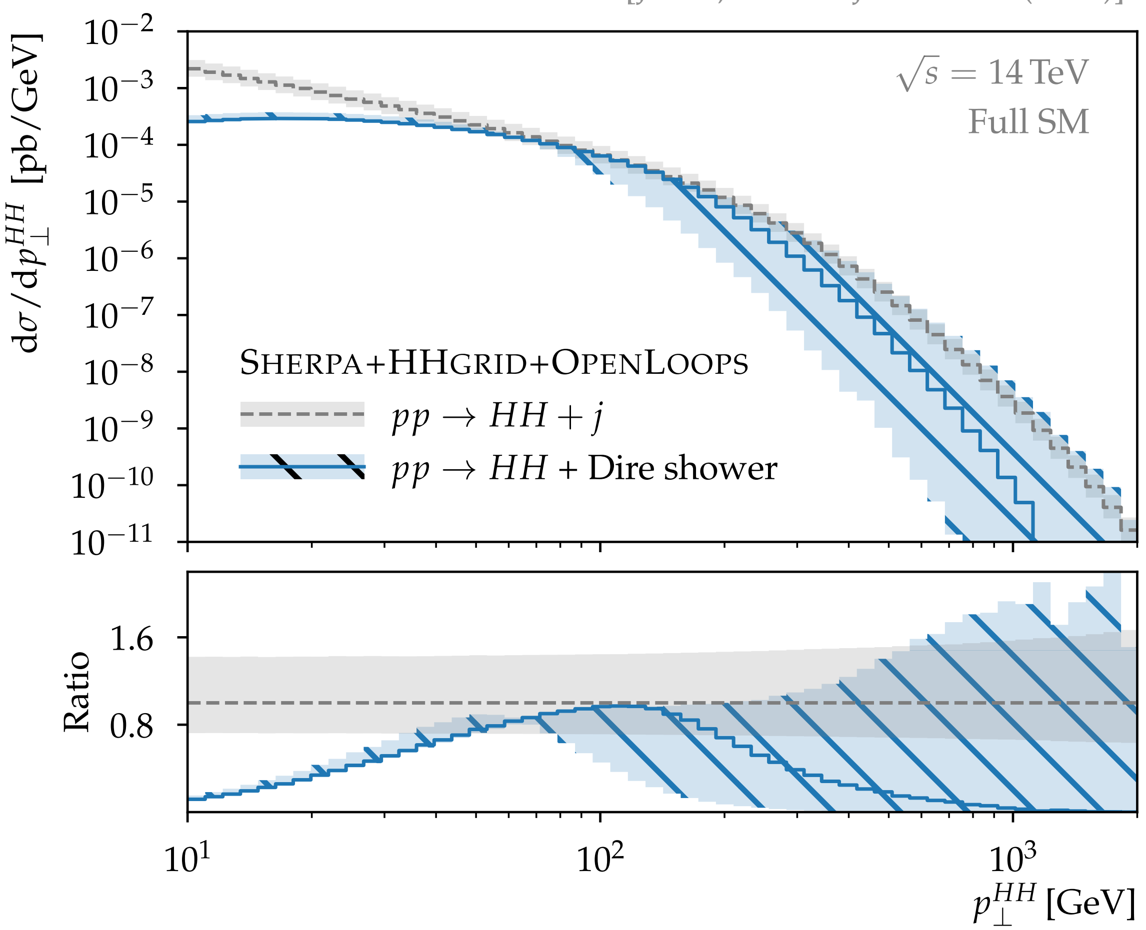


[Jones, S. et al: JHEP 1802 (2018)]



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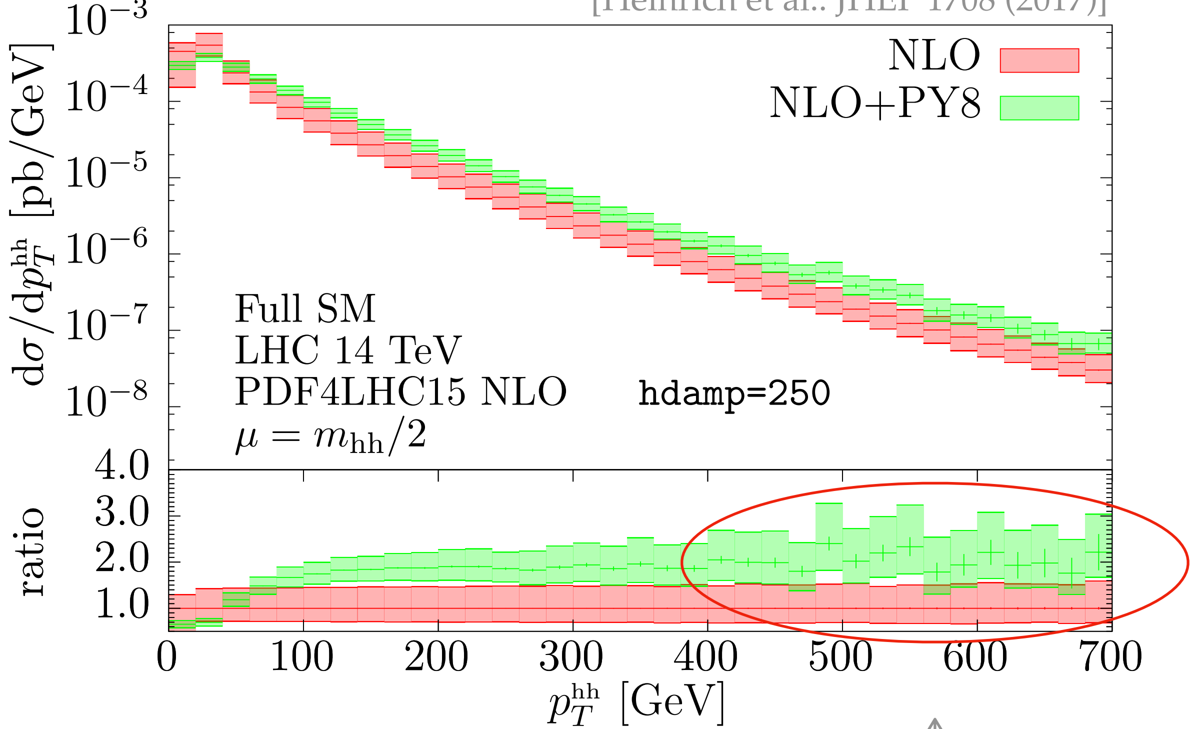

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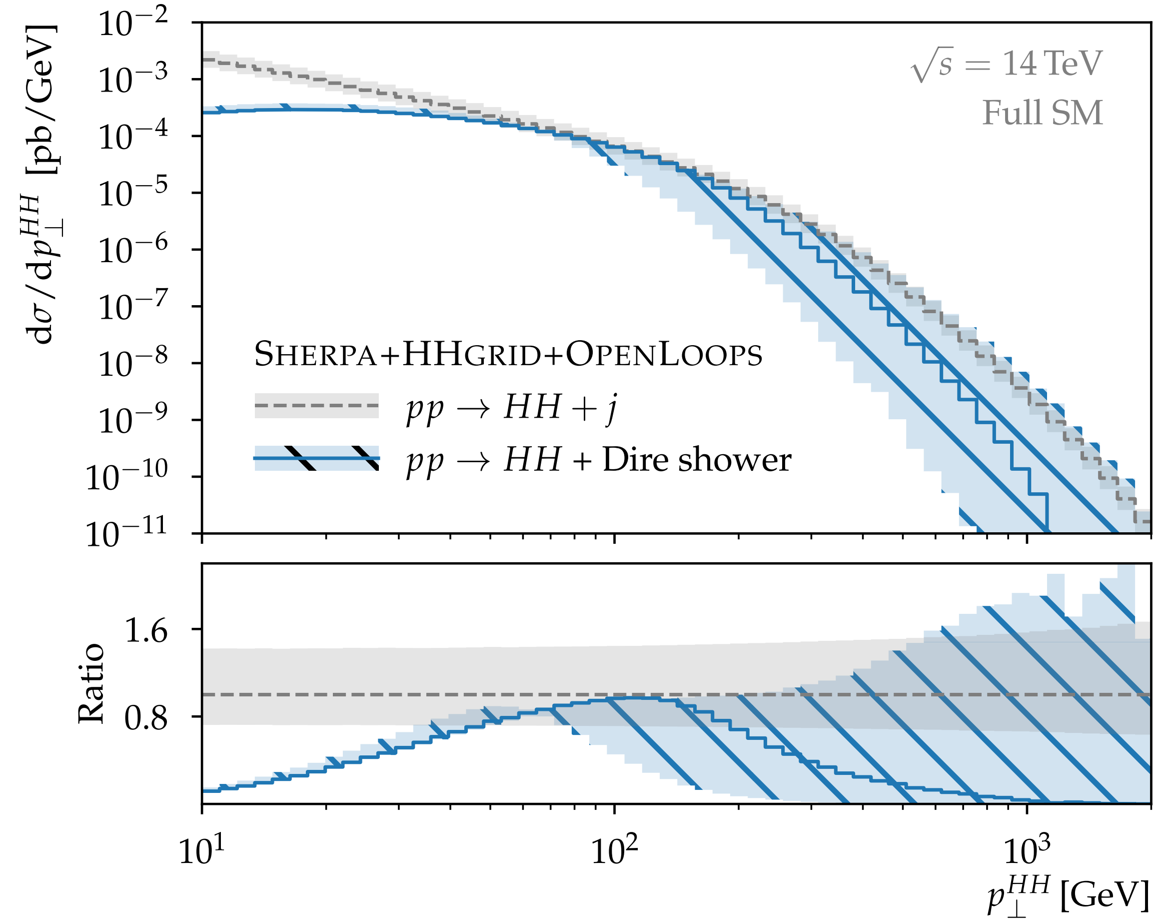

Showered result doesn't match NLO in the tail

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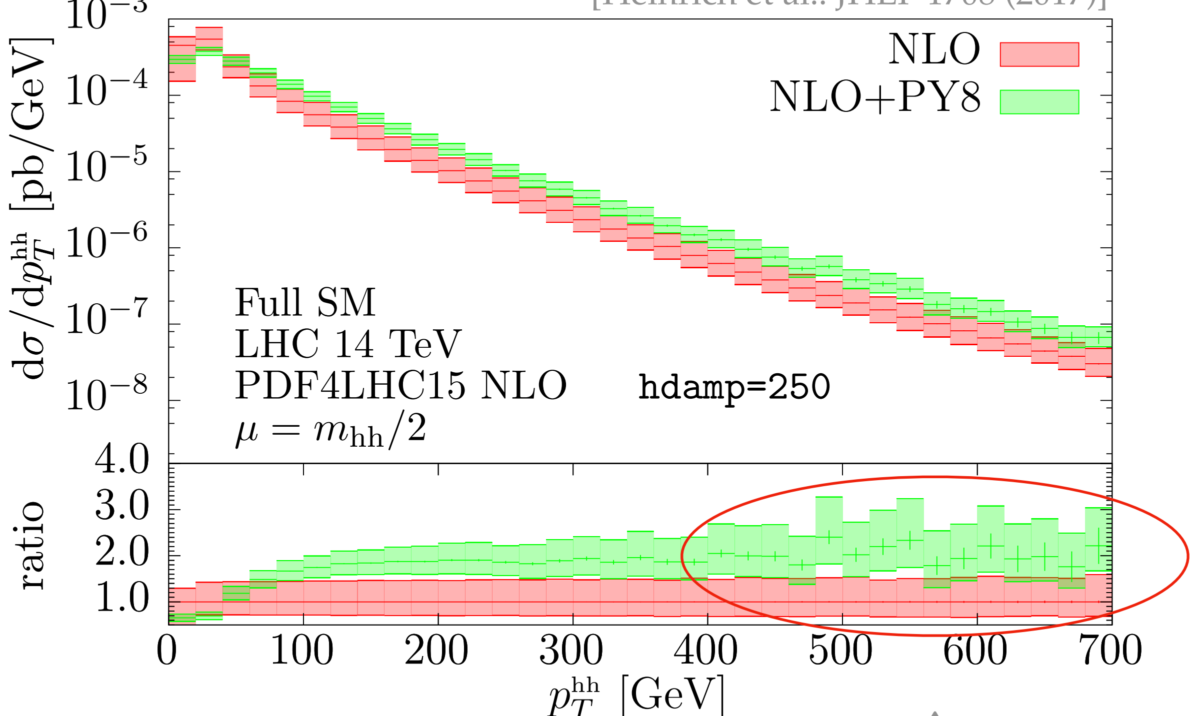
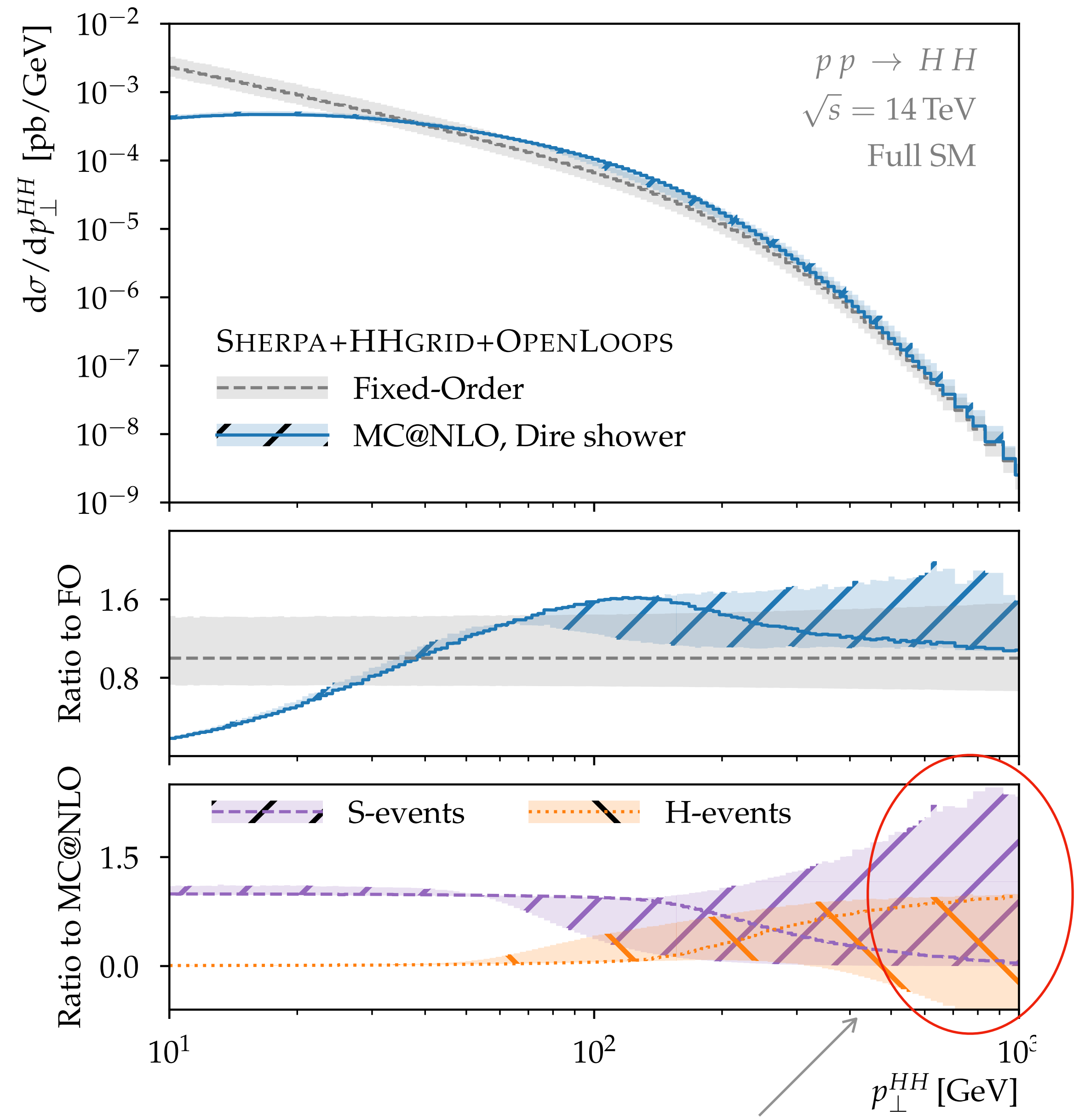
[Heinrich et al.: JHEP 1708 (2017)]



Showered result doesn't match NLO in the tail

[Jones, S. et al: JHEP 1802 (2018)]



Large uncertainties from S events

NLO matched to parton shower

What causes this mismatch?

[Jones, S. et al: JHEP 1802 (2018)]

MC@NLO general expression:

$$\langle O \rangle = \int d\phi_B \left(B(\phi_B) + V(\phi_B) + I(\phi_B) \right) O(\phi_B) \times$$

$$\times \left[\Delta(t_0, \mu_{PS}^2) + \int d\phi_1 \Delta(t, \mu_{PS}^2) \frac{D(\phi_B, \phi_1)}{B(\phi_B)} \Theta(\mu_{PS}^2 - t) \Theta(t - t_0) \right] + \qquad \text{S events}$$

$$+ \int d\phi_R H(\phi_R) O(\phi_R) \qquad \text{H events}$$

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S events

$$+ \int d\phi_R H(\phi_R) O(\phi_R)$$

H events

For observables insensitive to Born kinematical configuration

$$\langle O \rangle = \int d\phi_B \left(B(\phi_B) + V(\phi_B) + I(\phi_B) \right) O(\phi_B) \times$$

$$\times \left[\cancel{\Delta(t_0, \mu_{PS}^2)} + \int d\phi_1 \Delta(t, \mu_{PS}^2) \frac{D(\phi_B, \phi_1)}{B(\phi_B)} \Theta(\mu_{PS}^2 - t)\Theta(t - t_0) \right] +$$

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H events

For observables insensitive to Born kinematical configuration and focussing on the high energy tail

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It goes to 1

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$$\longrightarrow$$

$$\boxed{\begin{aligned} \langle O \rangle = & \int d\phi_B \left(V(\phi_B) + I(\phi_B) \right) O(\phi_B) \times \\ & \times \int d\phi_1 \frac{D(\phi_B, \phi_1)}{B(\phi_B)} \Theta(\mu_{PS}^2 - t) + \\ & + \int d\phi_R R(\phi_R) O(\phi_R) \end{aligned}}$$

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For observables insensitive to Born kinematical configuration and focussing on the high energy tail

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To recover the real emission result the first term in the r.h.s. must be negligible. This requirement is spoiled if the following conditions are met:

- Large **K factor**
- Non-negligible **splitting function** in that energy region
- Energy **region accessible** to the parton shower

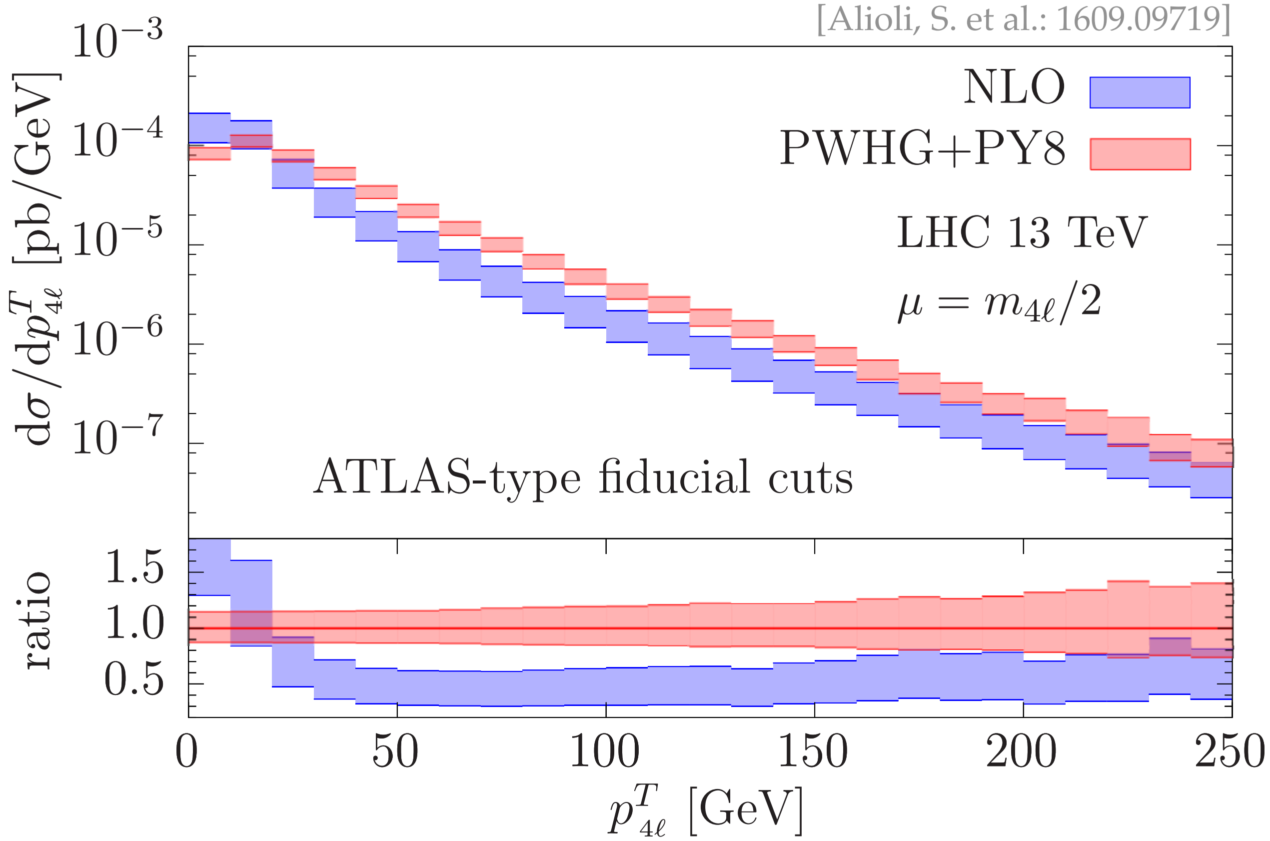
What comes next?

- Study parton shower matching uncertainty for other processes, e.g. $gg \to VV$:

[von Manteuffel, A. et al.: 1503.08835]
Using **VVamp** c++ code

$gg \to ZZ$ shows a similar discrepancy in the tail as $gg \to HH$

[Alioli, S. et al.: 1609.09719]



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- Study parton shower matching uncertainty for other processes, e.g. $gg \to VV$:
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- Resummation effects and relative uncertainties using dedicated Sherpa module

Conclusions

- Moving towards LHC@HL makes the good modeling of these processes an important step for future high precision studies and BSM analyses
- These processes suffer from theoretical uncertainties more than others. In particular for what concern the parton shower matching uncertainties
- A more detailed study of these uncertainties is needed to have a reliable MC@NLO and solutions to improve the showered sample are required

Thanks for the attention