INTERFERENCE - RESURRECTING OBSERVABLES AND WHERE TO FIND THEM

Matteo Maltoni

HEFT Workshop, Bologna 12/06/24

Based on arXiv:2403.16894 [hep-ph]

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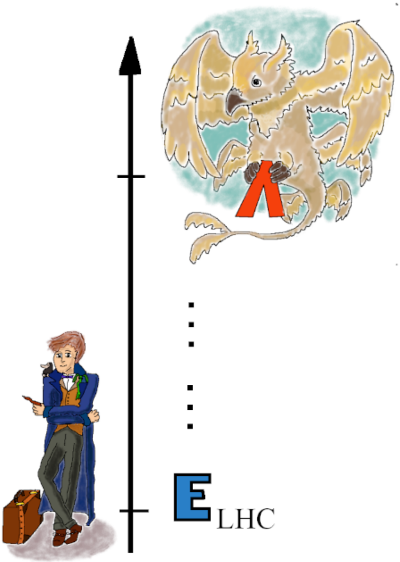
Outline

1. What interference suppression is and how to revive it
2. Application to the O_W operator
   - EW Zjj Vector Boson Fusion
   - Fully leptonic WZ production
   - Leptonic $W\gamma$ production
3. Bounds

The SMEFT parametrises small deviations from the SM

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_i \frac{C_i}{\Lambda^{d-4}} O_i^d$$



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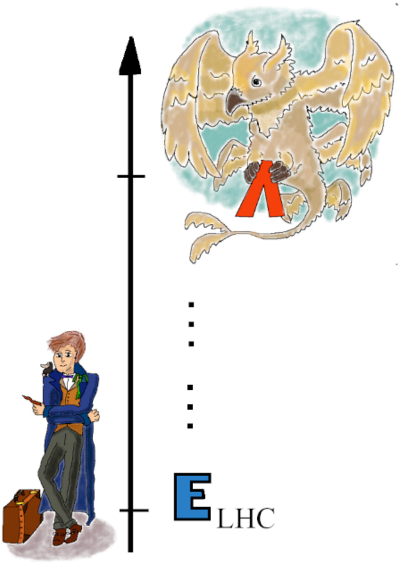

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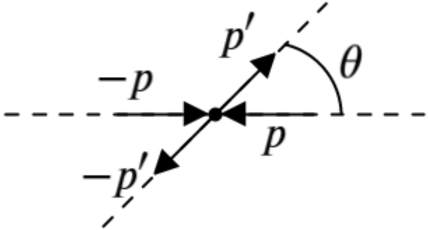

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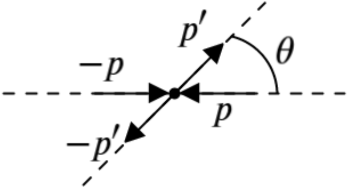

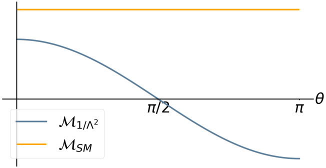

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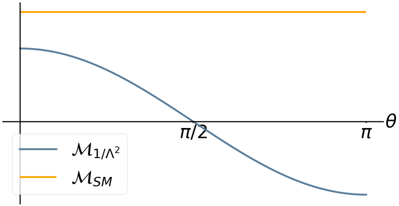

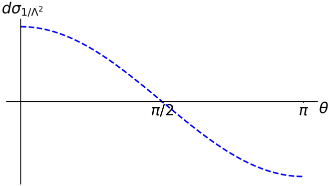

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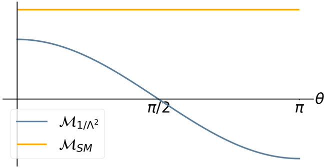

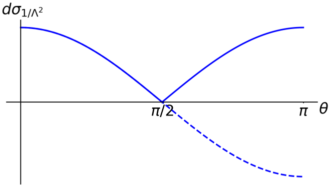

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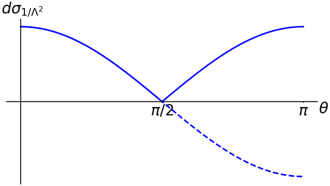
Some quantities can estimate how much of the interference is restorable at experiments



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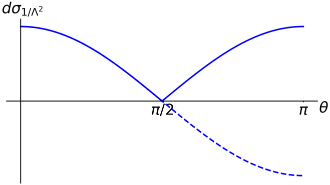

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$$R_{w\pm} = \frac{\mathrm{wgt} > 0 - \mathrm{wgt} < 0}{\mathrm{wgt} > 0 + \mathrm{wgt} < 0}$$

Interference suppression is usually due to helicity mismatch

Three-field-strength operators are known to produce different helicity configurations than the SM in 2-to-2 processes

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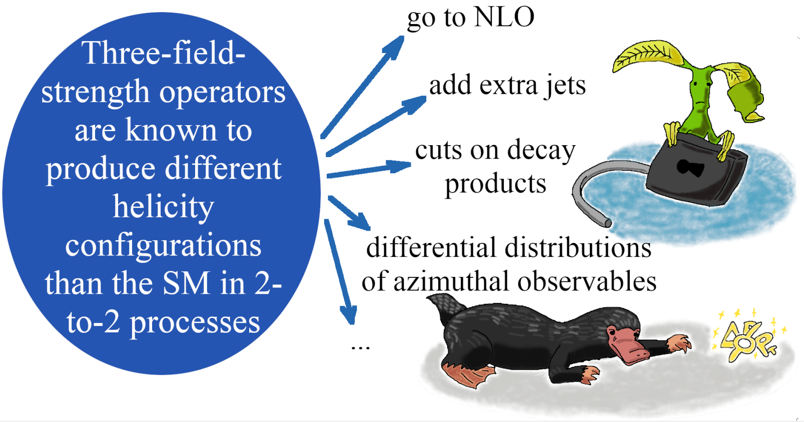

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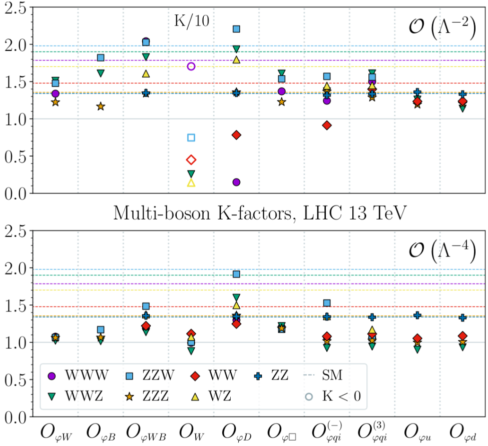
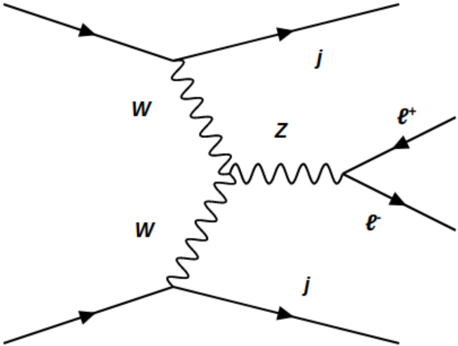


C. Degrande, G. Durieux, F. Maltoni, K. Mimasu, E. Vryonidou, C. Zhang, *Automated one-loop computations in the SMEFT*, [2008.11743] (2020)

In the EW Zjj case, $\Delta\phi_{jj}$ can lift the suppression considerably



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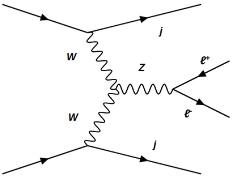

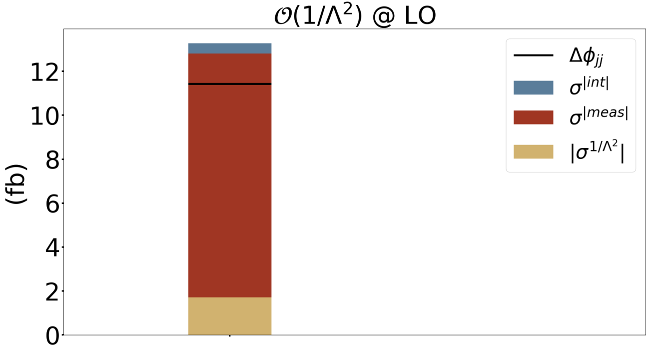

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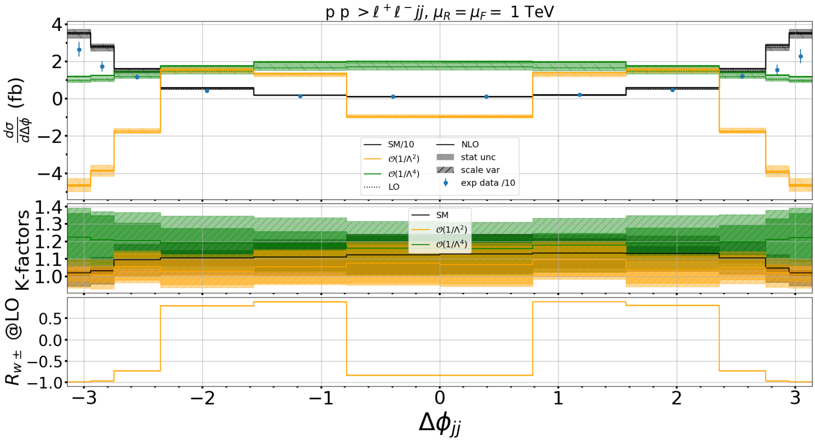

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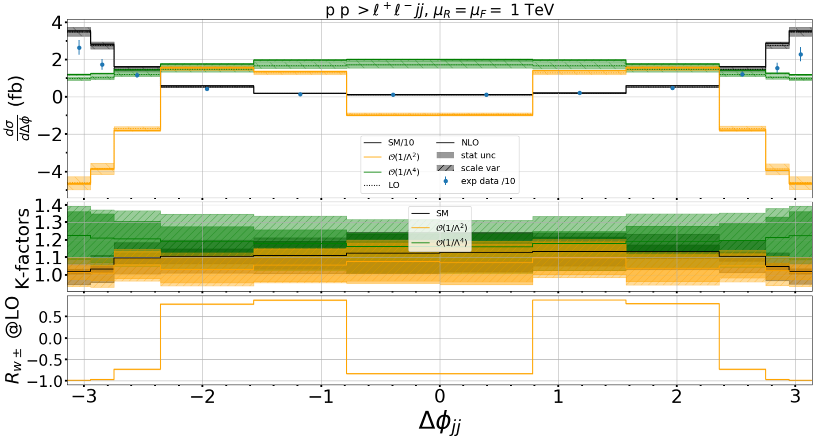
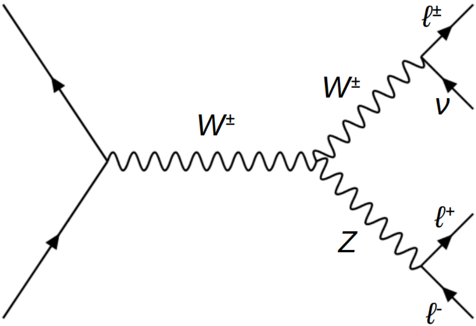


For WZ, interference is suppressed by neutrino reconstruction and muon helicities



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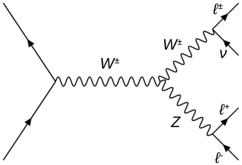

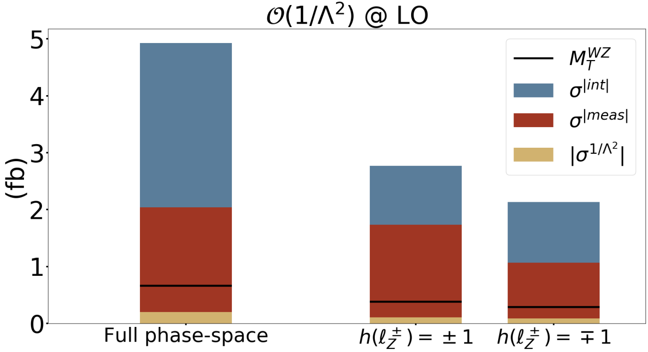

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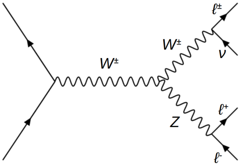
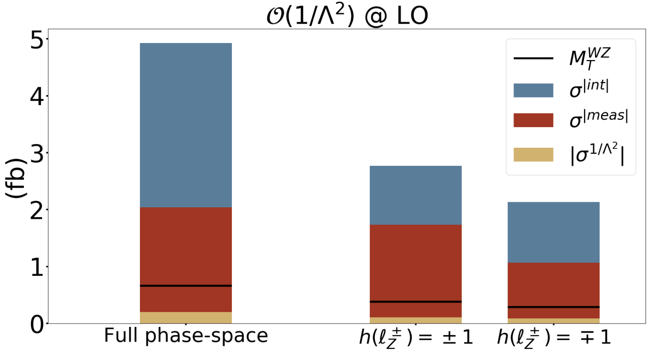


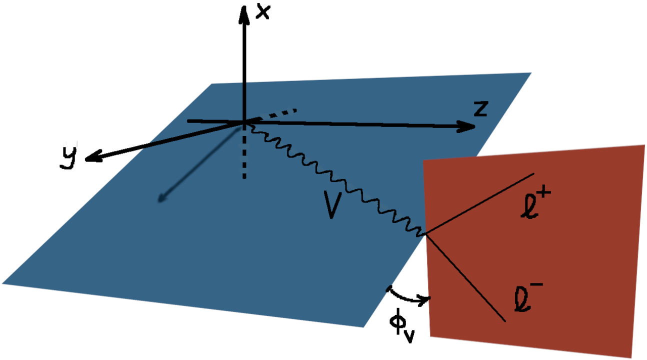
$$M_T^{WZ} = \sqrt{\left(\sum_\ell p_T^\ell + p_T^\nu\right)^2 - \left(\sum_\ell \vec{p}_T^{\,\ell} + \vec{p}_T^{\,\nu}\right)^2}$$



Suitable phase-space cuts can restore the interference in WZ

The interference is known to be proportional to

$$\phi_{WZ} = \cos(2\phi_W) + \cos(2\phi_Z)$$



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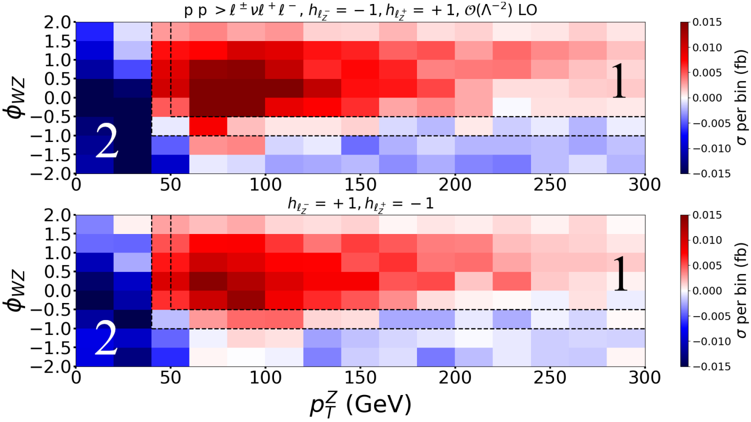

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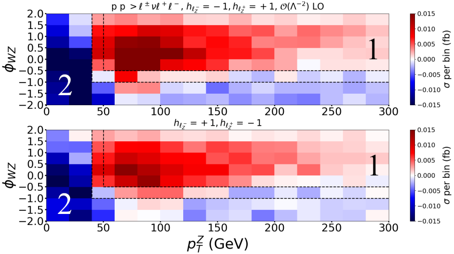

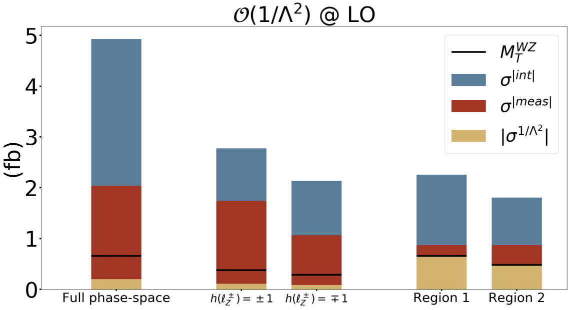

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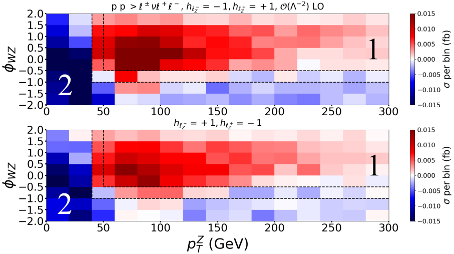

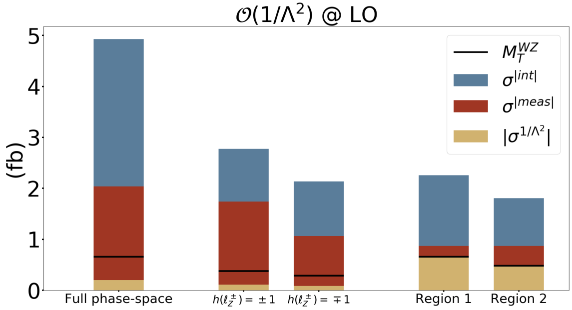

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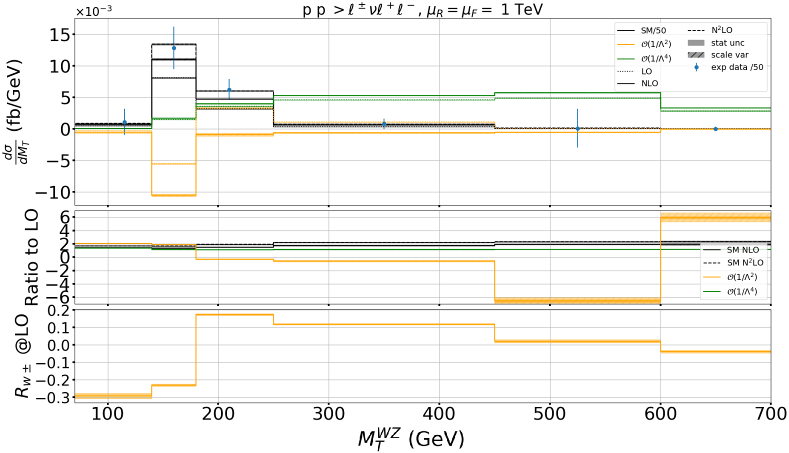

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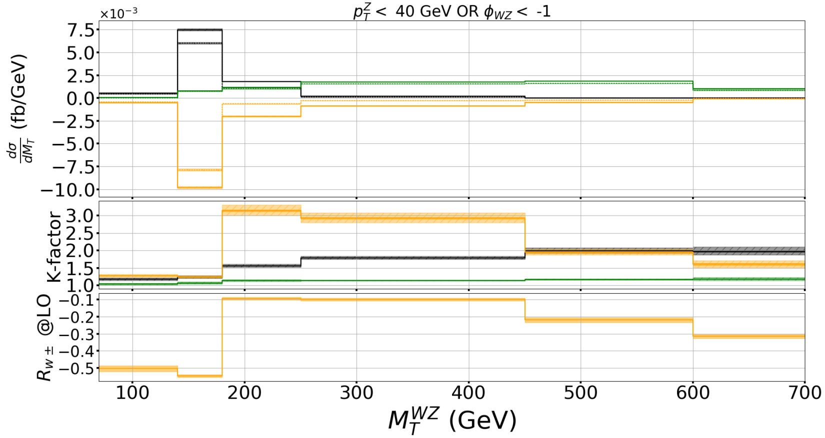
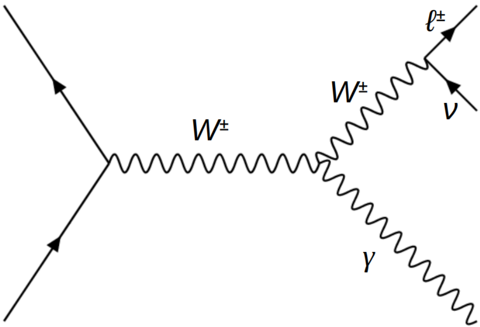


For $W\gamma$, the interference is suppressed by the presence of a neutrino in the final state



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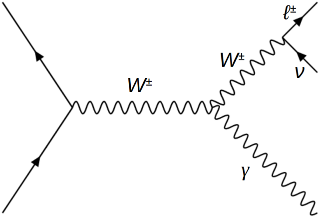

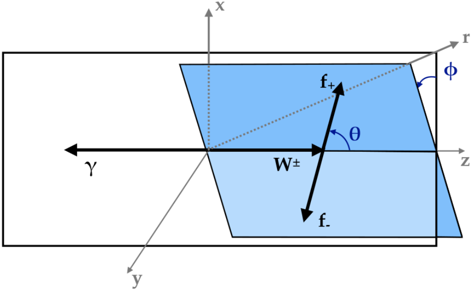

CMS Collaboration, *Measurement of $W^{\pm}\gamma$ differential cross sections in proton-proton collisions at $\sqrt{s}$ = 13 TeV and effective field theory constraints*, [2111.13948] (2021)

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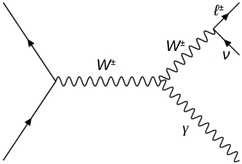

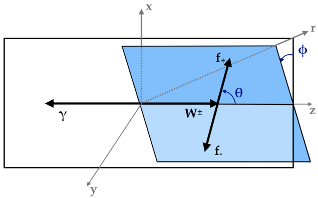

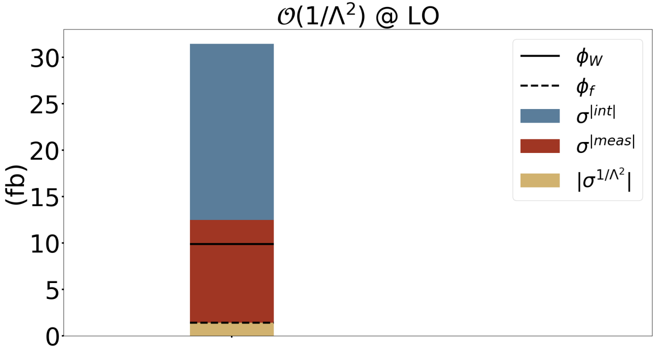

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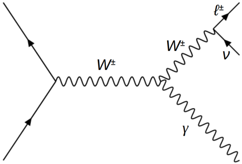
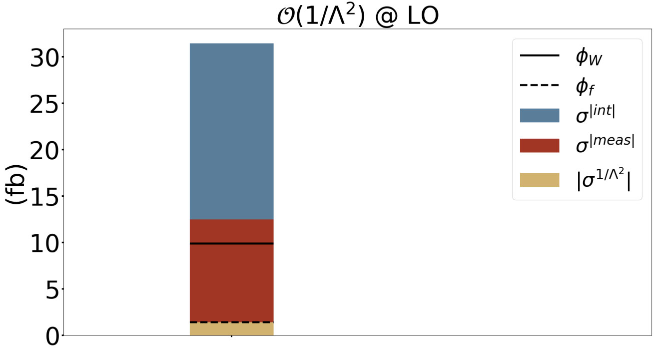
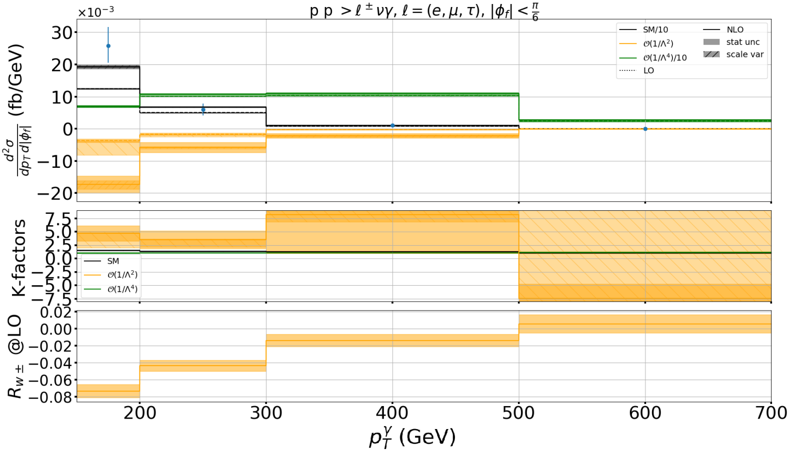




A suitable choice of azimuthal observables can yield more reasonable K-factors



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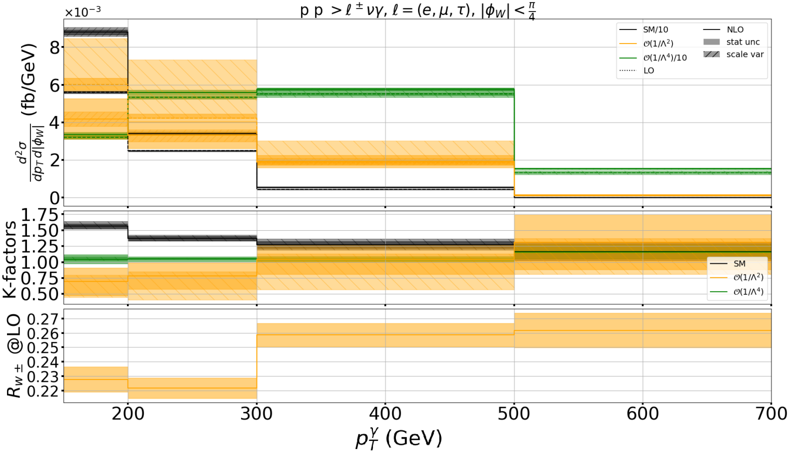
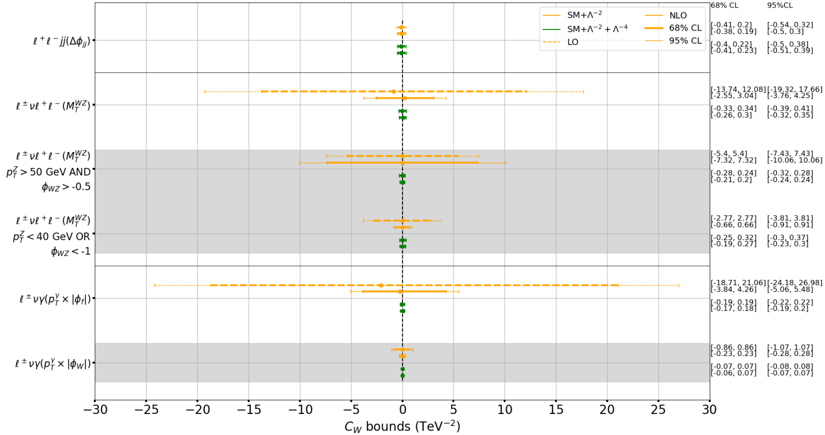


Some of these observables can yield $\mathcal{O}(1/\Lambda^2)$ bounds that are competitive with the ones at $\mathcal{O}(1/\Lambda^4)$ level

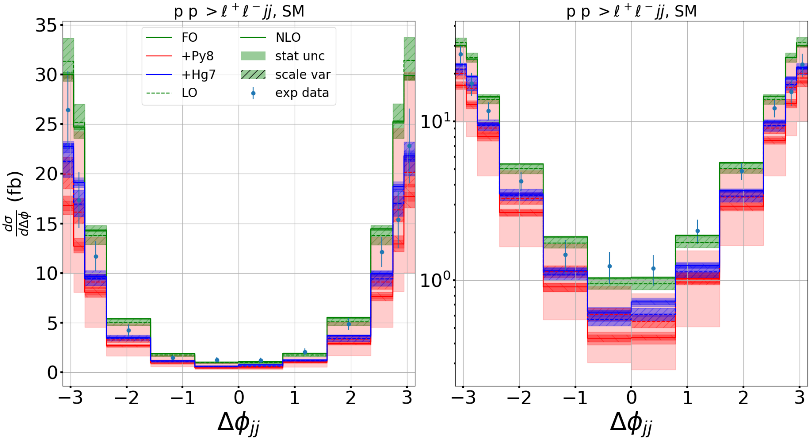


Take-aways

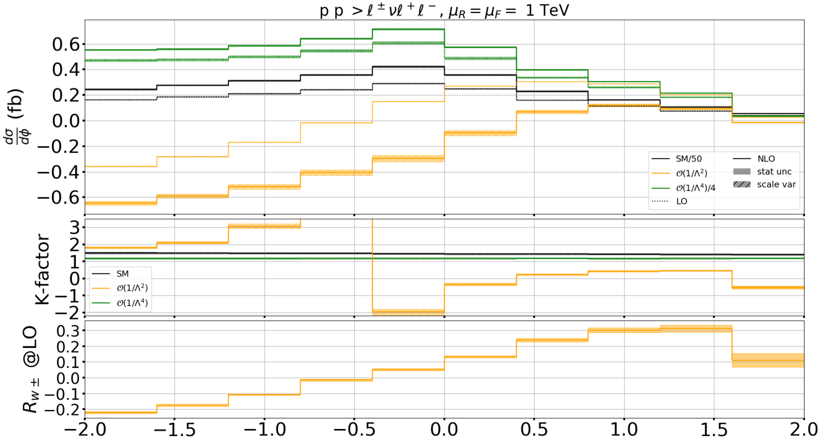
- The interference cross-section between the SM and some SMEFT operators can be suppressed because of a cancellation over the phase-space
- When this happens at LO, large and negative K-factors may result for the interference
- Suitable variables and phase-space cuts can lift the suppression, yielding reasonable K-factors and bounds that can be competitive with the $\mathcal{O}(1/\Lambda^4)$ level
- This method can be used even outside SMEFT and in parallel with Machine Learning techniques

BACKUPS

Zjj VBF results seem to be largely dependent on the shower choice



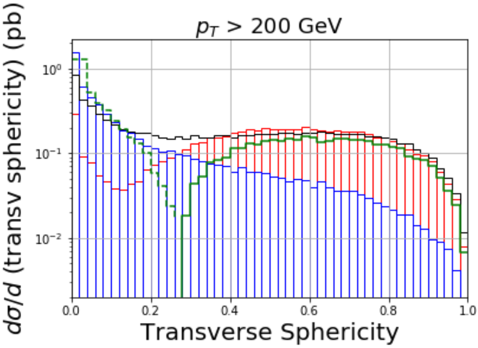
The K-factor sign flips when the cancellation crosses zero



For the O_G operator, the interference in three-jets is restored by event-shape observables

$$O_G = g_S f_{abc}\, G_\nu^{a,\mu} G_\rho^{b,\nu} G_\mu^{c,\rho}$$

$$M_{xy} = \sum_{i=1}^{N_{\text{jets}}} \begin{pmatrix} p_{x,i}^2 & p_{x,i}p_{y,i} \\ p_{y,i}p_{x,i} & p_{y,i}^2 \end{pmatrix} \Rightarrow Sph_T = \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$



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$\Lambda = 1$ TeV, 68% CL					
$p_{T,min}$ [GeV]	Distribution	Sph_T cut	Bins	SM+$\mathcal{O}(1/\Lambda^2)$	SM+$\mathcal{O}(1/\Lambda^2)$+$\mathcal{O}(1/\Lambda^4)$
50	$p_T[j_3]$ vs Sph_T	0.23	34	$[-2.5 \cdot 10^{-1}, 2.5 \cdot 10^{-1}]$	$[-1.2 \cdot 10^{-1}, 1.1 \cdot 10^{-1}]$
200	S_T vs Sph_T	0.27	34	$[-7.5 \cdot 10^{-2}, 7.5 \cdot 10^{-2}]$	$[-2.4 \cdot 10^{-2}, 2.3 \cdot 10^{-2}]$
500	$M[j_2 j_3]$ vs Sph_T	0.31	21	$[-5.5 \cdot 10^{-2}, 5.5 \cdot 10^{-2}]$	$[-3.5 \cdot 10^{-2}, 5.3 \cdot 10^{-2}]$
1000	$M[j_2 j_3]$ vs Sph_T	0.35	7	$[-2.6 \cdot 10^{-2}, 2.6 \cdot 10^{-2}]$	$[-1.8 \cdot 10^{-2}, 1.9 \cdot 10^{-2}]$

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