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$gg \to VV$ + 0,1 jet modelling in Sherpa+OpenLoops

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Joint off-shell and heavy Higgs discussion, 23 June 2015

Toolkit

- SHERPA including its automated multi-jet merging — Gleisberg et al.; arXiv:0811.4622
- OPENLOOPS automated 1-loop QCD matrix elements including the COLLIER tensor integral reduction — Cascioli, Maierhöfer, Pozzorini; arXiv:1111.5206; Denner, Dittmaier, Hofer; arXiv:1407.0087

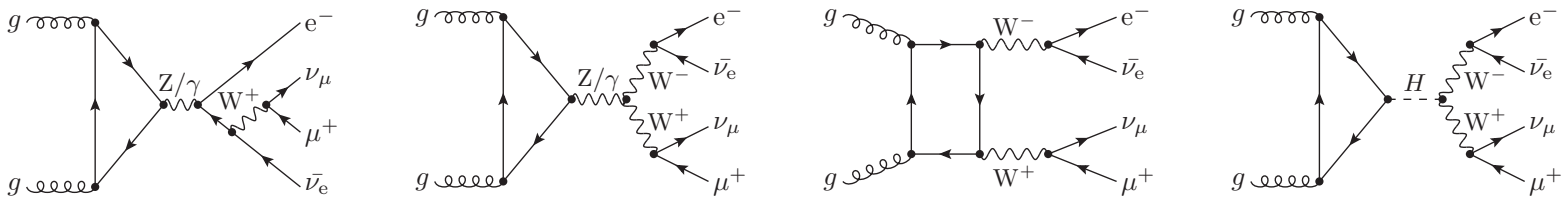
Phenomenological setup: $pp \to e^- \bar{\nu}_e \mu^+ \nu_\mu$ + jets

- All results in the following for LHC $\sqrt{s} = 8$ TeV, using CT10 PDFs
- Squared quark-loop contributions for $+0, 1$ jets
- Full off-shell, interference and spin-correlation effects, using complex mass scheme
- Predictions shown here for background-only by setting $m_H \to \infty$ but can also include Higgs signal and interference

- Central scale choice: $\mu_0 = \frac{1}{2}(E_{T,W^+} + E_{T,W^-})$
- CKKW-like scale prescription in merged jet emissions: $\alpha_s(k_\perp)$
- Uncertainties: independent variations of $\mu_{F,R} = \mu_0/2 \ldots 2\mu_0$ and resummation scale $\mu_Q = \frac{\mu_0}{2}/\sqrt{2} \ldots \sqrt{2}\frac{\mu_0}{2}$

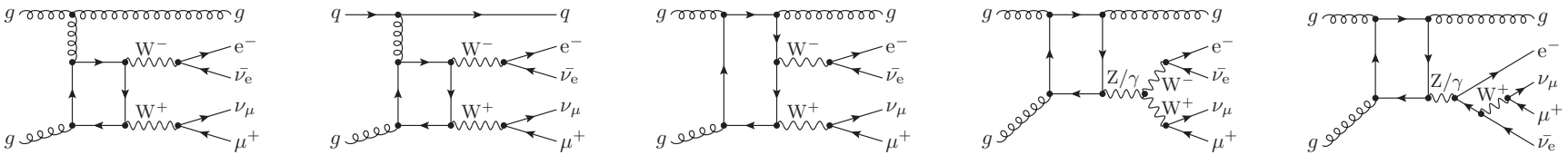
0-jet production: Examples for $gg \to 4\ell$ diagrams

- all diagrams leading to the given 4ℓ final state, not just doubly-resonant



1-jet production: Examples

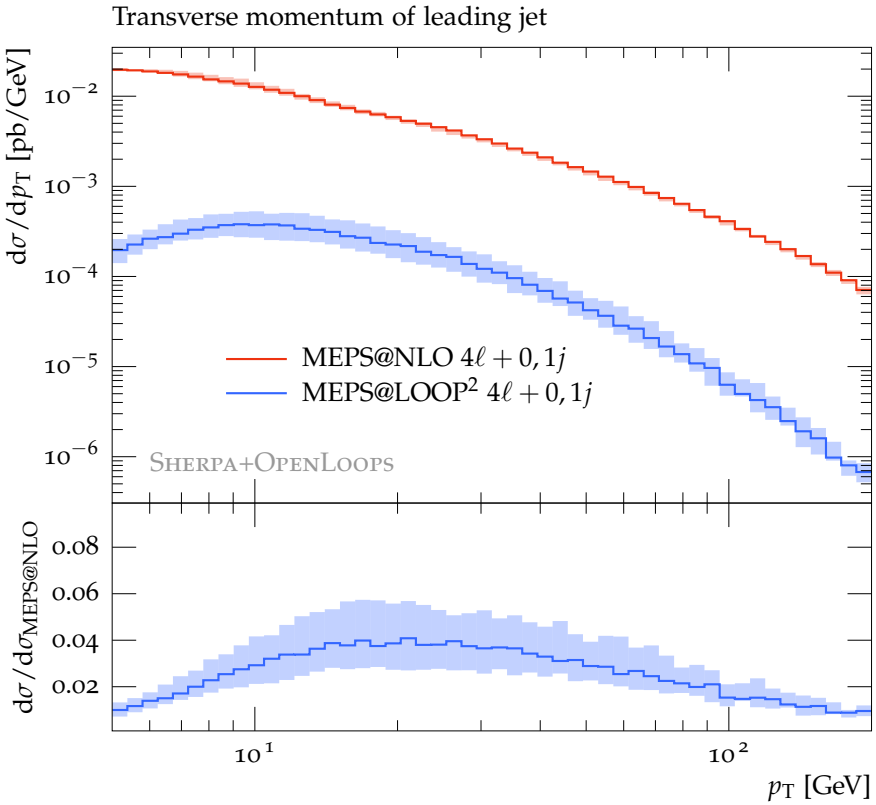
- requirement for finite contributions: vector bosons coupling to pure quark loop

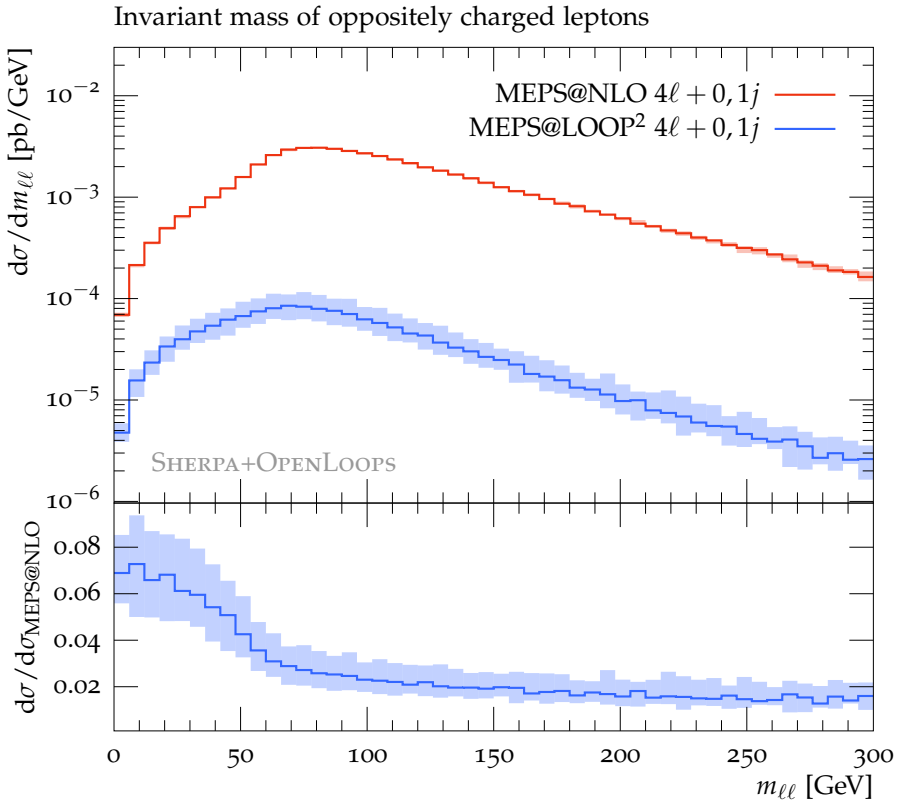


- first merging of 0-jet and 1-jet squared-loop contributions
- tree-level merging techniques since all MEs are finite
- shower on top of $gg \to 4\ell \Rightarrow$ consistency requires MEs for qg, $\bar{q}g$ and $q\bar{q}$ initial states

Impact of Loop^2 contributions

Cascioli, Höche, Krauss, Maierhöfer, Pozzorini, FS; arXiv: 1309.0500





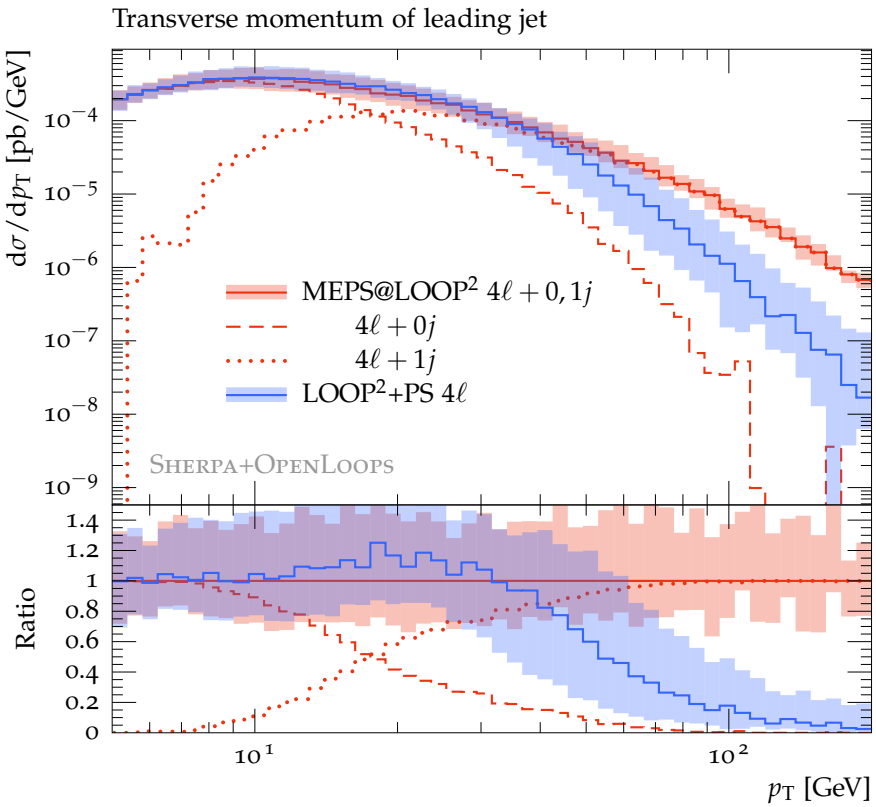
- Inclusive contribution of a few %
- Shape distortions: more significant impact in Higgs signal region (e.g. low $m_{\ell\ell}$)

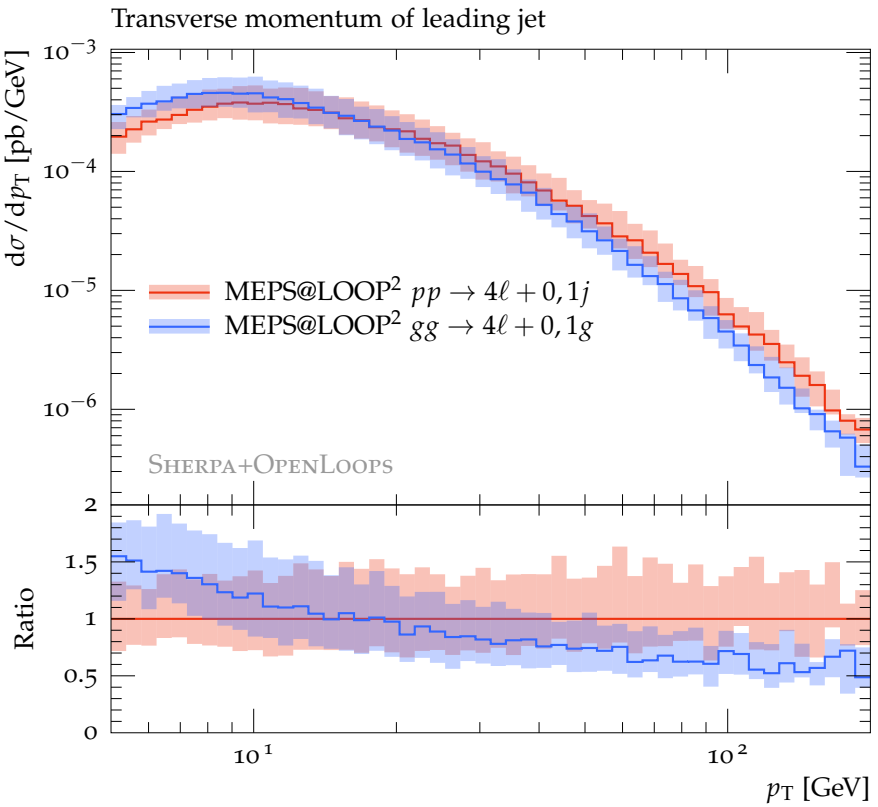
Comparison of different simulation levels

LOOP^2 simulations	0-jet	1-jet	2-jet
LOOP^2 4ℓ	LO	-	-
LOOP^2 $4\ell + 1j$	-	LO	-
LOOP^2+PS 4ℓ	LO+PS	PS	PS
LOOP^2+PS $4\ell + 1j$	-	LO+PS	PS
MEPS@LOOP^2 $4\ell + 0, 1j$	LO+PS	LO+PS	PS

Features of LOOP^2 contributions

Cascioli, Höche, Krauss, Maierhöfer, Pozzorini, FS; arXiv: 1309.0500





Merging effects

- Inclusion of LOOP^2 $4\ell + 1j$ in merging: harder $p_\perp$ spectrum
- Significant reduction of uncertainties (wrt resummation scale) in high-$p_\perp$ region

Non-gluonic initial states

- Inclusion of quark-channels $\rightarrow$ harder tail
- Naturally, lower Sudakov suppression without quark splittings
- Shape distortion
  $\Rightarrow$ opposite effects in 0/1 jet bins

Rivet implementation of Higgs analyses

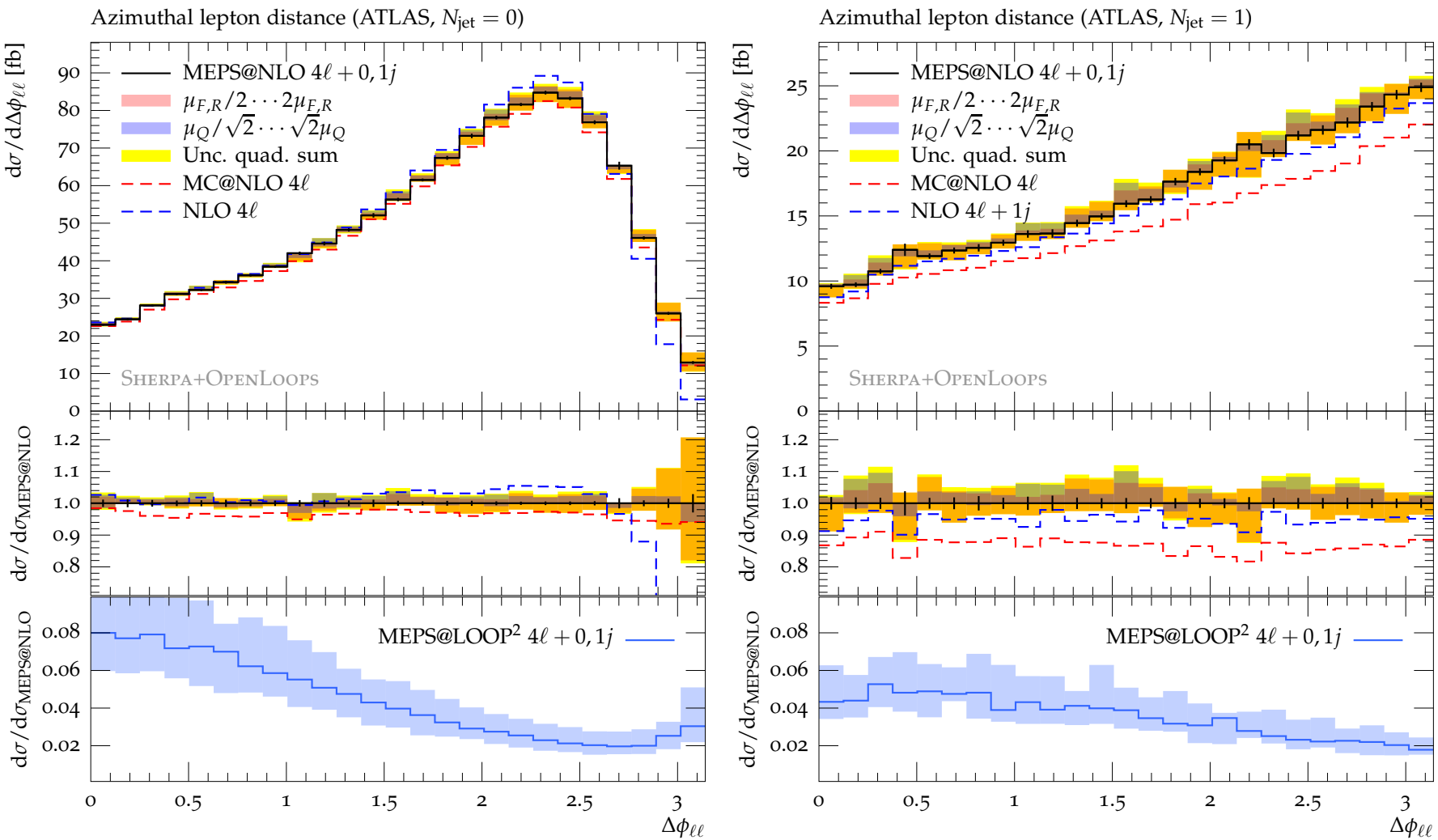
- 8 separate analyses: {ATLAS,CMS} × {0-jet, 1-jet} × {signal region, control region}
- Differential predictions in relevant observables: $p^j_\perp$, $m_{\ell\ell}$, $\Delta\phi_{\ell\ell}$, m_T

Findings

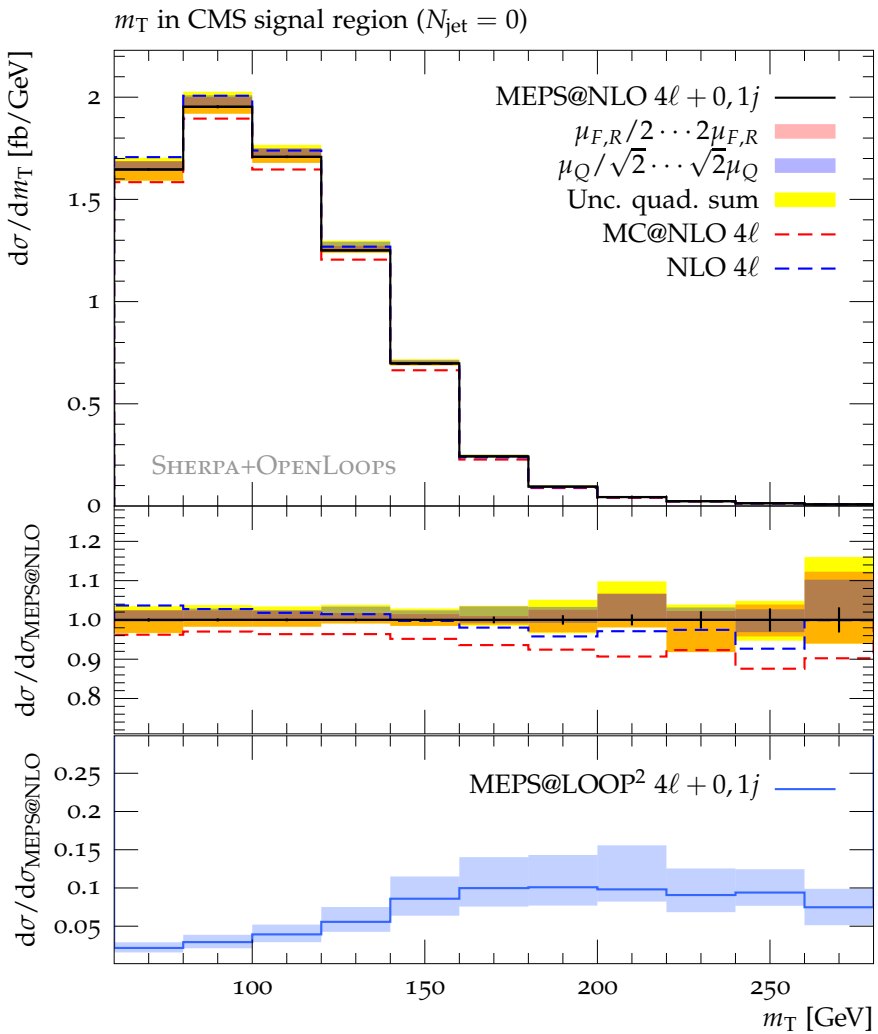
- Uncertainty bands for best $q\bar{q} \to 4\ell$ prediction (ME+PS@NLO) at the few-% level as estimated from $\mu_{R,F} \oplus \mu_Q$ variations

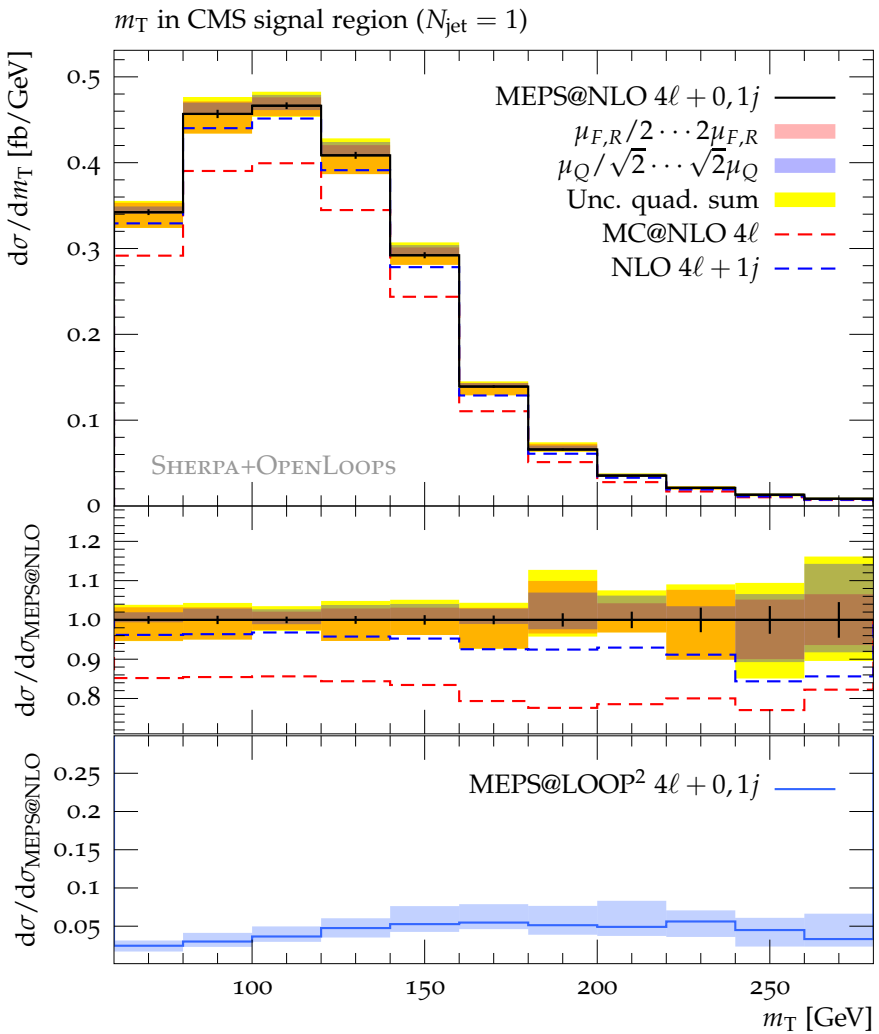
$\Rightarrow$ have to include the few-% loop-induced contributions at this accuracy level

Example from ATLAS analysis



Example from CMS analysis

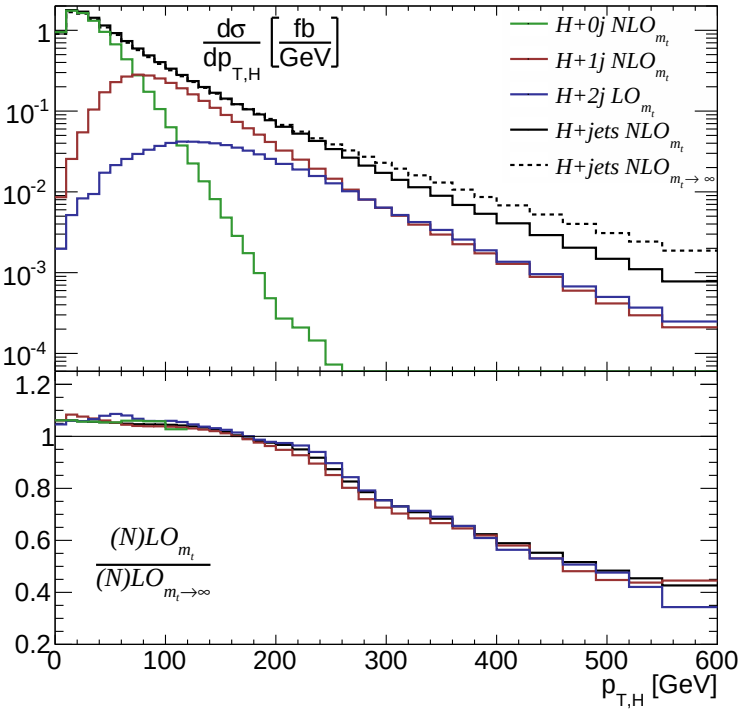




Top mass effects for $gg \to H$

- Alternative to MEPS@LOOP^2 for signal: NLO multi-jet merging in effective theory
- Typically in the $m_t \to \infty$ limit
- Finite m_t corrections using full (LO) loop-squared matrix elements from OpenLoops

$$r_t^{(n)} = \frac{\left|\mathcal{M}^{(n)}(m_t)\right|^2}{\left|\mathcal{M}^{(n)}(m_t \to \infty)\right|^2}$$



- Embedded into NLO multi-jet merging through

$$\mathrm{d}\sigma^{\text{S-MC@NLO}} = \mathrm{d}\Phi_n\, r_t^{(n)} \left[\mathcal{B} + \mathcal{V} + \int \mathrm{d}\Phi_1 \mathcal{D}\right] \left(\Delta(t_0) + \int \mathrm{d}\Phi_1 \frac{\mathcal{D}}{\mathcal{B}} \Delta(t)\right) + \mathrm{d}\Phi_{n+1} \left[r_t^{(n+1)} \mathcal{R} - r_t^{(n)} \mathcal{D}\right]$$

Summary

- Finite loop^2 contributions for $4\ell + 0, 1j$ production taken into account in merged approach
- Offshell studies possible by allowing signal-only, background-only and signal+background+interference setups
- Multi-jet merging improves accuracy in particular in high-$p_\perp$ regions by reducing dependence on parton shower
- For Higgs signal: finite m_t corrections in NLO multi-jet merged sample possible
- Application of MEPS@LOOP^2 to other processes in preparation

Goncalves, Krauss, Kuttimalai, Maierhöfer; in prep.