NLOPS ttbb comparisons: status and next steps

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based on work with

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ttH-HXSWG Discussion on tt+bb (MC comparisons),
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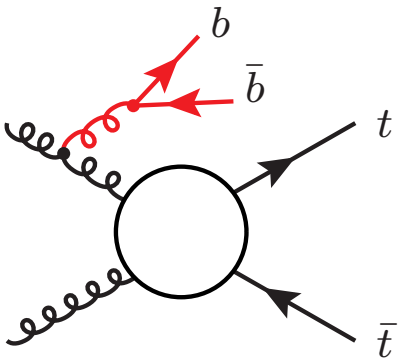
Outline

1. Effects of $t\bar{t}b\bar{b}$ K-factor and μ_R reduction

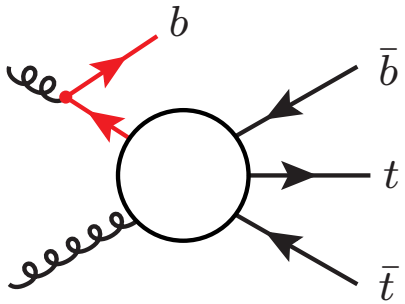
2. Shower recoil and bin migrations

$t\bar{t}b\bar{b}$ background to $t\bar{t}H(b\bar{b})$

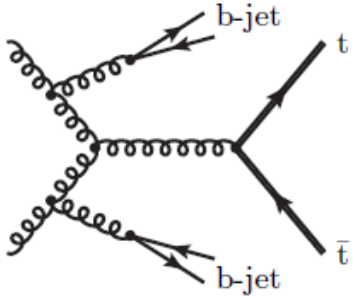
Relevant topologies



FS $g \to b\bar{b}$ dominate



IS $g \to b\bar{b}$ subleading

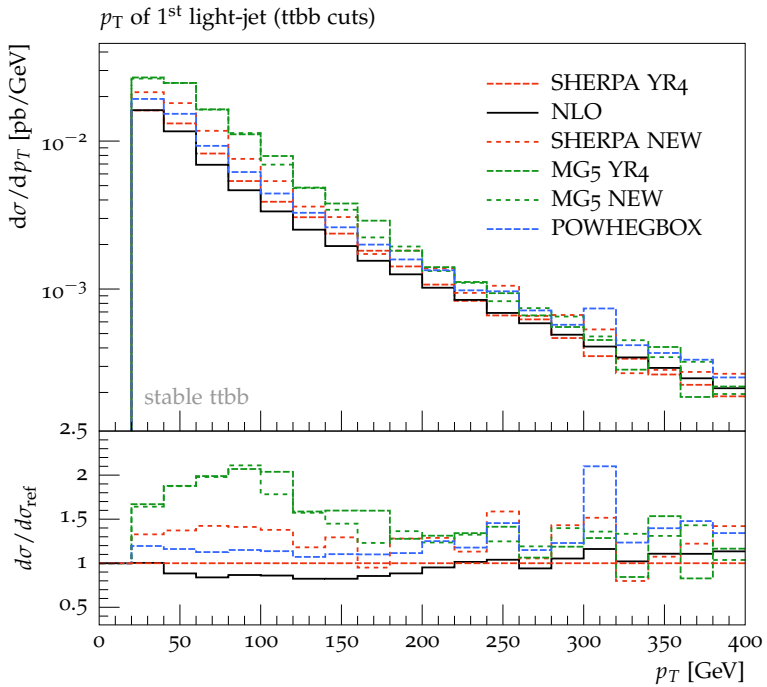


double $g \to b\bar{b}$ at NLOPS

NLOPS $pp \to t\bar{t}b\bar{b}$ in 4F scheme

- default scales: $\mu_{\mathrm{R,def}} = \left(E_{T,t}E_{T,\bar{t}}\,E_{T,b}E_{T,\bar{b}}\right)^{1/4}$ and $\mu_F = \mu_{\mathrm{sh}} = h_{\mathrm{damp}} = H_T/2$

NLOPS $t\bar{t}b\bar{b}$ discrepancies (since YR4)



Phase space with $N_b \geq 1$

- good agreement (although one b unresolved!)

Phase space with $N_b \geq 2$

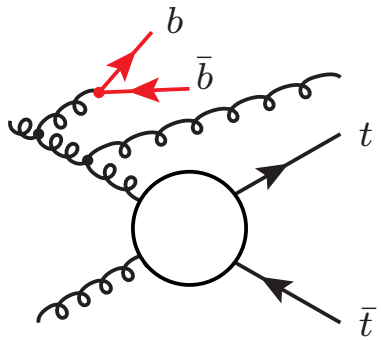
- NLOPS/NLO effect and MC spread up to 40% (beyond NLO uncertainty)
- related to NLOPS enhancements in light-jet p_T spectrum

Interpretation of MC discrepancies (physical effect or not?)

Hypothesis on origin enhacement of jet-p_T spectrum

- large NLO K-factor, $\sigma_{\rm NLO}/\sigma_{\rm LO} \sim 1.9$
- and usage of shower approx. ($R_{\rm soft}$) in regions where $R_{\rm soft} \gg R$

$$\frac{\mathrm{d}\sigma^{\rm NLOPS}}{\mathrm{d}\Phi_{t\bar{t}b\bar{b}j}} = \underbrace{R}_{t\bar{t}b\bar{b}j\ \mathrm{ME}} + \underbrace{R_{\rm soft}}_{\text{shower}} \times \underbrace{\left[\frac{\bar{B}_{\rm soft}}{B}\Delta - 1\right]}_{\gtrsim 100\%\ \text{instead of}\ \mathcal{O}(\alpha_S)}$$

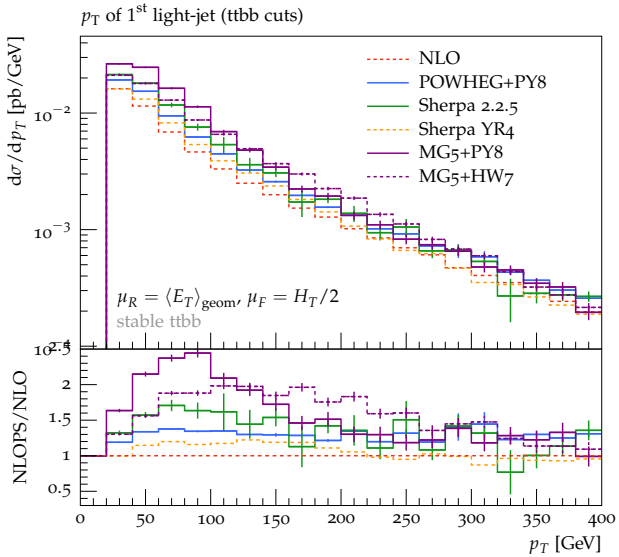


Possible remedies

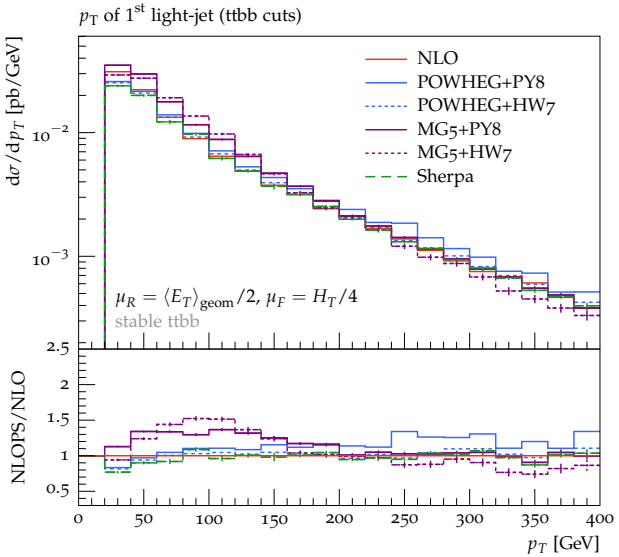
- reduction of shower starting scale $\mu_{\rm sh}$
  - reduces NLOPS/NLO differences but not supported by any TH motivation
  - we need coherent prescription for choice of $\mu_{\rm sh}$ in different MCs
- reduction of large $t\bar{t}b\bar{b}$ K-factor?
  - possible through 0.5 rescaling of μ_R (together with μ_F and $\mu_{\rm sh}$)
  - motivated by $pp \to t\bar{t}b\bar{b}j$ at NLO [Buccioni etal, arXiv:1907.13624]

0.5 rescaling of $\mu_R, \mu_F, \mu_{\rm sh}$ **(good news)** $p_{T,j}$ (ttbb cuts)

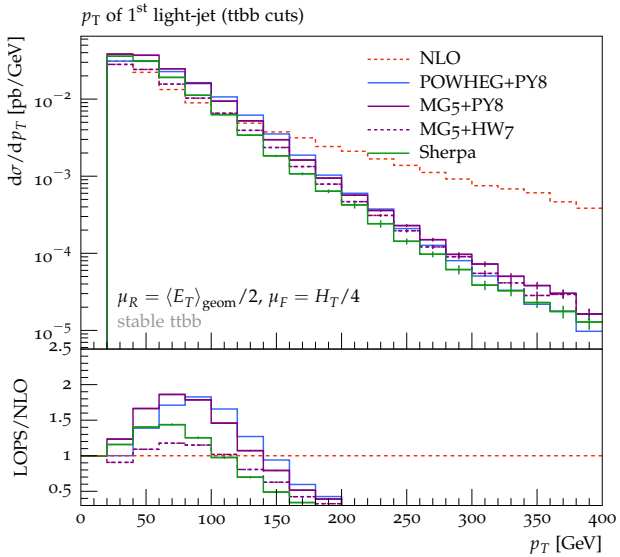
NLOPS YR4 scales



NLOPS 0.5 rescaling



LOPS 0.5 rescaling

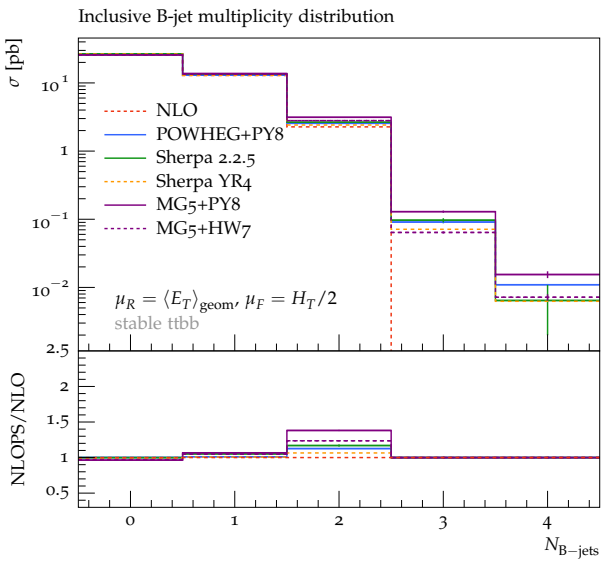


- scale reduction significantly reduces NLOPS/NLO and MC spread (form 2.5 to 1.5)

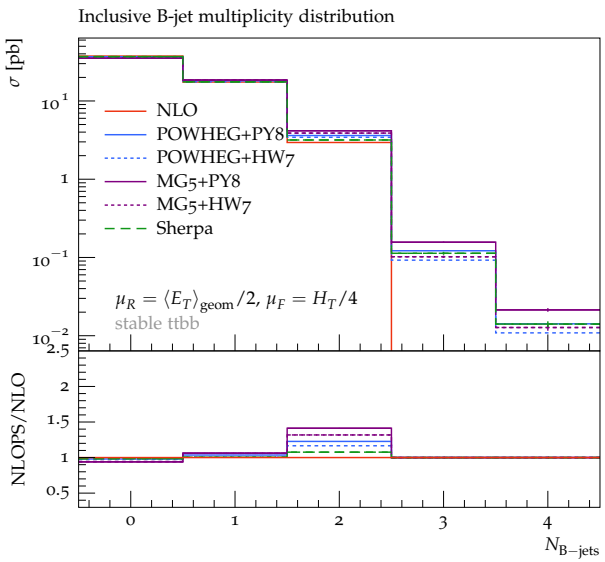
0.5 rescaling of $\mu_R, \mu_F, \mu_{\rm sh}$ **(not so good news)**

N_b

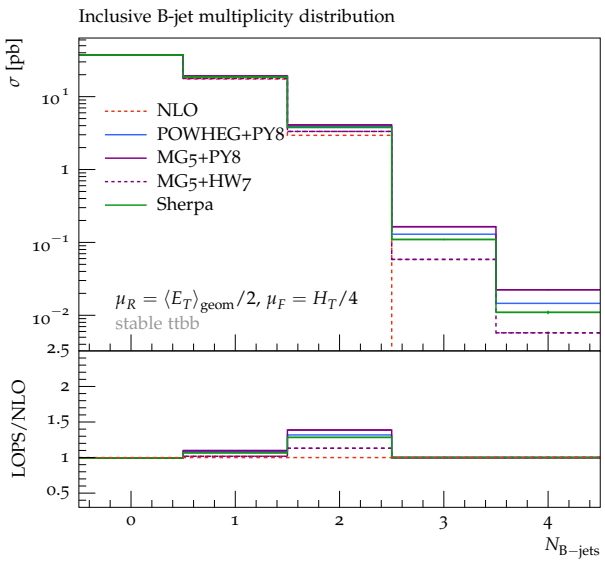
NLOPS YR4 scales



NLOPS 0.5 rescaling



LOPS 0.5 rescaling



No significant change of NLOPS/NLO effects and MC spread

- for $N_b \geq 1$ they are small, while for $N_b \geq 2$ they remain between 15–40%
- what is the origin of a so large uncertainty in $\sigma(N_b \geq 2)/\sigma(N_b \geq 1)$ ratio?
- note: such effects already present in LOPS/NLO $\Rightarrow$ bin migrations?

Outline

Bin migrations and recoil observables

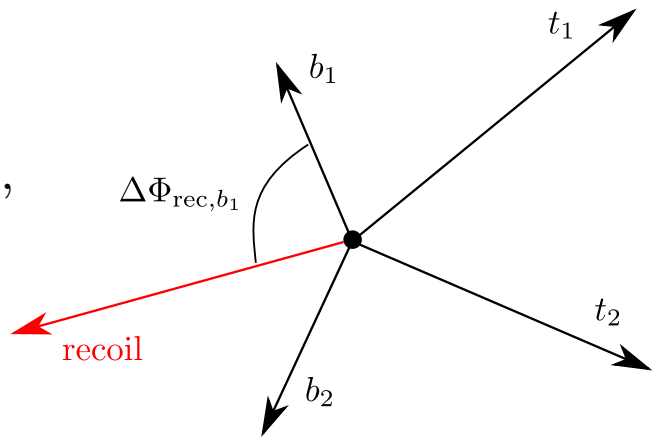
Hypothesis of bin migrations and recoil effects

- Enhancement of XS with $N_b \geq 2$ due shower-induced migrations of events from bins with $N_b = 0, 1$.
- It was found that N_b migrations are dominated by kinematic shifts in $p_{\mathrm{T},b}$ (rather than η_b or $\Delta R_{b1,b2}$) $\Rightarrow$ they most likely arise from shower recoil effects

NLOPS recoil/migration effects can be studies through recoil observables

$$\Delta\phi_{\mathrm{rec},X} = \Delta\phi\left(\vec{p}_{\mathrm{rec}}, \vec{p}_X\right), \qquad \vec{p}_{\mathrm{rec}} = -\sum_{t,\bar{t},b_1,b_2} \vec{p}_i,$$

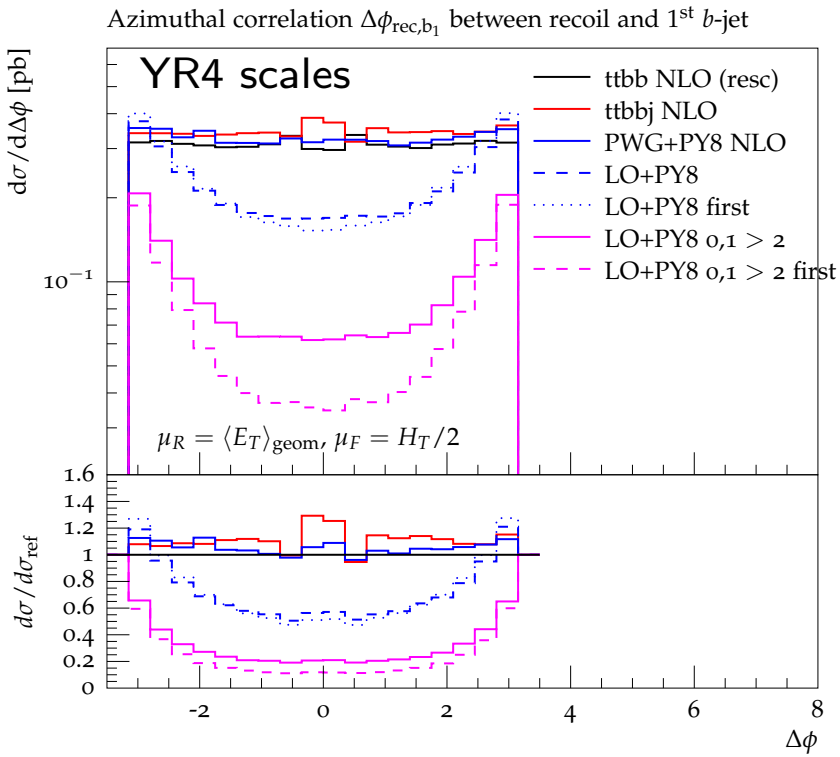
$$p_{\mathrm{T,rec}} > 15\,\mathrm{GeV}$$

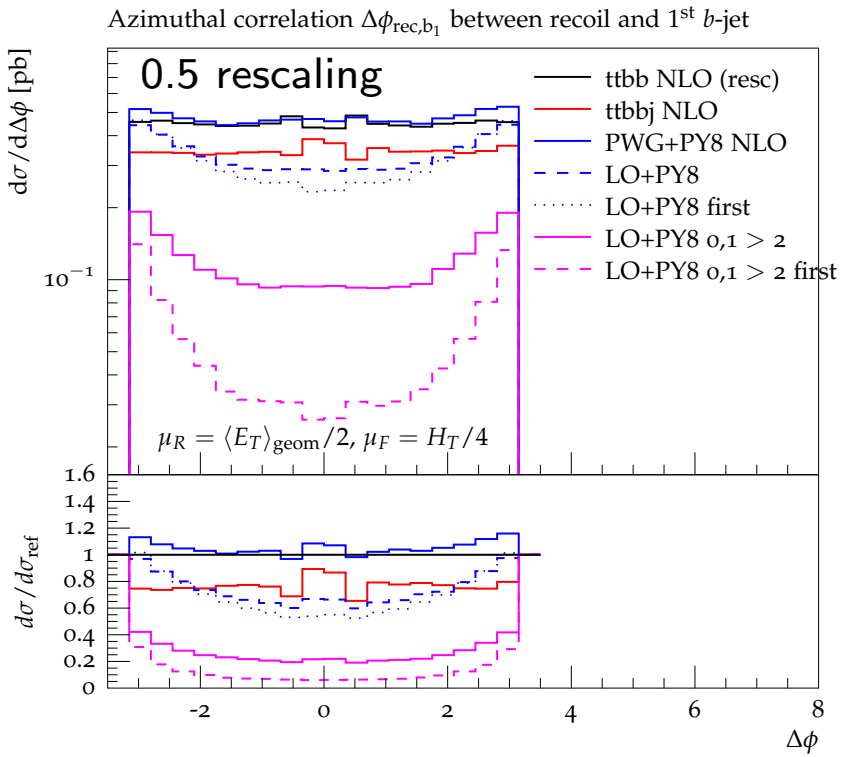


When recoil of the QCD radiation absorbed by object X $\Rightarrow$ peak at $\Delta\phi_{\mathrm{rec},X} = \pm\pi$

Bin migrations vs recoil pattern

$\Delta\Phi^{15\,\mathrm{GeV}}_{\mathrm{rec},b_1}$ (ttbb cuts)

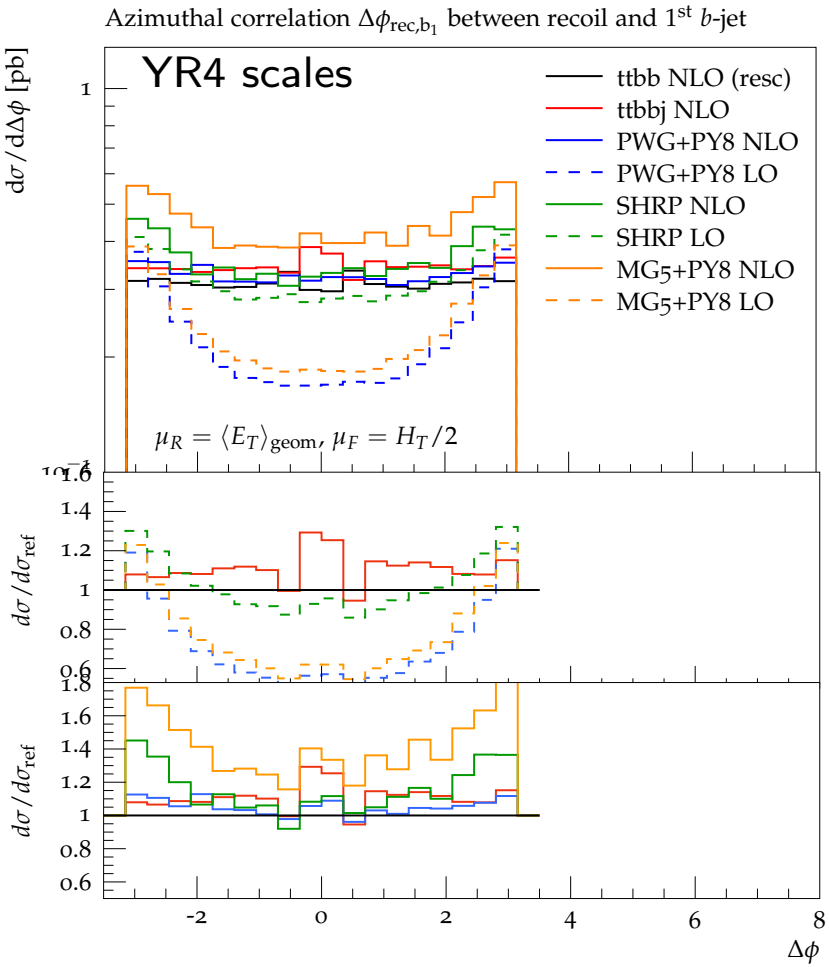


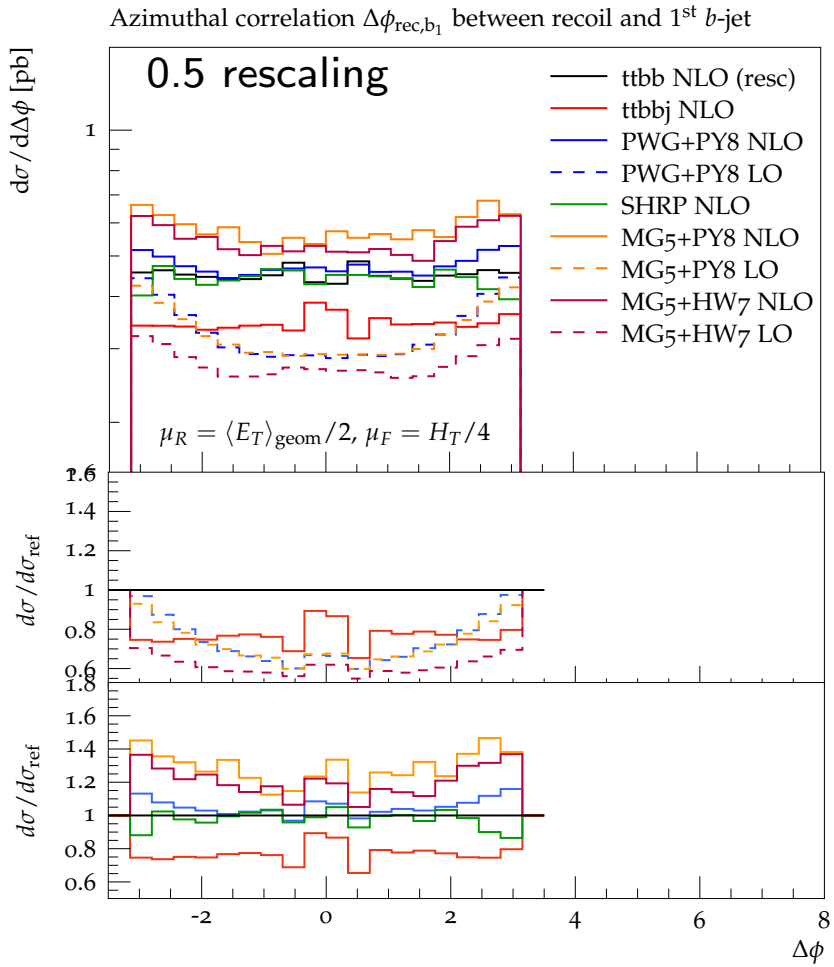


- b_1 gets strong recoil in LO+PY8 (a bit less with 0.5 rescaling)
- dominated by 1st emission and strongly correlated to migrations and excess in $p_{\mathrm{T},j}$ spectrum (see backup)
- unphysical since no evidence of recoil in ttbb, ttbbj, PWG+PY8 at NLO

MC comparison of recoil observables

$\Delta\Phi^{15\,\mathrm{GeV}}_{\mathrm{rec},b_1}$ (ttbb cuts)

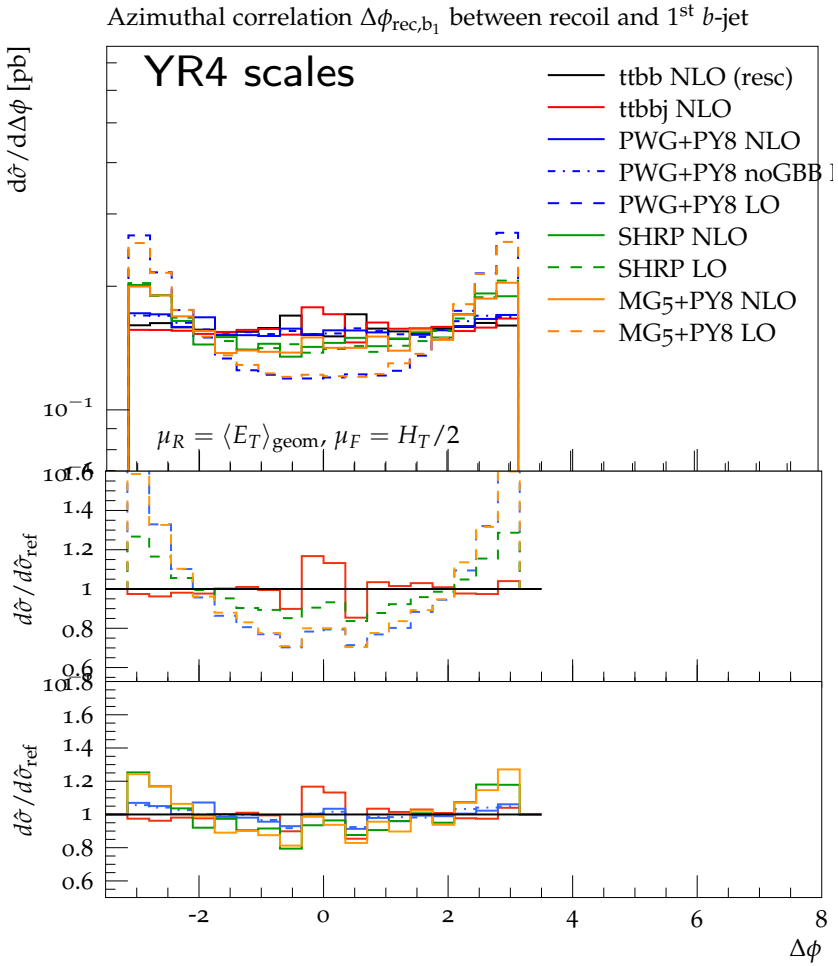


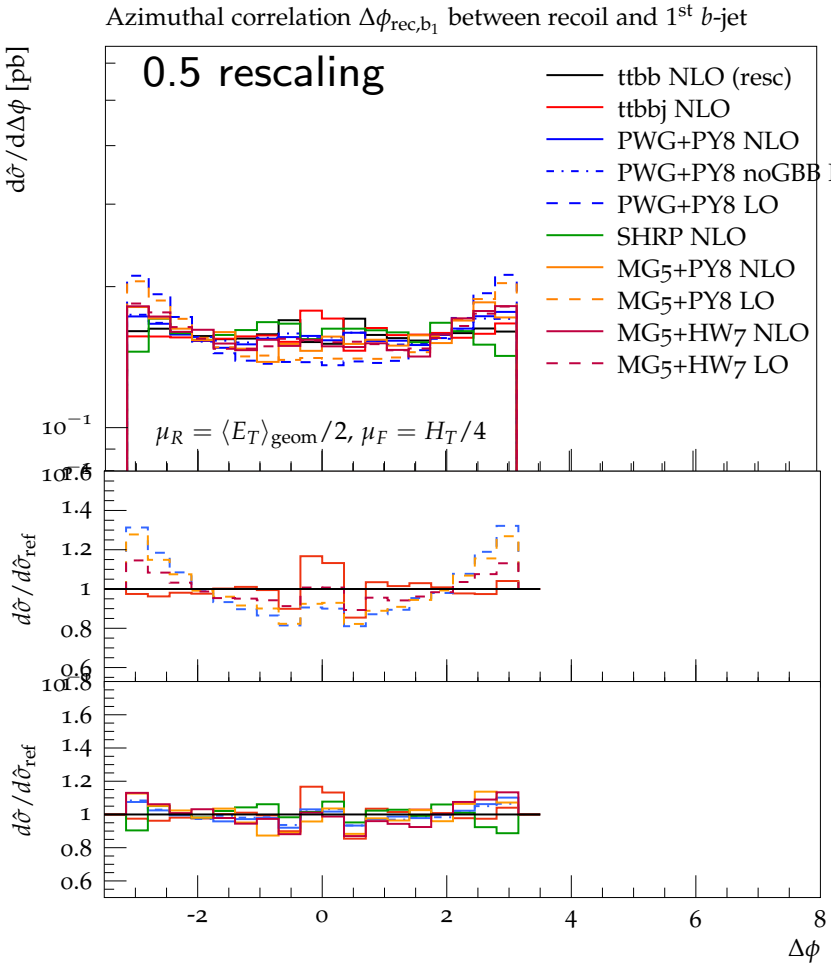


- YR4 scales: unphysical recoil stronlgy suppressed only by Powheg / attenuated by MC@NLO matching (MG and Sherpa)
- 0.5 rescaling: shapes look more similar (high-stat shape analysis needed. . .)
- Note: unphysical LOPS recoil milder with Sherpa and Herwig

Same with normalised distributions

$\Delta\Phi^{15\,\mathrm{GeV}}_{\mathrm{rec},b_1}$ (ttbb cuts)





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Lessons and how to finalise these studies

Analysis of recoil observables

- recoil/migration explanation of $\sigma(N_b \geq 2)$ excess plausile consistent with recoil observables
- however 0.5 rescaling improves agreement of recoil observables without solving $\sigma(N_b \geq 2)$ excess!

$\Rightarrow$ origin of $\sigma(N_b \geq 2)$ excess remains unexplained

Move to MC comparison with different scale setting philosophy

- keep the same perturbative scales μ_R, μ_F in all MCs
- abandon idea of uniform $\mu_{\rm sh}$ choice and use $t\bar{t}b\bar{b}j$ at NLO as guideline for MC specific $\mu_{\rm sh}$ choice

$\Rightarrow$ tune $\mu_{\rm sh}$ in different MC such as to match spectrum of jet radiation predicted by ttbbj@NLO (tune to higher-order TH instead of tuning to data)

- $\Rightarrow$ removes MC differences that are inconsistent with state-of-the art TH
- $\Rightarrow$ remaining MC differences can be regarded as irreducible uncertainties

Concrete proposal

Final choice of μ_R, μ_F

- Coming soon based on new $t\bar{t}b\bar{b}j$ analysis with cuts at 25 GeV

Choice of $\mu_{\rm sh}$

- to be tuned together with MC authors based on ttbbj@NLO benchmarks for selected ttbbj and recoil observables
- candidate scales: H_T/n with $n = 2, 3, 4, 5, 6$ also less?

Other parameter choices and variations

- α_S in the shower's 1st emission, shower tune, ...

Intrinsic MC uncertainties

- factor-2 $\mu_{\rm sh}$ variations
- $g \to bb$ splittings in PY8, ...

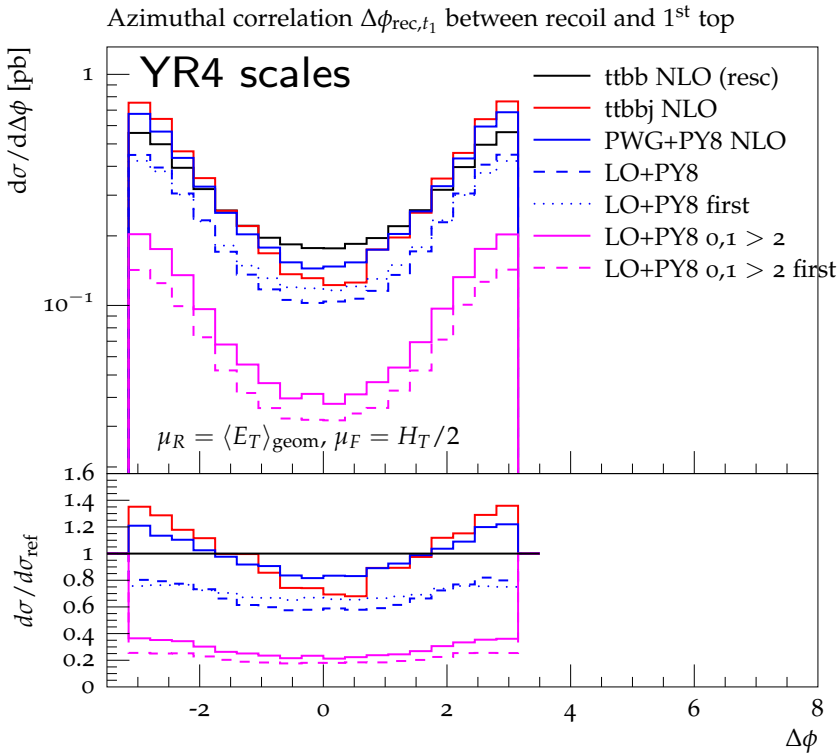
Perturbative uncertainties

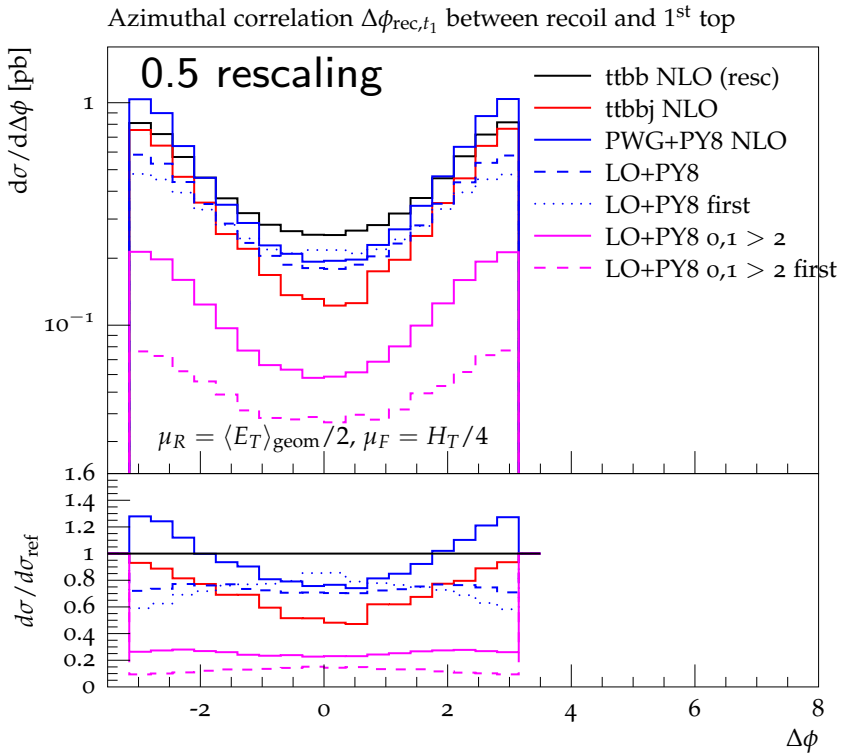
- 7-point μ_R, μ_F variations
- dynmaic scale variations? PDF variations?

Backup Slides

Bin migrations vs recoil pattern

$\Delta\Phi^{15\,\mathrm{GeV}}_{\mathrm{rec},t_1}$ (ttbb cuts)

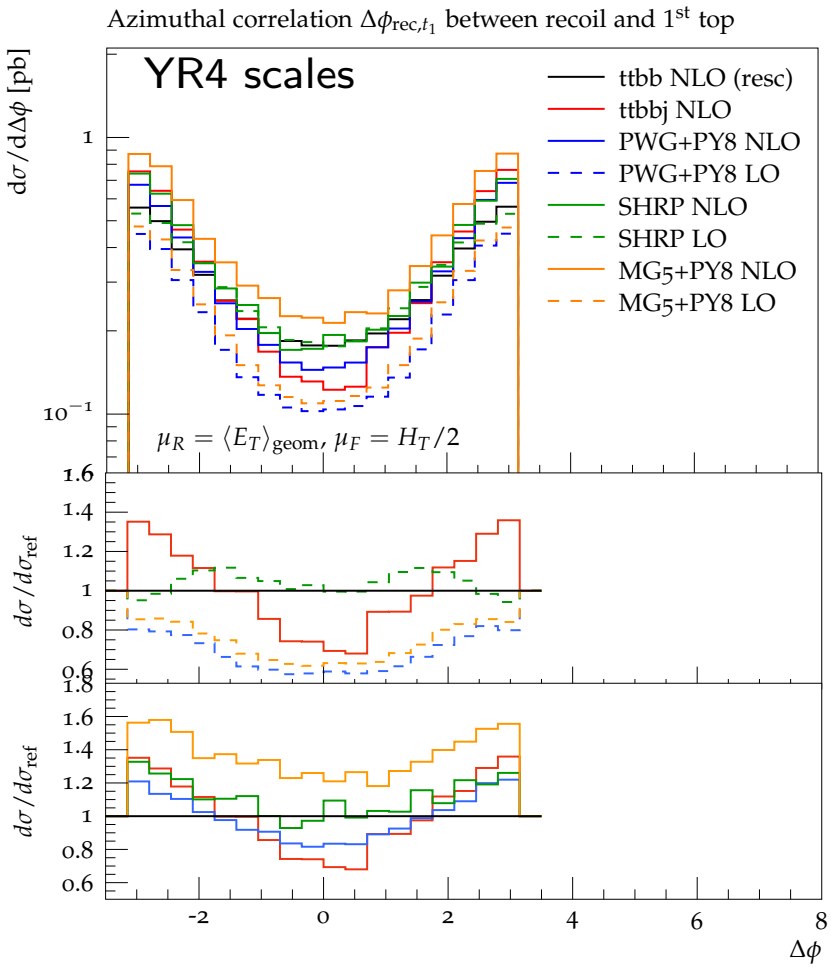


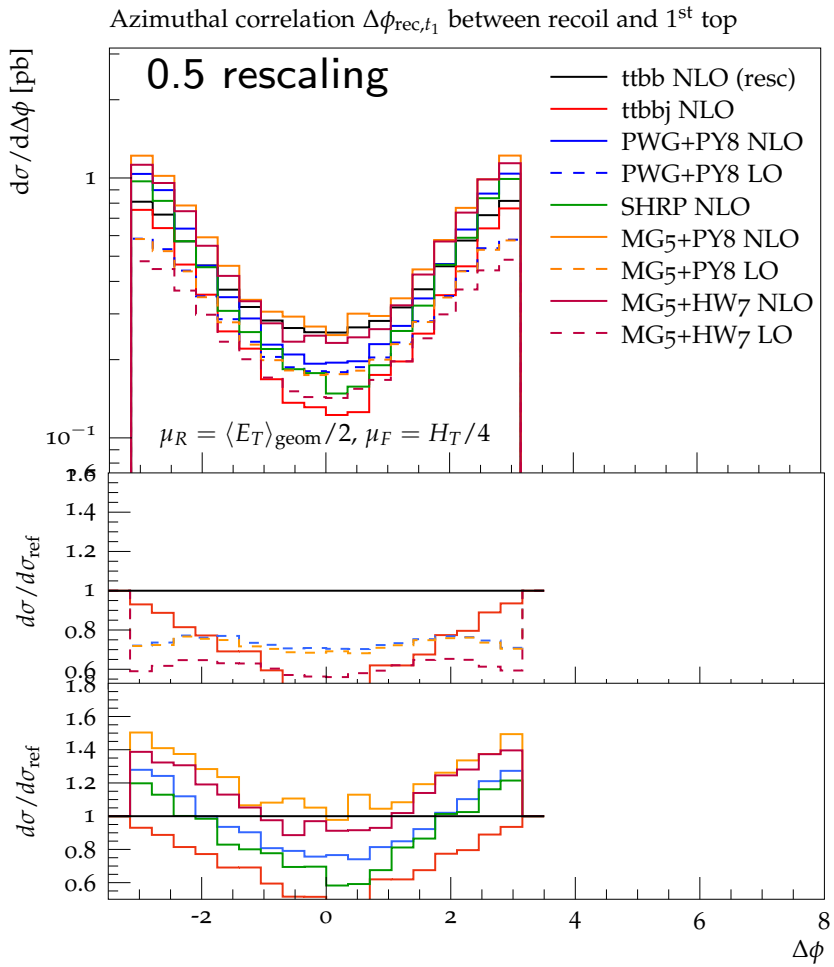


- leading top (t_1) absorbs strong recoil form QCD radiation
- 1st shower emission dominates $\Rightarrow$ can be tested against fixed-order calculations
- NLOPS enhancement of recoil well consistent with ttbbj at NLO (nontrivial!)
- no distinctive shape of migrating events

MC comparison of recoil observables

$\Delta\Phi^{15\,\mathrm{GeV}}_{\mathrm{rec},t_1}$ (ttbb cuts)





- reasonable LOPS and NLOPS agreement between PWG, MG5, Sherpa