ttb\bar{b} hadroproduction at NLO accuracy matched with parton shower

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Outline

- Motivation
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Motivation
Need for $\bar{t}t\bar{b}\bar{b}$ at the hadron level
Need for $t\bar{t}b\bar{b}$ at the hadron level

- $pp \rightarrow t\bar{t}H$ process is heavily investigated to measure the $t\bar{t}H$ coupling
Need for $t\bar{t}b\bar{b}$ at the hadron level

- $pp \to t\bar{t}H$ process is heavily investigated to measure the $t\bar{t}H$ coupling
- *signal is small, the background is overwhelming*
  - At $\sqrt{s} = 8$ TeV
    - $\sigma(t\bar{t}H) = 0.130$ pb for $m_H = 125$ GeV
    - $\sigma(tt) = 245.8$ Pb
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- And is also very uncertain
  - Experimentally: systematics, JES, b-tagging
  - Theoretically: scale uncertainties, effect of PS and hadronization
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- small signal production requires the use of the dominant $H$ decay channel, $H \rightarrow b\bar{b}$ for $m_H = 125$ GeV
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- In this work we neglect the mass of the $b$-quarks
Method
PowHel: three frameworks combined

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**RESULT:**

Les Houches file of Born and Born+1st radiation events (LHE) ready for processing with SMC followed by almost arbitrary experimental analysis
Comparison to NLO
A track was considered as a possible jet constituent if $|\eta^{\text{track}}|<5$, t-quarks were excluded from the set of possible tracks, jets were reconstructed with the $k_T$-algorithm using $R=0.4$.
Selection cuts in NLO studies

- A track was considered as a possible jet constituent if $|\eta^{\text{track}}| < 5$, t-quarks were excluded from the set of possible tracks, jets were reconstructed with the $k_T$-algorithm using $R=0.4$

- Events with invariant mass of the $b\bar{b}$-jet pair below $m_{\text{min}_{bb}} = 20 \text{ GeV}$ were discarded
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- Events with invariant mass of the $b\bar{b}$-jet pair below $m_{b\bar{b}}^{\text{min}} = 20$ GeV were discarded.
- We require $p_{T \text{min},j} = 20$ GeV and
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- We require $p_{T\text{min},j} = 20 \text{ GeV}$ and

- at least two, one $b$- and one $\bar{b}$-jet, with $|y_{b(\bar{b})}| < 2.5$
Distribution of the transverse momentum of the $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (14 TeV)

Our NLO agrees with Bevilacqua et al [0907.4723]
Distribution of the invariant mass of the $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (14 TeV)

$\bar{s} = 14$ TeV

- $m_t = 172.6$ GeV
- $p_{\perp,\text{jet}} > 20$ GeV
- $|y_{b(\bar{b})}| < 2.5$, $R = 0.4$
- $m_{\perp,b\bar{b}} > 100$ GeV

$\mu_0 = m_t$, $\mu \in [\mu_0/2, 2\mu_0]$

POWHEG vs. NLO

13. július 18., csütörtök
Separation in rapidity-azimuthal angle plane of the $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (14 TeV)
Distribution of the transverse momentum of the $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (14 TeV)

NLO with dynamical scale by Bredenstein et al [1001.4006]
Distribution of the invariant mass of the $b\bar{b}$ jet pair in $pp \to t\bar{t} b\bar{b}$ at LHC (14 TeV)

 POWHEG fixed scale vs. NLO dynamical scale

- $\sqrt{s} = 14\text{TeV}$
- $m_t = 172.6\text{GeV}$
- $p_{\perp,jet} > 20\text{GeV}$
- $|y_{b(\bar{b})}| < 2.5$, $R = 0.4$
- $m_{b\bar{b}} > 100\text{GeV}$

LHE, $\mu_0 = E_{\text{thr}}/2$, $\mu \in [\mu_0/2, 2\mu_0]$

BDDP NLO, $\mu_0^2 = m_t \sqrt{p_{\perp,b} p_{\perp,\bar{b}}}$
Message:
we can trust the LHE’s, so can make
Predictions
Four possible forms of predictions

**LHE:** distributions from events at BORN+1st radiation

**Decay:** on-shell decays of heavy particles (t-quarks), shower and hadronization effects turned off

**PS:** decays, parton showering (PYTHIA or HERWIG) included
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Four possible forms of predictions

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Number and type of particles are very different => to study the effect of SMC we employ selection cuts to keep the cross section fixed
Applied on the LHE’s:

- A track was considered as a possible jet constituent if $|\eta^{\text{track}}| < 5$, t-quarks were excluded from the set of possible tracks. Jets were reconstructed with the $k_T$-algorithm using $R=0.4$. 
Selection cuts for decay vs. SMC

- Applied on the LHE’s:
  - A track was considered as a possible jet constituent if $|\eta^{\text{track}}| < 5$, t-quarks were excluded from the set of possible tracks. Jets were reconstructed with the $k_T$-algorithm using $R=0.4$.
  - Events with invariant mass of the $b\bar{b}$-jet pair below $m^{\text{min}_{bb}} = 100 \text{ GeV}$ were discarded.
Selection cuts for decay vs. SMC

- **Applied on the LHE’s:**
  - A track was considered as a possible jet constituent if $|\eta^{\text{track}}|<5$, t-quarks were excluded from the set of possible tracks. Jets were reconstructed with the $k_T$-algorithm using $R=0.4$.
  - Events with invariant mass of the $b\bar{b}$-jet pair below $m^{\text{min}_{b\bar{b}}}=100$ GeV were discarded.

- **Applied on LHE’s and checked also on the existing particles at different stages of evolution:**
  - we require $p_{T\text{min},j}=25$ GeV and
  - at least two, one $b$- & one $\bar{b}$-jet with $|\eta_{b(\bar{b})}|<2.5$. 

13. július 18., csütörtök
Distribution of the invariant mass of the hardest $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (8TeV)
Separation in rapidity-azimuthal angle plane of the hardest $b\bar{b}$ in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (8TeV)
Decay vs. full SMC

Distribution of the invariant mass of next hardest $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (8TeV)
Separation in rapidity-azimuthal angle plane of next hardest $b\bar{b}$ in $pp \rightarrow t\bar{t} b\bar{b}$ at LHC (8TeV)
Decay vs. full SMC

Distribution of the transverse momentum of the positive lepton in $pp \rightarrow \bar{t}t \bar{b}b$ at LHC (8TeV)
Distribution of the invariant mass of the hardest $b\bar{b}$ jet pair in $pp \rightarrow t\bar{t}H$ and $t\bar{t}bb$ at LHC (14 TeV)
**ttH signal on ttbb background**

Distribution of the invariant mass of the hardest $b\bar{b}$ jet pair in $pp \rightarrow ttH$ and $tt\bar{b}b$ at LHC (14 TeV)

\[
\frac{d\sigma}{d m_{b_1\bar{b}_2}} \quad [\text{fb/GeV}] \\

\sqrt{s} = 14 \text{ TeV}
\]
Conclusions
Conclusions

✓ First computation of $pp \to t\bar{t}b\bar{b}$ at NLO + SMC accuracy [A. Kardos and Z.T. arXiv:1303.6291]

✓ NLO cross sections agree with published predictions

✓ Effects of SMC are often important, depending on shower setup, variables and cuts strongly

✓ LHE event files for $pp \to t\bar{t}$, $t\bar{t}H$, $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}jet$, $t\bar{t}b\bar{b}$ processes available, to put into SMC and perform experimental analyses on events with hadrons

➡ Predictions for LHC with NLO + SMC accuracy and optimization of selections for $pp \to t\bar{t}H$ is in progress
The end