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Single Top Production in the Wt Mode with MC@NLO

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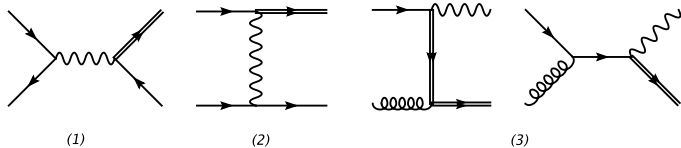
[arXiv:0805.3067 \[hep-ph\]](https://arxiv.org/abs/0805.3067)

Overview

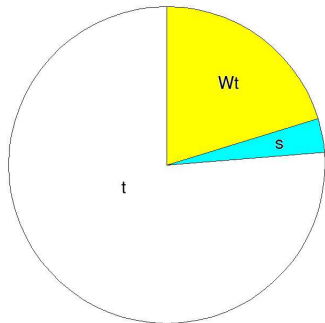
Can we isolate single top production in the Wt mode?

- ▶ Single top production modes.
- ▶ Interference of Wt mode with $t\bar{t}$ production...
- ▶ ...and their separation.
- ▶ Implementation in MC@NLO.
- ▶ Outlook.

Single Top Production

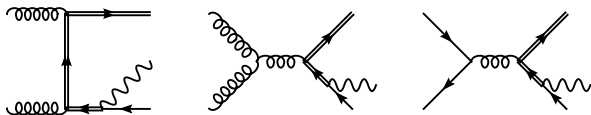


- ▶ Three modes of single top production at LO - s channel; t channel; Wt channel.
- ▶ Total LHC cross-section $\sim 320\text{pb}$ (c.f. $\sigma_{t\bar{t}} \sim 830\text{pb}$):
- ▶ Direct probe of V_{tb} etc.
- ▶ Also sensitive to new physics.



Interference Problem

- ▶ NLO real emission contributions to Wt production include:



- ▶ $\Rightarrow Wt$ and $t\bar{t}$ production interfere beyond LO - problem arises for gg and $q\bar{q}$ initial states.
- ▶ Can one separate the two processes in a well-defined way (i.e. theoretically and experimentally)?
- ▶ First time this has been considered in a full event generation context.

Interference Problem - Previous NLO Solutions

- ▶ Basic idea is to restrict the invariant mass of the associated W and its accompanying b quark so as to lie away from the top mass.
- ▶ Previous ideas include a cut on the Wb invariant mass (Belyaev, Boos & Dudko) and the subtraction of all diagrams containing a $t\bar{t}$ pair (Tait).
- ▶ These two approaches give the same σ_{NLO} for $|M_{bW} - m_t| > 15\Gamma_t$.
- ▶ In MCFM (Campbell & Tramontano) diagrams with a qq initial state are removed; so are some gg states.
- ▶ Also, a veto is imposed upon the p_t of the additional b quark (if present) in the NLO final state.
- ▶ Harder b 's tend to have come from a top decay...

Interference Problem - Previous NLO Solutions

- ▶ Theoretical problems with these approaches:
 1. Rely on diagrammatic reasoning - not suitable for experiment.
 2. Violation of renormalisation group invariance.
 3. Removal of particular initial states not suitable when initial state showers present.
- ▶ However, can use some of these ideas in the MC@NLO setting.
- ▶ We define two separation methods.
- ▶ If results agree, can be confident that Wt can be isolated.

Interference Problem - MC@NLO Solution

- ▶ Have implemented two different methods:
 1. Diagram removal (DR): simply don't include diagrams with a $t\bar{t}$ pair.
 2. Diagram subtraction (DS): subtract resonant $t\bar{t}$ contributions locally from the cross-section.
- ▶ In addition, we implement a p_t veto by analogy with MCFM, this time on the second hardest b particle (quark or hadron) in each event:

$$p_t^b < p_{t,veto}$$

- ▶ Each approach has some implementational difficulty, and theoretical distastefulness...

Diagram Removal

- ▶ In DR, remove diagrams that also enter $t\bar{t}$ production, at the amplitude level.
- ▶ Thus interference term with LO $t\bar{t}$ production completely removed.
- ▶ Potential problem: violation of EW and QCD gauge invariance.
- ▶ Have performed detailed checks in different gauges.
- ▶ Subtraction (DS) is a little more complicated...

Diagram Subtraction

- ▶ Schematically, one requires:

$$\sigma_{ab \rightarrow Wt} = \sigma_{ab} - \sigma_{ab}^{subt},$$

where σ_{ab} describes a Wtb final state and σ_{ab}^{subt} removes resonant top pair contributions if present.

- ▶ This is now completely gauge invariant.
- ▶ Difference with DR is mostly due to interference term between Wt and LO $t\bar{t}$.
- ▶ Now need a suitable subtraction term...

Subtraction Term

- ▶ Naïvely, one can write:

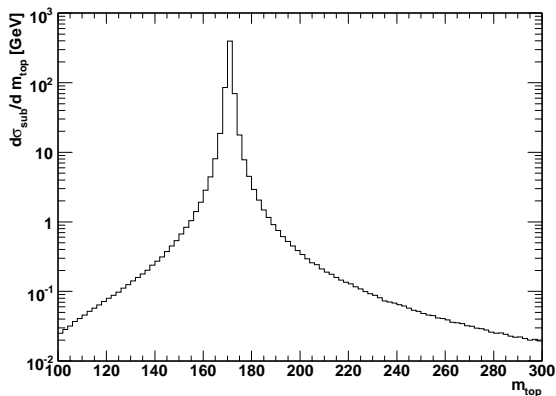
$$\sigma_{ab}^{subt} = |\mathcal{A}(ab \rightarrow t\bar{t})|^2 \times f_{BW}(M_{\bar{b}W}) \times |\mathcal{A}(\bar{t} \rightarrow W\bar{b})|^2,$$

where f_{BW} is the Breit-Wigner function. However:

1. Kinematics on the LHS is from $ab \rightarrow tWb$, but need \bar{t} on-shell on the RHS.
 2. Spin correlations of the top decay products are not included - needed for local matching of matrix elements.
- ▶ Hence we define the subtraction term:

$$\sigma_{ab}^{subt} = \underbrace{|\tilde{\mathcal{A}}(ab \rightarrow tW\bar{b})_{t\bar{t}}|^2}_{\text{Reshuffled kinematics} \rightarrow \bar{t} \text{ on-shell}} \times \overbrace{\frac{f_{BW}(M_{\bar{b}W})}{f_{BW}(m_t)}}^{\text{Damp if } M_{\bar{b}W} \text{ far from top mass.}} .$$

Subtraction Term



- Strongly peaked at top mass, as required.

DR & DS - Summary

Diagram Removal

- ▶ $t\bar{t}$ removed at amplitude level.
- ▶ Not gauge invariant.
- ▶ Easy to implement spin correlations.
- ▶ Defined fully exclusively, at any order.

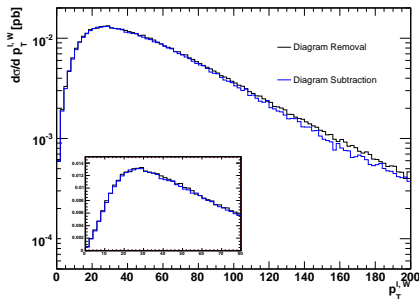
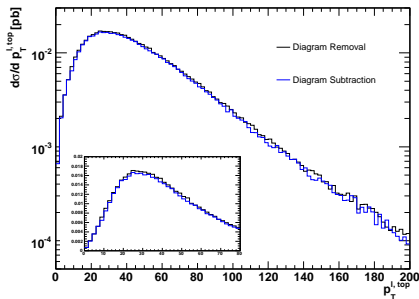
Diagram Subtraction

- ▶ $t\bar{t}$ removed at cross-section level.
- ▶ Gauge invariant.
- ▶ Difficult to implement spin correlations.
- ▶ Defined fully exclusively, at any order.

Implementation in MC@NLO

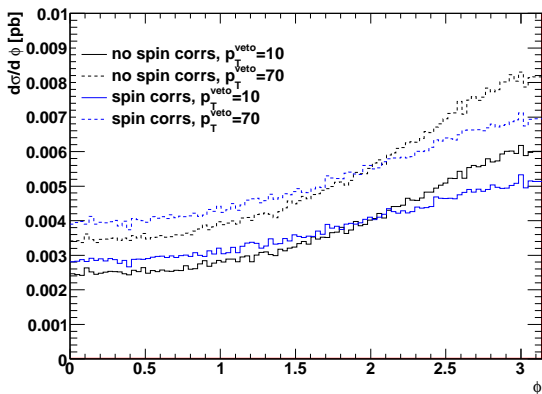
- ▶ MC@NLO combines NLO matrix element with LL parton shower, and avoids double counting [Frixione, Webber](#).
- ▶ NLO Wt cross-section was recalculated in the FKS formalism...
- ▶ ... then implemented with both separation mechanisms in MC@NLO.
- ▶ Spin correlations of top decay products included in DR (using method of [Frixione, Laenen, Motylinski & Webber](#)).
- ▶ Can present preliminary results to examine the effect of:
 1. Different subtraction mechanisms.
 2. Effect of spin correlations.
 3. Scale dependence (μ_F & μ_R).
- ▶ Take, as an example, fully leptonic decay of the Wt final state.

Results - Effect of Subtraction Mechanism



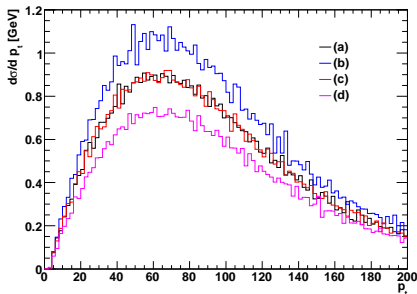
- ▶ Subtraction and Removal give very similar results, except at very high p_t (here $p_{t, \text{veto}} = 50\text{GeV}$).
- ▶ Here the cross-section is very small.

Results - Effect of Spin Correlations



- ▶ ϕ is the azimuthal angle between the leptons from the t and W decays (presented for DR).
- ▶ Clearly see a significant difference in distributions.

Results - Scale Variation



- ▶ Results here shown for DR at NLO level...
- ▶ Distributions relatively flat if $\mu_F = \mu_R = \mu$ (as reported by [Campbell & Tramontano](#)).
- ▶ More sensitivity if $\mu_F \neq \mu_R$.

Conclusions

Can we isolate the Wt mode beyond NLO?

- ▶ Yes, subject to adequate cuts.
- ▶ Have defined two separation mechanisms for use in an all orders context.
- ▶ Each has theoretical ambiguities, but they agree well.
- ▶ Difference between separation mechanisms less than e.g. spin correlations.
- ▶ More detailed phenomenology to come...