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Single Top Production in the Wt Mode with MC@NLO

Work done in collaboration with S. Frixione, E. Laenen, P. Motylinski, B. Webber

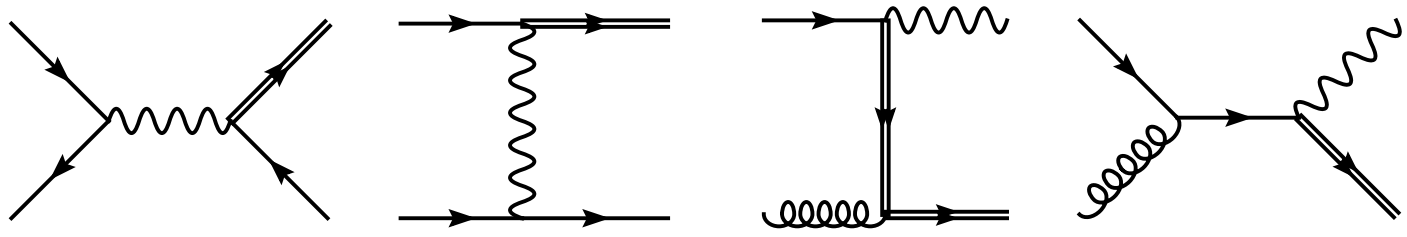
DIS 2008

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

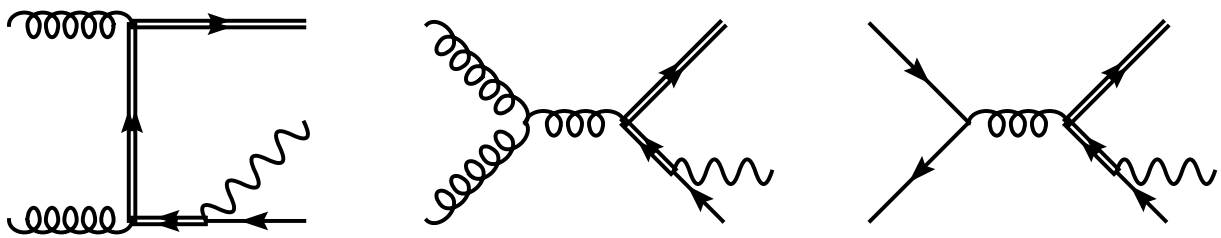


(1) *(2)* *(3)*

- Three modes of single top production at LO.
- Here we focus on Wt mode.
- Cross-section too small for Tevatron, but significant at LHC.
- Directly probes top weak interactions and V_{tb}, and is a background to e.g. $t\bar{t}$ production and $gg \rightarrow H(\rightarrow W^+W^-)$.
- Top sector of interest in new physics models.

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 gg initial state are removed.
- Also, a veto is imposed upon the p_t of the second 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.
- 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.
- Not a problem as long as one is confident we are close to a gauge invariant result.
- Subtraction (DS) is a little more complicated...

Diagram Subtraction

- Schematically, one requires:

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

  where σ_{ab} describes a Wtb final state and $\sigma_{ab}^{subt.}$ 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:

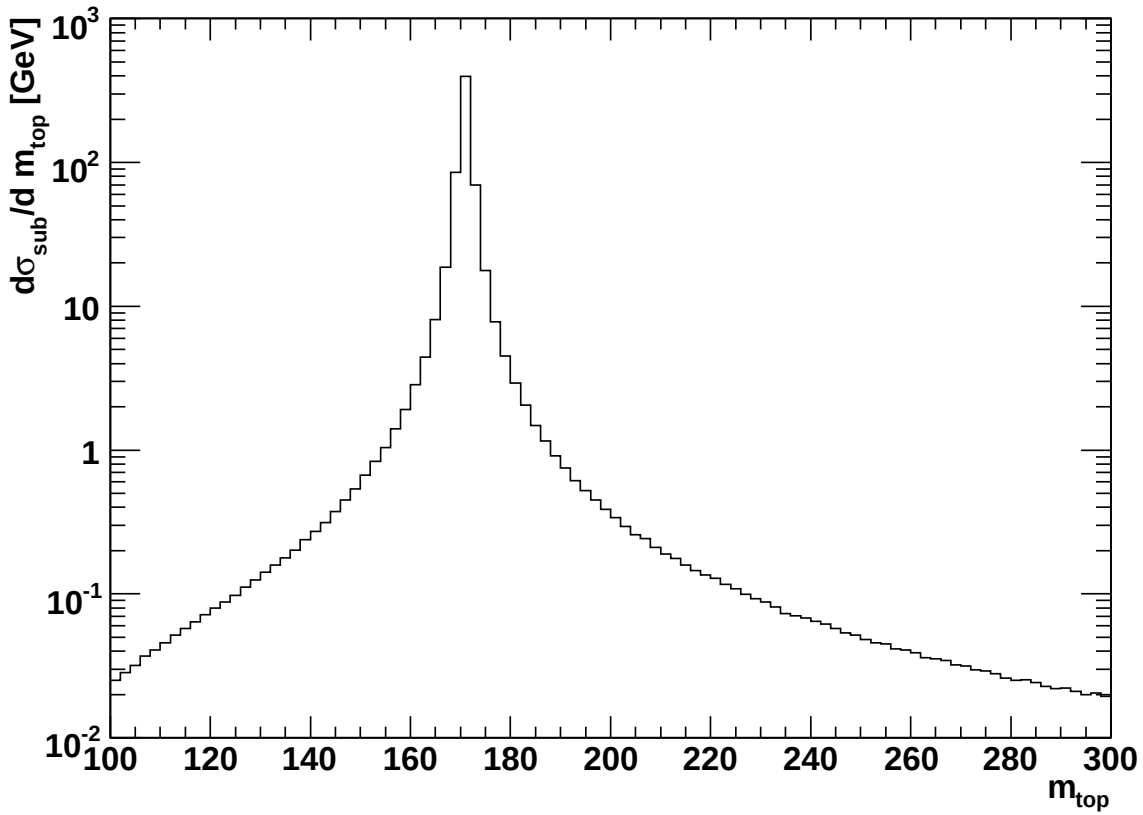
$$\sigma_{ab}^{subt} = |\mathcal{A}(ab \to t\bar{t})|^2 \times f_{BW}(M_{\bar{b}W}) \times |\mathcal{A}(\bar{t} \to W\bar{b})|^2,$$

  where f_{BW} is the Breit-Wigner function. However:
  1. Kinematics on the LHS is from $ab \to tWb$, 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:

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

Subtraction Term

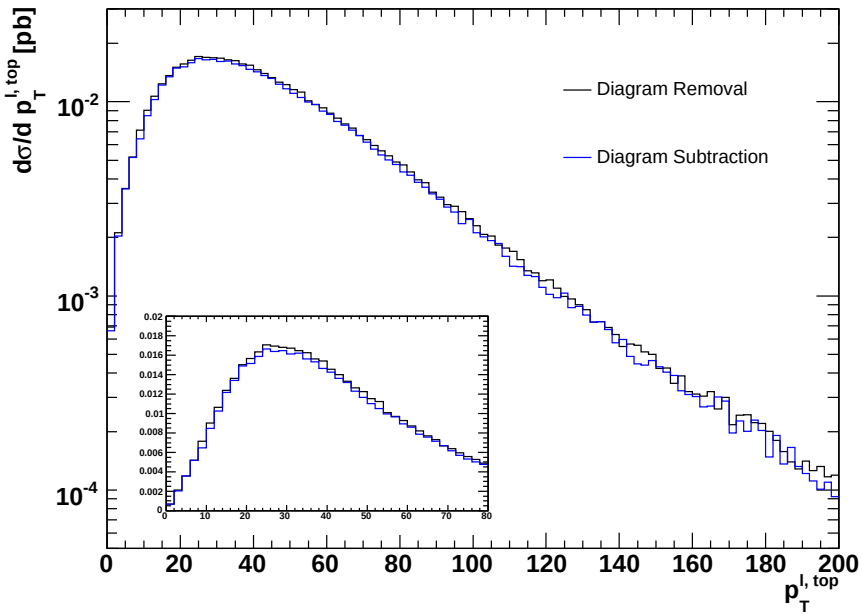


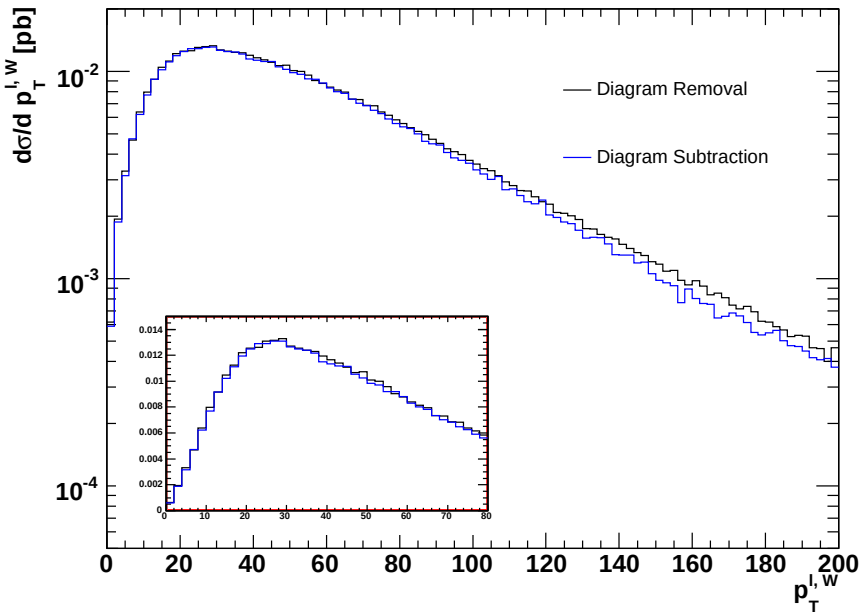
- Strongly peaked at top mass, as required.

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.

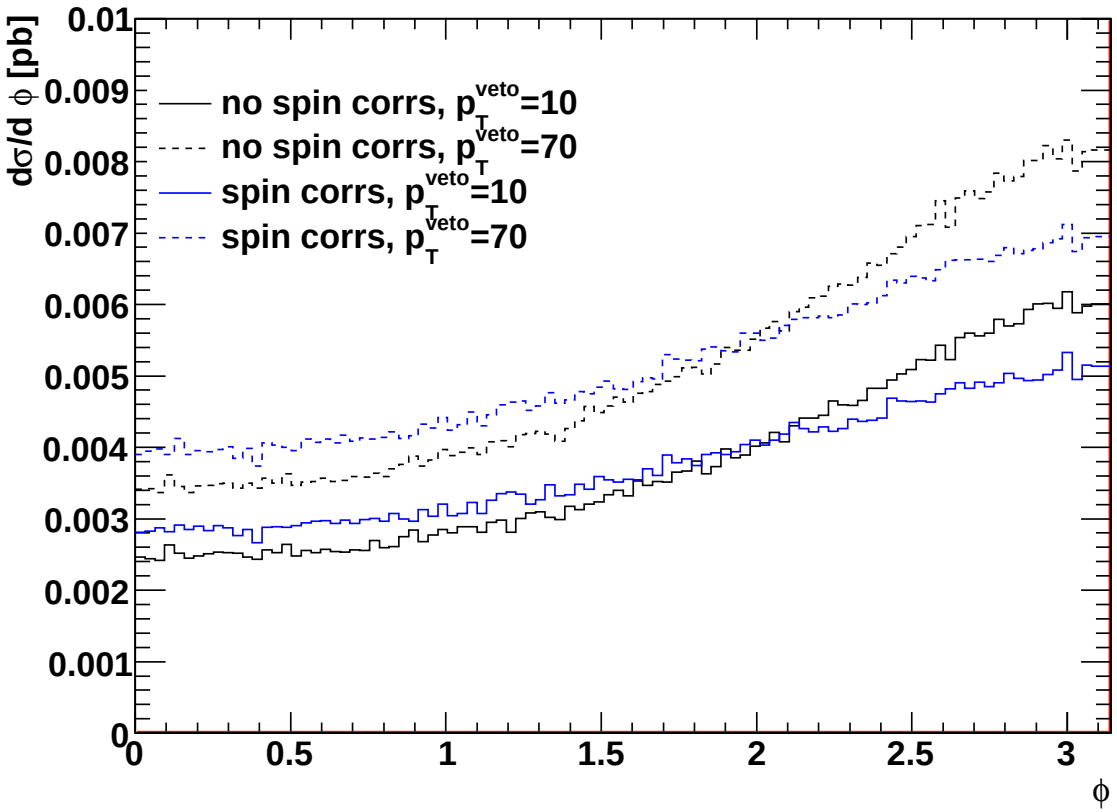
Results - Effect of Subtraction Mechanism





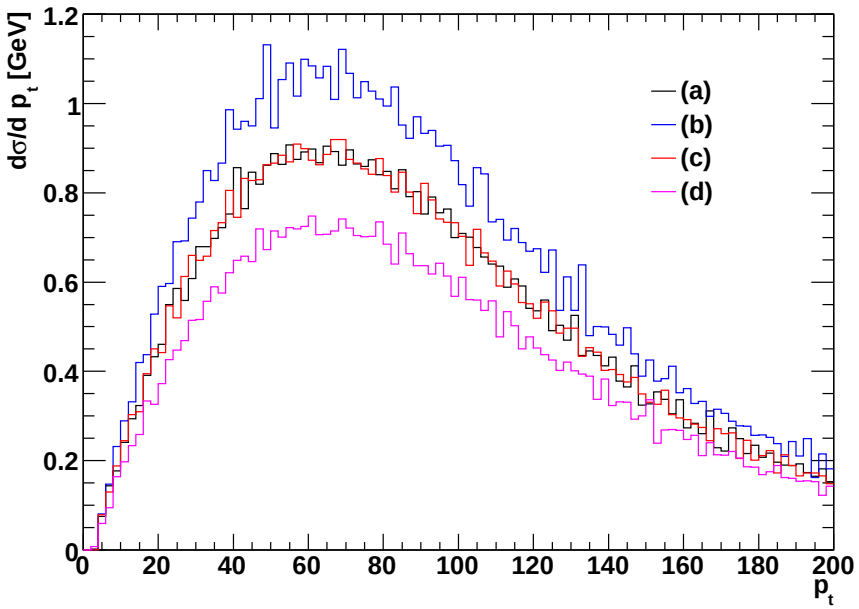
- Subtraction and Removal give very similar results, except at very high p_t.
- Here the cross-section is very small.

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.
- Final checks taking place.
- More detailed phenomenology to come...