Single Top Production and Decay in MC@NLO

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Outline

Motivations For Single-Top

- Direct Measurement of V_{tb}
- Test the charged current coupling of the top quark
- Determine b quark density
- Single-top processes are important backgrounds for new physics ($W', Z', \ldots$)

There are already several NLO calculations for single-top processes:

- B.W. Harris, E. Laenen, L. Phaf, Z. Sullivan, S. Weinzierl
- Z. Sullivan (ZTOP)
- J. Campbell, R.K. Ellis, F. Tramontano (MCFM)
- Q.-H. Cao, R. Schwienhorst, C.P. Yuan

Single Top in MC@NLO

(S. Frixione, E. Laenen, P. Motylinski, B. Webber: *hep-ph/0512250*)

- Matching NLO with Parton Showers (gives better final state description)
- MC@NLO is an event generator (!)
- Hardest p_T emission is computed exactly in agreement with NLO calculation

What had to be done:

- Compute NLO using FKS subtracion method
- Construct MC counter terms
- A LOT of testing...

THE FKS METHOD

(S. FRIXIONE, Z. KUNSZT, A. SIGNER)

- Soft and/or collinear divergencies are dealt with through subtraction method
- Essentially partitioning phase space according to:
  - No overlapping regions
  - At most *one* collinear and *one* soft singularity in each region

How is this done for the single top process in MC@NLO?
Introducing functions with the properties:

$$1 = \mathcal{S}_i^{(\mathrm{IN})} + \mathcal{S}_i^{(\mathrm{OUT})} \quad \forall i$$

$$d\sigma = \int d\mathrm{PS}|\mathcal{M}|^2 \left(\mathcal{S}_i^{(\mathrm{IN})} + \mathcal{S}_i^{(\mathrm{OUT})} \right)$$

In case of single top: we use $i = 3$.

$\mathcal{S}^{(\mathrm{IN})}{}_i = 1$ where particle i becomes collinear with one of the incoming particles. Similarly $\mathcal{S}^{(\mathrm{OUT})}{}_i = 1$ where particle i becomes collinear with one of the outgoing particles.

$$\mathcal{S}_3^{(\mathrm{IN})} = \frac{(k_3 \cdot k_1)^a (k_3 \cdot k_2)^a}{(k_3 \cdot k_1)^a (k_3 \cdot k_2)^a + (k_3 \cdot p_1)^a (k_3 \cdot p_2)^a}$$
$$\mathcal{S}_3^{(\mathrm{OUT})} = \frac{(k_3 \cdot p_1)^a (k_3 \cdot p_2)^a}{(k_3 \cdot k_1)^a (k_3 \cdot k_2)^a + (k_3 \cdot p_1)^a (k_3 \cdot p_2)^a}$$

Thus in each region of phase space the corresponing part of the cross section is treated separately.$\Rightarrow$ In case of singularity: subtraction method applied to this part of the cross section.

MC counterterm

- Analogous to $BQ(x)/x$ (see next slide)
- Needed in final state (recoil jet)
  Special in the single-top case:
  - first inclusion of final state jet in MC@NLO
- Easy colour structure

How MC@NLO works:

$$\left(\frac{d\sigma}{d\mathcal{O}}\right) = \int_0^1 dx \Bigg[\underbrace{I_{MC}(\mathcal{O}, x_M(x)) \frac{\alpha(R(x) - \overbrace{BQ(x)}^{\text{parton shower @ }\mathcal{O}(\alpha)})}{x}}_{\text{Real emission + MC shower}} + \underbrace{I_{MC}(\mathcal{O}, 1)\left(B + \alpha V - \frac{\alpha B(Q(x) - 1)}{x}\right)}_{\text{(LO \& virtual) + MC shower}} \Bigg]$$

where

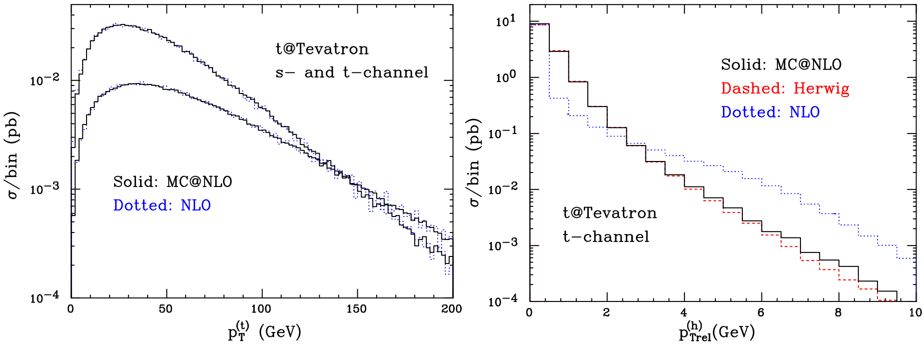
B is the Born cross section

V is the virtual correction

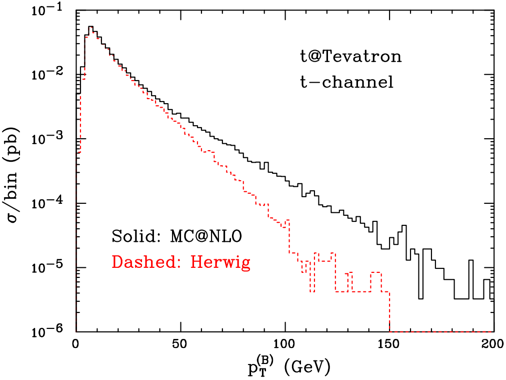
R is describes real corrections

x_M is the maximal energy available for subsequent photon emission (via showers)

I_{MC} is the interface-to-MC: $I_{MC}(\mathcal{O}, x_M)$ is the diff. cross section obtained by running MC starting at scale x_M.



Left: p_T of the top quark
Right: p_T of particles included in the jet relative to the axis of the jet.


t@Tevatron
t−channel
Solid: MC@NLO
Dashed: Herwig
σ/bin (pb)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
50
100
150
200
$p_T^{(B)}$ (GeV)

Top Decay and Spin Correlations

(S. Frixione, E. Laenen, P. Motylinski, B. Webber: *hep-ph/0702198*)

The aim of studying spin correlations in (single) top decay is to determine the handed-ness of the EW coupling of the top. (Std. Model: purely left-handed)

Due to strong correlation with the decay products it will be possible to measure the coupling. (100% correlation between top-spin and lepton direction)

The full (leptonic) matrix element is bounded from above by an overall constant times the undecayed matrix elements, i.e.:

$$\frac{d\sigma_{l\nu b}}{dPS} \leq \frac{4g_W^4|V_{tb}|^2(r\cdot k_2)(p\cdot k_1)}{\left(\left(q^2-m_W^2\right)^2+\left(m_W\Gamma_W\right)^2\right)\left(\left(p^2-m_t^2\right)^2+\left(m_t\Gamma_t\right)\right)}d\sigma_t$$

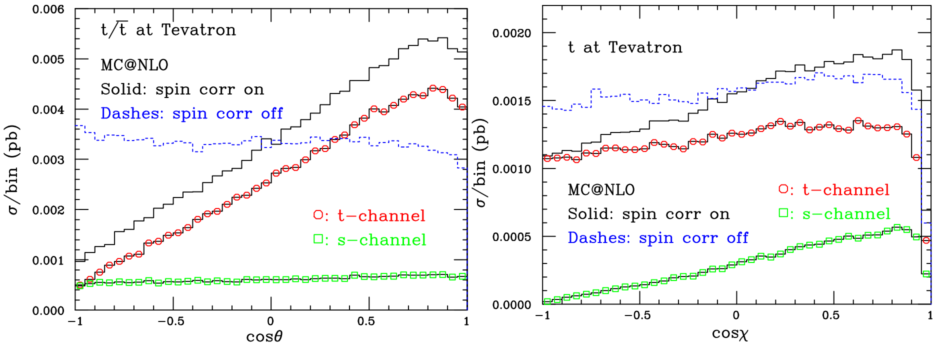
How is this done in MC@NLO?
Make angular correlations precise to

- NLO only for real (hard) emissions
- LO for soft/collinear regions

In practice

1. Integrate undecayed matrix element via MC@NLO (creates set of events)
2. Generate hard events using result from step 1
3. For each hard event generate lepton and b quark momenta in the decay space of the top
4. Compute (full) lepton matrix element (using MadGraph) using momenta from 3, and compute undecayed matrix element using momenta from step 2.
5. Do hit-and-miss

Effects of Spin Correlations



where
θ is the angle between the direction of flight of the lepton (from top decay) and the hardest non-b jet
χ is the the angle between the direction of flight of the lepton (from top decay) and the anti-proton beam.

"The Last Slide"

Angular correlations are now included for the single top process in MC@NLO ver. 3.3!

Angular correlations are included for

- $t\bar{t}$ production
- VV production