Soft gluon resummation for the associated production of a top quark pair with a W or Z boson at the LHC

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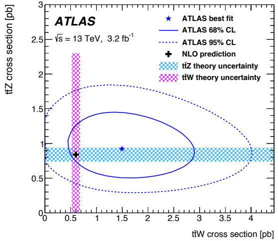

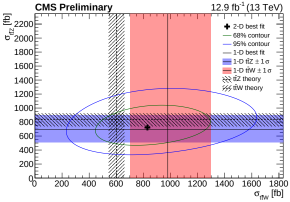

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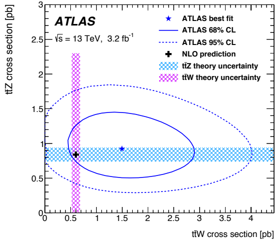

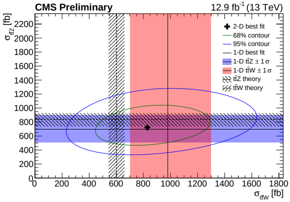

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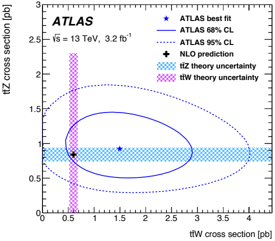
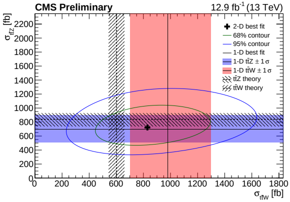
- resummation: class of corrections beyond NLO





Status of $t\bar{t}V$

- $t\bar{t}W/t\bar{t}Z$: NLO QCD, matched to PS, EW NLO corrections
  [Lazopoulos, Melnikov, Petriello, '08] [Lazopoulos, McElmurry, Melnikov, Petriello, '08] [Garzelli, Kardos, Papadopoulos, Trocsanyi, '12] [Campbell, Ellis, '12] [Kardos, Trocsanyi, Papadopoulos '12] [Alwall, Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Zaro '14] [Frixione, Hirschi, Pagani, Shao, Zaro, '15]

Status of $t\bar{t}V$

resummation:

- $t\bar{t}H$:
  - direct QCD approach (Mellin space approach) [Kulesza, Motyka, Stebel, Theeuwes, '15 '16 '17]
  - SCET-based methods [Broggio, Ferroglia, Pecjak, Signer, Yang, '16] [Broggio, Ferroglia, Pecjak, Yang, '17]
- $t\bar{t}W/t\bar{t}Z$:
  - SCET-based methods [H. T. Li, C. S. Li, S. A. Li, '14] [Broggio, Ferroglia, Ossola, Pecjak, '16] [Broggio, Ferroglia, Ossola, Pecjak, Sameshima '17]

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- Mellin space for factorisation of phase space

$$\sigma(N) = \int_0^1 \tau^{N-1} \sigma(\tau)$$

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invariant mass threshold resummation:

- resummed logarithms

$$\alpha_S^m \left(\frac{\log^n (1 - \hat{\tau})}{1 - \hat{\tau}} \right)_+ \qquad m \leq 2n - 1$$

$$\int_0^1 \mathrm{d}x (f(x))_+ = \int_0^1 \mathrm{d}x (f(x) - f(x_0))$$

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- turn into $\log(N) = L$ in Mellin space

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$$\frac{d\tilde{\sigma}^{res}_{ij\to t\bar{t}V}}{dQ^2} = \mathrm{Tr}[\mathbf{H}_{ij\to t\bar{t}V}\mathbf{S}_{ij\to t\bar{t}V}]\Delta_i\Delta_j$$

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calculations done in singlet octet colour basis

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- Δ_i: soft and collinear radiation for incoming partons

$$\Delta_i = \exp\left[\int_0^1 dz \frac{z^{N-1}-1}{1-z}\int_{\mu^2}^{Q^2(1-z)^2}\frac{dq^2}{q^2}A_i(\alpha_S(q^2))\right]$$

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- $\mathbf{S}_{ij\to t\bar{t}V}$ soft wide angle radiation, at NLL and in the basis in which the one-loop soft anomalous dimension matrix Γ is diagonal:

$$\mathbf{S}_{ij\to t\bar{t}V,R,IJ} = \mathbf{S}^{(0)}_{ij\to t\bar{t}V,R,IJ}\exp\left[\int_{\mu}^{Q/N}\frac{dq}{q}(\lambda^*_{R;I}+\lambda_{R,J})\right]$$

- $\lambda_{R,J}$: eigenvalues of Γ

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- $\mathbf{H}_{ij\to t\bar{t}V} = \mathbf{H}^{(0)}_{ij\to t\bar{t}V} + \frac{\alpha_S}{\pi}\mathbf{H}^{(1)}_{ij\to t\bar{t}V} + \ldots$: hard contributions

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- at NLL accuracy $\mathbf{H}_{ij\to t\bar{t}V} = \mathbf{H}^{(0)}_{ij\to t\bar{t}V}$(Born cross section)
- improvement beyond NLL: $\mathbf{H}^{(1)}_{ij\to t\bar{t}V}$ included (for full NNLL resummation $\mathbf{S}, \Delta_i, \Delta_j$ need to be upgraded to NNLL)

Cross sections for $t\bar{t}W$

total inclusive cross sections, $\sqrt{S} = 13\,\text{TeV}$, $\mu_R = \mu_F = m_t + \frac{m_V}{2}$, MMHT2014

NLO: [Garzelli, Kardos, Papadopoulos, Trocsanyi '11][Garzelli, Kardos, Papadopoulos, Trócsányi '12]:

- $\sigma_{t\bar{t}W^+} = 422.1^{+12.8\%}_{-11.5\%}\,\text{fb}$
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Preliminary

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NLL with $\mathbf{H}^{(1)}$ matched to NLO:

- $\sigma_{t\bar{t}W^+} = 418.4^{+12.8\%}_{-10.0\%}$ fb
- $\sigma_{t\bar{t}W^-} = 214.4^{+13.4\%}_{-10.1\%}$ fb   Preliminary

Cross sections for $t\bar{t}W$

total inclusive cross sections $\mu_F = \mu_R = Q$
NLO:

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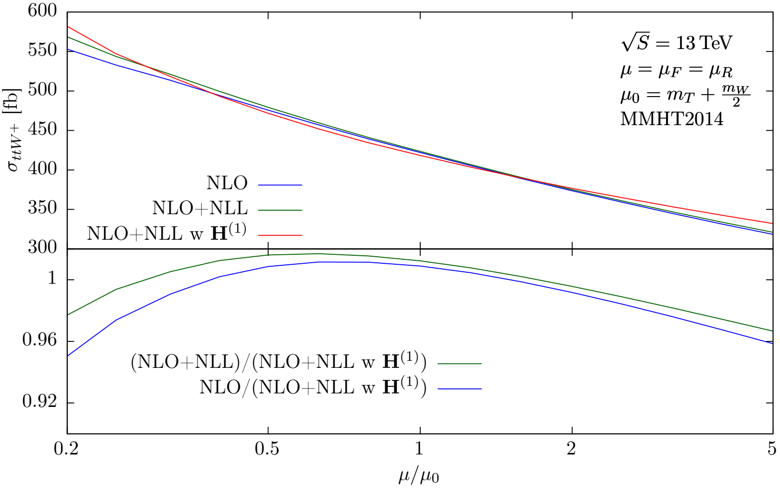
NLL with $\mathbf{H}^{(1)}$ matched to NLO:

- $\sigma_{t\bar{t}W^+} = 341.1^{+10.7\%}_{-8.6\%}$ fb
- $\sigma_{t\bar{t}W^-} = 175.3^{+9.9\%}_{-8.4\%}$ fb   Preliminary

Scale dependence $t\bar{t}W^+$ $\mu = m_t + \frac{m_W}{2}$



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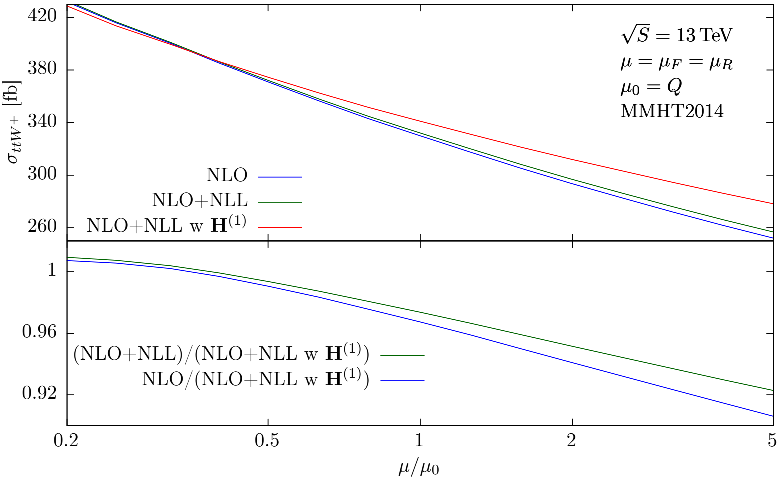

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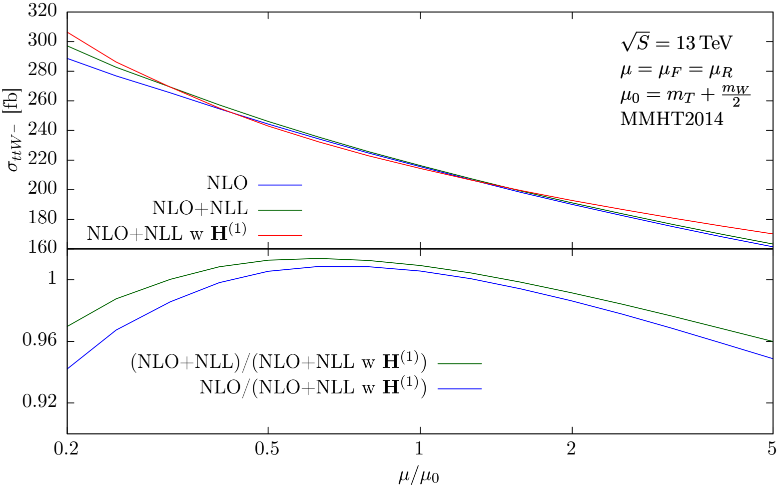

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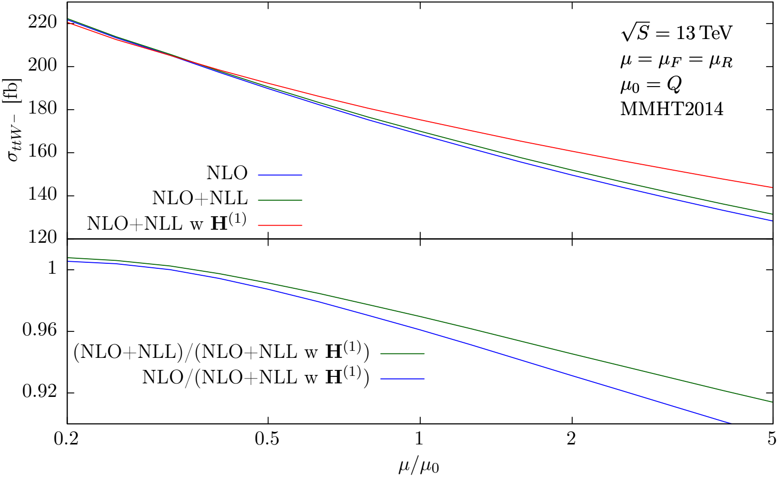

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