Theory proposals for reference single-top cross sections

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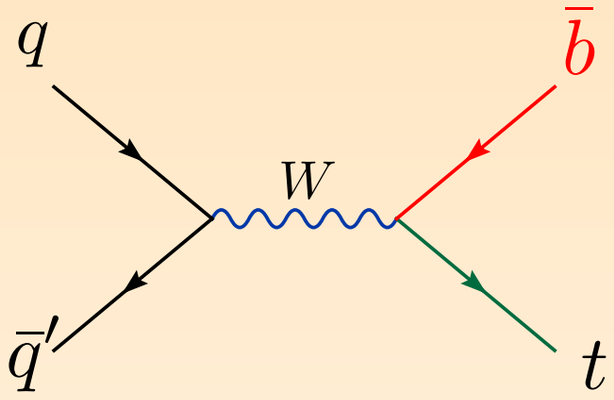
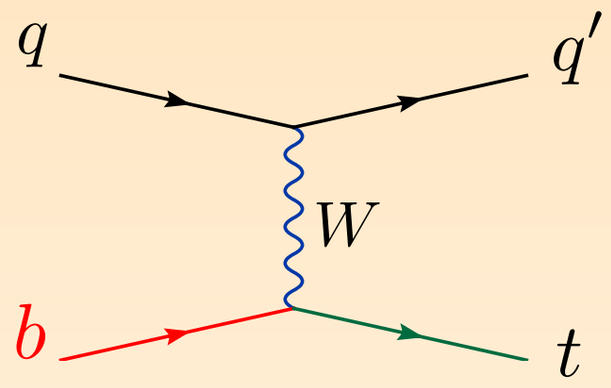
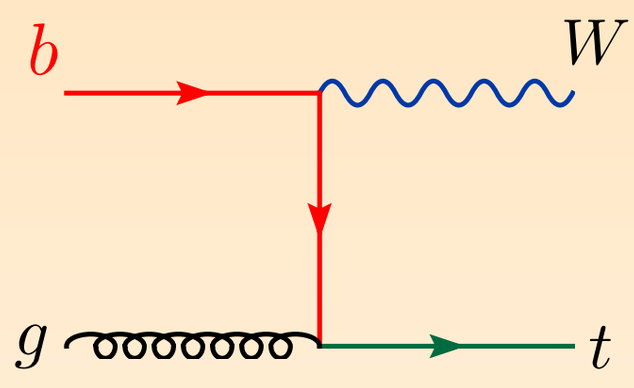
The three single top channels







- It is customary to define the three LO channels of producing a top quark as separate processes
- This is a picture based on LO perturbation theory, but can no longer hold when higher order corrections are taken into account. It is simply not physical to separate processes based solely on the virtuality of the W-boson (space-like (t-channel), time-like (s-channel), on-shell (Wt associated production))
- Therefore, in the long run, we should consider it as a single process

What that means

- It no longer makes sense to quote separate inclusive cross sections for each of these channels

- However, they can be defined using fiducial cross section measurements

- This also means that we as theorist should work to include these interference effects in our predictions

Is this already a problem now?

- Not really yet. At least not for t-channel and s-channel production
- Their interference only enters at NNLO (in the 5 Flavour scheme) and is expected to be small enough to be neglected
  - Moreover, separating them allows one to compute t-channel in the 4FS, which results in a better description of the spectator b quark
- On the other hand, it does make sense to quote also fiducial cross sections and not only the total one
- Currently, using NLO+PS 4 flavour-scheme prediction, normalised to the inclusive NNLO 5 flavour-scheme prediction is the state of the art for t-channel single top production

Uncertainties in the t-channel

- t-channel single-top total rate is under very good theoretical control
- The cross section to quote is the recent NNLO one
  [Brucherseifer, Caolo, Melnikov, 2014]

$$\sigma_{\text{NNLO}} = 54.2^{+0.5}_{-0.2}\ \text{pb} \qquad \sigma_{\text{NNLO},\bar{t}} = 29.7^{+0.3}_{-0.1}\ \text{pb}$$

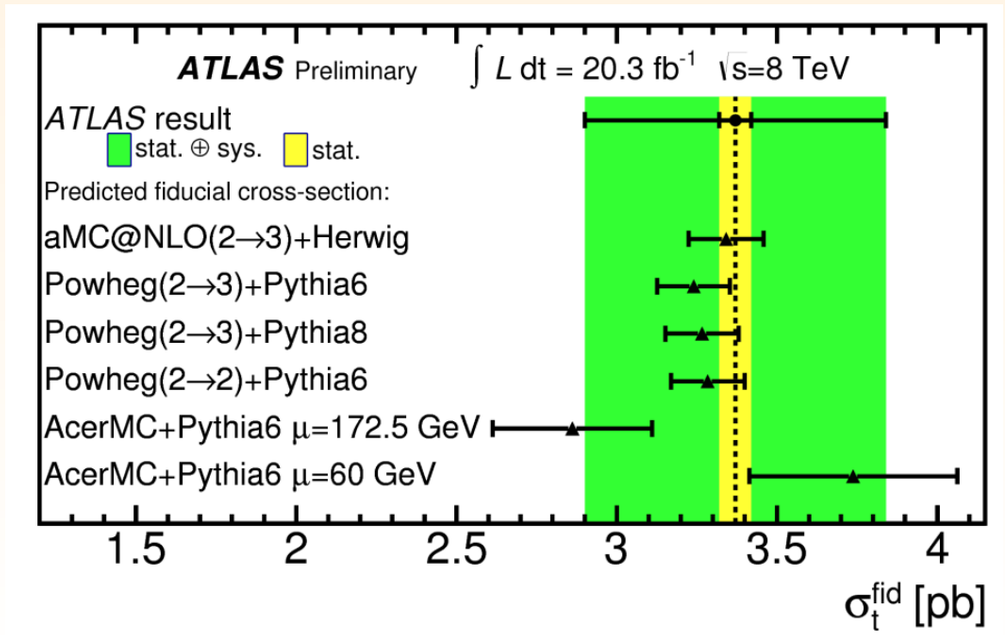
  - Scale uncertainties on the total rate are below the % level
  - PDF uncertainties are only slightly larger
  - The bottom quark mass effects are larger as well!
    in the 2->3 process explicitly in the matrix elements,
    in the 2->2 process in the PDF
    - varying the bottom quark (pole) mass by +/-250 MeV changes the cross section by about +/- 2%
    - Effect on (normalised) distributions should be very small, though

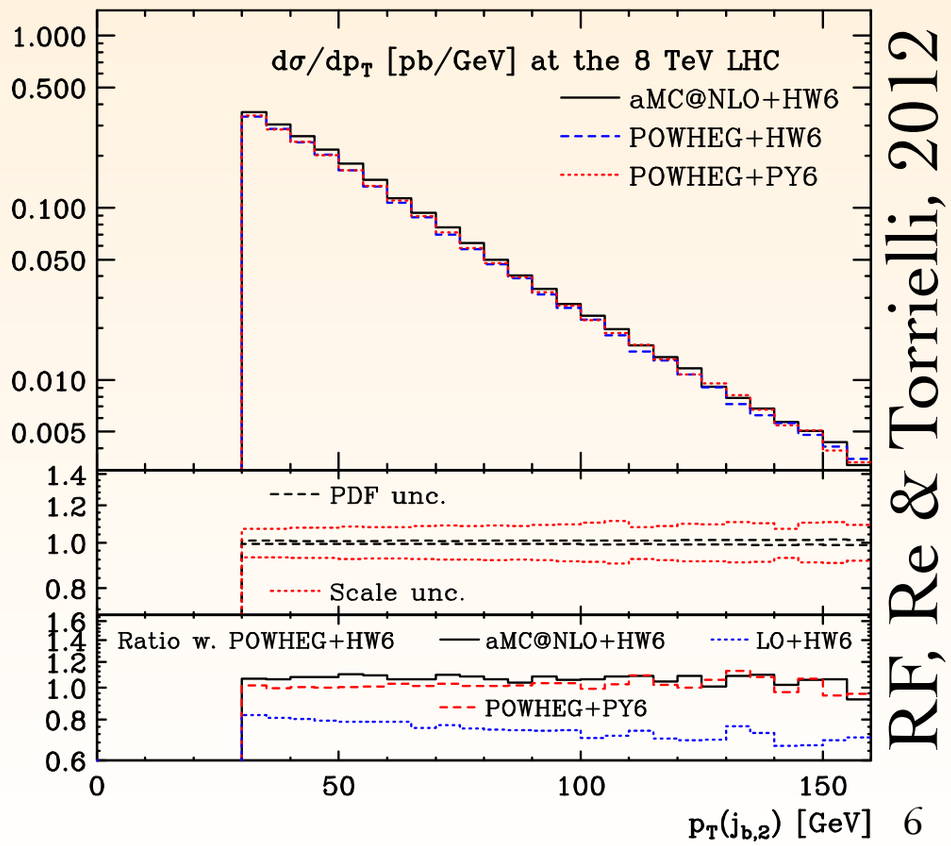
DISTRIBUTIONS

- However, total rate is for fiducial cross section measurements not so relevant.
- Distributions are also under good control when including at least NLO corrections

Fabrizio Caola

$p_\perp$	$\sigma_{\rm LO}$, pb	$\sigma_{\rm NLO}$, pb	$\delta_{\rm NLO}$	$\sigma_{\rm NNLO}$, pb	$\delta_{\rm NNLO}$
0 GeV	$53.8^{+3.0}_{-4.3}$	$55.1^{+1.6}_{-0.9}$	$+2.4\%$	$54.2^{+0.5}_{-0.2}$	-1.6%
20 GeV	$46.6^{+2.5}_{-3.7}$	$48.9^{+1.2}_{-0.5}$	$+4.9\%$	$48.3^{+0.3}_{-0.02}$	-1.2%
40 GeV	$33.4^{+1.7}_{-2.5}$	$36.5^{+0.6}_{-0.03}$	$+9.3\%$	$36.5^{+0.1}_{+0.1}$	-0.1%
60 GeV	$22.0^{+1.0}_{-1.5}$	$25.0^{+0.2}_{+0.3}$	$+13.6\%$	$25.4^{-0.1}_{+0.2}$	$+1.6\%$





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Summary so far

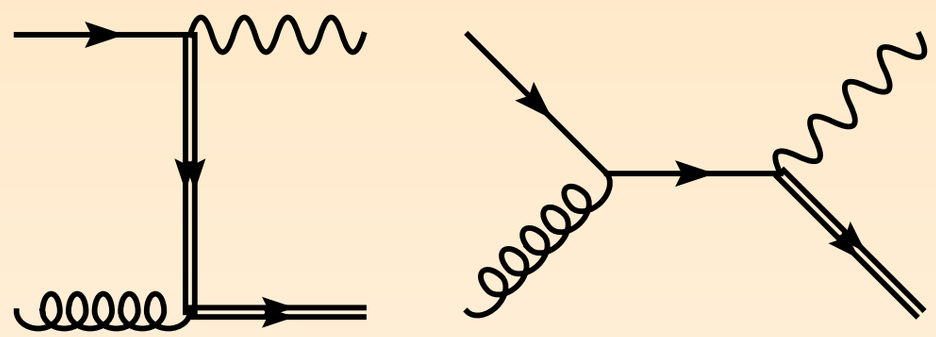
- t-channel single-top cross section in under good theoretical control (the NNLO corrections are now known). Also distributions (NLO +PS) well-understood
- However, in principle it is not a physical process because it relies on the virtuality of the W-boson
- In the long run, it can no longer be distinguished from s-channel production: at best we can measure a fiducial cross section that enhances t-channel contributions over s-channel ones (or s-channel over t-channel)
- ATLAS already measured the first fiducial cross section for the t-channel (although s-channel was considered a background in this measurement, and not simply part of the the signal)

W-t associated production

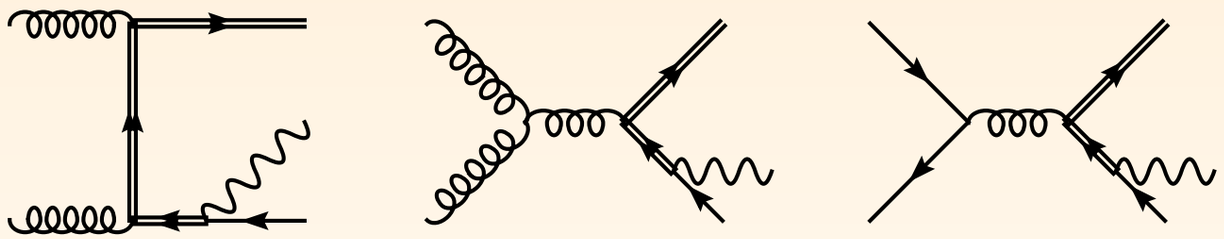
- The problem of being non-physical is much more severe for Wt production than for t-channel or s-channel
- Already at LO (in the 4FS) it cannot be defined uniquely: it has the same final state as top pair production (WbWb)
- In the 5FS this is postponed to NLO
- It is much more natural to consider it as simply part of WbWb production, and not as a separate process on its own

W-t channel 5FS

- At lowest order in perturbation theory, these are the two diagrams contributing to W-t production in the 5 FS



- At NLO, the real-emission diagrams have a contribution from top pair production

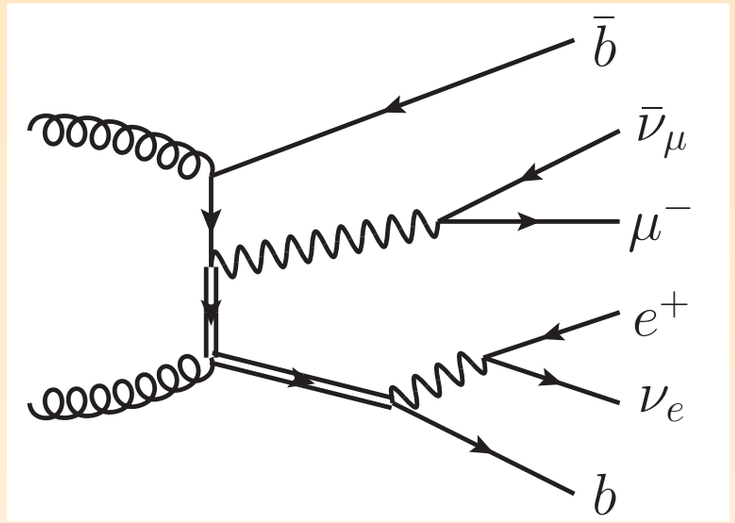


- "Perturbation theory breaks down": the full NLO corrections to Wt production are much larger than the Born, because they receive a contribution from LO top pair production

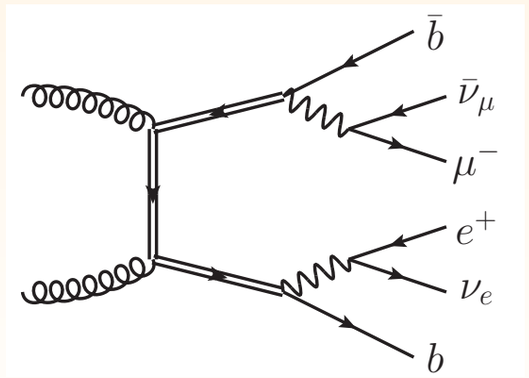
- The ad-hoc DR and DS prescriptions have been developed to remove or subtract them

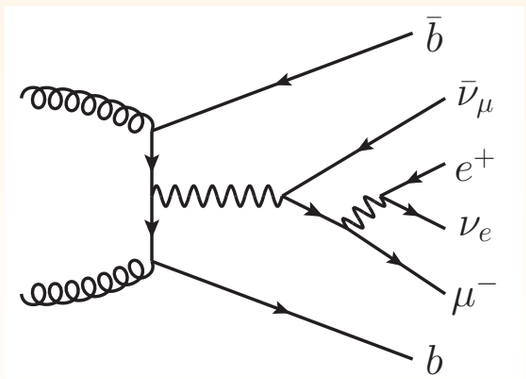
4-flavour Wt-channel

- In the 4-flavour scheme, the problem is even more severe
- Already at LO Wt and ttbar interfere, but no "break down of perturbation theory"
- However the solution is much simpler:



- No longer a separate definition of Wt and ttbar production
- Single and double and non-resonant contributions included
- All interferences included
- All off-shell effects included
- Technical challenge to compute beyond LO, but possible
  [RF, 2013], [Cascioli, et al. 2013]



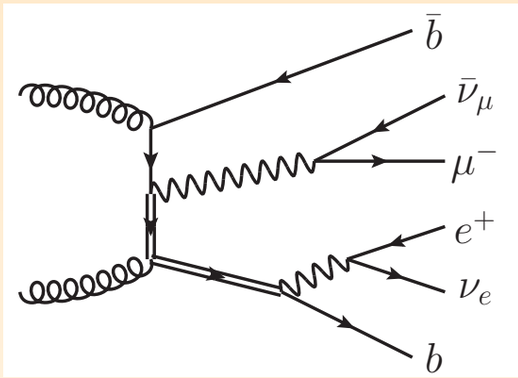


What is Wt?

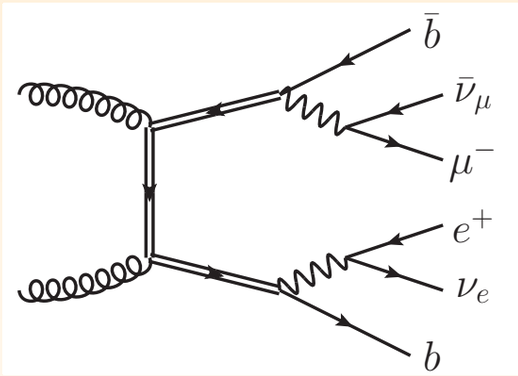
- Wt can then be "defined" as the single-resonant contribution to WbWb production.
- No separation from from ttbar (nor non-resonant contributions)
- Phase-space cuts can be used to enhance this contribution over the double resonant once
  - For example by inverting the ttbar selection cuts on a b quark and veto-ing the 2nd b-jet
- Needed: consistent NLO+PS predictions for WbWb production
  - Several technical issues are being solved, see yesterday's talks by Nason and Papanastasiou
  - (Today a paper appeared on the arXiv matching NLO WbWb to the PS, but non of these issues have been addressed in that work)

WbWb and Vtb

- All double and single resonant contributions to WbWb are proportional to $|V_{tb}|^2$.
- One cannot separate $|V_{tb}|$ from the R-ratio and from the single-top production: they contribute in the same way



- On the other hand, for non-zero $|V_{ts}|$ and $|V_{td}|$, the whole idea of the complete Wt being part of WbWb breaks down; only the part proportional to $|V_{tb}|^2$ is part of it.



- Going back to 5FS does not solve it; ttbar contributions remain a problem
- Can we find a consistent picture…?

SUMMARY

- Fiducial cross section measurements are the way to go
- The separation of t-channel and s-channel contributions is non-physical, however, phase-space cuts can be applied to enhance one over the other. In practice this is not so much of a problem
- For Wt separation from ttbar, it is a much more severe problem. Wt production on its own is ill-defined: it should be considered part of WbWb production (*4*FS, so where the b's might go unobserved)
  - However, this picture does not make too much sense when one wants to measure the possible $|V_{ts}|$ and $|V_{td}|$ contributions to Wt production

Atlas cuts for t-channel fiducial measurement

	Cuts
1 muon or electron	$p_T > 25$ GeV ($\lvert\eta\rvert < 2.5$)
2 jets 1 b-tagged	$p_T > 30$ ($\lvert\eta\rvert < 4.5$) / $p_T > 35$ GeV ($2.75 < \lvert\eta\rvert < 3.5$)
additional cuts	$E_T^{miss} > 30$ GeV, $m_T^W > 50$ GeV, $p_T(l) > 40\,GeV\left(1 - \frac{\pi - \lvert\Delta\phi(j_1, l)}{\pi - 1}\right)$