t-channel predictions and modelling uncertainties

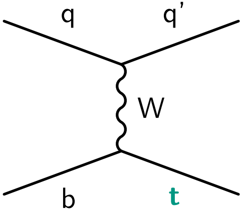
TopLHCWG open meeting

January 12, 2015

Benedikt Maier on behalf of the ATLAS and CMS collaborations

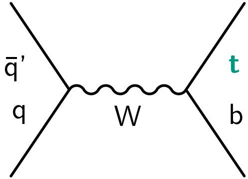
Karlsruhe Institute of Technology

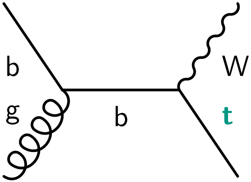
Production mechanisms



t-channel

s-channel





tW-channel

Guideline

1. t-channel predictions

2. t-channel modelling uncertainties

Motivation & intention

Motivation

- Until recently, ATLAS and CMS have used different values for the t-channel cross sections (and necessarily then R_{t}) and different approaches for evaluating the uncertainties assigned to it.*

Intention

- Harmonizing the predictions among the two collaborations, and for this using automated tools that make it easy to modify, adjust and calculate things according to our needs

*e.g. central value for m_{t}, treatment of α_S+PDF unc's, ...

Past, present, future

- Using Kidonakis numbers until now
- Switching to automated NLO (QCD) tool Hathor 2.1
- Want to adopt NNLO calculation as soon as it is easily configurable & usable for the collaborations

Setup for NLO computations

- 5-flavour-scheme calculation
- $m_{\mathrm{t}} = 172.5\,\mathrm{GeV}$
- m_{b} enters only in PDFs
- $\mu_R = \mu_F = m_{\mathrm{t}}$
- Strong coupling: α_S depends on chosen PDF
- Full CKM matrix (PDG 2012)
- Other: α, $(\hbar c)^2$, $\sin\theta_{\mathrm{W}}$, ... $\rightarrow$ use common electroweak scheme (cf. MCFM)
- PDFs:
  PDF4LHC (CT10nlo, MSTW2008nlo, NNPDF23nlo) $\rightarrow$ central value and PDF+α_S unc's
  MSTW2008nlo used for all non PDF-uncertainties

Uncertainty computations

Scales:

- Vary μ_R, μ_F independently by $1/2, 1, 2$
- Skip the combinations $1/2 \cdot 2$, $2 \cdot 1/2$
- Take min/max x-section variations as up/down uncertainty

PDF + α_S:

- Use PDF4LHC prescriptions
- Compute inter & intra PDF uncertainties for CT10nlo,MSTW2008nlo, NNPDF23nlo (including α_S uncertainty for each)
- Take half width of the resulting envelope as (symmetric) PDF uncertainty
- Take envelope centre as central x-section value

Uncertainty computations

Scales:

- Vary μ_R, μ_F independently by $1/2, 1, 2$
- Skip the combinations $1/2 \cdot 2$, $2 \cdot 1/2$
- Take min/max x-section variati... up/d...wn uncert...

PDF + α_S:

- Use PDF4L... prescri...
- C... ...ate in... ...ertainty for C...F1... ...nlo, N... ...3nlo (including α_S ...ncert... each)
- ...e half... of the resulting envelope as (symmetric) PDF u...inty
- Take envelope centre as central x-section value

Central value of envelope purely political choice

PDF4LHC recommendations overly complicated!

ATLAS + CMS collaborations should have interest in simplicity here

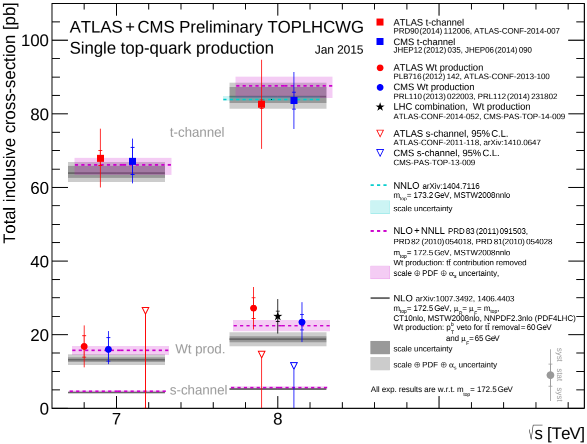
Need dialogue with PDF-fitters community!

Cross-section numbers

7 TeV					
Mode	Central value	Scale uncert.	PDF+alphaS uncert.	Total uncert.	Mass uncert.
top	41.80	+1.24 -0.82	+1.28 -1.28	+1.78 -1.52	+0.42 -0.42
anti-top	22.02	+0.67 -0.43	+1.08 -1.08	+1.27 -1.16	+0.24 -0.23
top + anti-top	63.89	+1.92 -1.25	+2.19 -2.19	+2.91 -2.52	+0.65 -0.65
8 TeV					
Mode	Central value	Scale uncert.	PDF+alphaS uncert.	Total uncert.	Mass uncert.
top	54.87	+1.64 -1.09	+1.60 -1.60	+2.29 -1.94	+0.52 -0.52
anti-top	29.74	+0.92 -0.59	+1.39 -1.39	+1.67 -1.51	+0.30 -0.30
top + anti-top	84.69	+2.56 -1.68	+2.76 -2.76	+3.76 -3.23	+0.82 -0.82
13 TeV					
Mode	Central value	Scale uncert.	PDF+alphaS uncert.	Total uncert.	Mass uncert.
top	136.02	+4.09 -2.92	+3.52 -3.52	+5.40 -4.57	+1.11 -1.11
anti-top	80.95	+2.53 -1.71	+3.18 -3.18	+4.06 -3.61	+0.71 -0.70
top + anti-top	216.99	+6.62 -4.64	+6.16 -6.16	+9.04 -7.71	+1.81 -1.81
14 TeV					
Mode	Central value	Scale uncert.	PDF+alphaS uncert.	Total uncert.	Mass uncert.
top	154.76	+4.66 -3.39	+3.96 -3.96	+6.12 -5.21	+1.23 -1.24
anti-top	93.28	+2.92 -2.01	+3.58 -3.58	+4.62 -4.11	+0.80 -0.79
top + anti-top	248.09	+7.58 -5.40	+6.98 -6.98	+10.30 -8.82	+2.03 -2.03

- Everything documented in the TWiki https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SingleTopRefXsec
- Mass uncert. (± 1 GeV) quoted for the record. Not part of total unc.

Cross-section numbers



t-channel predictions summary

- Established plan to switch to automated tools (Hathor) for obtaining t-channel cross-sections
- Numbers in good agreement with other predictions, cross-checked against MCFM, aMCatNLO, POWHEG
- Working on uncertainty predictions for R_{t} values
- PDF topic needs to be discussed with the PDF community

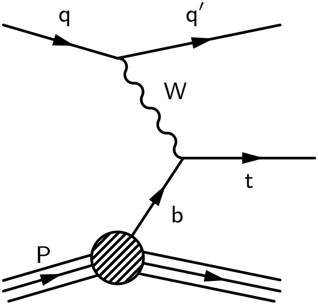
Guideline

1. t-channel predictions

2. t-channel modelling uncertainties

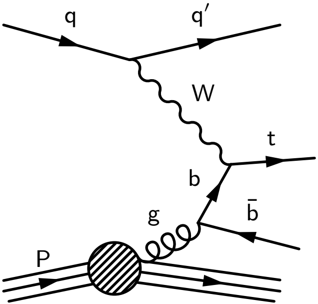
t-channel description at LO

Five-flavor scheme ($2 \to 2$)



- b quark inside proton ($m_{\mathrm{b}} = 0$) with dedicated b PDF
- add. b jet comes from backwards-evolution in parton shower ($\sim$ LO accuracy)

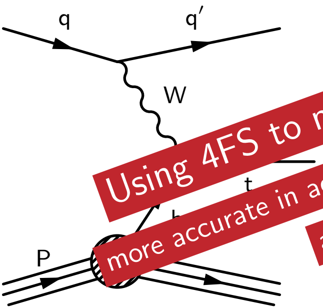
Four-flavor scheme ($2 \to 3$)



- $\mathrm{gb\bar{b}}$ vertex already present in matrix element
- gives NLO accuracy in description of add. b quark

t-channel description at LO

Five-flavor scheme ($2 \to 2$)



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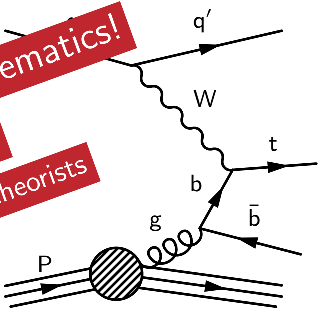


- $\mathrm{gb\bar{b}}$ vertex already present in matrix element
- gives NLO accuracy in description of add. b quark

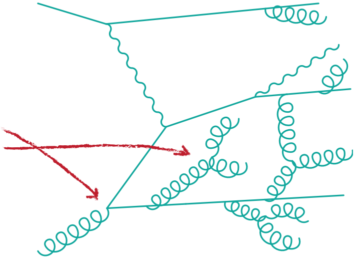
Using 4FS to model kinematics!

more accurate in add. b quark

advised by theorists

Scale uncertainties

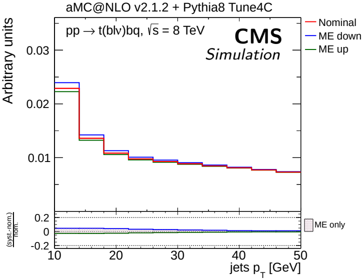
- The scale enters basically at two stages of the event evolution:
  - at matrix-element level
  - at parton-shower level

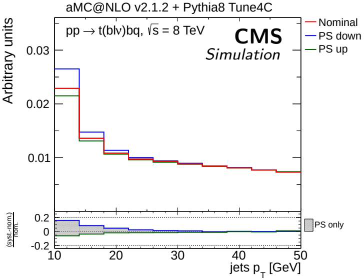


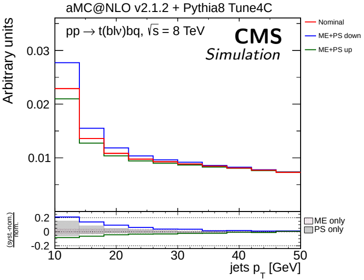
- Affecting cross section and shapes of observables ($\rightarrow$ selection acceptance)
- Question: Are scales in ME and PS to be treated correlated or independently?

Scale in ME: $\mu = 4\sqrt{m_b^2 + p_{T,b}^2}$, scale in PS: $\mu = \Sigma p_T$

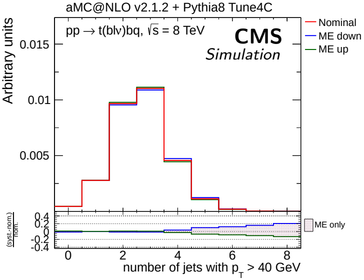
Generated jet p_T

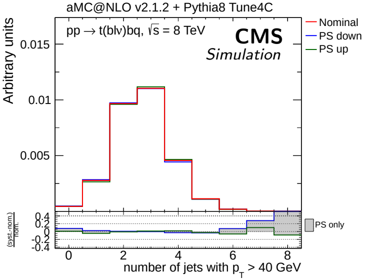


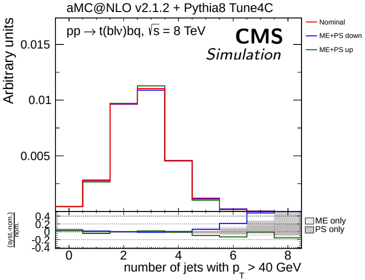




Generated jet multiplicities ($p_T > 40$ GeV)







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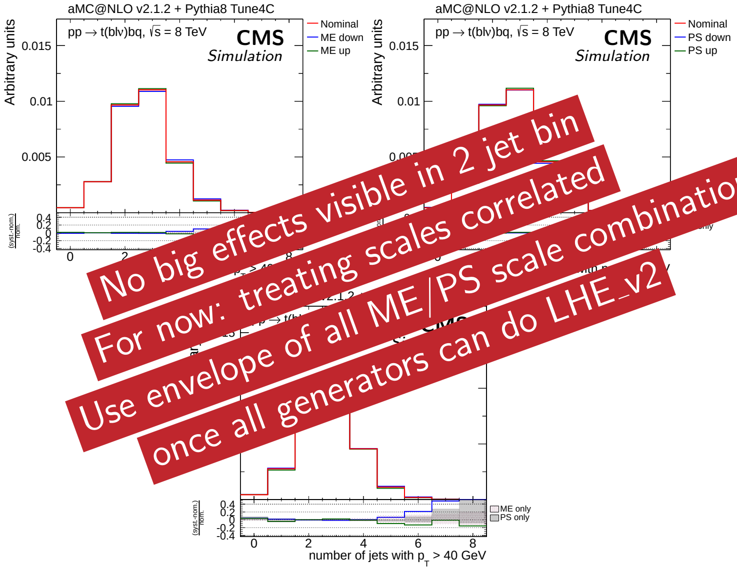


No big effects visible in 2 jet bin

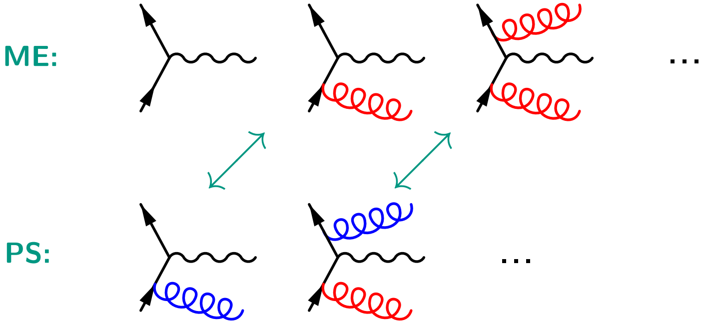
For now: treating scales correlated

Use envelope of all ME/PS scale combinations,

once all generators can do LHE_v2

Matching matrix element to parton shower

- Jet double counting between ME at higher orders and PS:



- For NLO generators, ISR/FSR increases jet multiplicity
- ME “needs to know” about gluon emission in PS
- → NLO generators require ME/PS matching

NLO subtraction scheme

Powheg

- modifies the event so that Powheg itself does the hardest emission
- therefore needs veto on hardest emission in PS
- otherwise is independent from PS used afterwards

(a)MC@NLO

- uses subtraction terms to remove its contribution to $n + 1$ jet multiplicity $\rightarrow$ events with negative weights
- needs to know which PS is going to be used

NLO subtraction scheme

Powheg

- modifies the event so that Powhe[illegible]es th[illegible]dest emission
- therefore needs [illegible] harde[illegible] in PS
- other[illegible] depen[illegible] PS [illegible]wards

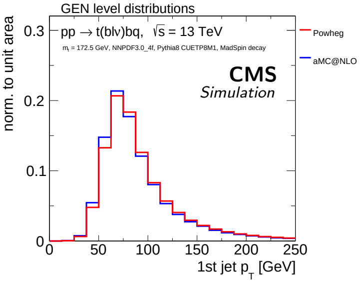
(a)MC@NLO

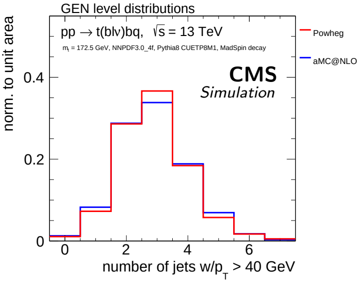
- us[illegible] subtra[illegible]ns to remove its contribution to $n+1$ jet mul[illegible] events with negative weights
- [illegible]eds to know which PS is going to be used

Comparing those two is a way to quantify the ME/PS matching uncertainty

Investigating how to evaluate it within same generator

First look





- Comparing aMCatNLO with Powheg
- Subtle differences in jet p_{T}
- To be studied on full analysis level

aMCatNLO: dedicated settings used in Py8 (e.g. `globalrecoil:on`)
Powheg: power shower setting used. Role of `hdamp` not clear for single top

t-channel modelling summary

Flavor scheme

- Using the 4FS for the t-channel. Keeping 5FS as cross-check, but not for an unc.

Scale uncertainties

- Vary the scales coherently in ME and PS

ME/PS matching uncertainty

- aMCatNLO vs. Powheg, using the same shower

Parton shower uncertainty

- Pythia8 vs. Herwig(++) when validated by both experiments

Applies also to tW channel (+DR/DS).

Agreed amongst TopLHCWG.

Backup

Event weights

Events optionally carry an additional set of weights:

- corresponding to a 2.0/0.5 variation in factorisation and renormalisation scales.
- corresponding to PDF variations.
- or to other customized variation (no restrictions at LO)

LHE_v1 information

weight sign

```
<event>
 5     66 -.24112377E+03 0.41954975E+02 0.75467716E-02 0.11115114E+00
        2 -1    0    0  502    0 0.00000000E+00 0.00000000E+00 0.11212409E+04 0.11212410E+04 0.33000000E+00 0.0000E+00 0.0000E+00
       21 -1    0    0  501  503 0.00000000E+00 0.00000000E+00 -.30318644E+02 0.30318644E+02 0.00000000E+00 0.0000E+00 0.0000E+00
        6  1    1    2  501    0 -.14323418E+02 -.35620577E+02 0.71213875E+03 0.73373826E+03 0.17250000E+03 0.0000E+00 0.0000E+00
       -5  1    1    2    0  503 -.18845621E+02 0.97720106E+01 -.11964390E+02 0.24817056E+02 0.47000000E+01 0.0000E+00 0.0000E+00
        1  1    1    2  502    0 0.33169040E+02 0.25848566E+02 0.39074791E+03 0.39300429E+03 0.33000000E+00 0.0000E+00 0.0000E+00
#aMCatNLO 1  6  2  2  4 0.54435660E+02 0.54096971E+02 9  0  0 0.99999959E+00 0.13415706E+01 0.76657668E+00 0.00000000E+00 0.00000000E+00
 <rwgt>
  <wgt id='1001'> -.24112E+03 </wgt>
  <wgt id='1002'> -.23157E+03 </wgt>
  <wgt id='1003'> -.25085E+03 </wgt>
  <wgt id='1004'> -.19249E+03 </wgt>
  <wgt id='1005'> -.18484E+03 </wgt>
  <wgt id='1006'> -.20029E+03 </wgt>
  <wgt id='1007'> -.31098E+03 </wgt>
  <wgt id='1008'> -.29868E+03 </wgt>
  <wgt id='1009'> -.32348E+03 </wgt>
 </rwgt>
 </event>
```

Weights for fact./renorm. scales variations (new with LHE_v2)