Theoretical uncertainties of the σ (ttbb)/ σ (ttjj) ratio @ 7 TeV

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- The cross section ratio instead of individual cross sections
- Many uncertainties are expected to cancel
- PDF and α_s uncertainties for example, top decay description, etc…
- What about 'theoretical error' for the ratio ? Not necessarily

The theoretical uncertainty of the total cross section, associated with neglected higher order terms in the perturbative expansion, can be estimated by varying the renormalization and factorization scales in α_s and PDFs, up and down by a factor 2 around the central scale

ttbb – new generated results

@ 7 TeV
b massless

m_t = 172.5 GeV

PDFs via LHAPDF:
CT09MC1 at LO
CT10 at NLO

b-quarks excluded from PDFs

Dynamical common scale:

$$\mu_R^2 = \mu_F^2 = \mu_0^2 = m_t \cdot \sqrt{p_T(b) \cdot p_T(\bar{b})}$$

IR-safe anti-k_T algorithms with separation R = 0.7

pT (b) > 20 GeV
| y(b) | < 2.5
R(b, b) > 0.7

ttjj – already existing results

@ 7 TeV
where j = u, d, c, s, b – all massless
Processes like ttbb, ttbg, etc. included
m_t = 173.3 GeV

PDFs via LHAPDF:
MSTW2008LO at LO
MSTW2008NLO at NLO

b-quarks included in PDFs

Common fixed scale:

$$\mu_R = \mu_F = \mu_0 = m_t$$

IR-safe anti-k_T algorithms with separation R = 0.5

pT (j) > 50 GeV
| y(j) | < 2.5
R(j, j) > 0.5

Fairly inconsistent (for now) !!!

ttbb

7 TeV

PROCESS	$\sigma_{\rm LO}$ [fb]	$\sigma_{\rm NLO}^{\alpha_{\max}=1}$ [fb]	$\sigma_{\rm NLO}^{\alpha_{\max}=0.01}$ [fb]	K-FACTOR	[%]
$pp \to t\bar{t}b\bar{b} + X$	416.7 (5)	458.3 (8)	458 (1.4)	1.10	+10

$$\sigma_{\rm LO}^{t\bar{t}b\bar{b}}({\rm LHC}_{7{\rm TeV}}, m_t = 172.5 \text{ GeV}, {\rm CT09MC1}) = 416.7\,^{+380.7(91\%)}_{-183.2(44\%)} \text{ fb}$$

$$\sigma_{\rm NLO}^{t\bar{t}b\bar{b}}({\rm LHC}_{7{\rm TeV}}, m_t = 172.5 \text{ GeV}, {\rm CT10}) = 458.3\,^{+119.7(26\%)}_{-123.1(27\%)} \text{ fb}\,.$$

$\xi \cdot \mu_0$	$0.5 \cdot \mu_0$	$1 \cdot \mu_0$	$2 \cdot \mu_0$
$\sigma_{\rm LO}$ [fb]	797.4 (9)	416.7 (5)	233.5 (3)
$\sigma_{\rm NLO}$ [fb]	578 (3)	458.3 (8)	335.2 (8)

NLO QCD Corrections
K = NLO/LO = 1.10 (+10%)

Scale dependence
LO 91% (68%) → **NLO 27%**

ttjj

7 TeV

PROCESS	$\sigma_{\rm LO}$ [pb]	$\sigma_{\rm NLO}^{\alpha_{\rm max}=1}$ [pb]	$\sigma_{\rm NLO}^{\alpha_{\rm max}=0.01}$ [pb]	K-FACTOR	[%]
$pp \to t\bar{t}jj + X$	13.398 (4)	9.81 (1)	9.82 (2)	0.73	−27

$$\sigma_{\rm LO}^{t\bar{t}jj}({\rm LHC_{7TeV}}, m_t = 173.3~{\rm GeV}, {\rm MSTW2008lo}) = 13.398\,^{+11.713(87\%)}_{-5.788(43\%)}~{\rm pb}$$

$$\sigma_{\rm NLO}^{t\bar{t}jj}({\rm LHC_{7TeV}}, m_t = 173.3~{\rm GeV}, {\rm MSTW2008nlo}) = 9.82\,^{-1.48(15\%)}_{-1.47(15\%)}~{\rm pb}\,.$$

$\xi \cdot \mu_0$	$0.5 \cdot \mu_0$	$1 \cdot \mu_0$	$2 \cdot \mu_0$
$\sigma_{\rm LO}$ [pb]	25.111 (8)	13.398 (4)	7.610 (2)
$\sigma_{\rm NLO}$ [pb]	8.34 (4)	9.82 (2)	8.35 (1)

NLO QCD Corrections
K = NLO/LO = 0.73 (-27%)

Scale dependence
LO 87% (65%) → **NLO 15%**

ttbb/ttjj – First Crude Estimate

7 TeV

$$\mathcal{R}_{\rm LO} = \sigma^{t\bar{t}b\bar{b}}_{\rm LO}(\mu_0)/\sigma^{t\bar{t}jj}_{\rm LO}(\mu_0) = 0.031 = 3.1\%$$

$$\mathcal{R}_{\rm NLO} = \sigma^{t\bar{t}b\bar{b}}_{\rm NLO}(\mu_0)/\sigma^{t\bar{t}jj}_{\rm NLO}(\mu_0) = 0.047 = 4.7\%$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}}(2\mu_0)/\sigma^{t\bar{t}jj}(2\mu_0)$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}}(2\mu_0)/\sigma^{t\bar{t}jj}(0.5\mu_0)$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}}(0.5\mu_0)/\sigma^{t\bar{t}jj}(2\mu_0)$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}}(0.5\mu_0)/\sigma^{t\bar{t}jj}(0.5\mu_0)$$

For the individual NLO cross sections scale uncertainty of the order of 27% & 15%

For the ttbb/ttjj ratio asymmetric scale uncertainty @ NLO 47% & 15%

After symmetrization 31%

$$\mathcal{R}_{\rm LO} = 0.031^{+0.062(200\%)}_{-0.001(\;\;3\%)}$$

$$\mathcal{R}_{\rm NLO} = 0.047^{+0.022(47\%)}_{-0.007(15\%)}$$

ttbb/ttjj – First Crude Estimate

7 TeV

- Why not additional ratios for the error estimation ?

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}(2\mu_0)} / \sigma^{t\bar{t}jj(\mu_0)}$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}(0.5\mu_0)} / \sigma^{t\bar{t}jj(\mu_0)}$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}(\mu_0)} / \sigma^{t\bar{t}jj(2\mu_0)}$$

$$\mathcal{R} = \sigma^{t\bar{t}b\bar{b}(\mu_0)} / \sigma^{t\bar{t}jj(0.5\mu_0)}$$

$$\frac{\sigma^{t\bar{t}b\bar{b}}_{\rm NLO}}{\sigma^{t\bar{t}jj}_{\rm NLO}}$$

Asymmetric error 28% & 17%
After symmetrization and
including all previous ratios 26%

- What's the best definition for the error estimation of the ratio ?

$$\frac{\sigma^{t\bar{t}b\bar{b}}_{\rm NLO}}{\sigma^{t\bar{t}jj}_{\rm NLO}} = \frac{\sigma^{t\bar{t}b\bar{b}}_{\rm LO} + \delta\sigma^{t\bar{t}b\bar{b}}_{\rm NLO}}{\sigma^{t\bar{t}jj}_{\rm LO} + \delta\sigma^{t\bar{t}jj}_{\rm NLO}} \sim \frac{\sigma^{t\bar{t}b\bar{b}}_{\rm LO}}{\sigma^{t\bar{t}jj}_{\rm LO}} \left(1 + \frac{\delta\sigma^{t\bar{t}b\bar{b}}_{\rm NLO}}{\sigma^{t\bar{t}b\bar{b}}_{\rm LO}} - \frac{\delta\sigma^{t\bar{t}jj}_{\rm NLO}}{\sigma^{t\bar{t}jj}_{\rm LO}} \right)$$

$\sigma_{\rm LO}$ with NLO PDFs

Plan & Outlook

- Consistent study for both processes @ 7 and 8 TeV
- Same PDFs, same cut selection, etc.
- Most probably
    - $pT(j) > 30$ GeV (need to be confirmed for the ttjj case)
    - $|y(j)| < 2.5$
    - $R(j, j) > 0.5$
- MSTW2008 at LO and NLO in both cases
- anti-k_T jet algorithm with $R = 0.5$
- Dynamical scale in both cases, e.g. H_T
    - scale dependence plots to confirm the scale choice
- For the ttjj case:
    - $j = u, d, s, c$ (?)
    - b-quark contribution has to be excluded
- The same study can be done at the distribution level

References

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