$t\bar{t}$ modelling uncertainties and further questions to theory

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Introduction

TOP LHC WG effort on $t\bar{t}$ generator modelling:
Harmonization: use and quote TH uncertainties in comparable manner. Benefits:

- ATLAS and CMS combination
- comparing ATLAS and CMS top group analyses results

Data-MC comparisons:

- use both ATLAS and CMS data to select good MC model setups.

etc. (exchange of info on generator cards)

Started and program outlined @ 1st TOPLHC OPEN ws:
`https://indico.cern.ch/event/189617/`

Status summarized at:
`https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TheorySystematics`

$t\bar{t}$ modelling categories

$t\bar{t}$ modelling is evaluated using **generator vs generator comparisons**, **different tunes or generator parameter variations** or **other prescriptions**.

- **Generator modelling:**
  - comparison of central predictions from different generators (+ sources not fitting any other category). E.g. POWHEG +HERWIG vs MC@NLO +HERWIG .
  - general guidelines for $t\bar{t}$ signal: use at least one multileg generator and at least one NLO generator
- **Radiation description:**
  - Vary parameters controlling QCD radiation in each of Matrix Element (ME) and Parton Shower (PS). Currently LO generators used by ATLAS and CMS.
  - renormalisation and factorisation scale currently listed in this category.
- **Matching (multi-leg):** change ME and PS gen. matching thresholds
- **Hadronization**: compare at least two different hadronization models. Typically by comparing PYTHIA6 and HERWIG . See also talk by T. Carli.
- **Underlying Event (UE) and Colour Reconnection(CR):** using PYTHIA6 tunes with different levels of UE and CR activity
- **Parton Distribution Function (PDF) and top mass**

ATLAS vs CMS:

- agree and use similar evaluation for PDF, UE/CR, top mass
- differ in how they quote Radiation, Hadronization, Generator modelling

Talk Outline

Updates and studies relevant for Radiation and Generator modelling

1) radiation systematics with LO generators

- settings used in Run I and their recent updates
- inclusive x-section, jet gap fraction and jet multiplicity

2) NLO modelling uncertainties:

- Powheg **w/wo hdamp** @ particle level
- Powheg **vs** aMC@NLO for gap fraction
- **incl.** ***newer*** **setups (aMC@NLO, Herwig++)**

+

questions to theory

More information and plots:

- jet multiplicities: ATLAS-CONF-2012-155, arXiv:1404.3171 [hep-ex], CMS-PAS-TOP-12-041 .
- gap fraction: Eur. Phys. J. C72 (2012) 2043, arXiv:1404.3171 [hep-ex], CMS-PAS-TOP-12-041 . Incl. comparisons with MC@NLO, Powheg, Sherpa and fractions for 2nd additional jet.
- info and studies related to this talk: ATL-PHYS-PUB-2014-005

Radiation systematics with LO generators

Run I CMS and ATLAS variation samples

- CMS: MadGraph +Pythia6 (multi-leg), vary ren. scale (Q [GeV]) in ME and PS simultaneously by 1/2 and 2. In addition: vary fac. scale simultaneously as well.
- ATLAS (since summer 2013): Alpgen +Pythia6 (multi-leg), vary ren. scale (Q [GeV]) in ME and PS simultaneously by 1/2 and 2. In addition: retune UE. No fac. scale variation.
- ATLAS: AcerMC +Pythia6 (Born-level), vary ren. scale (Q [GeV]) in PS (but not in ME) by $\sim$ 1/2 and 2 (exact range from data limits). In addition: vary hardest emission scale PARP(67)(data limits)
- Details on ren. scale variations: [NB: ISR $\alpha_s(\; (\mathrm{PARP64} \cdot Q^2) \; / \; \mathrm{PARP61}^2 \;)$]:

	CMS MadGraph +Pythia6	ATLAS Alpgen +Pythia6	AcerMC +Pythia6 **7 TeV (8 TeV)**
nominal sample settings			
FSR: `PARP(72)`	0.25 GeV	0.26 GeV	0.26 (0.527) GeV
ISR: `PARP(64)`	1.0	1.0	1.0 (0.68)
`PARP(61)`	0.25 GeV	0.26 GeV	0.26 (0.192) GeV
ME: `alpsfact/ktfac`	1.0	1.0	-
Less PS (as_down,radLo) sample settings			
FSR: `PARP(72)`	0.125 GeV	0.13 GeV	0.11 (0.150) GeV
ISR: `PARP(64)`	4.0	-	3.50 (4.08)
`PARP(61)`	-	0.13 GeV	same as nominal
ME: `alpsfact/ktfac`	2.0	2.0	-
More PS (as_up,radHi) sample settings			
FSR: `PARP(72)`	0.50 GeV	0.52 GeV	0.37 (0.425) GeV
ISR: `PARP(64)`	0.25	-	0.90 (1.02)
`PARP(61)`	-	0.52 GeV	same as nominal
ME: `alpsfact/ktfac`	0.5	0.5	-

ATLAS AcerMC +Py vs Alpgen +Py

Since summer 2013 most of ATLAS analyses are moving from:

- AcerMC +Pythia6 variations (AcerMC: tree level Born/lowest mult. ME)
- Alpgen +Pythia6 variations (Alpgen = multi-leg ME)

NB: CMS uses MadGraph +Pythia6 (MadGraph = multi-leg ME) variations, similar to Alpgen +Pythia6 ones

- comparison of AcerMC +Py vs Alpgen +Py for **incl. $t\bar{t}$ cross-section, ATLAS-CONF-2013-097**, done at $\sqrt{s} = 8$ TeV
- count events in $e\mu$ chan. with exactly 1 or at least 2 b-tags and simult. determine the σ and *b*-tagging efficiency

$$\sigma_{t\bar{t}} = 237.7 \pm 1.7 \text{ (stat.)} \pm 7.4 \text{ (syst.)} \pm 7.4 \text{ (lumi.)} \pm 4.0 \text{ (beam energy) pb},$$

- relative total(systematic) uncertainty of the measurement is 4.8(3.1) %.
- preselection efficiency $\epsilon_{e\mu}$ of events with exactly 1 e and μ with $p_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.5$
- tagging correlation C_b between b-tagged jets

	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
AcerMC +Pythia6	0.76 ± 0.06	0.26 ± 0.12	1.23 ± 0.18
Alpgen +Pythia6	1.36 ± 0.03	0.21 ± 0.08	1.78 ± 0.11

AcerMC +Pythia6 **and** Alpgen +Pythia6 **uncertainties size comparable.**

gap fraction

from M. Owen's talk @ Nov. 2012 TOPLHC WG MTG

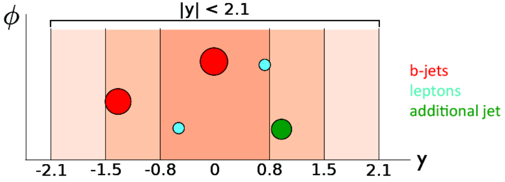
- Study the fraction of ttbar events that do not contain an additional jet, in a central rapidity region, with $p_T > Q_0$:

$$f_{\mathrm{gap}}(Q_0) = \frac{n_{\mathrm{gap}}(Q_0)}{N_{t\bar{t}}}$$

- Alternatively, we can take the sum of the p_T of the jets falling into each rapidity region and define:

$$f_{\mathrm{gap}}(Q_{\mathrm{sum}}) = \frac{n_{\mathrm{gap}}(Q_{\mathrm{sum}})}{N_{t\bar{t}}}$$

- Use dilepton events with two reconstructed b-jets to easily identify the additional jet(s).



ATLAS:

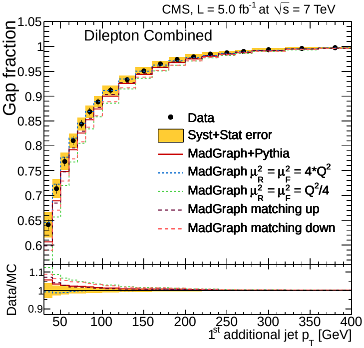
- 7TeV: Eur.Phys.J. C72 (2012) 2043

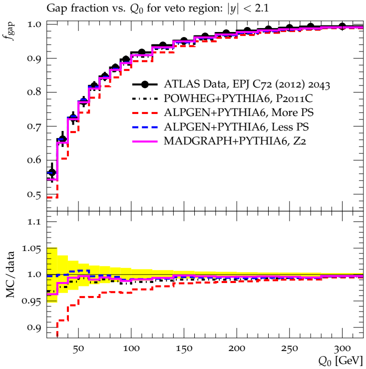
CMS:

- 7TeV: arXiv:1404.3171 (April 2014)
- 8Tev: CMS-PAS-TOP-12-041

radiation systematics: gap fraction, 7 TeV

- left: CMS MadGraph +Pythia6, right: ATLAS Alpgen +Pythia6
- NB: inverted ratio plots; CMS: Data/MC, ATLAS: MC/data !
- Spread between radiation systematics samples comparable, up to ∼10% for low Q_0. ATLAS bands possibly a bit larger for high-p_T ($p_T > 150$ GeV).





NB: differences in object and event selection. E.g. jet cone size 0.5(0.4) for CMS(ATLAS)!

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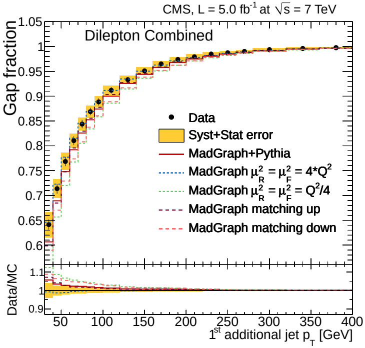

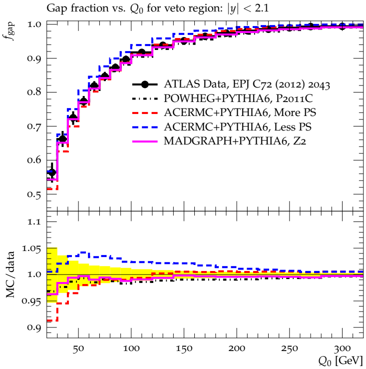

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radiation systematics: jet # (pt>60 GeV), 7 TeV

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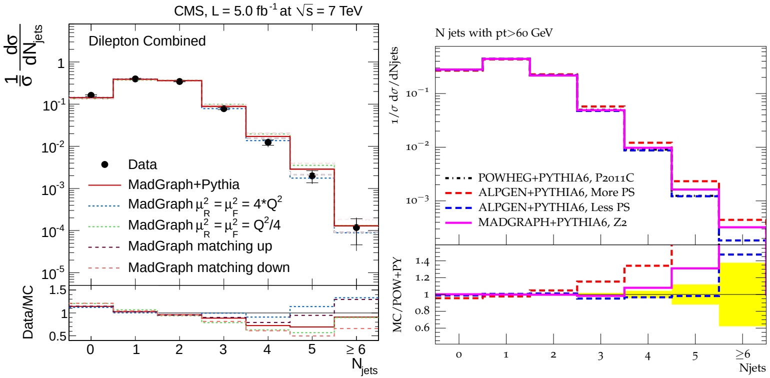
- Spread between radiation systematics samples comparable.



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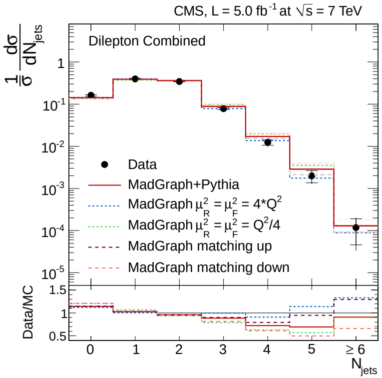

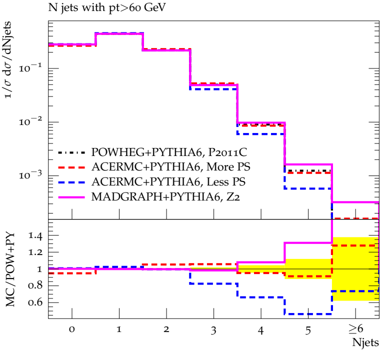

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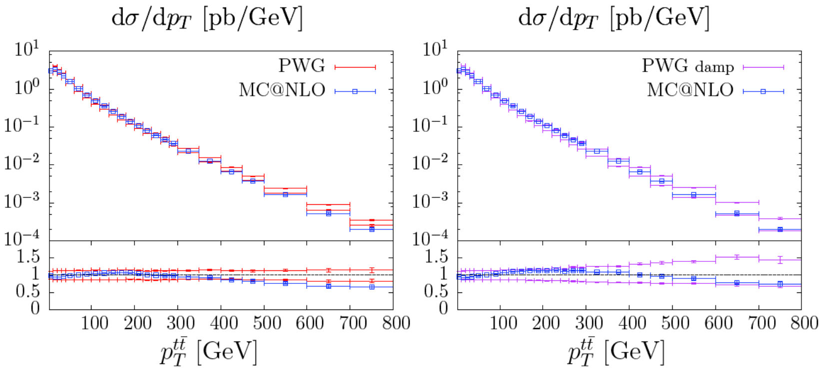
POWHEG w/wo damping

POWHEG and hdamp

- **K. Hamilton, Top2012** `http://indico.cern.ch/event/180665`:
  Theory perspective on top quark signal modeling uncertainties, **parton level study**

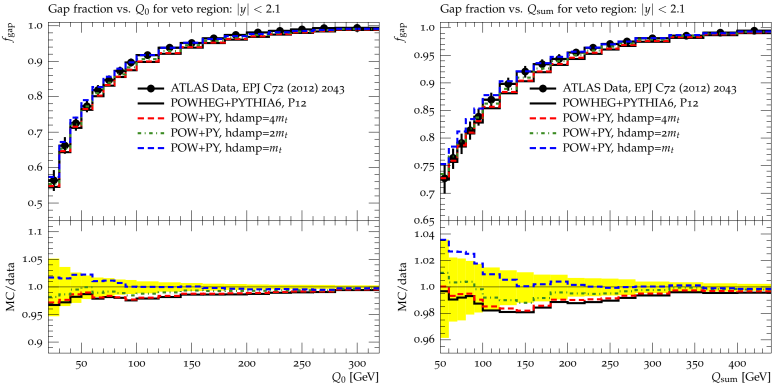


- POWHEG needs damping switched on or else scale dependence underestimated at high-p_{T}
- damping = p_{T}-dependent effect on hardest emission in POWHEG, still NLO accurate
- need to turn on damping = POWHEG-specific, no need to do it in MC@NLO

POWHEG w/wo damping, 7 TeV

How about particle-level?

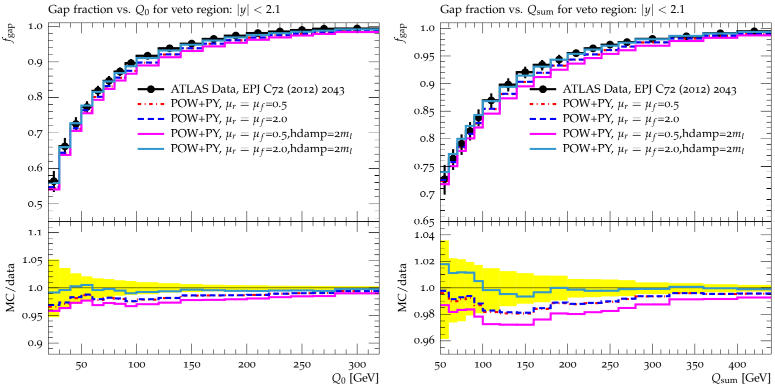
- observable effect of using/not using damping
- more damping (lower hdamp) predicts less QCD radiation activity (expected)



POWHEG w/wo damping, 7 TeV

Ren/fac scale variations:

- variations wo damping ∼ flat
- variations with damping notably larger
- in synch with Hamilon's observations at parton level

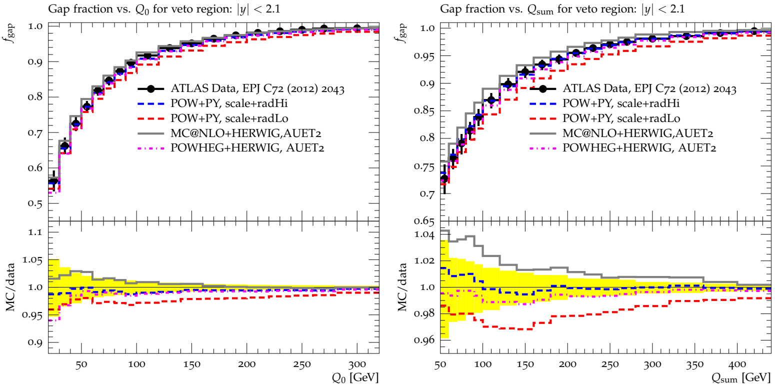


using powheg-internal reweighting to evaluate scale variations, hence stat. unc = small

POWHEG vs (a)MC@NLO

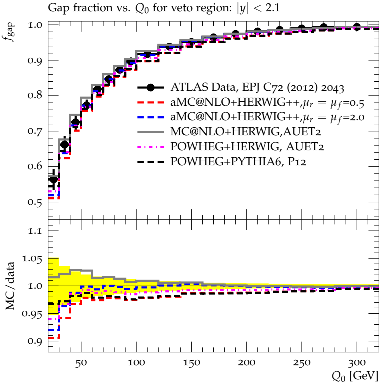
POWHEG unc. bands, 7 TeV

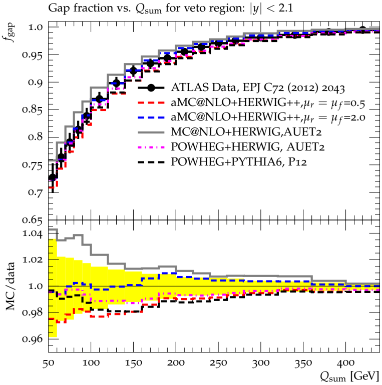
- POWHEG +PYTHIA6: ren/fac scale variation in presence of damping + parton shower variation (P2012 radLo/radHi) to maximize variation effect for the observable
- unc. band brackets POWHEG +HERWIG (variation wo damping would not bracket it!)
- unc. band does not bracket MC@NLO +HERWIG



aMC@NLO unc. bands, 7 TeV

- aMC@NLO: parton shower settings fixed to UEEE4 LO** tune
- unc. band brackets POWHEG +HERWIG and PYTHIA6, apart from low Q_0 regions
- unc. band does not bracket MC@NLO +HERWIG (ideas on reasons from theory?)





Conclusions

radiation systematics with LO generators

- Run I: CMS MadGraph +Pythia6 (multi-leg), ATLAS Alpgen +Pythia6 (multi-leg) or AcerMC +Pythia6 (Born-level)
- newer Alpgen +Pythia6 rather similar to MadGraph +Pythia6; simultaneous variations of ren. scale (Q [GeV]) in Matrix Element and Parton Shower. (but differences in factorisation scale and underlying event treatment)
- ATLAS Alpgen +Pythia6 and CMS MadGraph +Pythia6 variation samples observed to be similar for gap fraction and jet multiplicity observables
- old ATLAS AcerMC +Pythia6 performance was similar to Alpgen +Pythia6 and MadGraph +Pythia6 too (inclusive x-section, gap fraction, jet multiplicity)

NLO modelling uncertainties:

- Powheg **w/wo hdamp:** x-check of Powheg author's work at particle level: Powheg scale variations should be done in presence of damping, else it is under-estimated. hdamp has significant effect on Powheg prediction. We'll likely want to play with this parameter in the near future.
- **a**MC@NLO **and** Herwig++ **with a**MC@NLO **and** MC@NLO**:** perform rather well for gap fraction observables - looking fwd to using these setups more soon.
- a couple of questions remain on NLO generators uncertainty bands (next in questions to theory section)

questions to theory

powheg hdamp

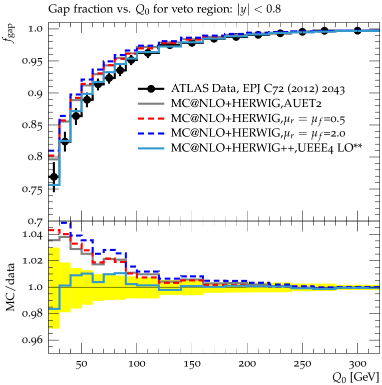
Documentation and Info

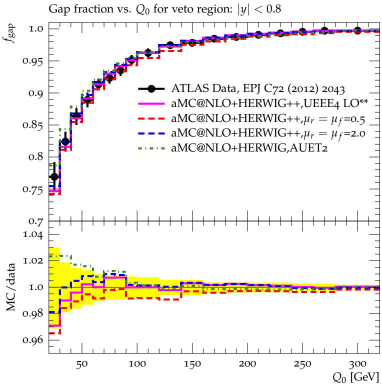
- documentation in POWHEG-BOX manual of what exactly the parameter does: current documentation is scarce in the manual and reference quoted therein (JHEP 1006, 043 (2010)). Could manual be updated with more (up-to-date) info? (e.g. how exactly if hdamp different than hfact etc.)
- could any closed/non-published talks (e.g. closed TOPLHC wg sessions) with studies of hdamp effects by POWHEG authors please be made publicly available?
- when h(damp)>0 the damping factor is evaluated as: dampfac=h**2/(pt2+h**2), according to POWHEG-BOX manual. In this expression, how exactly is pt2 evaluated?

(a)MC@NLO + fHw vs Hw++

gap fraction observables, soft (<100 GeV), central (y<0.8) Q_0 :

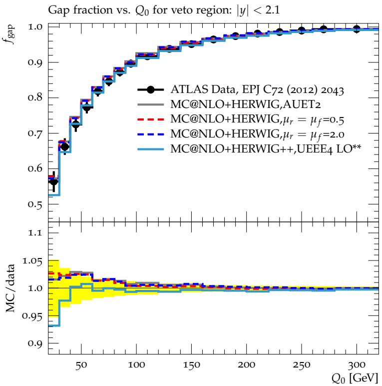
- less radiation activity wrt to data and other generators for MC@NLO +HERWIG
- previously explained by K. Hamilton as to possibly be due to dead regions for PS
- aMC@NLO + HERWIG++is doing better. Expected? Why exactly? Is it in synch with dead regions for PS explanation?





fWw vs Hw++ scale unc. band

- band with aMC@NLO+Hw++ (rhs) notably larger than the band with MC@NLO+fHerwig (lhs)
- Expected? If yes, what is the reason?
- also unc. band does not bracket MC@NLO +HERWIG, cf p19; ideas on reasons from theory?



POWHEG:

- we observe that POWHEG and aMC@NLO #newweight print-out formats currently differ; are there plans to change format of the #newweight lines wrt to current format in the next POWHEG-BOX releases?

aMC@NLO:

- we understand that aMC@NLO pdf reweighting currently only works for PDF-s contained in the error-set of the nominal PDF used for event generation.
- are there plans to extend pdf reweighting to pdf-s not contained in the nominal pdf error-set ?
- We are curious: for the implementation, what exactly is the difference between pdf-s not contained in the nominal pdf error-set and pdf-s contained in the nominal pdf error set?

Extra

Q^2 parameter variations, courtesy of M. Gosselink (CMS)

Variation of Q (Q^2) with a factor 0.5 and 2.0 (0.25 and 4.0)

More explicitely:

- matrix element:
  - $Q^2 = m_t^2 + \sum p_T^2$ (MadGraph) and $Q^2 = m_t^2$ (POWHEG)
  - `scalefact`/`facscfact` (scale factor for event-by-event scales)
  - `alpsfact`/`renscfact` (scale factor for QCD emission vx)
- parton shower:
  - factor for k_T^2 evolution scale in α_s (space-like, ISR)
    `PARP(64)=0.25/4.0` (D=1.0)
  - Λ scale in α_s (time-like, FSR)
    `PARP(72)=0.5/0.125` (D=0.25), but `MSTP(3)=2` (D)
  - NOTE: implicitly starting scale of the PS changes accordingly

Hadronisation and Generator Modelling

ATLAS vs CMS:

Hadronisation:

- compare at least two different hadronization models. Currently, the comparison is typically done between PYTHIA6 and HERWIG .
- agreed to document the effect in all papers, no agreement reached on whether it needs to be added to the total uncertainty.

Generator modelling:

- comparison of central predictions from different generators (+ sources not fitting any other category)
- general guidelines for $t\bar{t}$ signal: use at least one multileg generator and at least one NLO generator
- agreed to document the effect in all papers, no decision if it should be used only as cross check or added to the total uncertainty.
- ATLAS and CMS use different MC models to evaluate this contribution.