# Recent improvements on Monte Carlo modelling at ATLAS


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# Introduction

• The ATLAS Run 2 experimental environment will be challenging more where many aspects becoming gradually more stressful, notably hard event and pile-up modelling :

**Run 1 conditions:**
**$\sqrt{s}$ = 900 GeV, 7 & 8 TeV**
**L ~ 7 x $10^{33}$ $cm^{-2}$ $s^{-1}$**
**Pile-up: up to 35**
**Int. Lum ~ 30 $fb^{-1}$**

**More Energy !**

**Run 2 conditions:**
**$\sqrt{s}$ = 13 TeV**
**L ~ 1.6 x $10^{34}$ $cm^{-2}$ $s^{-1}$**
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• MC event modelling is needed for both experimental understanding of QCD, V+jets etc as backgrounds to new physics; and to allow theory/data comparison as much as possible.

• ATLAS is using a wide range of Monte Carlo Generators where the MC parameters are expected to be **common** and describe various processes in several types of collider at different energies.

• Basically, the non-perturbative MC parameters of the models have to be tuned since they are not making predictions (Hadronization & UE). However, some parts of MC simulation like ME (especially NLO), parton shower, QED, etc can derive first principles.

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**Today:** Just the recent  tuning results of MC modeling @ ATLAS will be presented: A14 and ATTBAR tunes; hdamp setting for ttbar modeling

# The ATLAS simulation: state of the art

**Parton level MC**
- SUSY (MadGaph5), - Exotics (MadGaph5, CalcHEP ...)

**LHE file**
- Standalone generation then registration on grid.
- On-The-Fly generation on the grid

**Event Generation**
- Les Houches Event interface
- MadGraph/Powheg inputs
- Multi-purpose generators: Pythia6, Pythia8, Sherpa, Herwig++

**EVNT file (HepMC)**

**ATLAS Event Generation** → interface to detector, Particle gun

**Detector simulation** → Geant4, Fast calorimetry and tracking

**Digitization** → Emulate electronics

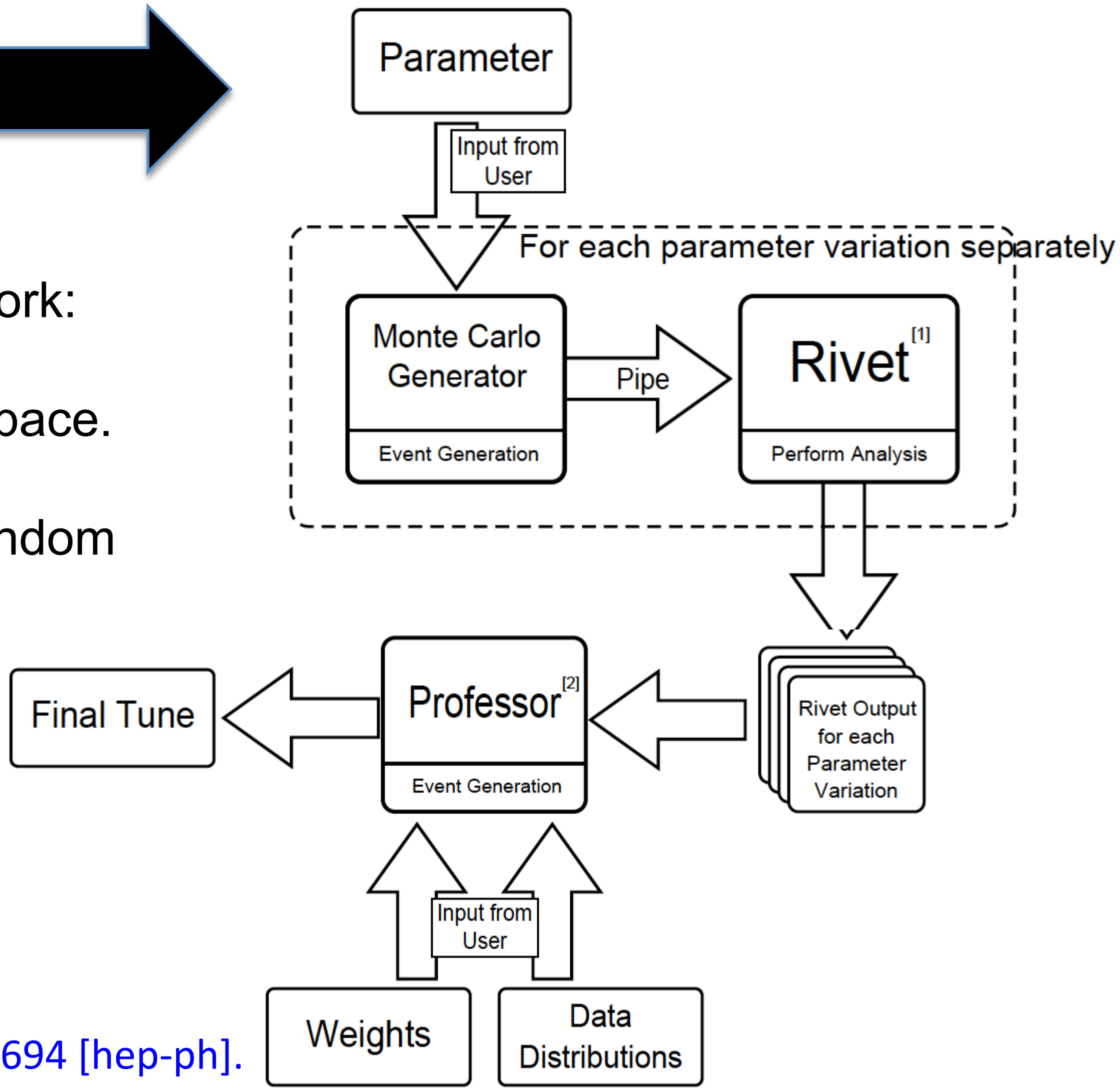
**Reconstruction** → Cells, clusters, tracks; e,μ,τ, γ, jet, MET

**Ntuplization** → Analysis based ROOT-tuples

Yellow box: **Significant CPU time**

Grey box: **Dominating CPU time**

# MC tuning workflow in ATLAS




The main steps for the tuning framework:

1 - Definition of tuning parameter space.

2 - Event samples generation for random parameter points.

3 - Performing analyses for each event using Rivet ( see [1] ).

4 - Tuning using Professor ( see [2] ).

[1] - A. Buckley et al, Rivet user manual, 1003.0694 [hep-ph].
[2] - A. Buckley et al, Systematic event generator tuning for the LHC, 0907.2973 [hep-ph]

# A14: global tune of Shower and MPI

- A14 (ATLAS 14) is a set of Pythia8 tunes combining in a single step ISR, FSR and MPI tunes (500 points of 3 M events in 10 parameters hypercube).

- Exploiting all ATLAS 7 TeV data.

- Performing four separate tunes to LO PDFs: CTEQ6L1, MSTW2008LO, NNPDF23LO and HERAPDF15LO leads to four tunes designated as A14 tune series (at the end, there is no preference of any PDF, so we choose NNPDF23LO as the primary).

- The data used in this tuning includes ATLAS observables sensitive to UE, Jet structure and observables sensitive to additional jet emissions above lowest-order process ( ttbar gap fraction, 3/2 jet ratio, Z-pT …etc).

A14

| Parameter | Definition | Sampling range |
|---|---|---|
| `SigmaProcess:alphaSvalue` | The $\alpha_S$ value at scale $Q^2 = M_Z^2$ | 0.12 – 0.15 |
| `SpaceShower:pT0Ref` | ISR $p_T$ cutoff | 0.75 – 2.5 |
| `SpaceShower:pTmaxFudge` | Mult. factor on max ISR evolution scale | 0.5 – 1.5 |
| `SpaceShower:pTdampFudge` | Factorisation/renorm scale damping | 1.0 – 1.5 |
| `SpaceShower:alphaSvalue` | ISR $\alpha_S$ | 0.10 – 0.15 |
| `TimeShower:alphaSvalue` | FSR $\alpha_S$ | 0.10 – 0.15 |
| `BeamRemnants:primordialKThard` | Hard interaction primordial $k_\perp$ | 1.5 – 2.0 |
| `MultipartonInteractions:pT0Ref` | MPI $p_T$ cutoff | 1.5 – 3.0 |
| `MultipartonInteractions:alphaSvalue` | MPI $\alpha_S$ | 0.10 – 0.15 |
| `BeamRemnants:reconnectRange` | CR strength | 1.0 – 10.0 |

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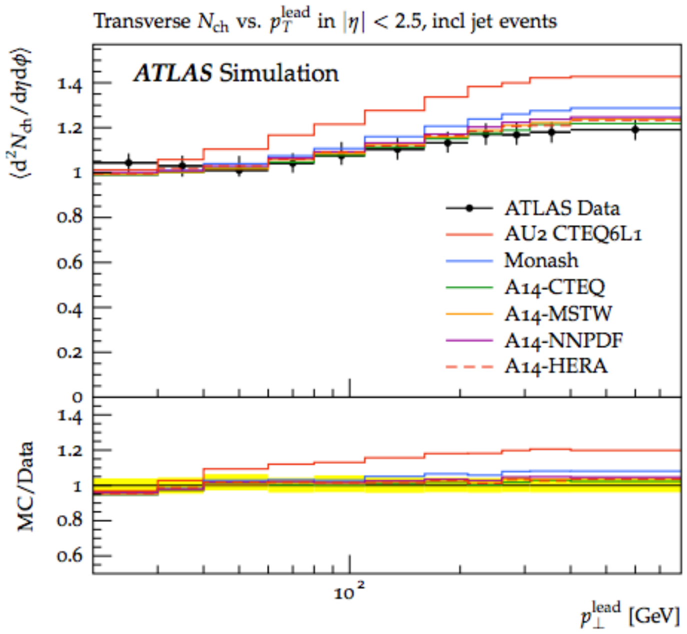
A14

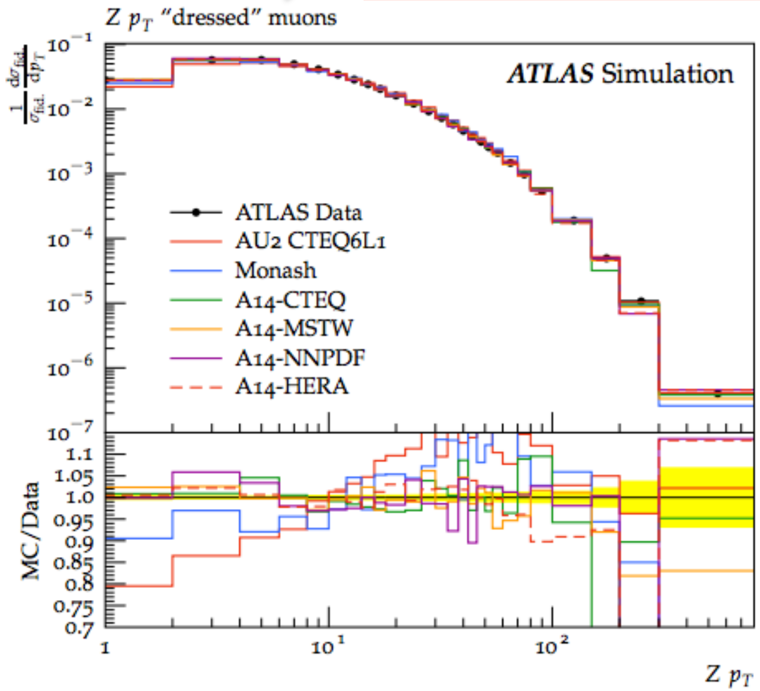
| Param | CTEQ | MSTW | NNPDF | HERA |
|---|---|---|---|---|
| SigmaProcess:alphaSvalue | 0.144 | 0.140 | 0.140 | 0.141 |
| SpaceShower:pT0Ref | 1.30 | 1.62 | 1.56 | 1.61 |
| SpaceShower:pTmaxFudge | 0.95 | 0.92 | 0.91 | 0.95 |
| SpaceShower:pTdampFudge | 1.21 | 1.14 | 1.05 | 1.10 |
| SpaceShower:alphaSvalue | 0.125 | 0.129 | 0.127 | 0.128 |
| TimeShower:alphaSvalue | 0.126 | 0.129 | 0.127 | 0.130 |
| BeamRemnants:primordialKThard | 1.72 | 1.82 | 1.88 | 1.83 |
| MultipartonInteractions:pT0Ref | 1.98 | 2.22 | 2.09 | 2.14 |
| MultipartonInteractions:alphaSvalue | 0.118 | 0.127 | 0.126 | 0.123 |
| BeamRemnants:reconnectRange | 2.08 | 1.87 | 1.71 | 1.78 |

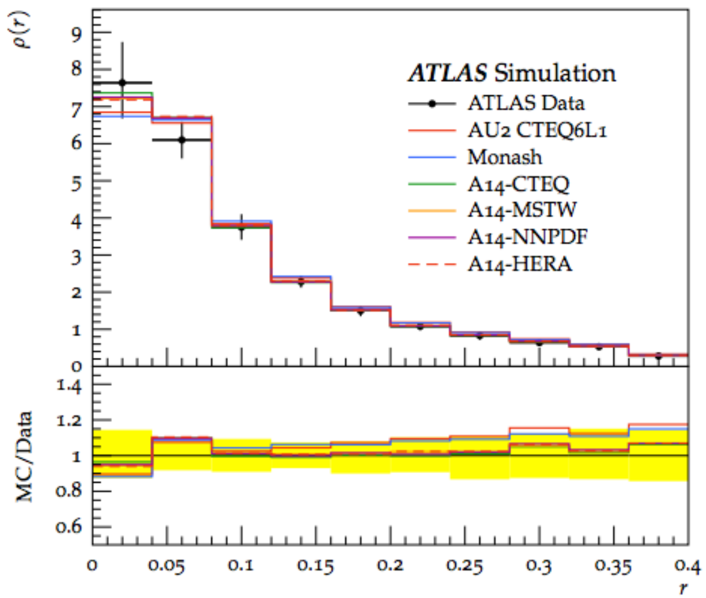
# A14: global tune of Shower and MPI

- This tune uses Monash as starting point and thus builds on the work of the others.
- A14-NNPDF tune gives a good performance on jets, W/Z jets and ttbar processes.
- More work is on-going for a matched shower-NLO tune, but that is accounting for the additional emission in higher order ME and it is not adding higher order corrections to the shower.

**ATL-PHYS-PUB-2014-021**



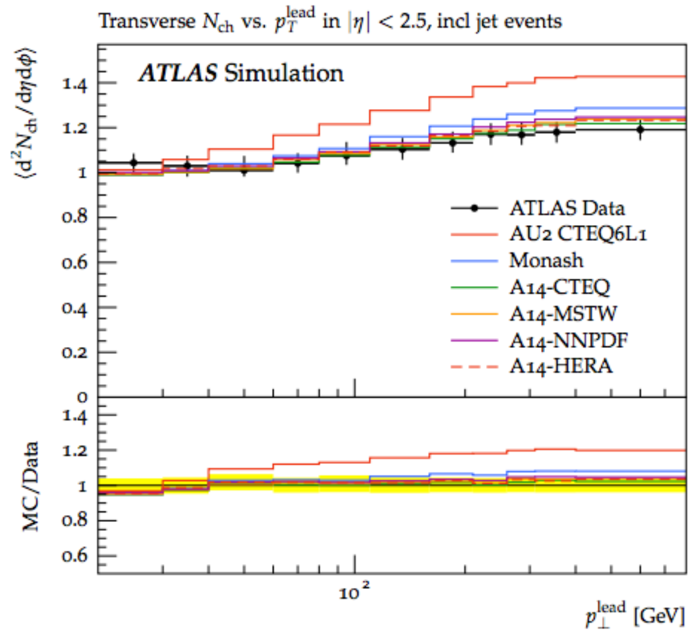



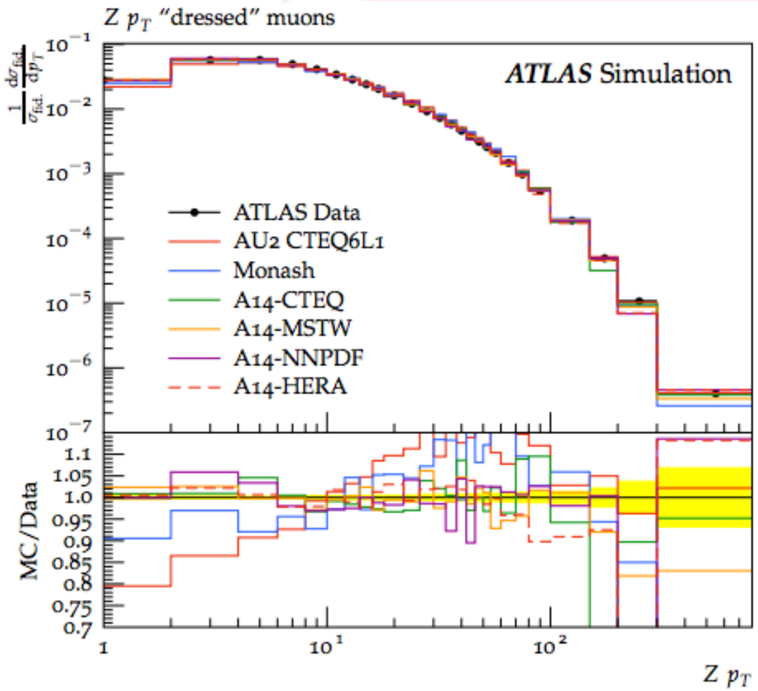



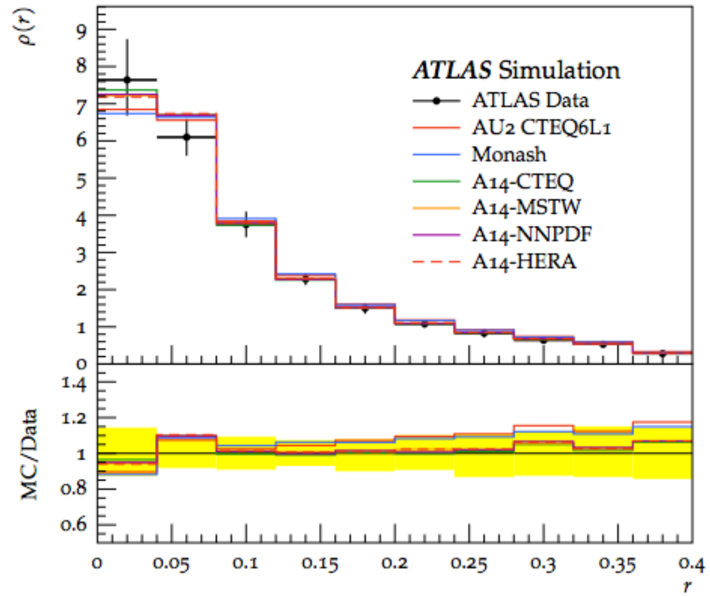
# A14: global tune of Shower and MPI

- A14 → suitable for use in high pT processes and using four different PDFs. These tunes simultaneously optimised MPI and parton shower (ISR,FSR) parameters since these model features affect data observables in combination.

**ATL-PHYS-PUB-2014-021**



# ATTBAR tune of ttbar observables

- In many ttbar measurements, the ISR & FSR modelling is crucial since it is one of the dominant uncertainties.

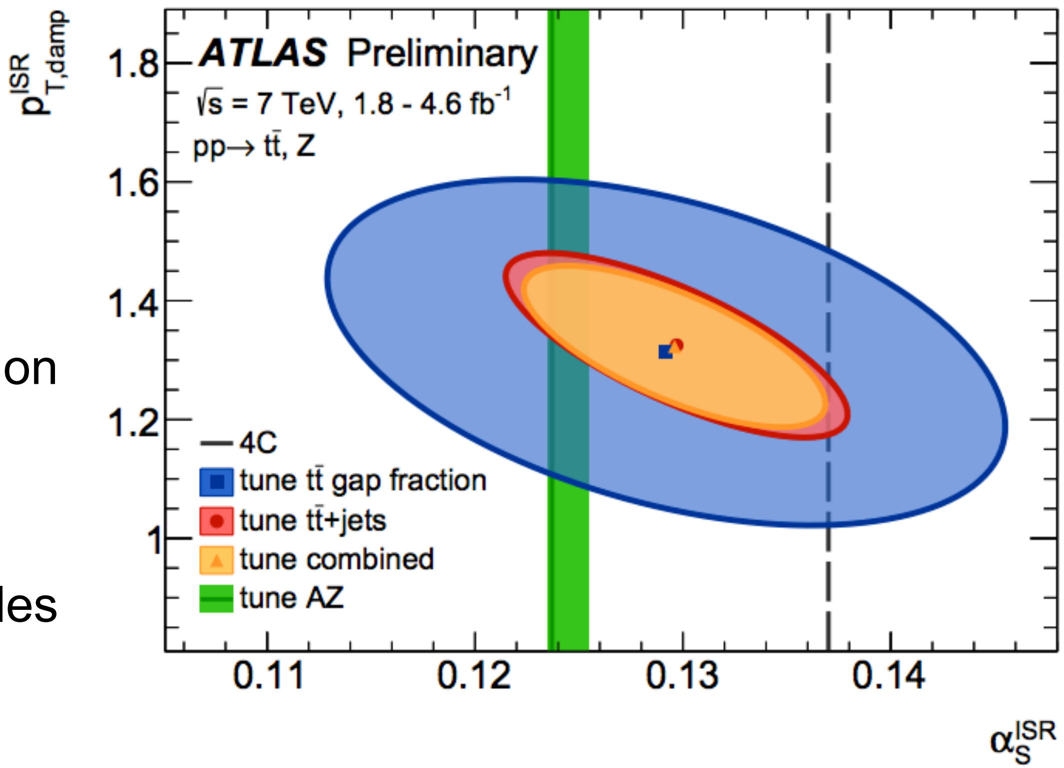
- Significant reduction of the modelling uncertainty can be achieved by verifying the universality of the parton shower model between Z boson and ttbar production.

- A simultaneous tune for ISR & FSR parameters is applied : **ATTBAR**

**ATL-PHYS-PUB-2015-007**

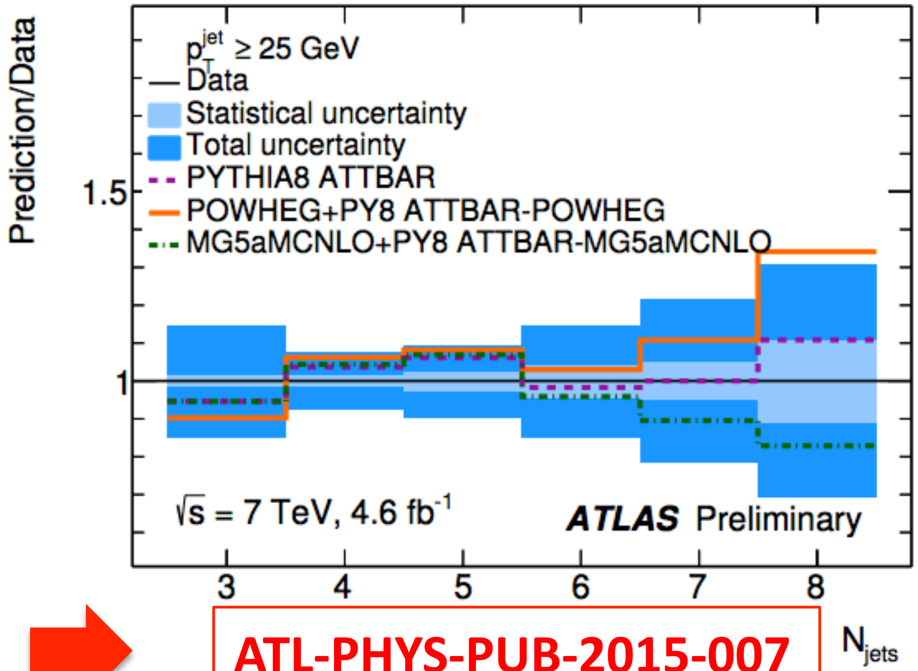
- For the first time in the context of PS tuning in MC simulations, the correlation of the experimental uncertainties is included in $\chi 2$ definition.

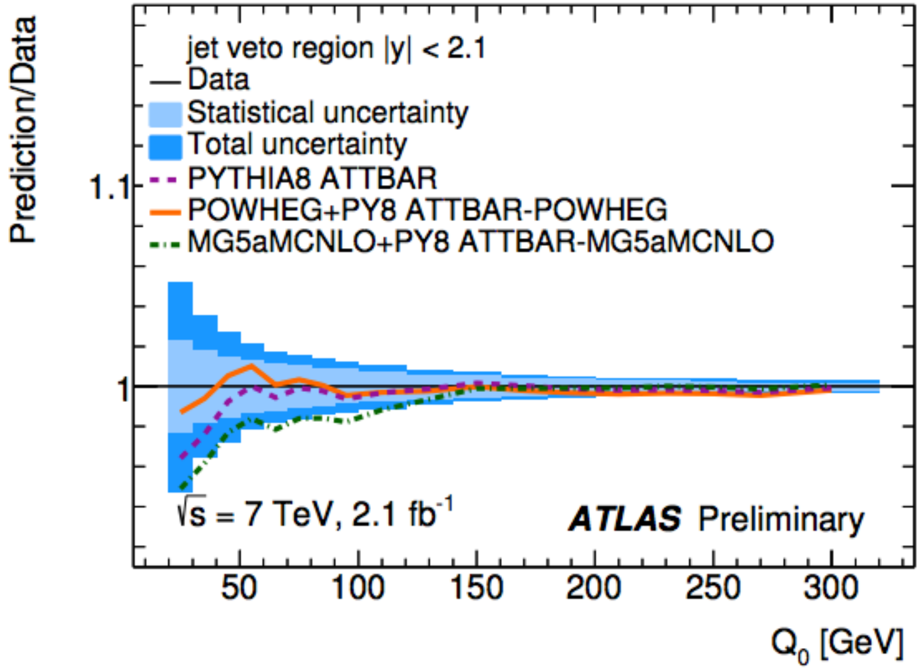
- The sensitivity of the various observables to the PS parameters is improved.



# ATTBAR tune of ttbar observables

- The ATTBAR tune is applied to the NLO PS generators POWHEG & MadGraph5_aMC@NLO.
- By lowering hdamp parameter (a variable which effectively regulates the high-pT radiation in POWHEG) to 1.8 $m_t$ , good agreement between ttbar data and Powheg+Pythia8 predictions.
- However this opens-up more important points: FSR cut-off in Pythia8, Global recoil in aMC@NLO, b-jet shapes.



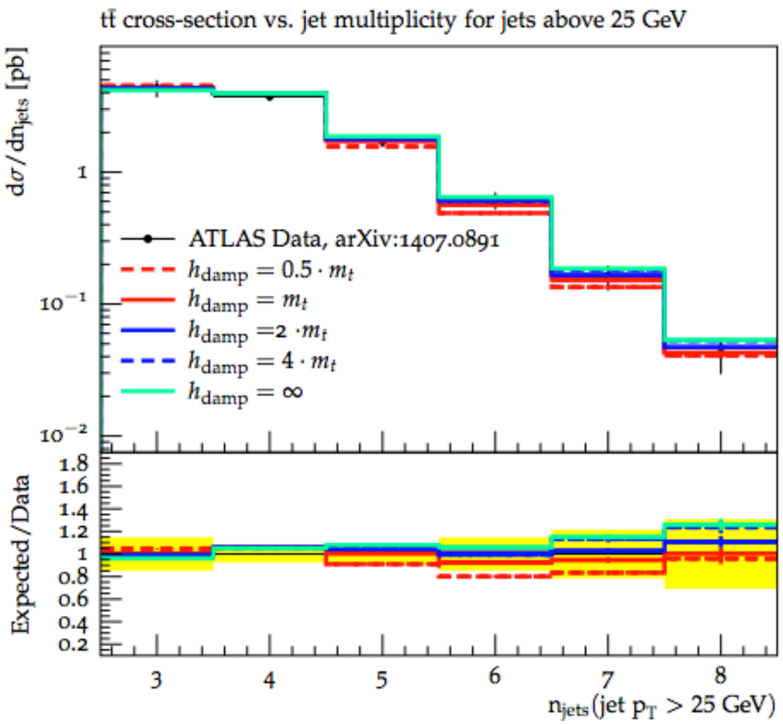



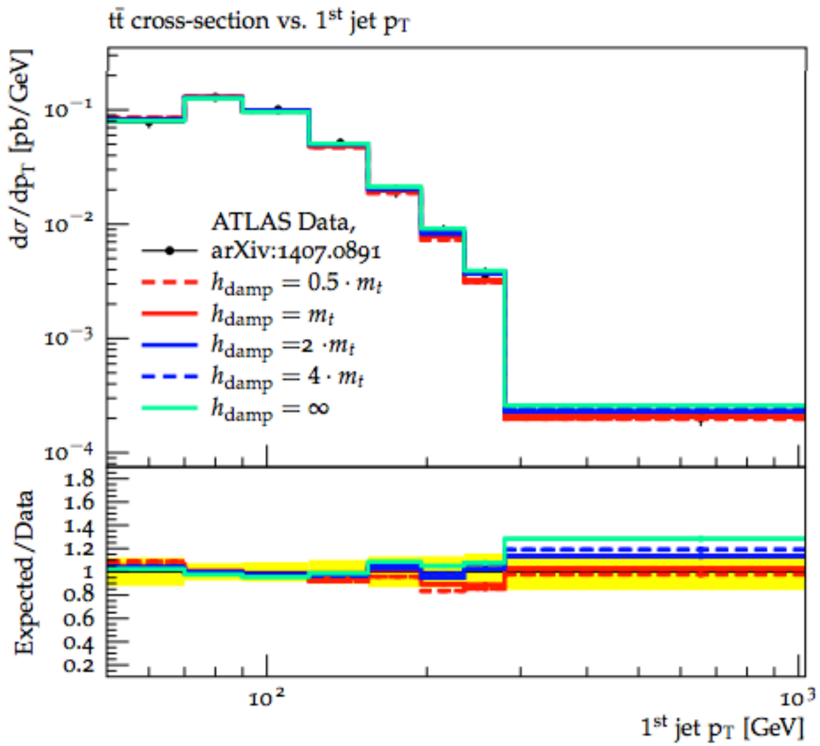

**ATL-PHYS-PUB-2015-007**

# ttbar modeling with hdamp and scale variation

• **@ Run1**:
 - Powheg(CT10)+Pythia6 with P2011C tune and CTEQ6L1 is being the default.
 - Switching $h_{damp}$= infinity to $h_{damp}$= $m_{top}$ is found best to describe the data and improves T(ttbar) but not pT(top).

**ATL-PHYS-PUB-2015-002**



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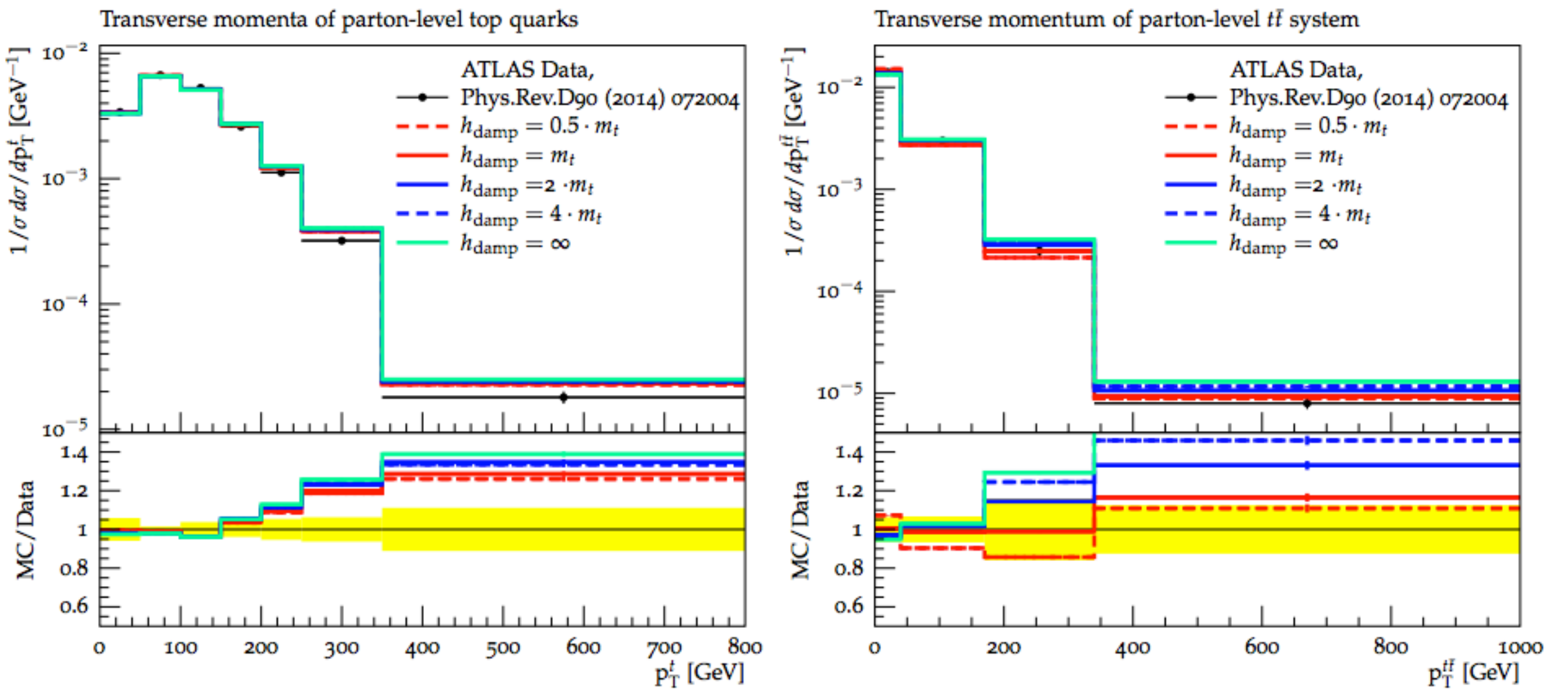
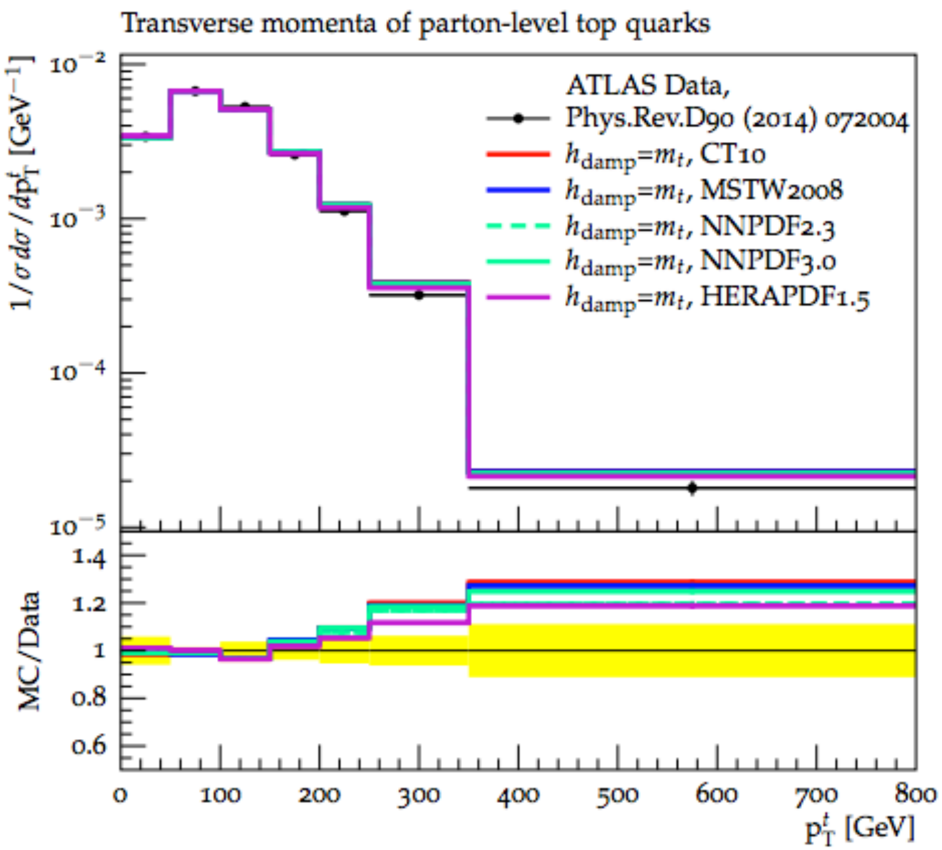
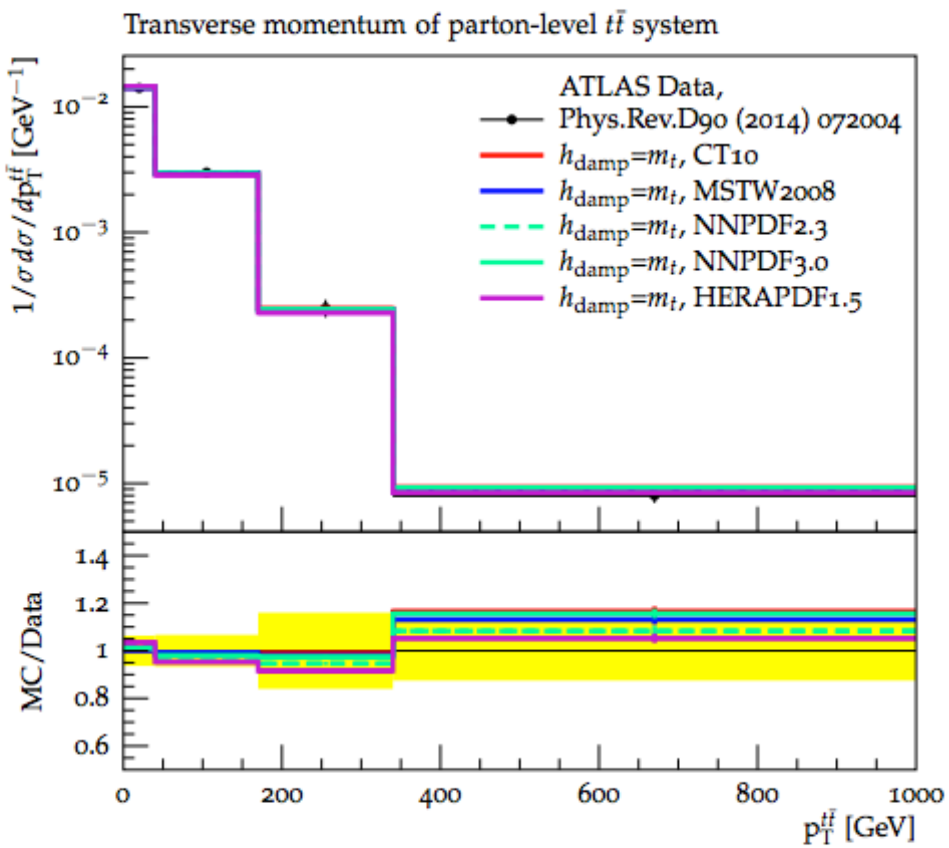
→ The main improvement here is ttbar pT, the pT top distribution (which is highly correlated with $m_{tt}$) is less improve.



# ttbar modeling with hdamp and PDF variation

- The choice of the PDF can have quiet significant impact on the kinematics of the ttbar production.
- For this reason, a variety of NLO PDF sets have been studied.
- But again, the discrepancy between the prediction and the experimental data for high top quark pT cannot be solved by any of the used PDF sets !

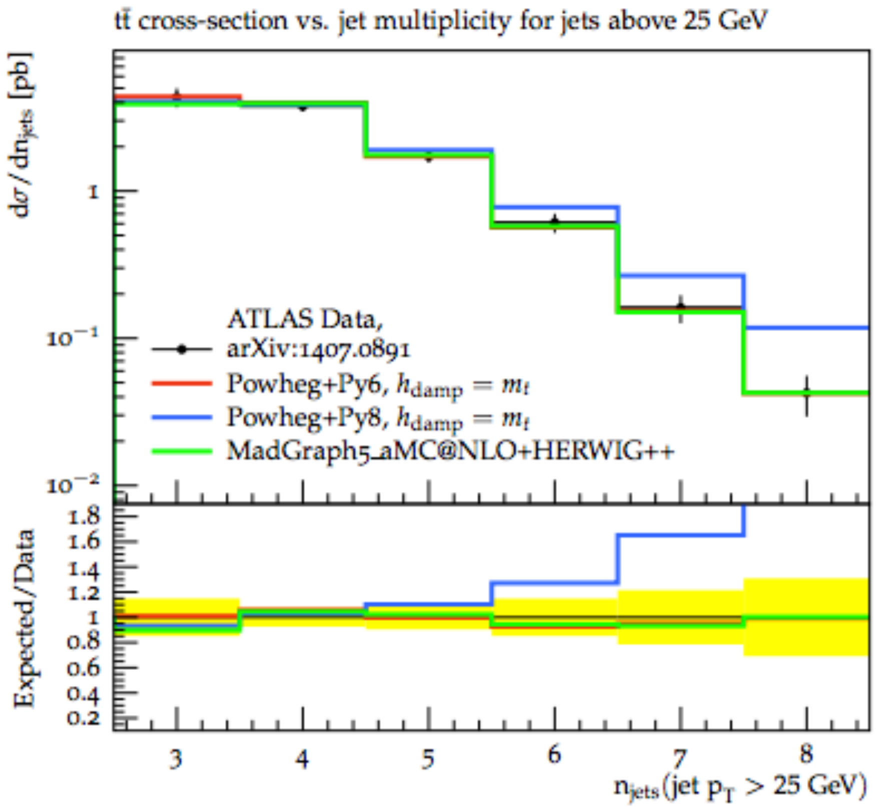


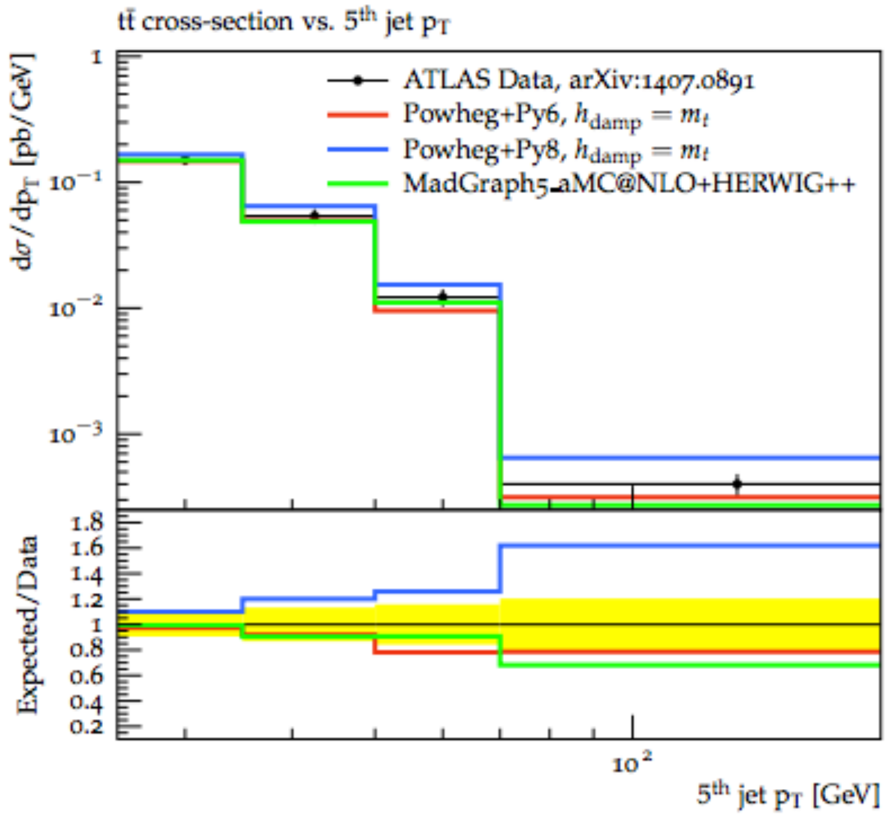



# ttbar modeling with new C++ generators

- The ATLAS baseline ttbar sample (Powheg+Pythia6 with $h_{damp} = m_{top}$) is compared to new generator setups: Powheg+Pythia8 using AU2 tune (also with $h_{damp} = m_{top}$) and MadGraph5_aMC@NLO+Herwig++ with UEEE5 tune.

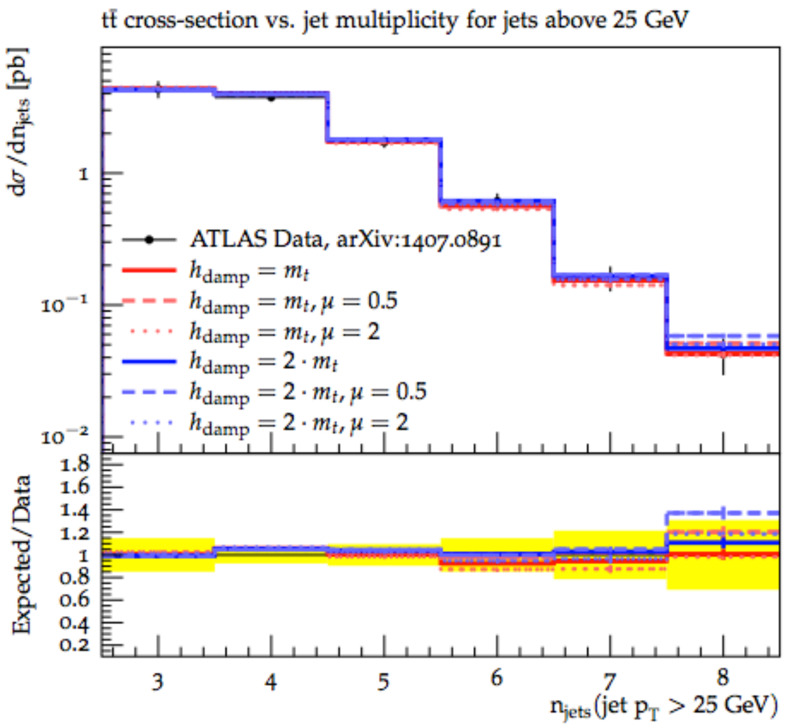
Powheg+Pythia8 ➔ produces too many additional jet
MadGraph5_aMC@NLO+Herwig++ → give a better description of the data

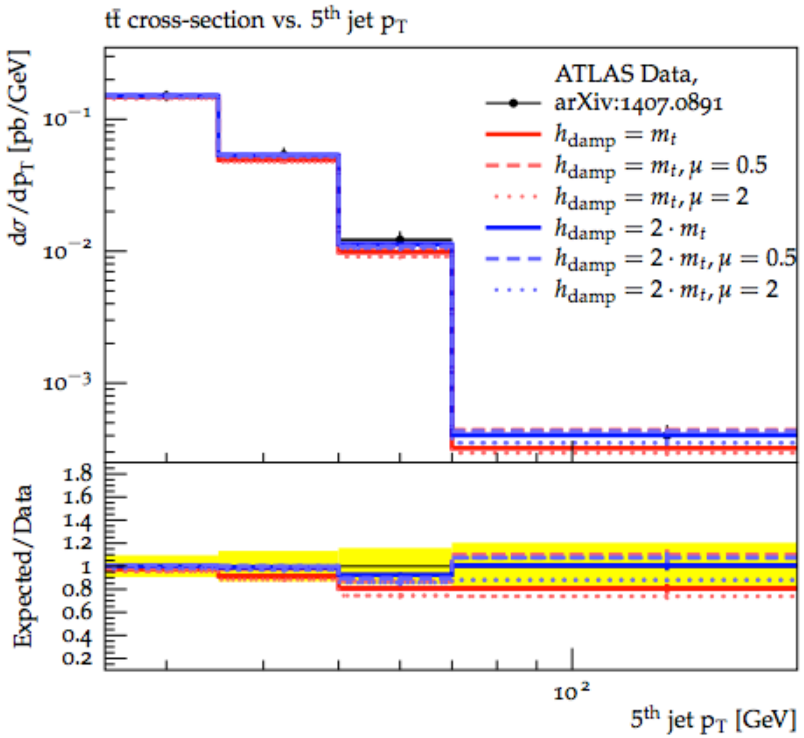


# New radiation systematics for ttbar production

- 2 samples of Powheg+Pythia6 (with $h_{damp} = m_{top}$ and $h_{damp} = 2\ m_{top}$) are compared to access the systematic variations connected to the extra radiation activity.
- For each sample the factorization and renormalization scale are simultaneously ($\mu = \mu_f = \mu_r$) varied by a factor of 0.5 (for $h_{damp} = m_{top}$) and 2 (for $h_{damp} = 2\ m_{top}$).
- Variation of the scale in the shower: use of Perugia2012radLo and radHi



# Conclusions

- Due to time limit, I didn't cover the MC studies in Higgs production for ATLAS Run 2. See **ATL-PHYS-PUB-2014-022**
- The ATLAS recent performed tunes: AT14 as baseline tune and ATTBAR as specific tune for ttbar production.
- The new $h_{damp} = m_{top}$ setting is found to best describe the data, although none of the settings provide a good description of pT(top).
- The MC modeling & production is a very expensive and time-consuming activity. Therefore one have to be precise from the beginning of MC generator level.
- With the LHC-Run2 we will have completely new data and new era starting.
- A lot of efforts were/are needed to provide proper MC estimates for signal and backgrounds at 13 (14) TeV.

# Thanks for your attention !

Backup

# A14 tunes

- Observable–weight combinations used for the tuning

| Observable | Fit range | Weight |
|---|---|---|
| **Track jet properties** [6] | | |
| Charged jet multiplicity (50 distributions) | | 10.0 |
| Charged jet $z$ (50 distributions) | | 10.0 |
| Charged jet $p_T^{rel}$ (50 distributions) | | 10.0 |
| Charged jet $\rho_{ch}(r)$ (50 distributions) | | 10.0 |
| **Jet shapes** [7] | | |
| Jet shape $\rho$ (59 distributions) | | 10.0 |
| **Dijet decorr** [10] | | |
| Decorrelation $\Delta\phi$ (9 distributions) | $\Delta\phi > 0.75$ | 20.0 |
| **Multijets** [12] | | |
| 3-to-2 jet ratios (8 distributions) | | 100.0 |
| $p_T^Z$ [13, 14] | | |
| $Z$-boson $p_T$ (20 distributions) | $p_T^Z < 50$ GeV | 10.0 |
| **Substructure** [9] | | |
| Jet mass, $\sqrt{d_{12}}$, $\sqrt{d_{23}}$, $\tau_{21}$, $\tau_{23}$ (36 distributions) | | 5.0 |
| $t\bar{t}$ **gap** [11] | | |
| Gap fraction vs $Q_0$, $Q_{sum}$ for $\|y\| < 0.8$ | | 100.0 |
| Gap fraction vs $Q_0$, $Q_{sum}$ for $0.8 < \|y\| < 1.5$ | | 80.0 |
| Gap fraction vs $Q_0$, $Q_{sum}$ for $1.5 < \|y\| < 2.1$ | | 40.0 |
| Gap fraction vs $Q_0$, $Q_{sum}$ for $\|y\| < 2.1$ | | 10.0 |

and more. See ATL-PHYS-PUB-2014-021 for further details.