# **ATLAS** and **CMS** Top Quark Simulations

## LHC*top*WG

**Benjamin Nachman**

*SLAC, Stanford University*

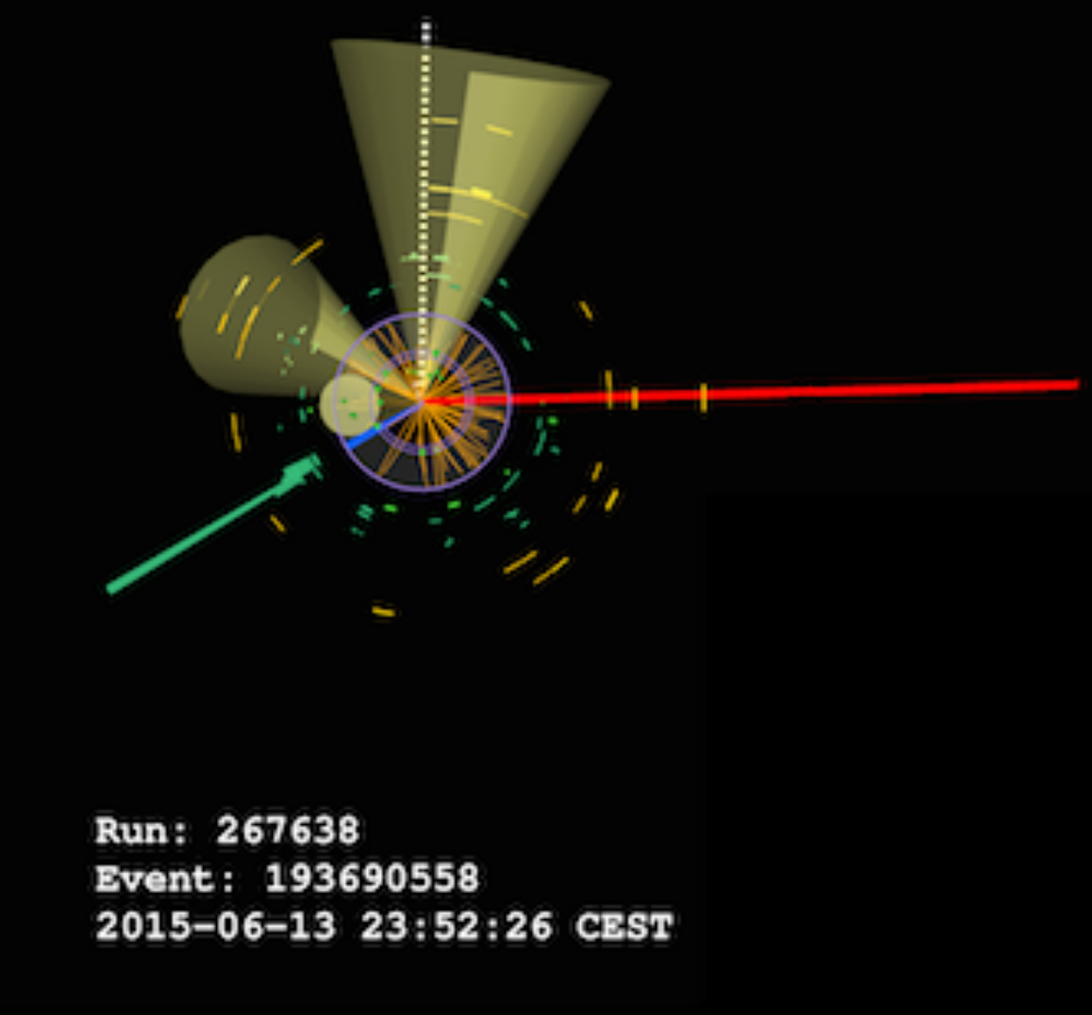
November 18, 2015

LHC TOP WG Meeting

*CERN*

*(thank you to the WG contacts for help preparing this talk!)*

# Introduction




1) Overview of NLO MC setups

-aMC@NLO+Pythia 8

-aMC@NLO+Herwig++

-Powheg+Pythia 6/8

-Powheg+Herwig++

-Sherpa

2) PDFs

3) Particle Level Definitions

# NLO tt̄ MC @ ATLAS and CMS



(more details in subsequent slides)

| ME | Shower | CMS | ATLAS |
|---|---|---|---|
| **aMC@NLO** | **Pythia 8** | **available** and in general use (multiple flavors) | **available**, not in general use |
| **aMC@NLO** | **Herwig++** | **available** and in general use (multiple flavors) | **available** and in general use |
| **Powheg** | **Pythia 6** | deprecated | Nominal |
| **Powheg** | **Pythia 8** | Nominal | **available**, not in general use |
| **Powheg** | **Herwig++** | **available** and in general use | **available** and in general use |
| **Sherpa 2.1** | **Sherpa** | **not available** | **available** and in general use |

flavors = LO+multileg+PS(MLM), NLO+PS(MC@NLO matching), NLO+multileg+PS(FxFx)

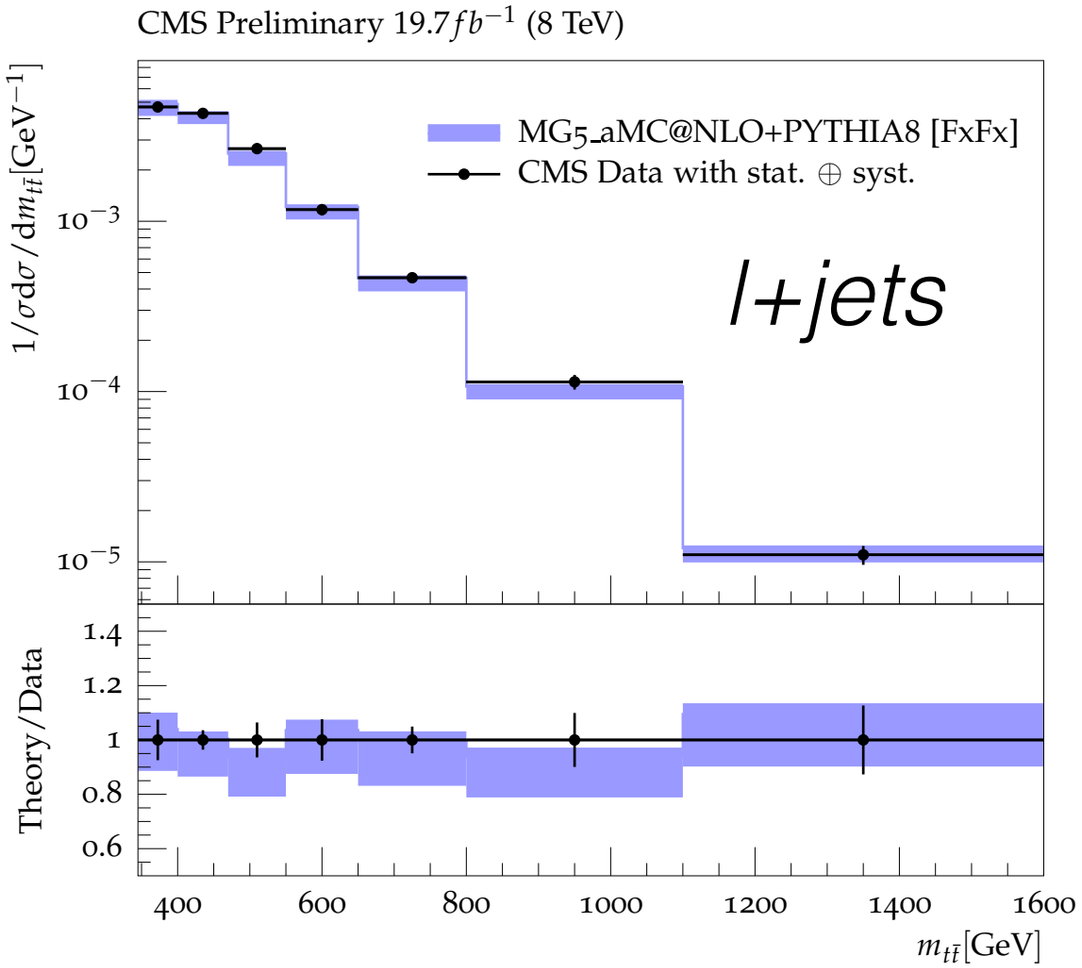
# aMC@NLO+Pythia 8: **CMS** *focus on the ME*



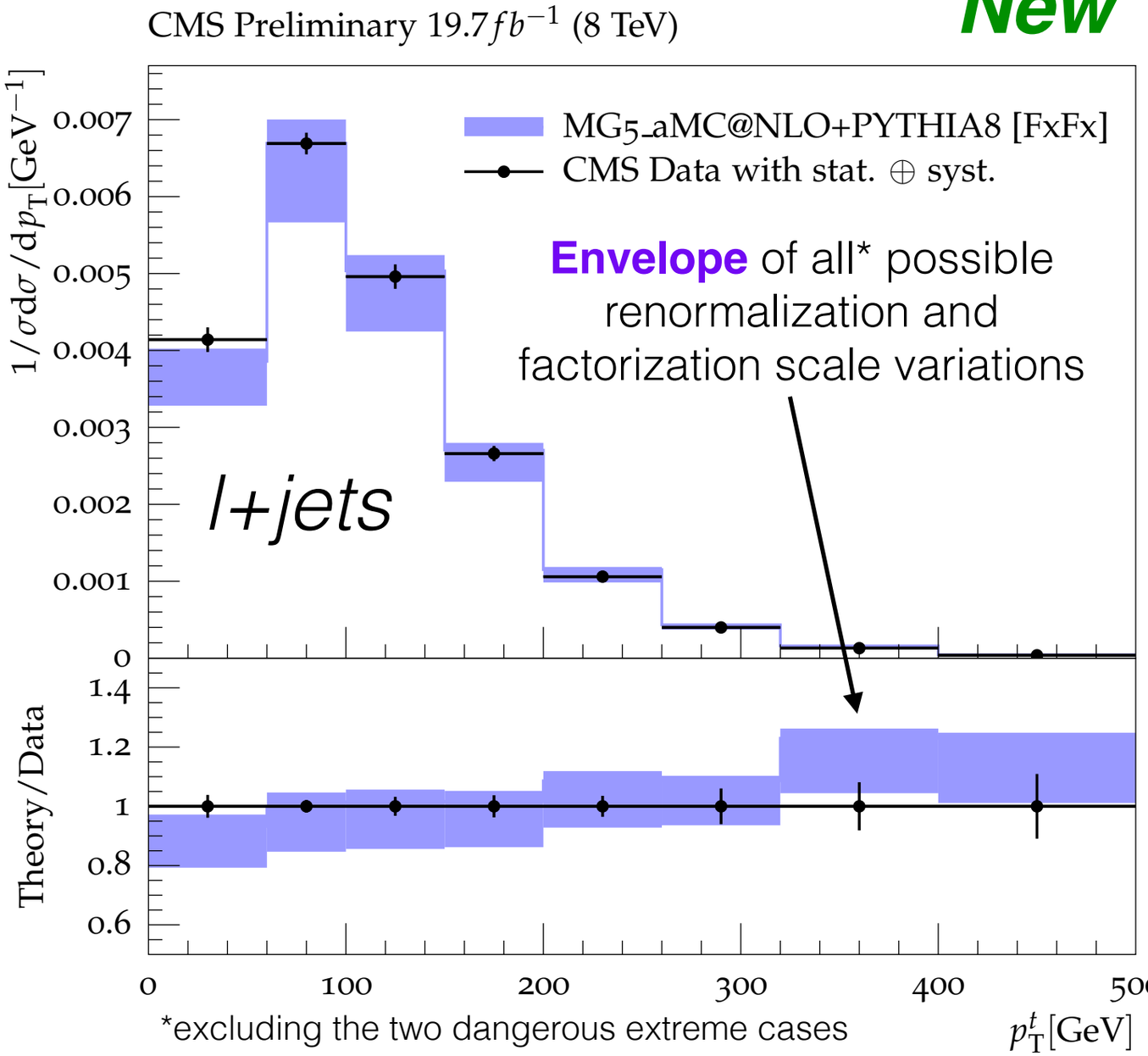
*Configurations*

$t\bar{t}$ + 0,1,2 jets [NLO/FxFx]

$t\bar{t}$ + 0,1,2,3 jets [LO/MLM]




**New**




Generally good agreement within the ~10% ME uncertainties

➡ See CMS-PAS-TOP-15-011 for details

# aMC@NLO+Pythia 8: **ATLAS** *focus on the PS*



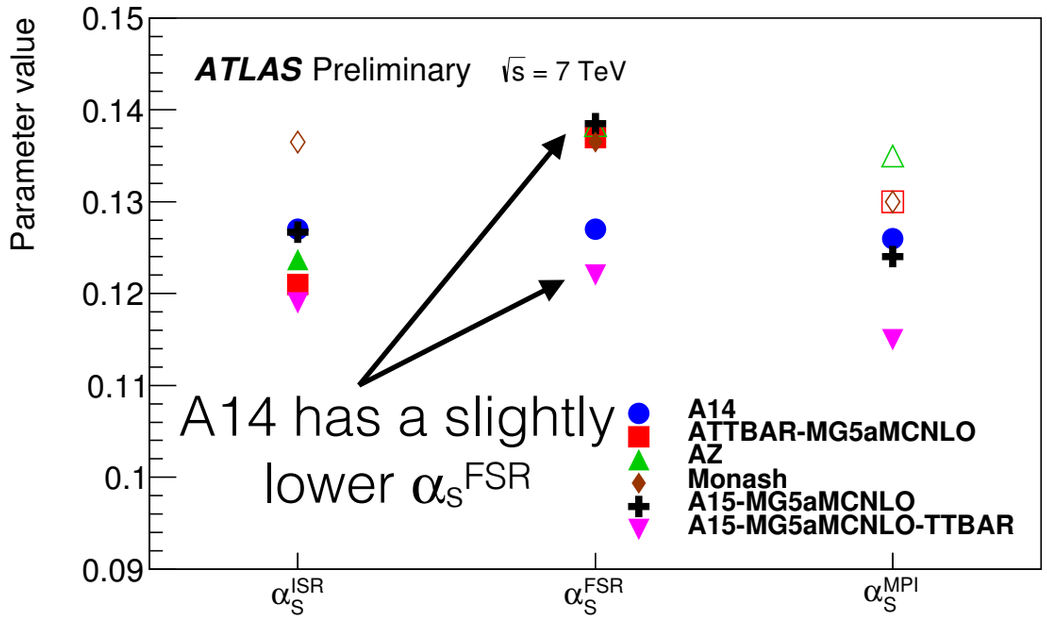
*Configuration*

NLO+PS
(MC@NLO Matching)

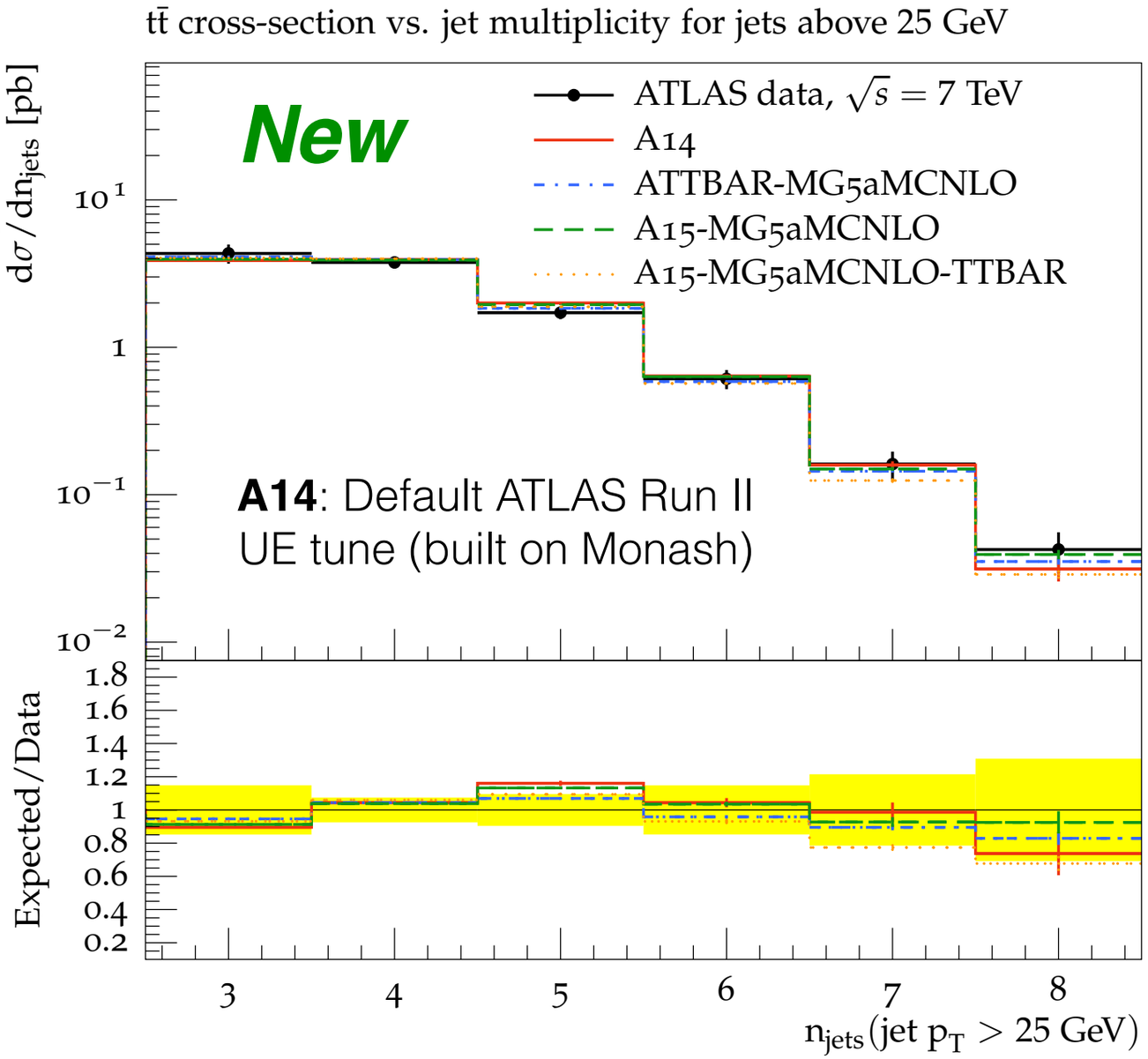
Idea: perform a dedicated tune of aMC@NLO+Pythia 8 sensitive to PS, UE, MPI modeling

**A15-MGaMCNLO**: Z+jets, Dijets, $t\bar{t}$

**A15-MGaMCNLO-TTBAR**: $t\bar{t}$ only




## How universal are our tunes?




**Conclusion**: generally consistent with A14

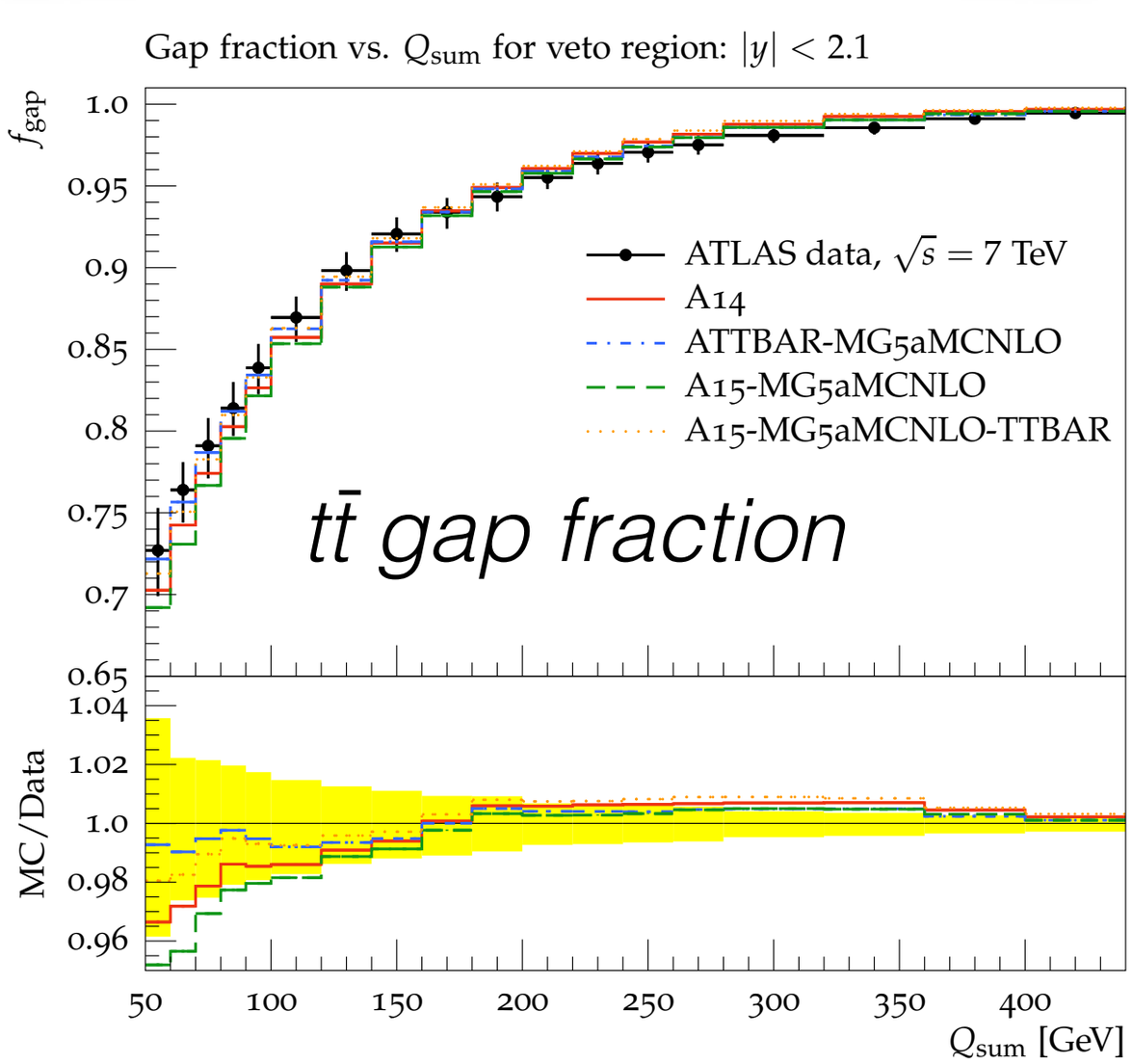
➡ See ATL-PHYS-PUB-2015-048 for details

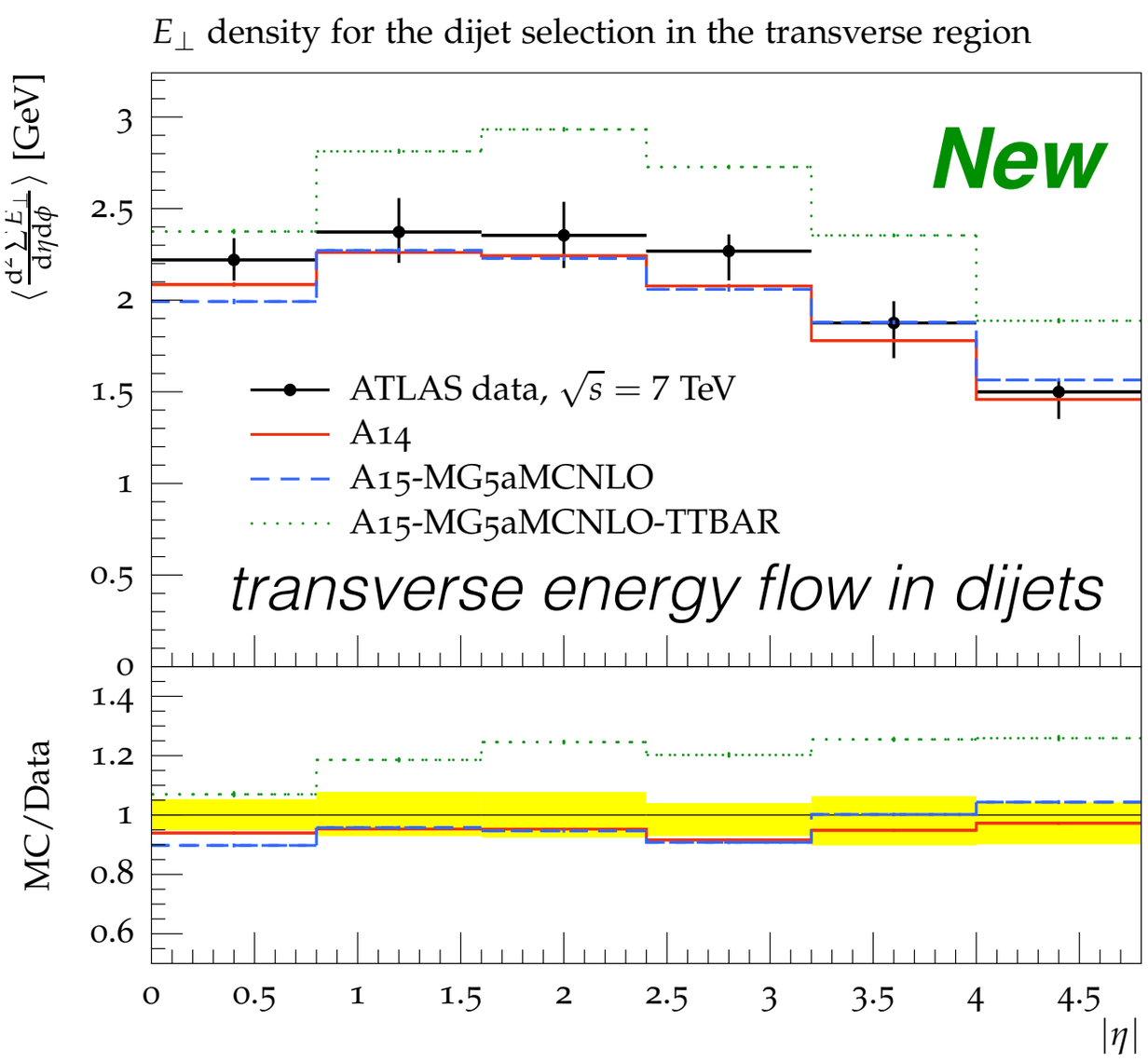
# aMC@NLO+Pythia 8: **ATLAS** *focus on the PS*

*Configuration*

NLO+PS
(MC@NLO Matching)

…mostly universal, but there are a few places where the dedicated tune differs




➡ See ATL-PHYS-PUB-2015-048 for details

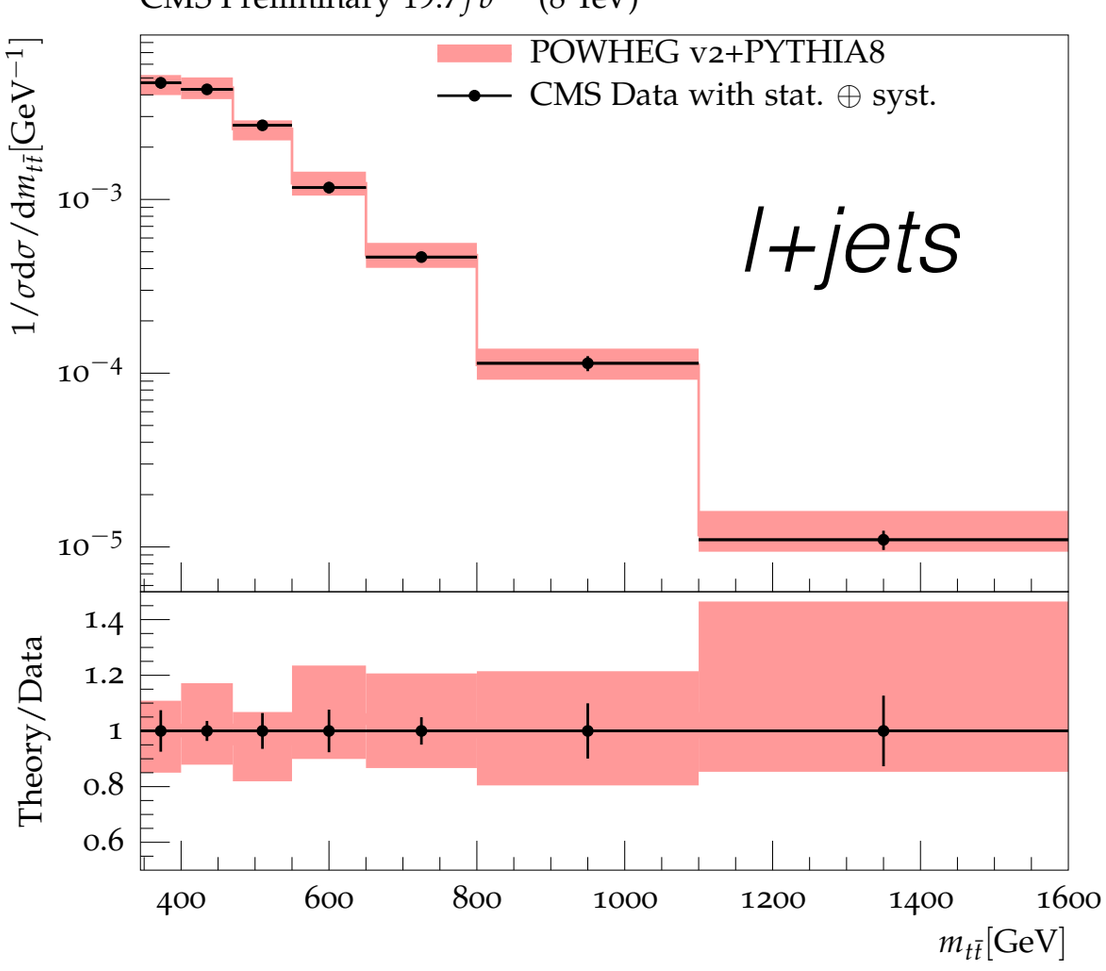
# Powheg+Pythia 8: **CMS**

*Configuration*

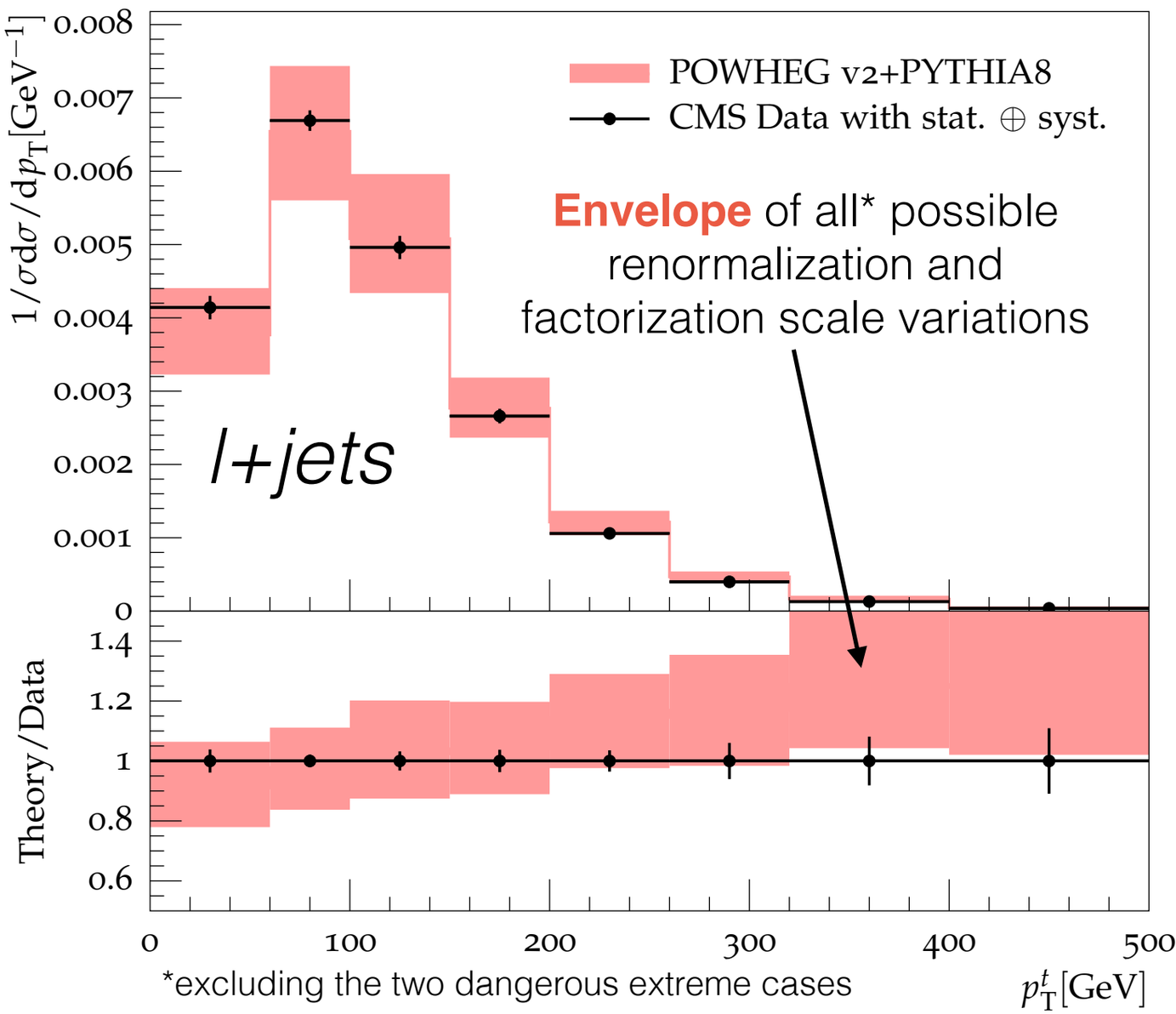
NLO+PS

(Pythia 8 **Main31** matching)

More symmetric than for aMC@NLO and slightly larger




**New**




Generally good agreement within the ~10% ME uncertainties

➡ See CMS-PAS-TOP-15-011 for details

# Powheg+Pythia 8: **ATLAS**

*Configuration*

NLO+PS

(Pythia 8 Main31 matching)

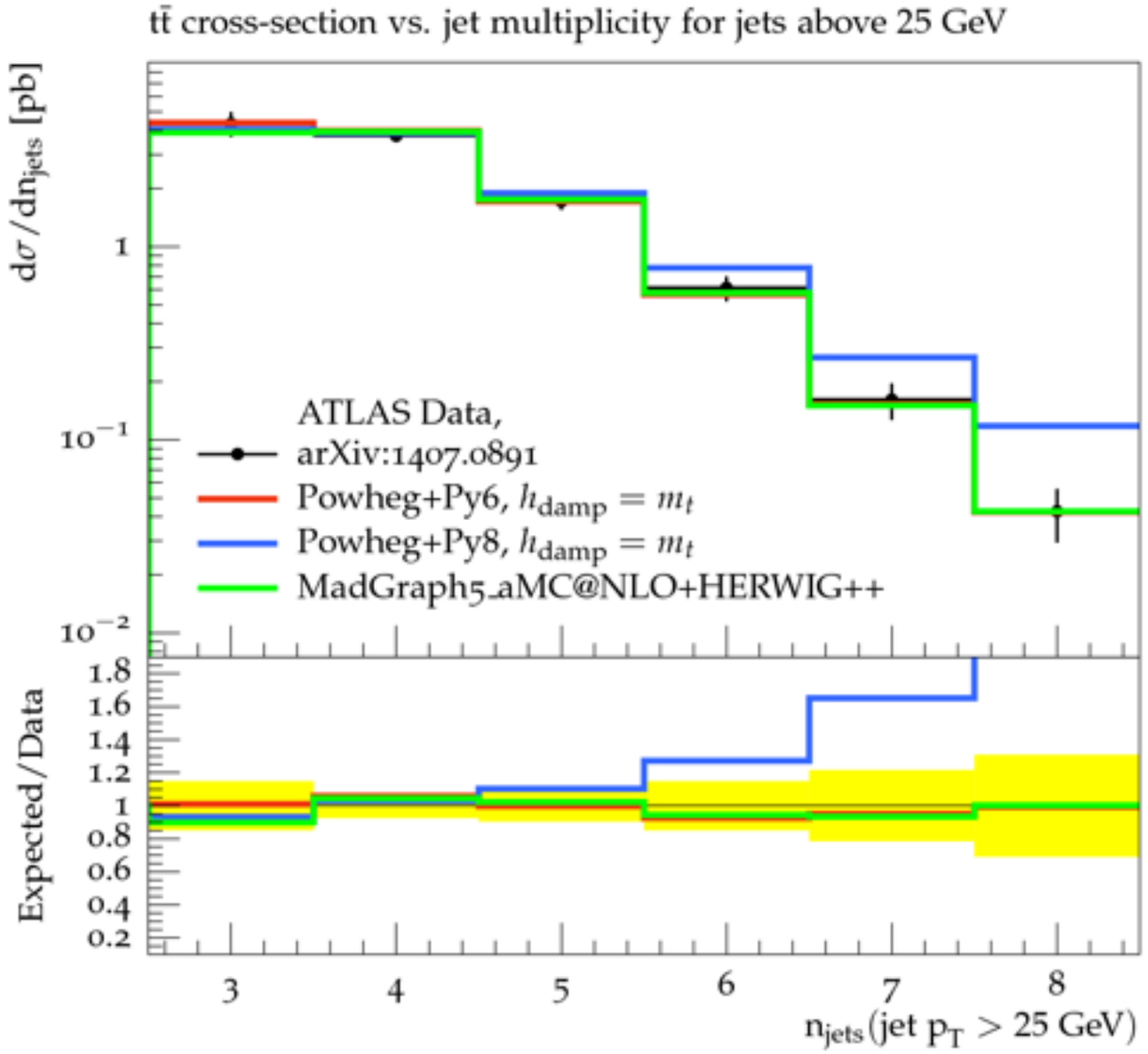
We observe that Powheg +Pythia 8 has **too much jet activity**

This is fixed by setting `pThard=2`

Now finalizing radiation variations (via A14) and will likely switch for MC samples for 2016

Early Run II ATLAS default is Powheg+Pythia 6

ATL-PHYS-PUB-2015-002



# Powheg+Herwig++

The ATLAS top MC team[a] has dedicated a lot of time and effort to understand significant data/MC differences for this setup.

This saga has involved a lot of positive interactions between ATLAS and CMS[b] as well as with the Herwig++ authors[c]!

*Overview*

| Problem | Solution |
|---|---|
| top p | momentum reshuffling parameter |
| y(tt) | CT10 -> NNPDF3.0 |
| njets | shower scale |
| jet p | Not yet fixed! |

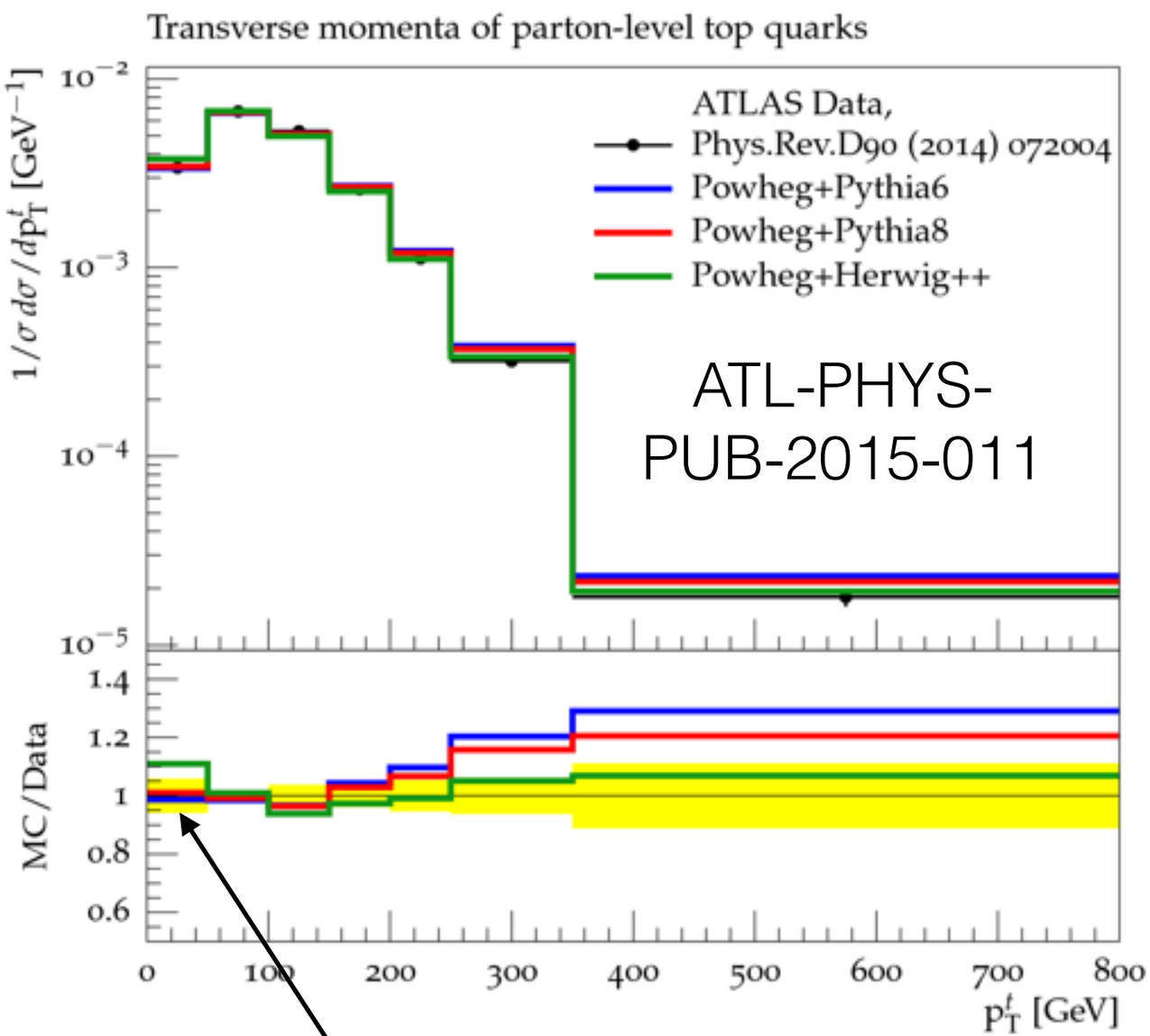
[a]Herwig++ efforts lead by Dominic Hirschbuehl
[b]Thank you Markus Seidel and Benedikt Maier
[c]Thank you Peter Richardson

# Powheg+Herwig++ *ME Kinematics*



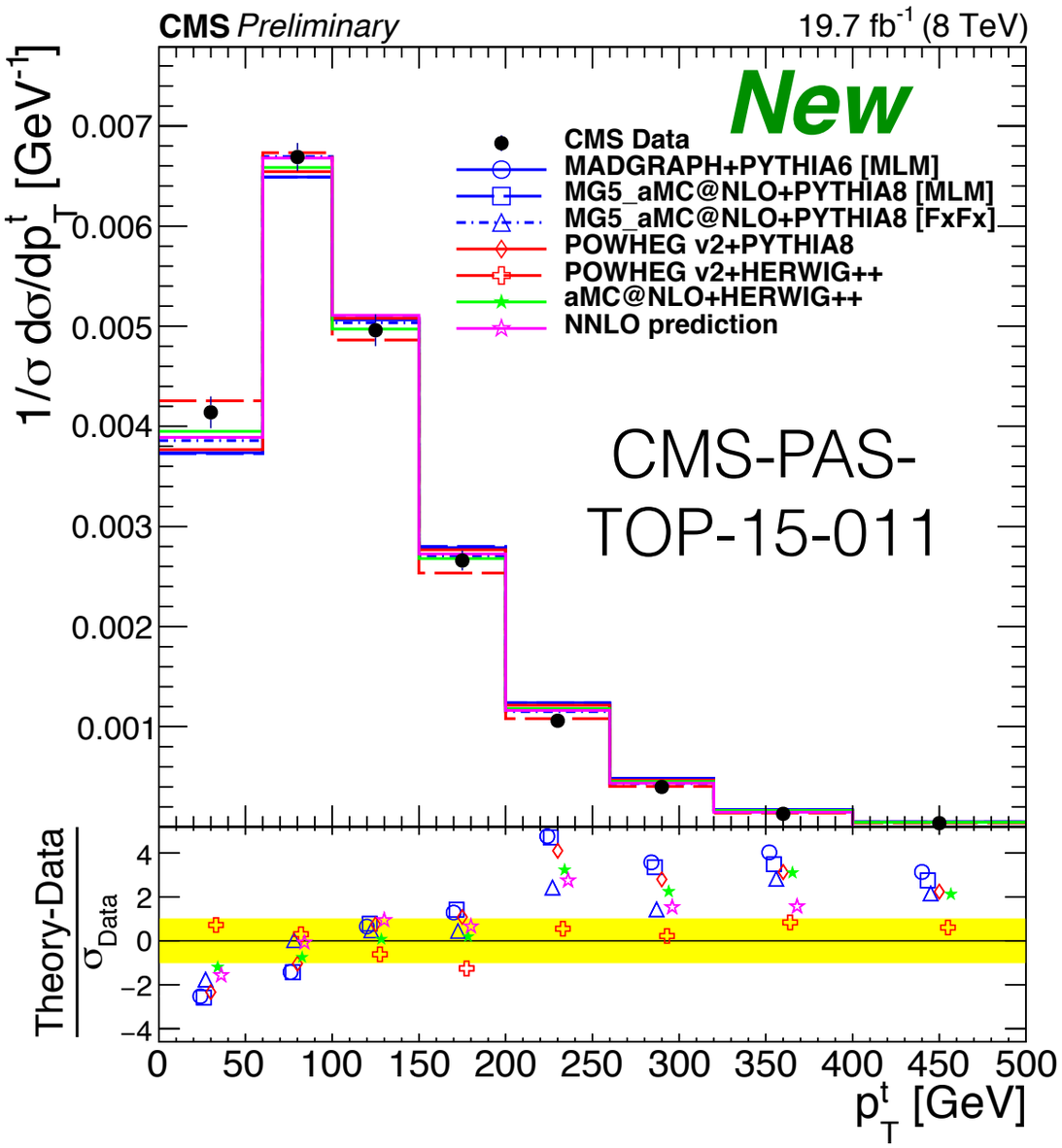
In general, ME distributions look (just as) good (as other generators)

*One exception is the top $p_T$, but this has a known solution*




Fixed with momentum re-shuffling:

`FinalStateReconOption 1`



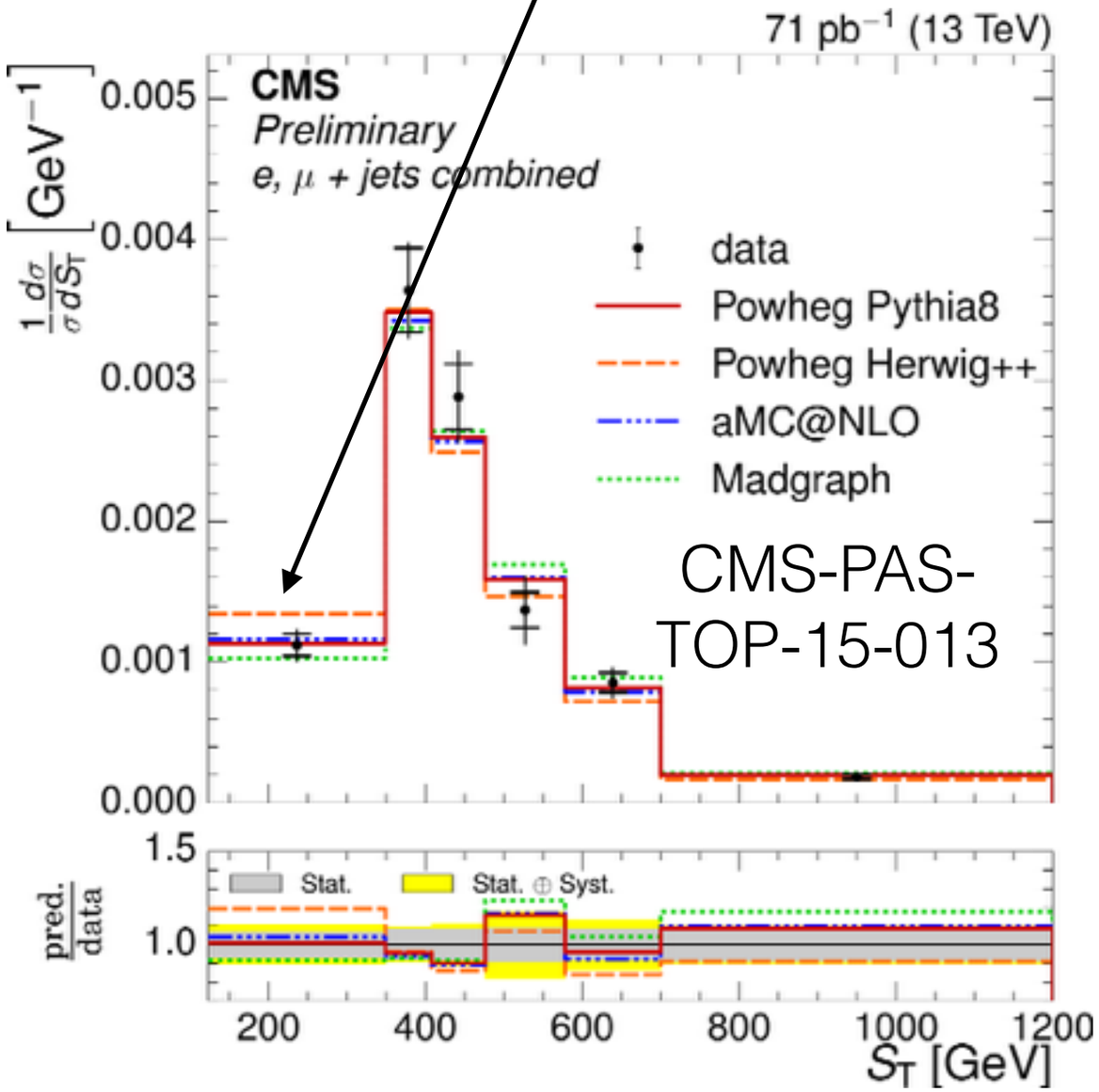

Already used by CMS!

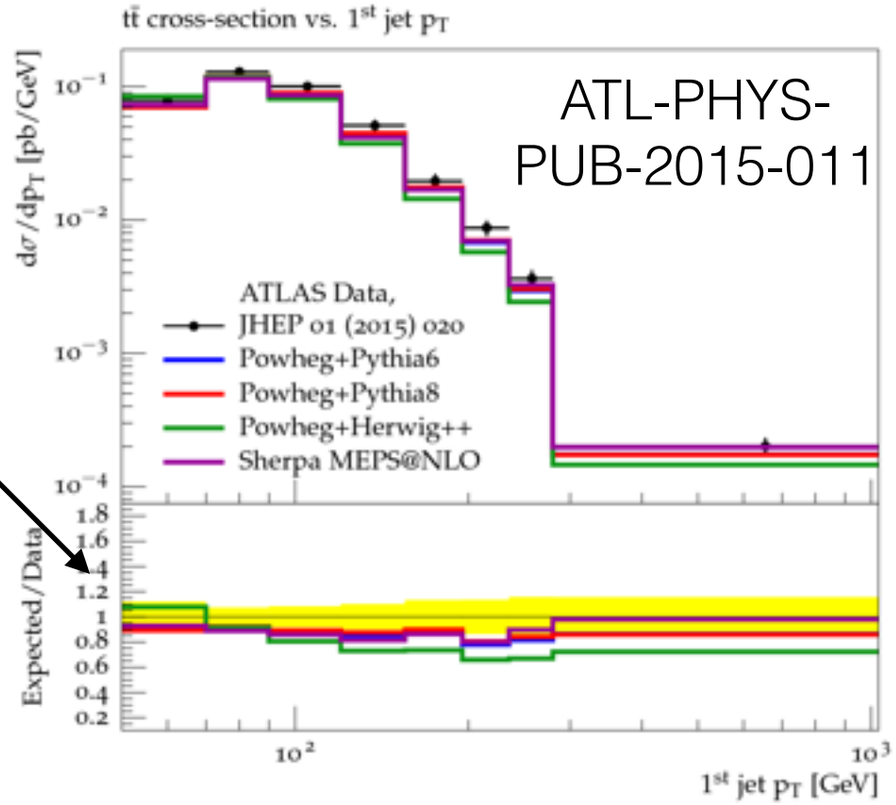
(*why is Powheg+Pythia 8 so different?*)

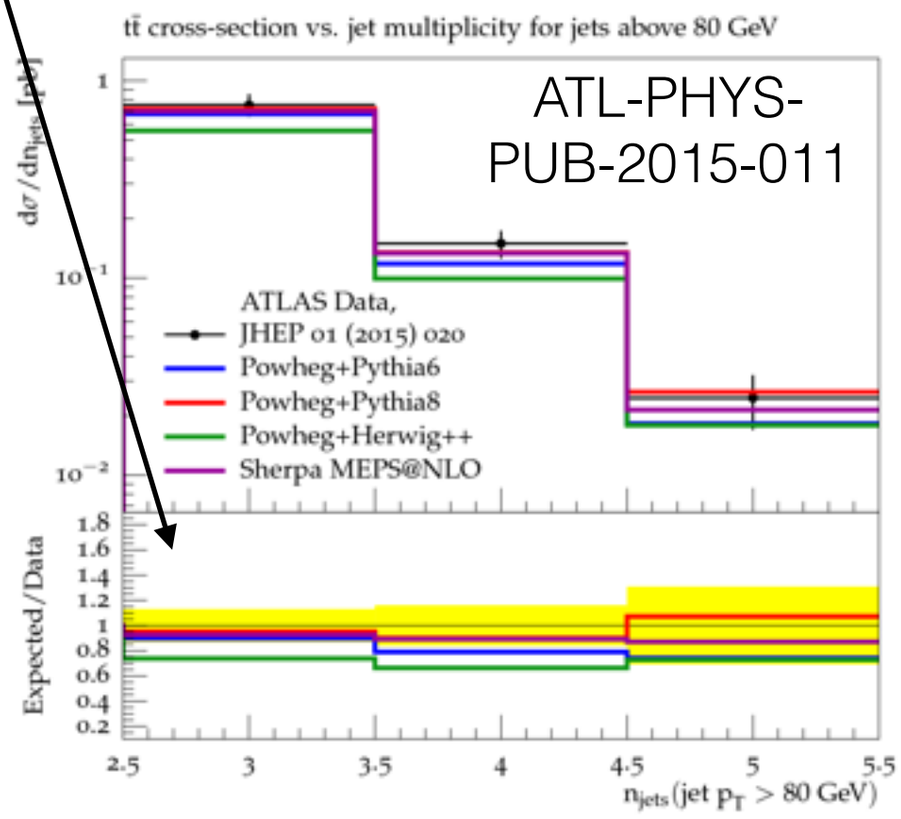
# Problem: hard jets are too soft

Unfortunately, most significant plots not public, but can see indications from public plots

…and at 13 TeV!



# Powheg+Herwig++ *impact on the cross-section*



## CMS-TOP-15-003

(1510.05302)

| Source | $\Delta\sigma_{t\bar{t}}$ (pb) | $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%) |
|---|---|---|
| Trigger efficiencies | 34 | 4.4 |
| Lepton efficiencies | 26 | 3.4 |
| Lepton energy scale | <1 | ≤0.1 |
| Jet energy scale | 12 | 1.5 |
| Jet energy resolution | <1 | ≤0.1 |
| Pileup | 5.4 | 0.7 |
| QCD scales | 1.5 | 0.2 |
| NLO generator of $t\bar{t}$ signal | 15 | 1.9 |
| Modeling of $t\bar{t}$ signal | 14 | 1.8 |
| PDF | 18 | 2.4 |
| Single top tW background | 13 | 1.7 |
| VV background | 3.5 | 0.5 |
| Drell-Yan background | 4.2 | 0.5 |
| Nonprompt leptons background | 7.9 | 1.0 |
| Total systematic (w/o luminosity) | 55 | 7.2 |
| Integrated luminosity | 92 | 12 |
| Statistical uncertainty | 60 | 7.8 |
| Total | 123 | 16 |

## ATLAS-CONF-2015-033

| Uncertainty | $\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%) | $\Delta C_b/C_b$ (%) | $\Delta\sigma/\sigma$ (%) |
|---|---|---|---|
| Data statistics | | | 6.0 |
| NLO modelling | 1.9 | -0.3 | 2.2 |
| hadronisation | -4.0 | 0.5 | 4.5 |
| Initial/final state radiation | -1.1 | 0.1 | 1.2 |
| Parton distribution functions | 1.3 | - | 1.4 |
| Single-top generator* | - | - | 0.5 |
| Single-top/ interference* | - | - | 0.1 |
| Single-top $Wt$ cross-section | - | - | 0.5 |
| Diboson modelling* | - | - | 0.1 |
| Diboson cross-sections | - | - | 0.0 |
| $Z$+jets extrapolation | - | - | 0.2 |
| Electron energy scale/resolution | 0.2 | 0.0 | 0.2 |
| Electron identification | 3.6 | 0.0 | 4.0 |
| Electron isolation | 1.0 | - | 1.1 |
| Muon momentum scale/resolution | 0.0 | 0.0 | 0.1 |
| Muon identification | 1.1 | 0.0 | 1.2 |
| Muon isolation | 1.0 | - | 1.1 |
| Lepton trigger | 1.3 | 0.0 | 1.3 |
| Jet energy scale | -0.3 | 0.0 | 0.3 |
| Jet energy resolution | -0.1 | 0.0 | 0.1 |
| $b$-tagging | - | 0.1 | 0.3 |
| Misidentified leptons | - | - | 1.3 |
| Analysis systematics | 6.4 | 0.6 | 7.3 |
| Integrated luminosity | - | - | 10.0 |
| Total uncertainty | 6.4 | 0.6 | 13.7 |

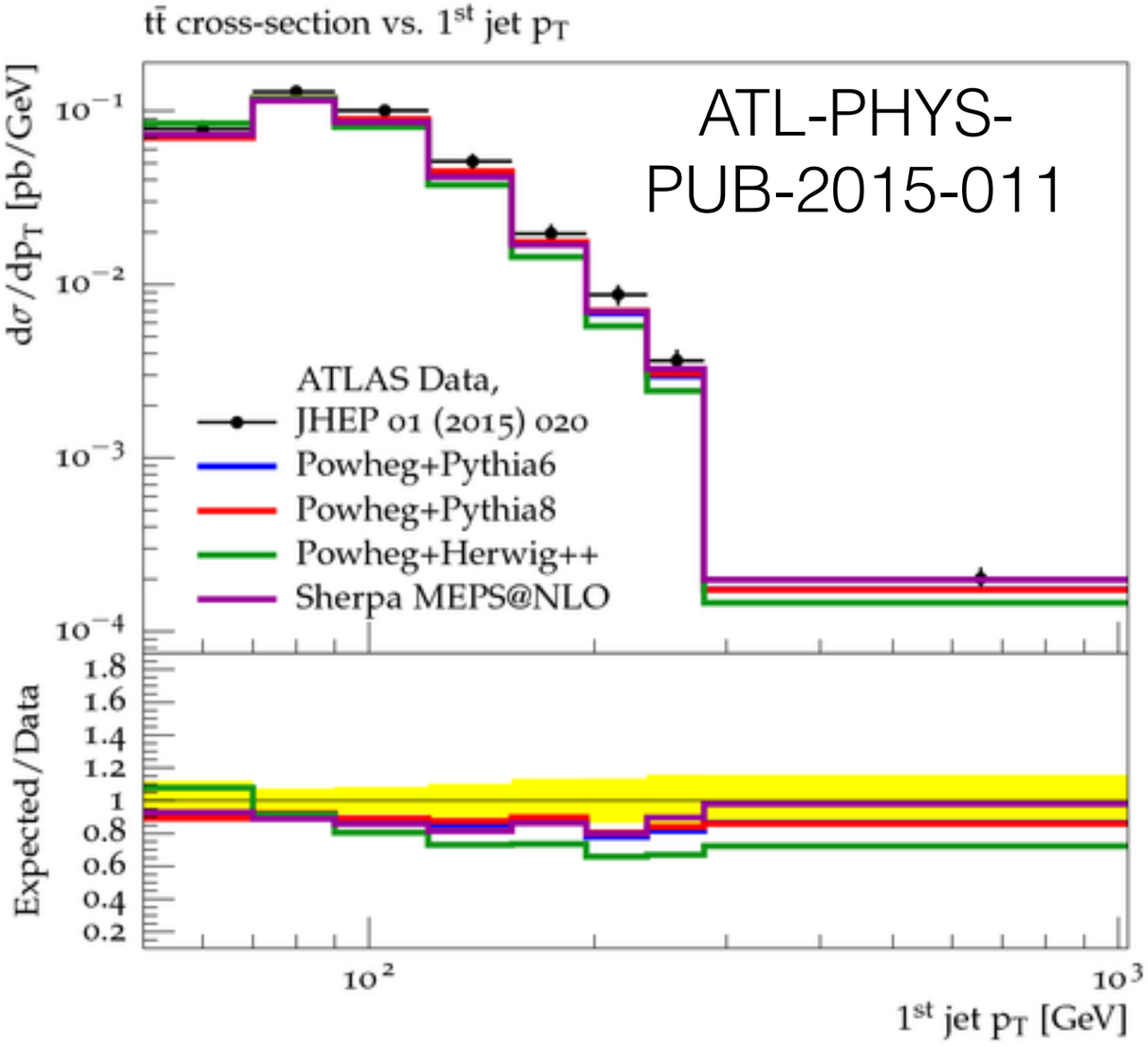
(Different analysis strategies, so don't a priori expect uncertainties to be of the same size)

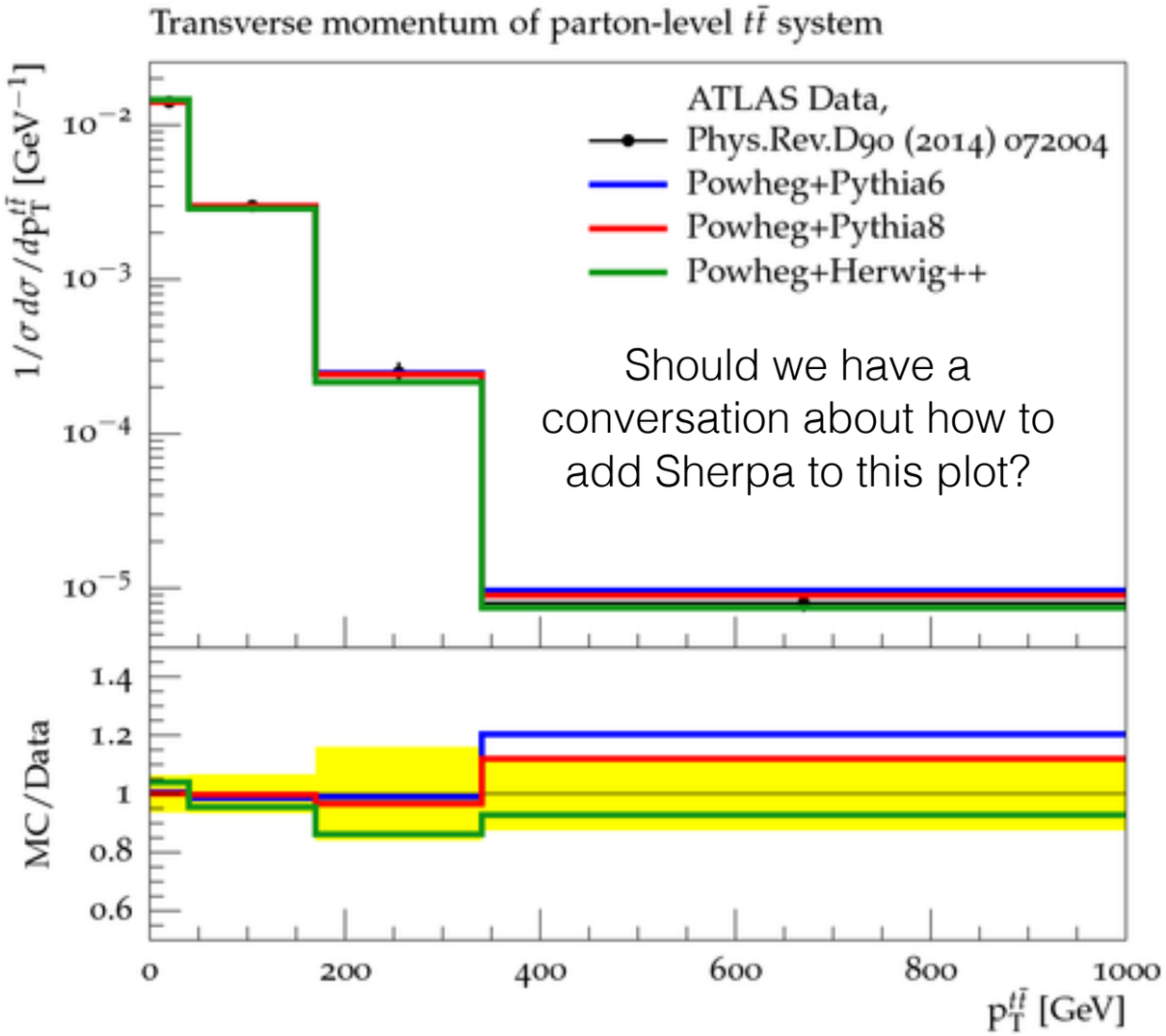
# Sherpa



How can we use Sherpa to complement our existing Powheg and aMC@NLO setups?

In ATLAS:
Sherpa 2.1
$t\bar{t}$+0,1j@NLO+2,3,4@LO




Samples exist in ATLAS but are used only for cross-checks and not currently for any final analysis results

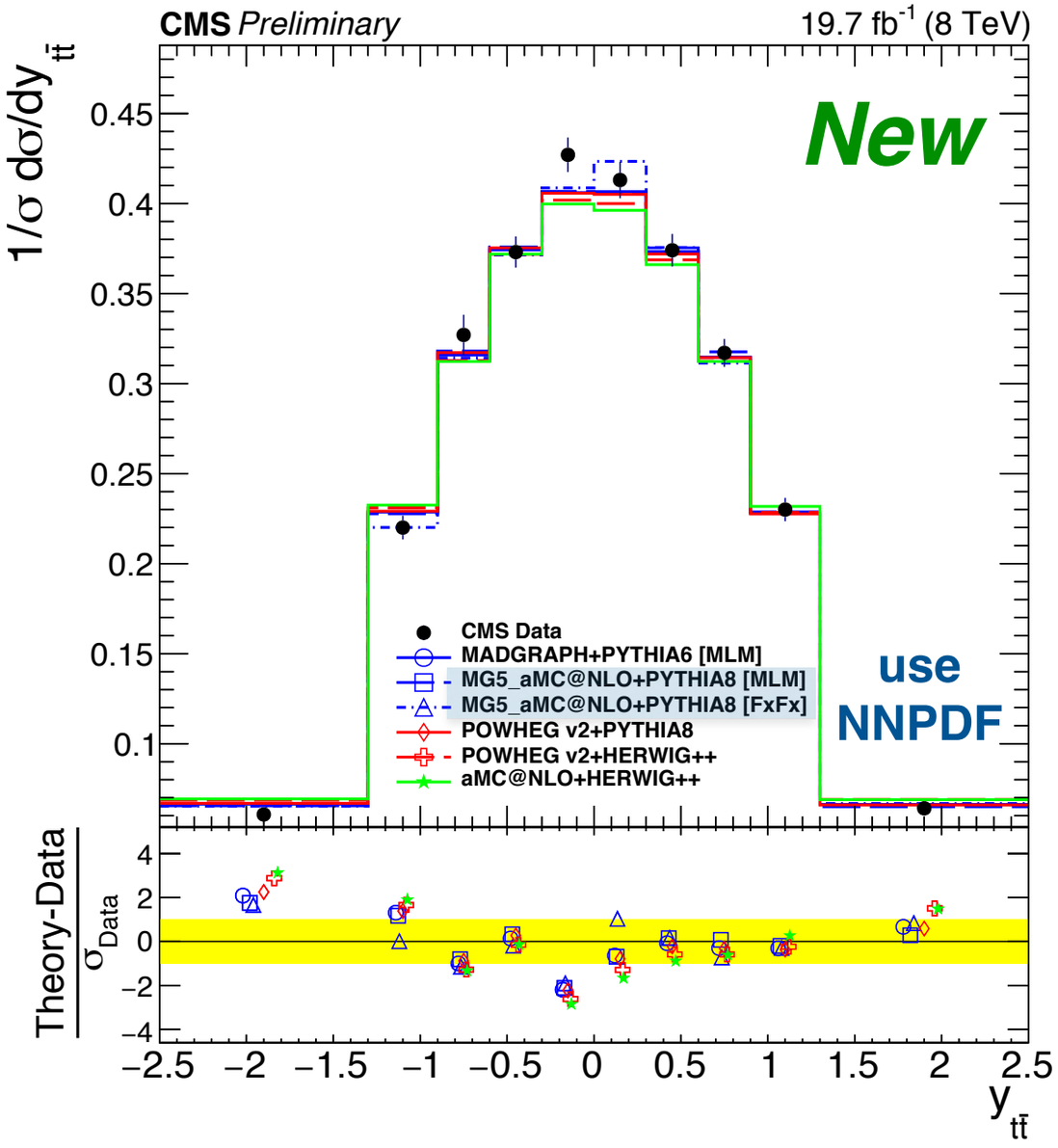
# Now for a few miscellaneous items.

http://www.bbc.co.uk/programmes/b00n7sf5

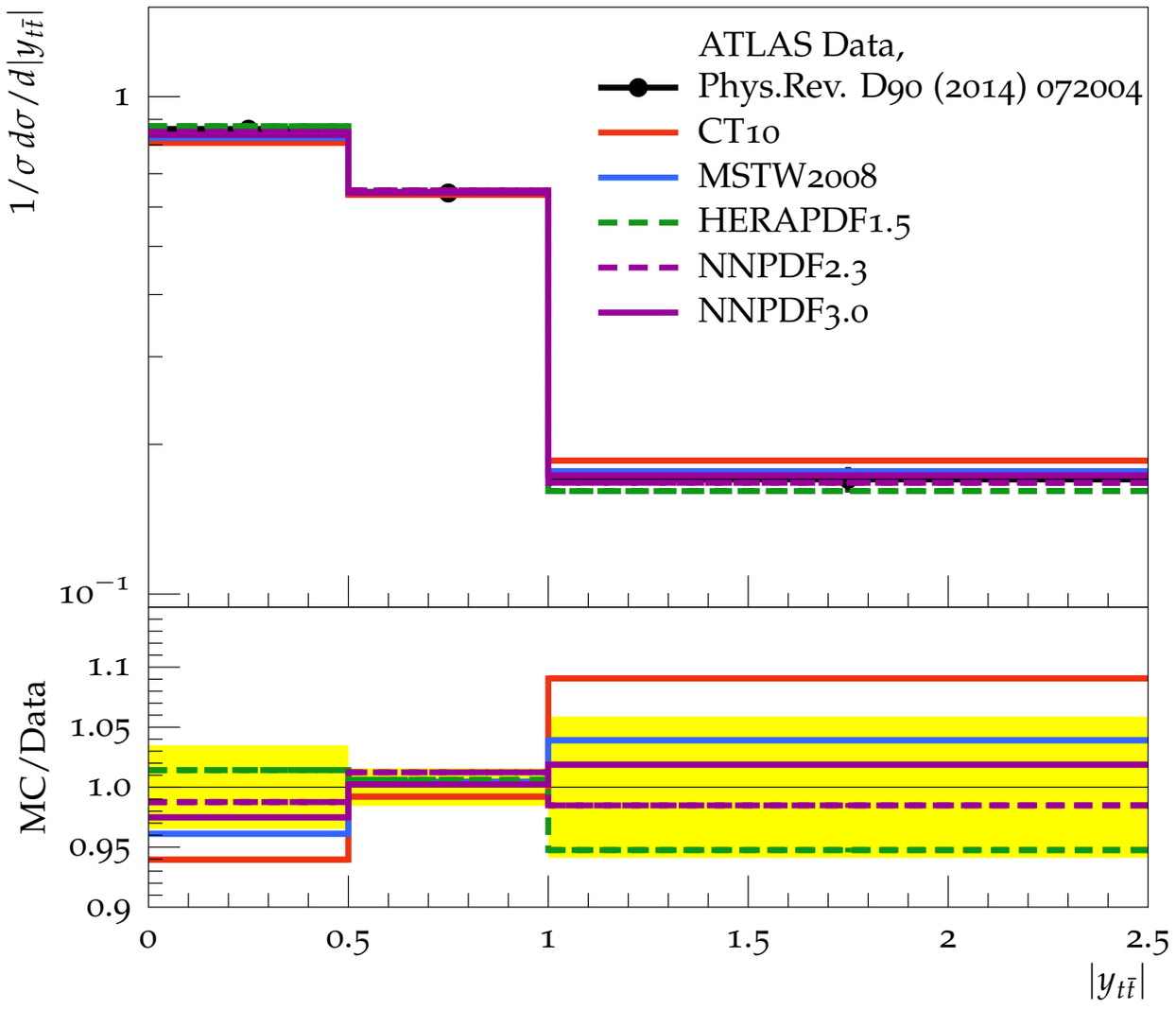
# A quick note about PDFs



## CMS-PAS-TOP-15-011




## ATL-PHYS-PUB-2015-011




The change from CT10 -> NNPDF significantly improves the rapidity distribution

*(but unfortunately has little impact on the top $p_T$)*

# EvtGen

in **ATLAS**…

Powheg+Pythia/Herwig and aMC@NLO+Herwig++
all use **EvtGen** as an after-burner.

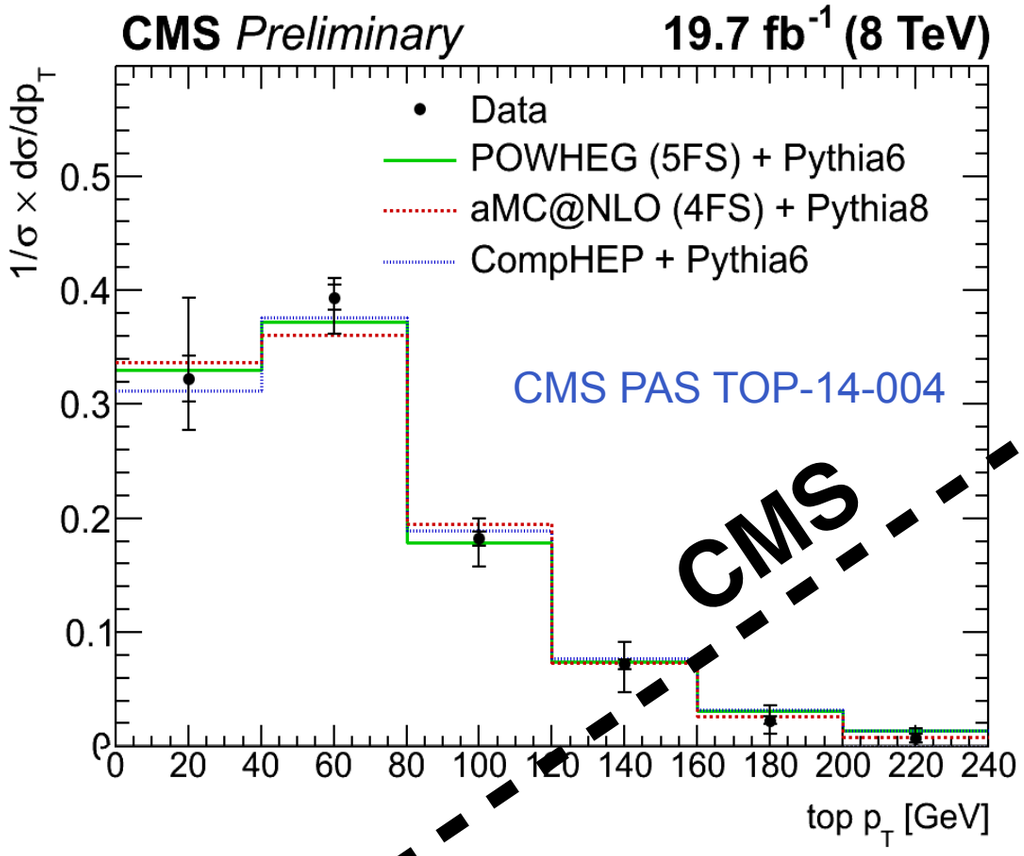
This makes the B-decay tables the
**same** for **all generators**.

# Single top

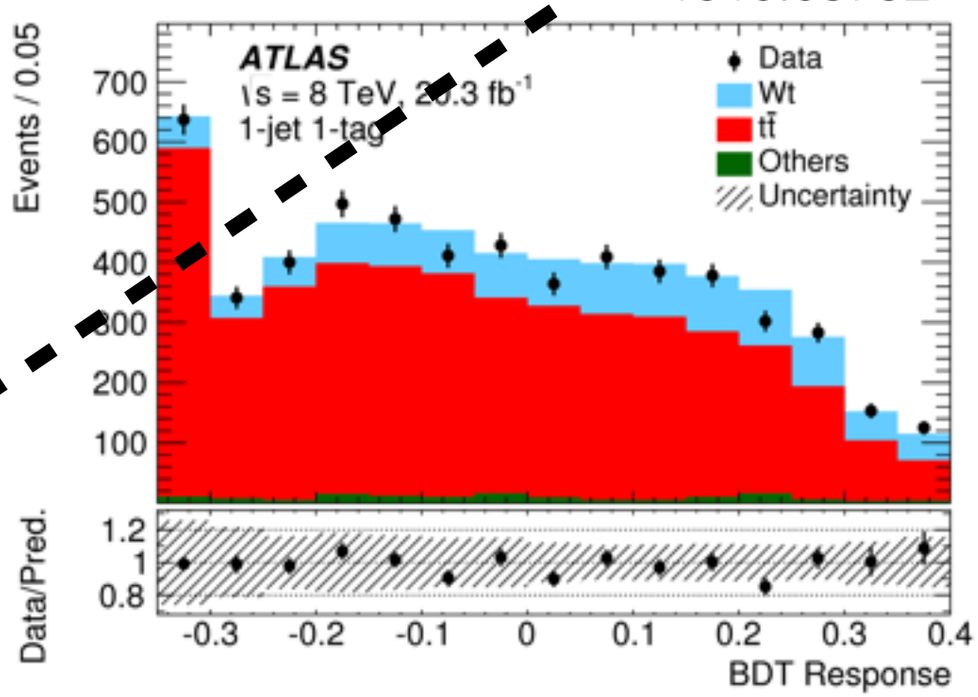
t-channel aMC@NLO+Pythia 8

Powheg+MadSpin+Pythia 8

Wt-channel Powheg+Pythia 8




1510.03752




CMS

ATLAS

Nominal: Powheg+Pythia 6

aMC@NLO+Herwig++ and Powheg +Herwig++ (alternatives)

***Good**: same setup as nom. tt* (but getting there…)

***Less good**: nominals are not quite the same*

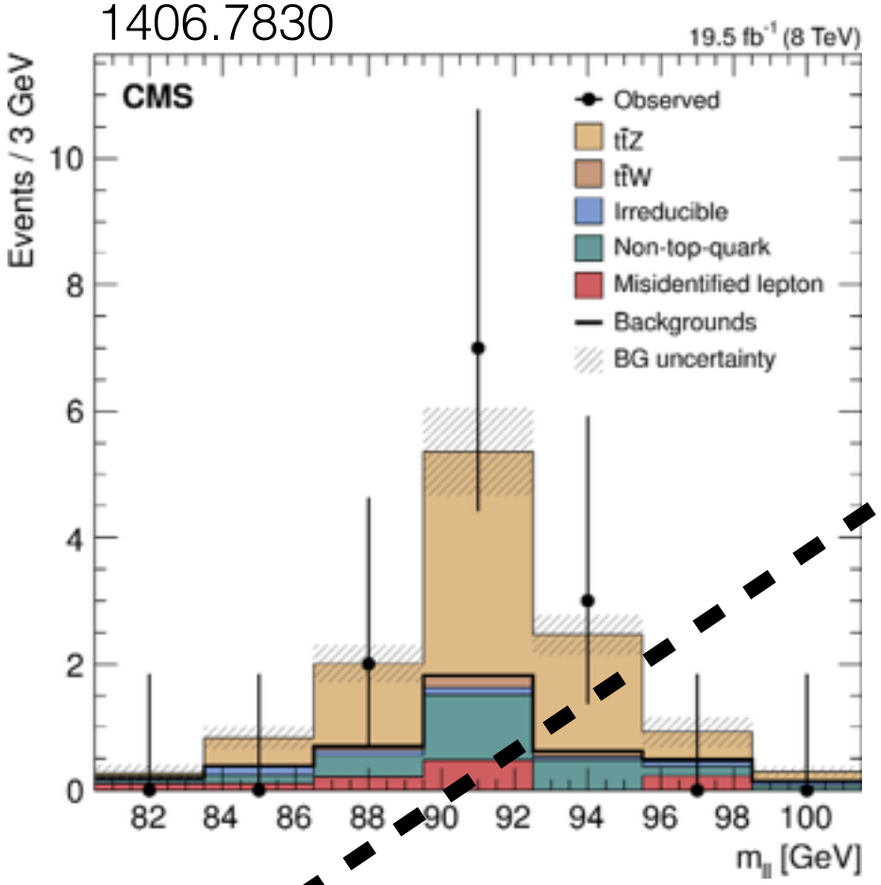
# tt+V

ttW: aMC@NLO+Pythia 8 [FxFx]

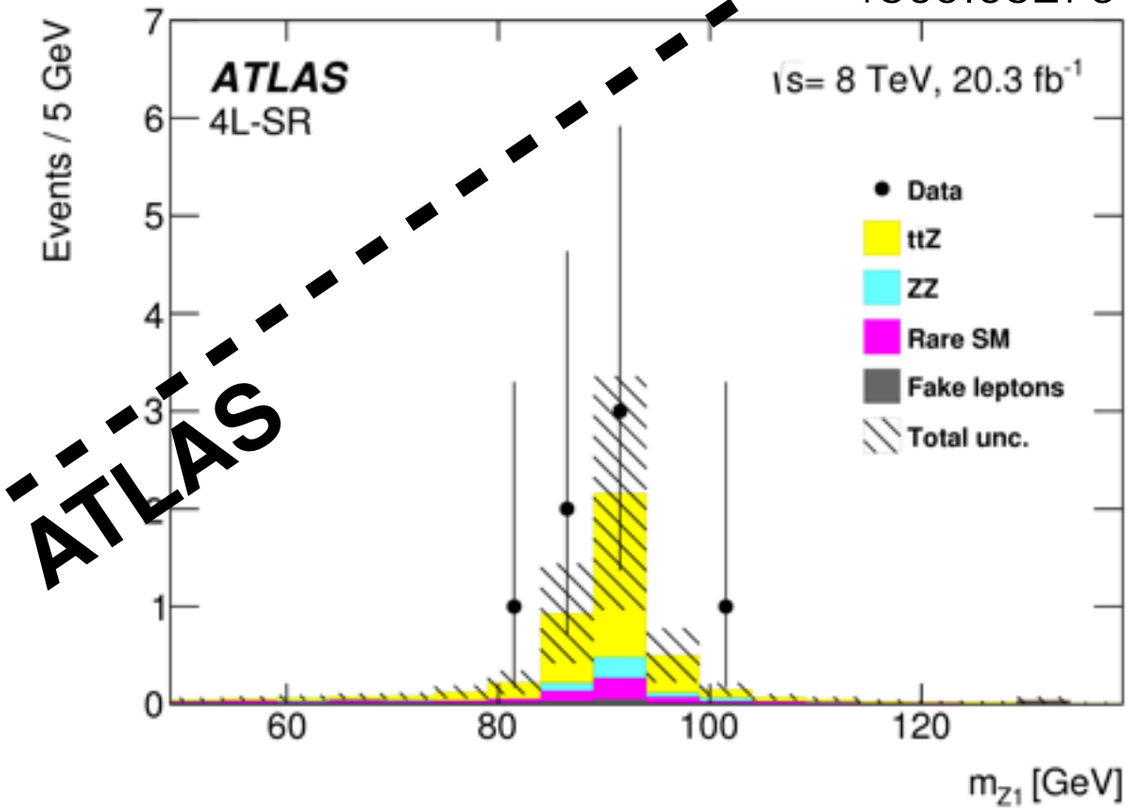
ttZ: aMC@NLO+Pythia 8

ttγ: aMC@NLO+Pythia 8 [FxFx]

1406.7830




1509.05276




ttW/Z: MadGraph+Pythia 8 (default)

ttγ: MadGraph+Pythia 8

ttW/Z: aMC@NLO+Pythia 8 and Sherpa 2 (alternatives)

# Particle-level definitions

The definitions for ATLAS and CMS seem to be converging, but there are still a few differences

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/ParticleLevelTopDefinitions

| | CMS | ATLAS |
|---|---|---|
| **Photons (for dressing)** | anti-kt with R=0.1 | $\Delta R<0.1$* |
| **jets** | exclude non-prompt neutrinos | include non-prompt neutrinos |

Everything else is (surprisingly) consistent…aside from R=0.4 versus R=0.5 which is phasing out.

*ability to switch to the clustering algorithm also now implemented!

# A common setup

…between ATLAS and CMS

*Internal checks leading up to this workshop were really great!*

*Relied on Rivet routines…need more of that (also a common LHE file?)*

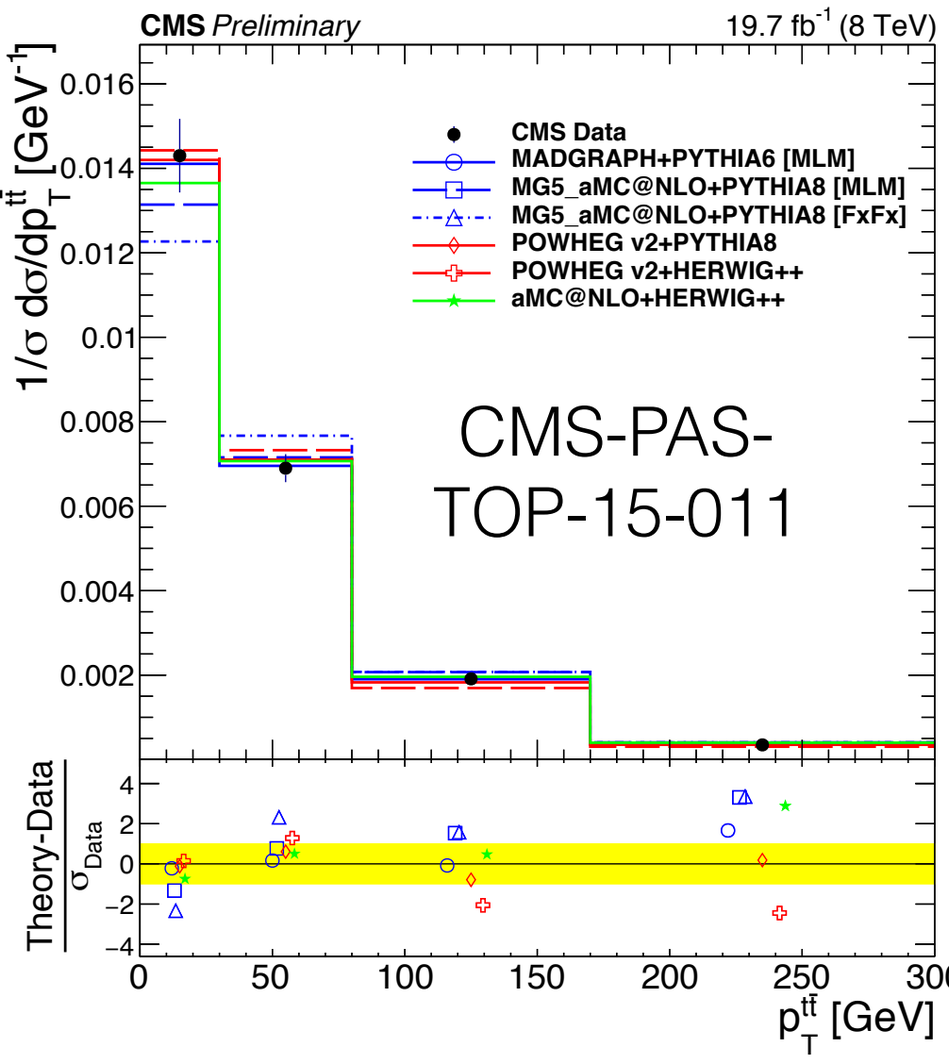
…between experimentalists and theorists

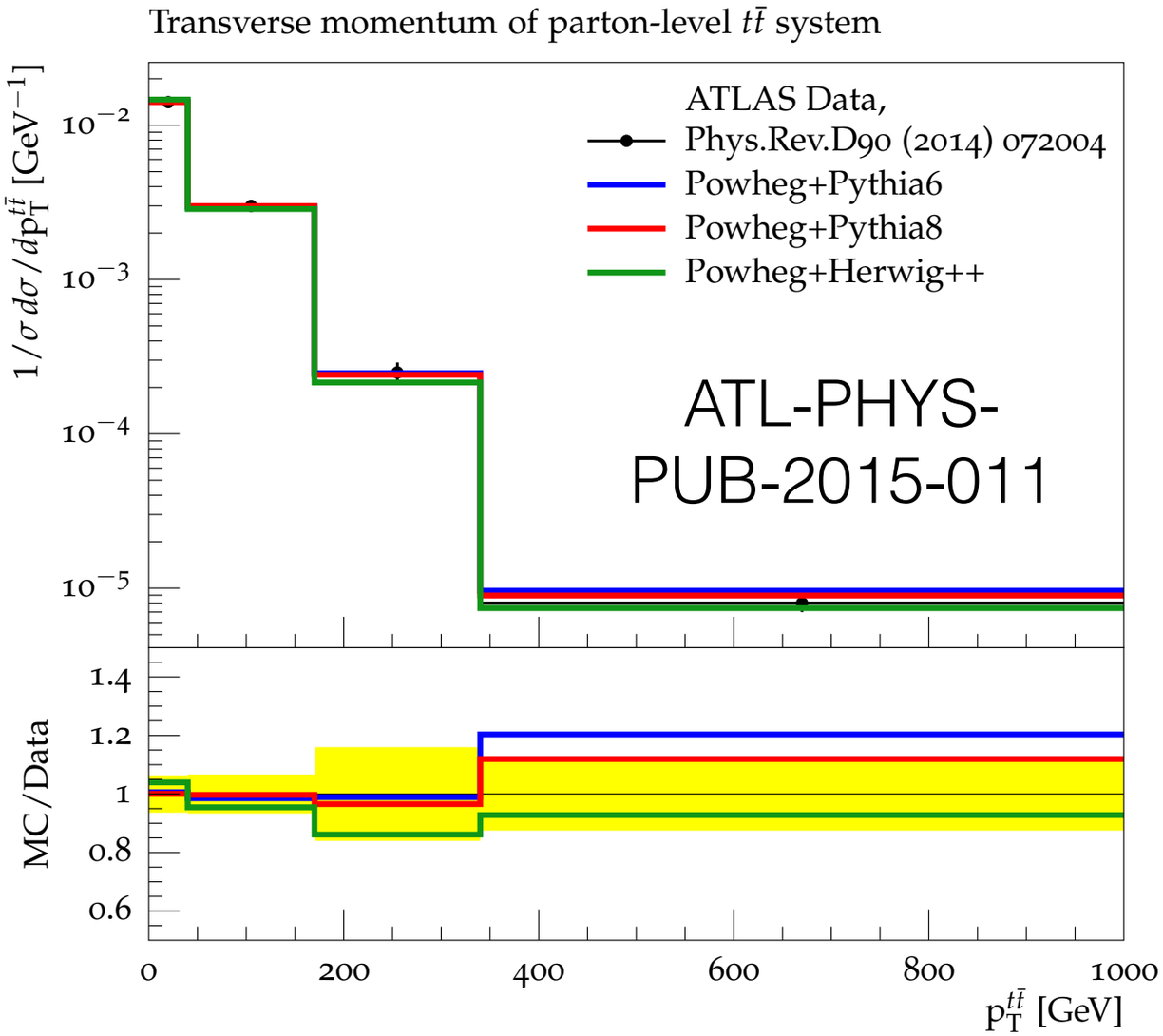
*Can we get HepMC events to make sure we have implemented the latest and great correctly?*

(Markus's idea)

# Overview

The $h_{damp}$ story is a thing of the past and the momentum re-shuffling will be soon as well.




As we move to more complicated setups, we must continue to be vigilant in comparing setups to each other and to the data!

# Conclusions

We have a extensive suite of generator setups and more in the pipeline for 2015 and beyond

**It is crucial that we continue to compare the various models with the data:**

-parton level

-particle level (final-state observables)

-extreme regions of phase space

*This continues to be an interesting challenge that will allow us to probe the unexplored with confidence at 13 TeV!*

# The unexplored? (600 GeV large R jet with $m_{jet}$ ~180 GeV and MET ~ 500 GeV)