a place of mind

THE UNIVERSITY OF BRITISH COLUMBIA

PHYSICS ASTRONOMY

Differential $t\bar{t}$ cross section measurements at the LHC

– as a function of kinematics variables –

Steffen Henkelmann

University of British Columbia (UBC)

On Behalf of the ATLAS and CMS Collaborations

top 2016

September 20th, 2016

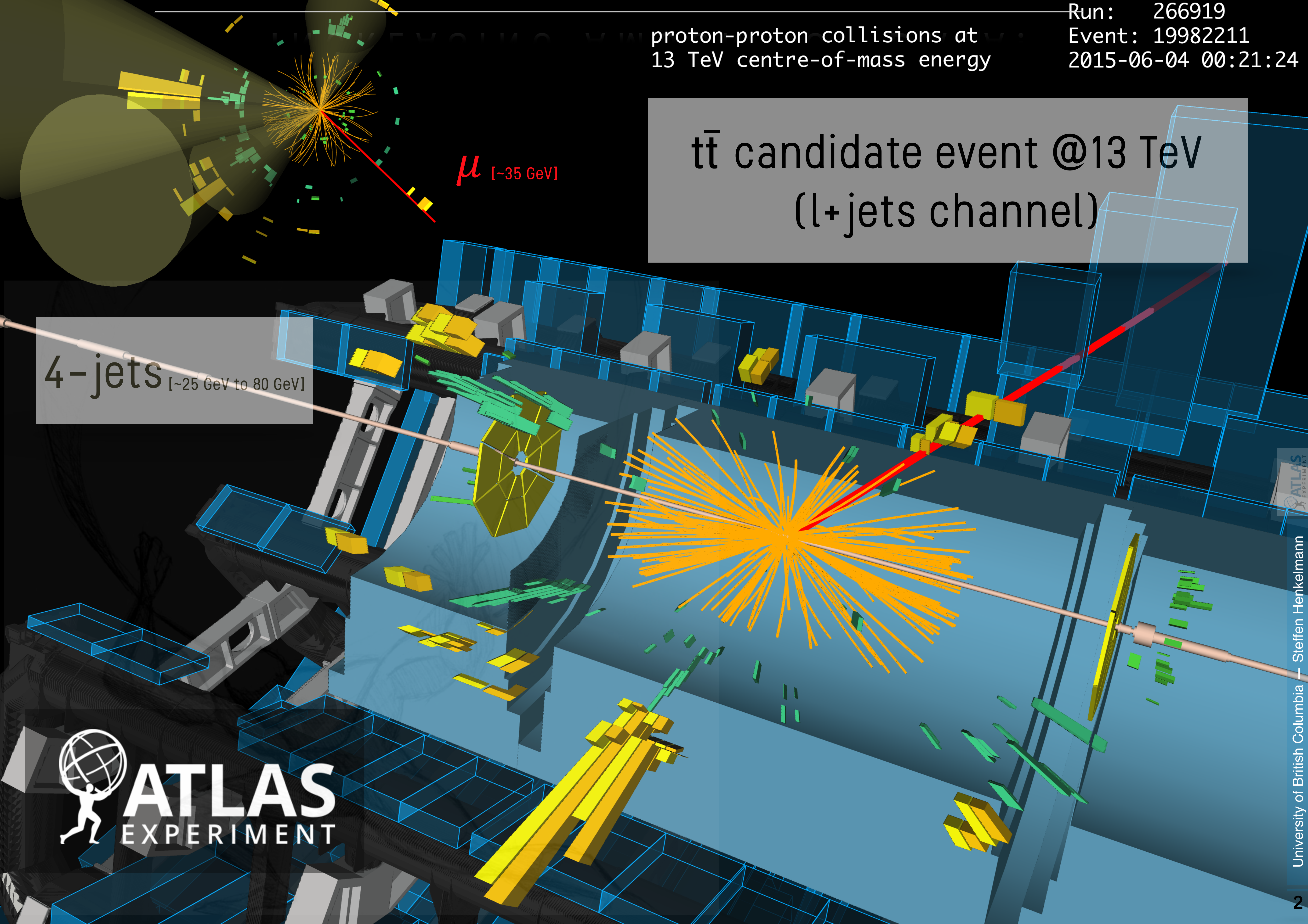
Olomouc, CZ

CERN

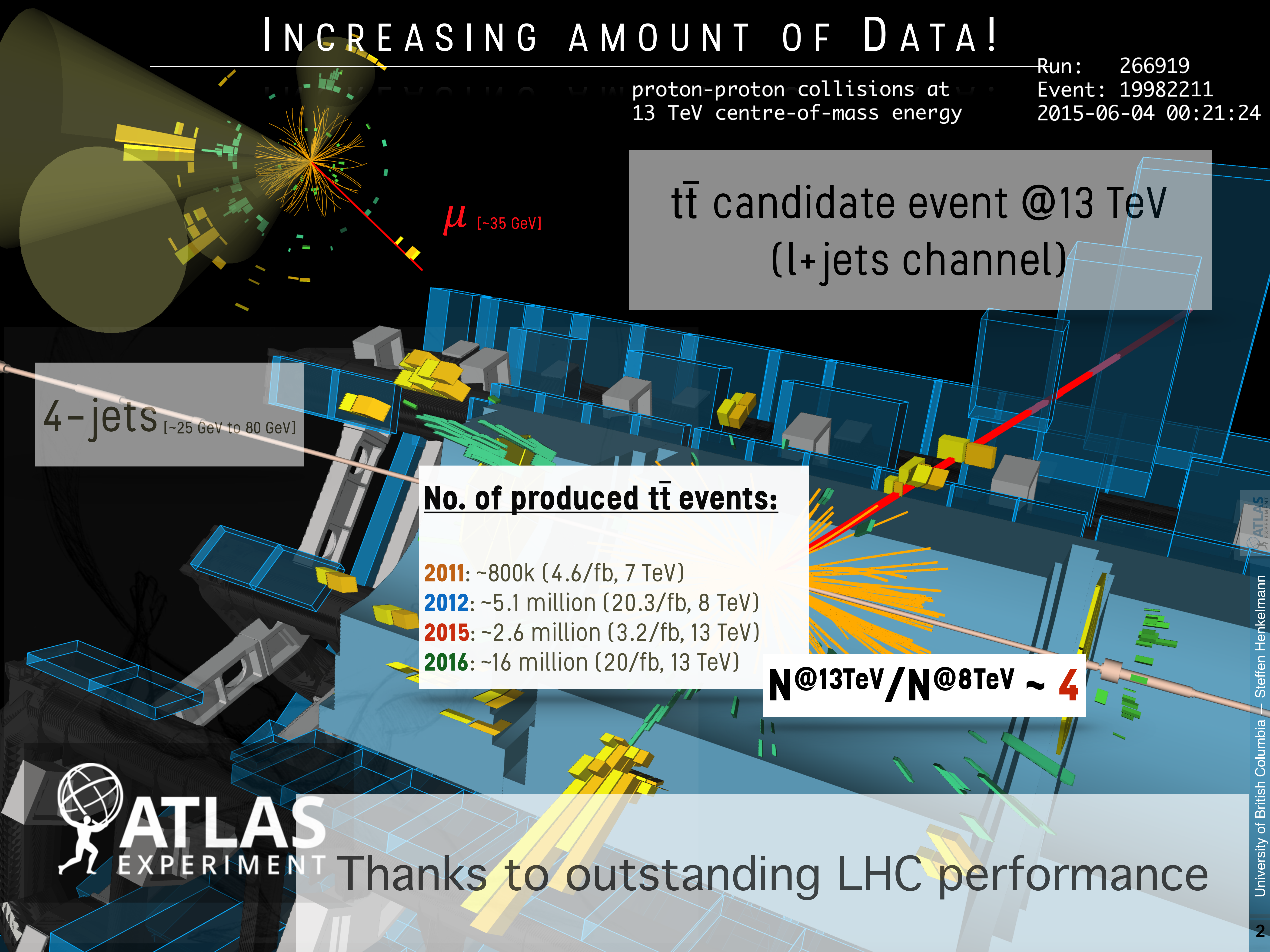
ATLAS EXPERIMENT

CMS Compact Muon Solenoid

Increasing amount of Data!



INCREASING AMOUNT OF DATA!



$t\bar{t}$ candidate event @13 TeV
(l+jets channel)

<u>No. of produced $t\bar{t}$ events:</u>

2011: ~800k (4.6/fb, 7 TeV)
2012: ~5.1 million (20.3/fb, 8 TeV)
2015: ~2.6 million (3.2/fb, 13 TeV)
2016: ~16 million (20/fb, 13 TeV)

N@13TeV/N@8TeV ~ 4

Thanks to outstanding LHC performance

$t\bar{t}$ production at the LHC

Run: 266919
Event: 19982211
2015-06-04 00:21:24

Mainly produced through gluon-gluon-fusion

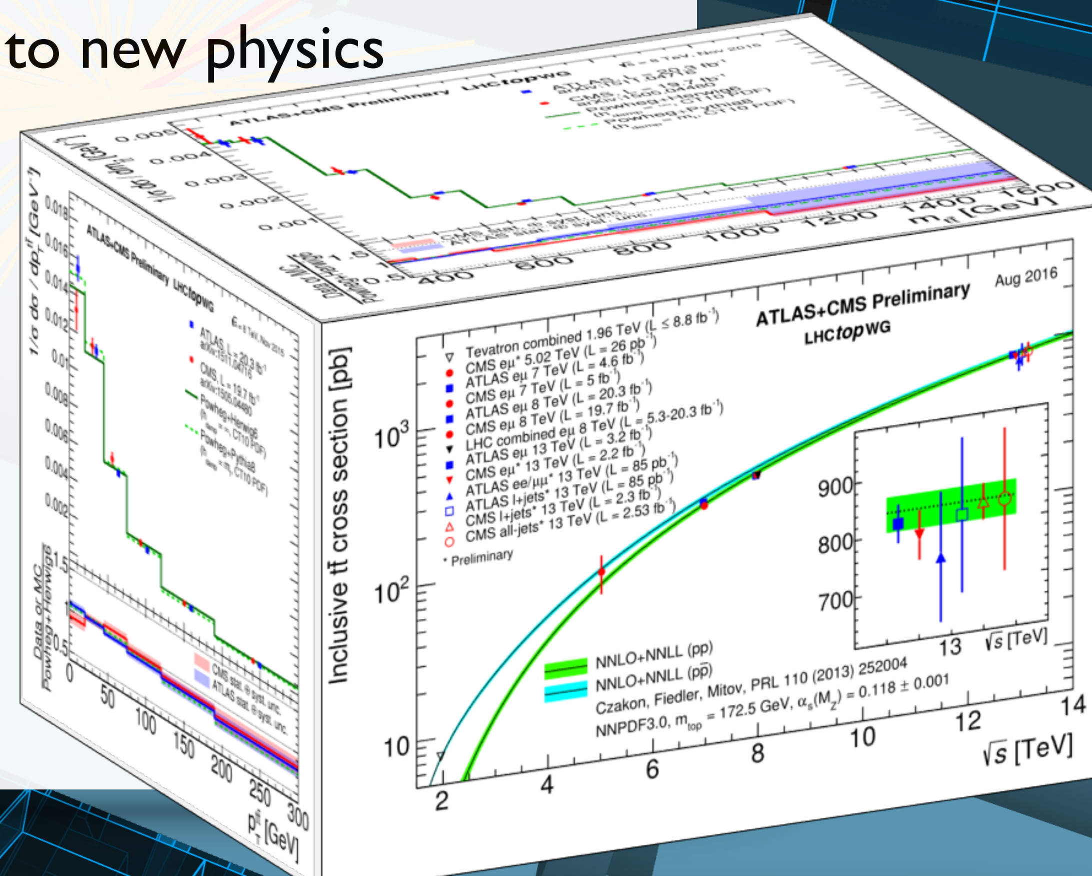
- Constrain gluon PDFs especially at high x
- Extract α_S, M_{top}, ...

Probe pQCD to higher orders

- Probe different renormalization and factorization scales
- Probe matching procedures and tuning parameters
- Constrain modelling of parton shower and hadronisation

Similar signature to new physics searches

- Deviations in differential distributions that might not be detectable with inclusive cross-section measurements
- Reduced modelling uncertainties enhance sensitivity to new physics
- Important background for searches



University of British Columbia — Steffen Henkelmann

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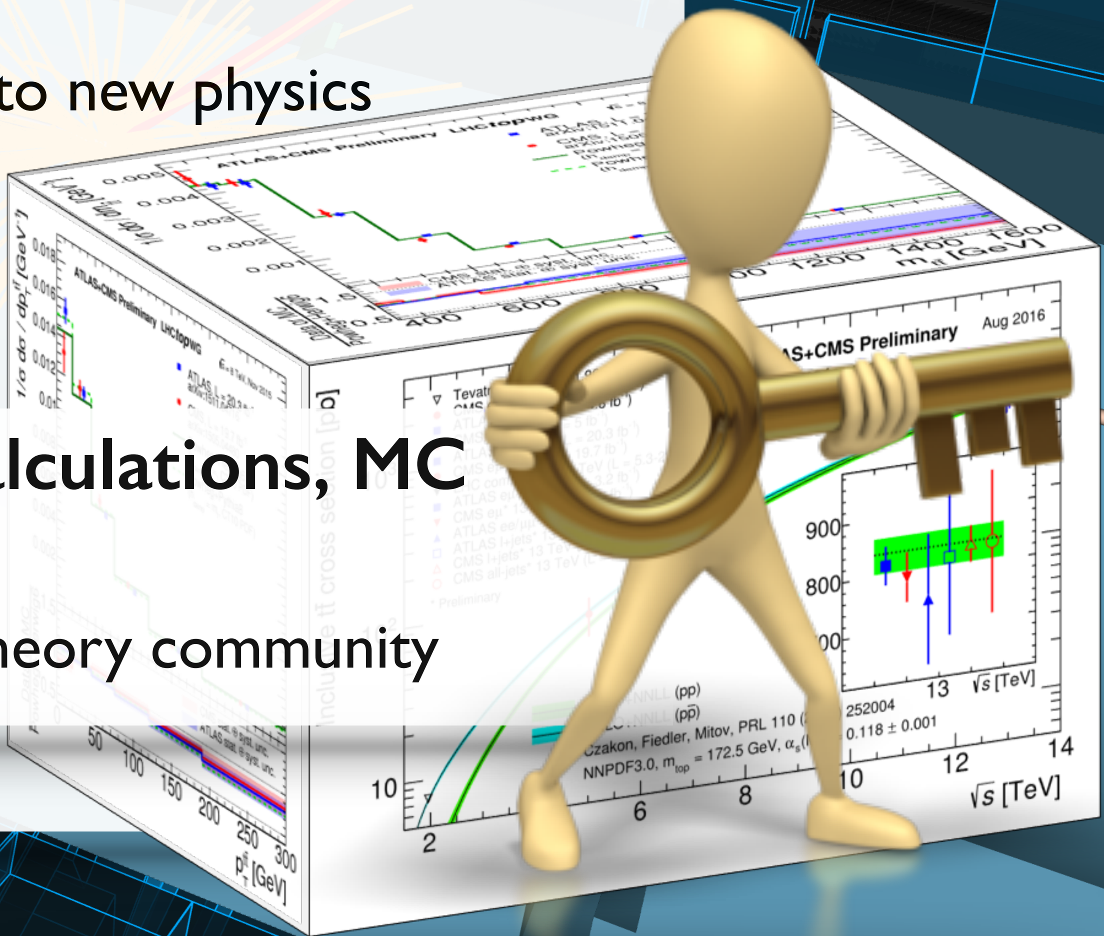
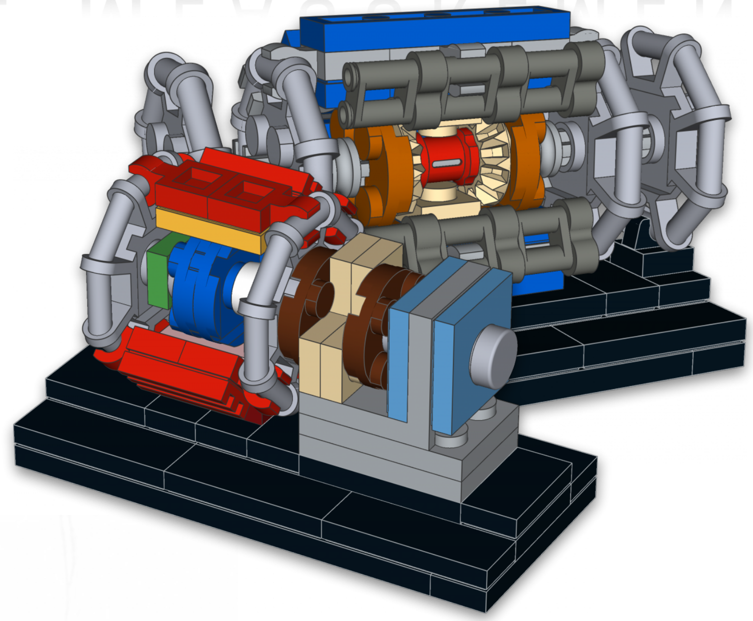
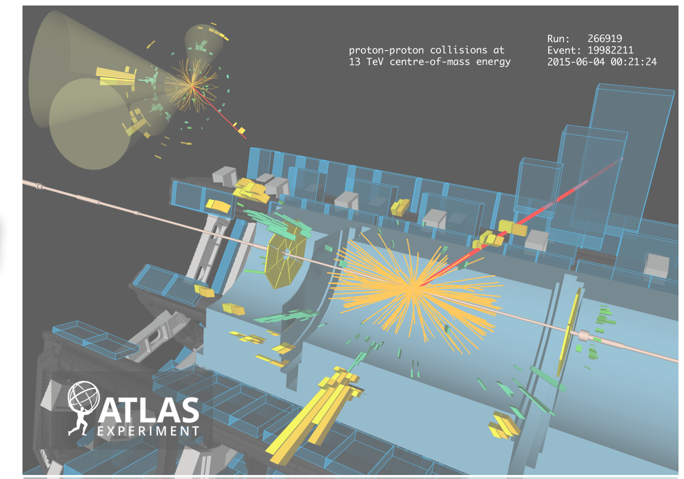
Interface between state-of-the art theory calculations, MC generators and experiment

- Common definitions across ATLAS and CMS and theory community



Differential Measurements

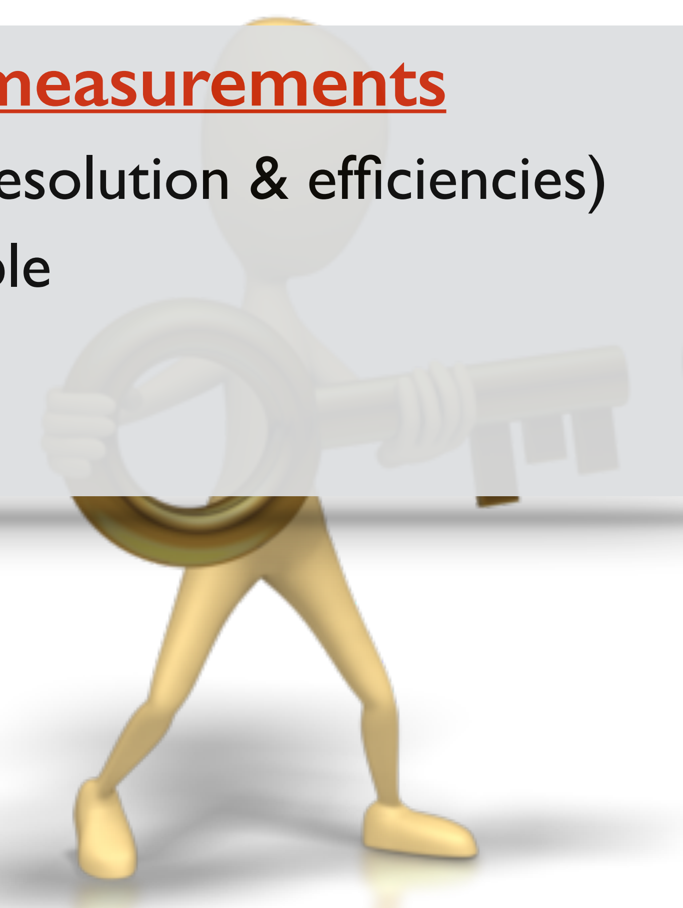




- **Top-quark definition**
  - **detector level**
  - particle level
  - parton level
- **Covered phase-space**
  - **detector**
  - fiducial
  - full
- **Decay topology**
  - boosted
  - resolved
- **Cross-section definition**
  - normalized
  - absolute

Detector phase-space, detector level measurements

- Depends on detector response modelling (resolution & efficiencies)
- Experiment dependent, not theorist accessible



Differential Measurements

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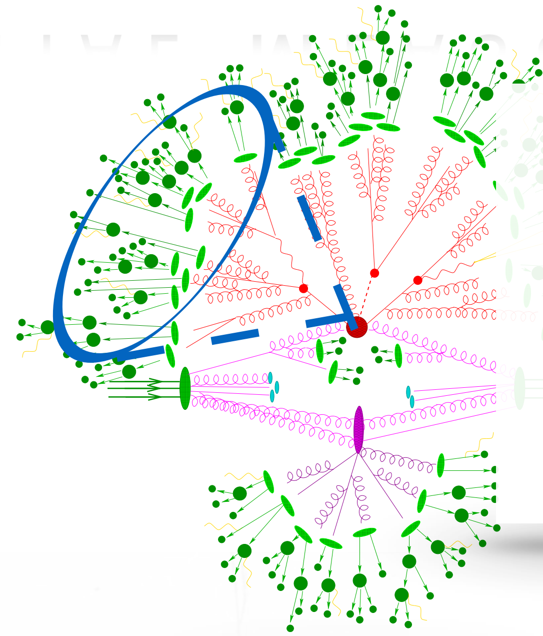

- **Top-quark proxy** using reconstructed decay products after hadronisation

→ directly measurable quantities

Differential Measurements

- **Top-quark definition**
  - detector level
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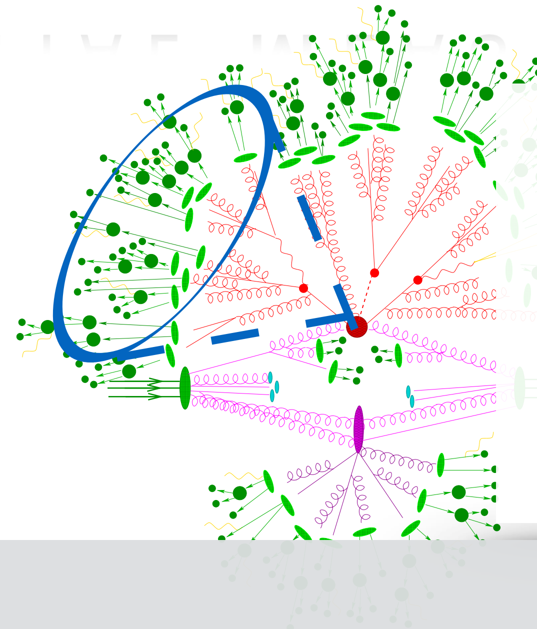
  - **fiducial**
- **De**
- **Cr**



- **Top-quark proxy** using reconstructed decay products after hadronisation
  → directly measurable quantities

LHCtopWG

Truth object definitions
(based on particles with $\tau_{particle} = 3 \times 10^{-11}$ s)

- **Leptons—** *Prompt either directly or through τ-decay (not from hadronic decays)*
  - *Charged (e/μ): Additionally corrected for non-measurable radiative effects*
    → add prompt-photons in $\Delta R < 0.1$
- **Particle jets—** *Clustering of all stable particles, except the dressed leptons and photons, using anti-k_T algorithm (R = 0.4[0.5])*
- **Jet flavour ID—** *b-jets are jets containing a B-hadron using ghost matching*
  → re-cluster jets including B hadrons (p_T > 5 GeV) with momentum scaled to negligible value
- **Large R-jets—** *To be discussed*

Top-quark proxy identification

- Algorithm to define the top quark pair using constraints on M_t, M_W, ΔR-separation, p_T, …
- Kinematic- and fiducial volume selection similar to detector acceptance

Differential Measurements

Top-quark definition

- detector level
- **particle level**
- parton level

Covered phase-space

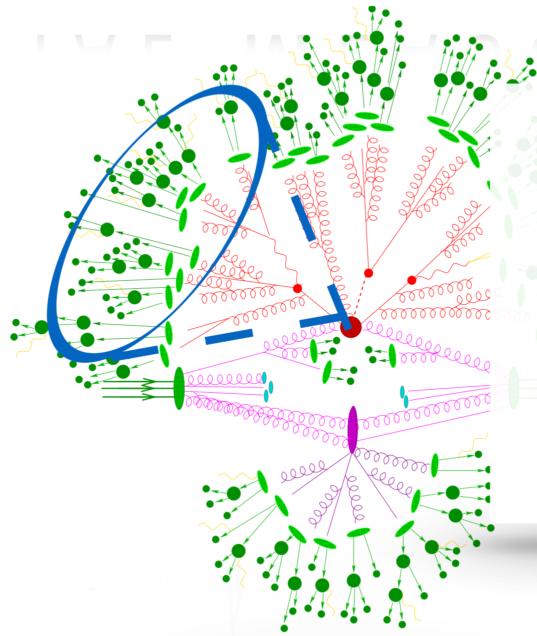
- detector
- **fiducial**
- full

Decay topology

- boosted
- resolved

Cross-section definition

- normalized
- absolute



- **Top-quark proxy** using reconstructed decay products after hadronisation
  →directly measurable quantities

Fiducial phase-space, particle level measurements

- Based on well defined quantities
- Matches detector phase-space closely
  → minimizes theoretical uncertainties from experimental side
- Unfolding procedure for detector response needed
- Probe of parton shower and hadronisation models
- Not directly comparable to ME calculations

Top-quark definition
- detector level
- particle level
- **parton level**

Covered phase-space
- detector
- fiducial
- **full**

Decay topology
- boosted
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Cross-section definition
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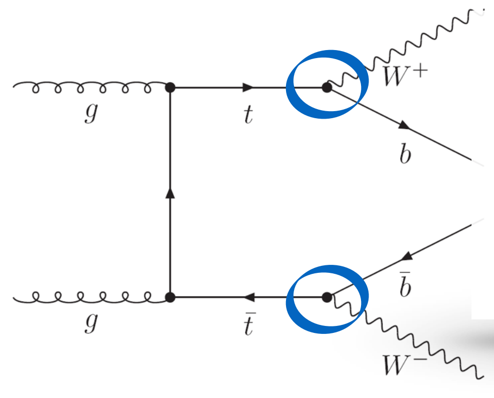


- **Top-quark** after radiation but before decay

Full phase-space, parton level measurements

- Probe latest $N^{(N)}LO + N^{(N)}LL$ pQCD
- Constrain PDFs
- Extract α_S, M_{top}, …
- Increased model dependence

Recent Results

NEW results ≥ June 2016

7 / 8 TeV

	l+jets	dilepton	all-had
ATLAS EXPERIMENT	Phys. Rev. D93 (2016) 032009 boosted, parton/particle arXiv:1511.04716 resolved, parton/particle JHEP 06 (2015) 100 resolved, parton/particle	arXiv:1607.07281 resolved, parton	
CMS	arXiv:1607.00837 resolved, particle arXiv:1605.00116 boosted, parton/particle	TOP-14-013 resolved, parton	arXiv:1509.06076 resolved parton/particle
CMS	Eur. Phys. J. C 75 (2015) 542 resolved, parton/particle		

13 TeV

	l+jets	dilepton	all-had
ATLAS EXPERIMENT	CONF-2016-040 resolved/boosted, particle	TOPQ-2016-04* resolved, particle	CONF-2016-100* boosted, particle
CMS	TOP-16-008* resolved, parton/particle	TOP-16-007 resolved, particle TOP-16-011 resolved parton	TOP-16-013 resolved/boosted, parton

complete lists:

ATLAS

CMS [1,2]

Dilepton Measurements

New results on 7, 8 & 13 TeV

NEW

NEW

NEW*

NEW

Available on the CERN CDS information server

CMS Physics

Contact: cms-pag-conveners-top@cern.ch

Measurement of double

quark pair production

Available on the CERN CDS information server **CMS PAS TOP-16-007**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-top@cern.ch 2016/08/04

Measurement of particle level differential $t\bar{t}$ cross sections in the dilepton channel at $\sqrt{s} = 13$ TeV

The CMS Collaboration

Abstract

Normalised differential cross sections for top quark pair production are measured in the dilepton (e^+e^-, $\mu^+\mu^-$, and $\mu^\mp e^\pm$) decay channel in proton-proton collisions at a center-of-mass energy of 13 TeV. The measurements are performed with data corresponding to an integrated luminosity of 2.2 fb^{-1} collected in 2015 using the CMS detector at the LHC. The cross section is measured differentially as a function of the kinematic properties of the leptons, b jets, top quarks, and top quark pairs at particle level. The results are compared to several models of perturbative QCD and found to be in agreement with the standard model predictions.

ATLAS Paper

Measurements of top-quark pair differential cross-sections in the $e\mu$ channel in *pp* collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector

Abstract

This article presents the measurement of $t\bar{t}$ differential cross-sections in events with exactly one electron and one muon, using an integrated luminosity of 3.2 fb^{-1} of proton-proton data at a center-of-mass energy of $\sqrt{s} = 13$ TeV recorded by the ATLAS experiment at the LHC in 2015. Differential cross-sections are measured as a function of the transverse momentum and absolute rapidity of the top quark, and of the transverse momentum, absolute rapidity and invariant mass of the $t\bar{t}$ system. The $t\bar{t}$ events are selected by requiring one electron and one muon, and at least two jets, one of which must be tagged as containing a b-hadron. The measured differential cross-sections are compared to predictions of NLO generators matched to parton showers and the results are found to be consistent with all models within the experimental uncertainties with the exception of the POWHEG-Box + Herwig++ MC, which differs significantly from the data in both $p_T(t)$ and $m(t\bar{t})$.

CLEAR RESEARCH (CERN)

CERN-EP-2016-144

July 27, 2016

ential cross-sections in the

= 7 and 8 TeV with ATLAS

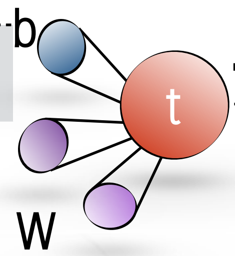
*FIRST TIME PRESENTED

ATLAS: DILEPTON

Event selection / reconstruction

e/μ with p_T > 25 GeV, $|\eta|$ < 2.47 (excluding crack 1.37 < $|\eta|$ < 1.52)
anti-k_t jets (R =0.4) with p_T > 25 GeV, $|\eta|$ < 2.5
exactly two oppositely charged leptons (opposite flavour)

≥2 jets (≥1 b-tagged)



Top system reconstruction

- *using neutrino weighting method*
  - *Constraints on M_t, M_W to find optimal comb. for $\eta(\nu_{1,2})$*
  - *→ two possible solutions compared to measured MET*

- Quantitative comparison to NLO MC generators using χ^2-test and p-values
- Dominant uncertainties
  - Statistics, Signal modelling (generator, PS/hadronization and extra radiation), Jet energy scale

NEW*

TOPQ-2016-04
(to be submitted to EPJC)
September 20, 16

Overview

13 TeV
dilepton (eμ)
3.2/fb
particle level
fiducial phase space
normalized

p_T^t	$\|y^t\|$	
$m^{t\bar{t}}$	$p_T^{t\bar{t}}$	$\|y^{t\bar{t}}\|$

ATLAS: DILEPTON

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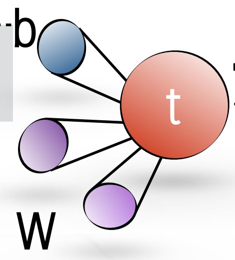

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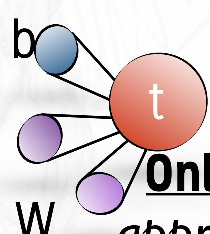
@7TeV also uses same flavour channels → cuts to remove Z background



Only $t\bar{t}$ system variables

- *approx 4-mom. of $t\bar{t}$ system from 2 leptons, 2 jets and MET*
- ***observable resolution ~ 20-35%***

- Comparison to NLO MC generators, latest NNLO predictions and PDF sets
- Dominant uncertainties
  - Signal modelling, JES

ATLAS EXPERIMENT

NEW*

TOPQ-2016-04
(to be submitted to EPJC)
September 20, 16

Overview

13 TeV
dilepton (eμ)
3.2/fb
particle level
fiducial phase space
normalized

p_T^t	$\|y^t\|$	
$m^{t\bar{t}}$	$p_T^{t\bar{t}}$	$\|y^{t\bar{t}}\|$

ATLAS EXPERIMENT

NEW

arXiv:1607.07281
(submitted to PRD)
July 25, 16

7 & 8 TeV
dilepton
4.6, 20.2/fb
parton level
full phase space
absolute & normalized

$m^{t\bar{t}}$	$p_T^{t\bar{t}}$	$\|y^{t\bar{t}}\|$

CMS: DILEPTON

TOP-16-007 NEW
August 4, 16

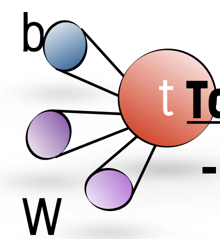
Measurement at particle level complements TOP-16-011 & Eur. Phys. J. C 75 (2015) 542

Event selection / reconstruction

e/μ with p_T > 20 GeV, |η| < 2.4
anti-k_t jets (R =0.4) with p_T > 30 GeV, |η| < 2.4
exactly two oppositely charged leptons

≥2 jets (≥1 b-tagged)

\+ additional cuts to remove Z background in same flavour channels



Top reconstruction
- algebraic reconstruction of neutrino momenta
  - p_T balance, M_t, M_W constraints
- smearing according to detector resolution

→ increase number of solvable events ~90%

Overview

13 TeV
dilepton
2.2/fb
particle level
visible phase space
normalized

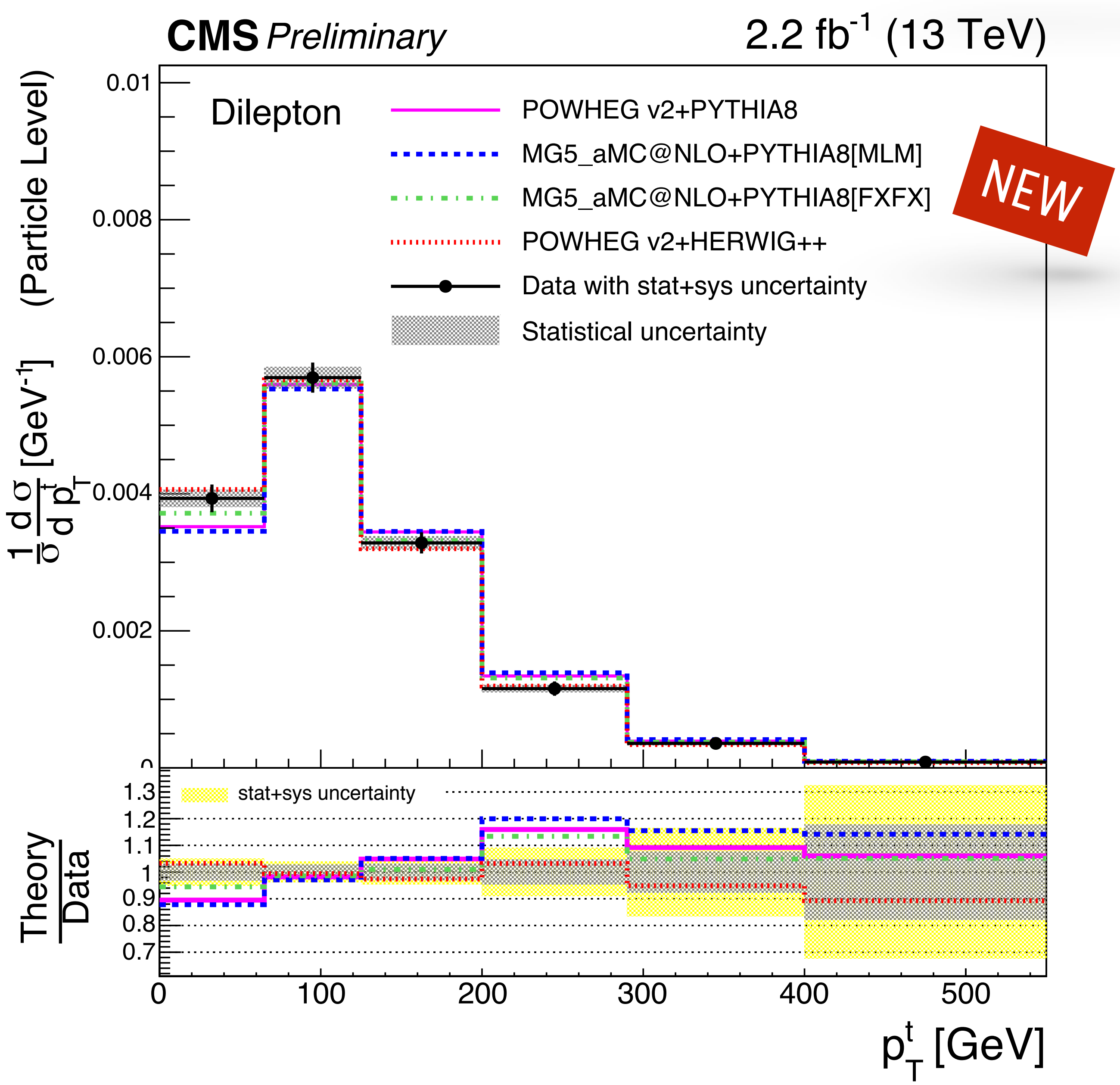
p_T^{l}	p_T^{jet}	p_T^{t}
y^{t}	$p_T^{t\bar{t}}$	$y^{t\bar{t}}$
$m^{t\bar{t}}$	$\Delta\phi^{t\bar{t}}$	

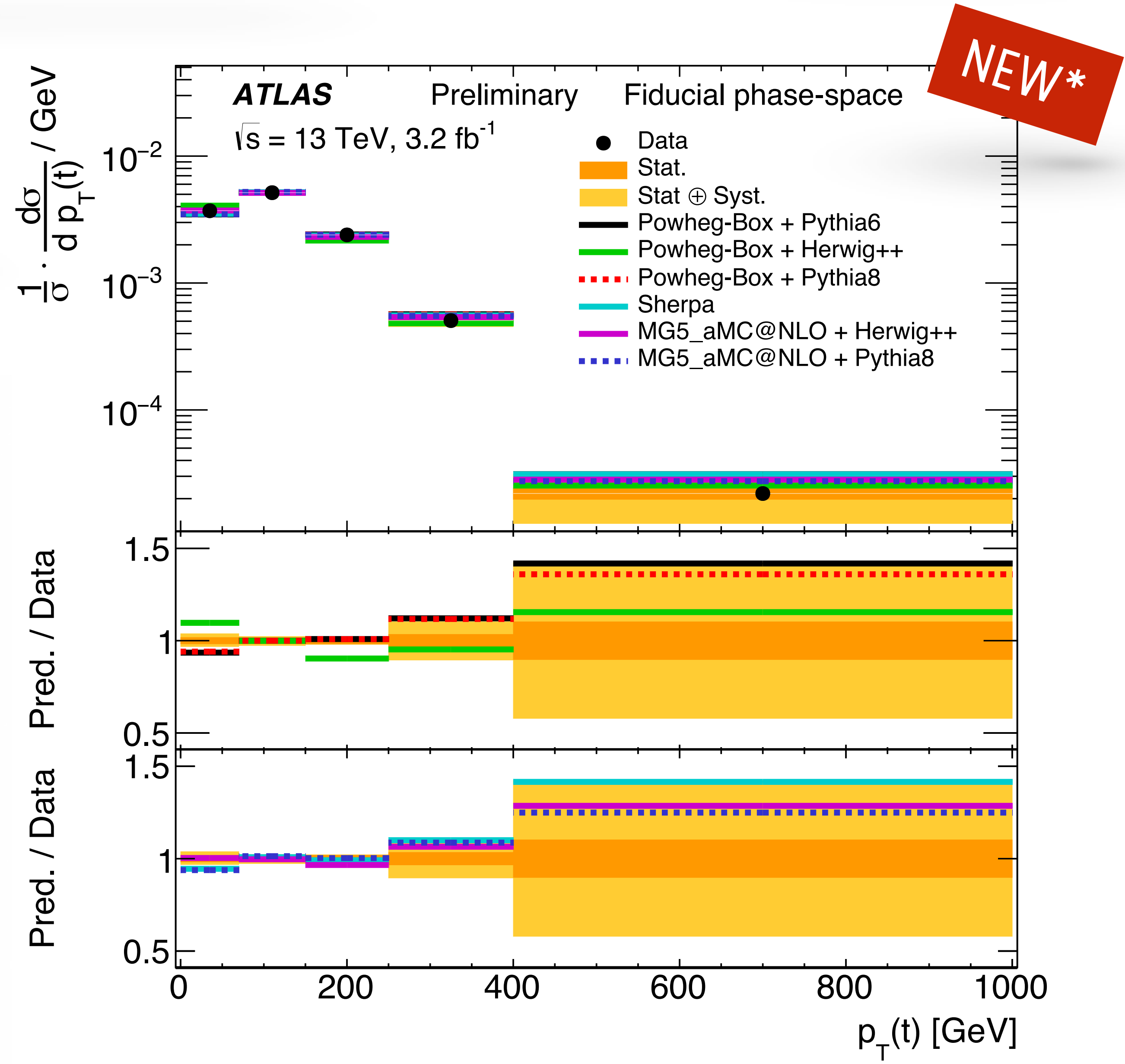
- Comparison to NLO MC generators, different NLO matching schemes
- Dominant uncertainties
  - Signal modelling and background estimation

TOP p_T & $M_{t\bar{t}}$ SPECTRUM

13 TeV | particle level

TOPQ-2016-04
TOP-16-007



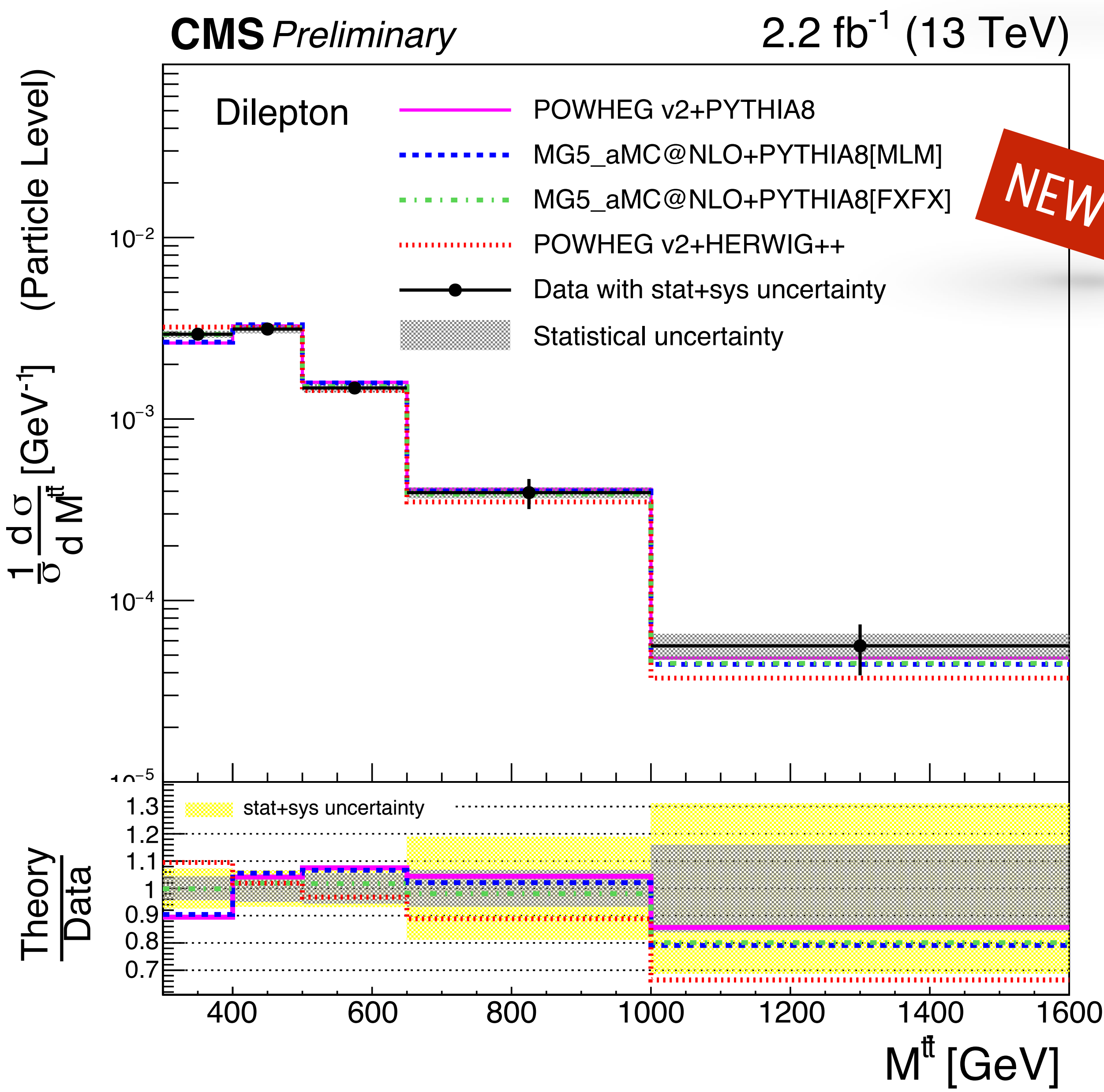


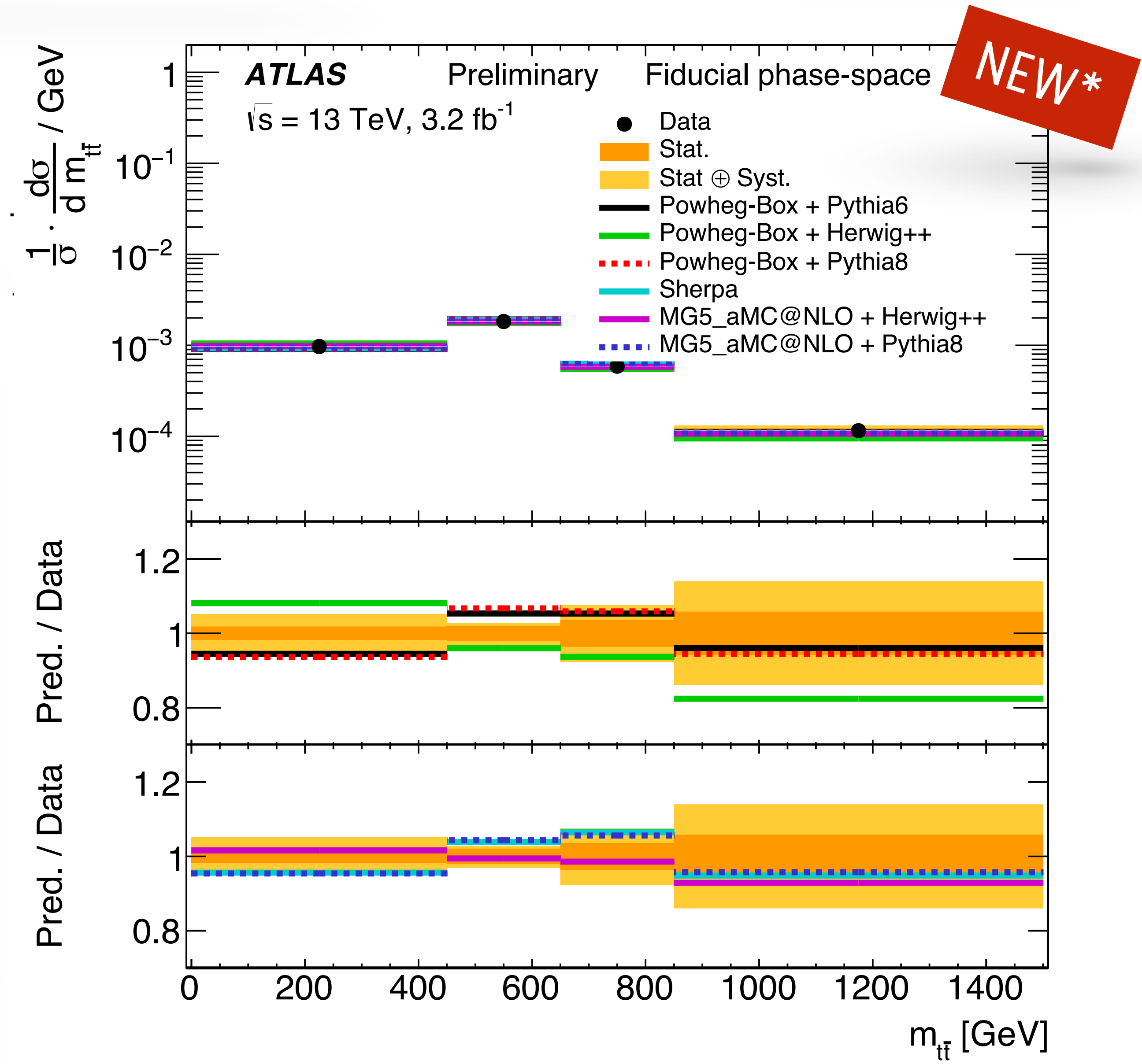
- Comparisons of variety of NLO MC generators using different showering models
  - Including comparisons to Multileg Generators
- MC generator are in agreement with results from CMS and ATLAS
  - *ATLAS*: Powheg+HW++ deviates from data in the $p_T{}^t$ and $m^{t\bar{t}}$ (p-value ≤ 0.02)
  - $m^{t\bar{t}}$: Powheg+Py8 & MG5_aMC@NLO shows same trend in ATLAS and CMS!

TOP p_T & $M_{t\bar{t}}$ SPECTRUM

13 TeV | particle level

TOPQ-2016-04
TOP-16-007





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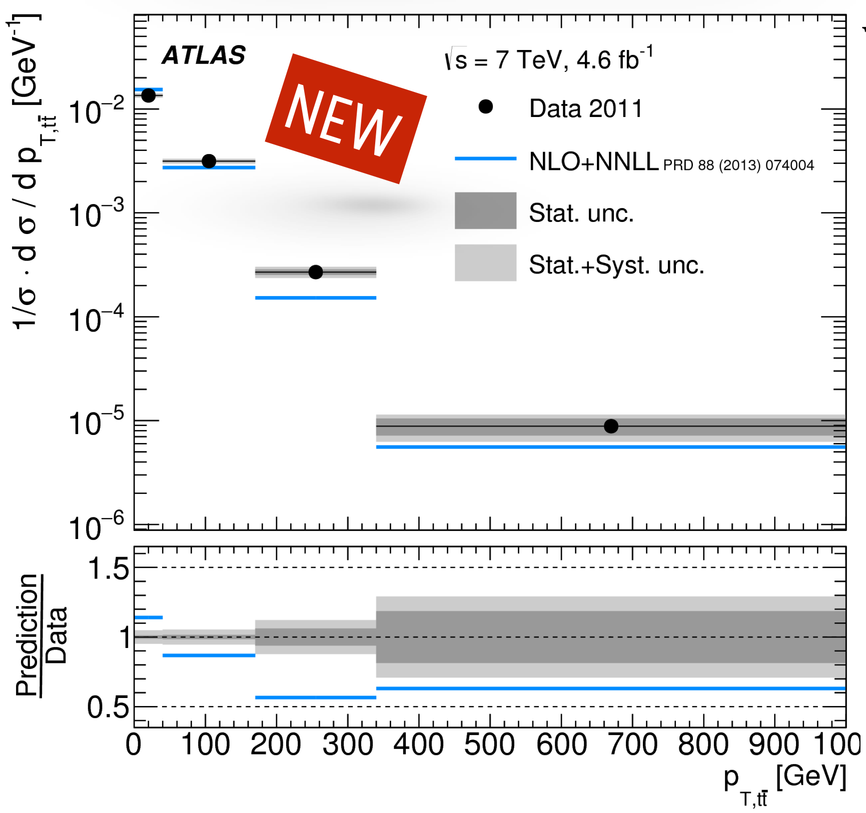
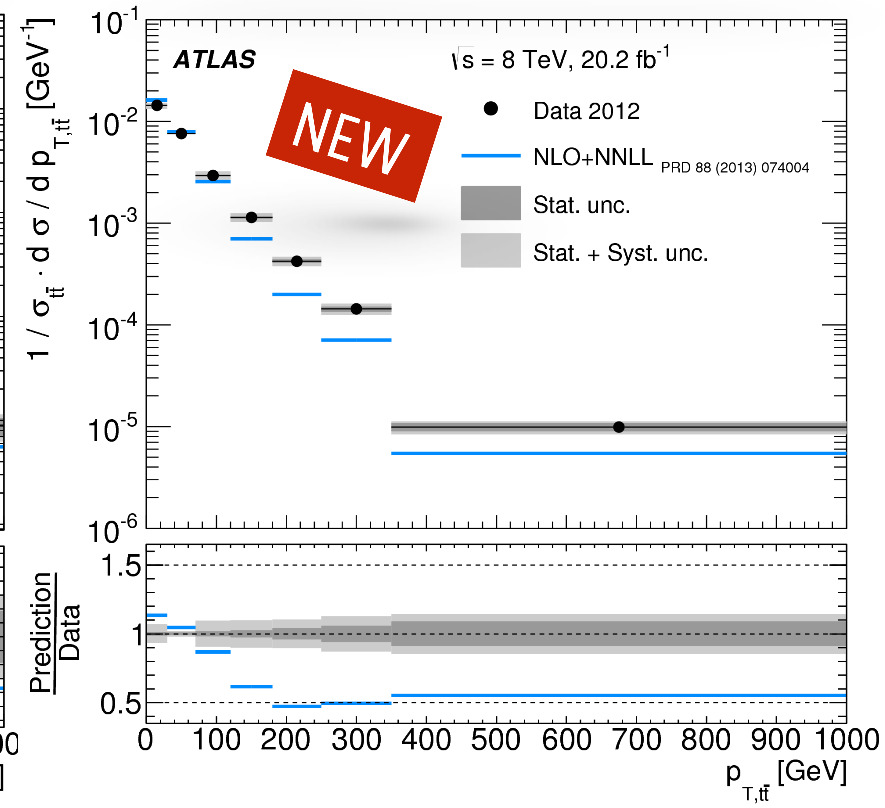
NLO PREDICTIONS AT 7 & 8 TEV

Eur. Phys. J. C 75 (2015) 542
arXiv:1607.07281

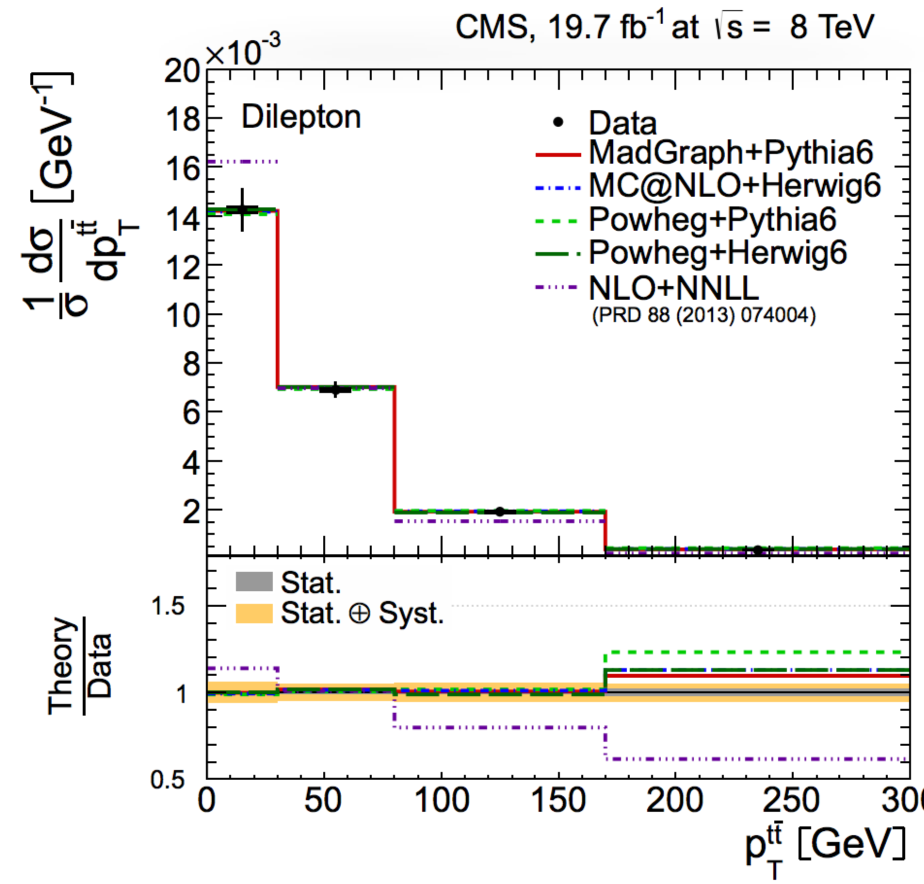
7 TeV | parton level



8 TeV | parton level



8 TeV | parton level



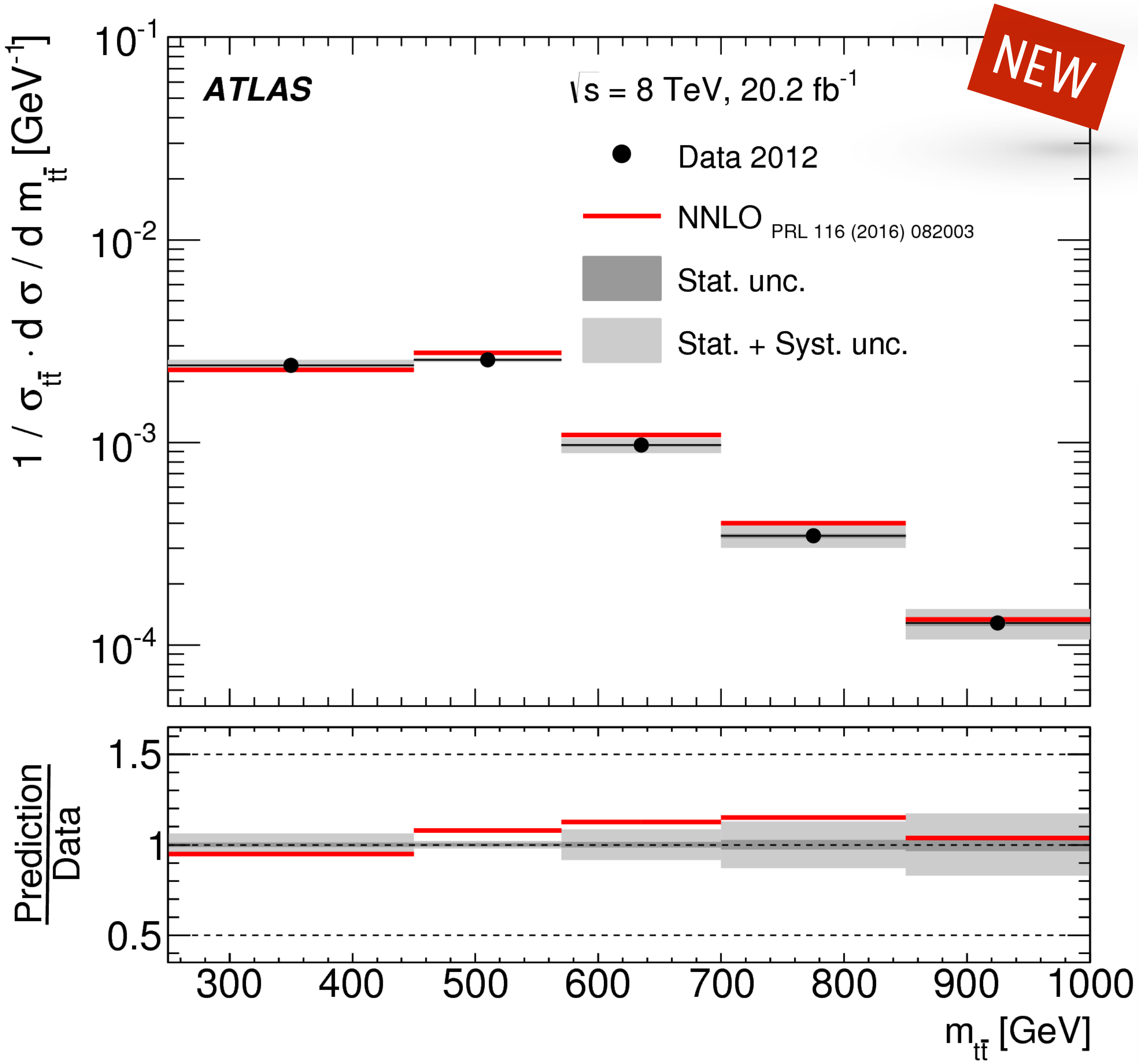
- $p_T^{t\bar{t}}$ sensitive to MC tuning parameters and scale settings
- Mis-modelling in $p_T^{t\bar{t}}$ at 7 and 8 TeV
  - Confirmed by ATLAS (p-value < 0.01)

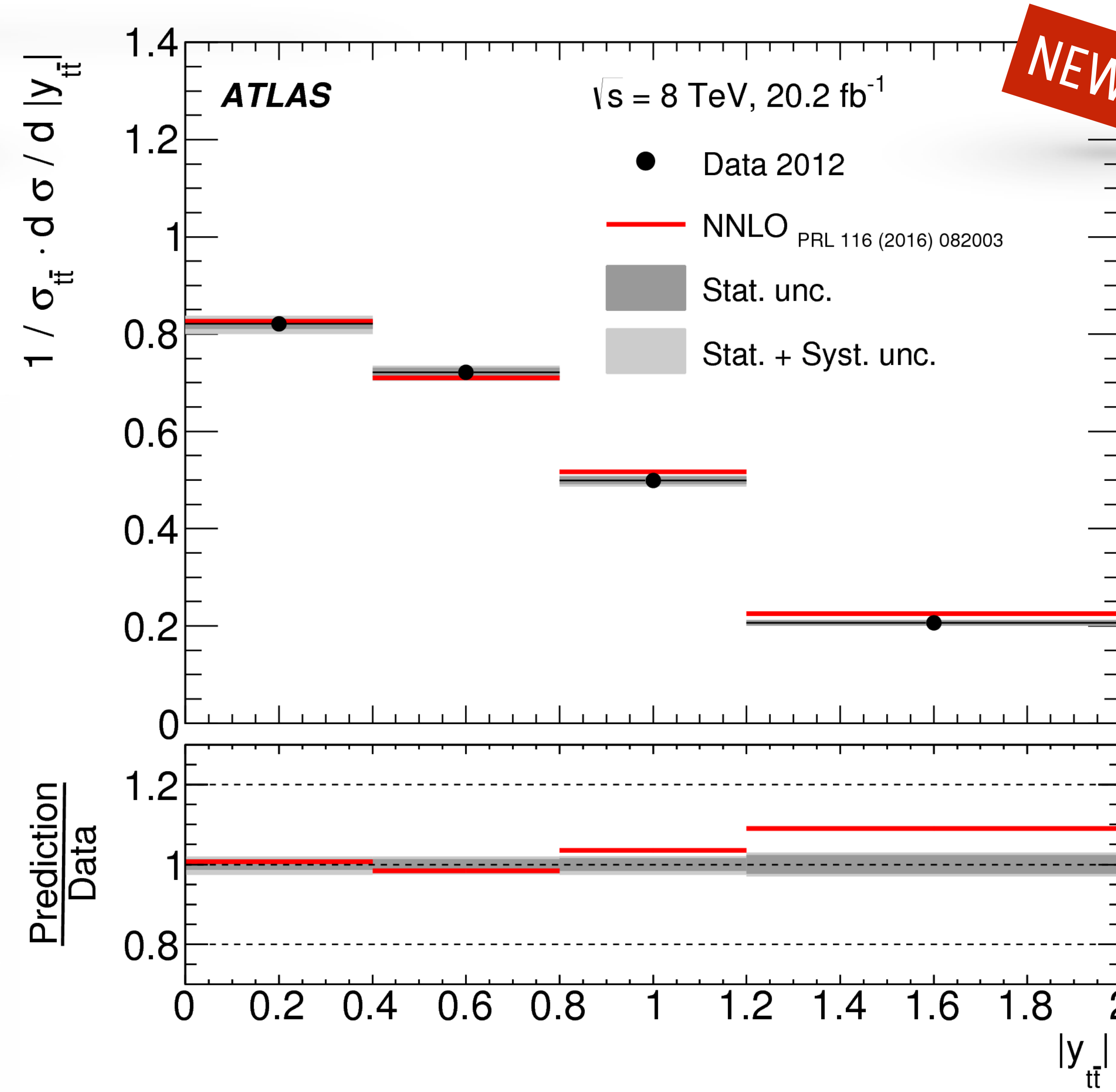
NNLO predictions at 8 TeV

arXiv:1607.07281 July 25, 16

NEW

8 TeV | parton level

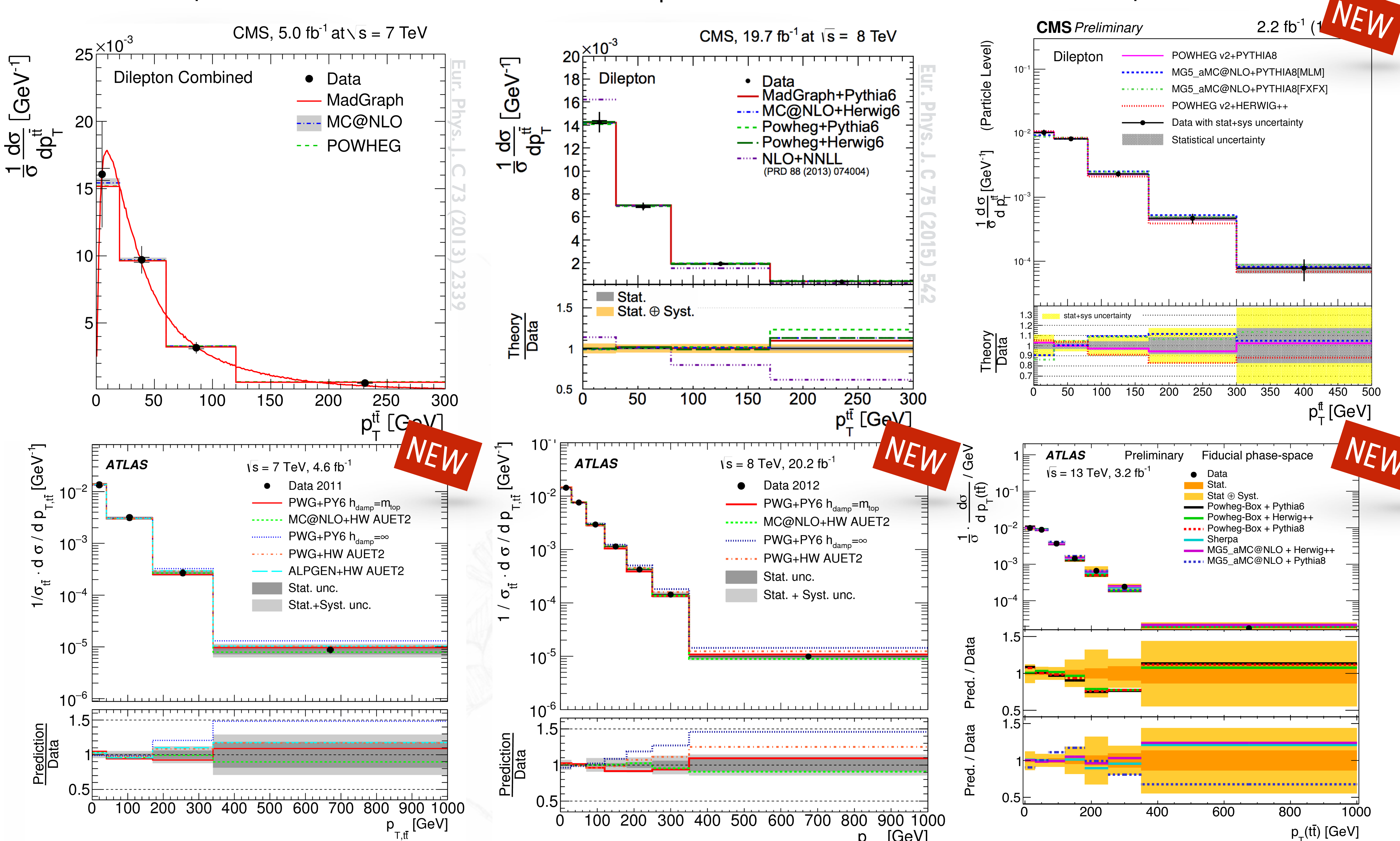




- NNLO at 8 TeV shows
  - Good agreement in $m_{t\bar{t}}$
  - Tension in high rapidity regime of $t\bar{t}$ system
    - Rapidity distribution sensitive to PDFs (might yield better NNLO agreement with different PDF choice)

Dilepton measurements in full energy range

7 TeV | parton level **8 TeV** | parton level **13 TeV** | particle level



- Numerous measurements from both collaborations in a wide energy range and observables
  - Comparisons to state-of-the art predictions

CMS: DILEPTON

Double differential measurement @ 8 TeV (*1st of its kind @LHC*)

- Imposing tighter constraints on global PDF fits
  → improved resolution of momentum fraction
- Quantitative comparison to state-of-the art predictions (up to aNNLO $O(\alpha_S^4)$)
  → Power to distinguish between modern PDF sets
- Measurement follows procedures in Eur. Phys. J. C 75 (2015) 542
- Unfolding performed simultaneously in bins of two variables
- Dominant uncertainties O(syst~stat)
  - Signal model & JES

Overview

8 TeV
dilepton ($e\mu$)
19.7/fb
parton level
full phase space
normalized
resolved

- p_T^t vs. $|y^t|$
- $|y^t|$ vs. $M_{t\bar{t}}$
- $|y^{tt}|$ vs. $M_{t\bar{t}}$
- $p_T^{t\bar{t}}$ vs. $|y^t|$
- $\Delta\eta^{t\bar{t}}$ vs. $M_{t\bar{t}}$
- $\Delta\phi^{t\bar{t}}$ vs. $M_{t\bar{t}}$

CMS: DILEPTON

TOP-14-013
July 30, 16

NEW

Double differential measurement @ 8 TeV (*1st of its kind @LHC*)

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  → improved resolution of momentum fraction
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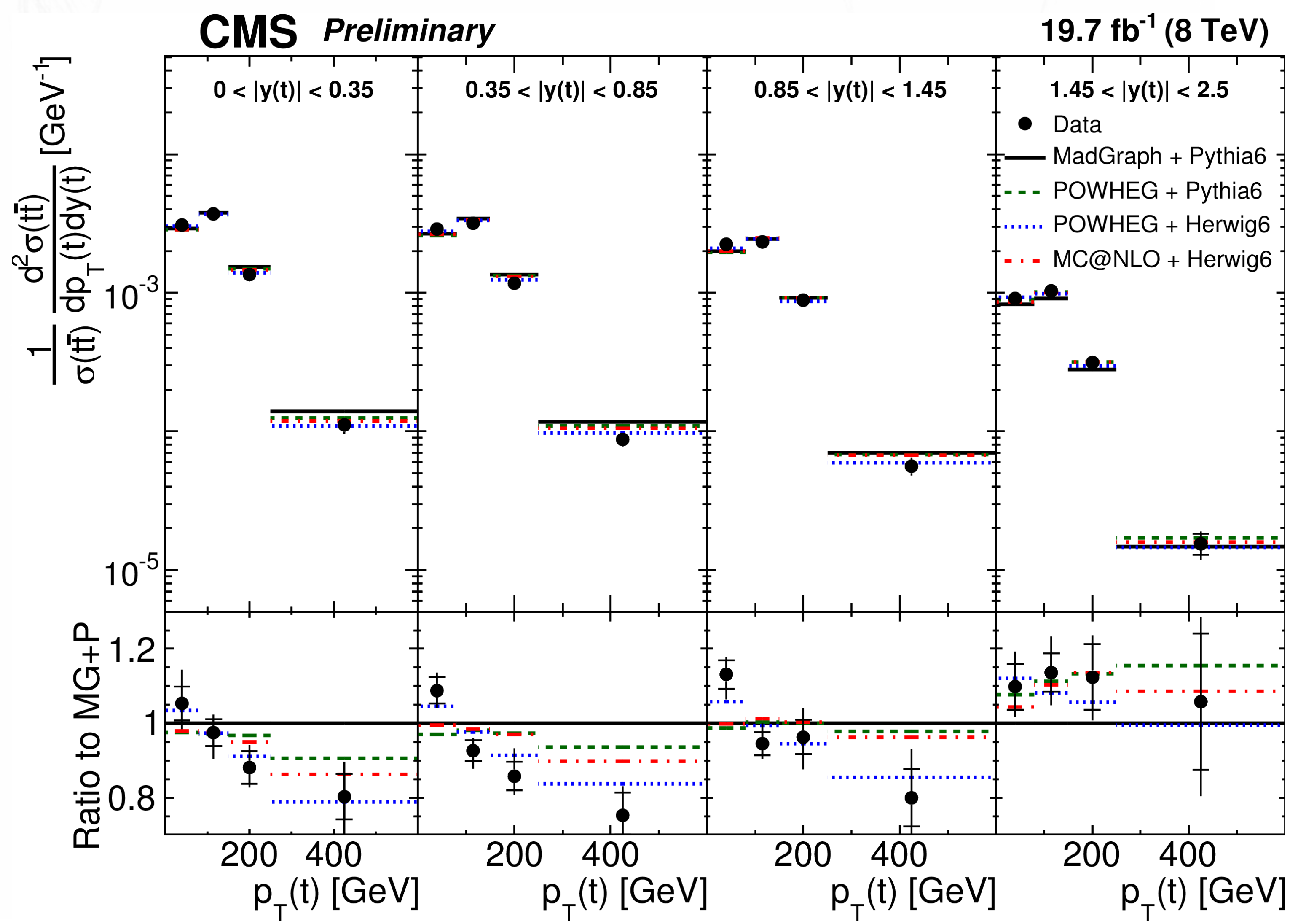

p_T^t vs. $|y^t|$

Observations

- p_T^t: Data softer than predictions
- except for high $|y^t|$

Bottom line

- None of the considered MC generators correctly describes all distributions

NEW

TOP-14-013
July 30, 16

8 TeV
dilepton ($e\mu$)
19.7/fb
parton level
full phase space
normalized
resolved

- p_T^t vs. $|y^t|$
- $|y^t|$ vs. $M_{t\bar{t}}$
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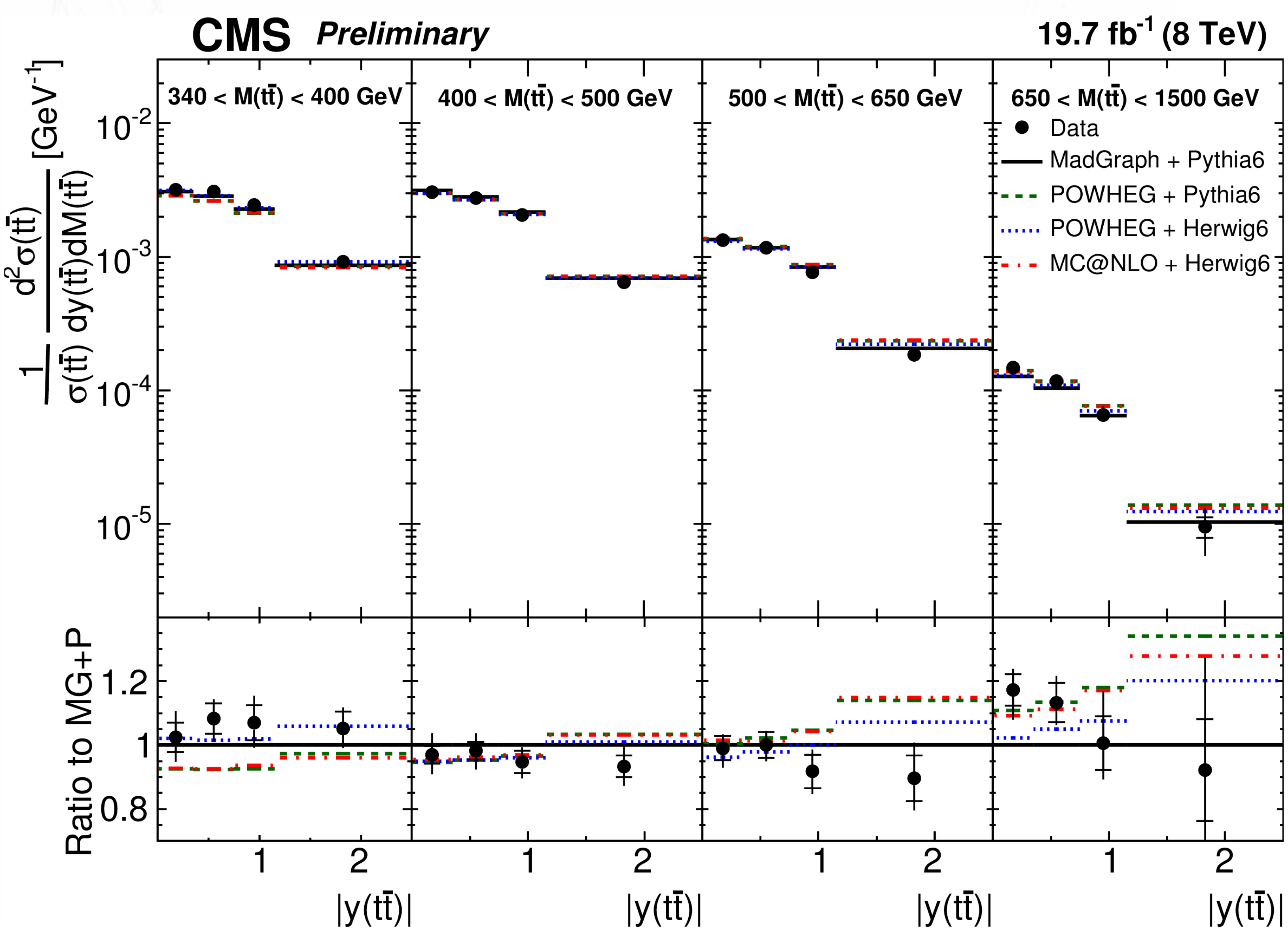


$|y^{tt}|$ vs. $M_{t\bar{t}}$

Observations

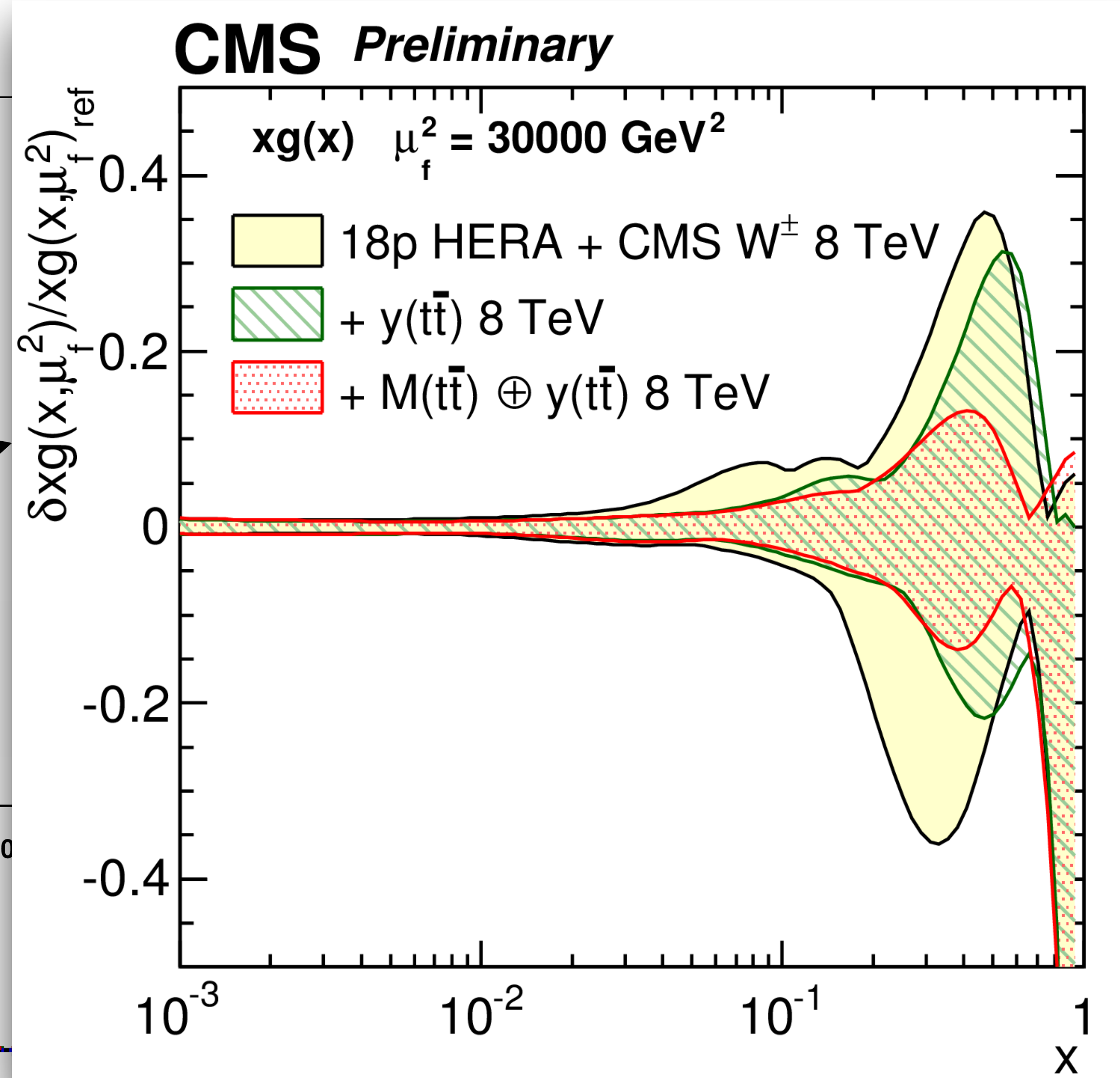
- Good agreement at low $M_{t\bar{t}}$
- MC deviates from data at high $M_{t\bar{t}}$ where predictions are less central
- Gluon PDF: Sensitive to x ~ 0.25

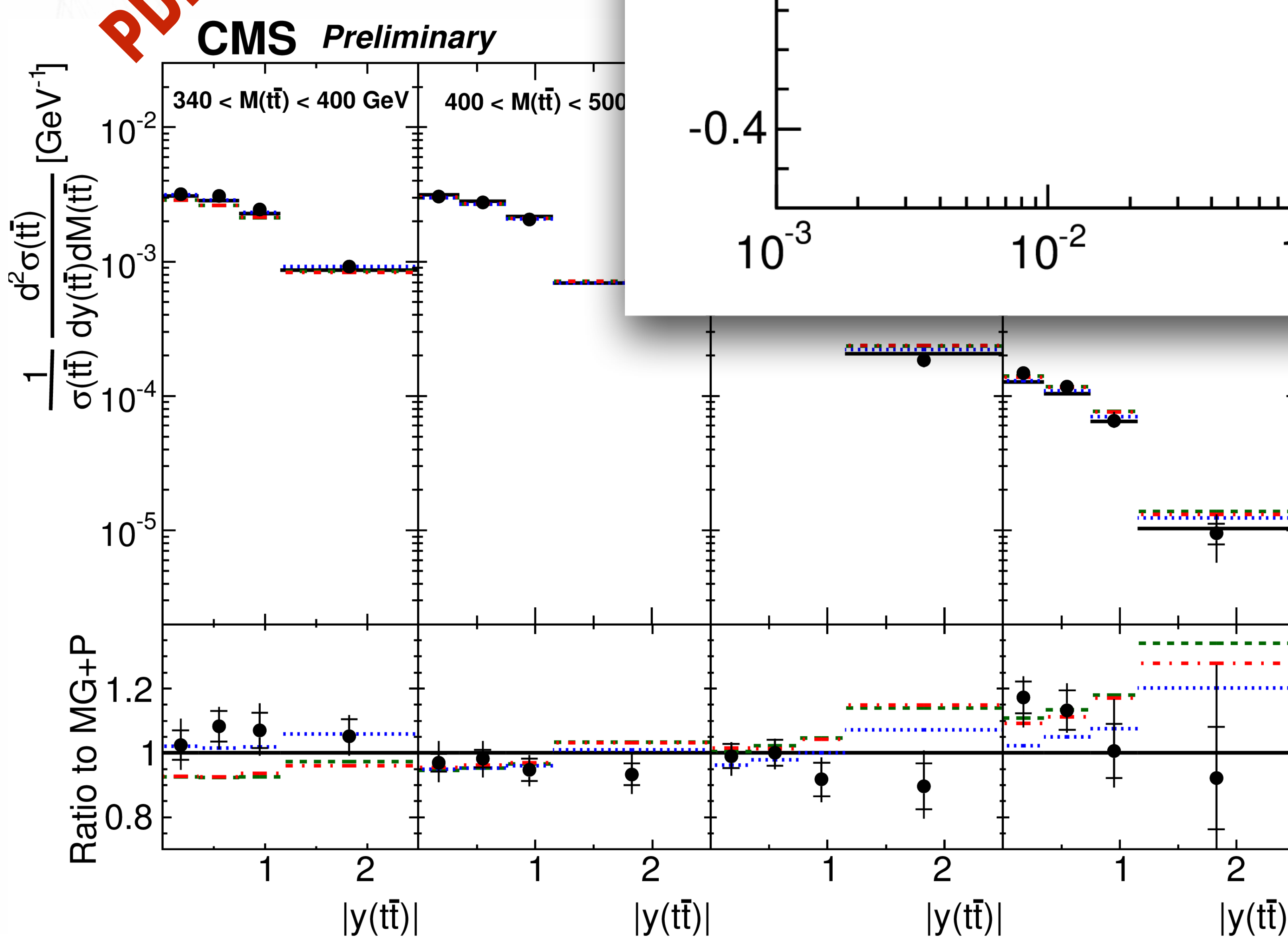
$$x = \frac{M(t\bar{t})}{\sqrt{s}} e^{\pm y(t\bar{t})}$$

CMS: DILEPTO

Significant constraining power results →reduction of PDF uncertainties at high x

PDF constraints





TOP-14-013
July 30, 16

NEW

8 TeV
dilepton (eμ)
19.7/fb
parton level
full phase space
normalized
resolved

- p_T^t vs. $|y^t|$
- $|y^t|$ vs. $M_{t\bar{t}}$
- $|y^{tt}|$ vs. $M_{t\bar{t}}$
- $p_T^{t\bar{t}}$ vs. $|y^t|$
- $\Delta\eta^{t\bar{t}}$ vs. $M_{t\bar{t}}$
- $\Delta\phi^{t\bar{t}}$ vs. $M_{t\bar{t}}$

tt̄

Observations

- Good agreement at low $M_{t\bar{t}}$
- MC deviates from data at high $M_{t\bar{t}}$ where predictions are less central
- Gluon PDF: Sensitive to x ~ 0.25

$$x = \frac{M(t\bar{t})}{\sqrt{s}} e^{\pm y(t\bar{t})}$$

L+jets Measurements

New results on 13 TeV

NEW*

CMS PAPER TOP-16-008

CMS Paper

2016/09/18

Measurement of differential cross sections for top quark pair production using the lepton+jets final state in proton-proton collisions at 13 TeV

The CMS Collaboration

Abstract

Differential and double-differential cross sections for the production of top quark pairs in proton-proton collisions at 13 TeV are measured as a function of jet multiplicity and of kinematic variables of the top quarks and the top quark-antiquark system. This analysis is based on data collected by the CMS experiment at the LHC corresponding to an integrated luminosity of 2.3 fb^{-1}. The measurements are performed in the lepton+jets decay channels with a single muon or electron in the final state. The differential cross sections are presented at particle level, within a phase space close to the experimental acceptance, and at parton level in the full phase space. The results are compared to several standard model predictions.

NEW

ATLAS NOTE

ATLAS-CONF-2016-040

1st August 2016

Measurements of top-quark pair differential cross-sections in the lepton+jets channel in pp collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector

The ATLAS Collaboration

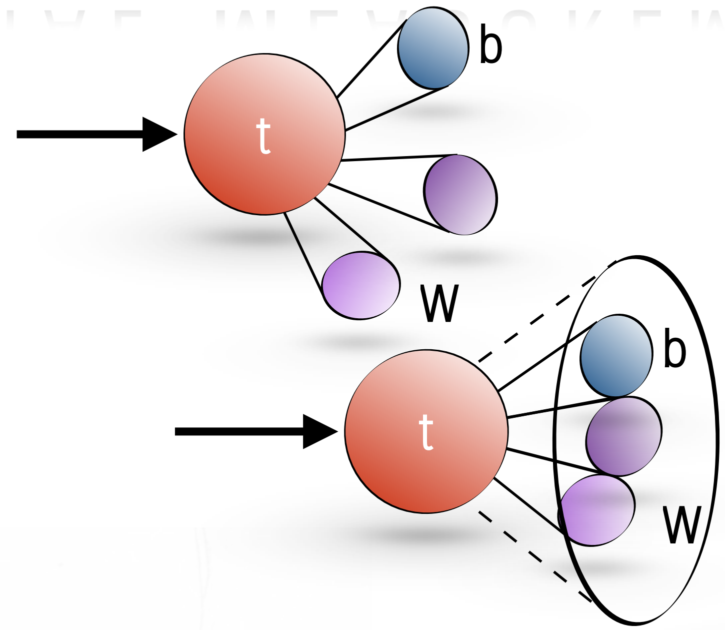
Abstract

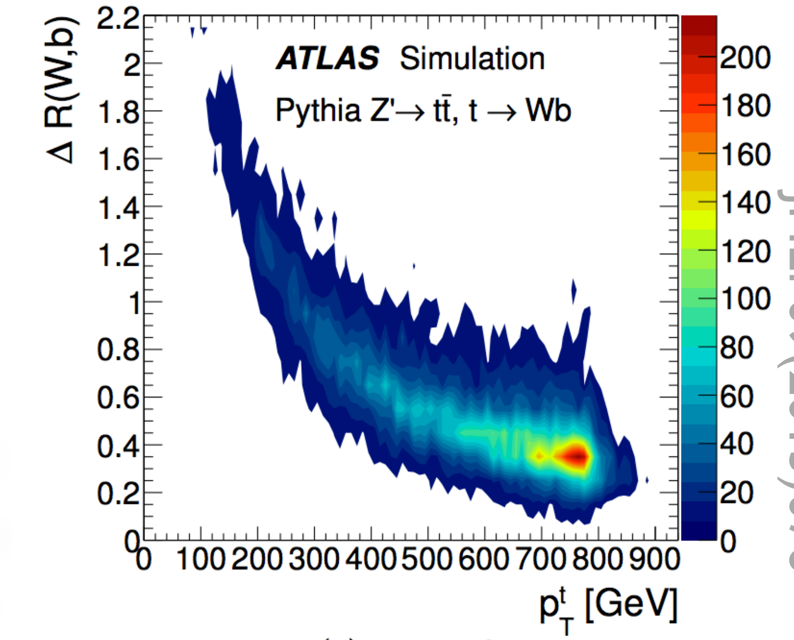
Measurements of differential cross-sections of top-quark pair production are presented as a function of the top-quark and $t\bar{t}$ system kinematic observables in proton–proton collisions at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV. The dataset corresponds to an integrated luminosity of 3.2 fb^{-1}, recorded in 2015 with the ATLAS detector at the CERN Large Hadron Collider. Events with one lepton and jets in the final state are used for the measurement. Two separate selections are applied that each focus on different top-quark momentum phase-spaces, denoted as resolved and boosted topologies of the $t\bar{t}$ final state. The measured spectra are corrected for detector effects and are compared to several Monte Carlo simulations. The results are in fair agreement with the predictions over a wide kinematic range. Nevertheless, most event generators predict a harder top-quark transverse momentum distribution at high values than what is observed in the data.

*First time presented

Differential Measurements

- **Top-quark definition**
  - detector level
  - particle level
  - parton level
- **Covered phase-space**
  - detector
  - fiducial
  - full
- **Decay topology**
  - **boosted**
  - **resolved**
- **Cross-section definition**
  - normalized
  - absolute



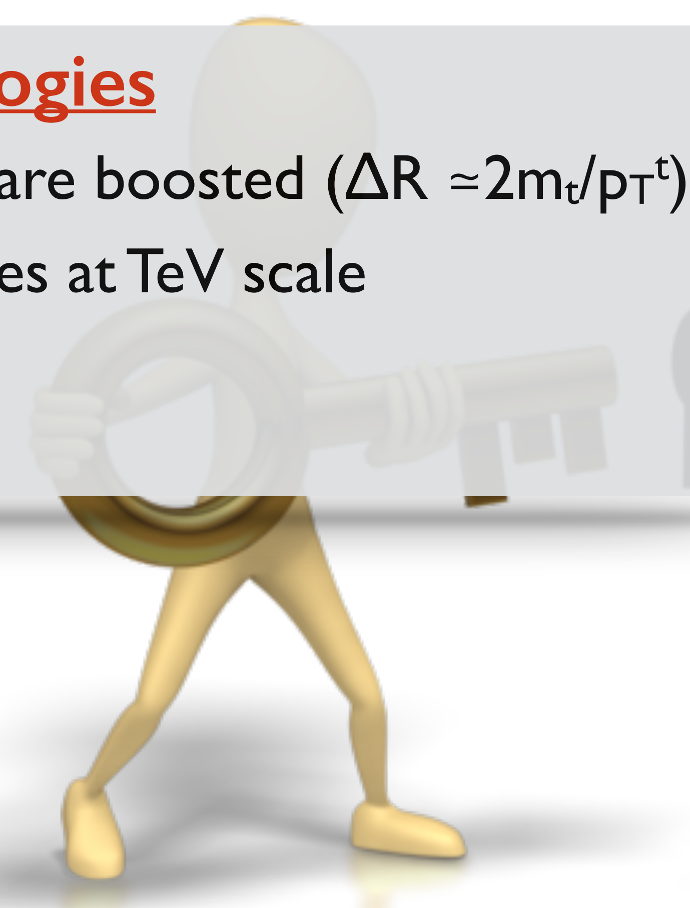


(a) $t \to Wb$

JHEP09(2013)076

Resolved and boosted top-quark topologies

- Higher energies, more top-quark candidates are boosted ($\Delta R \simeq 2m_t/p_T^t$)
- Variety of theory models predict new particles at TeV scale
- Probe both low and high p_T regimes



ATLAS: 13TeV, L+JETS

- Pseudo-top measurement complements
- Comparisons to NLO MC generator

Phys. Rev. D93 (2016) 032009
arXiv:1511.04716 (accepted by EPJC)
JHEP 06 (2015) 100

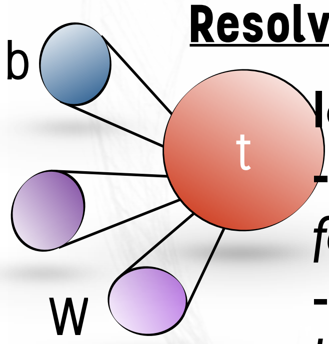
CONF-2016-040 NEW

Particle event selection / reconstruction

e/μ and anti-k_t jets (R =0.4) with p_T > 25 GeV, $|\eta|$ < 2.5
anti-k_t large jets (R =1.0, trimmed[rsub = 0.2, p_T^{sub}/p_T^{large} < 5%] with $p_T \in$ [300-1500] GeV, $|\eta|$ < 2.0, m ≥ 50 GeV
exactly one lepton

Resolved channel

≥4 small-R jets (≥2 b-tagged)



Resolved tops (pseudo-top algorithm)

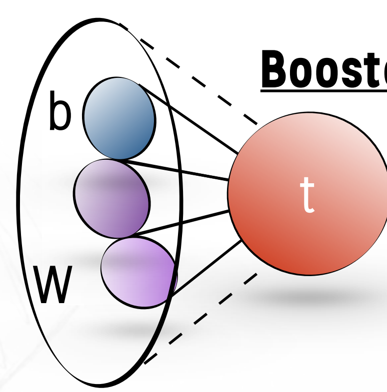
leptonic:
- Imposes W-mass constraint to solve for neutrino $|p_z|$
- Pairs W and b-jet closest in ΔR to lepton

hadronic:
-Pair non b-tagged jets closest to m_W with remaining second hardest b-tagged jet

Boosted channel

≥1 small-R jets & ≥1 large-R jets
(at least either b-tagged)

MET > 20 GeV, MET + m_T^W > 60 GeV



Boosted top

leptonic:
- At least one small-R jet with ΔR(lepton, small-R jet) < 2.0

hadronic:
-top-tagged large R-jet (m > 100 GeV, τ_{32} > 0.75)

Overview

13 TeV
l+jets
3.2/fb

particle level
fiducial phase space
absolute & normalized

resolved

$p_T^{t,had}$	$\lvert y^{t,had}\rvert$
$p_T^{t\bar{t}}$	$m^{t\bar{t}}$
$\lvert y^{t\bar{t}}\rvert$	

boosted

$p_T^{t,had}$	$\lvert y^{t,had}\rvert$

University of British Columbia — Steffen Henkelmann

ATLAS: 13TeV, l+jets

- Pseudo-top measurement complements
- Comparisons to NLO MC generator

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CONF-2016-040 NEW

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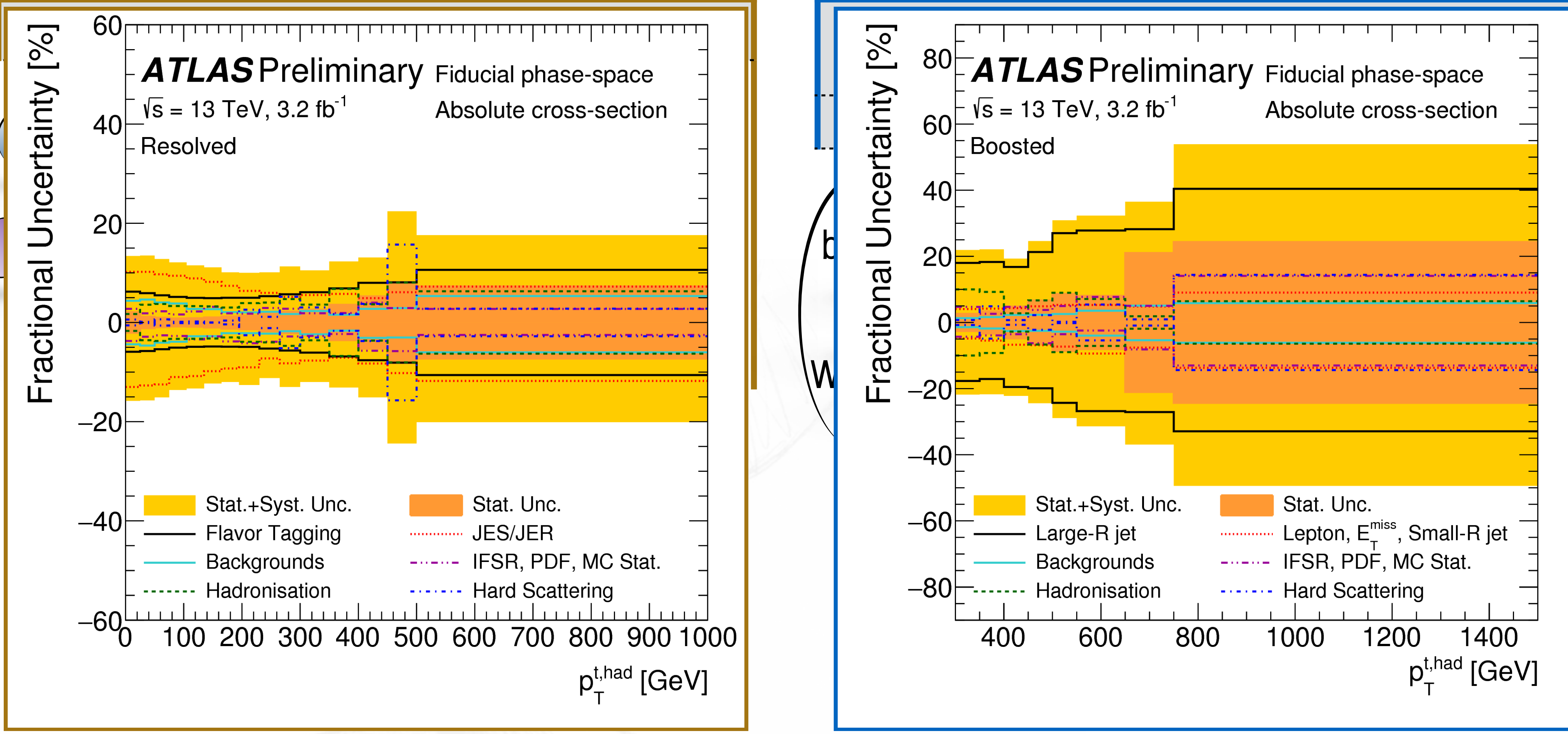
exactly one lepton

Resolved channel	Boosted channel



- Dominant uncertainties
  - *Resolved*: JES and flavour tagging
  - *Boosted*: Large R-jet (→JES dominant)

Overview

13 TeV
l+jets
3.2/fb

particle level
fiducial phase space
absolute & normalized

resolved
$p_T^{t,had}$, $|y^{t,had}|$, $p_T^{t\bar{t}}$, $m^{t\bar{t}}$, $|y^{t\bar{t}}|$

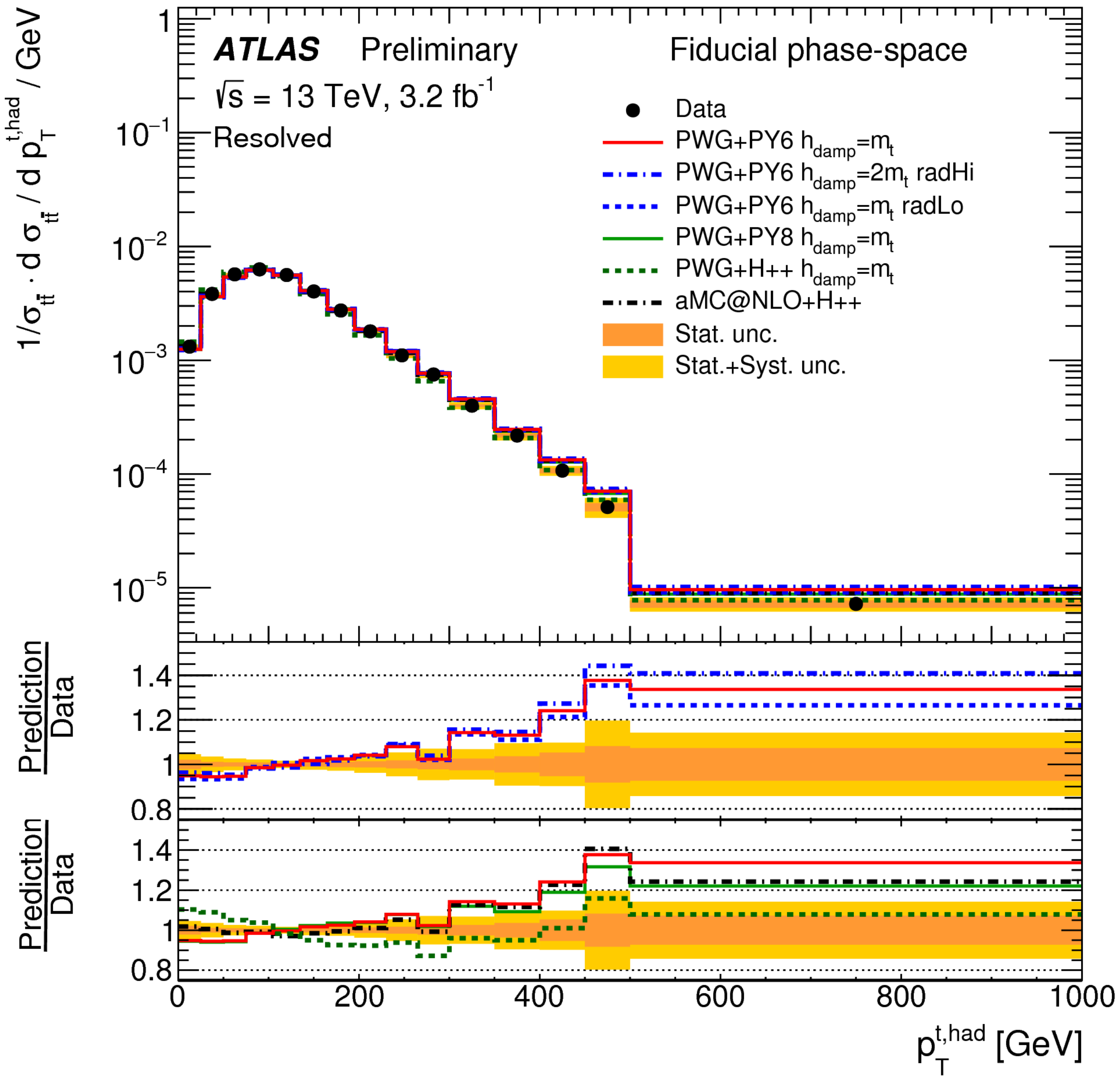
boosted
$p_T^{t,had}$, $|y^{t,had}|$

ATLAS: 13 TeV, L+JETS

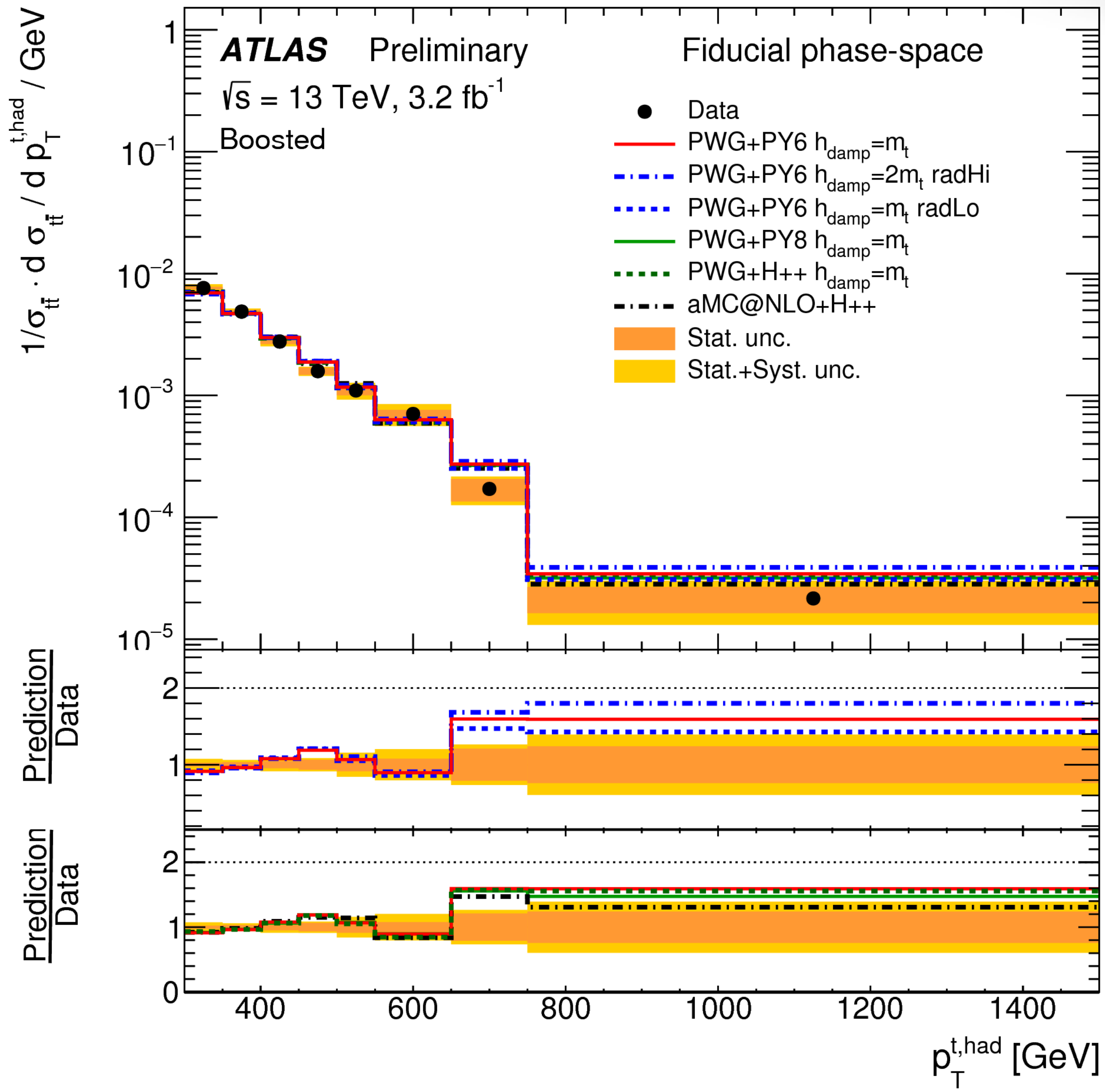
CONF-2016-040

NEW

resolved



boosted



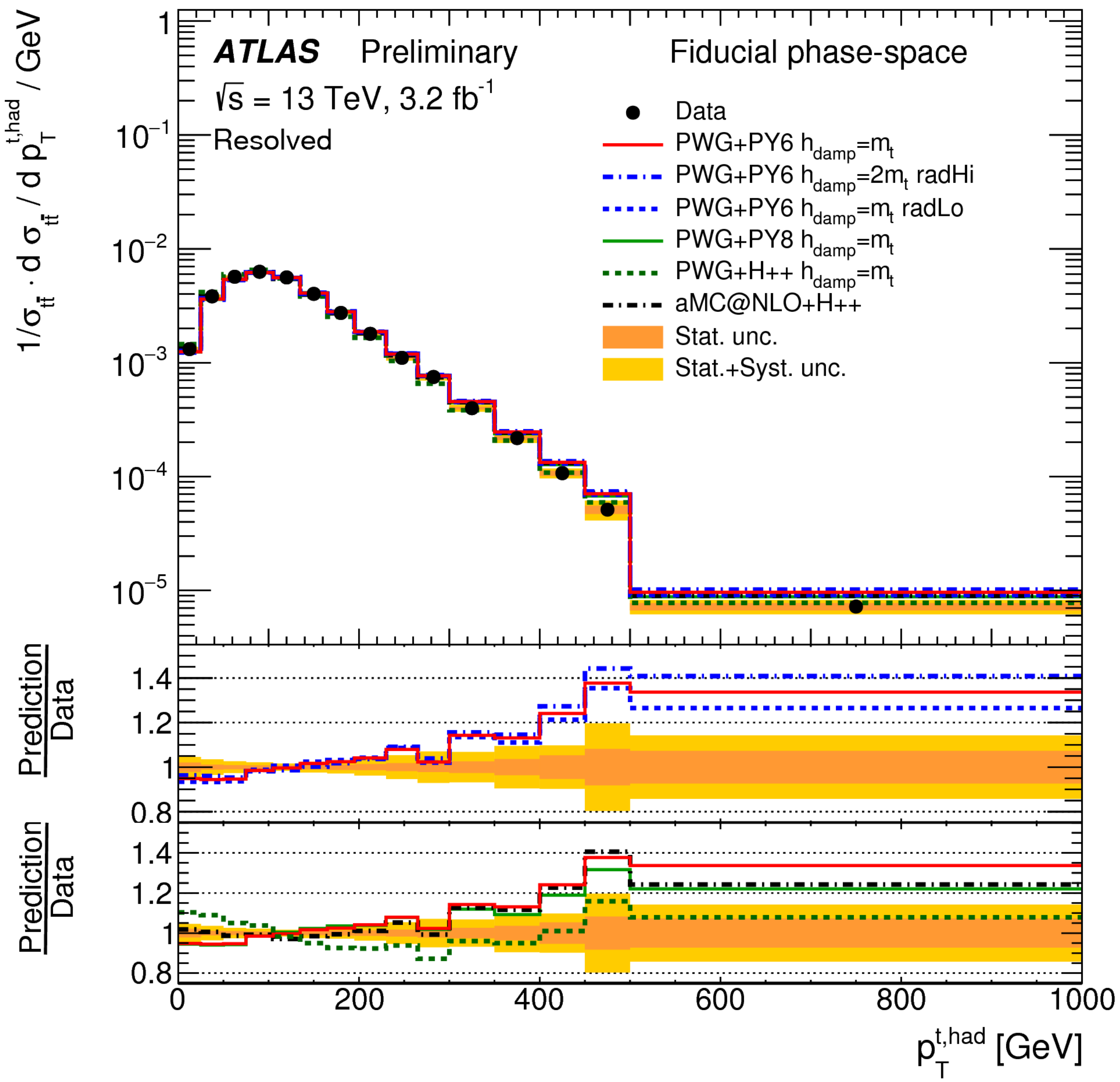
- Data seems softer at high p_T in both resolved and boosted channels
- $p_T^{t,had}$: Trends of NLO MC generators similar to previous results
- $|y^{t,had}|$, $m^{t\bar{t}}$, $|y^{t\bar{t}}|$ & $p_T^{t\bar{t}}$: Level of agreement within quoted uncertainties
- $p_T^{t\bar{t}}$ sensitive to extra radiation and choice of scales

ATLAS: 13 TeV, L+JETS

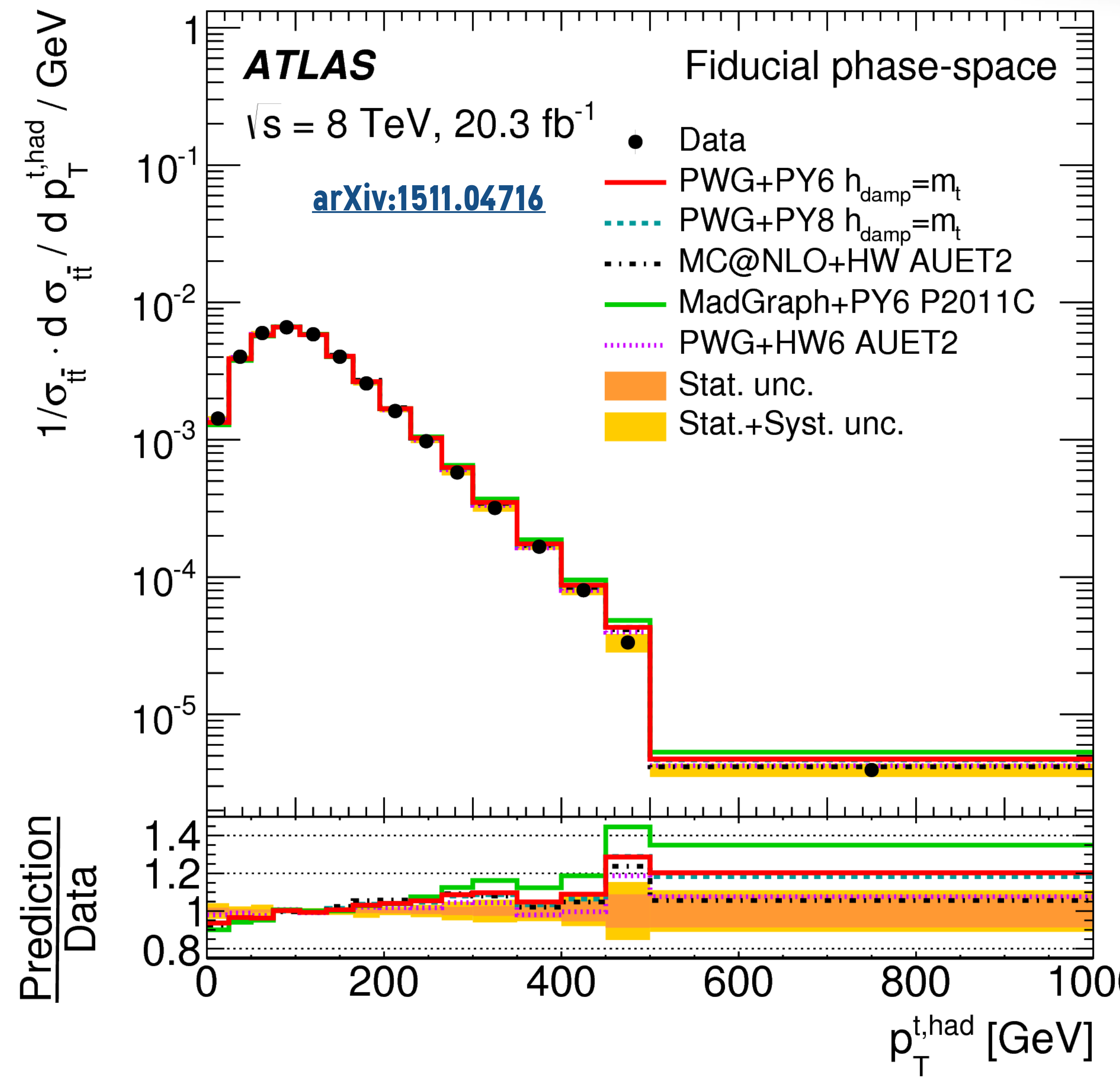
CONF-2016-040

NEW

resolved



resolved



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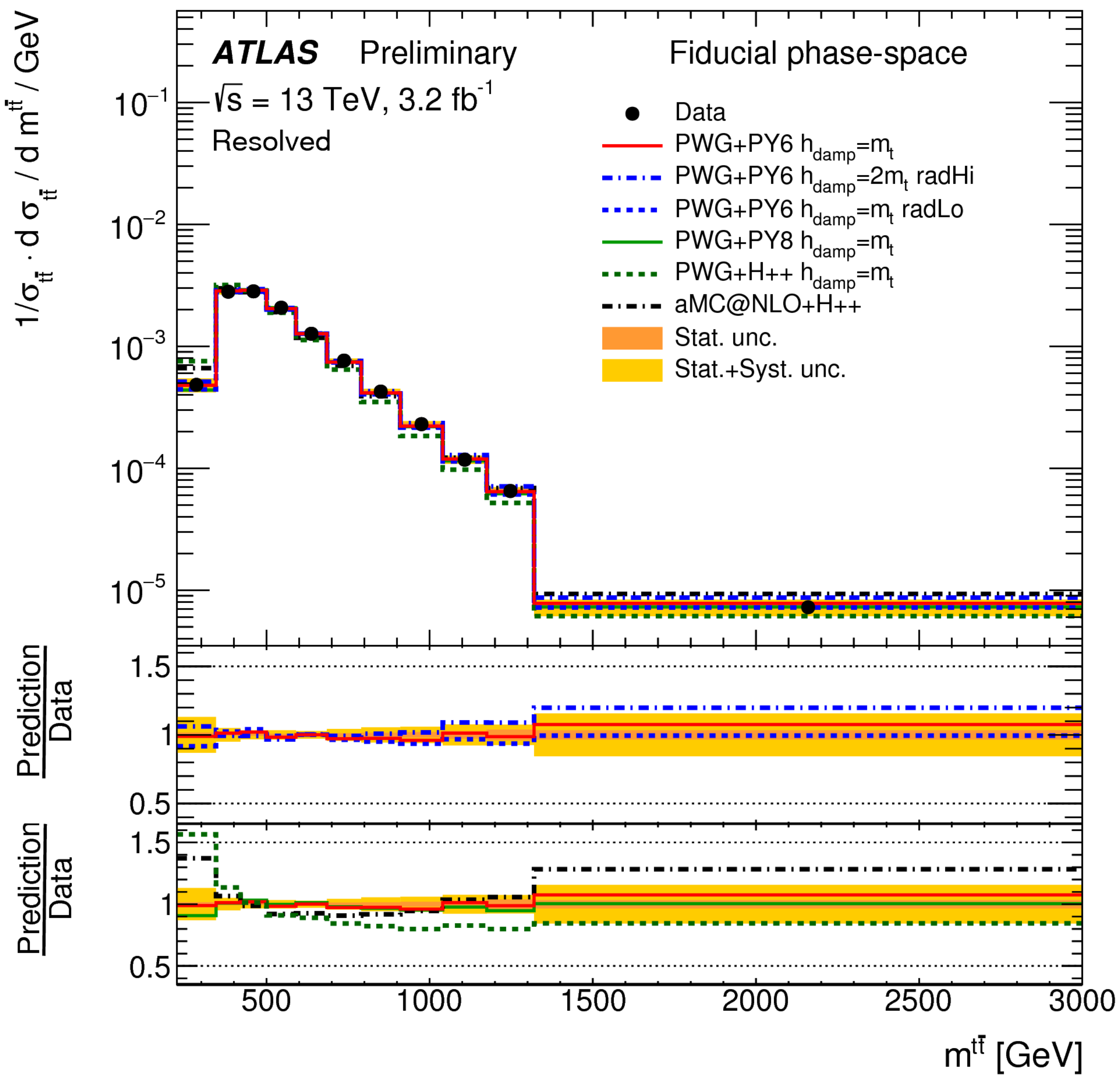
- $p_T^{t\bar{t}}$ sensitive to extra radiation and choice of scales

ATLAS: 13TeV, l+jets

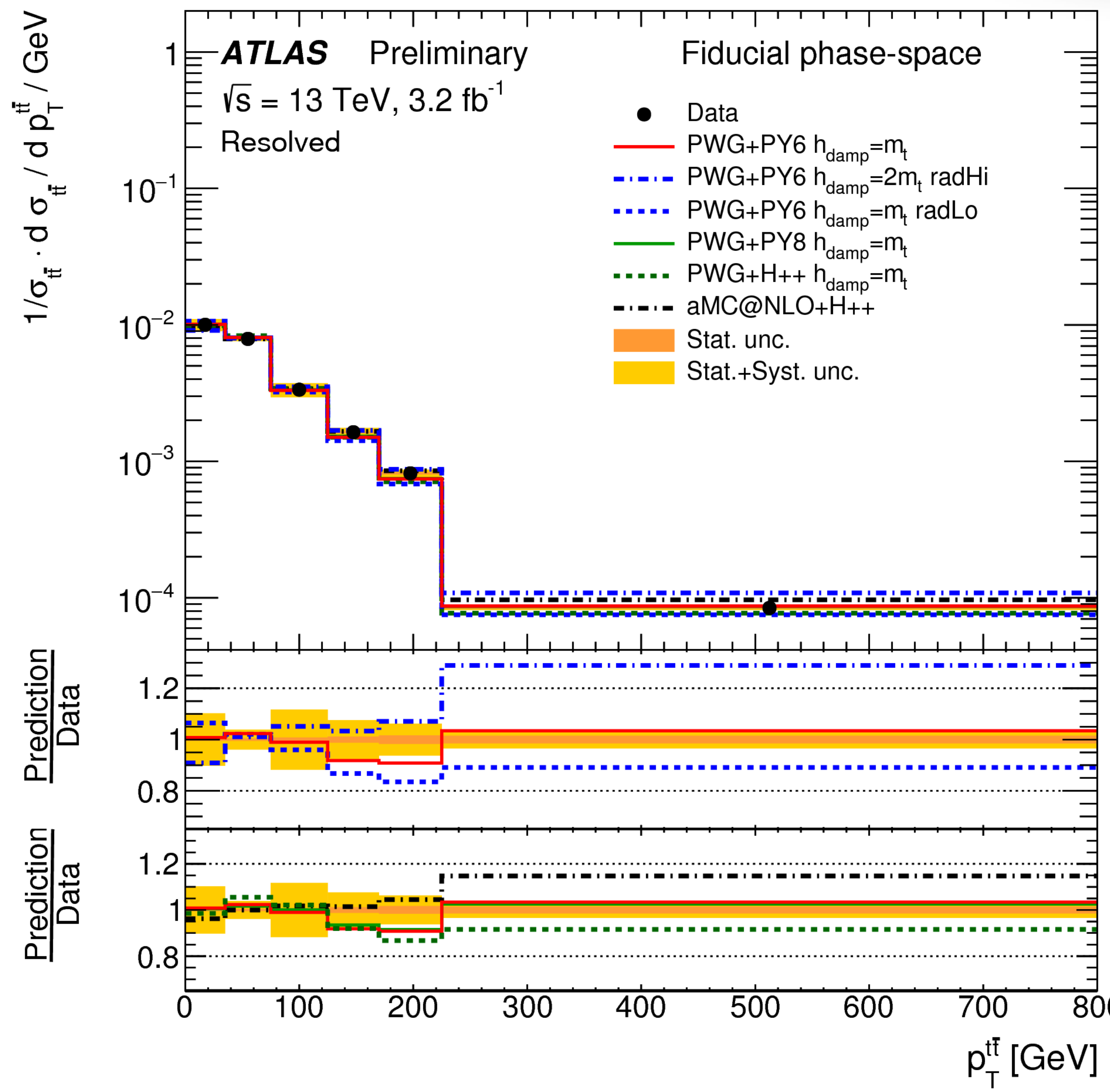
CONF-2016-040

NEW

resolved



resolved



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- $p_T^{t\bar{t}}$ sensitive to extra radiation and choice of scales

NEW

1D Measurement complements

arXiv:1607.00837 (accepted for PRD)
arXiv:1605.00116 (submitted to PRD)

+ double differential measurements

- Comparisons to NLO MC generator and up to $N^{(3)}LO$ $O(\alpha_S^5)$ theory prediction

- Dominant uncertainties
  - *Particle level*: exp. → JES, b-tagging efficiency
  - *Parton level*: Parton shower & had. model

Typical uncertainty ranges of uncertainties in the bins

Source	Particle level [%]	Parton level [%]
Statistical uncertainty	1–5	1–5
Jet energy scale	5–8	6–8
Jet energy resolution	< 1	< 1
$\vec{p}_T^{miss}$ (non jet)	< 1	< 1
b tagging	2–3	2–3
Pileup	< 1	< 1
Lepton selection	3	3
Luminosity	2.7	2.7
Background	1–3	1–3
PDF	< 1	< 1
Fact./ren. scale	< 1	< 1
Parton shower scale	2–5	2–9
POWHEG + PYTHIA8 vs. HERWIG++	1–5	1–12
NLO event generation	1–5	1–10
m_t	1–2	1–3

NEW*
TOP-16-008
(to be submitted to PRD)
September 20, 16

Overview

13 TeV
l+jets
2.3/fb

parton level
full phase space
absolute & normalized

particle level
fiducial phase space
absolute & normalized

resolved

1D

p_T^t | $|y^t|$
$p_T^{t\bar{t}}$ | $|y^{t\bar{t}}|$ | $m^{t\bar{t}}$

2D

$p_T^{t,had}$ vs. $|y^{t,had}|$
$|y^{t\bar{t}}|$ vs. $M_{t\bar{t}}$
$p_T^{t\bar{t}}$ vs. $M_{t\bar{t}}$

CMS: 13 TeV, l+jets

1D Measurement complements

arXiv:1607.00837 (accepted for PRD) NEW
arXiv:1605.00116 (submitted to PRD)

TOP-16-008 (to be submitted to PRD) September 20, 16 NEW*

+ double differential measurements

- Comparisons to NLO MC generator and up to $N^{(3)}LO$ $O(\alpha_S^5)$ theory prediction
- Dominant uncertainties
  - *Particle level*: exp. → JES, b-tagging efficiency
  - *Parton level*: Parton shower & had. model

Typical uncertainty ranges of uncertainties in the bins

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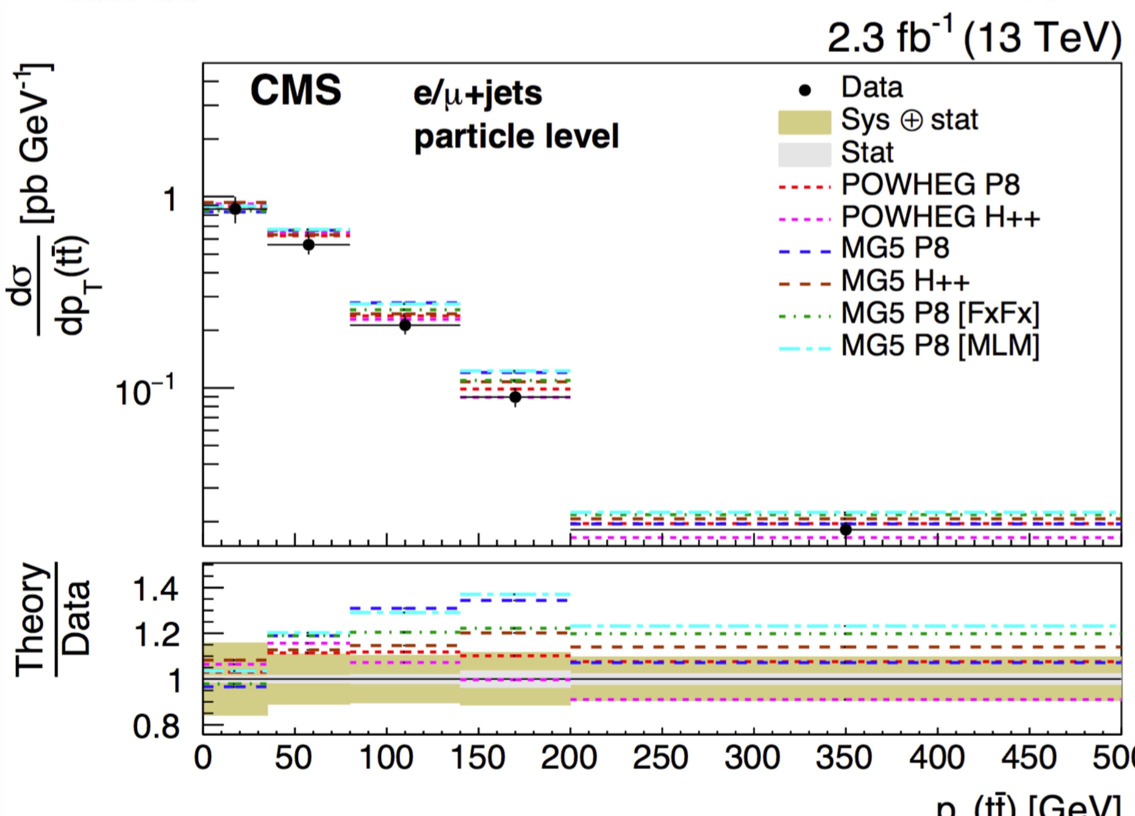
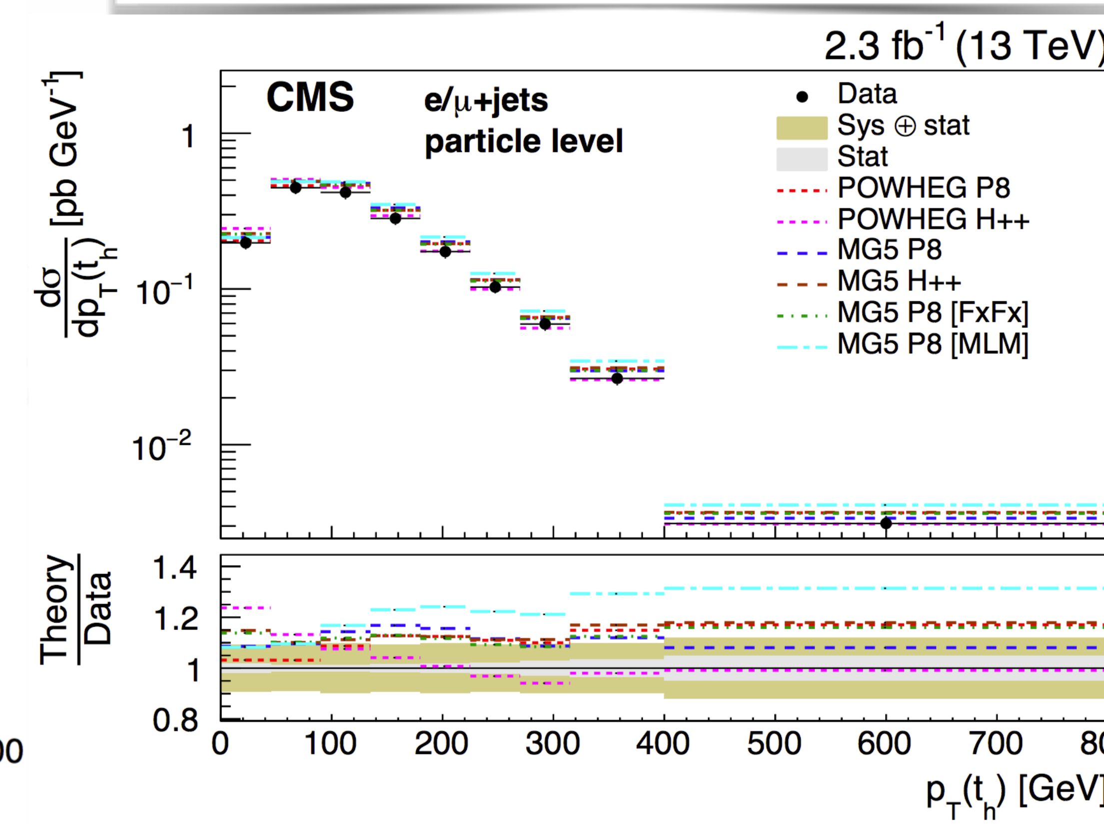
PDF	< 1	< 1
Fact./ren. scale	< 1	< 1
Parton shower scale	2–5	2–9
POWHEG + PYTHIA8 vs. HERWIG++	1–5	1–12
NLO event generation	1–5	1–10
m_t	1–2	1–3





Overview

13 TeV
l+jets
2.3/fb

parton level
full phase space
absolute & normalized

particle level
fiducial phase space
absolute & normalized

resolved

1D
p_T^t | $|y^t|$
$p_T^{t\bar{t}}$ | $|y^{t\bar{t}}|$ | $m^{t\bar{t}}$

2D
$p_T^{t,had}$ vs. $|y^{t,had}|$
$|y^{t\bar{t}}|$ vs. $M_{t\bar{t}}$
$p_T^{t\bar{t}}$ vs. $M_{t\bar{t}}$

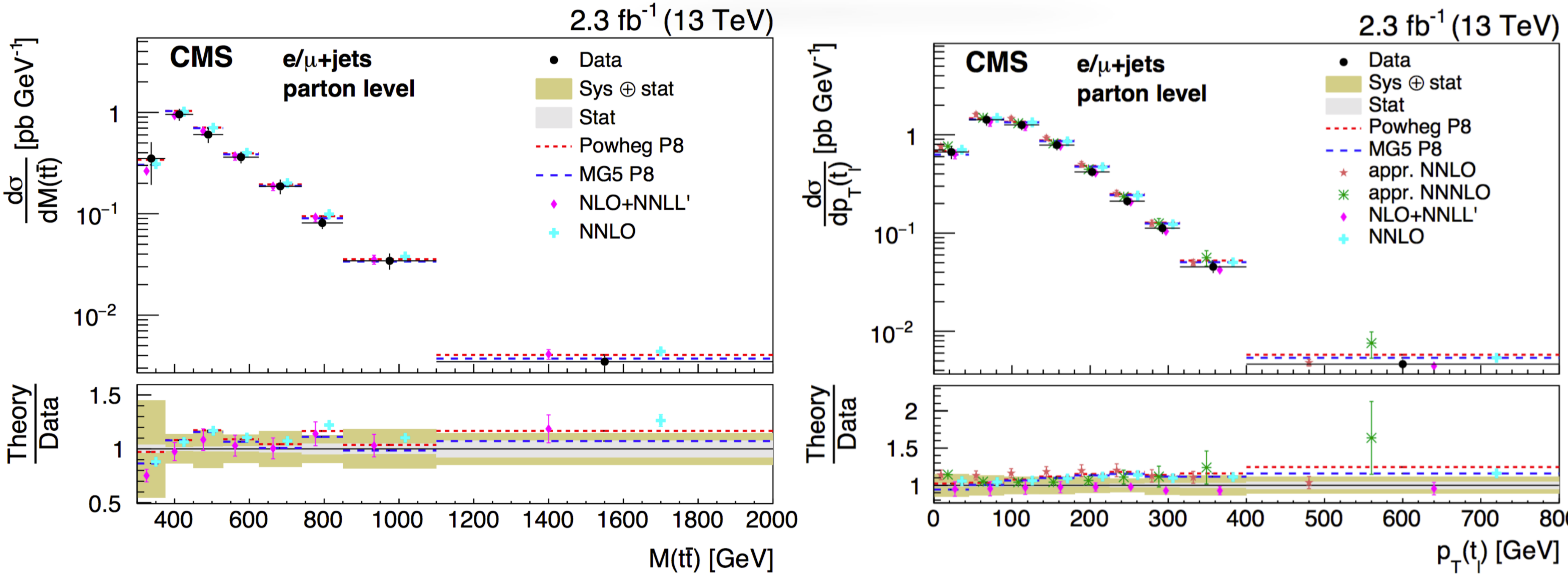
- Comparison between inclusive and NLO Multileg generators → large impact of PS and had. modelling
- $p_T^{t\bar{t}}$ best described by Powheg + Py8 (p-value = 0.805)
- $p_T^{t,had}$ best described by MG5_aMC@NLO+Py8 [FxFx] (p-value = 0.83)
- $p_T^{t,had}$, $p_T^{t\bar{t}}$ and $m^{t\bar{t}}$: Powheg+HW++ deviates from data (p-value < 0.01)

N(N)LO PREDICTIONS AT 13 TEV

TOP-16-008 (to be submitted to PRD) September 20, 16

NEW*

13 TeV | parton level



- NLO + NNLL seems to predict slightly harder $M_{t\bar{t}}$ spectrum (p-value = 0.14)
  - Trend observed in 7 TeV & 8 TeV by ATLAS (p-value ~ 0.3) and at 8 TeV by CMS in dilepton channel
- $p_T^{t,lep}$ spectrum:
  - Good description by NNLO & NLO + NNLL QCD calculations
  - aN$^{(2,3)}$LO prediction show tension at moderate $p_T^{t,lep}$ with p-value < 0.01 (same trend observed in dilepton channel)

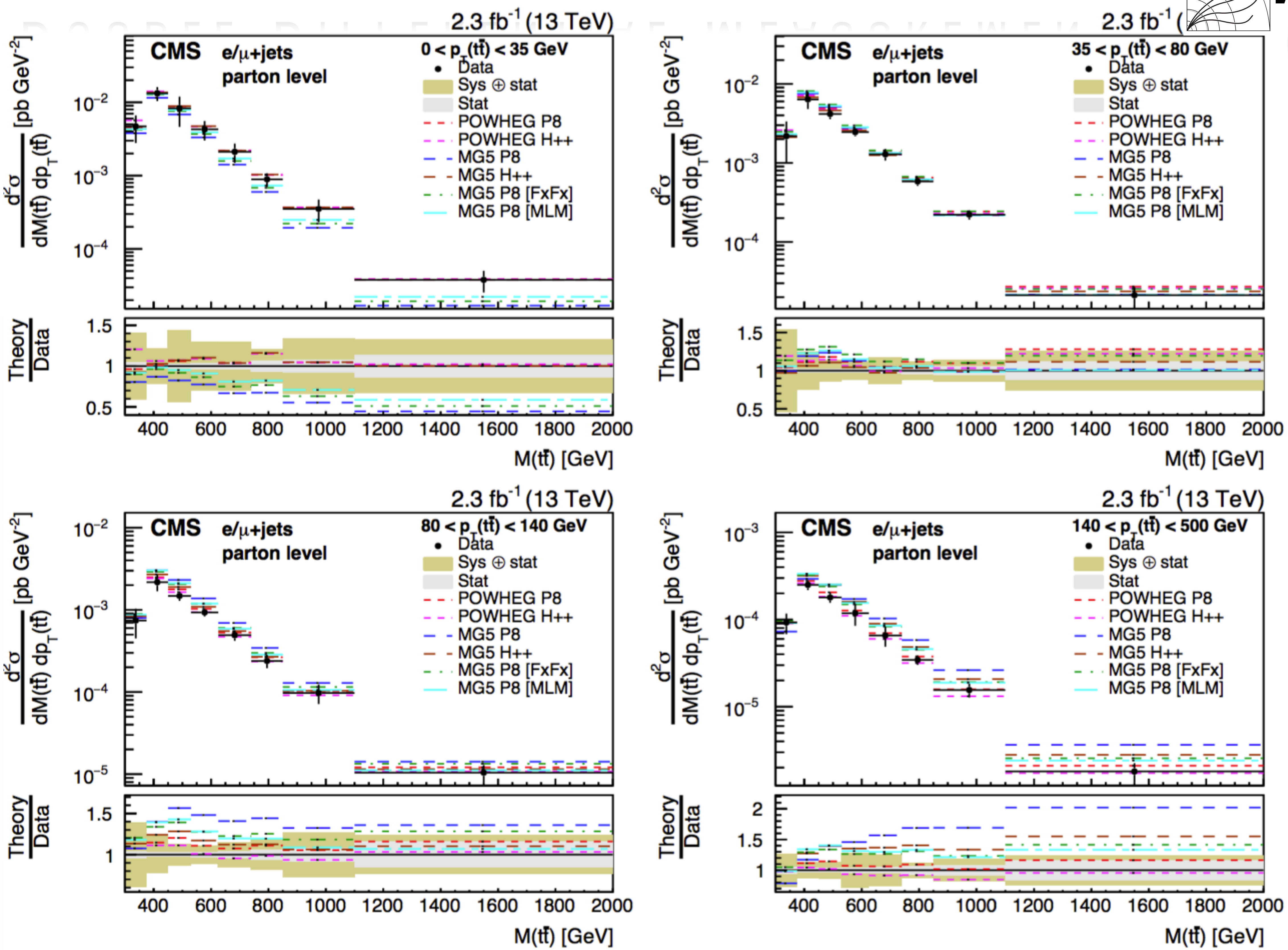
DOUBLE DIFFERENTIAL MEASUREMENT

NEW*

TOP-16-008

(to be submitted to PRD)

September 20, 16



- Only Powheg predictions seem to model spectra adequately (MG5_aMC@NLO → p-values < 0.01)

All-hadronic Measurements

New results on 13 TeV

NEW

EUROPEAN ORGANIZATION FOR NUCLEAR

CMS-TOP-14-018

Measurement of the $t\bar{t}$ production cros
all-jets final state in pp collisions at

The CMS Collaboration*

Abstract

The cross section for $t\bar{t}$ production in the all-jets final state is m
at a centre-of-mass energy of 8 TeV at the LHC with the CMS
sponding to an integrated luminosity of 18.4 fb^{-1}. The inclusi
to be 275.6 ± 6.1 (stat) ± 37.8 (syst) ± 7.2 (lumi) pb. The norm
sections are measured as a function of the top quark transv
compared to predictions from quantum chromodynamics. Th
detector, parton, and particle levels. In all cases, the measure
are significantly softer than theoretical predictions.

Published in the European Physical Journal C as doi:10.1140/epj

arXiv:1509.06076v2 [hep-ex] 14 Mar 2016

Available on the CERN CDS information server **CMS PAS TOP-16-013**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-top@cern.ch 2016/06/15

Measurement of the $t\bar{t}$ production cross section at 13 TeV in the all-jets final state

The CMS Collaboration

Abstract

covered by Konstantinos Kousouris

NEW*

ATLAS CONF Note

Measurements of $t\bar{t}$ differential cross-sections in the all-hadronic channel with the ATLAS detector using highly boosted top quarks in pp collisions at $\sqrt{s} = 13$ TeV

ATLAS-CONF-TOP-2016-03

Abstract

A measurement of the boosted top-quark pair production differential cross-section in 13 TeV pp collisions in the all-hadronic decay mode is presented, performed using 14.7 fb^{-1} of data collected by the ATLAS detector in 2015 and 2016. The $t\bar{t}$ process is measured by requiring two top-quark candidates, one with $p_T > 500$ GeV and a second with $p_T > 350$ GeV, with each candidate reconstructed as anti-k_t jets with radius parameter $R = 1.0$. The top quark candidates are separated from the multijet background using the jet substructure and the presence of a b-quark tag in each jet. The observed kinematic distributions are unfolded to recover the differential cross-sections in a limited phase-space region and compared with Standard Model predictions. The cross-section for $t\bar{t}$ production in a fiducial phase-space defined by the requirements on the top-quark candidates is 374 ± 13 (stat)$^{+111}_{-92}$ (syst) fb, in good agreement with Standard Model calculations.

*First time presented

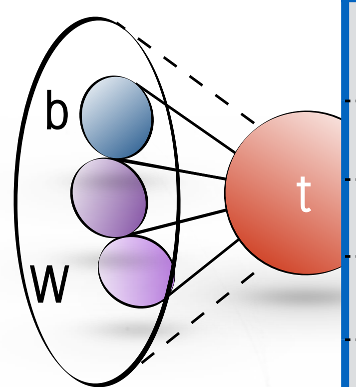
CONF-2016-100
September 20, 16

NEW*

Event selection / reconstruction

anti-k_t jets (R =0.4) with p_T > 25 GeV, |η| < 2.5
anti-k_t large jets (R =1.0, trimmed[rsub = 0.2, p_T^{sub}/p_T^{large} < 5%] with p_T > 300 GeV, |η| < 2.0

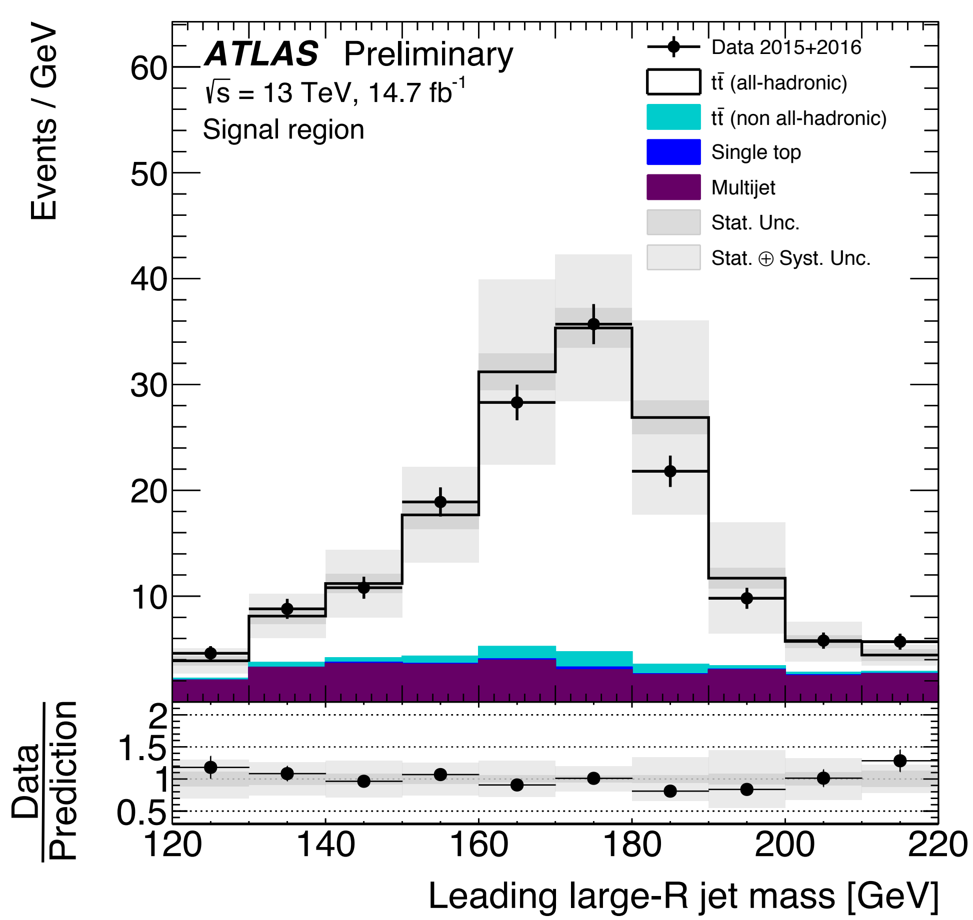
lepton veto



Boosted channel
≥2 large-R jets (both top-tagged)
$p_T^{(l)}$ > 500 GeV
≥2 small-R jets (both b-tagged)
ΔR(small-R jet, large-R jet) < 1.0
122.5 GeV < m < 222.5 GeV
τ_{32} p_T dependent cut → 50% top-tagging eff. WP

- Data-driven QCD background estimation (5CR, 1VR) → clean channel
- Comparisons to NLO MC generators
- Dominant uncertainties

Large-R jets	+18 / -15
Monte Carlo signal modelling	±17
b-tagging	+13 / -12
Pileup	±2.9
Luminosity	±2.9
Small-R jets	±1.0
Total Systematic Uncertainty	+29 / -24



Overview

13 TeV
all-hadronic
14.7/fb

particle level
fiducial phase space
absolute & normalized

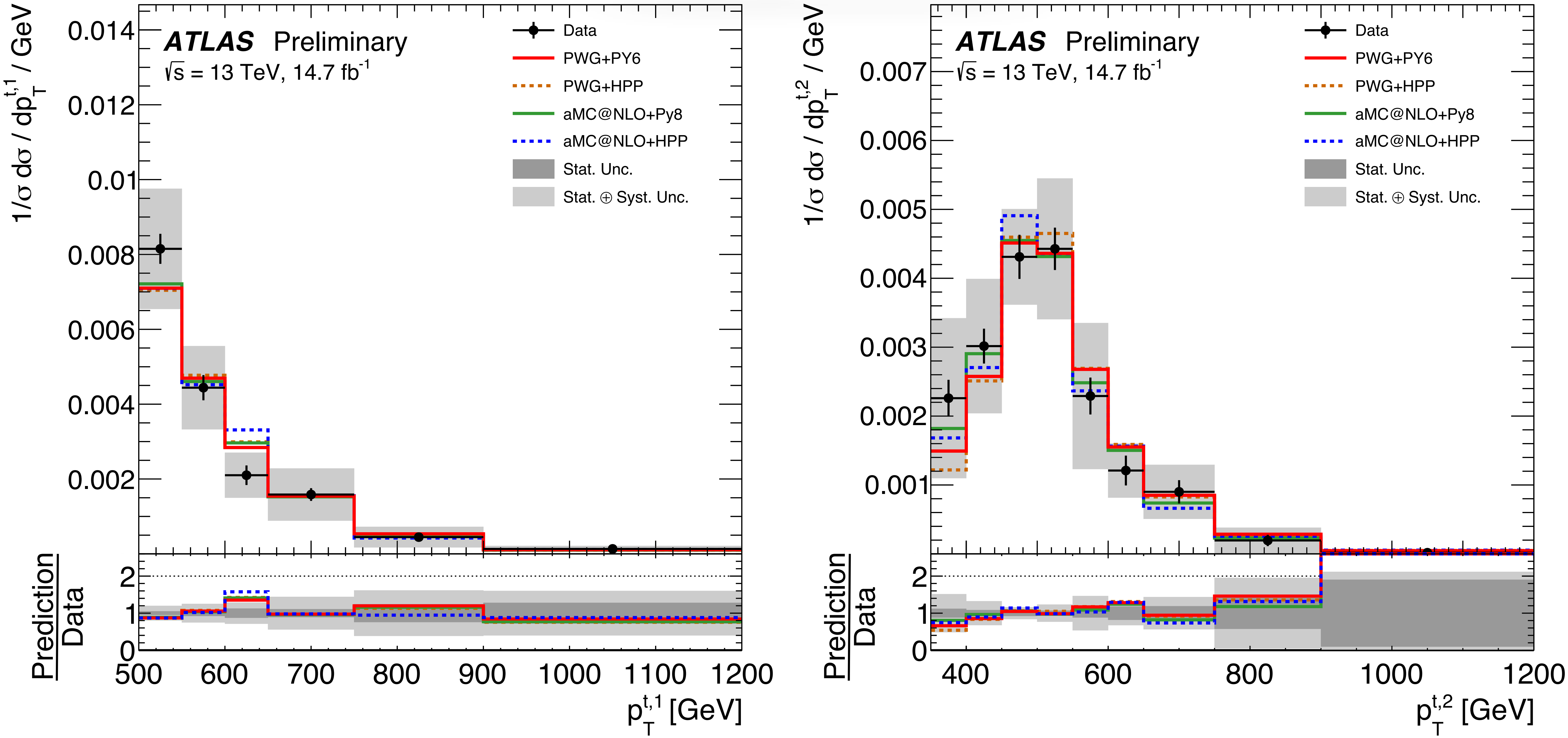
boosted

p_T^{t1}	p_T^{t2}	$|y^{t1}|$
$|y^{t2}|$	$|y^{t\bar{t}}|$	$m^{t\bar{t}}$
$p_T^{t\bar{t}}$	$H_T^{t\bar{t}}$	$\Delta\phi^{t\bar{t}}$
$y_B^{t\bar{t}}$	$\chi^{t\bar{t}}$	
$|\cos\theta^*|$	$p_{Tout}^{t\bar{t}}$	

ATLAS: ALL-HADRONIC

NEW*
CONF-2016-100
September 20, 16

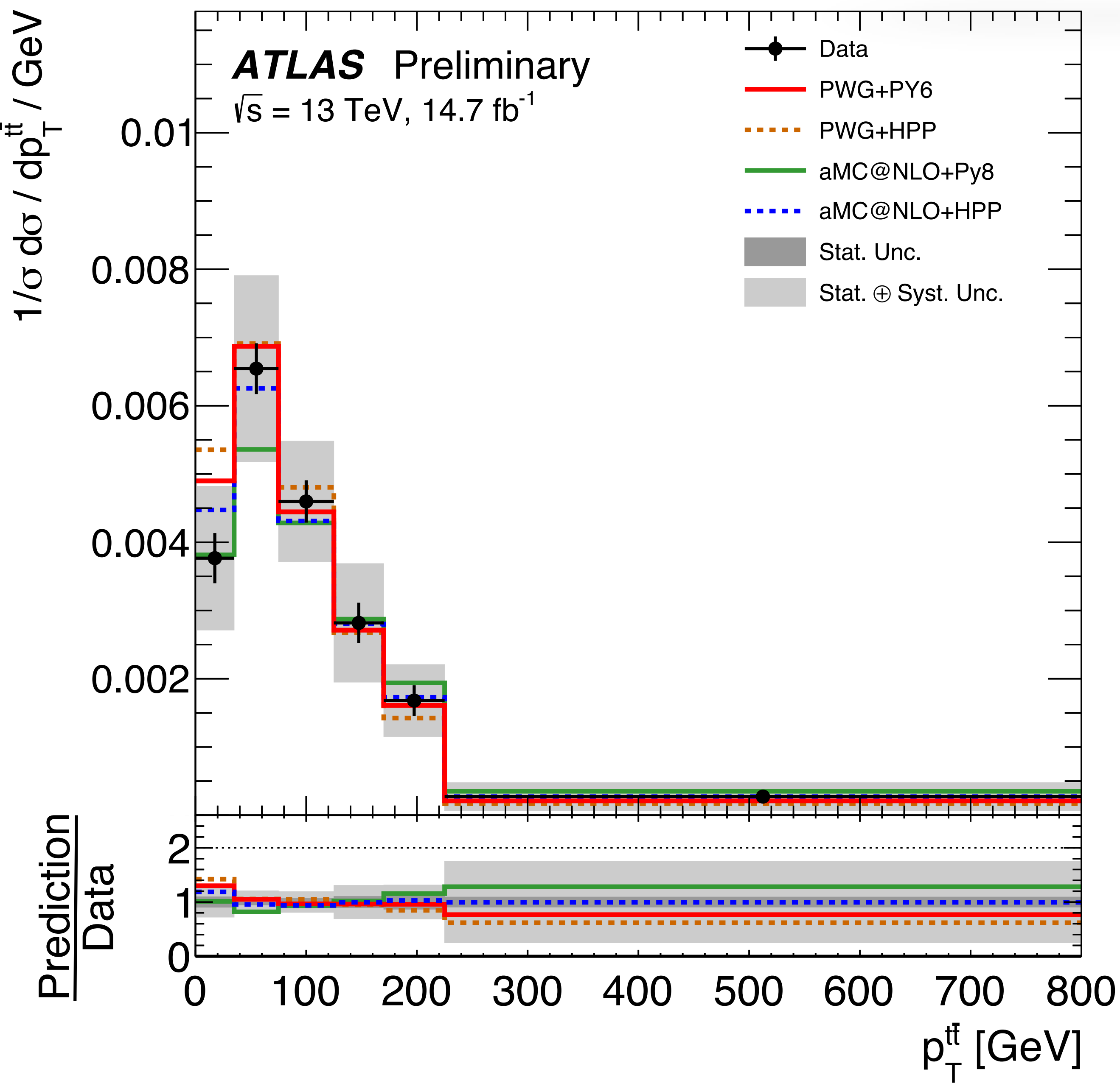
13 TeV | particle level

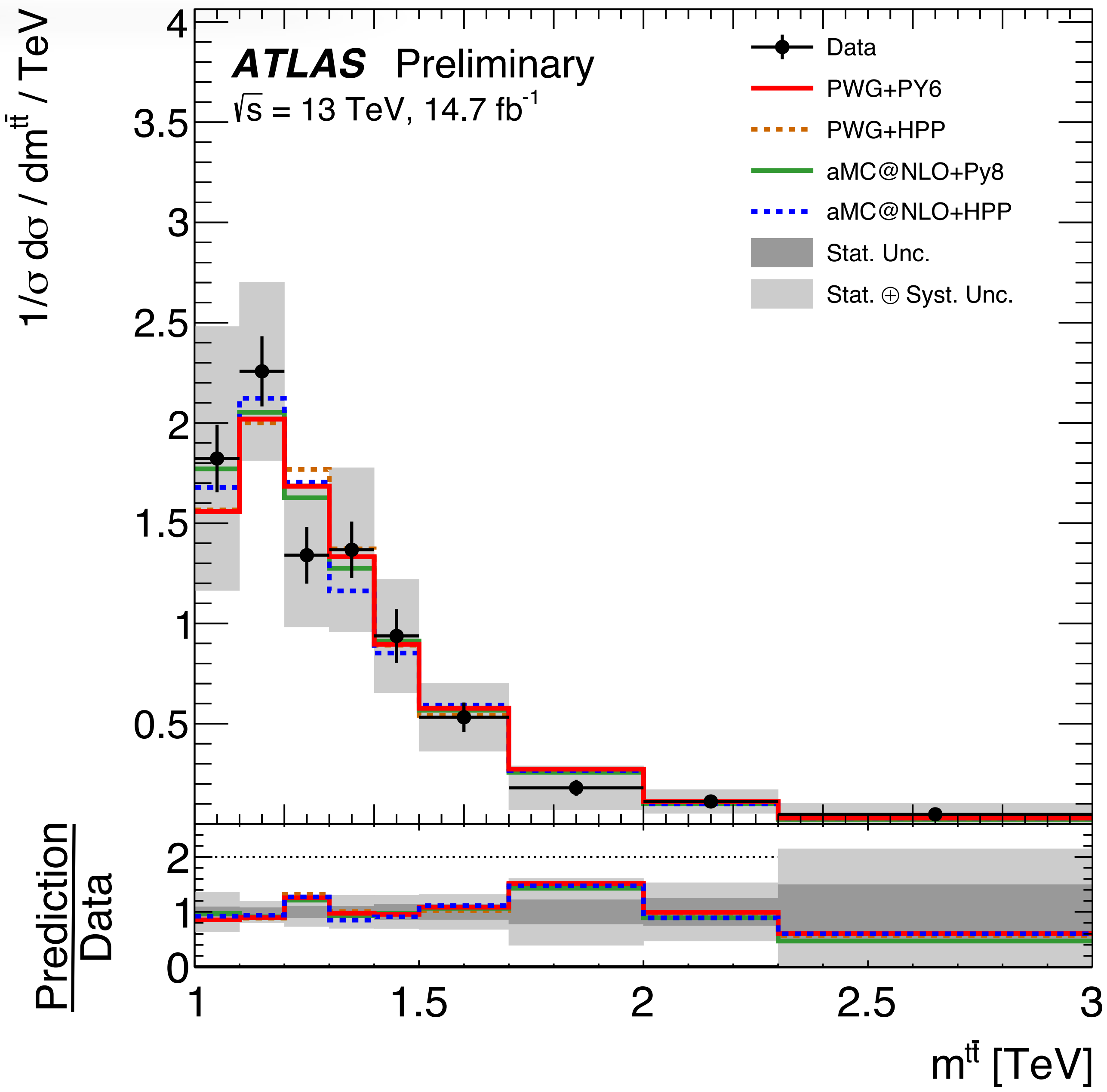


- Good agreement for leading and sub-leading top p_T (sensitive to ~1 TeV)
- $t\bar{t}$ system produced with modest p_T slowly falling $m^{t\bar{t}}$ → good agreement with SM

CONF-2016-100 NEW*
September 20, 16

13 TeV | particle level





- Good agreement for leading and sub-leading top p_T (sensitive to ~1 TeV)
- $t\bar{t}$ system produced with modest p_T slowly falling $m^{t\bar{t}}$ → good agreement with SM

ATLAS: MC Modelling Studies

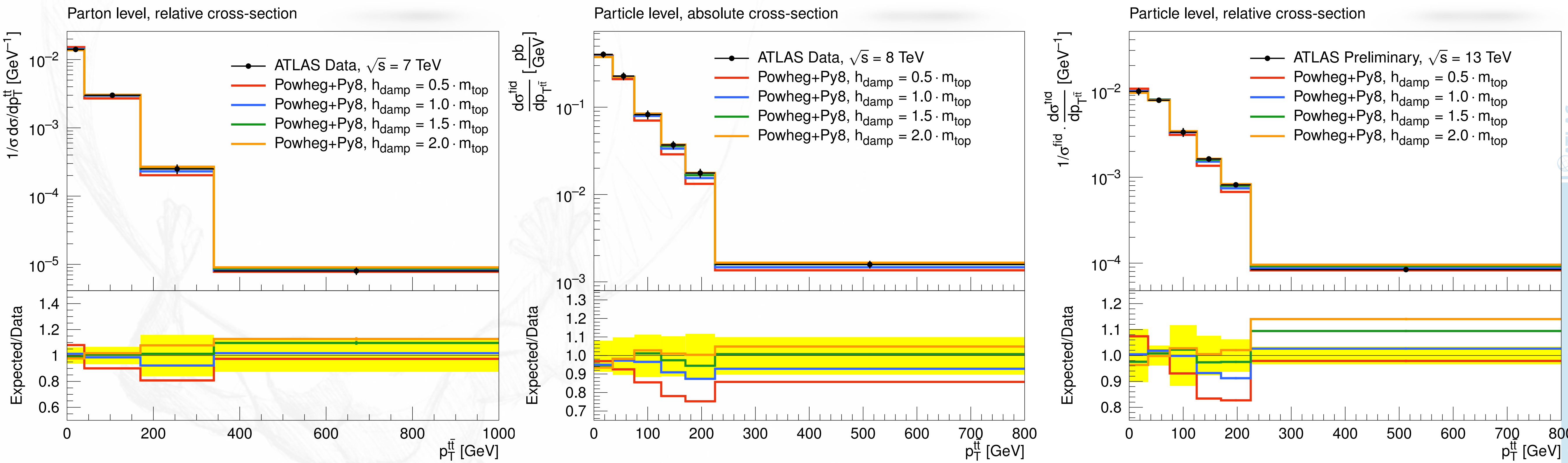
NEW
PUB-2016-020
September 19, 16
→A. Knue poster

- Studies complement PUB-2016-016, PUB-2016-004 & PUB-2015-002

- Comparison between unfolded ATLAS data and various MC generator predictions
  - 7, 8, 13 TeV RIVET routines

- Improve modelling of data through development of new MC generator configurations
  - Optimization of Powheg + {Pythia8, Herwig7}
    - Tune intrinsic merging and matching parameters

7 TeV **8 TeV** **13 TeV**



- Comparisons of
  - Variation of scales and tune
  - Different parton shower interfaces
  - Different NLO generators including NLO multileg generator

University of British Columbia – Steffen Henkelmann

Summary & Take Home Messages

Broad range of differential $t\bar{t}$ cross-section measurements at full LHC energy range

- Analyses with pseudo-top, particle, and parton provide variety of interfaces to theory
- 13 TeV results complement 7 and 8 TeV measurements in all decay channels
- Enough statistics to perform differential measurements in dilepton channel at 7, 8, 13 TeV
- L+jets & all-hadronic channels exploit boosted reconstruction techniques
  - New systematic sources and evaluations become important

Take home messages

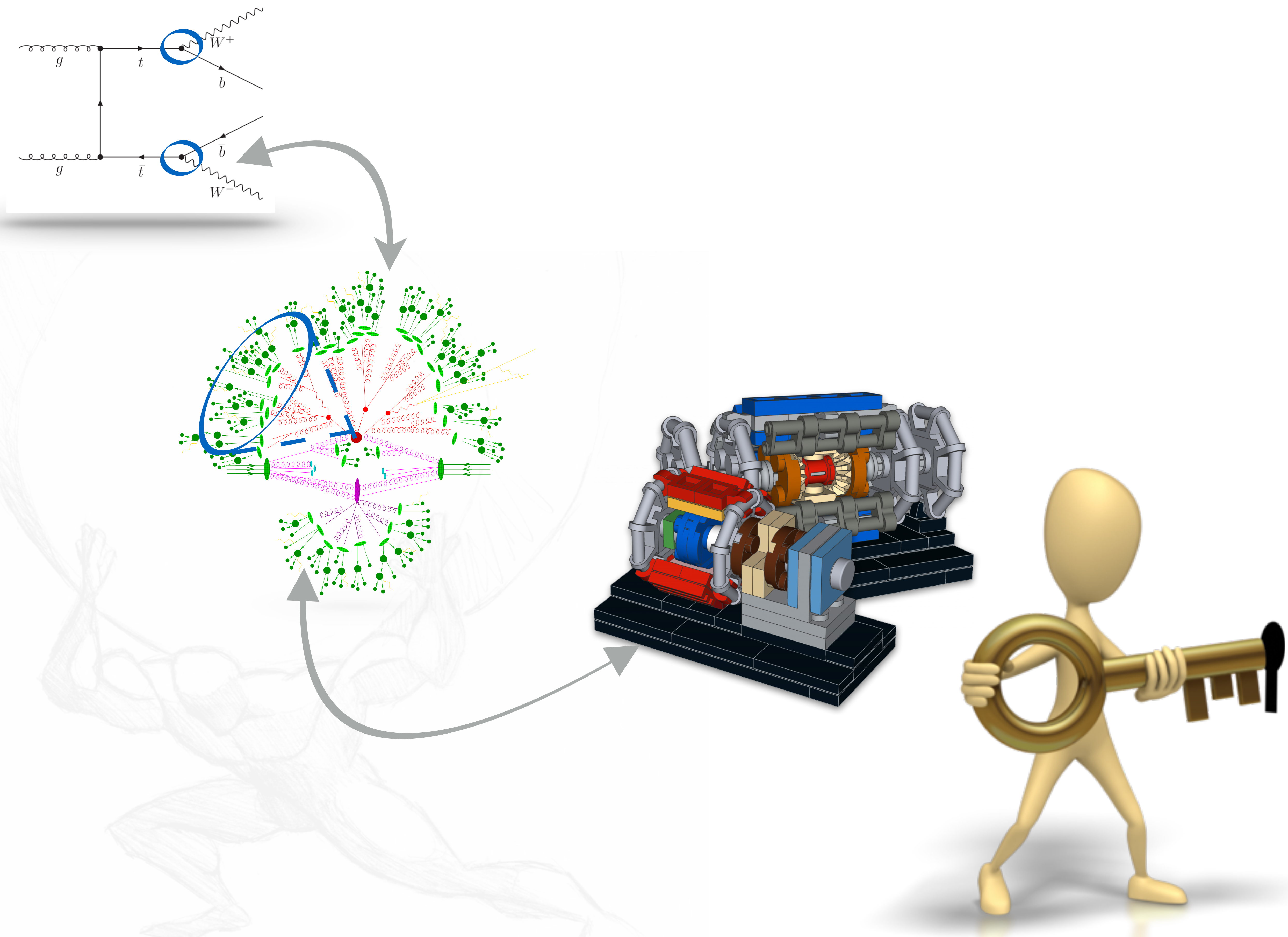
- Entering era of double differential measurements at the LHC
- Extension of resolved measurements with increasing data
- Probing high top p_T regimes using boosted decay topologies
- Measurements show discriminating power between MC models and tuning parameters

Outlook

- MC tuning studies on-going
- Looking forward to seeing ATLAS and CMS plots super-imposed or compared
- More to come, 13 TeV results with 2016 data

ATLAS EXPERIMENT more CMS more [1,2]

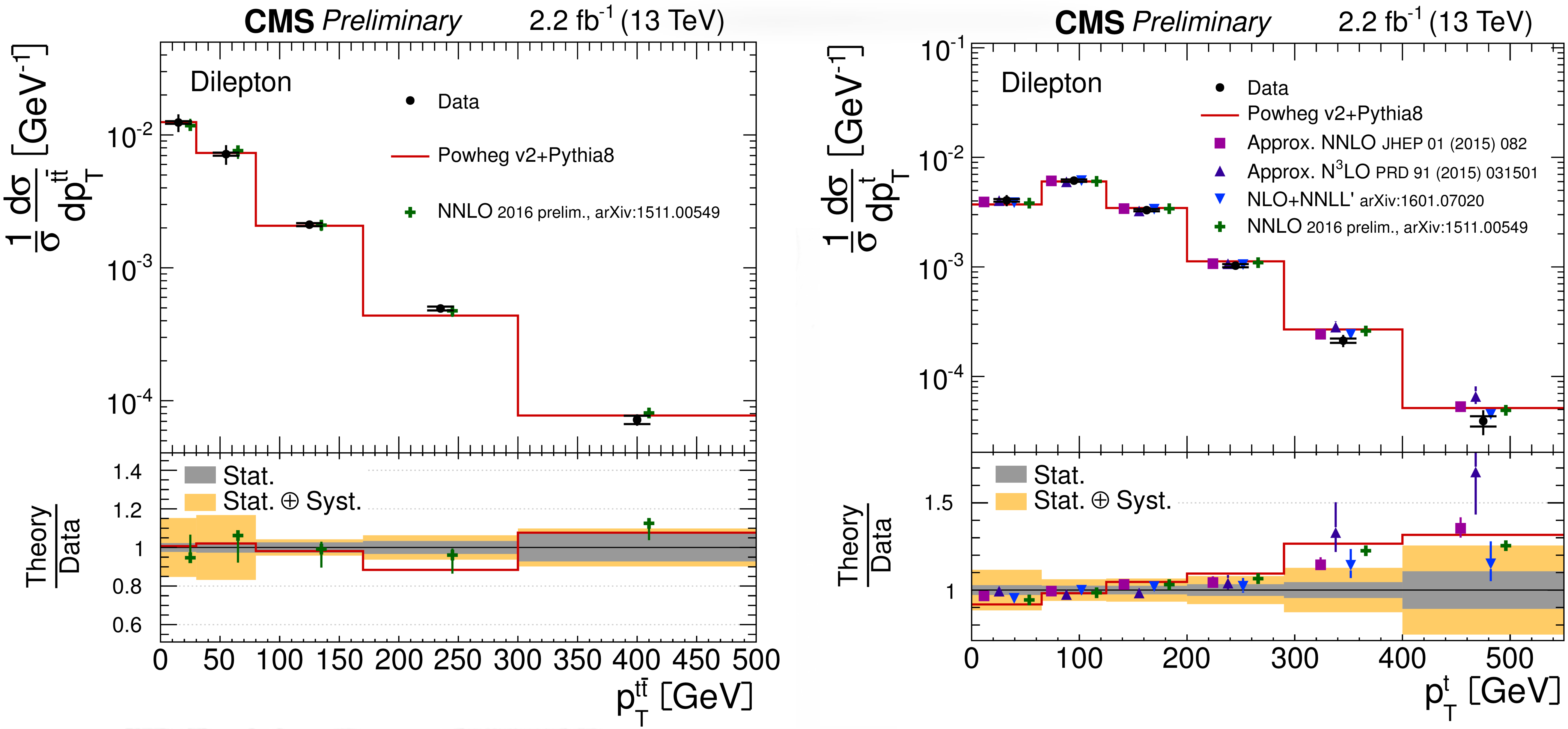
Thanks for your attention



ADDITIONAL THINGS

TOP-16-011

13 TeV | parton level



- NNLO and Powheg+Py8 describe $p_T^{t\bar{t}}$ better than other tested predictions
- NNLO & NLO+NNLL predictions model the softer top p_T spectrum more accurately
  - Consistent with 7 and 8 TeV ATLAS and CMS measurements

CMS: DILEPTON

Systematic uncertainty	Median of p_T^t [%]	Median of $p_T^{t\bar{t}}$ [%]	Median of $\Delta\phi^{t\bar{t}}$ [%]	Maximum of median [%]
Trigger	1	1	1	1
Pileup	1	1	1	1
Lepton SF	1	1	1	1
JES	1	1	1	2
JER	2	1	1	2
b jet SF	1	2	1	2
Background	3	3	4	6
μ_F and μ_R	1	4	5	5
MC modelling	3	7	12	12
Top quark mass	1	4	5	5
Hadronisation	6	4	2	6
PDF	1	1	1	2

MC modelling, Powheg/MG5_aMC@NLO

NEW

TOP-16-007

August 4, 16

Overview

13 TeV
dilepton
2.2/fb
particle level
visible phase space
normalized

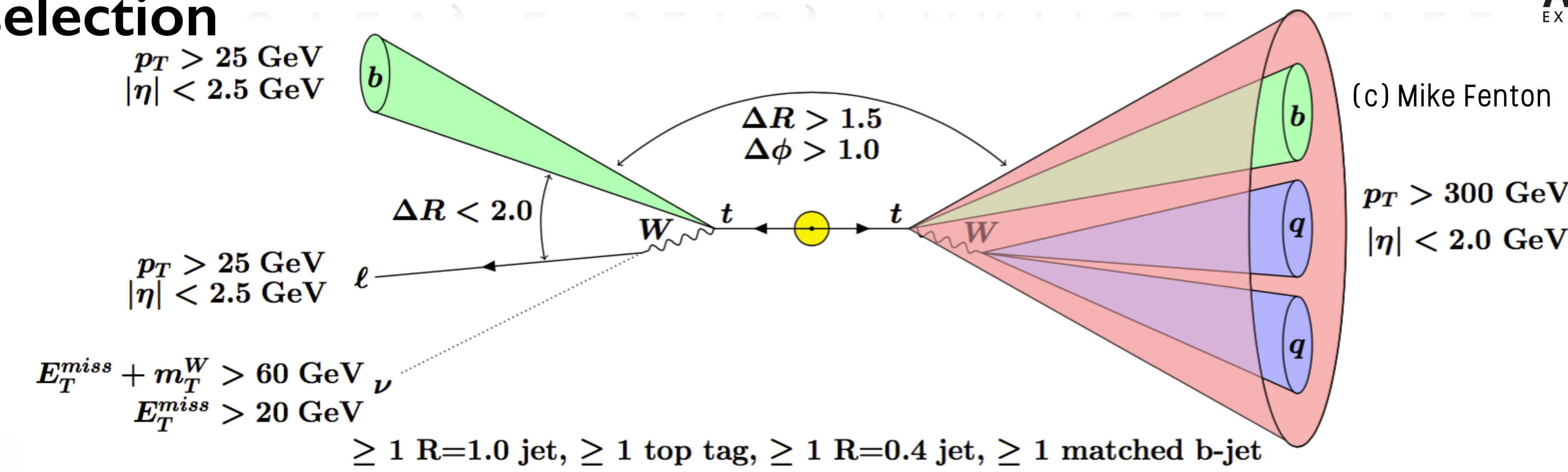
p_T^l	p_T^{jet}	p_T^t
y^t	$p_T^{t\bar{t}}$	$y^{t\bar{t}}$
$m^{t\bar{t}}$	$\Delta\phi^{t\bar{t}}$	

University of British Columbia — Steffen Henkelmann

CONF-2016-040

NEW

Event selection



Level	Detector		Particle
Topology	Resolved	Boosted	
Leptons	$\lvert d_0/\sigma(d_0)\rvert < 5$ and $\lvert z_0 \sin\theta\rvert < 0.5$ mm Track-Calo-based Isolation $\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.47$ (**e**) $\lvert\eta\rvert < 2.5$ (**μ**) E_T (**e**), p_T (**μ**) > 25 GeV		$\lvert\eta\rvert < 2.5$ $p_T > 25$ GeV
Small-R jets	$p_T > 25$ GeV $\lvert\eta\rvert < 2.5$ JVT cut (if $p_T < 60$ GeV and $\lvert\eta\rvert < 2.4$)		$\lvert\eta\rvert < 2.5$ $p_T > 25$ GeV
Num of small-R jets	$\geq$ 4 jets	$\geq$ 1 jets	
E_T^{miss}, m_T^W		$E_T^{miss} > 20$ GeV, $E_T^{miss} + m_T^W > 60$ GeV	same as detector level
Leptonic top		At least one small-R jet with $\Delta R(\ell$, small-R jet$) < 2.0$	
Hadronic top	kinematic top quark reconstruction for detector and particle level	the leading-p_T trimmed large-R jet has: 300 GeV $< p_T <$ 1500 GeV, $m >$ 50 GeV, TopTagging at 80% efficiency ΔR(large-R jet, small-R jet)> 1.5, $\Delta\phi(\ell$, small-R jet)> 1.0	**Boosted:** 300 $< p_T <$ 1500 GeV Top-tagging: $m >$ 100 GeV, $\tau_{32} < 0.75$
b-tagging	at least 2 b-tagged jets	at least one of: 1) the leading-p_T small-R jet with $\Delta R(\ell$, small-R jet)< 2.0 is b-tagged 2) at least one small-R jet with ΔR(large-R jet, small-R jet)< 1.0 is b-tagged	ghost-matched B-hadron

Particle level

Distribution	χ^2/dof	p-value	χ^2/dof	p-value	χ^2/dof	p-value
	POWHEG+P8		POWHEG+H++		MG5_AMC@NLO+P8 MLM	
	Order: NLO		Order: NLO		Order: LO, up to 3 add. partons	
$p_T(t_h)$	14.3/9	0.111	26.3/9	< 0.01	34.9/9	< 0.01
$\|y(t_h)\|$	4.76/7	0.690	7.61/7	0.368	9.08/7	0.247
$p_T(t_\ell)$	22.9/9	< 0.01	40.8/9	< 0.01	54.6/9	< 0.01
$\|y(t_\ell)\|$	7.14/7	0.415	10.6/7	0.156	18.2/7	0.011
$M(t\bar{t})$	9.25/8	0.322	173/8	< 0.01	13.4/8	0.100
$p_T(t\bar{t})$	2.31/5	0.805	39.6/5	< 0.01	48.9/5	< 0.01
$\|y(t\bar{t})\|$	1.37/6	0.967	2.44/6	0.876	14.5/6	0.025
Additional jets	27.6/5	< 0.01	16.2/5	< 0.01	36.3/5	< 0.01
Additional jets vs. $p_T(t\bar{t})$	70.3/20	< 0.01	95.4/20	< 0.01	168/20	< 0.01
Additional jets vs. $p_T(t_h)$	96.2/36	< 0.01	218/36	< 0.01	180/36	< 0.01
$\|y(t_h)\|$ vs. $p_T(t_h)$	60.1/36	< 0.01	212/36	< 0.01	128/36	< 0.01
$M(t\bar{t})$ vs. $\|y(t\bar{t})\|$	28.2/24	0.251	280/24	< 0.01	41.2/24	0.016
$p_T(t\bar{t})$ vs. $M(t\bar{t})$	16.7/32	0.988	465/32	< 0.01	97.6/32	< 0.01
	MG5_AMC@NLO+P8		MG5_AMC@NLO+H++		MG5_AMC@NLO+P8 FXFX	
	Order: NLO		Order: NLO		Order: NLO, up to 2 add. partons	
$p_T(t_h)$	13.1/9	0.159	6.85/9	0.653	5.05/9	0.830
$\|y(t_h)\|$	9.91/7	0.194	13.5/7	0.060	8.12/7	0.322
$p_T(t_\ell)$	13.4/9	0.147	8.02/9	0.533	7.97/9	0.538
$\|y(t_\ell)\|$	14.3/7	0.045	7.24/7	0.404	15.9/7	0.026
$M(t\bar{t})$	10.9/8	0.206	34.2/8	< 0.01	33.0/8	< 0.01
$p_T(t\bar{t})$	40.0/5	< 0.01	7.65/5	0.177	27.8/5	< 0.01
$\|y(t\bar{t})\|$	2.72/6	0.843	2.77/6	0.837	3.58/6	0.733
Additional jets	36.2/5	< 0.01	15.7/5	< 0.01	10.8/5	0.056
Additional jets vs. $p_T(t\bar{t})$	237/20	< 0.01	192/20	< 0.01	87.2/20	< 0.01
Additional jets vs. $p_T(t_h)$	251/36	< 0.01	76.0/36	< 0.01	45.6/36	0.132
$\|y(t_h)\|$ vs. $p_T(t_h)$	48.9/36	0.074	100/36	< 0.01	49.1/36	0.071
$M(t\bar{t})$ vs. $\|y(t\bar{t})\|$	25.1/24	0.403	53.4/24	< 0.01	56.7/24	< 0.01
$p_T(t\bar{t})$ vs. $M(t\bar{t})$	133/32	< 0.01	157/32	< 0.01	109/32	< 0.01

NEW*
TOP-16-008
September 23, 16

Overview

13 TeV
l+jets
2.3/fb

parton level
full phase space
absolute & normalized

particle level
fiducial phase space
absolute & normalized

resolved

1D

p_T^t | $|y^t|$ | $p_T^{t\bar{t}}$ | $|y^{t\bar{t}}|$ | $m^{t\bar{t}}$

2D

$p_T^{t,had}$ vs. $|y^{t,had}|$

$|y^{t\bar{t}}|$ vs. $M_{t\bar{t}}$

$p_T^{t\bar{t}}$ vs. $M_{t\bar{t}}$

CMS: 13 TeV, L+JETS

Parton level

Distribution	χ^2/dof	p-value	χ^2/dof	p-value	χ^2/dof	p-value
	POWHEG+P8 Order: NLO		POWHEG+H++ Order: NLO		MG5_AMC@NLO+P8 MLM Order: LO, up to 3 add. partons	
$p_T(t_h)$	12.0/9	0.216	9.43/9	0.398	20.5/9	0.015
$\|y(t_h)\|$	5.02/7	0.657	5.59/7	0.589	5.81/7	0.562
$p_T(t_\ell)$	18.1/9	0.034	10.9/9	0.285	48.5/9	< 0.01
$\|y(t_\ell)\|$	13.2/7	0.067	15.2/7	0.034	14.0/7	0.051
$M(t\bar{t})$	6.08/8	0.639	11.6/8	0.172	48.1/8	< 0.01
$p_T(t\bar{t})$	1.35/5	0.930	5.53/5	0.354	18.3/5	< 0.01
$\|y(t\bar{t})\|$	2.35/6	0.885	2.43/6	0.876	5.85/6	0.440
Additional jets	9.55/5	0.089	6.47/5	0.263	5.71/5	0.335
Additional jets vs. $p_T(t\bar{t})$	90.6/20	< 0.01	144/20	< 0.01	145/20	< 0.01
Additional jets vs. $p_T(t_h)$	108/36	< 0.01	49.5/36	0.067	84.2/36	< 0.01
$\|y(t_h)\|$ vs. $p_T(t_h)$	59.4/36	< 0.01	57.3/36	0.014	67.2/36	< 0.01
$M(t\bar{t})$ vs. $\|y(t\bar{t})\|$	20.4/24	0.674	19.6/24	0.719	51.5/24	< 0.01
$p_T(t\bar{t})$ vs. $M(t\bar{t})$	15.8/32	0.993	27.8/32	0.679	109/32	< 0.01
	MG5_AMC@NLO+P8 Order: NLO		MG5_AMC@NLO+H++ Order: NLO		MG5_AMC@NLO+P8 FXFX Order: NLO, up to 2 add. partons	
$p_T(t_h)$	11.6/9	0.240	16.8/9	0.052	10.6/9	0.301
$\|y(t_h)\|$	6.91/7	0.438	6.85/7	0.444	5.23/7	0.632
$p_T(t_\ell)$	18.7/9	0.028	32.4/9	< 0.01	14.6/9	0.102
$\|y(t_\ell)\|$	19.1/7	< 0.01	12.7/7	0.079	18.7/7	< 0.01
$M(t\bar{t})$	11.3/8	0.186	6.59/8	0.582	29.8/8	< 0.01
$p_T(t\bar{t})$	40.0/5	< 0.01	25.8/5	< 0.01	19.7/5	< 0.01
$\|y(t\bar{t})\|$	3.01/6	0.808	2.52/6	0.866	2.86/6	0.826
Additional jets	19.9/5	< 0.01	4.37/5	0.497	6.78/5	0.237
Additional jets vs. $p_T(t\bar{t})$	390/20	< 0.01	294/20	< 0.01	127/20	< 0.01
Additional jets vs. $p_T(t_h)$	112/36	< 0.01	49.0/36	0.072	56.5/36	0.016
$\|y(t_h)\|$ vs. $p_T(t_h)$	91.8/36	< 0.01	123/36	< 0.01	53.1/36	0.033
$M(t\bar{t})$ vs. $\|y(t\bar{t})\|$	29.8/24	0.192	19.2/24	0.741	38.7/24	0.030
$p_T(t\bar{t})$ vs. $M(t\bar{t})$	275/32	< 0.01	78.2/32	< 0.01	104/32	< 0.01
	appr. NNLO		appr. NNNLO		NLO+NNLL'	
$p_T(t_h)$	25.3/9	< 0.01	69.1/9	< 0.01	9.68/9	0.377
$\|y(t_h)\|$	8.90/7	0.260	4.78/7	0.686	-	-
$p_T(t_\ell)$	23.1/9	< 0.01	189/9	< 0.01	4.41/9	0.882
$\|y(t_\ell)\|$	6.40/7	0.494	7.28/7	0.400	-	-
$M(t\bar{t})$	-	-	-	-	12.2/8	0.143
	NNLO					
$p_T(t_h)$	9.40/9	0.402				
$\|y(t_h)\|$	4.08/7	0.770				
$p_T(t_\ell)$	10.8/9	0.291				
$\|y(t_\ell)\|$	10.4/7	0.168				
$M(t\bar{t})$	11.2/8	0.190				
$p_T(t\bar{t})$	4.61/5	0.466				
$\|y(t\bar{t})\|$	2.26/6	0.894				

NEW*

TOP-16-008
September 23, 16

Overview

13 TeV
l+jets
2.3/fb
parton level
full phase space
absolute & normalized
particle level
fiducial phase space
absolute & normalized

resolved
1D
p_T^t | $|y^t|$
$p_T^{t\bar{t}}$ | $|y^{t\bar{t}}|$ | $m^{t\bar{t}}$
2D
$p_T^{t,had}$ vs. $|y^{t,had}|$
$|y^{t\bar{t}}|$ vs. $M_{t\bar{t}}$
$p_T^{t\bar{t}}$ vs. $M_{t\bar{t}}$

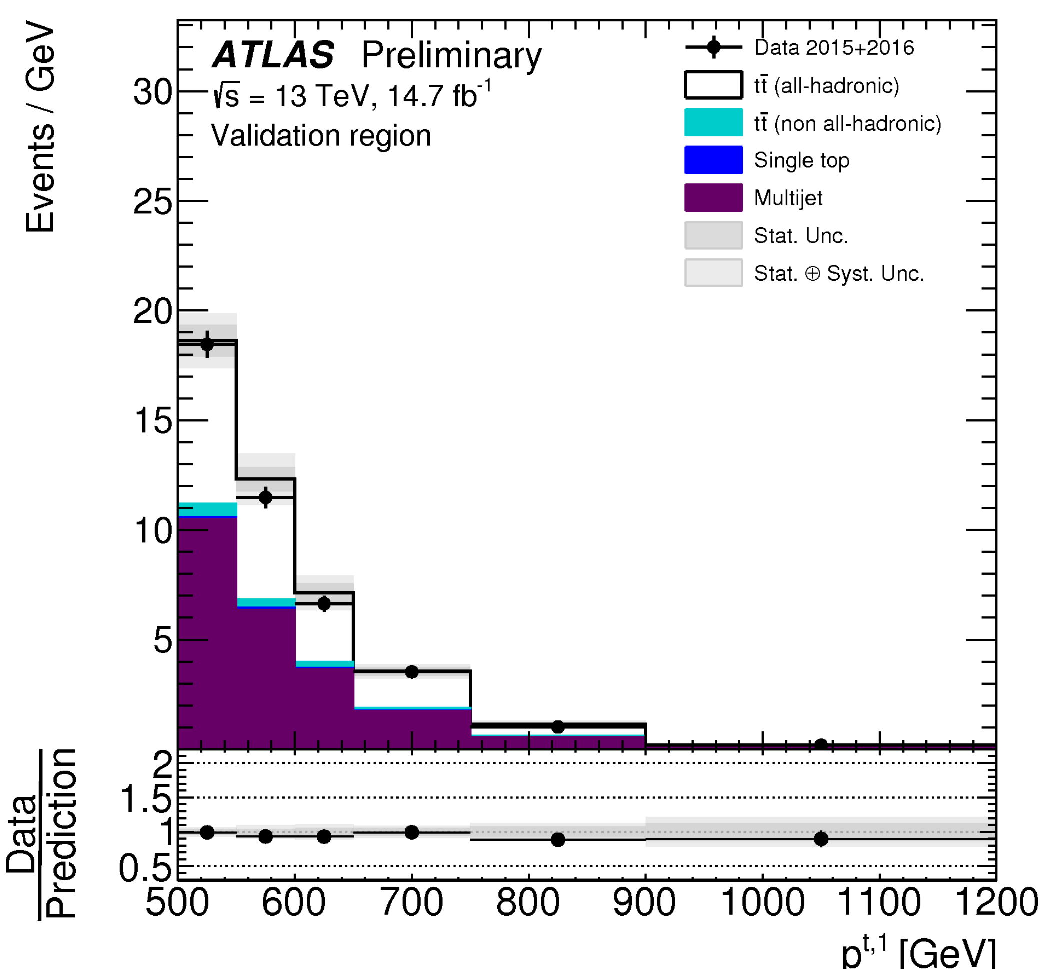
QCD estimation

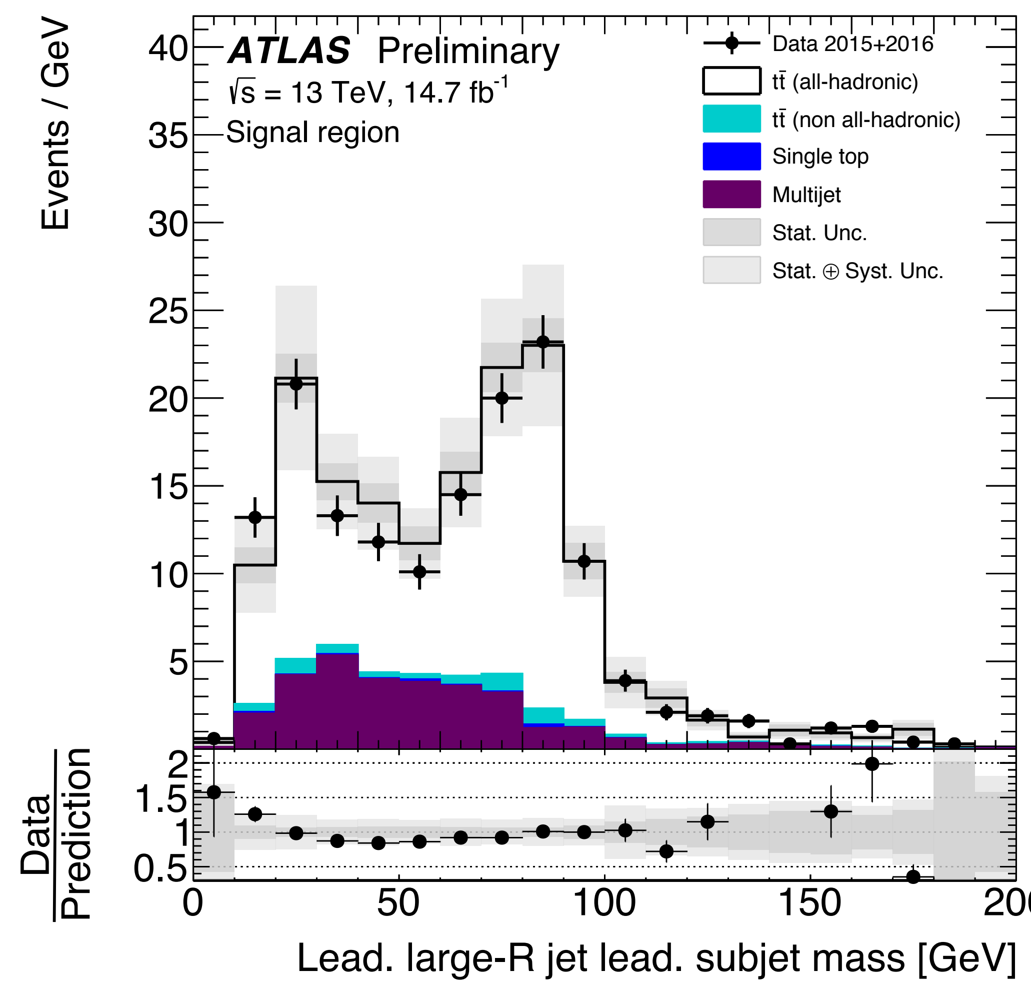
- A,B,C, G & H, number of observed events after substraction of $t\bar{t}$ and singletop production
- Validation region F

$$S_{bg} = \frac{1}{2}\left(\frac{G}{A} + \frac{H}{B}\right) \times C$$

	0 t	1 t	2 t
0 b	A	D	G
1 b	B	E	H
2 b	C	F	S

$t\bar{t}$ (all-hadronic)	1190	±	240
$t\bar{t}$ (non all-hadronic)	60	±	15
Single top-quark	9	±	5
Multijet events	300	±	20
Prediction	1570	±	260
Data (14.7 fb^{-1})	1512		





NEW
TOP-16-013
June 15, 16

Measurement complements arXiv:1509.06076 (accepted for Eur. Phys. J. C)

Event selection / reconstruction

anti-k_t jets (R =0.4) with p_T > 30 GeV, $|\eta|$ < 2.4
anti-k_t large jets (R =0.8, softdrop[z_{cut} = 0.1, β=0]) with p_T > 200 GeV, $|\eta|$ < 2.4, $m_{softdrop}$ = 50 GeV

lepton veto

Resolved channel	Boosted channel
≥6 small-R jets (≥2 b-tagged)	≥2 large-R jets (both contain b-tagged jet)
$p_T^{(6)}$ > 45 GeV, $\Delta R(b,b)$ > 2.0	$p_T^{(1)}$ > 450 GeV
H_T > 500 GeV	150 < $m^{(1)}_{SD}$ < 200 GeV
kinematic fit prob. > 0.02	$\mathcal{F}$ > 0 [build from τ_{32} & τ_{31} *of leading jets*]
150 < m_t < 200 GeV	

- Comparison to LO & NLO MC generator
- Dominant uncertainties
  - Parton level
    - QCD bgr modelling at low p_T
    - JES, b-tagging

Overview

13 TeV
all-hadronic
2.53/fb
parton level
full phase space
absolute
resolved
boosted
p_T^t

CMS: All-hadronic

Measurement complements arXiv:1509.06076 (accepted for Eur. Phys. J. C)

TOP-16-013 NEW
June 15, 16

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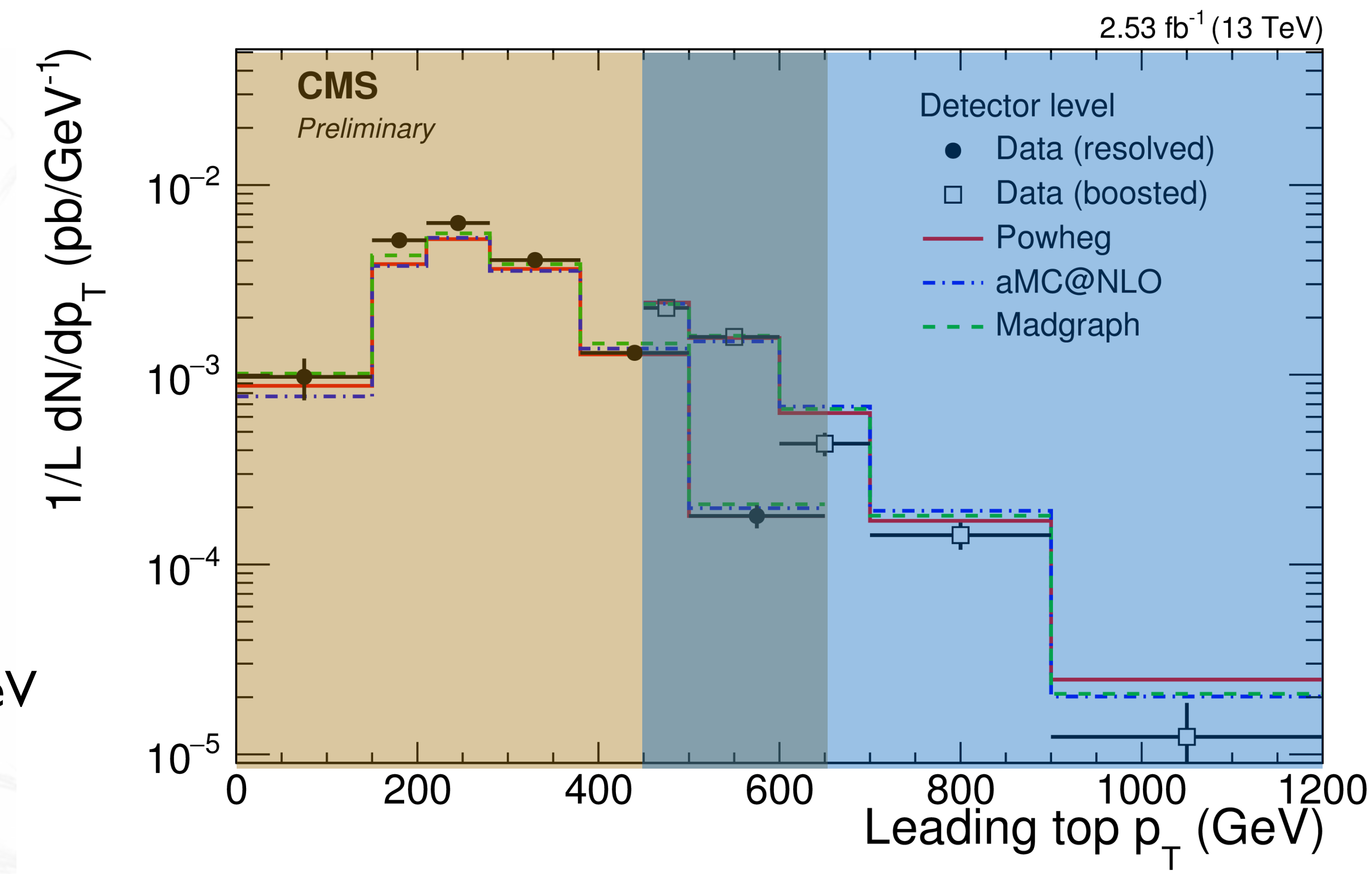
- Comparison to LO & NLO MC generator
- Dominant uncertainties
  - Parton level
    - QCD bgr modelling at low p_T
    - JES, b-tagging
- Limited by the stat. uncertainty above ~500 GeV
- Agreement between resolved & boosted



Overview

13 TeV
all-hadronic
2.53/fb
parton level
full phase space
absolute
resolved
boosted
p_T^t

CMS: ALL-HADRONIC

Measurement complements arXiv:1509.06076 (accepted for Eur. Phys. J. C)

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lepton veto

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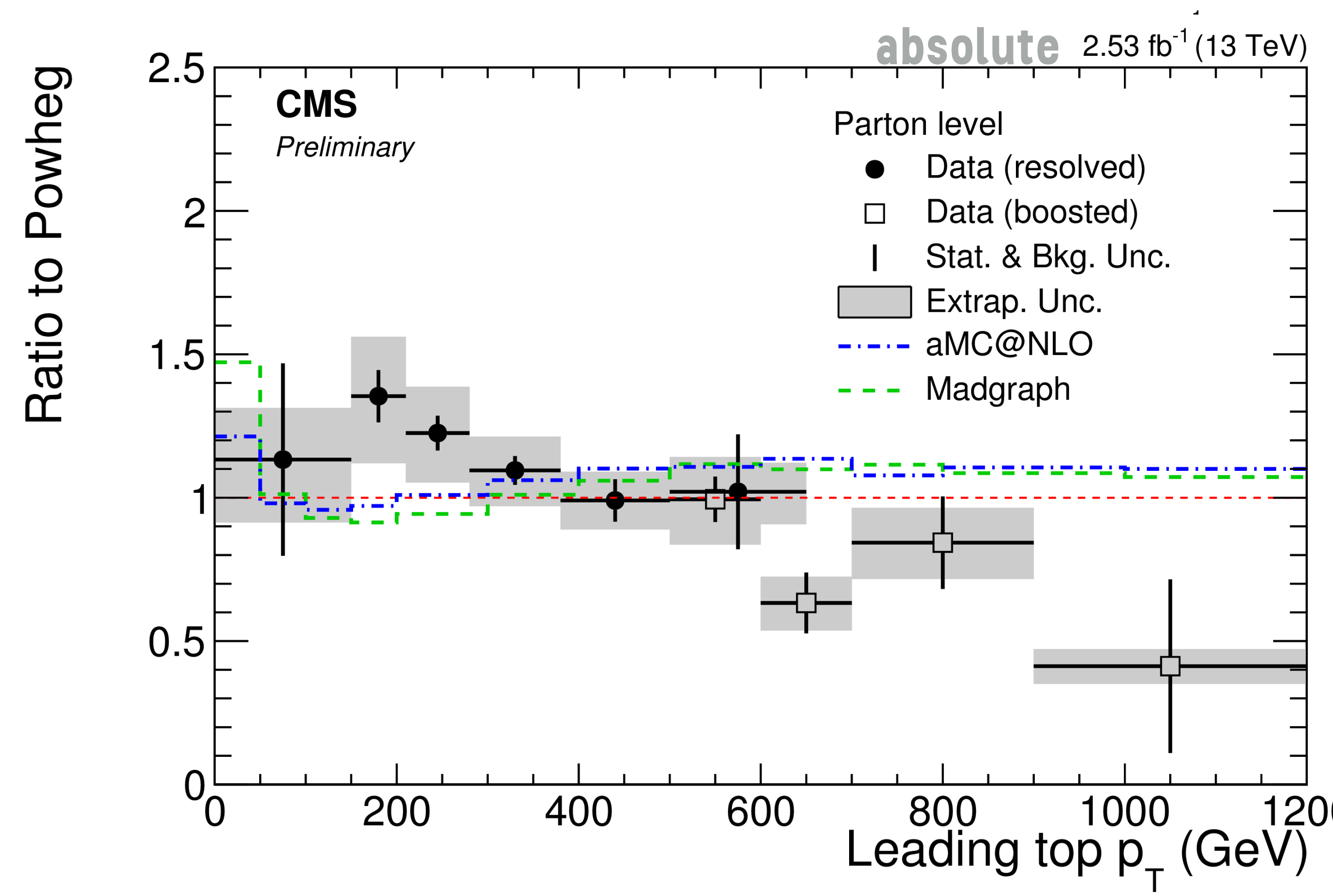


NEW
TOP-16-013
June 15, 16

Overview

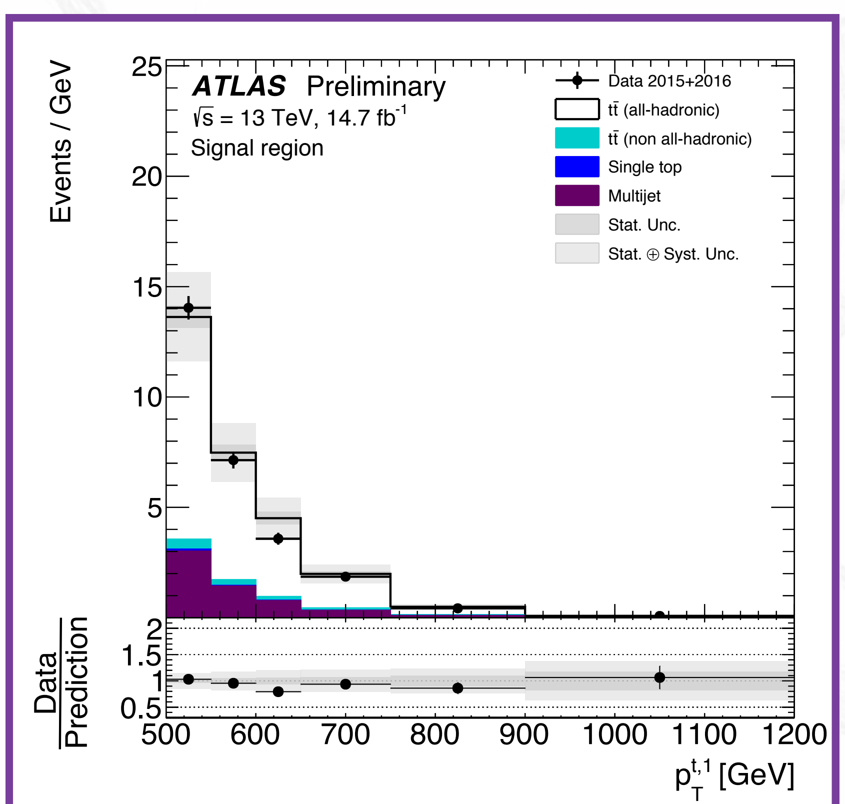
13 TeV
all-hadronic
2.53/fb
parton level
full phase space
absolute
resolved
boosted
p_T^t

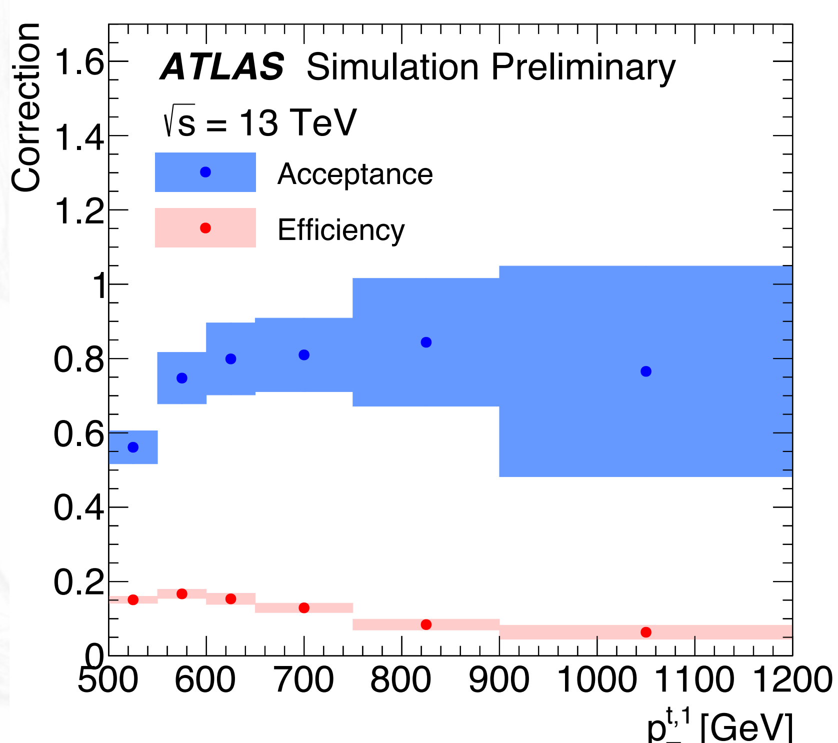
UNFOLDING

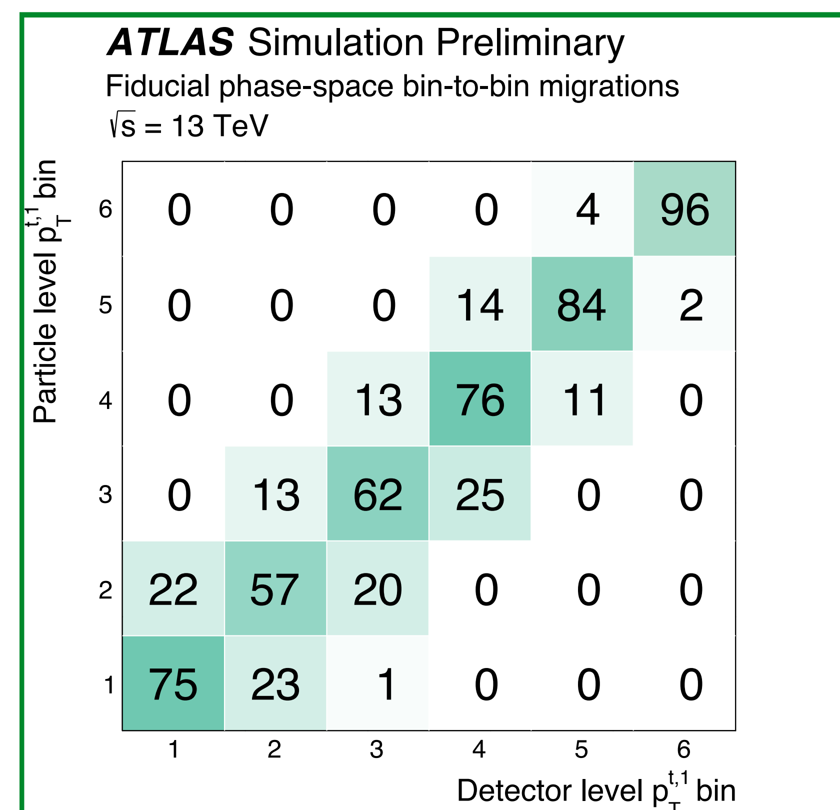
- Iterative Bayesian method (D'Agostini) [Nucl. Instrum. Meth. A362 (1995) 487–498]
  - Used to correct detector level events to the fiducial phase space

$$\frac{d\sigma^{\mathrm{fid}}}{dX^i} \equiv \frac{1}{\int \mathcal{L}\, dt \cdot \Delta X^i} \cdot \frac{1}{\epsilon^i_{\mathrm{eff}}} \cdot \sum_j \mathcal{M}^{-1}_{ij} \cdot f^j_{\mathrm{acc}} \cdot \left(N^j_{\mathrm{reco}} - N^j_{\mathrm{bg}}\right)$$

  - Subtraction of background from detector level observable
  - Acceptance correction f_{acc} is applied to account for events generated outside the fiducial phase space but pass the detector acceptance, spatial matching of detector level and particle level objects to account for resolution and combinatorial effects
  - Correction for events that pass the particle level selection but are not reconstructed at detector level, ε_{eff}
  - Migration matrix derived from simulated events maps particle level events to detector-level events (j(i); bins in X at detector level (particle level))







Unfolding

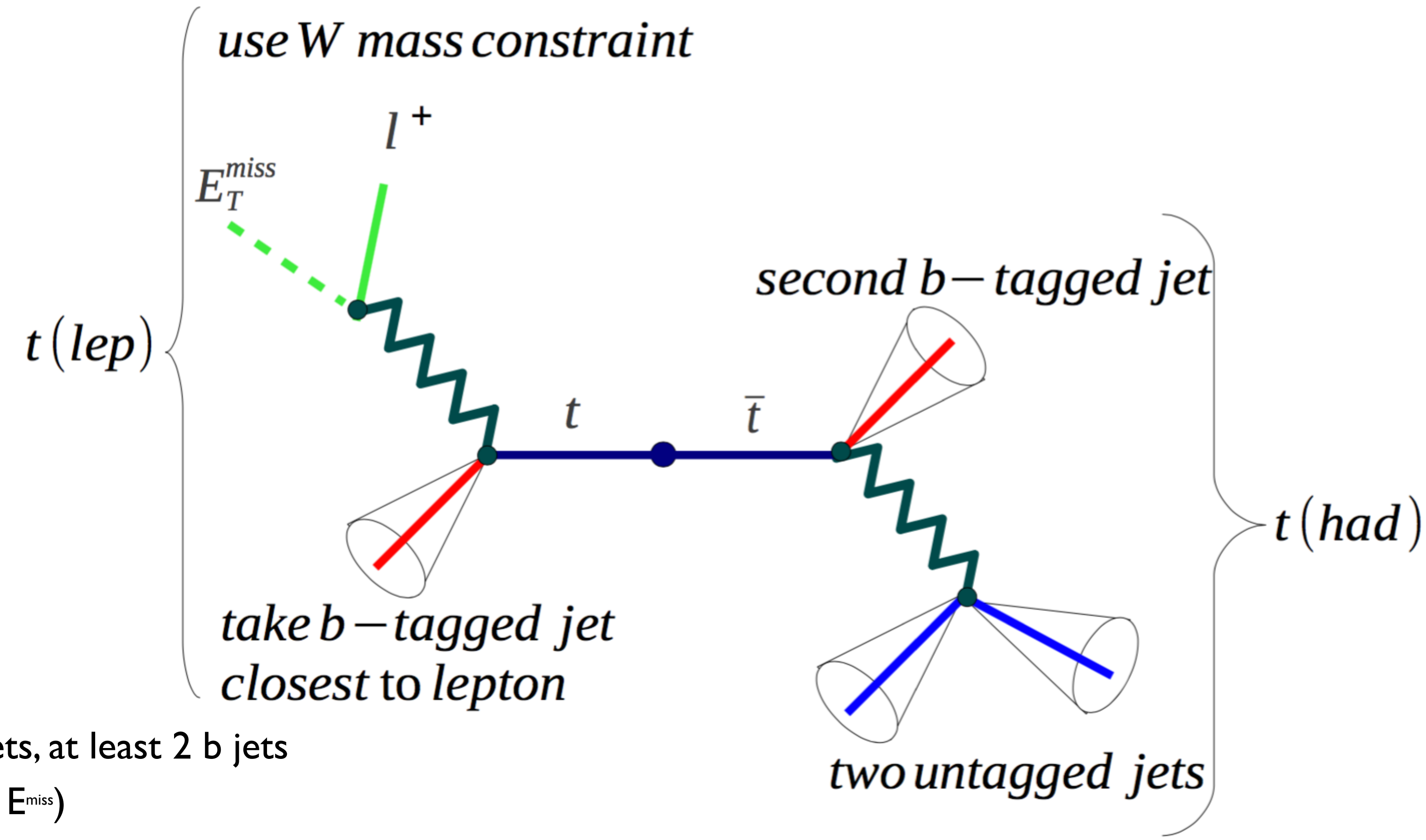
- Unfolding to parton level
  - Account for both the detector response and parton shower and hadronization → introduces large theoretical uncertainties
  - Correct for events only representing respective top decay channel

- 2D unfolding
  - Generalization of D'Agostini unfolding with *n* bins on one and *m* bins in the other measured observable.
    - Using vector with n*m entries
    - Migration matrix (n * m) x (n*m)

Top-Proxy reconstruction (Pseudo-Top)

Reconstruction of $t\bar{t}$ pair using well defined objects at particle level

- Run same algorithm on particle and detector level



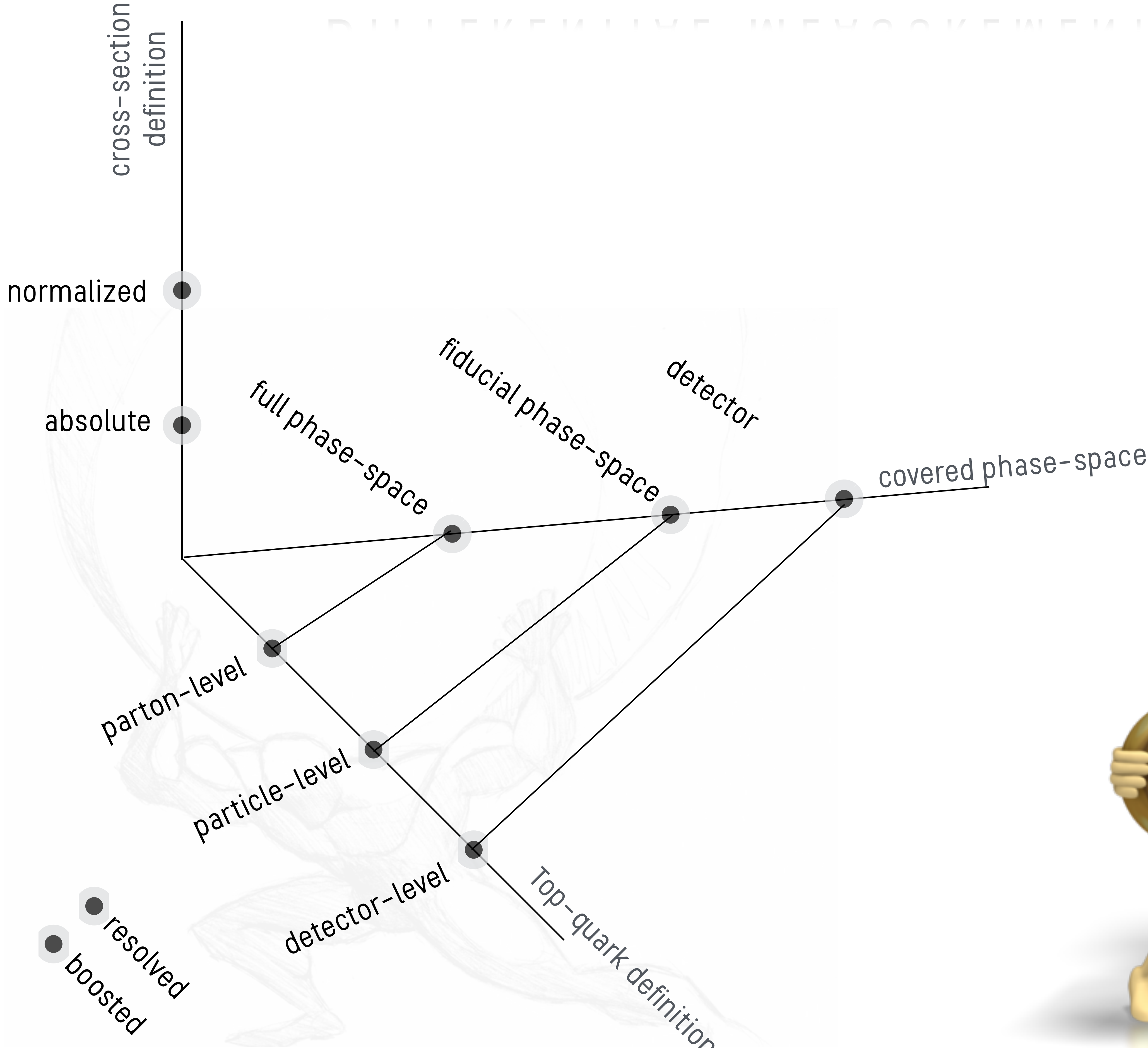
How-to

1. Define pseudo-top constituents
   - e.g. l+jets:
     - electrons, muons, and jets: $p_T > 25$ GeV, $|\eta| < 2.5$
     - exactly one lepton (not from hadron) at least four jets, at least 2 b jets
     - $E_T^{miss} > 30$GeV, $M_T(W) > 35$GeV (defined by lepton and E_T^{miss})

2. Define pseudo-top system
   - e.g.:
     - two hardest b jets belong to pseudo-top pair system
     - Define the leptonic W by combining the lepton with the ETmiss and solving for pz assuming the W mass (highest pz from two-fold ambiguity)
     - the b jet closer to lepton (ΔR) is part of the leptonic top decay
     - the two remaining jets that are not b-tagged with highest p_T are the hadronically decaying W and combine with left b-tagged jet

- Unfolding to particle level → allow for comparison to MC generator predictions

Differential Measurements



Picture courtesy:

- https://ixquick-proxy.com/do/spg/show_picture.pl
- www.elegrity.com
- https://build-your-own-particle-detector.org/
- http://atlas.physicsmasterclasses.org/