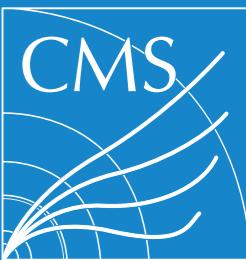


13.02.2016

DIS2016, Hamburg



Top-quark cross-section measurements with CMS

The latest of **7TeV**, **8TeV** and **13TeV** results

Nazar Bartosik

(*Istituto Nazionale di Fisica Nucleare di Torino*)

for the CMS collaboration

Outline

1 → Top-quark production and decay

2 → Inclusive cross sections

- dilepton
- lepton+jets

3 → Differential cross sections

- dilepton
- lepton+jets
- boosted *top*-quarks

4 → *Top*-quark production in association with jets

- inclusive
- differential

Top-quark position in SM

The heaviest SM particle: $m_t = 172.33 \pm 0.49$ GeV (CMS combination)
[arXiv:1509.04044](https://arxiv.org/abs/1509.04044)

Life time (10^{-25} s) shorter than hadronisation time scale (10^{-24} s)
bare quark properties accessible: mass, $|V_{tb}|$, spin, charge,...

Top-quark mass – important Standard Model parameter

EPJC74:3046

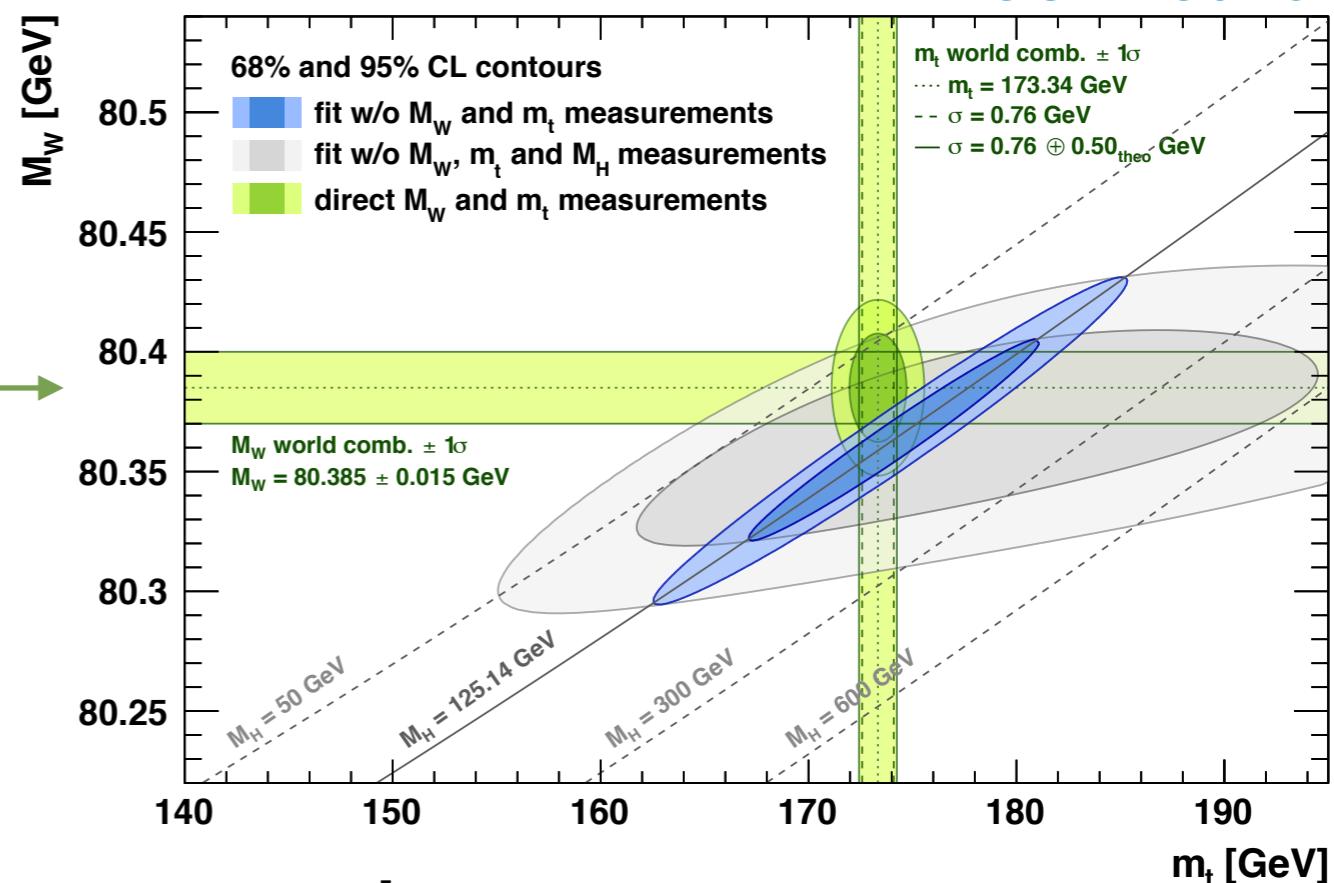
Essential for testing the SM

- pQCD precision tests
- consistency of m_t , m_H , m_W

Defines Yukawa coupling to the Higgs boson: close to 1.0

Constraining PDFs

Important background in many BSM searches



Top-quark production

LHC – top-quark factory

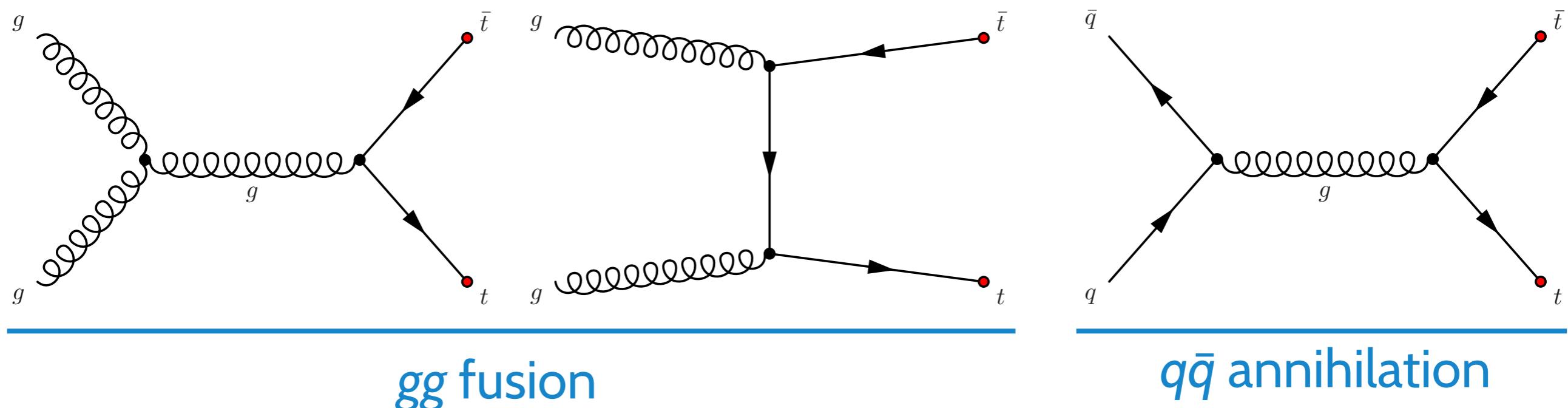
Run I

Run II

[arXiv:1112.5675](https://arxiv.org/abs/1112.5675)

NNLO+NNLL ^{Top++(v2)}	$\sqrt{s}=7 \text{ TeV}$	$\sqrt{s}=8 \text{ TeV}$	$\sqrt{s}=13 \text{ TeV}$	$\sqrt{s}=14 \text{ TeV}$
$\sigma(pp \rightarrow t\bar{t}) \text{ [pb]}$	$177 \pm 7\%$	$253 \pm 6\%$	$832 \pm 5\%$	$985 \pm 5\%$

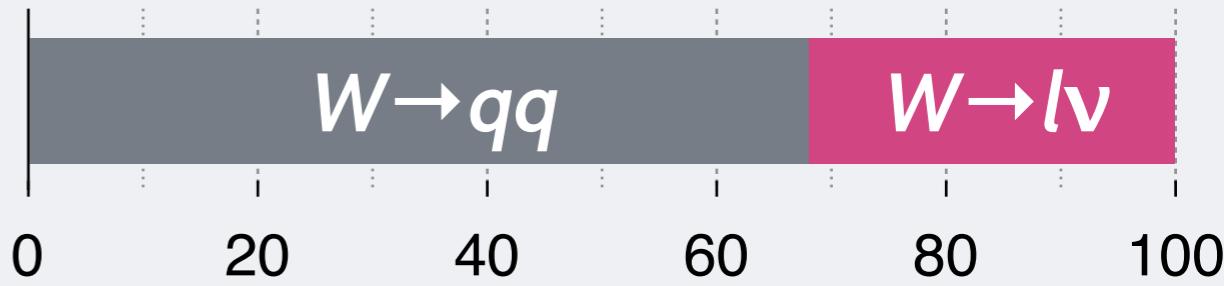
Top-quark pairs: via QCD interactions dominant at LHC



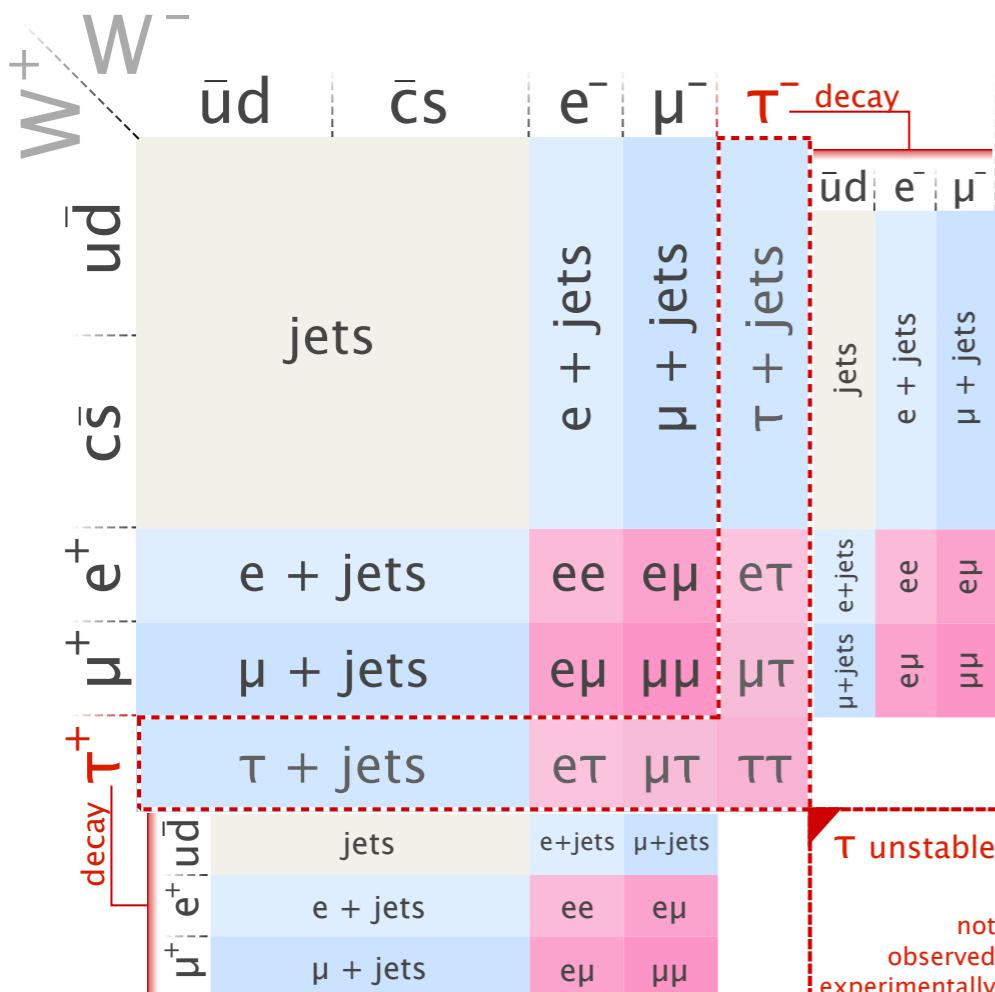
Single top quarks: via EWK interactions see talk by [Soureek Mitra](#)

Top-quark decay

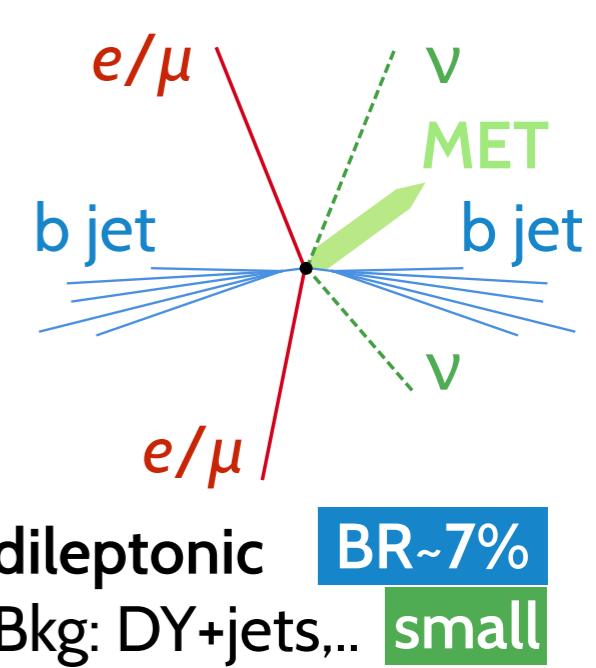
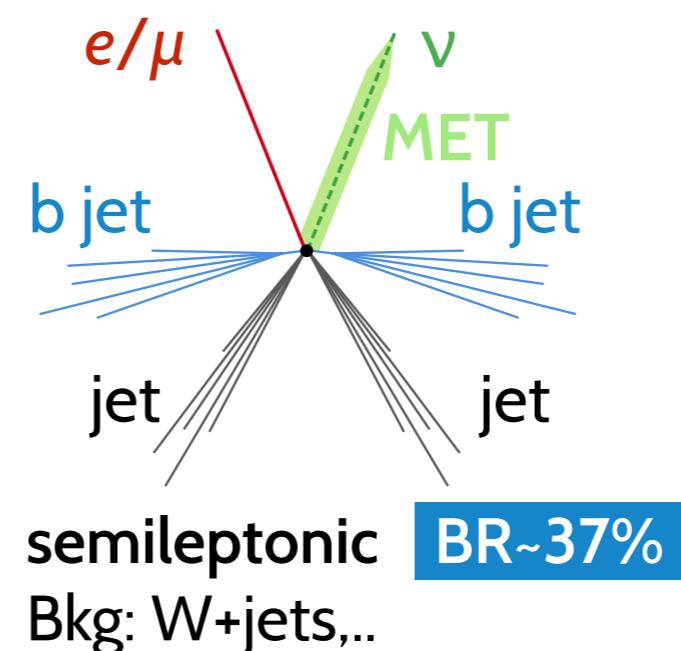
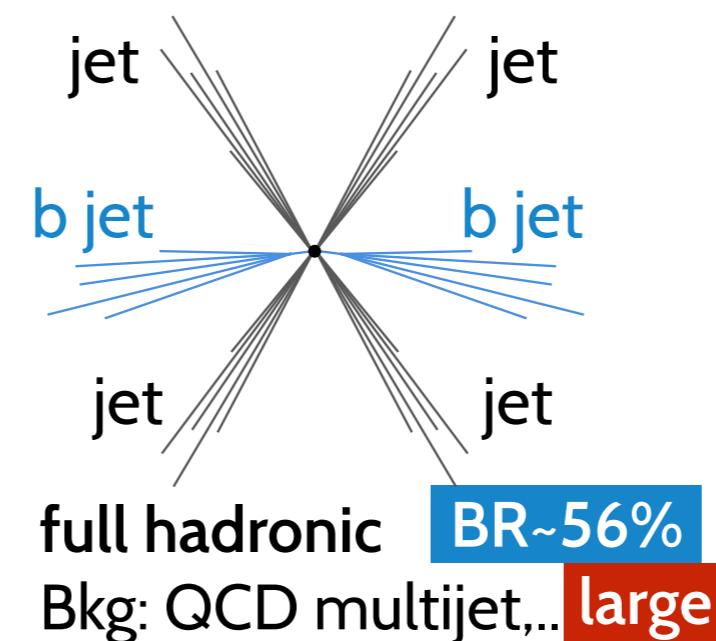
Almost exclusively decays: $t \rightarrow bW$



W decay defines the tt final state



- full hadronic
- semileptonic
- dileptonic



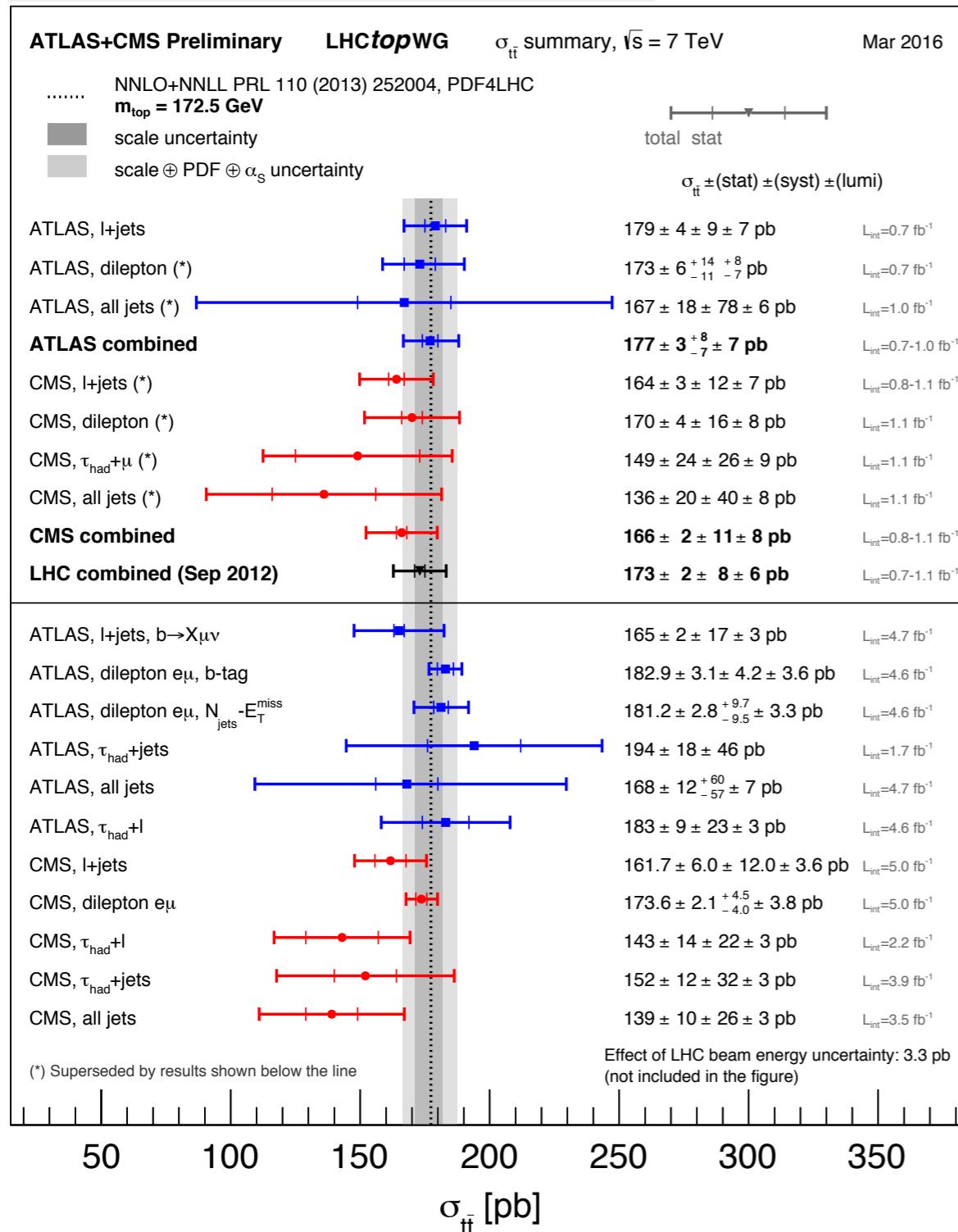
INCLUSIVE CROSS SECTIONS

- testing perturbative QCD predictions
- related to fundamental SM parameters: m_t , α_s
- searches for new physics

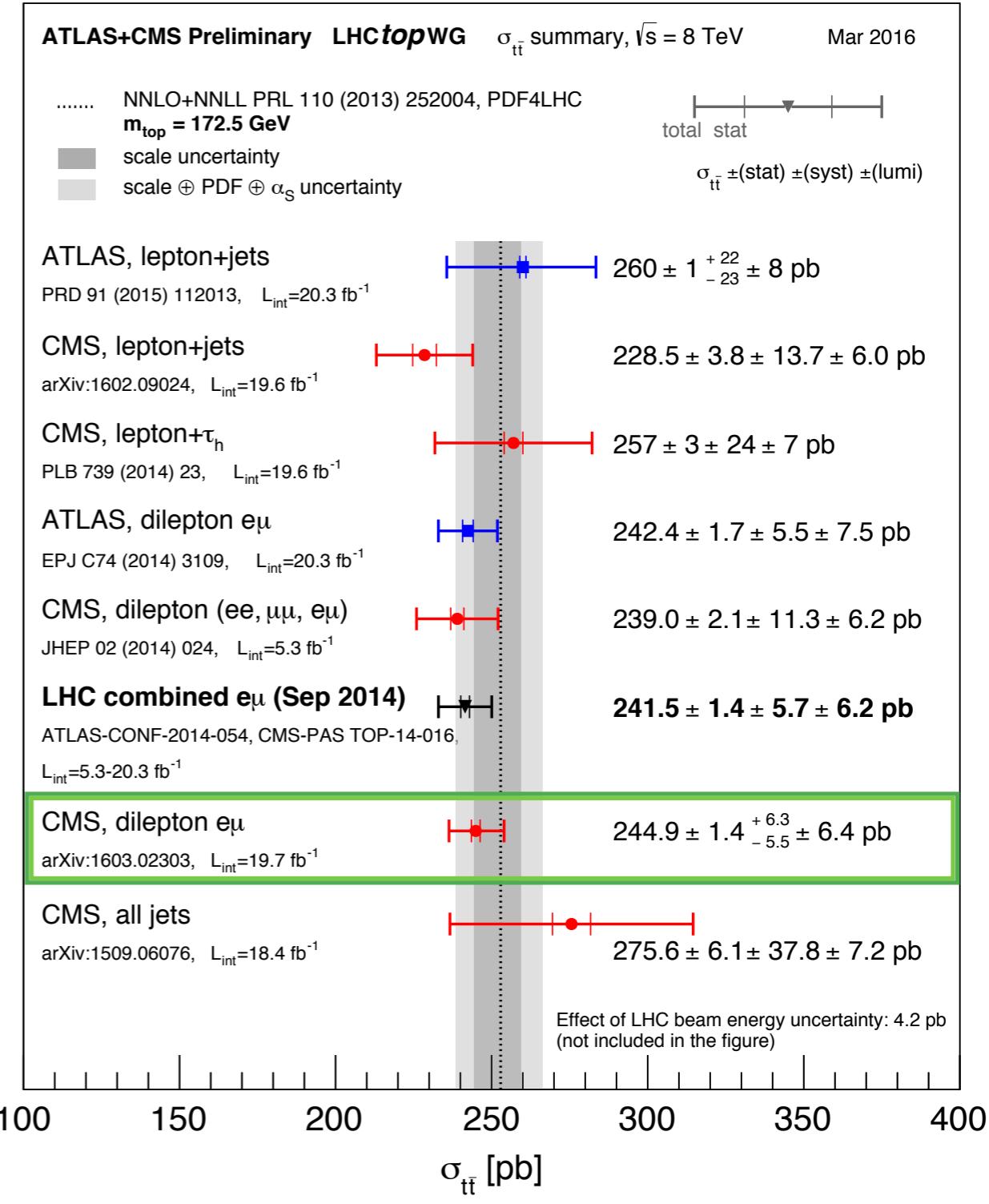
Cross-sections overview: ATLAS+CMS

Run I

7 TeV: $173 \text{ pb} \pm 6\%$



8 TeV: $241.5 \text{ pb} \pm 3.5\%$



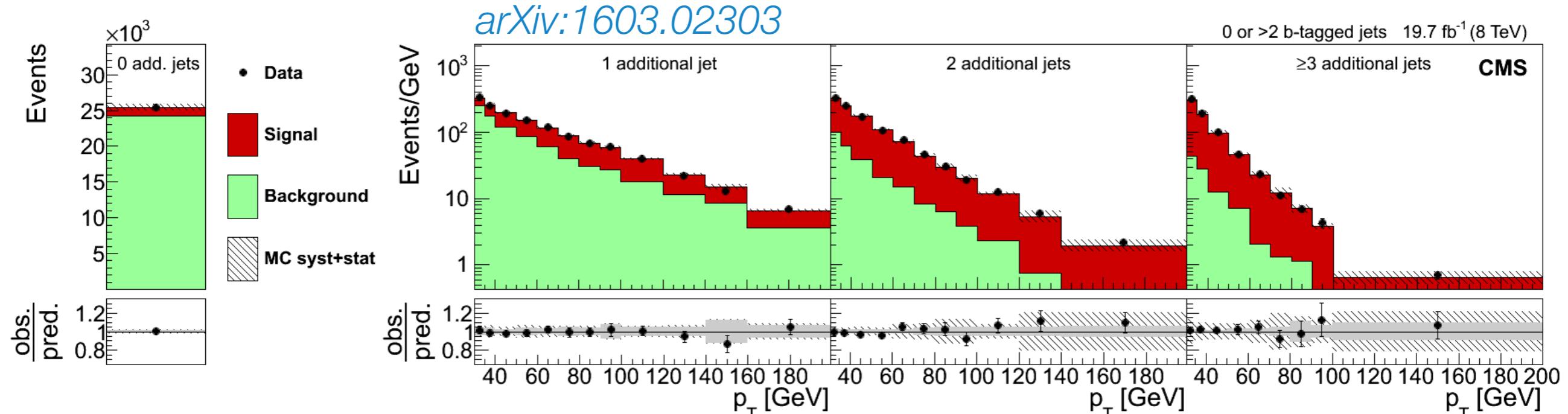
No tension with SM. Precision driven by dilepton analyses.

Inclusive cross-section: $e + \mu$

Run I

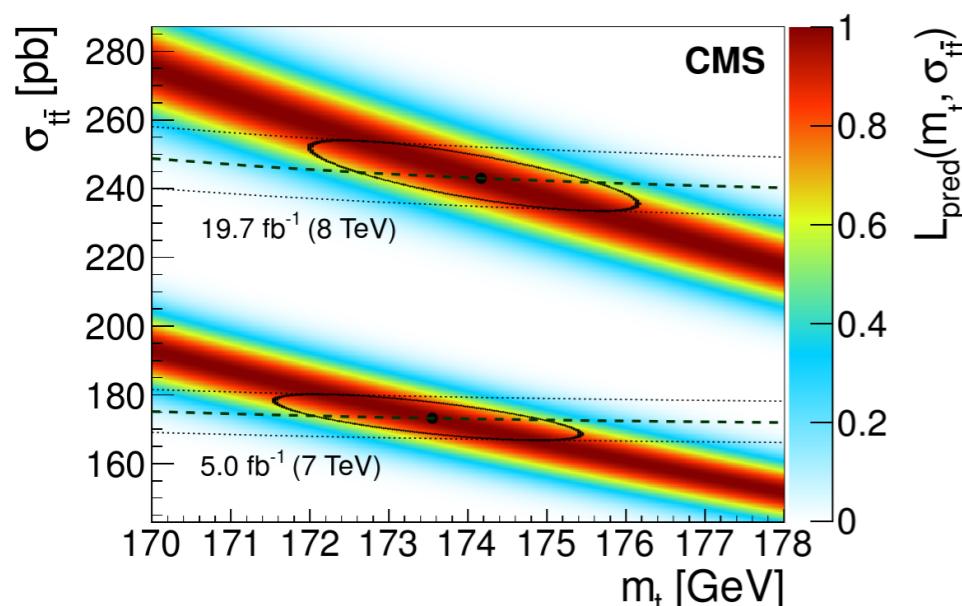
Multidimensional fit to: p_T of the softest non-b-tagged jet

Categorised by *N b-tagged jets vs N add. jets*: 12 categories in total



$$\sigma_{tt} = 244.9 \pm 1.4^{\text{stat}} \pm 6.3^{\text{syst}} \pm 6.4^{\text{lumi}} \text{ pb} \quad | \quad 3.7\% \text{ total}$$

$\sqrt{s}=8 \text{ TeV}$



↳ σ_{tt} also used to constrain *top-squark production cross section*

arXiv:1603.02303

$$m_t = 173.8 \text{ GeV} \pm 1\%$$

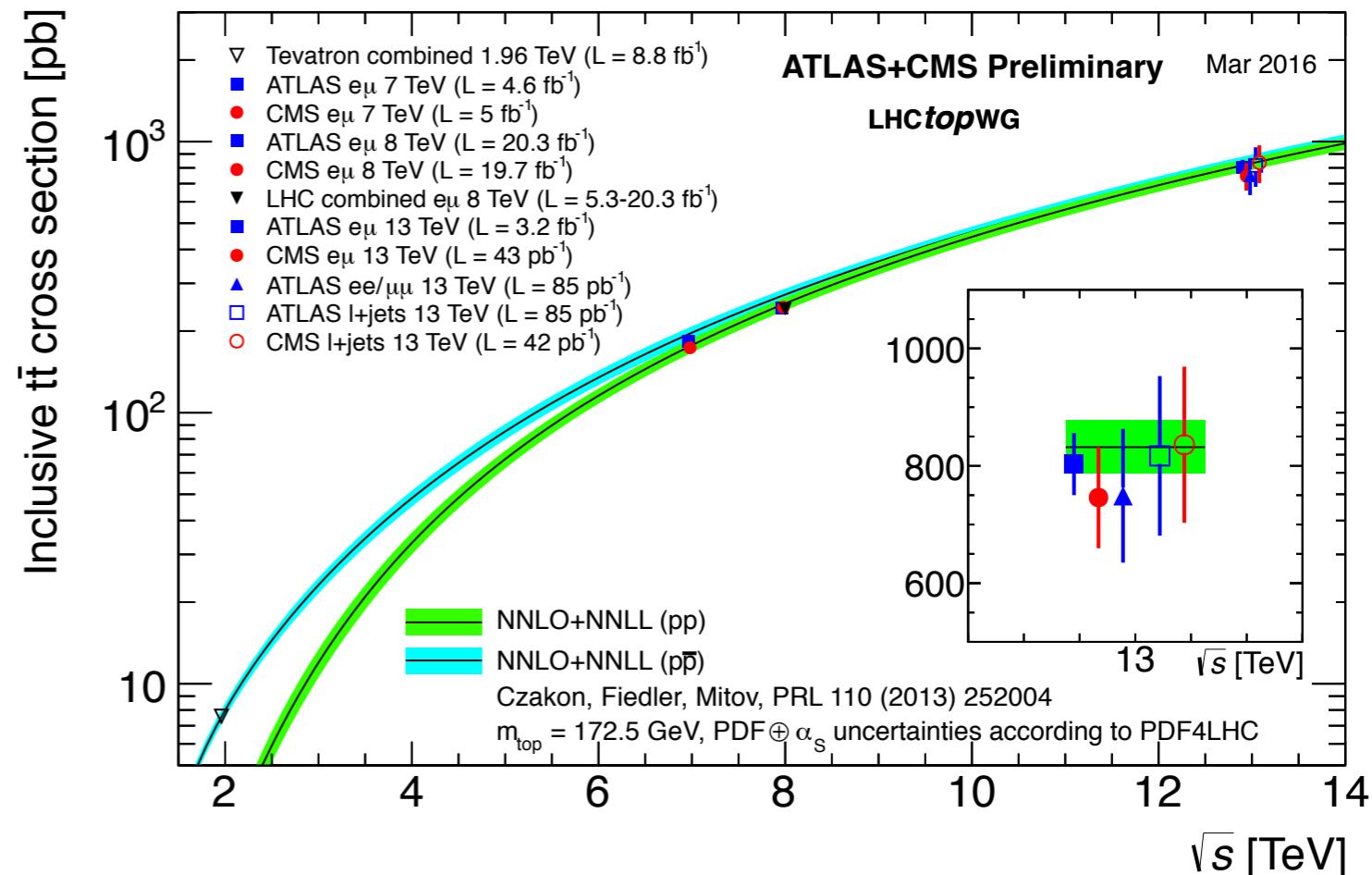
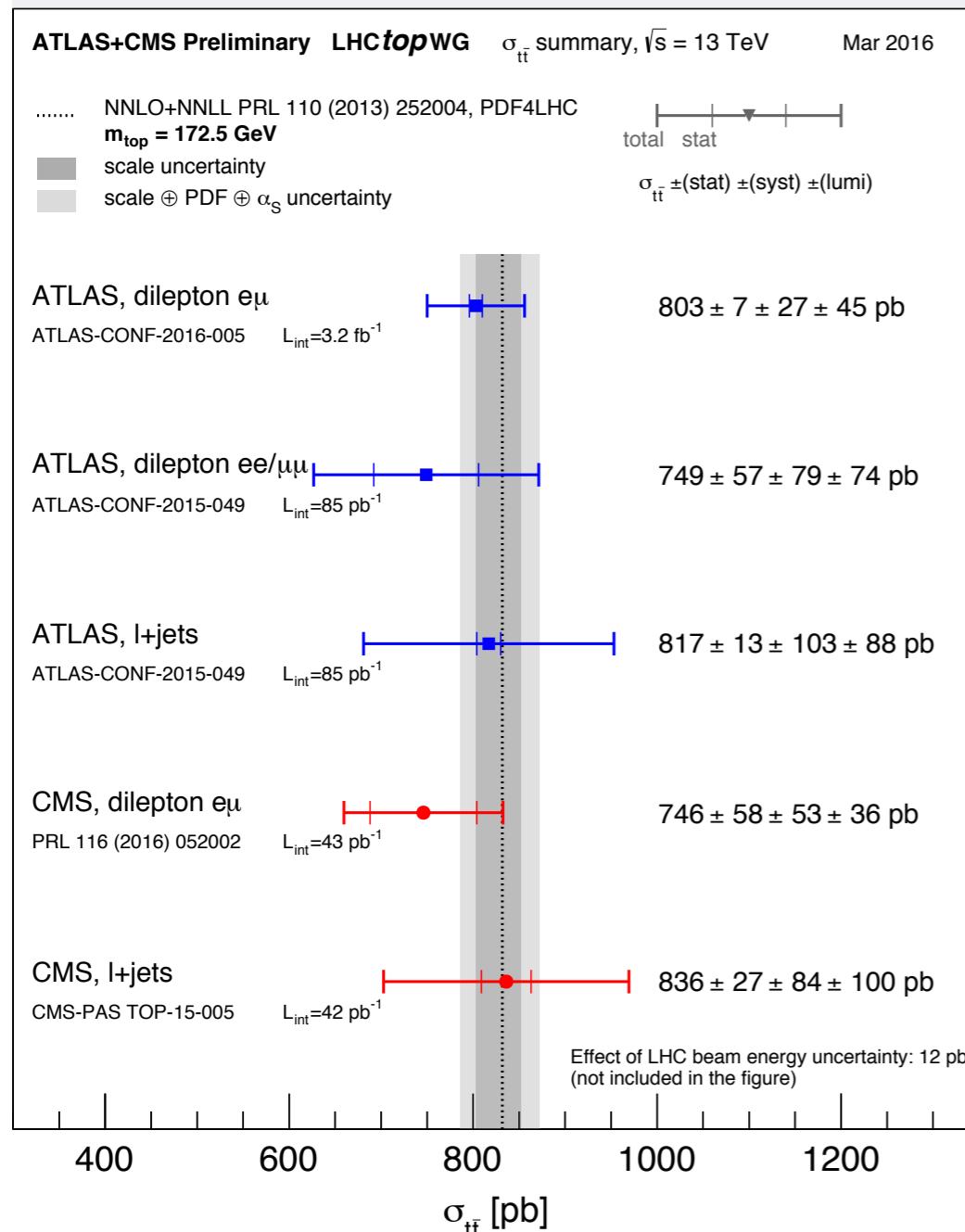
NNPDF3.0

more on m_t in talk by Simon Spannagel

Cross-sections overview: ATLAS+CMS

Run II

13 TeV: $\pm 6.6\%$ Mar. 2016



Evolution with \sqrt{s} is well understood
Measurements approaching the limit of theoretical precision

The most recent CMS result not included: covered in the following

Using all 13TeV data recorded by CMS: $\mathcal{L}^{\text{int}} = 2.2 \text{ fb}^{-1}$

Counting high-purity $e\mu$ events: rejecting Drell-Yan $m_{e\mu} > 20 \text{ GeV}$

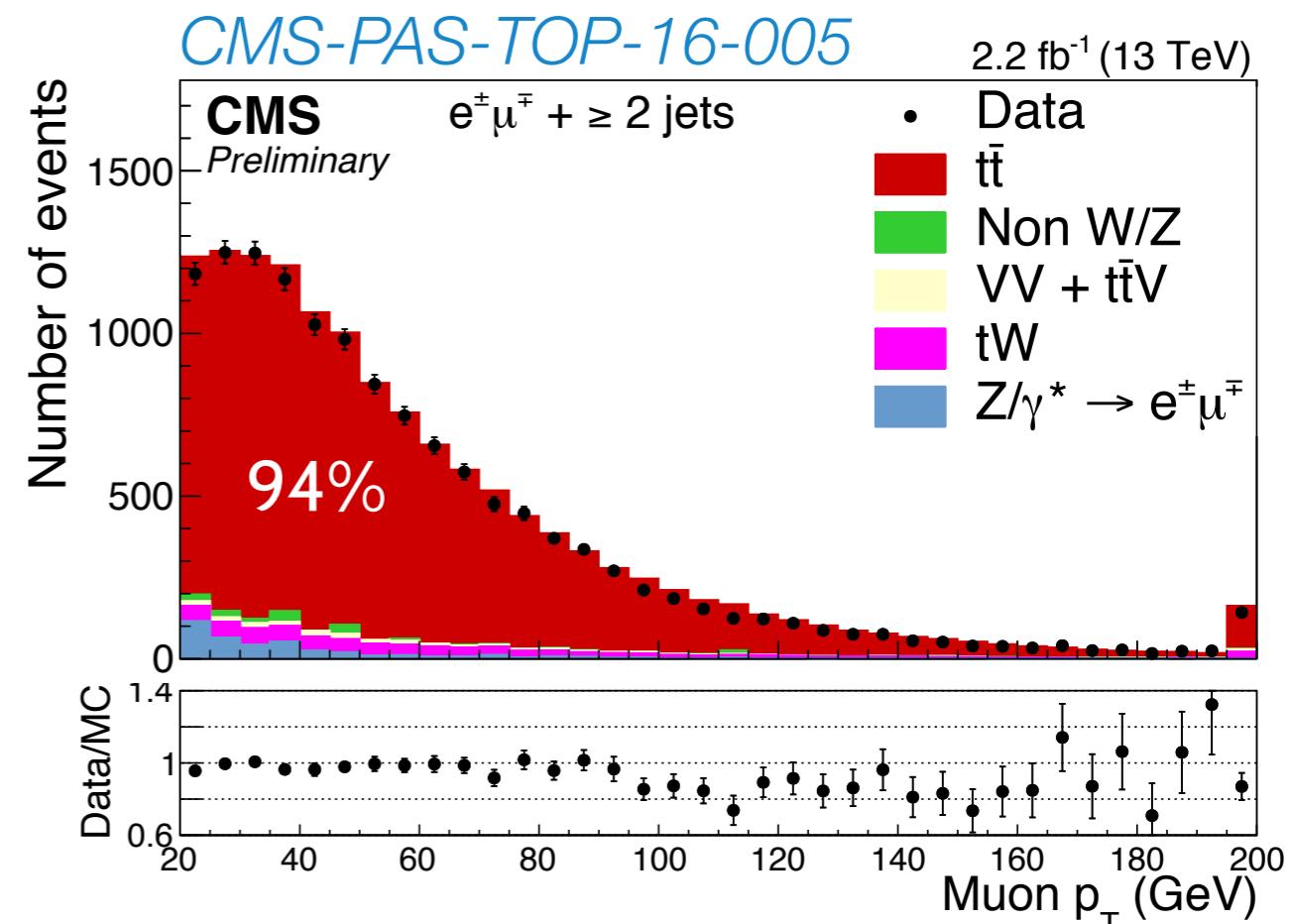
- 2 isolated leptons: $e^\pm\mu^\mp$
- ≥ 2 jets (≥ 1 b-tagged)

Main backgrounds:

- single top quark: tW (from MC)
- Drell-Yan, fake e/μ (from Data)

Dominant systematics:

- trigger/lepton efficiencies, JES, b-tagging



$\sigma_{tt} = 793 \pm 8 \text{ stat} \pm 38 \text{ syst} \pm 21 \text{ lumi pb} \quad | 5.6\% \text{ total}$

most precise yet

DIFFERENTIAL CROSS SECTIONS

- additional constraints on SM parameters, new physics
- top quarks need to be reconstructed
- correction for detector + parton-shower effects
needed for comparison to theory predictions
- closer-to-experiment definitions can be used: *pseudotop*

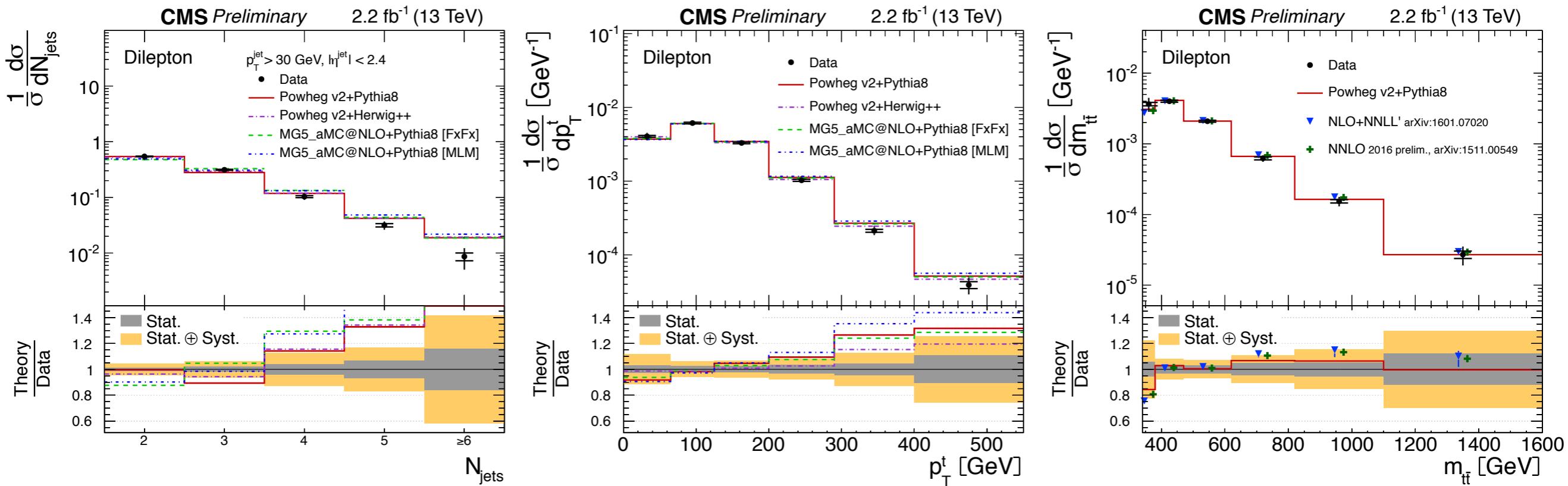
Differential cross-section: dilepton

Run II

Normalised σ_{tt} vs N_{jets} , m_{tt} , p_T , y | t, tt

[CMS-PAS-TOP-16-011](#)

Corrected for detector effects: regularised unfolding



In general good description by all considered NLO predictions

$N_{\text{jets}} > 4$ not well described by predictions: parton-shower dominated

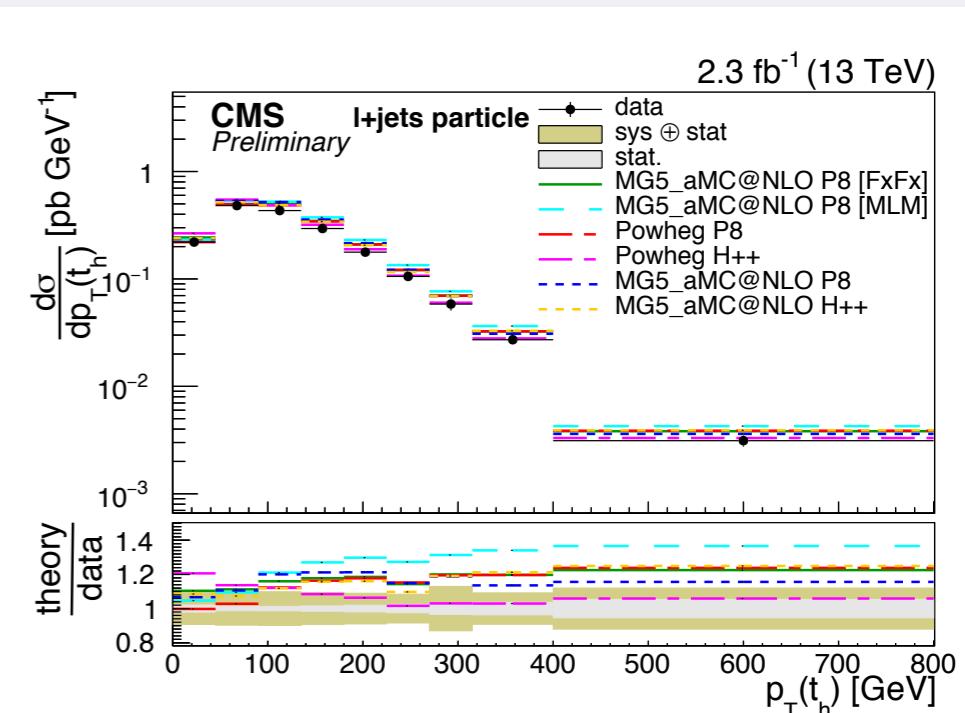
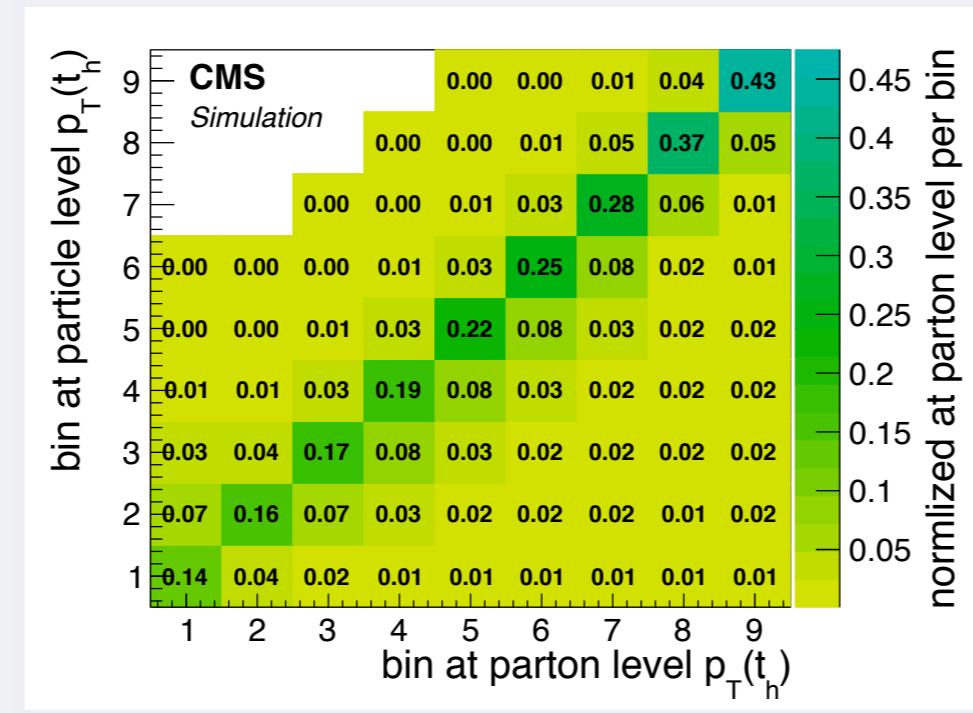
Top-quark p_T better described by *Powheg v2 + Herwig++* as in Run I

Absolute σ_{tt} vs $N_{\text{add. jets}}, m_{tt}, p_T, y |^{t, \bar{t}}$

[CMS-PAS-TOP-16-008](#)

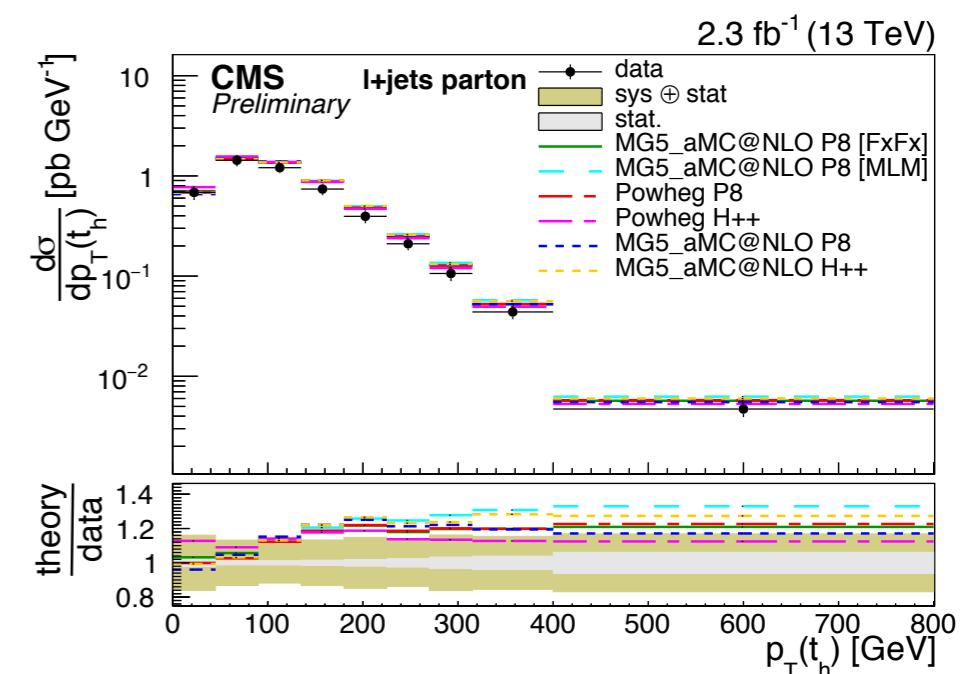
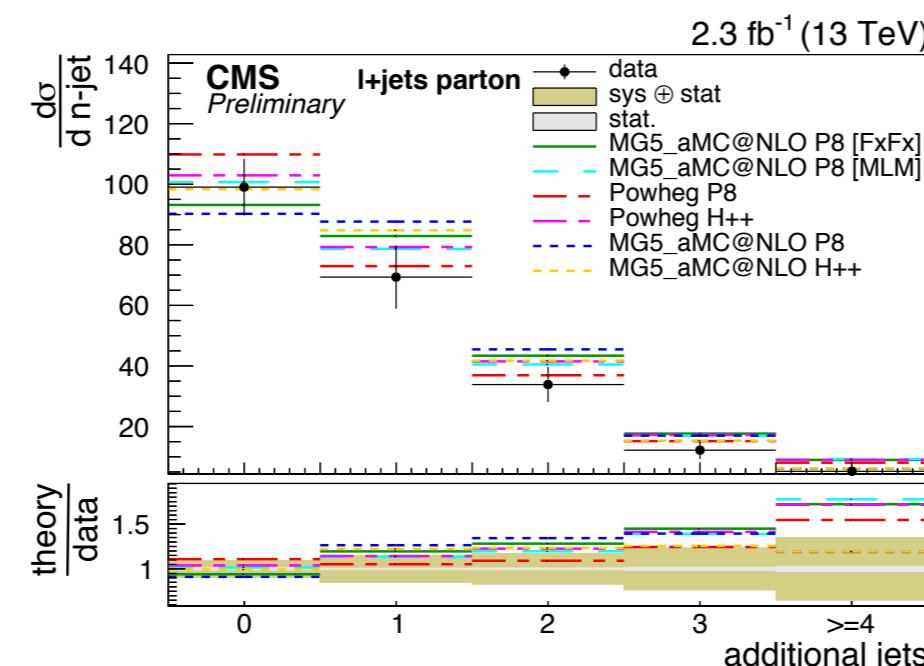
Measured with parton-level and particle-level definitions

- e/μ dressed with photons
- all ν summed
- jets, b jets



Dominant syst.:
JES, PS modeling

Conclusions
similar to
dilepton results



Probing top quarks in the boosted regime: $p_T > 400 \text{ GeV}$

Decay products merged into jets: lepton+jets

CMS-PAS-TOP-14-012

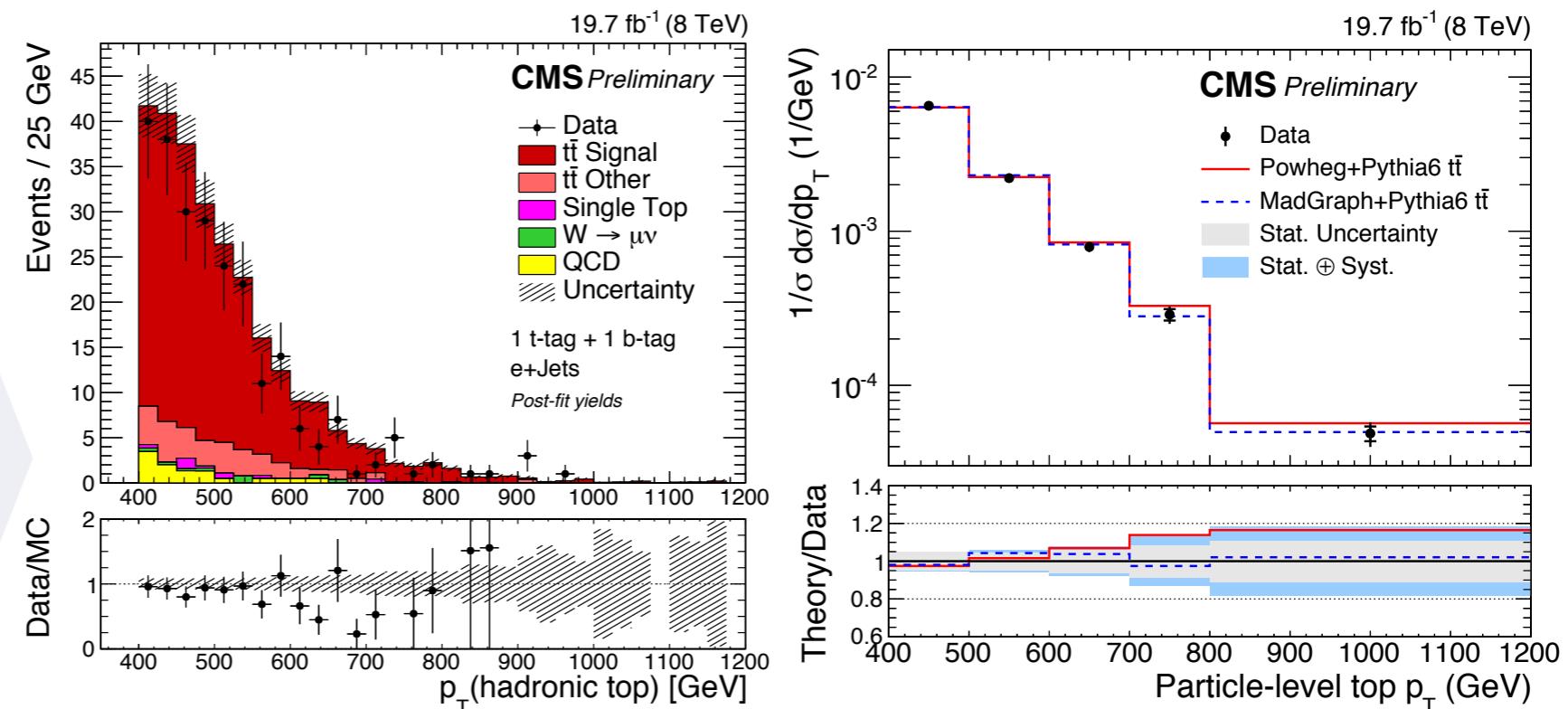
Anti- k_T jets

- $R = 0.5$ *leptonic*

Cambridge-Aachen jets

- $R = 0.8$ *hadronic*

→ top tagging algorithm
(jet substructure)



Measured with parton-level and particle-level definitions

Similar top-quark p_T trend as in non-boosted analyses

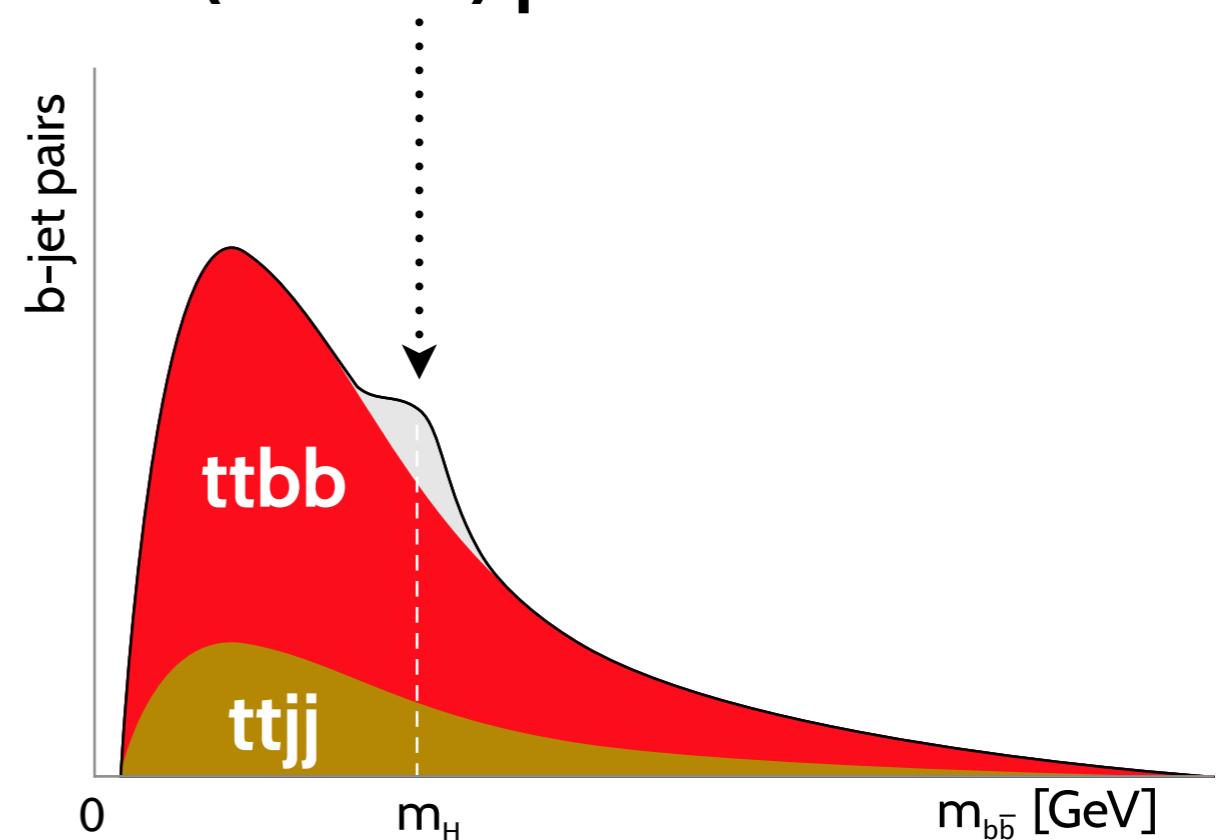
Inclusive σ_{tt} underestimated in POWHEG by 14%, but consistent

$$\sigma_{tt} = 1.28 \pm 0.09^{\text{stat+syst}} \pm 0.10^{\text{PDF}} \pm 0.09^{\text{Q2}} \pm 0.03^{\text{lumi}} \text{ pb}$$

particle

tt + (b) jets CROSS SECTIONS

- dominant background to the $ttH(H \rightarrow bb)$ production
 - **ttbb** - irreducible
 - background to various BSM signatures

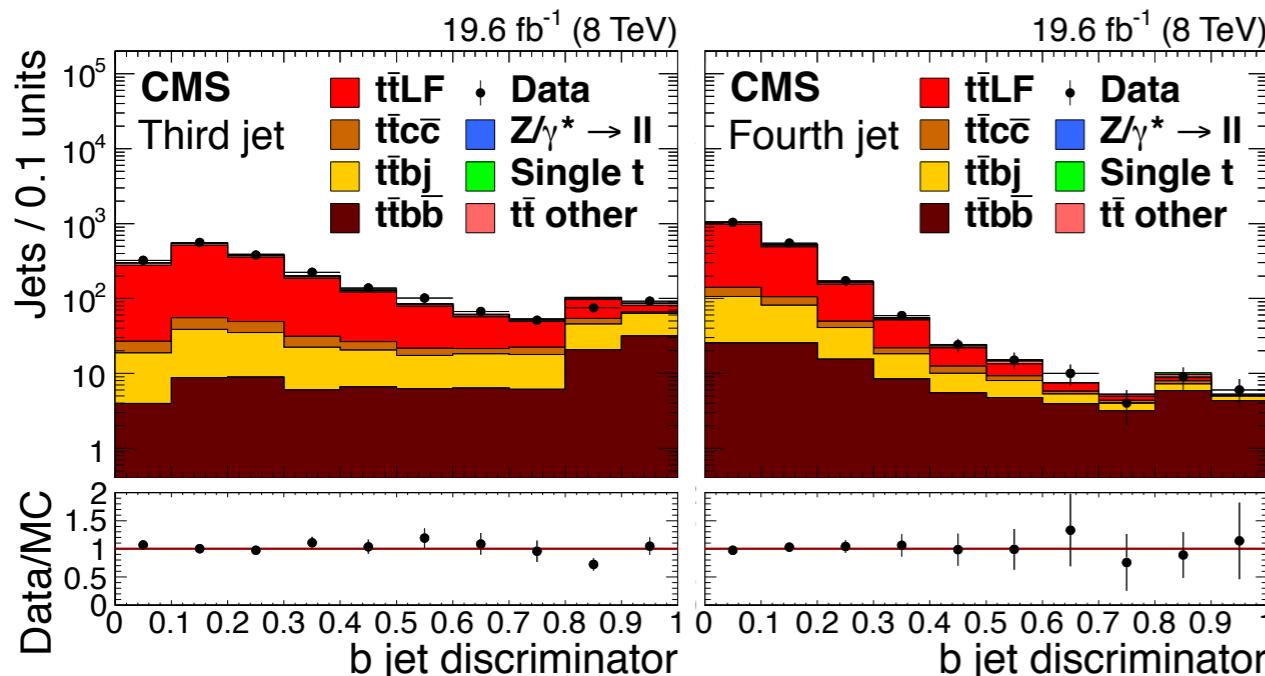


Inclusive cross-sections: $t\bar{t} + (b)$ jets

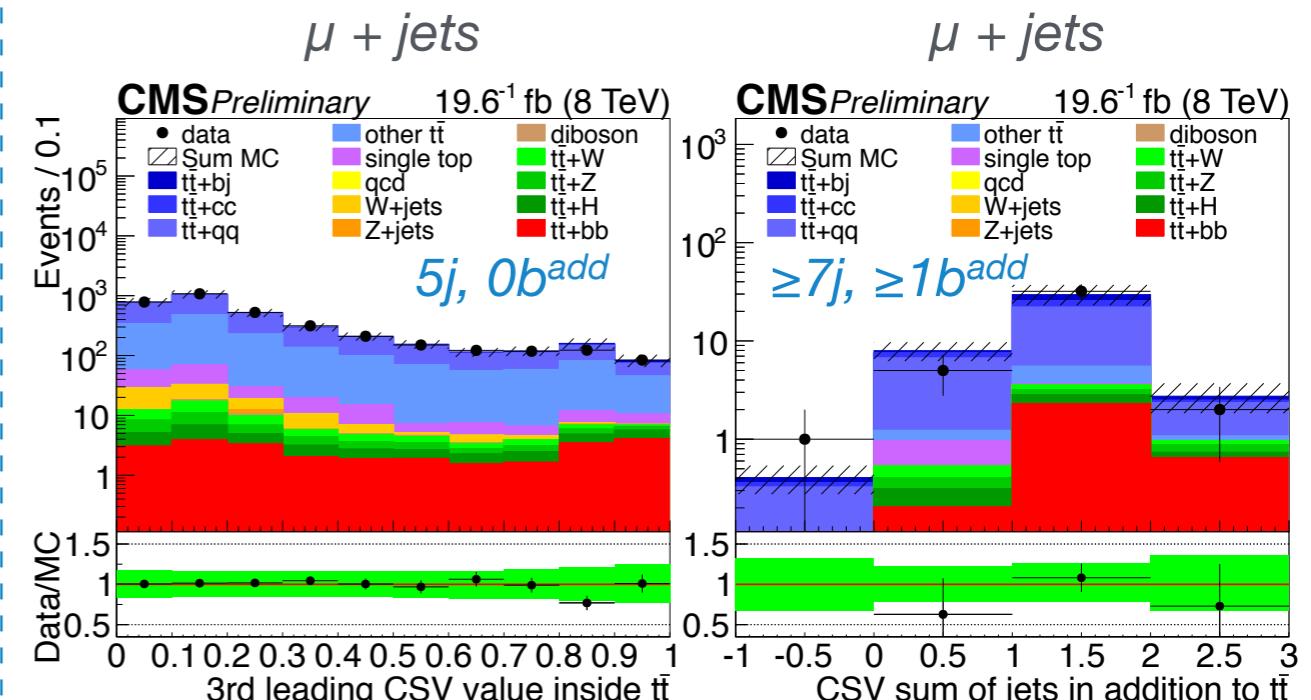
Run I

Absolute σ_{ttjj} , σ_{ttbb} , $\sigma_{ttbb}/\sigma_{ttjj}$: additional (b) jet $p_T > 40$ GeV, $|n| < 2.5$

Dileptonic [PLB 746 \(2015\) 132](#)



[CMS-PAS-TOP-13-016](#) Semileptonic



Simultaneous template fit to extract $ttbb/ttjj$ cross-sections ratio

2 templates: 3rd + 4th jets

26 templates: $Nj, Nb^{add} \times e + \mu$
+ Kinematic reco. + MVA classifier

$$\sigma_{ttjj}$$

$$16.1 \pm 2.2^{\text{total}} \text{ pb}$$

NLO

$$21.0 \pm 2.9^{\text{total}} \text{ pb}$$

$$\sigma_{ttbb}$$

$$0.36 \pm 0.13^{\text{total}} \text{ pb}$$

$$0.23 \pm 0.05^{\text{total}} \text{ pb}$$

$$23.1 \pm 3.8^{\text{total}} \text{ pb}$$

$$0.27 \pm 0.11^{\text{total}} \text{ pb}$$

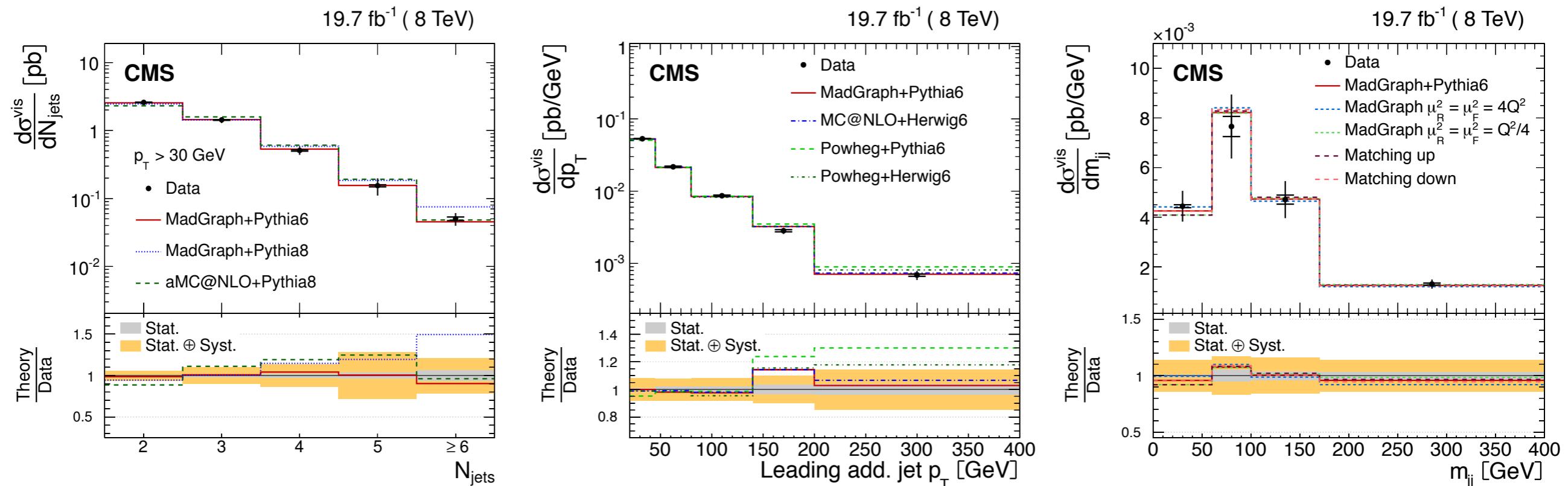
Differential cross-section: $t\bar{t} + \text{jets}$

Run I

Absolute σ_{tt} vs N_{jets} , H_T , m , $dR|^{jj}$, p_T , $|\ln|^{j1, j2}|$

[arXiv:1510.03072](https://arxiv.org/abs/1510.03072)

Kinematic reconstruction of the $t\bar{t}$ system: dileptonic channel



Predictions normalised to data: shapes reasonably described

Absolute σ_{tt} underestimated: as seen from inclusive measurements

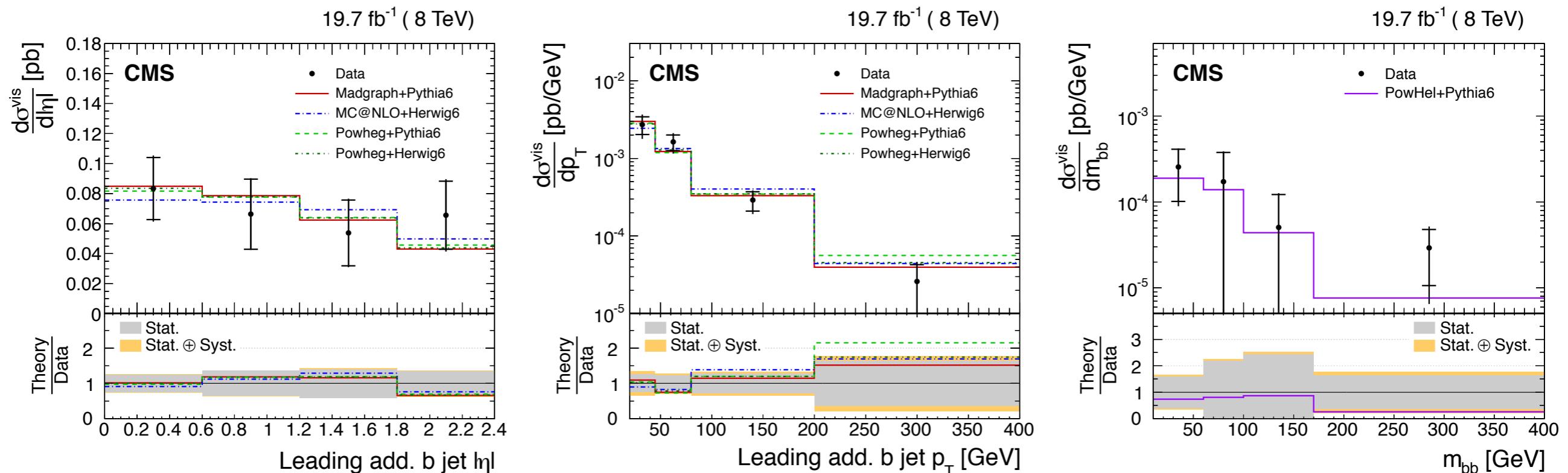
Dominant uncertainties: JES, μ_R , μ_F , hadronisation model

- model dependence of the measurement needs to be reduced

Absolute σ_{tt} vs $m, dR|^{bb}, p_T, |\eta| |^{b1, b2}$

[arXiv:1510.03072](https://arxiv.org/abs/1510.03072)

B-jet assignment to the $t\bar{t}$ system by a BDT: dileptonic channel



Non-trivial signal definition: many b jets in the final state

m_{bb} spectrum softer than m_{jj} : larger contribution from gg scattering

First comparison to NLO calculation: identical signal definitions

Statistically limited: will improve significantly with Run II data

Summary

Important physics results still being extracted from Run I data

**Run II top-quark measurements becoming competitive
with Run I *in terms of statistical precision***

No significant deviations from Standard Model observed so far

Exploring new kinematic regions boosted top

Modelling uncertainties becoming increasingly important

- NLO+PS simulations widely adopted now
- particle-level signal definitions becoming more common

**Reduction of systematic uncertainties is the primary goal of
experiment- and theory-side efforts during Run II**



Thank you
for attention

Particle-level top-quark definition

[CMS-PAS-TOP-16-008](#)

- 1 prompt e/μ lepton corrected for final-state radiation
 - clustering photons within a jet [anti- k_T , $R=0.1$]
- All prompt ν neutrinos: origin not in a hadron decay
- ≥ 4 Jets: all stable particles except prompt $e/\mu/\nu$ [anti- k_T , $R=0.5$]
 - ≥ 2 b jets: ghost* b hadron included during the jet clustering
*b-hadron momentum scaled \downarrow to a negligible value

→ Finding permutation of jets minimising the equation:

$$K^2 = [M(p_N + p_\ell + p_{b_1}) - \mathbf{m}_t]^2 + [M(p_{j_1} + p_{j_2}) - \mathbf{m}_w]^2 + [M(p_{j_1} + p_{j_2} + p_{b_2}) - \mathbf{m}_t]^2$$

$$\mathbf{m}_t = 172.5 \text{ GeV}$$

$$\mathbf{m}_w = 80.4 \text{ GeV}$$

Particle-level *top-quark definition*[CMS-PAS-TOP-14-012](#)1 prompt e/μ lepton

- $p_T > 45 \text{ GeV}$, $|\eta| < 2.1$

 ≥ 1 jet in the same hemisphere: $dR(l, \text{jet}) < \pi/2$ [anti- k_T , $R=0.5$]

- $p_T > 30 \text{ GeV}$, $|\eta| < 2.4$

 ≥ 1 fat jet in the opposite hemisphere: $dR(l, \text{jet}) > \pi/2$ [CA, $R=0.8$]

- $p_T > 400 \text{ GeV}$, $|\eta| < 2.4$