Recent $t\bar{t}$ and single top inclusive and differential cross sections results in CMS

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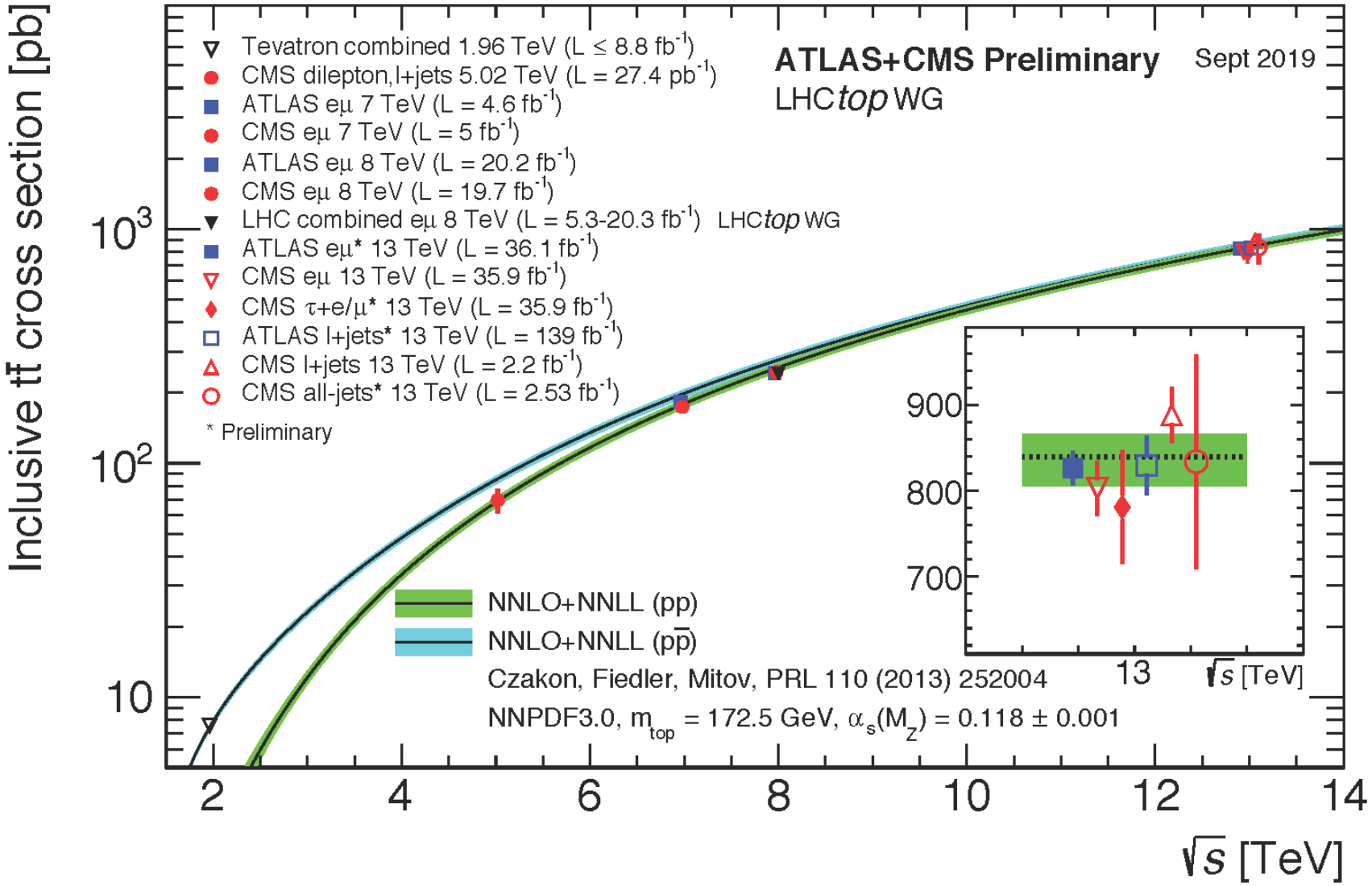
Introduction and motivations

- The top quark plays a special role in the SM
  - The heaviest elementary particle known to date!
  - It decays before hadronizing: BR(t->Wb)~1, $\tau \sim < 10^{-25}$s
  - Unique opportunity to measure bare quark properties!
  - The Higgs boson couples preferentially to the top
  - Several NP scenarios foresee a preferred coupling to the top sector
- CMS has a very rich program of measurements of/with the top quark
  - In this talk, only a selection of results by CMS on cross section measurements is reported

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

$t\bar{t}$ inclusive cross section

LHC TOP WG

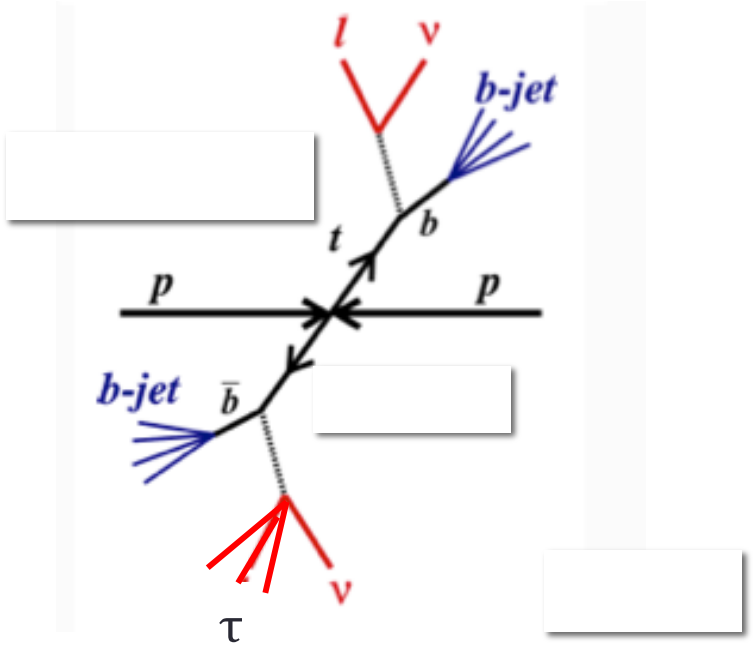


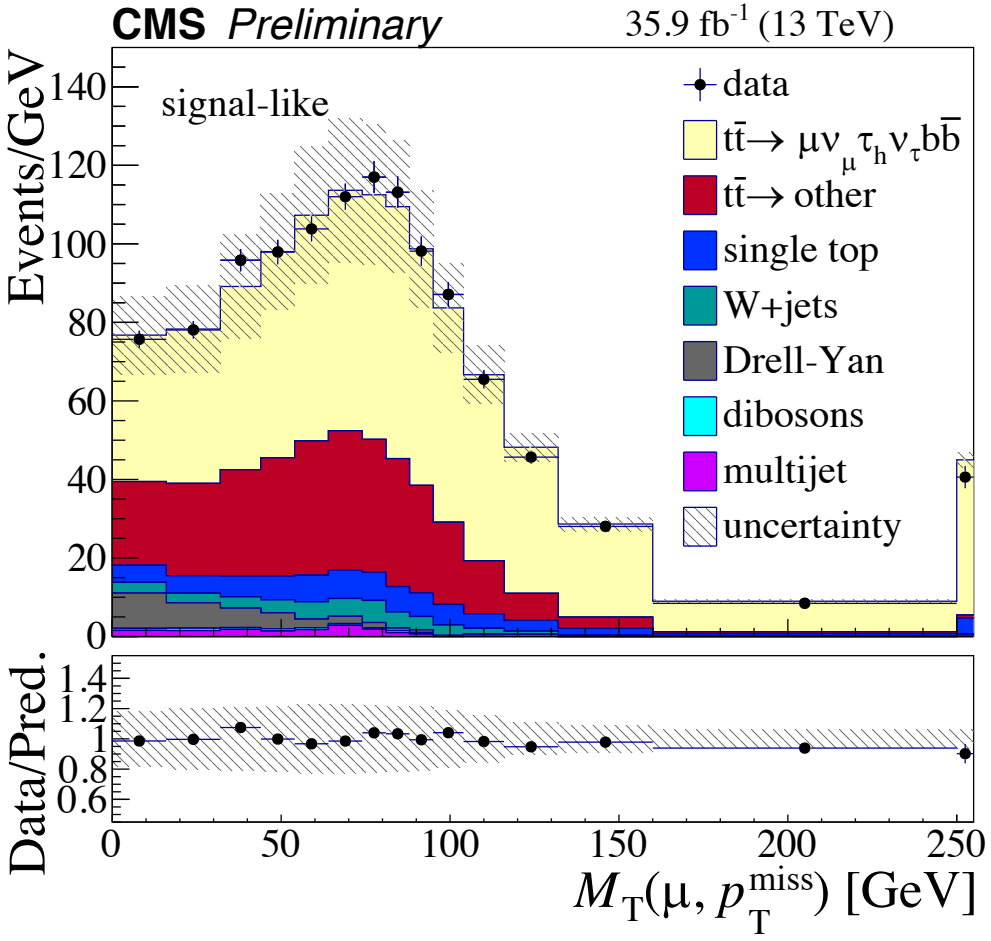
Great improvement on the precisions (single measurements at the level of 3.5%). Precisions comparable to theory

Dilepton channel with τ, 35.9 fb^{-1} at 13 TeV

NEW! The most recent inclusive cross section measurement by CMS: dilepton channel including a tau.

Fit to m_T(lepton, p_T^{miss}) in signal-like and background-like regions





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$\sigma_{t\bar{t}}$ = 781 ± 7 (stat) ± 62 (syst) ± 20 (lum) pb

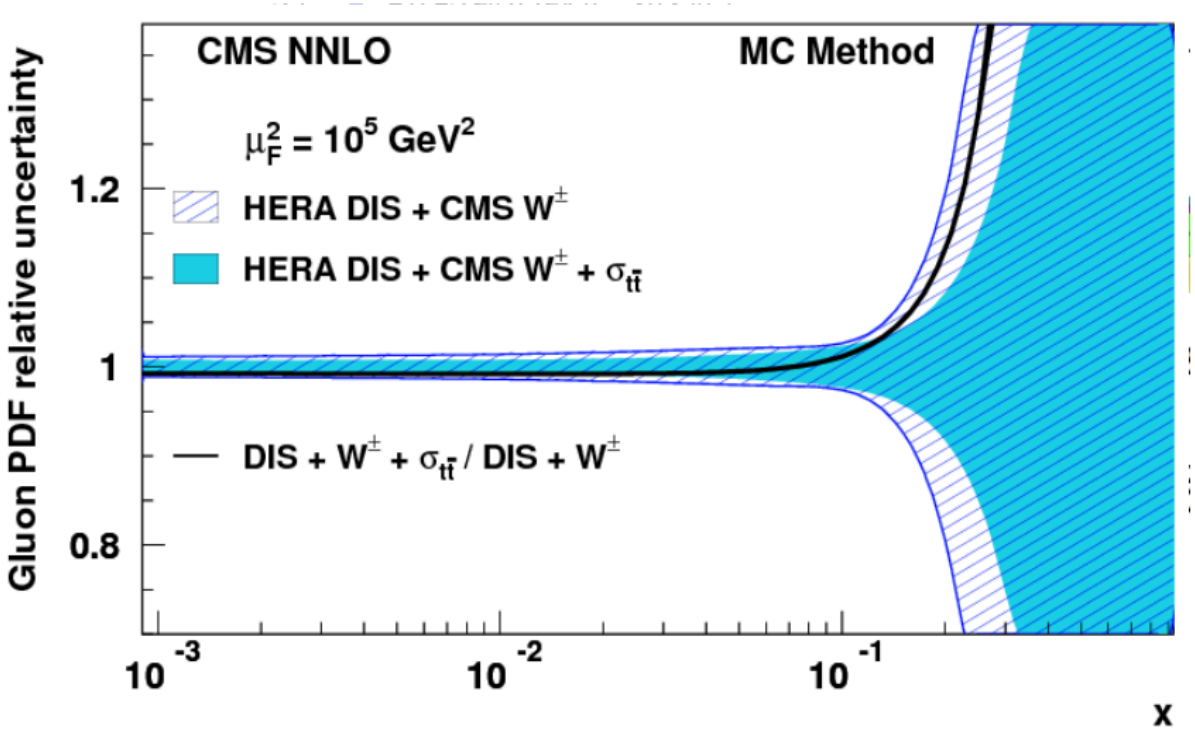
CMS is also probing lepton universality in the top sector using l+τ events (see Eur. Phys. J. C (2019) **79**: 368): **$R_{l\tau/ll}$ = 0.973 ± 0.009 (stat) ± 0.066 (syst)**

Semileptonic and dileptonic channels, 27.4 pb^{-1} at 5.02 TeV

$t\bar{t}$ production at 5.02 TeV

Not only 7, 8 and 13 TeV data!

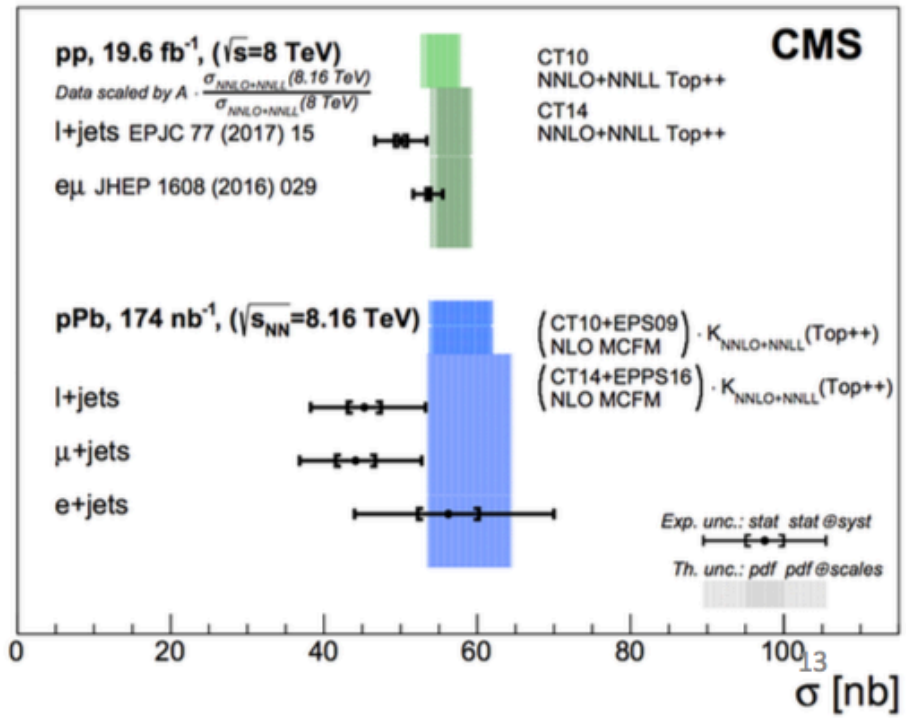
JHEP 1803 (2018) 115



- The fraction of tt initiated with gluon-gluon collisions grows monotonically with $\sqrt{s}$
- It can constrain gluon PDF at large momentum fraction: moderate improvement on the uncertainty at large x
- Also a reference for measurements in heavy ion collisions

Semileptonic channel, 174 nb^{-1} at 8.16 TeV

$t\bar{t}$ production in p-Pb collisions



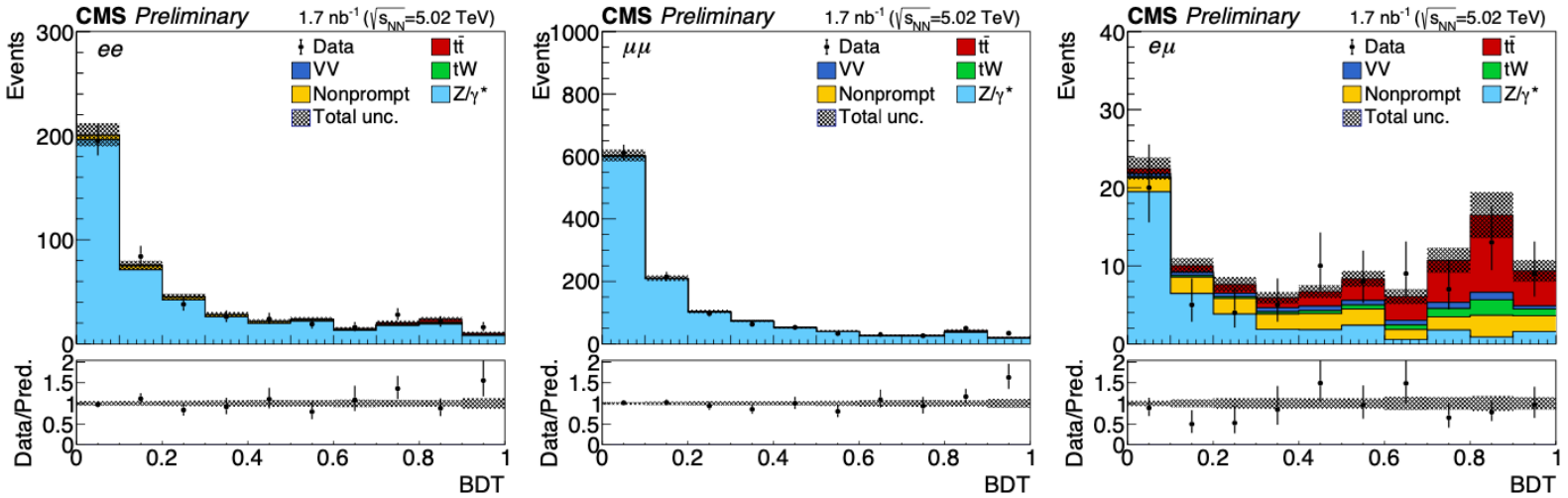
PRL 119, 242001 (2017)

- Information on nuclear parton distribution functions
- Probe of nuclear gluon density in the high Bjorken-x region ($x>2m_t/\sqrt{s}\approx0.05$)
- Consistent with perturbative QCD.
- No evidence of nuclear modifications

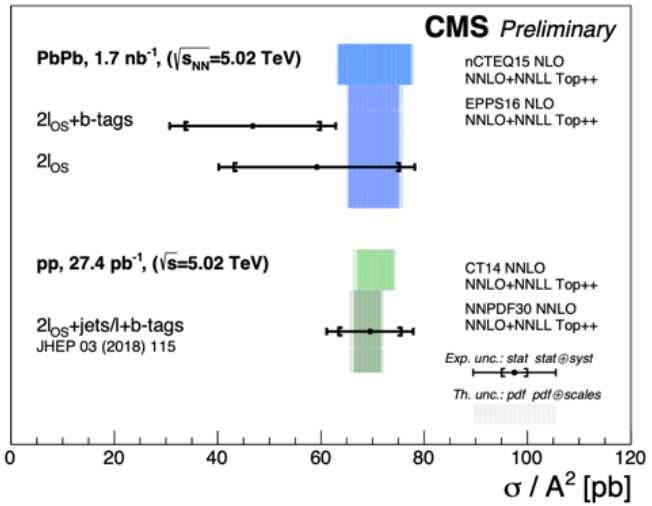
Dileptonic channel, 1.7 nb^{-1} at 5.02TeV

$t\bar{t}$ production in Pb-Pb collisions

CMS-PAS-HIN-19-001



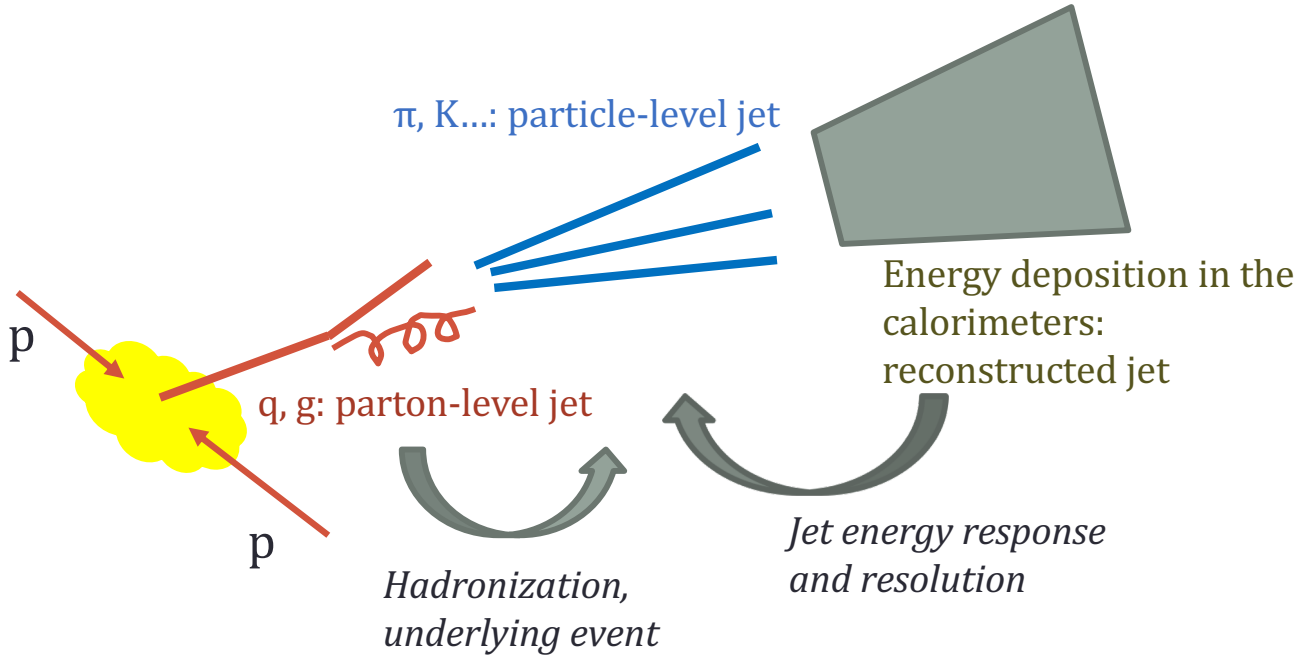
First evidence!



- Probe of the nuclear gluon density in the poorly explored high Bjorken-*x* region.
- Analysis performed both without and with requesting b-jet reconstruction: study of medium-induced parton energy loss.

$t\bar{t}$ differential cross sections

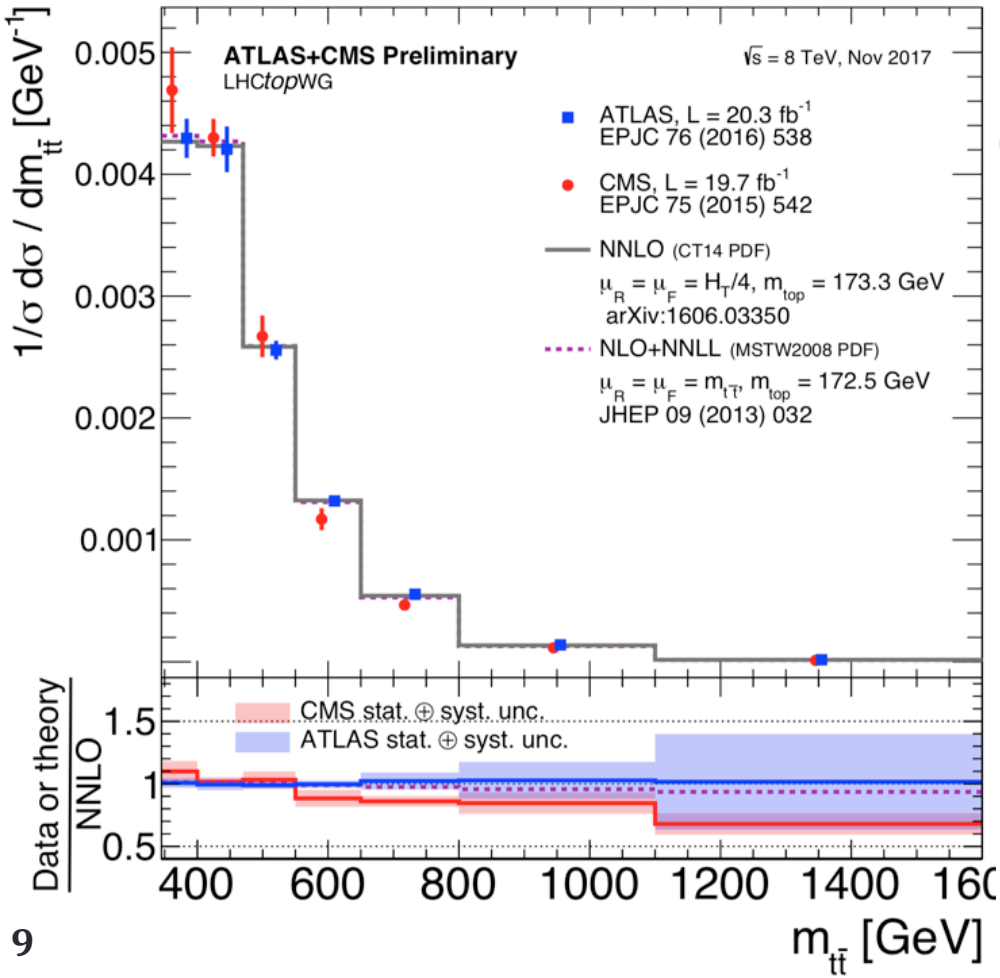
- Measurement of the cross section as a function of various quantities, at either particle or parton level.
  - Parton level: extrapolation to the full phase space; comparison with fixed-order calculations
  - Particle level: reduced model dependence because no extrapolation to the full phase space.
- Comparison with theory and MC predictions (feedback to improve MC descriptions).
- Search for New Physics in corners of the phase space.

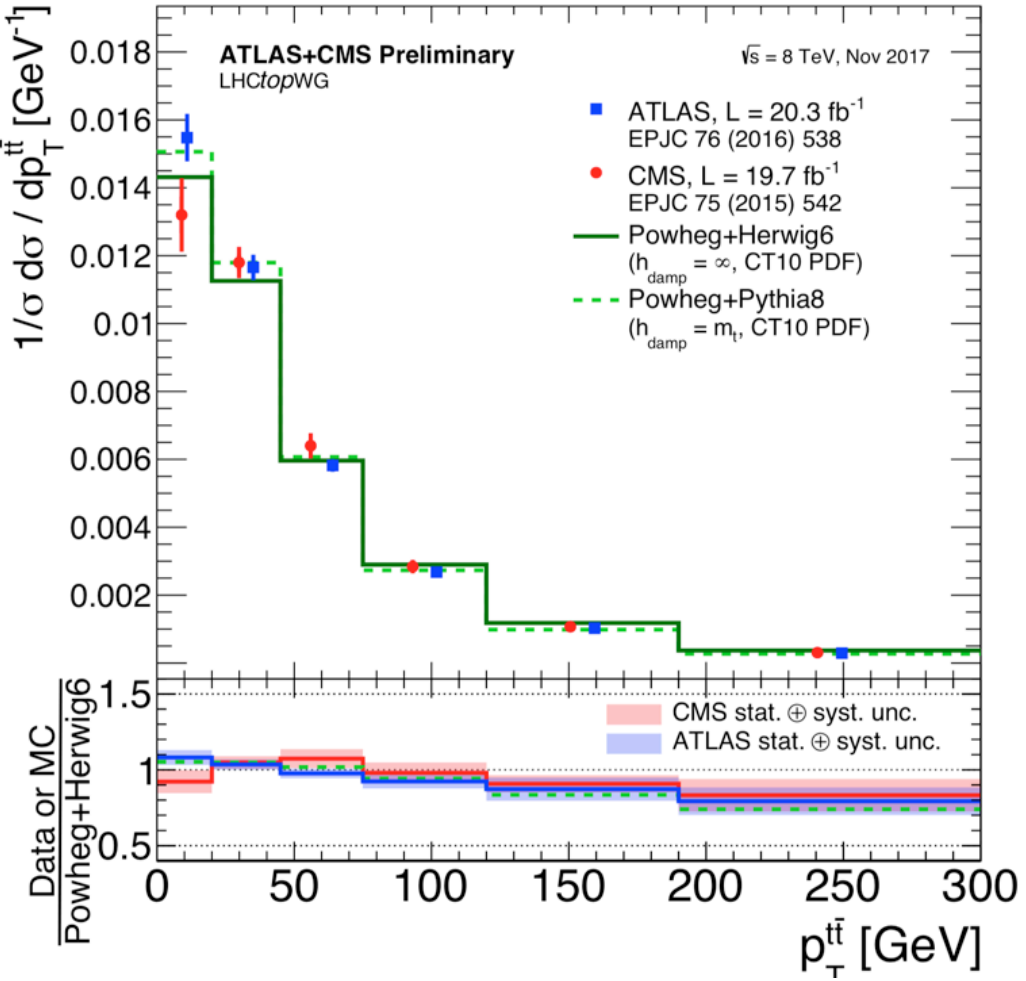


$t\bar{t}$ differential cross sections

LHC TOP WG

- Detailed analysis of the cross section as a function of various variables. Precise test of pQCD. In general, good agreement with predictions

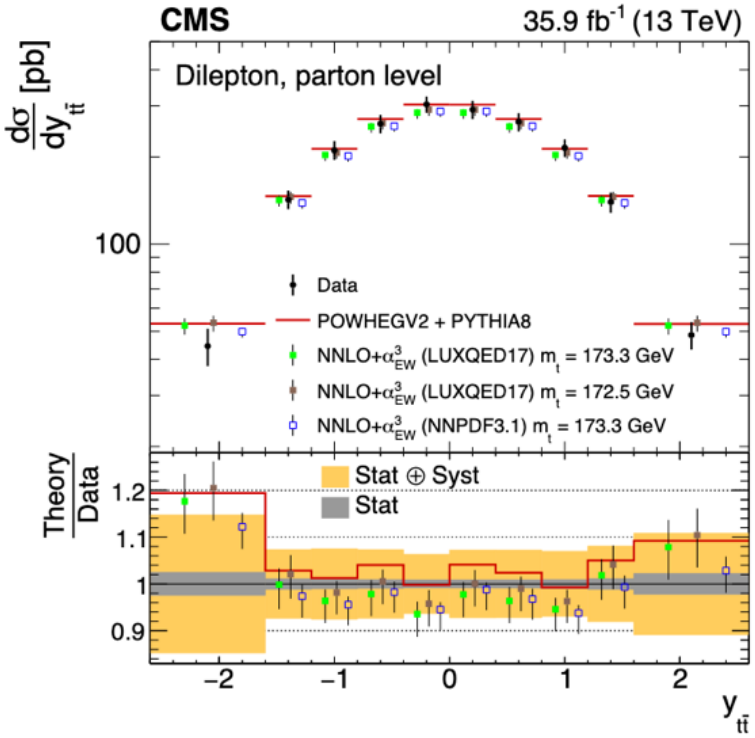


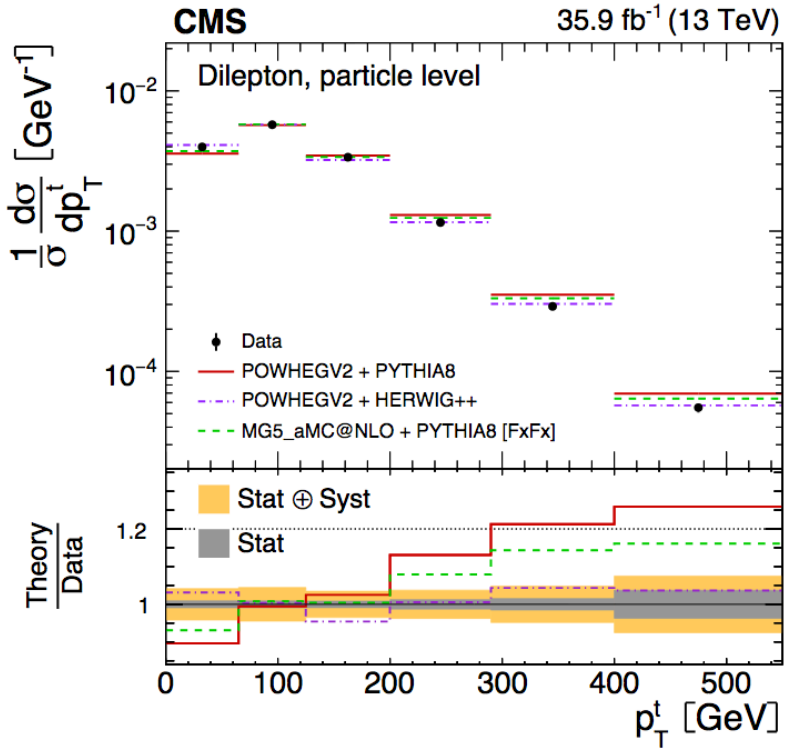


$t\bar{t}$ differential cross sections

Dilepton channel, 35.9 fb^{-1} at 13 TeV

Unfolding at both parton and particle level.





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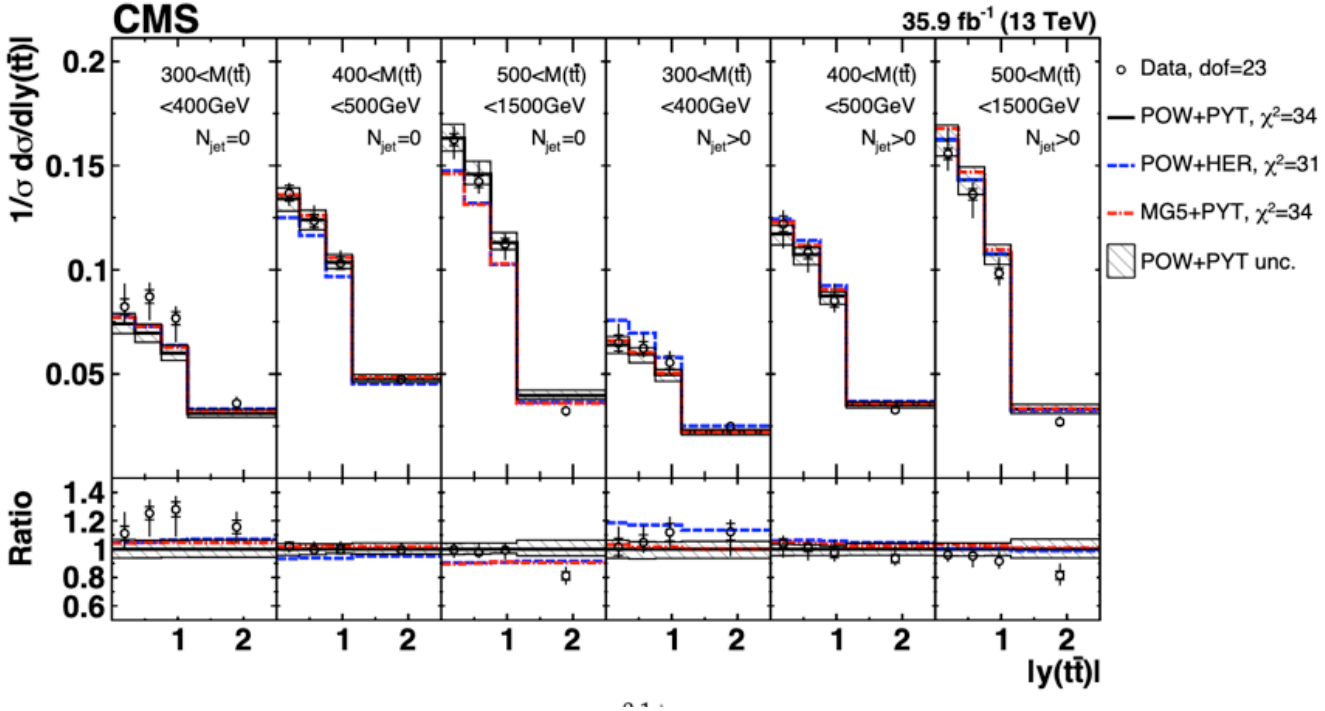
- Good agreement overall, but some discrepancies. The measurements confirm a softer p_T than expected.
- Also, constraints on top quark chromomagnetic dipole moment at NLO

$t\bar{t}$ differential cross sections

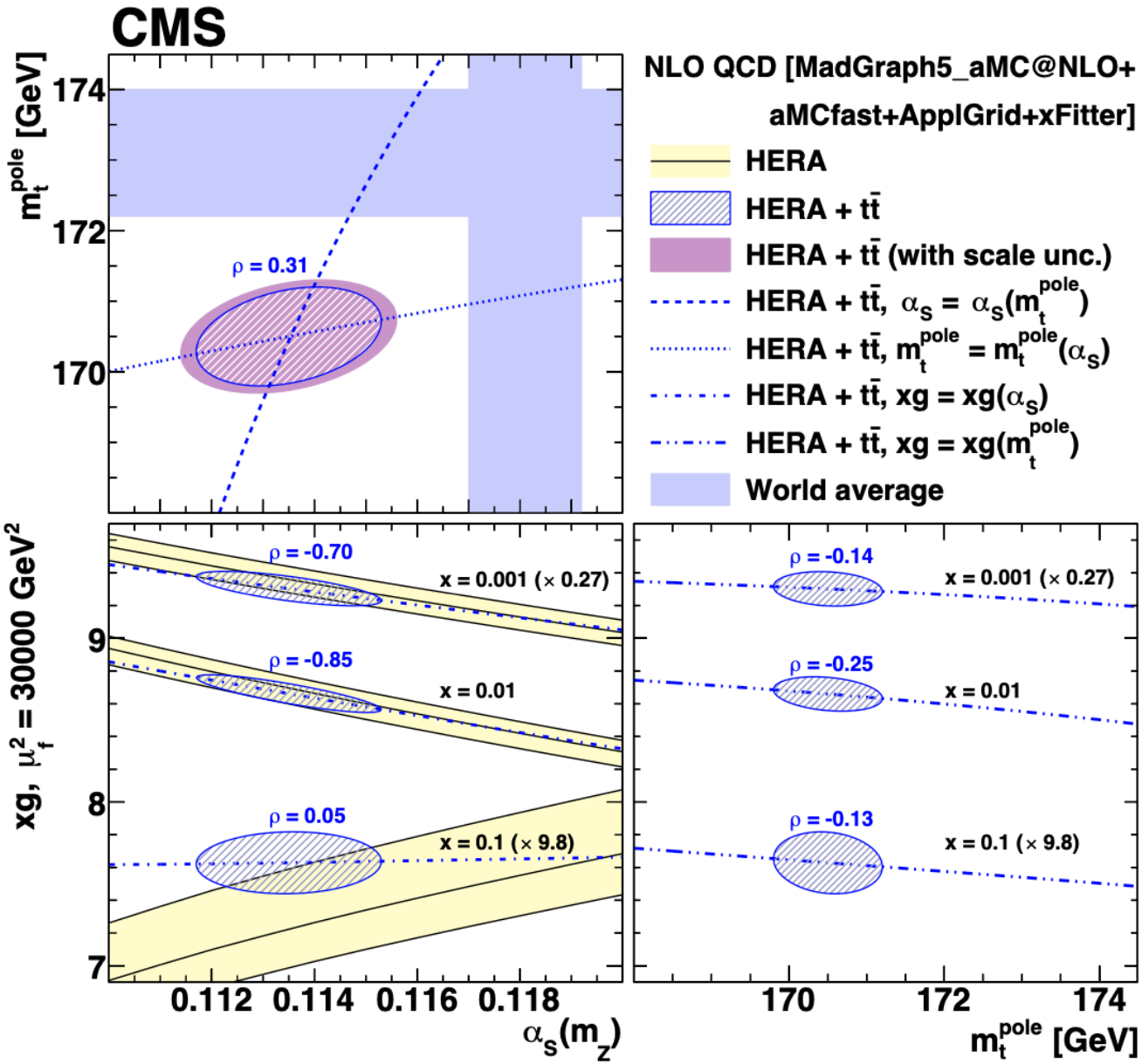
Dilepton channel, 35.9 fb^{-1} at 13 TeV

2D and also 3D diff. X-sections versus various variables of the top, of the $t\bar{t}$ pair or of the number of jets



arXiv:1904.05237, submitted to EPJC

No single MC generator is capable to describe well all the measured distributions



- The measured 3D cross sections have been incorporated into two specific fits of QCD parameters at NLO order, together with the inclusive deep inelastic scattering data from HERA.
- In a simultaneous fit of α_s, m^t_{pole}, and PDFs, the inclusion of the new multi-differential $\overline{\text{tt}}$ measurements has a significant impact on the extracted gluon PDF at large x

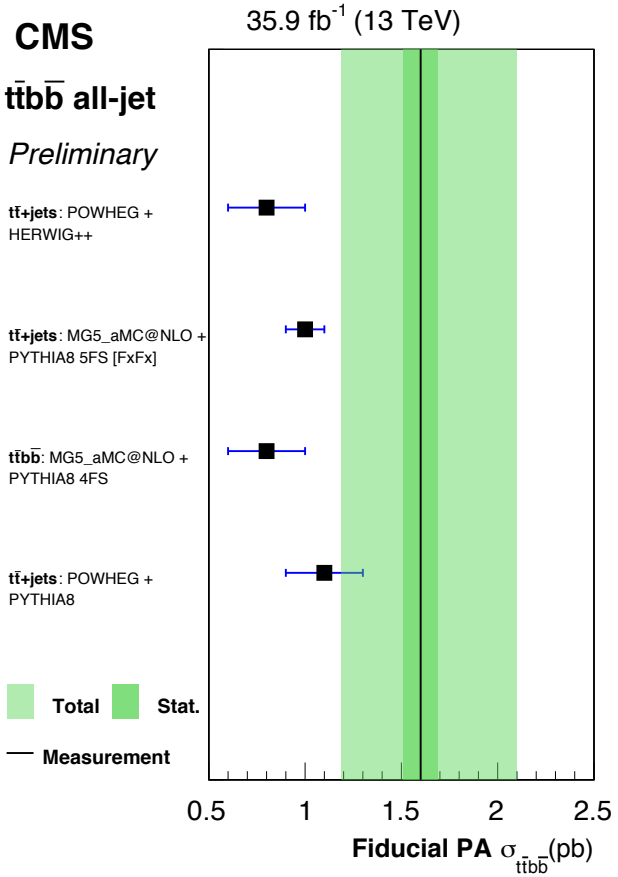
arXiv:1904.05237, submitted to EPJC

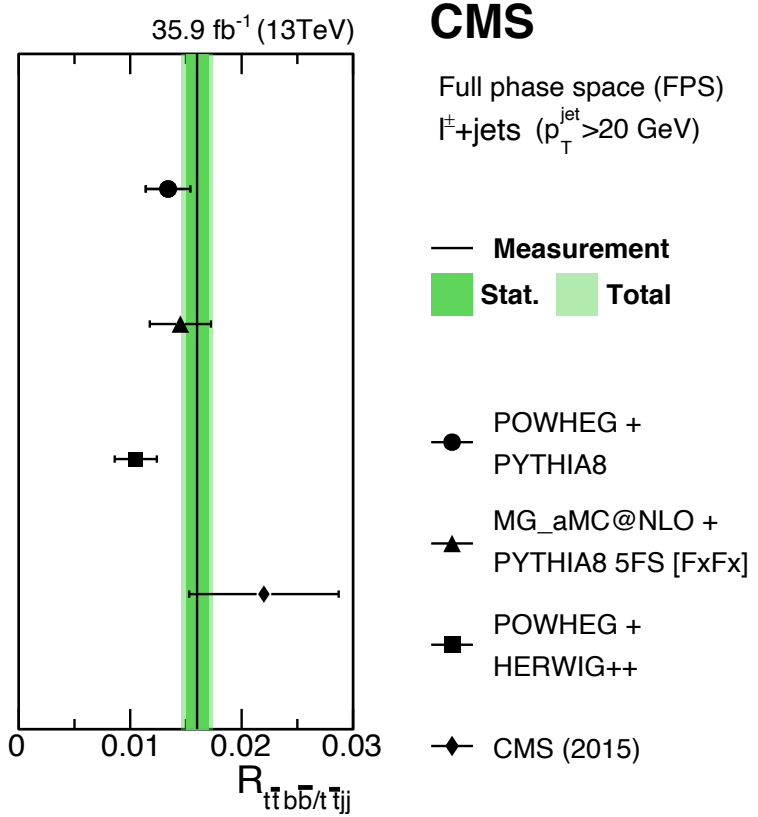
All hadronic channel, 35.9 fb^{-1} at 13 TeV

Semileptonic and dileptonic channels, 35.9 fb^{-1} at 13 TeV

Inclusive $t\bar{t}$ + $b\bar{b}$ and $t\bar{t}$ + jj

$t\bar{t}b\bar{b}$: tests of higher order calculations. Important background for $t\bar{t}H$ and $t\bar{t}t\bar{t}$
Not easy to model nor separate the signals of $t\bar{t}b\bar{b}$ and $t\bar{t}$jj

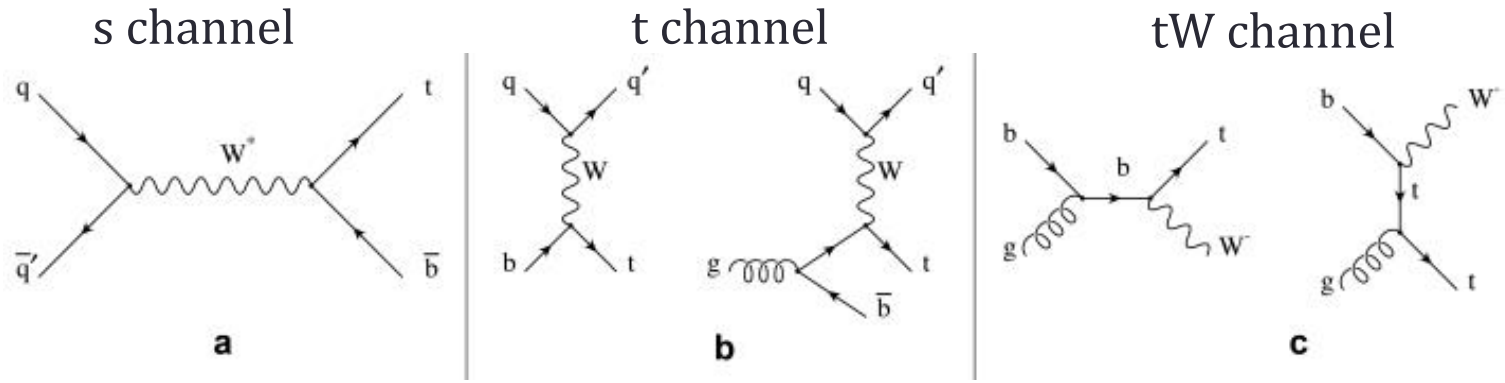


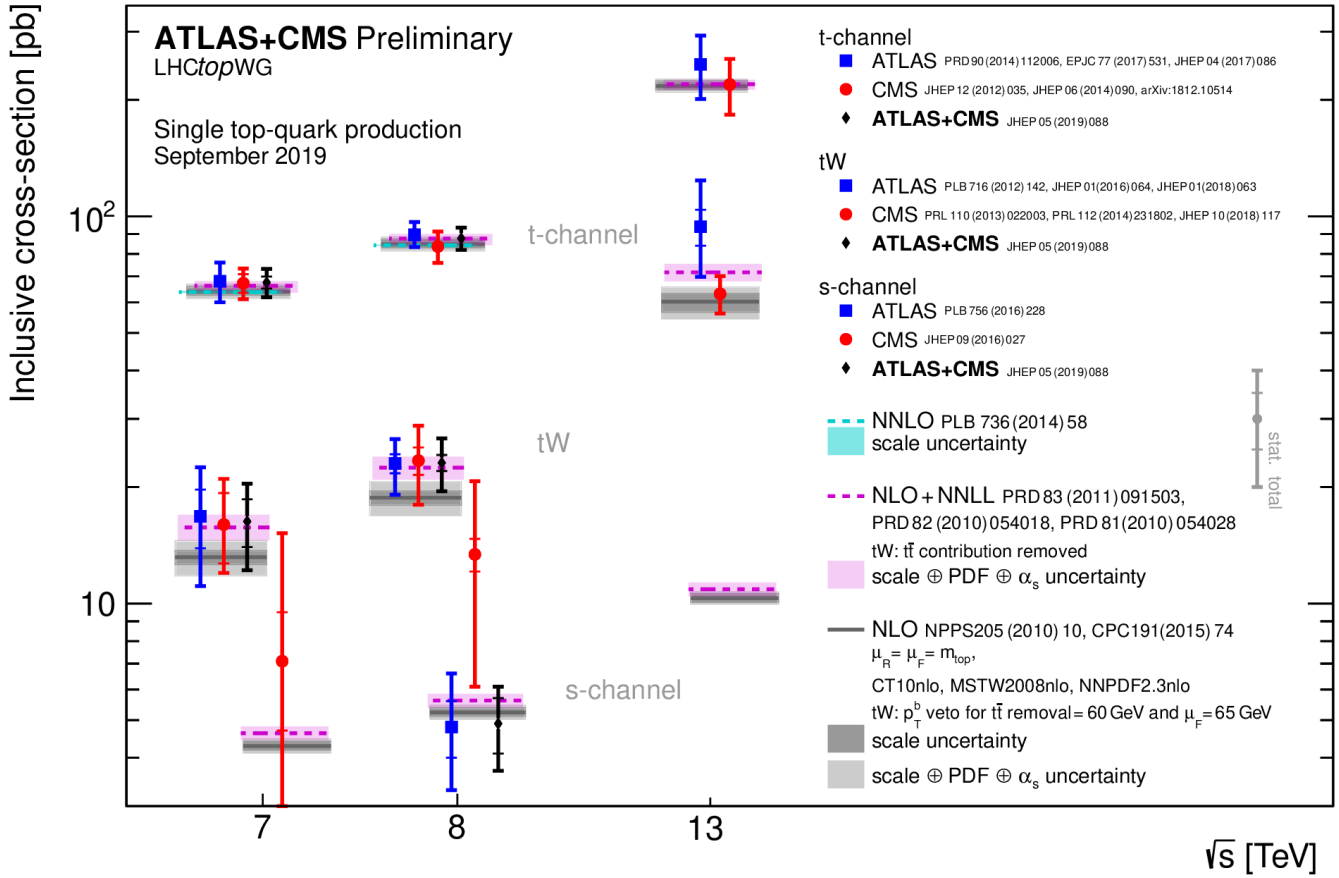


PLB 803 (2020) 135285

CMS-TOP-PAS-18-002

Electroweak production

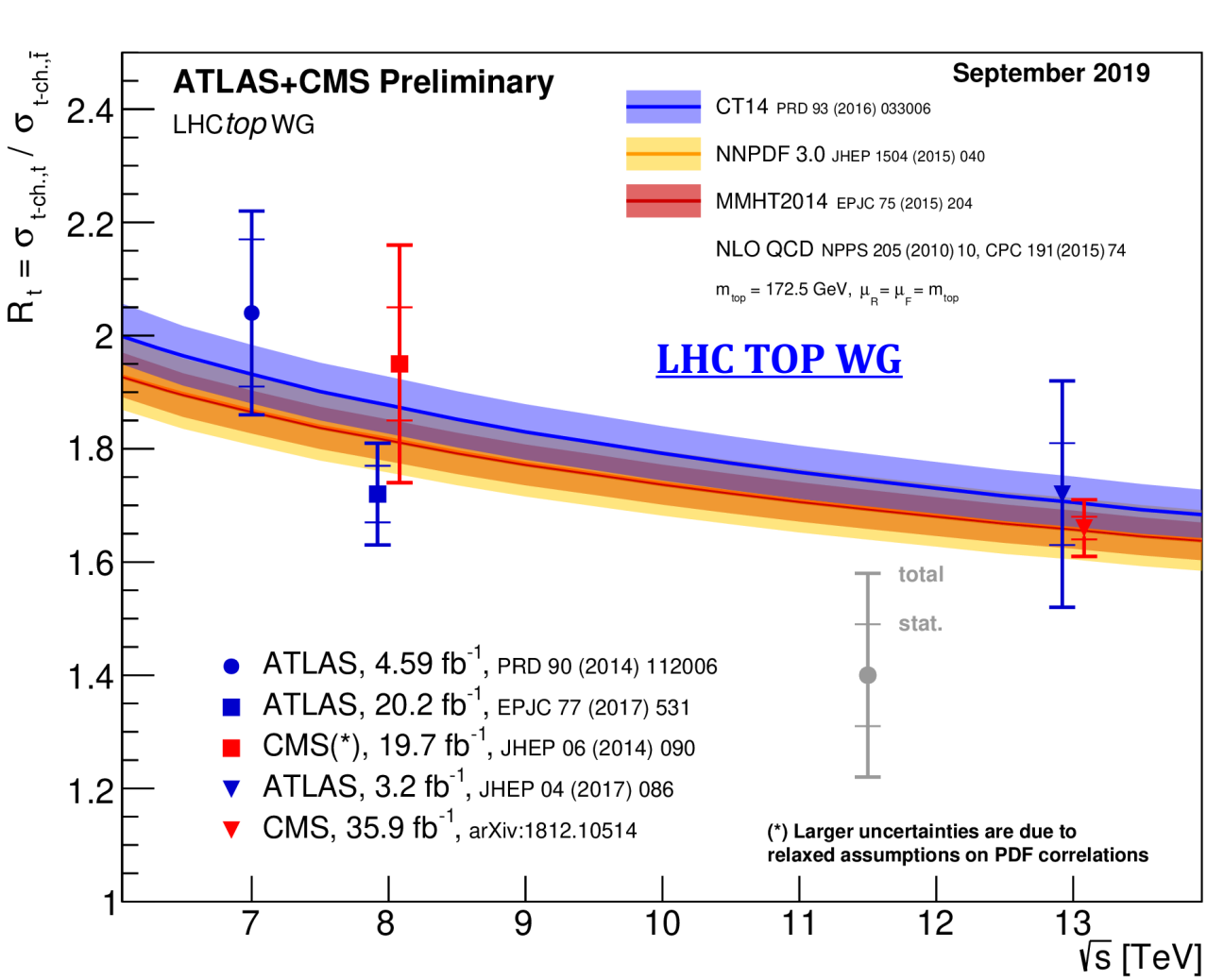


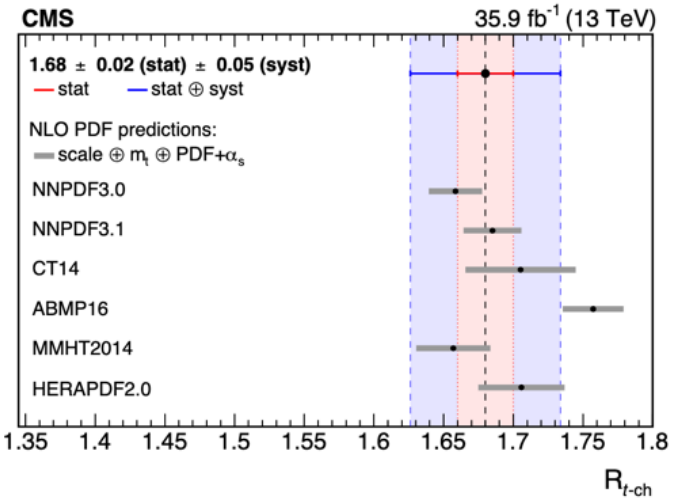


[LHC TOP WG]

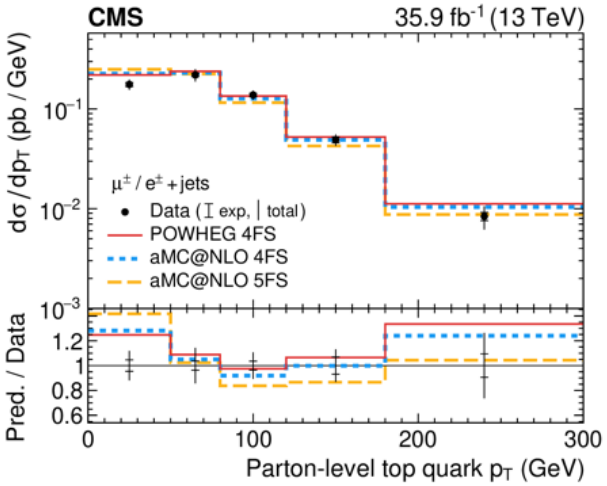
Ratio of single top to single antitop

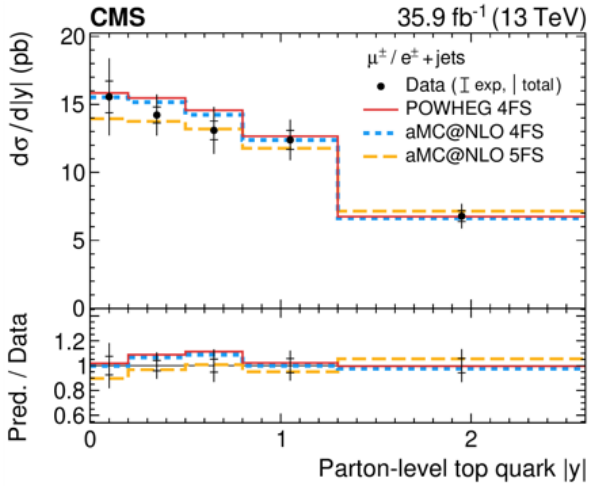
PLB 800 (2019) 135042

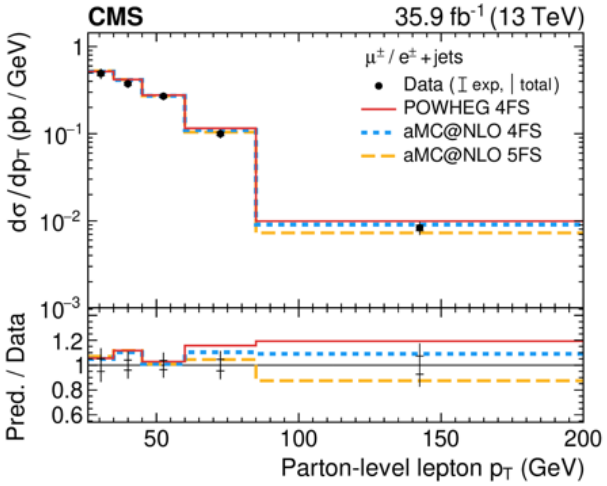


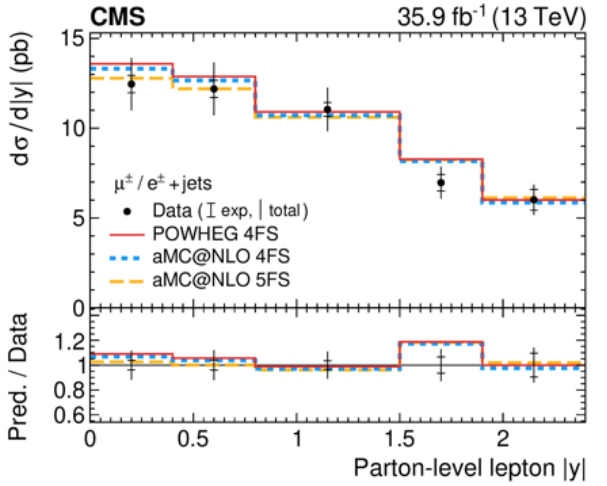


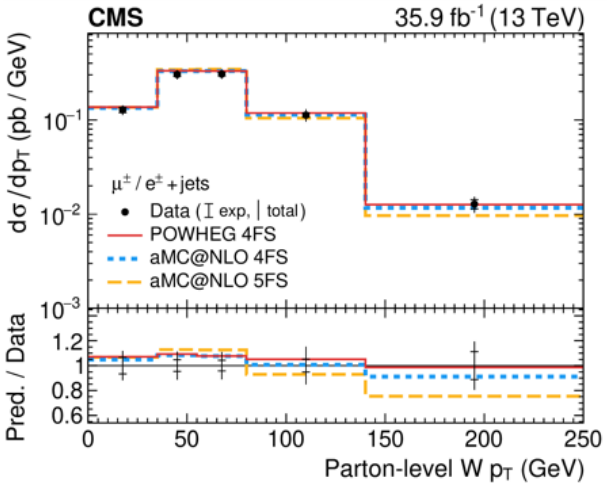
The ratio can be used to test the predictions from different PDF sets for their compatibility with data.

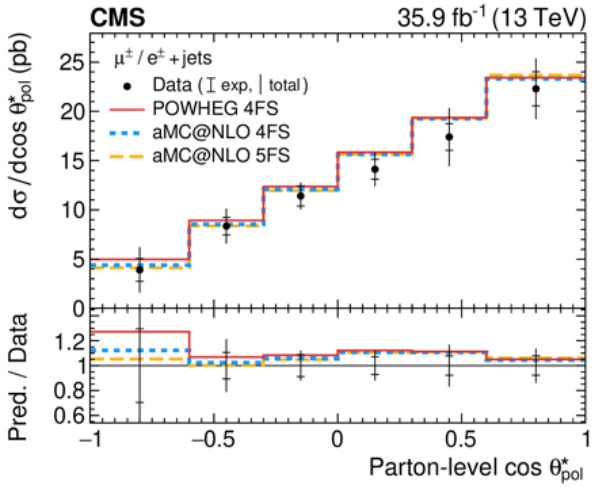












t-channel, 36 fb^{-1} at 13 TeV

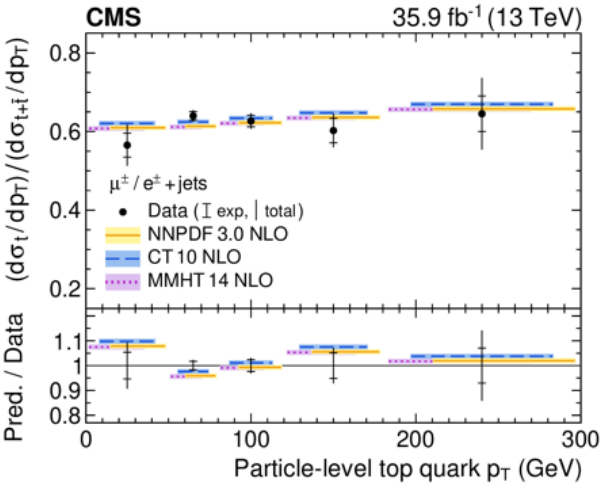
Differential cross sections in single top t-channel

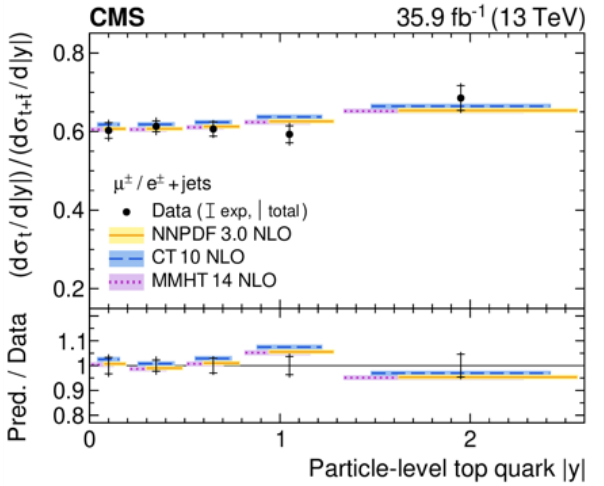
Also measured the spin asymmetry, sensitive to the top quark polarisation, from the differential distribution of the polarisation angle at parton level: 0.439 ± 0.062, in agreement with SM

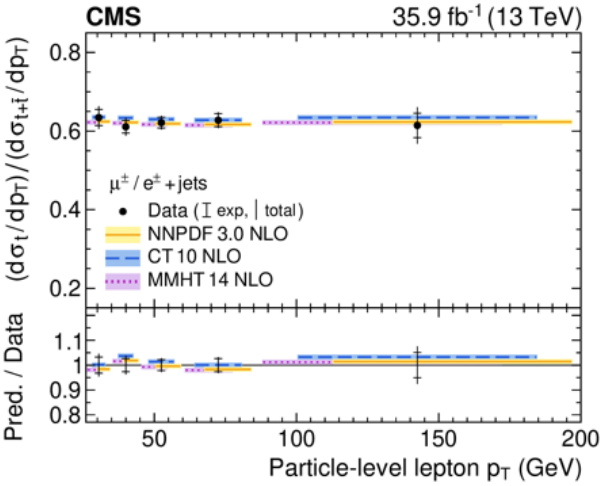
CMS-TOP-PAS-17-023, accepted by EPJC

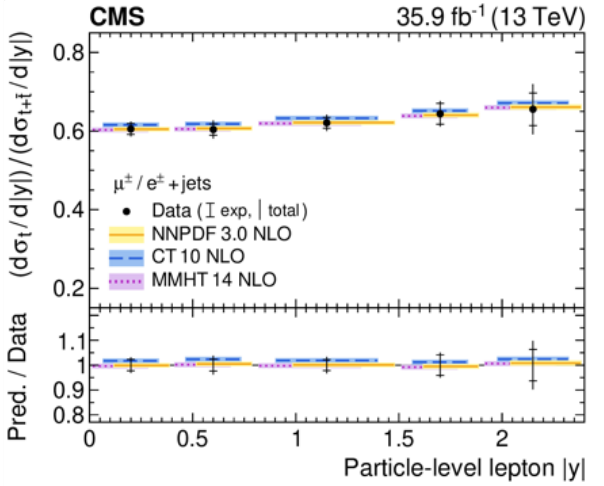
t-channel, 36 fb^{-1} at 13 TeV

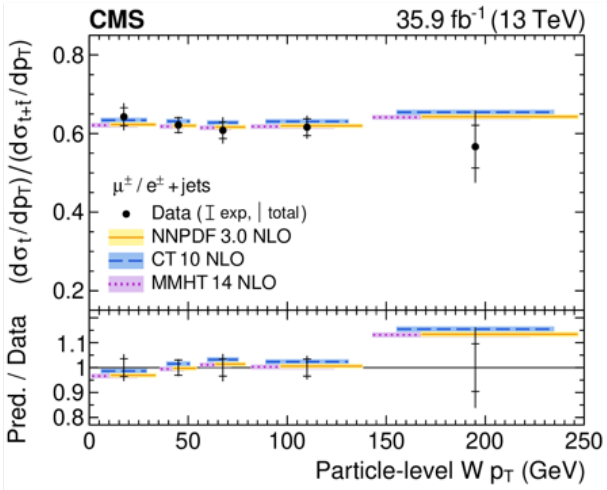
Differential cross sections in single top t-channel







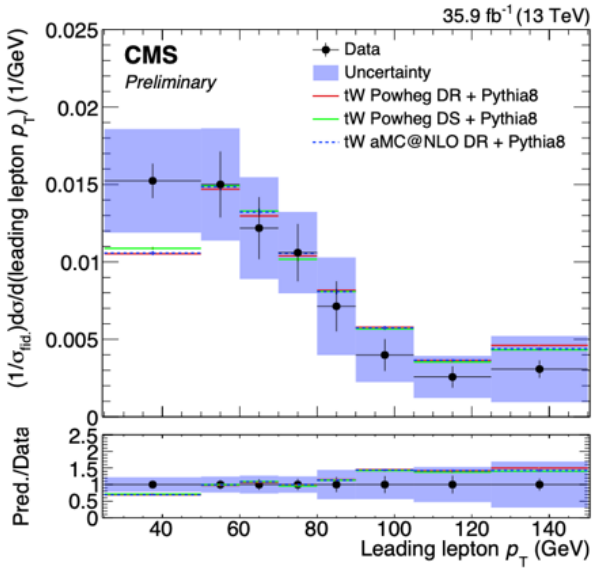


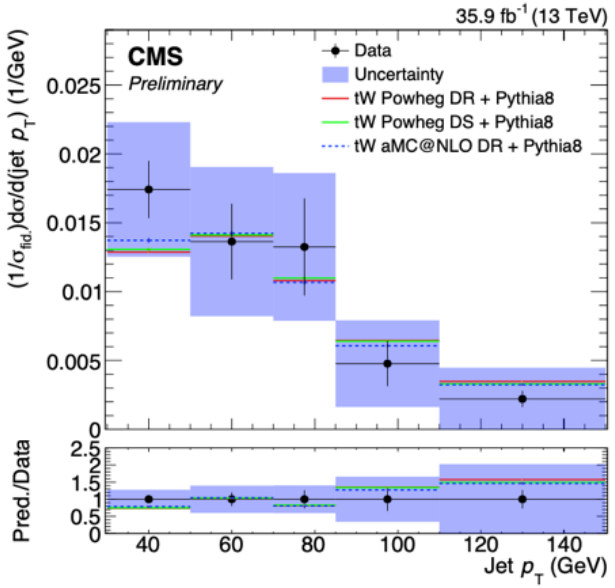


Measurement of top over top-antitop cross sections: sensitive to the ratio of the up to down quark content of the proton. Consistent with varius PDF sets.

CMS-TOP-PAS-17-023, accepted by EPJC

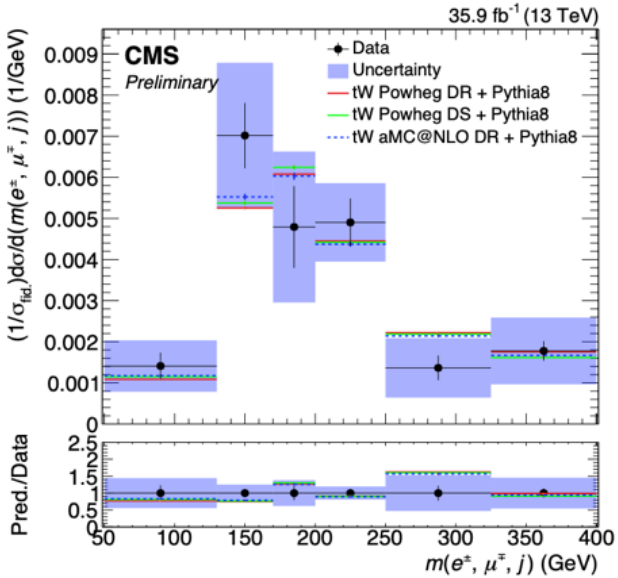
Differential cross sections in single top tW-channel

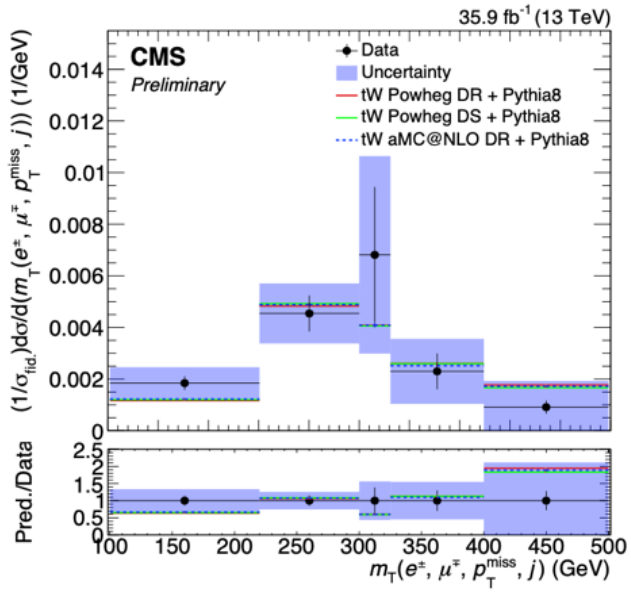




CMS-TOP-PAS-19-003

Good agreement with theoretical expectations



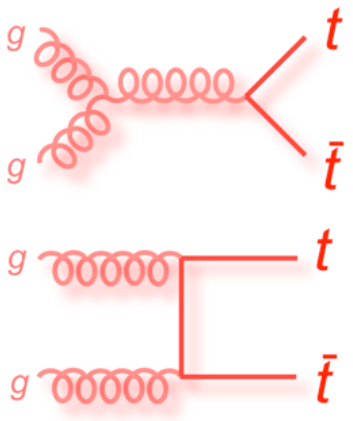


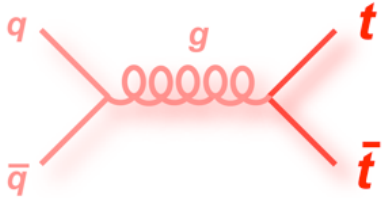
Conclusions

- Many results from pp collisions at 7, 8 and 13 TeV (and not only!)
  - It starts to be very hard to collect all measurements in a single talk!
- CMS was very prompt to analyse 13 TeV data and excellent results have been collected
  - Inclusive and differential cross sections for both $t\bar{t}$ and single top
- Many improvements are possible with more data and new tools
  - Improve both on statistics and systematics (theory, objects….)
  - Stay tuned for more results!

BACKUP SLIDES

Top-quark production at the LHC





tt pairs

$t\bar{t}$ pairs: dominant production mechanism (QCD)

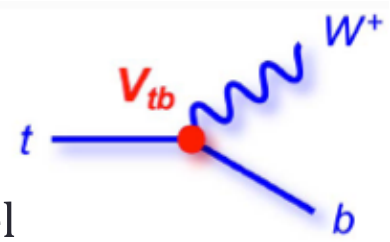
The LHC is a **top factory**!

Cross sections at 13 TeV:

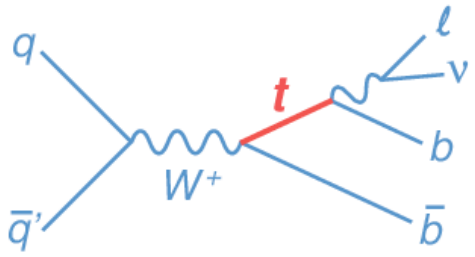
≈830 pb for $t\bar{t}$;

≈220 pb for single top t-channel

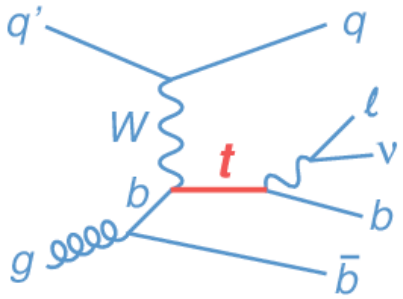
120M $t\bar{t}$ pairs and 30 M single top quarks!



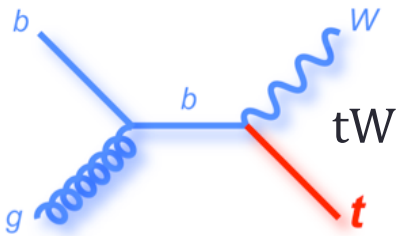
EWK production: single top



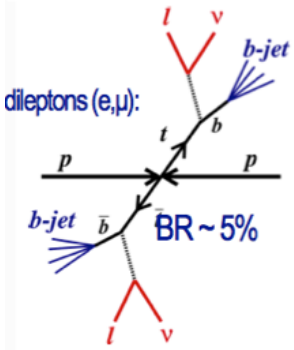
s channel

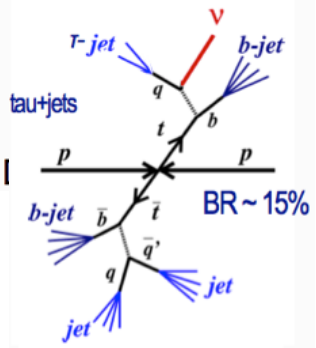


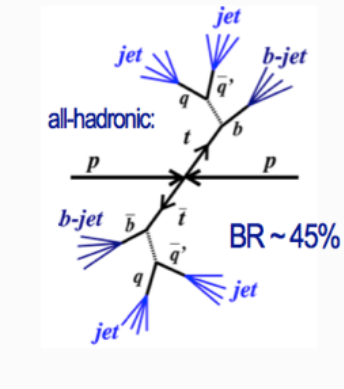
t channel

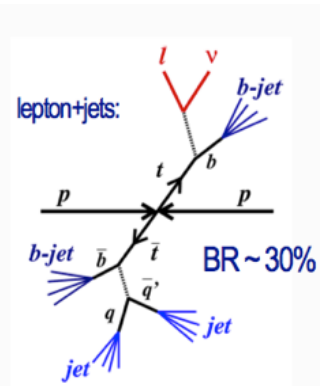


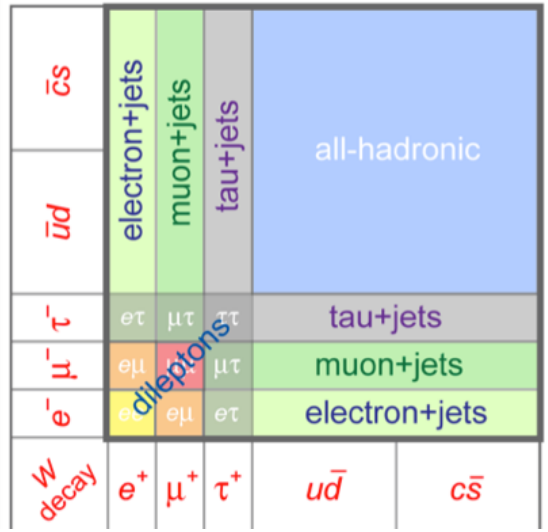
tW channel



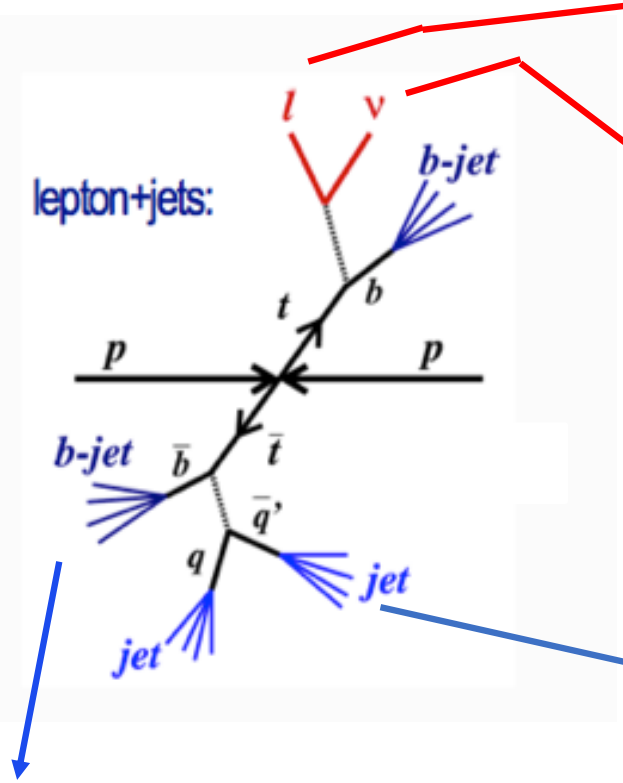








Example of selections



Electrons and muons: $p_T > 30$ GeV; $|\eta| < 2.4$; isolation

Neutrino: total missing p_T computed from the sum of all reconstructed particles; if needed: mass constrain to derive the neutrino 4-momentum

Jets: anti-k_T algorithm, with R=0.4; $p_T > 30$ GeV; $|\eta| < 2.4$

b jets: Deep CSV algorithm (70% efficiency for b jets, 12% mistag rate for c jets and 1% mistag rate for lighter jets)

Example of systematic uncertainties

Source	$R_{t\bar{t}b\bar{b}/t\bar{t}jj}$ [%]		$\sigma_{t\bar{t}jj}$ [%]	
	Dilepton	Lepton+jets	Dilepton	Lepton+jets
Lepton uncertainties				
Trigger	< 0.1	0.2	1.0	0.5
Lepton identification	0.6	0.2	1.1	1.3
Lepton energy scale	–	< 0.1	–	0.1
Jet uncertainties				
Jet energy resolution (JER)	0.4	0.3	0.3	0.7
Jet energy scale (JES)	1.5	1.2	2.9	3.6
b tagging uncertainties				
c flavor b tag lin.	2.2	2.0	1.0	0.3
c flavor b tag quad.	0.7	1.2	0.3	0.2
Heavy flavor b tag	4.0	0.1	0.5	0.9
Heavy flavor b tag lin.	0.9	0.4	1.5	0.5
Heavy flavor b tag quad.	2.0	0.3	1.5	0.8
Light flavor b tag	4.9	0.9	5.5	4.9
Light flavor b tag lin.	0.1	0.2	0.3	1.1
Light flavor b tag quad.	0.7	0.7	0.1	1.4
Theory uncertainties				
Initial state radiation (ISR)	1.0	2.2	2.5	1.2
Final state radiation (FSR)	0.8	0.7	2.5	5.9
ME-PS matching	0.5	< 0.1	1.8	1.9
Underlying events (UE)	1.5	1.5	0.4	1.4
Q^2 scale (ME)	0.1	0.4	0.1	1.4
top-p_T	0.2	0.4	1.6	0.3
Ratio $R^{MC}_{t\bar{t}bj/t\bar{t}b\bar{b}}$	1.4	0.2	1.3	0.7
Other uncertainties				
Pileup	0.7	0.2	1.3	0.1
Backgrounds	0.3	2.0	0.7	1.2
Simulated sample size	1.5	2.8	0.1	2.2
Luminosity	0.2	0.5	2.6	3.1
Total	8.0	5.5	8.8	10.0

Example from the cross section measurement of ttbb and ttjj in the semileptonic and dileptonic channels