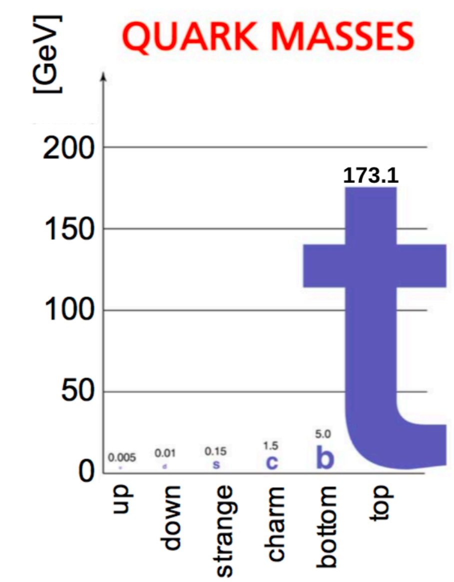
Inclusive $t\bar{t}$ + single top (SM) cross-section measurements

12th International Workshop on Top Quark Physics (TOP2019)
IHEP, Beijing (China) - September 22 – 27, 2019

C. Escobar on behalf of the ATLAS and CMS Collaborations

Instituto de Física Corpuscular (IFIC) - CSIC/UV

Introduction



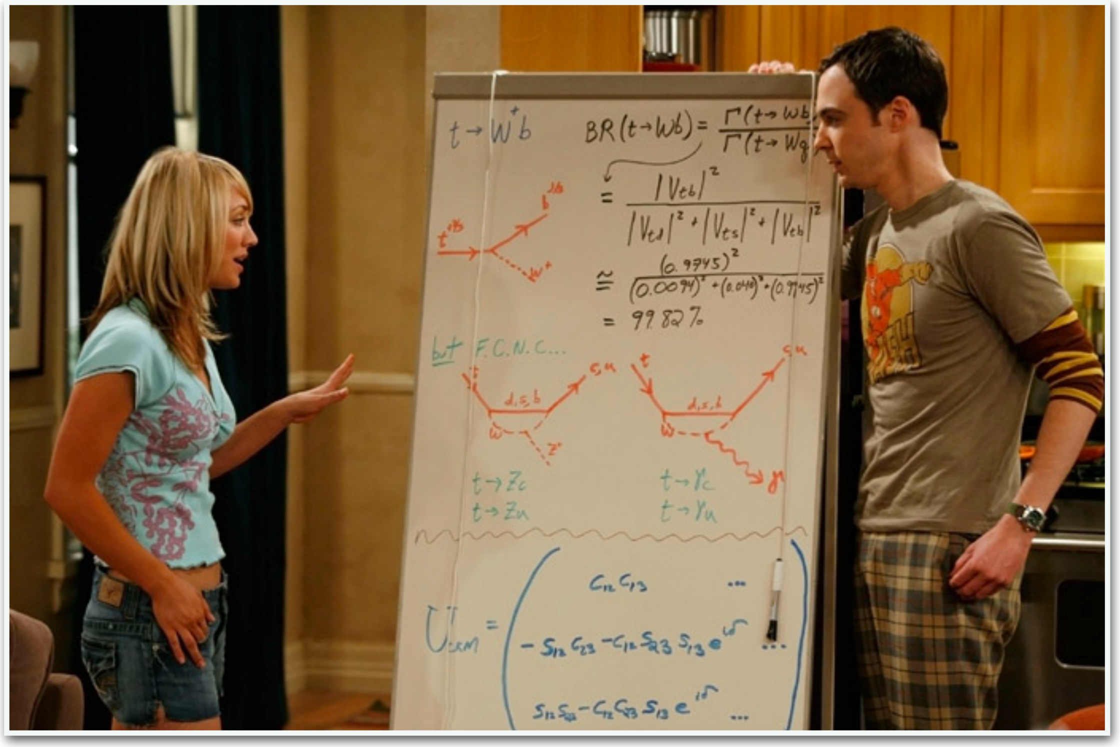
The **top quark** is the heaviest known elementary particle.

At hadron colliders, top quarks are produced:

- Predominantly in **pairs** ($t\bar{t}$) via the flavour-conserving strong interaction.
- Alternatively, **singly** through the electroweak interaction.

The top quark was discovered by CDF/D0 at Tevatron in 1995 in $t\bar{t}$ events.

- The single top-quark production was discovered in 2009 by CDF/D0 and observed in 2011 by ATLAS/CMS.



Why is interesting?

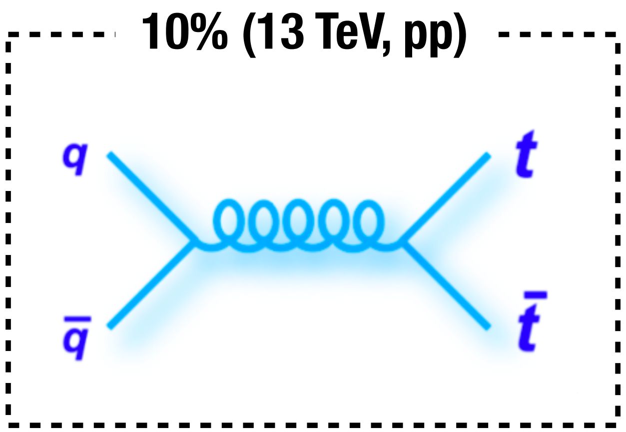
- Unique quark:
    - Decays before hadronising.
    - Most of its properties can be directly measured.
- Allows to test pQCD at NNLO precision (fixed-order).
- Constrains proton PDFs, α_S, top-quark pole mass.
- Window to New Physics.
- Main background in plenty of BSM searches.
- The tWb vertex can be studied at production and the decay (e.g. direct measurement of CKM element $|V_{tb}|$)

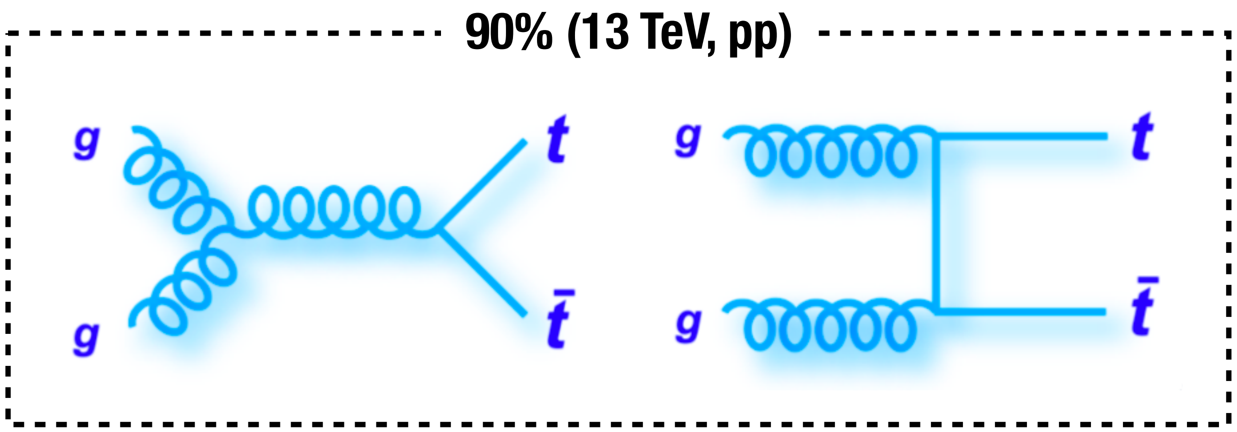
Will focus on most recent publications using Run 1 data (7 and 8 TeV) and Run 2 data (13 TeV)

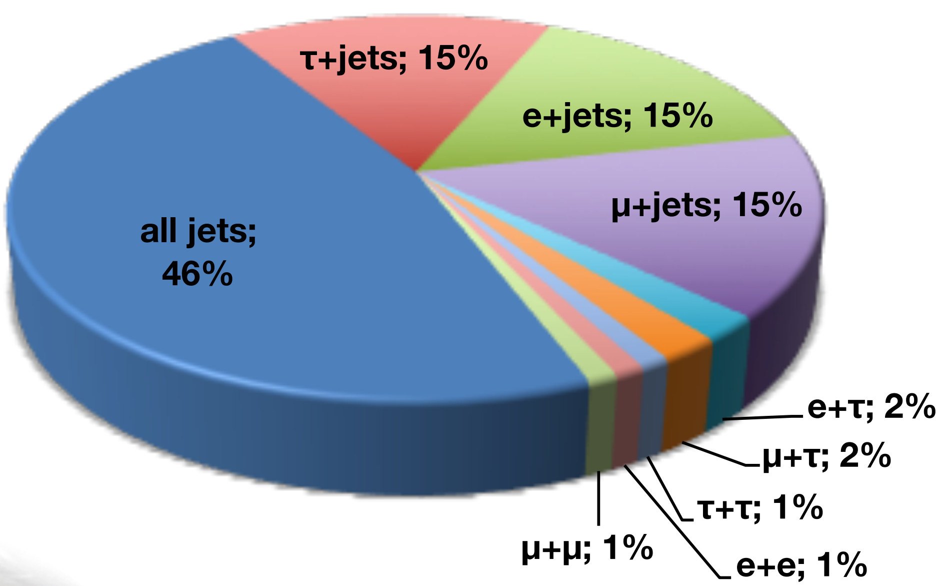
- **$t\bar{t}$ inclusive production cross-section analyses:**
  - CMS $t\bar{t}$ (dilepton) (EPJC 79 (2019) 368)
  - CMS $t\bar{t}$ (lepton+ had. τ) (CMS-PAS-TOP-18-005)
  - ATLAS $t\bar{t}$ (dilepton (eμ)) at 13 TeV (ATLAS-CONF-2019-041) new
  - ATLAS $t\bar{t}$ (lepton+jets) at 13 TeV (ATLAS-CONF-2019-044) new

- **single top-quark inclusive production cross-section analyses:**
  - ATLAS+CMS combinations of single top-quark production cross-section measurements and combinations of $|f_{LV}V_{tb}|$ determinations from Run 1 (JHEP 05 (2019) 088).
  - CMS t-channel at 13 TeV (arXiv:1812.10514)
  - ATLAS t-channel at 13 TeV (JHEP 04 (2017) 086)
  - CMS tW (dilepton) at 13 TeV (JHEP 10 (2018) 117)

Inclusive $t\bar{t}$ cross-section measurements







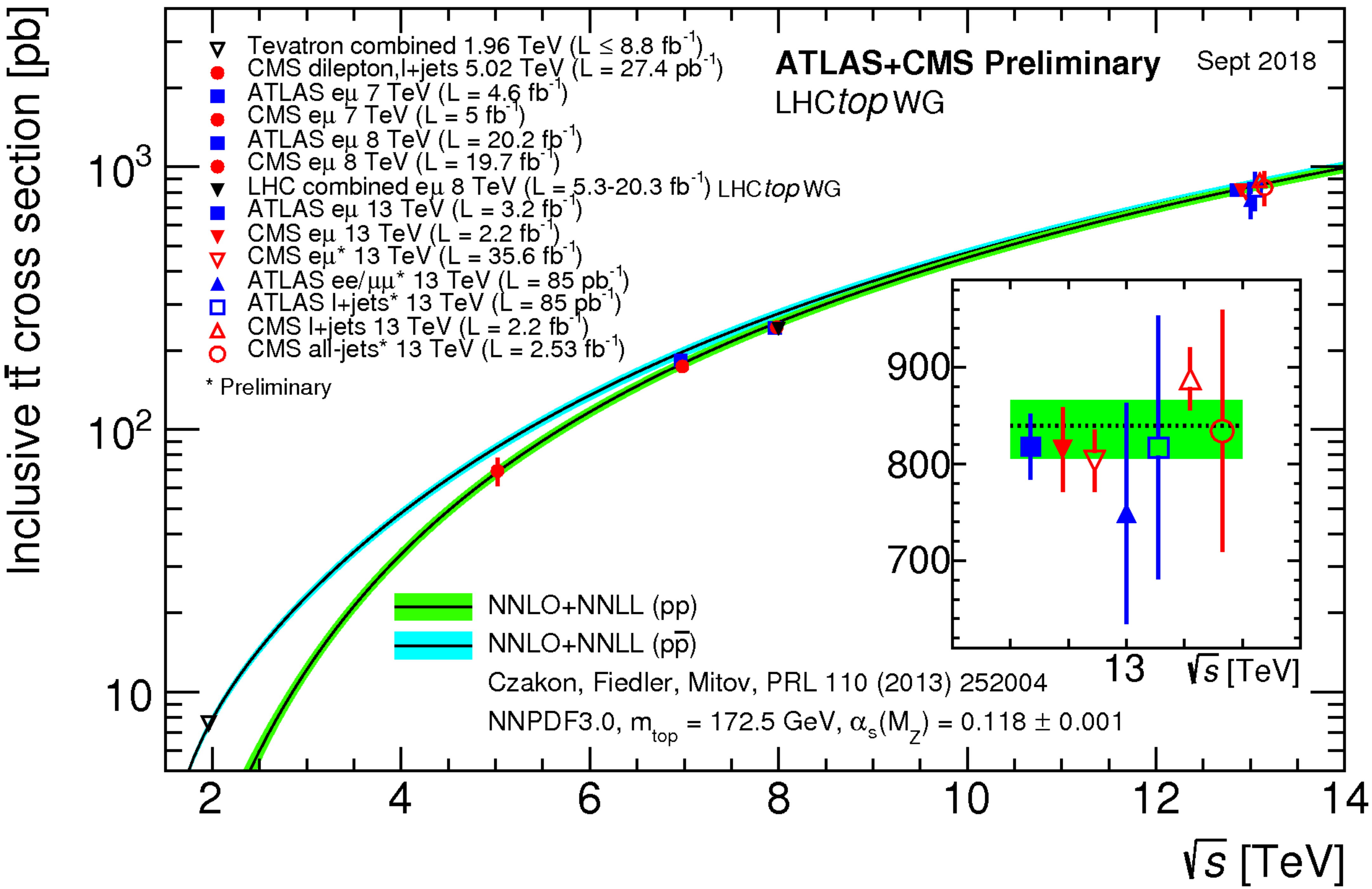
NNLO+NNLL

$\sigma_{t\bar{t}}$ (7 TeV) = $177.3^{+3.7}_{-3.2}$ pb	6.6%
$\sigma_{t\bar{t}}$ (8 TeV) = $252.9^{+15.3}_{-16.3}$ pb	6.2%
$\sigma_{t\bar{t}}$ (13 TeV) = $831.8^{+45.5}_{-49.9}$ pb	5.7%

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

Production cross-section measurements by ATLAS and CMS during Run 1 and 2 from $t\bar{t}$ process.

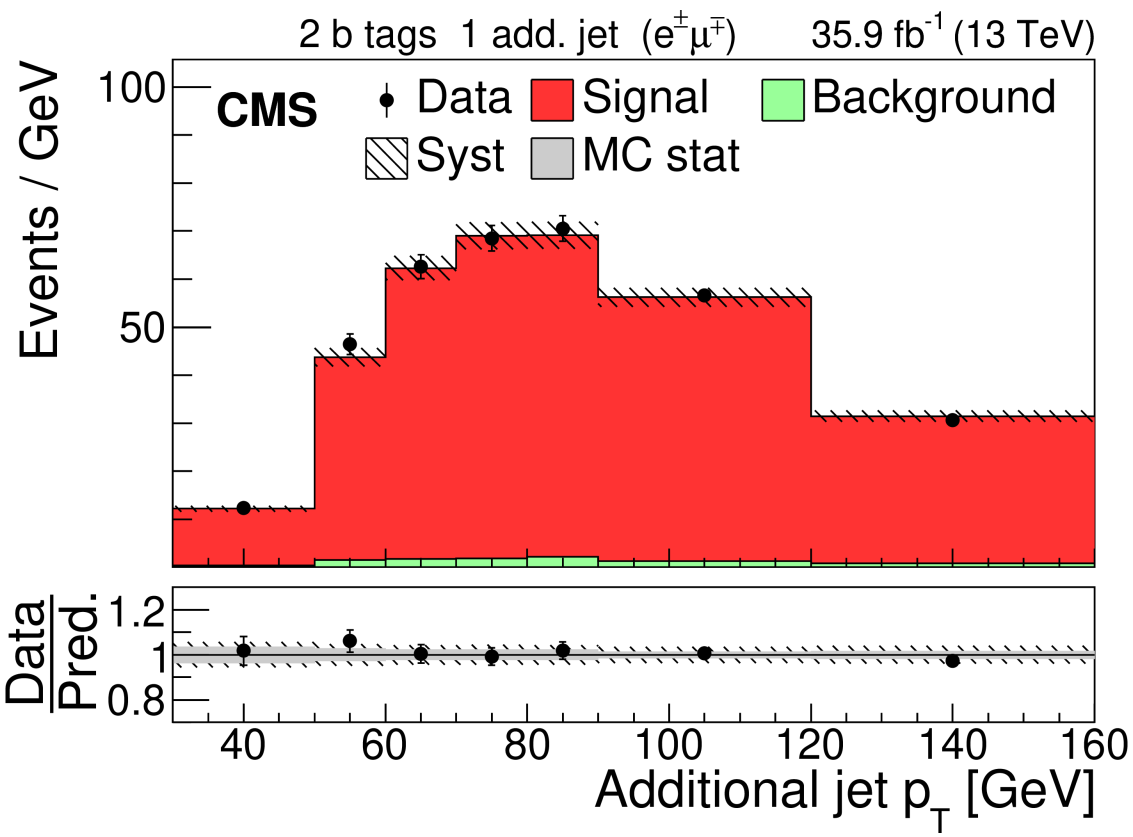
- Theory band: uncertainties due to μ_R and μ_F scale, PDF and the strong coupling.



- **All measurements in agreement with the SM predictions.**

EPJC 79 (2019) 368
35.9 fb^{-1}, 13 TeV

- Event selection: isolated opposite-sign dilepton pairs in ee/μμ/eμ categories.
- Events classified according to the number of jets (N_{jets}) and number of b-tagged jets (N_{bjets}).
  - 12 regions in N_{jets} and N_{bjets} categories → sensitivity to constrain modelling uncertainties.
- Profile likelihood fit (PLH) in the visible region and extrapolated to the full phase space.
  - Fitted distributions: jet p_T in regions of lepton flavour and jet and b-tag multiplicities.



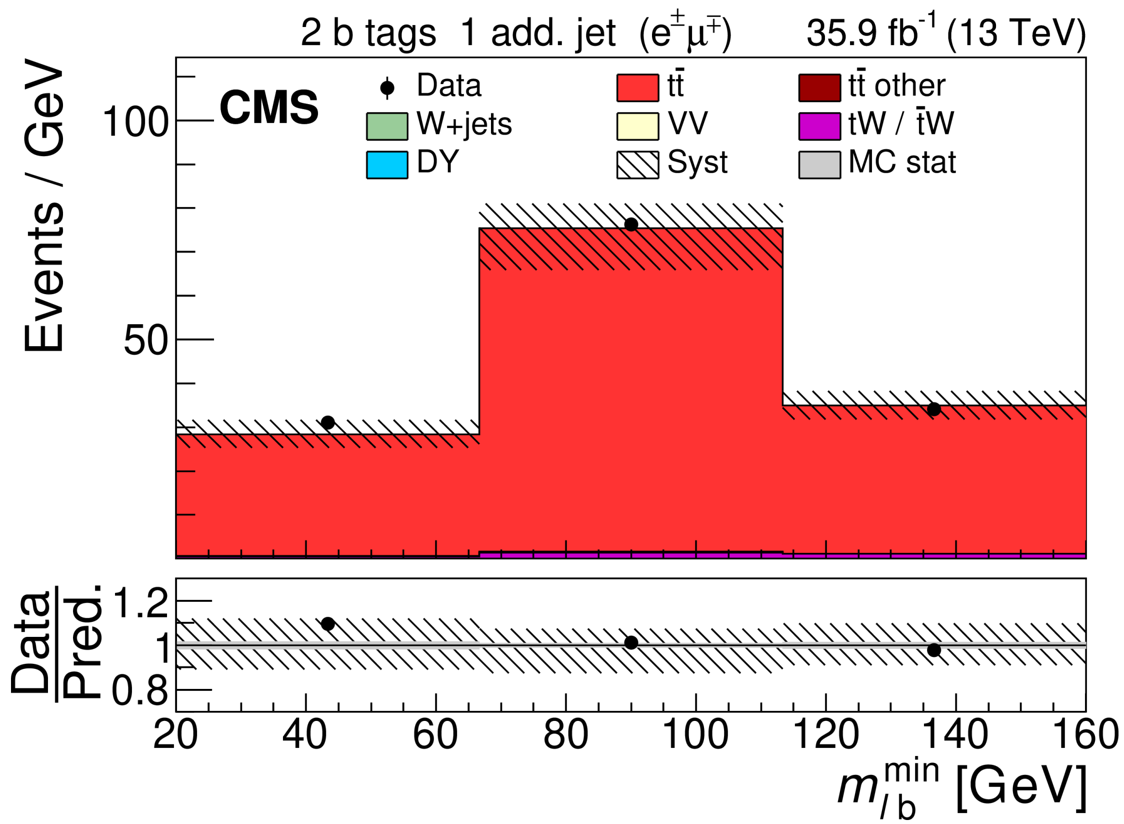
- Systematic uncertainties are taken as nuisance parameters and constrained in the fit.
- Dominant uncertainties:
  - Luminosity (2.5%).
  - Lepton id. and isolation (2.0%). **Constrained using ee/μμ/eμ events**
  - PDF (1.1%).

Lepton isolation efficiencies directly measured in the $t\bar{t}$ dominated eμ+b-jet samples

- Fit result (m_t^{MC} = 172.5 GeV): **$\sigma_{t\bar{t}}$ (ll) = 803 ± 2 (stat.) ± 25 (syst.) ± 20 (lumi.) pb.** **4.0%**
- **In agreement with the NNLO+NNLL prediction (unc. 5.7%).**

Additionally, another fit is performed to extract simultaneously the $t\bar{t}$ cross-section and the m_t^{MC}.

- Same number of jets and number of b-tagged jets categories as in the main measurement.
- The distribution of m_{lb}^{min} is used to maximases the sensitivity to m_t^{MC}.

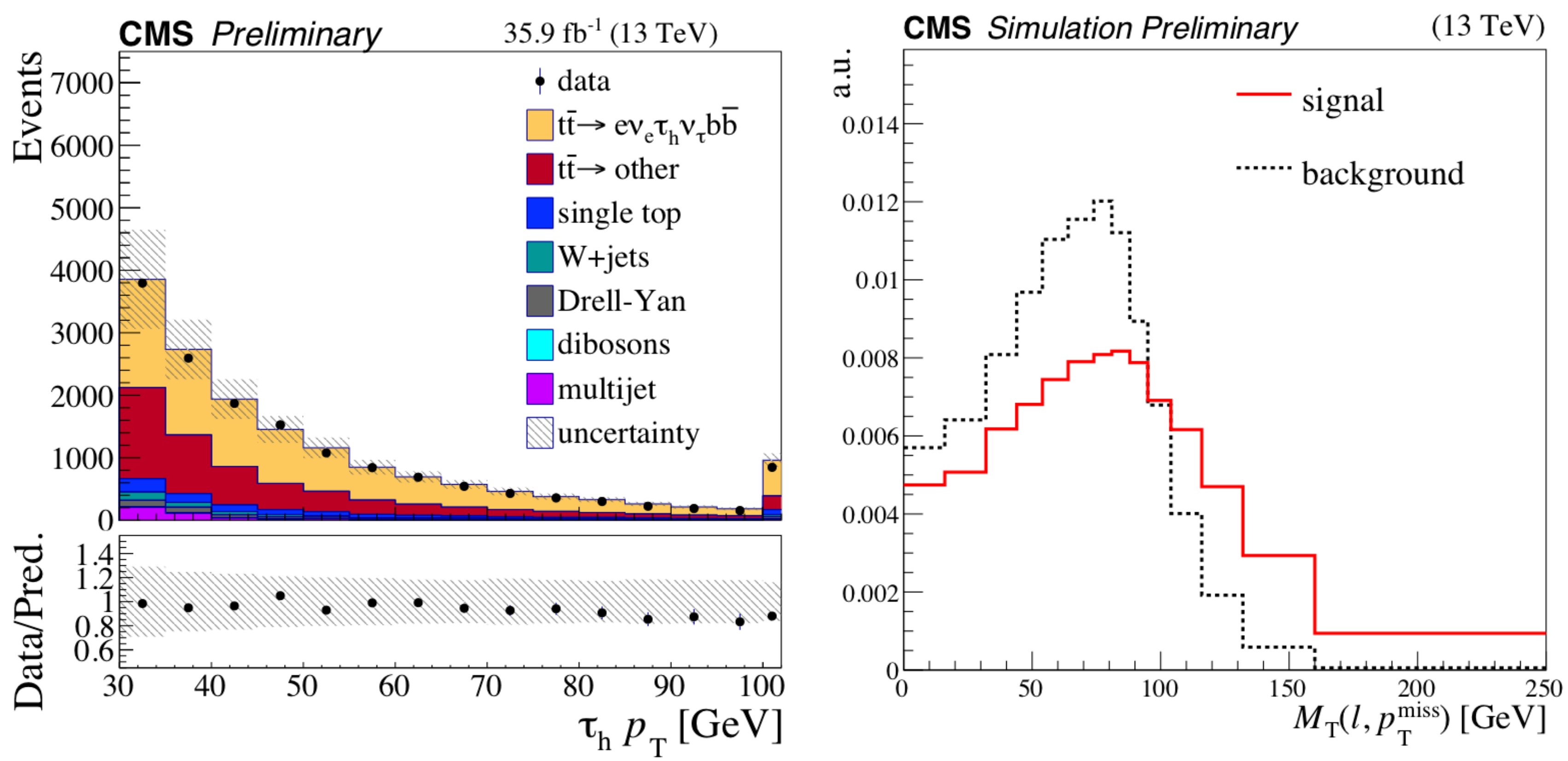


- Systematic uncertainties are taken as nuisance parameters and constrained in the fit.
- Dominant uncertainties:
  - Luminosity (2.5%).
  - Lepton id. and isolation (2.2%).
  - NLO generator modelling (1.2%).
  - MC statistics (1.2%).

4.3% 0.4%

- Fit result: **$\sigma_{t\bar{t}}$ (ll)= 815 ± 2 (stat.) ± 29 (syst.) ± 20 (lumi.) pb** and **m_t^{MC} = 172.33 ± 0.14 (stat.) $^{+0.66}_{-0.72}$ (syst.) GeV.**
  - Correlation between $t\bar{t}$ cross-section and m_t^{MC} is 12%.
  - Used to extract m_t and α_S using fixed-order calculations (see backup slides).
- **In agreement with the NNLO+NNLL prediction (unc. 5.7%).**

- Event selection: 1 lepton (e or μ) and ≥ 3 jets (≥ 1 b-jet + one is identified as a hadronically decaying τ lepton).
- PLH to $m_T(l, p_T^{miss})$ in the two lepton (e, μ) categories.



- Dominant uncertainties:
  - $\tau_{had.}$ jet identification (4.5%).
  - Luminosity (2.5%).
  - $t\bar{t}$ background norm. (2.3%).
  - Pile-up (2.3%).

- Fit result: **$\sigma_{t\bar{t}}$ ($l\tau_{had.}$) = 781 ± 7 (stat.) ± 62 (syst.) ± 20 (lumi.) pb.** 8.4%
- **In agreement with the NNLO+NNLL prediction (unc. 5.7%).**

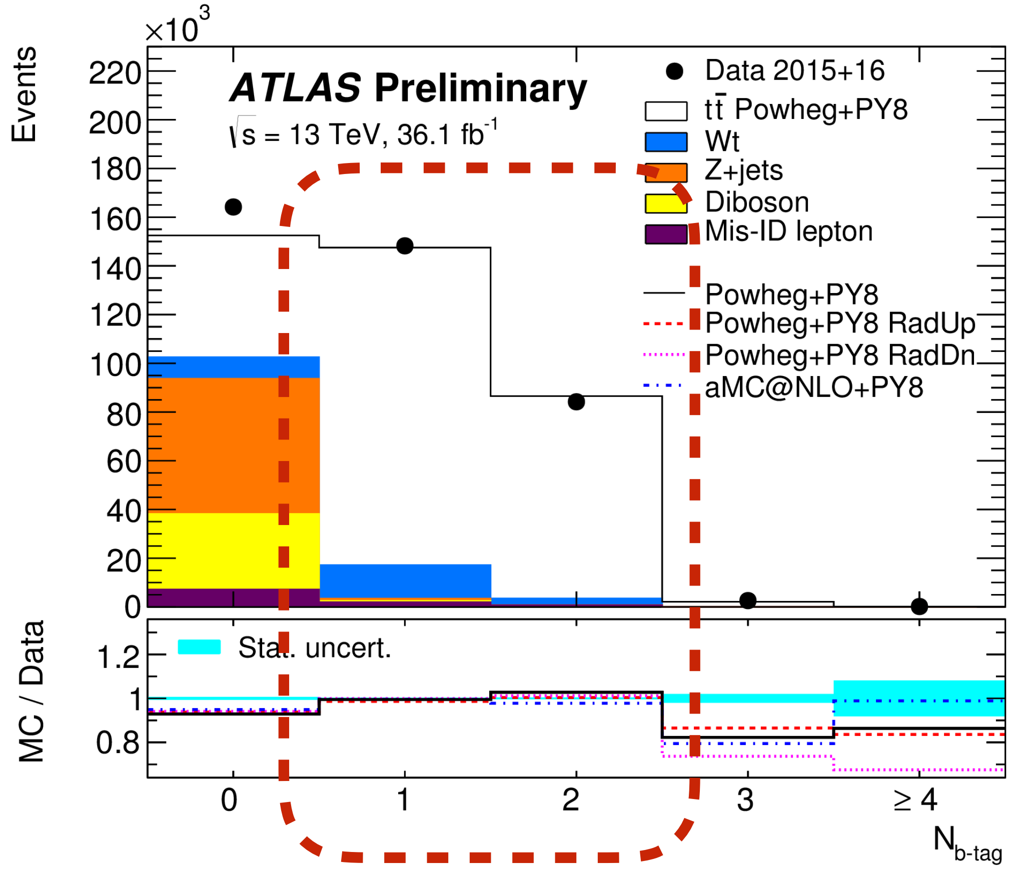
Additionally…

- **$R_{l\tau had/ll}$ = 0.973 ± 0.009 (stat.) ± 0.066 (syst.)**
  - **Consistent with unity (lepton flavour universality).**
- **$\Gamma_{t\rightarrow\tau\nu\tau b}/\Gamma_{total\ (ll)}$ = 0.1050 ± 0.0009 (stat.) ± 0.0071 (syst.).**
  - **Consistent with the SM expectation value.**

- Event selection: isolated opposite-sign eμ pair and 1 or 2 b-jets.
- Cross-section measured by counting events:
  - Double-tagging technique suppress jet/b-tag uncertainties.

$$N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\rm bkg}$$
$$N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{\rm bkg}$$

- Analyse 2015 and 2016 data separately
  - Combine using BLUE, taking into account uncorrelated uncertainties, in particular on luminosity
  - Combination gives 9% smaller uncertainty than that from all data treated as one sample



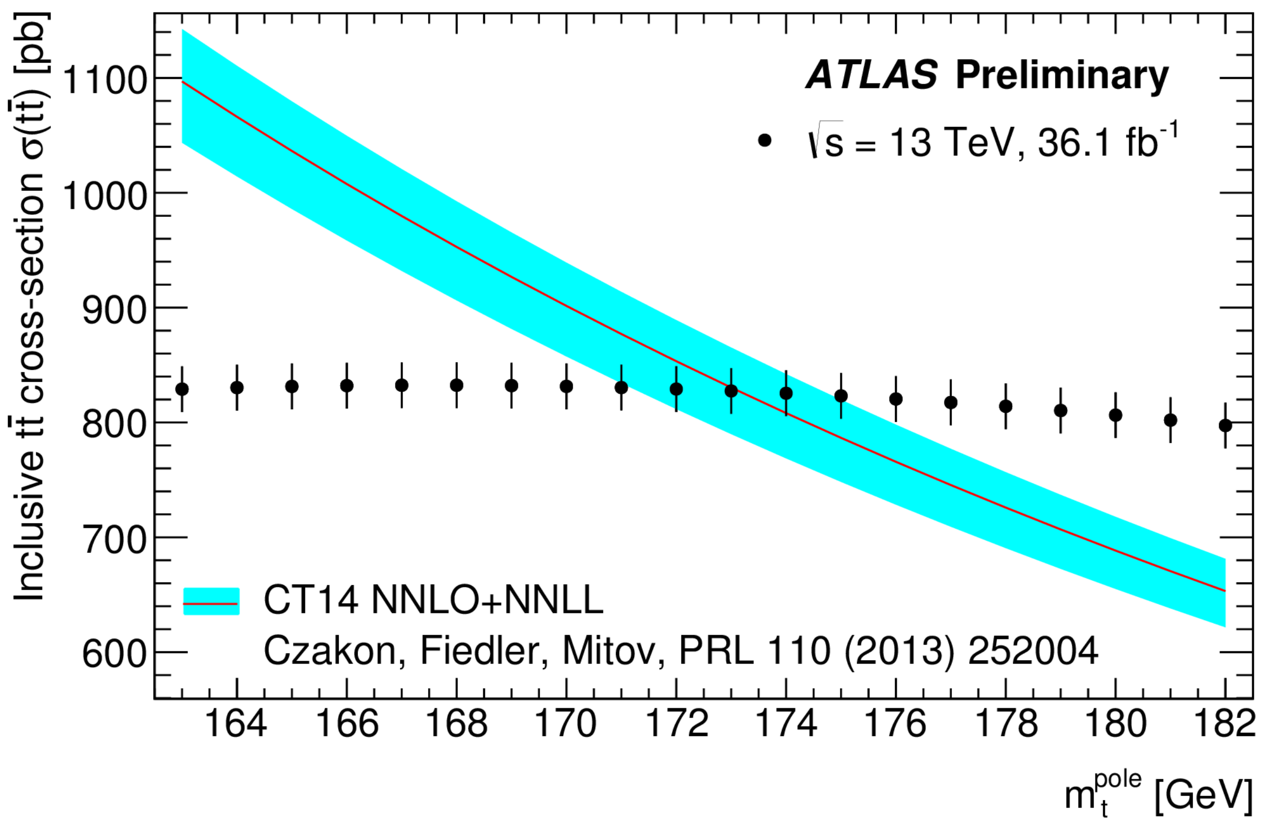
- Dominant systematics:
  - Luminosity (1.9%).
  - Background cross-section (single top-quark) (0.5%).
  - $t\bar{t}$ shower/hadronisation modelling (0.5%).
  - $t\bar{t}$ ISR/FSR modelling (<0.5%).

- Fit result: **$\sigma_{t\bar{t}}$ (ll) = 826 ± 3.6 (stat.) ± 11.5 (syst.) ± 15.7 (lumi.) ± 1.9 (beam) pb.** 2.4%
  - Also measure fiducial cross-section with same precision.
- **In agreement with the NNLO+NNLL prediction (unc. 5.7%).**

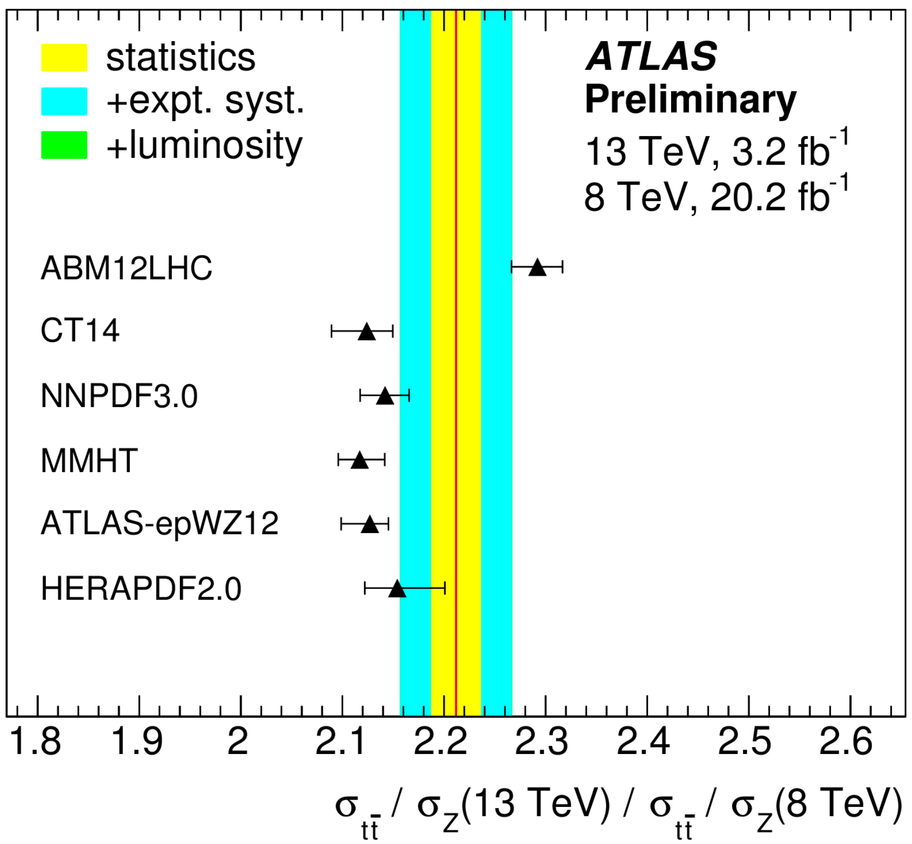
Additionally…

- Extraction of m_t^{pole} from $\sigma_{t\bar{t}}$ (ll) using prediction with the CT14 PDF set: $\mathbf{m_t^{pole} = 173.1^{+2.0}_{-2.1}}$ **GeV.**

  Experimental unc. ~1 GeV, rest due to prediction



- Ratios of cross-sections at different energies (combined with previous measurements)



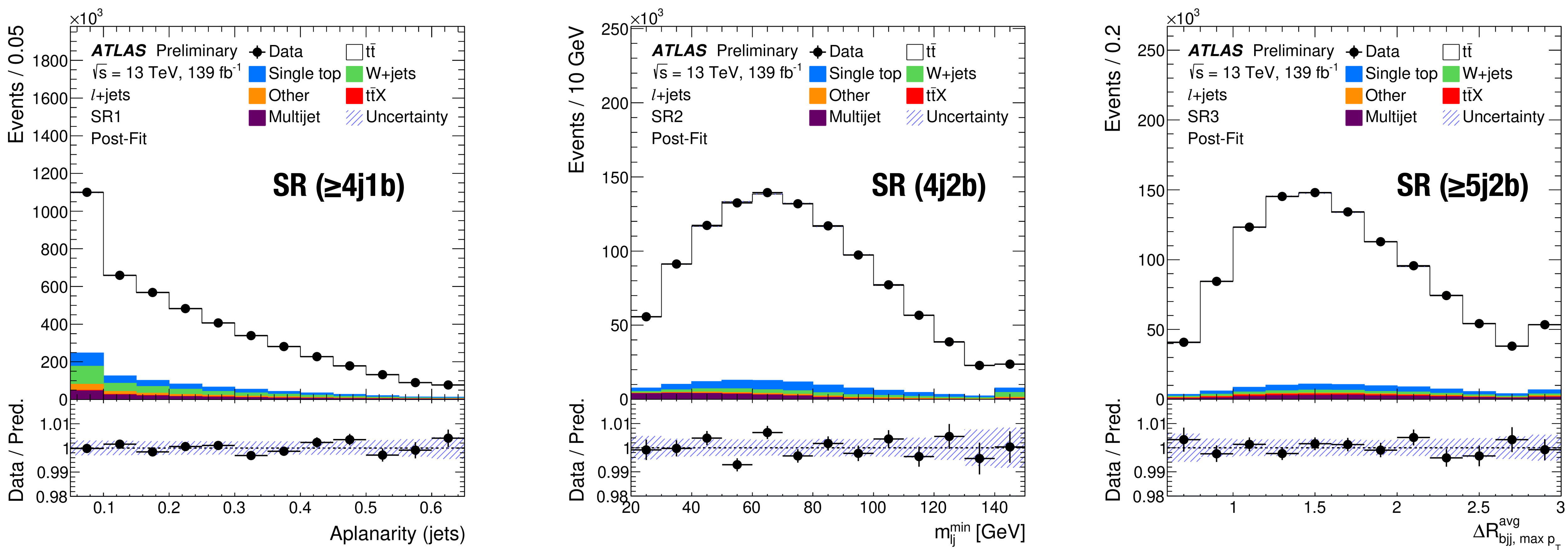
- $\sigma_{t\bar{t}}$(13/7) and $\sigma_{t\bar{t}}$(13/8) **3.9 and 3.6%**
- Double ratios $t\bar{t}$/Z (13/7 and 13/8) **3.0 and 2.5%**

- **In agreement with all the predictions within two standard deviations, with the exception of ABM12LHC for $R_{t\bar{t}/Z}$**
  (attributed to lower gluon density at high Bjorken-x in ABM12LHC compared to the other considered PDF sets)

new

ATLAS-CONF-2019-044
$139\ fb^{-1}$, 13 TeV

- Event selection: 1 lepton (e or μ) and ≥ 4 jets (≥ 1 b-jet).
- PLH fit to different distributions (small sensitivity to $t\bar{t}$ modelling unc.) in the 3 regions (≥4j1b, 4j2b, ≥5j2b).

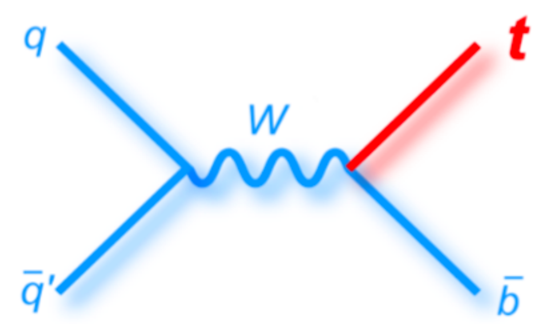


- Systematic uncertainties are taken as nuisance parameters and constrained in the fit.
- Dominant uncertainties:
  - $t\bar{t}$ shower/hadronisation modelling (2.7%).
  - $t\bar{t}$ scale variation (2.6%).
  - Jet reconstruction (2.4%).
- Fit result: **$\sigma_{t\bar{t}}$ (l+jets) = 829.7 ± 0.4 (stat.) $^{+35.3}_{-34.5}$ (syst.) pb.** 4.3%
  - Also measure fiducial cross-section (separate fit) and extrapolated to the full phase space with similar precision.
- **In agreement with the NNLO+NNLL prediction (unc. 5.7%).**

Inclusive single top-quark cross-section measurements

t-channel (~73% at LHC)

Golden channel



NLO

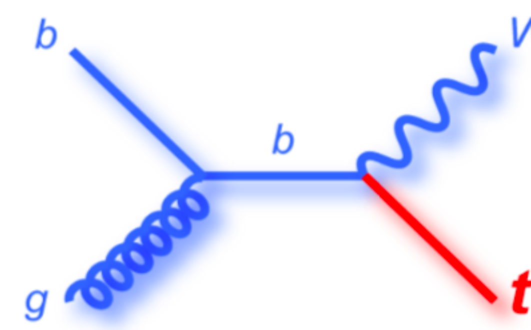
$\sigma_{t\text{-ch}}$ (7 TeV) = 63.9 $^{+2.9}_{-2.5}$ pb   4.5%

$\sigma_{t\text{-ch}}$ (8 TeV) = 84.7 $^{+3.7}_{-3.2}$ pb   4.4%

$\sigma_{t\text{-ch}}$ (13 TeV) = 217.0 $^{+9.0}_{-7.7}$ pb   4.1%

tW (~24% at LHC)

Observed at the LHC



approx. NNLO

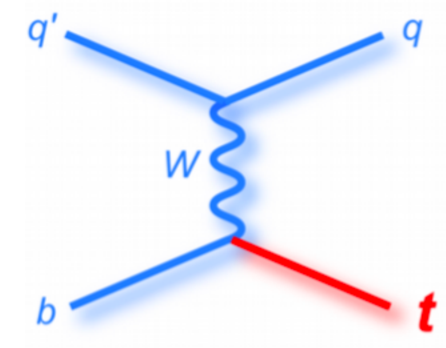
σ_{Wt} (7 TeV) = 15.7 ± 1.2 pb   7.6%

σ_{Wt} (8 TeV) = 22.4 ± 1.5 pb   6.7%

σ_{Wt} (13 TeV) = 71.7 ± 3.8 pb   5.3%

s-channel (~3% at LHC)

Challenging at the LHC



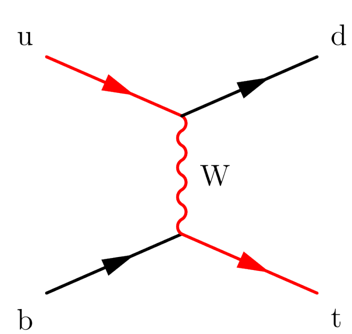
NLO

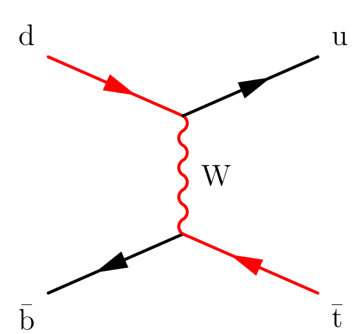
$\sigma_{s\text{-ch}}$ (8 TeV) = 4.3 ± 0.2 pb   4.7%

$\sigma_{s\text{-ch}}$ (8 TeV) = 5.2 ± 0.2 pb   3.9%

$\sigma_{s\text{-ch}}$ (13 TeV) = 10.3 ± 0.4 pb   3.9%

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





- Different production rates for t and $\bar{t}$ owing to proton PDF
- Direct sensitivity to V_{tb}

Combinations of cross-section measurements per production mode and per centre-of-mass energy.

- 10 input measurements from ATLAS and CMS at 7 and 8 TeV.
- Combinations done using the iterative BLUE method.
- Convergence reached when the central value and total uncertainty change by <1% compared to the previous iteration.

As an example…

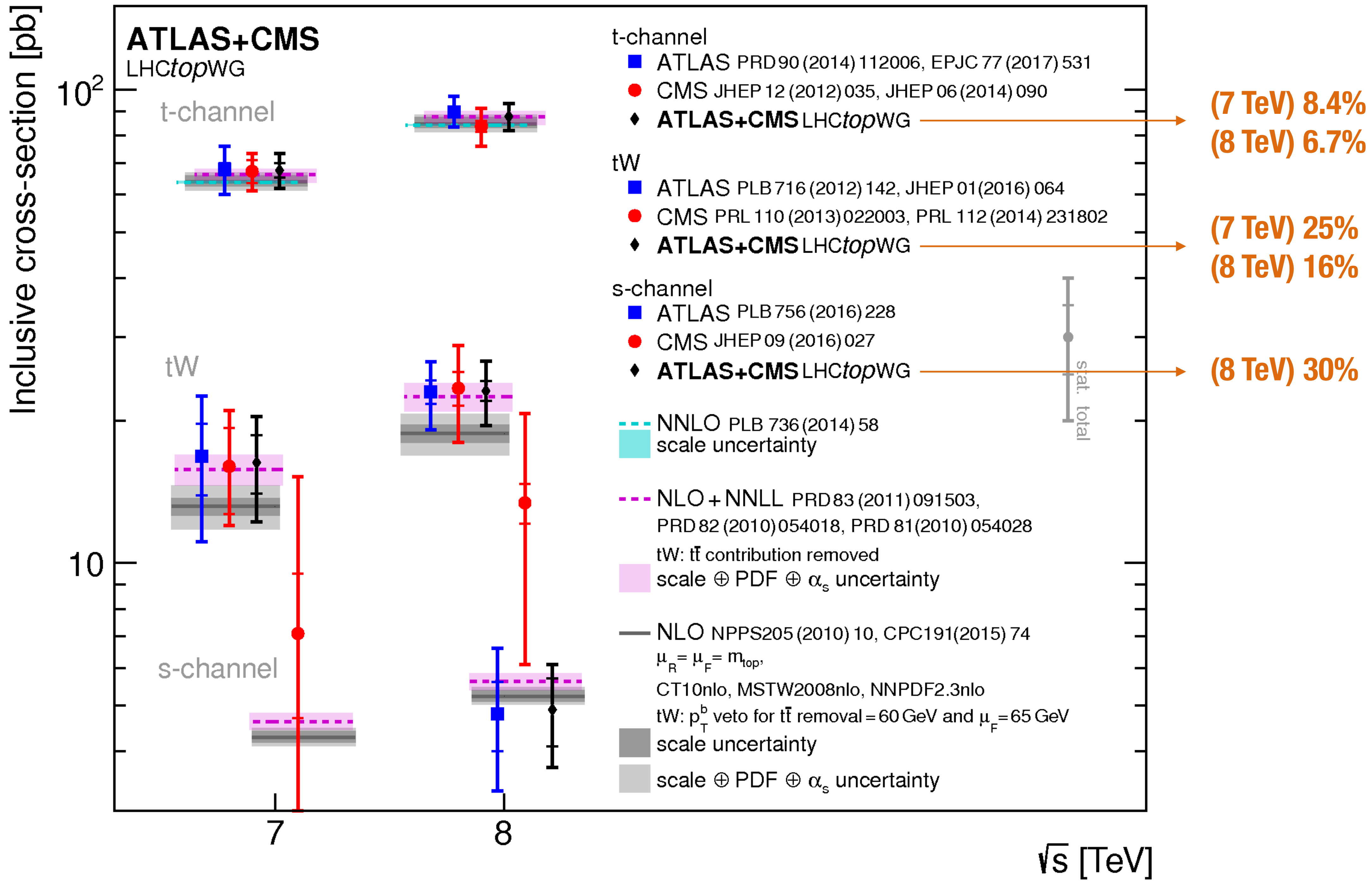
	$\sigma_{t\text{-chan.}}$, $\sqrt{s}$ = 8 TeV	
Combined cross-section	87.7 pb	
Uncertainty category	Uncertainty	
	(%)	(pb)
Data statistics	1.3	1.1
Simulation statistics	0.6	0.5
Luminosity	1.7	1.5
Theory modelling	5.3	4.7
Background normalisation	1.2	1.1
Jets	2.6	2.3
Detector modelling	1.8	1.6
Total syst. unc. (excl. lumi.)	6.3	5.5
Total syst. unc. (incl. lumi.)	6.5	5.7
Total uncertainty	6.7	5.8

- Experimental systematic uncertainties and their correlations carefully taken into account.
- Uncertainty on the top-quark mass dependence not included in the combinations (but impact provided when possible).
- Dominant systematics:
  - Theory modelling.
  - Jets.
  - Detector modelling.
  - Data statistics (just for s-channel combination).

- The stability of the combinations with respect to the correlation assumptions checked for the dominant uncertainty contributions → very stable results.

JHEP 05 (2019) 088

Combinations of cross-section measurements for each production mode and per centre-of-mass energy.



- **All combinations are consistent with their corresponding SM predictions.**

JHEP 05 (2019) 088

Combinations of $|f_{LV}V_{tb}|$ determinations for each production mode and full combination.

- Experimental and theoretical systematic uncertainties and their correlations carefully taken into account.
- Combining $|f_{LV}V_{tb}|^2$ values since they are linear with the cross-section measurements.
- The term $|f_{LV}V_{tb}|^2$ does not depend on the production mode or the centre-of-mass energy.

Combined $\|f_{LV}V_{tb}\|^2$	1.05	
Uncertainty category	Uncertainty	
	[%]	$\Delta\|f_{LV}V_{tb}\|^2$
Data statistical	1.8	0.02
Simulation statistical	0.9	0.01
Integrated luminosity	1.3	0.01
Theory modelling	4.5	0.05
Background normalisation	1.3	0.01
Jets	2.6	0.03
Detector modelling	1.6	0.02
Top-quark mass	0.7	0.01
Theoretical cross-section	4.3	0.04
Total syst. unc. (excl. lumi.)	7.1	0.07
Total syst. unc. (incl. lumi.)	7.2	0.08
Total uncertainty	7.4	0.08

$$|f_{LV}V_{tb}| = \sqrt{\frac{\sigma_{meas.}}{\sigma_{theo.}}}$$

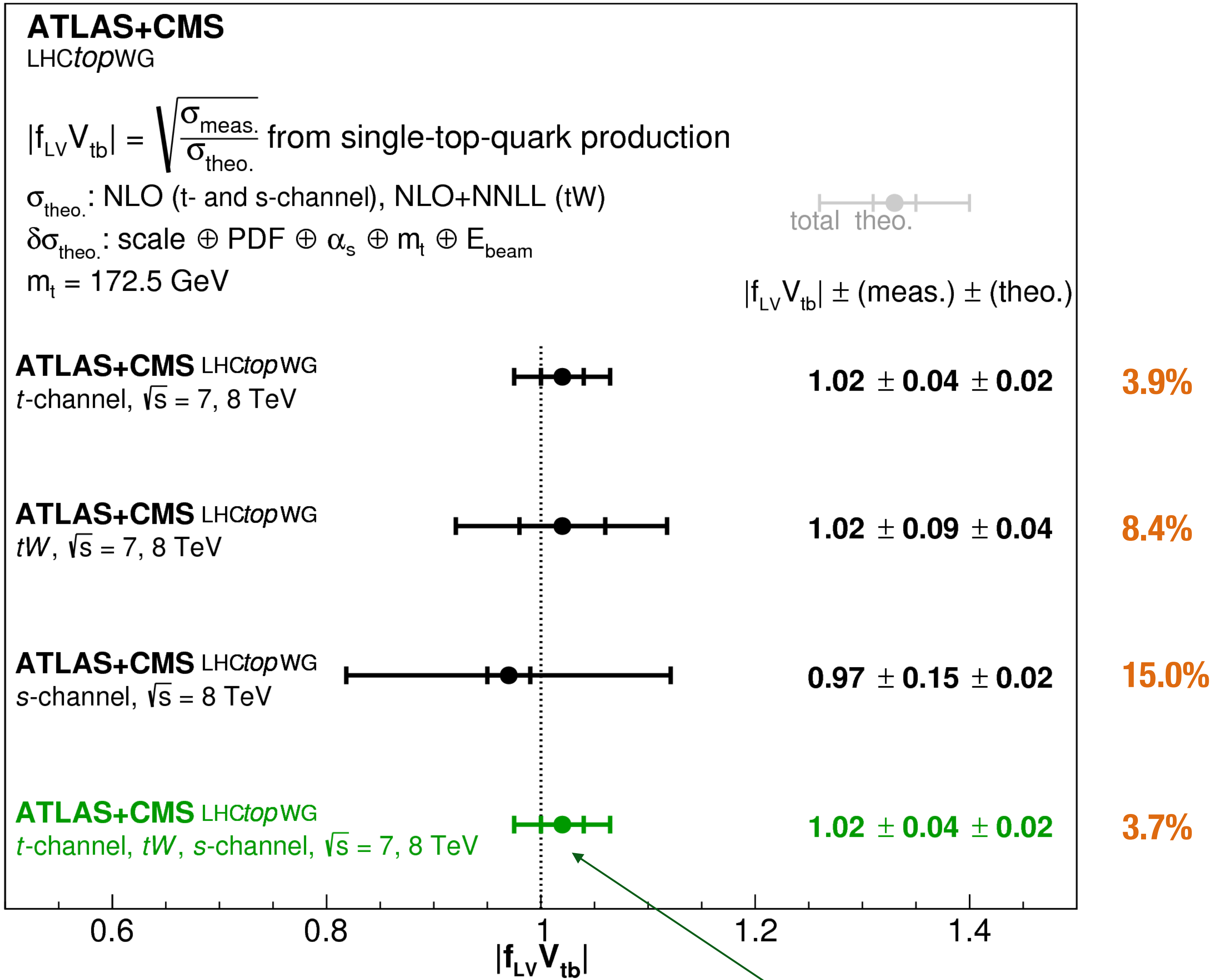
f_{LV}: model-independent left-handed form factor that encapsulates non-SM contributions.

- Uncertainties on the top-quark mass dependence included.
- Dominant systematics:
  - Theory modelling.
  - Theoretical cross-section.
  - Jets.

- The stability of the combinations with respect to the correlation assumptions is checked for the dominant uncertainty contributions → very stable results.

JHEP 05 (2019) 088

Combinations of $|f_{LV}V_{tb}|$ determinations for each production mode and full combination.



- CMS s-channel analysis not used.
- Driven by t-channel measurements.

- **All combinations are consistent with the SM prediction.**

Measuring t-channel production of single top quarks and antiquarks.

CMS arXiv:1812.10514
35.9 fb^{-1}, 13 TeV

- Event selection: 1 e or μ, and multiple jets.
- Events classified by jet and b-jet multiplicity (2j1b, 3j1b, 3j2b) and BDT discriminators.
- Likelihood fit to BDT output in all categories.

- Systematic uncertainties are either taken as NP (profiled uncertainties) or using varied templates.
- Dominant uncertainties:
  - t-channel PS scale (13%).
  - t-channel PDF (8%).
  - t-channel μ_R and μ_F scale (6%).

  } **Nonprofiled uncertainties**

- Fit result:

$\sigma_{t\text{-}ch}(t) = 136 \pm 1\,(stat.) \pm 22\,(syst.)$ pb, **16%**

$\sigma_{t\text{-}ch}(\bar{t}) = 82 \pm 1\,(stat.) \pm 14\,(syst.)$ pb. **17%**

ATLAS JHEP 04 (2017) 086
3.2 fb^{-1}, 13 TeV

- Event selection: 1 e or μ, and 2 jets (1 b-jet).
- Maximum likelihood fit to the NN output distribution.

- Systematic uncertainties are taken as nuisance parameters.
- Dominant uncertainties:
  - t-channel shower/hadronisation modelling (14%).
  - b-tagging efficiency (7%).
  - Top-quark background NLO matching (7%).

- Fit result:

$\sigma_{t\text{-}ch}(t) = 156 \pm 5\,(stat.) \pm 27\,(syst.) \pm 3\,(lumi.)$ pb, **18%**

$\sigma_{t\text{-}ch}(\bar{t}) = 91 \pm 4\,(stat.) \pm 18\,(syst.) \pm 2\,(lumi.)$ pb. **20%**

- **In agreement with the NLO prediction (unc. 4% for t; unc. 5% for $\bar{t}$).**

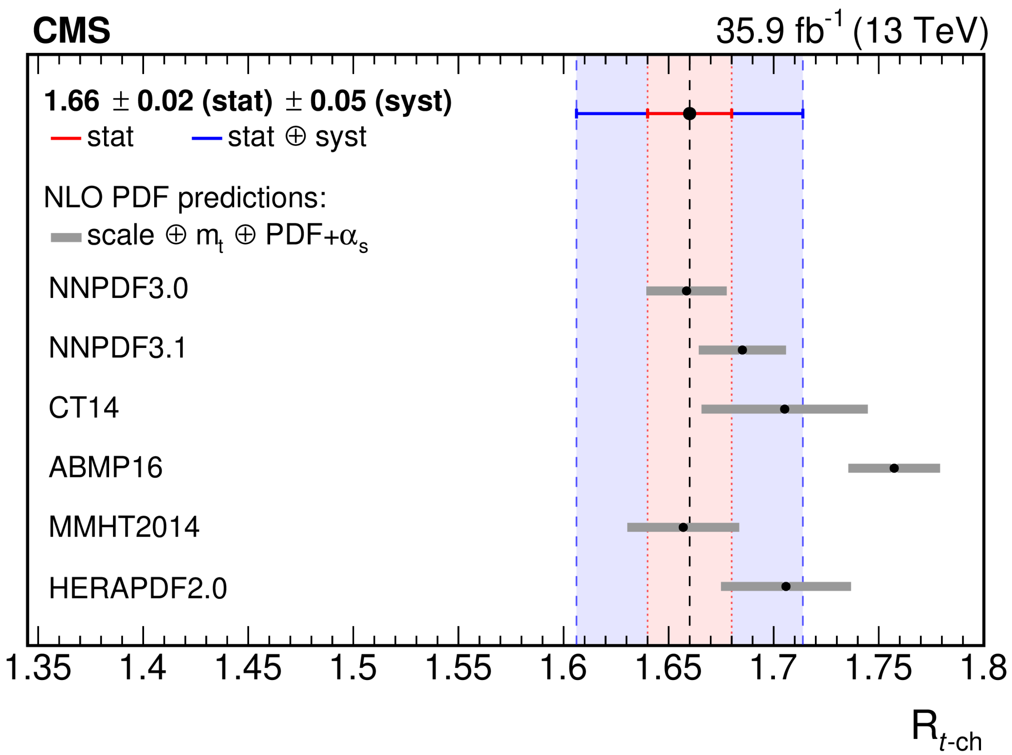
arXiv:1812.10514
$35.9\ fb^{-1}$, 13 TeV

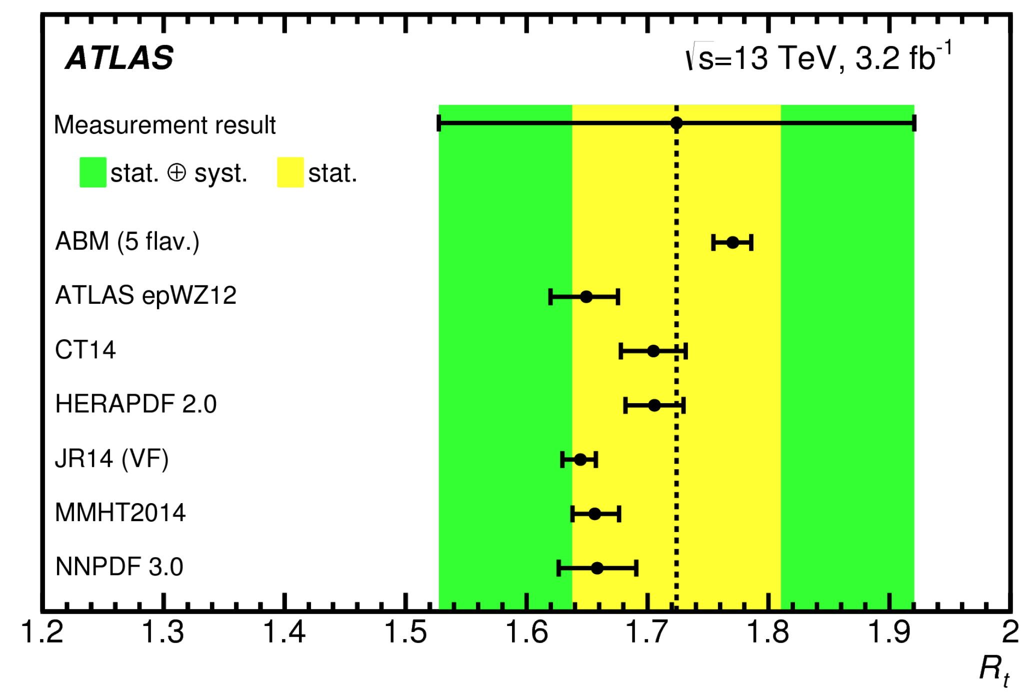
JHEP 04 (2017) 086
$3.2\ fb^{-1}$, 13 TeV

- Total cross-section used to calculate V_{tb}:

- **$|f_{LV}V_{tb}| = 1.00 \pm 0.08$ (exp.) ± 0.02 (theo.).** 8.3%
- **$|f_{LV}V_{tb}| = 1.07 \pm 0.09$ (exp.) ± 0.02 (theo.).** 8.4%

- Ratio $R_{t\text{-}ch} = \sigma_{t\text{-}ch;t}/\sigma_{t\text{-}ch;\bar{t}}$ measured for different PDF set:





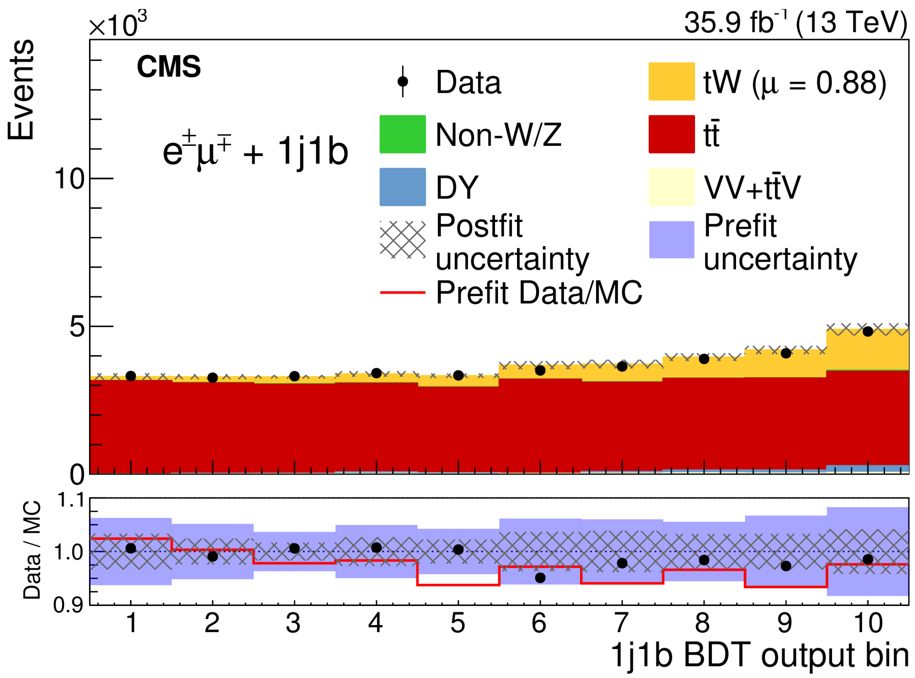
- Dominant uncertainties:
  - MC sample size (2.6%). **Nonprofiled uncertainty**
  - t-channel PDF (2.4%). **Profiled uncertainty**
- **$R_{t\text{-}ch} = 1.66 \pm 0.02$ (stat.) ± 0.05 (syst.)** 3%

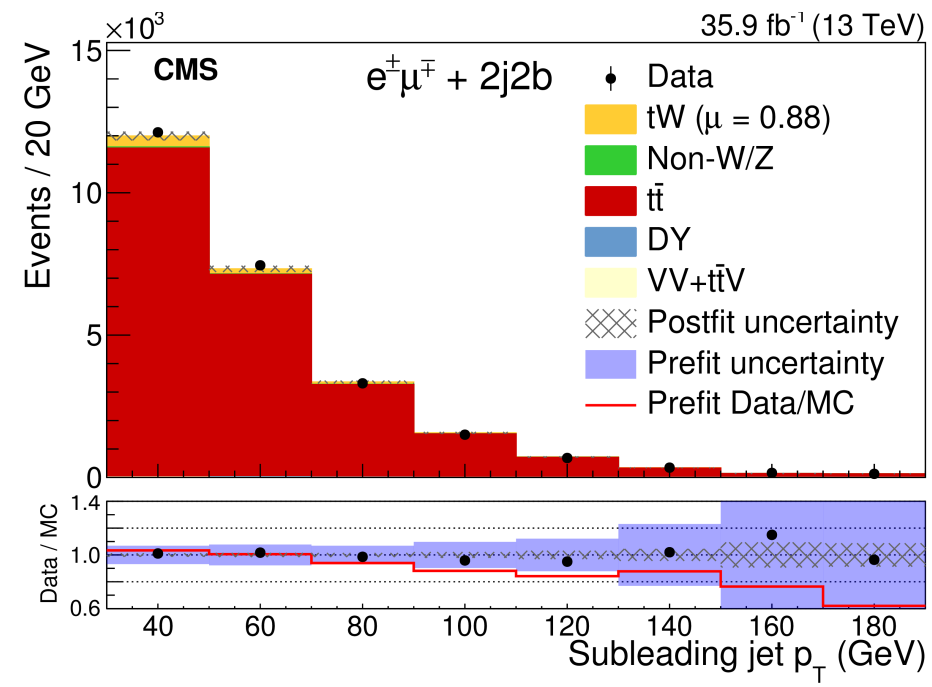
- Dominant uncertainties:
  - MC sample size (5.1%).
  - Data statistics (5.0%).
- **$R_{t\text{-}ch} = 1.72 \pm 0.09$ (stat.) ± 0.18 (syst.)** 11%

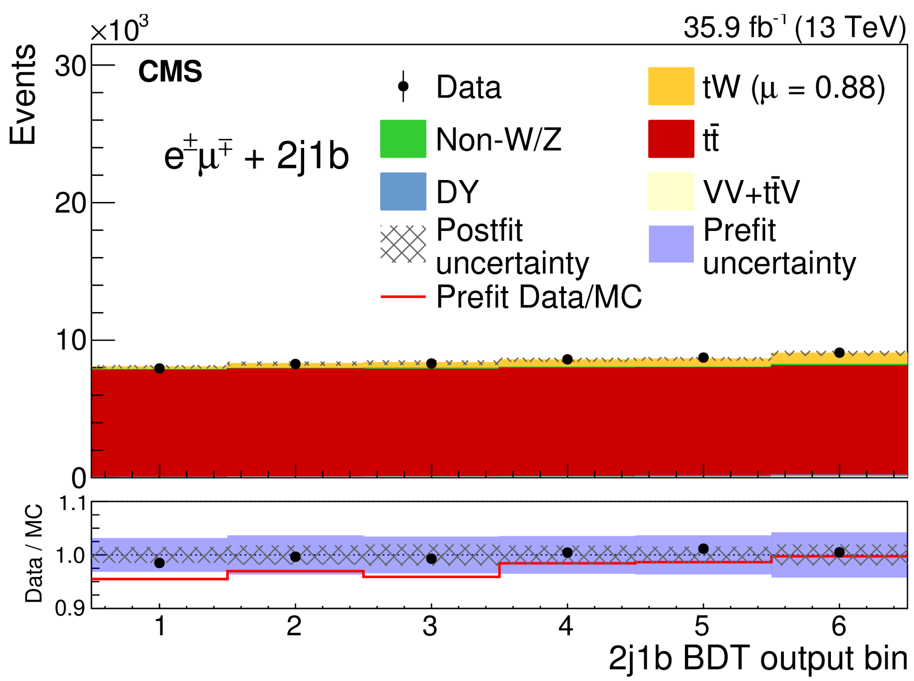
- **Good agreement between the measurement and most predictions is found.**

Inclusive cross-section measurement requiring 1 lepton (e or μ) and at least one b-jet.

- Maximum likelihood fit to the distribution of a BDT in two of the categories + sub-leading jet p_T in 2j2b.



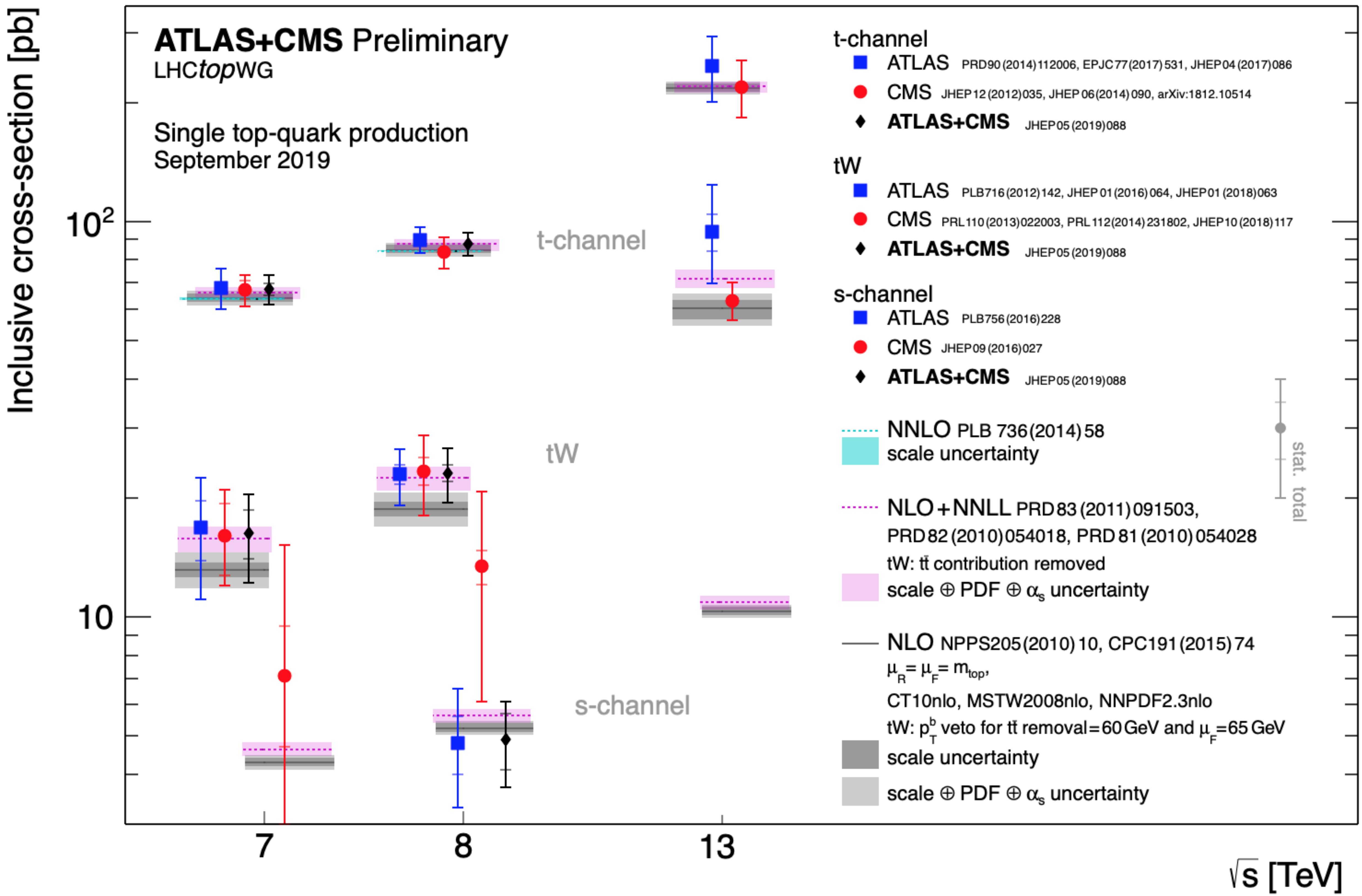




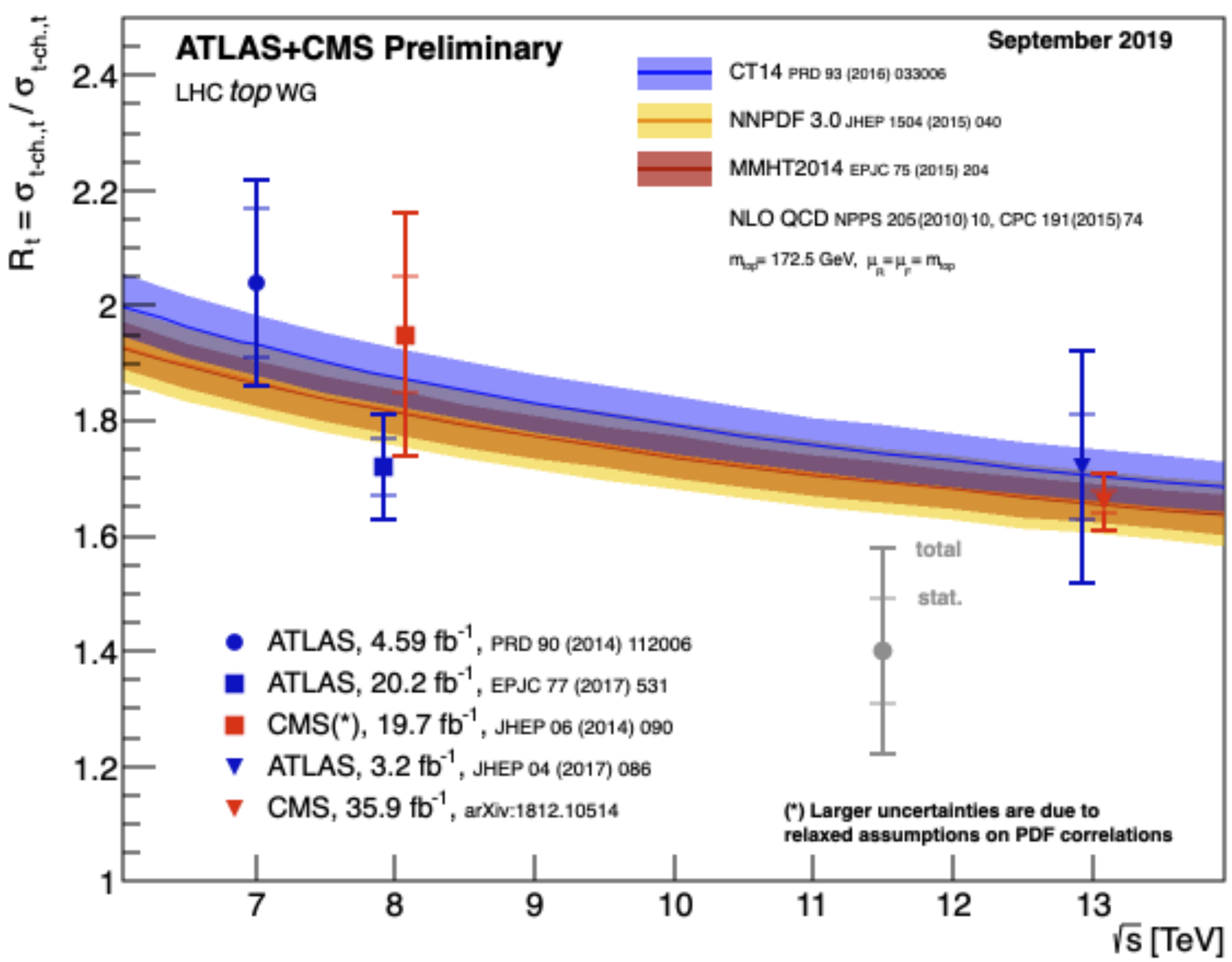
- DR used to account for $t\bar{t}$ interference.
- Dominant uncertainties:
  - Lepton efficiencies (3.3%).
  - Pile-up (3.3%).
  - Data statistics (2.8%).
  - $t\bar{t}$ background normalization (2.8%).

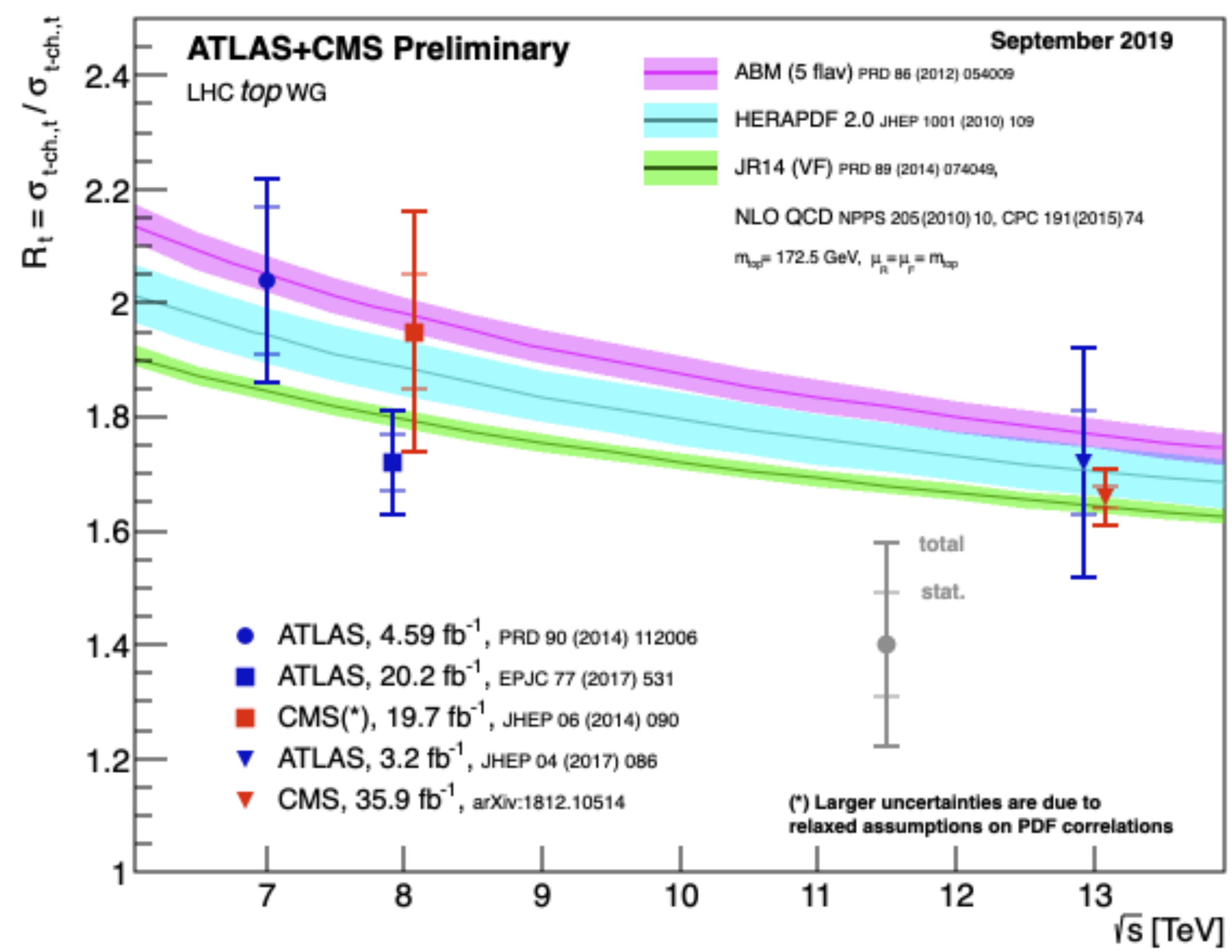
- Fit result: **σ_{tW} (ll) = 63.1 ± 1.8 (stat) ± 6.4 (syst) ± 2.1 (lumi) pb.** **11%**
- **In agreement with NNLO prediction (5.3%).**

Summary of single top-quark cross-section measurements

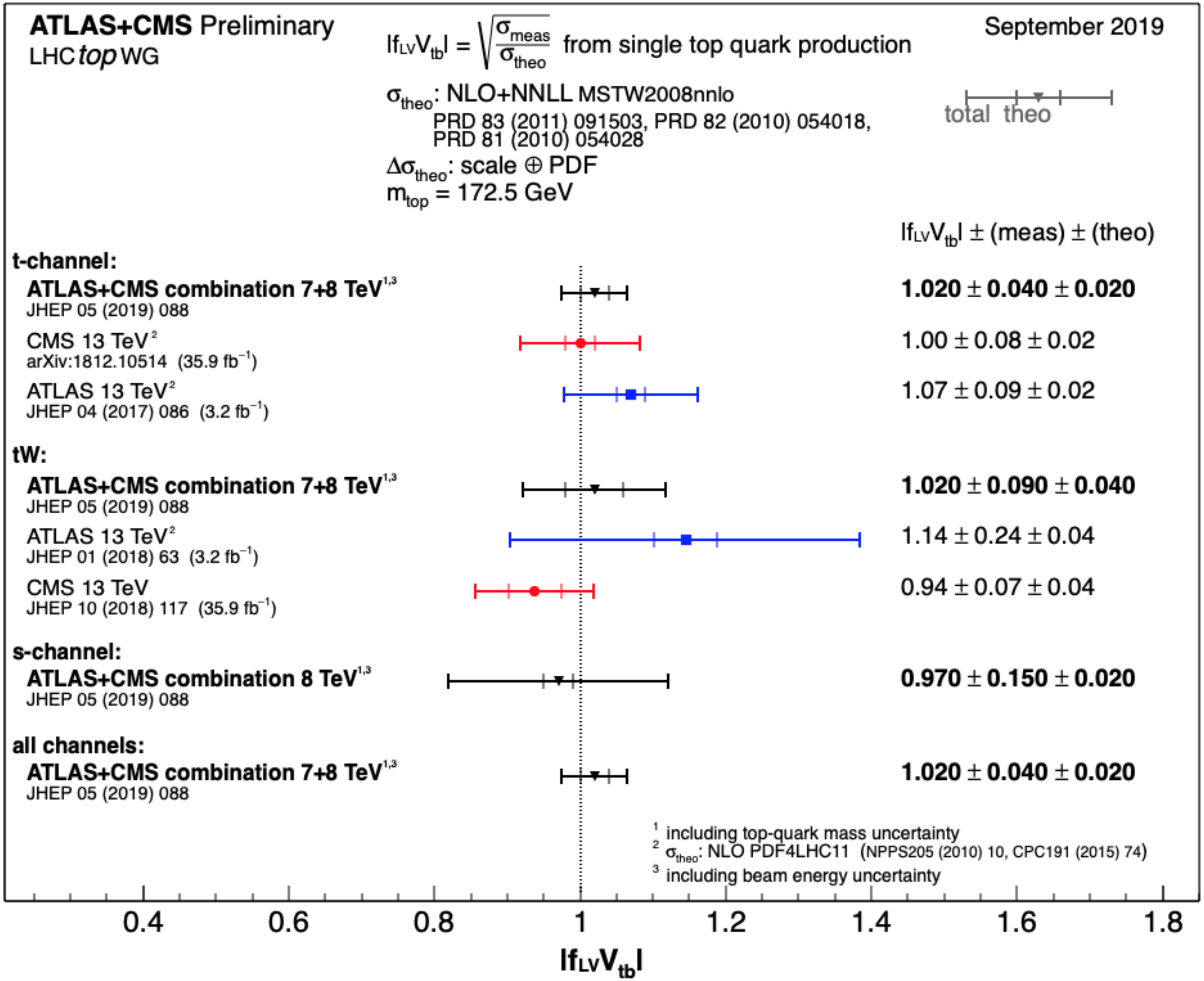


Summary of single top-quark cross-section measurements





Summary of single top-quark cross-section measurements



Probing Nature with many measurements in top-quark sector with ATLAS and CMS.

- Combinations between ATLAS and CMS results using full Run 1 published.
- First measurements exploiting Run 2 data are now being published, achieving high-precision results.

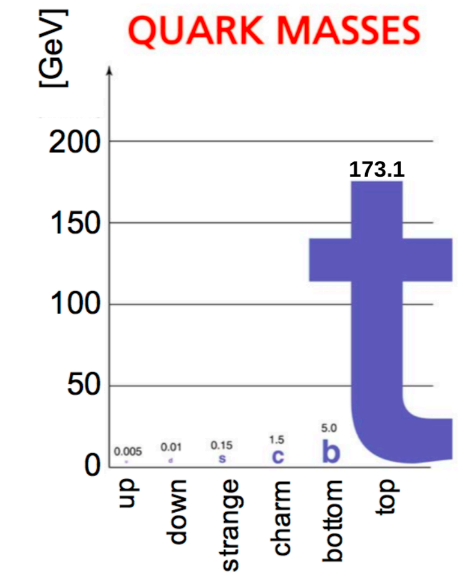
- So far, all measurements are consistent with the SM predictions.
  - No sign of new physics yet with the achieved precision.

- Next generation of new exciting results to come with study of full Run2 data from LHC! Stay tuned!
  - ATLAS Top Physics Results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults.
  - CMS Top Physics Results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP.

12th International Workshop on Top Quark Physics (TOP2019)
IHEP, Beijing (China) - September 22 – 27, 2019

BACKUP

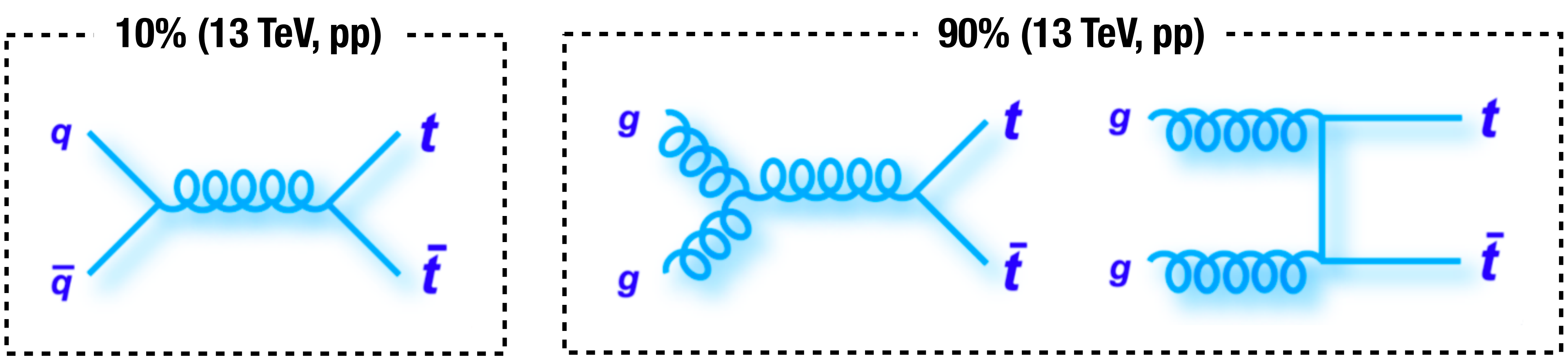
Inclusive $t\bar{t}$ + single top (SM) cross-section measurements



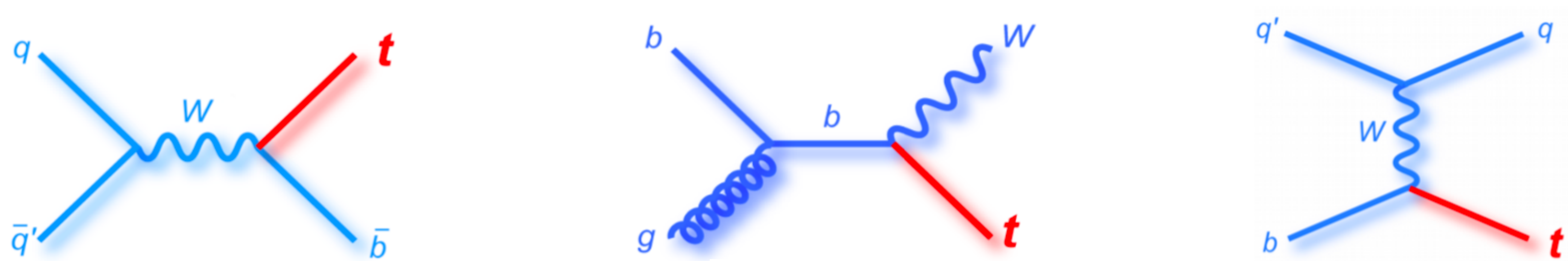
The **top quark** is the heaviest known elementary particle.

At hadron colliders, top quarks are produced:

- Predominantly in **pairs** ($t\bar{t}$) via the flavour-conserving strong interaction.



- Alternatively, **singly** through the electroweak interaction.

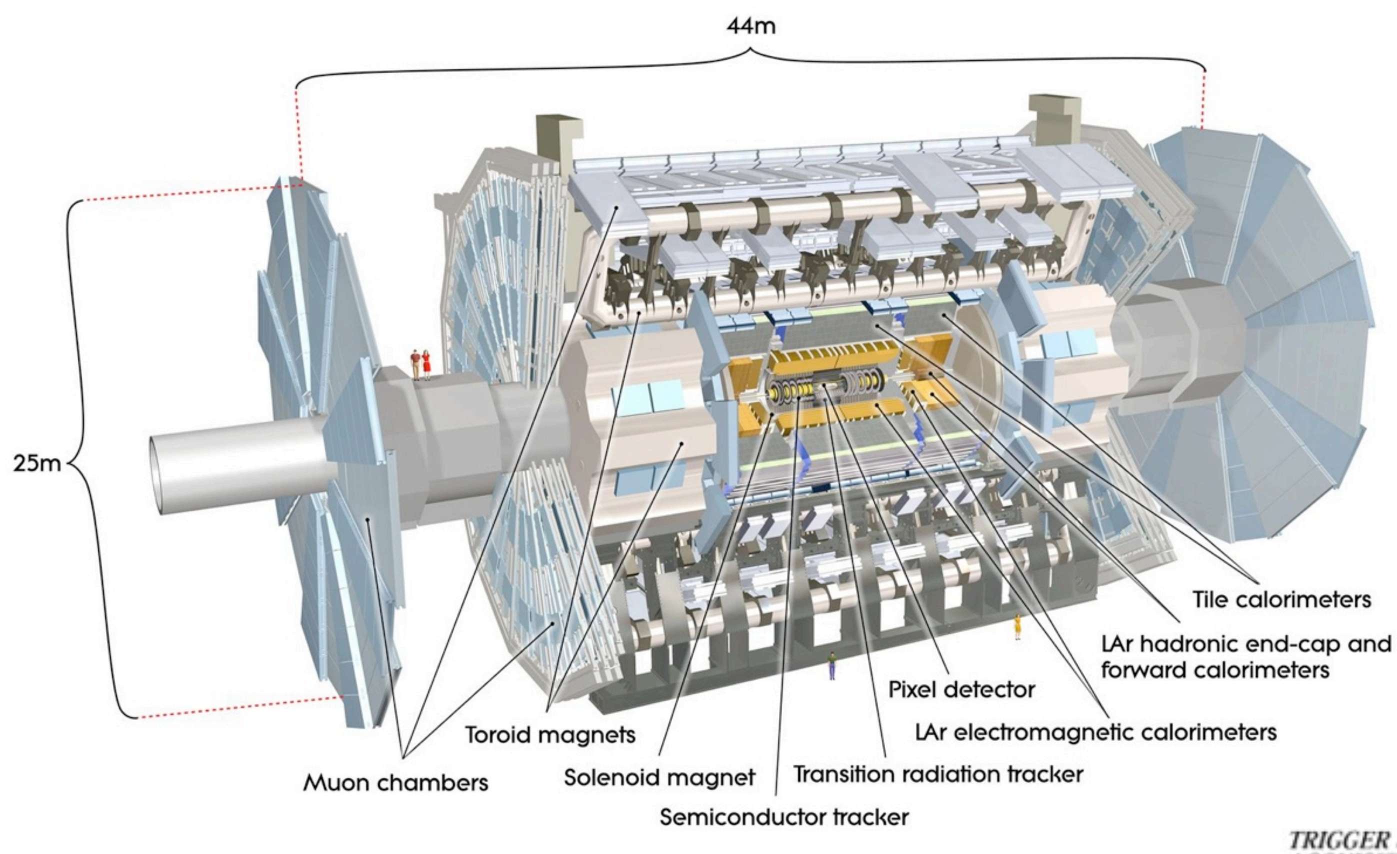


t-channel (~73% at LHC) **tW (~24% at LHC)** **s-channel (~3% at LHC)**

The top quark was discovered by CDF/D0 at Tevatron in 1995 in $t\bar{t}$ events.

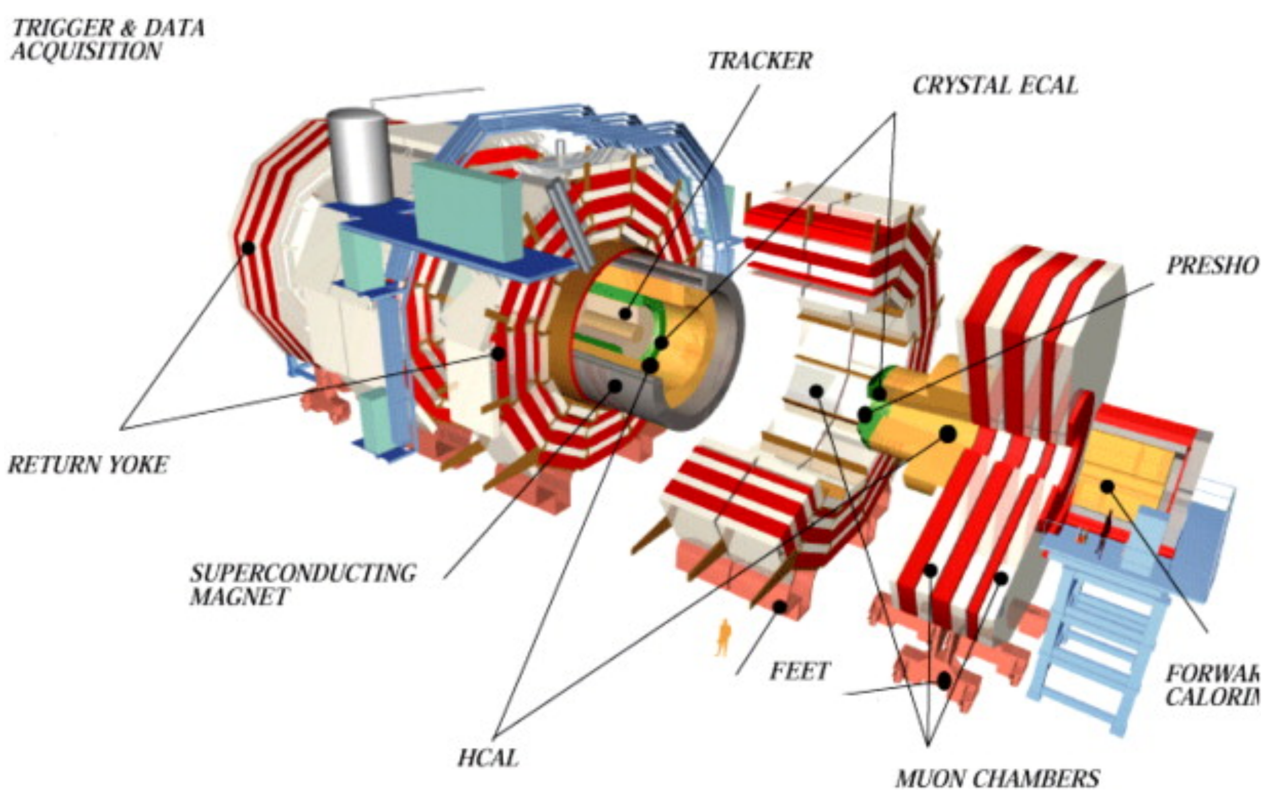
- The single top-quark production was discovered in 2009 by CDF/D0 and observed in 2011 by ATLAS/CMS.

General purpose detectors at the LHC



ATLAS

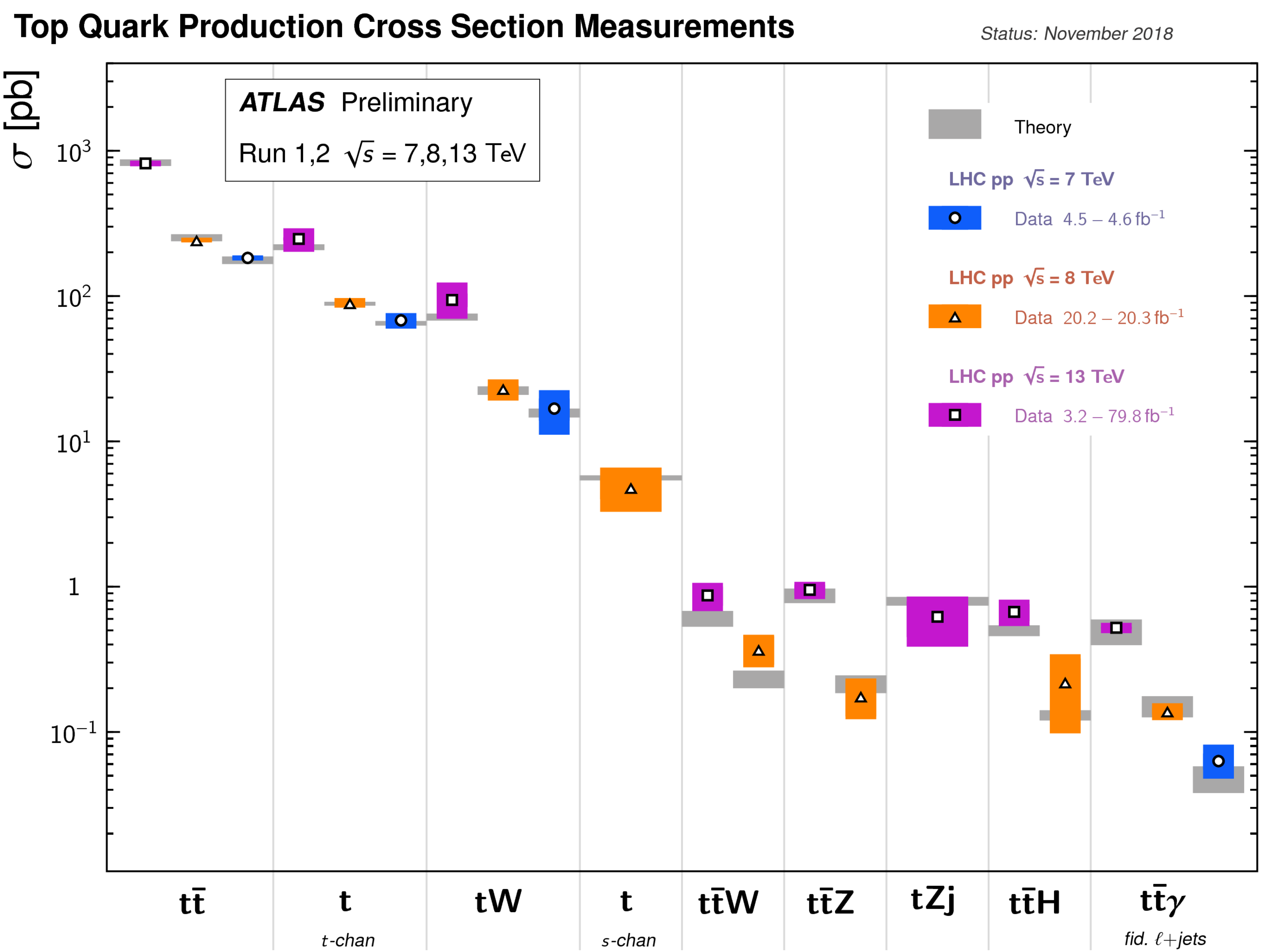
- Length: 44 m, diameter: 25 m
- Mass: ~7.0 ktons
- Two magnet fields:
    - Solenoid (ID): 2 T
    - Toroid (Muon System): 2-8 Tm



CMS

- Length: 21 m, diameter: 15 m
- Mass: ~ 12.5 ktons
- Solenoid: 4 T

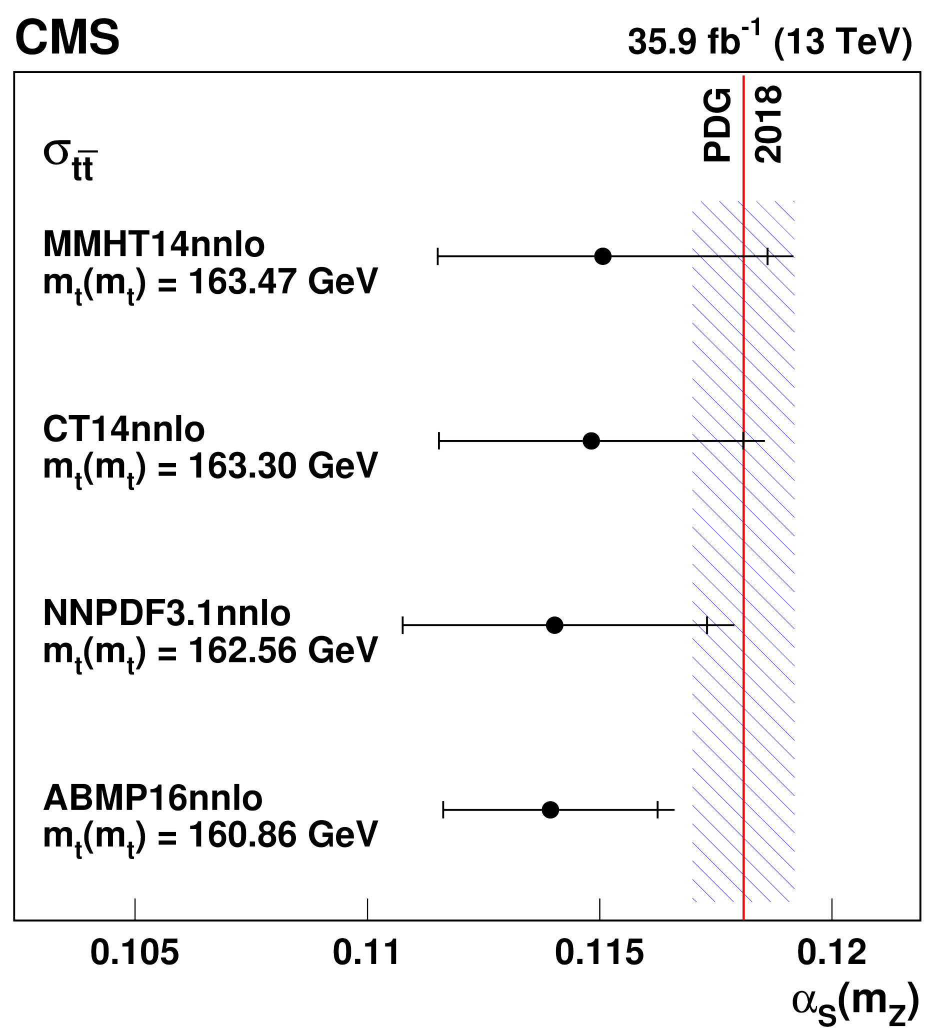
Summary of several top-quark related production cross section measurements, compared to the corresponding theoretical expectations. All theoretical expectations were calculated at NLO or higher.

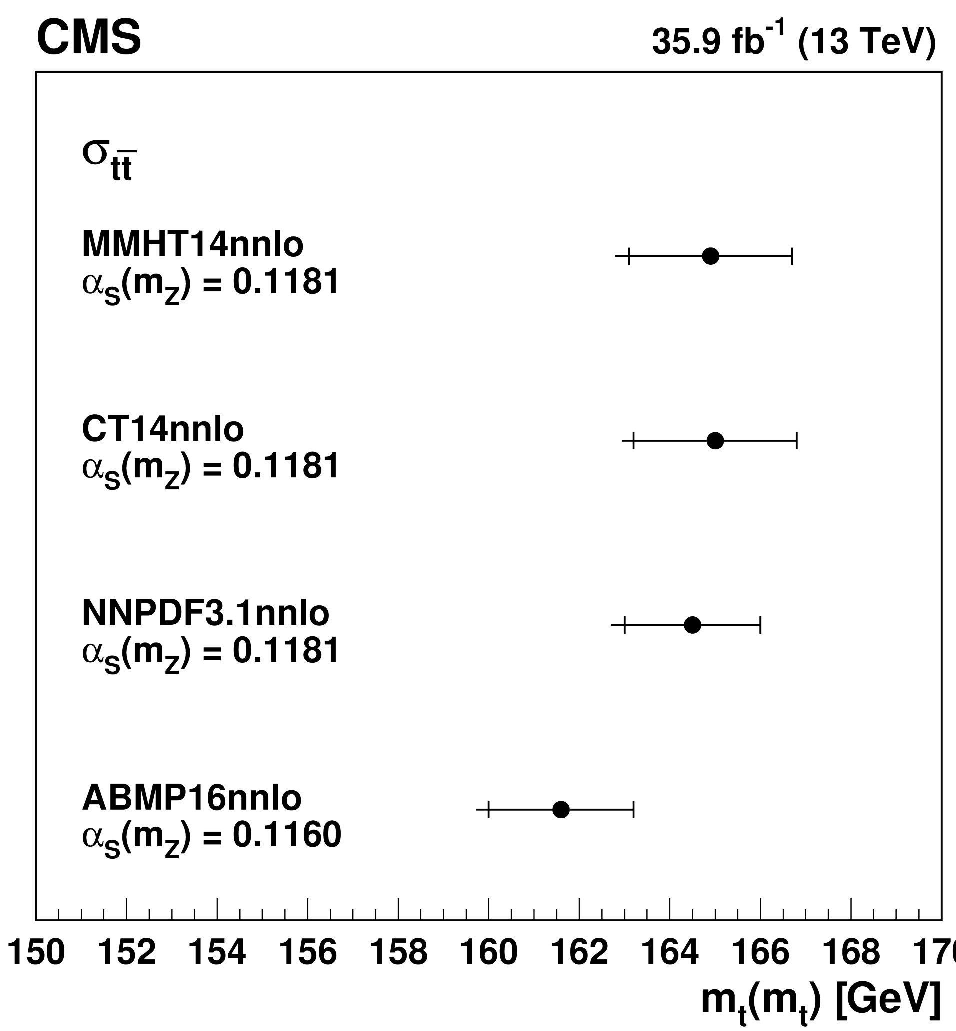


EPJC 79 (2019) 368
35.9 fb^{-1}, 13 TeV

Additionally, another fit is performed to extract simultaneously the $t\bar{t}$ cross-section and the m_t^{MC}.

- Allow the extracting m_t and α_S using fixed-order calculations with different sets of PDFs.





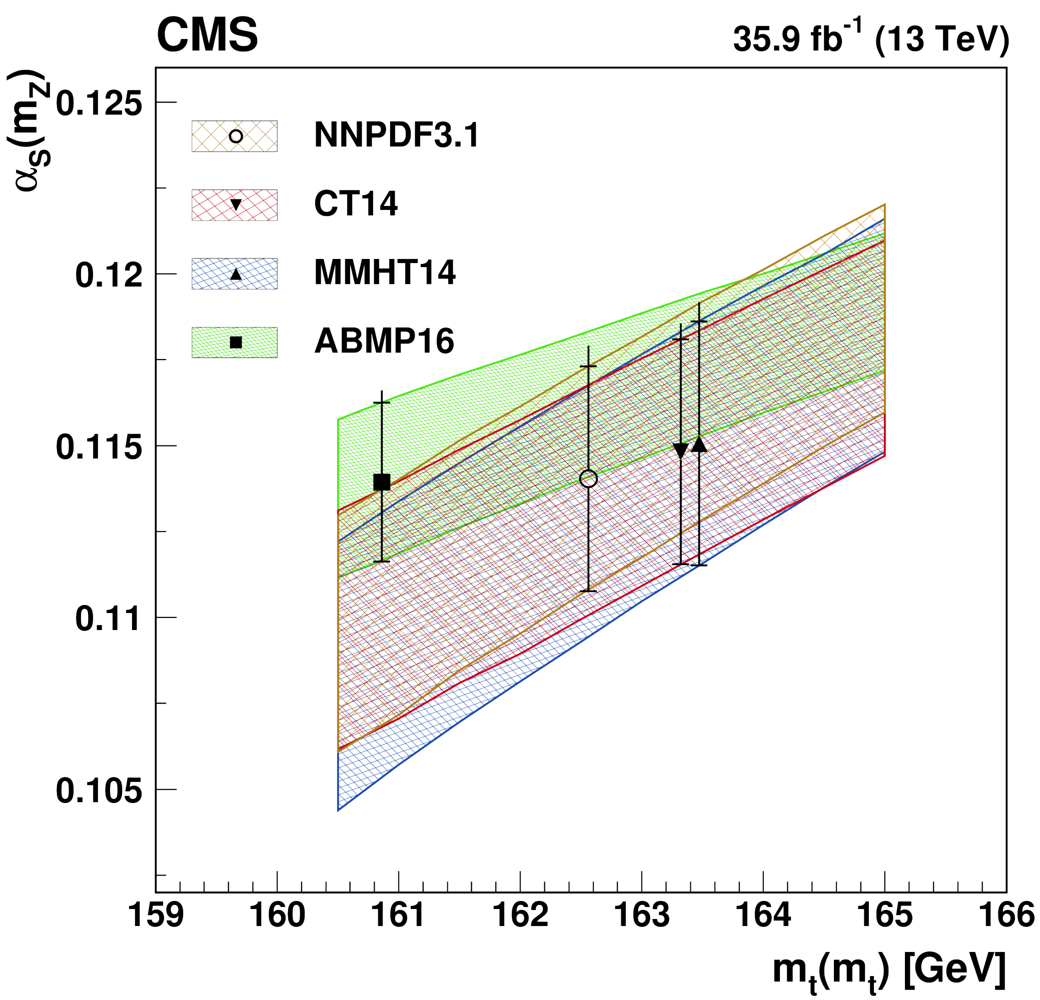
PDF set	$\alpha_S(m_Z)$
ABMP16	0.1139 ± 0.0023 (fit + PDF) $^{+0.0014}_{-0.0001}$ (scale)
NNPDF3.1	0.1140 ± 0.0033 (fit + PDF) $^{+0.0021}_{-0.0002}$ (scale)
CT14	0.1148 ± 0.0032 (fit + PDF) $^{+0.0018}_{-0.0002}$ (scale)
MMHT14	0.1151 ± 0.0035 (fit + PDF) $^{+0.0020}_{-0.0002}$ (scale)

PDF set	$m_t(m_t)$ [GeV]
ABMP16	161.6 ± 1.6 (fit + PDF + α_S) $^{+0.1}_{-1.0}$ (scale)
NNPDF3.1	164.5 ± 1.6 (fit + PDF + α_S) $^{+0.1}_{-1.0}$ (scale)
CT14	165.0 ± 1.8 (fit + PDF + α_S) $^{+0.1}_{-1.0}$ (scale)
MMHT14	164.9 ± 1.8 (fit + PDF + α_S) $^{+0.1}_{-1.1}$ (scale)

EPJC 79 (2019) 368
35.9 fb^{-1}, 13 TeV

Additionally, another fit is performed to extract simultaneously the $t\bar{t}$ cross-section and the m_t^{MC}.

- Allow the extracting m_t and α_S using fixed-order calculations with different sets of PDFs.



- The extraction of m_t is repeated in the pole mass scheme using the Top++ 2.0 program using the NNLO+NNLL prediction.

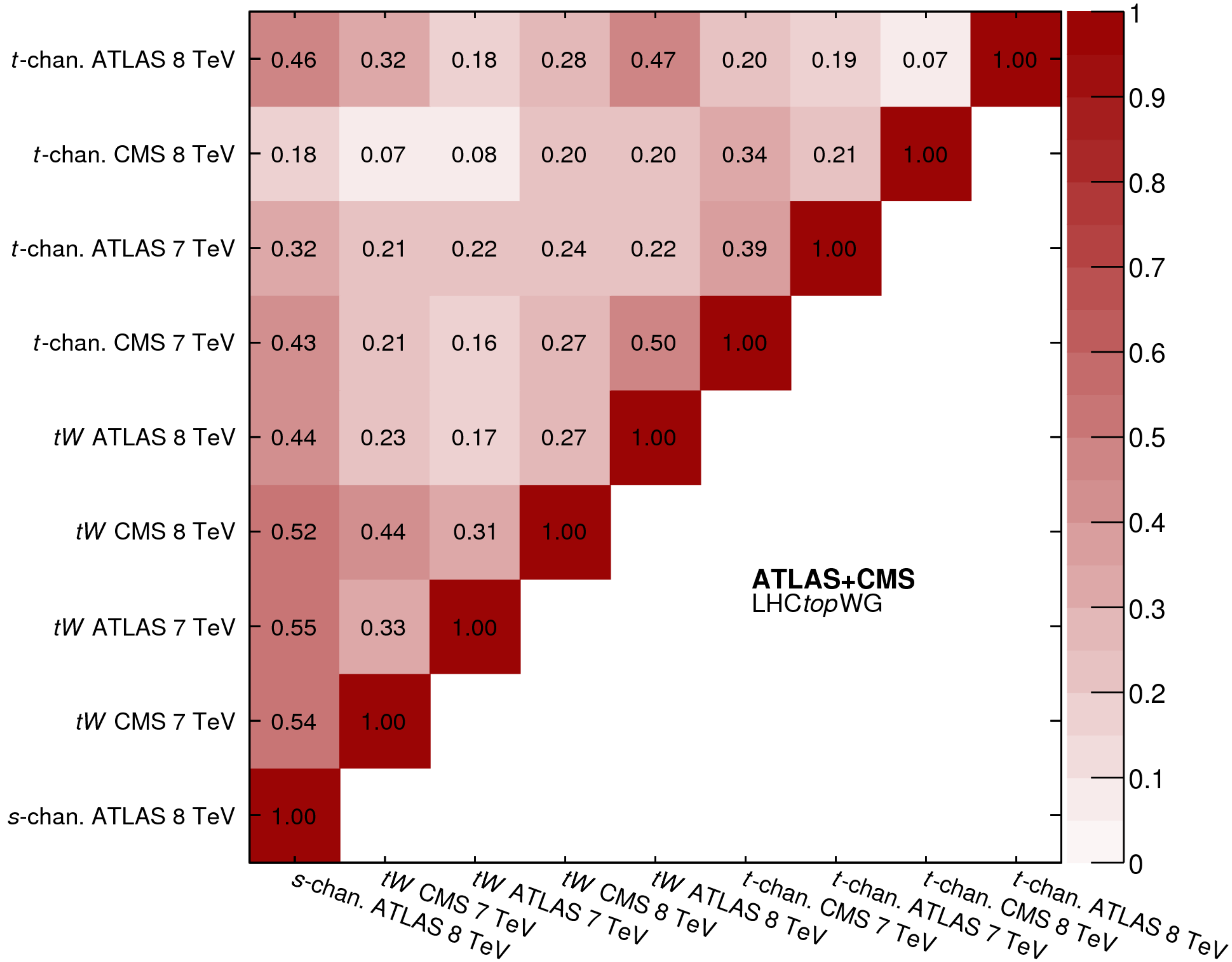
PDF set	m_t^{pole} [GeV]
ABMP16	169.9 ± 1.8 (fit + PDF + α_S) $^{+0.8}_{-1.2}$ (scale)
NNPDF3.1	173.2 ± 1.9 (fit + PDF + α_S) $^{+0.9}_{-1.3}$ (scale)
CT14	173.7 ± 2.0 (fit + PDF + α_S) $^{+0.9}_{-1.4}$ (scale)
MMHT14	173.6 ± 1.9 (fit + PDF + α_S) $^{+0.9}_{-1.4}$ (scale)

JHEP 05 (2019) 088

Inputs: ATLAS and CMS individual $|f_{LV}V_{tb}|^2$ determinations and their experimental uncertainties.

	t-channel ATLAS 8 TeV	t-channel CMS 8 TeV	t-channel ATLAS 7 TeV	t-channel CMS 7 TeV	tW ATLAS 8 TeV	tW CMS 8 TeV	tW ATLAS 7 TeV	tW CMS 7 TeV	s-channel ATLAS 8 TeV
$\|f_{LV}V_{tb}\|^2$	1.06	0.99	1.06	1.05	1.03	1.05	1.07	1.02	0.92
Uncertainties:									
Data statistical	0.01	0.03	0.03	0.06	0.06	0.09	0.18	0.21	0.15
Simulation statistical	0.01	0.01	0.02	0.02	0.01	0.03	0.02	–	0.11
Integrated luminosity	0.02	0.03	0.02	0.02	0.05	0.03	0.07	0.04	0.05
Theory modelling									
ISR/FSR, ren./fact. scale	0.04	0.02	0.03	0.04	0.09	0.13	0.05	0.03	0.06
NLO match., generator	0.03	0.05	0.02	0.04	0.03	–	0.11	–	0.10
Parton shower	0.02	–	–	0.01	0.02	0.15	0.16	0.10	0.02
PDF	0.01	0.02	0.03	0.01	0.01	0.02	0.02	0.02	0.03
DS/DR scheme	–	–	–	–	0.04	0.02	–	0.06	–
Top-quark p_T rew.	–	–	–	–	–	<0.01	–	–	–
Background normalisation									
Top-quark bkg.	<0.01	0.02	0.02	0.01	0.02	0.02	0.06	0.06	0.05
Other bkg. from sim.	0.01	<0.01	<0.01	0.03	0.02	0.03	0.09	0.04	0.05
Bkg. from data	<0.01	0.02	0.01	0.01	<0.01	–	0.02	–	0.01
Jets									
JES common	0.03	0.04	0.08	0.01	0.05	0.04	0.17	0.15	0.05
JES flavour	<0.01	–	0.02	–	0.02	–	–	–	0.01
JetID	<0.01	–	0.01	–	<0.01	–	0.05	–	0.01
JER	<0.01	0.01	0.02	<0.01	0.07	0.01	0.02	0.04	0.11
Detector modelling									
Leptons	0.02	0.01	0.03	0.04	0.03	0.02	0.07	0.05	0.02
HLT (had. part)	–	–	–	0.02	–	–	–	–	–
E_T^{miss} scale	<0.01	<0.01	0.03	<0.01	0.06	<0.01	–	0.03	0.01
E_T^{miss} res.	<0.01	–	–	–	<0.01	–	–	–	0.01
b-tag	0.01	0.02	0.04	0.02	0.01	0.01	–	0.02	0.07
Pile-up	<0.01	0.01	<0.01	0.01	0.03	<0.01	0.11	0.01	0.01
Top-quark mass	0.01	<0.01	0.01	–	0.05	0.05	–	–	–
Theoretical cross-section									
PDF+α_s	0.03	0.03	0.04	0.04	0.06	0.07	0.08	0.07	0.03
Ren./fact. scale	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Top-quark mass	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
E_{beam}	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total systematic uncertainty	0.09	0.09	0.13	0.10	0.18	0.23	0.34	0.24	0.24
Total uncertainty	0.09	0.10	0.13	0.12	0.19	0.24	0.38	0.32	0.28

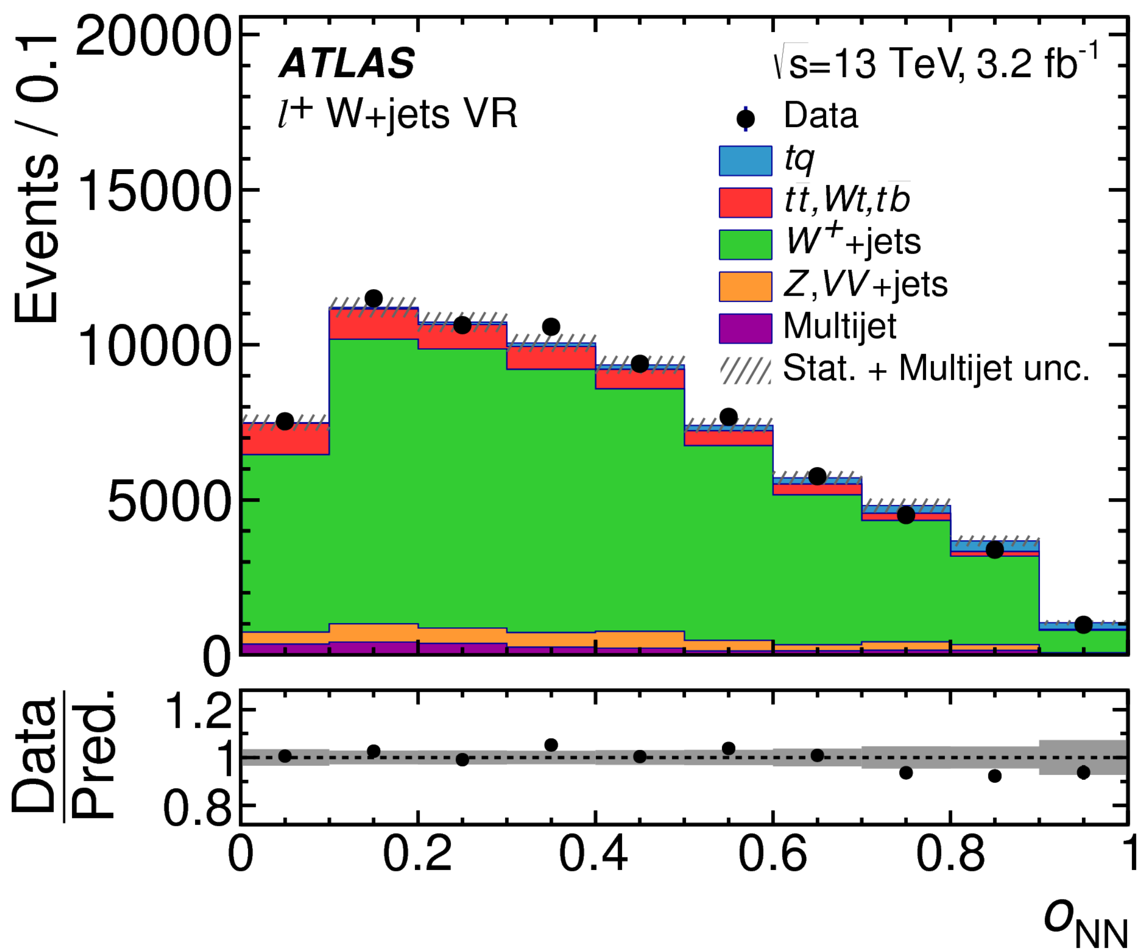
Correlation matrix of the overall $|f_{LV}V_{tb}|^2$ combination. Each bin corresponds to a measurement in a given production mode, experiment, and at a given centre-of-mass energy.



JHEP 04 (2017) 086
3.2 fb-1, 13 TeV

Measuring t-channel production of single top quarks and antiquarks.

- Event selection: 1 e or μ, and 2 jets (1 b-jet).
- Maximum likelihood fit to the NN output distribution.



- Systematic uncertainties are taken as nuisance parameters.
- Dominant uncertainties:
  - t-channel shower/hadronisation modelling (14%).
  - b-tagging efficiency (7%).
  - $t\bar{t}$ and single top-quark NLO matching (<7%).

- Fit result:

  $\sigma_{t\text{-ch}}$(t) = 156 ± 5 (stat.) ± 27 (syst.) ± 3 (lumi.) pb, 18%

  $\sigma_{t\text{-ch}}$($\bar{t}$) = 91 ± 4 (stat.) ± 18 (syst.) ± 2 (lumi.) pb. 20%

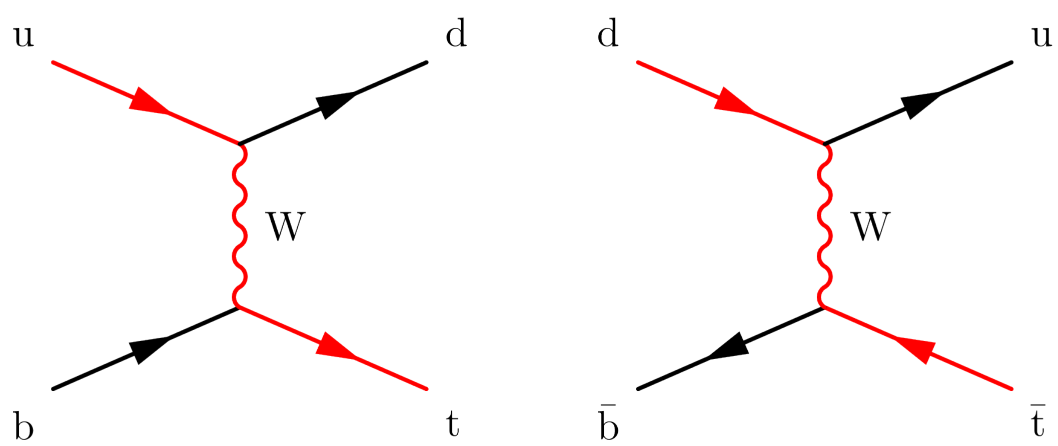
- **In agreement with the NLO prediction (unc. 4% for t; unc. 5% for $\bar{t}$).**

arXiv:1812.10514
35.9 fb^{-1}, 13 TeV

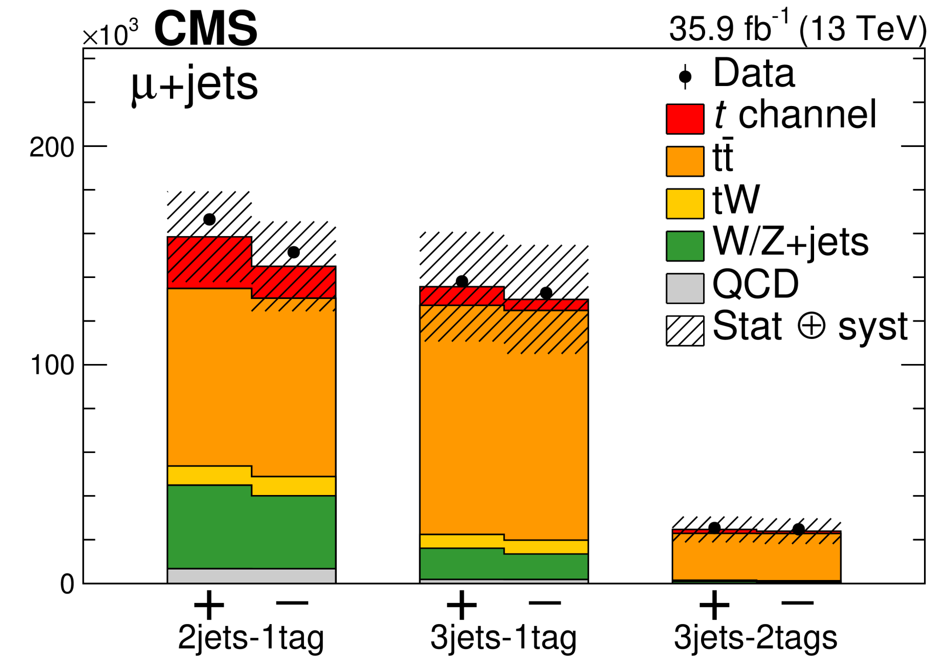
Measuring t-channel production of single top quarks and antiquarks.

- Event selection: 1 e or μ, and multiple jets.
- Events classified by jet and b-jet multiplicity and BDT discriminators.

Different production rates for t and $\bar{t}$ owing to proton PDF



Direct sensitivity to Vtb



- Cross-sections measured from a likelihood fit to BDT output in all categories.
- Systematic uncertainties are either taken as nuisance parameters (profiled uncertainties) or using varied templates.
- Dominant uncertainties:
  - t-channel PS scale (~13%).
  - t-channel PDF (~8%).
  - t-channel μ_R and μ_F scale (~6%).

  } **Nonprofiled uncertainties**

- Fit result:

$\sigma_{t\text{-}ch}$ (t) = 136 ± 1 (stat.) ± 22 (syst.) pb, 16%

$\sigma_{t\text{-}ch}$ ($\bar{t}$) = 82 ± 1 (stat.) ± 14 (syst.) pb. 17%

- **In agreement with the NLO prediction (unc. 4% for t; unc. 5% for $\bar{t}$).**

submitted to PLB

Production cross-section measurements by ATLAS and CMS during Run 1 and 2 from tt̄ process.

- The theory band represents uncertainties due to renormalisation and factorisation scale, PDF and the strong coupling.
- All measurements are in agreement with the SM predictions