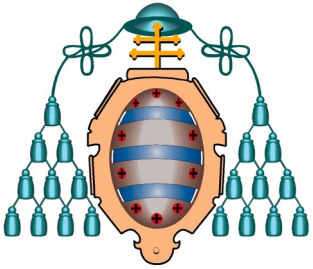

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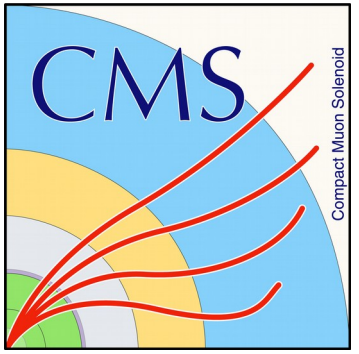


Recent $t\bar{t}$ and single top inclusive cross sections results in CMS

EPS-HEP 2019, 10 - 17 July 2019,
Ghent, Belgium.

Juan R. González Fernández

(Universidad de Oviedo - ICTEA)
on behalf of the CMS Collaboration

11 July 2019

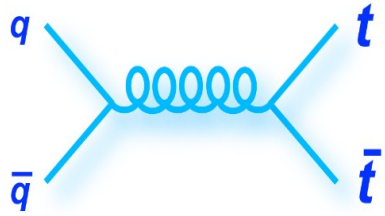
Top quark inclusive cross section

Top quark: the only quark that **decays before hadronizing**.
Essential for probing SM through **pQCD** precision tests.

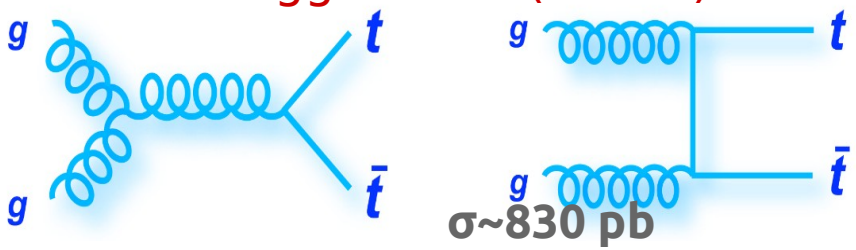
Differential x-secs in Otto's talk

In pp collisions, it is mainly produced in pairs

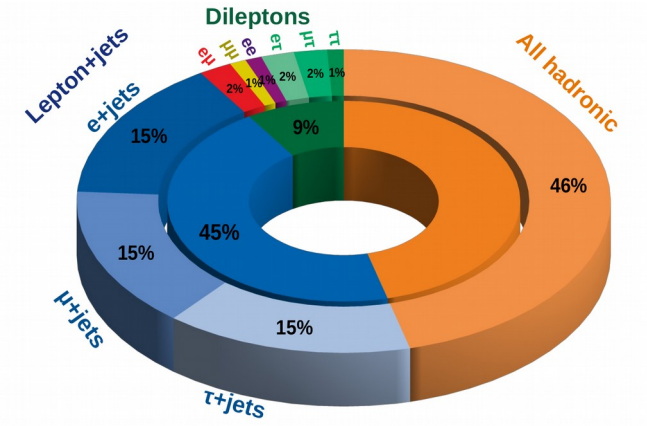
qq annihilation (~10%)



gg fusion (~90%)

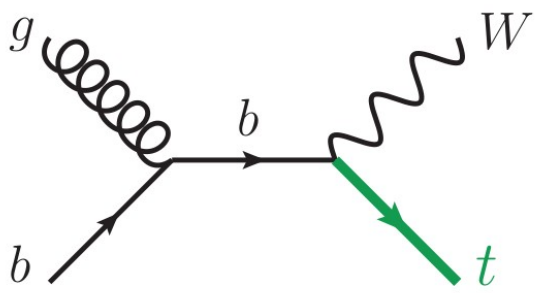


σ~830 pb

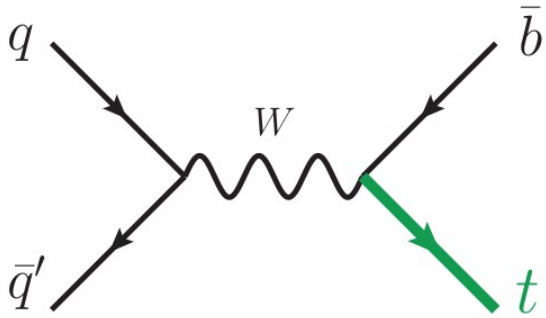


- Constrains **proton PDFs** , **α**s, top quark pole mass and **new physics**.
- **Main background** in plenty of BSM searches.

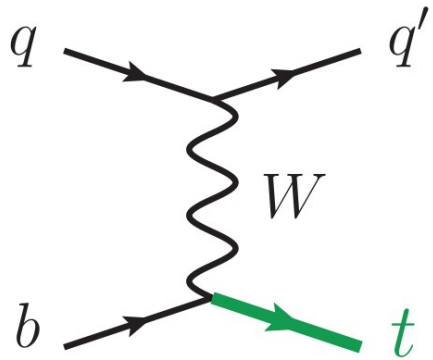
Single top production: probing EW top production.



tW associated production ($\sigma \sim 70$ pb)



s-channel production ($\sigma \sim 10$ pb)

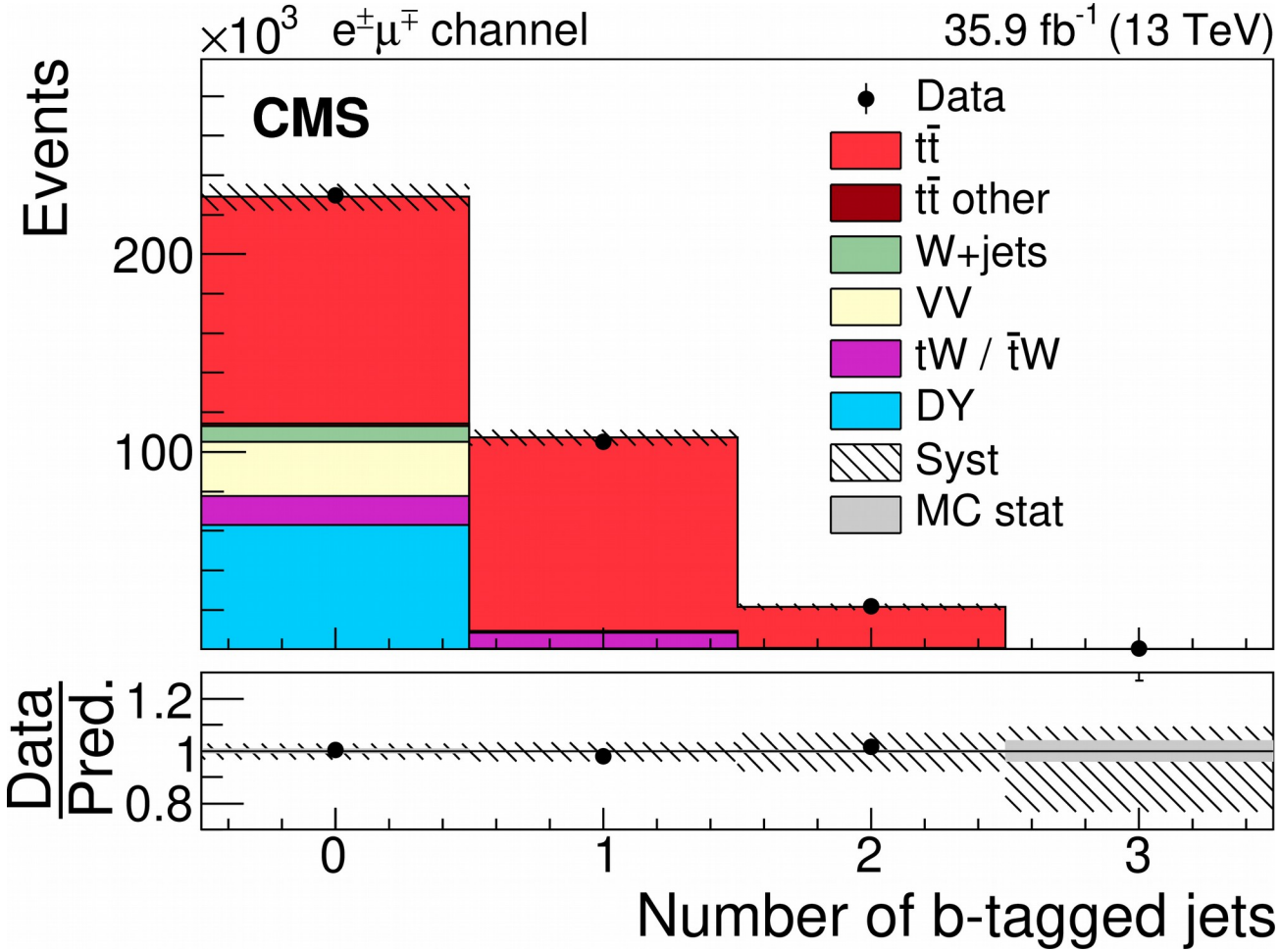


t-channel production ($\sigma \sim 220$ pb)

Direct measurement of $|V_{tb}|$.

$t\bar{t}$ inclusive cross section (1)

Eur. Phys. J. C 79 (2019) 368



- Isolated opposite-sign dilepton pairs in ee/μμ/eμ categories.
- Events are classified according to the number of jets with p_T > 30 GeV and number of b-tagged jets.

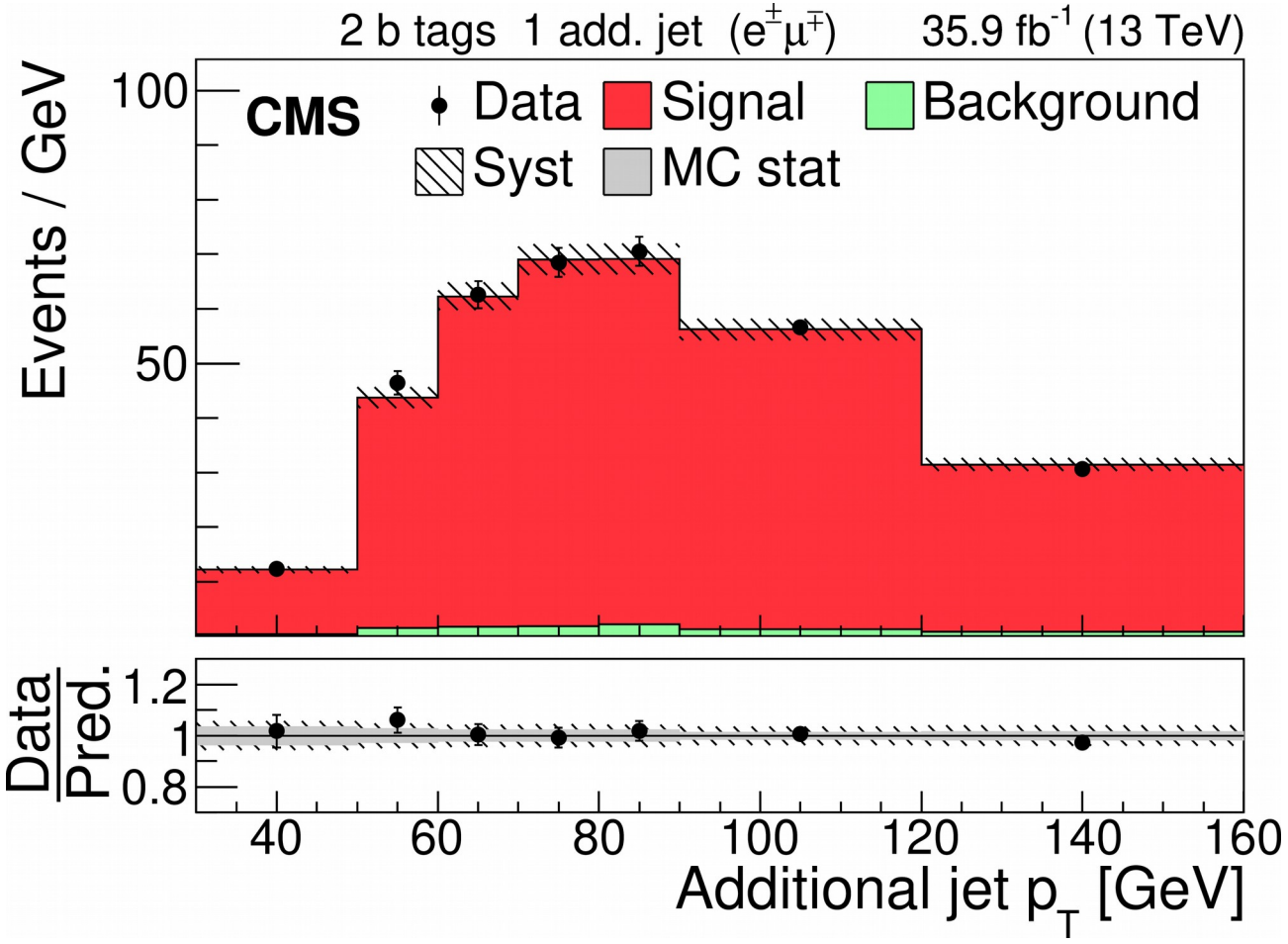
Following the legacy 7 and 8 TeV measurement:

JHEP. 08 (2016) 029

The cross section is measured using a PLR fit in the visible region and extrapolated to the full phase space.

$t\bar{t}$ inclusive cross section (2)

Fitted distributions: jet p_T in regions of lepton flavour and jet and btag multiplicities.



- 12 regions in njet and nbjets categories.

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Systematic uncertainties are taken as nuisance parameters and constrained in the fit.

Largest uncertainties:

- Lepton efficiencies: constrained using ee/μμ/eμ events.
- FSR scale uncertainty.
- Luminosity.

NNLO+NNLL prediction:

$\sigma_{tt} = 832^{+20}_{-29}(\text{scale}) \pm 35\ (\text{PDF}+\alpha_S)\text{pb}$

JHEP 01(2013)080

σ_{tt} = 803 ± 2 (stat) ± 25 (syst) ± 20 (lumi) pb for m_t^{MC} = 172.5 GeV

Precision beyond the theoretical predictions!

$t\bar{t}$ inclusive cross section (2)

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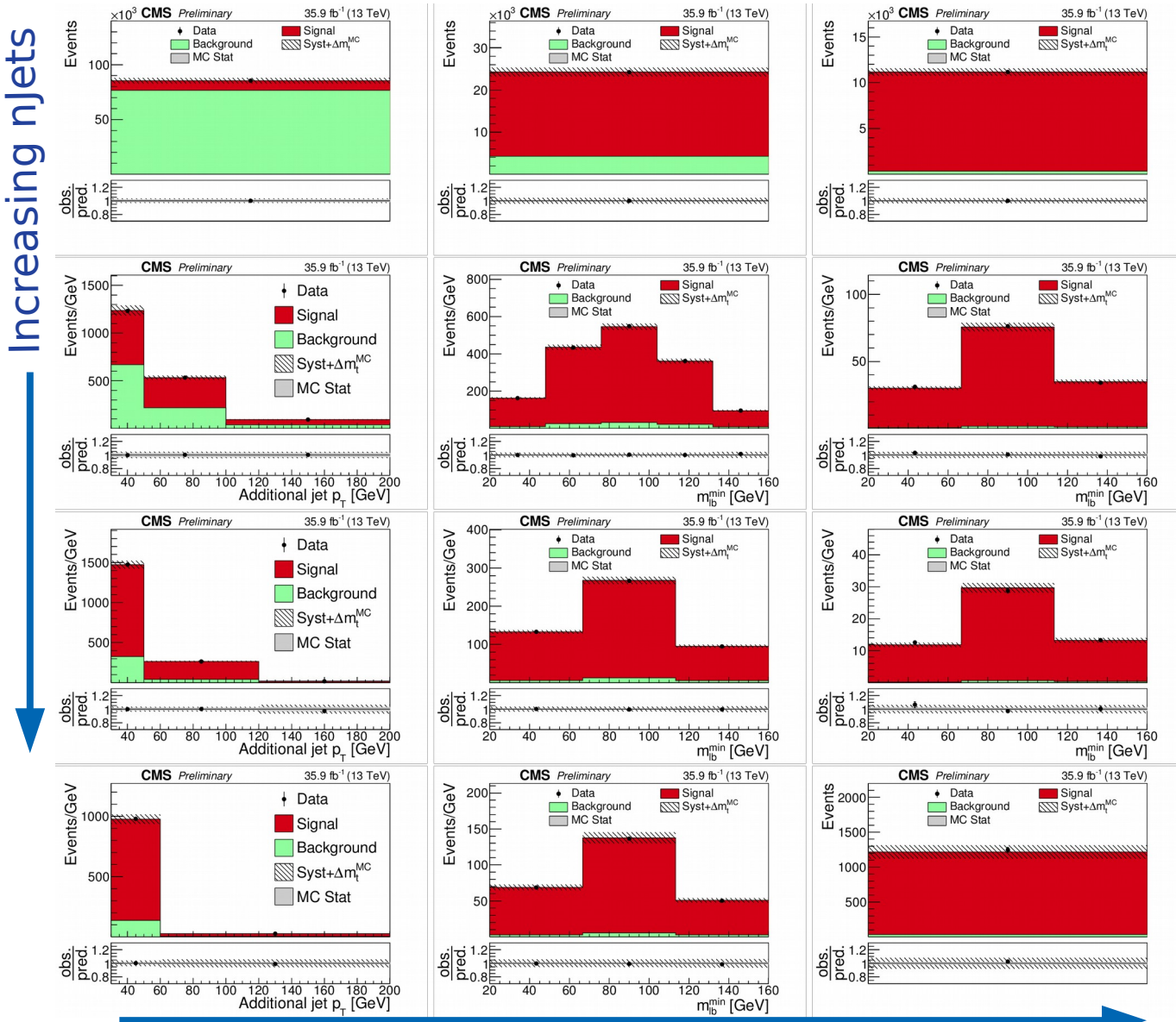
- Additionally, a fit is performed to extract simultaneously the $t\bar{t}$ cross section and m_t^{MC}.
- The distribution of m_{lb}^{min} is used to increase the sensitivity to m_t^{MC}.
- Same njets-btags categories as in the main measurement.



Results

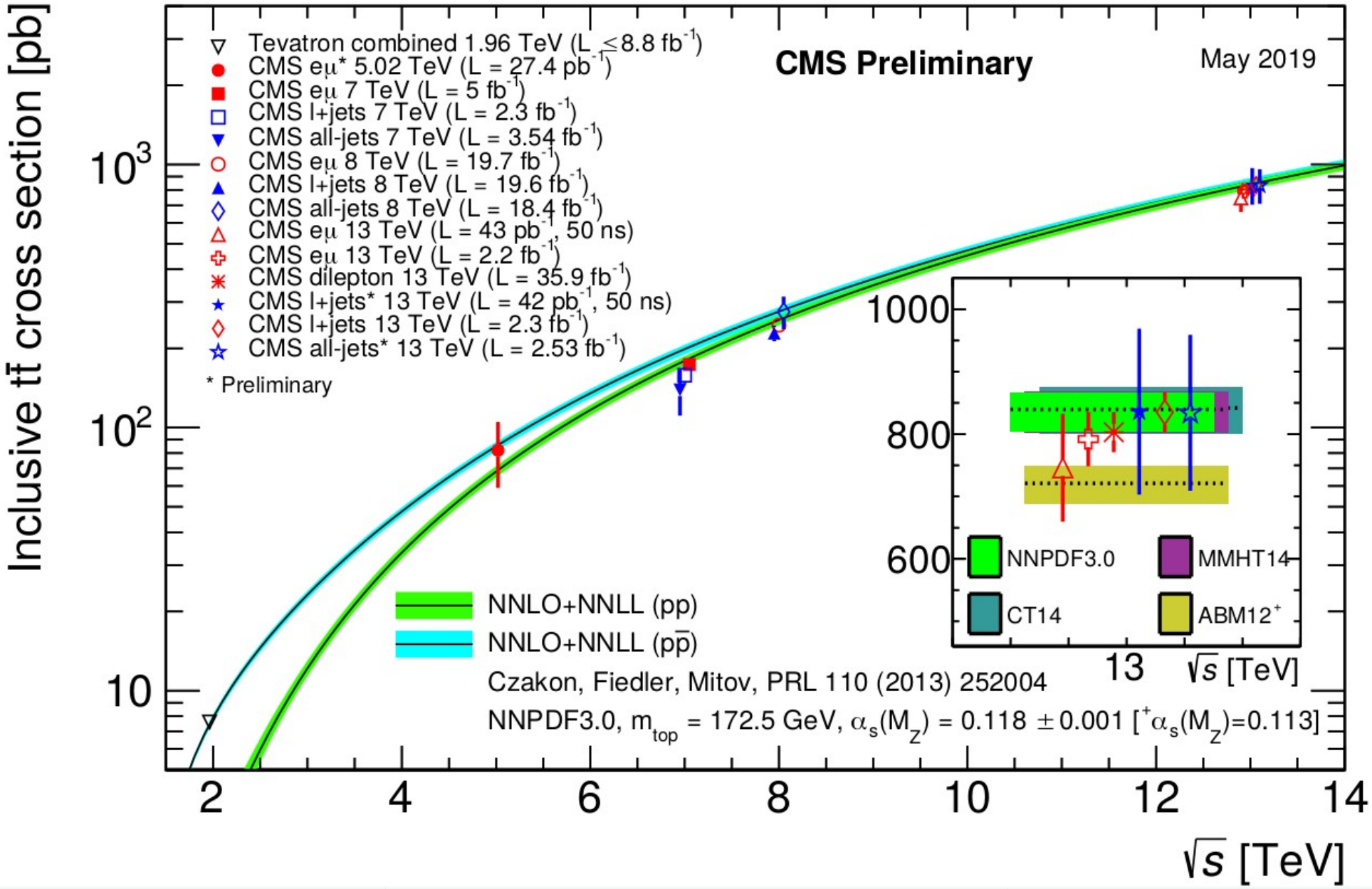
σ_{tt} = 815 ± 2 (stat) ± 29 (syst) ± 20 (lumi) pb

m_t^{MC} = 172.33 ± 0.14 (stat) $^{+0.66}_{-0.72}$ (syst) GeV

m_t^{pole} and α_s in Agostino's talk

Summary of $t\bar{t}$ inclusive cross section

Results in agreement with the SM predictions at 5.02, 7, 8 and 13 TeV in pp collisions.

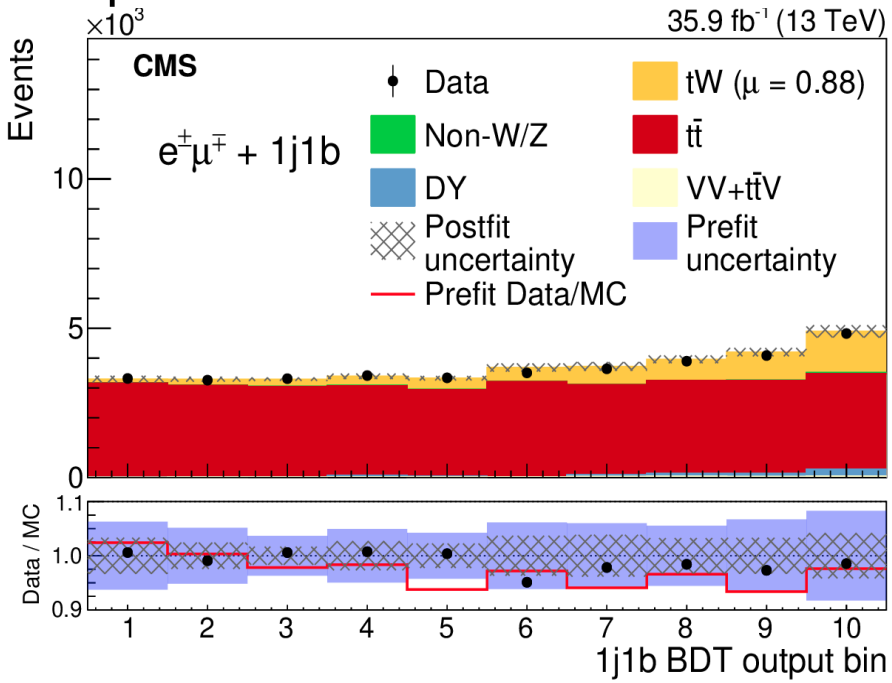


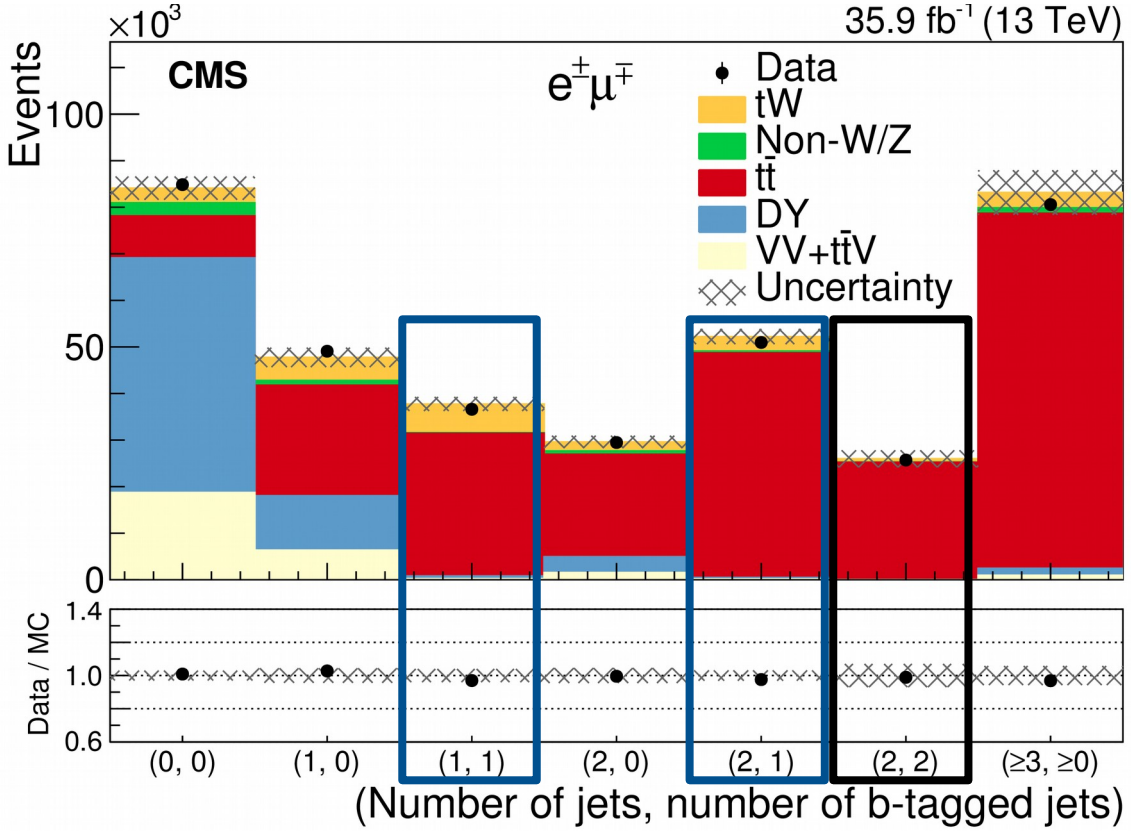
tW inclusive cross section

JHEP 10 (2018) 117

Inclusive cross section measurement using a BDT + subleading jet p_T in 2j2b.

Postfit distribution of the BDT output:





Main uncertainties:
Lepton efficiencies, pileup, signal μ_R and μ_F scales, $t\bar{t}$ background.

Total uncertainty of ~11%.

NNLO prediction: arXiv:1506.04072

71.7 ± 1.8 (scale)± 3.4 (PDF) pb

See the poster by Víctor

63.1 ± 1.8 (stat) ± 6.4 (syst) ± 2.1 (lumi) pb in agreement with the SM.

t-channel inclusive cross section: e/μ + jets

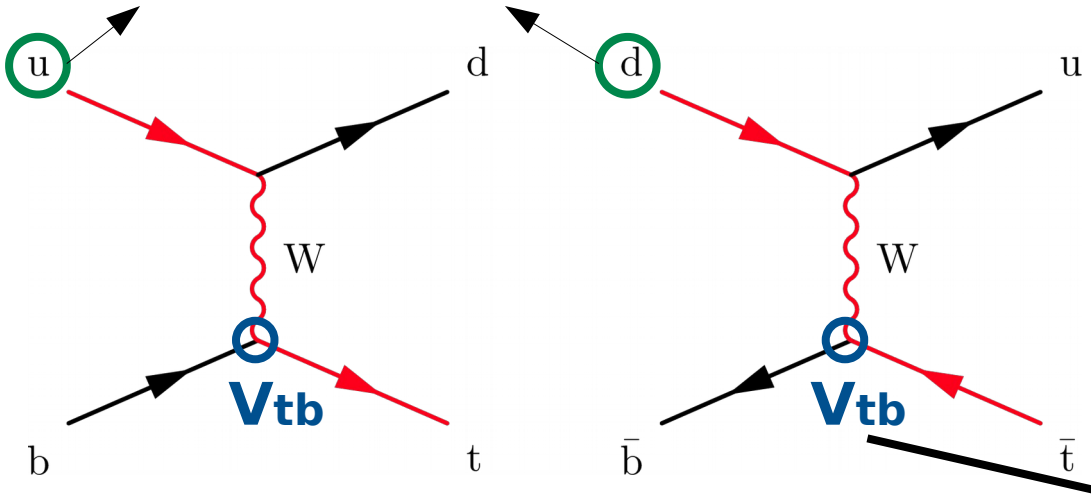
35.9 fb^{-1} (2016). Single lepton + jets.

arXiv:1812.10514

Experimental signature:

- e/μ + MET → Can be used to compute m_T^W.
- One b-jet → Associated to the W to reconstruct the (anti) top quark.
- One high-energetic light jet (not associated to the top quark decay).

Asymmetry in pp collisions: proton PDF



Main backgrounds

- tt → l+jets
- W+Jets
- QCD multijet

The ratio between top and antitop t-channel cross sections is measured.

NLO cross section:

Comput.Phys.Commun. 191 (2015) 74-89

$$\sigma_{t\text{-ch,t}} = 136.0^{+4.1}_{-2.9}(\text{scale}) \pm 3.5(\text{PDF}+\alpha_S)\ \text{pb}$$

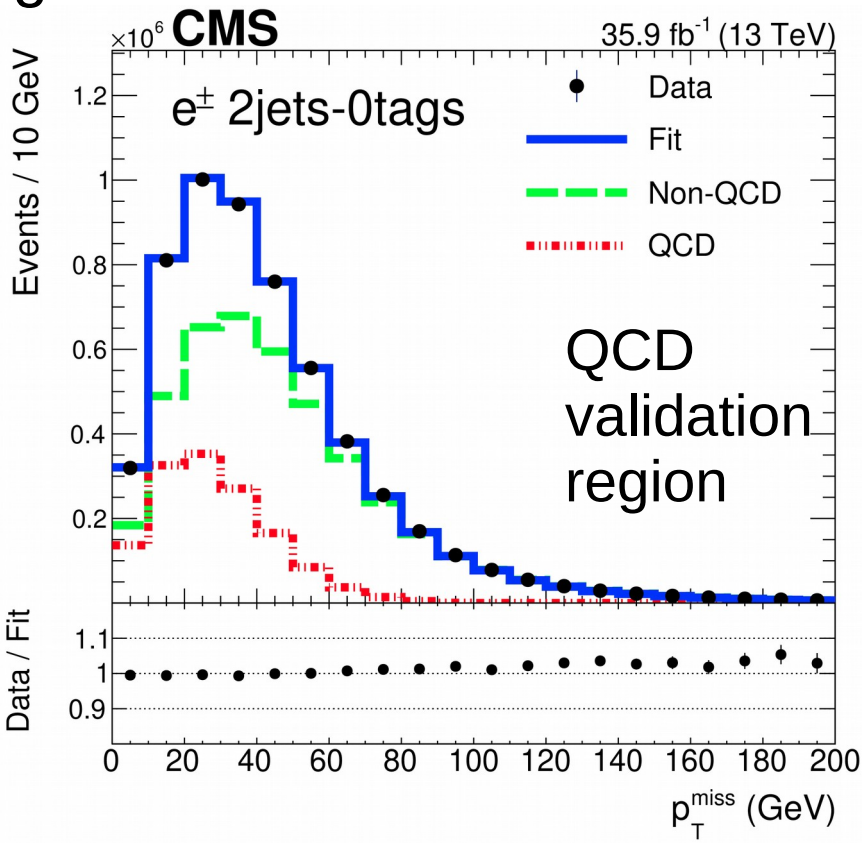
$$\sigma_{t\text{-ch,}\bar{t}} = 81.0^{+2.5}_{-1.7}(\text{scale}) \pm 3.2(\text{PDF}+\alpha_S)\ \text{pb}$$

Direct sensitivity to Vtb.

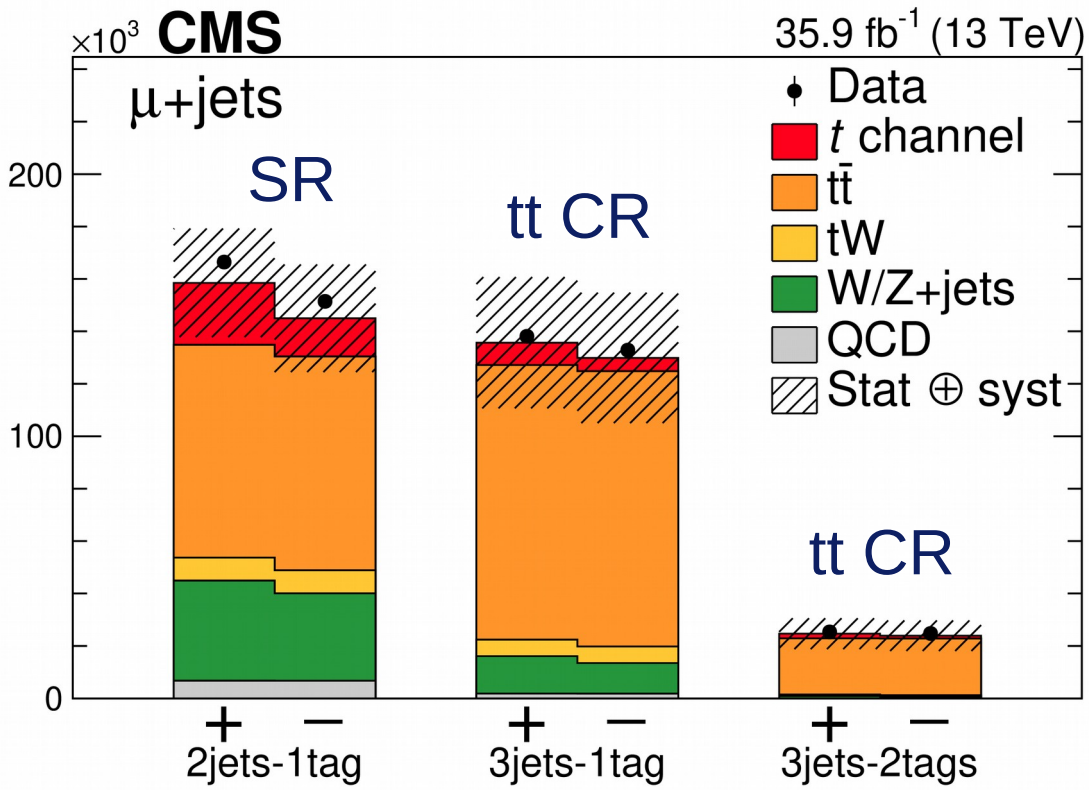
t-channel inclusive cross section: e/μ + jets (2)

arXiv:1812.10514

QCD background is suppressed by selecting events with MET > 30 GeV and m_T^W > 50 GeV. Remaining events are estimated from data in a sideband region defined by inverting the isolation of the lepton.



Categories of number of jets and btags.

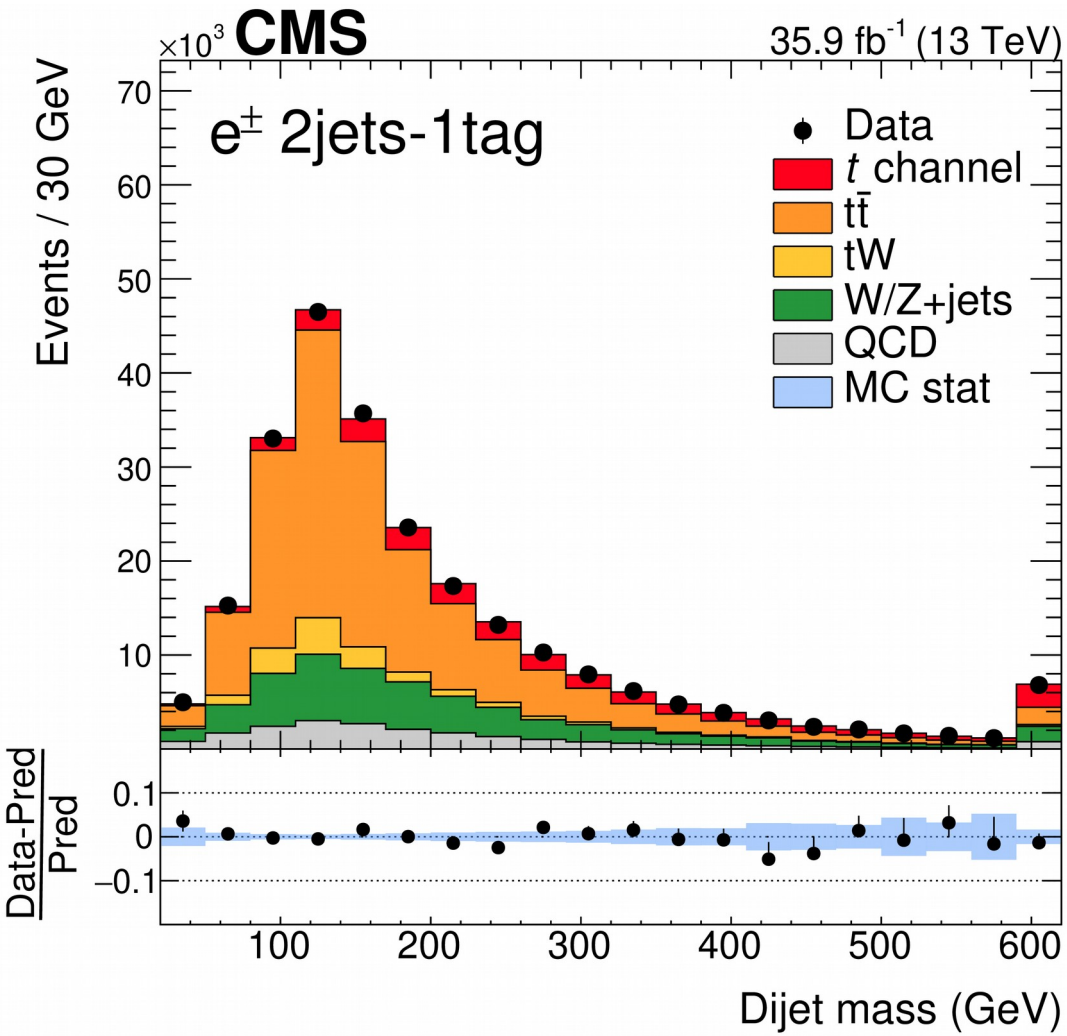


Signal region (SR) + two tt control regions (CR).

t-channel inclusive cross section: e/μ + jets (3)

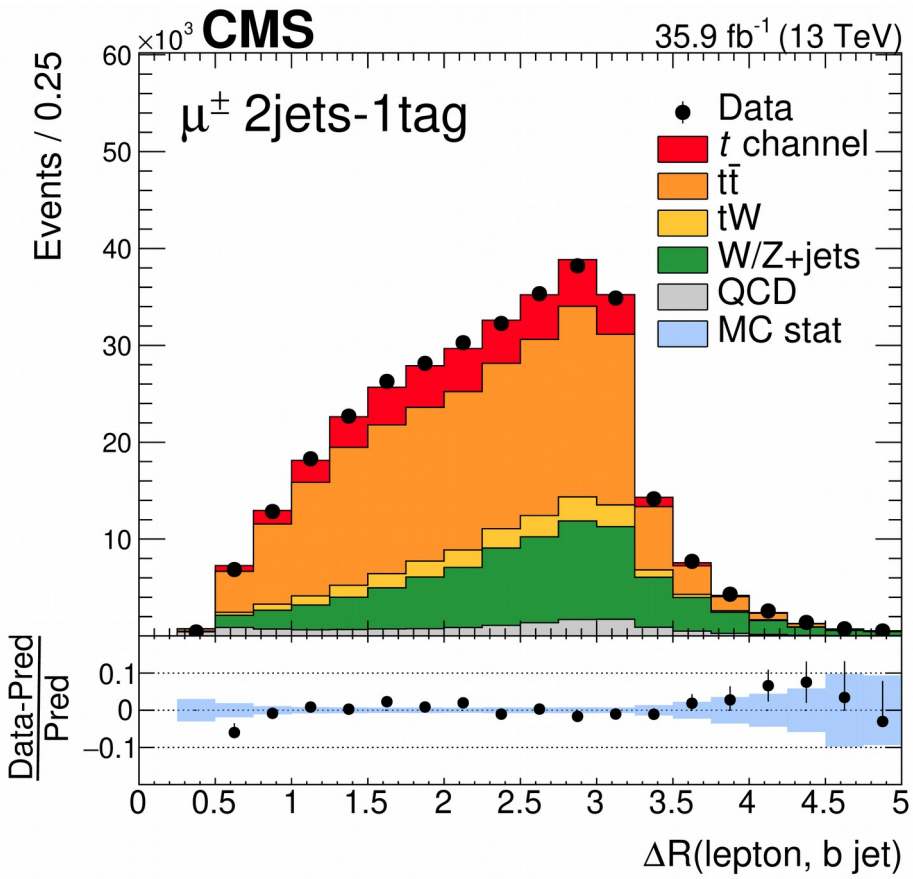
arXiv:1812.10514

A BDT is trained in the signal categories using 12 different observables.



5 most rated variables

- Light-quark jet |η|
- Reconstructed m_{top}
- m(light-quark jet, b-tagged jet from the top quark)
- ΔR(lepton, b-tagged jet)
- cosθ* = cos(light-quark jet, lepton)



t-channel inclusive cross section: e/μ + jets (4)

arXiv:1812.10514

Maximum likelihood fit to the BDT output in 12 categories: two lepton charges, two lepton flavors, three jet-btag multiplicity categories → The uncertainties on the tt backgrounds are constrained in the fit.

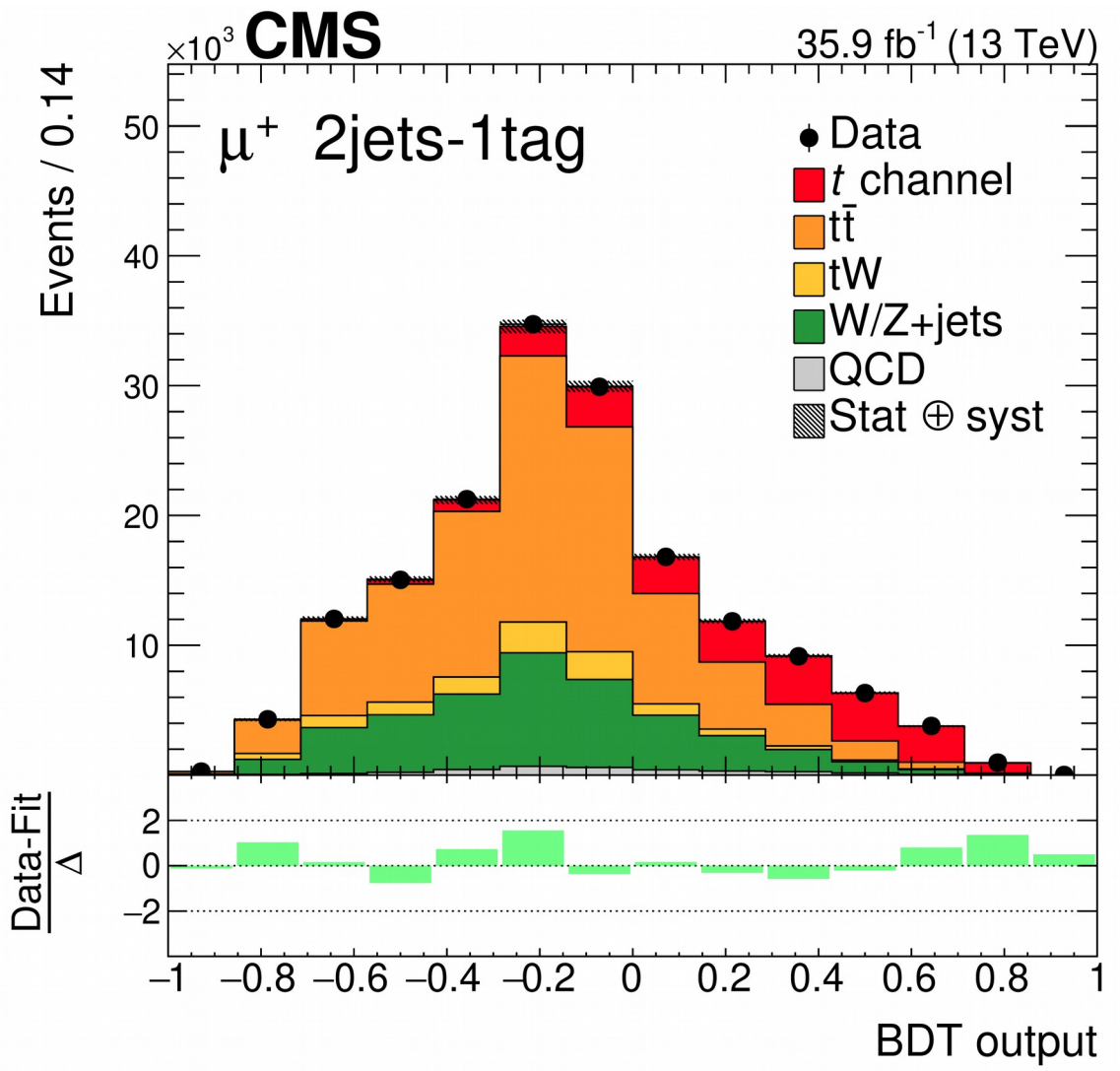
Uncertainties

- Signal modeling uncertainties are externalised.
- Main uncertainties: signal PS scale, proton PDF, jet energy scale..

Results

$$\sigma_{t\text{-ch,t}} = 136 \pm 22\,\text{pb}$$

$$\sigma_{t\text{-ch,}\bar{\text{t}}} = 82 \pm 14\,\text{pb}$$



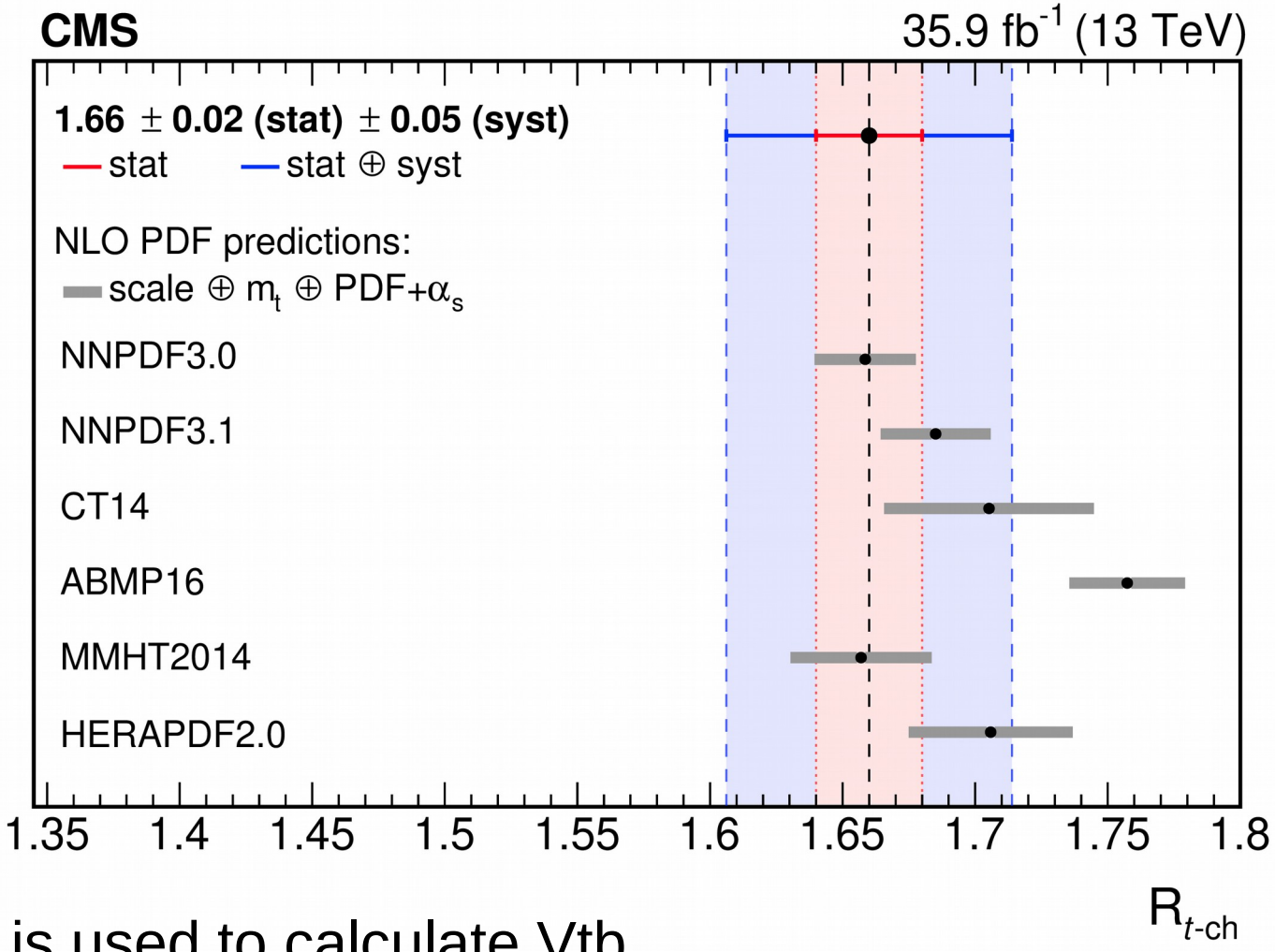
t-channel cross section ratio and Vtb

The ratio between cross sections is measured for different PDF sets. $R_{t\text{-ch}} = \sigma_{t\text{-ch},t}/\sigma_{t\text{-ch},\bar{t}}$.

arXiv:1812.10514

The correlated uncertainties are partially canceled when computing the ratio.

Most precise ratio of top quark cross section up to date.



The total cross section is used to calculate Vtb.

$$|f_{\mathrm{LV}} V_{tb}| = \sqrt{\frac{\sigma_{\mathrm{meas.}}}{\sigma_{\mathrm{theo.}}\ (V_{tb}=1)}} = 1.00 \pm 0.08\ (\mathrm{exp}) \pm 0.02\ (\mathrm{theo}).$$

LHC combination 7,8 TeV results in Martijn's talk.

Conclusions

- Recent top-quark cross section result in the dilepton channel:
  - Precision beyond theoretical predictions.
  - Cross section and top MC mass measured simultaneously.
  - Constrain α_s and top quark pole mass.
  - Results in agreement with predictions.

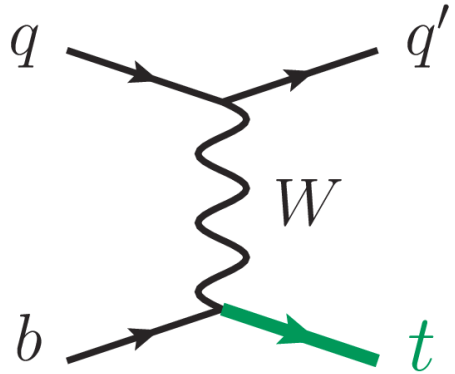
- New single top t-channel cross section measurement in the e/μ+jets channel:
  - Measurement in agreement with the SM with a ~15% uncertainty.
  - Precise measurement of the top/antitop ratio: sensitive to proton PDF.
  - Constrain on Vtb element of the CKM matrix.

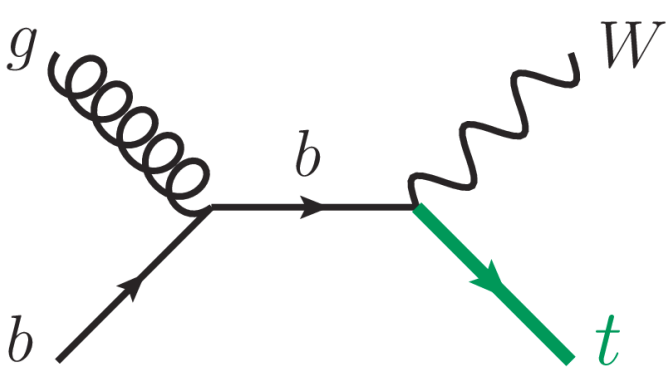
Thank you for your attention!!

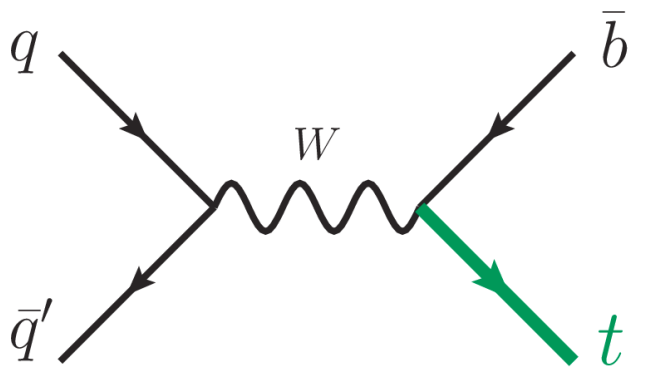
BACK UP SLIDES

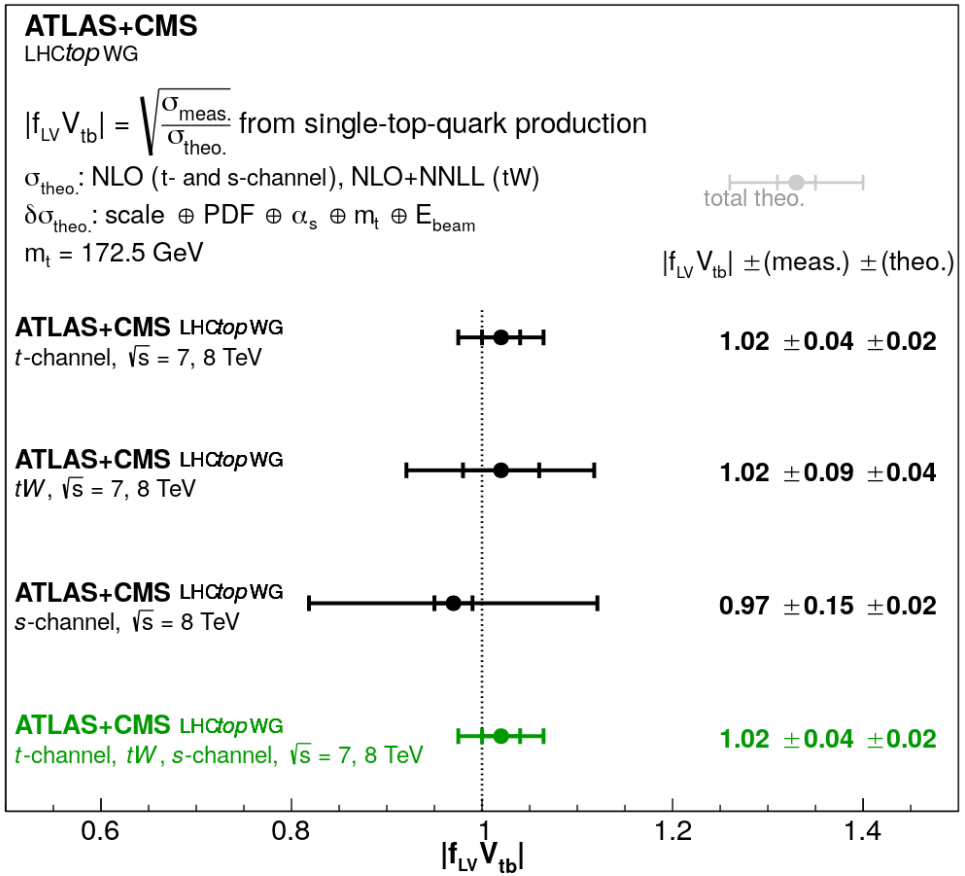
Single top combination (CMS+ATLAS) at 7 and 8 TeV

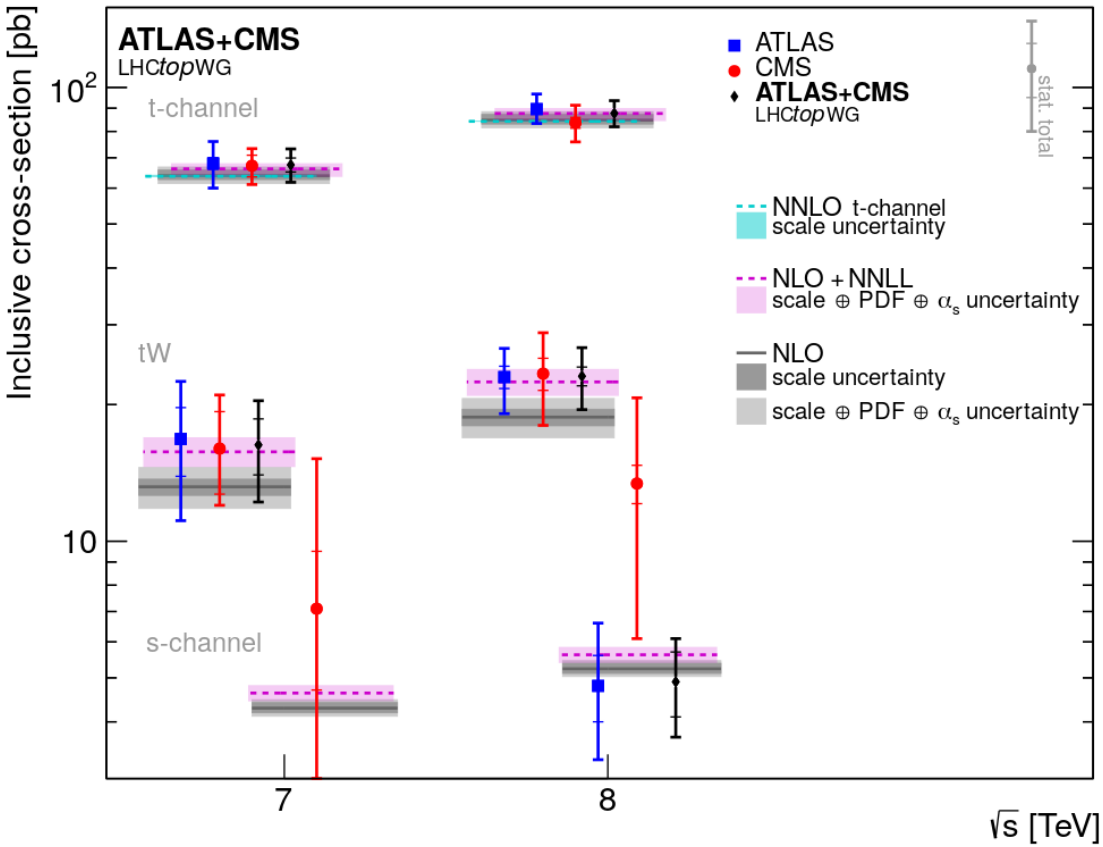
JHEP 05 (2019) 088





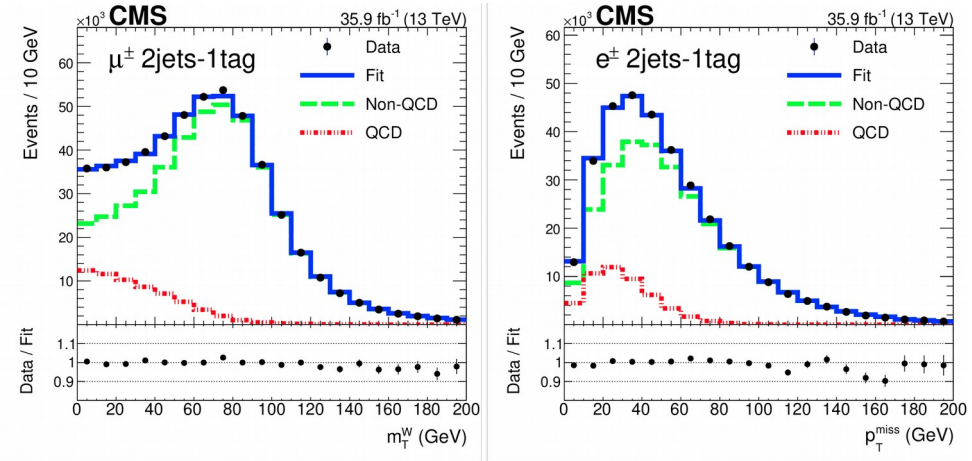


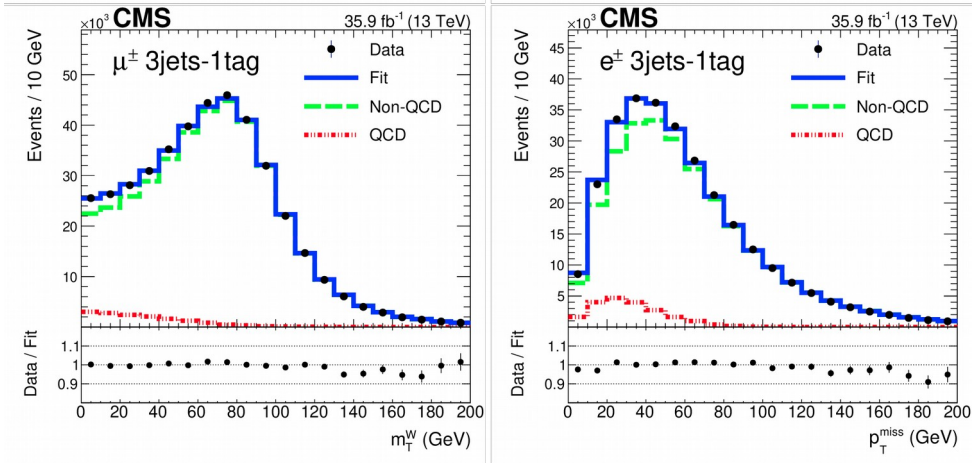


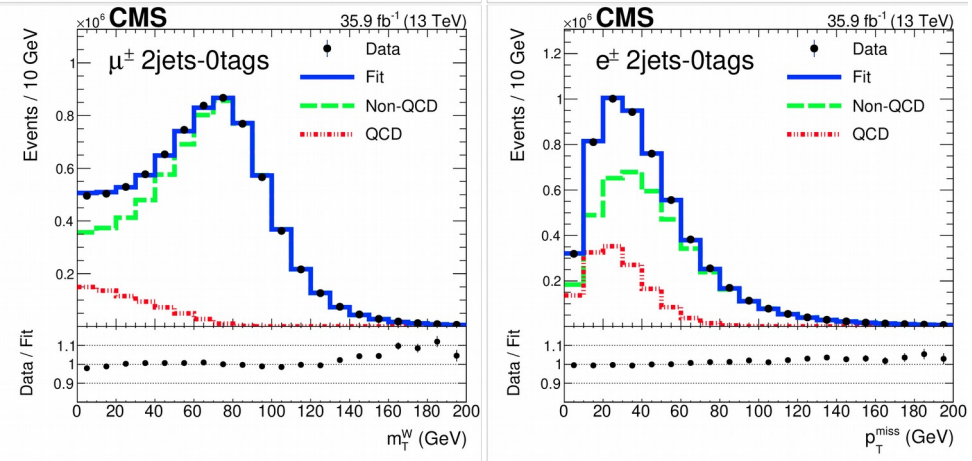


Dominant uncertainties: modeling, jets (jet energy scale, b-tagging).

Single top inclusive cross section: QCD







QCD control regions in the different categories of jet-btag multiplicity.

Single top inclusive cross section

Variable	Description
Light-quark jet $\lvert\eta\rvert$	Absolute value of the pseudorapidity of the light-quark jet
Top quark mass	Invariant mass of the top quark reconstructed from the lepton, the neutrino, and the b-tagged jet associated to the top quark decay
Dijet mass	Invariant mass of the light-quark jet and the b-tagged jet associated to the top quark decay
ΔR (lepton, b jet)	ΔR between the momentum vectors of the lepton and the b-tagged jet associated with the top quark decay
$\cos\theta^*$	Cosine of the angle between the lepton and the light-quark jet in the rest frame of the top quark
Jet p_{T} sum	Scalar sum of the transverse momenta of the light-quark jet and the b-tagged jet associated to the top quark decay
$m_{\mathrm{T}}^{\mathrm{W}}$	Transverse mass of the W boson
$p_{\mathrm{T}}^{\mathrm{miss}}$	Missing momentum in the transverse plane of the event
ΔR (light jet, b jet)	ΔR between the momentum vectors of the light-quark jet and the b-tagged jet associated to the top quark decay
Lepton $\lvert\eta\rvert$	Absolute value of the pseudorapidity of the selected lepton
W boson $\lvert\eta\rvert$	Absolute value of the pseudorapidity of the reconstructed W boson
Light-quark jet mass	Invariant mass of the light-quark jet

Single top inclusive cross section

$$\begin{aligned}
\sigma_{t\text{-ch,t}} &= 136 \pm 1\,(\text{stat}) \pm 3\,(\text{prof}) \pm 21\,(\text{sig-mod}) \pm 4\,(\text{lumi})\,\text{pb} \\
&= 136 \pm 1\,(\text{stat}) \pm 22\,(\text{syst})\,\text{pb} \\
&= 136 \pm 22\,\text{pb}, \\
\sigma_{t\text{-ch,}\bar{\text{t}}} &= 82 \pm 1\,(\text{stat}) \pm 3\,(\text{prof}) \pm 14\,(\text{sig-mod}) \pm 2\,(\text{lumi})\,\text{pb} \\
&= 82 \pm 1\,(\text{stat}) \pm 14\,(\text{syst})\,\text{pb} \\
&= 82 \pm 14\,\text{pb}.
\end{aligned}$$

$$\begin{aligned}
R_{t\text{-ch}} &= 1.66 \pm 0.02\,(\text{stat}) \pm 0.03\,(\text{prof}) \pm 0.04\,(\text{sig-mod}) \\
&= 1.66 \pm 0.02\,(\text{stat}) \pm 0.05\,(\text{syst}) \\
&= 1.66 \pm 0.05.
\end{aligned}$$

Single top inclusive cross section

	$\Delta R_{t\text{-ch}}/R_{t\text{-ch}}$	$\Delta\sigma/\sigma(\mathrm{t})$	$\Delta\sigma/\sigma(\bar{\mathrm{t}})$
Nonprofiled uncertainties			
μ_R/μ_F scale t channel	0.1	6.2	6.5
ME-PS scale matching t channel	0.5	2.9	2.3
PS scale t channel	0.6	12.9	13.3
PDF t channel	2.4	7.1	9.5
Luminosity	—	2.5	2.5
Profiled uncertainties			
JES	0.5	1.7	2.1
JER	0.2	0.1	0.3
Unclustered energy	0.2	0.1	0.3
b tagging	0.1	1.2	1.2
Muon and electron efficiencies	0.2	1.1	1.0
Pileup	0.4	0.9	1.2
QCD bkg. normalization	0.2	0.3	0.5
MC sample size	2.6	2.3	3.3
$\mathrm{t\bar{t}}$ bkg. model and normalization	0.6	1.1	1.5
Top quark p_T	< 0.1	0.5	0.5
tW bkg. normalization	0.1	0.4	0.5
W/Z+jets bkg. normalization	0.2	0.3	0.5
μ_R/μ_F scale $\mathrm{t\bar{t}}$, tW, W/Z+jets	0.8	0.3	0.5
PDF $\mathrm{t\bar{t}}$, W/Z+jets	0.6	0.2	0.7

Measurement of m_t^{pole} and α_s

The cross section measurement is used to constrain the top quark pole mass and α_s using different PDF sets.

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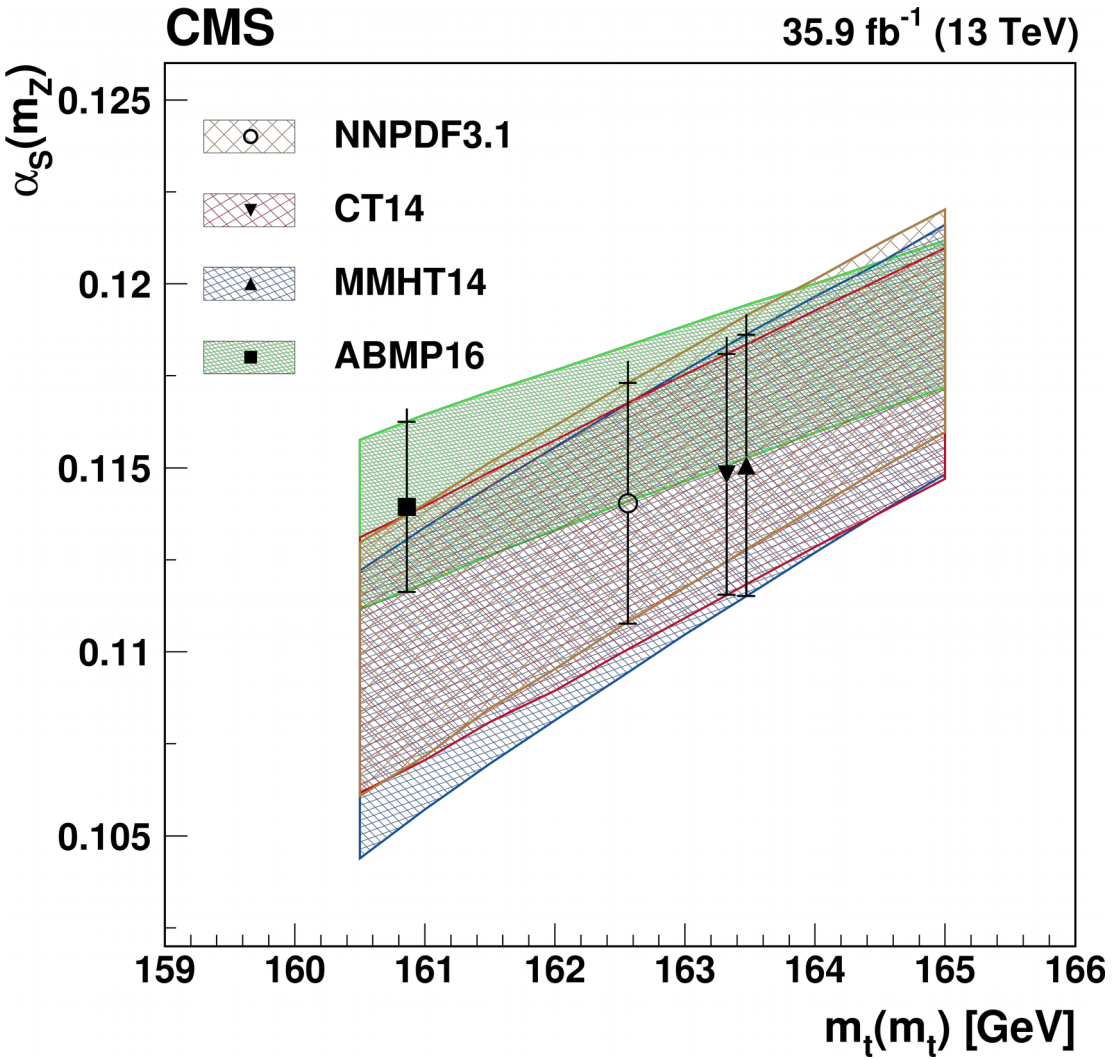
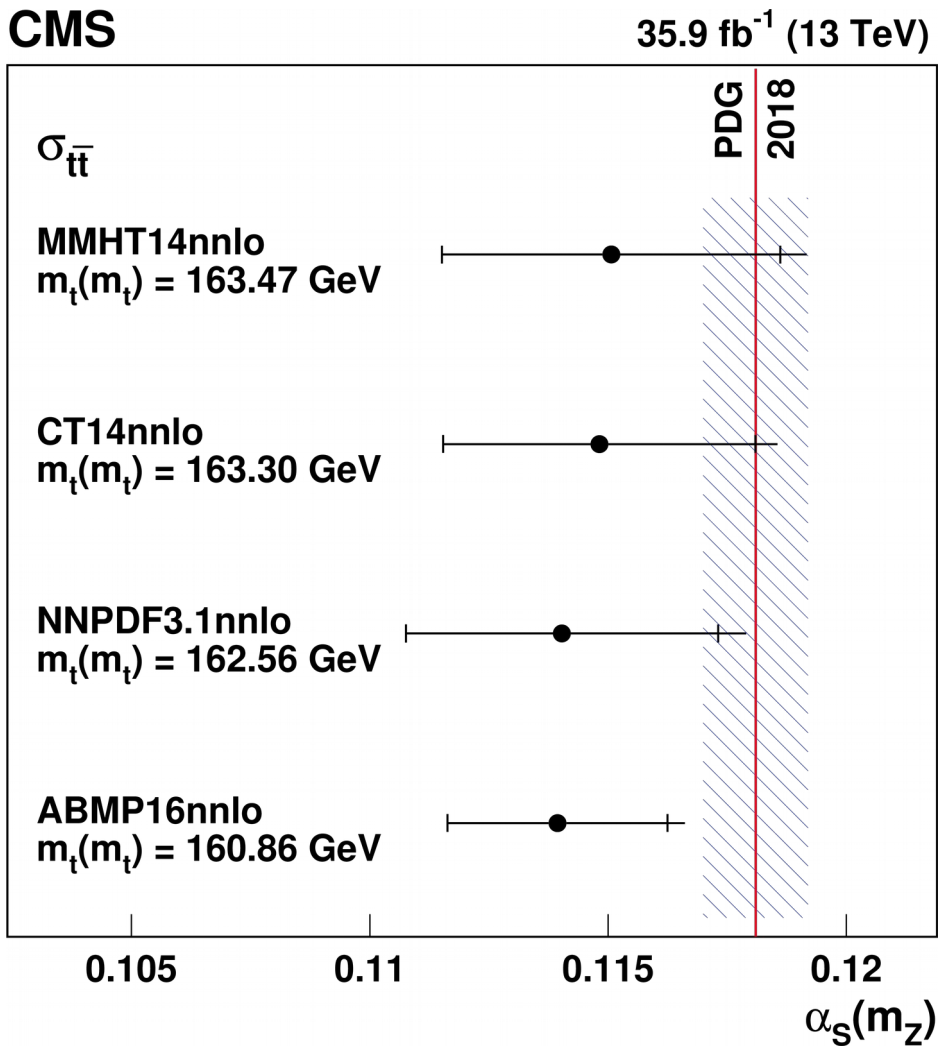
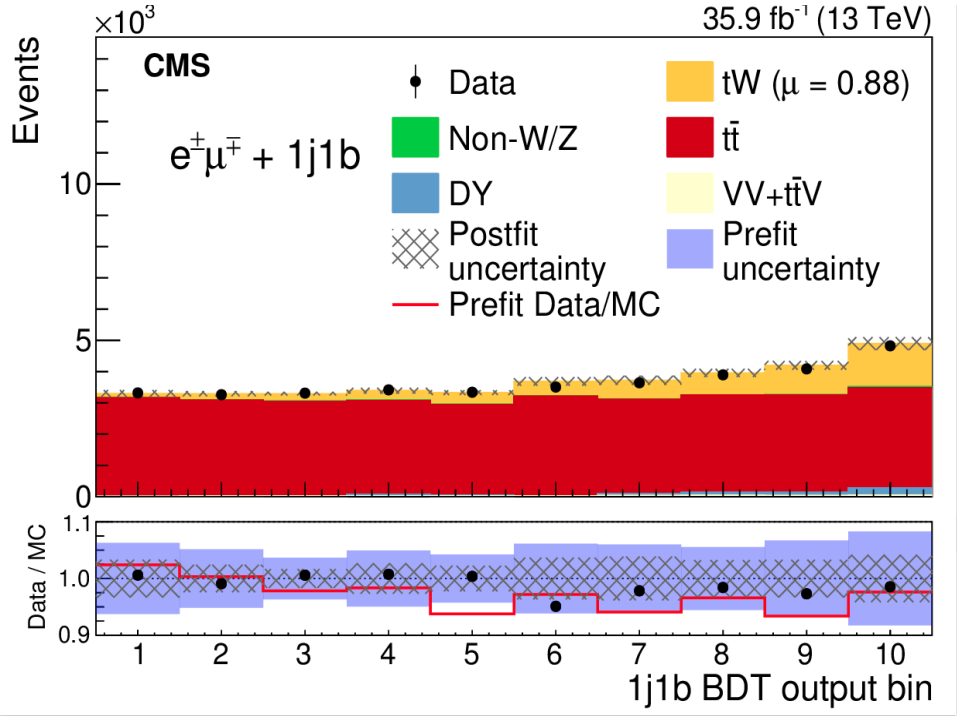
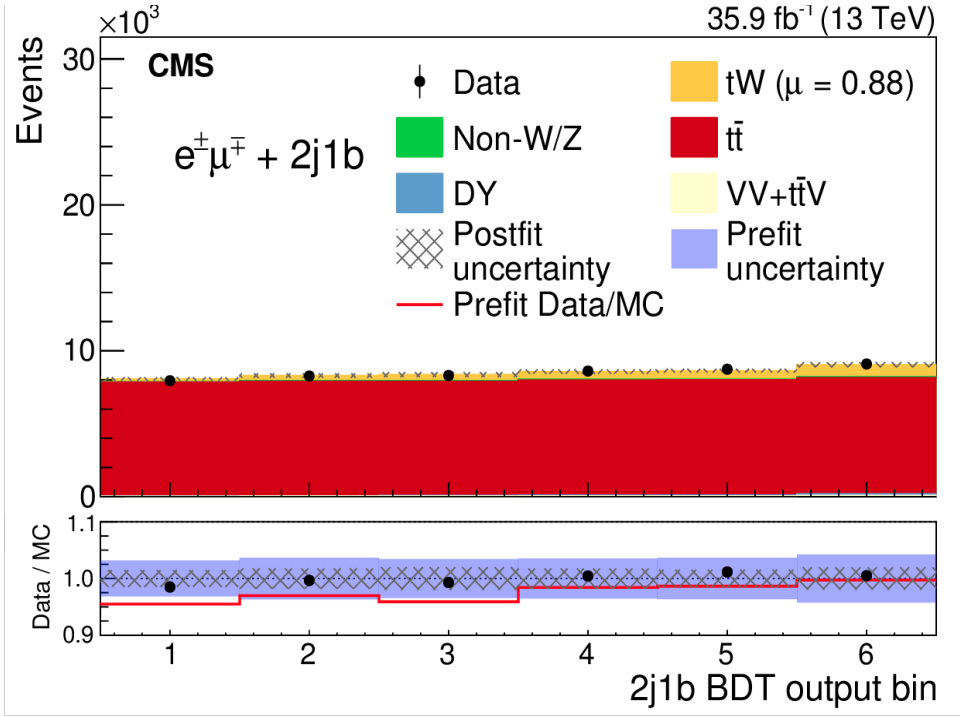


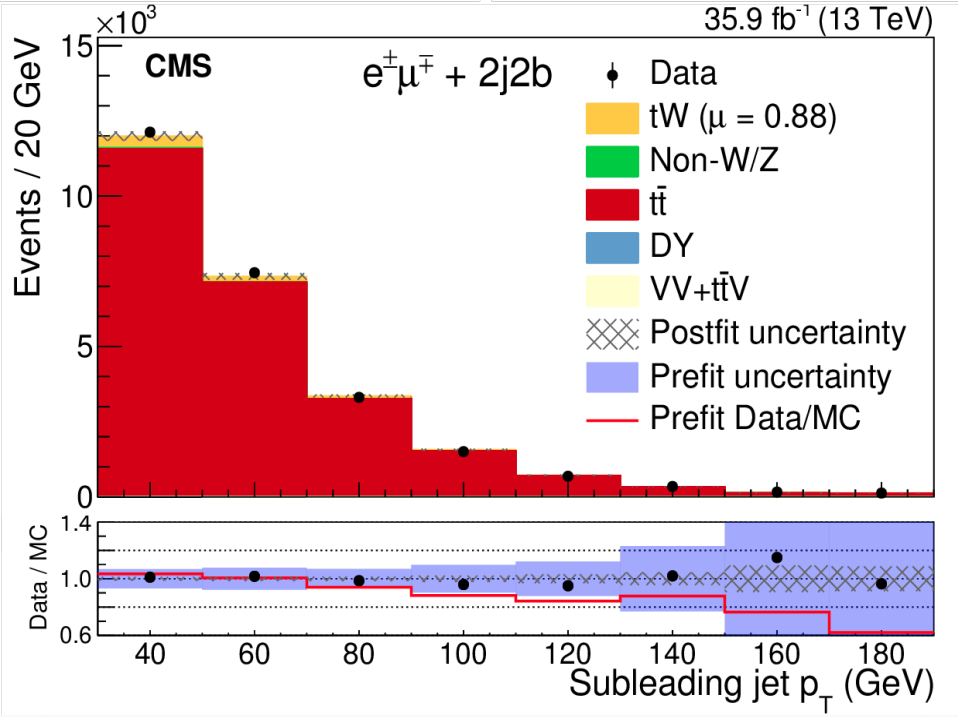


Strong coupling constant in agreement but consistently below the world average.

tW inclusive cross section

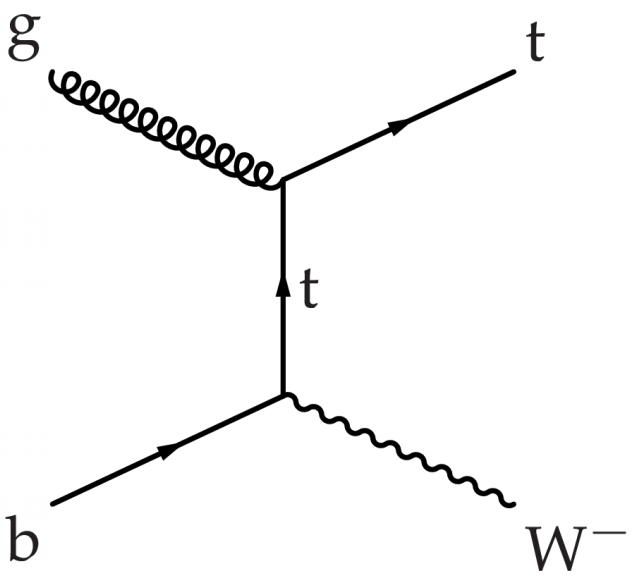


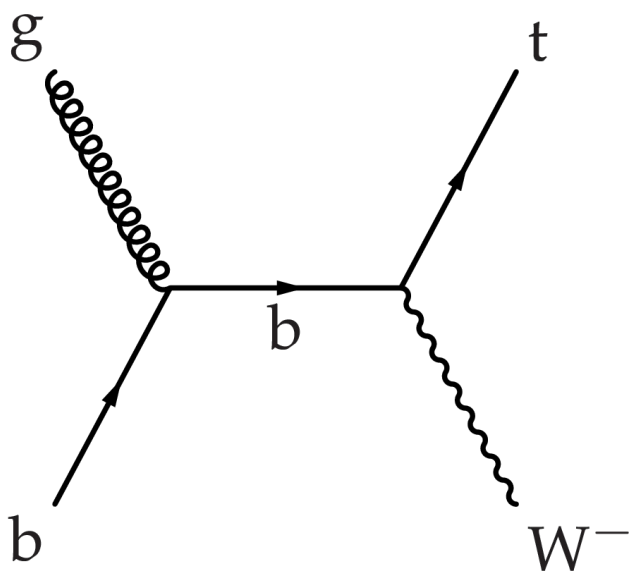




tW inclusive cross section

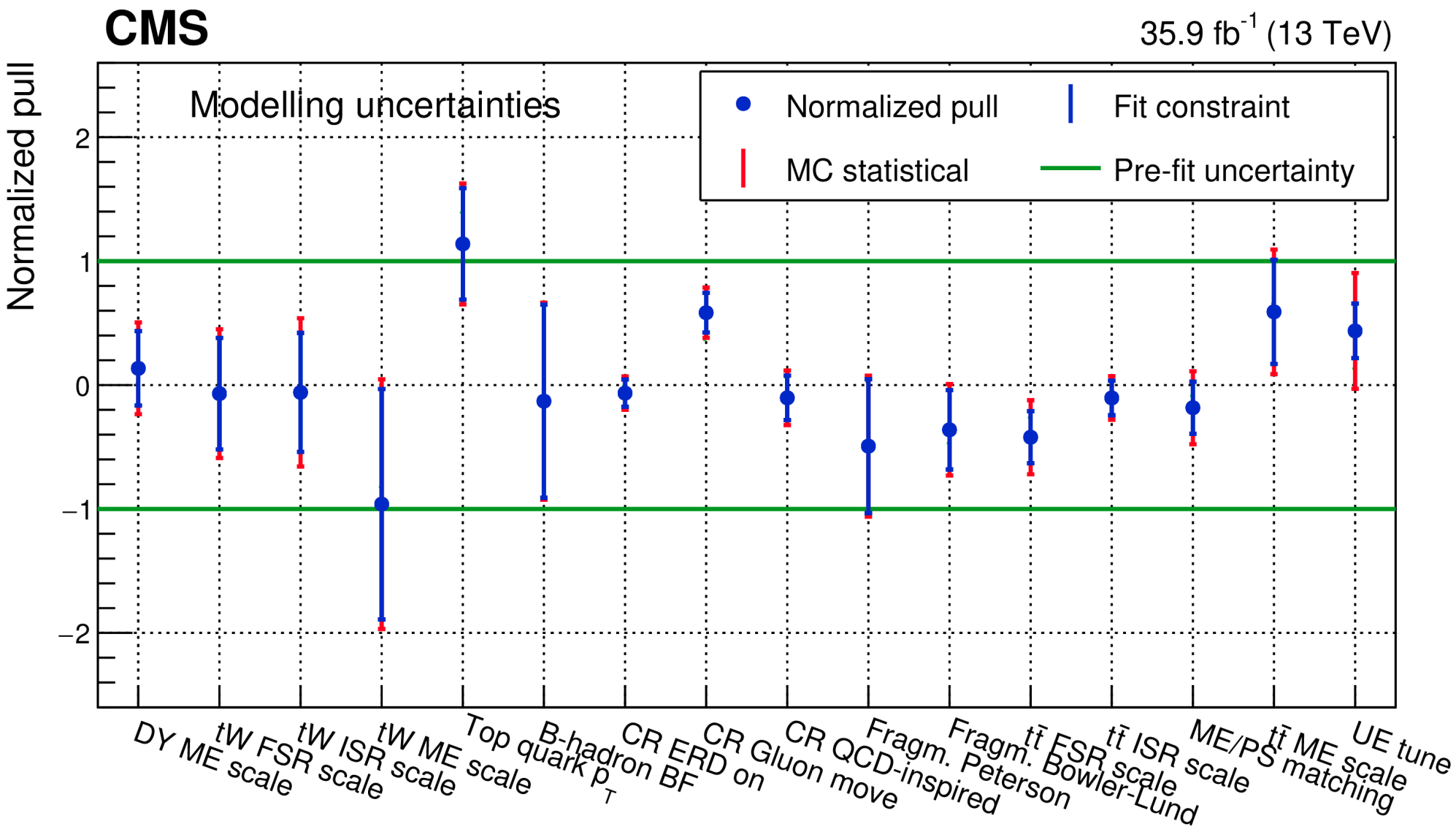
Source	Uncertainty (%)
Experimental	
Trigger efficiencies	2.7
Electron efficiencies	3.2
Muon efficiencies	3.1
JES	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistag rate	0.2
Pileup	3.3
Modeling	
$t\bar{t}$ μ_R and μ_F scales	2.5
tW μ_R and μ_F scales	0.9
Underlying event	0.4
Matrix element/PS matching	1.8
Initial-state radiation	0.8
Final-state radiation	0.8
Color reconnection	2.0
B fragmentation	1.9
Semileptonic B decay	1.5
PDFs	1.5
DR-DS	1.3
Background normalization	
$t\bar{t}$	2.8
VV	0.4
Drell–Yan	1.1
Non-W/Z leptons	1.6
$t\bar{t}V$	0.1
MC finite sample size	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	10.1
Integrated luminosity	3.3
Statistical	2.8
Total	11.1



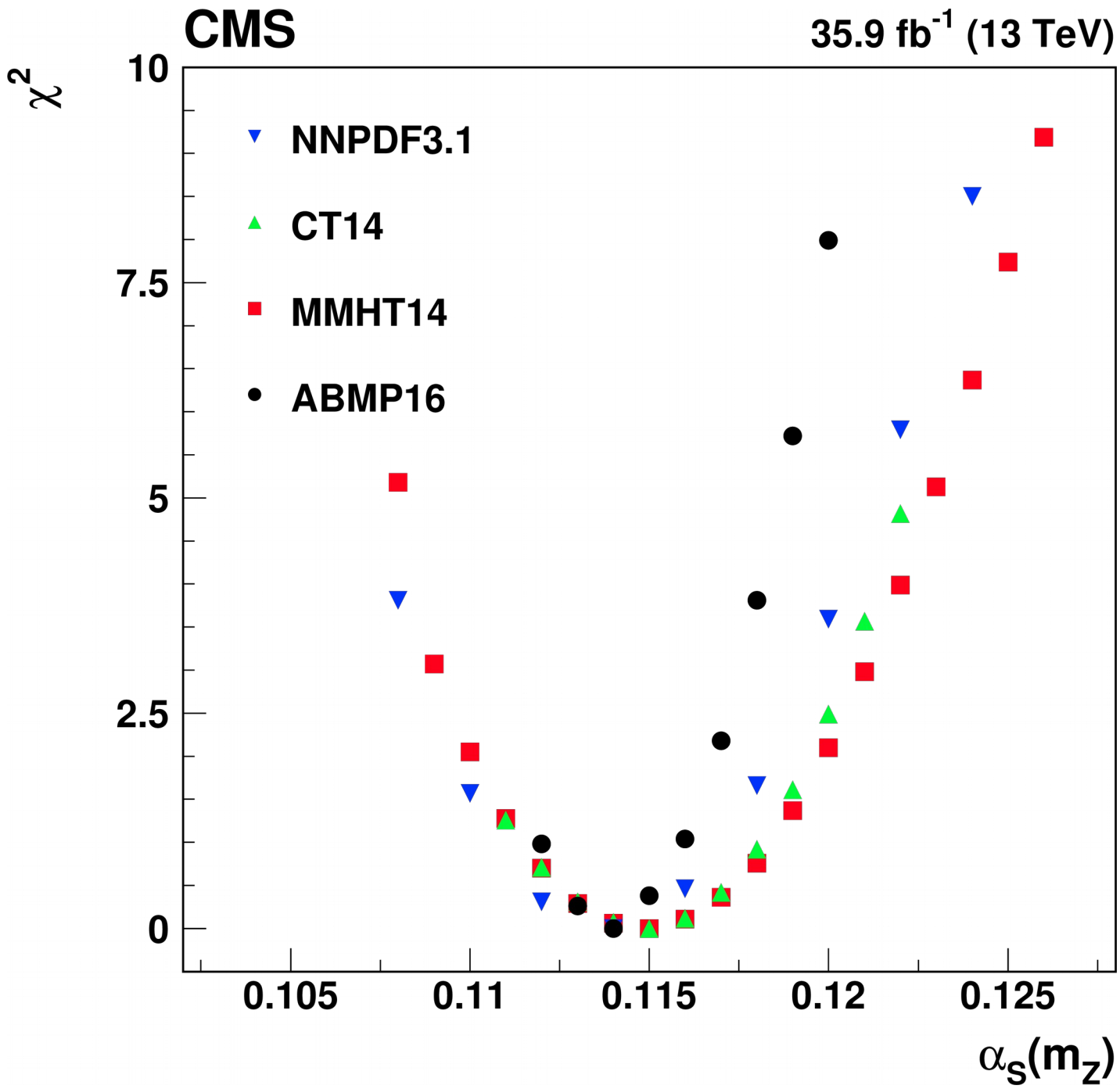


	Prefit		Postfit	
Region	tW	$t\bar{t}$	tW	$t\bar{t}$
1j1b	6147 ± 442	30622 ± 1862	5440 ± 604	30592 ± 582
2j1b	3125 ± 294	48484 ± 1984	2888 ± 321	47436 ± 612
2j2b	725 ± 85	25052 ± 2411	719 ± 88	25114 ± 281

tt inclusive cross section



alpha s from tt inclusive cross section



$t\bar{t}$ cross section measurement at 5.02 TeV

2015 dataset, 27.4 pb^{-1}.

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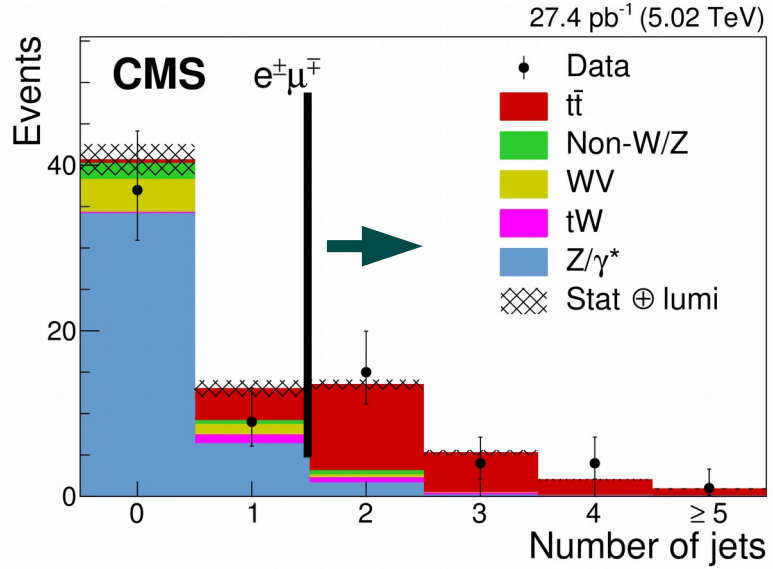
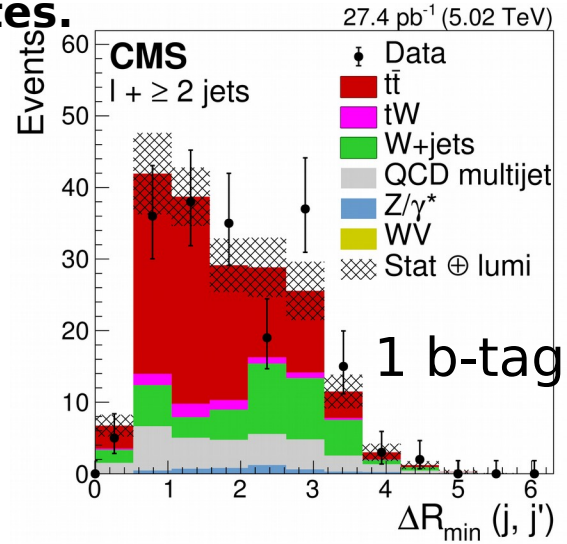
Prediction:

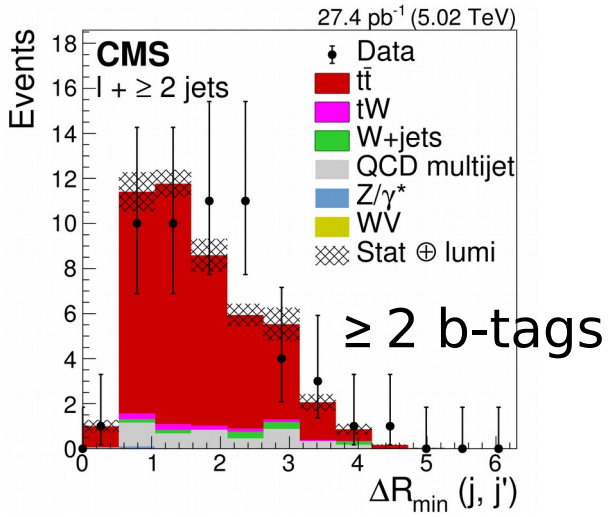
$$\sigma_{t\bar{t}}^{NNLO} = 68.9^{+1.9}_{-2.3}(\text{scale}) \pm 2.3(\text{PDF})^{+1.4}_{-1.0}(\alpha_S)\ \text{pb}$$

lepton+jets, eμ and μμ final states.



Combination measurement in

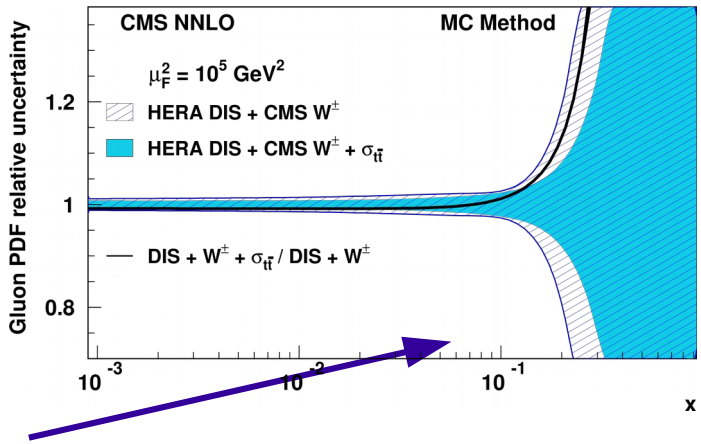




Dilepton, counting experiment.

Combined result:

σ_{tt}(5.02 TeV) = 69.5 ± 6.1 (stat) ± 5.6 (syst) ± 1.6 (lumi) pb = 69.5 ± 8.4 (12%) pb



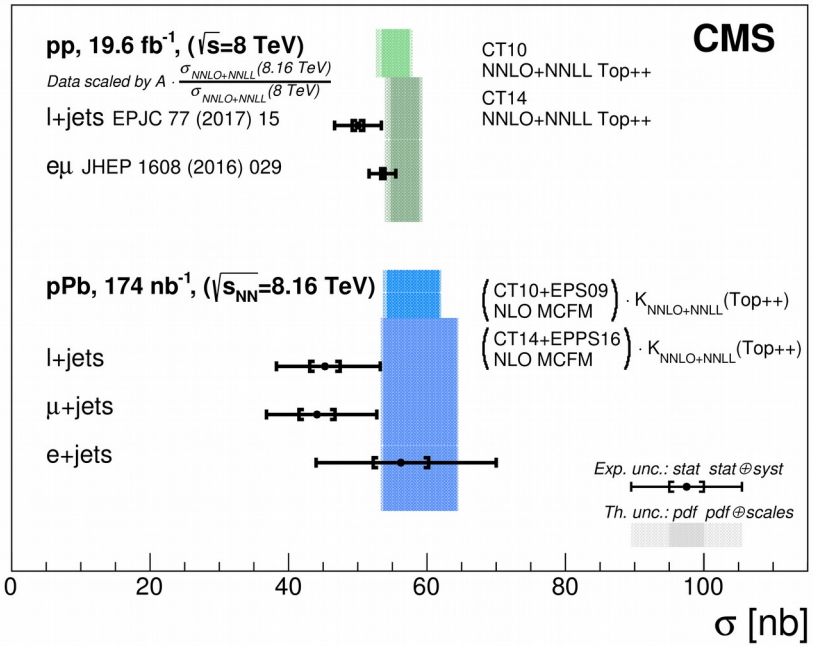
$t\bar{t}$ observation in pPb collisions at 8.16 TeV

Phys. Rev. Lett. 119, 242001 (2017)

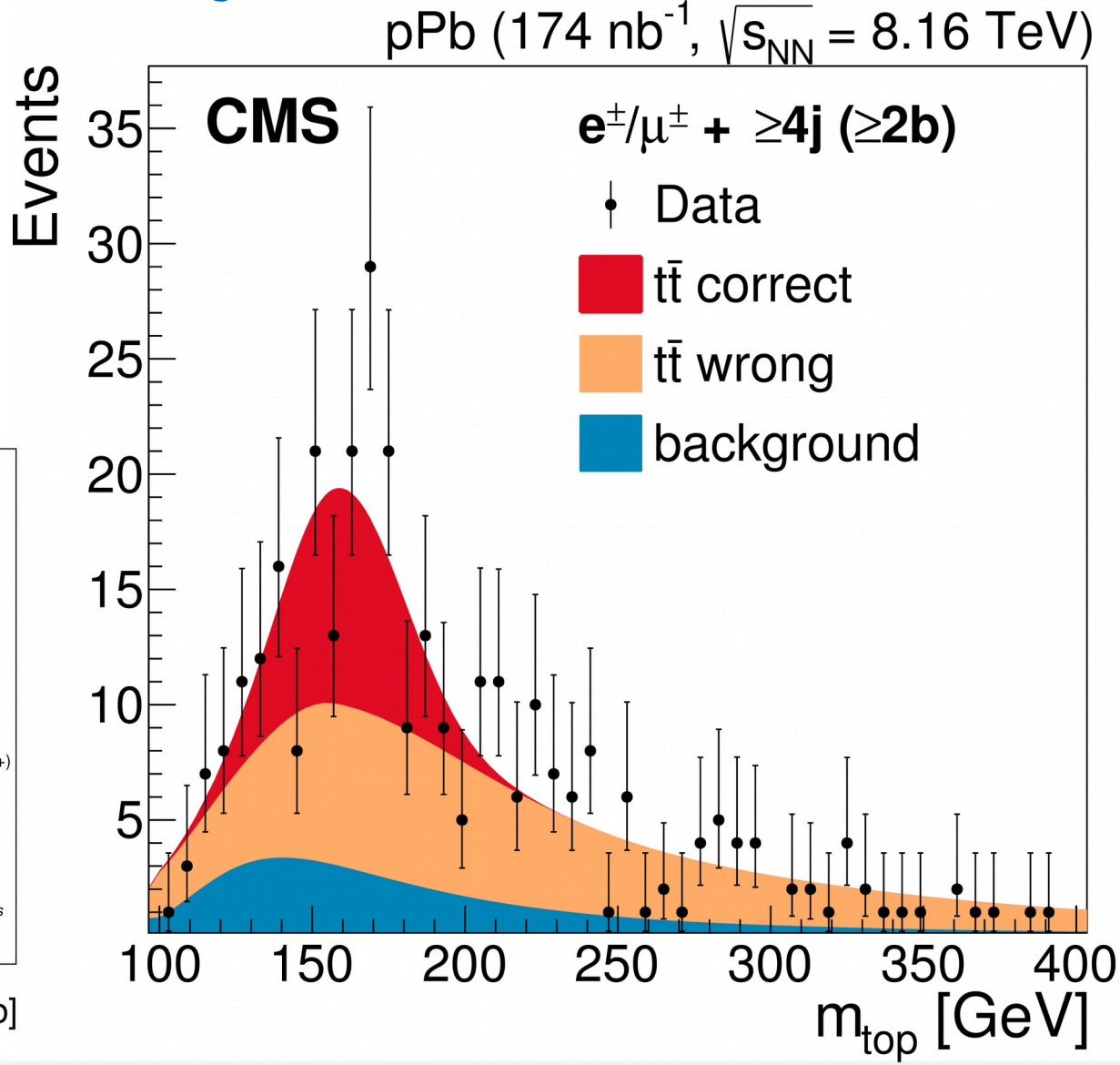
- √(s[NN]) = 8.16 TeV
- Lumi: 174 nb^{-1}
- Measured cross section:

45 ± 8 nb

- Result in agreement with NNLO+NNLL pQCD with NLO proton/nuclear PDFs.



- Signal extraction based on fits of the W→jj' mass in different b-jet and lepton flavor categories



Legacy inclusive cross sections at 7 and 8 TeV

Precision measurement with 5.0 fb^{-1} at 7 TeV, 19.7 fb^{-1} at 8 TeV, eμ.

Binned likelihood fit to multi-differential distributions, jet and b-jet multiplicity.

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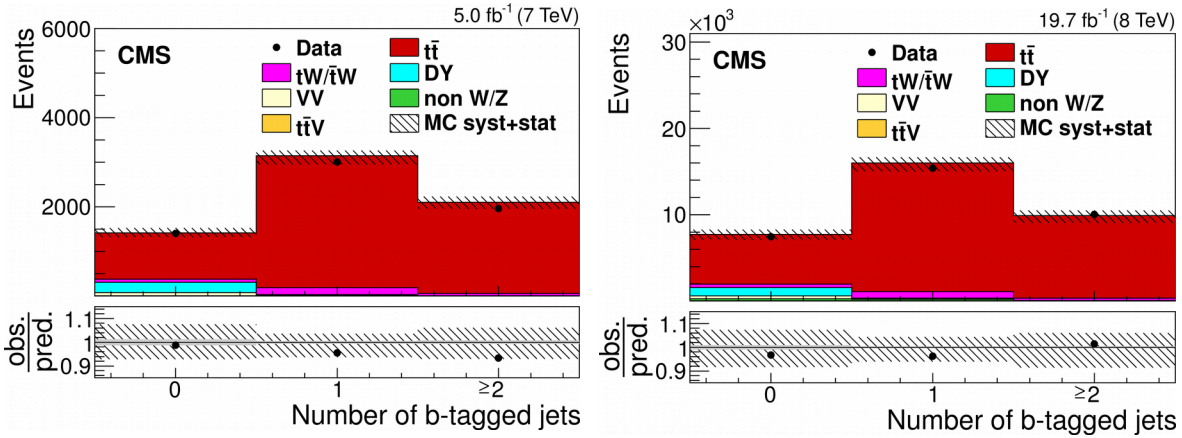
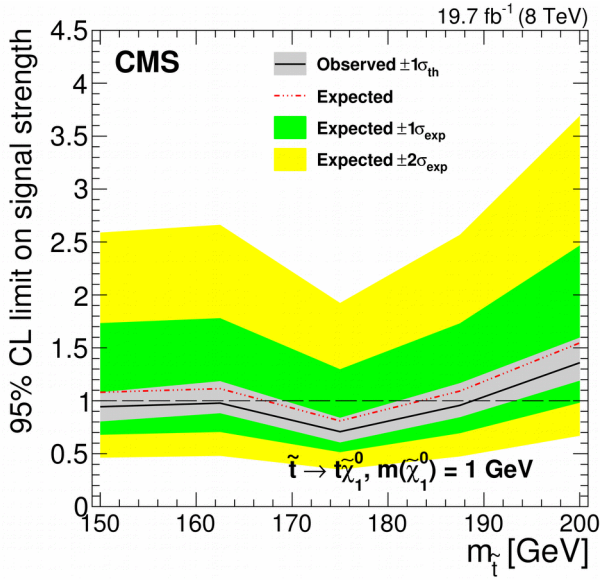


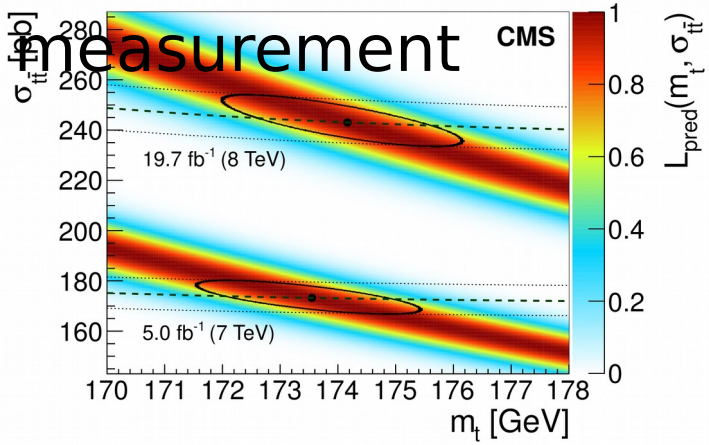


Precision higher than theory

√s	Value	Stat	Syst	Lumi	Total
7 TeV	173.6	2.1	+4.5, -4.0	3.8	6.2 (3.6%)
8 TeV	244.9	1.4	+6.3, -5.5	6.4	9.1 (3.7%)

√s	Theory	Scales	PDF+α_s	Total
7 TeV	173.3	+4.7, -6.0	9.0	10.8 (6.1%)
8 TeV	252.9	+6.4, -8.6	11.7	14.5 (5.7%)

Pole-mass measurement



Previous measurements at 13 TeV with 2.3 fb^{-1}

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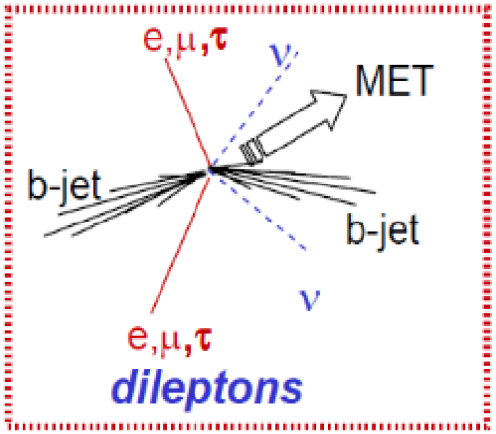
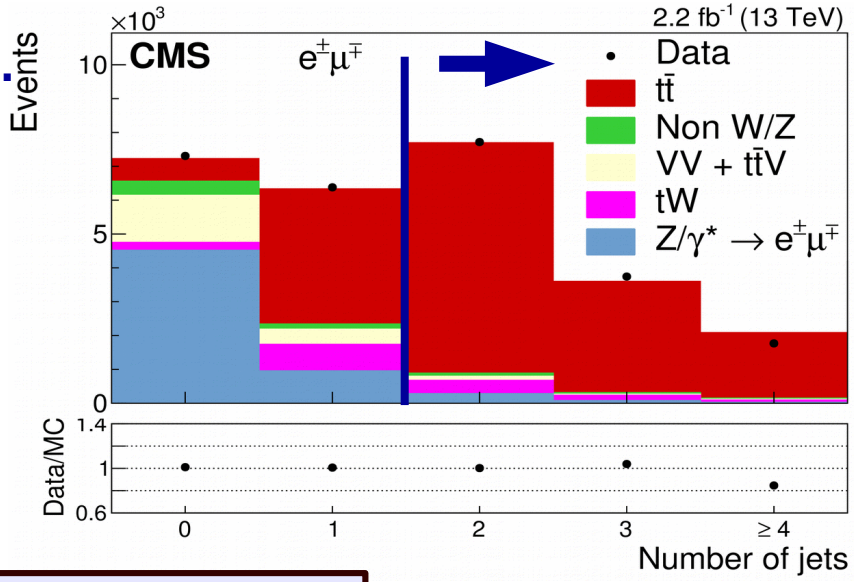
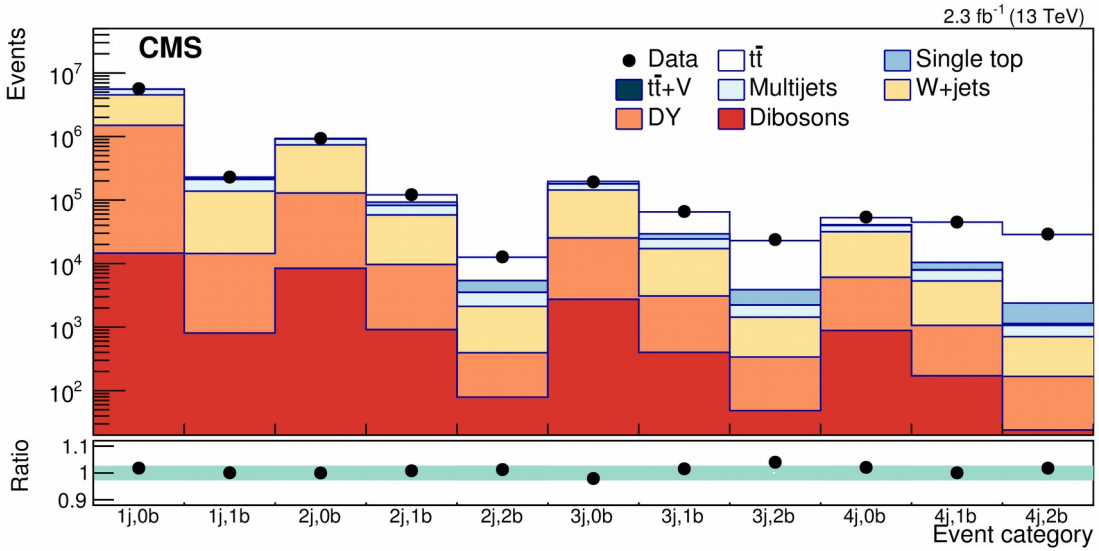


- **Very pure final state (> 95%).**
- Counting method to extract the cross section.
- Main uncertainties: **JES and modeling** (hadronization, NLO generator).

$$\sigma_{t\bar{t}} = \frac{N - N_B}{\mathcal{BR} \cdot \varepsilon \cdot \mathcal{A} \cdot \mathcal{L}'}$$



σ_{tt}(13 TeV) = 815 ± 9 (stat) ± 38 (syst) ± 18 (lumi) pb = 815 ± 43 (5.3%) pb



- **PLR fit to jet / b-tag categories.** Syst. unc. as nuisances.
- **QCD** and **W+Jets** estimated from data.
- Main uncertainties: W+Jets, modeling, luminosity.

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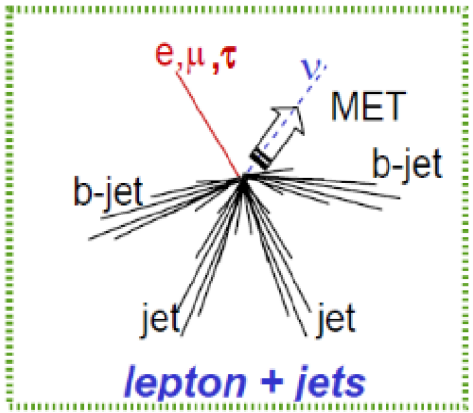

σ_{tt}(13 TeV) = 888 ± 2 (stat) +28, -26 (syst) ± 20 (lumi) pb = 888 ± 34 (3.9%) pb