Measurement of the single top quark and antiquark production cross sections in the *t* channel and their ratio at 13 TeV

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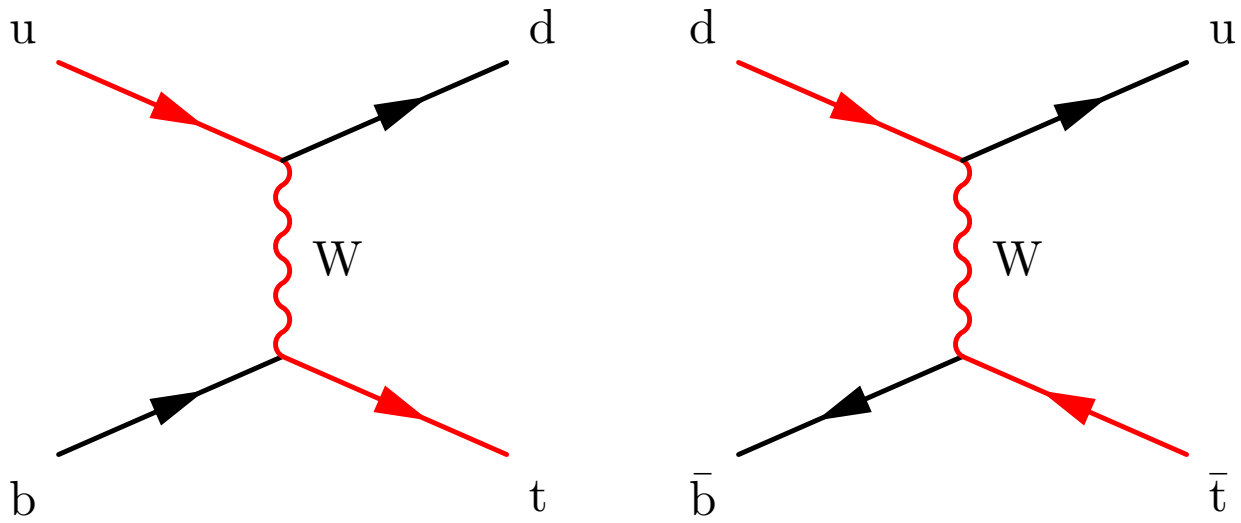
Introduction

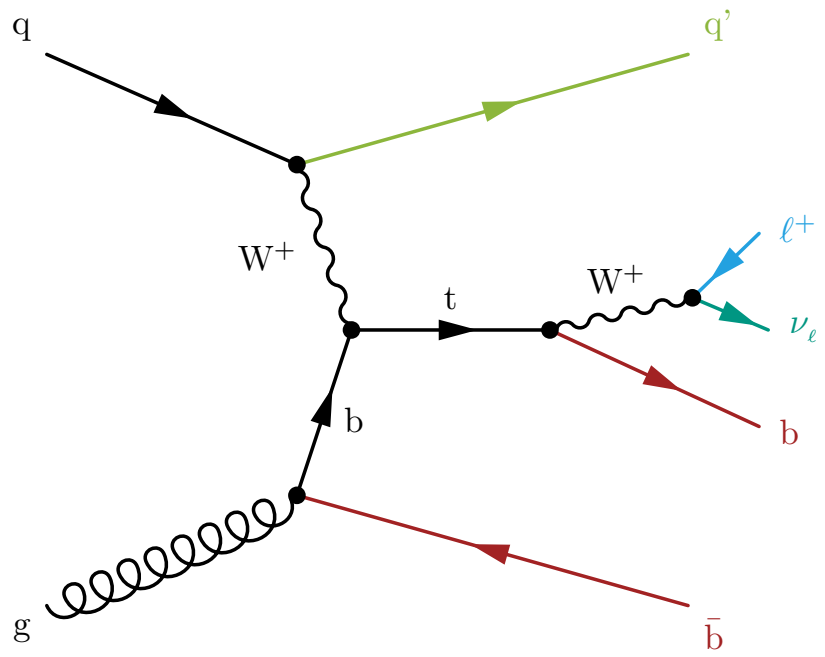
- Electroweak production of single top quarks
- Most dominant production mode: t channel
- Ratio $R_{t\text{-ch}} = \sigma_{t\text{-ch,t}} / \sigma_{t\text{-ch,}\bar{\text{t}}}$ provides insight into inner proton structure
  $\rightarrow$ sensitive to PDFs
- Direct measurement of CKM matrix element $|V_{\text{tb}}|$
- Analysis of 2016 data set ($35.9\,\text{fb}^{-1}$)



Analysis

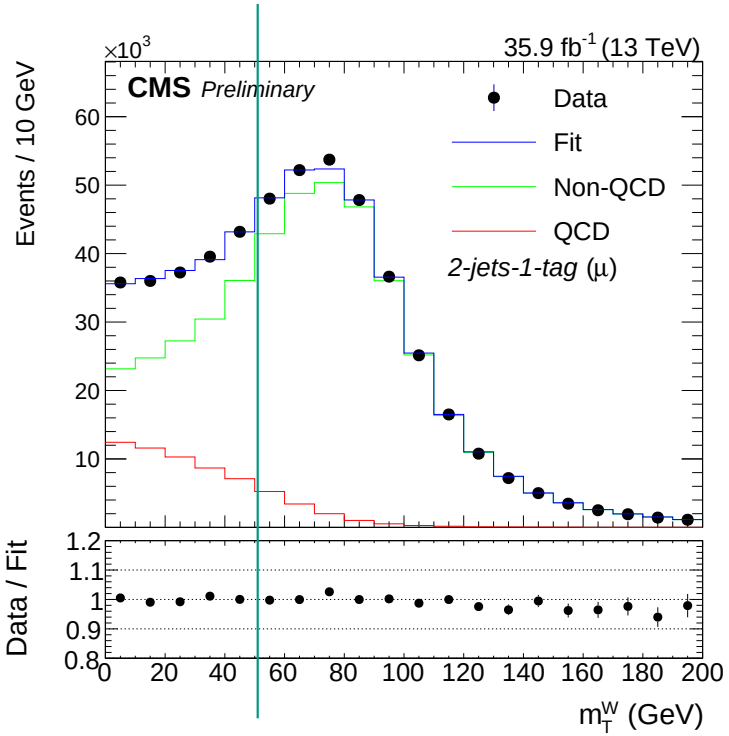
- Signature of *t*-channel process (leptonically decaying top quark):
  - Light quark in forward direction
  - Hard b quark
  - Second soft b quark (often not detected)
- Event selection:
  - One isolated muon (electron) with $p_T > 26\ (35)$ GeV and $|\eta| < 2.4\ (2.1)$
  - Jets with $p_T > 40$ GeV and $|\eta| < 4.7$ (2.4 for b-tagged jets)

- Signal and background categories:
  - 2-jets–1-tag (signal category)
  - 3-jets–1-tag and 3-jets–2-tags ($t\bar{t}$ control categories)



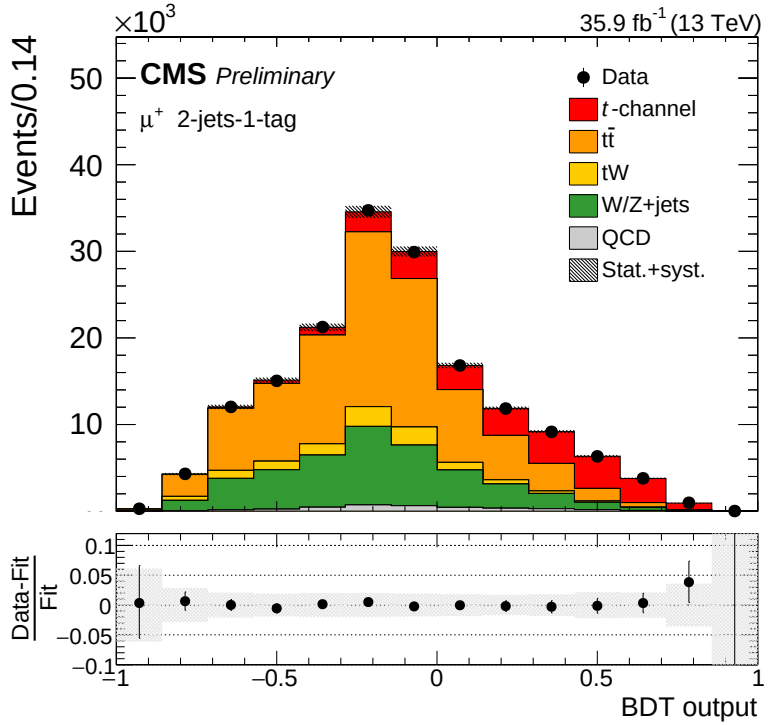
QCD estimation

- Suppress QCD contribution as much as possible: $m_T^W > 50\,\text{GeV}$ (muon), $p_T^{miss} > 30\,\text{GeV}$ (electron)
- Poor estimation/modeling of QCD from MC
- Model QCD distribution from data in sideband region:
  - Require exactly one anti-isolated lepton
  - Remove requirement on m_T^W (μ) and p_T^{miss} (e)
- Estimate QCD contribution:
  - Discriminating variable for QCD template: m_T^W (μ) and p_T^{miss} (e)
  - Perform maximum likelihood fit on discriminating variable
  - Extrapolate to $m_T^W > 50\,\text{GeV}$ (μ) and $p_T^{miss} > 30\,\text{GeV}$ (e)



Signal extraction

- Separate signal from background with BDTs
  - Training in 2-jets–1-tag category, separately for muons and electrons
  - Considered backgrounds: $t\bar{t}$, W+jets, QCD
  - Most important variables: light-quark jet $|\eta|$, m_{t}, m_{qb}
- Apply BDT to 2-jets–1-tag, 3-jets–1-tag, 3-jets–2-tags categories, separately for lepton flavors and charges
- Perform maximum likelihood fit simultaneously on twelve BDT outputs
  - Fit parameters: $\sigma_{t\text{-ch,t}}$, $\sigma_{t\text{-ch,}\bar{\mathrm{t}}}$, and $R_{t\text{-ch}}$
  - Correlations between parameters taken into account automatically



Systematic uncertainties

- Two types of systematic uncertainty sources:
  - Profiled uncertainty sources: nuisance parameters in fit
  - Externalized uncertainty sources (signal modeling): repeat fit with systematically varied templates
- Luminosity uncertainty of 2.5% not included in fit
- Most dominant for $R_{t\text{-ch}}$: signal PDF
- Most dominant for cross sections: signal parton shower scale, JES

	$\Delta R/R$	$\Delta\sigma/\sigma(\mathrm{t})$	$\Delta\sigma/\sigma(\bar{\mathrm{t}})$
PDF t channel	1.4	0.7	0.6
PS-scale t channel	1.1	12.5	13.8
ME-PS scale matching t channel	0.2	1.5	1.8
$\mu_\mathrm{R}/\mu_\mathrm{F}$ scale t channel	0.1	6.3	6.2
QCD normalization	2.1	1.7	3.8
JES	1.9	6.6	8.4
$\mathrm{t\bar{t}}$ modeling and normalization	1.9	0.8	3.2
Top quark p_T	1.2	4.0	5.2
MC sample size	0.9	1.8	0.5
$\mu_\mathrm{R}/\mu_\mathrm{F}$ scale	0.8	1.0	0.3
Pileup	0.4	1.4	1.8
Muon and electron efficiencies	0.3	0.1	0.5
JER	0.2	0.4	0.7
b tagging	0.2	1.2	1.4
PDF	0.1	0.1	0.2
Unclustered energy	0.1	0.4	0.6
W/Z+jets normalization	0.1	0.9	0.9
tW normalization	< 0.1	0.2	0.2

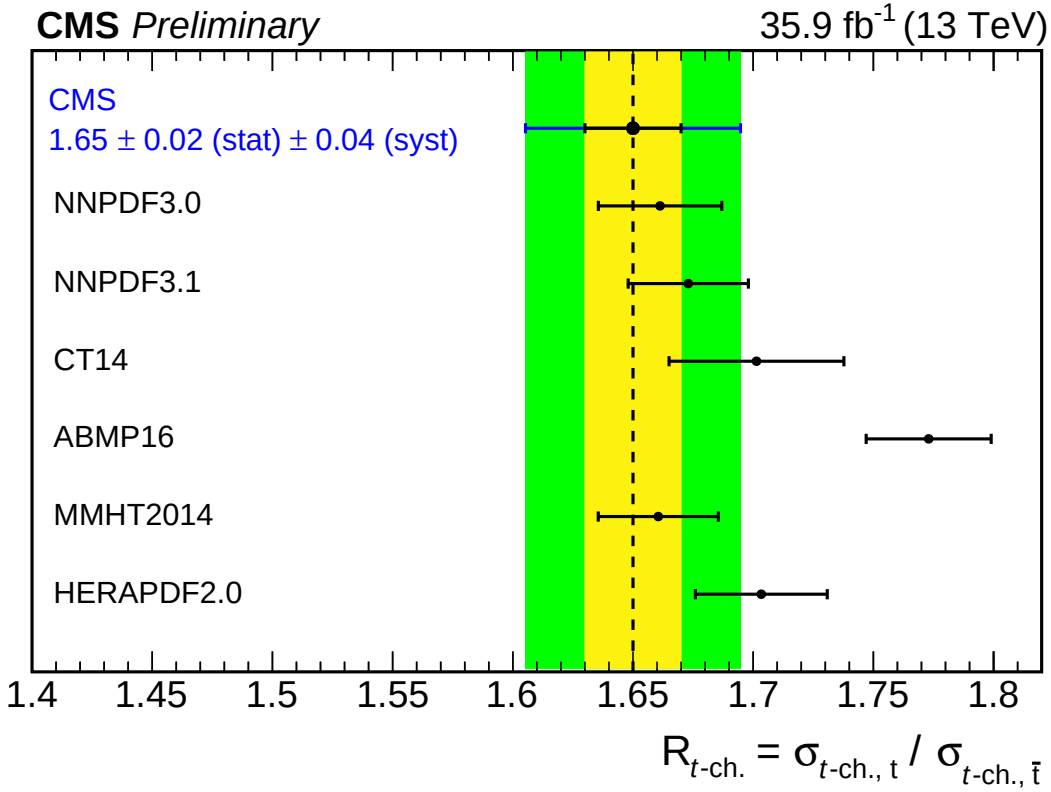
Results

- Measurement:

$$
\begin{aligned}
R_{t\text{-ch}} &= 1.65 \pm 0.02\,(\text{stat}) \pm 0.03\,(\text{prof}) \pm 0.03\,(\text{ext}) \\
\sigma_{t\text{-ch,t}} &= 136.3 \pm 1.1\,(\text{stat}) \pm 3.4\,(\text{prof}) \pm 19.4\,(\text{ext}) \pm 3.4\,(\text{lumi})\,\text{pb} \\
\sigma_{t\text{-ch,}\bar{\text{t}}} &= 82.7 \pm 1.1\,(\text{stat}) \pm 2.7\,(\text{prof}) \pm 12.6\,(\text{ext}) \pm 2.1\,(\text{lumi})\,\text{pb} \\
\sigma_{t\text{-ch,t+}\bar{\text{t}}} &= 219.0 \pm 1.5\,(\text{stat}) \pm 6.1\,(\text{prof}) \pm 32.0\,(\text{ext}) \pm 5.5\,(\text{lumi})\,\text{pb}
\end{aligned}
$$

- SM predictions [Hathor v2.1]:
  $R_{t\text{-ch}} = 1.68$, $\sigma_{t\text{-ch,t}} = 136.0\,\text{pb}$, $\sigma_{t\text{-ch,}\bar{\text{t}}} = 81.0\,\text{pb}$, and $\sigma_{t\text{-ch,t+}\bar{\text{t}}} = 217.0\,\text{pb}$
- Good agreement with prediction, systematically dominated
- Improvement of $R_{t\text{-ch}}$ result compared to Phys. Lett. B 772 (2017) 752:
  $R_{t\text{-ch}} = 1.81 \pm 0.18\,(\text{stat}) \pm 0.15\,(\text{syst})$

Results



- Calculation of $|V_{tb}|$:

$$|f_{LV} V_{tb}| = \sqrt{\frac{\sigma_{t\text{-ch,t+}\bar{t}}}{\sigma^{theo}_{t\text{-ch,t+}\bar{t}}}} = 1.00 \pm 0.05\,(exp) \pm 0.02\,(theo)$$

Summary

- Measurement of t-channel single top quark and antiquark production and their ratio presented
- 2016 data set ($35.9\,\mathrm{fb}^{-1}$) analyzed
- Systematic uncertainties dominant
- All results consistent with SM predictions
- Improvement of $R_{t\text{-ch}}$ compared to previous analysis at same center-of-mass energy due to larger data set and electron final state
- Enough precision to be sensitive to different PDF sets
- Analysis public: CMS-PAS-TOP-17-011