Top quark decay width measurement with $\sqrt{s} = 13 TeV$ data

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Outline

- Introduction
- Event selection
- m(lb) variable and categorization
- Uncertainty studies
- Fit procedure
- Expected results
- Summary
A direct measurement of top quark decay width $\Gamma_t$ to a relative uncertainty of 40%.

Simultaneous measurements of top mass and width.

Dilepton final states from $t\bar{t}$ decay events in proton-proton collisions at 13 TeV.

Observable - $m(lb)$ invariant mass of lepton and b-jet pairs.
Prediction of top decay width $\Gamma_t$ with electroweak and QCD corrections to next-to-leading order

$$\Gamma_t = \frac{G_F m_t^3}{8 \pi \sqrt{2}} \left(1 - \frac{M_W^2}{m_t^2}\right)^2 \left(1 + 2 \frac{M_W^2}{m_t^2}\right)^2 \left[1 - \frac{2 \alpha_s}{3 \pi} \left(\frac{2 \pi^2}{3} - \frac{5}{2}\right)\right]$$

Data were taken in 2016 by the CMS detector from Run 2 of LHC at center of energy of 13 TeV.

Monte Carlo (MC) simulation samples are used for the calibration. Simulations to leading order in the decay of top quark. MC samples: ttbar, tW, di-boson, Drell-Yan.
Reweighting at generator level

The way to produce distribution of observables of alternative $m_t, \Gamma_t$: generator level $m_t$ distribution has a relativistic Breit-Wigner lineshape

$$BW(s|m_t, \Gamma_t) = \frac{Nm_t\Gamma_t\sqrt{m_t^2(m_t^2+\Gamma_t^2)}}{((s^2-m_t^2)^2+m_t^2\Gamma_t^2)^{3/2}+\sqrt{m_t^2(m_t^2+\Gamma_t^2)}}$$

event weight

$$\frac{BW(s_1|m', \Gamma')}{BW(s_1|m_{SM}, \Gamma_{SM})} \times \frac{BW(s_2|m', \Gamma')}{BW(s_2|m_{SM}, \Gamma_{SM})}$$

$m_{SM} = 172.5$ GeV, $\Gamma_{SM} = 1.31$ GeV

Example(figure)

$m' = 173.5$ GeV, $\Gamma' = 1.34$ GeV
Event selection

- Trigger: dilepton triggers or single lepton triggers.
- At least 2 leptons $p_T > 20$ GeV, $|\eta| < 2.5$;
  Leading lepton $p_T > 25$ GeV;
  Two leptons have opposite signs;
  $M_{ll} > 20$ GeV;
  Z pole mass region vetoed $|M_{ll} - 91| > 15$ GeV for $ee$ and $\mu\mu$ events.
- At least 2 AK4 jets with $p_T > 30$ GeV, $|\eta| < 2.5$, $\Delta R(l, jet) > 0.4$;
  At least one jet is b-tagged.
- lb pairs: take highest $p_T(lb)$ pairs in order to use most correct assigned lb as possible.
Width effects lead to a deviation of the end point of $m(lb)$, and of its shape.

Categories
lepton: $ee, \mu\mu, e\mu$;
number of bjets: $1 b, \geq 2 b$;
Boost: $pT(l, b) > 100$ GeV (highpt) or $pT(l, b) < 100$ GeV (lowpt).

$m(lb)$ binning - based on generator level selection from ttbar events, each bin contains same number of l-b pairs.
**m(lb) variable**

![Graph showing m(lb) variable distribution](image)

**Figure:** pT(lb) distribution

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**Text:**

CMS Work in progress, 35.9 fb⁻¹ (13 TeV)

Events vs. m(lb) [GeV]

- Data (tt, eµ, ee, μμ)
- Single top
- DY
- Multiboson

Percentage vs. p_T(lb) [GeV]

- PDF (a.u.)
- Correct assignments

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**Author:** Wenyu Zhang

**Date:** Aug 2019

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pT<100 GeV, 6 categories

CMS Work in progress

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1b ≥ 2b
### pT > 100 GeV, 6 categories

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**1b**

**2b**

**Ratio**

- **ee**
- **eμ**
- **μμ**

**CMS Work in progress**

- 35.9 fb⁻¹ (13 TeV)

- 1 b-tag

- 2 b-tags
Uncertainty studies
Systematic uncertainties

Experimental uncertainties:
- pileup
- trigger efficiency
- selection efficiency
- lepton energy scale
- jet energy scale
- jet energy resolution
- b-fragmentation and semileptonic
- B decay branching ratios
- Drell-Yan normalization
- integrated luminosity

Theory uncertainties:
- QCD scale
- resummation scale
- parton shower scale (ISR, FSR)
- non-perturbative QCD
- (underlying events and color reconnection)
- top pt
- tW top mass and width
- PDFs
- tt/tW interference
Uncertainty studies

MC Statistical uncertainty

- Accounted as bin-by-bin uncertainty. Local uncertainty uncorrelated with other bins or categories.
- Taken from m(lb) shapes in signal, backgrounds.
- Bin-by-bin uncertainty of systematic samples are summed in quadrature for each signal/background shape.

Figure: Bin-by-bin uncertainty for $t\bar{t}$ m(lb) shape (left), systematic bin-by-bin uncertainty for $t\bar{t}$ m(lb) (right)
Two-dimensional likelihood fit

- 400+ \((m_t, \Gamma_t)\) scenarios
- Profile likelihood fit
  \[
  \mathcal{L}(x | \mu \cdot s + b, m_t, \Gamma_t, \nu) = \frac{\max_{\nu} \mathcal{L}(x | \mu \cdot s + b, m_t, \Gamma_t, \nu)}{\max_{\mu', \nu} \mathcal{L}(x | \mu' \cdot s + b, m_t, \Gamma_t, \nu)}
  \]
  signal strength \((\mu)\) and nuisances \((\nu)\)

Figure: Left: e\(\mu\), middle: dilepton inclusive (3 categories), right: final (12 categories)
Expected results (in progress)

Figure: Fit with $t\bar{t}bar_{SM}$ as pseudo-data

40% total relative uncertainty in $\Gamma_t$
Summary

- Showed a simultaneous measurement of top quark mass and decay width. The most precise measurement of width up to date from a direct measurement.

- Expect the measurement has an uncertainty of 40%.

Outlook

- Fit check with alternative MC samples (other \((m_t, \Gamma_t)\)).
- b-tagging scale factor method under discussion.
THANK YOU
Backup
The latest measurement performed by CDF yields an upper limit \( \Gamma_t < 6.38 \text{ GeV} \) at 95\% CL. (CDF Collaboration, Direct Measurement of the Total Decay Width of the Top Quark, Phys. Rev. Lett. 111 (2013), no. 20, 202001)

\[
\Gamma_t = 1.75 \pm 0.33^{+0.79}_{-0.68} \text{ (stat)}^{+0.79}_{-0.68} \text{ (syst)} \text{ GeV assuming } m_t = 172.5 \text{ GeV} \text{ (ATLAS Collaboration, Direct top-quark decay width measurement in the } t \bar{t} \text{ lepton+jets channel at } \sqrt{s} = 8 \text{ TeV with the ATLAS experiment)}
\]
MC corrections

- Pileup-rewighting
- Trigger efficiency
- Lepton tracking/reconstruction, identification and isolation efficiency
- Jet energy scale and resolution
- b-tagging efficiency
- Generator level weights
- L1 prefire efficiency
Systematic samples

- **ttbar:**
  - ttbarisrdown, ttbarhdampup/down, ttbarfsrup/down, ttbarueup/down, ttbarcrrerd, ttbarqcdBased, ttbargluonmove.

- **tw:**
  - tw175.5, tw169.5, twDS (for tt/tW interference), twisrup/down, twfsrup/down.