Measurement of $t\bar{t} \to b\bar{b}\ell\tau$ cross-section in 13 TeV CMS data and lepton universality test

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LIP, CMS

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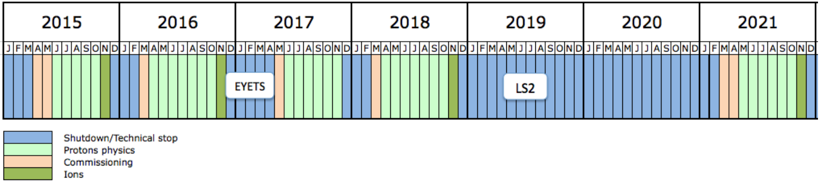
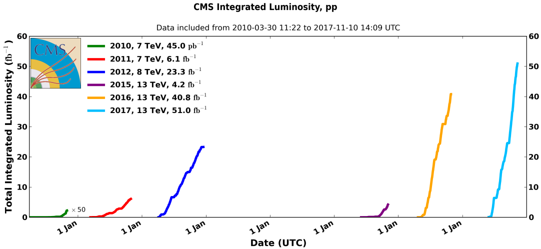
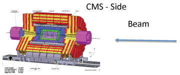
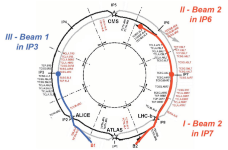
CMS detector, available data



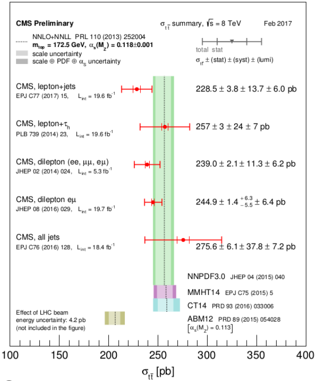






The LHC schedule and luminosity collected by CMS, promising perspective of $100 fb^{-1}$ of 13 TeV data at end of Run 2.

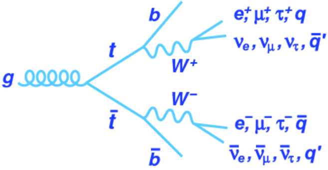
Motivation



Cross-section measurements in $t\bar{t}$ channels at 8 TeV CMS data from 2012.

- Measurement in $t\bar{t} \rightarrow b\bar{b}l\tau$ channel
- Improved uncertainty in estimation of main background
- It serves as preliminary work for further measurements in similar final states
- The plan is to proceed to precise lepton universality measurement in $t\bar{t}$ decay

Features of $t\bar{t} \to b\bar{b}\ell\tau$ channel, measurement method



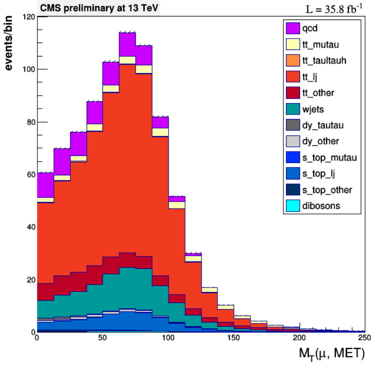
Many particular final products:

- 2 b-jets (displaced vertex of jet)
- 1 lepton (muon or electron)
- 2 neutrinos
- 1 hadronicaly decaying tau lepton

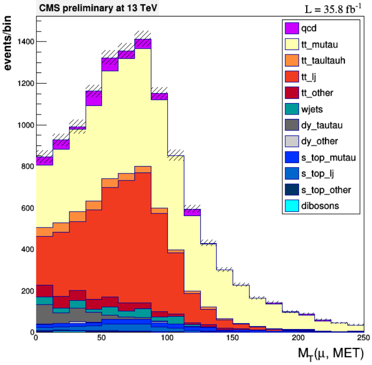
- Sample of $t\bar{t}$ events is selected with simple cuts and identification requirements.
- Main background from fake taus in $t\bar{t} \to \ell\nu_\ell q\bar{q}$ channel.
- The events are separated into background-rich and signal-rich categories according to kinematics of jets.
- The shape fit of $M_T(\ell, E_T^{miss})$ distributions is performed.
- Both methods constrain background of misidentified taus and cross-check each other.

Standard algorithms are employed: Particle Flow for basic objects, anti-Kt jet clustering, MVA-based b-tagging, quality requirements for muons and electrons, MVA-based tau ID etc.

Require: 1 lepton, ≥ 3 jets, ≥ 1 b-tagged and 1 tau lepton.

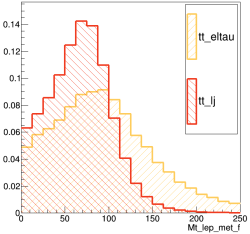


no tau requirement

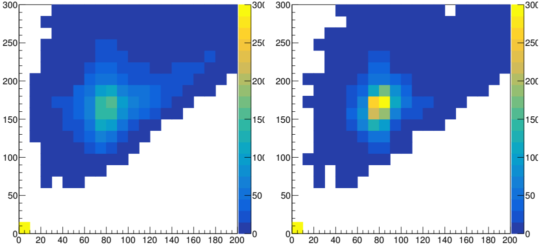


tau of Opposite Sign to muon

No loss of kinematic information in $W \to q\bar{q}$ of the background ℓj provides separation between this background and signal via the shape of transverse mass distributions $M_T(\ell, E_T^{miss})$ and kinematic difference in jets.



transverse mass $M_T(\ell, E_T^{miss})$



masses of jet combinations for W and t mass constraint in signal (left) and background (right)

Profile Likelihood Ratio (PLR) shape fit in two categories

- Background- or signal-rich categories are defined by jet kinematic parameter. Profile likelihood ratio fit is performed in bins of M_T distribution.
- Likelihood function includes per-bin yields and systematic uncertainties as constraint nuisance parameters:

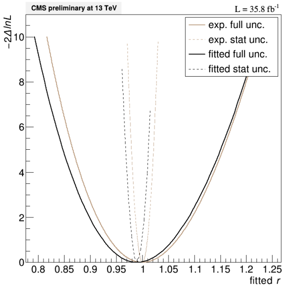
$$\mathcal{L}(\boldsymbol{\mu}, \theta_i) = \prod_k \mathcal{P}_{oisson} \left[N_k | \hat{N}_k(\boldsymbol{\mu}, \theta_i) \right] \cdot \prod_i pdf(\theta_i, 0, 1) \quad (1)$$

- Based on the likelihood function the PLR test statistic is defined:

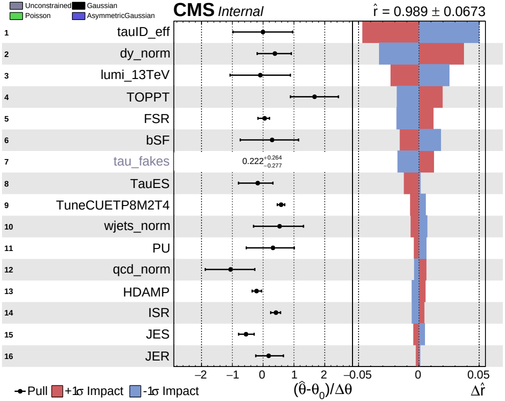
$$\lambda(\boldsymbol{\mu}) = \frac{\mathcal{L}(\boldsymbol{\mu}, \hat{\hat{\theta}}_i(\mu))}{\mathcal{L}(\hat{\boldsymbol{\mu}}, \hat{\theta}_i)} \quad (2)$$

— scans over $\lambda(\mu)$ provide estimation of uncertainties.

Preliminary results for fit in both $e\tau_h$ and $\mu\tau_h$



Scan of signal strength.

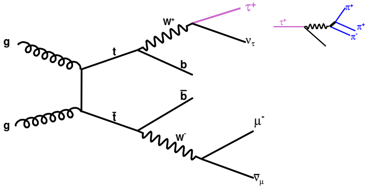


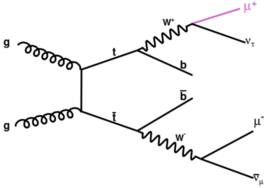
Impacts of uncertainties on signal strength.

Results show agreement with SM and uncertainty of about 6-7% in both channels. Plots show simultaneous fit over both channels. The largest uncertainty is 5% from Tau ID.

Prospects, lepton universality test

The goal is to measure precisely (on order 2%) the ratio $\frac{W \to \ell\nu}{W \to \tau\nu}$:





The ratio cancels most of systematic uncertainties:

$$\begin{aligned} \sigma(\mu\tau) &= \sigma_{pp}(t\bar{t})B(W \to \mu)B(W \to \tau) \\ \sigma(\mu\mu) &= \sigma_{pp}(t\bar{t})B(W \to \mu)(B(W \to \mu) + B(W \to \tau \to \mu)) \end{aligned} \tag{3}$$

$$\frac{\sigma(\mu\tau)}{\sigma(\mu\mu)} = \frac{B(W \to \tau)}{B(W \to \mu) + B(W \to \tau \to \mu)} = \frac{\frac{B(W \to \tau)}{B(W \to \mu)}}{1 + \frac{B(W \to \tau)}{B(W \to \mu)}B(\tau \to \mu)} \tag{4}$$

But the remaining uncertainty due to tau ID is big (about 5%).

Current measurement

$\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ $\qquad\qquad$ Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
1.046±0.023 OUR FIT				
0.961±0.061	980	[42] ABBOTT 00D	D0	$E^{p\bar{p}}_{\rm cm}$= 1.8 TeV
0.94 ±0.14	179	[43] ABE 92E	CDF	$E^{p\bar{p}}_{\rm cm}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[44] ALITTI 92F	UA2	$E^{p\bar{p}}_{\rm cm}$= 630 GeV
1.02 ±0.20 ±0.12	32	ALBAJAR 89	UA1	$E^{p\bar{p}}_{\rm cm}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.995±0.112±0.083	198	ALITTI 91C	UA2	Repl. by ALITTI 92F
1.02 ±0.20 ±0.10	32	ALBAJAR 87	UA1	Repl. by ALBAJAR 89

from Particle Data Group (2012)

$W \to e\nu$	(10.75 ± 0.13) %
$W \to \mu\nu$	(10.57 ± 0.15) %
$W \to \tau\nu$	(11.25 ± 0.20) %

- measurements from LEP in WW channel
- Tevatron in W+jets
- excess of about 2.5σ with relative uncertainty $\approx$ 3.5%
- at LHC: enough energy for on-shell $t\bar{t}$ and a lot of luminosity
- current measurements lack precision (about 6-10%, when 2% needed)
- with the luminosity we can sacrifice efficiency for purity

Plans

Finalizing the measurement of the top quark section in the final state with one tau lepton

On-going investigation of possibilities to improve tau ID for the ratio measurement includes:

- simultaneous fit with DY processes
- tau parameters: Secondary Vertex, Dalitz parameters of the decay
- other physics in the event: better b-tagging, kinematics and OS/SS contribution of backgrounds
- and machine learning algorithms based on these inputs