Lepton Universality test in top quark pair decays

Physics

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Motivation

Lepton Universality

The interactions between leptons (electron, muon, tau) and other elementary particles are observed to be equal and the mass is found to be the only distinguishing parameter of different types of leptons. This observation is implemented in theory as the principle of Lepton Universality.

Current measurements

However, the measurements of the previous experiments (LEP, Tevatron) show noticeable discrepancy in the rates of the leptonic decays of W boson (see Table 1).

$\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ 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	$E^{p\bar{p}}_{cm}$= 1.8 TeV
0.94 ±0.14	179	[43] ABE	92E	CDF	$E^{p\bar{p}}_{cm}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[44] ALITTI	92F	UA2	$E^{p\bar{p}}_{cm}$= 630 GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89	UA1	$E^{p\bar{p}}_{cm}$= 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

TABLE 1: The ratio of decay rates of W boson to tau and electron, measured in LEP and Tevatron experiments (from Particle Data Group 2016).

Top quark pair at LHC

Large energy of LHC collisions produces many top quark pairs, which is a new convenient channel for the measurement of the ratio between the branching ratios of the decays of W boson with a tau or other leptons in the final state: Br(W→tau)/Br(W→e). The necessary precision of the measurement can be achieved in the channel where the tau decays into hadrons. The main challenge is the identification of hadronic taus in the detector.

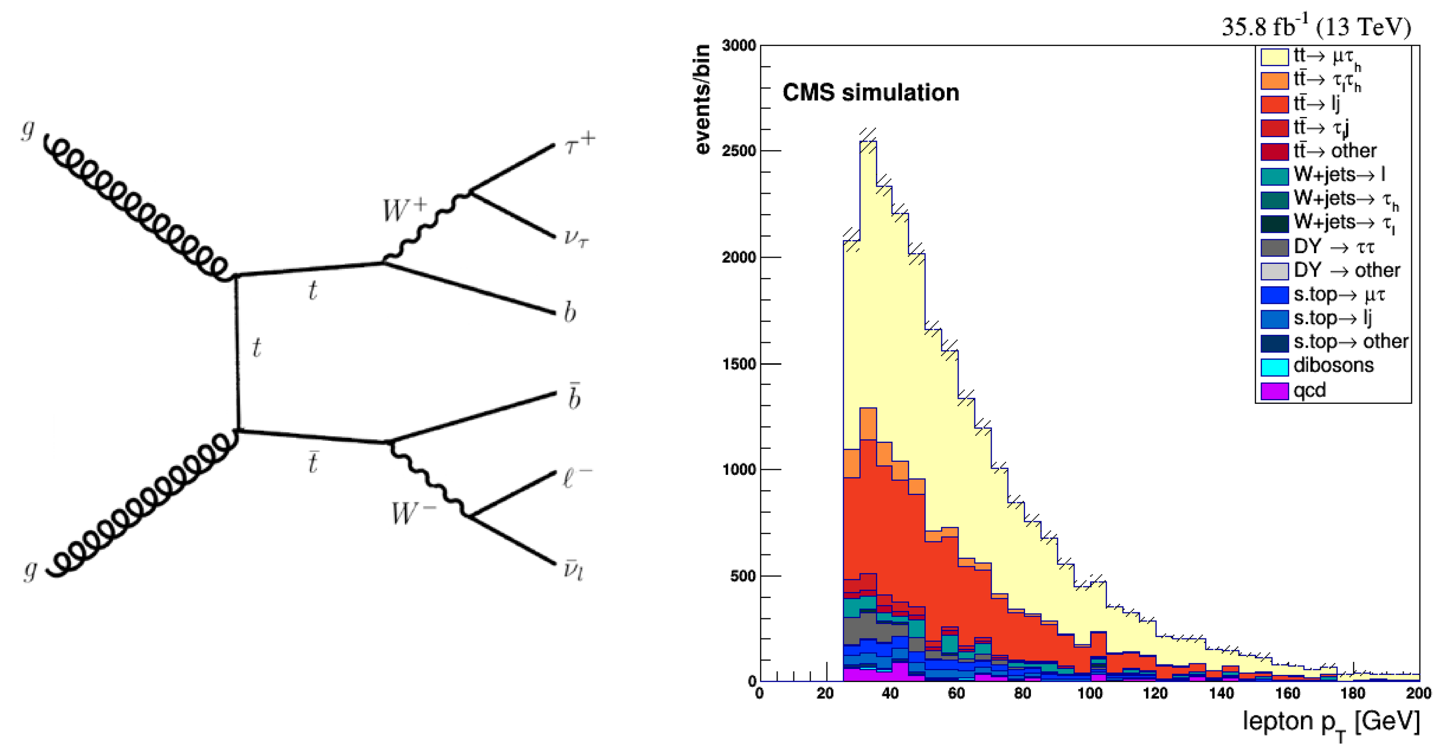

FIGURE 1: The top quark decay chain with a tau and another lepton in the final state (left). The distribution on the transverse momentum of the lepton in a typical event selection for this final state (right). The signal events are shown in yellow, the main background is in red.

Method

Ratio between top quark pair decays

The ratio of the event yield of top quark pair decay with lepton and tau to the decay with two leptons in the final state gives access to the ratio of W boson branching ratios. Also a number of common systematic uncertainties cancel out. But the largest uncertainties are due to the large background of mis-identified taus (see Figure 1, right) and the uncertainty of the tau identification algorithm.

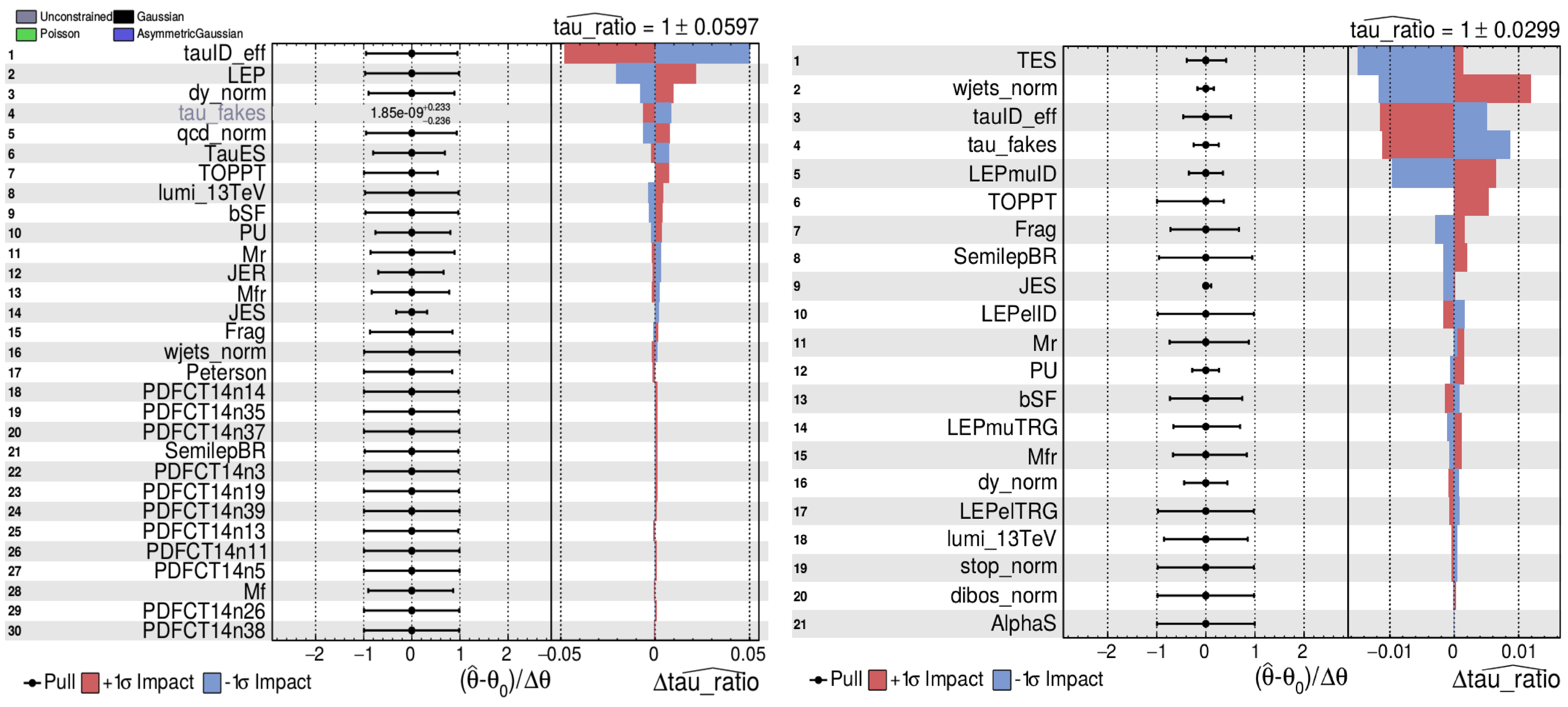

FIGURE 2: The statistical study of the effect of different systematic uncertainties on the measurement of the ratio of branching ratios of W boson in: the ratio between lepton-tau and dilepton final states of top quark pair (left), the double ratio with DY processes. The overall uncertainty is reported in the top-right corners of the diagrams. The dominant effect of the uncertainty due to tau identification is clearly seen on the left. The uncertainty of 3% (on the right) is achieved under assumption of using full Run2 dataset of CMS (2016-2018).

Double ratio with Drell-Yan processes

The effect of the uncertainty of tau identification can be reduced if the ratio is measured with respect to a known process with a hadronic tau in the final state, such as Drell-Yan process (DY). Using the following symmetrical construction with pure selection of taus in DY process the uncertainty of tau identification can cancel out with the sufficient statistics:

$$\frac{\sigma(t\bar{t}\to\mu\tau_h)}{\sigma(t\bar{t}\to\mu\mu)} \Big/ \frac{\sigma(DY\to\mu\mu)}{\sigma(DY\to\tau_\mu\tau_h)}$$

The statistical studies of the expected yields of corresponding processes shows that the precision of about 3% of overall relative uncertainty can be achieved in the full Run2 dataset of CMS (see Figure 2). Which is enough to improve the current measurements.