Measurement of Lepton Flavour Universality in top quarks pairs events at CMS

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LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

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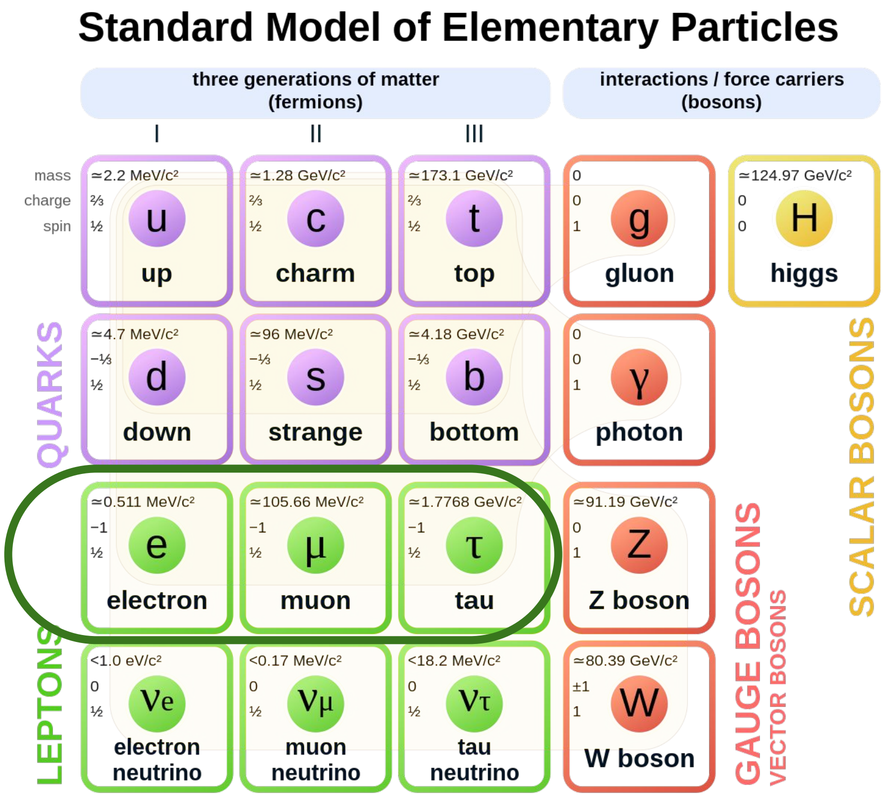
What is the Lepton Flavour Universality (LFU)?

The Standard Model (SM) is the current theory that describes the fundamental constituents of our universe and their interactions.

The SM predicts that all **charged leptons** have the same weak coupling.

Deviation from this behaviour would be a clear signal of New Physics.

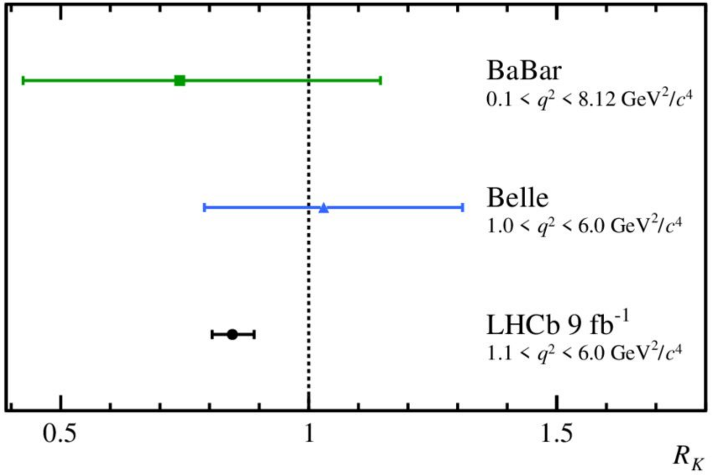


LFU: Current measurements

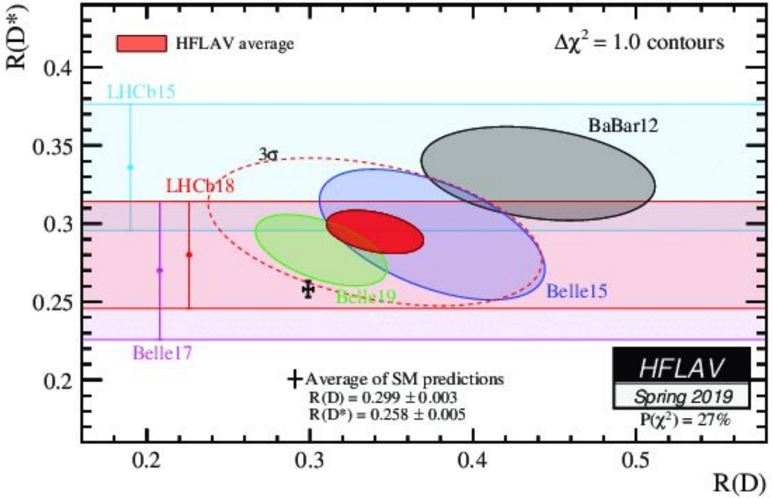
Many searches to test this prediction, some showing some tensions with the SM predictions, for example in the semileptonic decays of B mesons.

$$R_{K^{(*)}} = \frac{\mathcal{B}\left(B \to K^{(*)}\mu^+\mu^-\right)}{\mathcal{B}\left(B \to K^{(*)}e^+e^-\right)}$$

$$R_D = \frac{\Gamma(\bar{B} \to D\tau\nu)}{\Gamma(\bar{B} \to D\ell\nu)}, \qquad R_{D^*} = \frac{\Gamma(\bar{B} \to D^*\tau\nu)}{\Gamma(\bar{B} \to D^*\ell\nu)}$$



From arXiv:2103.11769v1 [hep-ex] 22 Mar 2021



From https://doi.org/10.1051/epjconf/202023401004

Motivation for my PhD thesis

LEP finds a disagreement with the SM in W bosons decays in τ and μ :

$R_{\tau/\mu}$: $\mathcal{B}(\mathrm{W} \rightarrow \tau\overline{\nu}_{\tau}) \,/\, \mathcal{B}(\mathrm{W} \rightarrow \mu\overline{\nu}_{\mu}) \;=\; 1.070 \pm 0.026$ https://doi.org/10.1016/j.physrep.2013.07.004

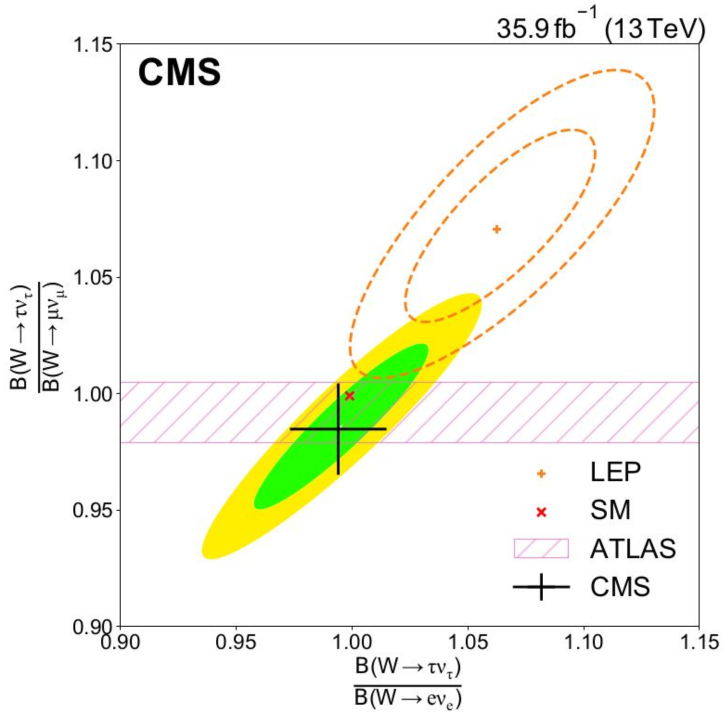
ATLAS [http://dx.doi.org/10.1038/s41567-021-01236-w] and CMS [http://dx.doi.org/10.1103/PhysRevD.105.072008] collaborations studied this observable, finding agreement with the SM.

More precision studies, exploiting both Run2 and Run3 data, could help further test the LFU hypothesis.

	CMS	LEP	ATLAS
$R_{\tau/\mu}$	0.985 ± 0.020	1.070 ± 0.026	0.992 ± 0.013

Measured all branching ratios of W

Used $\tau \rightarrow \mu$

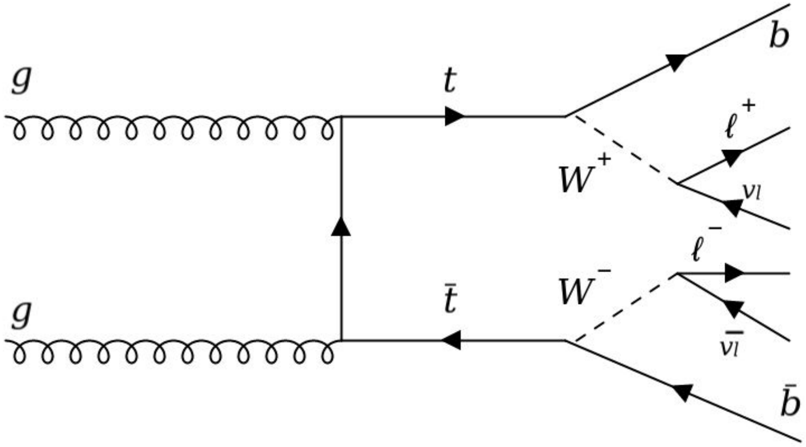


Foreseen procedure

We need a pure sample of W bosons:

➔ Exploit the fact that (almost) all top quarks decay in Wb, use b-jet arising from b-quark to tag the event and reject backgrounds

Study top quark pairs events, where both W decay leptonically (e, μ, τ)

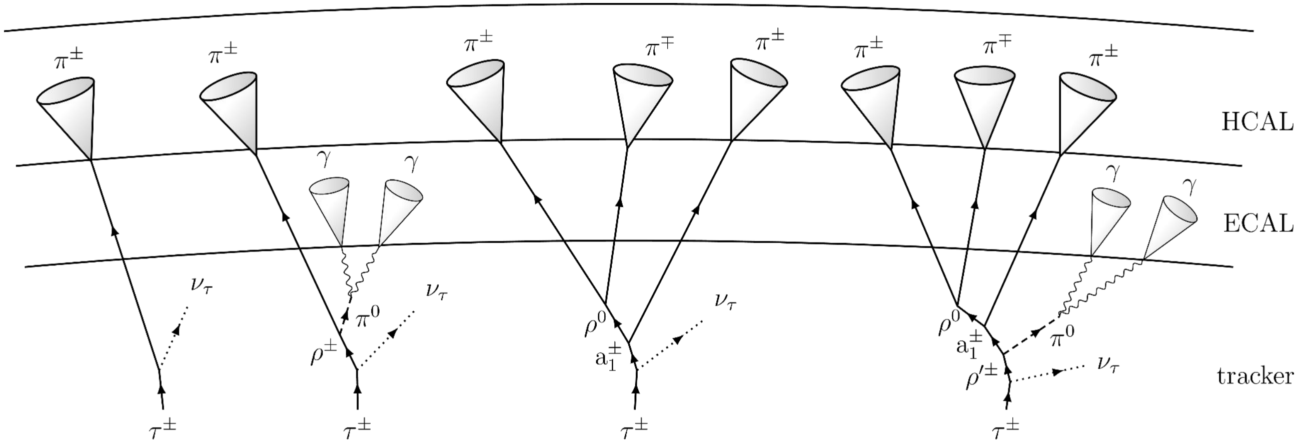


Foreseen procedure

The aim, in these top quark pairs events, is to compute:

$$\frac{N(\mathrm{t\bar{t}} \to \ell\tau_{\mathrm{h}}\nu_\ell\nu_\tau \mathrm{b\bar{b}})}{N(\mathrm{t\bar{t}} \to \ell\ell\nu_\ell\nu_\ell \mathrm{b\bar{b}})} \approx \frac{\mathcal{B}(\mathrm{W} \to \tau\nu_\tau)}{\mathcal{B}(\mathrm{W} \to \ell\nu_\ell)}$$

Where τ_{h} is a τ reconstructed hadronically in 3 charged pions (with the possibility of also using the one prong decay)



Foreseen procedure

Start from an initial study of Oleksii Toldaiev [https://cds.cern.ch/record/2745770?ln=en] to reduce systematic uncertainties, use a double ratio with Drell Yan events

$$\frac{N(\mathrm{t\bar{t}} \to \ell\tau_\mathrm{h}\nu_\ell\nu_\tau \mathrm{b\bar{b}})}{N(\mathrm{t\bar{t}} \to \ell\ell\nu_\ell\nu_\ell \mathrm{b\bar{b}})} \frac{N(\mathrm{DY} \to \ell\ell)}{N(\mathrm{DY} \to \tau_\ell\tau_\mathrm{h})} \approx \frac{\mathcal{B}(\mathrm{W} \to \tau_h\nu_\tau)}{\mathcal{B}(\mathrm{W} \to \ell\nu_\ell)} \frac{\mathcal{B}(\mathrm{DY} \to \ell\ell)}{\mathcal{B}(\mathrm{DY} \to \tau_\ell\tau_\mathrm{h})}$$

Dominating uncertainty from hadronic τ reconstruction efficiency: if enough statistic is present, with this double ratio it is possible to reduce its impact.

But many events are needed to reduce statistical fluctuations (Run3 data will come in handy!)

Foreseen procedure

A first feasibility study was performed using:

$$\frac{N(WW \rightarrow \tau_h e)}{N(WW \rightarrow \mu e)} \cdot \frac{N(DY \rightarrow \mu\mu)}{N(DY \rightarrow \tau_h \tau_\mu)}$$

The motivation of the final state is due to:

- exploit the higher reconstruction efficiency of μ (vs e)
- exploit the lower p_T threshold on the trigger on μ (vs e)
- choose channels with smaller background (WW$\rightarrow\mu$e)

Foreseen procedure

$$\frac{N(WW \rightarrow \tau_h e)}{N(WW \rightarrow \mu e)} \cdot \frac{N(DY \rightarrow \mu\mu)}{N(DY \rightarrow \tau_h \tau_\mu)}$$

Yield of events with taus in the final state obtained using a fit on m_T to constrain the background

$$m_{\mathrm{T}} = \sqrt{2|\vec{p}_{\mathrm{T}}^{\,a}||\vec{p}_{\mathrm{T}}^{\,b}|(1 - \cos\Delta\varphi)}$$

where $\Delta\varphi$ is the angle between P_T^a and P_T^b

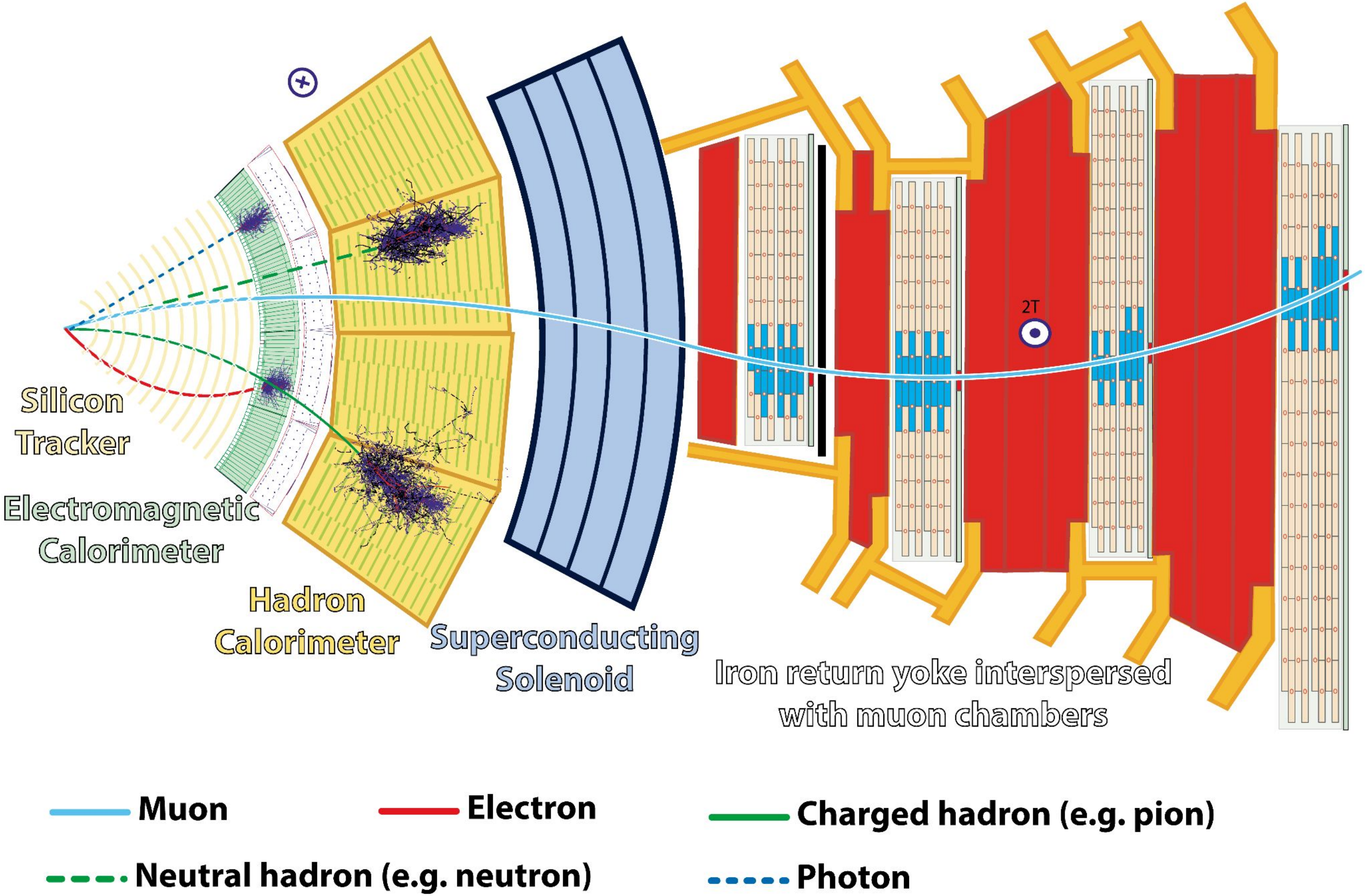
In my work I will:

- ➢ first study this with full Run2 and include Run3 data as they will become available
- ➢ Use 3-prong and (possibly 1-prong) τ_h
- ➢ include other channels (other ℓ in the final state)
- ➢ try to improve the event selection and hadronic tau reconstruction efficiency, also with the use of Machine Learning techniques.

Thank you for your attention!

Backup

CMS detector



What is the Lepton Flavour Universality (LFU)?

LFU tests usually study ratio of observables to simplify correlated uncertainties and provide the best possible precisions.
Several tests were performed in the years in different sectors, below a non-comprehensive table with some of the results, where the 1σ uncertainty is shown within brackets.

	$\Gamma_{\tau\to\mu}/\Gamma_{\tau\to e}$	$\Gamma_{\pi\to\mu}/\Gamma_{\pi\to e}$	$\Gamma_{K\to\mu}/\Gamma_{K\to e}$	$\Gamma_{K\to\pi\mu}/\Gamma_{K\to\pi e}$	$\Gamma_{W\to\mu}/\Gamma_{W\to e}$
$\|g_\mu/g_e\|$	1.0018 (14)	1.0021 (16)	0.9978 (20)	1.0010 (25)	0.996 (10)
	$\Gamma_{\tau\to e}/\Gamma_{\mu\to e}$	$\Gamma_{\tau\to\pi}/\Gamma_{\pi\to\mu}$	$\Gamma_{\tau\to K}/\Gamma_{K\to\mu}$	$\Gamma_{W\to\tau}/\Gamma_{W\to\mu}$	
$\|g_\tau/g_\mu\|$	1.0011 (15)	0.9962 (27)	0.9858 (70)	1.034 (13)	
	$\Gamma_{\tau\to\mu}/\Gamma_{\mu\to e}$	$\Gamma_{W\to\tau}/\Gamma_{W\to e}$			
$\|g_\tau/g_e\|$	1.0030 (15)	1.031 (13)			

A. Pich, "Precision Tau Physics", Prog. Part. Nucl. Phys. 75 (2014) 41, arXiv:1310.7922

Tau Decay branching ratios

Decay modes	TAUOLA-CLEO
$\tau \rightarrow e\nu_e\,\nu_\tau$,	17.8 %
$\tau \rightarrow \mu\nu_\mu\,\nu_\tau$	17.4 %
$\tau \rightarrow h^\pm neutr.\nu_\tau$ (single-prong)	49.5 %
$\tau \rightarrow \pi^\pm\nu_\tau$	11.1 %
$\tau \rightarrow \pi^0\pi^\pm\nu_\tau$	25.4 %
$\tau \rightarrow \pi^0\pi^0\pi^\pm\nu_\tau$	9.2 %
$\tau \rightarrow \pi^0\pi^0\pi^0\pi^\pm\nu_\tau$	1.1 %
$\tau \rightarrow K^\pm neutr.\nu_\tau$	1.6 %
$\tau \rightarrow h^\pm h^\pm h^\pm neutr.\nu_\tau$ (three-prong)	14.6 %
$\tau \rightarrow \pi^\pm\pi^\pm\pi^\pm\nu_\tau$	9.0 %
$\tau \rightarrow \pi^0\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	4.3 %
$\tau \rightarrow \pi^0\pi^0\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	0.5 %
$\tau \rightarrow \pi^0\pi^0\pi^0\pi^\pm\pi^\pm\pi^\pm\nu_\tau$	0.1 %
$\tau \rightarrow K_S^0X^\pm\nu_\tau$	0.9 %
$\tau \rightarrow (\pi^0)\pi^\pm\pi^\pm\pi^\pm\pi^\pm\pi^\pm\nu_\tau$ (five-prong)	0.1 %
other modes with K	1.3 %
others	0.03 %

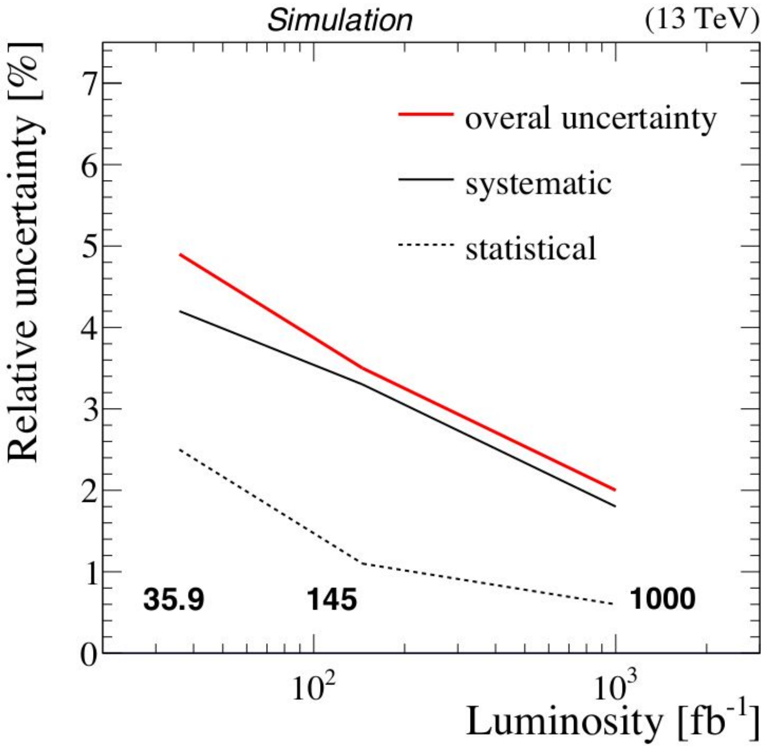
Expected N events from Oleksii Toldaiev feasibility study

Assuming integrated luminosity of 35.9 fb^{-1} (data of 2016)

Process	$t\bar{t} \rightarrow e\tau_h$	$t\bar{t} \rightarrow e\mu$	$DY \rightarrow \mu\tau_h$	$DY \rightarrow \mu\mu$
$t\bar{t} \rightarrow W^+W^-b\bar{b}$ genuine	1900 ± 40	186000 ± 400	360 ± 20	202000 ± 400
$t\bar{t} \rightarrow W^+W^-b\bar{b}$ misidentified	800 ± 20	2000 ± 40	280 ± 20	2000 ± 30
tW genuine	190 ± 10	17000 ± 90	80 ± 10	37000 ± 200
tW misidentified	70 ± 5	2000 ± 50	30 ± 5	0 ± 0
Other single top	0	50 ± 10	10 ± 5	0 ± 0
$DY \rightarrow \tau_\ell\tau_h$	100 ± 50	400 ± 100	15000 ± 500	0
$DY \rightarrow \mu\mu$	10 ± 10	0	50 ± 50	41510000 ± 30000
Other DY	0	50 ± 50	0	1000 ± 500
W + jets	0	120 ± 120	3700 ± 650	3200 ± 700
Total	3050 ± 70	209000 ± 500	19500 ± 850	$(41760 \pm 30) \times 10^3$
Data		209387		42831×10^3

[https://cds.cern.ch/record/2745770?ln=en]

Expected uncertainty from Oleksii Toldaiev feasibility study



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