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

Da Molin Giacomo

CMS Physics Group of LIP Lisboa

IDPASC/LIP PhD Students Workshop,
17/10/2024

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

Fundação para a Ciência e a Tecnologia

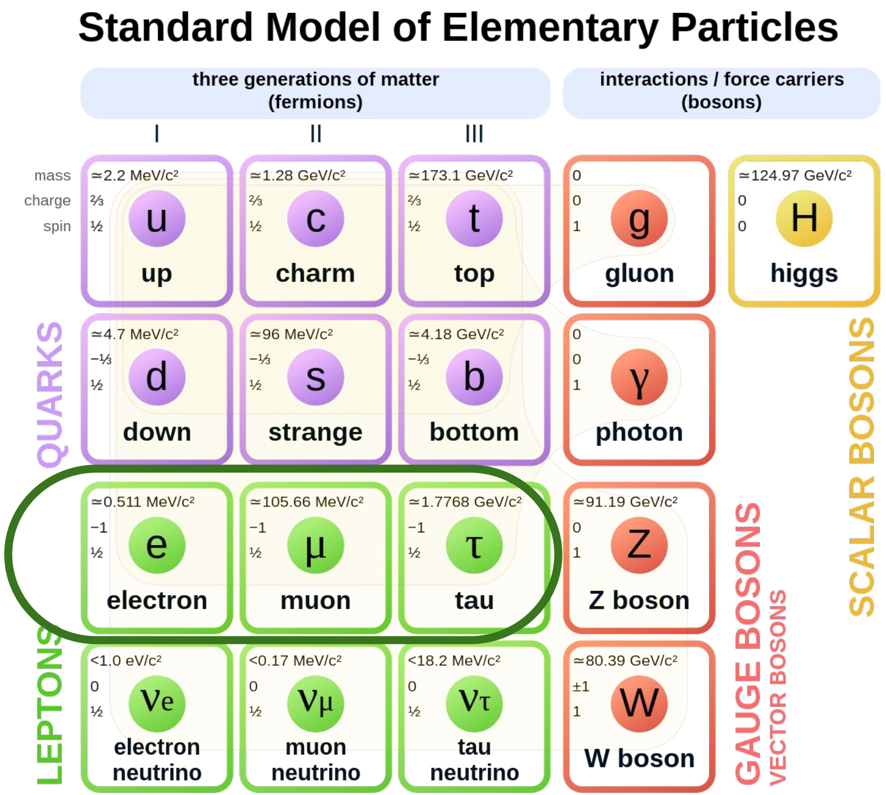
TÉCNICO LISBOA

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.



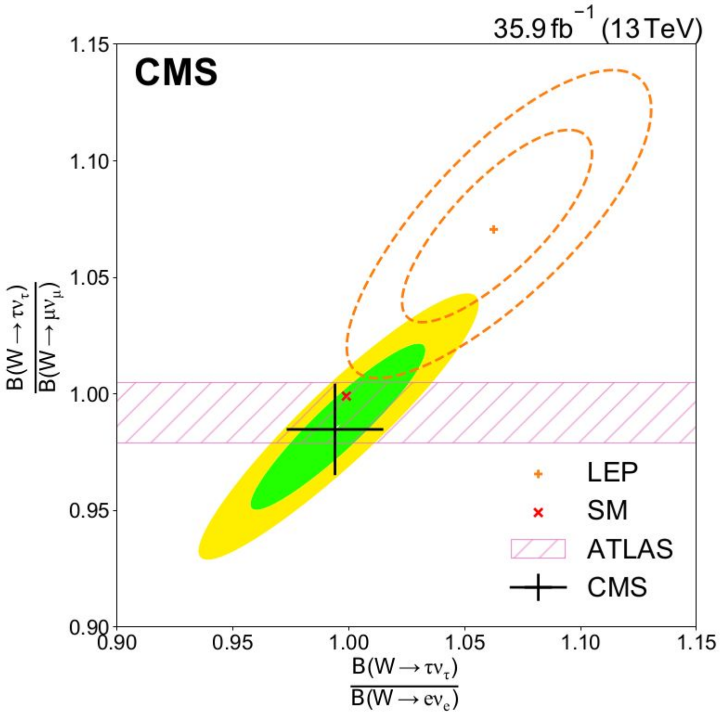
Motivation for my PhD thesis

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

$$R_{\tau/\mu}:\ \mathcal{B}(\mathrm{W}\to\tau\bar{\nu}_\tau)\,/\,\mathcal{B}(\mathrm{W}\to\mu\bar{\nu}_\mu) \;=\; 1.070\pm0.026$$ **[0]**

ATLAS [1] and CMS [2] collaborations studied this observable, finding agreement with the SM.
More precision studies could help further test the LFU hypothesis.

	CMS	LEP	ATLAS
$R_{\tau/e}$	0.994 ± 0.021	1.063 ± 0.027	—
$R_{\tau/\mu}$	0.985 ± 0.020	1.070 ± 0.026	0.992 ± 0.013
	Measured all branching ratios of W		Used $\tau\to\mu$

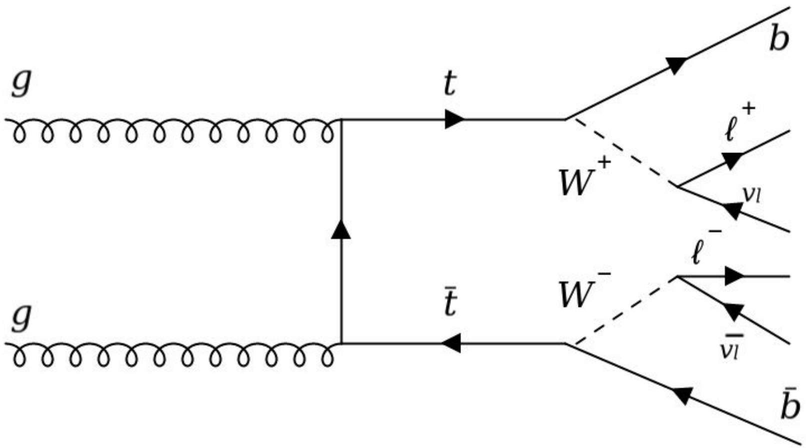


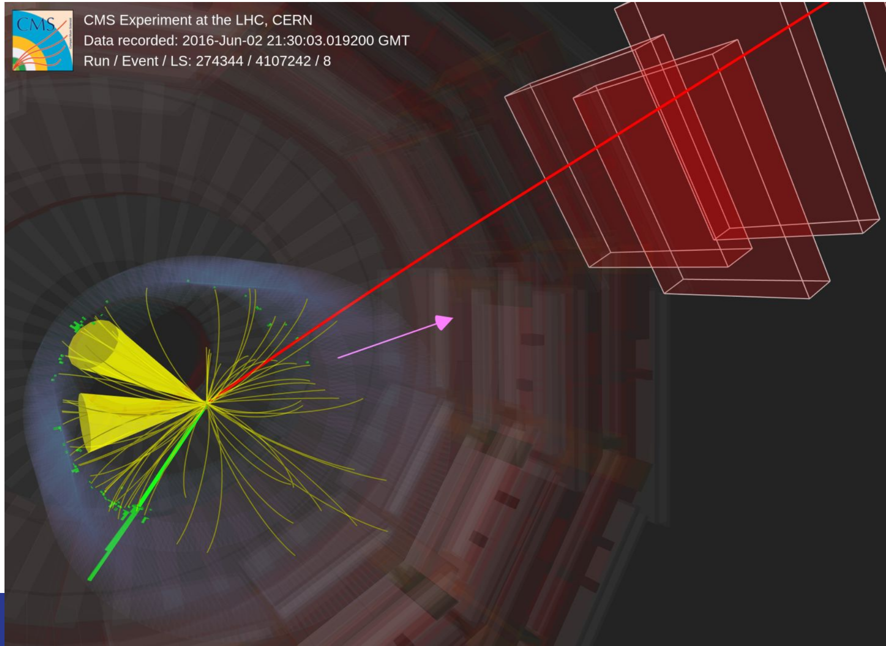
Procedure

We need a pure sample of W bosons:

➔ Exploit the fact that (almost) all **top quarks decay in W boson + a b-quark**, 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)





Procedure

Start from an initial study [3] to reduce systematic uncertainties, use:

- ➢ Optimized observables exploiting normalization with Drell Yan events

$$R_{\tau/\mu} = \frac{\frac{N(t\bar{t} \to e\tau_h\nu_e\nu_\tau b\bar{b})}{N(t\bar{t} \to e\mu\nu_e\nu_\mu b\bar{b})} + \frac{N(t\bar{t} \to \mu\tau_h\nu_\mu\nu_\tau b\bar{b})}{N(t\bar{t} \to \mu\mu\nu_\mu\nu_\mu b\bar{b})}}{2} \cdot \frac{N(DY \to \mu\mu)}{N(DY \to \tau_\mu\tau_h)}$$

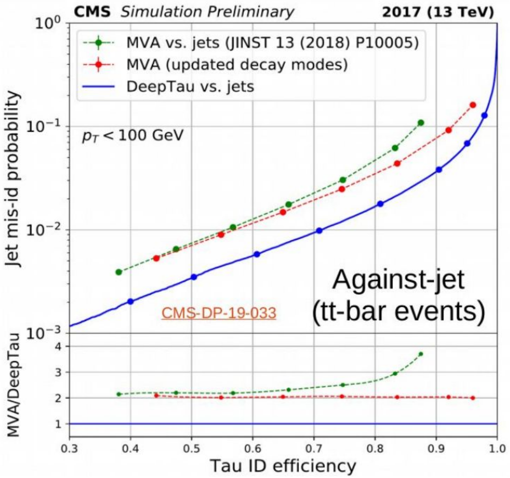
$$R_{\tau/e} = \frac{\frac{N(t\bar{t} \to \mu\tau_h\nu_\mu\nu_\tau b\bar{b})}{N(t\bar{t} \to e\mu\nu_e\nu_\mu b\bar{b})} + \frac{N(t\bar{t} \to e\tau_h\nu_e\nu_\tau b\bar{b})}{N(t\bar{t} \to ee\nu_e\nu_e b\bar{b})}}{2} \cdot \frac{N(DY \to ee)}{N(DY \to \tau_e\tau_h)}$$

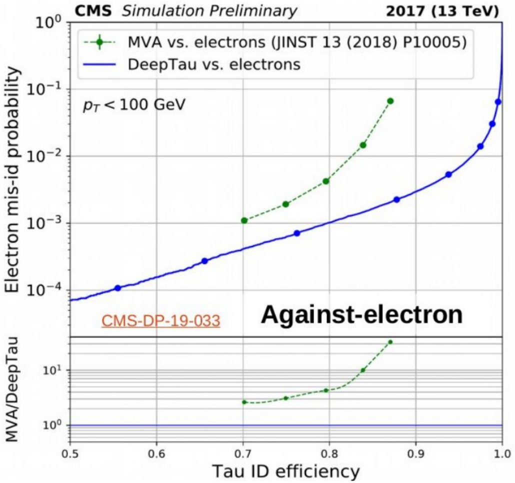
- ➢ Tuned selections and corrections to equilibrate efficiency and symmetry between different regions

➢ **Reduce effect of** (otherwise dominating) **lepton related systematics**

Procedure

- Use Machine Learning:
  - the **DeepTau** Deep Neural Network to separate hadronically decaying τ from e, μ, jets
  - Multiclass BDTs to separate signal and backgrounds





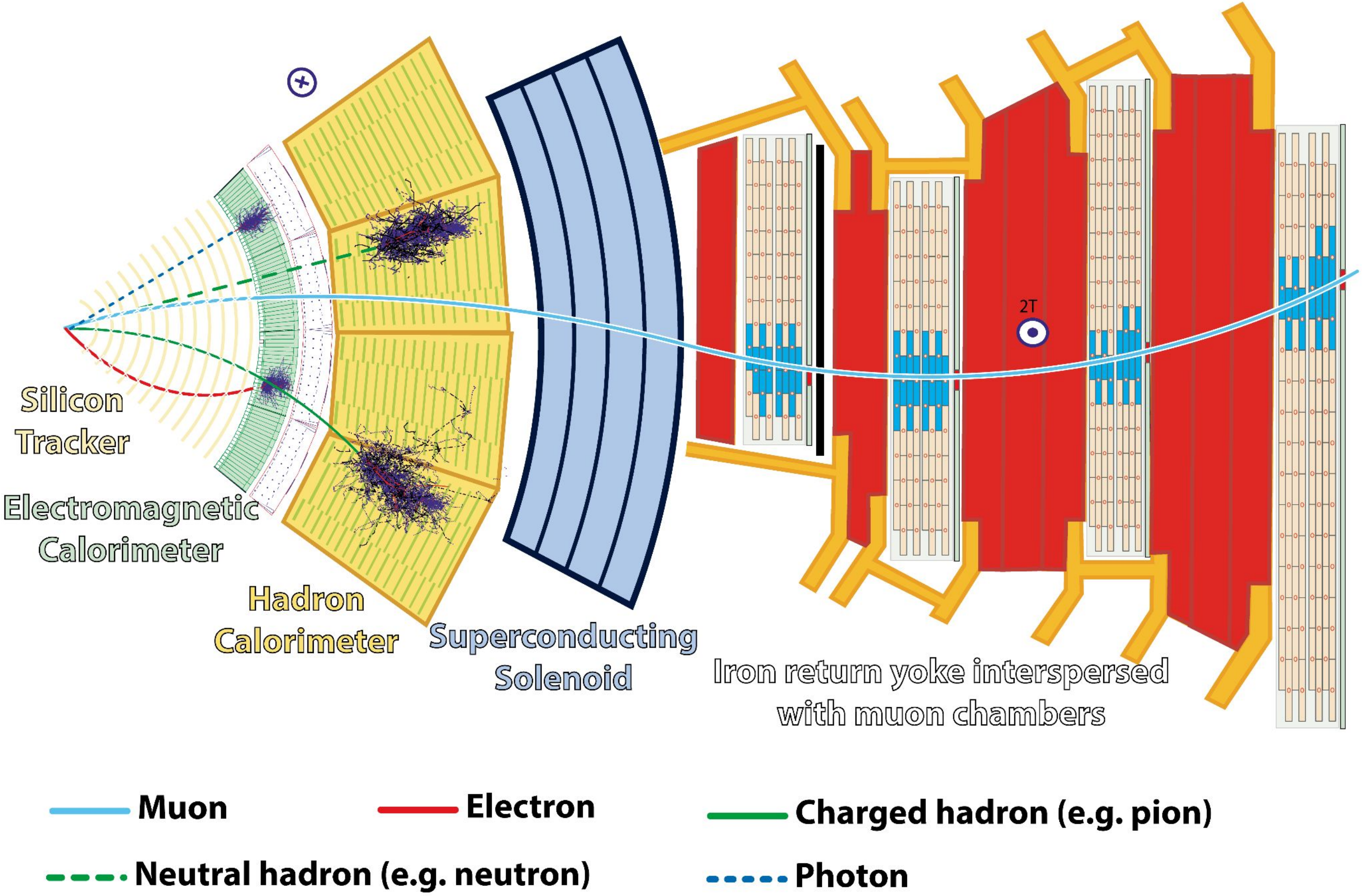
AIM:

Measure the coupling of the W bosons with e, μ, τ and produce a precision test of the Standard Model using CMS Run2 data.

Thank you for your attention!

Backup

CMS detector

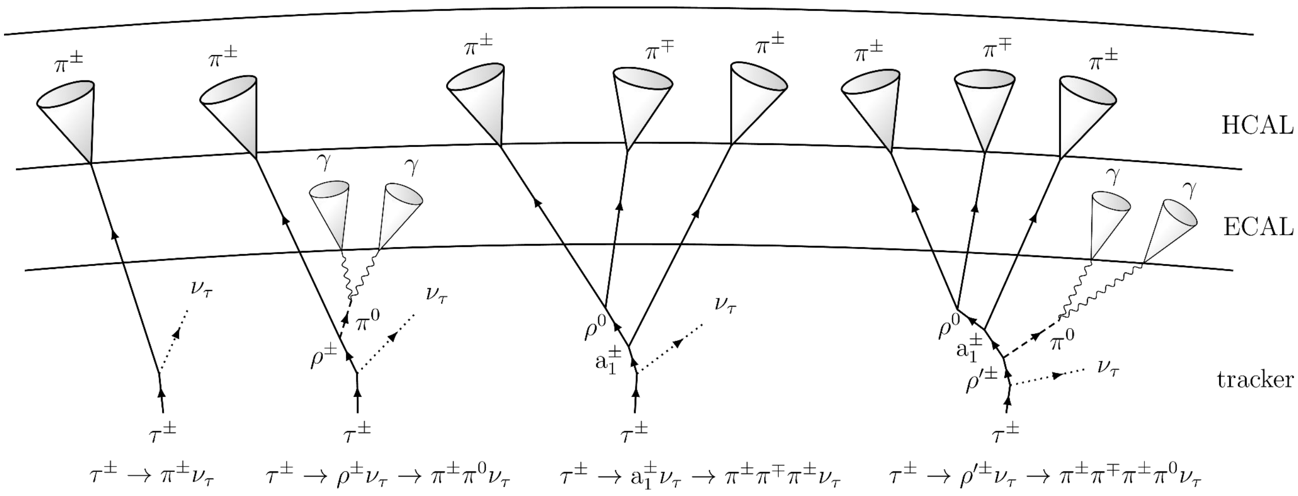


Procedure

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)



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.

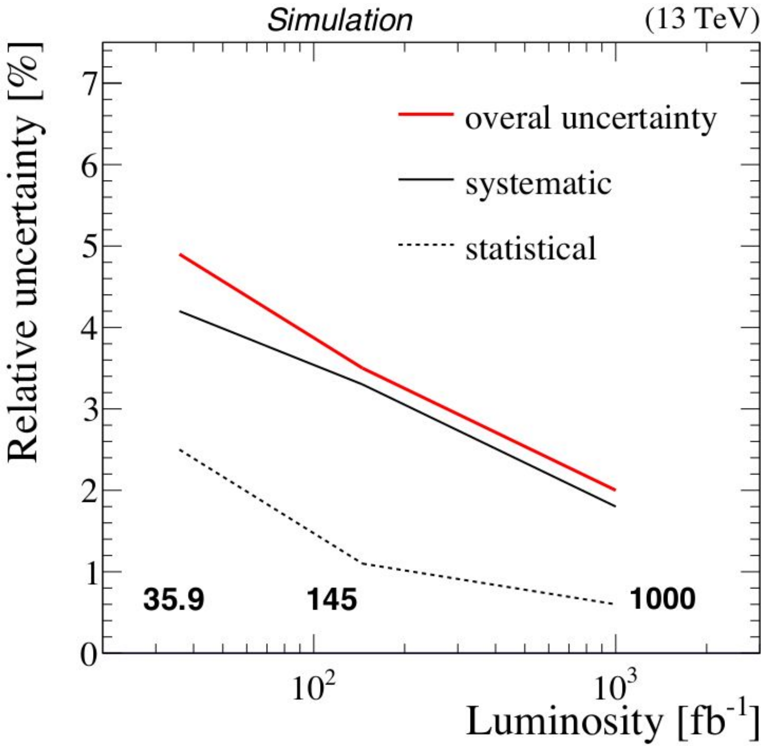
	$\Gamma_{\tau\to\mu}/\Gamma_{\tau\to e}$	$\Gamma_{\pi\to\mu}/\Gamma_{\pi\to e}$	$\Gamma_{K\to\mu}/\Gamma_{K\to e}$	$\Gamma_{K\to\pi\mu}/\Gamma_{K\to\pi e}$	$\Gamma_{W\to\mu}/\Gamma_{W\to e}$
$\lvert g_\mu/g_e\rvert$	1.0018 (14)	1.0021 (16)	0.9978 (20)	1.0010 (25)	0.996 (10)
	$\Gamma_{\tau\to e}/\Gamma_{\mu\to e}$	$\Gamma_{\tau\to\pi}/\Gamma_{\pi\to\mu}$	$\Gamma_{\tau\to K}/\Gamma_{K\to\mu}$	$\Gamma_{W\to\tau}/\Gamma_{W\to\mu}$	
$\lvert g_\tau/g_\mu\rvert$	1.0011 (15)	0.9962 (27)	0.9858 (70)	1.034 (13)	
	$\Gamma_{\tau\to\mu}/\Gamma_{\mu\to e}$	$\Gamma_{W\to\tau}/\Gamma_{W\to e}$			
$\lvert g_\tau/g_e\rvert$	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
$\tau \to e\nu_e \nu_\tau$, $\tau \to \mu\nu_\mu \nu_\tau$	17.8 % 17.4 %
$\tau \to h^{\pm} neutr. \nu_\tau$ (single-prong)	49.5 %
$\tau \to \pi^{\pm}\nu_\tau$	11.1 %
$\tau \to \pi^0\pi^{\pm}\nu_\tau$ $\tau \to \pi^0\pi^0\pi^{\pm}\nu_\tau$ $\tau \to \pi^0\pi^0\pi^0\pi^{\pm}\nu_\tau$	25.4 % 9.2 % 1.1 %
$\tau \to K^{\pm} neutr. \nu_\tau$	1.6 %
$\tau \to h^{\pm}h^{\pm}h^{\pm} neutr. \nu_\tau$ (three-prong)	14.6 %
$\tau \to \pi^{\pm}\pi^{\pm}\pi^{\pm}\nu_\tau$ $\tau \to \pi^0\pi^{\pm}\pi^{\pm}\pi^{\pm}\nu_\tau$ $\tau \to \pi^0\pi^0\pi^{\pm}\pi^{\pm}\pi^{\pm}\nu_\tau$ $\tau \to \pi^0\pi^0\pi^0\pi^{\pm}\pi^{\pm}\pi^{\pm}\nu_\tau$	9.0 % 4.3 % 0.5 % 0.1 %
$\tau \to K^0_S X^{\pm} \nu_\tau$	0.9 %
$\tau \to (\pi^0)\pi^{\pm}\pi^{\pm}\pi^{\pm}\pi^{\pm}\pi^{\pm}\nu_\tau$ (five-prong)	0.1 %
other modes with K	1.3 %
others	0.03 %

Expected uncertainty from Oleksii Toldaiev feasibility study



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

References:

[0]:https://doi.org/10.1016/j.physrep.2013.07.004
[1]:http://dx.doi.org/10.1038/s41567-021-01236-w
[2]:http://dx.doi.org/10.1103/PhysRevD.105.072008
[3]:https://cds.cern.ch/record/2745770?ln=en