1st Year PhD Report

# Using $Z \to \tau\tau$ events to calculate Tau ID scale factors using high $p_T$ Tau leptons

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# Declaration

I hereby declare, that I am the sole author and composer of my thesis and that no other sources or learning aids, other than those listed, have been used. Furthermore, I declare that I have acknowledged the work of others by providing detailed references of said work.
I hereby also declare, that my Thesis has not been prepared for another examination or assignment, either wholly or excerpts thereof.

Place, Date

Signature

# Abstract

foo bar

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# 1 Introduction

# 2 Tau physics overview

This chapter is a review of the Tau lepton properties. They include the nature of this particle, its interactions with other Standard Model (SM) particles, its main decay modes and the physics implications of the so called Lepton Universality (LU), one of the SM predictions.

## 2.1 The Tau Lepton

The Tau is a spin-$\frac{1}{2}$, electrically charged particle that belongs to the same family of particles as the electron, the muon and the neutrinos, they are all called *]leptons*. Leptons are elementary particles that interact only via the weak and electromagnetic interactions, for the latter case only if they have electric charge.

The first hints for the tau existence came from experiments conducted at the Stanford Linear Accelerator Center and Lawrence Berkeley National Laboratory [2]. They discovered 64 events of the form:

$$e^+ + e^- \rightarrow e^\pm + \mu^\mp + \geq 2 \text{ undetected particles,} \tag{1}$$

for which there was no conventional explanation at that time. Later on, it was discovered that these events came from the production of a pair of tau particles and then a its subsequent decay on one electron, a muon and four neutrinos. Events like,

$$e^+ + e^- \to \tau^+\tau^- \to e^\pm + \mu^\mp + 4\nu, \quad (2)$$

were later explored to derive tau mass and spin, confirming the existence of a third generation of leptons.

The tau mass being $1776.86 \pm 0.12$ MeV allows this lepton not only to decay into the other lighter lepton generations (*leptonic tau decays*), as its shown on Fig.1 , but into *hadrons*. These are particle made of quarks, all the decay channels of the tau containing hadrons in the final state are called *hadronic tau decays*. An example of this decay mode is shown in Fig.2

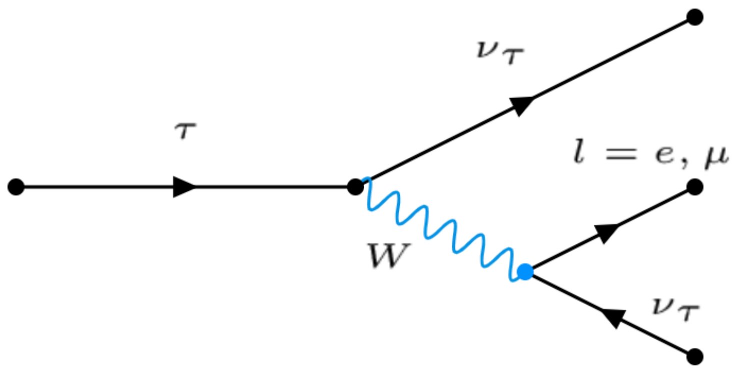


**Figure 1:** Tau leptonic decay mode. Tau lepton is kinematically allowed to decay into muons or electrons, not that in this decay mode two neutrinos of different flavour are produced.

Naively, if we were to estimate the branching fraction for hadronic and leptonic tau decay modes, defined as:

$$\beta(\tau \to X\nu_\tau) = \frac{\Gamma(\tau \to X\nu_\tau)}{\Gamma_{\text{tot}}}, \quad (3)$$

where X could be any group of leptons or hadrons and $\Gamma_{\text{tot}}$ is the total decay width for the tau, we could argue that the contribution from the hadronic decays triples the one for the leptonic channels. This is because in any hadronic decay, we would have

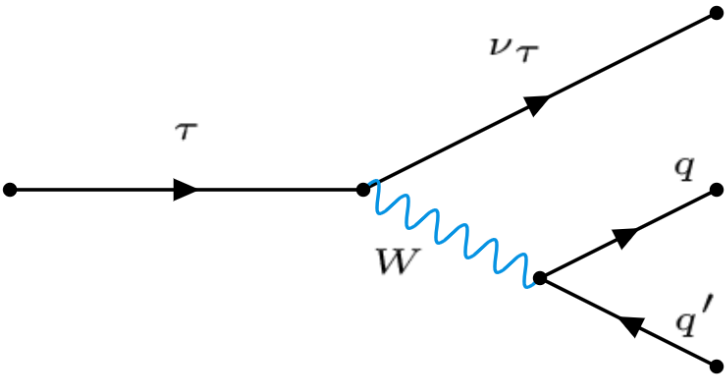


**Figure 2:** Tau hadronic decay mode. Tau lepton is kinematically allowed only to decay into hadrons containing up, down and strange quarks. This results on final states containing multiple pions or kaons [1].

to count 3 different diagrams, like the one in Fig.2 because of the 3 colour possibility for the quarks.

Thus,

$$\beta(\tau \to l\nu_l\nu_\tau) \approx 20\% \qquad l = e, \mu; \tag{4}$$

$$\beta(\tau \to X\nu_\tau) \approx 60\% \qquad X = \text{hadrons+neutrinos} \tag{5}$$

in fact, this naive estimation is not so bad. Actual values for the leptonic branching ratios are [3]:

$$\beta(\tau \to e\nu_e\nu_\tau) = 17.82 \pm 0.04\% \tag{6}$$

$$\beta(\tau \to \mu\nu_\mu\nu_\tau) = 17.39 \pm 0.04\%, \tag{7}$$

and the small difference is due to the mass variation between the muon and the electron.

On the other hand, the hadronic decays of the tau are more varied and can contain much more particles in the final states. The vast majority of hadronic tau decays have charged or neutral pions in the final states, but more exotic decays including

| Decay mode | Branching fraction |
|---|---|
| $\pi^{\pm}\nu_{\tau}$ | 11.1 % |
| $\pi^{\pm}\pi^{0}\nu_{\tau}$ | 25.4% |
| $\pi^{\pm} \geq 2\pi^{0}\nu_{\tau}$ | 9.1% |
| $3\pi^{\pm}\nu_{\tau}$ | 9.1% |
| $3\pi^{\pm} \geq 1\pi^{0}\nu_{\tau}$ | 4.6% |
| others | 5.5% |

**Table 1:** Tau hadronic decay modes branching fractions.

kaons also happen. Branching ratios for the most important tau hadronic decays are showed on Table 1.

## 2.2 Lepton Universality

# 3 Analysis

Explain the math and notation.

## 3.1 The LHC and the ATLAS experiment

## 3.2 Tau Identification on the ATLAS detector

## 3.3 Monte Carlo Samples

## 3.4 The Collinear Approximation

## 3.5 Event Selection

$$\text{a} \longrightarrow \text{b}$$

**Figure 3:** Use tikz to draw nice graphs!

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**Algorithm 1** Stochastic Gradient Descent: Neural Network

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Create a mini batch of $m$ samples $\mathbf{x}_0 \ldots \mathbf{x}_{m-1}$
**foreach** sample $\mathbf{x}$ **do**
  $\mathbf{a}^{\mathbf{x},0} \leftarrow \mathbf{x}$ ▷ Set input activation
  **foreach** Layer $l \in \{1 \ldots L-1\}$ **do** ▷ Forward pass
    $\mathbf{z}^{\mathbf{x},l} \leftarrow \mathbf{W}^l \mathbf{a}^{\mathbf{x},l-1} + \mathbf{b}^l$
    $\mathbf{a}^{\mathbf{x},l} \leftarrow \varphi(\mathbf{z}^{\mathbf{x},l})$
  **end for**
  $\boldsymbol{\delta}^{\mathbf{x},L} \leftarrow \nabla_{\mathbf{a}} C_{\mathbf{x}} \odot \varphi'(\mathbf{z}^{\mathbf{x},L})$ ▷ Compute error
  **foreach** Layer $l \in L-1, L-2 \ldots 2$ **do** ▷ Backpropagate error
    $\boldsymbol{\delta}^{\mathbf{x},l} \leftarrow ((\mathbf{W}^{l+1})^T \boldsymbol{\delta}^{\mathbf{x},l+1}) \odot \varphi'(\mathbf{z}^{\mathbf{x},l})$
  **end for**
**end for**
**foreach** $l \in L, L-1 \ldots 2$ **do** ▷ ▷ Gradient descent
  $\mathbf{W}^l \leftarrow \mathbf{W}^l - \frac{\eta}{m} \sum_{\mathbf{x}} \boldsymbol{\delta}^{\mathbf{x},l} (\mathbf{a}^{\mathbf{x},l-1})^T$
  $\mathbf{b}^l \leftarrow \mathbf{b}^l - \frac{\eta}{m} \sum_{\mathbf{x}} \boldsymbol{\delta}^{\mathbf{x},l}$
**end for**

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# 4 Results

The approach usually starts with the problem definition and continues with what you have done. Try to give an intuition first and describe everything with words and then be more formal like 'Let $g$ be ...'.

## 4.1 $\mu\tau$ Final state

## 4.2 $e\tau$ Final state

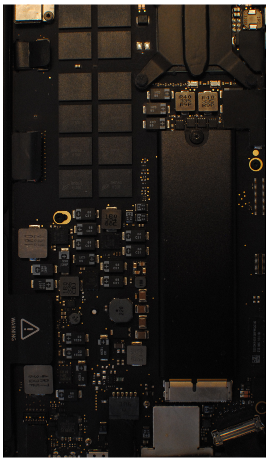
Start with a very short motivation why this is important. Then, as stated above, describe the problem with words before getting formal.

## 4.3 Monte Carlo and data discrepancies

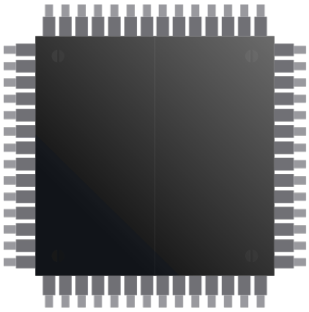
# 5 Conclusions and prospects

| Type | Accuracy |
|---|---|
| A | $82.47 \pm 3.21$ |
| B | $78.47 \pm 2.43$ |
| C | $84.30 \pm 2.35$ |
| D | $86.81 \pm 3.01$ |

**Table 2: Table caption.** foo bar...



**(a)** Some cool graphic



**(b)** Some cool related graphic

**Figure 4: Caption that appears under the fig** Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

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