HUNTING FOR NEW PHYSICS WITH IMPROVED TESTS OF LEPTON FLAVOR UNIVERSALITY AT LHC
WHAT ARE WE TESTING? WHAT ARE WE MEASURING?

- Lepton Flavour Universality (LFU)
  - The couplings of the vector gauge bosons to three lepton generations are equal ($g_e = g_\mu = g_\tau = g$)
  - Measuring the ratio of branching fractions of $W$-boson decays to $\tau$ and light leptons in $t\bar{t}$ events with the ATLAS detector

\[
R \left( \frac{\tau}{l} \right) = \frac{BR(W \rightarrow \tau\nu)}{BR(W \rightarrow e\nu)} \times \frac{BR(W \rightarrow \tau\nu)}{BR(W \rightarrow \mu\nu)} = ??
\]

where $l = e, \mu$
PREVIOUS WORK/MOTIVATIONS

- Motivated by previous measurements at LEP, as well as LHCb, Belle, and BaBar in their measurement of $R(D^*)$

- Particle Data Group averages are $1.8\sigma$ for $R\left(\frac{\tau}{e}\right)$ and $2.7\sigma$ for $R\left(\frac{\tau}{\mu}\right)$ away from SM predictions

- LEP achieved a precision of $\sim 2.5\%$ for both the electron and muon channels

- Goal is to significantly improve on these previous measurements

- Currently focusing only on $R\left(\frac{\tau}{\mu}\right)$
MY SUMMER PROJECT

▸ Test the sensitivity of Lepton Flavour Universality at High Luminosity LHC (HL-LHC) (3000 fb⁻¹)
MEASUREMENT STRATEGY

- Use $t\bar{t}$ events in the di-lepton decay mode [1]
- Distinguish leptons from $\tau$ decay than prompt leptons ($e, \mu$) by:
  - Impact parameter $d_0$ [2, 3]
  - Lepton $p_T$ spectra [3]
Use “tag-and-probe” approach

Trigger 1 lepton ($\mu, e$)

Require 2 b-jets

Probe 2nd lepton of opposite charge ($\mu$)

A two-dimensional fit is performed in $p_T$ and the $d_0$ of the probe lepton

We are using the Run 2 fit model

Asimov, Monte Carlo data sets are generated using data sets from Run 2 analysis
INPUT TO RATIO EXTRACTION

- $d_0(\mu)$ distributions for each of the $e\mu$ channel $p_T$ bins are inputs to the 2D fit to extract $R^{(T)}_\mu$

- We also look at $d_0\mu\mu$ channel, which by design has an important $Z \rightarrow \mu\mu$ background

- Split $p_T$ bins into 5-10 GeV (left), 10-20 GeV (middle), and 20-250 GeV (right)

- Discriminating power between prompt (light green), tau (dark green), and fake lepton (yellow) backgrounds

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**ATLAS**

$\sqrt{s} = 13$ TeV, 3000 fb$^{-1}$

- $e\mu$ channel, 9 bin

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**HUNTING FOR NEW PHYSICS WITH IMPROVED TESTS OF LEPTON FLAVOR UNIVERSALITY AT HL-LHC**

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**ATLAS**

$\sqrt{s} = 13$ TeV, 3000 fb$^{-1}$

- $e\mu$ channel, 9 bin
**INPUT TO RATIO EXTRACTION**

- \(d_0(\mu)\) distributions for each of the \(e\mu\) channel \(p_T\) bins are inputs to the 2D fit to extract \(R(\tau^T)\).
- We also look at \(d_\mu\mu\) channel, which by design has an important \(Z \to \mu\mu\) background.
- Split \(p_T\) bins into 5-10 GeV (left), 10-20 GeV (middle), and 20-250 GeV (right).
- Discriminating power between prompt (light green), tau (dark green), and fake lepton (yellow) backgrounds.
INPUT TO RATIO EXTRACTION

- \( d_0(\mu) \) distributions for each of the \( e\mu \) channel \( p_T \) bins are inputs to the 2D fit to extract \( R^{(T)}_{\mu} \)

- We also look at \( d_0 \mu\mu \) channel, which by design has an important \( Z \to \mu\mu \) background

- Split \( p_T \) bins into 5-10 GeV (left), 10-20 GeV (middle), and 20-250 GeV (right)

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\( \mu\mu \) channel, 9 bin
INPUT TO RATIO EXTRACTION

- $d_0(\mu)$ distributions for each of the $e\mu$ channel $p_T$ bins are inputs to the 2D fit to extract $R^{(T)}(\mu)$

- We also look at $d_0 \mu\mu$ channel, which by design has an important $Z \rightarrow \mu\mu$ background

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\[ \mu\mu \text{ channel, 3 bin} \]
The systematic uncertainties considered in the fit that have the largest impact on the $\Delta R(\tau/\mu)$ are shown:

- 9-bin fit, Run 2 uncertainties scaled to 3000 fb$^{-1}$
- One of the highest ranked uncertainties is due to Monte Carlo modelling of the $d_0$ templates
- Compare to Powheg + Herwig 7 (shower) and aMC@NLO + Pythia 8 AP8 (matching) to Powheg + Pythia 8 (nominal) event generator Asimov data sets
DOMINANT SYSTEMATIC UNCERTAINTIES (CONTINUED)

- Compare Powheg + Herwig 7 (shower) and aMC@NLO + Pythia 8 (matching) to Powheg + Pythia 8 (nominal) event generator Asimov data sets

For HL-LHC prospects, it has been agreed to reduce by a factor of 2 the current theoretical uncertainties.
SENSITIVITY WITH INCREASED LUMINOSITY?

\[ \Delta(R(\tau/\mu)) \] vs. Integrated Luminosity

**Scenario 1:** Full systematic uncertainties

**Scenario 2:** Halved theoretical uncertainties

**Scenario 3:** Halved theoretical uncertainties and low \( p_T \) muon uncertainty

**Scenario 4:** Halved theoretical uncertainties and low \( p_T \) muon uncertainty excluding Monte Carlo uncertainties

RUN 3

HL-LHC
CONCLUSIONS

- Increasing the luminosity from 140 fb to 3000 fb improves the sensitivity by ~2.5x
- In the best case scenario (halving the theory systematics), a precision of ~0.27% is obtainable
- The 9-bin fit has higher sensitivity than the 3-bin fit
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