FAKE FACTOR METHOD IN SEARCH FOR CHARGED HIGGS BOSONS DECAYING VIA $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau}$

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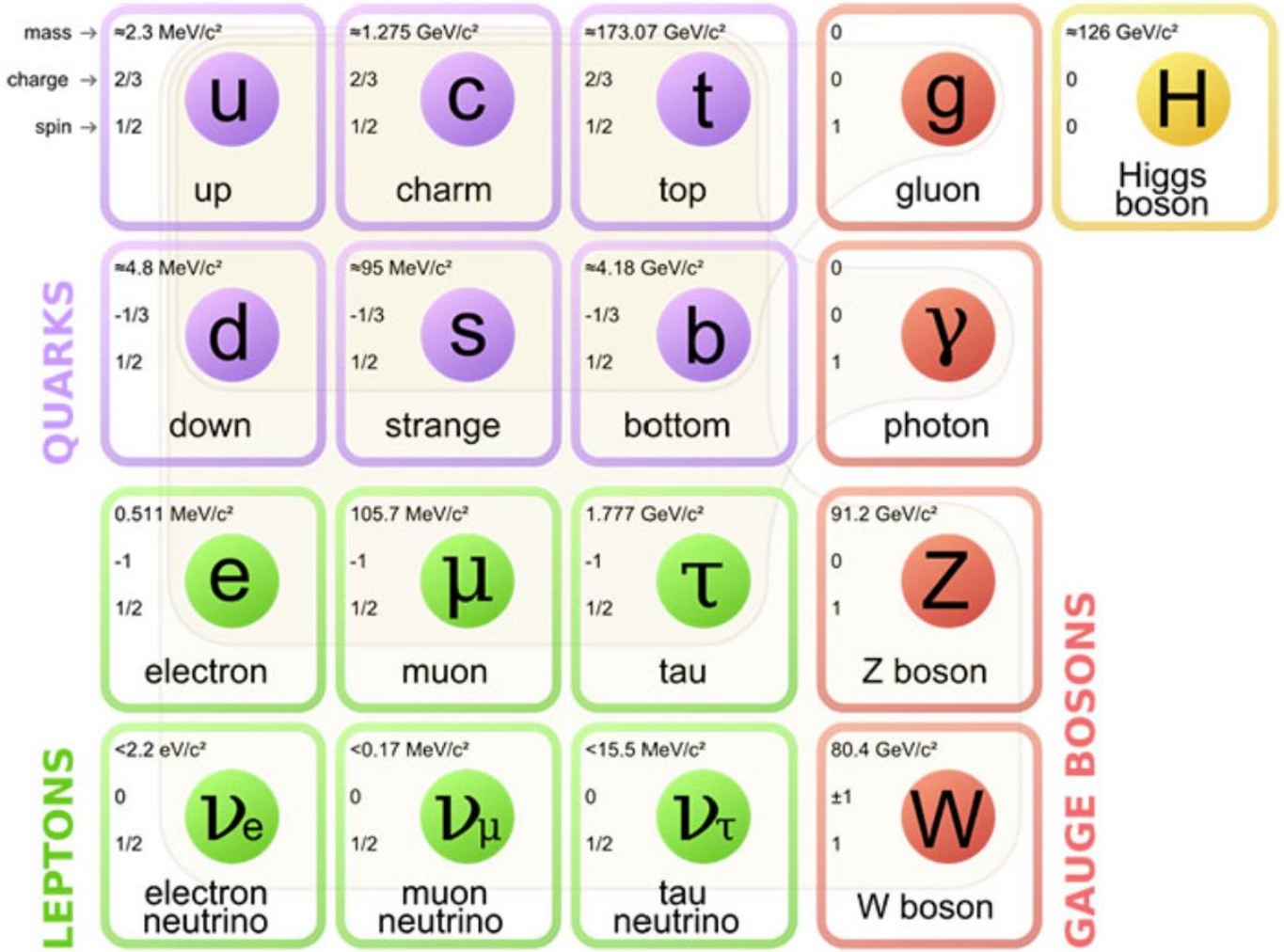
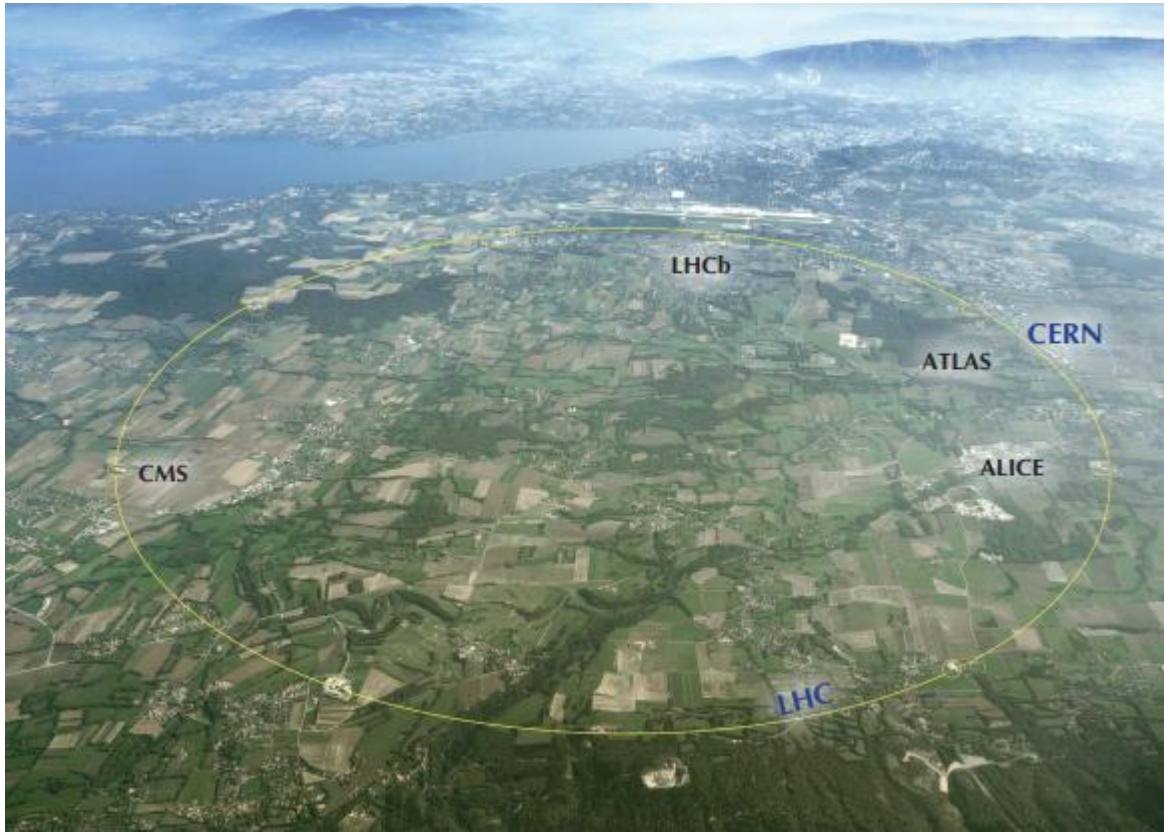
Purpose: How to estimate background coming from hadron jets misidentified as leptons τ_{had} in search for charged Higgs bosons decaying via $H^{\pm} \rightarrow \boldsymbol{\tau}^{\pm}\nu_{\boldsymbol{\tau}}$

STANDARD MODEL



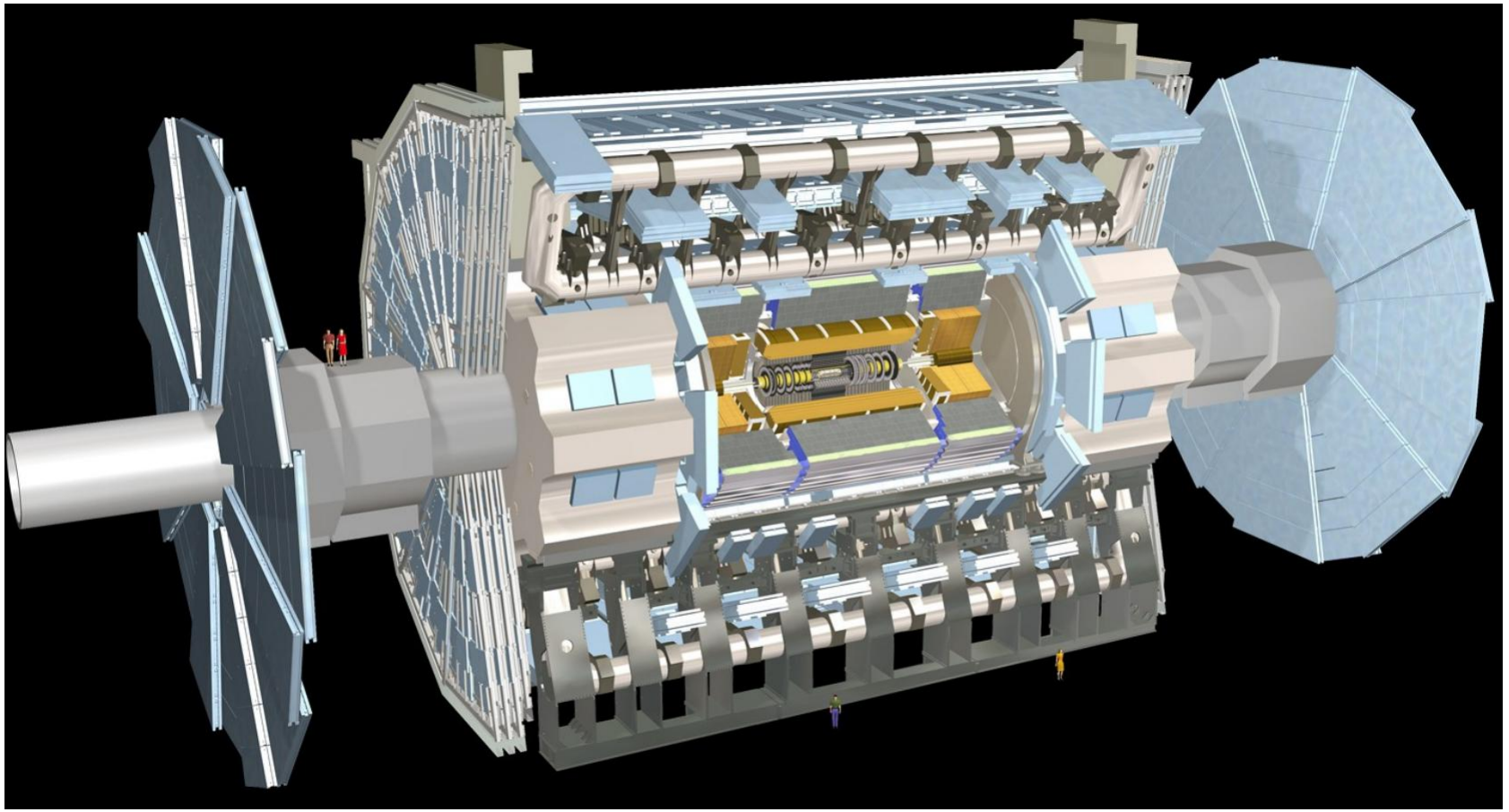
- The Higgs particle is a massive scalar boson that interacts with particles whose mass arises from their interactions with the Higgs Field
- Predicted in 1964
- Discovered in 2012 by the ATLAS and CMS experiments at the Large Hadron Collider (LHC)
- Nobel Prize in Physics in 2013

LHC



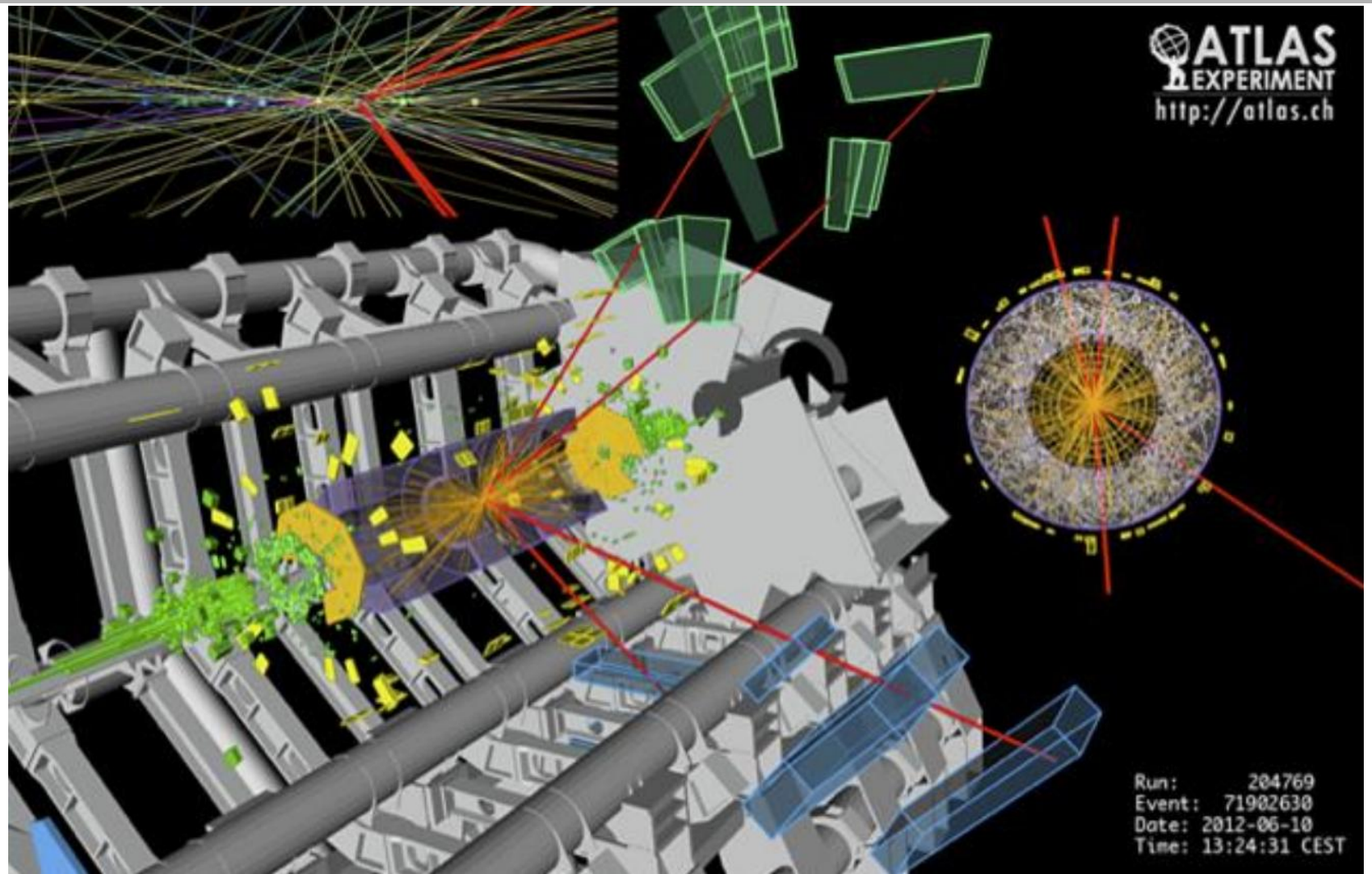
- Particle accelerator that pushes protons or ions to near the speed of light
- 27-kilometre ring
- 100 metres underground
- The beams inside the LHC are made to collide at four locations - ATLAS, CMS, ALICE , and LHCb

ATLAS DETECTOR



- 46 m long, 25 m high and 25 m wide
- Designed in layers made up of detectors of different types, each of which is designed to observe specific types of particles
- The different traces that particles leave in each layer of the detector allow for effective particle identification and accurate measurements of energy and momentum

H → ZZ* →4L CANDIDATE



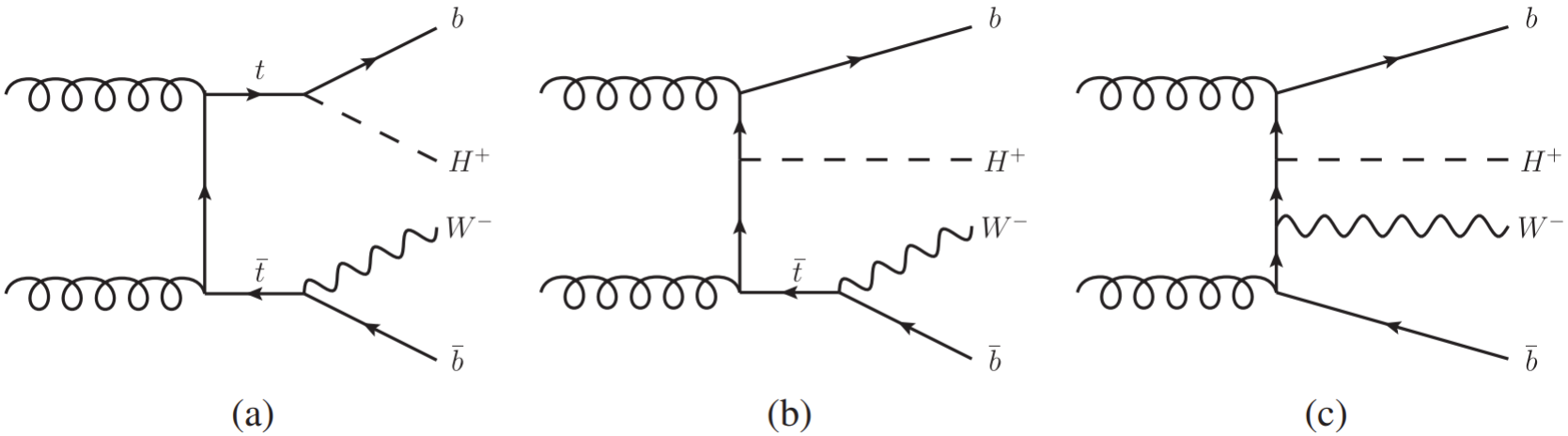
BEYOND STANDARD MODEL

- The Standard Model doesn't explain the Higgs naturalness problem, dark matter and dark energy, matter-antimatter asymmetry…
- Variety of theoretical physics models extending the Standard Model
- Two-Higgs Doublet Models (2HDMs)- propose the existence of an additional Higgs doublet
- SUSY- introducing an additional symmetry between bosons and fermions, called Supersymmetry
  - The simplest version of SUSY - Minimal Supersymmetric Standard Model

- ATLAS and CMS collaborations are extensively studying MSSM Higgs sector parameter space and its constraints

CHARGED HIGGS BOSONS

- Predicted in several extensions of the Standard Model
- For H^+ masses below the top-quark mass ($m_{H^+} < m_t$), the decay $H^{\pm} \rightarrow \boldsymbol{\tau}^{\pm}\nu_{\boldsymbol{\tau}}$ usually dominates in a two Higgs-doublet model (2HDM) type-II



(a) double-resonant top-quark production that dominates at low H^+ masses, (b) single-resonant top-quark production that dominates at large H^+ masses, (c) top-quark exchange production.

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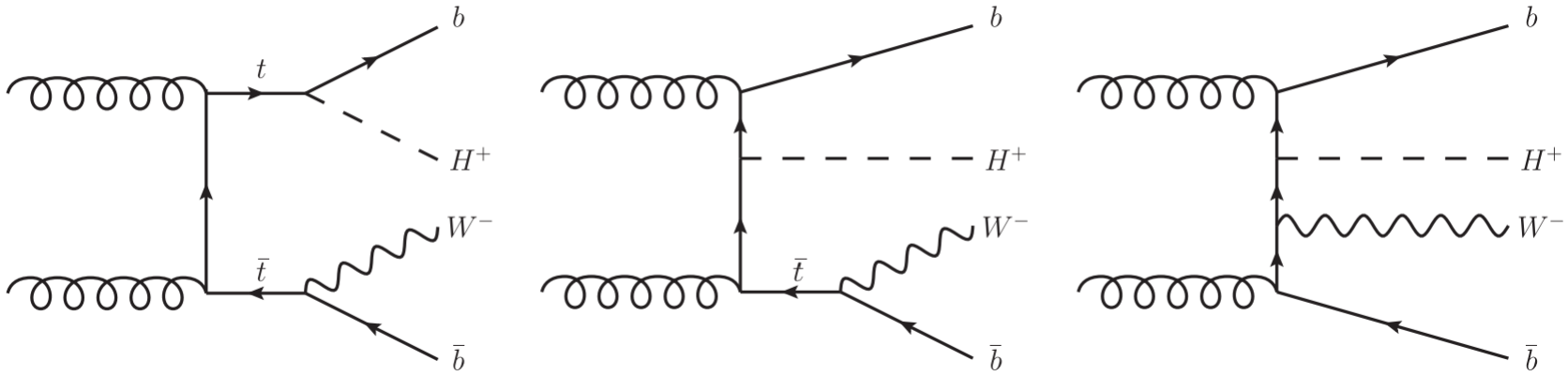
SEARCHES FOR CHARGED HIGGS BOSONS AT COLLIDERS

- The Large Electron–Positron Collider (LEP) experiments excluded the H^+ mass below 80 GeV at 95% confidence level
- Recent results from search for charged Higgs bosons produced in top-quark decays or in association with top quarks and decaying via $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau}$ in 13 TeV pp collisions with the ATLAS detector
  - For the mass range of 80 ≤ m_{H^+} ≤ 3000 GeV, upper limits at 95% confidence level are set on the production cross section of the charged Higgs boson times the branching fraction B($H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau}$) in the range 4.5 pb–0.4 fb
  - ATLAS Data from Run 2

SEARCHES FOR CHARGED HIGGS BOSONS AT COLLIDERS

- I'm part of the search for charged Higgs bosons decaying via $H^{\pm} \rightarrow \boldsymbol{\tau}^{\pm}\nu_{\boldsymbol{\tau}}$ in Run 3 data from ATLAS
- We reserch $H^{\pm} \rightarrow \boldsymbol{\tau}^{\pm}\nu_{\boldsymbol{\tau}}$, with a subsequent decay of the τ-lepton into a neutrino and hadrons
- Depending on the decay mode of the W boson originating from the top quark produced together with the H^{+} , two channels are targeted: τ_{had} + jets if the W boson decays into a $q\bar{q}$ pair, or τ_{had} + lepton if the W boson decays into an electron or muon and at least one neutrino (directly or via a leptonically decaying τ lepton)



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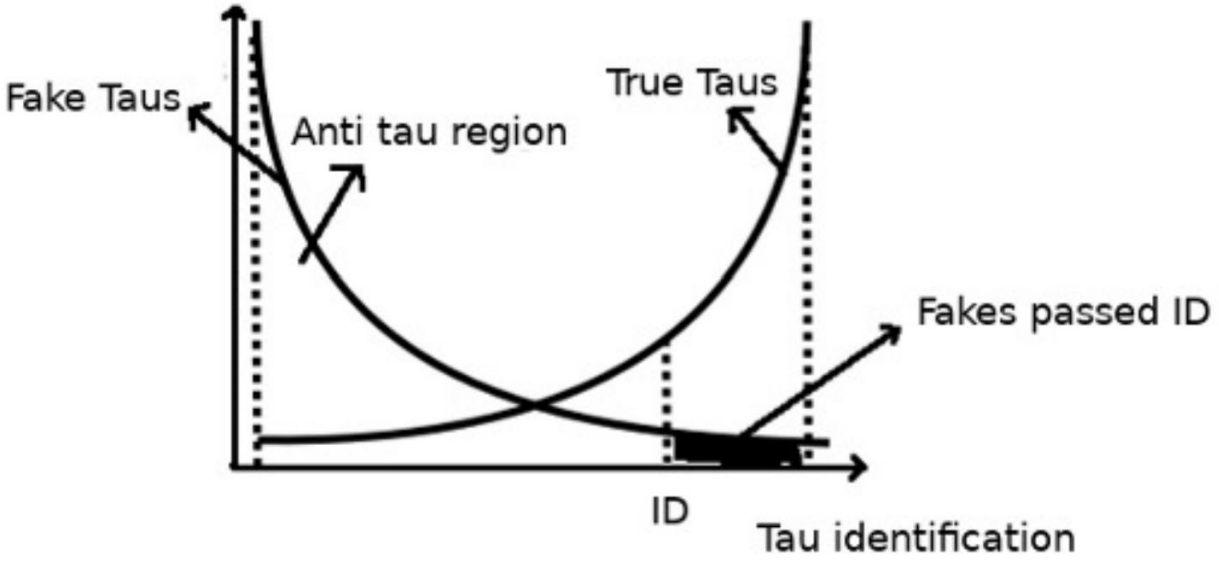
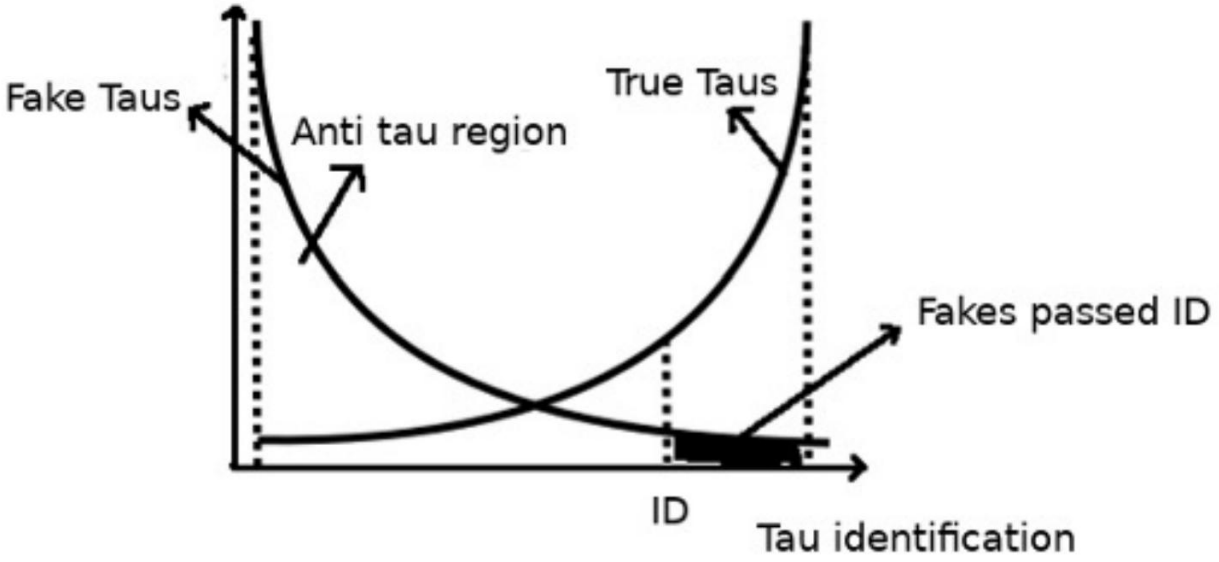
FAKE-FACTOR METHOD

- Motivation: Events that contain quark-or gluon-initiated jets can enter the signal region when one of these jets is reconstructed and identified as a τ_{had} candidate



FAKE-FACTOR METHOD

- Motivation: Events that contain quark-or gluon-initiated jets can enter the signal region when one of these jets is reconstructed and identified as a τ_{had} candidate
- These backgrounds are poorly modelled due to statistical limitations in the sample of simulated events and due to the absence of a good understanding of systematic uncertainties related to those objects
- A data-driven approach is used to estimate this background



FAKE-FACTOR METHOD

- Idea: Estimate fake leptons in the signal region (SR) by extrapolating from anti-ID leptons
- Measure FF in a region with similar jet composition

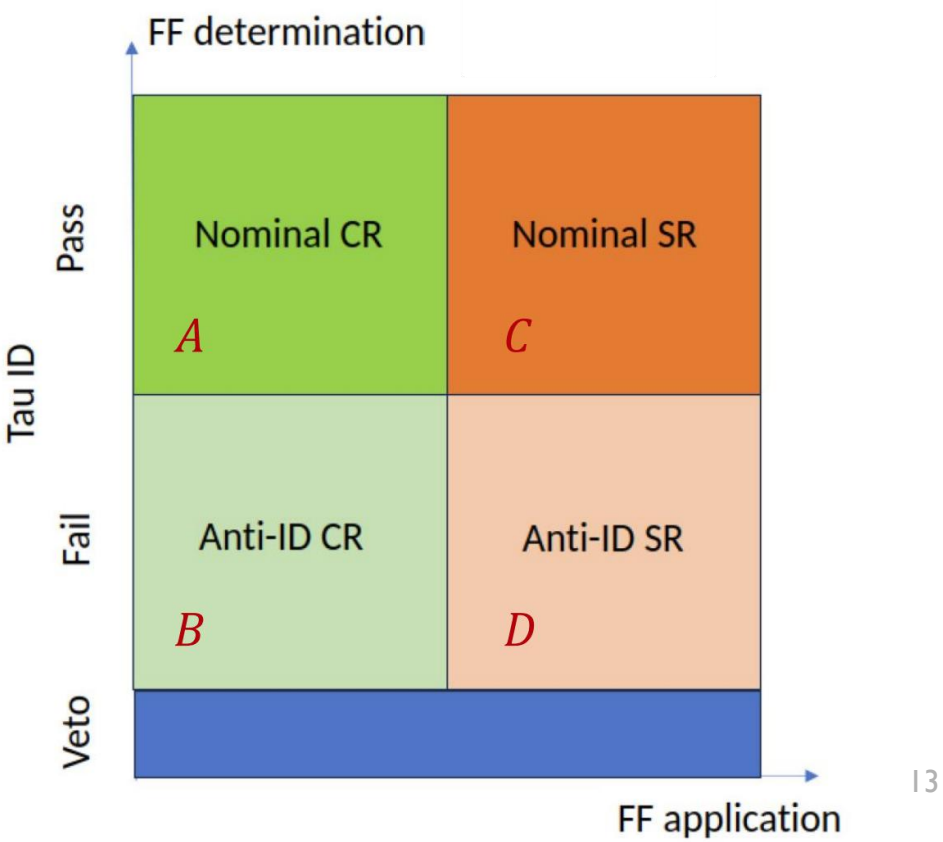
$$C_{pass}^{SR} = D_{fail}^{SR} \times \frac{A_{pass}^{CR}}{B_{fail}^{CR}}$$

Meets the identification criteria

Rejected by identification

Fakes that pass the indentification

extrapolation factor FF



FAKE-FACTOR METHOD

- Idea: Estimate fake leptons in the signal region (SR) by extrapolating from anti-ID leptons
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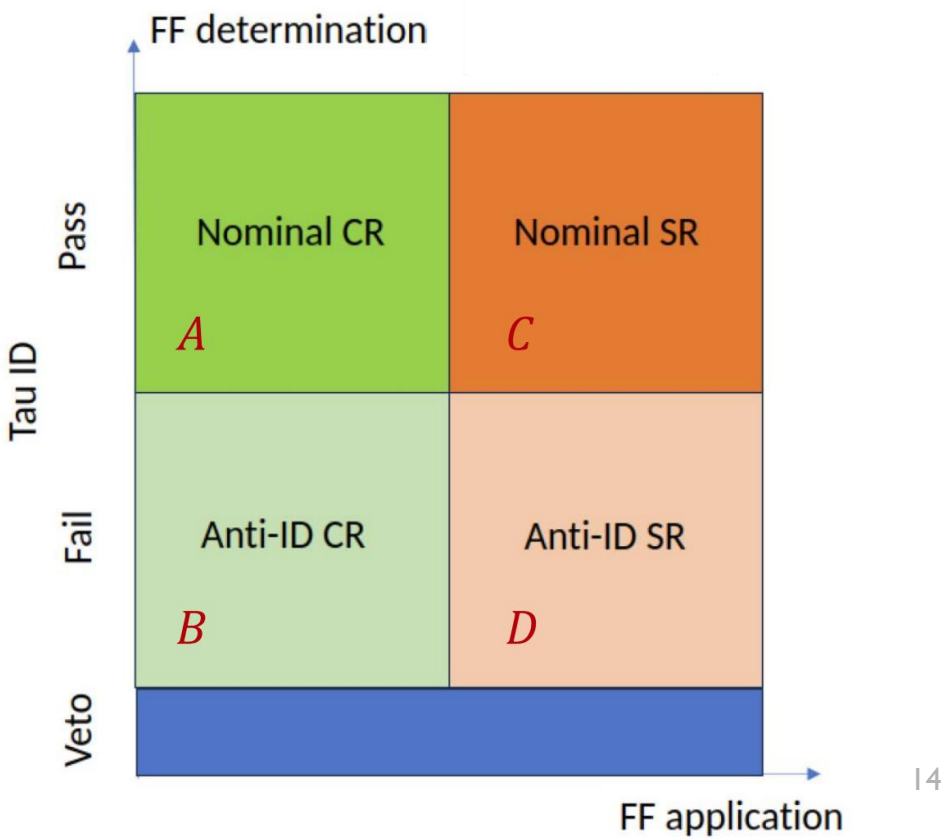
$$C_{pass}^{SR} = D_{fail}^{SR} \times \frac{A_{pass}^{CR}}{B_{fail}^{CR}}$$

Meets the identification criteria

Rjected by identification

- There can be one or several control regions (CR) where FFs are measured. For one CR, one must ensure that the fake τ composition is close to the one in the SR. Otherwise, one should measure FFs in several CRs that have different fake τ compositions and then combine them
- 2 CRs- multi-jet CR & W+jets CR

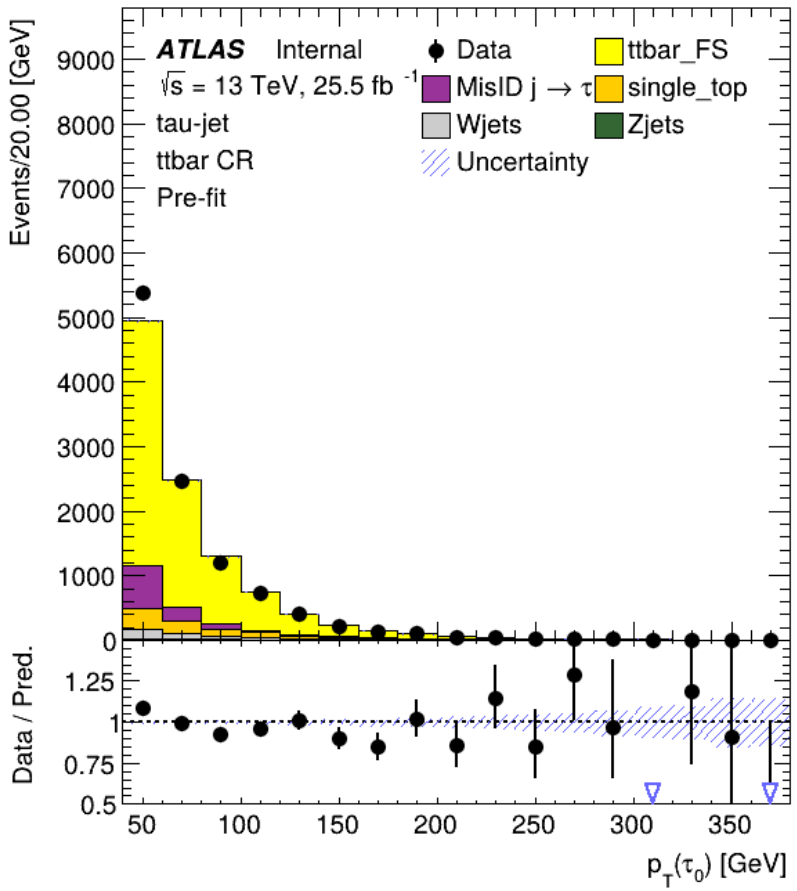


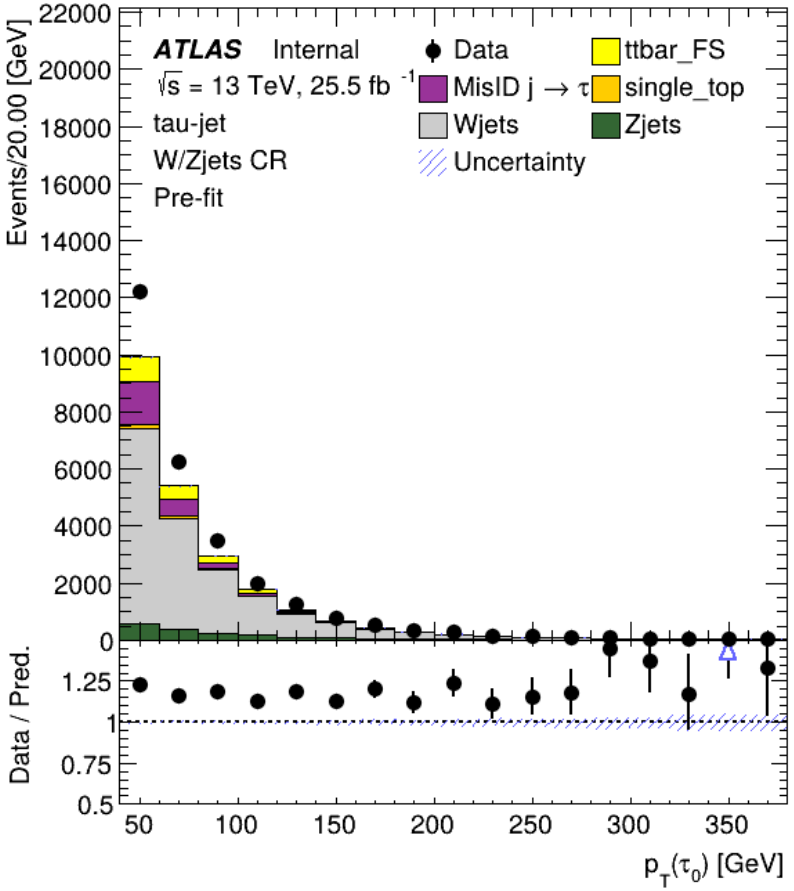
BACKGROUND MODELLING

- Besides CRs for the FF method, there are also CRs used to validate data/background agreement
- We apply the FFs to those CRs
- We have data and MC produced for 2023 for data taken from the ATLAS detector
- My job - implement code for CRs used in our analyses, and estimate background from jets misidentified as τ

BACKGROUND MODELLING

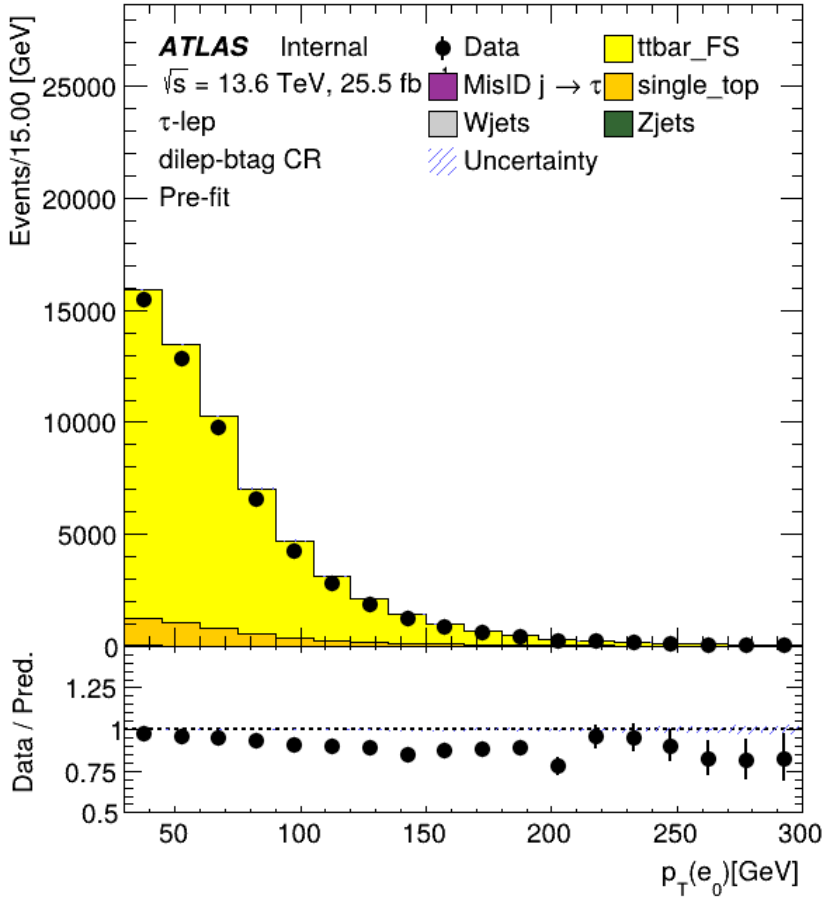
- τ + jets channel CRs - probe the modelling of the $t\bar{t}$ background, in a multi-jet environment

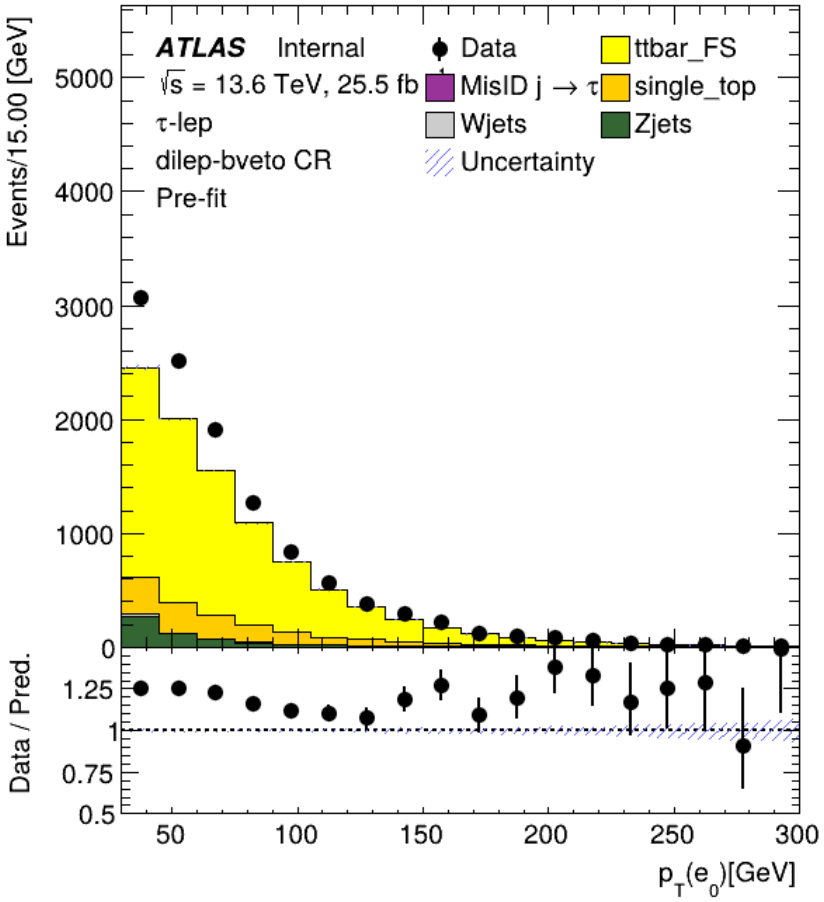




BACKGROUND MODELLING

- Dilepton background

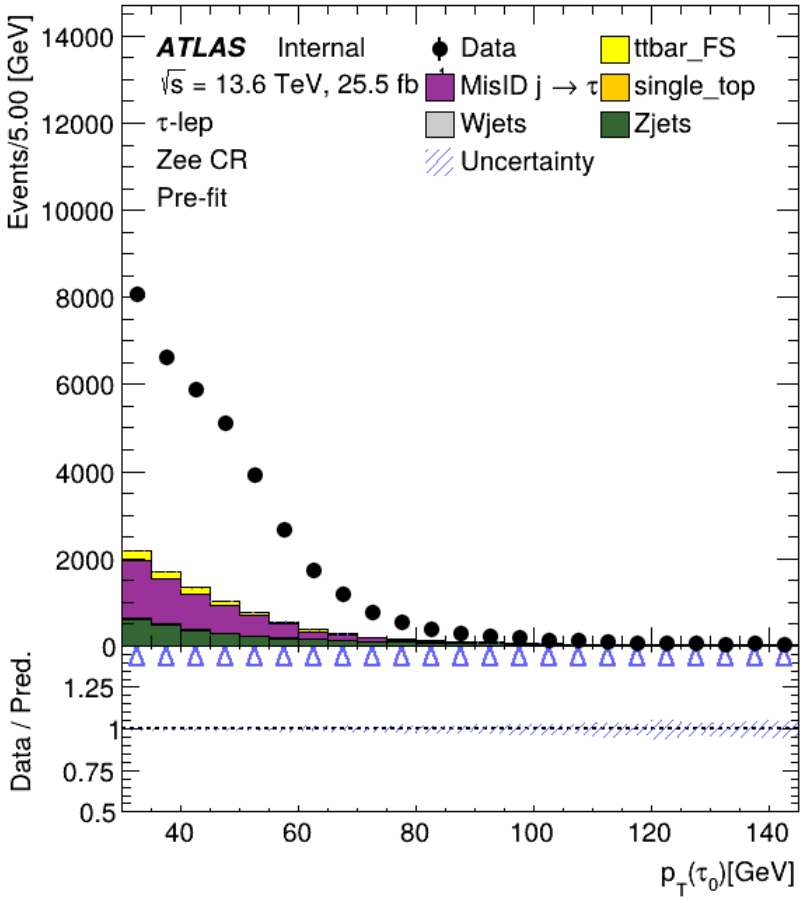




BACKGROUND MODELLING

- τ + lepton channel
  - Electrons faking τ_{had} candidates are not guaranteed to be well modelled in simulation
  - Dedicated CR enriched in $Z \rightarrow ee$ events

⟶ It is necessary to improve the FFs estimation



SUMMARY

- The Standard Model is not the ultimate theory of matter and forces in the Universe
- Charged Higgs bosons are predicted in several extensions of the Standard Model
- Minimal Supersymmetric Standard Model is one of the theoretical physics models extending the Standard Model
  - extensively studied by the ATLAS
- Fake factor method is the used to calculate correct estimation of the background coming from hadron jets misidentified as τ_{had}
- Background Modelling – work in progress

BIBLIOGRAPHY

- ATLAS Collaboration. Search for charged Higgs bosons produced in top-quark decays or in association with top quarks and decaying via $H^{\pm} \rightarrow \boldsymbol{\tau}^{\pm}\nu_{\boldsymbol{\tau}}$ in 13 TeV pp collisions with the ATLAS detector . In: Phys. Rev. D 111 (7 2025), p. 072006.