Analysis of "Non-Prompt" Backgrounds in Lepton Events at the Large Hadron Collider

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Introduction

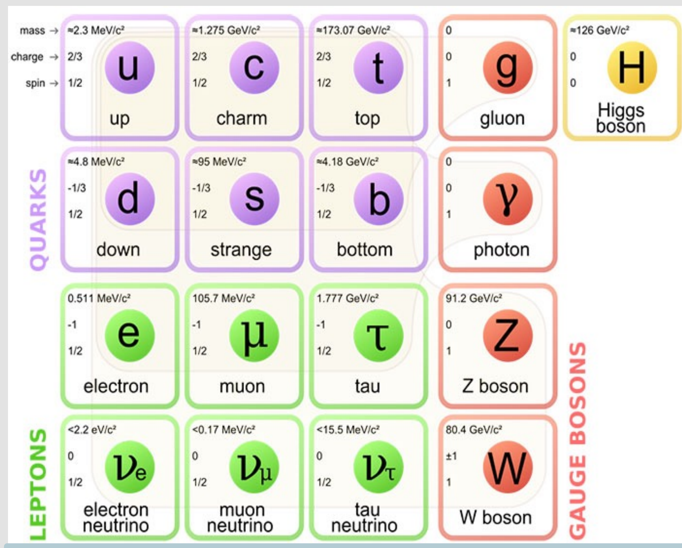

Figure 1: The Standard Model. Divides fundamental particles into quarks, leptons, and bosons.

The **Standard Model (SM)** attempts to describe all elementary particles and their interactions.

Though repeatedly tested and validated, problems such as the mystery of dark matter imply the existence of physics **Beyond the Standard Model (BSM).**

The Large Hadron Collider (LHC) and the ATLAS experiment at CERN in Geneva, Switzerland aim to produce and observe theorized BSM and SM particles.

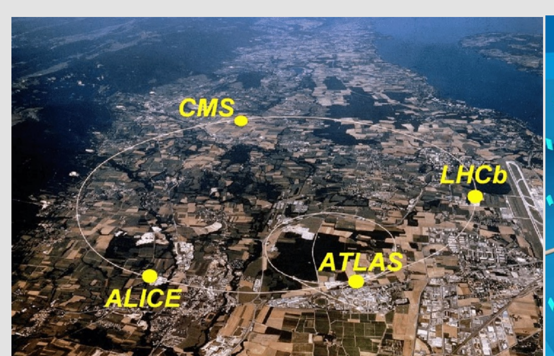

Figure 2: The Large Hadron Collider, with surrounding experiments

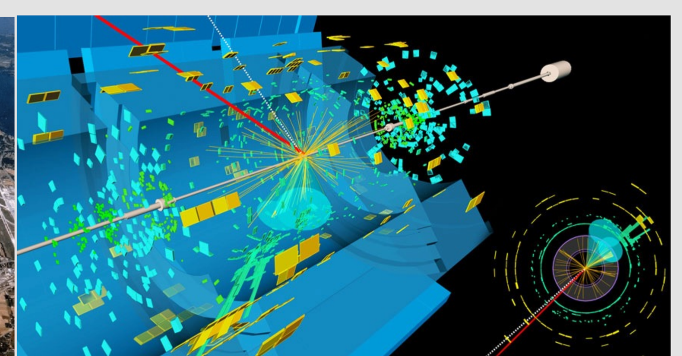
Figure 3: A visualization of a reconstructed proton-proton collision in ATLAS.

LHC: accelerates and collides protons at nearly the speed of light
ATLAS: surrounds the collision point to detect resulting particles and **reconstruct** particle trajectories

Challenges
1. Likelihood of producing a particle of interest is extremely small
2. Short-lived particles decay before reaching the detector

Therefore, we require a high collision frequency and a precise understanding of particle decays, resulting in an ever-growing dataset and a complex reconstruction process.

Leptons as Probes for New Physics

Events with leptons, i.e., electrons and muons, are
- probes of SM processes, such as Higgs boson decays
- sensitive to BSM theories, such as Supersymmetry
- allow for a clean separation between processes of interest and background

Prompt leptons are produced by some process of interest (Figure 4).

Non-prompt leptons are produced by other processes, such as secondary decays of remaining proton fragments or mis-reconstructions.

Goal: suppress non-prompt as much as possible and estimate remaining non-prompt so we can subtract it from data.

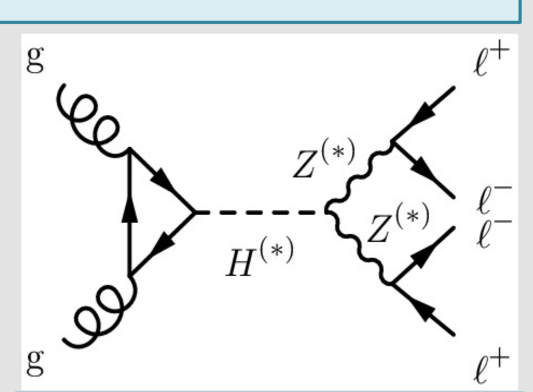

Figure 4: An example of a process of interest. A Higgs boson (H) decays to four leptons (ℓ) that are detected by ATLAS.

Event Backgrounds and Goals

The **suppression criteria** are designed to detect and reject non-prompt leptons based on surrounding activity and path origin (Figures 5, 6).

However, non-prompt leptons have a non-negligible **"survival rate"**, or the ratio of non-prompts that pass suppression criteria. These events must be subtracted from data.

Since backgrounds tend to include rare detector effects, they are evaluated through **data driven fake factor** analysis.

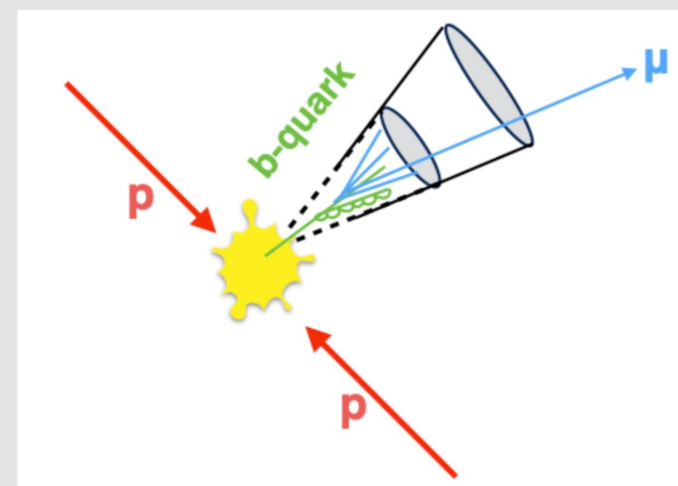

Figure 5: An example of a non-prompt lepton μ that fails the suppression criteria.

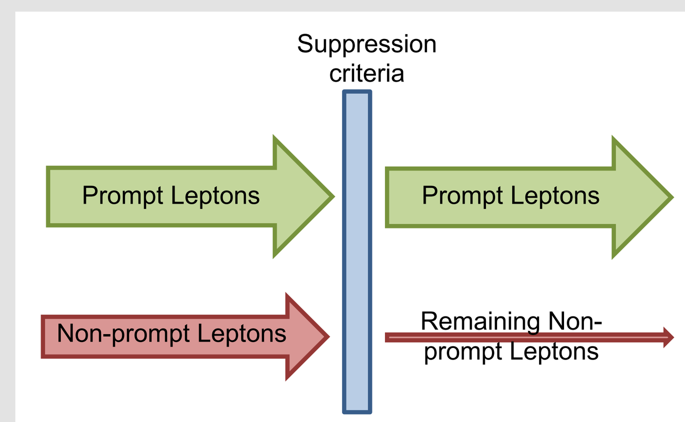

Figure 6: Nearly all prompt leptons pass suppression criteria, while a tiny fraction of non-prompt leptons do. This fraction is the fake factor (survival rate).

Project Goal: study non-prompt leptons backgrounds using real collision data to improve the fake factor method

Methodology

(1) Select samples pure in non-prompt leptons.

Prompt leptons falsify the survival rate measurement, so the aim is to reduce prompt lepton sources as much as possible. This is done by enriching processes yielding non-prompt leptons and removing processes yielding prompt leptons.

⇩

(2) Measure non-prompt lepton survival rate.

By applying suppression criteria to the sample of almost all non-prompt leptons, the survival rate and fake factor can be estimated. These measurements can then be used to subtract residual non-prompt sources from collision data.

Tools:
- Programming packages (i.e., ROOT) for constructing data visualizations, particularly histograms and ratio plots of lepton kinematic properties.
- Grid computing for event reconstruction and preselection.
- Samples were constructed using selection **cuts**, or certain thresholds a particle much achieve to be included in the selection.
- The **Monte Carlo (MC)** statistical simulations predict data from specified processes based on theoretical models. They are used to infer the composition of processes that contribute to collision data though data-MC comparisons.

Results

The following plots focus on the **top quark pairs (ttbar)** region of analyzed data, where two leptons are prompt and other **additional leptons** are non-prompt. Each plot represents a specified selection of ttbar events.

- Solid colors represent MC simulated processes, stacked so that together they represent the total SM prediction from simulation.
- Black points represent collision data from the LHC.
- Top panels are histograms, and bottom panels are ratio plots of data and simulation components over the total SM prediction.

A second process (Z boson production) was used to probe another collision environment, yielding similar results (not shown here).

Idea: The ttbar events (in green) are expected to be non-prompt while other events are prompt. The aim is to eliminate prompt components using cuts on kinematic variables.

Application of suppression criteria

Purification from prompt leptons

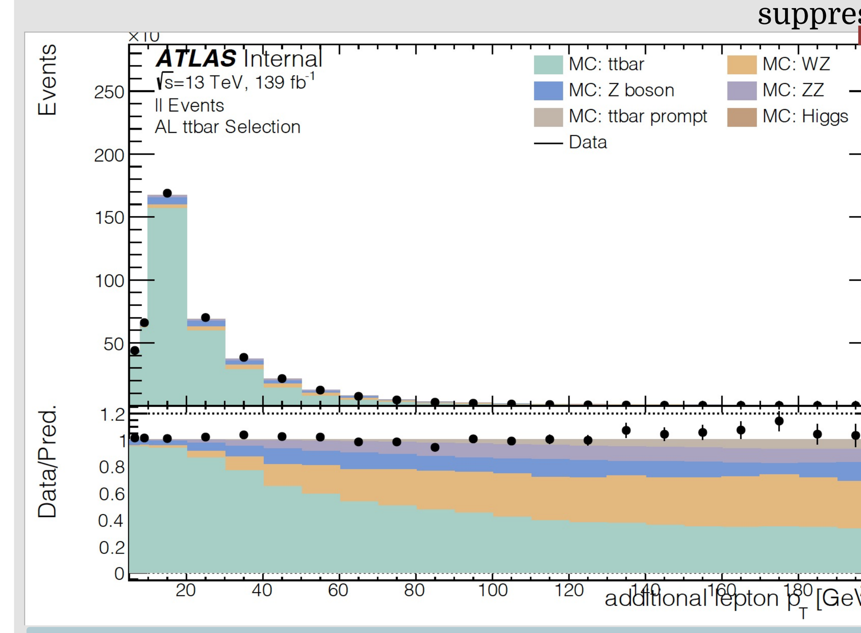

Figure 7: Energy of additional leptons from the ttbar event region.

Inferring composition from MC predictions, the sample consists of data mainly from ttbar events with some contamination from other events.

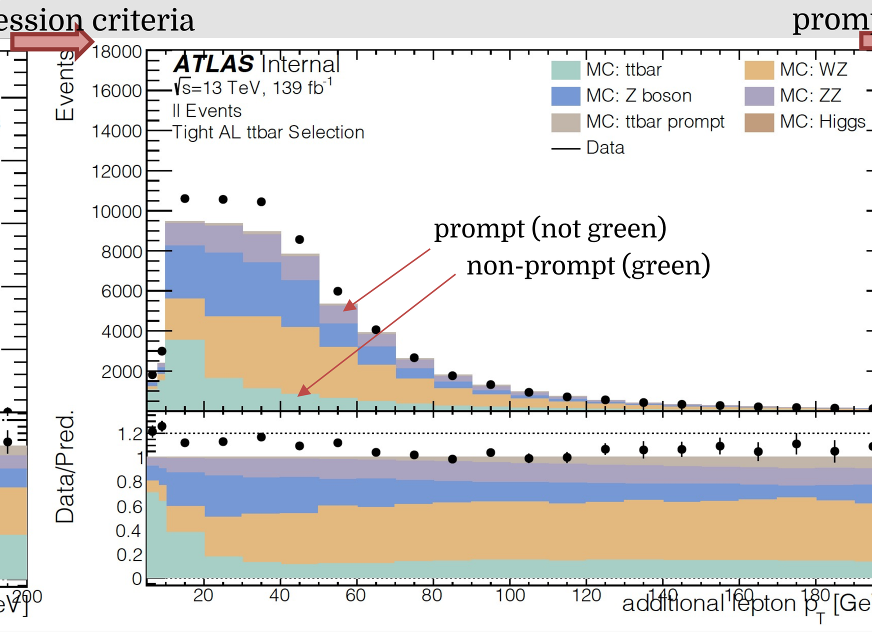

Figure 8: Energy of ttbar event region passing suppression criteria.

Most non-prompt leptons have been eliminated, but a large fraction of prompt leptons remain. These falsify the measurement of survival rate.

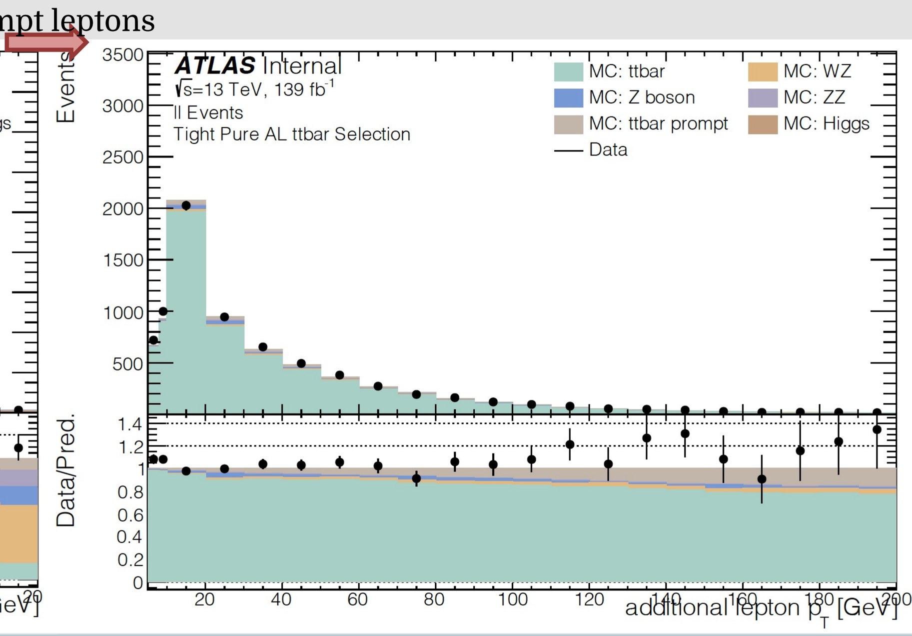

Figure 9: Energy of ttbar event region satisfying suppression criteria and purity cuts.

After applying cuts to purify the selection, nearly all prompt lepton sources have been eliminated and collision data closely matches MC. This selection primarily consists of non-prompt leptons passing suppression criteria and can be used to evaluate survival rate.

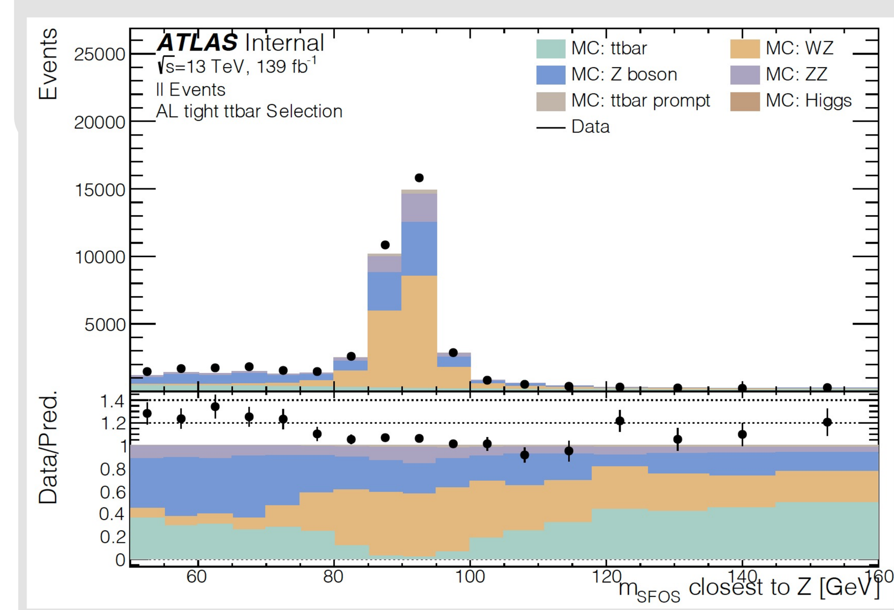

Figure 10: A version of reconstructed mass from the ttbar event region.

This is an example of how a region is purified – most events with prompt leptons are clustered in the same area, so events between 80 and 100 GeV were excluded.

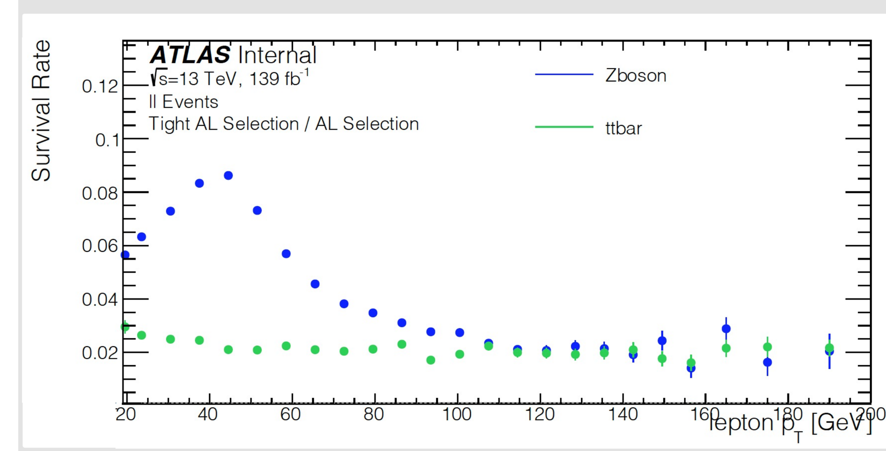

Figure 11: Estimate of survival rate for various particle energies, using the purified region.

The uniform distribution in ttbar events suggests sufficient elimination of prompt sources. The Z boson region does not reflect this and requires further study.

Conclusion

Selections for ttbar and Z boson events have been identified. While the ttbar region has been satisfactorily purified, the Z boson sample has yet to achieve the same degree of purity and requires future studies.

The study will continue the process of evaluating survival rate and fake efficiency with the introduced purity cuts.

Purity cuts are being applied to related selections to continue lepton background analysis and refine the non-prompt lepton region.

Acknowledgements

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