Foundation of b-Tagging applied to Long-lived particles

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Linkedin

Objectives

B-jets

- **B-jets** are streams of particles that **originate from b-quarks**.
- **B-jets** are one of the easiest to detect because of the quark's **long lifetime(~1.3ps)**, in addition, **the b-quark is the second most massive quark (under top , 4.18 GeV/c^2)** meaning massive particles such as the **Higgs can be detected via the decay into b-anti-b-quark pairs.**
- In fact, b-quarks are some of the most abundant decay products of a Higgs in the golden state for these reasons.

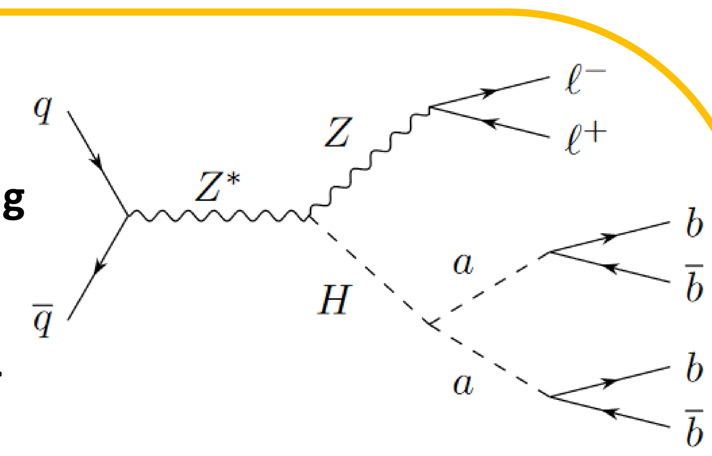

Figure 1: Feynman Diagram of long-lived particle production

Long Lived Particles

- **Detecting pairs of b-jets originating far away from the primary vertex may help search for long lived Particle**s through processes similar to Figure 1.
- **The long-lived particles** we are looking **for can't be directly detected** but are **Higgs-like** (a from figure-1).

*Long lived particles usually are denoted as particles that may be directly detected in the inner detector. LLP may live 1.5ps or travel 450 micrometers.

- **These particles appear in certain models beyond the standard model and if confirmed may fix the hierarchy problem in the known standard model, leading to confirmation of Super symmetry and more.**

Samples

- **tt-bar** is a sample of **simulated top-anti-top quark pairs** that **decays into a b-quark** and a W boson.
- tt-bar pairs are **abundantly produced** at the LHC which makes it **great for calibrating b-tagging algorithms.** Eventually, the goal is to apply the same calibrations to ZH (LLP) events.
- **The goal of this study** is to find a way to **extrapolate the b-tagging performance found on tt-bar to ZH events**, taking in account the different properties.

The Experiment

The Large Hadron Collider

- **Protons** are **accelerated** in **the Large Hadron Collider** by superconducting electromagnets.
- Protons reach a net energy of **6.5 Tev per beam**.
- The Collisions are then approximated to be head on creating **a collision of mass energy 13Tev.**

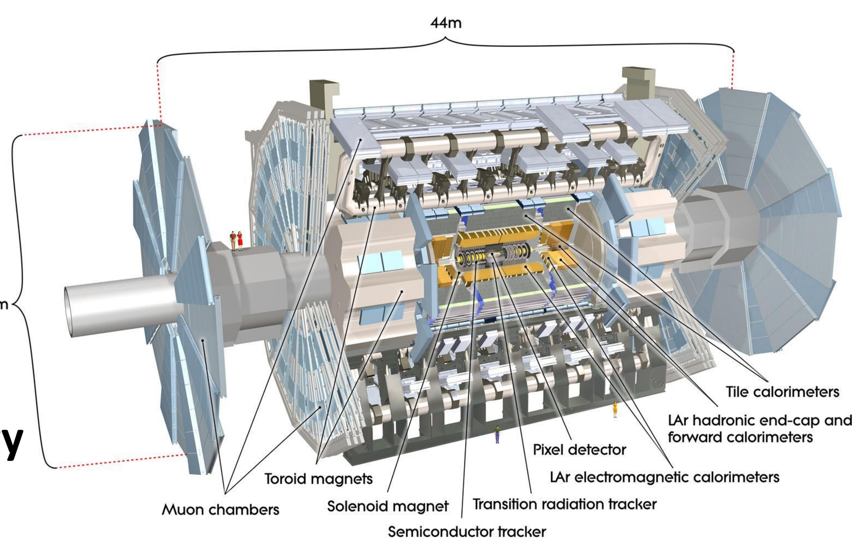

Figure 2: Atlas detector

The ATLAS Detector

- **The inner detectors** (pixel detector, Semi-Conductor Tracker, and Transition Radiation tracker) **trace the charged particles** and **measure their momentum.**
- The **Electromagnetic calorimeter** absorbs and measures **the energy of electrons and photons.**
- **Hadron calorimeter** absorbs and measures the energy of **particles that interact via strong force.**
- **Muon spectrometer** measures **momenta muons.**

Monte Carlo

- **Monte Carlo** is a simulation that **models the probability of different outcomes** built from real physics inputs of a given theory.
- Monte Carlo simulations can **help explain different models** that have yet to be experimented, as well as being used **to accurately measure data** and construct likelihood ratio functions.

Production

- During the Hard collision, **Quantum Chromodynamics** takes place allowing **quarks to interact creating new particles** through a process called hadronization.
- **Hadronization radiates particle jets** that are made of smaller **particles that originate from the primary vertex. (Figure 4)**

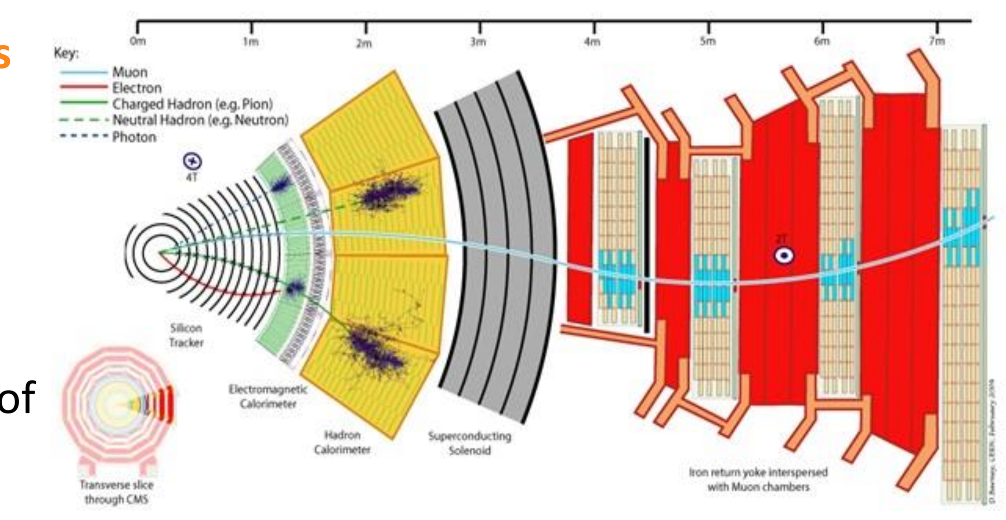

Figure 3: Atlas Detector layers in depth

Algorithms

High Level algorithms

- **MV2c10** (**multivariate, 7% c-jets background**) takes in values from low level algorithms and is a **boosted decision tree algorithm** that makes better selections.
- **DL1** (**(Deep Learning Neural network**) is trained with Kera/TensorFlow and provides a **multidimensional output for corresponding probabilities for each jet flavor** (b-jet, c-jet, and light) that is then used in a log likelihood-function for final selections

Low Level algorithms

- **IP3D** (**Impact Parameter**) uses transverse (D_0) and longitudinal impact parameters (Z_0) with **a probability density function to associate with b-jets, c-jets, and light-flavor jets**. Log-Likelihood ratio functions are then used to acquire the number of b-jets.
- **SV1** (**secondary vertex tagging**) – **Reconstructs a single displaced secondary vertex**, by identifying possible two-track vertices and rejecting other tracks.

***Efficiency of identifying b-jets reduces closer to the origin because the b-jets become very similar to lights jets. (0-10mm figure 5)**

***When using the algorithms efficiency increases with the number of statistics/events because of training and better selections (figure 5)**

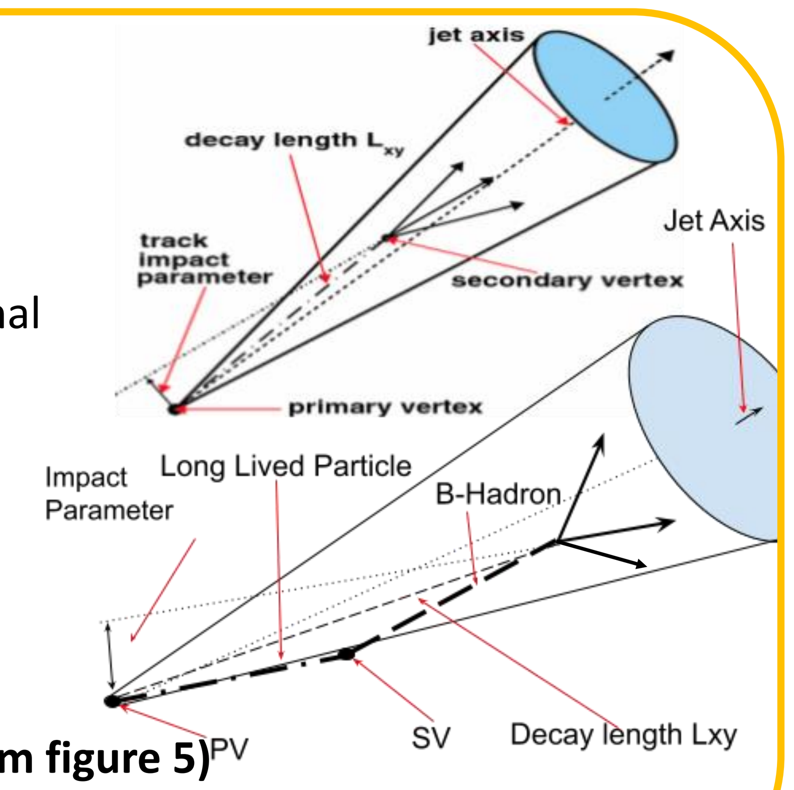

Figure 4: IP Description, top-tt, bottom-ZH

Analysis

- **B-tagging Efficiency** – The probability of b-jets being tagged.
- **Mistag** is when an algorithm tags something else as a b-jet.
- **Reweighting** data refers to manipulating data to resemble a desired population for analysis. In this case, **reweighting kinematics(eta and pt) of tt-bar sample to resemble ZH**. (Shown **in Figure 7** reweighting was done to make b-tagging performance closer)
- **Applying cuts** is excluding certain values that may contribute to lower efficiencies.
- **Shown in Figure 8** is the b-tagging efficiency from the b-jets in the ZH sample **after applying an upper cut on the impact parameter** of the B-hadron (IP figure 4). The b-tagging efficiency for the zh events, due to the selected **B-hadrons being collinear with the long-lived particles,** is close to the ttbar events.

Plots

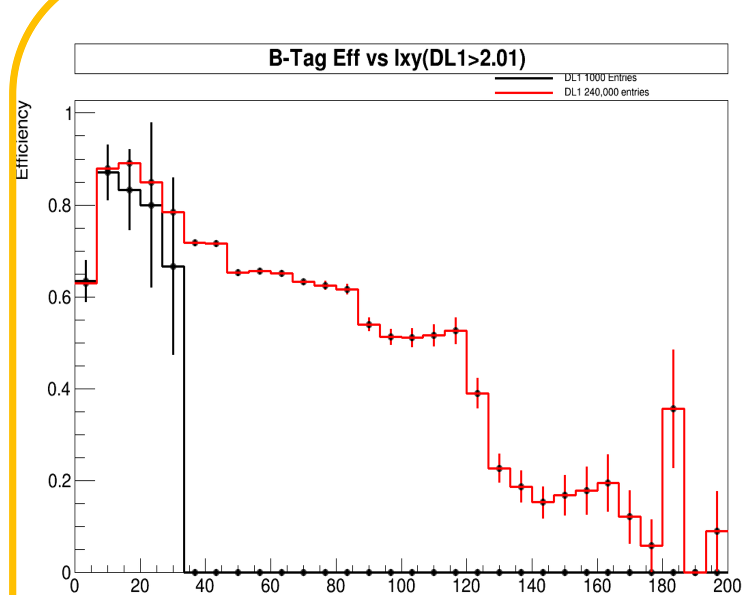

Figure 5: Difference in efficiency with statistics

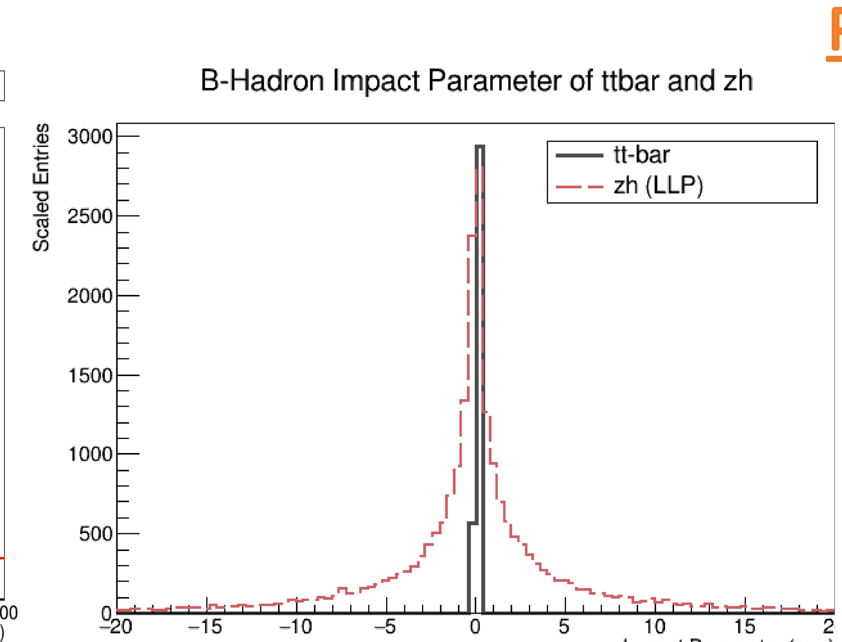

Figure 6: Impact parameter tt vs. zh

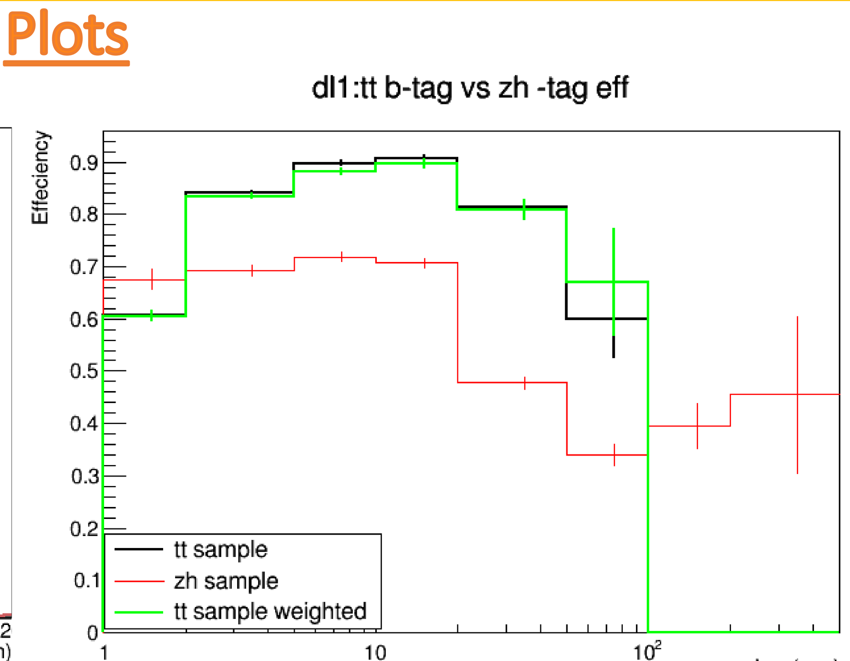

Figure 7: Reweighing of samples

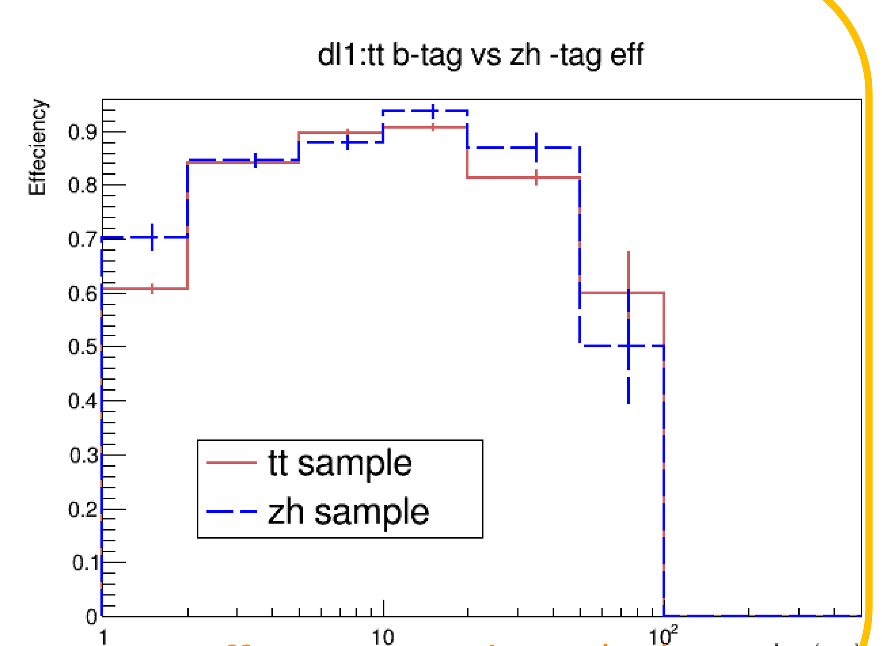

Figure 8: Efficiencies with cut |IP|<.2mm

Conclusion

- Current algorithms are **not optimized for tagging b-jets from Long Lived Particle decays.**
- The b-tagging algorithms **expect the b-quarks to originate from the beam interaction point**, however, **ZH samples originate** farther from the beam interaction point. (**figure 6**)
- Due to this big difference in Impact Parameter the reweighting of kinematics was not efficient shown in figure 7..

Future work

- **More events** need to be acquired for better studying and efficiencies.
- **Modify the algorithms** to improve performance for b-jets originating away from the beam interaction point.
- **Extrapolate b-tagging uncertainties** derived on ttbar events to the LLP search.

References

[1] "ATLAS b-jet identification performance and efficiency measurement with ttbar events in pp collisions at sqrt(s)=13TeV," G.Aad et al. [ATLAS Collaboration], Eur. Phys. J. C 79, 970(2019). https://doi.org/10.1140/epjc/s10052-019-7450-8

[2] "Search for exotic decays of the Higgs boson into long-lived particles in pp collisions at sqrt(s)=13TeV using displaced vertices in the ATLAS inner detector, "G. Aad et al. [ATLAS Collaboration], arXiv:2107.06092.

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