SEARCH FOR THE FLAVOR-CHANGING NEUTRAL CURRENT IN TOP PAIR EVENTS WITH AN ASSOCIATED PHOTON USING 13 TEV PROTON-PROTON COLLISION DATA COLLECTED WITH THE ATLAS DETECTOR

by

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DISSERTATION ABSTRACT

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Abstract for FCNC here.

This dissertation includes previously published and unpublished co-authored material.

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INTRODUCTION

The Standard Model of particle physics has proven itself an exceptional and resilient theory since the combination of the electromagnetic and weak interactions in 1961[1]. Further theoretical work combined the Higgs Mechanism[2, 3] with the electroweak theory[4, 5]. The resiliency of this theoretical model has been tested to further degrees of accuracy over the decades with one of my most recent portions being the experimental confirmation of the Higgs Boson in 2012[6, 7] using the Large Hadron Collider (LHC). Further precision measurements are ongoing at various experiments at the LHC, including the ATLAS experiment.

However, the Standard Model is known to have flaws and disagreements with nature. For example, the Standard Model predicts massless neutrinos which is in conflict with experimental observation of neutrino flavor oscillation and doesn't provide an explanation for dark matter particles or their interactions with currently known particles. While these large gaps in the Standard Model are well known every precision measurement made has yet to give any significant new hints toward physics beyond the Standard Model. One new pathway to look for these hints at the LHC is through top quark decays.

1.1. The Standard Model Top Quark

The top quark was first observed at Fermilab's Tevatron in 1995[8] but the increase in energy and amount of data at the LHC has produced orders of magnitude more top quarks than previously seen opening up a pathway to precision measurements of the properties of the top quark. The top quark is the heaviest fundamental particle with a mass of 172.51 ± 0.27 (stat) ± 0.42 (syst)[9]. This large mass also means that top top quark lifetime is very short ($5 * 10^{-25}$ s) and decays before it can hadronize. This allows us to probe its' branching ratios and decay modes directly. The Standard Model predicts that the top quark decays through the charged current mode nearly 100% of the time; $t \rightarrow qW$ (q = b,s,d)[10]. The Standard Model also predicts a rare branching ratio of the top quark through a flavor changing neutral current (FCNC) process, to a neutral boson (photon, Z boson, Higgs Boson, or gluon) and up type quark with a branching ratio on the order of 10^{-14}.

1.2. Searching for FCNC Top Quark Decays

Precision measurements are an important litmus test for the Standard Model. Predicted branching ratios for FCNC processes in top quark decays are far beyond the experimental reach of the LHC and any observation of these decay modes would be a sure sign of new physics. Branching ratios are an important measurement due to a litany of theories for new physics beyond the Standard Model (BSM). These BSM theories predict enhancements in the top sector by many orders of magnitude such as Minimal Supersymmetric models[11], R-parity-violating Supersymmetic models[12] and two Higgs doublet models[13] can all increase this branching ratio many orders of magnitude. Even a null result to a search will set an upper limit on the branching ratio that can assist in ruling out future physical models based on their amount of large top sector enrichment.

This dissertation presents a search for top FCNCs using the entire Run 2 dataset at the LHC, containing combined 2015-2018 datasets taken by the ATLAS experiment totaling 139 fb^{-1} of integrated luminosity taken at $\sqrt{s}$= 13 TeV. The analysis presented looks for an excess of events coming from top quark pair produced events where one top quark decays to the most likely decay mode (a bottom quark and W boson) and the other to an up type quark (up or charm) and a photon. Chapter II a theoretical background will be presented for both the Standard Model with a closer view on the usual extensions to include the FCNC vertices. Following this Chapter III will discuss the LHC and the ATLAS experiment used in the creation of the dataset used in the analysis. In Chapter IV the special signal simulation requirements will be presented as well as the common background event simulation methodology. The search strategy including the creation of signal, control and validation regions and the training of a neural network will be examined in Chapter V. Chapter VI will discuss the results and the conclusions drawn from these results will be presented in Chapter VII.

CHAPTER II

THEORY

In this chapter a theoretical background will be presented on the Standard Model of particle physics with special attention paid to the top quark's properties and decays. This will include discussion of all of the fundamental particles and their interactions through the fundamental forces of nature: electromagnetism and the strong and weak nuclear forces.

2.1. The Standard Model

2.2. Particle Interactions

CaCa

2.3. The Top Quark

DaFuck is This

CHAPTER III

THE LARGE HADRON COLLIDER AND THE ATLAS DETECTOR

This chapter details the experimental details of the collider complex at the LHC and specifically the ATLAS detector used to produce, collect and measure various particle properties.

3.1. The Large Hadron Collider

Section:LHC

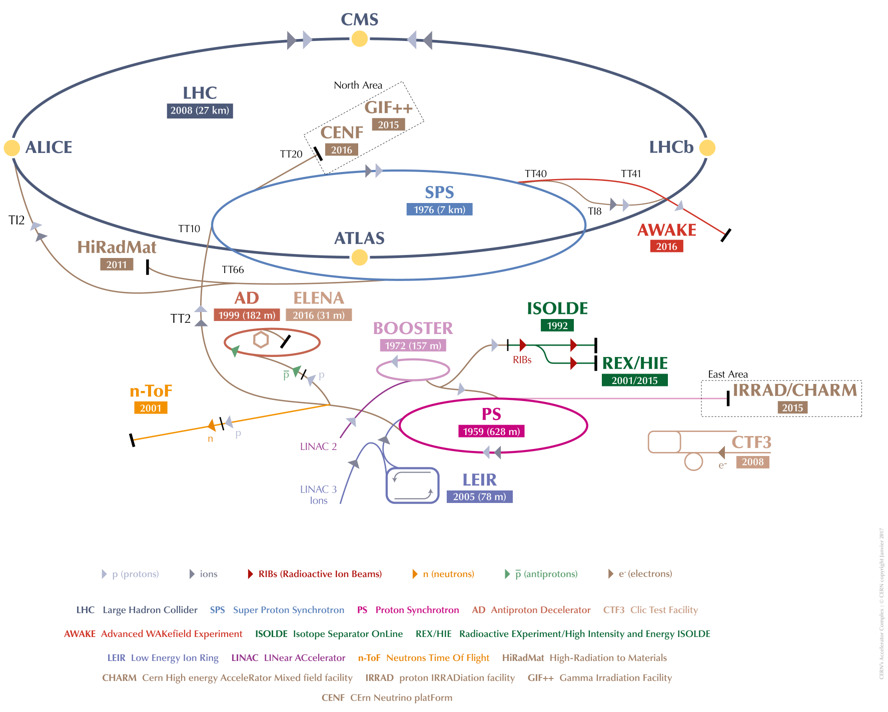

FIGURE 3.1. Schematic of the CERN accelerator complex.[14]

3.2. The ATLAS Detector

Section:ATLAS

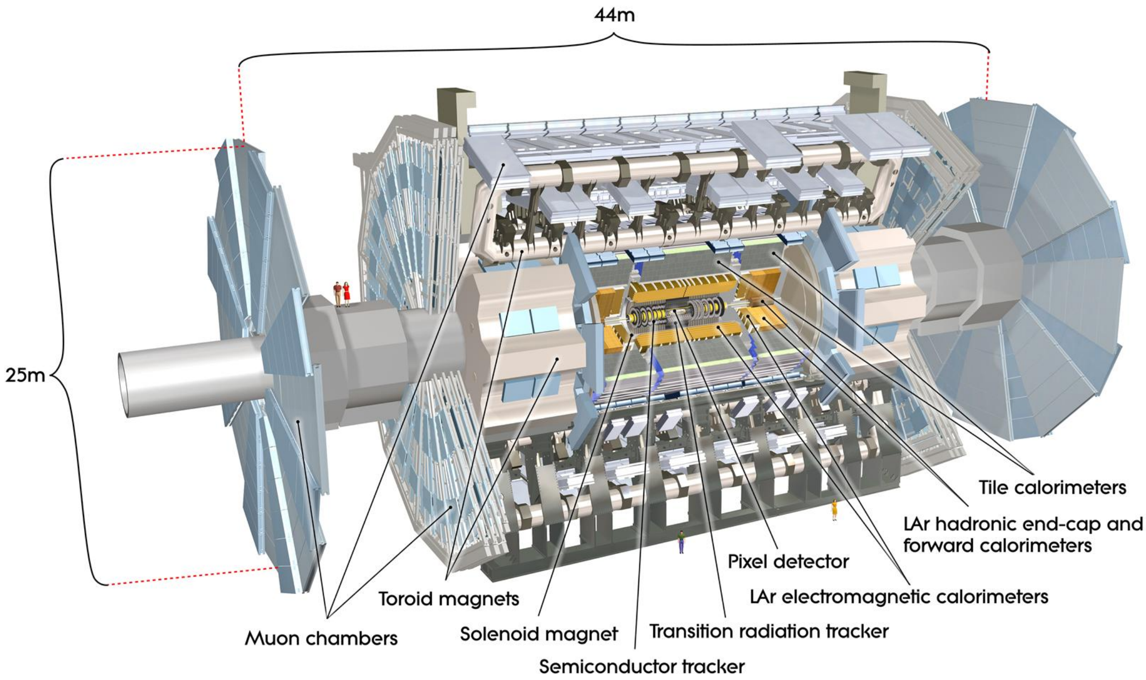

FIGURE 3.2. Schematic of the ATLAS detector.[15]

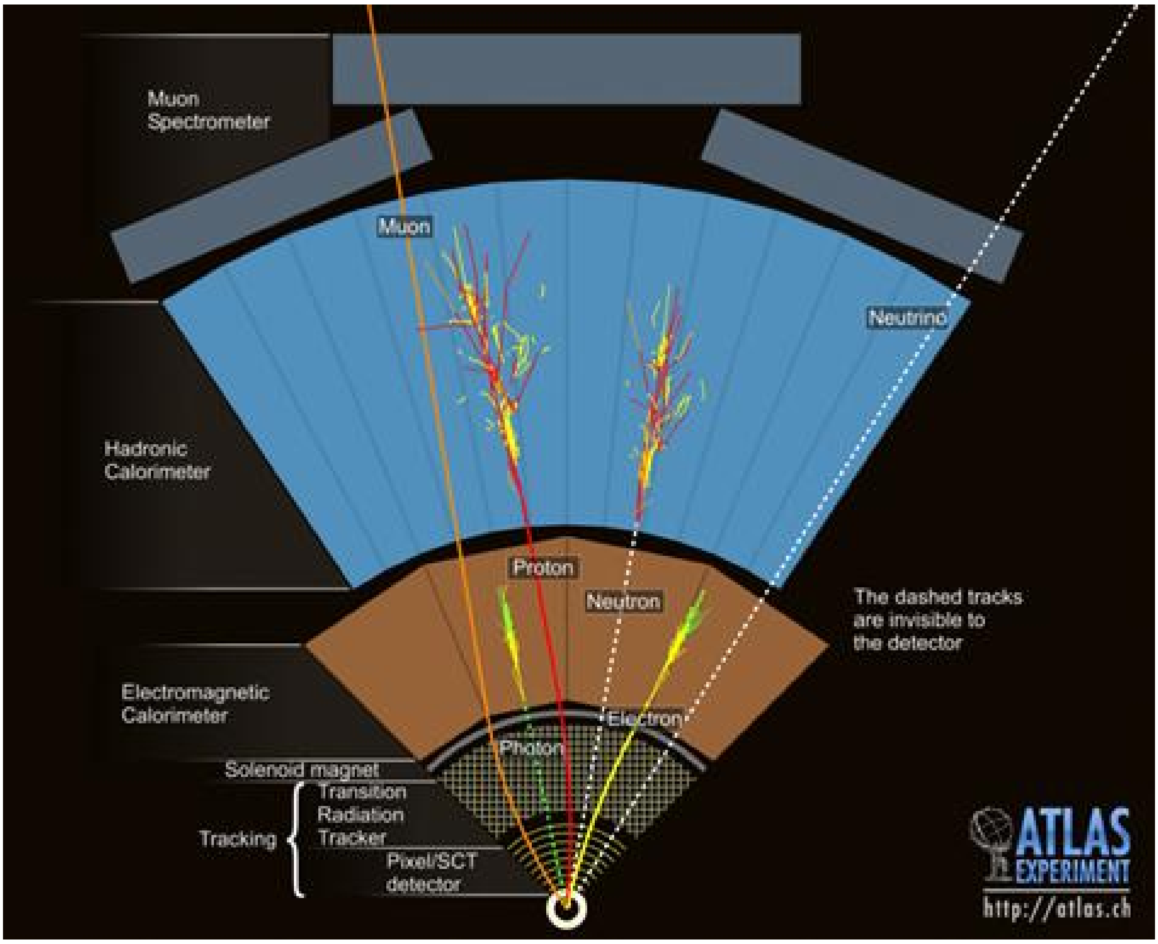

FIGURE 3.3. Cross section of a simulated ATLAS detector showing how various particles interact with ATLAS subsystems.[16]

3.2.1. Coordinate System

Coords

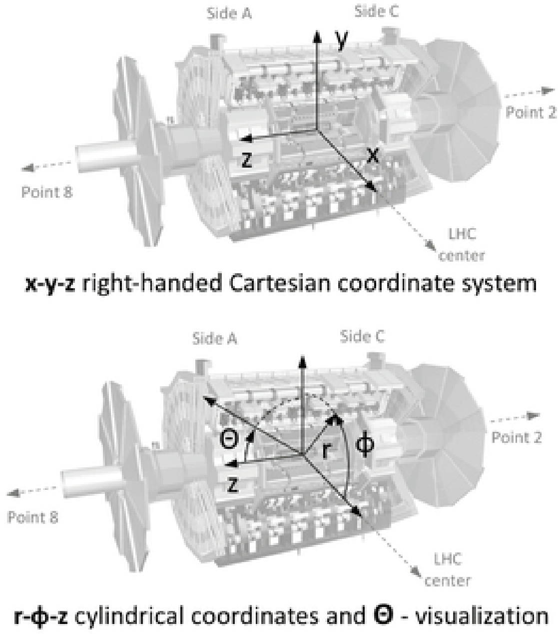

FIGURE 3.4. Coordinate system used in the ATLAS Collaboration.[17]

3.2.2. Magnet Setup

Magnets yay, toroid yay

3.2.3. SubDetectors

3.2.3.1. Inner Detector

Inner

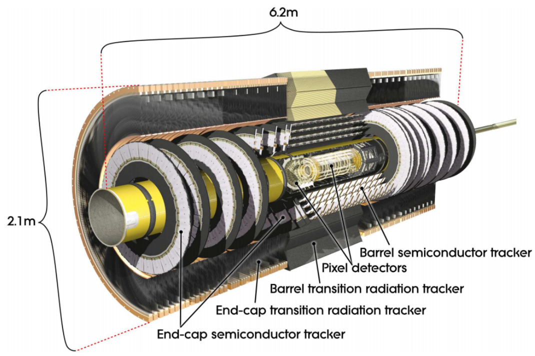

FIGURE 3.5. Schematic of the ATLAS inner detector.[15]

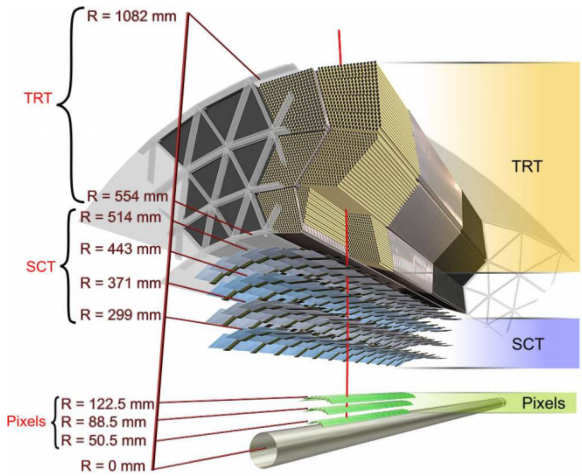

FIGURE 3.6. Schematic of the structure of the ATLAS inner detector.[15]

3.2.3.2. Middle Layers, EMCal, HCal

Middle chunks

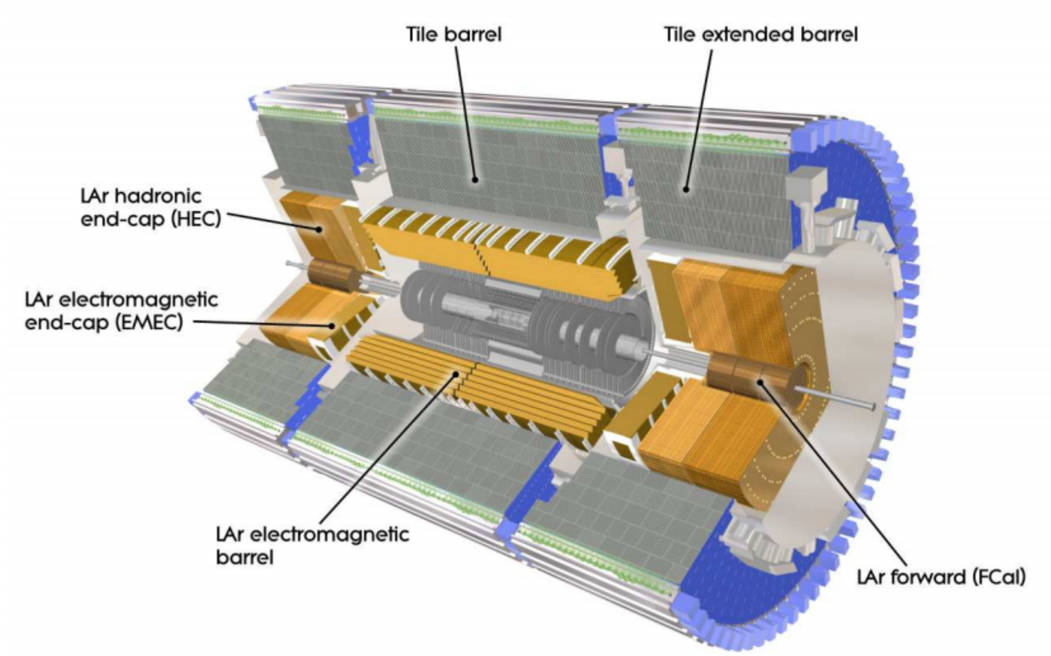

FIGURE 3.7. Schematic of the ATLAS calorimeter system.[15]

3.2.3.3. Muon Calorimeter

Muons have to get picked up I guess

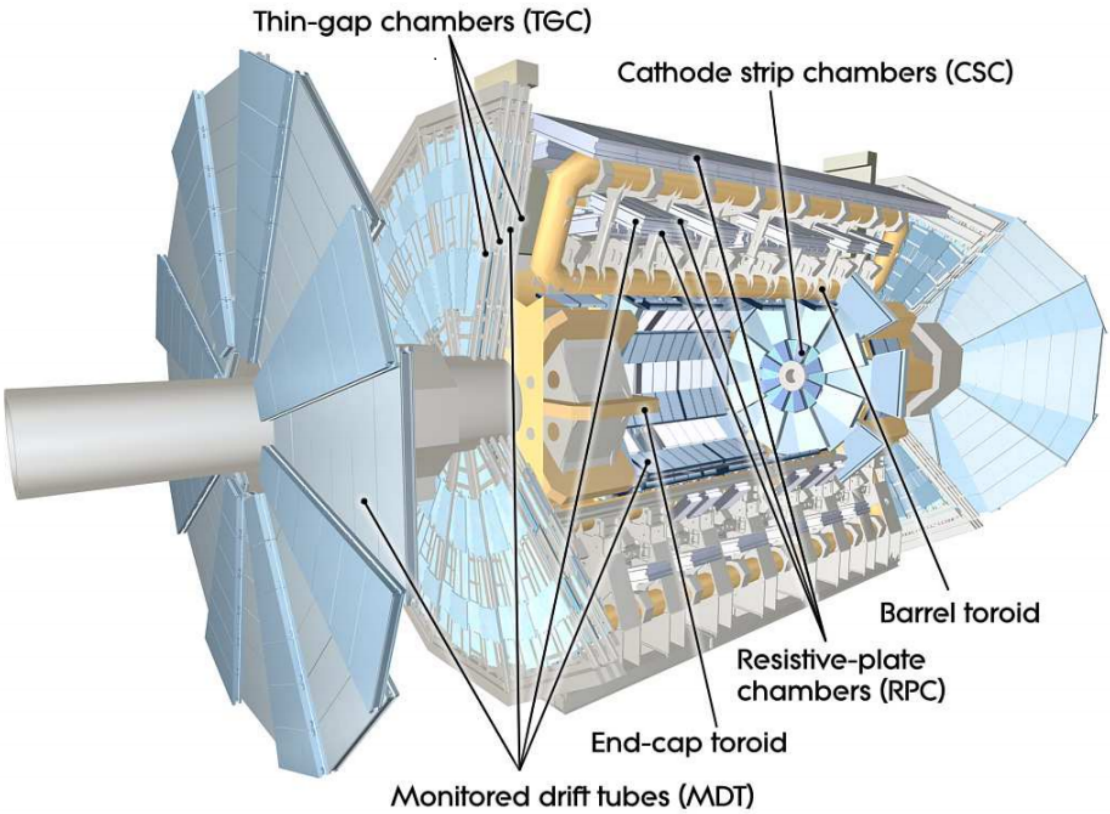

FIGURE 3.8. Schematic of the ATLAS muon detector.[15]

3.2.4. Trigger and Data Acquisition

All of these subsystems lead into actual data farm

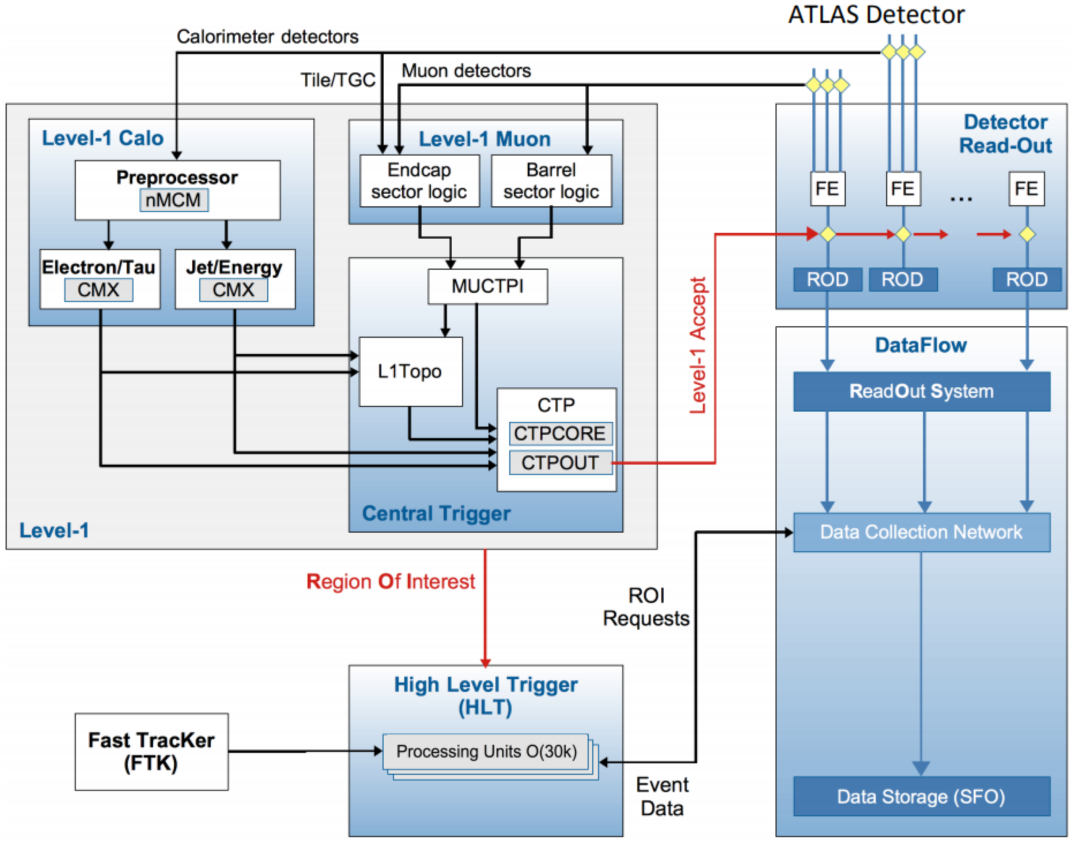

FIGURE 3.9. Layout of the ATLAS trigger and data acquisition system used in Run 2.[18]

3.2.4.1. L1Calo

3.2.4.2. HLT

3.2.4.3. Luminosity Measurements

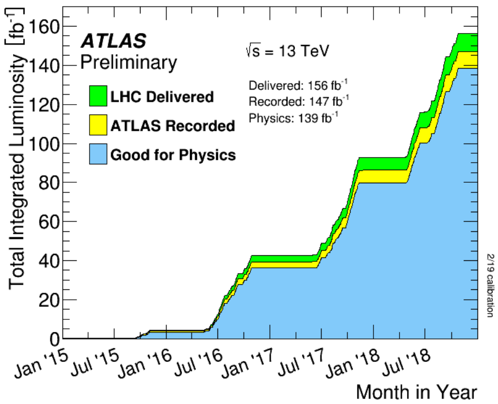

FIGURE 3.10. Total integrated luminosity as a function of time delivered by the LHC(green), recorded (yellow) and declared good for physics analysis (blue) by the ATLAS detector throughout Run 2 consisting entirely of 13 TeV *pp* collisions.

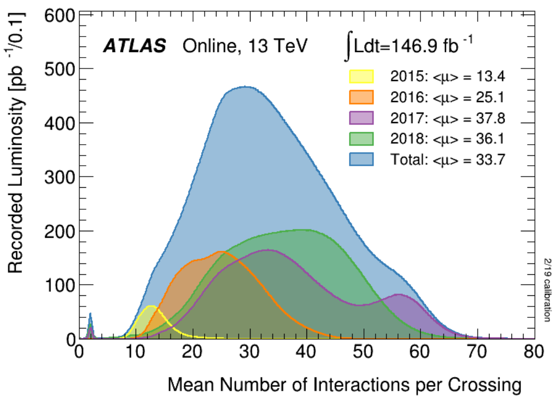

FIGURE 3.11. Luminosity-weighted distribution of the mean number of interactions per bunch crossing for the entirety of Run 2 shown by individual years (2015-2018) as well as an integrated total (blue).

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Comparison of kinematics between standard ttbar events ATLAS Production of these events TopQ1 Slimming/Skimming

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