Jet energy scale and resolution in the High-Granularity Timing Detector in ATLAS upgrades at HL-LHC

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Abstract

The large increase of pileup is one of the main experimental challenges for the High Luminosity-Large Hadron Collider (HL-LHC) physics program. HL-LHC is expected to start in 2027 and to provide an integrated luminosity of 3000fb^{-1} in ten years, a factor 10 more than what will be collected by 2023. A powerful new way to address this challenge is to exploit the time spread of the interactions to distinguish between collisions occurring very close in space but well separated in time. A High-Granularity Timing Detector (HGTD), based on low gain avalanche detector technology, is proposed for the ATLAS Phase-II upgrade. Covering the pseudo rapidity region between 2.4 and 4.0, with a timing resolution of 30 ps for minimum-ionizing particles. The impact of HGTD in reducing pileup track contamination in the jets reconstruction in the forward region is investigated. The improvement of the jet energy scale and resolution in the forward region by reducing the pileup track contamination in hard scatter jets from nearby pileup interactions is presented. The performance is evaluated in terms of jet energy response and resolution as a function of pseudo rapidity η, transverse momentum p_T .

Introduction

The HL-LHC is scheduled to begin in 2027 and will deliver associate degree integrated luminosity of up to 4000 fb^{-1} in concerning 10 years. The instant luminosity ought to reach up to 7.5$10^{34}$cm^{-2} s^{-1}, compared to the present value of 2.10^{34}cm^{-2} s^{-1}. Associate upgrade of the ATLAS detector [1] are required before the beginning of this new phase to deal with the high-radiation environment and therefore the large increase within the number of collisions per bunch crossing.

In the new HL-LHC conditions, pileup will be one of the biggest challenges. For the nominal operating scheme, the interaction region will have a Gaussian spread of 45 mm along beam axis 1 and a pileup of 200 simultaneous proton-proton interactions on average ($<\mu>= 200$), corresponding to an average interaction density of 1.8 collisions/mm, compared to the 0.24 collisions/mm of run 2. Under these conditions, a major challenge is to reject the charged particles generated by the pile-up. The resolution of the longitudinal trajectory impact parameter (Z_0) must be better than the average distance between interaction points (0.6 mm for HL-LHC). The Z_0 resolution is well below this limit in the central region, but becomes very large in the forward region, reaching up to 5 mm for particles with low transverse momentum (p_T). As a result, tracks cannot be associated to the correct vertices in an unambiguous way, leading to reduced performance in terms of heavy flavour tagging, lepton isolation and the identification of jets originating from pileup interactions.

In this context, the High Granularity Time Detector (HGTD) is introduced [2, 3], to augment the new all-silicon Iner Tracker in the forward region. Offering a time resolution of 30 ps in the forward region, this detector will be able to reject stacks from $|\eta|$ = 2.4 up to $|\eta|$ = 4. More generally, this detector will improve the performance of the ATLAS detector in the forward region to a level similar to that of the central region and will provide a powerful tool for luminosity measurements.

Jet Energy Response and Resolution

Pileup is very crucial for the reconstruction and identification of objects at the HL-LHC. In the case of jets, pileup can affect the reconstruction in a different way. One is that particles from a pileup interaction can infect a jet from hard scatter and change its reconstructed energy and modify its reconstructed energy. Pure pileup jets from an interaction other than hard scatter can also be created, due to a QCD process during the pileup interaction, more likely at high p_T, or because of a random combination of particles from different interactions, more likely at low p_T. A key element for the rejection of pileup jets is the association of the jets tracks with the primary vertices. The main variable used to separate the pileup vertices from the hard scatter one is the ratio between the sums of the p_T of all tracks originating from the hard scatter vertex associated with the jet and the p_T of the jet. This variable should be large for the hard scatter jets and low for pileup ones. Unfortunately, in high pileup environment and especially in the forward region it is possible to have pileup vertices that appear to be merged with the hard scatter vertex. In that case the discriminating power of this variable is greatly reduce. The Pileup-Track contamination at the hard scatter jets is illustrated in Figure 1.

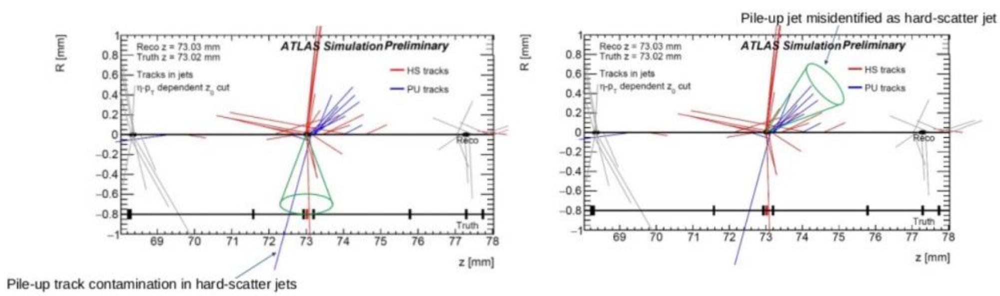

Fig-1: All tracks associated with primary vertices illustrating the PU contamination

This letter presents the jet performance study, which shows a promising results for pileup rejection using HGDT. HGDT is a powerful new tool to address the pileup challenge in the forward region, and can play an important role in many jet and ETmiss HL-LHC studies [3].

References

[1]: ATLAS Collaboration. Technical design report: A high-granularity timing detector for the atlas phase-2 upgrade. Technical report, 2020.
[2]: ATLAS Collaboration. Technical proposal: A high-granularity timing detector for the atlas phase-2 upgrade. Technical report, 2018.
[3]: Georges Aad, et al. Search for supersymmetry at root $\sqrt{s} = 13$ TeV in final states with jets and two same-sign leptons or three leptons with the atlas detector.