Using FTK tracks for particle flow reconstruction at the high-level trigger of ATLAS

CERN Summer Student Report

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Abstract

The Fast TracKer (FTK) enables the ATLAS high-level trigger (HLT) to have early access to global tracking information. The project of my Summer Student Internship at CERN was to investigate the potential of using particle flow reconstruction with FTK tracks at the ATLAS HLT. This report shortly summarizes my studies, ranging from comparison of FTK tracks with offline tracks to more sophisticated analyses, such as assessing the jet resolution and trigger related properties.

1 Introduction

This report is intended to give an overview of my contributions to the project I was working on, during my Summer Student Internship at CERN. I worked together with a group of the University of Geneva involved in the ATLAS experiment. My studies were complementary to those of another summer student, Barbara Skrzypek. A more detailed review of the work we did, can be found in the ATLAS internal document [1].
The reader is expected to have general knowledge about the ATLAS experiment as well as the physics happening at hadron colliders.

2 Particle flow and the FTK

Particle flow is a hadronic reconstruction algorithm that combines information from the inner detector and the calorimeter. Its central function is to match tracks to energy clusters in the calorimeter and produce so called charged particle flow objects. The energy from the charged particles is subtracted from the calorimeter leaving only (ideally) the energy deposited by neutral particles. Jet reconstruction is subsequently performed with the remaining energy depositions - so called neutral particle flow objects - and selected charged particle flow objects. The main advantage of using particle flow is the effective mitigation of pile-up effects, as well as improvements in momentum and angular resolution. More information on the particle flow algorithm can be found in ref. [2].

The FTK is a hardware system that provides the HLT of ATLAS with high-quality tracks at level-1 rates. It uses the information of the pixel and semiconductor trackers and is planned to be installed in the ATLAS detector during 2016/2017. More information on the FTK can be found in ref. [3].

CPU-timing constraints do not allow fullscan[1] tracking at high rate, making it impossible to run the full offline particle flow algorithm at the HLT. Enabling the HLT to have early access to global tracking information rises the opportunity to use a modified particle flow reconstruction at trigger level. The track extrapolation - where the tracks are propagated through the ATLAS magnetic field to find matching energy clusters in the calorimeter - is the most time consuming component of the particle flow algorithm. Therefore, a simplified track extrapolation method would need to be implemented. Studies concerning the simplified track extrapolation in the particle flow algorithm were done by Barbara Skrzypek. My project included the study of FTK tracks for the use within the particle flow algorithm. Therefore, the tracks reconstructed with the FTK are compared to offline reconstructed tracks at first, trying to find and understand the major discrepancies. Subsequently the performance of jet reconstruction when using FTK tracks is analyzed and compared to offline particle flow reconstruction as well as other jet containers. Finally, trigger properties of a potential particle flow algorithm at the HLT are assessed.

All the studies were done using Monte-Carlo simulations of $t\bar{t}$ processes. The following sections describe shortly the main work I did and describe my contributions to this project.

[1] Fullscan here denotes a reconstruction within the full detector. In the current trigger system of the ATLAS detector tracking is only done in certain regions of interest (RoIs).

3 Comparison of FTK tracks with offline tracks

Since the track reconstruction with the FTK needs to satisfy the trigger timings, it is expected to be less efficient than tracks reconstructed software-based and offline. To have a fair comparison between offline and FTK tracks the following selection cuts are applied to the offline tracks:

- Number of pixel plus semiconductor hits on the track plus the number of inactive modules crossed by the track must be at least nine
- There must be no pixel holes on the track

Additionally the offline tracks are required to satisfy an impact parameter $|d0|$ smaller than 2 mm and $|z0|$ less than 110 mm as well as a transverse momentum of greater than 1 GeV. This ensures that the compared offline tracks are within the phase space of the FTK tracks.
For the comparison a track matching is applied by requiring $\Delta R_{\text{Off-FTK}} < 0.1$. Consequentially one finds an efficiency measurement of FTK tracks by

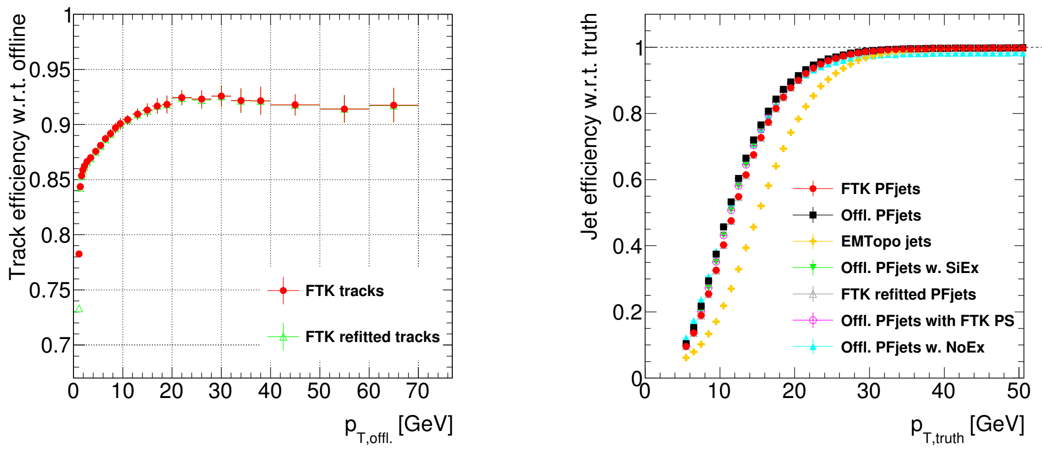
$$\frac{N_{\text{Off}}(\Delta R_{\text{Off-FTK}} < 0.1)}{N_{\text{Off}}},$$

where N_{Off} is the number of offline tracks and $N_{\text{Off}}(\Delta R_{\text{Off-FTK}} < 0.1)$ the subset with a matched FTK track in a cone of $\Delta R = \sqrt{(\eta_{\text{FTK}} - \eta_{\text{Off}})^2 + (\phi_{\text{FTK}} - \phi_{\text{Off}})^2} < 0.1$. Figure 1(a) shows the track efficiency measurement. The FTK tracks are especially inefficiently reconstructed for p_{T} less than 10 GeV. FTK tracks with p_{T} greater than 15 GeV are reconstructed with an efficiency of about 92% with respect to offline tracks. The FTK tracks refitted with an offline algorithm behave similar compared to the FTK tracks. Angular distributions and the behaviour of the impact parameter $|d0|$ and $|z0|$ of the tracks show no significant differences between offline and FTK tracks.

The next step is to assess the properties of the charged and neutral particle flow objects produced by the particle flow algorithm when using FTK tracks. The angular distributions look similar to the respective distributions for the tracks and no major discrepancy is found. Because of the FTK inefficiencies, particle flow with FTK tracks produces less charged particle flow objects and more neutral particle flow objects compared to the offline algorithm. This will influence the jet reconstruction since a different energy population is used in both cases. The impact of this, as well as studies to the overall particle flow jet reconstruction performance when using FTK tracks, is discussed in the following.

4 Comparison of jet properties

For comparing jet properties a truth matching is applied for the reconstructed jets by requiring $\Delta R_{\text{truth-reco}} < 0.4$, whereas "reco" stands for reconstructed. Additionally a jet energy scale calibration is implemented. The correction factor is obtained by the inverse



(a)

(b)

Figure 1: *(a) Track reconstruction efficiency as a function of $p_{T,offl.}$ for FTK tracks and FTK refitted tracks. (b) Jet reconstruction efficiency as a function of $p_{T,truth}$ for various jet collections.*

of the jet response, which is defined as

$$R\left(p_{\mathrm{T}}, \eta\right) = \langle \frac{p_{\mathrm{T,reco}}}{p_{\mathrm{T,truth}}} \rangle. \tag{1}$$

The calibration was derived within this project in η bins of size 0.1 and p_{T} bins of size 5 GeV (10 GeV above a p_{T} of GeV). The efficiency of the jet matching as a function of truth-particle p_{T} can be seen in figure 1(b). Several different jet containers are compared:

- Offl. PFjets: particle flow jets built with offline tracks
- FTK PFjets: particle flow jets built with FTK tracks
- FTK refitted PFjets: particle flow jets built with FTK tracks refitted with the offline track fitter.
- Offl. PFjets w. FTK PS: particle flow jets built with offline tracks which satisfy the FTK phase space
- Offl. PFjets w. SiEx: particle flow jets built with offline tracks with a simplified track extrapolation through the magnetic field
- Offl. PFjets w. NoEx: particle flow jets built with offline tracks with no track extrapolation through the magnetic field
- EMTopo jets: offline jets built from calorimeter topoclusters

The efficiency is near 100% for jet $p_{\mathrm{T}} > 30$ GeV.[2] Below that the calorimeter jets show inefficiencies and also jets reconstructed with FTK tracks are less efficiently reconstructed

[2]Offline particle flow jets with no track extrapolation show no saturation at 100% efficiency. This behaviour still needs to be understood.

compared to the other particle flow container . This is probably again due to the FTK track reconstruction inefficiencies, especially at low p_T .

Figure 2 shows the mean and the resolution of the jet response, as defined in 1, for calibrated jets as a function of $p_{T,truth}$ and η_{truth}. The values are extracted from gaussian fits to the calibrated response distributions, whereas the standard deviation of the gaussian fit is interpreted as the jet resolution. The transverse momenta of the reconstructed jets agree with the truth-particle jet p_T within about 2-4 % for jet $p_T > 20$ GeV (30 GeV for the calorimeter jets). The jet resolution varies for the different jet containers. The particle flow jets with FTK tracks perform better compared to the calorimeter jets, especially at $p_T < 45$ GeV the resolution improves by 15 %. The resolution is further improved when considering refitted FTK tracks. However, there are clear discrepancies visible compared to the other particle flow jets reconstructed with offline tracks. This behaviour is valid for $|\eta| < 1$. The jet resolution is also highly dependent on the η regime. For higher $|\eta|$ the jet resolution worsens especially for the particle flow jets, which become comparable to the calorimeter jets in resolution.

Additional to the transverse momentum resolution the angular resolution was studied. Particle flow jets with FTK tracks perform similarly to the offline particle flow jets and show great improvement relative to calorimeter jets in the angular resolution.

5 Trigger efficiencies

After evaluating the jet reconstruction performance of particle flow jets built with FTK tracks and the potential improvements, it is the goal to analyze, if significant improvements can be made in the event selection at the HLT. Therefore, different trigger properties were studied, such as the efficiency of multi-jet triggers and missing transverse energy (MET[3]) trigger. For example the efficiency of the MET trigger can be seen in 3. The potential of using particle flow at the HLT is clearly visible.

6 Conclusion

My studies investigated the performance of potential particle flow reconstruction with FTK tracks at the HLT. The efficiency of the FTK track reconstruction was assessed and the impact of this on the particle flow algorithm studied. The jet reconstruction performance was investigated and major trigger related properties of potential particle flow with FTK tracks analyzed. Overall the FTK seems to perform very well, but there are more studies needed to determine the possible improvements of particle flow at the HLT.

[3]MET is defined as the vectorial sum of all jet transverse momenta

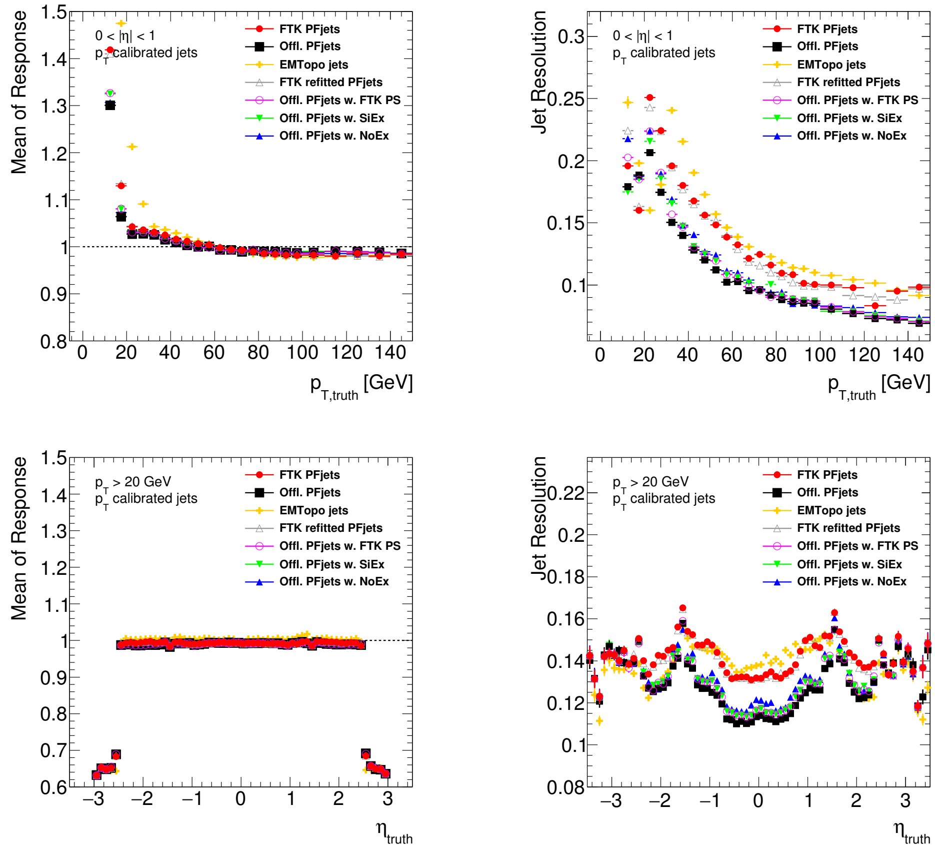


Figure 2: *Mean and resolution of the jet response for calibrated jets as a function of $p_{T,truth}$ and η_{truth}.*

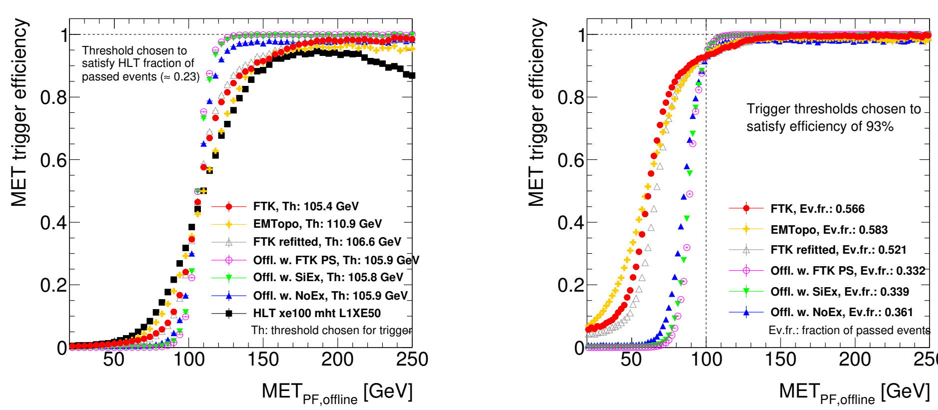


Figure 3: *MET trigger efficiencies as a function of MET, calculated from particle flow jets with offline tracks, for thresholds chosen to satisfy (left) the same fraction of passed events in the $t\bar{t}$ sample as the HLT and (right) the same efficiency at $MET_{PF,\ offline} = 100\,\text{GeV}$.*

References

[1] Benjamin Paul Jaeger, Barbara Skrzypek, Teng Jian Khoo, Marco Valente, Anna Sfyrla, and Christopher John Young. Performance studies for potential particle flow reconstruction in the ATLAS High Level Trigger. Technical Report ATL-COM-DAQ-2016-145, CERN, Geneva, Sep 2016.

[2] Ian Brock, Mark Hodgkinson, Marianna Testa, Teng Jian Khoo, Christopher John Young, Irina Antonela Cioara, David Delgove, Heather Gray, Jean-Francois Grivaz, Maike Christina Hansen, and Matthew Henry Klein. Jet Reconstruction and Performance Using Particle Flow with the ATLAS Detector. Technical Report ATL-COM-PHYS-2016-047, CERN, Geneva, Jan 2016.

[3] M Shochet, L Tompkins, V Cavaliere, P Giannetti, A Annovi, and G Volpi. Fast TracKer (FTK) Technical Design Report. Technical Report CERN-LHCC-2013-007. ATLAS-TDR-021, Jun 2013. ATLAS Fast Tracker Technical Design Report.