Rejecting $g \rightarrow b\bar{b}$ Jets in the ATLAS $b$-jet Trigger

Maggie Chen$^{a,*}$

$^a$University of Oxford,
Oxford, United Kingdom
E-mail: meiqi.chen@cern.ch

The ATLAS $b$-jet trigger system is crucial as it is important to be able to efficiently select events containing $b$-jet at the trigger level for analyses that involve many $b$-quarks in the final states, such as the search for $HH \rightarrow 4b$ production. However, in Run-2 the ATLAS $b$-tagger did not distinguish between jets containing a single $b$-hadron ($b$-jets) and jets containing 2 $b$-hadrons ($bb$-jet). Collision events involving small-angle $g \rightarrow b\bar{b}$ splitting, resulting in $bb$-jet are common in the LHC. Rejecting them in real-time would significantly reduce the readout rates of multi-$b$-jet triggers and ensure efficient signal extraction, which is particularly important for analyses that use multi-$b$-jet trigger chains. The proposed poster shows an approach to reject $bb$-jets in the ATLAS online $b$-taggers, the proposed implementation and the implications for the ATLAS Run-3 physics programme.
This proceeding presents a study on rejecting $bb$-jets arising from $g \rightarrow b\bar{b}$ splitting using the flavour-tagging algorithms for the High Level $b$-jet trigger at ATLAS. The current baseline algorithm GN1 [1] used in the $b$-jet trigger is found to identify single-$b$-jets (signals to be kept) and $bb$-jets (background to be rejected) inclusively. This is evident in the overlapping distributions in the $b$-jet discriminant score between the two jet flavours in Figure 1.

![Figure 1](image)

**Figure 1**: Distributions of the HLT $b$-jet discriminant score for the GN1 algorithm, for $b$-jets, $c$-jets, light-flavour jets and $bb$-jets. The algorithm was evaluated on HLT Particle Flow jets from a $t\bar{t}$ sample. Red vertical lines indicate the 85%, 77%, 70% and 60% $b$-jet efficiency working points.

A deep neural network algorithm DL1dbb, based on the DL1 architecture [2] is trained to further separate single-$b$-jets from $bb$-jets, by exploiting the same input features as GN1 but between these two jet flavours only. The $b$-jet discriminant score of DL1dbb shows improved separation between them, shown in Figure 2. DL1dbb is applied to jets that are tagged at the 85% $b$-jet efficiency working point of GN1 to form a combined tagging scheme. Compared to GN1 alone, the $bb$-jet rejection achieved with this combined tagging scheme is roughly a factor of three at the 77% $b$-jet efficiency, shown in Figure 3.

The combined tagging scheme is implemented in the ATLAS $b$-jet trigger in a multi-$b$-jet chain. The rejection of QCD multijet events with fewer than 3 single-$b$-jets (background) as a function of the efficiency of non-resonant $HH \rightarrow 4b$ events with at least 4 single-$b$-jets (signal) are estimated. It is evaluated while requiring 4 Particle Flow jets, with jet $p_T$ thresholds of 80 GeV, 55 GeV, 28 GeV, 20 GeV, at least three of which are required to be above the $b$-tagging threshold. The background rejections achieved by the combined tagging scheme of GN1 and DL1dbb algorithms at lower $b$-jet efficiencies (70%, 75%, 77%) are found to be higher than GN1 alone, shown in Figure 4.

In conclusion, a dedicated algorithm is trained to further separate single-$b$-jets from $bb$-jets in jets tagged by the baseline $b$-tagging algorithm GN1 in the ATLAS $b$-jet trigger. In conjunction with the 85% $b$-jet efficiency working point of GN1, a factor of 3 in $bb$-jet rejection is achieved, and higher rejections of the QCD multijet background events are achieved while maintaining the same $HH \rightarrow 4b$ signal efficiencies at lower HLT $b$-jet efficiency working points.
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**Figure 2:** Distributions of the HLT $b$-jet discriminant score for the DL1dbb algorithm, for $b$-jets and $bb$-jets. The algorithm was evaluated on HLT Particle Flow jets from $t\bar{t}$ and QCD multi-jet samples. The red vertical line indicates the 77% $b$-jet efficiency working point.

**Figure 3:** $bb$-jet rejection as a function of the HLT $b$-jet efficiency of the combined GN1 and DL1dbb algorithms, in comparison to GN1 alone. The rejection is evaluated on a $t\bar{t}$ sample. The 85%, 77%, 70% and 65% $b$-jet efficiencies are indicated by red vertical lines.
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Figure 4: Rejection of QCD multijet events with fewer than three single-$b$-jets as a function of efficiency of non-resonant $HH \rightarrow 4b$ events with at least 4 single-$b$-jets, evaluated while requiring 4 Particle Flow jets, with jet $p_T$ thresholds of 80 GeV, 55 GeV, 28 GeV, 20 GeV, at least three of which are required to be above the $b$-tagging threshold. The background rejections of GN1 only at a range of $b$-jet efficiency working points are indicated by stars, ad the rejections of GN1 and DL1dbb combined are indicated by triangles.

References
