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SELECTION OF EVENTS WITH BEAUTY AND TAU WITH THE ATLAS AND CMS DETECTORS

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Abstract

The expected selection performance for events with b quarks and τ leptons in the final state with the ATLAS and CMS detectors are discussed. Reconstruction tools and trigger strategies are also reviewed.

1 Introduction

ATLAS and CMS are general purpose detectors that will be installed at the Large Hadron Collider at CERN. Their main target is discovering new physics, especially in the Higgs and Supersymmetry sectors. In particular the Standard Model Higgs decay into $b\bar{b}$ is expected to be the dominant decay channel for a light Higgs boson ($m_H \lesssim 130$ GeV) while the Higgs decay into τ leptons is particularly important for a Minimal Supersymmetric Standard Model Higgs. The detection of b quarks and τ is therefore crucial to increase the the new physics discovery potential at LHC.

2 Tracking System Layout

Both the ATLAS [1] and CMS [2] detectors have been designed in order to optimize physics coverage at an affordable cost. They essentially consist of three subdetector systems: the Tracking system, closest to the beam pipe, the Calorimetric system and the Muon chambers.

ATLAS and CMS will make use of a detector based on silicon pixels in the the innermost part of the Tracking systems. The Pixel detector grants the most precise spatial measurement in the Tracking system, providing a three-dimensional position information. In addition, the Pixel system is also characterized by a very low occupancy (with a maximum of $\mathcal{O}(10^{-4})$ hits per pixel at each bunch crossing, at LHC design luminosity) even in the high density environment of proton-proton collisions at LHC.

Table 1: *Main parameters of the ATLAS and CMS Pixel detectors.*

	ATLAS	CMS
Barrel layers	3	3
Forward disks	3	2
Minimal radius (cm)	5.05	4.3
Pixel size (μm^2)	50x400	100x150
Number of channels	8.2 10^7	6.6 10^7
rϕ resolution (μm)	7	10
z resolution (μm)	70	15

The main characteristics of the Pixel detectors of ATLAS and CMS are summarized in Table 1. Spatial resolutions of Pixel systems strongly depend on the track impact angle and the size of clusters, so the quoted numbers only give an average rough estimation. In the transverse plane, the effect of the smaller pixel size of ATLAS with respect to CMS is partially balanced by the smaller internal radius of the CMS Pixel detector.

After the Pixel system, both ATLAS and CMS detectors have silicon-microstrip layers, some of them present a stereo tilt angle to allow a three-dimensional position measurement. For the outer tracking, the two experiments made a different choice: CMS still uses silicon micro-strips detectors, while ATLAS uses a Transition Radiation Detector to allow a better particle identification.

3 Track and Vertex Reconstruction Performance

In order to identify b and τ a very precise track and vertex reconstruction is needed. All the results given in the following refer to a track reconstruction algorithms based on a standard Kalman Filter. The efficiency to reconstruct tracks depends on many factors, such as the event topology, luminosity conditions and detector efficiency. Single muon tracks are reconstructed with an efficiency close to 100% in the tracker acceptance assuming a perfectly aligned detector.

Figure 1: *Track reconstruction efficiency for single pions (left: the effect of pile-up events is shown by filled circles) in ATLAS and for jets (right: red and blue dots correspond to $E_t = 50,\ 200$ GeV respectively) in CMS.*

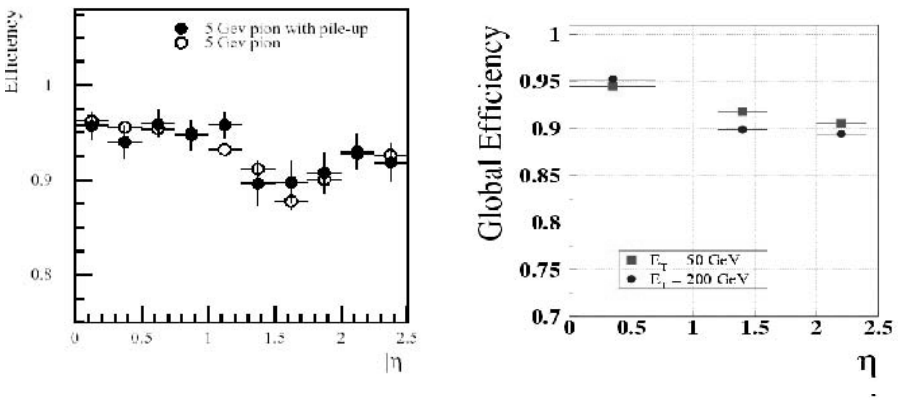


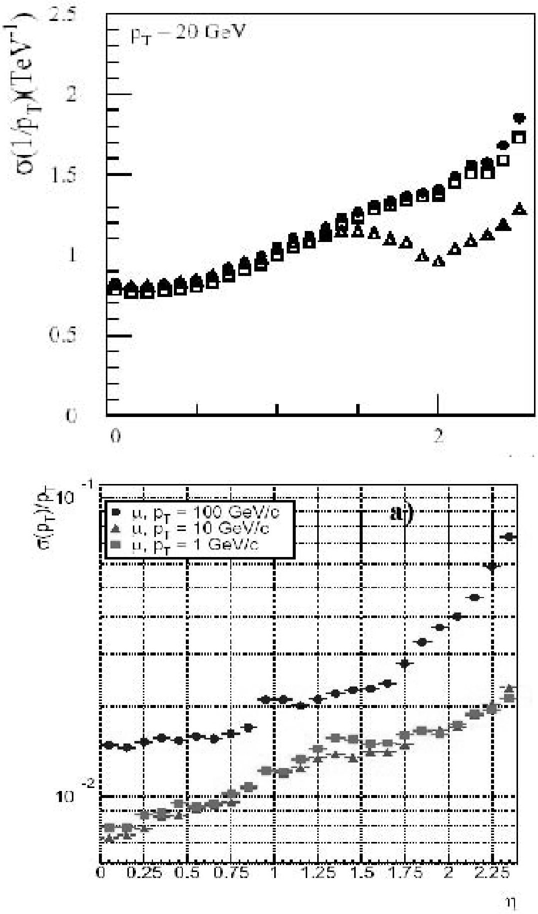
Figure 1 shows the track reconstruction efficiency as a function of the pseudorapidity for single pions with the ATLAS detector simulation and for jets with the CMS detector simulations. In both the cases the efficiency does not fall below 85%.

The relative transverse momentum (p_{T}) resolution for single muon tracks is shown in Figure 2 as a function of the pseudorapidity. ATLAS and CMS detectors reach similar performance, obtaining a relative p_T resolution of a few percent for single muons at high energies.

The impact parameter resolutions, evaluated on high p_T tracks, are listed in Table 2. ATLAS has a slightly better transverse impact parameter resolution and CMS shows a significant advantage in the longitudinal coordinate, this clearly reflects the different cell sizes in the Pixel detectors.

The vertex finding process is accomplished in two steps: first of all, primary vertices are reconstructed, identifying the one which triggered the event, and subsequently the reconstruction of displaced vertices from high lifetime particles, like b and τ, is performed. The performance on vertex reconstruction is clearly related to the quality of the track reconstruction. The reconstruction of primary vertices can also be performed at an early stage, without using the information from all the tracking system. Both ATLAS and CMS show that it is possible to reconstruct and identify the primary vertex of the signal event using only the Pixel detector. The main advantage of such an approach is that it is fast, so that it can be used for event selection at trigger level and it can also be used to constrain the track reconstruction with the full Tracker information in order to not reconstruct tracks belonging to pile-up events.

Figure 2: *Relative p_T resolution for single muon tracks as a function of the pseudorapidity in ATLAS (top) and CMS (bottom).*



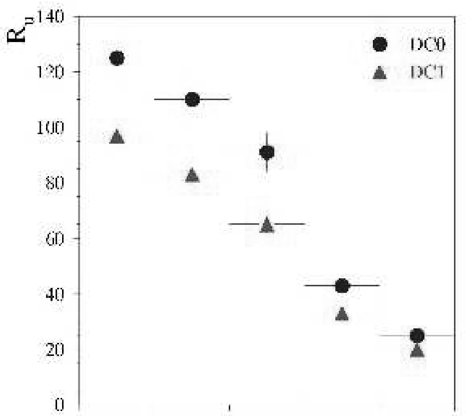
CMS has shown that in most interesting signal events at low luminosity, the efficiency to identify the primary vertex is above 95% except for some signal event, like H $\rightarrow \gamma\gamma$ where the low charged track multiplicity does not allow the primary vertex to be identified as the signal one. Dedicated algorithms have to be used to identify the primary vertex for low multiplicity signal topologies.

Table 2: *Impact parameter resolution in ATLAS and CMS.*

	ATLAS	CMS
$\sigma(d_0)$ at η=1	15 μm	20 μm
$\sigma(z_0)$ at η=1	95 μm	40 μm

The resolution in the z position determination is about 50μm for low luminosity events and improves up to 30μm using the full tracker information. To reconstruct secondary vertices the information from the all Tracker system are needed. The efficiency of secondary vertex finding depends on the impact parameter of tracks belonging to a displaced vertex and the required purity on the same set of tracks. Once the set of tracks coming from a secondary vertex have been identified, a fit is needed to estimate the position of the secondary vertex from which the decay length is computed.

Figure 3: *Light-quark rejection in* WH *(*H $\rightarrow$ b$\bar{\text{b}}$*) events as a function of the pseudorapidity in ATLAS while 60% of* b *quarks are retained.*

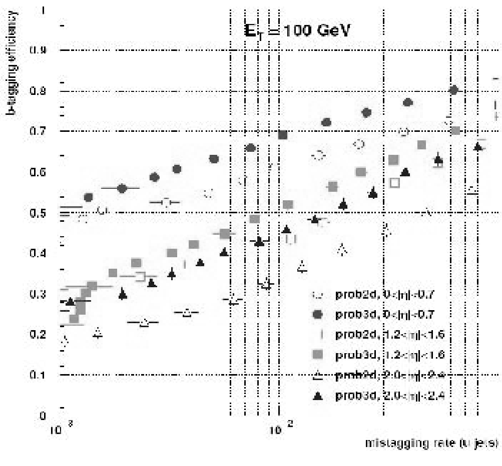


4 B-Tagging

The main characteristic of jets coming from b quarks with respect to light-quark jets is that they contain large impact parameter tracks originating from a secondary vertex, in fact the lifetime of B hadrons (1.6 ps) corresponds at a decay length of around half a millimeter in the rest frame. Track reconstruction has to be precise enough to identify tracks with a large impact parameter in order to combine the information provided by these tracks in different ways to finally tag a jet as a “b-jet”.

To perform b-tagging online the processing time has to be reduced as much as possible, both CMS and ATLAS have performed studies to check what are the minimal tracker informations needed. For online purpose the impact parameter significances of tracks belonging to a jet are directly used to tag the jet. The High Level Trigger of CMS consists of only one trigger level using the same algorithms as offline, made faster with a regional reconstruction. Using a partially reconstructed tracks CMS studies have shown that it is possible to select about 50% of b-quark jets with a light-quark jets rejection from 25 to 50 depending on the pseudorapidity regions. The expected offline performance with the same b-tagging algorithm do not change significantly. ATLAS developed a dedicated algorithm for online track reconstruction, compatible with the latency constraint. At Level 2 trigger, a rejection of light-quark jets of about 15 is expected, while retaining an efficiency of b-quark jets of 50%. In the next trigger selection, called Event Filter, offline quality algorithms allow to improve the light quark rejection up to a factor 10.

Figure 4: *Light-quark rejection in* WH ($H \rightarrow b\bar{b}$) *events as a function of the efficiency in* $b\bar{b}$ *events in CMS for different pseudorapidity bins.*



Offline b-tagging techniques are not limited by the processing time, thus more sophisticated observables can be adopted to evaluate the probability, for a given jet, to come from a light quark.

It is not straightforward to make a direct comparison of the offline b-tagging performance in CMS and ATLAS, because different event samples are used and results are presented in a different way. Nevertheless, Figures 3 and

4 show the results obtained, in the two experiments, adopting very similar b-tagging algorithms, both based on the likelihood-ratio method and exploiting the transverse impact parameter significance of the reconstructed tracks. In particular, the left plot shows, for ATLAS, the rejection against u-jets produced in the decay of a 120 GeV Higgs boson (WH associated production, $H \rightarrow u\bar{u}$ decay) as function of the pseudorapidity, corresponding to 60% efficiency on b-jets (from the $H \rightarrow u\bar{u}$ decay). The right plot shows, instead, the mistagging rate in CMS, as a function as a function of the efficiency in $b\bar{b}$ events for different pseudorapidity ranges.

To further improve b-tagging, the information of the track impact parameter inside a jet can be combined with the search for secondary vertices and other kinematic variables (like invariant mass and charged track multiplicity at the secondary vertex). CMS is finalizing this combined b-tagging approach, while ATLAS has shown that adding the information of the secondary vertex improves by a factor up to three the b-tag performance. Even if the displaced tracks in a jet give the most powerful feature to discriminate b-quark from light-quark jets, a lepton-based b-tag can also be useful. In this case the b-tagging efficiency is limited by the branching ratio of the leptonic b decay which is around 20%. In both ATLAS and CMS experiments b-tagging techniques based on the lepton reconstruction and identification are under developing.

5 B-Tagging performance at Startup

The b-tagging performance presented in the previous section refer to a perfectly optimized detectors. The effect of the realistic conditions of the detector, like misalignment, readout inefficiency and dead channels, precise description of the magnetic field and material budget, is presently under intensive study.

In particular, it is possible that in the startup phase only the inner and middle barrel layers of the CMS pixel detector will be installed. A similar startup condition was suggested in the past also for ATLAS, but is now discarded. The effect of these staged scenarios have been deeply investigated, especially for b-tagging where the information from the pixel detectors is essential to precisely evaluate track parameters and reconstruct secondary vertices.

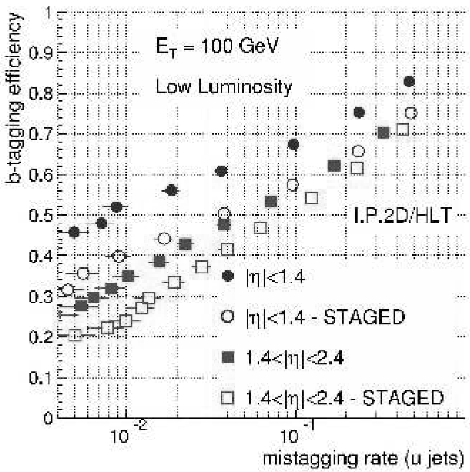
Table 3: *Ratios of light quark rejection for staged and not-staged ATLAS pixel scenarios, for the* WH *and* ttH *benchmark channels at low luminosity.*

	u-jet rejection: perfect alignment	u-jet rejection: misaligned
ϵ_b=50%	164 ± 4	106 ± 2
ϵ_b=60%	53 ± 1	39 ± 1

The ATLAS Collaboration also evaluated b-tagging performance in the benchmark channel ttH both with H → b$\bar{\text{b}}$, in case of misalignments in the pixel detector; the results listed in Table 3 correspond to a 20 μm misalignment in the $R\Phi$ plane and 60 μm along Z. The effects of misalignment become negligible below 5 and 15 μm for the two coordinates respectively.

The effect of the CMS staged scenario is instead shown in Figure 5 in terms of b-tagging efficiency in b$\bar{\text{b}}$ events as a function of the mistagging rate in light q$\bar{\text{q}}$ events. The mistagging rate increases by a factor two with a staged scenario, while 60% of b-quark jets are retained.

Figure 5: *The b-tagging efficiency in* b$\bar{\text{b}}$ *events as a function of the mistagging rate in light* q$\bar{\text{q}}$ *events at low luminosity for a staged and not-staged CMS pixel scenarios.*

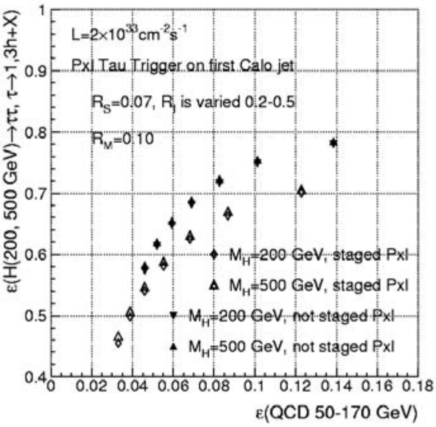


6 Tau-Tagging

The signature of a τ-lepton decaying into hadrons consists on one or three prongs jets. The τ-lepton identification is mainly based on the search for collimated jets using the information from both the Tracker and Calorimetric systems with a significant amount of missing energy due to the neutrinos. Being the τ lifetime (0.3 ps) significantly lower than the one of b hadrons, the detection of displaced tracks is only used at the offline stage, when all the precise information from the Tracker system are available. The leptonic τ decays are also considered: the electron decay is treated as the hadronic case and the muon decay needs the track impact parameter to be reconstructed.

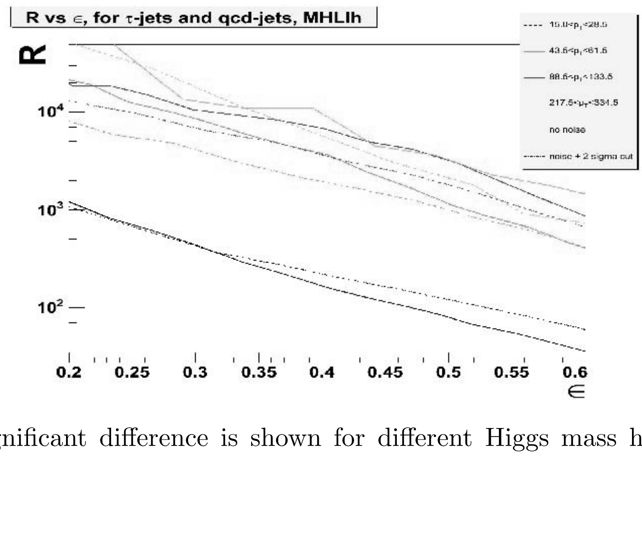
At present, ATLAS mostly performed offline studies after the Level 1 trigger selection and CMS presented detailed strategies for the High Level Trigger chain, while offline strategies are under investigation. If the only calorimetric information are used to define an isolation variable for narrow jets, CMS shows that 86% of H $\rightarrow \tau^+\tau^-$ signal can be selected when around 30% of QCD events are retained [3]. The performance on τ-isolation criteria can be improved by checking for tracks reconstructed in a cone around the direction of the τ jet. In order to optimize the processing time at HLT, the Pixel detector response can be used to reconstruct tracks in the cone. In Figure 6, the signal efficiency is

Figure 6: *The τ-tagging efficiency at High Level Trigger in* H $\rightarrow \tau^+\tau^-$ *events as a function of the QCD efficiency in light* $q\bar{q}$ *events at low luminosity for a staged and not-staged CMS pixel scenarios.*



presented as a function of the QCD efficiency varying the isolation cone in the Pixel detector.

Figure 7: *The τ-tagging efficiency in* H $\rightarrow \tau^+\tau^-$ *events as a function of the QCD rejection and for different p_T bins with ATLAS.*



No significant difference is shown for different Higgs mass hypotheses, while in the case of a staged scenario the performance decreases of about 10%. Using all the Tracker response improves the signal efficiency of 15%, but the processing time increases of a factor 2. At the offline stage the whole information from the Tracker can be used and displaced decay vertices can be reconstructed. ATLAS uses a likelihood approach to search for H $\rightarrow \tau^+\tau^-$ decays based on isolation variables.

ATLAS shows (Figure 7) the τ identification efficiency as a function of the QCD rejection. Rejection rates at the same signal efficiency can vary a lot, depending on the p_T of the tau.

7 Conclusions

Many interesting channels relevant for discovery physics studies at LHC, such as searches of Higgs bosons or supersymmetrical particles, will contain in the final state jets coming from b-quarks or tau leptons. Both ATLAS and CMS experiments have developed efficient trigger and offline selection strategies to identify this kind of events.

In this contribution the current performance for the two experiments was reviewed, for both the online and the offline implementations, showing that it should be well adapted to the physics requirements at LHC. Anyway, the comparisons between the experiments are far from being complete, due to many factors: different event samples are often used; different development stages for the online and offline strategies; intrinsic difficulties in comparing online results, due to infrastructural differences in the approach to the trigger selection.

The comparison between the two experiments will become even more interesting as soon as performance studies will heavily focus on the commissioning phase. Common event samples will be probably used, and a throghout review of the selection methods will be performed in similar ways. Examples of this kind of studies, such as those on the impact of misalignments or of staged detector scenarios, are already provided in this contribution.

References

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