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Quark-gluon tagging: Application to the search of the Higgs boson in the ATLAS experiment at LHC

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Summary. — The possibility to discriminate between events with jets coming from quarks or gluons (quark-gluon tagging) can constitute a new tool to improve the sensitivity of some particular analyses. This study presents the implementation of a discriminant to be used in quark-gluon tagging based upon neural networks without supervision, the so-called Self Organizing Maps (SOM). This method has been applied on the search for production of a particle that decays in a couple of Z bosons, with two leptons and two jets in its final state, using data recorded by the ATLAS experiment.

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The spin and the color-charge induce different experimental properties for quark and gluon jets. Leading order calculations foresee a higher track multiplicity for gluon-jets with respect to quark-jets [1]. Similar calculations have been applied also on angular variables and they show that gluon jets are on average wider than quark-jets.

In ATLAS two quantities have been used: the number of charged tracks inside the jets ($nTrk$) and the jet width ($Width$) [2]. The separation power of these two variables can be evaluated with Monte Carlo (MC) dijets samples using standard likelihood ratio method using

$$R = \frac{L_s(i)}{L_s(i) + L_b(i)}\,, \tag{1}$$

where $L_s(i)$ and $L_b(i)$ represent the likelihood for the signal (light quark jets) and background (gluon jets) obtained using the probability density function for the two variables above.

The jets present in the Higgs decay process $H \to ZZ \to \ell^+\ell^- q\bar{q}$ ($\ell = e, \mu$) derive from the hadronic decay into quarks of one of the Z bosons. In the search for this process with

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Table I. – *Global significance changes into the* $H \to ZZ \to \ell^+\ell^- q\bar{q}$ *analysis for Electron and Muon channels* (*for a Higgs mass of* 130 GeV). *The studies have been perform with two different MC training samples* (*PYTHIA and HERWIG++*) *in order to understand the possible systematic uncertainties.*

	Significance changes	
Channel	PYTHIA	HERWIG++
Electron	+5.7%	+6.5%
Muon	+0.1%	+0.7%

the ATLAS detector at the Large Hadron Collider, the analysis has been divided into Muon channel and Electron channel referring to the flavour of the corresponding leptonic Z decay. The main background process in this analysis is the Z boson production in association with jets, followed by its lepton decay. In this process the gluon radiation plays an important role ($\simeq$ 45% of the jets in this background come from gluons) [2].

Discriminating variables relative to the flavour of the jet that allow to distinguish the jet-origin constitute an interesting tool to improve the experimental analysis.

In the mentioned analysis a large fraction of the events shows a mixing between different jet flavours (1 quark + 1 gluon jet, 1 quark + 1b-quark jet, ...) and for this kind of events the separation power of the standard likelihood method has been found to be very poor. For this reason an alternative approach based on a self-organizing map has been used.

A self-organizing map (SOM) [3] is a type of artificial neural network that is trained using unsupervised learning to produce a low-dimensional, discretized representation of the input space of the training samples, called *map*.

In the $H \to ZZ \to \ell^+\ell^- q\bar{q}$ analysis of 2011 ATLAS data[2], the vector input into SOM is represented by the *nTrk* and *Width* of each of the two jets in the selected events, thus leading to 4-dimensional input space and 4×4 rectangular SOM maps.

Cuts on the SOM output have been optimised to increase the significance with respect to the standard analysis and checked to be stable with respect to the MC used in training (table I).

A conservative approach in SOM cuts definition leads to an overall background reduction of $\simeq$ 15% and a global significance improvements of up to 5% [4].

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