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# QCD at LHC with ATLAS

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**Abstract.** The LHC will allow QCD studies to be performed at very high energy including precision tests and measurements in an as yet unexplored kinematic region. A detailed understanding of QCD is important for almost all physics processes to be studied at the LHC, as the production mechanisms are mostly controlled by QCD. This talk will review various measurements of QCD-related processes to be performed at the LHC, based on final states containing leptons, photons and jets. The kinematic reach and the expected statistical uncertainties will be described for selected examples. The achievable constraints on the parton distribution functions of the proton and a measurement of the strong coupling constant at very large scales will be presented. Where already studied, sources of systematic uncertainties and contributions from background processes are going to be discussed. At the end the beauty production aspects related to the QCD tests will be presented.

## 1 Introduction

The production mechanisms for most processes at LHC will be controlled by QCD and a detailed understanding of these is mandatory for precision measurements. Furthermore proton-proton collisions at a center-of-mass energy of $\sqrt{s}$ = 14 TeV will represent a regime, where QCD as the theory of strong interactions can be precisely tested at the highest energy. Besides these tests, studies of QCD related processes at LHC will allow for detailed measurements leading to new information on the parton densities of the proton and possibly also measurements of the strong coupling constant, both in as yet unexplored kinematical regions.

This report presents an overview of QCD studies with ATLAS at LHC and discusses several related experimental aspects. First, a brief description of the ATLAS detector will be given and then examples for measurements related to final states containing high $p_T$ jets, photons and leptons will be discussed. At the end the beauty production aspects related to the QCD tests will be discussed together with a short description of the possible influence of these measurements on the knowledge of parton densities.

## 2 The ATLAS detector

The ATLAS detector is a multi-purpose $4\pi$ detector (coverage up to $\|\eta\|$=5), designed to operate at the LHC design luminosity of $10^{34}$ $cm^{-2}$ $s^{-1}$. At these conditions, on average 23 inelastic events ("minimum bias events") occur at each bunch crossing. Most of the QCD related measurements are expected to be performed however during the first years of operation at lower luminosities $\leq 10^{33}$ $cm^{-2}$ $s^{-1}$, where on average only $\leq$ 2.3 minimum bias events are expected per bunch crossing).

The interaction region is surrounded by silicon pixel and silicon strip detectors, followed by a transition radiation tracker (TRT), providing robust tracking and precise vertex measurement for $\|\eta\| \leq 2.5$. Outside the tracking detector, a 2 T solenoid is located in front of the calorimetry, which consists of a LAr calorimeter for the e.m. part and scintillator tile based and LAr based calorimeters for the hadronic part. The calorimeter coverage extends up to $\|\eta\|$ = 5, where the very finely segmented e.m. part being restricted to $\|\eta\| \leq 2.5$. Muons are measured (for $\|\eta\| \leq 2.7$) in an air-core toroid system with muon detectors. More details about the detector and the expected performance can be found in [1].

## 3 Jet physics

The measurement of jet production will allow to access smallest distances due to large cross-section. Jet production is induced by initial states containing both quarks and gluons. The statistical uncertainties will be small e.g. for an integrated luminosity of only 30 $fb^{-1}$ (to be reached after 3 years of initial data taking), more than 4 x $10^5$ (3 x $10^3$ or 40) events are expected with a jet of $E_T \geq 1$ TeV ($\geq$ 2 TeV or 3 TeV). Important systematic uncertainties are for example how to best define a jet (jet algorithm), the knowledge of the energy scale (which will be the dominating source at very large values of $E_T$) and the effect of the underlying event. The expected jet energy resolution is well described by a parametrization of $\sigma$/E = $50/\sqrt{E}$

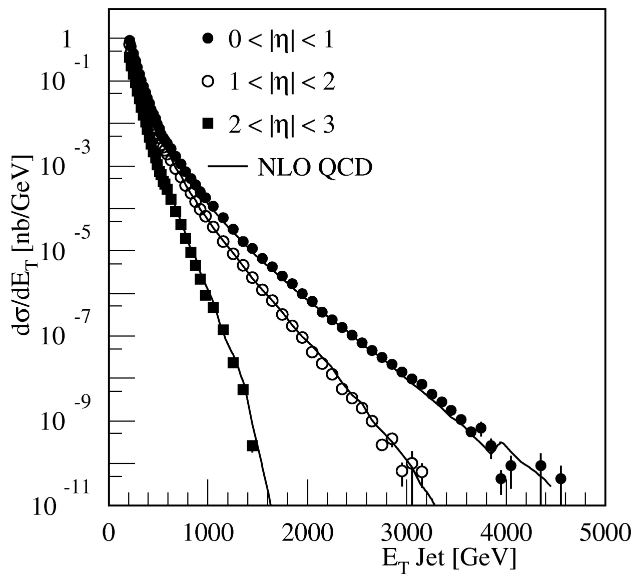


**Fig. 1.** The expected cross section for inclusive jet production as a function of the $E_T$ of the leading jet. The *circles* indicate the expected statistical accuracy for the cross-section measurement with an integrated luminosity of 300 $fb^{-1}$

% ± 3 %. The knowledge of the absolute energy scale is expected to be accurate to 1%, using a variety of physics processes for in-situ callibration.

An example for the expected inclusive jet cross-section is shown in the Fig.1, for three choices of pseudo-rapidity ranges, indicating the ultimate possible reach in transverse energy. A measurement of di-jet production allows to constrain the fractional momenta $x_{1,2}$ of the partons entering the hard scattering for the scale $Q^2$ (related to $E_T^2$). The kinematic reach for $x_i \geq 0.1$ extends to $Q^2 \geq 10^7$ $GeV^2$. For $Q^2 = 10^5$ $GeV^2$ (i.e. above the HERA kinematical limit), values of $x_i$ down to $10^{-3}$ are covered.

Jet production could possibly be used to determine the strong coupling constant $a_s$ over a wide range of scales, reaching up to scales of O(TeV). For inclusive jet production, there is however a strong correlation between $\alpha_s$ and the gluon density, which might be avoided by extracting as from the ratio of 3-jet to 2-jet production.

## 4 Photon physics

Direct photon production is one of the processes to obtain information on the gluon density. The experimental challenge is to reduce background from jets (containing for example a leading $\pi^0$), which can fake a photon signature. The expected ratio of the inclusive photon cross-section to the inclusive jet cross-section has a value of about $10^{-3}$. As shown in Fig.2 (a) the achievable jet rejection is larger than 3 x $10^3$ for values of $E_T \geq 40$ GeV, thus providing a good signal-to-background ratio. For this rejection, achieved mostly due to the finely segmented LAr calorimeter, the photon identification efficiency is more than 80% (at low luminosity) as shown in Fig.2 (b).

Photons with $E_T \geq 40$ GeV (i.e. $Q^2 \geq 10^3 GeV^2$) allow to reach values of Bjorken-x down to 5 x $10^{-4}$ (for $\|\eta\|$ $\leq$2.5). Statistics will not be a problem, as for example more than 2 x $10^4$ events with a photon of $E_T \geq 500$ GeV are expected for 30 $fb^{-1}$.

A study of the ratio of the inclusive photon cross-section to the cross-section for inclusive jet production (as a function of $E_T$) could allow one to determine the strong coupling constant at a well defined scale [2]. More studies are needed (as in the case of jet production) to access the expected uncertainties.

## 5 Lepton physics

The measurement of Drell-Yan lepton pair production and the production of W and Z bosons (with a leptonic decay to electrons or muons) will allow one to constrain the quark and anti-quark densities of the proton at a scale given by the invariant mass of the lepton pair (respectively by the W/Z boson mass) over a wide range in Bjorken x. In case of electrons, the experimental challenge is to reject background from jets faking electron signature. By using a combination of a shower shape in the finely segmented LAr calorimeter, of the search for matching tracks and of the transition radiation information from the TRT, a rejection of up to 5 x $10^5$ can be achieved. The absolute energy scale for leptons is expected to be determined with an accuracy of 0.1% (or better).

As an example, the measurement of Z boson production allows one to cover the range of 3 x $10^{-4} \leq$ x $\leq 0.1$ in Bjorken-x at $Q^2 = 8$ x $10^3$ $GeV^2$ (for comparison: the HERA collider is kinematically limited to x $\geq 0.1$ at $Q^2$ $\geq 10^4$ $GeV^2$). Again, the LHC will provide huge sample: during one year at $10^{33}$ $cm^{-2}$ $s^{-1}$ about $10^7$ ($10^6$) events with W $\rightarrow$ e $\nu$ (Z $\rightarrow e^+e^-$) will be produced.

## 6 Beauty production and QCD tests

The high rate of beauty production at LHC will allow one to extend b-production measurements up to transverse momenta of several hundred GeV. Correlations between b and $\bar{b}$ quarks and events with more than one heavy-quark pair, that were difficult to address in previous experiments due to limited statistics, will be investigated in detail.

Multiple CDF and D0 measurements gave the cross section of single-b quark production approximately 2 times higher than calculated in NLO QCD. The RUN-I statistics was not sufficient to fully explore b$\bar{b}$ correlations. Using semi-inclusive B-decay modes required an application of isolation cuts leading finally to an information loss in the configurations where the b and $\bar{b}$ quarks were produced close to each other. This region is sensitive to higher order QCD distributions.

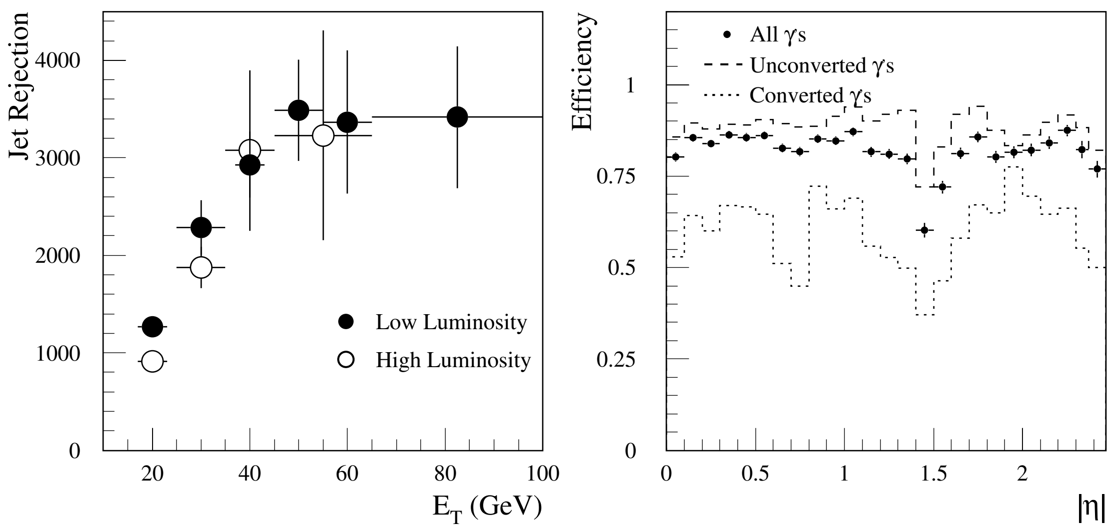


**Fig. 2.** **a** Rejection against jets for photon identification (with an efficiency as shown in **b** as a function of the jet $E_T$ at low and high luminosity. **b** Photon identification as a function of the photon $p_T$, for photons from Higgs boson decay ($m_H = 100$ GeV)

The ATLAS performance studies were done for two channels selected to measure the azimuthal angle difference $\Delta\phi(\mathrm{b}\bar{b})$ between b and $\bar{b}$ quarks:

$\bar{b} \to B_d$ J/$\psi(\mu\mu)$ $K^0$, b $\to \mu$X

$\bar{b} \to B_s$ J/$\psi(\mu\mu)\phi$, b $\to \mu$X

The numbers of events expected for 30 $fb^{-1}$ as might be achieved after 3 years of running at a luminosity of $10^{33}$ $cm^{-2}$ $s^{-1}$ are 4.8 x $10^4$ and 3.2 x $10^4$ respectively for these channels. No isolation cuts are needed to separate exclusively reconstructed B- decays from the muon produced in the semi-leptonic decay of the other B-particle in the event. The reconstruction efficiency remaines high in topologies where the azimuthal angle difference $\Delta\phi$(J/$\psi$-$\mu$) between J/$\psi$ and the muon is small.

Special attention was devoted to background events in which the muon is produced from the decays $K^{\pm}$, $\pi^{\pm}$ $\to \mu^{\pm}$X instead of b $\to \mu$X. The study showed that this background is not problematic in $B_d$ decays, however it is important in the case of $B_s^0$ meson. This particle is composed of b and s quarks and so is always accompanied by the associated strange quark, which mostly hadronizes to a K meson. The characteristic feature of this background is that the muon from the K decay is correlated with the $B_s^0$ meson. After applying cuts to reject $K^{\pm}$, $\pi^{\pm} \to \mu^{\pm}$X the contribution of this background is still significant especially for high $p_T$ events, $p_T$ $(B_s^0) \geq 50$ GeV. The beauty production studies will be extended to the semi-inclusive events containing b$\bar{b} \to$ J/$\psi(\mu^+\mu^-)$X and to b-jets to access high-$p_T$ region.

## 7 Conclusions

Studies of QCD processes with ATLAS at LHC will provide further tests of QCD as the theory of strong interactions at the energy frontier of 14 TeV. The expected performance of the ATLAS detector will allow in addition precision measurements of QCD processes to be performed. These measurements should lead to improvements in the knowledge of the proton structure (in as yet unexplored kinematical regions) and possibly measurements of the strong coupling constant up to the highest values. Large statistics of exclusive or semi-inclusive B-decay channels, will allow one to get QCD in central b-quark production and in particular, using angular corrections between b and $\bar{b}$ quarks.

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