ATLAS commissioning and early physics of resonance and jet production

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Abstract As early physics programs with the ATLAS detector, we present J/ψ and Υ production cross section and spin alignment measurements, and the strategy for the jet energy calibration.

Key words ATLAS, quarkonium, spin alignment, jet energy calibration

PACS 13.85.Ni, 14.20.Lq, 14.20.Mr

1 Introduction

The ATLAS detector [1] is being commissioned to explore the physics in the energy regime accessible at the Large Hadron Collider (LHC) [2], the 14 TeV proton-proton collider at CERN. The ATLAS physics program and expected results in the early data taking period are discussed in Ref. [3]. Here we summarize the J/ψ and Υ production and jet energy scale determination.

The LHC will produce charm and beauty quarks in copious quantities, even in its early low luminosity runs. The J/ψ and Υ onia will provide important signals for detector calibration and many physics studies especially in their leptonic final states which are well separated from the huge hadronic background. The separation of prompt and indirect production, for example, will be achieved by means of the tracks' impact parameters. Since such measurements require a good understanding of the detector alignment and calibration, the leptons from well identified onia are suitable for them. From the physics point of view, the production mechanism of quarkonium has many features which are still unexplained and even early measurements can provide important information.

The LHC allows us to explore QCD to much shorter distances. Among other studies, the measurement of the jet cross section to high momentum is of prime importance to find any deviation from the Standard Model expectation. The jet energy calibration is crucial in order to perform reliable measurements.

2 J/ψ and Υ production

2.1 Overview

The CDF J/ψ production cross section measurement [4] highlighted a mysterious aspect in the onium production mechanism, in that the measured value was nearly 50 times larger than the prediction by the Color Singlet Model (CSM) [5, 6], with different p_{T} dependence. The Color Octet Model (COM) was then proposed [7] to rescue the situation, where quarkonia produced with color becomes a singlet by radiating soft gluons in longer distance. The COM was successful in describing the cross section and its p_{T} dependence but turned out not to describe the polarization parameter[2)] α in quarkonium decay [8]. The COM predicts positive α whereas the Tevatron measurements are in general negative for J/ψ.

The Tevatron measurements, however, are also not yet conclusive. The Υ spin alignment measurement [9] by D0 Run2 is not consistent with CDF Run1 measurement, and both disagree with theoretical models. A recent calculation to NNLO* based on the CSM [10] alone can be consistent with the CDF Υ cross section, providing a negative α prediction consistent partially with D0 measurement. From

Received 19 January 2010

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2) The polarization parameter α is defined by $\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*}=C\frac{3}{2\alpha+6}(1+\alpha\cos^2\theta^*)$, where θ^* is the angle between μ^+ in the ψ rest frame and ψ direction in the laboratory frame.

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the experimental systematics point of view, the limited $\cos\theta^*$ coverage (typically $|\cos\theta^*| < 0.6$ by CDF) makes the measurement less reliable.

2.2 Expected ATLAS performance

We present the expected quarkonium production measurements in the muonic decay mode. Two trigger schemes will be used, giving two separate data samples. The first is a dimuon trigger, requiring two muons with $p_T^{\mu 1} > 6$ GeV/c and $p_T^{\mu 2} > 4$ GeV/c. The second is a single muon trigger, requiring one muon with $p_T > 10$ GeV/c. The first favors low $|\cos\theta^*|$ and the second favors high $|\cos\theta^*|$.

In the first sample, at the offline level pairs of reconstructed muons are taken to form the J/ψ candidates, while in the second we form J/ψ's from muon plus track pairs. In each case the common vertex of a dimuon or muon and track is reconstructed at the offline analysis stage to separate the prompt and indirect production. By requiring the pseudo-proper time to be less than 0.2 ps, prompt J/ψ can be selected at 93% efficiency with 92% purity [3].

By combining the two data samples, a wider and flat $\cos\theta^*$ range will be covered as shown in Fig. 1, where reliable spin alignment measurements should be possible both for J/ψ and Υ.

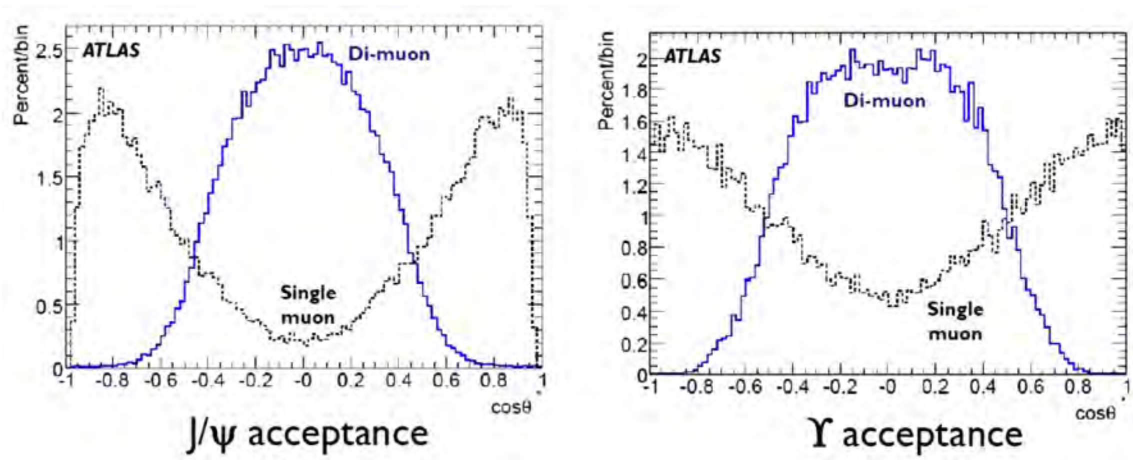

Fig. 1. $\cos\theta^*$ acceptance of (left) J/ψ and (right) Υ, shown for μ6μ4 and μ10 triggers. The events are generated flat in $\cos\theta^*$.

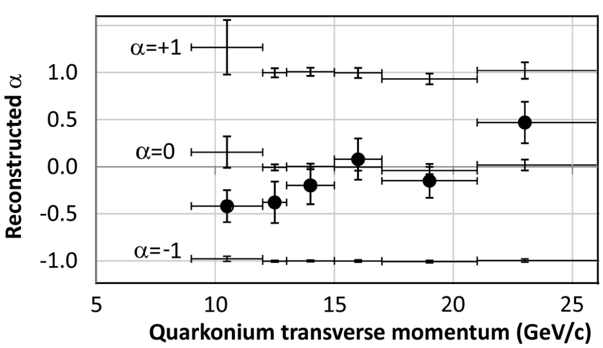

Fig. 2. Reconstructed α at 10 pb^{-1} as a function of quarkonium p_T, shown for J/ψ for input $\alpha = 0, \pm 1$ and for (with circles) Υ for input $\alpha = 0$.

We have estimated the measurement sensitivity to α at 10 pb^{-1} of data at $\sqrt{s} = 1.4$ TeV [3]. The mass resolution of J/ψ (Υ) in the dimuon decay mode is 53 (161) MeV, with negligible background consisting mainly of Drell-Yan events. The mass resolution is not degraded in single-muon triggered events, but the hadronic background will be substantial. The signal-to-noise ratio in the mass window is approximately one for J/ψ and 1/4 for Υ. The background subtraction is manageable for J/ψ with 10 pb^{-1} but is not justified for Υ, for which we require more luminosity.

The precision of the α measurement is shown in Fig. 2, estimated at 10 pb^{-1}. The input α is reconstructed with a precision of 0.02 to 0.06 in J/ψ p_T range of $10 < p_T < 20$ GeV/c, which is comparable to the Tevatron results obtained with ~ 1 fb^{-1} of data. The determination is less precise for Υ due to the limited achievable signal-to-noise ratio.

3 Jet energy scale

The large center-of-mass energy of the LHC allows us to explore the QCD to much shorter distance. Hundreds of jets with $E_T > 1$ TeV can be produced for 10 pb^{-1}, whereas the maximum E_T attainable is 0.7 TeV at the Tevatron.

The jet production measurement involves a number of theoretical uncertainties such as the parton distribution functions (PDFs), and in the factorization and renormalization scales in the QCD calculation. Among the experimental uncertainties, the jet energy scale (JES) contributes most significantly. The steeply falling jet E_T spectrum requires good control of the jet energy. At 1 TeV, 1% (5%) energy scale uncertainty corresponds to 10% (30%) error on the cross section. The typical cross section uncertainty at $E_\mathrm{T}\sim 1$ TeV due to the QCD scale uncertainty is 10% for $p_\mathrm{T}^\mathrm{max}/2<\mu<2p_\mathrm{T}^\mathrm{max}$, and to the PDF uncertainty is 15% estimated using CTEQ6, 6.1 PDF set. Comparing with these theoretical uncertainties, control of JES to 1%–2% is regarded as the target to achieve.

The jet energy measurement starts from signals recorded in the calorimeter cells, followed by two major steps: detector effects corrections (e.g. non-uniform response and non-compensation [3]) and jet-to-particle corrections. The latter step includes the effects such as clustering, initial and final state radiation (ISR and FSR), and the underlying event (UE). The final step is to translate the energy to the parton level.

The validation of the jet calibration will be performed *in-situ* using physics processes. QCD di-jet events are used to check the uniformity of the calibration over the detector prior to the absolute JES calibration, which is performed using energy-balanced processes. Among many possible processes, we present the method using the p_T balance between the jet and γ/Z boson. At very high jet energies, the statistics of these events vanishes. After the validation of JES in the limited p_T range, higher JES will be validated using QCD multijet events by balancing the leading energy jet to the momentum sum of the other jets.

In the energy range $10<E_\mathrm{T}<100-200$ GeV, the Z-jet balance method is effective, as shown in Fig. 3. The p_T of Z is reconstructed from the dilepton into which it decays. A statistical uncertainty of 0.8%–1% can be achieved below 200 GeV with an integrated luminosity of 100 pb^{-1}. The method is sensitive to the correct modeling of the radiation, given by the difference between ALPGEN and PYTHIA data samples. A typical JES systematics is 5%–10% at low E_T due to ISR/FSR and UE uncertainties and 1%–2% at $E_\mathrm{T}\sim 200$ GeV.

The energy range $100–200<E_\mathrm{T}<500$ GeV is covered by the γ-jet balance method (see Fig. 4). The main background is QCD jets, where one of the jets is misidentified as a photon. The leading jet produced in the hemisphere opposite to the leading photon is examined. Two photon selections are considered with tight selection to reduce further the QCD background. At 100 pb^{-1} a statistical precision of 1%–2% is achievable with another 1%–2% from ISR/FSR and UE uncertainties.

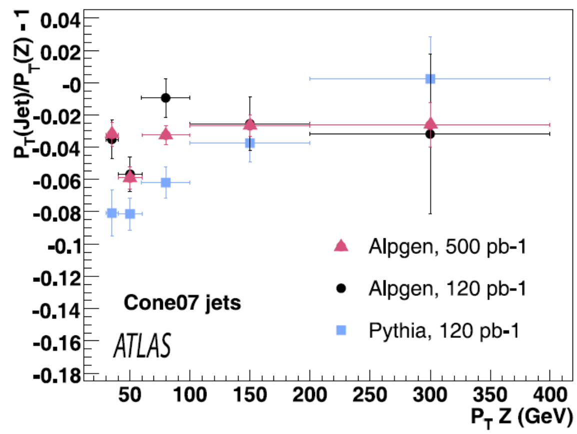

Fig. 3. Jets energy scale obtainable by Z-jet p_T balance method.

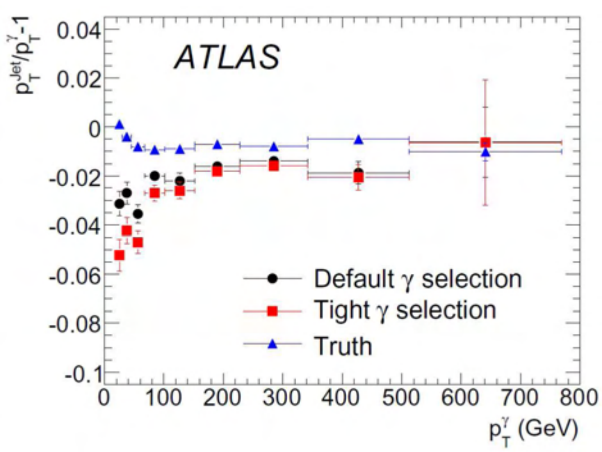

Fig. 4. Jet energy scale obtainable by γ-jet p_T balance method.

In the higher energy range ($E_\mathrm{T}>500$ GeV), the leading jet in multijet events is balanced to the sum of lower energy jets with the JES, which is already calibrated. This method is examined with ALPGEN and PYTHIA generators. A statistical uncertainty of 2% is achieved with 1 fb^{-1} up to 1 TeV while a systematics of 7% is expected due to uncertainty in lower energy jet JES.

To further improve the JES, understanding of ISR/FSR and UE is crucial. ATLAS plans to study these first with the beam[1)]. The azimuthal dijet decorrelation is another piece of information which can quantify the ISR contribution [11].

4 Summary

The ATLAS detector is being commissioned to explore new energy regimes. In early data with 10 pb^{-1} to 1 fb^{-1} integrated luminosity, ATLAS should provide important information on the quarkonium production mechanism and the jet cross section.

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