

LHCb results in proton-nucleus collisions at the LHC

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DOI: <http://dx.doi.org/10.3204/DESY-PROC-2014-04/251>

The forward acceptance of the LHCb detector allows it to probe proton-ion collision in a unique kinematic range, complementary to the other LHC experiments. The production of J/Ψ and Υ -mesons decaying into two muons is studied at the LHCb experiment in proton-lead collisions at a proton-nucleon centre-of-mass energy $\sqrt{s_{NN}} = 5$ TeV. The analysis is based on a data sample corresponding to an integrated luminosity of 1.6 nb^{-1} . The nuclear modification factor and the forward-backward production ratio are determined for J/Ψ and $\Upsilon(1S)$ mesons. Clear suppression of prompt J/Ψ production is observed with respect to the production in pp collisions at large rapidity, while the suppression of J/Ψ from b -hadron decays is less pronounced. The nuclear modification factor for $\Upsilon(1S)$ mesons in the forward region is found to be similar to those for J/Ψ from b -hadron decays. Furthermore a first observation of Z bosons in proton-lead collisions is reported.

1 Introduction

In ultra-relativistic heavy-ion collisions, the production of heavy quarkonia or electroweak bosons are expected to be suppressed with respect to proton-proton collisions, if a quark-gluon plasma, QGP, is created [1]. The suppression of heavy quarkonia and Z boson production with respect to pp collisions can also take place in proton-nucleus (pA) collisions, where a quark-gluon plasma is not expected to be created and only cold nuclear matter effects, such as nuclear absorption, parton shadowing and parton energy loss in initial and final states occur [2, 3, 4]. The study of pA collisions therefore provides important input to disentangle the QGP effects from cold nuclear effects, probe nuclear parton distribution functions which are poorly constrained, and provide a reference sample for nucleus-nucleus collisions.

In early 2013, the LHCb detector [5] collected two data samples corresponding to 1.6 nb^{-1} of proton-lead collisions at a centre-of-mass energy per proton-nucleon pair of $\sqrt{s_{NN}} = 5$ TeV. The two data samples correspond to two different beam configurations, with the proton (lead) beam into the direction of LHCb, referred to as forward (backward). Owing to the asymmetric beam configuration the LHCb acceptance corresponds to $1.5 < y < 4.0$ ($-5.0 < y < -2.5$) for the forward (backward) configuration. Results on J/Ψ [6], Υ [7] and Z [8] production are reported below.

2 J/Ψ and Υ production

J/Ψ [6] and Υ [7] mesons are reconstructed in the di-muon final states with the transverse momentum, p_T , of the di-muon system restricted to $p_T < 14$ GeV/c ($p_T < 15$ GeV/c) for J/Ψ (Υ). The excellent vertexing capability of LHCb allows a separation of prompt J/Ψ mesons and J/Ψ mesons from b -hadron decays (J/Ψ from b). The number of prompt J/Ψ and J/Ψ from b candidates are determined by a combined fit to the di-muon invariant mass and pseudo-proper time distributions. The pseudo-proper time is defined as $t_z = (z_{J/\Psi} - z_{PV}) \times M_{J/\Psi}/p_z$, where $z_{J/\Psi}$ is the z position of the J/Ψ decay vertex, z_{PV} that of the primary vertex, p_z the z component of the measured J/Ψ momentum, and $M_{J/\Psi}$ the mass of the J/Ψ .

Figure 1 shows the projections of the combined fit in two rapidity (y) bins in the forward and the backward region. The number of candidates for J/Ψ from b is about a factor of 10 smaller than for prompt J/Ψ .

The invariant di-muon mass distribution for the Υ candidates of the two samples are shown in Fig. 2. Higher combinatorial background in the backward region is observed for J/Ψ and Υ production due to the larger multiplicity in lead-proton collisions. Measurements for J/Ψ production are performed in three bins of rapidity; the low statistics of the Υ sample do not allow a differential measurement.

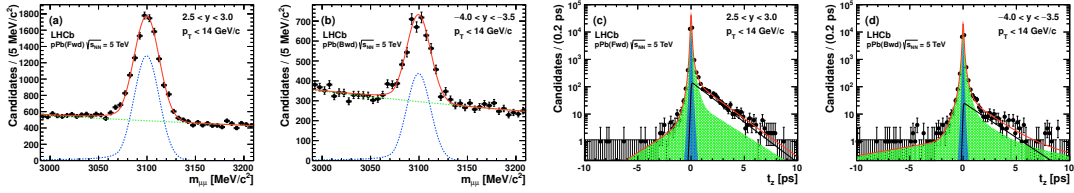


Figure 1: Projections of the combined fit: di-muon invariant mass (left two plots) and pseudo-proper time (right two plots) in the forward and backward region [6].

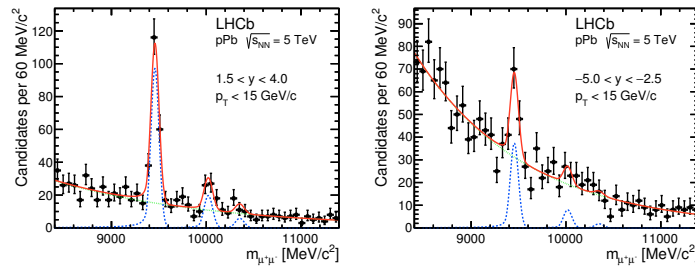


Figure 2: Di-muon invariant mass distribution for Υ candidates in the forward (left) and backward (right) region [7].

3 Cold nuclear effects

Nuclear effects are usually characterised by the nuclear modification factor R_{pA} and the forward-backward production ratio R_{FB} ,

$$R_{pA} = \frac{d\sigma_{pA}/dy}{Ad\sigma_{pp}/dy}, \quad R_{FB} = \frac{d\sigma_{pA(y>0)}/dy}{d\sigma_{pA(y<0)}/dy}, \quad (1)$$

which depend on the production cross-section of a given particle in pA collisions and for R_{pA} also on the cross-section in pp collisions at the same centre-of-mass energy as well as the atomic number A . The advantage of measuring the R_{FB} is that it does not rely on the knowledge of the production cross-section in pp collisions and that experimental systematic uncertainties and theoretical scale uncertainties cancel partially.

To determine the nuclear modification factor R_{pA} , the reference cross-sections in pp collisions at $\sqrt{s_{NN}} = 5$ TeV are needed [9, 10]. These are obtained by a power-law fit to the previous LHCb measurements of J/Ψ and Υ production at 2.76 TeV, 7 TeV and 8 TeV. Figure 3 shows the nuclear modification factors (left two plots) and the forward-backward production ratios (right two plots), for prompt J/Ψ mesons and J/Ψ from b as functions of rapidity [6], compared to different theoretical predictions [2, 11, 3, 4]. A clear suppression of about 40% at large rapidity is observed for prompt J/Ψ production. The measurements agree with most predictions. The data show a modest suppression of J/Ψ from b production in the forward region, with respect to that in pp collisions. This is the first indication of the suppression of b hadron production in proton-lead collisions. The nuclear modification factor and forward-backward production ratio for J/Ψ from b reflect that cold nuclear matter effects on b hadrons are less pronounced than for J/Ψ .

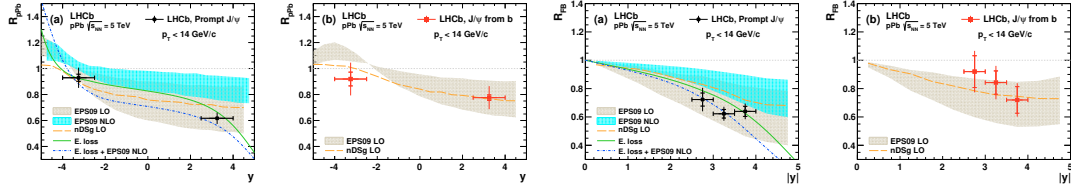


Figure 3: Forward-backward production ratios (R_{FB} , left two plots) and nuclear modification factor (R_{pA} , right two plots) for prompt J/Ψ and J/Ψ from b as functions of rapidity [6] together with theoretical predictions from (yellow dashed line and brown band) [2, 11], (blue band) [3], and (green solid and blue dash-dotted lines) [4].

Figure 4 shows R_{pA} and R_{FB} for $\Upsilon(1S)$ [7] together with the LHCb results of prompt J/Ψ and J/Ψ from b with theoretical predictions. The data are consistent with a suppression in the forward region and a possible enhancement in the backward region. In the forward region, the suppression of $\Upsilon(1S)$ mesons is smaller than that of prompt J/Ψ mesons and similar to J/Ψ from b , indicating that the cold nuclear matter effects on $\Upsilon(1S)$ mesons and J/Ψ from b are similar. Data and theoretical predictions which include coherent energy loss and nuclear shadowing as parametrised with EPOS9 [4] agree within the large experimental uncertainties.

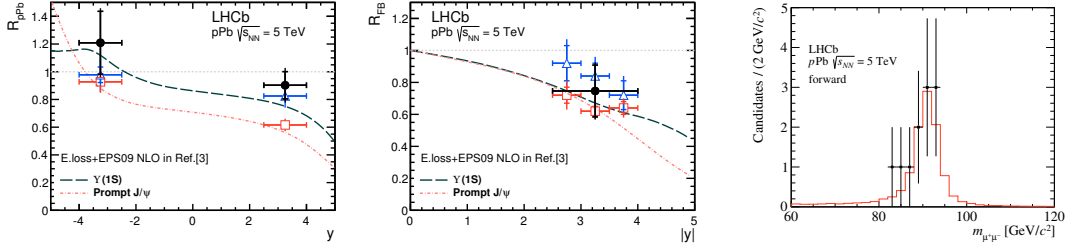


Figure 4: R_{FB} and R_{pA} for Υ , prompt J/ψ and J/ψ from b as functions of rapidity [7] (left two plots) with theoretical predictions including energy loss and nuclear shadowing [4]. Di-muon invariant mass for the Z candidates in the forward sample (right plot) [8].

4 Inclusive Z boson production in proton-lead collisions

The Z candidates are reconstructed in the di-muon final state [8]. Background contributions from muon mis-identification and the decay of heavy flavour mesons are determined from data. A total of 15 candidates are selected with a purity of above 99%, corresponding to a significance of $10.4\sigma(6.8\sigma)$ for the Z signal in the forward (backward) direction. Figure 4 (right plot) shows the di-muon invariant mass of the Z candidates in the forward direction. The inclusive Z boson production cross-section is measured to be $\sigma(Z \rightarrow \mu\mu) = 13.5^{+5.4}_{-4.0} \pm 1.2$ nb in the forward and $\sigma(Z \rightarrow \mu\mu) = 10.7^{+8.4}_{-5.1} \pm 1.0$ nb in the backward configuration, where the first uncertainty is statistical and the second systematic. The large experimental uncertainties do not allow definite conclusions on the presence of nuclear effects.

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