Measurements of Forward Jet Production in Polarized \(pp\) Collisions at \(\sqrt{s} = 500\) GeV\(^1\)

L. Nogach for the \(A_s\)DY collaboration

Institute of High Energy Physics, Protvino, Russia

Abstract — The \(A_s\)DY project at RHIC was proposed to measure the analyzing power for Drell–Yan production. Test runs took place during polarized proton operations of RHIC in 2011 and 2012 with a model of the \(A_s\)DY apparatus in place. In total, an integrated luminosity of 9 pb\(^{-1}\) with beam polarization of 50\% was sampled. The primary detector components were a hadron calorimeter (HCal) that spanned the pseudorapidity interval \(2.4 < \eta < 4.0\) and a small electromagnetic calorimeter (ECal). Basic goals for \(A_s\)DY test running were to establish the impact of a third interaction region on RHIC performance and to demonstrate HCal calibration. Energy scale of HCal was established using neutral pion reconstruction and checked with hadronic response. In addition, data with a trigger based on HCal energy sum were taken to study jet events. First measurements of analyzing power in the forward jet production are reported.

DOI: 10.1134/S1063779614010705

1. INTRODUCTION

Large transverse single spin asymmetries (SSA) measured in inclusive pion production in \(pp\)-collisions [1, 2] have stimulated significant theory development to understand the spin structure of the proton. However, this process is not easy to describe due to contributions from several mechanisms related to initial and final state interactions. Simpler processes from the theoretical point of view, such as Drell–Yan, prompt photon or jet production, should be considered to disentangle the different mechanisms. In particular, inclusive jet production is of interest since it has no final state (Collins effect) contribution, and arises only from the Sivers effect. From naive expectations, jet SSA should be small because jets integrate over charged and neutral pions, and opposite sign asymmetry for \(\pi^+\) and \(\pi^-\) leads to cancellations. Theoretical models also expect jet SSA in the forward region to be small [3, 4].

First measurements of forward jet production in polarized \(pp\)-collisions were performed at RHIC 2 o'clock interaction region (IP2) during two \(A_s\)DY test runs: at \(\sqrt{s} = 500\) GeV in 2011 and \(\sqrt{s} = 510\) GeV in 2012. The \(A_s\)DY setup in 2011 run is described in [5], and included zero-degree calorimetry (ZDC) for luminosity monitoring and a check of polarization response. In addition, data with a trigger based on HCal energy sum were taken to study jet events. First measurements of analyzing power in the forward jet production are reported.

2. JET RECONSTRUCTION

The energy scale for HCal was set based on neutral pion calibration [6] with a crude adjustment for hadronic compensation from PYTHIA/GEANT simulations: \(E' = 1.12 \times E - 0.1\) GeV, where \(E\) is the incident energy. This calibration enabled \(\pi^0\) and \(E'\) for HCal cells to be used in jet reconstruction. \(\pi^0\) and \(E'\) for HCal cells were used in jet finding for the 2011 run.

Two algorithms were used for jet reconstruction. The cone jet finder starts from a seed (high tower in the triggering region of the detector), sums energy in the cone of radius \(R = 0.7\) in \((\eta - \phi)\) space (where \(\eta\) is the pseudorapidity and \(\phi\) is the azimuthal angle relative to the beam direction) around the high tower and defines the jet axis from energy-weighted \(\langle \eta \rangle\) and \(\langle \phi \rangle\). Then an iterative procedure is applied until convergence of the jet axis: (1) sum energy in the cone of radius \(R\) about \(\langle \eta N \rangle\), \(\langle \phi N \rangle\) \((N\) is the iteration number); and (2) compute energy-weighted \(\langle \eta_{N+1} \rangle\), \(\langle \phi_{N+1} \rangle\).

The recently developed anti-kT algorithm [7] introduces a distance measure and uses sequential recombination of cells (clusters) to form jets. For cluster pair \(i\) and \(j\), the distance is computed as \(d_{ij} = \min(k_{T,i}^2, k_{T,j}^2) \times (R_{ij}^2/R^2)\), where \(k_{T,i} = E_i/cosh(\eta_i)\) is higher compared to the 2011 run. Data were taken with two basic triggers: (1) energy sum in HCal Left/Right half, excluding two outer perimeters to ensure that jets are contained in the detector, with the threshold \(\sim 35\) GeV; (2) energy sum in ECal to measure trigger bias on jets.

\(^1\) The article is published in the original.
the transverse momentum assuming zero mass for the incident particle, \( R^2_{ij} = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2 \), and \( R = 0.7 \) is used. If \( d_{ij} < 1/k^2_{T,j} \) for any \( i \), the clusters are merged and the procedure is repeated, otherwise cluster \( j \) is considered as a jet. Finally, energy and acceptance cuts were imposed to select “good” jets: \( E_{\text{jet}} \geq 30 \text{ GeV}, |\eta_{\text{jet}} - 3.25| < 0.25, |\phi_{\text{jet}} - \phi_{\text{off}}| < 0.5 \), where \( \phi_{\text{off}} = 0 (\pi) \) for the Left (Right) module.

Jet shape and transverse momentum distributions from the two algorithms are shown in Fig. 1 for the jet-triggered data and simulations. There is good agreement between the data and simulations above the trigger threshold for both algorithms. There are some quantitative differences between the algorithms: cone jets have more steeply falling \( p_T \) distribution and more narrow jet shape than observed for anti-\( k_T \) jets. This is likely related to additional “out-of-cone” cells acquired by the anti-\( k_T \) algorithm. Hard-scattered partons are strongly correlated with jets, and the jet energy scale is checked by correlating “tower” jets reconstructed from PYTHIA/GEANT (i.e., full detector response) simulations versus jets reconstructed from particles generated by PYTHIA, as shown in Fig. 1c.

3. JET ANALYZING POWER

The jet asymmetry was calculated from yields in the Left/Right module sorted by the polarization direction of the beam heading towards the detector for \( x_F > 0 \) and the opposite beam for \( x_F < 0 \):

\[
\epsilon = P_{\text{Beam}} A_N = \frac{N^{+}_{L(R)} - N^{-}_{L(R)}}{N^{+}_{L}N^{-}_{R} + N^{-}_{L}N^{+}_{R}},
\]

where \( N^{\pm}_{L(R)} \) is the number of jet events in the Left (Right) module for the spin direction up (down), as determined from our measured ZDC spin asymmetries. This method relies on mirror symmetry in the setup geometry, and cancels systematics, such as detector and luminosity asymmetries, through second order. To check time-dependent systematics, the asymmetry \( \epsilon \) was computed in \( x_F \) bins for each RHIC fill and fitted by a constant function. \( \chi^2 \) per degree of freedom from these fits were close to 1, meaning that systematic errors are small. Bunch shuffling, i.e. random reversing of the spin direction for half of the filled bunch crossings that creates effectively unpolarized collisions, was used as another estimate of systematics. Mean value of the asymmetry calculated for ~100 random patterns was \( \sim 10^{-4} \), resulting in the systematic uncertainty in \( A_N \) less than 2 \times 10^{-4}.

The analyzing power \( A_N \) was calculated using fill-averaged beam polarization 0.52 for both beams, and is shown in Fig. 2 for the cone and anti-\( k_T \) jet finders. The results from the two algorithms are consistent within statistical errors. \( A_N \) at \( x_F > 0 \) is small (\( \sim 10^{-3} \)) and positive (up to 6\( \sigma \)). Jet \( A_N \) was also measured for...
ECal-triggered events, and turned out to be at the level $(1-3)\%$ for $x_F > 0$. This likely means that trigger bias imposed by electromagnetic calorimeter prefers jets that fragment to a hard neutral pion.

We have found the jet analyzing power to be small and positive. Although our measurements can help to further constrain the Sivers functions, it is most important to measure the analyzing power for Drell-Yan production as a test of present understanding.

The work was partially supported by RFBR grant 12-02-00797.

**Fig. 2.** Jet $A_N$ as a function of $x_F$ for jet-triggered events. Cone jet points are shifted from the mean $x_F$ value in the bin by $-0.01$, and anti-$k_T$ jet points are shifted by $0.01$. Error bars indicate statistical errors.

### REFERENCES

1. D. L. Adams et al., Phys. Lett., Ser. B 261, 201 (1991); **264**, 462 (1991).
2. B. Abelev et al., Phys. Rev. Lett. **101**, 222001 (2008).
3. U. D'Alesio, F. Murgia, and C. Pisano, arXiv:1011.2692.
4. Z.-B. Kang et al., arXiv:1103.1591.
5. L. Nogach et al., arXiv:1112.1812.
6. C. Perkins, arXiv:1109.0650.
7. M. Cacciari, G. P. Salam, and G. Soyez, JHEP **0804**, 063 (2008).