Angular Distributions of Pion-induced Drell–Yan Production

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on behalf of COMPASS Collaboration

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The angular distributions of unpolarized pion-induced Drell–Yan process are important information from which we explore both perturbative and non-perturbative QCD effects. We measure the Drell–Yan production from a 190 GeV π^- beam interacting with NH_3 and W targets in the COMPASS experiment at CERN. We present the estimated statistical uncertainty of unpolarized azimuthal asymmetries (λ, μ, ν) in the pion-induced Drell–Yan process from the data taken in 2015 in comparison with results published by the past NA10 and E615 experiments.

KEYWORDS: COMPASS, Drell–Yan process, Unpolarized Azimuthal Asymmetries, QCD

1. Introduction

1.1 The Drell–Yan Process

The Drell–Yan (DY) process occurring in hadron-hadron collisions is the annihilation of a quark and antiquark into a lepton pair which goes through intermediate virtual photon production. It is an important tool to access the Parton Distribution Functions (PDF) of the colliding hadrons. The DY unpolarized azimuthal asymmetries are commonly defined in the Collins–Soper (CS) frame [1]. The frame is sketched in Fig. 1.
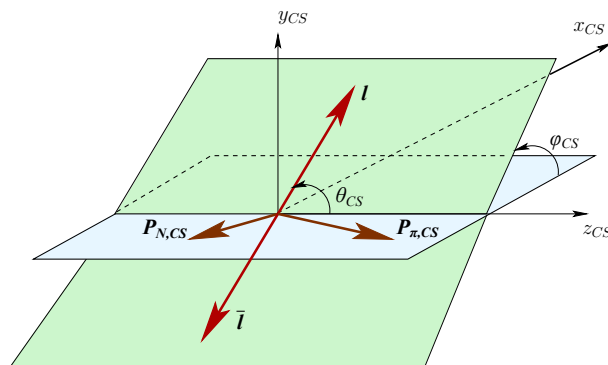

Fig. 1.: The Collins-Soper virtual-photon rest frame.

1.2 Unpolarized Azimuthal Asymmetries

The unpolarized part of the DY differential cross section in $d\Omega = d(\cos\theta_{CS})d(\varphi_{CS})$ can be written as follows:

$$\frac{d\sigma}{d\Omega} \propto \frac{3}{4\pi}\frac{1}{\lambda+3}\left[1 + \lambda\cos^2\theta_{CS} + \mu\sin 2\theta_{CS}\cos\varphi_{CS} + \frac{\nu}{2}\sin^2\theta_{CS}\cos 2\varphi_{CS}\right] \qquad (1)$$

In the naive DY model, the virtual photon which is formed by annihilation of quark and antiquark is transversely polarized, meaning that the lepton angular distribution varies as $1+\cos^2\theta_{CS}$ (i.e. $\lambda = 1$, $\mu = 0$, $\nu = 0$). Beyond the purely electromagnetic naive DY model, if one takes into account QCD corrections, the so-called Lam–Tung relation [2] is still expected to hold: $1-\lambda = 2\nu$, which translates into an additional non-zero dependence on $\cos 2\varphi_{CS}$. But the Lam–Tung relation was found to be violated in past pion-induced DY experiments [3,4].

An explanation to the $\cos 2\varphi_{CS}$ dependence observed in the DY process was meanwhile proposed, by introducing a non-perturbative transverse-momentum dependent (TMD) Boer–Mulders function [5] at small transverse momentum of the lepton pair.

The amplitudes of the azimuthal modulations appearing in the cross section description are usually called unpolarized azimuthal asymmetries (UAs). The DY UAs were studied by two fixed-target experiments in the past. During the '80s, NA10 [3] at CERN was one of the pioneering DY-experiments. The experiment performed a series of pion-induced DY measurements using different beam energies (140, 194 and 286 GeV). A large sample of 152,000 DY events for dimuon masses $M_{\mu\mu} > 4.05$ GeV/c^2, was collected using the 194 GeV beam and a tungsten target.

In the meantime during the '80s, unpolarized DY measurements were also performed by the E615 collaboration at Fermilab, using 252 GeV π^- beam scattering off a tungsten target. The results, presented in Ref. [4], were obtained from the analysis of 36,000 DY events with $M_{\mu\mu} > 4.05$ GeV/c^2.

2. CERN/COMPASS-II Experiment

COMPASS is a high-energy physics fixed-target experiment at the CERN M2 beam line. It aims at studying hadron structure and hadron spectroscopy with high intensity muon and hadron beams. The first world measurement of polarized Drell–Yan was performed by COMPASS in 2015, with a beam of negative pions and a transversely polarized proton target. After this successful measurement, a second year of DY data taking followed in 2018.

3. Ongoing Data Analysis

The statistical uncertainty projections of DY UAs presented here are based on DY data collected by COMPASS in 2015. The 190 GeV/c π^- beam interacted with two NH$_3$ target cells transversely polarized in opposite directions, followed by an aluminum target and, more downstream, several tungsten cells which acted as beam dump. Events with two outgoing muons originating from the target region fired the physics trigger, being recorded for analysis. The reconstructed vertices are formed by one beam track and one opposite sign muon pair. The vertices distribution along the beam direction is presented in Fig. 2 left panel. The event selection criteria are nearly identical to those used in the COMPASS DY TSAs (Transverse Spin Asymmetries) analysis [7]. The contamination in the DY sample from other physics sources is estimated by Monte-Carlo simulation, as shown in the dimuon mass spectrum of Fig. 2 right panel, for events from the NH$_3$ target. In the chosen invariant mass range, between 4.3 and 8.5 GeV/c^2, the DY purity is estimated to be about 96%. A stricter invariant mass cut of $4.7 < M_{\mu\mu}/(\text{GeV}/c^2) < 8.5$ and z-vertex cut $-30 < z/(cm) < -20$ was adopted for W target.
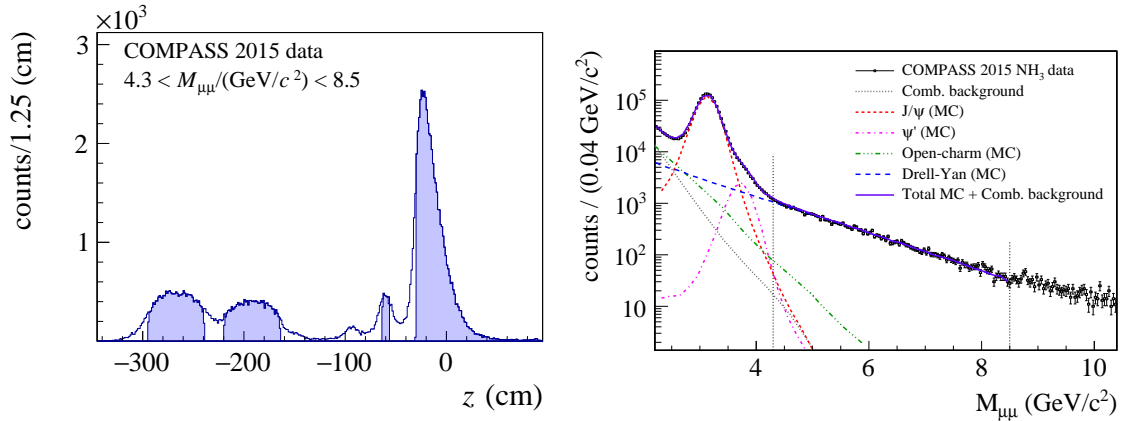
Fig. 2.: Left panel: The reconstructed vertex distribution along the beam line. Right panel: The invariant mass distribution from NH_3 target.

4. Statistical Uncertainty Projection

The projected statistical uncertainties of DY UAs from the COMPASS 2015 data are presented in Fig. 3, as a function of the transverse momentum of the lepton pair (q_T). In the same figure, the published results from NA10 [6] and E615 [4] experiments are also shown for comparison. The fact that the COMPASS statistical uncertainties are expected to be larger in the UAs from W target as compared to NH_3 target is due to the stricter lower mass cut at 4.7 GeV/c^2, and also to the selection of events originating in only the first 10 cm of W target. The latter allows to minimize the contamination from Drell–Yan events induced by secondary hadrons.

The smaller COMPASS q_T coverage as compared to other experiments is due to an additional cut applied: $0.4 < q_T/(GeV/c) < 3$. The lower limit is set to ensure a reasonably good resolution for the azimuthal angles, and the upper limit is to remove badly reconstructed events, while ensuring the applicability of TMDs approach. The significant inconsistency in the UAs extraction (a factor of 2 in ν) between NA10 and E615 result is observed in the region $q_T < 1.5$ GeV/c.

Once the analysis is finalized, the COMPASS extracted Drell–Yan unpolarized asymmetries may contribute to clarify the observed discrepancies, and to test the Lam–Tung relation taking into account all the statistical and systematical uncertainties involved.

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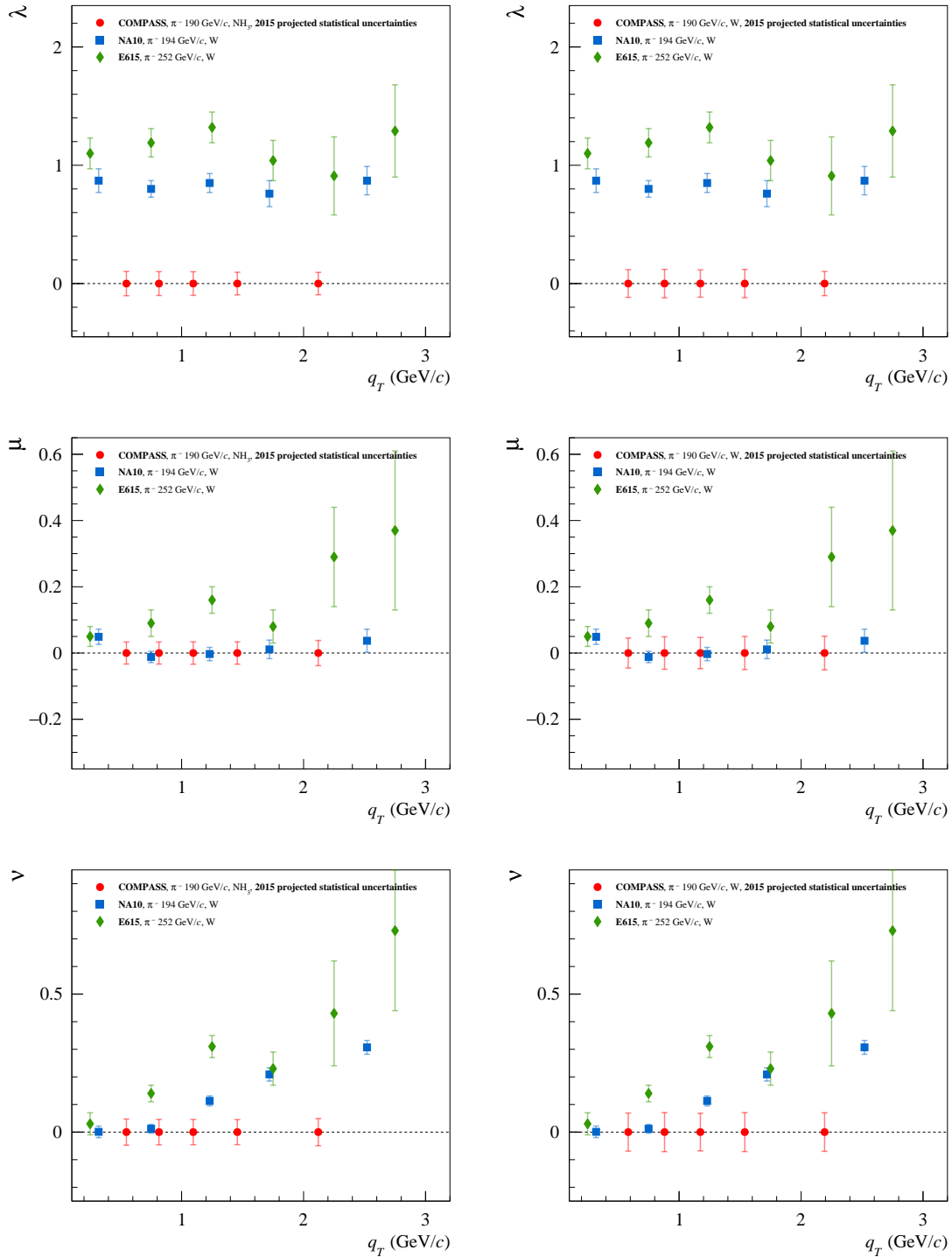
Fig. 3.: The projected statistical uncertainties of λ (top row), μ (middle row) and ν (bottom row) as a function of q_T. Left column: COMPASS asymmetry uncertainties from NH_3 target. Right column: COMPASS asymmetry uncertainties from W target. Published results from NA10 and E615 results are also shown for comparison.