Polarization of exclusive dielectron production in pion-nucleon collisions

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Introduction

A detailed understanding of elementary hadronic reactions is an important prerequisite for studies of nuclear collisions. The HADES collaboration at GSI has recently studied pion-induced reactions, including dielectron production. First preliminary data have been presented at the NSTAR2015 conference [1].

\begin{itemize}
  \item Study $\pi N \to R \to N e^+ e^-$ in terms of an effective Lagrangian model at the center of mass energy of the HADES experiment.
  \item GOAL: extract information on the quantum numbers of the intermediate resonance $R$ by means of the anisotropy coefficient.
  \item Help to disentangle different sources in hadron collisions and potentially in heavy-ion collisions.
\end{itemize}

Anisotropy coefficient

Angular distribution:

$$\frac{d\sigma}{dM \cos \theta_c d \cos \theta_e} \sim \sum_\perp (1 + \cos^2 \theta_e) + \sum_\parallel (1 - \cos^2 \theta_e),$$

(1)

$\sum_\perp$ and $\sum_\parallel$ are the contributions of the transverse and parallel polarizations of the virtual photon. $M$ is the dilepton invariant mass.

$$B(\theta, M) = \frac{\sum_\perp - \sum_\parallel}{\sum_\perp + \sum_\parallel},$$

(2)

$B$ is the anisotropy coefficient (first studied in [2]). $B$ provides information on the polarization of the virtual photon and hence on the quantum numbers of the baryon resonance.

Angular momentum coupling:

$$J_R = L + S_N,$$

(4)

$$M_R = M_L + M_N = M_N = \pm \frac{1}{2} \quad (Y_L M_L(0, 0) = 0 \text{ for } M_L \neq 0).$$

(5)

– Resonance with $J_R = \frac{1}{2}$ ⇒ all the states are populated
⇒ Isotropic distribution in $\theta_{\gamma^*}$.

– Resonance with $J_R = \frac{3}{2}$ ⇒ not all the states are populated
⇒ Anisotropic distribution in $\theta_{\gamma^*}$.

The model

\begin{itemize}
  \item Gauge invariant vector meson dominance for the $p-\gamma^*$ vertex [4]:
  $$\mathcal{L}_{p\gamma} = -\frac{e}{2m_p} F_{\mu\nu} p_\mu p_\nu.$$
\end{itemize}

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$ and $p_{\mu\nu} = \partial_\mu p_\nu - \partial_\nu p_\mu$.

Effective interaction Lagrangians for baryons up to spin-5/2 with $\pi$ & $\rho$ [3]:

\begin{align*}
\mathcal{L}_{R\pi NN} &= -\frac{9R N}{m_\pi} \bar{\psi}_R \Gamma^{\mu\nu} \gamma_\mu \gamma_\nu \psi_N \cdot \partial_\nu \vec{\sigma} + h.c., \\
\mathcal{L}_{R\rho NN} &= -\frac{9R N}{m_\rho} \bar{\psi}_R \gamma_\mu \gamma_\nu \psi_N \cdot \partial_\nu \partial_\mu + h.c., \\
\mathcal{L}_{R\pi NN} &= -\frac{9R N}{m_\pi} \bar{\psi}_R \gamma_\mu \gamma_\nu \psi_N \cdot \partial_\nu \partial_\mu + h.c., \\
\mathcal{L}_{R\rho NN} &= -\frac{9R N}{m_\rho} \bar{\psi}_R \gamma_\mu \gamma_\nu \psi_N \cdot \partial_\nu \partial_\mu + h.c., \\
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\mathcal{L}_{R\rho NN} &= -\frac{9R N}{m_\rho} \bar{\psi}_R \gamma_\mu \gamma_\nu \psi_N \cdot \partial_\nu \partial_\mu + h.c.,
\end{align*}

(7) \quad (8) \quad (9) \quad (10) \quad (11) \quad (12)

$\Gamma = \gamma_5 \mu_0$ for $J^P = 1/2^+$, $3/2^-$ and $5/2^+$ resonances and $\Gamma = 1$ otherwise, and $\Gamma = \gamma_5 \mu_0$ and $\psi_{\mu_0}$ are the Rarita-Schwinger fields for the spin-3/2 and -5/2 baryon resonance, respectively.

Results (preliminary)

The anisotropy coefficient as a function of $\theta_\gamma$ for hypothetical resonance states with different spins and parities at $M = 0.5$ GeV. The resonance masses and widths are chosen to be $\pm 0.5$ and $\pm 0.1$ GeV. Left panel: Only the $s$-channel is included. Right panel: The $s$- and $n$-channel contributions and their interference are included.

Spin and parity of the intermediate resonance is reflected in a characteristic angular dependence of the anisotropy coefficient.

Outlook

\begin{itemize}
  \item Add non-resonant terms.
  \item Study hadronic final states.
  \item Consider interaction Lagrangians which contain only physical degrees of freedom for higher-spin resonances [6].
  \item Study polarization effects in hot and dense nuclear systems.
\end{itemize}

References