Polarization of exclusive dielectron production in pion-nucleon collisions

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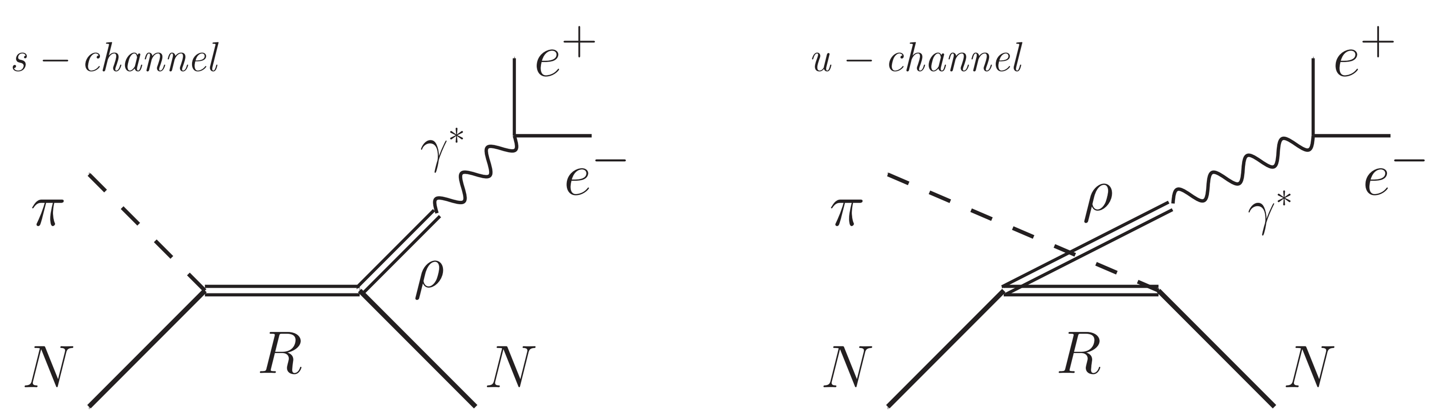
Introduction

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 dilepton production. First preliminary data have been presented at the NSTAR2015 conference [1].

- Study $\pi N \to R \to Ne^+e^-$ in terms of an effective Lagrangian model at the center of mass energy of the HADES experiment.



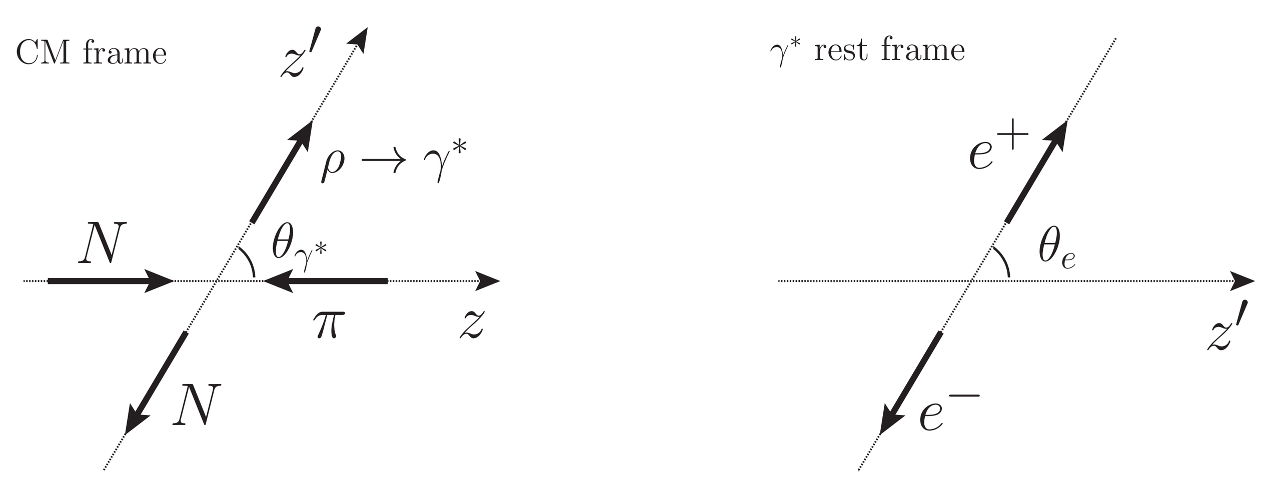
- GOAL: extract information on the quantum numbers of the intermediate resonance R by means of the anisotropy coefficient.
- Help to disentangle different sources in hadron collisions and potentially in heavy-ion collisions.

Anisotropy coefficient

Angular distribution:

$$\frac{d\sigma}{dM d\cos\theta_{\gamma^*} d\cos\theta_e} \sim \Sigma_\perp (1+\cos^2\theta_e) + \Sigma_\parallel (1-\cos^2\theta_e), \tag{1}$$

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



$$\frac{d\sigma}{dM d\cos\theta_{\gamma^*} d\cos\theta_e} \sim A(1+B\cos^2\theta_e), \tag{2}$$

$$B(\theta_{\gamma^*}, M) = \frac{\Sigma_\perp - \Sigma_\parallel}{\Sigma_\perp + \Sigma_\parallel}. \tag{3}$$

- 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:

$$\vec{J}_R = \vec{L} + \vec{S}_N \tag{4}$$

$$M_R = M_L + M_N = M_N = \pm\frac{1}{2} \qquad (Y_{LM_L}(0,0) = 0 \text{ for } M_L \neq 0) \tag{5}$$

- Resonance with $J_R = \frac{1}{2} \Rightarrow$ all the states are populated
  $\Rightarrow$ Isotropic distribution in θ_{γ^*}.
- Resonance with $J_R \geq \frac{3}{2} \Rightarrow$ not all the states are populated
  $\Rightarrow$ Anisotropic distribution in θ_{γ^*}.

The model

- Gauge invariant vector meson dominance for the ρ-γ^* vertex [4]:

$$\mathcal{L}_{\rho\gamma} = -\frac{e}{2g_\rho} F^{\mu\nu}\rho_{\mu\nu}, \tag{6}$$

$F^{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ and $\rho_{\mu\nu} = \partial_\mu \rho_\nu - \partial_\nu \rho_\mu$.

- Effective interaction Lagrangians for baryons up to spin-5/2 with π & ρ [3]:

$$\mathcal{L}_{R_{1/2}N\pi} = -\frac{g_{RN\pi}}{m_\pi}\bar{\psi}_R \Gamma\gamma^\mu \vec{\tau}\psi_N \cdot \partial_\mu\vec{\pi} + \text{h.c.}, \tag{7}$$

$$\mathcal{L}_{R_{3/2}N\pi} = \frac{g_{RN\pi}}{m_\pi}\bar{\psi}_R^\mu \Gamma \vec{\tau}\psi_N \cdot \partial_\mu\vec{\pi} + \text{h.c.}, \tag{8}$$

$$\mathcal{L}_{R_{5/2}N\pi} = \frac{g_{RN\pi}}{m_\pi}\bar{\psi}_R^{\mu\nu} \Gamma \vec{\tau}\psi_N \cdot \partial_\mu\partial_\nu\vec{\pi} + \text{h.c.}, \tag{9}$$

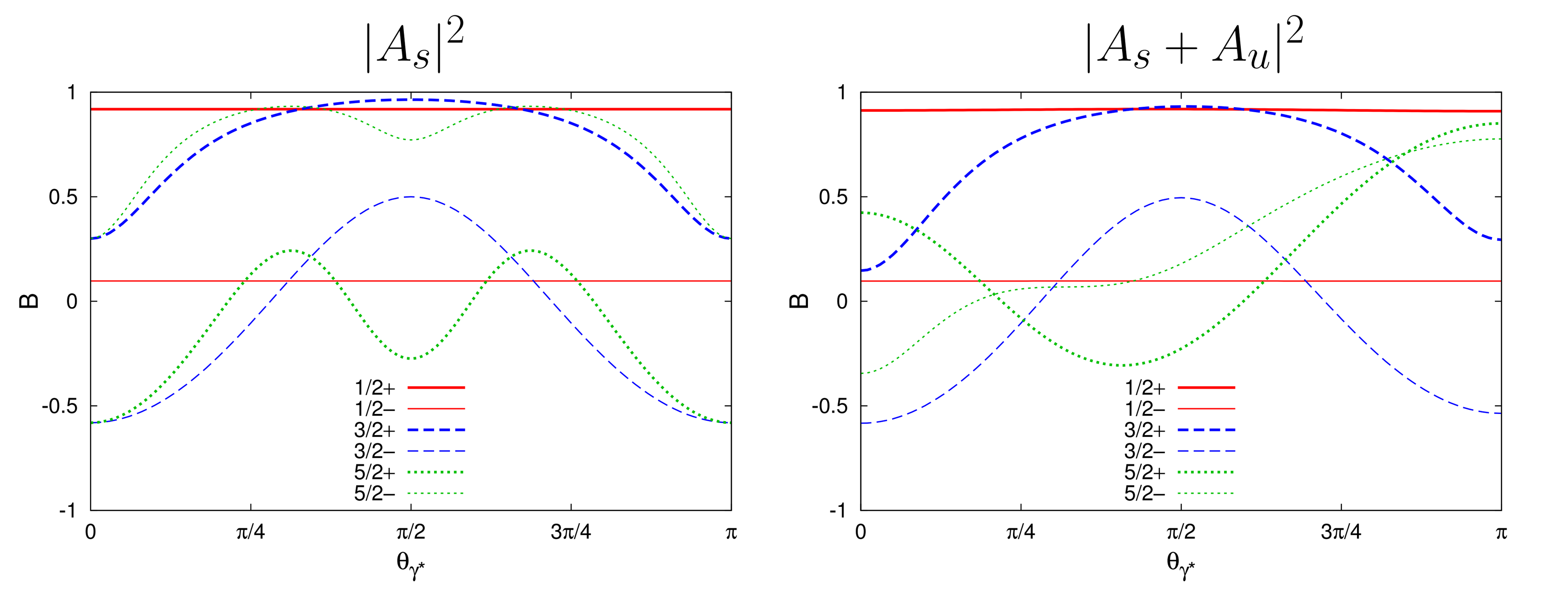
$$\mathcal{L}_{R_{1/2}N\rho} = \frac{g_{RN\rho}}{2m_\rho}\bar{\psi}_R \vec{\tau}\sigma^{\mu\nu}\tilde{\Gamma}\psi_N \cdot \vec{\rho}_{\mu\nu} + \text{h.c.}, \tag{10}$$

$$\mathcal{L}_{R_{3/2}N\rho} = -\frac{ig_{RN\rho}}{m_\rho}\bar{\psi}_R^\mu \vec{\tau}\gamma^\nu\tilde{\Gamma}\psi_N \cdot \vec{\rho}_{\mu\nu} + \text{h.c.}, \tag{11}$$

$$\mathcal{L}_{R_{5/2}N\rho} = -\frac{ig_{RN\rho}}{m_\rho}\bar{\psi}_R^{\mu\rho} \vec{\tau}\gamma^\nu\tilde{\Gamma}(\partial_\rho\psi_N) \cdot \vec{\rho}_{\mu\nu} + \text{h.c.} \tag{12}$$

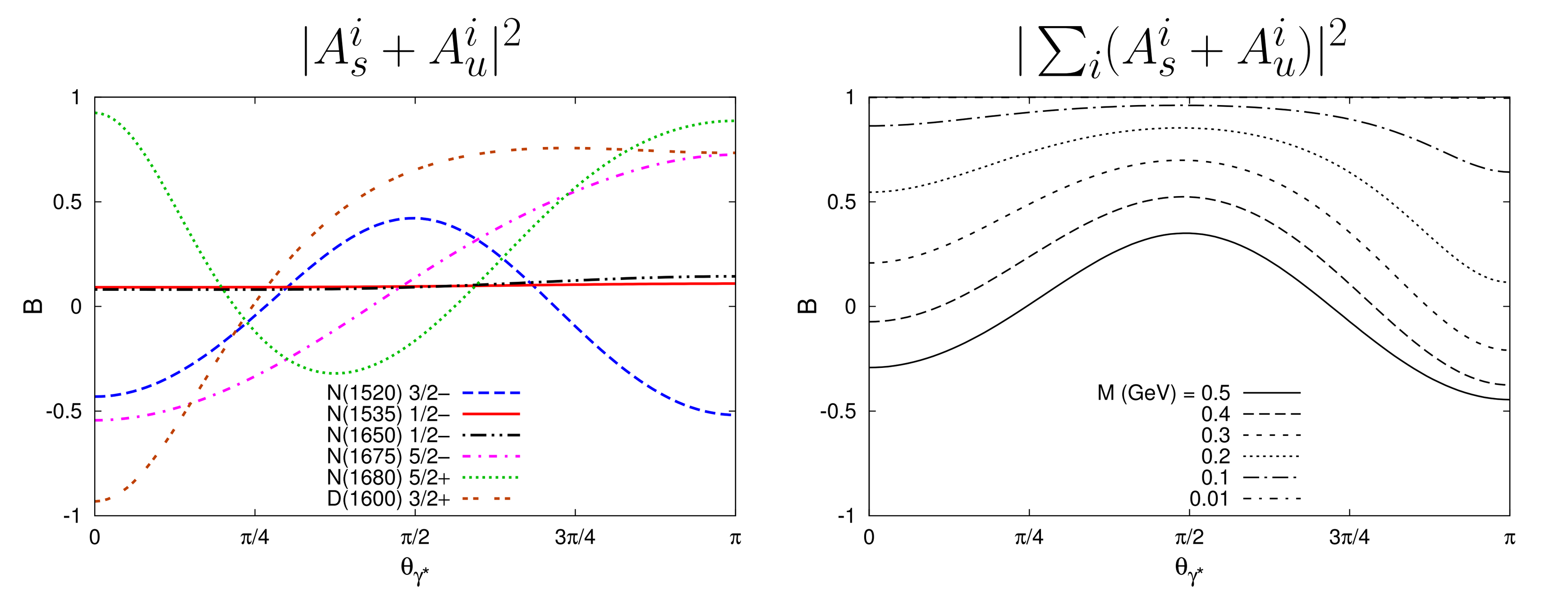
$\Gamma = \gamma_5$ for $J^P = 1/2^+, 3/2^-$ and $5/2^+$ resonances and $\Gamma = 1$ otherwise, and $\tilde{\Gamma} = \gamma_5\Gamma$. ψ_R^μ and $\psi_R^{\mu\nu}$ are the Rarita-Schwinger fields for the spin-3/2 and -5/2 baryon resonance, respectively.

Results (preliminary)



The anisotropy coefficient as a function of θ_{γ^*} for hypothetical resonance states with different spins and parities at $M = 0.5$ GeV. The resonance masses and widths are chosen to be $\sqrt{s} = m_R = 1.49$ GeV and $\Gamma_R = 0.15$ GeV. Left panel: Only the s-channel is included, Right panel: The s- and u-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.



The anisotropy coefficient as a function of θ_{γ^*} at $\sqrt{s} = 1.49$ GeV obtained with six different resonance states using the physical masses [5]. The s- and u-channel diagrams are computed including the interference terms. Left panel: The contribution of the individual resonances at $M = 0.5$ GeV. Right panel: The resonance amplitudes are added coherently for different values of M.

- Shapes are modified by the off-shellness ($\sqrt{s} \neq m_R$) of the s-channel resonance contributions. Model dependence is still to be explored.
- Rough binning both in M and θ_{γ^*} would be sufficient for extracting information on polarization.

Outlook

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

References

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