Has vector meson polarization the impact on its interaction with matter?

Sergey Gevorkyan

LHEP, Joint Institute for Nuclear Research

CHPI-2020, 05 February

Vector mesons $V = \rho, \omega, \varphi, K^*(892)$ etc. can be transversely (helicity $\lambda = \pm 1$) or longitudinally $\lambda = 0$ polarized.

Why the knowledge of $\sigma_T(VN)$ and $\sigma_L(VN)$ is important?

Color transparency:

According to QCD hard exclusive processes select configurations, where the quarks are close together forming a color neutral object with transverse size $r \sim 1/Q$. Similar effect is well known in QED in photoproduction of e^+e^- pairs (Chudakov effect).

The effect of color transparency is seen in electroproduction of vector mesons on nuclei as a grows of nuclear transparency $T_A = \frac{d\sigma_A}{Ad\sigma_N}$ with the mass of virtual photon Q^2 (weakening absorption)

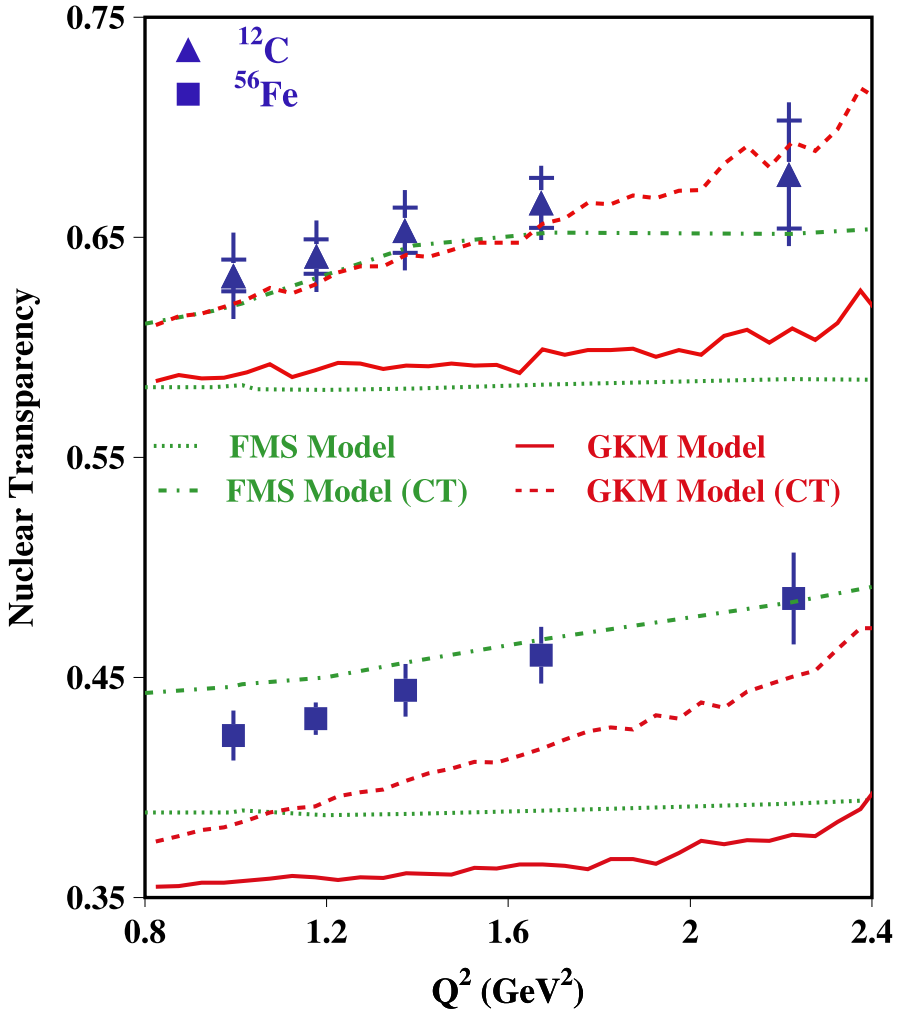
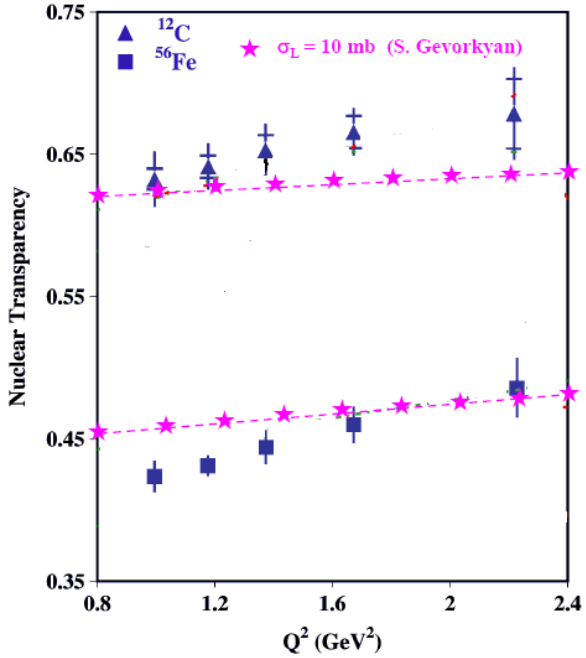


Figure: Nuclear transparency $T_A = \frac{d\sigma_A}{A d\sigma_N}$ as a function of Q^2.



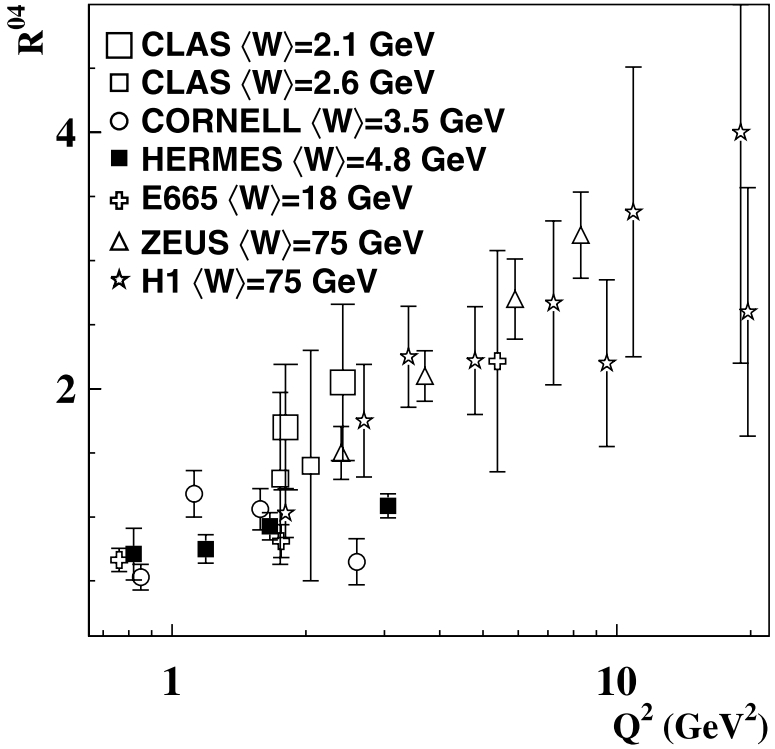


Figure: Nuclear transparency $T_A = \frac{d\sigma_A}{Ad\sigma_N}$ as a function of Q^2. Experimental data are from CLAS, JLab (left). Q^2 dependence of the ratio of the longitudinal-to-transverse cross sections $R = \frac{\sigma(\gamma+p\to\rho_L+p)}{\sigma(\gamma+p\to\rho_T+p)}$ for exclusive ρ^0 electroproduction on the proton(right).

Vector mesons absorption in nuclei

In the late 60's and early 70's many experiments on vector mesons $V(\rho, \omega, \phi)$ photoproduction on nuclei have been done at SLAC, DESY, Cornell etc. to check the predictions of vector dominance model and quark model which for instance predict:
$\sigma(\rho N) = \sigma(\omega N) = \frac{\sigma(\pi^+ N)+\sigma(\pi^- N)}{2}$.
At that time the possibility of vector meson polarization impact on its interaction with nucleons has not been considered, as the naive quark model predicts that $\sigma_T(VN) = \sigma_L(VN)$.
Moreover in vector mesons coherent photoproduction which is huge and has clear and unique theoretical predictions, only transverse vector mesons can be produced. As to the incoherent region to extract $\sigma_L(VN)$ one has to pick out the process, where the longitudinally polarized vector mesons can be produced, which is not the case for ρ, φ photoproduction, where s-channel helicity conservation takes place at moderate momenta transfer.

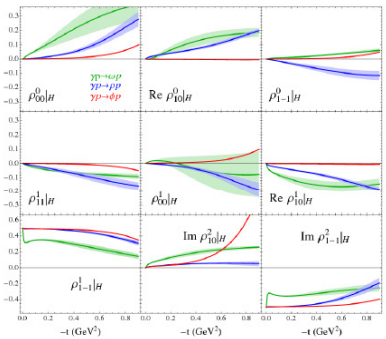
ω meson photoproduction off nuclei

Recently we proposed to measure the incoherent photoproduction of ω mesons on nuclei, where appreciable part of ω's can be produced longitudinally polarized.

1.E. Chudakov, SG, A. Somov " Photoproduction of ω mesons off nuclei and impact of polarization on meson-nucleon interaction.",Phys. Rev. C93, 015203 , 2016

2.E. Chudakov, SG, A. Somov "Study of ω mesons photoproduction off nuclei with the Gluex detector." A Letter of Intend to Jefferson Lab, PAC-43,2015

3. GlueX collaboration "Photoproduction of vector mesons on nuclei with GlueX" Proposal PAC46,2018



- Regge model, fit to SLAC data
- Detailed prediction for t-dependence of ρ, ω and ϕ meson production
- s-channel helicity conservation at $t = 0$

Mathieu *et al.* [Phy. Rev. D, 97 (2018) 094003]
→ Single and Double Meson Production at JLab (Tuesday)

The vector meson forward scattering amplitude off spinless target reads:

$$f(\vec{k}, \vec{k}') = f_0(0) + f_1(0)(\vec{S}\vec{n})^2$$

with $\vec{S}$ the spin of the vector meson and $\vec{n} = \vec{k}/k$ the unit vector in the direction $\vec{k}$. According to the optical theorem imaginary parts of complex functions $f_0(0), f_1(0)$ can be expressed in terms of the corresponding total cross sections σ_T, σ_L:

$$Imf_0(0) = \frac{k}{4\pi}\sigma_L, \quad Imf_1(0) = \frac{k}{4\pi}(\sigma_T - \sigma_L)$$

A vivid example of the dependence of vector particle interaction on its polarization is the deuteron interaction. The D-wave component in the deuteron wave function leads to different absorption in the matter for transversely and longitudinally polarized deuterons.

Deuteron interaction with matter

Spin dichroism (dependence of interaction on particle polarization) leads to the appearance of tensor polarization. The intensity of unpolarized deuteron beam ($I^0_{+1} = I^0_{-1} = I^0_0 = 1/3$) after it passage the distance z in the target with density ρ depends on the value of total cross sections of deuteron interaction with atoms of the target $\sigma_{\pm 1}, \sigma_0$

$$I_{\pm 1}(z) = I^0_{\pm 1} e^{-\sigma_{\pm 1}\rho z}; I_0(z) = I^0_0 e^{-\sigma_0 \rho z}$$

The deuteron beam tensor polarization is determined by the difference $\sigma_0 - \sigma_{\pm 1}$:

$$p_{zz}(z) = \frac{I_{+1}(z) + I_{-1}(z) - 2I_0(z)}{I_{+1}(z) + I_{-1}(z) + I_0(z)} \approx \frac{2}{3}(\sigma_0 - \sigma_{\pm 1})\rho z$$

Thus the difference of the tensor polarization from zero indicates that interaction of deuterons with target atoms depends on the deuteron polarization.

The spin dichroism was experimentally measured at JINR, Dubna in interaction of unpolarized deuteron beam with momenta $p_d = 5Gev/c$ with carbon target (L. Azhgirey et al. Phys. Part. Nucl. Lett.,2008; 2010)
The effect is noticeable:

$$\Delta\sigma = \sigma_{\pm}(dC) - \sigma_0(dC) = 38mb; \sigma(dC) = 650mb$$

$\sigma_{\pm}(dC) > \sigma_0(dC)$ result of D-wave in deuteron!!!
The similar effect take place at much lower deuteron energies E=5-10MeV (H. Seyfarth et al. Phys. Rev. Lett.,2010), Juelich

Color dipole model of strong interaction.

SG, A. Kotzinian, V. Jaloyan, Phys.Lett., 1988 ; N. Nikolaev, B. Zakharov, Zeit. Phys.,1991
Before interaction the vector meson fluctuate into a virtual $\bar{Q}Q$ pair which than scatter diffractively off a nucleon.

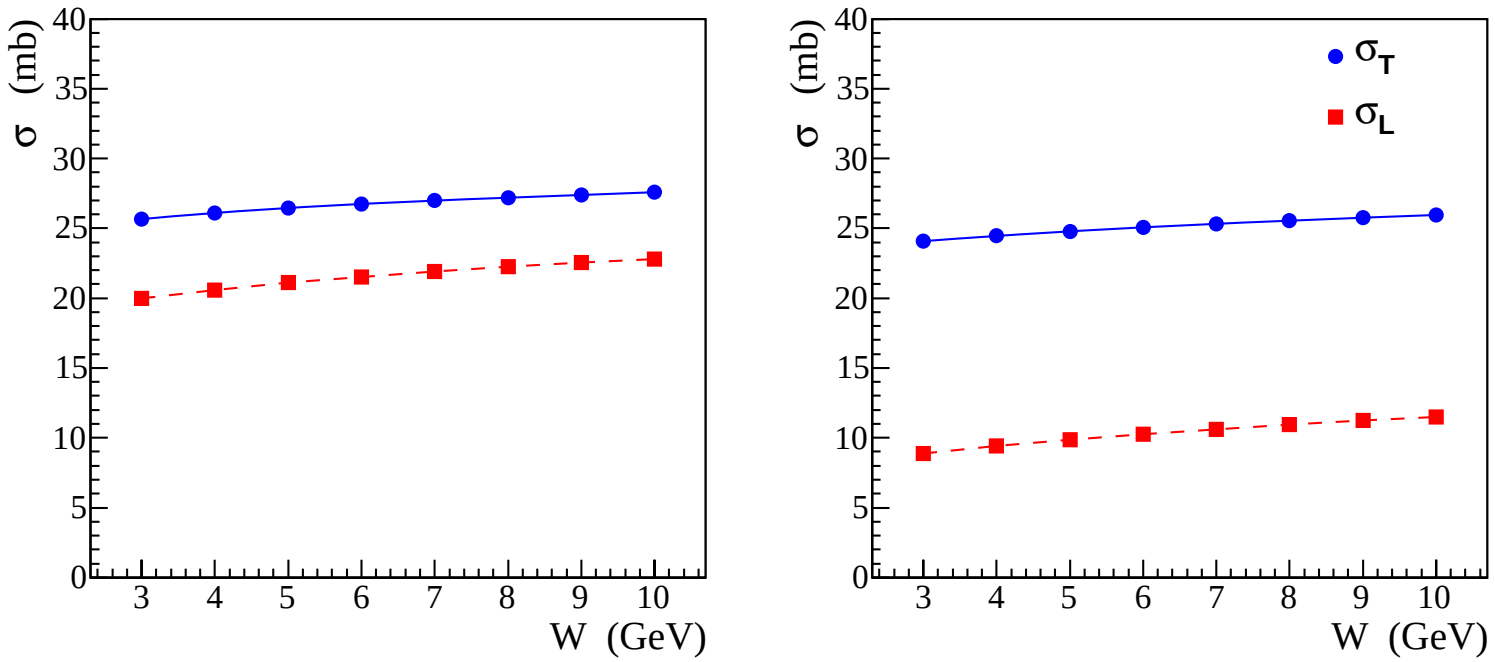


Figure: Vector meson total cross section with nucleon in different parameterizations for the wave function. a) Boosted Gaussian (left) b) Forshaw & Sandapen (right) ADS/QCD

The determination of σ_L.

1) ITEP: $\pi^- + A \to \rho^0 + A'$, G. Leksin et al. p_π=3.7 GeV/c; C,Ne, Preprint ITEP 1973; p,C,Al,Cu,Pb Yad. Phys. 1978
Spin density matrix element $\rho_{.}00 \approx 0.7$ Result:
$\sigma(\rho N) = 27.6 \pm 4.5 mb$.
From coherent photoproduction:$\sigma(\rho N) = 31.3 \pm 2.3 mb$
Account of the decay of ρ mesons in nuclei leads to much smaller cross section A. Pak, A. Tarasov, Yad. Phys. 1975.
2) Argon: $\pi^+ + Ne \to \rho^0(f(1270)) + Ne', p_\pi = 3.7 GeV/c$ B. Chaudhary et al. Nucl. Phys. 1973;
Account of mesons decay in nuclei leads $\sigma(\rho N) \approx 12 mb$ in sharp disagreement with photoproduction data!!!!

Vector mesons production at high energy (COMPASS).

$\tau = \frac{p_V}{m_V \Gamma_V}$. At COMPASS energies decays take place out of the nuclei!!!
We (Letter of Intend. "Vector mesons production off nuclei with the COMPASS-like detector. Physics motivation." SG , A. Guskov, I. Savin) propose to measure at COMPASS the production of light vector mesons $V = \rho, \omega, f(1270), K^*(892)$ on nuclei targets by high energy pions $\pi^- + A \to V + A'$ at small transfer momenta $0.1(GeV/c)^2 < t < 0.5(GeV/c)^2$. This allows uniquely determine the unknown longitudinal cross section $\sigma_L(VN)$!!!
In the presence of kaon beam COMPASS++/AMBER can investigate the charge exchange process $K^\pm + A \to K^* + A'$.

Production of $K^*(892)$ mesons in kaon beam

Recently Alice Collaboration at LHC measure the polarization of $K^*(892)$ in $pp \to K^*(892)X$ and $Pb + Pb \to K^*(892)X$ as a function of centrality and K^* transverse momenta.

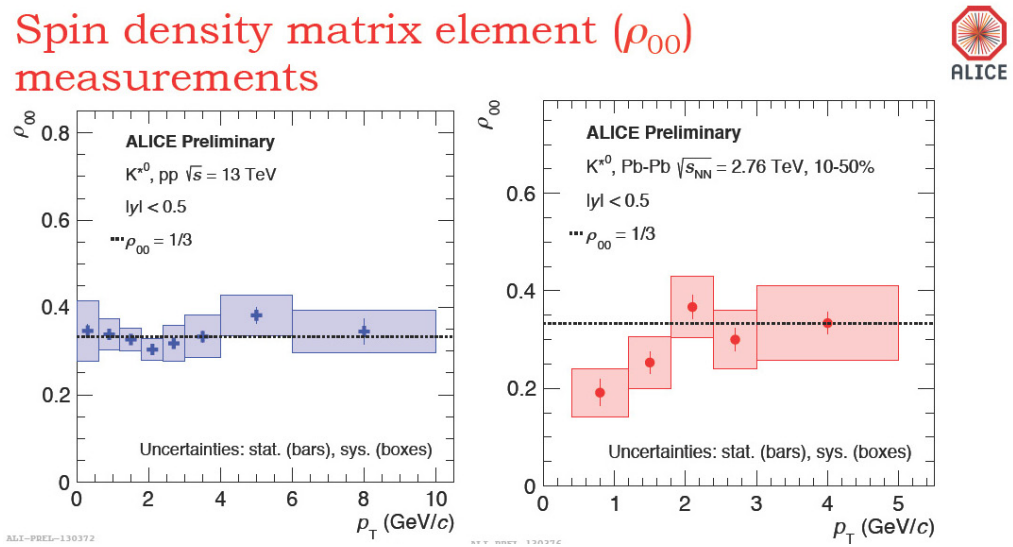


Figure: Left: The dependence of ρ_{00} on the transverse momenta of K^{*0} in the reaction $p + p \to K^{*0} + X$; Right: The same dependence in lead-lead collisions $Pb + Pb \to K^{*0} + X$

Summary

The difference in interaction of transversely and longitudinally polarized vector mesons with nucleons is a result of presence of D-wave in the vector meson wave function.
Measuring the absorption of vector mesons with different polarization in nuclei (ω mesons photoproduction off nuclei,GlueX JLAB) and in charge exchange reactions on different nuclei $\pi^- + A \to V + A'$ (COMPASS, COMPASS++/AMBER,CERN) allows to extract the $\sigma_T(VN)$ and $\sigma_L(VN)$ and get the information on the presence and magnitude of orbital momenta in vector mesons.

Thanks for attention