Spin effects in low-energy electron-nucleon scattering with two-photon exchange: Analysis based on $1/N_c$ expansion of QCD

Cintia WILLEMYNS - University of Mons

collaboration with José Goity and Christian Weiss

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Outline

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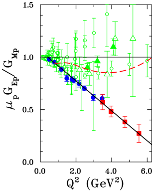
1. Two photon exchange
2. Overview of Target Single Spin Asymmetries (TSSA)
3. The $1/N_c$ expansion approach for TSSA in the Δ region
4. Results
5. Summary

- TPE & SSA topics are very old $>$ 60 years. Many works!

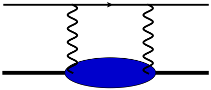
- Historical works for SSAs: [Barut & Fronsdal; Leroy & Piketty; De Rujula, Kaplan & De Rafael; Gunther & Rodenberg]

- Numerous works since the 2000's on TPE and SSA's: [Guichon & Vanderhaeghen; Blunden, Melnitchouk & Tjon; Afanasev et al.; in DIS: Metz, Schlegel & Goeke; Afanasev, Strikman & Weiss; many more...]

Two-photon exchange in electron-nucleon scattering

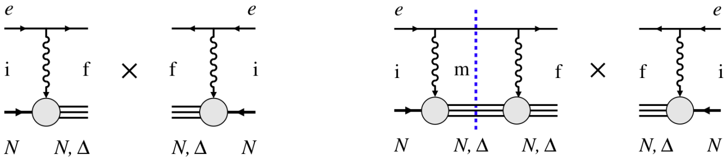


- TPE has shown to be needed in the extraction of the G_E^p/G_M^p
- There are numerous works; elastic and inelastic contributions
- General description requires the (virtual) Compton amplitude
- A particularly clean observable: transverse TSSA
- TSSA occurs first at TPE level (absorptive part of TPE amplitude)
- In our work, we set up a framework to study the TSSA at low energies (up to above the Δ). We focus on the inclusive scattering
- Our framework is based on the $1/N_c$ expansion of QCD and provides a sistematic expansion at low energy to study TSSA's in that regime



TSSA generalities

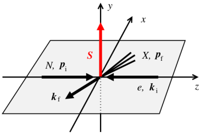
- Unlike double polarization asymmetries that occur at LO in QED, SSAs occur at NLO [Christ-Lee theorem]



SSA's arise from interference between absorptive part of box diagram and OPE

- Definition of the TSSA

$$\boxed{d\sigma_{TSSA} \propto (\vec{k}_f \times \vec{k}_i) \cdot \vec{S} \qquad \frac{d\sigma_{TSSA}}{d\sigma_{OPE}} = A_y sin\phi}$$



- The contribution to the SSA by the box diagram is free of IR and collinear divergencies

Why use $1/N_c$ expansion?

- The $1/N_c$ expansion is a fundamental expansion of QCD
- It can be rigorously implemented at hadronic level
- It has tested phenomenological impact, also through LQCD
- Particularly powerful for baryons: spin-flavor $SU(4)$ or $SU(6)$ symmetry at large N_c
- Unifies key aspects of nucleon and Δ physics
- More recently, BChPT unified with $1/N_c$ expansion has shown many advantages

N_c scalings:

$M_B = \mathcal{O}(N_c)$
$M_\Delta - M_N = \mathcal{O}(1/N_c)$
$\Gamma_\Delta = \mathcal{O}(1/N_c^2)$
SU(4) (contracted) symmetry

EM current expanded in $1/N_c$

$$V^\mu_{EM} = \tfrac{1}{2} V^\mu_0 + V^\mu_3$$

at LO in $1/N_c$:

$$V^\mu_0 = g^{\mu 0} G^0_E(Q^2) - \tfrac{i}{\Lambda_0} G^0_M(Q^2) \epsilon^{0\mu ij} q_i \hat{S}_j$$
$$V^\mu_3 = g^{\mu 0} G^1_E(Q^2) \hat{I}_3 - \tfrac{i}{\Lambda_1} G^1_M(Q^2) \epsilon^{0\mu ij} q_i \hat{G}_{j3}$$

where $\{\hat{S}_j, \hat{I}_a, \hat{G}_{ia}\}$ are the generators of $SU(4)$

The spatial part of convection and time part of spin currents are sub-leading in $1/N_c$

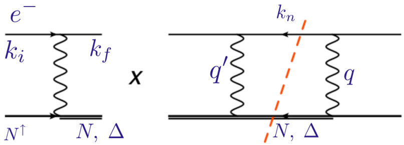
- Implementation of a low energy & $1/N_c$ power counting is possible

$$p \sim \frac{\Lambda_{hadronic}}{N_c} \sim \mathcal{O}(\xi)$$ [Calle-Cordon & Goity]

$BChPT \times 1/N_c$ has been applied to $SU(3)$ vector currents (this involves EM currents)

[Flores-Mendieta & Goity, Fernando & Goity]

TSSA in eN scattering



$$d\sigma_{TSSA} = \frac{\alpha}{8\pi^2}\frac{M_N M_f M_n k_f k_n}{s^{3/2} t(s - M_N^2)}\ \ Im\int d\Omega_K \frac{L^{\mu\nu\rho} H_{\mu\nu\rho}}{q^2 q'^2}$$

- The hadronic tensor in t-channel can be decomposed into angular momentum and isospin components. This allows for systematic organization of such terms in powers of $1/N_c$
- We can determine the separate effects of N and Δ in the box
- IR and collinear divergencies cancel ✓

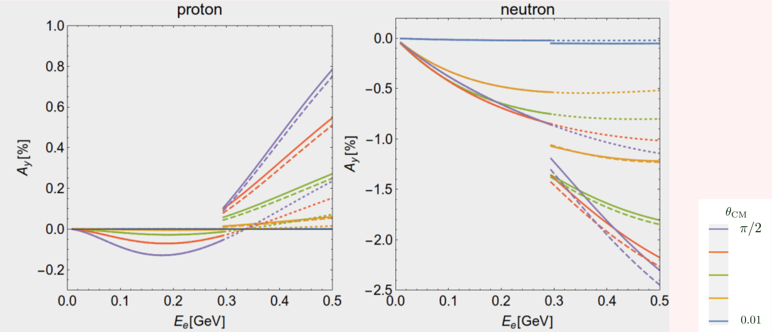
TSSA in *eN* scattering

- Energy domain of calculation: small energy expansion ($M_\Delta - M_N = \mathcal{O}(1/N_c)$ taken as small)
- Form factor effects are subleading; easy to include and done with dipole model
- Behaviour at Δ threshold requires inclusion of its width (sub-sub-leading: $\Gamma_\Delta = \mathcal{O}(1/N_c^2)$)

Sample result

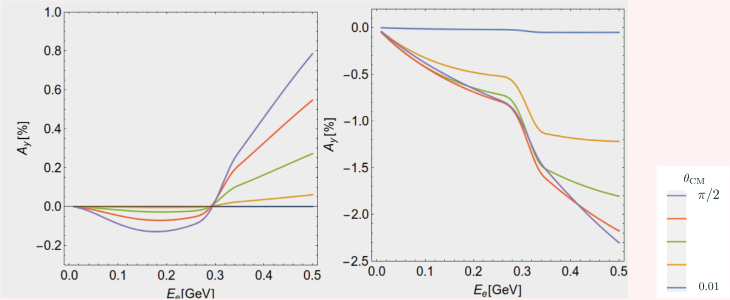
$$d\sigma_{\mathrm{TSSA}}(\mathrm{N},\triangle) = \frac{k\,\alpha^3 \sin\Theta}{500\, s^{3/2}\, t^2\, \Lambda^3} \left(G_M^n - G_M^p\right)^2 M_N^2 \left(k \log\left(\sin^2\frac{\Theta}{2}\right) \left(-t + 4 \left(k + M_N - M_\triangle\right)^2\right) + 2\, t \left(k + M_N - M_\triangle\right)\right) M_\triangle \left(-1 + N_c\right)\left(5 + N_c\right)\left(5\, \Lambda\, G_E^p + k\, G_M^n \left(-3 + N_c\right) - k\, G_M^p \left(7 + N_c\right)\right)$$

$A_y(\theta)$ with $\Gamma_\Delta = 0$

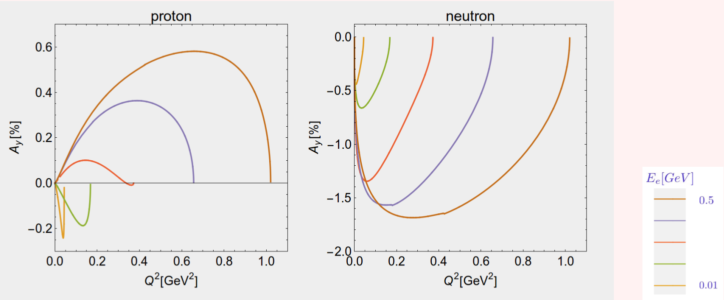


Full lines: inelastic
Dotted lines: elastic
Dashed lines: $eN \to eN$ including intermediate Δ

$A_y(\theta)$ including Γ_Δ



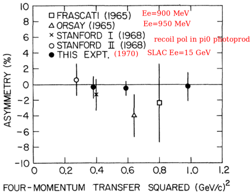
$A_y(Q^2)$

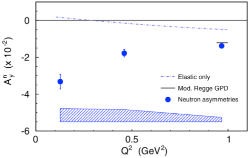


$$Q^2 = -t = (k_i - k_f)^2$$

Experiments

- Old experiments at low energy have large errors
- JLab Hall A for neutron:
  Energy too high for direct comparison but consistent in order of magnitude
- HERMES: DIS with e^- and e^+ beam
  Energy above our range
- New proposal for JLab Hall A [Grauvogel et al]:
  $Ee > 2.2 GeV$ (will also use e^+)
- MAMI facility in Mainz with e^- beam
  Energy to measure TSSA in the region of our interest
- Having results at low to intermediate energies would very interesting because of the evolution of TSSA in the Δ region





JLab Hall A ^{3}He target (2015)

Summary

- The $1/N_c$ expansion allows for a systematic approach at low energy. We can study the TSSA's by considering the inclusive $e^- N$ scattering
- The $1/N_c$ expansion unifies the nucleon and Δ physics. The inclusion of the Δ state plays a very prominent role
- It would be very interesting to have results from experiments in the low energy range where the TSSA has important evolution across the Δ resonance region

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Thank you for your attention