ELECTROPRODUCTION OF HYPERNUCLEI

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Motivation of studying electroproduction of hypernuclei in Distorted Wave Impulse Approximation

$$E_k + e + A \rightarrow e' + H + K^+$$

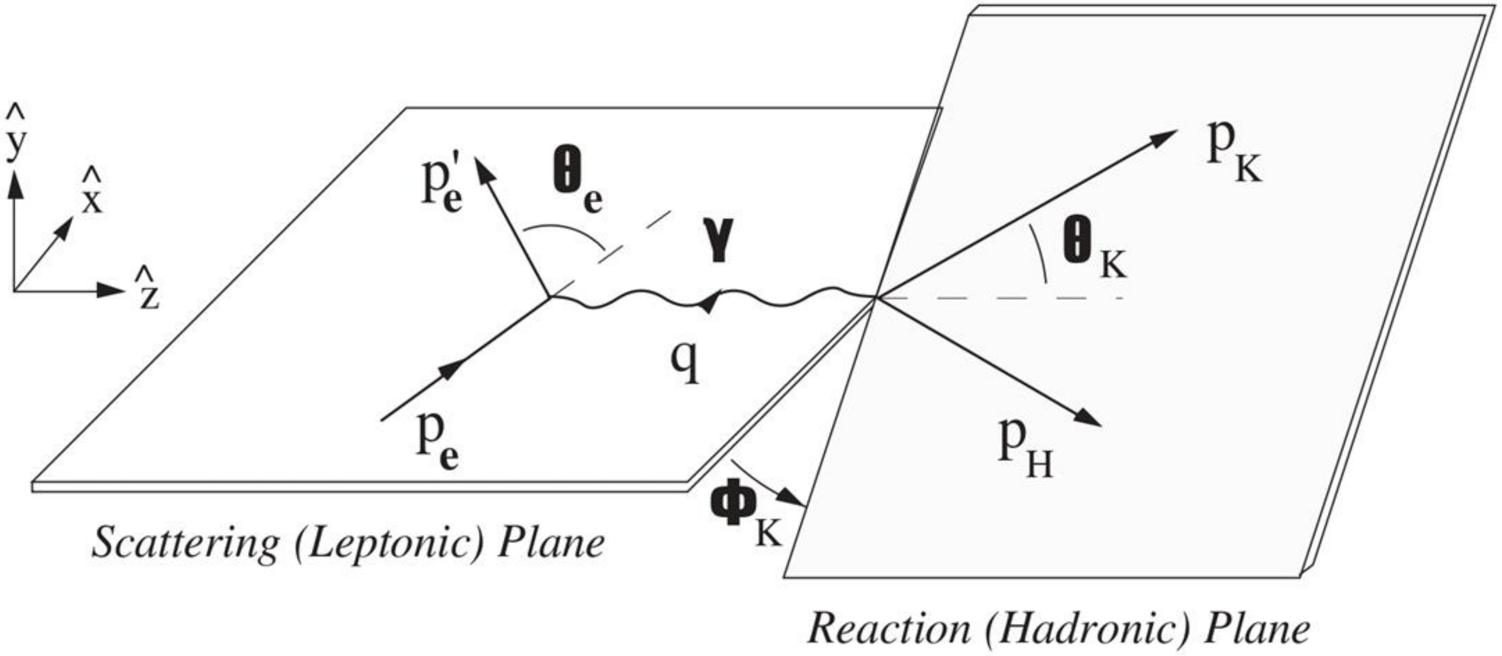
- The electro-magnetic part of the interaction is well known which simplifies description of the process.
- The impulse approximation is well justified.
- The DWIA formalism is developed and proved to work well. (F.Garibaldi et al, Phys Rev. C 99, 054309(2019))
- We obtain information on the spin-dependent part of the hyperon-nucleon interaction.
- One can achieve a better experimental resolution than in hadron-induced reactions.

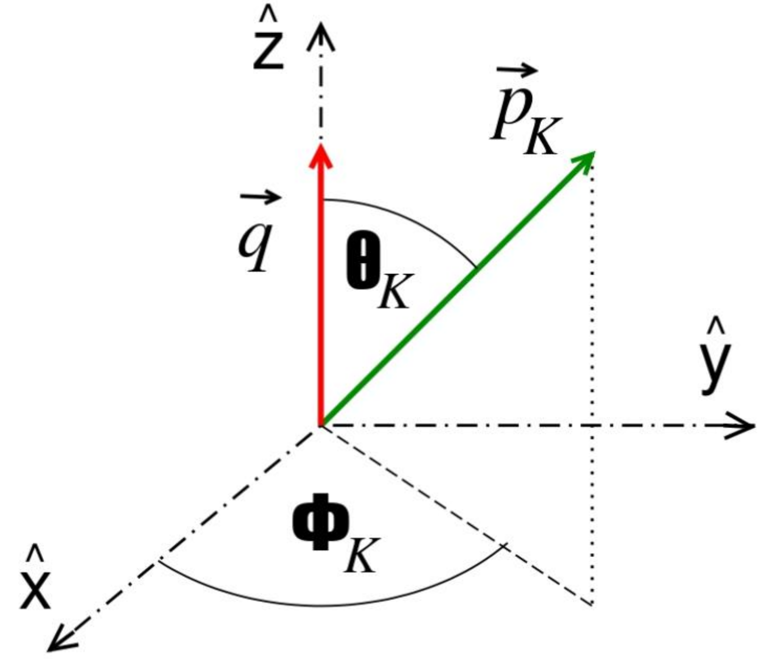
Kinematics

Input: $E(e), E(e'), \theta_e, \phi_K, \theta_K$

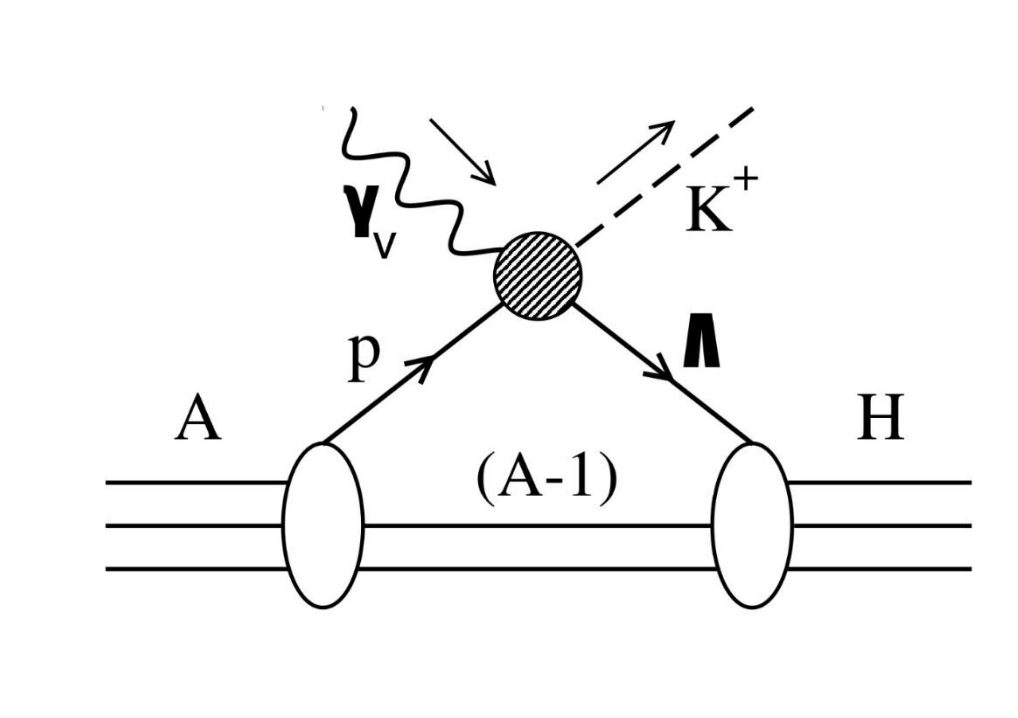
Calculated: $P_\gamma, P_K, P_H \ldots$

Lab reference frame: $\vec{P}_A$=0





Momentum and Energy conservation in IA



- $\gamma_\nu(P_\gamma) + A(P_A) \to H(P_H) + K^+(P_K)$
- 3-momentum conservation in each vertex

$$\vec{P}_\gamma + \vec{p}_p = \vec{P}_K + \vec{p}_\Lambda, \vec{P}_A = \vec{p}_c + \vec{p}_p,$$

$$\vec{p}_c + \vec{p}_\Lambda = \vec{P}_H \Rightarrow \vec{P}_A + \vec{P}_\gamma = \vec{P}_H + \vec{P}_\mathrm{K}$$

- Energy conservation

$$\mathrm{E}_A = \sqrt{M_C^2 + (\vec{P}_A - \vec{p}_p)^2} + \sqrt{m_p^2 + \vec{p}_p^2} + \epsilon_p$$

$$\mathrm{E}_H = \sqrt{M_C^2 + (\vec{P}_A - \vec{p}_p)^2} + \sqrt{m_\Lambda^2 + \vec{p}_\Lambda^2} + \epsilon_\Lambda$$

In the frozen-proton approximation ($\vec{p}_p$= 0) and Lab frame: $M_A = M_C + m_p + \varepsilon_p$ (has been used till now in our calculations).

◦ Energy conservation in the elementary vertex (the on-energy shell amplitude)

$$\mathrm{E}_\gamma + \sqrt{m_p^2 + \vec{p}_p^{\,2}} = \mathrm{E}_K + \sqrt{m_\Lambda^2 + \vec{p}_\Lambda^{\,2}}$$

$$\Rightarrow E_\gamma + E_A = E_K + E_H + \epsilon_{\mathrm{p}} - \epsilon_\Lambda$$

$$\epsilon_{\mathrm{p}} - \epsilon_\Lambda \approx 10\ \mathrm{MeV}\ ,\ E_\gamma + E_A \approx 10\ \mathrm{GeV}$$

◦ To keep the many-body energy conserved $E_\gamma + E_A = E_K + E_H$ =>

$\mathrm{E}_\gamma + \sqrt{m_p^2 + \vec{p}_p^{\,2}} = \mathrm{E}_K + \sqrt{m_\Lambda^2 + \vec{p}_\Lambda^{\,2}} + \epsilon_\Lambda - \epsilon_{\mathrm{p}}$ => off-energy-shell amplitude.

◦ How to deal with the off-shell amplitude?

Determination of P_K

- Energy conservation in the elementary (two-body) system

$$\mathrm{E}_\gamma + m_p = \sqrt{m_K^2 + \vec{P}_K^2} + \sqrt{m_\Lambda^2 + (\vec{P}_\gamma - \vec{P}_K)^2}$$

- Energy conservation in the many-body system (Lab)

$$\mathrm{E}_\gamma + M_A = \sqrt{m_K^2 + \vec{P}_K^2} + \sqrt{M_\mathrm{H}^2 + (\vec{P}_\gamma - \vec{P}_K)^2}$$

- "Optimum on-shell" proton momentum, for which equations would be solvable with a given momentum transfer $\vec{\Delta} = \vec{P}_\gamma - \vec{P}_K$

$$\mathrm{E}_\gamma - \sqrt{m_K^2 + \vec{P}_K^2} = \sqrt{m_\Lambda^2 + \left(\vec{\Delta} + \vec{p}_p\right)^2} - \sqrt{m_p^2 + \vec{p}_p^2} = \sqrt{M_\mathrm{H}^2 + \vec{\Delta}^{\,2}} - M_A$$

Many-particle matrix element

- Matrix element with the production amplitude

$$M_\mu = (2\pi)^3\delta^{(3)}(\vec{P}_A + \vec{P}_\gamma - \vec{P}_K - \vec{P}_H)T_\mu$$

- The laboratory amplitude in the optimum factorization and in PWIA using the 3-momentum conservation:

$$T_\mu = Z\int d^3\xi d^3\xi_1 \ldots d^3\xi_{A-2}\Phi_H^*\left(\vec{\xi}_1, \ldots \vec{\xi}_{A-2}, \vec{\xi}\right) J_\mu(\vec{P}_K, \vec{P}_\gamma, \vec{p}_{eff})\Phi_A\left(\vec{\xi}_1, \ldots \vec{\xi}_{A-2}, \vec{\xi}\right) \times e^{i\frac{A-1}{A-1+\gamma}\vec{\Delta}\cdot\vec{\xi}}$$

- Due to the gauge invariance of the amplitudes

$$T^\mu\varepsilon_\mu \to \vec{T}\vec{\epsilon} = \sum(-1)^{-\lambda}T_\lambda^{(1)}\epsilon_{-\lambda}^{(1)}$$

Elementary amplitude

- The invariant amplitude

$$M \cdot \varepsilon = \overline{u_\Lambda}\gamma_5 \left(\sum_{j=1}^{6} M_j \cdot \varepsilon A_j \right) u_p = X_\Lambda^+ (\vec{J} \cdot \vec{\epsilon}) X_p$$

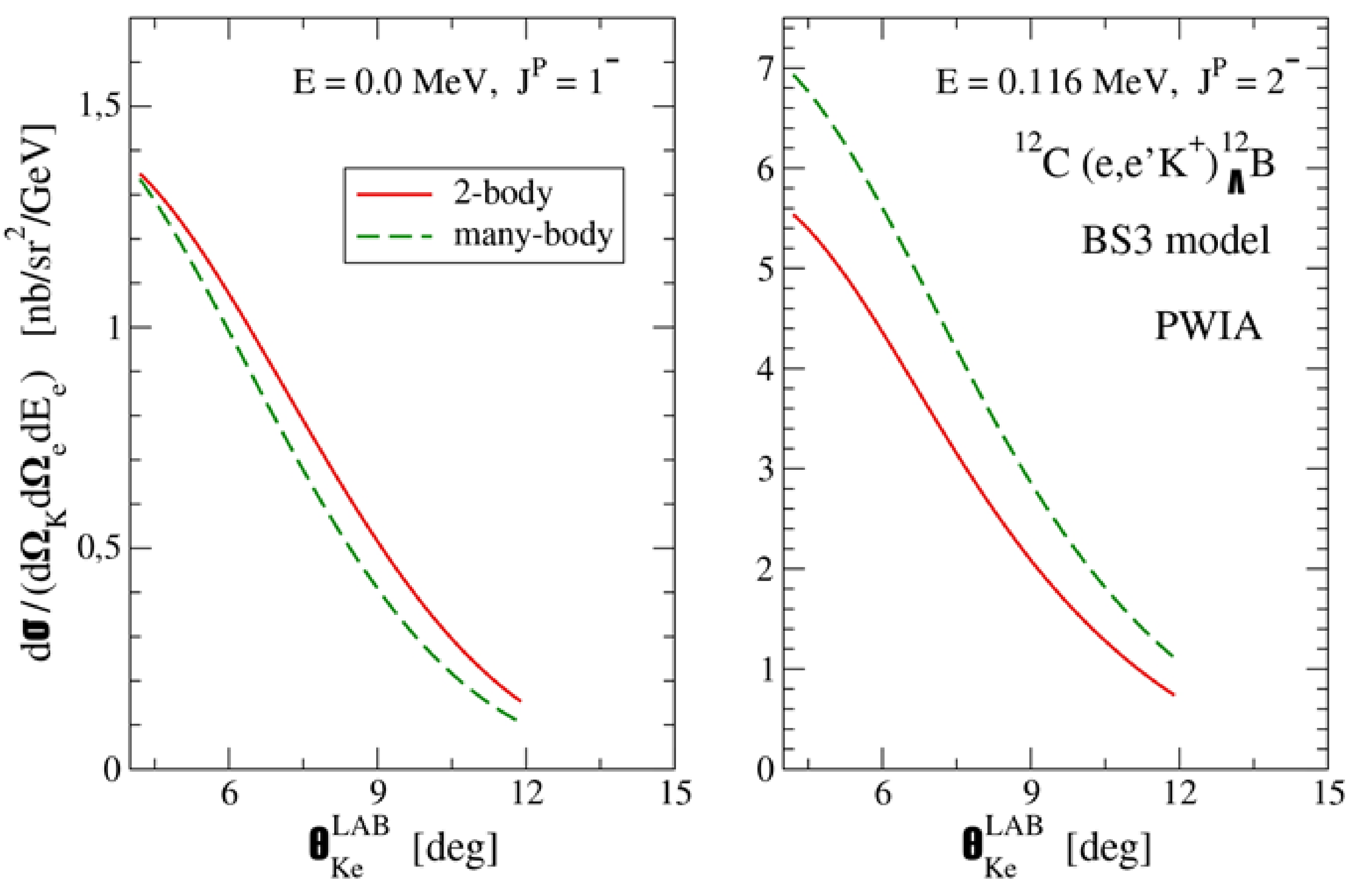
- The elementary amplitude in the spherical coordinates

$$\vec{J} \cdot \vec{\epsilon} = \sum_{\lambda = \mp 1, 0} (-1)^{-\lambda} J_\lambda^{(1)} \epsilon_{-\lambda}^{(1)}$$

- The spherical components of $J^{(1)}$can be defined via 12 spherical amplitudes $F_{\lambda,\xi}^{S}$ with *S* = *0, 1* and λ, ξ = ±1, 0

$$J_\lambda^{(1)} = \sum_{\lambda,\xi,S} F_{\lambda,\xi}^{S} \sigma_\xi^{S}$$

Cross sections for hypernucleus electroproduction in the PWIA



E_i =3.77 $E_f{}'$ =1.56 GeV
$\vec{p}_p$= 0 θ_{Ke} = 6.1, $\theta_{K\gamma}$ = 1.9

Energy conservation:
2-body P_k =1.93 E_k= 1.99
many-body P_k =1.96 E_k=2.02

Energy conservation violation:
2-body 1.63% 0.24 %
many-body -1.20% -0.18 %
E_K ≈2 GeV, E_{tot} ≈13 GeV

Nucleus structure: shell-model calculations D.S. Miller, Nucl. Phys. A 804, 84 (2008)

Summary and outlook.

- We have derived the two-component formalism for the elementary amplitude with a non-zero proton momentum (the CGNL-like and spherical amplitudes).
- Now we are checking and modifying the formalism to calculate in IA the radial integrals with harmonic-oscillator and Woods-Saxon single-particle wave functions, cross sections for hypernucleus electroproduction and extending the formalism for the s-d shell nuclei.
- Numeric calculations of the cross sections for hypernucleus electroproduction in the DWIA will be performed soon.
- We plan to continue studying a dependence of the cross sections on the kinematics, input parameters (kaon distortion), various values of the target-proton momentum, wave functions and elementary amplitudes.

THANK YOU FOR ATTENTION.