Extracting Hypernuclear Properties from the $(e, e'K)$ Cross Section

Omar Benhar

INFN and Department of Physics, "Sapienza" University
I-00185 Roma, Italy

Hypernuclear 2016
Thomas Jefferson National Accelerator Facility
March 14-15, 2016

Outline

- Motivation & disclaimer
- The $(e, e'K^+)$ cross-section
  - Kinematics
  - Nuclear and hypernuclear dynamics
- Outlook

THE $\mathrm{A(e, e'K^+)}_Y A$ CROSS SECTION

- Consider the process

$$e(k) + A(p_A) \to e'(k') + K^+(p_K) + {}_Y A(p_{{}_Y A})$$

- Cross section $(i, j = 1,\ 2,\ 3)$

$$d\sigma \propto L_{\mu\nu} W^{\mu\nu}$$

  - The lepton tensor L_{ij} , fully specified by the measured electron kinematical variables
  - The tensor W^{ij} , describing the nuclear response, contains all the information on both nuclear and hypernuclear dynamics

⋆ Lepton tensor

$$L = \begin{pmatrix} \eta_+ & 0 & -\sqrt{\epsilon_L \eta_+} \\ 0 & \eta_- & 0 \\ -\sqrt{\epsilon_L \eta_+} & 0 & \epsilon_L \end{pmatrix} ,$$

$$\eta_\pm = \frac{1}{2}(1 \pm \epsilon) \;\; , \;\; \epsilon = \left(1 + 2\frac{|\mathbf{q}|^2}{Q^2} \; \tan^2 \frac{\theta_e}{2}\right)^{-1} \;\; , \;\; \epsilon_L = \frac{Q^2}{\omega^2}\, \epsilon$$

⋆ Target response tensor

$$W^{ij} = \langle 0 | J^i_A(q) | F \rangle \langle F | J^j_A(q) | 0 \rangle \; \delta^{(4)}(q + p_0 - p_F)$$

⋆ Building blocks

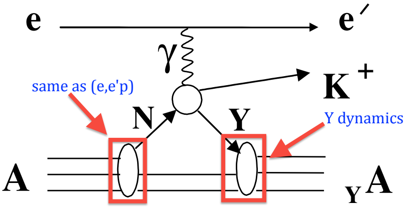
$$|0\rangle = |A\rangle \quad , \quad J^i_A = \sum_{n=1}^{A} j^i(n) \quad , \quad |F\rangle = |K^+, {}_Y A\rangle$$

⋆ The one-body current j^i drives the elementary process

$$e + p \to e' + Y + K^+$$

Impulse Approximation and Factorization

- ⋆ Impulse approximation: at momentum transfer $|\mathbf{q}|^{-1} \ll d$, d being the average nucleon-nucleon separation distance in the target nucleus, the beam particles interact with individual (bound, moving) nucleons



- ⋆ Within this scheme, the nuclear transition amplitude factorizes into the amplitude of the elementary process, a purely nuclear amplitude and a hypernuclear amplitude. the

Nuclear transition amplitude

- Isolate the bilding blocks

$$\mathcal{M}_{0\to F} = \langle K^+, {}_Y A | J_A^i | 0 \rangle$$
$$= \sum_n \sum_{k_p, k_Y} \Big\{ \langle {}_Y A | (A-1)_n \rangle | Y \rangle \Big\} \langle K^+ Y | j^i | p \rangle \Big\{ \langle p | \langle (A-1)_n | 0 \rangle \Big\}$$

- Relation to the spectral function formalism of $(e, e'p)$

$$P_N(k_p, E_p) = \sum_n |\langle p | \langle (A-1)_n | 0 \rangle|^2 \delta(E_p - E_n + E_0)$$

  - probability of remiving a proton of momentum k_p from the nuclear target, leaving the residual nucleus with energy E

$$P_Y(k_Y, E_Y) = \sum_n |\langle Y | \langle (A-1)_n | {}_Y A \rangle|^2 \delta(E_Y - E_n + E_0)$$

  - probability of remiving the hyperon Y, carrying momentum k_Y from the final state hypernucleus, leaving the residual nucleus with energy E

KINEMATICS

- ⋆ Conservation of Energy $\omega = E_e - E_{e'}$

$$\omega + M_A = E_{K^+} + E_{{}_Y A}$$

  - ▷ from the nuclear amplitude

$$M_A = E_p + E_n$$

  - ▷ from the hypernuclear amplitude

$$E_{{}_Y A} = E_Y + E_n$$

- ⋆ Missing energy $E_{\text{miss}} = \omega - E_{K^+}$

$$\omega = E_{K^+} + E_Y - E_p \Longrightarrow E_{\text{miss}} = E_Y - E_p$$

- ⋆ Note: in $(e, e'p)$

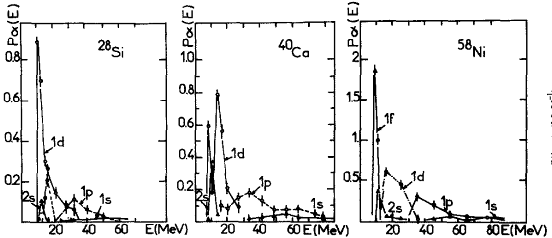
$$E_{\text{miss}}^{(e,e'p)} = -E_p \Longrightarrow E_Y = E_{\text{miss}} - E_{\text{miss}}^{(e,e'p)}$$

Missing Energy Spectrum

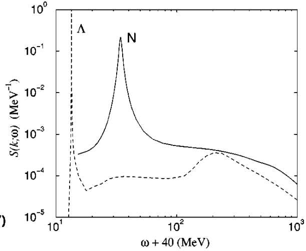
⋆ Within the independent particle model

$$P_N(k_p, E_p) \sim \sum_\alpha \delta(E_p - \epsilon_p^\alpha) \quad , \quad P_Y(k_Y, E_Y) \sim \sum_\alpha \delta(E_Y - \epsilon_Y^\alpha)$$

▷ $P_N(k_p, E_p)$ from $(e, e'p)$



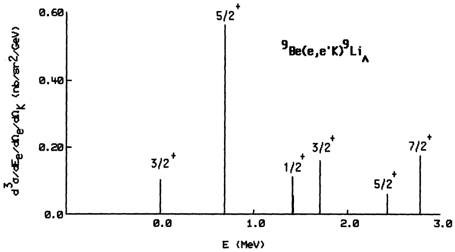
▷ $P_\Lambda(k_\Lambda, E_\Lambda)$ in isospin-symmetric nuclear matter

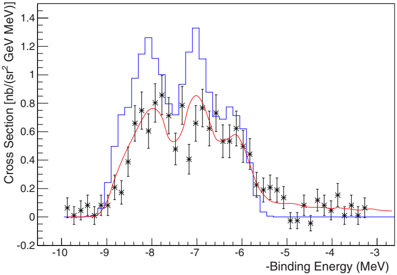


MISSING ENERGY SPECTRUM OF $^9Be(e,e'K^+)_\Lambda{}^9Li$

- ⋆ M. Sotona and S. Frullani
  PTP Supp. **117**, 151 (1994)

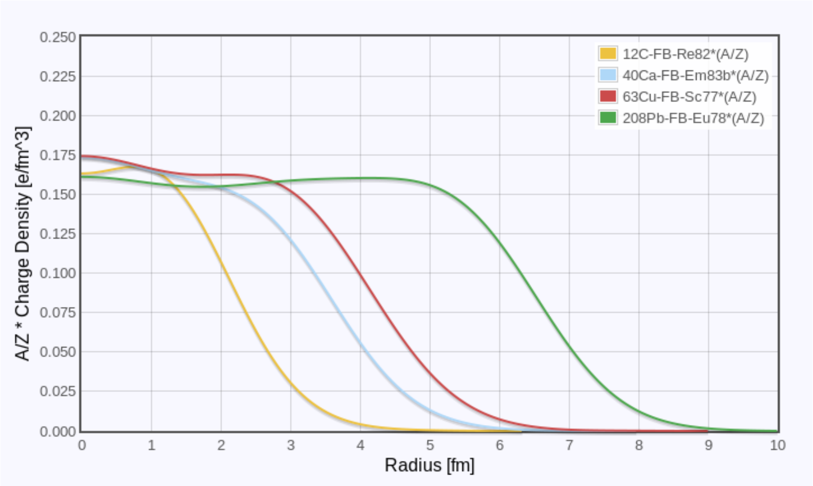
- ⋆ JLab experiment E94-107
  G. Urciuoli et al (JLab Hall A Collaboration), PRC **91**, 034308 (2015)



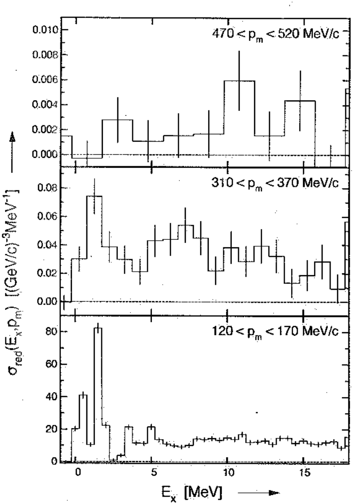


Backup slides

CHARGE DENSITY OF ^{208}Pb



$^{208}Pb(e, e'p)$ MISSING ENERGY SPECTRA



SPECTROSCOPIC FACTORS OF ^{208}Pb