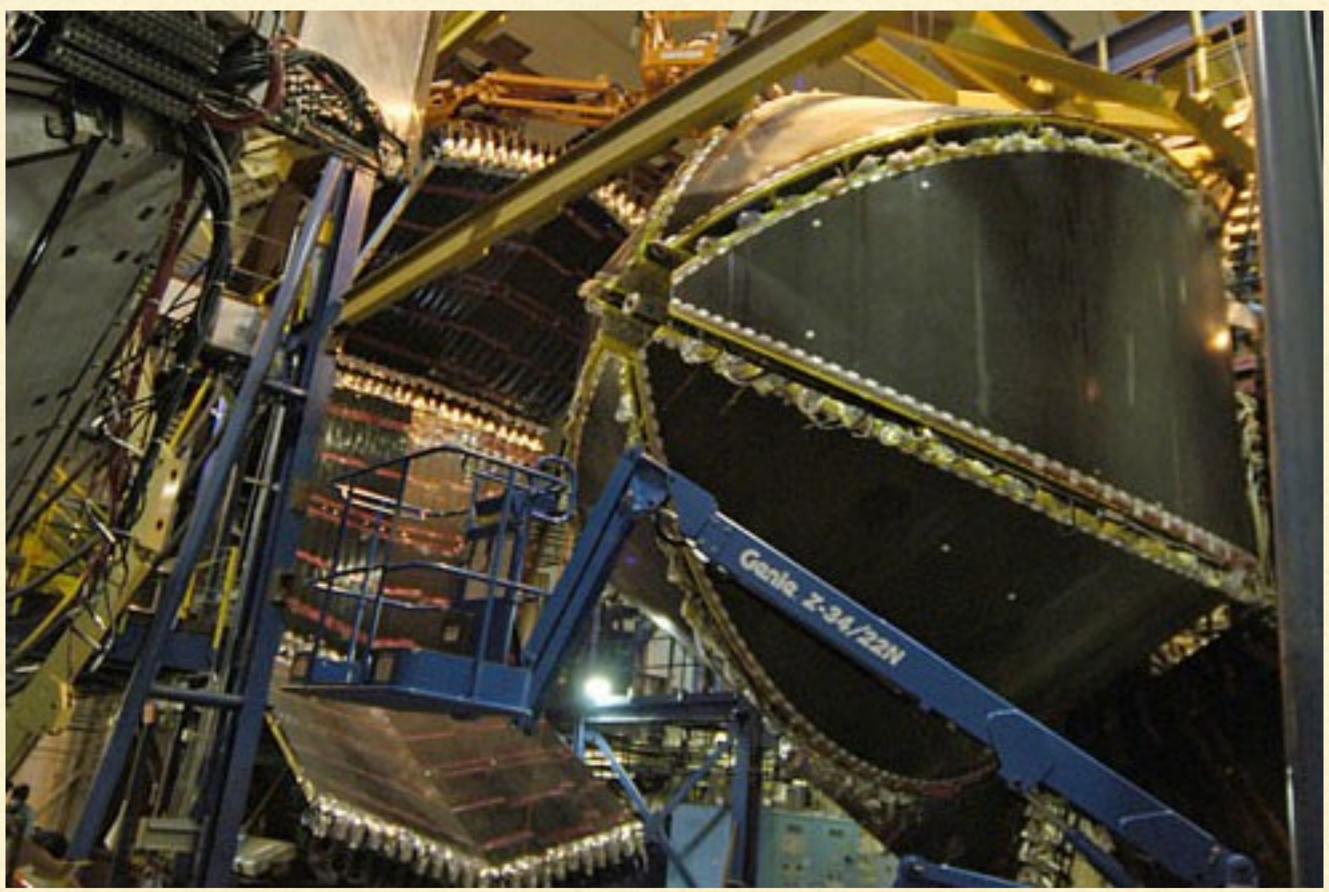
DISCUSSION FOR SESSION II

Workshop on Exploring Hadrons and Electromagnetic Probes: Structure, Excitations, Interactions@

Jefferson Lab
EXPLORING THE NATURE OF MATTER

CLAS-12 & GlueX



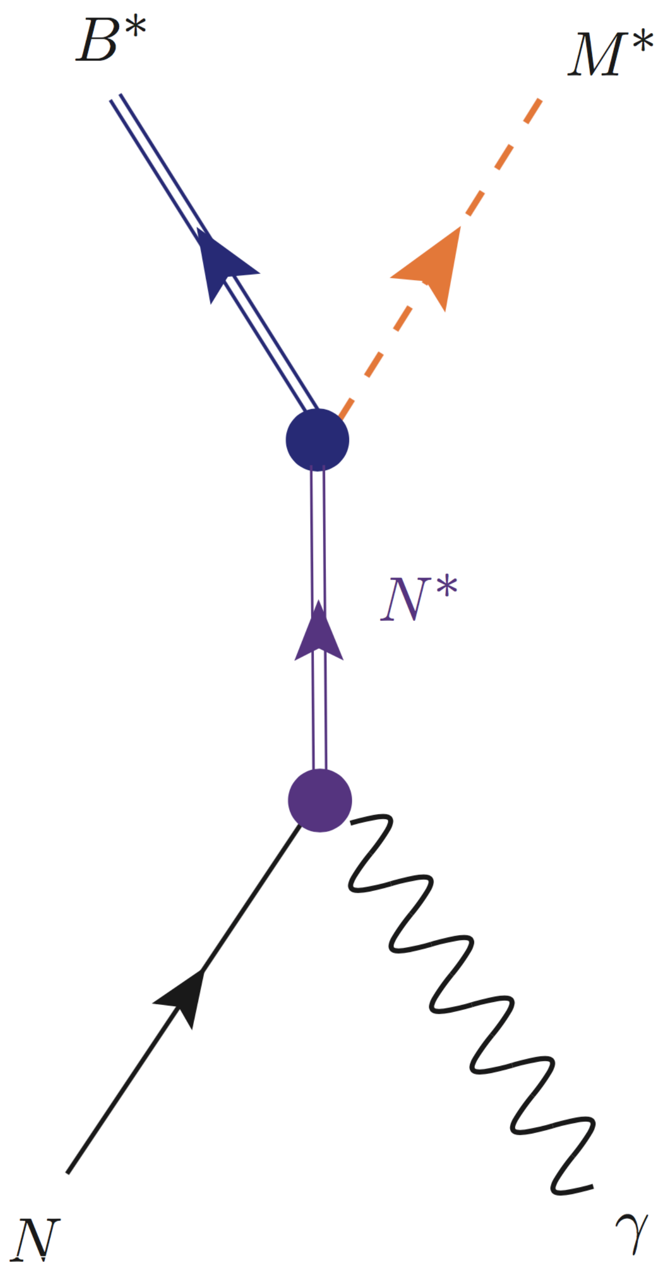
HADRONS IN NUCLEAR MEDIUM AND STRANGENESS

TALKS GIVEN

- Photoproduction of vector mesons off nuclei with the GlueX detector
- Features of omega meson photoproduction
- Resonances in hadronic medium
- Quarkonium in thermal environment
- Hypernuclear and strangeness physics
- Physics Perspectives for future K-long Facility
- Electro- and photo-production of Lambda(1405)

Photon probes

The photon has a tidy probe to study the production mechanism of **excited hadrons.**



Internal structure of excited baryons

- Strong vertices: Form factors & coupling constants
- EM vertices: photo-couplings
- With virtual photon, one can study EM form factors of excited ***N*** and hyperons.
- Production of **strangeness**

Theoretical uncertainties

- Form factors, always pain in the neck
- How to treat higher spins without any ambiguity

Excited hadrons

- Excited hadrons are constructed from multi-particle productions.
- Experimenters are trying to reconstruct two-body processes based on the following basic multi-particle reactions.

Basic reactions

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$$(\pi\pi)^{\mathrm{S-wave}}_{I=0} = \sigma \ \mathrm{or} \ f_0$$

$$(\pi\pi)^{\mathrm{P-wave}}_{I=1} = \rho$$

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Basic reactions

$$\gamma N \to \pi\pi N$$

$$(\pi N)_{J=1/2} = N^*$$

$$(\pi N)^{I=3/2}_{J=3/2} = \Delta$$

$$(\pi\pi)^{\mathrm{S-wave}}_{I=0} = \sigma \ \mathrm{or} \ f_0$$

$$(\pi\pi)^{\mathrm{P-wave}}_{I=1} = \rho$$

Excited hadrons

$$\gamma N \to \rho N$$

There exist mainly old calculations.

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Decays of N* to the rho meson

$$N^*(1440) \to \rho N < 8\,\%$$

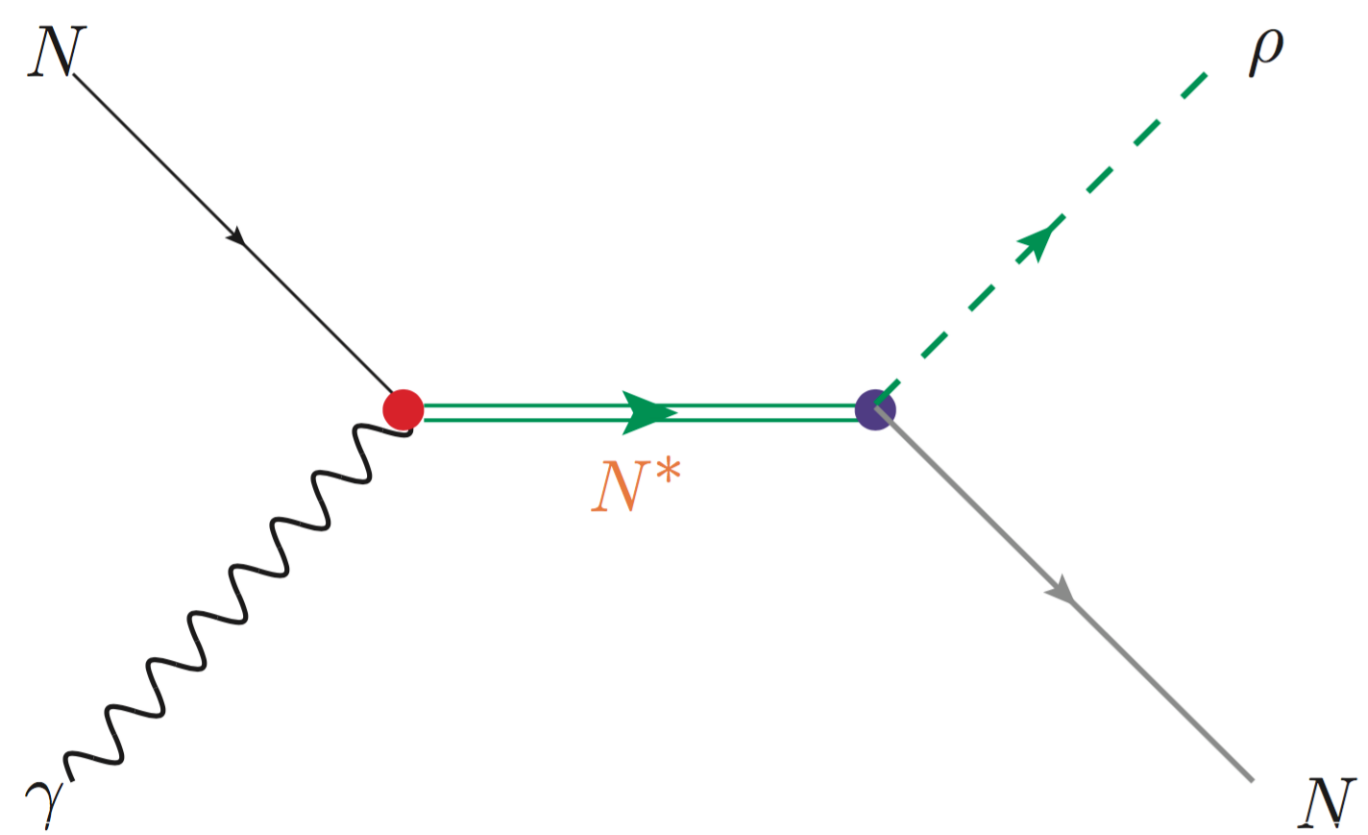
$$N^*(1535) \to \rho N < 4\,\%$$

$$N^*(1520) \to \rho N : \; (15 - 24)\,\%$$

$$N^*(1650) \to \rho N : \; (4 - 12)\,\%$$

$$N^*(1680) \to \rho N : \; (3 - 15)\,\%$$

$$N^*(1720) \to \rho N : \; (70 - 85)\,\%$$



PDG, 2014-2015

Excited hadrons

$$\gamma N \to K \pi \Lambda$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \rightarrow K\pi\Lambda$$

$$(K\pi)^{S-\mathrm{wave}}_{I=1/2} = K_0^*(800) \text{ or } \kappa$$

$$(K\pi)^{S-\mathrm{wave}}_{I=1/2} = K^*(892)$$

$$K_2^*(1430) - \text{ tensor meson}$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \rightarrow K\pi\Lambda \rightarrow \Sigma^*(1385),\ \Sigma^*(1670),\ \Sigma^*(1775)$$

$$(K\pi)^{S-\mathrm{wave}}_{I=1/2} = K_0^*(800) \text{ or } \kappa$$

$$(K\pi)^{S-\mathrm{wave}}_{I=1/2} = K^*(892)$$

$$K_2^*(1430) - \text{ tensor meson}$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \to K\bar{K}N$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \to K\bar{K}N$$

$$\gamma N \to \phi N$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \to K \bar{K} N$$

$$\gamma N \to K \Lambda^*(1520)$$

$$\gamma N \to K \Lambda^*(1670) \frac{1}{2}^-$$

$$\gamma N \to K \Lambda^*(1690) \frac{3}{2}^-$$

$$\gamma N \to K \Lambda^*(1820)$$

$$\gamma N \to K \Lambda^*(1830)$$

$\bar{K} N$ dominant

$$\gamma N \to \phi N$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \to \bar{K}\Theta^+$$

$$\gamma N \to K\bar{K}N$$

$$\gamma N \to K\Lambda^*(1520)$$

$$\gamma N \to K\Lambda^*(1670)\frac{1}{2}^-$$

$$\gamma N \to K\Lambda^*(1690)\frac{3}{2}^-$$

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$\bar{K}N$ dominant

$$\gamma N \to \phi N$$

PDG, 2014-2015

Excited hadrons

$$\gamma N \to K\pi\Sigma$$

Excited hadrons

$$\gamma N \to K\pi\Sigma$$

$$\gamma N \to K^*\Sigma$$

$$\gamma N \to K_2^*\Sigma$$

Excited hadrons

$$\gamma N \to K\pi\Sigma$$

$$\gamma N \to K\Lambda(1405)$$

$$\gamma N \to K^*\Sigma$$

$$\gamma N \to K_2^*\Sigma$$

Excited hadrons

$$\gamma N \rightarrow K \pi \Sigma$$

$$\gamma N \rightarrow K \Lambda(1405)$$ S.i. Nam's talk

$$\gamma N \rightarrow K^* \Sigma$$

$$\gamma N \rightarrow K_2^* \Sigma$$

Excited hadrons

$$\gamma N \to \pi\pi\pi N$$

Excited hadrons

$$\gamma N \to \pi\pi\pi N$$

$$\gamma N \to \omega N$$

$$\gamma N \to h_1 N$$

Excited hadrons

$$\gamma N \to \pi\pi\pi N$$

$$\gamma N \to \pi N^*$$
$$\gamma N \to \pi\Delta(1600)$$

$$\gamma N \to \omega N$$
$$\gamma N \to h_1 N$$

Excited hadrons

$$\gamma N \to \pi\pi\pi N$$

$$\gamma N \to \pi N^*$$
$$\gamma N \to \pi \Delta(1600)$$

$\gamma N \to \omega N$ B.G. Yu's talk & A. Somov's talk

$$\gamma N \to h_1 N$$

Excited hadrons

Excited hadrons

$$\gamma N \to \pi\pi K\Lambda \; :$$

$$\gamma N \to K^* \Sigma^*$$

$$\gamma N \to K_1 \Lambda$$

$$\gamma N \to K_2^* \Lambda$$

Excited hadrons

$$\gamma N \to \pi\pi K\Lambda \ :$$

$$\gamma N \to K^*\Sigma^*$$

$$\gamma N \to K_1\Lambda$$

$$\gamma N \to K_2^*\Lambda$$

$$\gamma N \to KKK\Omega$$

Excited hadrons

$$\gamma N \to \pi\pi K\Lambda \ :$$

$$\gamma N \to K^*\Sigma^*$$

$$\gamma N \to K_1\Lambda$$

$$\gamma N \to K_2^*\Lambda$$

$$\gamma N \to KKK\Omega$$

Extreme cases

$$\gamma N \to \pi\pi\pi\pi N (\gamma N \to b_1 N)$$

$$\gamma N \to \pi\pi\pi\pi\pi N (\gamma N \to X N)$$

GlueX Experiment: Searching for hybrid-exotics

Hadrons in nuclear medium

$\gamma + A \to \omega + A$

$\gamma + A \to \rho + A$

$\gamma + A \to \phi + A$

→

- Changes of vector mesons in medium
- Mass dropping in medium or not?
- Shift of the widths or not?

- If any, what is the merit of using photon beams to study the change of hadrons in medium?

Talks by A. Somov, S.-T. Cho, S. Kim

Hypernuclei

ΛN interaction   A talk by L. Tang

$NN, \quad \Lambda N, \quad \Lambda\Lambda$

- Hyperon-Nucleon interactions are still not much known.
- Hyperon-neutron: No single data.
- One can get access to Hyperon-Nucleon interactions via Hypernuclei

Λnn Resonance as T=1 3-body resonance

$^{3}H(e, e' K^{+})(\Lambda nn)$

K_L Physics

- Both S=1 and S=-1 physics are possible. I. Strakovsky's talk

$$K_L + p \to K_S + p$$
$$K_L + p \to K_L + p$$
$$K_L + p \to K^+ + n$$

→ Hyperon resonances can be studied

$$K_L + p \to \pi + \Lambda$$
$$K_L + p \to \pi + \Sigma$$

- Excited hyperons are still not much known.

→ Dynamics related to strange quarks

- Possible pentaquark study by direct formation.

Heavy flavors

$\gamma N \to J/\psi N$: Heavy pentaquarks P_c

$\gamma N \to D_c \Lambda_c^+$

$\gamma N \to D_c^* \Lambda_c^+$

Ω_c^* : Newly found excited Omega_cs by LHCb

- Charm photo-production is also a very exciting subject, since many things are unknown.
- Possibly, there are many heavy pentaquark states!
- For Heavy pentaquarks, coupled-channels will come into play.
- Effective Lagrangians may not be enough or even not correct!

QUESTIONS POSED

- What are the key goals of investigating **strangeness** in hadron physics?
- What are the connections between different areas of studying hadron interactions with nuclear medium?
- Hypernuclear Physics@JLAB & @J-PARC, what complementarity?
- Possible studies on heavy flavors using photon beams?