Interpretations of N^* Parameters

T.-S. H. Lee

Argonne National Laboratory
and
Excited Baryon Analysis Center (EBAC) at JLab

Questions:

- What do we want to learn ?
- What are needed ?
- What are being done ?
- What are the relations with empirical analyses ?

What do we want to learn ?

Objective :

Understand the structure of N^* within QCD

- Confinement of constituent quarks
- Interactions between constituent quarks
- Chiral dynamics of meson cloud of baryons
- Transitions to PQCD

Some specific questions

- Missing Resonances ?

  $\rightarrow$

  establish the symmetry of baryon spectrum (SU(6) or ???)

- 3q or q-2q configurations ?

  $\rightarrow$

  reveal the dominant interactions between constituent quarks

- How the meson cloud effects vary as Q^2 increases ?

  $\rightarrow$

  determine the scale of spontaneous breaking of chiral symmetry

- Are N^* mainly due to quark excitations or meson-baryon interactions ?

  $\rightarrow$

  understand how chiral dynamics determine baryon excitations ?

- $\cdots$

What are needed to do in practice ?

Develop theories to interpret the N^* parameters

- Masses and widths : M_{N^*}, Γ_{N^*}
- Form factors : $F_{N^*,MB}(q)$ ($MB = \gamma N, \pi N, \pi\Delta, KY \cdot\cdot$)

in terms of

- QCD-based Hadron models at the present time
- Lattice QCD in the near future .

Main problem :

N^* are unstable

$\rightarrow$

Structure is coupled to reaction channels

$\rightarrow$

Reaction cross sections are due to

- changes of internal structure ($N \rightarrow \Delta, N^*(1440), \cdot\cdot$)
- reaction mechanisms (Meson exchanges, gluon exchanges $\cdot\cdot$)

$\rightarrow$

Task : separate the contributions from structure and reaction mechanisms

$\rightarrow$

Develop Dynamical reaction models

General Considerations

N and N^* are composite particles

$\rightarrow$

$T = t + t^R$

- t: non-resonant (fast)

  Meson-exchange, gluon-exchange $\cdots$

- t^R: resonant (time-delayed)

  strong overlaps of the baryon continuum with reaction channels

  $\rightarrow$

  N^* is formed and decay

Requirments:

- Satisfy unitarity condition

  $S^{\dagger}S = 1 \quad S = 1 + iT$

  $\rightarrow$

  $Im[T] = -\pi T^{\dagger}T$

  $\rightarrow$

  Dynamical constraints :

  – In the N^* region:

    $T = t + t^R$

    $\rightarrow$

    $Im[t + t^R] = -\pi[t^{\dagger} + t^{R\dagger}][t + t^R]$

    $\rightarrow$

    t^R and t are not independent in any model

Example :

Dynamical Coupled-Channel Model at EBAC

(B. Julia-Diaz, T.-S. H. Lee, A. Matsuyama, M. Paris, T. Sato)

$$T_{a,b}(E) = t_{a,b}(E) + \sum_{N_i^*,N_j^*} \bar{\Gamma}^{\dagger}_{N_i^*,a}(E)[\frac{1}{E - M^* - \Sigma(E)}]_{i,j}\bar{\Gamma}_{N_j^*,b}(E)$$

$$\bar{\Gamma}_{N^*,a}(E) = \Gamma_{N^*,a} + \sum_{b} \Gamma_{N^*,b} G_b(E) t_{b,a}(E)$$

$$a, b = \gamma N, \pi N, \eta N, \pi\Delta, \rho N, \sigma N$$

$t_{a,b}(E)$ = Non-resonant term

$\rightarrow$

Interpretations of $\bar{\Gamma}_{N^*,a}(E)$ need a theoretical understanding of $t_{a,b}(E)$

$\rightarrow$

Comment on Empirical analyses based on

$T = t^{bg} + t^{R}(Briet - Wignerform)$

Extracted N^* parameters contain t^{bg}

$\rightarrow$

Can be interpreted only when t^{bg} is understood

$\rightarrow$

Phenomenological parameterizations (polynominal, separable) of t^{bg} must be justified.

– Unitarity condition:

$ImT = -\pi T^\dagger T$

$\rightarrow$

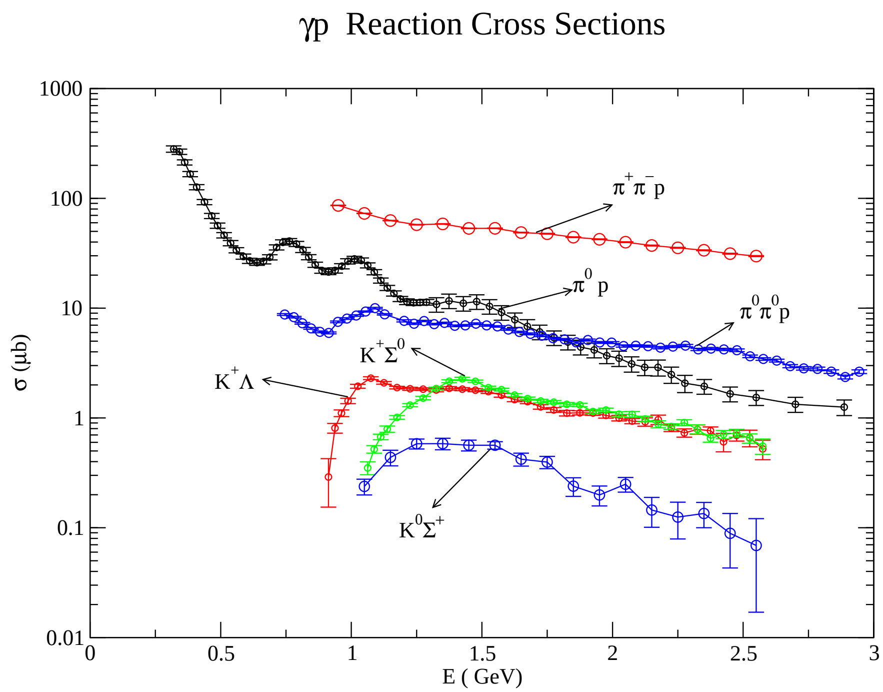
$$Im[T_{\gamma N,MB}] \propto \sum_{M'B'} [T^\dagger]_{\gamma N,M'B'} T_{M'B',MB}$$
$$\propto \sqrt{\sigma_{\gamma N,MB}}\sqrt{\sigma_{MB,KY}}$$

* $T_{a,b}$: reaction amplitude
* $MB = \gamma N, \pi N, \eta N, KY, \omega N, \pi\pi N(\rho N, \pi\Delta) \cdots$

* $\sigma_{a,b}$: cross section of $a \rightarrow b$

Example:

Consider KY photo-production



$\rightarrow$

Must include coupled-channel effects :

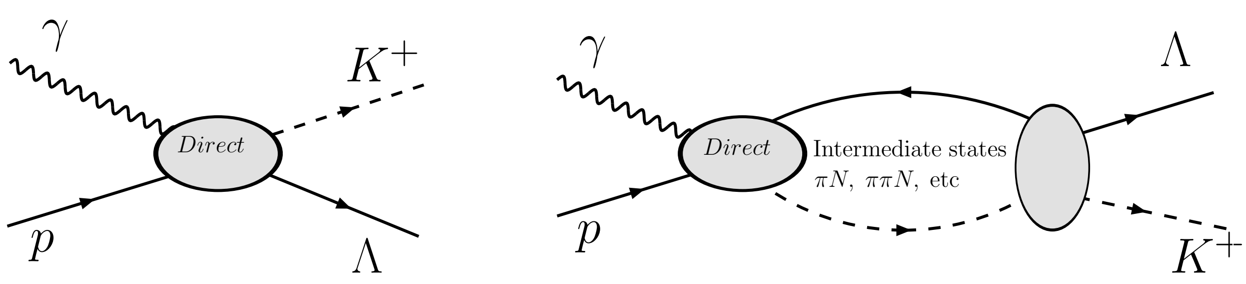
$* \ \gamma p \to \pi N \to KY$

$* \ \gamma p \to \pi\pi N \to KY$

Basic ingredients of a reaction Model :

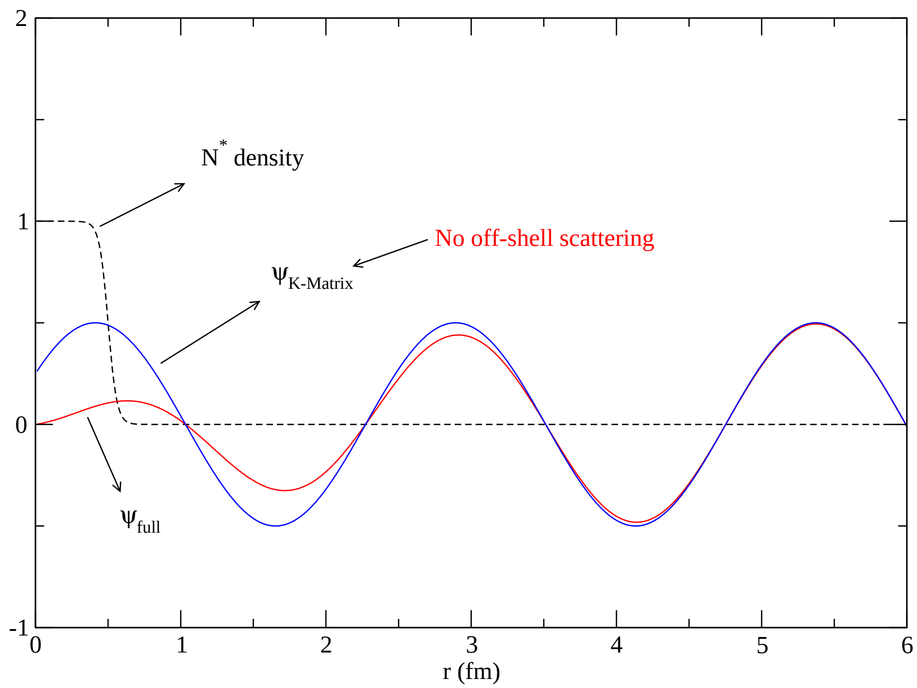
$*$ A direct reaction mechanism

$*$ Accounts for coupled channel effects



- Must account for reaction mechanisms at short distances (i.i. off-shell)

$$F_{N^*,MB} \sim \int [\Phi^*_{N^*}(\vec{r}) H_{N^*,N}(\vec{r}) \Phi_B(\vec{r})] \Psi_{Full}(\vec{r}) d\vec{r} \quad (1)$$



$$\Psi_{full}(r \to \infty) = \Psi_{K-Matrix}(r) = \frac{sin(kr+\delta)}{kr}$$

$[\Phi^*_{N^*}(\vec{r}) H_{N^*,N}(\vec{r}) \Phi_B(\vec{r})]$: contain structure

$\rightarrow$

It is essential to account for the reaction mechanisms at short distances (off-shell) where we want to map out the hadron structure

$\rightarrow$

Comment :

K-matrix models:

Extracted N^* parameters contain effects of reaction mecanisms

Coupled channel calculations of $\gamma p \to K^+\Lambda$

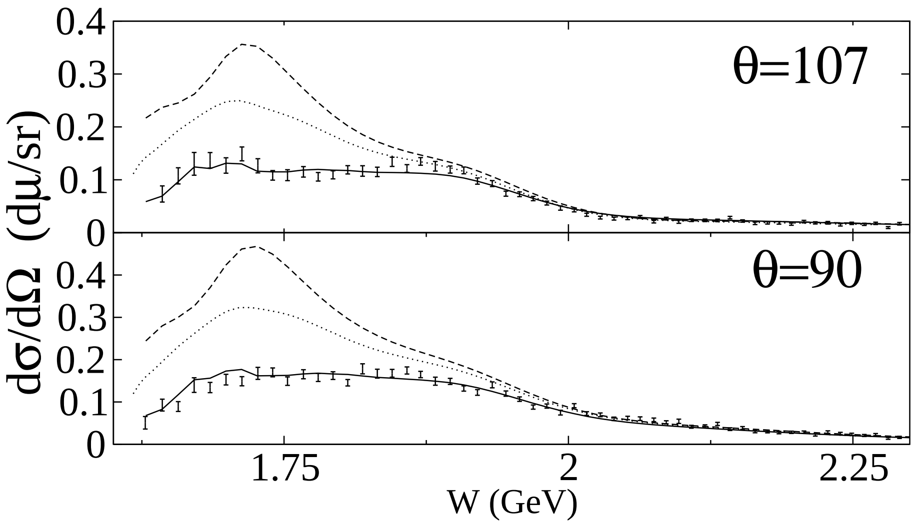
(B. Julia-Diaz, B. Saghai, T.-S. H. Lee, F. Tabakin, 2005)

Channels : γN, πN, $K\Lambda$, $K\Sigma$

Solid: Coupled channel

Dashed: no coupled-channel

Dotted : no off-shell effects



$\rightarrow$

To interpret N^* parameters, reaction models must include:

- Non-resonant amplitude from a theory (Chiral Lagrangians etc..)

  It is NOT an unimportant ”background” !!

- Coupled-channel effects
- Off-shell effects

Dynamical Models

Two equivalent approaches:

- Solve equations with $V = v + v^R$ directly :

$$T_{a,b}(E) = V_{a,b} + \sum_c V_{a,c} G_c(E) T_{c,b}(E)$$

$a, b, c = \pi N, \gamma N, \eta N, \pi\Delta \cdots$

- Solve equations with explicit resonant term

$$T_{a,b}(E) = t_{a,b}(E) + \sum_{N_i^*, N_j^*} \bar{\Gamma}^\dagger_{N_i^*,a} [D^{-1}(E)]_{i,j} \bar{\Gamma}_{N_j^*,b}$$

$$t_{a,b}(E) = v_{a,b} + \sum_c v_{a,c} G_c(E) t_{c,b}(E)$$

$$\bar{\Gamma}_{N^*,a} = \Gamma_{N^*,a} + \sum_b \Gamma_{N^*,b} G_b(E) t_{b,a}(E)$$

$\rightarrow$

Need to

- Solve integral equations involving off-shell

$$t(k, k_0, E) = v(k, k) + \int dk' \;\; v(k, k') \frac{1}{E - E_B(k') - E_M(k') + i\epsilon} t(k', k_0, E)$$

- define non-resonant interactions $v_{a,b}$

  Guided by Phenomenlogical Lagrangians with

  known physics (chiral symmetry, VDM, $\cdot\cdot$)

- define bare N^* parameters

  Guided by

  – Hadron structure calculations
    (Constituent quark models, Covariant DS models, $\cdot\cdot$)

  – Empirical analyses (K-matrx models, PWA $\cdot\cdot$)
    $\rightarrow$
    Empirical analyses and Dynamical models
    are complementary

Similar to the study of NN interactions at low energy

- Extract phase shifts by using the analyses incuding only one-pion-exchange tails. (i.e. no short range (off-shell) effects)
- The resulting phase shifts are then interpreted in terms of meson-exchange potentials within Field Theory

What are being done in developing dynamical models ?

- (a) Sato-Lee Model : πN, γN

  (b) Dynamical Coupled-channel model at EBAC :

  $$\gamma N, \pi N, \eta N, \pi\pi N \; (\pi\Delta, \rho N, \sigma N)$$

  (talk by B. Julia-Diaz)
- Juelich Model :πN, γN (talks by S. Krewald, H. Haberzettl)
- EFT Model : πN, γN (talk by V. Pascalutsa)

- DMT Model : πN, γN, ηN
- Fuda et al. : πN, γN
- Ohio-Utrecht Model : πN, γN
- Pitt-Saclay-ANL Model : γN, πN, KY
- Unitary Chiral SU(3) models : KY, ωN, γN, πN

Main challenge :

- Include effects due to $\pi\pi N$ channels

  $\rightarrow$

  Focus at EBAC

- How to relate to LQCD ?

  (Talk by D. Richards)