

Brief comparison between ongoing dynamical coupled-channels analyses for N^* extraction

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**...Advancing the Frontiers
of the Science of Light...**

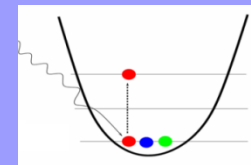
The issue: Facts

- Baryons have **structure**
- For already a **long time** we have been bombarding nucleons in an effort to understand what is going on inside
- **The overall picture is agreed**, since ~ 2 decades and with hand waving, i.e. quark model, arguments
- Precision (systematic) learning is tough

The issue: brief theory facts

- QCD does not provide quantitative predictions of how baryon structure actually is. **Meson production calculations still far ahead.** Computationally very challenging.
- Quantitative predictions from quark models are not seen in experiments. **Moreover most QM do not bear the “theory” blessings:** Lorentz covariance, gauge invariance, chiral symmetry, unitarity, ...
- Chiral Unitary approaches are used extensively to correlate pieces of data. Elegant, but **not directly useful to learn about N^* from the data measured in the labs.**

Baryon Resonances



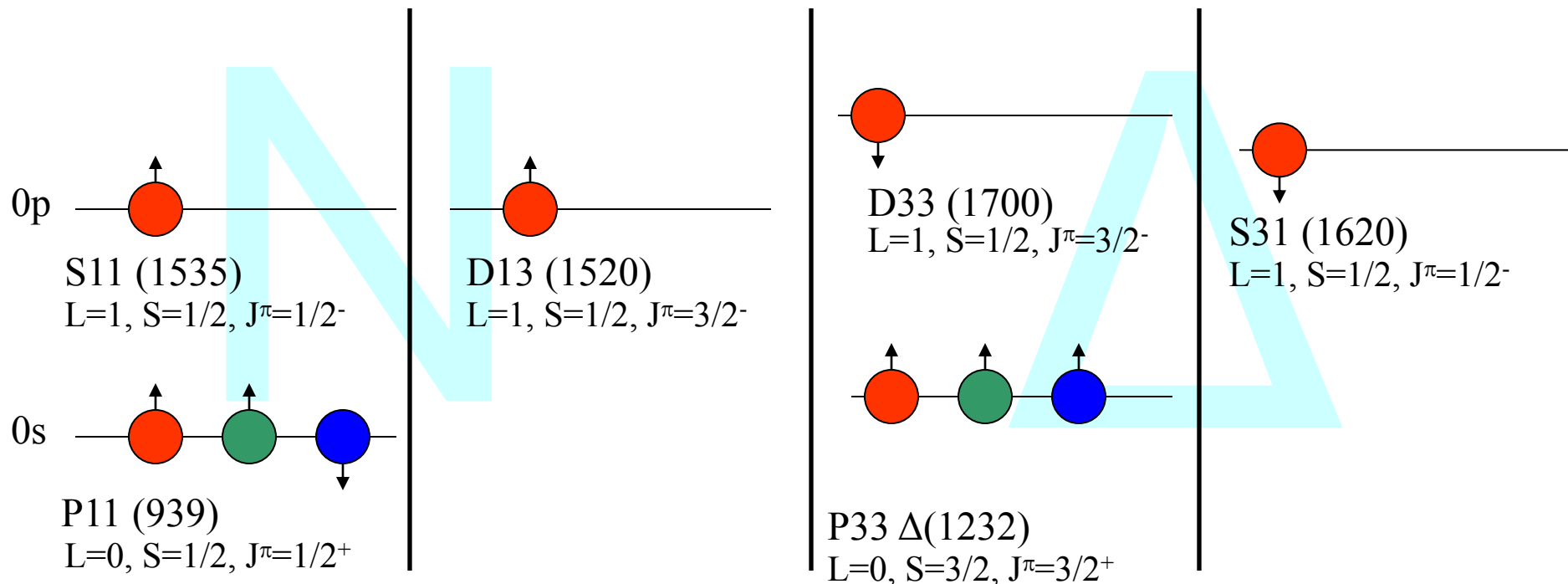
Exciting the substructure we can **learn about the forces which keep the quarks together**, e.g. using the **quark model picture** some of the predicted states are:

$J=1/2$

$J=3/2$

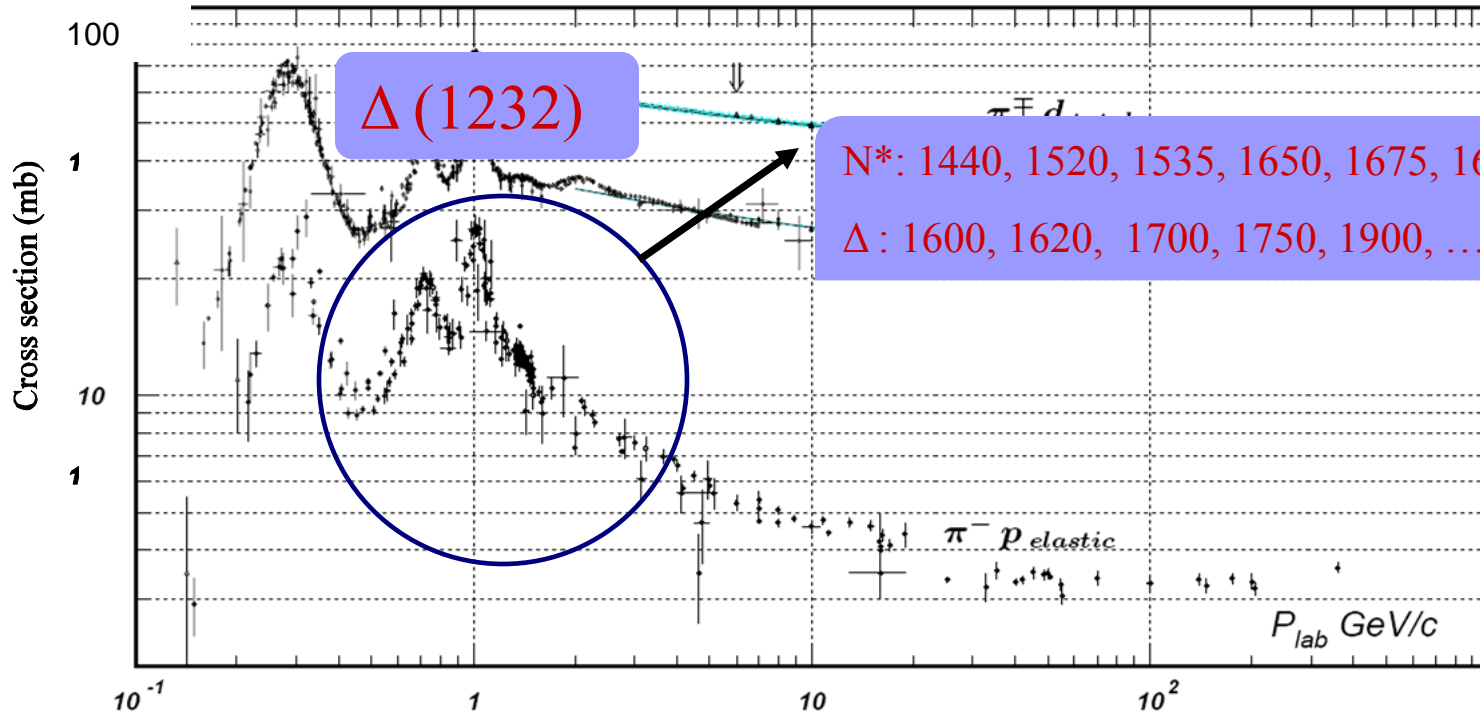
$J=3/2$

$J=1/2$

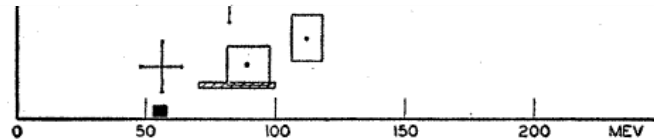


The Δ (1232) and others

$\pi N \rightarrow X, \pi N$



πp 1.2
 Ps GeV



20 30 40
 MEV

- The Δ (1232)
- The region $1.2 < P_{lab} < 1.5$ GeV/c

FIG. 1. Total cross sections of negative pions in hydrogen (sides of the rectangle represent the error) and positive pions in hydrogen (arms of the cross represent the error). The cross-hatched rectangle is the Columbia result. The black square is the Brookhaven result and does not include the charge exchange contribution.

Some questions on N^* s

All of these studies essentially agree on the existence and (most) properties of the 4-star states. For the 3-star and lower states, however, even a statement of existence is problematic.

Arndt, and collaborators, PRC 74 045205 (2006)

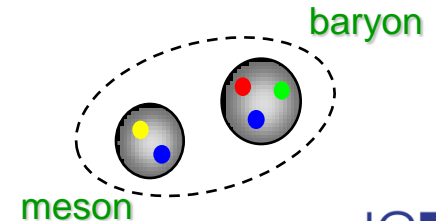
Particle	$L_{2I,2J}$ status	$N\pi$	$N\eta$	AK
$N(939)$	P_{11}	****		
$N(1440)$	P_{11}	****	****	*
$N(1520)$	D_{13}	****	****	***
$N(1535)$	S_{11}	****	****	****
$N(1650)$	S_{11}	****	****	* ***
$N(1675)$	D_{15}	****	****	* *
$N(1680)$	F_{15}	****	****	* **** **
$N(1700)$	D_{13}	***	***	* ? ** * **
$N(1710)$	P_{11}	***	***	** ** ** * **
$N(1720)$	P_{13}	****	****	* ** * * **
$N(1900)$	P_{13}	**	**	* ? *
$N(1990)$	F_{17}	**	**	* * *
$\Delta(1232)$	P_{33}	****	****	F ****
$\Delta(1600)$	P_{33}	***	***	o ? *** *
$\Delta(1620)$	S_{31}	****	****	r **** ****
$\Delta(1700)$	D_{33}	****	****	b * *** **
$\Delta(1750)$	P_{31}	*	*	? * * **
$\Delta(1900)$	S_{31}	**	**	d * * **
$\Delta(1905)$	F_{35}	****	****	d * ** **
$\Delta(1910)$	P_{31}	****	****	e * * *
$\Delta(1920)$	P_{33}	***	***	? n * **
$\Delta(1930)$	D_{35}	***	***	* **
$\Delta(1940)$	D_{33}	*	*	F **
$\Delta(1950)$	F_{37}	****	****	o * **** *

Are they all genuine quark/gluon excitations (with meson cloud)?

Need consistent analysis including inelastic channels ($\pi\pi N, \eta N, KY, \omega N, \dots$)

→ some could be understood as arising from meson-baryon dynamics

$$|N^*\rangle = |MB\rangle$$



The data

The N can be probed at $W < 2$ GeV:

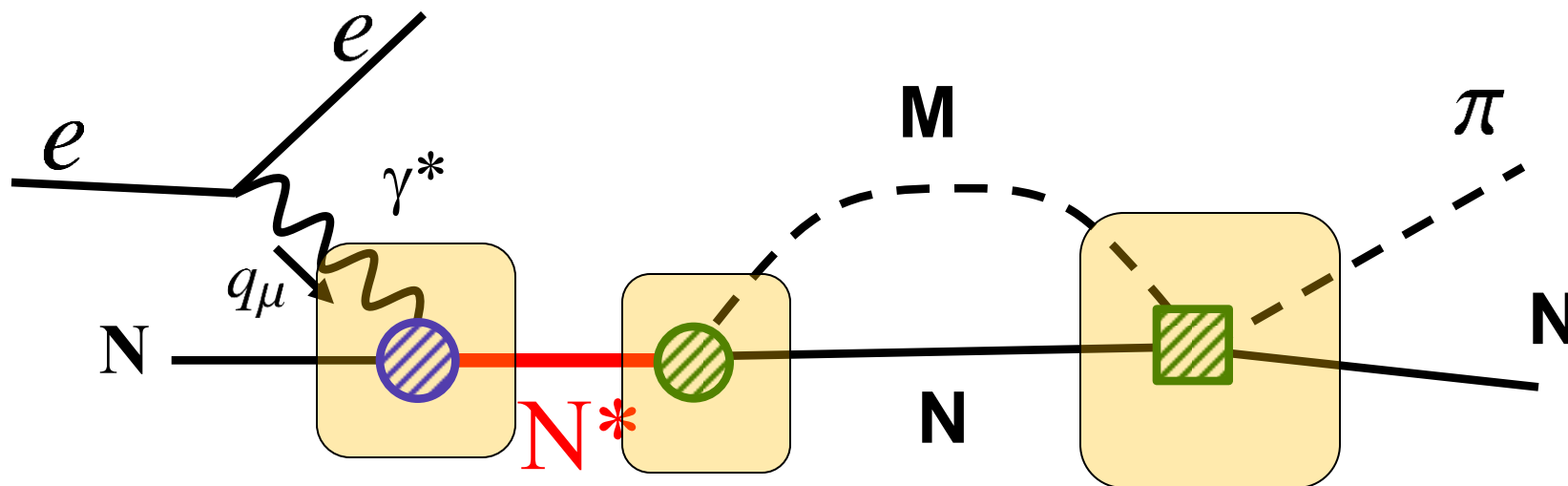
- πN , $\pi\pi N$, ηN , production:

(OLD) Hadronic production: $\pi N \rightarrow$

(RECENT) Photoproduction: $\gamma N \rightarrow$

(RECENT) Electroproduction: $\gamma^* N \rightarrow$

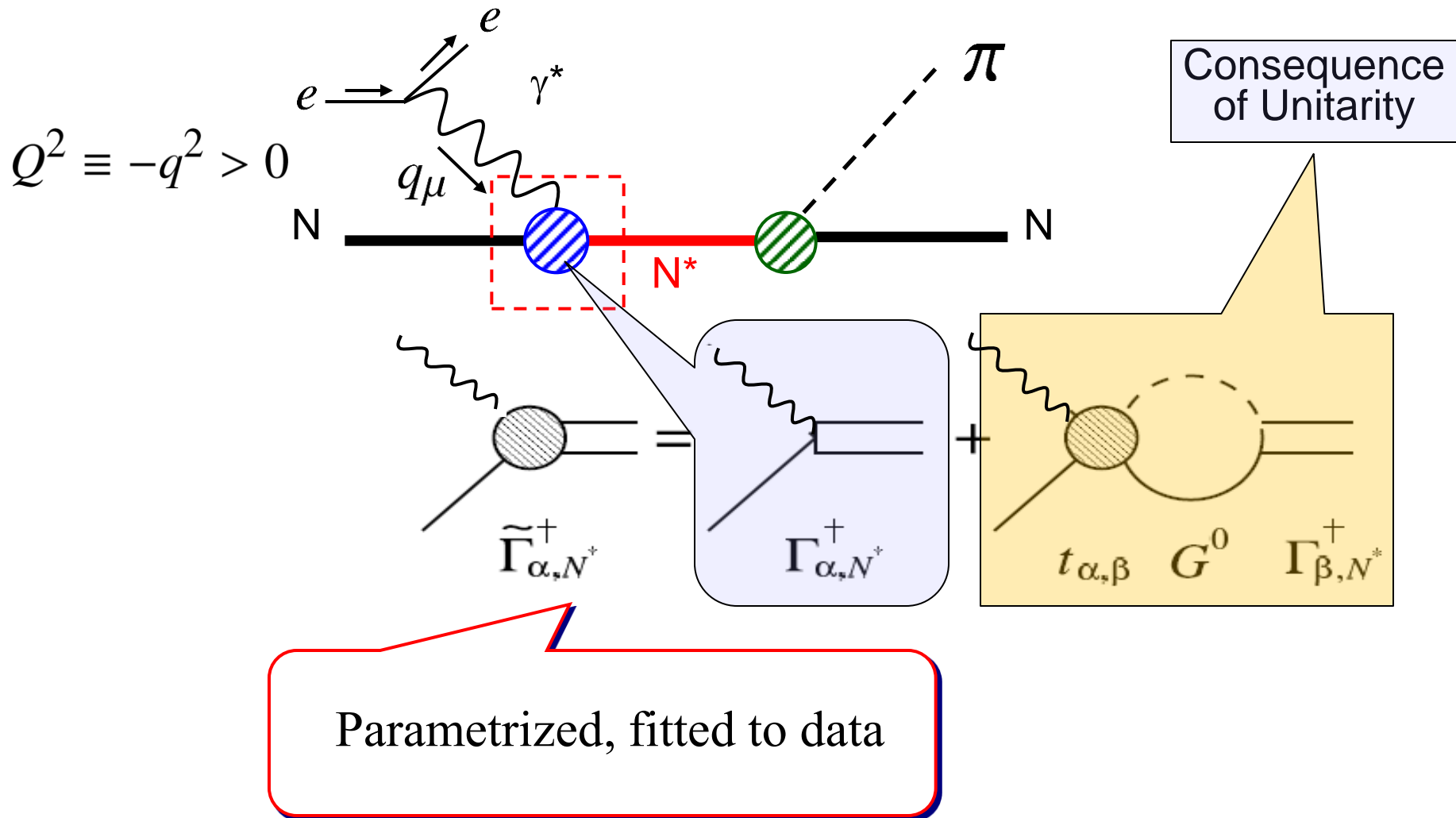
Electroproduction of mesons



Main theoretical elements:

1. Strong-strong interactions
2. Hadronic structure of Resonances
3. Electromagnetic structure of Resonances

Schematic view

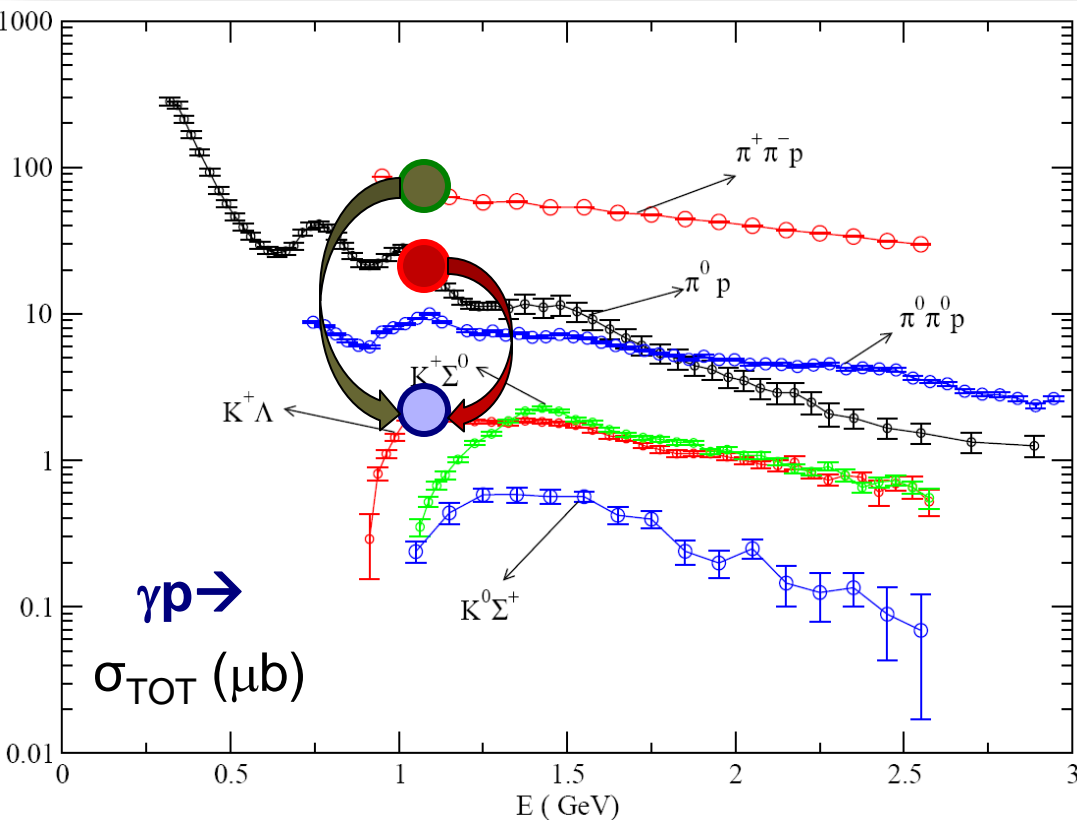


Desirable theoretical properties for reaction models

Basic properties

1. Unitarity constraint built in

Multi step (unitarity)



How do we produce meson-baryon states?

- Directly
 - Through MB states
 - Through MMB states
- ➔**
- We need to incorporate all the possibilities

➔ Unitarity: Coupled-channels, correlates large amounts of data, e.g. strong and electromagnetic production

Basic properties

1. Unitarity and analyticity
2. Gauge invariance (when dealing with electromagnetic forces)
 - Only fully respected in simplified models (up to now), important efforts by Juelich/Georgia

Basic properties

1. Unitarity and analyticity
2. Gauge invariance (when dealing with electromagnetic forces)
3. Covariance

3. Covariant three-dimensional reduction

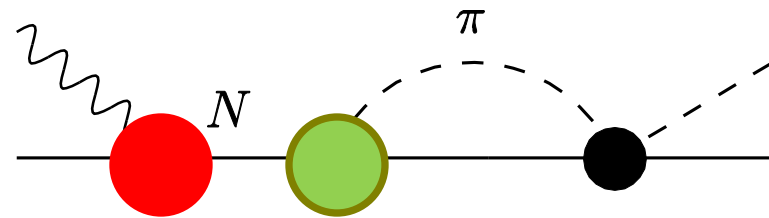
The present formalism is a fully covariant approach. To calculate any reaction amplitude in a full four-dimensional framework is a daunting numerical task. Therefore, in the present work, we approximate the full meson-baryon two-body propagator G_0 by the Kadyshevsky propagator [82], as speci-

Huang, Döring, Haberzettl, Haidenbauer, Hanhart, Krewald, Meißner, Nakayama PRC (2012)

Basic properties

1. Unitarity and analyticity
2. Gauge invariance (when dealing with electromagnetic forces)
3. Covariance
4. Simultaneous **treatment** of
 - Electromagnetic
 - Strong interactions

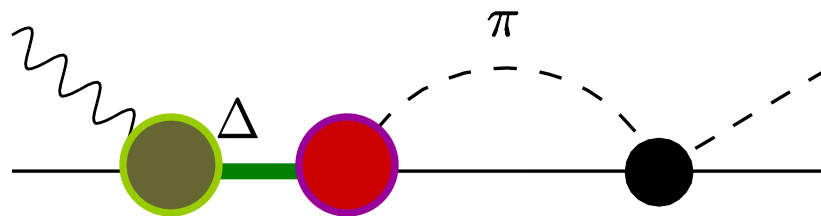
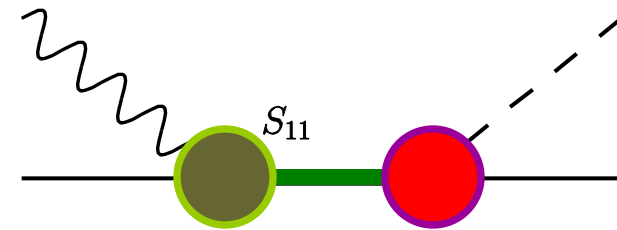
Basic properties | Consistency



e.g: $\gamma p \rightarrow \eta N$

■ Key points:

- Couplings of mesons to baryons
- Electromagnetic vertices



- Coupling of resonances to MB
- Electromagnetic structure of resonances

Basic properties

1. Unitarity and analyticity
2. Gauge invariance (when dealing with electromagnetic forces)
3. Covariance
4. Simultaneous **treatment** of
 - Electromagnetic
 - Strong interactions
5. Simultaneous **description** of:
 - Hadroproduction observables ($\pi N \rightarrow \pi N, \eta N, KY, \pi\pi N, \dots$)
 - Electroproduction observables ($\gamma N \rightarrow \pi N, \eta N, KY, \omega N, \pi\pi N, \dots$)

Sample DCC

- **Non-resonant + resonant**
- **Dressed resonant vertex**
- **Resonance self energies**
- **Non-resonant amplitude**
(resummation)

The diagram shows the Dyson equation for the transition amplitude $T_{\alpha,\beta}$. On the left is a square vertex labeled $T_{\alpha,\beta}$. This is equal to a bare vertex $t_{\alpha,\beta}$ (a circle) plus a series of diagrams representing the resummation of self-energy corrections. The first term in the series is a circle vertex connected to a horizontal chain of three circles, with the first and last circles connected to external lines. The chain is labeled with $\tilde{\Gamma}_{\alpha,N^*}^+$, $D^{-1}(E)$, and $\tilde{\Gamma}_{N^*,\beta}$.

$$T_{\alpha,\beta} = t_{\alpha,\beta} + \tilde{\Gamma}_{\alpha,N^*}^+ D^{-1}(E) \tilde{\Gamma}_{N^*,\beta}$$

Sample DCC (EBAC)

- ✓ Partial wave amplitude of **a** → **b** reaction:

$$T_{a,b}(p_a, p_b; E) = V_{a,b}(p_a, p_b; E) + \sum_c \int_0^\infty q^2 dq V_{a,c}(p_a, q; E) G_c(q; E) T_{c,b}(q, p_b; E)$$

- ✓ **R** (iii) Another class of approaches used to analyze pion- and photon-induced reactions are *K*-matrix models. Dynamical coupled-channels approaches require a price for what is delivered: one has to solve coupled integral equations. The technical effort can be reduced by approxi-

✓ **Potential:**

Huang, Döring, Haberzettl, Haidenbauer, Hanhart, Krewald, Meißner, Nakayama PRC (2012)

2-body **v** potential
(no $\pi\pi N$ cut)

2-body **Z** potential
(with $\pi\pi N$ cut)

bare N^* state

A. Matsuyama, T. Sato, T.-S.H. Lee, *Phys. Rep.* 2007

B. Juliá-Díaz, June 2012, ATHOS conference, Camogli

Concluding remarks

EBAC

- ✓ First group to aim at a(n ambitious) global dynamical coupled-channels analysis of strong and electromagnetic production of mesons in the N^* region
- ✓ Further details, see Sato's talk.

Juelich model

- ✓ Solid strong interaction model
- ✓ Important **recent** effort set in preserving covariance, gauge invariance and on the analytic extension of the amplitudes
- ✓ **Recent** step forward: photoproduction

Other models

- ✓ Avoid solving the integral equations
- ✓ Do not aim at describing strong and electromagnetic together

Concluding remarks

In addition to the statistical errors, there are systematic uncertainties inherent in all phenomenological effective Lagrangian approaches that stem from the implementation (or violation) of Lorentz covariance, unitarity, analyticity, and (for photoprocesses) gauge invariance, from the truncation of reaction channels and from how many intermediate resonances are taken into account. For the present approach, we expect

Huang, Döring, Haberzettl, Haidenbauer, Hanhart, Krewald, Meißner, Nakayama PRC (2012)

But what about N^* ?

- ✓ ...what have they learned about N^* from describing photo and electroproduction data? Any static property has been refined thanks to this data with DCC models?
- ✓ *Can these models build their “PDG” with no other input than the real data?*