What does EBAC at JLab hope to get from LQCD ?

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and

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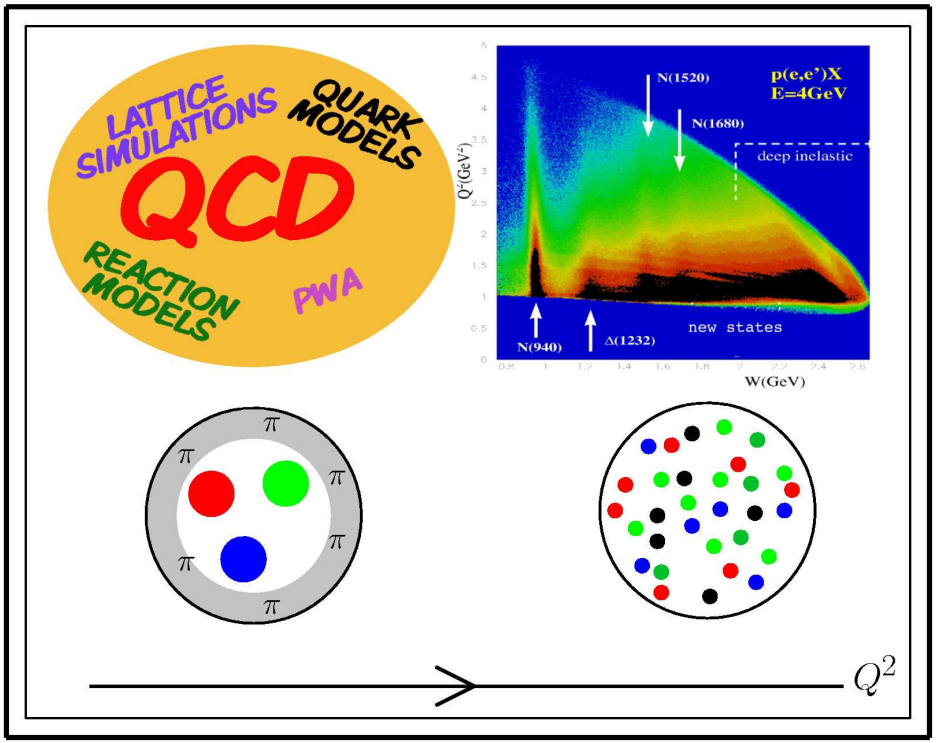

A long-standing problem :

What are the spectrum and structure of excited baryon states ?

- Recent development :

  Extensive and high precision data of photo- and electro-production of $\pi, \eta, K, \rho, \omega, \phi$ mesons have been obtained at JLab, Mainz, Bonn, GRAAL, and Spring-8.

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- Challenges:

  Extract and interpret the information on the excited nucleon states which couple with meson-baryon continuum to form resonances (N^*) in meson production reactions.

This talk :

Recent theoretical analyses of meson production data

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- Extract N^* parameters :

  Masses, Widths, Form factors

- Interpret N^* parameters :
  - Hadron models with effective degrees of freedom
  - Lattice QCD

$\rightarrow$

Understand non-perturbative QCD :

- Confinement mechanism
- Chiral dynamics of meson cloud of baryons
- ....

Current focus:

- Identify baryon excited states at $W > 1.7$ GeV

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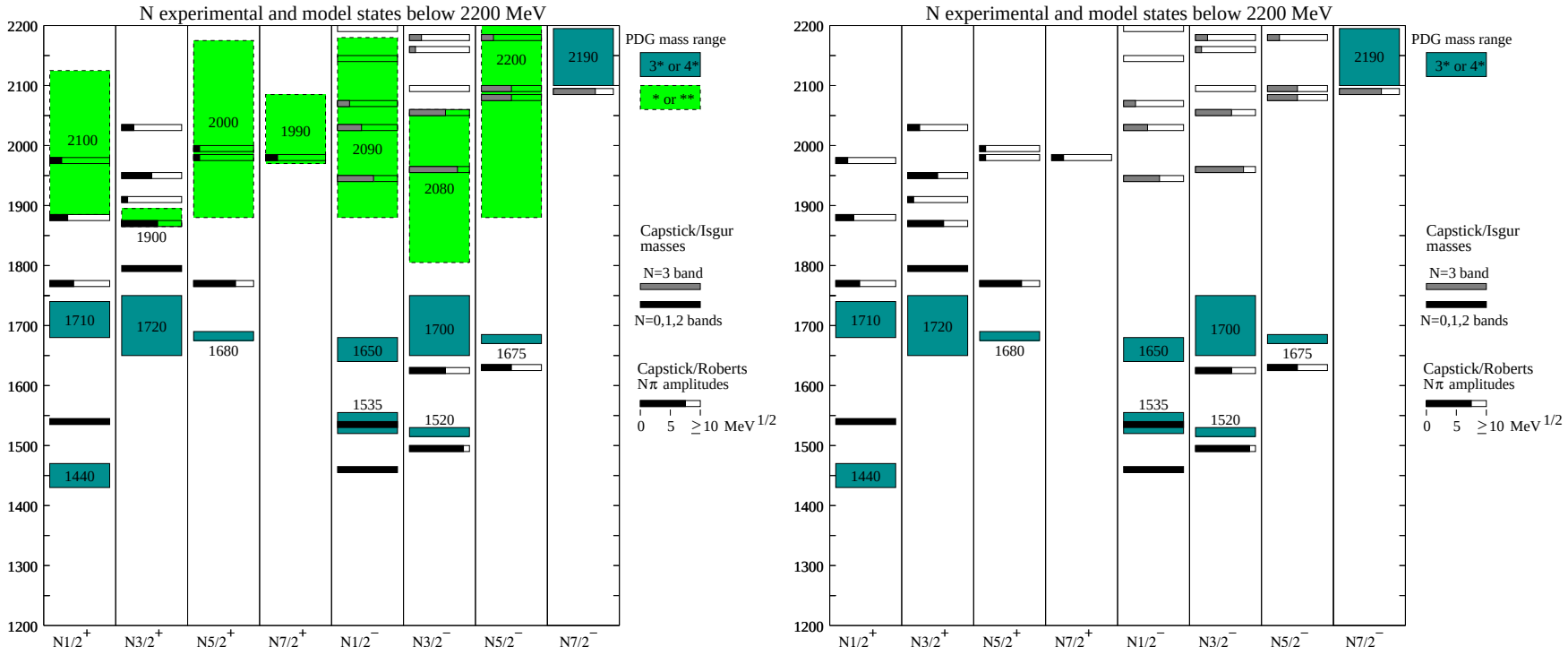
  Establish symmetry property ($SU(6) \oplus O(3)$ or ?????)

  ——— old ———->>>>>———current ———-



Recent PDG assessment : 1- and 2-star states are doubtful

- Extract and interpret N-N^* form factors

  $\rightarrow$

  Reveal

  – The quark sub-structure of baryon excited states

  – The meson cloud effects

General Considerations

- Baryon excited states are coupled to meson-baryon reaction channels to form resonances (N^*)

  $\rightarrow$

  Reaction amplitude : $T = t^R + t^{nr}$

  - t^R : changes of internal structure ($N \rightarrow \Delta, N(1440), \cdot\cdot$)
  - t^{nr} : non-resonant interactions between reaction channels (Meson exchanges $\cdots$)

- Many reaction channels

  $\gamma N, \pi N, \eta N, \omega N, K\Lambda, K\Sigma, \pi\pi N(\pi\Delta, \rho N, \sigma N)$

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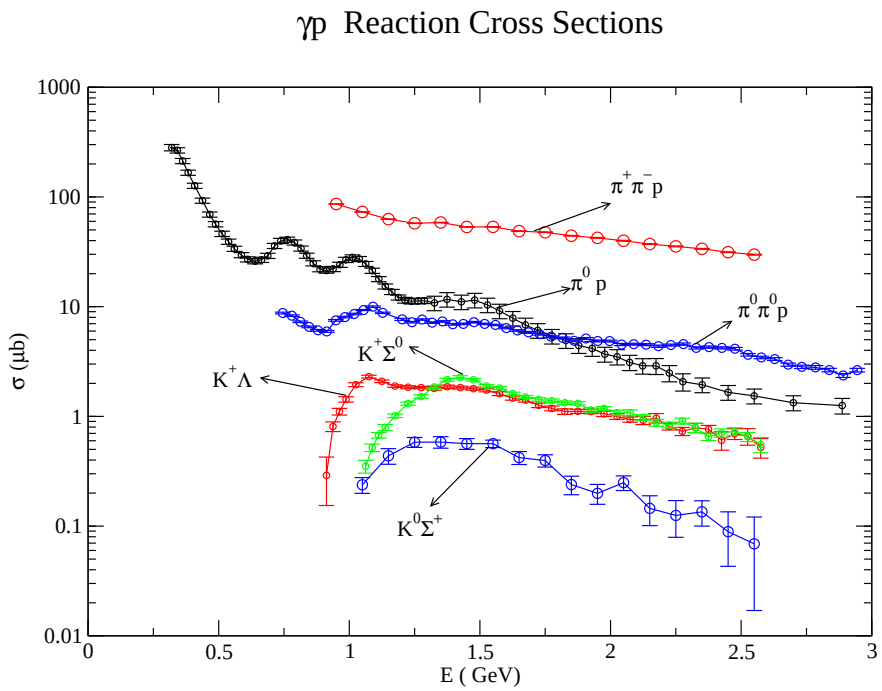
A multi-channel and multi-resonance reaction problem

Example: $\gamma N \to KY$



Must include:

- coupled-channel effects :
  - $\gamma p \to \pi N \to KY$
  - $\gamma p \to \pi\pi N \to KY$
- at least about 10 known N^* resonances

Theoretical Development

Very far from predicting meson-baryon reactions from QCD

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Current effort:

- Develop reaction models to extract N^* parameters
- Interpret N^* parameters using available hadron structure calculations

Note :

Analysis based on dispersion relations is difficult :

- can not handle multi-particle channels ($\pi\pi N$)
- not applicable at high Q^2 region

$\rightarrow$

Develop alternative reaction models

- K-matrix models (On-shell approximation, PWA)

$$\begin{aligned} S &= \frac{1+iK}{1-iK} \\ K &\sim V(tree-diagram) \end{aligned}$$

  - GWU-VPI (SAID), Mainz (MAID), JLab-Yerevan , CMU (PWA) Giessen, GWU, KVI , Bonn-Gatchina, JLab-MSU (JM06), Valencia, Hiroshima-Onomichi, $\cdots$

- Dynamical Models

$$
\begin{aligned}
S &= 1 + 2iT \\
T &= V + \int VGT
\end{aligned}
$$

$\rightarrow$

Account for reaction mechanisms in the short-range (off-shell) region where we want to map out N^* structure

  - Sato-Lee, Gross-Surya, Dubna-Mainz-Taipei, Fuda-Alharbi, Ohio-Utrecht, Saclay-Pitt-ANL, Pascalutsa-Vanderhaeghen, Julich, $\cdot\cdot$

Two approaches are complementary :

- K-matrix models solve algebraic equations

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  very efficient in processing multi-channel data to get

  first-run results of N^* parameters

- Dynamical models account for short-range (off-shell) mechanisms

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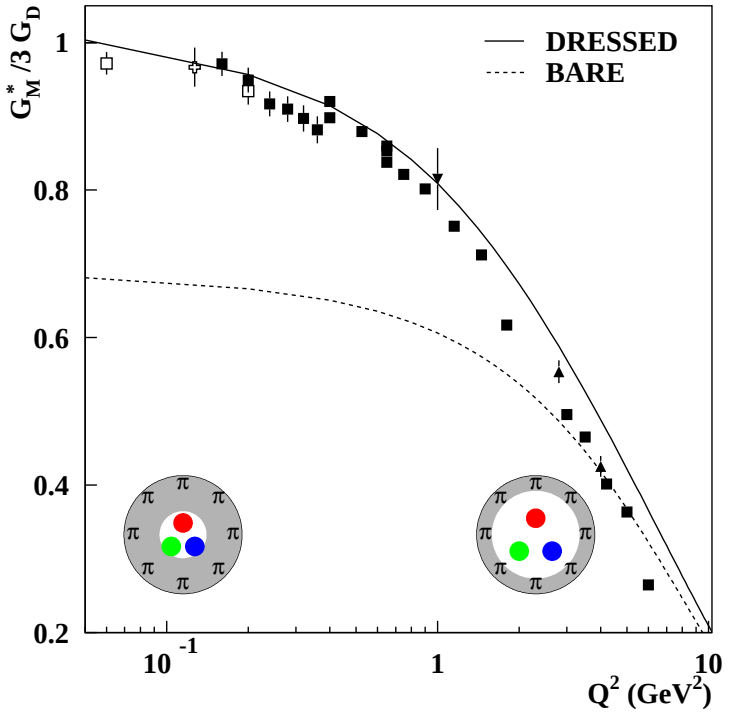
  related to hadron structure calculations for interpreting N^* parameters

Selected Recent Results

1. $\gamma N \to \Delta(1232)$ form factors

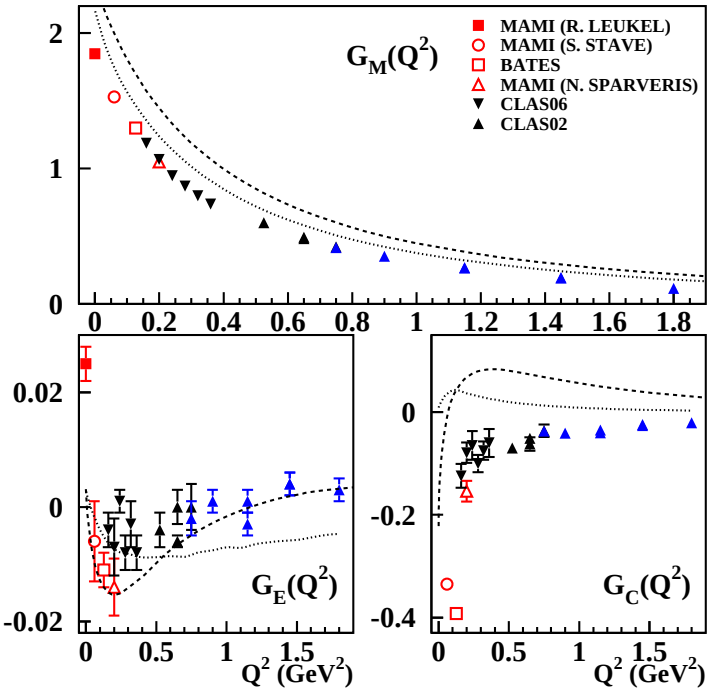
   - Q^2-evolution of meson cloud is discovered

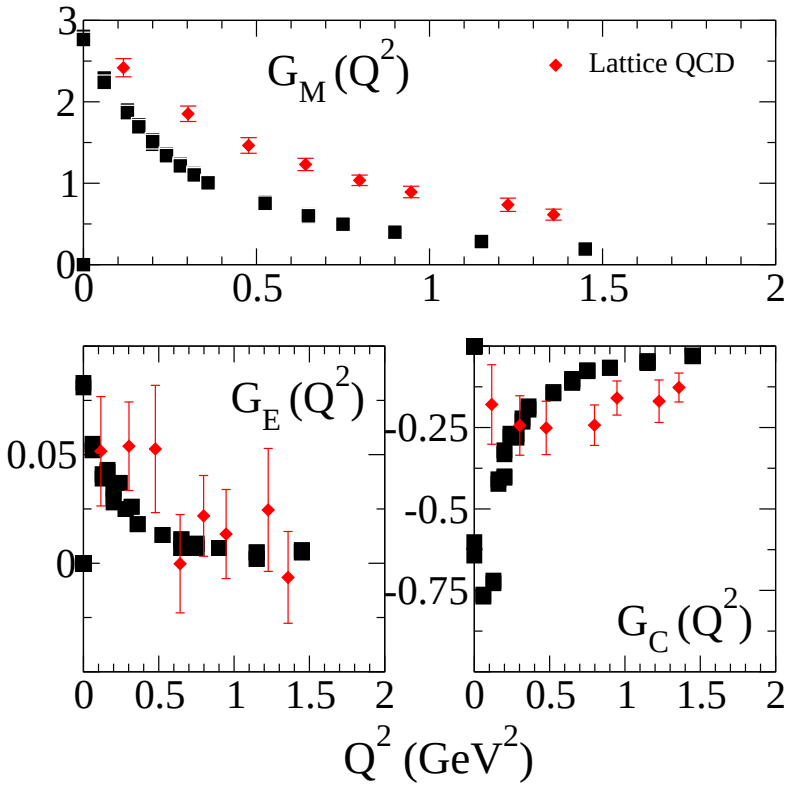


- Hadron structure calculations are tested

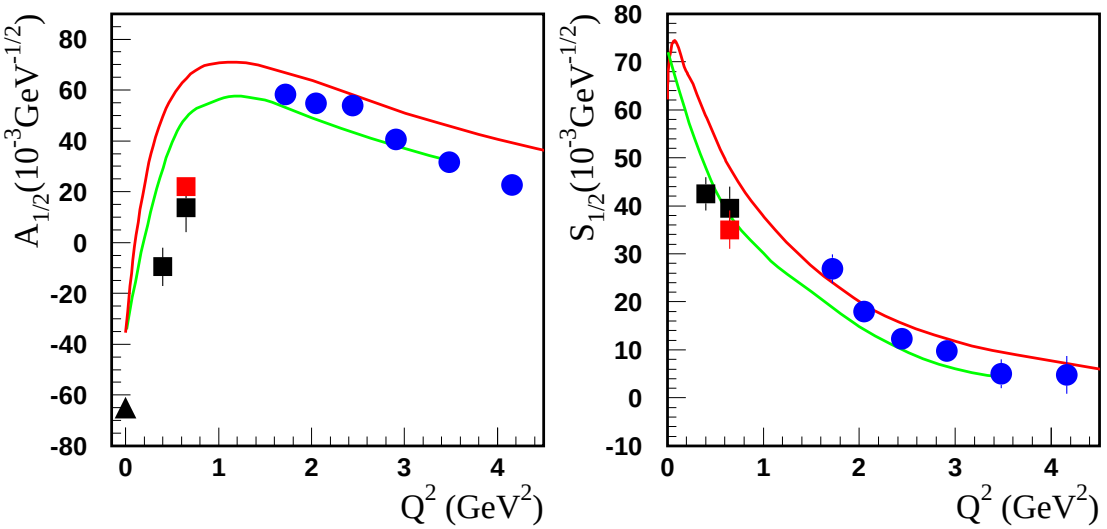
——— Quark Model ———————————-LQCD ———

———-(Bare) ———————————-(Dressed) ———-





2. N-$N^*(1440)$ form factors agree with Quark Model



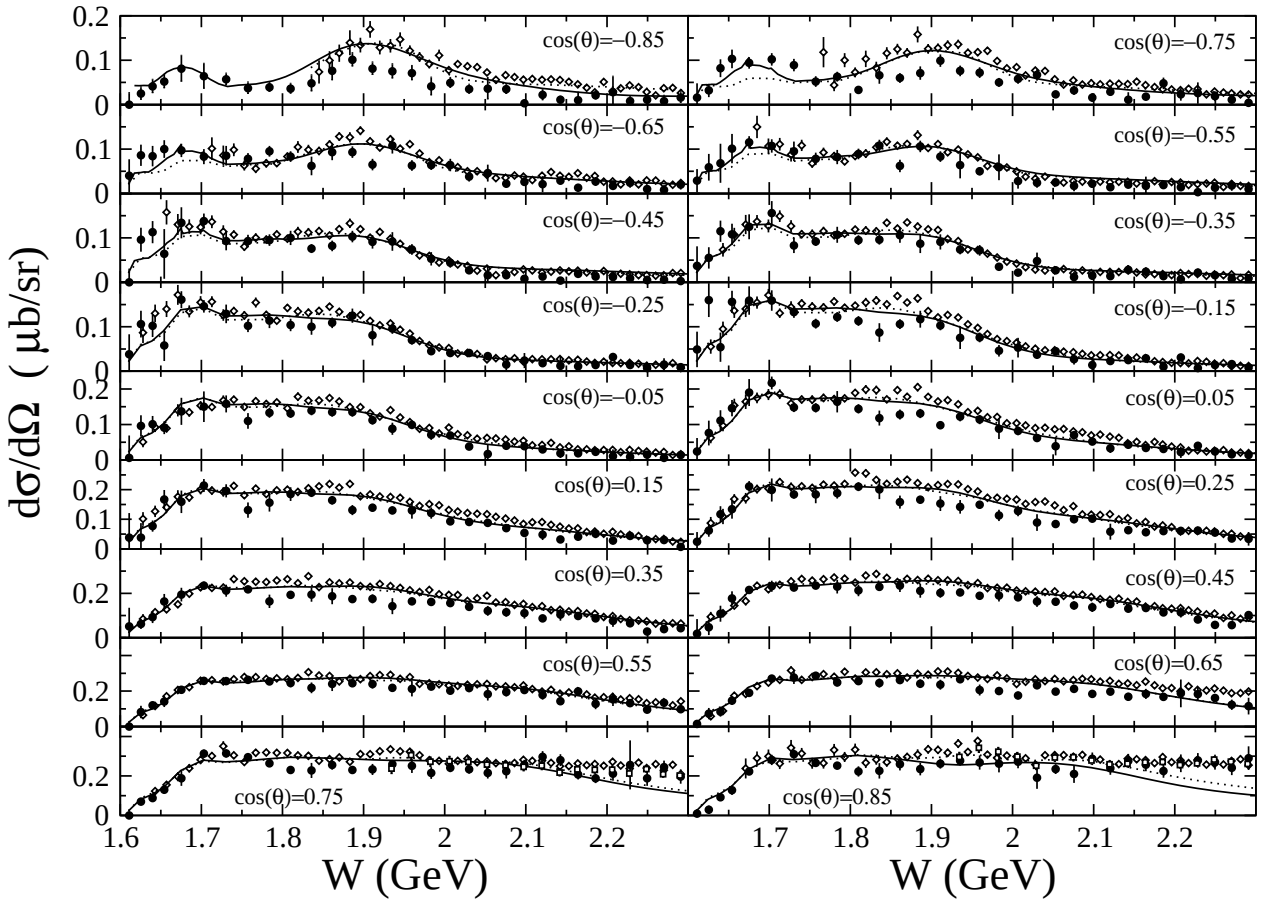
Red curves :S. Capstick and B.D. Keister

Green curves : I. Aznauryan

3. New states at $W > 1.7$ GeV are suggested

Example: Coupled-channel fit to $\gamma p \to K^+\Lambda$ data of JLab

(B. Julia-Diaz et al. 2006)



$\rightarrow$

New states	Mass	Width
S_{11}	1.833	0.288
P_{13}	1.974	0.108
D_{13}	1.912	0.316

Several new states have also been suggested in the K-matrix analyses by Giessen group, GWU group, Bonn-Gatchina group, CLAS collaboration (JM06)

Note :

- Need to be further confirmed by analyses including polarization data and more complete coupled-channel analyses.
- Need to be verified by dynamical model analyses

Necessary next step :

Strengthen the collaborations between

empirical analyses (PWA, K-matrix analyses)

and

theoretical efforts (dynamical models, hadron structure calculations)

$\rightarrow$

Establish Excited Baryon Analysis Center (EBAC)

at the Theory Center of Jefferson Laboratory

Excited Baryon Analysis Center (EBAC)

Theory Center, Jefferson Laboratory

- Established: January, 2006

- Goal : Reach a DOE milestone by 2009

  ”Complete the combined analysis of available single pion, eta and kaon photo-production data for nucleon resonances and incorporate analysis of two-pion final states into the coupled channel analysis of resonances.”

$\rightarrow$

1. On-going theoretical projects :

- Perform Dynamical Coupled-Channel Analysis

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

  K. Tsushima)

  - πN, ηN, $\pi\pi N$ production
  - ωN, $K\Lambda$ production

- Develop collaborations with other theoretical efforts

  - Coupled-channel analysis by the Julich group

    (J. Haidenbauer, C. Hanhart, S. Krewald, Ulf-G. Meißner,

    A. Sibirtsev, K. Nakayama, H. Haberzettl)

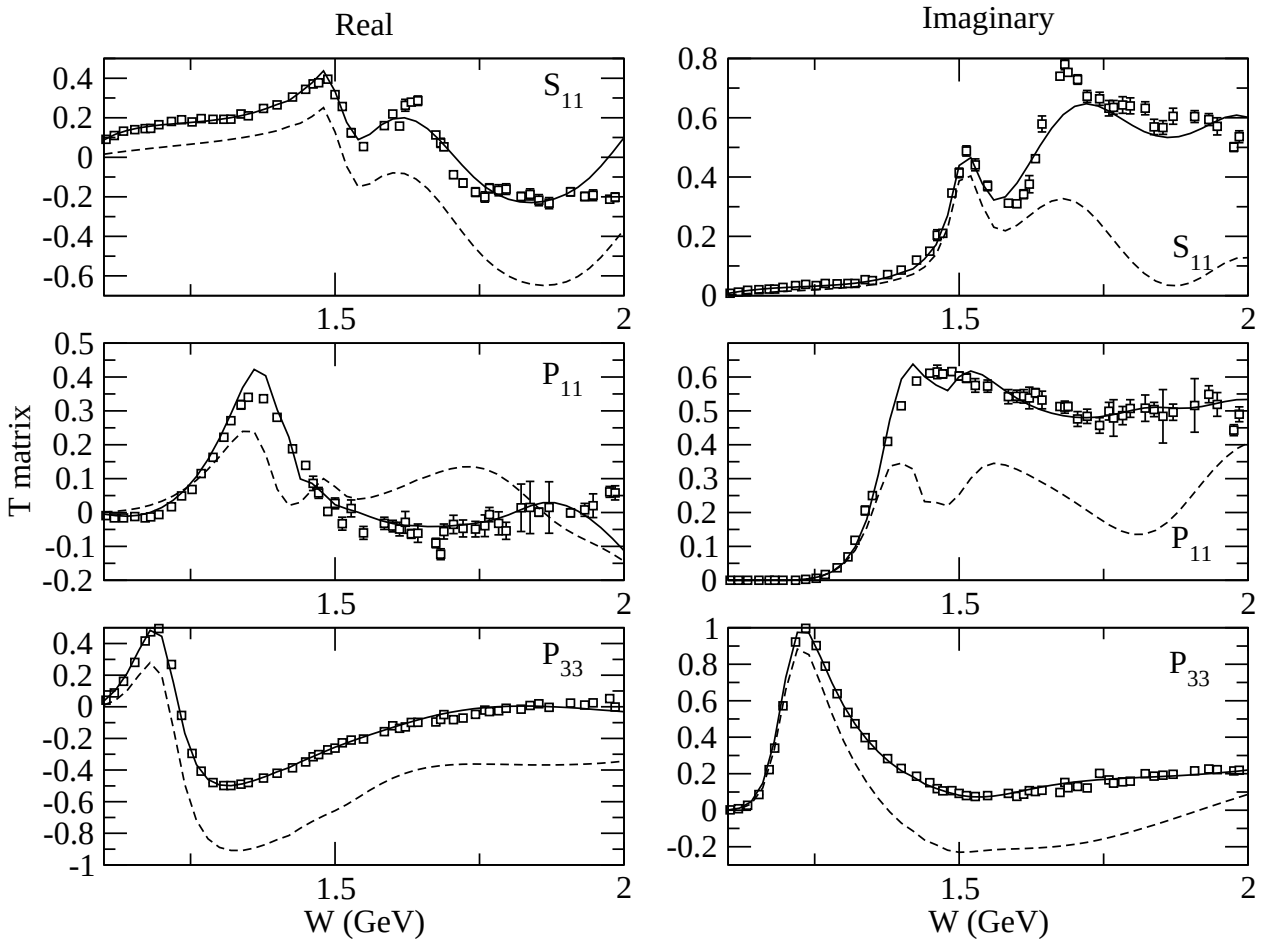
  - EBAC-Saclay Coupled-channel analysis of η, K photoproduction

    (J.-C. David, J. Durand, Jun He, B. Julia-Diaz, T.-S. H. Lee,

    B. Saghai, T. Sato)

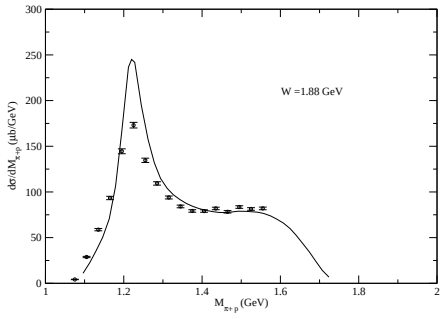
First results from EBAC

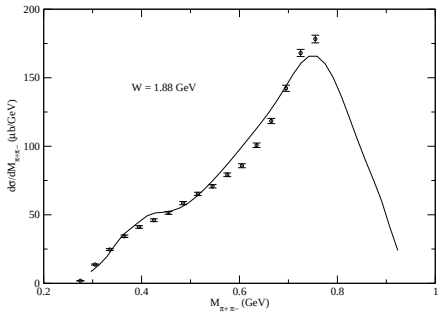
- Fits of πN amplitudes

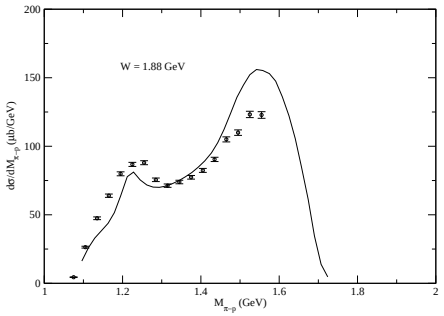


(dashed curves: N^* contributions)

- Start to analyze $\gamma p \to \pi^+ \pi^- p$ data of JLab







Plans :

- 2007 - 2008 : Analysis of $\pi, \eta, \pi\pi$ production data
- 2008 -2009 : full coupled analysis including ω, K production data

2. Provide theoretical input to the data analyses by experimental groups

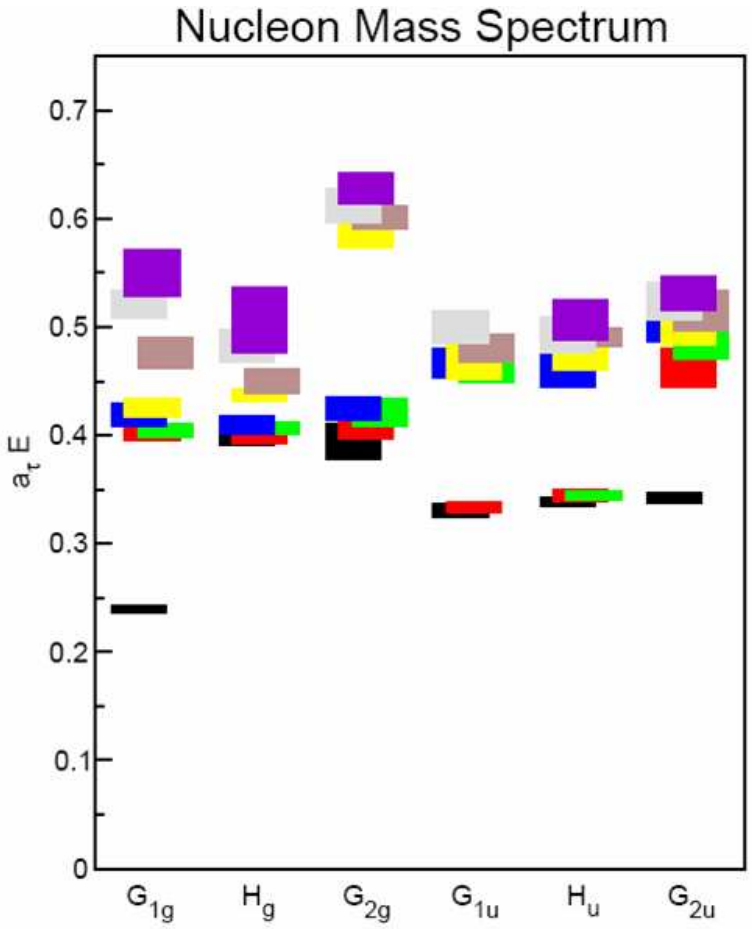
- Include the coupled-channel effects in the combined analyses of $\pi, \eta, \pi\pi$ production data by CLAS collaboration
- Collaborations with other experimental groups will be developed

3. Projects being developed :

- Development of reaction models at high Q^2 region, accessible to JLab's 12 GeV upgrade
- Investigation of the connections with Lattice QCD calculations

Recent LQCD Calculations

(Provided by LHPC)



Question :

How to compared with the extracted N^* resonance energies ?

Dynamical Coupled−Channel Analysis at EBAC

Theory Center, JLAB