Development of Excited Baryon Analysis Center (EBAC) at JLab

Reported by T.-S. Harry Lee

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- Objective
- General Considerations
- Current Efforts
- Future Directions

Objective :

Develop theoretically sound reaction models

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Perform dynamical analyses of meson production data

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- Extract N^* parameters from meson production data
- Interpret N^* parameters in terms
  - QCD-based Hadron models at the present time
  - Lattice QCD in the near future .

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Understand non-perturbative QCD :

- Confinement of constituent quarks
- Chiral dynamics of meson cloud of baryons

General Considerations

A theoretically sound reaction model must :

- Satisfy Unitarity Condition

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  crucial in extracting N^* parameters

- Account for off-shell scattering dynamics which determines the meson-baryon scattering wavefunctions in the short range region where we want to map out the structure of N^*.

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  crucial in interpreting the N^* parameters

Unitarity Condition:

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

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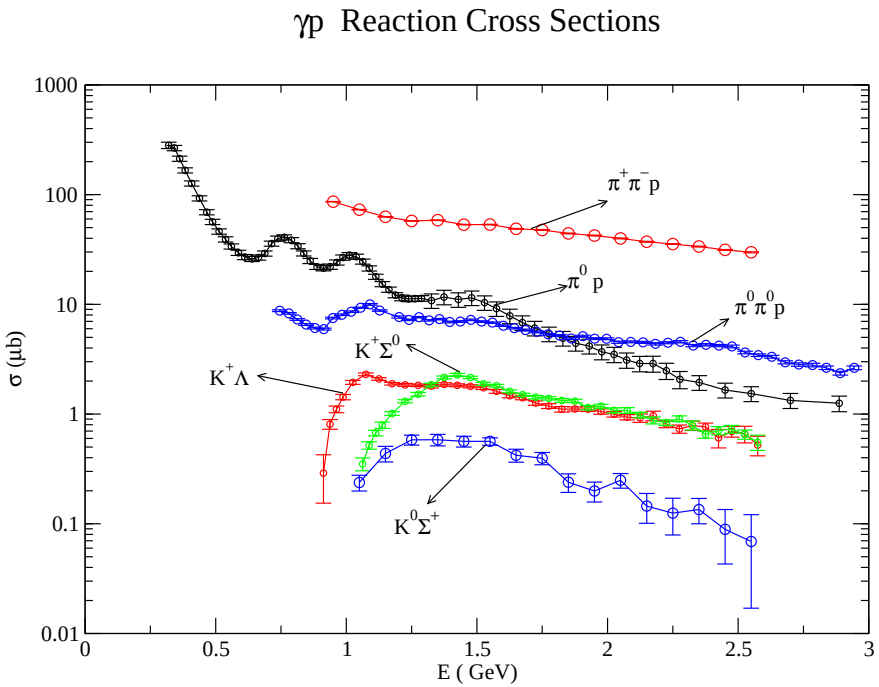
$$Im[T_{\gamma N, MB}] \propto \sum_{M'B'} [T^\dagger]_{\gamma N, M'B'} T_{M'B', MB}$$
$$\propto \sqrt{\sigma_{\gamma N, MB}} \sqrt{\sigma_{MB, KY}}$$

- $T_{a,b}$: 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 photoproduction



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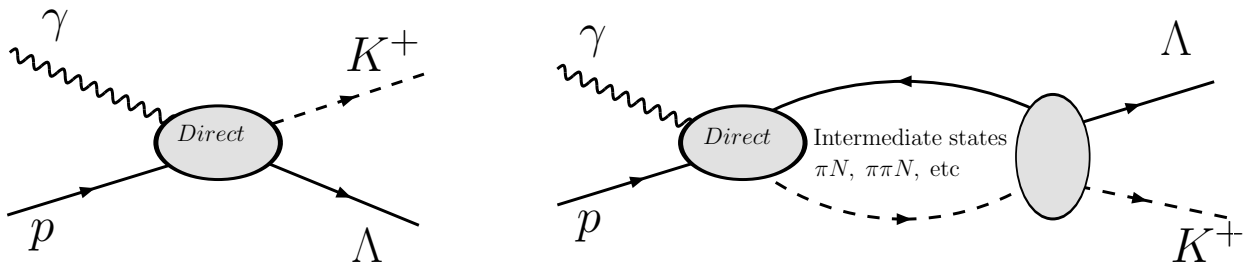
Must include coupled-channel effects :

- $\gamma p \rightarrow \pi N \rightarrow KY$
- $\gamma p \rightarrow \pi\pi N \rightarrow KY$

Basic ingredients of a reaction Model :

- A direct reaction mechanism
- Accounts for coupled channel effects



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

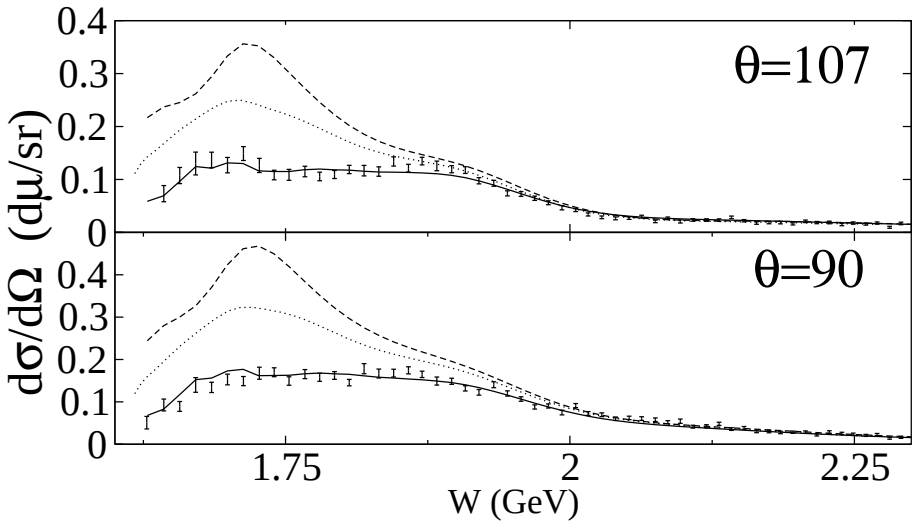
(B. Julia-Diaz, B. Saghai, T.-S. H. Lee, F. Tabakin, 2005)

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

Solid: Coupled channel

Dashed: no coupled-channel

Dotted : no off-shell effects



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To extract and interpret N^* parameters, analyses must include:

- Coupled-channel effects
- Off-shell effects

  Similar to what has been learned in Δ region

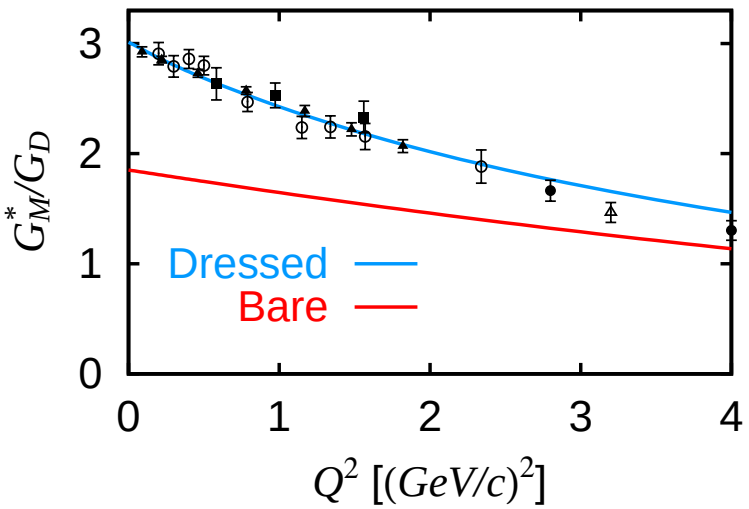
  M1 transition of $\gamma N \rightarrow \Delta$:

  – K-matrix model analysis (no off-shell effects):

  $G_{M1}^{exp}(0)/G_{M1}^{CQM}(0) \sim 1.4$
  CQM : Constituent Quark Model

  – Dynamical model analysis :
  $G_{M1}^{exp}(0) = G_{M1}^{CQM}(0)$ + meson cloud

Magnetic M1 transition of $\gamma N \to \Delta$



$$\bar{\Gamma}_{\gamma N\to\Delta} \quad = \quad \Gamma_{\gamma N\to\Delta} + \int v_{\gamma\pi} G_{\pi N}(E) \bar{\Gamma}_{\pi N\to\Delta}$$

$\to$

Finding : Extracted bare $\Gamma_{\gamma N\to\Delta}(0)$ agree with constituent quark model

Necessary next step :

Include $\pi\pi N$ channel

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Solve

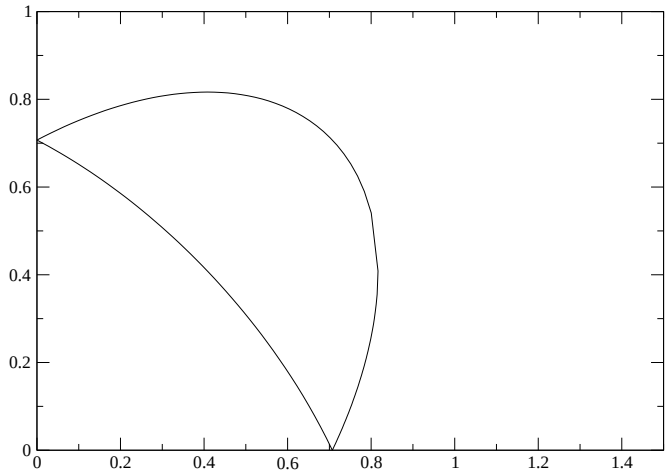
$$\begin{aligned} T(E) &= [v + Z(E)][1 + G(E)T(E)] \\ Z(E) &\leftarrow \pi\pi N \ cut \end{aligned}$$

channel-space :

$\gamma N \oplus \pi N \oplus \eta N \oplus KY \oplus \omega N \oplus \pi\pi N(\pi\Delta \oplus \rho N \oplus \sigma N)$

Numerical complications:

Singularity structure of $Z(E)$ (due to $\pi\pi N$ cut)



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Contour rotation method is not practical for two-pion production calculations

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Recent progress by Argonne-Osaka-Shizuoka collaboration :

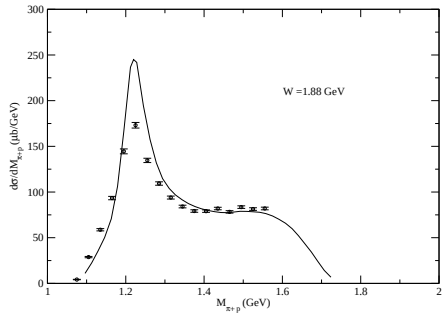
Develop a Spline-function expansion method

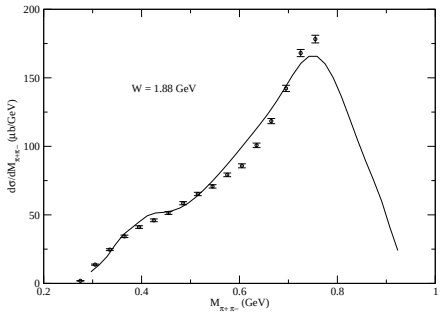
Model of Argonne-Osaka-Shizuoka collaboration

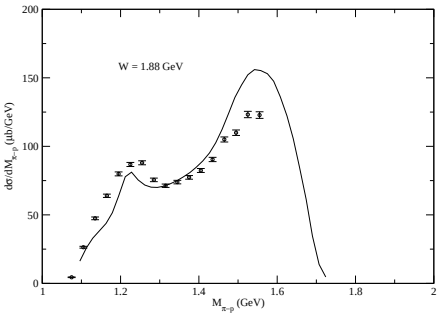
(A. Matsuyama, T. Sato, T.-S. H. Lee, 2003-2005)

First step:

Fit JLab data of $\gamma p \to \pi^+\pi^- p$ at $W = 1.88$ GeV







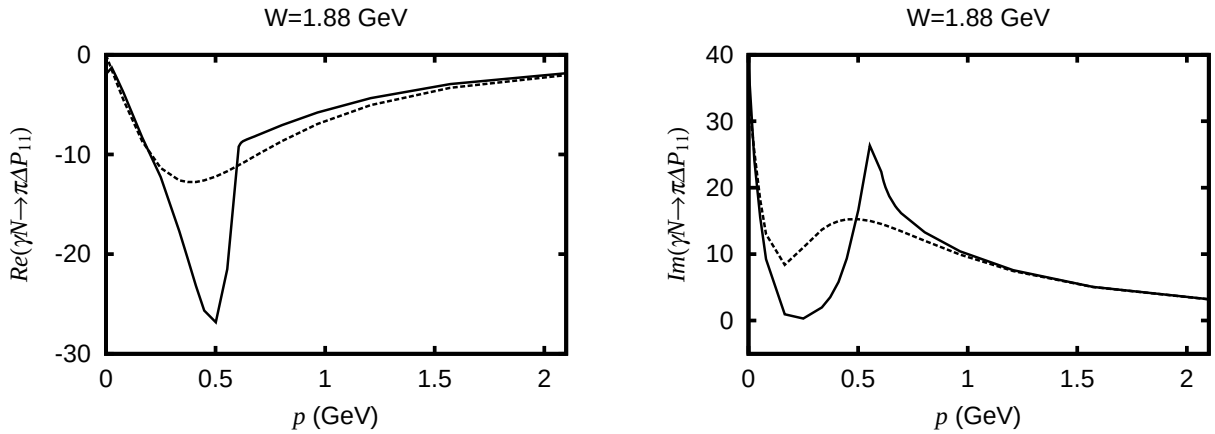
$\to$

Explore the effects due to $\pi\pi N$ cut

Findings :

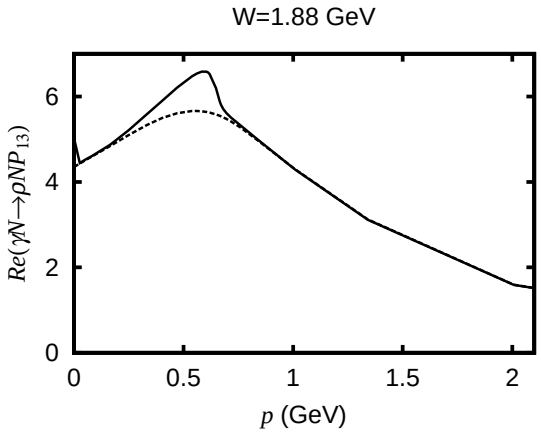
- Rapid energy-dependence of partial-wave amplitudes (consistent with the analysis of Aaron and Amado (1976))

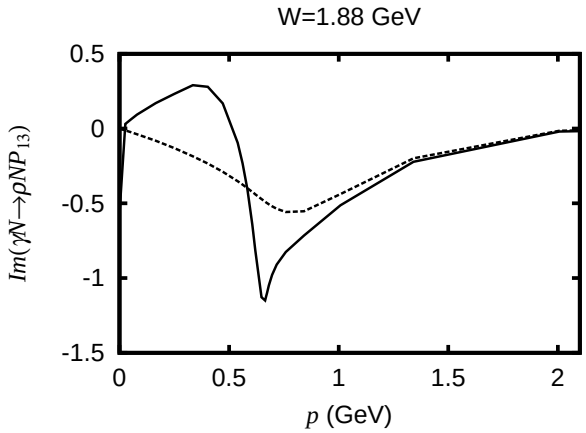
$\gamma N \to \pi\Delta$ in P_{11}



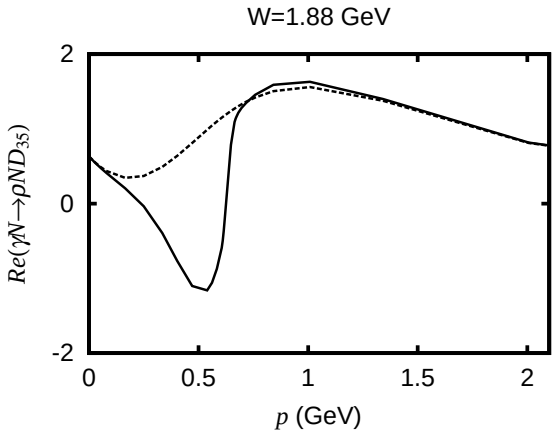
Dotted curves : set $Z(E) = 0$ (no $\pi\pi N$ cuts)

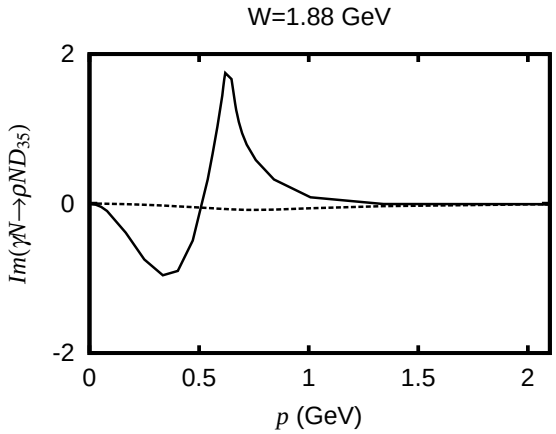
$\gamma N \to \rho N$ in P_{13}



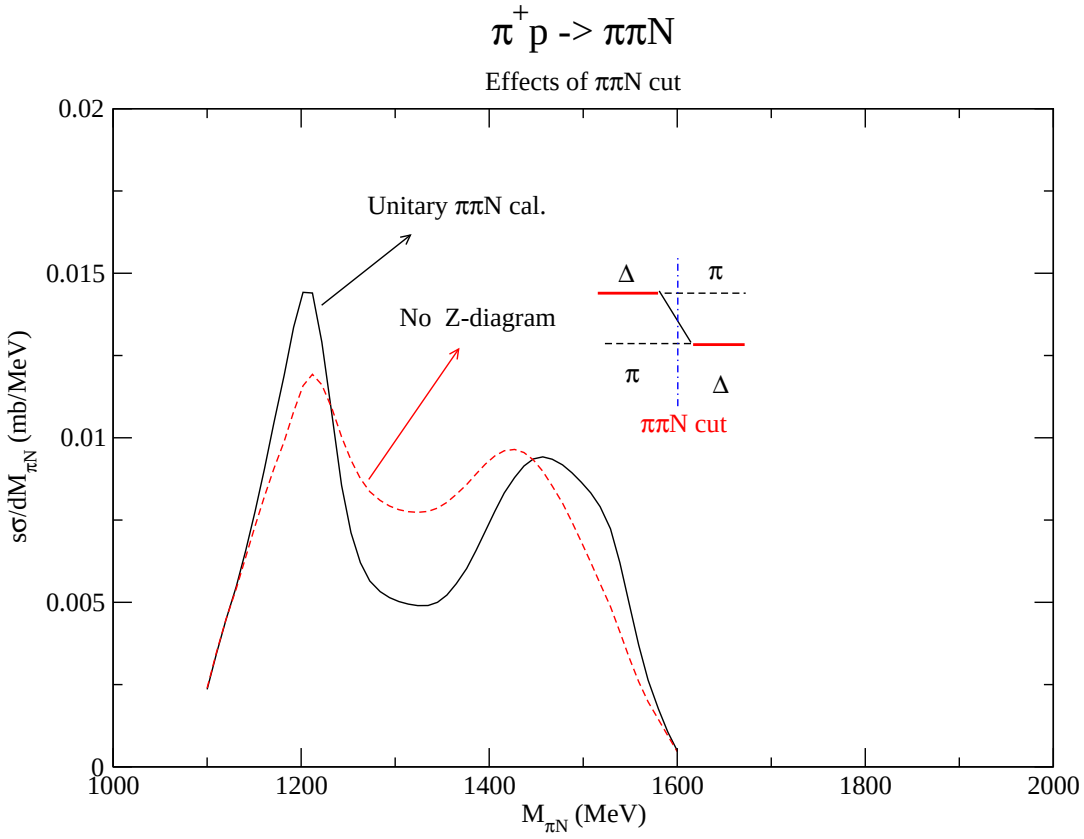


$\gamma N \to \rho N$ in D_{35}





- $\pi\pi N$ cut can have large effects on differential cross sections



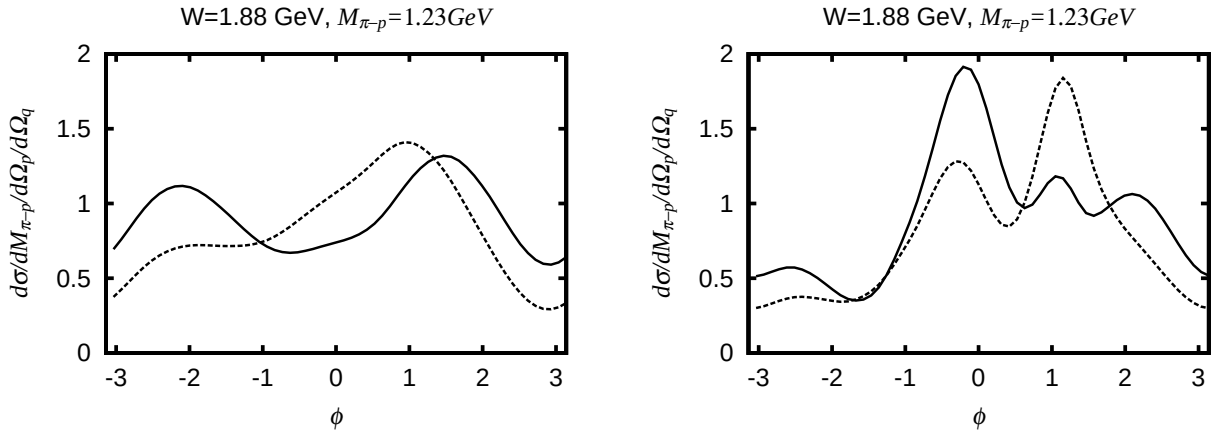
$\gamma p \to \pi^+ \pi^- p$ at W=1.88 GeV

Angular distributions $\frac{d\sigma}{dM_{\pi^- p} d\Omega_{\pi^+} d\Omega_{\pi^- p}}$

$M_{\pi^- p} = 1.23$ GeV

$\cos\theta_{\pi^+} = 0.183, \phi_{\pi^+} = -3.1$

Dependence on $\phi_{\pi^- p}$ (dotted : set $Z(E) = 0$)

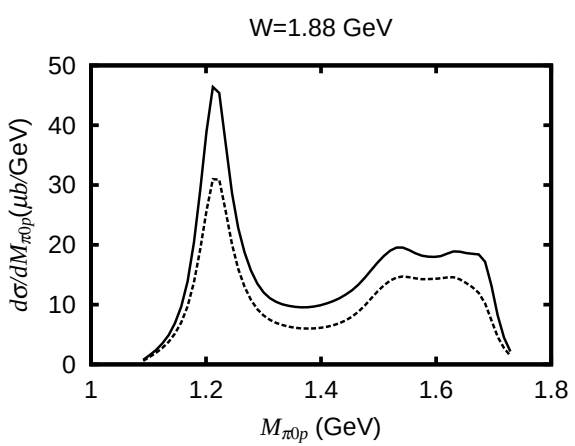


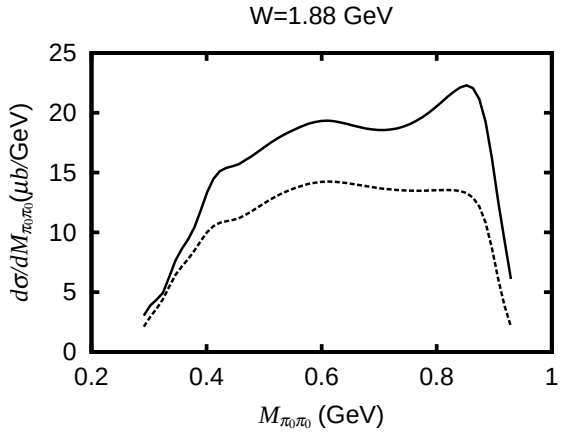
$\cos\theta_{\pi^- p} = -0.96, 1.83$

$\gamma p \to \pi^0\pi^0 p$ at $W = 1.88$ GeV

Invariant mass distributions: $\frac{d\sigma}{dM_{ab}}$, $ab = \pi^0 p, \pi^0\pi^0$

dotted curves : set $Z(E) = 0$





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Theoretically sound analyses of meson production data must :

- include coupled-channel effects
- include rapid energy-dependence due to $\pi\pi N$ cuts
- include off-shell scattering effects

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Can interpret the extracted N^* parameters in terms of

- QCD-based Hadron Models (at the present time)
- Lattice QCD calculations (in the near future)

Current Efforts at EBAC

Immediate Goal :

Reach 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.”

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1. On-going theoretical projects :

- Based on Argonne-Osaka-Shizuoka(AOS) Model :
  - πN, ηN, $\pi\pi N$ production
    (Matsuyama, Sato, Lee, Paris, Julia-Diaz)
  - KY production
    (Julia-Diaz, Saghai, Lee)
  - ωN production
    (Oh, Nakayama, Tsushima, Paris, Lee)
  - $\pi\eta N$ production
    (Kiswandhi, Capstick, Lee)
- Based on Julich Model :
  Being pursued by Nakayama and members of Julich Group

2. Establish collaboration with the on-going analyses by CLAS

- include coupled-channel effects generated from AOS model in the combined analysis of πN, ηN, $\pi\pi N$ production

  using on-shell models

  (Aznauryan, Mokeev, Smith, Matsuyama, Sato, Lee)

  $\rightarrow$

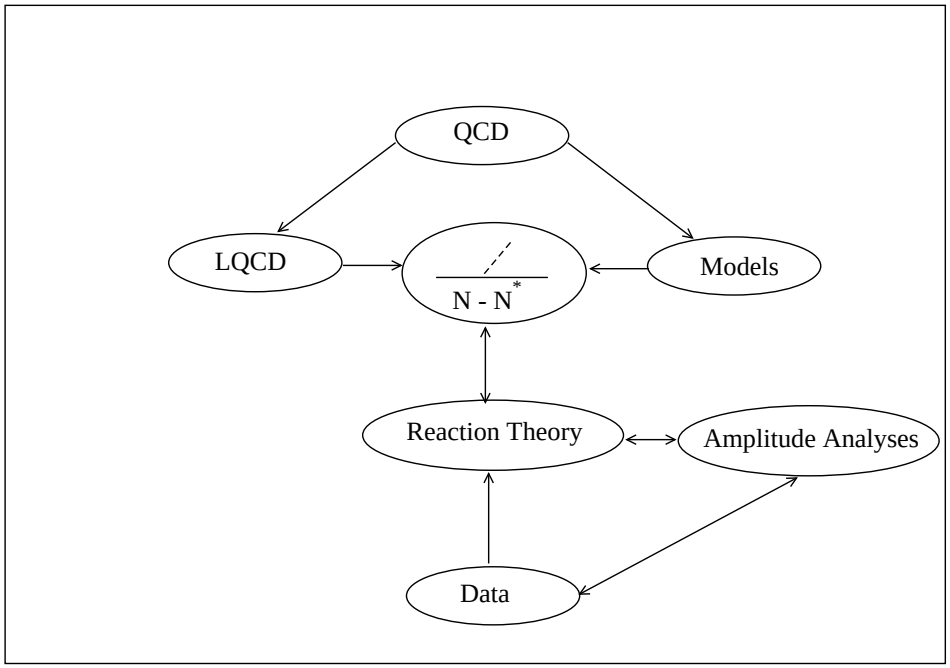
  Provide the starting parameters for dynamical coupled-channel analyses

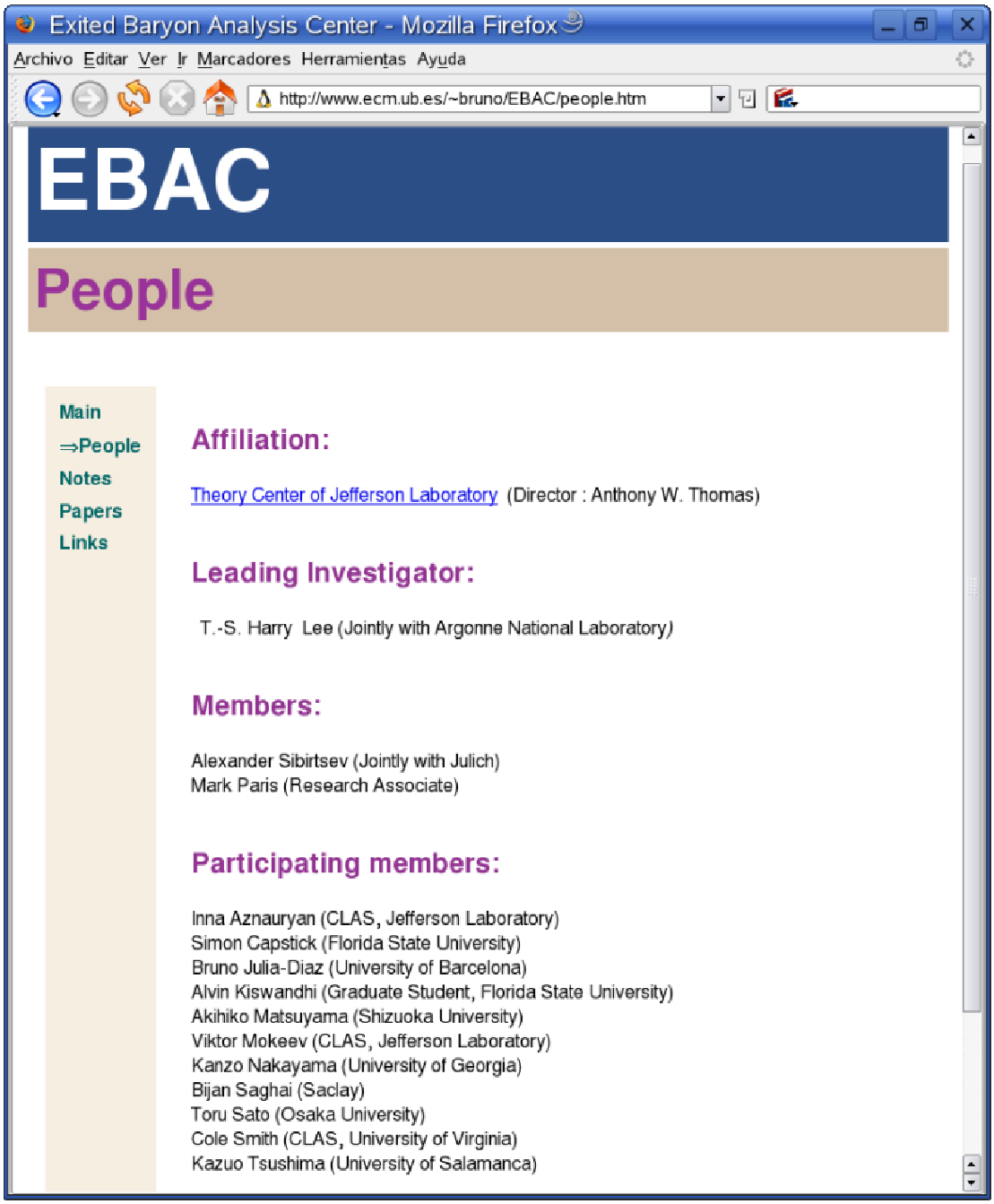
- to be further developed

Future Direction

- Explore deeper questions on reaction models:
  - How to relate the extracted N^* parameters to Lattice QCD ??
  - How to analyze the data from experiments with 12 GeV upgrade ??
  - How to develop reaction model directly in terms of quark-gluon degrees of freedom ??
  - . . ..

Focus of EBAC : Reaction Theory

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Affiliation:
Theory Center of Jefferson Laboratory (Director : Anthony W. Thomas)
Leading Investigator:
T.-S. Harry Lee (Jointly with Argonne National Laboratory)
Members:
Alexander Sibirtsev (Jointly with Julich)
Mark Paris (Research Associate)
Participating members:
Inna Aznauryan (CLAS, Jefferson Laboratory)
Simon Capstick (Florida State University)
Bruno Julia-Diaz (University of Barcelona)
Alvin Kiswandhi (Graduate Student, Florida State University)
Akihiko Matsuyama (Shizuoka University)
Viktor Mokeev (CLAS, Jefferson Laboratory)
Kanzo Nakayama (University of Georgia)
Bijan Saghai (Saclay)
Toru Sato (Osaka University)
Cole Smith (CLAS, University of Virginia)
Kazuo Tsushima (University of Salamanca)