Dynamical coupled-channels study of meson production reactions from EBAC@JLab

Hiroyuki Kamano

(Excited Baryon Analysis Center, Jefferson Lab)

MENU2010, May 31th - June 4th, 2010

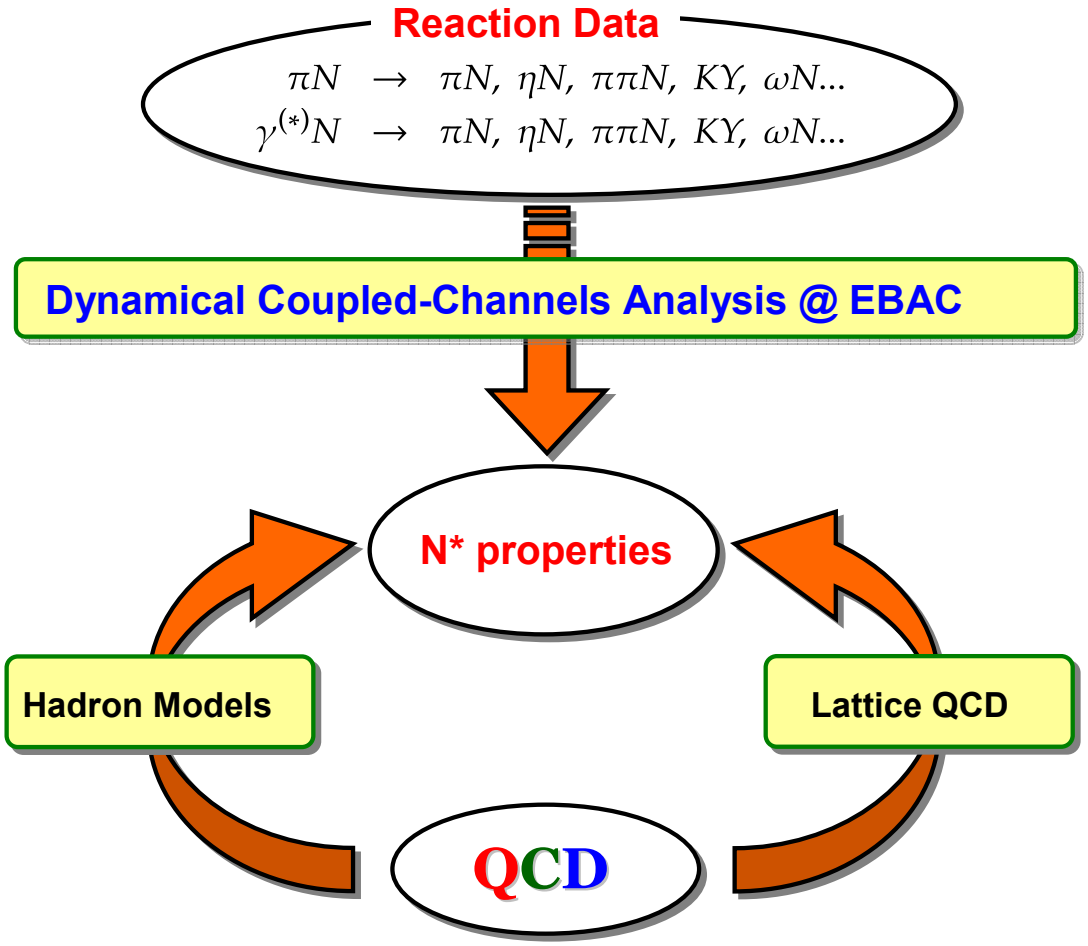
Outline

- ✓ Motivation for the N* study at Excited Baryon Analysis Center (EBAC) of Jefferson Lab
- ✓ Brief review of EBAC analysis in 2007-2009
- ✓ (Preliminary) results of $K\Lambda$ production reactions

Excited Baryon Analysis Center (EBAC) of Jefferson Lab

Founded in January 2006

http://ebac-theory.jlab.org/



Objectives and goals:

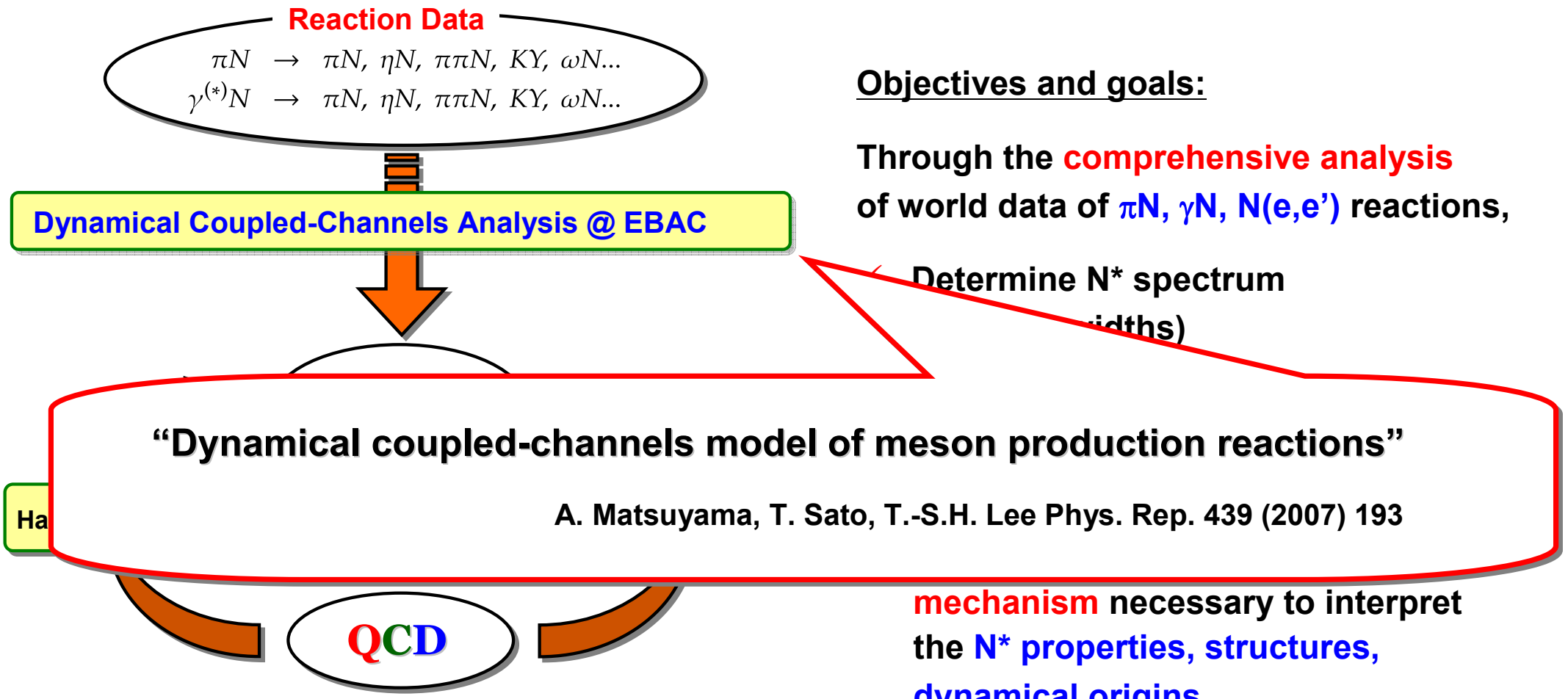
Through the comprehensive analysis of world data of πN, γN, N(e,e') reactions,

- ✓ **Determine N* spectrum (masses, widths)**
- ✓ **Extract N* form factors**
- ✓ **Provide information about reaction mechanism necessary to interpret the N* properties, structures, dynamical origins**

Excited Baryon Analysis Center (EBAC) of Jefferson Lab

Founded in January 2006

http://ebac-theory.jlab.org/



Objectives and goals:

Through the comprehensive analysis of world data of πN, γN, N(e,e') reactions,

Determine N* spectrum
idths)

"Dynamical coupled-channels model of meson production reactions"

A. Matsuyama, T. Sato, T.-S.H. Lee Phys. Rep. 439 (2007) 193

mechanism necessary to interpret the N* properties, structures, dynamical origins

Dynamical coupled-channels model of EBAC (EBAC-DCC model)

For details see Matsuyama, Sato, Lee, Phys. Rep. 439,193 (2007)

✓ **Partial wave (LSJ) amplitude of a → b reaction:**

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

coupled-channels effect

✓ **Reaction channels:**

$$a,b,c = (\gamma^{(*)}N,\ \pi N,\ \eta N,\ \pi\Delta,\ \sigma N,\ \rho N,\ K\Lambda,\ K\Sigma)$$

$\pi\pi N$

✓ **Transition potentials:**

$$V_{a,b} = v_{a,b} + \sum_{N^*} \frac{\Gamma^\dagger_{N^*,a}\Gamma_{N^*,b}}{E - M_{N^*}}$$

exchange potentials of ground state mesons and baryons

bare N* states

Dynamical coupled-channels model of EBAC (EBAC-DCC model)

For details see Matsuyama, Sato, Lee, Phys. Rep. 439,193 (2007)

7. $\pi(k,i) + N(p) \to \rho(k',j) + N(p')$:

$$\bar{V}(7) = \bar{V}_a^7 + \bar{V}_b^7 + \bar{V}_c^7 + \bar{V}_d^7 + \bar{V}_e^7$$

with

$$\bar{V}_a^7 = i\frac{f_{\pi NN}}{m_\pi} g_{\rho NN} \Gamma_{\rho'} S_N(p+k) \not{k} \gamma_5 \tau^i,$$

$$\bar{V}_b^7 = i\frac{f_{\pi NN}}{m_\pi} g_{\rho NN} \not{k} \gamma_5 \tau^i S_N(p-k') \Gamma_{\rho'},$$

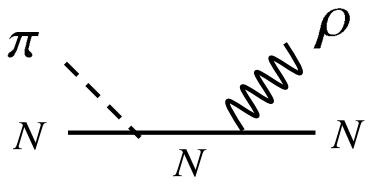
$$\bar{V}_c^7 = \frac{f_{\pi NN}}{m_\pi} g_{\rho\pi\pi} \epsilon_{ijl} \tau^l \frac{(q-k)\cdot \epsilon^*_{\rho'} \not{q} \gamma_5}{q^2 - m_\pi^2},$$

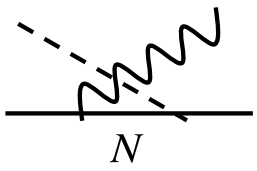
$$\bar{V}_d^7 = -\frac{f_{\pi NN}}{m_\pi} g_{\rho NN} \not{\epsilon}^*_{\rho'} \gamma_5 \epsilon_{jil} \tau^l,$$

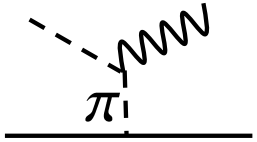
$$\bar{V}_e^7 = \frac{g_{\omega NN} g_{\omega\pi\rho}}{m_\omega} \delta_{ij} \frac{\epsilon_{\alpha\beta\gamma\delta} \epsilon^{*\alpha}_{\rho'} k'^\beta k^\gamma}{q^2 - m_\omega^2} \left[\gamma^\delta + \frac{\kappa_\omega}{4m_N}(\gamma^\delta \not{q} - \not{q}\gamma^\delta)\right],$$

where

$$\Gamma_{\rho'} = \frac{\tau^j}{2}\left[\not{\epsilon}^*_{\rho'} + \frac{\kappa_\rho}{4m_N}(\not{\epsilon}^*_{\rho'} \not{k}' - \not{k}' \not{\epsilon}^*_{\rho'})\right].$$







EBAC-DCC analysis (2007-2009)

πN, ηN, ππN (πΔ,ρN,σN) coupled-channels calculations were performed.

Hadronic part

✓ $\pi N \rightarrow \pi N$: fitted to the data up to W = 2 GeV.

Julia-Diaz, Lee, Matsuyama, Sato, PRC76 065201 (2007)

✓ $\pi N \rightarrow \pi \pi N$: cross sections calculated with the πN model.

Kamano, Julia-Diaz, Lee, Matsuyama, Sato, PRC79 025206 (2009)

✓ $\pi N \rightarrow \eta N$: fitted to the data up to W = 2 GeV

Durand, Julia-Diaz, Lee, Saghai, Sato, PRC78 025204 (2008)

Electromagnetic part

✓ $\gamma^{(*)} N \rightarrow \pi N$: fitted to the data up to W = 1.6 GeV and Q^2 = 1.5 GeV^2

(photoproduction) Julia-Diaz, Lee, Matsuyama, Sato, Smith, PRC77 045205 (2008)

(electroproduction) Julia-Diaz, Kamano, Lee, Matsuyama, Sato, Suzuki, PRC80 025207 (2009)

✓ $\gamma N \rightarrow \pi \pi N$: cross sections calculated with the γN & πN model.

Kamano, Julia-Diaz, Lee, Matsuyama, Sato, PRC80 065203 (2009)

Extraction of N* parameters

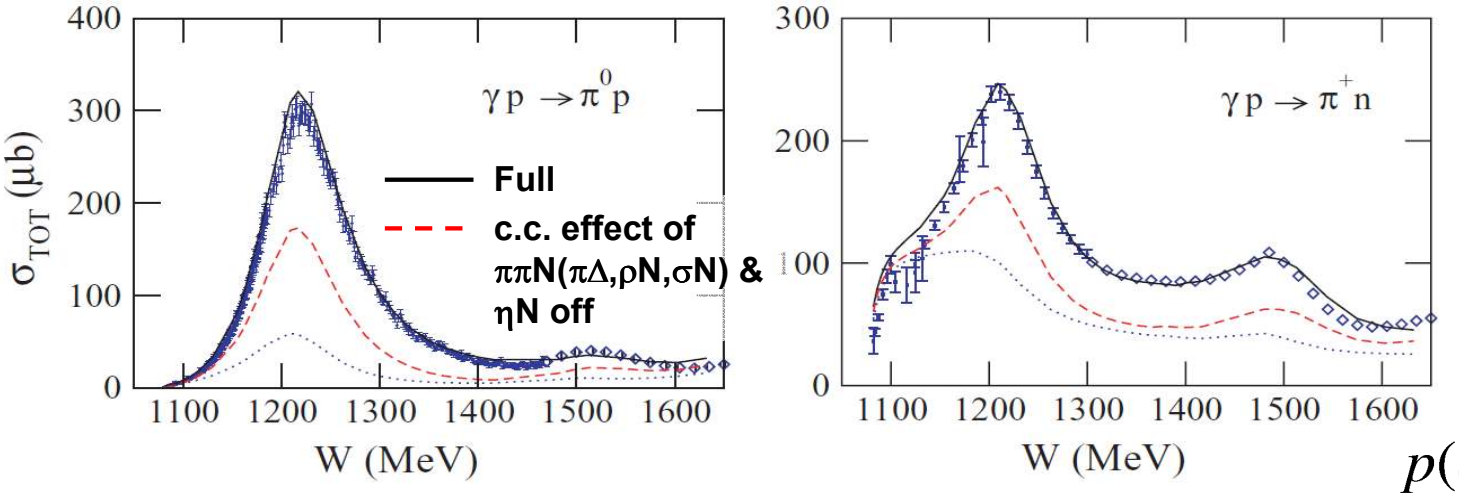
✓ Extraction of N* pole positions & new interpretation of dynamical origin of P11 N* states.

Suzuki, Julia-Diaz, Kamano, Lee, Matsuyama, Sato, PRL104 065203 (2010)

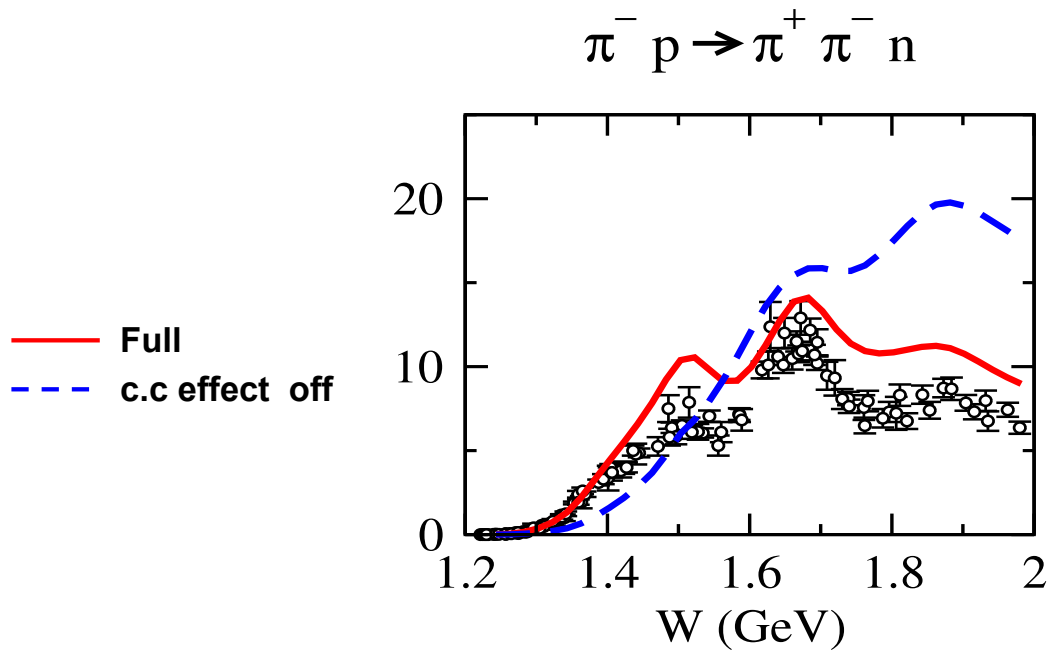
✓ Extraction of $\gamma N \rightarrow N^*$ electromagnetic transition form factors.

Suzuki, Sato, Lee, arXiv:0910.1742 [nucl-th]

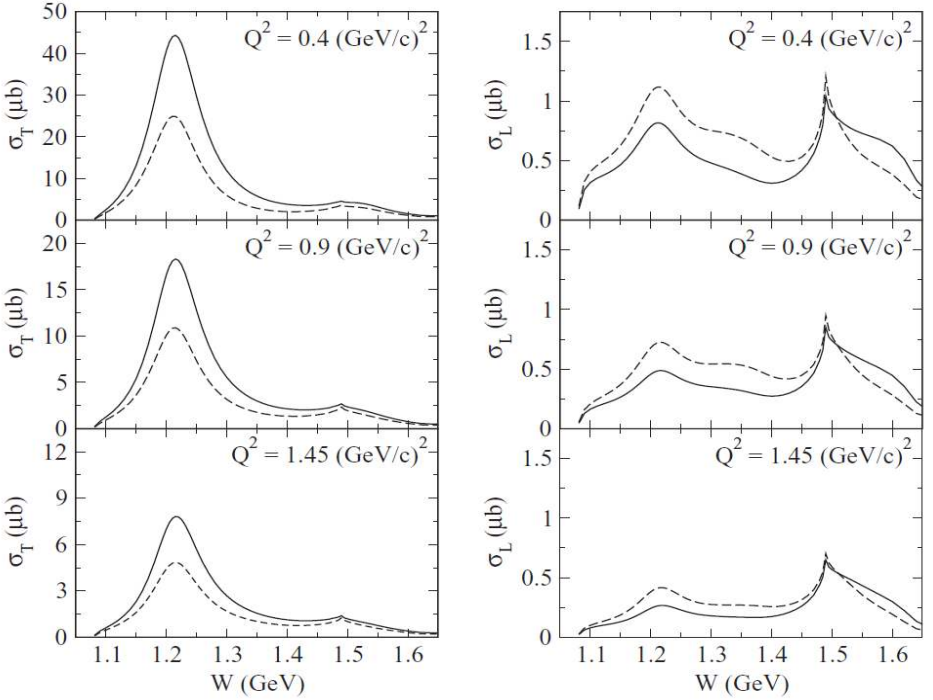
EBAC-DCC analysis (2007-2009)



Coupled-channels effect in various reactions



$p(e, e'\pi^0)p$



EBAC-DCC analysis 2010 ~

EBAC "second generation" model

Full combined analysis (global fit) of

~ End of 2010

- $\pi N \rightarrow \pi N$ (W < 2 GeV)
- $\pi N \rightarrow \eta N$ (W < 2 GeV)
- $\pi N \rightarrow KY$ (W < 2 GeV)
- $\gamma N \rightarrow \pi N$ (W < 1.6 GeV → 2 GeV)
- $\gamma N \rightarrow \eta N$ (W < 2 GeV)
- $\gamma N \rightarrow KY$ (W < 2 GeV)

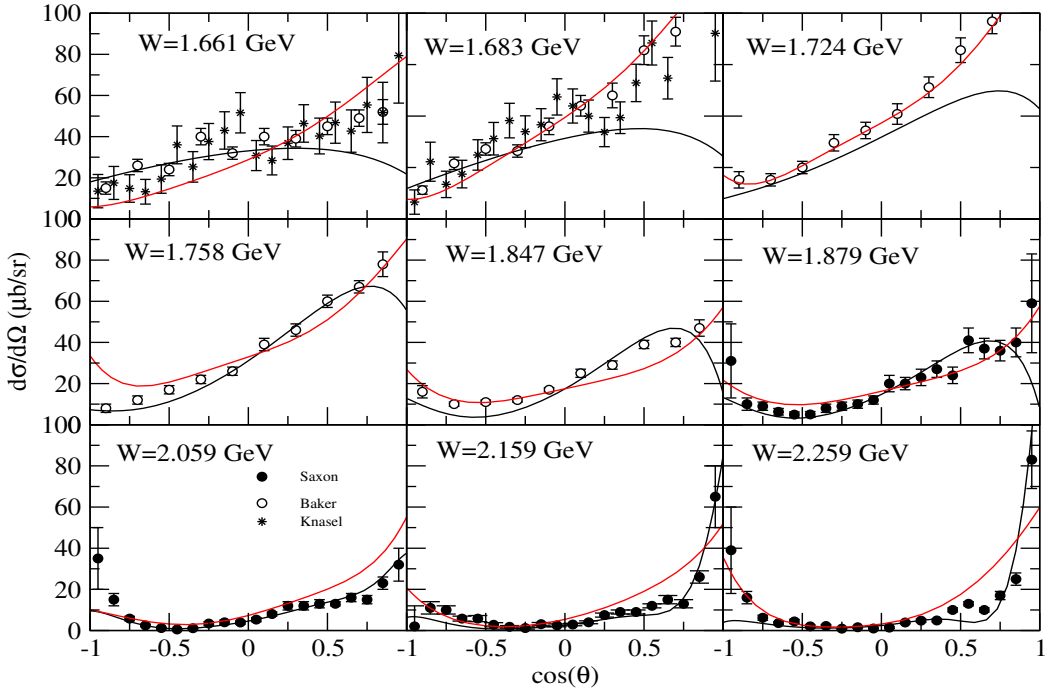
"Complete experiments" are planned by CLAS.

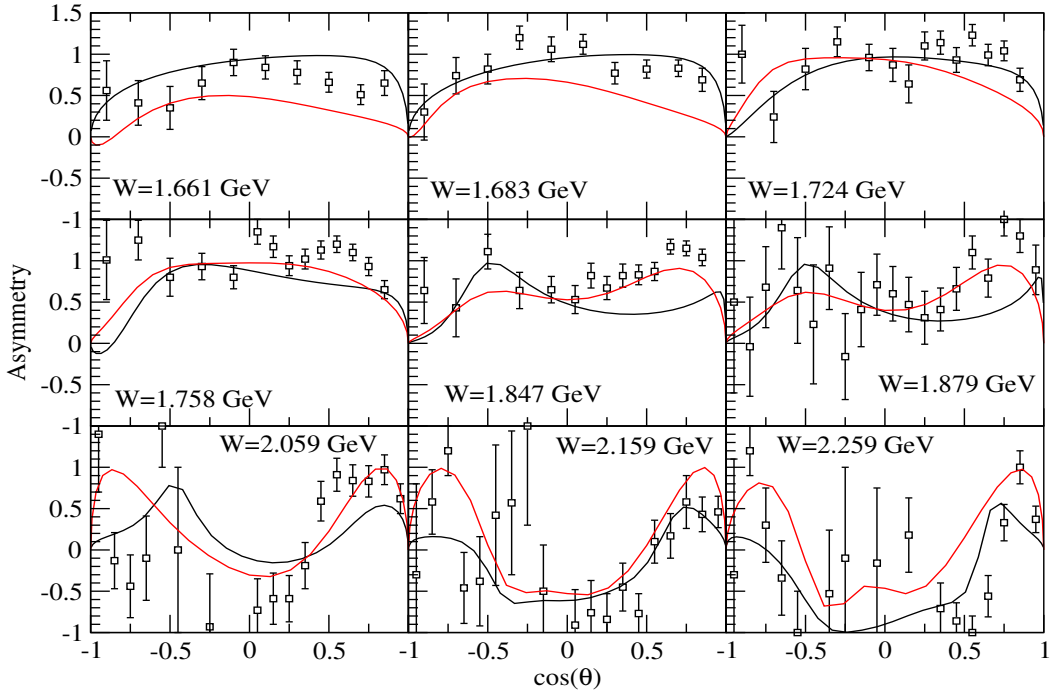
2010 ~ 2011

- $\pi N \rightarrow \pi\pi N$ (W < 2 GeV)
- $\gamma N \rightarrow \pi\pi N$ (W < 1.5 GeV → 2 GeV)

pi- p → K^0 Lambda

Preliminary





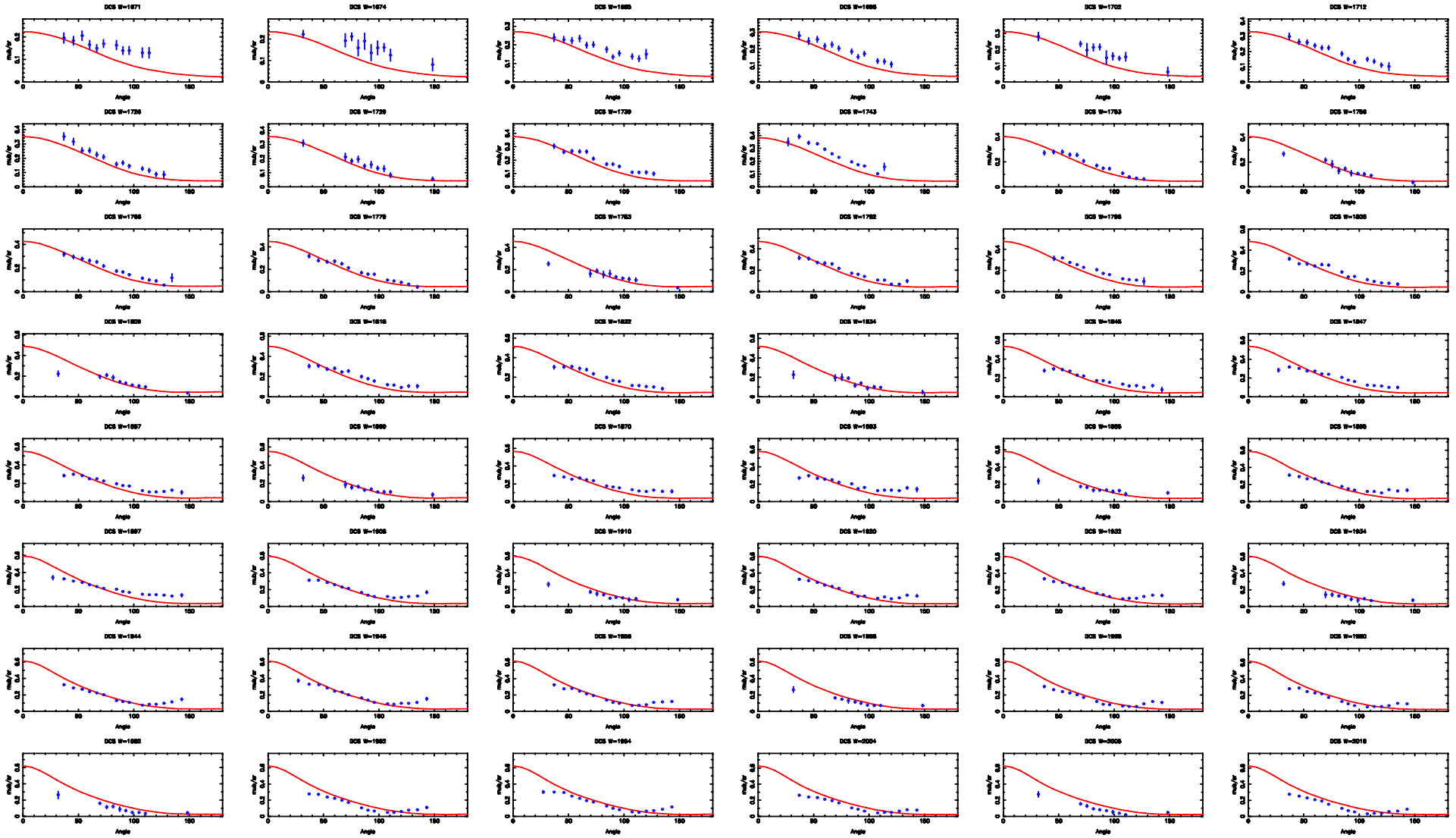
EBAC-DCC

Julia-Diaz, Saghai, Lee, Tabakin PRC73 055204

gamma p → K+ Lambda

dσ/dΩ at 1.65 < W < 2 GeV

Preliminary



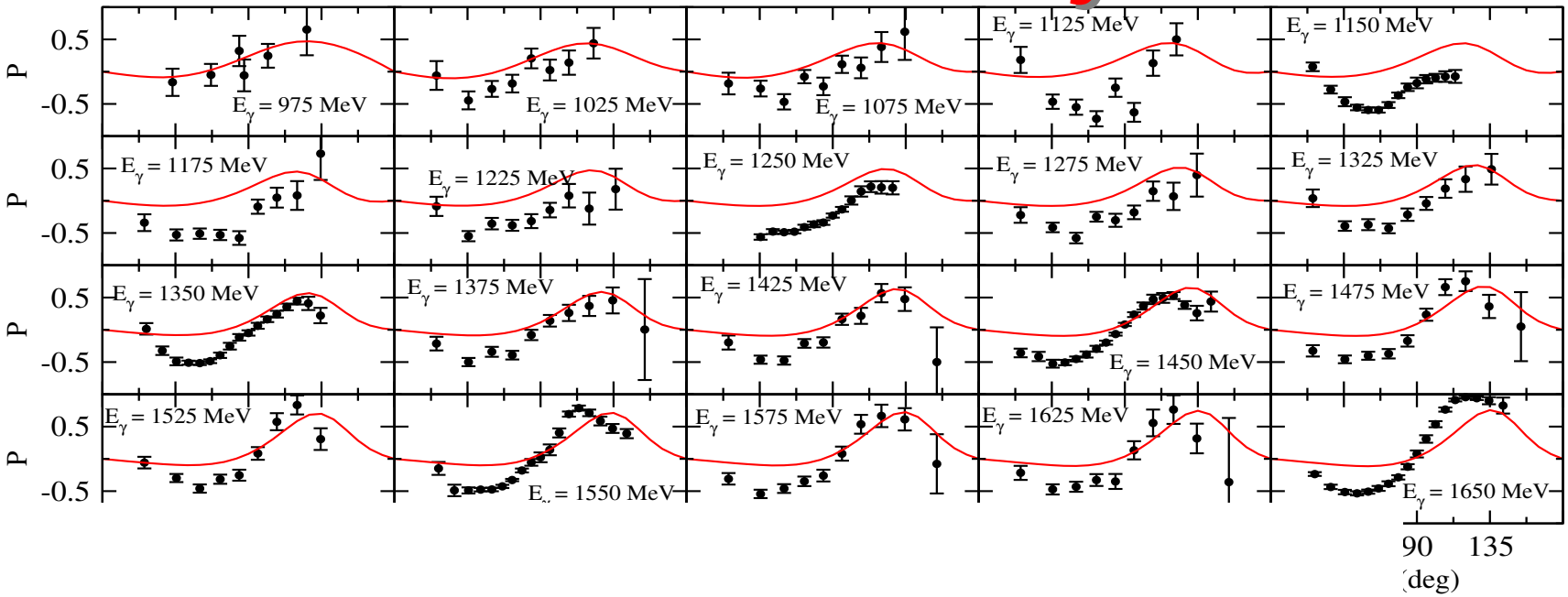
gamma p → K+ Lambda

Polarization observables

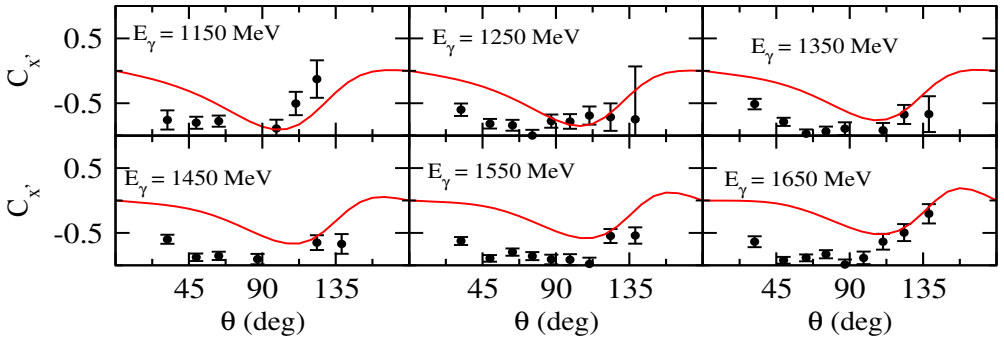
Formula for calculations of the polarization observables
→ Sandorfi, Hoblit, Kamano, Lee arXiv:0912.3505 [nucl-th]

Preliminary

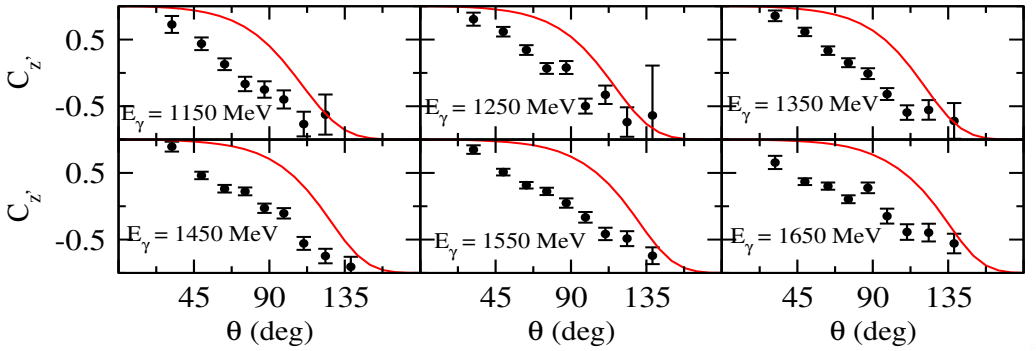
P



Cx'



Cz'



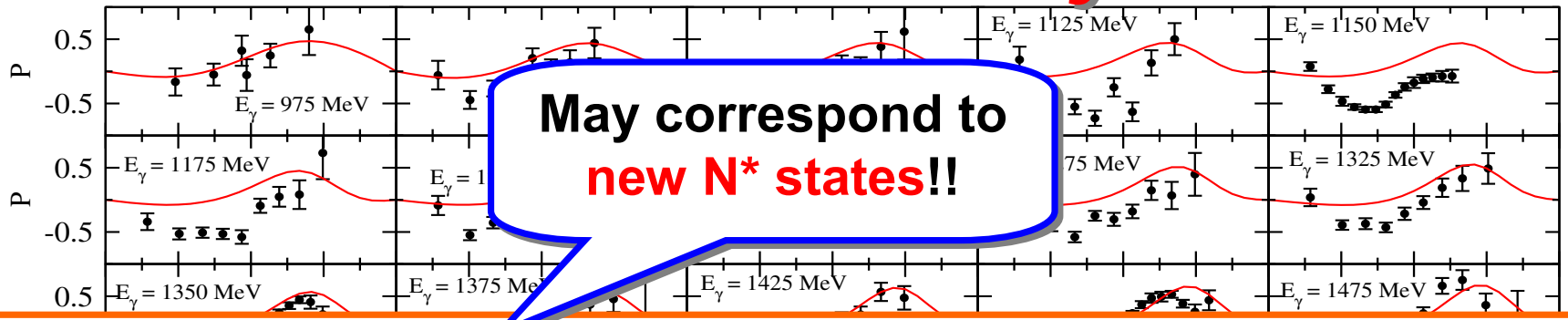
gamma p → K+ Lambda

Polarization observables

Formula for calculations of the polarization observables
→ Sandorfi, Hoblit, Kamano, Lee arXiv:0912.3505 [nucl-th]

Preliminary

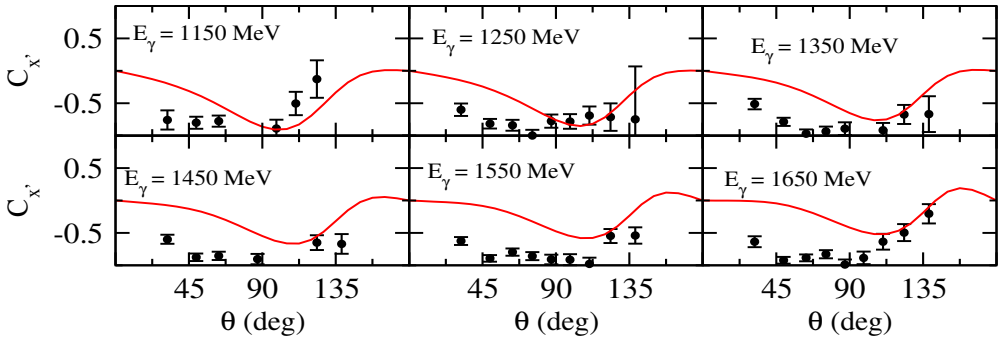
P



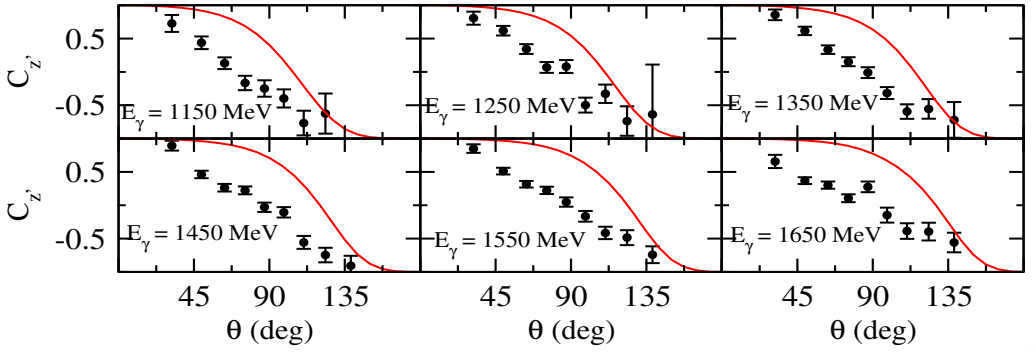
May correspond to new N* states!!

Additional bare N* states will be needed to improve the fit to the polarization observables.

Cx'

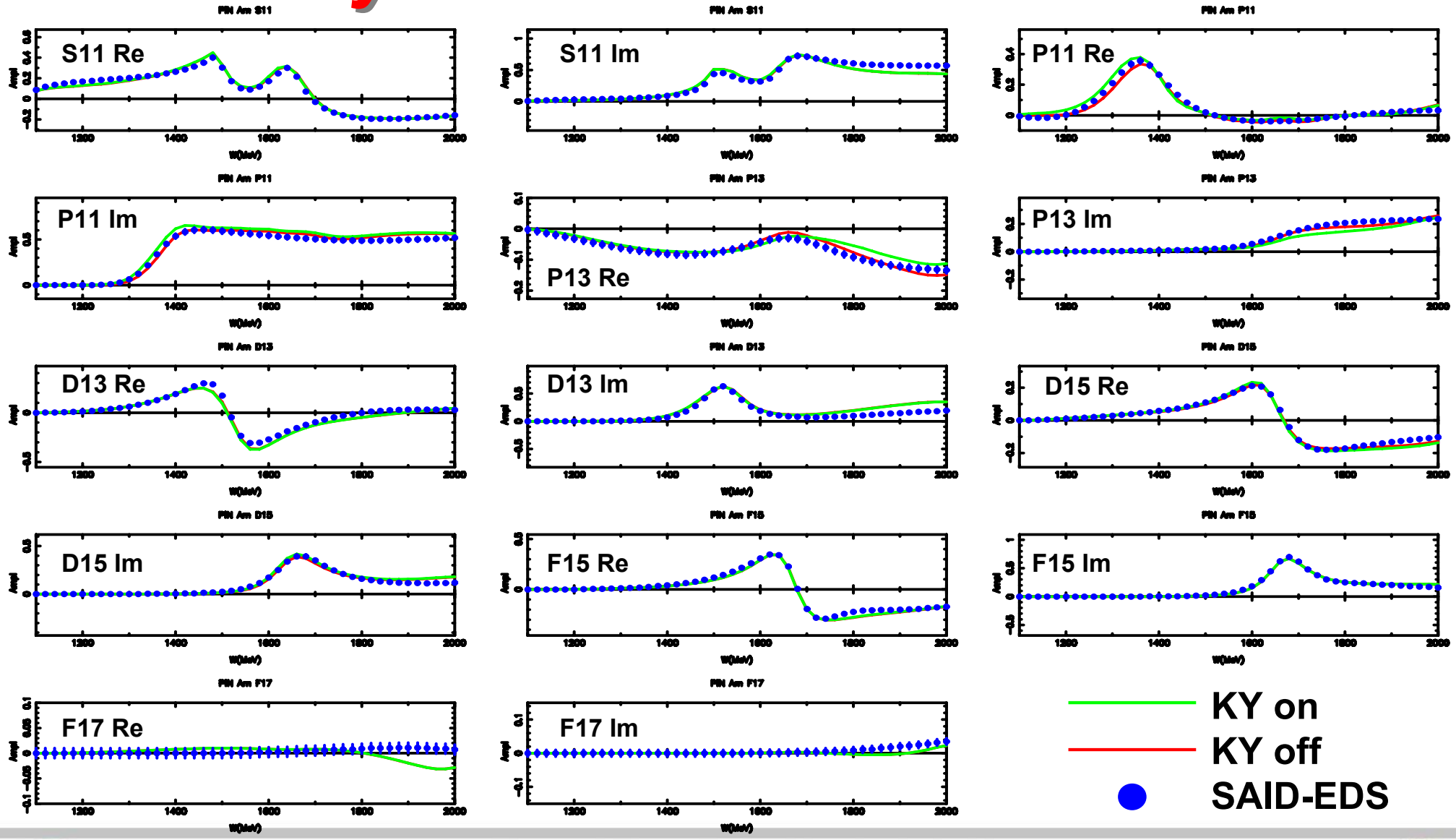


Cz'



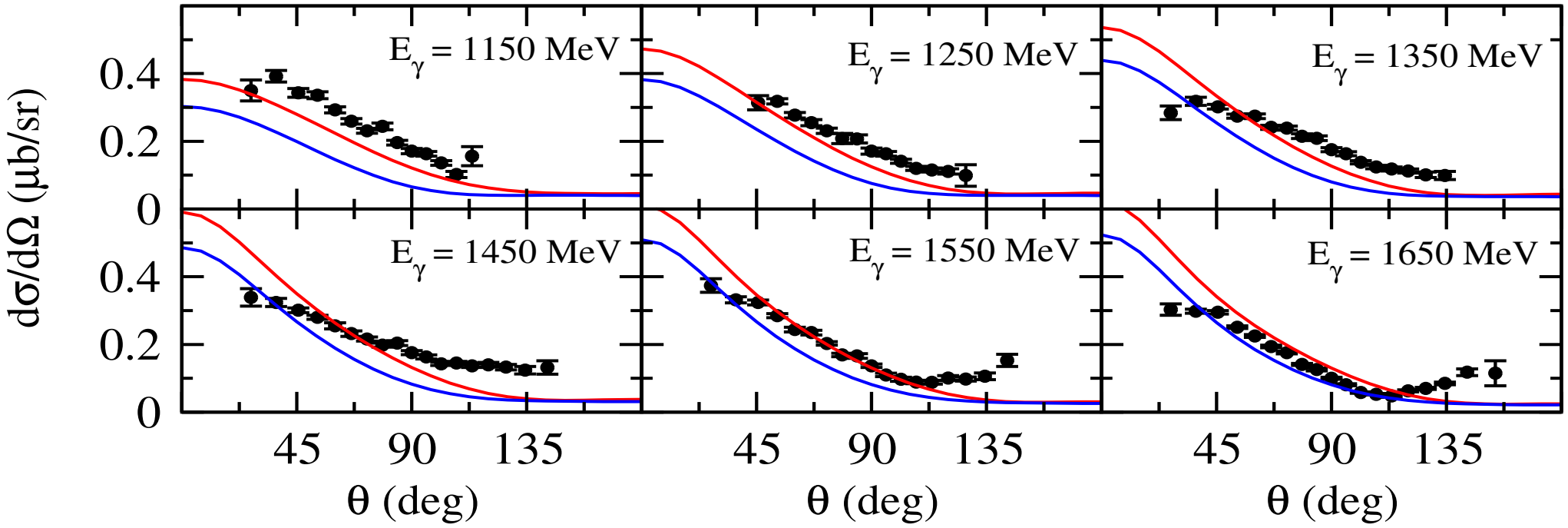
Coupling effect of KY channels on piN PWA

Preliminary



Coupling effect of piN, pipiN, etaN channels on KY observables

Preliminary



Current EBAC-DCC result

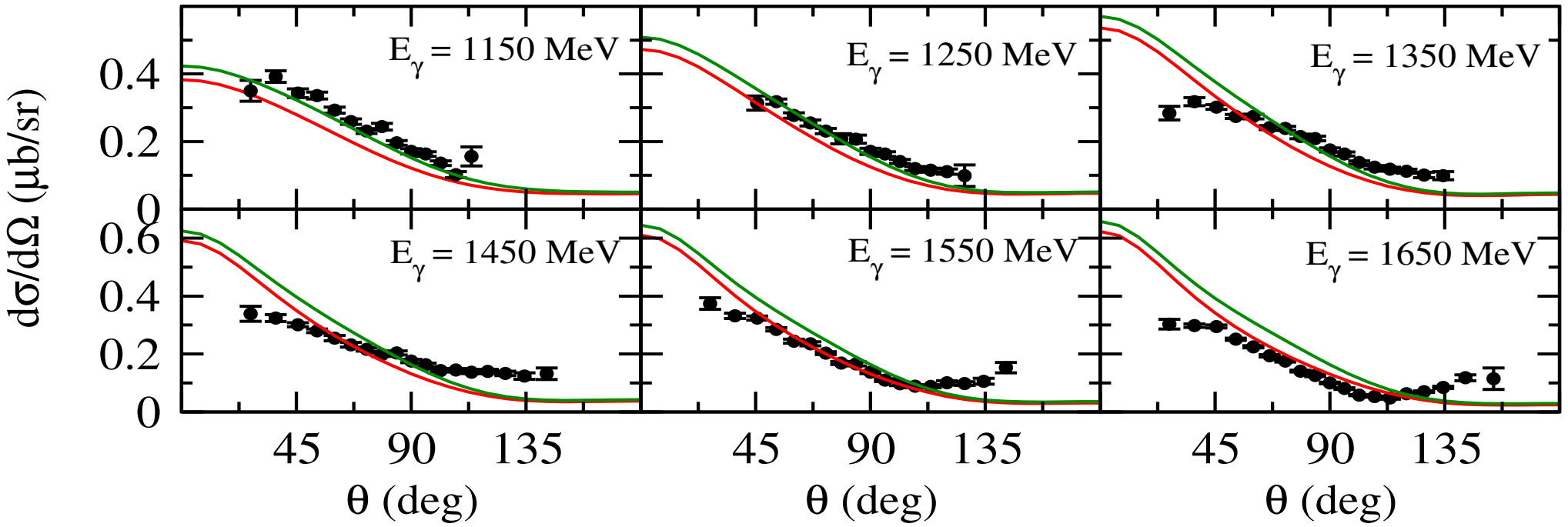
Couplings to πN, ηN, $\pi\pi$N channels off

(At least) about 20% reduction is observed except backward angles.

Summary

- ✓ **Full-combined analysis of πN, $\gamma N \rightarrow \pi N$, ηN, KY reactions is under way.**
- ✓ **Polarization observables will be a key to finding new N* states and complete experiments planned by CLAS are much desired.**
- ✓ **Effect of channel couplings (in the current model):**
  - ➢ **KY channel couplings to πN amps.: Negligible (visible a little in P11,P13)**
  - ➢ **πN, ηN, $\pi\pi N$, channel couplings to KY observables: Visible (~ 20%)**
- ✓ **Reaction model is kept improving:**
  - ➢ **Add new bare N* states & meson-exchange processes.**
  - ➢ **Add new reaction channels (ωN, $\bar{K}KN$, $\pi\eta N$,…)**

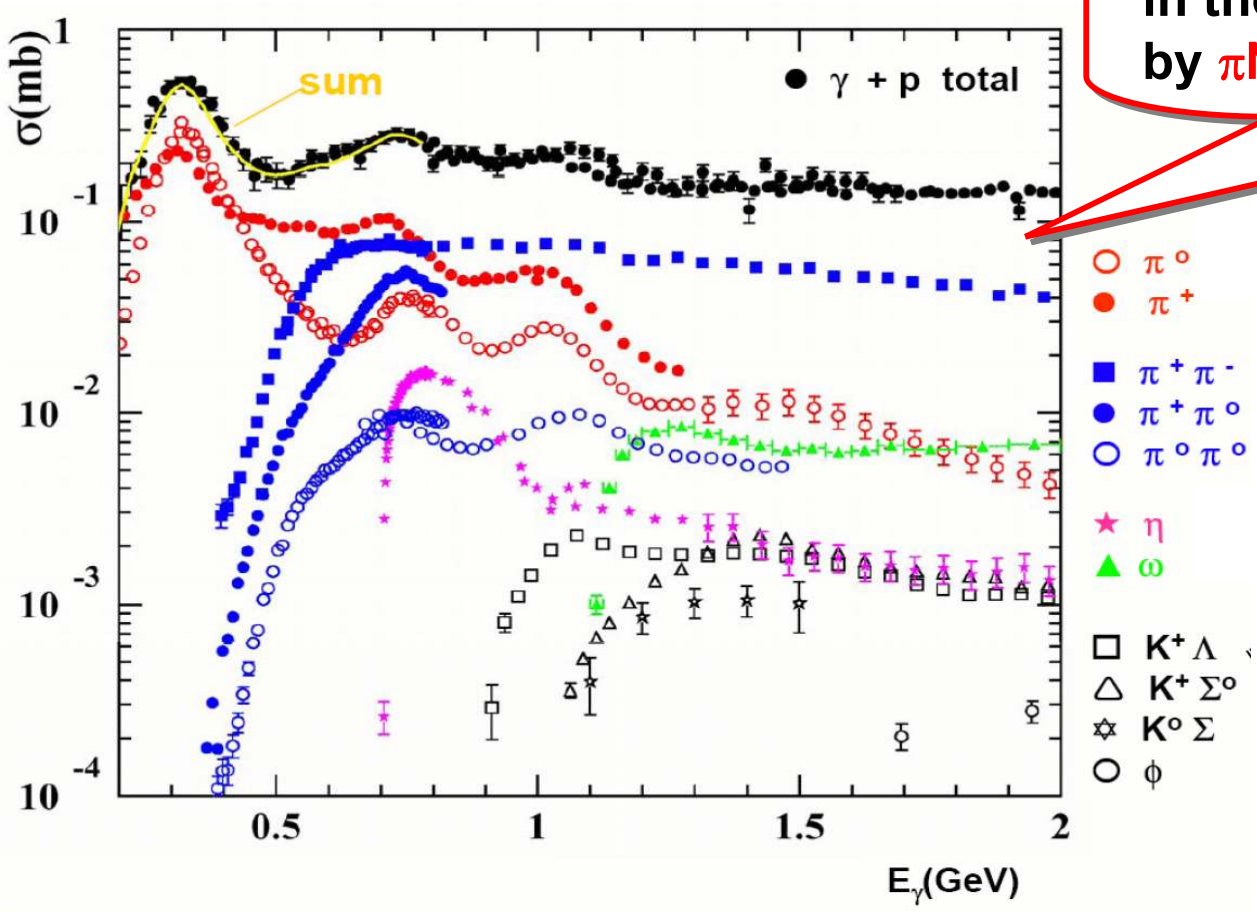
Back up



Current EBAC-DCC result

t-channel K* exchange potentials off

“Priority” of coupled-channels effect



γN (also πN) reaction cross sections in the resonance region are dominated by πN and ππN final states.

At least, the couplings of πN and ππN channels should be taken into account in the analyses of any γN (πN) → MB reactions.

Figure: E. Pasyuk’s talk at Hall-B/EBAC meeting

Exchange potentials for channels with strange hadrons

$\pi N \rightarrow K\Lambda$

3 diagrams
s-ch N
u-ch Σ
t-ch K*

$K\Lambda \rightarrow K\Lambda$

4 diagrams
s-ch N
u-ch Ξ
t-ch ω
t-ch ϕ

$K\Sigma \rightarrow K\Sigma$

5 diagrams
s-ch N
u-ch Ξ
t-ch ρ
t-ch ω
t-ch ϕ

$\pi N \rightarrow K\Sigma$

3 diagrams
s-ch N
u-ch Σ
u-ch Λ
t-ch K*

$K\Lambda \rightarrow K\Sigma$

3 diagrams
s-ch N
u-ch Ξ
t-ch ρ

Total 18 diagrams

At present, KY couples to non-strange channels through πN channel only. (ηN → KY is implementing)

2-body "v" potentials (non-strange channels)

$\pi N \rightarrow \pi N$

5 diagrams
s-ch N
u-ch N
u-ch Δ
t-ch ρ
t-ch σ

$\pi N \rightarrow \sigma N$

3 diagrams
s-ch N
u-ch N
t-ch π

$\pi N \rightarrow \eta N$

2 diagrams
s-ch N
u-ch N

$\pi N \rightarrow \rho N$

4 diagrams
s-ch N
u-ch N
t-ch π
t-ch ω

$\pi N \rightarrow \pi \Delta$

4 diagrams
s-ch N
u-ch N
u-ch Δ
t-ch ρ

$\eta N \rightarrow \eta N$

2 diagrams
s-ch N
u-ch N

$\eta N \rightarrow \pi \Delta$

1 diagram
s-ch N

$\eta N \rightarrow \sigma N$

2 diagrams
s-ch N
u-ch N

$\eta N \rightarrow \rho N$

2 diagrams
s-ch N
u-ch N

$\pi \Delta \rightarrow \pi \Delta$

2 diagrams
s-ch N
t-ch ρ

$\pi \Delta \rightarrow \sigma N$

1 diagram
s-ch N

$\pi \Delta \rightarrow \rho N$

2 diagrams
s-ch N
u-ch N

$\sigma N \rightarrow \sigma N$

2 diagrams
s-ch N
u-ch N

$\sigma N \rightarrow \rho N$

2 diagrams
s-ch N
u-ch N

$\rho N \rightarrow \rho N$

2 diagrams
s-ch N
u-ch N

Total 36 diagrams

gamma N → MB potentials

$\gamma N \rightarrow \pi N$

7 diagrams
- s-ch N
- u-ch N
- u-ch Δ
- t-ch π
- t-ch ρ
- t-ch σ
- contact

$\gamma N \rightarrow \eta N$

2 diagrams
- s-ch N
- u-ch N

$\gamma N \rightarrow \pi \Delta$

5 diagrams
- s-ch N
- u-ch N
- u-ch Δ
- t-ch π
- contact

$\gamma N \rightarrow \sigma N$

2 diagrams
- s-ch N
- u-ch N

$\gamma N \rightarrow \rho N$

4 diagrams
- s-ch N
- u-ch N
- t-ch ρ
- contact

$\gamma N \rightarrow K \Lambda$

6 diagrams
- s-ch N
- u-ch Λ
- u-ch Σ
- t-ch K
- t-ch K*
- contact

$\gamma N \rightarrow K \Sigma$

6 diagrams
- s-ch N
- u-ch Λ
- u-ch Σ
- t-ch K
- t-ch K*
- contact

Total 32 diagrams

Strategy for the N* study @ EBAC

Stage 1

Construct a reaction model through the comprehensive analysis of meson production reactions

Stage 2

Extract resonance information from the reaction model constructed

- **N* pole positions; N* → γN, MB transition form factors**
- **Confirm/reject N* with low-star status; Search for new N***

Stage 3

Make a connection to hadron structure calculations; Explore the structure of the N* states.

- **CQM, DSE, Large Nc, Soliton models,…**
- **Connection to the Lattice QCD data**

"Complete Experiment" of pseudoscalar meson photoproduction reactions

"Complete Experiment" = Measure **ALL** polarization observables needed to determine **amplitudes** up to overall phase

8 /16 observables needed!
Chiang, Tabakin PRC55 2054 (1997)

unpolarized diff. crs. sec.

$\rightarrow \quad d\sigma/d\Omega$

single spin

$\rightarrow \quad P, \ \Sigma, \ T$

beam-target

$\rightarrow \quad E, \ F, \ G, \ H$

beam-recoil

$\rightarrow \quad C_{x'}, \ C_{z'}, \ O_{x'}, \ O_{z'}$

target-recoil

$\rightarrow \quad T_{x'}, \ T_{z'}, \ L_{x'}, \ L_{z'}$

- ✓ Measurement of γN → KY pol. obs. is very active.
- ✓ **OVER-complete** experiments planned by **CLAS** for γ p → K$^+$ Λ, γ n → KY.

Provides critical information on N* → KY decays !!
Much room for new N* state searches