Strangeness Photoproduction

T.-S. H. Lee

Argonne National Laboratory

and

EBAC, Jefferson Laboratory

- Reaction models of KY photoproduction

  N^* study at EBAC

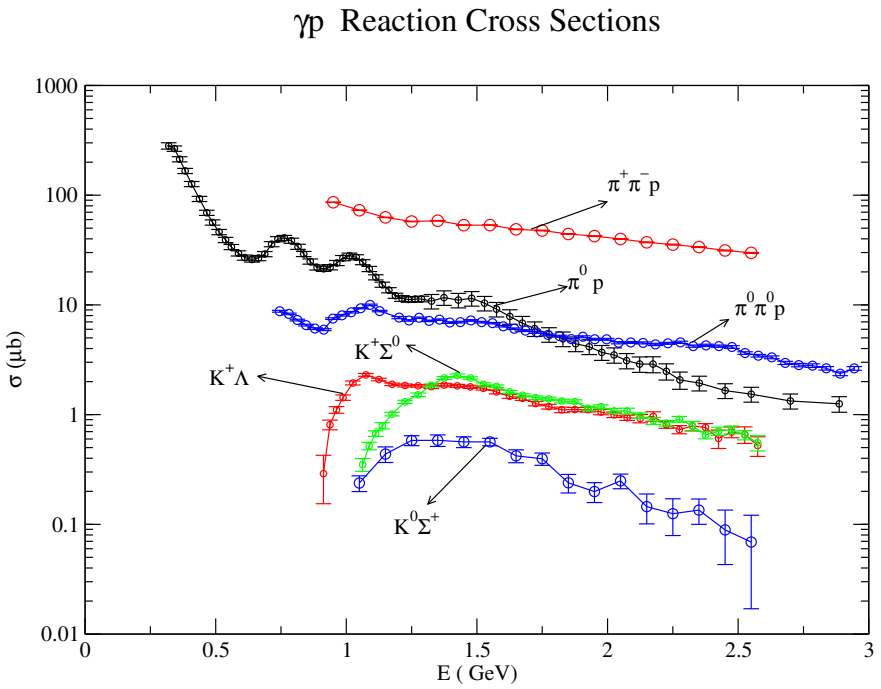
  Recent works on K^* production (Y. Oh, H, Kim)

- Theoretical predictions for experiments with RICH

  Form factors of K and K^*

  ϕ-N bound state due to gluon exchanges

N^* study with KY photoproduction



$\rightarrow$

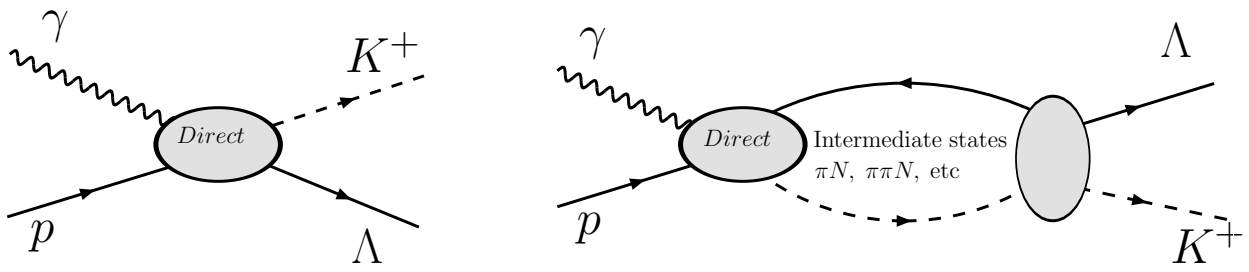
Must include coupled-channel effects :

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

$\longrightarrow$

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

- Coupled-channel effects



- Off-shell effects:

  due to reaction mechanisms at short distance where we want to map out the quark-gluon structure of N^*

EBAC approach:

$$
\begin{aligned}
T_{\alpha,\beta}(p_0,p_0;E) &= V_{\alpha,\beta}(p_0,p_0) \\
&\quad + \sum_{\gamma} \int_0^{\infty} dp' V_{\alpha,\gamma}(p_0,p') G_{\gamma}(p',E) T_{\gamma,\beta}(p',p_0,E) \\
V_{\alpha,\beta} &= v_{\alpha,\beta} + \sum_{N^*} \frac{\Gamma^{\dagger}_{N^*,\alpha}\Gamma_{N^*,\beta}}{E-M^*}
\end{aligned}
$$

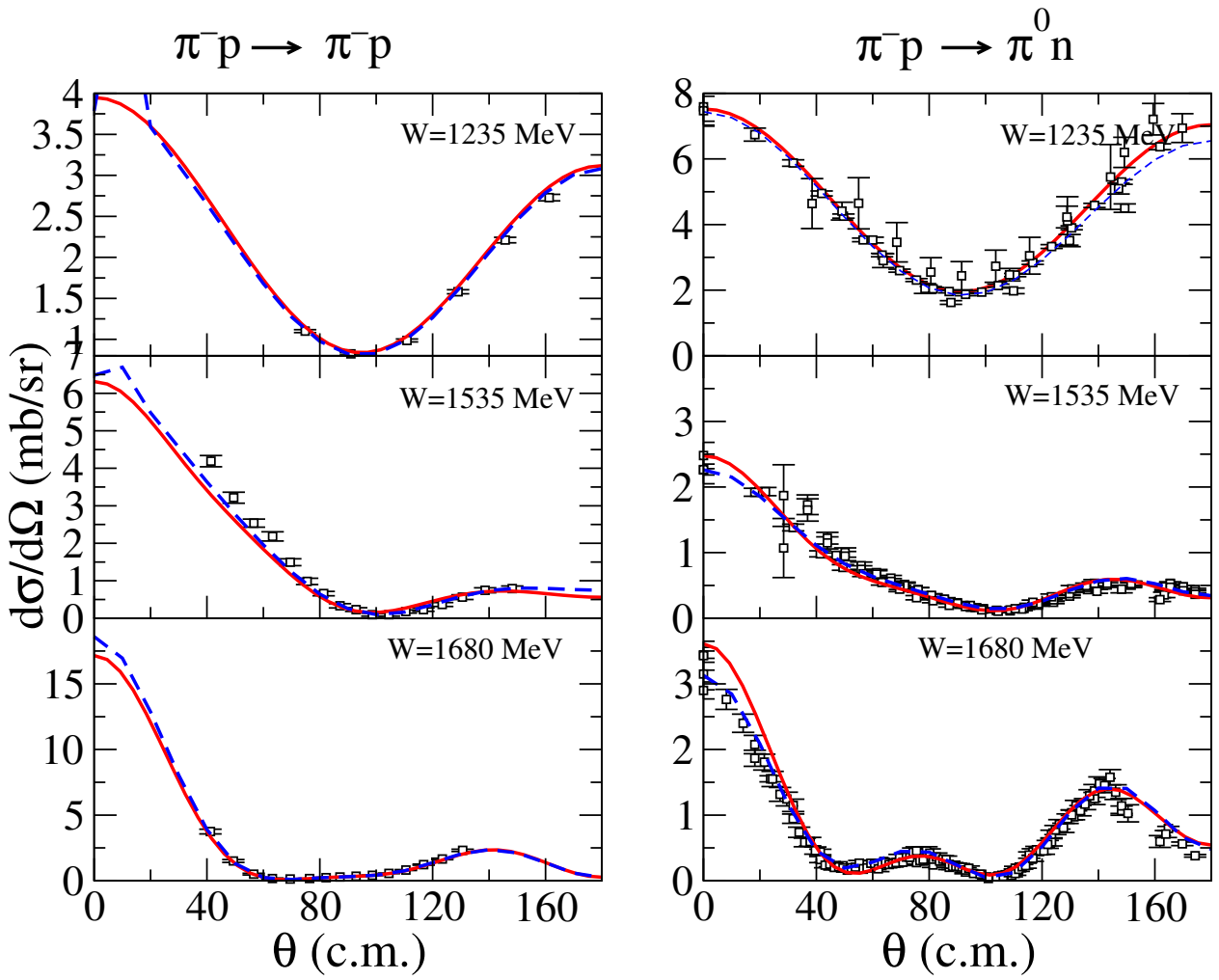
- $\alpha,\beta,\gamma = \gamma N, \pi N, \eta N, \omega N, KY, \pi\pi N$ ($\pi\Delta, \rho N, \sigma N$)
- $v_{\alpha,\beta}$: Meson-exchange mechanisms
- $\Gamma_{N^*,\beta}$: Hadron structure calculations
  - Hadron models with effective degrees of freedom
  - Lattice QCD

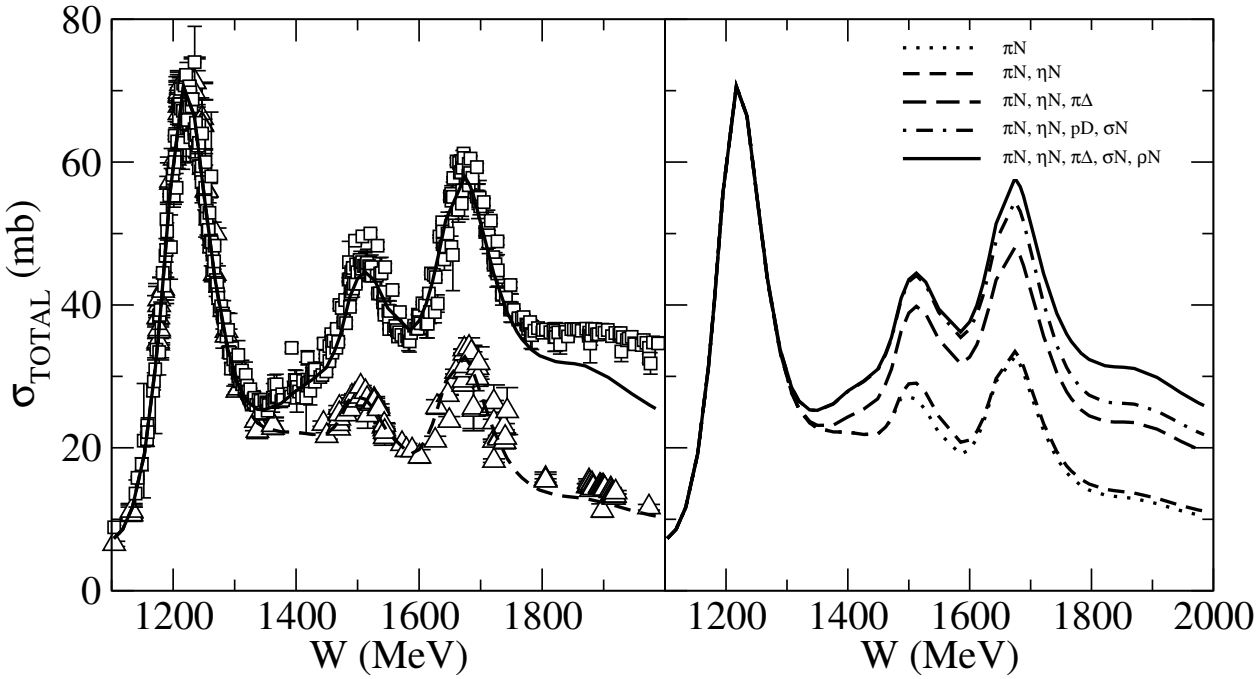
Status of EBAC :

- 21 N^* states have been identified from the world data of $\pi N \to \pi N$ and $\pi N \to \pi\pi N$.

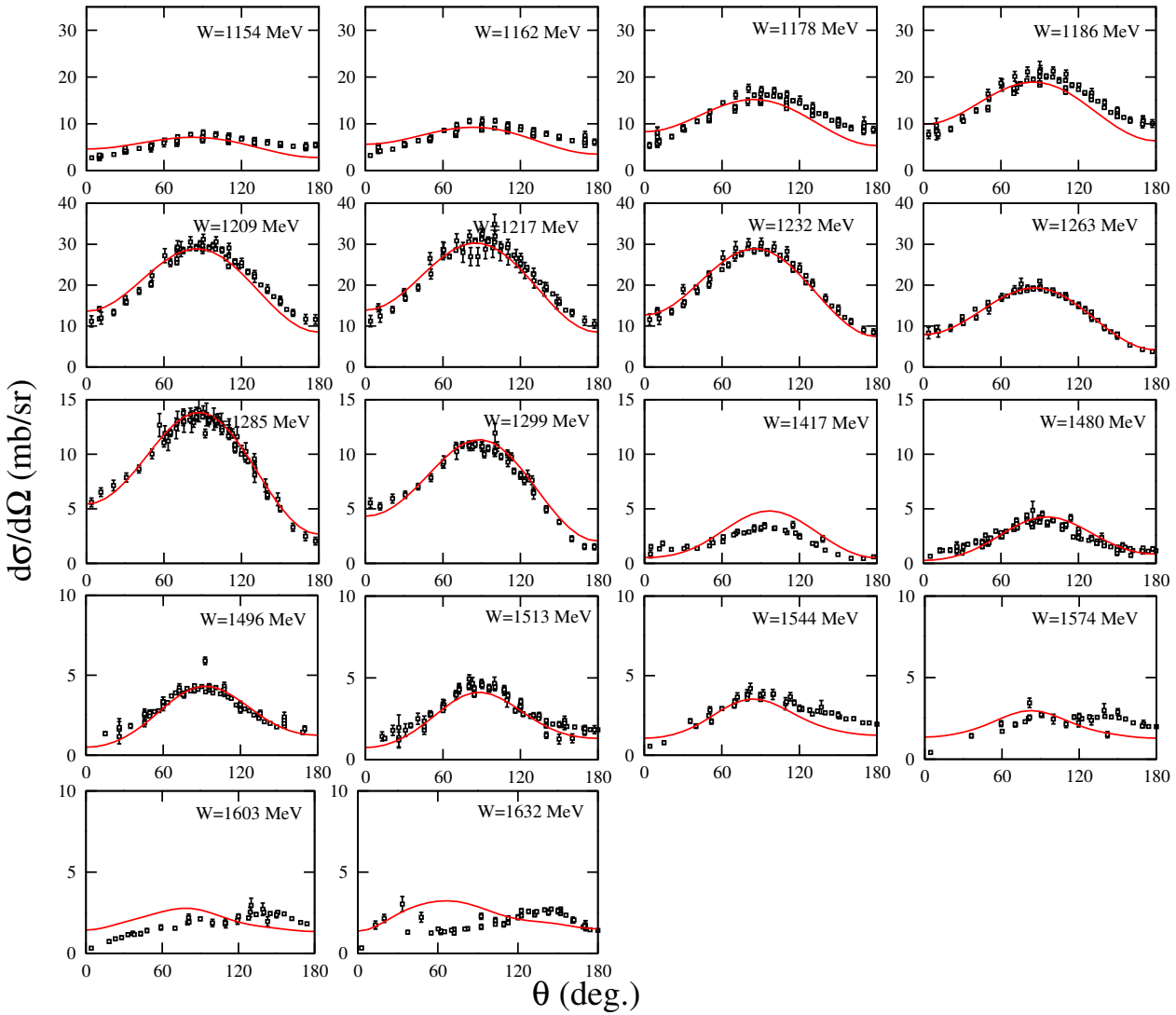
- $\gamma N \to N^*$ are being extracted by analyzing the data of π photoproduction and electroproduction

- Analyses of $\gamma N \to \pi\pi N, \omega N, KY$ are in progress

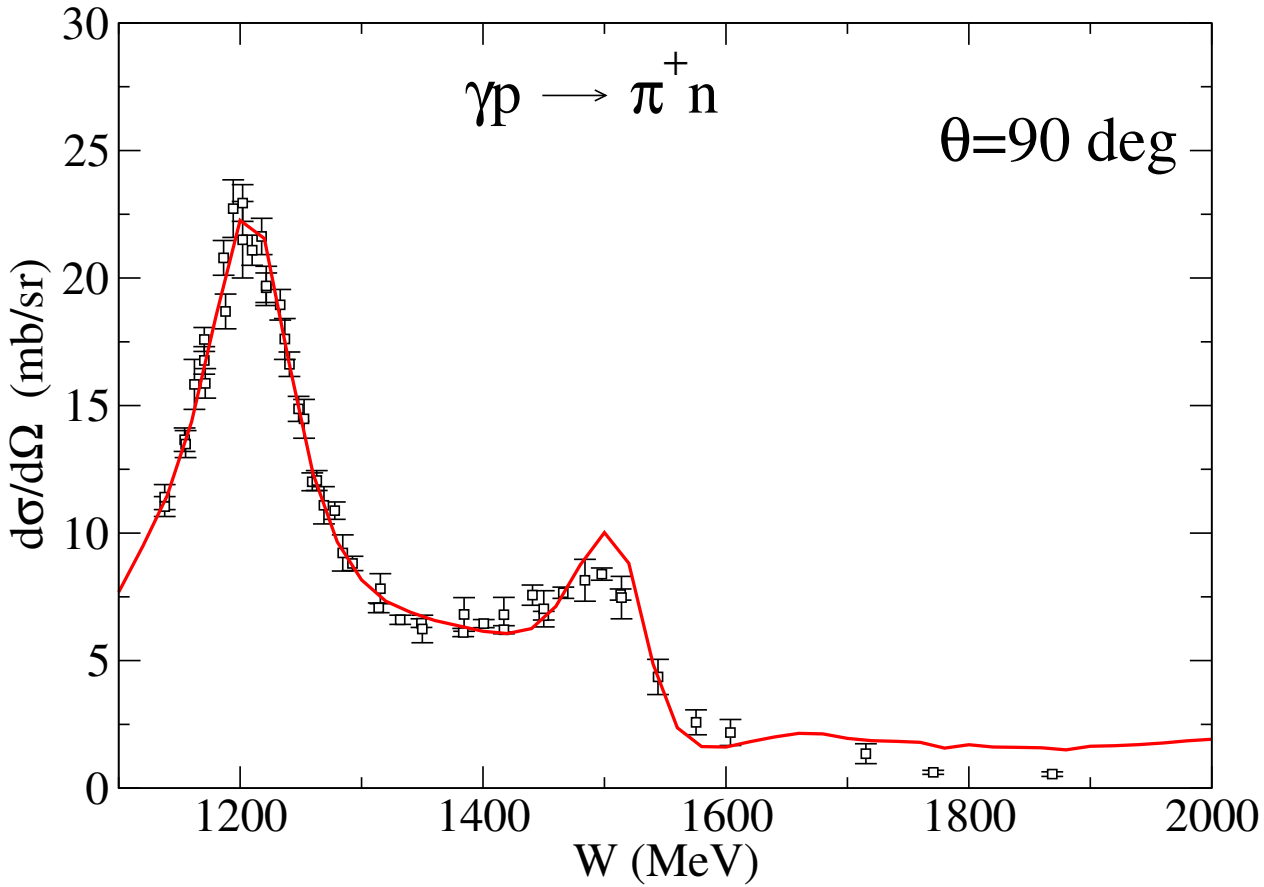

π⁻p ⟶ π⁻p
π⁻p ⟶ π⁰n
W=1235 MeV
W=1535 MeV
W=1680 MeV
dσ/dΩ (mb/sr)
θ (c.m.)
θ (c.m.)



Predicted $\pi^- p$ total cross sections



$d\sigma/d\Omega$ of $\gamma p \to \pi^0 p$



$\gamma p \to \pi^+ p$ up to $W = 2$ GeV

This talk :

Briefly report on KY production :

First objective :

Improve the analysis by Julia-Diaz, Saghai, Lee, Tabakin, 2005

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

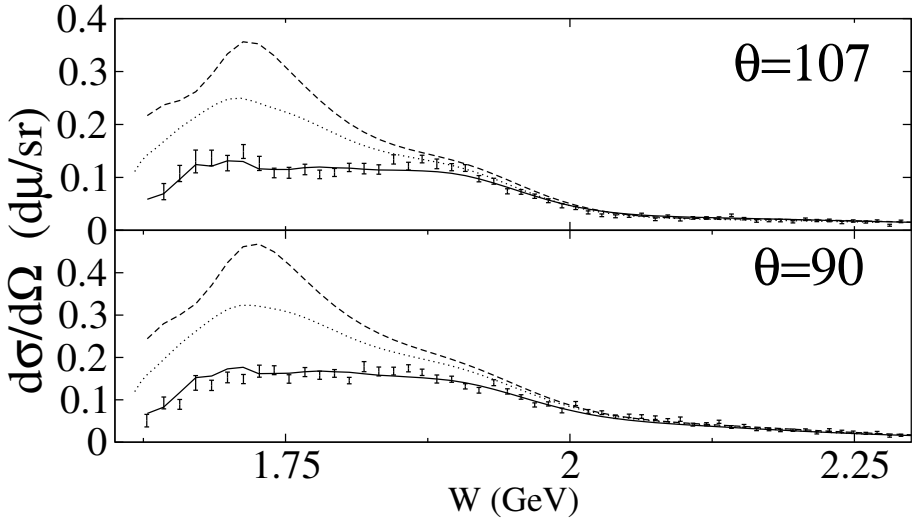
(B. Julia-Diaz, B. Saghai, T.-S. H. Lee, F. Tabakin, 2005)

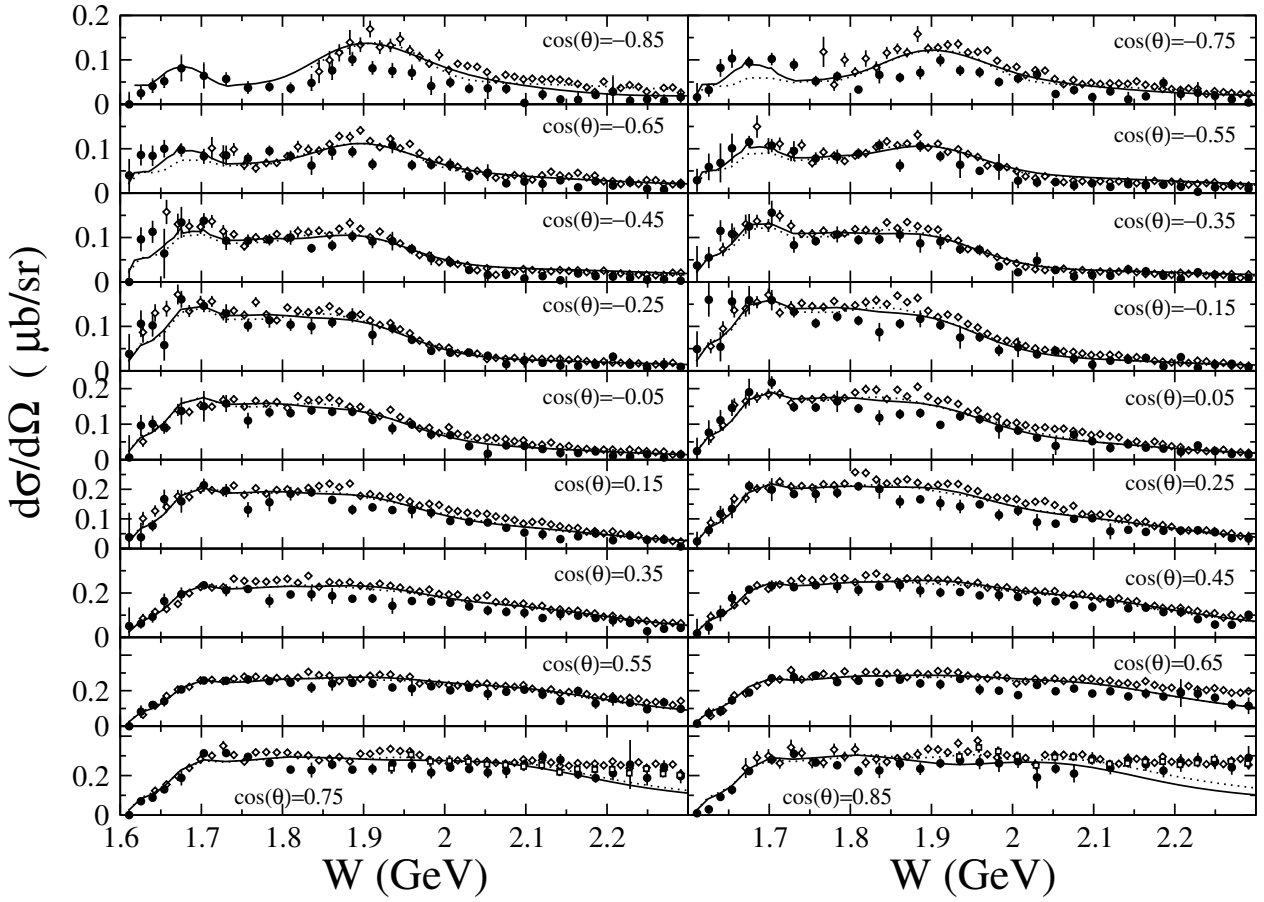
Channels : γN, πN, $K\Lambda$, $K\Sigma$

Solid: Coupled channel

Dashed: no coupled-channel

Dotted : no off-shell effects





$d\sigma/d\Omega$ of $\gamma p \to K^+\Lambda$

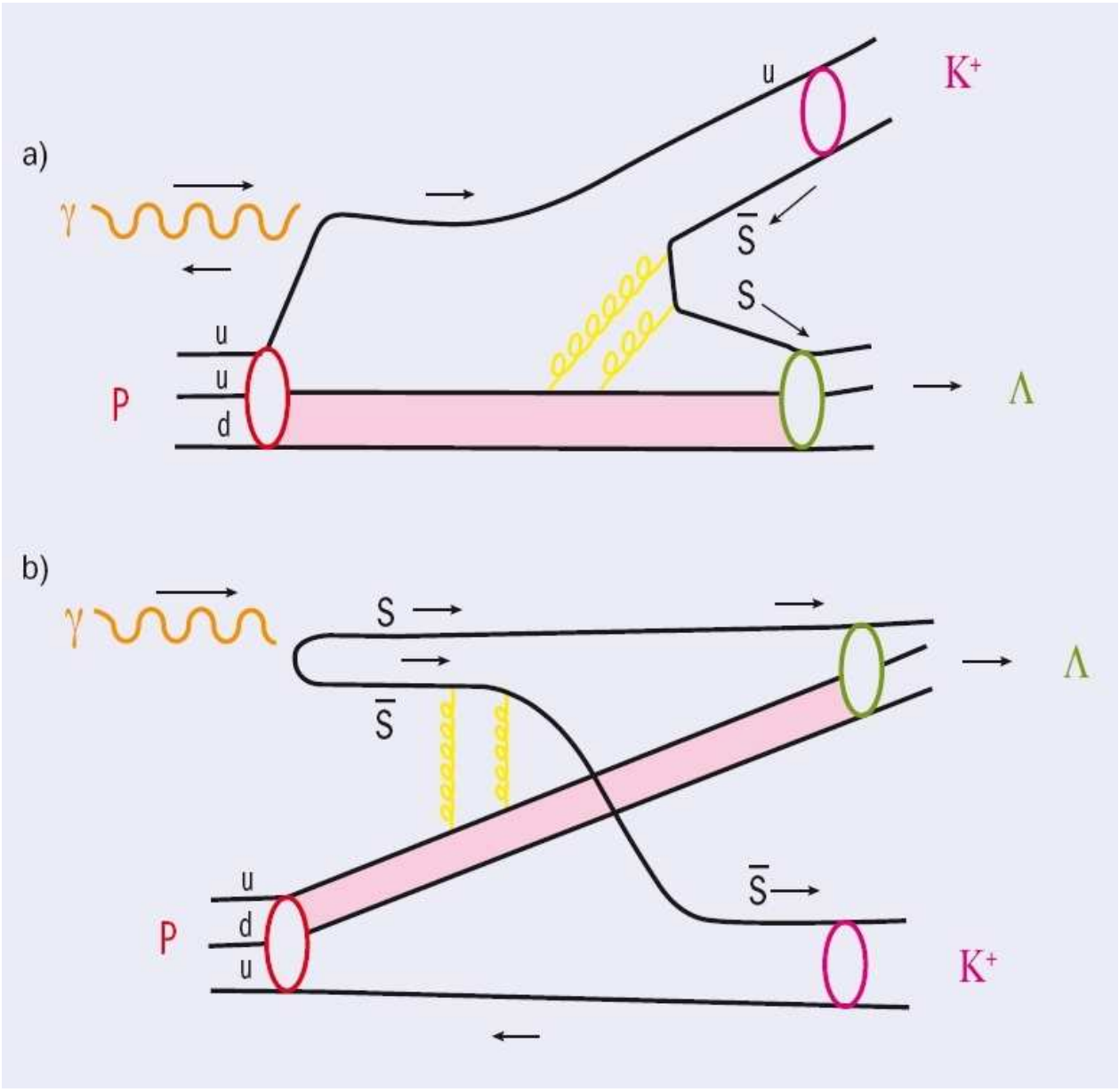
Steps:

- Examine all non-resonant mechanisms within SU(3) symmetry
- $\gamma N \to N^*$ parameters are consistent with those extracted from π, $\pi\pi$ photoproduction data
- Include full coupled-channel effects ($\pi N, \eta N, \pi\Delta, \rho N, \sigma N$, $K\Lambda$, $K\Sigma$)

Challenge :

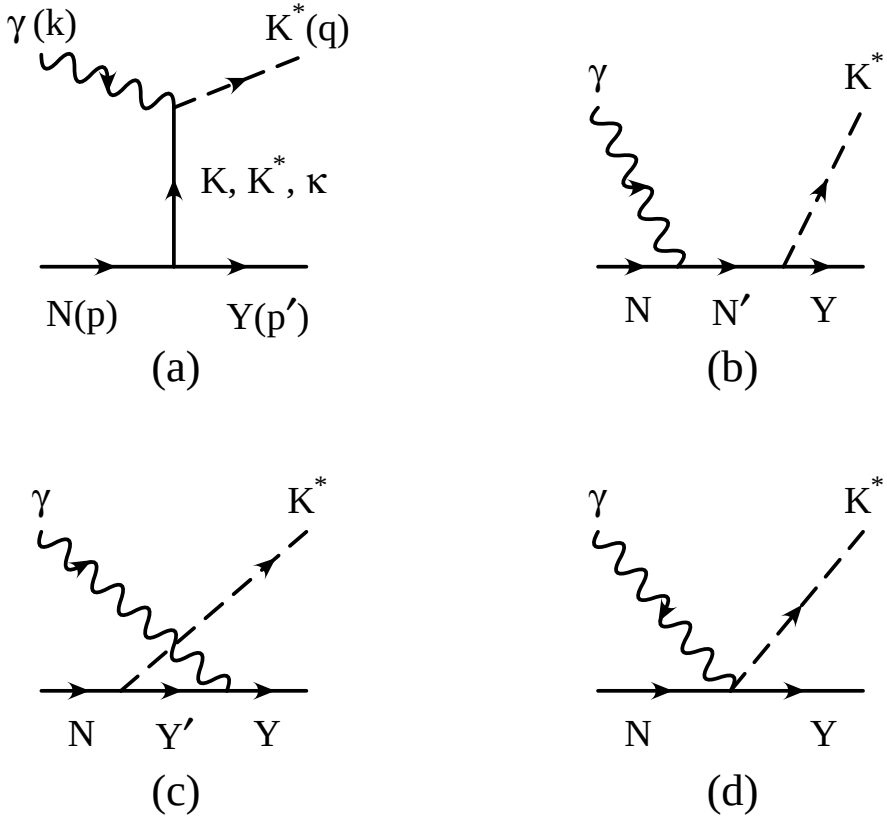
How to model quark-gluon reaction mechanisms

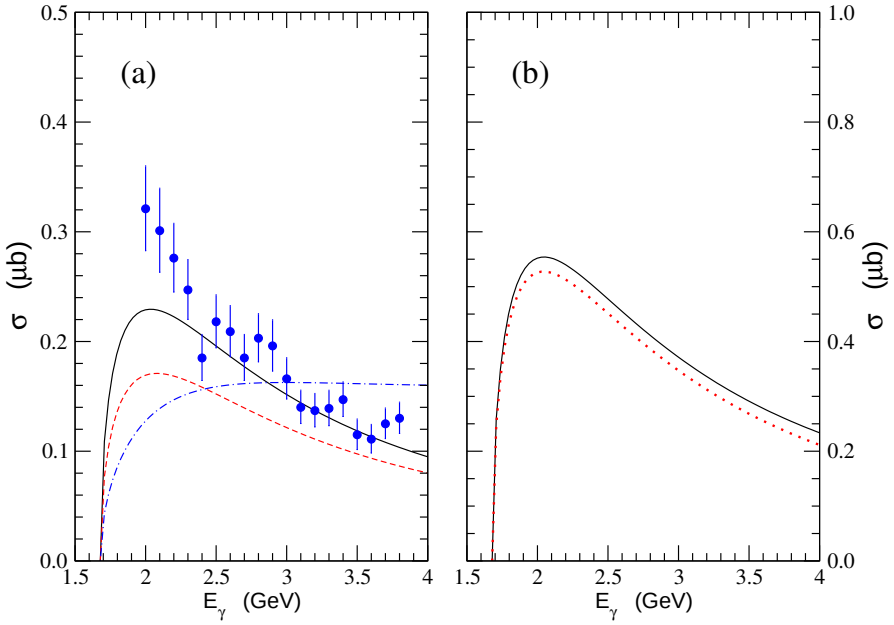
suggested by the JLAB data of spin observables ?


a)
γ
u
K+
S̄
S
u
u
d
P
Λ
b)
γ
S
S̄
Λ
u
d
u
P
S̄
K+

K^* production (Results from Oh and Kim, 2006)

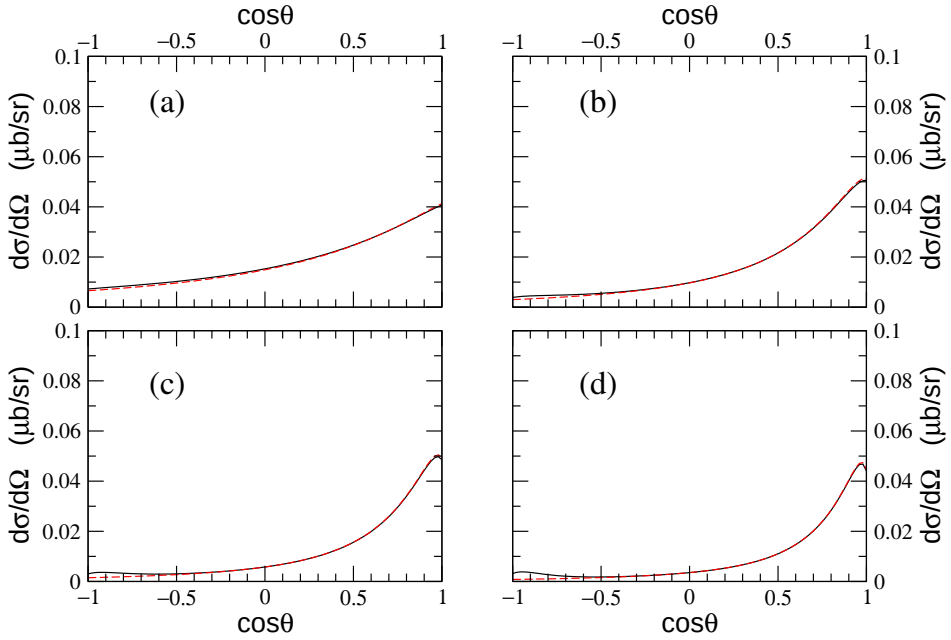
Mechanisms:





Left: $\gamma p \to K^{*+}\Lambda$ with cutoff $= 0.9, 1.0, 1.2$ GeV

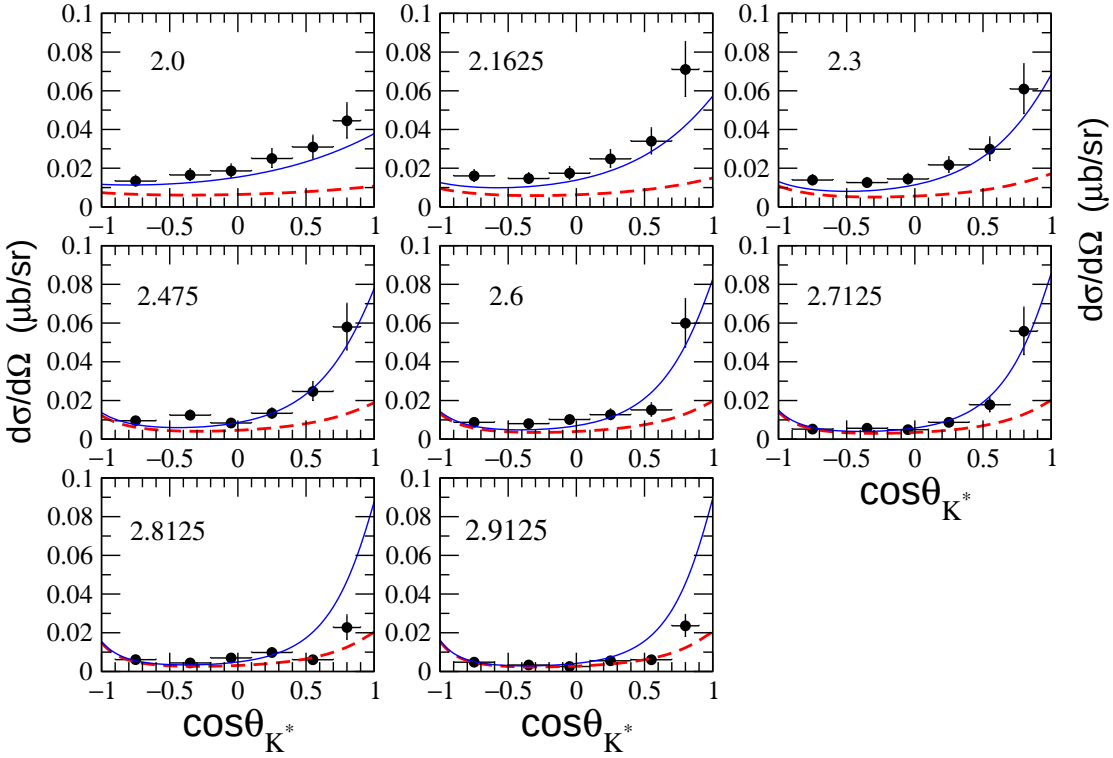
Right: $\gamma n \to K^{*0}\Lambda$, dotted : only K-exchange



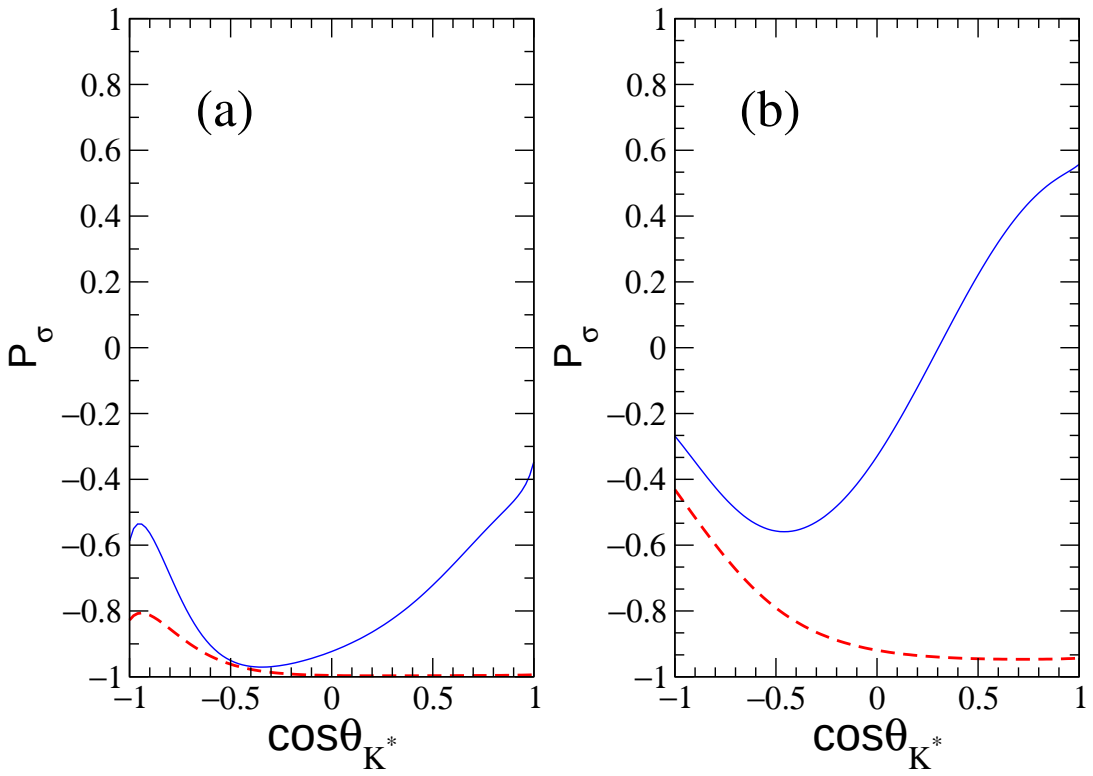
$\gamma p \to K^{*+}\Lambda$ at $E_\gamma = 2.0, 2.5, 3., 3.5$ GeV

Dotted : only K-exchange

$\gamma p \to K^{*0}\Sigma^{+}$



Sensitive to k-exchange


(a)
(b)
P_σ
$\cos\theta_{K^*}$
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−0.5
0.5

Dominance of K, K^*-exchange

$\rightarrow$

K, K^*, and K-K^* form factors can be extracted from electroproduction of KY, K^*Y.

$\rightarrow$

Can study QCD physics associated strange valance quarks :

Test

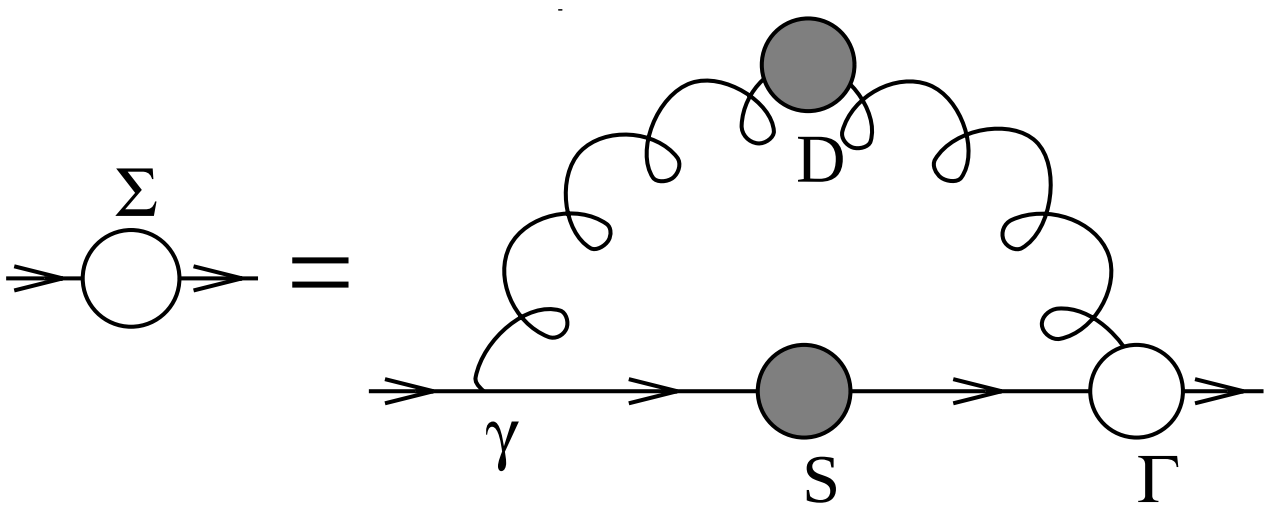
- Prediction from Covariant model based on Dyson-Schwinger Equation of QCD
- Prediction from relativisitic constituent quark models
- Lattice QCD calculations

Covariant model based on Dyson-Schwinger Equation of QCD

(P. Maris, P. Tandy, C.D. Roberts etc..)

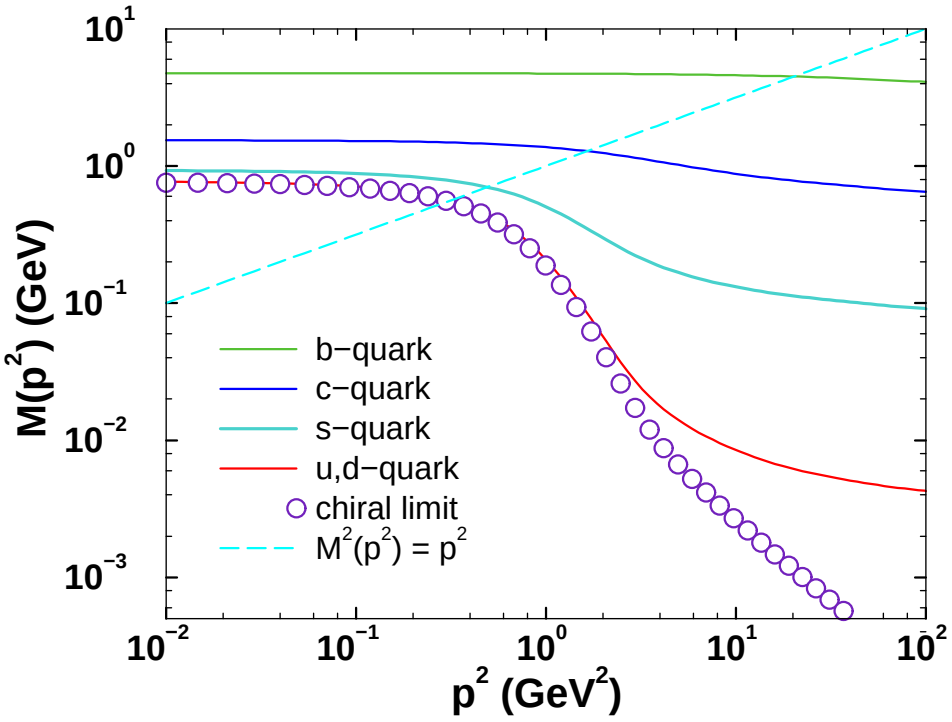
Steps:

- Model gluon propagator to solve DSE with appropriate approximations (consistent with crucial QCD symmetry properties)

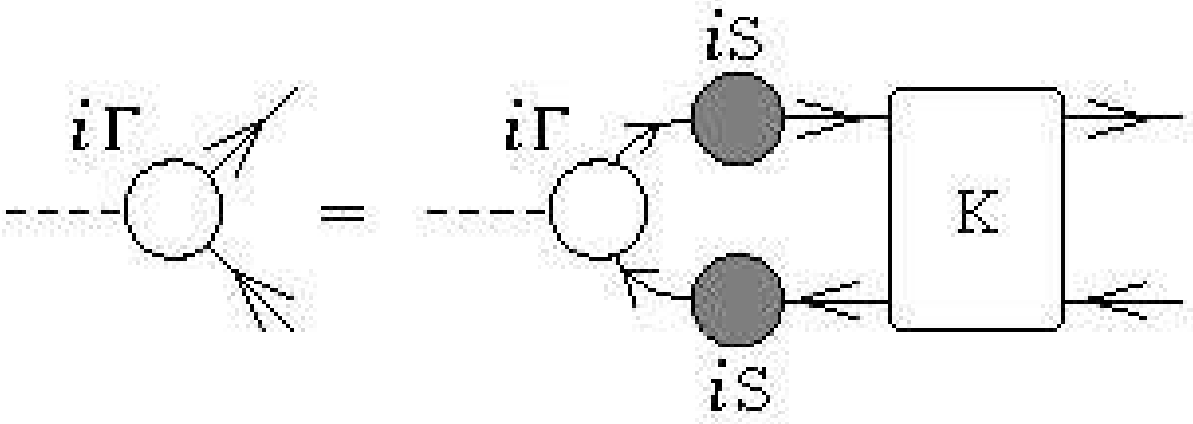


$\longrightarrow$

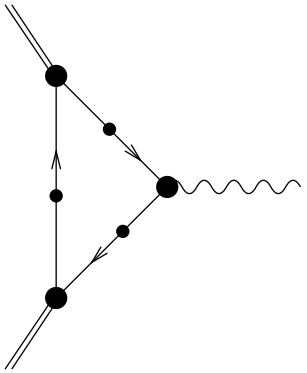
Obtain quark propagators



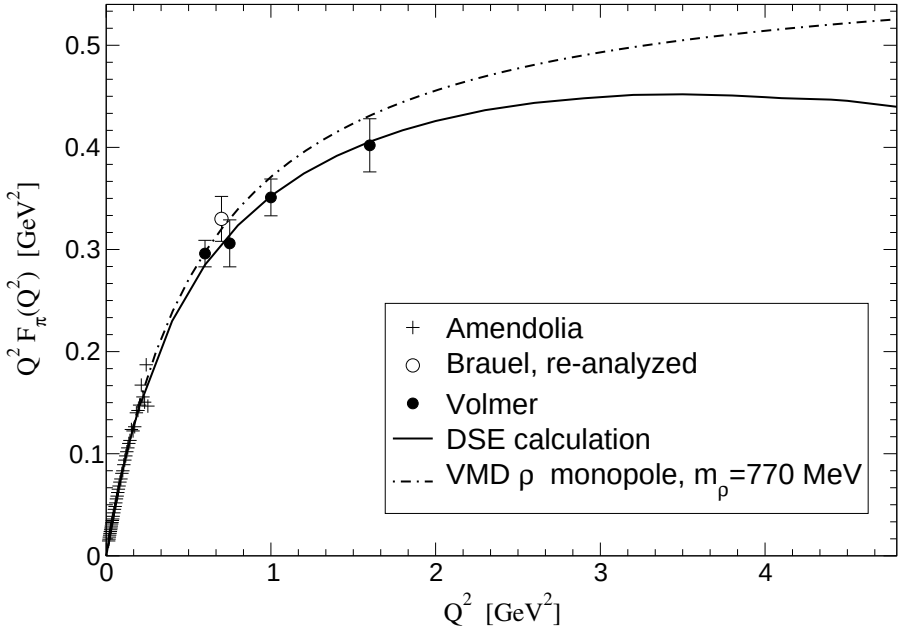
- Solve $q\bar{q}$ Bethe-Salpeter Equation to get bound state wave functions for π, K and K^*.



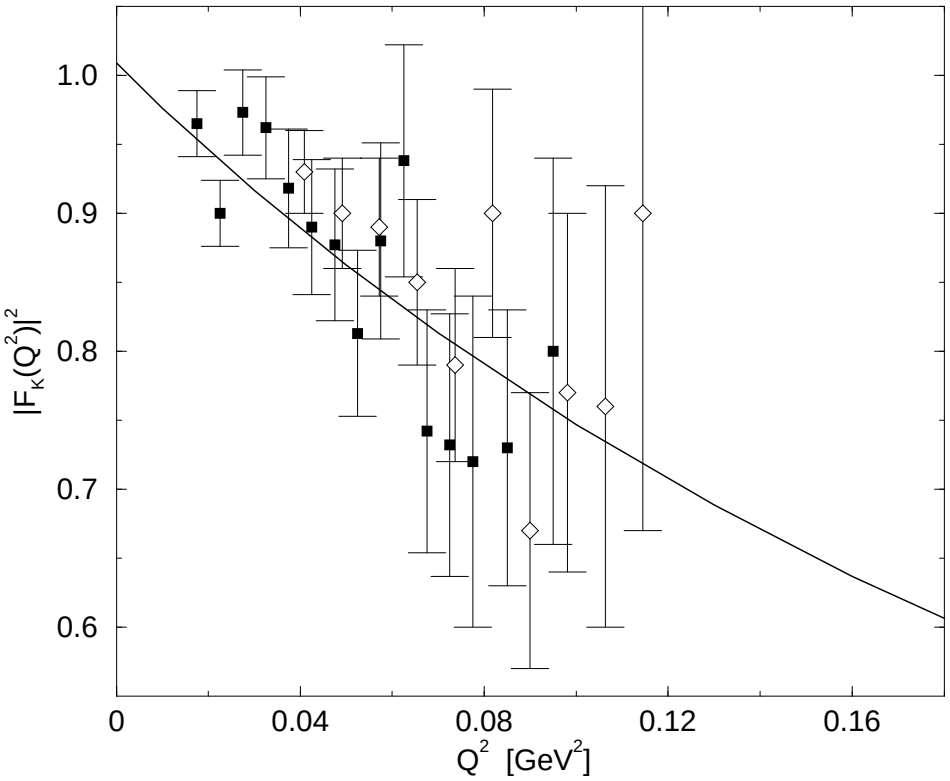
- Predict form factors



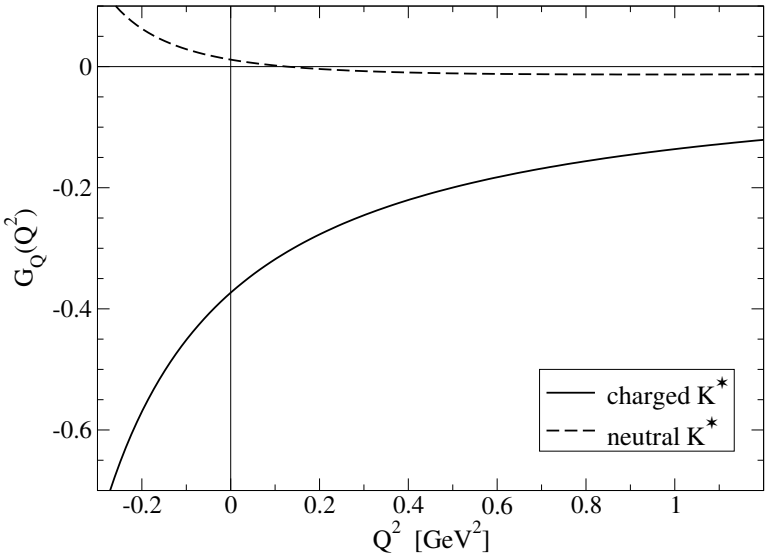
π form factor

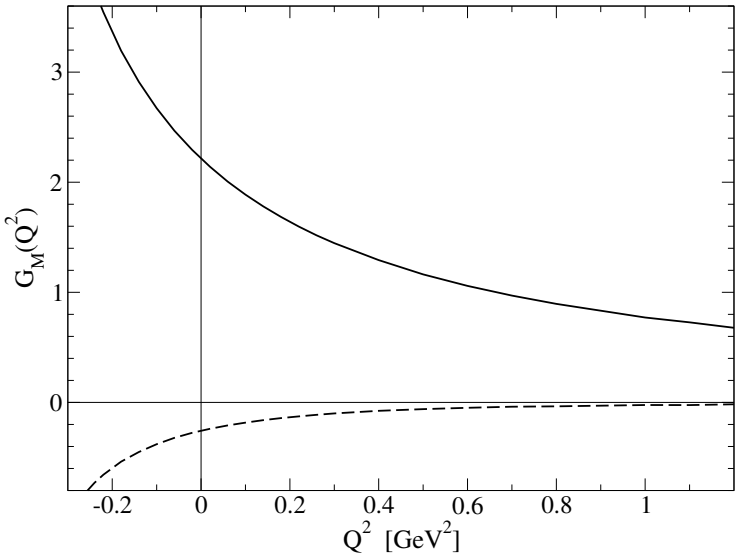


K form factor



Predicted K^* form factors

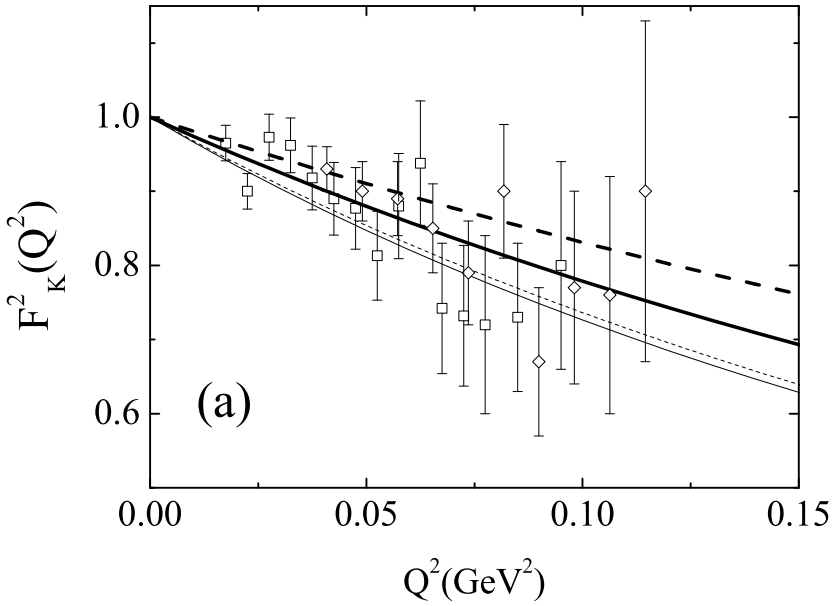




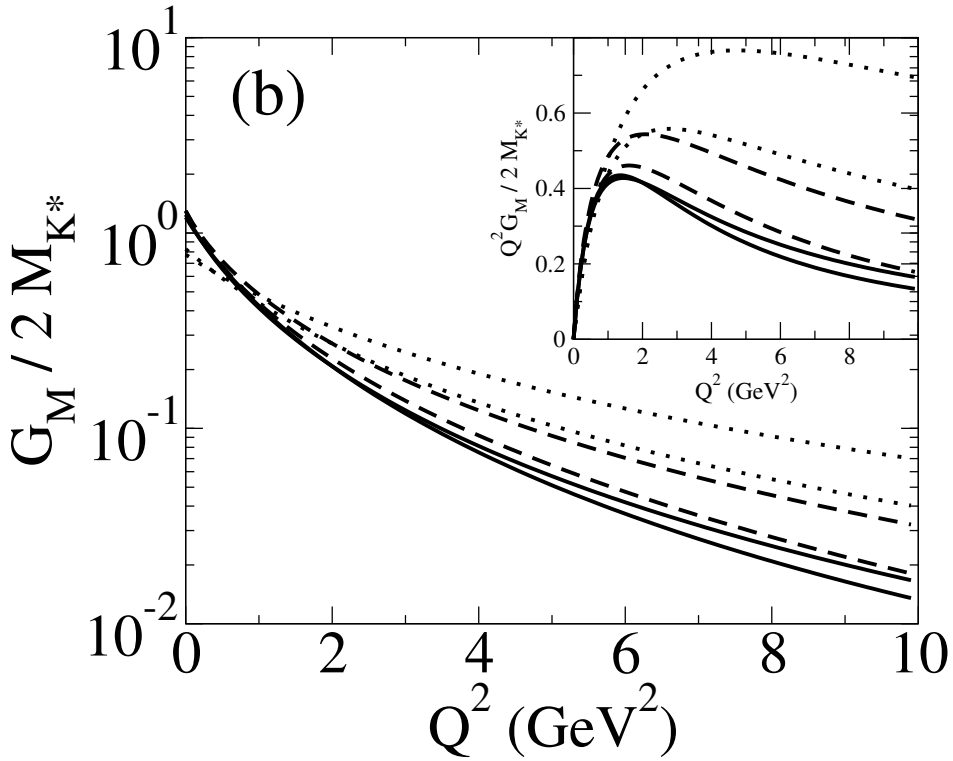
Relativistic Quark Model predictions

(B. Julia-Diaz, J. He, and Y.B. Dong, 2006)

K form factor

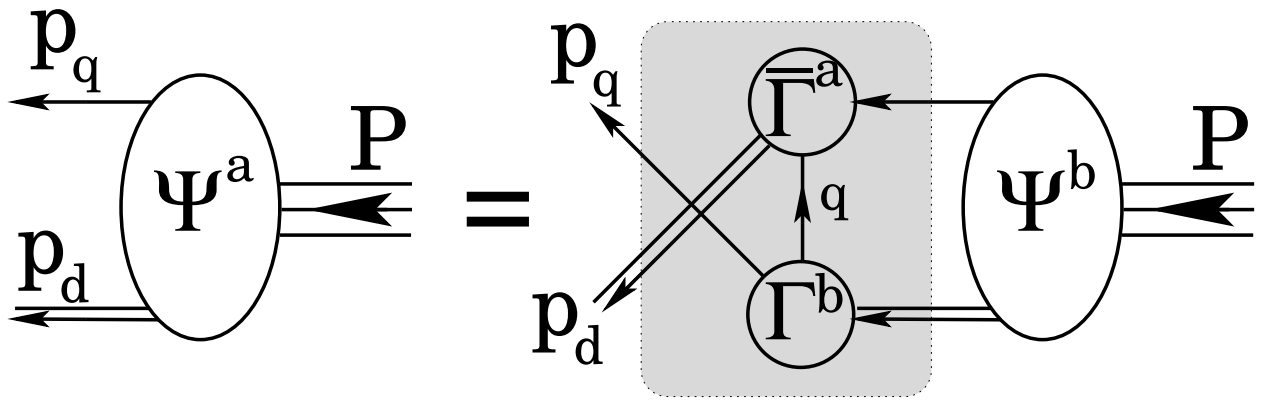


K^* form factor



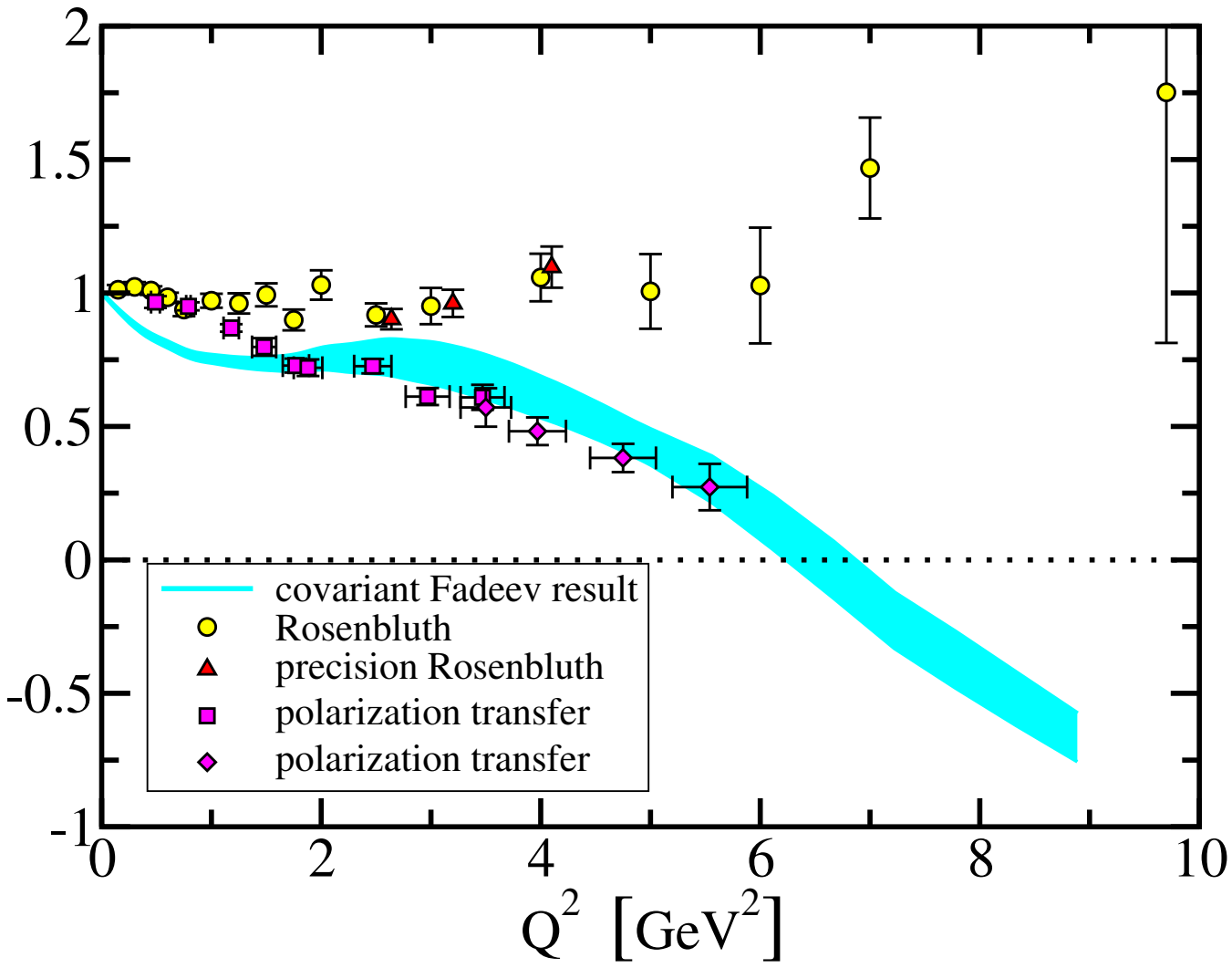
DSE model can also predict baryon form factors

Solve Faddeev Equation with di-quark-quark configurations



$\rightarrow$

- N form factors have been studied
- N-$\Delta(1232)$ form factors is in progress
- can also calculate form factors for Λ , Σ, etc..


2
1.5
1
0.5
0
-0.5
-1
0
2
4
6
8
10
Q^2 [GeV^2]
covariant Fadeev result
Rosenbluth
precision Rosenbluth
polarization transfer
polarization transfer

Photoproduction of ϕ-N bound state on nuclei

Motivation:

The interactions between $\Phi = (b\bar{b}), (c\bar{c}), (s\bar{s})$ and $p(uud)$ are due to gluon exchange

$$L_{int} = c_E \Phi^\dagger \Phi T^{\mu\nu}_{gluon} v_\mu v_\nu + ..$$

$\rightarrow$

$\Phi - N$ interaction energy is

$$U \sim < \Phi N | L_{int} | \Phi N > = c_E < N | T^{\mu\nu}_{gluon} | N >$$

Estimates:

- Peskin :

  $c_E = \frac{14\pi}{27}\Lambda_{QCD}^3 r_B^3$

  (in heavy quark limit and $1/N_C$ expansion)

- $< N|T^{\mu\nu}_{gluon}|N >= 2V_2(p^\mu p^\nu - \frac{1}{4}g^{\mu\nu}p^2)$

  $V_2 \sim 0.4$: gluon momentum fraction measured in DIS

M. Luke, A.V. Manohar, M.J. Savage(PL, B288, 355 (1992) :

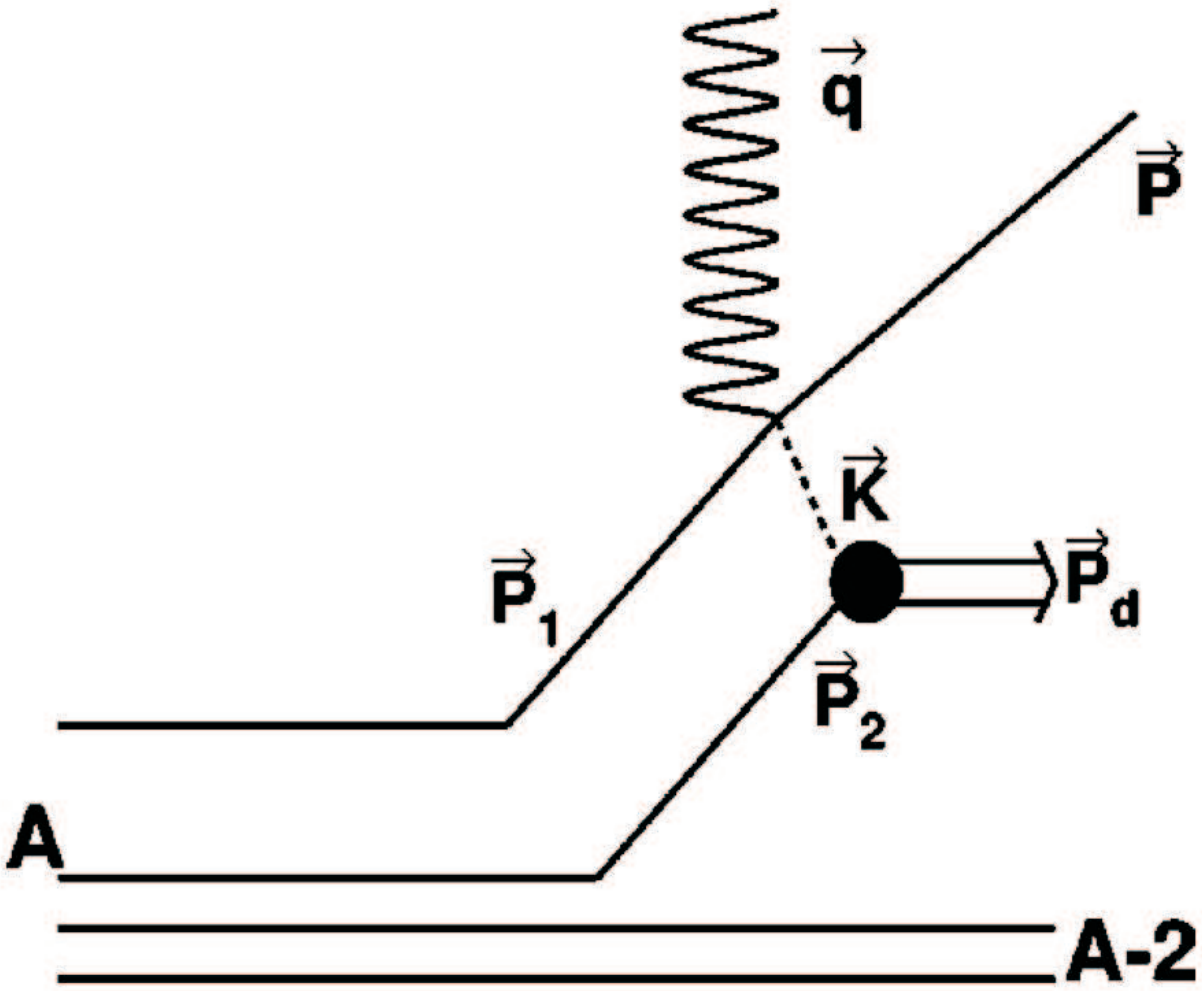
$r_B^{-1} = 640 - 750$ MeV for $J/\psi(c\bar{c})$

$$U(\Phi = J/\Psi) \sim 8 - 11\ MeV$$

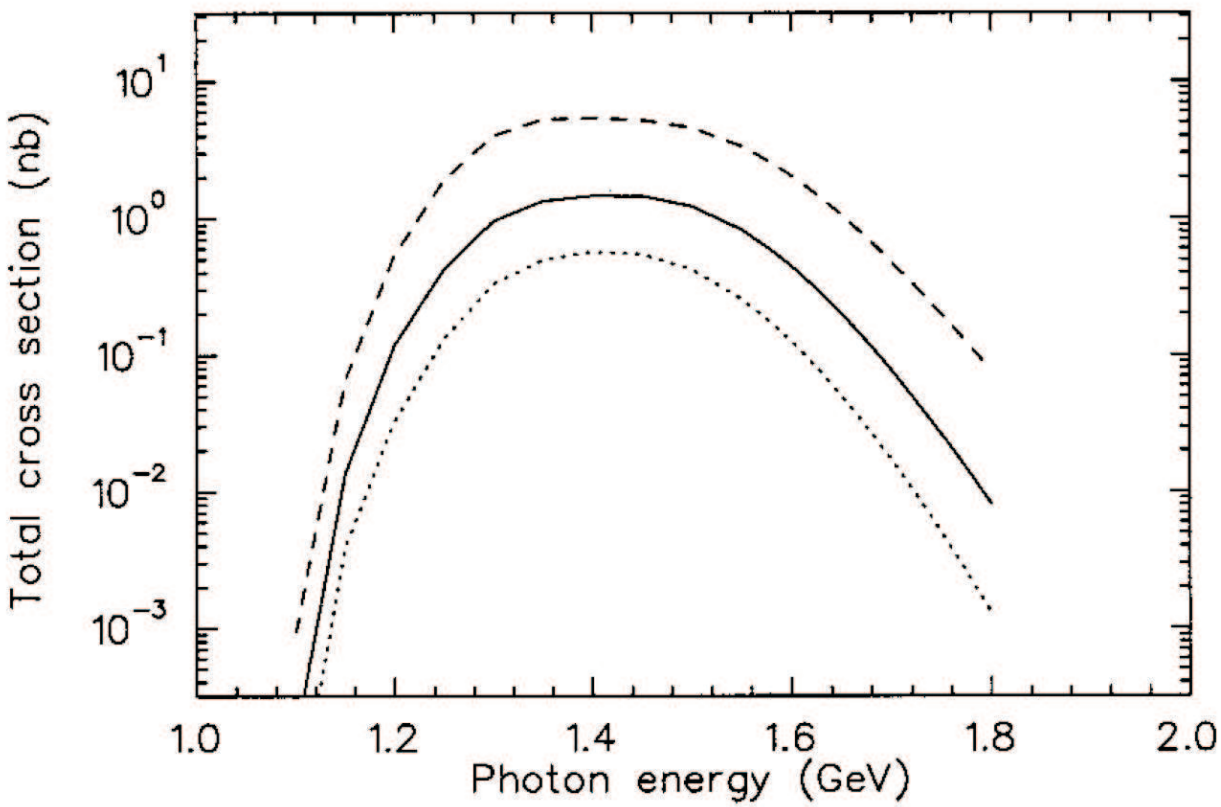
$r_B^{-1} \sim 500$ MeV for ϕ

$\rightarrow$

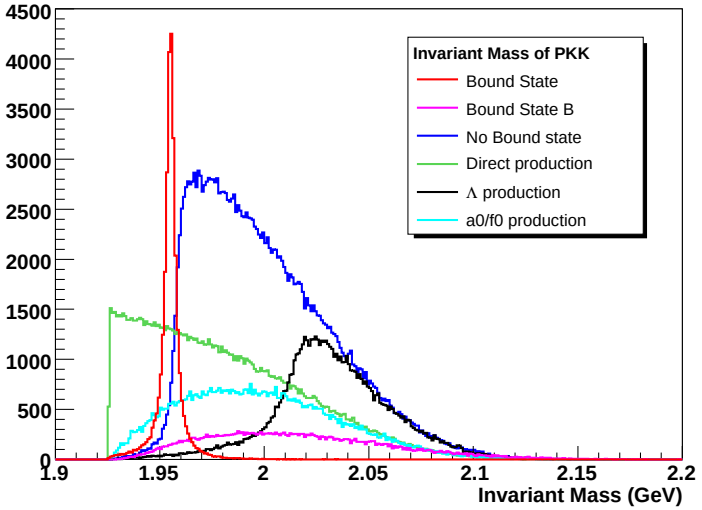
ϕ-N bound state could be formed in $A(\gamma, K\bar{K}N)$ reaction

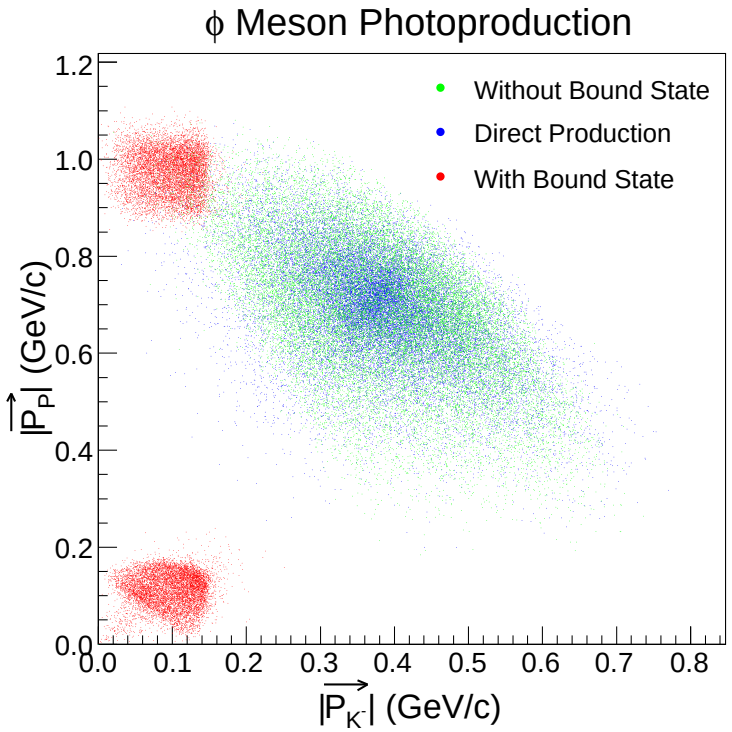

$\vec{q}$
$\vec{P}$
$\vec{K}$
$\vec{P}_1$
$\vec{P}_d$
$\vec{P}_2$
A
A-2

Model prediction (H. Gao, T.-S. H. Lee, V. Marinov (2001)) :



Analysis by S. Liska, H. Gao, W. Chen, X.Qian (Phys. Rev. C75 (2007))





Concluding Remarks

- EBAC has started to analyze KY production data in the N^* region
- Because of the coupled-channel effects, we need hadronic KY data to constrain the extraction of N^* parameters

  (Collaboration with JPARC)
- The predictions of K, K^* and K-K^* form factors are now availabe for experimental tests
- $A(\gamma, K^+K^-N)$ will test an important prediction of the gluon dynamics of QCD