

Meson production amplitudes from dynamical coupled channel model

T. Sato Osaka U

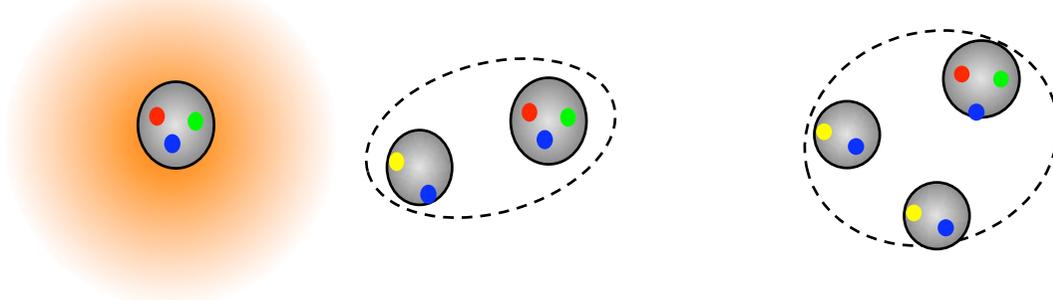
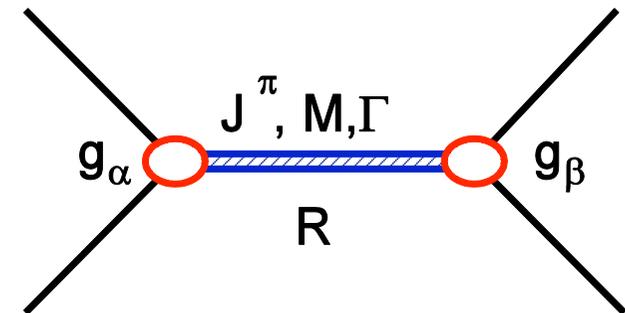
Report on our extended analysis of meson production reactions (ANL-Osaka)

H. Kamano, S. Nakamura, T. –S. H. Lee, T. Sato arXiv:1305.4351
to be appear in Phys. Rev.C

- ◆ Combined analysis of pion and photon induced meson production reactions.

$$\pi N, \eta N, \pi\pi N, K\Lambda, K\Sigma, \omega N$$

- ◆ Extract N^* parameters $W < 2\text{GeV}$
- ◆ Provide information of reaction mechanisms and possible role of meson-baryon dynamics on N^* structure



Extraction of N^* , Δ resonances properties

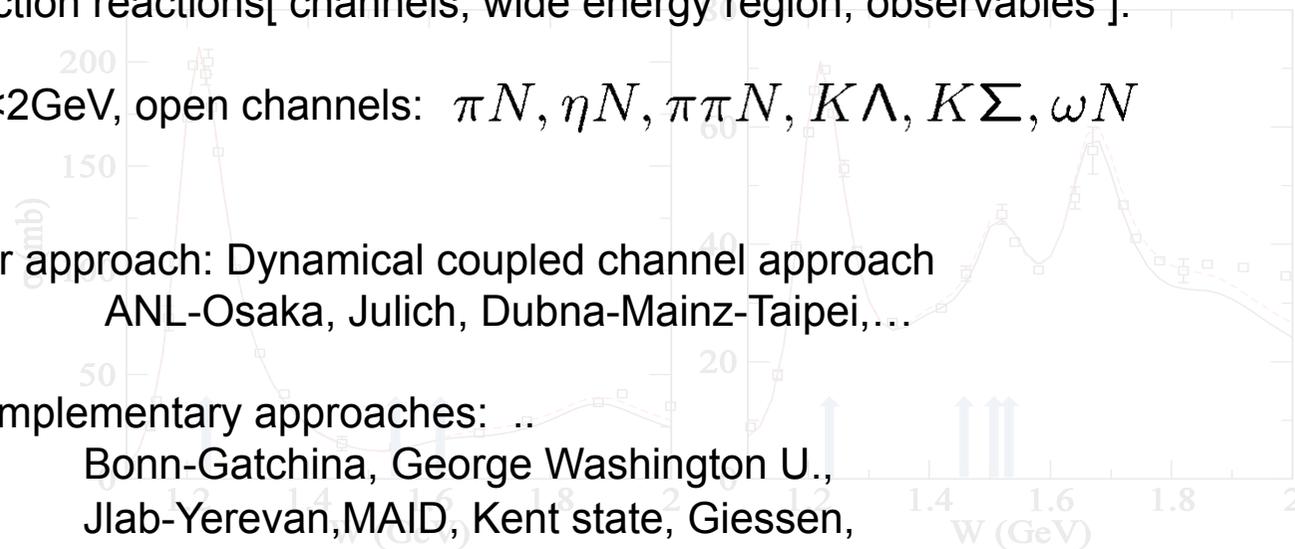
- excited states of nucleons are unstable particles and appear as resonance
- strong coupling of excited states with meson-baryon continuum
large width ($\sim > 100\text{MeV}$) and overlapping resonances

Extraction of resonance properties requires systematic analysis of meson production reactions [channels, wide energy region, observables].

$W < 2\text{GeV}$, open channels: $\pi N, \eta N, \pi\pi N, K\Lambda, K\Sigma, \omega N$

➤ Our approach: Dynamical coupled channel approach
ANL-Osaka, Julich, Dubna-Mainz-Taipei,...

➤ Complementary approaches: ..
Bonn-Gatchina, George Washington U.,
Jlab-Yerevan, MAID, Kent state, Giessen,



Contents

- Coupled channel approach of meson production reactions
- Analysis of meson production reactions
- Extraction of N^* parameters:
 N^* spectrum, residue of πN amplitude

Collaborators

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- N. Suzuki (Osaka)**
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dynamical coupled-channels (DCC) model

Dynamical Coupled Channel Approach

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

Start from effective, Hermite Hamiltonian of meson-baryon

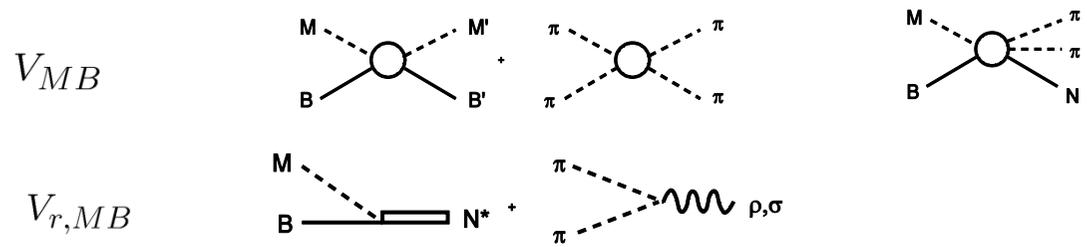
$$H = \begin{pmatrix} H_r & V_{r,MB} \\ V_{r,MB} & H_{MB} \end{pmatrix}$$

r: 'short range' $N^*, \Delta, \rho, \sigma$

MB: 'long range'

$\gamma N \oplus \pi N \oplus \eta N \oplus KY(\Lambda, \Sigma)$

$\pi\pi N(\sigma N, \rho N, \pi\Delta)$

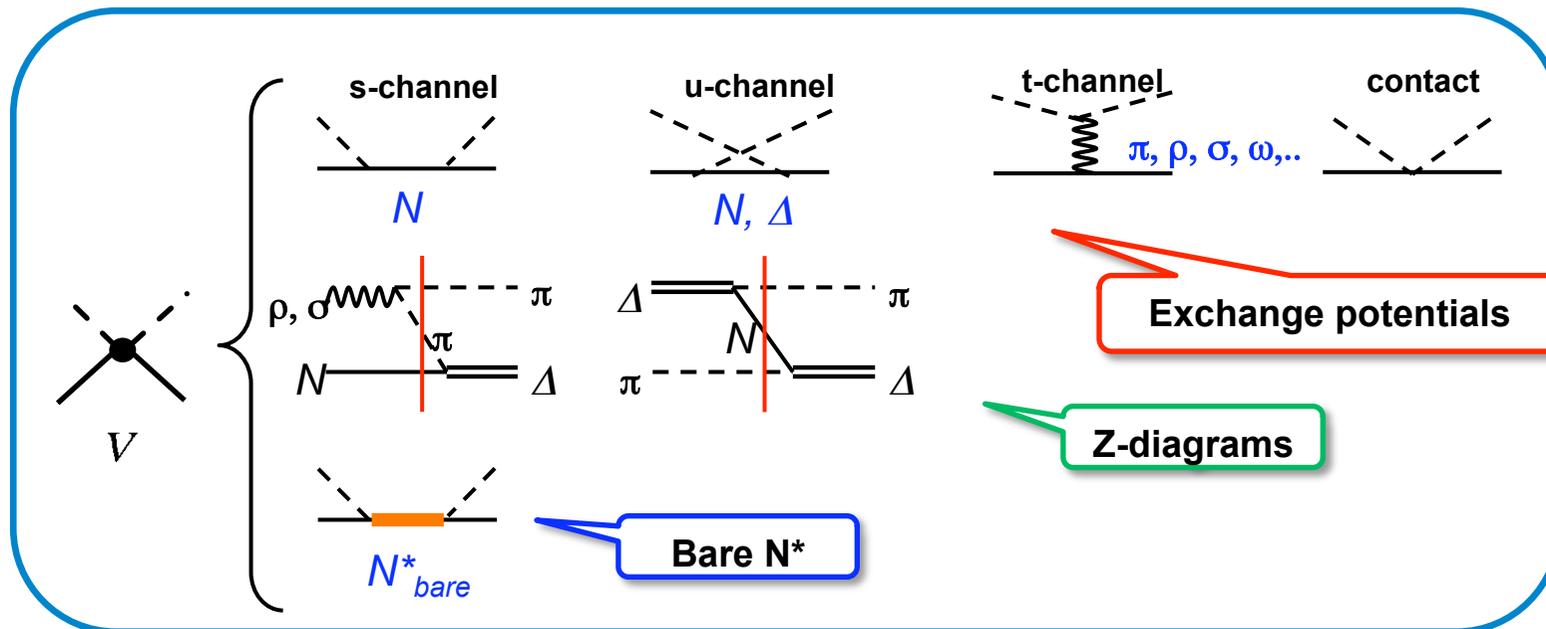


Scattering amplitude of pion and photon induced meson production amplitudes are obtained by solving coupled channel integral equation (3-dim reduction) in momentum space (partial waves [L,J,P])

$$T_{\beta,\alpha}^{IJP}(k', k, W) = V_{\beta,\alpha}^{IJP}(k', k) + \sum_{\gamma} \int dq q^2 V_{\beta,\gamma}^{IJP}(k', q) G_{\gamma}^0(q, W) T_{\gamma,\alpha}^{IJP}(q, k, W)$$

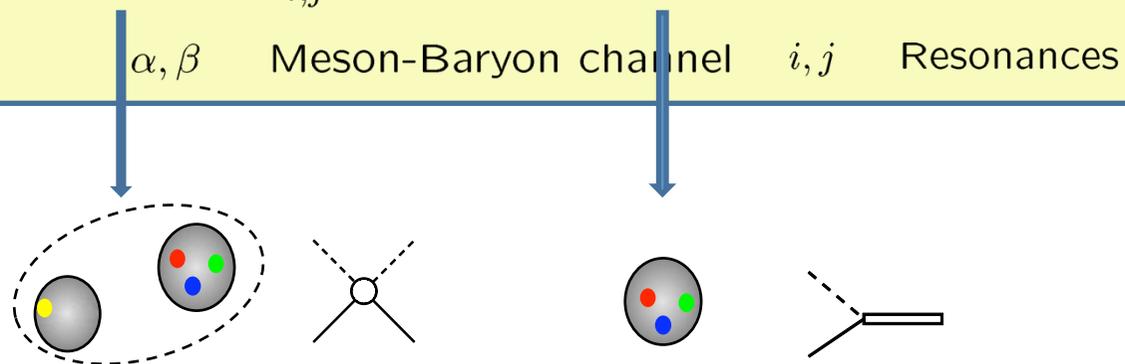
$$\alpha, \beta, \gamma = (\gamma^{(*)}N, \pi N, \eta N, \pi\Delta, \sigma N, \rho N, K\Lambda, K\Sigma, \dots)$$

$\pi\pi N$



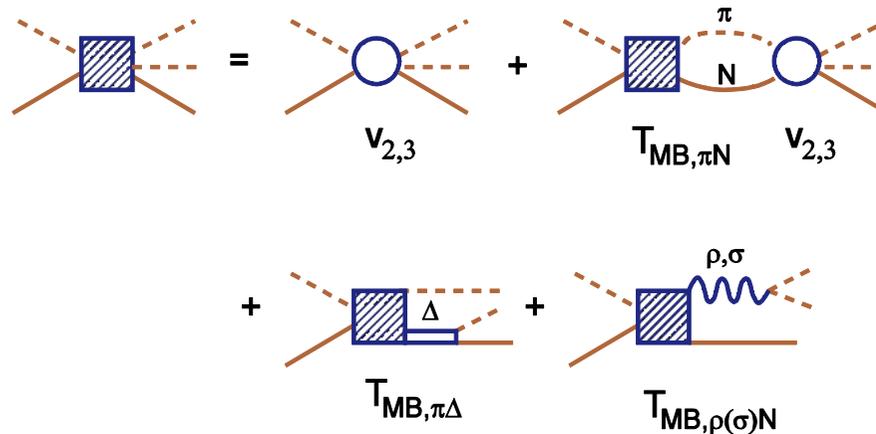
2-2 amplitudes

$$T_{\alpha,\beta}(W) = t_{\alpha,\beta}^{nr}(W) + \sum_{i,j} \bar{\Gamma}_{\alpha,i}(W) \left[\frac{1}{W - m_0 - \Sigma(W)} \right]_{ij} \bar{\Gamma}_{\beta,j}(W)$$



Two-pion production

$$T_{32} = v_{32} + \Gamma G_0^+ T_{22}$$



Analysis of meson production reactions

New ANL-Osaka Dynamical Coupled-Channels analysis

	(JLMS) 2006-2009	(ANL-Osaka) 2010-2013
channels	6 channels	8 channels
reactions	($\gamma N, \pi N, \eta N, \pi \Delta, \rho N, \sigma N$)	($\gamma N, \pi N, \eta N, \pi \Delta, \rho N, \sigma N, K\Lambda, K\Sigma$)
✓ $\pi p \rightarrow \pi N$	$W < 2 \text{ GeV}$	$< 2.3 \text{ GeV}$
✓ $\gamma p \rightarrow \pi N$	$< 1.6 \text{ GeV}$	$< 2.1 \text{ GeV}$
✓ $\pi^- p \rightarrow \eta n$	$< 2 \text{ GeV}$	$< 2.1 \text{ GeV}$
✓ $\gamma p \rightarrow \eta p$	—	$< 2.1 \text{ GeV}$
✓ $\pi p \rightarrow K\Lambda, K\Sigma$	—	$< 2.1 \text{ GeV}$
✓ $\gamma p \rightarrow K\Lambda, K\Sigma$	—	$< 2.1 \text{ GeV}$

- Extended to **include KY production reaction, higher W**
- Fully combined analysis of $\gamma N, \pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma$ reactions
SU(3) Meson (P,V octet), Baryon(octet,decuplet)
- omega N, ppi N are **not** included in fit
- Total 22,348 data points

(JLMS)B. Julia-Diaz, T.-S. H. Lee, A. Matsuyama, T. Sato, PRC76 065201(2007)

Data sets

$\pi N \rightarrow \pi N$

20 partial waves

Single energy solution of SAID

Partial Wave		Partial Wave	
S_{11}	65×2	S_{31}	65×2
P_{11}	65×2	P_{31}	61×2
P_{13}	61×2	P_{33}	65×2
D_{13}	61×2	D_{33}	59×2
D_{15}	61×2	D_{35}	40×2
F_{15}	48×2	F_{35}	43×2
F_{17}	32×2	F_{37}	44×2
G_{17}	42×2	G_{37}	32×2
G_{19}	28×2	G_{39}	32×2
H_{19}	34×2	H_{39}	31×2
Sum	994		944
			1938

- first step: $W < 1.4$ mainly non-resonant interaction + delta_33
- second step: $W < 2.3$ mainly N* parameters

Number of data points of hadronic processes

	$d\sigma/d\Omega$	P	β	Sum
$\pi^- p \rightarrow \eta p$	294	–	–	294
$\pi^- p \rightarrow K^0 \Lambda$	544	262	43	849
$\pi^- p \rightarrow K^0 \Sigma^0$	160	70	–	230
$\pi^+ p \rightarrow K^+ \Sigma^+$	552	312	7	871
Sum	1550	644	50	2244

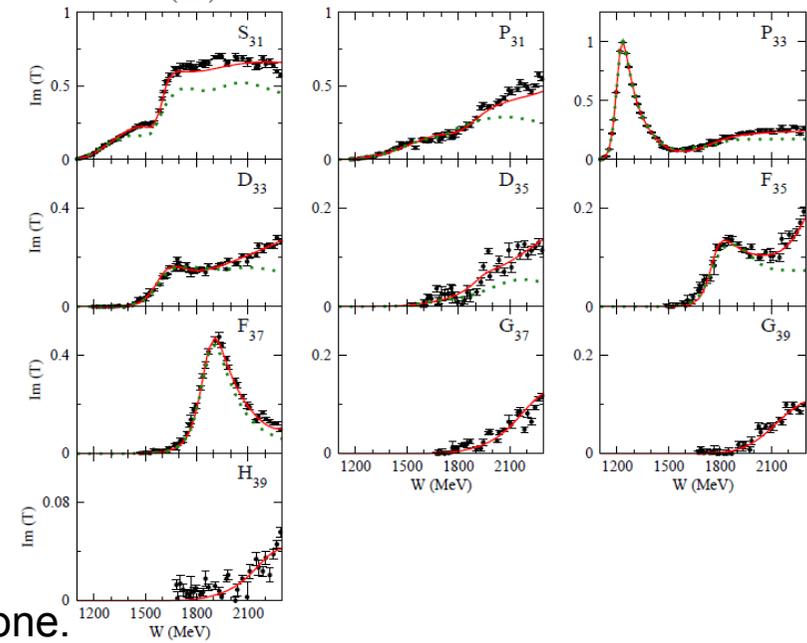
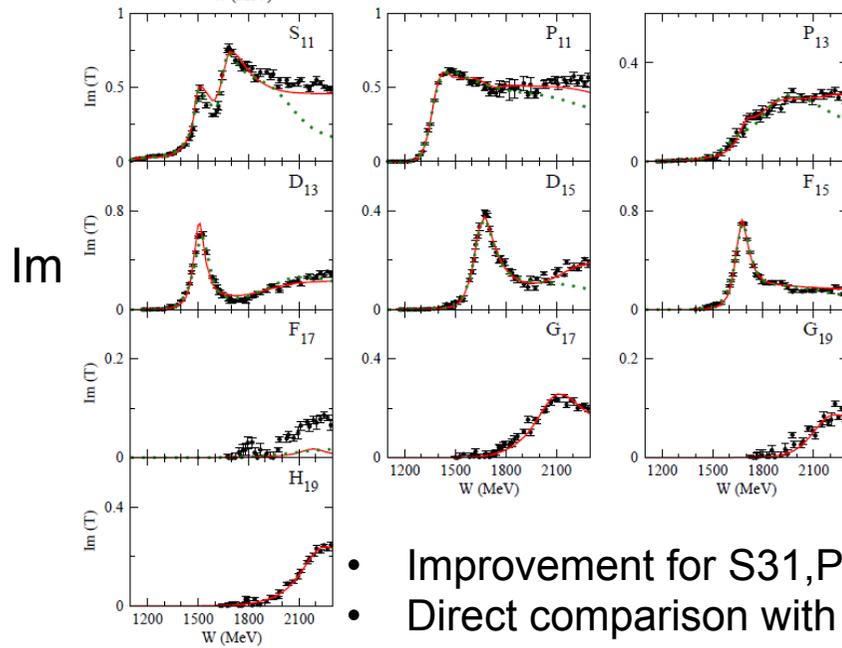
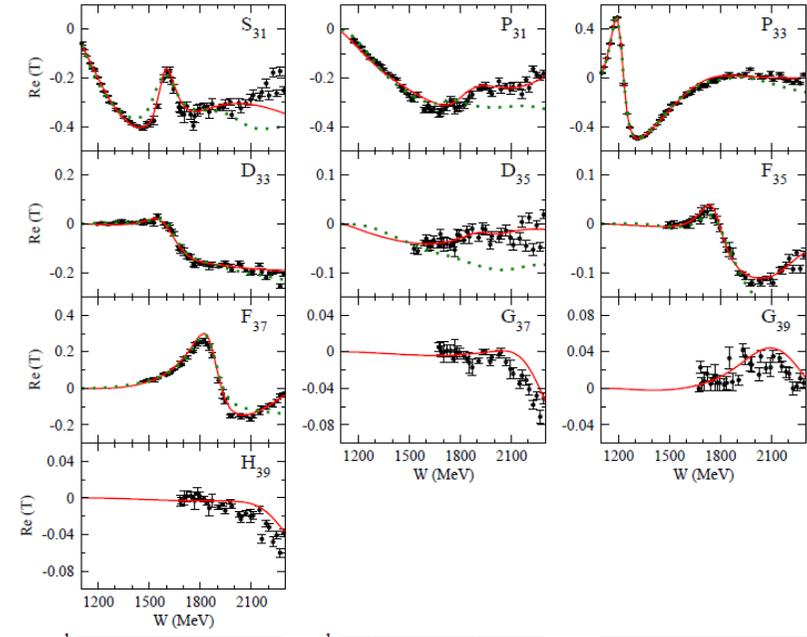
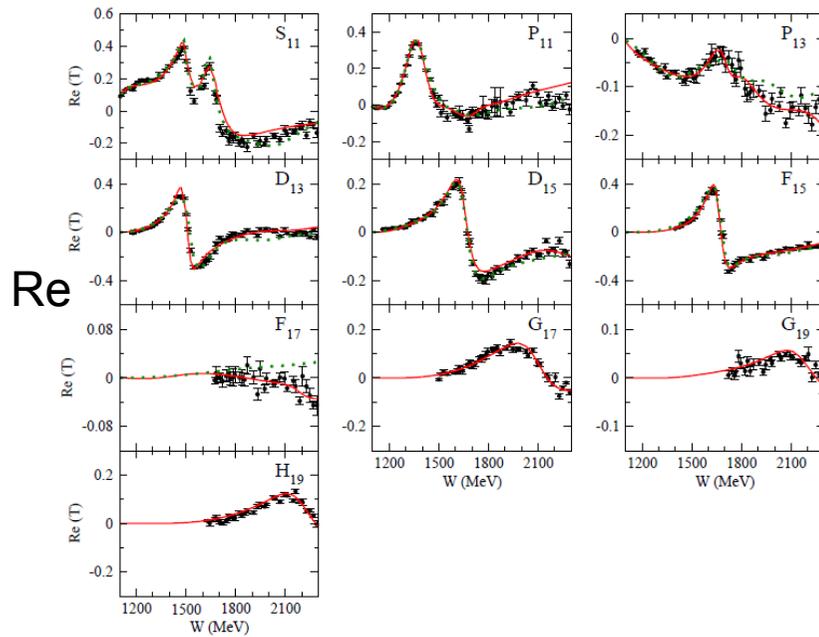
Number of data points of photoproduction processes

	$d\sigma/d\Omega$	Σ	T	P	\hat{E}	G	H	$O_{x'}$	$O_{z'}$	C_x	C_z	Sum
$\gamma p \rightarrow \pi^0 p$	4381	1128	380	589	140	125	49	7	7	–	–	6806
$\gamma p \rightarrow \pi^+ n$	2315	747	678	222	231	86	128	–	–	–	–	4407
$\gamma p \rightarrow \eta p$	3221	235	50	–	–	–	–	–	–	–	–	3506
$\gamma p \rightarrow K^+ \Lambda$	800	86	66	865	–	–	–	66	66	79	79	2107
$\gamma p \rightarrow K^+ \Sigma^0$	758	62	–	169	–	–	–	–	–	40	40	1069
$\gamma p \rightarrow K^0 \Sigma^+$	220	15	–	36	–	–	–	–	–	–	–	271
Sum	11695	2273	1174	1881	371	211	177	73	73	119	119	18166

πN amplitude

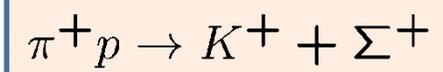
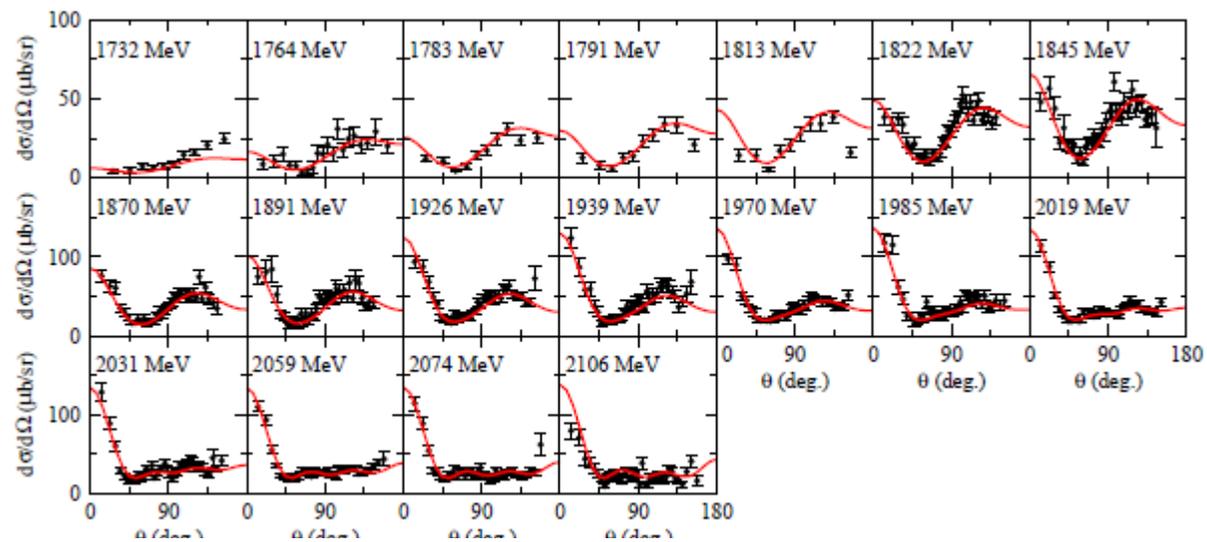
$I=1/2$

$I=3/2$

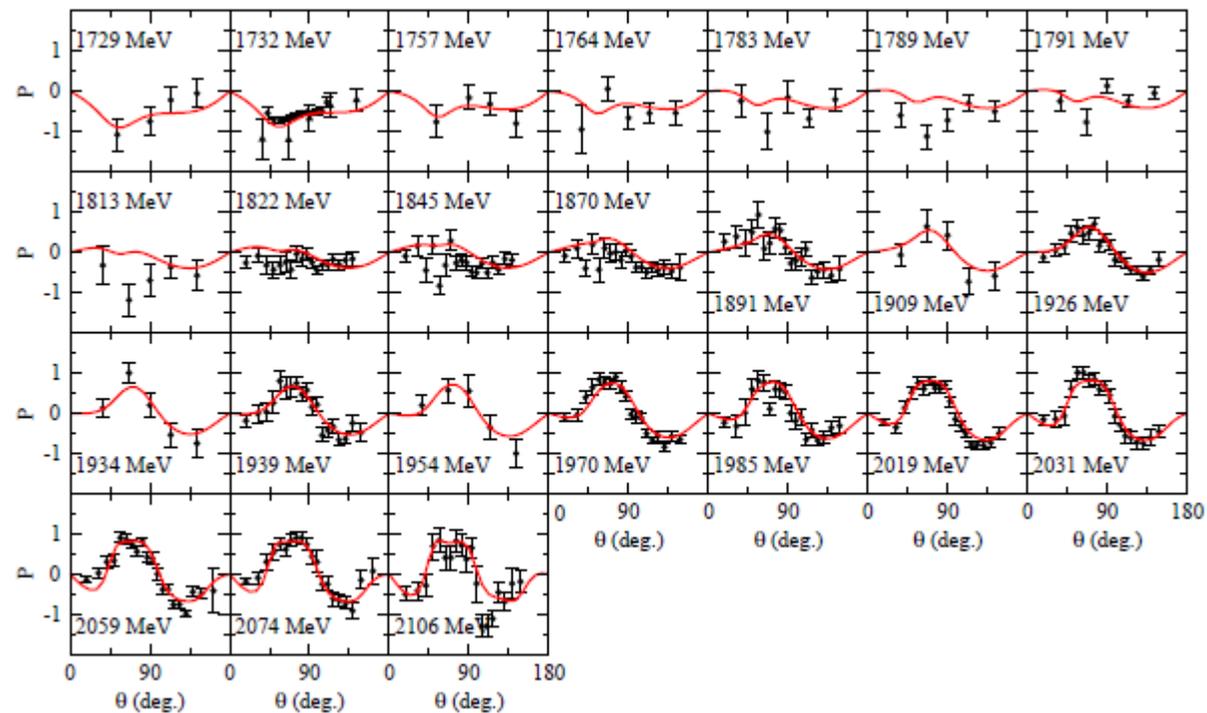


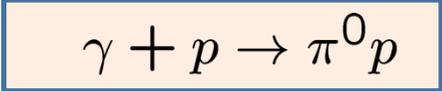
- Improvement for S31, P31, D35
- Direct comparison with obs. was done.

$$\frac{d\sigma}{d\Omega}$$

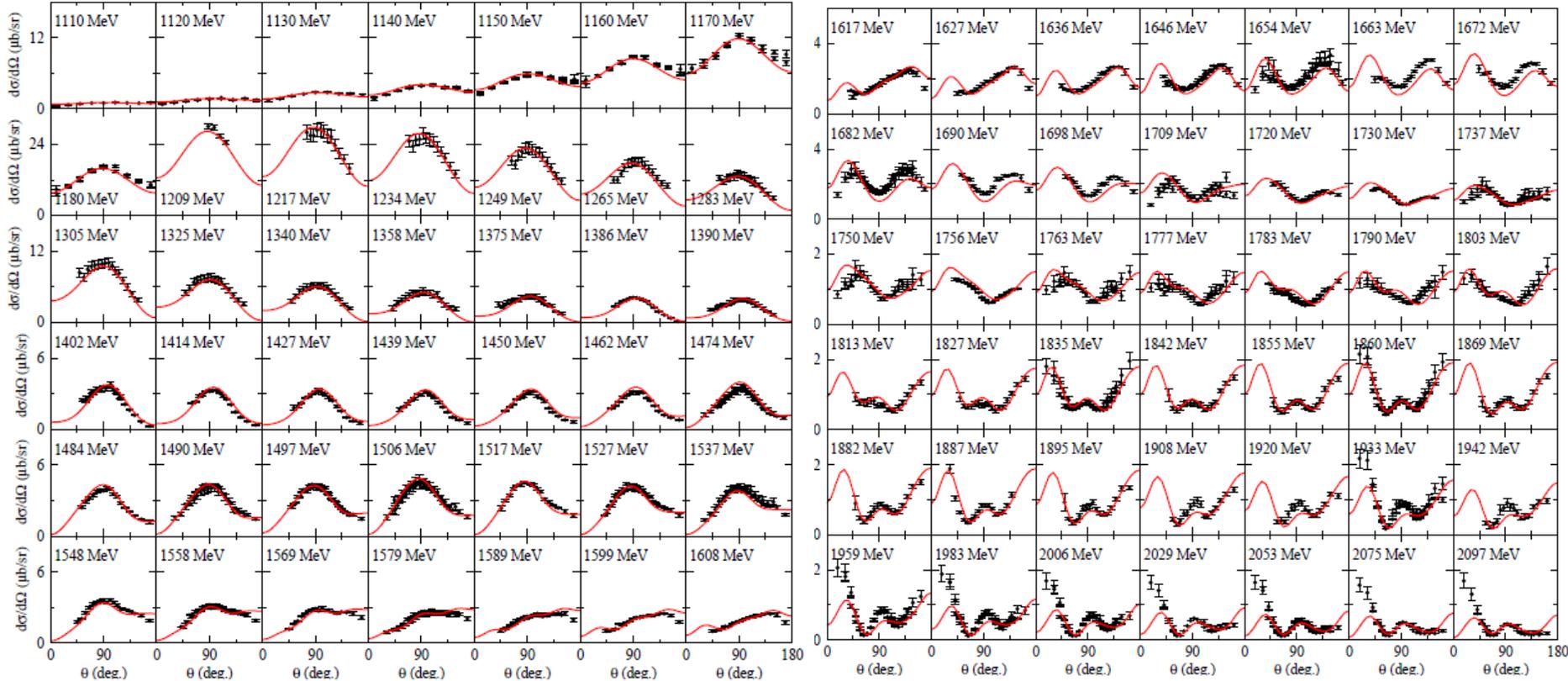


P



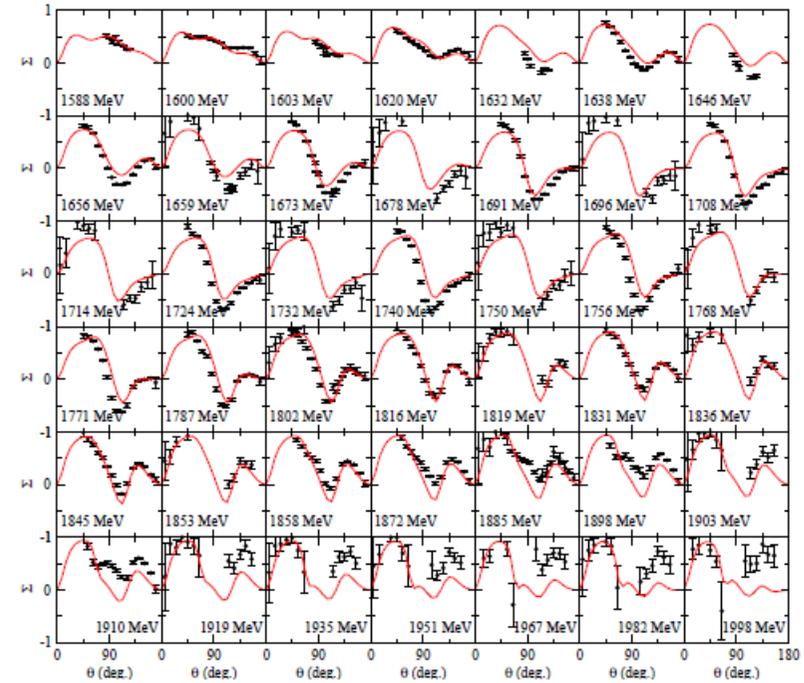
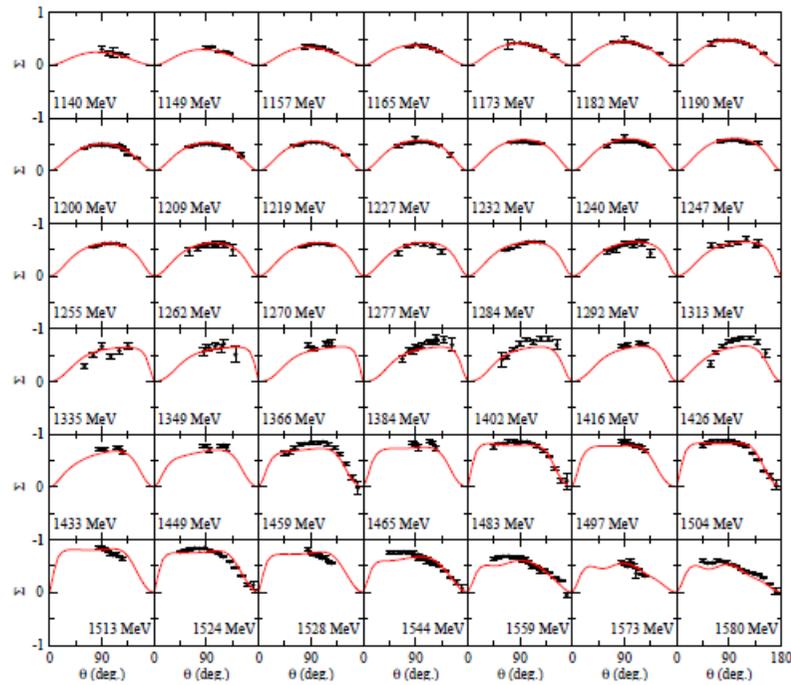


$$\frac{d\sigma}{d\Omega}$$



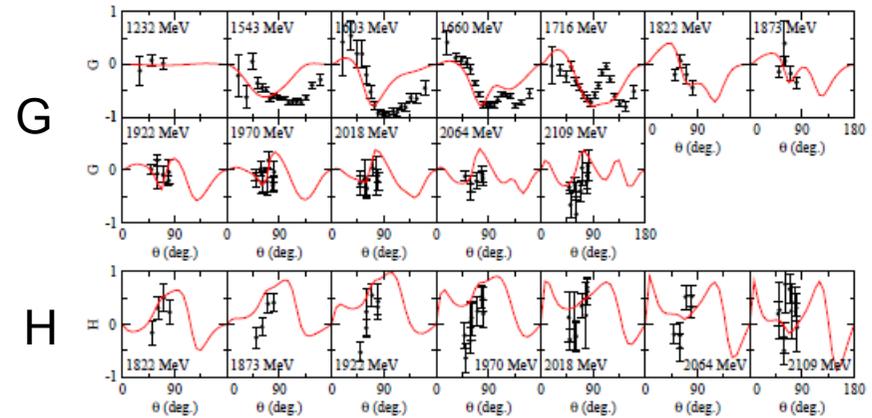
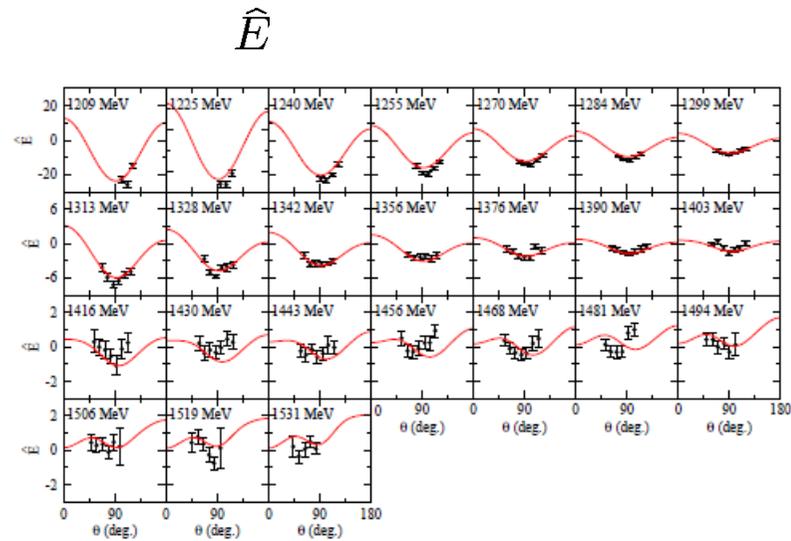
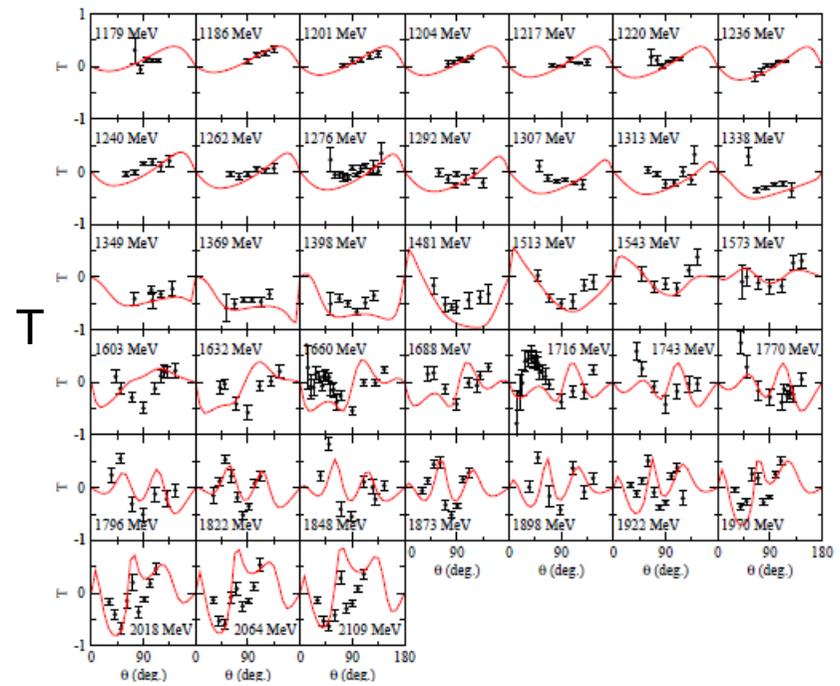
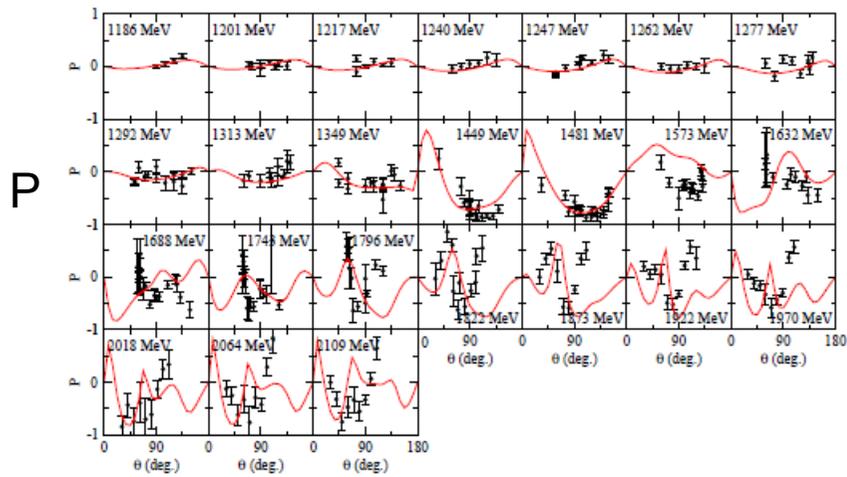
- Extensive data of differential cross section can be fitted very well for $W < 1.9\text{ GeV}$.
- Not able to account forward peak $W > 1.933\text{ GeV}$

$$\Sigma \text{ of } \gamma + p \rightarrow \pi^0 + p$$

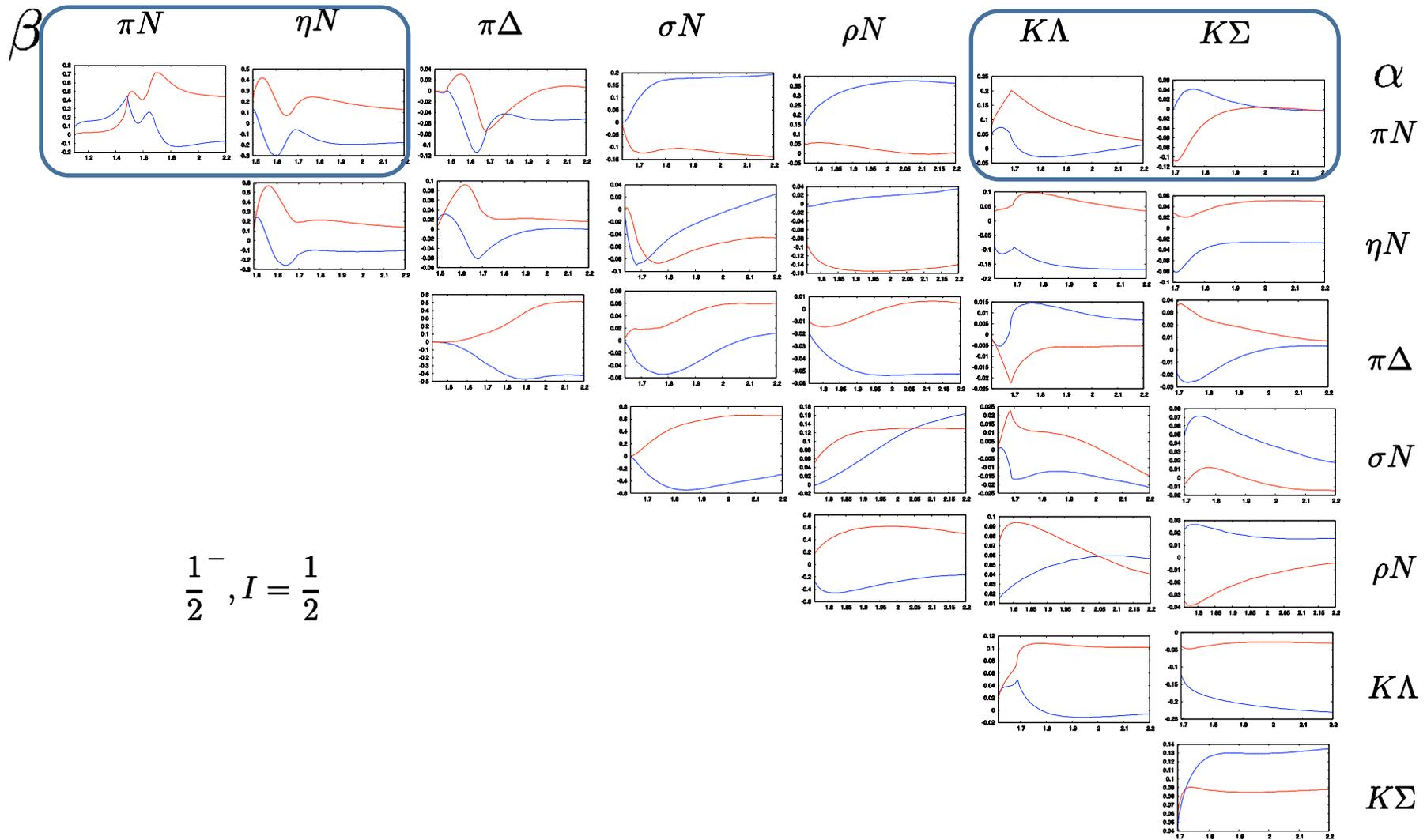


- Extensive data of Sigma can be fitted well for $W < 1.9 \text{ GeV}$.

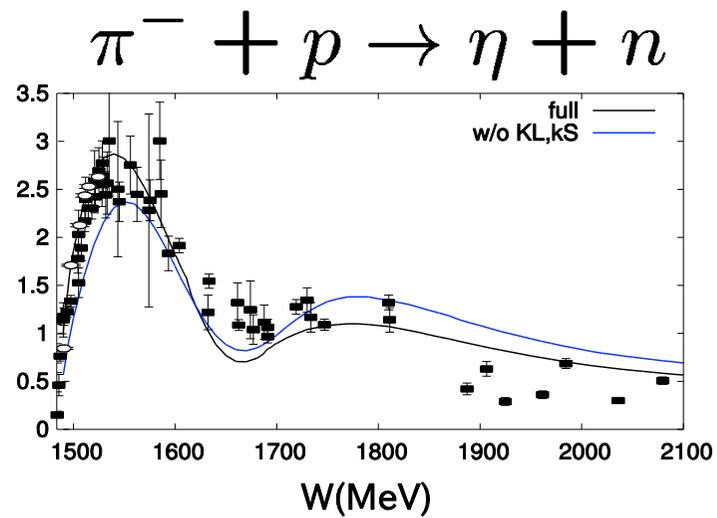
Polarization observables of $\gamma + p \rightarrow \pi^0 + p$



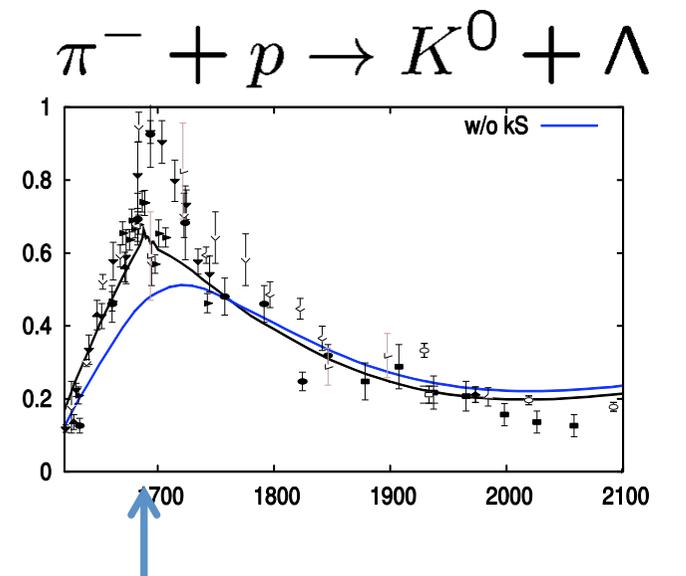
Scattering Amplitude $\mathcal{F}_{\beta,\alpha}(W)$



Effects of coupled channel (KY)



without $K\Lambda, K\Sigma$



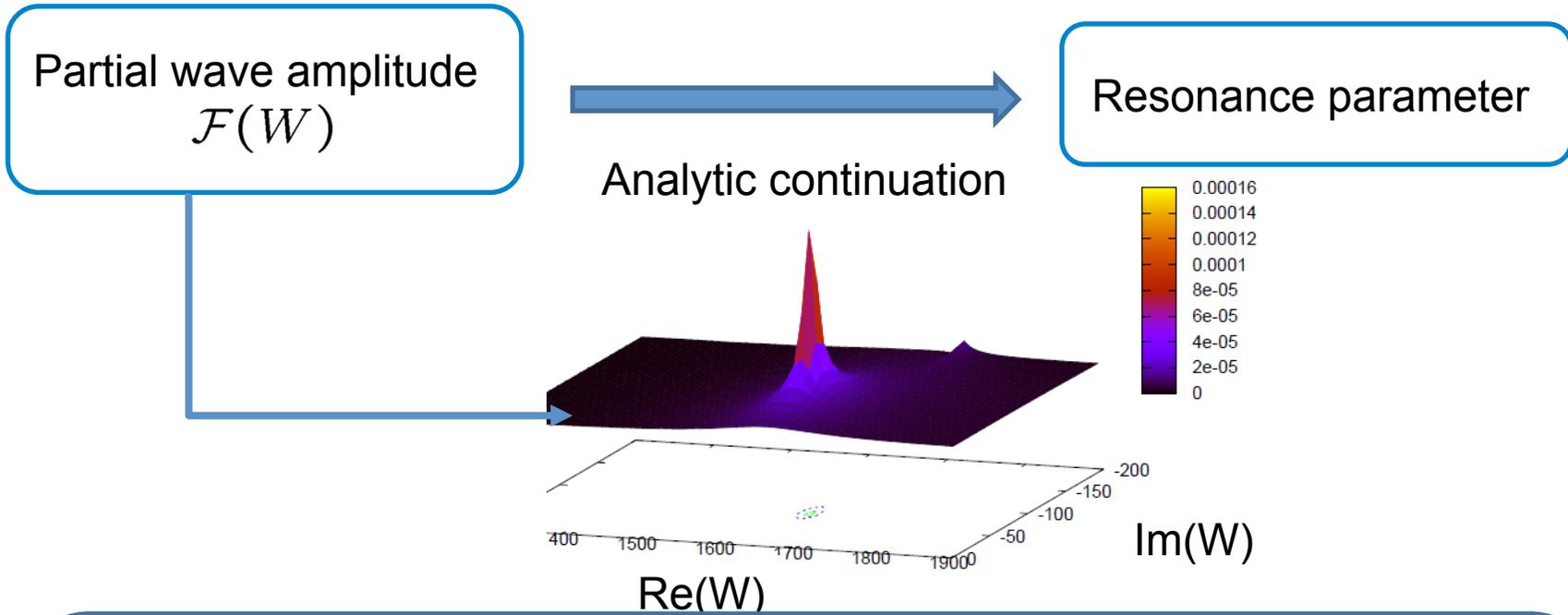
$K\Sigma$

without $K\Sigma$

Extraction of resonance poles and residues of scattering amplitudes

Extraction of resonance parameters

Resonance as a pole of S/T-matrix



$$\langle \beta | \mathcal{F}(W) | \alpha \rangle \sim - \frac{R_{\beta, \alpha}}{W - M_{N^*}}$$

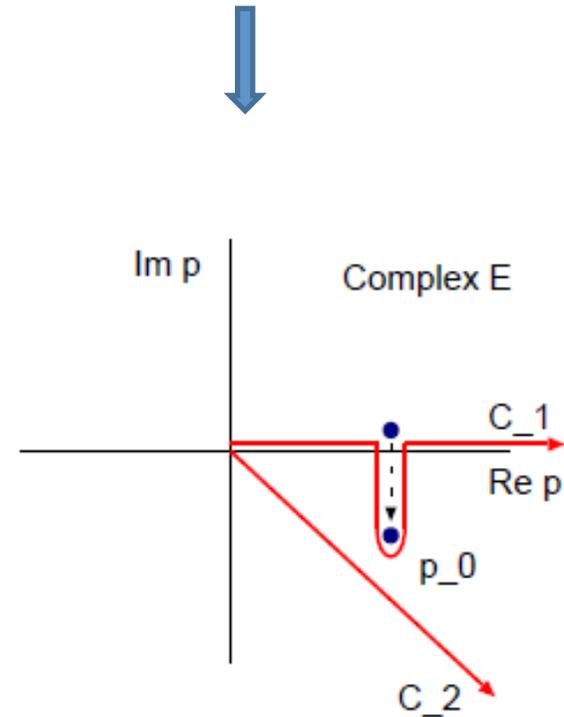
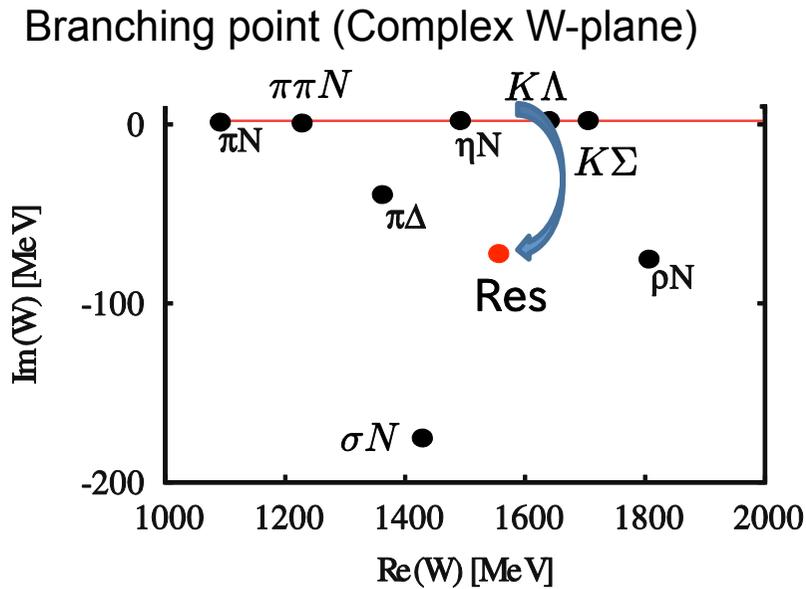
mass and width $M_{N^*} = M - i\Gamma/2$ residue $R_{\beta, \alpha}$

coupling constant
helicity amplitude $R_{\beta, \alpha} = g_{\beta, N^*} g_{\alpha, N^*}$ $-\pi < \arg(g_{\pi N, N^*}) \leq \pi$

Analytic continuation of $T(W)$ in practice

$$\langle p_\alpha | T(W) | p_\beta \rangle = \langle p_\alpha | V | p_\beta \rangle + \sum_\gamma \int dp_\gamma^2 p_\gamma^2 \frac{\langle p_\alpha | V | p_\gamma \rangle \langle p_\gamma | T(W) | p_\beta \rangle}{W - E_M(p_\gamma) - E_B(p_\gamma) + i\epsilon}$$

Cauchy Integral like formula



slide @ N* 2011

Stability of resonance parameters extracted from PWA

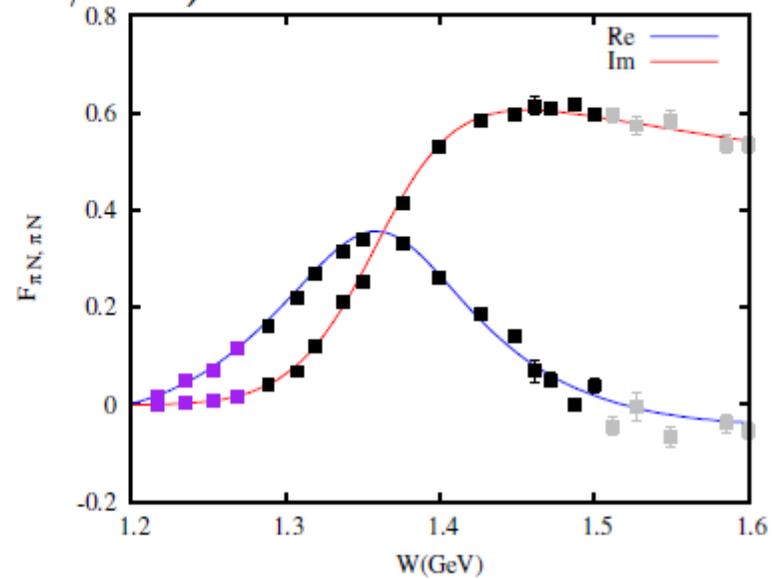
- Input: $T(E_i)$ from $\pi N - \pi N$ amplitude of VPI
- Output: $T(E)$ calculate pole and residue without physics input

Calculate $T(E)$ from known $T(E_i) i = 1, \dots, N$ (continued fraction)

$$T(E) = \frac{T(E_1)}{1+} \frac{a_1(E - E_1)}{1+} \frac{a_2(E - E_2)}{1+} \dots \quad a_1 = \frac{T(E_1)/T(E_2) - 1}{E_2 - E_1}, \dots$$

(Schlessinger)

πN input amplitude (GW/VPI)



Output:

Input	$M_P - i\Gamma_P/2$ (MeV)	Residue(MeV)
E-dep [1210-1500] 59pt	1362 -89i	4.9 -44i
E-dep [1300-1500] 41pt	1362 -90i	4.6 -45i
E-ind [1217-1500] 17pt	1366 -128i	10 -68i
E-ind [1289-1500] 13pt	1347 -93i	-11 -52i

resonance poles of ANL-Osaka analysis

	I=1/2		I=3/2	
	AO	JLMS	AO	JLMS
1/2 -	2	2	1+1*	1
3/2 -	1+1*	1	2	1
5/2 -	1	1	1	0
1/2+	2	2	1	0
3/2+	2	0	2	1
5/2+	1	1	1	2
7/2+	0	0	1	1

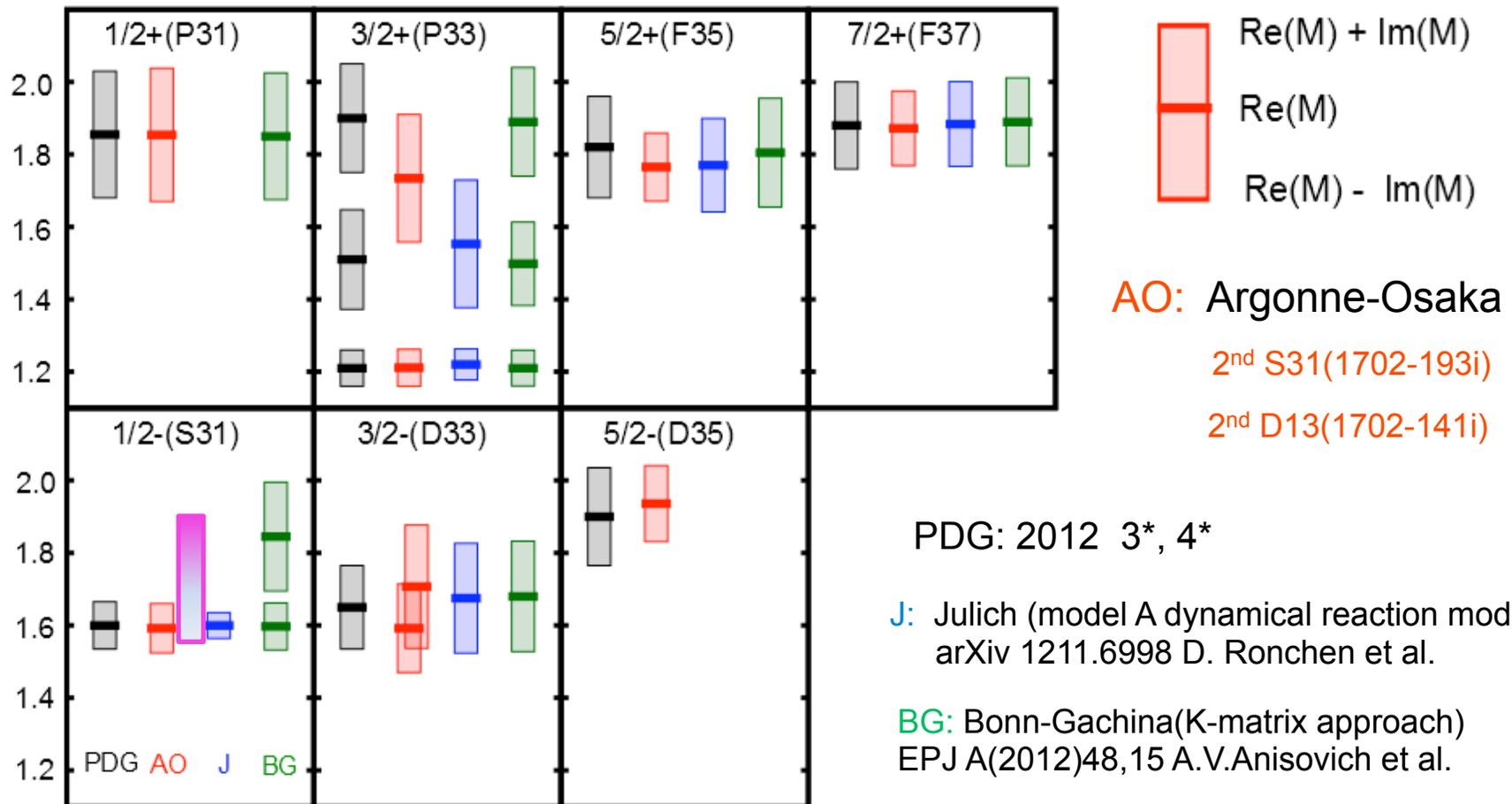
$\text{Re}(M) < 2\text{GeV}$, $\text{Im}(M) < 0.2\text{GeV}$, at closest sheet

Spectrum of nucleon resonances

$\text{Re}(M) < 2\text{GeV}$

Width $< 0.4\text{GeV}$, (AO only poles on the nearest sheet)

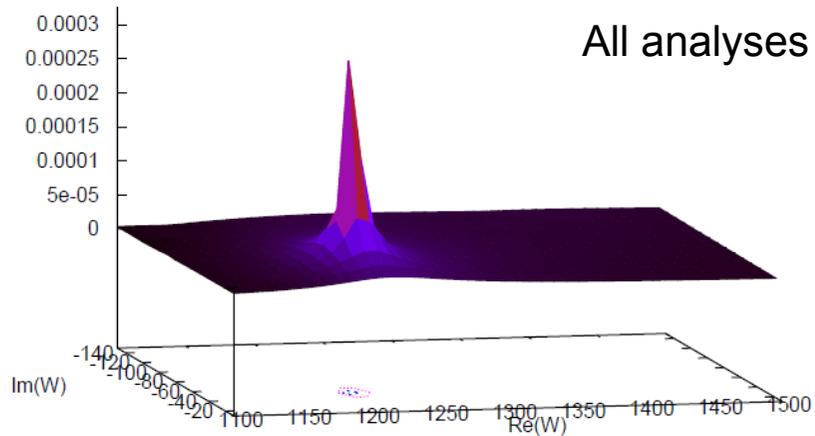
$\Delta \quad I=3/2$



Delta P33 (1232) and second P33

Delta(1232)

	ANL-Osaka	JLMS	Julich	Bonn-Gachina	GWU/VPI
Mass(MeV)	1211-51i	1211-50i	1220-53i	1211-50i	1211-50i
piN resid.(MeV)	37-39i	36-38i	36-25i	36-37i	35-38i
$A_{1/2}(10^{-3} \text{ GeV}^{-1/2})$	-129+34i	-117+10i	---	-124+4i	---
$A_{3/2}$	-257+12i	-249+12i	---	-251+39i	---

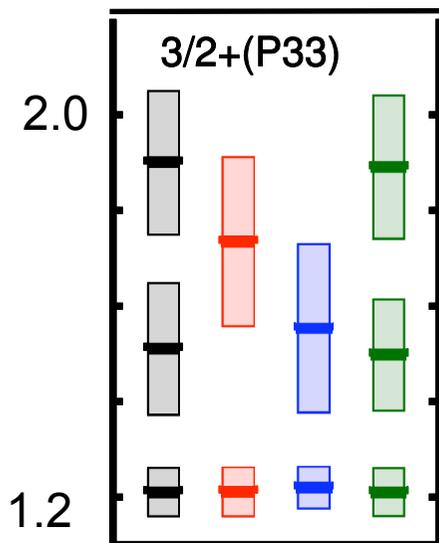


All analyses agree reasonably well with each other

piN amplitude $|F|$ on complex W plane

GWU/VPI
 Phys.Rev.C74(2006)045205, R. A. Arndt
 et al.

Second Delta33

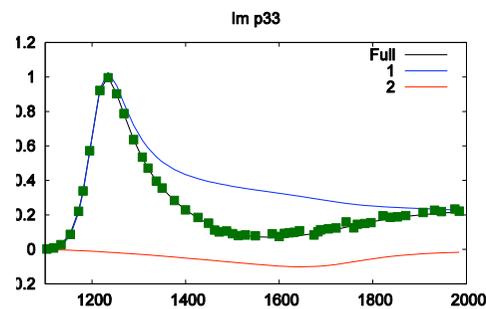
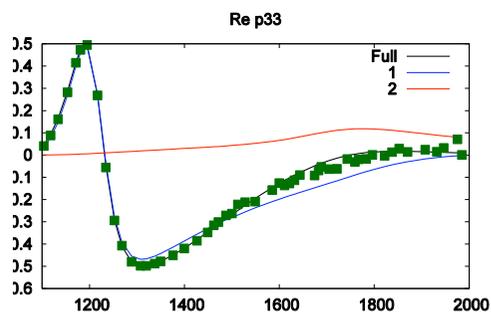


	ANL-Osaka	JLMS	JUlrich	Bonn-Gachina	GWVPI
Mass(MeV)	1734 -176i		1553-352i	1498 - 115i	1457-200i
piN resid.(MeV)	-4 -7i		-19-7.5i	-11-2.7i	-36+24i
A_1/2(10^-3 Gev^{-1/2})	23 +67i			-34+41i	
A_3/2	18 + 135i			-39+11i	

Weak coupling with piN, sizable coupling with gamma N

Second Delta33

Weak coupling with piN, sizable coupling with gamma N



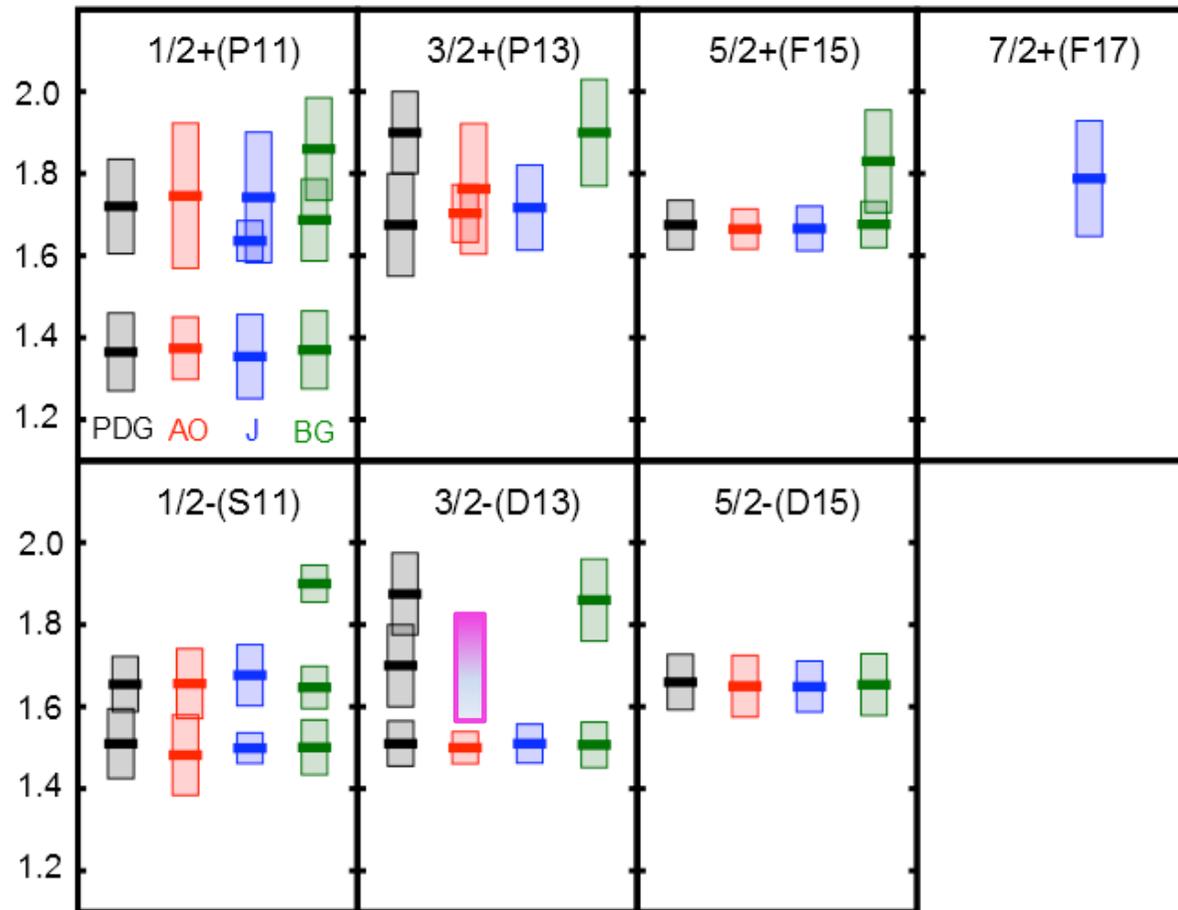
Re

Im

First P33

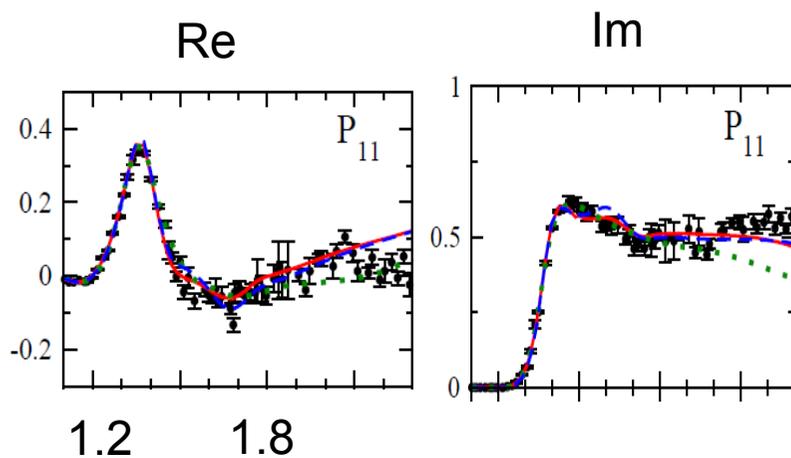
Second P33

$$N^* \quad I=1/2$$

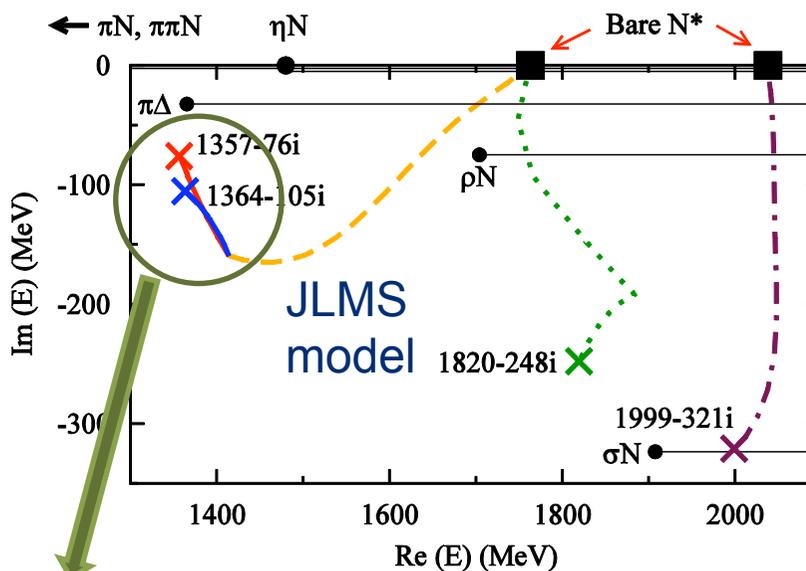


- AO agree with PDG for $W < 2\text{GeV}$ (3^* , 4^*) except no 3rd P33, D13, additional 2nd D33, 2nd S31
- Pole positions of AO, Julich, Bonn-Gachina agree well only for the first N^*

P11 resonance



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



'Roper'

	ANL-Osaka	JLMS	Julich	Bonn-Gachina	GWU/VPI
Mass(MeV)	1374-76i	1357-76i	1354-205i	1370-95i	1359-81i
piN resid.(MeV)	13 - 34i	37-111i	-14-56i	10-47i	-5-38i
A _{1/2} (10 ⁻³ GeV ^{-1/2})	-40 +10i	20 - 20i	---	-36+27i	---

'N*(1710)'

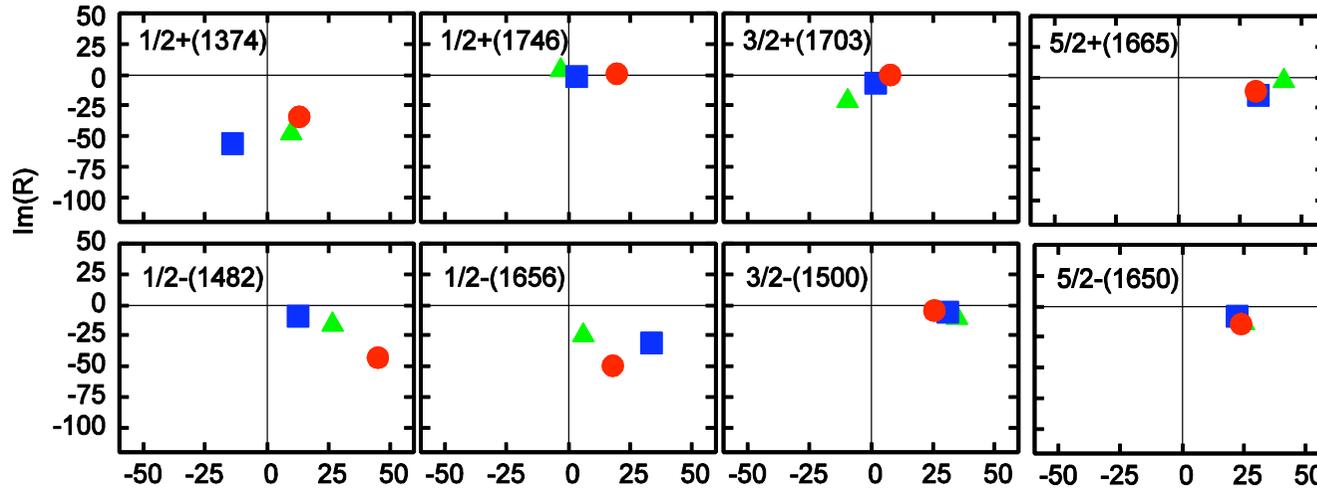
	ANL-Osaka	Julich	Bonn-Gachina	GWU/VPI
Mass(MeV)	1746-177i	1630-49i	1687-100i	
piN resid.(MeV)	20+i	3.5-2i	-3+5i	
A _{1/2} (10 ⁻³ GeV ^{-1/2})	49 -10i		54-9.6i	

$$R_{\pi N, \pi N}$$

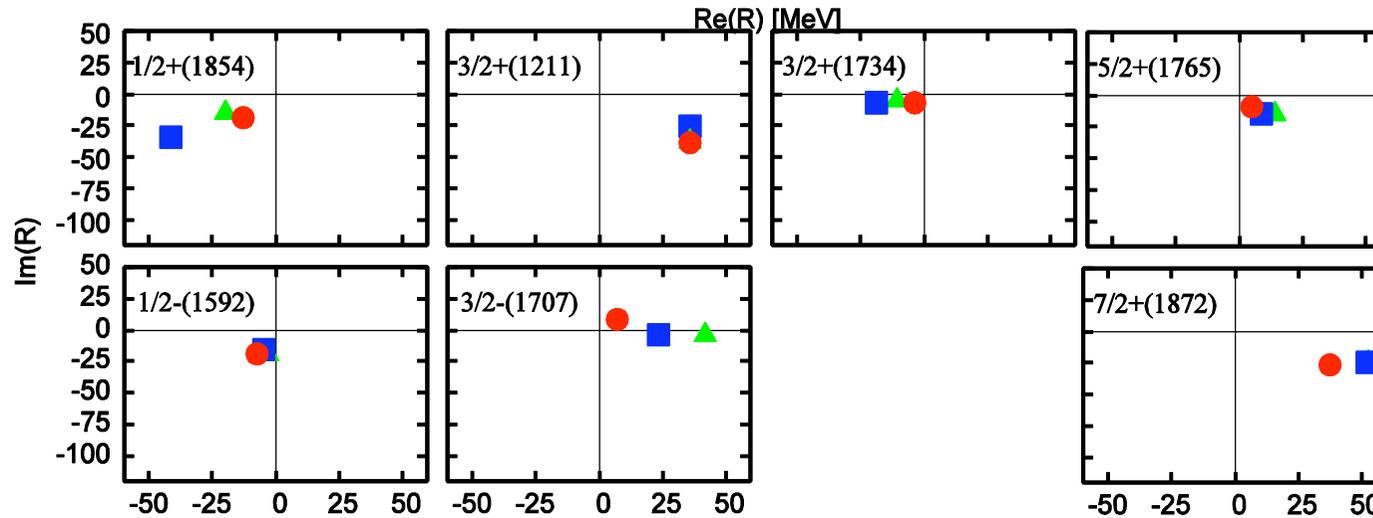
Residue of piN amplitude at resonance pole

AO ● J ■ BG ▲

$I=1/2$



$I=3/2$



- Three analyses for piN residue agree well for Delta(1232), for some states agree qualitatively. Similar situation for the photon helicity amplitudes.

Next step

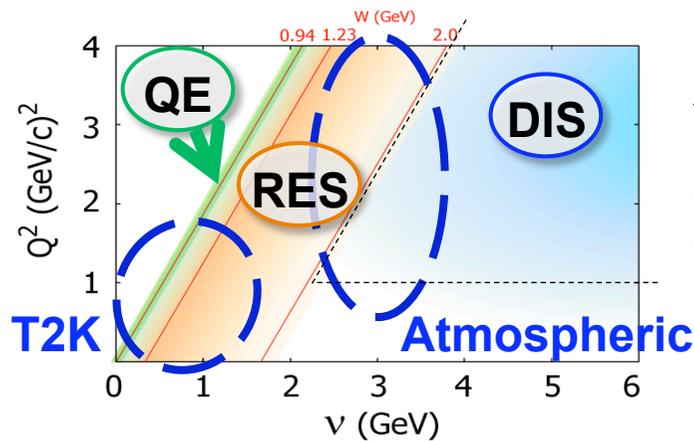
- Continue combined fit including **two pion** and **omega** production data to improve fits around $W \sim 2\text{GeV}$. combine information from new hyperon photo production data.

Proposal for J-PARC 50 GeV Proton Synchrotron

3-Body Hadronic Reactions for New Aspects of Baryon Spectroscopy

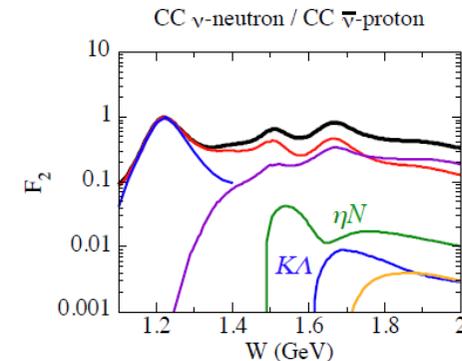
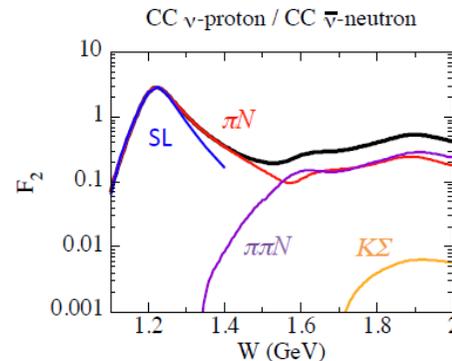
K.H. Hicks (Ohio University), H. Sako (JAEA), spokespersons

- Extract transition electromagnetic forms factor for major resonances
- Analysis on the nature of resonance poles
- a model for neutrino induced reaction.



Collaboration at J-PARC Branch of KEK theory center

Y. Hayato(ICRR, U. of Tokyo), M. Hirai(Tokyo Science U.), H. Kamano(RCNP, Osaka U.), S. Kumano(KEK), S. Nakamura(YITP, Kyoto U.), K. Saito(Tokyo Science U.), T. Sato(Osaka U.), M. Sakuda(Okayama U.)



backup

Near future improvements on the description of meson production reactions N^* extraction

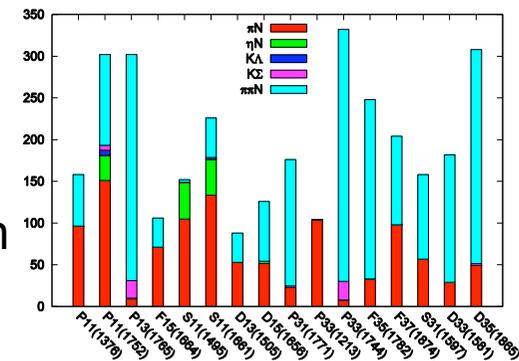
Resonances, photo coupling of higher energy resonances

Complete measurement of pseudo scalar meson production reaction

A. Sandorfi, S. Hoblit, H. Hamano, T.-S.H. Lee JPG 38 (2011) 053001.

Understanding of $\pi p i N$ dynamics

- large part of the meson production cross section
- large partial width of N^*
- poor data for $\pi i N \rightarrow \pi p i N$ reaction compared with photo-production data



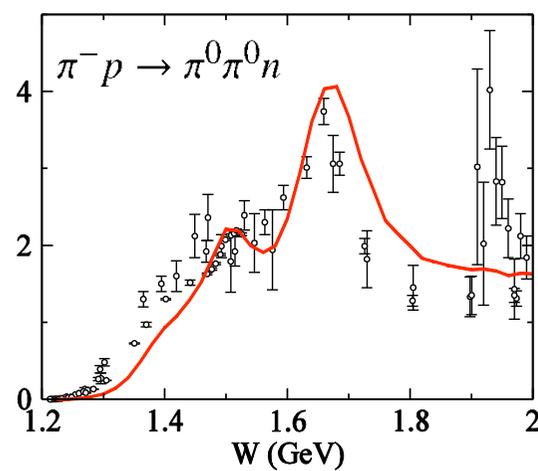
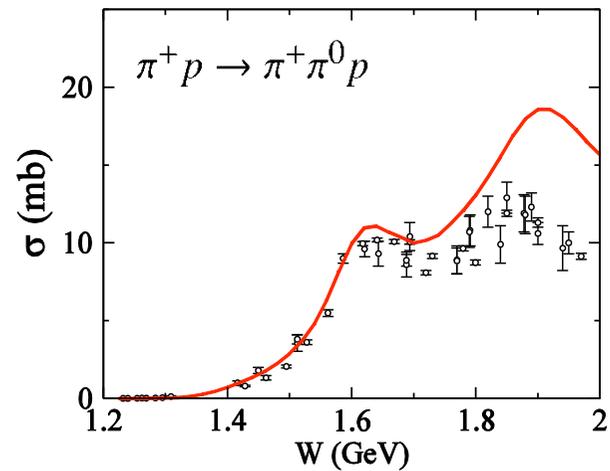
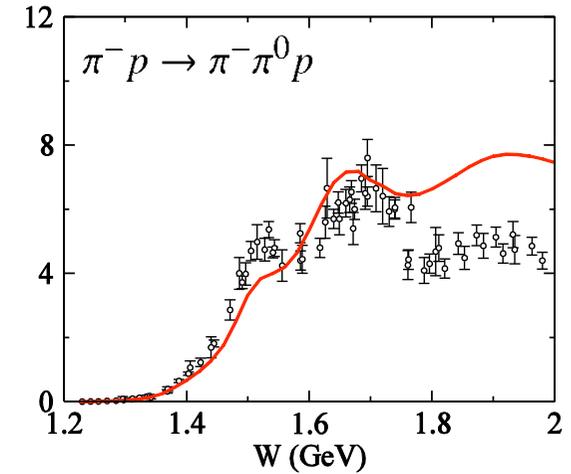
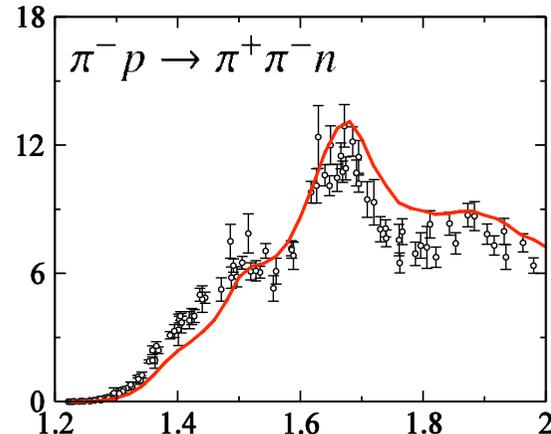
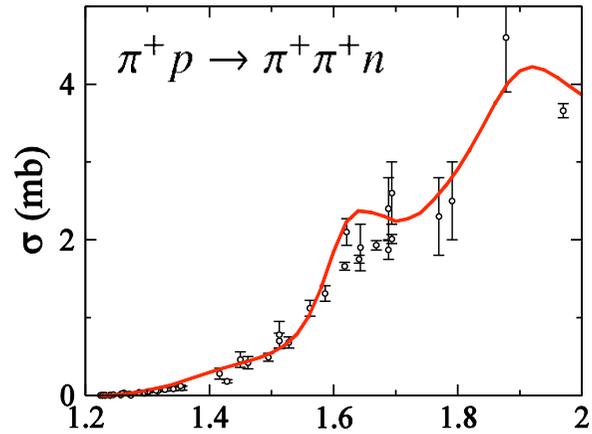
Proposal for JPARC

Proposal for J-PARC 50 GeV Proton Synchrotron

3-Body Hadronic Reactions for New Aspects of Baryon Spectroscopy

K.H. Hicks (Ohio University), H. Sako (JAEA), spokespersons

Predictions for $\pi\pi \rightarrow \pi\pi N$ total cross sections



**VERY
PRELIMINARY**

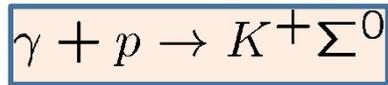
Estimation of resonance amplitude

$$T_{\alpha,\beta}(W) = t_{\alpha,\beta}^{nr}(W) + \sum_{i,j} \bar{\Gamma}_{\alpha,i}(W) \left[\frac{1}{W - m_0 - \Sigma(W)} \right]_{ij} \bar{\Gamma}_{\beta,j}(W)$$

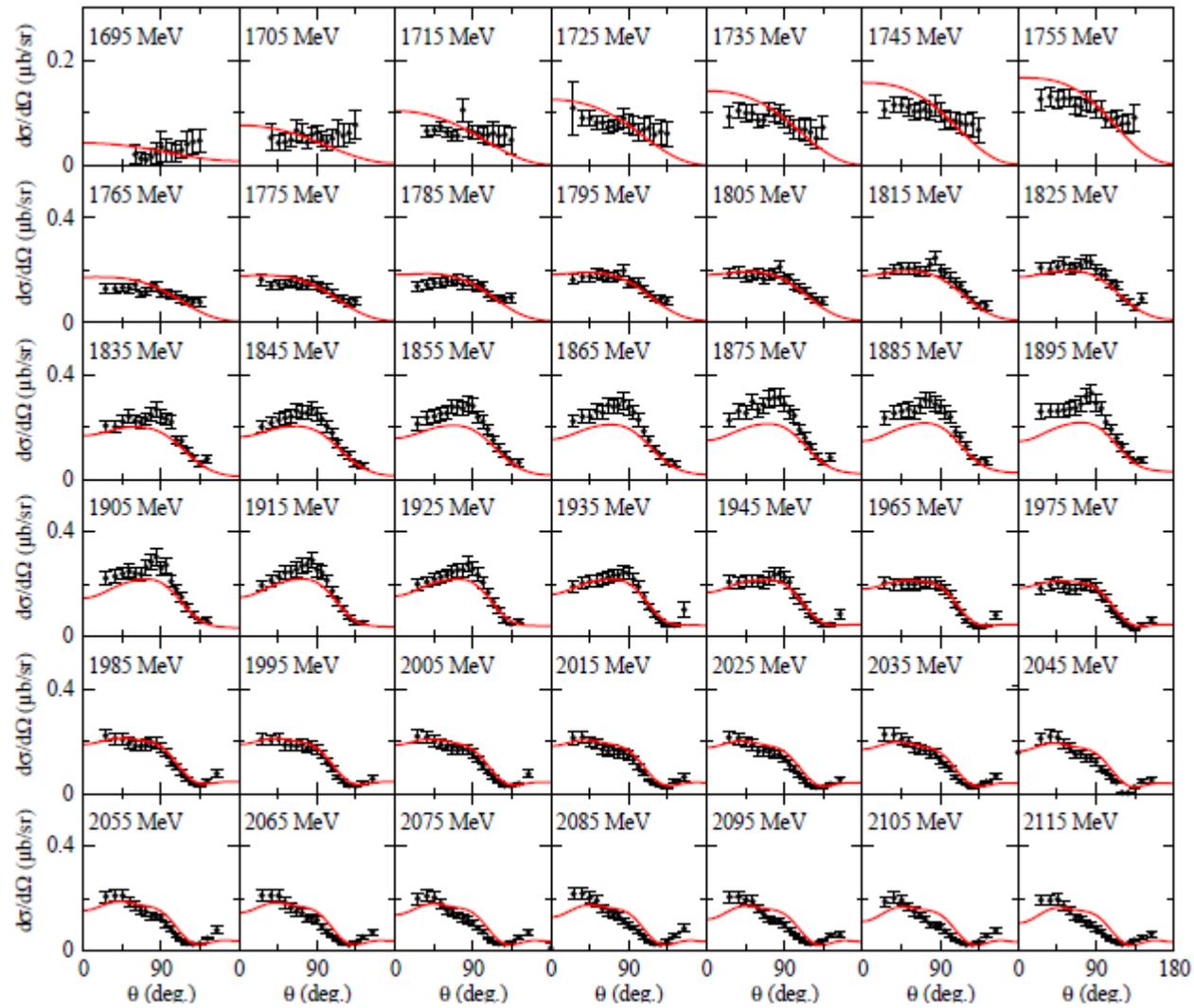
α, β Meson-Baryon channel i, j Resonances

$$\frac{c_i c_j}{W - M_{pole} + i\Gamma_{pole}/2}$$

$$T_{res} = \frac{(\sum_i \bar{\Gamma}_{\alpha,i}(W) c_i)(\sum_j \bar{\Gamma}_{\beta,j}(W) c_j)}{W - M_{pole} + i\Gamma_{pole}/2}$$

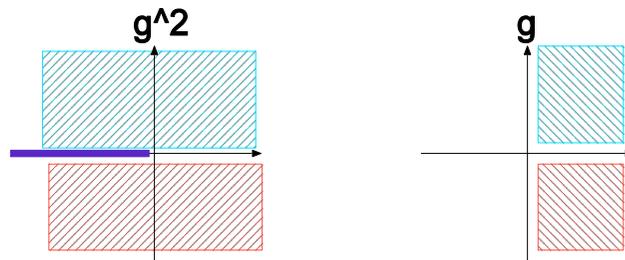


$$\frac{d\sigma}{d\Omega}$$

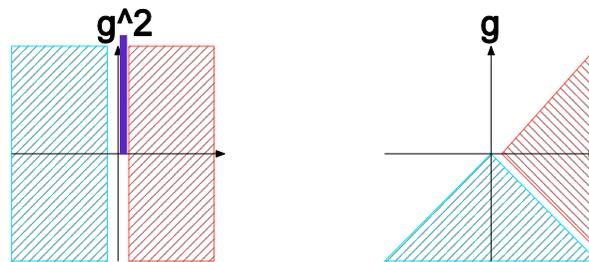


Choice of phase (Residue \rightarrow coupling constant)

$$R_{\pi N, \pi N} = g_{\pi N}^2 \quad R_{\pi N, \gamma N} = g_{\pi N} g_{\gamma N}$$



ANL-OSAKA



BG

Strategy of fitting

$$\chi^2 = \sum_O \sum_{i,j} \frac{[O^{\text{model}}(W_i, \theta_j) - O^{\text{exp.}}(W_i, \theta_j)]^2}{[\delta O^{\text{exp.}}(W_i, \theta_j)]^2}$$

Non-resonant interaction $W < 1.4$, piN-piN



piN-piN N^* up to 2.3 GeV



Global fit of piN and gammaN reactions



“Complete Experiment” of pseudoscalar meson photoproduction reactions

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

unpolarized diff. crs. sec.

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

single spin

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

beam-target

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

beam-recoil

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

target-recoil

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

8 /16 observables needed!

Chiang, Tabakin PRC55 2054 (1997)

- ✓ Measurement of $\gamma N \rightarrow KY$ pol. obs. is very active.
- ✓ **OVER-complete** experiments planned by **CLAS** for $\gamma p \rightarrow K^+ \Lambda$, $\gamma n \rightarrow KY$.



Provides critical information on **$N^* \rightarrow KY$** decays !!
Much room for new N^* state searches