Nucleon resonances from dynamical coupled channel approach of meson production reactions

T. Sato Osaka U

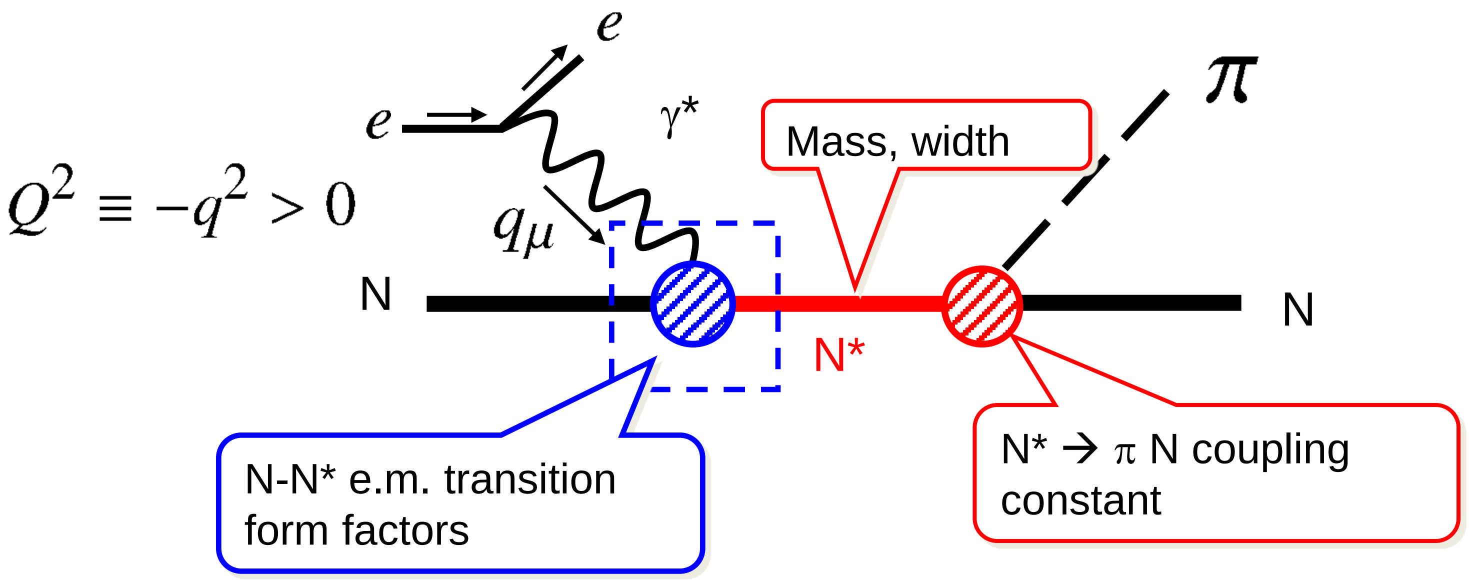
Report on our extended analysis of meson production reactions (ANL-Osaka)

H. Kamano, S. Nakamura, T. –S. H. Lee, T. Sato arXiv:1305.4351

Contents

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

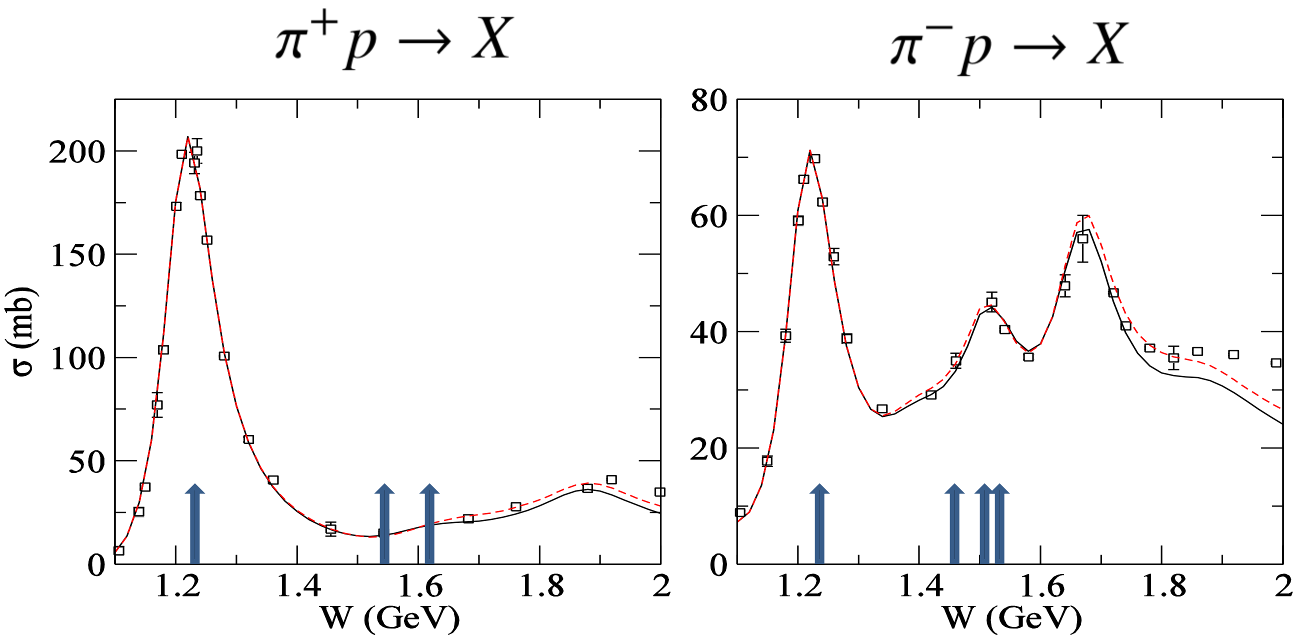
properties of nucleon resonances from meson production reactions



Extraction of mass, width, coupling constants, electromagnetic transition form factors from analysis of meson production reactions are important task to learn structures of baryons

Feature of N*,Δ resonances

- excite states of nucleons are unstable particles and appear as resonances
- strong coupling of excited states with meson-baryon continuum
  large width (~> 100MeV) and overlapping resonances



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 (~> 100MeV) and overlapping resonances

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

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

➢ Our approach: Dynamical coupled channel approach
  ANL-Osaka, Julich(M. Doring 27AM), Dubna-Taipei-Mainz,…

➢ Complementary approaches: ..
  Bonn-Gatchina(A. Sarantev 28AM),
  George Washington U.(I. Strakovsky 28AM),
  Jlab-Yerevan(V. Mokeev 28AM)
  MAID

Collaborators

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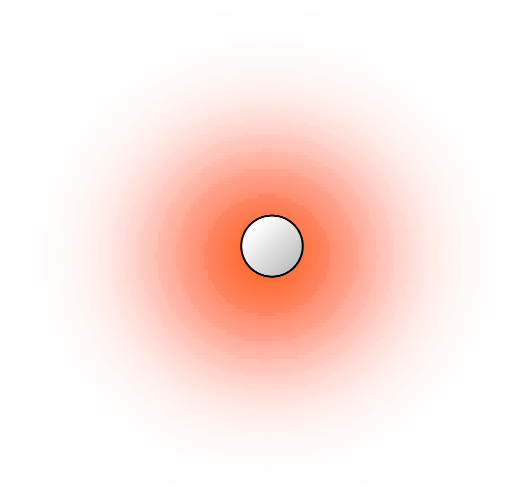
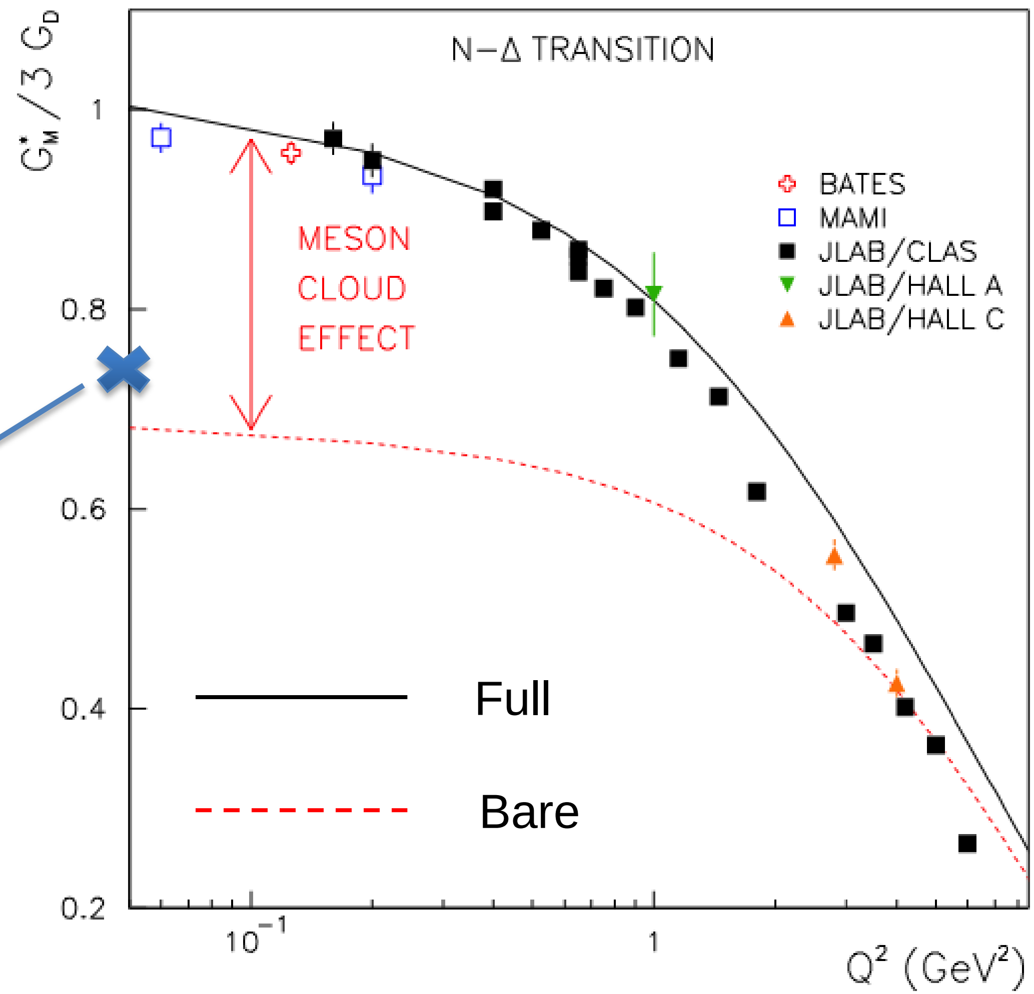
dynamical coupled-channels (DCC) model

$G_M(Q^2)$ for γ N → Δ (1232) transition

- meson-baryon reaction dynamics is part of the resonance properties





Note:
Most of the available static hadron models give $G_M(Q^2)$ close to “Bare” form factor.

Dynamical Coupled Channel Approach

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

start from Hamiltonian of meson-baryon system

'excited nucleon' continuum

$$|N^* > \qquad |\pi N >, |\eta N >, |K\Lambda >, |K\Sigma >, |\pi\pi N >$$

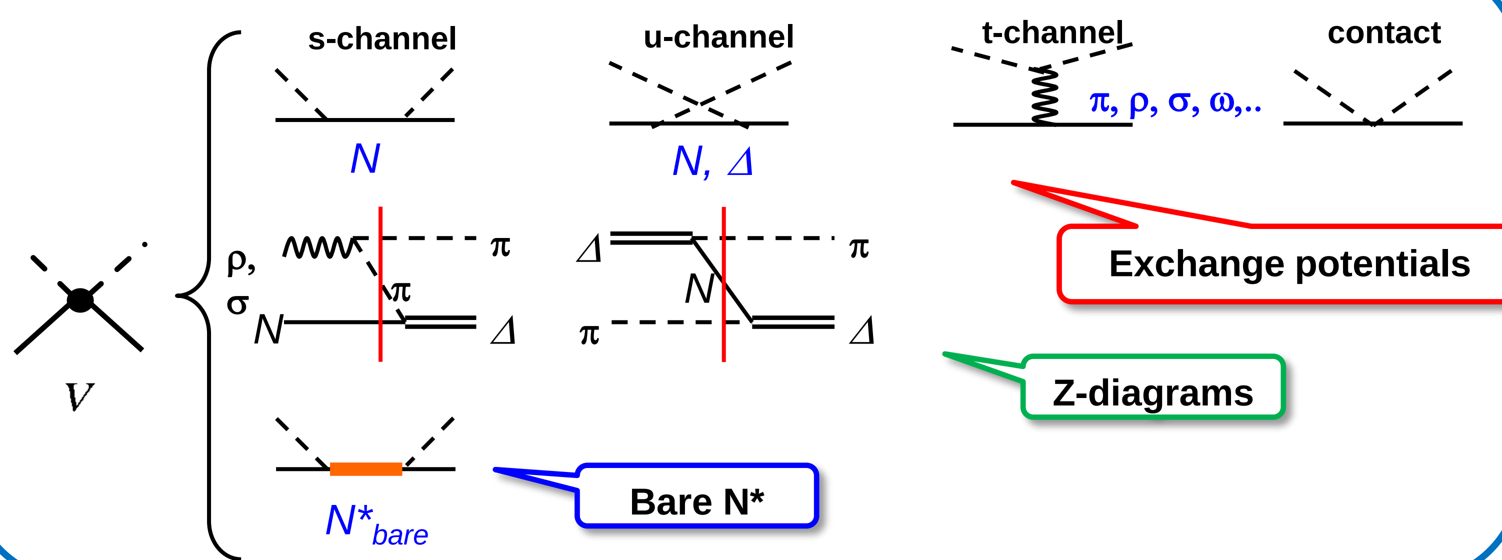
interaction $\Gamma_{N^* \leftrightarrow MB}$ $\quad V_{MB,M'B'}$

→ Solve scattering equation that satisfies three-body unitarity

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 [I,J,P])

$$T^{IJP}_{\beta,\alpha}(k',k,W) = V^{IJP}_{\beta,\alpha}(k',k) + \sum_{\gamma}\int dq q^2 V^{IJP}_{\beta,\gamma}(k',q) G^0_{\gamma}(q,W) T^{IJP}_{\gamma,\alpha}(q,k,W)$$

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



Analysis of meson production reactions

New ANL-Osaka Dynamical Coupled-Channels analysis

	(JLMS) 2006-2009	(ANL-Osaka) 2010-2013
channels	6 channels (γN,πN,ηN,$\pi\Delta$,ρN,σN)	8 channels (γN,πN,ηN,$\pi\Delta$,ρN,σN,KΛ,KΣ)
reactions		
✓ πp → πN	W < 2 GeV	< 2.3 GeV
✓ γp → πN	< 1.6 GeV	< 2 .1GeV
✓ π-p → ηn	< 2 GeV	< 2.1 GeV
✓ γp → ηp	—	< 2.1 GeV
✓ πp → KΛ, KΣ	—	< 2.1 GeV
✓ γp → KΛ, KΣ	—	< 2.1 GeV

- ***Extended to include KY production reaction, higher W***
- ***Fully combined* analysis of γN , πN → πN , ηN , KΛ, KΣ reactions**
  SU(3) Meson (P,V octet), Baryon(octet,decuplet)
- **omega N, pipi 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

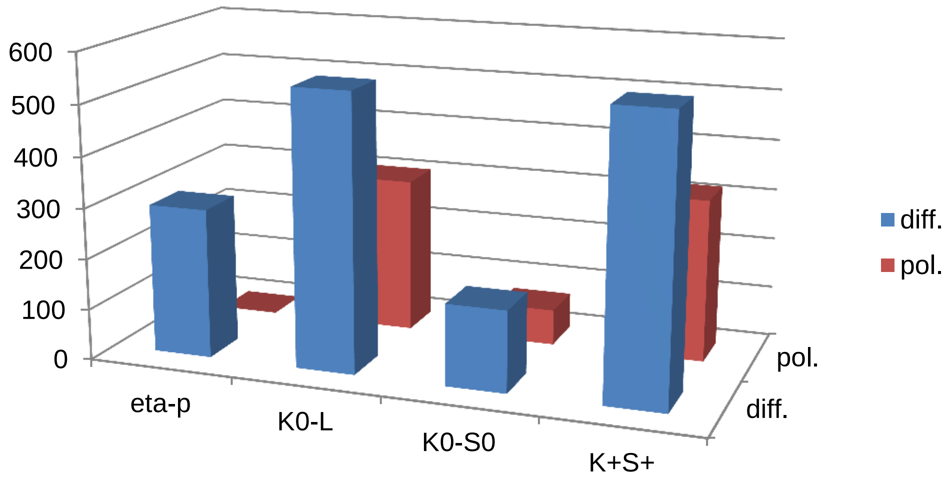
$\pi N \rightarrow \pi N$ 20 partial waves Single energy solution of SAID

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

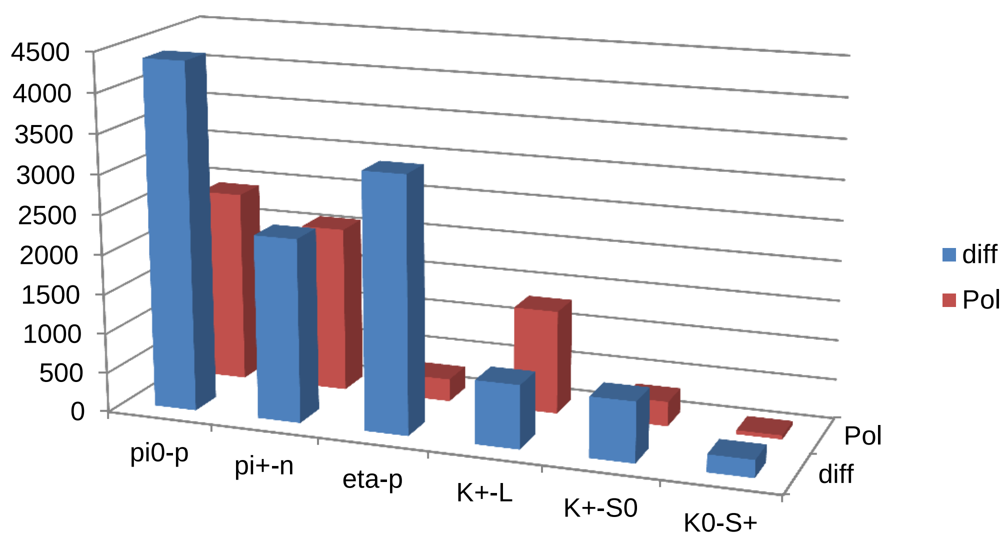
	$d\sigma/d\Omega$	P	β	Sum
$\pi^- p \to \eta p$	294	–	–	294
$\pi^- p \to K^0\Lambda$	544	262	43	849
$\pi^- p \to K^0\Sigma^0$	160	70	–	230
$\pi^+ p \to K^+\Sigma^+$	552	312	7	871
Sum	1550	644	50	2244



- pi-eta differential cross section (J.Durand et al.,PRC78 025204(2008))
- Third step: start global fit

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
$\gamma p \to \pi^0 p$	4381	1128	380	589	140	125	49	7	7	–	–	6806
$\gamma p \to \pi^+ n$	2315	747	678	222	231	86	128	–	–	–	–	4407
$\gamma p \to \eta p$	3221	235	50	–	–	–	–	–	–	–	–	3506
$\gamma p \to K^+ \Lambda$	800	86	66	865	–	–	–	66	66	79	79	2107
$\gamma p \to K^+ \Sigma^0$	758	62	–	169	–	–	–	–	–	40	40	1069
$\gamma p \to K^0 \Sigma^+$	220	15	–	36	–	–	–	–	–	–	–	271
Sum	11695	2273	1174	1881	371	211	177	73	73	119	119	18166



- Global fit of pion and photon induced reactions
- Loop: back to the first step

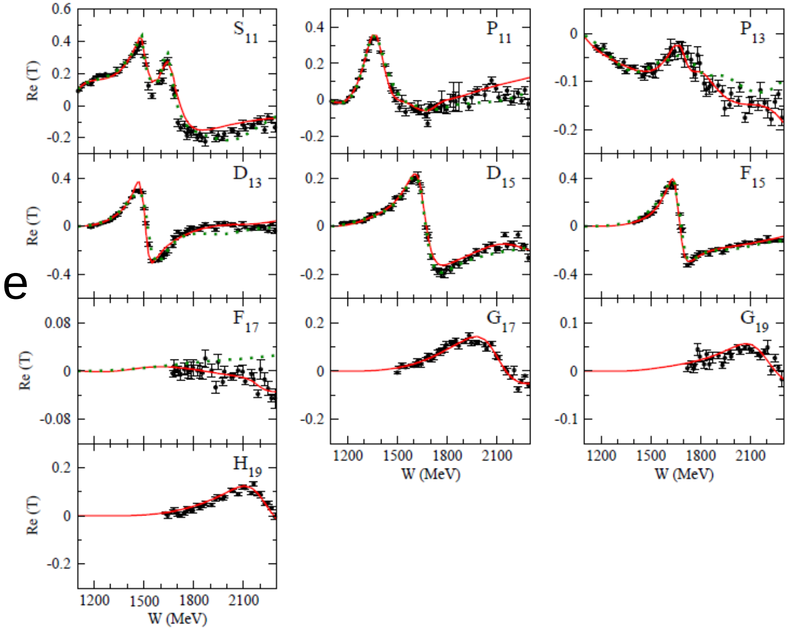
πN amplitude

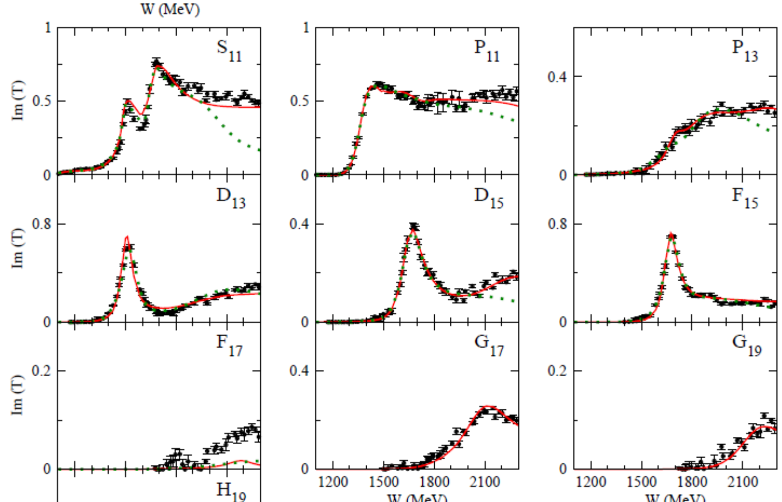
I=1/2

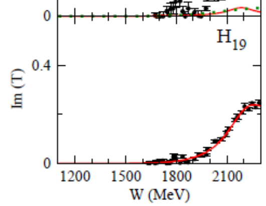
I=3/2

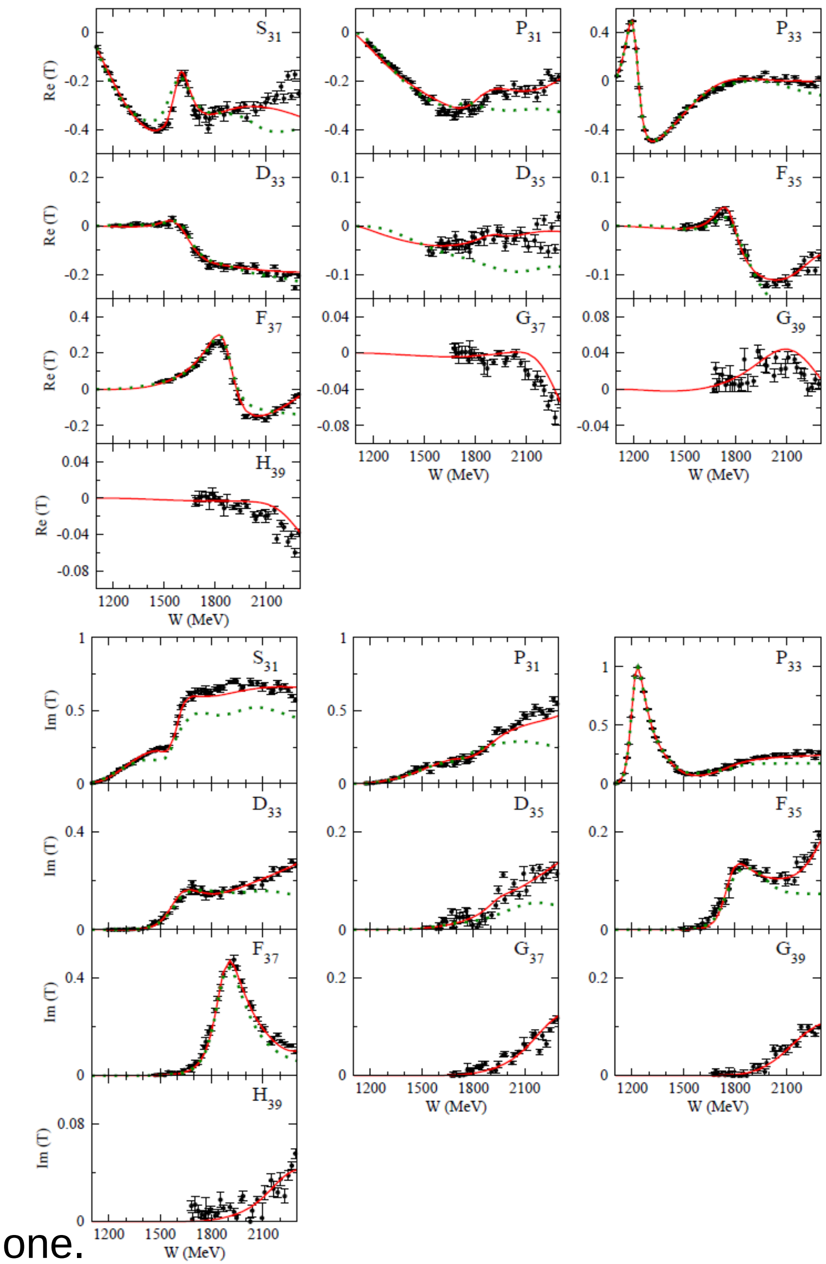
Re

Im



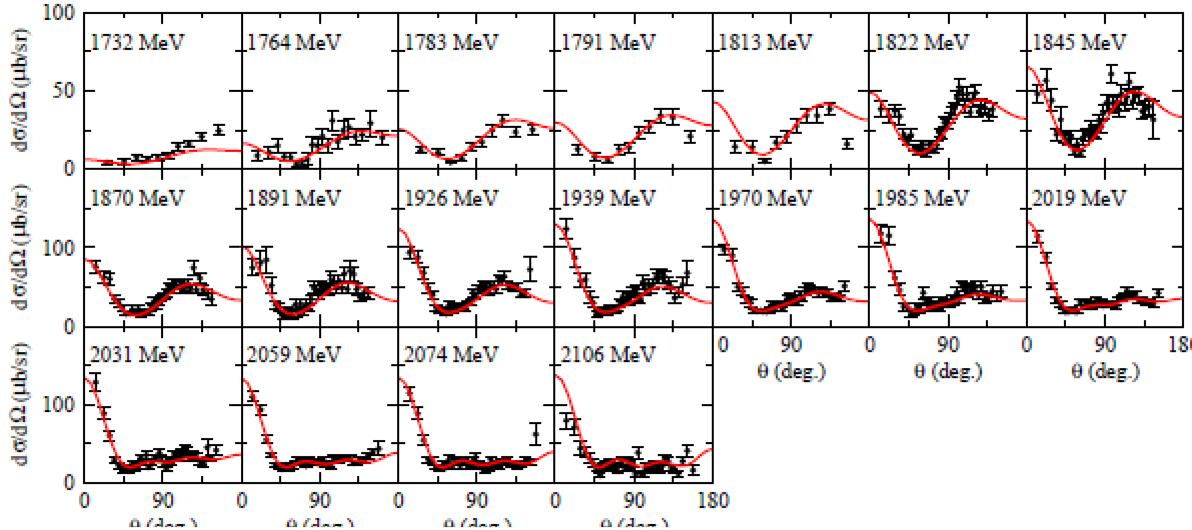






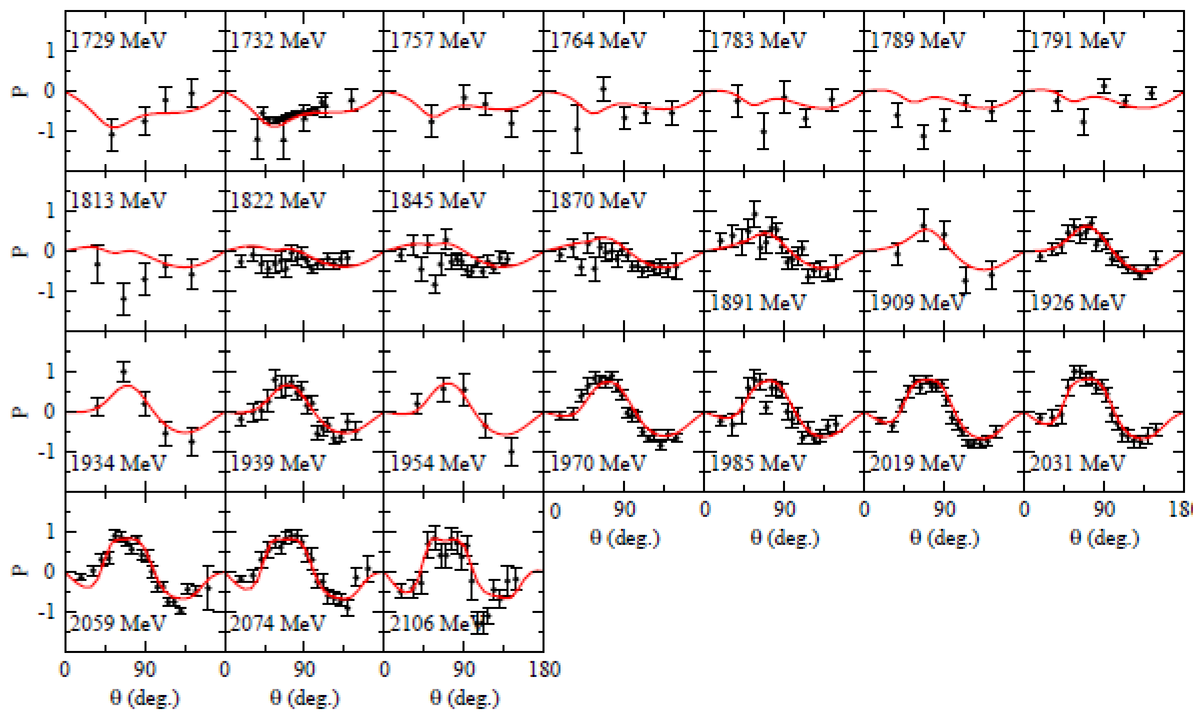
- Improvement for S31,P31,D35
- Direct comparison with obs. was done.

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



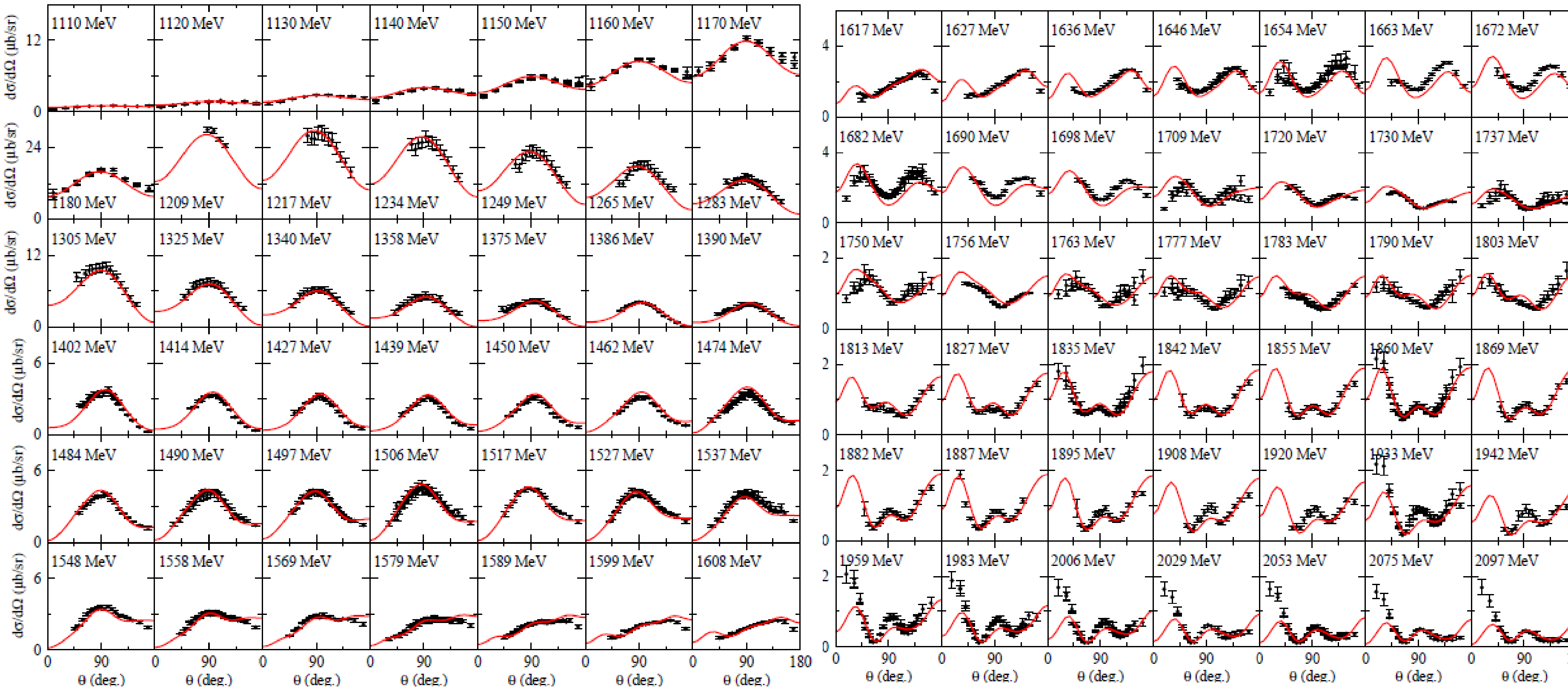
$$\boxed{\pi^{+} p \rightarrow K^{+} + \Sigma^{+}}$$

P



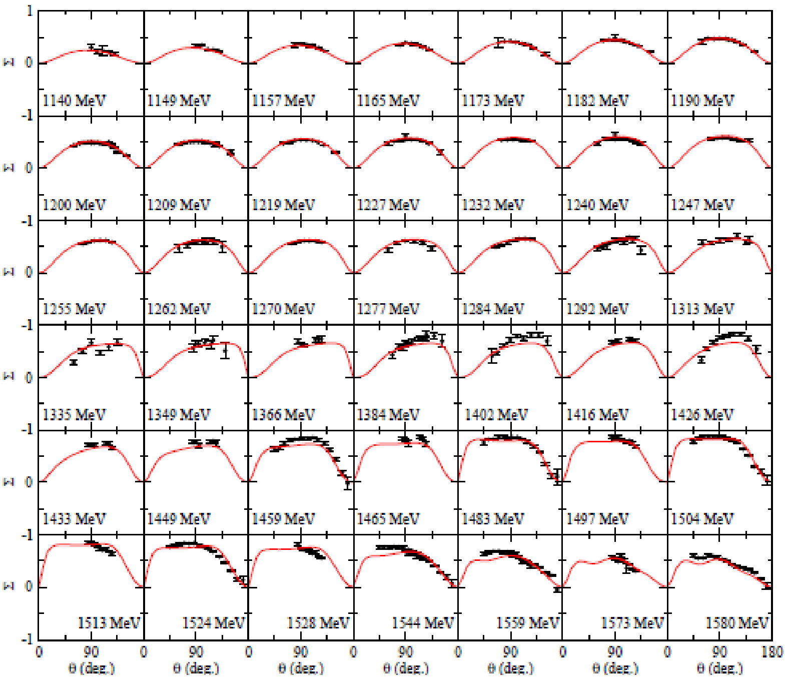
$$\gamma + p \to \pi^0 p$$

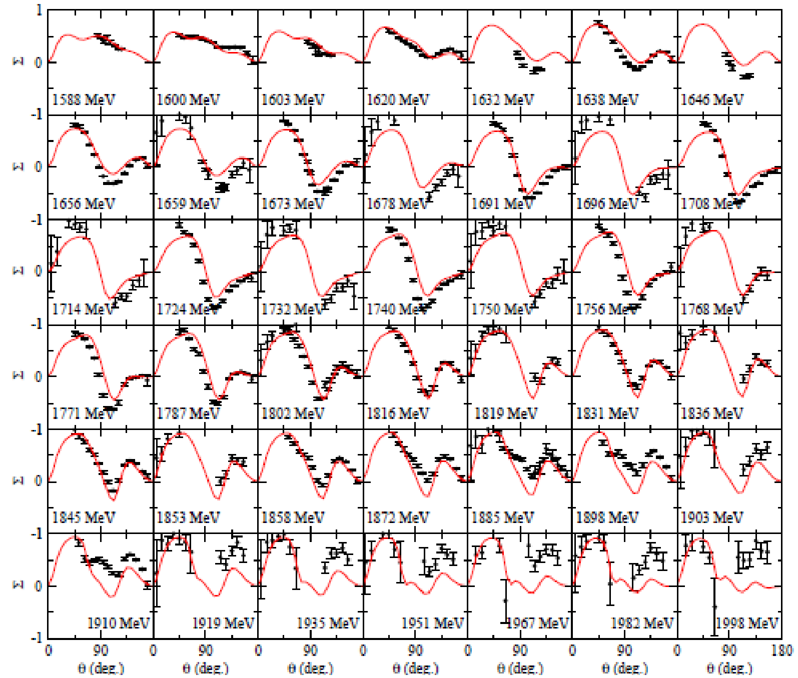
$$\frac{d\sigma}{d\Omega}$$



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

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

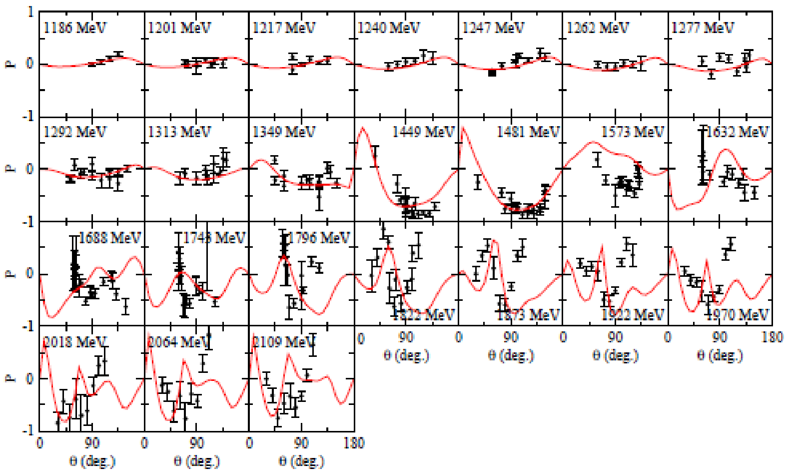




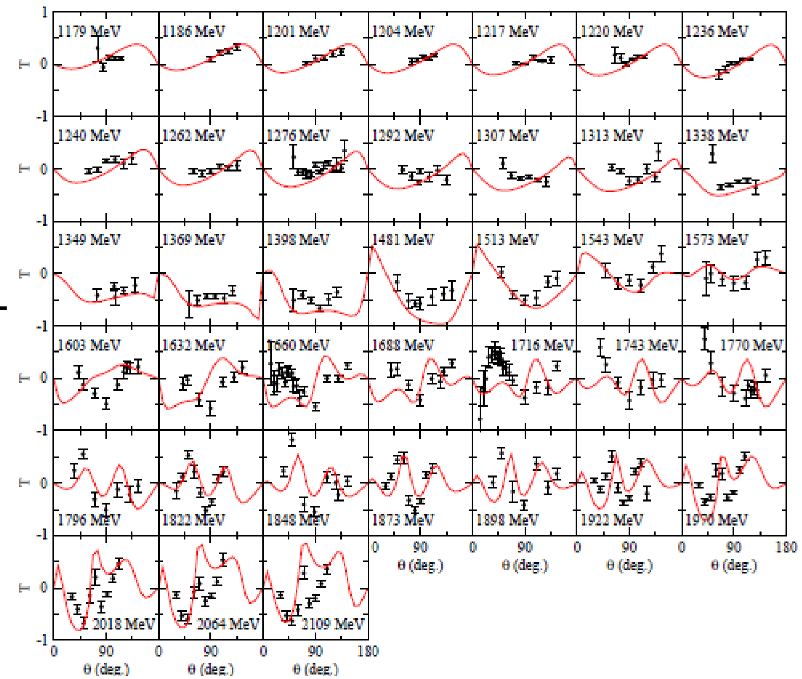
- Extensive data of Sigma can be fitted well for W<1.9GeV.

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

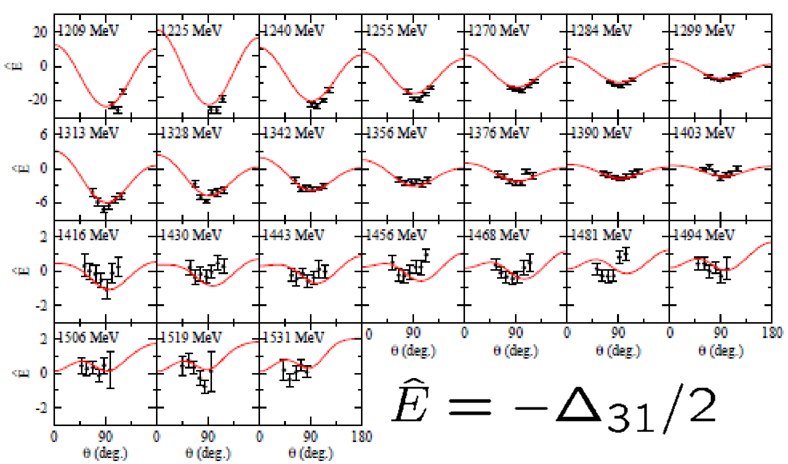
P



T

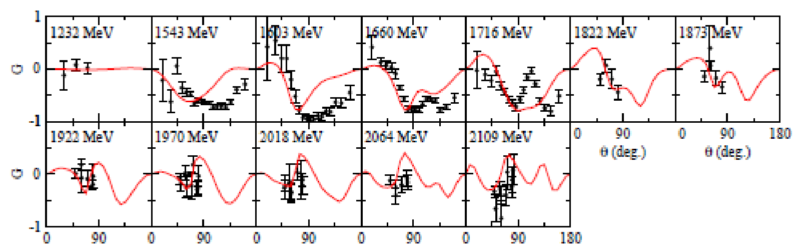


- Number of data points is much less than $d\sigma/d\Omega, \Sigma$

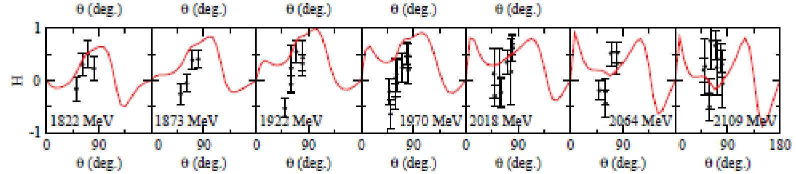


$$\widehat{E} = -\Delta_{31}/2$$

G

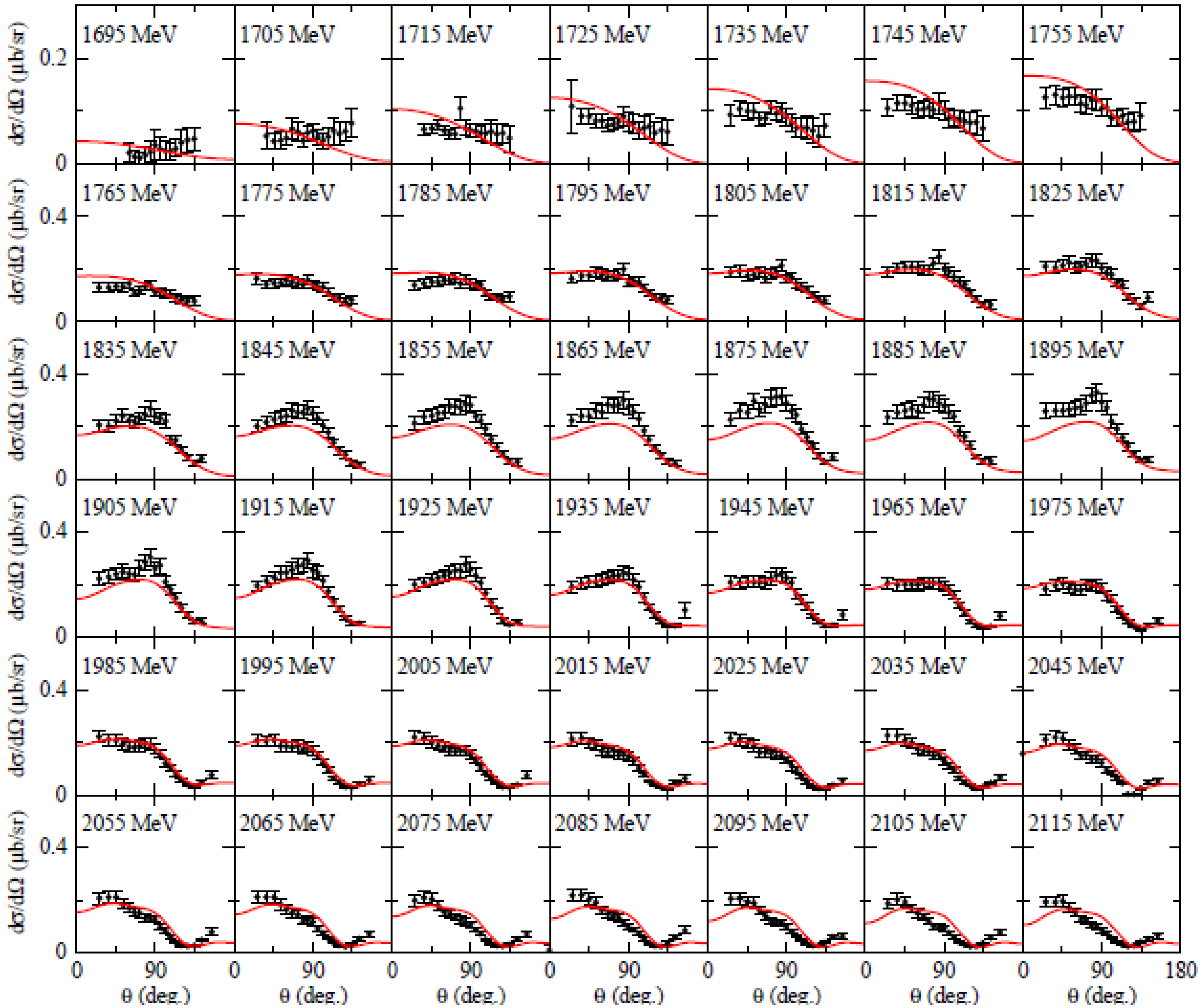


H



$\gamma + p \rightarrow K^+\Sigma^0$

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



Extraction of resonance poles and residues of scattering amplitudes

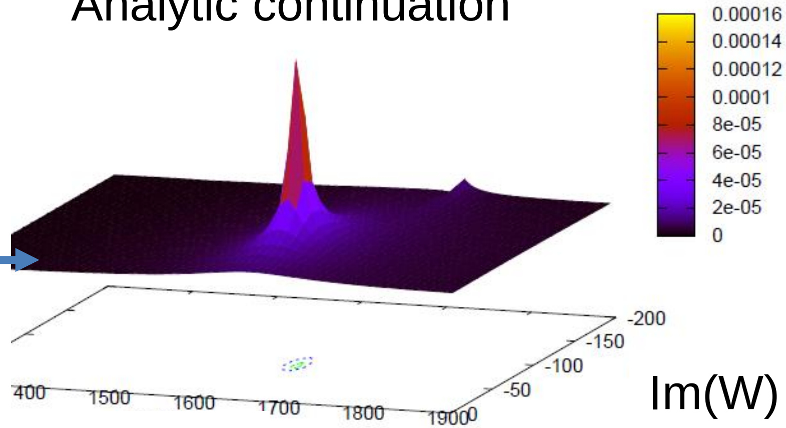
Extraction of resonance parameters

Resonance as a pole of S/T-matrix

Partial wave amplitude $\mathcal{F}(W)$

Analytic continuation

Resonance parameter



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

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

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

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

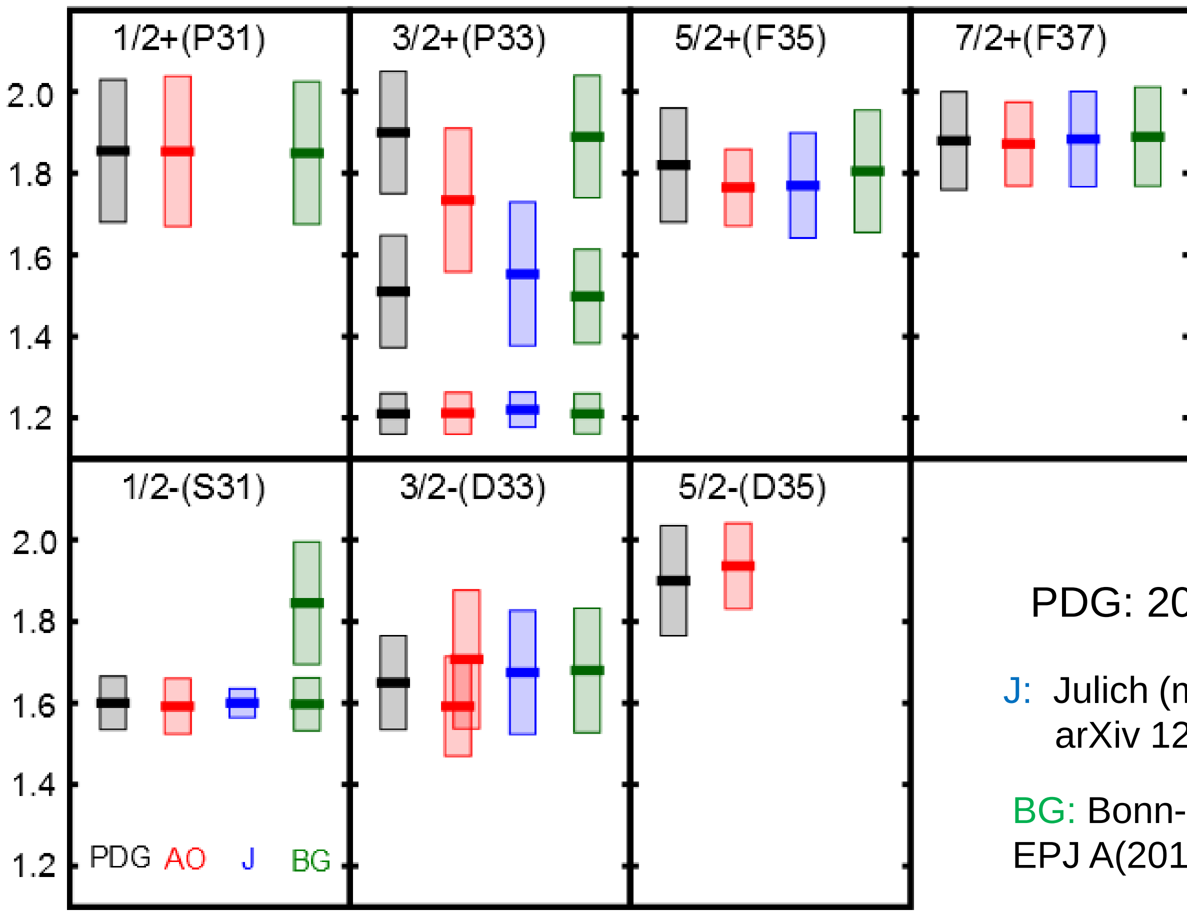
Re(M)< 2GeV, Im(M) < 0.2GeV, at closest sheet

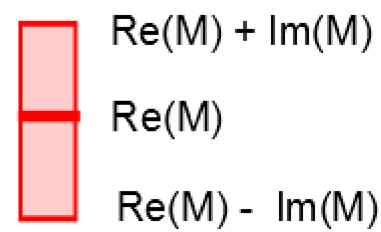
JLMS: Suzuki et al. PRL104(2010)042302

Spectrum of nucleon resonances

Re(M) < 2GeV
Width < 0.4GeV, (AO only poles on the nearest sheet)

Δ I=3/2





AO: Argonne-Osaka

2nd S31(1702-193i)

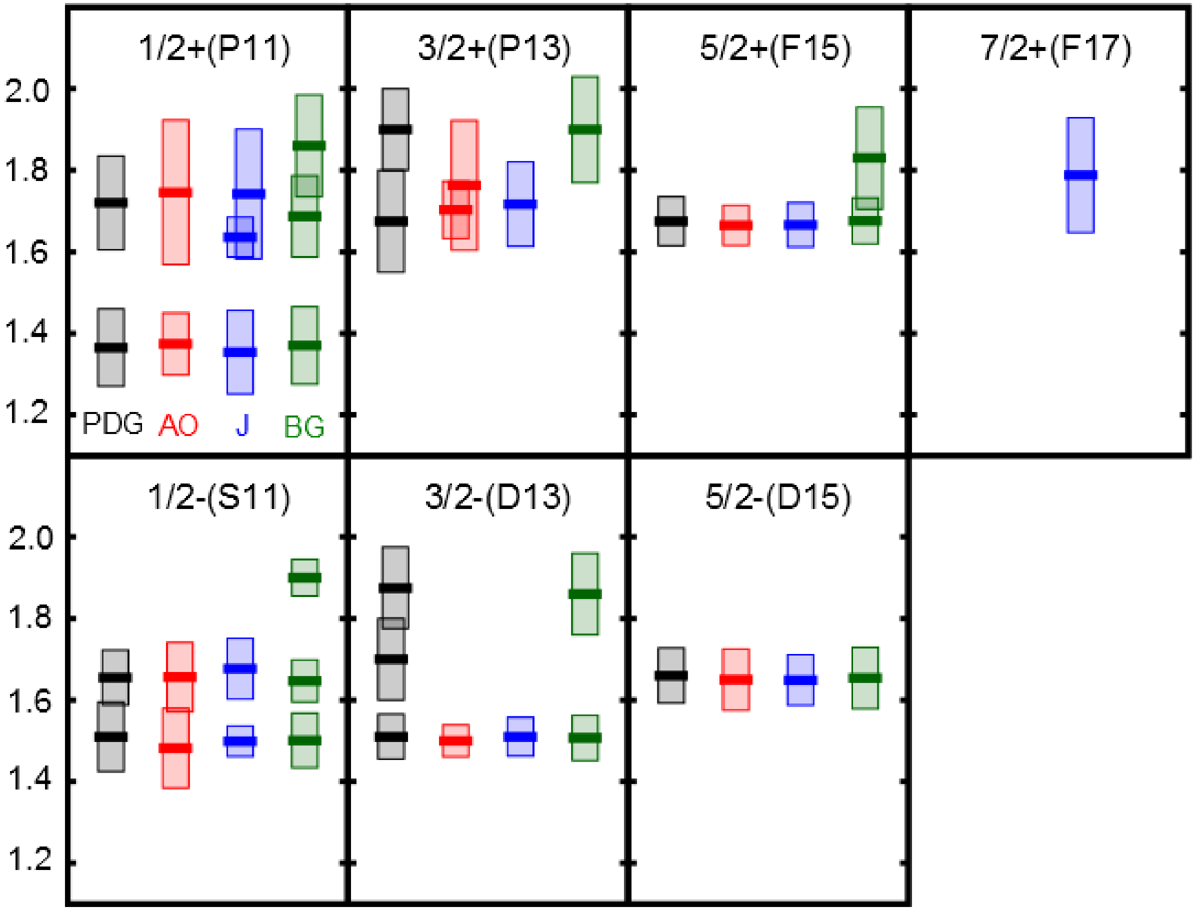
2nd D13(1702-141i)

PDG: 2012 3*, 4*

J: Julich (model A dynamical reaction model)
arXiv 1211.6998 D. Ronchen et al.

BG: Bonn-Gachina(K-matrix approach)
EPJ A(2012)48,15 A.V.Anisovich et al.

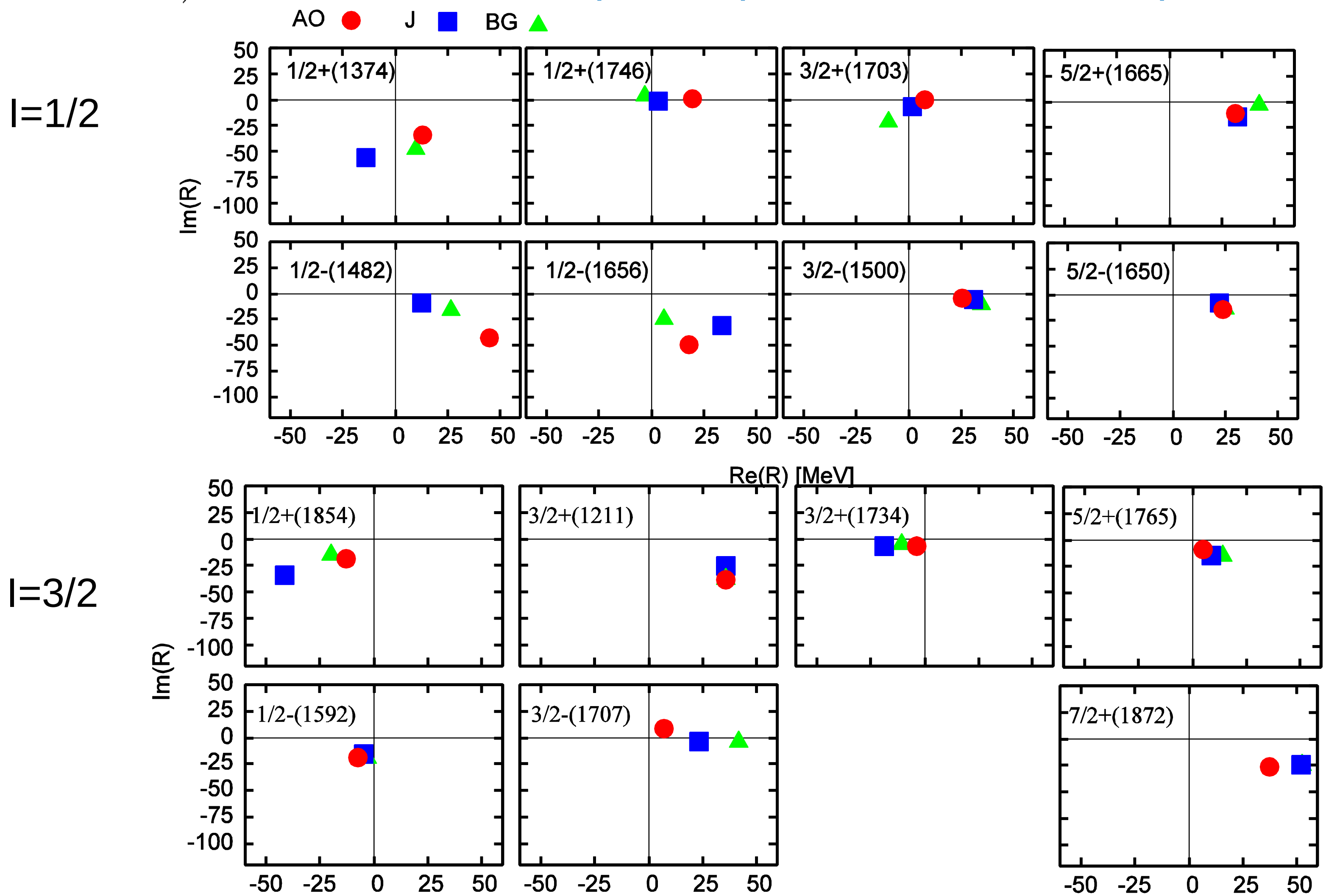
N^* I=1/2



- AO agree with PDG for W<2GeV(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*

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

Residue of piN amplitude at resonance pole



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

  residues are more sensitive to the analyses than pole positions

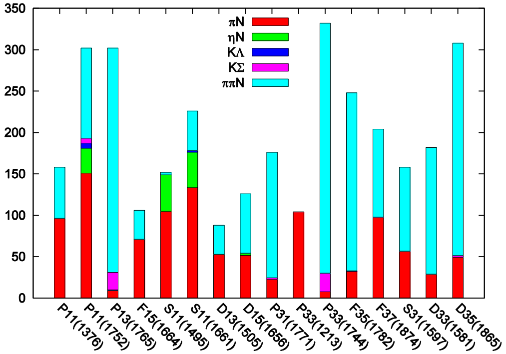
Near future improvements on the description of meson production reactions N* extraction

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 pipiN dynamics



- large part of the meson production cross section
- large partial width of N*
- poor data for piN → pipiN reaction compared with photo-production data

Proposal for JPARC

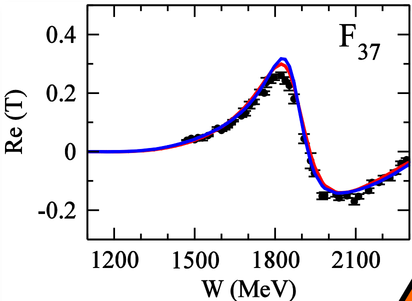
Proposal for J-PARC 50 GeV Proton Synchrotron

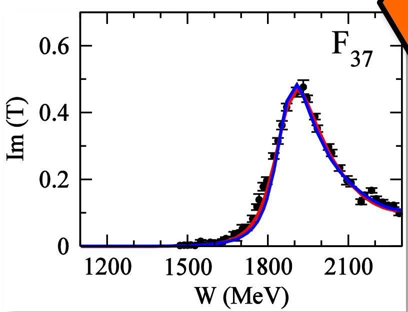
3-Body Hadronic Reactions for New Aspects of Baryon Spectroscopy

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

Importance of πN → ππN data

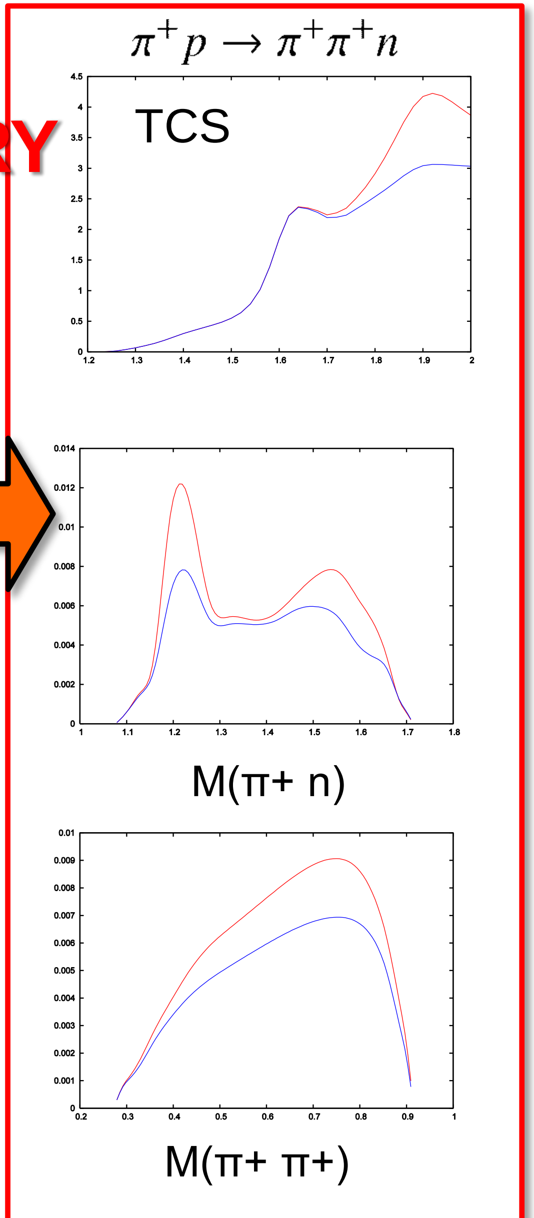
VERY PRELIMINARY

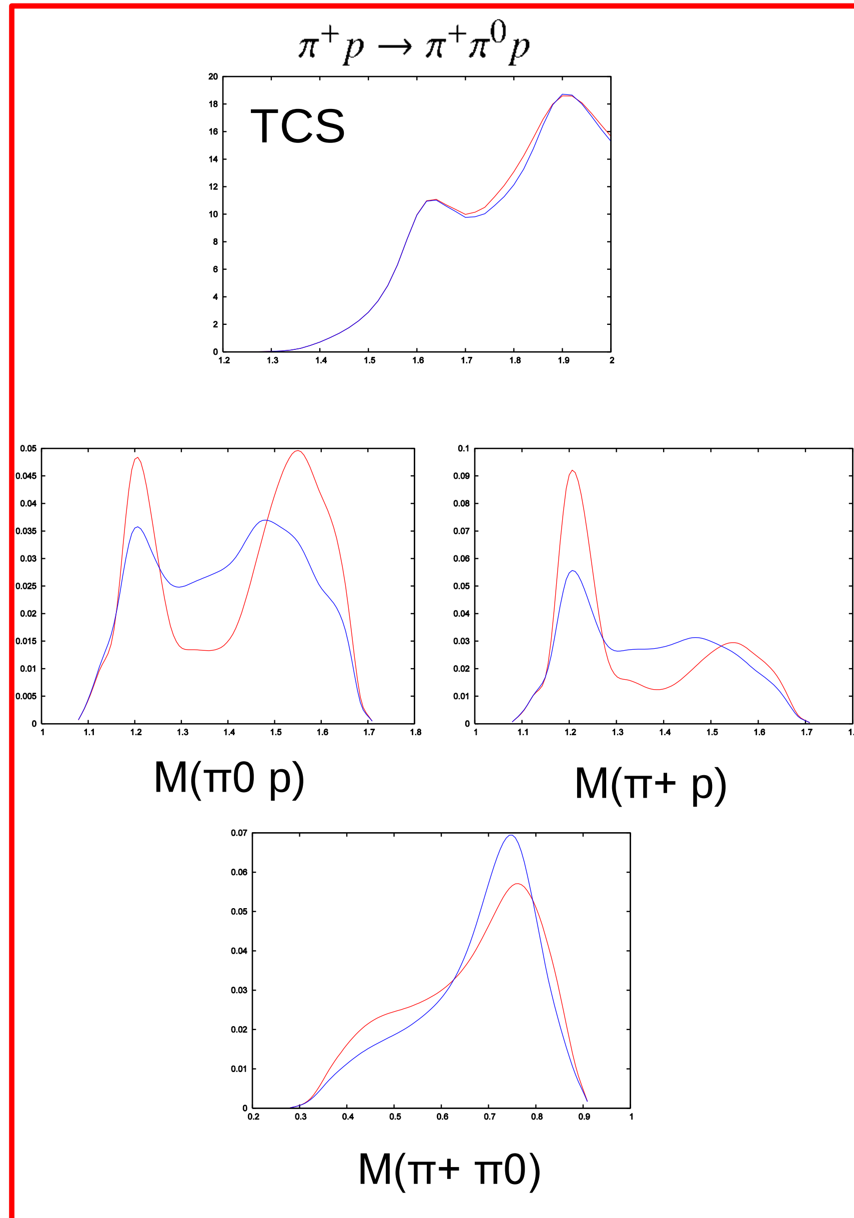




Current model

Refit F37 PWA keeping N* → πΔ off





Kamano at Tohoku 2012

Summary

- We have investigated within a dynamical coupled channel model of pi-N and gamma-N reactions up to 2GeV

- The meson baryon channels included in calculations are

$$\gamma N \ \pi N, \ \eta N, \ K\Lambda, \ K\Sigma \ \pi\pi N \ (\pi\Delta, \ \rho N \text{ and } \sigma N)$$

- Parameters for non-resonant interaction is mainly constrained by the fit to low energy region W<1.4GeV and N* parameters are determined by the fit up to W<2GeV

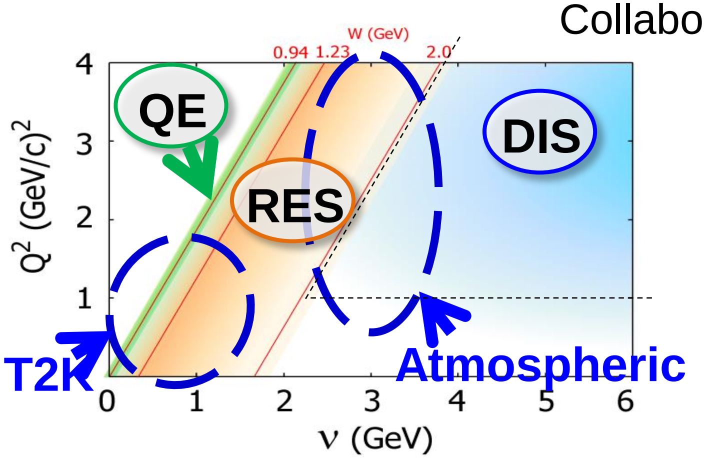
- Pole positions and residues(coupling constants of N*) are extracted by analytic continuation of the amplitudes.

- Recent analyses agree well only for the first N* in each spin parity Isospin(J,P,I).

- New hadronic data in particular piN → pipiN are needed to improve analysis and hope the results will converge in near future.

Next step

- Continue combined fit including two pion and omega production data to improve fits around W~ 2GeV. combine information from new hyperon photo production data.
- Extract transition electromagnetic forms factor for major resonances
- Analysis on the nature of resonance poles
- Urgent needs to extend a model for neutrino induced reaction.



Collaboration at J-PARC Branch of KEK theory center

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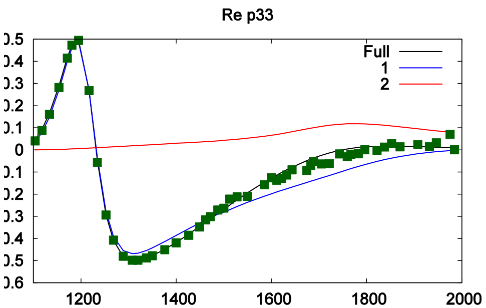
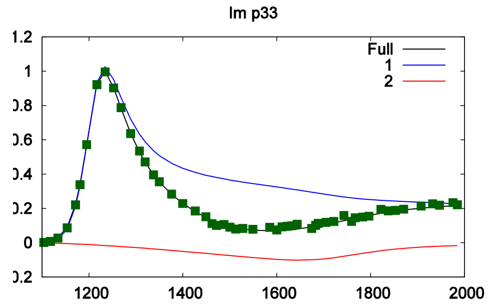
backup

Signal of weak resonances(Pi-N amplitude)

Second Delta33

Weak coupling with piN, sizable coupling with gamma N





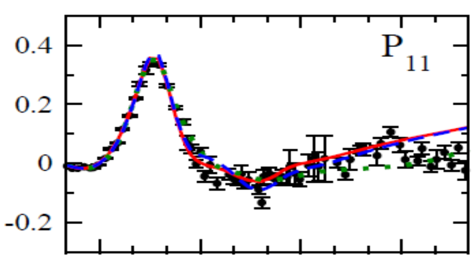
First P33

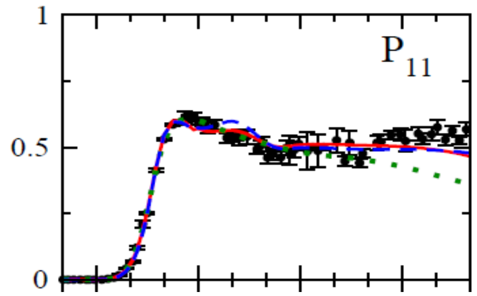
Second P33

Re

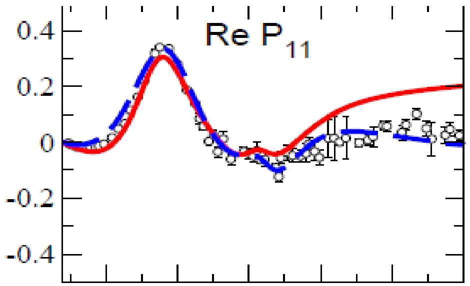
Im

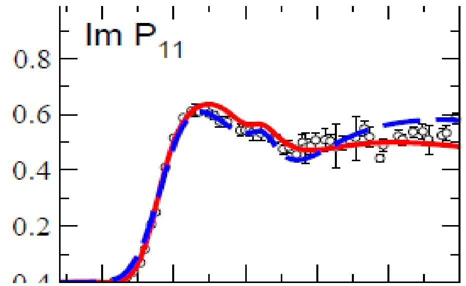
P11





ANL-Osaka





Julich

Estimation of resonance amplitude

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

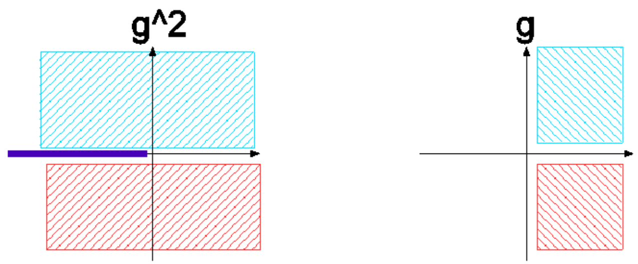
α, β Meson-Baryon channel i, j Resonances

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

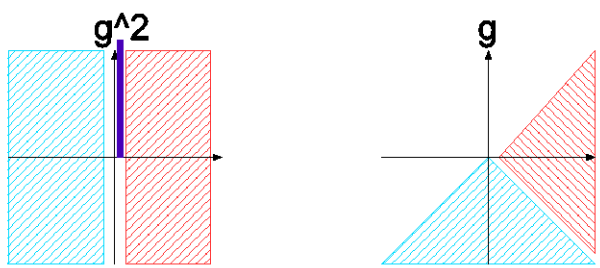
$$T_{res} = \frac{(\sum_i \bar{\Gamma}_{\alpha,i}(W) c_i)(\sum_j \bar{\Gamma}_{\beta,j}(W) c_j)}{W - M_{pole} + i\Gamma_{pole}/2}$$

Choice of phase (Residue -> coupling constant)

$$R_{\pi N,\pi N} = g^2_{\pi N} \qquad R_{\pi N,\gamma N} = g_{\pi N} g_{\gamma N}$$



ANL-OSAKA



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