Nucleon resonance from coupled channel approach for meson production reactions

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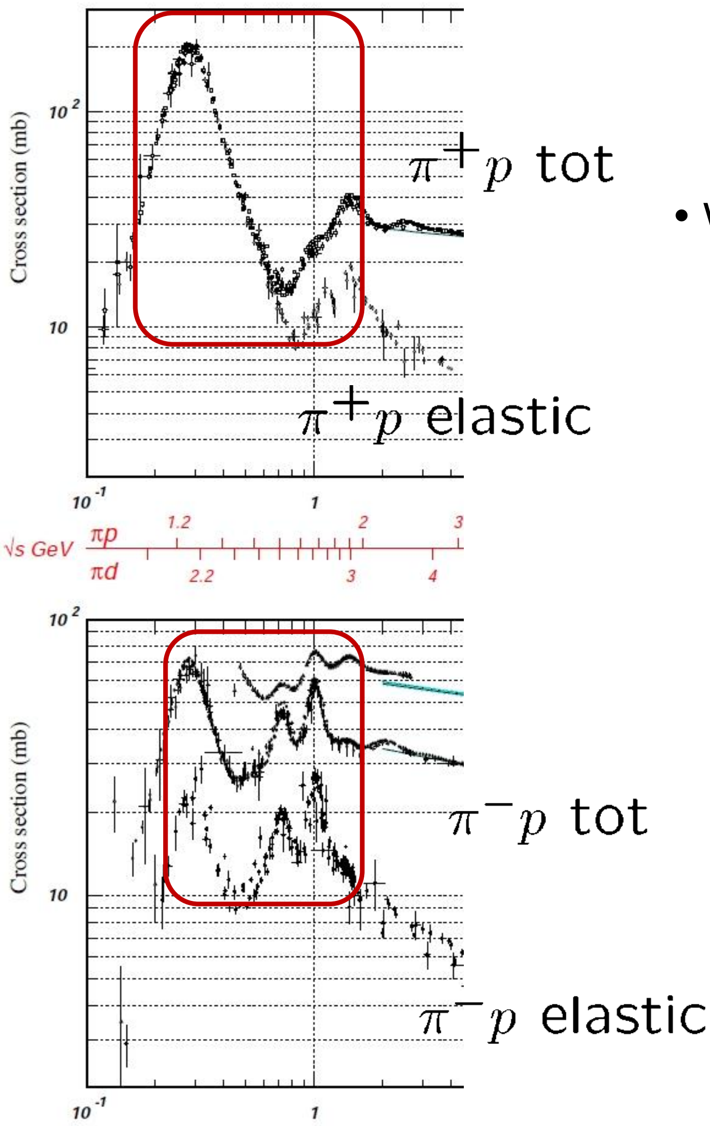
contents

- Motivation
- Dynamical coupled channel model of meson production reactions
- N* and Delta resonance parameters
- ✓ Resonance mass and width, photon coupling constants
- Signals of N* in pipiN, KY final states
- N* and neutrino reaction
- Summary

Nucleon Resonances

πN → X, πN

Δ (1232)



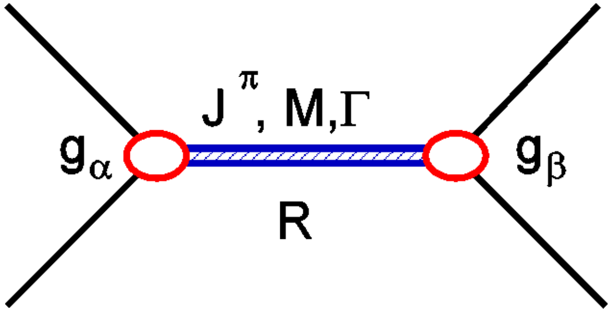
- W < 2 GeV ~ 20 resonances, up to 7/2^+ PDG

overlapping, $\Gamma \sim \mathcal{O}(100 MeV)$

PDG	1.4 < W < 2GeV	
	3* 4*	1* 2*
I=3/2	9	2
I=1/2	9	3

resonance parameters

- Spectrum: mass, width
- Coupling constants, form factor



extracted from meson production reactions

$$\pi N, \gamma^* N \to \pi N, \eta N, KY, \pi\pi N, \omega N$$

Extract N* infromation from data

- Determine high precision partial wave amplitude F(W) from accurate and complete experiments from combined analysis of meson production reaction

  data are incomplete and have errors

- Extract resonance poles and residues from F(W) for complex W by using analytic continuation of F(W)

  analytic continuation can be done within known analytic structure of each approaches

- Role of reaction dynamics on the properties of resonance:
  excited baryons are unstable particle and the spectrum and form factor are affected by coupling with meson-baryon continuum channels.

Our dynamical approach

framework

✓ dynamical reaction model for $\pi N, \gamma^* N \rightarrow \pi N, \eta N, KY, \pi\pi N, \omega N$

✓implement essential element of non-perturbative QCD as much as we can

✓reduce errors in extracting nucleon resonances by interpolating data by using dynamical reaction model

output

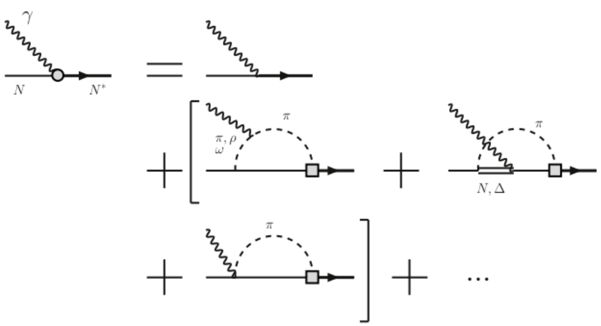
I. extract resonance parameters(pole,residue)

II. provide interpretations of the extracted resonance parameters

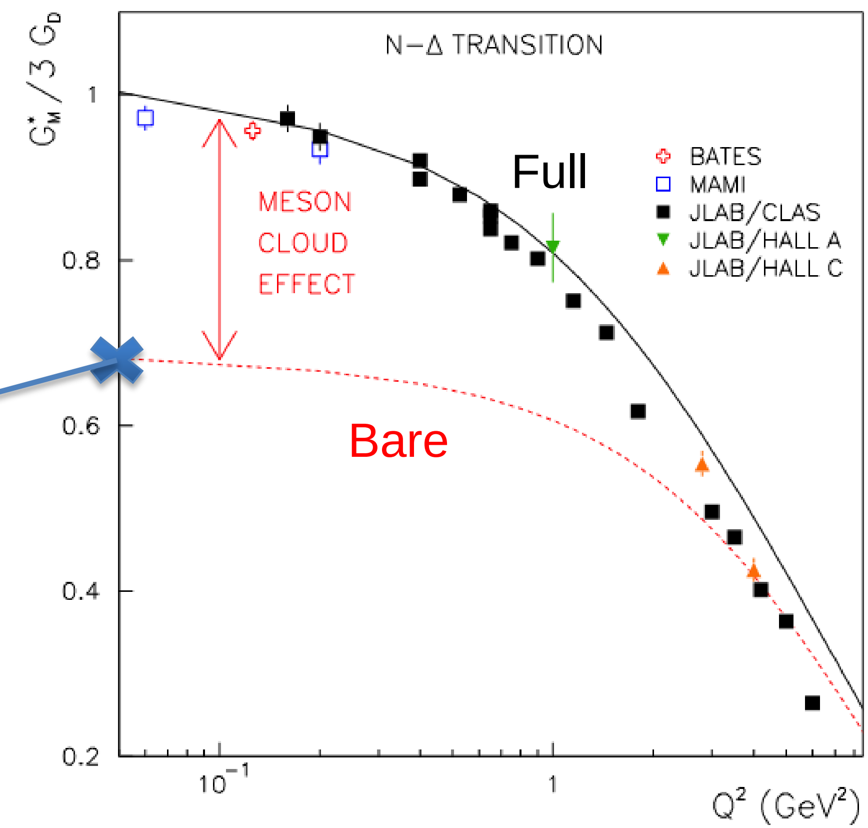
Dynamical coupled channel model of meson production reactions

analysis of (e,e'pi) in Delta(1232) reagion by dynamical reaction model :
T. Sato T.-S. H. Lee PRC 54(96),PRC62(01), B. Julia-Diaz et al. PRC69 (04).

- Vertex correction



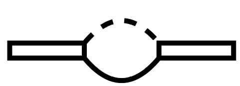
Note:
Most of the available static hadron models give $G_M(Q^2)$ close to "Bare" form factor.



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

- Mass shift

$$\Delta M = Re[\Sigma(W)]$$



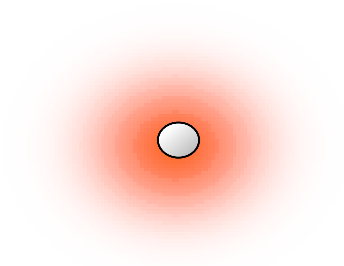
Dynamical coupled-channels (DCC) model for meson production reactions

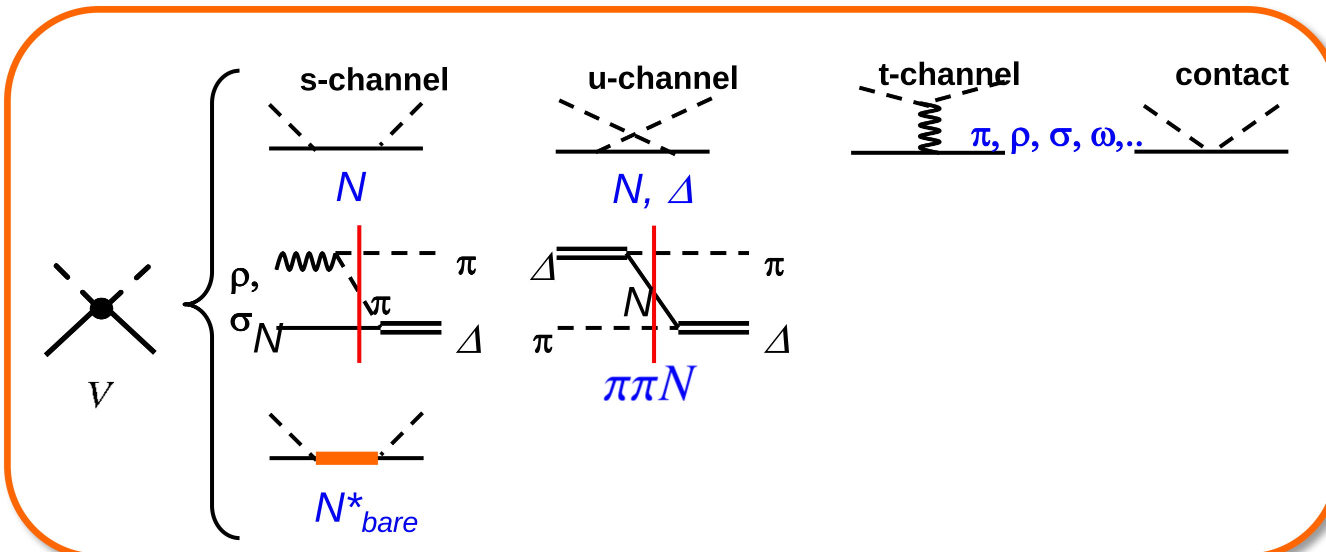
Matsuyama, Sato, Lee, Phys. Rep. 439,193 (2007)

start from Hamiltonian of meson-baryon system

Excited baryon	continuum
$\|N^* >$	$\|\pi N >, \|\eta N >, \|K\Lambda >, \|K\Sigma >, \|\pi\pi N >$
$\Gamma_{N^* \leftrightarrow MB}$	$V_{MB,M'B'}$

interaction





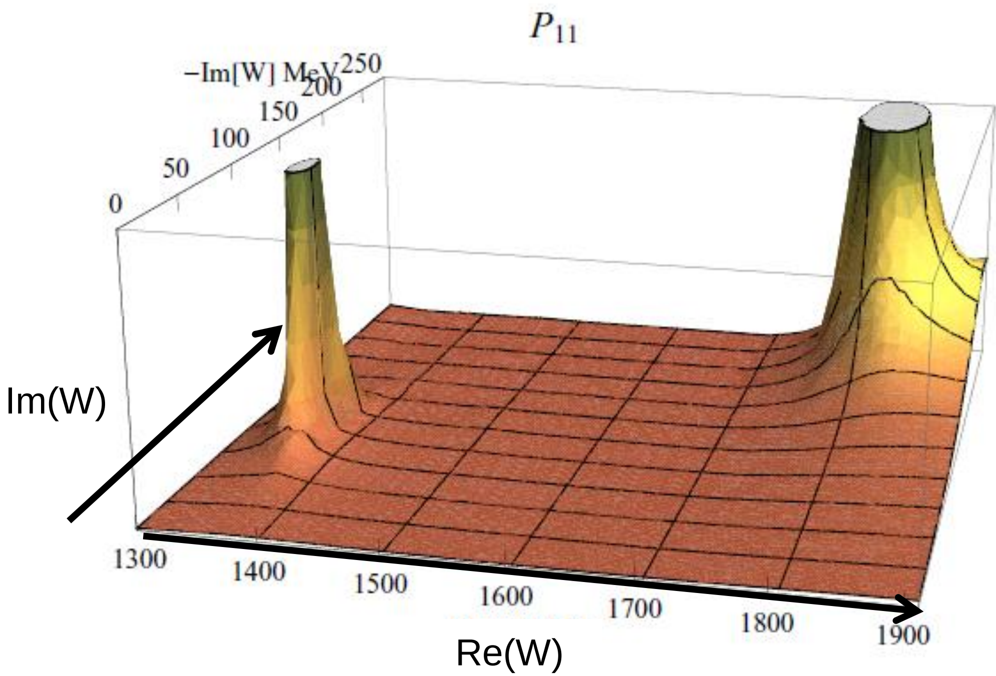
Scattering amplitude of pion and photon induced meson production amplitudes: solve coupled channel LS equation (3-dim reduction) in momentum space important and difficult task:

Analyze available pion and photon induced meson productions
by using DCC model → Hiroyuki Kamano's Talk

N* and Delta resonance parameters

Resonance parameters

characterize resonance:
pole position and residue of the Partial Wave Amplitude(PWA)

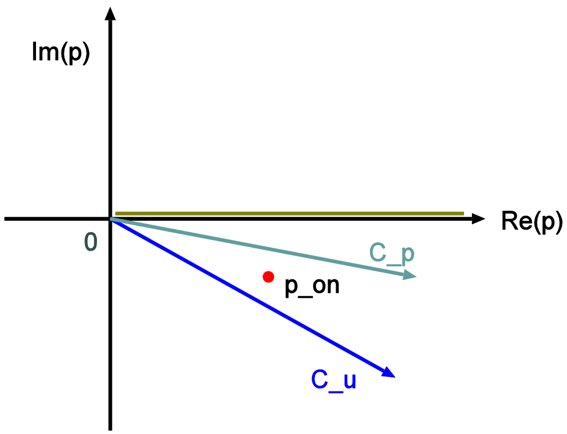


$$|T_{\pi N,\pi N}(W)|^2$$

Method of Analytic continuation of PWA within Dynamical Coupled Channel Model

◆ Deform contour of momentum integration

$$T_{\beta,\alpha}(k',k,W) = V_{\beta,\alpha}(k',k)+\sum_a \int_C dqq^2 V_{\beta,a}(k',q)G^0_a(q,W)T_{a,\alpha}(q,k,W)$$



2-body: B. C. Pears,B. F. Gibson PRC40(89) YN
J.Nieves PRD64(01) piN

3-body: W.Glockle PRC18(78) 3n
A. Matsuyama PLB408(97) pipiN
Y. Ikeda, T. Sato PRC76(07) KNN,Lambda(1405)
R. Longacre et al. PRD17(78) N*

◆ Application to DCC to extract N* parameter

N. Suzuki, T. Sato, T.-S. H. Lee, Proc. MENU07,PRC79(09),PRC82(10)
N. Suzuki et al. PRL104(10)
H. Kamano et al. PRD84(11) M->3pi

Pole and Residue

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

Case: ‘bare N*’

•[Determinant of $G_{N*}(W)^{-1}$] =0 gives resonance position

$$Det[(W - m_0 - \Sigma(W))_{ij}] = 0 \to \quad W = M - i\Gamma/2$$

$\Sigma(W)$: evaluate at complex W, on unphysical sheet

•Resonance form factors from residue of amplitude

$$\to [G_{N^*}]_{ij} = \frac{c_i c_j}{W - M + i\Gamma/2} + ... \to \quad \bar{\Gamma}_{Jem} = \sum_i c_i < \tilde{N}^*_i | Jem | N >$$

Case: No ‘bare N*’

Pole and residue of $t^{nr}_{\alpha,\beta}(W)$

Mass, width and form factors of resonances

Dynamical Coupled-Channels analysis

Fully combined **analysis of γN , πN → πN , ηN , KΛ, KΣ reactions !!**

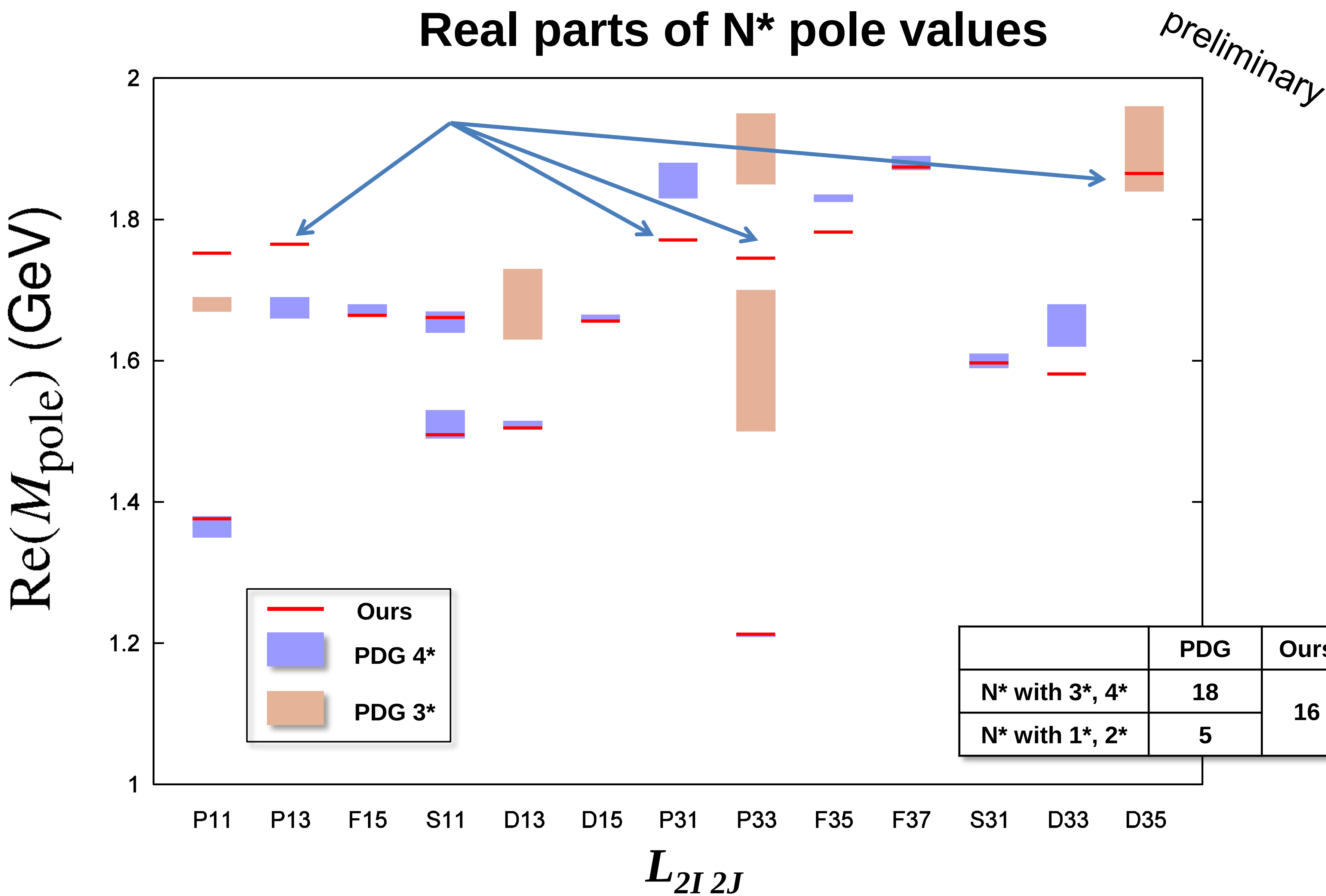
	2006-2009	2010-2012
✓ # of coupled channels	6 channels (γN,πN,ηN,πΔ,ρN,σN)	8 channels (γN,πN,ηN,πΔ,ρN,σN,KΛ,KΣ)
✓ πp → πN	< 2 GeV	< 2.1 GeV
✓ γp → πN	< 1.6 GeV	< 2 GeV
✓ π-p → ηn	< 2 GeV	< 2 GeV
✓ γp → ηp	—	< 2 GeV
✓ πp → KΛ, KΣ	—	< 2.2 GeV
✓ γp → KΛ, KΣ	—	< 2.2 GeV

Current situation: talk by H. Kamano

Kamano, Nakamura, Lee, Sato, 2012

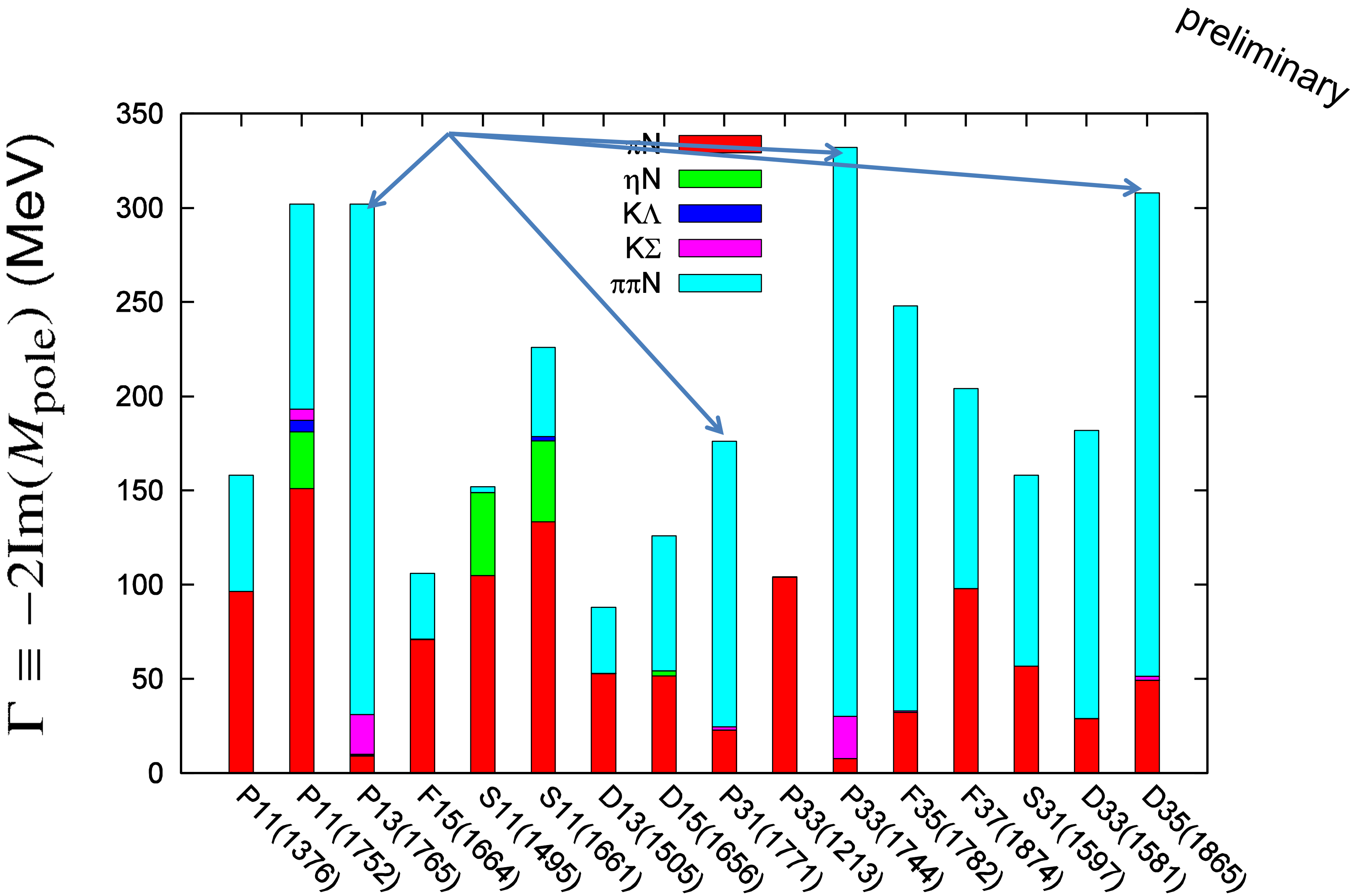
Spectrum of N* resonances

Kamano, Nakamura, Lee, Sato ,2012



	PDG	Ours
N* with 3*, 4*	18	16
N* with 1*, 2*	5	

Width of N* resonances

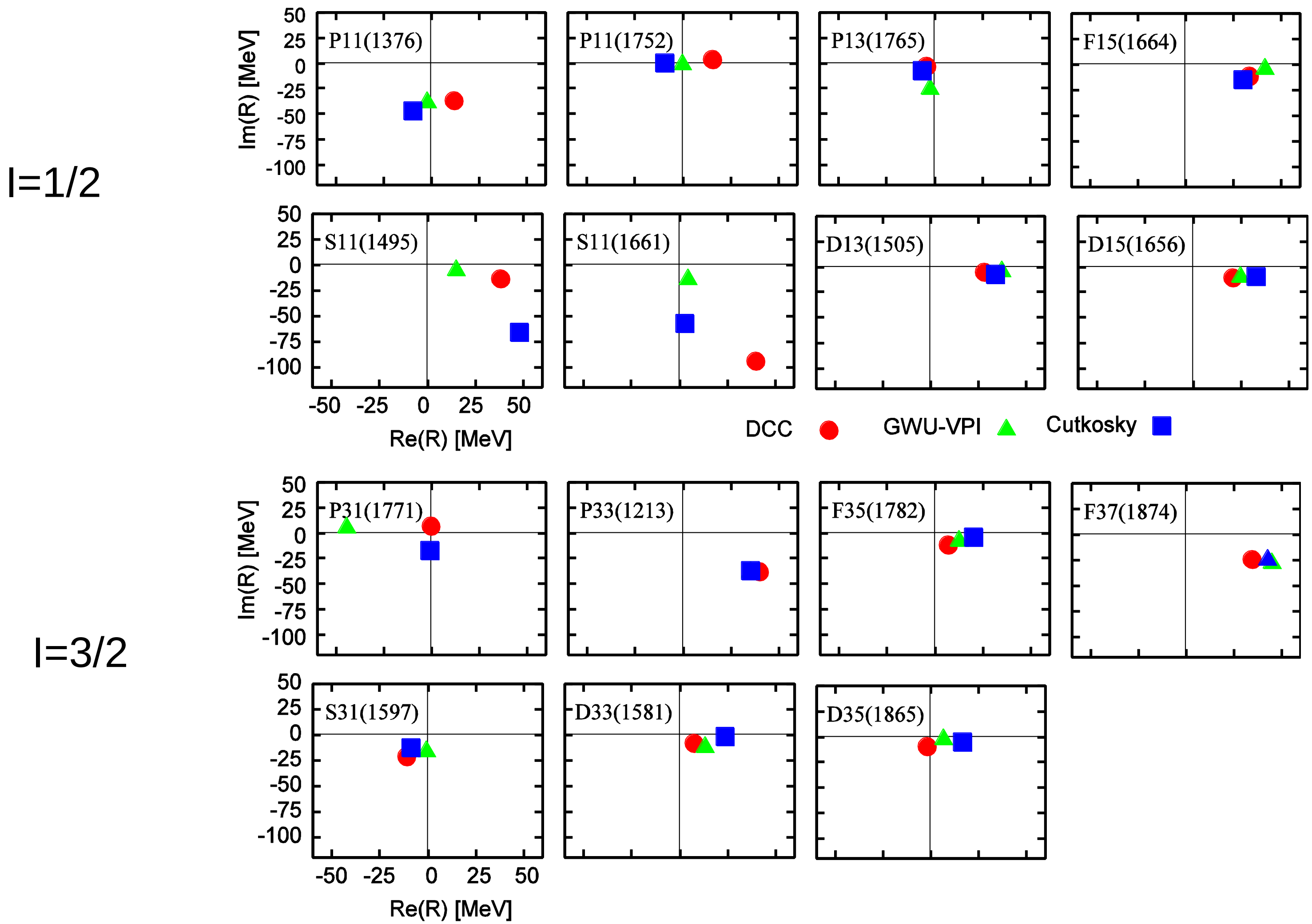


Kamano, Nakamura, Lee, Sato 2012

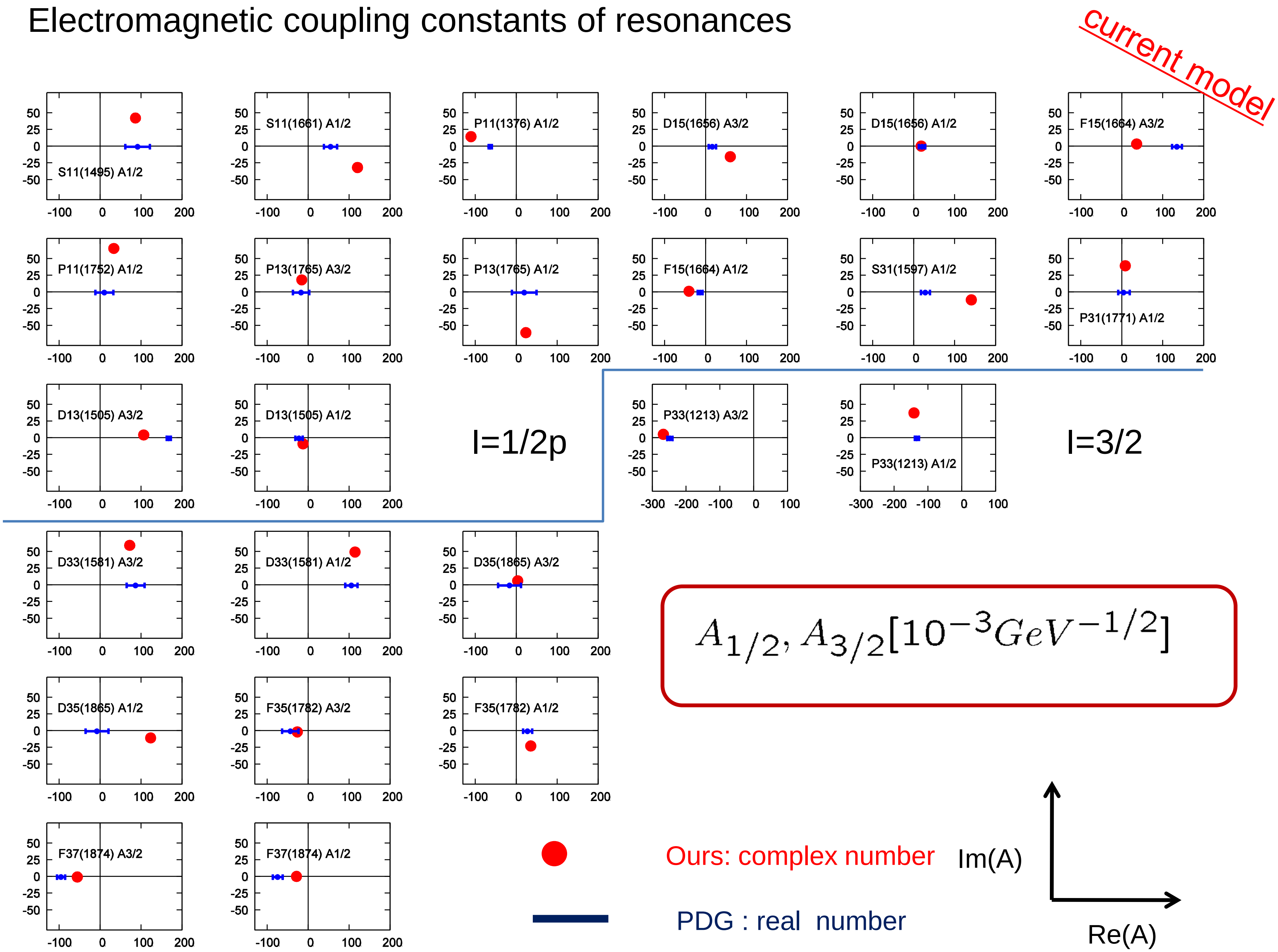
Residue of piN amplitude

$$F_{\pi N} = \frac{R}{M - i\Gamma/2 - W} + B(W)$$

current model



Electromagnetic coupling constants of resonances



Signals of N* in pipiN, KY final states

Signal of resonance in pipiN, YN PWA

Examine resonance strength in PWA for each meson-baryon channel within DCC model

→ Significance of resonances in pipiN, KY final state

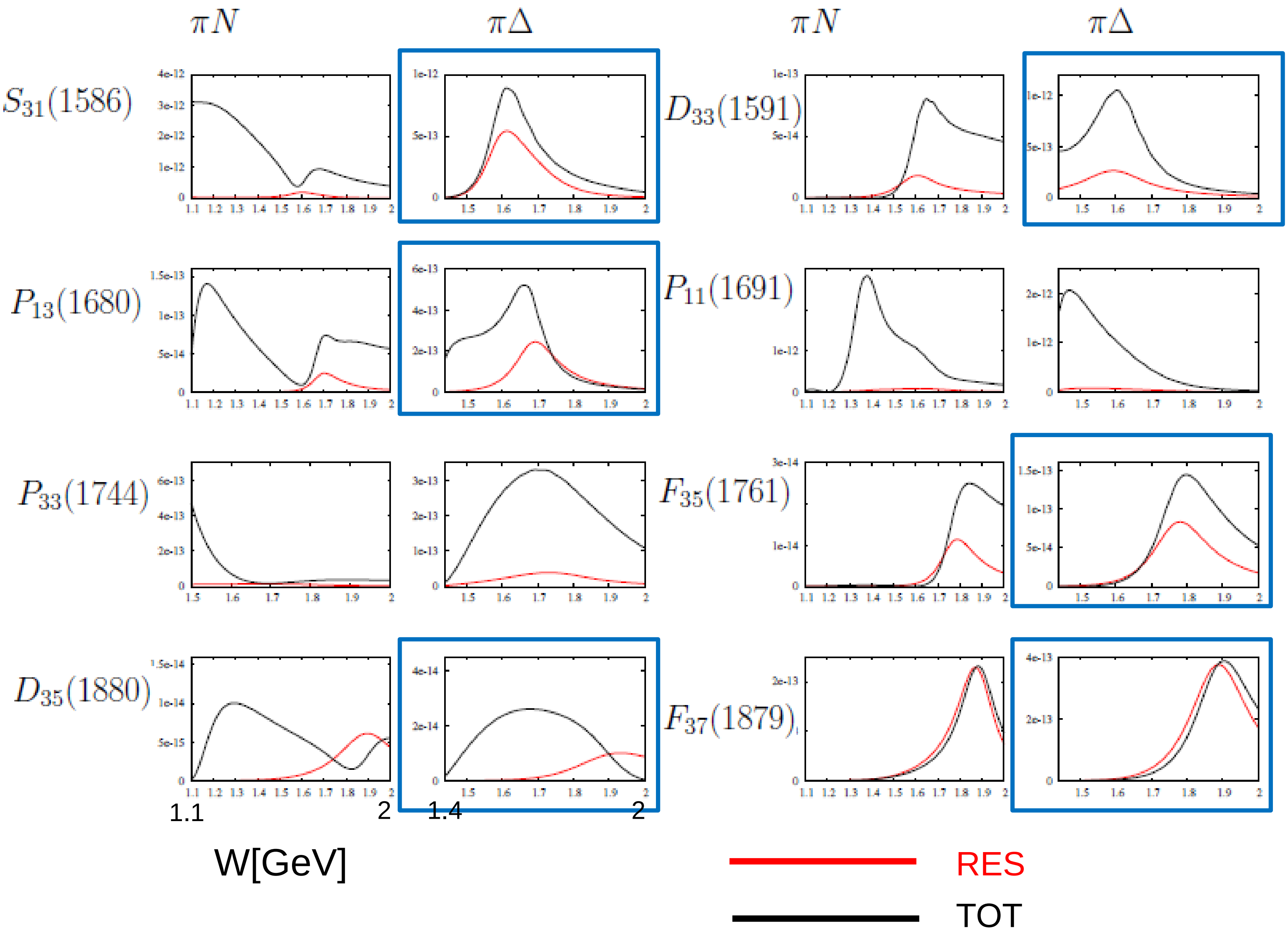
hadron beam exp. at J-PARC
complete measurement of photo kaon production at JLab

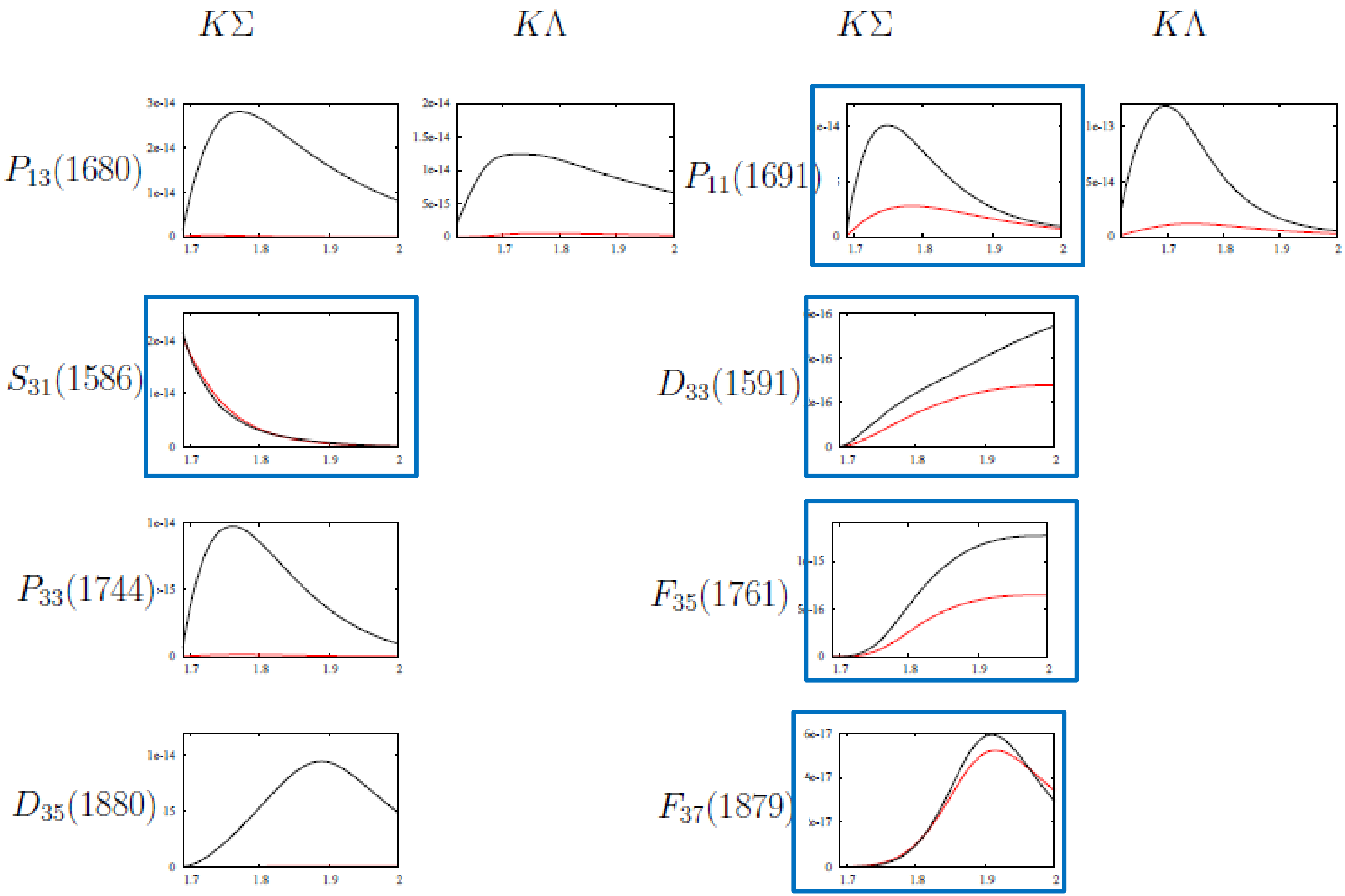
Define resonance amplitudes from the pole contribution of PWA

$$T^{RES}_{\alpha,\beta}(W) = \sum_{i,j} \bar{\Gamma}_{\alpha,i}(W)\left[\frac{c_i c_j}{W - M + i\Gamma/2}\right]\bar{\Gamma}_{\beta,j}(W)$$

Examine $|T^{TOT}(W)|^2, |T^{RES}(W)|^2$ of $\pi N \rightarrow \pi N, \pi\pi N, KY$ PWA

pipiN final state





$K\Sigma$
$K\Lambda$
$K\Sigma$
$K\Lambda$
$P_{13}(1680)$
$P_{11}(1691)$
$S_{31}(1586)$
$D_{33}(1591)$
$P_{33}(1744)$
$F_{35}(1761)$
$D_{35}(1880)$
$F_{37}(1879)$

	pipiN	KY
S31(1586)	*	*
D33(1591)	*	*
P13(1680)	*	-
P11(1691)	-	*
P33(1744)	-	-
F35(1761)	*	*
D35(1880)	*	-
F37(1879)	*	*

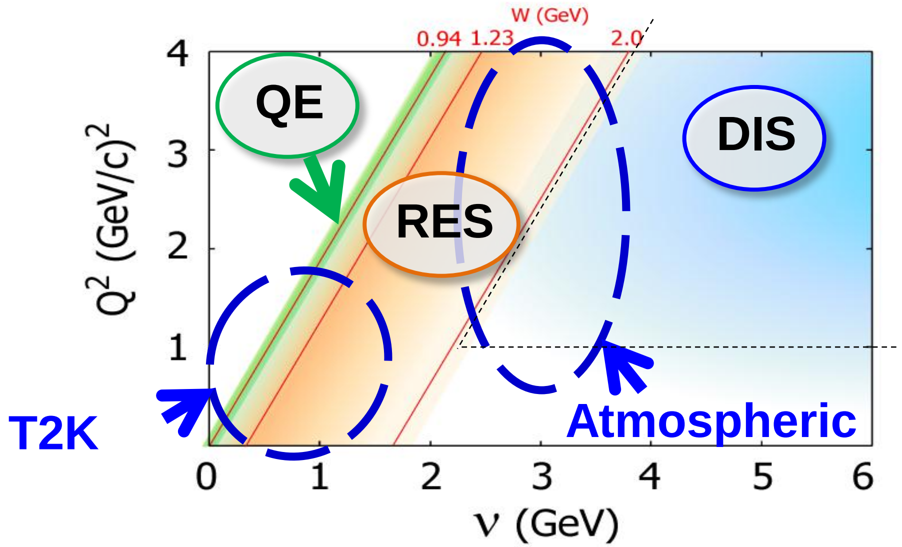
- Many of the N*,Delta with weak signal in piN can have stronger signal in pipiN, KY final state
- Further analysis for all resonances, photon induced reaction

Toward construction of unified model of lepton-nucleus interaction from a few hundred MeV to GeV region

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.)

Lepton-nucleus interactions in the new era of large θ_{13}

- **Less than 10% accuracy of the neutrino cross sections is required for the determination of mass hirarchy and CP-phase δ.**
- **Neutrino experiments probe *overlapping region* among Quasi-elastic(QE), Resonance(RES), and Deep-inelastic scattering (DIS).**



■ Delta(1232) resonance region (W<1.3GeV, SL model)

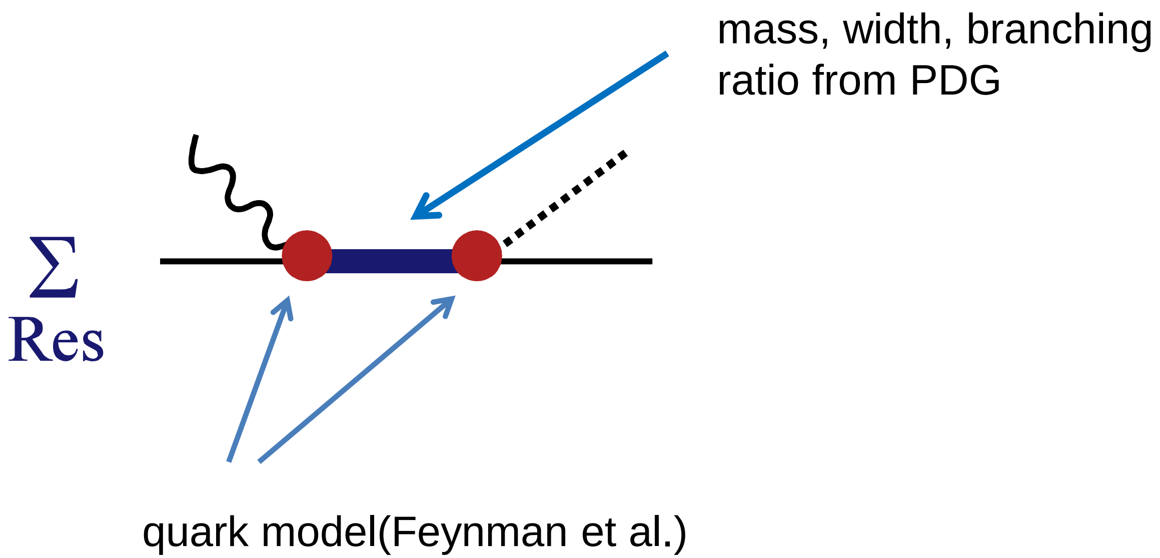
Start from Lagrangian based on chiral symmetry and electroweak Standard Model

Sato,Uno,Lee PRC67(2003) CC
Matsui,Sato,Lee PRC72(2005) NC, PV(e,e')

■ N* region

- model in event generator NEUT, GENIE

Single pion production Model of Rein-Sehgal AP133(80),ZPC35(87)



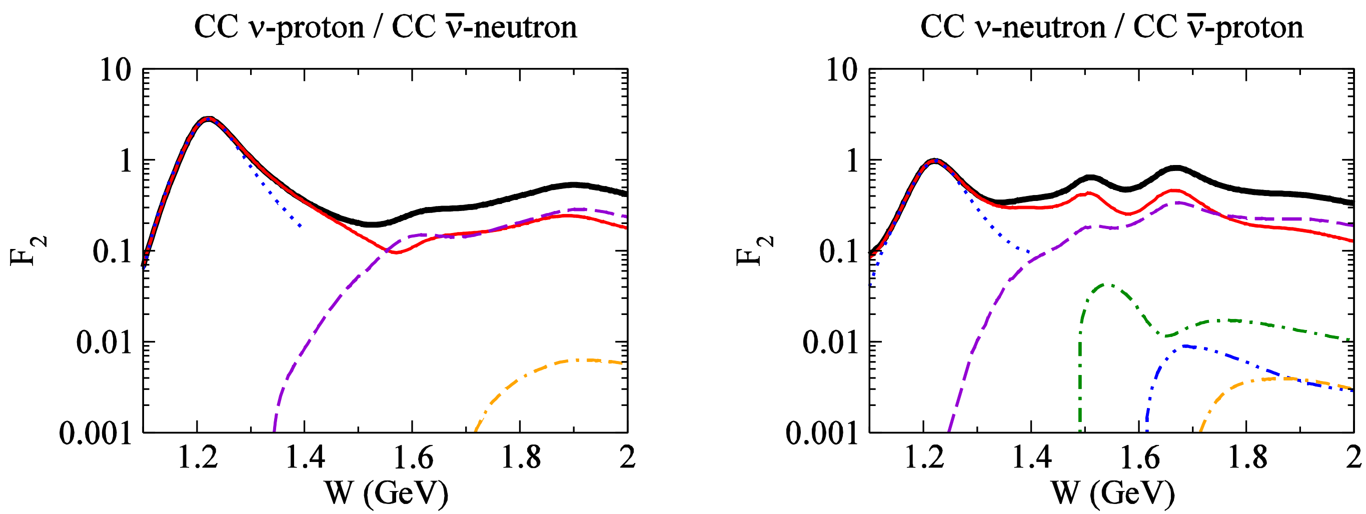
- Extend our DCC model of meson production $J^{\mu}_{em} \rightarrow V^{\mu} - A^{\mu}$

Forward neutrino induced meson production reaction
- application of DCC - arXiv:1207.5724

Objective: * benchmark for the future full meson production model
* eta,kaon production rate for back ground estimation of proton decay analysis

Use PCAC for $Q^2 = 0, m_l = 0$

$$\frac{d\sigma_\nu}{dE' d\Omega} = \frac{G_F^2 V_{ud}^2}{2\pi^2} \frac{E'^2}{E - E'} F_2 \quad , \quad F_2 = \frac{2 f_\pi^2}{\pi} \sigma(\text{virtual}\pi + N)$$



SL model (single pi via Delta)

Tot (including 2pi)
single pi
eta
K

Next Tasks

By extending the ANL-Osaka collaboration (since 1996)

1. **Complete the extraction of resonance parameters including N-N* form factors**

2. **Analysis on the structure of major resonances(S11,D13)**

3. **Make predictions for J-PARC projects on πN -> ππN, KΛ…**

4. **Complete model of weak meson production reaction**

Collaborators

J. Durand (Saclay)

B. Julia-Diaz (Barcelona)

H. Kamano (RCNP,JLab)

T.-S. H. Lee (ANL,JLab)

A. Matsuyama(Shizuoka)

S. Nakamura (YITP,Kyoto,JLab)

B. Saghai (Saclay)

T. Sato (Osaka)

C. Smith (Virginia, Jlab)

N. Suzuki (Osaka)

K. Tsushima (Adelaide,JLab)

Analysis Database

Pion-induced reactions (purely strong reactions)

	Waves	# of data	Waves	# of data
$\pi N \to \pi N$ PWA	S_{11}	56×2	D_{13}	52×2
	S_{31}	56×2	D_{15}	52×2
	P_{11}	56×2	D_{33}	50×2
	P_{13}	52×2	D_{35}	31×2
	P_{31}	52×2	F_{15}	39×2
	P_{33}	56×2	F_{17}	23×2
			F_{35}	34×2
			F_{37}	35×2
			Sum	1288

SAID

	$d\sigma/d\Omega$	P	R	a	Sum
$\pi^- p \to \eta p$	294	-	-	-	294
$\pi^- p \to K^0 \Lambda$	544	262	-	-	806
$\pi^- p \to K^0 \Sigma^0$	215	70	-	-	285
$\pi^+ p \to K^+ \Sigma^+$	552	312	-	-	864
Sum	1605	644	-	-	2249

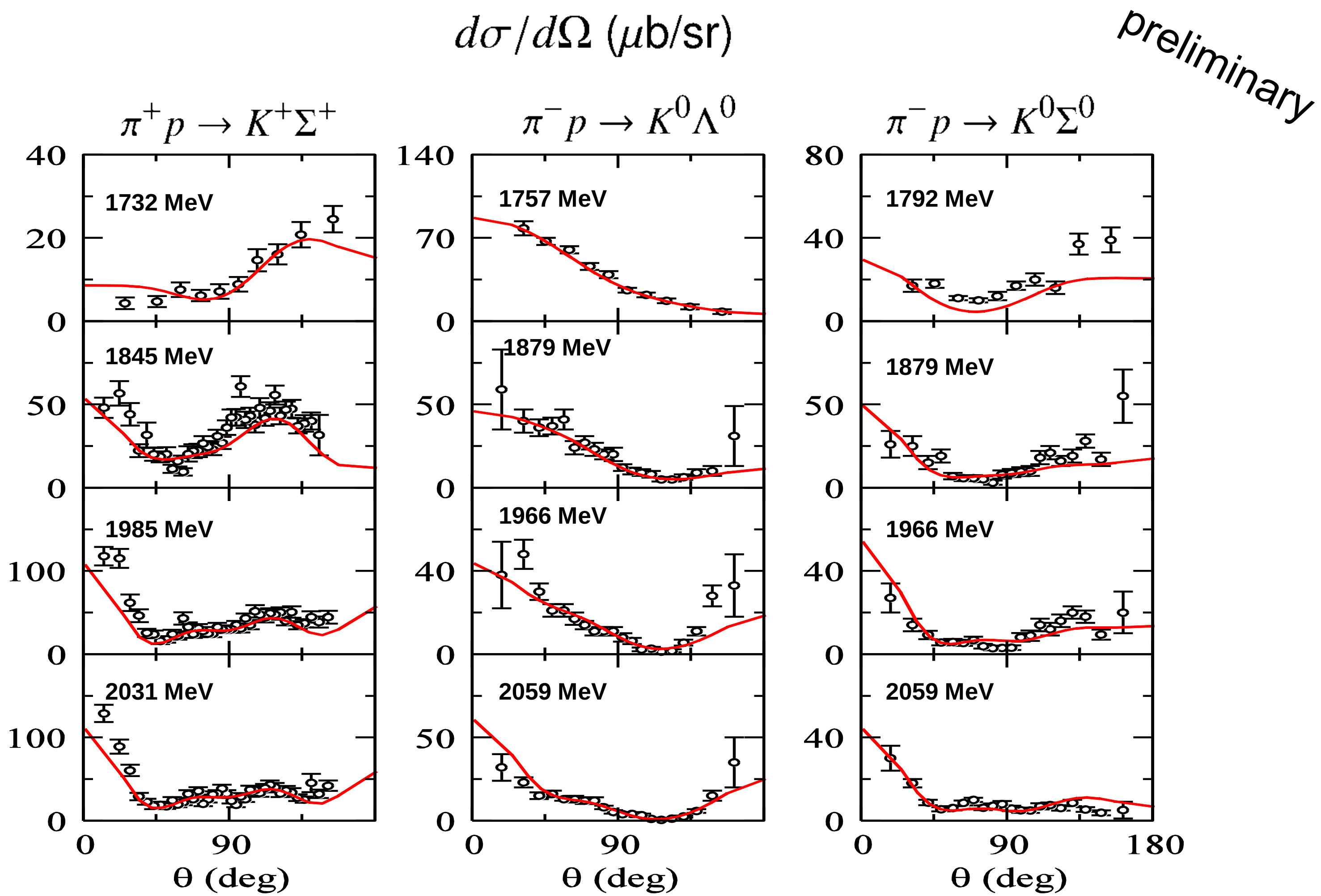
~ 28,000 data points to fit

Photo-production reactions

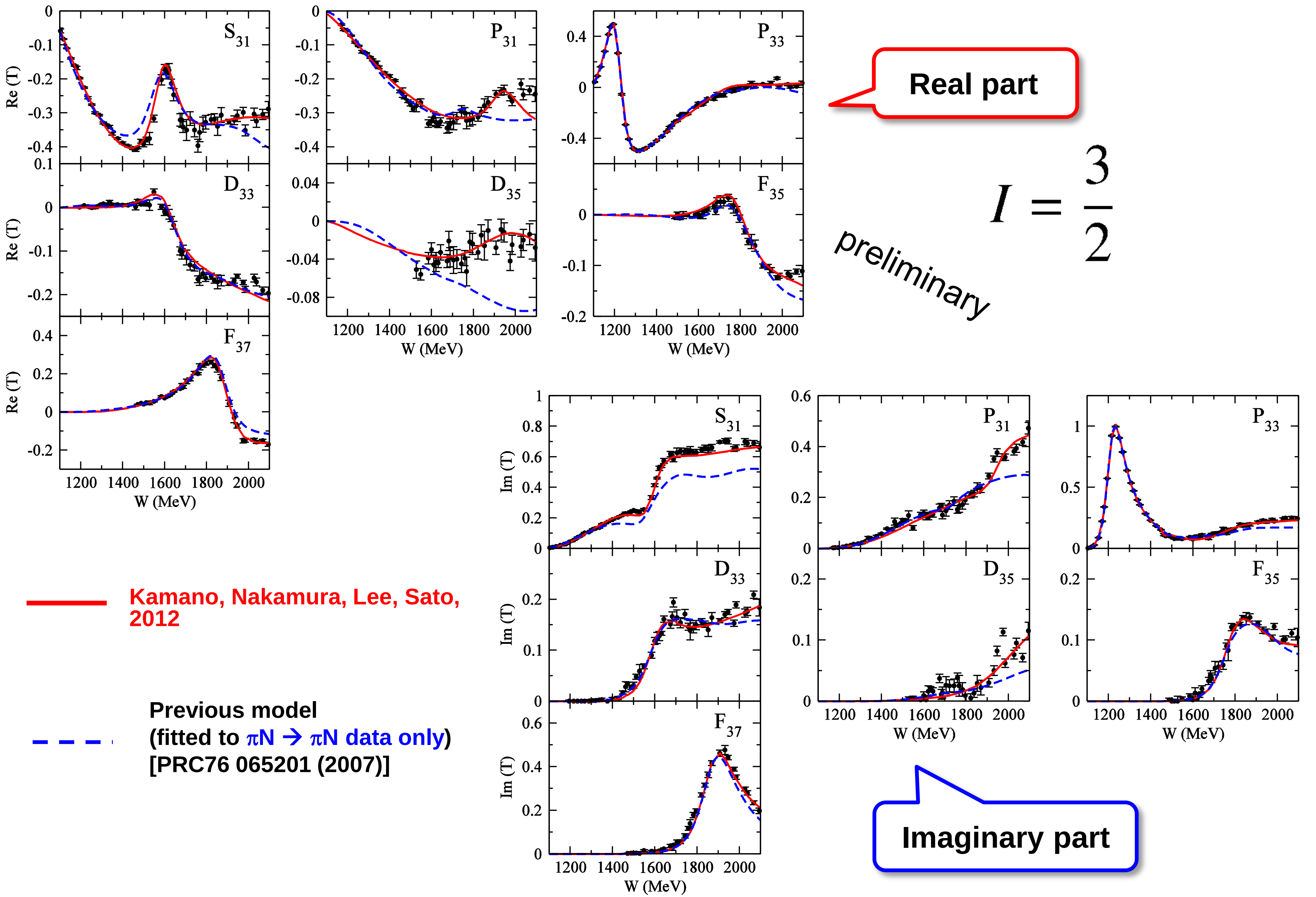
	$d\sigma/d\Omega$	Σ	T	P	G	H	E	F	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	sum
$\gamma p \to \pi^0 p$	8290	1680	353	557	28	24	-	-	-	-	-	-	-	-	-	-	10860
$\gamma p \to \pi^+ n$	5384	1014	661	221	75	123	-	-	-	-	-	-	-	-	-	-	7478
$\gamma p \to \eta p$	1076	197	50	-	-	-	-	-	-	-	-	-	-	-	-	-	1323
$\gamma p \to K^+ \Lambda$	611	118	69	410	-	-	-	-	66	66	89	89	-	-	-	-	1518
$\gamma p \to K^+ \Sigma^0$	2949	116	-	320	-	-	-	-	-	-	52	52	-	-	-	-	3489
Sum	18310	3043	1133	1508	103	147	-	-	66	66	141	141	-	-	-	-	24668

KY production reactions

Kamano, Nakamura, Lee, Sato, 2012



Partial wave amplitudes of pi N scattering

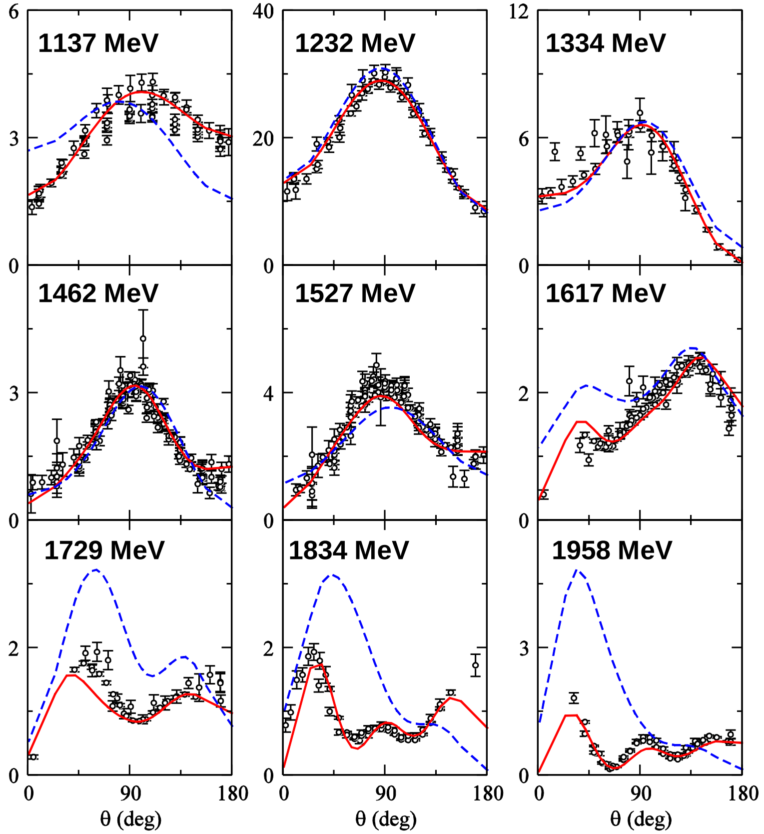


Single pion photoproduction

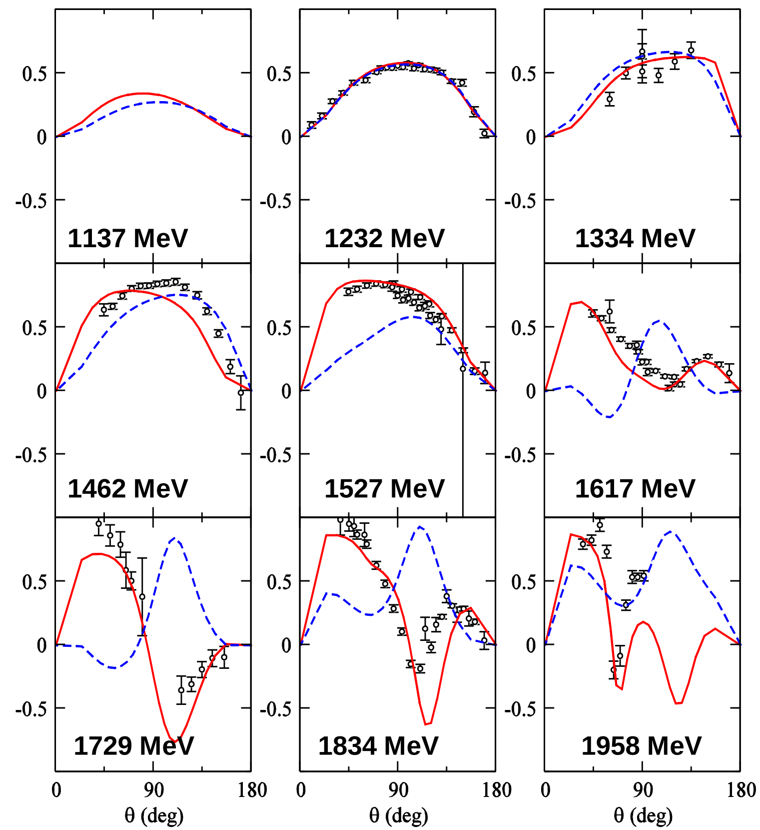
Kamano, Nakamura, Lee, Sato, 2012

$$\gamma p \rightarrow \pi^0 p$$

Angular distribution $d\sigma/d\Omega$ (μb/sr)



Photon asymmetry Σ



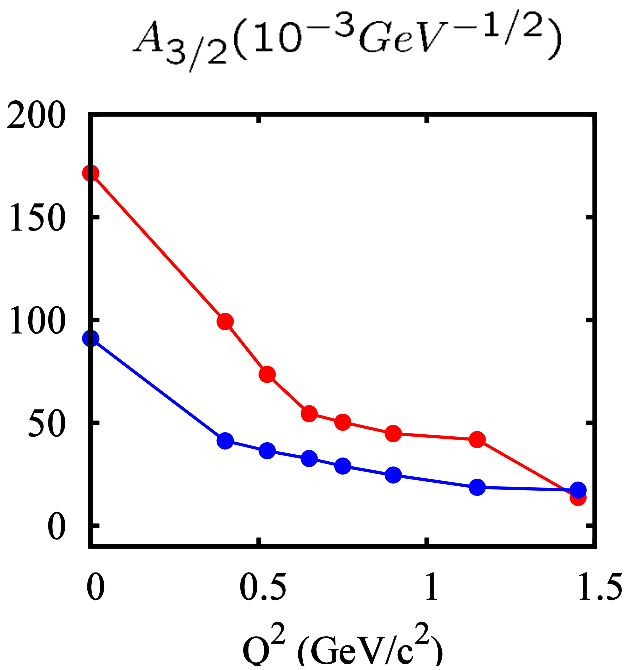
Kamano, Nakamura, Lee, Sato, 2012

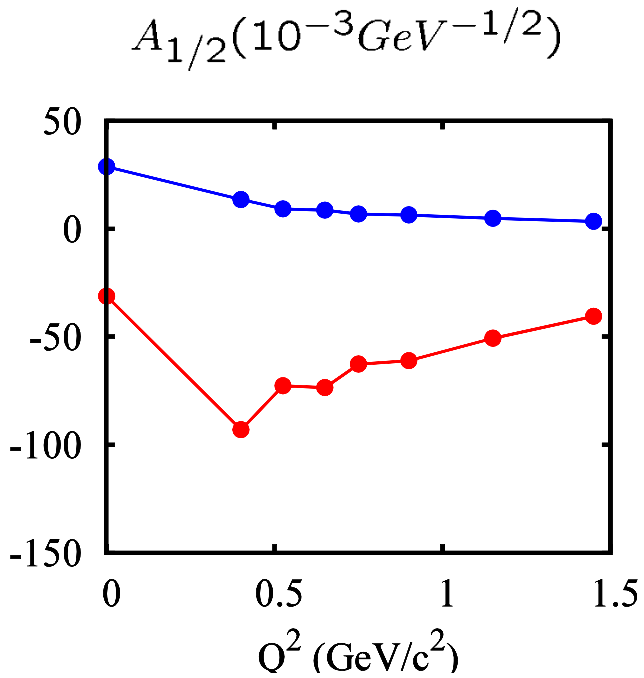
Previous model (fitted to γN → πN data *up to 1.6 GeV*)
[PRC77 045205 (2008)]

N-N* form factors at Resonance poles

Suzuki, Julia-Diaz, Kamano, Lee, Matsuyama, Sato, PRL104 065203 (2010)
Suzuki, Sato, Lee, PRC82 045206 (2010)

Nucleon - 1st D13 e.m. transition form factors

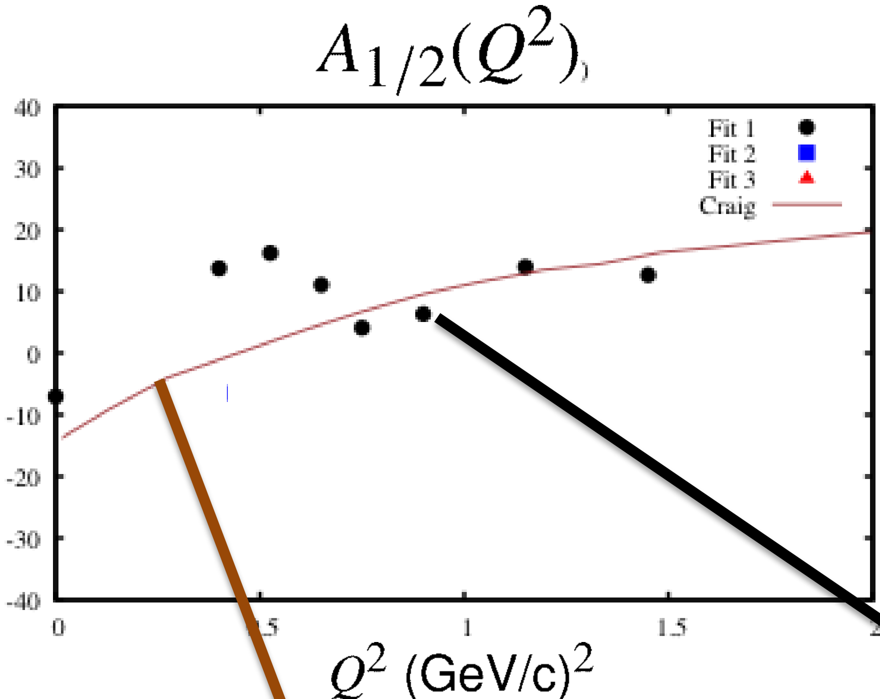


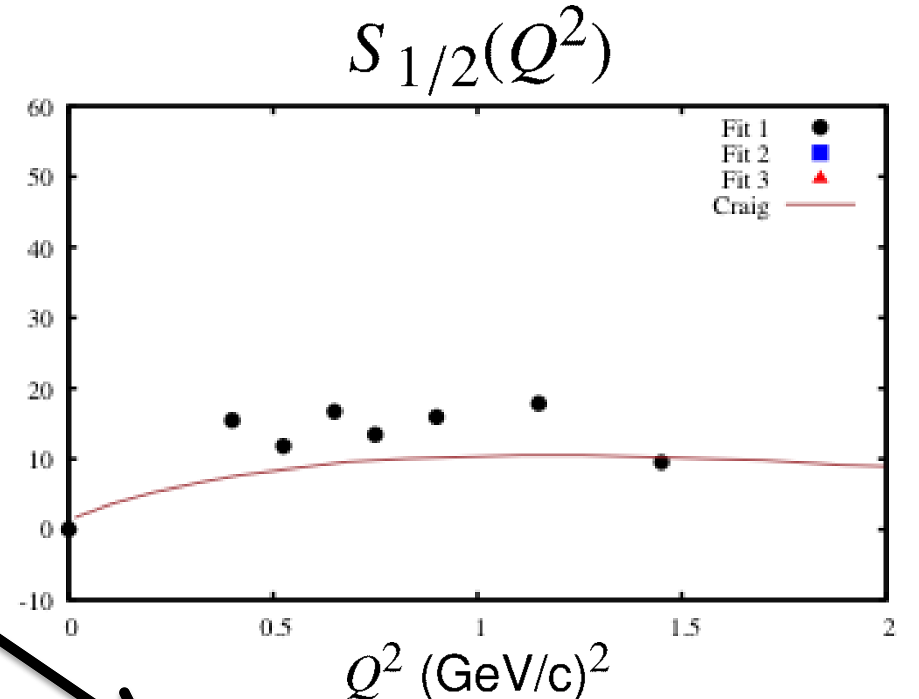


Real part —●—   Imaginary part - - -

Form factors(complex numbers) are derived from the residue of the amplitude at resonance pole.
Identified with exact solution of fundamental theory (QCD)

γ p → Roper e.m. transition

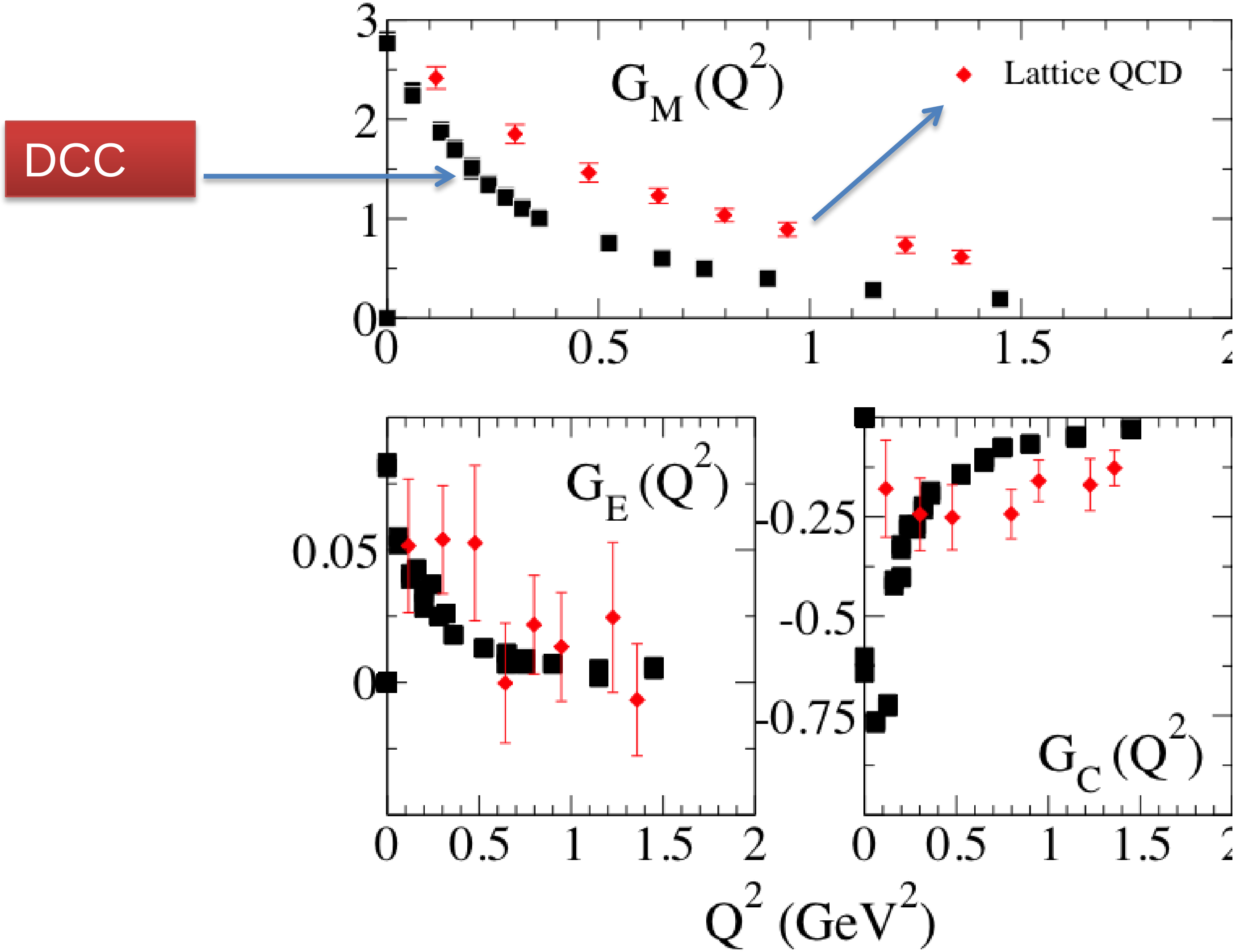




"Static" form factor from DSE-model calculation. (C. Roberts et al, 2011)

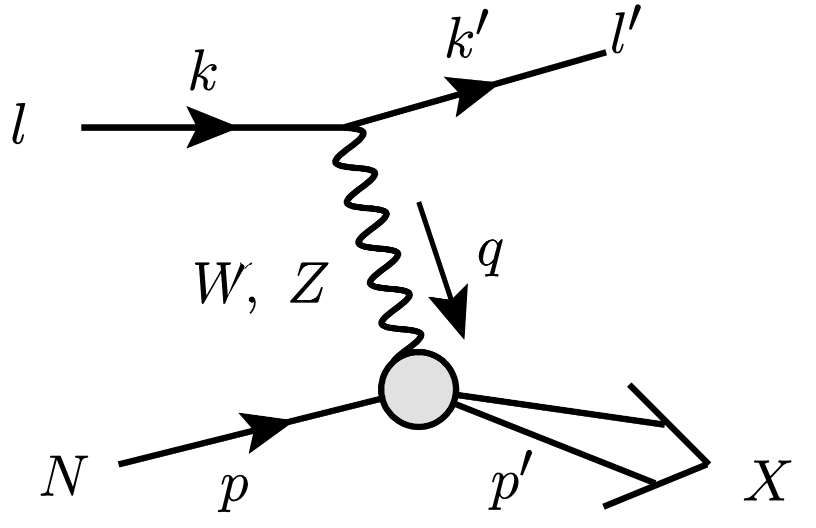
"Bare" form factor determined from our DCC analysis (2010).

γ N → Δ(1232) form factors compared with Lattice QCD data (2006)

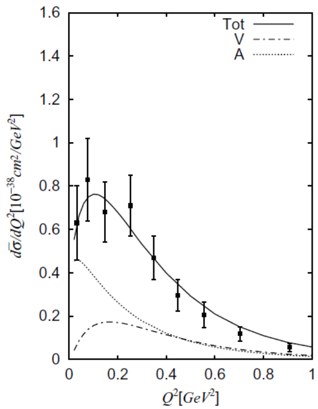


Neutrino reaction in resonance region W<2GeV

Opportunity to apply the knowledge of meson production reaction in the N* resonance region for electroweak reactions

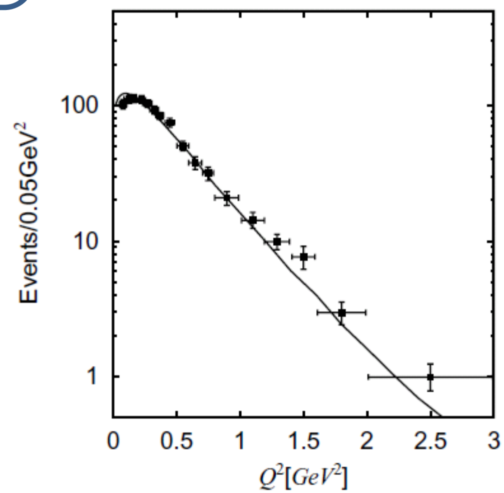


$$p(\nu_\mu, \mu^- \pi^+)p$$

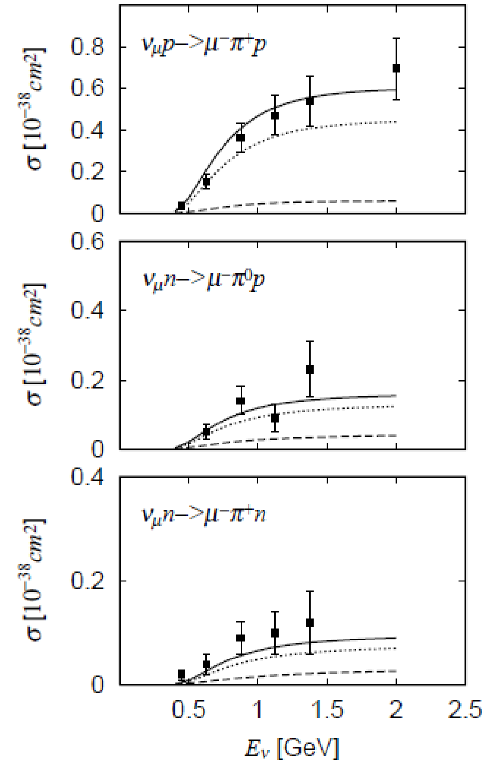


$0.5 < E_\nu < 6GeV$

Barish et al.(79) ANL



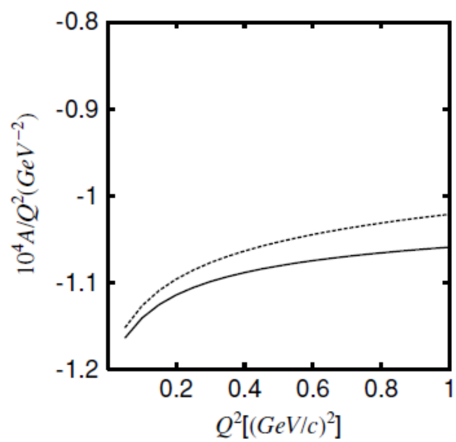
Kitagaki et al. (90) BNL



Parity violating asymmetry.

$$A = \frac{d\sigma(h_e = +1) - d\sigma(h_e = -1)}{d\sigma(h_e = +1) + d\sigma(h_e = -1)}$$

$$= -\frac{Q^2 G_F}{\sqrt{2}(4\pi\alpha)} \frac{N}{D},$$



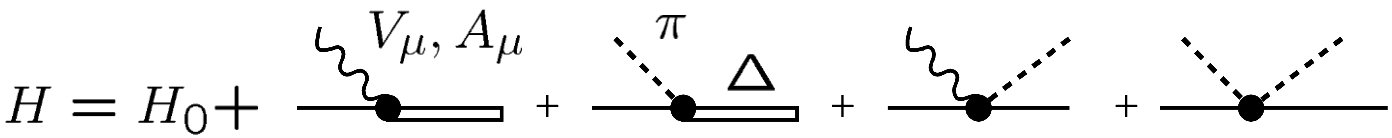
W=1.232, theta=110 deg

Delta(1232) resonance region (W<1.3GeV, SL model)

Start from Lagrangian based on chiral symmetry and electroweak Standard Model

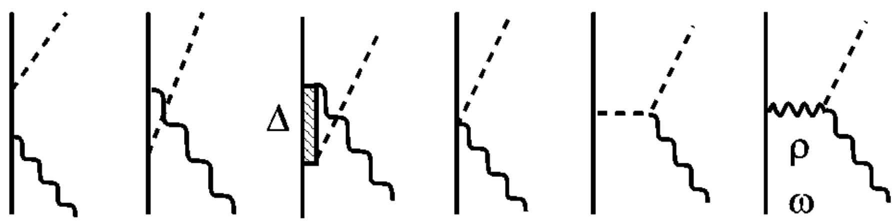
Sato,Uno,Lee PRC67(2003) CC
Matsui,Sato,Lee PRC72(2005) NC, PV(e,e')

Effective Hamiltonian



resonance Non-resonant int.

Vector



Axial vector