Nucleon resonances from dynamical coupled channel approach of meson production reactions

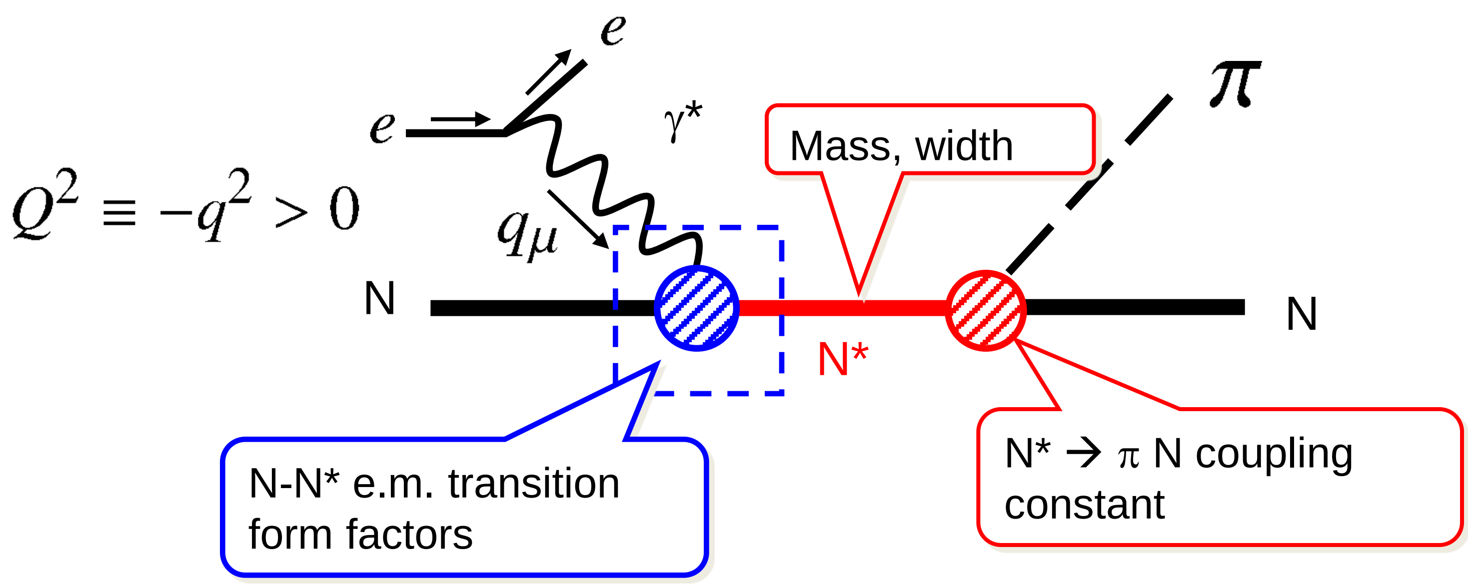
T. Sato Osaka U

Report on new results from our extended analysis of meson production reactions

Contents

- ➢ Coupled channel reaction model of meson production reaction
- ➢ Analysis of meson production reaction
- ➢ Extraction of resonance parameters
- ✓ Resonance mass and width
- ✓ Role of reaction dynamics on resonance properties
- ➢ Summary

Extract resonance parameters from meson production reactions

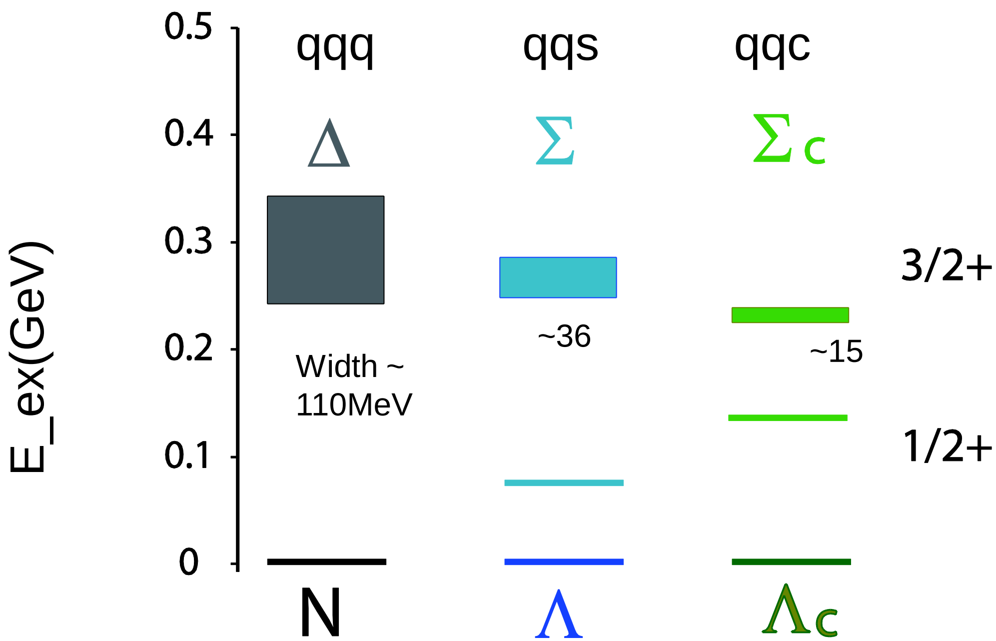


Recent high precision data of meson photo- and electro-production reactions open an opportunity for *quantitative* study of the N* structure.

Feature of N*,Δ resonances

- large width (~> 100MeV) and overlapping of nucleon resonances
- Unique system to examine interplay among scattering states and ‘excited’ state

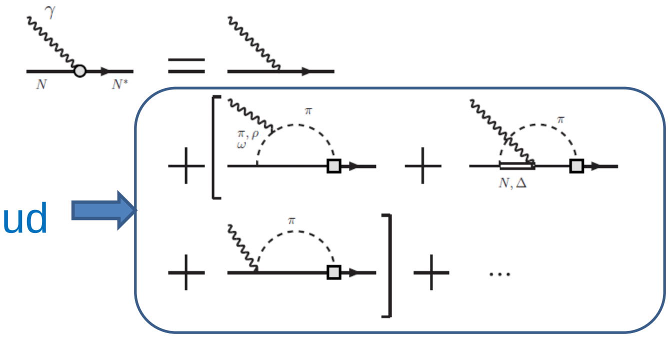
Properties of resonance states can be understood only when the interplay is properly considered



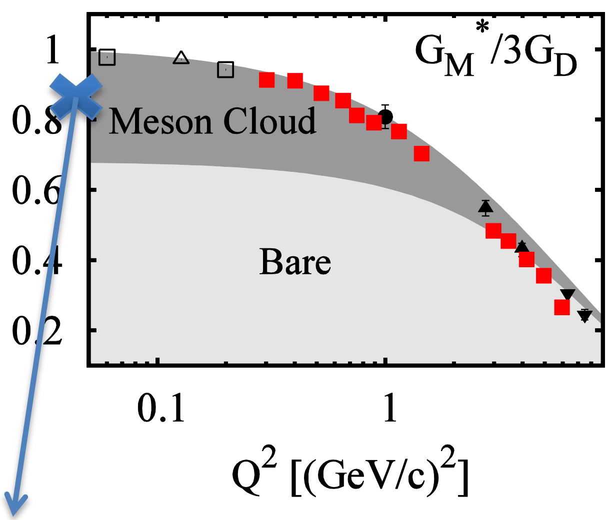
analyze properties of resonances

lesson from the electromagnetic form factors of Delta(1232) **γ N → Δ (1232)**

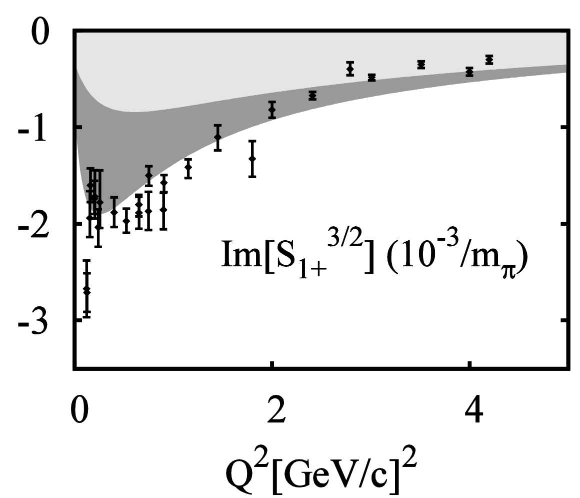
Meson cloud



M1: Magnetic dipole



C2: Coulomb quadrupole

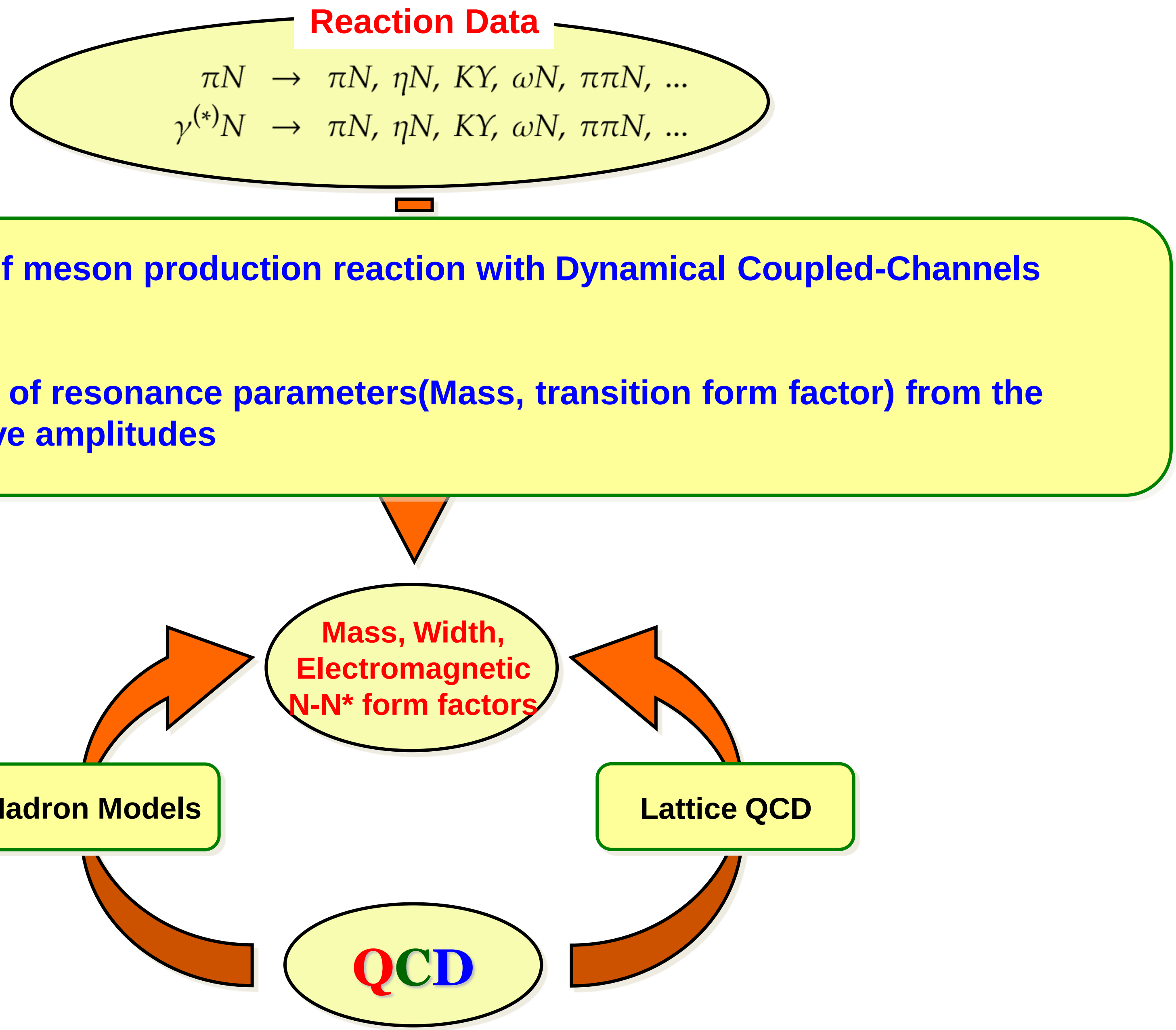


Note:
Most of the available static hadron models give $G_M(Q^2)$ close to "Bare" form factor.

Large deformation from pion cloud

Sato, Lee 96,01

Our approach



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

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

r: excited states $N^*, \Delta, \rho, \sigma$

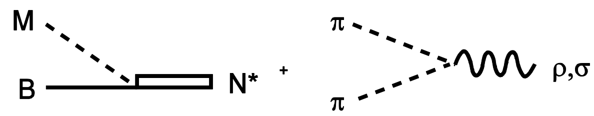
MB: scattering state ‘long range’

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

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

Excited baryon(N*,Delta) and meson : mass, decay vertex

m_0 (in H_0) $\Gamma_{r,MB}$

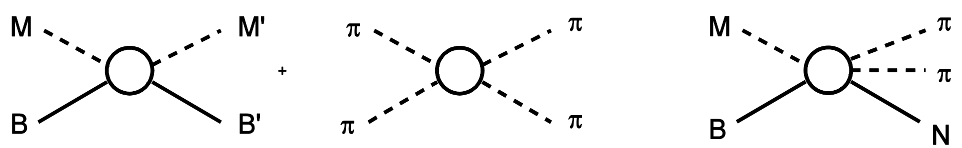


- Effective model of QCD
- Phenomenological parameters to be determined from data

For each N* and Delta, common vertex cutoff for all MB channel

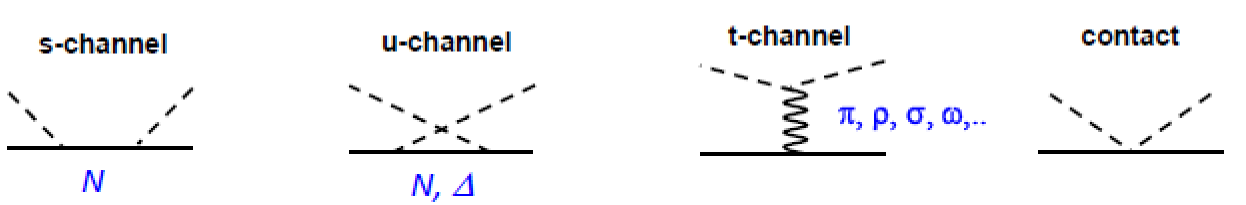
MB scattering states: non-resonant interaction with meson exchange picture

V_{MB}



Start from ‘chiral Lagrangian’ and construct meson-exchange ‘potential’

Use SU(3) for PBB, VBB vertex except KNS, improve pipi s-wave model.

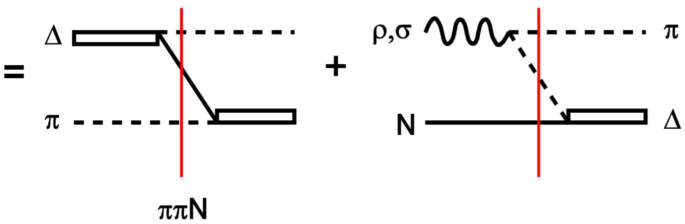


Scattering amplitude of pion and photon induced meson production amplitudes are given by solving coupled channel LS equation(3-dim reduction) in momentum space

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

Scattering amplitudes satisfy two-body and three-body unitarity

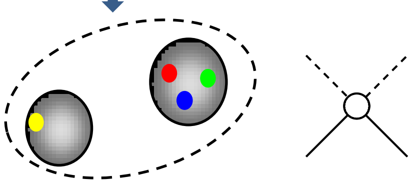
particle exchange interaction $Z^{(E)}$ =

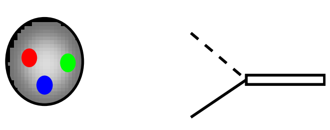


After manupilation of the formula

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

α, β Meson-Baryon channel i, j Resonances





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	< 2.1 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

Extended to include KY production reaction, higher W

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

omega N, pipi N are not included in fit

Kamano, Nakamura, Lee, Sato, 2013

Data sets

$\pi N \to \pi N$ Amplitudes from SAID analysis

Total 1940

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}	55×2
D_{15}	61×2	D_{35}	45×2
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		946

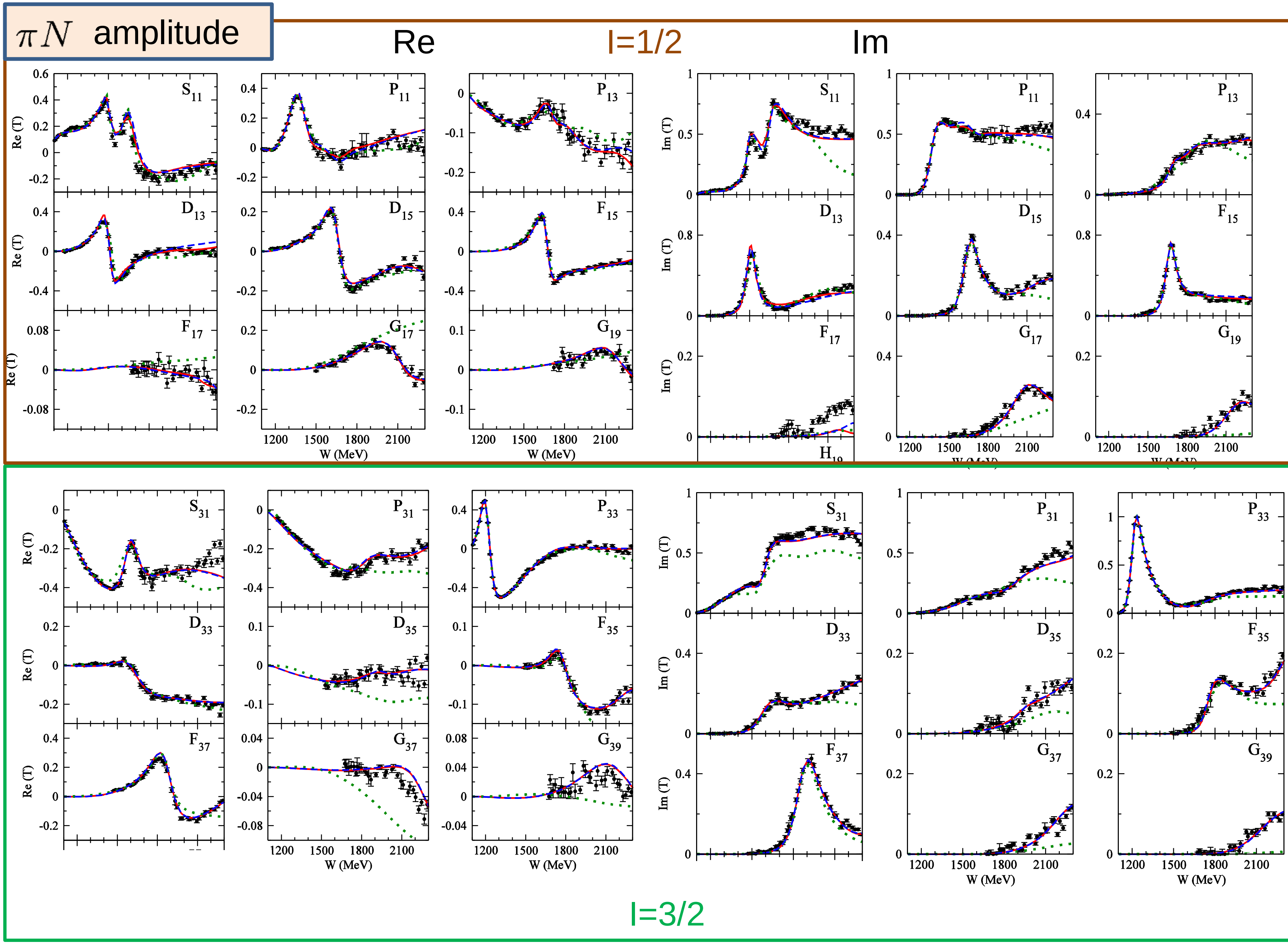
Hadronic processes: from the complication of Bonn-Gatchina

Total 2497

	$d\sigma/d\Omega$	P
$\pi^- p \to \eta p$	294	–
$\pi^- p \to K^0\Lambda$	587	354
$\pi^- p \to K^0\Sigma^0$	259	90
$\pi^+ p \to K^+\Sigma^+$	609	304
Sum	1749	748

TABLE IV. The number of data points of photoproduction processes included in our fits. The data are from compilation of Bonn-Gatchina.

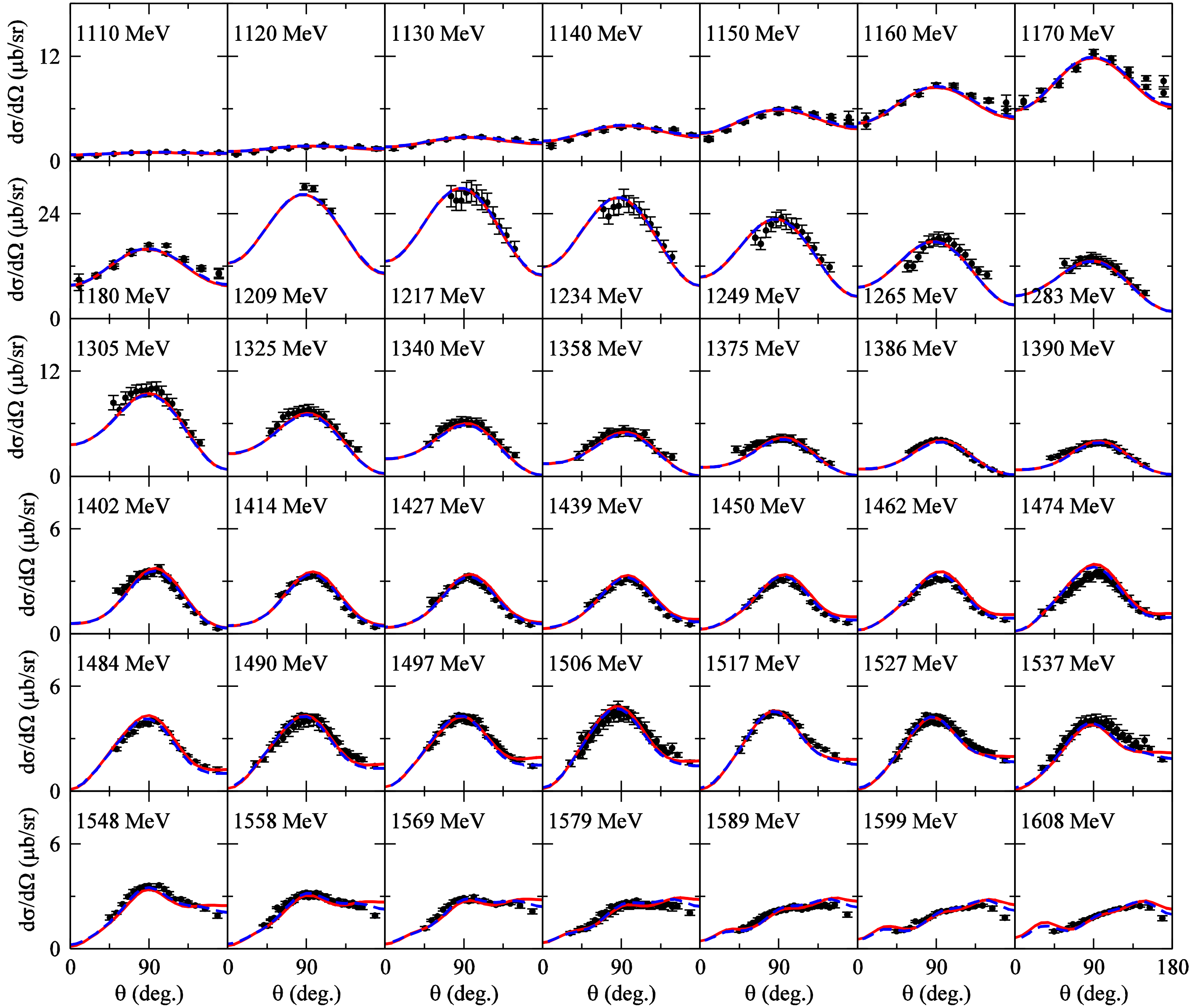
	$d\sigma/d\Omega$	Σ	T	P	G	H	E	F	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$	sum
$\gamma p \to \pi^0 p$	4414	1866	389	607	75	71	140	–	7	7	–	–	7576
$\gamma p \to \pi^+ n$	2475	899	661	252	86	128	231	–	–	–	–	–	4732
$\gamma p \to \eta p$	780	151	50	–	–	–	–	–	–	–	–	–	981
$\gamma p \to K^+\Lambda$	1320	118	66	1336	–	–	–	–	160	159	66	66	3291
$\gamma p \to K^+\Sigma^0$	1280	87	–	95	–	–	–	–	–	–	94	94	1650
$\gamma p \to K^0\Sigma^+$	276	15	–	72	–	–	–	–	–	–	–	–	363
Sum	10545	3136	1166	2362	161	199	371	–	167	166	160	160	18593



πN amplitude
Re
I=1/2
Im
I=3/2
W (MeV)

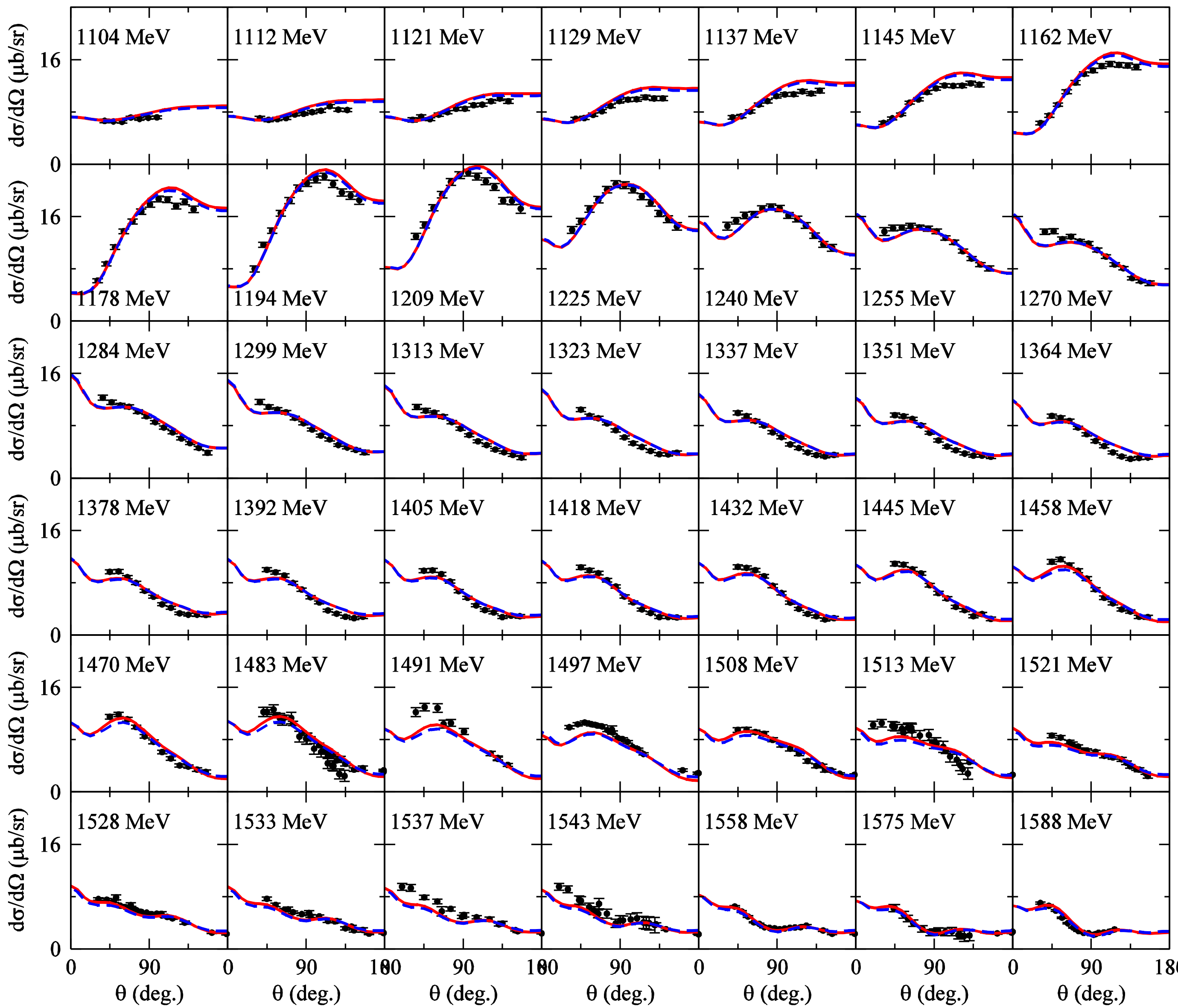
$$\gamma + p \to \pi^0 p$$

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

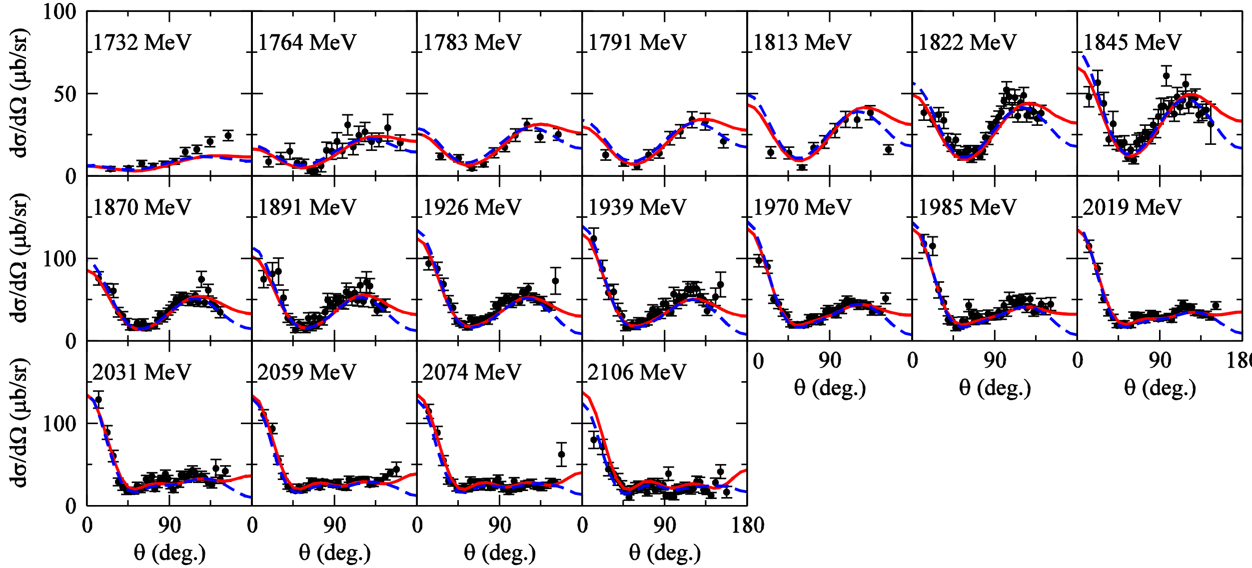


$\gamma + p \to \pi^+ n$

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

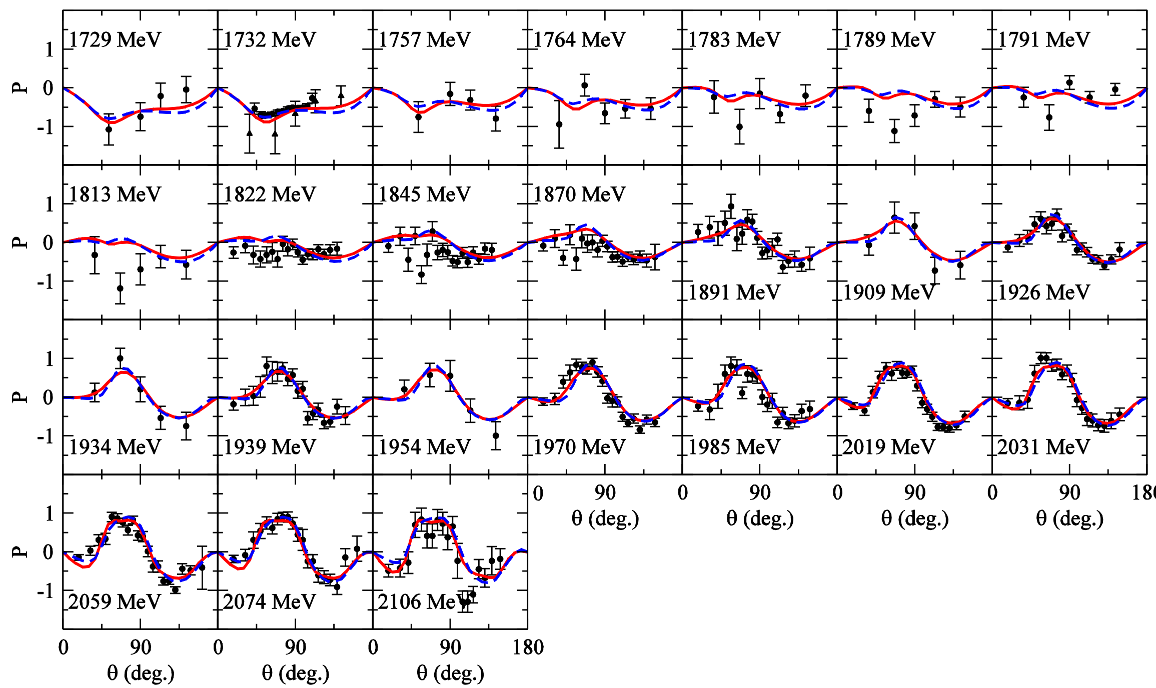


$$\frac{d\sigma}{d\Omega}$$



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

P



Extraction of resonance poles and residues of scattering amplitudes

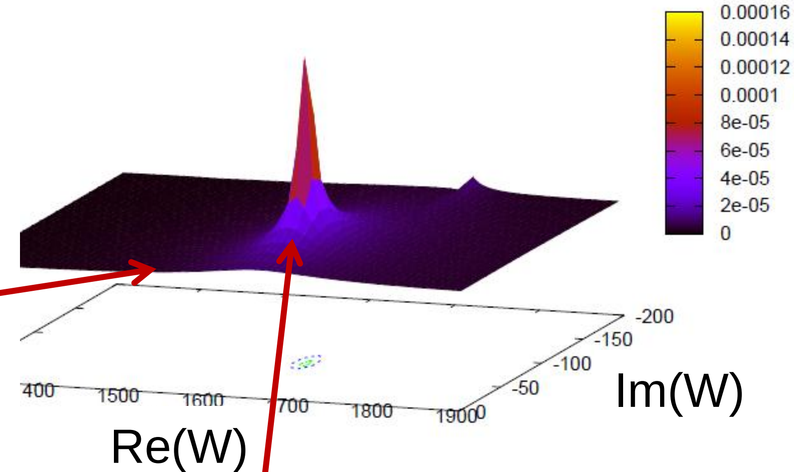
Extraction of resonance parameters

Observables: cross section, polarization

Coupled channel reaction model of meson production reactions

Partial wave amplitude

$$\mathcal{F}(W)$$



Analytic continuation to complex W

Characterize resonance from pole and residue of the amplitude

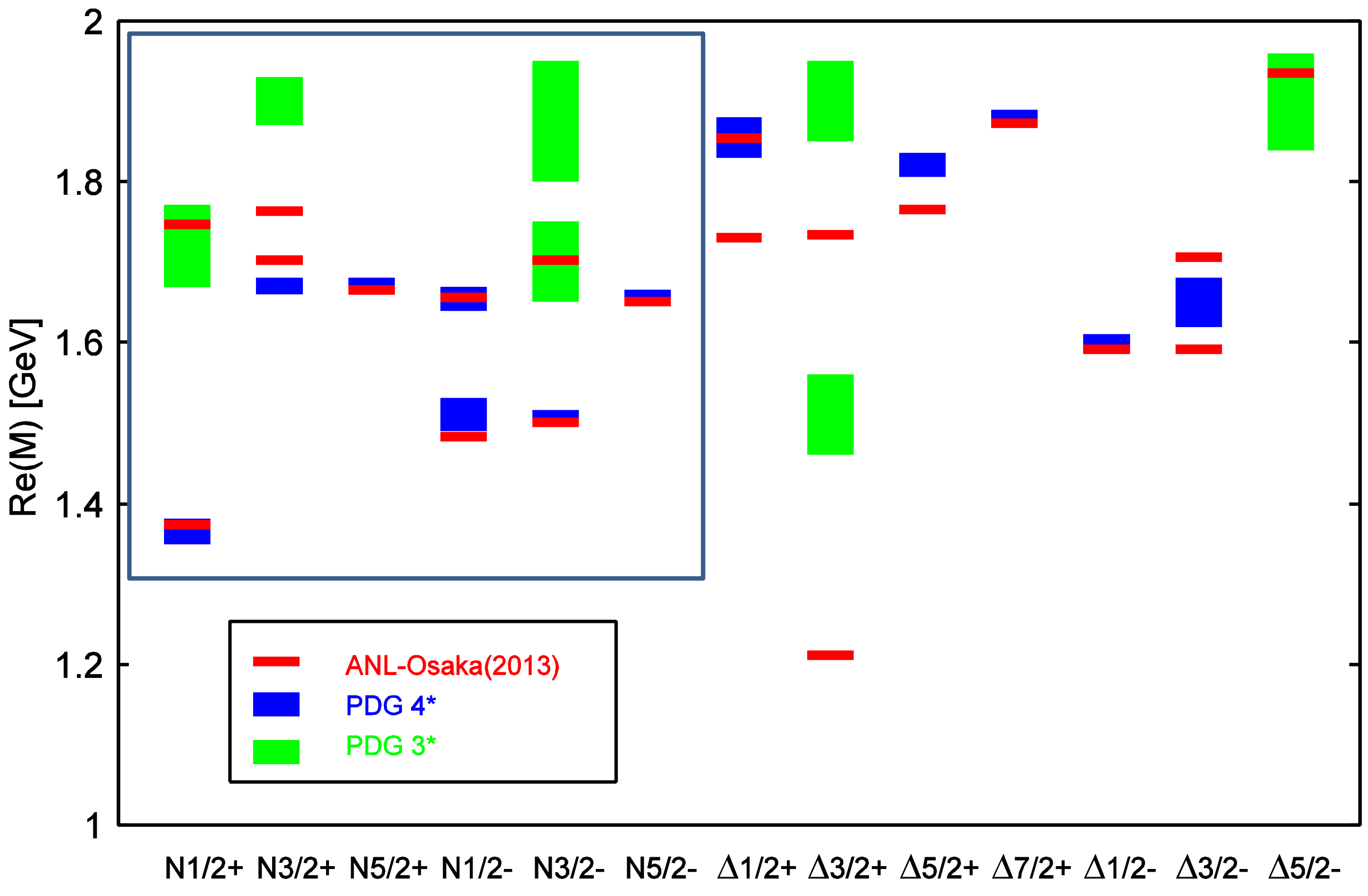
$$< f|\mathcal{F}(W)|i > \sim \frac{< f|V|\phi_R >< \tilde{\phi}_R|V|i >}{W - M + i\Gamma/2}$$

Resonance parameter

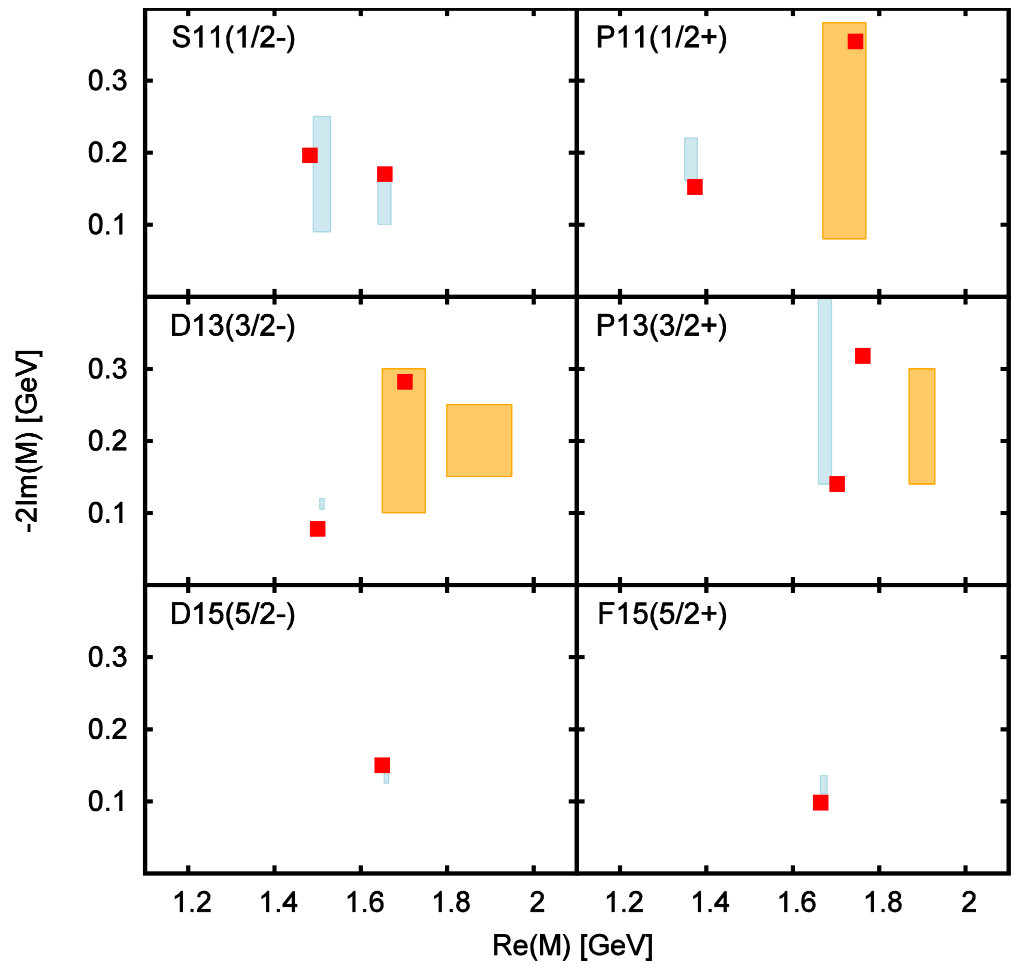
Pole position → mass, width

Residue → Form factors, coupling constants

Spectrum of nucleon resonances (N* and Delta)from the ANL-Osaka coupled channel analysis(2013 model) of meson production reactions Real part of the resonance pole position



N* mass and width ANL-Osaka(10)



PDG 4*(7) PDG 3*(4)

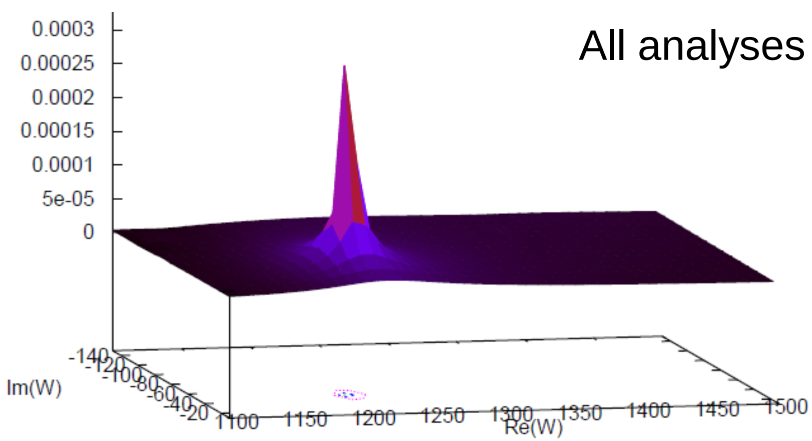
resonance properties

- P33
- P11:

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 Gev-{1/2}	-129+34i	-117+10i	---	-124+4i	---
A_3/2	-257+12i	-249+12i	---	-251+39i	---



piN amplitude |F| on complex W plane

All analyses agree reasonably well with each other

JLMS (our previous model)
Phys. Rev. C76 (2007)065201
B. Julia-Diaz et al.

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

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

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

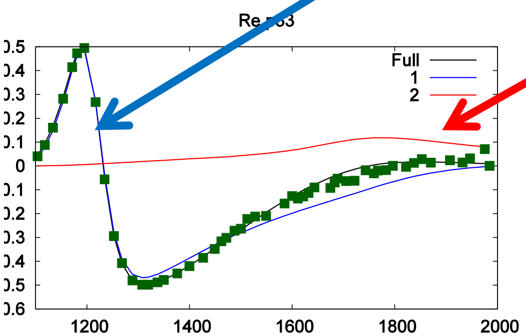
Second Delta33

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

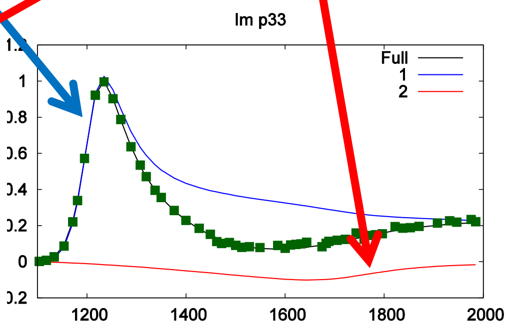
Weak coupling with piN, sizable coupling with gamma N

First P33

Second P33



Re

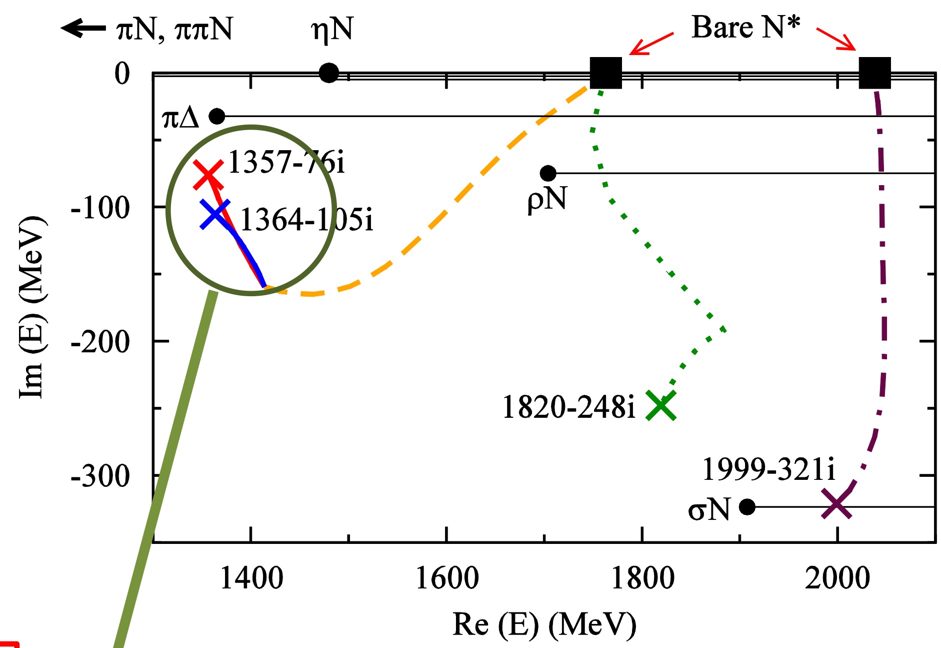


Im

Pi-N amplitude

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

P11 resonance



'Roper'

	ANL-Osaka	JLMS	Julich	Bonn-Gachina	GWU/VPI
Mass(MeV)	1374-76i/ 1429 -147i	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	

Summary

- We have investigated within a dynamical coupled channel model of piN and gammaN reactions up to 2GeV

- The meson baryon channels included in calculations are

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

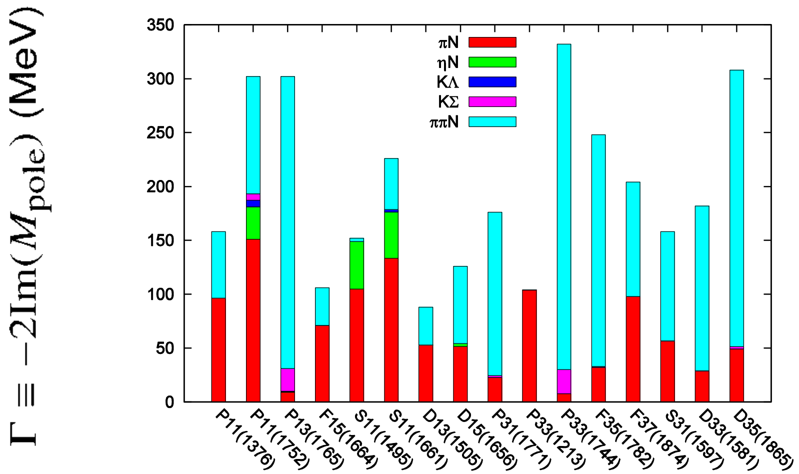
- Parameters for non-resonant interaction is mainly constrained by the fit to low energy region W<1.4GeV and N* parameters are determined by the fit up to W<2GeV

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

- Extracted pole positions are consistent with those listed by PDG, but some differences.

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 of the nature of resonance poles

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)

Estimation of resonance amplitude

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

α, β Meson-Baryon channel i, j Resonances

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

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