Development of the Bonn-Gatchina partial wave analysis method and search for parity partners

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Excited QCD 2013

3-9 February 2013, Sarajevo

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Data Base | Meson Spectroscopy | Baryon Spectroscopy | NN-interaction | Formalism

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- SPIRES
- PDG Homepage
- Durham Data Base
- Bonn Homepage

CB-ELSA Homepage

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Last changes: January 26th, 2010.

Search for baryon states

1. **Analysis of single and double meson photoproduction reactions.**
   $\gamma p \to \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N, \pi\eta N$, **CB-ELSA, CLAS, GRAAL, LEPS.**
2. **Analysis of single and double meson production in pion-induced reactions.**
   $\pi N \to \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N$.

Search for meson states

1. **Analysis of the $p\bar{p}$ annihilation at rest and $\pi\pi$ interaction data.**
2. **Analysis of the $p\bar{p}$ annihilation in flight into two and tree meson final state.**
3. **Analysis of the BES III data on J/Ψ decays (in collaboration with JINR Dubna).**

Analysis of NN interaction

1. **Analysis of single and double meson production $NN \to \pi NN$ and $\pi\pi NN$ (Wasa, PNPI, HADES)**
2. **Analysis of hyperon production $NN \to K\Lambda p$ (WASA, HADES)**

Energy dependent approach

In many cases an unambiguous partial wave decomposition at fixed energies is impossible. Then the energy and angular parts should be analyzed together:

$$A(s,t) \;=\; \sum_{\beta\beta' n} A_n^{\beta\beta'}(s) Q^{(\beta)+}_{\mu_1\ldots\mu_n} F^{\mu_1\ldots\mu_n}_{\nu_1\ldots\nu_n} Q^{(\beta')}_{\nu_1\ldots\nu_n}$$

1. **C. Zemach, Phys. Rev. 140, B97 (1965); 140, B109 (1965).**
2. **S.U.Chung, Phys. Rev. D 57, 431 (1998).**
3. **B. S. Zou and D. V. Bugg, Eur. Phys. J. A 16, 537 (2003)**

1. **Correlations between angular part and energy part are under control.**
2. **Unitarity and analyticity can be introduced from the beginning.**
3. **Parameters can be fixed from a combined fit of many reactions.**

1. Anisovich:2001ra A. V. Anisovich, V. V. Anisovich, V. N. Markov, M. A. Matveev and A. V. Sarantsev, J. Phys. G G 28, 15 (2002)
2. A. Anisovich, E. Klempt, A. Sarantsev and U. Thoma, Eur. Phys. J. A 24, 111 (2005)
3. A. V. Anisovich and A. V. Sarantsev, Eur. Phys. J. A 30, 427 (2006)
4. A. V. Anisovich, V. V. Anisovich, E. Klempt, V. A. Nikonov and A. V. Sarantsev, Eur. Phys. J. A 34, 129 (2007).

πN vertices

$$N^{+}_{\mu_1\ldots\mu_n} = X^{(n)}_{\mu_1\ldots\mu_n} \qquad N^{-}_{\mu_1\ldots\mu_n} = i\gamma_\nu\gamma_5 X^{(n+1)}_{\nu\mu_1\ldots\mu_n} \qquad (1)$$

γN vertices

$$Q^{(1+)\mu}_{\alpha_1\ldots\alpha_n} = \gamma_\mu i\gamma_5 X^{(n)}_{\alpha_1\ldots\alpha_n}\,, \qquad Q^{(1-)\mu}_{\alpha_1\ldots\alpha_n} = \gamma_\xi\gamma_\mu O^{(n+1)}_{\xi\alpha_1\ldots\alpha_n}\,,$$

$$Q^{(2+)\mu}_{\alpha_1\ldots\alpha_n} = \gamma_\nu i\gamma_5 X^{(n+2)}_{\mu\nu\alpha_1\ldots\alpha_n}\,, \qquad Q^{(2-)\mu}_{\alpha_1\ldots\alpha_n} = X^{(n+1)}_{\mu\alpha_1\ldots\alpha_n}\,,$$

$$Q^{(3+)\mu}_{\alpha_1\ldots\alpha_n} = \gamma_\nu i\gamma_5 X^{(n+1)}_{\nu\alpha_1\ldots\alpha_n} g^{\perp}_{\mu\alpha_n}\,, \qquad Q^{(3-)\mu}_{\alpha_1\ldots\alpha_n} = X^{(n-1)}_{\alpha_2\ldots\alpha_n} g^{\perp}_{\alpha_1\mu}\,.$$

Fermion propagator for $J = N + \frac{1}{2}$

$$F^{\mu_1\ldots\mu_L}_{\nu_1\ldots\nu_L}(p) = (m+\hat{p})O^{\mu_1\ldots\mu_L}_{\alpha_1\ldots\alpha_L}\frac{L+1}{2L+1}\left(g^{\perp}_{\alpha_1\beta_1} - \frac{L}{L+1}\sigma_{\alpha_1\beta_1}\right)\prod_{i=2}^{L} g_{\alpha_i\beta_i} O^{\beta_1\ldots\beta_L}_{\nu_1\ldots\nu_L}$$

$$\sigma_{\alpha_i\alpha_j} = \frac{1}{2}(\gamma_{\alpha_i}\gamma_{\alpha_j} - \gamma_{\alpha_j}\gamma_{\alpha_i})$$

Parameterization of the partial wave amplitude

$$A_{1i} = K_{1j}(I - i\rho K)^{-1}_{ji}$$

and

$$K_{ij} = \sum_\alpha \frac{g_i^\alpha g_j^\alpha}{M_\alpha^2 - s} + f_{ij}(s) \qquad f_{ij} = \frac{f_{ij}^{(1)} + f_{ij}^{(2)}\sqrt{s}}{s - s_0^{ij}}.$$

where f_{ij} is non-resonant transition part.

For the small coupled initial state, e.g. photoproduction:

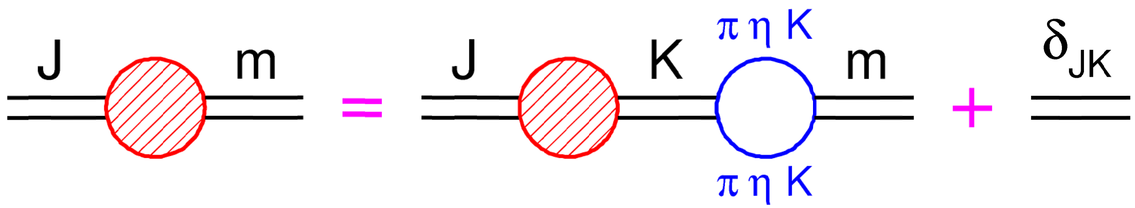
$$A_k = P_j(I - i\rho K)^{-1}_{jk}$$

The vector of the initial interaction has the form:

$$P_j = \sum_\alpha \frac{\Lambda^\alpha g_j^\alpha}{M_\alpha^2 - s} + F_j(s)$$

Here F_j is non-resonant production of the final state j.

N/D based (D-matrix) analysis of the data



$$D_{jm} = D_{jk} \sum_\alpha B_\alpha^{km}(s) \frac{1}{M_m - s} + \frac{\delta_{jm}}{M_j^2 - s} \qquad \hat{D} = \hat{\kappa}(I - \hat{B}\hat{\kappa})^{-1}$$

$$\hat{\kappa} = diag\left(\frac{1}{M_1^2 - s}, \frac{1}{M_2^2 - s}, \ldots, \frac{1}{M_N^2 - s}, R_1, R_2 \ldots\right)$$

$$\hat{B}_{ij} = \sum_\alpha B_\alpha^{ij} = \sum_\alpha \int \frac{ds'}{\pi} \frac{g_\alpha^{(R)i} \rho_\alpha(s', m_{1\alpha}, m_{2\alpha}) g_\alpha^{(L)j}}{s' - s - i0}$$

In the present fits we calculate the elements of the B^{ij}_α using one subtraction taken at the channel threshold $M_\alpha = (m_{1\alpha} + m_{2\alpha})$:

$$B^{ij}_\alpha(s) = B^{ij}_\alpha(M^2_\alpha) + (s - M^2_\alpha) \int\limits_{m^2_a}^{\infty} \frac{ds'}{\pi} \frac{g^{(R)i}_\alpha \rho_\alpha(s', m_{1\alpha}, m_{2\alpha}) g^{(L)j}_\alpha}{(s' - s - i0)(s' - M^2_\alpha)}.$$

In this case the expression for elements of the $\hat{B}$ matrix can be rewritten as:

$$B^{ij}_\alpha(s) = g^{(R)i}_a \left(b^\alpha + (s - M^2_\alpha) \int\limits_{m^2_a}^{\infty} \frac{ds'}{\pi} \frac{\rho_\alpha(s', m_{1\alpha}, m_{2\alpha})}{(s' - s - i0)(s' - M^2_\alpha)} \right) g^{(L)j}_\beta = g^{(R)i}_a B_\alpha g^{(L)j}_\beta$$

and D-matrix method equivalent to the K-matrix method with loop diagram with real part taken into account:

$$A = \hat{K}(I - \hat{B}\hat{K})^{-1} \qquad B_{\alpha\beta} = \delta_{\alpha\beta} B_\alpha$$

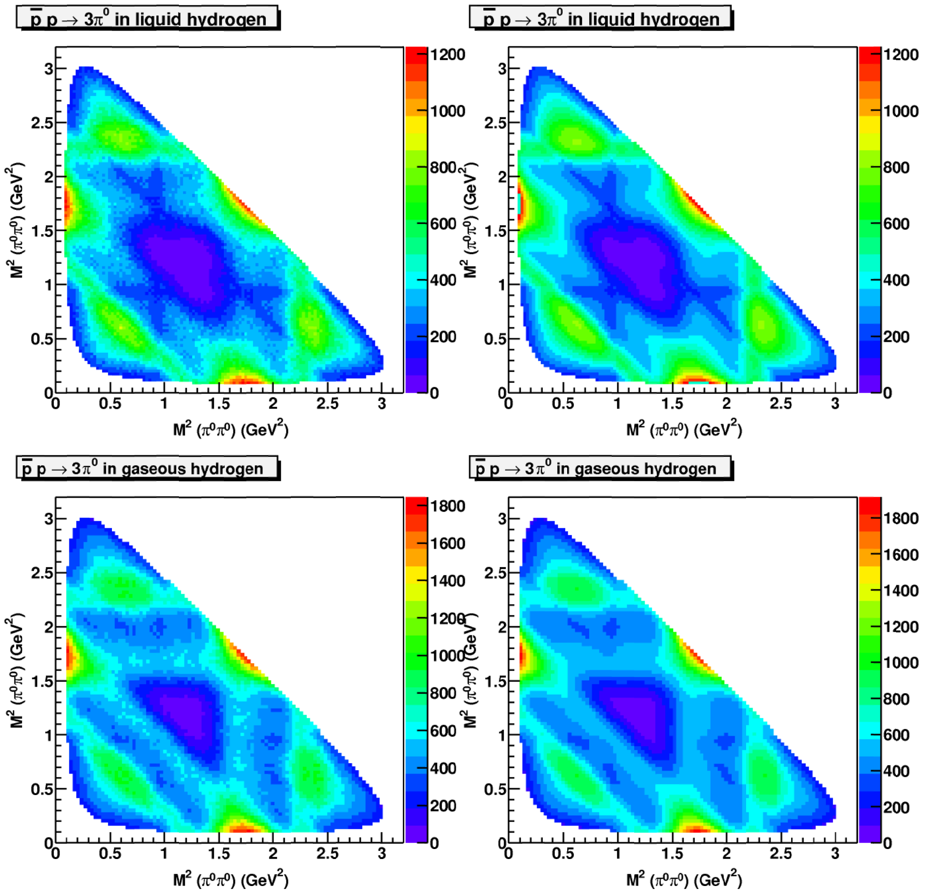
Meson spectroscopy. Two body reactions:

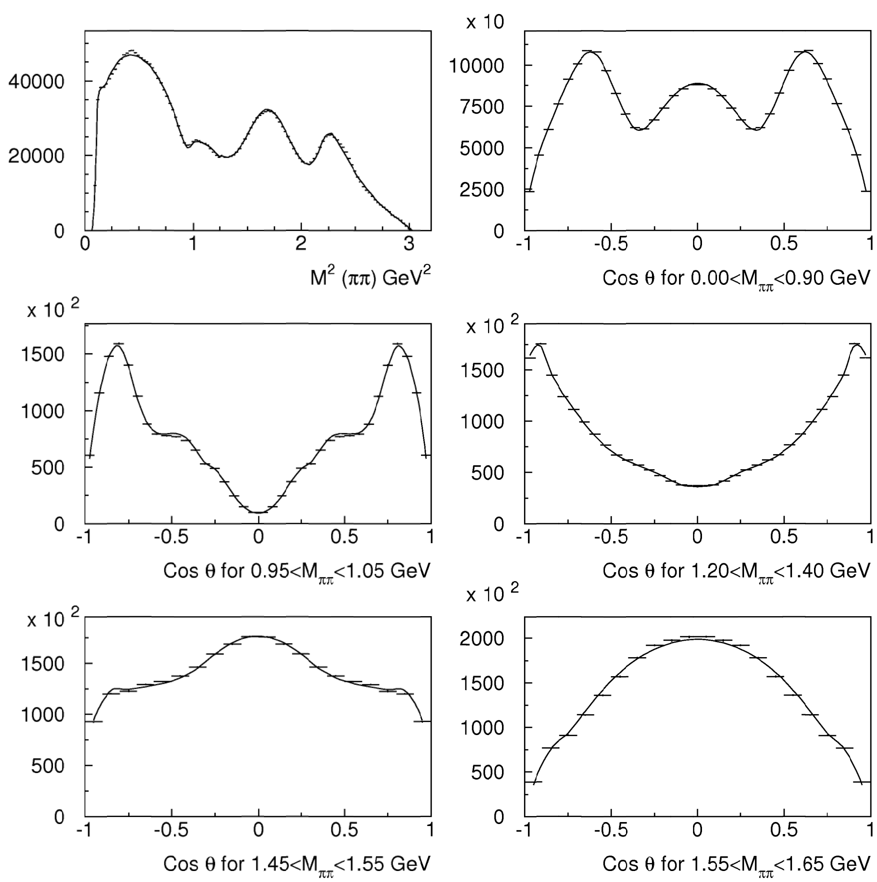
Reaction	Experiment	Reaction	Experiment
$\pi^+\pi^- \to \pi^+\pi^-$ (all waves)	CERN-Münich		
$\pi\pi \to \pi^0\pi^0$ (S-wave)	GAMS	$\pi\pi \to \pi^0\pi^0$ (S-wave)	E852
$\pi\pi \to \eta\eta$ (S-wave)	GAMS	$\pi\pi \to \eta\eta'$ (S-wave)	GAMS
$\pi\pi \to K\bar{K}$ (S-wave)	BNL	S-wave $\delta(\pi^+\pi^-)$	Ke4

Three body reactions from Crystal Barrel: (L-liquid, G-gaseous targets).

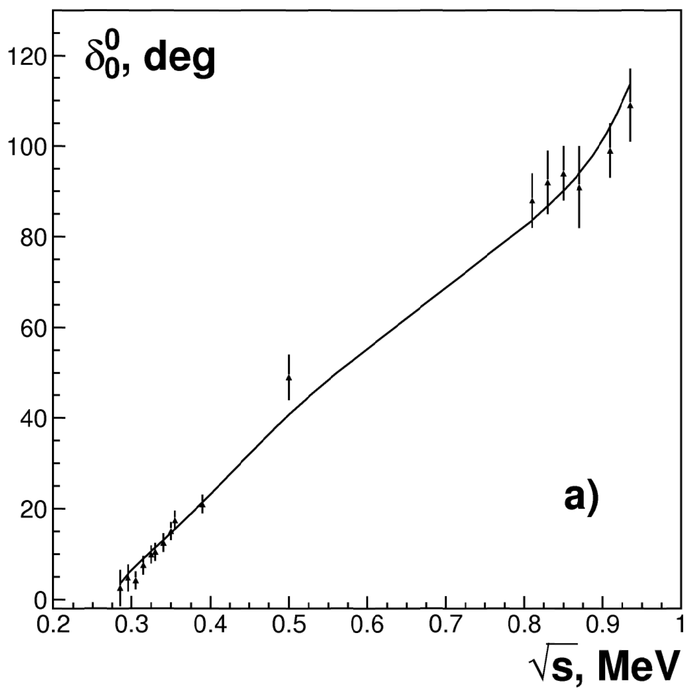
Reaction	Target	Reaction	Target	Reaction	Target
$\bar{p}p \to \pi^0\pi^0\pi^0$	(L) H_2	$\bar{p}p \to \pi^+\pi^0\pi^-$	(L) H_2	$\bar{p}p \to K_S K_S \pi^0$	(L) H_2
$\bar{p}p \to \pi^0\eta\eta$	(L) H_2	$\bar{p}n \to \pi^0\pi^0\pi^-$	(L) D_2	$\bar{p}p \to K^+K^-\pi^0$	(L) H_2
$\bar{p}p \to \pi^0\pi^0\eta$	(L) H_2	$\bar{p}n \to \pi^-\pi^-\pi^+$	(L) D_2	$\bar{p}p \to K_L K^\pm \pi^\mp$	(L) H_2
$\bar{p}p \to \pi^0\pi^0\pi^0$	(G) H_2			$\bar{p}n \to K_S K_S \pi^-$	(L) D_2
$\bar{p}p \to \pi^0\eta\eta$	(G) H_2			$\bar{p}n \to K_S K^- \pi^0$	(L) D_2
$\bar{p}p \to \pi^0\pi^0\eta$	(G) H_2				

Description of the $\bar{p}p \to 3\pi^0$ data (D-matrix method)

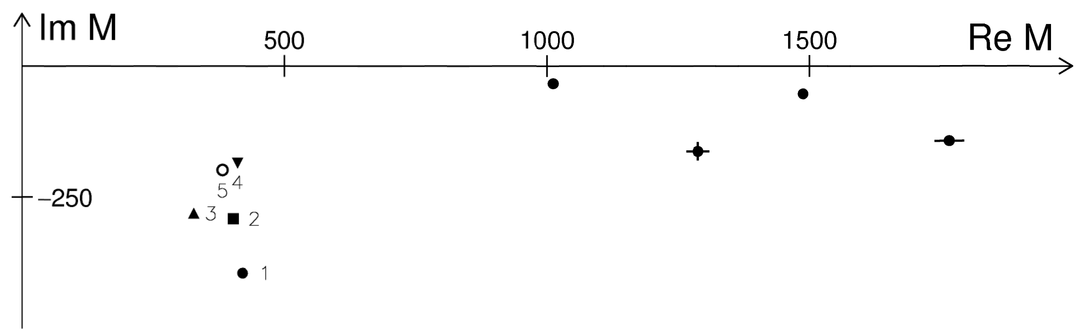




Pole position of the resonances



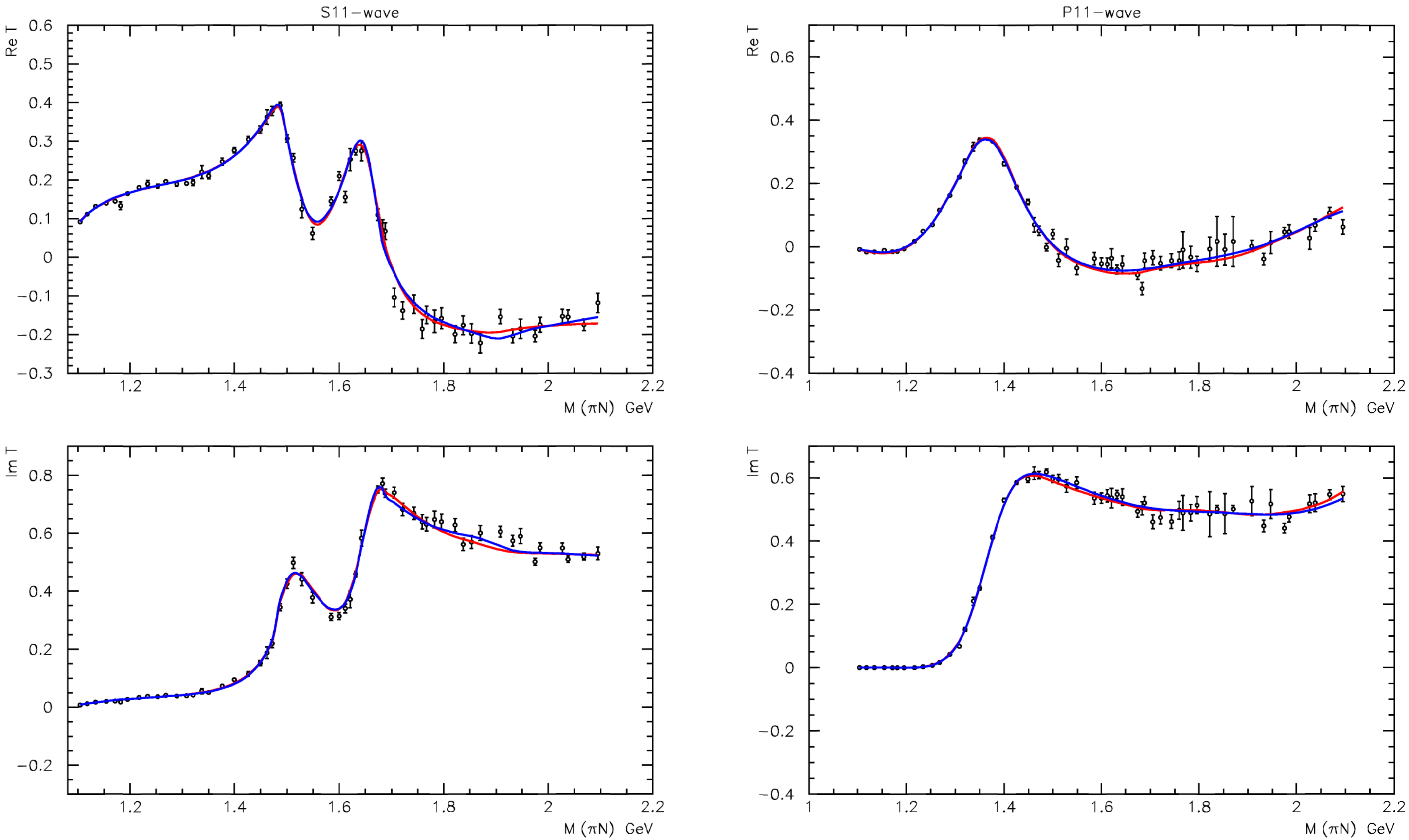
	K-matrix	D-matrix
σ-meson	420-i 395	407-i 281
$f_0(980)$	1014-i 31	1015-i 36
$f_0(1300)$	1302-i 140	1307-i 137
$f_0(1500)$	1487-i 58	1487-i 60
$f_0(1750)$	1738-i 152	1781-i 140



$445^{+16}_{-8} - i272^{+9}_{-13}$ **I.Caprini, G.Colangelo, and H.Leutwyler, Phys.Rev.Lett.96, 132001 (2006)**

$457^{+14}_{-15} - i279^{+11}_{-7}$ **R.Garcia-Martin, R.Kaminski, J.R.Pelaez, J.Ruiz de Elvira, and F.J.Yndurain**

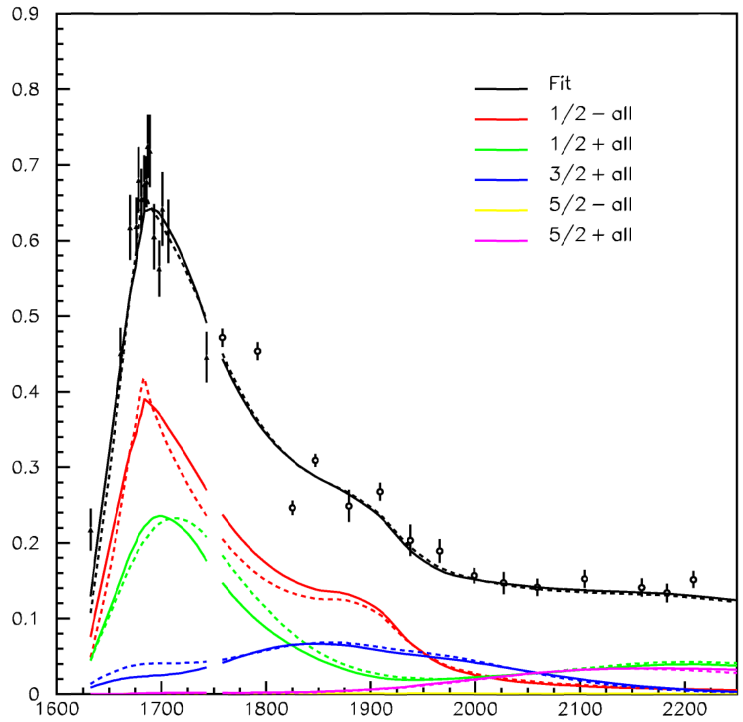
Description of the πN elastic amplitudes (GWU energy independent solution) with K-matrix and D-matrix solutions



The fit of the the $\pi^- p \to K\Lambda$ reaction

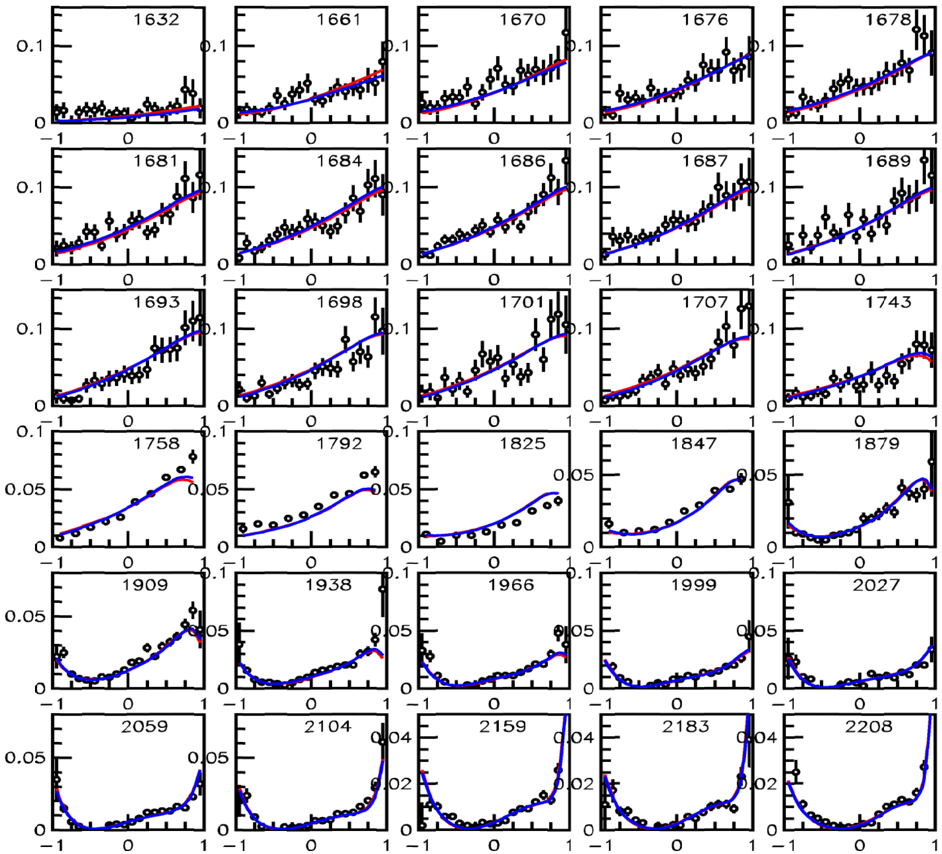
Full experiment for $\pi N \to K\Lambda$: differential cross section, analyzing power, rotation parameter.

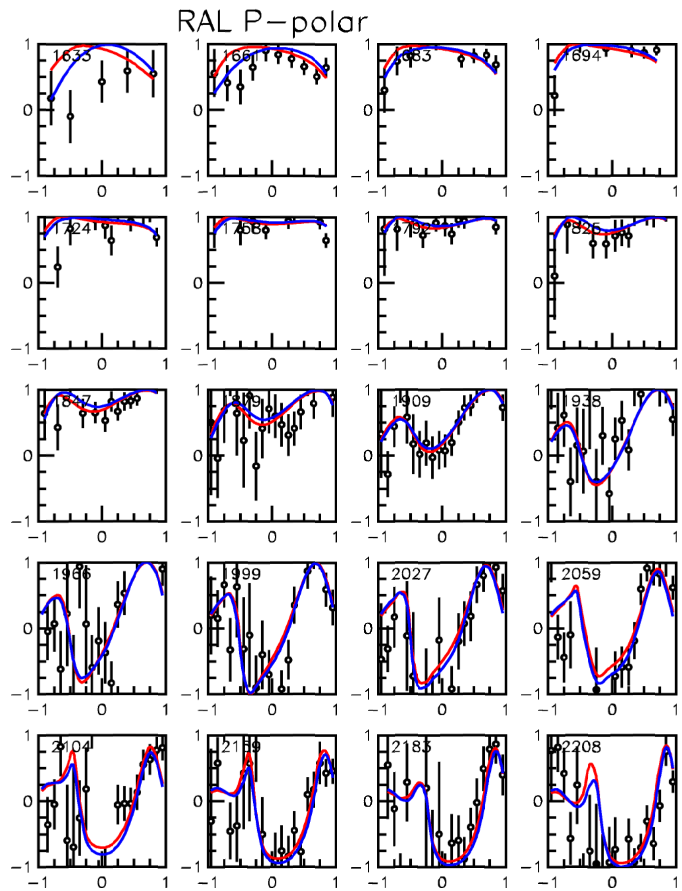
A clear evidence for resonances which are hardly seen (or not seen) in the elastic reactions: $N(1710)P_{11}$, $N(1900)P_{13}$,



The total cross section for the reaction $\pi^- p \to K^0\Lambda$ and contributions from leading partial waves in K-matrix (full) and D-matrix (dashed) solutions.

$\pi^- p \to K\Lambda$ $(d\sigma/d\Omega, P)$





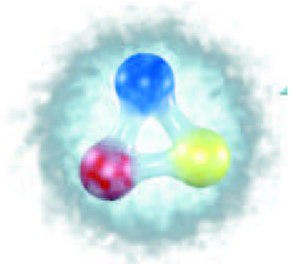
Pole parameters of the S_{11} states

	$N(1535)S_{11}$		$N(1650)S_{11}$		$N(1890)S_{11}$	
	K-matrix	D-matrix	K-matrix	D-matrix	K-matrix	D-matrix
$M_{\rm pole}$	1501±4	1494	1647±6	1651	1900±15	1905
$\Gamma_{\rm pole}$	134±11	116	103±8	95	90^{+30}_{-15}	106
Elastic residue	31±4	25	24±3	23	1±1	1.5
Phase	-(29±5)°	-38°	-(75±12)°	-62°	–	–
$\text{Res}_{\pi N\to N\eta}$	28±3	25	15±3	15	4±2	5
Phase	-(76±8)°	-69°	(132±10)°	140	(40±20)°	42°
$\text{Res}_{\pi N\to \Delta\pi}$	7±4	4	11±3	12	–	–
Phase	(147±17)°	157°	-(30±20)°	-40	–	–
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.116±0.010	0.107	0.033±0.007	0.029	0.012±0.006	0.010
Phase	(7±6)°	1°	-(9±15)°	0°	120±50°	150°

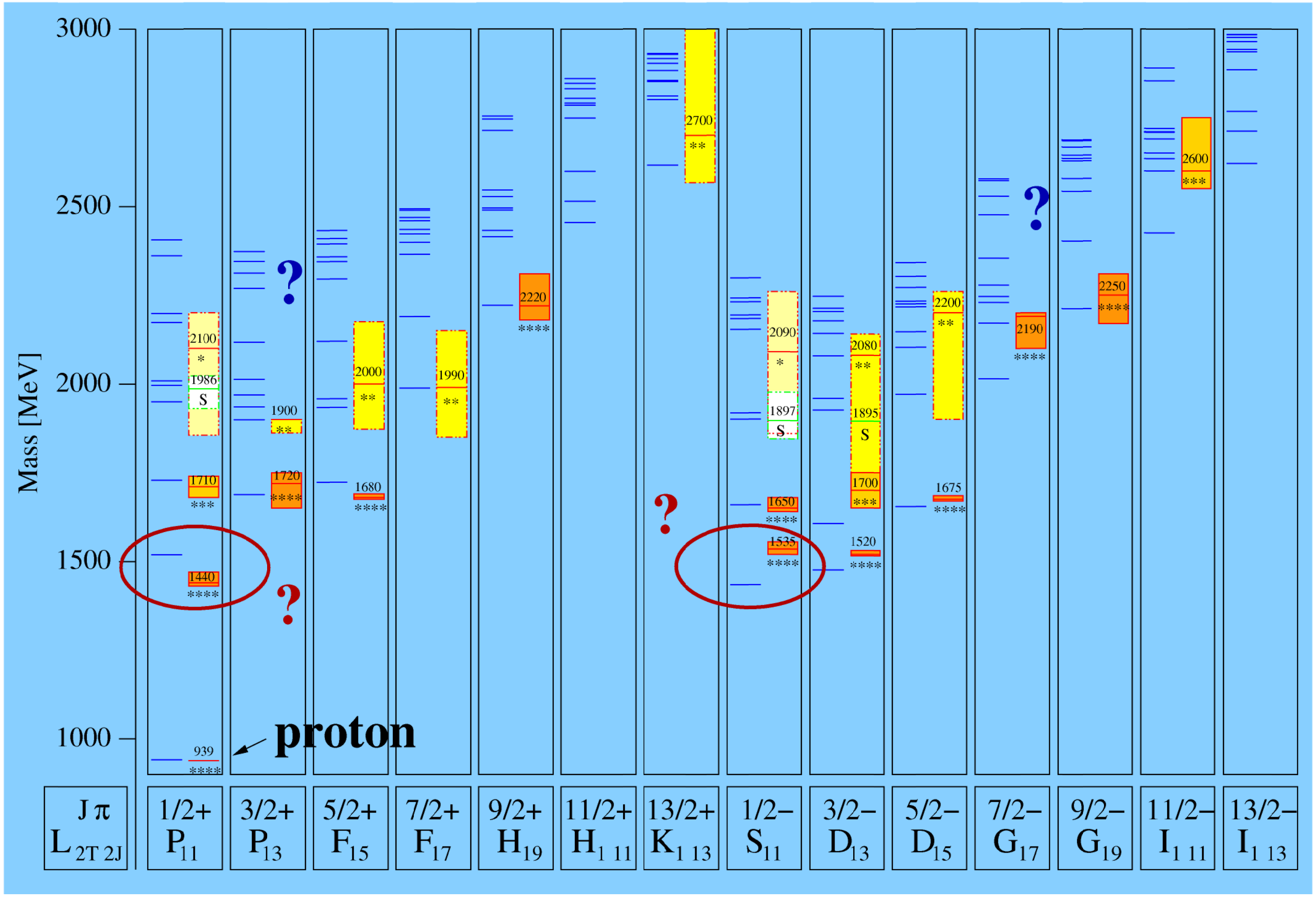
N^*- resonances in the quark model

Nukleon

10^{-15} m



U. Loering, B. Metsch, H. Petry et al. (Bonn)



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Constituent quarks

Confinement-potential

Residual interaction

Baryon data base

DATA	MAID	SAID	BnGa
$\pi N \to \pi N$ ampl.	SAID energy fixed	all data	SAID or Hoehler energy fixed
$\gamma p \to \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P, G, H, E$		
$\gamma n \to \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P$		$\frac{d\sigma}{d\Omega}, \Sigma, T, P$
$\gamma n \to \eta n$			$\frac{d\sigma}{d\Omega}, \Sigma$
$\gamma p \to \eta p$	$\frac{d\sigma}{d\Omega}, \Sigma, T$	$\frac{d\sigma}{d\Omega}, \Sigma$	$\frac{d\sigma}{d\Omega}, \Sigma$
$\gamma p \to K^+\Lambda$	$\frac{d\sigma}{d\Omega}, P$	–	$\frac{d\sigma}{d\Omega}, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}$
$\gamma p \to K^+\Sigma^0$	$\frac{d\sigma}{d\Omega}, P$	–	$\frac{d\sigma}{d\Omega}, \Sigma, P, C_x, C_z$
$\gamma p \to K^0\Sigma^+$	–	–	$\frac{d\sigma}{d\Omega}, \Sigma, P$
$\pi^- p \to \eta n$	–	$\frac{d\sigma}{d\Omega}$	$\frac{d\sigma}{d\Omega}$
$\pi^- p \to K^0\Lambda$	–	–	$\frac{d\sigma}{d\Omega}, P, \beta$
$\pi^- p \to K^0\Sigma^0$	–	–	$\frac{d\sigma}{d\Omega}, P$
$\pi^+ p \to K^+\Sigma^+$	–	–	$\frac{d\sigma}{d\Omega}, P, \beta$
$\pi^- p \to \pi^0\pi^0 n$	–	–	$\frac{d\sigma}{d\Omega}$
$\gamma p \to \pi^0\pi^0 p$	–	–	$\frac{d\sigma}{d\Omega}, \Sigma, E, I_c, I_s$
$\gamma p \to \pi^0\eta p$	–	–	$\frac{d\sigma}{d\Omega}, \Sigma, I_c, I_s$

Nucleon spectrum

$\mathbf{N(1700)\frac{3}{2}^-}$ or $N(1700)D_{13}$

$N(1700)\frac{3}{2}^-$ pole parameters (MeV)			
$M_{\rm pole}$	1770±40	$\Gamma_{\rm pole}$	420±180
Elastic pole residue	50±40	Phase	-(100±40)°
Residue $\pi N \to \Delta\pi_{L=0}$	75±50	Phase	-(60±40)°
Residue $\pi N \to \Delta\pi_{L=2}$	18±12	Phase	(90±35)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.044±0.020	Phase	(85±45)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	-0.037±0.012	Phase	(0±30)°

$N(1700)\frac{3}{2}^-$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1790±40	$\Gamma_{\rm BW}$	390±140
Br(πN)	12±5%		
Br($\Delta\pi_{L=0}$)	72±16%	Br($\Delta\pi_{L=2}$)	5±4%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.041±0.017	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	-0.034±0.013

Confirmed, but ambiguous

$\mathbf{N(1710)\frac{1}{2}^+}$ or $N(1710)P_{11}$

$N(1710)\frac{1}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	1687±17	$\Gamma_{\rm pole}$	200±25
Elastic pole residue	6±4	Phase	(120±70)°
Residue $\pi N \to N\eta$	11±4	Phase	(0±45)°
Residue $\pi N \to \Lambda K$	17±7	Phase	-(110±20)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.055±0.018	Phase	-(10±65)°

$N(1710)\frac{1}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1710±20	$\Gamma_{\rm BW}$	200±18
Br($N\pi$)	5±4%	Br($N\eta$)	17±10%
Br(ΛK)	23±7%		
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.052±0.015		

Confirmed

Nucleon spectrum

$N(1720)\frac{3}{2}^+$ or $N(1720)P_{13}$

$N(1720)\frac{3}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	1660±30	$\Gamma_{\rm pole}$	450±100
Elastic pole residue	22±8	Phase	-(115±30)°
Residue $\pi N \to N\eta$	7±5	Phase	not defined
Residue $\pi N \to \Lambda K$	14±10	Phase	-(150±45)°
Residue $\pi N \to \Delta\pi_{L=1}$	64±25	Phase	(80±40)°
Residue $\pi N \to \Delta\pi_{L=3}$	8±8	Phase	not defined
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.110±0.045	Phase	(0±40)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.150±0.035	Phase	(65±35)°

$N(1720)\frac{3}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1690^{+70}_{-35}	$\Gamma_{\rm BW}$	420±100
Br($N\pi$)	10±5%	Br($N\eta$)	3±2%
Br($\Delta\pi_{L=1}$)	75±15%	Br($\Delta\pi_{L=3}$)	2±2%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.110±0.045	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.150±0.030

$N(1860)\frac{5}{2}^+$ or $N(1860)F_{15}$

$N(1860)\frac{5}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	$1830^{+120}_{-\ 60}$	$\Gamma_{\rm pole}$	$250^{+150}_{-\ 50}$
Elastic pole residue	50±20	Phase	-(80±40)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.020±0.012	Phase	(120±50)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.050±0.020	Phase	-(80±60)°

$N(1860)\frac{5}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	$1860^{+120}_{-\ 60}$	$\Gamma_{\rm BW}$	$270^{+140}_{-\ 50}$
Br($N\pi$)	20±6%		
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	-0.019±0.011	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.048±0.018

Needs confirmation

Nucleon spectrum

$N(1875)\frac{3}{2}^-$ or $N(1875)D_{13}$

$N(1875)\frac{3}{2}^-$ pole parameters (MeV)			
$M_{\rm pole}$	1860±25	$\Gamma_{\rm pole}$	200±20
Elastic pole residue	2.5±1.0	Phase	not defined
Residue $\pi N \to \Lambda K$	1.5±1.0	Phase	not defined
Residue $\pi N \to \Sigma K$	5±3	Phase	not defined
Residue $\pi N \to N\sigma$	8±3	Phase	-(170±65)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.018±0.008	Phase	-(100±60)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.010±0.004	Phase	(180±30)°

$N(1875)\frac{3}{2}^-$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1880±20	$\Gamma_{\rm BW}$	200±25
Br($N\pi$)	3±2%	Br($N\eta$)	5±2%
Br(ΛK)	4±2%	Br(ΣK)	15±8%
Br($\Delta\pi$)	20±12%	Br($N\sigma$)	60±12%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.018±0.010	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	-0.009±0.005

$N(1880)\frac{1}{2}^+$ or $N(1880)P_{11}$

$N(1880)\frac{1}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	1860±35	$\Gamma_{\rm pole}$	250±70
Elastic pole residue	6±4	Phase	(80±65)°
Residue $\pi N \to \eta N$	13±8	Phase	-(75±55)°
Residue $\pi N \to K\Lambda$	4±3	Phase	(40±40)°
Residue $\pi N \to K\Sigma$	13±7	Phase	(95±40)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.014±0.004$^{(01)}$	Phase	-(130±60)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.036±0.012$^{(02)}$	Phase	(15±20)°

$N(1880)\frac{1}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1870±35	$\Gamma_{\rm BW}$	235±65
Br(πN)	5±3%	Br(ηN)	25^{+30}_{-20}%
Br($K\Lambda$)	2±1%	Br($K\Sigma$)	17±7%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)			-0.013±0.003 $^{(01)}$
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)			0.034±0.011 $^{(02)}$

Observed by BG group (needs confirmation)

Nucleon spectrum

$N(1895)\frac{1}{2}^-$ or $N(1895)S_{11}$

$N(1895)\frac{1}{2}^-$ pole parameters (MeV)			
$M_{\rm pole}$	1900±15	$\Gamma_{\rm pole}$	90^{+30}_{-15}
Elastic pole residue	1±1	Phase	not defined
Residue $\pi N \to \eta N$	3±2	Phase	(40±20)°
Residue $\pi N \to K\Lambda$	2±1	Phase	-(90±30)°
Residue $\pi N \to K\Sigma$	3±2	Phase	(40±30)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.012±0.006	Phase	(120±50)°

$N(1895)\frac{1}{2}^-$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1895±15	$\Gamma_{\rm BW}$	90^{+30}_{-15}
Br(πN)	2±1%	Br(ηN)	21±9%
Br($K\Lambda$)	18±5%	Br($K\Sigma$)	13±7%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	-0.011±0.006		

Observed by BG (needs confirmation)

$N(1900)\frac{3}{2}^+$ or $N(1900)P_{13}$

$N(1900)\frac{3}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	1900±30	$\Gamma_{\rm pole}$	260^{+100}_{-60}
Elastic pole residue	3±2	Phase	(10±35)°
Residue $\pi N \to \eta N$	6±3	Phase	(70±60)°
Residue $\pi N \to K\Lambda$	9±5	Phase	(135±25)°
Residue $\pi N \to K\Sigma$	5±3	Phase	(110±30)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.026±0.015	Phase	(60±40)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.060±0.030	Phase	(185±60)°

$N(1900)\frac{3}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1905±30	$\Gamma_{\rm BW}$	250^{+120}_{-50}
Br(πN)	3±2%	Br(ηN)	10±4%
Br($K\Lambda$)	16±5%	Br($K\Sigma$)	5±2%
Br($\Delta\pi_{L=1}$)	38±10%	Br($\Delta\pi_{L=3}$)	11±10%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.026±0.015	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	-0.065±0.030

Observed by BG (Confirmed)

Nucleon spectrum

$\boldsymbol{N(1990)\frac{7}{2}^+}$ or $N(1990)F_{17}$

$N(1990)\frac{7}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	2030±65	$\Gamma_{\rm pole}$	240±60
Elastic pole residue	2±1	Phase	(125±65)°
Residue $\pi N \to \Delta\pi_{L=3}$	8±5	Phase	(80±50)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.042±0.014	Phase	-(30±20)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.058±0.014	Phase	-(35±25)°

$N(1990)\frac{7}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	2060±65	$\Gamma_{\rm BW}$	240±50
Br(πN)	2±1%	Br($\Delta\pi_{L=3}$)	20±15%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.040±0.012	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.057±0.012

$\boldsymbol{N(2000)\frac{5}{2}^+}$ or $N(2000)F_{15}$

$N(2000)\frac{5}{2}^+$ pole parameters (MeV)			
$M_{\rm pole}$	2030±110	$\Gamma_{\rm pole}$	480±100
Elastic pole residue	35^{+80}_{-15}	Phase	-(100±40)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.035±0.015	Phase	(15±40)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.050±0.014	Phase	-(130±40)°

$N(2000)\frac{5}{2}^+$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	2090±120	$\Gamma_{\rm BW}$	460±100
Br(πN)	9±4%	Br(ΔN)	50±20%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.032±0.014	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.048±0.014

Two solutions

Nucleon spectrum

$\mathbf{N(2060)\frac{5}{2}^-}$ or $N(2060)D_{15}$

$N(2060)\frac{5}{2}^-$ pole parameters (MeV)			
$M_{\rm pole}$	2040±15	$\Gamma_{\rm pole}$	390±25
Elastic pole residue	19±5	Phase	-(125±20)°
Residue $\pi N \to \eta N$	15±8	Phase	(40±25)°
Residue $\pi N \to K\Lambda$	1±0.5	Phase	not defined
Residue $\pi N \to K\Sigma$	7±4	Phase	-(70±30)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.065±0.015	Phase	(15±8)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.055^{+15}_{-35}	Phase	(15±10)°

$N(2060)\frac{5}{2}^-$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	2060±15	$\Gamma_{\rm BW}$	375±25
Br(πN)	8±2%	Br(ηN)	4±2%
Br($K\Sigma$)	3±2%		
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.067±0.015	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.055±0.020

Observed by BG (Confirmed)

$\mathbf{N(2150)\frac{3}{2}^-}$ or $N(2150)D_{13}$

$N(2150)\frac{3}{2}^-$ pole parameters (MeV)			
$M_{\rm pole}$	2110±50	$\Gamma_{\rm pole}$	340±45
Elastic pole residue	13±3	Phase	-(20±10)°
Residue $\pi N \to K\Lambda$	5±2	Phase	(100±30)°
Residue $\pi N \to K\Sigma$	3±2	Phase	-(50±40)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.125±0.045	Phase	-(55±20)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.150±0.060	Phase	-(35±15)°

$N(2150)\frac{3}{2}^-$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	2150±60	$\Gamma_{\rm BW}$	330±45
Br(πN)	6±2%	Br($\Delta\pi$)	60±20%
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.130±0.045	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.150±0.055

Observed by BG (needs confirmation)

Parity doublets of N and Δ resonances at high mass region

Parity doublets must not interact by pion emission

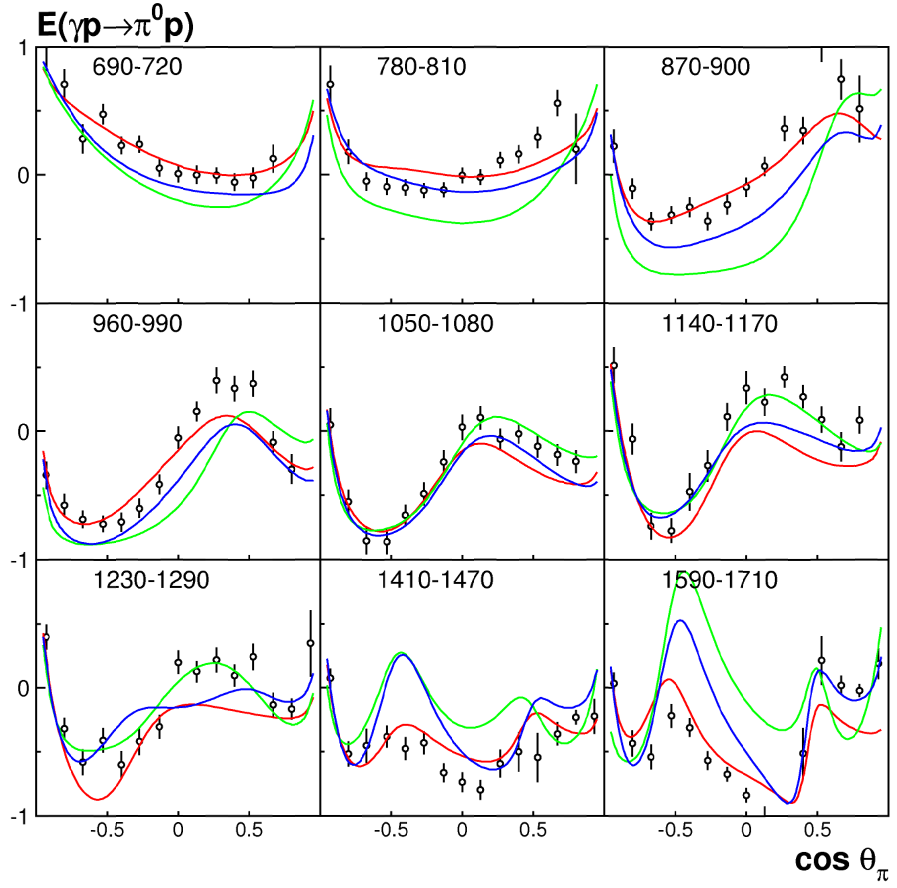
and could have a small coupling to πN.

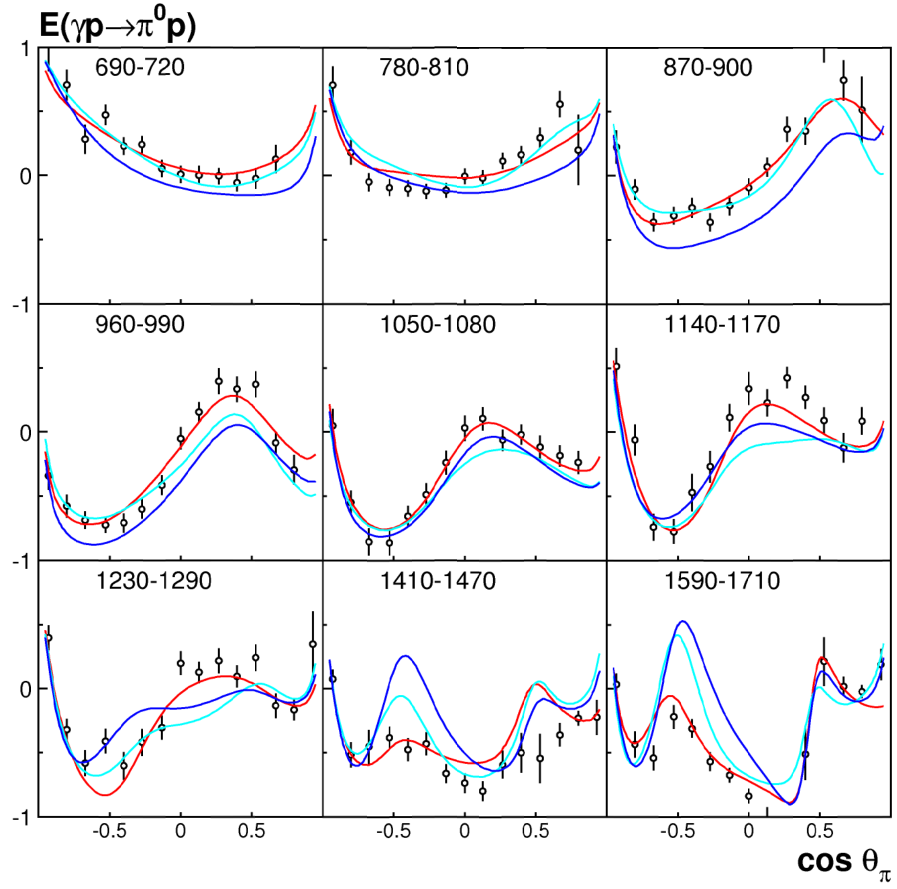
$J=\frac{1}{2}$	$N_{1/2+}(1880)$	**	$N_{1/2-}(1890)$	**	$\Delta_{1/2+}(1910)$	****	$\Delta_{1/2-}(1900)$	**
$J=\frac{3}{2}$	$N_{3/2+}(1900)$	***	$N_{3/2-}(1875)$	**	$\Delta_{3/2+}(1940)$	***	$\Delta_{3/2-}(1990)$	**
$J=\frac{5}{2}$	$N_{5/2+}(1880)$	**	$N_{5/2-}(2060)$	**	$\Delta_{5/2+}(1940)$	****	$\Delta_{5/2-}(1930)$	***
$J=\frac{7}{2}$	$N_{7/2+}(1980)$	**	$N_{7/2-}(2170)$	****	$\Delta_{7/2+}(1920)$	****	$\Delta_{7/2-}(2200)$	*
$J=\frac{9}{2}$	$N_{9/2+}(2220)$	****	$N_{9/2-}(2250)$	****	$\Delta_{9/2+}(2300)$	**	$\Delta_{9/2-}(2400)$	**

$J=\frac{5}{2}$	$N_{5/2+}(2090)$	**	$N_{5/2-}(2060)$	**	$\Delta_{5/2+}(1940)$	****	$\Delta_{5/2-}(1930)$	***
$J=\frac{7}{2}$	$N_{7/2+}(2100)$	**	$N_{7/2-}(2150)$	****	$\Delta_{7/2+}(1920)$	****	$\Delta_{7/2-}(2200)$	*
$J=\frac{9}{2}$	$N_{9/2+}(2220)$	****	$N_{9/2-}(2250)$	****	$\Delta_{9/2+}(2300)$	**	$\Delta_{9/2-}(2400)^{a}$	**

First double polarization data:

helicity asymmetry in $\gamma p \to \pi^0 p$





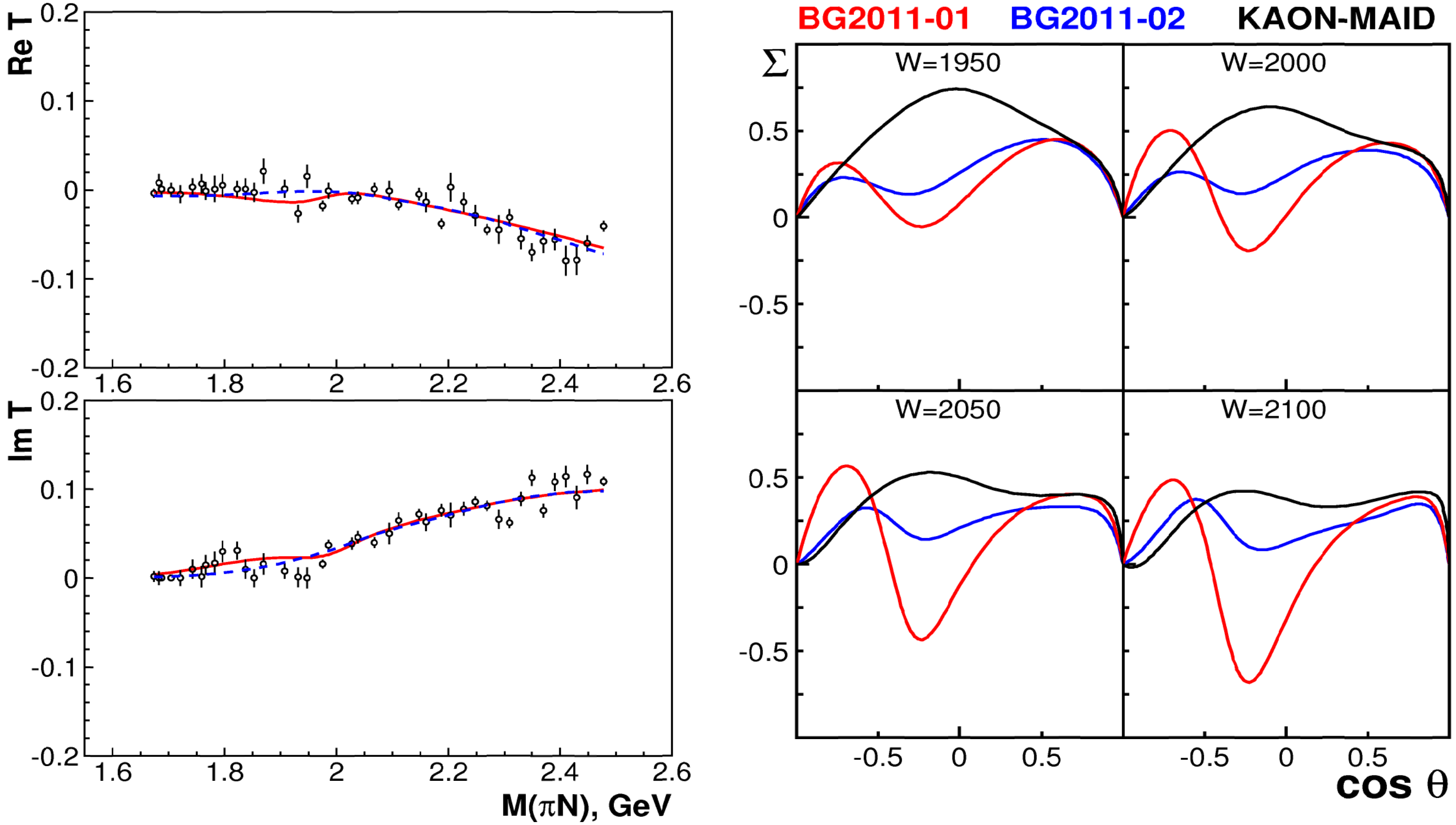
Bonn-Gatchina, SAID (SN11), MAID   **Bonn-Gatchina (fitted), SAID (SN11), SAID(CM12)**

Pole position of N(1990)$7/2^+$

N(2190)$7/2^-$: $M_{pole} = 2150 \pm 25$, $\Gamma_{pole} = 330 \pm 30$

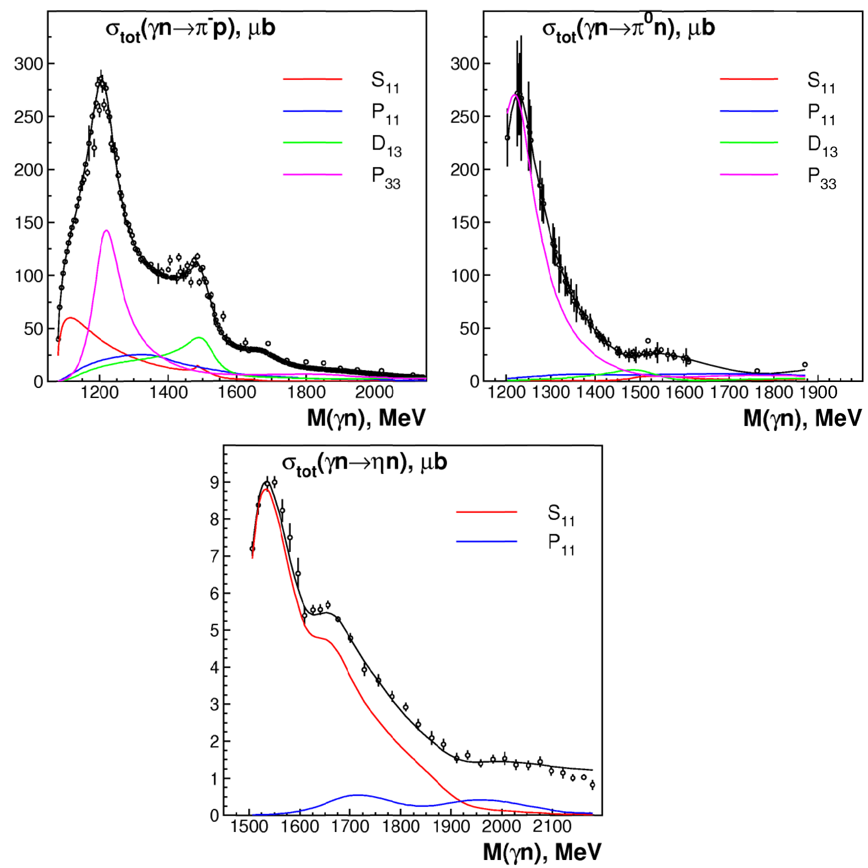
State		Solution 1	$A(\frac{1}{2})/A(\frac{3}{2})$	Solution 2	$A(\frac{1}{2})/A(\frac{3}{2})$
$N(1990)\frac{7}{2}^+$	Re	1980±25	$15/14^o$	2100±30	$76/50^o$
**	-2Im	180±30	$28/3^o$	300±60	$78/45^o$

Can be resolved by fitting the beam asymmetry data on $\gamma p \to K\Lambda$



Analysis of π^0 and η photoproduction off neutron

$\gamma n \to \pi^- p$	$N_{\rm data}$	χ^2_0	χ^2_f
$d\sigma/d\Omega$	1298	2.84	2.32
$d\sigma/d\Omega$	529	3.16	3.08
P	20	3.22	3.17
Σ	316	3.74	3.08
T	105	4.96	3.18
$\pi^- p \to \gamma n$			
$d\sigma/d\Omega$	495	1.65	1.53
P	55	4.59	3.11
$\gamma d \to \pi^0 n(p)$			
$d\sigma/d\Omega$	147	3.14	2.98
Σ	216	2.82	1.90
$\gamma d \to \eta n(p)$	$N_{\rm data}$	χ^2_0	χ^2_f
$d\sigma/d\Omega$	330	1.57	1.40
Σ	88	2.42	2.17

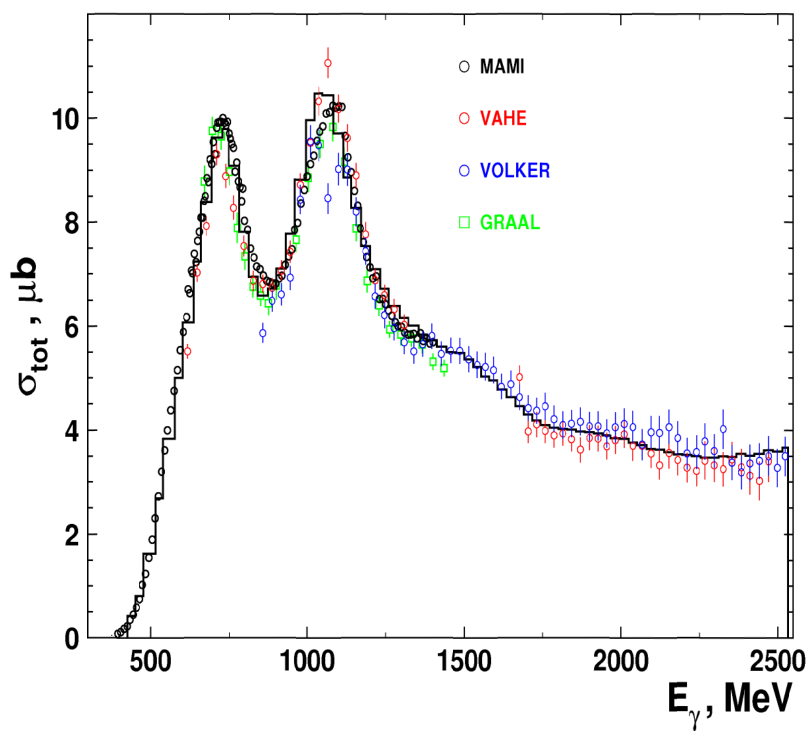


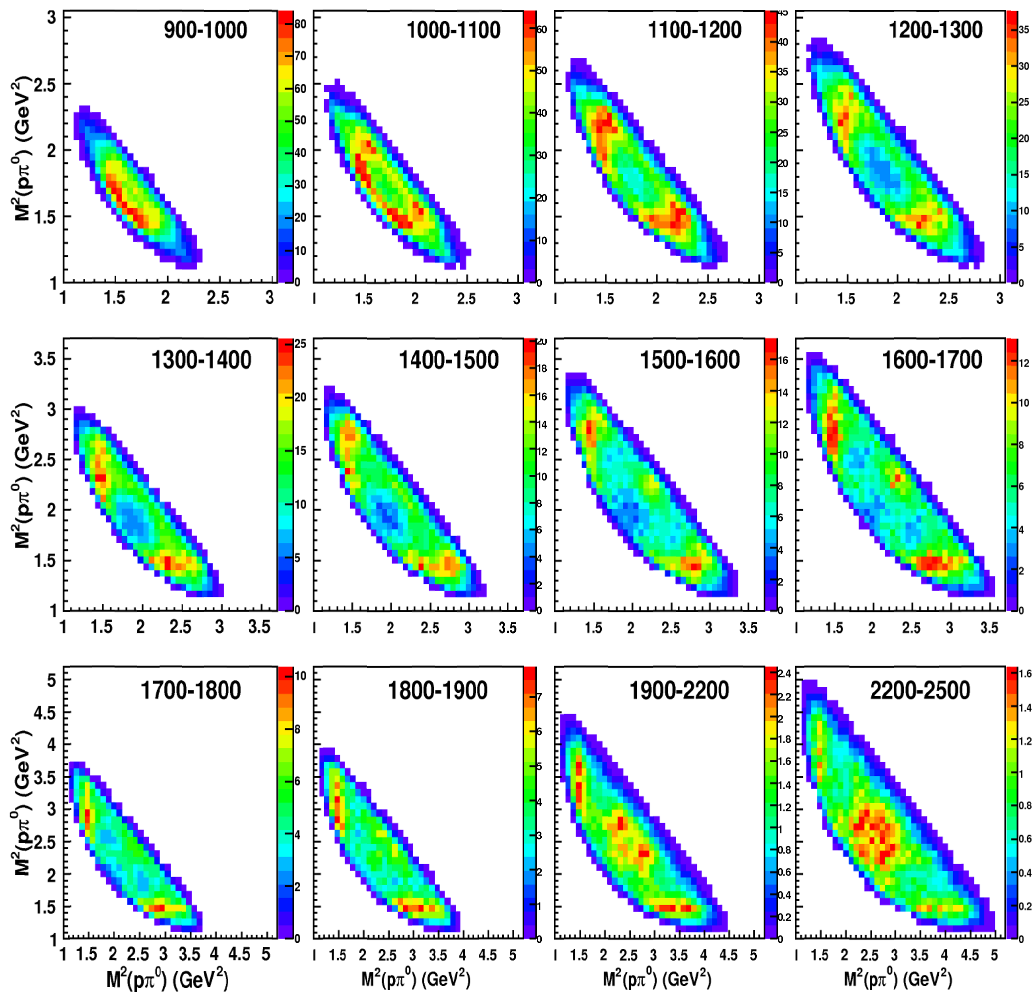
γn BW helicity couplings (GeV$^{-1/2}10^{-3}$)

	$\|A^{1/2}_{BW}\|$	$\|A^{3/2}_{BW}\|$		$\|A^{1/2}_{BW}\|$	$\|A^{3/2}_{BW}\|$
$N(1535)1/2^-$	-93±11		$N(1440)1/2^+$	43±12	
GB12	-58±6 (-85±15)		GB12	48±4	
SN11	-60±3		SN11	45±15	
MAID	-51		MAID	54	
PDG12	-46±27		PDG12	40±10	
$N(1650)1/2^-$	25±20		$N(1710)1/2^+$	-40±20	
GB12	-40±10 (?±?)		GB12		
SN11	-26±8		SN11		
MAID	9		MAID		
PDG12	-15±21		PDG12	2±14	
$N(1520)3/2^-$	-49±8	-113±12	$N(1720)3/2^+$	-80±50	-140±65
GB12	-46±6	-115±5	GB12	ambiguous	ambiguous
SN11	-47±2	-125±2	SN11	-21±4	-38±7
MAID	-77	-154	MAID	-3	-31
PDG12	-59±9	-139±11	PDG12	4±15	-10±20
$N(1675)5/2^-$	-60±7	-88±10	$N(1680)5/2^+$	34±6	-44±9
GB12	-58±2	-80±5	GB12	26±4	-29±2
SN11	-42±2	-60±2	SN11	50±4	-47±2
MAID	-62	-84	MAID	28	-38
PDG12	-43±12	-58±13	PDG12	29±10	-33±9

Solution BG2011-02 with $N(1990)7/2^+$ at a mass around 2100 MeV provides a notably better description of the data

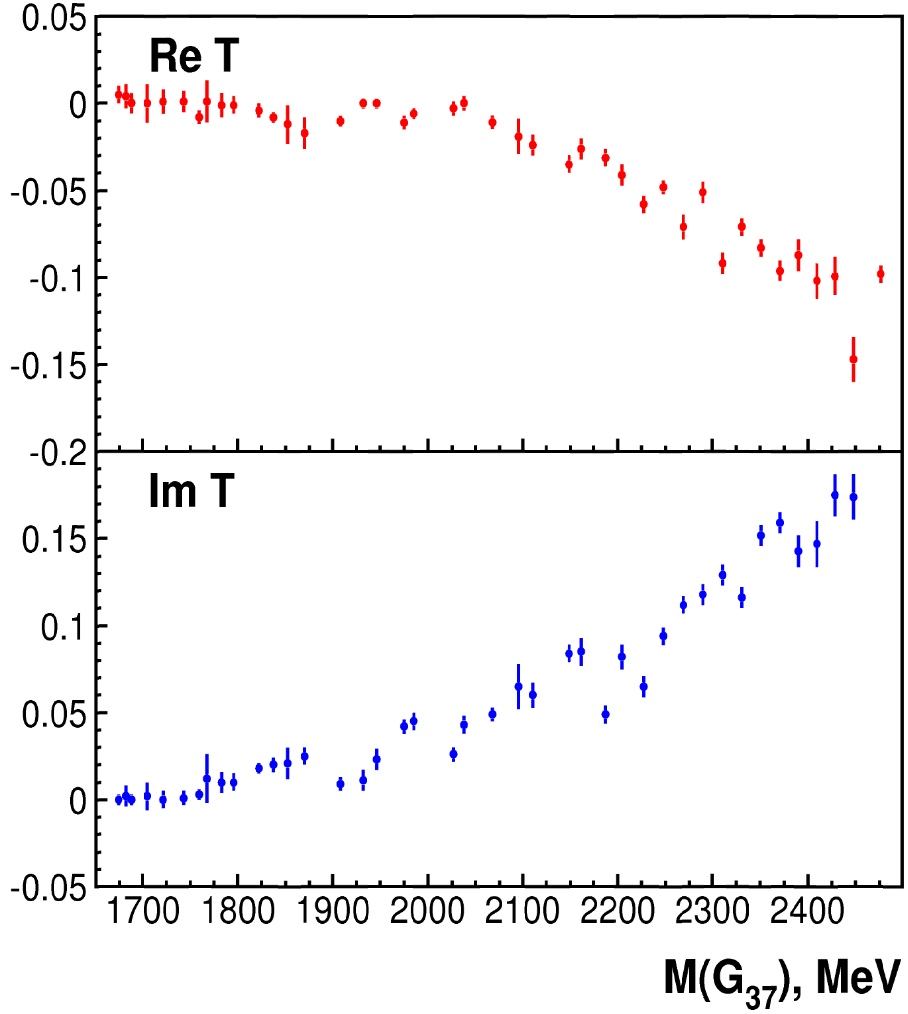
New data on $\gamma p \to \pi^0 \pi^0 p$

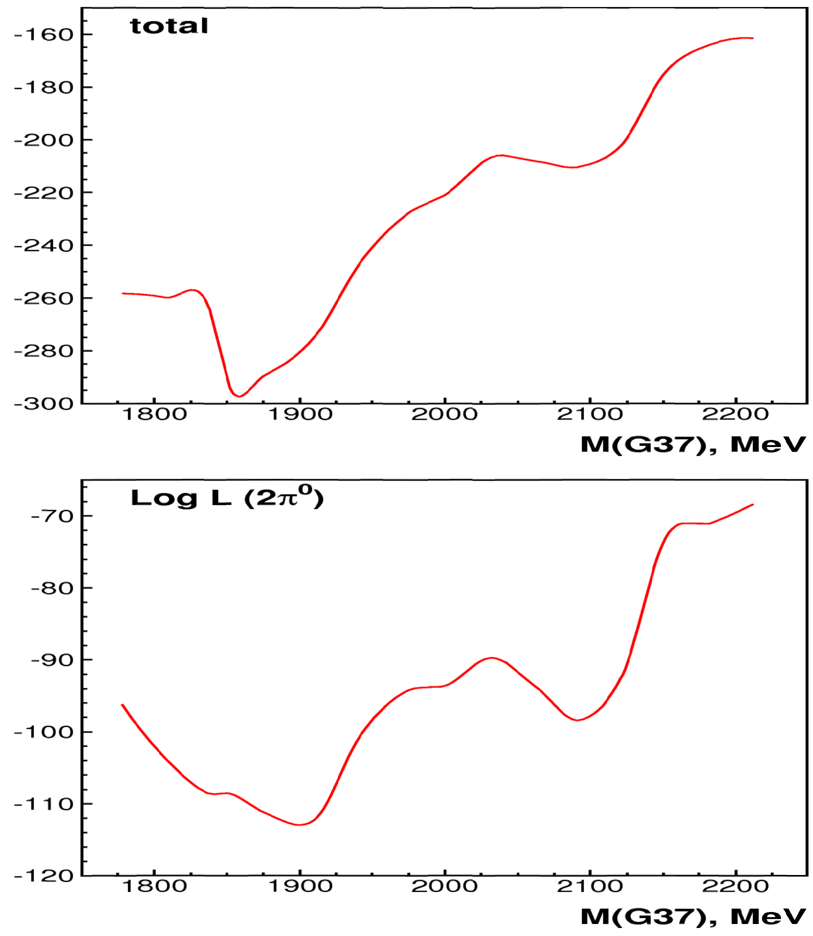




$\Delta(2200)(7/2^-)$ state

$\Delta(1950)7/2^+$: $M = 1915 \pm 6$, $\Gamma_{pole} = 246 \pm 10$





Summary

- **The new N/D-based method is developed and applied to the analysis of the high statistic data on production of meson and baryon resonances.**
- **The new analysis confirmed the result of the K-matrix analysis for high mass states and provides a better description of low energy part.**
- **The new data on γn initial state, double polarization data from CB-ELSA and new data on $2\pi^0$ and $\eta\pi^0$ photoproduction are included in the data base.**
- **The γn data favor solution BG2011-02 with mass of N(1990)$7/2^+$ at 2100 MeV.**
  The new data on $\gamma p \to 2\pi^0 p$ provide an indication for $\Delta(7/2^-)$ with the mass around 1900 MeV.
  Both results support parity doublet idea.