Relativistic properties of the few-body systems in the Bethe-Salpeter approach

S. Bondarenko, V. Burov, E. Rogochaya
Joint Institute for Nuclear Research, Dubna, Russia

N. Hamamoto, A. Hosaka, Y. Manabe, H. Toki
Research Center for Nuclear Physics, Osaka University, Osaka, Japan

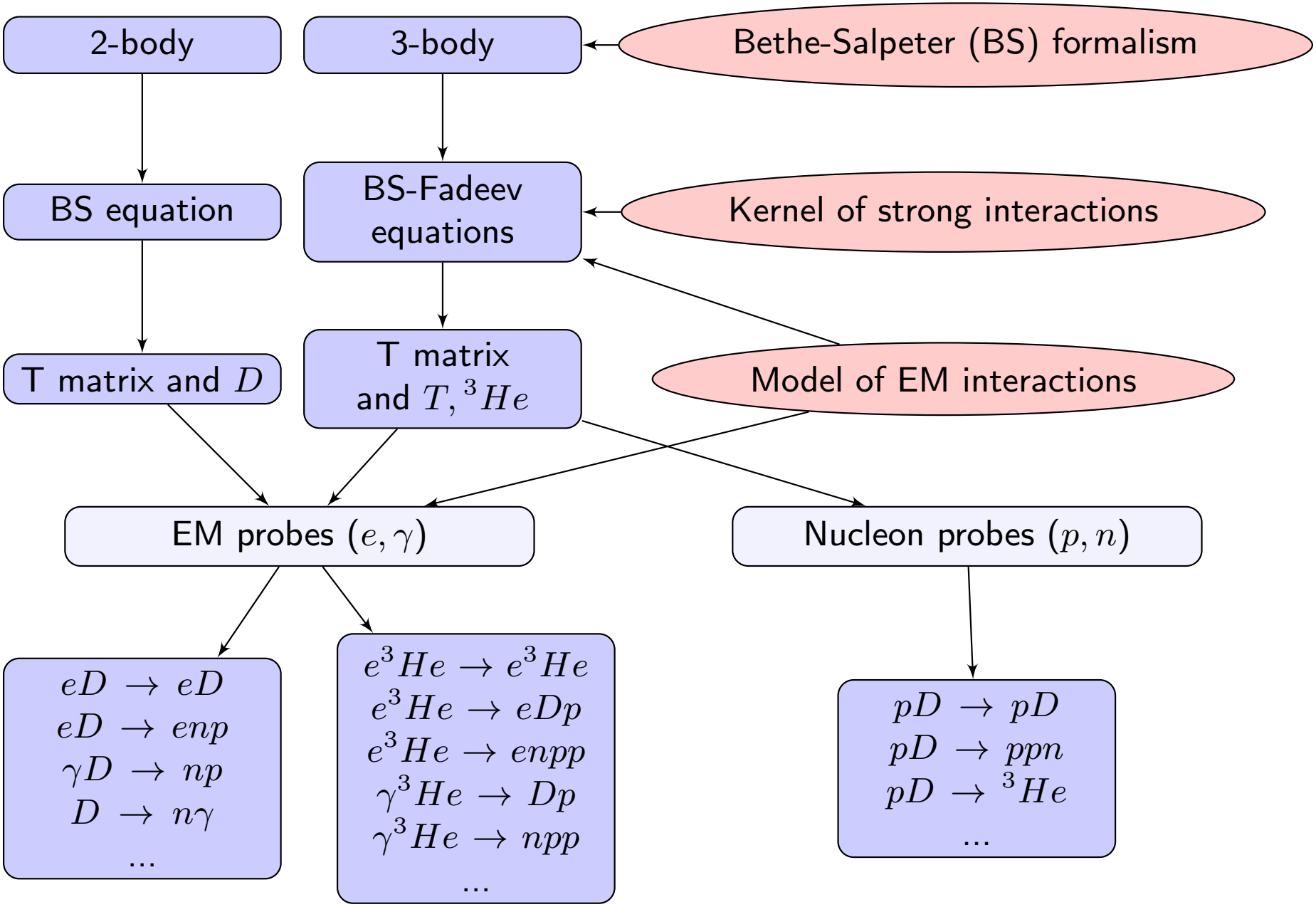
W-Y. Pauchy Hwang
National Taipei University, Taipei, Taiwan

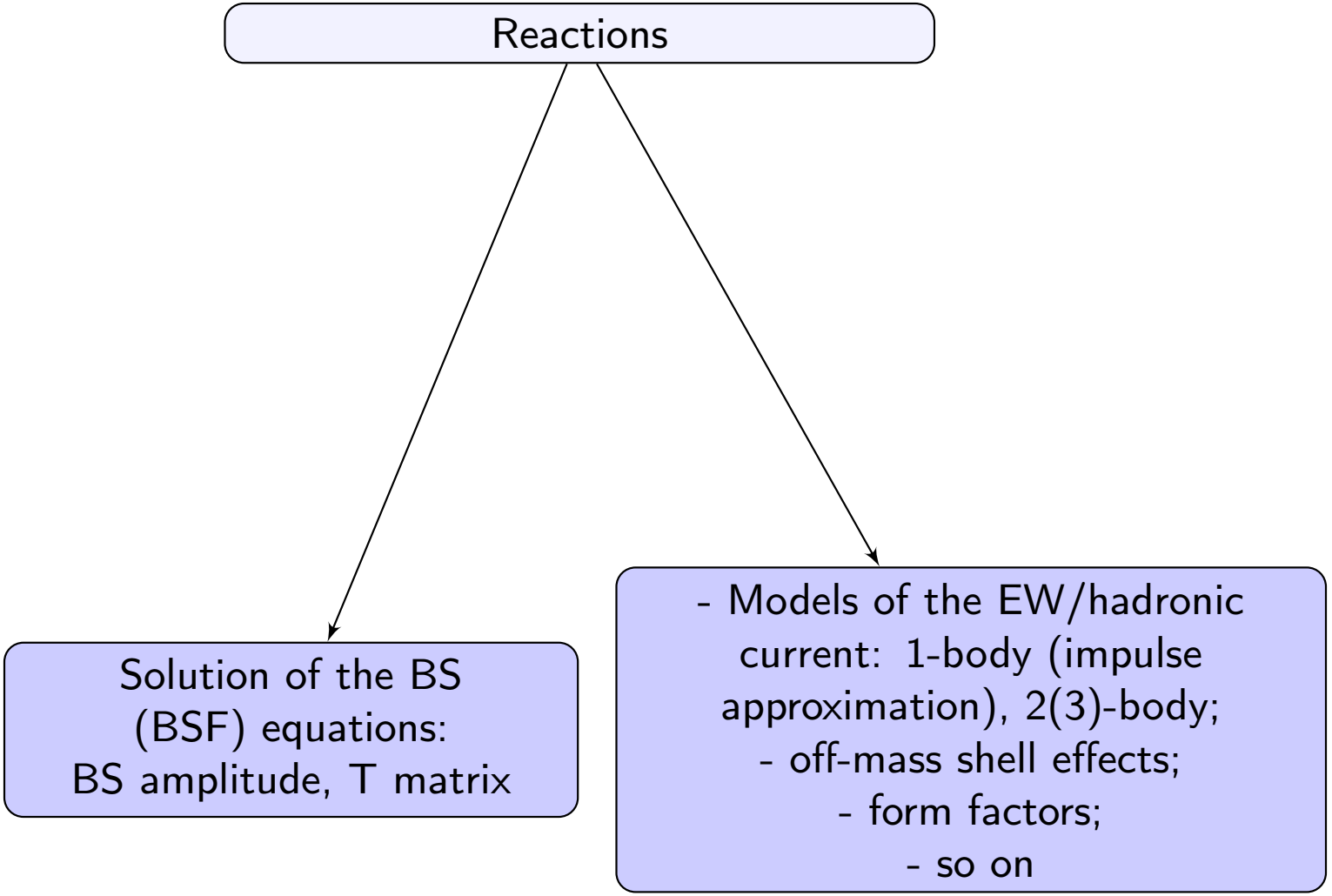
XXIV International Seminar Nonlinear Phenomena in Complex Systems
May 16, 2017, Minsk, Belarus

The Bethe-Salpeter approach is a powerful tool to investigate few-body compounds such as the deuteron, unbound neutron-proton (np) system, three-nucleon systems, elastic and nonelastic scattering. We have a great expiriance in working within such approach.

- Bethe-Salpeter equation and its solution for the separable kernel of interaction
- Yamaguchi-type of kernel functions and Graz-II relativistic kernel
- elastic eD-scattering
- modified Yamaguchi functions and fitting of parameters
- wide dibaryon resonances
- conclusion and symmary

Reactions in the BS approach




Reactions
Solution of the BS (BSF) equations: BS amplitude, T matrix
- Models of the EW/hadronic current: 1-body (impulse approximation), 2(3)-body;
- off-mass shell effects;
- form factors;
- so on

Bethe-Salpeter equation for the nucleon-nucleon T matrix

$$T(p',p;P) = V(p',p;P) + \frac{i}{4\pi^3}\int d^4k\, V(p',k;P)\, S_2(k;P)\, T(k,p;P)$$

p', p - the relative four-momenta
P - the total four-momentum

$V(p',p;P)$ - the interaction kernel

$S_2^{-1}(k;P) = \left(\frac{1}{2}\, P\cdot\gamma + k\cdot\gamma - m\right)^{(1)}\left(\frac{1}{2}\, P\cdot\gamma - k\cdot\gamma - m\right)^{(2)}$
free two-particle Green function

Separable kernels of the NN interaction

The separable kernels of the nucleon-nucleon interaction are widely used in the calculations. The separable kernel as a *nonlocal* covariant interaction representing complex nature of the space-time continuum.

Separable ansatz for the kernel

$$V_{a'a}(p_0', |\mathbf{p}'|; p_0, |\mathbf{p}|; s) = \sum_{m,n=1}^{N} \lambda_{mn}^{r[a'a]}(s) g_m^{[a']}(p_0', |\mathbf{p}'|) g_n^{[a]}(p_0, |\mathbf{p}|)$$

Solution for the T matrix

$$T_{a'a}(p_0', |\mathbf{p}'|; p_0, |\mathbf{p}|; s) = \sum_{i,j=1}^{N} \tau_{ij}(s)\, g_i^{[a']}(p_0', |\mathbf{p}'|)\, g_j^{[a]}(p_0, |\mathbf{p}|)$$

where

$$\Big[\tau_{ij}(s)\Big]^{-1} = \Big[\lambda_{mn}^{r[a'a]}(s)\Big]^{-1} + h_{ij}(s),$$

$$h_{ij}(s) = -\frac{i}{4\pi^3} \sum_a \int dk_0 \int \mathbf{k}^2 d|\mathbf{k}| \frac{g_i^{[a]}(k_0, |\mathbf{k}|) g_j^{[a]}(k_0, |\mathbf{k}|)}{(\sqrt{s}/2 - E_{\mathbf{k}} + i\epsilon)^2 - k_0^2},$$

$g_j^{[a]}$ - the model functions, $\lambda_{ij}^{[a'a]}(s)$ - a matrix of model parameters.

Separable kernel for Schrodinger equation with separable potential

Yoshio Yamaguchi "Two-Nucleon Problem When the Potential Is Nonlocal but Separable. I" Phys.Rev.95, 1628 (1954)
Yoshio Yamaguchi, Yoriko Yamaguchi "Two-Nucleon Problem When the Potential Is Nonlocal but Separable. II" Phys.Rev.95, 1635 (1954)

Nonlocal: $\langle \mathbf{r}|V|\mathbf{r}'\rangle \neq \delta^{(3)}(\mathbf{r}-\mathbf{r}')$
in configuration space

$$\langle \mathbf{r}|V|\mathbf{r}'\rangle = -(\lambda/m_N)v^*(\mathbf{r})v^*(\mathbf{r}')$$

in momentum space

$$\langle \mathbf{p}|V|\mathbf{p}'\rangle = (\lambda/m_N)g^*(\mathbf{p})g^*(\mathbf{p}')$$

for S-state: $g(p) = 1/(p^2+\beta^2)$
for D-state: $g(p) = p^2/(p^2+\beta^2)^2$
for the deuteron and scattering problem.

Separable nucleon-nucleon potential was widely uses for the two- and three-nucleon calculations in nonrelativistic nuclear physics

Willibald Plessas et al. Graz, Graz-II potentials, separable representation of the popular Bonn and Paris potentials

K. Schwarz, Willibald Plessas, L. Mathelitsch "Deuteron Form-factors And E D Polarization Observables For The Paris And Graz-II Potentials" Nuovo Cim. A76 (1983) 322-329.
J. Haidenbauer, Willibald Plessas "Separable Representation Of The Paris Nucleon Nucleon Potential" Phys.Rev. C30 (1984) 1822-1839.
Johann Haidenbauer, Y. Koike, Willibald Plessas "Separable representation of the Bonn nucleon-nucleon potential" Phys.Rev. C33 (1986) 439-446.

$$g(p) = \sum_n p^{2m}/(p^2 + \beta_n^2)^n,$$

m corresponds to angular momentum

Lippmann-Schwinger equation → Bethe-Salpeter equation

G. Rupp and J. A. Tjon "Relativistic contributions to the deuteron electromagnetic form factors" Phys. Rev. C41. 472 (1990)

$$\mathbf{p}^2 \to -p^2 = -p_0^2 + \mathbf{p}^2$$

$$g_p(p,P) = \frac{1}{-p^2+\beta^2} \xrightarrow{\text{c.m.}} \frac{1}{-p_0^2+\mathbf{p}^2+\beta^2+i\epsilon}$$

singularities: $p^0 = \pm\sqrt{\mathbf{p}^2+\beta^2} \mp i\epsilon$

Graz-II covariant kernel, rank III ($J = 1 :^3 S_1 -^3 D_1$ partial-wave states)

$$
\begin{aligned}
g_1^{(\mathrm{S})}(p_0, |\mathbf{p}|) &= \frac{1 - \gamma_1(p_0^2 - \mathbf{p}^2)}{(p_0^2 - \mathbf{p}^2 - \beta_{11}^2)^2}, \\
g_2^{(\mathrm{S})}(p_0, \mathbf{p}) &= -\frac{(p_0^2 - \mathbf{p}^2)}{(p_0^2 - \mathbf{p}^2 - \beta_{12}^2)^2}, \\
g_3^{(\mathrm{D})}(p_0, |\mathbf{p}|) &= \frac{(p_0^2 - \mathbf{p}^2)(1 - \gamma_2(p_0^2 - \mathbf{p}^2))}{(p_0^2 - \mathbf{p}^2 - \beta_{21}^2)(p_0^2 - \mathbf{p}^2 - \beta_{22}^2)^2}, \\
g_1^{(\mathrm{D})}(p_0, |\mathbf{p}|) &= g_2^{(\mathrm{D})}(p_0, |\mathbf{p}|) = g_3^{(\mathrm{S})}(p_0, |\mathbf{p}|) \equiv 0.
\end{aligned}
\tag{1}
$$

Table: Deuteron and low-energy scattering properties

	$p_{\mathrm{D}}(\%)$	ϵ_{D} (MeV)	Q_{D} (Fm^{-2})	μ_{D} $(e/2m)$	$\rho_{\mathrm{D/S}}$	r_0 (Fm)	a (Fm)
Covariant Graz-II	4	2.225	0.2484	0.8279	0.02408	1.7861	5.4188
Experimental data		2.2246	0.286	0.8574	0.0263	1.759	5.424

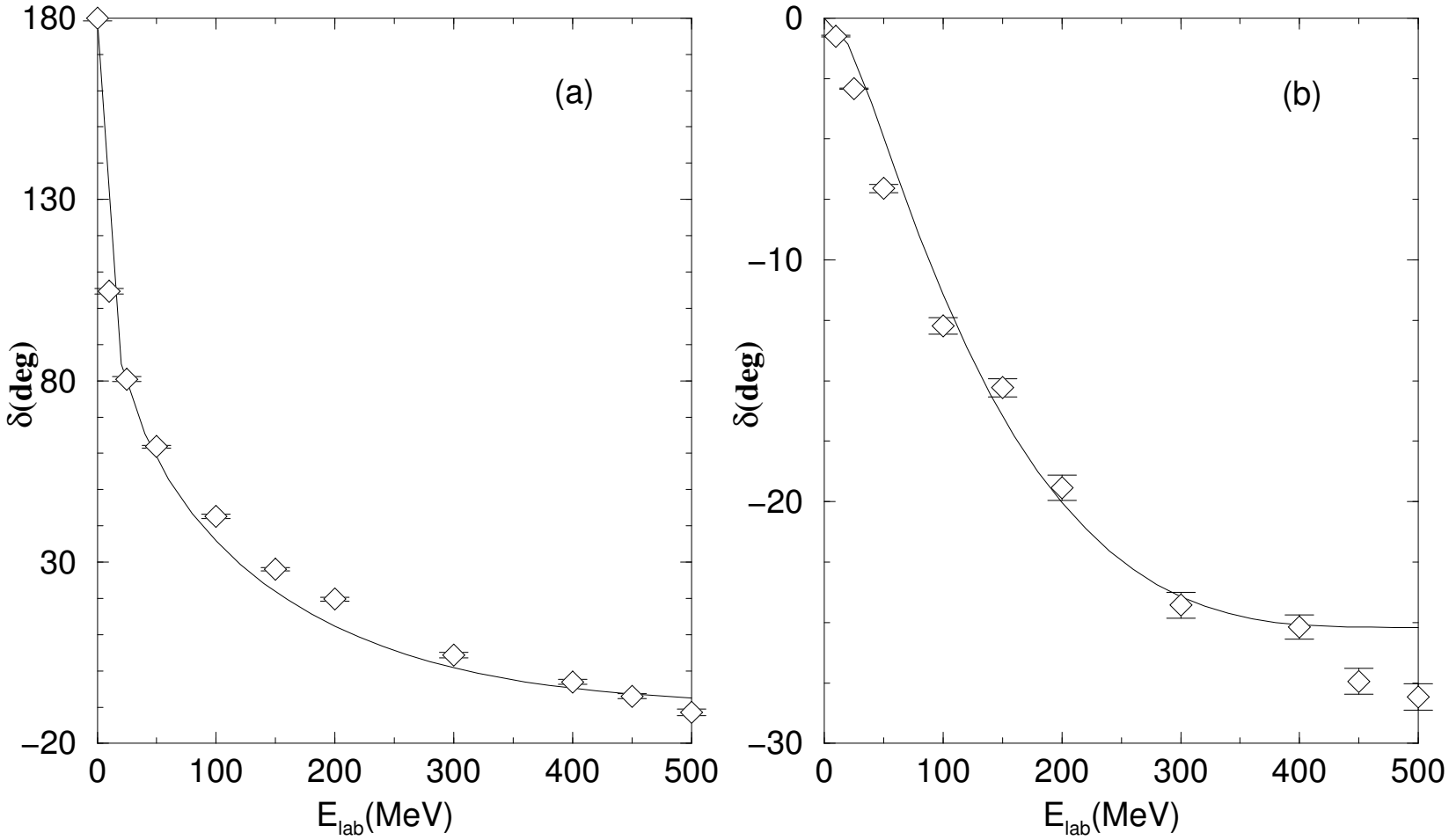


Figure: Phase shifts of the $^3S_1$ and $^3D_1$ partial states

Elastic eD scattering cross section

$$\frac{d\sigma}{d\Omega'_{\rm e}} = \left(\frac{d\sigma}{d\Omega'_{\rm e}}\right)_{\rm Mott}\left[A(q^2) + B(q^2)\tan^2\frac{\theta_{\rm e}}{2}\right],$$

$$\left(\frac{d\sigma}{d\Omega'_{\rm e}}\right)_{\rm Mott} = \frac{\alpha^2\cos^2\theta_{\rm e}/2}{4E_{\rm e}^2(1+2E_{\rm e}/M_d\sin^4\theta_{\rm e}/2)},$$

where $\theta_{\rm e}$ is the electron scattering angle, M_d is the deuteron mass, E_e is the incident electron energy.

Deuteron structure functions $A(q^2)$ and $B(q^2)$

$$A(q^2) = F_{\rm C}^2(q^2) + \frac{8}{9}\eta^2 F_{\rm Q}^2(q^2) + \frac{2}{3}\eta F_{\rm M}^2(q^2)$$

$$B(q^2) = \frac{4}{3}\eta(1+\eta)F_{\rm M}^2(q^2)$$

where $\eta = -q^2/4M_d^2 = Q^2/4M_d^2$

Relativistic impulse approximation (RIA)

Deuteron current matrix element

$$\langle D'\mathcal{M}'|J_\mu^{RIA}|D\mathcal{M}\rangle =$$

$$ie\int\frac{d^4k}{(2\pi)^4}\mathrm{Tr}\left\{\bar{\chi}^{1\mathcal{M}'}(P',k')\Gamma_\mu^{(\mathrm{S})}(q)\chi^{1\mathcal{M}}(P,k)(P\cdot\gamma/2-k\cdot\gamma+m)\right\}$$

$\chi^{1\mathcal{M}}(P,k)$ - the BS amplitude of the deuteron, $P'=P+q$ and $k'=k+q/2$.

The vertex of γNN interaction

$$\Gamma_\mu^{(\mathrm{S})}(q)=\gamma_\mu F_1^{(\mathrm{S})}(q^2)-\frac{\gamma_\mu q\cdot\gamma-q\cdot\gamma\gamma_\mu}{4m}F_2^{(\mathrm{S})}(q^2)$$

is chosen to be the form factor on mass shell.

The isoscalar form factors of the nucleon

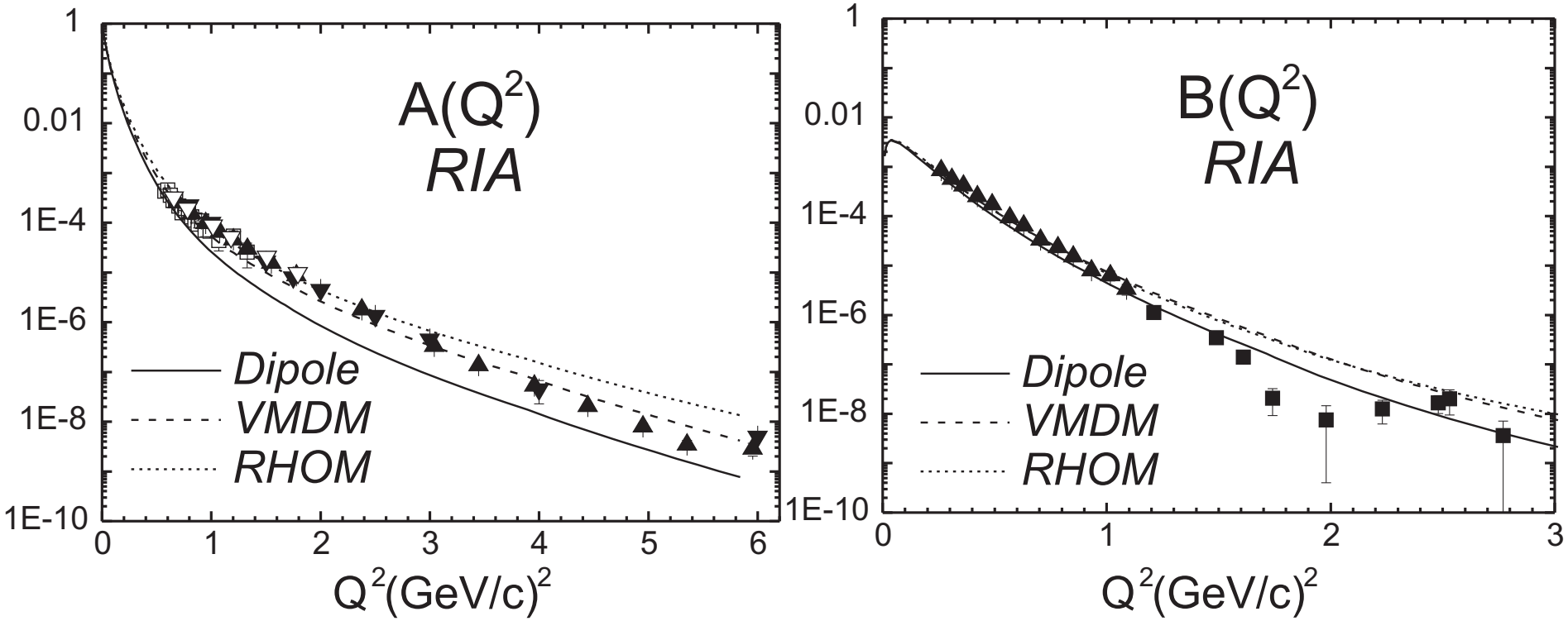
$$F_{1,2}^{(\mathrm{S})}(q^2)=(F_{1,2}^{(\mathrm{p})}(q^2)+F_{1,2}^{(\mathrm{n})}(q^2))/2$$

with normalization condition

$$F_1^{(\mathrm{S})}(0)=1/2,\quad F_2^{(\mathrm{S})}(0)=(\varkappa_p+\varkappa_n)/2$$

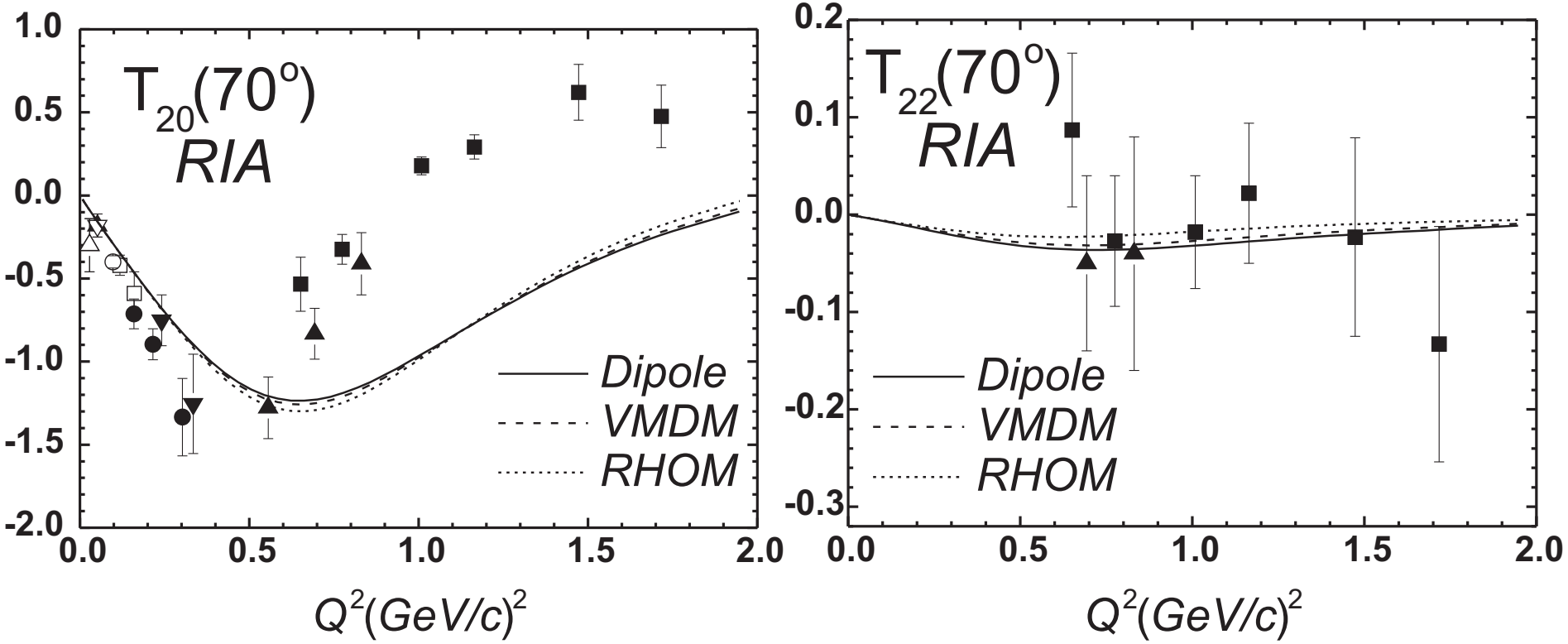
with $\varkappa_p=\mu_p-1$ and $\varkappa_n=\mu_n$ being anomalous parts of the proton μ_p and neutron μ_n magnetic moments, respectively.

Structure functions $A(q^2)$ and $B(q^2)$



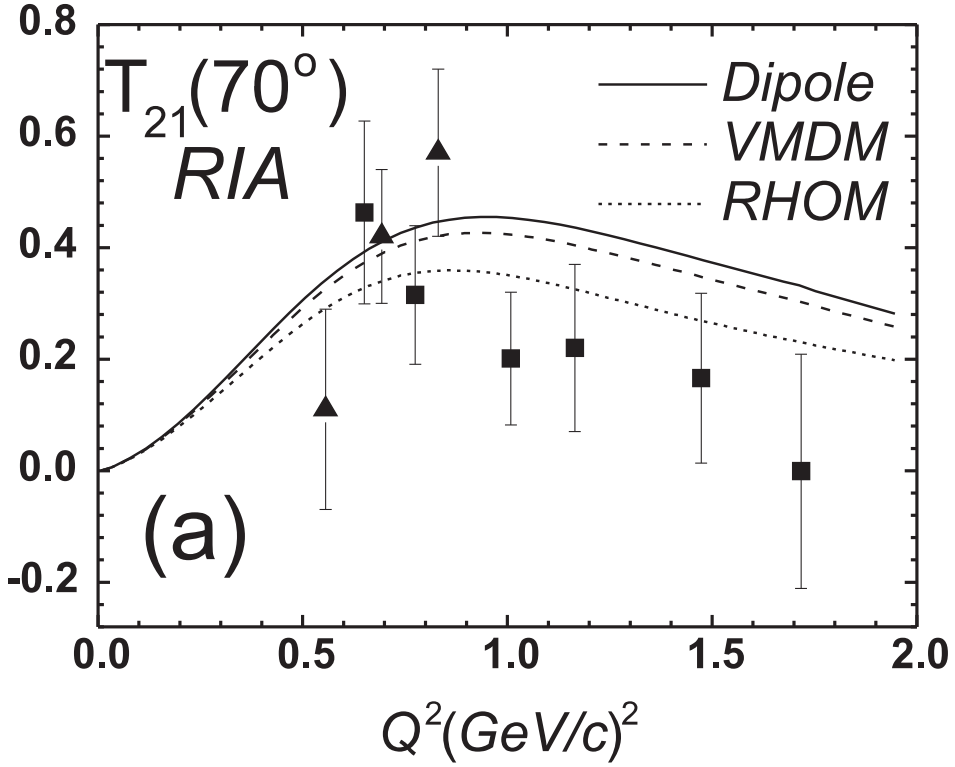
Long and short dashes represent calculations with the vector meson dominance model (VMDM) and relativistic harmonic oscillator model (RHOM) nucleon form factors, respectively. The solid curve corresponds to the dipole fit.

Tensor polarization components $T_{20}(q^2)$ and $T_{22}(q^2)$ calculated at $\theta_e = 70°$.



Long and short dashes represent calculations with the VMDM and RHOM nucleon form factors, respectively. The solid curve corresponds to the dipole fit.

Tensor polarization component $T_{21}(q^2)$ calculated at $\theta_e = 70^\circ$



Long and short dashes represent calculations with the VMDM and RHOM nucleon form factors, respectively. The solid curve corresponds to the dipole fit.

To investigate photo- and electrodisintegration of the deuteron the T matrix for partial-wave states ($^1S_0, ^1P_0, ^3S_1 - ^3D_1, ^1P_1, ^3P_1$ ...) is needed.

Analysis

$V(p,p') \to T_{off-mass-shell}(p,p') \to T_{on-mass-shell}(\bar{p},\bar{p}) \to (\delta, a_0, E_d ...)$

δ - the phase shifts, a_0, r_0 - the low-energy parameters (the scattering length, the effective range), E_d - the deuteron binding energy.

Procedure ($J = 0, 1$)

calculate the kernel parameters – $\lambda_{ij}(s)$-matrix and parameter of the g-functions – to minimize the function χ^2:

$$\chi^2 = \sum_{i=1}^{n} (\delta^{\exp}(s_i) - \delta(s_i))^2/(\Delta\delta^{\exp}(s_i))^2 \quad \text{– for all partial-wave states}$$
$$+(a_0^{\exp} - a_0)^2/(\Delta a_0^{\exp})^2 \quad \text{– for the } {}^1S_0^+ \text{ and } {}^3S_1^+ \text{ partial-wave states}$$
$$+(E_d^{\exp} - E_d)^2/(\Delta E_d^{\exp})^2 \quad \text{– for the } {}^3S_1^+\text{-}{}^3D_1^+ \text{ partial-wave states}$$
$$\{+...\}$$

Covariant generalization of the *Yamaguchi*-functions

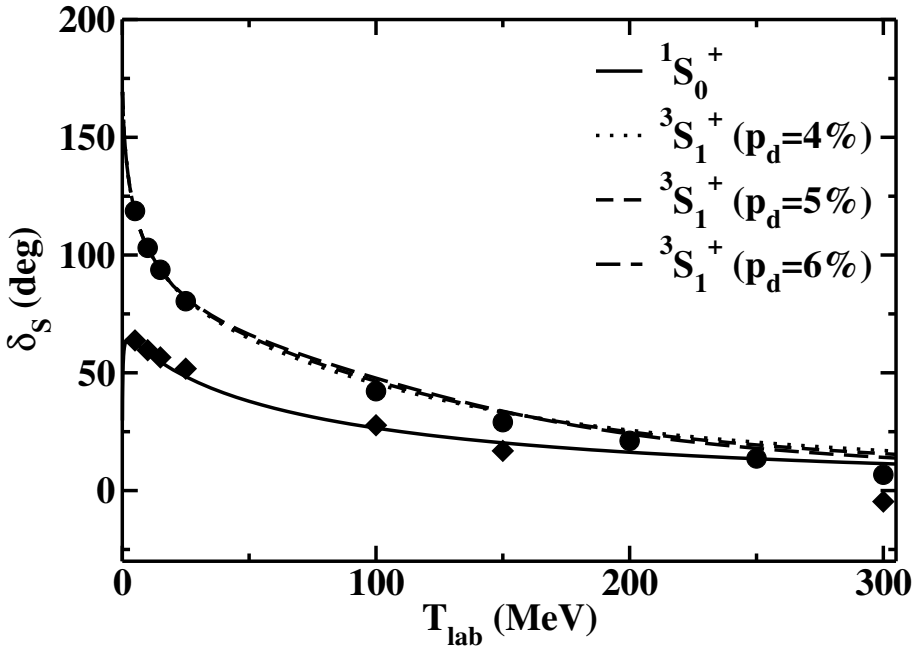
functions for $g^{[L]}(p_0, p)$:

$$g^{[S]}(p_0, p) = \frac{1}{p_0^2 - p^2 - \beta_0^2 + i0},$$

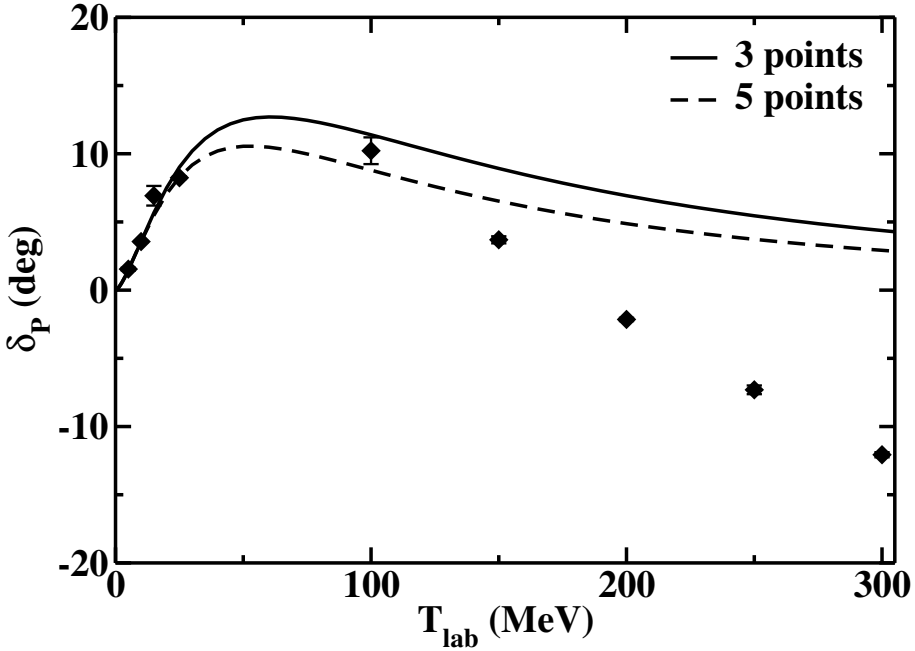
$$g^{[P]}(p_0, p) = \frac{\sqrt{|-p_0^2 + p^2|}}{(p_0^2 - p^2 - \beta_1^2 + i0)^2},$$

$$g^{[D]}(p_0, p) = \frac{C(p_0^2 - p^2)}{(p_0^2 - p^2 - \beta_2^2 + i0)^2}.$$

Results for the phase-shifts (one-rank)

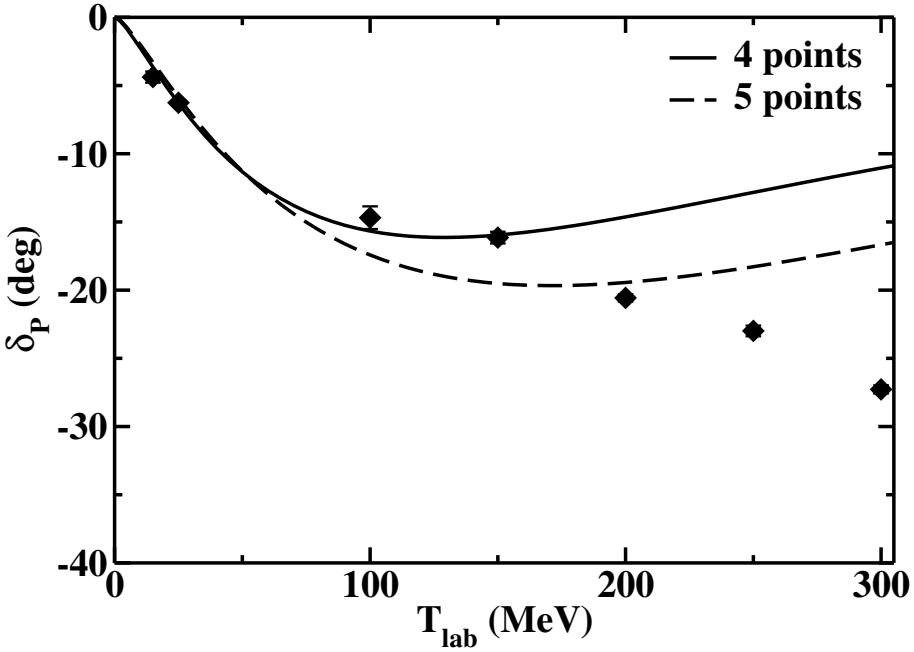


$^1S_0^+$ and $^3S_1^+$ channels phase shifts

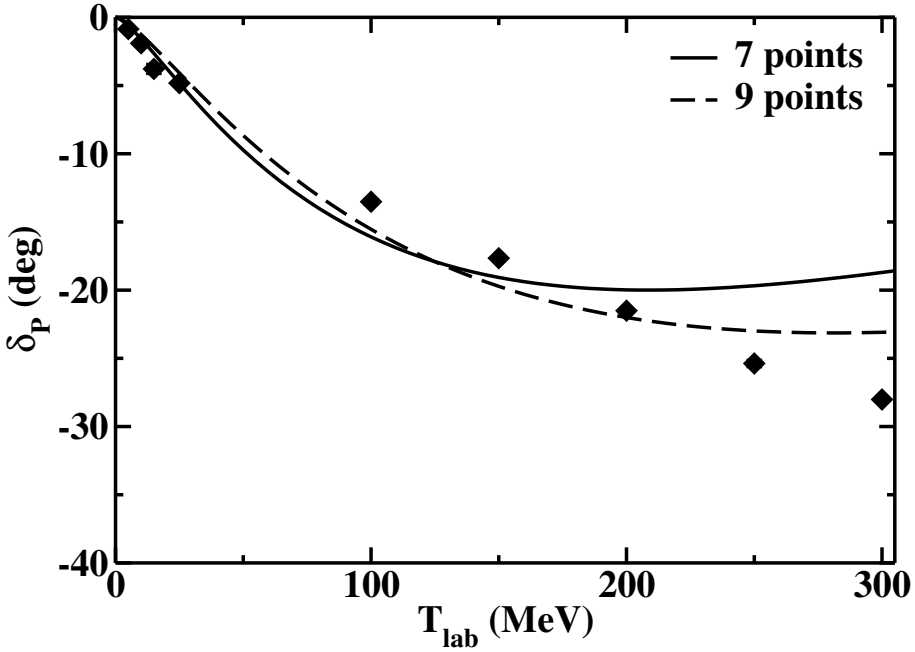


$^3P_0^+$ channel phase shifts

Results for the phase-shifts (one-rank)



$^1P_1^+$ channel phase shifts



$^3P_1^+$ channel phase shifts

Motivation for MY(I)N kernel

Consider integral

$$\int dk_0 \int \mathbf{k}^2 d|\mathbf{k}| \frac{[g(k_0,|\mathbf{k}|)]^2}{(\sqrt{s}/2 - E_{\mathbf{k}} + i\epsilon)^2 - k_0^2}$$

Simple poles of propagators

$$k_0^{(1,2)} = \pm\sqrt{s}/2 \mp E_{\mathbf{k}} \pm i\epsilon$$

Taking into account pole and Yamaguchi-like type of $g(k_0,|\mathbf{k}|) = 1/(k_0^2 - \mathbf{k}^2 - \beta^2)$

$$(2\pi i) \int \mathbf{k}^2 d|\mathbf{k}| \frac{1}{(s/4 - \sqrt{s}E_{\mathbf{k}} + m^2 - \beta^2)^2} \frac{1}{\sqrt{s} - 2E_{\mathbf{k}} + i\epsilon}$$

Motivation for MY(I)N kernel

Consider numerator $f = s/4 - \sqrt{s}E_{\mathbf{k}} + m^2 - \beta^2$

- If $4(m-\beta)^2 < s < 4(m+\beta)^2$ then always $f < 0$ and function $1/f^n$ is integrable for any integer n and any $E_{\mathbf{k}}$.
- For bound state $s = M_d^2 = (2m - \epsilon_D)^2$. Since for $\beta_{min} = 0.2$ GeV always $\beta_{min} > \epsilon_D/2$ then function $1/f^n$ is integrable for any integer n and any $E_{\mathbf{k}}$.
- If $4(m-\beta)^2 > s > 4(m+\beta)^2$ then f can be positive and negative and $1/f^n$ is non-integrable for even n and any $E_{\mathbf{k}}$.

Critical value for $s^c = 4(m+\beta)^2$ corresponds to laboratory kinetic energy of np pair $T_{lab}^c = 4\beta + 2\beta^2/m \simeq 4\beta$. If $\beta_{min} = 0.2$ GeV then $T_{lab}^{min} = 0.8$ GeV.

To avoid the non-integrable one needs to modify function $g(k_0, |\mathbf{k}|)$

$$g_{\mathrm{Y}}(k_0, |\mathbf{k}|) = 1/(k_0^2 - \mathbf{k}^2 - \beta^2) \to g_{\mathrm{MY}}(k_0, |\mathbf{k}|) = 1/((k_0^2 - \mathbf{k}^2 - \beta^2)^2 + \alpha^4)$$

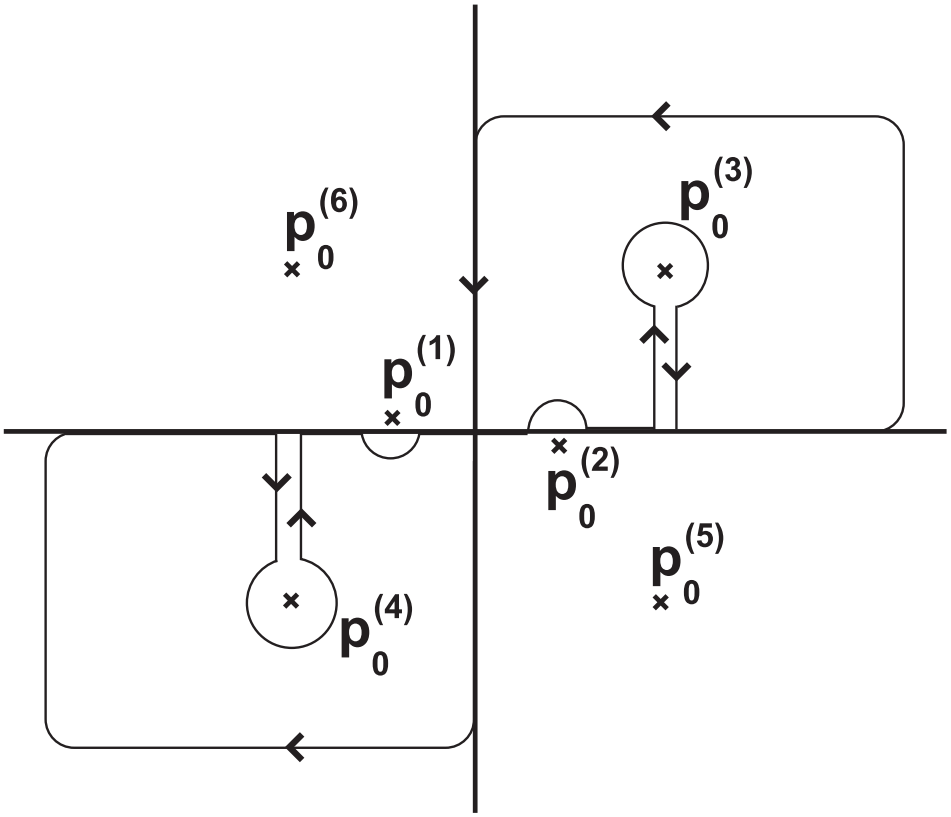
here Y stands for Yamaguchi-like and MY - for Modified Yamaguchi

Modified Yamaguchi functions

$$g_i^{[a]}(p_0, |\boldsymbol{p}|) = \frac{(p_{ci} - p_0^2 + \mathbf{p}^2)^{n_i}(p_0^2 - \mathbf{p}^2)^{m_i}}{((p_0^2 - \mathbf{p}^2 - \beta_{1i}^2)^2 + \alpha_{1i}^4)^{k_i}((p_0^2 - \mathbf{p}^2 - \beta_{1i}^2)^2 + \alpha_{1i}^4)^{l_i}}$$

All parameters - n_i, m_i, k_i, l_i (integer), $p_{ci}, \beta_{1i}, \beta_{2i}, \alpha_{1i}, \alpha_{2i}$ (real) - depend on channel $[a]$.

Contour for integration over p_0: the Wick rotation



Separable ansatz for complex kernel

$$V_{a'a}(p_0', |\mathbf{p}'|; p_0, |\mathbf{p}|; s) = \sum_{m,n=1}^{N} \left[\underline{\lambda_{mn}^{r[a'a]}(s)} + i\lambda_{mn}^{r[a'a]}(s)\right] \underline{g_m^{[a']}(p_0', |\mathbf{p}'|) g_n^{[a]}(p_0, |\mathbf{p}|)}$$

underlined part $\equiv$ MYN kernels, the sum $\equiv$ MYIN kernels

$$\lambda_{mn}^{i}(s) = \theta(s - s_{th}) \left(1 - \frac{s_{th}}{s}\right) \bar{\lambda}_{mn}^{i}$$

s_{th} - the inelasticity threshold. Here MY stands for Modified Yamaguchi.

Solution for the T matrix

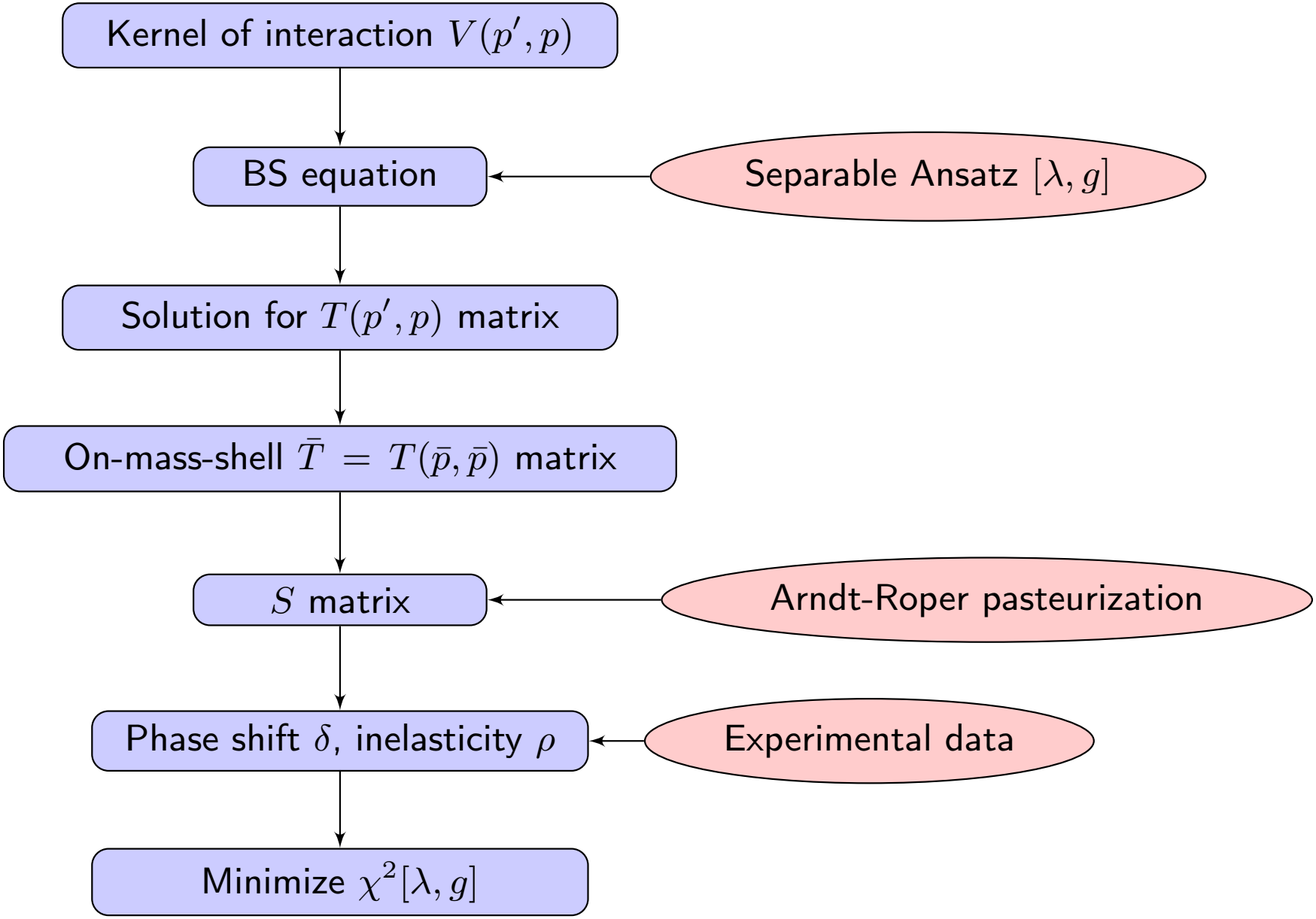
$$T_{a'a}(p_0', |\mathbf{p}'|; p_0, |\mathbf{p}|; s) = \sum_{i,j=1}^{N} \tau_{ij}(s)\, g_i^{[a']}(p_0', |\mathbf{p}'|)\, g_j^{[a]}(p_0, |\mathbf{p}|)$$

where

$$\Big[\tau_{ij}(s)\Big]^{-1} = \Big[\lambda_{mn}^{r[a'a]}(s) + i\lambda_{mn}^{r[a'a]}(s)\Big]^{-1} + h_{ij}(s),$$

$$h_{ij}(s) = -\frac{i}{4\pi^3} \sum_a \int dk_0 \int \mathbf{k}^2 d|\mathbf{k}| \frac{g_i^{[a]}(k_0, |\mathbf{k}|) g_j^{[a]}(k_0, |\mathbf{k}|)}{(\sqrt{s}/2 - E_{\mathbf{k}} + i\epsilon)^2 - k_0^2},$$

$g_j^{[a]}$ - the model functions, $\lambda_{ij}^{[a'a]}(s)$ - a matrix of model parameters


Kernel of interaction $V(p', p)$
BS equation
Separable Ansatz $[\lambda, g]$
Solution for $T(p', p)$ matrix
On-mass-shell $\bar{T} = T(\bar{p}, \bar{p})$ matrix
S matrix
Arndt-Roper pasteurization
Phase shift δ, inelasticity ρ
Experimental data
Minimize $\chi^2[\lambda, g]$

S matrix (Arndt-Roper pasteurization)

$$S = \frac{1 - K_i + iK_r}{1 + K_i - iK_r} = \eta \exp(2i\delta)$$

$$K = K_r + iK_i$$

$$K_r = \tan\delta, \quad K_i = \tan^2\rho$$

δ - the phase shift, ρ - the inelasticity parameter.

$$\eta^2 = \frac{1 + K^2 - 2K_i}{1 + K^2 + 2K_i} = |S|^2 \sim \sigma_{np}$$

$$K^2 = K_r^2 + K_i^2$$

$$\delta = \frac{1}{2}\{\tan^{-1}[K_r/(1 - K_i)] + \tan^{-1}[K_r/(1 + K_i)]\}$$

If there are no inelastic channels: $(\rho = 0)$, $\delta = \delta_e$, $\eta = 1$ and $S = S_e = \exp(2i\delta_e)$.

Procedure ($J = 0 - 3$)

calculate the kernel parameters – $\lambda_{ij}(s)$-matrix and parameter of the g-functions – to minimize the function χ^2:

$$\chi^2 = \sum_{i=1}^{n} (\delta^{\exp}(s_i) - \delta(s_i))^2/(\Delta\delta^{\exp}(s_i))^2 \quad \text{– for all partial-wave states}$$
$$\sum_{i=1}^{n} (\rho^{\exp}(s_i) - \rho(s_i))^2/(\Delta\rho^{\exp}(s_i))^2 \quad \text{– for all partial-wave states}$$
$$+(a_0^{\exp} - a_0)^2/(\Delta a_0^{\exp})^2 \quad \text{– for the } {}^1S_0^+ \text{ and } {}^3S_1^+ \text{ partial-wave states}$$
$$+(E_d^{\exp} - E_d)^2/(\Delta E_d^{\exp})^2 \quad \text{– for the } {}^3S_1^+\text{-}{}^3D_1^+ \text{ partial-wave states}$$
$$\{+...\}$$

δ - the phase shifts, a_0, r_0 - the low-energy parameters (the scattering length, the effective range), E_d - the deuteron binding energy.

$^3P_0$ partial-wave state

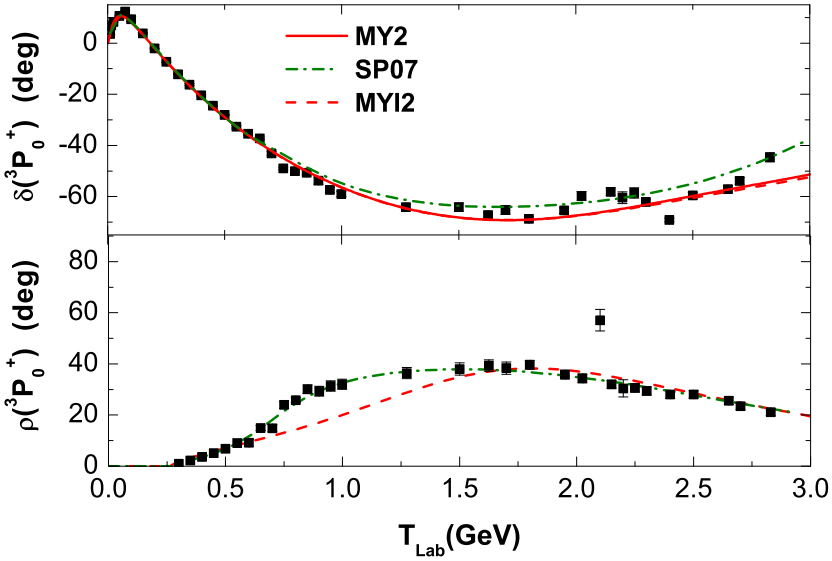


Figure: Phase shifts δ and inelasticity parameter ρ

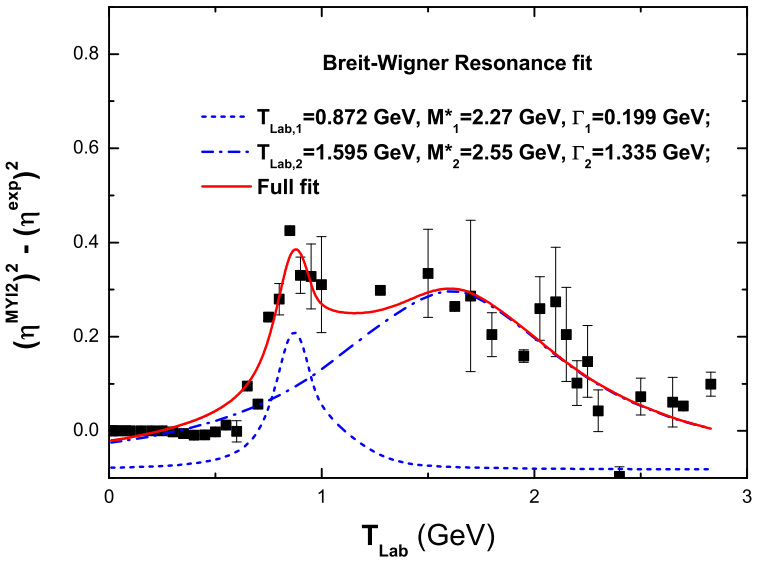


Figure: Difference $(\eta^{MYI})^2$-$(\eta^{exp})^2$

S.G. Bondarenko, V.V. Burov, E.P. Rogochaya. Phys.Lett. **B705** (2011) 264-268

$^3F_2$ partial-wave state

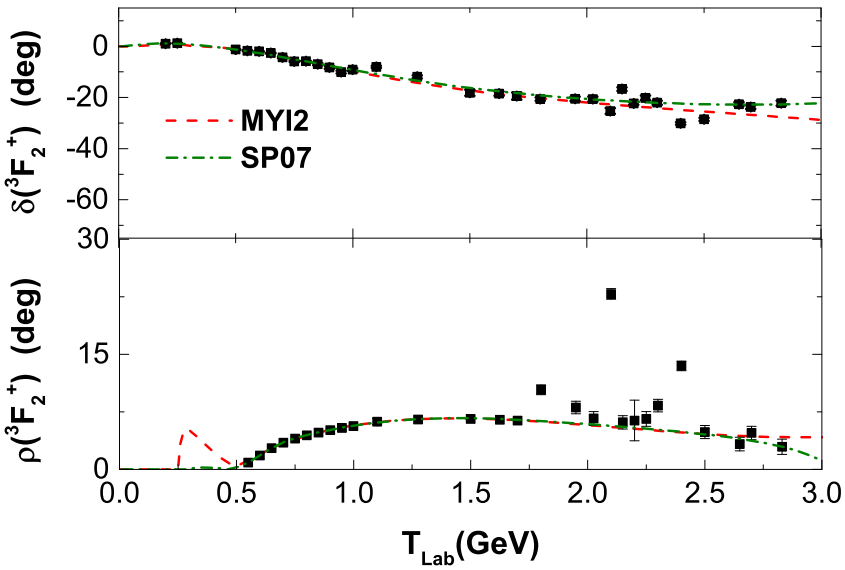


Figure: Phase shifts δ and inelasticity parameter ρ

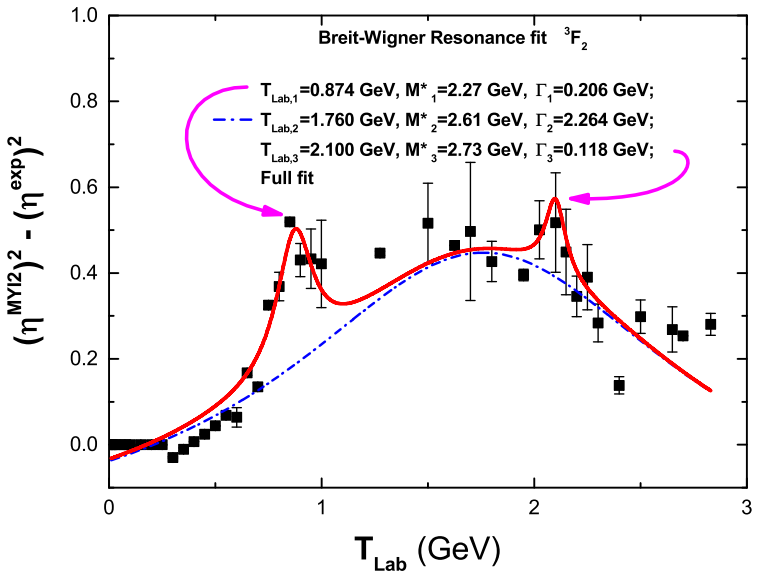


Figure: Difference $(\eta^{MYI})^2$-$(\eta^{exp})^2$

S.G. Bondarenko, V.V. Burov, E.P. Rogochaya. Nucl.Phys.Proc.Suppl. **245** (2013) 291-297

$^1D_2$ partial-wave state

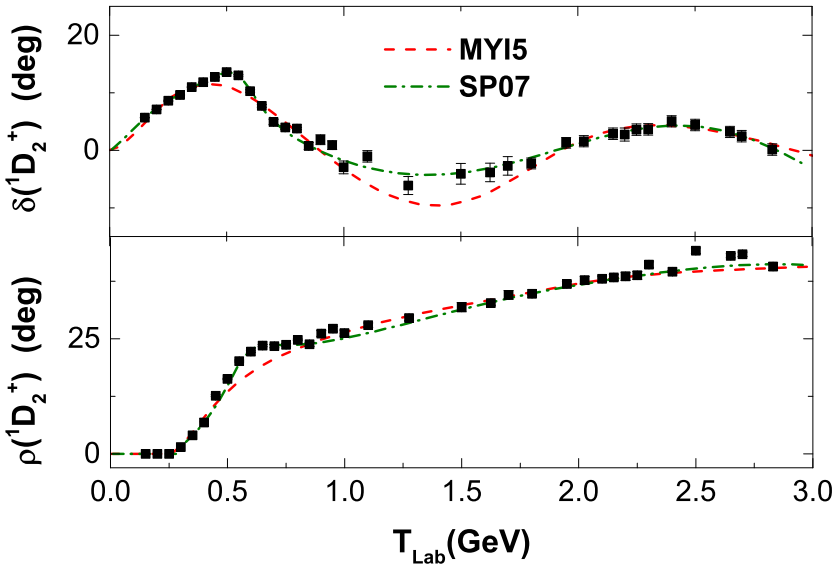


Figure: Phase shifts δ and inelasticity parameter ρ

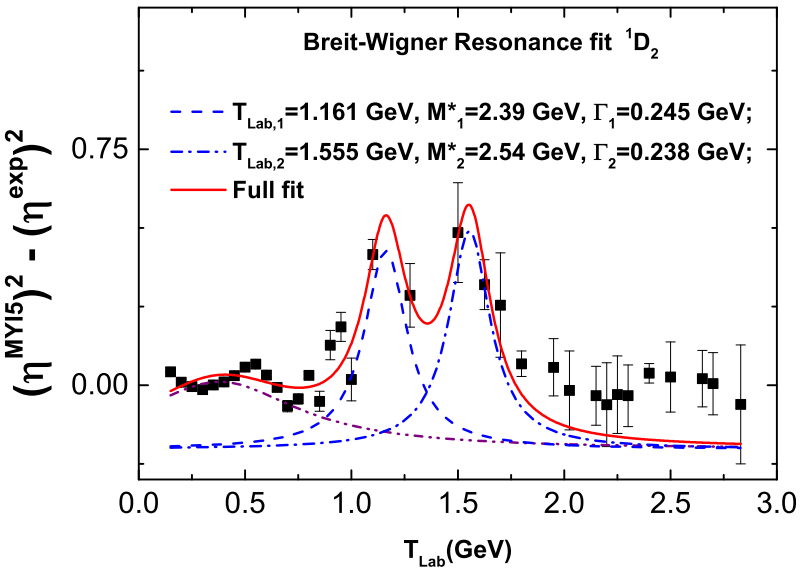


Figure: Difference $(\eta^{MYI})^2$-$(\eta^{exp})^2$

S.G. Bondarenko, V.V. Burov, S.E. Kemelzhanova, E.P. Rogochaya, N. Sagimbaeva. Proc. of the 12th International Workshop "Relativistic Nuclear Physics from Hundreds of MeV to TeV", Slovak Republic, Stara Lesna, June 16-20, 2014. JINR, Dubna. (2014) 70

$^1S_0$ partial-wave state

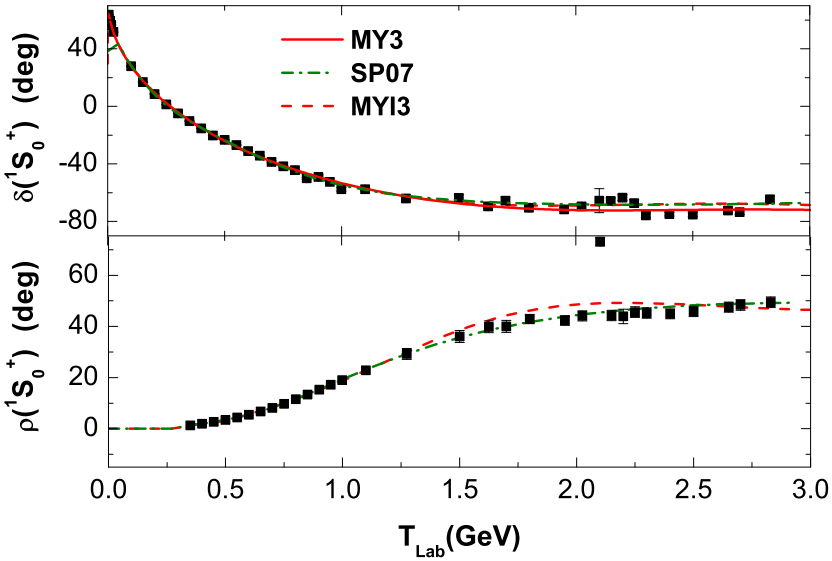


Figure: Phase shifts δ and inelasticity parameter ρ

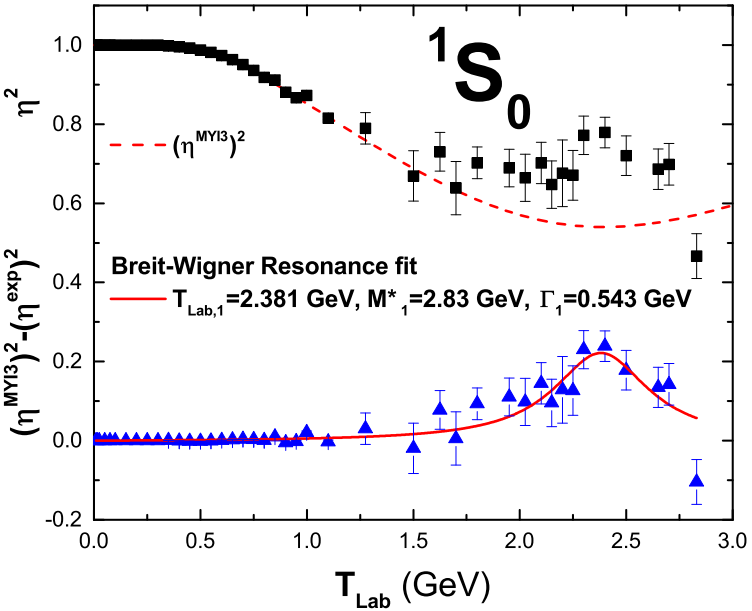


Figure: Function η^2 for MYI, experimental data and their difference

S.G. Bondarenko, V.V. Burov, E.P. Rogochaya. Proc. of the 16 th Small Triangle Meeting — Ptičie, October 5–8, 2014

$^1P_1$ partial-wave state

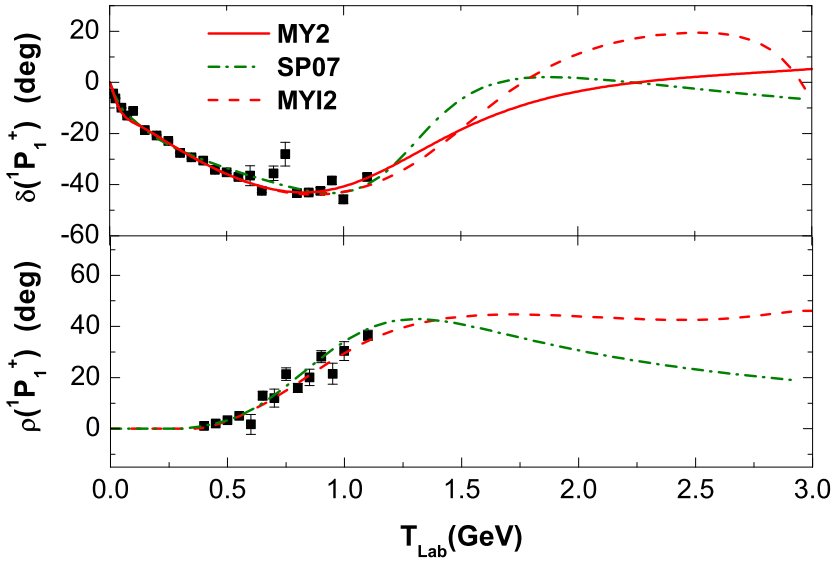


Figure: Phase shifts δ and inelasticity parameter ρ

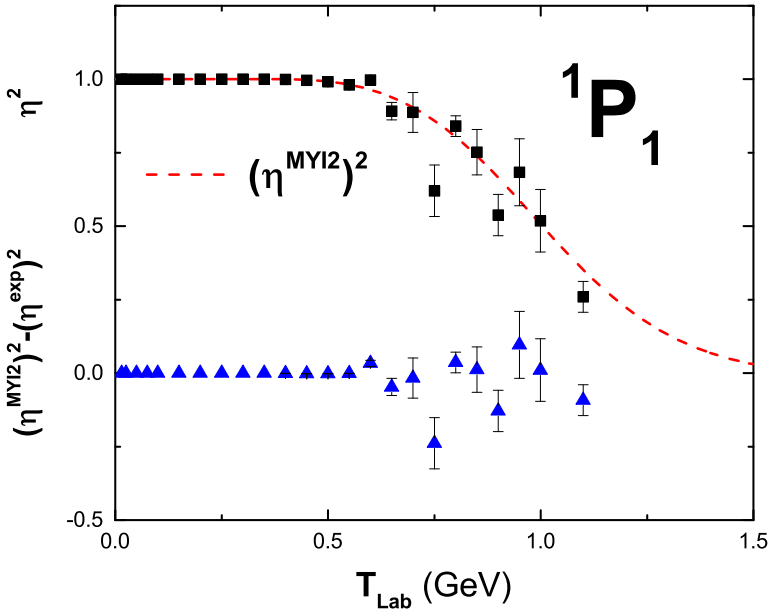


Figure: Function η^2 for MYI, experimental data and their difference

S.G. Bondarenko, V.V. Burov, E.P. Rogochaya. Proc. of the 16 th Small Triangle Meeting — Ptičie, October 5–8, 2014

$^3P_2$ partial-wave state

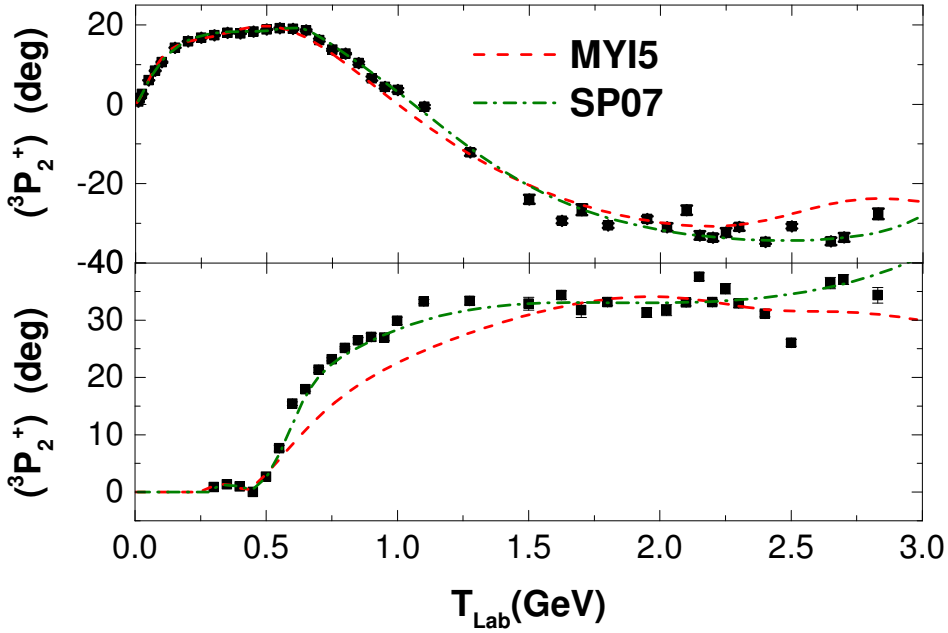


Figure: Phase shifts δ and inelasticity parameter ρ

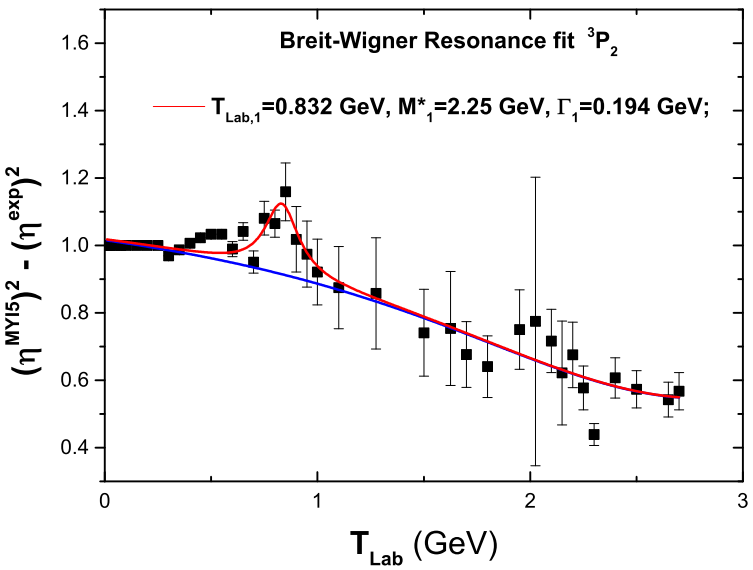


Figure: Difference $(\eta^{MYI})^2$-$(\eta^{exp})^2$

$^3F_3$ partial-wave state

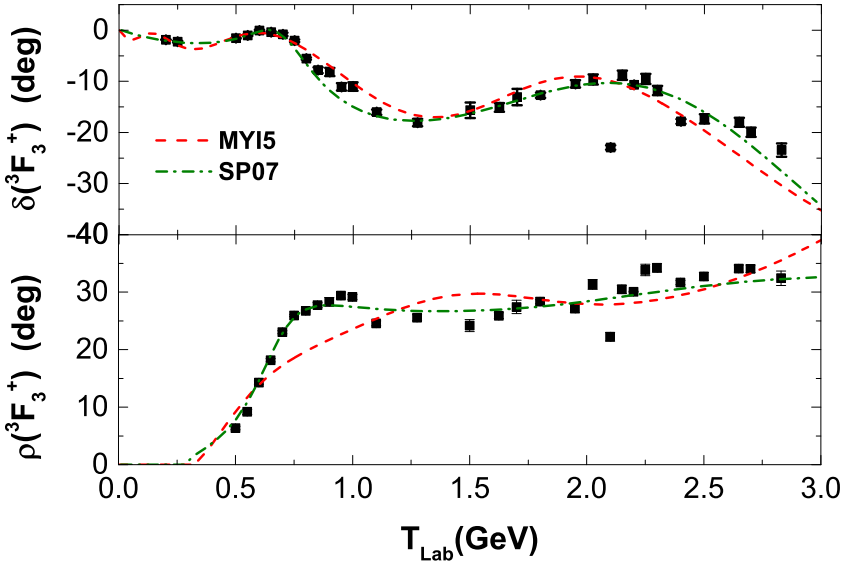


Figure: Phase shifts δ and inelasticity parameter ρ

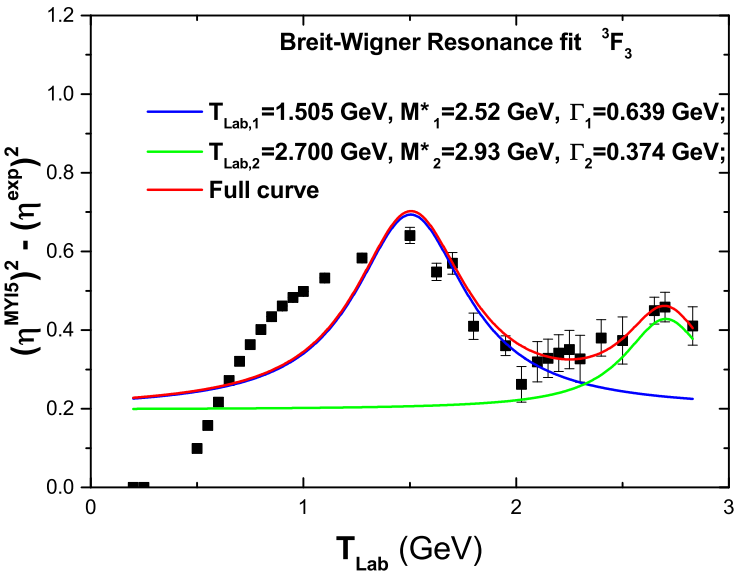


Figure: Difference $(\eta^{MYI})^2$-$(\eta^{exp})^2$

Parameters of wide dibaryons

T_{Lab} (GeV)	M^* (GeV)	Γ^* (GeV)	Partial-wave
0.856	2.26	0.200	$^3P_2$
0.872	2.27	0.199	$^3P_0$
0.874	2.27	0.206	$^3F_2$
1.161	2.39	0.245	$^1D_2$
1.505	2.52	0.639	$^3F_3$
1.555	2.54	0.238	$^1D_2$
1.595	2.55	1.335	$^3P_0$
1.760	2.61	2.264	$^3F_2$
2.100	2.73	0.118	$^3F_2$
2.381	2.83	0.543	$^1S_0$
2.700	2.93	0.374	$^3F_3$

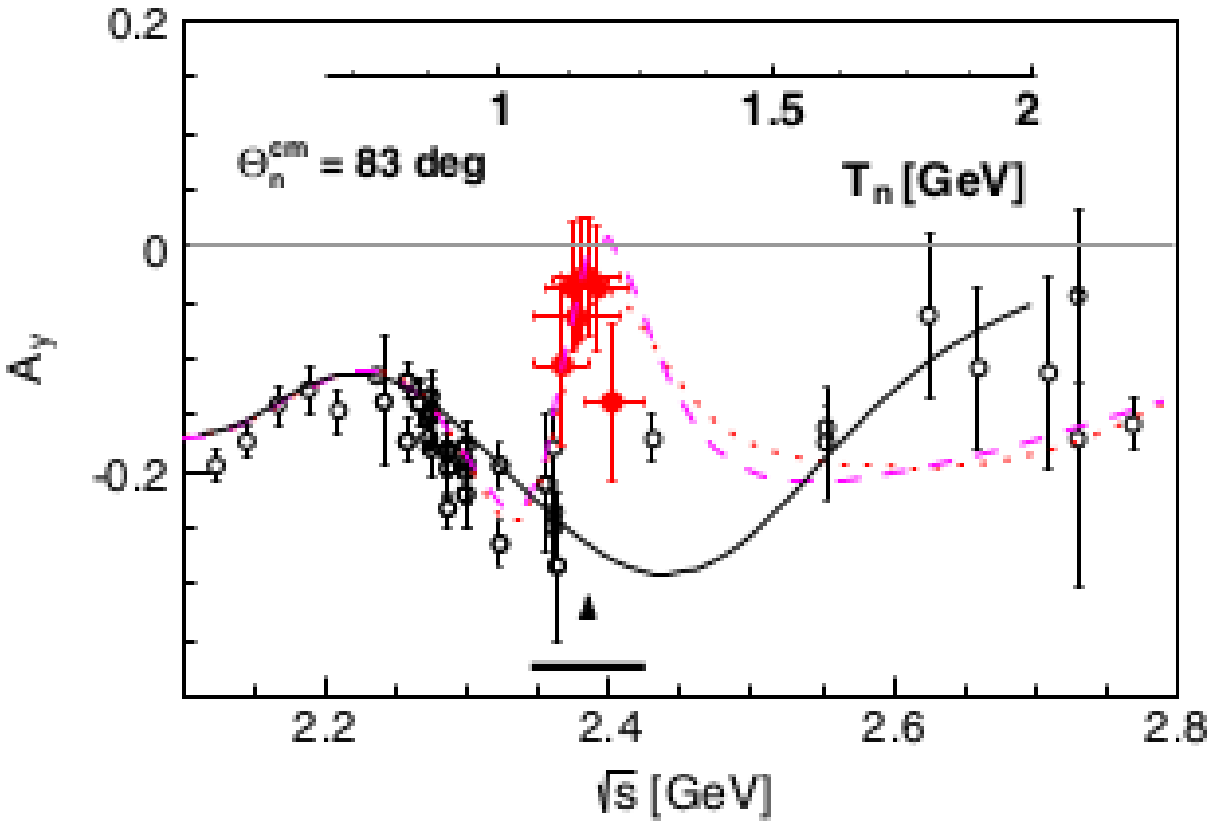


Figure: Narrow dibaryon structure ($M^* = 2380$ MeV, $\Gamma = 70$ MeV, $J = 3^+$) observed by COSY

PRL **112** 202301 (2014)

Conclusion

- The parameters of the complex separable kernel are obtained from the analysis of the experimental data for np scattering (phase shifts and inelasticities)
- The new $MYIN$ covariant functions obtaned from analysis were used to calculate exclusive electrodisintegration of the deuteron
- From the analysis of the cross-section of the np scattering in partial-waves the parameters of wide dibaryons are derived

Summary

The BS approach

- is a full covariant relativistic description of few-body systems (two and three);
- allows to describe the properties of the deuteron, NN phases and inelasticities with the separable potential
- allows investigate new phenomena - wide dibaryon resonances
- gives very reasonable explanation of structure functions, form factors and tensor polarization of deuteron in the elastic eD-scattering
- gives possibility to investigate electro- and photodisintegration of the deuteron
- allows investigate behavior of the ratios of structure functions of the light nuclei to the structure functions of the free nucleon
- gives possibility to extend formalism to three-body systems and study reactions with them