The pd->pdππ reaction with dibaryon d*(2380) excitation

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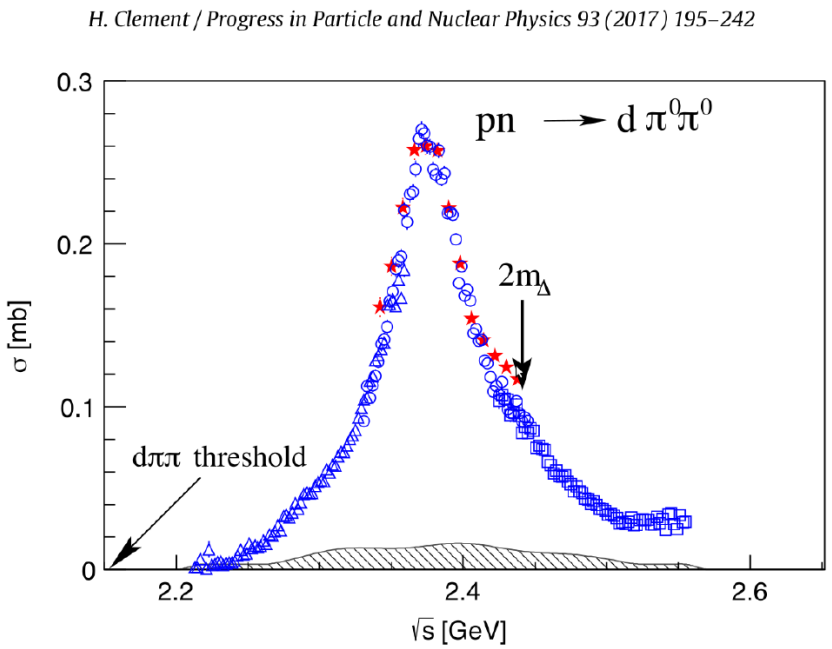
Introduction

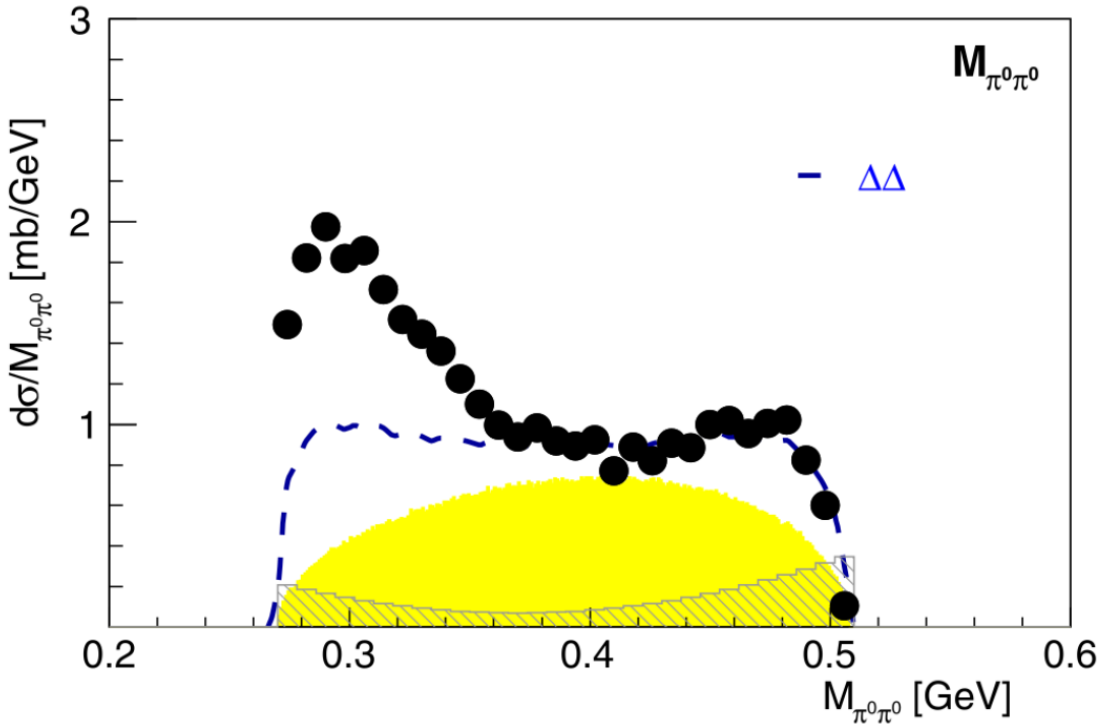
Search for dibaryon resonances in two-nucleon systems has a long history [1]. At present as one of the most realistic candidate to dibaryon is considered the resonance $D_{IJ} = D_{03}$ observed by WASA@COSY [2] in the total cross section of the reaction of two-pion production
$M_{D03} = 2.38$ GeV $\Gamma_{D03} = 70$ MeV $I = 0$ $J^P = 3^+$

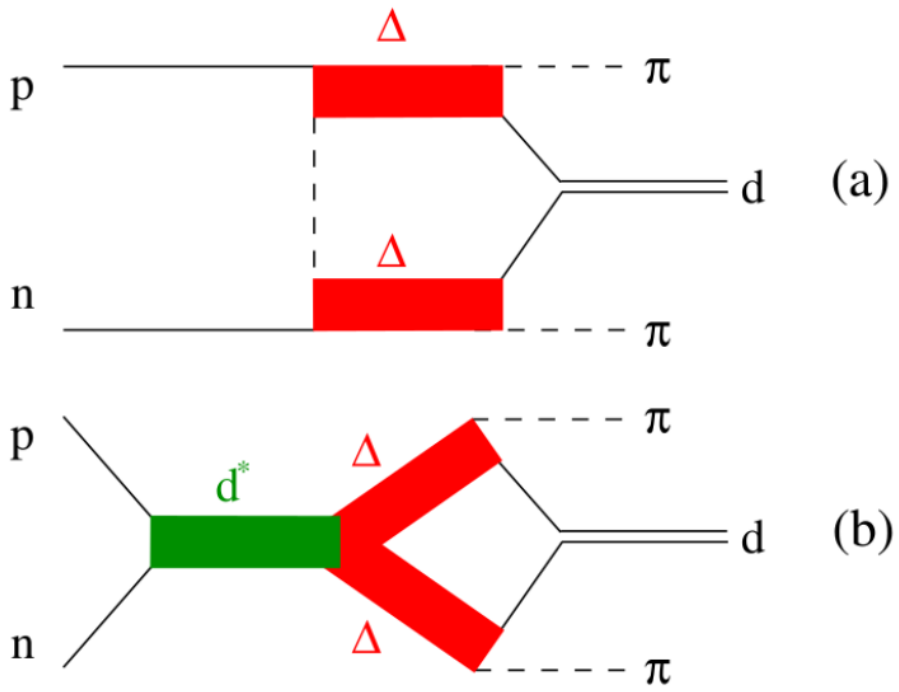


(i) 6q-models, – Y.-B. Dong, et al. (2016) (hidden colour);
(ii) hadron picture, πNΔ system – A.Gal, H.Garcilazo, PRL 111 (2013) 172301;
ΔΔ system – J. Niskanen, PRC 95 (2017) 054002 A. Gal PLB 769 (2017) 436

1. H. Clement, Prog. Part. Nucl. Phys. 93, 195 (2017).
2. P. Adlarson et al., (WASA@COSY Collab.), Phys. Rev. Lett. 106, 242302 (2011).

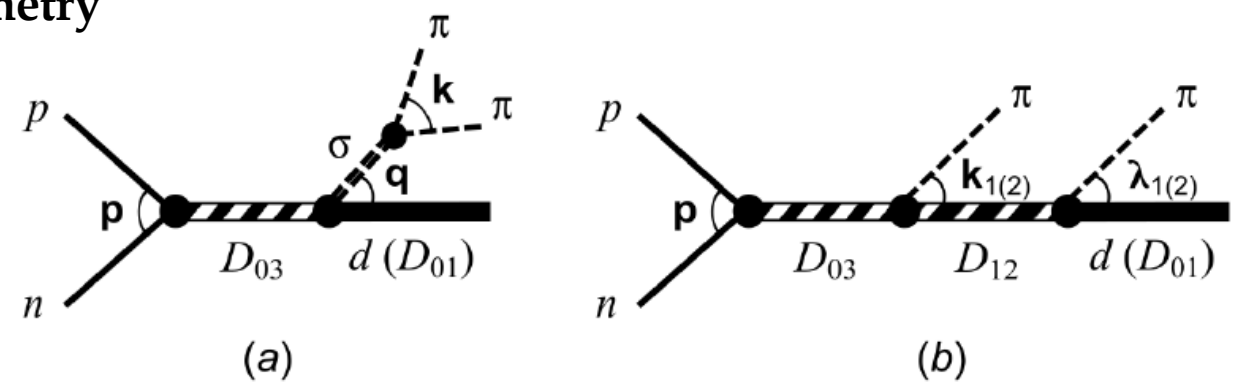
M. Bashkanov et al. / Nuclear Physics A 958 (2017) 129–146

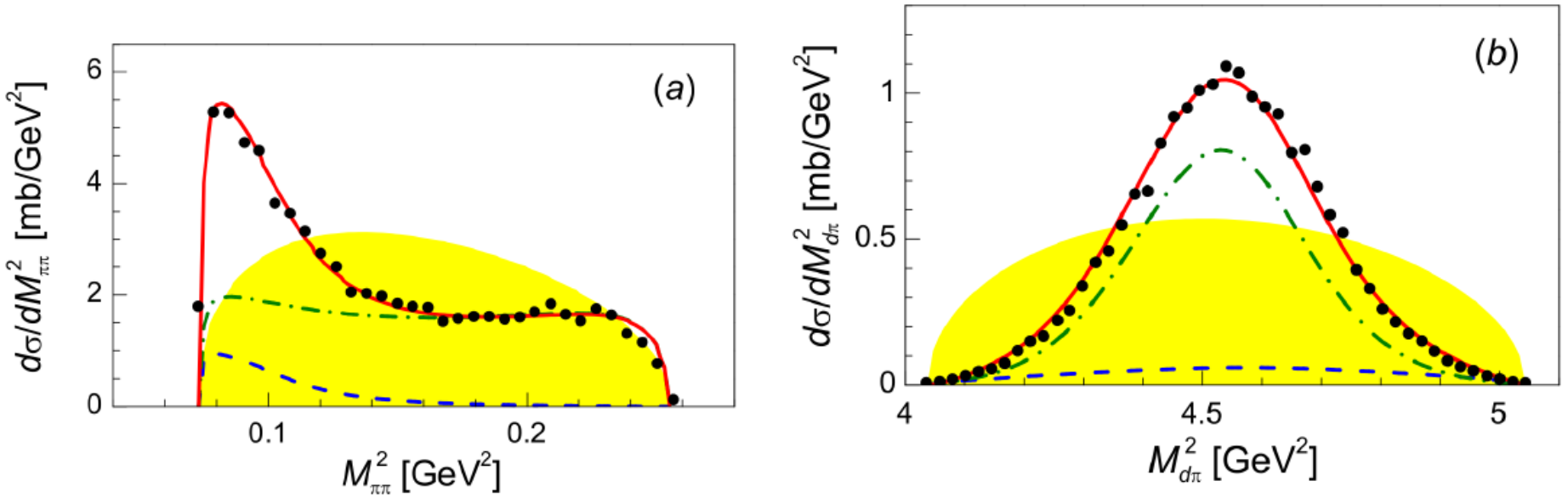




The enhancement took place near the threshold of the spectrum, Mππ ~ 300 MeV/c2, with a surprisingly small width of about 40 MeV/c2. This phenomenon got the name of the Abashian-Booth-Crowe (ABC) effect.

ABC effect as a signal of chiral symmetry restoration in hadronic collisions
M. N. Platonova and V. I. Kukulin
Phys. Rev. C 87, 2013





The contribution of the σ-production mechanism is shown by dashed lines while the contribution of the mechanism going through the intermediate dibaryon D_{12} is shown by dash-dotted lines. The solid lines correspond to the summed cross sections.

Isospin symmetry breaking in double-pion production in the region of d∗(2380) and the scalar σ meson

M. N. Platonova and V. I. Kukulin Phys. Rev. D 103, 114025, 2021

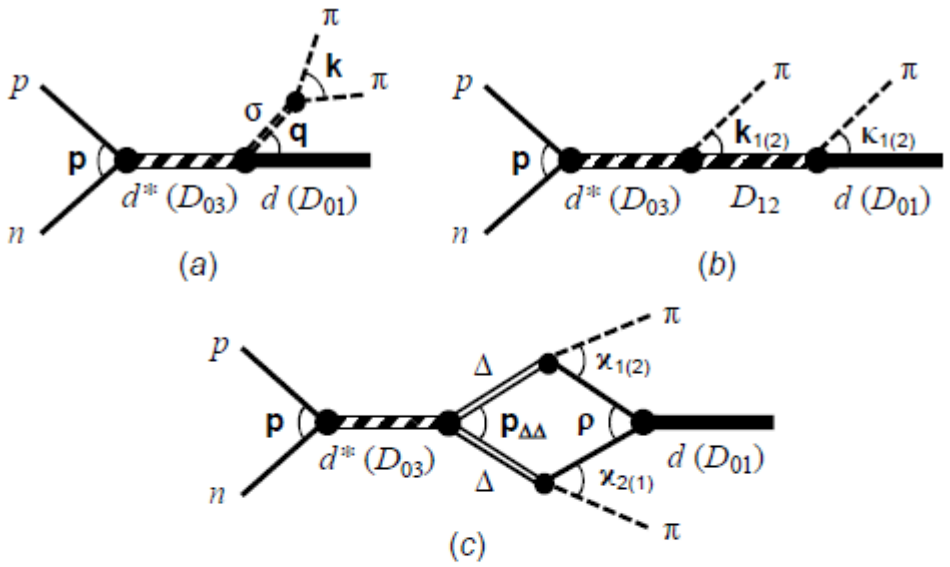


FIG. 1: Diagrams of different mechanisms for double-pion production in the region of the $\mathcal{D}_{03}$ (or $d^*(2380)$) resonance formation. The 3-momenta in the pair center-of-mass frames are indicated between the respective lines.

$$\mathcal{M}_{\lambda_p,\lambda_n,\lambda_d} = \frac{\sum_{\lambda_3} \mathcal{M}^{(D_{03})}_{\lambda_p,\lambda_n,\lambda_3} \left[\mathcal{M}^{(\sigma)}_{\lambda_3,\lambda_d} + \mathcal{M}^{(D_{12})}_{\lambda_3,\lambda_d} + \mathcal{M}^{(\Delta\Delta)}_{\lambda_3,\lambda_d}\right]}{s - M^2_{D_{03}} + i\sqrt{s}\Gamma_{D_{03}}(s)}$$

$$\mathcal{M}^{(D_{03})}_{\lambda_p,\lambda_n,\lambda_3} = F_{pn\to D_{03}}(p) C^{3\lambda_3}_{1\lambda_3 20} C^{1\lambda_3}_{\frac{1}{2}\lambda_p\frac{1}{2}\lambda_n} Y_{20}(\hat{p}),$$

$$\mathcal{M}^{(\sigma)}_{\lambda_3,\lambda_d} = \frac{F_{D_{03}\to d\sigma}(q) F_{\sigma\to\pi\pi}(k)}{M^2_{\pi\pi} - m^2_\sigma + iM_{\pi\pi}\Gamma_\sigma(M^2_{\pi\pi})} C^{3\lambda_3}_{1\lambda_d 2\mu} Y_{2\mu}(\hat{q}),$$

$$\mathcal{M}^{(D_{12})}_{\lambda_3,\lambda_d} = \frac{F_{D_{03}\to D_{12}\pi_1}(k_1) F_{D_{12}\to d\pi_2}(\kappa_1)}{M^2_{d\pi_2} - M^2_{D_{12}} + iM_{d\pi_2}\Gamma_{D_{12}}(M^2_{d\pi_2})}$$

$$\times \sum_{\lambda_2} C^{3\lambda_3}_{2\lambda_2 1\mu_2} C^{2\lambda_2}_{1\lambda_d 1\mu_1} Y_{1\mu_2}(\hat{k}_1) Y_{1\mu_1}(\hat{\kappa}_1) + (\pi_1 \leftrightarrow \pi_2),$$

$$\mathcal{M}^{(\Delta\Delta)}_{\lambda_3,\lambda_d} = \int \frac{d^3\rho}{(2\pi)^3} \varphi_d(\rho) F_{D_{03}\to\Delta\Delta}(p_{\Delta\Delta})$$

$$\times G_\Delta(M_{N_1\pi_1}) G_\Delta(M_{N_2\pi_2}) F_{\Delta\to N_1\pi_1}(\varkappa_1) F_{\Delta\to N_2\pi_2}(\varkappa_2)$$

$$\times \sum_{\lambda_{\Delta_1}\lambda_{N_1}} C^{3\lambda_3}_{\frac{3}{2}\lambda_{\Delta_1}\frac{3}{2}\lambda_{\Delta_2}} C^{\frac{3}{2}\lambda_{\Delta_1}}_{\frac{1}{2}\lambda_{N_1}1\mu_1} C^{\frac{3}{2}\lambda_{\Delta_2}}_{\frac{1}{2}\lambda_{N_2}1\mu_2} C^{1\lambda_d}_{\frac{1}{2}\lambda_{N_1}\frac{1}{2}\lambda_{N_2}}$$

$$\times Y_{1\mu_1}(\hat{\varkappa}_1) Y_{1\mu_2}(\hat{\varkappa}_2) + (\pi_1 \leftrightarrow \pi_2), \qquad (5)$$

TABLE I: Parameters of resonances R and their decay channels $R \to a + b$. For the parameter p_0, the given interval corresponds to all possible isospin channels.

R	M_R (MeV)	$\Gamma_R^{(0)}$ (MeV)	ab	l	p_0 (MeV)	$\Gamma_{R\to ab}^{(0)}$ (MeV)	Λ_{ab} (GeV)
			np	2	730	9	0.35
$\mathcal{D}_{03}$	2376	77	σd	2	350	2	0.18
			$\pi\mathcal{D}_{12}$	1	173–176	31	0.12
$\mathcal{D}_{12}$	2150	110	πd	1	221–223	33	0.15
Δ	1232	117	πN	1	226–229	117	0.16
σ	303	126	$\pi\pi$	0	72–80	126	0.09

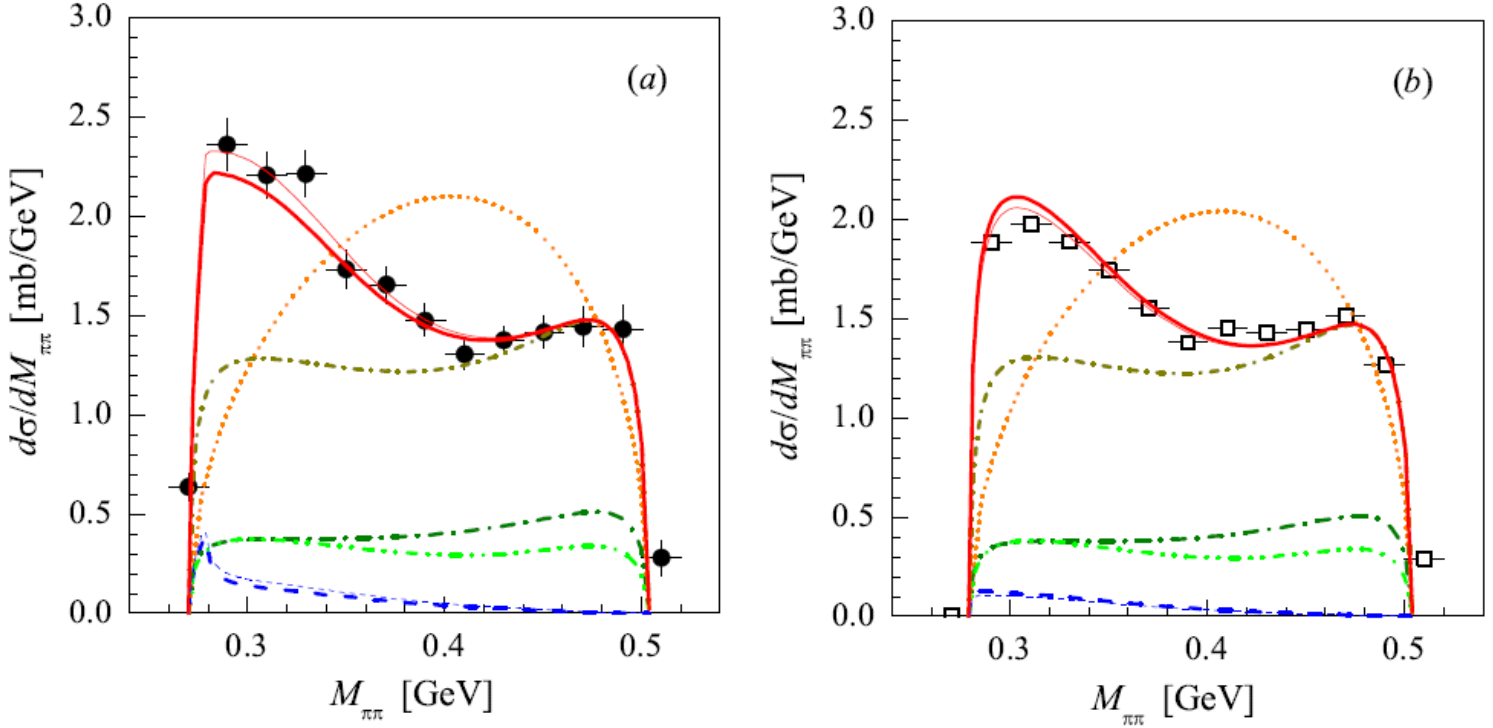
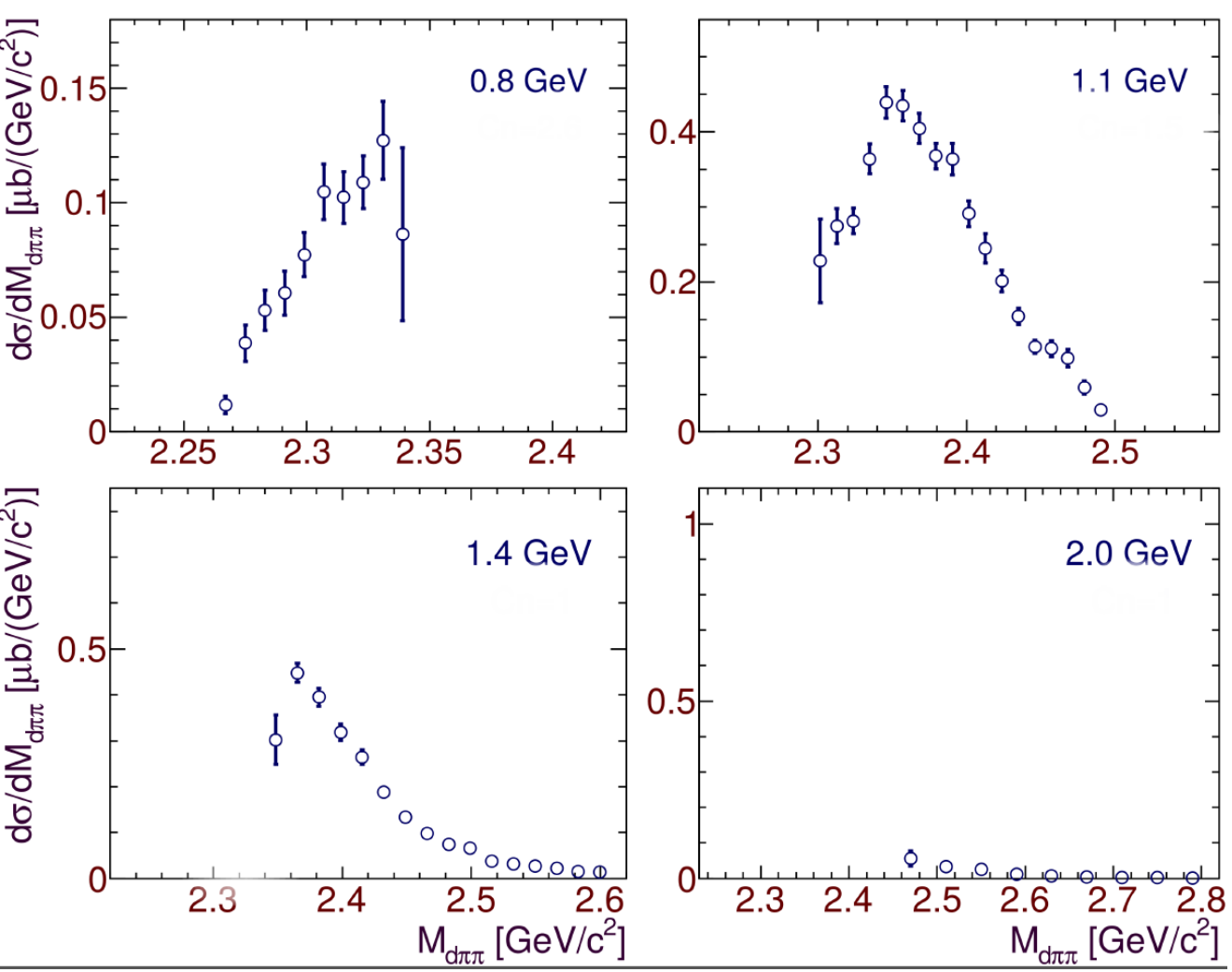
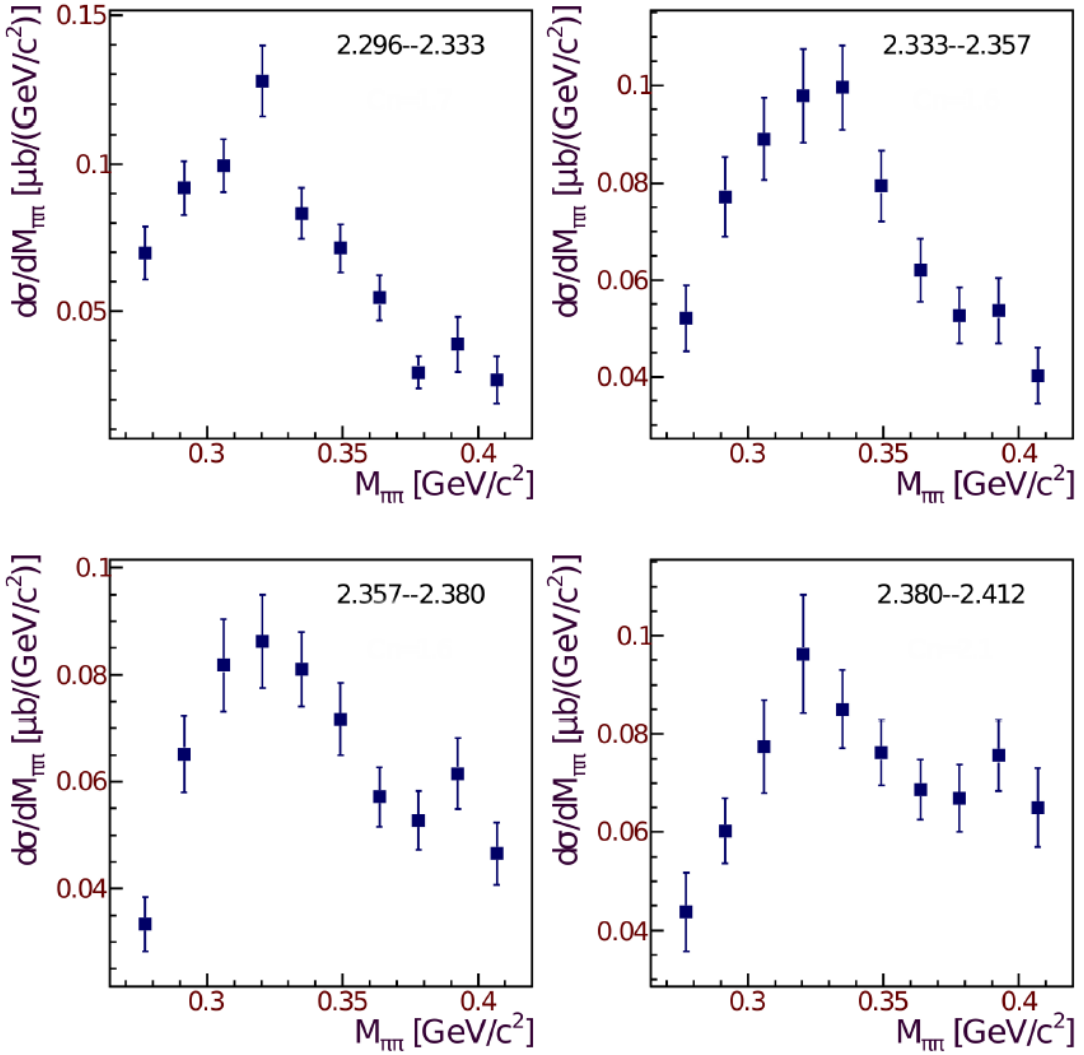


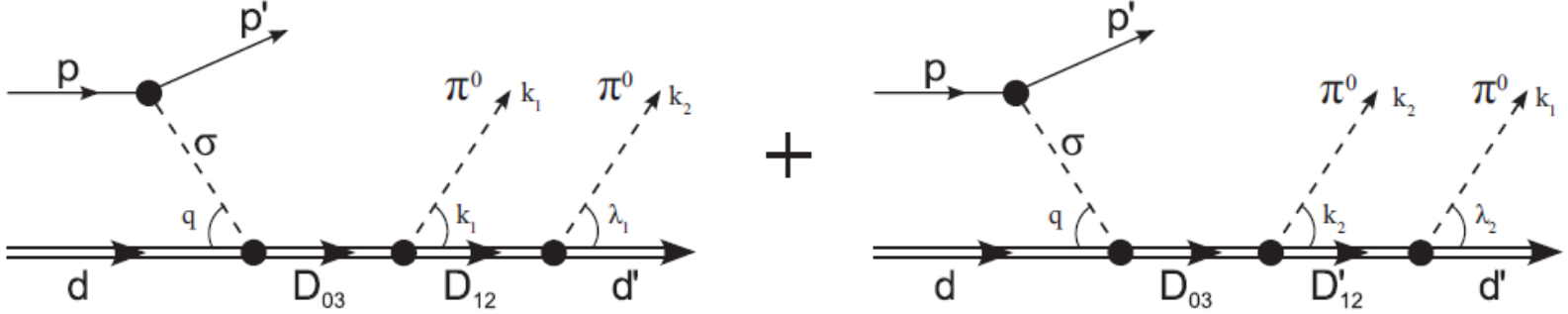
FIG. 6: (Color online) The $\pi\pi$ invariant-mass distributions in the reactions (*a*) $pn \to d\pi^0\pi^0$ (multiplied by 2) and (*b*) $pn \to d(\pi^+\pi^-)_0$ at $\sqrt{s} = 2.38$ GeV calculated with the model parameters from Tab. I. Shown are the distributions resulted from the $\mathcal{D}_{03} \to \mathcal{D}_{12} + \pi$ decay (dash-dotted lines), the $\mathcal{D}_{03} \to \Delta + \Delta$ decay (dash-dot-dotted lines), the $\mathcal{D}_{03} \to d + \sigma$ decay (dashed lines), and the coherent sum of these three $\mathcal{D}_{03}$ decay routes (solid lines). Upper dash-dotted lines (with short dashes) show the summed contribution of the $\mathcal{D}_{12} + \pi$ and $\Delta + \Delta$ excitation mechanisms. Dotted lines correspond to the pure phase-space distributions. Thin dashed and solid lines correspond to the σ-excitation mechanism and the total distributions with $\alpha = 0.23$ (see Eq. (15)). The theoretical calculations are compared to the experimental data on $2d\sigma/dM_{\pi^0\pi^0}$ (filled circles) and $d\sigma/dM_{\pi^+\pi^-} - \frac{1}{2}d\sigma/dM_{\pi^+\pi^0}$ (open squares) taken from Ref. [9].

$pd \to pd\pi\pi$ REACTION. ANKE@COSY DATA





Komarov, V.I., Tsirkov, D., Azaryan, T. *et al.* Resonance-like coherent production of a pion pair in the reaction pd->pdππ in the GeV region. *Eur. Phys. J. A* **54**, 206 (2018).



The two-step decay mechanism of the reaction $pd \to pd\pi\pi$:
$p + d \to p + D_{03} \to p + D_{12} + \pi_1 \to pd + \pi_1 + \pi_2$

$$\frac{d\sigma}{d\Omega} = \frac{(2\pi)^4}{4I}\int \overline{|M_{fi}|^2}\delta^{(4)}(P_i - P_f)\frac{d^3p_1}{(2\pi)^3 2E_1}\frac{d^3p_2}{(2\pi)^3 2E_2}\frac{d^3p_3}{(2\pi)^3 2E_3}\frac{d^3p_4}{(2\pi)^3 2E_4} \quad (2)$$

$$M^{\lambda'_p\lambda'_d}_{\lambda_p\lambda_d}(pd \to pd\pi\pi) = M^{\lambda'_p}_{\lambda_p}(p \to p'\sigma)\frac{1}{p_\sigma{}^2 - m_\sigma{}^2 + im_\sigma\Gamma_\sigma}M^{\lambda'_d}_{\lambda_d}(\sigma d \to d\pi\pi) \quad (3)$$

$$M^{\lambda'_d}_{\lambda_d}(\sigma d \to d\pi\pi) = \sum_{\lambda_2,\lambda_3,\mu,m_1,m_2}\frac{F_{D_{03}\to d\sigma}(q)F_{D_{03}\to D_{12}\pi_1(k_1)}}{P^2_{D_{03}} - M^2_{D_{03}} + iM_{D_{03}}\Gamma_{D_{03}}}\frac{F_{D_{12}\to d\pi_2(\lambda_1)}}{P^2_{D_{12}} - M^2_{D_{12}} + iM_{D_{12}}\Gamma_{D_{12}}}$$
$$\times (1\lambda_d 2\mu|3\lambda_3)\mathcal{Y}_{2\mu}(\hat{\mathbf{q}})(2\lambda_2 1m_1|3\lambda_3)\mathcal{Y}_{1m_1}(\hat{\mathbf{k}}_1)(1\lambda'_d 1m_2|2\lambda_2)\mathcal{Y}_{1m_2}(\hat{\lambda}_1) +$$
$$\frac{F_{D_{03}\to d\sigma}(q)F_{D_{03}\to D_{12}\pi_2(k_2)}}{P^2_{D_{03}} - M^2_{D_{03}} + iM_{D_{03}}\Gamma_{D_{03}}}\frac{F_{D_{12}\to d\pi_1}(\lambda_2)}{P^2_{D_{12}} - M^2_{D_{12}} + iM_{D_{12}}\Gamma_{D_{12}}}$$
$$\times (1\lambda_d 2\mu|3\lambda_3)\mathcal{Y}_{2\mu}(\hat{\mathbf{q}})(2\lambda_2 1m_1|3\lambda_3)\mathcal{Y}_{1m_1}(\hat{\mathbf{k}}_2)(1\lambda'_d 1m_2|2\lambda_2)\mathcal{Y}_{1m_2}(\hat{\lambda}_2) \quad (4)$$

The vertex factors F in eq. (4) are defined as in (3)

$$F_{D_{03}\to d\sigma}(q) = M_{D_{03}}(q)\sqrt{\frac{8\pi\Gamma^{(I=2)}_{D_{03}\to d\sigma}(q)}{q^5}}$$

$$\Gamma^{(I=2)}_{D_{03}\to d\sigma}(q) = \Gamma^{(I=2)}_{D_{03}\to d\sigma}\left(\frac{q}{q_0}\right)^5\left(\frac{q_0^2+\lambda_{d\sigma}^2}{q^2+\lambda_{d\sigma}}\right)^3$$

$$F_{D_{03}\to D_{12}\pi_1}(k_1) = M_{D_{12}\pi}(q)\sqrt{\frac{8\pi\Gamma^{(I=1)}_{D_{03}\to D_{12}\pi}(k_1)}{k_1^3}}$$

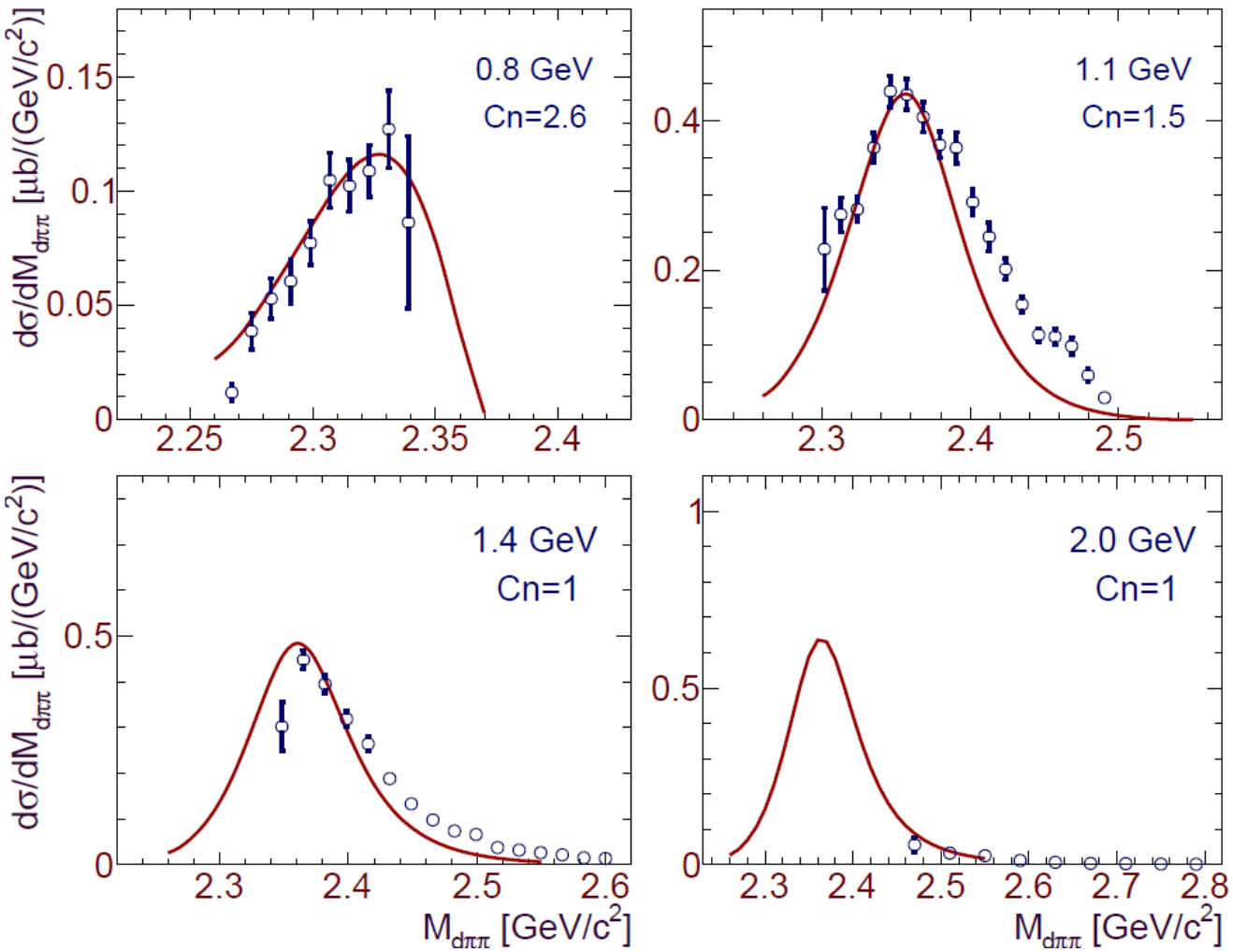
$$\Gamma^{(I=1)}_{D_{03}\to D_{12}\pi}(k_1) = \Gamma^{(I=1)}_{D_{03}\to D_{12}\pi}\left(\frac{k_1}{k_{10}}\right)^3\left(\frac{k_{10}^2+\lambda_{D_{12}\pi}^2}{k_1^2+\lambda_{D_{12}\pi}}\right)^2$$

$$F_{D_{12}\to d\pi_2}(\lambda_1) = M_{d\pi_2}(\lambda_1)\sqrt{\frac{8\pi\Gamma^{(I=1)}_{D_{12}\to d\pi}(\lambda_1)}{\lambda_1^3}}$$

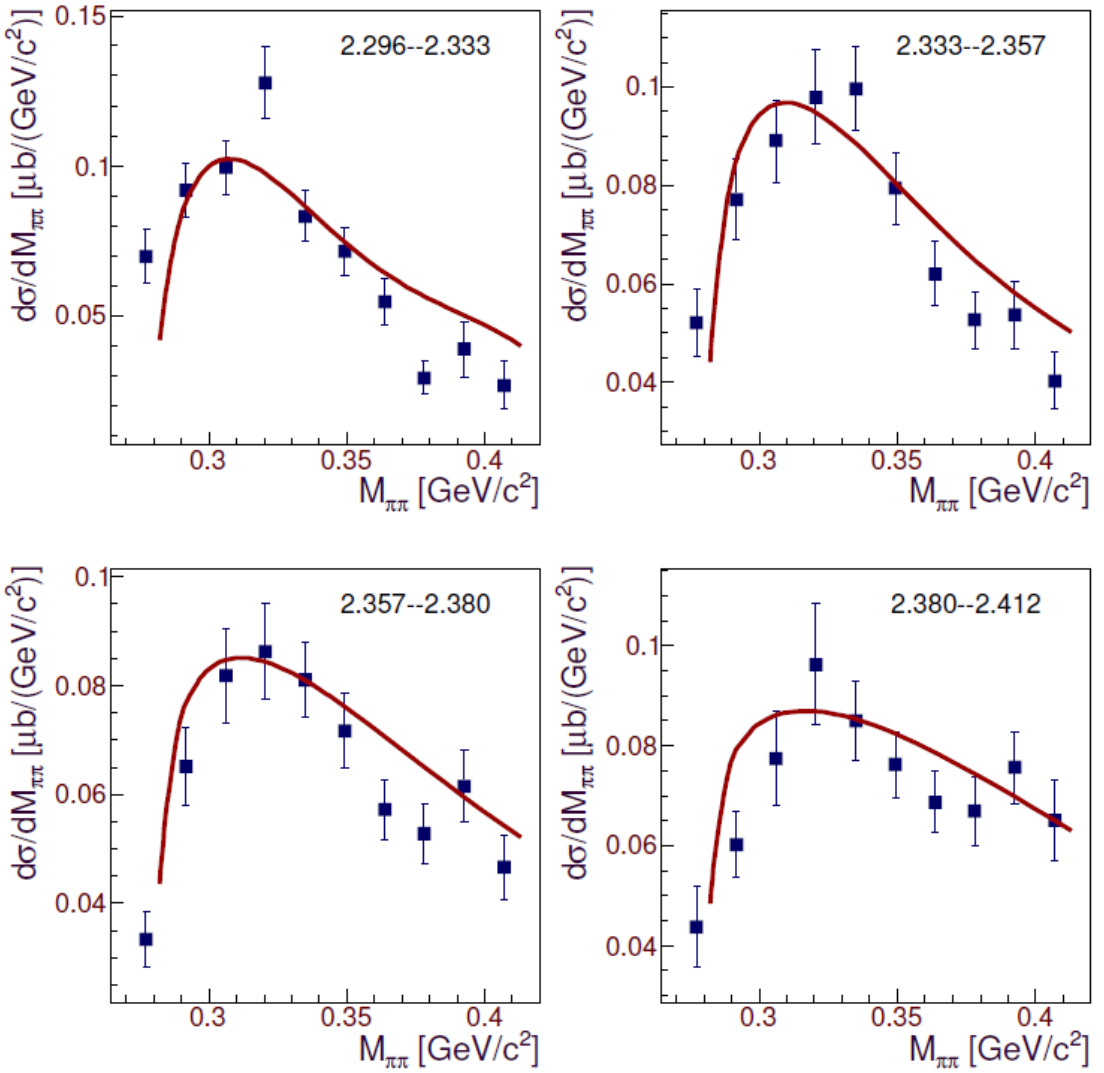
$$\Gamma^{(I=1)}_{D_{12}\to d\pi}(\lambda_1) = \Gamma^{(I=1)}_{D_{12}\to d\pi}\left(\frac{\lambda_1}{\lambda_{10}}\right)^3\left(\frac{\lambda_{10}^2+\lambda_{d\pi}^2}{\lambda_1^2+\lambda_{d\pi}}\right)^2 \quad (5)$$

$$M_{D_{03}} = 2.36\ GeV\ \ \Gamma_{D_{03}} = 110\ MeV$$
$$M_{D_{12}} = 2.15\ GeV\ \ \Gamma_{D_{12}} = 110\ MeV$$
$$M_\sigma = 0.4\ GeV\ \ \Gamma_\sigma = 0.4\ GeV$$
$$f_\sigma = 2.2$$
$$\Gamma^{(I=2)}_{D_{03}\to d\sigma} = 23\ MeV$$
$$\Gamma^{(I=1)}_{D_{03}\to D_{12}\pi} = 6.5\ MeV$$
$$\Gamma^{(I=1)}_{D_{12}\to d\pi} = 8.4\ MeV$$
$$k_{10} = 0.177\ GeV\ \ \lambda_{D_{12}\pi} = 0.12\ GeV$$
$$\lambda_{10} = 0.224\ GeV\ \ \lambda_{d\pi} = 0.25\ GeV$$
$$q_0 = 0.362\ GeV\ \ \lambda_{d\sigma} = 0.18\ GeV \quad (6)$$

$pd \to pd\pi\pi$ REACTION. ANKE@COSY DATA AND TWO-RESONANCE MODEL



$pd \to pd\pi\pi$ REACTION. $M_{\pi\pi}$ SPECTRA AT $T_p = 1.1 GeV$.



Tursunbayev, N., Uzikov, Y. (2020). Resonance Production of Two Pions in the Reaction pd->pdππ at 1–2 GeV. Recent Progress in Few-Body Physics. FB22 2018. Springer Proceedings in Physics, vol 238.

Table 1: The partial width $\Gamma_{D_{03}\to d\pi\pi}$ at different values of the orbital angular momenta l_1 and l_2 (see text for details)

l_1	l_2	$\Gamma^{i}_{D_{03}\to d\pi\pi}$ (MeV)	$\Gamma^{ii}_{D_{03}\to d\pi\pi}$ (MeV)
1	1	< 6.5	10
1	3	< 2.02	3.1
3	1	< 1.81	2.78
3	3	< 0.6	0.92
5	1	< 4.42	6.8
5	3	< 3.6	5.5

The D03(2380) dibaryon resonance excitation in the pd→pdππ reaction.
Nurbek Tursunbayev, Yuriy Uzikov SciPost Phys. Proc. 3, 056 (2020) · published 27 February 2020

Reaction of two pion production $pd \to pd\pi\pi$ in the resonance region
Yuriy Uzikov and Nurbek Tursunbayev EPJ Web Conf. **Volume** 204, 2019 XXIV International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics" (Baldin ISHEPP XXIV)

THANK YOU!