RESONANCE BEHAVIOUR OF THE REACTIONS $\mathbf{pp \to \{pp\}_s \pi^0}$ AND $\mathbf{pd \to pd\pi\pi}$ IN THE GEV REGION

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Preface

• **Dubna, 1957,** $p +^{12} C \to d + X$ **at 670 MeV,**
D.I. Blokhintsev: fluctons (6q) in nuclei.

• $\Delta(1232)$ **in** $pd \to dp$ **at** $\sim 500 - 600$ **MeV:**

N.S. Craigie, C. Wilkin, (1969) OPE; V.M. Kolybasov, N.Ya. Smorodinskya (1973)
L. Kondratyuk, F. Lev, L.Schevchenko (1979-1982) :
$\boldsymbol{\Delta} + \mathrm{B3}$, **TRIBARIONS (9q)!**

O.Imambekov, Yu.N. U., L.Schevchenko (1988-1989):
Δ**-dominates** $d\sigma/d\Omega$ **but does not solve the** T_{20} **puzzle!** $\Longrightarrow$ **Spin structure of** $NN \to N\Delta$ **is not well known.**

• $\Delta(1232)$ **is against of multiquark exotics**

• **How to suppress the** Δ**-contribution in** pd**- and** pN**-ineractions?**

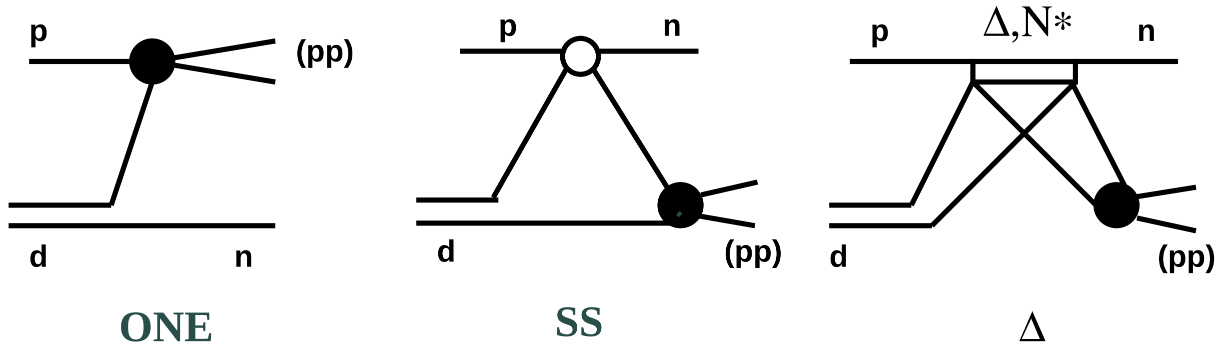
• **Reactions with the $^1S_0$ diproton $\{pp\}_s$ (i.e. $E_{pp} < 3$ MeV) at large Q can give more insight into underlying dynamics due to difference in quantum numbers**

deuteron $\Longrightarrow$ $(^1S_0)$pn singlet deuteron or
$\Longrightarrow$ $(^1S_0)$-diproton, $\{pp\}_s$

1. $\mathbf{pd \to dp \Longrightarrow p\{NN\}_s \to dN}$ **in A(p,Nd)B**
suppression of the Δ- and N^*-excitations as $1:9$

and $\mathbf{pd \to \{pp\}_s n}$

/O.Imambekov , Yu.N.Uzikov, Yad. Fiz. 52 (1990) 1361/



2. $\mathbf{pp} \to \mathbf{d}\pi^+$ & $\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\pi^\mathbf{0}$

$^1S_0$ **diproton:** $\mathbf{J}^\pi = \mathbf{0}^+,\ \mathbf{T} = \mathbf{1},\ \mathbf{S} = \mathbf{0},\ \mathbf{L} = \mathbf{0}$

deuteron: $\mathbf{J}^\pi = \mathbf{1}^+, \mathbf{T} = \mathbf{0},\ \mathbf{S} = \mathbf{1}, \mathbf{L} = \mathbf{0}, \mathbf{2}$

- $(-\mathbf{1})^{\mathbf{L}+\mathbf{S}+\mathbf{T}} = -\mathbf{1}$ **(Pauli principle)**
- **Spin-parity conservation:**

$\star$ $\mathbf{pp} \to \mathbf{d}\pi^+$**, odd and even** L_{pp}**,** $S = 1$ **and** $S = 0$**;**
$\Longrightarrow$ $\mathbf{\Delta N}$ **in S-wave (** N^*N**)** $\pi = +1$ **-***is allowed*
$\Longrightarrow$ $\Delta(1232)$ **dominates in the** $pp \to d\pi^+$ **at ≈600 MeV**

$\star$ $\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\pi^\mathbf{0}$ **odd** L_{pp}**,** $S = 1$
$\Longrightarrow$ $\mathbf{\Delta N}$ **in S-wave (or** N^*N**)** $\pi = +1$ **-** *is vorbidden*

Diproton physics at ANKE-COSY, 2000-2014

$\mathbf{pd} \to \{\mathbf{pp}\}_\mathbf{s}\mathbf{n}$, hard deuteron breakup 0.5 - 2.0 GeV

$\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\pi^\mathbf{0}$

$\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\gamma$

$\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\pi\pi$

$\mathbf{pn} \to \{\mathbf{pp}\}_\mathbf{s}\pi^-$, $T_p = 350$ MeV, the contact d-term for ChPT

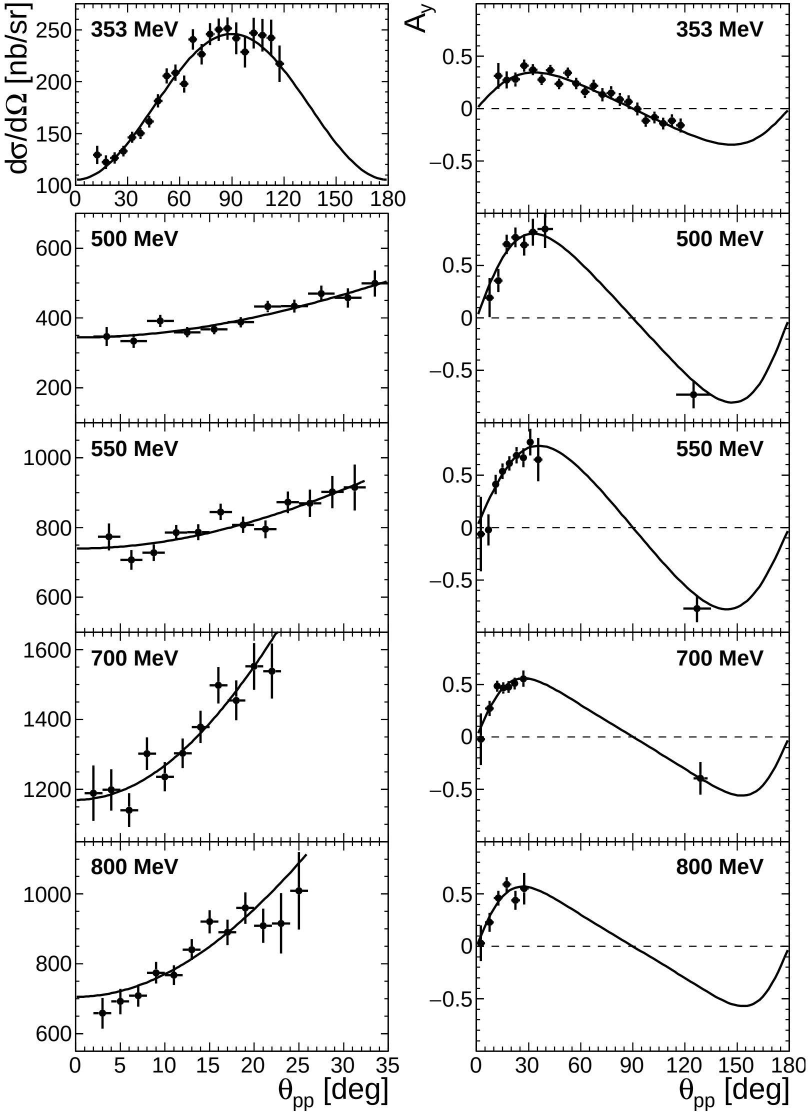
$\mathbf{dp} \to \{\mathbf{pp}\}_\mathbf{s}\mathbf{N}\pi$, $T_d = 1.6 - 2.3$ GeV $\pi N = \Delta$- excitation

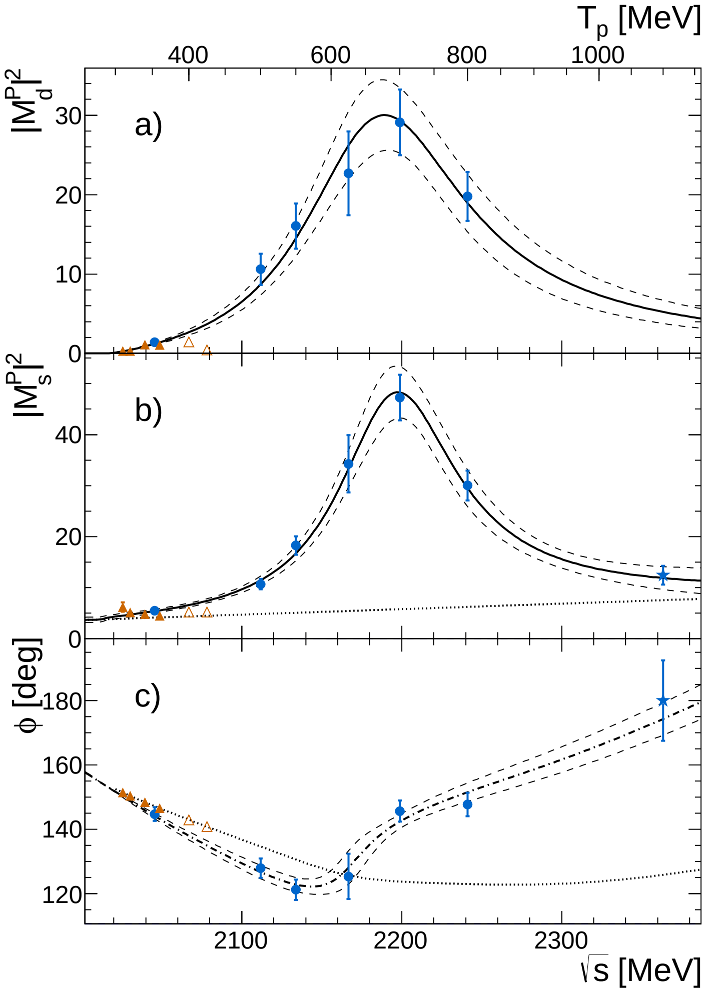
As was shown in CC approach, the resonance sructure in $\mathbf{pp} \to \mathbf{d}\pi^+$ at 500-800 MeV is dominated by the $\Delta(1232)$-isobar excitation (J. Niskanen, NPA(1978), Phys.Lett B141 (1984); C. Furget et al. Nucl.Phys. A655 (1999) 495).

M. Platonova, V. Kukulin, NPA **946** (2016) 117: the Δ mechanism alone is not sufficient, dibaryon resonances were introduced: ^1D_2p (2150 MeV, $\Gamma = 110$MeV), ^3F_3d (2200-2260 MeV $\Gamma = 150$ MeV) to get an agreement (including polarizations, PRD **94** (2016)) with $\mathbf{pp} \to \mathbf{d}\pi^+$.

Thus, it is important to study another channel: $pp \to \{pp\}_s\pi^0$ **at similar kinematics** .

ANKE@COSY $pp \to \{pp\}_s\pi^0$,

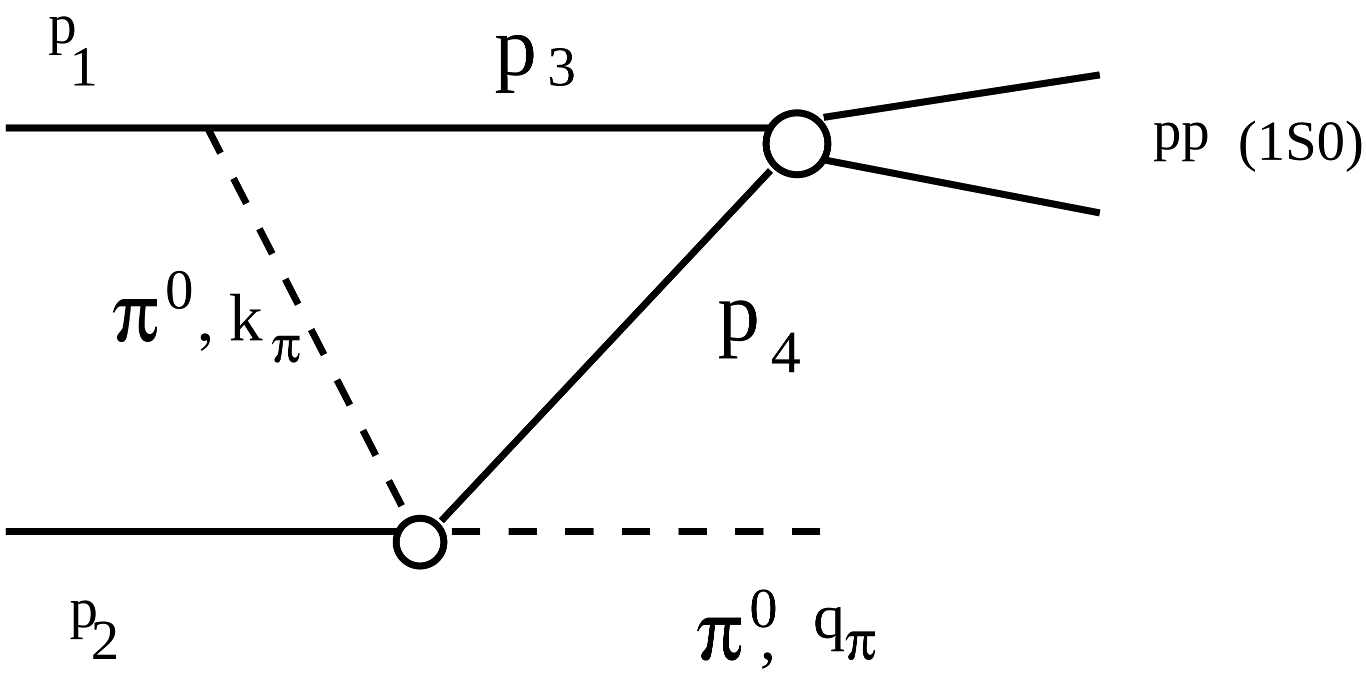




V.Komarov et al. PRC 94 (20016) 052301;

Two $T = 1$ resonances are found with almost equal masses 2205 MeV: $J^p = 0^-$ (^3P_0s), $J^p = 2^-$ (^3P_2d); $\Gamma_0 = 95 \pm 9$ MeV $\Gamma_2 = 170 \pm 32$ MeV,

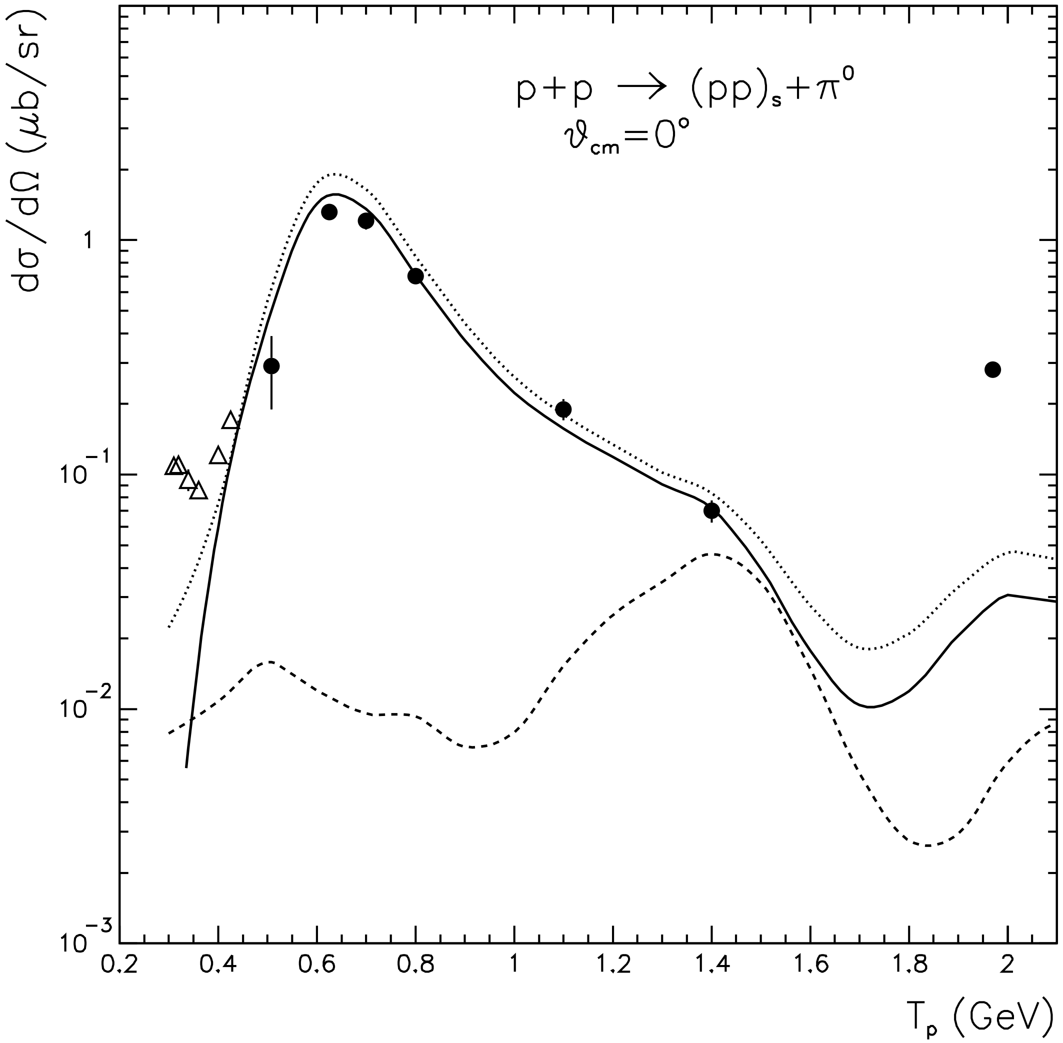
The OPE model



$pp \to \{pp\}_s \pi^0$

The $\pi N \to \pi N$ is taken off the loop integral
(similar to Yu.N.U., J. Haidenbauer, C. Wilkin, PRC **75** (2007) 014008)

$pp \to \{pp\}_s\pi^0$: The OPE results with (full line) and whithout (dashed) $\Delta(1232)$



Normalization factor $N = \frac{1}{2.5}$

• – COSY data at $T_p = 0.8$ GeV , V. Kurbatov et. al, PLB 661 (2008)

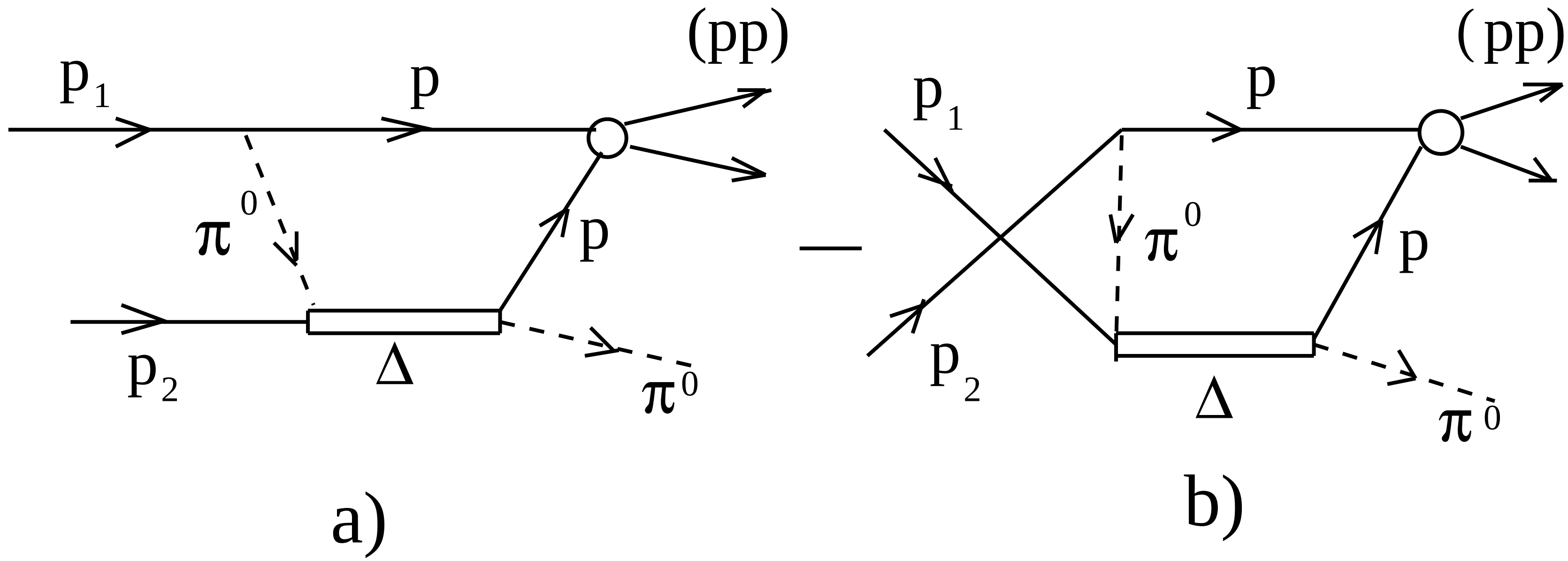
OPE: $pp \to \{pp\}_s\pi^0$, $pp \to \{pp\}_s\gamma$

The OPE mechanism does not allow one to take into account the Pauli principle $(-1)^{S+T+L} = -1$ because the direct and exchange diagrams are not involved explicitely.

Even L must be excluded.

An explicite consideration of the Δ-isobar is required.

The BOX-diagramm with Δ for $p\pi^0 \to p\pi^0$



$$A^{dir}_{\sigma_1\sigma_2} = -8m_\Delta m_p^2 N_{pp}\left(\frac{f_{\pi NN}}{m_\pi}\right)\left(\frac{f_{\pi N\Delta}}{m_\pi}\right)^2 \frac{2}{3}\frac{i}{\sqrt{2}} G^{dir}_{\sigma_1\sigma_2}\times$$

$$\times\int \frac{F_{\pi NN}(k_\pi^2)}{(m_\pi^2 - k_{\pi_a}^2 - i\varepsilon)}\frac{F_{\pi N\Delta}(k_\pi^2)}{(m_\Delta^2 - k_{\Delta_a}^2 - im_\Delta\Gamma)}\frac{<\Psi_k^{(-)}\mid V(^1S_0)\mid \mathbf{q}>}{(k_{pp}^2 - q^2 + i\varepsilon)}\frac{d^3\vec{q}}{(2\pi)^3} \qquad (1)$$

Yu.N. Uzikov, Izv.RAN, Ser.Fiz. 81 (2017) 815 / Bull. Rus. Ac. Sci: Physics, 81 (2017) 739/

πNN, $\pi N\Delta$-vertices; $\Gamma_\Delta(k)$

$$< \pi N_2|N_1 >= \frac{f_{\pi NN}}{m_\pi}\varphi_1^+(\boldsymbol{\sigma}\mathbf{Q})(\boldsymbol{\tau}\boldsymbol{\Phi}_\pi)\varphi_2 2m_N,$$

$$< \rho N_2|N_1 >= \frac{f_{\rho NN}}{m_\rho}\varphi_1^+([\boldsymbol{\sigma}\mathbf{Q}]\epsilon_\rho)(\boldsymbol{\tau}\boldsymbol{\Phi}_\rho)\varphi_2 2m_N,$$

$$< \pi N|\Delta >= \frac{f_{\pi N\Delta}}{m_\pi}(\boldsymbol{\Psi}_\Delta^+\mathbf{Q}'_\pi)(\mathbf{T}\boldsymbol{\Phi}_\pi)\varphi\sqrt{2m_N 2m_\Delta},$$

$$< \rho N|\Delta >= \frac{f_{\rho N\Delta}}{m_\rho}([\boldsymbol{\Psi}_\Delta^+\mathbf{Q}'_\rho]\boldsymbol{\epsilon}_\rho)(\mathbf{T}\boldsymbol{\Phi}_\rho)\varphi\sqrt{2m_N 2m_\Delta},$$

where

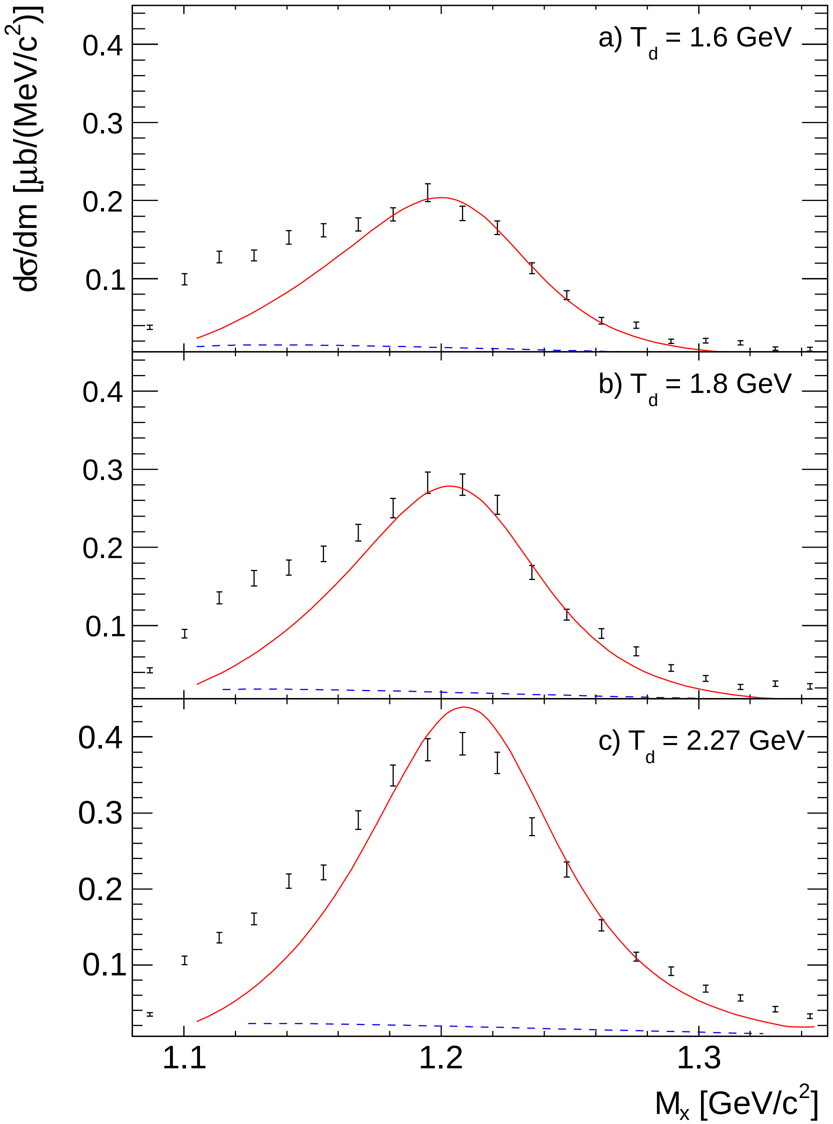
$$f_{\pi NN} = 1.00, f_{\pi N\Delta} = 2.15,$$
$$f_{\rho NN} = 6.20, f_{\rho N\Delta} = 13.33.$$

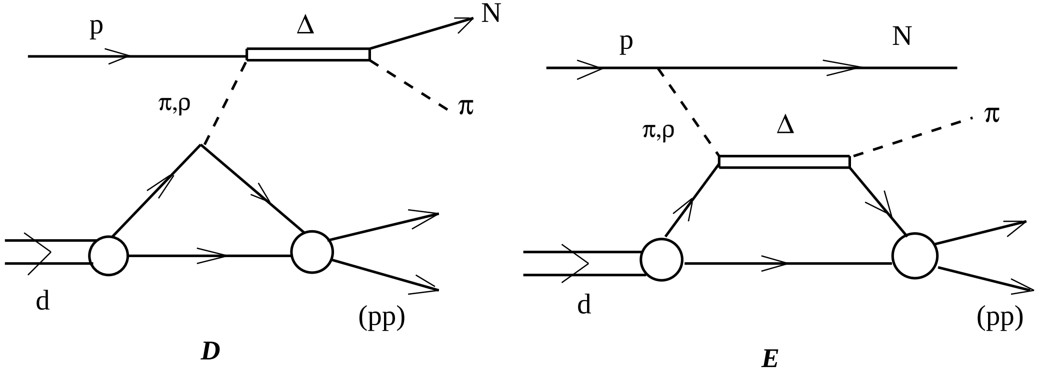
V.F. Dmitriev et al (1987)   M.Platonova, V.Kukulin, NPA (2016)

$$\Gamma(k) = \Gamma_0\left(\frac{k_{on}}{k_R}\right)^3\frac{k_R^2+\chi^2}{k_{on}^2+\chi^2}, \qquad \Gamma(k) = \Gamma_0\left(\frac{k_{on}}{k_R}\right)^3\left(\frac{k_R^2+\lambda^2}{k_{on}^2+\lambda^2}\right)^2,$$

$\mathbf{Z} = \frac{\mathbf{k_R^2}+\chi^2}{\mathbf{k_{on}^2}+\chi^2}$, $k_{on} = k(s_\Delta, m^2, m_\pi^2)$; $\chi = 0.18$ GeV, $\lambda = 0.3$ GeV; $\sqrt{Z} \to \pi N\Delta$.

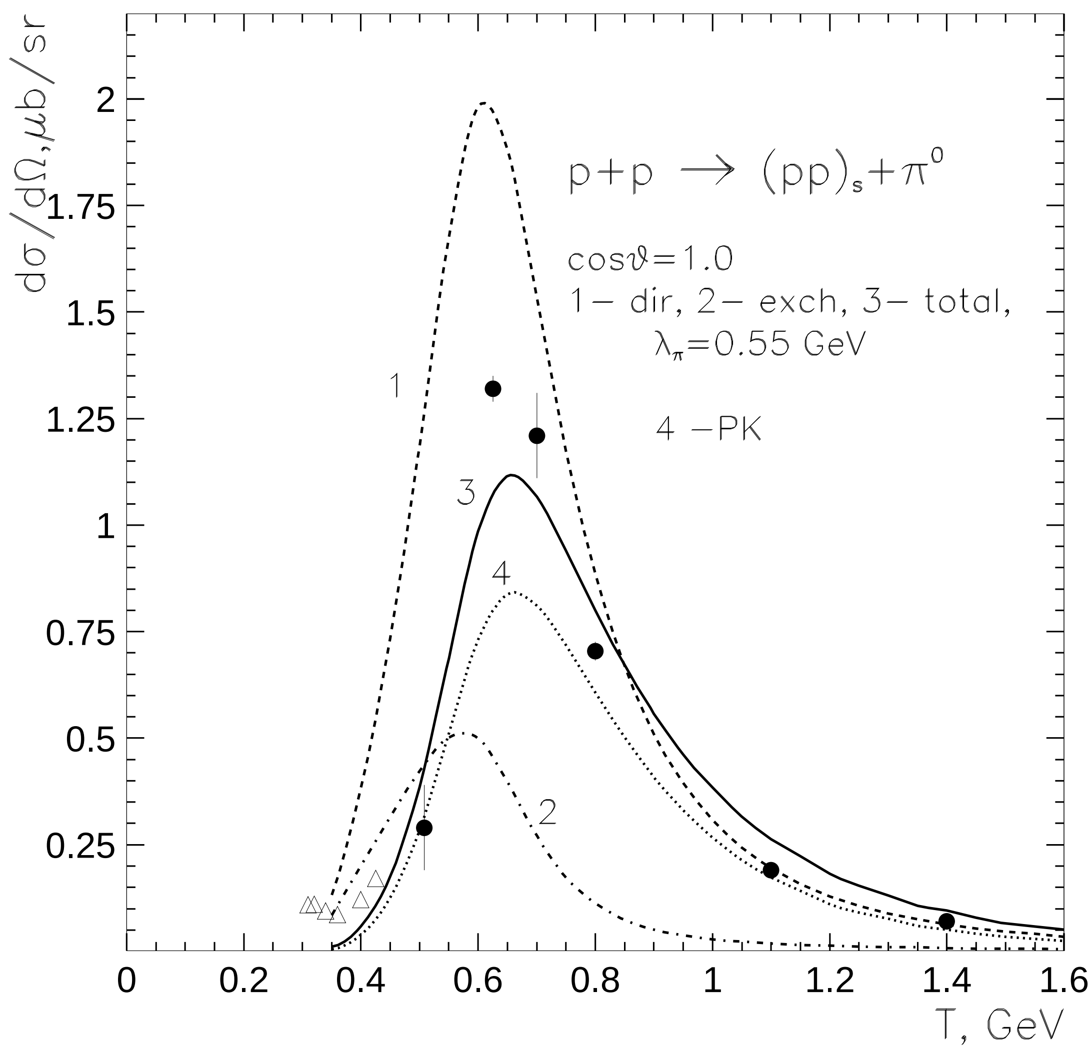
$dp \to \{pp\}_s\pi N$ Yu.N. U., J.Haidenbauer, C. Wilkin, PoS 93 (2015)





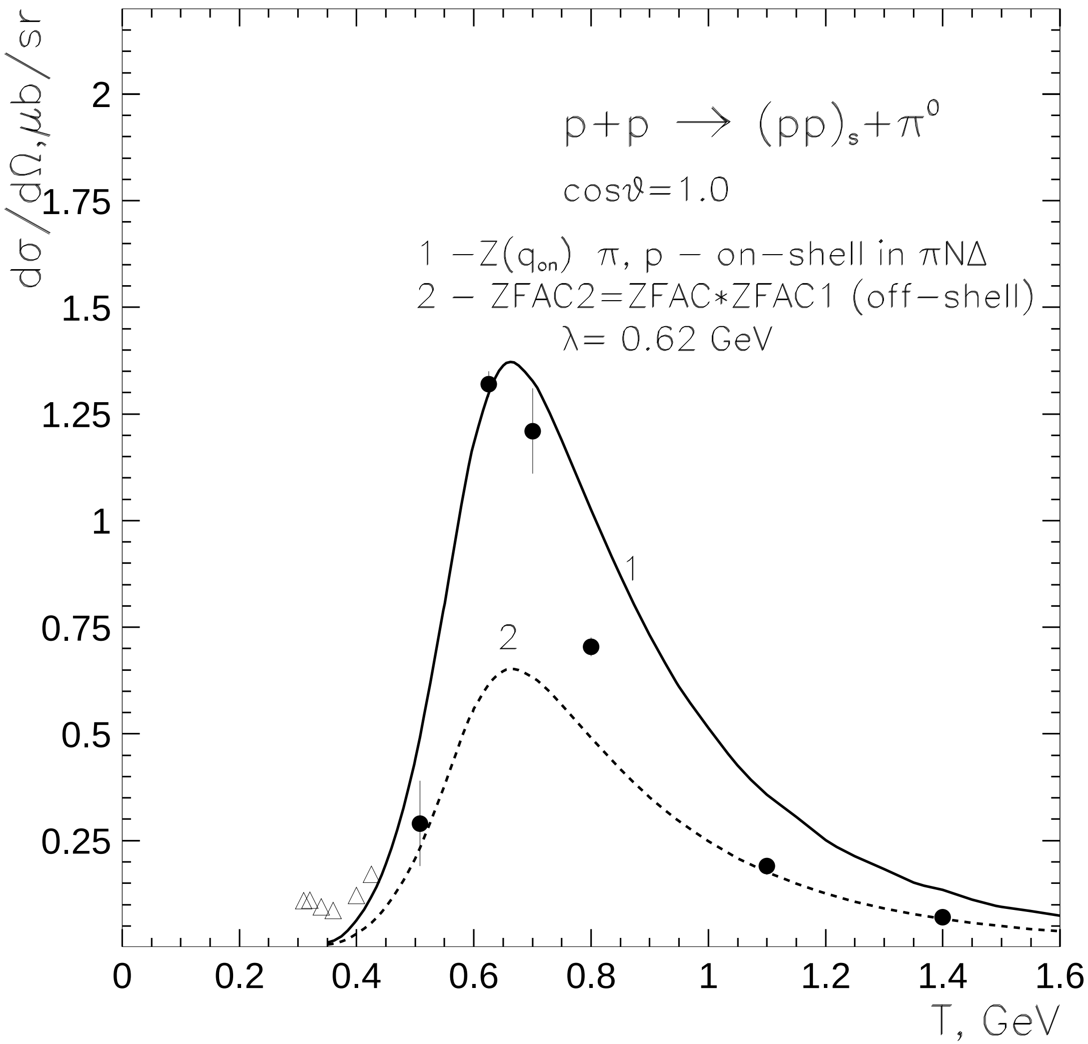
ANKE@COSY data • – D. Mchedlishvili et al., PRL (2013) $\lambda_\pi = 0.5$ GeV, and $\mathbf{T_{22}}$

Z, $\chi = 0.180$ GeV $pp \to \{pp\}_s\pi^0$



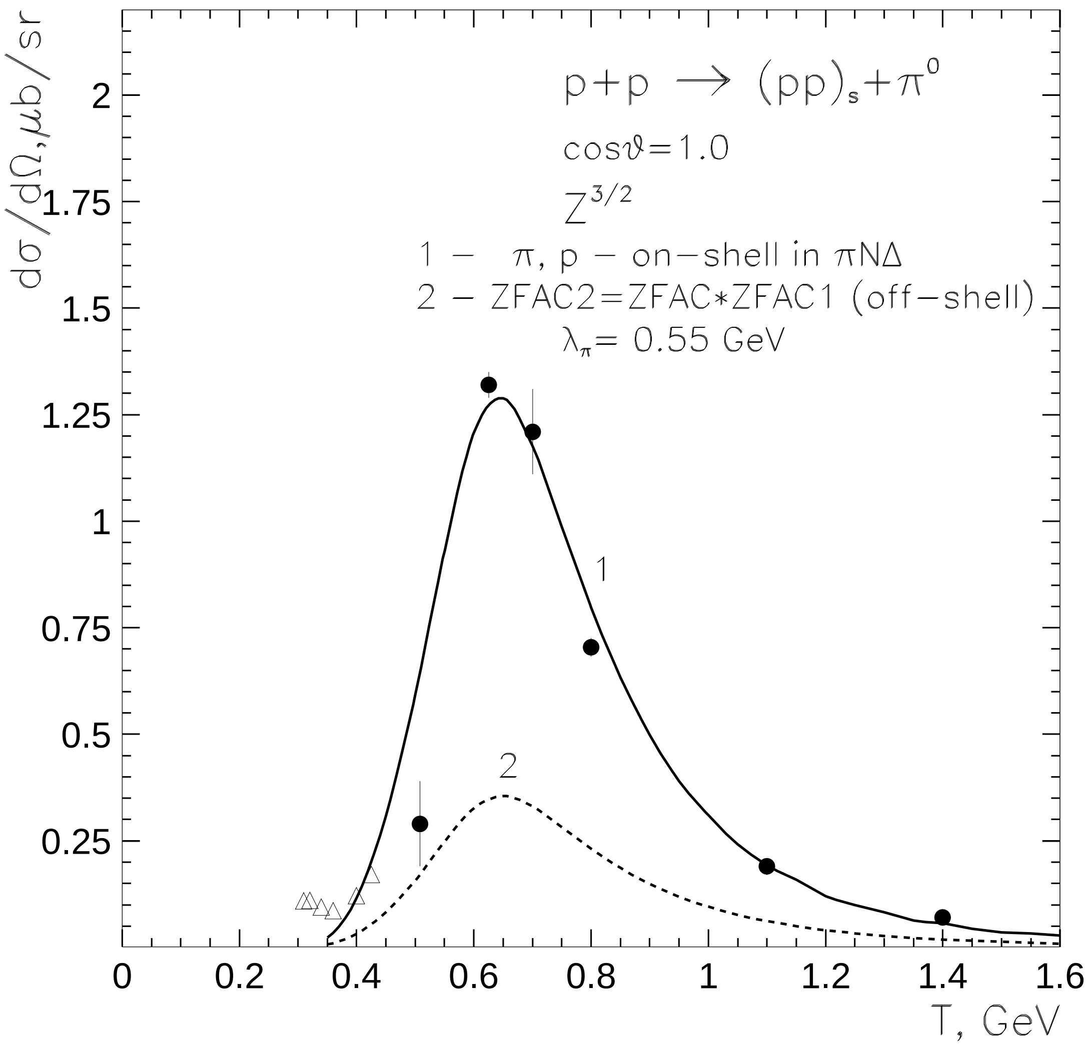
In $\sqrt{Z}$-factor in $\pi N\Delta$ $q = q_{on} = k(s_\Delta, m^2, m_\pi^2)$: 1- direct, 2-exchange, 3- total; 4 – total PK $\Gamma(k) = \Gamma_0 \left(\frac{k}{k_R}\right)^3 \frac{k_R^2+\chi^2}{k^2+\chi^2}$ $\chi = 0.180 GeV$, $\lambda_\pi = 0.55$ GeV

Influence of off-shell effects in $\pi N\Delta$-verices via $\sqrt{Z}$



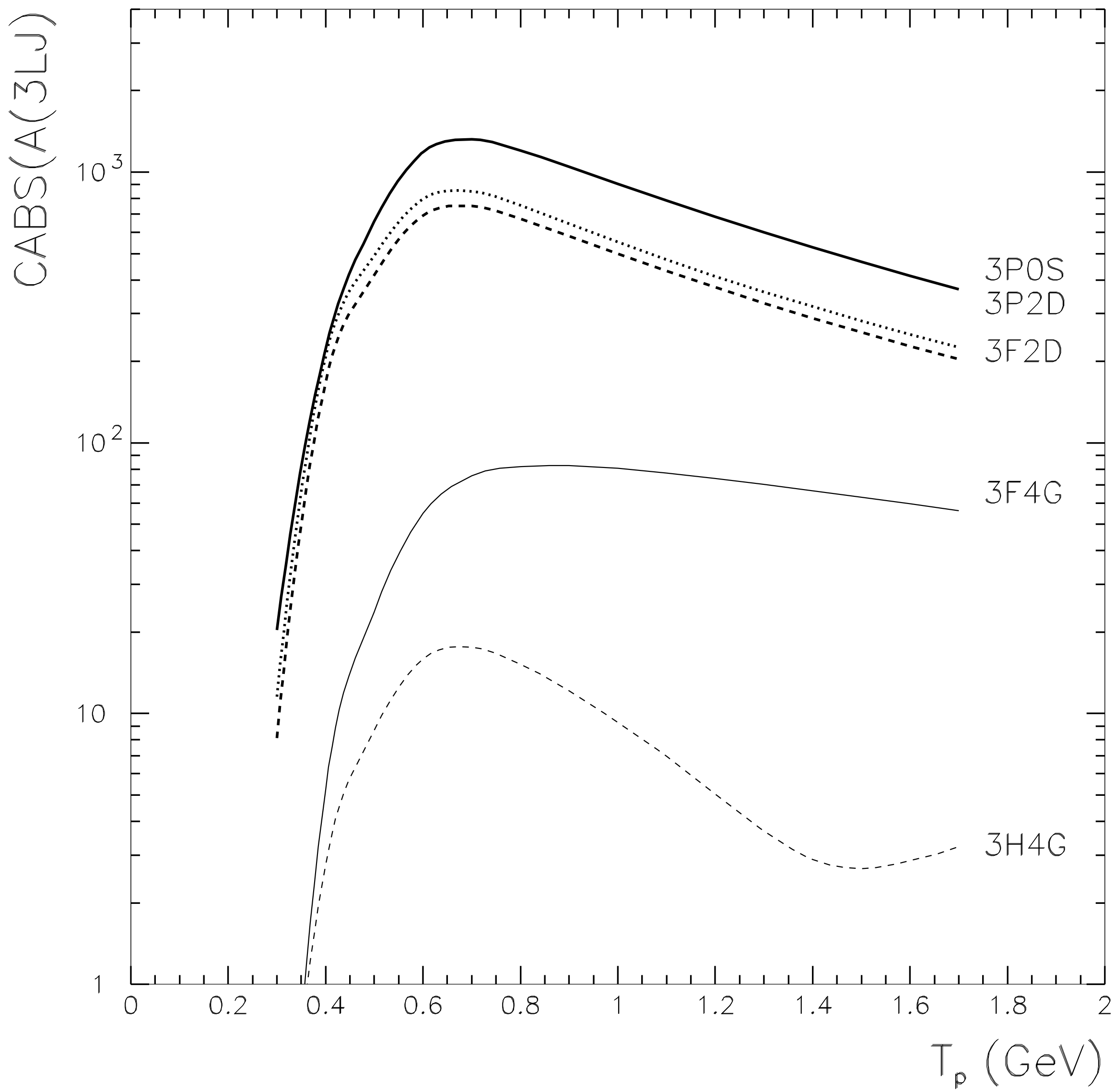
Off-shell $\sqrt{Z}$-factor in $\pi N\Delta-$ vertices diminishes $d\sigma/d\Omega$ (line 2).

$Z^{3/2}, \ pp \to \{pp\}_s \pi^0$



Off-shell $Z^{3/2}$-factor in $\Gamma(k)$ and in $\pi N\Delta-$ vertices improves the shape of $d\sigma/d\Omega$ at $T > 0.6$ GeV but disproves at $T < 0.6$ GeV

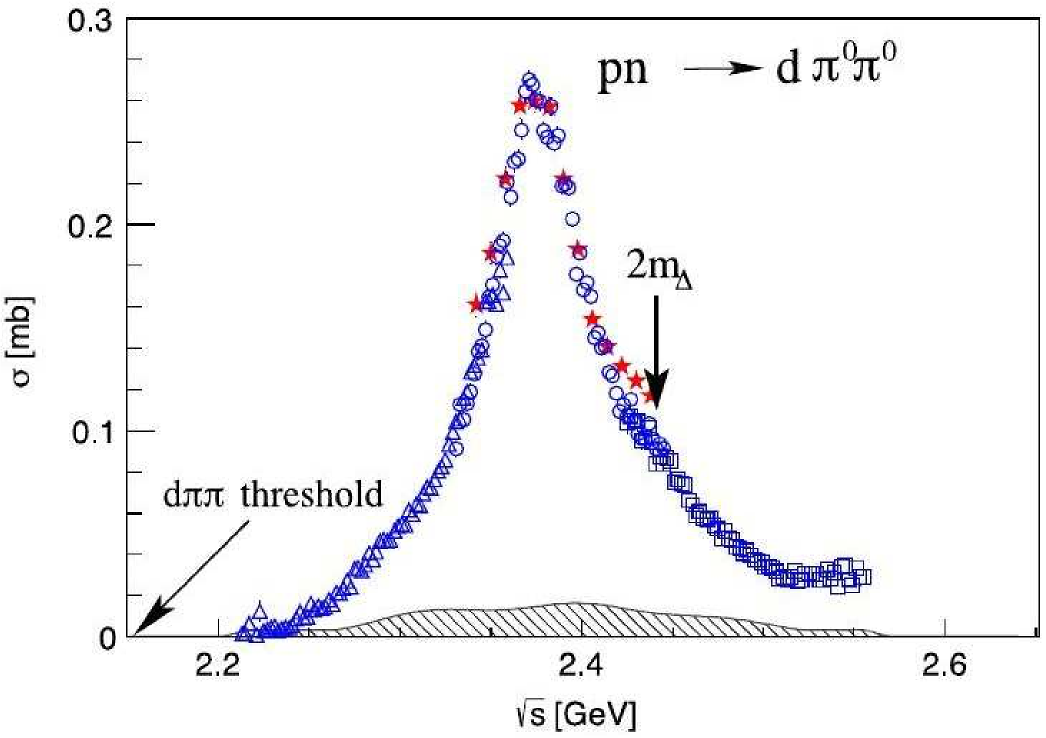
PWA for $pp \to \{pp\}_s\pi^0$ *within the* $\Delta-$ *model: three waves dominate*

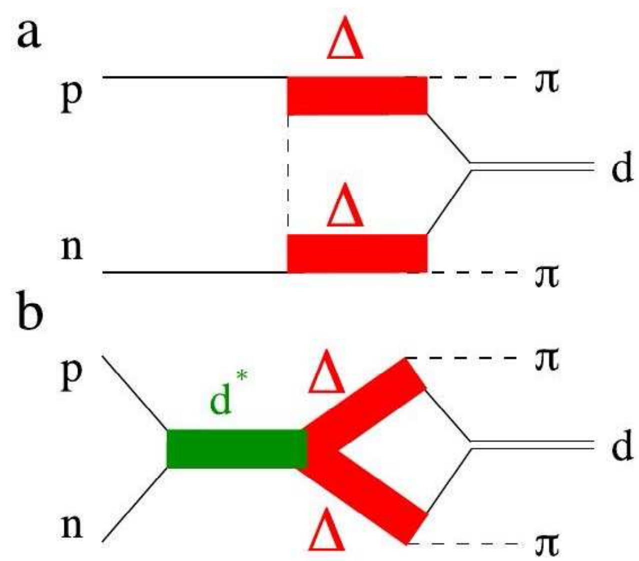


ANKE PWA analysis: ^3P_0s, ^3P_2d are sufficient for $\frac{d\sigma}{d\Omega}$ and $A_y(\theta)$.
The Δ-model: ^3F_2d cannot be neglected.

WASA@COSY $pn \to d\pi^0\pi^0$, $\Gamma = 70$ MeV

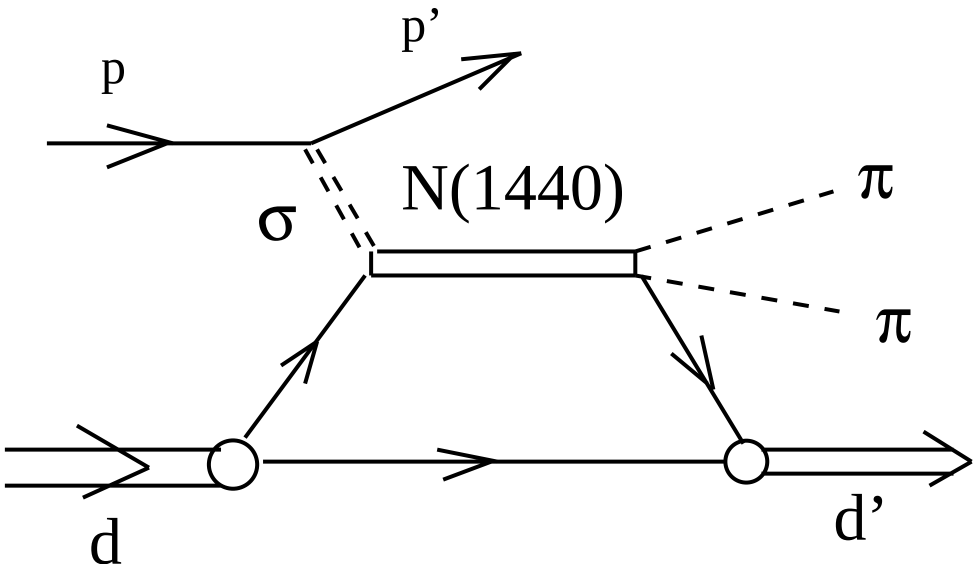
H. Clement / Progress in Particle and Nuclear Physics 93 (2017) 195–242

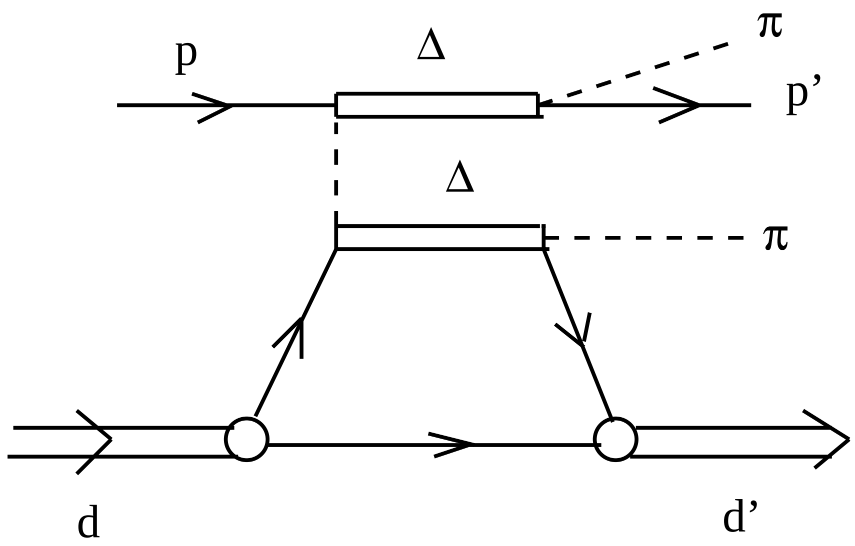




M.Bashkanov et al. PRL 102 (2009) 052301; **several others reactions**
Recent review H. Clement, Prog. Part. Nucl. Phys. 93 (2017) 195

Narrow width: (i) 6q-models, – Y.-B. Dong, et al. (2016) (hidden colour); (ii) hadron picture, $\pi N\Delta$ system – A.Gal, H.Garcilazo, PRL 111 (2013) 172301; $\Delta\Delta$ system – J. Niskanen, PRC 95 (2017) 054002 A. Gal PLB 769 (2017) 436 (see talks on 8 June, and T.Skorodko on 11 June).
New ANKE data on $pd \to pd\pi\pi$ (talk by D.Tsirkov tomorrow)

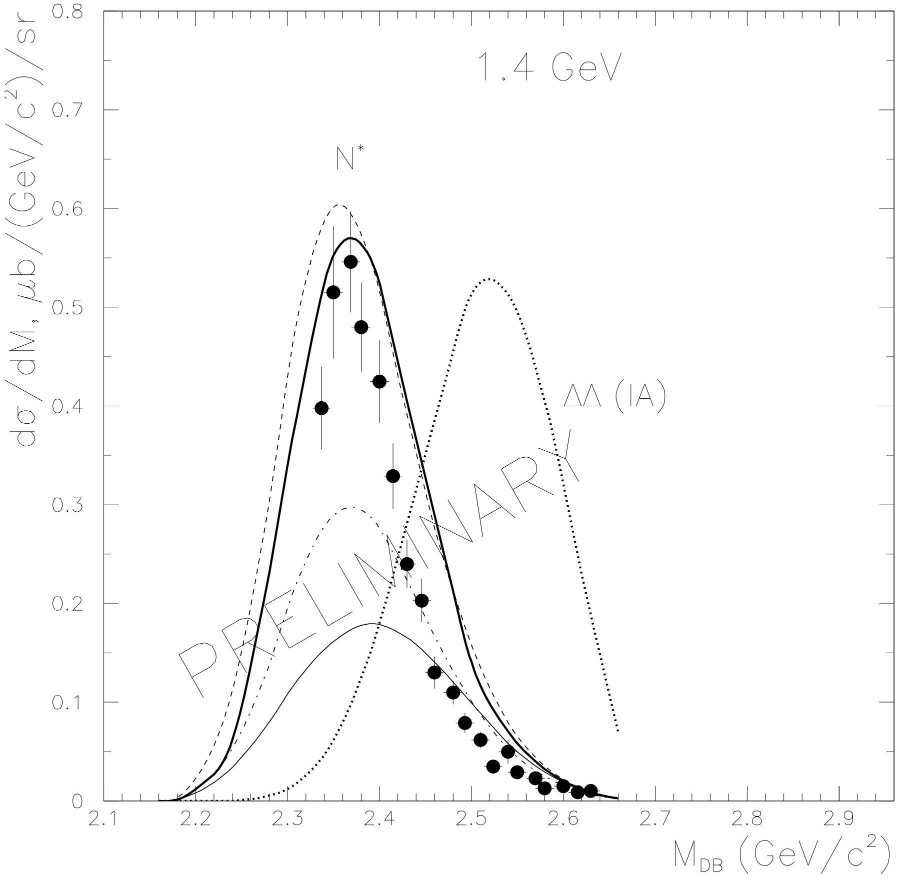




... underestimate the absolute value of the dif. cross section $pd \to pd\pi\pi$ **at ANKE@COSY kinematics by two orders of magnitude.**

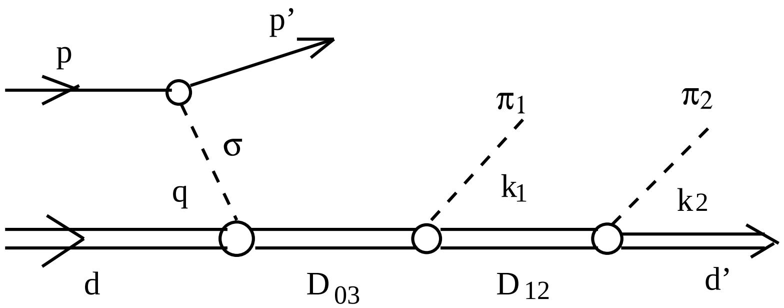
/Yu.N.U., Baldin ISHEPP, 2010, Dubna/

$N^*(1440)$ *and* $\Delta\Delta$ *for* $pd \to pd\pi\pi^0$ *at 1.4GeV*



Roper-resonance
parameters by Skorodjko et al. (dashed-dotted), Zao et al.(dashed), Alvarez-Russo et al. (full line); $\Delta\Delta$(IA).
Yu.N. Uzikov, in: Proc. of Baldin ISHEPP XX "Relativistic Nuclear Physics and Quantum Chromodynamics" (Dubna, October 4-9, 2010).

$pd \to pd\pi\pi$ reaction. Two-resonance model



$\boldsymbol{\Gamma(\mathbf{D_{03}} \to \mathbf{D_{12}}\pi) = 6.5}$ **MeV,** $\boldsymbol{\Gamma(\mathbf{D_{12}} \to \mathbf{d}\pi) = 10}$ **MeV,** $\boldsymbol{\Gamma(\mathbf{D_{03}} \to \mathbf{d}\sigma) = 5}$ **MeV,** $m_\sigma = 0.5$ **GeV,** $\Gamma_\sigma = 0.55$ **GeV.**

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

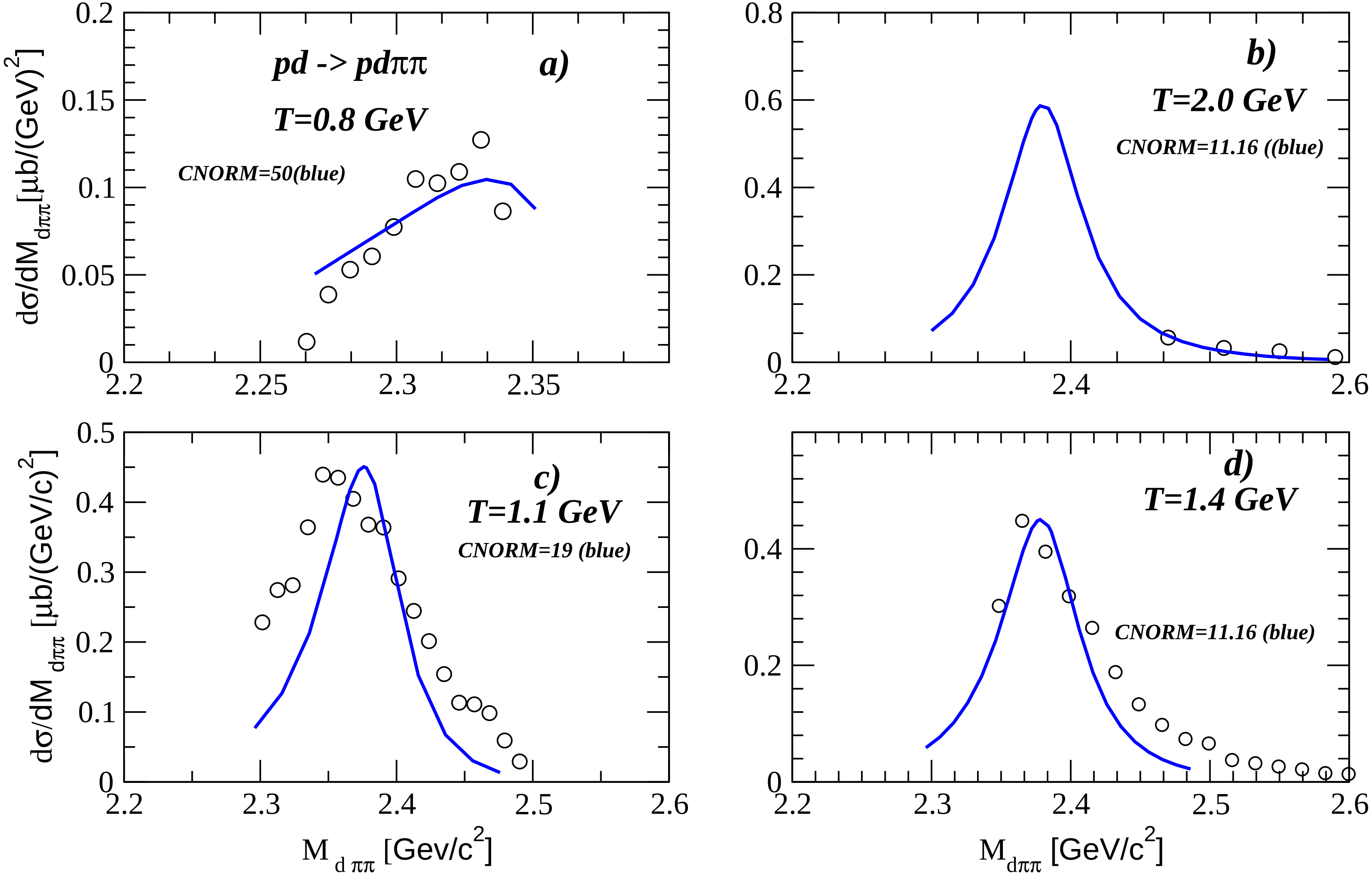
$$M_{\lambda_d}^{\lambda'_d}(\sigma d \to d\pi\pi) = \sum_{\lambda_2,\lambda_3,\mu,m_1,m_2} \frac{F_{D_{03}\to d\sigma}F_{D_{03}\to D_{12}\pi_1}}{P_{D_{03}}^2 - M_{D_{03}}^2 + iM_{D_{03}}\Gamma_{D_{03}}}\,\frac{F_{D_{12}\to d\pi_2}}{P_{D_{12}}^2 - M_{D_{12}}^2 + iM_{D_{12}}\Gamma_{D_{12}}}$$
$$\times(1\lambda_d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

$$F_{D_{03}\to d\sigma}(q) = M_{D_{03}}(q)\sqrt{\frac{8\pi\Gamma^{(l=2)}_{D_{03}\to d\sigma}(q)}{q^5}};\ \Gamma^{(l=2)}_{D_{03}\to d\sigma}(q) = \Gamma^{(l=2)}_{D_{03}\to d\sigma}\left(\frac{q}{q_0}\right)^5\left(\frac{q_0^2+\lambda_{d\sigma}^2}{q^2+\lambda_{d\sigma}}\right)^3,$$

$$F_{D_{12}\to d\pi_2}(k_2) = M_{d\pi_2}(k_2)\sqrt{\frac{8\pi\Gamma^{(l=1)}_{D_{12}\to d\pi}(k_2)}{k_2^3}};\ \Gamma^{(l=1)}_{D_{12}\to d\pi}(k_1) = \Gamma^{(l=1)}_{D_{12}\to d\pi}\left(\frac{k_2}{k_{20}}\right)^3\left(\frac{k_{20}^2+\lambda_{d\pi}^2}{k_2^2+\lambda_{d\pi}}\right)^2. \tag{4}$$

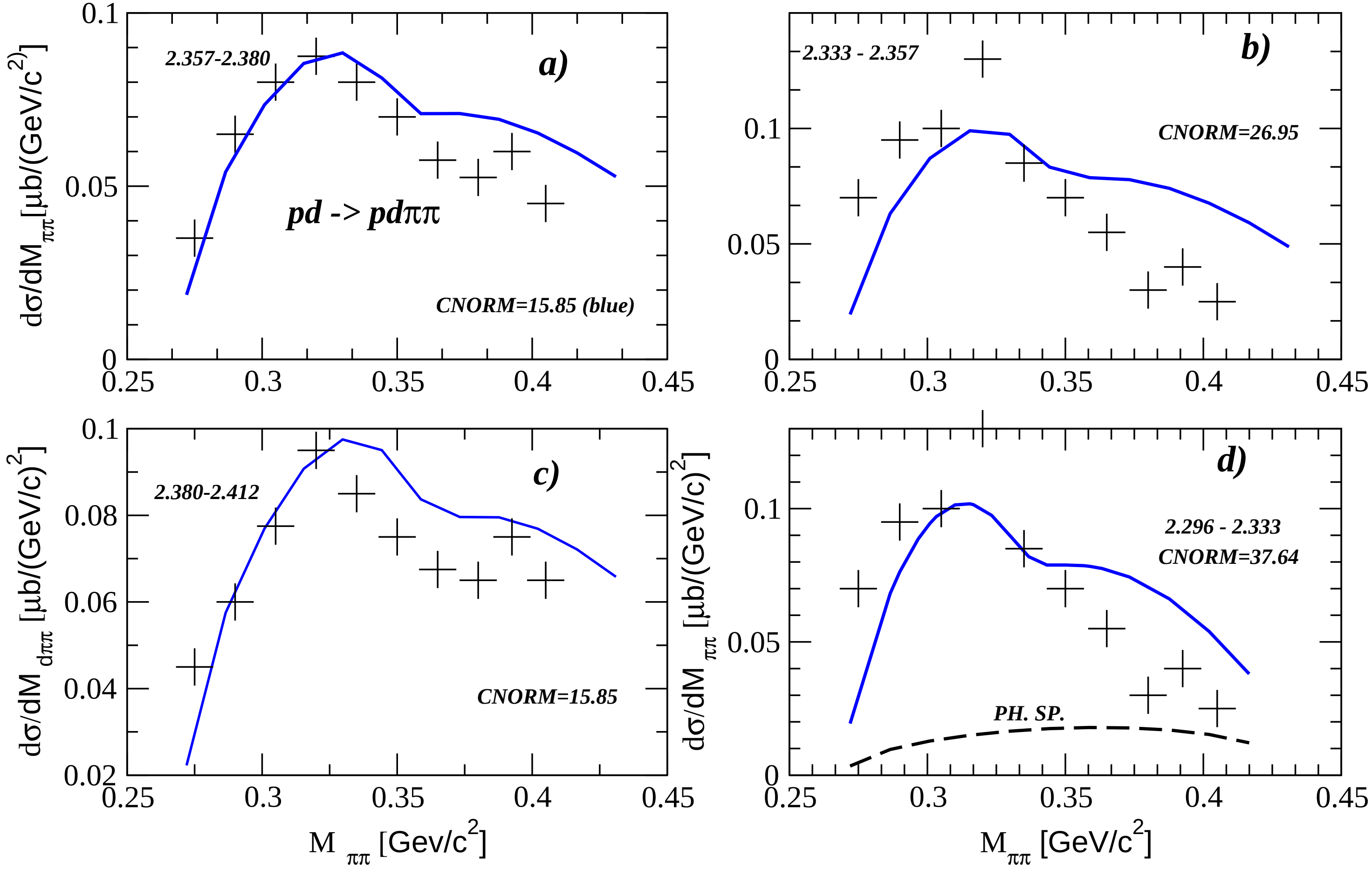
M.N. Platonova, V.I. Kukulin, PRC **87** (2013) 025202; NPA **946** (2016) 117 (whithout their σ-term)

$pd \to pd\pi\pi$ reaction. ANKE@COSY data and two-resonance model



• - V.Komarov et al.(for ANKE collab.) arxiv:1805.01493 [nucl-exp] (see talk by D.Tsirkov)

$pd \to pd\pi\pi$ reaction. $M_{\pi\pi}$ spectra at $T_p = 1.1$ GeV. ABC- effect ?



+ - V.Komarov et al.(for ANKE collab.) arxiv:1805.01493 [nucl-exp]

full lines – two-resonance model.

/Recent review M. Bashkanov, H. Clement, T. Skorodko. NPA 958 (2017) 129/

Summary & Outlook

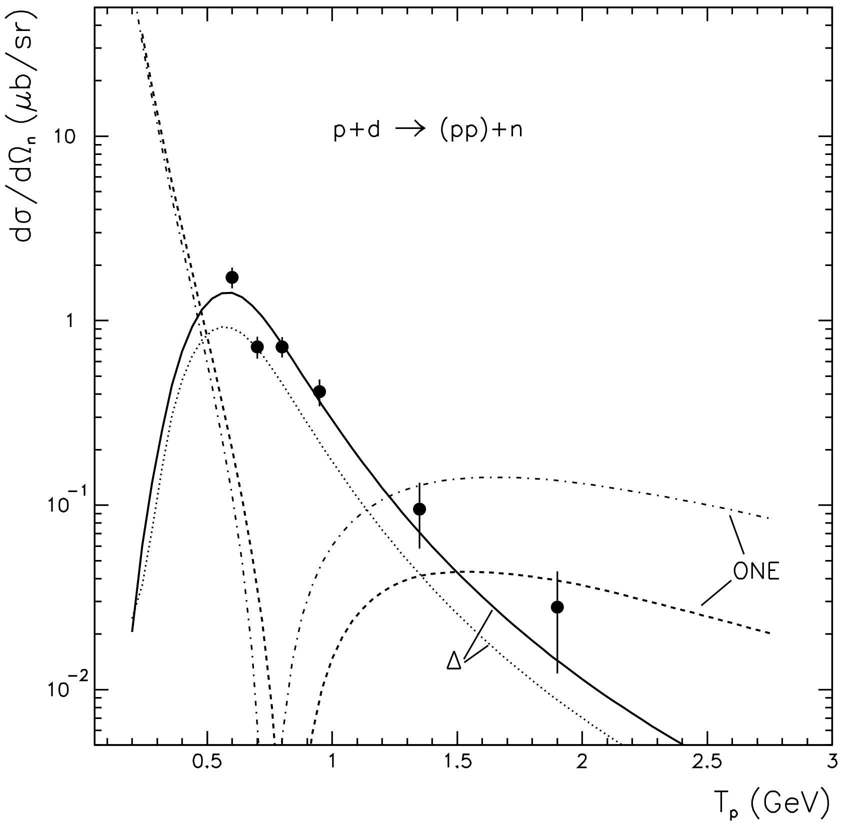
- **Two known resonance structures have been observed by ANKE@COSY at non-usual conditions:**
  - ⋆ **Δ-like resonance in the $pp \to \{pp\}_s\pi^0$ (negative parity);**
  - ⋆ **$D_{03}(2380)$- dibaryon like resonance in $pd \to pd\pi\pi$ at high transferred momentum to the deuteron.**

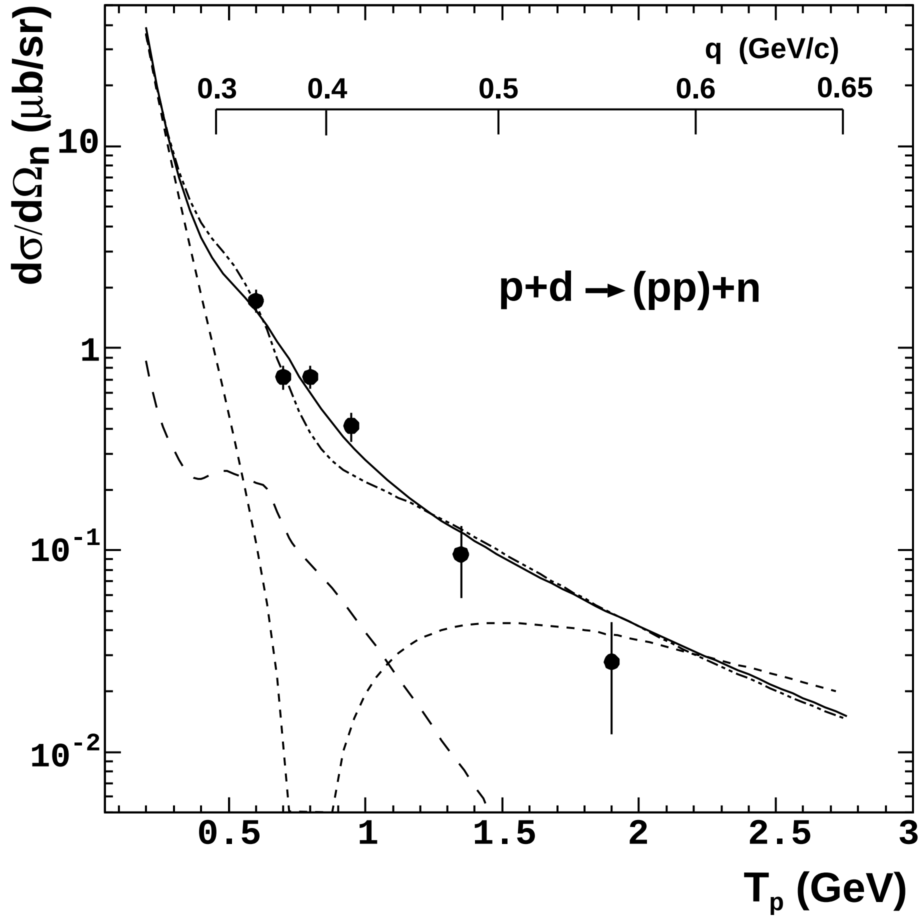
- **The Δ box-diagram completely fails to explain the angular dependence $d\sigma/d\Omega$ and A_y for $pp \to \{pp\}_s\pi^0$ in contrast to $pp \to d\pi^+$, although reproduces the E-shape of $d\sigma/d\Omega(0^\circ)$. Are there genuine dibaryons here – ^3P_0s, ^3P_2d? ^3F_2d ?**

- **Two-resonance (D_{03}, D_{12}) mechanism of the $pd \to pd\pi\pi$ (i) underestimates Γ of peaks, absolute value of $d\sigma$ is not yet determined since $\Gamma(D_{03} \to D_{12}\pi)$, $\Gamma(D_{03} \to d\sigma)$ are not known; (ii) but points out to the ABC effect in the maximum of the $D_{03}(2380)$-peak.**

Work is in progress ...

THANK YOU!





ONE+Δ+SS calculation *(J.Haidenbauer, Yu.Uzikov, Phys.Lett. B562(2003)227)*

When changing hard V_{NN} (RSC, Paris) to the soft V_{NN} (CD Bonn), ONE decreases and Δ-increases providing agreement with the COSY data V. Komarov et al., Phys. Lett. B553 (2003) 179.

Δ is still large!

The short range V_{NN} is rather soft like for the CD Bonn model, but not the RSC and Paris.

How to exclude Δ from $\pi^0 p \to \pi^0 p$?

$$\mathbf{A}(\pi^{\mathbf{0}}\mathbf{p} \to \pi^{\mathbf{0}}\mathbf{p}) = \frac{\mathbf{1}}{\mathbf{3}}\Big(\mathbf{a}_{\frac{1}{2}} + \mathbf{2a}_{\frac{3}{2}}\Big), \tag{5}$$

$$\mathbf{d}\sigma(\pi^{\mathbf{0}}\mathbf{p} \to \pi^{\mathbf{0}}\mathbf{p}) = \frac{\mathbf{1}}{\mathbf{2}}\Big\{\mathbf{d}\sigma(\pi^{+}\mathbf{p}) + \mathbf{d}\sigma(\pi^{-}\mathbf{p}) - \mathbf{d}\sigma(\pi^{\mathbf{0}}\mathbf{n} \to \pi^{-}\mathbf{p})\Big\}, \tag{6}$$

If the amplitude $a_{\frac{3}{2}}$ is excluded from Eq. (5)

$$\mathbf{d}\widetilde{\sigma}(\pi^{\mathbf{0}}\mathbf{p} \to \pi^{\mathbf{0}}\mathbf{p}) = \frac{\mathbf{1}}{\mathbf{18}}\Big\{\mathbf{3d}\sigma(\pi^{-}\mathbf{p}) - \mathbf{d}\sigma(\pi^{+}\mathbf{p}) + \mathbf{3d}\sigma(\pi^{\mathbf{0}}\mathbf{n} \to \pi^{-}\mathbf{p})\Big\}. \tag{7}$$