Δ-ISOBAR CONTRIBUTION TO THE PION PRODUCTION IN THE REACTION $\mathbf{pp \to \{pp\}_s \pi^0}$

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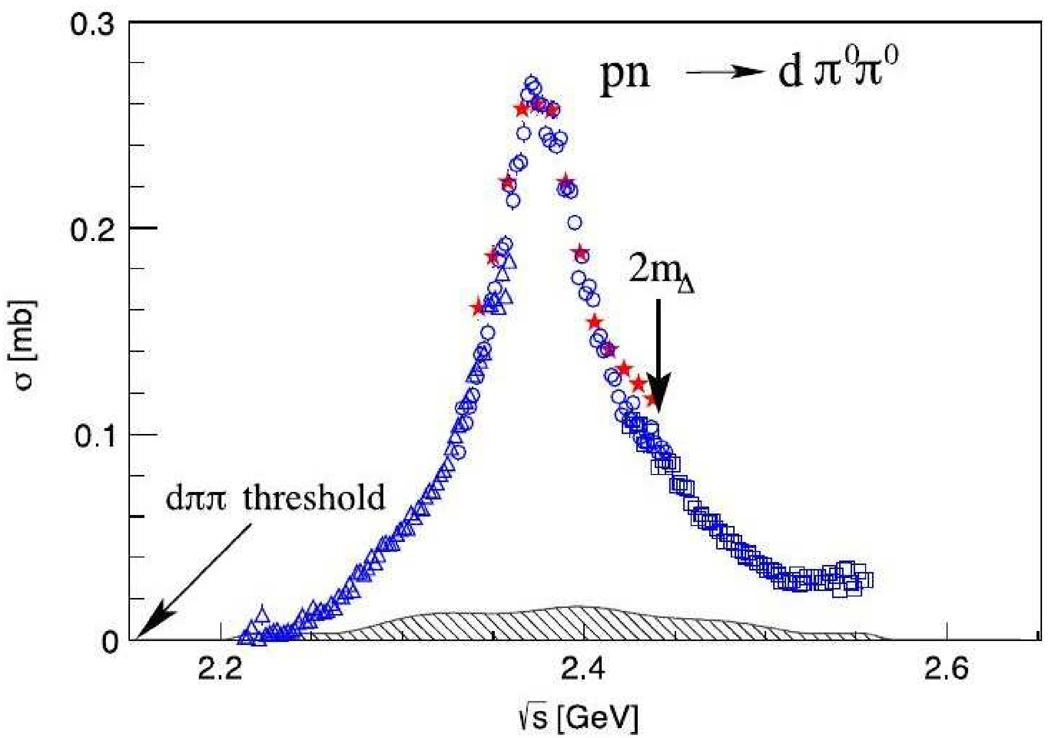
ABOUT CONTENT

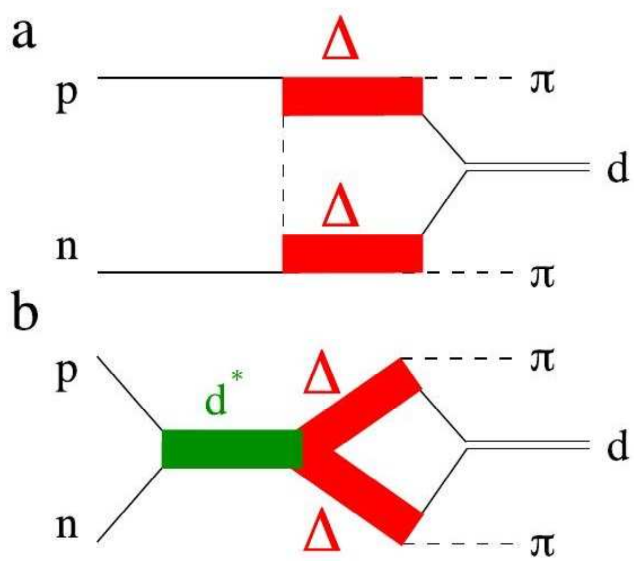
• **Renessance of dibaryon resonance physics in the nonstrange sector (H. Clement, Prog. Part. Nucl. Phys. 93 (2017) 195)**

• **ANKE@COSY data on $\mathrm{pp} \to \{\mathrm{pp}\}_\mathrm{s}\pi^0$ at 0.3-0.8 GeV and problems with its theoretical interpretation via the Δ-excitation mechanism**

WASA@COSY $pn \to d\pi^0\pi^0$, $M = 2380$ *MeV*, $\Gamma = 70$ *MeV*

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





M.Bashkanov et al. PRL 102 (2009) 052301; **several others reactions**

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

/Talk by N.Tursunbayev tomorrow/

- **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) :
$\mathbf{\Delta} + \mathrm{B3}$, **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**

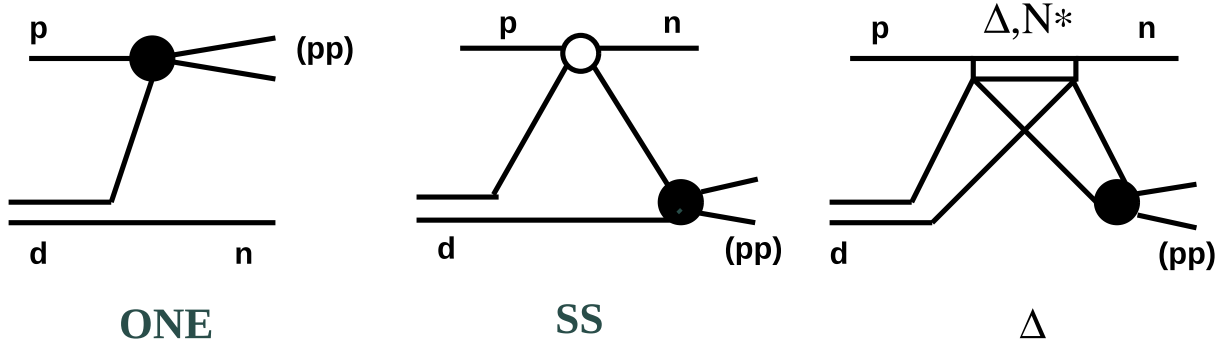
deuteron $\Longrightarrow$ $(^1S_0)$pn singlet deuteron or $\Longrightarrow$ $(^1S_0)$-diproton, $\{pp\}_s$

1. $\mathbf{pd \to dp \Longrightarrow p\{NN\}_s \to dN}$ in A(p,Nd)B

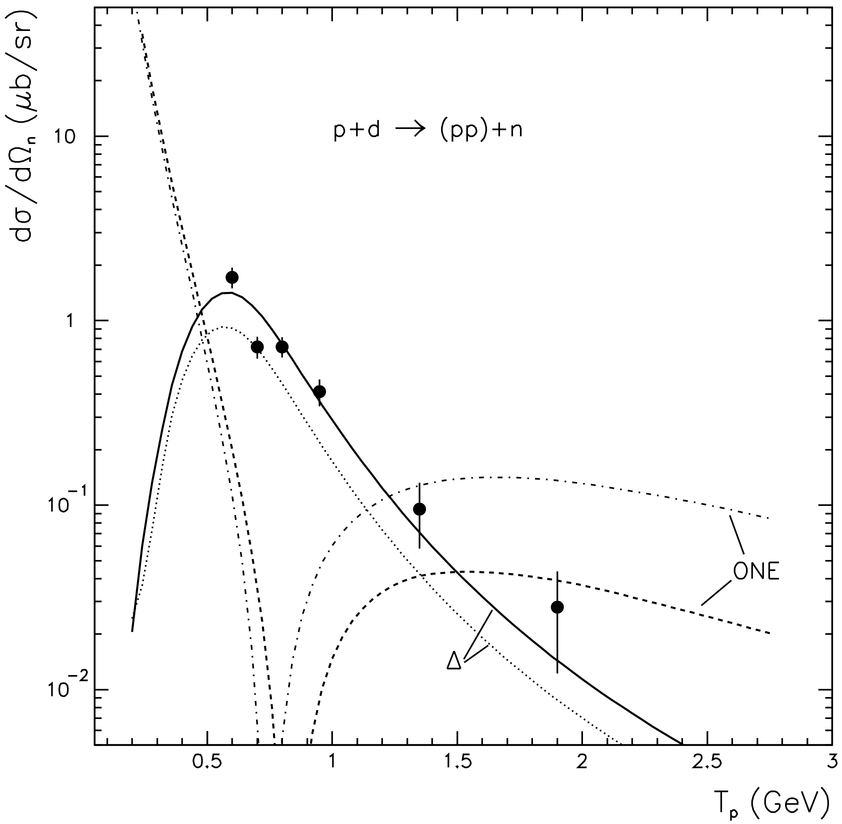
suppression of the Δ- and N^*-excitations as $1:9$

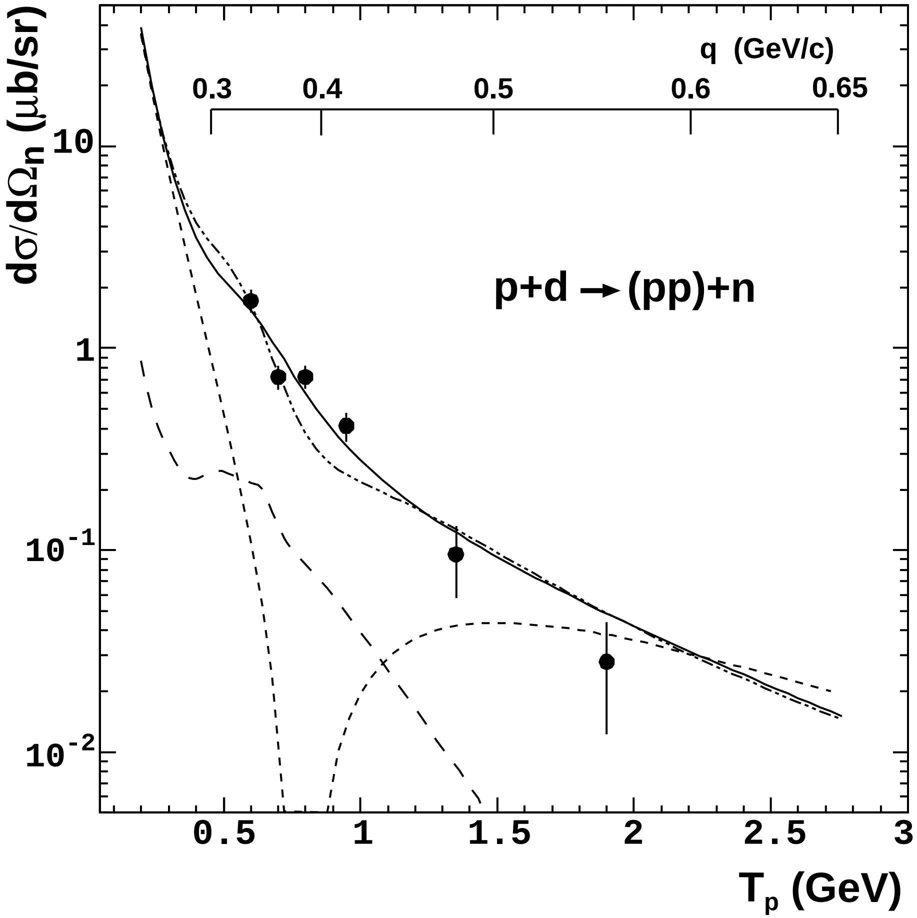
and $\mathbf{pd \to \{pp\}_s n}$

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



ANKE@COSY pd→ (pp)$_s$n

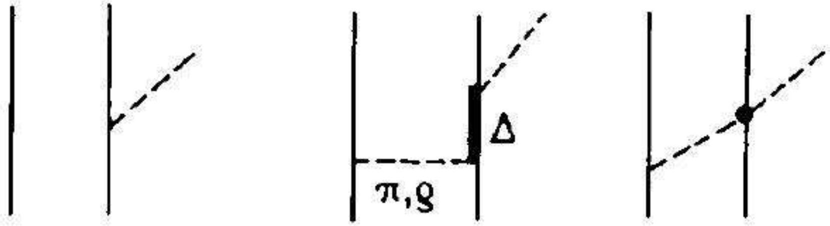


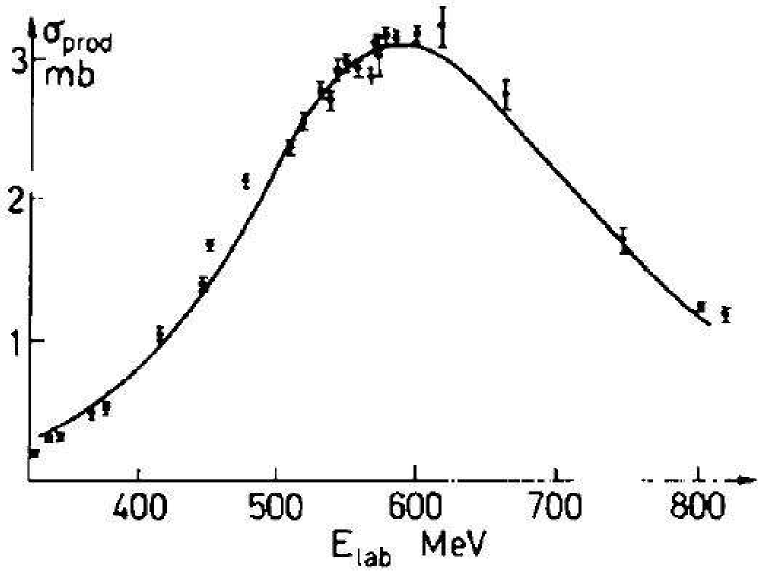


ONE+Δ+SS calculation *(J.Haidenbauer, Yu.Uzikov, Phys.Lett. B562(2003)227)*
When changing hard V_{NN} (RSC, Paris) to the soft V_{NN} (CD Bonn), ONE decreases and Δ-increases providing agreement with the COSY data V. Komarov et al., Phys. Lett. B553 (2003) 179.

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

$pp \to d\pi^+$ *in the* Δ*-region*





J. Niskanen, Phys.Lett. **141B** (1984) 301

But 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

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:**

⋆ $\mathbf{pp} \to \mathbf{d}\pi^+$, **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**

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

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

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

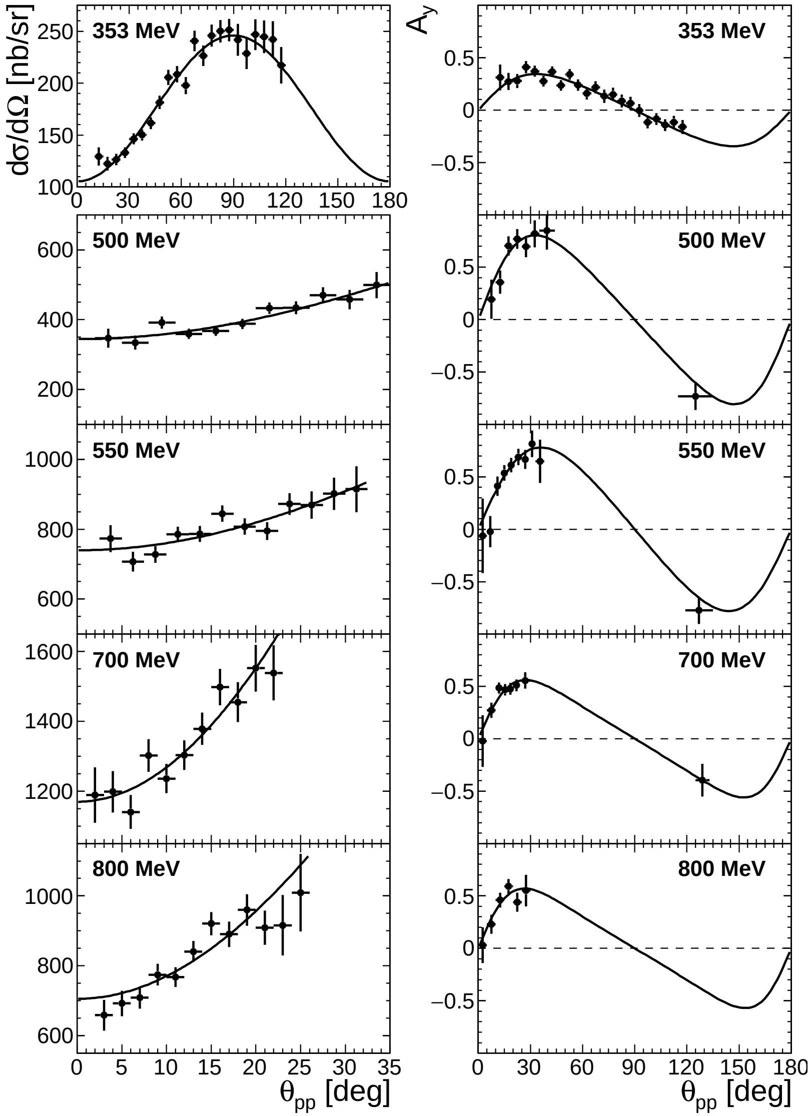
$\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\pi\pi$

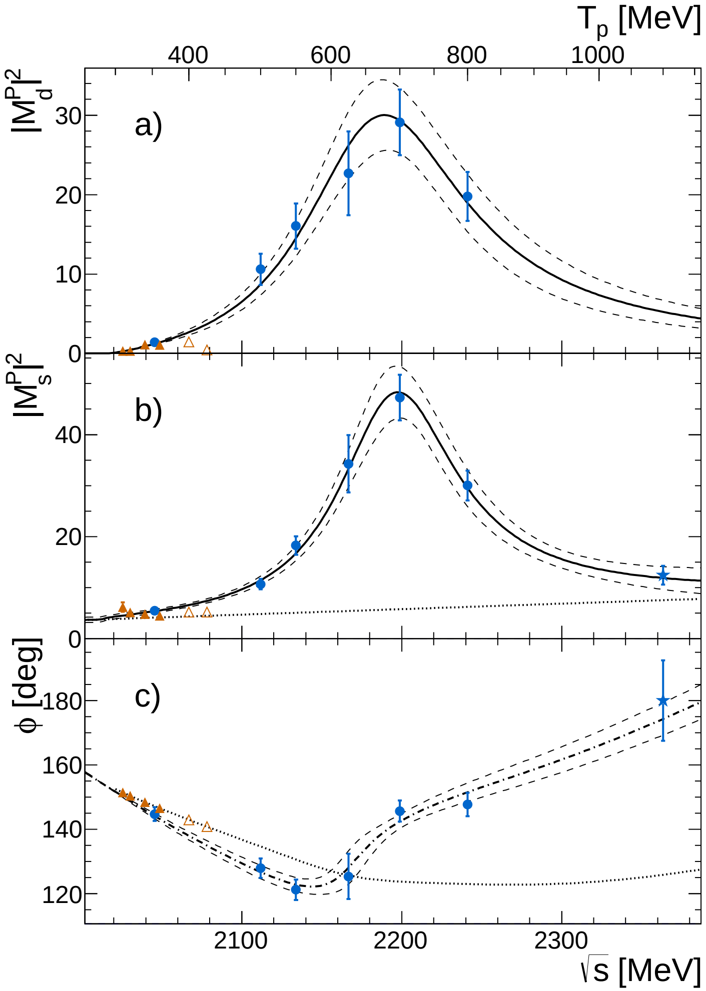
$\mathbf{pn} \to \{\mathbf{pp}\}_\mathbf{s}\pi^-$, $T_p = 350$ MeV, the contact d-term for ChPT

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

Talk by V. Kurbatov tomorrow on $\mathbf{pp} \to \{\mathbf{pp}\}_\mathbf{s}\pi^\mathbf{0}$ at 1.5 - 2.8 GeV

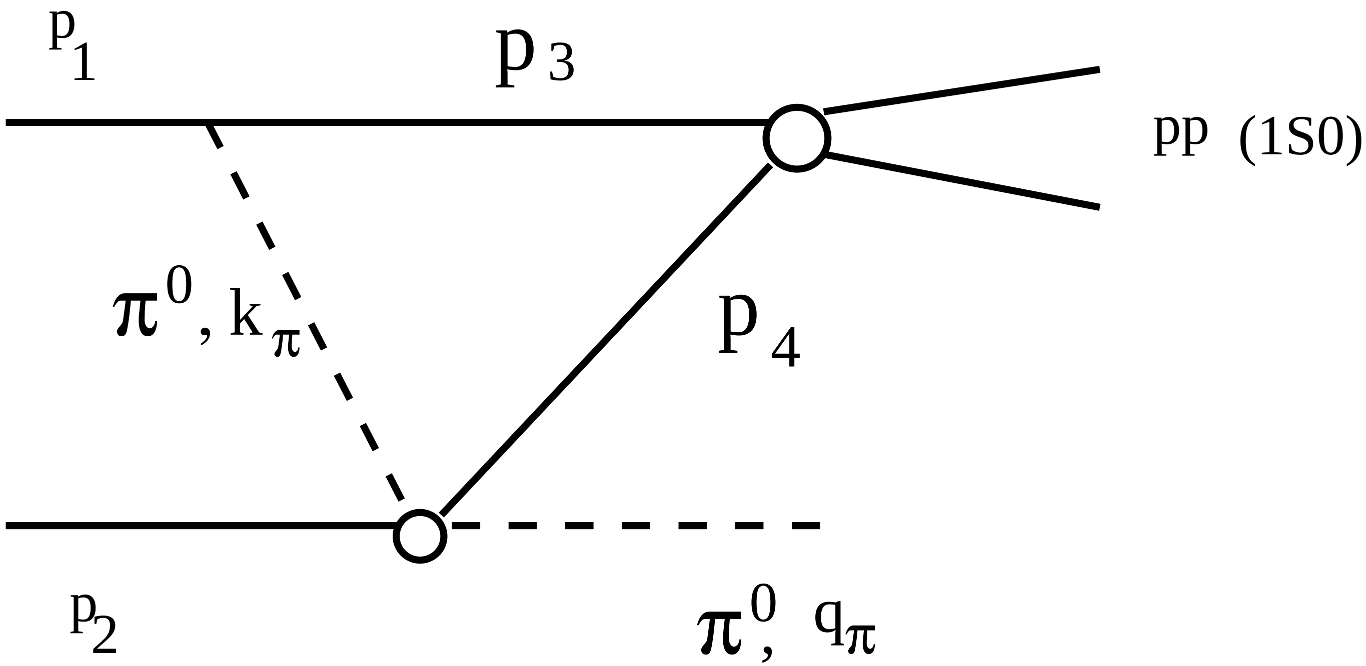
ANKE@COSY $pp \to \{pp\}_s \pi^0$, V.Komarov et al. PRC 94 (20016) 052301





Two $T = 1$ resonances are found with almost equal masses 2205 MeV: $J^p = 0^-$ ($^3P_0 s$), $J^p = 2^-$ ($^3P_2 d$); $\Gamma_0 = 95 \pm 9$ MeV $\Gamma_2 = 170 \pm 32$ MeV; anomalous angular dependence is osberved as compared to $pp \to d\pi^+$

The same approach with describes well $pp \to d\pi^+$ via Δ- mechanism fails in case of $pp \to \{pp\}_s\pi^0$ (J.Niskanen, PLB **642** (2006) 34). That's way we start with the OPE



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

The $\pi N \to \pi N$ is taken off the loop integral

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

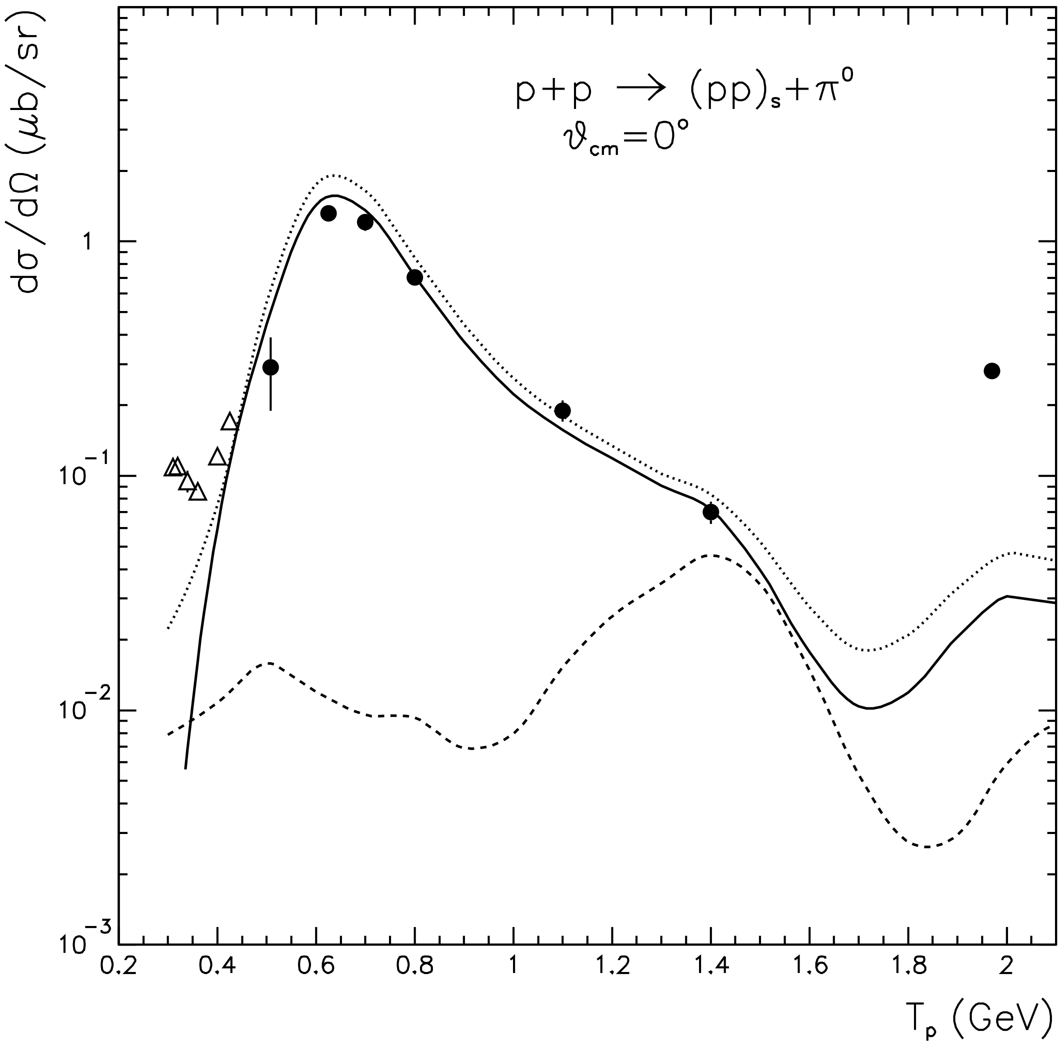
$$\mathbf{A}(\pi^{\mathbf{0}}\mathbf{p} \to \pi^{\mathbf{0}}\mathbf{p}) = \frac{\mathbf{1}}{\mathbf{3}}\Big(\mathbf{a}_{\frac{1}{2}} + \mathbf{2a}_{\frac{3}{2}}\Big), \tag{1}$$

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

If the amplitude $a_{\frac{3}{2}}$ is excluded from Eq. (1)

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

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



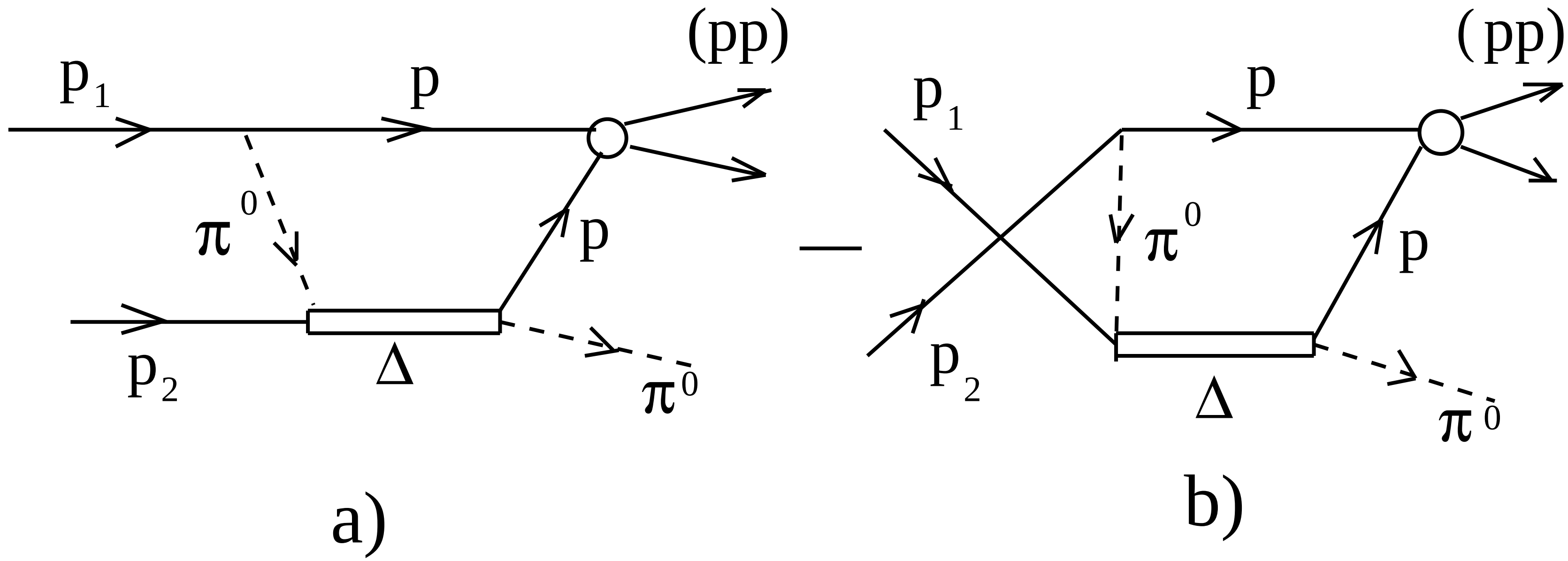
Normalization factor $N = \frac{1}{2.5}$

• – COSY data V. Kurbatov et. al, PLB 661 (2008) 33

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 $p\pi^0 \to p\pi^0$



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

$$\times\int \frac{F_{\pi NN}(k_\pi^2)}{(m_\pi^2 - k_{\pi_a}^2 - i\varepsilon)} \frac{F_{\pi N\Delta}(k_\pi^2)}{(m_\Delta^2 - k_{\Delta_a}^2 - im_\Delta\Gamma)} \frac{<\Psi_k^{(-)} \mid V(^1S_0) \mid \mathbf{q}>}{(k_{pp}^2 - q^2 + i\varepsilon)} \frac{d^3\vec{q}}{(2\pi)^3} \quad (4)$$

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

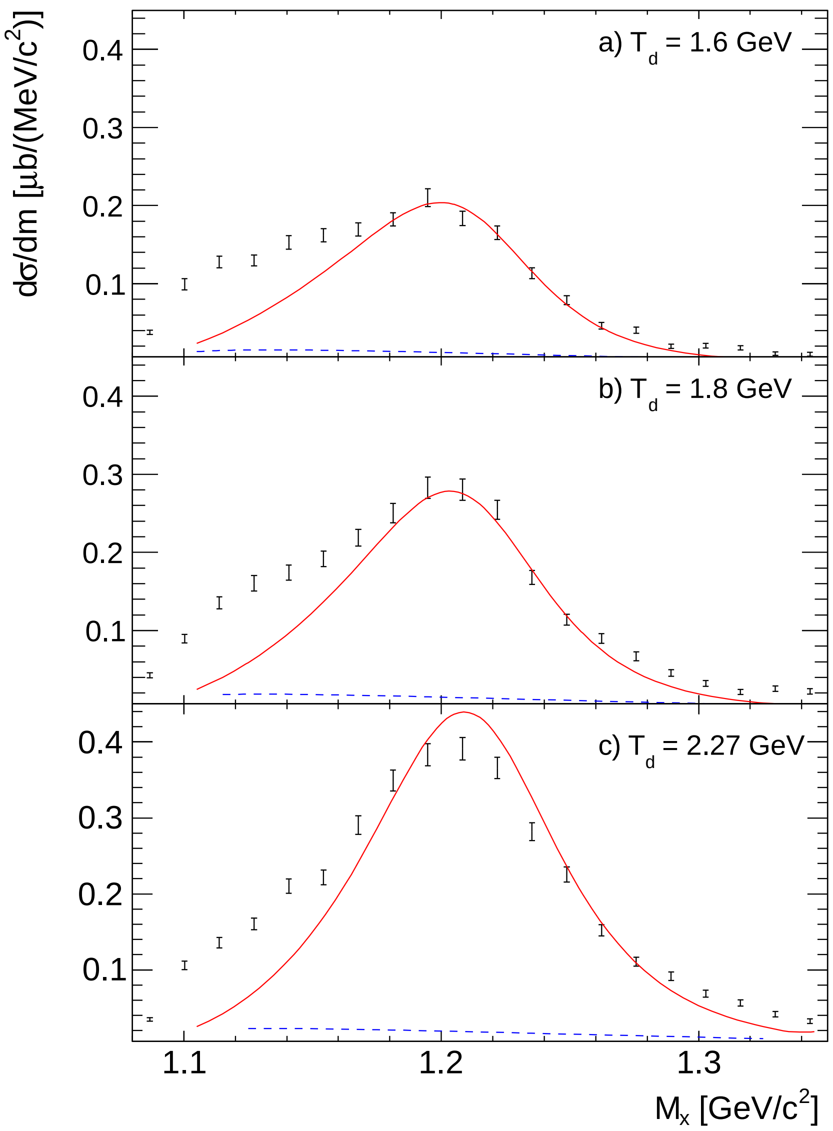
$$f_{\pi NN} = 1.00,\, f_{\pi N\Delta} = 2.15,$$
$$f_{\rho NN} = 6.20,\, f_{\rho N\Delta} = 13.33.$$

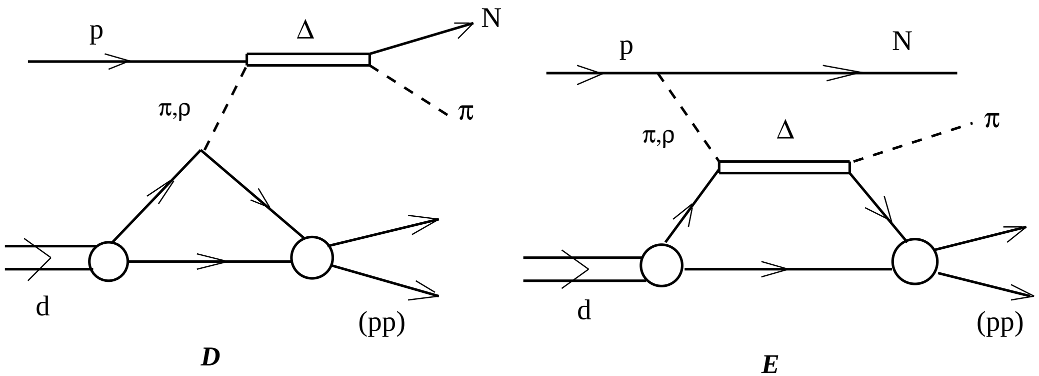
V.F. Dmitriev et al (1987)   M.Platonova, V.Kukulin, NPA (2016)

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

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

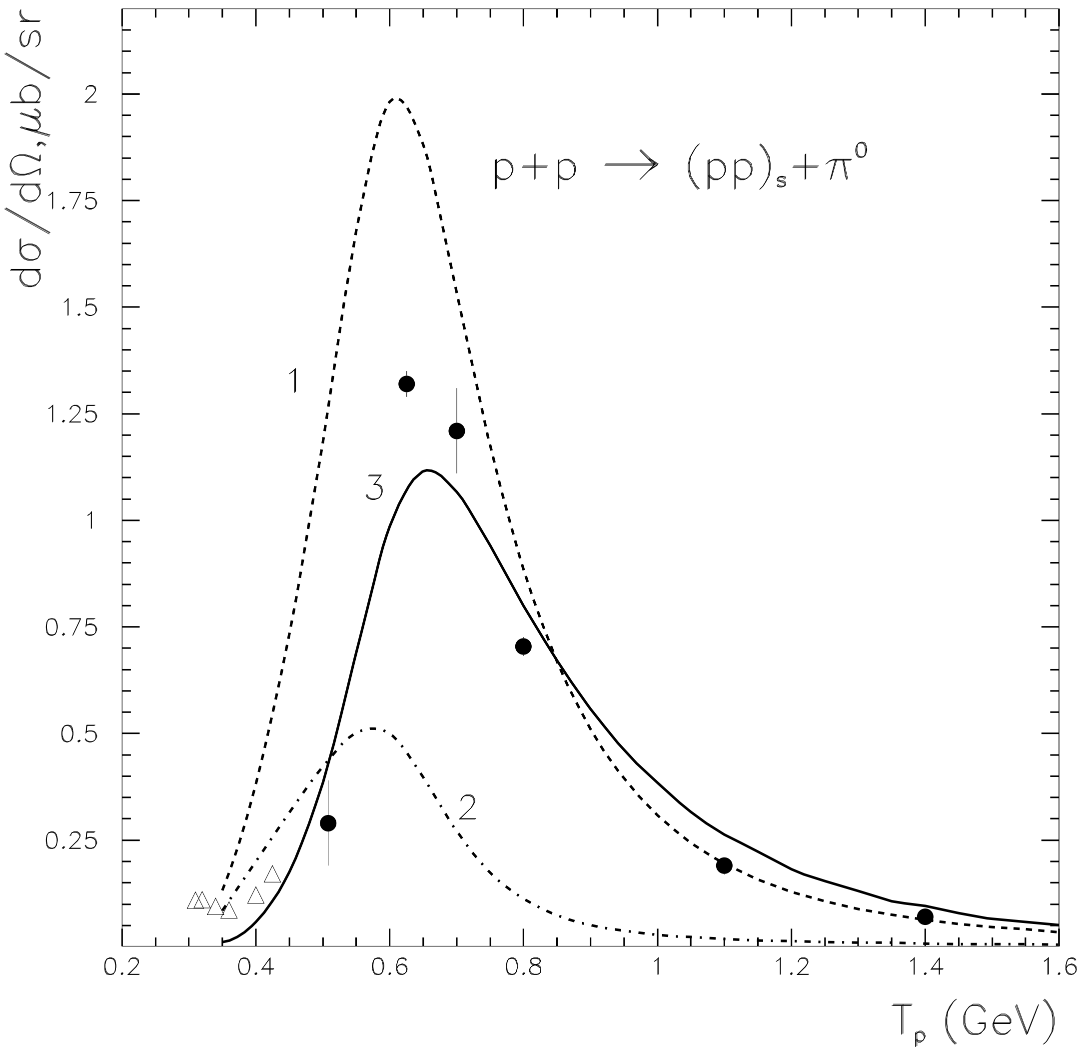
$dp \to \{pp\}_s \pi N$ Yu.N. U., J.Haidenbauer, C. Wilkin, PoS 93 (2015)





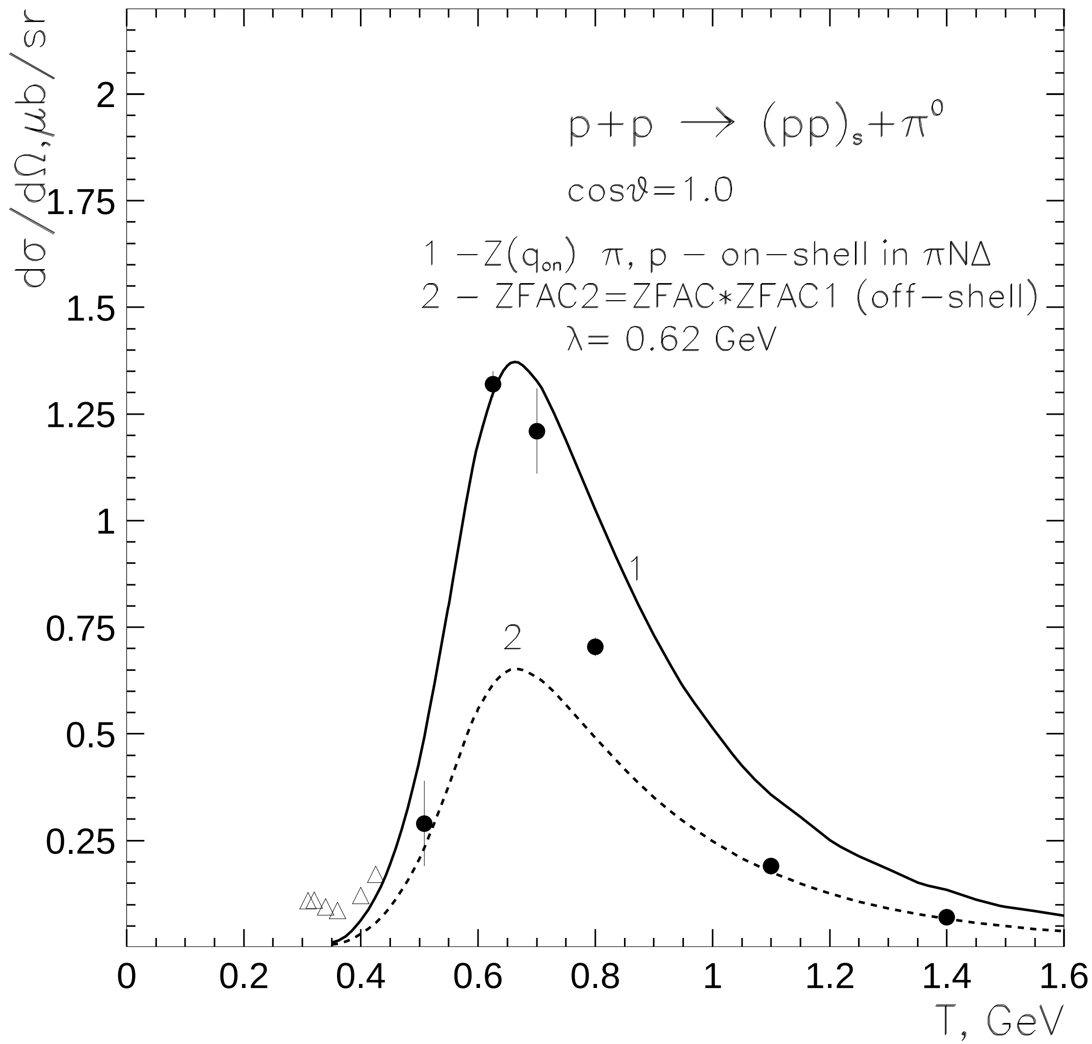
ANKE@COSY data • – D. Mchedlishvili et al., PRL (2013) $\lambda_\pi = 0.5$ GeV, and $\mathbf{T_{22}}$

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;
$\Gamma(k) = \Gamma_0\left(\frac{k}{k_R}\right)^3 \frac{k_R^2+\chi^2}{k^2+\chi^2}$ $\chi = 0.180GeV$, $\lambda_\pi = 0.55$ 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).

Matrix element of $pp \to \{pp\}_s\pi^0$.

$$M = \chi^T_{\sigma_2}(2)\frac{i\sigma_y}{\sqrt{2}}\left(A\vec{\sigma}\hat{\vec{p}} + B\vec{\sigma}\hat{\vec{q}}\right)\chi_{\sigma_1}(1) \tag{5}$$

$\vec{p}$ – the proton momentum, $\vec{q}$ – the pion momentum

$$\frac{d\sigma}{d\Omega} = |A|^2 + |B|^2 + 2ReAB^*\cos\theta, \tag{6}$$

$$A_y\frac{d\sigma}{d\Omega} = 2ImAB^*\sin\theta;$$

$$M_{\lambda_1=\frac{1}{2},\lambda_2=\frac{1}{2}} = -\frac{1}{\sqrt{2}}(A + B\cos\theta) \equiv \Phi_1,$$

$$M_{\lambda_1=\frac{1}{2},\lambda_2=-\frac{1}{2}} = \frac{1}{\sqrt{2}}B\sin\theta \equiv \Phi_2$$

Jacob, Wick (1959):

$$M_{\lambda_1\lambda_2} = \sum_J \frac{2J+1}{2}d^J_{\lambda,0}(\theta) < 00; JM|JM; l_\pi 0 >< JM; LS|JM; \lambda_1\lambda_2 > A(^{2S+1}L_J, l_\pi) \equiv$$

$$\equiv \sum_J \frac{2J+1}{2}d^J_{\lambda,0}(\theta)\Phi^{(J)}_{\lambda_1\lambda_2}(E),$$

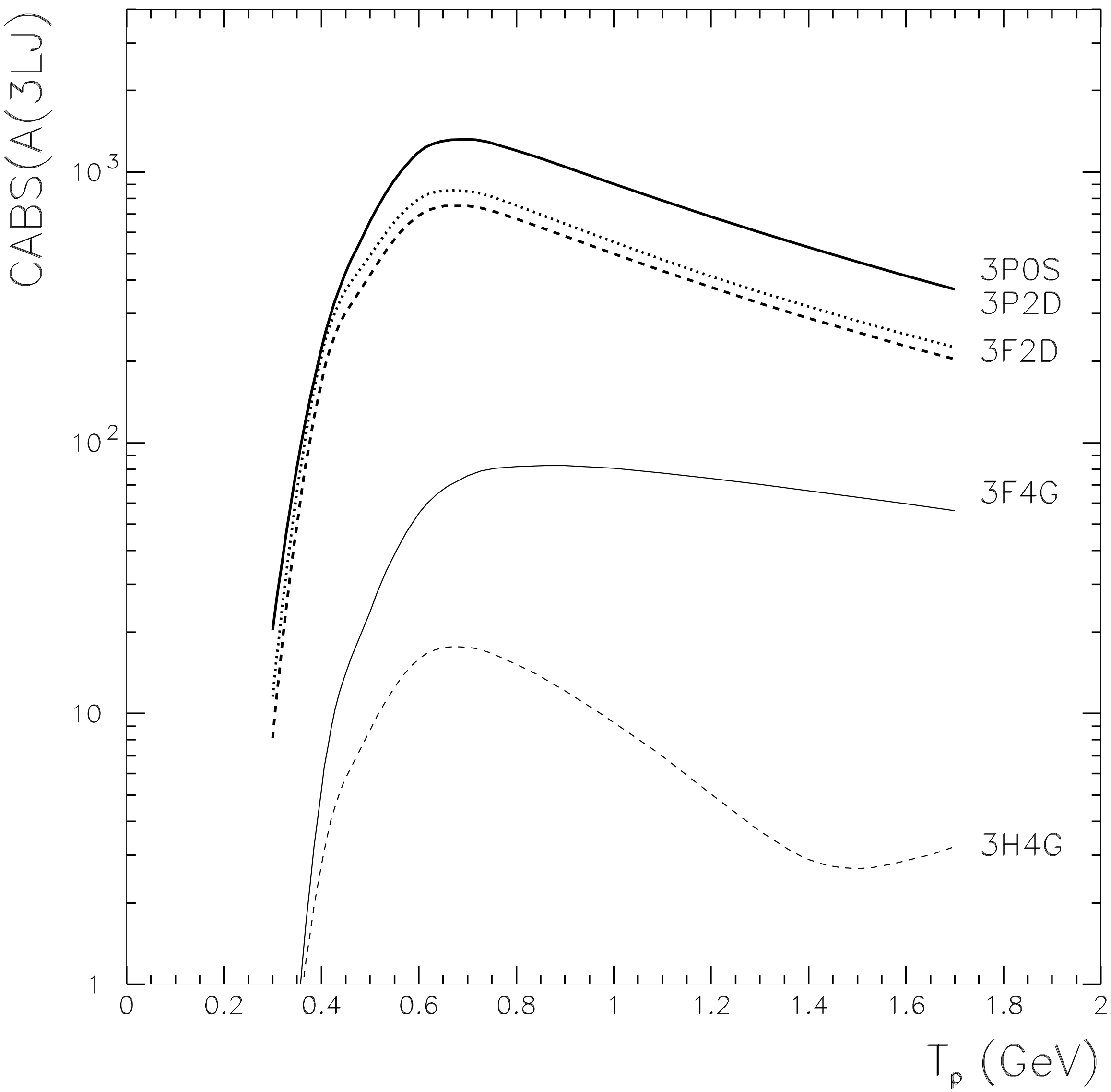
$$\Phi^{(J)}_{\lambda_1\lambda_2}(E) = \int_0^\pi M_{\lambda_1\lambda_2}(\theta) d^J_{\lambda,0}(\theta) \sin\theta d\theta. \tag{7}$$

For $J = 0, 2, 4$:

$$\begin{aligned}
A(^3P_0 s) &= -\frac{1}{\sqrt{2}}\Phi_1^{(J=0)}, \\
A(^3P_2 d) &= \frac{1}{\sqrt{5}}\Phi_1^{(J=2)} + \sqrt{\frac{3}{10}}\Phi_2^{(J=2)}, \\
A(^3F_2 d) &= -\sqrt{\frac{3}{10}}\Phi_1^{(J=2)} + \frac{1}{\sqrt{5}}\Phi_2^{(J=2)}, \\
A(^3F_4 g) &= \frac{\sqrt{2}}{3}\Phi_1^{(J=4)} + \frac{1}{3}\sqrt{\frac{5}{2}}\Phi_2^{(J=4)}, \\
A(^3H_4 g) &= -\frac{1}{3}\sqrt{\frac{5}{2}}\Phi_1^{(J=4)} + \frac{\sqrt{2}}{3}\Phi_2^{(J=4)}.
\end{aligned} \tag{8}$$

For $J = 0,\ 2$ coincides with V.Baru et al. (2014))

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



ANKE fit (V.I. Komarov et al. (2016): ^3P_0s, ^3P_2d are sufficient for $\frac{d\sigma}{d\Omega}$ and $A_y(\theta)$.
The Δ-model: ^3F_2d cannot be neglected!

Isospin ratio $R = d\sigma(pp \to \{pp\}_s\pi^0)/d\sigma(pn \to \{pp\}_s\pi^-)$

To test the mechanism:

$R = d\sigma(pp \to \{pp\}_s\pi^0)/d\sigma(pn \to \{pp\}_s\pi^-) = 2$
for the box diagram with the Δ-isobar,

$R = 1/2$ for N-Reggeon exchange

/Yu.N.U., J. Haidenbauer, C. Wilkin, PRC **75** (2007) 014008/

Summary & Outlook

• So far, indications to exotic (nonstrange) dibaryon resonances usually appear in the region of the Δ- or $\Delta\Delta$- excitation

• Attempts to suppres the Δ-contribution by isospin relations via change $d \to \{pp\}_s$, lead to nontrivial results, e.g. more insight into short-range NN-dynamics in $pd \to \{pp\}_s n$

• Well pronounced Δ-like resonance structure has been observed in the $pp \to \{pp\}_s \pi^0$, where S-wave is forbidden in ΔN intermediate state

• In contrast to $pp \to d\pi^+$, the box-diagram with Δ completely fails to explain θ-dependence $d\sigma/d\Omega(\theta)$ and A_y for $pp \to \{pp\}_s \pi^0$ and not enough convincing for E-shape of $d\sigma/d\Omega(0^\circ)$.
Thus, are the ${}^3P_0 s$, ${}^3P_2 d$ states new dibaryons?...

- $\star$ ${}^3F_2 d$ would not be neglected in the fit to the data
- $\star$ Neccessary to measure $\frac{d\sigma(pp\to\{pp\}_s\pi^0)}{d\sigma(pn\to\{pp\}_s\pi^-)}$

THANK YOU FOR ATTENTION!