POLARIZED DEUTERON CHARGE EXCHANGE $dp \to pp(^1S_0)N\pi$ IN THE Δ-ISOBAR REGION

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in collaboration with

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CONTENT

* What is the $pp(^1S_0)$={pn}_s diproton?

* **T20 problem** and pd → {pp}_s n instead of pd → dp (180°)

* "Soft" charge-exchange dp → {pp}_s n

* Charge-exchange with Δ: dp → {pp}_s X and NN→NΔ spin-structure

* Other reactions $pp \longrightarrow \{pp\}_s \pi^0$ $pp \longrightarrow \{pp\}_s \gamma$

* SUMMARY

COSY DATA with diproton (noncomplete list)

$pd \to \{pp\}_s n$ **at 0.5-2.0 GeV:**

V. Komarov et al., Phys. Lett. B553 (2003) 179;
S.Yaschenko et al., Phys.Rev. Lett. 94 (2005) 072304;
S. Dymov et al., Phys. Rev. C 81 (2010) 044001

$pp \to \{pp\}_s \pi^0$ **at 0.5-2.0 GeV:**

S. Dymov et al., Phys. Lett. B 635 (2006) 270.
V. Kurbatov et al., Phys. Lett. B 661 (2008) 22.
S.Dymov et al. Phys. Lett B (2012); D.Tsirkov et al. Phys. Lett. B (2012)

$pp \to \{pp\}_s \gamma$ **at 0.3-0.8 GeV:**

V. Komarov et al., Phys.Rev. Lett. 101 (2008) 102501;
D. Tsirkov et al., J.Phys. G:Nucl.Part.Phys. 37 (2010);

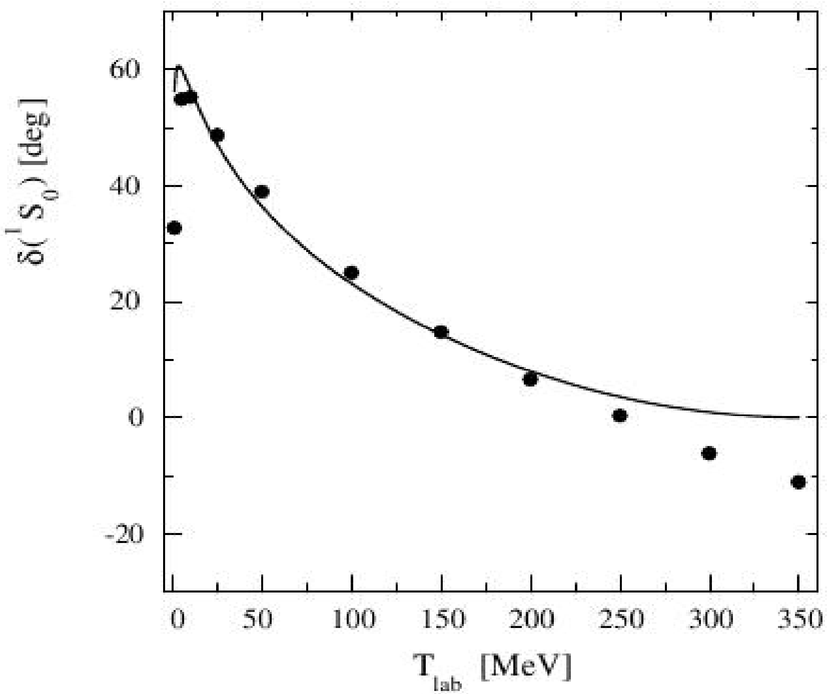
$pp \to \{pp\}_s \pi\pi$ **1.1-2.0 GeV**

S.Dymov et al, PRL 102 (2009) 192301 ; and dp→{pp}_sn

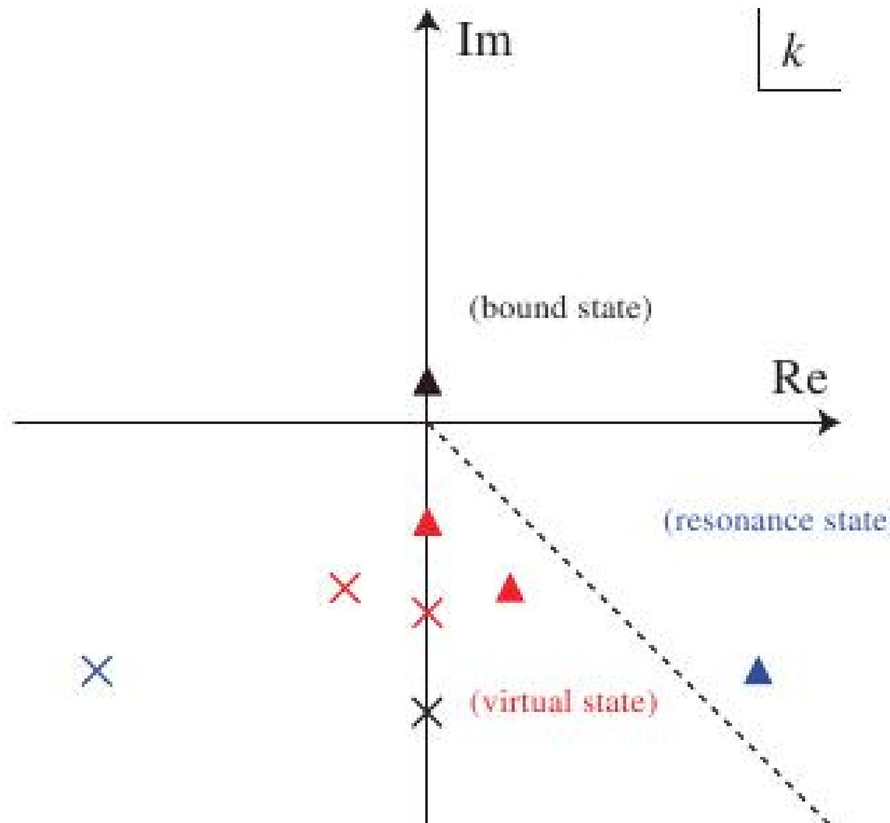
Diproton pp($^1S_0$) , Epp< 3 MeV

T=1,J=0,L=0 Anti-bound (virtual) state , zero width

E=-65 keV for the pn ($^1S_0$)



. **3.** The energy dependence of the $^1S_0$ *pp* phase sl

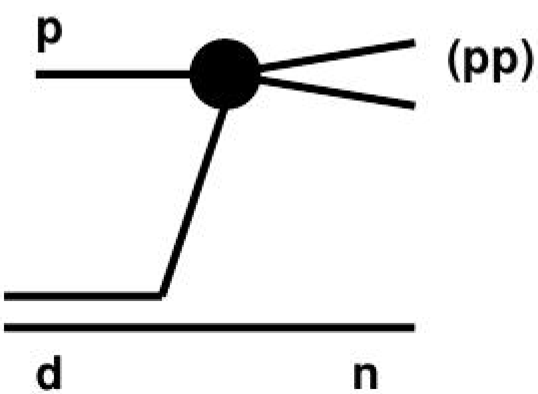


Y.Ikeda et al, arxiv:1101.5190 [nucl-th]

$^1S_0$ t(q,k) half-off-shell and ONE for the pd → {pp}n

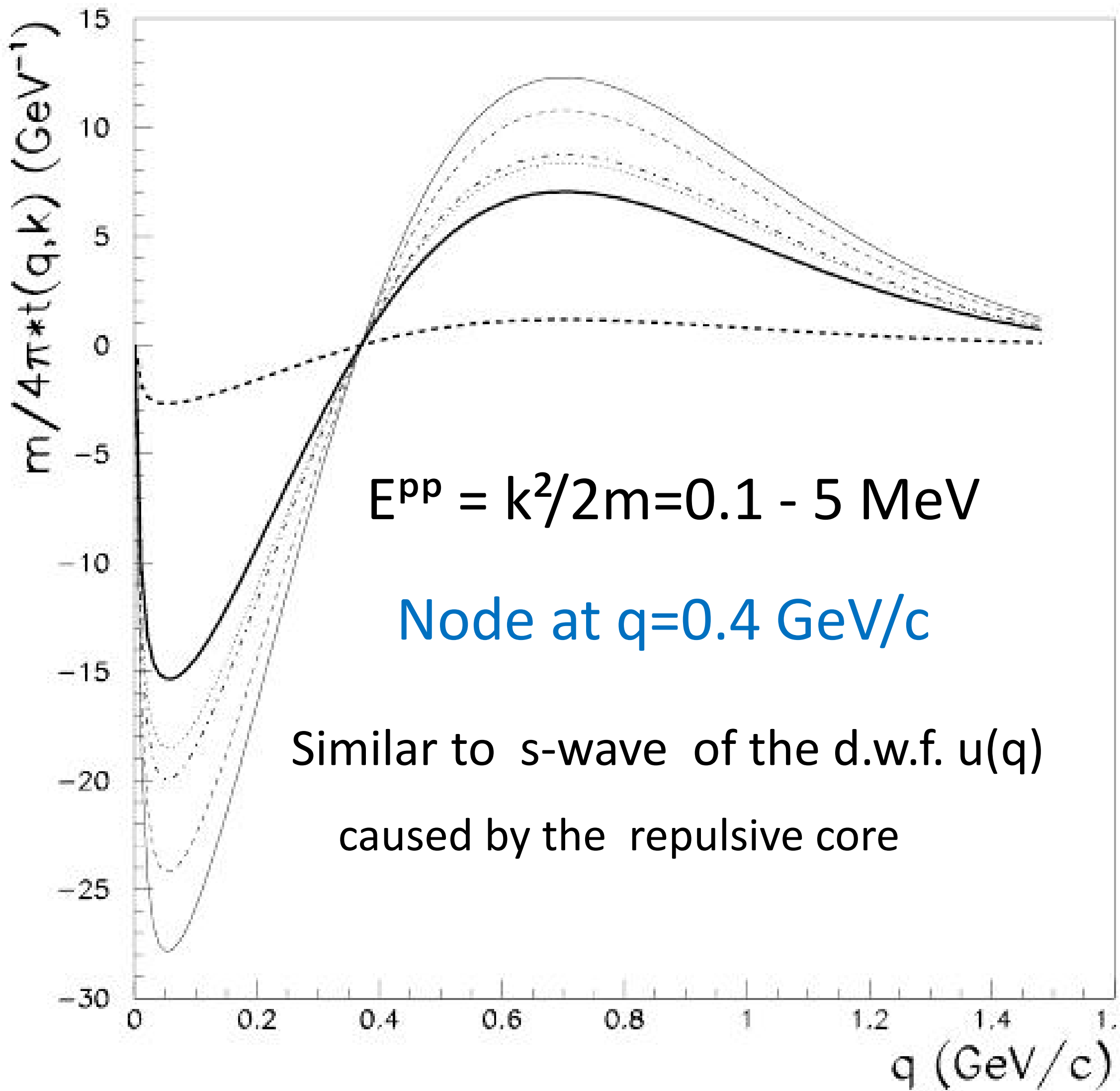
t-matrix of pp($^1S_0$) scattering, $\mathbf{t(q,k)} = <\psi_{\mathbf{k}}^{(-)}(^1\mathbf{S_0})|\mathbf{V}|\mathbf{q}>$

p+d → {pp}s+n



ONE nucleon exchange

$d^3k=k^2dk\,d\Omega$ K → 0



$E^{pp} = k^2/2m = 0.1 - 5$ MeV

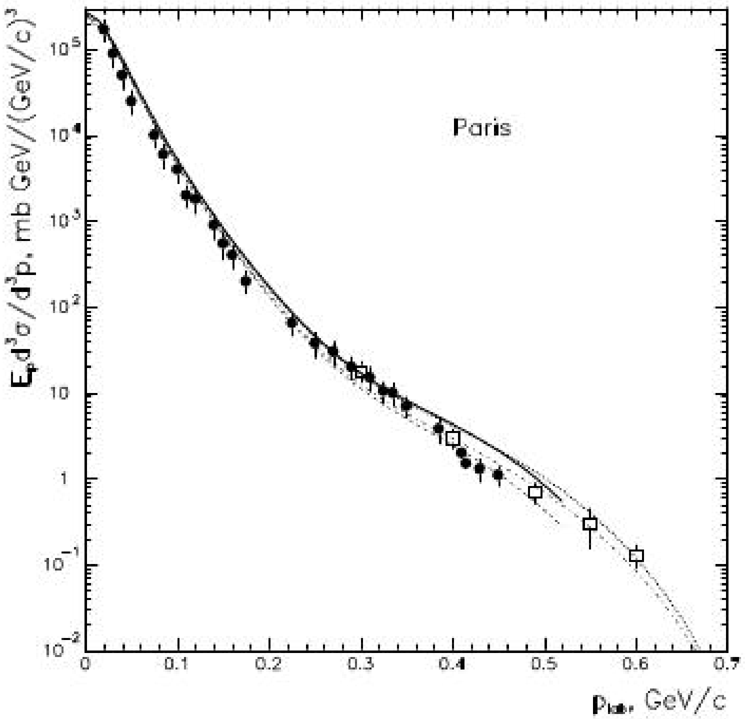
Node at q=0.4 GeV/c

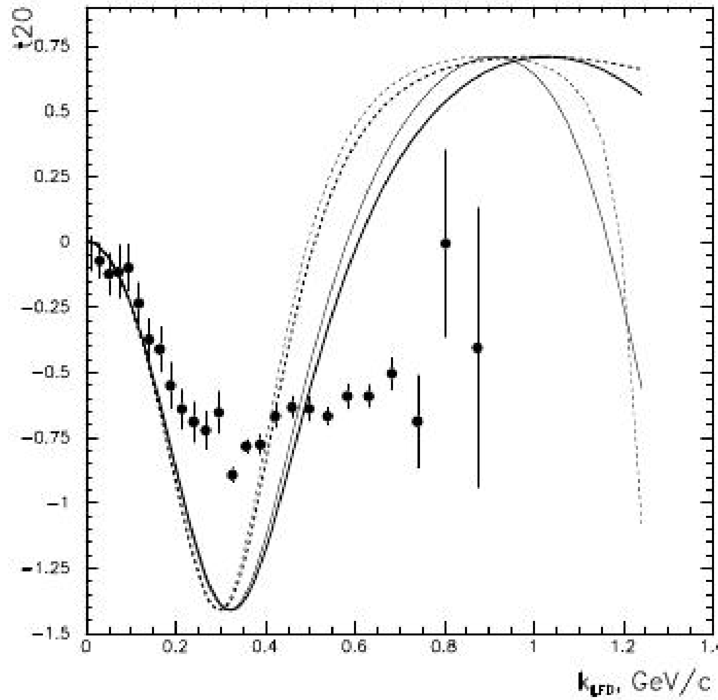
Similar to s-wave of the d.w.f. u(q)

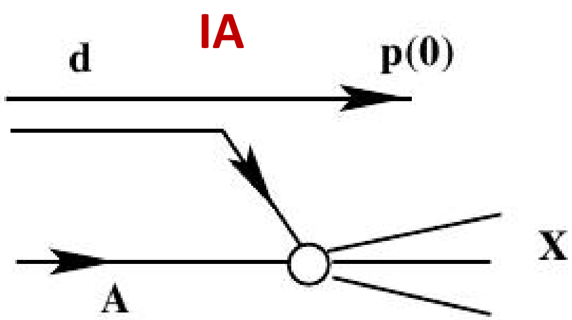
caused by the repulsive core

T20 puzzle

$d + {}^{12}C \rightarrow p(0^\circ) + X$ dp→ pd, dp → p(0°)X





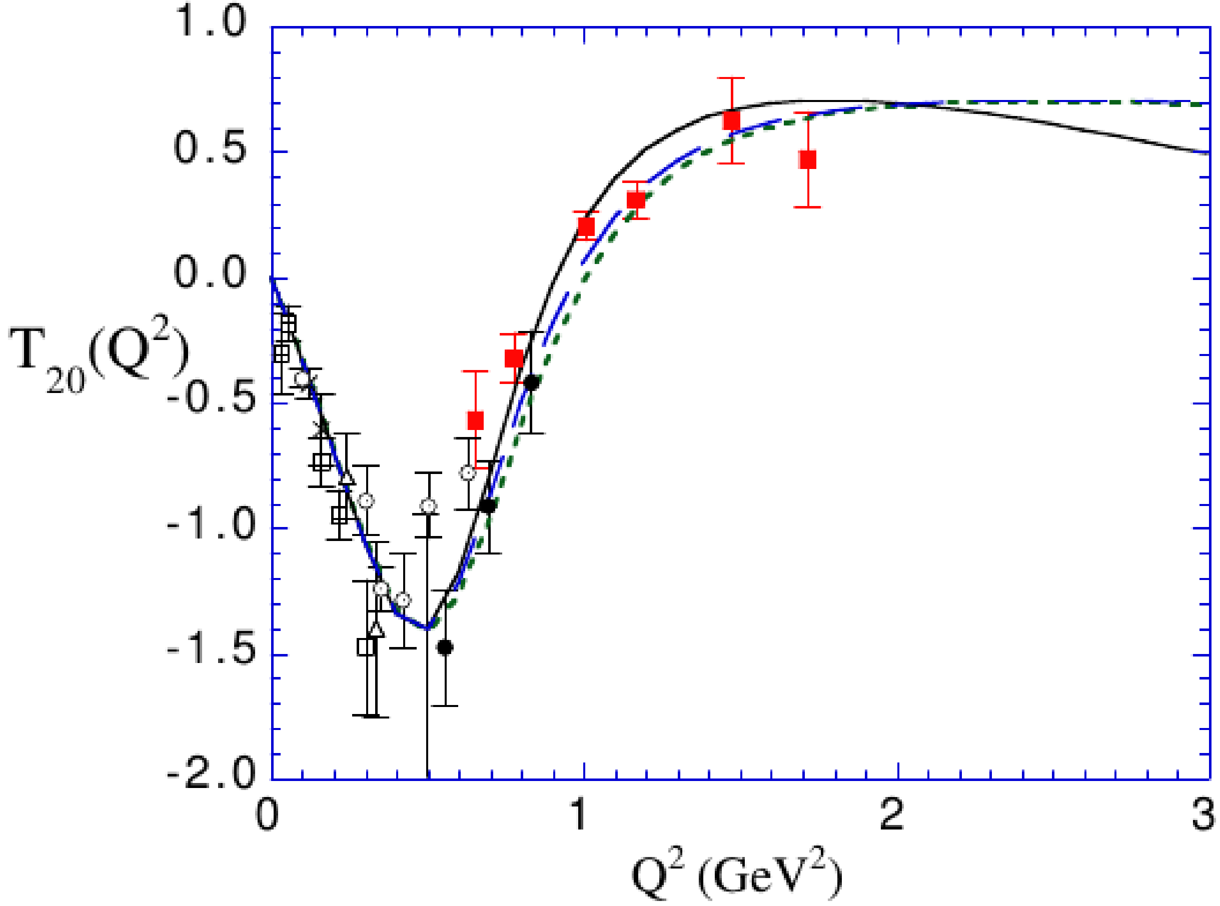


+ Δ,N*,…

?

Invariant cross section for $d + {}^{12}C \rightarrow p(0^\circ)$ X) at $T_d = 4.2$ GeV (•) (L.Anderson et al. Phys. Rev. C 28 (1983) 1224 and $p + d \rightarrow p(180^\circ)X$ at $T_p = 7.7$ GeV (A.M. Baldin et al. (1972)) (squares) as a function of the momentum of the final proton in the deuteron rest frame. Curves show the results of calculation within the IA (RHD) thick full line –for $d + {}^{12}C \rightarrow p(0^\circ)$ X),
dotted line – $p + d \rightarrow p(180^\circ)X$.

To compare: T20 in ed-elastic, IA +MEC

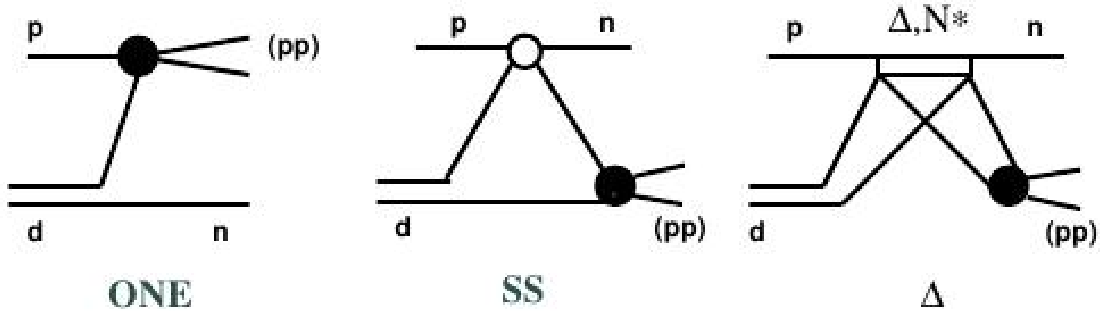


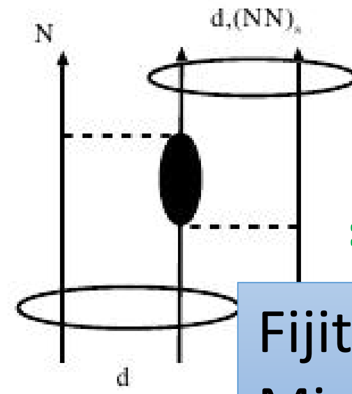
R.Gilman, F. Gross. G.Phys.G:Part.Nucl. B13 (2002)

1. pd →{pp}_s n reaction in kinematics of pd → dp (an attempt to solve T_20 problem)

O. Imambekov, Yu.N. Uzikov, Yad. Fiz. 52 (1990) 862.
A.V.Smirnov, Yu.N.U., Yad Fiz.61 (1998) 421.
Yu.N. Uzikov, JETP Lett. 75(2002) 5; J. Phys. G 28(2002)B13.

ONE+SS+Delta model





=3NF

Fijita-Miyazawa

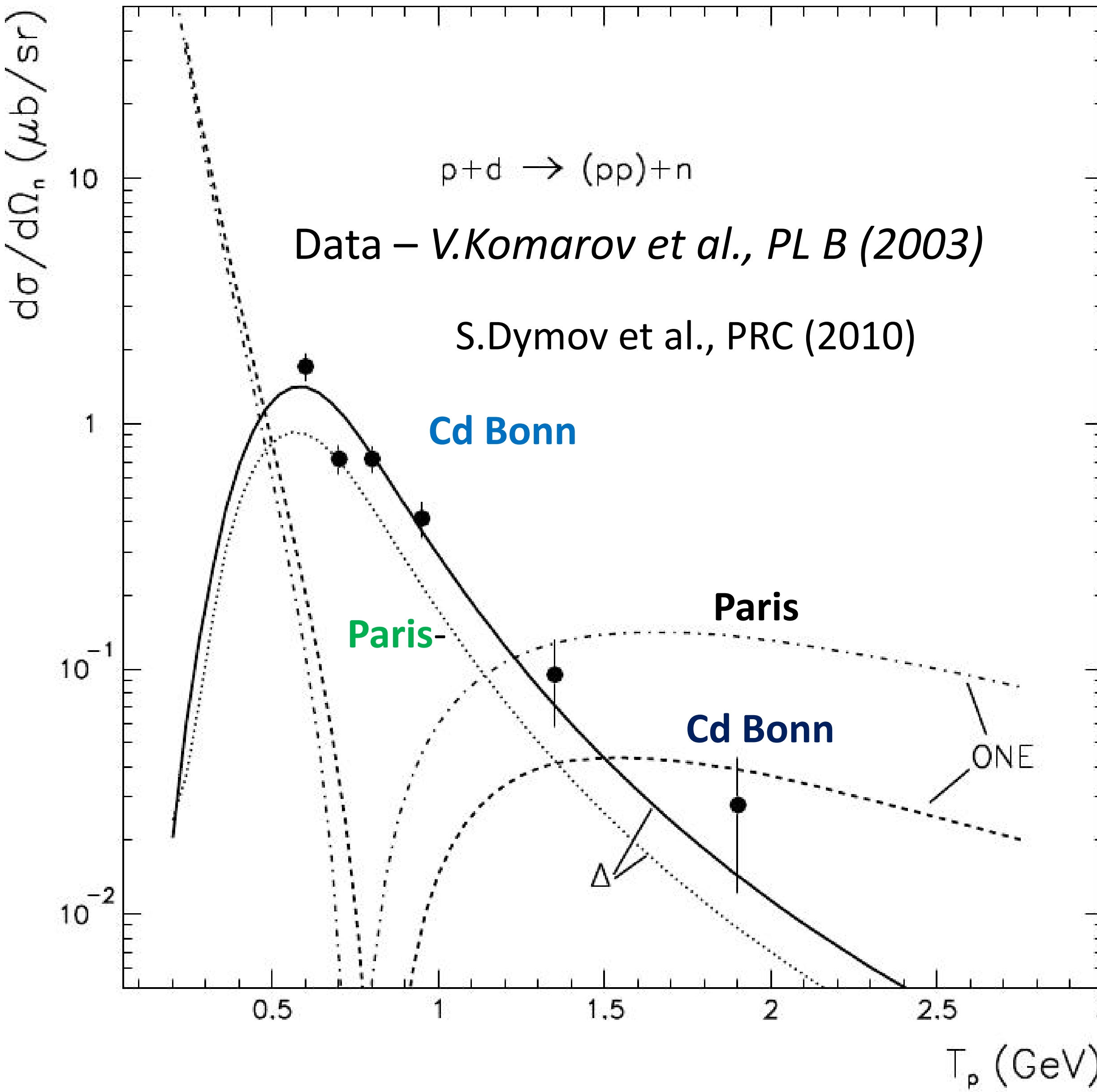
WHY $pd \to (pp)_s n$ AND NOT $pd \to dp$?

- Δ- and N^*- excitations (3NFs) are suppressed by 1/3 in amplitude due to isospin invariance.
- Isospin of the diproton is I=1.
  At $E_{pp} < 3$ MeV, (pp) is mainly in a $^1S_0$ state, as compared to the deuteron I=0, $^3S_1 -^3 D_1$.
- the node of t-matrix of pp$(^1S_0)$ $q \approx 0.4$ GeV/c

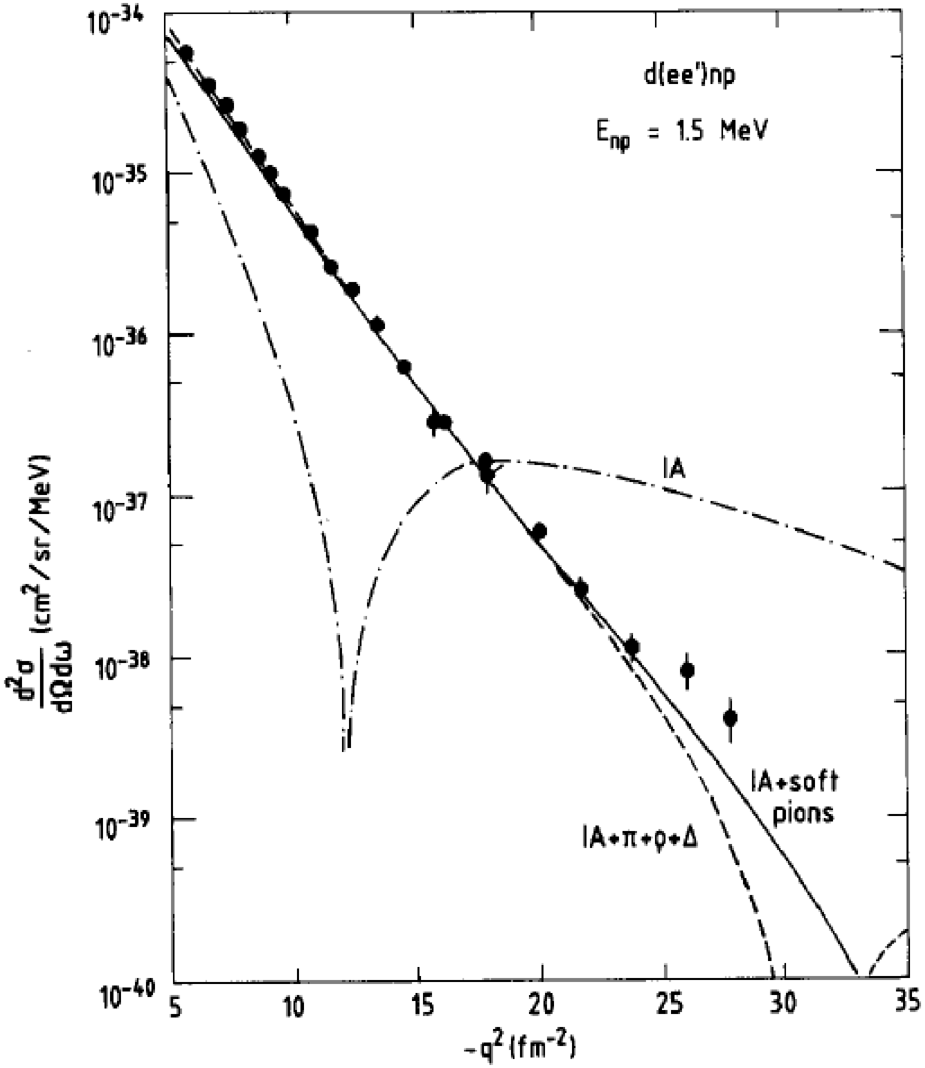
Yu.N. U., JETP Lett. **75**(2002) 5; J. Phys. G **28**(2002)B13.

SS+Δ+ONE : *J. Haidenbauer, Yu.N. Uzikov, PLB 562 (2003) 227*

Soft NN potential
like the Cd Bonn
is preferable!

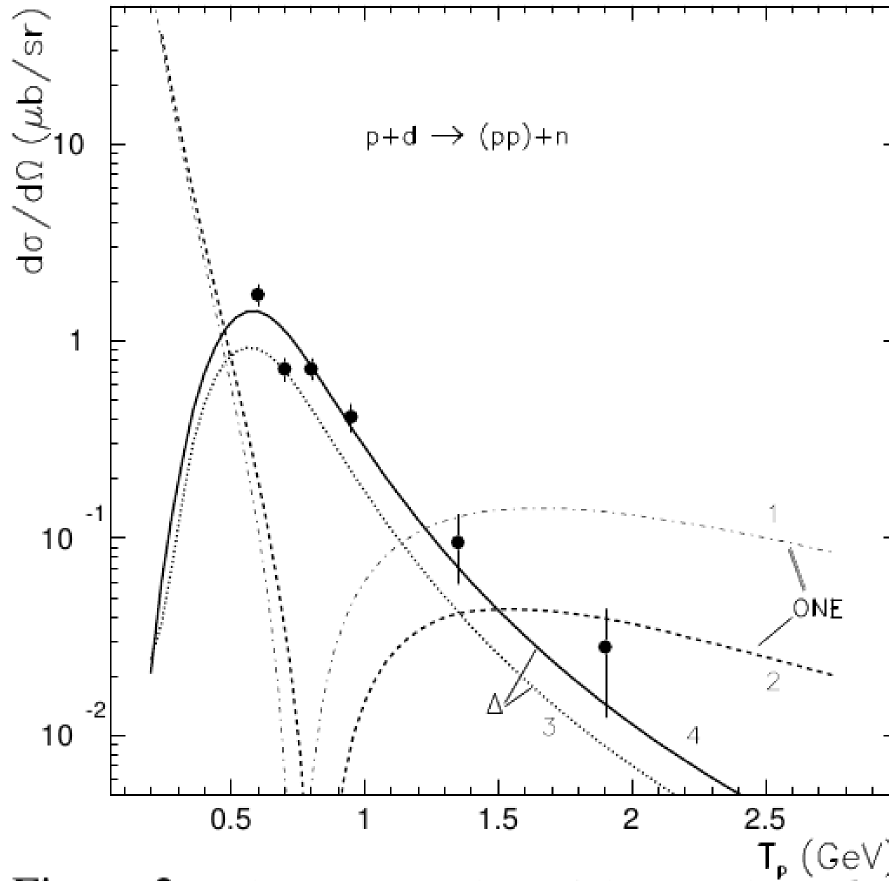


Meson Exchange Currents



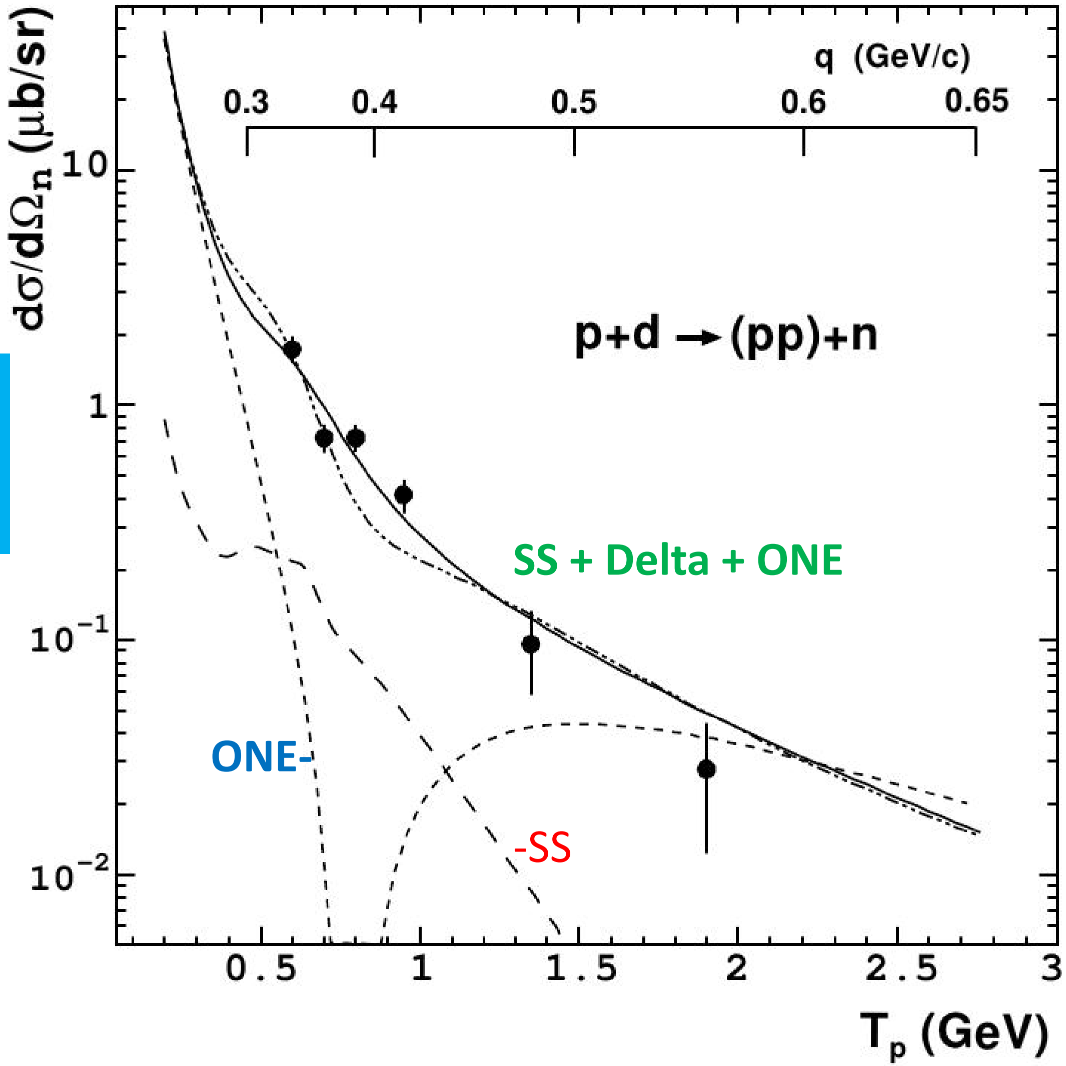
Mathiot J.F. Phys.Rep. 173 (1989)

3NF N-Δ-N



J.Haidenbauer, Yu.N.U, PLB (2003)

q - internal momentum in the deuteron for the ONE



T20 is not measured!

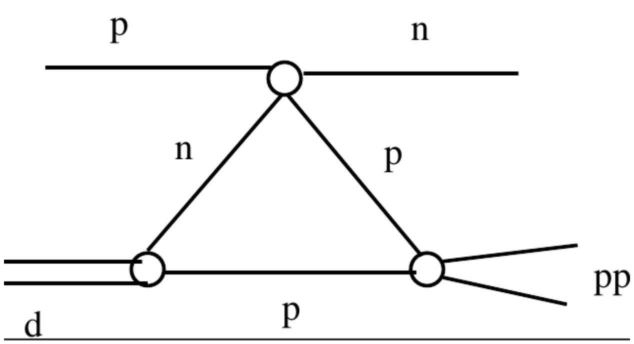
3NF of the N-Delta-N type dominates at 0.7- 0.9 GeV

2. Soft charge-exchange d+p→{pp}_s+n

I.Ya. Pomeranchuk, Dokl. AN SSSR (1951)

3S1 - >1S0 Spin-flip in the pn->np transition

D.Dean (1973) ,
D.Bugg, C. Wilkin (1986)



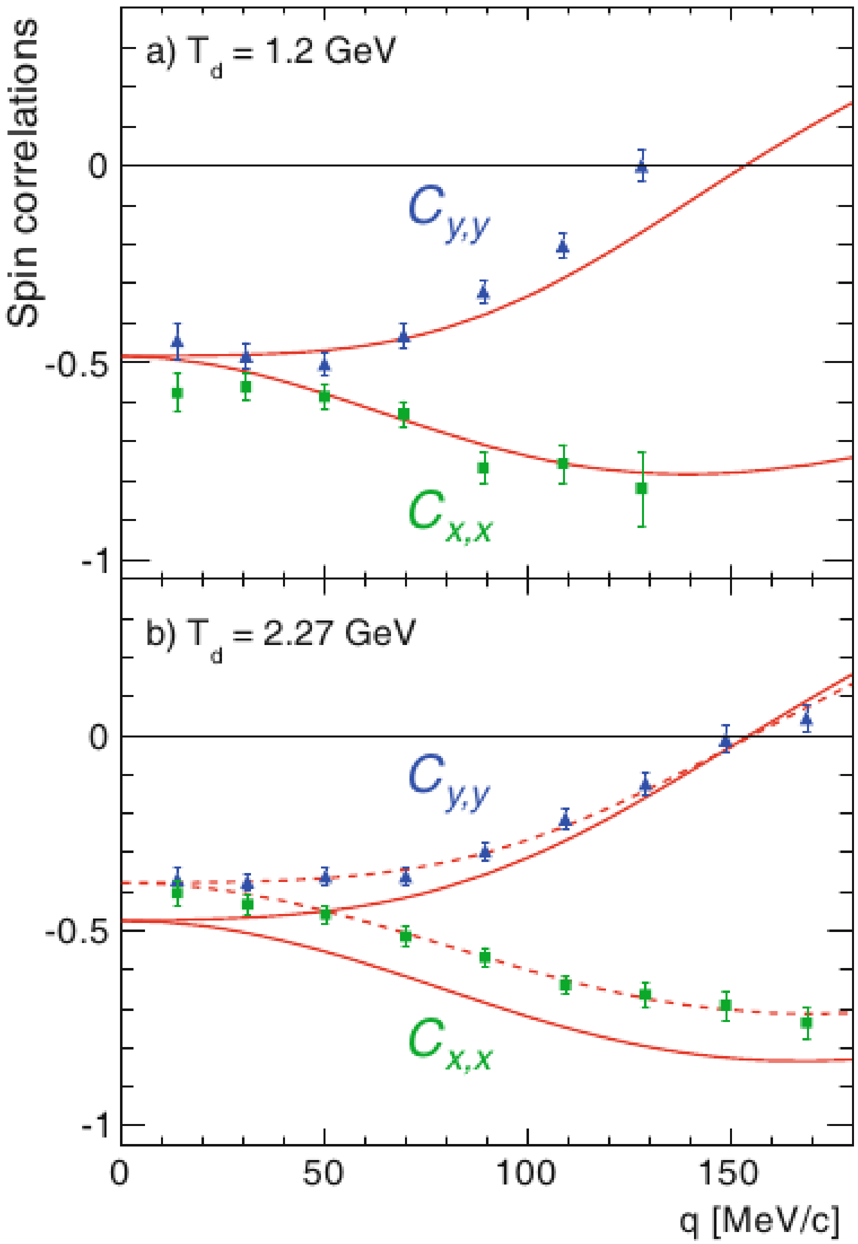
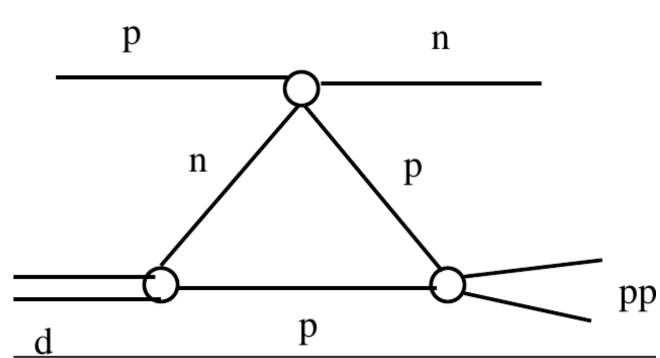


Fig. 13. The spin-correlation coefficients $C_{x,x}$ and $C_{y,y}$ for

Soft charge-exchange

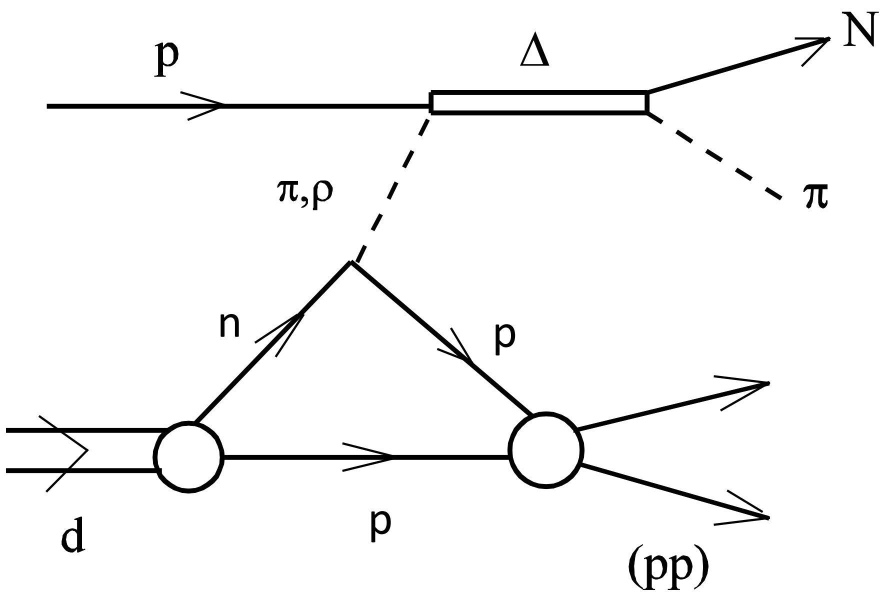
The pn → pn data has to be corrected !



See talks by V. Glagolev and R. Shindin at this conference

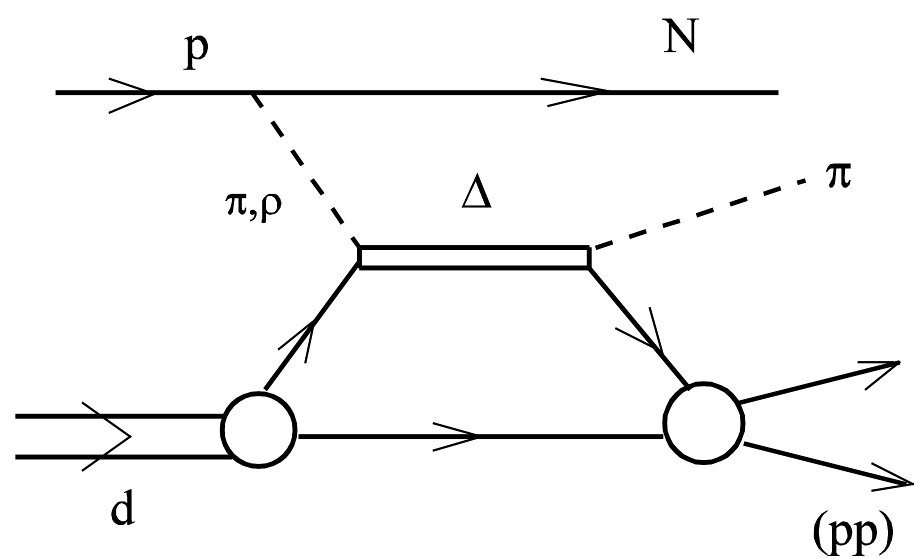
3. Deuteron charge-exchange with the Δ(1232)-isobar formation

Spin transfer $\vec{n}p \to \vec{p}\,\Delta$



a)

Direct



b)

Exchange

Vertexes and parameters

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

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

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

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

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

V.F. Dmitriev et al, Nucl.Phys.A(1986) NN-NΔ

O.Imambekov, Yu.N. Uzikov Yad. Fiz. (1988)
pp → p+n+π^+

$$\pi NN: \quad i\frac{f_\pi}{m_\pi}(\boldsymbol{\sigma q})(\boldsymbol{\tau\pi}),$$

$$\pi N\Delta: \quad i\frac{f^*_\pi}{m_\pi}(\boldsymbol{Sq})(\boldsymbol{T\pi}). \tag{3}$$

Here $\boldsymbol{q}$ is the meson momentum which enters into the vertex, $\boldsymbol{\sigma}$ is the spin Pauli matrix, and $\boldsymbol{S}$ is the transition spin operator [5]).

The effective lagrangian (1) with the coupling constants (2), corresponds to the case when all the particles are on mass shell. In the scattering problem (fig. 1) the intermediate mesom is off mass shell. To take this into account one usually introduces form factors F in the vertices. In the simplest parametrisation

$$F(t)=\frac{\Lambda^2-m^2}{\Lambda^2-t}, \tag{4}$$

where m is the meson mass, $t=q^2$ is the squared 4-momentum transfer, Λ is the parameter. For simplicity we assume that Λ for NN and NΔ vertices is the same. It seems reasonable, since the quark radial wave functions are the same for N and Δ. The parameter Λ should be fitted in accordance with the experimental data.

The differential cross sections of the reaction pp → nΔ^{++} can be written as [6]):

$$d\sigma=(2\pi)^4\delta^{(4)}(p_i-p_f)|M|^2\frac{1}{4I}\frac{d^3k_3}{(2\pi)^3 2\varepsilon_2}\frac{d^3k_4}{(2\pi)^3 2\varepsilon_4}, \tag{5}$$

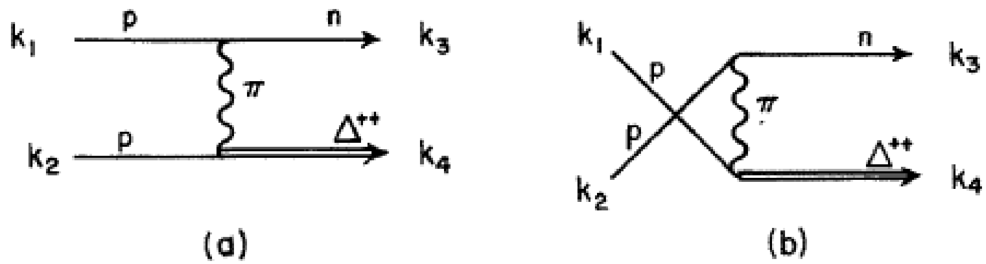


Fig. 1. Direct and exchange graphs for Δ-production in pp collisions.

$$\frac{d\sigma}{dM_X} = \frac{1}{128\pi^3 m K^2 s} \int_{t_1}^{t_2} dt \int_0^{k_{\max}} k^2 dk\, \rho(M_X)\, \overline{|\mathcal{M}_{fi}|^2}, \quad (1)$$

$$\rho(M_X) = \frac{1}{\pi} \frac{M_\Delta \Gamma\, Z(M_X^2, t)}{(M_X^2 - M_\Delta^2)^2 + \Gamma^2 M_\Delta^2} \qquad (2)$$

with

$$Z(M_X^2, t) = \frac{p^2(M_\Delta^2, t) + \kappa^2}{p^2(M_X^2, t) + \kappa^2}, \qquad (3)$$

where $p^2(M_X^2, t) = \lambda(M_X^2, m^2, t)/4M_X^2$ and $\lambda(a, b, c)$ is the triangle function. The width of the Δ-isobar is

$$\Gamma = \Gamma_0 \left(\frac{p(M_\Delta^2, m_\pi^2)}{p(M_X^2, m_\pi^2)} \right)^3 Z(M_X^2, m_\pi^2), \qquad (4)$$

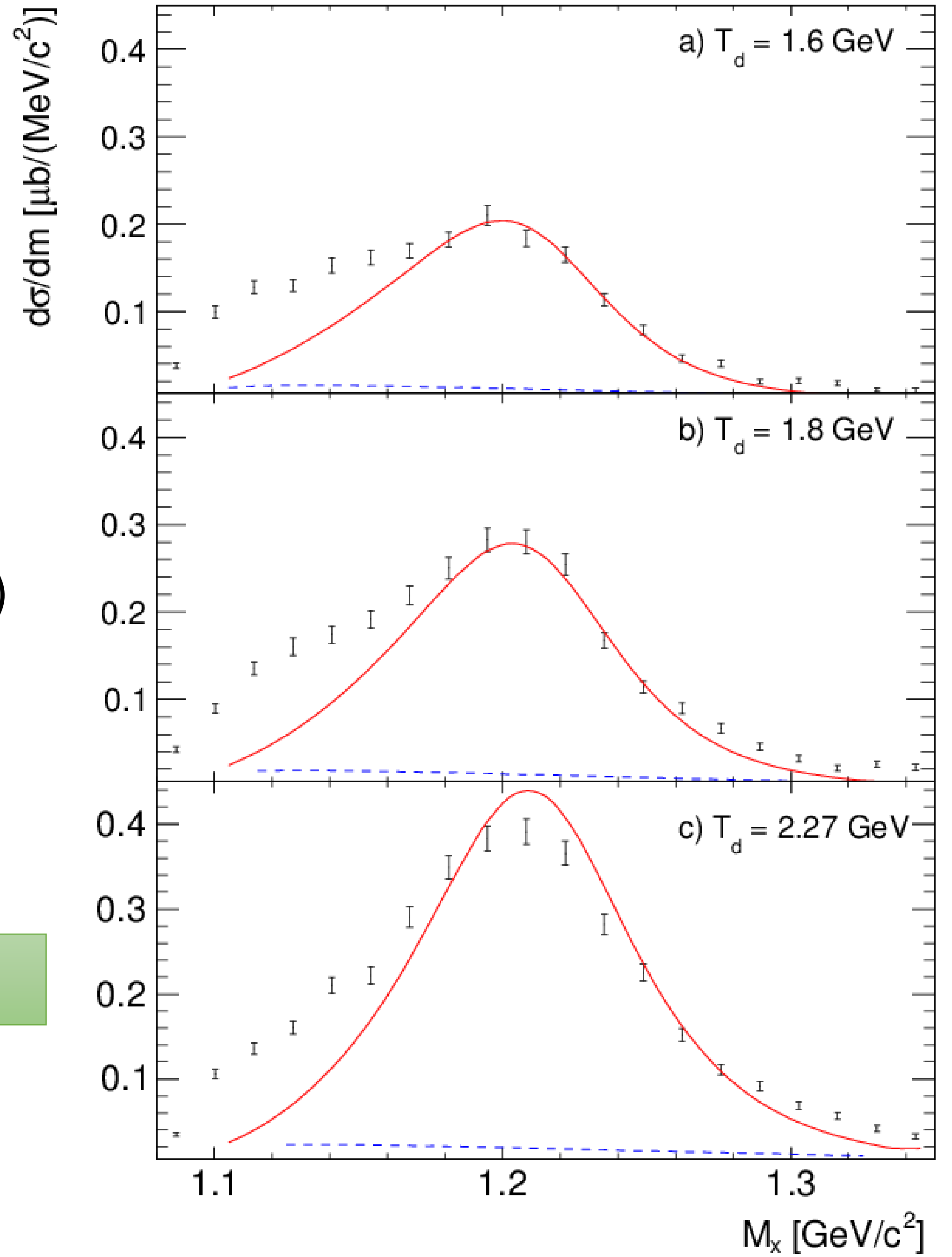
with the following parameters: $M_\Delta = 1.232$ GeV$/c^2$, $\Gamma_0 =$ 0.115 GeV$/c^2$, and $\kappa = 0.180$ GeV$/c$.

dp → {pp}_sX

data - D. Mchledlishvili et al., PLB (2013)

Theory: D-mechanism (full line)
E- mechanism (dashed)
λ=0.5 GeV/c (πNN)

Without normalization factor!



DIRECT MECHANISM:

OPE:

$$M_{fi} \sim \boldsymbol{q_\pi} \cdot \boldsymbol{\Psi}^+ \varphi_p F(t,k^2)\, \boldsymbol{q} \cdot \boldsymbol{\varepsilon},$$

q|| p_d, λ_d=0 q _t=0 $A_{xx} = A_{yy} = 1$

The tensor M_{ji} desribes the ρ-meson exchange:

ρ-exchange

$$M_{ji} = (S_s + \frac{1}{2}S_D)\big[(\mathbf{Q}\cdot\mathbf{Q}')\delta_{ji} - Q_j Q_i'\big] + \frac{3}{\sqrt{2}}S_D\big[(\mathbf{Q}\cdot\mathbf{Q}')n_j - (\mathbf{Q}'\cdot\mathbf{n})Q_j\big]n_i,$$

the one pion exchange ignoring integration over m_x

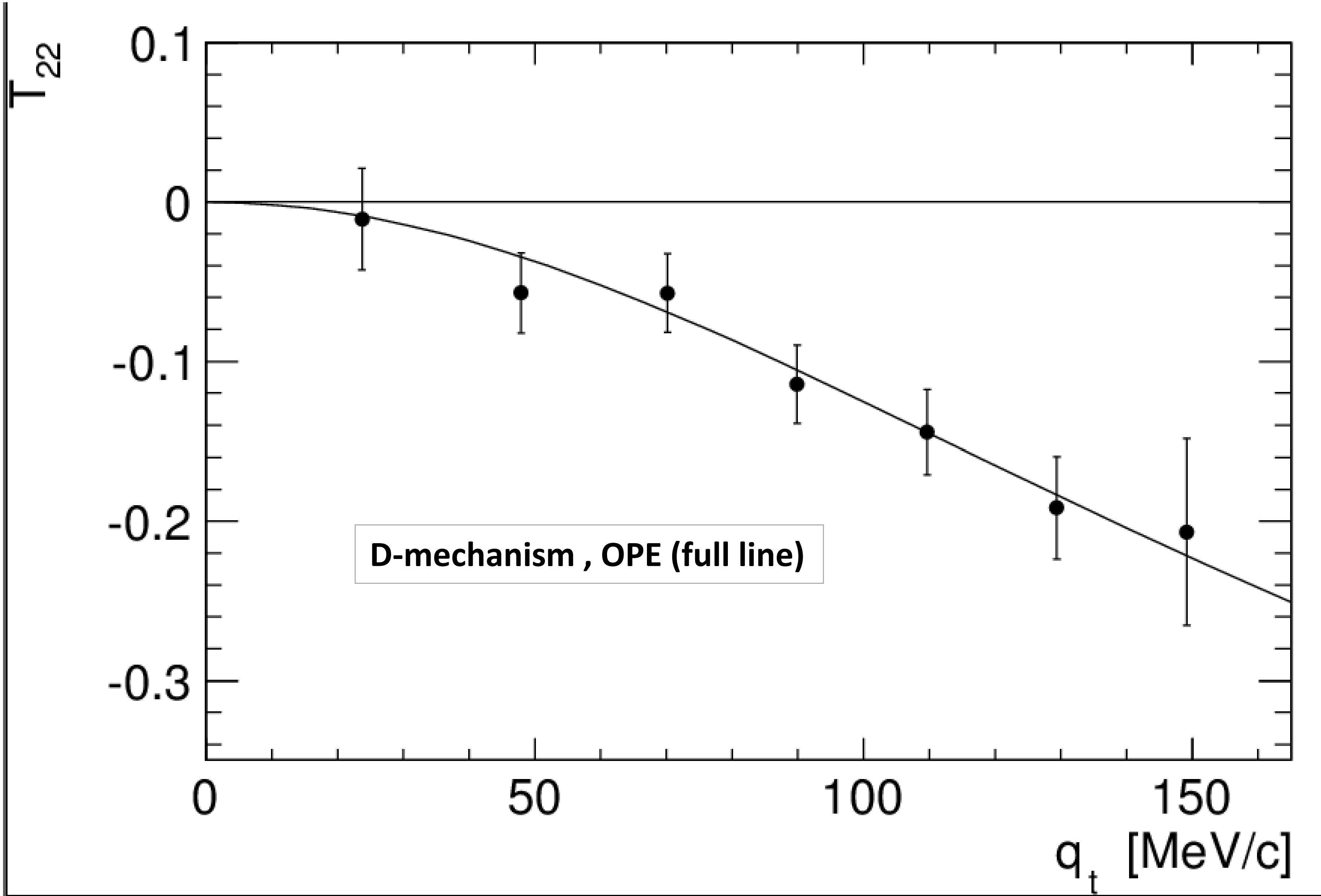
$$A^{\pi}_{xx} = 1 - 3\frac{q_x^2}{\mathbf{q}^2},\ A^{\pi}_{yy} = 1 - 3\frac{q_y^2}{\mathbf{q}^2},$$

Similary, for the pure ρ- meson exchange one has

$$A^{\rho}_{xx} = -\frac{1}{2} + 3\frac{q_x^2}{2\mathbf{q}^2},\ A^{\rho}_{yy} = -\frac{1}{2} + 3\frac{q_y^2}{2\mathbf{q}^2}.$$

dp →{pp}_s+N+π

T_22=(A_xx-A_yy)/(2√3)



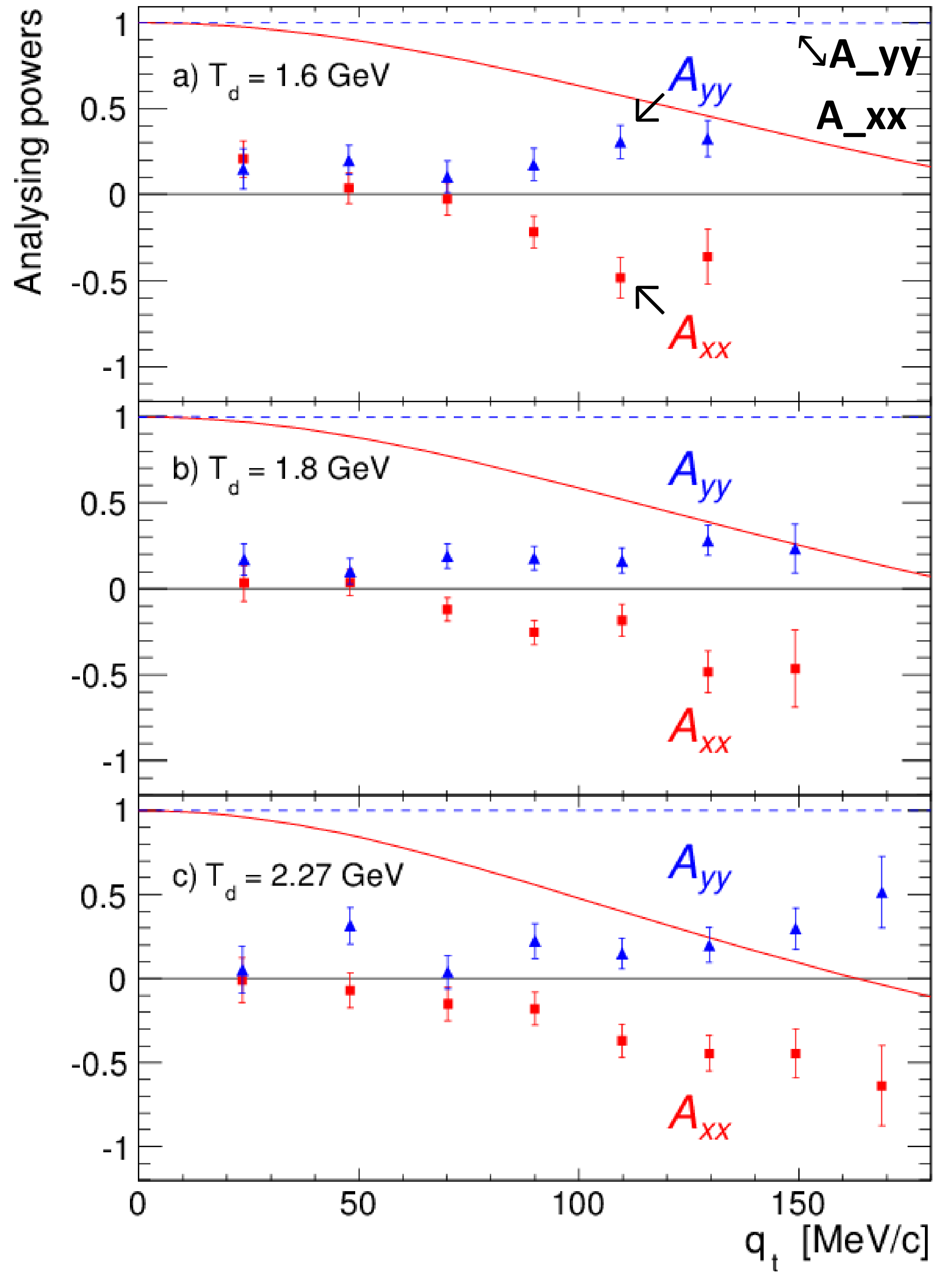
dp →{pp}_s +N+π

Failure of the OPE and π+ρ models

OPE: A_yy – dashed;
A_xx – full
Data: A_yy –blue (Δ);
A_xx - red (□)

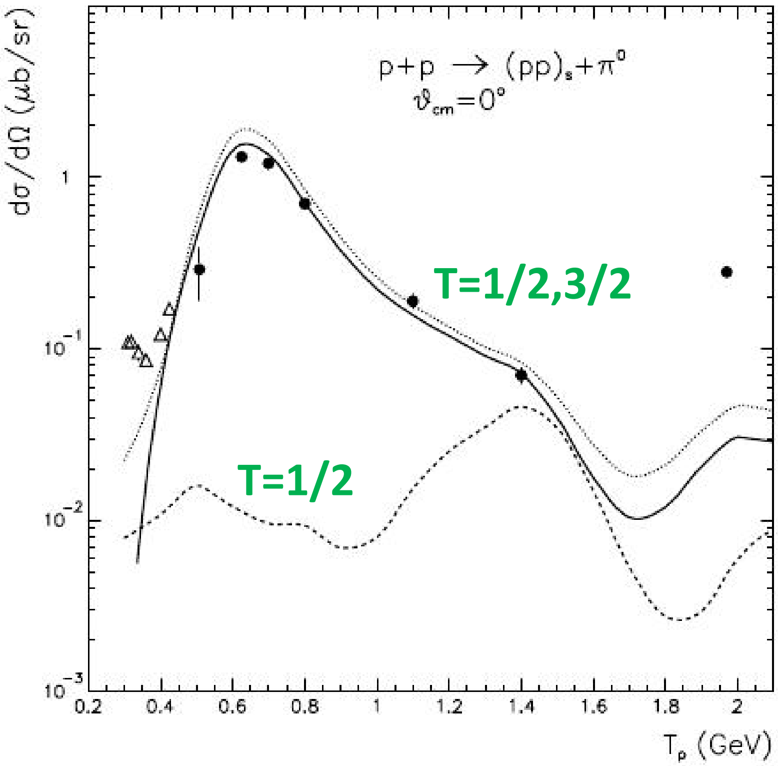
T_20=(A_xx+A_yy)/√2

A new T_20 problem, at low q



4. Formation of the 1S0 diproton in pp→{pp}_s π and pp→{pp}_s γ

The OPE results with and whithout $\Delta(1232)$



OPE model
Yu.N.U. , 19 th Baldin ISHEP (2008)

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

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

SUMMARY

- **Reactions with formation of the $^1S_0$-diproton give more insight into dynamics of ordinary reactions with the deuteron**

  * p+d →{pp}_s(180^0)+n :
   (i) dominance of the 3NF (N-Δ-N) at 0.7-1.0 GeV,
   (ii) soft NN-potential is more preferable than hard RSC, Paris

  * pp →{pp}_s π^0, pp →{pp}_sγ:
   The OPE model is surprisingly successful.
   Δ- isobar dominates in spite of its strong suppression by spin-parity and statistics
   Is it an indication to softness of the NN -interaction potential at short distances?

- **The dp->{pp}_s Δ data on d σ/dt , A_xx and A_yy at 1-2 GeV and our Δ-analysis clearly shows that π+ρ exchange in NN → NΔ is NOT sufficient to resolve the old T20 problem. Additional spin structure is required.**

THANK YOU FOR YOUR ATTENTION!

1. $\mathbf{pp \to d\pi^+}$ & $\mathbf{pp \to \{pp\}_s \pi^0}$

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

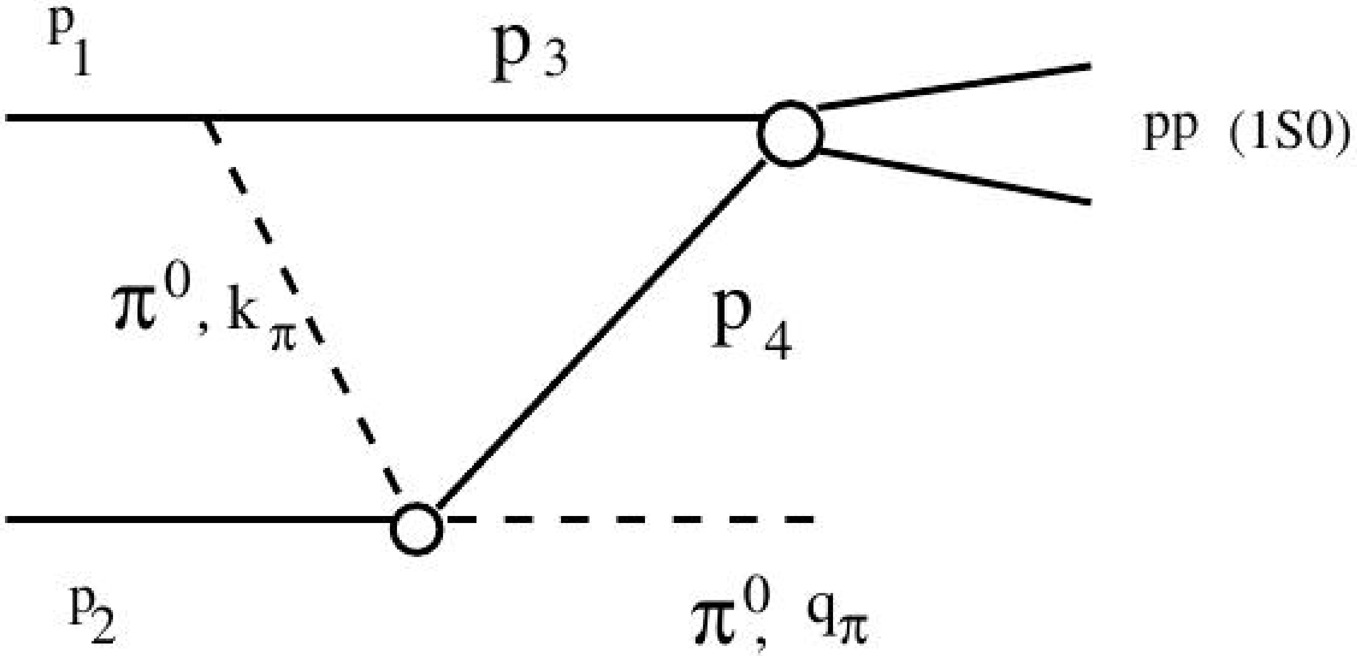
deuteron: $\mathbf{J^\pi = 1^+, T = 0,\ S = 1, L = 0, 2}$

- $(-\mathbf{1})^{\mathbf{L+S+T}} = -\mathbf{1}$

- **Spin-parity conservation:**

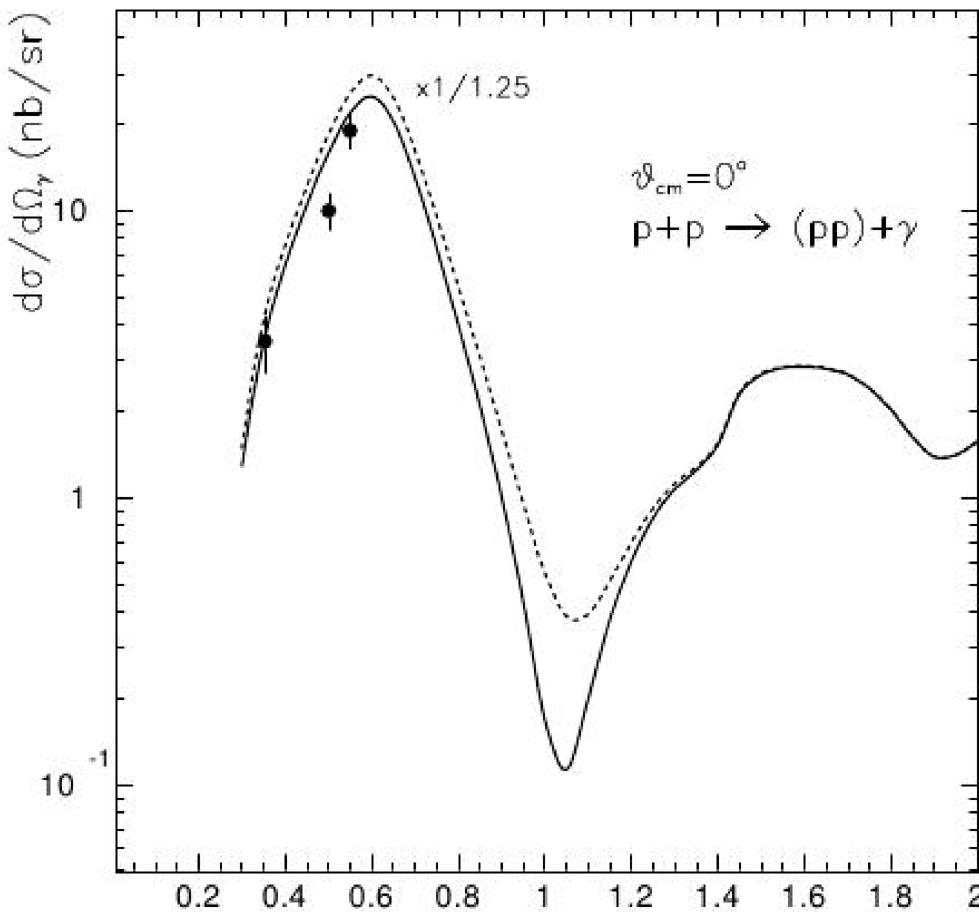
  $\star$ $\mathbf{pp \to \{pp\}_s \pi^0}$ $\mathbf{L - odd(L = 1, 3, \dots)T = 1,\ S = 1}$
  $\Longrightarrow$ $\mathbf{\Delta N}$ **in S-wave (or** N^*N**)** $\pi = +1$ - *vorbidden*

  $\star$ $\mathbf{pp \to d\pi^+}$ **L-odd and even,** $T = 1,\ S = 1$ **and** $S = 0$
  $\Longrightarrow$ $\mathbf{\Delta N}$ **in S-wave (** N^*N**)** $\pi = +1$ -*not vorbidden*
  $\Delta(1232)$ **dominates in the** $pp \to d\pi^+$ **at ≈600 MeV**
  $\mathbf{pp \to pn\pi^+}$ **LAMPF data 800 MeV**



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

The OPE is similar to that for $pd \to \{pp\}_s n$
/Yu.N.U., J. Haidenbauer, C. Wilkin, PRC **75** (2007) 014008/



OPE- model
Yu. N.U. , 19th Baldin ISHEP (2008)

PRL **101,** 102501 (2008) PHYSICAL REVIEW LETTERS week ending 5 SEPTEMBER 2008

Observation of Inverse Diproton Photodisintegration at Intermediate Energies

V. Komarov,[1] T. Azaryan,[1] D. Chiladze,[2,3] S. Dymov,[1,4,*] A. Dzyuba,[6] M. Hartmann,[2] A. Kacharava,[2] I. Keshelashvili,[2,3] A. Khoukaz,[5] A. Kulikov,[1] V. Kurbatov,[1] G. Macharashvili,[1,3] S. Merzliakov,[1,2] S. Mikirtychiants,[2,6] M. Papenbrock,[5] M. Nekipelov,[2,6] F. Rathmann,[2] V. Serdyuk,[1,2] H. Ströher,[2] D. Tsirkov,[1] Yu. Uzikov,[1] and C. Wilkin[7]