Deuteron breakup $p+d \to (pp)(^1S_0)+n$ and short-range NN properties

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(For ANKE-COSY Collaboration)

- **Motivation** (el.-mag. structure of the deuteron)
- **pd→ dp:**
  Δ- excitation and T_{20} problem
- $\vec{p}+\vec{d} \to$ **pp($^1S_0$)+n :**
  - **Why?**
  - **Interpretation of COSY data on $\frac{d\sigma}{d\Omega}$:**
    P-wave or NN-component?
  - **Spin observables**
- **Conclusion and outlook**

Motivation

$$\mathbf{r}_{NN} \leq 0.5\,\mathrm{fm}$$

$$\mathbf{q}_{NN} \geq \hbar/\mathbf{r}_{NN} \sim 0.4\ \mathrm{GeV/c}$$

$$|d> = |pn> + |\Delta\Delta> + |NN^*> + ... + |B_8 B_{\bar{8}}> +$$

$$... + |NN\bar{N}N> + ...$$

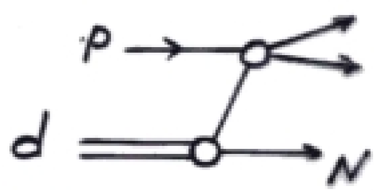
Transition region: hadrons $\Longrightarrow$ q,g

How far can we go with nucleon-meson -picture for the lightest nuclei in EM and hadron interactions with increasing Q^2?

ed→ epn, ed→ ed, γd → pn

pd→dX, pd→ pnp, pd→ dp

IA:



$$\sim \Psi_d(\mathbf{q})$$

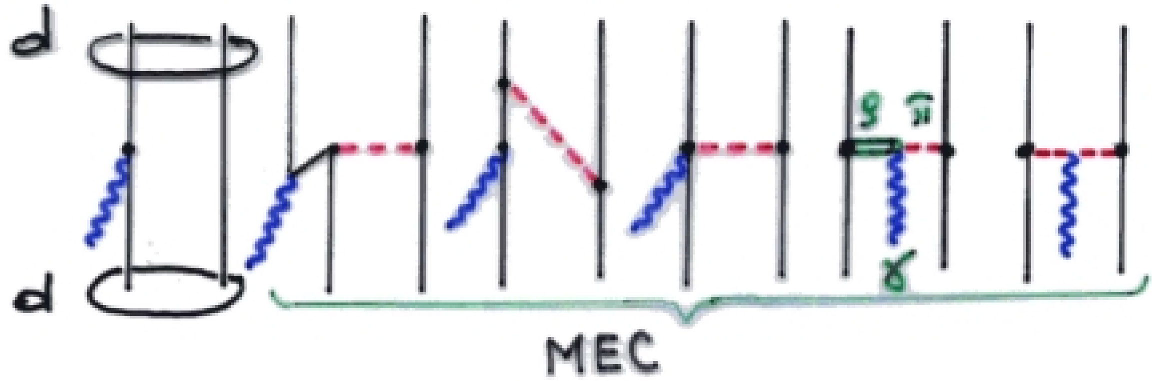
$\mathbf{q}_{NN} \leq 0.3\mathrm{GeV/c}$

M. Garcon, J.W. Van Orden, Adv.Nucl.Phys. 26(2001)293

R. Gilman, F. Gross, J.Phys.G: Part.Nucl. 28(2002)R37

Electromagnetic structure of the deuteron

ed→ ed



" Existing data on the $A(Q), B(Q)$ and $T_{20}(Q)$ at $Q \leq 1.2$GeV/c essentially probe momentum component of the d.w.f. $\varphi_d(q)$ to $q = 4m_\pi \approx 0.55$ GeV/c."
R.Sciavilla, V.R. Pandharipande. Phys. Rev. C 65 (2001) 064009

"..Consistent inclusion of all important relativistic contributions within a pure nucleonic one-boson-exchange model leads to satisfactory description of structure functions of elastic ed- scattering at $Q \leq 1$ GeV/c for the Bonn OBEPQ-A model.." A. Arenhövel et al. Phys.Rev. C 61(2000) 034002

R. Gilman, F. Gross, J. Phys. G: P.N. 28 (2002) R37

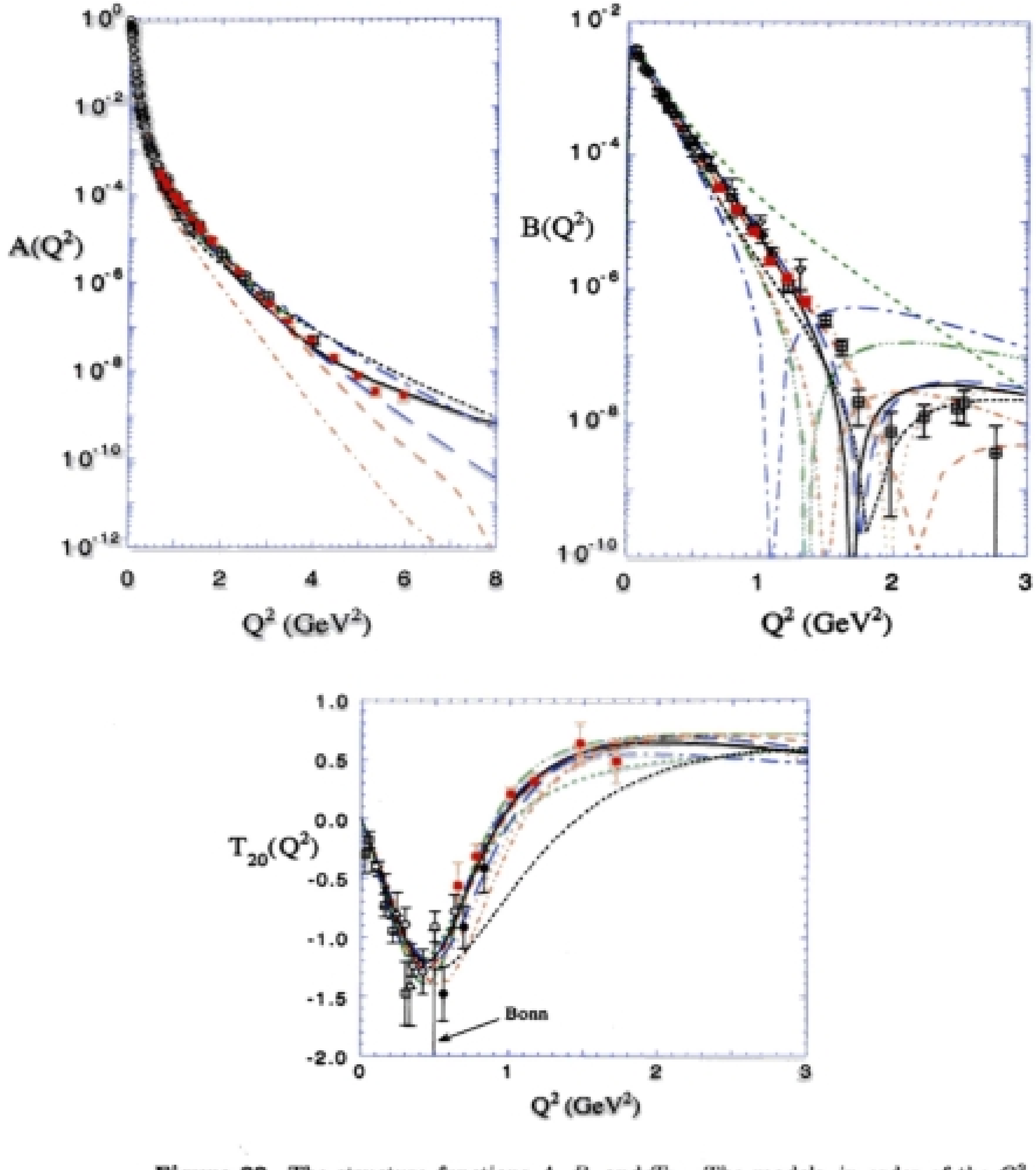


Figure 22. The structure functions A, B, and T_{20}. The models, in order of the Q^2 of their mimima in B, are: CK (long dot-dashed line), PWM (dashed double-dotted line), AKP (short dot-dashed line), VOG full calculation (as shown in Fig. 21 – solid line), VOG in RIA (long dashed line), LPS (dotted line), DB (widely spaced dotted line), FSR (medium dashed line), and ARW (short dashed line). See Tables 2, 3, and 4 for references to the data.

WHY pd → (pp)n AND NOT pd → dp ? dp→px ?

- 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, $^3S_1 - ^3D_1$.
- Δ- and N^*- excitations are suppressed by 1/3 in amplitude due to isospin invariance.
- t-matrix of pp($^1S_0$) scattering, $t(q, k)$, has a node at off-shell momentum $q \approx 0.4$ GeV/c

O. Imambekov, Yu.N. Uzikov. Sov. J. Nucl.Phys. **52** (1990) 862.
Yu.N. Uzikov, JETP Lett. **75** (2002) 5;
J. Phys. G **28** (2002) B13.

ANKE COSY

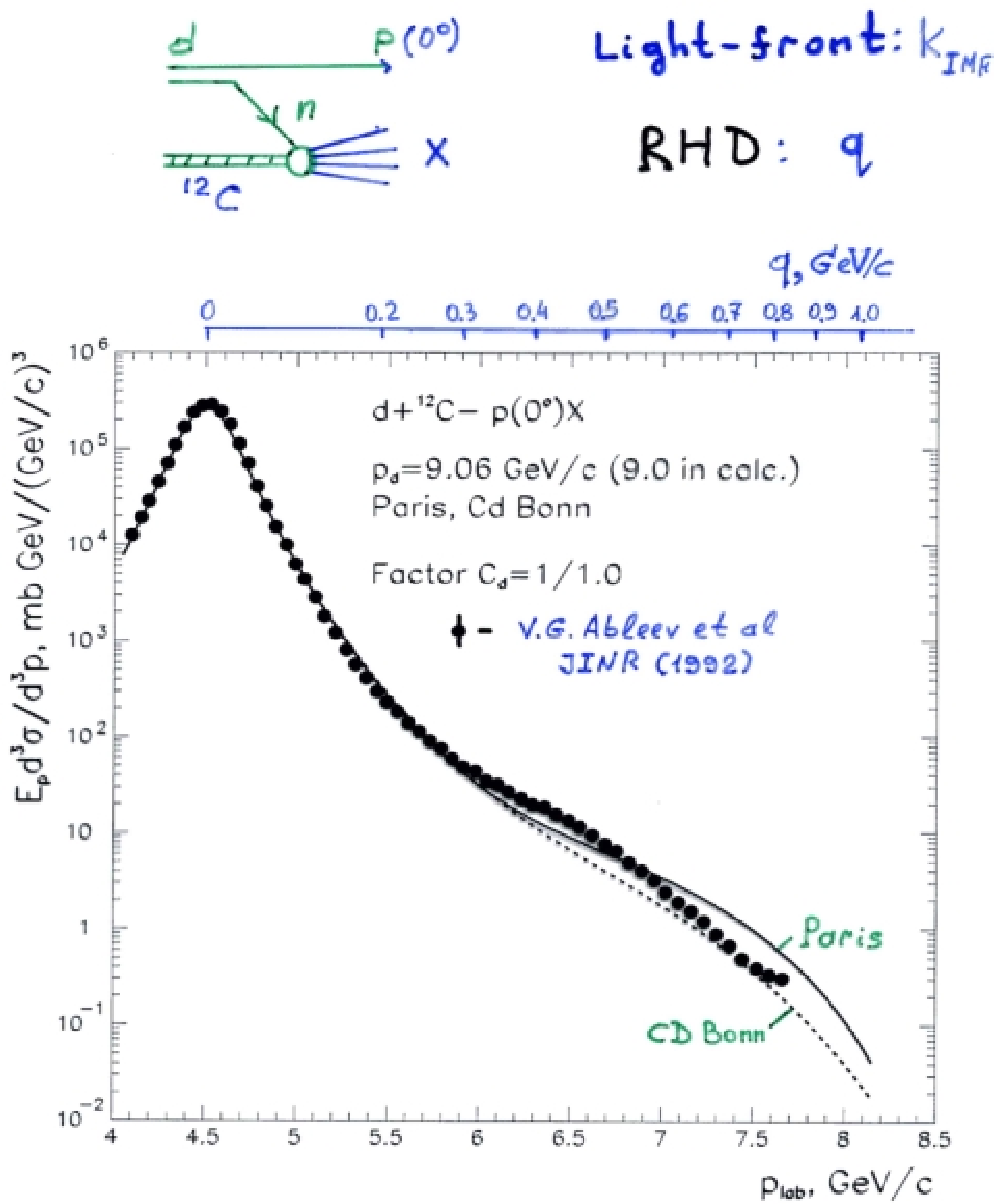


Figure 4: The invariant cross section of the reaction $d +^{12} C \to p(0^\circ)$ X), at $p_d = 9.06$ GeV/c (V. Ableev, 1991) versus lab. momentum of the final proton in comparison with the IA for the CD Bonn (dashed) and Paris (full) d.w.f. Calculation performed within the LFD-formalism are shown by thin lines (dotted -Paris, dashed-dotted- CD Bonn).

$d + {}^{12}C \to p(0^\circ) X$

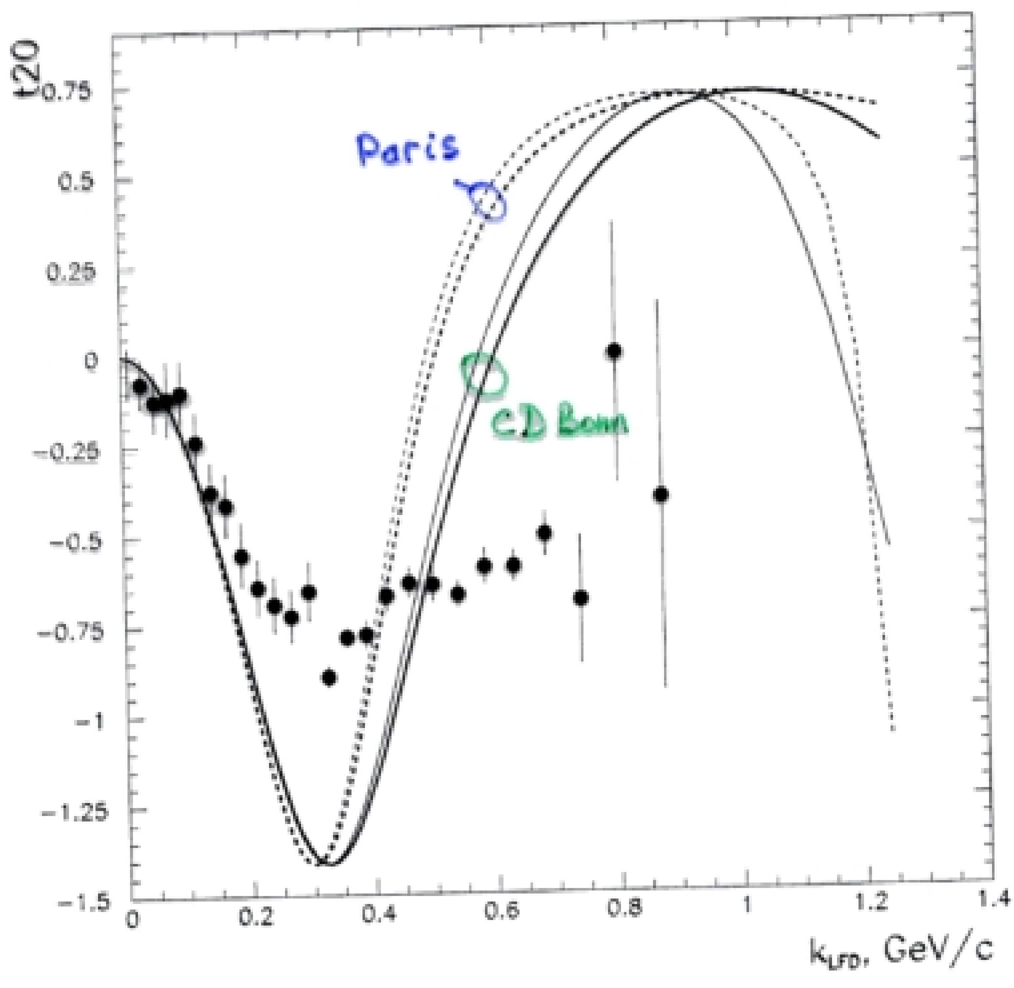
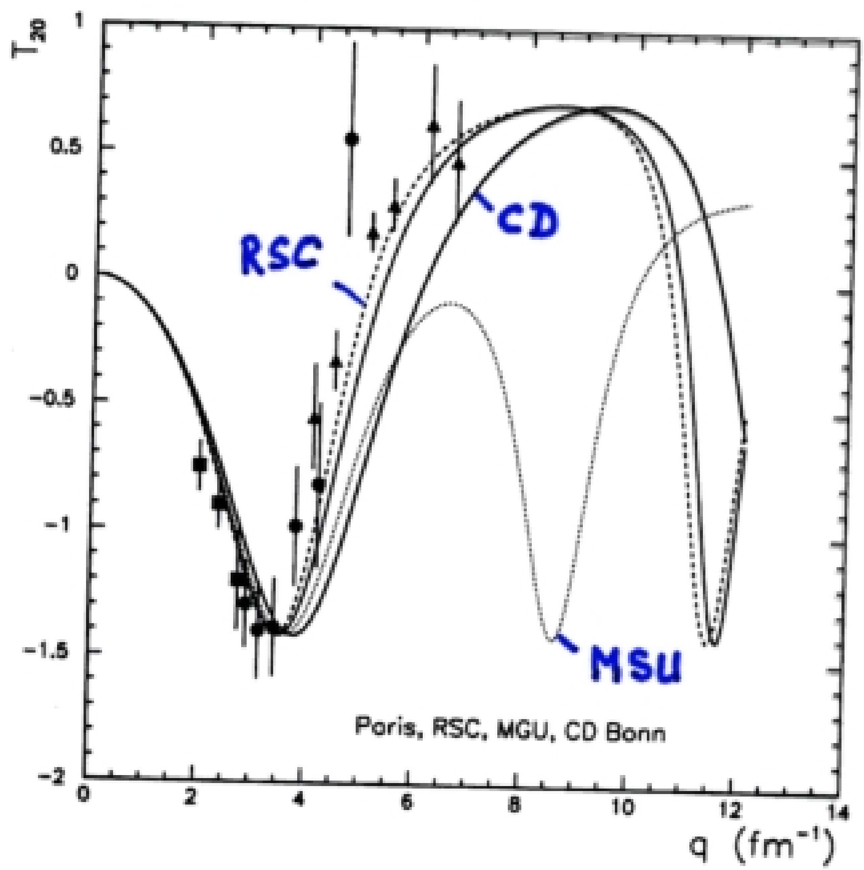


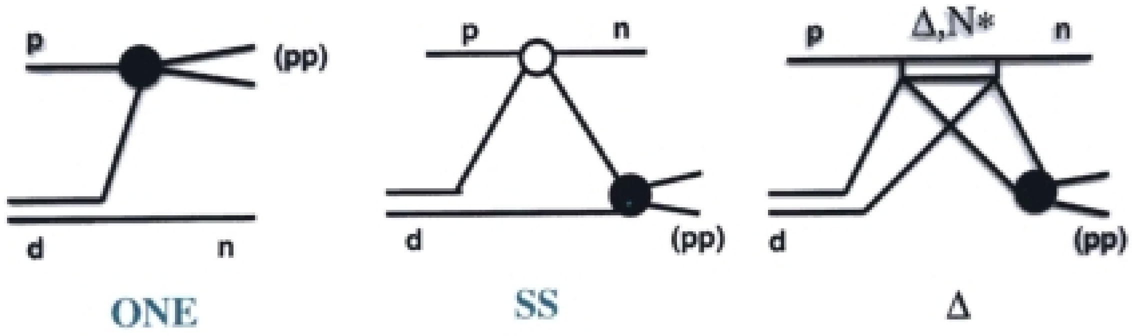
Figure 5: T_{20} in $d +^{12} C \to p(0^\circ)$ X), at $p_d = 9.06$ GeV/c (V. Ableev, 1991) versus the LFD-momentum IA for the CD Bonn (full) and Paris (dashed) Calculation performed within the LFD-formalism are shown by thin lines.

ed→ed

NRIA



ONE+Δ + SS Model



In the cms for $pd \to (pp)n$

$$\frac{d^3\sigma}{dk^2 d\Omega_n} = \frac{1}{(4\pi)^5}\frac{p_n}{p_i}\frac{k}{s\sqrt{m^2+k^2}}\frac{1}{2}\int\int d\Omega_{\mathbf{k}}\overline{|M_{fi}|^2} \quad (1)$$

$\mathbf{k}$ – the relative momentum in pp-system

$s = (p_p + p_d)^2$,
E_{pp} – excitation energy
$k^2 = m\,E_{pp}$, m is the nucleon mass.

Integration in Eq.(1) over
$\mathbf{E_{pp} = 0 - 3}$ **MeV** and
$\theta^*_{\mathrm{n}} = 172^\circ - 180^\circ$.

COSY

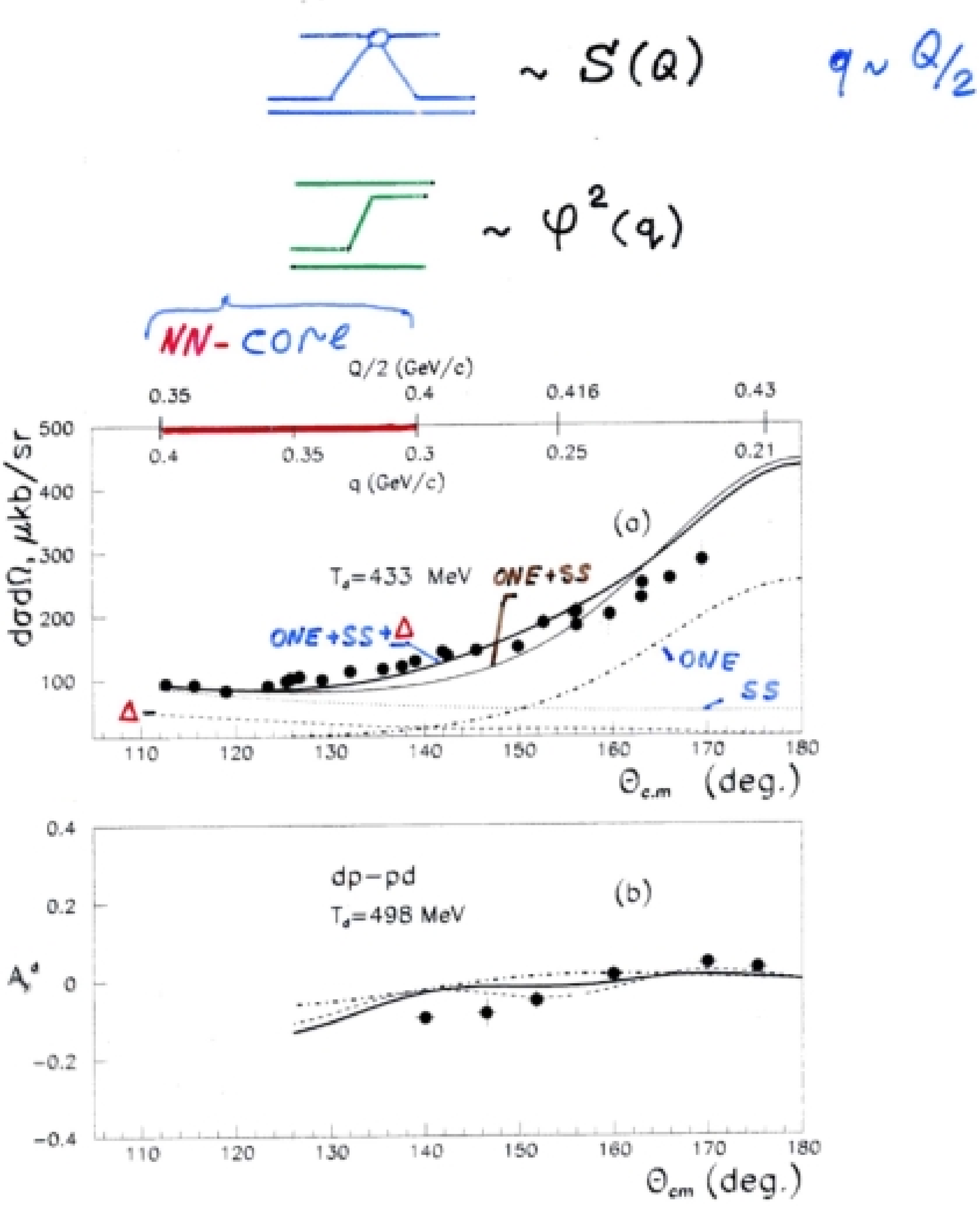
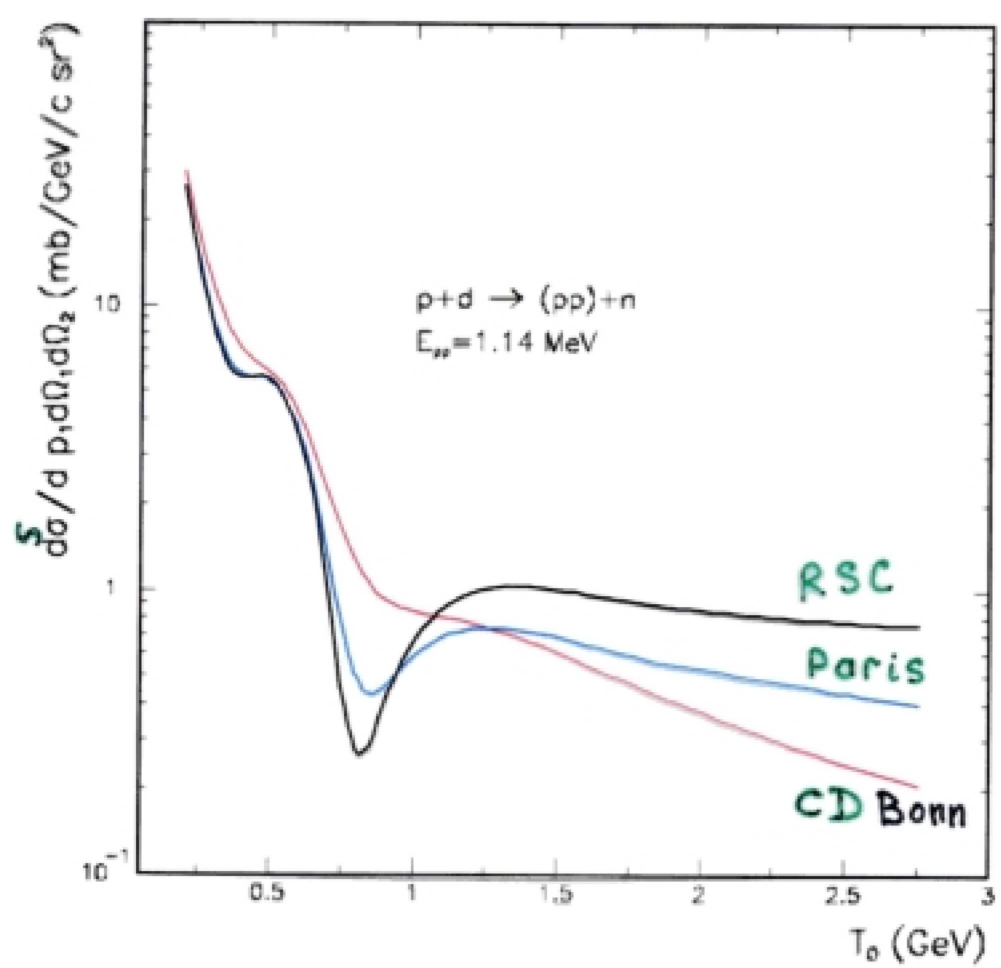
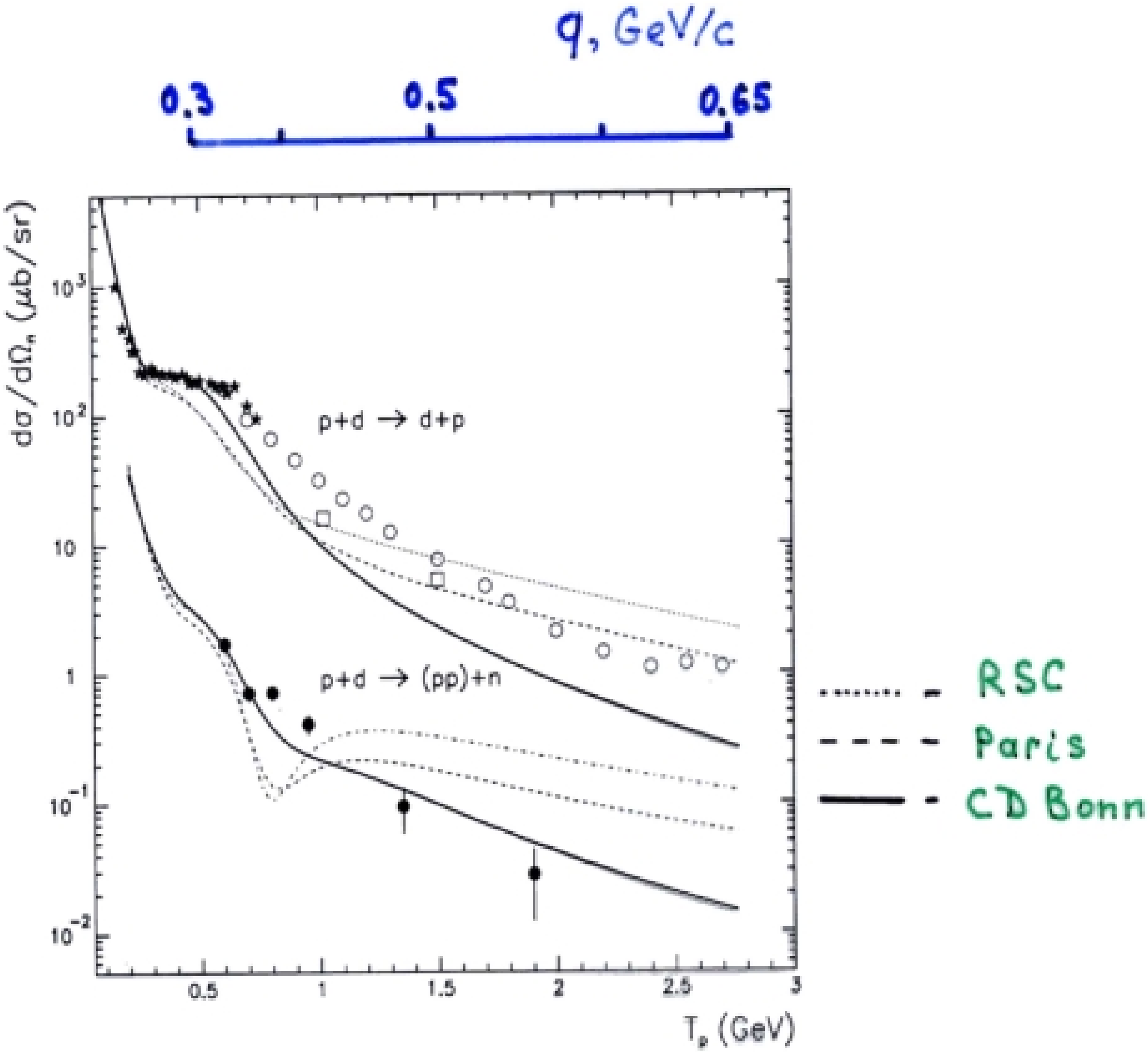


Figure 2: dp-pd



$\int d\sigma/d p_1 d\Omega_1 d\Omega_2$ (mb/GeV/c sr^2)
p+d → (pp)+n
E_{pp}=1.14 MeV
RSC
Paris
CD Bonn
10
1
10^{-1}
0.5
1
1.5
2
2.5
3
T_0 (GeV)



J.Haidenbauer, Yu.N. Uzikov. Phys. Lett. B562 (2003) 227

ONE + SS + Δ - model

$$M^{(\Delta)} \sim \int_0^\infty dr\, r^2\, \psi_{pp}^{(-)}(r)\, \frac{1}{r^2}\, \varphi_d(r) \cdots$$

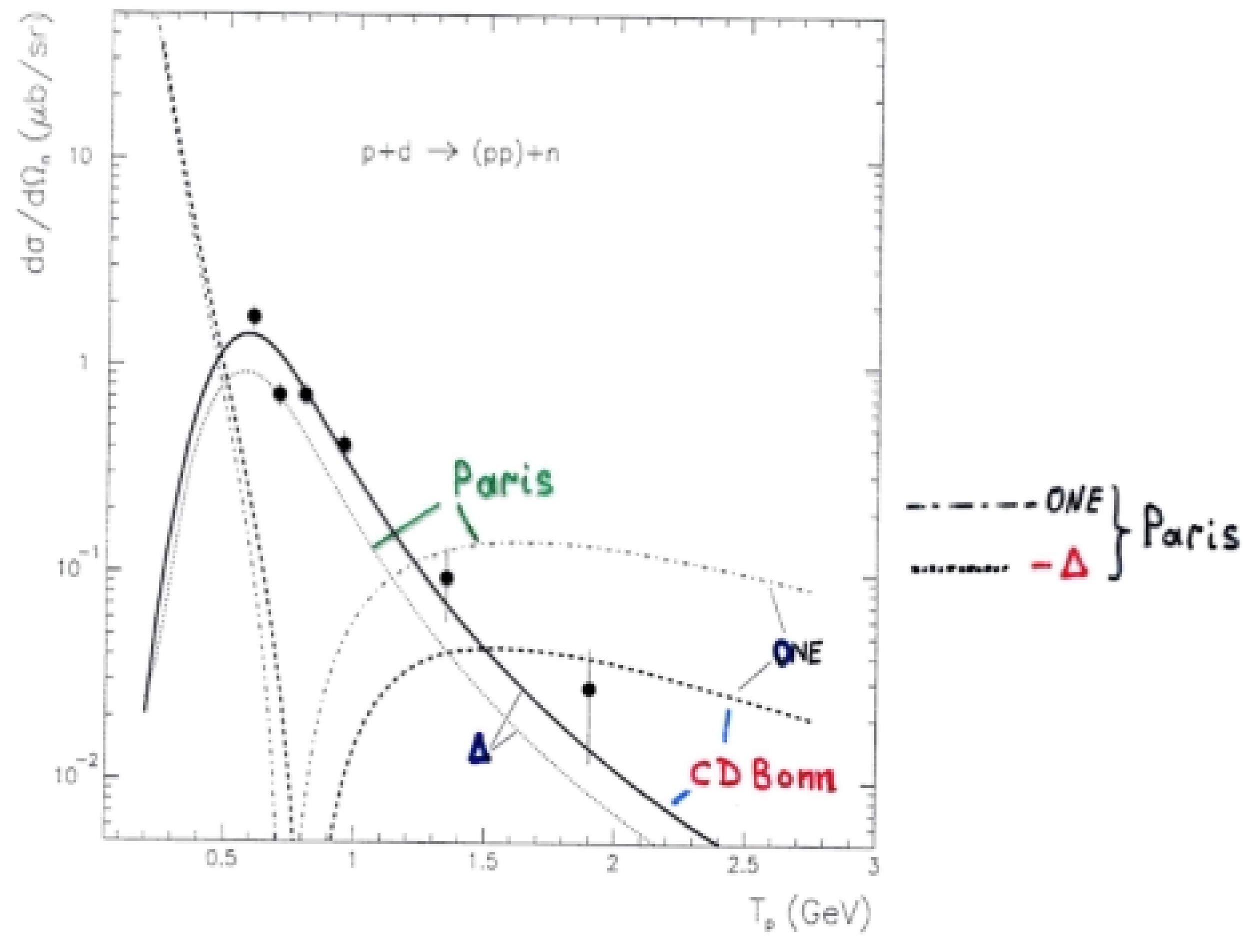


Fig. 3. Contributions of the considered reaction mechanisms to the cms differential cross section of the reaction $p + d \to (pp) + n$ at neutron scattering angle $\theta_n^* = 172 - 180^o$ and relative energies $E_{pp} = 0 - 3$ MeV of the two forward protons. Results are shown for the Paris (ONE – dash-dotted line, Δ – dotted line) and CD Bonn (ONE – dashed line, Δ – solid line) NN potentials. Data are from Ref. [12].

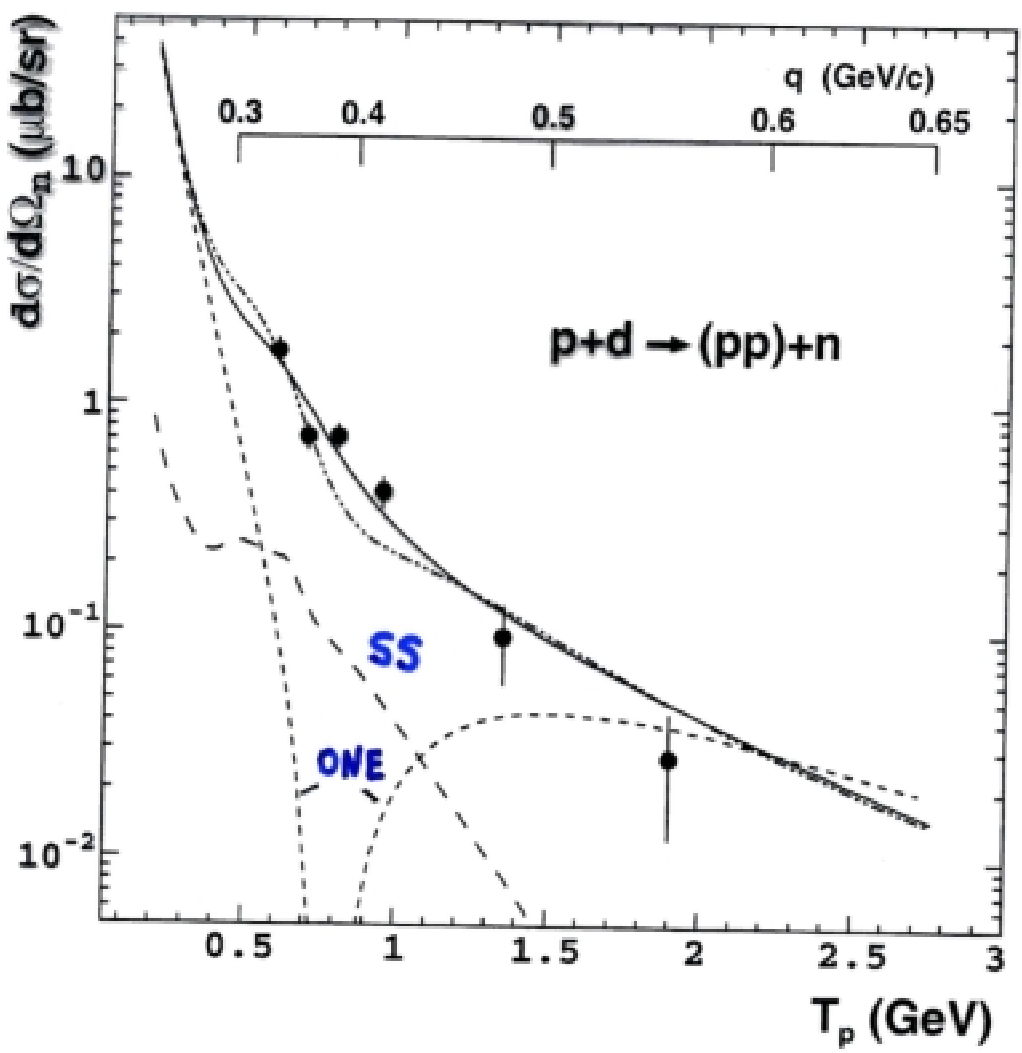
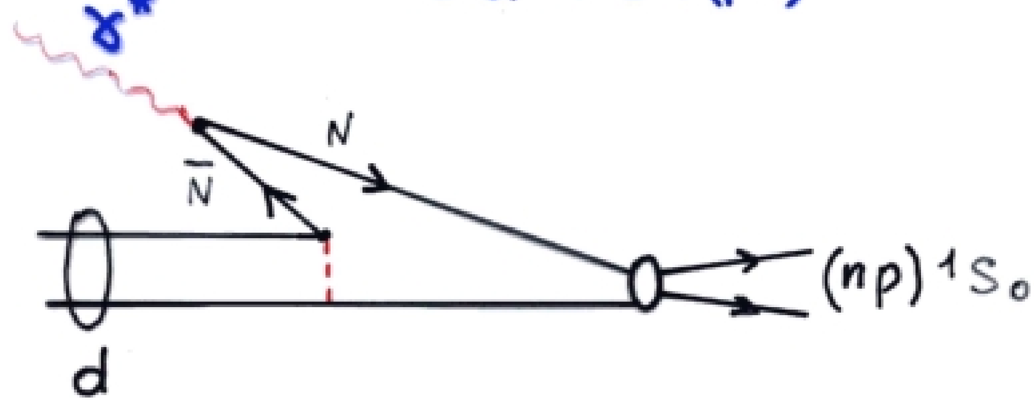
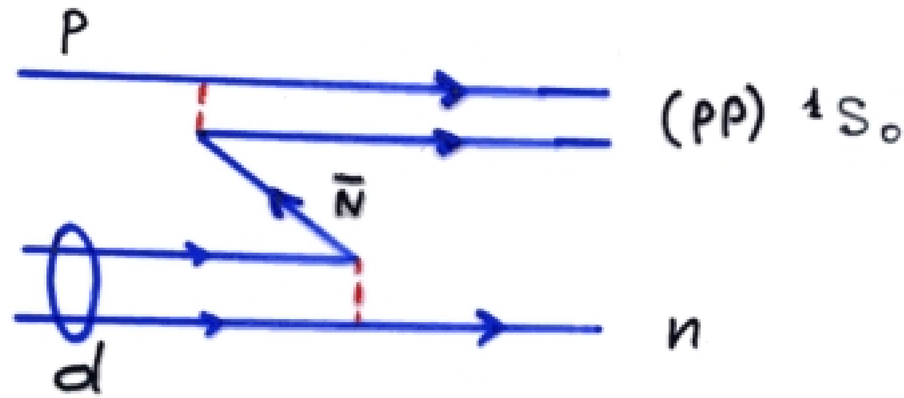


Fig. 4. The same as in Fig. 3, but using the CD Bonn NN potential only. ONE – short-dashed line; SS – long-dashed line; coherent sum of ONE+Δ with Coulomb effects included – solid line; ONE+SS+Δ with Coulomb effects included — dashed-double dotted line. In the latter two cases distortions in the ONE contribution are also included. The upper scale shows the internal momentum of the nucleons in the deuteron for the ONE, cf. Eq. (2).

$e\,d \to e + (pn)$





L.P. Kaptari et al. nucl-th/0212062

BS-eq. P-wave

Eur. Phys. J. A19 (2004) 301

CONCLUSION

- **pd → (pp)($1S_0$) n offers a new testing ground for short-range NN interaction and pd dynamics.**
- **Existing data ($\frac{d\sigma}{d\Omega}$ and the sign of A_y^p) are consistent with the ONE(DWBA)+Δ+SS model with the CD Bonn NN-interaction**
  ⟹ *Are the deuteron and diproton pp($^1S_0$) soft at short NN- distances as compared with the RSC and Paris picture?*] ?

Outlook:

- **Experiment:**
  T_{20}, $C_{y,y}$, $C_{z,z}$, A_y^d ? $A_y^p = A_y^d$? ONE
  Does T_{20} change its sign as in ONE?
  Universality of T_p- dependence in $d\sigma$ of pd→ dp, pd→ (pn)p at E_{pn}=10-200 MeV?
- **Theory:**
  ΔΔ-, NN^*−, components ···?,
  ISI − FSI