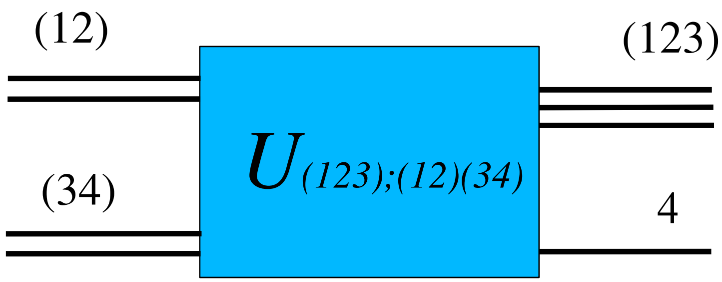
N.B. Ladygina

DIFFERENTIAL CROSS SECTIONS AND ANALYZING POWERS IN THE $dd \to {}^3He\ n$ REACTION AT INTERMEDIATE ENERGIES

- $dd \longrightarrow {}^3He\ n(tp)$ is considered at the deuteron kinetic energy between 200 MeV and 520 MeV.
- The theoretical model is suggested to describe differential cross sections and polarization observables.
- The calculation results for the differential cross sections are presented at the energies of 300-520 MeV.
- The vector and tensor analyzing powers are given at 200 MeV .

$dd \to {}^3He\ n$



$$U_{dd\to{}^3He\ n} = \delta(2E_d - E_h - E_n)\mathcal{J}$$

The matrix element of the transition operator U is a combination of two terms:

$$< n^3He\ |U|dd >= \frac{1}{\sqrt{6}}[< 4(123)_s|U|(12)_s(34)_s > - < 1(234)_s|U|(12)_s(34)_s >]$$

The initial state includes two antisymmetrized two-nucleon states

$$(12)_s = \frac{1}{\sqrt{2}}[(12) - (21)]$$

and the final state contains an antisymmetrized three-nucleon state

$$(123)_s = \frac{1}{\sqrt{6}}[(123) - (213) + (231) - (321) + (312) - (132)]$$

• Following P.Grassberger, W.Sandhas, Nucl.Phys.2, 181 (1967) we define transition operator as

$$U_{\beta\alpha}(z) = (1 - \delta_{\beta\alpha})(z - H_\alpha) + \sum_{ik \not\subseteq \beta} T_{ik}(z) G_0(z) U_{ik,\alpha}(z) + \sum_{ik \not\subseteq \beta} V_\alpha \delta_{\alpha,ik}$$

α, β are two-cluster partitions of the four-particle state.

• Reaction $dd \to {}^3He\ n$ corresponds to the case of
$\alpha = (ij)(kl) = (12)(34)$,
$\beta = (ijk) = (123)$ [or (234)]

• Interaction $V_{\alpha(\beta)}$ is defined by two-nucleon potential:

$$V_\alpha \equiv V_{(ij)(kl)} = V_{ij} + V_{kl}$$
$$V_\beta \equiv V_{(ijk)} = V_{ij} + V_{jk} + V_{ik}$$

$$U_{\beta\alpha}(z) = (1-\delta_{\beta\alpha})(z-H_\alpha) + \sum_{ik\not\subseteq\beta} T_{ik}(z)G_0(z)U_{ik,\alpha}(z) + \sum_{ik\not\subseteq\beta} V_\alpha \delta_{\alpha,ik}$$

The channel Hamiltonian H_α is defined as a sum of the free particles Hamiltonian H_0 and the interaction potential V_α

$$H_\alpha = H_0 + V_\alpha$$

$T_{ij}(z)$ is a two-body transition operator, which obeys the Lippmann-Schwinger equation

$$T_{ij}(z) = V_{ij} + V_{ij}G_0(z)T_{ij}.$$

As usually, $G_0(z)$ is a resolvent of the four-nucleon kinetic energy operator

$$G_0(z) = (z - H_0)^{-1}$$

Iterating AGS-equations up to I-order terms over T one obtains

$$U_{(123),(12)(34)} \approx (z - H_{12}) + T_{14}(z) + T_{24}(z)$$

$$U_{(234),(12)(34)} \approx (z - H_{34}) + T_{13}(z) + T_{14}(z)$$

Since the initial and final states are antisymmetrized, the contributions of the T_{24} and T_{14} matrix elements are equal to each other. It also concerns T_{13} and T_{14} matrix elements in the exchange contribution.

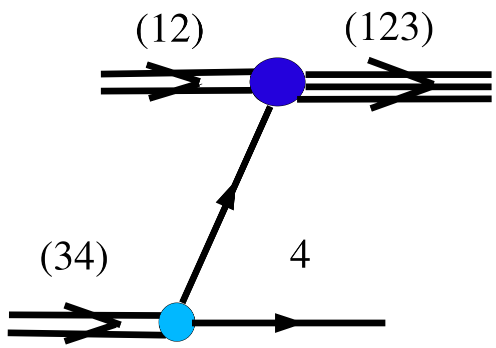
$$< 4(123)_s|T_{24}|(12)_s(34)_s > \; = \; < 4(123)_s|T_{14}|(12)_s(34)_s >$$
$$< 1(234)_s|T_{13}|(12)_s(34)_s > \; = \; < 1(234)_s|T_{14}|(12)_s(34)_s >$$

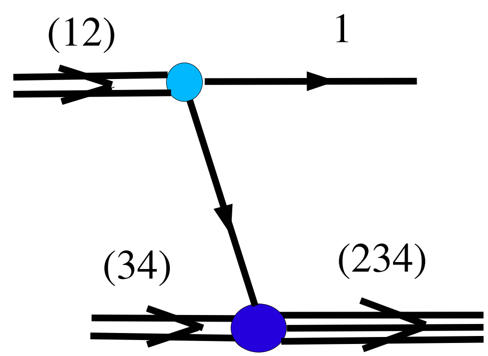
As consequence, we derive only three contributions into the reaction amplitude

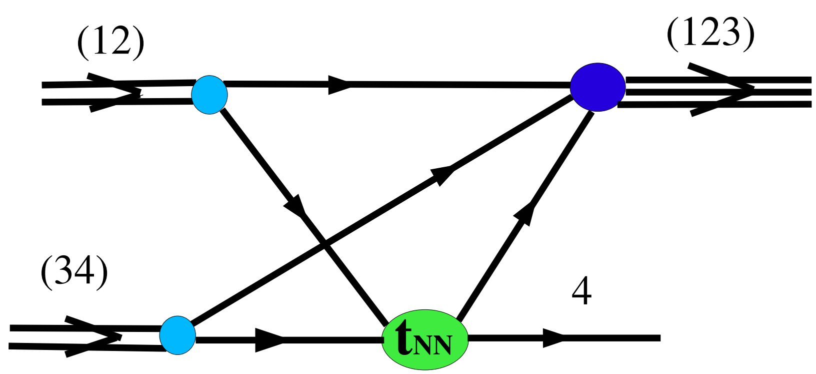
$$< n^3He|U|dd > \; = \; \frac{1}{\sqrt{6}}[< 1(234)_s|z - H_{12}|(12)_s(34)_s > - < 4(123)_s|z - H_{34}|(12)_s(34)_s > +2 < 4(123)_s|T_{14}^{sym}|(12)_s(34)_s >]$$

The nucleon-nucleon T-matrix is antysymmetrized: $T_{14}^{sym} = (1 - P_{14})T_{14}$

$dd \to {}^{3}He\ n$







Deuteron wave function

M. Lacombe et al. (1981) Phys.Lett.B101, 139
R.Machleidt (2001) Phys. Rev.C 63, 024001

The deuteron wave function in the standard form is used:

$$< \vec{P}_d/2 + \vec{p}_0, m_p; \vec{P}_d/2 - \vec{p}_0, m_n|\Phi(\vec{P}_d M_d) >=$$
$$\sum_{L=0,2} u_L(p_0) < \frac{1}{2}m_p \frac{1}{2}m_n|1M_s >< LM_L 1M_s|1M_d > Y_L^{M_L}(\hat{p}_0) \ ,$$

where $\hat{p}_0$ is the unit vector in $\vec{p}_0$ direction, and m_p, m_n are the proton and neutron spin projections, respectively.

The radial part of the DWF is presented by $u_0(p_0)$ and $u_2(p_0)$, which describe S and D components of the deuteron wave function:

$$u_0(p) = \sqrt{\frac{2}{\pi}} \sum_i \frac{C_i}{\alpha_i^2 + p^2} \ \ , \ \ u_2(p) = \sqrt{\frac{2}{\pi}} \sum_i \frac{D_i}{\beta_i^2 + p^2}$$

${}^3He$ wave function

V.Baru, J.Haidenbauer, C.Hanhart, and J.A.Niskanen, Eur.Phys.J. A16, 437 (2003)

The parametrized wave function of a three-nucleon system is used as a ${}^3He$ wave function. This wave function is fully antisymmetrized

$$|\Psi >= |\psi[(12)3] > +|\psi[(23)1] > +|\psi[(31)2] >$$

and defined in terms of the nucleon pair and spectator momentum:

$$< \vec{p}_0\vec{q}\nu|\Psi > \; = \; < \vec{p}_0\vec{q}\nu|\psi[(12)3] > + < \vec{p}_0\vec{q}\nu|\vec{p}_{23}\vec{q}_1\nu_{23} >< \vec{p}_{23}\vec{q}_1\nu_{23}|\psi[(23)1] > +$$

$$+ \; < \vec{p}_0\vec{q}\nu|\vec{p}_{31}\vec{q}_2\nu_{31} >< \vec{p}_{31}\vec{q}_2\nu_{31}|\psi[(31)2] >$$

The kinematical variables: pair relative momentum $\vec{p}_0$ and spectator momentum $\vec{q}$ are defined as:

$$\vec{p}_0 \; = \; \frac{\vec{p}_1 - \vec{p}_2}{2}, \qquad \vec{q} = \vec{p}_3 - \frac{\vec{P}}{3}, \qquad \vec{P} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 = \vec{P}_h$$

$$\vec{p}_{ij} \; = \; \frac{\vec{p}_i - \vec{p}_j}{2}, \qquad \vec{q}_k = \vec{p}_k - \frac{\vec{P}}{3}$$

The radial part of the three-nucleon wave function is presented as a sum of two terms each of them has a separable form:

$$< p_0 q\nu|\Psi >= v_1^\nu(p_0) w_1^\nu(q) + v_2^\nu(p_0) w_2^\nu(q),$$

where $v_\lambda^\nu(p_0)$, $w_\lambda^\nu(q)$ are defined as:

$$v^\nu(p_0) = \sum_{n=1}^{5} \frac{a_n^\nu}{p_0^2 + (m_n^\nu)^2}, \qquad w^\nu(q) = \sum_{n=1}^{5} \frac{b_n^\nu}{q^2 + (M_n^\nu)^2}$$

The wave function was derived by fitting the full Faddeev wave function obtained with CD Bonn and Paris NN-potentials. Two sets of the coefficients $a_n^\nu, b_n^\nu, m_n^\nu$, and M_n^ν exist.

Quantum numbers of the partial waves included into the definition of the three-body wave function. $\boldsymbol{T, S, \mathcal{L}, J}$ refer to the isospin, spin, orbital momentum and total angular momentum of the NN-subsystem. $\boldsymbol{l}$ is the relative orbital momentum of the spectator and $\boldsymbol{K}$ is the channel spin.

ν	Label	Subsystem	$\mathcal{L}$	S	J^{π}	T	K	l
1	${}^1s_0S$	${}^1s_0$	0	0	0^+	1	1/2	0
2	${}^3s_1S$	${}^3s_1$	0	1	1^+	0	1/2	0
3	${}^3s_1D$	${}^3s_1$	0	1	1^+	0	3/2	2
4	${}^3d_1S$	${}^3d_1$	2	1	1^+	0	1/2	0
5	${}^3d_1D$	${}^3d_1$	2	1	1^+	0	3/2	2

Nucleon-Nucleon t-matrix

W.G.Love, M.A.Franey, Phys.Rev.C24, 1073 (1981)

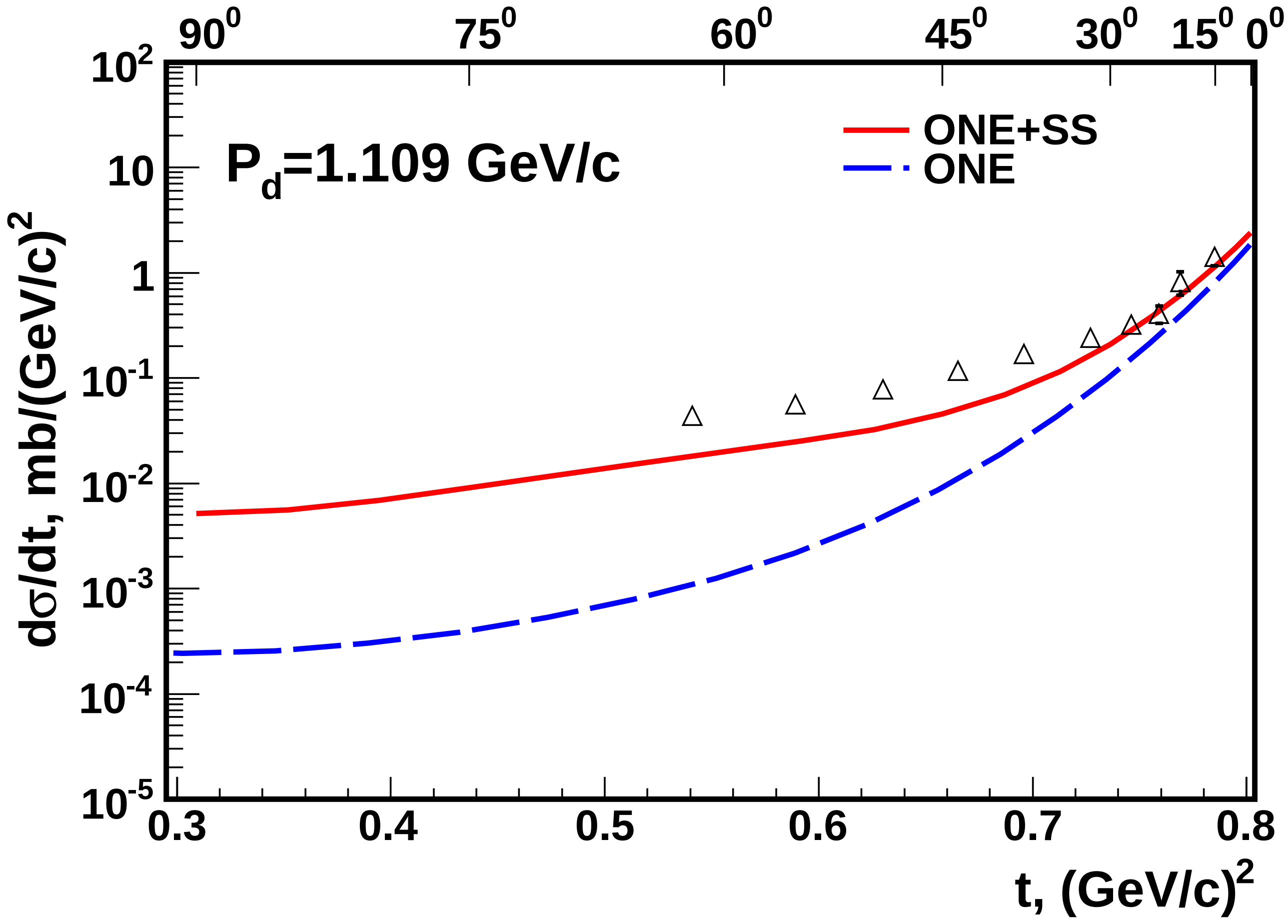
N.B.Ladygina,nucl-th/0805.3021

$$< \kappa' m_1' m_2' | t | \kappa m_1 m_2 > \; = \; < \vec{\kappa}' m_1' m_2' | A + B(\vec{\sigma}_1 \hat{N}^*)(\vec{\sigma}_2 \hat{N}^*) + C(\vec{\sigma}_1 + \vec{\sigma}_2) \cdot \hat{N}^* + D(\vec{\sigma}_1 \hat{q}^*)(\vec{\sigma}_2 \hat{q}^*) + F(\vec{\sigma}_1 \hat{Q}^*)(\vec{\sigma}_2 \hat{Q}^*) | \vec{\kappa} m_1 m_2 >$$

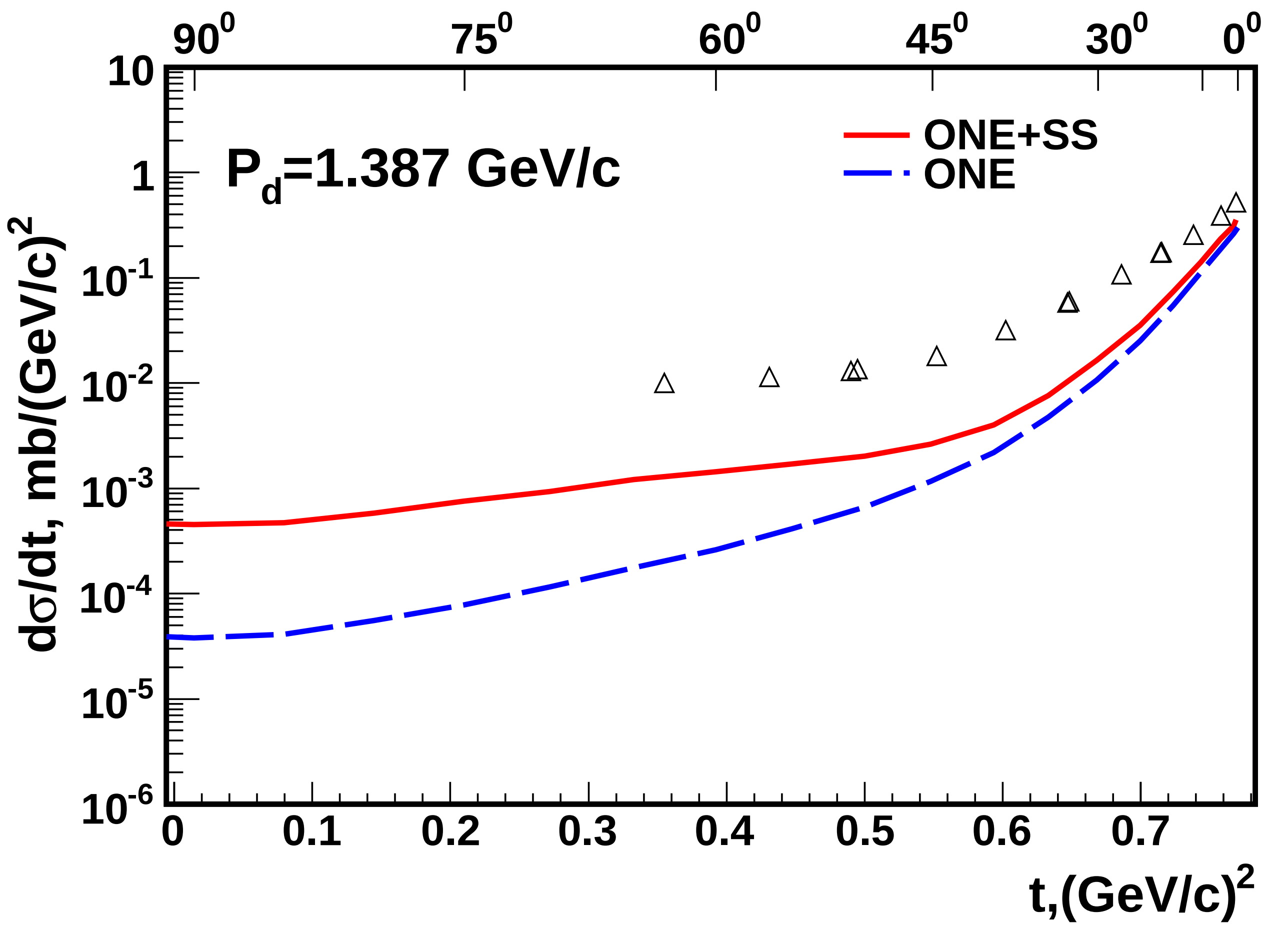
where the orthonormal basis is combinations of the nucleons relative momenta in the initial $\vec{\kappa}$ and final $\vec{\kappa}'$ states

$$\hat{q}^* = \frac{\vec{\kappa} - \vec{\kappa}'}{|\vec{\kappa} - \vec{\kappa}'|} \quad , \quad \hat{Q}^* = \frac{\vec{\kappa} + \vec{\kappa}'}{|\vec{\kappa} + \vec{\kappa}'|} \quad , \quad \hat{N}^* = \frac{\vec{\kappa} \times \vec{\kappa}'}{|\vec{\kappa} \times \vec{\kappa}'|}$$

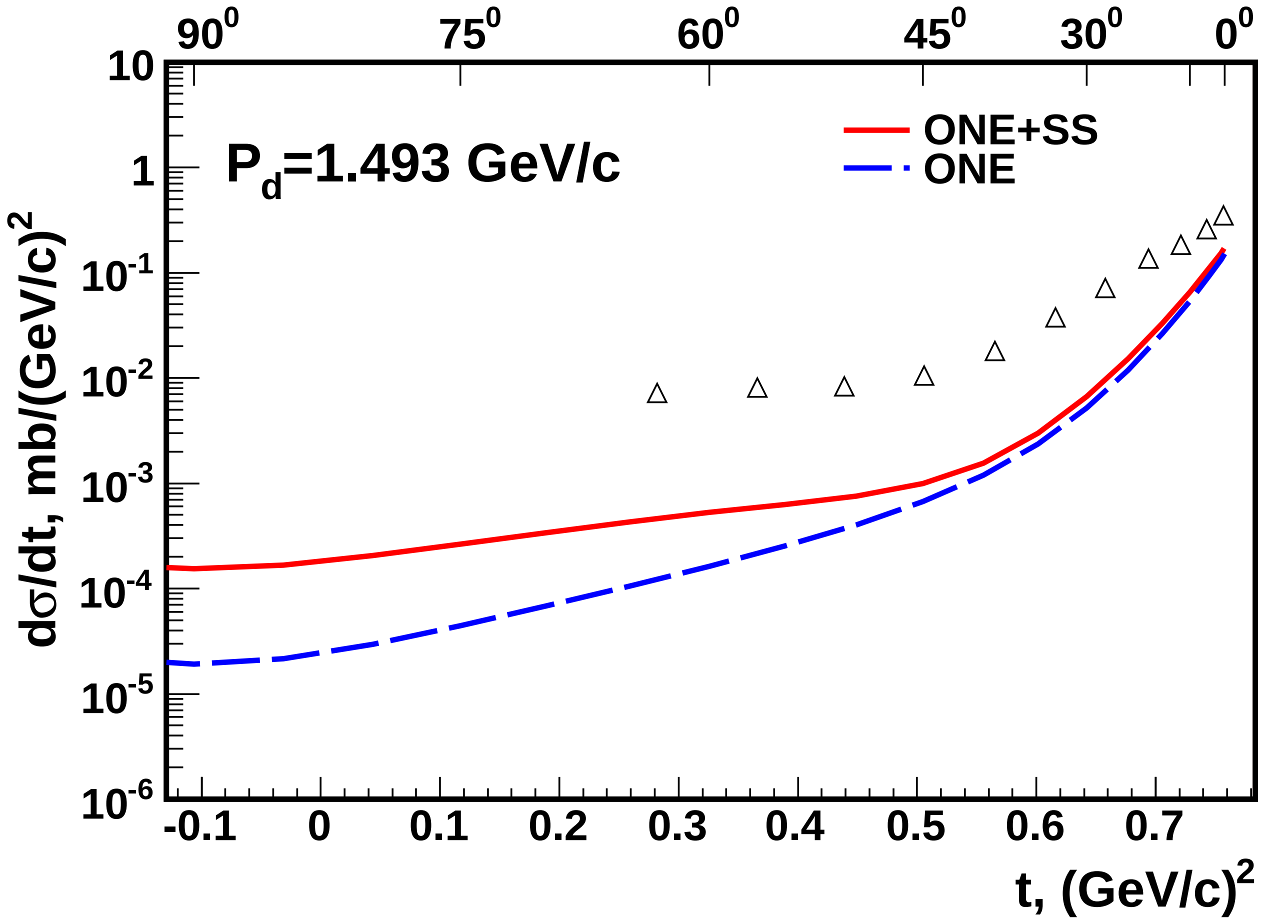
$$< \vec{p}' \vec{p}_3'; m' m_3' | t | \vec{p} \vec{p}_3; m m_3 > \sim < \kappa' m_1' m_2' | W^{\dagger}_{1/2}(\vec{p}') W^{\dagger}_{1/2}(\vec{p}_3') \; t \; W_{1/2}(\vec{p}) W_{1/2}(\vec{p}_3) | \kappa m_1 m_2 >$$



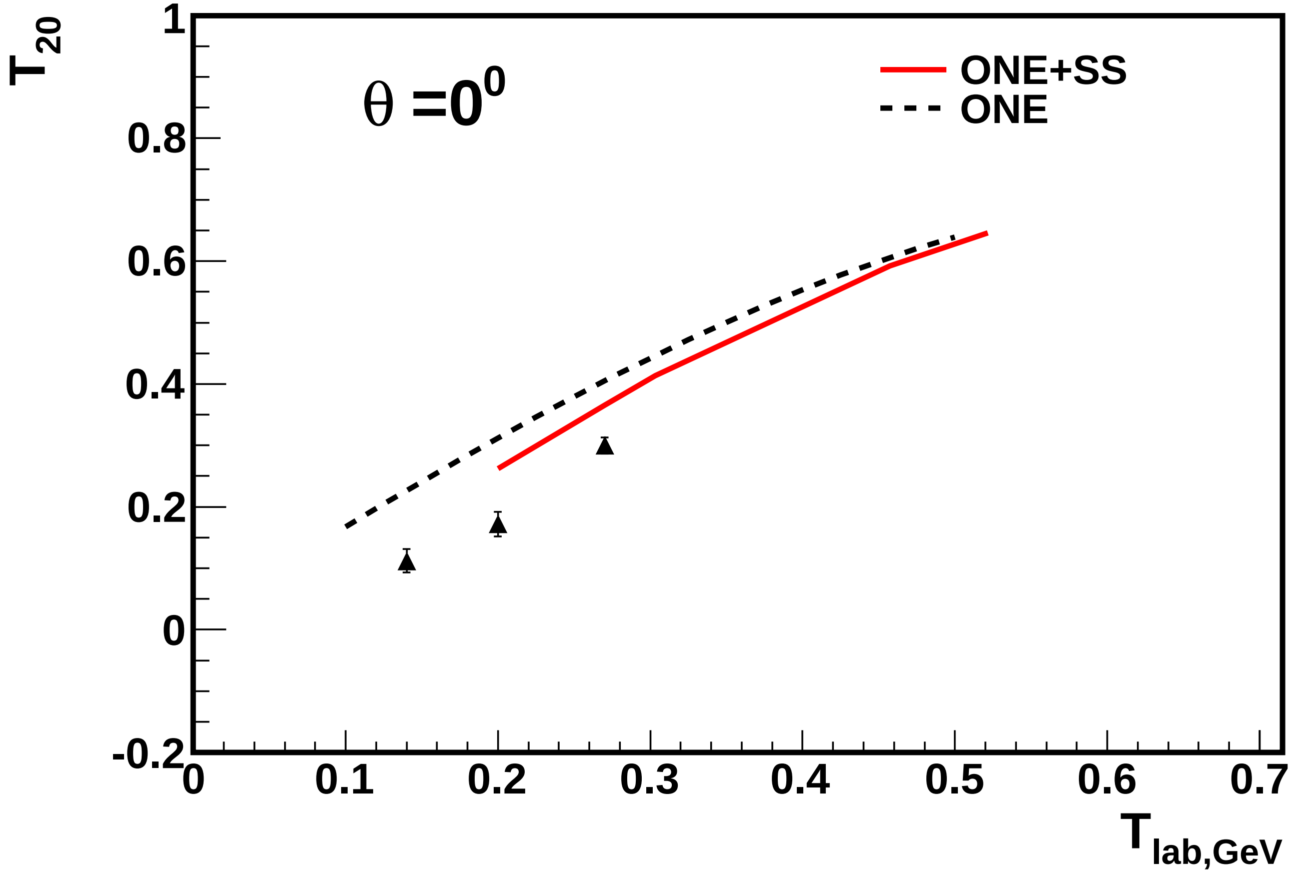
▲ - G.Bizard, et al.,Phys.Rev.C 22, p.1632, 1980



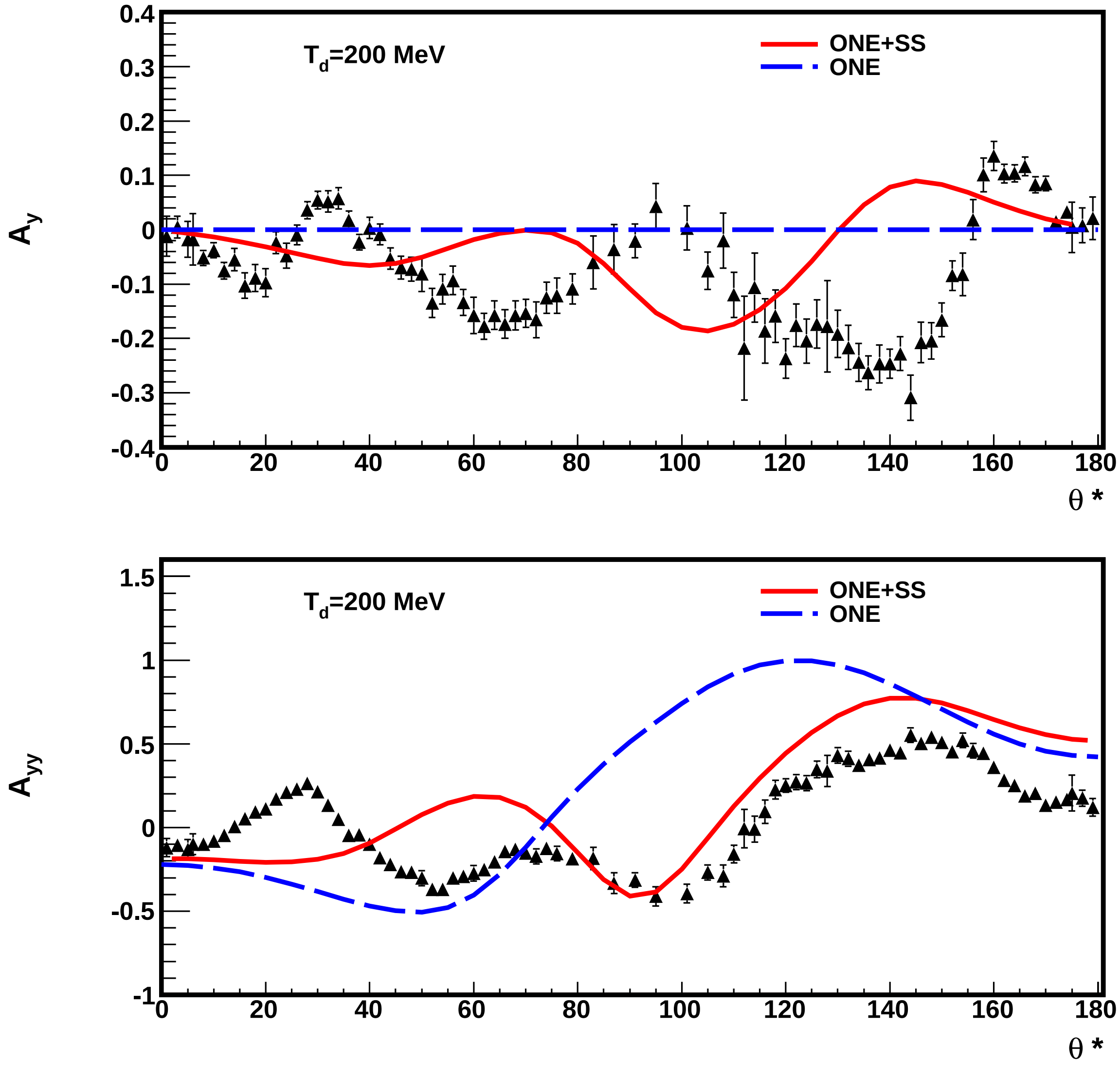
▲ - G.Bizard, et al.,Phys.Rev.C 22, p.1632, 1980



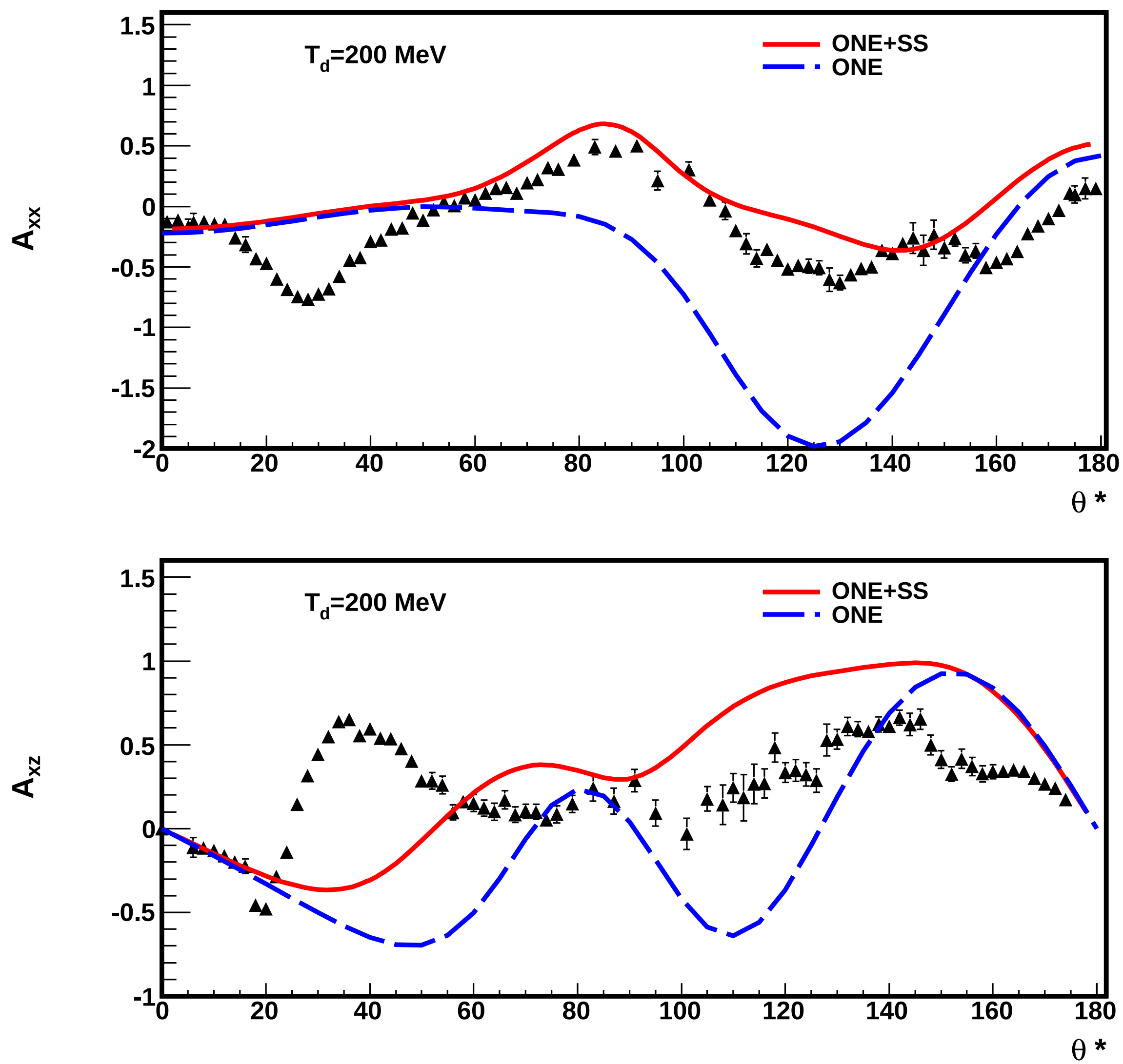
▲ - G.Bizard, et al.,Phys.Rev.C 22, p.1632, 1980



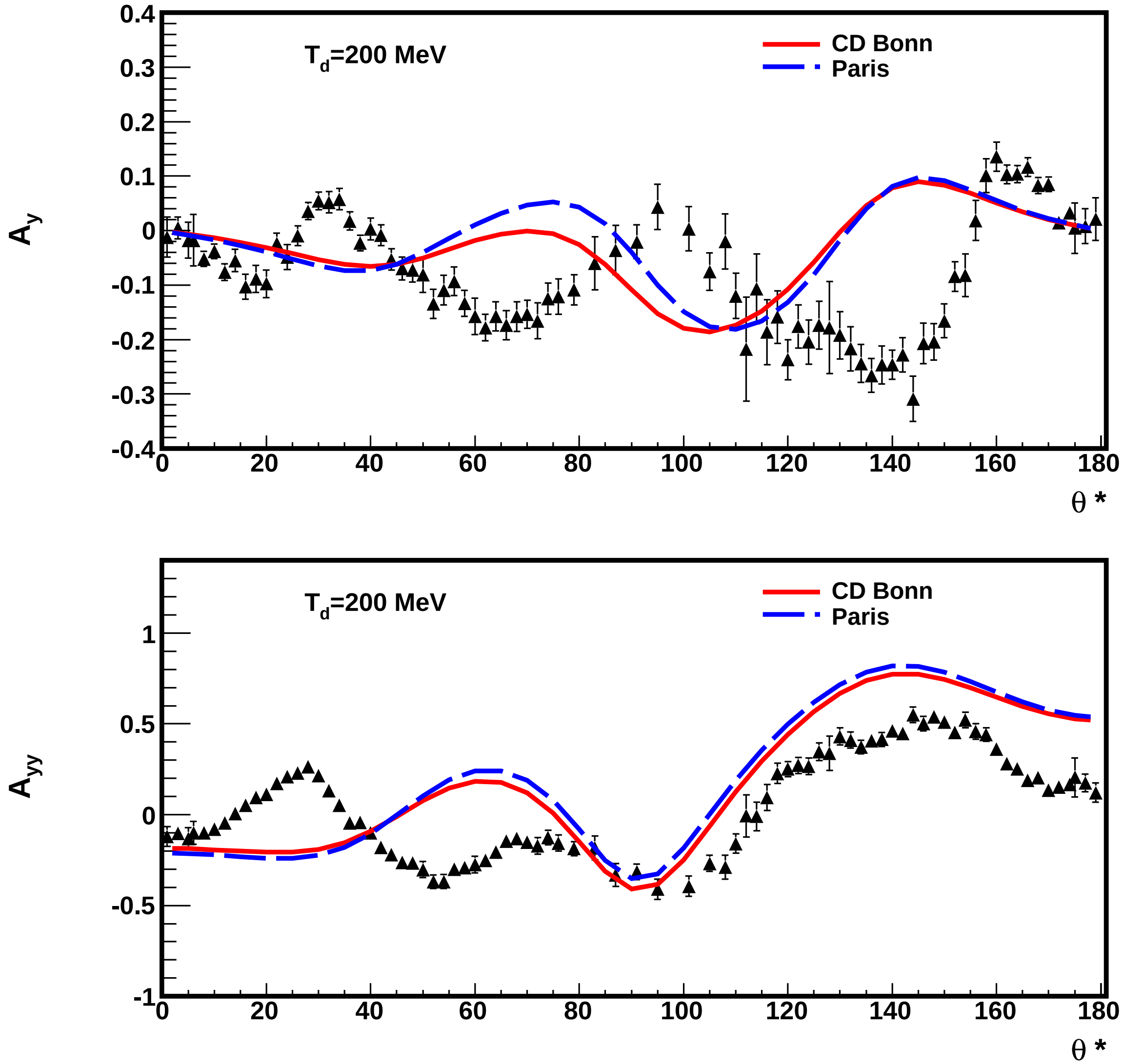
▲ - V.P. Ladygin et al., Phys. Lett. B598 (2004) 47;
V.P. Ladygin et al., Phys.Atom.Nucl.69 (2006) 1271.



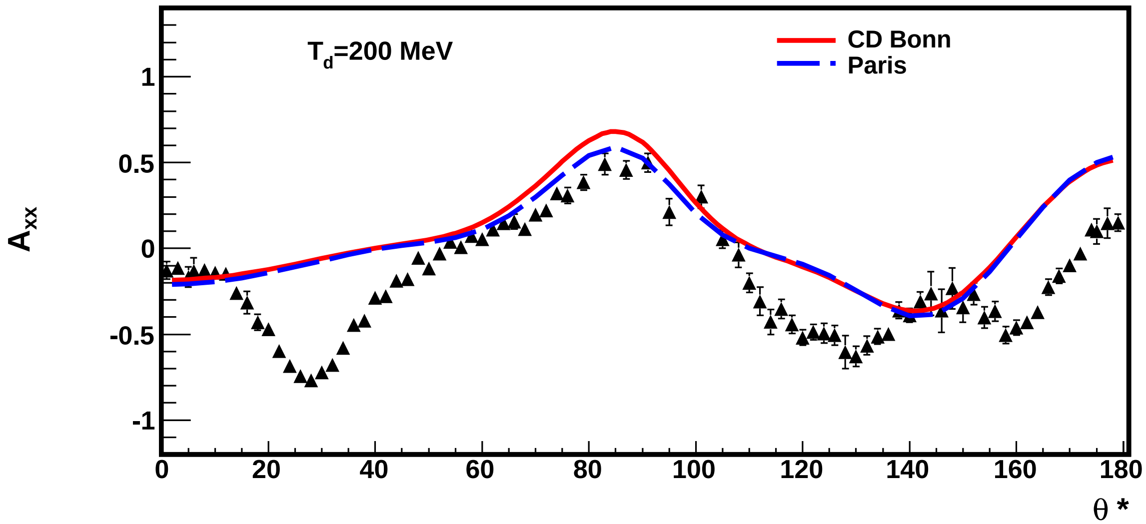
▲ - A.K. Kurilkin et al., Int.J.Mod.Phys. A24 (2009) 526-529

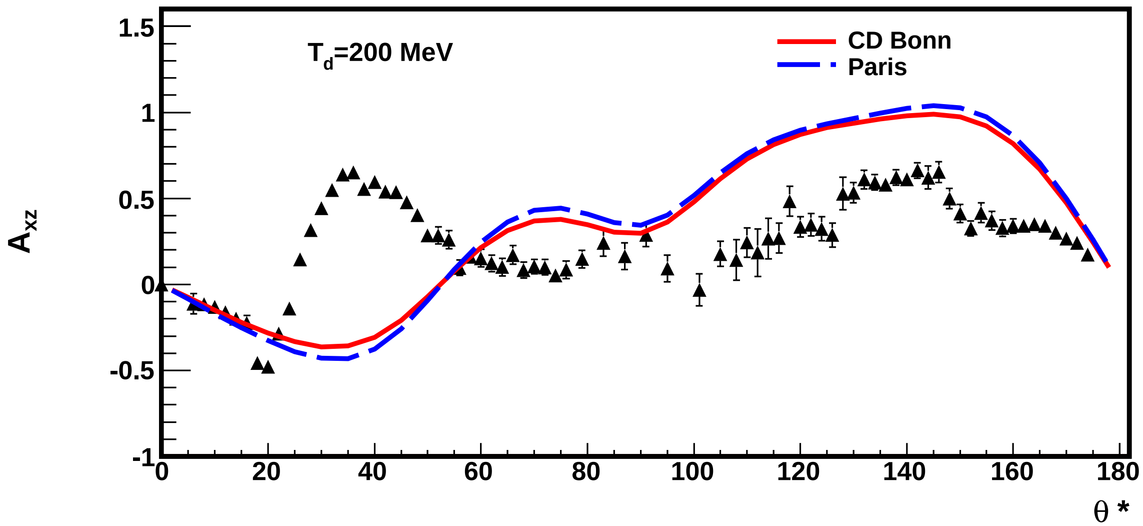


▲ - A.K. Kurilkin et al., Int.J.Mod.Phys. A24 (2009) 526-529



▲ - A.K. Kurilkin et al., Int.J.Mod.Phys. A24 (2009) 526-529





▲ - A.K. Kurilkin et al., Int.J.Mod.Phys. A24 (2009) 526-529

Conclusions

- $dd \longrightarrow {}^3He\ n$ reaction is considered for the deuteron energies between 200 MeV and 520 MeV.

- The theoretical model for description of this process is suggested. This model is based on the multiple scattering expansion formalism taking relativistic kinematics and relativistic spin theory into account.

- The one-nucleon-exchange and single-scattering reaction mechanisms have been included into consideration.

- A reasonable agreement between the theoretical predictions and experimental data was obtained both for differential cross section and analyzing powers.