Spin observables in dd->npd and pd->pd processes

Yu. Uzikov
and
A. Datta, I. Denisenko
V.P. Dzhelepov Laboratory of Nuclear Problems, JINR
uzikov@jinr.ru

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MOTIVATION

- **NN forces** is a basis of nuclear and hadronic physics. **Spin–dependent pp- and pn-elastic scattering amplitudes are necessary for theoretical interpretation** of nuclear data on spin observables, but **not derived from QCD theory.**

- Phenomenological (Regge/Regge-eikonal) models for helicity pN elastic amplitudes were developed at SPD NICA energies (Refs. are below).

- Spin-dependent Glauber theory of pd-elastic scattering with well established pN-amplitudes (SAID) is very successful for pd-pd observables and, therefore, can be used **to make an effective test for existing pN models.**

- Direct relations between spin observables A^d_y , A^p_y , A_{yy}, $C_{y,y}$, $C_{y,yy}$ of the $dd \to npd$ reaction and those for the $pd \to pd$ **are established here in the IA** .

- **A. Datta**: preliminary results of MC simulations for $dd \to npd$ / $pd \to pd$.

Phenomenological models for NN helicity amplitudes

Data on the NN spin amplitudes:

SAID: Arndt R.A. et al. PRC 76 (2007) 025209; $\sqrt{s_{NN}} = 1.9 - 2.4 GeV$

A. Sibirtsev et al., Eur. Phys. J. A 45 (2010) 357; arXiv:0911.4637 [hep-ph] (pp, Regge-type parametrization); $\sqrt{s_{NN}} = 2.5 - 15 GeV$

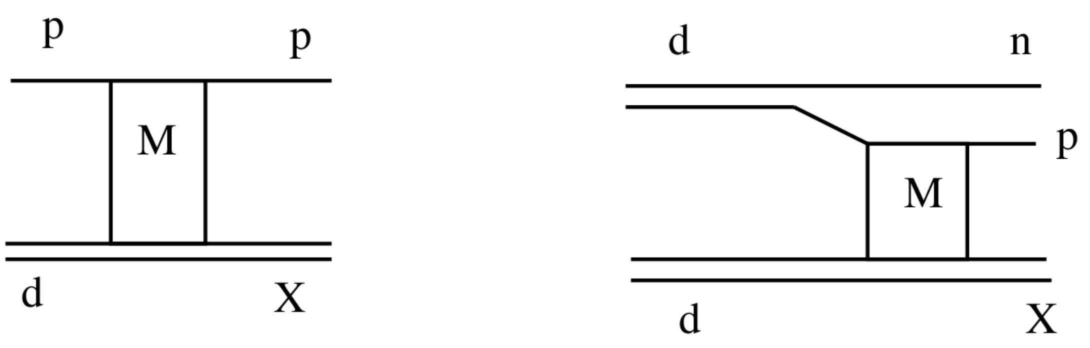
W.P. Ford, J. van Orden, Phys. Rev. C 87 (2013) $\sqrt{s_{pN}} = 2.5 - 3.5 GeV$
(pp, pn; Regge);

O.V. Selyugin, Symmetry., 13 N2 (2021) 164; (Regge –eikonal);
Phys.Rev.D 110 (2024) 11, 114028 ; e-Print: 2407.01311 [hep-ph] $\sqrt{s_{NN}} = 5 - 25 GeV$

Spin-dependent Glauber model for pd elastic scattering as a test of pN amplitudes

pd-pd is the simplest process **with both pp-** and **pn**-amplitudes involved.

dd-dd *elastic is much more complicated, spin- Glauber formalism is not yet developed*.

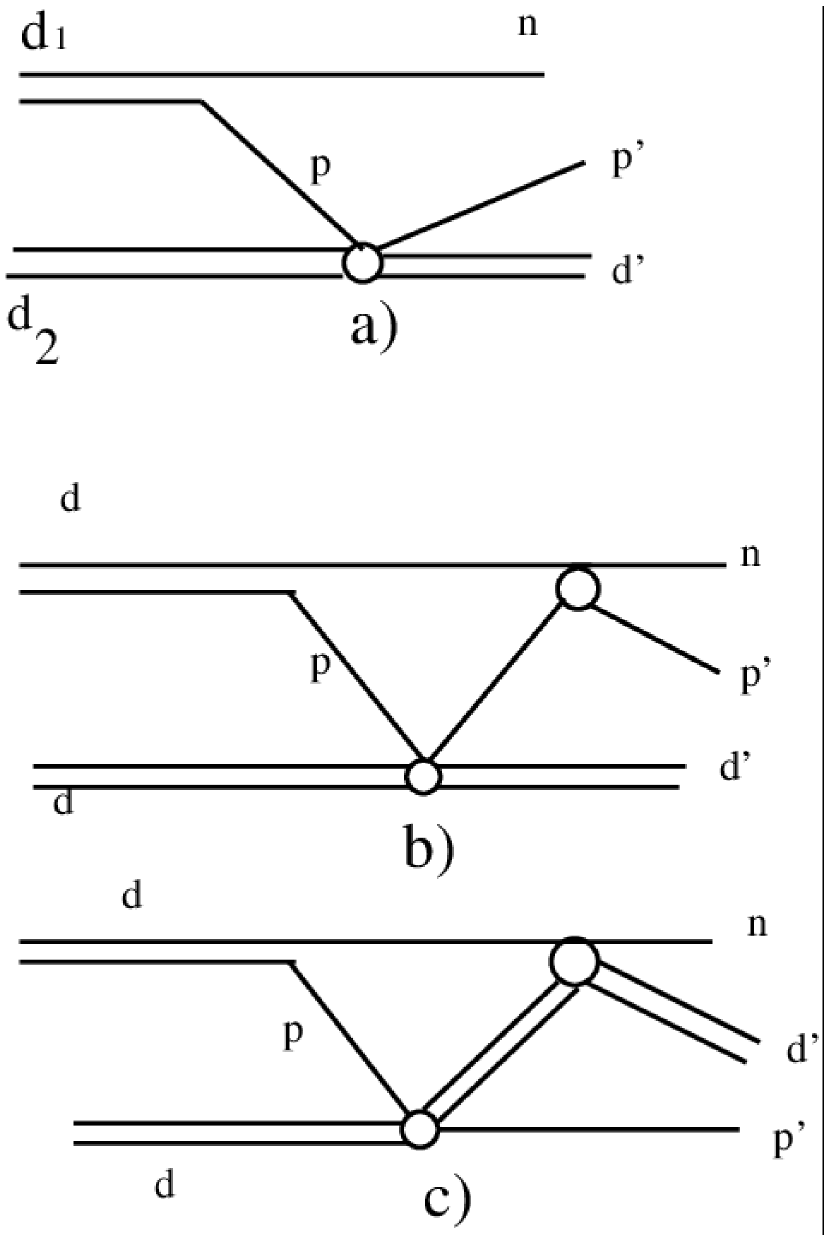


a) b)

$$T(dd \to n + pX) = \Sigma_{\sigma'} < \sigma_n, \sigma_{p'} | \psi_d^{\lambda}(\vec{q}) > T_{\lambda\sigma'}^{M_X \sigma_p}(pd \to pX)$$

'hen the final neutron takes one half c
-wave dominance, suppressed p_T mo
ıe pd->pd amplitude can be extracted

$$\vec{p}_n = \vec{p}_d / 2$$



Relations between dd→ npd and pd→ pd

$$|M(dd \to npd)|^2 = K[u^2(q) + w^2(q)]\,|M(pd \to pd)|^2$$

$d_2^{\uparrow}$: Vector or tensor polarized deuteron

$$A_Y^d(dd_2^{\uparrow} \to npd) = A_Y^d(pd^{\uparrow} \to pd),$$

$$A_{YY} = (dd_2^{\uparrow} \to npd) = A_{YY}(pd^{\uparrow} \to pd)$$

$d_1^{\uparrow}$: Vector polarized deuteron

$$A_Y^d(d_1^{\uparrow} d \to npd) = \frac{2}{3} A_Y^p(p^{\uparrow} d \to pd)$$

Both d_1 and d_2 deuterons are vector or tensor polarized:

$$C_{Y,Y}(d^{\uparrow} d^{\uparrow} \to npd) = \frac{2}{3} C_{y,y}(p^{\uparrow} d^{\uparrow} \to pd)$$

$$C_{Y,YY}(d^{\uparrow} d^{\uparrow} \to npd) = \frac{1}{3} C_{y,yy}(p^{\uparrow} d^{\uparrow} \to pd)$$

Rescatterings b), c) will be taken into account

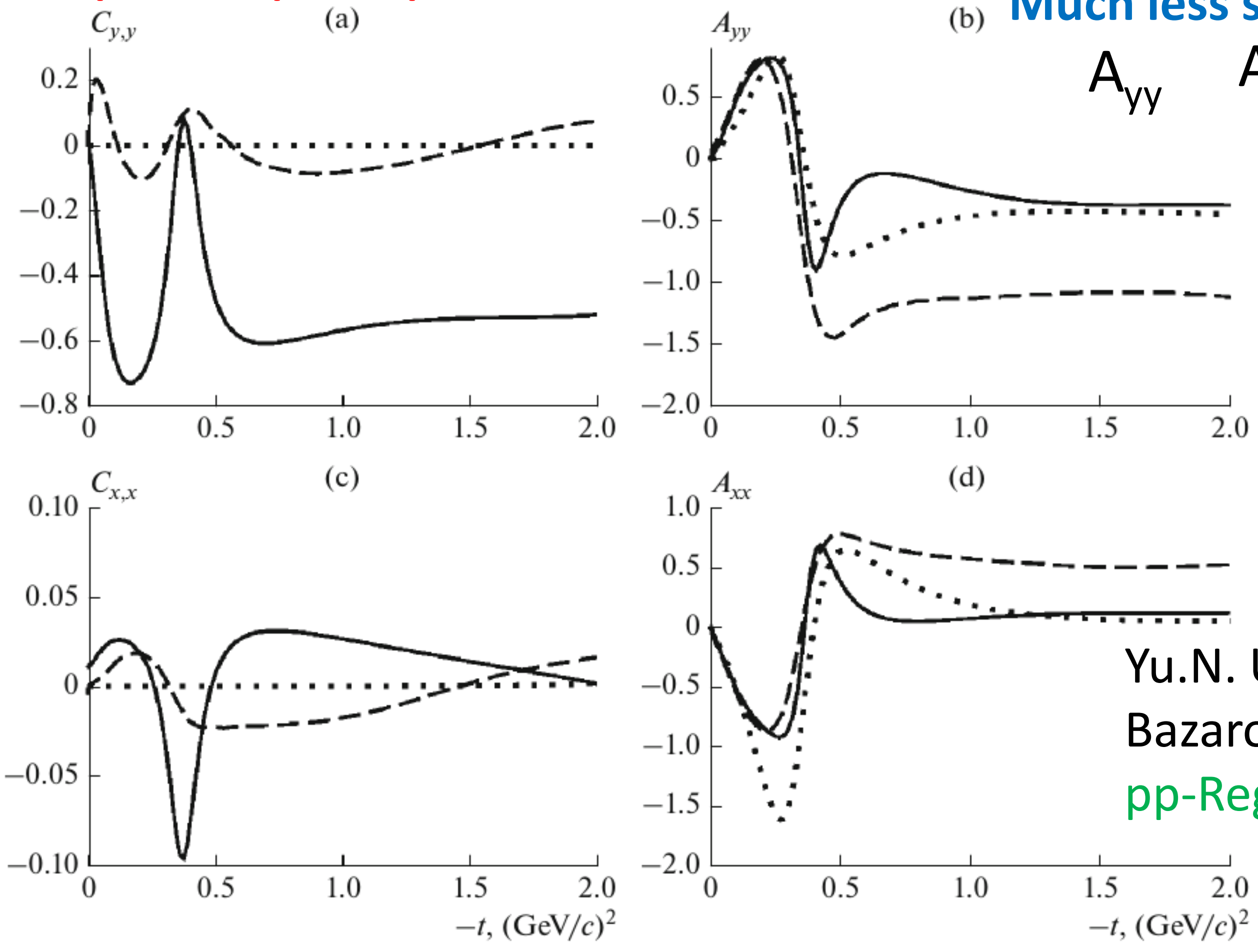
Dotted : with spin-independent pN-ampl.

High sensitive:

A_y, $C_{y,y}$, $C_{y,yy}$, $C_{x,x}$

Much less sensitive:

A_{yy} A_{xx}



Full line - 45 GeV/c

Dashed – 4.8 GeVc

Dotted – without spin ampl.

Yu.N. U., J. Haidenbauer, A. Temerbayev, Bazarova, Phys.Part. Nucl. 53 (2022) 419;

pp-Regge: A. Sibirtsev et al. EPJ A(2010)

Fig. 4. Results for spin-dependent *pd* observables. Same description of curves as in Fig. 3. The dotted lines are results where the spin-dependent *pN* amplitudes have been omitted in the calculation.

General information

Observables: spin observables A_y, A_{yy} ,$C_{y,y}$, $C_{y,yy}$ **of the reaction dd→npd** and **pd→pd**.
Physics being addressed: spin amplitudes of pp- and pn-elastic scattering
Theoretical motivation papers: [1-6].
Competitiveness: low-energy collisions at SPD are the optimal tool for the proposed studies
Previous results: RIKEN, IUCE, KVI, SATURNE, ANKE@COSY
Actuality: actual
Importance: pN- spin amplitudes is a basis for theoretical interpretation of spin observables in nucleus-nucleus interactions

Experimental requirements:

Beam species: dd
Collision energy: $\sqrt{s_{dd}}$ = 7.5 – 15 GeV
Luminosity: $5 \cdot 10^{28} - 10^{30}$ cm^{-2} s^{-1}
Polarization: Vector and tensor polarizations of one deuteron or both deuterons
Involved SPD subsystems: MVD, Straw tracker, ZDC
Optimal duration of data taking: TBD
Minimal duration of data taking: TBD

Expected performance:

Simulation information used: Custom event generator based on phase space of interest for signal study
Total statistics: TBD
Statistical accuracy: TBD
Main sources of systematics: uncertain signal-to-background ratio in MC study, detector systematics

Amaresh Datta: talk about results of MC simulations.

References

[1] M.N. Platonova, V.I. Kukulin, Refined Glauber model versus Faddeev calculations and experimental data for pd spin observables *Phys.Rev.C* 81 (2010) 014004, *Phys.Rev.C* 94 (2016) 6, 069902; (erratum) e-Print: 1612.08694 [nucl-th]

[2] M.N. Platonova, V.I. Kukulin, Theoretical study of spin observables in pd elastic scattering at energies Tp = 800-1000 MeV, *Eur.Phys.J.A* 56 (2020) 5, 132; e-Print: 1910.05722 [nucl-th]

[3] A. Sibirtsev, J. Haidenbauer, S. Krewald, U.-G.Meissner, *Proton-proton scattering above 3 GeV/c* *Eur.Phys.J.A* 45 (2010) 357-372 e-Print: 0911.4637 [hep-ph].

[4] W.P. Ford, J. van Orden, Regge model for NN spin-dependent amplitudes, Phys. Rev. C87(2013) (pp, pn).

[5] O.V. Selyugin, Elastic scattering at sqrt{s}=6 GeV up to sqrt{s}=13TeV: Proton-proton; proton-antiproton, and proton-neutron, *Phys.Rev.D* 110 (2024) 11, 114028 ; e-Print: 2407.01311 [hep-ph].

[6] Yu. Uzikov, J. Haidenbauer, A. Bazarova, A. Temerbaev, Spin Observables of Proton–Deuteron Elastic Scattering at SPD NICA Energies within the Glauber Model and pN Amplitudes - *Phys.Part.Nucl.* 53 (2022) 2, 419-425, e-Print: 2011.04304 [nucl-th]

Preliminary SUMMARY

OBSERVABES to be measured : $A_y, A_{yy}, C_{y,y}, C_{y,yy}$ **,…for the reaction dd→npd directly related to those for pd→ pd.**

- Actual problem, important for hadron spin physics.
- Suitable for the first stage of SPD.
- Large pd→ pd cross section in forward hemisphere .
- The study can be extended to the dd- elastic scattering at SPD.

What has to be done:

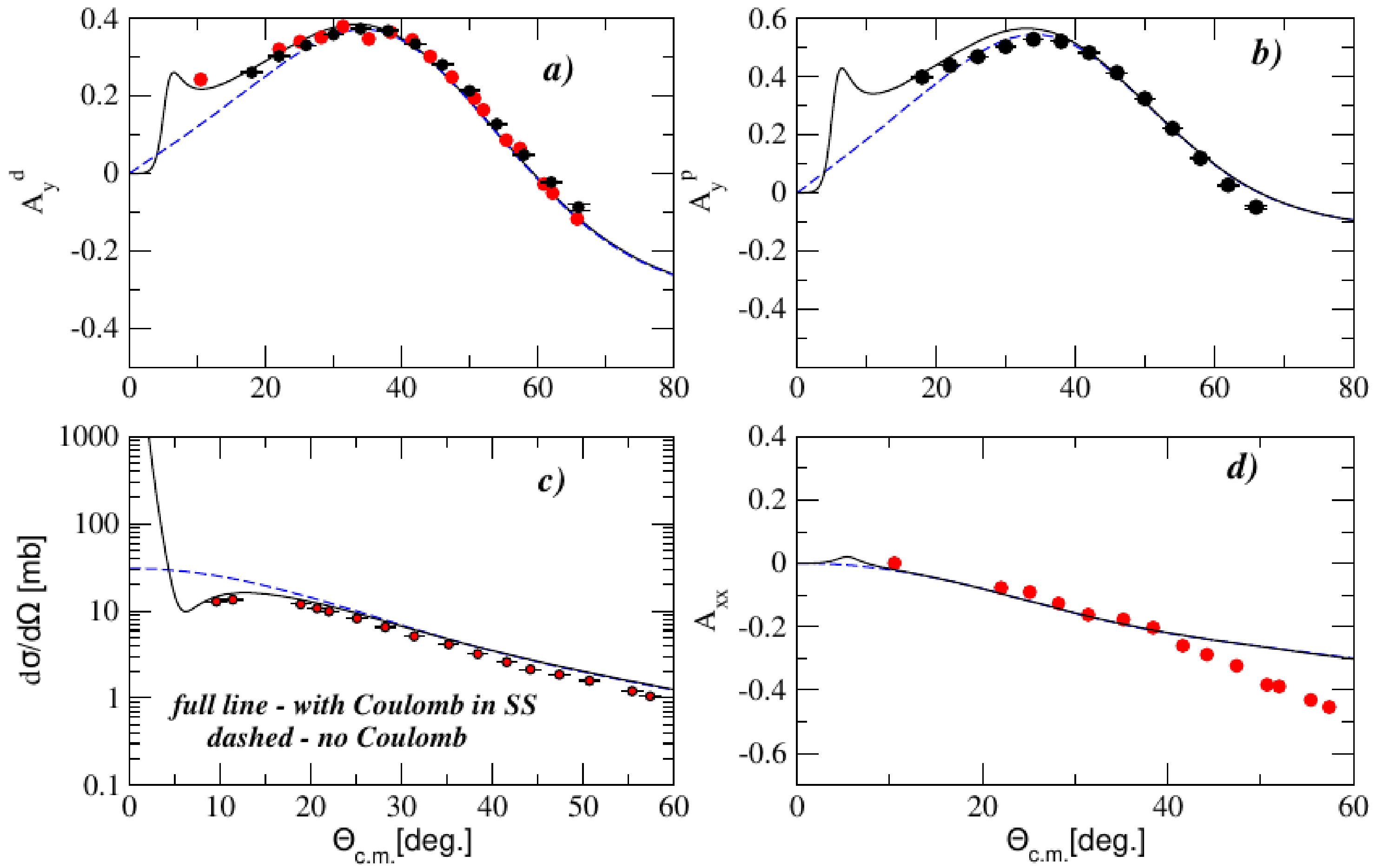
- ♦ Estimation for FSI effects.
- ♦ Calculations of $A_y, A_{yy}, C_{y,y}, C_{y,yy}$ for pd-pd with different pN models.

THANK YOU FOR ATTENTION!

Test calculations: pd elastic scattering at 135 MeV

A.A. Temerbayev, Yu.N.Uzikov, Yad. Fiz. **78** (2015) 38

Comparable with results of Faddeev calculations



Data: K. Sekiguchi et al. PRC (2002); B. von Przewoski et al. PRC (2006)
See also Faddeev calculations: A.Deltuva, A.C. Fonseca, P.U. Sauer, PRC 71 (2005) 054005.

A.A. Temerbayev, Yu.N. Uzikov, Yad. Fiz, 78 (2015) 38

$C_{y,y}$, $C_{x,z}$, $C_{z,x}$, $C_{xz,y}$

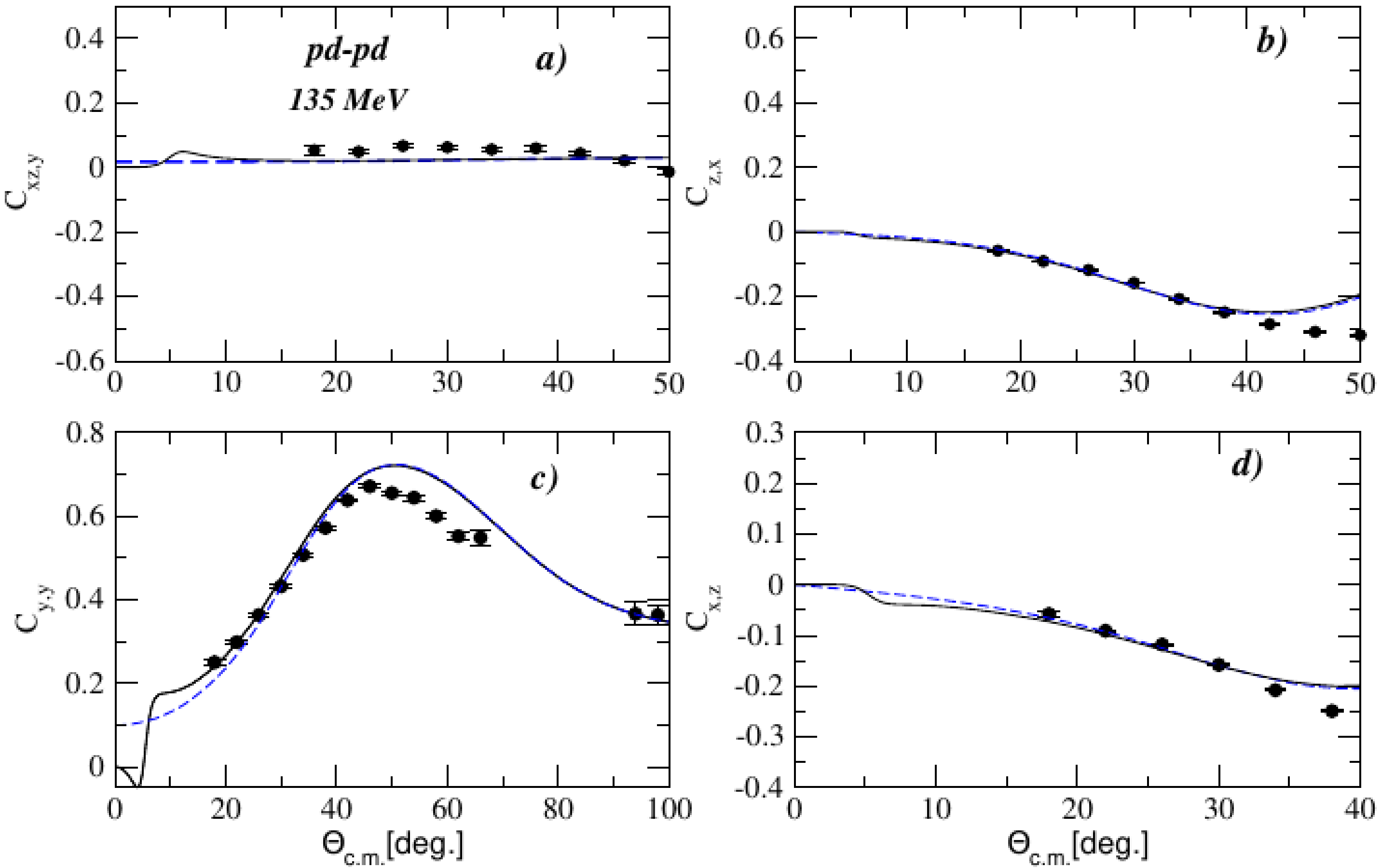
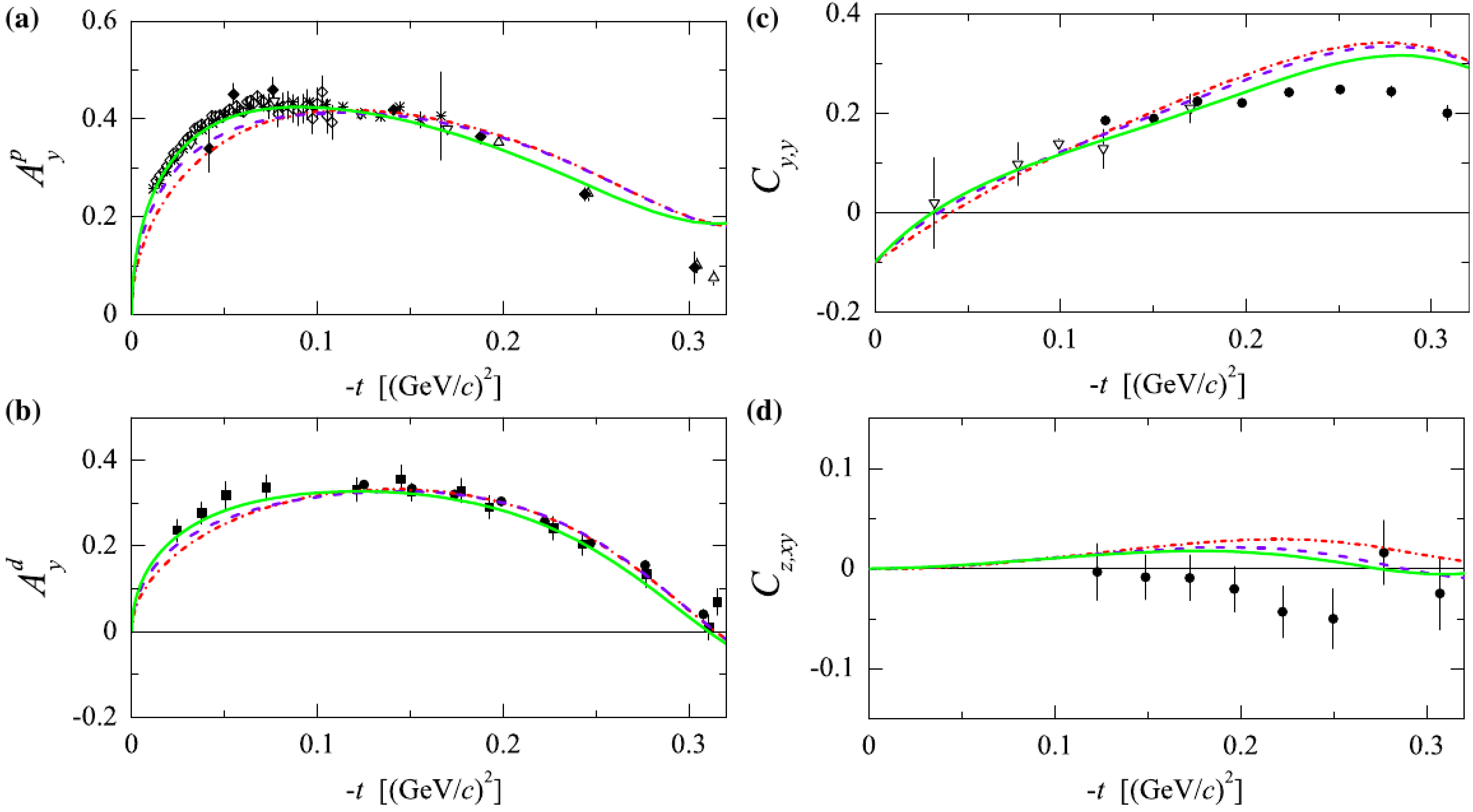
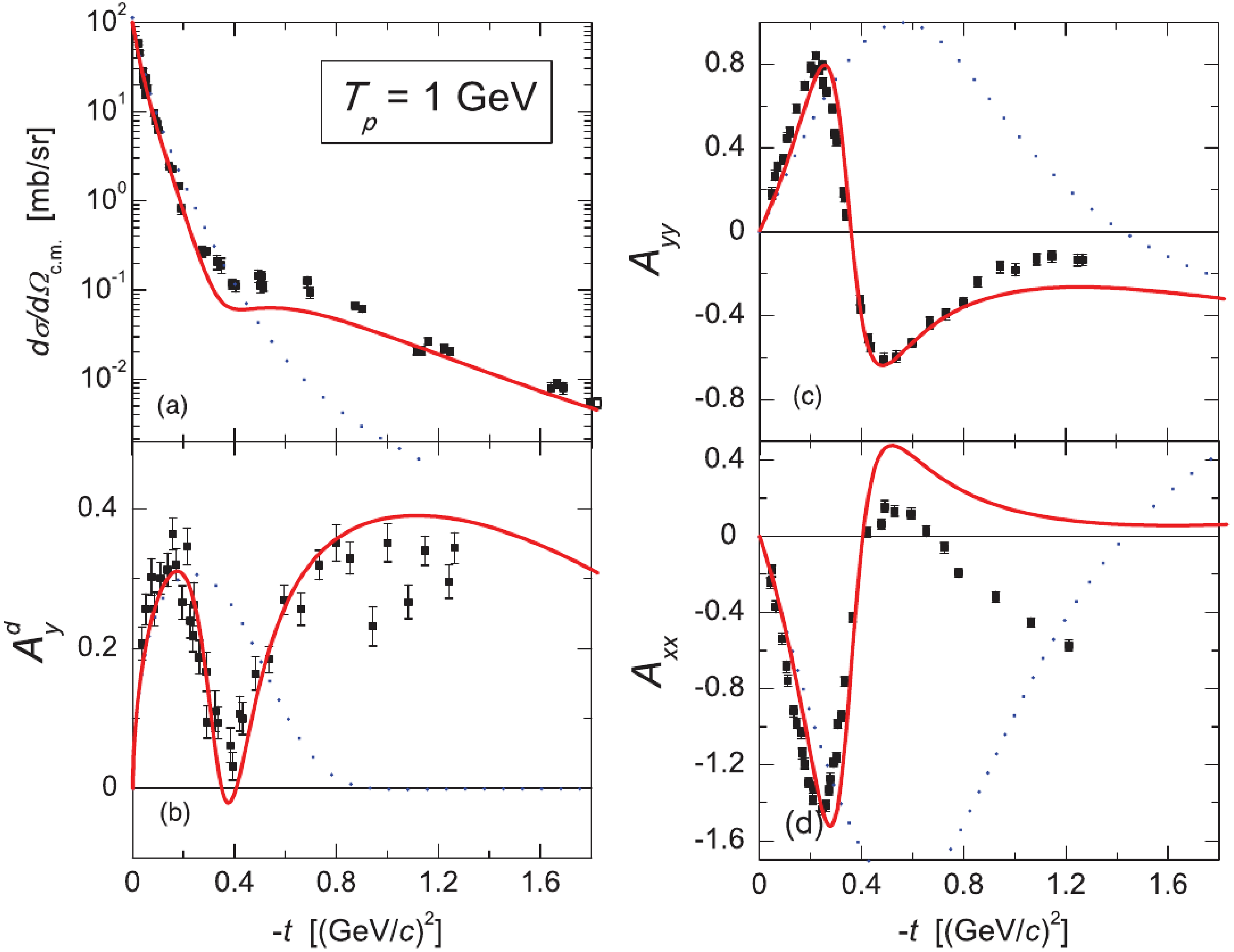


Figure 1: Spin correlation coefficients $C_{xz,y}$ (a), $C_{z,x}$ (b), $C_{y,y}$ (c), $C_{x,z}$ (d) at 135 MeV versus the c.m.s. scattering angle calculated within the modified Glauber model [15] without (dashed lines) and with (full) Coulomb included in comparison with the data from [22].

M.N. Platonova, V.I. Kukulin, *Eur.Phys.J.A* 56 (2020) 5, 132

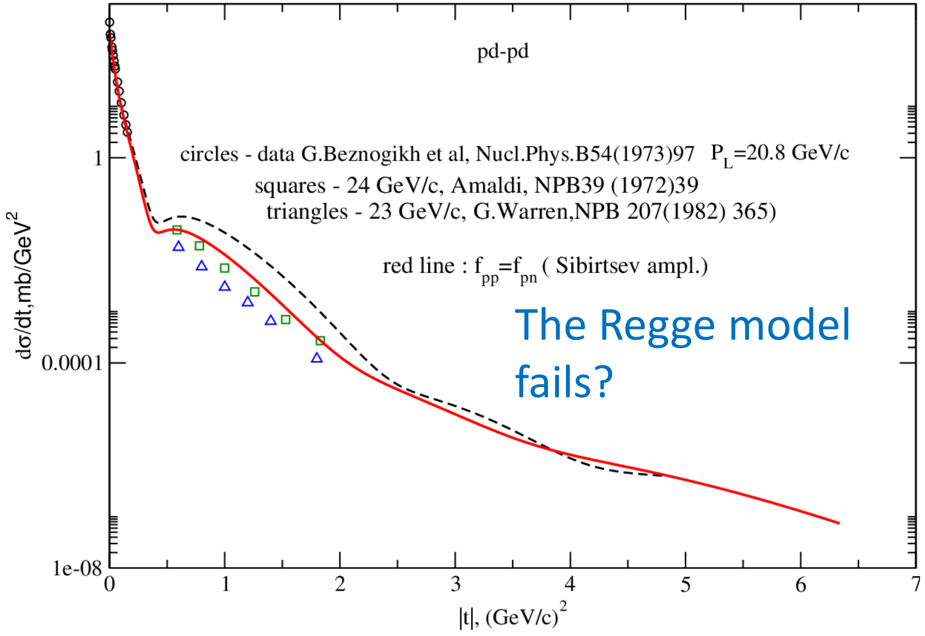


M.N. Platonova, V.I. Kukulin, PRC 81(2010) 014004

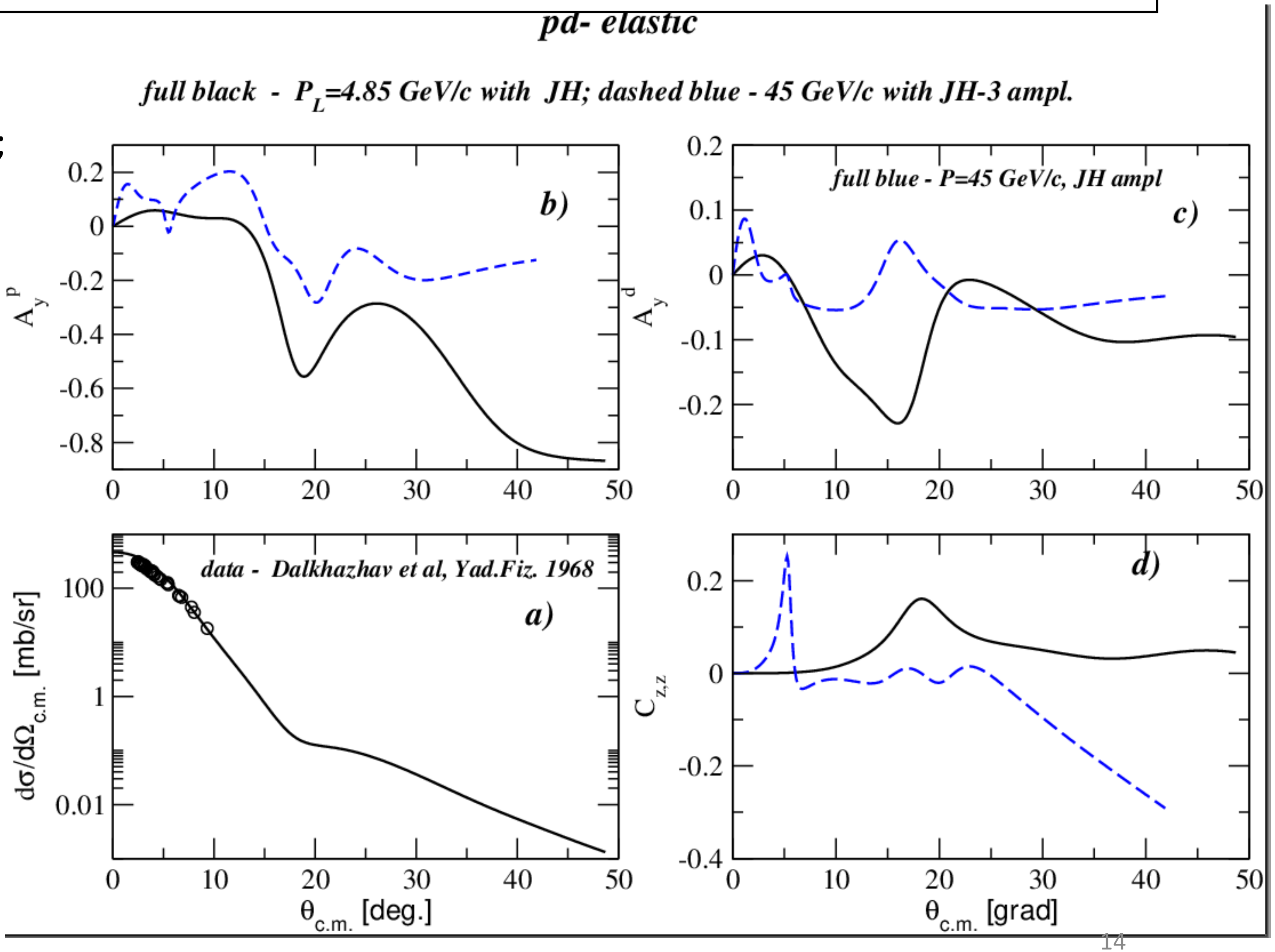


Towards test of pN amplitudes at higher energies in *pd* elastic scattering within the Glauber model

Yu.N. U., J. Haidenbauer, A. Temerbayev, Bazarova, Phys.Part. Nucl. 53 (2022) 419;
NN-Regge: A.Sibirtsev et al. EPJ A(2010)



The Regge model fails?

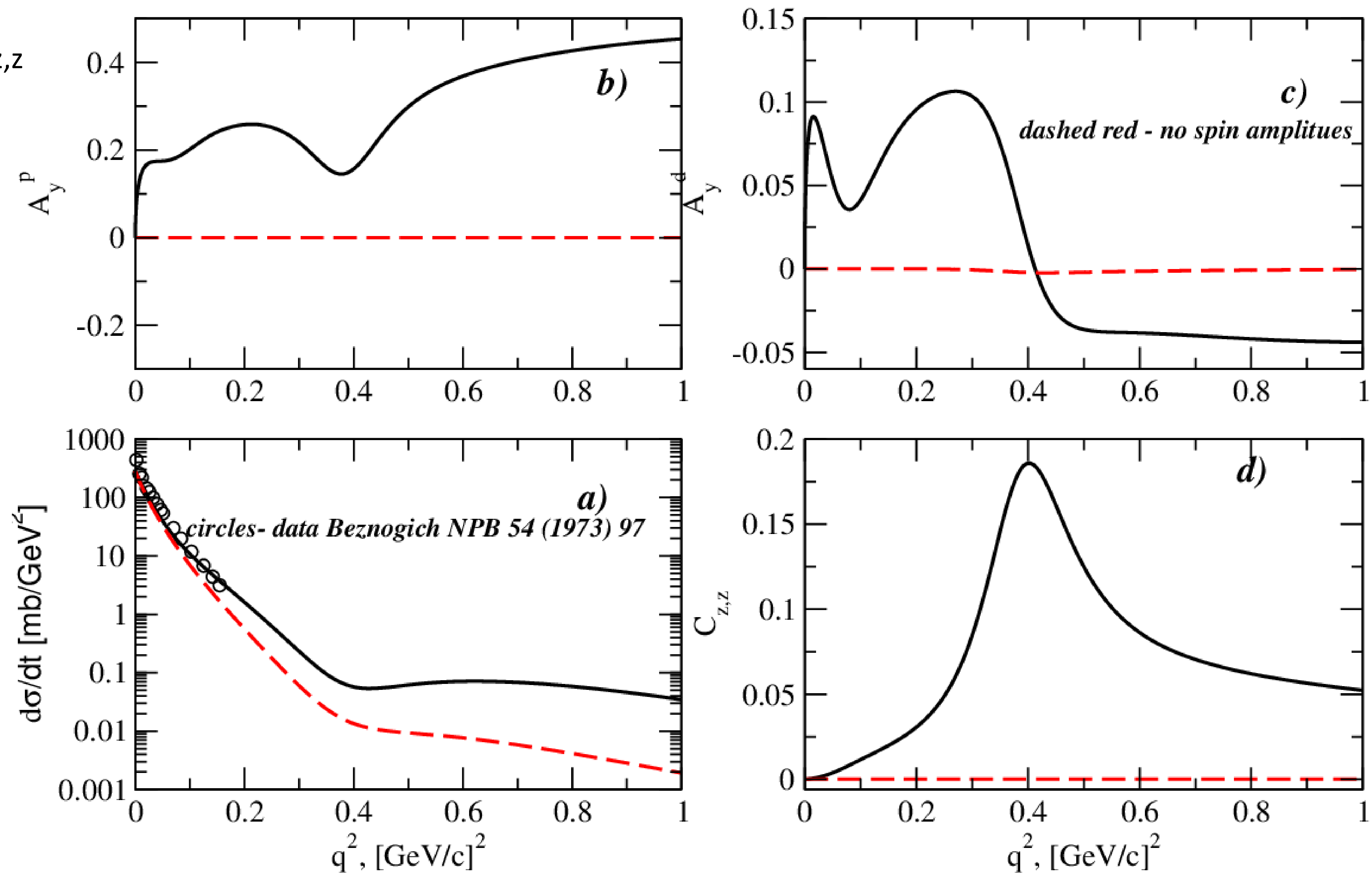


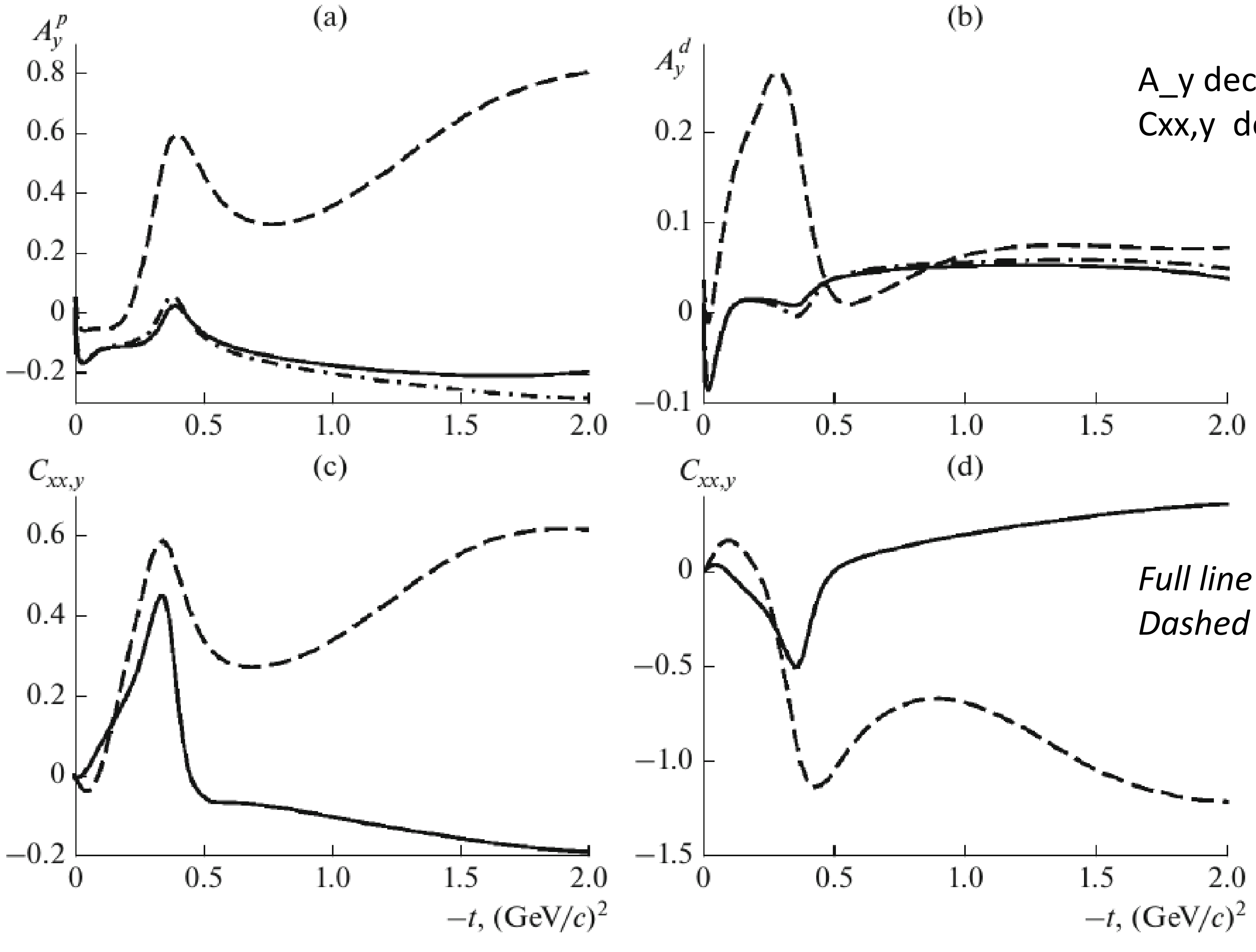
pd- elastic

High sensitivity to spins:

full black - P_L=20.4 GeV/c with Sibirtsev amplitudes

A_y^p A_y^d $C_{z,z}$





A_y decreases with energy, Cxx,y does not

Full line - 45 GeV/c
Dashed – 4.8 GeVc

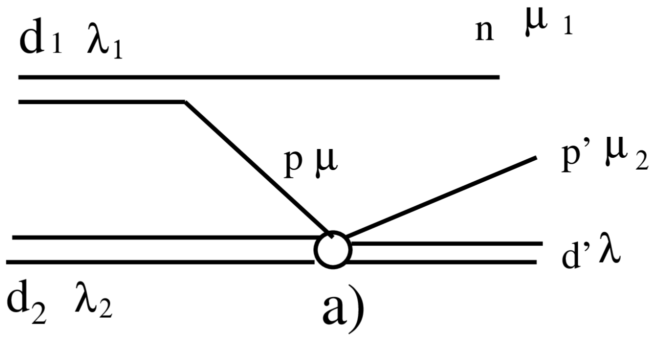
Fig. 3. Results for spin-dependent *pd* observables. Predictions for $p_{\mathrm{lab}} = 4.8$ GeV/*c* are shown by dashed lines while those at 45 GeV/*c* correspond to the solid lines. For the latter, the effect of the Coulomb interaction is indicated by the dash-dotted lines.

Transition matrix element for the $dd \to npd$ in IA, S-wave :

$$M^{\mu_1\mu_2\lambda'}_{\lambda_1\lambda_2} = K\sum_{\mu}(\frac{1}{2}\mu_1\frac{1}{2}\mu|1\lambda_1)u(q)M^{\lambda'\mu_2}_{\lambda_2\mu}(pd \to pd). \quad (1)$$

where $K = \sqrt{2m_d/4\pi}$.

IA =



$$\overline{|M^{\mu_1\mu_2\lambda'}_{\lambda_1\lambda_2}|^2} = K^2\overline{|M^{\lambda'\mu_2}_{\lambda_2\mu}(pd \to pd)|^2}. \quad (2)$$

$$d\sigma_{\lambda_2} = \frac{1}{3}\sum_{\lambda_1}\sum_{\mu_1\mu_2\lambda'}|M^{\mu_1\mu_2\lambda'}_{\lambda_1\lambda_2}(dd \to npd)|^2 = K^2\frac{1}{2}\sum_{\mu\lambda'\mu_2}|M^{\lambda'\mu_2}_{\lambda_2\mu}(pd \to pd)|^2.$$

The differential cross section for collision of two spin-1 particles:

H. Ohlsen, Rep. Prog. Phys. 35 (1972) 717

$$I = I_0\left(1 + \frac{3}{2} P_y A_y + \frac{3}{2} P_y^T A_y^T + \frac{9}{4} P_y P_y^T C_{y,y}\right), \qquad (3)$$

Vector analyzing power $A_y^{d_2}$:

$$A_y^{d_2}(d_1 \vec{d}_2 = npd) = \frac{d\sigma_{\lambda_2=+1} - d\sigma_{\lambda_2=-1}}{d\sigma_{\lambda_2=+1} + d\sigma_{\lambda_2=0} + d\sigma_{\lambda_2=-1}} = A_y^d(p\vec{d} \to pd)$$

Vector analyzing power $A_y^{d_1}$:

$$A_y^{d_1}(\vec{d}_1 d_2 \to npd) = \frac{d\sigma_{\lambda_1=+1} - d\sigma_{\lambda_1=-1}}{d\sigma_{\lambda_1=+1} + d\sigma_{\lambda_1=0} + d\sigma_{\lambda_1=-1}} = \frac{2}{3} A_y^p(\vec{p}d \to pd)$$

$OZ \uparrow\uparrow \vec{p}_d$

$OY \uparrow\uparrow [\vec{p}_d \times \vec{p}_{d'}]$

Tenzor analyzing power

$$A_y^d(d_1\vec{d}_2 \to npd) = \frac{d\sigma_{\lambda_2=+1} + d\sigma_{\lambda_2=-1} - 2d\sigma_{\lambda_2=0}}{d\sigma_{\lambda_2=+1} + d\sigma_{\lambda_2=0} + d\sigma_{\lambda_2=-1}} = A_{yy}^d(p\vec{d} \to pd)$$

$C_{y,y}$ ($C_{yy,y}$ with $P_Y = 0$, $P_{YY} = \pm 1$)) needs four options for dd-collision: (i) $P_y = P_y^T = \frac{2}{3}$ (ii) $P_y = \frac{2}{3}$, $P_y^T = -\frac{2}{3}$ and the same for $P_y = -\frac{2}{3}$. The cross section $I_{\uparrow\uparrow}$ for the option (i), a $I_{\uparrow\downarrow}$ for (ii) From Eq.(3) one can find:

$$C_{y,y} = \frac{(I_{\uparrow\uparrow} - I_{\uparrow\downarrow}) + (I_{\downarrow\downarrow} - I_{\downarrow\uparrow})}{(I_{\uparrow\uparrow} + I_{\uparrow\downarrow}) + (I_{\downarrow\downarrow} + I_{\downarrow\uparrow})}, \quad (4)$$

$$C_{yy,y} = \frac{(I_{+\uparrow} - I_{+\downarrow}) + (I_{-\downarrow} - I_{-\uparrow})}{(I_{+\uparrow} + I_{+\downarrow}) + (I_{-\downarrow} + I_{-\uparrow})}. \quad (5)$$

Yu.N. Uzikov, A.A. Temerbayev, Phys. Part. Nucl. **55 (2024) 895;**
e-Print: 2311.12605 [nucl-th]; dd-> npnp and hard pN-elastic scattering

A. Sibirtsev et al, EPJA (2010)