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

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CONTENT

- Motivation:
  Spin–dependent pp- and pn- elastic scattering amplitudes are necessary for theoretical interpretation of **nuclear spin observables**, but **not yet derived from QCD theory .**

- Phenomenological models (Regge, Regge-eikonal) for spin-dependent pN elastic scattering at SPD energies.

- Glauber spin-dependent theory of pd-elastic scattering and pN-amplitudes.

- Relations between spin observables for dd→n+p+d and pd->pd.

- Summary

Amaresh Datta: MC simulations for dd →npd with separation of pd→pd.

pN ELASTIC SCATTERING

NN forces is a basis of nuclear and hadronic physics.

NN-> NN data on spin dependent pN- amplitudes are noncomplete for pp at T>3 GeV and scare for pn at T>1.2 GeV .

Important TASK: Measurement @ test of spin amplitudes of NN elastic scattering in soft and hard NN- collisions.

$$\phi_1(s,t) = \langle + + |M| + + \rangle,$$
$$\phi_2(s,t) = \langle + + |M| - - \rangle,$$
$$\phi_3(s,t) = \langle + - |M| + - \rangle,$$
$$\phi_4(s,t) = \langle + - |M| - + \rangle,$$
$$\phi_5(s,t) = \langle + + |M| + - \rangle.$$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}\{|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2\}.$$
$$A_N\frac{d\sigma}{dt} = -\frac{4\pi}{s^2}\,\mathrm{Im}\{\phi_5^*(\phi_1 + \phi_2 + \phi_3 - \phi_4)\},$$
$$A_{NN}\frac{d\sigma}{dt} = \frac{4\pi}{s^2}\{2|\phi_5|^2 + \mathrm{Re}(\phi_1^*\phi_2 - \phi_3^*\phi_4)\},$$

>10 Observables are required for complete polarization experiment

Amplitudes: 5 – pp, 6 – pn, TV gives additional terms

Phenomenological models of NN-elastic amplitudes

NN helicity amplitudes:

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

Models:

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

Isospin and G-parity:

$$\phi(pp) = -\phi_\omega - \phi_\rho + \phi_{f_2} + \phi_{a_2} + \phi_P,$$
$$\phi(pn) = -\phi_\omega + \phi_\rho + \phi_{f_2} - \phi_{a_2} + \phi_P.$$

- **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] $\sqrt{s_{NN}} = 5 - 25 GeV$

pd elastic scattering within the spin-dependent Glauber model and test of pN amplitudes

pd-pd: The simplest process with both **pp-** and pn-amplitudes involved.

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

Elastic $pd \to pd$ transitions

$$\hat{M}(\mathbf{q},\mathbf{s}) =$$
$$\exp\left(\frac{1}{2}i\mathbf{q}\cdot\mathbf{s}\right)M_{pp}(\mathbf{q}) + \exp\left(-\frac{1}{2}i\mathbf{q}\cdot\mathbf{s}\right)M_{pn}(\mathbf{q}) +$$
$$+\frac{i}{2\pi^{3/2}}\int \exp\left(i\mathbf{q}'\cdot\mathbf{s}\right)\left[M_{pp}(\mathbf{q}_1)M_{pn}(\mathbf{q}_2) + p \leftrightarrow n\right]d^2\mathbf{q}'.$$

Single pN-scattering

Double scattering

On-shell elastic pN scattering amplitude (**T-even, P-even**)

$$\begin{aligned} M_{pN} &= A_N + (C_N\boldsymbol{\sigma}_1 + C'_N\boldsymbol{\sigma}_2)\cdot\hat{\mathbf{n}} + B_N(\boldsymbol{\sigma}_1\cdot\hat{\mathbf{k}})(\boldsymbol{\sigma}_2\cdot\hat{\mathbf{k}}) + \\ &+ (G_N - H_N)(\boldsymbol{\sigma}_1\cdot\hat{\mathbf{n}})(\boldsymbol{\sigma}_2\cdot\hat{\mathbf{n}}) + (G_N + H_N)(\boldsymbol{\sigma}_1\cdot\hat{\mathrm{q}})(\boldsymbol{\sigma}_2\cdot\hat{\mathrm{q}}) \end{aligned}$$

M. Platonova, V. Kukulin, PRC **81** (2010) 014004:

GENERAL SPIN STRUCTURE OF THE pd-pd AMPLITUDES AND SPIN OBSERVABLES

A.A. Temerbayev, Yu. N. U. Yad. Fiz. 78 (2015) 38; Bull. Rus, Ac. Sci. v.80 №3 (2016) 242. **Madison ref. frame**

Yu. N. Uzikov, A. Bazarova, A.A. Temerbayev,

Physics of Particles and Nuclei, 2022, Vol. 53, No. 2, pp. 419—425.

$$\langle p'\mu', d'\lambda'|T|p\mu, d\lambda\rangle = \varphi^{+}_{\mu'} e^{(\lambda')*}_{\beta} T_{\beta\alpha}(\mathbf{p}, \mathbf{p}', \boldsymbol{\sigma}) e^{(\lambda)}_{\alpha} \varphi_{\mu}, \quad (1)$$

$$\begin{array}{lll} T_{xx} = M_1 + M_2\sigma_y & T_{xy} = M_7\sigma_z + M_8\sigma_x & T_{xz} = M_9 + M_{10}\sigma_y \\ T_{yx} = M_{13}\sigma_z + M_{14}\sigma_x & T_{yy} = M_3 + M_4\sigma_y & T_{yz} = M_{11}\sigma_x + M_{12}\sigma_z \\ T_{zx} = M_{15} + M_{16}\sigma_y & T_{zy} = M_{17}\sigma_x + M_{18}\sigma_z & T_{zz} = M_5 + M_6\sigma_y, \end{array}$$

12 independent spin amplitudes (i=1,…,12) M_i for P-and T-invariance included.

Any spin observables can be calculated for pd-pd using M_i

Some spin observables for pd-pd

$$\frac{d\sigma}{dt} = \frac{1}{6}\mathrm{Tr}MM^{+}, \quad \mathrm{Tr}MM^{+} = 2\sum_{i=1}^{18}|M_i|^2, \qquad (3)$$

$$A_y^d = \mathrm{Tr}MS_yM^{+}/\mathrm{Tr}MM^{+} = -\frac{2}{\sum_{i=1}^{18}|M_i|^2}\mathrm{Im}(M_1M_9^{*}$$
$$+ M_2M_{10}^{*} + M_{13}M_{12}^{*} + M_{14}M_{11}^{*} + M_{15}M_5^{*} + M_{16}M_6^{*}),$$

$$A_y^p = \mathrm{Tr}M\sigma_yM^{+}/\mathrm{Tr}MM^{+} = \frac{2}{\sum_{i=1}^{18}|M_i|^2}[\mathrm{Re}(M_1M_2^{*}$$
$$+ M_9M_{10}^{*} + M_3M_4^{*} + M_{15}M_{16}^{*} + M_5M_6^{*})$$
$$- \mathrm{Im}(M_8M_7^{*} + M_{14}M_{13}^{*} + M_{11}M_{12}^{*} + M_{17}M_{18}^{*})],$$

$$A_{yy} = \mathrm{Tr}MP_{yy}M^{+}/\mathrm{Tr}MM^{+} = 1 - \frac{3}{\sum_{i=1}^{18}|M_i|^2}$$
$$\times (|M_3|^2 + |M_4|^2 + |M_7|^2 + |M_8|^2 + |M_{17}|^2 + |M_{18}|^2),$$

$$A_{xx} = \mathrm{Tr}MP_{xx}M^{+}/\mathrm{Tr}MM^{+} = 1 - \frac{3}{\sum_{i=1}^{18}|M_i|^2}$$
$$\times (|M_1|^2 + |M_2|^2 + |M_{13}|^2 + |M_{14}|^2 + |M_{15}|^2 + |M_{16}|^2),$$

$$C_{y,y} = \mathrm{Tr}MS_y\sigma_yM^{+}/\mathrm{Tr}MM^{+} = -\frac{2}{\sum_{i=1}^{18}|M_i|^2}$$
$$\times [\mathrm{Im}(M_2M_9^{*} + M_1M_{10}^{*} + M_{16}M_5^{*} + M_{15}M_6^{*})$$
$$+ \mathrm{Re}(M_{14}M_{12}^{*} - M_{13}M_{11}^{*})],$$

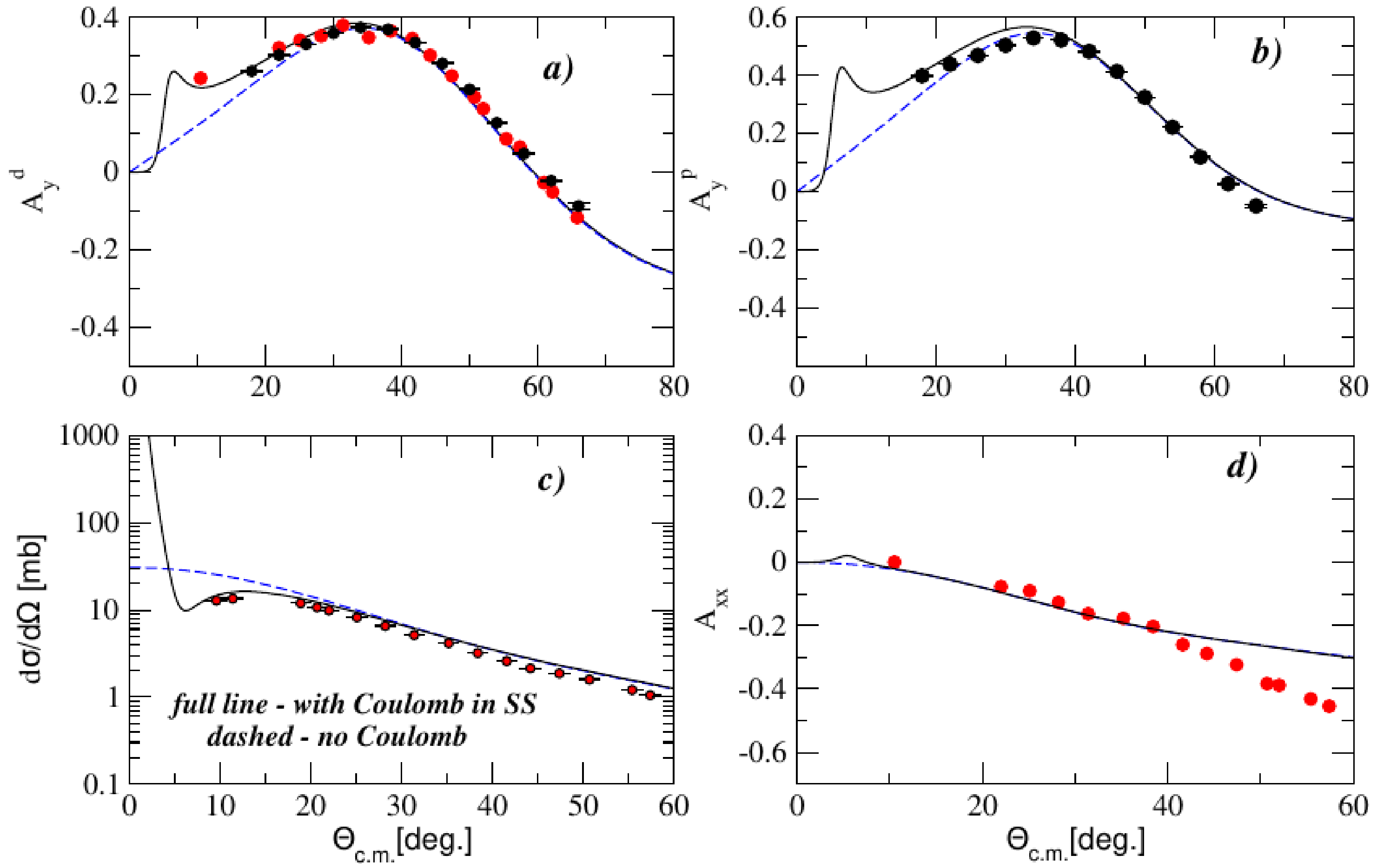
$$C_{x,x} = \mathrm{Tr}MS_x\sigma_xM^{+}/\mathrm{Tr}MM^{+}$$
$$= -\frac{2}{\sum_{i=1}^{18}|M_i|^2}[\mathrm{Im}(M_8M_9^{*} + M_3M_{11}^{*} + M_{17}M_5^{*})$$
$$+ \mathrm{Re}(M_7M_{10}^{*} - M_4M_{12}^{*} + M_{18}M_6^{*})],$$

$$C_{xx,y} = \mathrm{Tr}M_{xx}\sigma_yM^{+}/\mathrm{Tr}MM^{+} = A_y^p - \frac{6}{\sum_{i=1}^{18}|M_i|^2}$$
$$\times [\mathrm{Re}(M_2M_1^{*} + M_{16}M_{15}^{*}) - \mathrm{Im}(M_{14}M_{13}^{*}),$$

Test calculations: pd elastic scattering at 135 MeV

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

Glauber is 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

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

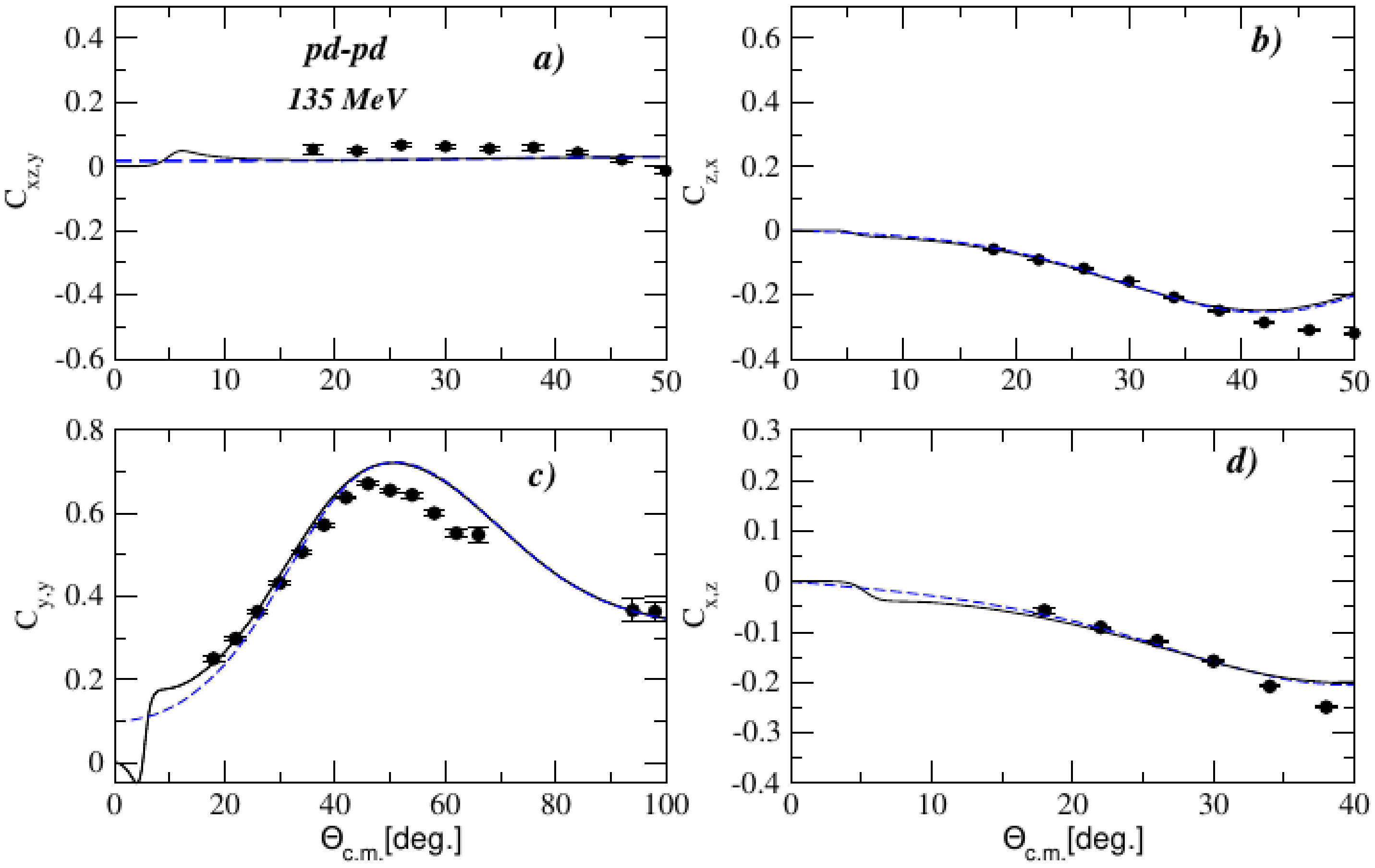
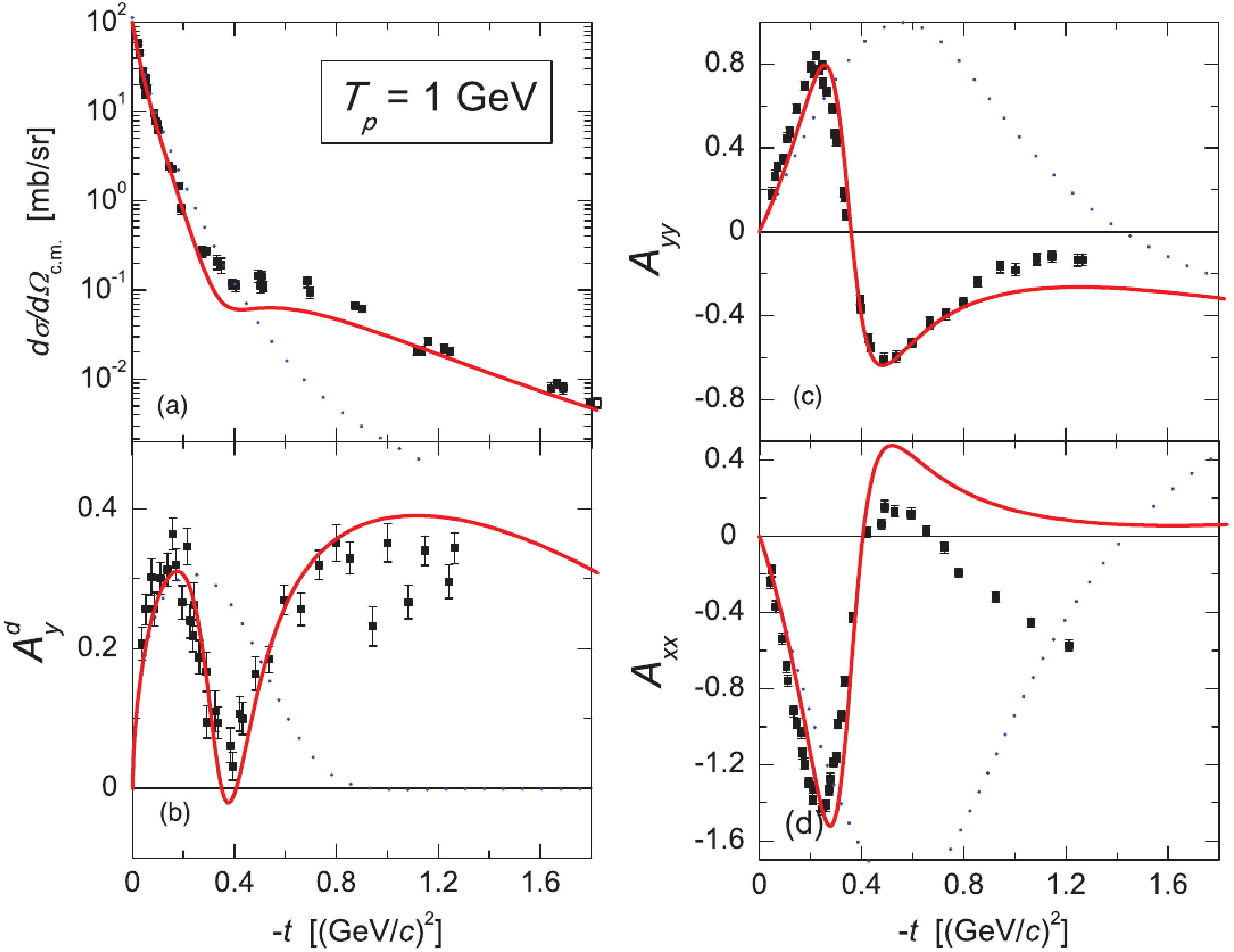


Figure 1: Spin correlation coefficients $C_{xz,y}$ (a), $C_{z,x}$ (b), $C_{y,y}$ (c), $C_{x,z}$ (d) at 135 MeV versus the c.m.s. scattering angle calculated within the modified Glauber model [15] without (dashed lines) and with (full) Coulomb included in comparison with the data from [22].

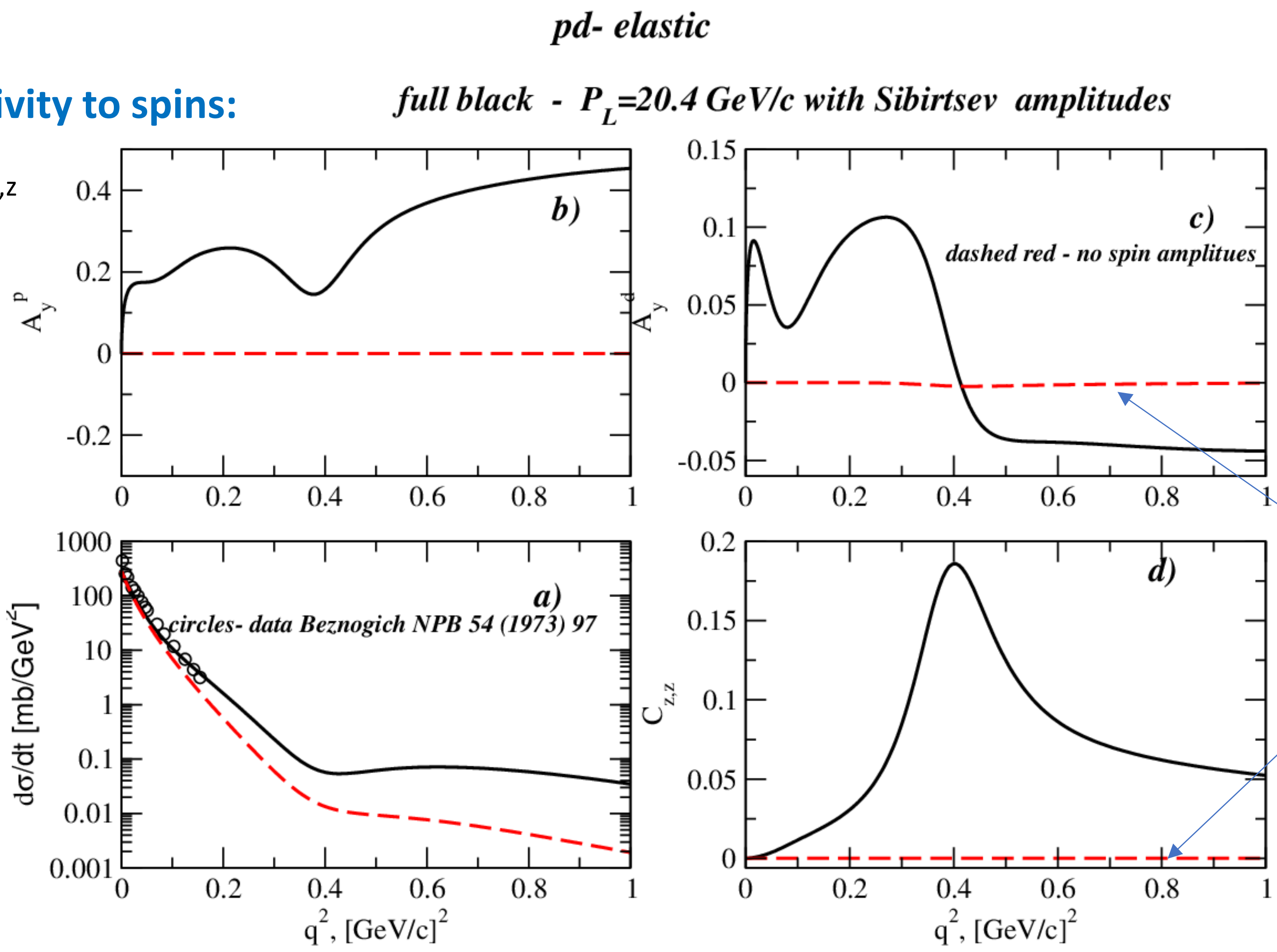
M.N. Platonova, V.I. Kukulin, PRC 81(2010) 014004



pd elastic scattering at SPD energies in Glauber model

High sensitivity to spins:

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



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

pN- amplitudes from A. Sibirtsev et al. EPJ A (2010)

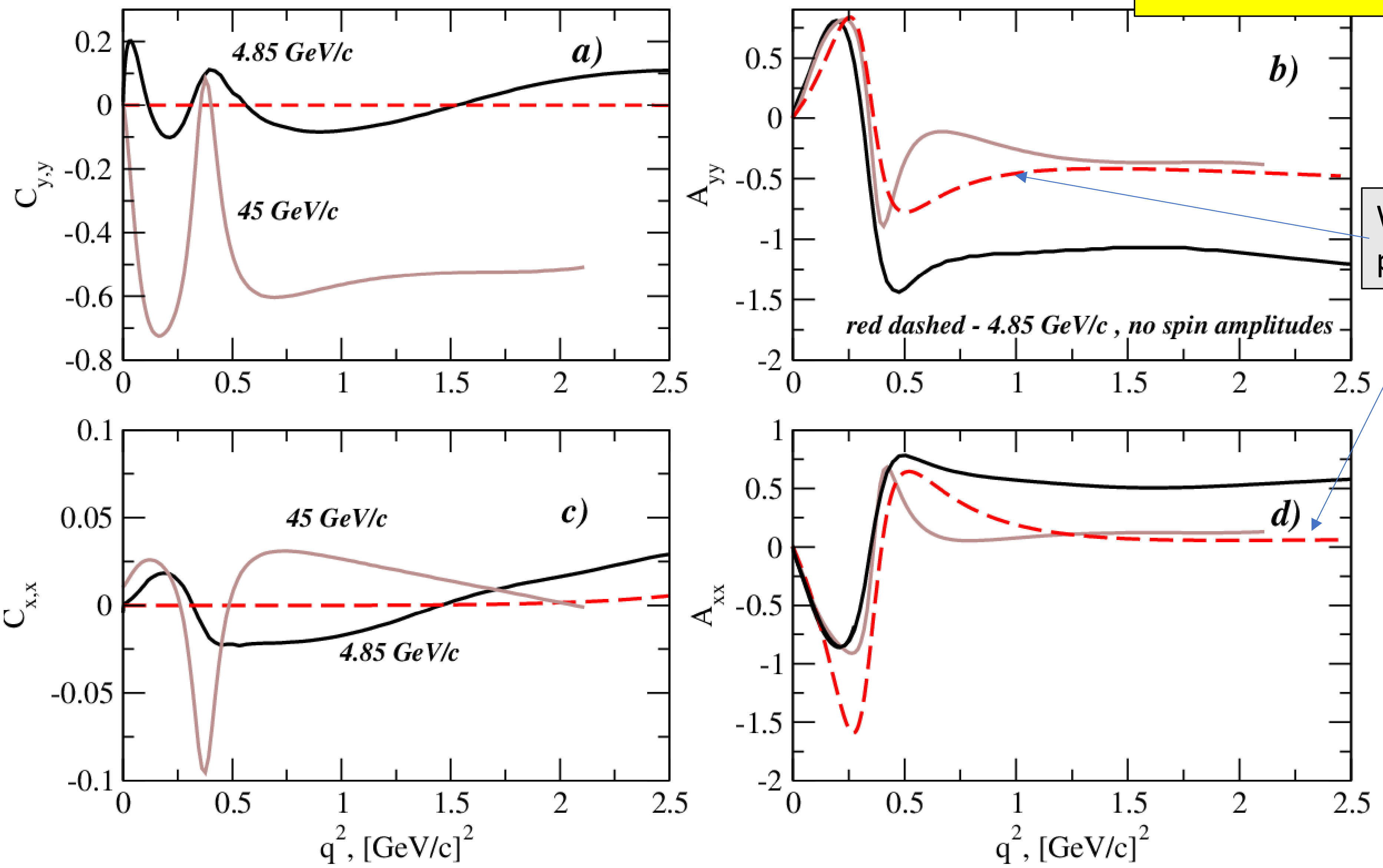
Without spin-dependent pN-amplitudes

Highly sensitive: $C_{y,y}$, $C_{x,x}$

pd- elastic *with A. Sibirtsev (2010) amplitudes*

dashed red - without spin dependent pN amplitudes 4.85 GeV/c

Much less sensitive:



Without spin pN amplitudes

Search for T-invariance violation in double polarized pd,^{3}Hed, dd- collisions and pN-elastic amplitudes

BAU problem: R_{exp}=6.7 10^{-10} , R_{SM}~ 10^{-19}

CP violation beyond the SM (or T-violation under CPT-inv.)

L. B. Okun, "Note concerning CP parity," Sov. J. Nucl. Phys. **1**, 670 (1965).

TVPC NN forces:
n^{165}Ho, P.R. Huffman et al. PRC 55 (1997)

No data on TVPC effect at SPD NICA energies

T-even P-even pN single spin-flip amplitude **phi5** and also **phi1**, **phi3** are necessary to extract the null-test signal of T-violation

Y. Uzikov, M. Platonova, A. Kornev *et al.*, Int. Jour. Mod. Phys. E https://doi.org/10.1142/S0218301324410039 (2024)

Y. N. Uzikov and A. Temerbayev, Phys. Rev. C **92**, 014002 (2015), arXiv: 1506.08303

Y. N. Uzikov and J. Haidenbauer, Phys. Rev. C **94**, 035501 (2016), arXiv: 1607.04409

Y. N. Uzikov and M. N. Platonova, JETP Lett. **118**, 785 (2023), arXiv: 2311.10841

M.N. Platonova, Yu. N. Uzikov, Chin. Phys. C 49, N3 (2025) 034108

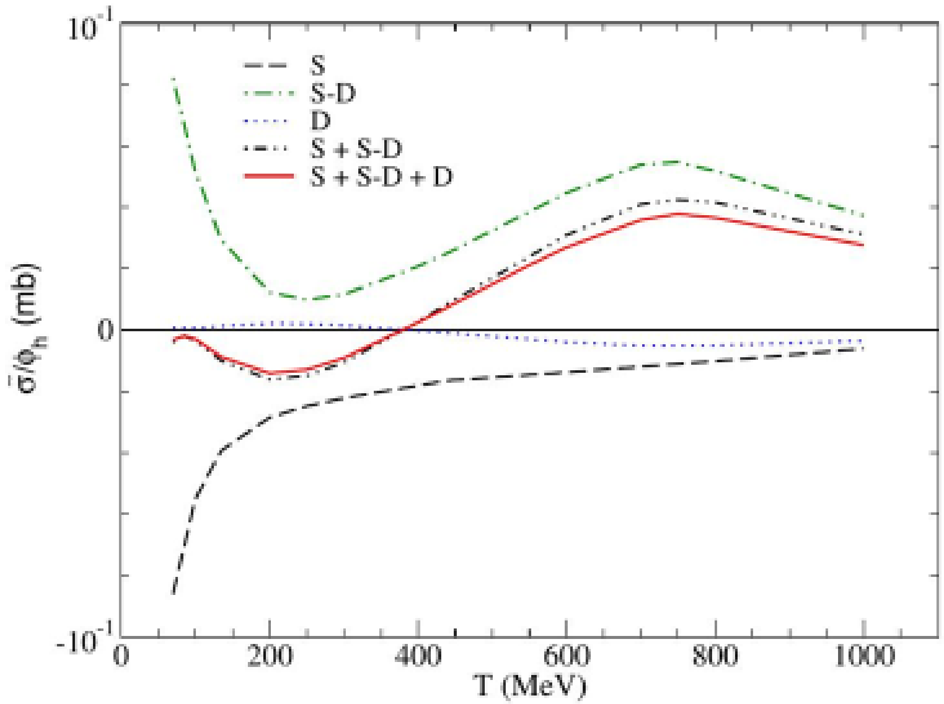
$p^{\uparrow}d^{\uparrow}$

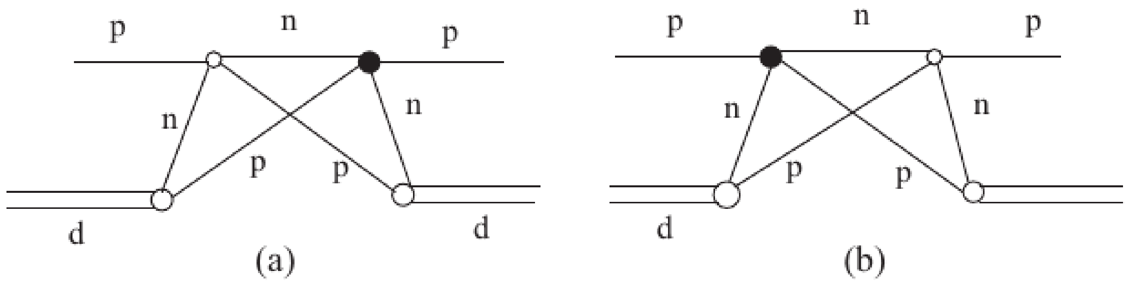
$$\sigma_{tot} = \underbrace{\sigma_0 + \sigma_1 \mathbf{p}^p \cdot \mathbf{P}^d + \sigma_2 (\mathbf{p}^p \cdot \hat{\mathbf{k}})(\mathbf{P}^d \cdot \hat{\mathbf{k}}) + \sigma_3 P_{zz}}_{T-even,P-even} + \underbrace{\widetilde{\sigma}_{tvpc} p_y^p P_{xz}^d}_{T-odd,P-even}$$

$$C' \approx i\phi_5 + iq/2m(\phi_1 + \phi_3)/2$$

Yu.N.U., A.A. Temerbayev, PRC 92 (2015) 014002;
Yu.N.U., J. Haidenabuer, PRC 94 (2016) 035501.

TVPC. The S- and D- wave contributions-I

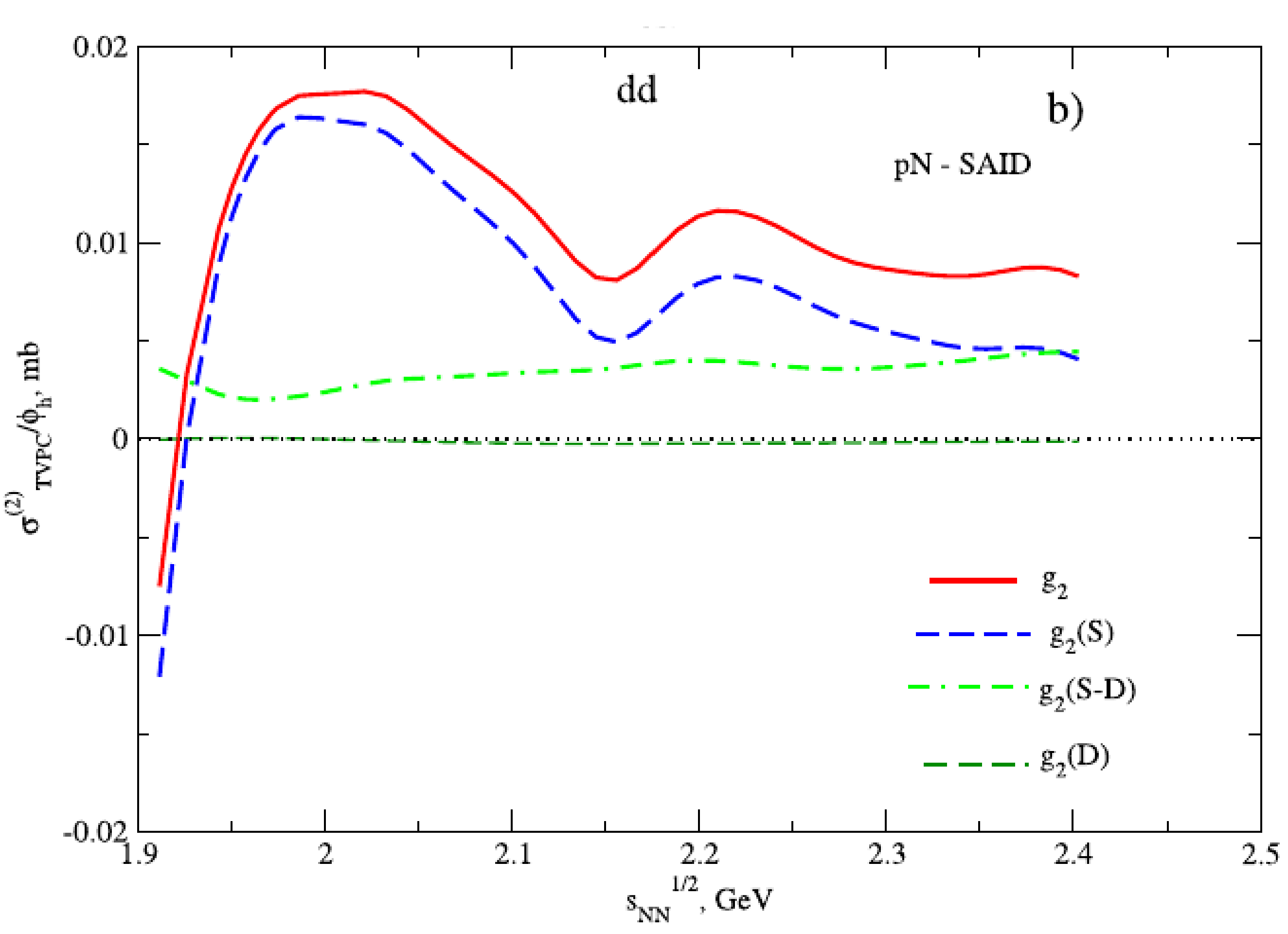




Null-test signal:

$$\widetilde{g} = \frac{i}{4\pi m_p} \int_0^{\infty} dq q^2 \Big[S_0^{(0)}(q) - \sqrt{8} S_2^{(1)}(q) - 4 S_0^{(2)}(q) + \sqrt{2}\frac{4}{3} S_2^{(2)}(q) + 9 S_1^{(2)}(q) \Big] [-C_n'(q) h_p + C_p'(q)(g_n - h_n)]$$

d↑d↑: ***M.N. Platonova, Yu. N. Uzikov, Chin. Phys. C 49, N3 (2025) 034108***



Null-test signal in dd:

$$g_2 = \frac{i}{2\pi m}\int_0^\infty dq q^2 \left[Z_0 + Z(q)\right]\zeta(q) h_N(q)\left(C'_n(q) + C'_p(q)\right)$$

T-even P-even

$$M_N = A_N + C_N \boldsymbol{\sigma}_p \cdot \hat{\mathbf{n}} + C'_N \boldsymbol{\sigma}_N \cdot \hat{\mathbf{n}},$$
$$+ B_N(\boldsymbol{\sigma}_p \cdot \hat{\mathbf{k}})(\boldsymbol{\sigma}_N \cdot \hat{\mathbf{k}}),$$
$$+ (G_N + H_N)(\boldsymbol{\sigma}_p \cdot \hat{\mathbf{q}})(\boldsymbol{\sigma}_N \cdot \hat{\mathbf{q}}),$$
$$+ (G_N - H_N)(\boldsymbol{\sigma}_p \cdot \hat{\mathbf{n}})(\boldsymbol{\sigma}_N \cdot \hat{\mathbf{n}});$$

$$A_N = (\phi_1 + \phi_3)/2, \quad B_N = (\phi_3 - \phi_1)/2,$$

$$C_N = i\phi_5, \;\; G_N = \phi_2/2, \;\; H_N = \phi_4/2;$$

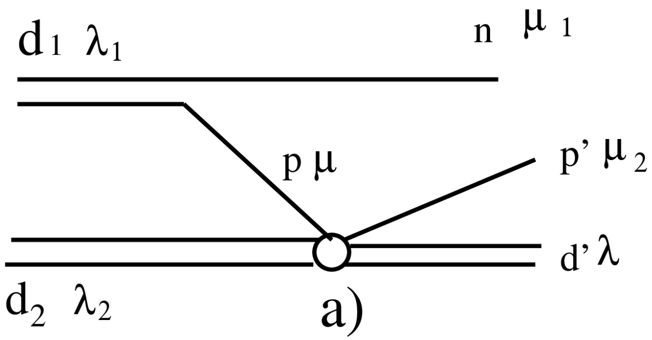
$$C'_N = C_N + \frac{iq}{2m} A_N.$$

T-odd P-even (TVPC)

$$t_N = h_N[(\boldsymbol{\sigma}_p \cdot \hat{\mathbf{k}})(\boldsymbol{\sigma}_N \cdot \hat{\mathbf{q}})$$
$$+ (\boldsymbol{\sigma}_p \cdot \hat{\mathbf{q}})(\boldsymbol{\sigma}_N \cdot \hat{\mathbf{k}}) - \frac{2}{3}(\boldsymbol{\sigma}_N \cdot \boldsymbol{\sigma}_p)(\mathbf{q} \cdot \hat{\mathbf{k}})]$$
$$+ g_N[\boldsymbol{\sigma}_p \times \boldsymbol{\sigma}_N] \cdot [\hat{\mathbf{q}} \times \hat{\mathbf{k}}](\boldsymbol{\tau}_p - \boldsymbol{\tau}_N)_z$$
$$+ g'_N(\boldsymbol{\sigma}_p - \boldsymbol{\sigma}_N) \cdot i[\hat{\mathbf{q}} \times \hat{\mathbf{k}}][\boldsymbol{\tau}_p \times \boldsymbol{\tau}_N]_z;$$

FACTORIZATION of the dd-npd SQUARED MATRIX ELEMENT to pd-pd and d.w.f.

IA =

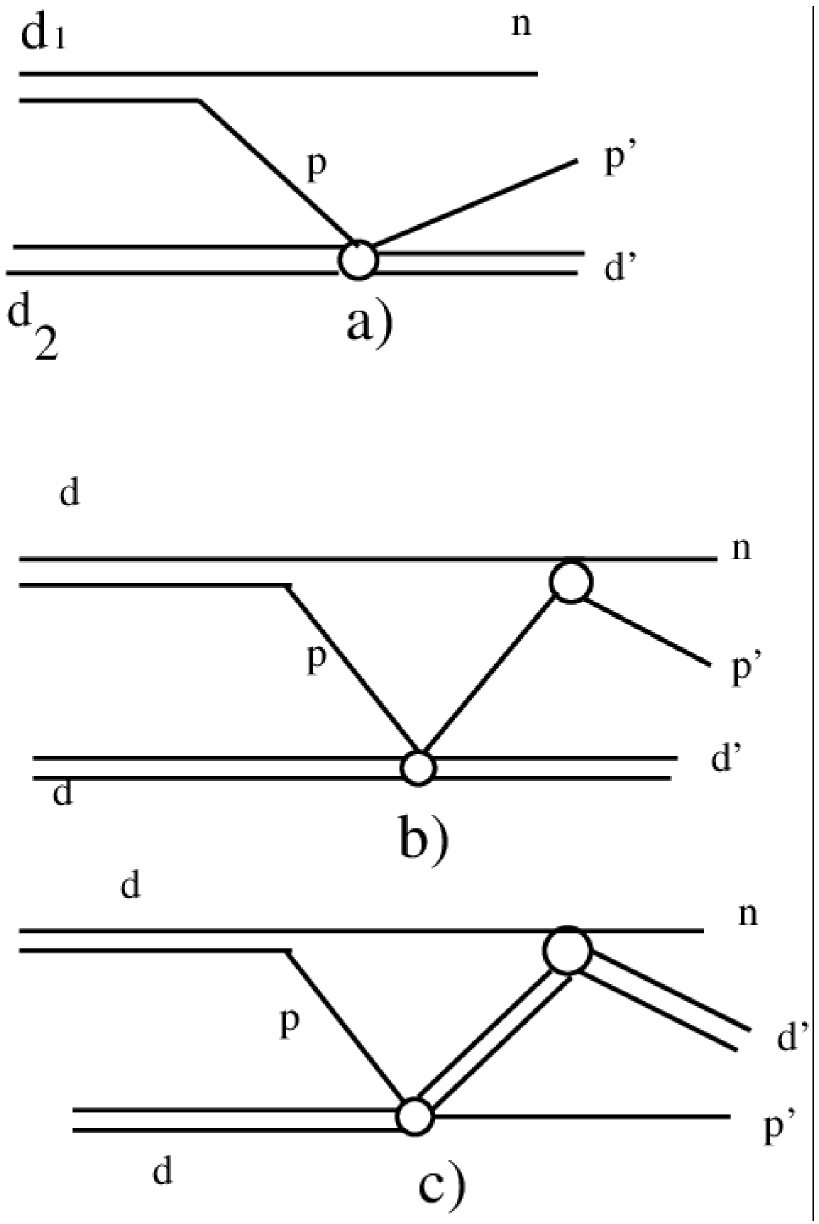


Transition matrix element for the $dd \to npd$ in IA, S-wave of d.w.f. :

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

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

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



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

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

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

$d_1^{\uparrow}$: Vector Polarized

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

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

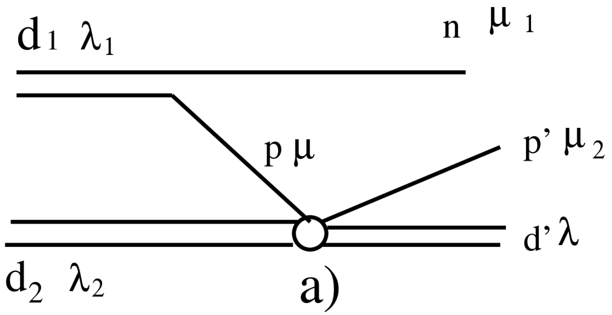
The differential cross section for collision $\vec{1}+\vec{1}$

$$I = I_0\Big[1+\frac{3}{2}P_yA_y+\frac{3}{2}P_y^TA_y^T+\frac{1}{2}P_yP_{yy}^TC_{y,yy}+\frac{1}{2}P_{yy}P_y^TC_{yy,y}+ \frac{9}{4}P_yP_y^TC_{y,y}+\frac{1}{3}P_{yy}A_{yy}+\frac{1}{3}P_{yy}^TA_{yy}^T+\frac{1}{9}P_{yy}P_{yy}^TC_{yy,yy}\Big]. \quad (3)$$

Similarly for collision $\vec{1}+\vec{\frac{1}{2}}$

$$I = I_0\Big[1+\frac{3}{2}P_yA_y+P_y^TA_y^T+\frac{1}{3}P_{yy}A_{yy}+\frac{3}{2}P_yP_y^TC_{y,y}+\frac{1}{3}P_{yy}P_y^TC_{yy,y}\Big]. \quad (4)$$

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 $A_y^{d_1}$:

$$A_y^{d_1}(\vec{d}_1d_2\to npd)=\frac{d\sigma_{\lambda_1=+1}-d\sigma_{\lambda_1=-1}}{d\sigma_{\lambda_1=+1}+d\sigma_{\lambda_1=0}+d\sigma_{\lambda_1=-1}}=\frac{2}{3}A_y^p(\vec{p}d\to pd)$$

Tenzor analyzing power

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

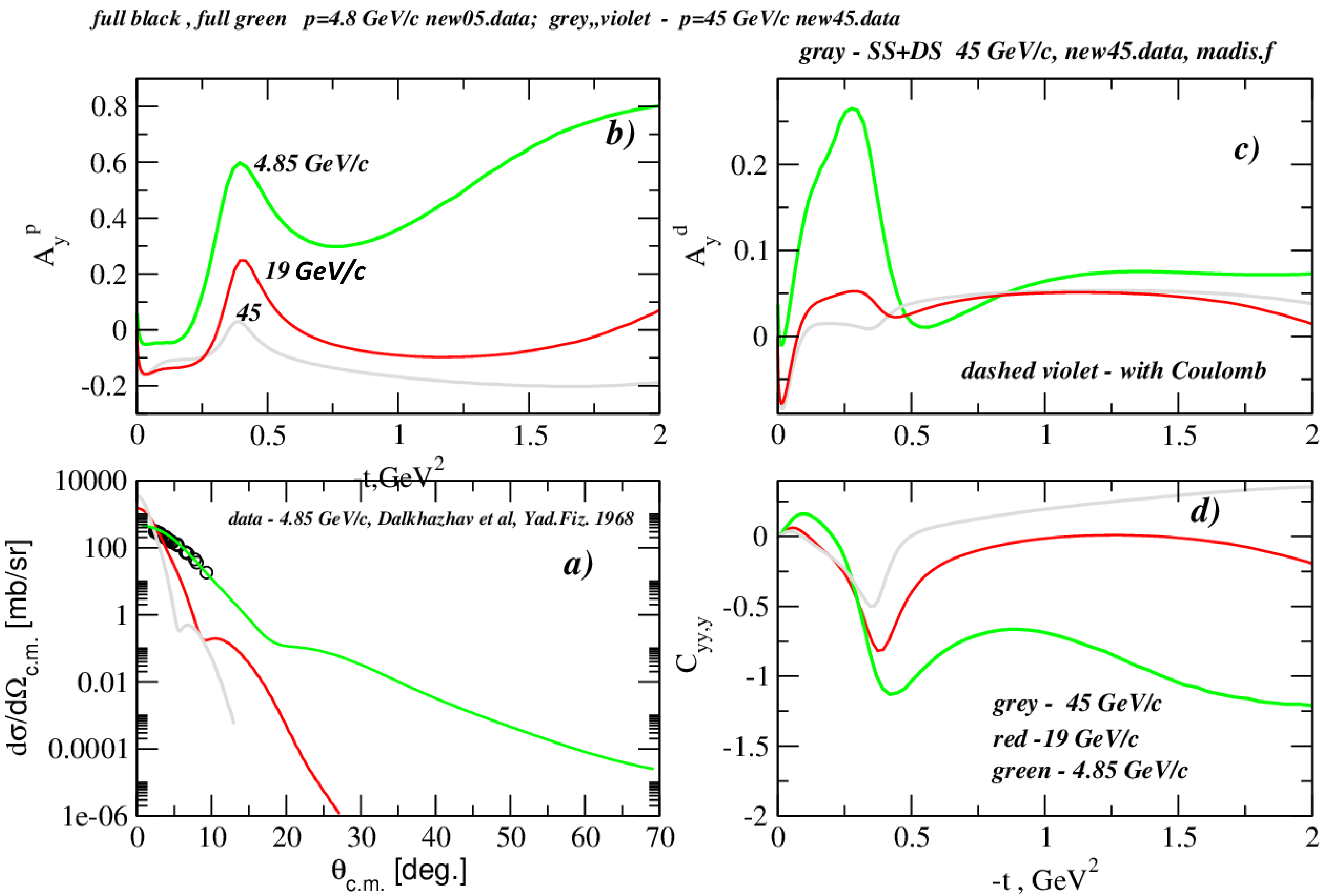
$C_{y,y}$ needs four options for dd-collision: (i) $P_y = P_y^T = \frac{2}{3}$ (ii) $P_y = \frac{2}{3}$, $P_y^T = -\frac{2}{3}$ and the same for $P_y = -\frac{2}{3}$. One can find the cross section $I_{\uparrow\uparrow}$ for the option (i), a $I_{\uparrow\downarrow}$ for (ii) from Eq. (4). Similarly for $C_{yy,y}$ we use four options with $P_y = 0, P_{yy} = \pm 1$ for d_1 and $P_y = \pm\frac{2}{3}, P_{yy} = 0$ for d_2. One gets

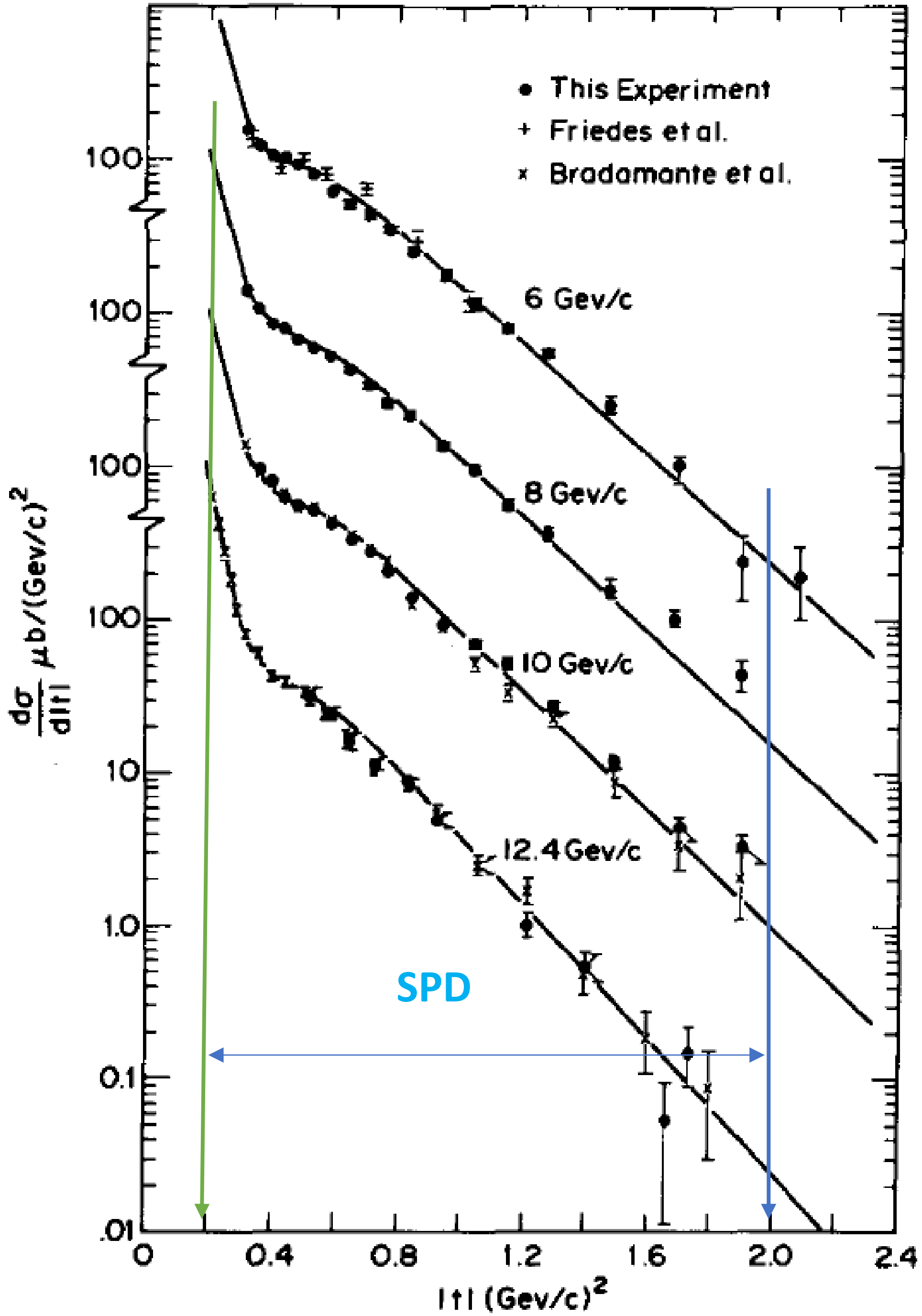
$$C_{y,y} = \frac{(I_{\uparrow\uparrow} - I_{\uparrow\downarrow}) + (I_{\downarrow\downarrow} - I_{\downarrow\uparrow})}{(I_{\uparrow\uparrow} + I_{\uparrow\downarrow}) + (I_{\downarrow\downarrow} + I_{\downarrow\uparrow})}, \quad (5)$$

$$C_{yy,y} = \frac{(I_{+\uparrow} - I_{+\downarrow}) + (I_{-\downarrow} - I_{-\uparrow})}{(I_{+\uparrow} + I_{+\downarrow}) + (I_{-\downarrow} + I_{-\uparrow})}. \quad (6)$$

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

Numerical results for pd- elastic





P. Chanowski et al. PLB 61 (1976)

nd-elastic scattering

Preliminary MC simulation: evening talk by A. Datta

SUMMARY

- NN-NN spin dependence is important for hadron spin physics.
- Can be studied at the first stage of SPD.
- Diffraction-> large cross section.
- **Spin observables** A_y, A_{yy} , $C_{y,y}$,$C_{y,yy}$ **of the reaction dd→npd are directly related to those for pd->pd in the IA :**

  A^p_y, A^d_y, $C_{y,y}$, $C_{y,yy}$ - highly sensitive to pN spin amplitudes (*phi5, phi1, phi3 for search of T-violation*)

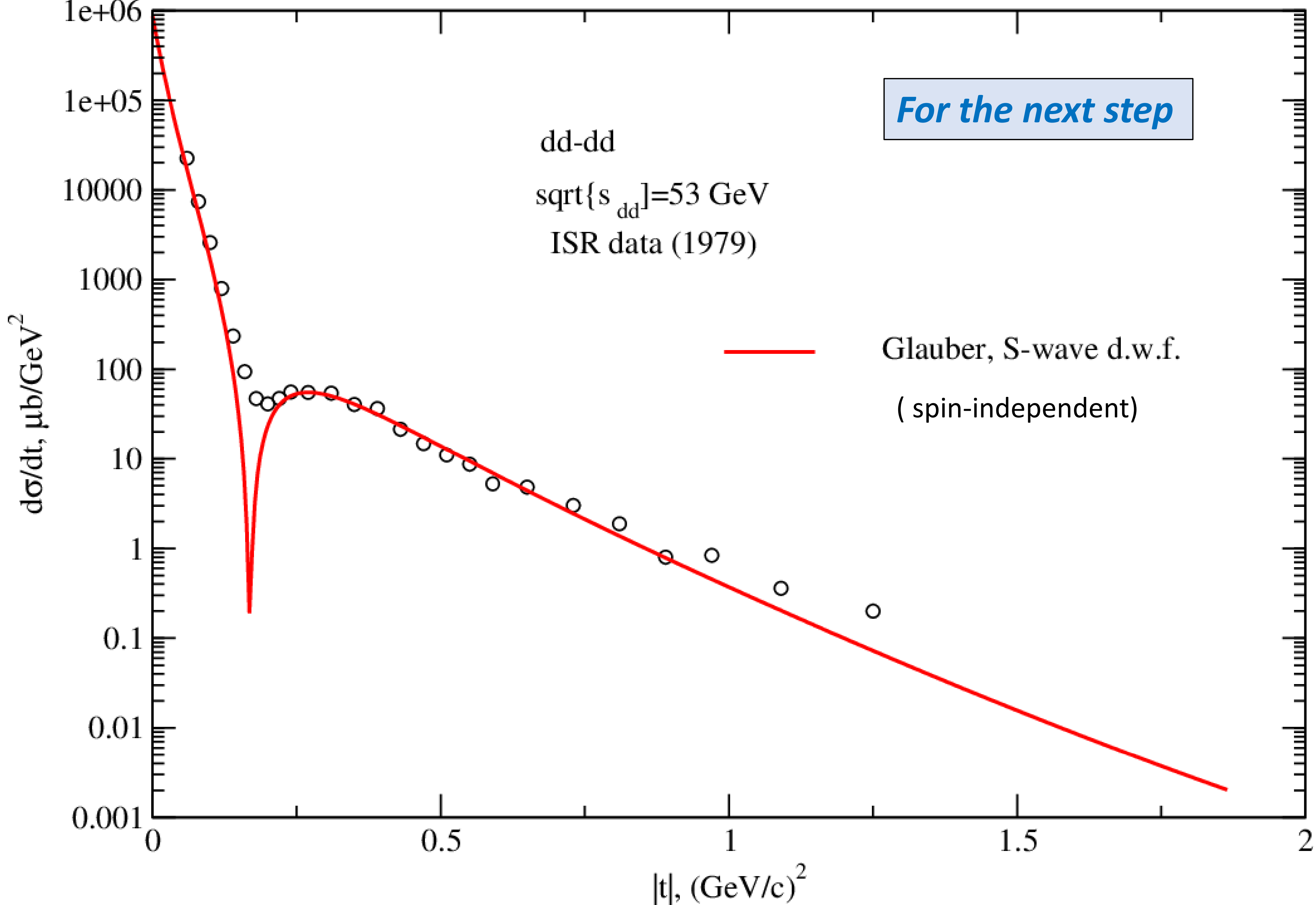
  A_{yy} , A_{xx} - stable observables, suitable for tensor polarimetry.
- The study can be extended to the dd- elastic scattering at SPD.

What else 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.
- Theory of dd-elastic scattering with full spin-dependence.

THANK YOU FOR ATTENTION!

APPENDIX



For the next step
dd-dd
sqrt{s dd]=53 GeV
ISR data (1979)
Glauber, S-wave d.w.f.
(spin-independent)
dσ/dt, μb/GeV²
|t|, (GeV/c)²
1e+06
1e+05
10000
1000
100
10
1
0.1
0.01
0.001
0
0.5
1
1.5
2

AT HIGHER ENERGIES $\sqrt{s_{pN}} = 3-10GeV^2$

A.Sibirtsev et al., Eur.Phys. J. A 45 (2010) 357

$$\phi_{ai}(s,t) = \pi\beta_{ai}(t)\frac{\xi_i(s,t)}{\Gamma(\alpha(t))}; i = \rho, \omega, a_2, f_2, P; a = 1-5;$$

$$\xi_i(t,s) = \frac{1+S_i\exp[-i\pi\alpha(t)]}{\sin[\pi\alpha_i(t)]}\left[\frac{s}{s_0}\right]^{\alpha_i(t)},$$

$$\alpha_i(t) = \alpha_i^0 + \alpha_i^{'}t,$$

$$\beta_{1i}(t) = c_{1i}\exp(b_{1i}t),$$

$$\beta_{2i}(t) = c_{2i}\exp(b_{2i}t)\frac{-t}{4m_N^2},$$

$$\beta_{3i}(t) = c_{3i}\exp(b_{3i}t),$$

$$\beta_{4i}(t) = c_{4i}\exp(b_{4i}t)\frac{-t}{4m_N^2},$$

$$\beta_{5i}(t) = c_{5i}\exp(b_{5i}t)\left[\frac{-t}{4m_N^2}\right]^{1/2}.$$

The Regge formalism for pp-helicity amplitudes at proton beams momenta p_L= 3-50 GeV/c includes single- Pomeron exchange and trajectories ρ, ω, f_2, a_2
pp- data on $d\sigma / dt$ **, A_N, A_{NN}**

PHYSICAL REVIEW C **82**, 014003 (2010)

Vector and tensor analyzing powers in deuteron-proton breakup at 130 MeV

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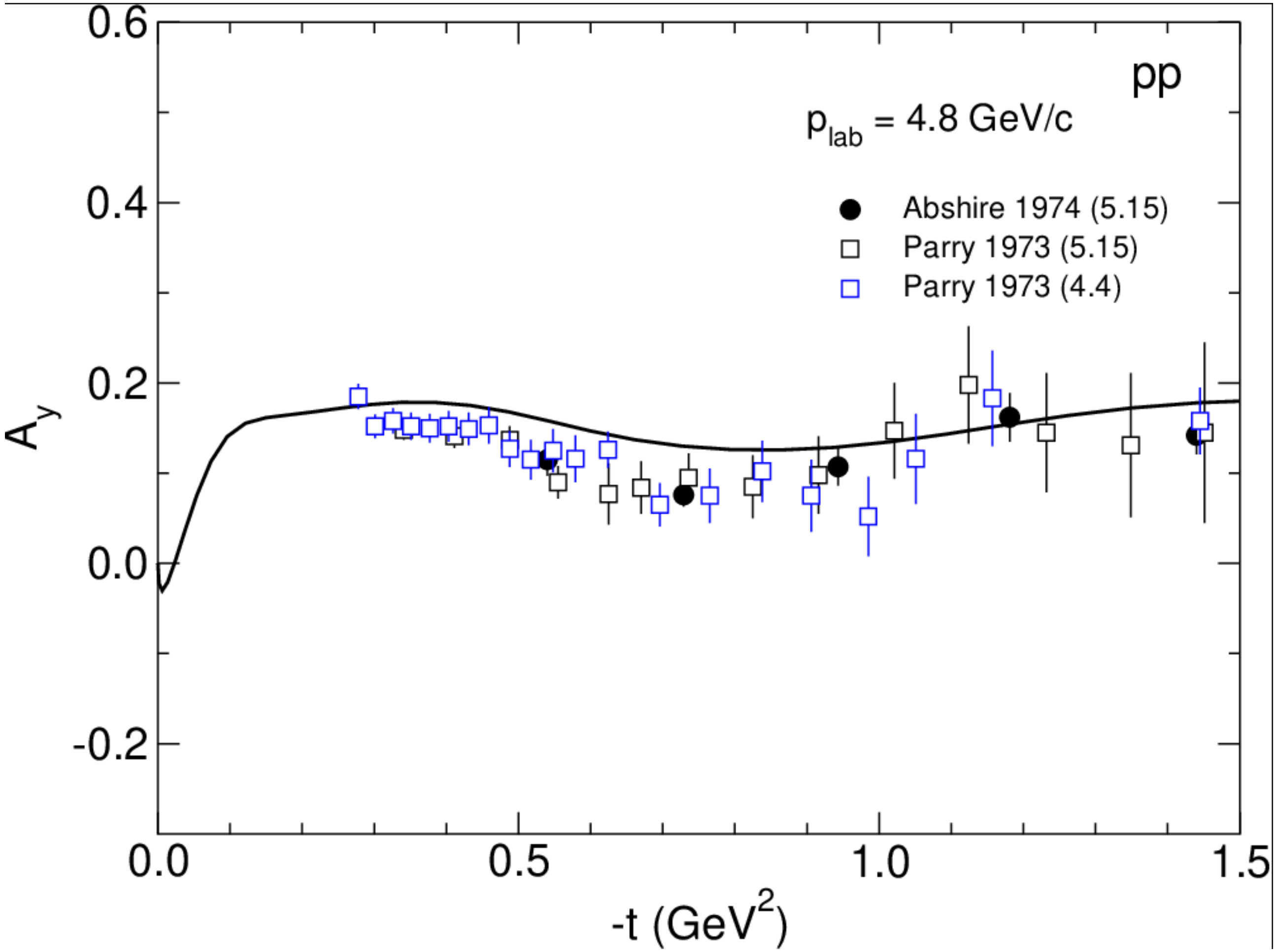
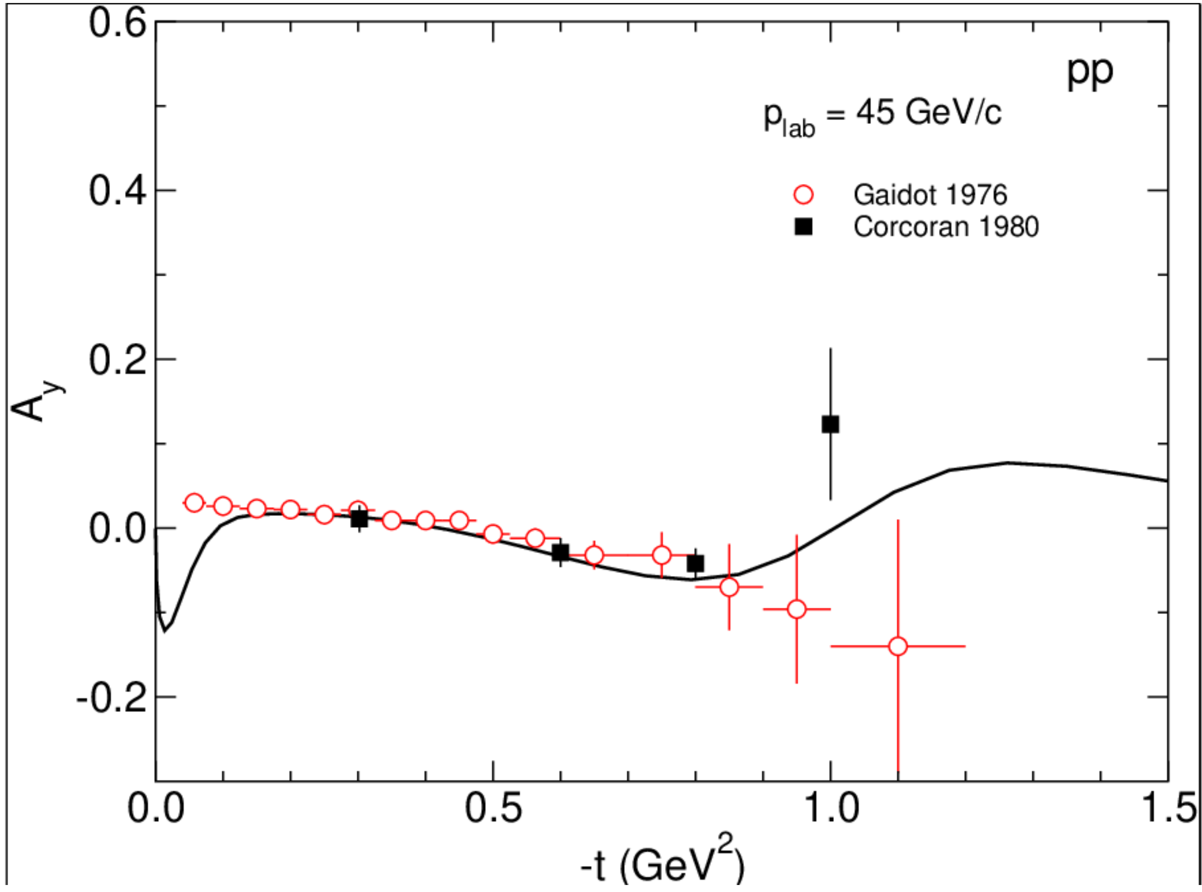
TABLE I. Set of the polarization states used in the $^1\mathrm{H}(\vec{d},pp)n$ breakup experiment. The maximum polarizations P_Z, P_{ZZ} (for 100% efficiency of transitions in the ion source) and corresponding combinations of the magnetic fields are shown. The x indicates that the magnetic field is switched on, whereas the—indicates that the magnetic field is switched off. I_f denotes the full beam intensity. In the case of transitions with medium field on, the beam intensity is reduced to 2/3 of I_f in the case of 100% efficient transitions.

Polarization states		Magnetic fields				Beam intensity
P_Z	P_{ZZ}	SF1	SF2	MF	WF	
0	0	–	–	–	–	I_f
$+\frac{1}{3}$	+1	x	–	–	–	I_f
$+\frac{1}{3}$	−1	–	x	–	–	I_f
0	+1	x	–	x	–	$\frac{2}{3}I_f$
0	−2	–	x	x	–	$\frac{2}{3}I_f$
$+\frac{2}{3}$	0	x	x	–	–	I_f
$-\frac{2}{3}$	0	–	–	–	x	I_f

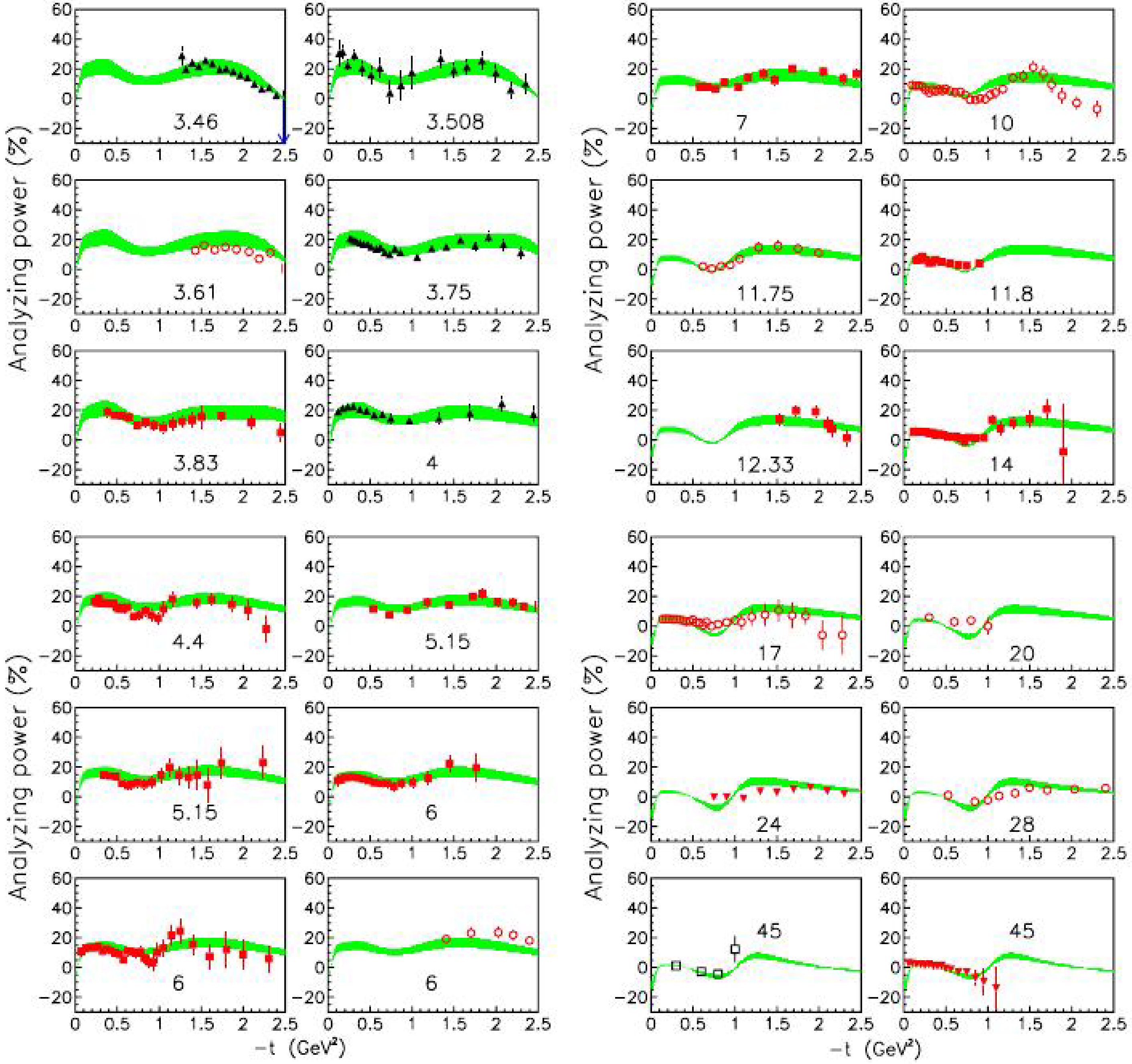
$P_{yy}=0$ for $P_y=+2/3, -2/3$

A. Sibirtsev et al, EPJA (2010)





A. Sibirtsev et al, EPJA (2010)



Two sets of deuterons beams:

$P_1 = +\frac{2}{3}, P_2 = +\frac{2}{3}$

N_1

$P_1 = +\frac{2}{3}, P_2 = -\frac{2}{3}$

N_2

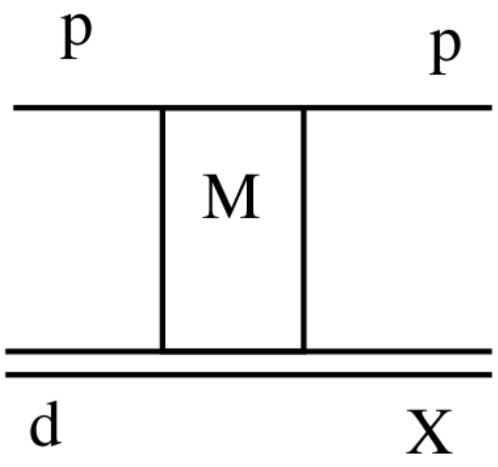
$$A^{dd}_{YY} = \frac{\mathcal{N}_1 - \mathcal{N}_2}{\mathcal{N}_1 + \mathcal{N}_2}$$

In terms of $d\sigma_{\lambda_1\lambda_2}$

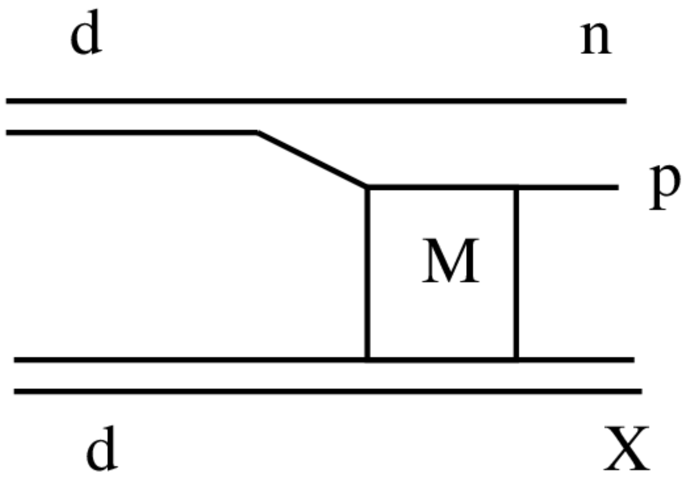
$$A^{dd}_{YY} = \frac{2\cdot 2d\sigma_{++} + 2d\sigma_{+0} + 2d\sigma_{0+} + d\sigma_{00} - (2\cdot 2d\sigma_{+-} + 2d\sigma_{+0} + 2d\sigma_{0-} + d\sigma_{00})}{2\cdot 2d\sigma_{++} + 2d\sigma_{+0} + 2d\sigma_{0+} + d\sigma_{00} + (2\cdot 2d\sigma_{+-} + 2d\sigma_{+0} + 2d\sigma_{0-} + d\sigma_{00})}$$

Yu.N. Uzikov, A.A. Temerbayev, Phys. Part. Nucl. 55 (2024) 895;
e-Print: 2311.12605 [nucl-th]

pd->pd subprocess in dd->npd



a)



b)

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

When the final neutron takes one half of the deuteron momentum
(S-wave dominance, suppressed p_T momenta), then
the pd->pd amplitude can be extracted with minimum distortions,

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