Search for T-invariance violation in double polarized pd, ^{3}He-d and dd scattering and test of pN spin amplitudes at NICA energies

Yu.N. Uzikov

Dzhelepov Laboratory of Nuclear Problems, JINR

uzikov@jinr.ru

In collaboration with M.N. Platonova (Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University)

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CONTENT

- Motivation: **Baryon Asymmetry of the Universe (BAU)**
- Time-violation Parity-conserving (TVPC) NN interaction
- Null-test signal of TVPC effects σ_{TVPC} in double polarized pd,^{3}Hed, dd scattering
- Glauber spin-dependent theory for TVPC signal σ_{TVPC} and numerical results
- Test of spin pN-amplitudes using Glauber theory of **pd->pd**
- NICA SPD: Possibility of studying spin observables of **pd->pd** via the **dd-> n+p+d**
- Summary and outlook

BAU - **Baryon Asymmetry of the Universe (WMAP+COBE)**:
A. Sakharov conditions. Problem.
New source of CP-violation (or T-violation under CPT) is required beyond the SM.

$$\eta_{\exp} = \frac{n_B - n_{\bar{B}}}{n_\gamma} \sim 6\times 10^{-10} \gg \eta_{SM} \sim 10^{-19}$$

~~CP~~ observed in K^0,B,D meson physics and baryons decay (2025): $\varepsilon \sim 10^{-3}$

Experiments for search of additional CP- violation:

* Permanent **EDM** of neutron, atoms, p,d, ^{3}He, leptons.
* Neutrino sector, δ_{CP} phase in PMNS matrix, lepton asymmetry via **B-L** conservation to **BAU**

Both are T-violating and P-parity violating (TVPV) effects

Much less attention was paid to T-violating P-conserving (TVPC) flavor conserving effects

first considered by L. Okun and J. Prentki, M. Veltman, L. Wolfenstein (1965) to explain CP violation in kaons; do not arise in SM, being detected at current level of exp. accuracy will be a **direct evidence of physics beyond the SM**

Experimental limits on TVPC effects are much weaker then for EDM

EFT: **Available experimental restrictions to EDM put no constrains on TVPC with a scenario “B” for EDM**
A. Kurylov et. al. PRD 63 (2001) 076007 -> in contrast, to R.S. Conti, I.B. Khriplovich, PRL 68 (1992) 3262

Review: S. N. Vergeles, N.N. Nikolaev, Yu.N. Obukhov, A.Yu. Silenko, O. Teryaev, UFN 66 (2023) 109

Direct experimental constraints on TVPC

- Test of the detailed balance $^{27}Al(p,\alpha)^{24}Mg$ and $^{24}Mg(\alpha,p)^{27}Al$, $\Delta = (\sigma_{dir} - \sigma_{inv})/(\sigma_{dir} + \sigma_{inv}) \leq 5.1 \times 10^{-3}$ (E.Blanke et al. PRL **51** (1983) 355). Numerous statistical analyses including nuclear energy-level fluctuations are required to relate to the NN T-odd P-even interaction (J.B. French et al. PRL **54** (1985) 2313) $\alpha_T < 2 \times 10^{-3}$ ($\bar{g}_\rho \leq 1.7 \times 10^{-1}$).

- $\vec{n}$ transmission through tensor polarized ^{165}Ho (P.R. Huffman et al. PRC **55** (1997) 2684)

$$\Delta = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-) \leq 1.2 \times 10^{-5}$$

$$\alpha_T \leq 7.1 \times 10^{-4} \quad (\text{or } \bar{g}_\rho \leq 5.9 \times 10^{-2})$$

- Elastic $\vec{p}n$ and $\vec{n}p$ scattering, A^p, P^p, A^n, P^n; CSB ($A = A^n - A^p$) (M. Simonius, PRL **78** (1997) 4161)

$$\alpha_T \leq 8 \times 10^{-5} \ (\text{ or } \bar{g}_\rho < 6.7 \times 10^{-3})$$

Remark: **In view of BAU problem, the TVPC can be much stronger at higher energies (NICA) , however, no data are available so far at NICA.**

Null-test TVPC signal in double polarized scattering: pd, ^{3}He-d and dd

Null-test signal of Time-invariance Violating Parity Conserving (TVPC) effects is a part of total cross section of pd-, ^{3}Hed-, dd- scattering with one colliding particle being vector polarized (p^b_y) and another one tensor polarized (P_{xz}).

V. Baryshevsky, Sov. J. Nucl. Phys. 38 (1983) 699; A.L. Barabanov, Yad.Fiz. 44 (1986) 1163.
H.E. Conzett, PRC 48 (1993) 423

Advantages:

- Only one observable. Not necessary to measure two observables (A_y and P_y) and determine their very small difference (for T-invariance $A_y = P_y$).
- Cannot be imitated by ISI@FSI.

To compare: EDM (electric dipole moment) of particles and nuclei is a signal of T- and P-violation.

T-invariance: $< f \,|\, S \,|\, i > = < i_T \,|\, S \,|\, f_T >$

On-shell TVPC NN interaction (M. Beyer, NPA , 1993)

$$t_{pN} = \underbrace{h[(\boldsymbol{\sigma}_1 \cdot \mathbf{p})(\boldsymbol{\sigma}_2 \cdot \mathbf{q}) + (\boldsymbol{\sigma}_2 \cdot \mathbf{p})(\boldsymbol{\sigma}_1 \cdot \mathbf{q}) - (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)(\mathbf{p} \cdot \mathbf{q})]}_{h1-meson} +$$

$$+ \underbrace{g[\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2] \cdot [\mathbf{q} \times \mathbf{p}](\boldsymbol{\tau}_1 - \boldsymbol{\tau}_2)_z}_{abnormal\, parity\, OBE\, exchanges} + \underbrace{g'(\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2) \cdot i\,[\mathbf{q} \times \mathbf{p}][\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2]_z}_{\rho-meson}$$

$\mathbf{p} = \mathbf{p}_f + \mathbf{p}_i$, $\mathbf{q} = \mathbf{p}_f - \mathbf{p}_i$

$$T: \vec{p}_i \to -\vec{p}_f, \vec{p}_f \to -\vec{p}_i \Rightarrow \vec{p} \to -\vec{p}, \vec{q} \to \vec{q}$$

$$\vec{n} = [\vec{q} \times \vec{p}] \to -\vec{n}, \vec{\sigma} \to -\vec{\sigma};$$

g'-term is T-odd due to:

$$< n, p|[\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2]_z|p, n >= -i2, \;\; < p, n|[\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2]_z|n, p >= i2,$$

in contrast to strong interaction, $M^{str}_{pn\to np} = M^{str}_{np\to pn}$.

TVPC constants h, g, g’ are not known.

TIVOLI: pd-experiment was planned at COSY, Tp=135 MeV; ***P. Lenisa et al. EPJ- Tech. Instr. (2019) 6***

TVPC ($\equiv$ T-odd P-even) interactions in terms of boson exchanges :
M.Simonius, Phys. Lett. **58B** *(1975) 147; PRL* **78** *(1997) 4161*

$\star$ $J \geq 1$
$\star$ π, σ-exchanges do not contribute
$\star$ The lowest mass meson allowed is the ρ-meson $/I^G(J^{PC}) = 0^+(1^{--})/$
$\star$ Natural parity exchange $(P = (-1)^J)$ must be charged

The TVPC Born NN-amplitude

$$\widetilde{V}_\rho^{TVPC} = \bar{g}_\rho \frac{g_\rho \kappa}{2M} [\vec{\tau}_1 \times \vec{\tau}_2]_z \frac{1}{m_\rho^2 + |\vec{q}|^2} \times i[(\vec{p}_f + \vec{p}_i) \times \vec{q}] \cdot (\vec{\sigma}_1 - \vec{\sigma}_2) \quad (1)$$

C-odd (hence T-odd), only charged ρ's. No contribution to the nn or pp.

$\vec{q} = \vec{p}_f - \vec{p}_i$ dissappeares at $\vec{q} = 0$

Axial $a_1(1170)$-meson exchange $I^G(J^{PC}) = 0^-(1^{+-})$ ...

The most general structure contains 18 terms *P. Herczeg, Nucl.Phys.* **75** *(1966) 655*

TVPC in pd- transmission experiment /under P-conservation/

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

Null-test signal

TIVOLI – exp. planned at COSY, T_p=135 MeV; P. Lenisa et al. EPJ Tech. Instr. (2019) 6

$$OZ \uparrow\uparrow \vec{k}, OY \uparrow\uparrow \vec{p}^p; OX \uparrow\uparrow [\vec{p}^p \times \vec{k}]$$

k – beam momentum

p^p (P^d) - proton (deuteron) polarization

$$A_{TVPC} = (T^+ - T^-)/(T^+ + T^-),$$

T^+ (T^-) – transmission factor for $p_y^p P_{xz} > 0$ ($p_y^p P_{xz} < 0$).

The goal is to improve the direct upper bound on TVPC by one order of magnitude up to $A_{TVPC} \sim 10^{-6}$

Static spins: The P^d_y has to be diminished also to 10^{-6}

General Decomposition of the pd total X-section (k = collision axis)

$$\sigma_{\rm tot} = \sigma_0 + \sigma_{\rm TT}\left[\left(\mathbf{P}^{\rm d}\cdot\mathbf{P}^{\rm p}\right) - \left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right)\right]$$ PC TT

$$+ \sigma_{\rm LL}\left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) + \sigma_{\rm T} T_{mn} k_m k_n$$ LL & PC tensor

$$+ \sigma^{\rm p}_{\rm PV}\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) + \sigma^{\rm d}_{\rm PV}\left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)$$ PV single spin at NICA

$$+ \sigma^{\rm T}_{\rm PV}\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) T_{mn} k_m k_n$$ PV tensor

$$+ \sigma_{\rm TVPV}\left(\mathbf{k}\cdot\left[\mathbf{P}^{\rm d}\times\mathbf{P}^{\rm p}\right]\right)$$ TVPV

TVPC $$+ \underline{\sigma_{\rm TVPC} k_m T_{mn} \epsilon_{nlr} P^{\rm p}_l k_r} \,.$$ (TRIC Proposal in Juelich)

$$k_m T_{mn} \epsilon_{nlr} P^{\rm p}_l k_r = T_{xz} P^{\rm p}_y - T_{yz} P^{\rm p}_x$$

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N. Nikolaev, F. Rathman, A. Silenko, Yu. U., PLB 811 (2020) 135983

The main idea: precessing polarization of the deuteron beam in horizontal plane & Fourier analysis

TIVOLI pd-exp. planned at COSY, T_p=135 MeV
P. Lenisa et al. EPJ Tech. Instr. (2019) 6

Previous theory for pd:

M. Beyer, Nucl.Phys. A 560 (1993) 895;
d-breakup channel only, 135 MeV;
Y.-Ho Song, R. Lazauskas, V.Gudkov, PRC 84 (2011) 025501; Faddeev eqs., nd-scattering at 100 keV; pd at 2 MeV

We use the Glauber theory:
A.A. Temerbayev, Yu.N. Uzikov, Yad. Fiz. **78** (2015) 38;
M.N. Platonova, V.I. Kukulin, Phys. Rev. C **81**, 014004 (2010)

Yu.N. U., A.A. Temerbayev, PRC 92 (2015); **pd**
Yu.N. U., J. Haidenbauer, PRC 94 (2016); **pd**
Yu.N. U., M.N. Platonova, JETP Lett. 118 (2023) 11 ; **^{3}He-d**
Yu.N. U.,M.N. Platonova et al. Int. J. Mod. Phys. E (2024); **dd**
M.N. Platonova, Yu.N. U. Chin. Phys. C 49, N3 (2025) 034108; **dd**

Calculation of TVPC signal for pd-transmission experiment (under P-invariance)

[Yu. N. Uzikov, A.A. Temerbayev, Phys.Rev. C 92 (2015) 014002]

T-even (TCPC) amplitude of forward pd-elastic scattering (has to be multiplied by the polarization vector of the deuteron $\varepsilon^*_\beta(\varepsilon_\alpha)$):

$$M_{\beta\alpha}(0) = g_1\delta_{\beta\alpha} + (g_2 - g_1)\hat{k}_\beta\hat{k}_\alpha + ig_3\sigma_i\epsilon_{\beta\alpha i} + i(g_4 - g_3)\sigma_i\hat{k}_i\hat{k}_j\epsilon_{\beta\alpha j}$$

$$\sigma_{tot} = \underbrace{\sigma_0 + \sigma_1 p_y^p p_y^d + \sigma_3 P_{zz}}_{\text{TCPC}} + \underbrace{\sigma_{TVPC} p_y^p P_{xz}}_{\text{TVPC null-test signal}}$$

Generalized optical theorem:

$$\sigma_0 = \frac{4}{3}\sqrt{\pi}\,\mathrm{Im}(2g_1 + g_2), \quad \sigma_1 = -4\sqrt{\pi}\,\mathrm{Im}g_3, \quad \sigma_3 = 4\sqrt{\pi}\,\mathrm{Im}(g_1 - g_2).$$

Additional TVPC-term to $M_{\beta\alpha}(0)$: $\tilde{g}_5\sigma_i\hat{k}_\gamma(k_\alpha\epsilon_{\gamma\beta i} + k_\beta\hat{k}_\gamma\epsilon_{\gamma\alpha i})$

$$\sigma_{TVPC} = -4\sqrt{\pi}\frac{2}{3}\,\mathrm{Im}\tilde{g}_5$$

No interference with T-even P-even terms

To measure $A_{TVPC} = (T^+ - T^-)/(T^+ + T^-)$,

T^+ (T^-) – transmission factor for $p_y^p P_{xz} > 0$ ($p_y^p P_{xz} < 0$).

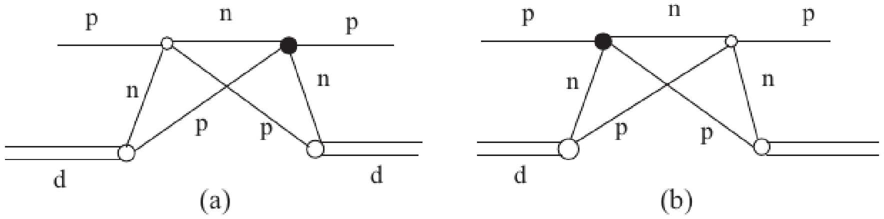
The goal is to improve the direct upper bound on TVPC by one order of magnitude up to $A_{TVPC} \sim 10^{-6}$

TVPC signal in pd-collision

$$\widetilde{g}_5 = \frac{1}{(2\pi)^{3/2}} \int d^2q' \left\langle \mu' = \frac{1}{2}, \lambda' = 0 \middle| M(\mathbf{q}=0, \mathbf{q}'; \mathbf{S}, \boldsymbol{\sigma}) \middle| \mu = -\frac{1}{2}, \lambda = 1 \right\rangle$$

$$\widetilde{g}_5 = \frac{i}{4\pi m_p} \int_0^\infty dq q^2 \Big[S_0^{(0)}(q) - \sqrt{8} S_2^{(1)}(q) - 4 S_0^{(2)}(q) + \sqrt{2}\frac{4}{3} S_2^{(2)}(q) + 9 S_1^{(2)}(q) \Big] [-C_n'(q) h_p + C_p'(q)(g_n - h_n)]$$

In the Glauber theory for two-step scattering (single scattering gives zero)



Deuteron form factors:

$$S_0^{(0)}(q) = \int_0^\infty dr\, u^2(r) j_0(qr),$$

$$S_0^{(2)}(q) = \int_0^\infty dr\, w^2(r) j_0(qr),$$

$$S_2^{(1)}(q) = 2\int_0^\infty dr\, u(r) w(r) j_2(qr),$$

$$S_2^{(2)}(q) = -\frac{1}{\sqrt{2}} \int_0^\infty dr\, w^2(r) j_2(qr),$$

$$S_1^{(2)}(q) = \int_0^\infty dr\, w^2(r) j_1(qr)/(qr).$$

TCPC pN-amplitude:

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

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

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

+ TVPC (h_N, g_N, g'_N)

The g'_N-term is zero due to symmetry properties

General decomposition of the total dd cross section

$$\sigma_{tot} = \sigma_0 + \sigma_{\perp\perp}[\mathbf{P}^{(1)} \cdot \mathbf{P}^{(2)} - (\mathbf{P}^{(1)} \cdot \mathbf{k})(\mathbf{P}^{(2)} \cdot \mathbf{k})]$$
$$+\sigma_{LL}(\mathbf{P}^{(1)} \cdot \mathbf{k})(\mathbf{P}^{(2)} \cdot \mathbf{k}) + \sigma_{T_1} P^{(1)}_{mn} k_m k_n + \sigma_{T_2} P^{(2)}_{mn} k_m k_n +$$
$$\sigma_{T_1T_2} P^{(1)}_{mn} P^{(2)}_{mn} + \sigma_T P^{(1)}_{mn} k_m k_n P^{(2)}_{ij} k_i k_j + \sigma^{(1)}_{PV} \mathbf{P}^{(1)} \cdot \mathbf{k} + \sigma^{(2)}_{PV} \mathbf{P}^{(2)} \cdot \mathbf{k} +$$
$$\sigma^{(T_1P_2)}_{PV} \mathbf{P}^{(2)} \cdot \mathbf{k} P^{(1)}_{mn} k_m k_n + \sigma^{(T_2P_1)}_{PV} \mathbf{P}^{(1)} \cdot \mathbf{k} P^{(2)}_{mn} k_m k_n +$$
$$\sigma_{TVPV}(\mathbf{k} \cdot [\mathbf{P}^{(1)} \times \mathbf{P}^{(2)}]) +$$
$$\sigma^{(1,2)}_{TVPC} k_m P^{(1)}_{mn} \epsilon_{nlr} P^{(2)}_l k_r + \sigma^{(2,1)}_{TVPC} k_m P^{(2)}_{mn} \epsilon_{nlr} P^{(1)}_l k_r .$$

T-even P-even (first two lines)

PV (lines three and four)

TVPV

TVPC

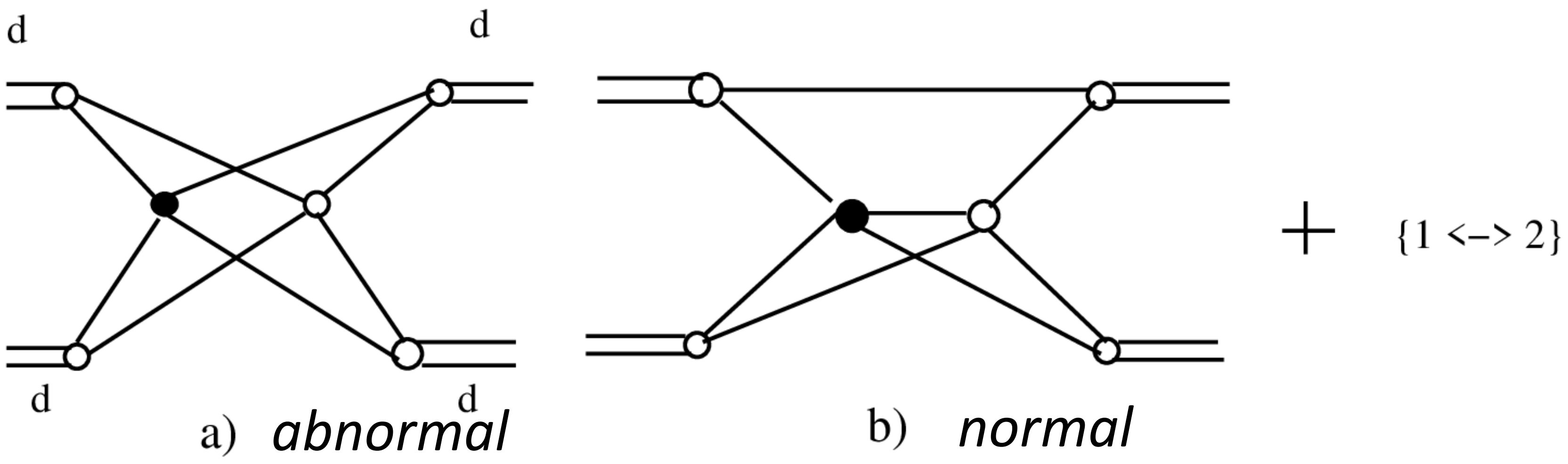
$$k_m P^{(1)}_{mn} \varepsilon_{nlr} P^{(2)}_l k_r = P^{(1)}_{xz} P^{(2)}_y - P^{(1)}_{yz} P^{(2)}_x$$

Simplifications: $\sigma_{LL}, \sigma_{\perp\perp}$ *are excluded at* $\vec{P}^{(1)}\vec{k} = 0, \vec{P}^{(2)}\vec{k} = 0$

$\sigma_{0}, \sigma_{T_1}, \sigma_{T_2}, \sigma_{T_1T_2}, \sigma_T$ excluded in asymmetry A_{TVPC}

TVPV and PV are negligible ($A \sim 10^{-7}$);

Spin-dependent Glauber theory for the amplitudes g_1 and g_2



Generalized optical theorem:

$$\begin{aligned}\sigma_{\rm TVPC} &= 4\sqrt{\pi}{\rm Im\,Tr}(\hat{\rho}_i\hat{M}_{\rm TVPC}(0)) \\ &= 4\sqrt{\pi}{\rm Im}\left(\frac{g_1}{9}\right)(P^{(1)}_{xz}P^{(2)}_{y} - P^{(1)}_{zy}P^{(2)}_{x}) \\ &+ 4\sqrt{\pi}{\rm Im}\left(\frac{g_2}{9}\right)(P^{(2)}_{xz}P^{(1)}_{y} - P^{(2)}_{zy}P^{(1)}_{x}).\end{aligned}$$

TVPC amplitudes for dd

$$g_1 = g_1^{(n)} + g_1^{(a)}$$
$$g_2 = g_2^{(n)} + g_2^{(a)}$$

$$g_1^{(n)} = \frac{i}{\sqrt{2}\pi m_N} Z_0 \int_0^\infty dq q^2 \zeta(q)[h_p(q)C_n(q) + h_n(q)C_p(q)],$$

$$g_2^{(n)} = \frac{i}{\sqrt{2}\pi m_N} Z_0 \int_0^\infty dq q^2 \zeta(q)[h_p(q)C'_n(q) + h_n(q)C'_p(q)],$$

$$g_1^{(a)} = \frac{i}{\sqrt{2}\pi m_N} \int_0^\infty dq q^2 Z(q)\zeta(q)[h_p(q)C_p(q) + h_n(q)C_n(q)],$$

$$g_1^{(a)} = \frac{i}{\sqrt{2}\pi m_N} \int_0^\infty dq q^2 Z(q)\zeta(q)[h_p(q)C_p(q) + h_n(q)C_n(q)],$$

TVPC — ordinary hadron pN ampl.

Form factors

$$Z(q) = S_0^{(0)}(q) - \frac{1}{2}S_0^{(2)}(q) - \frac{1}{\sqrt{2}}S_2^{(1)}(q) + \sqrt{2}S_2^{(2)}(q),$$

$$Z_0 = Z(0) = S_0^{(0)}(0) - \frac{1}{2}S_0^{(2)}(0) = 1 - \frac{3}{2}P_D,$$

$$\zeta(q) = S_0^{(0)}(q) + \frac{1}{10}S_0^{(2)}(q) - \frac{1}{\sqrt{2}}S_2^{(1)}(q) + \frac{\sqrt{2}}{7}S_2^{(2)}(q) + \frac{18}{35}S_4^{(2)}(q)$$

M.N. Platonova, Yu.N. Uzikov, Chin.Phys. C49 N3 (2025)034108

Numerical results

Ordinary NN helicity amplitudes:

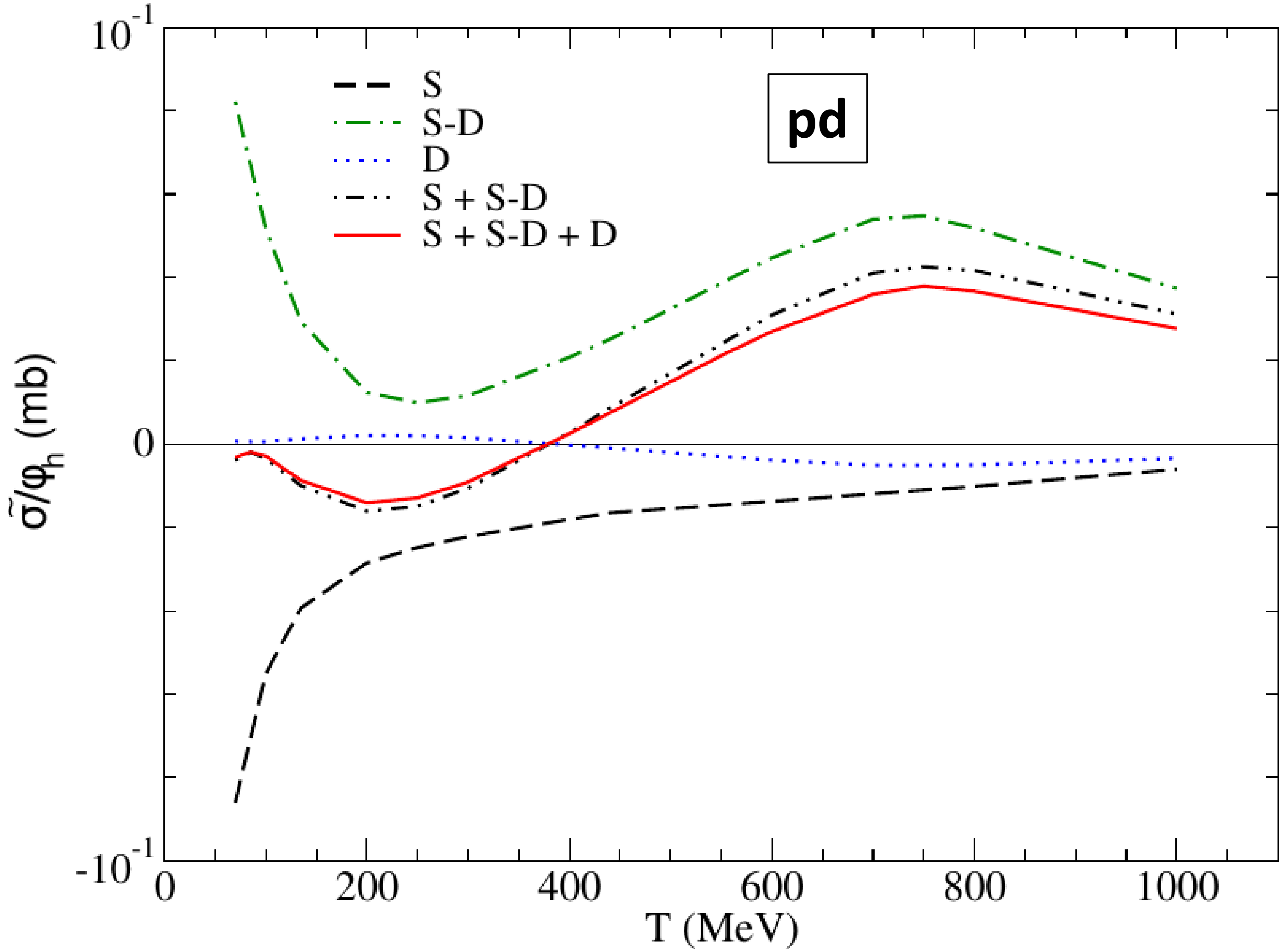
SAID: Arndt R.A. et al. PRC 76 (2007) 025209; $\sqrt{s_{NN}} = 1.9 - 2.4 GeV$

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

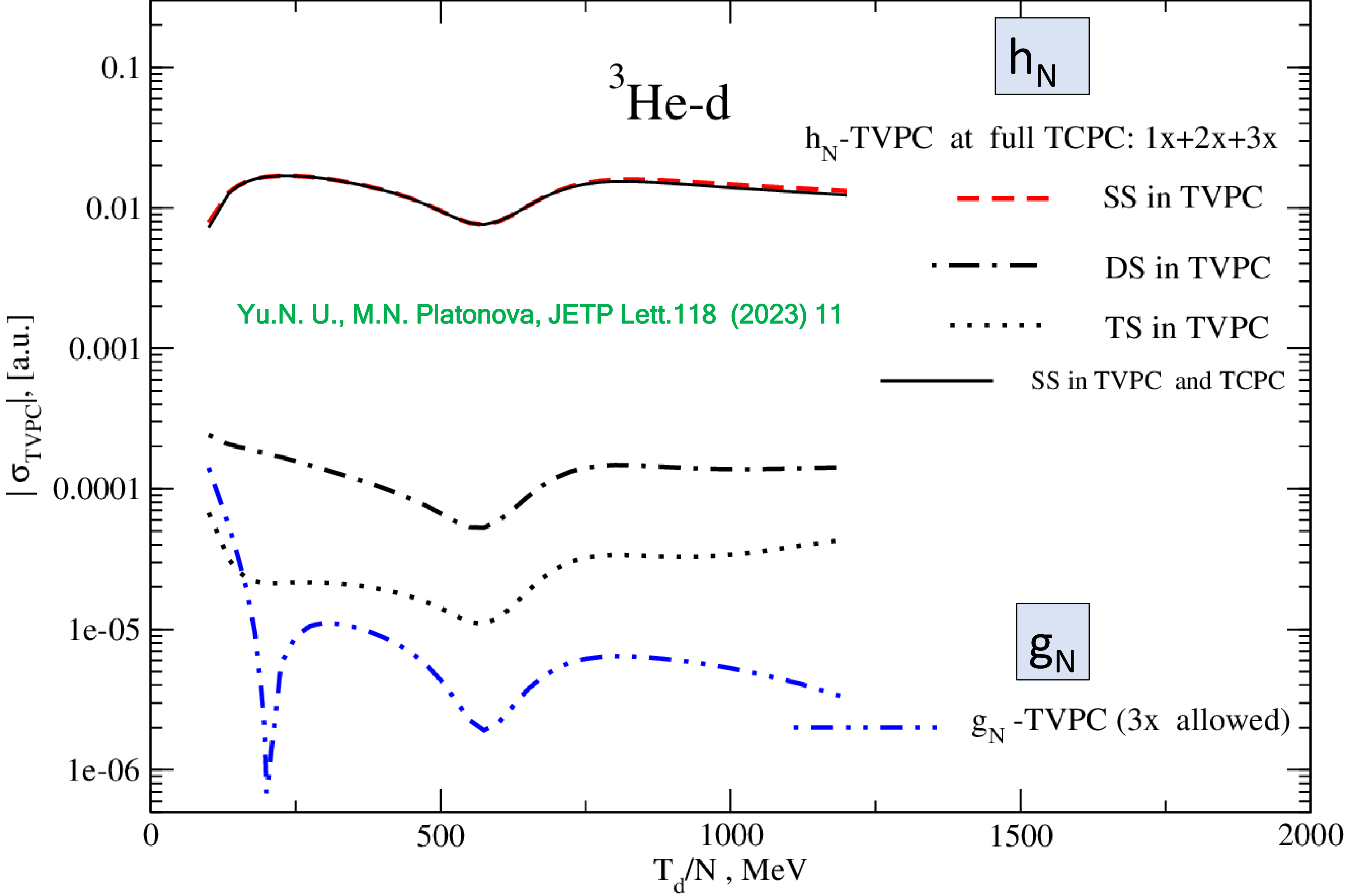
Selyugin O.V., Symmetry., 13 N2 (2021) 164; (HEGS –model);
arxi:2407.01311[hep-ph] $\sqrt{s_{NN}} = 5 - 25 GeV$

TVPC signal in *pd*-scattering accounting for *S*- и *D*-waves of the deuteron

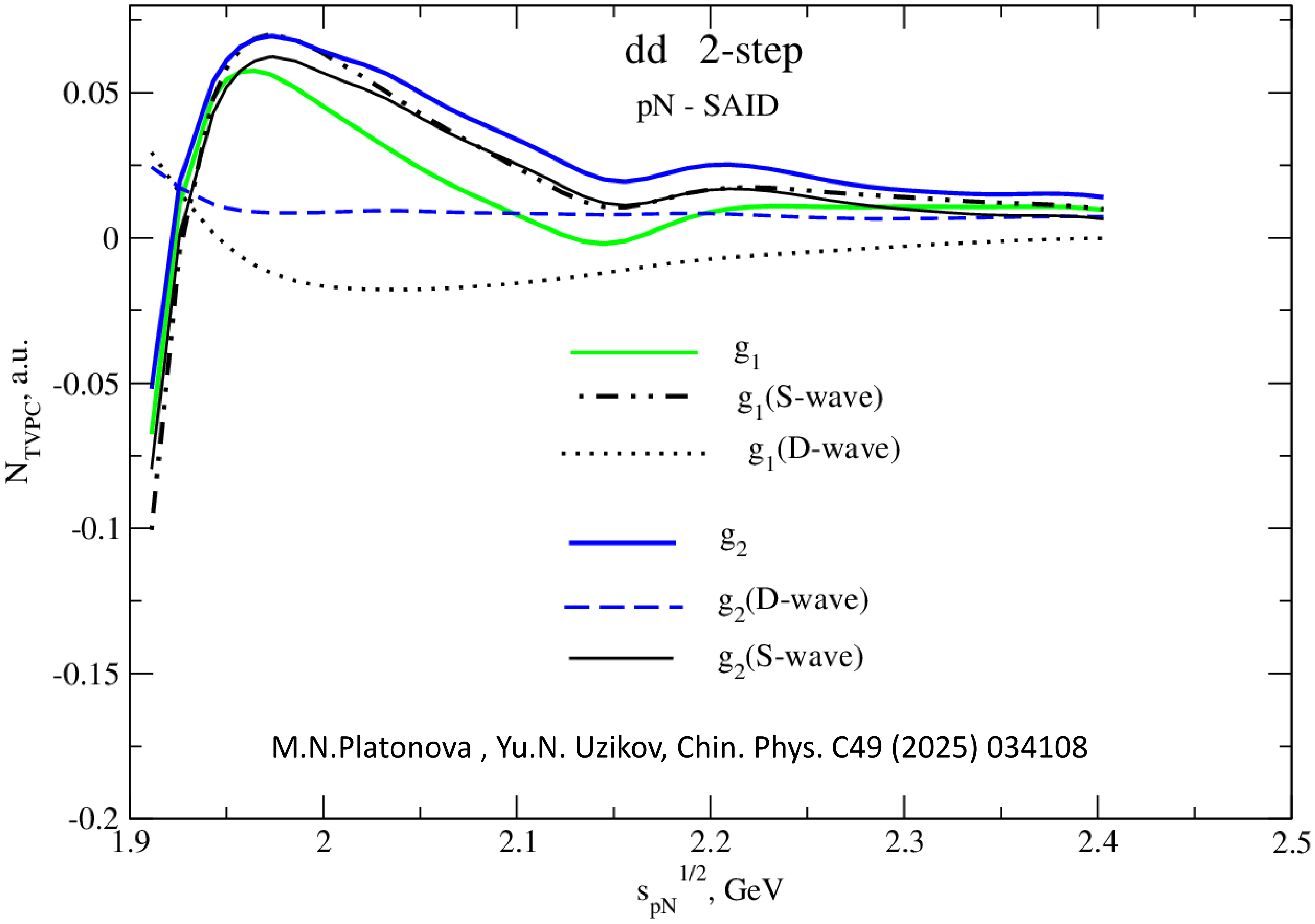
(in units of unknown TVPC constant of h-type)



Yu.N. Uzikov, J.Haidenbauer, PRC 94 (2016) 035501



h_N
³He-d
h_N-TVPC at full TCPC: 1x+2x+3x
SS in TVPC
DS in TVPC
TS in TVPC
SS in TVPC and TCPC
Yu.N. U., M.N. Platonova, JETP Lett.118 (2023) 11
g_N
g_N -TVPC (3x allowed)
|σ_TVPC|, [a.u.]
0.1
0.01
0.001
0.0001
1e-05
1e-06
0
500
1000
1500
2000
T_d/N , MeV



dd 2-step
pN - SAID
g1
g1(S-wave)
g1(D-wave)
g2
g2(D-wave)
g2(S-wave)
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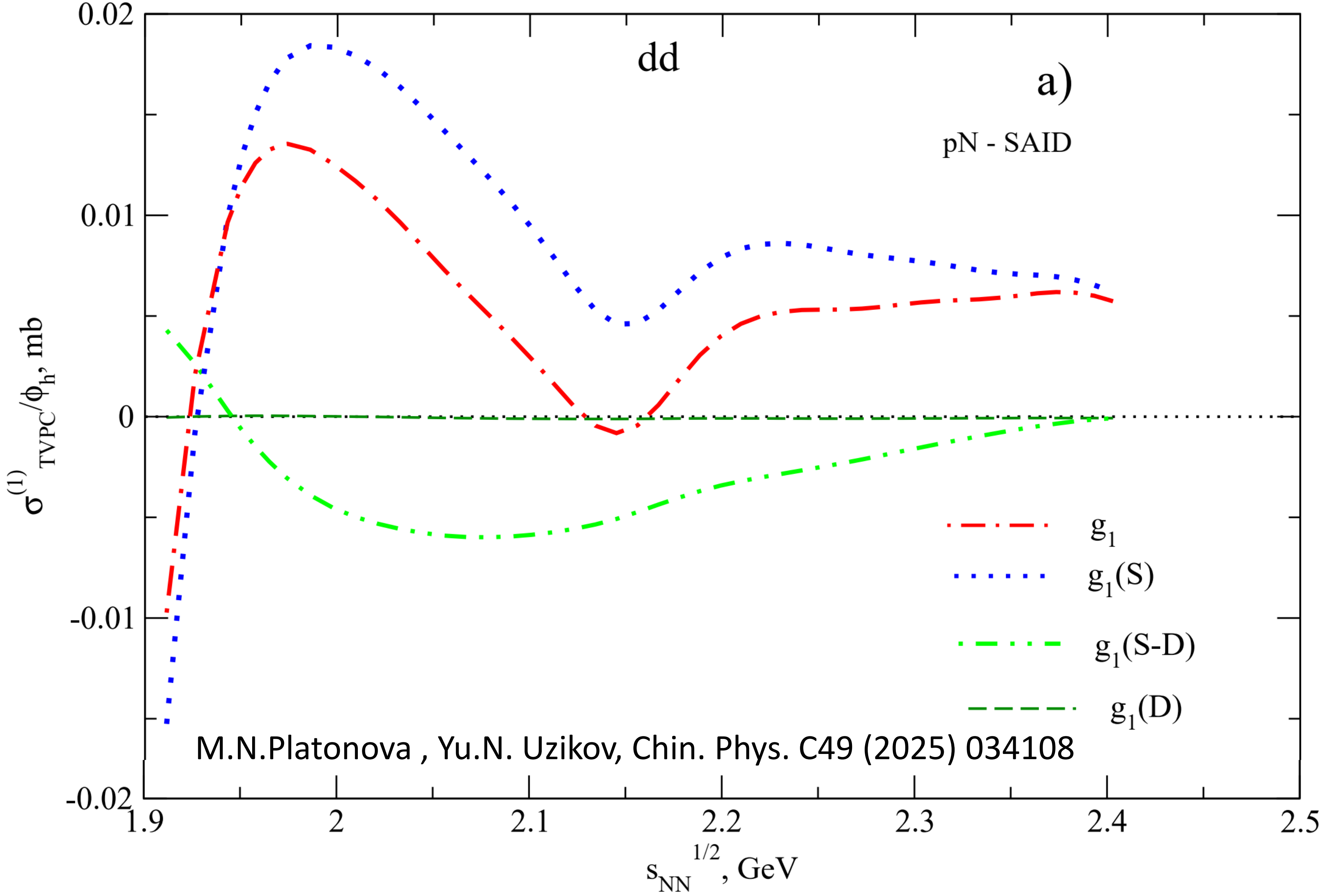
0.05
0
-0.05
-0.1
-0.15
-0.2
1.9
2
2.1
2.2
2.3
2.4
2.5
N_TVPC, a.u.
s_pN^1/2, GeV



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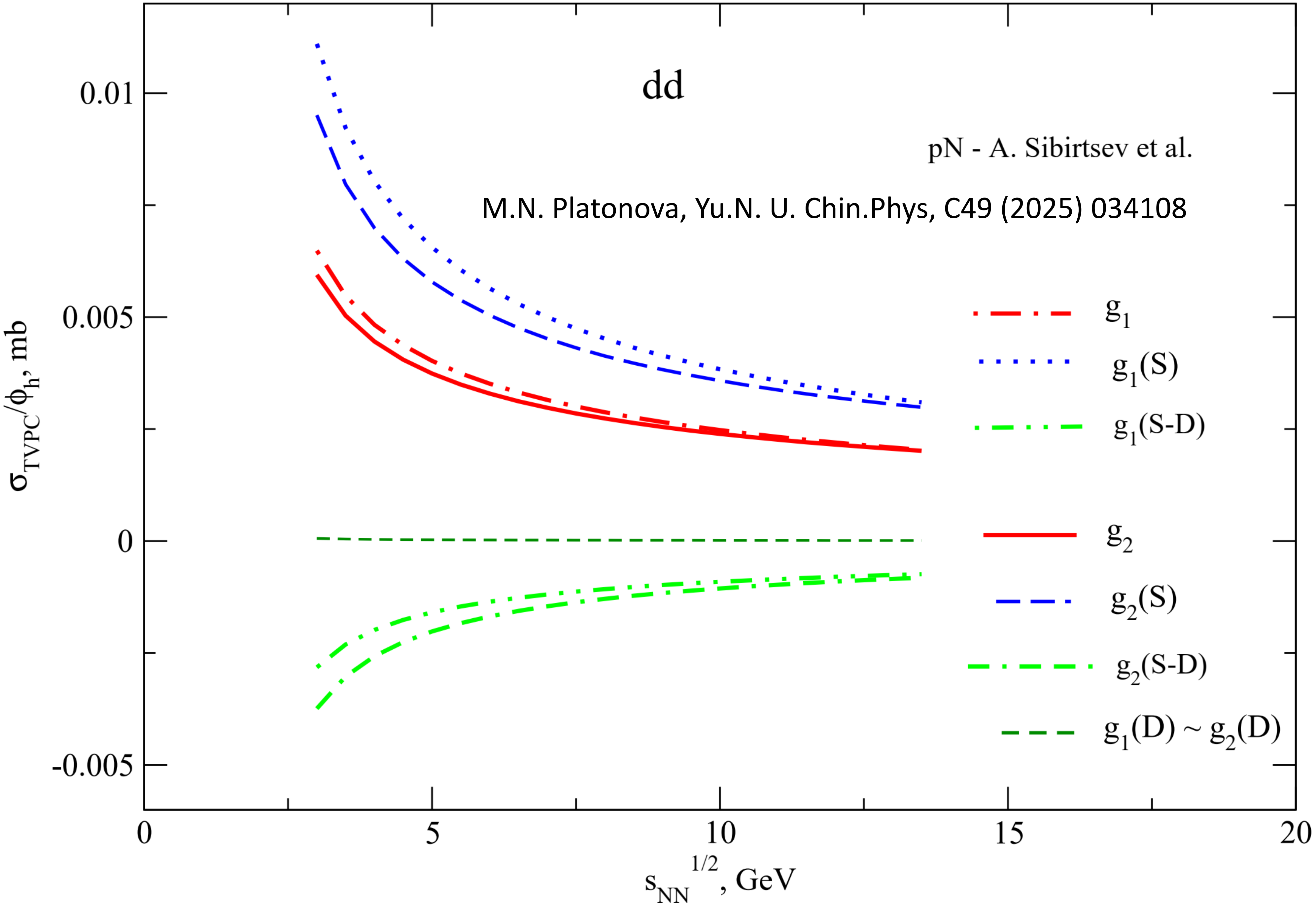
dd
pN - A. Sibirtsev et al.
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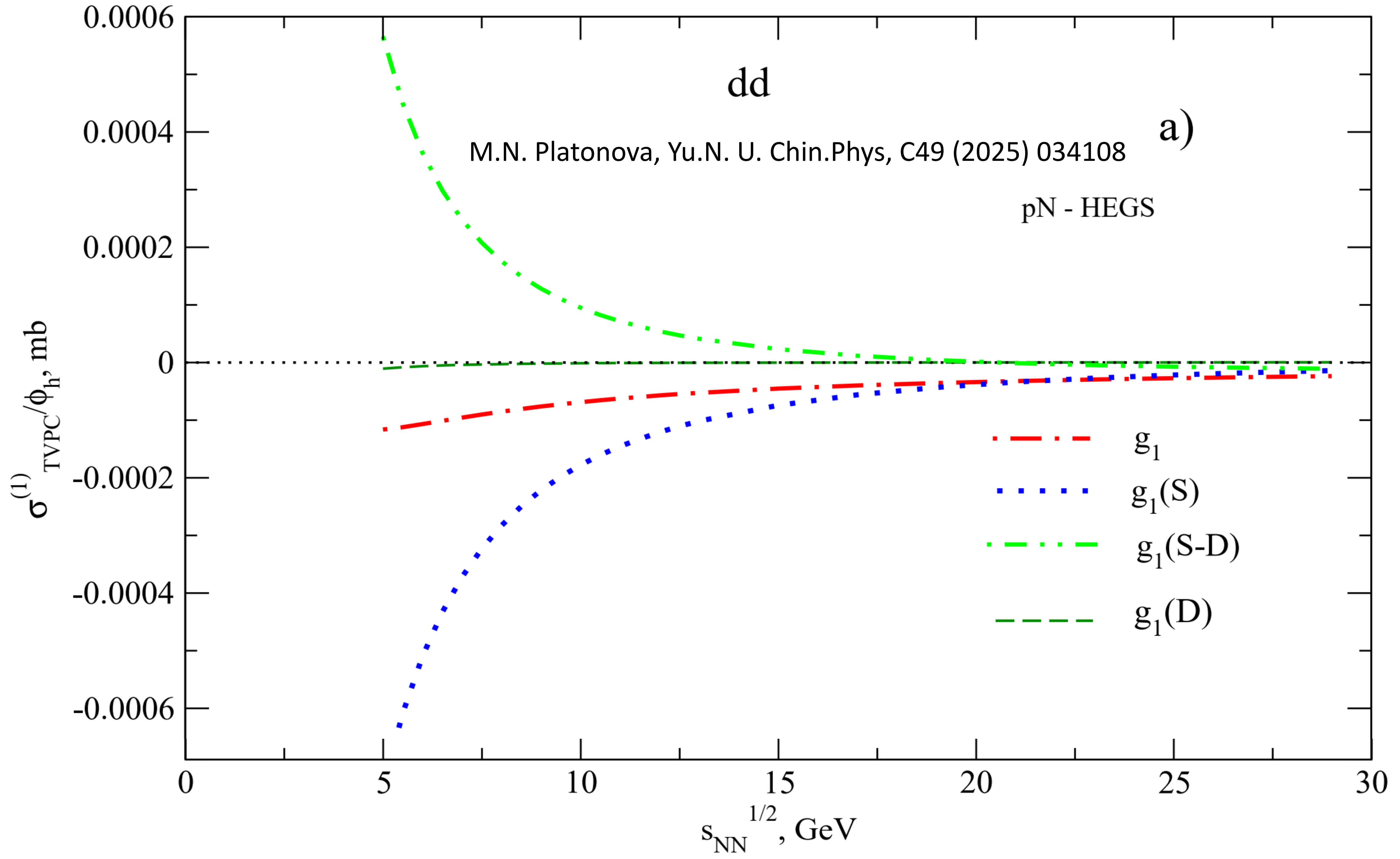
g_1
$g_1(S)$
$g_1(S\text{-}D)$
g_2
$g_2(S)$
$g_2(S\text{-}D)$
$g_1(D) \sim g_2(D)$
σ_{TVPC}/ϕ_h, mb
0.01
0.005
0
-0.005
0
5
10
15
20
$s_{NN}^{1/2}$, GeV



dd
a)
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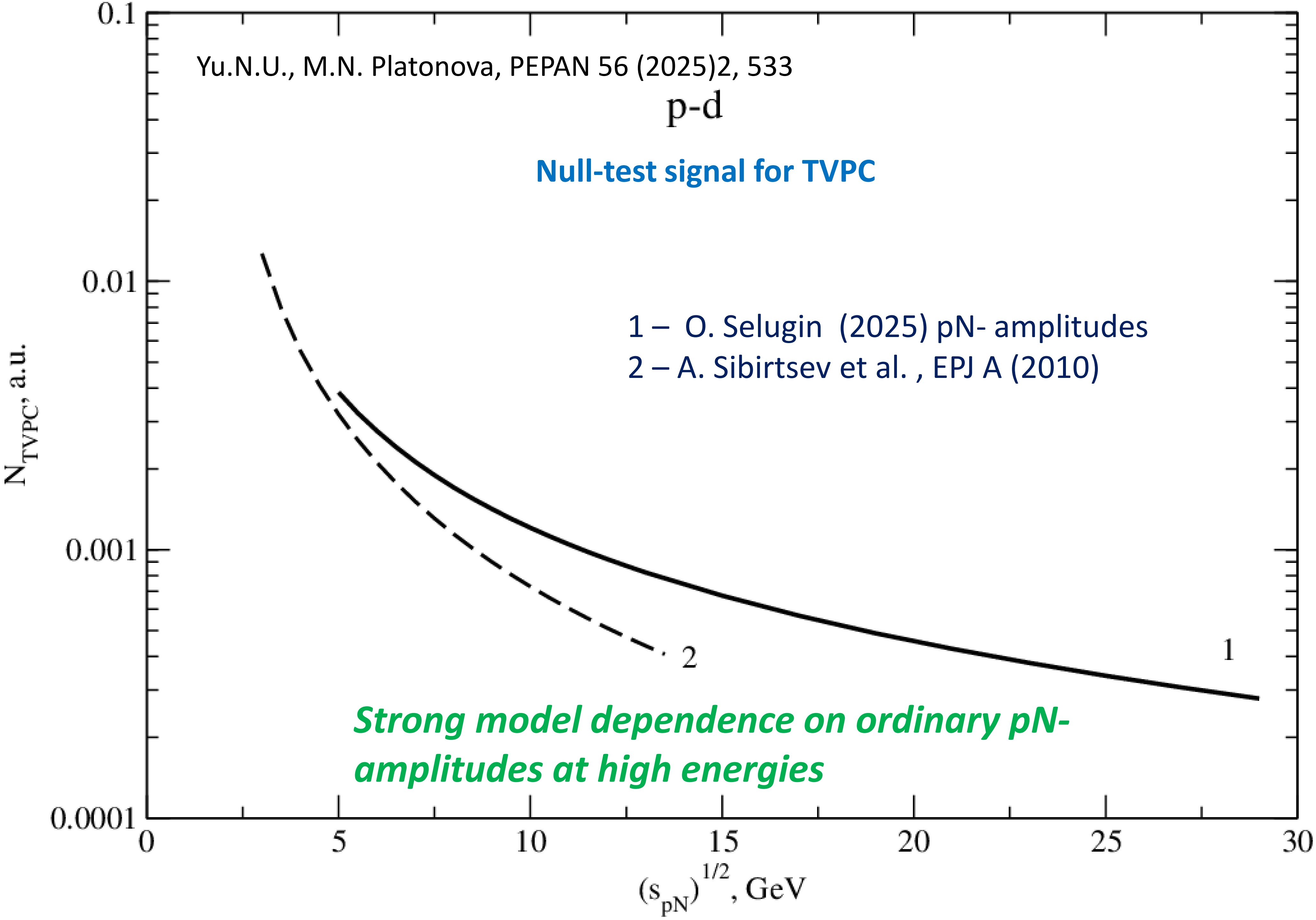
pN - HEGS
g_1
$g_1(S)$
$g_1(S\text{-}D)$
$g_1(D)$
$\sigma^{(1)}_{TVPC}/\phi_h$, mb
$s_{NN}^{1/2}$, GeV
0.0006
0.0004
0.0002
0
-0.0002
-0.0004
-0.0006
0
5
10
15
20
25
30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p-d
Null-test signal for TVPC
1 – O. Selugin (2025) pN- amplitudes
2 – A. Sibirtsev et al. , EPJ A (2010)
Strong model dependence on ordinary pN-amplitudes at high energies
0.1
0.01
0.001
0.0001
0
5
10
15
20
25
30
1
2
N_{TVPC}, a.u.
$(s_{pN})^{1/2}$, GeV

g’ – type of TVPC vanishes in dd-dd, also in pd- and ^{3}He-d for double pN scattering mechanism, in view of <np|g’|pn>= - <np|g’|pn>

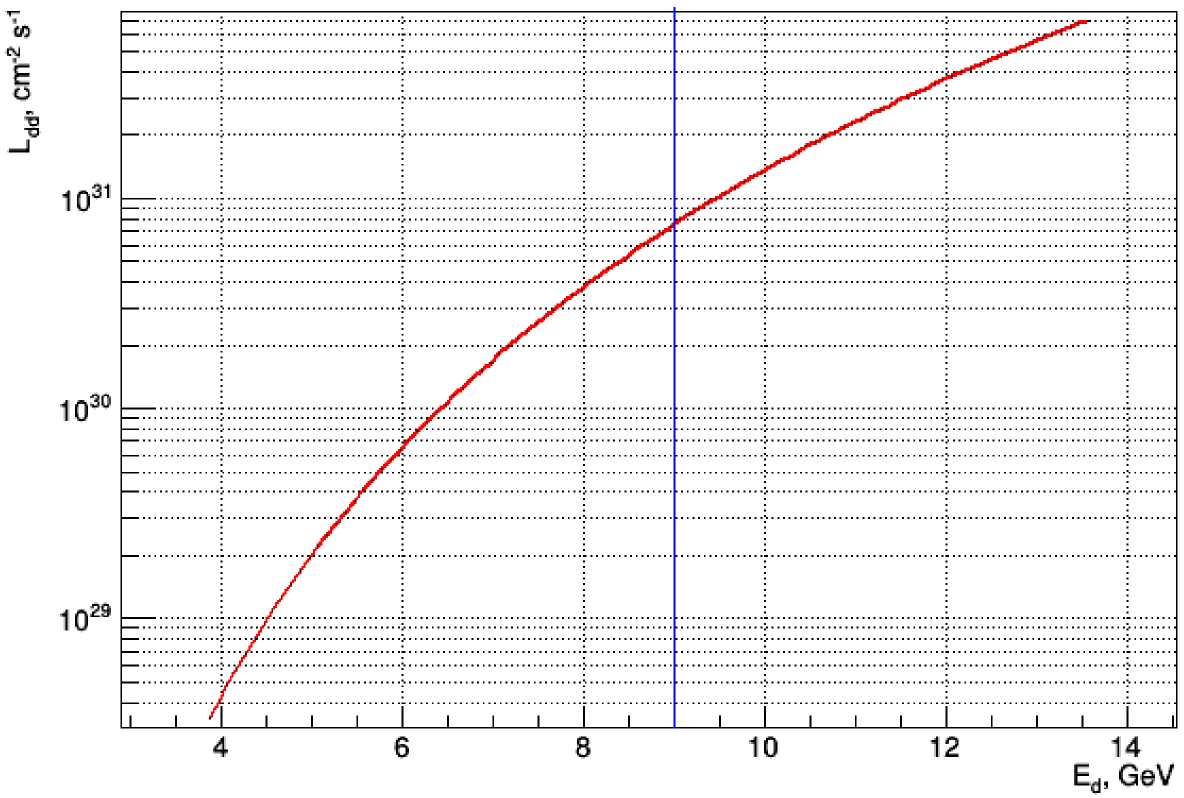
g- type vanishes due to <np|g|np>= - <pn|g|pn> and presence of the $(\tau_i - \tau_j)_z - operator$

h- type of TVPC dominates in dd –dd

That is important for its separation from the corresponding data.

Luminosity in dd-collision,

E_d is the c.m.s energy of the deuteron



TVPC spin effect decreases with energy by one order of magnitude, but the luminosity at SPD increases by three orders.

A possible point of view: due to available BAU problem, the TVPC coupling constant at NICA energies can be much stronger than at low energies ~ few MeV.

A high accuracy for the first measurement at high energies is not obligatory.

Glauber spin-dependent theory of *pd-pd* and a test of pN amplitudes

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

dd-dd elastic is also suitable, but much more complicated,

spin-dependent Glauber formalism is not yet developed.

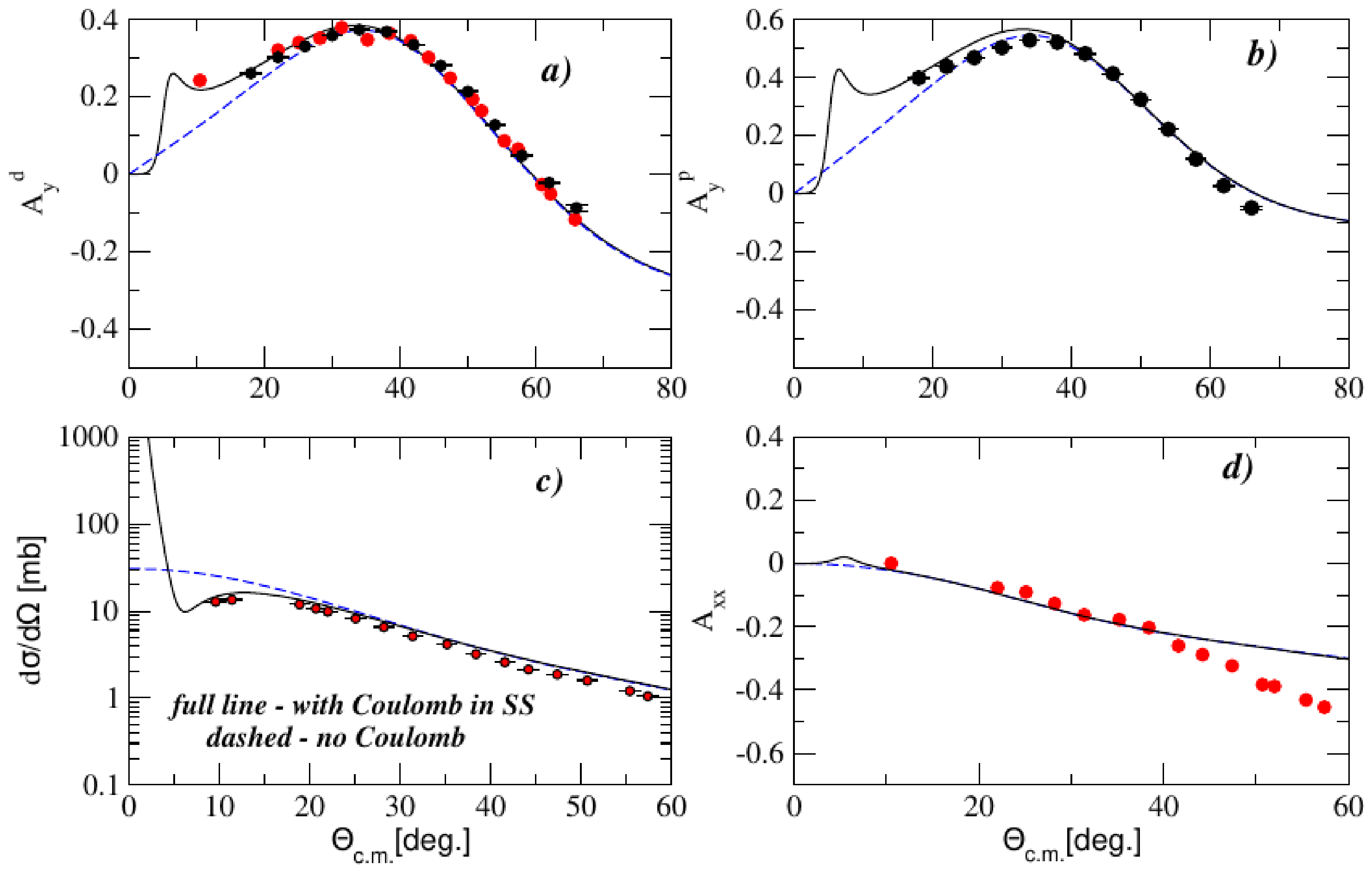
M.N. Platonova, V.I. Kukulin, Phys.Rev.C 81 (2010) 014004, Phys.Rev.C 94 (2016) 6, 069902;
M.N. Platonova, V.I.Kukulin, Eur.Phys.J.A56 (2020) 5, 132; e-Print: 1910.05722[nucl-th]

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

Test calculations: pd elastic scattering at 135 MeV

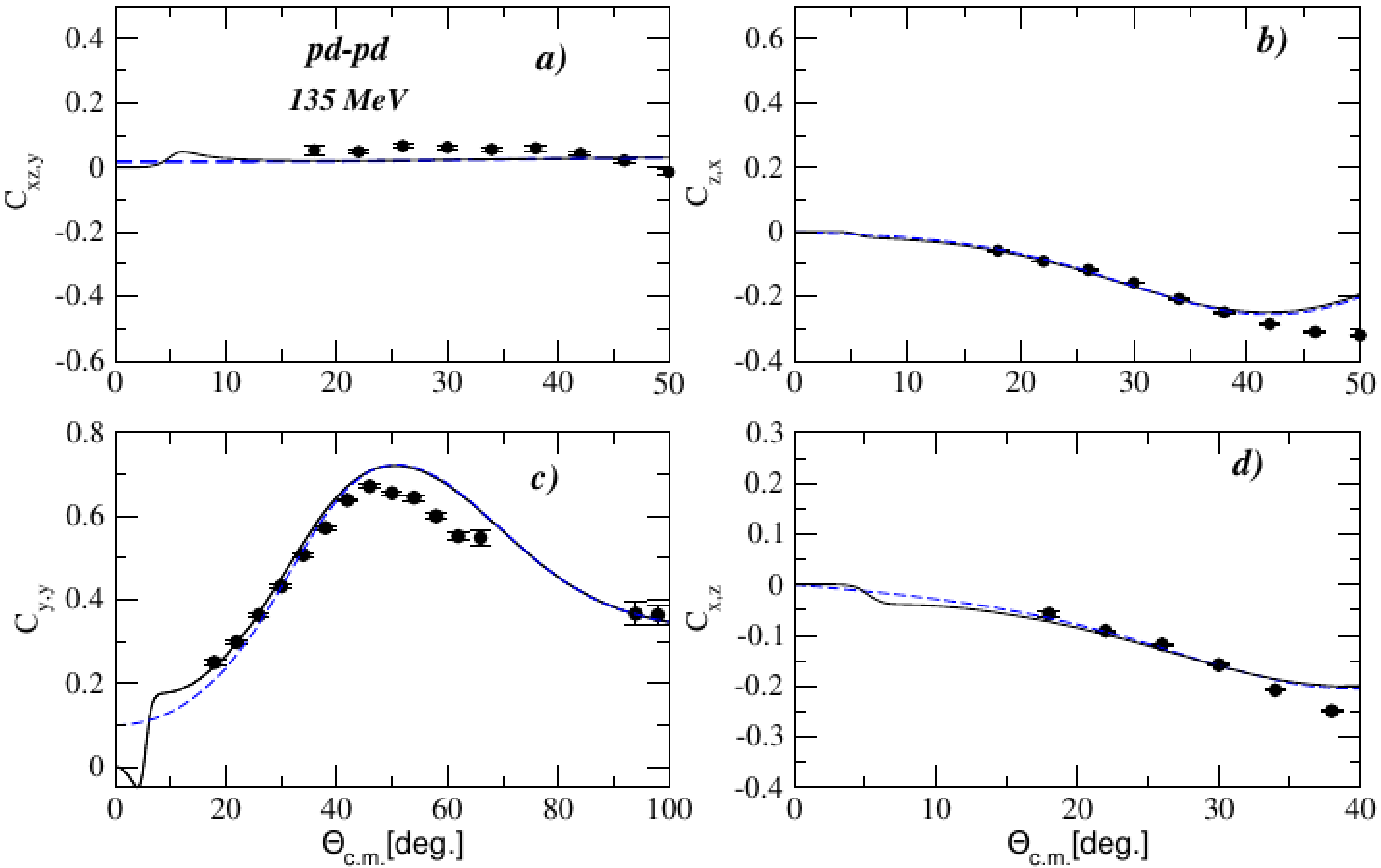
A.A. Temerbayev, Yu.N.Uzikov, Yad. Fiz. **78** (2015) 38

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.

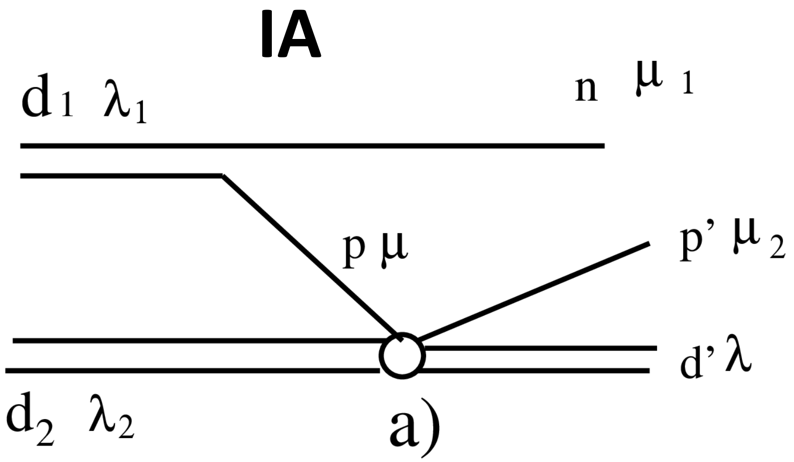
A.A. Temerbayev, Yu.N. Uzikov, Yad. Fiz, 78 (2015) 38



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

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].

Relations between dd→ npd and pd→ pd in the IA



S-wave dominates at q<0.15 GeV/c and rescatterings are suppressed

Asymmetric pd-mode will be not available at NICA SPD, while symmetric dd mode will be established.

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

$d_2^{\uparrow}$: 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:

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

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

Yu. N. Uzikov, e-Print: 2506.17799 [nucl-th] (accepted by PEPAN Lett.)

MC simulations: A. Datta, I.I. Denisenko ,Yu.N. U. (in preparation)

SUMMARY AND OUTLOOK

- σ_{TVPC} **is a true null-test observable**, not generated by **ISI&FSI**, analog of EDM.
- Energy dependence of the σ_{TVPC} $(pd,{}^3He d,dd)$ is **calculated in the spin-dependent Glauber theory** in broad range of energy.
- d↑d↑ does not contain the *g'*- and g-type of TVPC, i.e. is **optimal to search for the h-type of TVPC**.
- **Strong model dependence on** ordinary TCPC pN amplitudes. **Test of these amplitudes** at NICA energies **is developed** by studying spin observables of **pd-pd** via **dd-npd** at SPD.
- **No data on TVPC** effects are available so far **at NICA energies.**

For measurement at SPD or Nuclotron:
Precessing polarization of the beam & Fourier analysis

N. Nikolaev, F. Rathman, A. Silenko, Yu. U., PLB 811 (2020) 135983

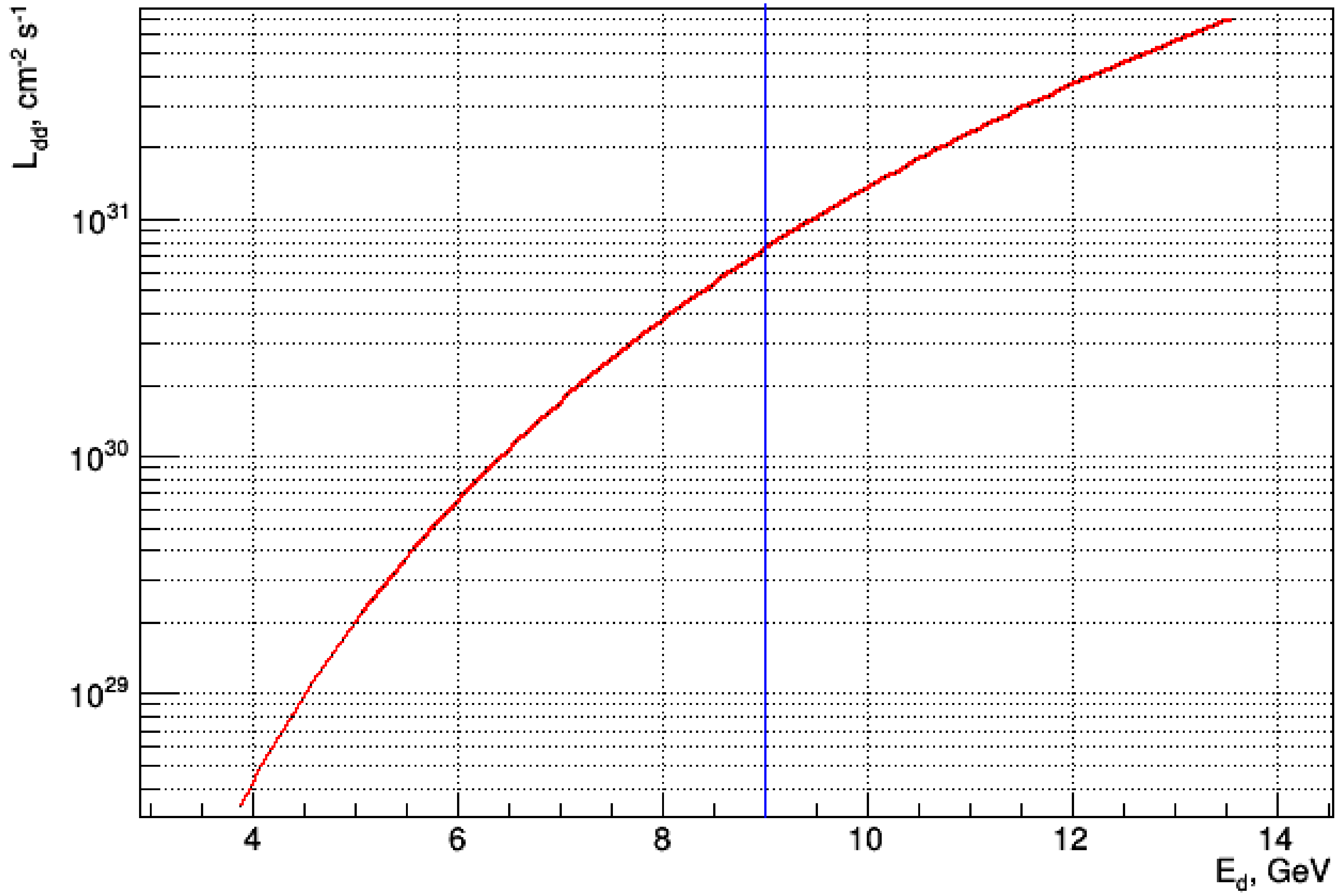
The basic question:

"How did it happen that there is enough matter left in the universe to be able to create galaxies, stars, planet and us ?"

B.H.J.McKellar, AIP Conf. Proc. 1657 (2015) 03001

THANK YOU FOR ATTENTION!

Luminosity at SPD NICA for dd-collisons



Minimal energy of the deuteron in c.m.s. = 4GeV

$$\vec{S}(n) = \mathbf{R}_{\text{evol}}(n)\vec{S}(0)\,,$$

$$\mathbf{R}_{\text{evol}}(n) = \mathbf{R}_{\text{idle}}(n)\mathbf{R}_{\text{env}}(n)\,,$$

At the boundary condition $\langle\vec{S}(0)\rangle = P_y^{\text{d}}(0)\vec{e}_y$ one has

$$\vec{S}(n) = S_y(0)[\cos(\epsilon n)\vec{e}_y + \sin(\epsilon n)[\cos(\theta_s n)\vec{e}_x - \sin(\theta_s n)\vec{e}_z]\,, \quad (8)$$

$$\mathbf{Q}(n) = \mathbf{R}_{\text{evol}}(n)\,\mathbf{Q}(0)\,\mathbf{R}^{\text{T}}_{\text{evol}}(n)\,,$$

$$T_{xz}(n) = -\frac{3}{4}T_{yy}(0)\cdot\sin^2\epsilon n\cdot\sin 2\theta_s n\,.$$

$$A_{\text{TVPC}}(n) = -\frac{3}{4}\cdot\frac{\sigma_{\text{TVPC}}}{\sigma_0}T_{yy}(0)P_y^{\text{p}}\cdot\sin^2\epsilon n^*\cdot\sin 2\theta_s n\,,$$

N. Nikolaev, F. Rathman, A. Silenko, Yu. U., PLB 811 (2020) 135983

$$
\begin{aligned}
\sigma_{\rm tot} = \sigma_0 &+ \sigma_{\rm TT}\left[\left(\mathbf{P}^{\rm d}\cdot\mathbf{P}^{\rm p}\right) - \left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right)\right] \\
&+ \sigma_{\rm LL}\left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) + \sigma_{\rm T} T_{mn}k_m k_n \\
&+ \sigma^{\rm p}_{\rm PV}\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) + \sigma^{\rm d}_{\rm PV}\left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right) \\
&+ \sigma^{\rm T}_{\rm PV}\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) T_{mn}k_m k_n \\
&+ \sigma_{\rm TVPV}\left(\mathbf{k}\cdot\left[\mathbf{P}^{\rm d}\times\mathbf{P}^{\rm p}\right]\right) \\
&+ \sigma_{\rm TVPC} k_m T_{mn}\epsilon_{nlr} P^{\rm p}_l k_r\,.
\end{aligned}
$$

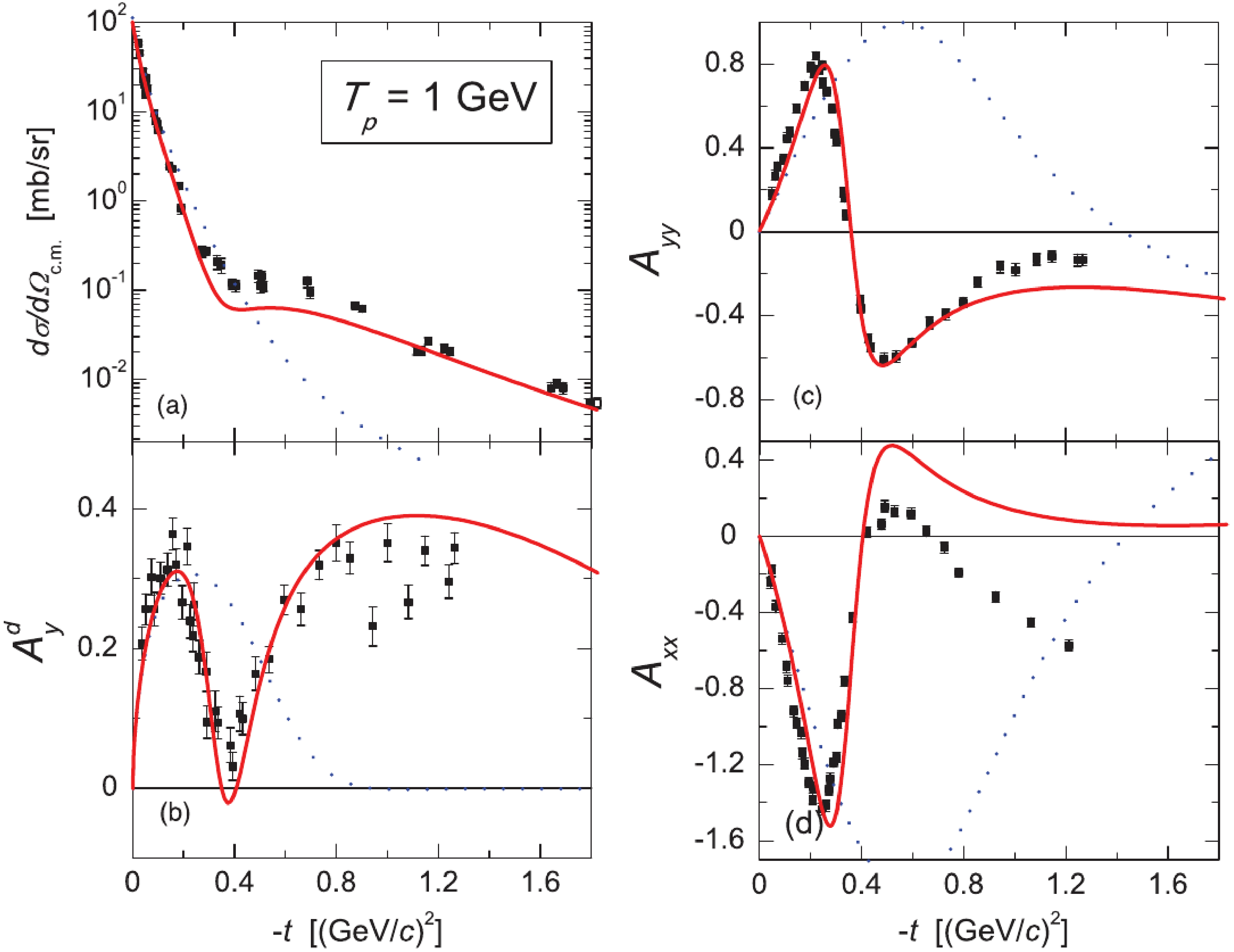
$$
\begin{aligned}
T_{yy}(n) &= \frac{1}{2}T_{yy}(0)\cdot\left[-1+3\cos^2\epsilon n\right], \\
T_{xx}(n) &= \frac{1}{2}T_{yy}(0)\cdot\left[-1+3\sin^2\epsilon n\cdot\cos^2\theta_s n\right], \\
T_{zz}(n) &= \frac{1}{2}T_{yy}(0)\cdot\left[-1+3\sin^2\epsilon n\cdot\sin^2\theta_s n\right], \\
T_{yx}(n) &= \frac{3}{2}T_{yy}(0)\cdot\sin\epsilon n\cdot\cos\epsilon n\cdot\cos\theta_s n\,, \\
T_{yz}(n) &= -\frac{3}{2}T_{yy}(0)\cdot\sin\epsilon n\cdot\cos\epsilon n\cdot\sin\theta_s n\,, \\
T_{xz}(n) &= -\frac{3}{4}T_{yy}(0)\cdot\sin^2\epsilon n\cdot\sin 2\theta_s n\,.
\end{aligned}
$$

$$\sigma_{tot} = \sigma_0 + \sigma_{TT} p_y^p P_y^d + \sigma_t P_{zz} + \sigma_{tvpc} p_y^p P_{xz};$$

$$A = \frac{T^+ - T^-}{T^+ + T^-} \sim \sigma_{tvpc}; (P_y^d \Rightarrow 0)$$

$$T^+ \Rightarrow p_y^p P_{xz} > 0, T^- \Rightarrow p_y^p P_{xz} < 0$$

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



Time-Reversal Violation in the Kaon and B^0 Meson Systems

- CP-violation in K- and B-meson physics (under CPT) $\Longrightarrow$ T-violation
- T violation in the K-system:

$K^0 \to \bar{K}^0$ and $\bar{K}^0 \to K^0$

Difference between probabilities was observed

A.Angelopoulos et al. (CPLEAR Collaboration) Phys. Lett. **B 444** (1998) 43.

These channels are connected both by T- and CP- transformation!

- Direct observation of T-violation in

$\bar{B}^0 \to B_- $ and $B_- \to \bar{B}^0$ $\qquad B\_ = c\bar{c}K_S^0$

connected only by T-symmetry transformation

(There are three other independet pairs)

J.P. Lees et al. (BABAR Collaboration) PRL **109** (2012) 211801

The results are consistent with current CP-violating measurements obtained invoking CPT-invariance

We will focus on TVPC flavor conserving effects.

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

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