Test of T-invariance in Scattering of Polarized ^{3}He Nuclei on Tensor-Polarized Deuterons

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CONTENT

- Motivation (**BAU**)

  Time-Reversal Invariance test (TIVOLI) was planned at COSY in **pd** at 135 MeV.

  Theory: Yu.N.U., A. Temerbayev ,PRC 92 (2015); Yu.U., Haidenbauer, PRC 94(2016)

  ^{3}He-d, d-d ? NICA SPD?
- T-invariance Violating P-parity conserving (TVPC) NN interactions
- Null-test signal TVPC for ^{3}He-d scattering:

  Glauber spin-dependent theory for p-^{3}He and ^{3}He-d elastic scattering.
- Numerical results at 0.1- 1 GeV and higher
- Conclusion

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Search for T-invariance violation in scattering of polarized protons, ^{3}He nuclei and deuterons on polarized deuterons.
https://www.rscf.ru/project/23-22-00123

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

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

Experiments for search of CP- violation:

* Permanent **EDM** of neutron, neutral atoms, p,d, 3He, 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 as a fundamental interaction.

Experimental limits on TVPC effects are much weaker then for EDM

EFT: **Available experimental restrictions to EDM put no constrains on TVPC (for scenario "B") for EDM**
A. Kurylov et. al. PRD 63 (2001) 076007 -> in contrast to **(scenario "A"**) 2 R.S. Conti, I.B. Khriplovich, PRL 68 (1992) 3262
-> next slide

EDM and TVPC interactions

J.Engel, P.H. Framton, R.P. Springer, PRD **53** (1996) 5112:

$$\mathcal{L}_{NEW} = \mathcal{L}_4 + \frac{1}{\Lambda_{TVPC}}\mathcal{L}_5 + \frac{1}{\Lambda_{TVPC}^2}\mathcal{L}_6 + \frac{1}{\Lambda_{TVPC}^3}\mathcal{L}_7 + \ldots$$

The lowest-dimension flavor conserving TVPC interactions have $d = 7$
/R.S. Conti, I.B. Khriplovich, PRL 68 (1992)/.
These new TVPC can generate a permanent EDM in the presence of a PV SM radiative corrections.
J.Engel et al.: $\bar{g}_\rho \sim 10^{-8}$
M.J. Ramsey-Musolf, PRL 83 (1999): $\Lambda_{TVPC} > 150$ TeV

A.Kurylov, G.C. McLaughlin, M.Ramsey-Musolf , PRD 63(2001)076007:

EDM at energies below Λ_{TVPC}

$$d = \beta_5 C_5 \frac{1}{\Lambda_{TVPC}} + \beta_6 C_6 \frac{M}{\Lambda_{TVPC}^2} + \underbrace{\beta_7 C_7 \frac{M^2}{\Lambda_{TVPC}^3}}_{the first\, contrb. from TVPC}$$

C_d are *a priori* unknown coefficients , β_d calculable quantities from loops, $M < \Lambda_{TVPC}$ - dynamical degrees of freedom

TVPC scale and EDM

Scenario "A":

P-parity invariance is restored at some scale $\mu \leq \Lambda_{TVPC}$
C_5, C_6 (both TVPV) vanish at tree level in EFT. The first contributions to the EDM arise from C_7 operator

$$\bar{g}_\rho \sim 10^{-8}$$

$\Lambda_{TVPC} > 150$ TeV

"Scenario "B":

P-parity invariance is restored at $\mu \geq \Lambda_{TVPC}$
C_5, C_6 (are both TVPV) do not vanish at tree level in EFT.
The EDM results do not provide direct constraint on the $d = 7$ operator, i.e. on the TVPC effects.

No constraints on TVPC within the "B"-scenario
(see also B.K. El-Menoufi, M.J. Ramsey-Musolf, C.-Y. Seng, PLB **765** (2017) 62; right-handed neutrino and β-decay of polarized n)

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)

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

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

Search for T-invariance violation in doble polarized p-d and ^{3}He-d scattering

Null-test signal of Time-invariance Violating Parity Conserving (TVPC) effects is a total cross section of double polarized 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.

Advantages:

- 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.

Disadvantage:

- Requires to suppress / exclude the contribution of the P_y^t

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

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

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 $A_{TVPC} \sim 10^{-6}$

pd TRANSMISSION experiment

Previous Theory:

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)

TVPC NN interactions

TVPC ($\equiv$ T-odd P-even) interactions

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

In terms of boson exchanges :
M.Simonius, Phys. Lett. ***58B*** *(1975) 147; PRL* ***78*** *(1997) 4161*

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

The TVPC Born NN-amplitude

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

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 $h_1(1170)$-meson exchange $I^G(J^{PC}) = 0^-(1^{+-})$ ...

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

On-shell TVPC NN interaction t-operators (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, $M^{str}_{pn \to np} = M^{str}_{np \to pn}$.

Collinear kinematics

Forward elastic pd scattering amplitude (P-even, T-even):

$^3He d$

$$e'^{*}_{\beta}\hat{M}_{\alpha\beta}(0)e_{\alpha} = g_1[\mathbf{e}\,\mathbf{e}'^{*} - (\hat{\mathbf{k}}\mathbf{e})(\hat{\mathbf{k}}\mathbf{e}'^{*})] + g_2(\hat{\mathbf{k}}\mathbf{e})(\hat{\mathbf{k}}\mathbf{e}'^{*}) +$$
$$ig_3\{\boldsymbol{\sigma}[\mathbf{e}\times\mathbf{e}'^{*}] - (\boldsymbol{\sigma}\hat{\mathbf{k}})(\hat{\mathbf{k}}\cdot[\mathbf{e}\times\mathbf{e}'^{*}])\} + ig_4(\boldsymbol{\sigma}\hat{\mathbf{k}})(\hat{\mathbf{k}}\cdot[\mathbf{e}\times\mathbf{e}'^{*}]) + \quad (3)$$

M.P. Rekalo et al., Few-Body Syst. 23, 187 (1998)

... and plus **T-odd P-even (TVPC) term**

$$\cdots + \widetilde{g}_5\{(\boldsymbol{\sigma}\cdot[\hat{\mathbf{k}}\times\mathbf{e}])(\mathbf{k}\cdot\mathbf{e}'^{*}) + (\boldsymbol{\sigma}\cdot[\hat{\mathbf{k}}\times\mathbf{e}'^{*}])(\mathbf{k}\cdot\mathbf{e})\}; \quad (4)$$

Non-diagonal:

$$< \mu' = \frac{1}{2}, \lambda' = 0|M^{TVPC}|\mu = -\frac{1}{2}, \lambda = 1 >= i\sqrt{2}\widetilde{g}_5. \quad (5)$$

Generalized Optical theorem:

$$Im\frac{Tr(\hat{\rho}_i\hat{M}(0))}{Tr\hat{\rho}_i} = \frac{k}{4\pi}\sigma_i \quad (6)$$

Total polarized cross sections pd or ³He-d scattering

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

Null-test signal

with

$$\sigma_0 = \frac{4\pi}{k} Im \frac{2g_1 + g_2}{3}, \sigma_1 = -\frac{4\pi}{k} Im g_3,$$
$$\sigma_2 = -\frac{4\pi}{k} Im(g_4 - g_3), \sigma_3 = \frac{4\pi}{k} Im \frac{g_1 - g_2}{6}.$$

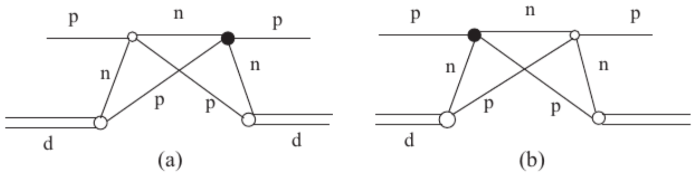
/Yu.N. Uzikov, J. Haidenbauer, PRC ***87*** *(2013) 054003/*

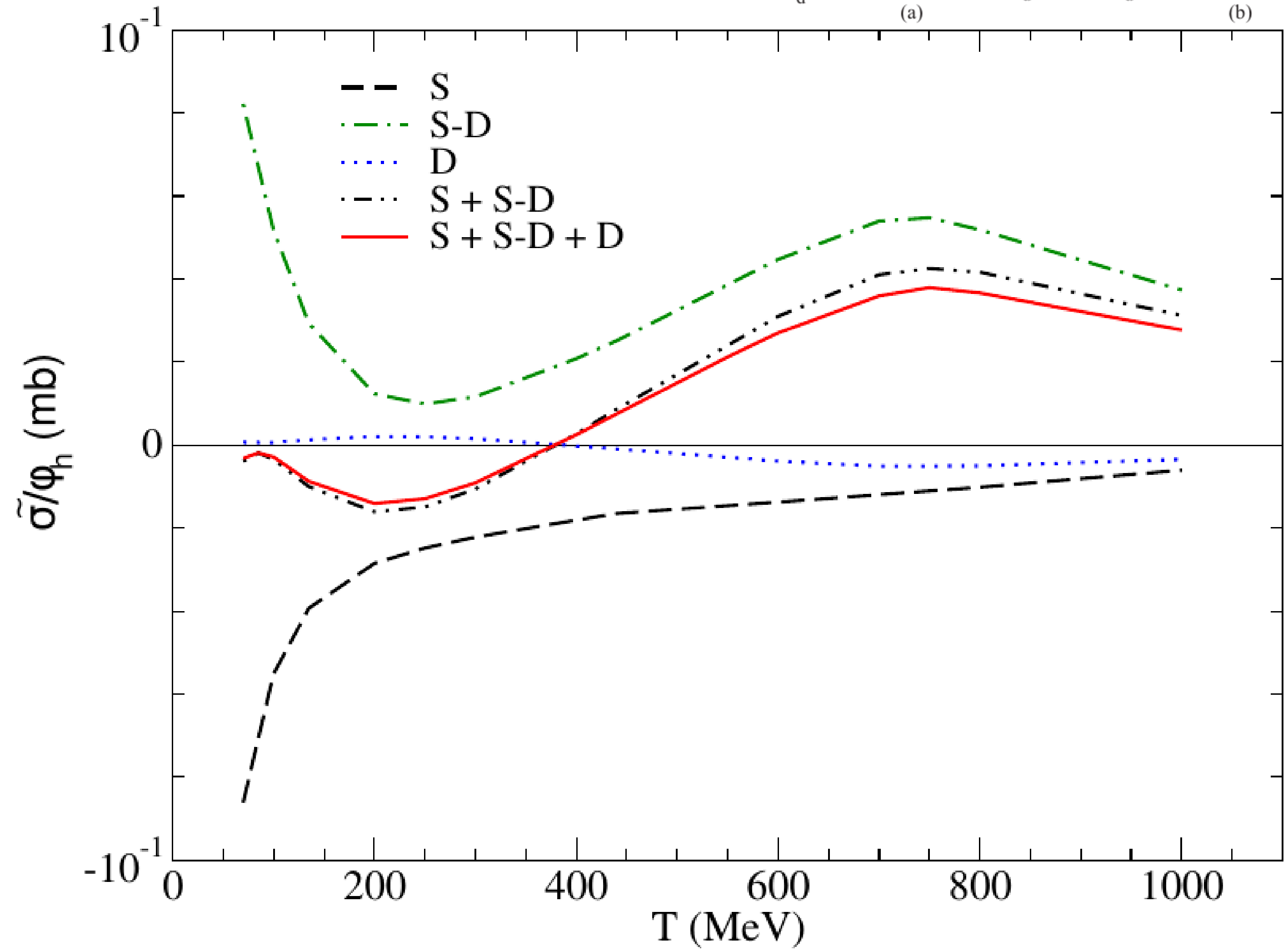
$$\widetilde{\sigma}_{tvpc} = -\frac{4\pi}{k} Im \frac{2}{3} \widetilde{g}_5 \quad (7)$$

/Yu.N. Uzikov, A.A. Temerbayev, Phys. Rev. C ***92*** *(2015)/*

ISI@FSI effects are included yet into $\tilde{g}_5 \Rightarrow \tilde{\sigma}_{TVPC}$
No interference of TVPC with T-invariant P-even terms.
True null-test for TVPC

Null-test signal in units of ϕ_h = TVPC constant. The S- and D- wave included.





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

TVPC signal in double polarized ^{3}He-d scattering

- ^{3}He – d has the ½+ 1 spin structure as in pd.
- Polarization of ^{3}He in S-wave approximation caused solely by the polarization of the neutron.
- ^{3}He –d scattering within the Glauber model can be considered like p-d with replacement of the pN-amplitudes by the p^{3}He ones.
- Is the g' –term of TVPC nonvanishing in the null-test signal in ^{3}He-d?

$$p^3He \to p^3He:$$

$$F = A_1 + A_2\boldsymbol{\sigma}(p)\hat{\mathbf{n}} + A_3\boldsymbol{\sigma}(\tau)\hat{\mathbf{n}} + A_4(\boldsymbol{\sigma}(p)\cdot\hat{\mathbf{k}})(\boldsymbol{\sigma}(\tau)\cdot\hat{\mathbf{k}})$$
$$+(A_5 + A_6)(\boldsymbol{\sigma}(p)\cdot\hat{\mathbf{q}})(\boldsymbol{\sigma}(\tau)\cdot\hat{\mathbf{q}}) + (A_5 - A_6)(\boldsymbol{\sigma}(p)\cdot\hat{\mathbf{n}})(\boldsymbol{\sigma}(\tau)\cdot\hat{\mathbf{n}})$$
$$\underline{+h_{\tau N}[(\boldsymbol{\sigma}(p)\cdot\hat{\mathbf{k}})(\boldsymbol{\sigma}(\tau)\cdot\hat{\mathbf{q}}) + (\boldsymbol{\sigma}(\tau)\cdot\hat{\mathbf{q}})(\boldsymbol{\sigma}(p)\cdot\hat{\mathbf{k}}) - \frac{2}{3}(\boldsymbol{\sigma}(\tau)\cdot\sigma(p))(\mathbf{q}\cdot\hat{\mathbf{k}})]}$$
$$+\underline{g_{\tau N}[\boldsymbol{\sigma}(p)\times\boldsymbol{\sigma}(\tau)]\cdot[\hat{\mathbf{q}}\times\hat{\mathbf{k}}]}$$
$$+\underline{g'_{\tau N}(\boldsymbol{\sigma}(p) - \boldsymbol{\sigma}(\tau)\cdot i[\hat{\mathbf{q}}\times\hat{\mathbf{k}}][\boldsymbol{\tau}(p)\times\tau(\tau)]_z}$$

$$\hat{\mathbf{k}} = \frac{\mathbf{p}+\mathbf{p}'}{|\mathbf{p}+\mathbf{p}'|}, \hat{\mathbf{q}} = \frac{\mathbf{p}'-\mathbf{p}}{|\mathbf{p}'-\mathbf{p}|}, \hat{\mathbf{n}} = [\hat{\mathbf{k}}\times\hat{\mathbf{q}}]$$

Spin amplitudes in Gauber spin-dependent theory: **T-even P-even** A_1,…, A_6 ,
TVPC $h_{\text{tau N}}$, $g_{\text{tau N}}$, $g'_{\text{tau N}}$

M.N. Platonova, N.T. Tursunbayev, Yu. N. U. , ***Phys.Atom.Nucl.*** **86 (2023) 6, 1267-1274**

THE MOST CUMBERSOME TASK:
spin matrix elements of products of pN spin-operators and extraction of invariant spin amplitudes of N-^{3}He scattering

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

T-invariant P-conserving
TCPC pN amplitudes

$$\mathbf{q} = (\mathbf{p} - \mathbf{p}'),\ \ \mathbf{k} = (\mathbf{p} + \mathbf{p}')\ \ \text{and}\ \ \mathbf{n} = [\mathbf{k} \times \mathbf{q}]$$

Double scattering ~$M_N(q_1)M_N(q_2)$

Triple scattering ~$M_N(q_1)M_N(q_2)M_N(q_3)$

$$t_{pN} = h_N[(\boldsymbol{\sigma}\cdot\mathbf{k})(\boldsymbol{\sigma}_N\cdot\mathbf{q}) + (\boldsymbol{\sigma}_N\cdot\mathbf{k})(\boldsymbol{\sigma}\cdot\mathbf{q})$$
$$- \tfrac{2}{3}(\boldsymbol{\sigma}_N\cdot\boldsymbol{\sigma})(\mathbf{k}\cdot\mathbf{q})]/m_p^2$$
$$+ g_N[\boldsymbol{\sigma}\times\boldsymbol{\sigma}_N]\cdot[\mathbf{q}\times\mathbf{k}][\boldsymbol{\tau}-\boldsymbol{\tau}_N]_z/m_p^2$$
$$+ g'_N(\boldsymbol{\sigma}-\boldsymbol{\sigma}_N)\cdot i\,[\mathbf{q}\times\mathbf{k}][\boldsymbol{\tau}\times\boldsymbol{\tau}_N]_z/m_p^2.$$

TVPC pN

$$\Psi^{A} = \psi_x^{\ S} \xi^{a};$$

Antisymmetric full wave function of ^3He

$$\xi^{a} = \frac{1}{\sqrt{2}}(\chi' \rho'' - \chi'' \rho') - spin - isospin$$

$$\chi' = \frac{1}{\sqrt{2}} \alpha_1 (\alpha_2 \beta_3 - \alpha_3 \beta_2); \alpha = |+\frac{1}{2}>, \beta = |-\frac{1}{2}>$$

$S_{23}=0$

$$\chi'' = \frac{1}{\sqrt{6}}[\alpha_1(\alpha_2\beta_3 + \alpha_3\beta_2) - 2\beta_1\alpha_2\alpha_3];$$

$S_{23}=1$

$$\psi_x^{\ S} = N e^{-c^2 (r_1^2 + r_2^2 + r_3^2)};$$

Symmetic s^3

$$F^{(1)} = \frac{3k_{p\tau}}{k_{pN}} S(q) < \xi^{a} | f_1(\vec{q}) | \xi^{a} >;$$

Single scattering

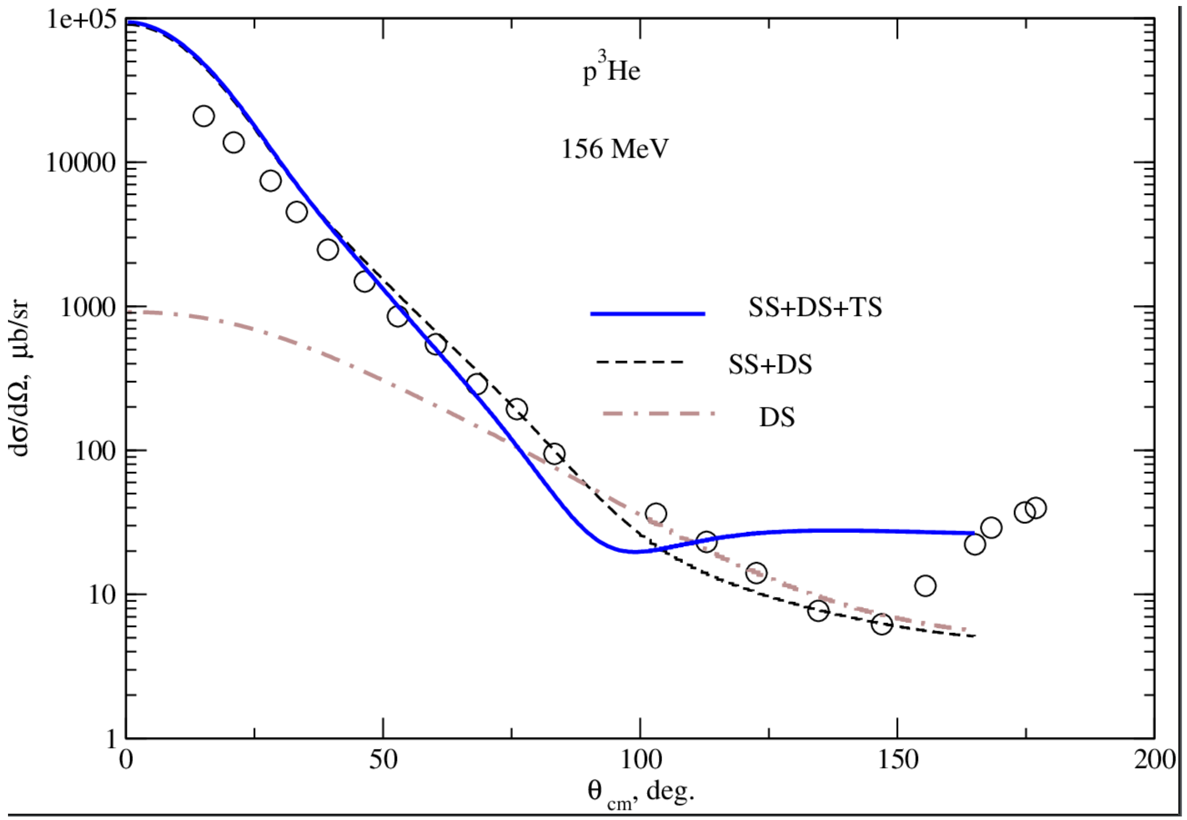
$$F^{(2)} = -\frac{3k_{p\tau}}{2\pi i (k_{pN})^2} S(\frac{q}{2}) \int d^2 q' S(\sqrt{3} q') < \xi^{a} | f_1(\vec{q}_1) f_2(\vec{q}_2) | \xi^{a} >;$$

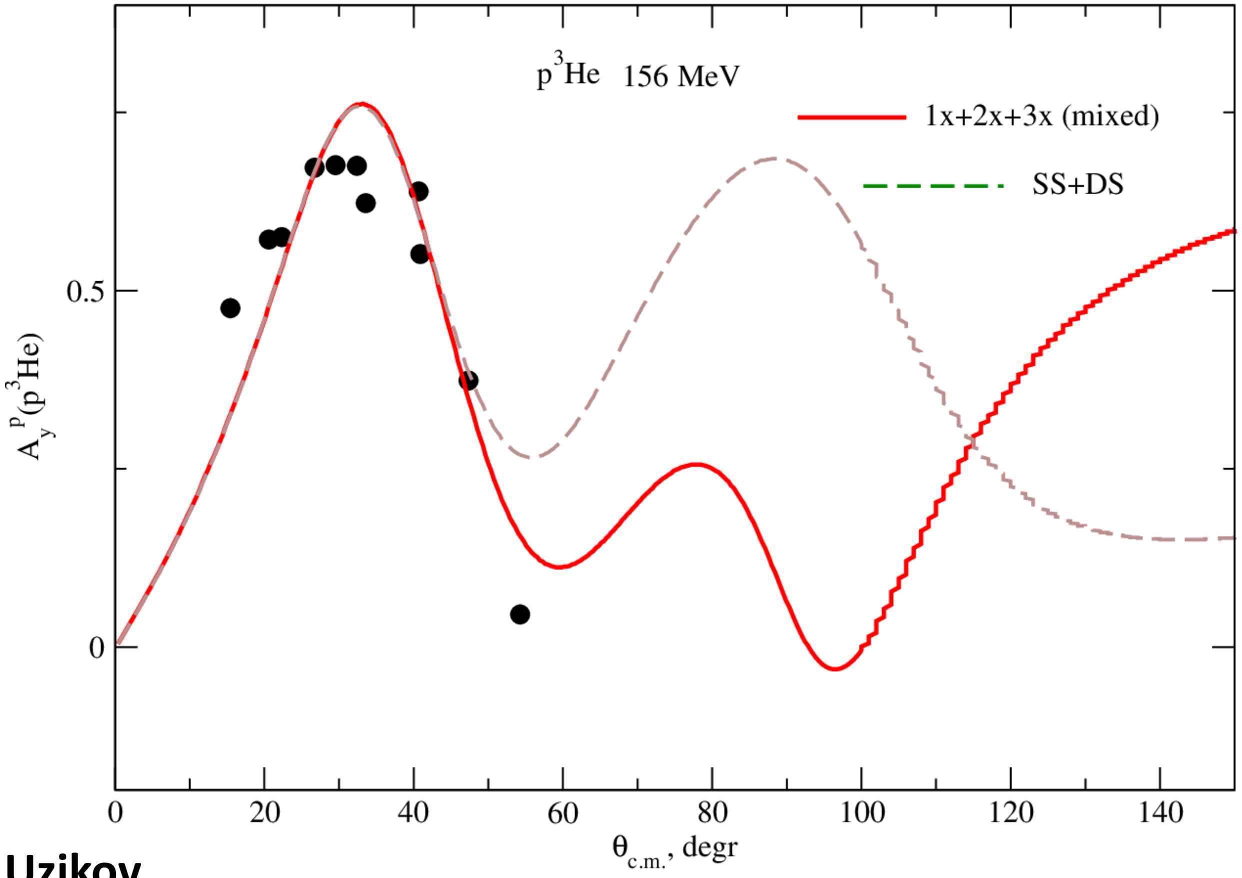
Double scattering

$$F^{(3)} = -\frac{k_{p\tau}}{4\pi^2 (k_{pN})^3} \int d^2 q' \int d^2 q'' S(\sqrt{3} q') S(\frac{3q''}{2}) < \xi^{a} | f_1(\vec{q}_1) f_2(\vec{q}_2) f_3(\vec{q}_3) | \xi^{a} >$$

Triple sc.

NUMERICAL RESLUTS for p^3He





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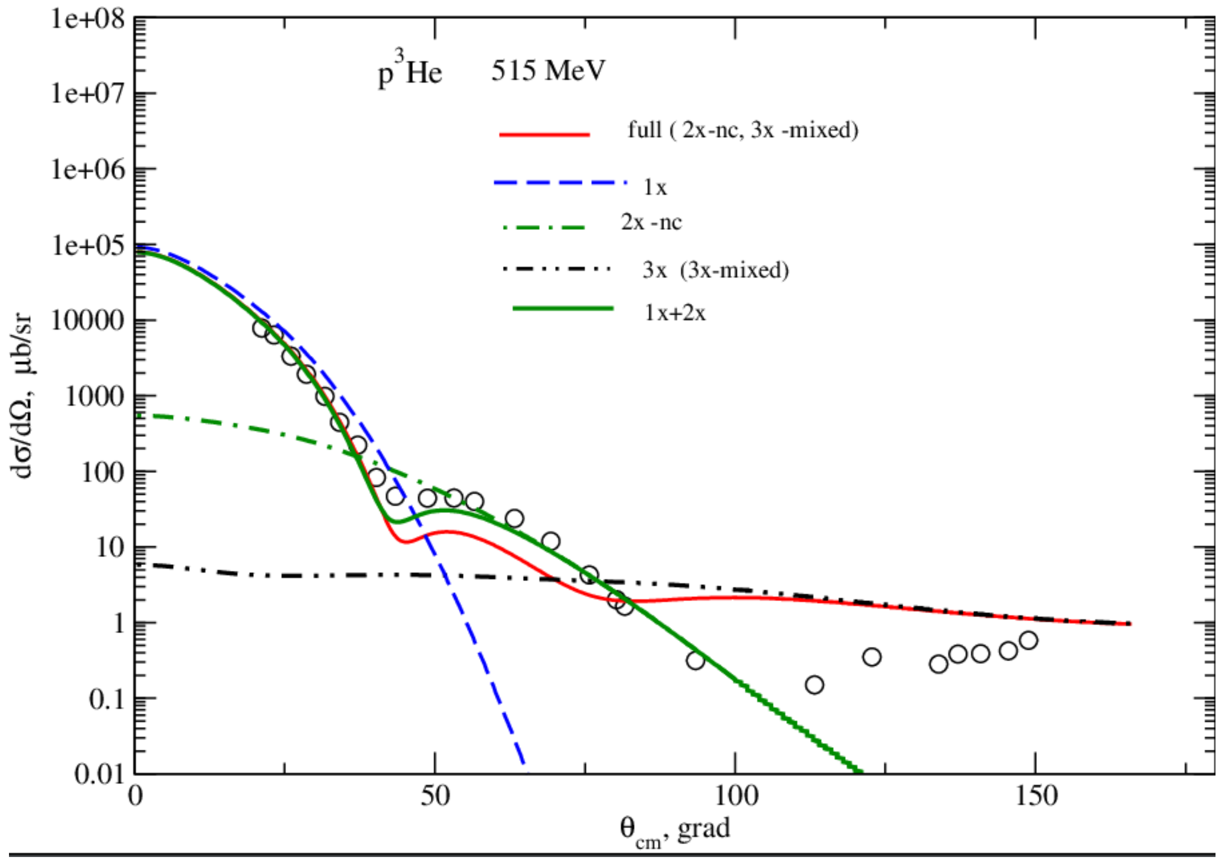
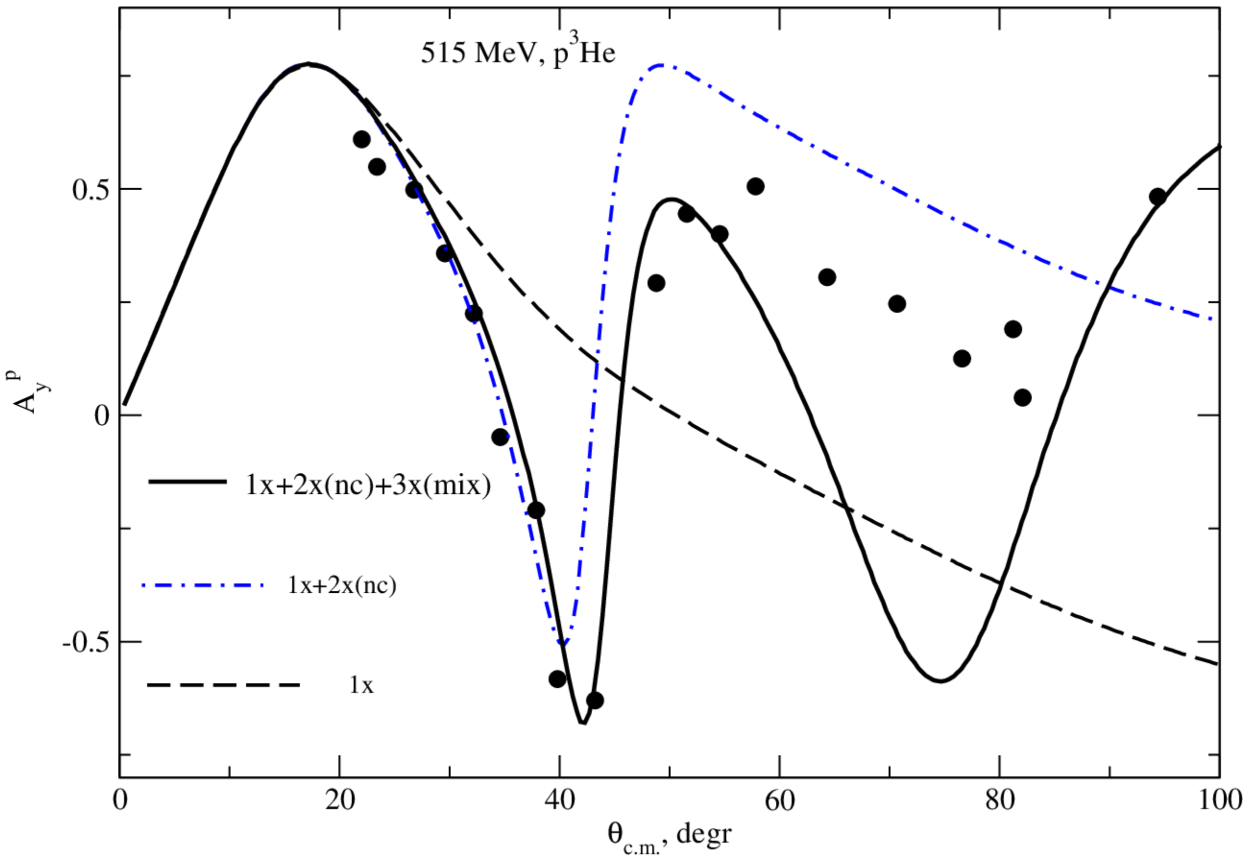
***Phys.Atom.Nucl.* 86 (2023) 6, 1267-1274**

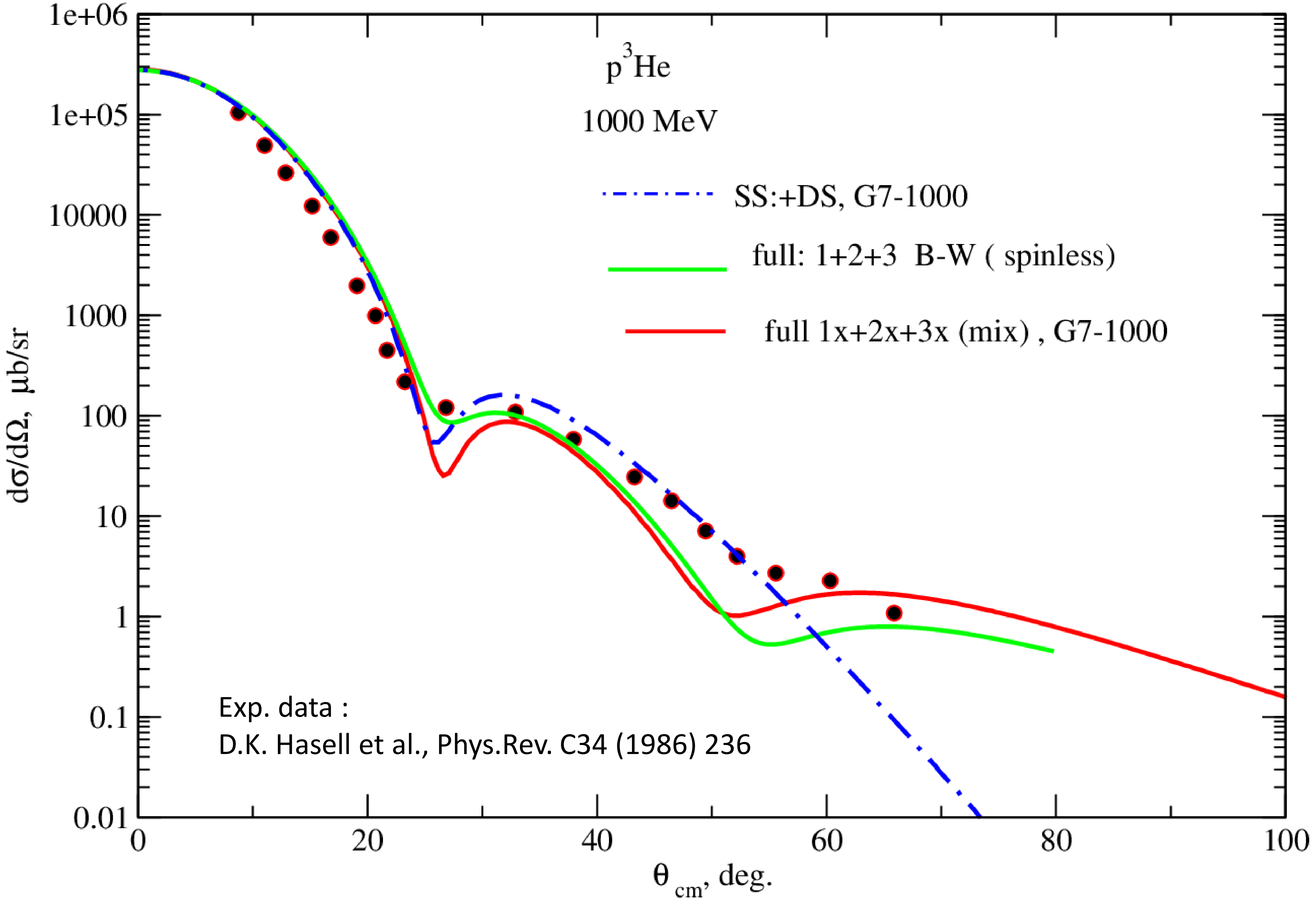
Exp. data : D.K. Hasell et al., Phys.Rev. C34 (1986) 236

NUMERICAL RESULTS p^3He

Exp. data : D.K. Hasell et al., Phys.Rev. C34 (1986) 236



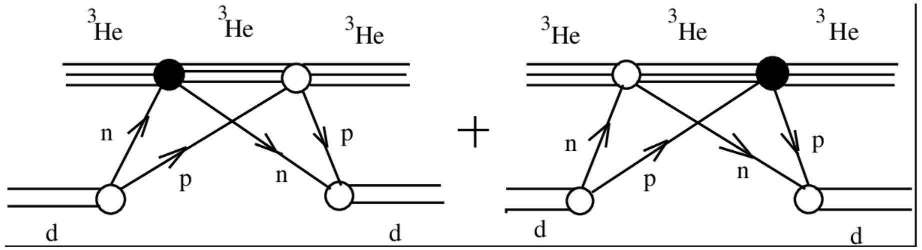



p^{3}He
1000 MeV
SS:+DS, G7-1000
full: 1+2+3 B-W (spinless)
full 1x+2x+3x (mix) , G7-1000
Exp. data :
D.K. Hasell et al., Phys.Rev. C34 (1986) 236
dσ/dΩ, μb/sr
θ cm, deg.
1e+06
1e+05
10000
1000
100
10
1
0.1
0.01
0
20
40
60
80
100

TVPC Null-test signal in ^{3}He-d scattering

pd : Yu.N. U., J. Haidenbauer, PRC, 94 (2016)

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



$$C'_{\tau N}, h_{\tau N}, g_{\tau N}$$

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

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

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

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

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

p^{3}He-, n^{3}He- elastic

h_N, g_{N} terms only

Optical theorem:

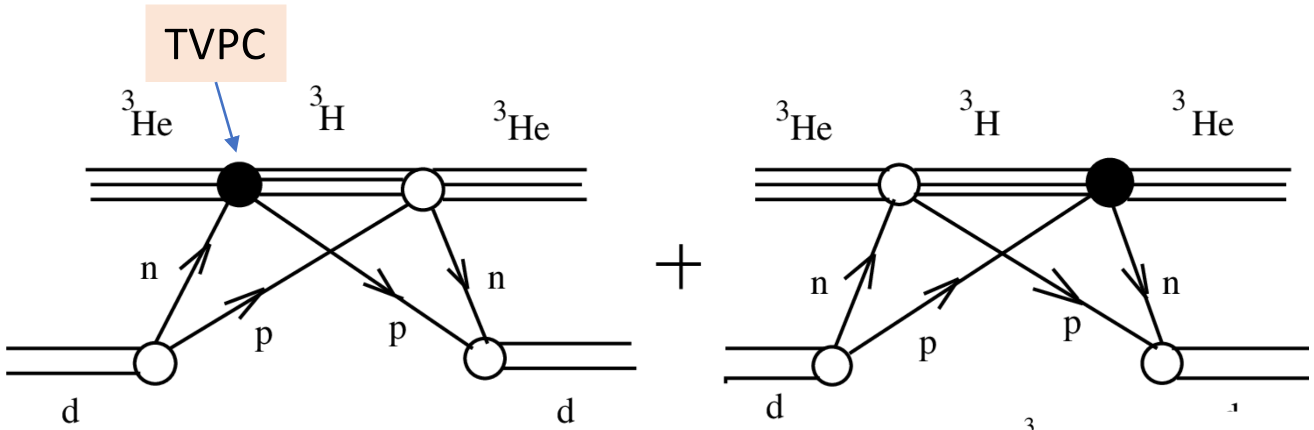
$$\tilde{\sigma} = -4\sqrt{\pi}\frac{2}{3}\mathrm{Im}\,\tilde{g}.$$

$$A_y^p = 2\mathrm{Re}[A_1 A_2^* + (A_5 - A_6)A_3^*]\Sigma^{-1}$$

g' –term of TVPC in ^{3}He-d.

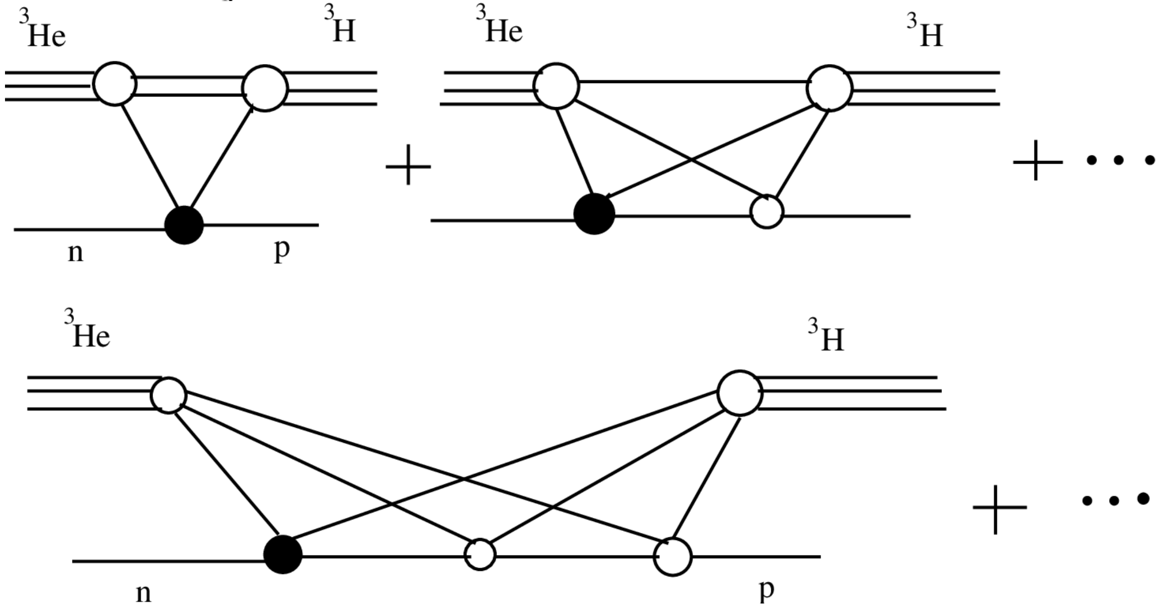
Charge-exchange pn<->np:

$$\langle n,p|[\boldsymbol{\tau}\times\boldsymbol{\tau}_N]_z|p,n\rangle = -i2, \quad \langle p,n|[\boldsymbol{\tau}\times\boldsymbol{\tau}_N]_z|n,p\rangle = i2.$$



= 0

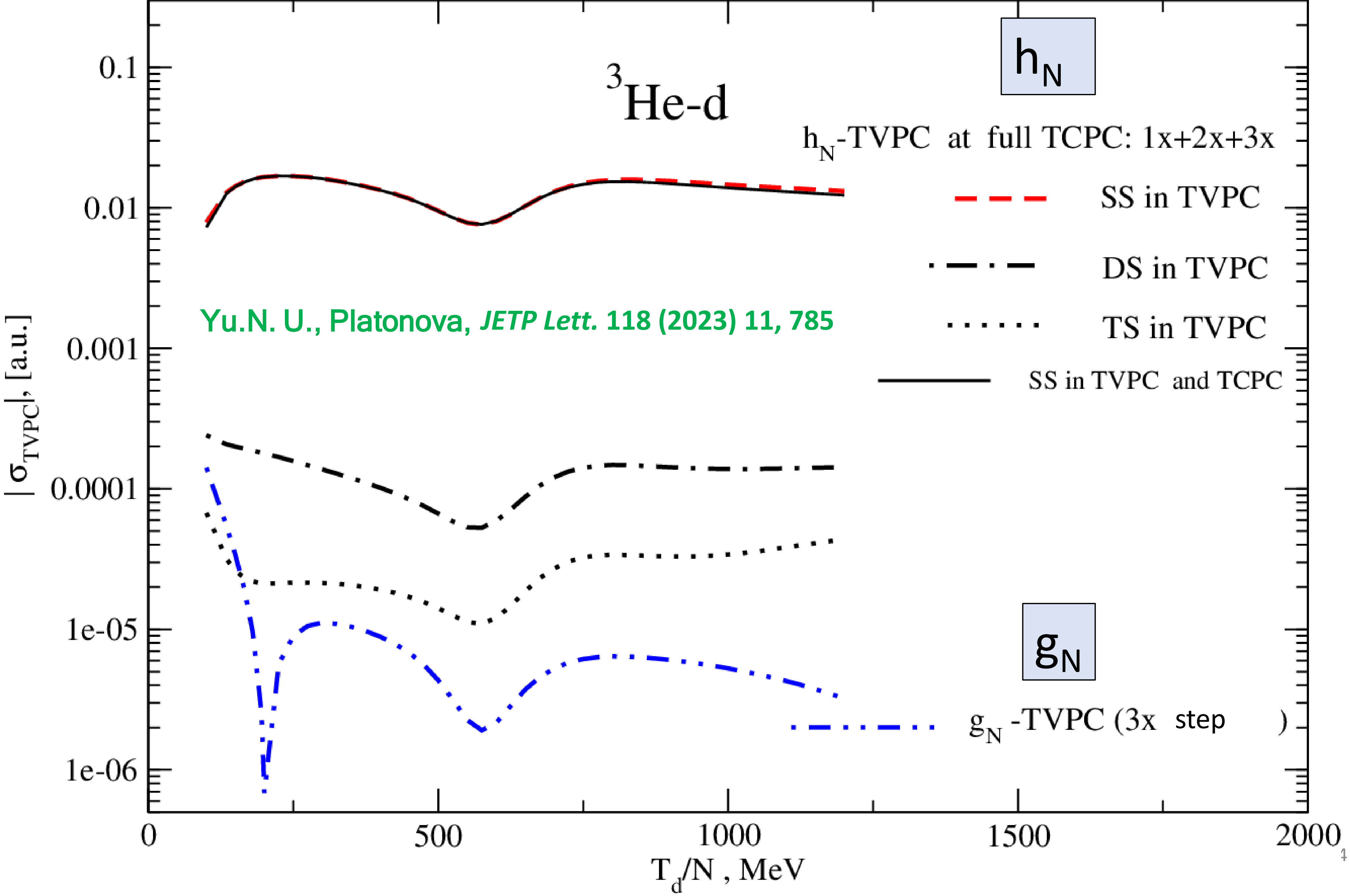
$$< 3Hen\,|\,\hat{g}'\,|\,3Hp >= - < 3Hp\,|\,\hat{g}'\,|\,3Hen >$$



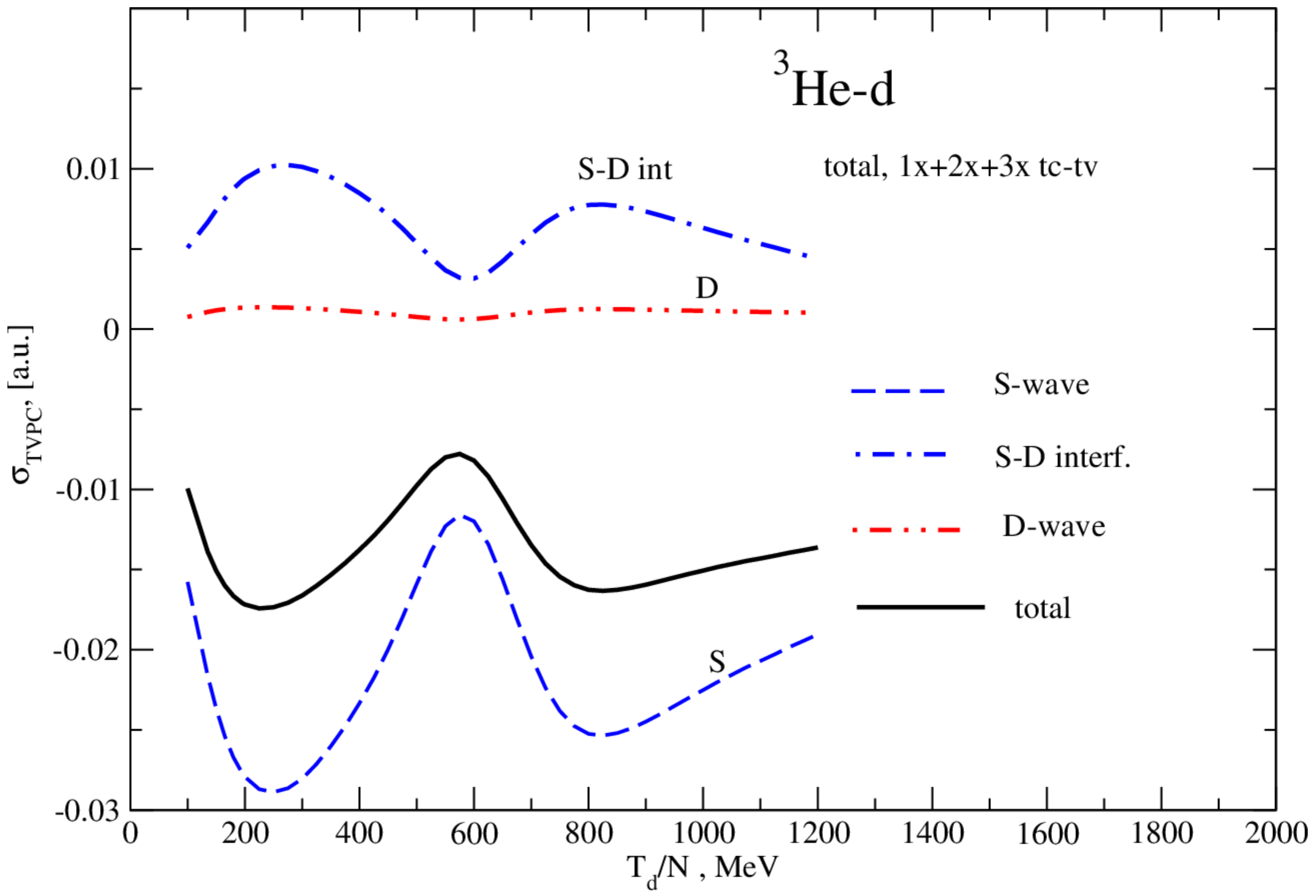
$F_{TCPC}(n^3He \rightarrow p^3H) = F_{TCPC}(p^3H \rightarrow n^3He)$

g'-term in ^{3}He-d vanishes like in pd

ENERGY DEPENDENCE OF the TVPC NULL-TEST SIGNAL in ^{3}He-d SCATTERING



^{3}He-d
h_N
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., Platonova, *JETP Lett.* 118 (2023) 11, 785
g_N
g_N -TVPC (3x step)
0.1
0.01
0.001
0.0001
1e-05
1e-06
$|\sigma_{TVPC}|$, [a.u.]
0
500
1000
1500
2000
T_d/N , MeV



Contribution of the S- and D- components of the deuteron w.f.

S-D interference is destructive

h_N –TVPC term

Yu.N. U., Platonova, JETP Lett. 118 (2023)11,785

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

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

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

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

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

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

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

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

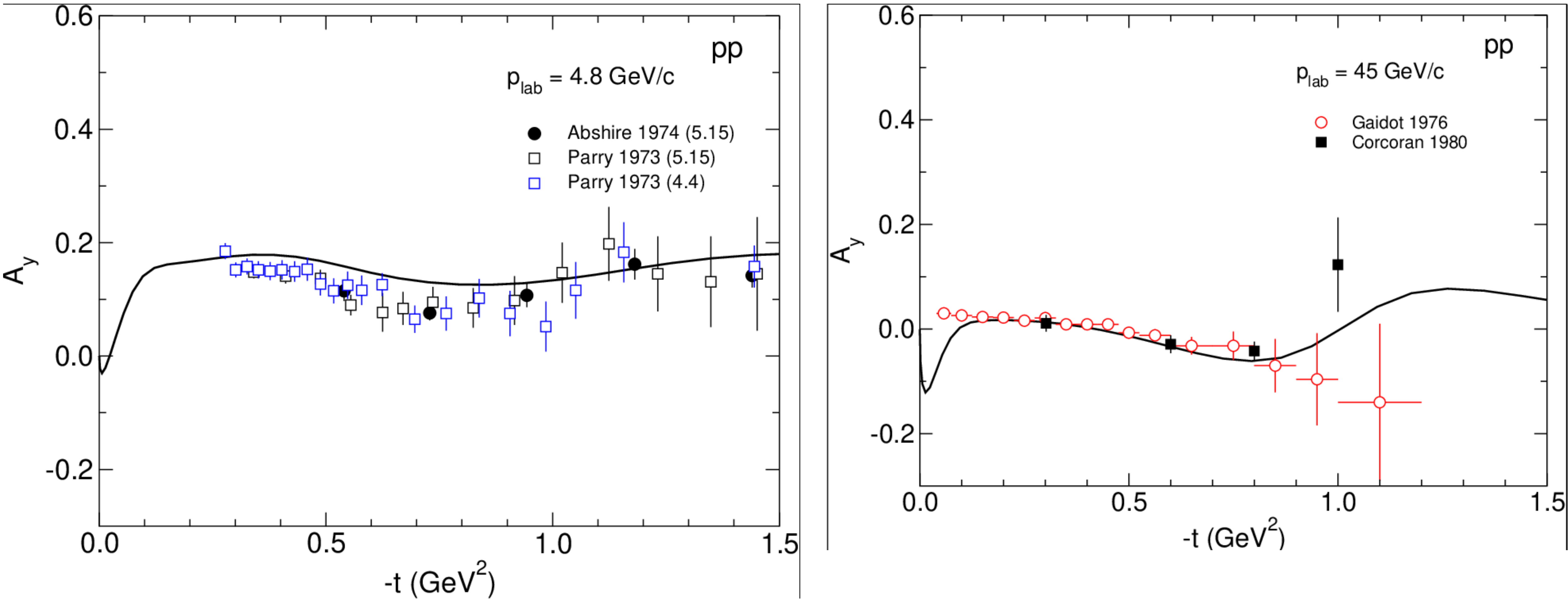
$$\beta_{4i}(t) = c_{4i}\exp(b_{4i}t)\frac{-t}{4m_N^2},$$

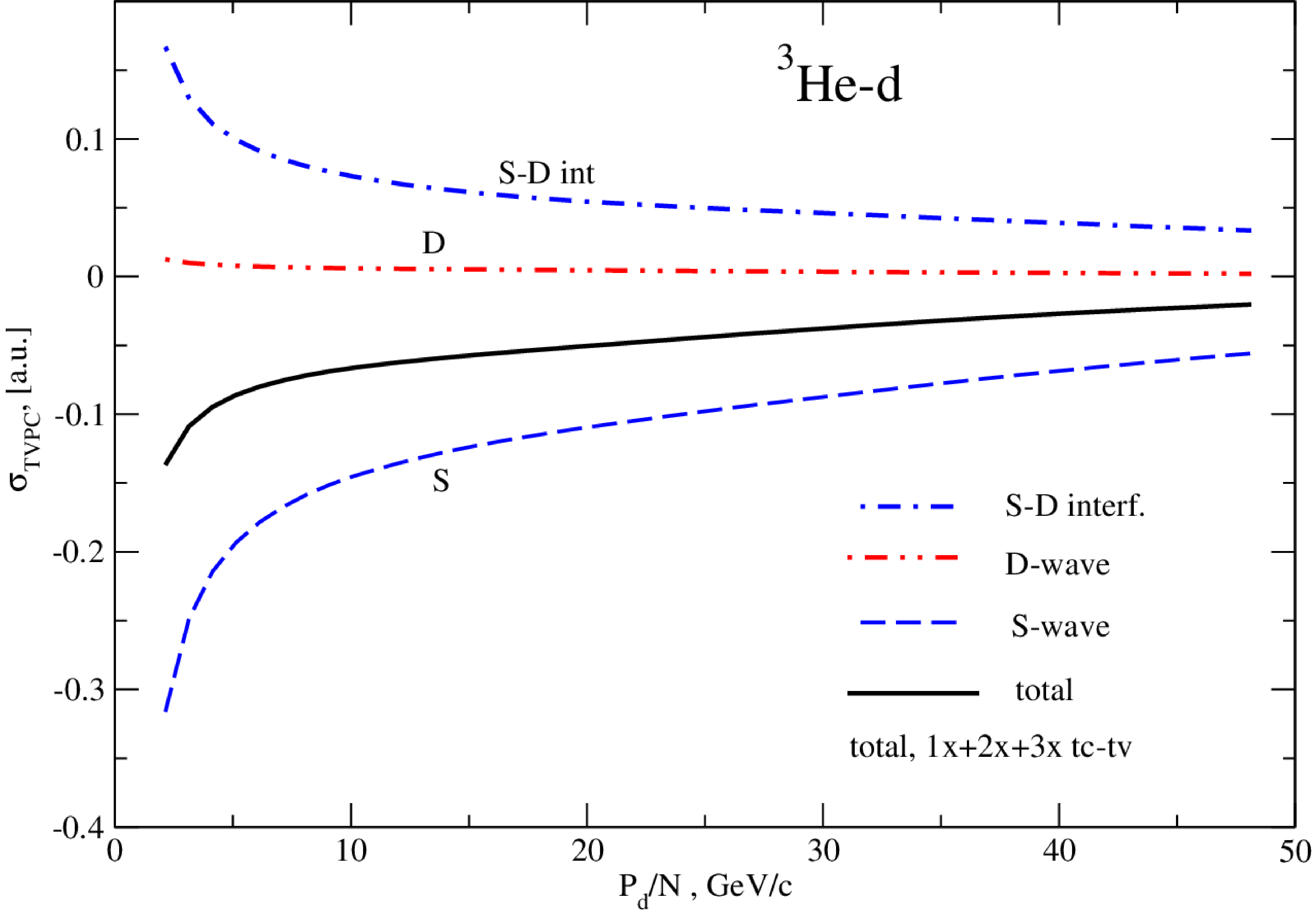
$$\beta_{5i}(t) = c_{5i}\exp(b_{5i}t)\left[\frac{-t}{4m_N^2}\right]^{1/2}.$$

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

Data on $d\sigma / dt$, A_N, A_{NN}

A. Sibirtsev et al, EPJA (2010)





^{3}He-d
S-D int
D
S
S-D interf.
D-wave
S-wave
total
total, 1x+2x+3x tc-tv
σ_{TVPC}, [a.u.]
P_d/N , GeV/c
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50

σ_{TVPC}

CONCLUSION AND OUTLOOK

- Is a true null-test observable, not generated by ISI&FSI, analog of EDM (=null-test signal for TVPV).

- T_p –dependence of the σ_{TVPC}(^3He-d) for h_N and g_N type is calculated within the Glauber theory at 0.1-1.2 GeV using SAID data. Estimations are done at p_L=3-50 GeV/c using Regge parametrizations for pN.
- ^{3}He-d does not contain the g'_N- type of TVPC.
- TVPC in dd scattering is in progress

- How to measure at SPD?

  Precessing polarization of the beam & Fourier analysis

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

THANK YOU FOR YOUR ATTENTION!

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

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

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

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

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

$$k_m T_{mn}\epsilon_{nlr} P_l^{\rm p} k_r = T_{xz}P_y^{\rm p} - T_{yz}P_x^{\rm p}$$

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

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

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.

The T-invariance:

$$T\mathcal{H}T^{-1} = \mathcal{H},$$

then the S-matrix

$$S = \lim_{t_1\to\infty} \lim_{t_2\to\infty} = \exp^{-i\mathcal{H}(t_2-t_1)},$$

transforms as

$$T\mathcal{S}T^{-1} = \mathcal{S}^{+},$$

or $T^{-1}\mathcal{S}^{+}T = \mathcal{S}$. Therefore (T is antilinear)

$$< f, S\, i >=< f, T^{-1}S^{+}T\, i >=< Tf, S^{+}T\, i >^{*}=< f_T, S^{+}i_T >^{*}$$

in other words, the T-invariance:

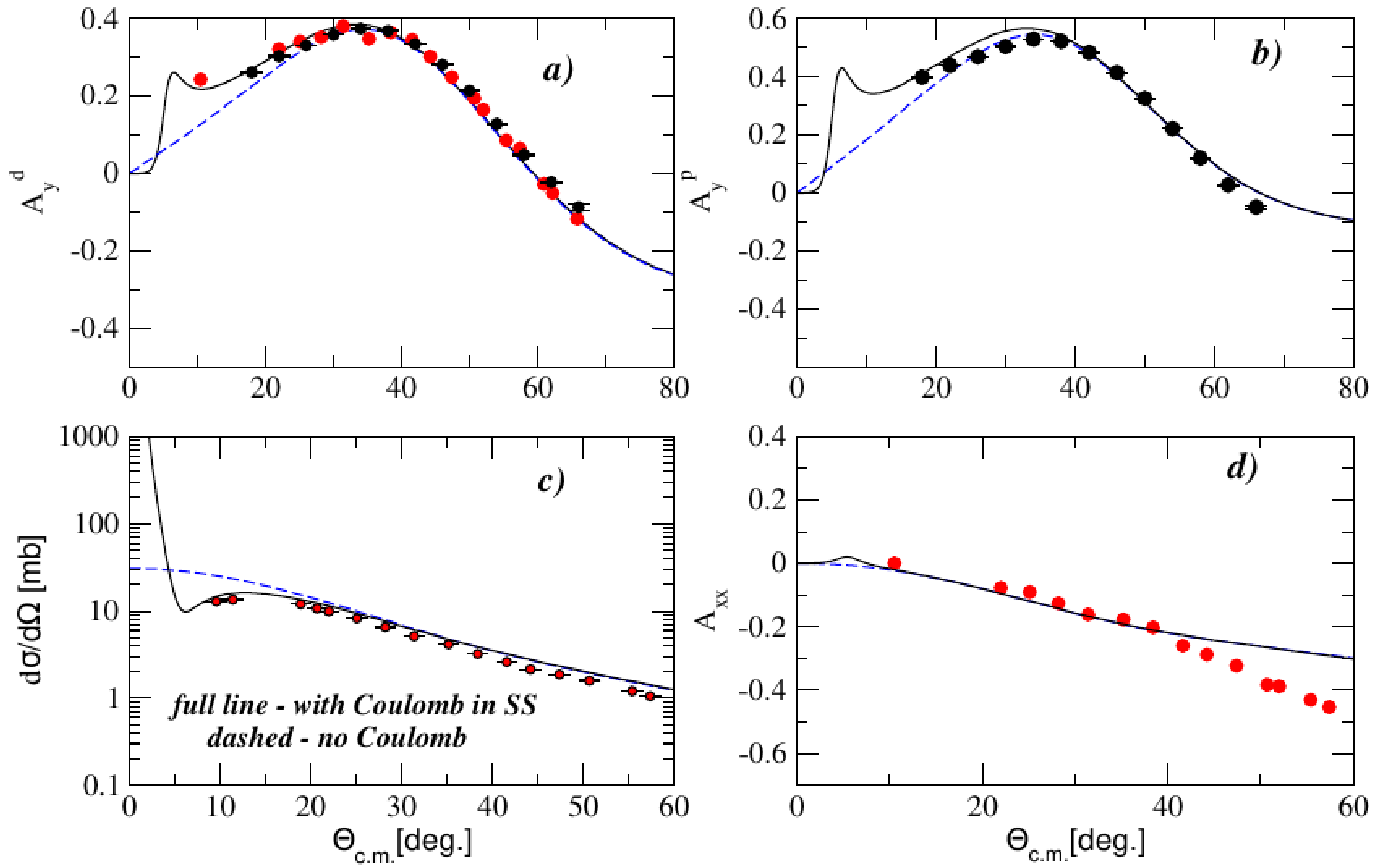
$$< f|\mathcal{S}|i >=< i_T|S|f_T >$$

(See, S.M. Bilen'kii, L.I. Lapidus, R.M. Ryndin, Usp. Phys. Nauk. 95 (1968) 489
J.R.Taylor, Sattering Theory. Quantum theory of Nonrelativistic collisions, N-Y, 1972)

$$S^{J}_{a,b} = S^{J}_{b,a}$$

Test calculations: pd elastic scattering at 135 MeV

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



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.