

Search for T-reversal Invariance Violation in Double Polarized pd Scattering

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- Motivation:
P-even **T**-**R**eversal **I**nvariance test planned at **COSY** (TRIC) (Jülich, Germany) in pd at ~ 100 MeV
- Null-test signal for T-odd P-even effects for pd , $\tilde{\sigma}$
- Capability of the Glauber model at ~ 100 - 200 MeV
- Coulomb effects, S- and D- wave of d.w.f. and $\tilde{\sigma}$
- Sources of some false effects
- T-odd P-even effects in pd -elastic: $(A_y, P_y, K_z^{x'}, K_x^{z'})$
- Summary

Yu.N. Uzikov, A.A. Temerbaev, PRC 92, 014002 (2015);

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

Why search for Time-invariance Violation?

Baryon Asymmetry of the Universe (BAU) → today:

$$\eta = \left(\frac{n_B - n_{\bar{B}}}{n_\gamma} \right) \approx \left(\frac{n_B}{n_\gamma} \right) \approx 6 \times 10^{-10}$$

(WMAP + COBE, 2003; Steigman 2012)

SM: Estimates of baryon excess much too small, $n_B / n_\gamma \approx 5 \times 10^{-19}$

✦ $(n_B - n_{\bar{B}})$ larger than expected → new sources of CP needed

Sakharov: Three Requirements:

- Baryon number violation
- Violation of C and CP symmetries
- Departure from thermodynamic equilibrium

A. Sakharov; JETP Lett, 5, 24

There must be CP violation beyond the SM. (B.H.J. McKellar, AIP Conf. Proc. 1657 (2015) 030001)

Planned experiments to search for CP violation beyond the SM

- Detecting a non-zero **EDM** of elementary fermion (neutron, atoms, charged particles). The current experimental limit

$$|d_n| \leq 2.9 \times 10^{-26} e cm$$

is much less as compared the SM estimation (B.H.J. McKellar et al. PLB 197 (1987)

$$1.4 \times 10^{-33} e cm \leq |d_n| \leq 1.6 \times 10^{-31} e cm$$

- Search for CP violation in the **neutrino sector** ($\theta_{13} \neq 0$, then generation of lepton asymmetry and via $B - L$ conservation to get the BAU).

Those are T-violating and Parity violating (TVPV) effects.

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

Why search for Time-invariance Violating P-conserving Effects?

- The T- violating, P-violating (TVPV) effects arise in SM through CP violating phase of CKM matrix and through the QCD θ - term. EDM. Various efforts are undertaken.
- T-violating P-conserving (TVPC) (flavor-conserving) effects do not arise in SM as Fundamental interactions, although can be generated through weak corrections to TVPV interactions
 - ★ CP violation in SM leads to simultaneous violation of CP and P-invariance. Therefore, to produce CP-odd P-even term one should have one additional P-odd term in the effective interaction: $g \sim M^4 G_F^2 \sin \delta \sim 10^{-10}$

V.P. Gudkov, Phys. Rep. **212**(1992)77
 - ★ ... much larger g is not excluded as the low energy limit of some unknown interaction beyond the SM
 - ★ **Experimental limits on T-odd P-even effects are much weaker than for EDM.**

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

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

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

$$\vec{q} = \vec{p}_f - \vec{p}_i \quad \text{dissappears at } \vec{q} = 0$$

★ Axial $h_1(1170)$ -meson exchange $I^G(J^{PC}) = 0^-(1^{+-}) \dots$

EDM and TVPC interactions

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

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

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): $\alpha_T \leq 10^{-15}$, $\Lambda_{TVPC} > 150$ TeV

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

EDM at energies below Λ_{TVPC}

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

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

TVPC scale and EDM

"A"-scenario:

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

$$\alpha_T \leq 10^{-15}$$

$$\Lambda_{TVPC} > 150 \text{ TeV}$$

"B"-scenario:

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 $^{27}\text{Al}(p, \alpha)^{24}\text{Mg}$ and $^{24}\text{Mg}(\alpha, p)^{27}\text{Al}$,
 $\Delta = (\sigma_{dir} - \sigma_{inv}) / (\sigma_{dir} + \sigma_{inv}) \leq 5.1 \times 10^{-3}$ (E.Blanke et al. PRL **51** (1983) 355) is not simply related to the NN T-odd P-even interaction
Numerous statistical analyses including nuclear energy-level fluctuations (J.B. French et al. PRL **54** (1985) 2313) $\alpha_T < 2 \times 10^{-3}$
- \vec{n} transmission through ^{165}Ho (P.R. Huffman et al. PRC **55** (1997) 2684)
$$\alpha_T \leq 7.1 \times 10^{-4} \quad (\text{or } \bar{g}_\rho \leq 5.9 \times 10^{-2})$$
- 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)
$$\alpha_T \leq 8 \times 10^{-5} \quad (\text{or } \bar{g}_\rho < 6.7 \times 10^{-3})$$

Experiments are not very sensitive to TVPC, in part because a single pion is unable to transmit the TVPC interaction.

TRIC experiment

- TRIC (D. Eversheim, B. Lorentz, Yu. Valdau. COSY proposal N 215):
 $\vec{p}(p_y^p) + d(P_{xz})$ transmission in the COSY ring

The goal is to improve the **direct** upper bound on **TVPC** by one order of magnitude.

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, 100 keV;

We use the Glauber theory:

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

A.A. Temerbayev, Yu.N.Uzikov, Bull. Rus. Ac. Sc. **80** (2016) 242;

Yu.N. Uzikov, A.A.Temerbaeyv, PRC **92**, 014002 (2015);

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

Phenomenology of the $pd \rightarrow pd$ transition

$$\frac{1}{2} + 1 \rightarrow \frac{1}{2} + 1$$

$(2 + 1)^2(2\frac{1}{2} + 1)^2 = 36$ transition amplitudes

P-parity \implies 18 independent amplitudes

T-invariance \implies 12 independent amplitudes

At $\theta_{cm} = 0 \implies$ 4 (for T-inv. P-inv.) + 1 (T- viol. P-inv.)

Phenomenology of the $pd \rightarrow pd$ transition

$$\hat{\mathbf{q}} = (\mathbf{p} - \mathbf{p}'), \quad \hat{\mathbf{k}} = (\mathbf{p} + \mathbf{p}')/, \quad \hat{\mathbf{n}} = [\mathbf{k} \times \mathbf{q}] - \text{unit vect.} \quad (Z \uparrow\uparrow \hat{\mathbf{k}}, X \uparrow\uparrow \hat{\mathbf{q}}, Y \uparrow\uparrow \hat{\mathbf{n}})$$

$$M = (A_1 + A_2 \boldsymbol{\sigma} \hat{\mathbf{n}}) + (A_3 + A_4 \boldsymbol{\sigma} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{q}})^2 + (A_5 + A_6 \boldsymbol{\sigma} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{n}})^2 + A_7(\boldsymbol{\sigma} \hat{\mathbf{k}})(\mathbf{S} \hat{\mathbf{k}}) + \\ A_8(\boldsymbol{\sigma} \hat{\mathbf{q}}) [(\mathbf{S} \hat{\mathbf{q}})(\mathbf{S} \hat{\mathbf{n}}) + (\mathbf{S} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{q}})] + (A_9 + A_{10} \boldsymbol{\sigma} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{n}}) + A_{11}(\boldsymbol{\sigma} \hat{\mathbf{q}})(\mathbf{S} \hat{\mathbf{q}}) + \\ A_{12}(\boldsymbol{\sigma} \hat{\mathbf{k}}) [(\mathbf{S} \hat{\mathbf{k}})(\mathbf{S} \hat{\mathbf{n}}) + (\mathbf{S} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{k}})]$$

$$+ (T_{13} + T_{14} \boldsymbol{\sigma} \hat{\mathbf{n}}) [(\mathbf{S} \hat{\mathbf{k}})(\mathbf{S} \hat{\mathbf{q}}) + (\mathbf{S} \hat{\mathbf{q}})(\mathbf{S} \hat{\mathbf{k}})] + T_{15}(\boldsymbol{\sigma} \hat{\mathbf{q}})(\mathbf{S} \hat{\mathbf{k}}) + T_{16}(\boldsymbol{\sigma} \hat{\mathbf{k}})(\mathbf{S} \hat{\mathbf{q}}) + \\ T_{17}(\boldsymbol{\sigma} \hat{\mathbf{k}}) [(\mathbf{S} \hat{\mathbf{q}})(\mathbf{S} \hat{\mathbf{n}}) + (\mathbf{S} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{q}})] + T_{18}(\boldsymbol{\sigma} \hat{\mathbf{q}}) [(\mathbf{S} \hat{\mathbf{k}})(\mathbf{S} \hat{\mathbf{n}}) + (\mathbf{S} \hat{\mathbf{n}})(\mathbf{S} \hat{\mathbf{k}})]$$

T-even P-even: $A_1 \div A_{12}$

(see M. Platonova, V.I. Kukulín, PRC **81** (2010) 014004)

$T_{13} \div T_{18} : \text{TVPC}$

The polarized elastic differential pd cross section

$$\left(\frac{d\sigma}{d\Omega} \right)_{pol} = \left(\frac{d\sigma}{d\Omega} \right)_0 \left[1 + \frac{3}{2} p_j^p p_i^d C_{j,i} + \frac{1}{3} P_{ij}^d A_{ij} + \dots \right]. \quad (2)$$

$$C_{y,y} = \text{Tr} M S_y \sigma_y M^+ / \text{Tr} M M^+, \quad \dots \quad (3)$$

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

$$e'_{\beta}{}^* \hat{M}_{\alpha\beta}(0) e_{\alpha} = g_1[\mathbf{e} \mathbf{e}'^* - (\hat{\mathbf{k}}\mathbf{e})(\hat{\mathbf{k}}\mathbf{e}'^*)] + g_2(\hat{\mathbf{k}}\mathbf{e})(\hat{\mathbf{k}}\mathbf{e}'^*) + ig_3\{\boldsymbol{\sigma}[\mathbf{e} \times \mathbf{e}'^*] - (\boldsymbol{\sigma}\hat{\mathbf{k}})(\hat{\mathbf{k}} \cdot [\mathbf{e} \times \mathbf{e}'^*])\} + ig_4(\boldsymbol{\sigma}\hat{\mathbf{k}})(\hat{\mathbf{k}} \cdot [\mathbf{e} \times \mathbf{e}'^*]) + \quad (4)$$

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

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

$$\dots + \tilde{g}_5\{(\boldsymbol{\sigma} \cdot [\hat{\mathbf{k}} \times \mathbf{e}])(\mathbf{k} \cdot \mathbf{e}'^*) + (\boldsymbol{\sigma} \cdot [\hat{\mathbf{k}} \times \mathbf{e}'^*])(\mathbf{k} \cdot \mathbf{e})\}; \quad (5)$$

Non-diagonal:

$$\langle \mu' = \frac{1}{2}, \lambda' = 0 | M^{TVPC} | \mu = -\frac{1}{2}, \lambda = 1 \rangle = i\sqrt{2}\tilde{g}_5. \quad (6)$$

Generalized Optical theorem:

$$Im \frac{Tr(\hat{\rho}_i \hat{M}(0))}{Tr \hat{\rho}_i} = \frac{k}{4\pi} \sigma_i \quad (7)$$

Total polarized cross sections pd

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

with

$$\sigma_0 = \frac{4\pi}{k} \text{Im} \frac{2g_1 + g_2}{3}, \quad \sigma_1 = -\frac{4\pi}{k} \text{Im} g_3,$$

$$\sigma_2 = -\frac{4\pi}{k} \text{Im}(g_4 - g_3), \quad \sigma_3 = \frac{4\pi}{k} \text{Im} \frac{g_1 - g_2}{6}.$$

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

$$\tilde{\sigma}_{tvpc} = -\frac{4\pi}{k} \text{Im} \frac{2}{3} \tilde{g}_5 \quad (8)$$

/Yu.N. Uzikov, A.A. Temerbayev, Phys. Rev. C **92** (2016)/

Null-test of T -reversal invariance

Measurement of total $\tilde{\sigma}_{tvp\bar{c}}$ in $\vec{p} - \vec{d}$ scattering:

- a true null-test for T -invariance
- independent on dynamics
- FSI & ISI are yet included into $F(0)$

Comments to "Nonexistence proof":

"It is impossible to construct, in any reaction in atomic, nuclear, or particle physics, a null experiment that would unambiguously test the time-reversal invariance independently of dynamical assumptions"

F.Arash, M.J. Moravcsik, G.R. Goldstein, Phys.Rev.Lett. 54(1985) 2649

Proof holds for bilinear ($\sim |F_{if}|^2$) observables only

H.E. Conzett, Phys. Rev. C 48 (1993) 423

Transmission experiments are not included into that proof;

V.E. Bunakov, L.B. Pikelner, Prog. Part. Nucl. Phys. 39 (1997) 377

Elastic $pd \rightarrow pd$ transitions

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

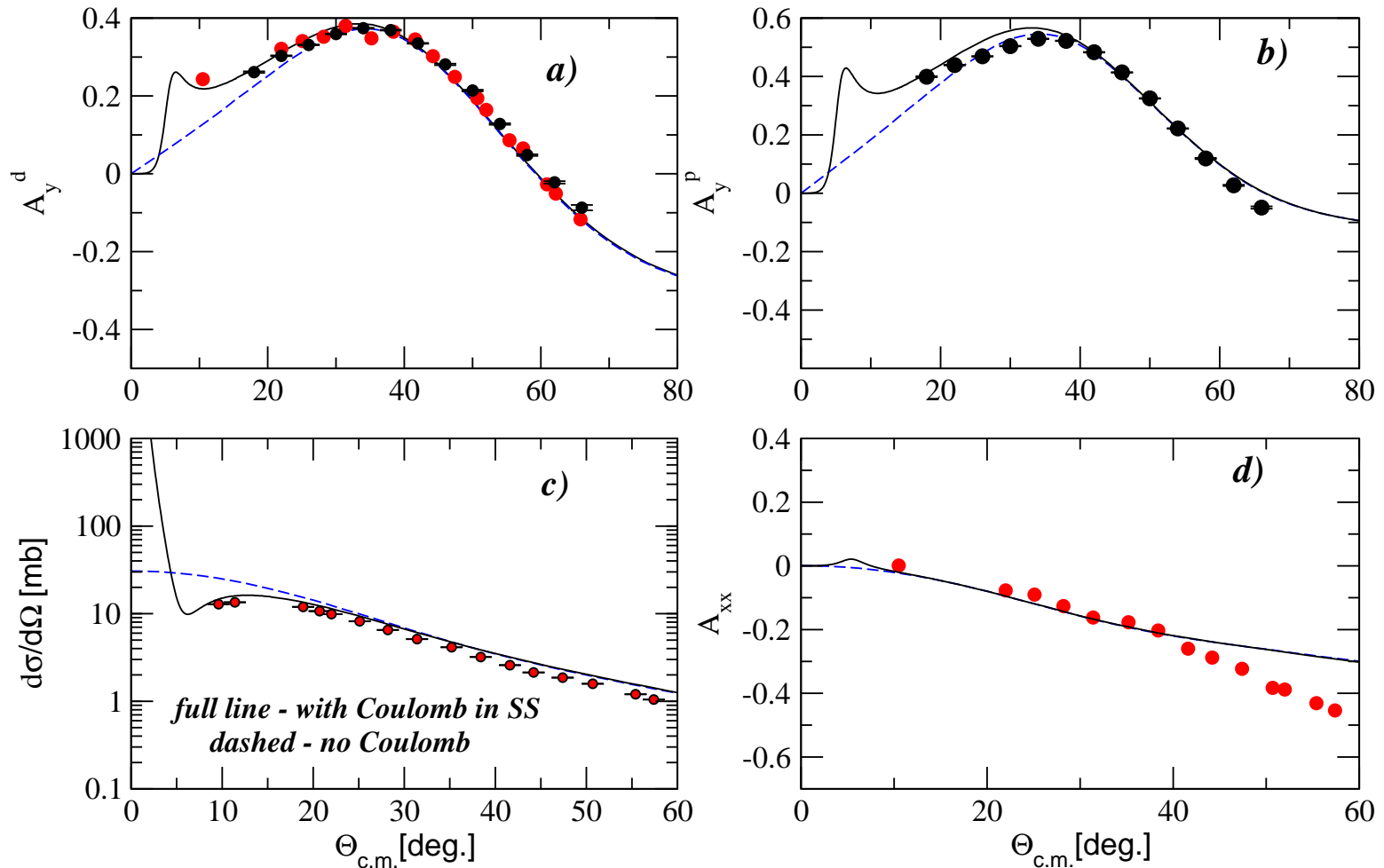
On-shell elastic pN scattering amplitude (**T-even, P-even**)

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

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

Test calculations: pd elastic scattering at 135 MeV

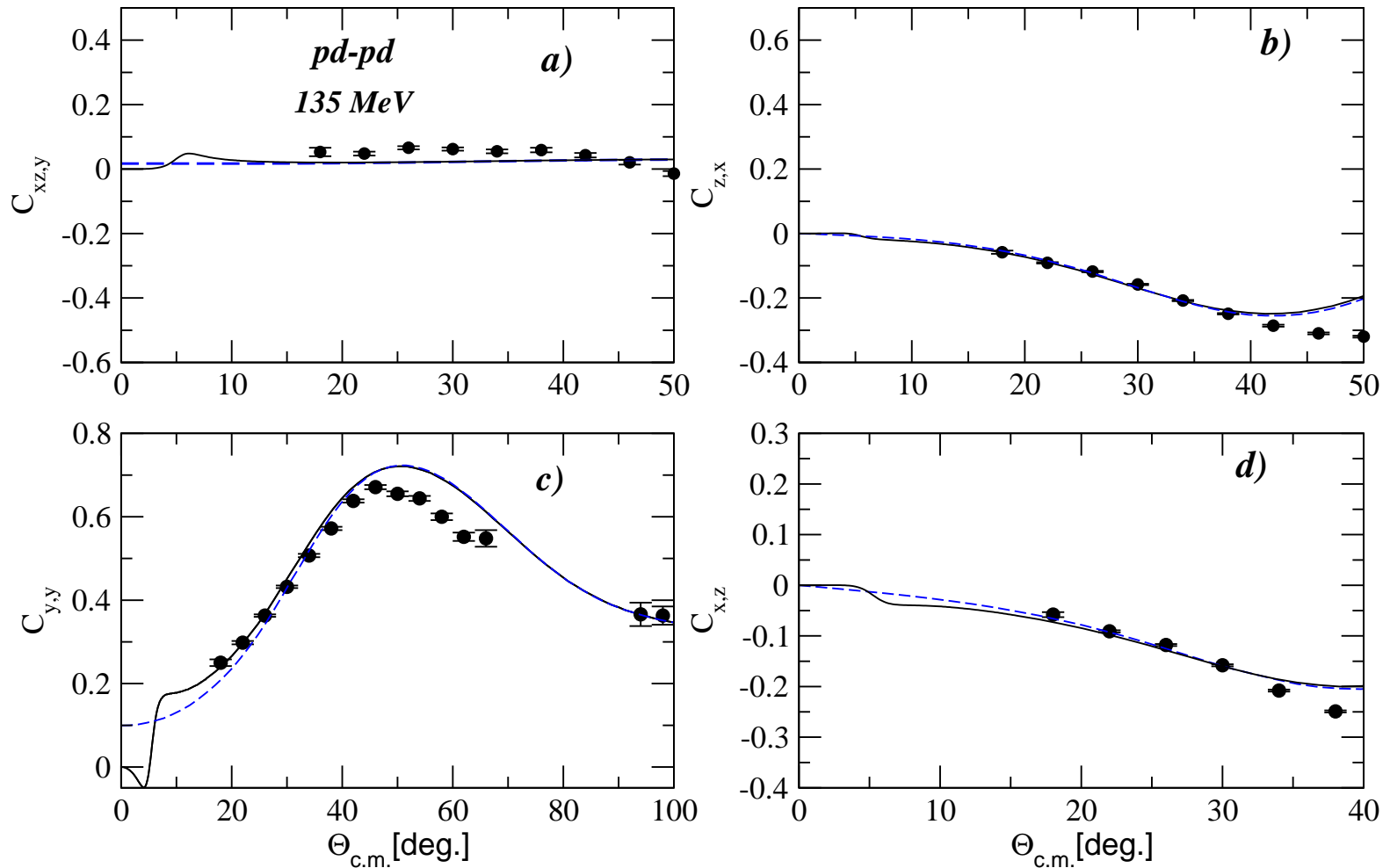
A.A. Temerbavev, Yu.N.Uzikov, Yad. Fiz. **78** (2015) 38



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.

Test calculations-II: *nd* elastic scattering at 135 MeV



Curves: the modified Glauber model; A.A. Temerbayev, Yu.N.Uzikov, *Yad. Fiz.* **78** (2015) 38

Data: von B.Przewoski et al. *PRC* 74 (2006) 064003

TVPC NN interactions and σ_{TVPC}

$$t_{pN} = \underbrace{h_p [(\boldsymbol{\sigma} \cdot \mathbf{p})(\boldsymbol{\sigma}_p \cdot \mathbf{q}) + (\boldsymbol{\sigma}_p \cdot \mathbf{p})(\boldsymbol{\sigma} \cdot \mathbf{q}) - (\boldsymbol{\sigma}_p \cdot \boldsymbol{\sigma})(\mathbf{p} \cdot \mathbf{q})]}_{h1\text{-meson}} + \\ + g_p [\boldsymbol{\sigma} \times \boldsymbol{\sigma}_p] \cdot [\mathbf{q} \times \mathbf{p}] + \underbrace{g'_p (\boldsymbol{\sigma} - \boldsymbol{\sigma}_p) \cdot i [\mathbf{q} \times \mathbf{p}] [\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2]_z}_{\rho\text{-meson}} + (p \leftrightarrow n)$$

Glauber transition operator:

$$O(\boldsymbol{\sigma}, \boldsymbol{\sigma}_n, \boldsymbol{\sigma}_p) = U(\boldsymbol{\sigma}) + \underbrace{\mathbf{V}_n(\boldsymbol{\sigma}) \cdot \boldsymbol{\sigma}_n + \mathbf{V}_p(\boldsymbol{\sigma}) \cdot \boldsymbol{\sigma}_p}_{\mathbf{VS}=0, \rho\text{-meson}} + W_{ij}(\boldsymbol{\sigma}) \cdot (\sigma_{ni}\sigma_{pj} + \sigma_{nj}\sigma_{pi}),$$

$$\int e^{i\mathbf{Q}\mathbf{r}} \Psi_d O \Psi_d d^3r = US_0 + \mathbf{VSS}_0^{(0)} + (W_{ij} \{S_i, S_j\} - W_{ii}) S_0^{(0)} + \dots \quad (9)$$

is diagonal for the beam proton spin, whereas

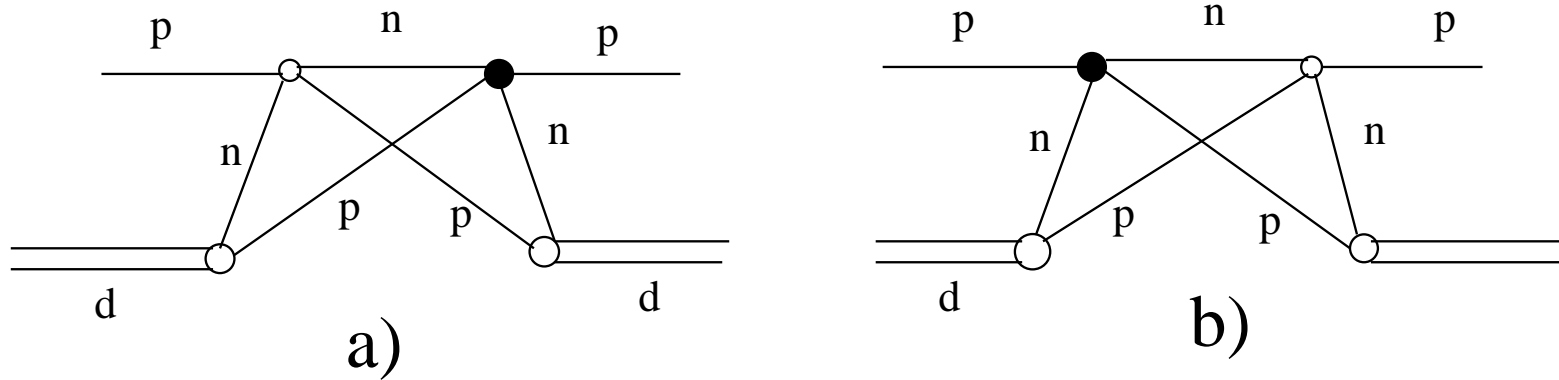
$$\langle \mu' = \frac{1}{2}, \lambda' = 0 | F^{TVPC} | \mu = -\frac{1}{2}, \lambda = 1 \rangle = i\sqrt{2}\tilde{g}_5. \quad (10)$$

Therefore, for g' :

$$\tilde{g}_5 = 0$$

ρ -meson does not contribute!

TVPC. Double scattering mechanism



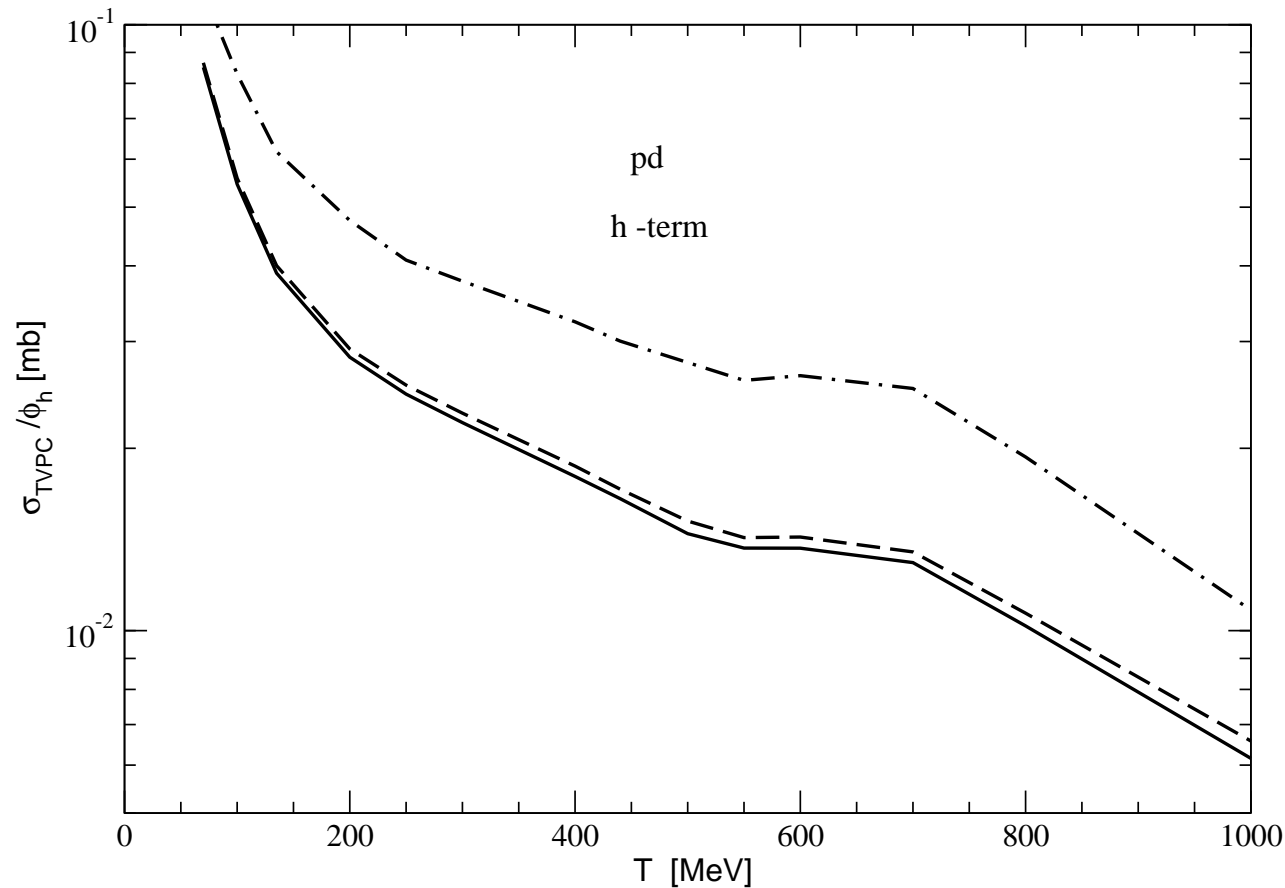
Single scattering mechanism gives zero contribution to $\tilde{\sigma}$

Details in:

Yu.N.U. EPJ Web of Conferences, 113 (2016) 04027

TVPC. S-wave. Energy dependence. *Coulomb contribution is negligible*

$$\tilde{g}_5 = \frac{ik_{pd}}{2\sqrt{\pi}} \int_0^\infty dq q^2 S_0^{(0)}(q) [C'_n(q)(h_p - g_p) + C'_p(q)(h_n - g_n)], \quad C'_p(q) = C_p + \frac{q}{2M}(A_p + F_{pp}^C), \quad (11)$$



Yu.N. Uzikov, A.A. Temerbaevy, PRC 92 (2015) 014002. Coulomb incl. (—), excl. (— — —)

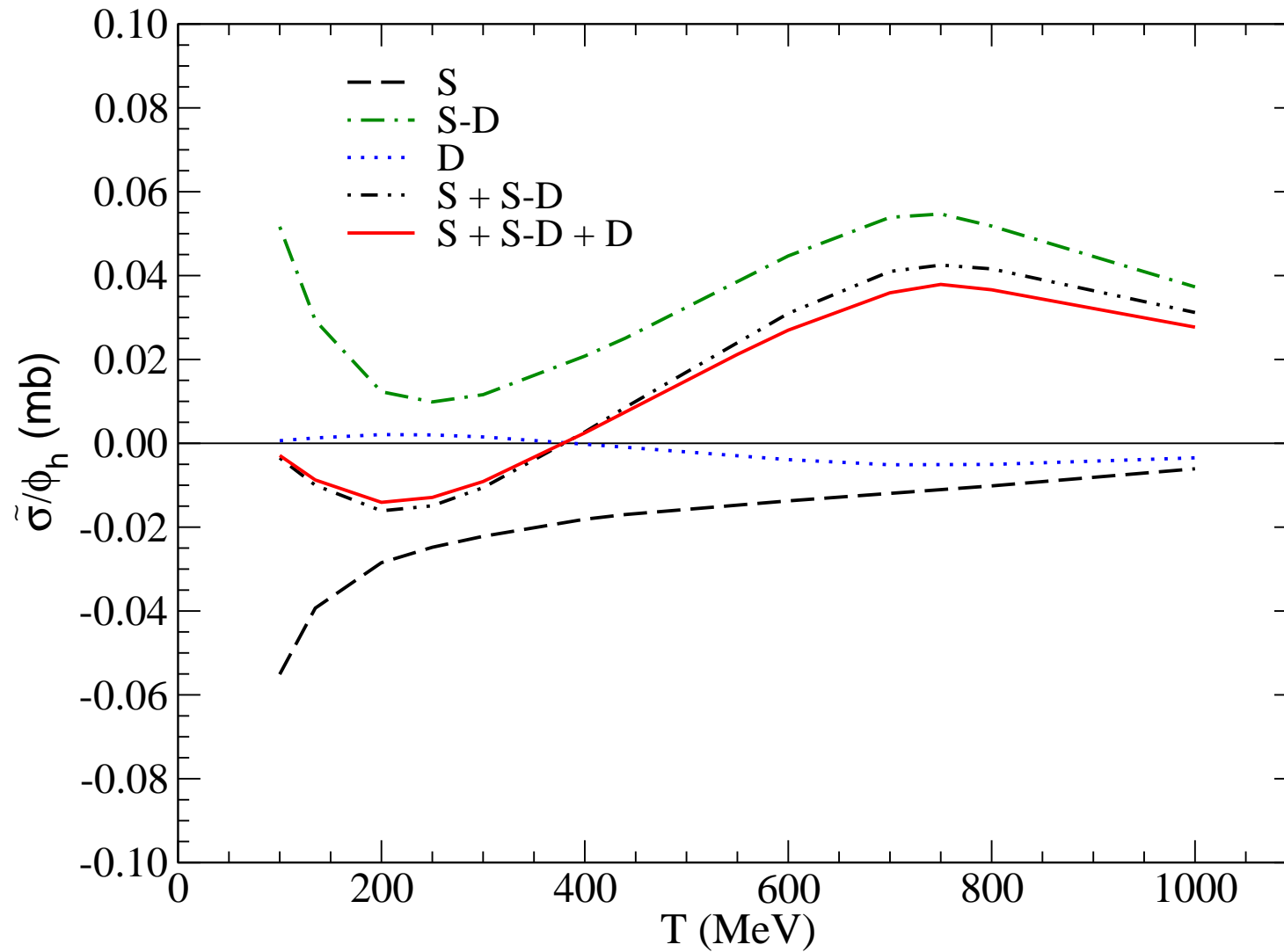
TVPC-amplitude \tilde{g}_5 .

$$\tilde{g}_5 = \frac{i}{4\pi m_p} \int_0^\infty dq q^2 \left[S_0^{(0)}(q) - \sqrt{8} S_2^{(1)}(q) - 4 S_0^{(2)}(q) + \sqrt{2} \frac{4}{3} S_2^{(2)}(q) + 9 S_1^{(2)}(q) \right] \\ \times [-C'_n(q) h_p + C'_p(q)(g_n - h_n)],$$

where

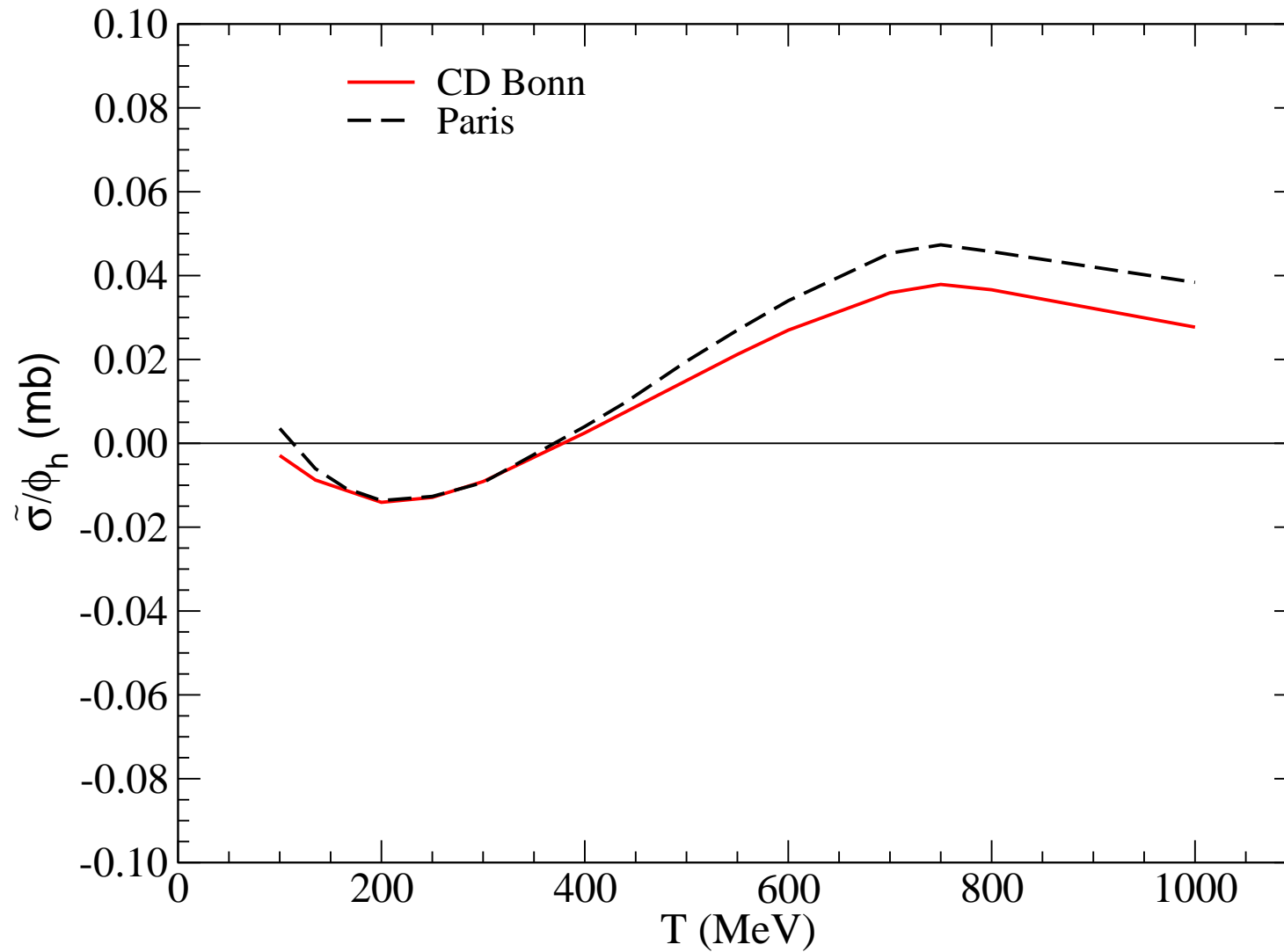
$$S_0^{(0)}(q) = \int_0^\infty dr u^2(r) j_0(qr), \quad S_0^{(2)}(q) = \int_0^\infty dr w^2(r) j_0(qr), \\ S_2^{(1)}(q) = 2 \int_0^\infty dr u(r) w(r) j_2(qr), \\ S_2^{(2)}(q) = -\frac{1}{\sqrt{2}} \int_0^\infty dr w^2(r) j_2(qr), \\ S_1^{(2)}(q) = \int_0^\infty dr w^2(r) j_1(qr) / (qr).$$

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



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

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



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

Total polarized T-even P-even pd cross sections and restrictions to P_y^d

$$\sigma_{tot} = \sigma_0 + \sigma_1 \mathbf{p}^p \cdot \mathbf{P}^d + \sigma_2 (\mathbf{p}^p \cdot \hat{\mathbf{k}}) (\mathbf{P}^d \cdot \hat{\mathbf{k}}) + \sigma_3 P_{zz} + \tilde{\sigma} p_y^p P_{xz}^d \quad (12)$$

$$\underline{T_0 = 135 \text{ MeV:}}$$

$$\sigma_0 = 78.5 \text{ mb}, \quad \sigma_1 = 3.7 \text{ mb}, \quad \sigma_2 = 12.4 \text{ mb}, \quad \sigma_3 = -1.1 \text{ mb}$$

$$\frac{\sigma_1}{\sigma_0} = 0.047$$

The goal of TRIC: $\delta R_T \leq 10^{-6}$, where

$$R_T = \frac{\tilde{\sigma}}{\sigma_0}$$

then from $\frac{P_y^d \sigma_1}{\tilde{\sigma}} \sim 10^{-1}$ and $R_T \leq 10^{-6} \implies P_y^d \leq 2 \times 10^{-6}$

The deuteron vector polarization has to be adjusted to be zero in the atomic beam source

SUMMARY

- $\tilde{\sigma}_{tvpc}$ is a true null-test observable. Not affected by ISI&FSI, will be measured by TRIC. $\tilde{\sigma}_{tvpc}$ and uncertainties can be reasonable estimated within the Glauber theory
- Calculated energy dependence of $\tilde{\sigma}_{tvpc}$: $T_p \sim (200 - 700)$ MeV – max.
- The ρ -meson contribution to $\tilde{\sigma}_{tvpc}$ vanishes...
- The Coulomb interaction does not lead to divergence of the null-test observable $\tilde{\sigma}_{tvpc}$!
- Integrated polarized pd cross sections $\sigma_1, \sigma_2, \sigma_3$ are calculated $\implies \sigma_1/\sigma_0$ gives essential restriction: $p_y^d \leq 10^{-6}$.
- $\phi_h = \bar{G}_h/G_h < 0.001 \div 0.002$ for $\tilde{\sigma}/\sigma_0 < 10^{-6}$ at TRIC
or $|K_z^{x'}(p-d) + K_x^{z'}(d-p)| \leq 10^{-4}$ or $|A_y^p - P_y^p| \leq 3 \times 10^{-5}$.
- D- wave is very important inspite of $q = 0$
- TVPC components of the d.w.f.?

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 ?”

THANK YOU FOR ATTENTION!

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

- CP-violation in K- and B-meson physics (under CPT) \implies T-violation

- T violation in the K-system:

$$K^0 \rightarrow \bar{K}^0 \text{ and } \bar{K}^0 \rightarrow K^0$$

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

$$\bar{B}^0 \rightarrow B_- \text{ and } B_- \rightarrow \bar{B}^0$$

connected only by T-symmetry transformation

(There are three other independent 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.

Sources for false effects

Involved Spins: $\frac{1}{2} + 1 \rightarrow \frac{1}{2} + 1$

<u>I_{0,0}</u>	<u>A_{0,X}</u>	<u>A_{0,Y}</u>	<u>A_{0,Z}</u>	A _{0,XX}	A _{0,YY}	A _{0,ZZ}	<u>A_{0,XY}</u>	<u>A_{0,YZ}</u>	<u>A_{0,XZ}</u>
<u>A_{X,0}</u>	A _{X,X}	<u>A_{X,Y}</u>	<u>A_{X,Z}</u>	<u>A_{X,XX}</u>	<u>A_{X,YY}</u>	<u>A_{X,ZZ}</u>	<u>A_{X,XY}</u>	A _{X,YZ}	<u>A_{X,XZ}</u>
<u>A_{Y,0}</u>	<u>A_{Y,X}</u>	A_{Y,Y}	<u>A_{Y,Z}</u>	<u>A_{Y,XX}</u>	<u>A_{Y,YY}</u>	<u>A_{Y,ZZ}</u>	<u>A_{Y,XY}</u>	<u>A_{Y,YZ}</u>	A_{Y,XZ}
<u>A_{Z,0}</u>	<u>A_{Z,X}</u>	<u>A_{Z,Y}</u>	A _{Z,Z}	<u>A_{Z,XX}</u>	<u>A_{Z,YY}</u>	<u>A_{Z,ZZ}</u>	<u>A_{Z,XY}</u>	<u>A_{Z,YZ}</u>	<u>A_{Z,XZ}</u>

Line cancels because of : **Protonspinflip**
 p_x, p_z negligible for protons

Quantity cancels because of : ~~R~~, ~~P~~

From talk by D. Eversheim, ECT, (Trento, October, 2012)

$$A_y^p = P_y^p, \quad A_y^d = P_y^d \quad (13)$$

In Madison frame:

$$\begin{aligned} K_z^{x'} &= K_z^x \cos \theta - K_z^z \sin \theta, \\ K_x^{z'} &= K_x^z \cos \theta + K_x^x \sin \theta; \end{aligned} \quad (14)$$

$$\begin{aligned} K_z^x(p \rightarrow p) &= \frac{\text{Tr} M \sigma_z M^+ \sigma_x}{\text{Tr} M M^+}, \quad K_z^x(p \rightarrow d) = \frac{\text{Tr} M \sigma_z M^+ S_x}{\text{Tr} M M^+}, \\ K_z^x(d \rightarrow p) &= \frac{\text{Tr} M S_z M^+ \sigma_x}{\text{Tr} M M^+}, \quad K_z^x(d \rightarrow d) = \frac{\text{Tr} M S_z M^+ S_x}{\text{Tr} M M^+}. \end{aligned}$$

$$\begin{aligned} K_x^{z'}(p \rightarrow p) &= -K_z^{x'}(p \rightarrow p), \\ K_x^{z'}(p \rightarrow d) &= -K_z^{x'}(d \rightarrow p), \\ K_x^{z'}(d \rightarrow p) &= -K_z^{x'}(p \rightarrow d), \\ K_x^{z'}(d \rightarrow d) &= -K_z^{x'}(d \rightarrow d), \end{aligned} \quad (15)$$

$(A_y - P_y, K_x^{z'} + K_z^{x'})$: A.A. Temerbaev, Yu.N.U., Izv.RAN, Ser. Fiz. **80** (2016)

