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

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CONTENT

- Motivation (BAU):
  P-even **T**ime-**R**eversal **I**nvariance test planned at **C**OSY (TRIC) (Jülich, Germany) in pd at $\sim$100 MeV
- T-violating P-conserving NN interactions
- Null-test signal for T-odd P-even effects for pd, $\widetilde{\sigma}$
- Capability of the Glauber model and $\widetilde{\sigma}$ at $\sim$100-1000MeV
- How to measure $\widetilde{\sigma}$?
- Possible source of false effect
- Summary
- T-violation in pd-elastic: $(A_y = P_y,\ K_z^{x'} = -K_x^{z'})$

Yu.N. Uzikov, A.A.Temerbayev, PRC **92**, *014002 (2015);*
Yu.N. Uzikov, J.Haidenbauer, PRC **94**, *035501 (2016)*
Yu.N. U. EPJ, Web of Conferences **138**, *08001 (2017)*

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 $\not{C}\!P$ 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).

Thouse 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 $\theta-$ term. EDM.

- 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

  ⋆ Observed (in K^0, B^0) CP violation in SM leads to simultaneous violation of T- and P-invariance.
  Therefore, to produce T-odd P-even term one should have one additional P-odd term in the effective interaction: $\mathbf{g \sim M^4 G_F^2} \sin\delta \sim \mathbf{10^{-10}}$

  V.P. Gudkov, Phys. Rep. **212**(1992)77

  ⋆ ...much larger g is not excluded by unknown interaction beyond the SM.

  ⋆ **Experimental limits on TVPC effects are much weaker than for EDM.**

Time Reversal in Quantum Mechanics

$$i\frac{\partial\psi(t)}{\partial t} = \mathcal{H}\psi(t) \quad (1)$$

$t \to -t$ and $\psi(-t) \to \psi^*(-t)$,
if $H = H^*$ then $\psi'(t) = \psi^*(-t)$ is a solution of Eq. (1).

In general case, the T-transformation $t \to t = -t$:

$$\psi'(t') = T\psi(-t), Q' = TQT^{-1}$$

T-inversion: $\mathbf{x}' = \mathbf{x}$, $\mathbf{p}' = -\mathbf{p}$,
$\mathbf{L} = [\mathbf{r} \times \mathbf{p}] \to -\mathbf{L}$, and, therefore, $\boldsymbol{\sigma} \to -\boldsymbol{\sigma}$
Then $[p_i, x_j] = -i\delta_{ij}$ requires

$$TiT^{-1} = -i$$

Thus, T is an antilinear operator.
The operator T must have the properties:
$T = UK,\ KzK^{-1} = z^*,\ \ UU^+ = 1$,
K is the operator for complex congugation
$K^2 = 1$, $K^{-1} = K$, $T^{-1} = KU^+$
$T\psi = U\psi^*$

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)

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

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)

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

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*

$\star$ $J \geq 1$

$\star$ π, σ-exchanges do not contribute

$\star$ The lowest mass meson allowed is the ρ-meson $/I^G(J^{PC}) = 1^+(1^{--})/$

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 $\vec{q} = 0$

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

On-shell TVPC NN interactions

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

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

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

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, $M^{str}_{pn\to np} = M^{str}_{np\to pn}$.

EDM and TVPC interactions

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

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

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

A.Kurylov, G.C. McLaughlin, M.Ramsey-Musolf , PRD 63(2001)076007:
EDM at energies below Λ_{TVPC}

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

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

TVPC scale and EDM

<u>"A"-scenario</u>:

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

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

$\Lambda_{TVPC} > 150$ TeV

<u>"B"-scenario</u>:

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) 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) $\alpha_T < 2 \times 10^{-3}$ ($\bar{g}_\rho \leq 1.7 \times 10^{-1}$).

- $\vec{n}$ transmission through ^{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)

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

Search for T-violation in other processes

- Search for T-violation in decays

A.G. Beda, V.P. Skoy, Elem.Chat. At. Yadr. **37** (2007) 1477

$\vec{n} \to p\, e \tilde{\nu}$ or triple nuclear fussion

$$W_{if} \sim X\mathbf{s_n}[\mathbf{k}_n \times \mathbf{k}_\nu] + R\mathbf{s}_n[\mathbf{k}_n \times \mathbf{s}_e]$$

i) FSI with Coulomb

ii) Not all T-odd correlations are related to the true T-invariance violation

- Total cross section of the nA interaction from forward nA scattering amplitude

$$f = \underbrace{A + p_n p_T B(\mathbf{s}\cdot\mathbf{I})}_{strong} + \underbrace{p_n C(\mathbf{s}\cdot\mathbf{k})}_{PV} + \underbrace{p_n p_T D(\mathbf{s}\cdot[\mathbf{k}\times\mathbf{I}])}_{TVPV} + \underbrace{p_T E(\mathbf{k}\cdot\mathbf{I})}_{PV} + \underbrace{p_n p_T F(\mathbf{k}\cdot\mathbf{I})(\mathbf{s}\cdot[\mathbf{k}\times\mathbf{I}])}_{TVPC}$$

T-odd correlations in forward elastic scattering (=in total cross section):

Three-fold $(\mathbf{s}\cdot[\mathbf{k}\times\mathbf{I}])$ – TVPV

five-fold $(\mathbf{k}\cdot\mathbf{I})(\mathbf{s}\cdot[\mathbf{k}\times\mathbf{I}])$ – TVPC

TRANSMISSION experiment!

TRIC experiment

- TRIC (D. Eversheim et al. COSY proposal N 215,2012):
  $\vec{p}(p_y^p) + d(P_{xz})$ 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 at 100 keV; pd at 2 MeV
  We use the Glauber theory:
  A.A. Temerbayev, Yu.N. Uzikov, Yad. Fiz. **78** (2015) 38;

Phenomenology of the $pd \to pd$ transition

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

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

P-parity $\Longrightarrow$ 18 independent amplitudes

T-invariance $\Longrightarrow$ 12 independent amplitudes

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

Collinear kinematics

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

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

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

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

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/*

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

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

Null-test of T-reversal invariance

Measurement of total $\widetilde{\sigma}_{tvpc}$ in $\vec{p}-\vec{d}$ scattering:

- independent on dynamics
- FSI $\&$ ISI are yet included into $F(0)$
- a true null-test for TVPC, like EDM is a null-test for TVPV.

Comments to "Nonexistence proof":

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*

A very similar to $\widetilde{\sigma}_{tvpc}$ TVPC observable occurs in deep-inelastic lepton-$\vec{N}$ scattering (O.V. Teryaev, Chech. J. Phys. **53**, 47A (2003))

Glauber formalism

Elastic $pd \to pd$ transitions

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

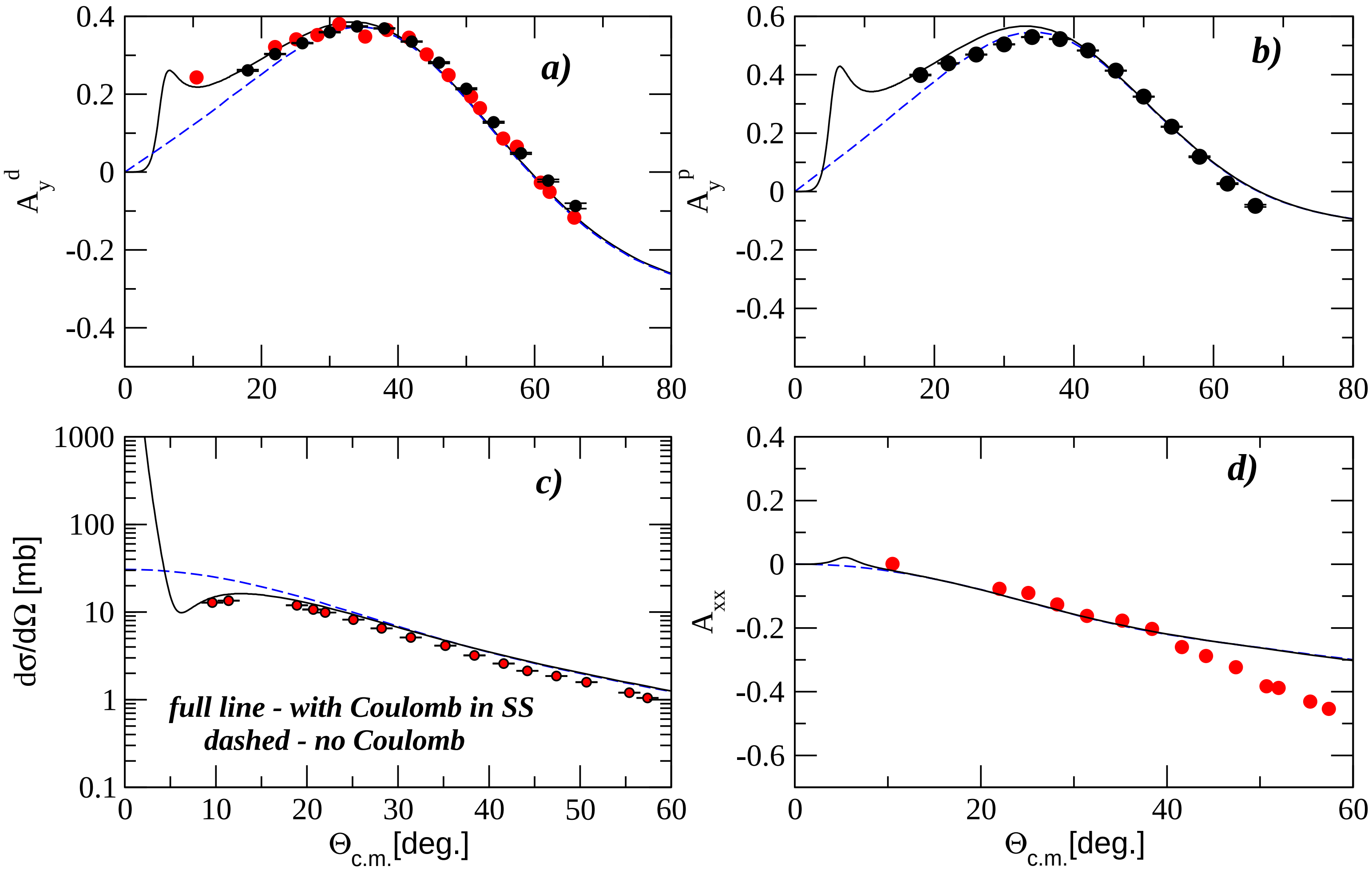
On-shell elastic pN scattering amplitude (**T-even, P-even**)

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

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

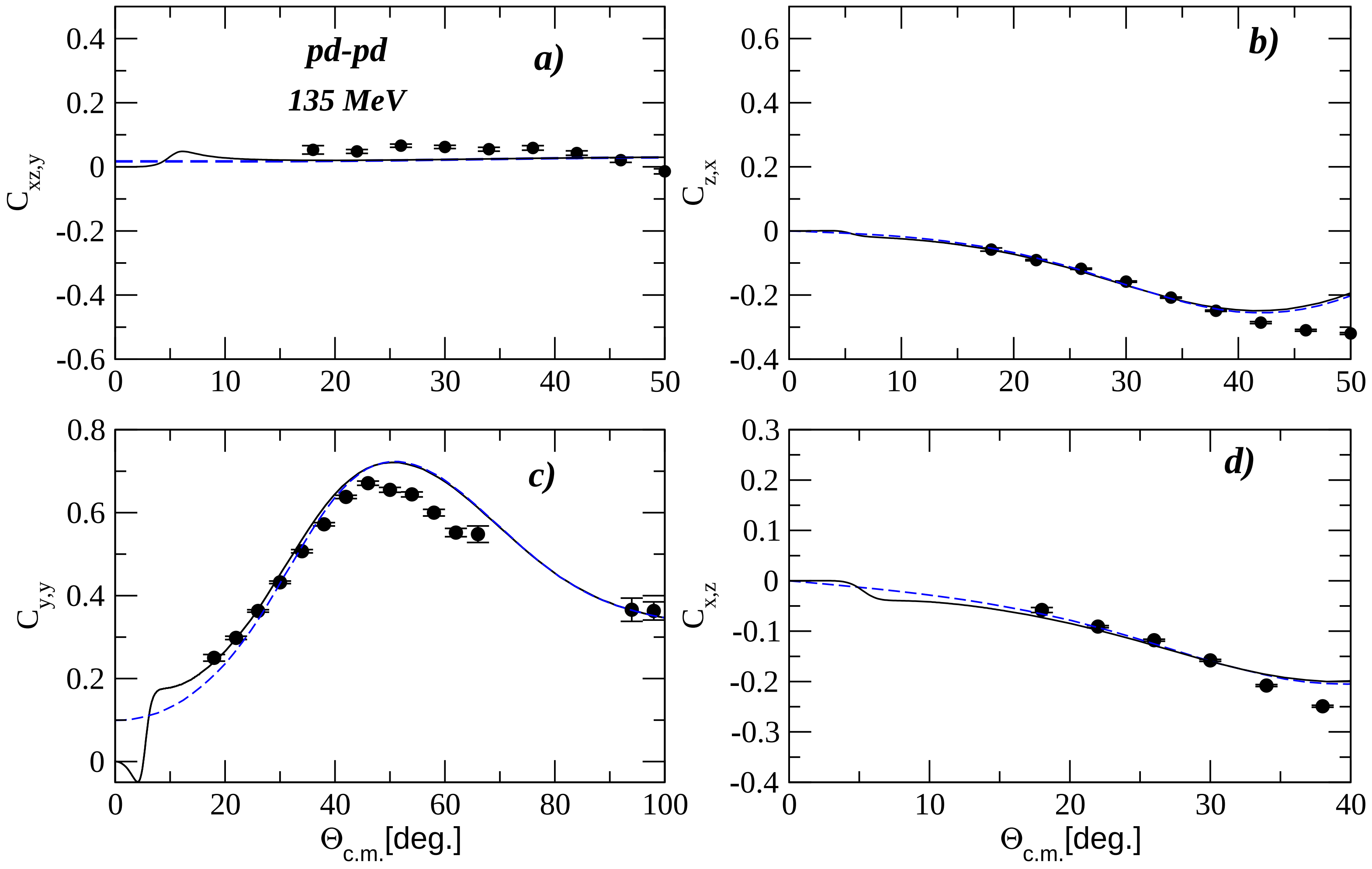
Test calculations: pd elastic scattering at 135 MeV

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



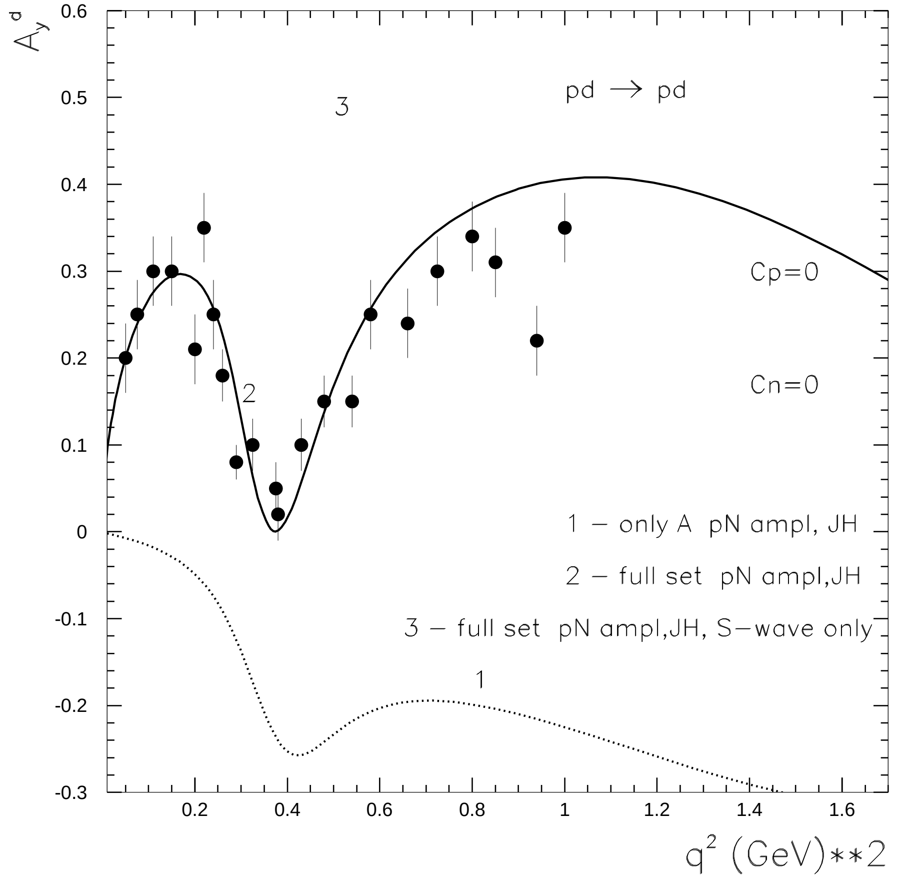
Data: K. Sekiguchi et al. PRC (2002); B. von Przewoski et al. PRC (2006)
See also Faddeev calculations: A.Deltuva, A.C. Fonseca, P.U. Sauer, PRC 71 (2005) 054005.

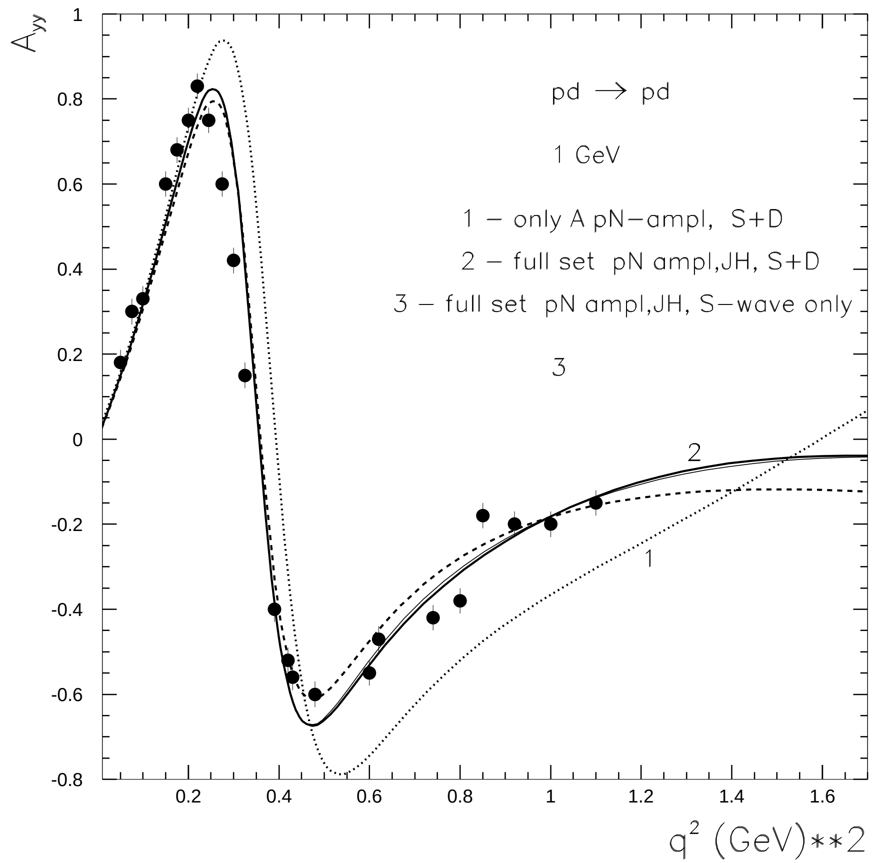
Test calculations-II: pd elastic scattering at 135 MeV



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

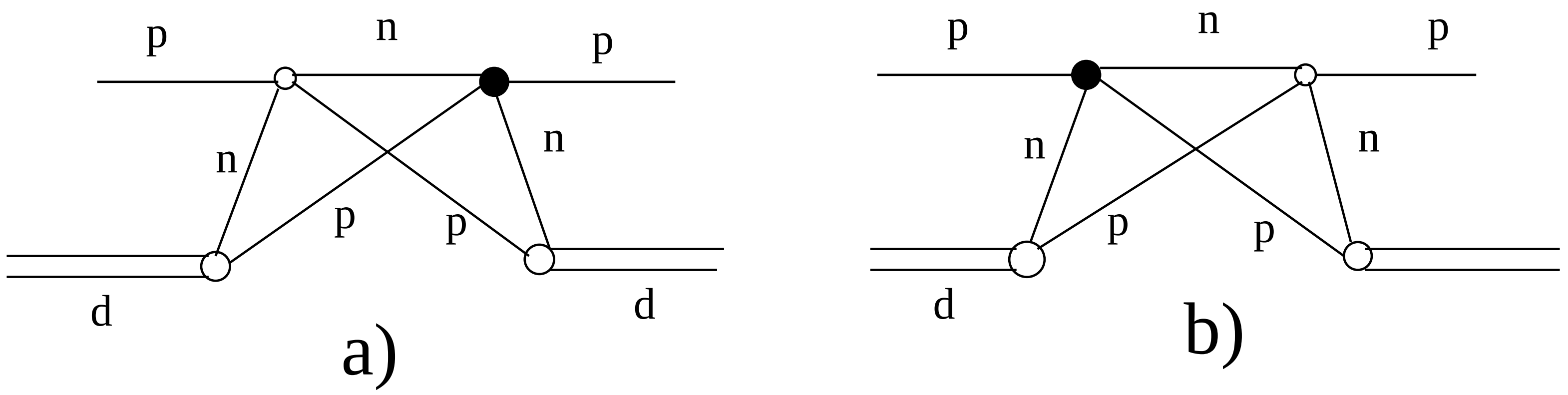
Test calculations: pd elastic scattering at 1 GeV





Yu.N.U., J.H. Haidenbauer (unpublished)

TVPC. Double scattering mechanism with charge-exchange



However, for g'-term the sum is zero due to

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

ρ-meson does not contribute!

(Single scattering mechanism gives zero contribution to $\widetilde{\sigma}$, $\mathbf{q} = 0$.)

TVPC-amplitude $\widetilde{g}_5$.

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

where

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

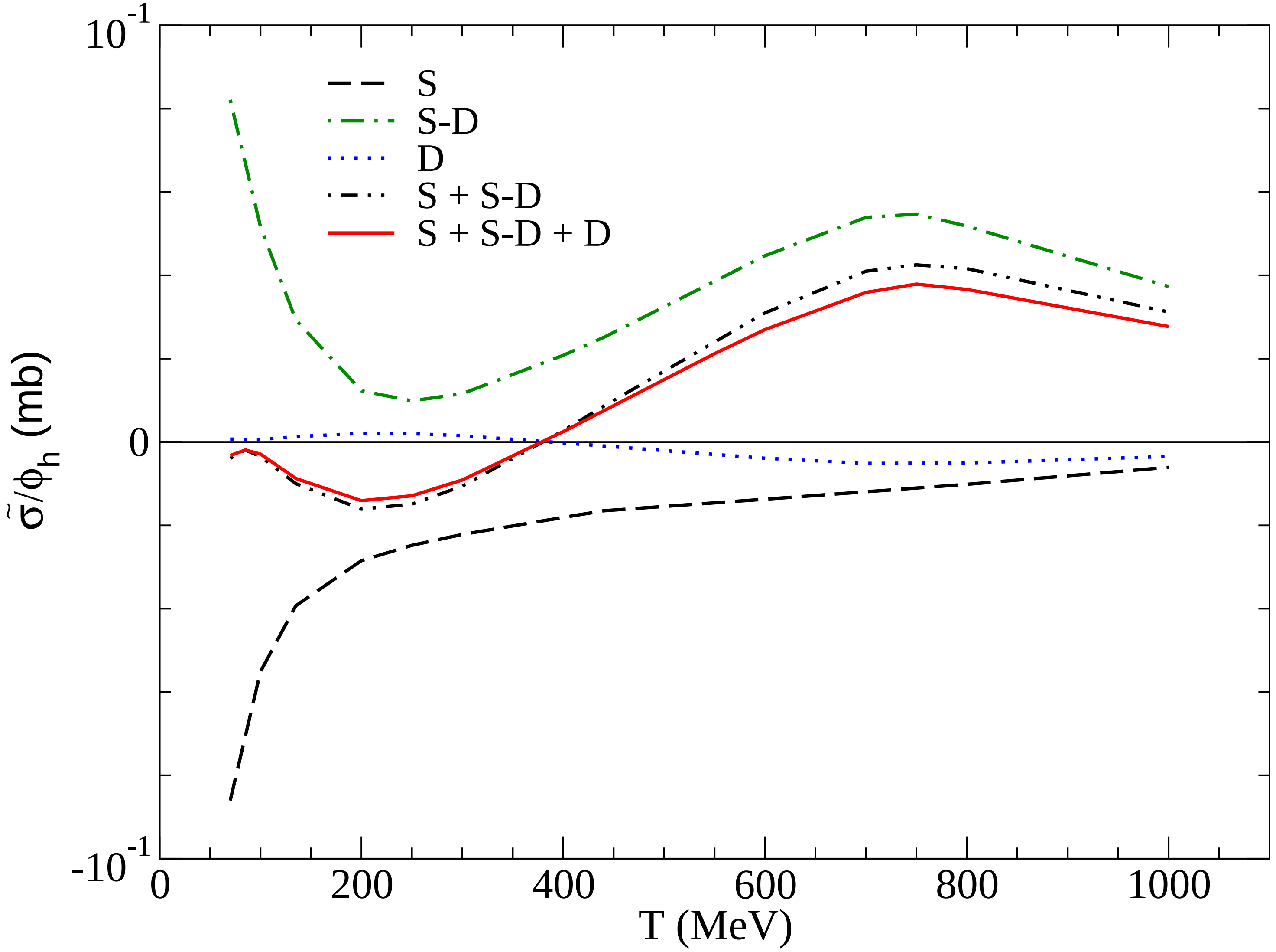
$$S_2^{(1)}(q) = 2\int_0^\infty dr\, u(r) w(r) j_2(qr),$$

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

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

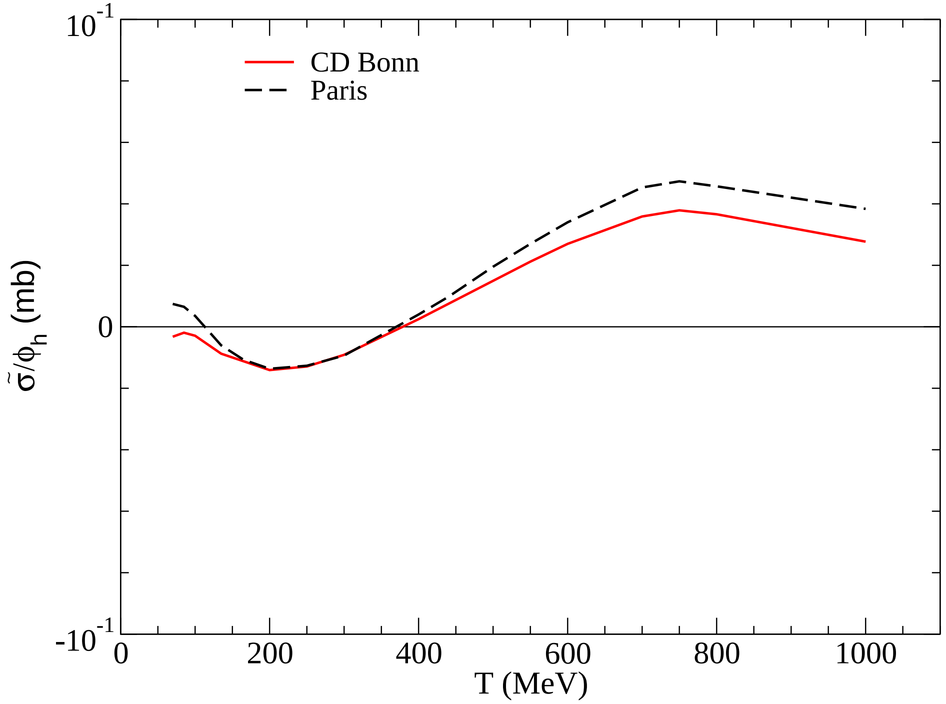
Yu.N. U., A.A.Temerbayev, PRC **92**, 014002 (2015),
Yu.N. U., J.Haidenbauer, PRC 94, 035501 (2016)

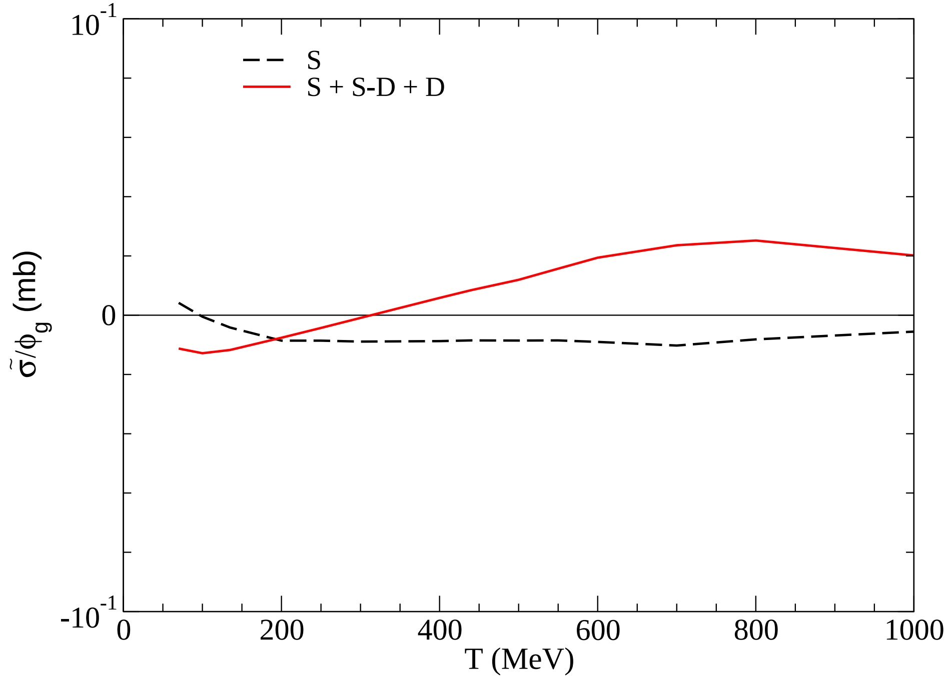
TVPC. The S- and D- wave contributions-I



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

TVPC. Different NN-models with S- and D- waves. h-, g-terms





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

HOW TO MEASURE ?

This process is described by the transmission factor T(n):

$$T(n) = I(n) / I(0) = \exp(-(\sigma_T \rho d\, n)) \qquad (5)$$

with:
- $I(0)$ - Intensity of the primary beam
- $I(n)$ - Intensity of the beam having passed n times the internal target with density ρ and thickness d
- σ_T - Total cross-section
- ρd - The areal target density

For the case of polarized particles σ_T has to be replaced by:

$$\sigma_T = \sigma_{y,xz} + \sigma_{Loss} = \sigma_o (1 + P_y P_{xz} A_{y,xz}) + \sigma_{Loss} \qquad (6)$$

with:
- σ_o - Unpolarized total cross-section
- σ_{Loss} - Loss cross-section, taking account of beam losses outside of the target

$$\Delta T_{y,xz} = \frac{T^{+} - T^{-}}{T^{+} + T^{-}} = \frac{\exp\text{-}(\chi^{+}) - \exp\text{-}(\chi^{-})}{\exp\text{-}(\chi^{+}) + \exp\text{-}(\chi^{-})} \quad (7)$$

with: T^{+} -Transmission factor for the proton-deuteron spin-configuration with $P_y \cdot P_{xz} > 0$

T^{-} -Transmission factor for the time reversed situation, i.e. $P_y \cdot P_{xz} < 0$

$\chi^{+/-}$ -Is the product of the factors $(\sigma T \cdot \rho d \cdot n)$ with respect to the proton-deuteron spin-alignment

this gives:

$$\Delta T_{y,xz} = -\tanh(\sigma_o \Delta d\, n\, P_y\, P_{xz}\, A_{y,xz}) \quad (8)$$

Is the argument of the tanh in equation (8) small, then:

$$\Delta T_{y,xz} = -\sigma_o \rho d\, n\, P_y\, P_{xz}\, A_{y,xz} =: -S\, A_{y,xz} \quad (9)$$

mbox

Possible source of false effect. Total polarized T-even P-even pd cross sections.

$$\sigma_{tot} = \sigma_0 + \sigma_1 \mathbf{p}^p \cdot \mathbf{P}^d + \sigma_2 (\mathbf{p}^p \cdot \hat{\mathbf{k}})(\mathbf{P}^d \cdot \hat{\mathbf{k}}) + \sigma_3 P_{zz} + \widetilde{\sigma} p_y^p P_{xz}^d \qquad (8)$$

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

$\sigma_0 = 78.5\, mb$, $\sigma_1 = 3.7\, mb$, $\sigma_2 = 12.4\, mb$, $\sigma_3 = -1.1\, mb$

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

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

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

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

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

SUMMARY

- **$\widetilde{\sigma}_{tvpc}$ is a true null-test observable. Not affected by ISI&FSI, similar to EDM = null-test signal for TVPV, will be measured by TRIC at 135 MeV only, T_p-dependence of $\widetilde{\sigma}_{tvpc}$ and uncertainties can be reasonable estimated within the Glauber theory**
- Measurement has to be done at higher energies 600 - 800 MeV and not at one point, but at two - three points.
- Search for TVPC can be performed at any energy, but for at $T_p < 1.3$ GeV all modulating factors $\widetilde{\sigma}_{tvpc}$ can be eliminated using Glauber theory.
- The ρ-meson contribution to $\widetilde{\sigma}_{tvpc}$ vanishes...
- Integrated polarized pd cross sections σ_1, σ_2, σ_3 are calculated $\Longrightarrow$
  σ_1/σ_0 gives essential restriction: $p_y^d \leq 10^{-6}$.
- **How to measure $\widetilde{\sigma}_{tvpc}$ at SPD?**

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) $\Longrightarrow$ 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 $B_- \to \bar{B}^0$

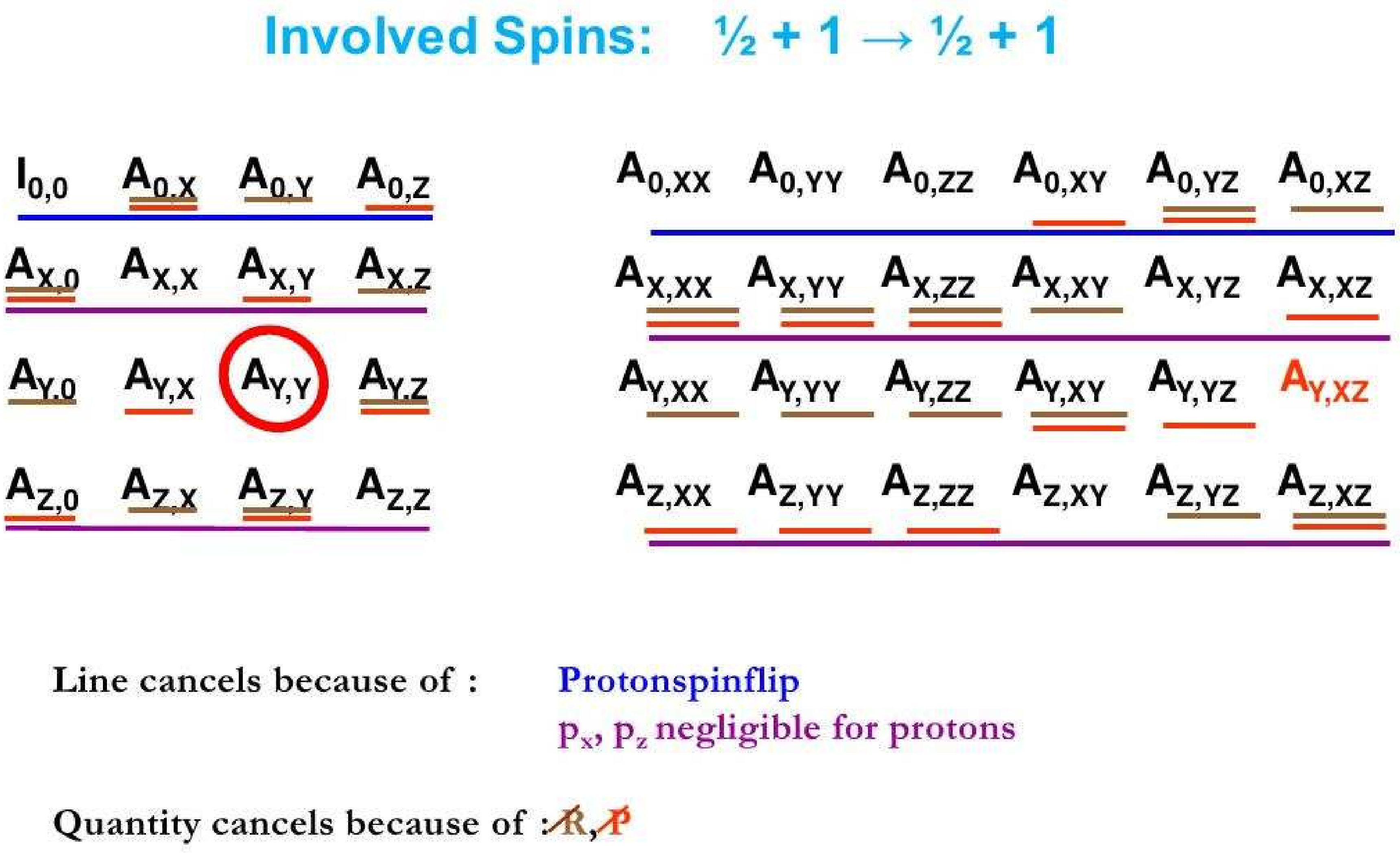
connected only by T-symmetry transformation

(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.



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

T-INVARIANCE P-INVARIANCE in pd- elastic

$$A_y^p = P_y^p, \;\; A_y^d = P_y^d \tag{9}$$

In Madison frame:

$$K_z^{x'} = K_z^x \cos\theta - K_z^z \sin\theta, \tag{10}$$
$$K_x^{z'} = K_x^z \cos\theta + K_x^x \sin\theta;$$

$$K_z^x(p \to p) = \frac{TrM\sigma_z M^+\sigma_x}{TrMM^+}, \; K_z^x(p \to d) = \frac{TrM\sigma_z M^+ S_x}{TrMM^+},$$
$$K_z^x(d \to p) = \frac{TrMS_z M^+\sigma_x}{TrMM^+}, \; K_z^x(d \to d) = \frac{TrMS_z M^+ S_x}{TrMM^+}.$$

$$K_x^{z'}(p \to p) = -K_z^{x'}(p \to p), \tag{11}$$
$$K_x^{z'}(p \to d) = -K_z^{x'}(d \to p),$$
$$K_x^{z'}(d \to p) = -K_z^{x'}(p \to d),$$
$$K_x^{z'}(d \to d) = -K_z^{x'}(d \to d),$$

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