Search for T-reversal Invariance Violation in Double Polarized pd and $\bar{p}d$ Scattering

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- Motivation:
  P-even **T**ime-**R**eversal **I**nvariance test planned at **C**OSY (TRIC) (Jülich, Germany) in pd at $\sim$100 MeV
- Null-test signal for T- violation in pd and $\bar{p}d$, $\widetilde{\sigma}$
- Capability of the Glauber model in pd- at $\sim$100-200 MeV
- Coulomb effects, S- and D- wave of d.w.f. and $\widetilde{\sigma}$
- Sources of some false effects
- Summary

Yu.N. Uzikov, A.A.Temerbaeyv, PRC ***92****, 014002 (2015);*
Yu.N. Uzikov, J.Haidenbauer, PRC ***94****, 035501 (2016)*
Yu. N. Uzikov, J.Haidenbauer, PRC 87 (2013) 054003;PRC ***88*** *(2013) 027001*

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 $\not{C}\not{P}$ 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. 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: $\mathbf{g} \sim \mathbf{M^4 G_F^2} \sin\delta \sim \mathbf{10^{-10}}$

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

  ⋆ . . . much larger g is not excluded 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 ($\equiv$ T-odd P-even) NN 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 charge-exchange amplitude $pn \leftrightarrow np$ (or $\bar{p}p \leftrightarrow \bar{n}n$)

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

C-odd (hence T-odd), only charged ρ's. No contribution to the nn or pp (and to $\bar{p}p \to \bar{p}p$, $\bar{p}n \to \bar{p}n$)

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

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

TVPC on-shell NN and $\bar{N}N$ interactions

$$\mathbf{p} = \mathbf{p}_i + \mathbf{p}_f, \;\; \mathbf{q} = \mathbf{p}_f - \mathbf{p}_i, \, \mathbf{n} = [\mathbf{p} \times \mathbf{q}]/|[\mathbf{p} \times \mathbf{q}]|$$

$$t_{pN} = \underbrace{h_p[(\boldsymbol{\sigma} \cdot \mathbf{p})(\boldsymbol{\sigma}_p \cdot \mathbf{q}) + (\boldsymbol{\sigma}_p \cdot \mathbf{p})(\boldsymbol{\sigma} \cdot \mathbf{q}) - (\boldsymbol{\sigma}_p \cdot \boldsymbol{\sigma})(\mathbf{p} \cdot \mathbf{q})]}_{h1-meson} + \qquad (2)$$

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

M. Beyer, Nucl. Phys. A 560 (1993) 895
In notations of J.Bystricky, F. Lehar, P. Winternitz, J.Physique, 45 (1984) 207:
and P.LaFrance F.Lehar, B.Loiseau, P.Winternitz 16 independent terms if no P-,T-,C-symmetryes are assumed. P-parity conservation left 8 amplitudes, only two of them are T-violating terms ($\mathbf{l} \uparrow\uparrow \mathbf{p}$, $\mathbf{m} \uparrow\uparrow \mathbf{q}$):

$$g(\sigma_{1l}\sigma_{2m} + \sigma_{1m}\sigma_{2l}) \Longrightarrow h_N$$
$$h(\sigma_{1l}\sigma_{2m} - \sigma_{1m}\sigma_{2l}) \Longrightarrow g_N$$

For $\bar{p}N$- scattering momentum-spin-isospin structrure of the TVPC interaction is the same with an exception that g'_N-term i.e. $\bar{p}p \leftrightarrow \bar{n}n$ is not elastic.

EDM and TVPC interactions

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

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

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

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

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

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

TVPC scale and EDM

"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

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

$\Lambda_{TVPC} > 150$ 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 $^{27}Al(p,\alpha)^{24}Mg$ 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) $\alpha_T < 2 \times 10^{-3}$

- $\vec{n}$ 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)

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

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 $pd \to pd$ and $\bar{p}d \to \bar{p}d$ 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.)

Phenomenology of the $pd \to pd$ and $\bar{p}d \to \bar{p}d$ transition

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

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

– –

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

T-even P-even: $A_1 \div A_{12}$
(see M. Platonova, V.I. Kukulin,PRC **81** (2010) 014004)

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

The polarized elastic differential pd cross section

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

$$C_{y,y} = TrMS_y\sigma_y M^+/TrMM^+, \quad \ldots \quad (4)$$

Forward elastic pd and $\bar{p}d$ scattering amplitude (P-even, T-even):

$$e'^{*}_{\beta}\hat{M}_{\alpha\beta}(0)e_{\alpha} = g_1[\mathbf{e}\,\mathbf{e}'^{*} - (\hat{\mathbf{k}}\mathbf{e})(\hat{\mathbf{k}}\mathbf{e}'^{*})] + g_2(\hat{\mathbf{k}}\mathbf{e})(\hat{\mathbf{k}}\mathbf{e}'^{*}) +$$
$$ig_3\{\boldsymbol{\sigma}[\mathbf{e}\times\mathbf{e}'^{*}] - (\boldsymbol{\sigma}\hat{\mathbf{k}})(\hat{\mathbf{k}}\cdot[\mathbf{e}\times\mathbf{e}'^{*}])\} + ig_4(\boldsymbol{\sigma}\hat{\mathbf{k}})(\hat{\mathbf{k}}\cdot[\mathbf{e}\times\mathbf{e}'^{*}])+ \quad (5)$$

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

. . . and plus **T-odd P-even (TVPC) term (Yu.N.Uzikov, A.A. Temerbayev, PRC92 (2016)**

$$\cdots + \widetilde{g}_5\{(\boldsymbol{\sigma}\cdot[\hat{\mathbf{k}}\times\mathbf{e}])(\mathbf{k}\cdot\mathbf{e}'^{*}) + (\boldsymbol{\sigma}\cdot[\hat{\mathbf{k}}\times\mathbf{e}'^{*}])(\mathbf{k}\cdot\mathbf{e})\}; \quad (6)$$

Non-diagonal:

$$< \mu' = \frac{1}{2}, \lambda' = 0|M^{TVPC}|\mu = -\frac{1}{2}, \lambda = 1 >= i\sqrt{2}\widetilde{g}_5. \quad (7)$$

Generalized Optical theorem:

$$Im\frac{Tr(\hat{\rho}_i\hat{M}(0))}{Tr\hat{\rho}_i} = \frac{k}{4\pi}\sigma_i \quad (8)$$

Total polarized pd and $\bar{p}d$ cross sections

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

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/*

$$\widetilde{\sigma}_{tvpc} = -\frac{4\pi}{k} Im \frac{2}{3} \widetilde{g}_5 \qquad (9)$$

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

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

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

Elastic $pd \to pd$ and $\bar{p}d \to \bar{p}d$ transitions

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

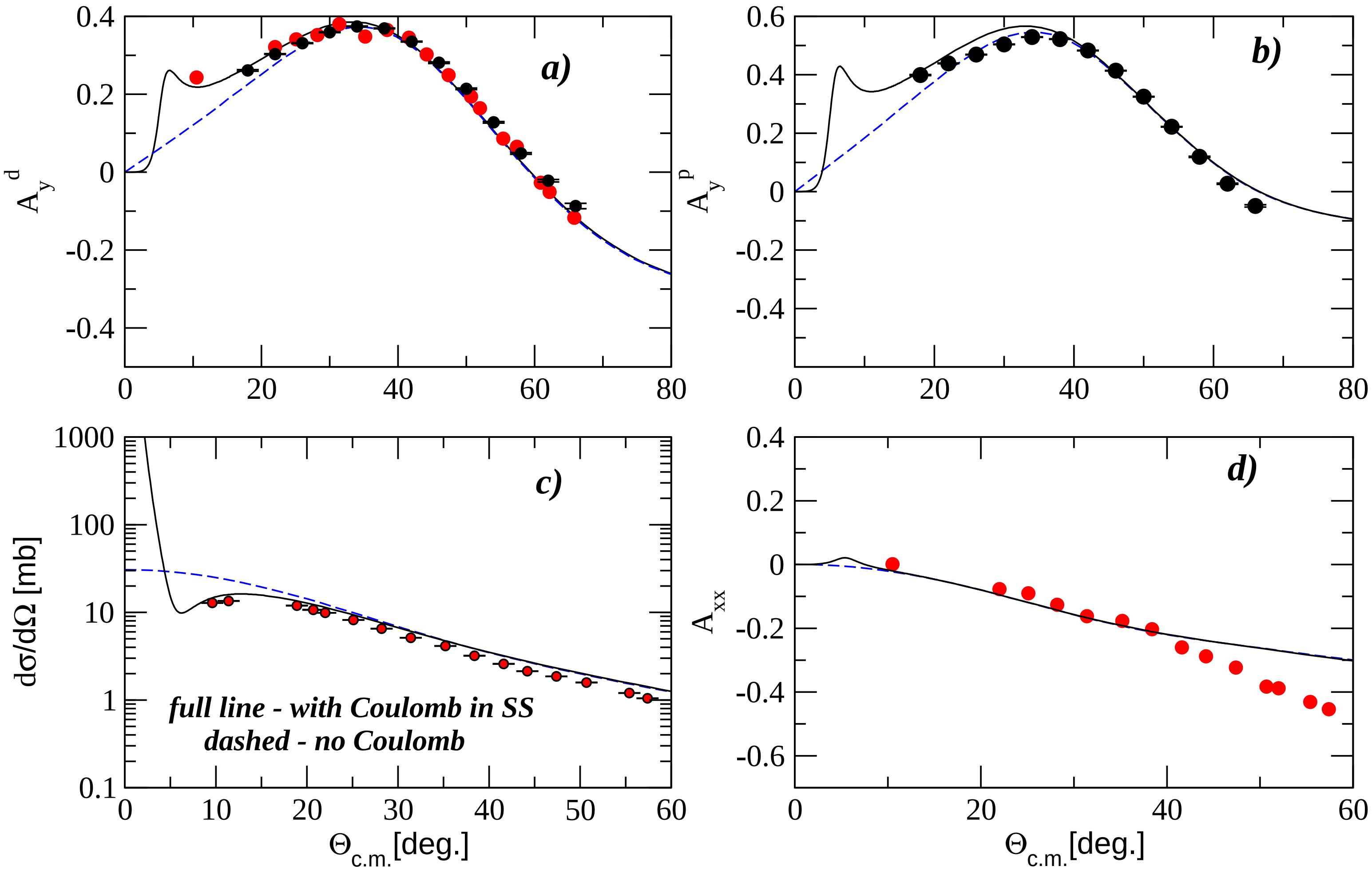
On-shell elastic pN (or $\bar{p}N$) scattering amplitude (**T-even, P-even**)

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

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

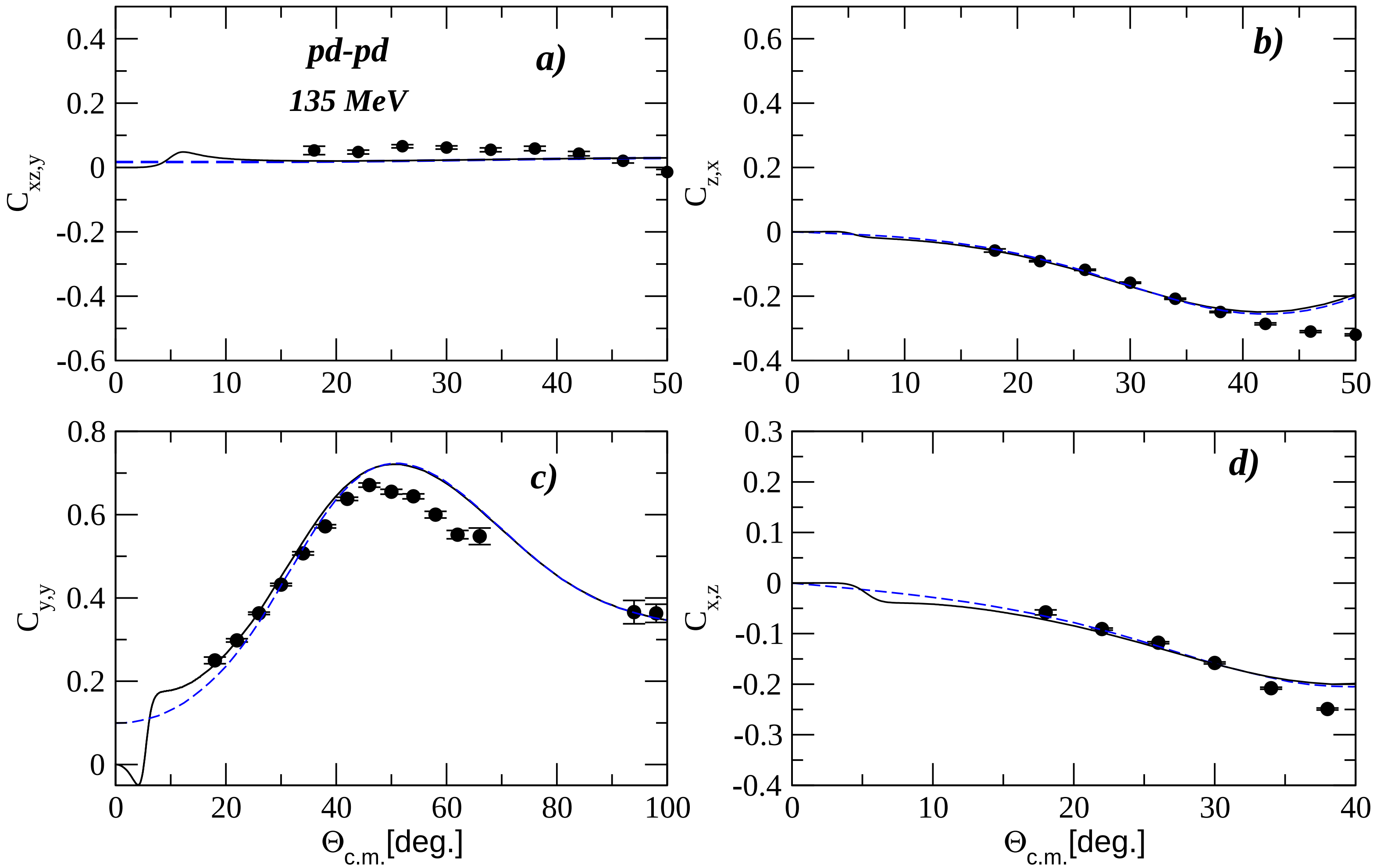
Test calculations: pd elastic scattering at 135 MeV

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

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

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

Glauber transition operator:

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

$$\int e^{i\mathbf{Qr}}\Psi_d \mathrm{O}\Psi_d d^3r = US_0 + \mathbf{VS}S_0^{(0)} + \left(W_{ij}\left\{S_i,S_j\right\} - W_{ii}\right)S_0^{(0)} + \dots \quad (10)$$

is diagonal for the beam proton spin, whereas one needs

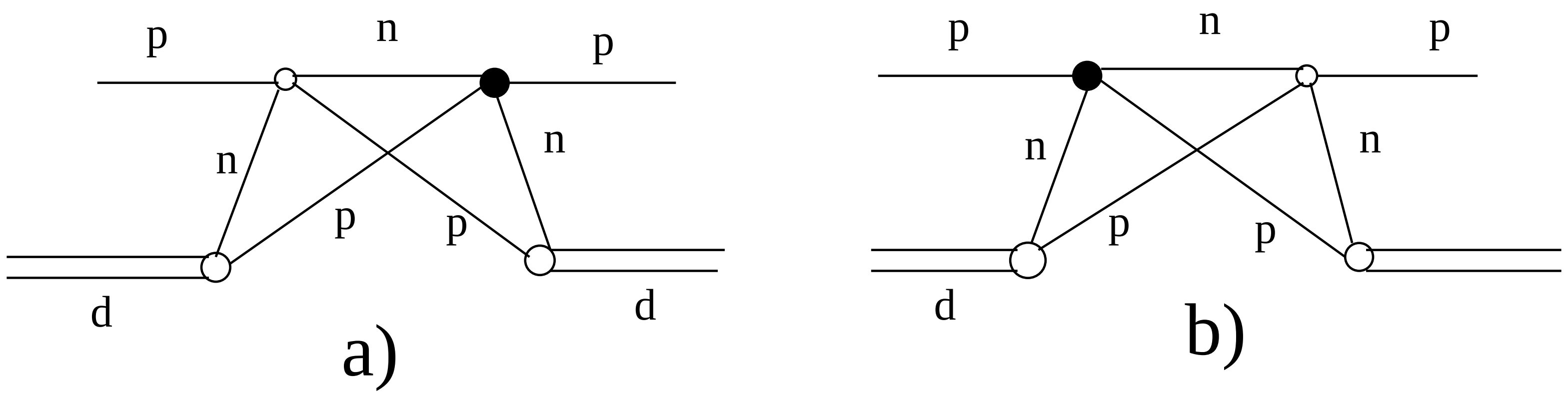
$$<\mu' = \frac{1}{2}, \lambda' = 0|F^{TVPC}|\mu = -\frac{1}{2}, \lambda = 1 >= i\sqrt{2}\widetilde{g}_5. \quad (11)$$

Therefore, for g':

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

ρ-meson does not contribute!

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



Charge exchange $pn \to np$, $np \to pn$:

$$< np|[\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2]_z|pn >= -i2,\ < pn|[\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2]_z|np >= +i2,$$

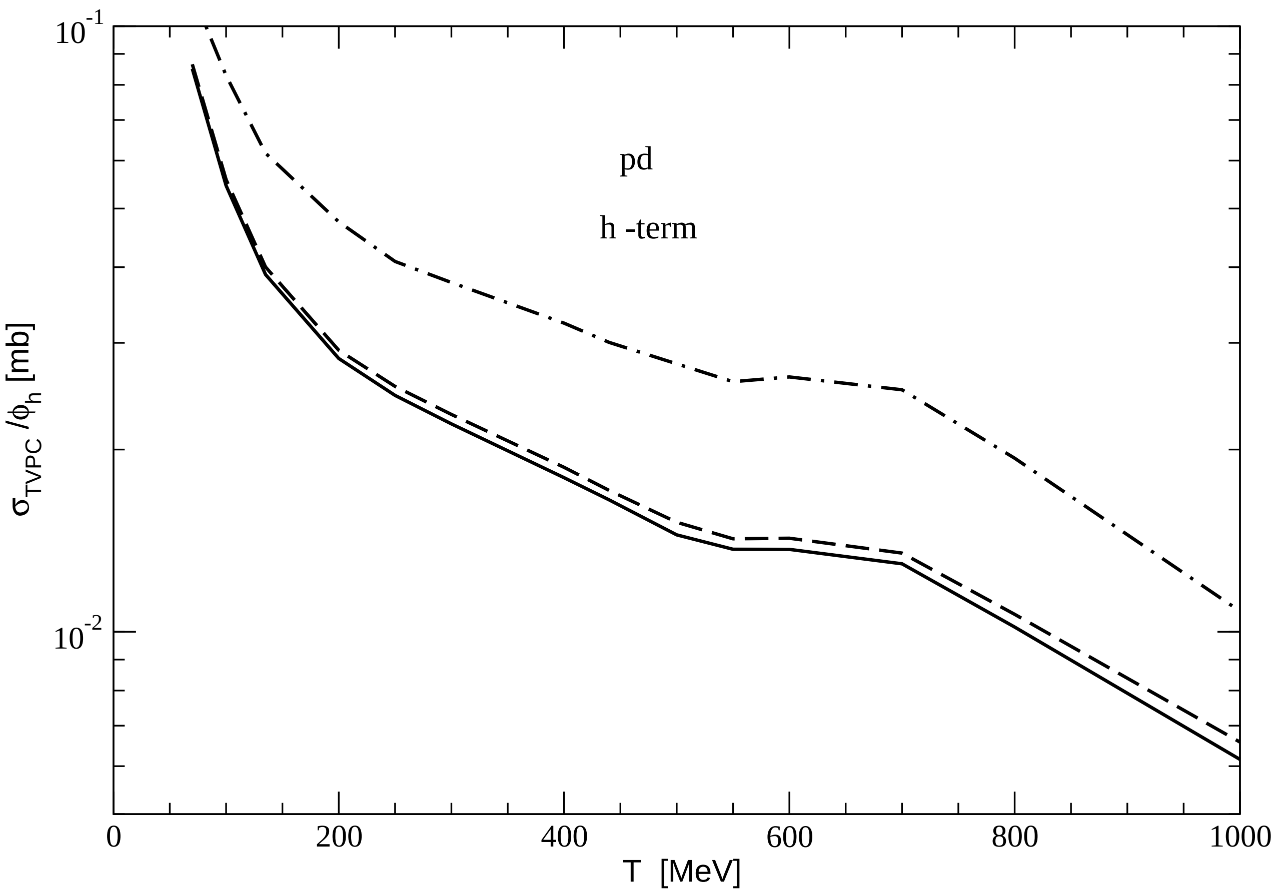
This leads to zero contribution of g' to the null-test signal.
Similarly for $\bar{p}p \to \bar{n}n$

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

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

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

$$\widetilde{g}_5 = \frac{ik_{pd}}{2\sqrt{\pi}}\int_0^\infty dqq^2 S_0^{(0)}(q)[C_n'(q)(h_p-g_p)+C_p'(q)(h_n-g_n)],\ C_p'(q)=C_p+\frac{q}{2M}(A_p+F_{pp}^C), \quad (12)$$



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

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

for $pd \to pd$ (g_N term is excluded for pp-scattering)

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

for $\bar{p}d \to \bar{p}d$ (g_N term is excluded for $\bar{p}n \to \bar{p}n$-scattering)

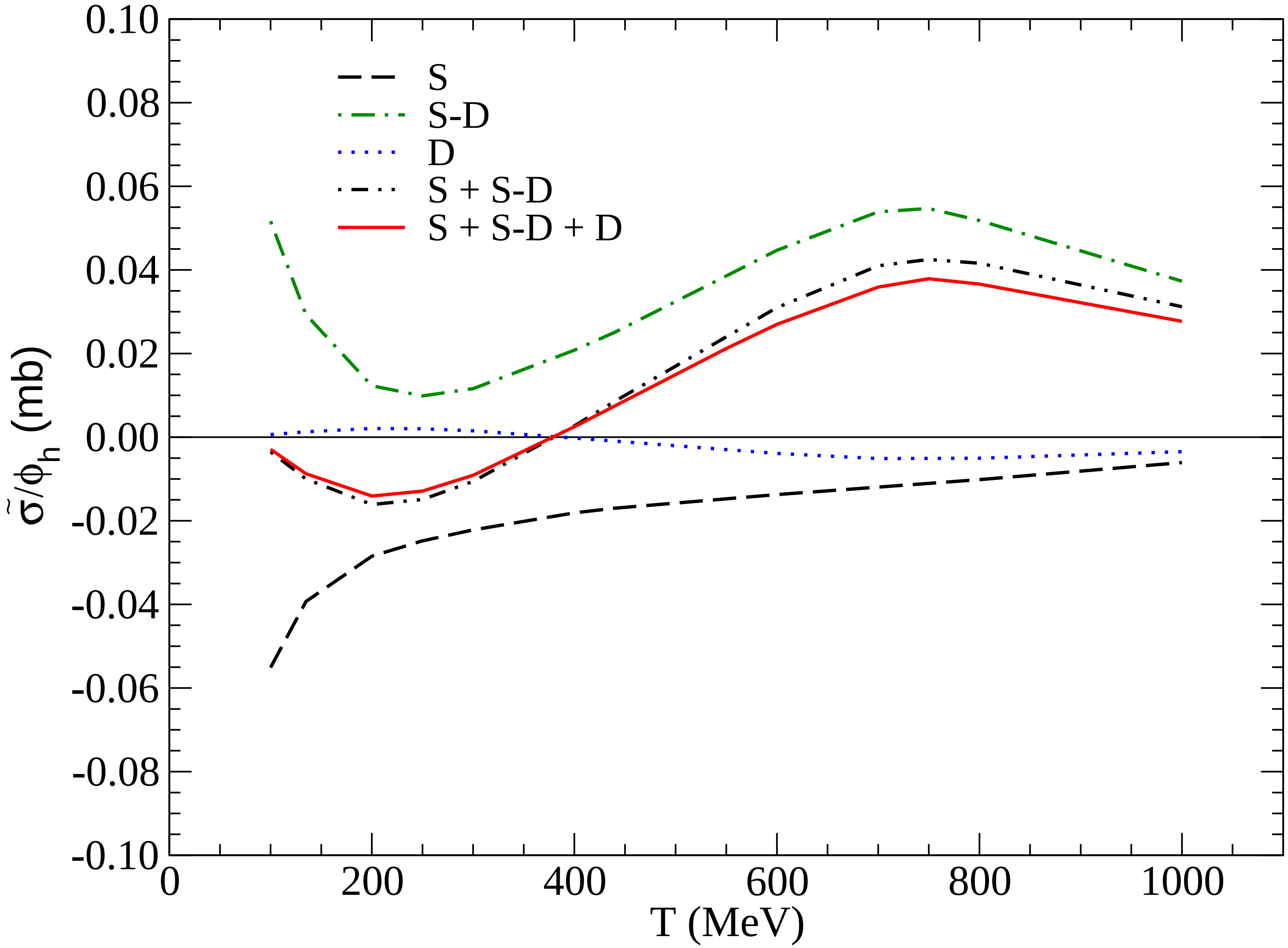
$$\widetilde{g}_5 = \frac{i}{4\pi m_p}\int_0^\infty dq q^2\, [\dots] \quad \times[-C'_{\bar{p}n(q)}\,(h_{\bar{p}p} - g_{\bar{p}p}) - C'_{\bar{p}p}(q)h_{\bar{p}n}],$$

where

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

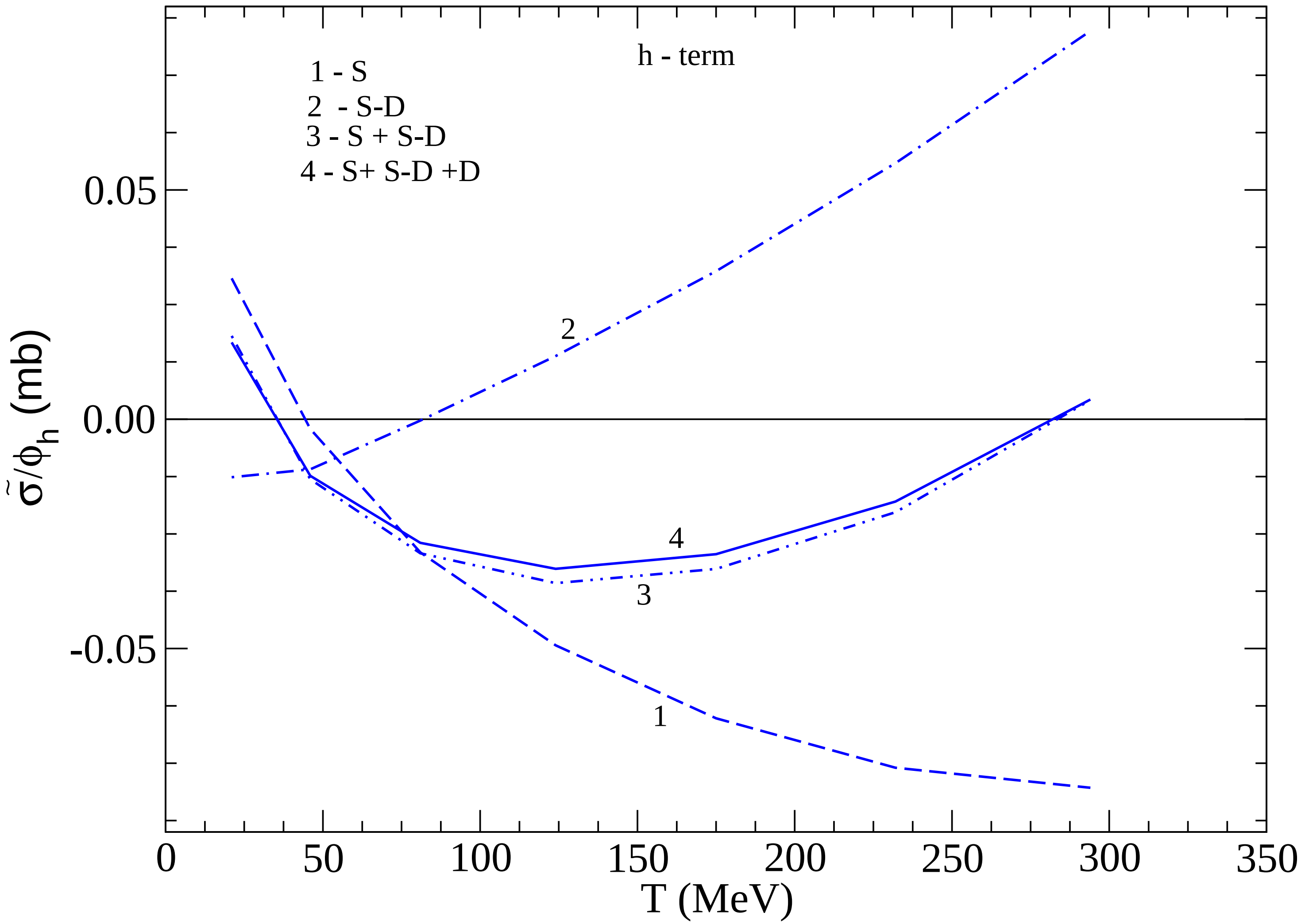
$$S_2^{(1)}(q) = 2\int_0^\infty dr\, u(r)w(r)j_2(qr),\, S_2^{(2)}(q) = -\frac{1}{\sqrt{2}}\int_0^\infty dr\, w^2(r)j_2(qr),$$

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

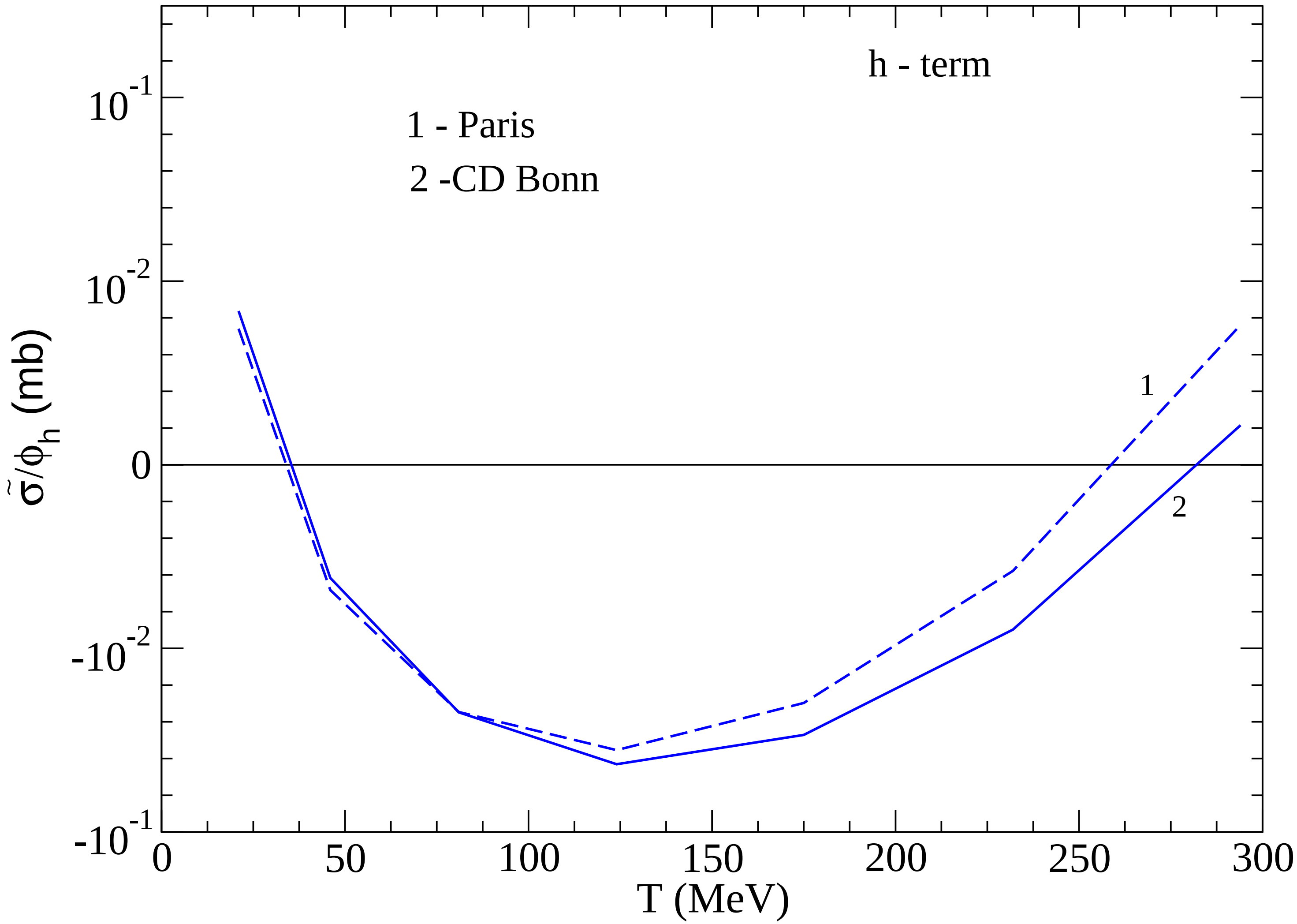


Yu.N. Uzikov, J.Haidenbauer, PRC 94 (2016) 035501

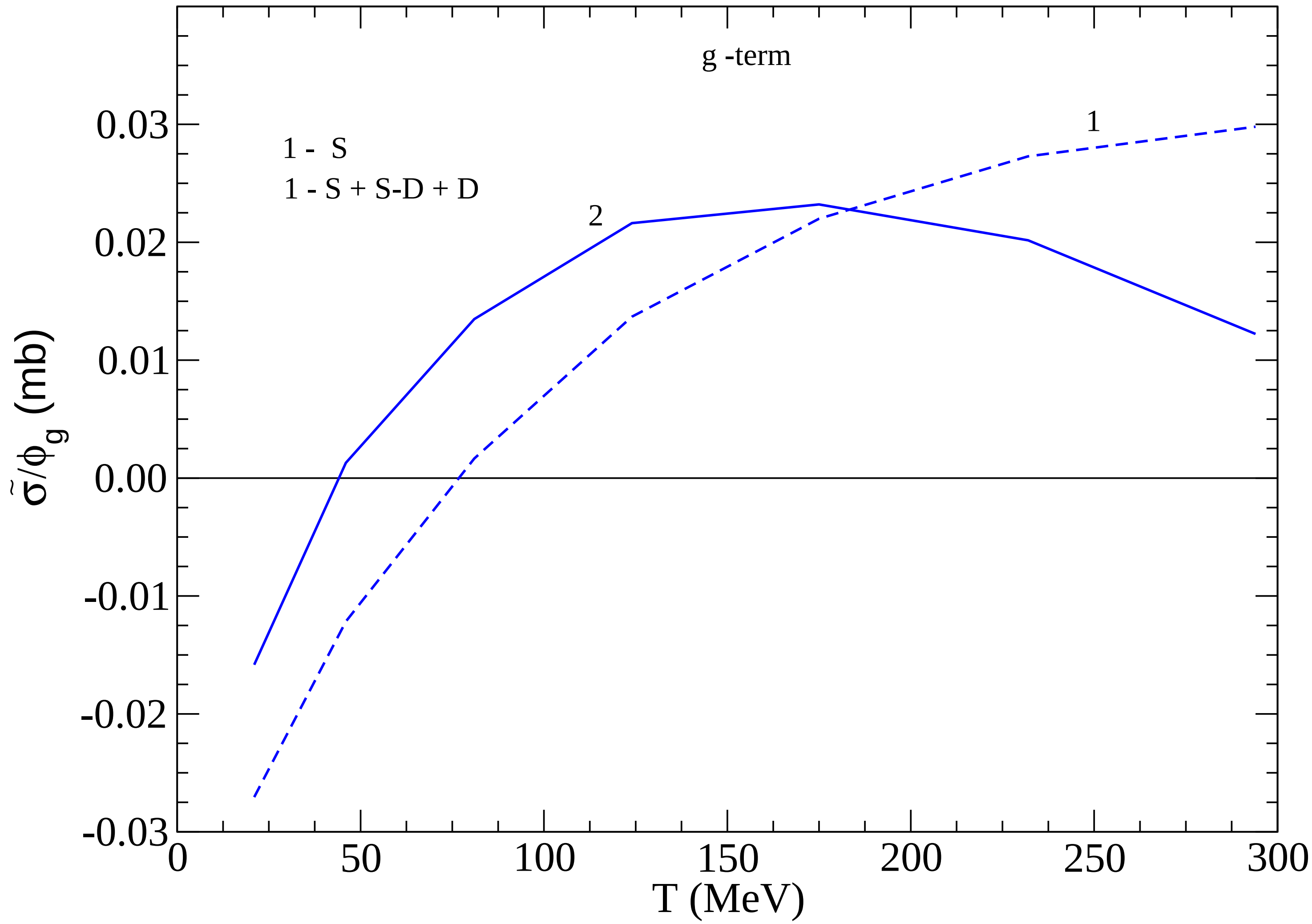
$\bar{p}d$



$[C'_{\bar{p}n}, C'_{\bar{p}p}]$ taken from Yu. N. Uzikov, J.Haidenbauer, PRC 87 (2013) 054003; PRC 88 (3013) 027001
Nijmegen: D.Zhou, R.G.E. Timmermans, PRC 86 (2012) 044003


h - term
1 - Paris
2 -CD Bonn
1
2
10^{-1}
10^{-2}
0
-10^{-2}
-10^{-1}
$\tilde{\sigma}/\phi_h$ (mb)
0
50
100
150
200
250
300
T (MeV)

$\bar{p}d$


g -term
1 - S
1 - S + S-D + D
1
2
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
0
50
100
150
200
250
300
T (MeV)
$\tilde{\sigma}/\phi_g$ (mb)

SUMMARY

- **$\widetilde{\sigma}_{tvpc}$ is a true null-test TVPC observable. Not affected by ISI&FSI, for pd will be measured by TRIC. $\widetilde{\sigma}_{\bar{p}d}$ can be reasonable estimated at 100-300 MeV within the Glauber theory**
- Calculated $\widetilde{\sigma}_{\bar{p}d}$ has a maximum at $T_p \sim 150$ MeV.
- The ρ-meson contribution to $\widetilde{\sigma}_{\bar{p}d}$ vanishes as in pd-scattering
- The Coulomb interaction does not lead to divergence of the null-test observable $\widetilde{\sigma}_{tvpc}$!
- Integrated polarized $\bar{p}d$ cross sections σ_1, σ_2, σ_3 were calculated (Yu.U., J.Haidenbauer, PRC 88 (2013)), for the model A: $\sigma_1 = 0$ at ~ 100 MeV $\Longrightarrow$

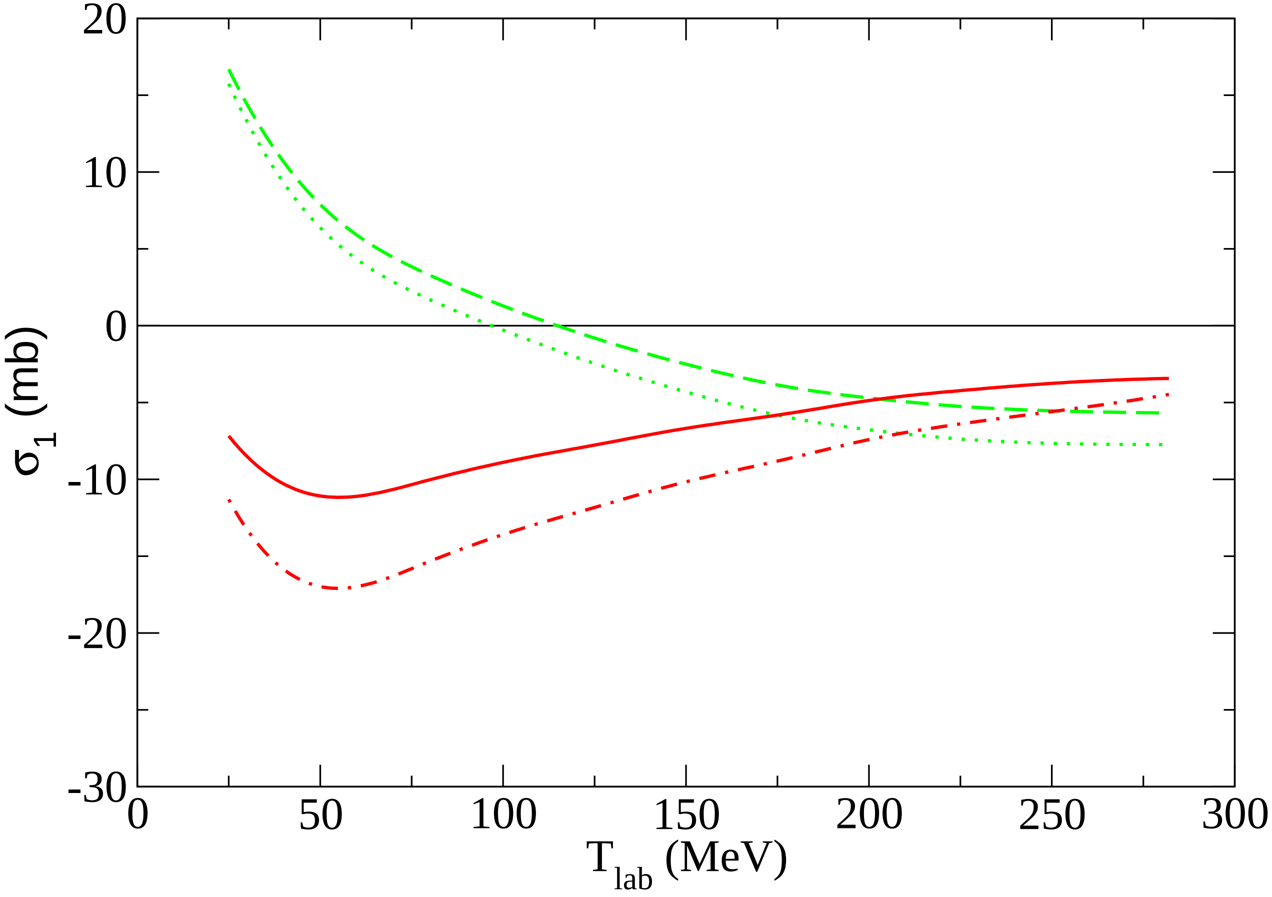
  In pd $\sigma_1/\sigma_0 \approx 0.05$ gives essential restriction: $p_y^d \leq 10^{-6}$.
- D- wave is very important inspite of $q = 0$
- TVPC components of the d.w.f.?

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!

σ_1 **for** $\bar{p}d$



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