Search for spatial parity violation effects in reactions of cold polarized neutrons with lightest nuclei

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The goal of experiments is to study electroweak NN interaction at low energy.

The measurement of asymmetry in angular distribution of reaction products emission with respect to the neutron spin direction.

$^{6}Li(n,\alpha)^{3}H$, $^{10}B(n,\alpha)^{7}Li^{*} \rightarrow {}^{7}Li + \gamma$, $^{10}B(n,\alpha)^{7}Li$

Fundamental problems:

Search for the neutral currents in the weak NN-interaction.

Test of the validity of descriptions of the weak NN-force.

Interpretation of the P-odd observables in complex nuclei and in the eN scattering experiments.

Electro-weak interaction at low energy as useful tools to study the strongly interacting limit of QCD.

NN electroweak interactions at low energy

Description of the parity nonconservation NN interaction:

Potential (meson-exchange) description:

R. J. Blin-Stoil. *Phys. Rev. 118 (1960)1605*;
G. Barton. *Nuovo Cimento 19 (1961) 512*; B. H. J. McKellar. *Phys. Lett. B26 (1967)* ;
E. M. Heinly. *Ann. Rev. Nucl. Part. Sci.19(1969) 367*; E. Fischbach, D. Tadic. *Phys. Rep. C6 (1973) 123*;
M. Gari. *Phys. Rep. C6(1973) 318*;
B. Desplanques, J. Donoghue, B. Holstein. *Ann. Phys. 124 (1980) 449*; B. Desplanques. *Phys. Rep. 297 (1998) 1.*

Amplitude description:

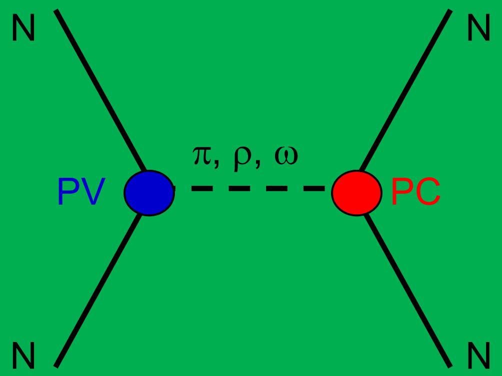
G. S. Danilov. *Phys. Lett. 18 (1971) 35*,
M. A.Box, B. H. J. McKellar, P. Pick, K. R. Lassey *J. Phys. G1 (1975) 493*;
B. Desplanques, J. Missener. *Nucl. Phys. A300 (1978) 286.*

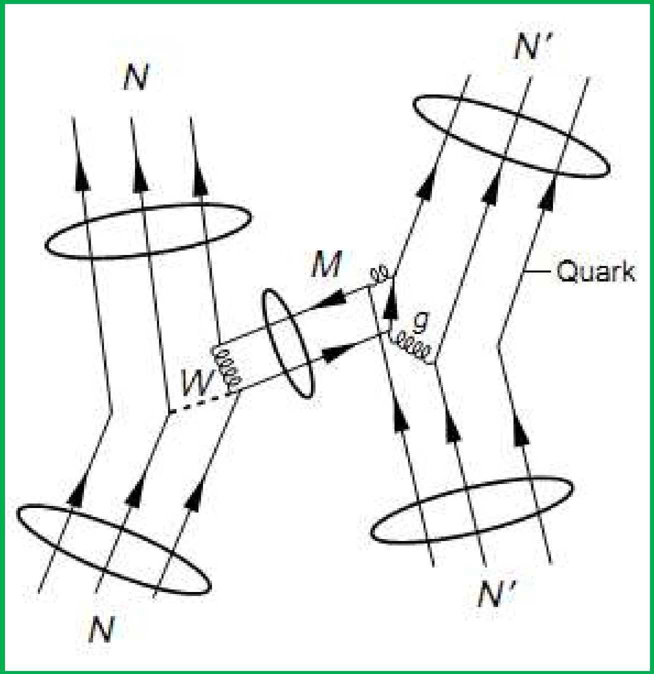
Analysis using an EFT and chiral perturbation; calculation with use of lattice gauge theory:

S.-L. Zhu, J. Puglia, B. R. Holstein, M. J. Ramsey-Musolf. *Phys. Rev. D63 (2001) 033006*.
M. J. Ramsey-Musolf, S. A. Page, *Ann. Rev. Nucl. Part. Sci.* **58** (2006) 1.
C.-P. Liu, *Phys. Rev. C* **75** (2007) 065501.

One meson exchange model

π^0, η, η' - exchange is forbidden, due to the CP-invariance; ϕ - exchange is strongly suppressed





Amount of isospin transfer

$\pi^{\pm}$ - ΔT=1

ρ - ΔT=0, 1, 2

ω - ΔT=0, 2

At low energy : ΔS = 0,

ΔT = 0, 2 – charged current;

ΔT = 1 – neutral current

One meson exchange model

PNC NN potential is characterized by weak meson exchange coupling constants [B. Desplanques. *Phys. Rep.297 (1998) 1*] : $h_\pi^1(f_\pi), h_\rho^0, h_\rho^1, h_\rho^2, h_\omega^0, h_\omega^1$

$$V^{PNC}(r_{12}) = i\frac{1}{2}(\boldsymbol{\tau}_1\times\boldsymbol{\tau}_2)^z(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)\left[\frac{\mathbf{p}_1-\mathbf{p}_2}{2M}\frac{g_{\pi NN}}{\sqrt{2}}h_\pi^1 f_\pi(r) - g_{\rho NN}h_\rho^1 f_\rho(r)\right] -$$

$$-g_{\rho NN}\left(h_\rho^0\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2 + \frac{1}{2}h_\rho^1(\tau_1^z+\tau_2^z) + \frac{1}{2}\frac{h_\rho^2}{\sqrt{6}}(3\tau_1^z\tau_2^z - \boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2)\right)\times$$

$$\times\left((\boldsymbol{\sigma}_1-\boldsymbol{\sigma}_2)\left\{\frac{\mathbf{p}_1-\mathbf{p}_2}{2M}f_\rho(r)\right\} + i(1+\chi_\rho)(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\left[\frac{\mathbf{p}_1-\mathbf{p}_2}{2M}f_\rho(r)\right]\right) -$$

$$-g_{\omega NN}(h_\omega^0 + \frac{1}{2}h_\omega^1(\tau_1^z+\tau_2^z))\times$$

$$\times\left((\boldsymbol{\sigma}_1-\boldsymbol{\sigma}_2)\left\{\frac{\mathbf{p}_1-\mathbf{p}_2}{2M}f_\omega(r)\right\} + i(1+\chi_\omega)(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_2)\left[\frac{\mathbf{p}_1-\mathbf{p}_2}{2M}f_\omega(r)\right]\right) -$$

$$-\frac{1}{2}(\tau_1^z-\tau_2^z)(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)\left\{\frac{\mathbf{p}_1-\mathbf{p}_2}{2M}g_{\omega NN}h_\omega^1 f_\omega(r) - g_{\rho NN}h_\rho^1 f_\rho(r)\right\}$$

Weak meson-nucleon coupling constants (in units of 10^{-7}):

	DDH range	DDH "best values"	DZ	FCDH range	FCDH "best values"	KM
f_π	$0 \to 11.4$	4.6	1.1	$0 \to 6.5$	2.7	0.19
h_ρ^0	$-31 \to 11.4$	-11.4	-8.4	$-31 \to 11$	-6.1	-1.9
h_ρ^1	$-0.38 \to 0$	-0.19	0.38	$-1.1 \to 0.4$	-0.4	-0.02
h_ρ^2	$-11.0 \to -7.6$	-9.5	-6.8	$-9.5 \to -6.1$	-6.8	-3.8
h_ω^0	$-10.3 \to 5.7$	-1.9	-3.8	$-10.6 \to 2.7$	-4.9	-3.8
h_ω^1	$-1.9 \to -0.8$	-1.1	-2.2	$-3.8 \to -1.1$	-2.3	-1.0

DDH – B. Desplanques, J. F. Donoughu, B. R. Holstein;
DZ – V. M. Dubovik, S. V. Zenkin;
FCDH - G. B. Feldman, G. A. Crawford, J. Dubach, B. R. Holstein;
KM – N. Kaiser, U. G. Meissner.
G. A. Lobov: $f_\pi = 3.4 \cdot 10^{-7}$
Due to uncertainties in the effects of strong QCD, the range of predictions is broad.

f_π **: long range part of potential; ΔT = 1 – neutral current**

One meson exchange model

Theories of PV phenomena in nuclei starts with solution of the strong, PV conserving, nuclear Hamiltonian Ψ and the admix P-odd components ϕ treating the weak meson-exchange potential as a perturbation:

$$\Psi' = \Psi + \frac{\langle \phi | V^{PNC} | \Psi \rangle}{\Delta E} \phi$$

The PV observables are given by a linear combination of weak MNN constants:

$$A_{PNC} = Af_{\pi} + Bh_{\rho}^{0} + Ch_{\rho}^{1} + Dh_{\rho}^{2} + Eh_{\omega}^{0} + Fh_{\omega}^{1}$$

Task: using this theory to calculate electroweak effects in the NN interaction and to determine the weak couplings from experiment.

Problems:
Theoretical – for more than a few bodies the nuclear wave functions can not be exactly calculated;
Experimental – the small size of weak amplitudes relative to strong amplitudes ~10^{-7}.

One meson exchange model

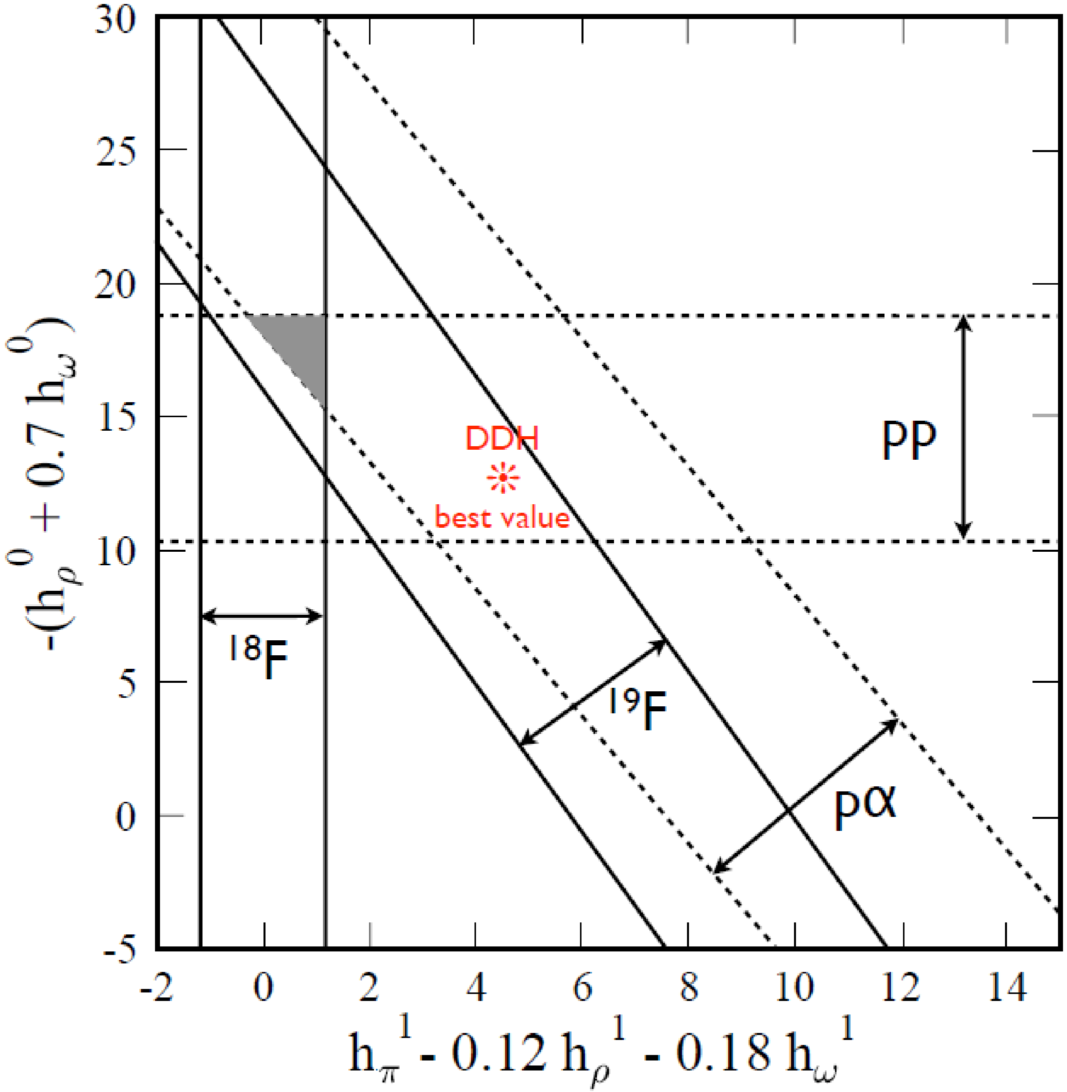
PNC observables and corresponding theoretical predictions, decomposed into the weak-coupling combinations, with $\tilde{f}_\pi = f_\pi - 0.12 h^1_\rho - 0.18 h^1_\varpi$ and $\tilde{h}^0 = h^0_\rho + 0.7 h^0_\varpi$

Taken from : C. Haxton, C. E. Wieman, Ann. Rev. Nucl . Csi. 51 (2001)

Observable	**Exp. ($\times 10^7$)**	$\tilde{f}_\pi$	$\tilde{h}^0$	h^1_ρ	h^2_ρ	h^0_ω	h^1_ω
$A_z^{pp}(13.6)$	-0.93 ± 0.21		0.043	0.043	0.017	0.009	0.039
$A_z^{pp}(45)$	-1.57 ± 0.23		0.079	0.079	0.032	0.018	0.073
$A_z^{pp}(221)$	prelim.		-0.030	-0.030	-0.012	0.021	
$A_z^{p\alpha}(46)$	-3.34 ± 0.93	-0.340	0.140	0.006		-0.039	-0.002
$P_\gamma(^{18}\mathrm{F})$	1200 ± 3860	4385		34			-44
$A_\gamma(^{19}\mathrm{F})$	-740 ± 190	-94.2	34.1	-1.1		-4.5	-0.1
$\langle \vert\vert A_1 \vert\vert \rangle / e$, Cs	800 ± 140	60.7	-15.8	3.4	0.4	1.0	6.1
$\langle \vert\vert A_1 \vert\vert \rangle / e$, Tl	370 ± 390	-18.0	3.8	-1.8	-0.3	0.1	-2.0

The PNC constraints and f_π problem

Taken from : C. Haxton, C. E. Wieman, Ann . Rev . Nucl. Csi. 51 (2001)



$$A_z^{pp} = 0.074 h_\rho^0 + 0.074 h_\rho^1 + 0.030 h_\rho^2 + 0.065 h_\varpi^0 + 0.065 h_\omega^1$$

$$P_\gamma = -4490 f_\pi + 594 h_\rho^1 + 570 h_\omega^1$$

^{18}F(1.081 MeV), $P\gamma$:

$$-1.0 \cdot 10^{-7} \le f_\pi \le 1.1 \cdot 10^{-7}$$

In order to solve this problem, one needs more independent interpretable experiments.

$$\vec{n} + p \rightarrow d + \gamma$$

$$A_\gamma = -0.045 (f_\pi - 0.02 h_\rho^1 + 0.02 h_\omega^1)$$

Expected value $A_\gamma = -2 \cdot 10^{-8}$

P-odd effects in light nuclei

Cluster and multiclaster schemes:

$$^7Li \;\rightarrow\; \alpha + 2n + p \;\rightarrow\; \alpha + t$$

$$^6Li \;\rightarrow\; \alpha + n + p \;\rightarrow\; \alpha + d'$$

$$^9Be \;\rightarrow\; 2\alpha + n$$

$$^{10}B \;\rightarrow\; 2\alpha + 2n$$

$$^{11}B \;\rightarrow\; 2\alpha + 3n$$

The interaction of neutrons with light nuclei can be considered as a few-nucleon reaction, influenced by the potential of one or a few α-particles.

P-odd effects in light nuclei

N. N. Nesterov, I. S. Okunev. JETPh Let. 48 (1988):
P-odd asymmetry in the $^{6}Li(n,\alpha)^{3}H$ reaction with polarized neutrons.

$$\alpha_t = -0.45 f_\pi + 0.06 h_\rho^0$$

Expected value (with DDH best values): $\alpha_t = -2.8 \cdot 10^{-7}$

Contribution from π-exchange ~75%

σ_{nt}=940 b at E_{th}

S. Yu. Igashov, A. V. Sinykov, Yu. M. Tchuvilsky. In: Proc. ISINN-11. Dubna 2003, 34 : P-odd asymmetry in the γ-emission by the de-excitation of the 1st excited state of ^{7}Li for the reaction $^{10}B(n,\alpha)^{7}Li^*$ with polarized neutrons.

$$\alpha_\gamma = 0.16 f_\pi - 0.028 h_\rho^0 - 0.0094 h_\rho^1 - 0.014 h_\omega^0 - 0.014 h_\omega^1$$

Expected value (with DDH best values): $\alpha_\gamma = 1.1 \cdot 10^{-7}$

Contribution from π-exchange ~66%

$\sigma_{n\alpha}$=3940 b at E_{th}

Integral method of measurement

$$W(\theta) \sim 1 + \alpha \cos\theta$$

$$\alpha = \frac{N_+ - N_-}{N_+ + N_-}$$

$$\alpha \sim 10^{-7} - 10^{-8} \rightarrow N_{\pm} \sim 10^{16}$$

ILL, Grenoble, France

PF1B instrument:

λ_n = 4.7 Å,

$F_n \sim (3 - 5)\cdot 10^{10}$ s^{-1}

Integral method of measurement; special experimental technique and data treatment

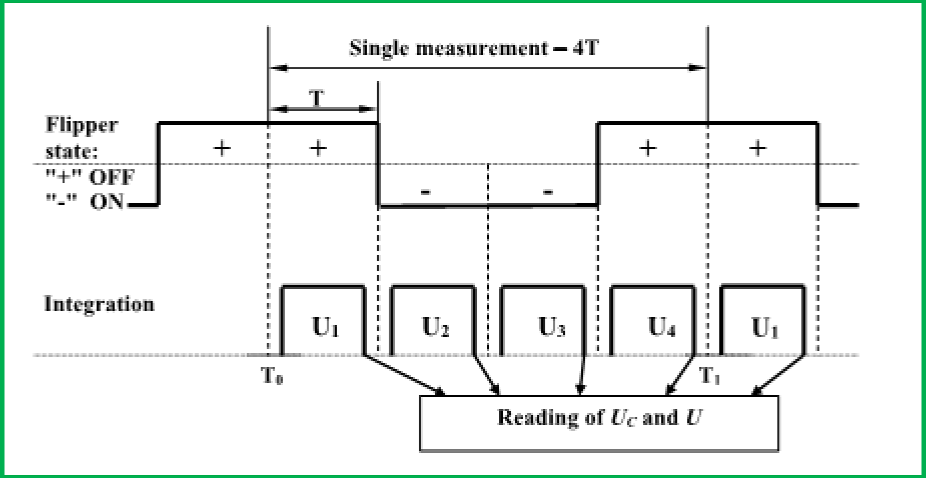
[V. M. Lobashev. *Phys. At. Nucl. 5 (1965) 957*; V. M. Lobashev et. al *Phys. Lett. (1967) 104*; Yu. M. Gledenov et. al. *NIM* ***A350*** *(1994) 517*.]

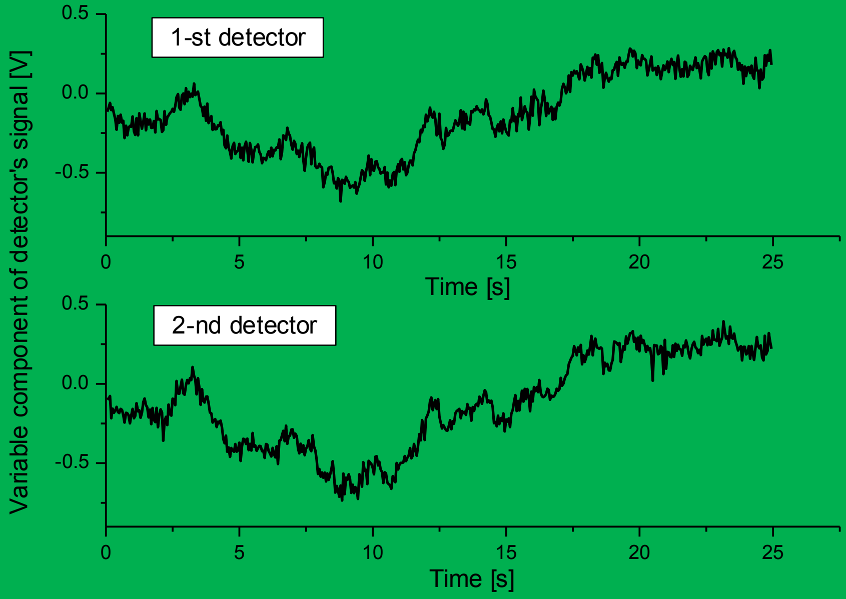
1. Current method of the event detection.
2. Two-channel detector system.
3. Linear drift compensation.
4. Compensation for the reactor power fluctuations.
5. Reversal guiding neutron spin magnetic field at the detector.
6. “0”-experiment

Current mode of the events detection

$F_n \sim (3-5)\cdot 10^{10}\ s^{-1}$

$$I_{det}(t) \sim NE(t) \sim F_n(t)\,(\sigma/4\pi)(1+\alpha\cos\theta)$$

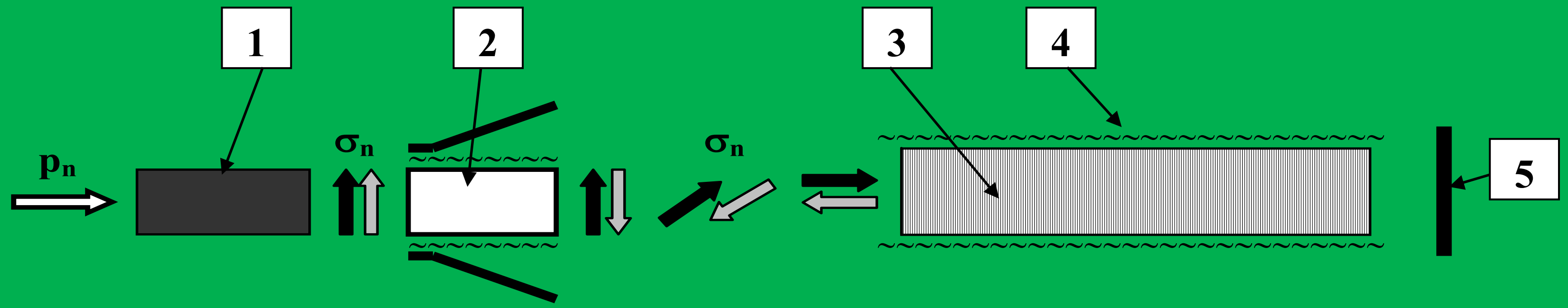




$$\alpha = \frac{N_+ - N_-}{N_+ + N_-} \Longrightarrow \alpha = \frac{I_+ - I_-}{I_+ + I_-}$$

P-odd asymmetry in the $^6Li(n,\alpha)^3H$ reaction with cold polarized neutrons

V. A. Vesna, Yu. M. Gledenov, V. V. Nesvizhevsky, A. K. Petoukhov, P. V. Sedyshev, T. Soldner, O. Zimmer, E. V. Shulgina. Phys. Rev. ***C77*** *(2008) 03550.*



1 – polarizer; 2 – resonance spin-flipper; 3 – ionization chamber; 4 – guiding field; 5 – beam-stop. $\boldsymbol{p_n}$ - neutron momentum; σ_n - neutron spin.

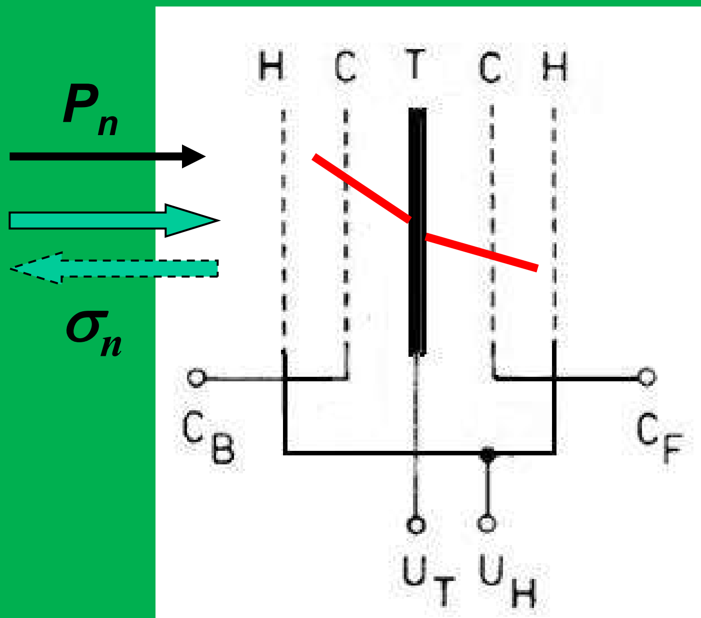
Geometry of experiment: $\sigma_n \,||\, \boldsymbol{P_n} \,||\, \boldsymbol{P_t}$: target plate is perpendicular to the beam axis. The accuracy of the alignment: $\varepsilon < 10^{-2}$.

Ionization chamber

The detector is an assembly of ionization chambers placed in a cylindrical duralumin vessel. The entrance and exit 70×150 mm windows are zirconium foils of thickness 0.5 mm.

Detector includes 24 identical double ionization chambers.

Ionization chamber



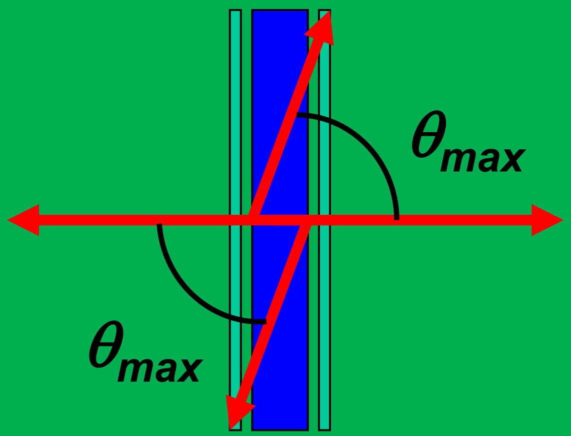
The double ionization chamber:
H – high-voltage electrode;
C – signal electrode;
T – target electrode.

Distances: TC=CH=10.5 mm
The working gas: Ar, p=2 at.

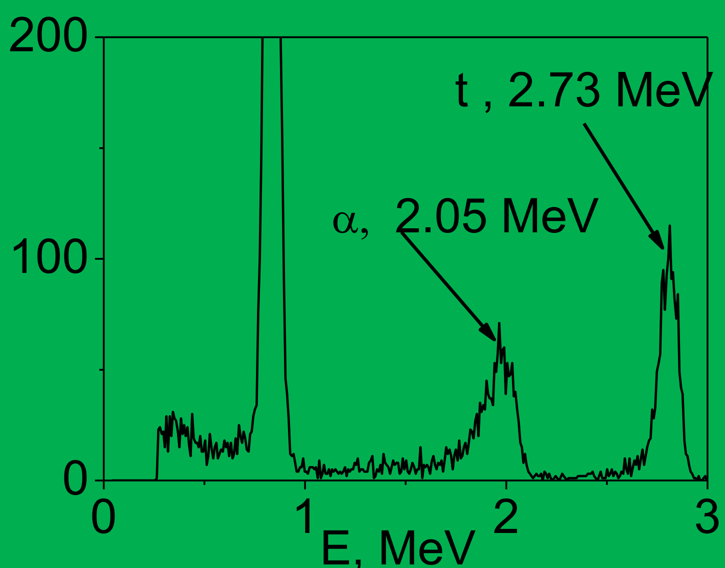
The detector was designed as a two-channel system.
The signs of investigated P-odd effect in the detector channels was opposite at synchronous measurements.

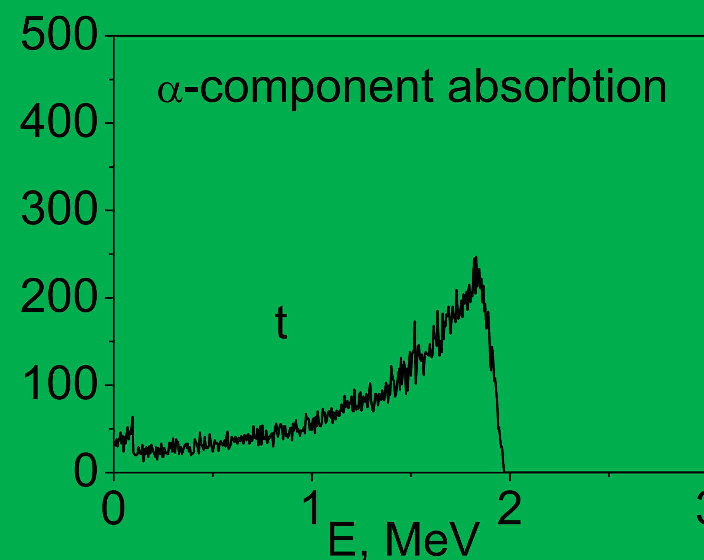
Targets

The lithium targets are 450 μg/cm^2 layers of LiF (the enrichment with ^{6}Li of 95 %) with size of 140x60 мм. Lithium fluoride is evaporated onto 14 μm aluminum foil and covered with the foil of the same thickness. Targets absorbed 60% of beam intensity.

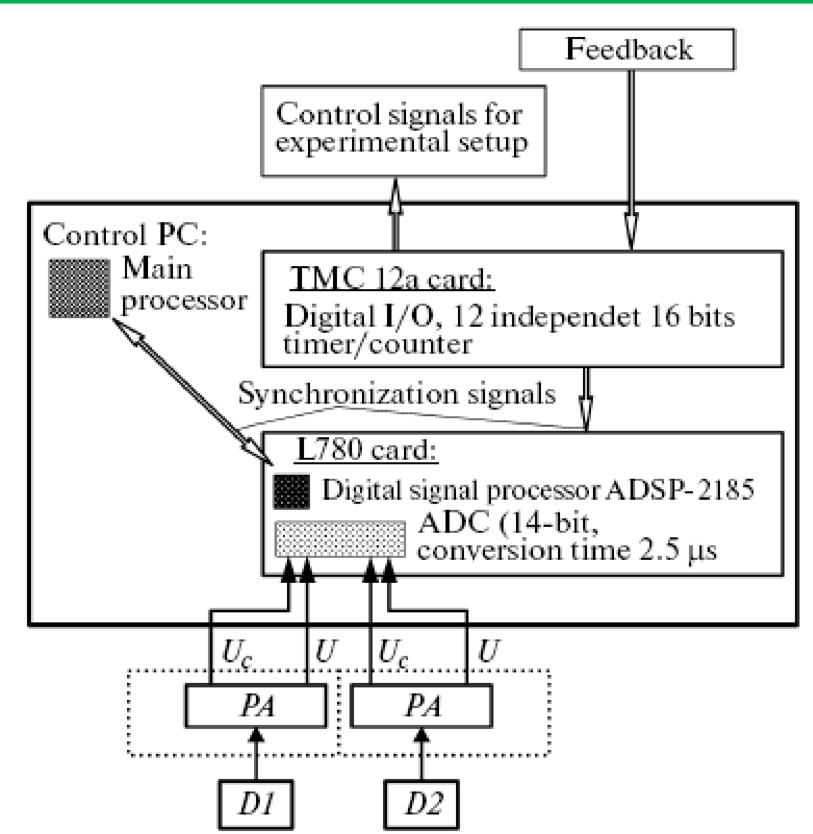


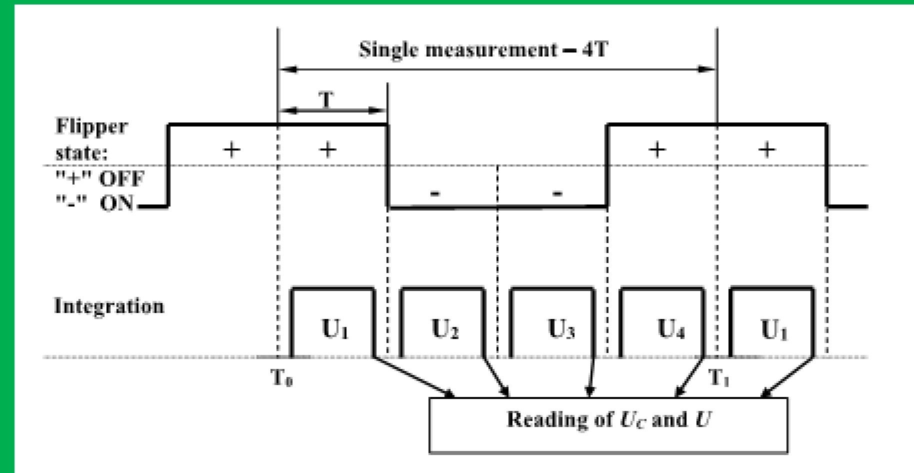
$\langle \cos\theta \rangle = 0.75$





The data acquisition system



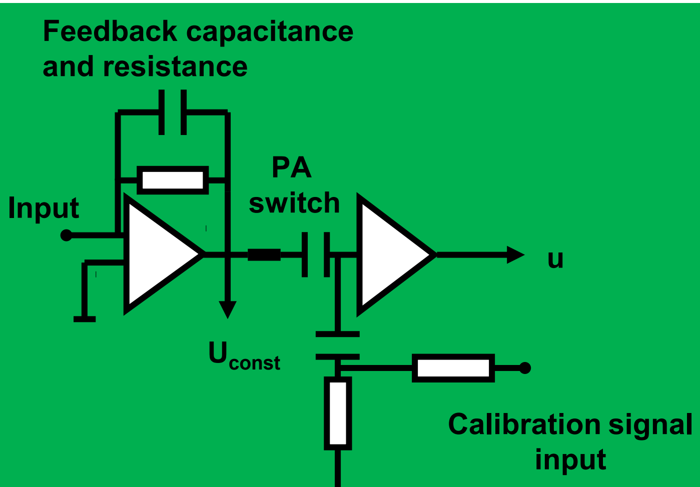


f_{sampl} = 99 kHz

Change of lipper state 4T = 0.2 s

Measurement time T = 0.1 s

Integration time – 0.09 s

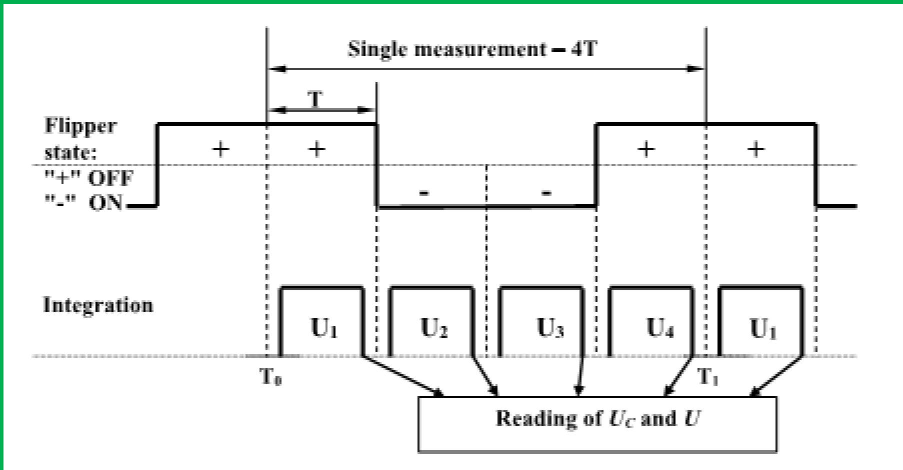


Preamplifier: I $\rightarrow$ U converter:

$U_{out} = I_{det} R_{fb}$

Data acquisition procedure

$u_1^+, u_2^-, u_3^-, u_4^+$ - Values are measuring synchronously for each detector channel.

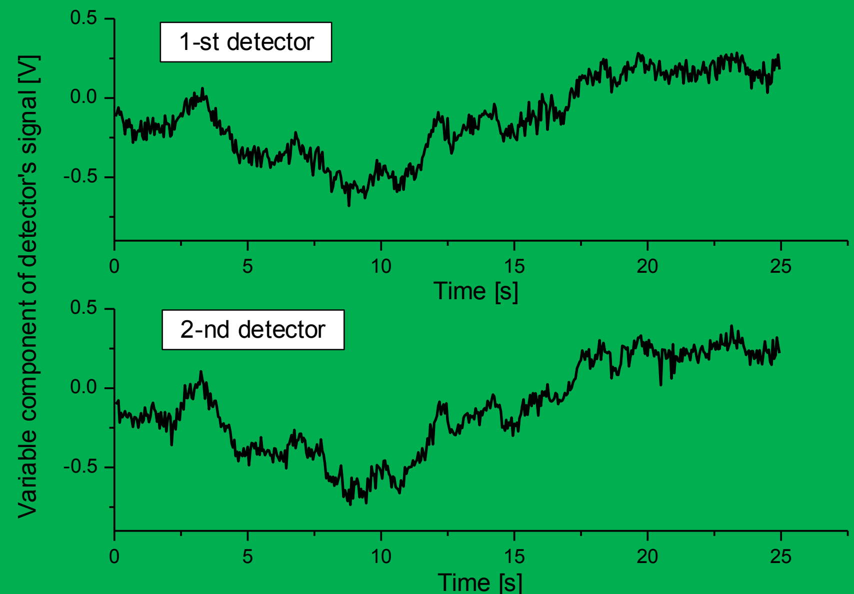


4 sequence values are jointed with a + - - + pattern:

$$u^+ = u_1^+ + u_4^+ \qquad u^- = u_2^- + u_3^-$$

$$\delta u = \left(u^+ - u^-\right)$$ - A single measurement

The N sequence single measurements are joined into a series: N = 128.



U_c^+, U_c^- - are recorded one time per series.

$$\alpha = \frac{(U_c^+ + u^+/K) - (U_c^- + u^-/K)}{(U_c^+ + u^+/K) + (U_c^- + u^-/K)}$$

$$U_c^+ \cong U_c^- = U_c$$

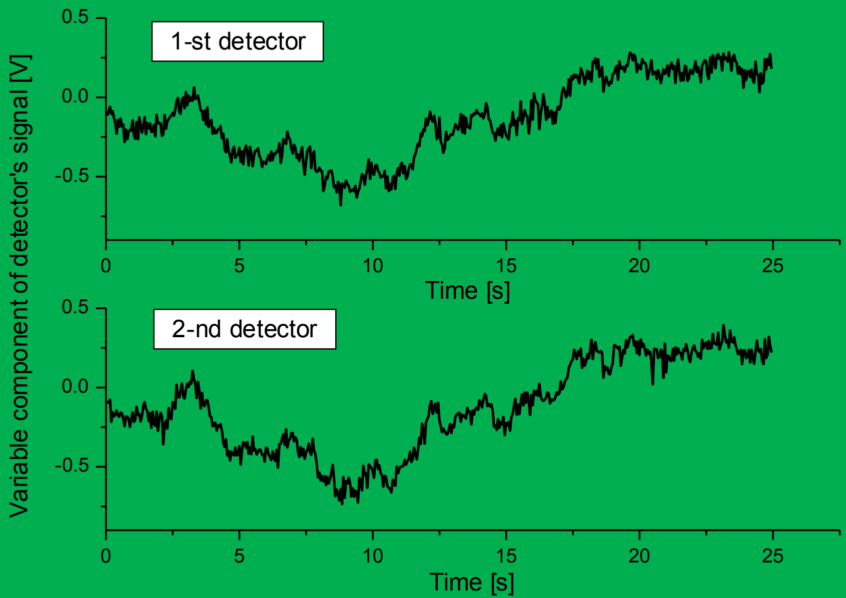
$$U_c \gg u/K$$

$$\alpha_i = \frac{\delta u_i}{K \cdot 2U}$$

Compensation for the reactor power fluctuations

Synchronous values

$$\left.\begin{array}{l}\alpha_i^f, i = 1 - N \\ \alpha_i^b, i = 1 - N\end{array}\right\}$$



$$\alpha_i = \alpha_i^f - L\alpha_i^b, i = 1 - N$$

$$\alpha_i^f = \alpha + \Delta_F$$

$$\alpha_i^b = -\alpha + \Delta_F$$

$\boldsymbol{L}$ – compensation coefficient

Compensation for the reactor power fluctuations

Compensation coefficient is determined over a series meeting the requirement of minimal subtraction dispersion

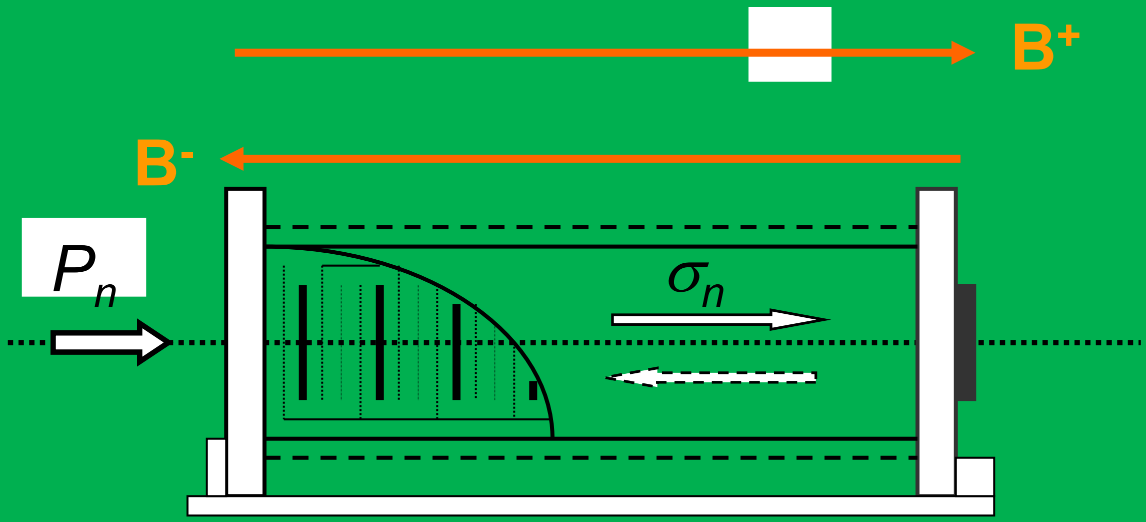
$$\overline{\alpha} = \frac{1}{N}\left(\sum_{i-1}^{N}\alpha_i^f - L\sum_{i=1}^{N}\alpha_i^b\right) \qquad D(\alpha) = \frac{1}{N(N-1)}\sum_{i=1}^{N}\left(\alpha_i - \overline{\alpha}\right)^2$$

$$\frac{dD}{dL} = 0 \qquad L = \frac{\sum\limits_i \alpha_i^f \alpha_i^b - \frac{1}{N}\sum\limits_i \alpha_i^f \sum\limits_i \alpha_i^b}{\sum\limits_i \left(\alpha_i^b\right)^2 - \frac{1}{N}\left(\sum\limits_i \alpha_i^b\right)^2}$$

Suppression of the apparatus asymmetries

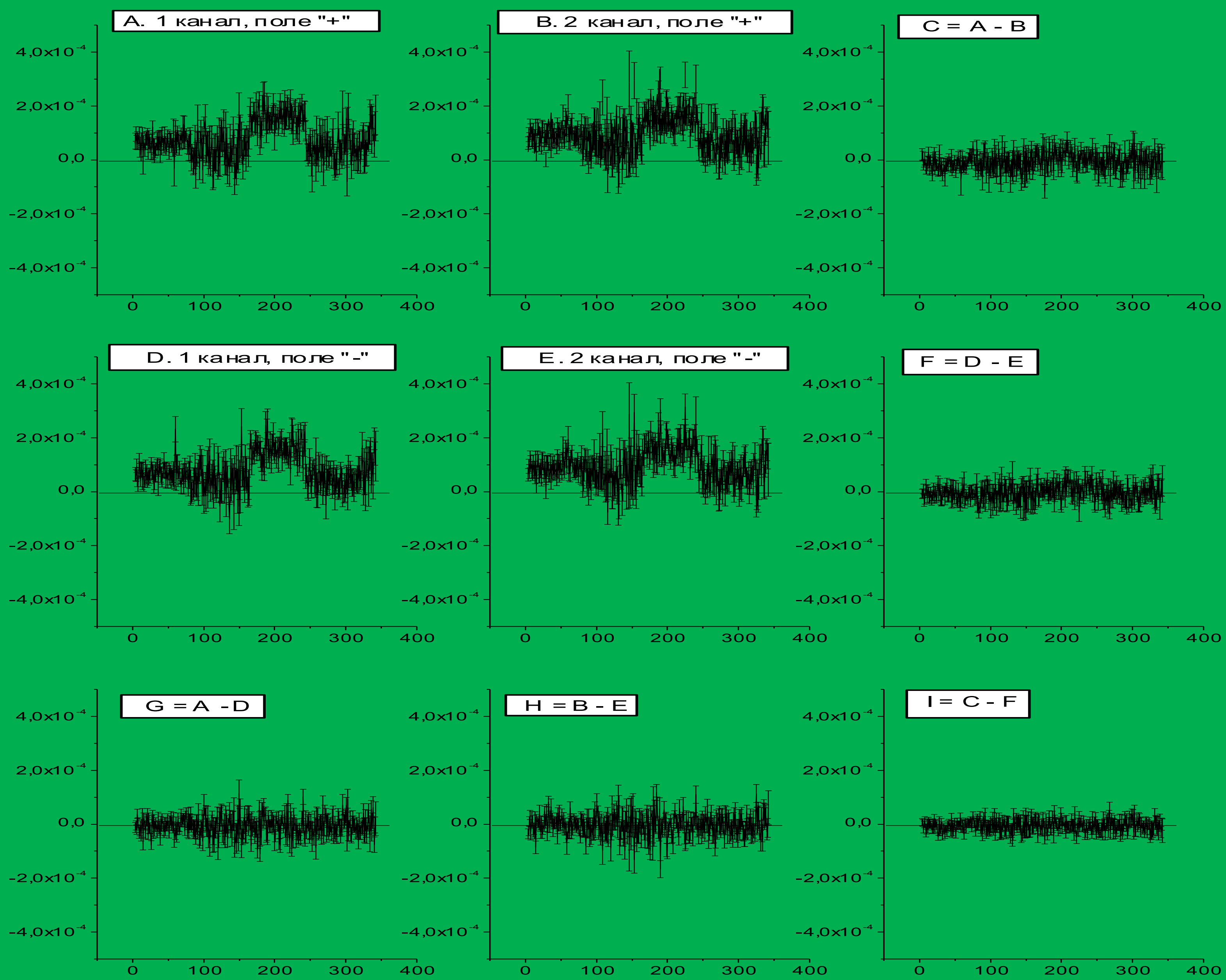
Main sources: signal of the flipper control;
signals in the ground circuit;
scattering electromagnetic fields of the working facilities

To avoid false asymmetries, the direction of magnetic field in the chamber (guiding the neutron spin) is reversed after each series.



B^+/B^-: 4 min.

Suppression of the apparatus asymmetries



The left-right asymmetry: $^6Li(n,\alpha)^3H$: $\alpha_{lr} = (1.06 \pm 0.04)\cdot 10^{-4}$

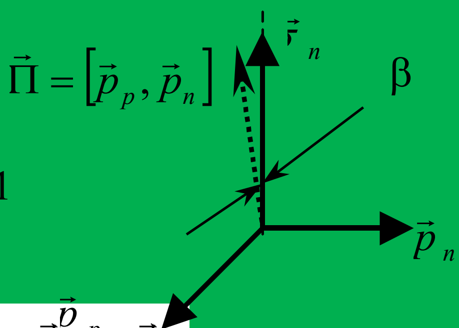
$W(\Theta) \sim 1 + \alpha_{LR}\vec{\sigma}_n\left[\vec{p}_n, \vec{p}_p\right]$: $\qquad \vec{\Pi} = \left[\vec{p}_n, \vec{p}_p\right]$, $\quad \alpha_{LR} \sim (\vec{\sigma}_n, \vec{\Pi})$

$W(\Theta) \sim 1 + \alpha\,(\vec{\sigma}_n\,, \vec{p}_p)$: $\qquad \alpha \sim (\vec{\sigma}_n, \vec{p}_p)$

$\underline{\vec{\sigma}_n \perp \vec{p}_n \perp \vec{p}_p}$

$\vec{\Pi} \sim \sin(90^o)$, $\beta \approx 0^o$,

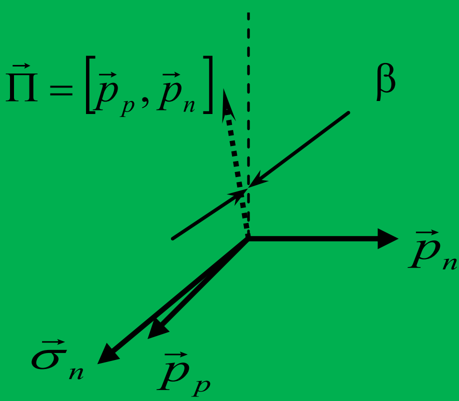
$\alpha_{LR} \sim (\vec{\sigma}_n, \vec{\Pi}) \sim \sin(90^o)\cdot\cos(\beta) \approx 1$



$\underline{\vec{\sigma}_n \| \vec{p}_p \perp \vec{p}_n}$

$\vec{\Pi} \sim \sin(90^o) = 1$, $\beta \approx 0^o$,

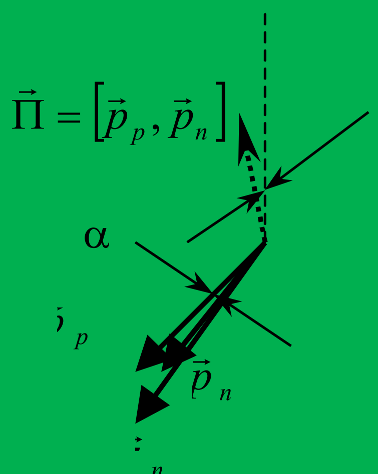
$\alpha_{LR} \sim (\vec{\sigma}_n, \vec{\Pi}) \sim \cos(90^o - \beta) = \sin(\beta) \approx \beta$



$\underline{\vec{\sigma}_n \| \vec{p}_n \| \vec{p}_p}$

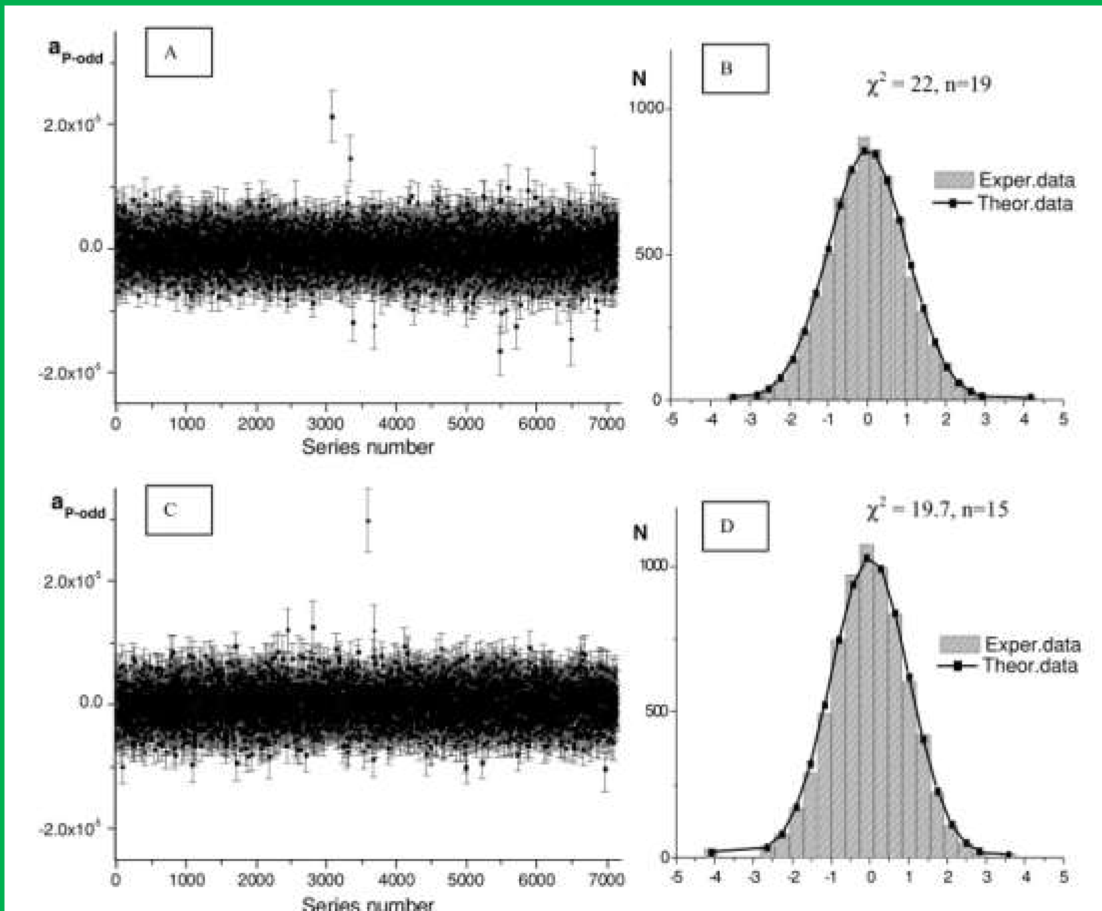
$\vec{\Pi} \sim \sin(\alpha) \approx \alpha$, $\beta \approx 0^o$, $\alpha \approx 0^o$,

$\alpha_{LR} \sim (\vec{\sigma}_n, \vec{\Pi}) \sim \alpha\cdot\cos(90^o - \beta) = \alpha\cdot\sin(\beta) \approx \alpha\cdot\beta$



P-odd asymmetry in the $^6Li(n,\alpha)^3H$ reaction with cold polarized neutrons

Experiments at ILL : 1 exp. (2002) - 18 days main run;
2 exp. (2005): 48 days main run;
3 exp. (2006): 25 days, 0-exp.;



$$\alpha = -(8.6 \pm 2.0) \cdot 10^{-8}$$

Results of the P-odd effect measurements at the ILL for two opposite directions of the guiding magnetic field: "→"(A),and"←"(C). The corresponding histograms for the statistical distribution of these values and the fits by Gaussian distribution are given in B and D including the values of χ2 and the numbers of degrees of freedom

0-experiment

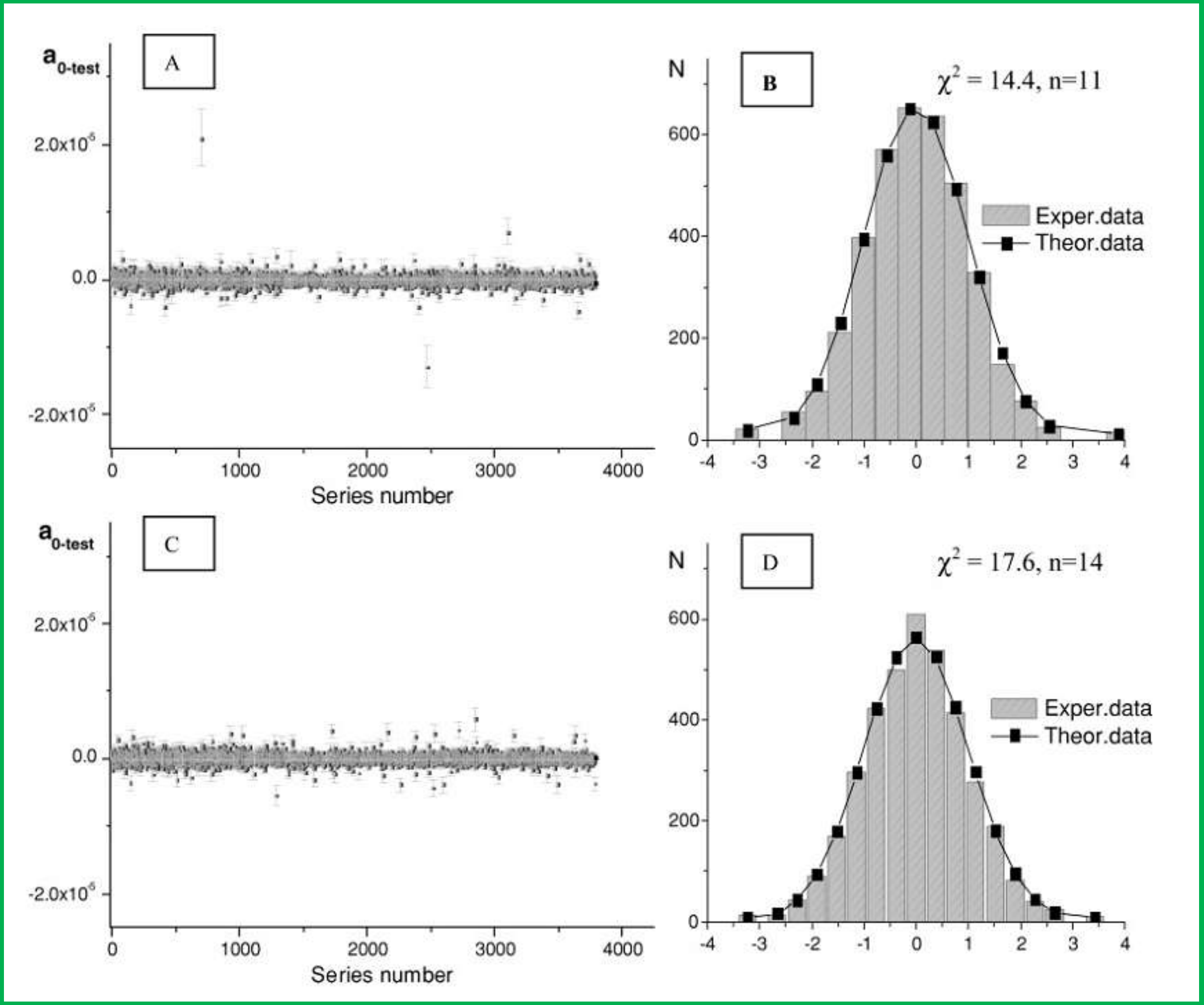
$$N_{eff} + N_b \qquad N_b/(N_{eff}+N_b) \approx 10^{-2}$$

$$\alpha = \frac{(N_{eff}+N_b)^+ - (N_{eff}+N_b)^-}{(N_{eff}+N_b)^+ + (N_{eff}+N_b)^-} \cong \alpha_{eff} + \alpha_b \frac{N_b^+ + N_b^-}{(N_{eff}+N_b)^+ + (N_{eff}+N_b)^-}$$

1. ^{8}Li, β^-, E_{max} = 16.0 MeV, $T_{1/2}$ = 0.84 s, $\alpha = -(0.08 \pm 0.01)$
2. ^{20}F, β^-, E_{max} = 7.0 MeV, $T_{1/2}$ = 11.0s, α - ?
3. $^{35}Cl(n,p)^{35}S$, E_p = 0.6 MeV, $\alpha = -(1.5 \pm 0.34)\cdot 10^{-4}$
4. Al, Ar, N: γ, β, α, p - ?

All targets were cloused by aluminum foils with the thickness of 20 μm.

0-experiment



$$\alpha_0 = -(0.0 \pm 0.5)\cdot 10^{-8}$$

Results of the “0”-test are shown for two opposite directions of the guiding magnetic field: “→”(A),and“←” (C). The corresponding histograms for statistical distribution of these values and fits by Gaussian distributions are given in B and D including the values of χ2 and the numbers of degrees of freedom.

Results

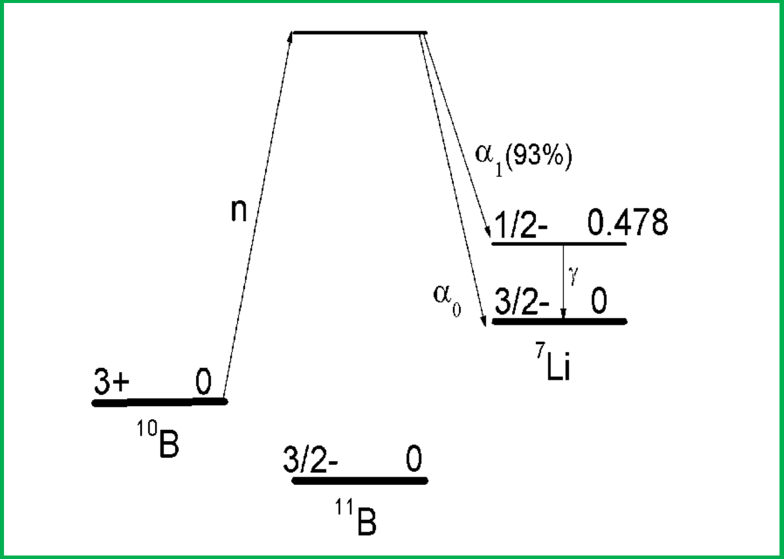
	$P\langle\cos\Theta\rangle$	α_{PNC}	α_0
PNPI	0.66	$-(5.4 \pm 6.0)\cdot 10^{-8}$	$(2.0 \pm 1.7)\cdot 10^{-8}$
ILL, PF1B	0.66	$-(8.1 \pm 3.9)\cdot 10^{-8}$	
ILL, PF1B	0.70	$-(9.3 \pm 2.5)\cdot 10^{-8}$	
ILL, PF1B	0.70		$(0.0 \pm 0.5)\cdot 10^{-8}$
		$-(8.6 \pm 2.0)\cdot 10^{-8}$	$(0.2 \pm 0.5)\cdot 10^{-8}$

$$\alpha_t^{\exp} = -(8.8 \pm 2.1) \cdot 10^{-8}$$

$$\boxed{f_\pi \leq 1.1\cdot 10^{-7}}$$

$^{10}B(n,\alpha)^{7}Li^{*}\rightarrow{}^{7}Li+\gamma$ experiment

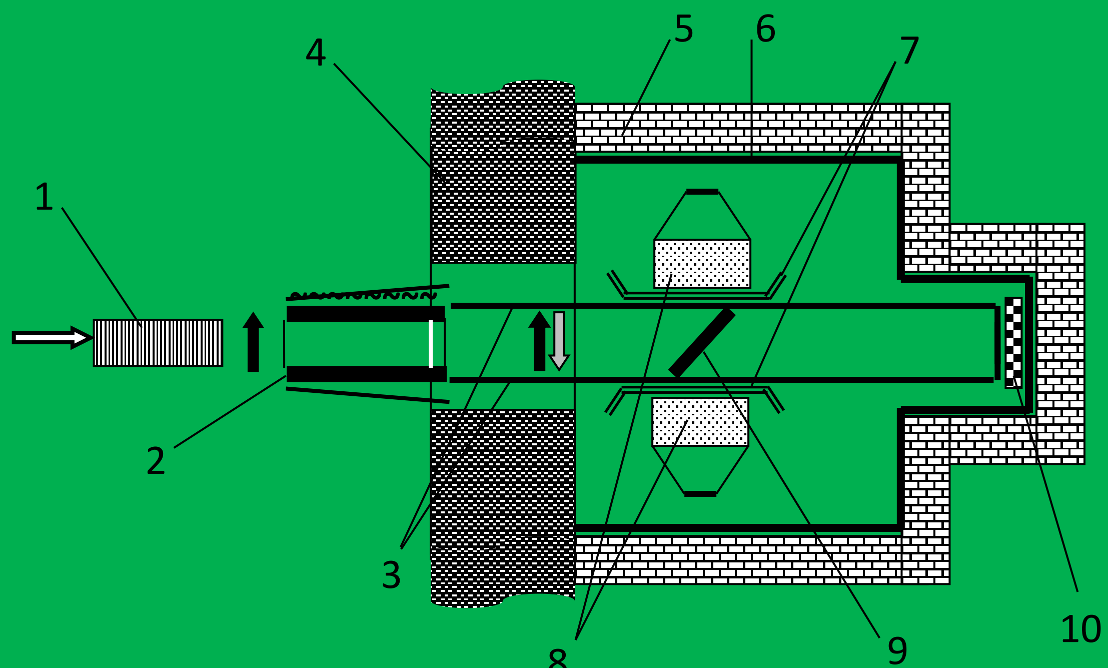
V. A. Vesna, Yu. M. Gledenov, V. V. Nesvizhevsky, P. V. Sedyshev, E. V. Shulgina. European Physical Journal A - Hadrons and Nuclei 47 (2011) 43



PF1B instrument of the ILL reactor, Grenoble, France.

1st Experiment (ILL, 2001)
2nd Experiment (ILL, 2002)
3rd Experiment (ILL, 2007)
4th Experiment (ILL, 2009)

$^{10}B(n,\alpha)^{7}Li^{*} \rightarrow {}^{7}Li+\gamma$ experiment



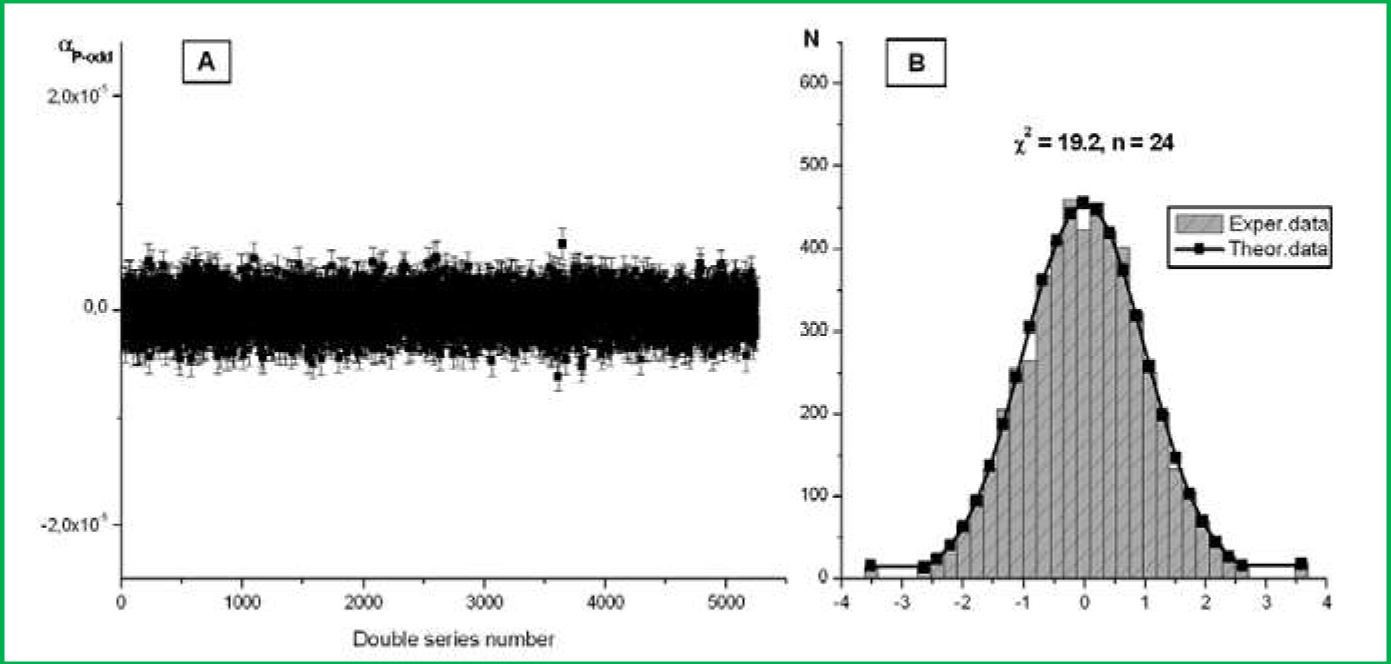
1 – polarizer; 2 – adiabatic “spin-flipper”; 3 – tube made of boron rubber filled in with flowing-through ^{4}He; 4 – concrete wal; 5 – lead shielding; 6 – boron rubber; 7 – Helmholtz coils; 8 – detectors; 9 – the sample; 10 – lithium absorber

Detectors: NaJ(Tl) ∅200 mm × 100 mm.
Sample: 50 g of ^{10}B, 85%, size 160×180×5 mm, 14 μm Al-foil. Sample absorbed all neutrons.
For the light detection the “Hamamatsu” photodiodes S3204-04 (18 x 18 mm) were used.

The signs of investigated P-odd effect in the detector channels are opposite at synchronous measurements.

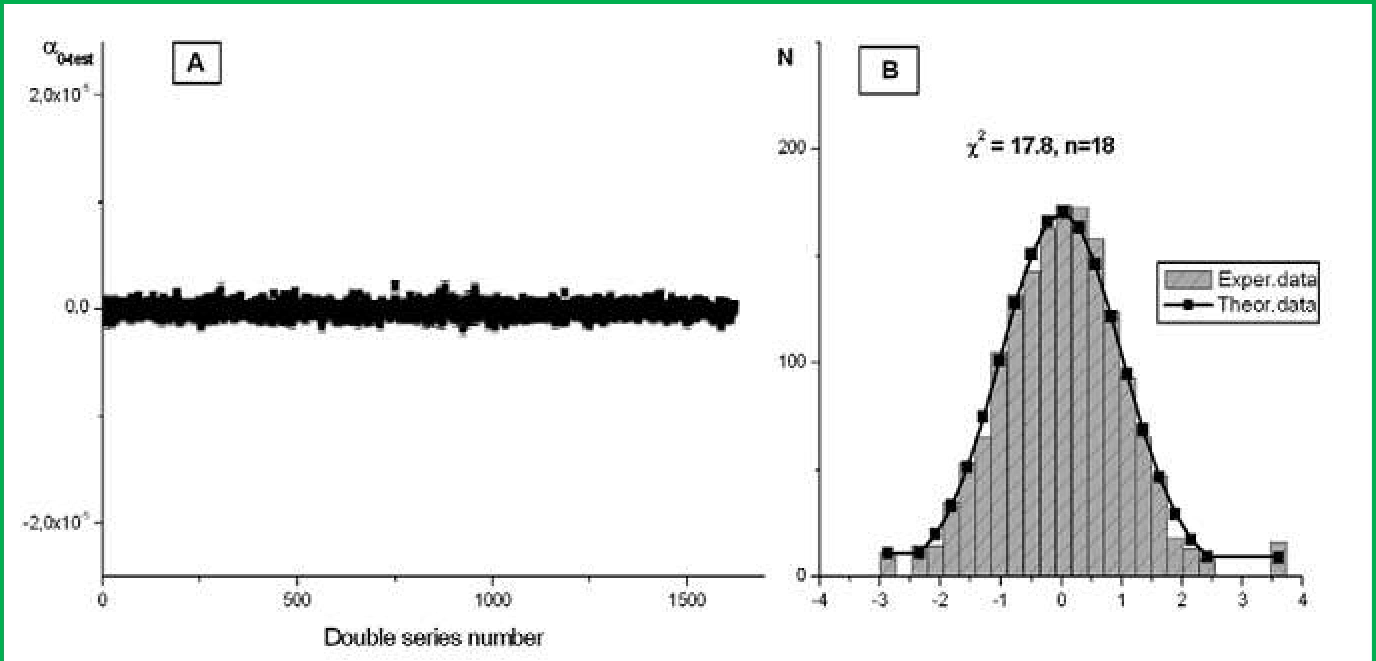
View of the PF1B experimental area

Main runs



(A) Results of the measurement of the P-odd asymmetry coefficient of γ-quanta emission in the reaction 10B(n, α)7Li∗→γ → 7Li(g.s.); the sign of the guiding magnetic field is taken into account: αP-odd = α(→)−α(←) for each of the two consecutive series of the measurement corresponding to the opposite field directions "→"and"←". (B) Corresponding histogram of the statistical distribution of the measured differences compared to the normal distribution. All data are taken into account; no 3σ-cut is applied. The χ2 values and the number of degrees of freedom are given. This experiment was carried out in 2009.

0-experiment



(A) The results of the “0-test” measurement normalized by constant signals in the main measurements; the sign of the guiding magnetic field is taken into account α0-test = α0(→) − α0(←). (B) Corresponding histogram of the values distribution compared to the Gauss distribution. All data are taken into account; no 3σ-cut is applied. The χ2 values and the number of degrees of freedom are given. This experiment was carried out in 2009.

Result

Table 1.

	${}^{\text{raw}}\alpha^{^{10}\text{B, exp.}}_{P\text{-odd}}$	$\alpha^{^{10}\text{B}}_{0\text{-test}}$	$\alpha^{^{10}\text{B, exp.}}_{P\text{-odd}}$	
ILL, 2001-2002	$(2.7 \pm 3.8) \times 10^{-8}$	$-(0.9 \pm 4.8) \times 10^{-8}$	$(3.6 \pm 6.1) \times 10^{-8}$	[6,7]
ILL, 2007	$(3.1 \pm 3.8) \times 10^{-8}$	$(4.2 \pm 7.3) \times 10^{-8}$	$-(1.1 \pm 8.2) \times 10^{-8}$	[19]
ILL, 2009	$-(2.0 \pm 2.5) \times 10^{-8}$	$-(1.3 \pm 1.6) \times 10^{-8}$	$-(0.7 \pm 3.0) \times 10^{-8}$	
Average measured value			$(0.0 \pm 2.6) \times 10^{-8}$	

Table 2.

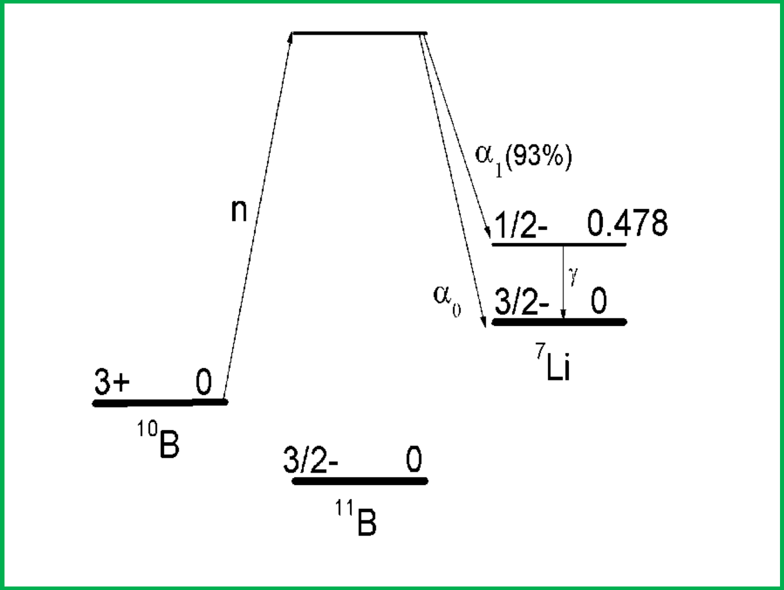
1) Neutron polarization	$(92 \pm 2)\%$ (*)
2) Left-right asymmetry	$< 10^{-9}$ (**)
3) Stern-Gerlach steering asymmetry	$< 10^{-10}$ (*)
4) ^{8}Li beta decay	$< 9 * 10^{-12}$ (**)
5) False P-odd effect from impurities	$\leq 8 * 10^{-10}$ (*)/(**)
6) P-odd asymmetry in secondary reactions involving α-particles emitted from the studied reaction	$\lvert\alpha_n^{\text{sec}}\rvert < 1.6 \times 10^{-13}$ —for fast neutrons, $\lvert\alpha_\gamma^{\text{sec}}\rvert < 4 \times 10^{-17}$ —for γ-quanta. (**)
7) Asymmetry caused by the difference in energy of emitted γ-quanta	$\lvert\alpha^{\text{Dop}}\rvert \leq 8 \times 10^{-9}$ (**)
8) Electromagnetically induced false effect	$\alpha_{\text{noise}} = (-5.1 \pm 7.1) * 10^{-9}$ (*)
9) "0"-test	$\alpha^{^{10}\text{B, exp.}}_{0\text{-test}} = -(1.3 \pm 1.6) \times 10^{-8}$ (*)

(*) Measured effects.
(**) Estimated effects.

$$\alpha^{^{10}B,\,\text{exp.}}_{P-odd} = (0.0 \pm 2.6(stat.) \pm 1.1(sys.)) \times 10^{-8} \qquad f_\pi \leq 0.6 \times 10^{-7}$$

Reaction $^{10}B(n,\alpha)^{7}Li$

Yu. M. Gledenov, V. V. Nesvizhevsky ,P. V. Sedyshev, E. V. Shul'gina P. Szalanski,V. A. Vesna. Phys. Lett. B 769 (2017) 111-116

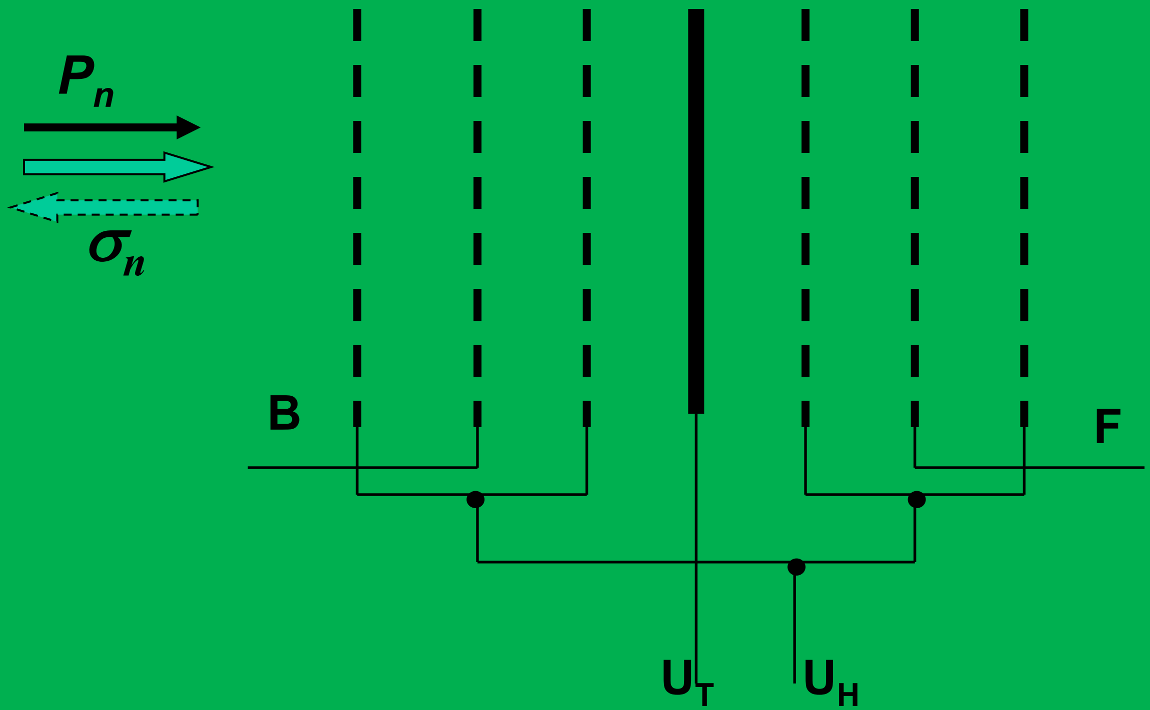


$Q = 2.79$ MeV
$E_{\alpha 0} = 1.78$ MeV
$E_{Li0} = 1.01$ MeV
$E_{\alpha 1} = 1.47$ MeV
$E_{Li1} = 0.84$ MeV
$E_{\gamma} = 0.478$ MeV

I.S.Okunev. *In: "Time reversal invariance and parity violation in neutron reactions"* [Ed. C.R.Gould, J.D.Bowman, Yu.P.Popov. World Scientific, 1994, p.90-96]

$\alpha_{\alpha 0} \sim 10^{-7} - 10^{-6}$

Ionization chamber



Distances: 9 mm
The working gas: Ar, p= 0.3 at.

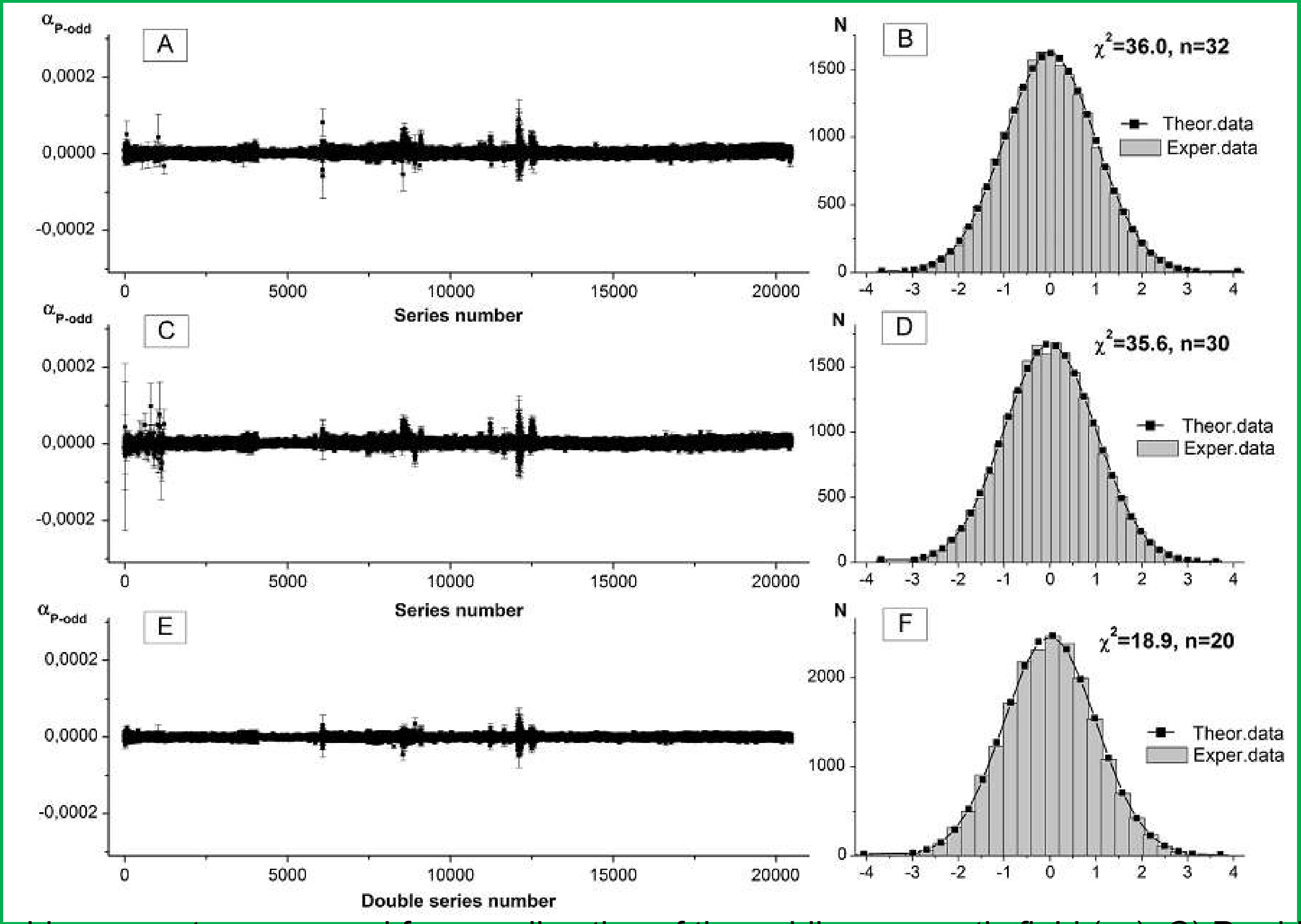
α_0 (1.78 MeV) – 11.4%
Li_0 (1.01 MeV) – 0.8%
α_1 (1.47 MeV) – 82.0%
Li_1 (1.78 MeV) – 5.8%

$\langle\cos\theta\rangle_{\alpha 0} = 0.77$

Targets are 180 $\mu g/cm^2$ layers of amorphous ^{10}B (the enrichment of 95 %) with size of 140x60 mm. Targets are produced using sedimentation of amorphous suspended in acetone to foils with the thickness of 20 μm.
Targets absorbed 80% of beam intensity.

The detector is designed as a two-channel system.
The signs of investigated P-odd effect in the detector channels was opposite at synchronous measurements.

Results



A) P-odd asymmetry measured for one direction of the guiding magnetic field (→), C) P-odd asymmetry measured for the opposite direction of the guiding magnetic field (→), E) The resulting P-odd asymmetry. B), D), F) respective distributions, in comparison with Gaussian distributions (the x-axis is in standard deviations).

Results

Measurements in PNPI, Gatchina: $\alpha_\alpha = -(17.4 \pm 12.2) \cdot 10^{-8}$

Measurements in ILL, Grenoble: $\alpha_\alpha = -(10.7 \pm 3.5) \cdot 10^{-8}$

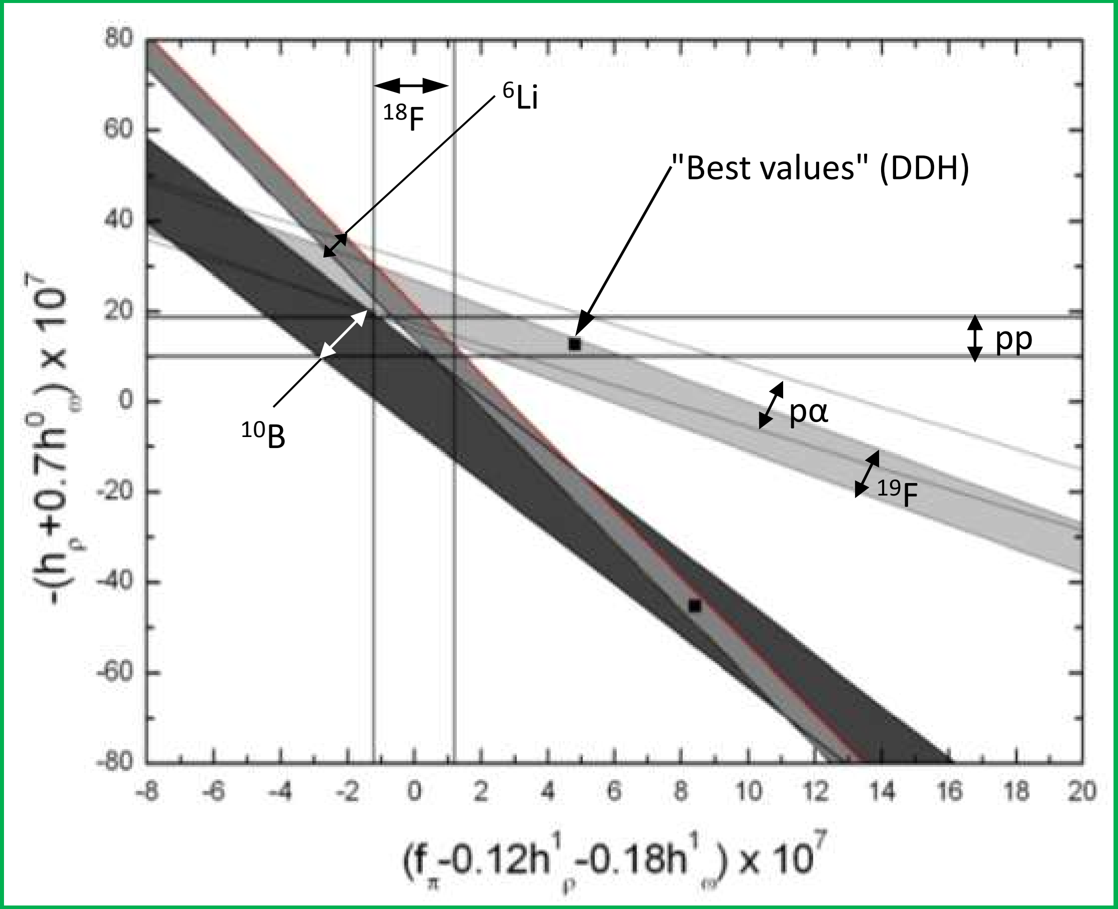
$$\alpha_\alpha = -(11.2 \pm 3.4) \cdot 10^{-8}$$

Table 1
Possible systematic effects.

1) "0"-test (the targets were completely covered with aluminum foil)	$\alpha_{0\text{-test}} = (0.2 \pm 0.5) \cdot 10^{-8}$ [a]
2) Electromagnetically induced false effect (neutron beam was switched off)	$\alpha_{noise} = -(0.6 \pm 0.5) \cdot 10^{-8}$ [a]
3) Left–Right asymmetry	$< 0.3 \cdot 10^{-8}$ [b]
4) False effect in the interaction of the neutron magnetic moment with the guiding field	$< 0.1 \cdot 10^{-8}$ [b]
5) False P-odd effect from eventual impurities	$< 0.06 \cdot 10^{-8}$ [a,b]
6) Stern–Gerlach steering asymmetry	$< 0.01 \cdot 10^{-8}$ [a]
7) Additional P-odd asymmetry due to γ-quanta	$< 0.01 \cdot 10^{-8}$ [b]

[a] Measured effects.
[b] Estimated effects.

Experimental constraints for the weak-interaction constants



$^6Li(n,\alpha)^3H \quad f_\pi \le 1.1\cdot 10^{-7}$

$^{10}B(n,\alpha)^7Li^* \to {}^7Li+\gamma$

$f_\pi \le 0.6\cdot 10^{-7}$

Thank you
for your attention.