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DEAD-TIME DISTORTIONS IN POLARIZATION MEASUREMENTS

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1 Introduction

Many experimental programs at intermediate and high energies require the measurement of polarization. The knowledge of polarization with a good accuracy is very important for such a kind of experiments to recognize between the predictions of different theoretical models. Apart from the required good statistical error of such measurements, possible systematic errors leading to the distortion of the polarization value should be carefully investigated.

Dead-time distortions are one of the possible sources of systematics during polarization measurements. Such effects were studied in the measurements of the deuteron beam polarization at SATURNE-2 [1]. It is shown that the values of tensor and vector polarizations of the beam must be corrected for 14% and 6 – 9%, respectively, under typical operating conditions of low-energy polarimeter [2]. These corrections are not negligible and very important to obtain reliable information during the experiments.

In this paper, we investigate the influence of the dead-time distortion on the measured value of deuteron beam tensor polarization at the Laboratory of High Energies, Joint Institute for Nuclear Researches. The importance of such an effect is discussed for a few polarization experiments.

2 Distortions of the polarization at a large dead-time

Let us assume that we have Poisson statistics process and the corresponding number of events N_f per measurement time T. In this case, the number of stored events N_b is defined as [3]:

$$N_b = \frac{N_f}{1 + N_f \cdot \tau/T}, \tag{1}$$

where τ is the dead time of the setup (or a slow detector).

The dependence of the number of stored events N_b per cycle on the number of incident events N_f obtained using the SPHERE setup described elsewhere (see, for instance, [4]) is shown in Fig.1. The solid line is a linear dependence of N_b on N_f. The dashed line is the result of the fitting by expression (1). The fit gave the parameter $\tau/T = (0.754 \pm 0.008) \cdot 10^{-3}$. The dead time of the setup τ can be estimated as ~ 300 μs for a typical beam burst duration of $T \approx 400$ ms.

During the measurements of beam polarization, the counting rate in different polarization states depends on the value of asymmetry:

$$N^{\pm} = N^0(1 + \epsilon^{\pm}), \tag{2}$$

where N^0 is the counting rate for an unpolarized beam and $\epsilon^{\pm}$ is the asymmetry for different states of the beam polarization. In case of a tensor polarized beam and a zero detection angle:

$$\epsilon^{\pm} = -\frac{1}{2\sqrt{2}} p_{zz}^{\pm} T_{20}, \tag{3}$$

where $p_{zz}^{\pm}$ is the polarization of the beam in different states and T_{20} is the tensor analyzing power of the reaction used for the polarimetry.

The values of polarization $p_{zz}^{\pm}$ can be easily obtained from the following expressions:

$$p_{zz}^{\pm} = -\frac{2\sqrt{2}}{T_{20}} \cdot \epsilon^{\pm} = -\frac{2\sqrt{2}}{T_{20}} \cdot \frac{N^{\pm} - N^0}{N^0} \tag{4}$$

Here N^0 and $N^{\pm}$ are the number of events incident on the detection system. In case of a small dead-time of the setup, the number of stored events used to determine the values of polarization are equal to the number of events incident on the setup. Therefore, the values of polarization usually obtained from the ratio of stored events are equal to the "true" values of polarization. However, in case of non-negligible dead-time effects, the measured values of polarization $\hat{p}_{zz}^{\pm}$ differ from the "true" values:

$$\hat{p}_{zz}^{\pm} = \frac{p_{zz}^{\pm}}{1 + N_f^0 \cdot (1 + \epsilon^{\pm}) \cdot \tau/T}, \tag{5}$$

where N_f^0 is the number of events incident on the detectors and obtained with an unpolarized beam. One can see that the measured values of polarization $\hat{p}_{zz}^{\pm}$ depend on the number of incident particles N_f^0 and asymmetry ϵ. The value of $\hat{p}_{zz} = (|\hat{p}_{zz}^{+}| + |\hat{p}_{zz}^{-}|)/2$ can be expressed as:

$$\hat{p}_{zz} = \frac{p_{zz}}{1 + N_f^0 \cdot (1 - \epsilon^2) \cdot \tau/T}, \tag{6}$$

where $p_{zz} = (|p_{zz}^{+}| + |p_{zz}^{-}|)/2$ is the "true" value of polarization and $\epsilon = (|\epsilon^{+}| + |\epsilon^{-}|)/2$ is the "true" asymmetry.

The ratios of the measured to the "true" polarizations $\hat{p}_{zz}/p_{zz}$ versus the number of incident events N_f for different values of beam polarization are presented in Fig.2. The curves shown by solid, dashed and dotted lines were obtained using the value of tensor analyzing power $T_{20} = -0.87$ and $|p_{zz}^{\pm}|$ values of 0.75, 0.5 and 0.25, respectively. One can see a fast decrease of these ratios versus N_f as well as the dependence on the value of beam polarization: the measured value of $\hat{p}_{zz}^{+}$ decreases, whereas $\hat{p}_{zz}^{-}$ increases with the increasing of $|p_{zz}|$ value according the expression (5). This effect depends on the sign of the tensor analyzing power: in case of a positive value of T_{20}, the measured value of $\hat{p}_{zz}^{+}$ and $\hat{p}_{zz}^{-}$ increases and decreases, respectively. The $\hat{p}_{zz}$ (Fig2.c) is less sensitive to the value of asymmetry and does not depend on the sign of the analyzing power (see (6)).

From the measured asymmetry $\epsilon'^{\pm} = (N_b^{\pm} - N_b^0)/N_b^0$, one can easily obtain "true" asymmetry $\epsilon^{\pm}$ using the following expression:

$$\epsilon^{\pm} = \frac{\epsilon'^{\pm} \cdot (1 + N_f^0 \cdot \tau/T)}{1 - \epsilon'^{\pm} \cdot N_f^0 \cdot \tau/T} \tag{7}$$

However, it should be noted that such a method of the dead-time corrections can be applied only in case of a very stable beam intensity and beam location on the target, especially, for the tensor polarization measurement at a zero angle. Linear corrections of the polarization values [1] can be used up to a dead-time of about 10-15% only.

When beam polarization is obtained from the measurements of left-right asymmetry, the measured value of $\epsilon'^{\pm}$ is related to "true" asymmetry $\epsilon^{\pm}$ following:

$$\epsilon'^{\pm} = \frac{\epsilon^{\pm}}{1 + N_f^0 \cdot (1 - \epsilon^{\pm 2}) \cdot \tau/T} \tag{8}$$

The ratio $R = \epsilon'/\epsilon$ has the same behaviour as the ratio $\hat{p}_{zz}/p_{zz}$ in Fig.2c. Expression (8) was obtained under the assumption that false asymmetry equals zero. In this case, the value of asymmetry is not sensitive to the stability of the beam intensity, but requires a precise location of the beam on the target.

The considered above distortions of the asymmetry values due to a large dead-time of the setup take place during the measurements of polarization in the absence of beam intensity monitoring. These measurements can be performed using either a fixed angle detector, or a left-right polarimeter. Linear corrections of the polarization values can be applied up to 10 – 15% of dead-time only [1]. At a larger dead-time of the setup due to non-linearity, the reconstruction of the "true" polarization is difficult and gives a large error. The monitoring of the beam intensity decreasing the dead-time distortion is desirable at a high rate of events.

3 Measurement of the deuteron tensor polarization at LHE

The tensor polarization of the deuteron beam produced by the ion source POLARIS [5] at the Laboratory of High Energies, Joint Institute for Nuclear Researches, has been measured using the SPHERE setup [4]. Deuteron inclusive breakup on nuclear targets at a zero proton emission angle, $d + A \to p(0^o) + X$, is used as an analyzing reaction [6]. This reaction has a large tensor analyzing power T_{20} [7] which is only weakly dependent on the atomic number of the target. The $|T_{20}|$ has a maximum value of about 0.8 at the proton momentum $P_p \approx \frac{2}{3} P_d$ independently of the initial momentum of the deuteron beam between 2.5 and 9.0 GeV/c [7]. Due to a large cross section of the process, the statistic error provided with this method can be very small. However, the systematic error of the method was estimated to be $\sim 5\%$ [6].

The values of tensor polarization $p_{zz}^{\pm}$ can be obtained from the number of protons in each polarization state of the beam using expressions (4), where N_b must be replaced by the normalized to the corresponding monitor value (counts of the ionization chamber) number of protons $n_b = N_b/M_b$.

However, in case of a large dead-time of the setup, the ratio of stored events N_b to the blocked monitor M_b is not equal to the ratio of incident particles N_f to the value of monitor M_f, eg. $N_b/M_b \neq N_f/M_f$. Therefore, the measured values of polarization differ from the "true" polarization.

The dependence of $n_b = N_b/M_b$ on $n_f = N_f/M_f$ is presented in Fig.3. The points are the results obtained during the measurement of the polarization using the SPHERE setup [4]. The solid line represents a linear dependence of n_b on n_f. The dashed line is the result of fitting by the function:

$$n_b = \frac{n_f}{1 + a \cdot n_f}, \tag{9}$$

with the parameter $a = 0.01110 \pm 0.00043$. The dotted line is the result of the cubic polynomial fit. The deviation from the linear dependence begins at a dead-time of about $25 - 30\%$. The fit taken in the form (9) reproduces the behaviour of the data up to a dead-time of $\sim 60 - 70\%$ only whereas the cubic polynomial fit perfectly describes the data up to a dead-time of $\sim 85\%$.

The ratios of the measured to the "true" polarization values R for different beam polarization states versus the fraction of lifetime M_b/M_f are shown in Fig.4. The "true" values of polarization have been obtained from the ratios of N_f/M_f for different beam polarization states corrected for a small admixture of inelastically scattered deuterons ($\sim 6\%$) with the same momentum as protons. The open circles and triangles represent the ratios of $\hat{p}^-_{zz}/p^-_{zz}$ and $\hat{p}^+_{zz}/p^+_{zz}$, respectively. The ratio $\hat{p}_{zz}/p_{zz}$ is shown by full squares. One can see that these ratios are about 0.9-0.95 at a dead-time of $\sim 50\%$ and fall to 0.6-0.7 at a dead-time of $\sim 80\%$.

4 Reconstruction of beam polarization

In principle, the polarization values can be reconstructed using expression (7), where the parameter τ/T is replaced by the parameter $a = 0.0111$, if the number of stored events n_b depends on the number of incident particles n_f by relation (9). The ratios of the reconstructed to the "true" values of polarization are shown in Fig.5 by open triangles and circles for positive and negative signs of beam polarization, respectively. One can see a good agreement of reconstructed and "true" polarizations at a dead-time of about 50%. Such a correction cannot restore the value of polarization at a larger dead-time of the setup. However, it gives a better agreement of the measured and "true" polarizations.

Another way to reconstruct the polarization is to obtain the number of incident protons n_f^p from the number of stored events n_b^p for different beam polarization states. Then "true" polarizations can be obtained from expression (4). Such a procedure is defined by the used parametrization of the n_b dependence on n_f.

The ratios of the reconstructed to the "true" polarization values are presented in Fig.6. The reconstructed numbers of protons n_f were obtained using expression (9). The symbols are the same as in Fig.4. This method provides a good restoration of the polarization values up to a dead-time of about $50 - 60\%$. However, it gives larger errors than the use of expression (7). In case of the cubic dependence of n_b

on n_f, the restored values of polarizations coincide with the "true" values, but the errors are enormously large (see Fig.7).

Since the events at 3 different beam polarization states of the ion source POLARIS [5], n_b^+, n_b^- and n_b^0, are stored during the measurements of the polarization, one can obtain the dependence of n_b on n_f for each measurement. Using this dependence, one can reconstruct the number of incident protons n_f^p for each state of beam polarization. The results of reconstruction of the beam polarization using a linear dependence of n_b on n_f for each measurement is shown in Fig.8. The symbols are the same as in Fig.4. One can see a good agreement of the obtained polarization with the "true" polarization up to a dead-time of $\sim 60\%$. The averaged polarization p_{zz} can be reconstructed up to 80% of dead-time.

5 Polarization experiments at a large dead-time

The same problem of dead-time distortion exists in experiments requiring asymmetry measurements.

For instance, the behaviour of the measured tensor analyzing power T_{20} and vector polarization transfer κ_0 in the deuteron inclusive breakup reaction at a zero emission angle of the protons strongly depend on the fraction of setup dead-time. Fig.9 shows the T_{20} dependence on the internal momentum of the proton inside the deuteron, k, at a different dead-time of the setup. The solid line represents the result of the theoretical prediction [8]; the dash-dotted, dotted and dashed lines are the behaviour of T_{20} obtained with 30, 50 and 80 % of the setup dead-time [4], respectively. The dependence of vector polarization transfer κ_0 on the fraction of dead-time is presented in Fig.10. The lines are the same as in Fig.9. One can see that the deviation of the theoretical values from the "measured" ones is smaller than 2%, $\sim 6\%$ and $\sim 30\%$ for a dead-time of 30, 50 and 80%, respectively. However, the dead-time effect does not change the sign of the polarization observables.

The measured values of T_{20} or κ_0 in deuteron inclusive breakup for a large dead-time depend on the admixture and polarization of background: it increases (decreases) if the background has the opposite (the same) sign of polarization as the studied process. However, all the above systematic effects do not exceed $\sim 2\%$ in case of a setup dead-time of about 30%, which is comparable to other sources of systematic errors (like the knowledge of the polarization value).

Another type of experiments requires the measurement of the secondary particle vector polarization using focal plane polarimeters [9] by studying of the azimuthal angle (ϕ) distribution of an analyzing reaction products. In this case, the number of events produced at azimuthal angle ϕ in different beam polarization states can be written as:

$$N^{\pm}(\phi) = N^0 \cdot (1 \pm P \cdot A \cdot cos(\phi)), \tag{10}$$

where N^0 is the number of events produced with an unpolarized beam, A is the analyzing power of the reaction, P is the vector polarization of the particle incident on the polarimeter. In this case, the ratio

$$R = \frac{N^+ - N^-}{N^+ + N^-} = P \cdot A \cdot cos(\phi) \qquad (11)$$

is defined by asymmetry $P \cdot A$ varying as a function of $cos(\phi)$. The dependence of the R- ratio on the setup dead-time is presented in Fig.11. The solid line is the "true" ratio. The dash-dotted, dotted and dashed lines represent the "measured" R in case of 30, 50 and 80% of the dead-time, respectively. One can also see, that a large dead-time reduces the value of asymmetry, but cannot change its sign.

If the analyzing power A is known, one can obtain the polarization of particle P. The ratio of the "measured" to the "true" polarizations versus setup dead-time [4] is shown in Fig.12. The "measured" polarization is systematically smaller and differs from the "true" polarization by $\sim$ 30% at a setup dead-time of 80%. The same effect takes place in case of the tensor polarization measurement.

6 Conclusions

The results of this work can be summarized as follows:

- It is shown that the dead-time effects are very significant during polarization measurements.
- The recommended maximum fraction of the setup dead-time during polarization measurements is 15% and 30% for measurements without and with beam intensity monitoring. In the first case, the polarization values can be reconstructed using linear corrections. In the second one, the systematic error due to dead-time distortion does not exceed $1 - 2\%$.

  At a larger dead-time (up to 50–60%), the values of asymmetry, can be in principle reconstructed with a reasonable error. However, all of the polarization reconstruction methods require a good knowledge of the n_b (N_b) dependence on n_f (N_f).
- It is shown that a large dead-time of the setup reduces the absolute values of the measured polarization observables. Due to dead-time, the measured asymmetry is weakly dependent on the fraction and polarization of the background, as well. However, the systematic error due to all the considered effects does not exceed $\sim$ 2% at a dead-time of about 30%, which is comparable to other sources of systematic errors.

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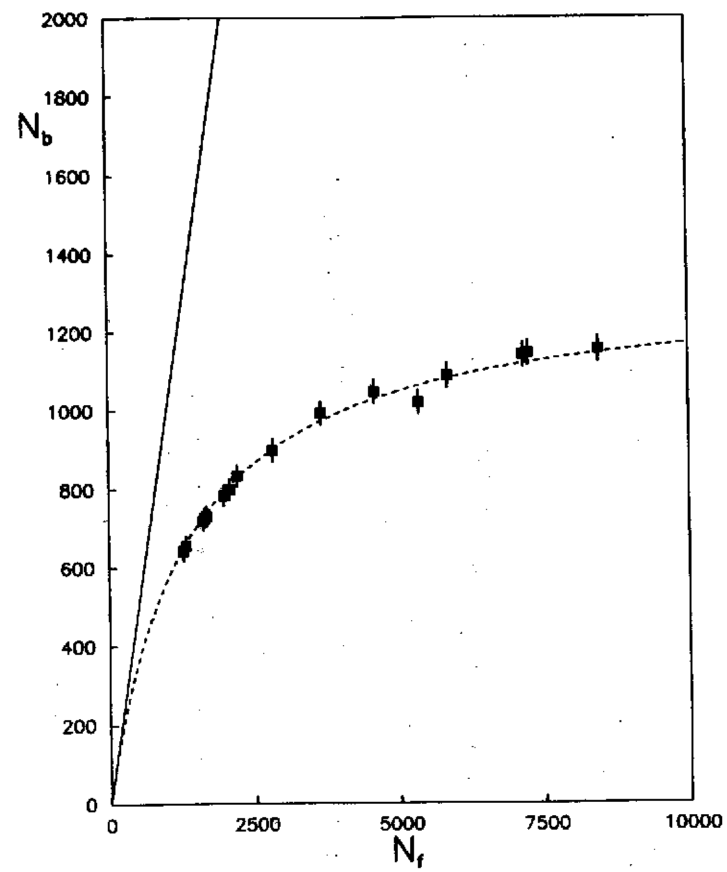

Fig.1. The dependence of the number of stored events N_b per cycle on the number of incident events N_f per cycle obtained using the SPHERE setup [4]. The solid line is a linear dependence of N_b on N_f. The dashed line is the result of fitting by expression (1).

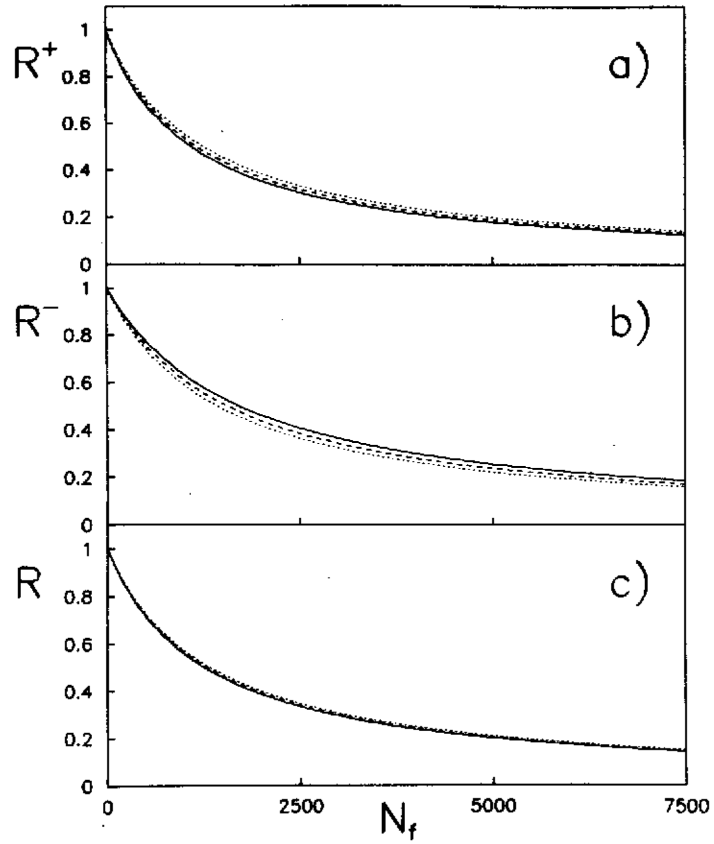

Fig.2. The ratios R of the measured to the "true" values of tensor polarization: a) $R^{+} = \hat{p}_{zz}^{+}/p_{zz}^{+}$; b) $R^{-} = \hat{p}_{zz}^{-}/p_{zz}^{-}$ and c) $R = (\hat{p}_{zz}^{+} - \hat{p}_{zz}^{-})/(p_{zz}^{+} - p_{zz}^{-})$.

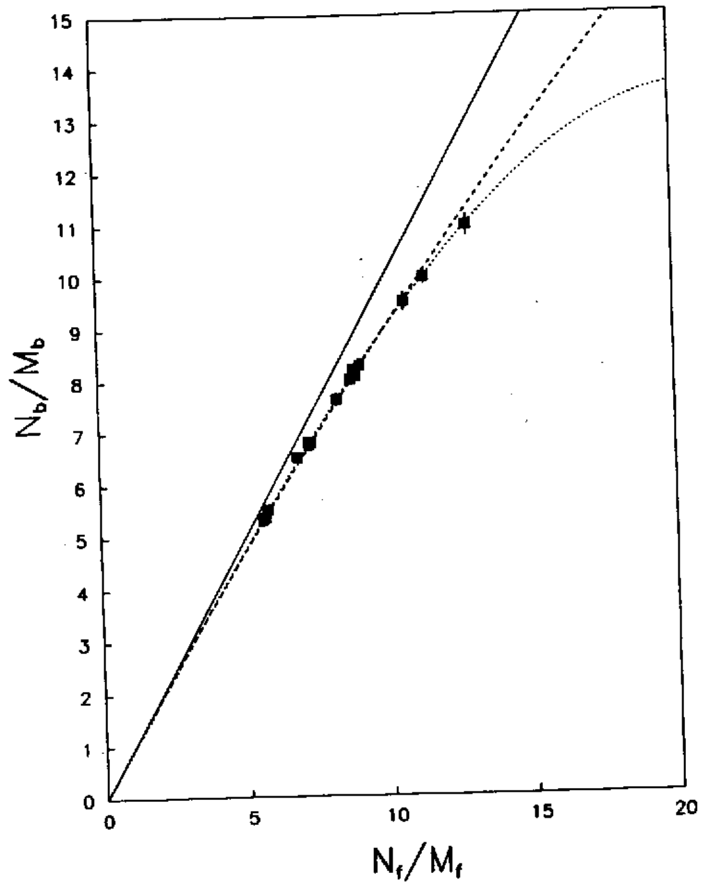

Fig.3. The dependence of N_b/M_b on N_f/M_f. The points are the results obtained during the measurement of the polarization using the SPHERE setup [4]. The solid line represents a linear dependence. The dashed line is the result of fitting by function (9). The dotted line is the result of cubic polynomial fit.

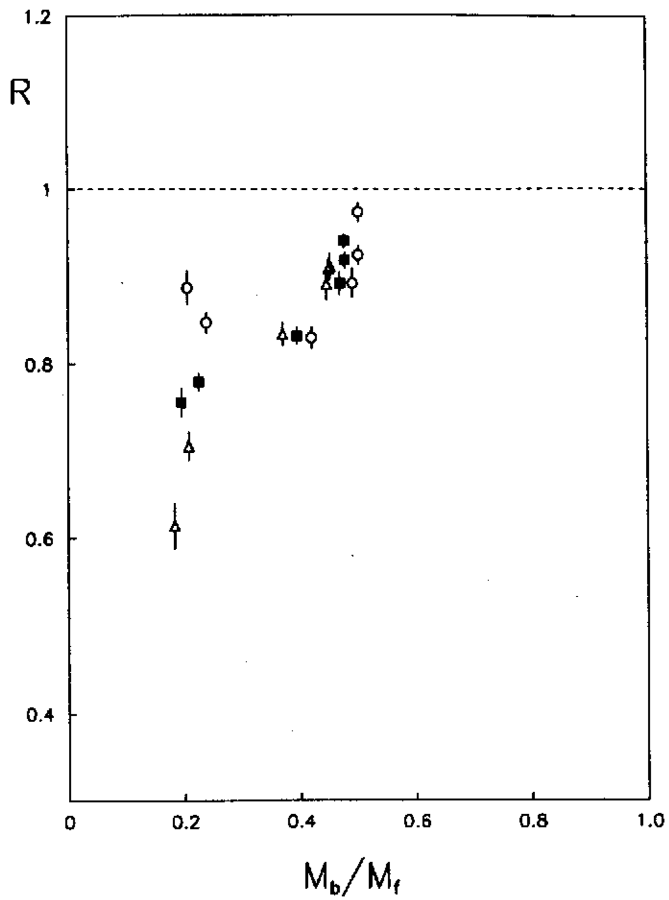

Fig.4. The ratios of the measured to the "true" polarization values R for different beam polarization states versus the fraction of lifetime M_b/M_f.

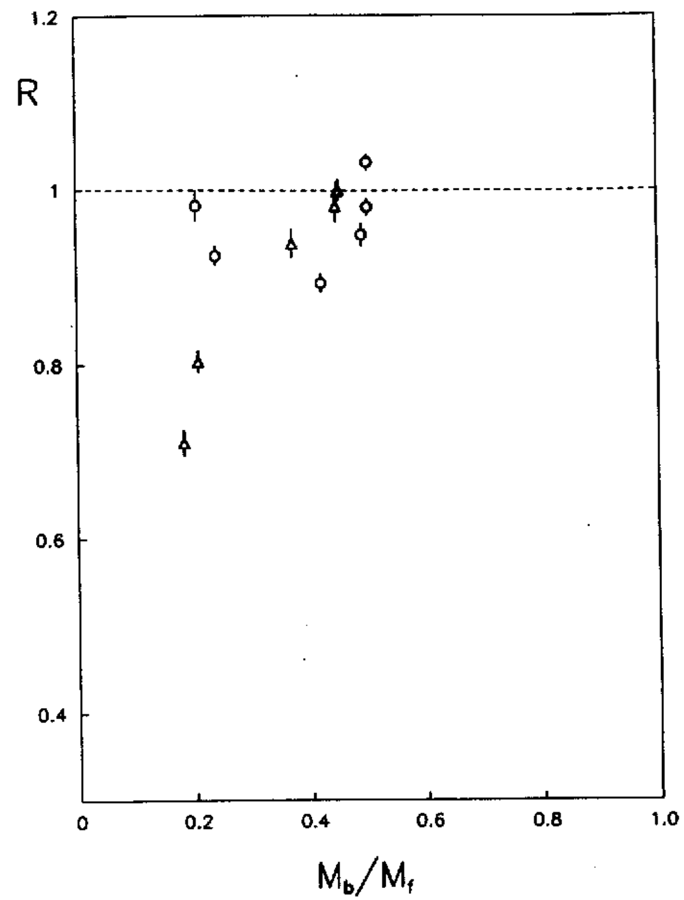

Fig.5. The ratio of the reconstructed (using modified expression (7)) to the "true" values of the polarizations. The open triangles and circles correspond to positive and negative signs of beam polarization.

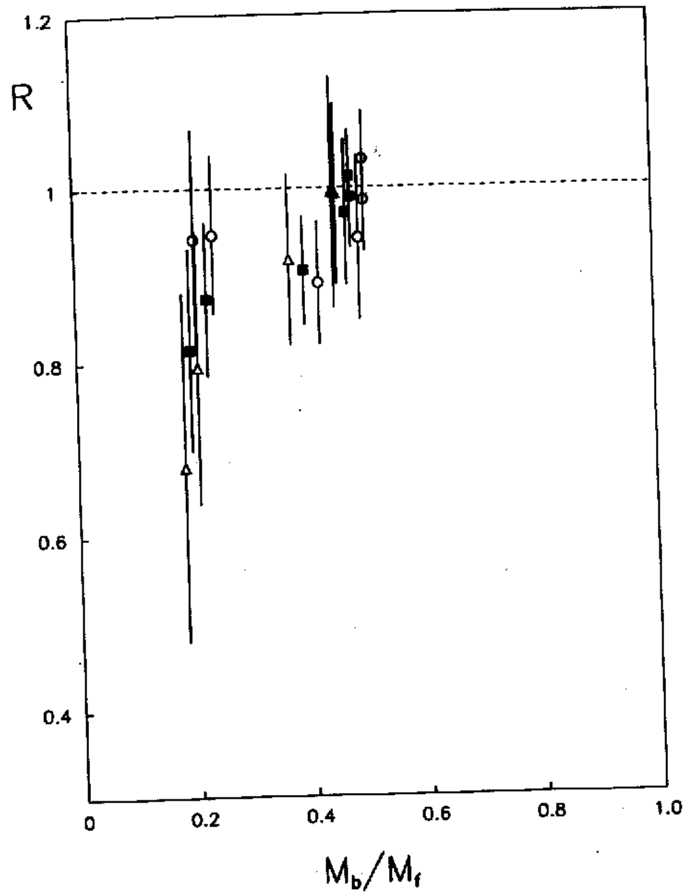

Fig.6. The ratio of the reconstructed to the "true" values of polarizations. The numbers of protons n_f are obtained using expression (9). The symbols are the same as in Fig.4.

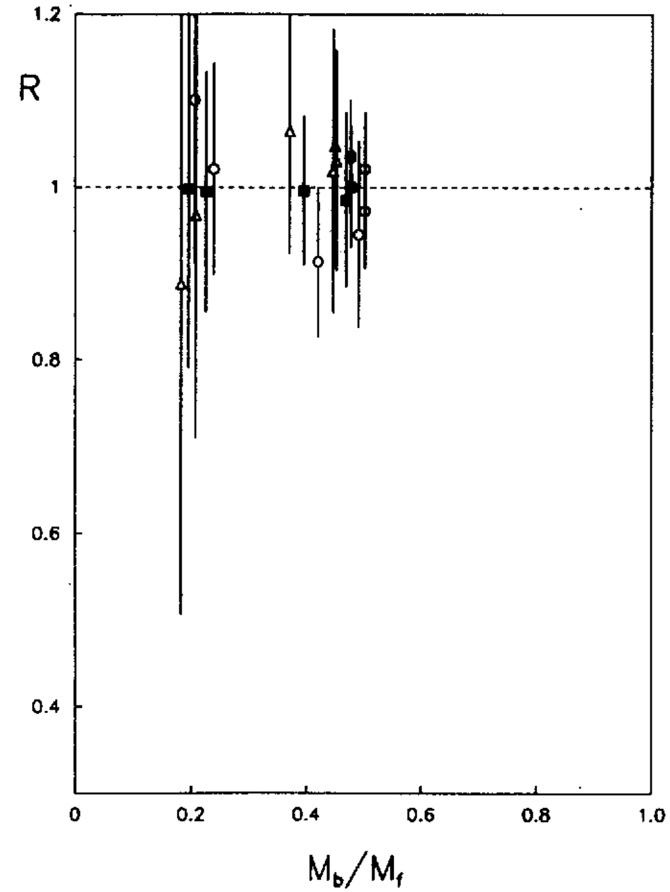

Fig.7. The ratio of the reconstructed to the "true" values of polarizations. The numbers of protons n_f are obtained from the cubic dependence of n_b on n_f. The symbols are the same as in Fig.4.

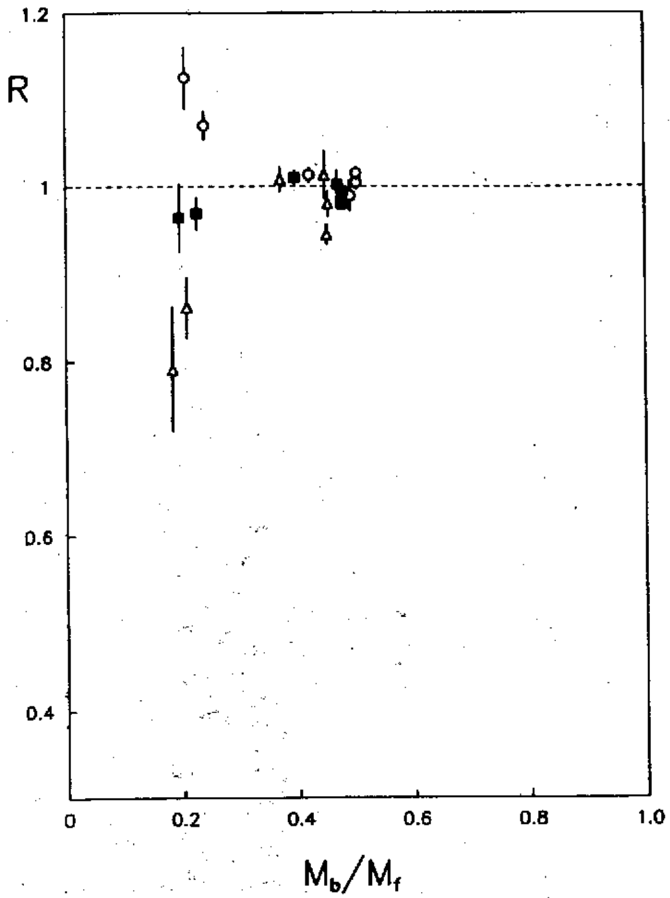

Fig.8. The ratio of the reconstructed to the "true" values of polarizations. The numbers of protons n_f are obtained from a linear dependence of n_b on n_f for each measurement. The symbols are the same as in Fig.4.

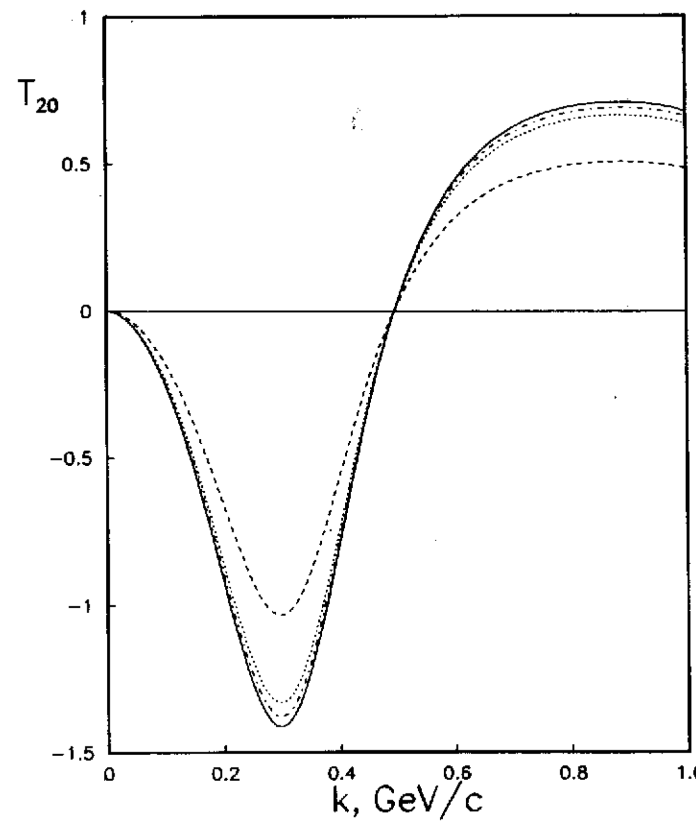

Fig.9. T_{20} versus internal proton momentum inside the deuteron, k. The solid line represents the result of the theoretical prediction [8]. The dash-dotted, dotted and dashed lines are the behaviour of T_{20} obtained with 30, 50 and 80 % of the setup dead-time [4], respectively.

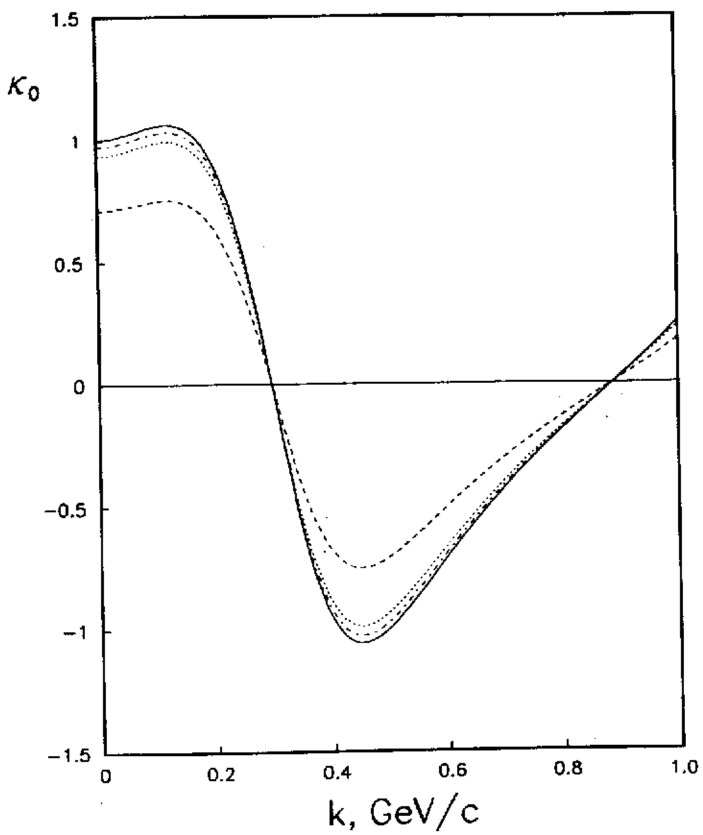

Fig.10. The dependence of vector polarization transfer κ_0 on the dead-time of the setup [4]. The lines are the same as in Fig.9.

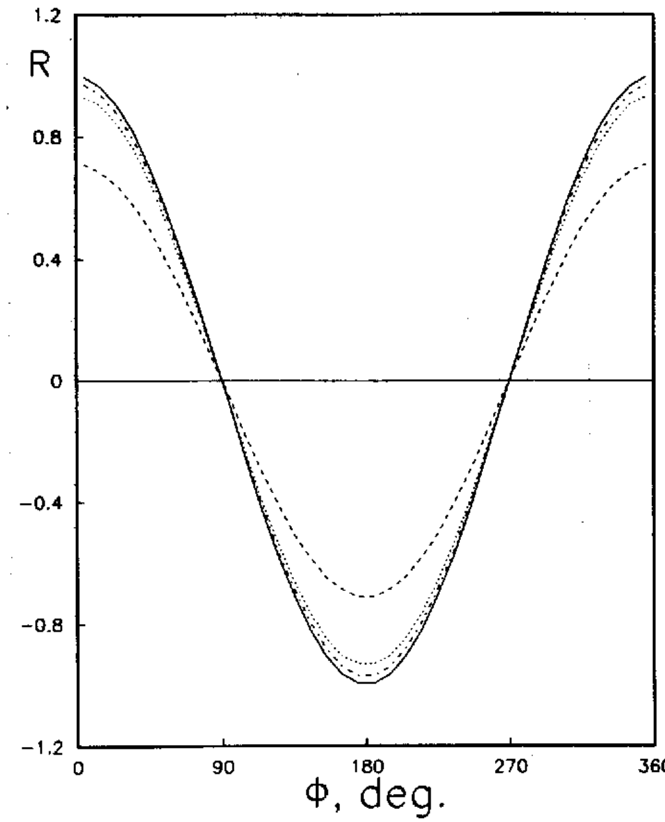

Fig.11. The azimuthal angle distribution of the R- ratio. The solid line is the "true" ratio; the dash-dotted, dotted and dashed lines represent the "measured" R in case of 30, 50 and 80% of the dead-time, respectively.

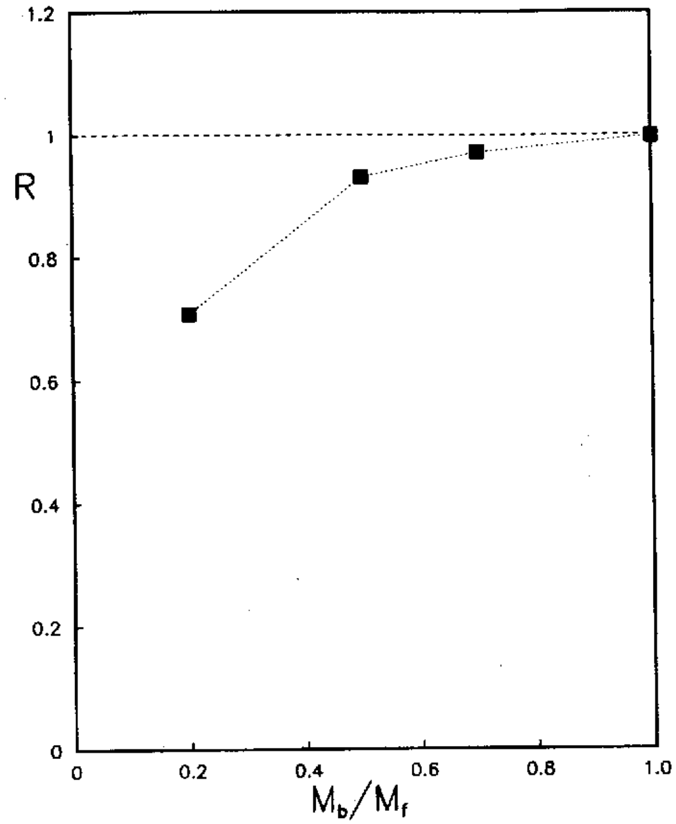

Fig.12. The ratio of the "measured" to the "true" polarizations obtained from the ϕ- distribution versus setup dead-time [4].

References

[1] E.Tomasi-Gustafsson et al., Preprint LNS/Ph/91-27, 1991, Gif-sur-Yvette.

[2] J.Arvieux et al., Nucl.Instr. and Meth. A273 (1988) 48.

[3] V.A.Grigoriev et al., M. Energoatomizdat (1988) 180.

[4] S.V.Afanasiev et al., Phys.Lett. B434 (1998) 21.

[5] N.G.Anishchenko et al., Proc. 5-th Int.Symp. on High Energy Spin Physics (Brookhaven, 1982), AIP Conf.Proc. 95 (N.Y.1983) 445.

[6] L.S.Zolin et al., JINR Rapid Comm. 2[88]-98 (1998) 27. (in Russian)

[7] C.F.Perdrisat et al.,Phys. Rev.Lett. 59 (1987) 2840;
V.Punjabi et al., Phys. Rev. C39 (1989) 608;
V.G.Ableev et al., Pis'ma Zh.Eksp.Teor.Fiz. 47 (1988) 558;
V.G.Ableev et al.,JINR Rapid Comm. 4[43]-90 (1990) 5;
T.Aono et al., Phys.Rev.Lett. 74 (1995) 4997;
L.S.Azhgirey et al., Phys.Lett. B387 (1996) 37.

[8] M.Lacombe et al., Phys.Lett. B101 (1981) 139.

[9] B.Bonin et al., Nucl.Instr. and Meth. A288 (1991) 379, 389;
N.E.Cheung et al., Nucl.Instr. and Meth. A363 (1995) 561;
E.Tomasi-Gustafsson et al., Nucl.Instr. and Meth. A366 (1995) 96;
V.P.Ladygin et al., Nucl.Instr. and Meth. A404 (1998) 129.

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