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THE SEARCH OF LARGE CROSS SECTION ASYMMETRIES IN THE PAIR PRODUCTION PROCESS BY POLARIZED PHOTONS[1]

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Abstract

The regions of pair particle energies and emergence angles in the process of photoproduction of e^+e^- - pairs in the coulomb field by polarized photons are found in which a value of cross section asymmetry is essentially large. The distributions of pair particles on energy and on angles are calculated by the Monte-Carlo method. The obtained results for pair particle yield and asymmetry permit us to conclude that on their basis can be developed a new effective method for polarized photon polarimetry.

Recently the interest towards the methods of measuring of photon beam linear polarization degree at energies of 10 GeV and higher are renewed. This is due the fact that in the large centers in USA (JLAB, photon energy 4-10 GeV) and in Europe (CERN, photon energy 100-150 GeV) the experiments on investigation of photoproduction processes are planned to be carried out by the polarized photon beams [1,2]. For the monitoring of the photon beam polarization the measurement of photon beam polarization degree will be carried out parallel to basic experiment. Hence in the preparation period of the experiment the suitable method for the polarization measurement will be chosen. The following methods for measurement of photon beam linear polarization are well known: a) the measurement of the asymmetry e^+e^- - pair particle yield in amorphous and crystal media [3,4], b) the measurement of the asymmetry in the angular distribution of recoil electrons in the process of e^+e^- - pair production in the field of atomic electrons (triplet

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production) [5], c) measurement of the asymmetry in nuclear reactions of deuteron photodisntegration, the photoproduction π- mesons and the measurement of asymmetry in angular distributions of $\pi^+\pi^-$- mesons of the decay products photoproduced ρ^0-mesons [6]. As polarization measurement will be carried out in parallel with the basic experiment a concrete requirements should be provided for the polarization measurement method:

a) The value of the asymmetry should be sufficently large in order to diminish influence of systematic errors.

b) The polarimeter should not have essential influence on the photon beam intensity (less then 1%).

c) The method should provide small errors $(2-5\%)$.

d) The polarimeter should be sufficiently simple, inexpensive and reliable and should work in a full-automatic regime.

The comparison of the above mentioned methods brought us to the conclusion that for the application in the JLAB experiment the most suitable methods are the ones based on the measurement of asymmetry in the processes of triplet photoproduction and e^+e^- - pair production in the amorphous and crystal media. The first process is more suitable from the point of view of the measurement methodic - one needs to measure the recoil electron asymmetry at large angles (larger then 15%), however the value of the asymmetry is not large (about 10%) and yield of reaction is relatively small (proportional to Z). The value of the asymmetry of the pair production in crystals grows with photon energy and is essentially large at the energies $\omega > 10$ GeV. Although this method has some technical difficulties connected with a use of goniometrical system, magnetic spectrometer etc., nevertheless it has an essential advantage - the value of the asymmetry does not depend on multiple scattering of pair particles. It should be pointed out that this method is the best at high photon energies of order 10 GeV or more.

The method of measurement of asymmetry in the process of e^+e^- - pair production in amorphous media is relatively simple [3,7]. In the experiment the asymmetry in the pair particle yield in the certain regions of polar and azimuth angles is measured. In review report in [1] (p.67) the known results of this method were discussed in details. In particular the results obtained in [7] are discussed. In this paper the asymmetry of

production of nearly coplanar pairs with respect of polarization plane was considered. The results for the asymmetry were obtained in the case when one pair paricle emerges in the polarization plane or in the plane perpendicular to it and over azimuth angle of second particle the integration is carried out in the small interval $2\Delta\phi$ or outside of this interval (so called wedge method). In both cases the asymmetry was calculated for total pair yield and for symmetric pairs afther integration cross section over polar angles. The maximal value of the asymmetry makes up 18%. These investigations have found their promotion in paper [8]. In this work the dependence of the asymmetry upon the angle between polarization and pair emergence planes was considered. Authors confirm that in this way the large values for the asymmetry can be obtained (29% for $\omega = 0.5$ GeV and 24% for $\omega = 4$ GeV for the carbon target).

Here the distributions of the pair particles on energies and on polar and azimuth angles produced by polarized photons are calculated. The calculations are carried out for the coulomb filed by Monte-Carlo simulation. We proceed from the formulae of the e^+e^-- pair production differential cross section in the high energy and small angle approximation [9]:

$$d^5\sigma_p = \frac{\sigma_0}{\pi^2}\frac{y(1-y)}{\Delta^2}dy(X_{unp} - \xi_3 X_{pol})du_+^2 du_-^2 d\varphi_+ d\varphi_-, \tag{1}$$

where $\sigma_0 = Z^2 r_0^2 \alpha$, Z is the nuclear charge, $r = e^2/m$ the classical electron radius ($\hbar = c = 1$), $\alpha = 1/137$, $y = \varepsilon_\pm/\omega$, $\varepsilon_\pm, \omega$ - are the positron (electron) and photon energies, $\varphi(y) = y/(1-y) + (1-y)/y$, $u_\pm = \gamma_\pm \vartheta_\pm$, $\gamma_\pm = \varepsilon_\pm/m, \xi_\pm = 1/(1+u_\pm^2), \varphi_\pm$ are the azimuth angles, counted from the polarization plane, ξ_3 - is the photon Stock's parameter,

$$\Delta = \delta^2/m^2 + u_+^2 + u_-^2 + 2u_+u_-\ cos(\varphi_+ - \varphi_-) + \beta^2, \tag{2}$$

$$X_{unp} = (\xi_+ - \xi_-)^2 + \frac{1}{2}\varphi(y)\xi_+\xi_-[u_+^2 + u_-^2 + 2u_+u_-\cos(\varphi_+ - \varphi_-)], \tag{3}$$

$$X_{pol} = \xi_+^2 u_+^2 \cos 2\varphi_+ + \xi_-^2 u_-^2 \cos 2\varphi_- + 2\xi_+\xi_- u_+ u_- \cos(\varphi_+ + \varphi_-), \tag{4}$$

$\delta = m^2/2\omega y(1-y)$ is the minimum momentum trasfer to the nuclei and $(m\beta)^{-1} = R = 0,4685.Z^{-1/3}(\mathring{A})$ is the screening radius.

The calculations are carried out for the photons with an energy of 4 Gev and for copper terget. For the verification of obtained results we repeated the calculations of

the wedge method [7] by the Monte-Carlo simulation. The results are shown in Fig. 1 (curves a and b). At small $\Delta\phi$ results coincide with that of [7], but with increasing $\Delta\phi$ the discrepancy arises and grows. Obviously this is connected with the fact, that results in [7] are obtained in the approximation $\Delta\phi \ll 1$ neglecting terms of higher order of $\Delta\phi$ in (1). Our results are obtained directly from (1) without additional assumptions.

In [7] the integration over azimuth angle of one particle is carried out in the interval $2\Delta\phi$ while for another particle it is assumed $\varphi = 0$ or $\varphi = \pi/2$ (i. e. $\Delta\varphi = 0$). In experiment as particles are registered in certain intervals $\Delta\varphi$ we have investigated the influence of $\Delta\varphi$ on results. It occurs that at $\Delta\phi \geq \Delta\varphi$ the influence of $\Delta\varphi$ is negligibly small and becomes essential at $\Delta\phi < \Delta\varphi$ (curvess a' and b' in Fig. 1).

It is also turned out that the dependence of asymmetry upon polar angles is sufficently sharp. In Fig. 2 the distribution of pair particles on azimuth angles $\varphi_\pm$ is shown (independently of particle charge, i. e. distribution of vertices) in cases of selection in different regions of polar angles. Curves illustrate the complete picture of pair particle distribution in the vertical plane. In the case of integrated cross sections over pair particle energies in the region $0 \leq \varepsilon_\pm \leq \omega$ and over polar angles in the region $0 \leq \gamma\vartheta_\pm \leq 28$ with $\gamma = \omega/m$ the value of asymmetry is no more than 11% (cuve 1) but in case of symmetric pairs with polar angles in the region 0.2 mrad $\leq \vartheta_\pm \leq$ 0.4 mrad or $1.56 \leq \gamma\vartheta_\pm \leq 3.13$ (ring method) the value of asymmetry is up to 33% (curve 3). The ring $1.56 \leq \gamma\vartheta_\pm \leq 3.13$ includes 9% of total numbers of events. Note that the wedge method brought to the small increase of asymmetry i. e. 18% instead of 15% in [9]. Another significant consequence of pair particle selection in polar angles is that almost rectangular spectral distribution transforms into the Gaussian with a center in $\varepsilon_+ = \varepsilon_- = \omega/2$ (Fig. 3). The width of Gaussian distribution decreases with narrowing polar angle interval (with diminishing the width of ring). Curve 2 in Fig. 2 corresponds to this case, the asymmetry is about 24%, width of ring is $1.56 \leq \gamma\vartheta_\pm \leq 3.13$. Transformation of spectral distribution into the Gaussian is an essential effect and brings to the important conclusion. It is well known that the asymmetry is higher in case of symmetrical pairs (18% in [7] and 24% in [8]). But for registration of symmetrical pairs the unwieldy setup of pair-spectrometer will be used. Practically one needn't measure the pair particle energy if we select them in certain

polar angle regions. In Fig. 3 the pair particle spectral distribution is shown after the integration over azimuthal angles, polar angles are in the interval $1.56 \leq \gamma\vartheta_{\pm} \leq 3.13$.

It follows from aforesaid that especially good results for the asymmetry can be obtained combining two methods by selecting particles in azimuth angles (the wedge method) and in polar angles (the ring method).

The results of such selection are illustrated in Fig. 4 and 5. The curves a and b in Fig. 4 are the same as curves a and b in Fig. 1, but now paricles are selected also in interval $1.56 \leq \gamma\vartheta_{\pm} \leq 3.13$ of polar angles. The asymmetry is large - 44%. This results are obtained in the ideal case when one particle has an azimuth angle $\varphi = 0$ or $\pi/2$ (i. e. $\Delta\varphi = 0$) and the energies of symmetric pair particles are accurately equal $\varepsilon_+ = \varepsilon_- = \omega/2$. The curves showing in Fig. 5 are more real in the sense of expected results in the experiment. The curves are calculated with the account of $\Delta\varphi$ ($\Delta\varphi = 0.05$ rad or $\Delta\varphi/\beta = 1.98$). Curve 1 is calculated in the case of $0 \leq \varepsilon_{\pm} \leq \omega$ and $1.56 \leq \gamma\vartheta_{\pm} \leq 3.13$, the asymmetry is about 27%. Curve 2 corresponds to the case of $0.475\omega \leq \varepsilon_{\pm} \leq 0.525\omega$ and $1.56 \leq \gamma\vartheta_{\pm} \leq 3.13$. The asymmetry is large 43%. In first case the asymmetry is less but the pair yield is higher and there is no need of pair spectrometer setup. Curve 3 is calculated for symmetric pairs with polar angles in interval $1.56 \leq \gamma\vartheta_{\pm} \leq 3.13$. The asymmetry is about 44% (cp. with the curve a in Fig. 4).

When it is difficult to recover complete kinematics of the reaction $\gamma \to e^+e^-$ (especially the photon propagation direction) it may be suuggested a new, more appropriate, method for asymmetry measuring (so called coordinate method). It suggests to measure the electron and positron energies and their coordinates $x_{\pm}$ and $y_{\pm}$ in directions parallel and perpendicular to the polarization plane. The asymmetry is defiend as $A = (N_{\parallel} - N_{\perp})/(N_{\parallel} + N_{\perp})$ where $N_{\parallel}$ and $N_{\perp}$ are numbers of pairs with $\Delta x \geq k\Delta y$ and $\Delta y \geq k\Delta x$, respectively, where $\Delta x = |x_+ - x_-|, \Delta y = |y_+ - y_-|$ and k is constant quantity value of which must be chosen. Results of such calculations are collected in Table 1. The calculations are carried out for the statistics of 1 million produced pairs in the interval $0 \leq \gamma\vartheta_{\pm} \leq 28$. In Table 1 numbers of pairs $N_{\parallel}$ and $N_{\perp}$ and values of asymmetry and statistical errors are presented in cases of selection of pairs in certain intervals on energy $y = e_{\pm}/\omega$ and on angle $\alpha = \gamma d/L$, where d is distance between electron and positron in

the vertical plane and L is distance between converter and detector. Results in Table 1 show that the cross section asymmetry increases essentially with decreasing of selection angle α. At a same time the statistical errors are almost the same. As for quantity k his influence on the asymmetry is small. Large values for asymmetry can be obtained only at $k \geq 100$. But in this case the cross sections are negligiblity small. The situation is same as in the wedge method [7] when over azimuth angle φ_- is carried out integration in small interval $(-\Delta\phi, \Delta\phi)$ with $\Delta\phi/\beta < 0.4$ (see Fig.1, curve a). The coordinate method is close in essence to one of selection of pairs on angle ω [8]. Unfortunately in [8] it does not noted concrete conditions under which the quantities $\sigma_{\|}$ and $\sigma_{\perp}$ are calculated. As a consequence it is not clear that the value of asymmetry of 24% is a result of transition to the angle of ω or it is conditioned by detector size and magnitude of parameter d i.e. is a result of selection on the angle α.

The results obtained in this work can be presented as a theoretical basis for elaboration of setup for polarized photon polarimetry at photon energies of a few GeV. In this article some different methods are considered for cross section asymmetry measurement and every one have advantages and lacks in comparison with each other. But the polarimeter can be constructed such a way that it becomes possible to obtain value of asymmetry by this methods simultaneously. This permits to use possibilities of each method and decrease statistical errors. In the following paper we will give description of specific setup for polarized photon polarimetry for JLAB taking into account of experimental conditions.

References

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Figure Captions

Fig.1. Dependence of the ratio $d\sigma(\varphi_+ = 0)/d\sigma(\varphi_+ = \pi/2)$ upon angle $\Delta\phi/\beta$ for pairs of equal energy $\varepsilon_+ = \varepsilon_- = \omega/2$ and polar angles in the interval $0 \leq \gamma\vartheta_\pm \leq 28$. Over azimuth angle φ_- the integration is carried out in the interval $(-\Delta\phi,\ \Delta\phi)$ or outside this interval $(\pi - \Delta\phi,\ \pi + \Delta\phi)$ (curves a and b, correspondingly). The azimuth angles are counted out from the polarization plane. Curves a' and b' show the same dependencies but now the azimuth angle of first particle is in interval $-\Delta\varphi \leq \varphi_+ \leq \Delta\varphi$ or $\pi/2 - \Delta\varphi \leq \varphi_+ \leq \pi/2 + \Delta\varphi$ with $\Delta\varphi/\beta = 1.98$.

Fig.2. The distribution of pair particles on azimuth angles $\varphi_\pm$. Curve 1 for $0 \leq \gamma\vartheta_\pm \leq 28$ and curve 2 for $1.56 \leq \gamma\vartheta_\pm \leq 3.13$ in the case of $0 \leq \varepsilon_\pm \leq \omega$. Curve 3 for the case of $1.56 \leq \gamma\vartheta \leq 3.13$ and symmetrical pairs $\varepsilon_+ = \varepsilon_- = \omega/2$.

Fig.3. Pair particle spectral distribution after integration over $\varphi_\pm$. The polar angles are in the interval $1.56 \leq \gamma\vartheta_\pm \leq 3.13$.

Fig. 4. Dependence of the ratio of cross sections at $\varphi_+ = 0$ and $\varphi_+ = \pi/2$ upon $\Delta\phi/\beta$. The cross sections are integrated over φ_- in the wedge interval (curve a) and outside the wedge interval (curve b). Curves are calculated in the case of $\Delta\varphi = 0$, $\varepsilon_+ = \varepsilon_- = \omega/2$ and $1.56 \leq \gamma\vartheta_\pm \leq 3.13$ (cp. with curves a and b in Fig. 1.).

Fig. 5. The ratio of cross-sections $d\sigma(\varphi_+)$ as in Fig. 4. but now -$\Delta\varphi \leq \Delta\varphi$ ($\Delta\varphi/\beta = 1.98$). Curve 1 for $0 \leq \varepsilon_\pm \leq \omega$ and $1.56 \leq \gamma\vartheta_\pm \leq 3.13$. Curve 2 for $0.475\omega \leq \varepsilon_\pm \leq 0.525\omega$ and $1.56 \leq \gamma\vartheta_\pm \leq 3.13$. Curve 3 for $\varepsilon_+ = \varepsilon_- = \omega/2$ and $1.56 \leq \gamma\vartheta_\pm \leq 3.13$.

Table 1.

	$0 \leq y \leq 1$ $0 \leq \alpha \leq 55$	$0 \leq y \leq 1$ $1.17 \leq \alpha \leq 3.9$	$0.475 \leq y \leq 0.525$ $0 \leq \alpha \leq 55$	$0.475 \leq y \leq 0.525$ $1.17 \leq \alpha \leq 3.9$
$N_{\parallel}(k=5)$	138431	59224	7258	4172
$N_{\perp}(k=5)$	113550	45098	5264	2738
A	9.87%	13.54%	15.24%	20.75%
$\Delta A/A$	$\pm 2\%$	$\pm 2.31\%$	$\pm 5.68\%$	$\pm 5.92\%$
$N_{\parallel}(k=8)$	87469	37426	4623	2681
$N_{\perp}(k=8)$	71322	28248	3220	1658
A	10.17%	13.98%	17.89%	23.58%
$\Delta A/A$	$\pm 2.48\%$	$\pm 2.82\%$	$\pm 6.41\%$	$\pm 6.62\%$

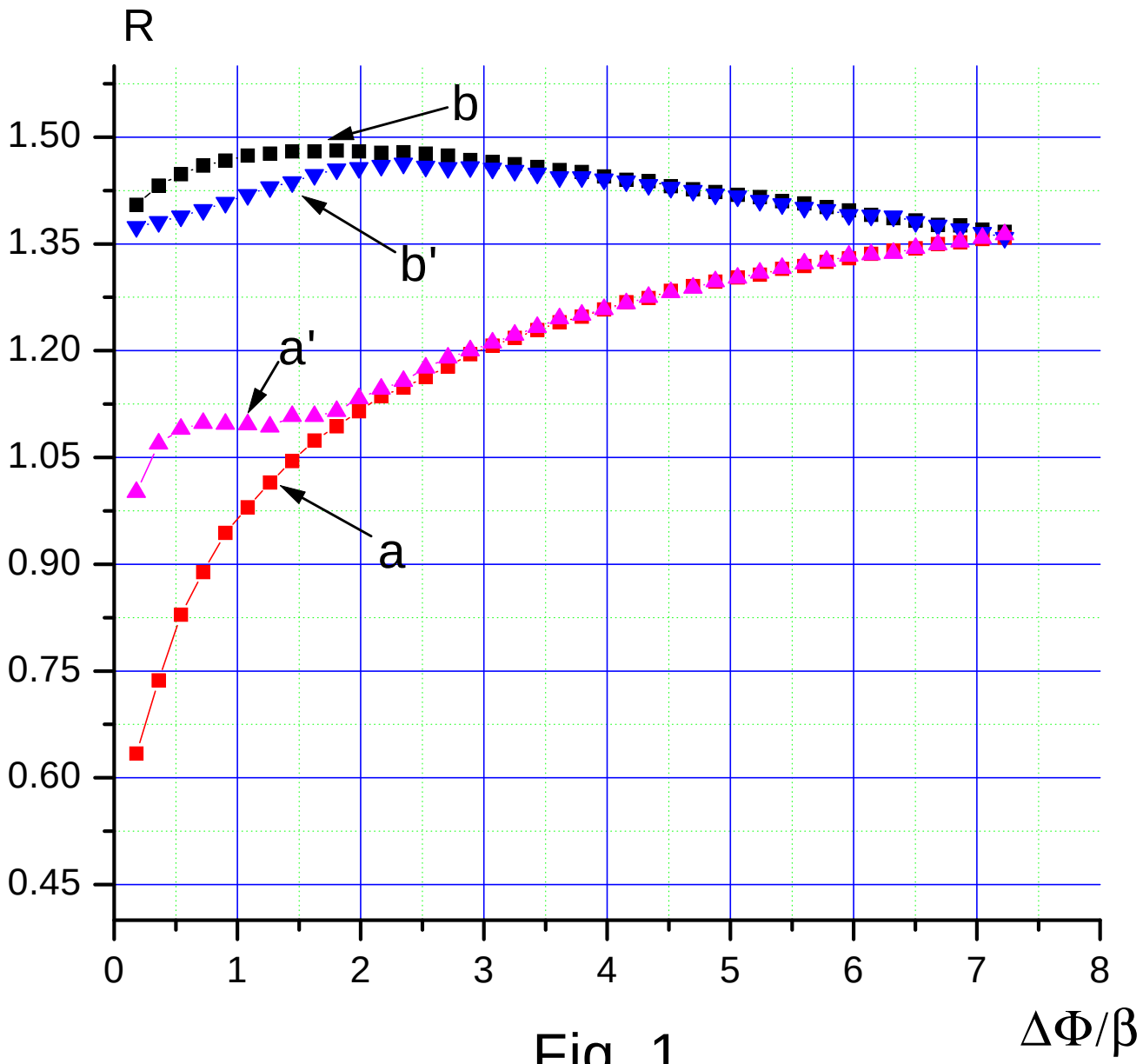
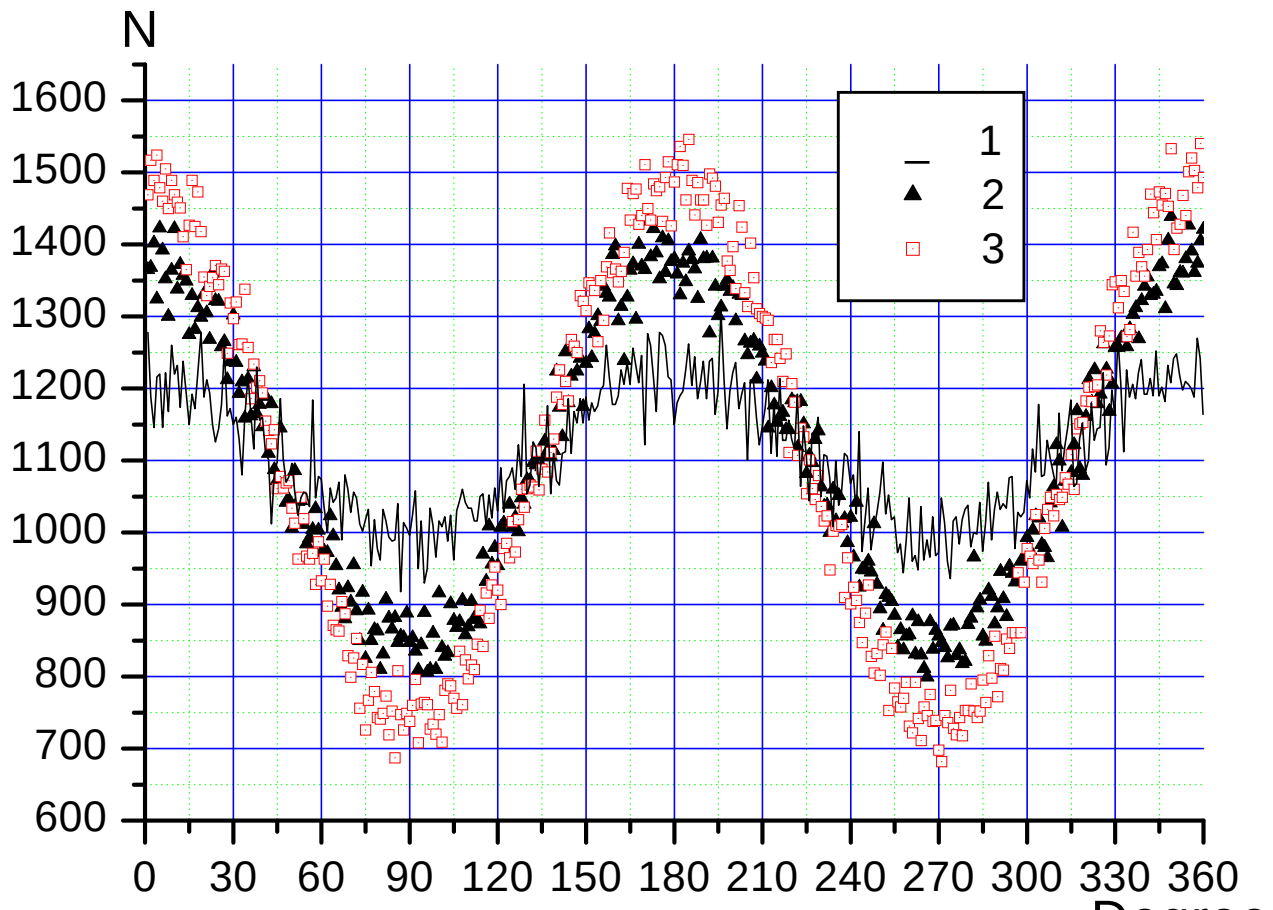


Fig. 1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Degree
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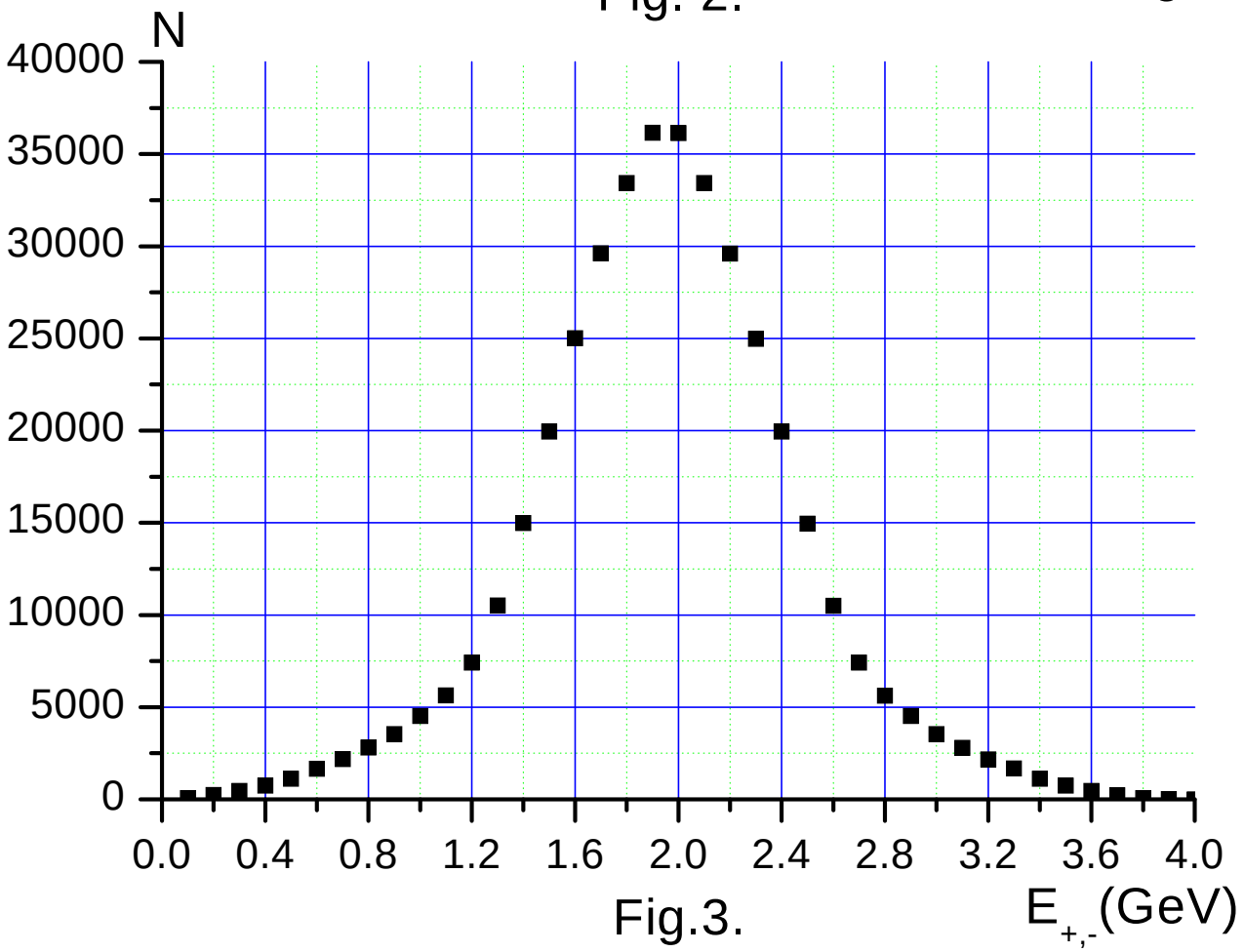
Fig. 2.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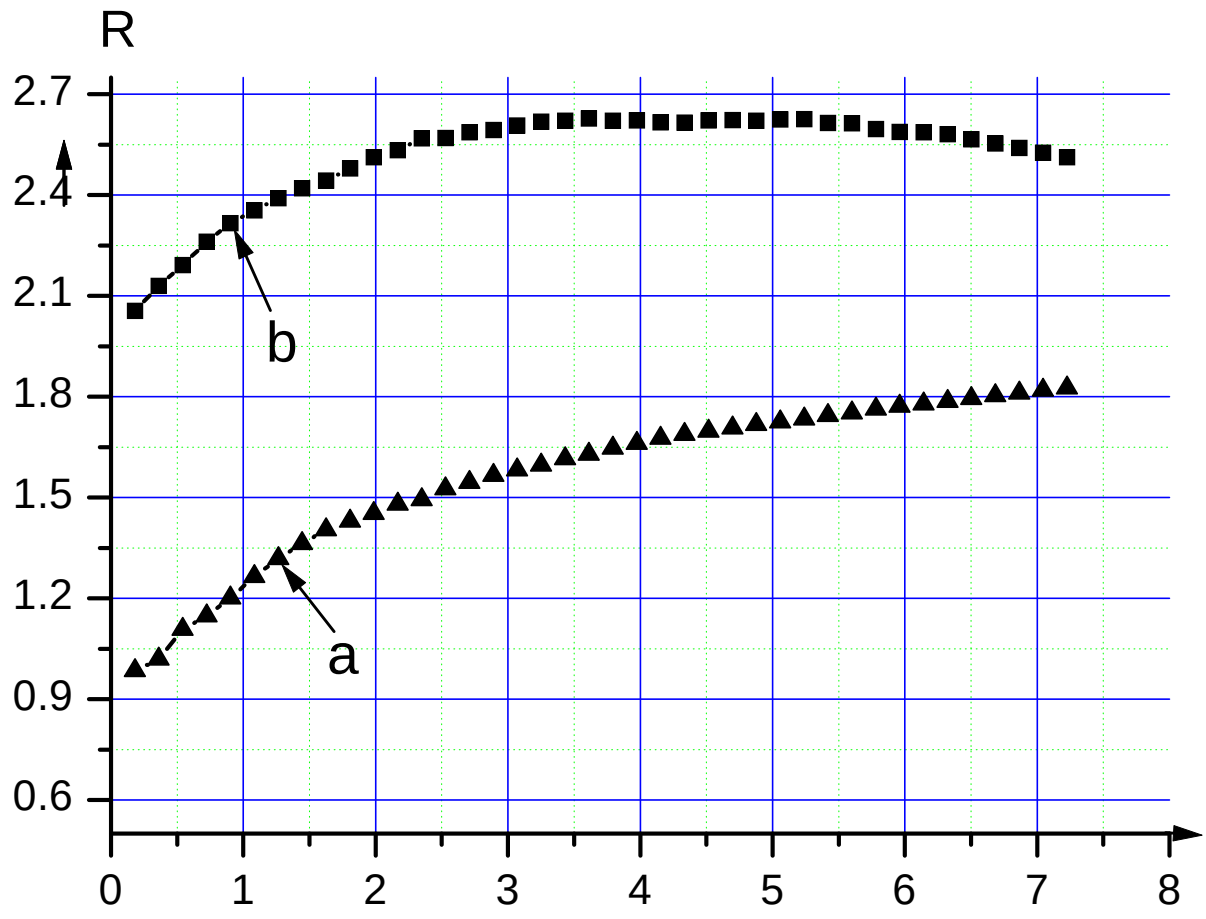
E+,- (GeV)

Fig.3.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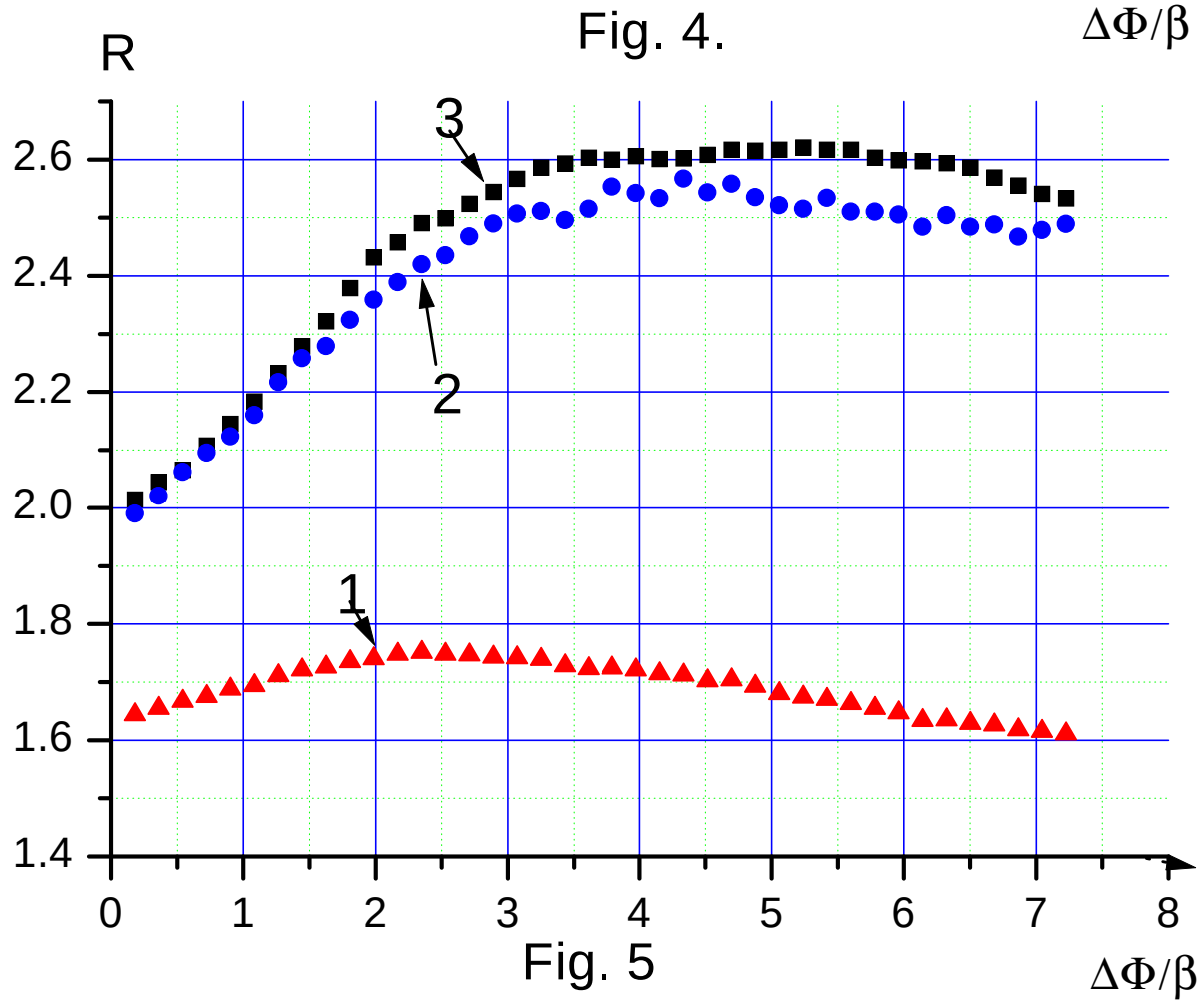
ΔΦ/β

Fig. 4.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ΔΦ/β

Fig. 5