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A STUDY OF THE TWO-PHOTON INTERACTIONS TAGGED AT AN AVERAGE $\langle Q^2 \rangle$ OF 90 GeV^2

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Multihadronic tagged two-photon events were used to make a preliminary measurement of F_2^γ. The 102.7 pb^{-1} integrated luminosity data were unfolded to correct the data on the experimental effects. The measured F_2^γ agrees well with the predictions based on the naive quark-parton model and QCD as well. The result on the Q^2 evolution of the photon structure function is presented.

The investigation has been performed at the Laboratory of High Energies, JINR.

Измерение двухфотонных взаимодействий при среднем значении $\langle Q^2 \rangle = 90$ ГэВ^2

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Мультиадронные двухфотонные события (специально отобранные) использовались для измерения функции F_2^γ. Экспериментальные данные, соответствующие интегральной светимости 102,7 пб$^{-1}$, были скорректированы с помощью процедуры анфолдинга для учета эффектов экспериментальных искажений. Измеренное значение хорошо согласуется с предсказанным на основе наивной кварк-партонной модели и КХД. Представлен также результат Q^2-эволюции структурной функции фотона.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

The reaction $e^+e^- \to e^+e^-X$, where X is a multihadronic system produced by the collision of two photons coming from the beam particles, was studied under experimental conditions, where one of the scattered leptons was detected (tagged) in the Forward ElectroMagnetic Calorimeter (FEMC) of the DELPHI set-up (Figure 1). Another scattered lepton was undetected and corresponding photon could be assumed to be almost on-shell

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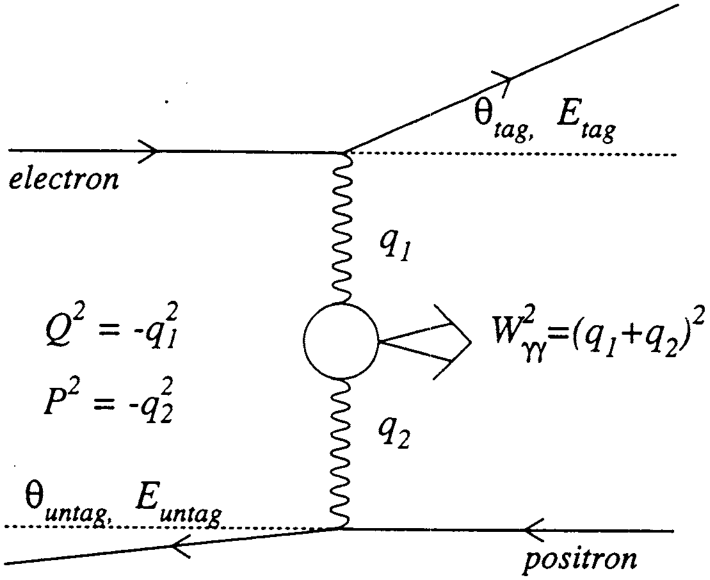

Fig.1. Feynman diagram of two-photon interaction

($q_2^2 \simeq 0$). If the transferred four-momentum q_1 is large enough, the process is viewed as the deep inelastic scattering (DIS) of the tagged lepton off the quasi-real target photon.

The cross section of the process is:

$$\frac{d\sigma}{dE_{\text{tag}} d\cos(\theta_{\text{tag}})} = \frac{4\pi\alpha^2 E_{\text{tag}}}{Q^4 y} [(1+(1-y)^2)F_2^\gamma(x, Q^2) - y^2 F_L(x, Q^2)] \quad (1)$$

with

$$y = 1 - E_{\text{tag}}/E_b \cos^2(\theta/2),$$

$$x = \frac{Q^2}{Q^2 + W_{\gamma\gamma}^2},$$

$$Q^2 = 4E_{\text{tag}}E_b \sin^2(\theta_{\text{tag}}/2).$$

E_{tag} and θ_{tag} are the energy and scattering angle of the tagged lepton, respectively; E_b is the beam energy; $W_{\gamma\gamma}$ is the invariant mass of produced hadron system; $F_2(x, Q^2)$ and $F_L(x, Q^2)$ are structure functions. Experimentally, a scattered lepton is tagged in FEMC at relatively large angles. Taking into account that $\langle y \rangle \simeq 0.15$ under experimental conditions, the cross section of the process is defined mainly by the structure function F_2^γ.

The theoretical basis of the photon structure function can be found elsewhere [1], the technique of the experiment on F_2^γ measurement is described in [2,3]. F_2^γ is the unique object. It is described in the perturbative QCD with high accuracy without any phenomenological assumptions. This fact isolates F_2^γ among other objects of hadron physics (including the proton structure function) and determines importance of any new results of its experimental study.

F_2^γ cannot be directly measured, since a part of produced hadrons escapes undetected in and around beam pipe so that the detected $x_{\rm vis}$ distribution must be unfolded to a produced $x_{\rm true}$. The unfolding algorithm is described in [4]. Tests of a relevant program realizing this algorithm are presented in [2]. They have shown that the DELPHI experimental conditions allow one to reach a stable unfolded result.

A detailed description of the DELPHI detector is given in Ref. [5]. Here we mention that the Forward ElectroMagnetic Calorimeter (FEMC) is located from 10 (143.5) to 36.5 (170) degrees of polar angle and the calorimeter consists of two 5 m diameter disks of a total of 9064 lead glass blocks. In order to select two-photon events tagged in FEMC, the following selection criteria have been used:

- There is a cluster of adjacent FEMC blocks with energy deposition greater than 30 GeV, while there is no cluster with energy greater than 15 GeV in the opposite arm of FEMC;
- There is no particle detected in the DELPHI luminosity monitor with the energy greater than 20 GeV;
- At least 3 charged tracks with momentum greater than 0.4 GeV and polar angles θ between 20° and 160° are required. The error in the momentum has to be less than 100%, while the impact parameter has to be smaller than 4 cm in $R\phi$ and 10 cm in z;
- The invariant mass W of the system (excluding tagged cluster) has to be greater than 2.0 GeV. W has been calculated using the pion mass assumption for charged particles and the zero mass for neutrals detected in HPC (threshold was set to 1 GeV) and FEMC (0.5 GeV threshold).

In order to remove the background coming from Z^0 produced events the additional criteria were used:

- variables* NTMB ≤ 0.2 and NLMB ≥ 0.6;
- the sum of charged particle momenta in the event was lower than 20 GeV;
- the polar angle of the tagged cluster was below 17 degree;
- the thrust (excluding the tagged cluster) was required to be smaller than 0.99.

It was checked that there was no essential disagreement between 1991–1994 data. The data were united into one sample. The requirement of the large energy cluster in the FEMC results in the efficiency to trigger $\gamma\gamma$ events to be close to 100%.

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*Normalized Longitudinal Momentum Balance (NLMB) and Normalized Transverse Momentum Balance (NTMB) are defined as follows:

$$\mathrm{NLMB} = \mathrm{sign}\,(p_z^{\rm tag})\,\frac{p_z^{\rm tag} + \Sigma_i p_z^{i,\rm hadron}}{E_b} \qquad (2)$$

$$\mathrm{NTMB} = \frac{\left|\left|\mathbf{p}_{T,\rm tag} + \Sigma_i \mathbf{p}_{i,\rm hadron}\right|\right|}{E_b}. \qquad (3)$$

On applying the above cuts, there were selected 192 events at the average $Q^2 \simeq 90$ GeV^2. The background from the Z^0 produced events estimated to be (16 ± 3) events, while the other sources of the background like τ pair production (both in two-photon and annihilation reactions), Bhabha events and beam-gas interactions were estimated as negligible.

A two-component model was used for the $\gamma\gamma$ event simulation. The naive quark parton model (QPM) describes a perturbative term of the process, where a photon splits into a quark pair (the point-like term). QCD corrections in leading order were included as calculated in the paper [6] based on Field–Kapusta–Poggioli approach [7] (the so-called FKP parametrization of the photon structure function) for light quark production. The non-perturbative part describing a bound state in the photon-quarks coupling (the hadron-like term) was introduced through generalized vector dominance model (GVDM). The study of F_2^γ improves the understanding of the transition region between perturbative and non-perturbative regimes of the two-photon interactions.

The TWOGAM $\gamma\gamma$ event generator [8] was used to produce quark pairs, while the JETSET7.3 string fragmentation scheme was used for the fragmentation of the produced quarks. The generated events were passed through the DELPHI detector simulation program and then through the reconstruction program developed for the real data processing.

The influence of radiative corrections on the target two-photon process was studied by comparing differential distributions and total cross sections obtained with TWOGAM event generator (without corrections) and BDK generator [9] (which takes into account the initial/final state radiation). The effect of the corrections was found below 2%, which value is small compared to the statistical errors in experimental data.

Comparison of data distributions and simulations for the charged multiplicity, invariant mass of the hadronic system, energy of the target lepton, charged particle transverse momentum, Q^2 and x_{vis} is shown in Figures 2(a–f), respectively. The data distributions are shown by bars, while solid (dashed) histograms represent the simulation of QPM + GVDM + remaining background of Z^0 (QCD + GVDM + Z^0) events. The contribution of the Z^0 produced events is shown on each plot by hatched histogram. Numerical values of the model predictions are (84 ± 6) for QPM (light quarks), (93 ± 5) for the QCD corrections (the production of light quarks), (43 ± 4) for the charm contamination and (47 ± 3) for GVDM.

The satisfactory agreement between the data and simulated distributions shows that the two-component model is good enough to be used for both the unfolding of the data and the measurement of F_2^γ. Let us remind that the simulation of the events generated with an input $F_2^\gamma(x)$ is used to get the correlation between «visible» and «true» x values. The details of how it works can be found in [2].

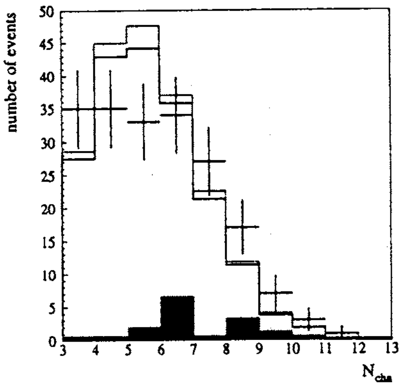

Fig.2a. Charged multiplicity

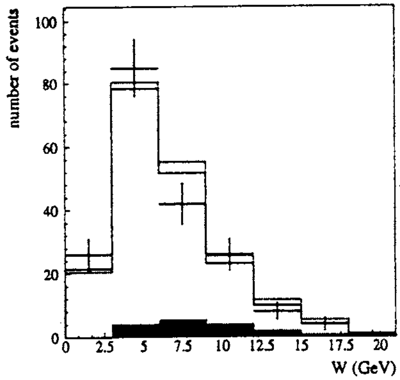

Fig.2b. Invariant mass

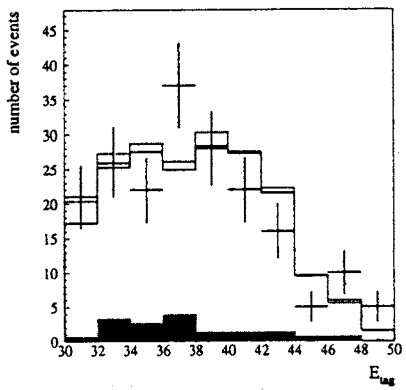

Fig.2c. Tagged particle energy

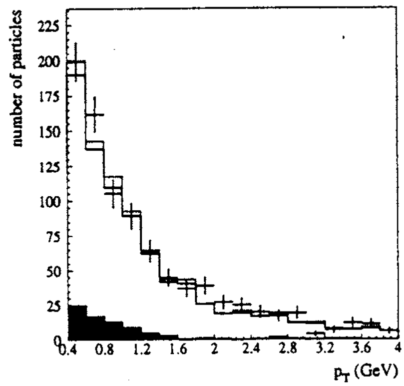

Fig.2d. Charged particle transverse momentum

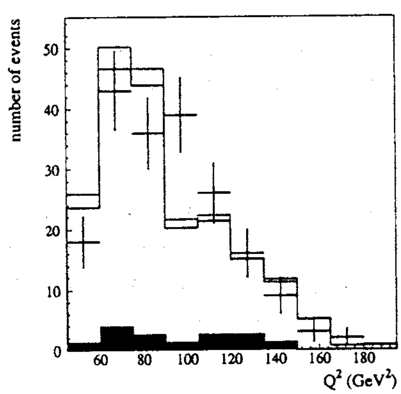

Fig.2e. Q^2

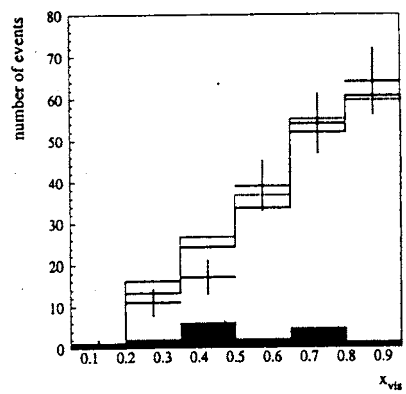

Fig.2f. x_{vis}

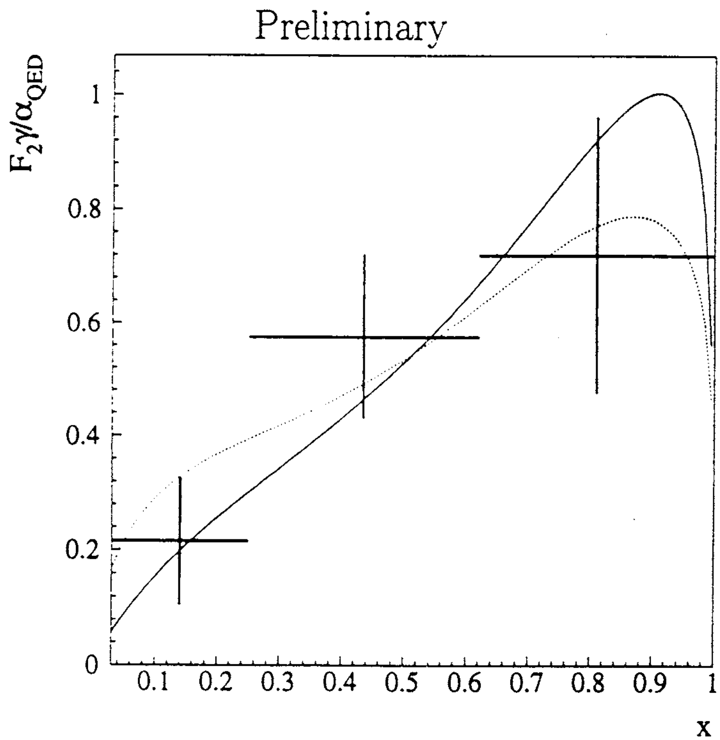

Fig.3. Unfolded F_2^γ for light quarks

The unfolded F_2^γ for the light quarks* is presented in Figure 3 together with F_2^γ dependence within the framework of QPM (QCD) drawn by solid (dashed) line. Within the measurement errors, F_2^γ agrees with both naive quark-parton model predictions and QCD based calculations as well.

The present measurement allows one to check QCD prediction on Q^2 evolution of the F_2^γ. Figure 4 (adapted from [2]) shows F_2^γ averaged for x between 0.3 and 0.8 for the different mean values of Q^2.

One has to note that the present result is different from the obtained earlier for the mean value Q^2 equal to 12 GeV^2 [2]. The latter measurement has shown that the QPM based prediction underestimates the visible cross section (number of selected events) at lower values of Q^2. Moreover the QCD based prediction, being in agreement with the data on the number of selected events, has shown a marked difference in the charged multiplicity

*The charm quark contamination was considered as a background and subtracted from the data according to the QPM prediction.

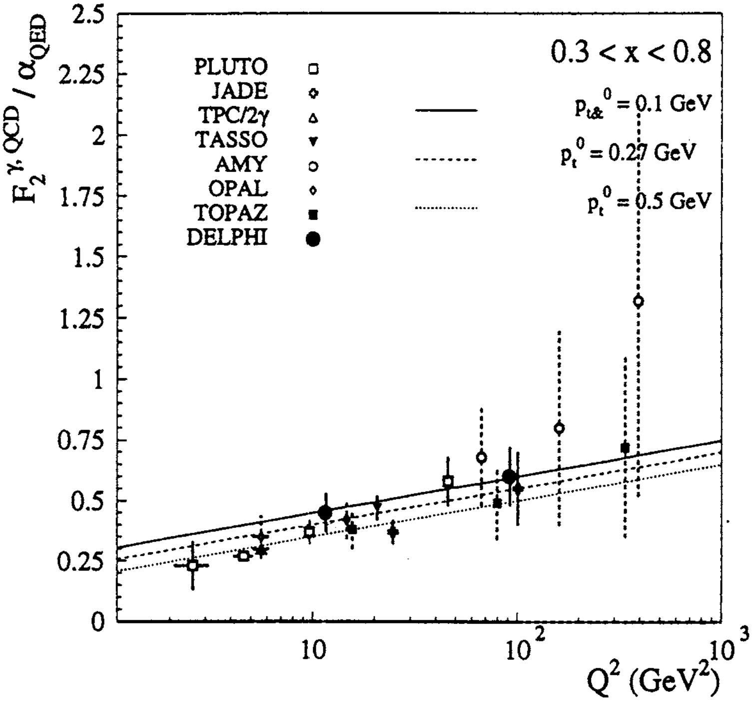

Fig.4. Q^2 evolution of F_2^γ averaged between 0.3 and 0.8 of x. The lines show QCD predictions with different phenomenological values of the cutoff parameter p_t^0 [6,7] — the transverse momentum of a quark inside the target photon

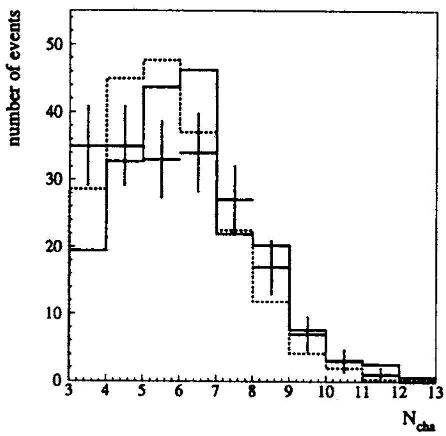

Fig.5a. Charged multiplicity distributions for the FEMC target events

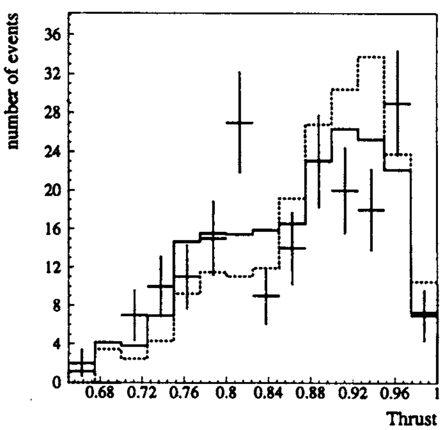

Fig.5b. Thrust distributions for the FEMC target events

distributions for both data and simulation. It was mentioned [2] that such difference comes from the gluon emission for small x. The present analysis is less sensitive to the low x behaviour of F_2^γ since most of the selected events come form the x domain greater than 0.1. Thus we consider the present result as an indirect proof of the effect of the gluon emission on the produced multihadronic final state.

Here we present the preliminary results of the use of HERWIG event generator [10] for DIS in an $e-\gamma$ mode. This generator emphasizes the perturbative description of jet evolution with some cluster model for fragmentation. Figures 5(a–b) show the distributions of the charged multiplicity of the data events (drawn by bars) and the simulation made with HERWIG (solid histogram) and TWOGAM (dashed) event generators. The HERWIG event generator gives higher multiplicities and, as a consequence, a smaller thrust, i.e., the detected invariant mass is shared between a larger number of particles.

In summary, the preliminary measurement of F_2^γ at the average Q^2 of 90 GeV ^{2} is presented. The result is consistent with the QCD based predictions for behaviour and Q^2 evolution as well. Two event generators, TWOGAM and HERWIG, were used for the comparison of the data and simulation events tagged in FEMC. The preliminary conclusion is that the HERWIG's approach for the description of the hadronic final state gives a better result. Additional work is needed for the study of systematic errors of the photon structure function measurement.

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