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STUDY OF SINGLE TAGGED MULTIHADRONIC $\gamma\gamma*$ EVENTS AT A $<Q^2> \cong 12$ GeV^2/c^4

DELPHI Collaboration

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1 Introduction

In the reaction $e^+e^- \to e^+e^-X$, where X is a multihadronic system produced by the collision of two virtual photons coming from the beam particles, one of the scattered leptons can be detected (tagged) at relatively large angles. Measuring the lepton energy E and scattering angle θ , the highly virtual photon squared momentum transfer is given $-Q^2 = -4EE_b\sin^2(\theta/2)$, where E_b is the beam energy. In these "single tag" events the other photon can be assumed to be almost on-shell, and the whole process is viewed as deep inelastic scattering of an electron off a quasi-real photon with a squared mass $-P^2 \simeq 0$. The corresponding cross section is, with $s = 4E_b^2$:

$$\frac{d\sigma}{dxdy} = \frac{4\pi\alpha^2 s}{Q^4}\left[(1+(1-y)^2)F_2^\gamma(x,Q^2) - y^2F_L(x,Q^2)\right]N_\gamma(z,\theta_{max})zdz \qquad (1)$$

where

$$y = 1-(E/E_b)\cos^2(\theta/2)$$
$$x = \frac{Q^2}{Q^2+W_{\gamma\gamma}^2}$$
$$z = \frac{E_\gamma}{E_b}$$

$N_\gamma(z,\theta_{max})$ describes the flux of target photons with energy E_γ [1], θ_{max} being the maximum scattering angle of the undetected electron and $Q^2/x = syz$.

Experimentally, since electrons are tagged at relatively small angles and high energies ($<y>\simeq 0.2$), we are only sensitive to $F_2^\gamma(x,Q^2)$.

Neglecting y, the deep inelastic scattering of an electron on a quasireal photon can be described through :

$$\frac{d\sigma}{dxdQ^2} = \frac{4\pi\alpha^2}{Q^4}\frac{F_2^\gamma(x,Q^2)}{x} \qquad (2)$$

A lot of previous experiments have studied the photon structure function at various Q^2 [2, 3, 4, 5], but LEP is offering a wider lever arm in Q^2 range and a higher $W_{\gamma\gamma}$ can be obtained, depending of course on the avalaible integrated luminosity.

In this paper we present a comparison of DELPHI data ,selected using SAT as the tagging detector, and VDM and QPM Monte Carlo predictions. These models are known to describe roughly the two photon processes for Q^2 above a few GeV^2.

In section 2 we sketch the photon structure function theoretical frame. Section 3 describes the data selection, while the background subtraction is disscussed in section 4. Finally in section 5 the results are presented.

2 Theoretical framework

The main interest in studying F_2^γ or $\sigma^{\gamma\gamma}$ in terms of total cross section comes from the fact that the photon exhibits a point-like coupling to quarks [6]. In the adopted terminology the direct contribution is described by QPM, if one forgets about the QCD corrections. It refers to the perturbative component where the p_T^2 of the quarks are greater than Q^2. For lower p_T^2, at least in a leading logarithm approximation, the photon parton content QCD evolution to the Q^2 scale has also to be taken into account. The target photon is then resolved in its constituents by the high Q^2 probe photon. Since the photon couples to vector meson bound states, this last contribution has to be added, using some physical hypothesis to avoid double counting. Moreover, since the quark p_T distributions are different in the two extreme domains [7], only a p_T or transfer cut can be used as an efficient tool for event generation over all the available phase space. But it impinges then on the F_2^γ sensitivity to Λ_{QCD} [8].

The double resolved contribution, where a high p_T^2 quark probes the structure of both photons is neglected here, due to the high Q^2 values considered here.

The fully non perturbative region is modelled through VDM [9] for example, defined by the formal relation :

$$\frac{F_2^\gamma(x,Q^2)}{\alpha} = \frac{Q^2}{4\pi^2\alpha^2}\sigma^{\gamma\gamma^*}(x,Q^2) \tag{3}$$

The final expression reads :

$$\frac{F_2^{\gamma VDM}}{\alpha} = \frac{Q^2}{4\pi^2\alpha^2}\left[A + \frac{B}{\sqrt{Q^2}}\sqrt{\frac{x}{1-x}}\right] F_{VDM}(Q^2)F_{VDM}(P^2) \tag{4}$$

with

$$F_{VDM}(Q^2) = \left[\sum_{V=\rho,\omega,\phi} r_V \frac{1+Q^2/4m_V^2}{(1+Q^2/m_V^2)^2} + \frac{0.22}{1+Q^2/m_0^2}\right] \tag{5}$$

where $A = 275\ nb$ and $B = 300\ nb * GeV$, which are roughly 10% higher than the standard Rosner formula values, m_V is vector meson mass and r_V is linked to the coupling constant of vector meson to the photon [10, 11]. The continuum term with $m_0 = 1.4\ GeV$ links to parametrizations of meson partonic densities.

The two photons are treated in a symmetric manner and VDM is then unambiguously defined.

The perturbative component is defined by QPM since we do not want to enter into a full QCD [12] description before unfolding the data.

For light quarks we get the following expression with an explicit target mass dependence and no p_T cut :

$$\begin{aligned} F_2^\gamma(x,Q^2,P^2) &= \frac{3x\alpha}{\pi}\sum_q e_q^4 \left[(x^2+(1-x)^2)\ln\left(\frac{Q^2(1-x)}{m_q^2 x + P^2x^2(1-x)}\right)\right. \\ &\left. + 8x(1-x) - 1 - \frac{P^2x(1-x)}{m_q^2 + P^2x(1-x)}\right] \end{aligned} \tag{6}$$

3 Event selection

Only the runs with a fully operational DELPHI detector were selected. The resulting integrated luminosity was $7.6 pb^{-1}$ and $18.4 pb^{-1}$ for 1991 and 1992 respectively.

The selection of single tag events relies on the detection of the scattered lepton in the Small Angle Tagger (SAT) and on the produced multihadronic final state. The Q^2 range goes from 4 to 30 GeV^2 with average of 12 GeV^2. From Monte Carlo were an average P^2 of 0.07 GeV^2 for QPM and 0.12 GeV^2 for VDM obtained.
The following selection criteria were used:

- At least 3 charged tracks with momentum larger than 0.4 GeV and polar angle θ between 20^0 and 160^0 were required. The error on the momenta had to be less than 100%, and the impact parameter smaller than 4 cm in $R\phi$ and 10 cm in z.

- Neutral particles are required to deposit at least 0.5 GeV in the Forward Electro-Magnetic Calorimeter (FEMC), 1.0 GeV in the barrel electromagnetic calorimeter High-density Projection Chamber (HPC) and 1.0 GeV in the HAdron Calorimeter (HAC).

- For the tag lepton, we require more than 30 GeV in one arm of the SAT (energy resolution $\sigma/E = 5\%$ at 45.5 GeV) and the energy deposition in the other SAT arm is not greater than 10 GeV (the antitagging requirement). Let us introduce two dimensionless variables : Normalized Longitudinal Momentum Balance

$$NLMB = sign(p_z^{tag})\frac{p_z^{tag} + \sum_i p_z^{i,hadron}}{E_{beam}} , \tag{7}$$

  and Normalized Transverse Momentum Balance

$$NTMB = \frac{\| \vec{p}_{T,tag} + \sum_i \vec{p}_{i,hadron} \|}{E_{beam}} \tag{8}$$

  Fig.1a shows the distribution of NTMB *vs* NLMB, where 10 GeV was used as a minimum energy of the tagged particle. The domain below 0.6 on the NLMB axis is background. Fig.1b shows the same distribution for the case where the minimum tagged particle energy was set to 30 GeV, while Fig.1c shows the Monte Carlo distribution. The choice of 30 GeV as a minimum for the tagged particle energy allows us to reduce the background and to simultaneously keep $< y >$ at a small value.

- The radial position of a shower in SAT is determined as the energy baricenter of hit sectors. In order to avoid edge effects, events were rejected if the reconstructed radius of the tagged particle was in the last ring.

- To avoid the resonance regions and problems with fragmentation reliability, the invariant mass of the hadron system was requested to be greater than 2 GeV.

After the selection we had 274 and 634 data events from 1991 and 1992 respectively.

The trigger study was based on single charged track trigger efficiencies in the forward and barrel regions [13]. It was checked by MC events that the efficiency to trigger $\gamma\gamma^*$ events was greater than 95 %.

4 Background rejection

4.1 The background from the Z^0

A 370000 Z^0 (12 pb^{-1}) MC hadronic event sample was processed taking into account the above selection criteria and only 20 events passed them. Most of those events had a large neutral component. To reject also these events, the following cuts on neutral energy were added:

- The energy deposition is lower than 5 GeV in FEMC and HPC. Fig.2 shows this distribution before the cut above.
- The energy deposition is lower than 10 GeV in hadron calorimeter;
- The invariant mass of the hadron system is below 8 GeV.

The background due to accidental coincidences of a signal in the SAT, coming from an off-momentum electron, with a Z^0 or an untagged $\gamma\gamma$ event can be decreased using the angle $\alpha_{R\phi}$ in the $R\phi$ plane between the $\vec{p}_T$ of the tagged particle and the $\vec{p}_T$ of the multihadronic system. Requiring that the total transversal momentum of the hadron system

- $p_T^{hadr} > 1\ GeV$

the cut

- $\alpha_{R\phi} > 2.8\ rad$

has been applied. These cuts reduce the background from Z events, especially those with a large neutral component, to less than 0.2 pb.

The background from the $Z^0 \rightarrow \tau^+\tau^-$ channel (where one τ decays into an electron and the other one into "3 prongs" hadrons) was negligible.

4.2 Other sources of a background

The contribution from $\gamma\gamma^* \rightarrow \tau^+\tau^-$ has been estimated using the NOT generator [14] and was found to be at a level of 0.5 pb. To remove this contamination the additional cut was used:

- The thrust of the hadrons is lower than 0.99

which decreases the $\tau^+\tau^-$ background to 0.2 pb and also to remove the events with energy photon conversion.

In order to determine the contamination of beam-gas events, the sidebands between 10 and 30 cm of the z impact parameter distribution were used. The beam-gas events were assumed to be uniformly distributed along Z. Their weight being 0.5, and since 5 events have been found in the above interval, the contamination from beam-gas events is then estimated to be of 2.5 events (0.1 pb)

The contribution from inelastic Compton events should be negligible [15].

5 Comparison of data and Monte Carlo

A two component model QPM and VDM was used for the $\gamma\gamma$ events simulation. NOT event generator [14] was used with default parameters, while JETSET7.3 program was used for fragmentation. The VDM multihadronic final system was generated as a $q\bar{q}$ system according to a quark $d\sigma/dp_T^2 \simeq \exp(-5p_T^2)$ distribution in the $\gamma\gamma$ center of mass system and fragmented 'a la JETSET7.3 with $\sigma_q =$ 450 MeV/c (the width of Gaussian transverse momentum distribution for primary hadrons) .

The following table gives the cross section σ_{tot} when one of the scattered lepton is within the angular range of the SAT, $\sigma_{vrtxcut}$ after the charged multiplicity cut but before detector simulation and σ_{cuts} after detector simulation and all cuts.

cross section in pb	VDM	QPM
σ_{tot}	142	113
$\sigma_{vrtxcut}$	62	50
σ_{cuts}	5	7

Figures 3 to 11 show the distributions for selected real data and absolutely normalized combined QPM and VDM $\gamma\gamma^*$ Monte Carlos (dashed) and QPM only (dotted). The agreement to the data is then reasonable. In figure 12, W_{vis}/W_{true} quantifies the effects of the detector acceptance and resolution, while the x_{vis}/x_{true} correlation is shown in fig.13.

6 Conclusions

Two photon single tagged events are shown to be selected with less than 5% of background. They are in qualitative agreement with the sum of two models: QPM and VDM, describing the point-like and bound state behaviours of the photon to quarks ccupling since the relatively high $< Q^2 >$ of 12 GeV^2 allows a dominant deep inelastic $e\gamma$ description.

QCD testing is foreseen through F_2^γ unfolding [16].

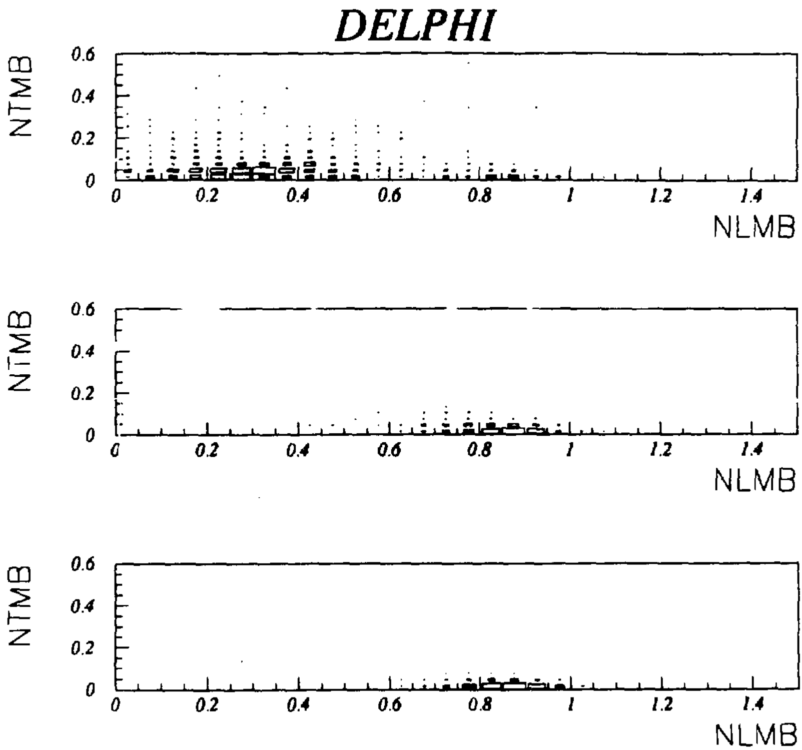

Figure 1: Data distribution NTMB and NLMB indroduced in section 3 for the tagged particle energy minimum is equal 10 *GeV* (a), the same for 30 *GeV* (b) and two-photon Monte Carlos for 30 *GeV* (c)

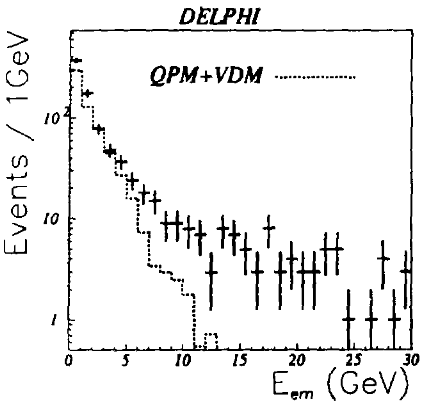

Figure 2: Energy deposition in electromagnetic calorimeters compared with QPM+VDM. The selection described in section 3 is used only.

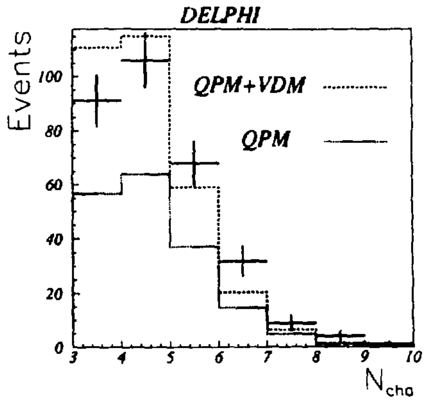

Figure 3: Charged multiplicity

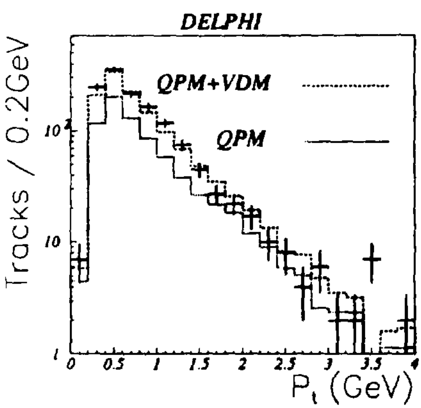

Figure 4: Inclusive transverse momentum for charged particles with respect to the beam axis.

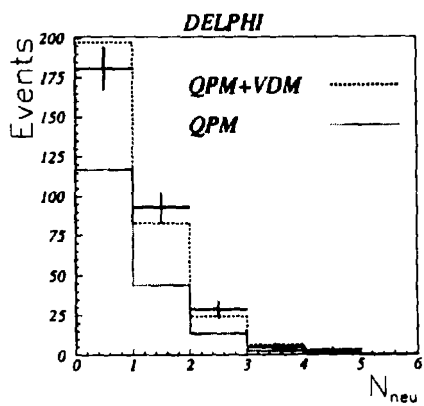

Figure 5: Neutral multiplicity

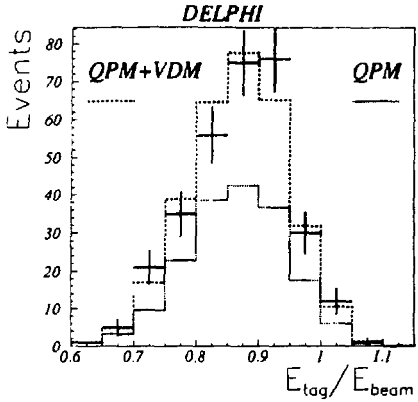

Figure 6: Normalized energy of tagged particle.

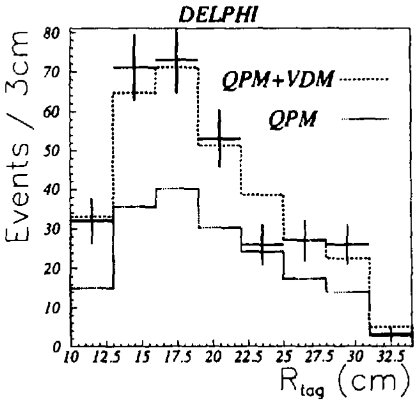

Figure 7: Reconstructed radius (cm) of tagged particle.

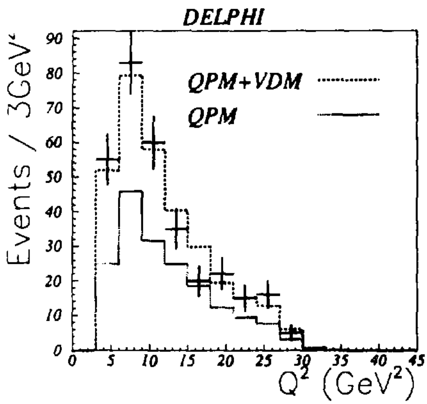

Figure 8: Q^2 distribution. The mean value of Q^2 is 12 GeV^2.

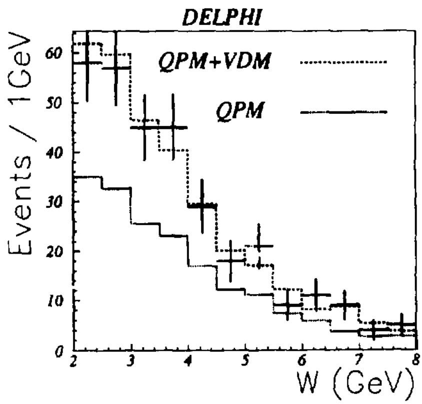

Figure 9: Distribution of the invariant mass calculated using charged and neutral particles.

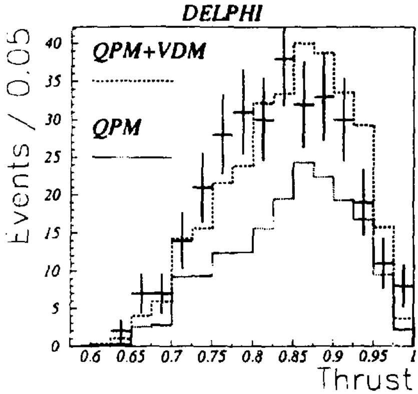

Figure 10: Thrust distribution

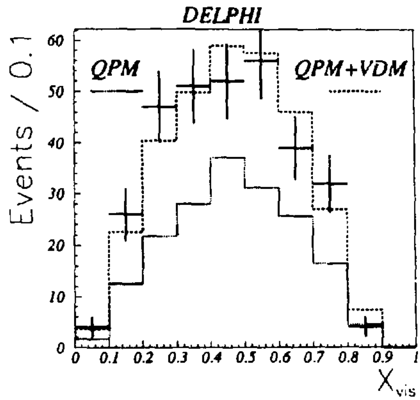

Figure 11: The distribution of X_{vis} value calculated using charged and neutral component of hadron system.

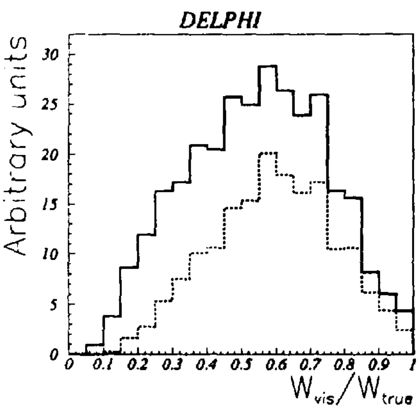

Figure 12: Ratio of the visible invariant mass to the true invariant mass for Monte Carlos (QPM term is dashed). The mean value is equal 0.53 and standart deviation is 0.21.

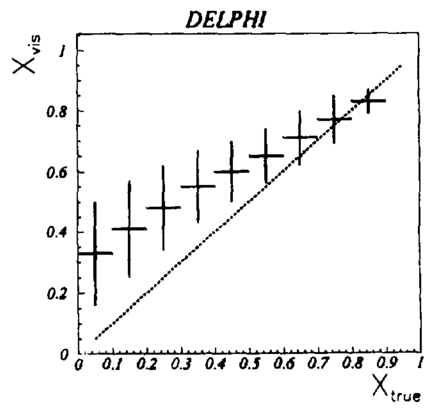

Figure 13: Correlation between X_{true} and X_{vis}. The error bar is the standart deviation for the $X_{visible}$ distribution within X_{true} bin. The line shows the correlation for a perfect 4π detector.

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Батюня Б. и др. E1-93-458
Изучение тагируемых мультиадронных $\gamma\gamma*$-событий
при $<Q^2> \cong 12$ ГэВ^2/с^4

Анализ двухфотонных событий с тагированием электрона или позитрона проводился для мультиадронного канала. Экспериментальные данные, соответствующие интегральной светимости 26 pb^{-1}, сравнивались с предсказанием двухкомпонентной модели, включающей обобщенную модель векторной доминантности (ВДМ) и кварк-партонную модель (КПМ), описывающие непертурбативный и пертурбативный процессы соответственно. Полученное согласие экспериментальных и моделированных данных является первым шагом перед применением процедуры анфолдинга для данных эксперимента и дальнейшей проверкой предсказаний КХД.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Batyunya B. et al. E1-93-458
Study of Single Tagged Multihadronic $\gamma\gamma*$ Events
at a $<Q^2> \cong 12$ GeV^2/c^4

An analysis of single tagged two photon events was performed in the multihadronic channel. Data corresponding to a 26.0 pb^{-1} integrated luminosity was compared to a two component model prediction: a generalized Vector meson Dominance Model (VDM) for the non perturbative part and a Quark Parton Model (QPM) describing the perturbative regime. The obtained reasonable agreement between data and MC is the first step before unfolding the data and testing QCD.

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

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