Study of the hadronic $\gamma\gamma$ interactions at $\sqrt{s} = 200$ GeV

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Abstract
A comparison between real data and Monte Carlo is presented, based on a data sample corresponding to the 84.3 pb$^{-1}$ recorded by the DELPHI detector in 1999, at centre-of-mass energy of 200 GeV. Two hadronic $\gamma\gamma$ generators have been used for this present analysis, TWOGAM 2.04 and PYTHIA 6.143.
1 Introduction

The $\gamma\gamma$ interactions represent a large fraction of events observed at LEP2, with the visible cross-section of the order of nanobarns. The overall description of observed $\gamma\gamma$ events has to interface the exact (generally LO) calculations of ‘hard’ processes (with a relatively large momentum transfer) with an appropriate phenomenological modelling of soft interactions. Obviously, the models cannot be more precise than the current understanding of the soft QCD, and much more work is needed both on theoretical and experimental side in order to reduce the intrinsic uncertainty of the simulation.

Recently, a major improvement of the modelling scheme was implemented in the general-purpose generator PYTHIA [1]. The comparison of the prediction of this scheme with data taken both at ep and $e^+e^-$ colliders is of a special interest for theorists and experimentalists likewise, providing a feedback for further development of the model.

In the present note, a comparison between the real data collected at a centre-of-mass energy of 200 GeV and the SM expectation is performed using the PYTHIA version 6.143 and the default DELPHI generator TWOGAM 2.04 [2].

2 Detector description

DELPHI is a general purpose detector with a magnetic field of 1.2 T provided by a large superconducting solenoid. The detector and its performance are described in [3]. The main tracking device is the Time Projection Chamber (TPC). Other tracking devices used to reconstruct charged particle tracks at large angles with respect to the beam axis (‘barrel region’) are the Vertex Detector, the Inner Detector (ID) and the Outer Detector. For particles emerging at smaller angles (‘forward region’), the forward drift chambers (FCA and FCB) supplement the TPC and the ID for track reconstruction. The electromagnetic calorimeters in the forward region are the Forward Electromagnetic Calorimeter (FEMC), an array of lead glass blocks covering the polar angular regions $8^\circ < \theta < 35^\circ$ and $145^\circ < \theta < 172^\circ$, and the STIC, a sampling electromagnetic calorimeter which covers the angular regions $1.7^\circ < \theta < 10.6^\circ$ and $169.4^\circ < \theta < 178.3^\circ$. The High density Projection Chamber (HPC), the electromagnetic calorimeter in the barrel, covers the angular range $43.1^\circ < \theta < 88.7^\circ$ and $91.3^\circ < \theta < 136.9^\circ$. The HPC has a total of 144 modules, each radially segmented into 9 layers. Photon detection in the regions between the electromagnetic calorimeters is achieved using information from dedicated taggers and other detectors. The $40^\circ$ taggers are a series of photon counters, each consisting of 2 cm of lead followed by a layer of scintillator, used to veto photons that could otherwise be missed in the $\theta$ regions near $40^\circ$ and $140^\circ$ between the HPC and FEMC. Similar taggers are installed at polar angles $88^\circ - 92^\circ$, between the two halves of the HPC. The Time of Flight detector (TOF), consisting of a single layer of 172 scintillation counters just outside the solenoid and covering the polar angular region $41^\circ < \theta < 139^\circ$, helps to increase the hermeticity in the regions in azimuthal angle between the modules of the HPC. The few azimuthal regions not covered by the TOF are equipped with another set of counters similar to the $40^\circ$ taggers. Using data taken at the Z resonance (LEP 1 data), it has been shown that the total photon detection efficiency of DELPHI is above 99% for photons of more than 5 GeV in the range $20^\circ < \theta < 160^\circ$ [4].

The hadron calorimeter (HCAL) is segmented radially into 4 layers and covers 98%
of the solid angle. Muon identification uses chambers placed between the third and the fourth HCAL layer and outside the fourth layer, covering nearly all the solid angle.

3 Data samples and event generators

The total integrated luminosity collected by DELPHI during 1999 at $E_{cm} = 200$ GeV is $84.3 \text{ pb}^{-1}$. This luminosity is used in the present analysis.

In the study presented in this note, the reference hadronic $\gamma\gamma$ Monte-Carlo samples were generated with PYTHIA version 6.143 and TWOGAM version 2.04 [2]. PYTHIA works with the SaS parameterization of the parton density of the photon, the GRS-LO parton density was used in TWOGAM. The default setup of JETSET fragmentation parameters was used for both generators. Calculation of the photon flux in TWOGAM includes radiative corrections. In order to reduce amount of events generated beyond the acceptance of the detector, the following cuts were applied at the generator level:

- minimal invariant mass of the $\gamma\gamma$ system is 3 GeV
- minimal transverse energy at the generator level is 3 GeV
- (PYTHIA only) at least 3 charged tracks in the acceptance of the detector (momentum above 0.1 GeV, polar angle above 10 degrees) required

Generated events were retained in the sample if the beam electron (positron) was scattered at the angle above 2 degrees while carrying at least 40% of its original energy (tagged events).

Other processes have been used in order to compute the exact SM expectation with the following samples:

- The background process $e^+e^- \rightarrow q\bar{q} \ (n\gamma)$ was generated with PYTHIA 5.7[5], while KORALZ[6] was used for $\tau^+\tau^-\gamma(\gamma)$ and $\mu^+\mu^-\gamma(\gamma)$.
- The generator BHWIDE of reference[7] was used for $e^+e^- \rightarrow e^+e^-\gamma(\gamma)$ events. Due to the high cross-section of this process, the angle of the electron emission was required to be greater than nine degrees.
- Other radiative processes as Compton events, $e^+e^- \rightarrow \gamma\gamma(\gamma)$ (QED) and $e^+e^- \rightarrow \nu\bar{\nu}(\gamma)$ were also generated using the KORALZ program. Compton events were simulated by requiring $\theta_e > 10^\circ$, $\theta_\gamma > 10^\circ$ and photon and electron energies greater than one GeV. In the case of $e^+e^- \rightarrow \nu\bar{\nu}(\gamma)$, the angle of the photon emission was required to be $40^\circ < \theta_\gamma < 140^\circ$ and a photon energy above 4 GeV.
- For the simulation of four-fermion samples, the program EXCALIBUR[8] was chosen. The $W^+W^-\gamma(\gamma)$ -like process includes $Z^0Z^0\gamma(\gamma)$, $W^+W^-\gamma$, $W_\nu\gamma$ and $Ze^+e^-\gamma$ backgrounds. The EXCALIBUR version used in the analysis uses the ISR program QEDPS[9] from GRACE[10], $\tau$ decays via TAUOLA and final state radiation (FSR) via JETSET. It takes into account all amplitudes leading to a given four-fermion final state. EXCALIBUR does not, however, include the transverse momentum of initial state radiation in the case where electrons are present in the final state. The GR4F generator[11] was used for the single $W$ channel where the electron escapes through the beam pipe in the region $\cos \theta_e > 0.9999$, which is not covered by EXCALIBUR.
- The generators of Berends, Daverveldt and Kleiss (BDK and BDKRC)[12] were used for leptonic $\gamma\gamma$ final states.
All the generation programs rely on JETSET 7.4[5], tuned to LEP1 data[13], for quark fragmentation.

The generated background events were passed through the detailed simulation of the DELPHI detector and then processed with the same reconstruction and analysis programs as the real data.

4 Event selection

In a first step, reconstructed charged particles are required to have momenta above 100 MeV/c with $\Delta p/p < 1$, where $\Delta p$ is the momentum error, and impact parameter below 5 cm in the transverse plane and below $4 \text{ cm} / \sin(\theta_{\text{particles}})$ in the beam direction. Clusters in the calorimeters are selected as neutral particles if they are not associated to charged particles and if their energy exceed 500 MeV in the HPC, 400 MeV in the FEMC, 300 MeV in the STIC and 900 MeV in the HCAL.

In the second step of the selection, hadronic events are selected. First, simulated Monte-Carlo events are removed if they are not accepted by the DELANA event filter. Then, the transverse energy is required to be greater than 4 GeV. Events must contain at least 3 tracks reconstructed using the TPC, and at least one charged particle with transverse momentum greater than 1.5 GeV/c. Figures 1 and 2 show the comparison between data and simulation at this step of the selection. As the single-tag and double-tag parts of the gamma-gamma signal are hidden by QCD events $e^+e^- \to Z^0, \gamma \to q\bar{q}(n\gamma)$ and by hadronic four fermions processes, an additional cut is imposed to reduce those backgrounds. The transverse charged energy is thus required to be less than 20 GeV. Figures 3 and 4 show the comparison between data and Monte-Carlo after this last cut.

5 Comments, conclusions

The event selections shown in this note represent typical preselected samples for many analyses oriented on the search for signs of new physics and the discrepancy observed in these regions between TWOGAM and the real data (even if not really surprising because of relatively simple modelling of soft interactions) was a permanent source of preoccupation since the beginning of LEP2. The improved PYTHIA scheme seems to resolve major part of the problems in these regions, and the overall agreement with data is quite satisfactory. The observed difference in the total multiplicity is most probably related to the simulation of the detector effect, as the charged multiplicity is very well described. The tagged events seem to be better described by TWOGAM, which is probably due to the incomplete implementation of the model for DIS events in the version 6.143. Therefore, it would be useful to repeat the study with the version 6.147 or later, with a special attention paid to the tagged events.

References

and references therein.


Figure 1: Comparison between DELPHI data collected at 200 GeV and simulation at the loosest step of the selection. The hashed region include the hadronic $\gamma\gamma$ interactions simulated with PYTHIA 6.143 and all relevant background from other SM processes, while the black line is obtained using TWOGAM 2.04.
Figure 2: Comparison between DELPHI data collected at 200 GeV and simulation at the loosest step of the selection. The hashed region include the hadronic $\gamma\gamma$ interactions simulated with PYTHIA 6.143 and all relevant background from other SM processes, while the black line is obtained using TWOGAM 2.04.
Figure 3: Comparison between DELPHI data collected at 200 GeV and simulation after the cut $E_{ch}^\gamma \leq 20$ GeV. The hashed region include the hadronic $\gamma\gamma$ interactions simulated with PYTHIA 6.143 and all relevant background from other SM processes, while the black line is obtained using TWOGAM 2.04.
Figure 4: Comparison between DELPHI data collected at 200 GeV and simulation after the cut $E_{ch}^T \leq 20$ GeV. The hashed region include the hadronic $\gamma\gamma$ interactions simulated with PYTHIA 6.143 and all relevant background from other SM processes, while the black line is obtained using TWOGAM 2.04.