1 Measurement of inclusive $J/\Psi$ production in $\gamma\gamma$ events (DELPHI)

The measurement of $J/\Psi$ production in $\gamma\gamma$ interactions provides an insight into heavy quark production and also a possibility to study the gluon parton density of a resolved photon.

Selection of the signal is done in two steps. First, preselection of hadronic $\gamma\gamma$ events is performed, defining the “visible” region (visible inv.mass $W_{\text{vis}}$ below 35 GeV/$c^2$, charged multiplicity $4 \leq N_{\text{ch}} \leq 30$, transverse energy above 3 GeV, cuts ensuring high trigger efficiency). The preselected sample contains about 1.2% of $Z^0/\gamma^*$ background. Please note that requirement of at least 4 reconstructed tracks suppress the $J/\Psi + \gamma$ final state.

Next, the $J/\Psi$ signal is obtained requiring a pair of identified muons. The mass spectrum of the muon pair in the region of interest is shown in Fig.1a, with a clear $J/\Psi$ signal ($36 \pm 7$ events) on top of combinatorial $\gamma\gamma$ background. The fit of the mass spectrum gives $M = 3.119 \pm 0.008$ GeV/$c^2$, $\Gamma(\text{obs}) = 0.035 \pm 0.007$ GeV.

In order to learn more about the production mechanism (the absolute predictions of Pythia 6.156 fall well below (~20%) the observed production rate), the relative fraction of resolved and diffractive processes was fitted to the shape of the transverse momentum squared of the reconstructed $J/\Psi$. For this study, the shapes of Pythia distributions, with full detector simulation and event selection, were used. Fig.1b shows the best fit

$$\frac{dN}{dp_t^2} = f \cdot \frac{dN}{dp_t^2} |_{\text{Resolved}} + (1 - f) \cdot \frac{dN}{dp_t^2} |_{\text{Diffractive}},$$

$$f = (74.0 \pm 22.0)\%,$$

suggested the dominant contribution of resolved processes, in agreement with the expectation (the fit is obviously driven by the tail of the transverse momen-
tum distribution). Within the statistics available, the renormalized mixture of Pythia processes describes data reasonably well (including multiplicity and invariant mass of the recoiling system), and the simulated data can be used to correct the visible cross-section.

The production rate per preselected event, using $Br(J/\Psi \rightarrow \mu^+\mu^-) = (5.88 \pm 0.1)\%$, and the visible cross-section are estimated at

\[ <n> = N(J/\Psi) \cdot (N_{ev} \cdot Br \cdot \epsilon_{vis})^{-1} = (6.7 \pm 1.3) \times 10^{-3} \]

\[ \sigma_{vis}(\gamma\gamma \rightarrow J/\Psi + X) = N(J/\Psi) \cdot (Br \cdot \epsilon_{vis} \cdot L)^{-1} = 2.98 \pm 0.58 \text{ pb}. \]

Work is going on direct comparison with NLO calculations (in the experimentally accessible part of the phase space).

2 Search for $\eta_b$ in $\gamma\gamma$ events (ALEPH)

The search for $\eta_b$ (the ground $b\bar{b}$ state) in $\gamma\gamma$ interactions is motivated by the possibility of the exclusive production of this resonance ($J^{PC} = 0^{-+}$).

The mass of the $\eta_b$ should lie just below the $Y$ vector meson, and various calculations (lattice, potential model, ...) predict a range of 9.36-9.42 GeV.
The production rate ($\sim 0.222$ pb at $\sqrt{s} = 197$ GeV) was estimated using the Coulomb potential approach and the measured $\Gamma_{\gamma\gamma}(\eta_c)$. The data used for the analysis were collected by ALEPH at the mean energy of $\sqrt{s} = 197$ GeV and correspond to the integrated luminosity of 700 pb$^{-1}$. The search for $\eta_b$ was performed in the 4 and 6 charged particles mode. Events with a neutral object, or identified muon/electron(s) were rejected. The total transverse momentum of charged tracks below 0.25 GeV was required, and further cuts on the thrust ($<0.95$) and polar angle of the thrust axis ($>45^o$) were added to suppress $\gamma\gamma$ continuum and $\tau\tau$ background (the latter was then reduced to the negligible fraction by direct cuts on the net charge and mass of particles in both hemispheres).

The selection and reconstruction efficiency were studied with help of simulated PHOT02 events, and found to be 15.7% and 10.1% in the 4 and 6 charged particles modes, respectively. The background, dominated by the $\gamma\gamma$ continuum, was estimated using the data rather than MC, and found to be $0.3 \pm 0.3$ ($0.8 \pm 0.4$) events in the 4(6) charged particle mode.

**Figure 2. Invariant mass spectrum of selected events.**

Invariant spectra of selected events are shown in Fig. 2. In the signal
region (9.0-9.8 GeV), 0 (resp. 1) candidates are left after all cuts in the 4 (resp. 6) particle mode (the dashed line indicates the expected signal assuming the corresponding branching ratio is 100%). The selected candidate is compatible with background expectations.

The measurement allows to set an upper limit on the partial widths and branching ratios of \( \eta_b \) into decay channels under study: \( \text{Br}(\eta_b \rightarrow 4 \text{ charged particles}) < 17\% \), \( \text{Br}(\eta_b \rightarrow 6 \text{ charged particles}) < 38\% \) at the 95\% confidence limit (using the estimated \( \Gamma_{\gamma\gamma}(\eta_b) = 416 \text{ eV} \)).

3 Double tagged hadronic cross section (ALEPH)

The double-tagged \( \gamma\gamma \) events were studied by ALEPH using the LEP2 data (640 pb\(^{-1} \) at c.m.s. energies between 189-208 GeV). The main selection criteria consist in detection of both scattered electrons - carrying at least 0.3 of the beam energy - in the polar angle range \( 35 \text{ mrad} < \Theta < 55 \text{ mrad} \). Additional cuts are imposed on the hadronic final state: visible mass above 3 GeV, at least 3 reconstructed charged tracks. Cuts on the minimal total energy (0.7 E\(_{\text{c.m.s.}}\)) and maximal opening angle of leptons (179.5\(^\circ\)) help to suppress the \( \tau\bar{\tau} \) background. The selected sample consists of 891 events (background expectation amounts to 206.1 events).

![Figure 3. Pseudorapidity distribution at the detector level. MC predictions are scaled to match the observed number of events.](image)

The measured spectra are generally in a good agreement with simulation after renormalization to the observed number of events. For example, Fig.3.
shows the pseudorapidity distribution observed in data versus MC predictions. Pythia 6.151 was rescaled by 30% and PHOT02 by 12% for this comparison.

After background subtraction and application of bin corrections for the detector acceptance, the differential cross-section was compared both with MC and NLO QCD calculations. The NLO calculations tend to underestimate the data, see Fig. 4.

A study of BFKL was done using the approximate relation $Y = \ln (s_{ee}/s_{\gamma\gamma}) \approx \ln (W_{\gamma\gamma}^2/\sqrt{Q_1^2 Q_2^2})$, valid for $W_{\gamma\gamma}^2 \gg Q^2$ (the differential cross section in this variable is plotted in Fig. 5). For comparison with BFKL calculations, additional cut $\log(Q_1^2/Q_2^2) < 1.0$ was added, ensuring both photons have similar virtuality, and the $\sigma_{\gamma\gamma}$ was extracted from the double tagged cross-section using photon flux calculated by GALUGA. The comparison with LL BFKL is shown in Fig. 6. Data do not show the enhancement with $Y$, which is - at least partly - understood (next-to-leading-log BFKL resummation brings large negative contribution; kinematical effects - like energy conservation - are neglected). Similar results were reported also by L3 and OPAL.

References

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Figure 5. $Y$ distribution of the corrected data, compared to the MC predictions (scaled to match the observed number of events) and NLO QCD calculations.

Figure 6. Comparison of the unfolded differential $\gamma\gamma$ cross-section (as a function of the relative inv.mass of the $\gamma\gamma$ system, $\sim Y$ variable) with the LL BFKL calculations.

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