Observation of forward neutron multiplicity dependence of dimuon acoplanarity in ultra-peripheral PbPb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

—Supplemental Material—

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Figure 1 (left) shows the correlation between energy distributions of the ZDC detectors, located on the positive (Plus) and negative (Minus) directions with respect to the CMS interaction point, for events selected in the analysis. Figure 1 (right) shows the measured Minus ZDC energy distribution together with a multi-Gaussian function fit.

For the measured neutron multiplicity class with asymmetric neutron numbers, the dimuon rapidity is divided into two hemispheres using the plane defined by $y = 0$. In each rapidity hemisphere, the $\alpha$ distribution from $\gamma\gamma \rightarrow \mu^+ \mu^-$ is normalized by the total yields in this neutron multiplicity class $((1/N_s) dN_{\text{rap}}^{\gamma\gamma}/d\alpha$, where the $N_s$ represents the total yields and $N_{\text{rap}}^{\gamma\gamma}$ represents the yields in each rapidity hemisphere), as shown in Fig. 2.

The yields of muon pairs from $\gamma\gamma$ scattering in the $\Upsilon$ mass region ($9 < m_{\mu\mu} < 11$ GeV) are extracted by a binned $\chi^2$ fit to the invariant mass spectrum, as shown in Fig. 3. Each $\Upsilon$ state is modeled by a Gaussian function. All the parameters of the $\Upsilon(1S)$ fit are left free. For the $\Upsilon(2S)$ and $\Upsilon(3S)$ states, the yields are allowed to vary while the mean and width are fixed to values found by multiplying those for $\Upsilon(1S)$ by the ratio of the published masses of the states [1]. The contribution of $\gamma\gamma$ scattering to dimuon pair production in the $\Upsilon$ mass region is extracted using a second order polynomial function.

FIG. 1. The left panel shows the correlation between energy distributions of the Minus and Plus ZDC detectors (one entry per event), while the right panel shows a multi-Gaussian function fit to the Minus ZDC energy distribution.

FIG. 2. Acoplanarity distributions of $\gamma \gamma \rightarrow \mu^+ \mu^-$ events for three different neutron multiplicity classes with asymmetric neutron numbers. The solid red (open blue) symbols correspond to events where the dimuon rapidity is in the hemisphere containing larger (smaller) neutron multiplicity. The vertical lines on data points depict the statistical uncertainties while the systematic uncertainties are shown as shaded areas.
FIG. 3. The efficiency corrected invariant mass distribution of muon pairs in inclusive ultraperipheral PbPb collisions, for the kinematic range $p_T^\mu > 3.5$ GeV, $|\eta\mu| < 2.4$, and $|y\mu\mu| < 2.4$. The result of the fit to the data is shown as solid blue line. The yields of muon pairs from $\gamma\gamma$ scattering in the $\Upsilon$ mass region are shown as dashed red line. The separate yields for each $\Upsilon$ state are shown as dotted violet lines.