Search for an invisible Z' in a final state with two muons and missing energy at Belle II

Belle II Collaboration

This material is submitted as supplementary information for the Electronic Physics Auxiliary Publication Service

We provide a text file with numerical results for the observed 90% CL upper limit on the cross section of $e^+e^- \to \mu^+\mu^- Z'$, with $Z' \to$ invisible as well as of the observed 90% CL upper limit on g' as functions of $M_{Z'}$.

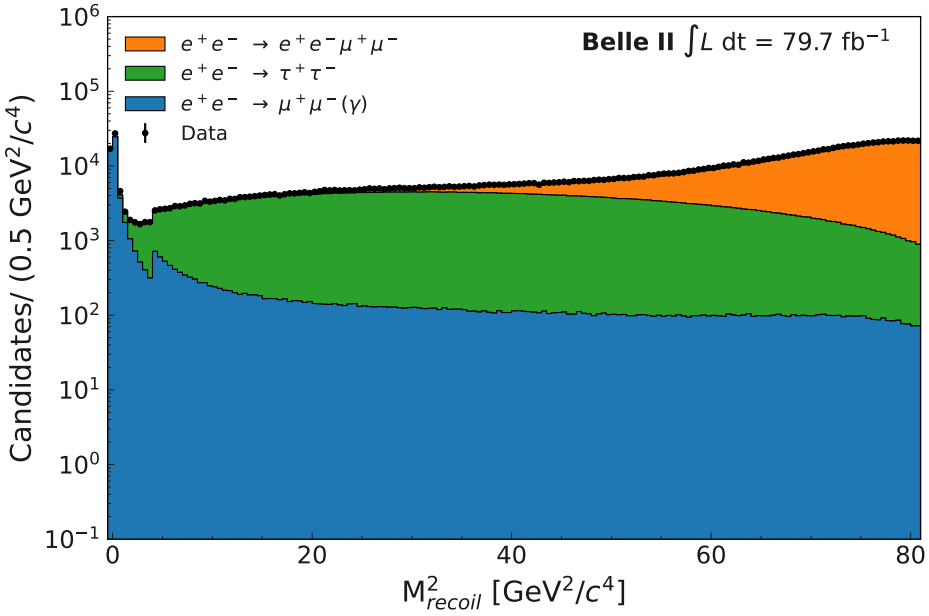

FIG. S1: Squared recoil mass spectrum for the $\mu^+\mu^-$ sample before the Punzi-net selection, compared with the stacked contributions from the various simulated background samples normalized to the integrated luminosity.

We also show the limits on g' as functions of $M_{Z'}$ on a logarithmic scale in Fig. S3 for the $L_\mu - L_\tau$ vanilla model and in Fig. S5 for the $L_\mu - L_\tau$ fully invisible model.

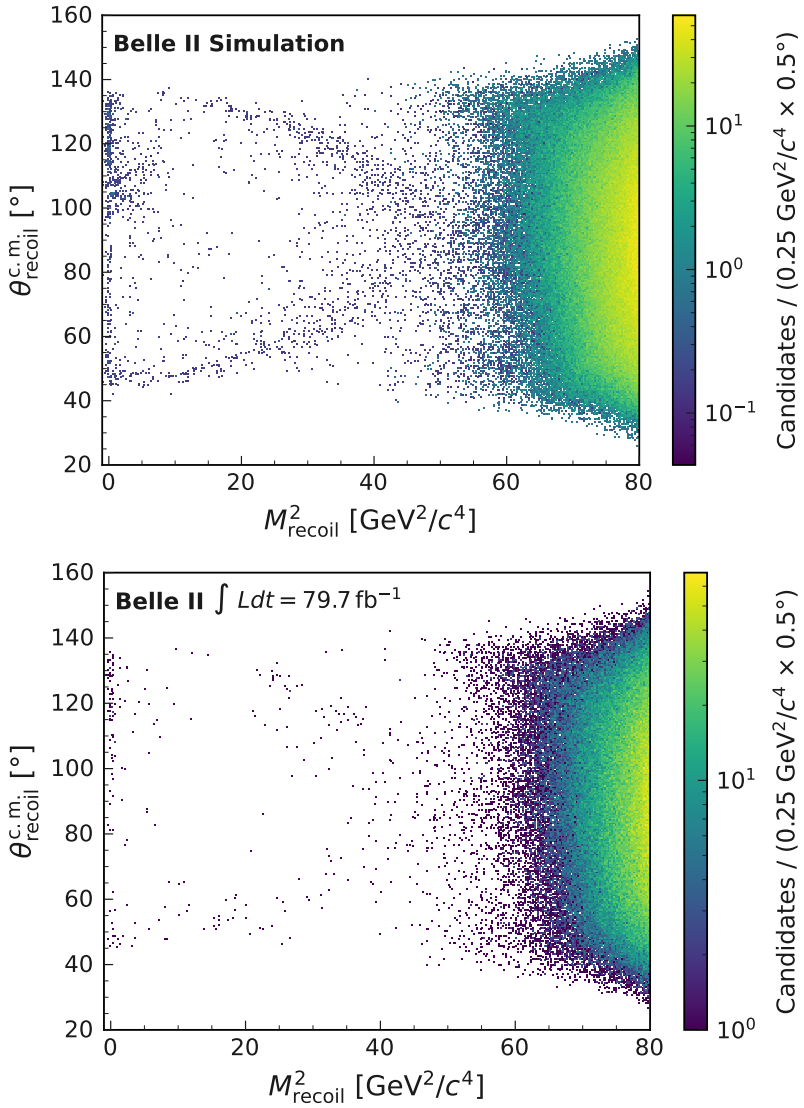

FIG. S2: Distribution of (top) expected background events and (bottom) data across the $\theta^{\mathrm{c.m.}}_{\mathrm{recoil}}$ versus M^2_{recoil} plane after all the analysis selections.

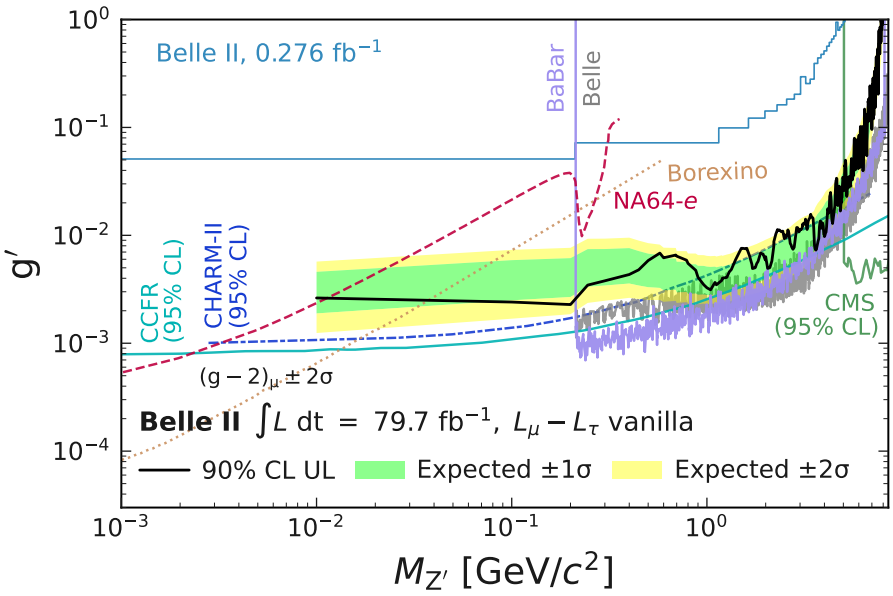

FIG. S3: Observed 90% CL upper limits on the coupling g' for the $L_\mu - L_\tau$ vanilla model as functions of $M_{Z'}$ on a logarithmic scale. Existing limits from BaBar [1], Belle [2], CMS [3] (95% CL), NA64-e [4], and Belle II [5] are shown, along with constraints (95% CL) derived from the trident production in neutrino experiments [6–8]. The red band shows the region that could explain the muon anomalous magnetic moment $(g-2)_\mu \pm 2\sigma$ [9].

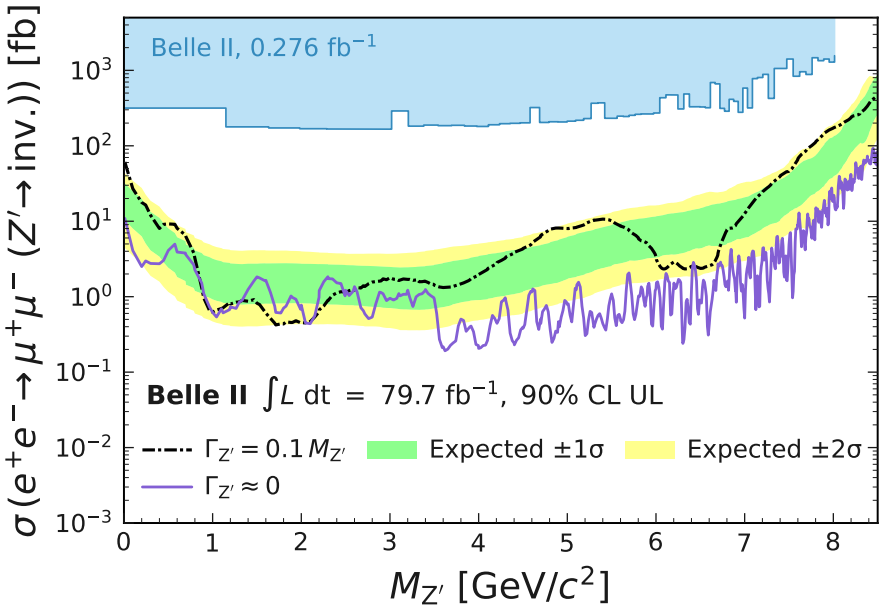

FIG. S4: Observed 90% CL upper limits on the cross section $\sigma(e^+e^- \to \mu^+\mu^- Z',\ Z' \to \text{invisible})$ as functions of the Z' mass for $\Gamma_{Z'} = 0.1 M_{Z'}$, including the ± 1 and $\pm 2\sigma$ bands around the expected limits. Also shown are previous limits from Belle II [5] and the observed limits for the negligible width case.

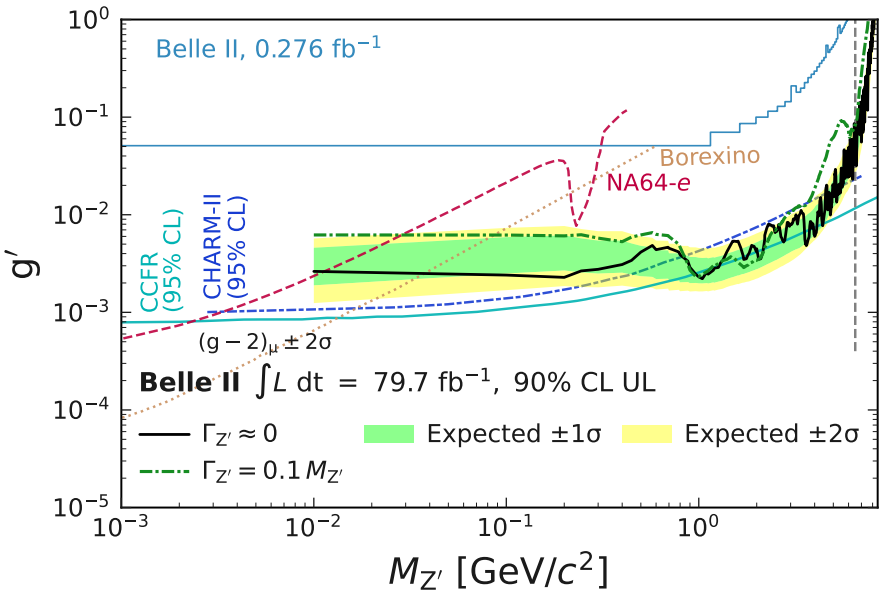

FIG. S5: Observed 90% CL upper limits on the coupling g' for the $L_\mu - L_\tau$ fully invisible model as functions of $M_{Z'}$ in logarithmic scale. Existing limits from NA64-e [4] and Belle II [5] are shown, along with constraints (95% CL) derived from the trident production in neutrino experiments [6–8]. The vertical dashed line indicates the limit beyond which the hypothesis $\mathcal{B}(Z' \to \chi\bar{\chi}) \approx 1$ is not valid in the negligible $\Gamma_{Z'}$ case. The red band shows the region that could explain the muon anomalous magnetic moment $(g-2)_\mu \pm 2\sigma$ [9].

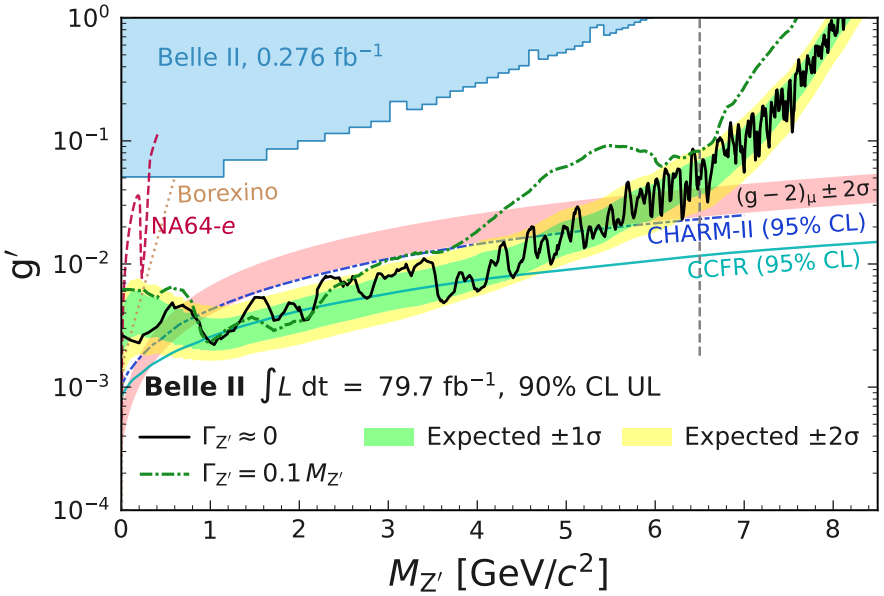

FIG. S6: Observed 90% CL upper limits on the coupling g' for the $L_\mu - L_\tau$ fully invisible model as functions of $M_{Z'}$. Existing limits from NA64-e [4] and Belle II [5] are shown, along with constraints (95% CL) derived from the trident production in neutrino experiments [6–8]. The vertical dashed line indicates the limit beyond which the hypothesis $\mathcal{B}(Z' \to \chi\bar{\chi}) \approx 1$ is not valid in the negligible $\Gamma_{Z'}$ case. The red band shows the region that could explain the muon anomalous magnetic moment $(g-2)_\mu \pm 2\sigma$ [9].

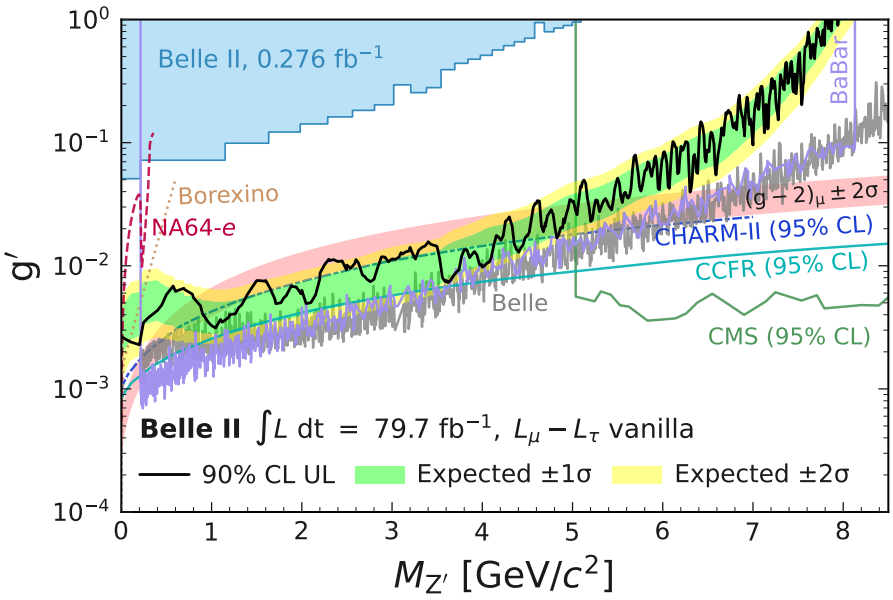

FIG. S7: Observed 90% CL upper limits on the coupling g' for the $L_\mu - L_\tau$ vanilla model as functions of $M_{Z'}$. Existing limits from BaBar [1], Belle [2], CMS [3] (95% CL), NA64-e [4], and Belle II [5] are shown, along with constraints (95% CL) derived from the trident production in neutrino experiments [6–8]. The red band shows the region that could explain the muon anomalous magnetic moment $(g-2)_\mu \pm 2\sigma$ [9].

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