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Search for Inelastic Dark Matter at Belle II: plots for approval for Long-lived particles at Belle II Workshop

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Simulation results are presented for the ongoing analysis to search for inelastic Dark Matter (iDM) at Belle II. iDM features a Long-Lived Particle detector signature and an unconstrained parameter space that can be explored with the 2020/2021 Belle II dataset. This note outlines the current iDM selection and presents plots for approval showing some characteristic features of the iDM signal as well as the background rejection achieved by key analysis variables. A radiative Bhabha control sample to be used for data validation studies is also briefly outlined. Using a simple cut and count technique the expected signal yield is shown for a 100 fb^{-1} dataset.

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1. FIGURES

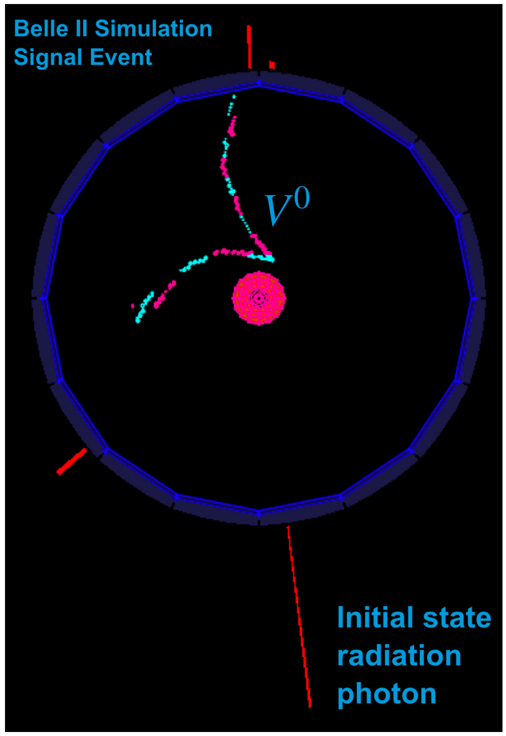

FIG. 1. A typical iDM event shown in the Belle II event display, including CDC hit information. Beam backgrounds are not shown. The detector observables are limited to an initial state radiation (ISR) photon, γ_{ISR}, and a displaced vertex (V^0) produced by the leptons emitted in the long-lived decay $\chi_2 \to \chi_1 l^+ l^-$ where $l = e, \mu$.

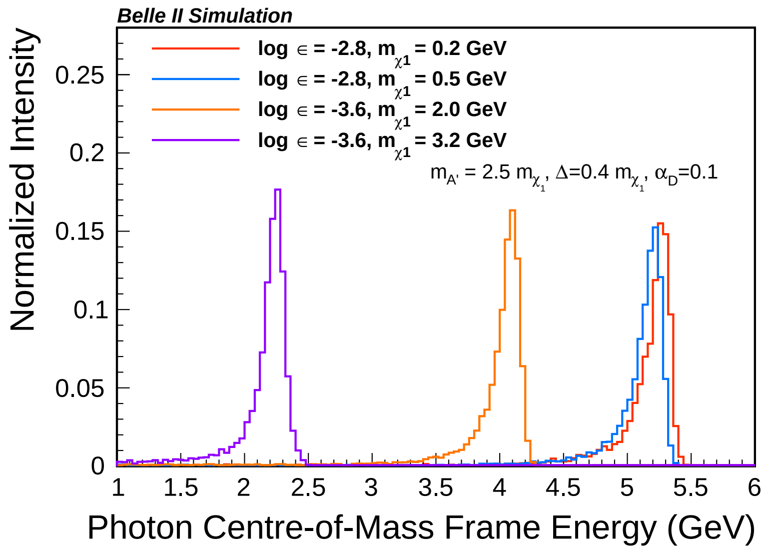

FIG. 2. Energy of the ISR photon in the centre-of-mass frame for several iDM signal models, all corresponding to $\Delta/m_{\chi 1} = 0.4$ and $m_{A'}/m_{\chi 1} = 2.5$. A feature of the iDM events studied in this analysis is that the ISR photon centre-of-mass energy distribution is peaking as the photon is recoiling against the on-shell production of the dark photon.

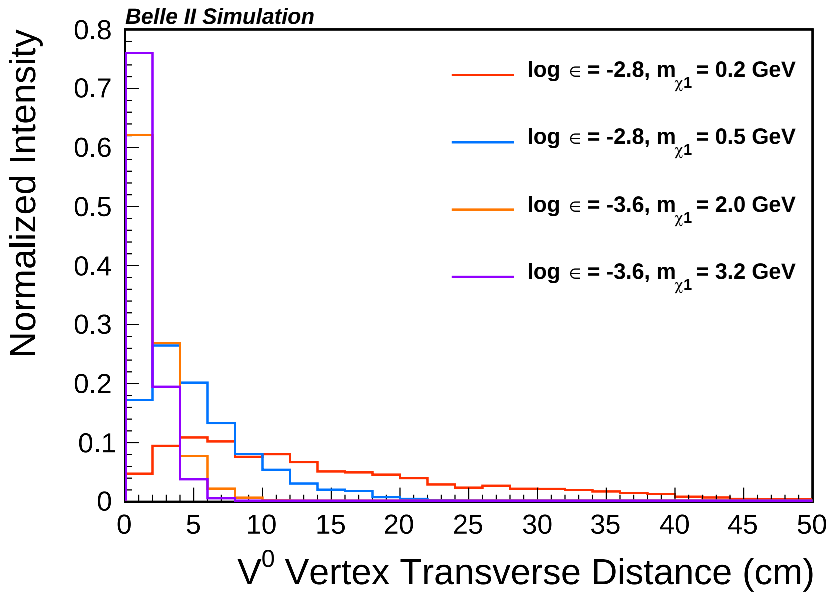

FIG. 3. Reconstructed distance of the V^0 vertex in the transverse plane (dr) shown for several different iDM signals, all corresponding to $\Delta/m_{\chi 1} = 0.4$ and $m_{A'}/m_{\chi 1} = 2.5$. As the χ_2 lifetime can vary with both ϵ and m_{χ_1}, this analysis will cover a range of V^0 displacements.

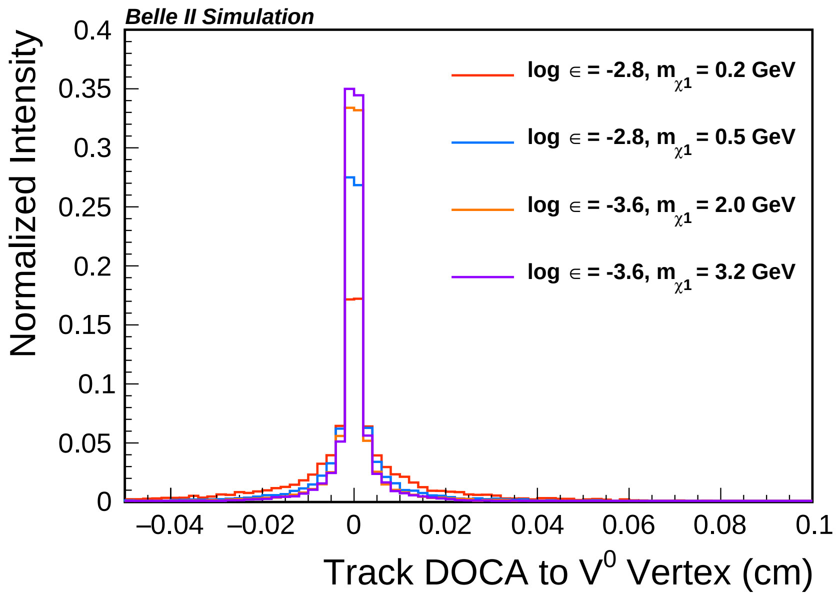

FIG. 4. Distance of closest approach in the transverse plane (DOCA) of the V^0 tracks to the V^0 vertex point. iDM signal models from figure 3 are shown. This quantity is observed to peak near zero as expected, demonstrating the V^0's are well reconstructed. The change in resolution for the different iDM signal models is correlated with the decay distance, as can be seen by comparing to figure 3.

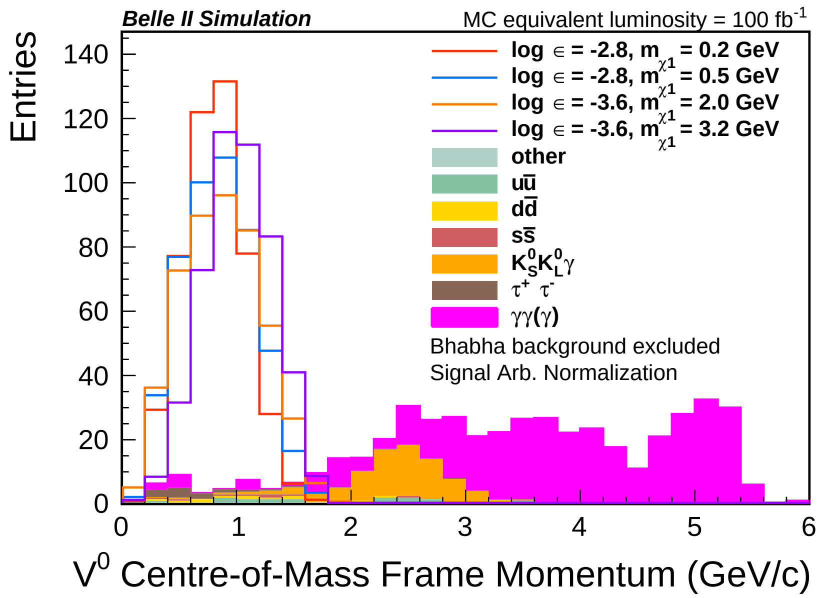

FIG. 5. Magnitude of the centre-of-mass frame momentum of the V^0 selected from background with several signal samples overlaid. Results are shown after the iDM selection is applied, excluding the $|\vec{p}^{\,CMS}_{V0}|$ cut [2]. As the χ_2 decay emits an undetected χ_1 in addition to the detected leptons which form the V^0, the V^0 in iDM signal events will tend to have lower momentum relative to the V^0 reconstructed in backgrounds from $e^+e^- \to\gamma\gamma(\gamma)$ and $e^+e^- \to K^0_S K^0_L(\gamma)$. The cut of $|\vec{p}^{\,CMS}_{V0}| < 2$ GeV/c rejects a large fraction of the $e^+e^- \to\gamma\gamma(\gamma)$ and $e^+e^- \to K^0_S K^0_L(\gamma)$ background while maintaining a high signal efficiency.

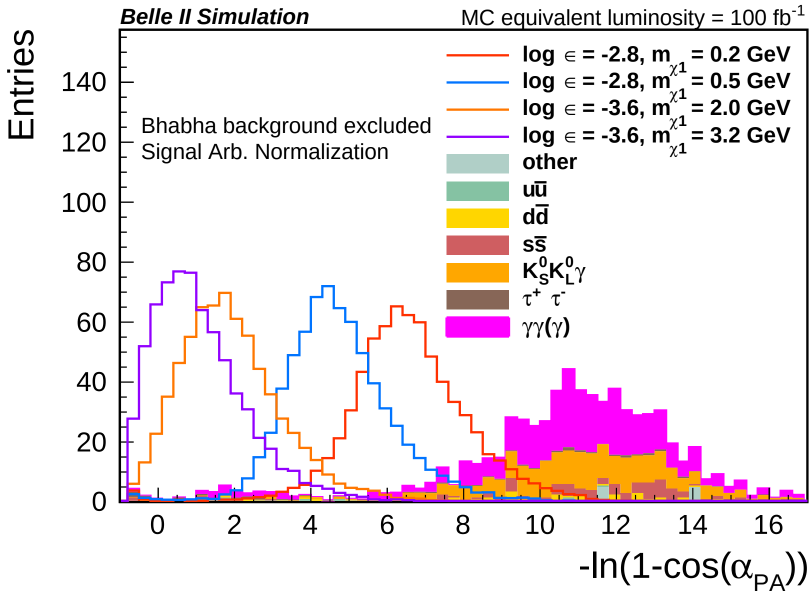

FIG. 6. The quantity $-\ln(1-\cos(\alpha_{PA}))$ is shown for the V^0 selected from background with several signal samples overlaid. Results are shown after the iDM selection is applied, excluding the α_{PA} cut [2]. The pointing angle, α_{PA}, is defined as the angle between the V^0 vertex vector and the V^0 momentum vector. To allow the structure of the distribution to be visualized the transformation $-\ln(1-\cos(\alpha_{PA}))$ is used. As the iDM V^0 originates from a 3-body decay it tends to result in a non-pointing V^0 relative to the V^0 selected from $e^+e^- \to \gamma\gamma(\gamma)$ and $e^+e^- \to K^0_S K^0_L(\gamma)$ backgrounds.

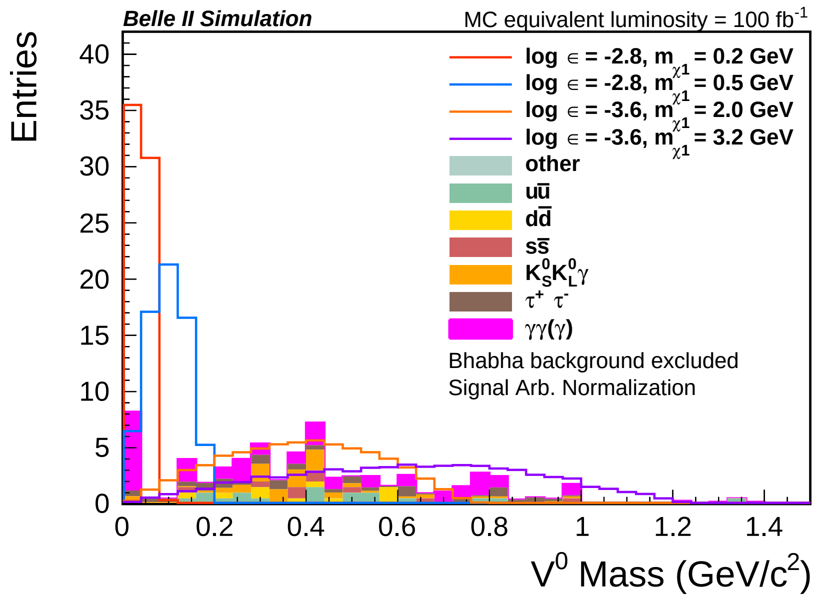

FIG. 7. Reconstructed invariant mass of the V^0's in the remaining background after the iDM selection is applied [2]. Tracks are reconstructed using the electron mass hypothesis. Using simulation truth information, the peak near zero is found to correspond to photon conversions and the higher mass V^0's correspond to charged hadrons emitted from material interactions or from K^0_S decays. Several iDM signal models are also overlaid, all corresponding to $\Delta/m_{\chi 1} = 0.4$ and $m_{A'}/m_{\chi 1} = 2.5$. A feature of the V^0 present in the iDM signal is that the reconstructed V^0 mass is a peaking distribution with a maximum value equal to the Δ parameter of the iDM model. To maximize the background rejection, the analysis applies a final cut of $m^{max}_{V0} < \Delta$ before performing the signal extraction for given set of iDM parameters.

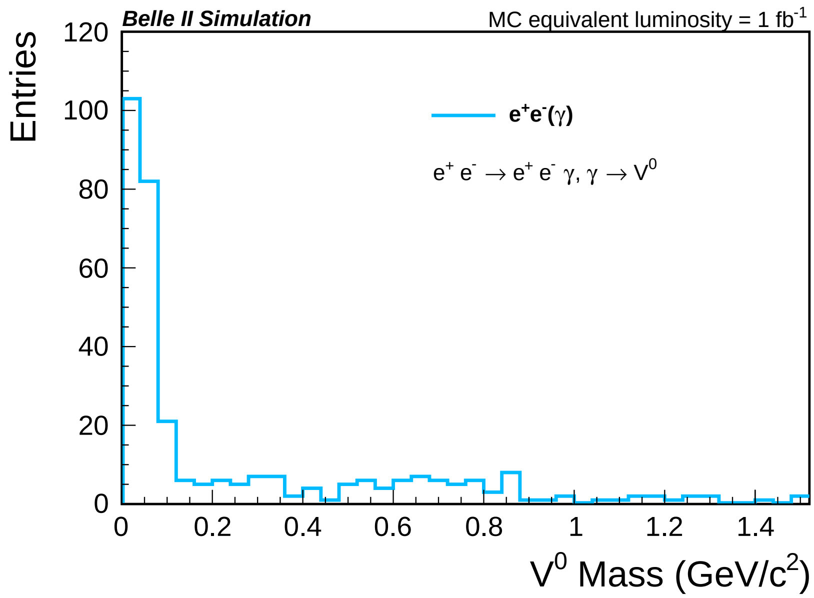

FIG. 8. Reconstructed invariant mass of the V^0's selected from the iDM control sample $e^+e^- \to e^+e^-\gamma, \gamma \to V^0$ after applying the iDM V^0 selection requirements. From simulation truth, the peak at zero is found to correspond to photon conversions and the higher mass V^0's are from charged hadrons emitted from photo-nuclear material interactions. The label $\gamma \to V^0$ is used to emphasize that the V^0 selected in this control sample can originate from photon conversions or photo-nuclear interactions. This result demonstrates that data validation of the iDM $e^+e^- \to \gamma\gamma(\gamma)$ background component can be completed using this control sample.

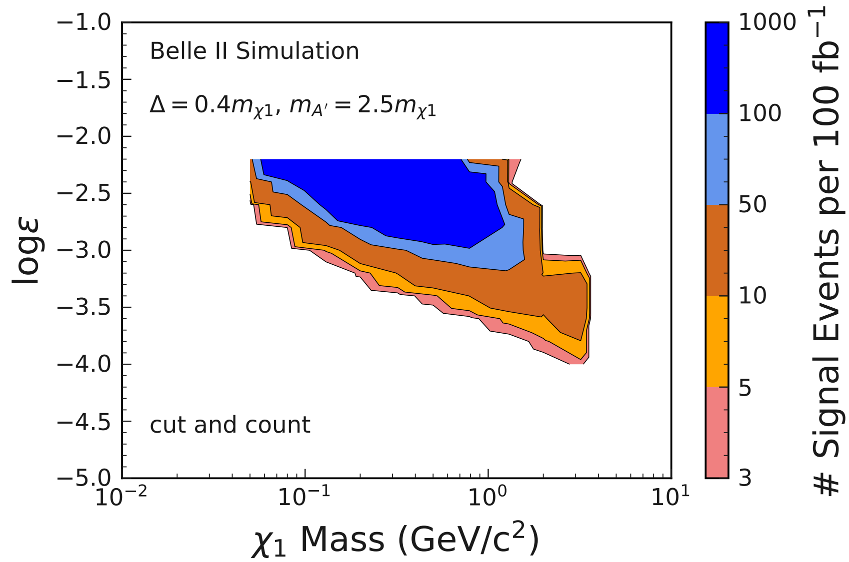

FIG. 9. Number of signal candidates predicted to be present in a 100 fb^{-1} dataset after applying the iDM selection [2], including the final V^0 mass threshold cut describe in the Figure 7 caption. This preliminary result uses a cut and count method to determine the signal yield whereas the final analysis will use a template fit. All signal models correspond to $\Delta/m_{\chi 1} = 0.4$ and $m_{A'}/m_{\chi 1} = 2.5$.

2. REFERENCES

[1] M. Duerr et al. “Invisible and displaced dark matter signatures at Belle II”. J. High Energ. Phys. 2020, 39 (2020). https://doi.org/10.1007/JHEP02(2020)039

[2] S. Longo. “Search for Inelastic Dark Matter at Belle II: plots for approval for Long-lived particles at Belle II Workshop”, BELLE2-NOTE-PH-2020-071.