Invisible Decays of a Dark Photon at Belle II

INVISIBLES21 (May 31st – June 4th)

Miho Wakai[1], Chris Hearty[1], Torben Ferber[2], Sam Cunliffe[2]

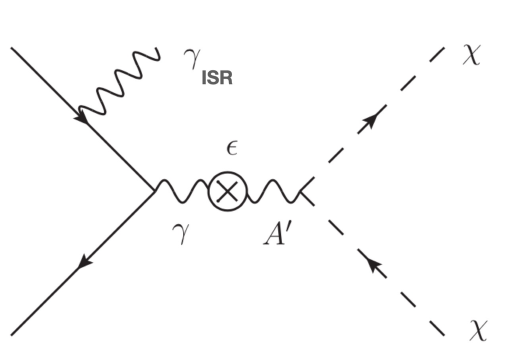
[1]University of British Columbia, [2]Deutsches Elektronen-Synchrotron

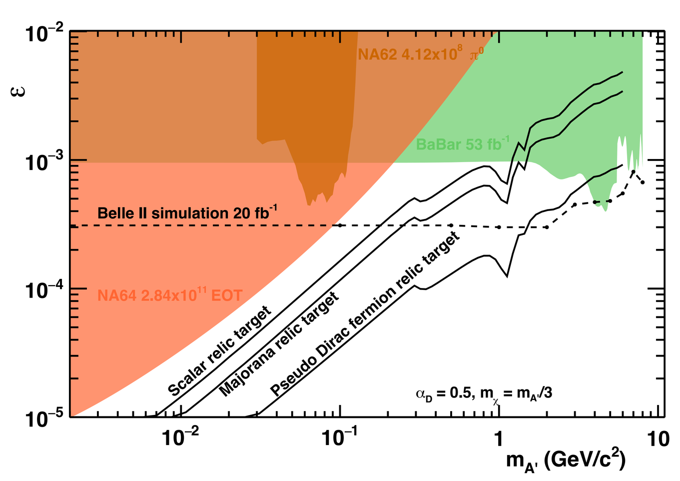
Introduction

- Dark photon (A') is a vector gauge singlet dark sector mediator which couples to the Standard Model (SM) photon. This is derived from a $U(1)'$ extension of the symmetry group[1].
- The coupling strength ϵ arises from the kinetic mixing of the hypercharge and the vector field strength.
- At Belle II, we are searching for a dark photon with signature $e^+e^- \to \gamma_{ISR}A'$, where γ_{ISR} is an initial state radiation and the A' decays invisibly to two dark matter candidates; $A' \to \chi\chi$. The final state is a single photon.
- The A' mass is obtained through the single photon energy;

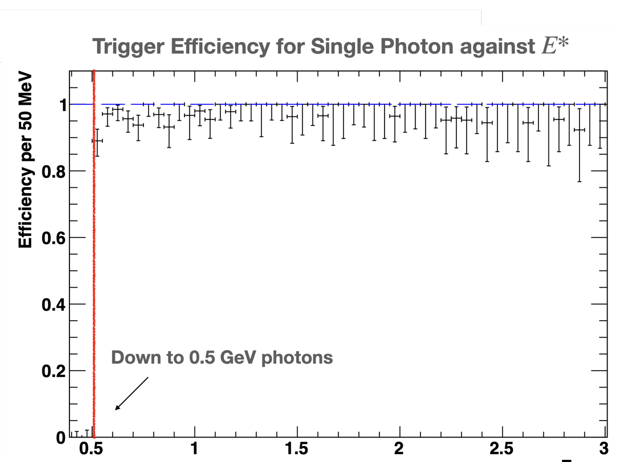
$$m_{A'}^2 = 4E^*_{beam}(E^*_{beam} - E^*_{\gamma ISR})$$

- The newly implemented trigger will allow these single photon events to be saved (down to 0.5 GeV), which was not possible for the previous experiment Belle.



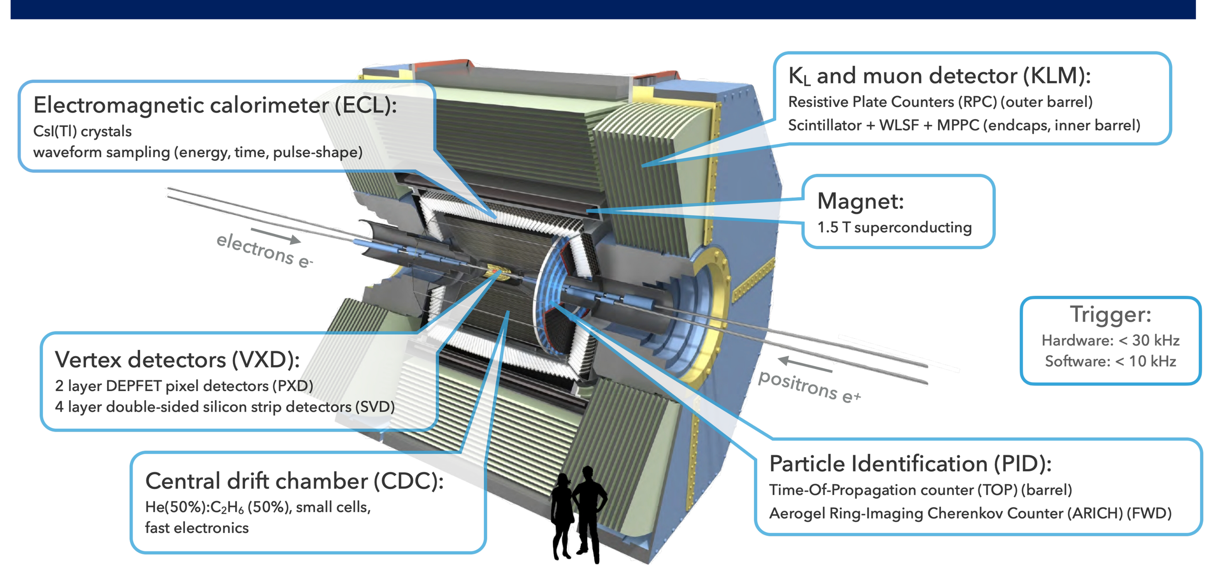


Based on arXiv:2104.10280[2]



Belle II Simulation Preliminary

Belle II and Super KEKB

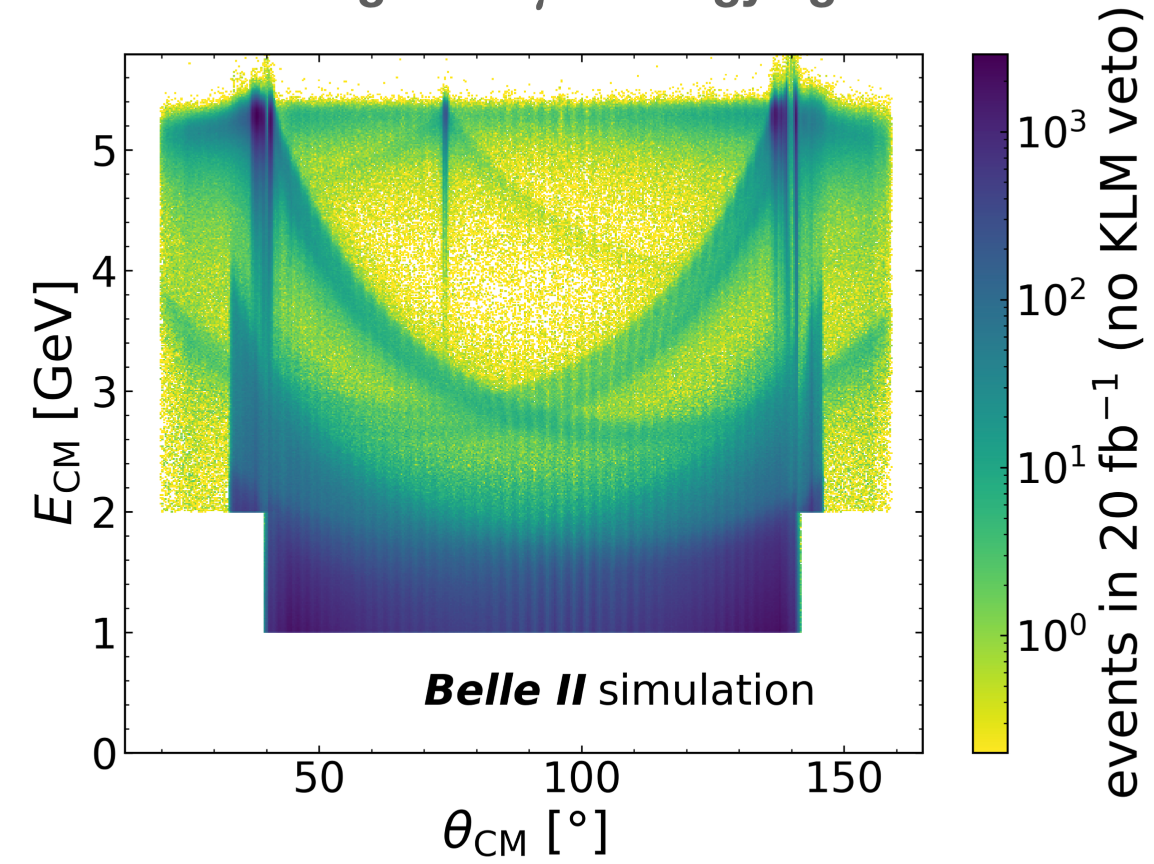


- SuperKEKB is an asymmetric particle accelerator with a circumference of 3 km located in Japan.
- Operates mainly at resonance energy of $\Upsilon(4S)$ at $10.58\ \mathrm{GeV}$.
- Current aim is to collect $50\ \mathrm{ab}^{-1}$ by 2031.

Analysis Process

- As we are at the pre-unblinding stage, we are studying background.
- The background can be split into 3 different regions as a function of the single photon center of mass energy, as the dominant background differs between regions.
  - Low E^* : $e^+e^- \to e^+e^-\gamma$, where both e^+e^- are out of the Central Drift Chamber acceptance
  - Middle E^* : $e^+e^- \to \gamma\gamma\gamma$, where 2 γs are not reconstructed
  - High E^* : $e^+e^- \to \gamma\gamma$, where 1 γ is not reconstructed.

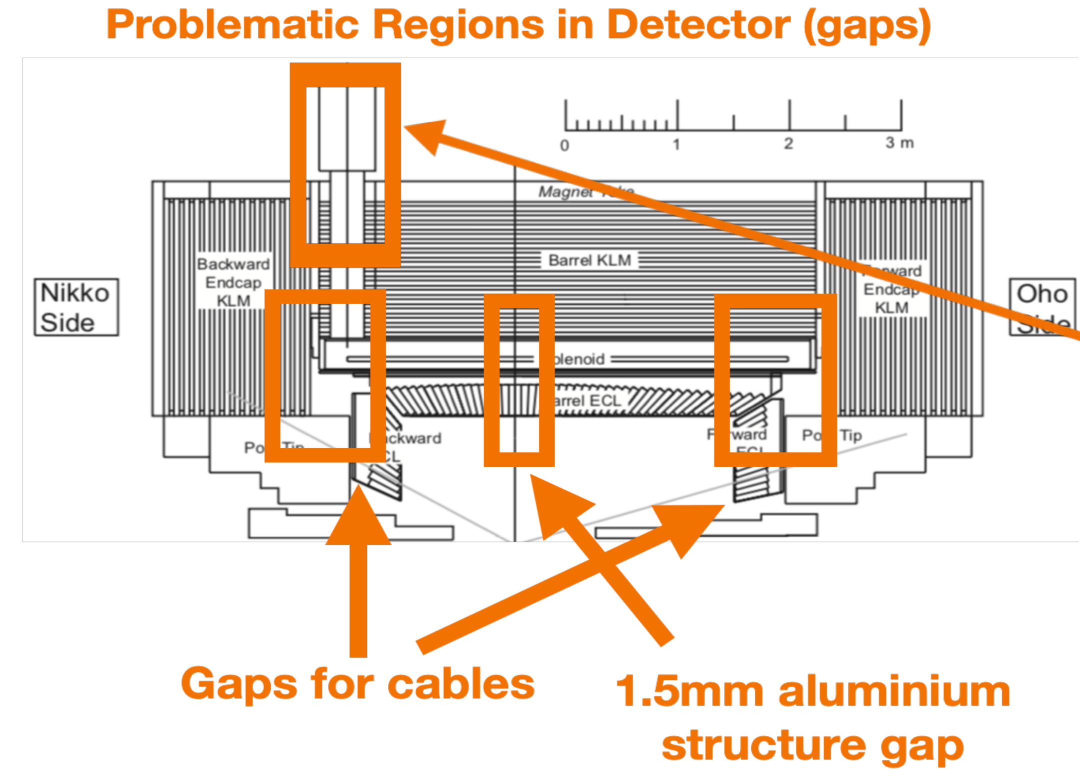
Predicted Background γ's Energy against Location



Belle II Simulation Preliminary

- In order to put an estimate on the number of backgrounds in the High E^* region, we seek the probability of missing a photon in the detector.
- The two main detectors we rely on are the Electromagnetic Calorimeter (ECL) and the Klong Muon Detector (KLM).
- Efficiency is reduced due to the gap structure of the detectors, hence photons in those regions are considered unreliable.

Problematic Regions in Detector (gaps)

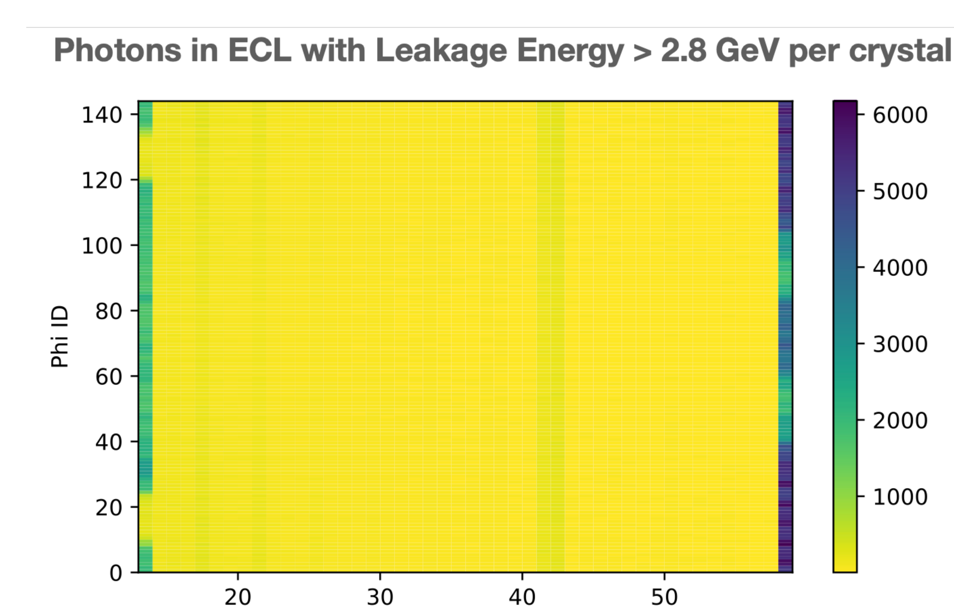


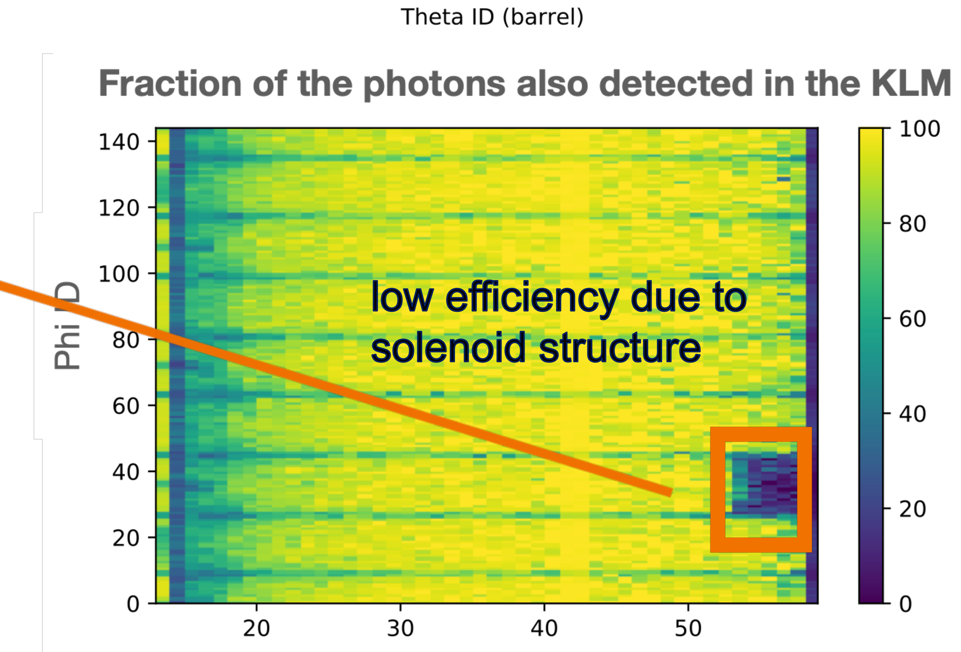
Further Analysis Process and Results

- To find the efficiency, we study $e^+e^- \to \gamma\gamma$ events where one of the photons is highly leaking, i.e. only deposits a fraction of the energy in the crystals of the ECL detector. We further look into the KLM and see whether or not this photon released some energy into the KLM.
- The leakage energy is defined by:

$$E_{leak} = E_{beam} - E_{calorimeter}$$

- Selection criteria of $e^+e^- \to \gamma\gamma$ event:
  - Use two most energetic photons that are back to back per event
  - No charged tracks from interaction point
- The two photons are split into tag and probe, where the tag is a photon which consists of $E^* > 4.5\ \mathrm{GeV}$. Analysis of efficiency is conducted using the probe photon.
- In order to look at the gap structure, the efficiency was measured through the individual crystals of the ECL, labeled as Theta ID and Phi ID.
- The efficiencies of the ECL and KLM detector are found by counting the hits both detectors had as a function of leakage energy of the photons.
- A hit in KLM is currently defined by:
  - Detected by at least 2 layers
  - Innermost layer of hit starts from 1 or 2, closest to the ECL
  - Hit has to be within $< 25°$ of the ECL hit

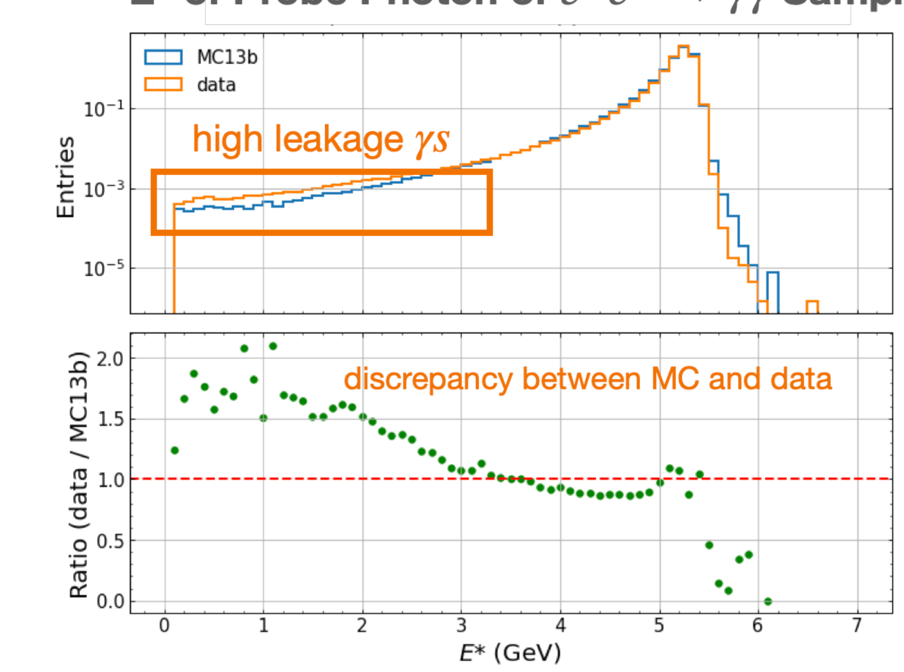


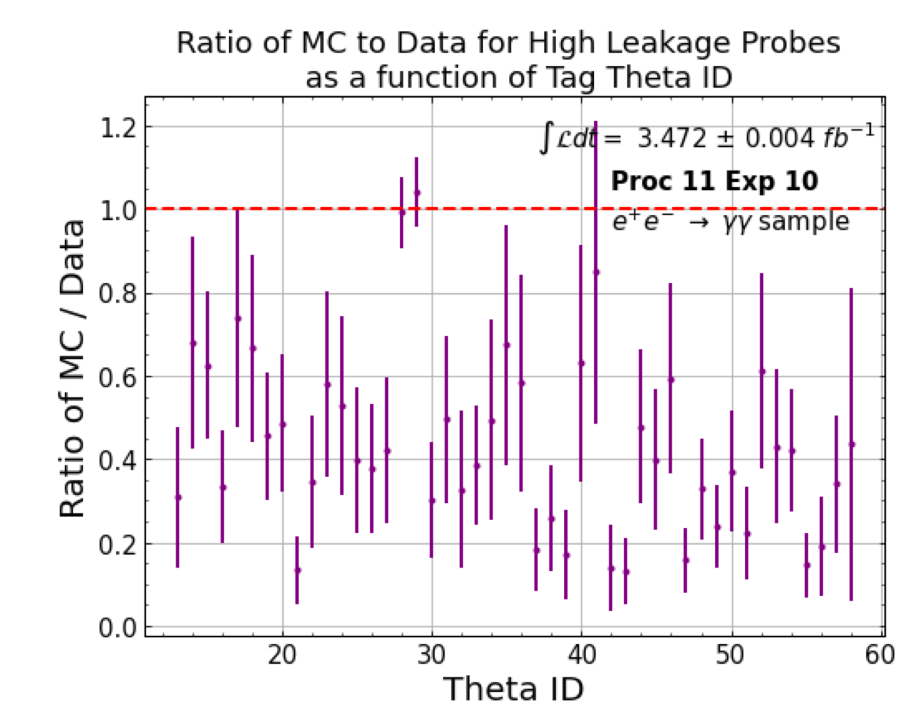


Belle II Simulation Preliminary

- In addition to the detector efficiency, the Monte Carlo (MC) and data discrepancy has been studied. This is to find the background estimate on data by scaling the MC events.

E* of Probe Photon of $e^+e^- \to \gamma\gamma$ Sample





Belle II Preliminary

- Results show that for highly leaking photons, the data has many more events than MC (~1.7) suggesting that the gaps between crystals may be larger in data than MC.
- Currently pursuing the correct scale factor for unblinding.

Conclusion and Outlook

- Currently quantifying the background of $e^+e^- \to \gamma\gamma$ in data by looking at the detector efficiencies and the data and MC discrepancy.
- Work in progress on MC signal samples for signal selection.
- The study is continuously being updated with new simulated samples of MC and data.
- We expect to achieve our sensitivity through using both the ECL and KLM sub-detectors.

References

1 B. Holdom, Physics Letters B166, 196 (1986).

2 M. Graham, C. Hearty, M. Williams, Annu. Rev. Nucl. Part. Sci. 2021. 71:37

Miho Wakai, University of British Columbia, miho@phas.ubc.ca