Invisible Decays of a Dark Photon at Belle II

CAP 2021

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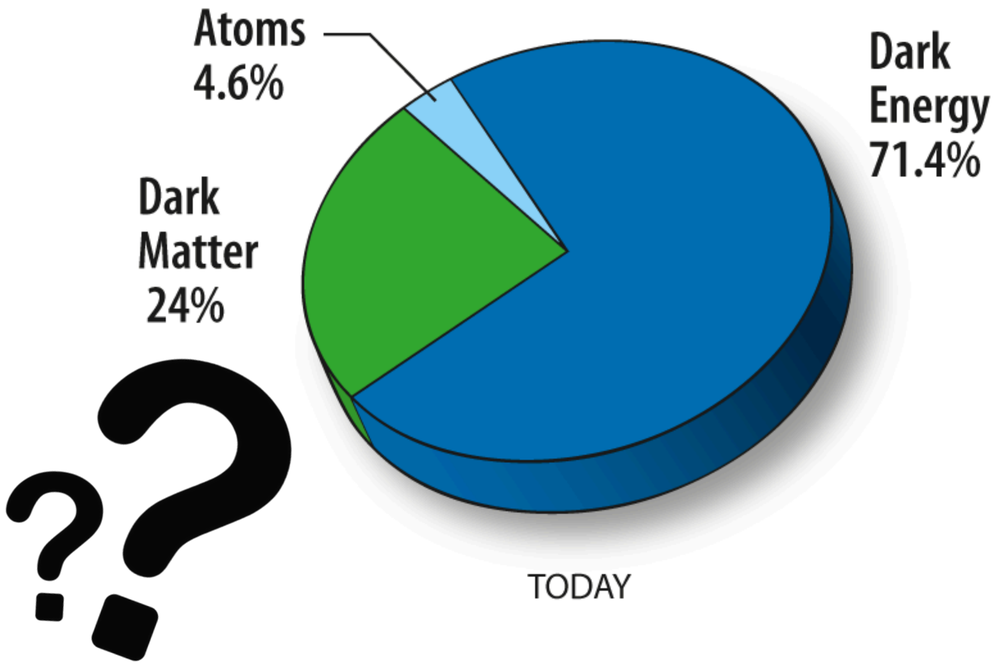
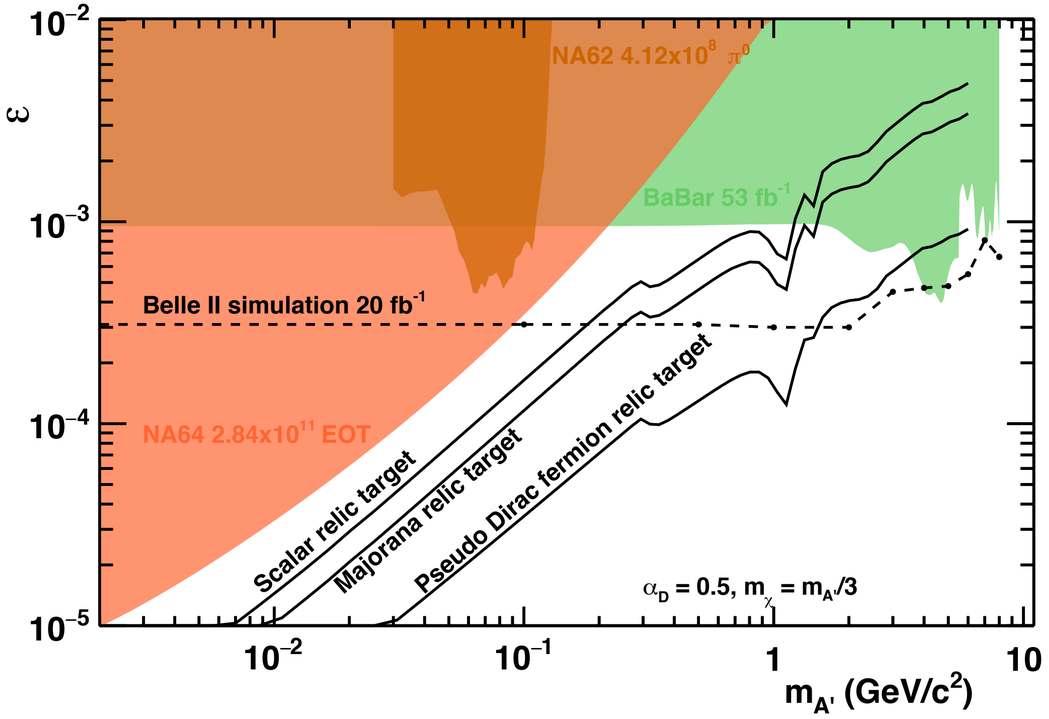
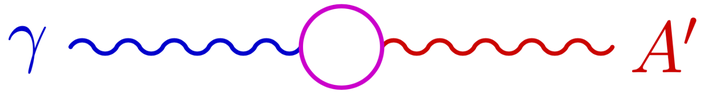
Dark Photons

What are we searching for?



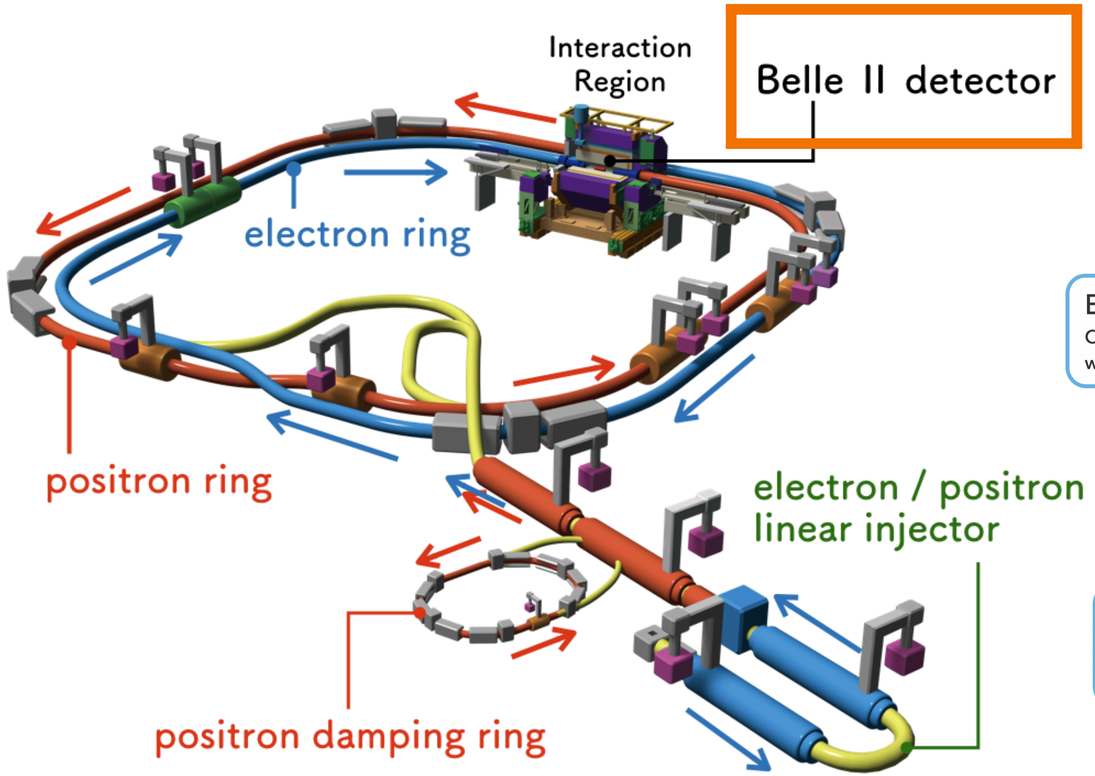


- Dark sector: Collection of hypothetical particles
- Dark sector mediator which mixes with the SM photon

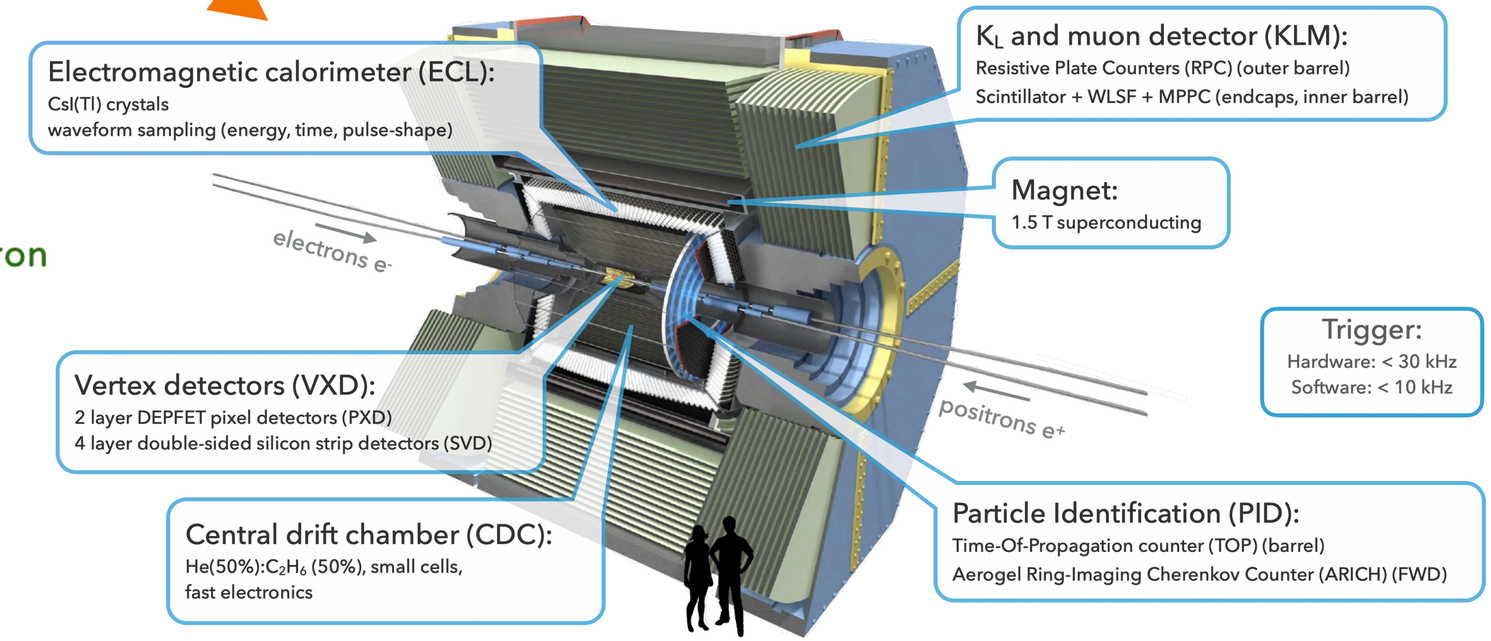


Based on M. Graham, C. Hearty, M. Williams, Annu. Rev. Nucl. Part. Sci. 2021. 71:37

SuperKEKB Accelerator & Belle II Experiment



SuperKEKB Accelerator



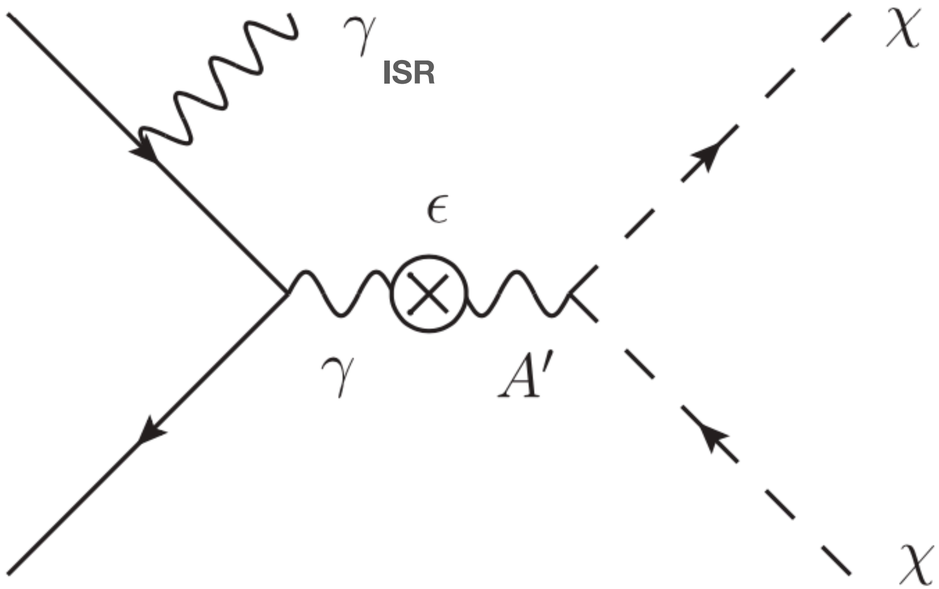
Belle II Detector

- Asymmetric e^+e^- collider with $\sqrt{s}$ = 10.58 GeV
- New instantaneous luminosity world record of $2.4 \times 10^{34} cm^{-2} s^{-1}$ achieved

Dark Photon at Belle II

What are we searching for?

- **Signature:** $e^+e^- \to \gamma_{ISR}\ A';\ \ A' \to \chi\chi$
- **Final state:** Single γ + Missing Energy
- **Finding A':** $m^2_{A'} = 4E^*_{beam}(E^*_{beam} - E^*_{\gamma_{ISR}})$
- **Good sensitivity:** Newly designed trigger allows sensitivity down to 0.5 GeV of single photon

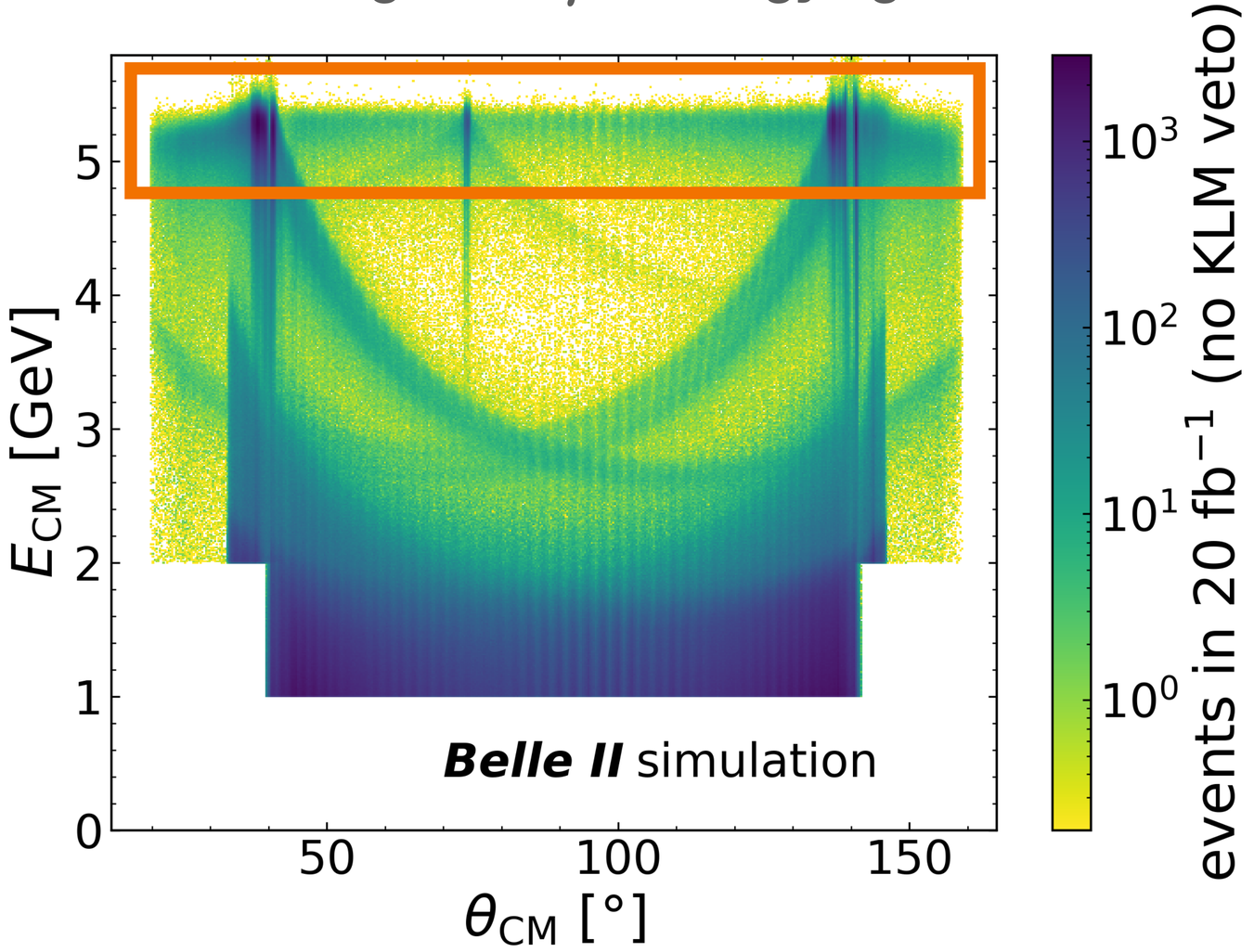


Overview of search

Background Studies

- When single photon has E^* ~ 5 GeV, dominant background: $e^+e^- \to \gamma\gamma$, missing 1 γ
- How likely are we to miss a γ in our detector?
- Main detectors: Electromagnetic Calorimeter (ECL) and K-Long Muon (KLM) Detector

Predicted Background γ's Energy against Location



Belle II Simulation Preliminary

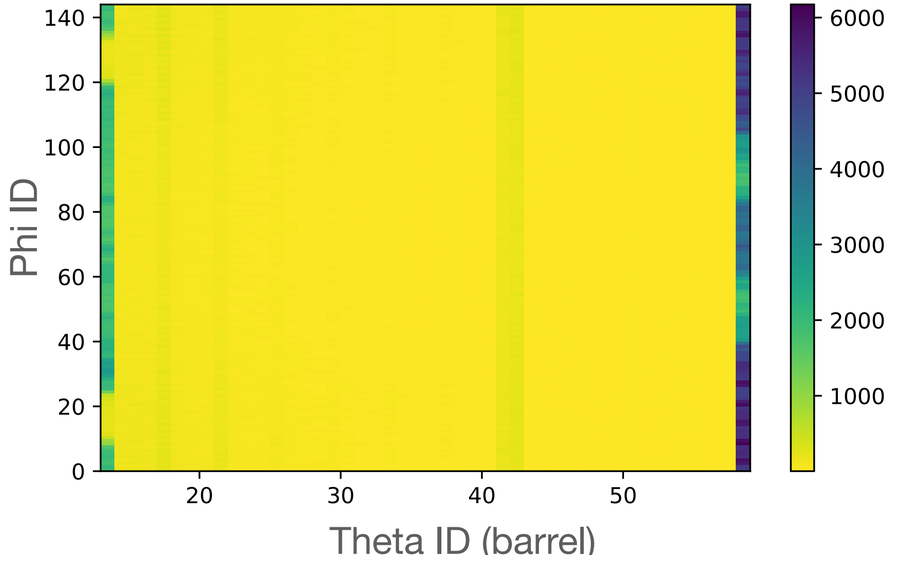
Working with $e^+e^- \rightarrow \gamma\gamma$ Background

Studying Efficiency of Sub-detectors

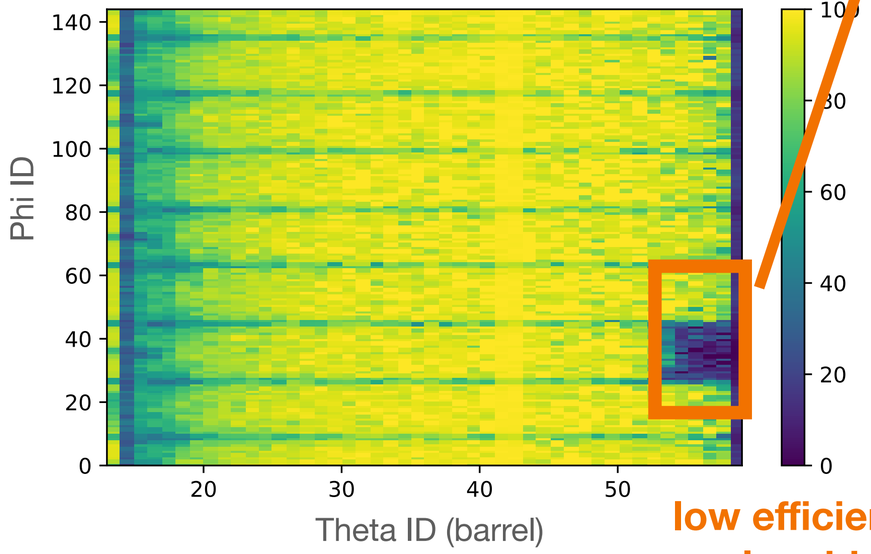
- Study efficiency of detectors as a function of leakage energy; $E_{leak} = E_{beam} - E_{calorimeter}$ using $e^+e^- \rightarrow \gamma\gamma$ control sample
- Most of background come from gaps in the detectors, with a "high leakage γ" (roughly 4% of all γs)

~ 4% of all photons are highly leaking

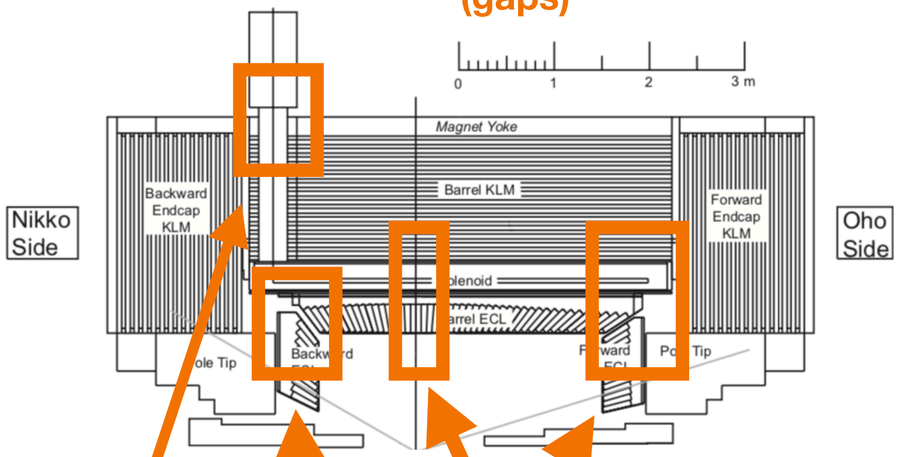
Photons in ECL with Leakage Energy > 2.8 GeV per crystal



Fraction of the photons also detected in the KLM



Problematic Regions in Detector (gaps)



gaps for cables

1.5mm aluminium structure gap

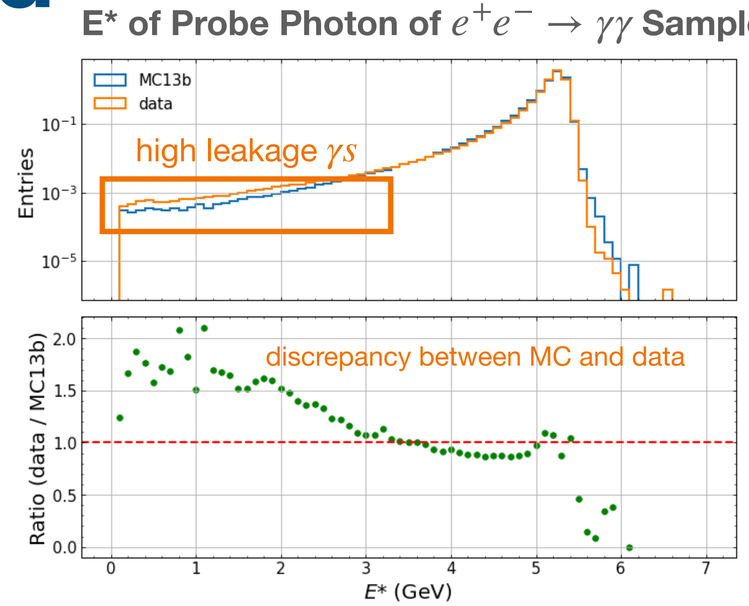
low efficiency due to solenoid structure

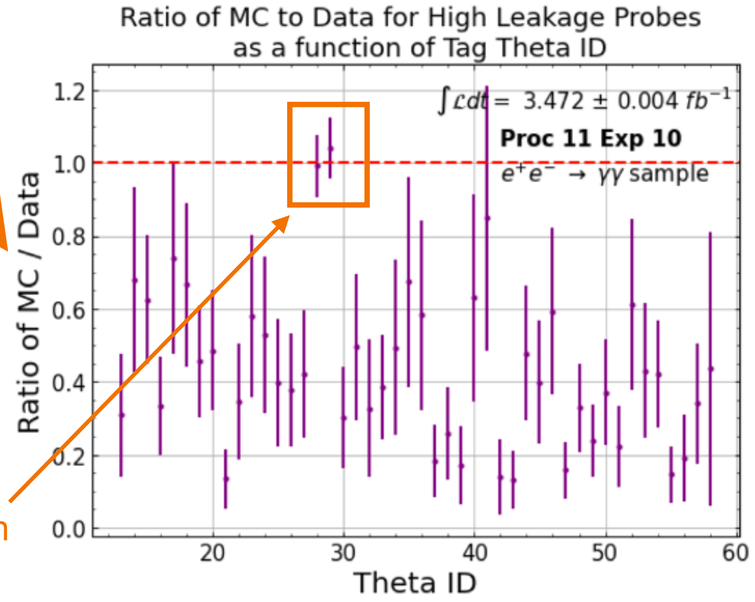
Belle II Simulation Preliminary

Working with $e^+e^- \to \gamma\gamma$ Background

Monte Carlo (MC) and Data discrepancy

- Next stage is to understand the background uncertainty on data (pre-blind process)
- Currently we see many more high leakage photons in data than in MC
- Gaps between crystals may be larger in data than MC
- Currently trying to quantify background in data by scaling MC





good agreement in 1.5 mm gap

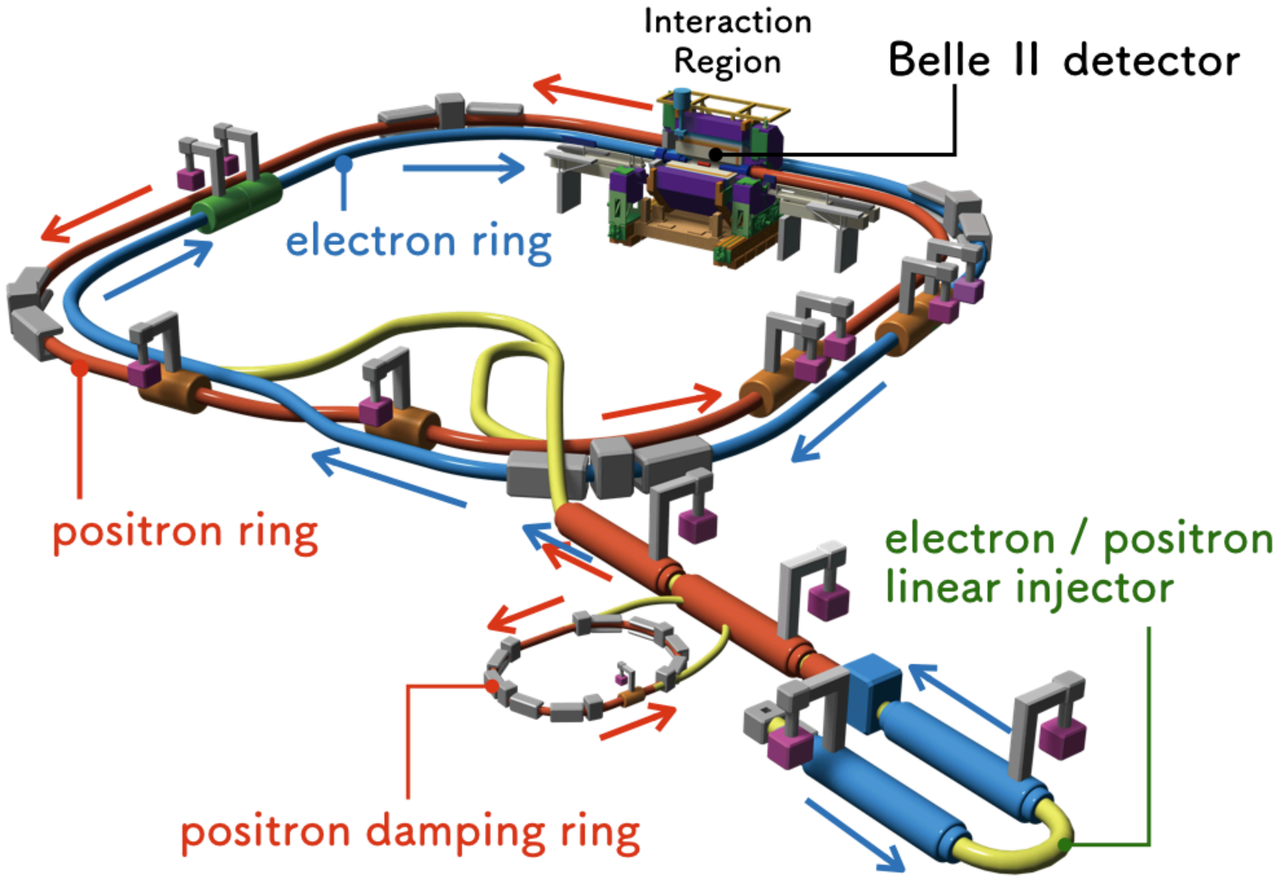
Belle II Preliminary

Belle II website
Twitter

- Belle II is an exciting experiment and taking data as we speak
- Lots of work in progress for the dark photon search at Belle II
- Thank you for listening ☺️

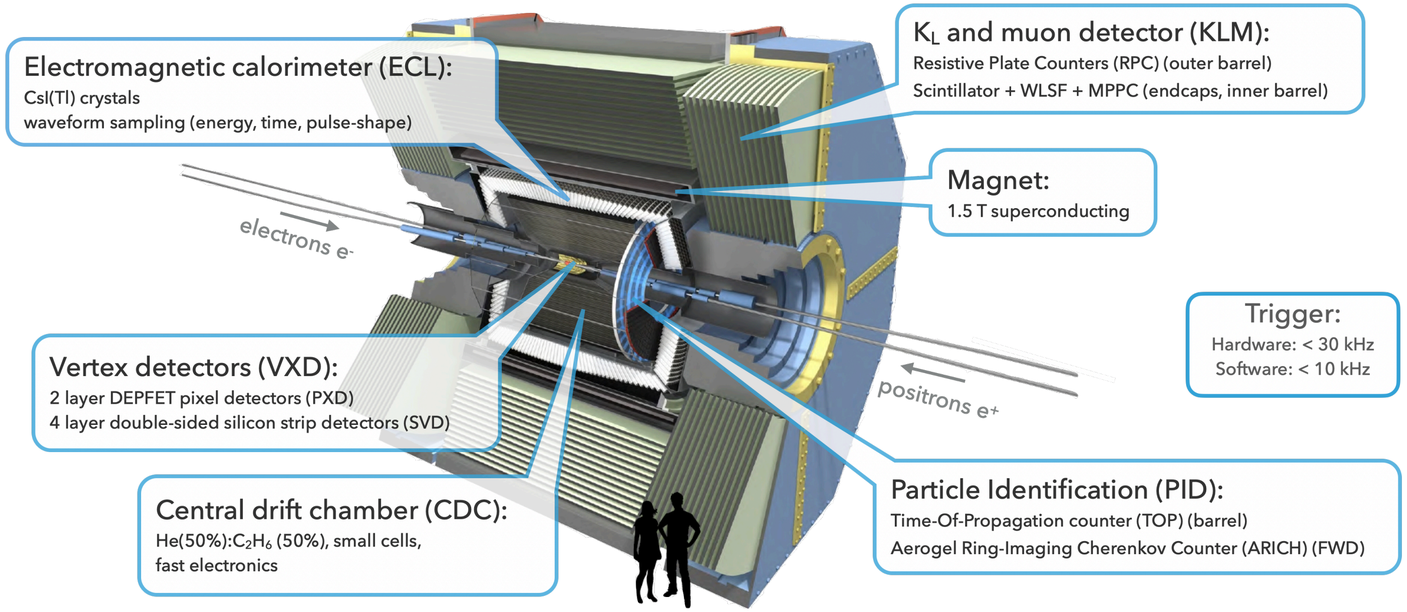
Backup Slides

SuperKEKB



- SuperKEKB is an asymmetric particle accelerator with a circumference of 3 km located in Japan.
- Operates at resonance energy of $\Upsilon(4S)$ at $10.58\ \mathrm{GeV}$.
- New world record for instantaneous luminosity of $2.4 \times 10^{34} cm^{-2} s^{-1}$ was achieved in June 2020.

Belle II



- TheBelleII experiment aims to make precise measurements of CP violation in the weak sector, as well as find New Physics Beyond the Standard Model of Particle Physics.
- Current aim is to collect $50ab^{-1}$ by 2031.
- International collaboration with nearly 1000 physicist and engineers from 115 institutions in 26 countries.

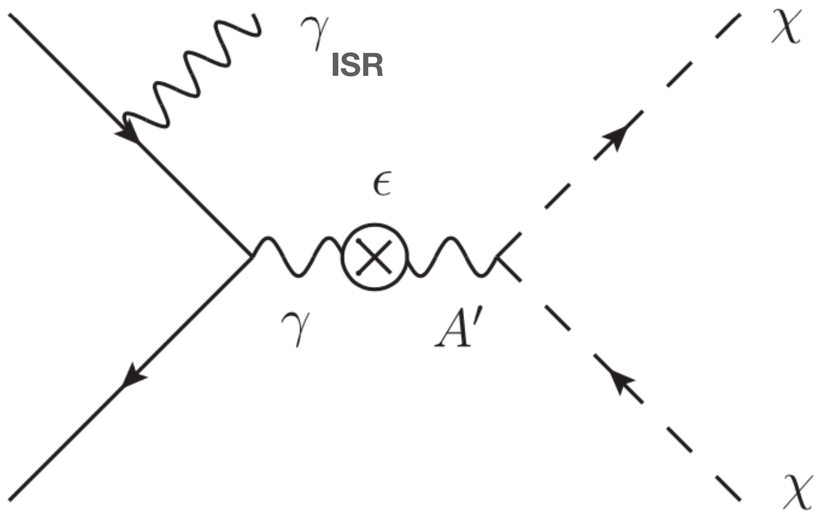
Searches in Other Experiments

- Direct competitor: BaBar

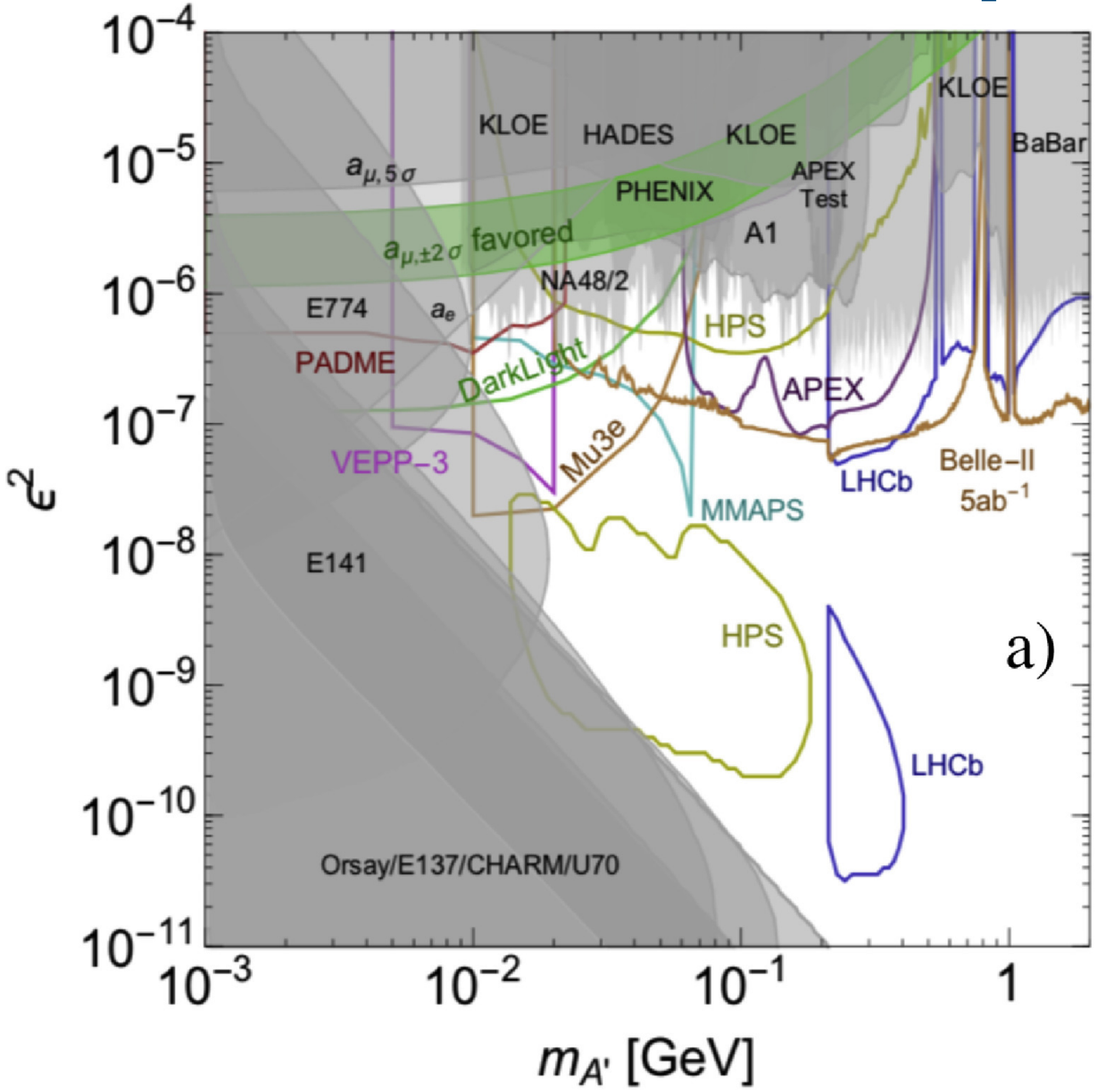
Phys. Rev. Lett.119 (2017) 13, 131804

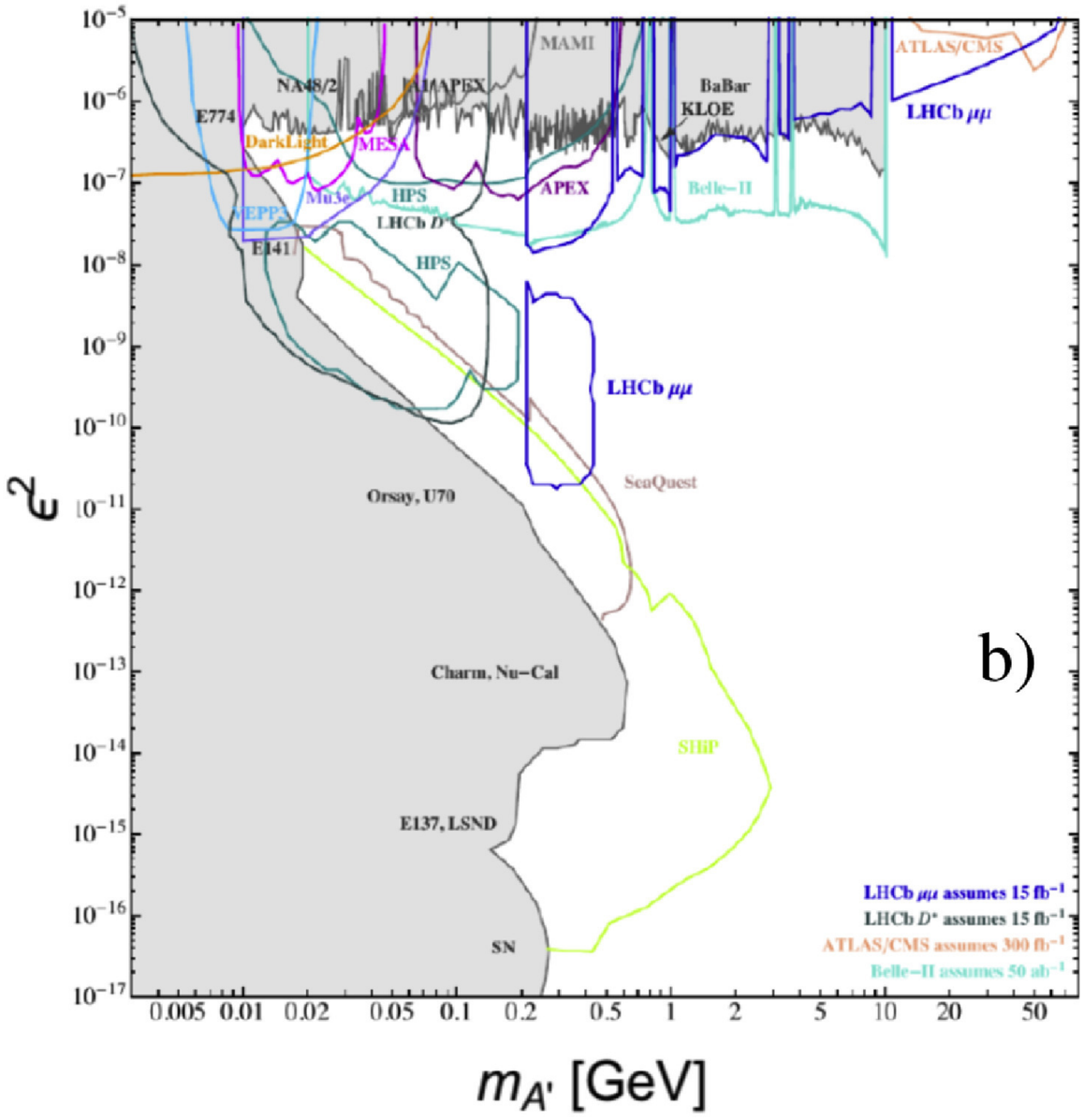
- Complementary search: NA64

https://arxiv.org/abs/1906.00176

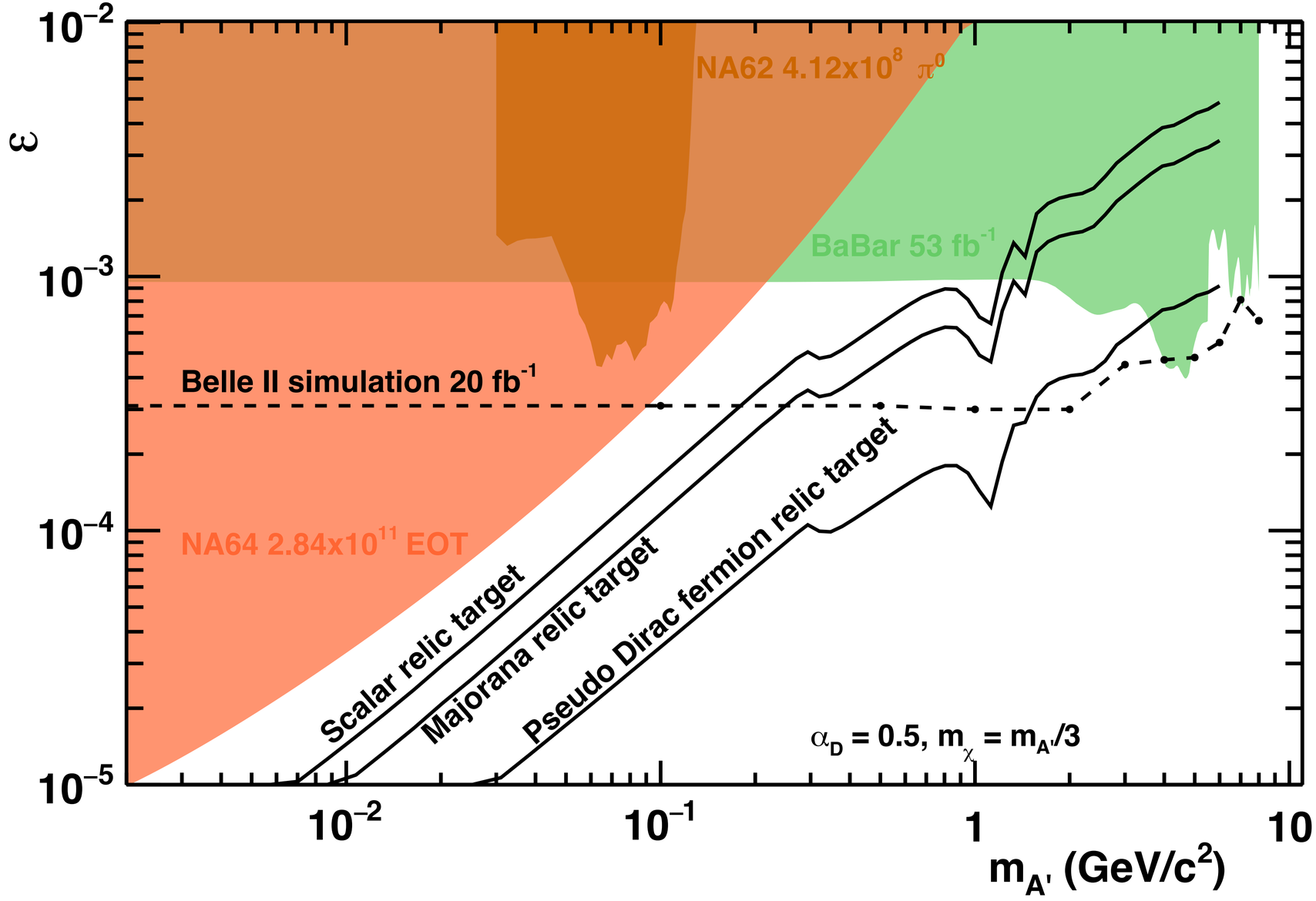


Searches in Other Experiments

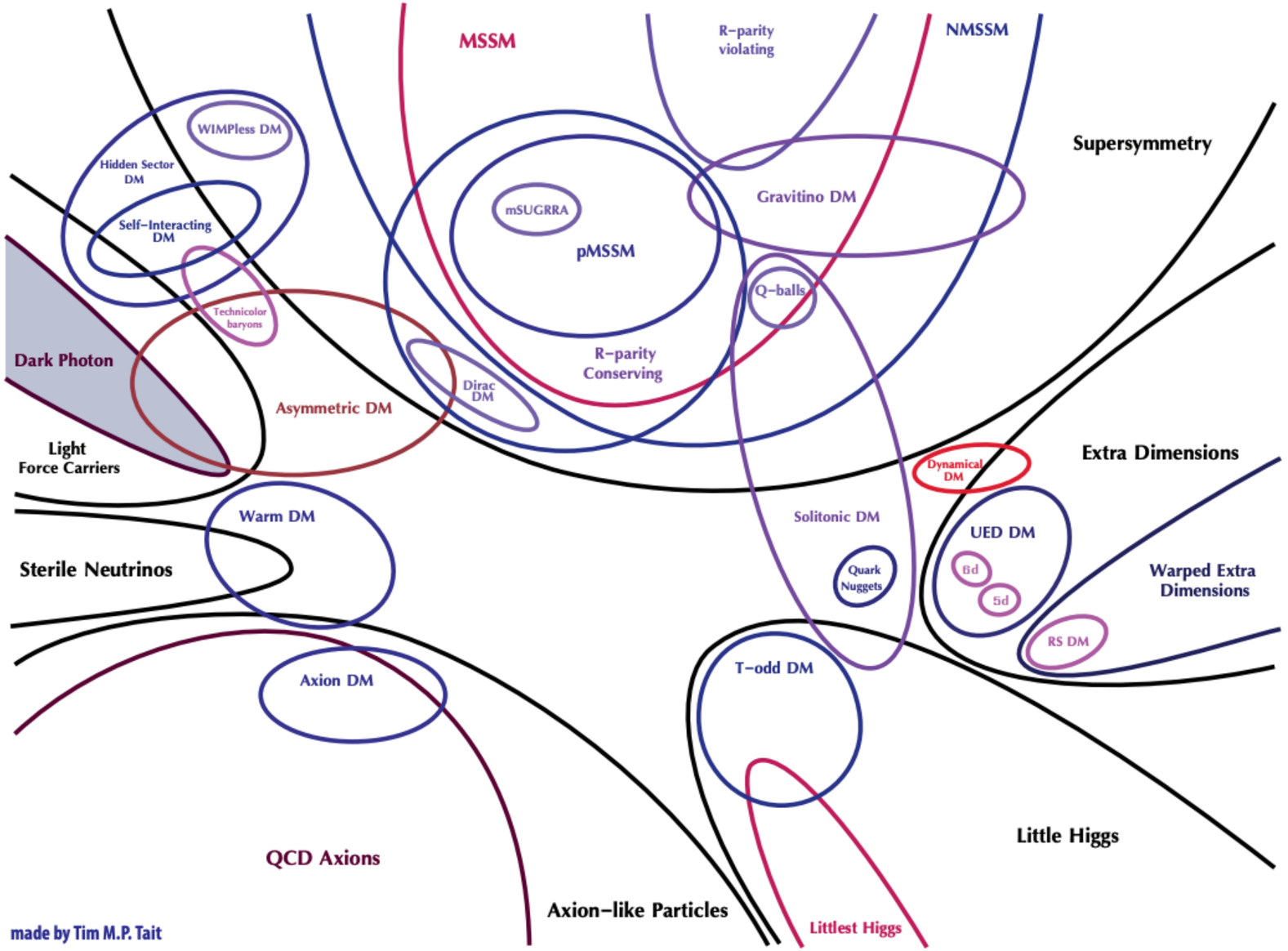




Sensitivity



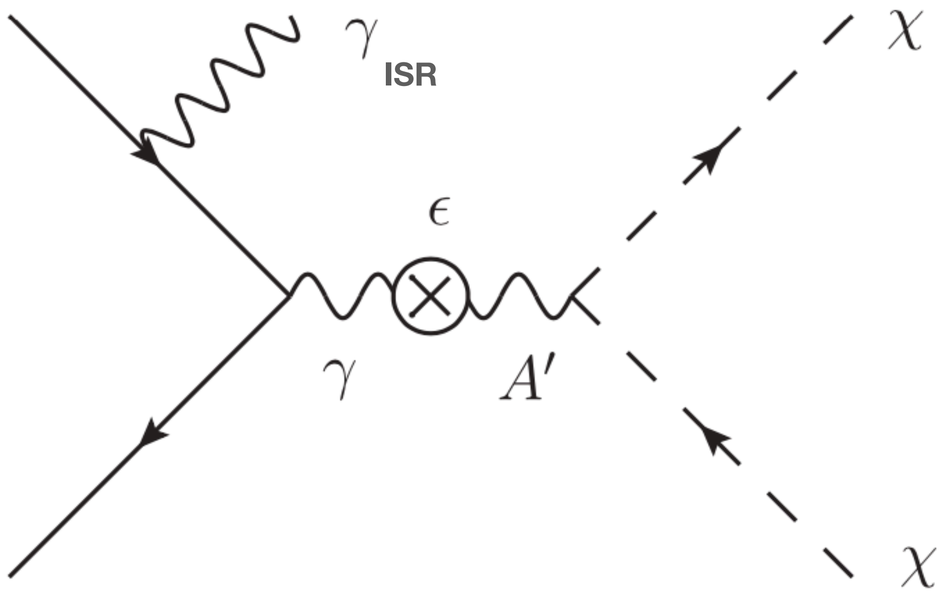
Dark Sector Theory



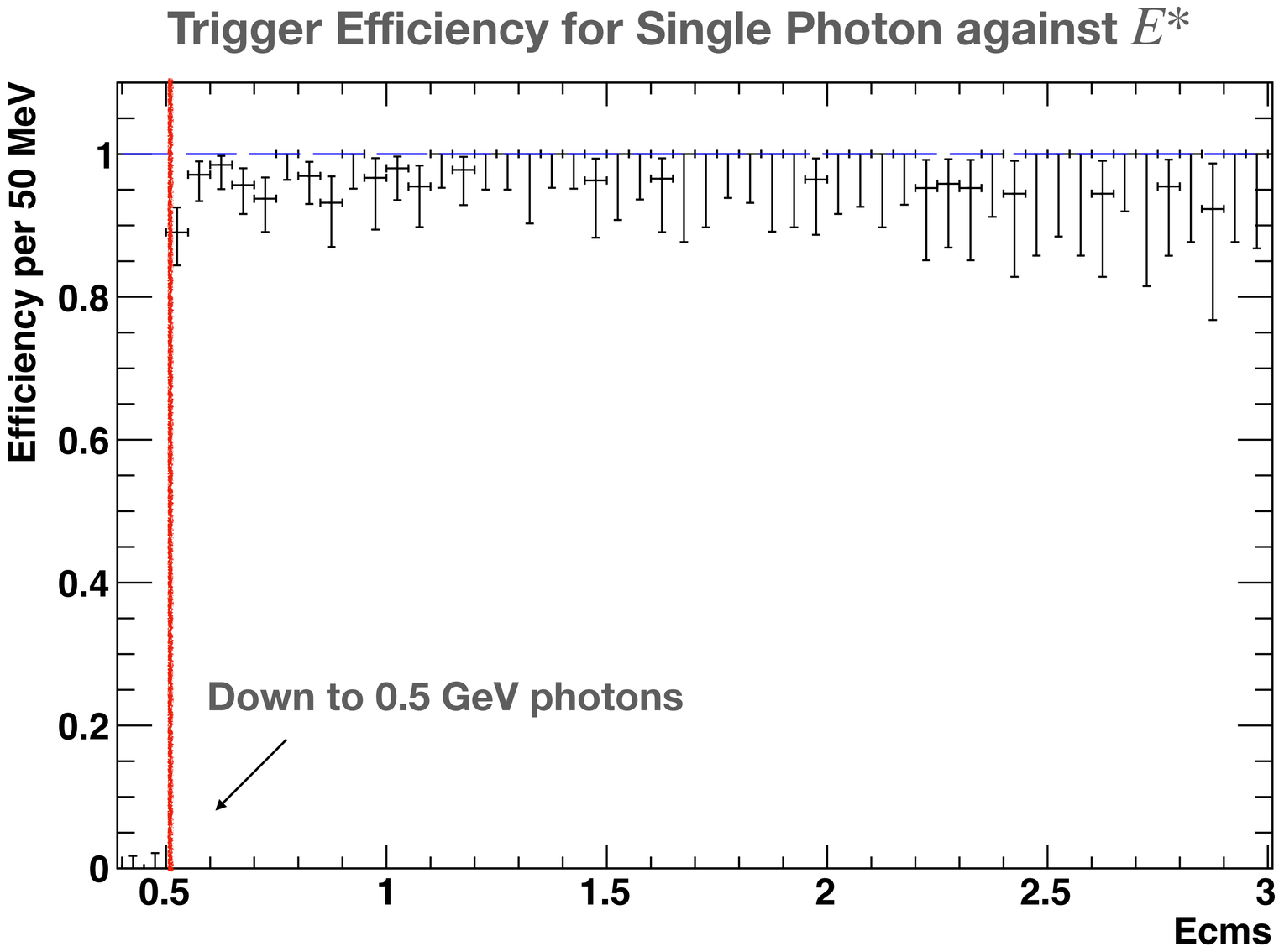
Feng J.L. et al., Planning the future of U.S. Particle Physics (Snowmass 2013): Chapter 4: Cosmic Frontier, 2014, Community Summer Study 2013: Snowmass on the Mississippi (CSS2013) Minneapolis, MN, USA, July 29-August 6, 2013, [arXiv:hepex/1401.6085]

Dark Photon Theory

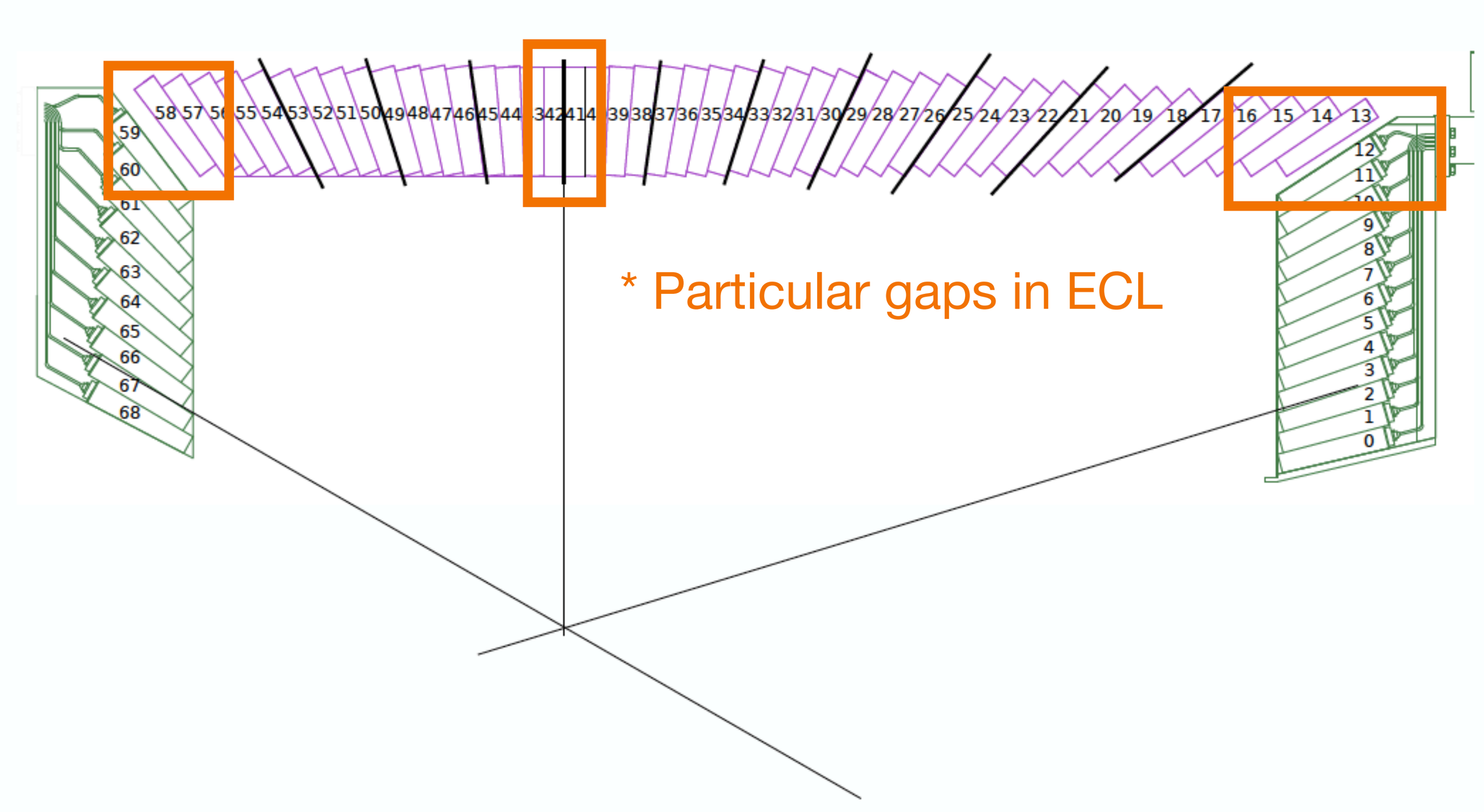
- Dark photon has a small coupling to the EM current from kinetic mixing between the SM hyper charge and A' field strength tensors
- Mixing induced coupling is suppressed by ϵ, providing a portal which dark photons interact with SM particles
- 3 unknown parameters: strength of kinetic mixing, dark photon mass, and decay branching fraction of the dark photon into invisible dark sector final states



Trigger Efficiency



Electromagnetic Calorimeter Geometry



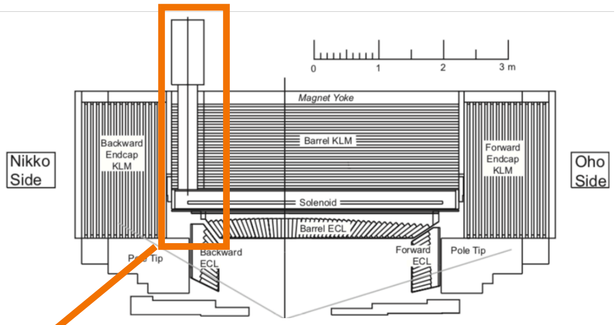
Event Selection of $e^+e^- \to \gamma\gamma$

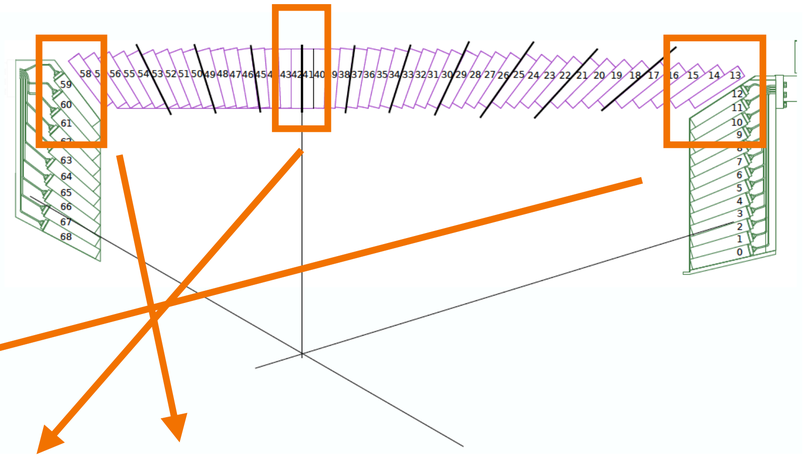
- use 2 most energetic photons per event
- $4.5 < E_0^* < 7.0$ GeV
- $0.1 < E_1^* < 7.0$ GeV
- no charged tracks with $p_t > 0.2$ GeV/c coming near from IP
- $\Delta\phi^* > 178°$
- $178° <$ theta sum* $< 182°$

- Using tag and probe method for both gg events:
  - Tag: E* > 4.5 GeV
  - Probe: Must be in barrel (Theta ID 14 to 57)
- Event can contain two tags/two probes

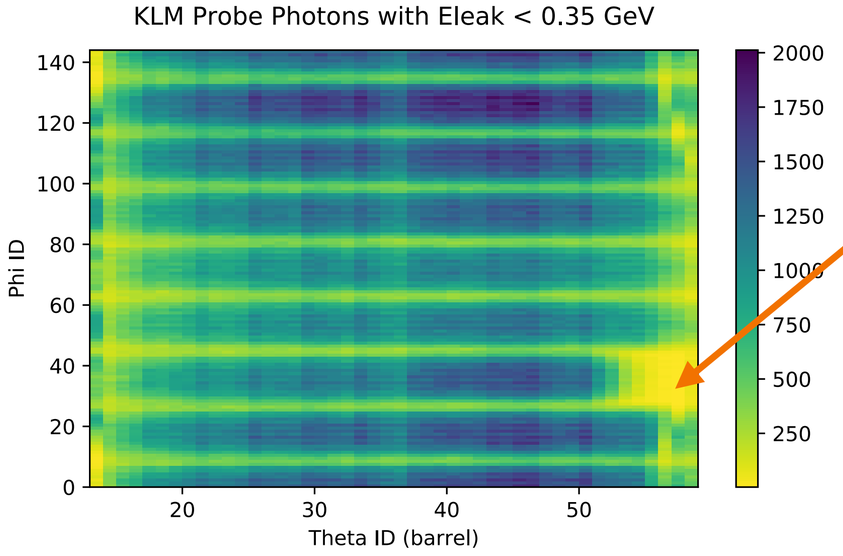
Detector Efficiency

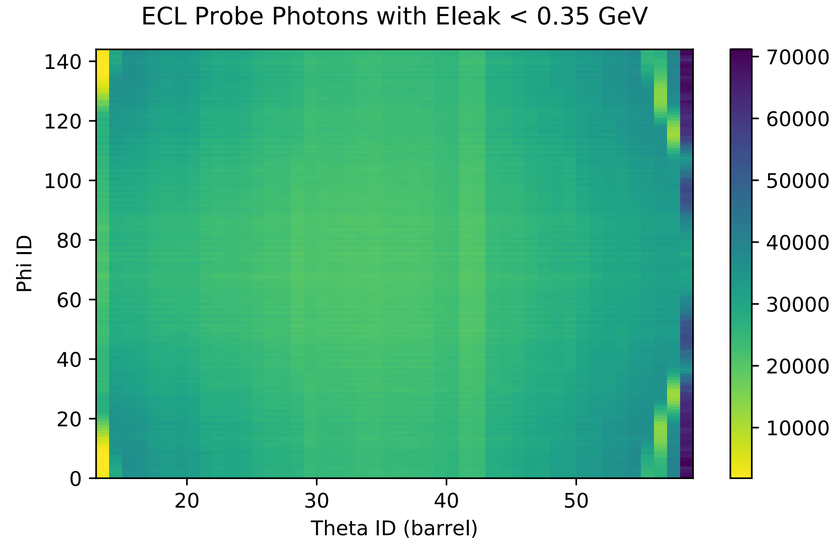
E_{leak} < 0.35 GeV (very little leakage)

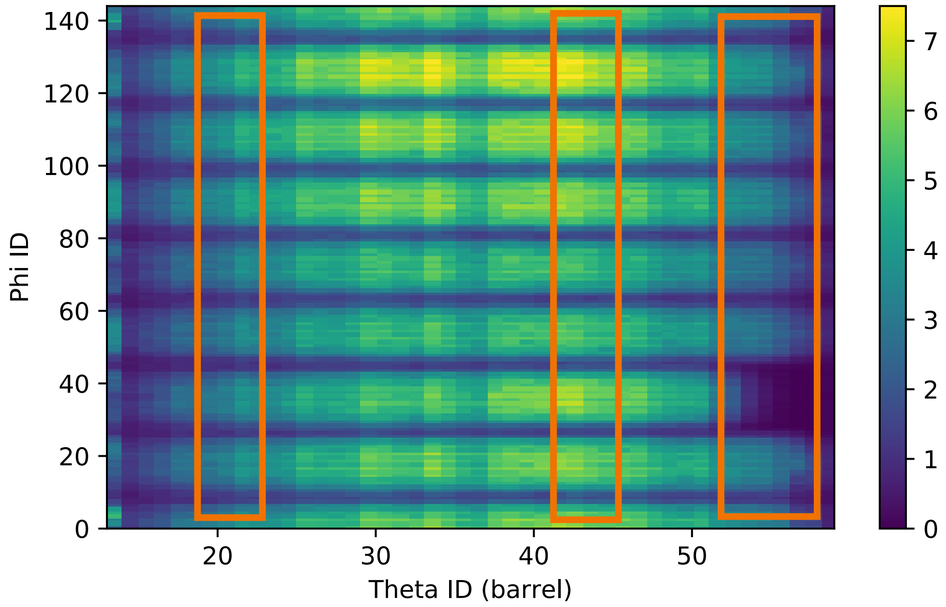




*Each bin is a crystal







Belle II Simulation Preliminary

Belle II Simulation Preliminary

Detector Efficiency

*Each bin is a crystal

E_{leak} > 2.8 GeV (very high leakage)