Search for a massless dark photon in $K_L \rightarrow \gamma + dark\ photon$ at the KOTO experiment

Tong Wu[1], Yee Bob Hsiung[1], Yu-Chen Tung[1]

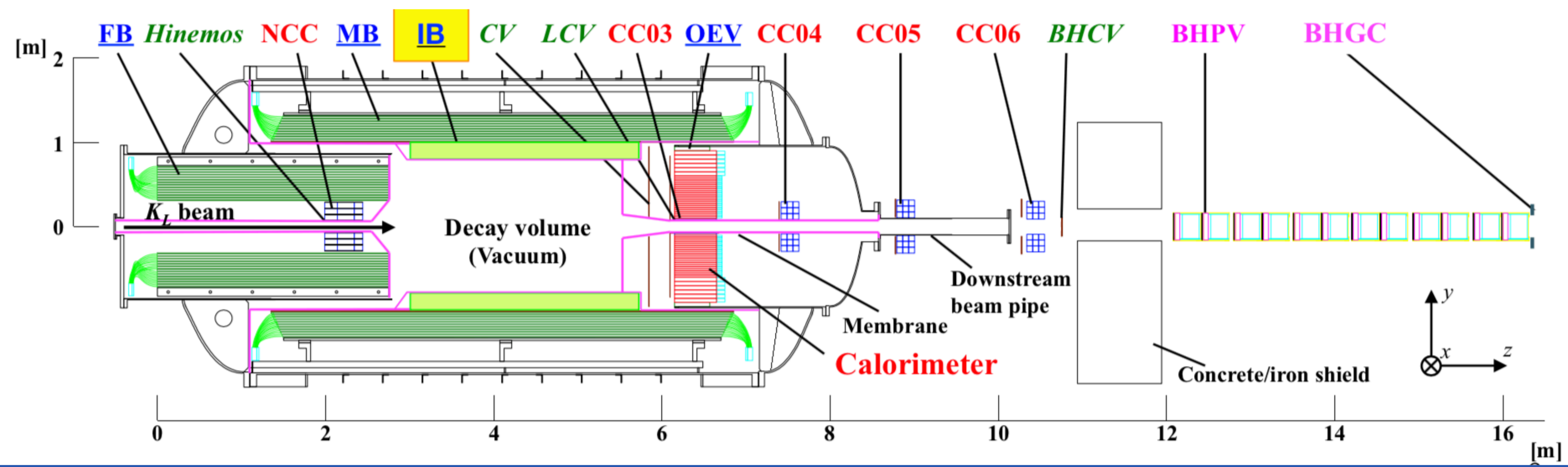
[1]National Taiwan University

Introduction

- The Dark sector has been explored in high energy physics for several years. There are many experiments searching for the massive dark photon(A') but nothing has been observed so far.
- The massless dark photon($\bar{\gamma}$) is different from the massive one because it has no direct mixing with the ordinary photon.
- Several massless dark photon decay modes are possible explored in the KOTO experiment, one of these is $K_L^0 \rightarrow \gamma\bar{\gamma}$.
- In some theoretical predictions, the BR($K_L^0 \rightarrow \gamma\bar{\gamma}$) can be enhanced to $\mathcal{O}(10^{-3})$[1], which is well within the sensitivity of KOTO.

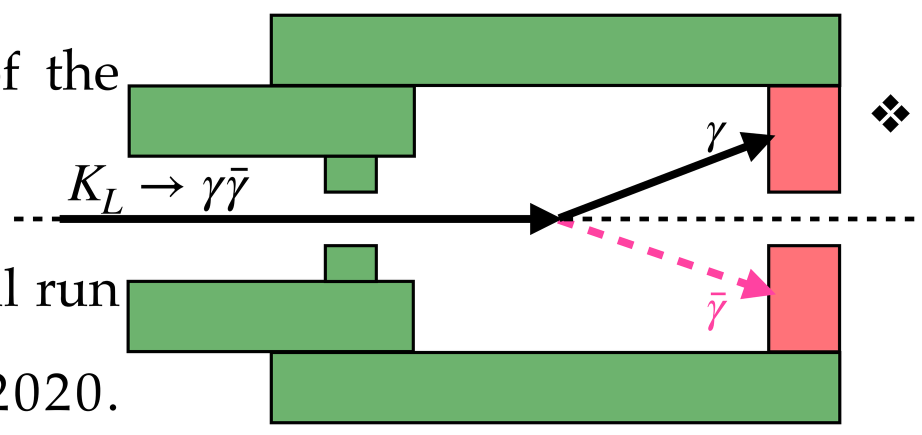
KOTO Detector @JPARC

- The KOTO experiment aims to search the rare kaon decay $K_L \rightarrow \pi^0\nu\bar{\nu}$.
- Single event sensitivity of the $K_L \rightarrow \pi^0\nu\bar{\nu}$ was estimated to be 7.2×10^{-10} in recent results[2].
- KOTO used the hermetic system to enclose the kaon decay region.
- KOTO detector consists of Calorimeter and Veto detectors.
- Calorimeter is comprised of 2716 undoped cesium iodide crystals (CsI) with a radius of 950 mm and a depth of 500 mm.
- Neutral hadron beam, K_L momentum distribution peaks at 1.4 GeV/c

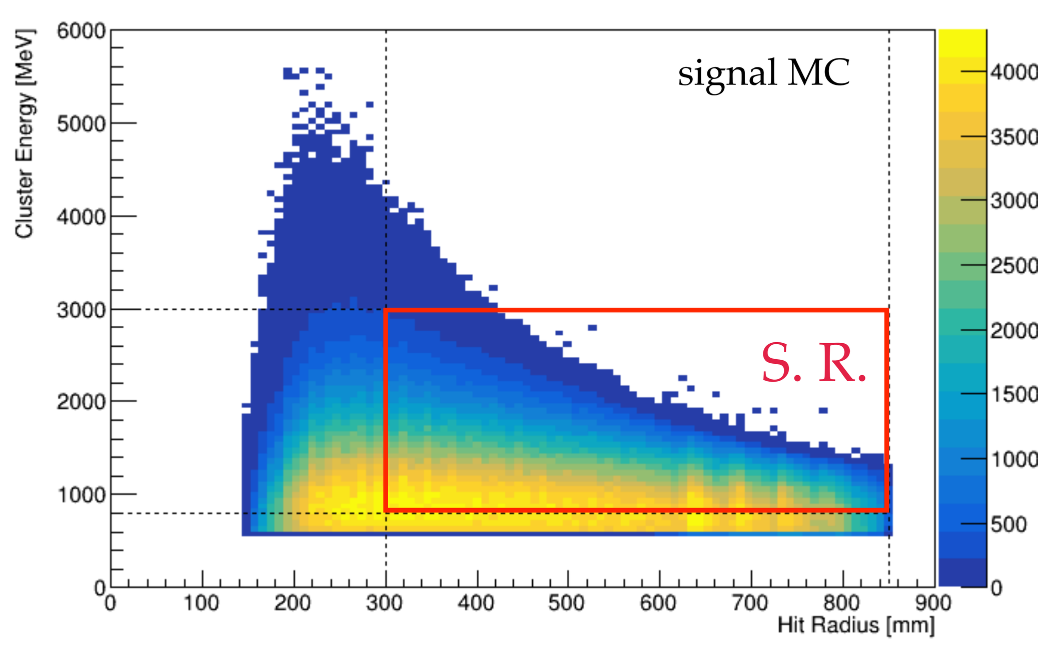


$K_L \rightarrow \gamma\bar{\gamma}$

- Signal signature is one photon cluster in CSI with no in-time hit in the rest of the detector.
- For this study, we took a 2-hour special run with single cluster trigger in 2020. Approximately 9.14×10^9 K_L decays.

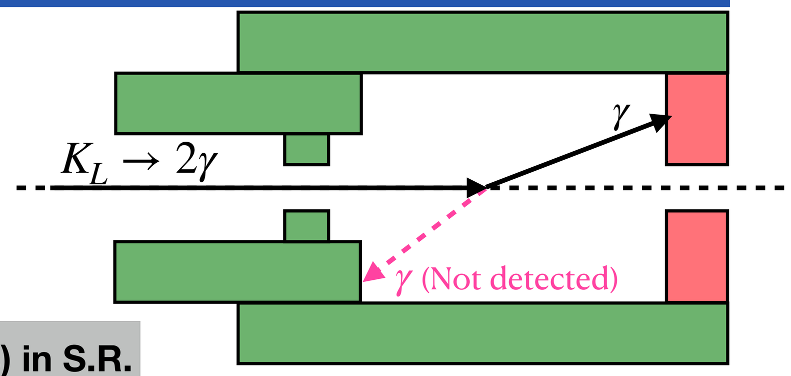


- The challenge in this study was the lack of kinematic variables.
  - Only the energy & radius of one cluster in CsI.
- Signal region: 300 < HitRadius < 850mm, 800 < ClusterEnergy < 3000MeV
- Backgrounds
  - K_L decays
  - Beam neutrons
    - dominant background.



KL background

- K_L background estimation
  - $\#(K_L \rightarrow 2\gamma) \approx 1.5 \pm 0.39$
  - #(other K_L decays) < 7.74 (90% C.L.)

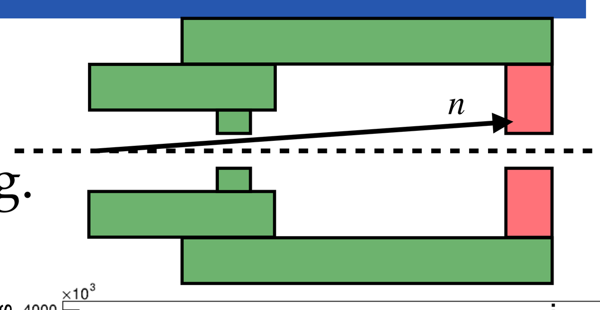


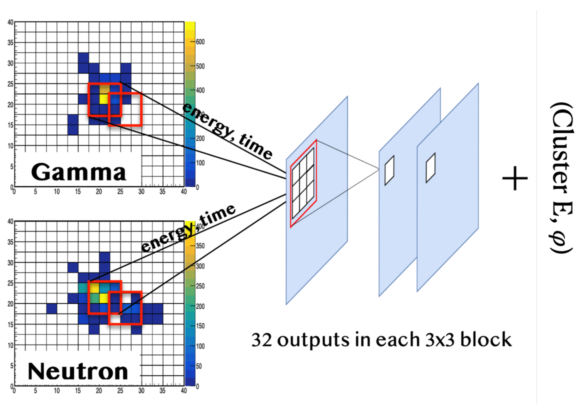
Channel	#Generated	Ratio to #data	Est. (#events) in S.R.
$K_L\rightarrow2\gamma$	5×10^7	10.00	1.5 ± 0.39 (15)
$K_L\rightarrow2\pi$	5×10^7	6.33	< 0.363
$K_L\rightarrow3\pi$	1.75×10^9	0.98	< 2.345
K_{e3}	5×10^9	1.35	< 1.705
$K_{\mu3}$	2.5×10^9	1.01	< 2.274
$K_L\rightarrow\pi^+\pi^-\pi^0$	2.5×10^9	2.18	< 1.054

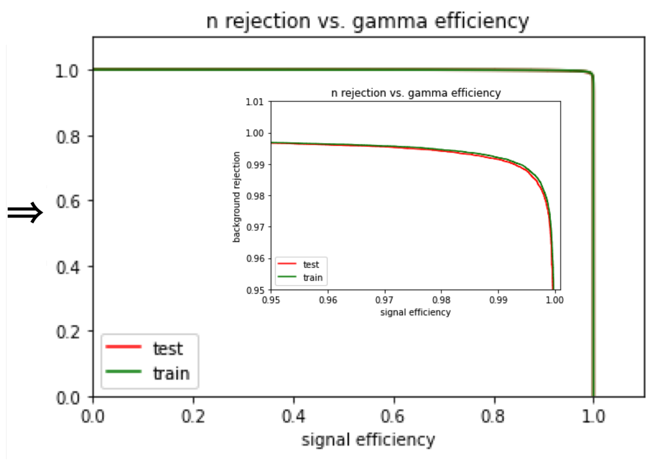
- K_L background is negligible if BR ~ $\mathcal{O}(10^{-3})$, #signal ~ $\mathcal{O}(10^5)$

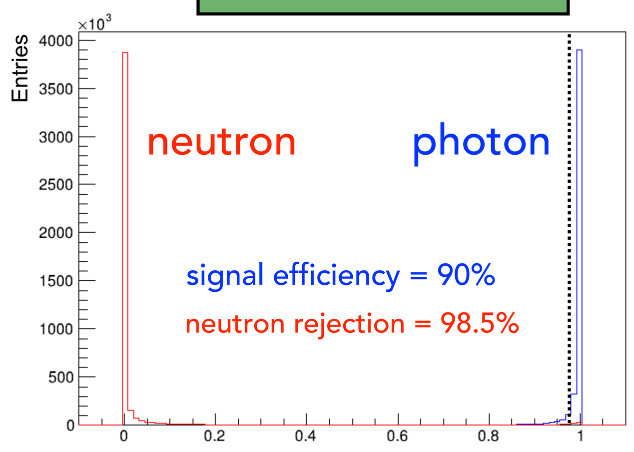
Neutron background

- Three tools to suppress neutron background.
- Cluster shape discrimination with deep learning.

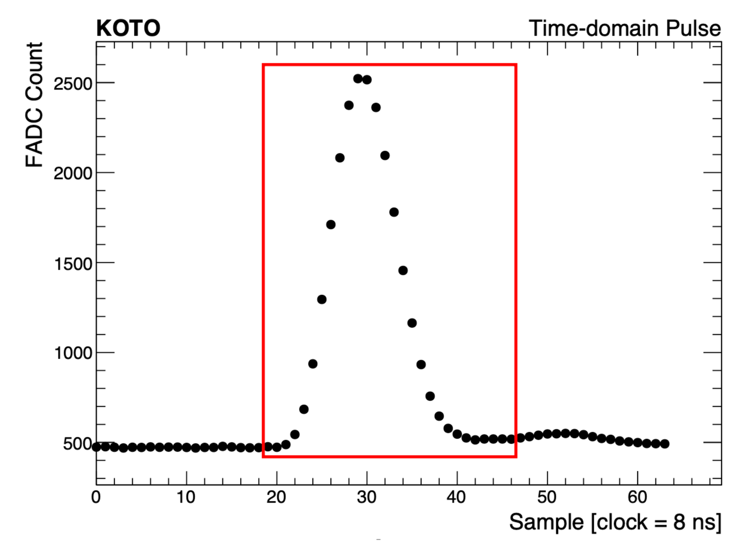


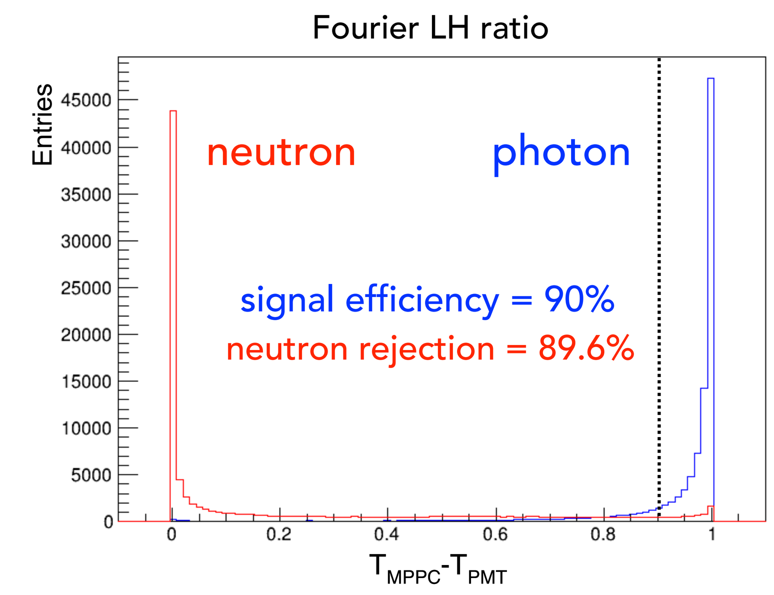




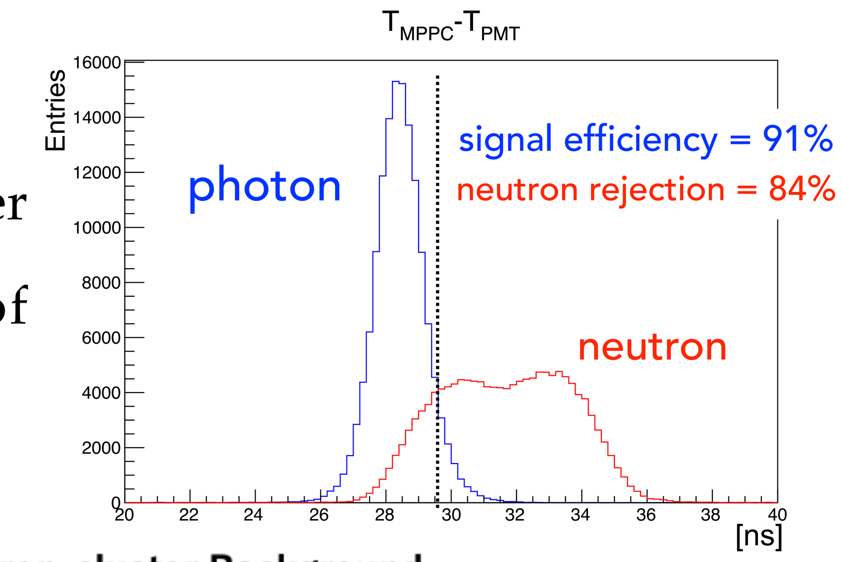


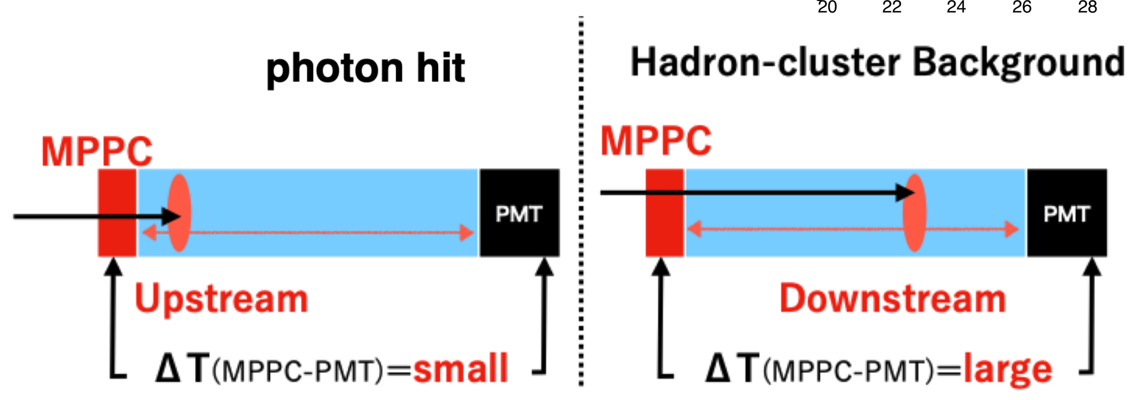
- Pulse shape discrimination by using Fourier analysis
  - neutron and gamma pulse shapes are different.
  - Apply FFT to the ADC raw pulse, then extract the differences between the neutron and gamma in the frequency domain.





- Both-end readout
  - radiation length of photon is shorter than the interaction length of neutron, resulting in a different ΔT.





Summary

- Performing the massless dark photon search in $K_L \rightarrow \gamma\bar{\gamma}$ decay at KOTO
- K_L background is negligible if BR ~ $\mathcal{O}(10^{-3})$.
- Neutron background reduction ~ $\mathcal{O}(10^{-4})$.
- Expect to prob the region : $\mathcal{O}(10^{-8})$ < BR < $\mathcal{O}(10^{-3})$.

[1] Su, JY., Tandean, J. Kaon decays shedding light on massless dark photons. Eur. Phys. J. C 80, 824 (2020).

[2] J.K. Ahn et al. (KOTO Collaboration), Phys. Rev. Lett. 126, 121801 (2021).