Dark Sector Studies with KOTO

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on behalf of KOTO collaboration

Motivations

- We proposed to search for massless dark photon ($\bar{\gamma}$) in neutral kaon decays.

- As suggested by arXiv:2006.05985 [hep-ph], $\bar{\gamma}$ might happen in some kaon decays within the sensitivity of KOTO.

- The upper bonds were derived by assuming $ds\bar{\gamma}$ process with constraints from Hyperons decays:

Potential searches at KOTO

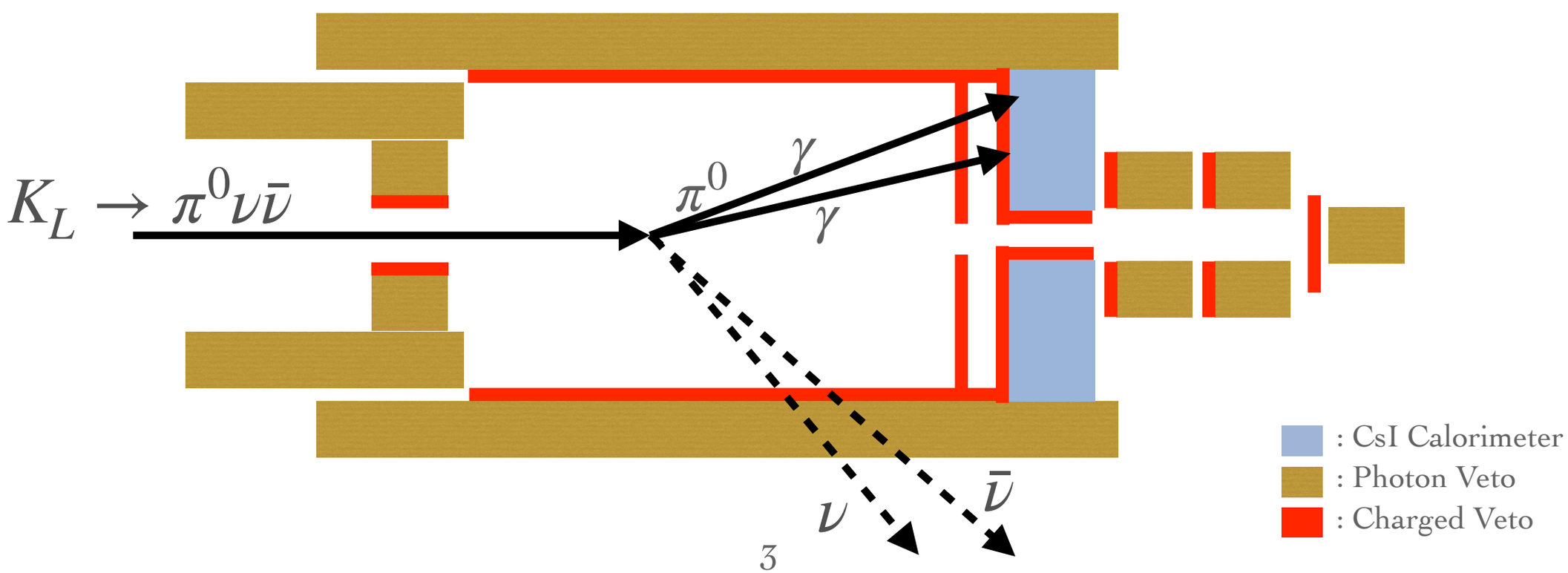
$$\boxed{\mathcal{B}(K_L \to \gamma\bar{\gamma}) < 1.2 \times 10^{-3},}$$
$$\boxed{\mathcal{B}(K_L \to \pi^0\gamma\bar{\gamma}) < 1.0 \times 10^{-6},}$$
$$\mathcal{B}(K_L \to \pi^+\pi^-\bar{\gamma}) < 9.8 \times 10^{-6},$$
$$\mathcal{B}(K^- \to \pi^-\gamma\bar{\gamma}) < 5.6 \times 10^{-7},$$

$$\mathcal{B}(K_S \to \gamma\bar{\gamma}) < 2.1 \times 10^{-6},$$
$$\mathcal{B}(K_S \to \pi^0\gamma\bar{\gamma}) < 1.8 \times 10^{-9},$$
$$\mathcal{B}(K_S \to \pi^+\pi^-\bar{\gamma}) < 1.7 \times 10^{-8},$$
$$\mathcal{B}(K^- \to \pi^-\pi^0\bar{\gamma}) < 2.4 \times 10^{-6}.$$

KOTO Experiment

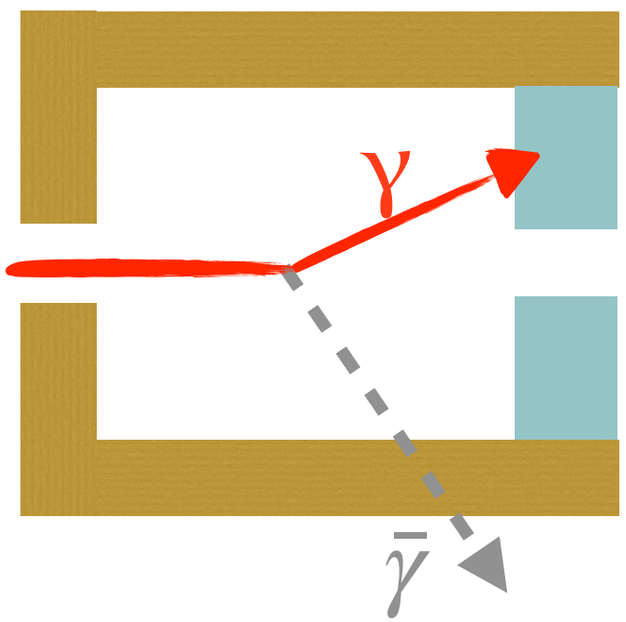
- KOTO is a running experiment at J-PARC, aiming to measure the $K_L \rightarrow \pi^0 \nu\nu$ decay.

- Hermetic detector also provides good opportunities for searching decays with dark photon.

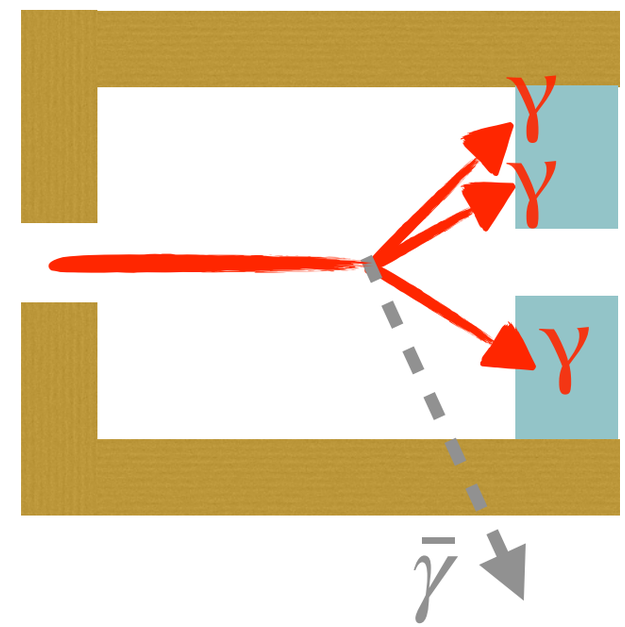


Potential By-products

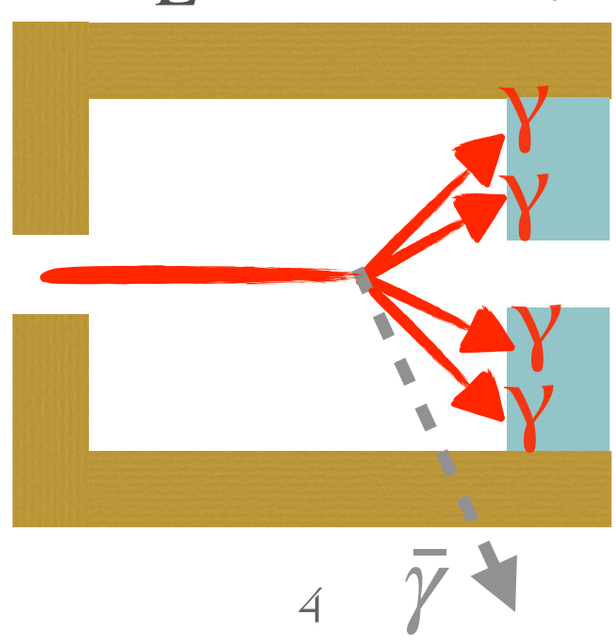
$K_L \to \gamma\bar{\gamma}$



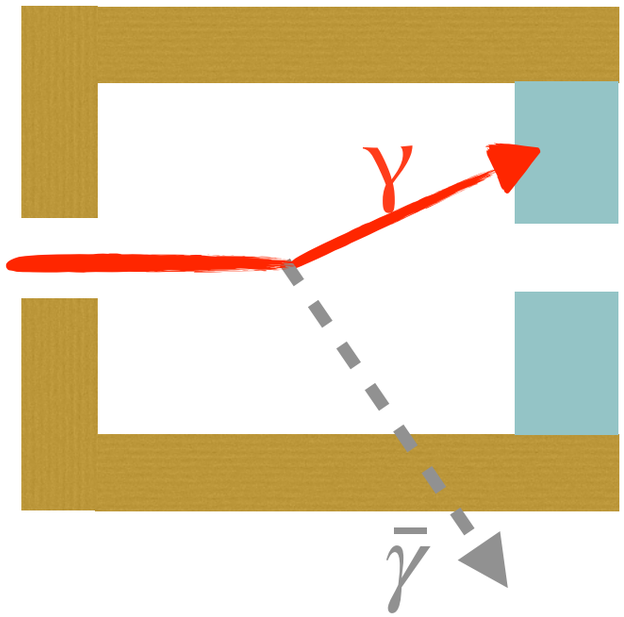
$K_L \to \pi^0\gamma\bar{\gamma}$



$K_L \to \pi^0\pi^0\bar{\gamma}$



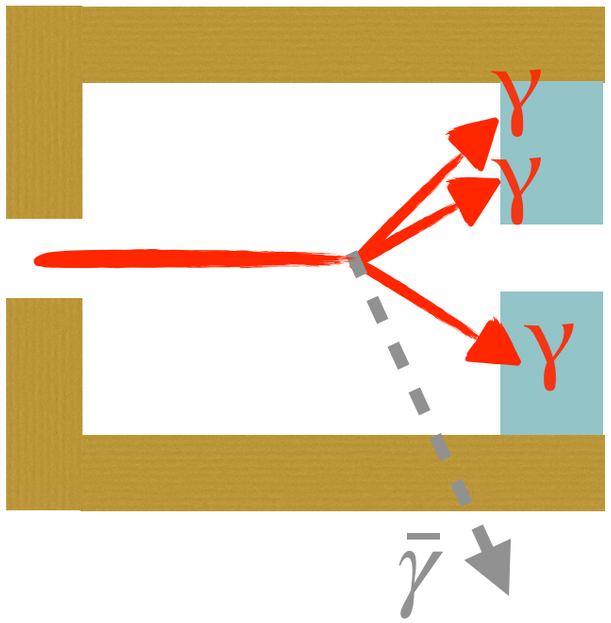
$K_L \to \gamma\bar{\gamma}$



- Backgrounds:
  - $K_L \to \gamma\gamma$ with one gamma missing.
  - Beam neutrons, suppressed by ~O(10^{-4}-10^{-3})
    - Cluster shape/Pulse shape discriminations.
    - Shower depth measurement with CsI dual-end readout (explained later).
  - Upstream decays with only a photon entering the detector.
- Status:
  - MC study is on-going.
  - Dedicated data was taken in Summer of 2020 for studying BG level at SES(10-3)
    - Will take more data in Spring of 2021 if BG is manageable.

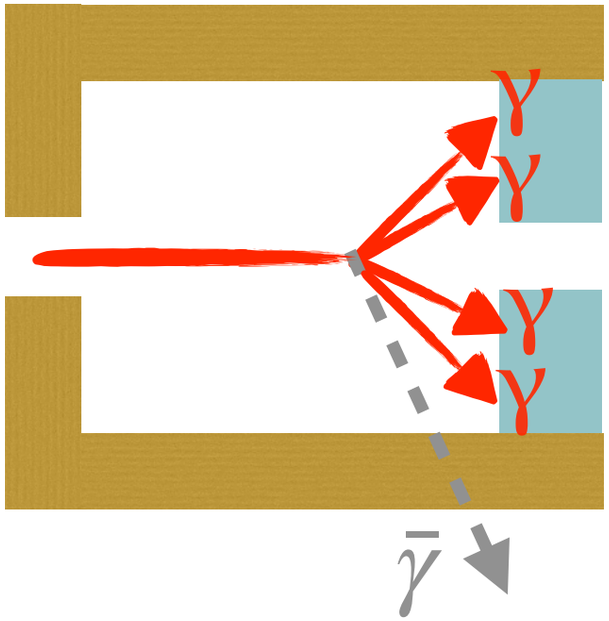
- Backgrounds:
  - $K_L \to \pi^0\pi^0$ & $K_L \to \pi^0\pi^0\pi^0$ with missing gammas.
- Data:
  - Common data for $K_L \to \pi^0\gamma$ [PRD.102.051103].

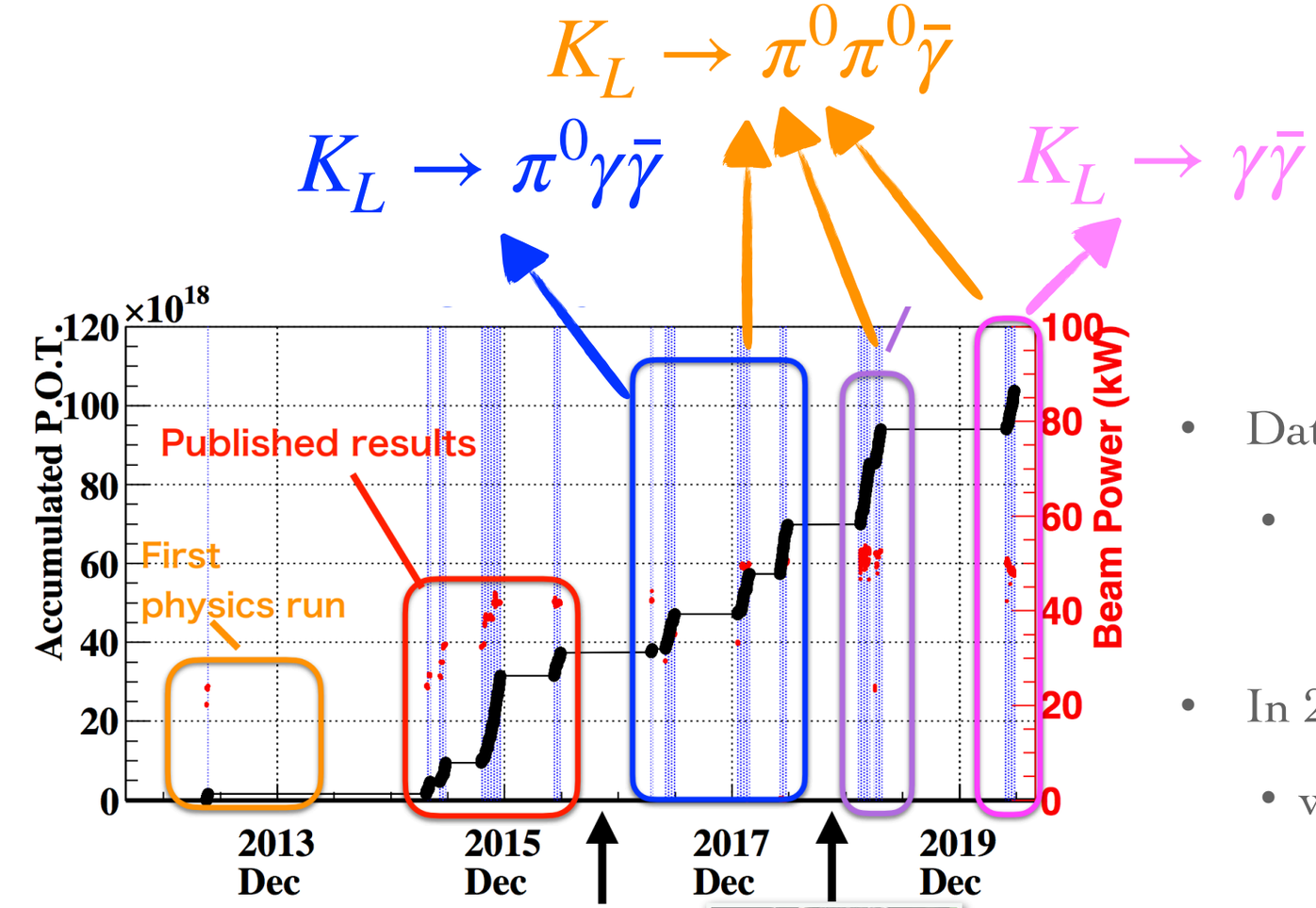
$K_L \to \pi^0\gamma\bar{\gamma}$

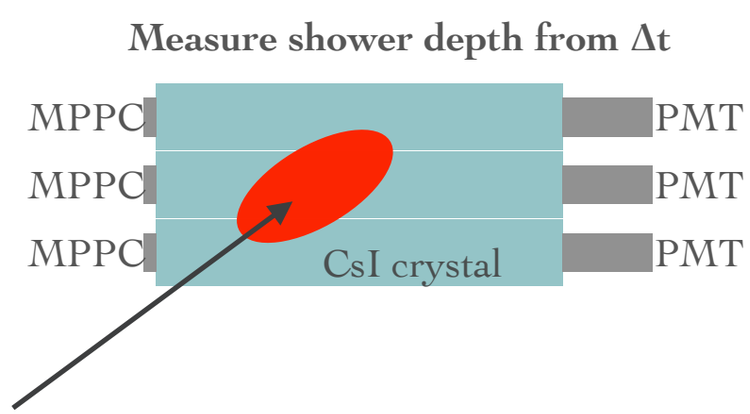


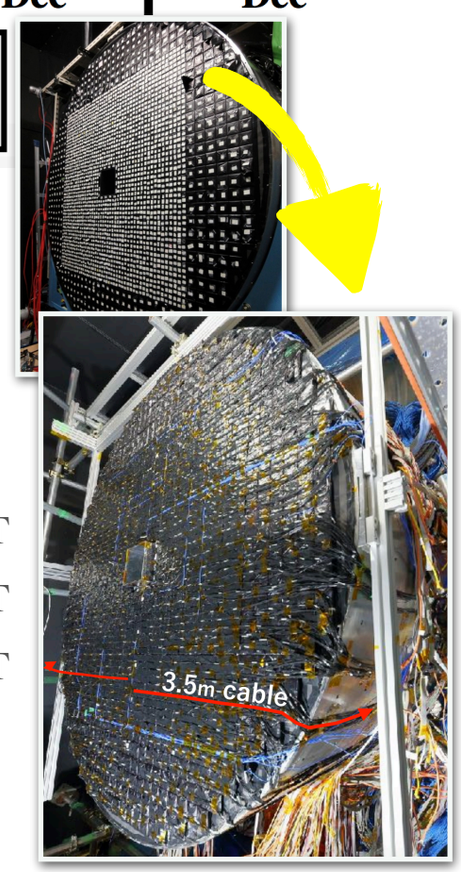
- Backgrounds:
  - $K_L \to \pi^0\pi^0\pi^0$ with missing gammas.
  - $K_L \to \pi^0\pi^0$ in high kaon P_T.
- Data:
  - Common data for kaon flux calculation.

$K_L \to \pi^0\pi^0\bar{\gamma}$









- Data are available for dark photon searches.
  - Analysis of $K_L \to \gamma\bar{\gamma}$ is on-going.
- In 2019, major upgrade in CsI readout system.
  - will explore new analysis techniques, such as:
    - optimal neutron rejection with dual-end readout.
    - photon angle reconstruction with shower profile.
- One year shutdown from summer of 2021 for J-PARC accelerator upgrade.
  - will have two-month run before the shutdown.
  - might collect more data for $\bar{\gamma}$ searches.

Summary

- KOTO is sensitive to some potential searches of massless dark photon, suggested by arXiv:2006.05985 [hep-ph]
- Old data are available for the searches addressed in LOI.
  - Analyses are at the start-up/discussion stage.
- Will take more data before J-PARC shutdown in 2021 if new detector is proven to have big impacts on dark photon searches.