Constraints on the kinetic mixing parameter for dark photons based on CDEX-10 experiment

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Outline

- Background
- CDEX-10 experiment
- Constraints
  - Solar dark photons
  - Dark photon dark matter
- Outlook
- Conclusion

Background

Dark Photon :SM is extended via introducing an extra $U(1)_V$ boson mixing with photon. Its effective Lagrangian below the electroweak scale:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}F_{\mu\nu}V^{\mu\nu} + \frac{m_V^2}{2}V_\mu V^\mu + eJ_{em}^\mu A_\mu$$

The Lagrangian for the interaction between dark photon and SM photon:

$$\mathcal{L}' = -\kappa e J_{em}^\mu V_\mu$$

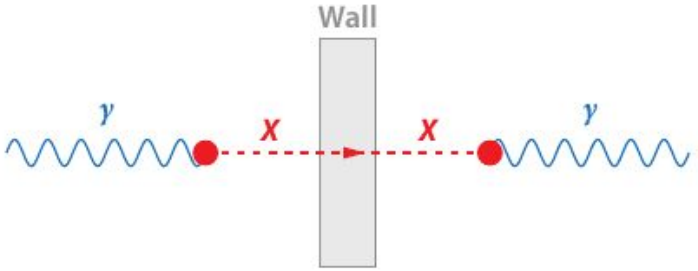
Weak interactions between dark photon and SM photon make dark photon as a possible portal between hidden sector and SM sector

Cold DM candidate

Background

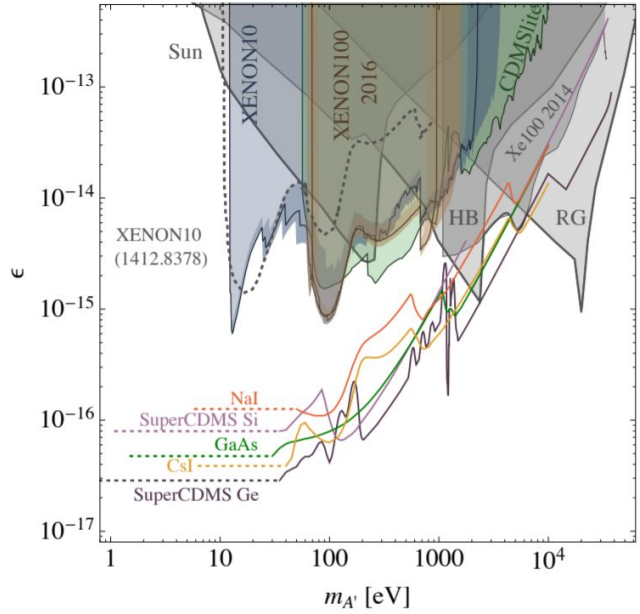
Heavy dark photons

1. colliders : annihilation, meson decay
2. Beam-dump : Bremsstrahlung, Drell-Yan
3. …



Light dark matter

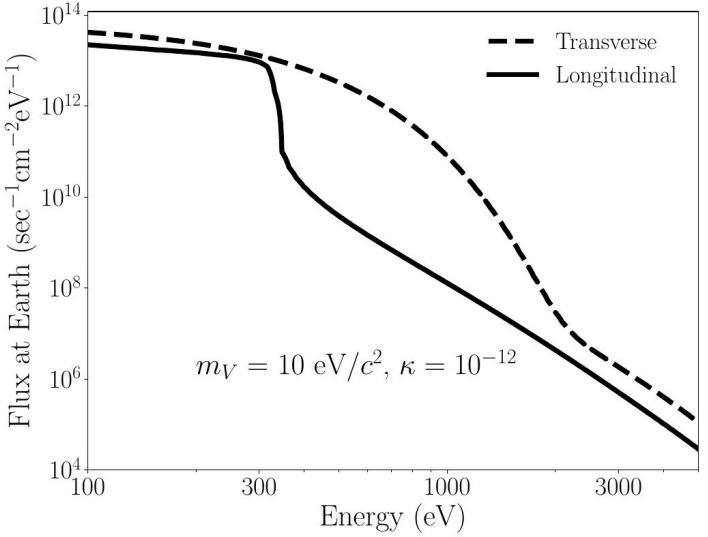
1. Nuclear experiments
2. Light-Shining through the Wall (LSW)
3. Helioscopes
4. Direct detection experiments on DM
5. …



Direct detections on dark photons focus on those with masses smaller than keV/c^2

Solar Dark Photon

1. The strongest natural gamma source at Earth
2. Depends on the solar model
3. **low energy and light mass** (at sub-eV~eV scale)
4. Transverse and Longitudinal modes
5. Its count is proportional to κ^4 (kinetic mixing parameter)
6. **Decay repadily as mass increases**

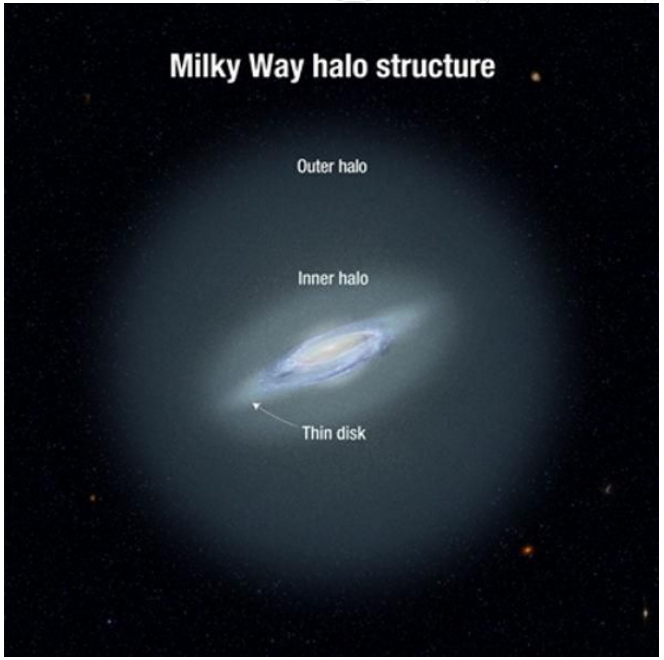


Low Threshold and Background

Background

Dark Photon DM

1. Light DM candidate
2. Mass at **eV~keV** scale
3. Based on the DM halo assumption
4. Converted into photns to be detected
5. Its count is proportional to κ^2



https://qph.fs.quoracdn.net/main-qimg-0a12e8cc3a15be232642128cdba1db06-c

Low Threshold and Background

CDEX-10 experiment

3strings * 3 PPCGe detectors immersed in the liquid nitrogen as cooling medium

The dataset of C10-B1 and C10-C1detectors are chosen

C10-B1: 1. Exposure: 205.4 kg-day

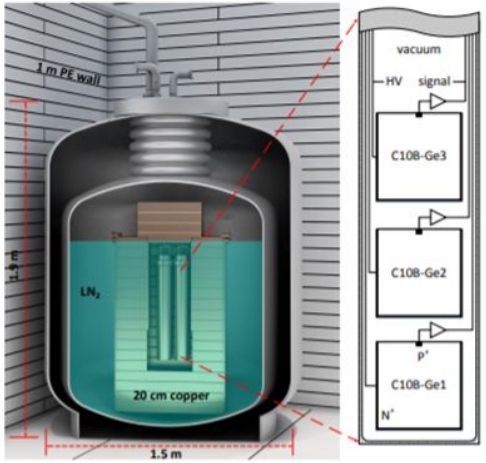
2. Threshold: 160 eVee

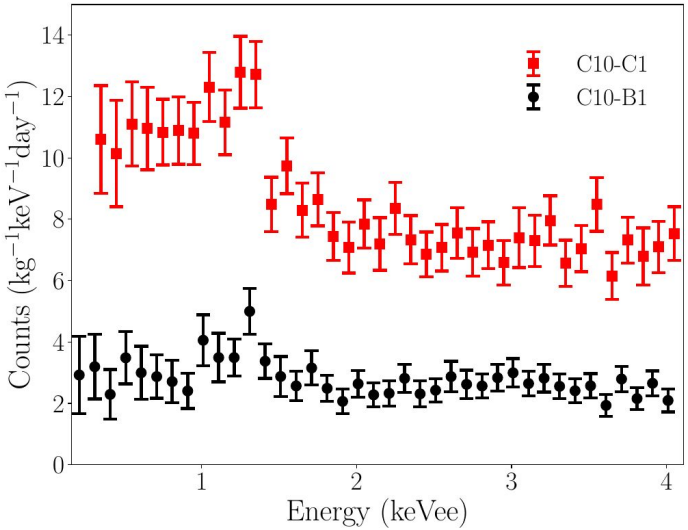
3. Background level at 2-4 keV: 2.5 cpkkd

C10-C1: 1. Exposure: 244.2 kg-day

2. Threshold: 300 eVee

3. Background level at 2-4 keV: 7.6 cpkkd





Constraints - solar dark photon

The rates of solar dark photons

$$\frac{dN}{dE} = Vt\frac{EdE}{|\vec{q}|}\left(\frac{d\Phi_T}{dE}\Gamma_T + \frac{d\Gamma_L}{dE}\Gamma_L\right)$$

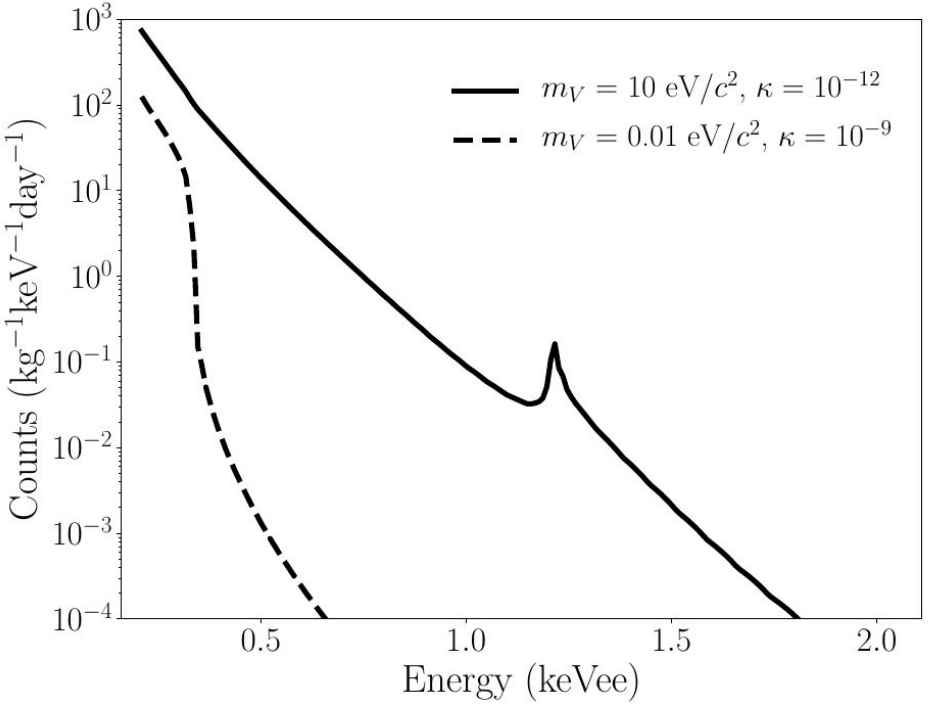
Flux $\frac{d\Phi_{T,L}}{dE}$ is calculated according to the solar model

Its absorption rate:

$$\Gamma_{T,L} = -\frac{\kappa_{T,L}^2 Im\Pi_{T,L}}{\omega}$$

$$\Pi_T = -\omega^2\Delta\varepsilon_r, \Pi_L = -q^2\Delta\varepsilon_r$$

$$\kappa_{T,L}^2 = \frac{\kappa^2 m_V^4}{(m_V^2 - Re\Pi_{T,L})^2 + (Im\Pi_{T,L})^2}$$



Constraints - Solar dark photon

Method: χ^2 + Feldman-Cousins method

$$\chi^2(m_V, \kappa) = \sum_i^N \frac{(n_{i,j} - S_i(m_V, \kappa) - B_i)^2}{\sigma^2_{stats,i} + \sigma^2_{sys,i}}$$

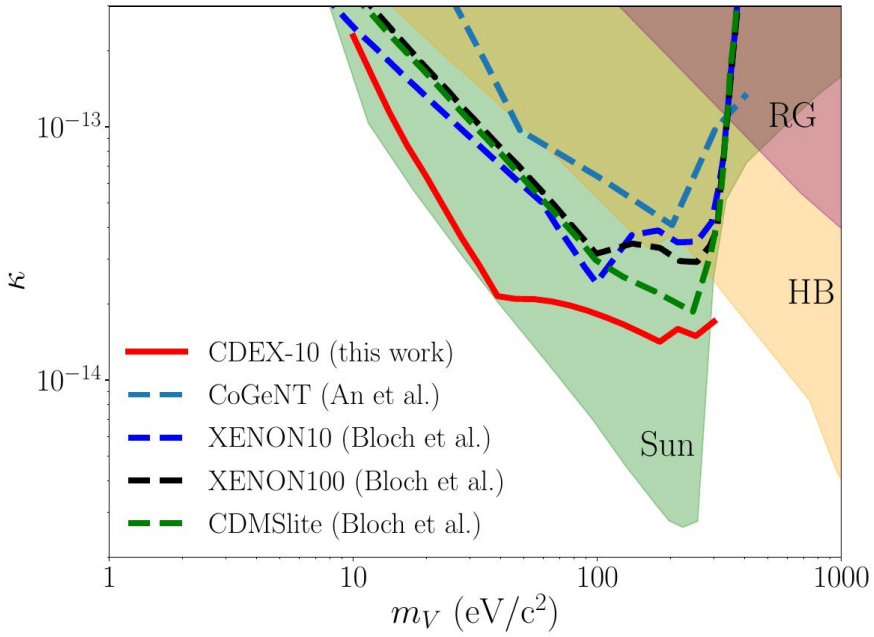
FC method is used to calculate the upper limits(90% C. L.)

$$\chi^2(\kappa, m_V) = \chi^2_{min}(\hat{\kappa}, m_V) + \Delta\chi^2$$

More requirements on threshold and background level

Based on the C10-B1 detector

1. Low analysis threshold: 160 eVee
2. Low background level: 2.5 cpkkd @ 2-4keV
3. Exposure: 205.4 kg-day

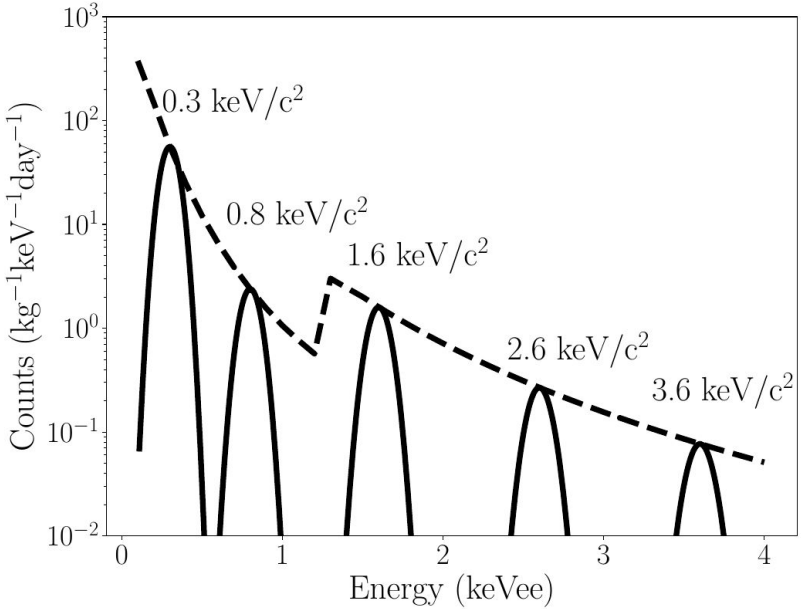


Dark photon DM

- DM halo, its number density $n_V = \frac{0.3GeV/cm^3}{m_V}$
- $m_V^2 \gg \Gamma \rightarrow \kappa_{T,L} \approx \kappa$
- **Non-realistic with β≅0.001**
- Its rate is described by

$$\frac{dN}{dE} = N_T \frac{\rho_{DM}}{m_V} \kappa^2 \sigma_\gamma(m_V)$$

- The mono-energy deposition is broaden as a Gaussian peak
- The maximum of Gaussian peaks are determined the photoelectric effect



Constraints - Dark photon DM

Method : χ^2 + Feldman-Cousins method

$$\chi^2(m_V,\kappa) = \sum_{j=1,2}\sum_{i}^{N_j} \frac{(n_{i,j} - S_i(m_V,\kappa) - B_i)^2}{\sigma^2_{stats,i} + \sigma^2_{sys,i}}$$

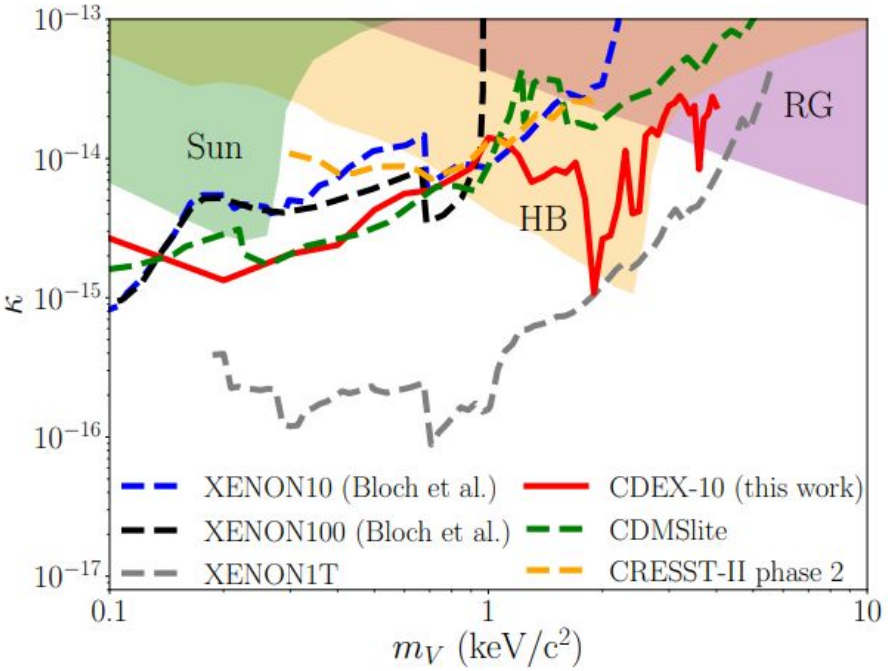
FC method is used to calculate the upper limits(90% C. L.)

$$\chi^2(\kappa, m_V) = \chi^2_{min}(\hat{\kappa}, m_V) + \Delta\chi^2$$

Combined analysis on the C10-B1 and C10-C1 detector

Larger exposure

1. C10-B1 : 205.4 kg-day
2. C10-C1 : 244.2 kg-day

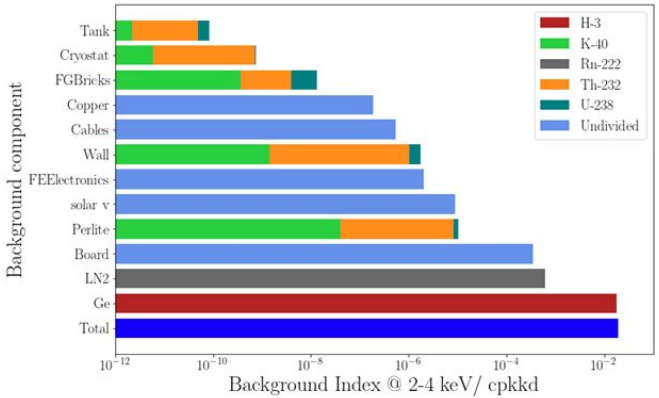


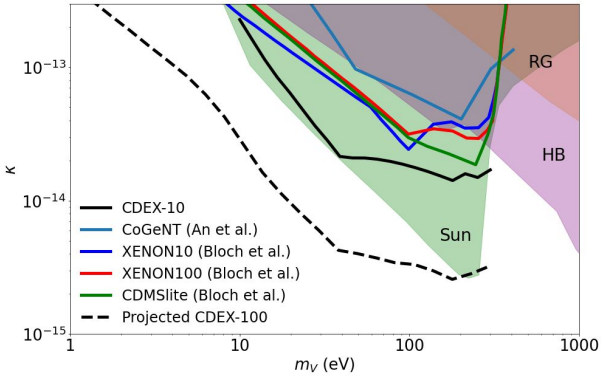
Outlook

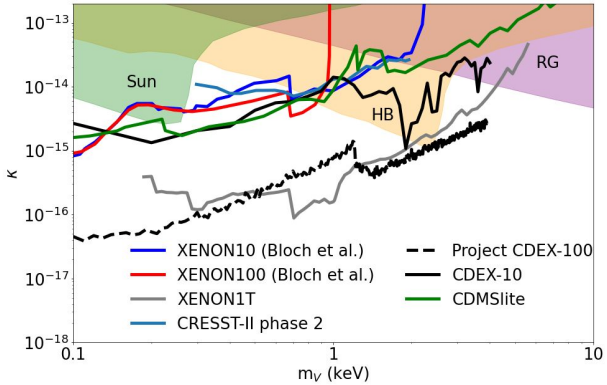
CDEX-50 DM: smaller threshold, lower background level and larger exposure

Constraints for solar dark photon are better than astropartical observations;

Constraints for dark photon DM are comparable with XENON1T







Conclusion

- Based on the 205.4 kg-day exposure of C10-B1 detector, we derive the upper limits (90% C. L.) on κ of solar dark photon, probing new parameter space with masses (mV) from 10 to 300 eV/c 2 in direct detection experiments.
- Combined with the 244.2 kg-day exposure of C10-C1 detector, upper limits (90% C. L.) dark photonDM with m_V from 0.1 to 4.0 keV/c 2 are explored.

Thanks for your attention!