KLEVER

Comments on dark-sector sensitivity

New Physics Searches at Kaon and Hyperon Factories, 12 July 2021

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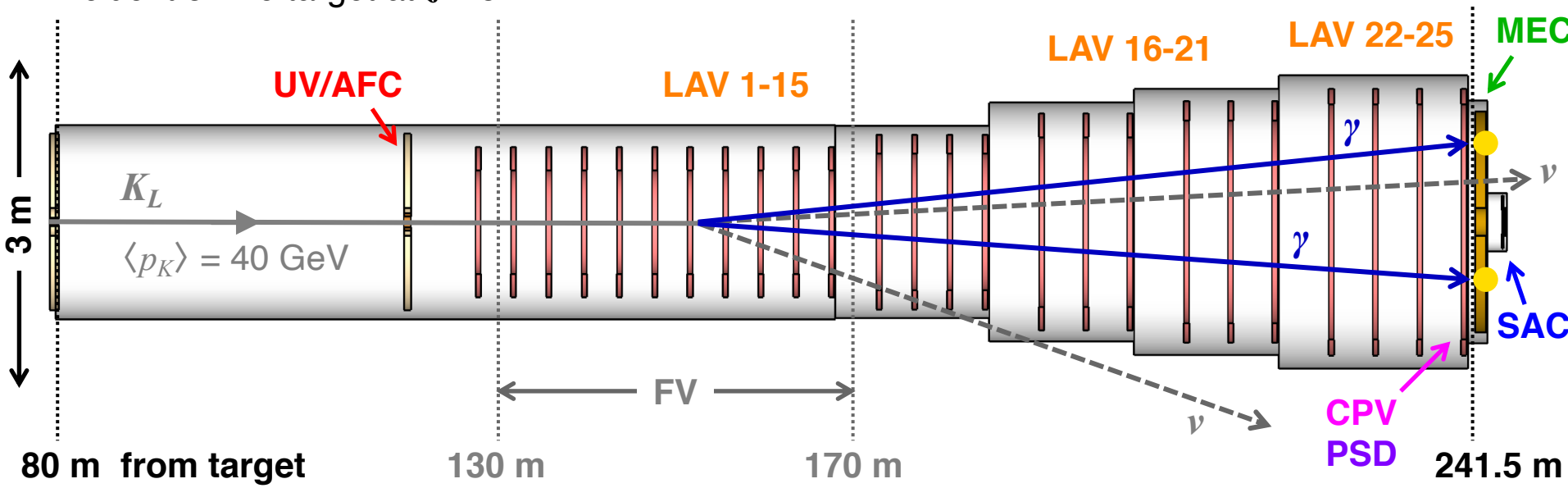
A $K_L \to \pi^0 \nu\bar{\nu}$ experiment at the SPS

400-GeV SPS proton beam (2×10^{13} pot/16.8 s)
incident on Be target at z **= 0 m**



KLEVER target sensitivity:
5 years starting Run 4

60 SM $K_L \to \pi^0 \nu\nu$
$S/B \sim 1$

δBR/BR($\pi^0 \nu\nu$) ~ 20%

Main detector/veto systems:

UV/AFC	Upstream veto/Active final collimator
LAV1-25	Large-angle vetoes (25 stations)
MEC	Main electromagnetic calorimeter
SAC	Small-angle vetoes
CPV	Charged particle veto
PSD	Pre-shower detector

Notes on dark-sector searches

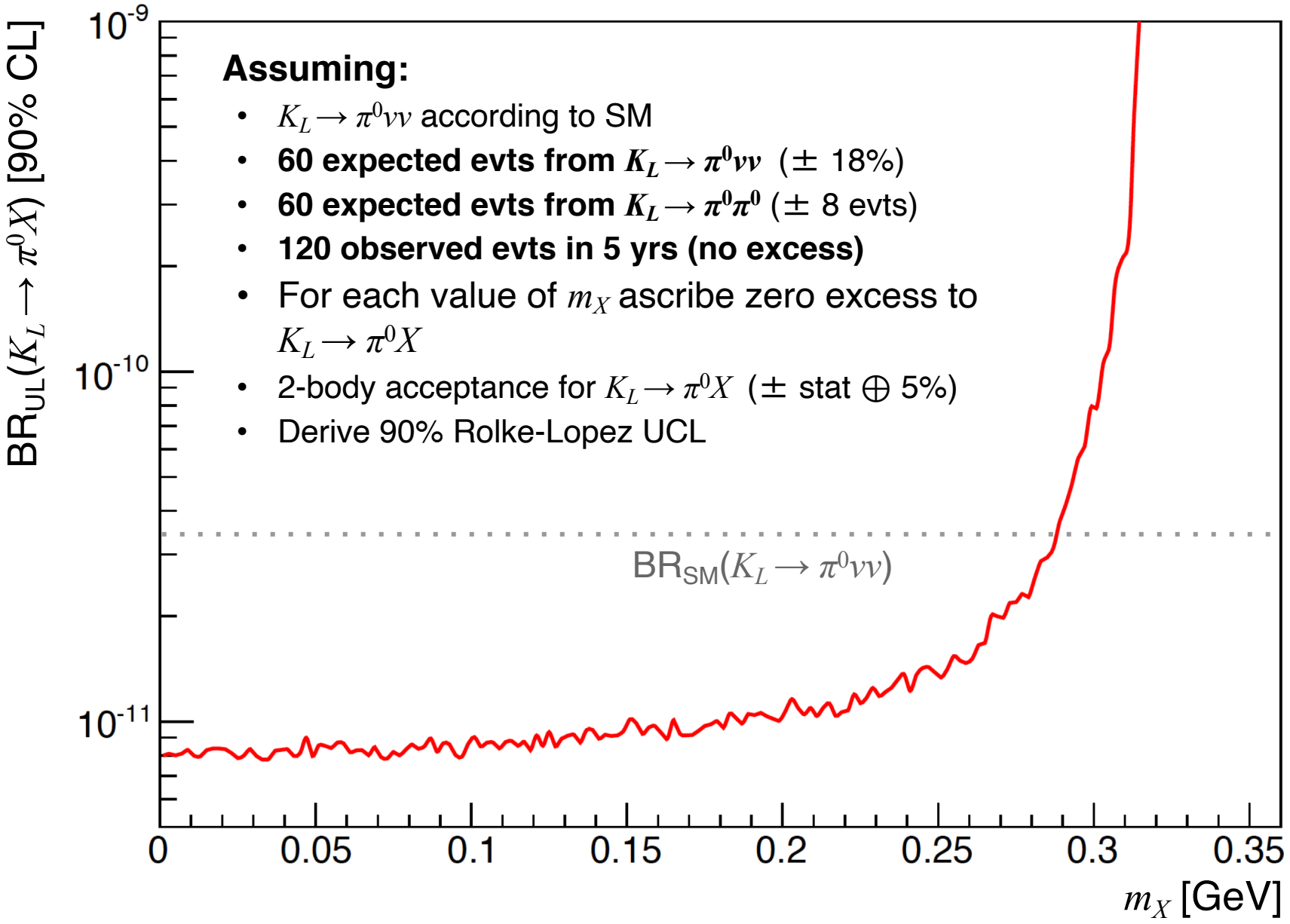
Limitations of KLEVER for dark-sector searches:

- K_L momentum is unknown at fixed target experiments
- KLEVER (like KOTO) does not have a tracking system for charged particles and only very limited PID capability
  - Optimization for $K_L \to \pi\nu\nu$ requires empty fiducial volume
  - Difficult to place spectrometer magnet
- No reconstruction of displaced vertices
- However: See notes on NA62/KLEVER integrated program!

What KLEVER can do:

- By products of $K_L \to \pi\nu\nu$: $K_L \to \pi^0 X$, $K_L \to \pi^0\pi^0 X$, etc.
  - Only sensitivity studies for $K_L \to \pi^0 X$ conducted so far
- Closed channels with em final states: $K_L \to \pi^0 e^+ e^-$, $K_L \to \pi^0\pi^0 e^+ e^-$
- E.g. searches for prompt ALP decay to $\gamma\gamma$ or e^+e^-
- Sensitivity not yet studied

Limits on $K_L \to \pi^0 X$ from $K_L \to \pi^0 \nu\bar{\nu}$

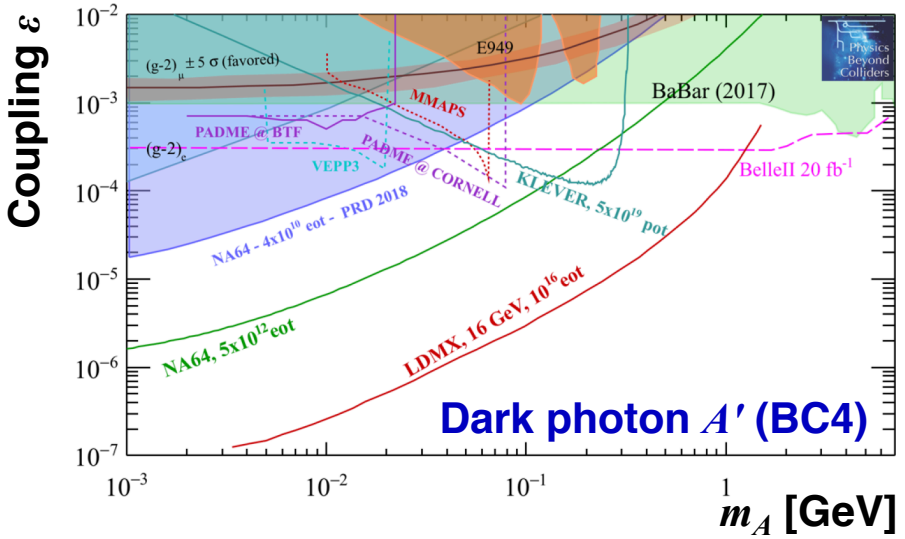


Exclusion potential from $K_L \to \pi^0 X$

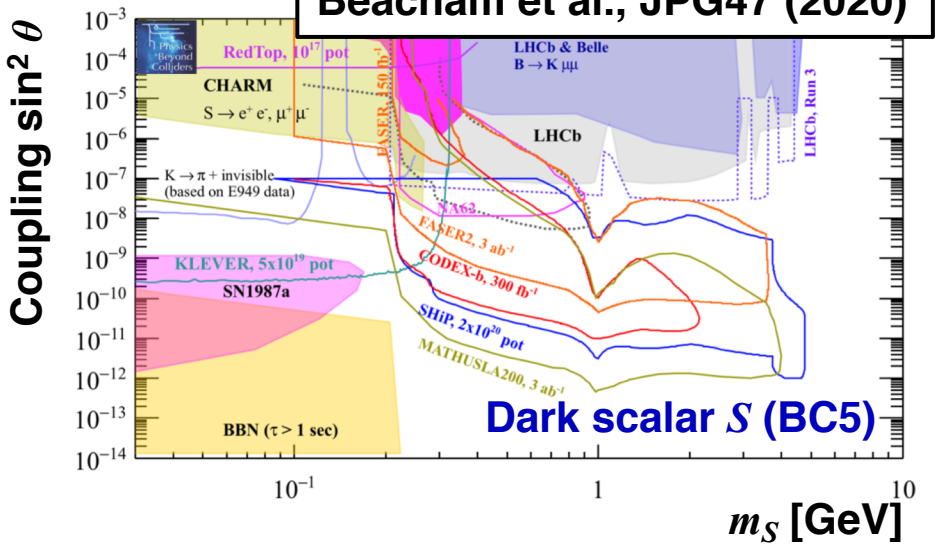
For $K_L \to \pi^0 X$, interpret X as:

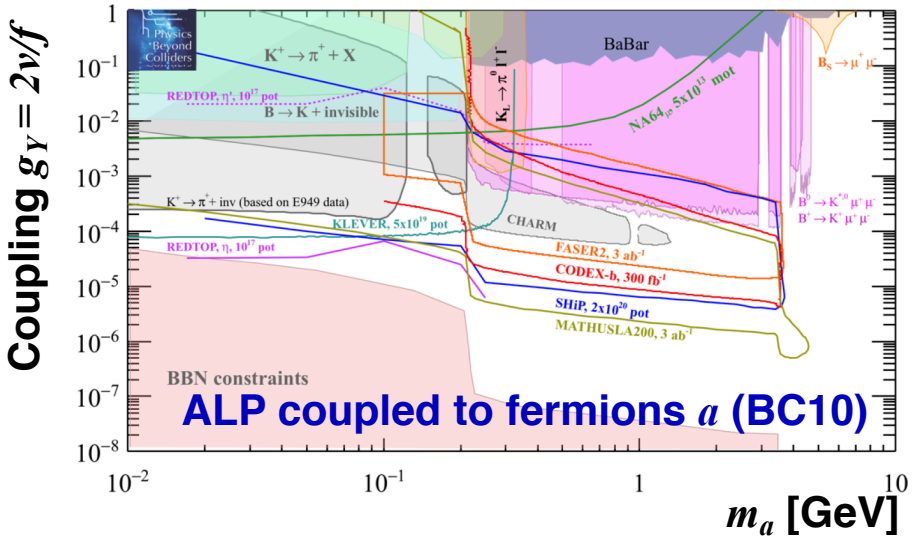
- Invisible dark photon A' (BC4)
- Higgs-mixed scalar S (BC5)
- Axion-like particle a with fermion couplings (BC10)

Obtain limits in coupling vs. mass plane for each scenario*



Beacham et al., JPG47 (2020)





* Calculation assumes that decaying particles escape the decay volume

Prospects for specific channels

By NP model, for relevant models discussed in Sec. 2

Model	Status/prospects
Higgs-portal scalar, long-lived or invisible	**Sensitivity estimated from $\pi\nu\nu$**
Long-lived ALP	**Sensitivity estimated from $\pi\nu\nu$**
Prompt ALP to $\gamma\gamma$ or e^+e^-	**Maybe possible**
Invisible dark photon	**Sensitivity estimate from $\pi\nu\nu$**
Massless dark photon, e.g. $K_L \to \gamma A'$	**Probably not possible**
GN-evading pion-less K_L decays, e.g. $K_L \to X\gamma\gamma$	**Probably not possible unless $\gamma\gamma$ from $X' \to X\gamma\gamma$ (then very difficult)**
$U(1)_d$ with $\gamma_d \to e^+e^-$, e.g. $K_L \to 2(e^+e^-)$	**Maybe possible**

Integrated program with K^+ and K_L

KLEVER

Availability of high-intensity K^+ and K_L beams at the SPS:
Important physics measurements at boundary of NA62 and KLEVER!

Example: Experiment for rare K_L decays with charged particles

- K_L beamline, as in KLEVER
- Tracking and PID for secondary particles, as in NA62

Physics objectives:

- $K_L \to \pi^0 \ell^+ \ell^-$
  Excellent π^0 mass resolution – look for signal peak over Greenlee background
- Lepton-flavor violation in K_L decays
- Radiative K_L decays and precision measurements
- K_L decays to dark-sector particles

Will provide valuable information to characterize neutral beam

- Example: Measurement of K_L, n, and Λ fluxes and halo
- Experience from KOTO and studies for KLEVER show this to be critical!

Just getting started!

Integrated program: examples

Photon veto not as good as for KLEVER (K_L stage), but many channels with visible decays become possible with tracking & PID

No claims yet about sensitivity or competitiveness

Model	Status/prospects
Higgs-portal scalar, **visible** decays	**Likely possible**
Prompt ALP to to $\gamma\gamma$ or e^+e^-	**Likely possible,** even with displaced vertex
Visible dark photon	**Likely possible,** even with displaced vertex
Massless dark photon, e.g. $K_L \to \gamma A'$	**Probably not possible**
GN-evading pion-less K_L decays, e.g. $K_L \to X\gamma\gamma$	**Probably not possible** unless $\gamma\gamma$ from $X' \to X\gamma\gamma$ (then very difficult)
$U(1)_d$ with $\gamma_d \to e^+e^-$, e.g. $K_L \to 2(e^+e^-)$	**Likely possible**
Heavy neutral lepton e.g. $K_L \to \pi\ell N$	**Unable to discriminate from $K_{\ell 3}$ unless N decay visible,** possibly with displaced vertex
LFV decays e.g. $K_L \to \mu e$, $\pi\mu e$	**Expect to be competitive**