THE DARK PHOTON

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a Snowmass 2021 RF6 presentation

Searches for Hidden Sectors at Kaon and Hyperon Factories

May 10, 2020

status of Section 2.4: dark photon

- introduction plus limits ✓
- identification most promising channels ✓
- BRs ✓

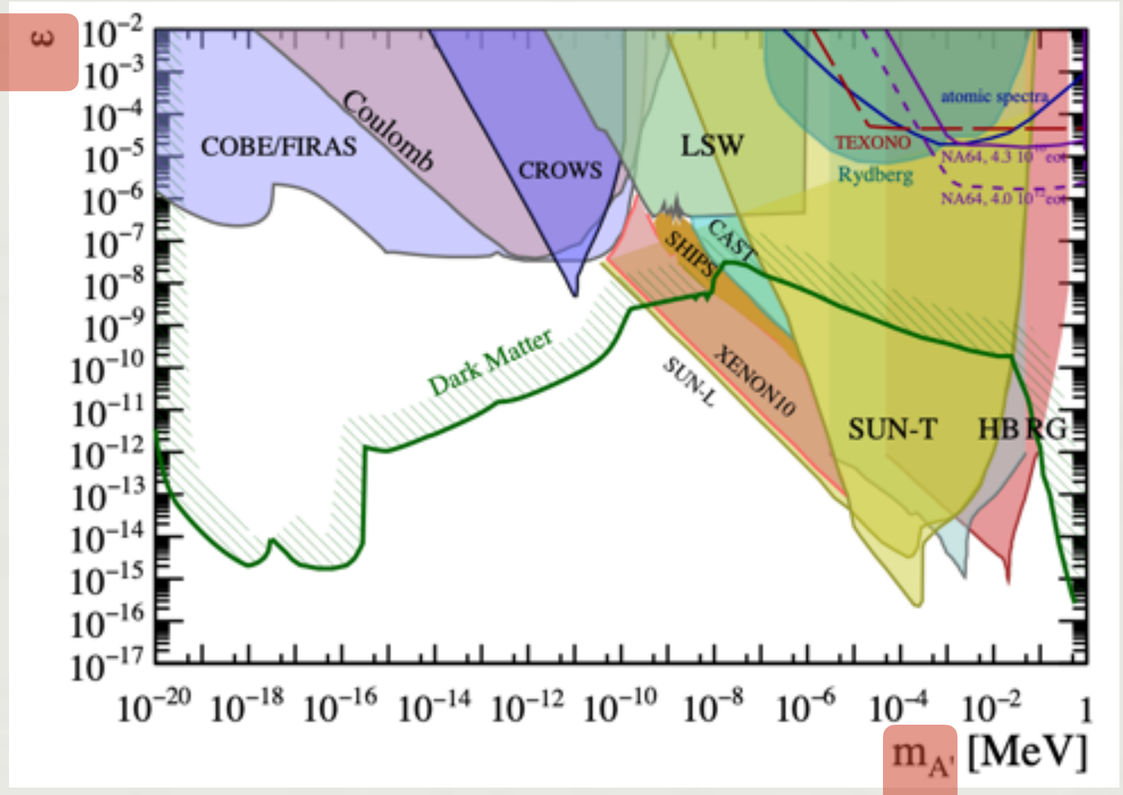
to do

feasibility of the actual experiments to explore the BRs

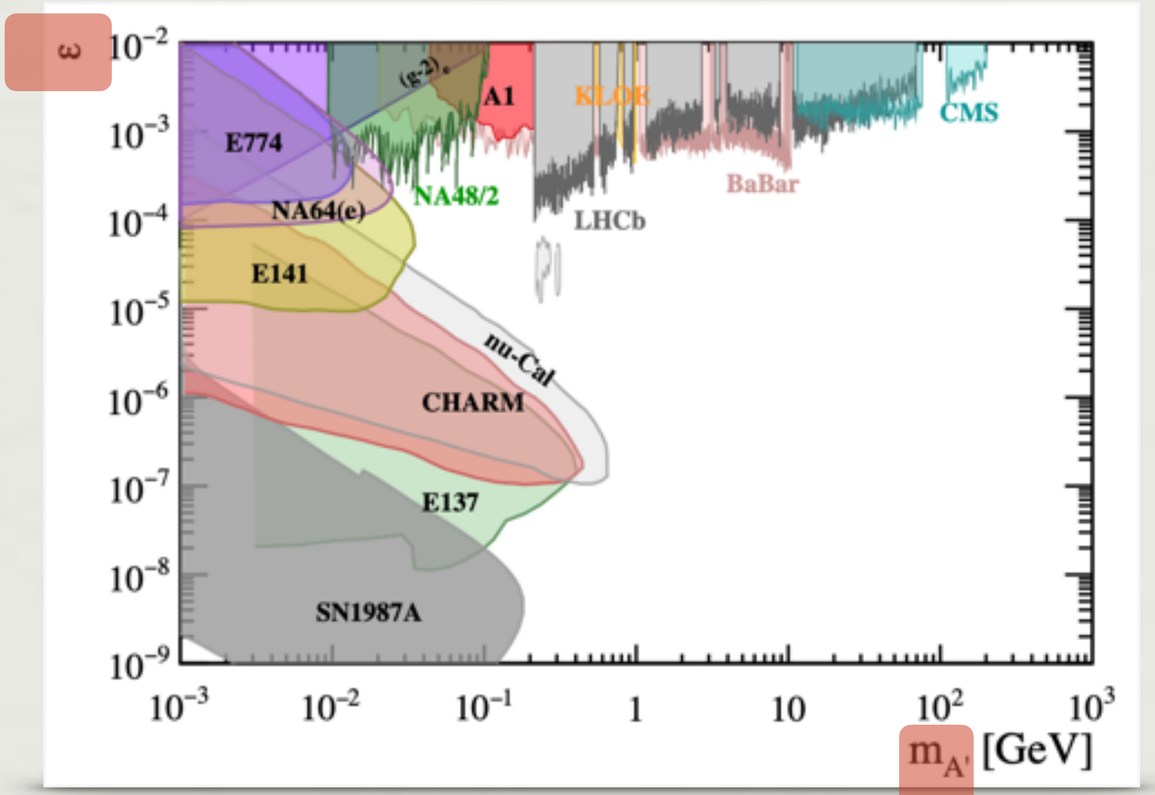
check BRs

massive dark photon

invisible

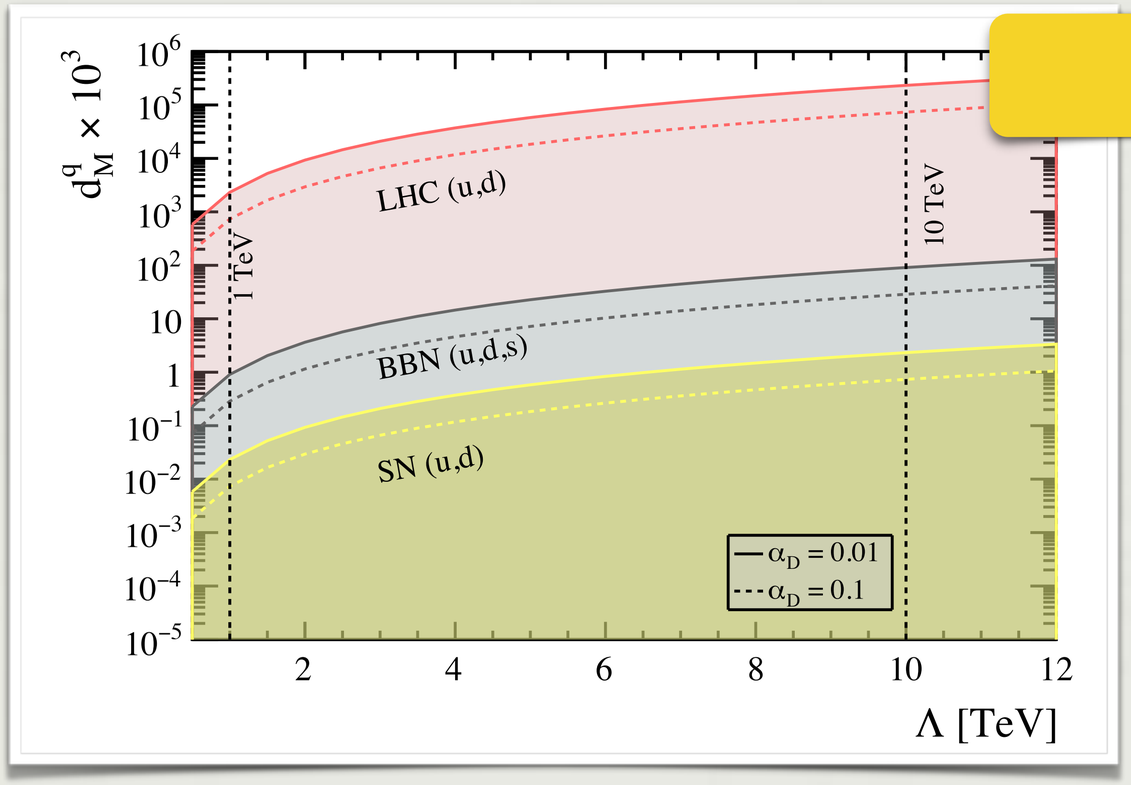


visible

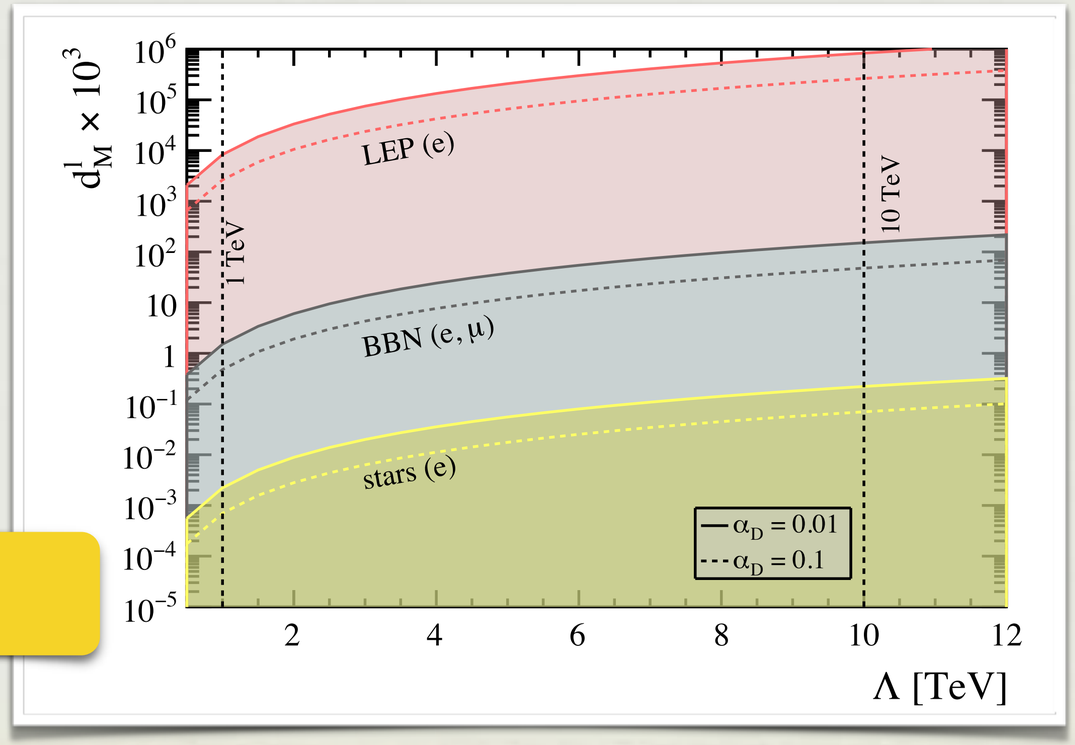


limits on massive dark photon [from arXiv:2005.01515]

massless dark photon



quarks



leptons

Kaon rare decays

- $K_L \to$ nothing (NA64)
- $K \to \pi A'$ (KOTO, NA62)
- $K \to \gamma A'$ (KOTO)
- $K \to \pi\gamma A'$ (KOTO)
- $K \to \pi\pi A'$ (NA62, KOTO)

Kaon decays

- $\Lambda/d_M^{sd}{}_{(\alpha_D=0.1)} = 2.9 \times 10^5$ TeV

Decay	Branching Ratio	Decay	Branching Ratio
$K^+ \to \pi^0\pi^+ A'$	1.6×10^{-7}	$K_L \to$ nothing	1.0×10^{-4}
$K^+ \to \pi^+ \not{E}$	1.8×10^{-10}	$K_L \to \pi^0 \not{E}$	1.5×10^{-9}

Δm_{LS} ?

Kaon and Hyperon decays

- $\Lambda/d_M^{sd}{}_{(\alpha_D=0.1)} = 3.9 \times 10^4$ TeV

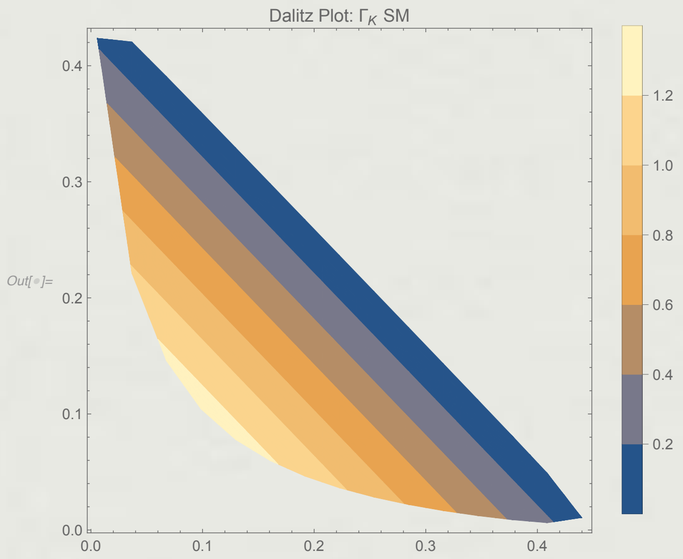
Decay	Branching Ratio	Decay	Branching Ratio
$K^+ \to \pi^0\pi^+ A'$	2.4×10^{-6}	$K_L \to \pi^0\gamma A'$	1.0×10^{-6}
$K^+ \to \pi^+\gamma A'$	5.6×10^{-7}	$K_L \to \pi^+\pi^- A'$	9.8×10^{-6}
$K_L \to \gamma A'$	1.2×10^{-3}	$K_L \to \pi^0\gamma A'$	1.0×10^{-6}
$\Sigma^+ \to pA'$	3.2×10^{-5}	$\Lambda \to nA'$	5.8×10^{-4}
$\Xi^0 \to \Sigma^0 A'$	3.4×10^{-4}	$\Xi^- \to \Sigma^- A'$	2.8×10^{-4}
$\Xi^0 \to \Lambda A'$	3.4×10^{-4}	$\Omega^- \to \Sigma^- A'$	1.1×10^{-3}

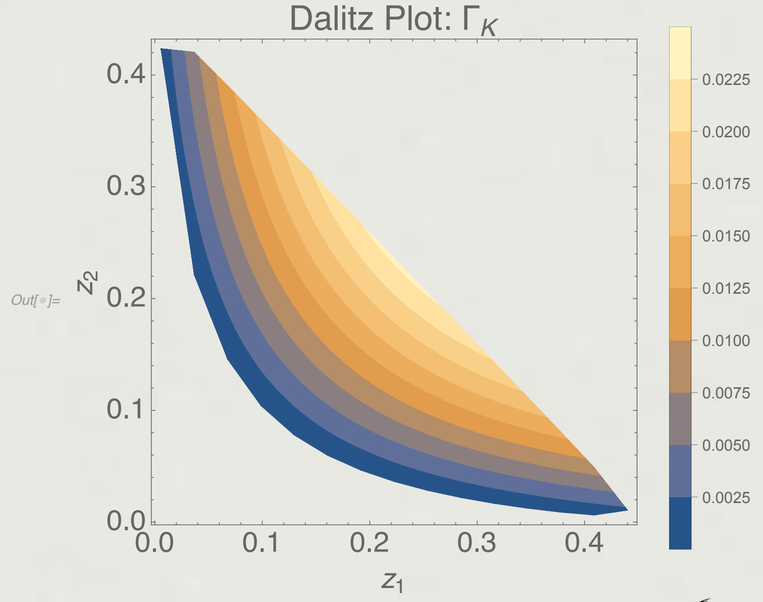
$K \to \pi A'$

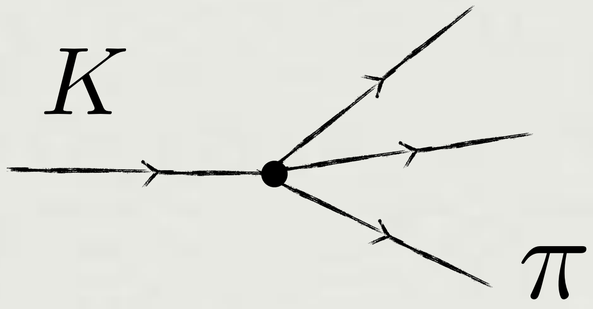
KOTO, NA62

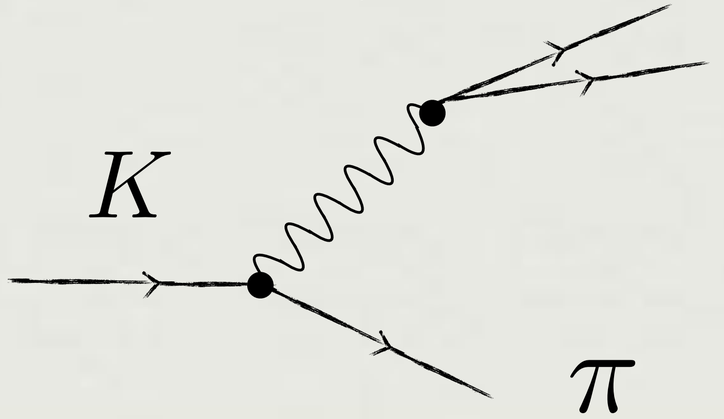
$K_L \to \pi^0 \nu\bar{\nu}$ $\quad$ $K^+ \to \pi^+ \nu\bar{\nu}$

contact interaction
vs.
long distance



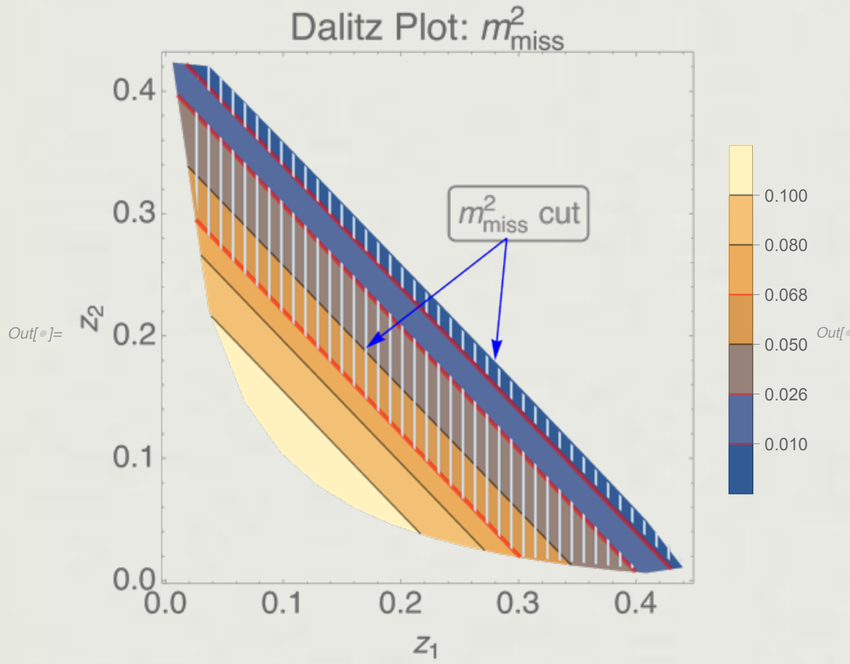


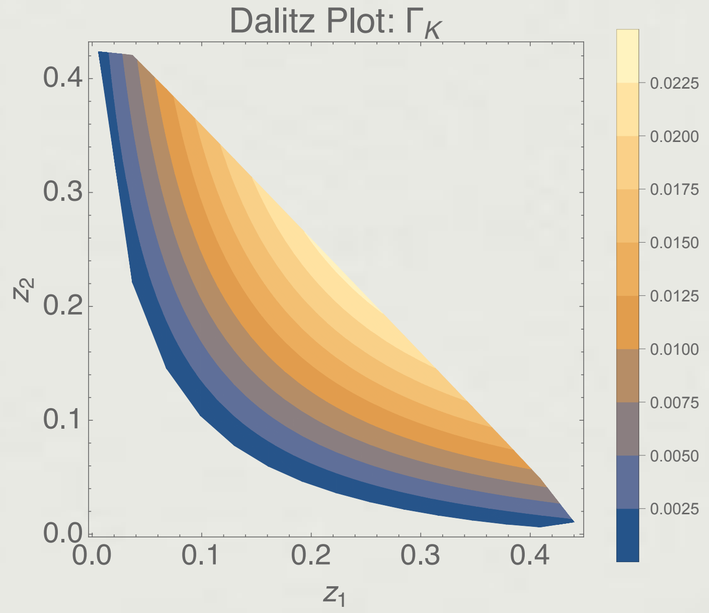


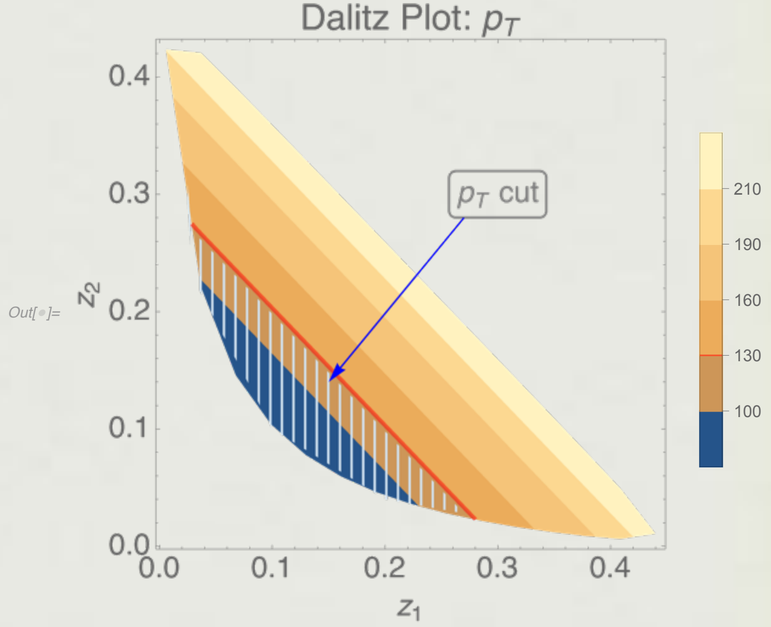


NA62 $K^+ \to \pi^+ Q\bar{Q}$

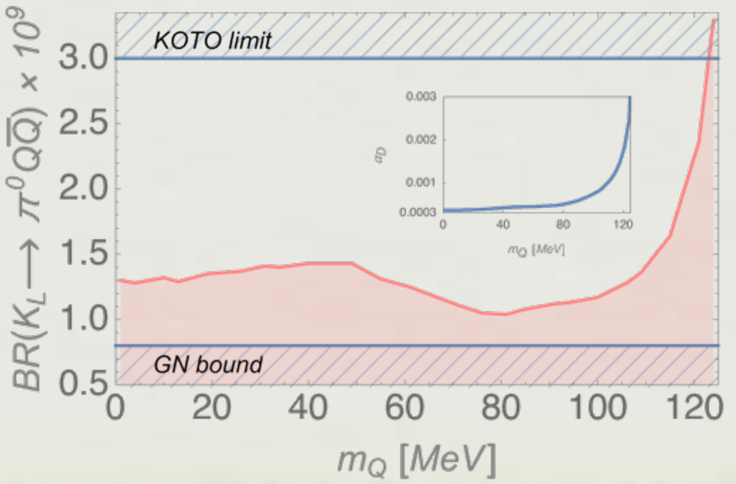
$K_L \to \pi^0 Q\bar{Q}$ KOTO





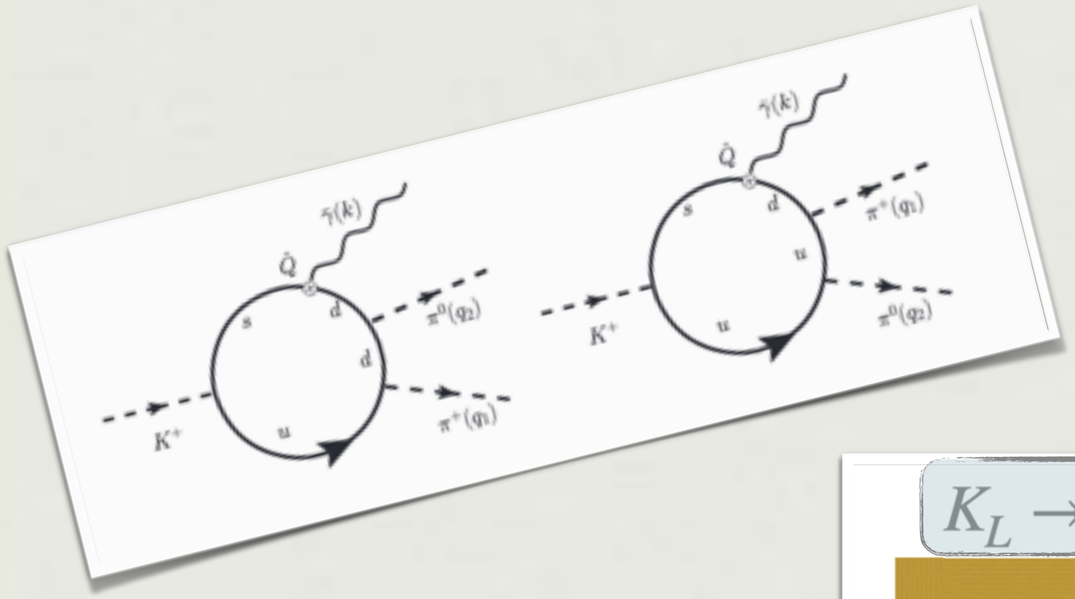


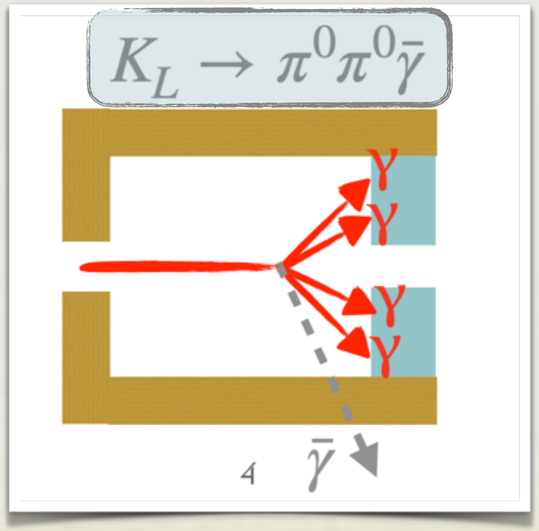
cuts bypass Grossman-Nir bound

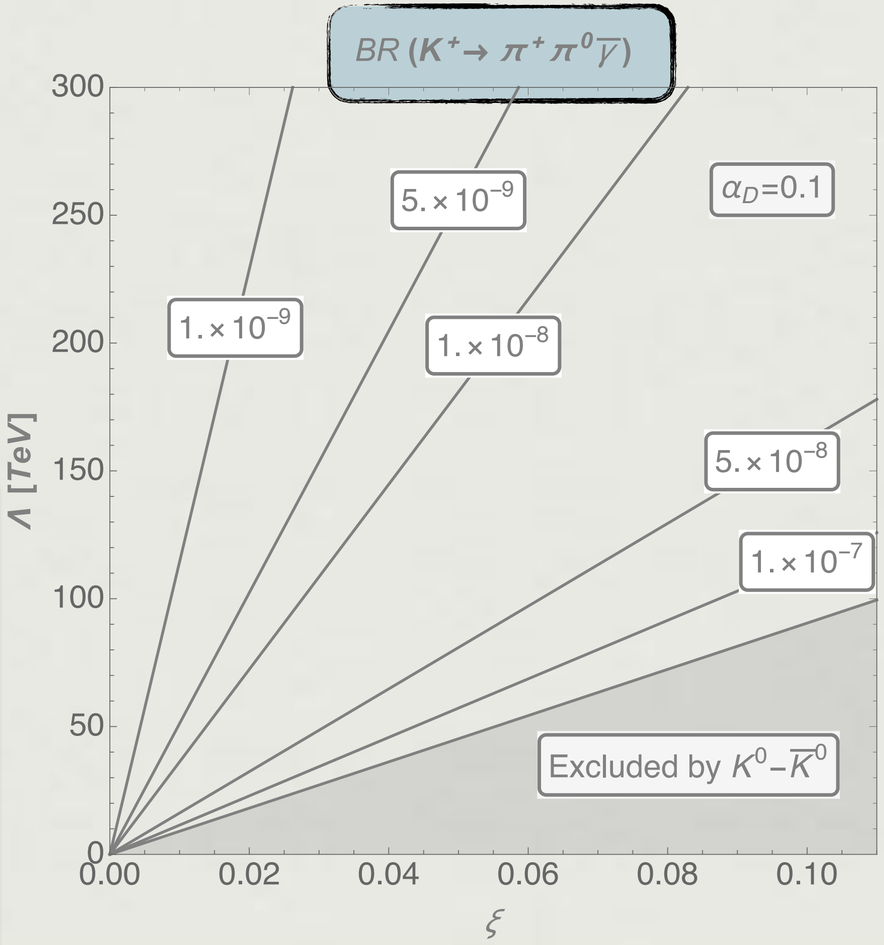


$K \to \pi\pi A'$

NA62, KOTO







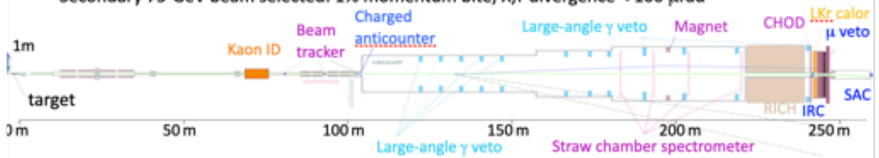
NA62: a high-intensity setup

Collect 100 $\pi\nu\bar{\nu}$ events in 2 years of data taking, 10% signal acceptance (10^{13} K^+)

High-intensity proton-produced charged hadron beam:

10^{12} 400-GeV p/s from ~3.5-s SPS spills onto a Be target

Secondary 75-GeV beam selected: 1% momentum bite, X,Y divergence < 100 μrad



Can **track 750 MHz beam** (6% K^+) and sustain ~5 MHz K^+ decay in a **60-m long volume in vacuum**

Excellent time resolution to match beam and daughter particle information

Kinematics, rejection of main K modes 10^4—10^5 via kinematic reconstruction

PID capability, μ vs π rejection of O(10^7) for 15 < p(π^+) < 35 GeV

High-efficiency veto, 10^8 rejection of π^0's for E(π^0) > 40 GeV

Trigger constraints

Three-level trigger:

L0. Hardware, conditions on single detectors ("primitives"): RICH, CHOD, LKr, MUVs

L1. Software, conditions on single detectors: KTAG, LAV, STRAW

L2. Software, conditions on multiple detectors

Bandwidth limits:

L0. Output < ~1 MHz → up to 700 KHz in 2017-2018

L1. Output < ~100 KHz → average of 60 KHz in 2017-2018

L2. Output < ~ 10 KHz

Approximate rates observed:

Single tracks at CHOD (K^+ → μν dominated) > 10 MHz in 2018

1 track + energy in LKr (K^+ → $\pi\pi^0$ dominated) > 2 MHz

slides kindly provided by Tommaso Spadaro

Statistics integrated

2016: 0.1 10^{12} K+ decays in the FV ← LKr trigger inefficient, might try to use L0 for πνν

2017: 1.5 10^{12} K+ decays in the FV ← can only exploit control trigger, downscaled by 400

2018: 2.7 10^{12} K+ decays in the FV ← can exploit control (1/400) and !μ (1/200) triggers

Signal selection efficiency: ~6% given a K^+ decay in the FV

15 < p(π^+) < 35 GeV, to ensure 40 GeV of energy for the π^0A' system

Detection of π^0 photons in the LKr calorimeter

Missing momentum direction pointing to the LKr calorimeter

Veto against additional in-time activity

Selection efficiency appears to be ~independent from the A' energy in the K^+ rest frame [to be cross-checked]

Expected number of selected events in 2017+2018: ~60 if BR(K^+ → $\pi\pi^0$A') = 10^{-7}

Conclusions

Signal cannot be triggered within the πνν L0 trigger line

L0 control trigger and !μ conditions in 2017-2018 data should provide sensitivity for BR = 10^{-7}

To reach 10^{-8} or better:

try to exploit 2016 data set (to be verified) or

better equip trigger lines in future data taking (to be agreed at the collaboration level)

Similar considerations for the search for K^+ → $\pi^+\pi^0$, π^0 -> γ A'

$$K \to \pi A' \qquad \text{vs} \qquad K \to \pi\pi A'$$

angular momentum conservation

Hyperon rare decays

- $\Sigma^+ \to pA'$ (BESIII)
- $\Xi^0 \to \Sigma^0 A'$ (BESIII)
- $\Xi^0 \to \Lambda A'$ (BESIII)

Kaon and Hyperon decays

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