LEPTONIC FORCE MEDIATORS

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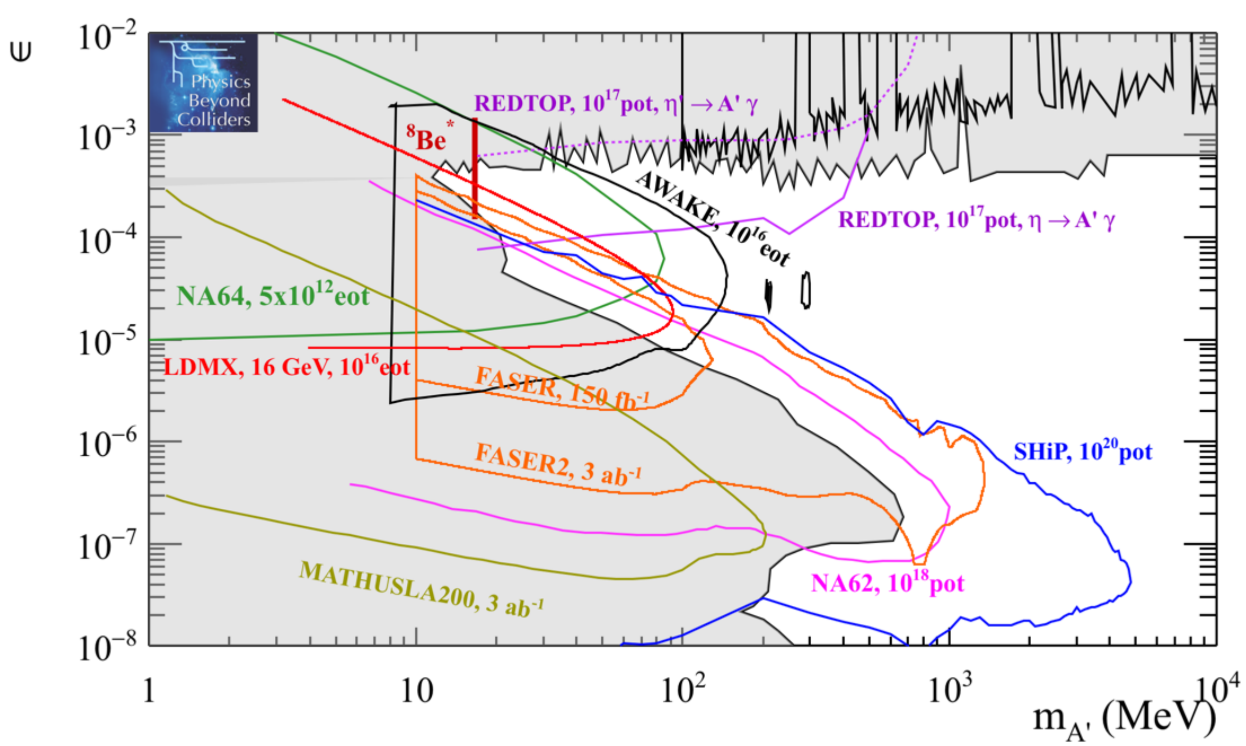
New Physics at Kaon & Hyperon Factories

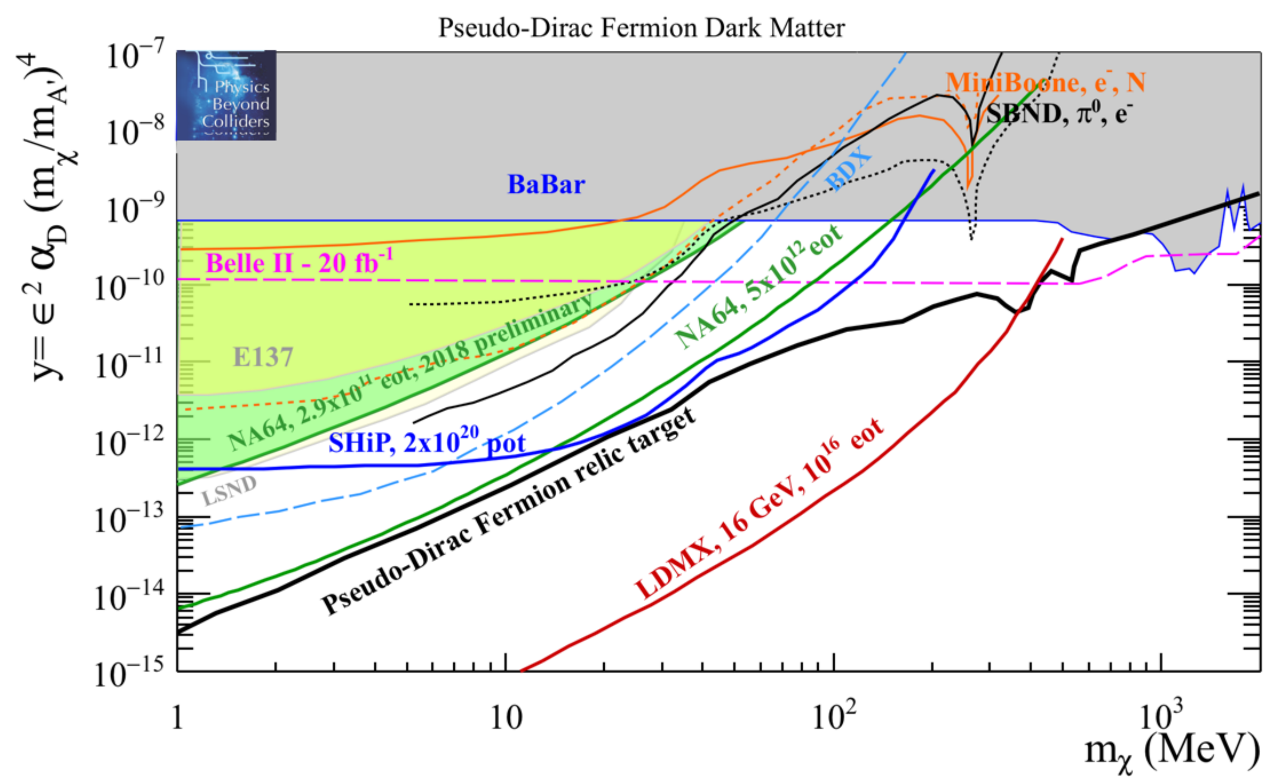
MOTIVATION

- Strong constraints on light hidden particles originates from couplings to electrons, light-flavor quarks, top quark in loops

dark photon (visible)



dark photon (invisible)



Physics Beyond Colliders, 1901.09966

MOTIVATION

- Constraints are **much** weaker if we have forces that couple predominantly to muons and/or taus

- Substantial parameter space still open to explain muon g-2, dark matter, flavor hints, etc.

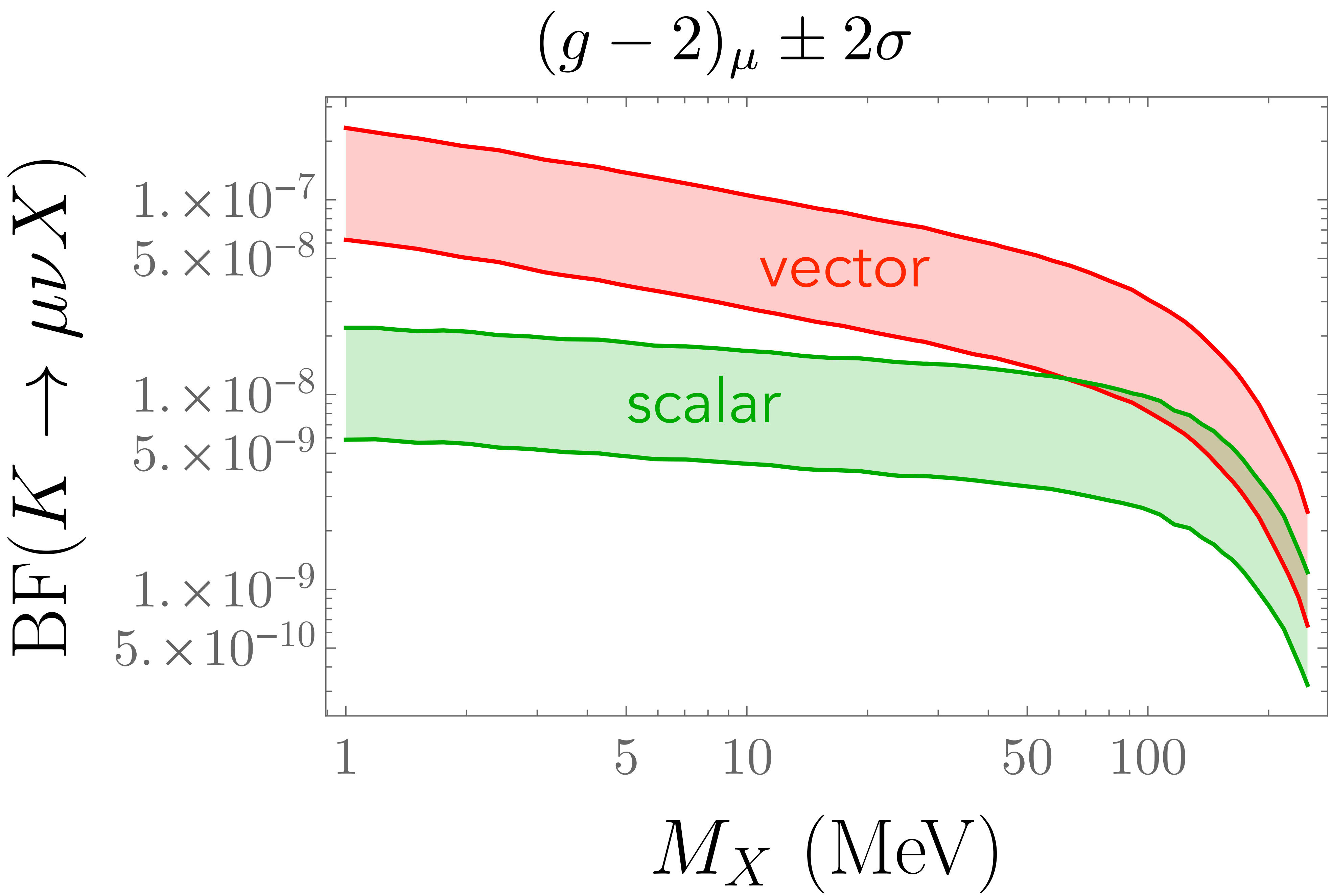
- Examples:
  - flavor non-universal Z′ $(L_\mu - L_\tau,\ \mu_{\rm R},\ {\rm etc.})$

    e.g., X. He *et al.*, 1991 [PRD]; B. Batell *et al.*, 1103.0721 [PRL]
  - leptophilic dark Higgs $(g_\ell \propto m_\ell/v)$, or different Yukawa texture

    e.g., C.Y. Chen *et al.*, 1511.04715 [PRD]; B. Batell *et al.*, 1606.04943 [PRD]

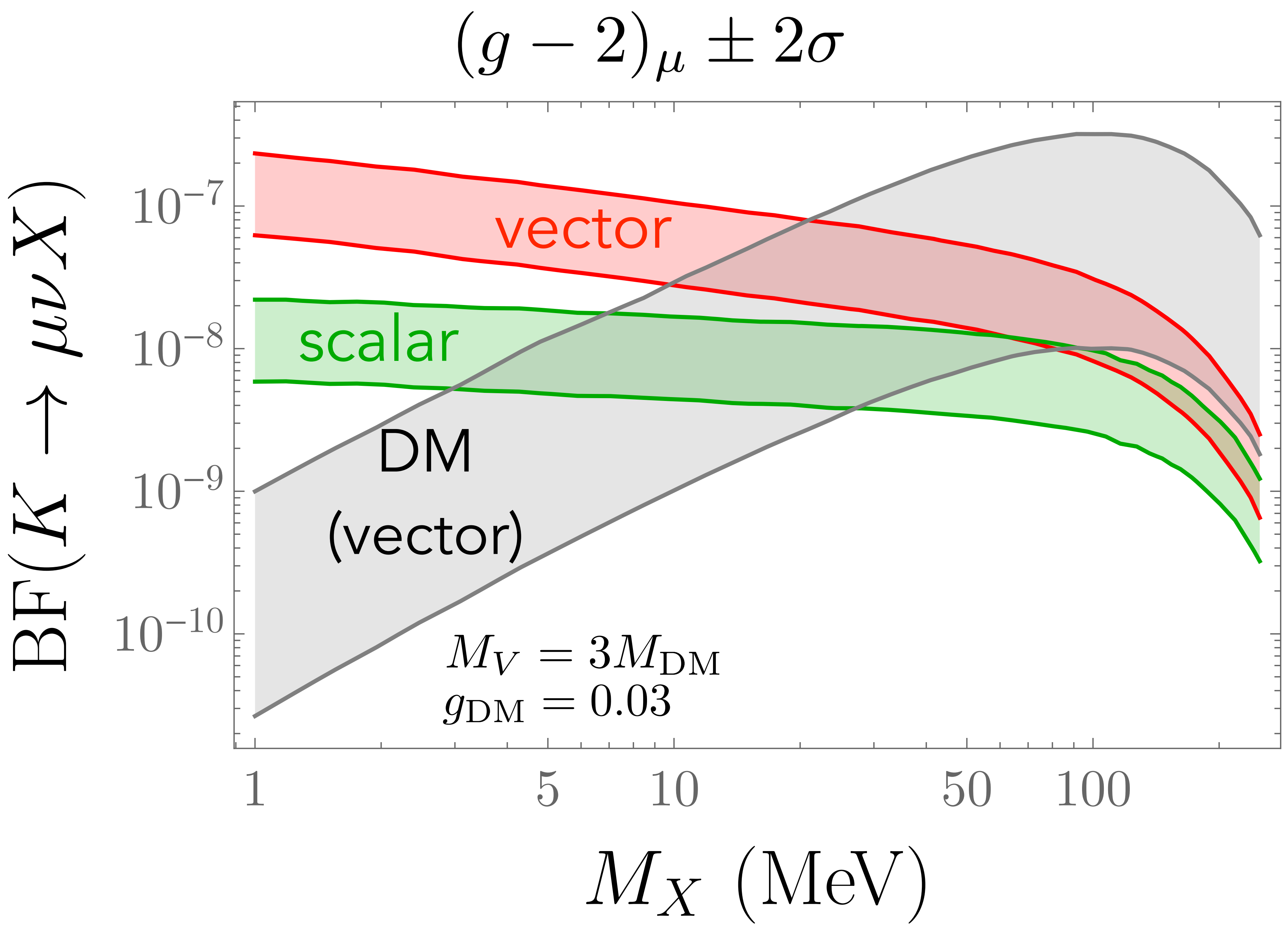
- I will focus in this talk on models that predominantly couple to leptons/give lepton signatures

BENCHMARKS



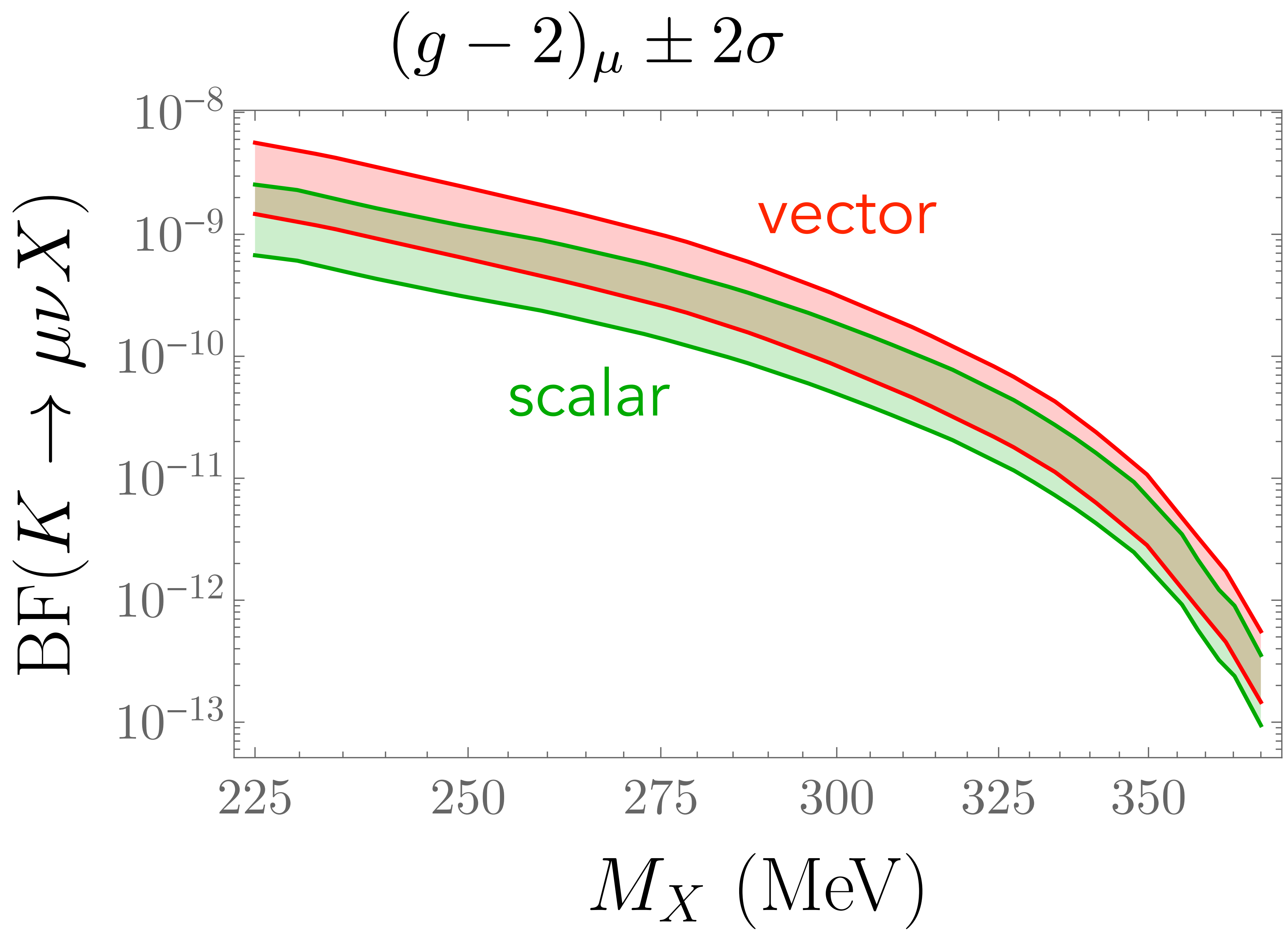
use results from G. Krnjaic *et al.*, 1902.07715

BENCHMARKS



$(g-2)_\mu \pm 2\sigma$
10^{-7}
10^{-8}
10^{-9}
10^{-10}
vector
scalar
DM
(vector)
$M_V = 3M_{\rm DM}$
$g_{\rm DM} = 0.03$
1
5
10
50
100
$\mathrm{BF}(K \to \mu\nu X)$
M_X (MeV)

BENCHMARKS



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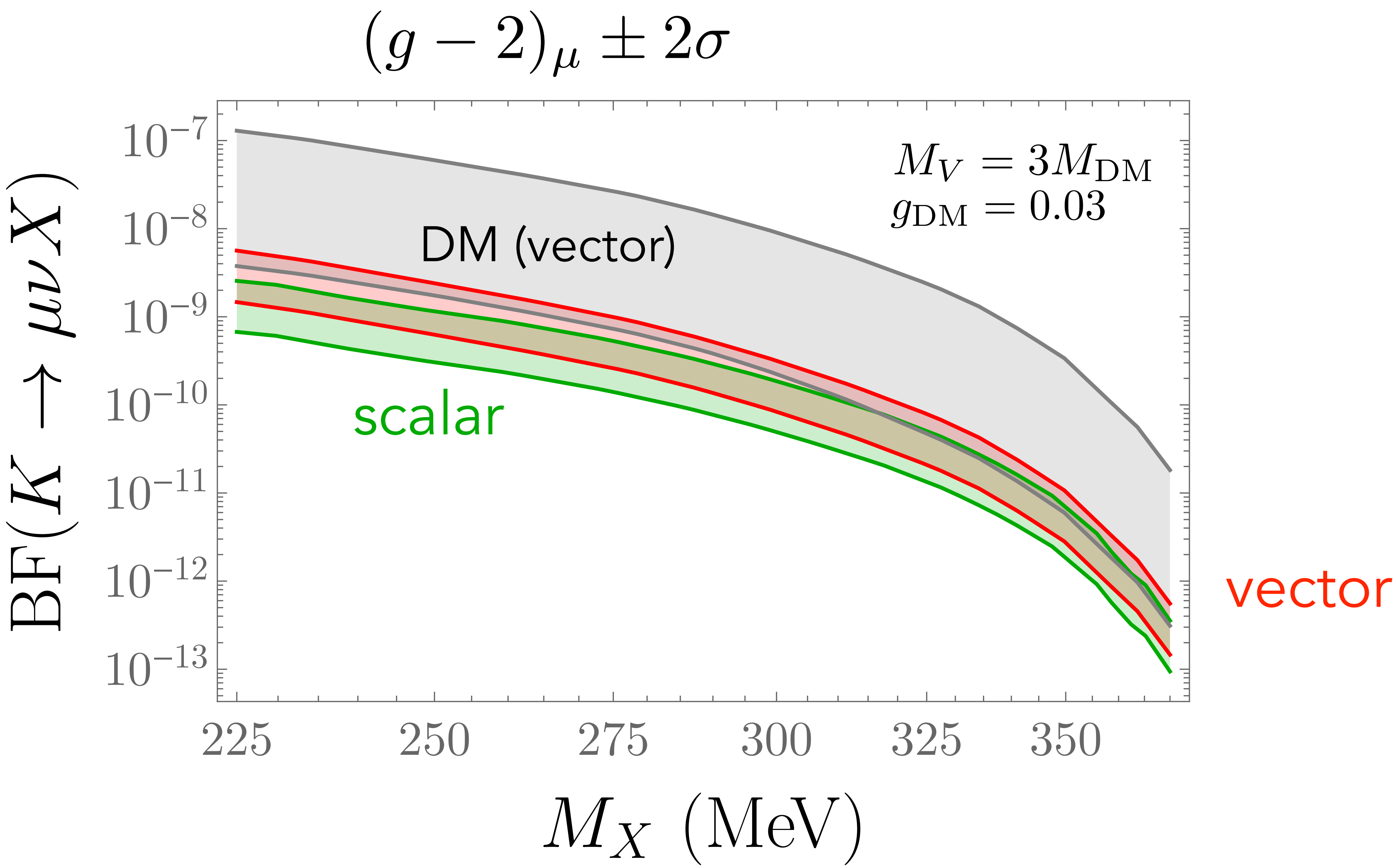
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
$\mathrm{BF}(K \to \mu\nu X)$
vector
scalar
225
250
275
300
325
350
M_X (MeV)

BENCHMARKS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SIGNATURES

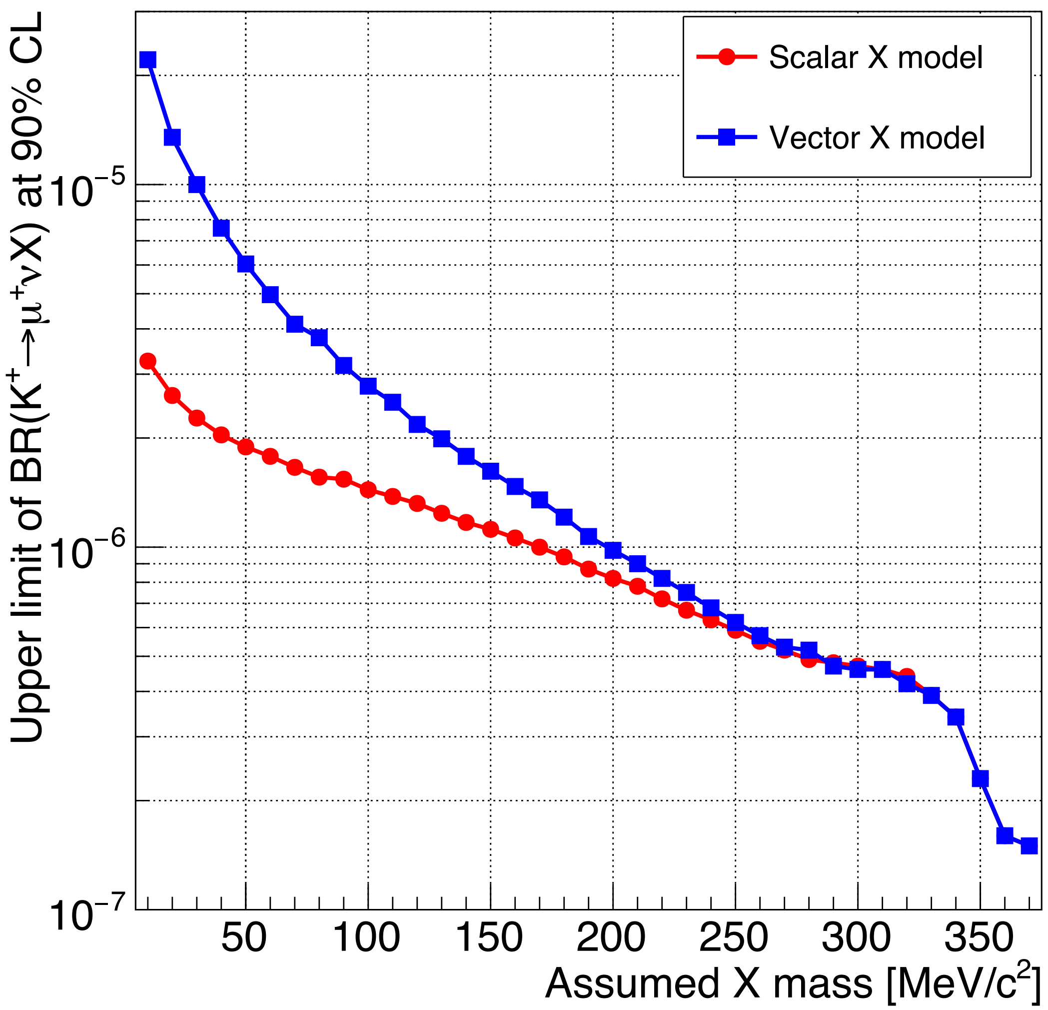
- Well-motivated *X* decay modes, prompt & long lived:
    - $X \to \text{invisible}$
    - $X \to \mu^+\mu^-$
    - $X \to \gamma\gamma$
    - $X \to e^+e^-$

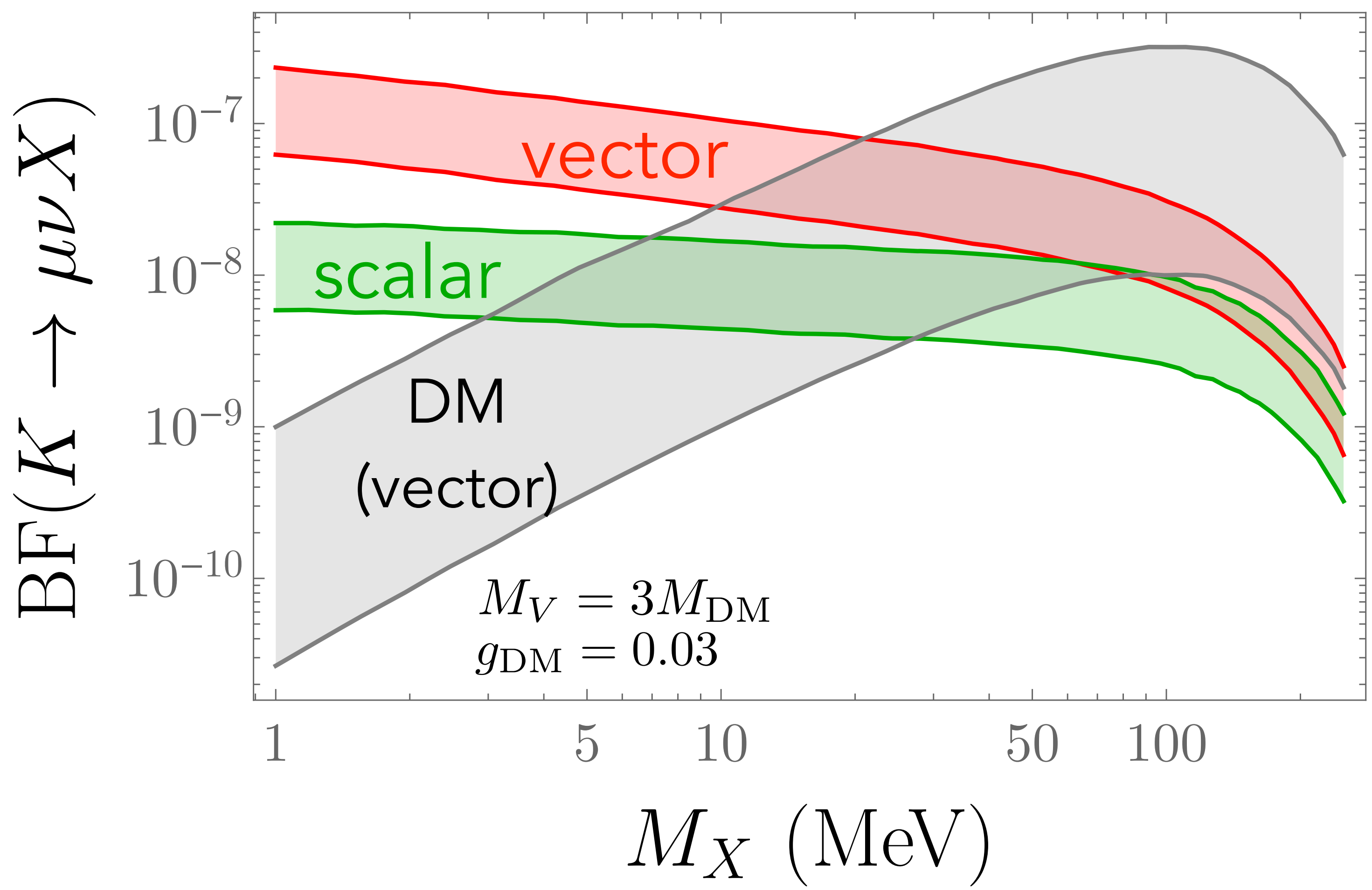
INVISIBLE DECAYS

$$K \to \mu\nu X$$

NA62: 10^{10} K

$(g-2)_\mu \pm 2\sigma$





NA62, 2101.12304

INVISIBLE DECAYS

$$K \to \mu\nu X$$

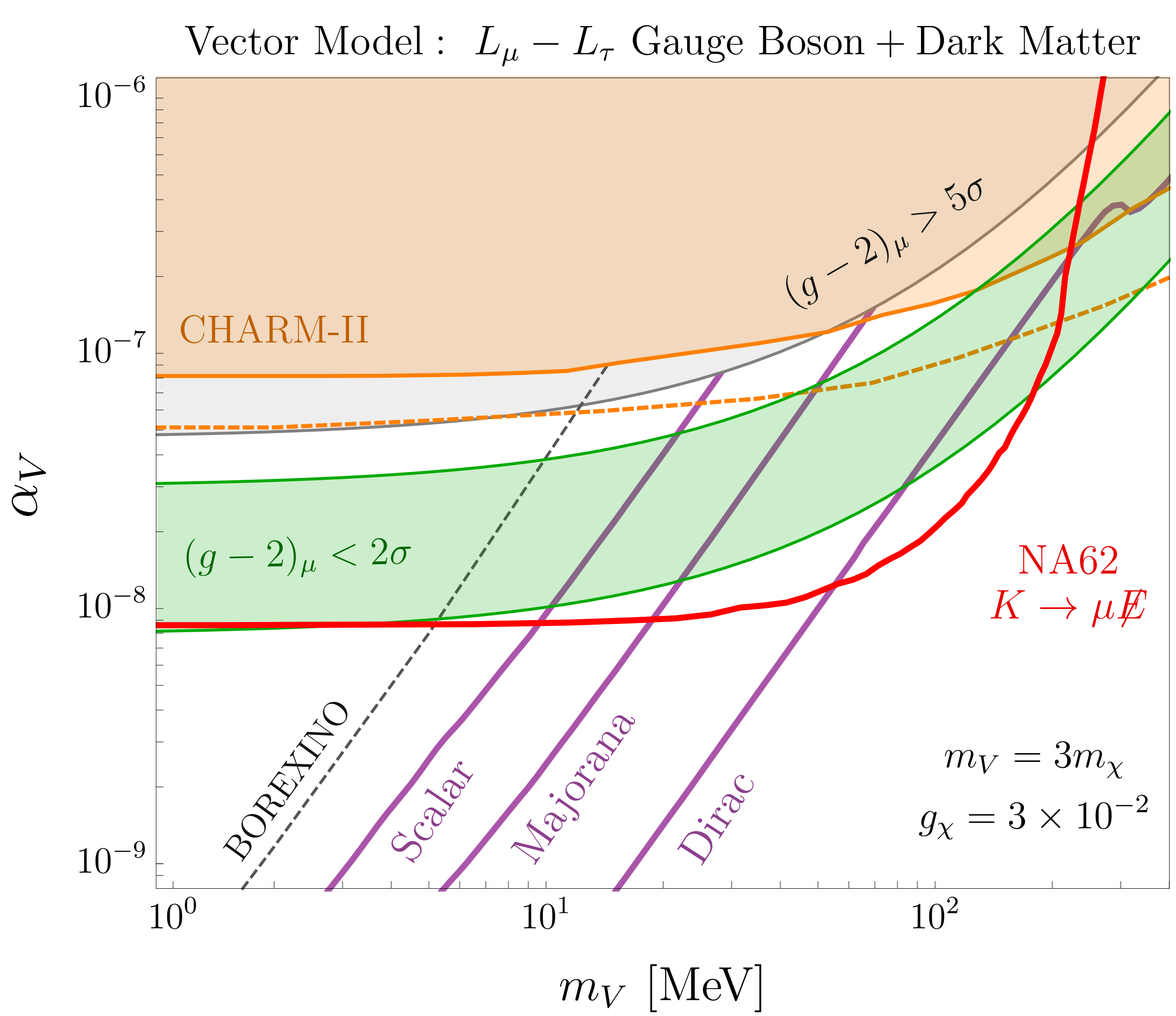
Table 1: Estimated backgrounds in the kinematic region $m^2_{\text{miss}} > 0.1\ \text{GeV}^2/c^4$ with their uncertainties. The uncertainties labelled "PV" are systematic due to the accuracy of the photon veto efficiency modelling (positively correlated among the background sources), and the one labelled "tail" is systematic and accounts for the accuracy of the non-Gaussian m^2_{miss} tail simulation.

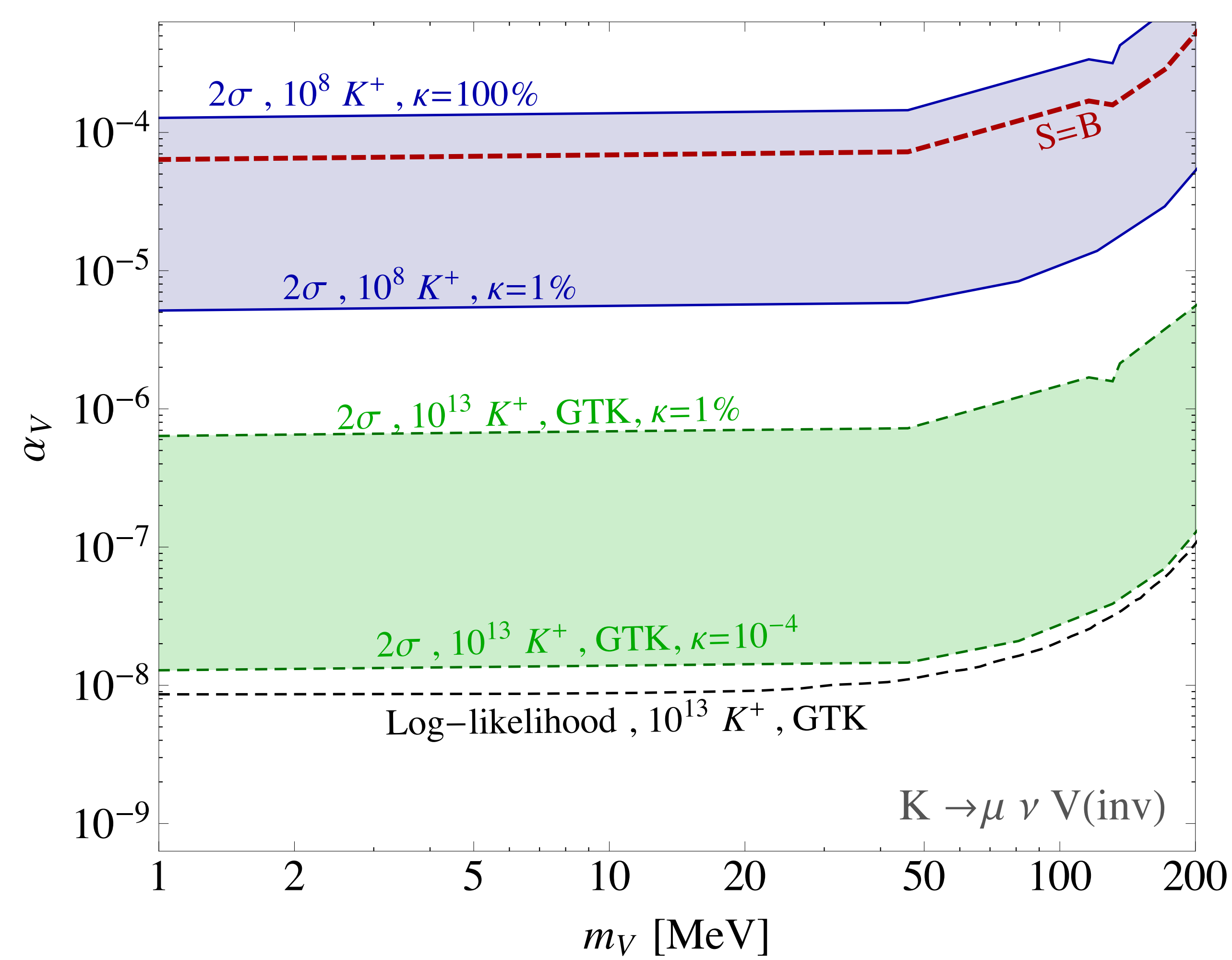
Background source	Estimated background
$K^+ \to \mu^+\nu\gamma$	$6224 \pm 105_{\text{stat}} \pm 333_{\text{PV}} \pm 780_{\text{tail}}$
$K^+ \to \pi^0\mu^+\nu$	$1016 \pm 47_{\text{stat}} \pm 178_{\text{PV}}$
$K^+ \to \pi^+\pi^+\pi^-$	$309 \pm 32_{\text{stat}}$
Total background	$7549 \pm 119_{\text{stat}} \pm 920_{\text{syst}}$

NA62, 2101.12304

INVISIBLE DECAYS

- Assumes trigger pre-scale of 1/400 can be removed with a dedicated trigger for high missing-momentum single muon events



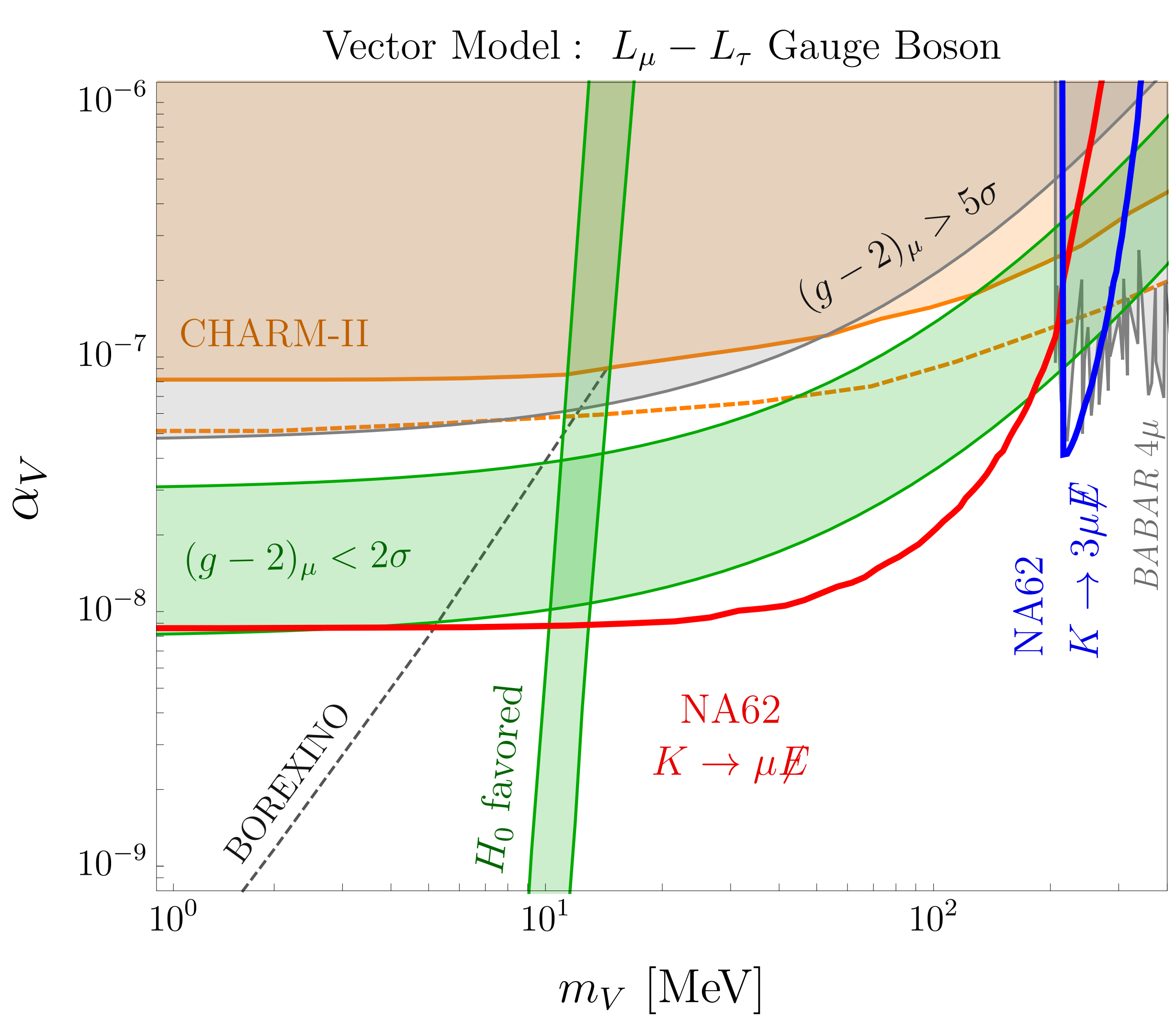


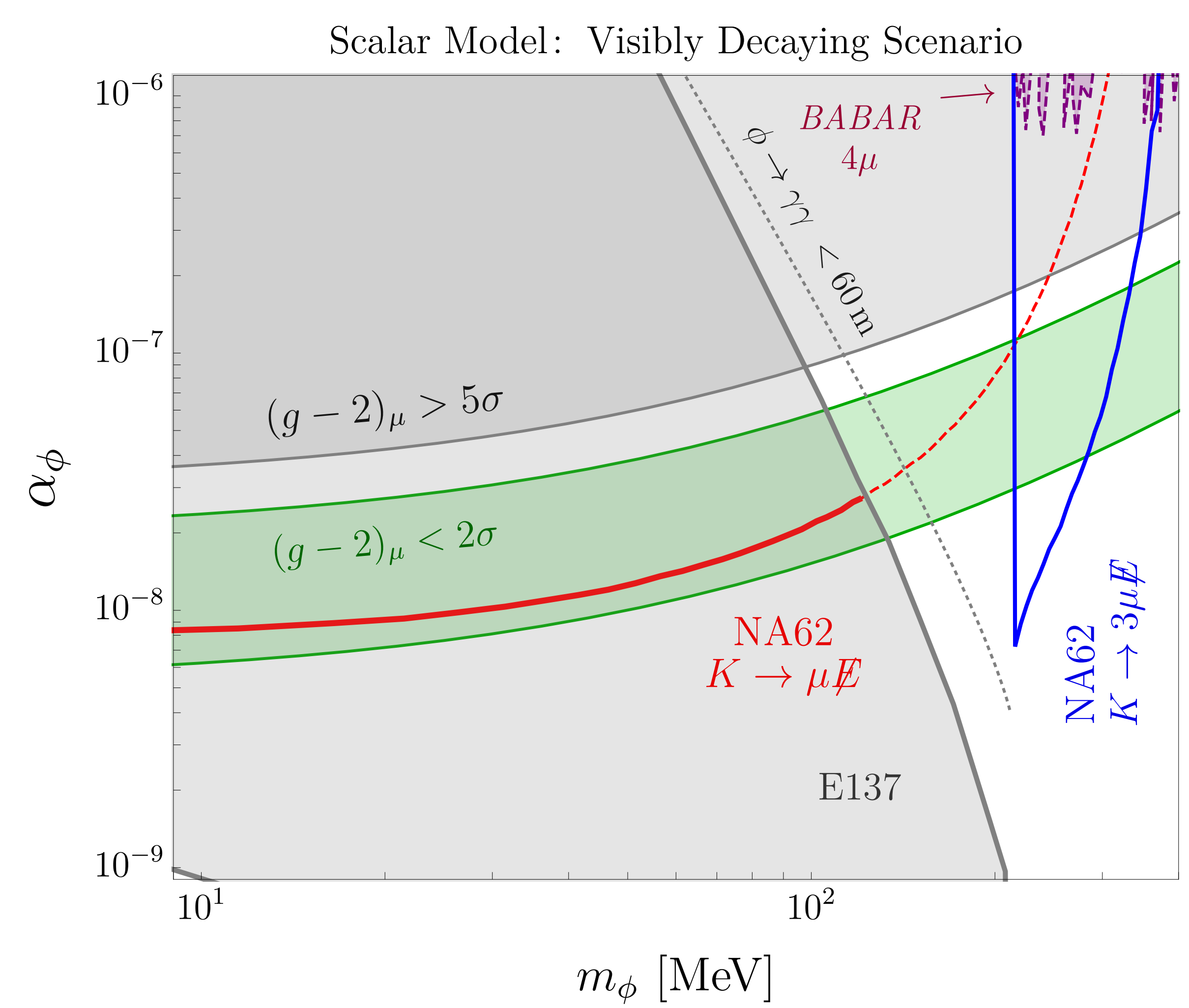
G. Krnjaic *et al.*, 1902.07715

DIMUON DECAYS

- Can dominate at higher masses > 210 MeV

$$K \to \mu\nu X,\ X \to \mu\mu$$





G. Krnjaic *et al.*, 1902.07715

DIPHOTON DECAYS

- Can dominate below the dimuon threshold when *X* is a scalar. Scalar typically long lived, so photons could be out of time!
- Need to estimate this sensitivity!
- Backgrounds include:

$$K \to \mu\nu\gamma\gamma \ \ (\sim 10^{-4}?)$$

$$K \to \pi^0\mu\nu \ \ (\sim 3\%)$$

$$K \to \pi^0\mu\nu\gamma \ \ (\sim 10^{-5})$$

$$K \to \pi^+\pi^0\pi^0 \ \ (\sim 2\%)$$

- While irreducible backgrounds shouldn't be too large, to what extent can other backgrounds be mitigated?

DIELECTRON DECAYS

- Can dominate below the dimuon threshold when *X* is a scalar
- Continuum backgrounds small!
- Backgrounds include:

$$K \to \mu\nu e^+e^- \;\; (\sim 7\times 10^{-8}, m_{ee} > 145\ \mathrm{MeV},\ \mathrm{E865})$$

$$K \to \pi\pi^0,\ \pi^0 \to \gamma e^+e^- \;\; (\sim 2\times 10^{-3})$$

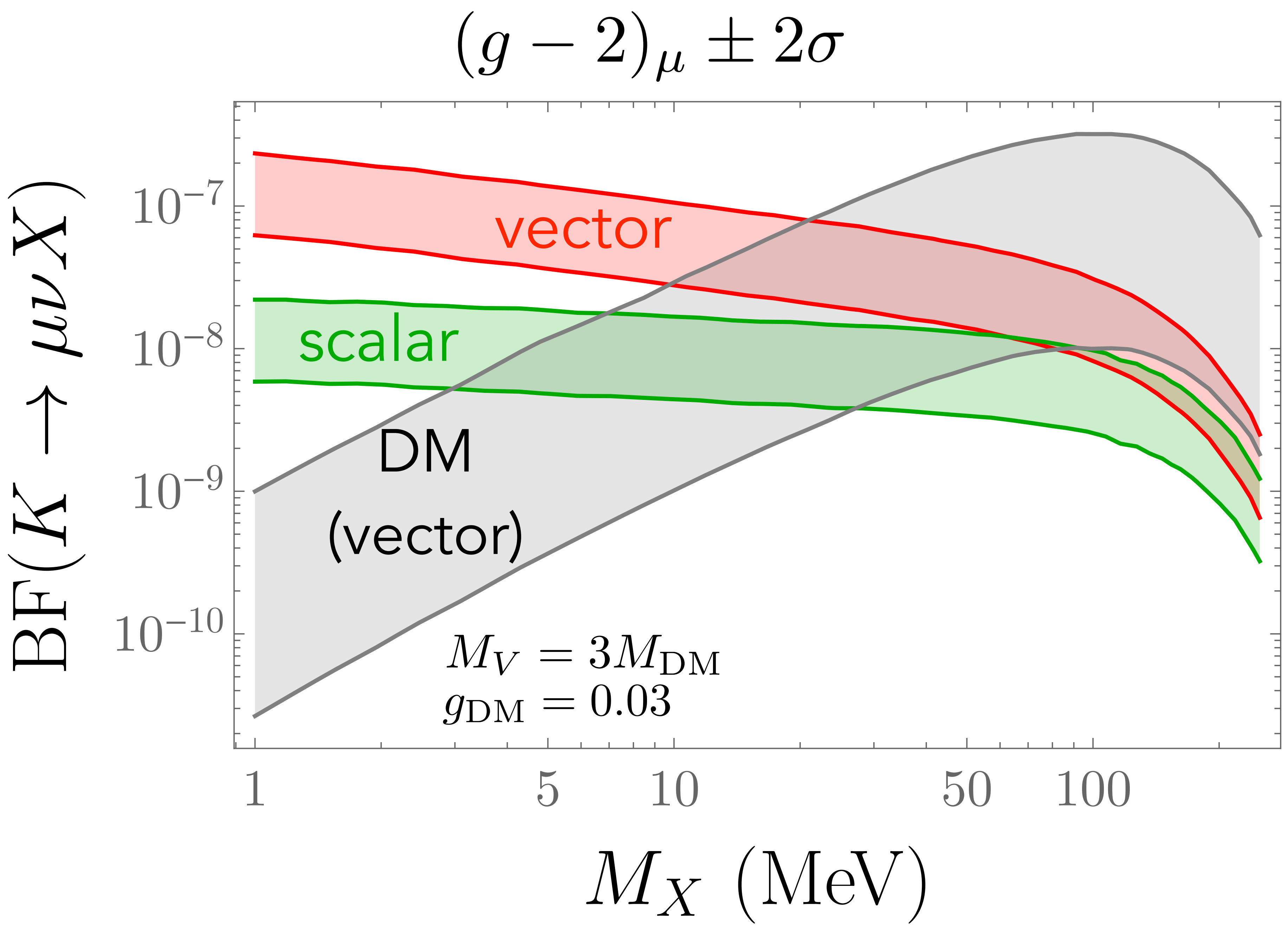
$$K \to \pi\pi^0 e^+e^- \;\; (\sim 4\times 10^{-6})$$

- Seems promising, but detailed studies are needed (and benchmarks can only be indirectly related to *g*-2)

WRITE-UP

- Some motivation and model details are there: should be easy to fill in the rest
- Starting to fill in signals and existing constraints/projections
- Biggest outstanding physics questions:
  - Invisible decays: how to make projects & improve sensitivity (given current trigger pre-scale, large systematics)?
  - Diphoton and dielectron decays: experimental input needed if we're going to get reasonable estimates, since dominant backgrounds are likely from mis-ID, fakes, etc.

BENCHMARKS



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QUESTIONS

- **What do we learn if the experiments don't find anything?**
  Leptonic force mediators are among the last remaining hope for low-mass explanations of *g*-2. A null result will strongly disfavor these explanations, and would also close the leptonic force loophole for dark matter mediators.

- **What is a good target branching fraction?**
  Having sensitivity to 10^{-9} would rule out *g*-2 below 200 MeV, strongly disfavor DM parameter space (together with Neff constraints). Better sensitivity would close loopholes close to kinematic threshold.