

Rare meson decay constraints on dark photon and the like

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§ Introduction

How to find/constrain new particles?

- Direct production
- Indirect searches
 - Rare processes in the SM.
 - EDM
 - Flavor violation
 - ...
 - Effects by unknown particles easily appear.

§ Dark photon and light vectors

Dark photon

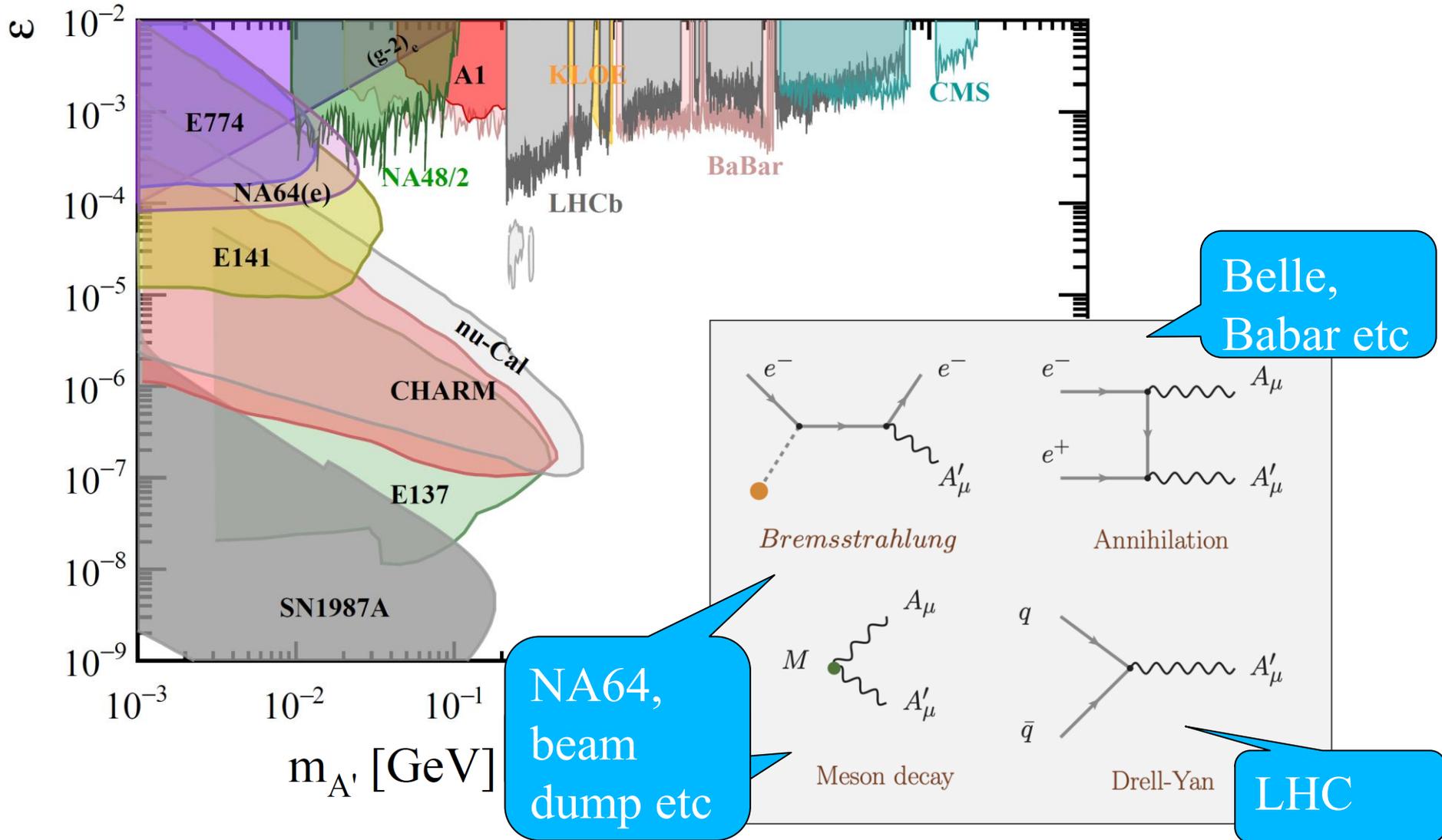
- Massive vector A' interacts with the SM only through the kinetic mixing [Holdom (1986)]
 - Gauge boson of broken $U(1)_D$ symmetry
 - All SM particles are not charged under $U(1)_D$
 - Unspecified origin of mass
- The tiny kinetic mixing
 - $\mathcal{L}_{\text{int}} \sim \epsilon \hat{F}_{\mu\nu} \hat{A}'^{\mu\nu}$induces
 - $\mathcal{L}_{\text{int}} \sim \epsilon A'_\mu J_{\text{em}}^\mu$

Light Z' boson

- Light gauge boson Z' interacts with small gauge coupling
 - Gauge boson of $U(1)_X$ symmetry
 - Well-motivated example :
 - $U(1)_{B-L}$: SM symmetry, neutrino mass, GUT...
 - $U(1)_R$: Forward-backward asym., ...
 - Some SM particles are charged under $U(1)_X$
 - Mass generated by Higgs mechanism
- The tiny gauge coupling
 - $D_\mu = \partial_\mu + \dots - iq_X g_X X_\mu$
 - The charge q_X depends on model

Searches

- **Dark photon** [Figs. from Fabbrichesi et al(2021)]



§ Models

Symmetry and particles

- Gauge sym.
 - $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$
 - $X = x_H Y + (B - L)$
 - $g_X \rightarrow 0$: dark photon
 - $x_H = 0$: $U(1)_{B-L}$
 - $x_H = -2$: $U(1)_R$
- Particle content
 - RH neutrinos for anomaly cancellation

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
Q_L^i	3	2	$\frac{1}{6}$	$\frac{1}{6}x_H + \frac{1}{3}$
u_R^i	3	1	$\frac{2}{3}$	$\frac{2}{3}x_H + \frac{1}{3}$
d_R^i	3	1	$-\frac{1}{3}$	$-\frac{1}{3}x_H + \frac{1}{3}$
L_L^i	1	2	$-\frac{1}{2}$	$-\frac{1}{2}x_H - 1$
e_R^i	1	1	-1	$-x_H - 1$
ν_R^i	1	1	0	-1
Φ_1	1	2	$\frac{1}{2}$	$\frac{1}{2}x_H + x_\Phi$
Φ_2	1	2	$\frac{1}{2}$	$\frac{1}{2}x_H$
Φ_X	1	1	0	2

To eliminate the mass mixing between Z and Z' .

To generate the mass of the extra gauge boson X and Majorana masses for RH neutrinos

Lagrangian

$$\mathcal{L}_{\text{Gauge}} = -\frac{1}{4}\hat{W}_{\mu\nu}\hat{W}^{\mu\nu} - \frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} + \frac{\sin\epsilon}{2}\hat{B}_{\mu\nu}\hat{X}^{\mu\nu}$$

$$\begin{aligned}\mathcal{L}_{\text{Yukawa}} = & -y^u\bar{Q}\tilde{\Phi}_2u_R - y^d\bar{Q}\Phi_2d_R - y^e\bar{L}\Phi_2e_R - y^\nu\bar{L}\tilde{\Phi}_2\nu_R \\ & -\frac{1}{2}y^{\nu R}\bar{\nu}_R^C\Phi_X\nu_R + \text{H.c.}\end{aligned}$$

$$\mathcal{L}_{\text{Higgs}} = |D_\mu\Phi_1|^2 + |D_\mu\Phi_2|^2 + |D_\mu\Phi_X|^2 - V,$$

$$V = V(\Phi_1, \Phi_2, \Phi_X)$$

Mass eigenstates by resolving the kinetic and mass mixing.

§ Favor changing rare meson
decay

Light $X = (A' \text{ or } Z')$ boson

- Modes

- $B^- \rightarrow K^- (X \rightarrow l^- l^+)$

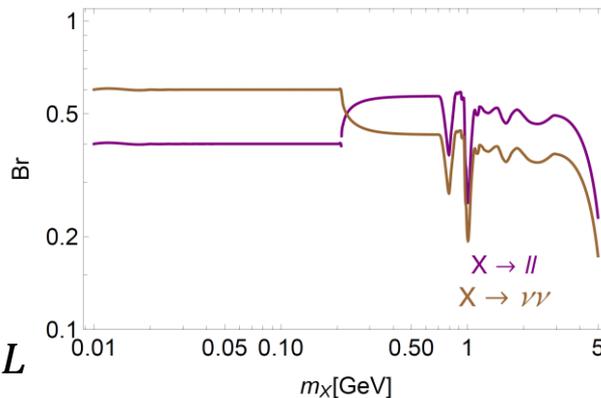
- $K^- \rightarrow \pi^- (X \rightarrow \nu \bar{\nu})$

- On shell X

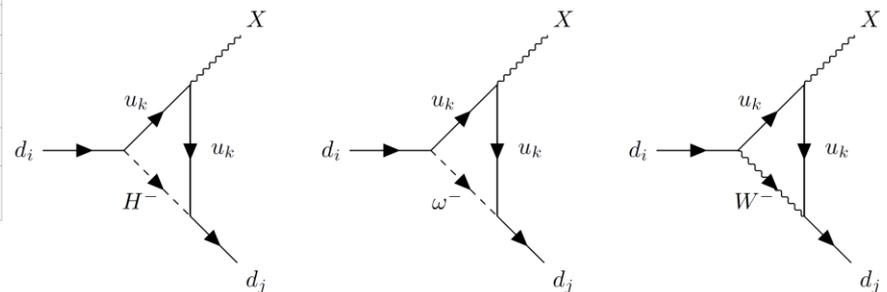
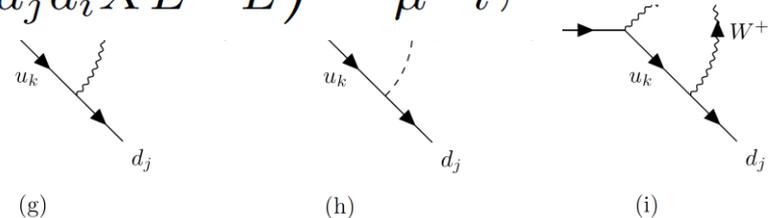
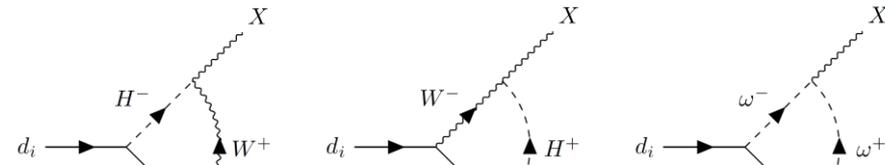
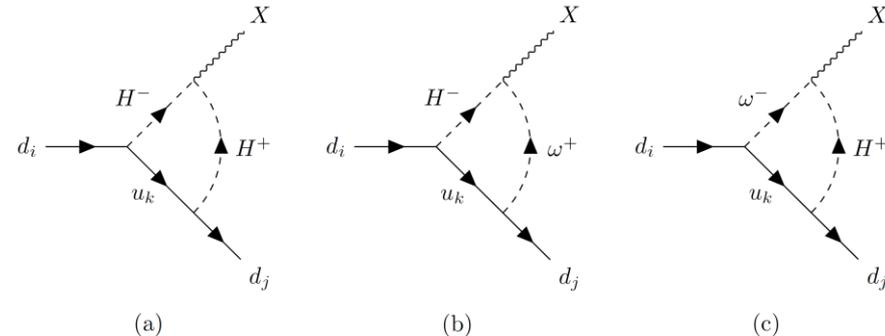
- Loop induced flavor changing vertex

$$\mathcal{L} \supset \bar{d}_j \gamma^\mu (C_{d_j d_i X R} P_R + C_{d_j d_i X L} P_L) X_\mu d_i,$$

- Decay of X



$U(1)_{B-L}$



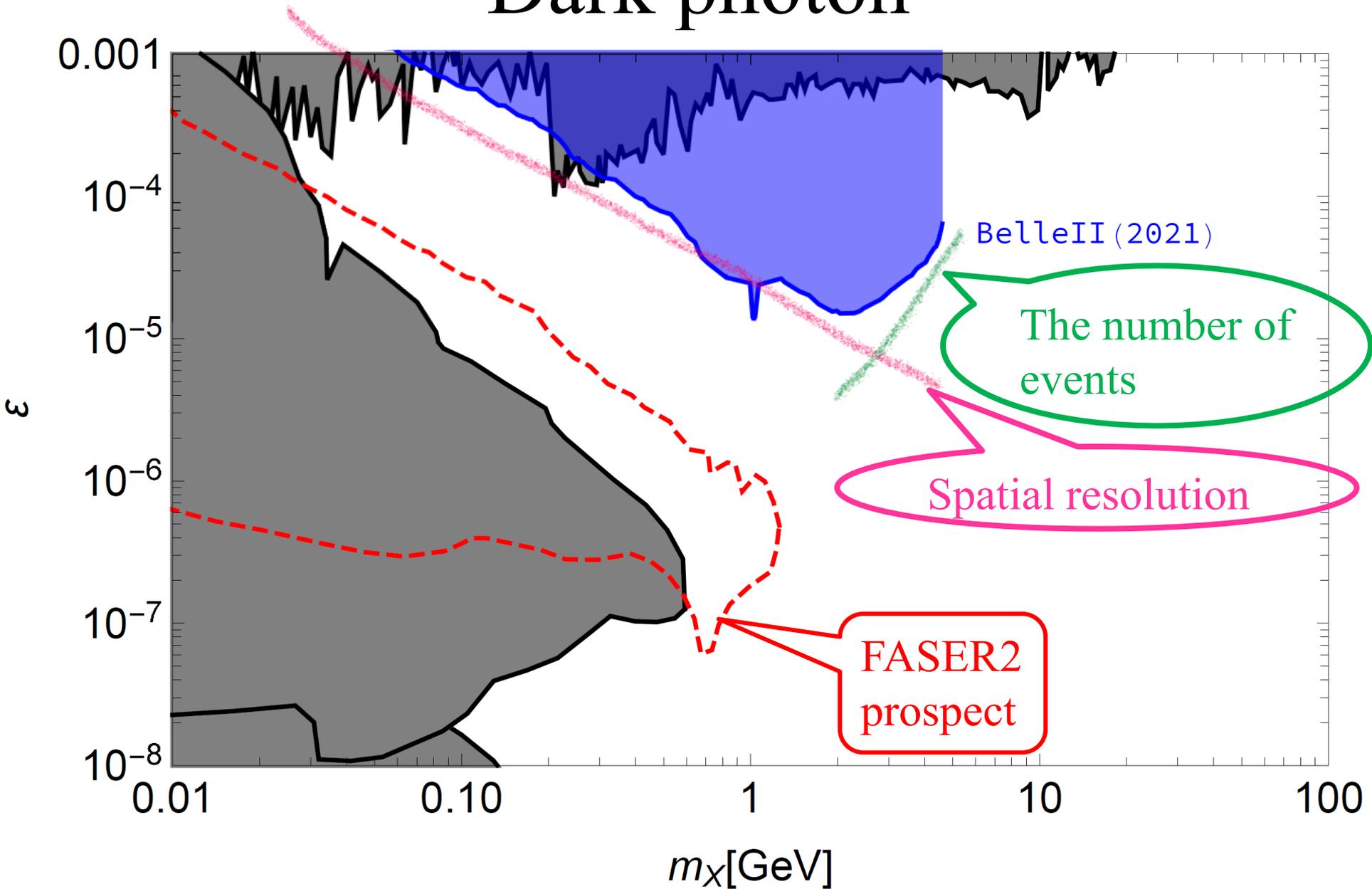
§ Results

Comparison with experiments

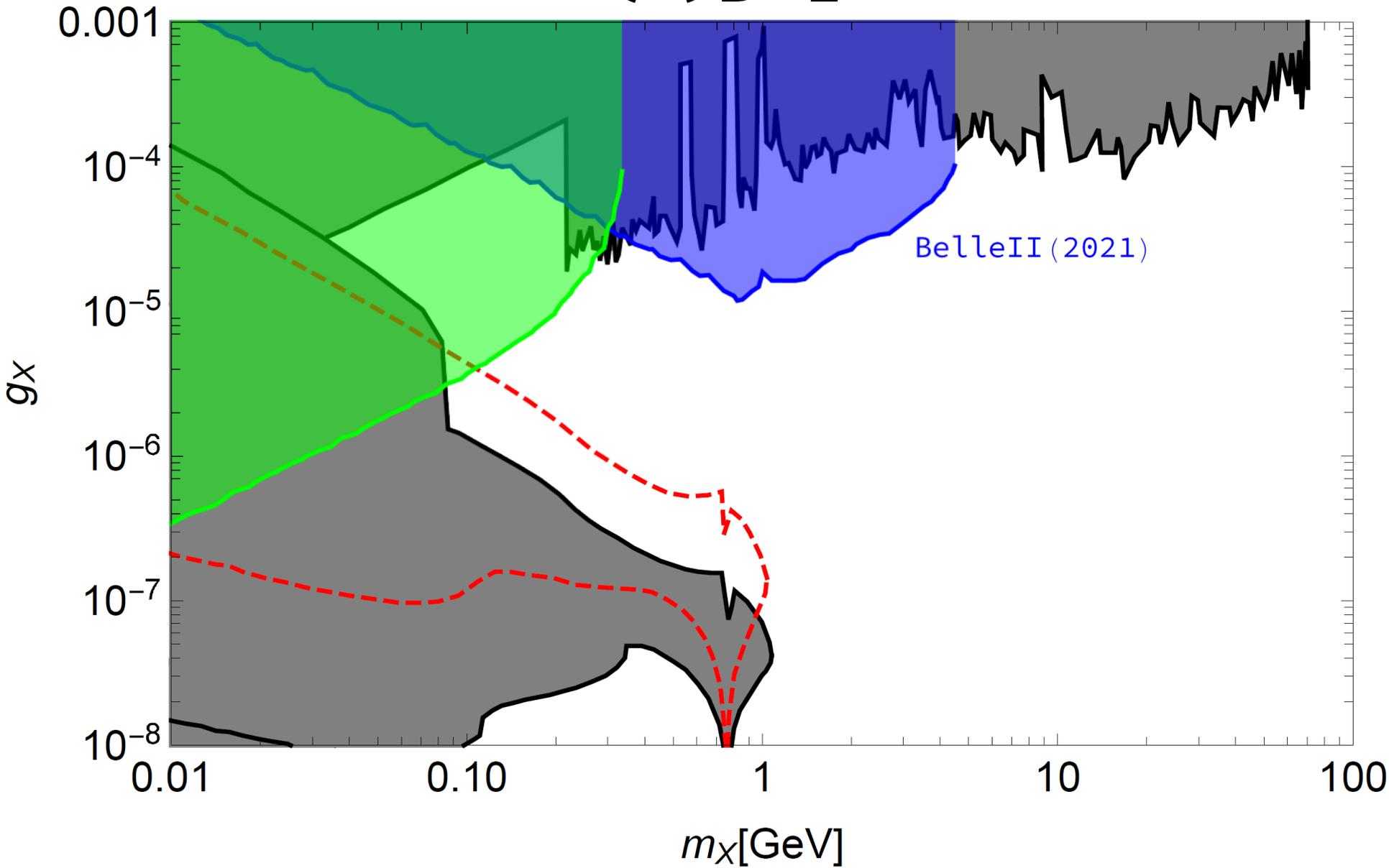
- $B^- \rightarrow K^- (X \rightarrow l^- l^+)$
 - SM $\text{Br}(B^- \rightarrow K^- l^- l^+) = (6.5 \pm 0.5) \times 10^{-7}$
 - Exp[PDG=Babar,LHCb,BelleII ave.] $4.7_{-0.5}^{+0.5} \times 10^{-7}$
 - Exp[BelleII(2021)] $5.99_{-0.43}^{+0.45} \times 10^{-7}$
 - We apply $\text{Br}(B^- \rightarrow K^- (X \rightarrow l^- l^+)) < 0.5 \times 10^{-7}$

- $K^- \rightarrow \pi^- (X \rightarrow \nu \bar{\nu})$
 - SM $\text{Br}(K^- \rightarrow \pi^- \nu \bar{\nu}) = (7.73 \pm 0.61) \times 10^{-11}$
 - Exp[E949, NA62 ave.] $1.14_{-0.33}^{+0.40} \times 10^{-10}$
 - We apply $\text{Br}(K^- \rightarrow \pi^- (X \rightarrow \nu \bar{\nu})) < 0.83 \times 10^{-10}$

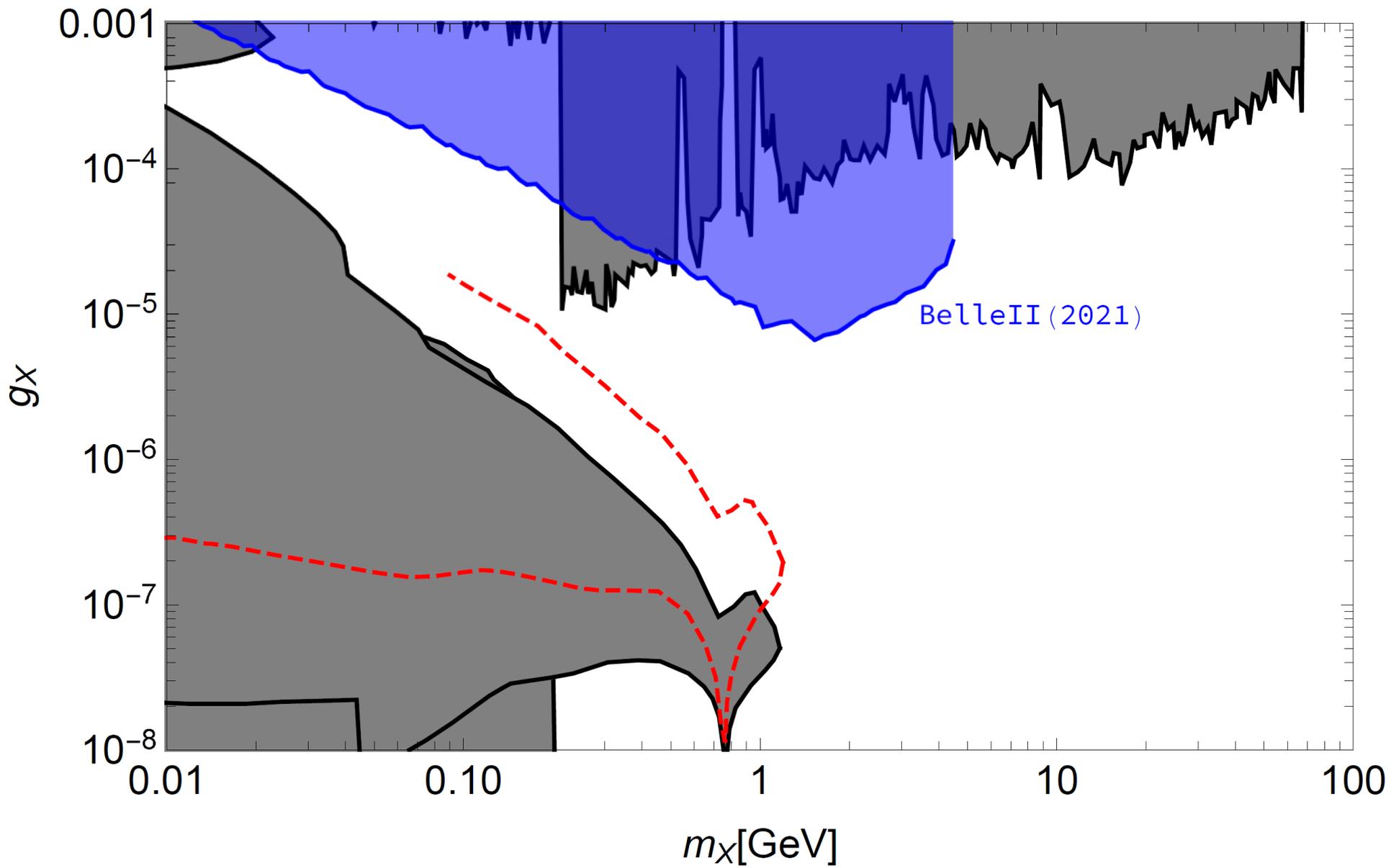
Dark photon



$U(1)_{B-L}$



$U(1)_R$



§ Summary

- MeV-GeV mass dark photon and other vector boson
- New constrains from rare meson decay
 - B meson decay and Kaon decay
 - Unexplored region changed