Dark Matter and New Physics from Belle-II Experiment

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Outline

- Introduction
- Light dark matter and mediators
- B-meson anomalies and new physics
- Conclusions

Light dark matter and mediators

Energy/Intensity interplay

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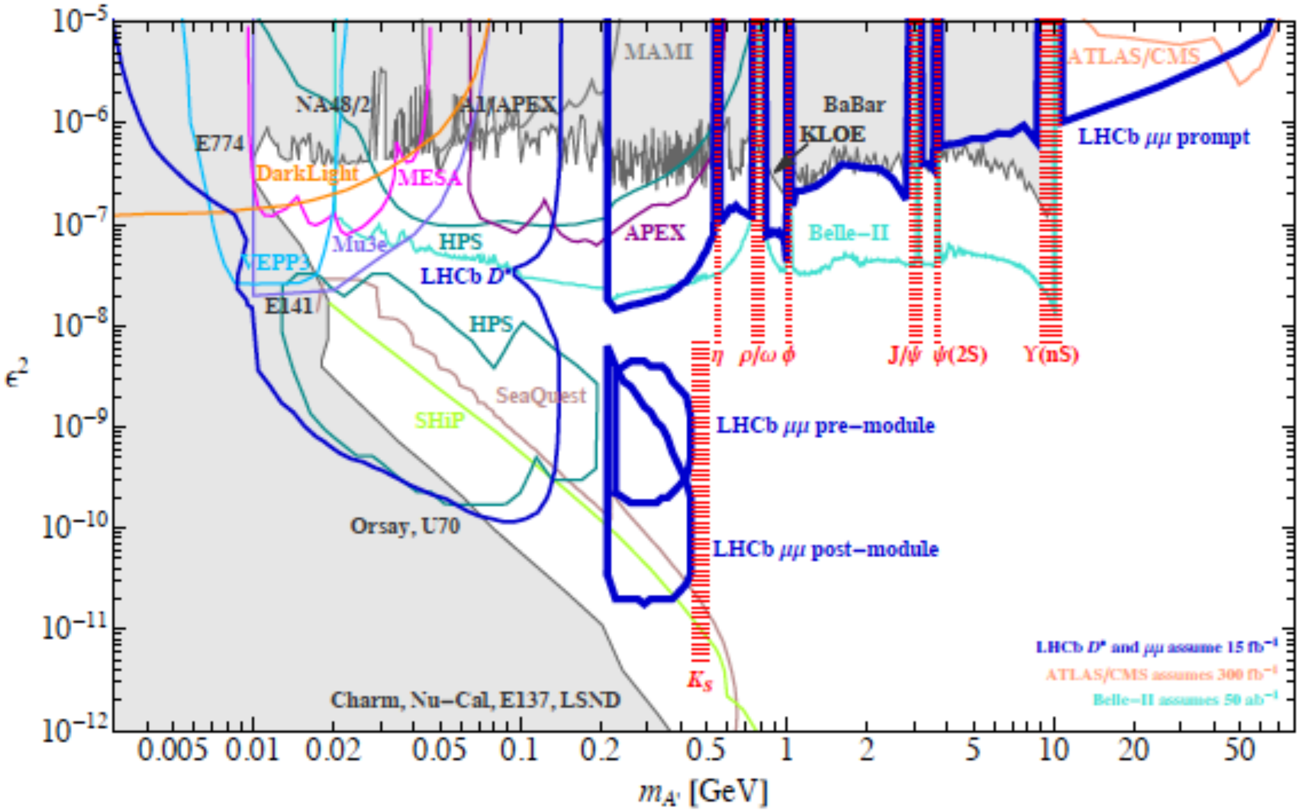
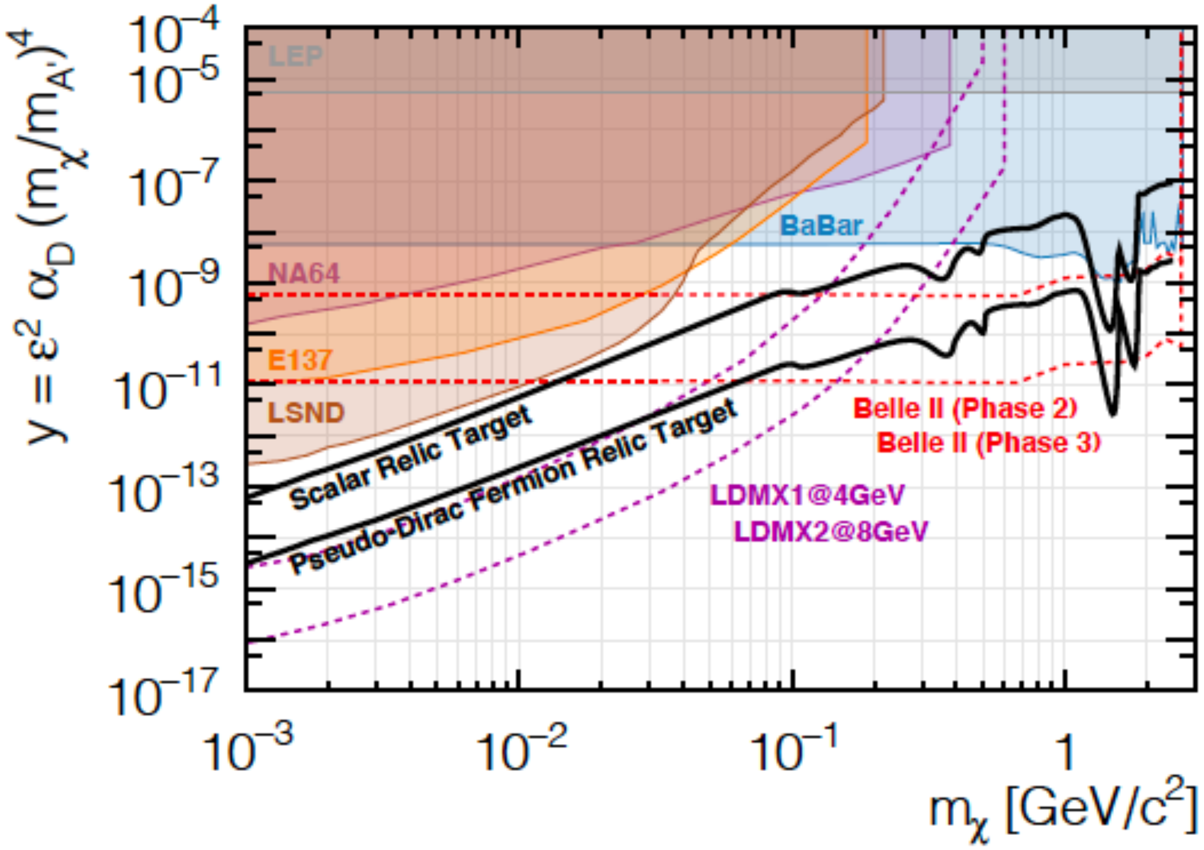


[Ilten et al, 2016]



[Belle-II,1808.10567]

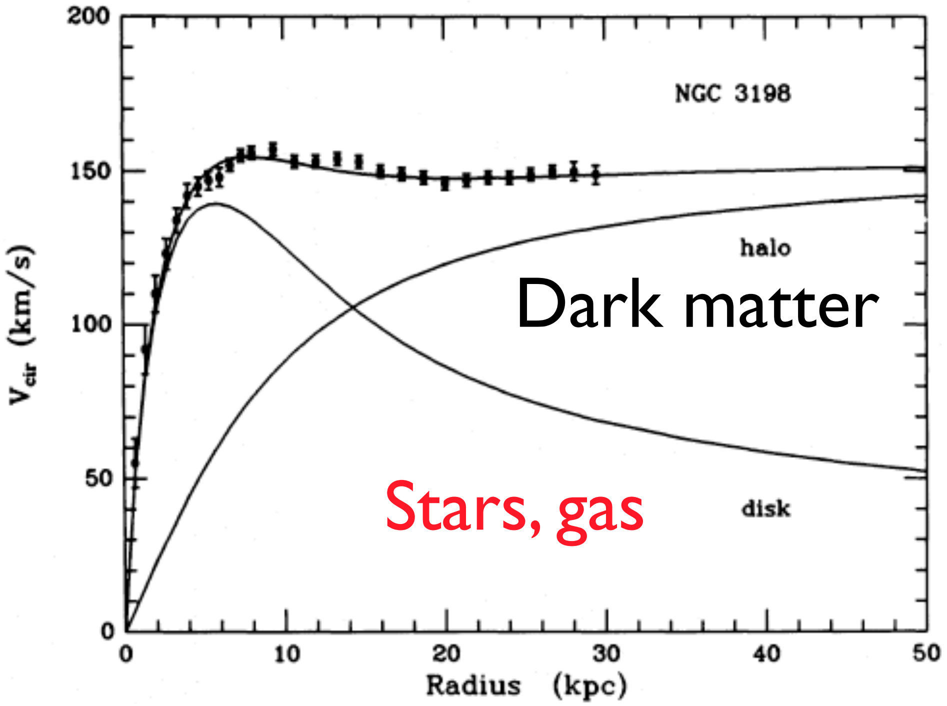
- No direct evidence for new physics at LHC.

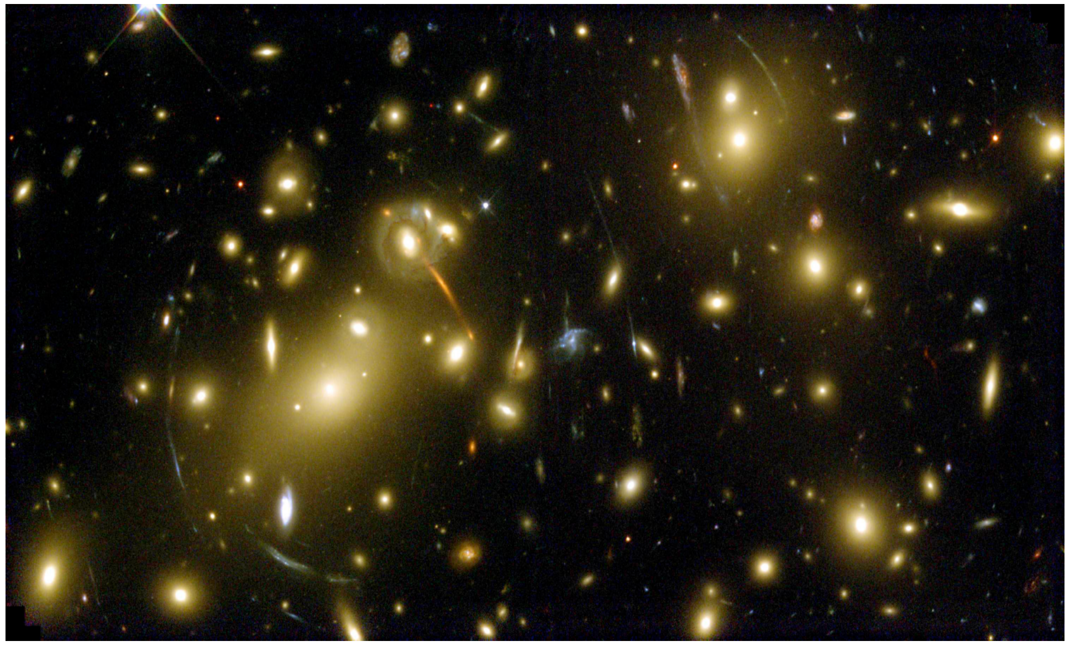
➡ Little hierarchy between weak scale and new physics?

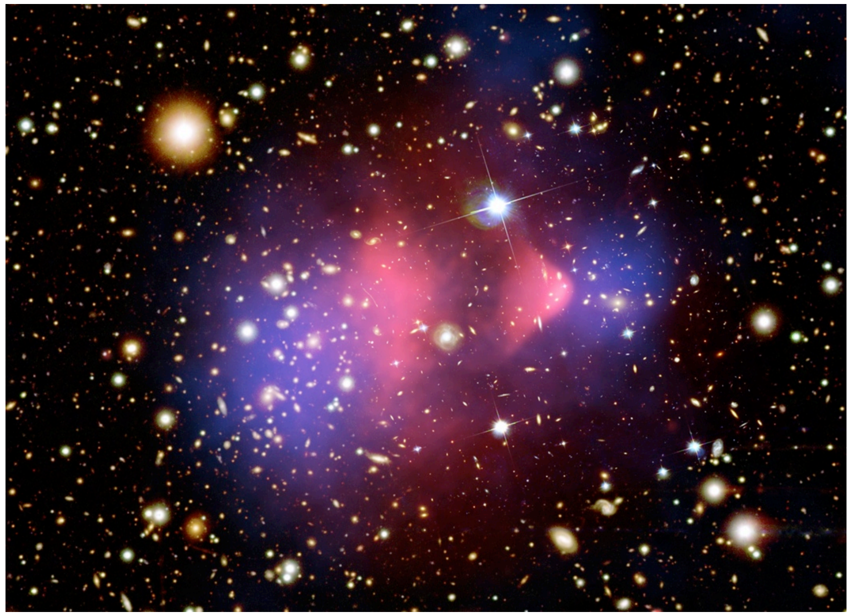
- New particles are very weakly coupled and/or light.

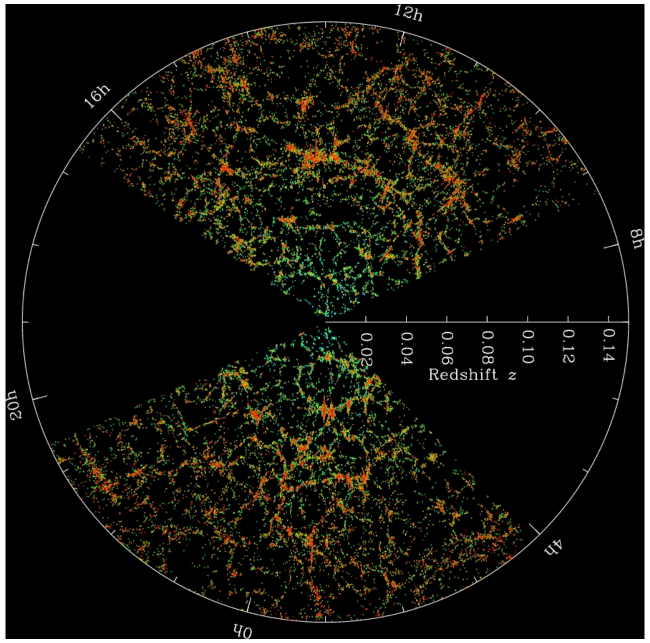
➡ Testable with precision and intensity experiments?

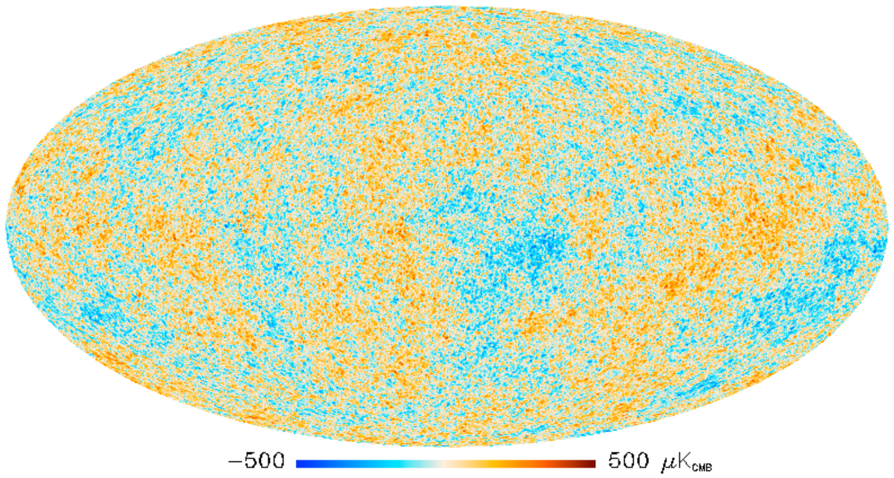
Evidences for dark matter





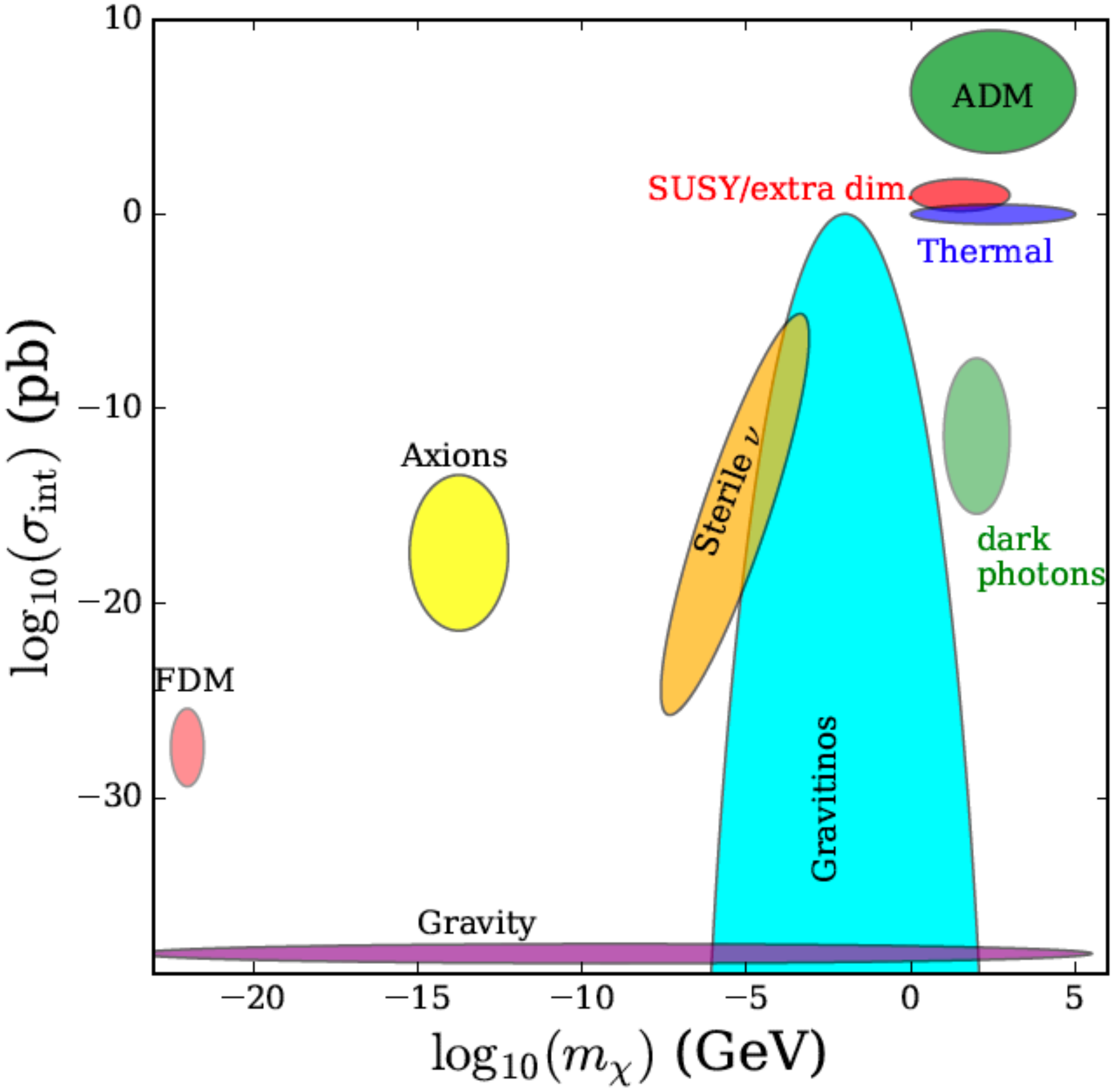


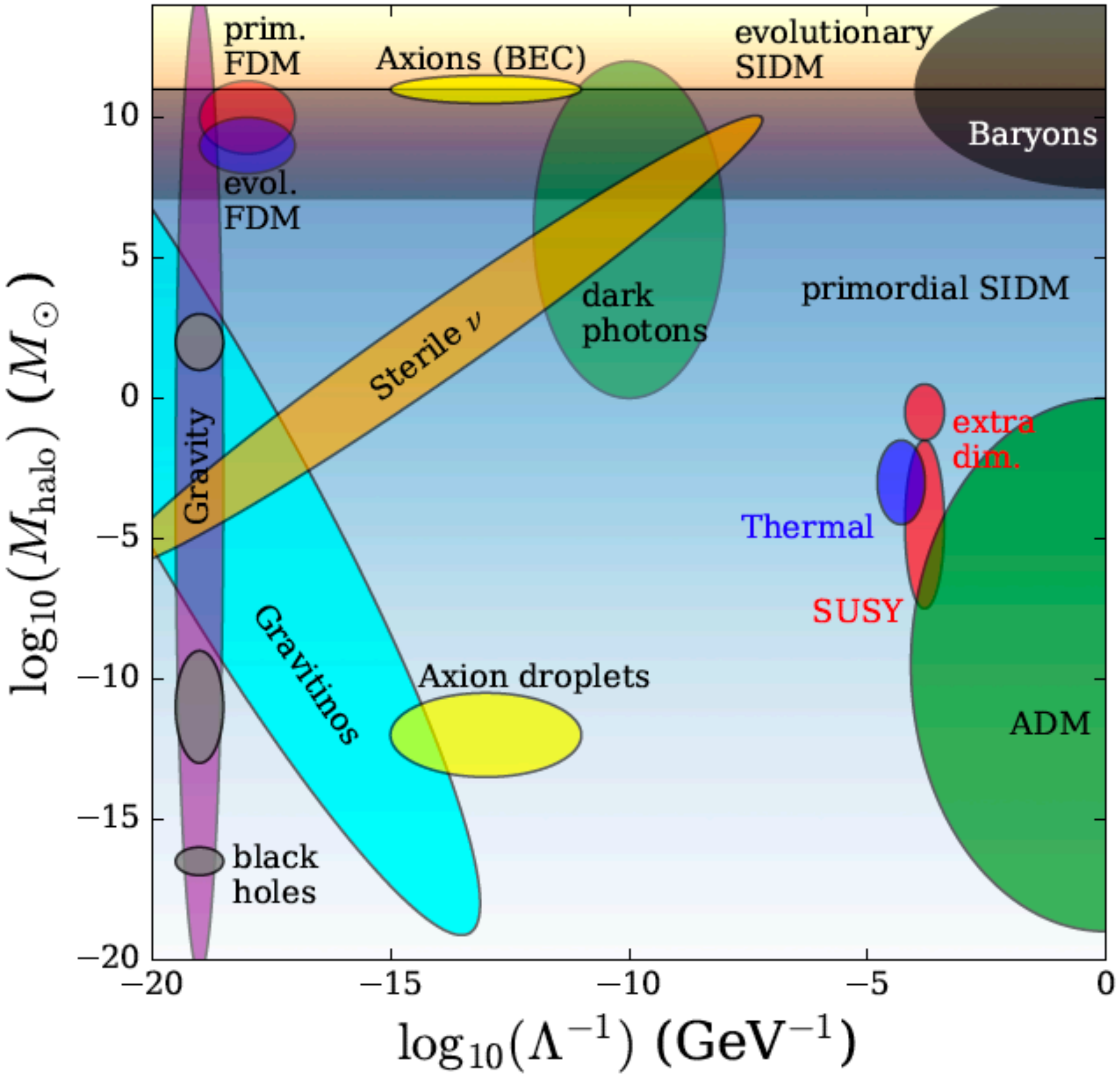




- Galaxy rotation curves, gravity lensing, Bullet cluster, CMB, hint at invisible mass, Dark Matter.

Status of DM models

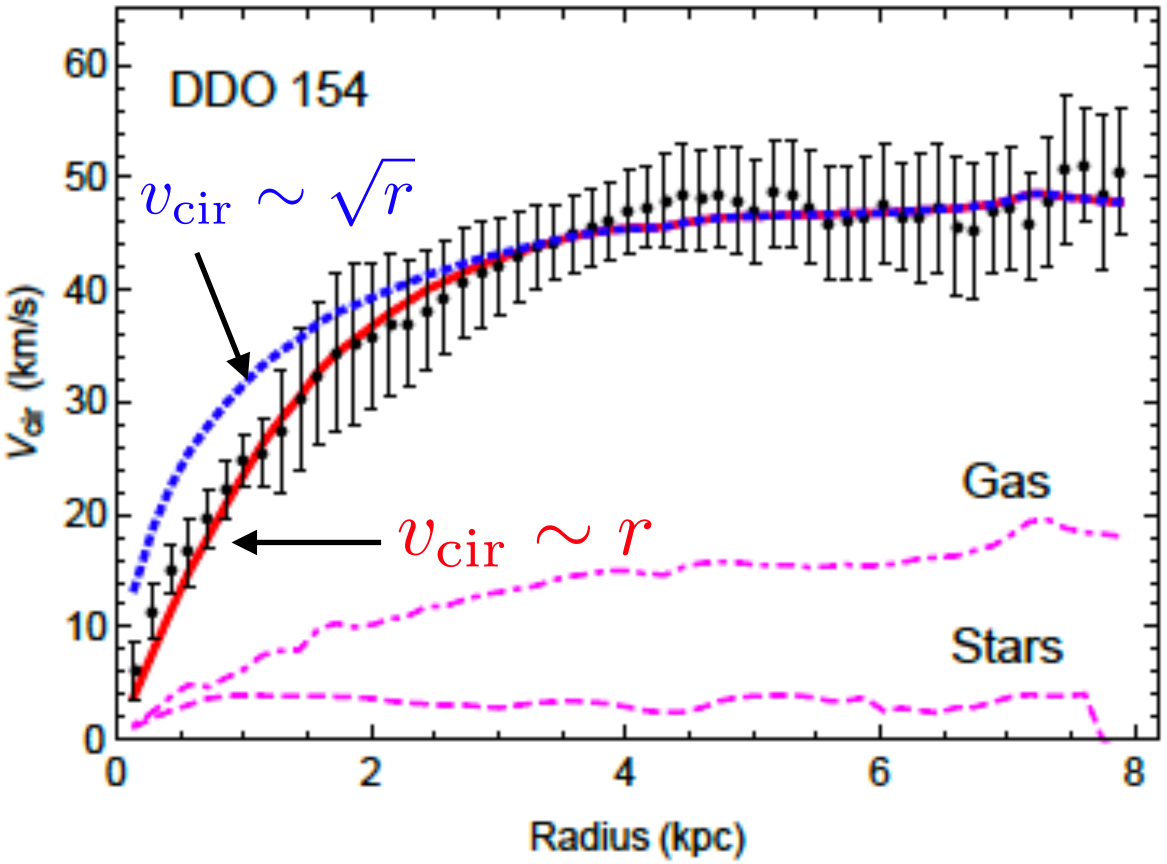


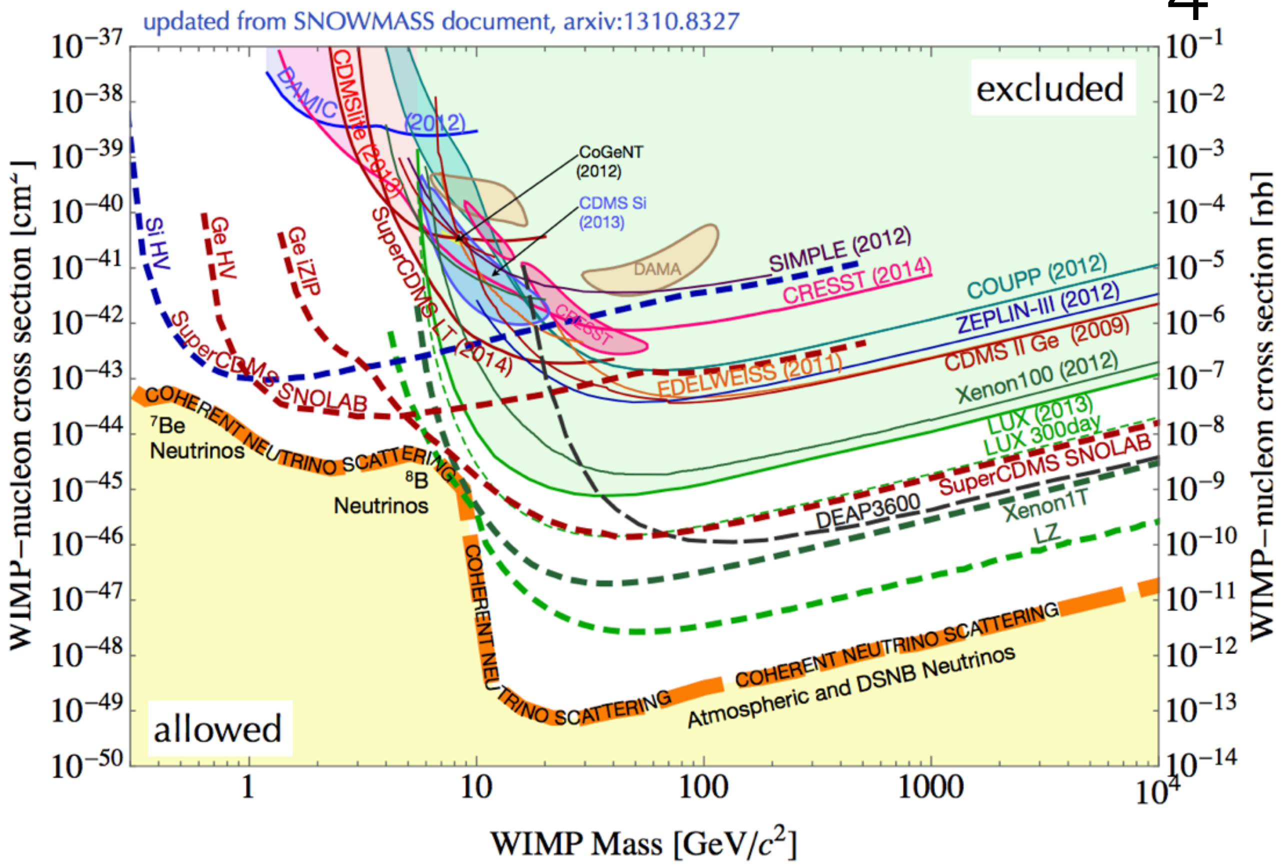


[M. Buckley, A. Peter, 1712.06615]

Astrophysics widens our view on dark matter:
WIMP, Axion, SIDM, etc, at colliders,
astrophysical observations, etc.

WIMP / CDM Crisis





[Spergel, Steinhardt, 2000; S.Tulin, H.Yu, 2017]

DM-nucleon scattering

- Core-cusp problem: galaxy rotation curves in conflict with WIMP simulations at <kpc scale.

Self-Interacting Dark Matter!

$$\frac{\sigma_{\rm self}}{m_{\rm DM}} \sim 1{\rm cm}^2/{\rm g}$$

Best candidate: light dark matter with sub-GeV mass.

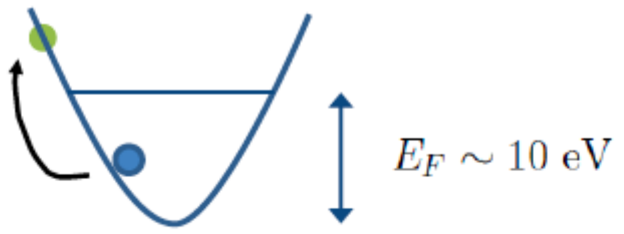
Challenging for direct detection!

Light DM detection

- DM-electron scattering is sensitive to light dark matter.

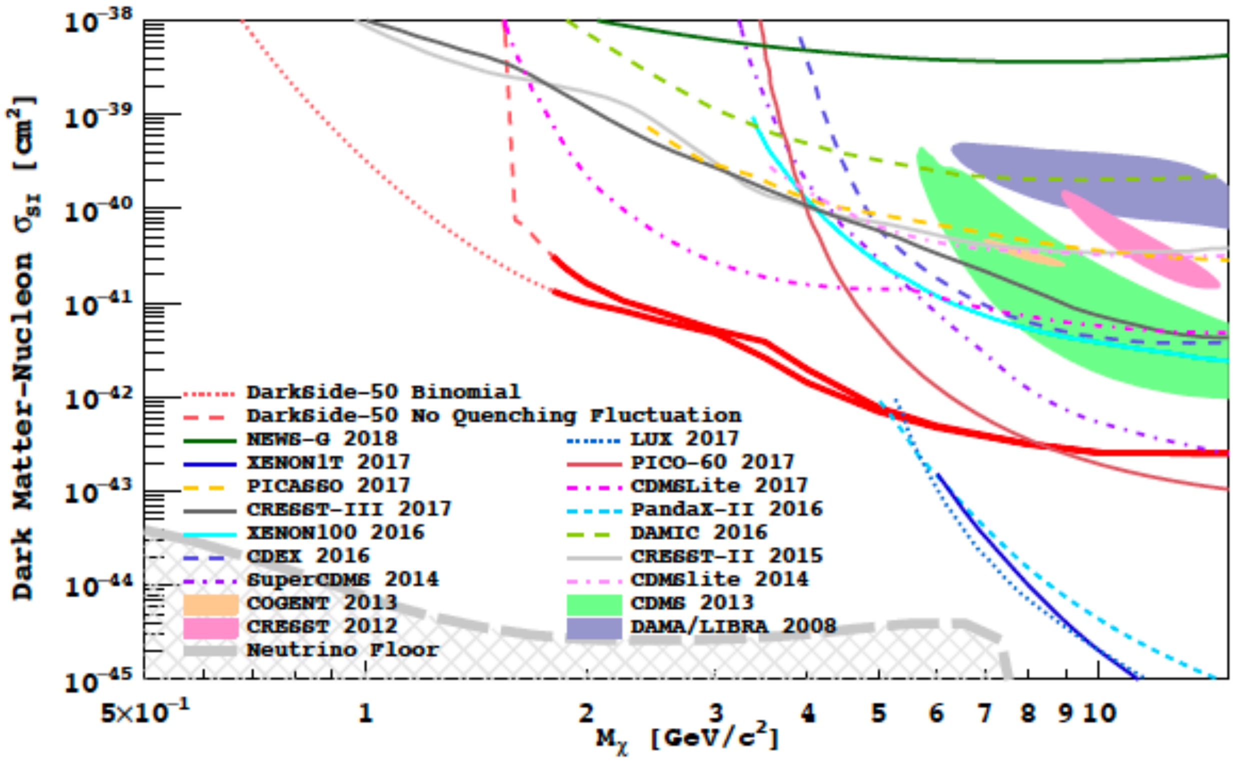
$$E_R \sim \frac{\mu^2 v_{\rm rel}^2}{m_e} \sim m_e v_{\rm rel}^2 \sim 0.3\,{\rm eV}\ -20\,{\rm eV}$$

[Hochberg et al (2015)]

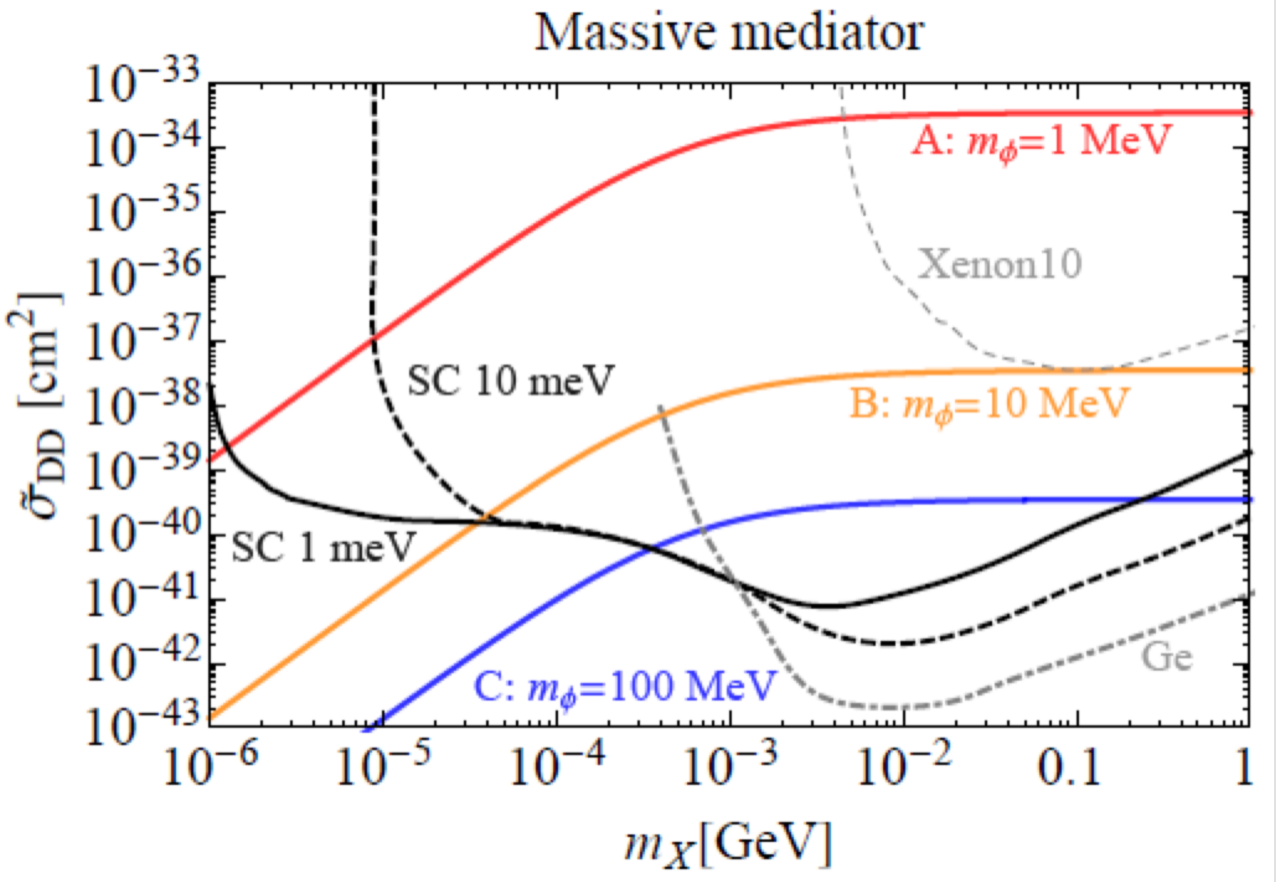


Cooper-pair breaking $m_{\rm DM} v^2 \gtrsim \Delta \sim {\rm meV}$

e.g. Al: $E_F = 11.7\,{\rm eV},\ v_{\rm rel} \sim v_F \sim 10^{-2}$



DM-nucleon scattering

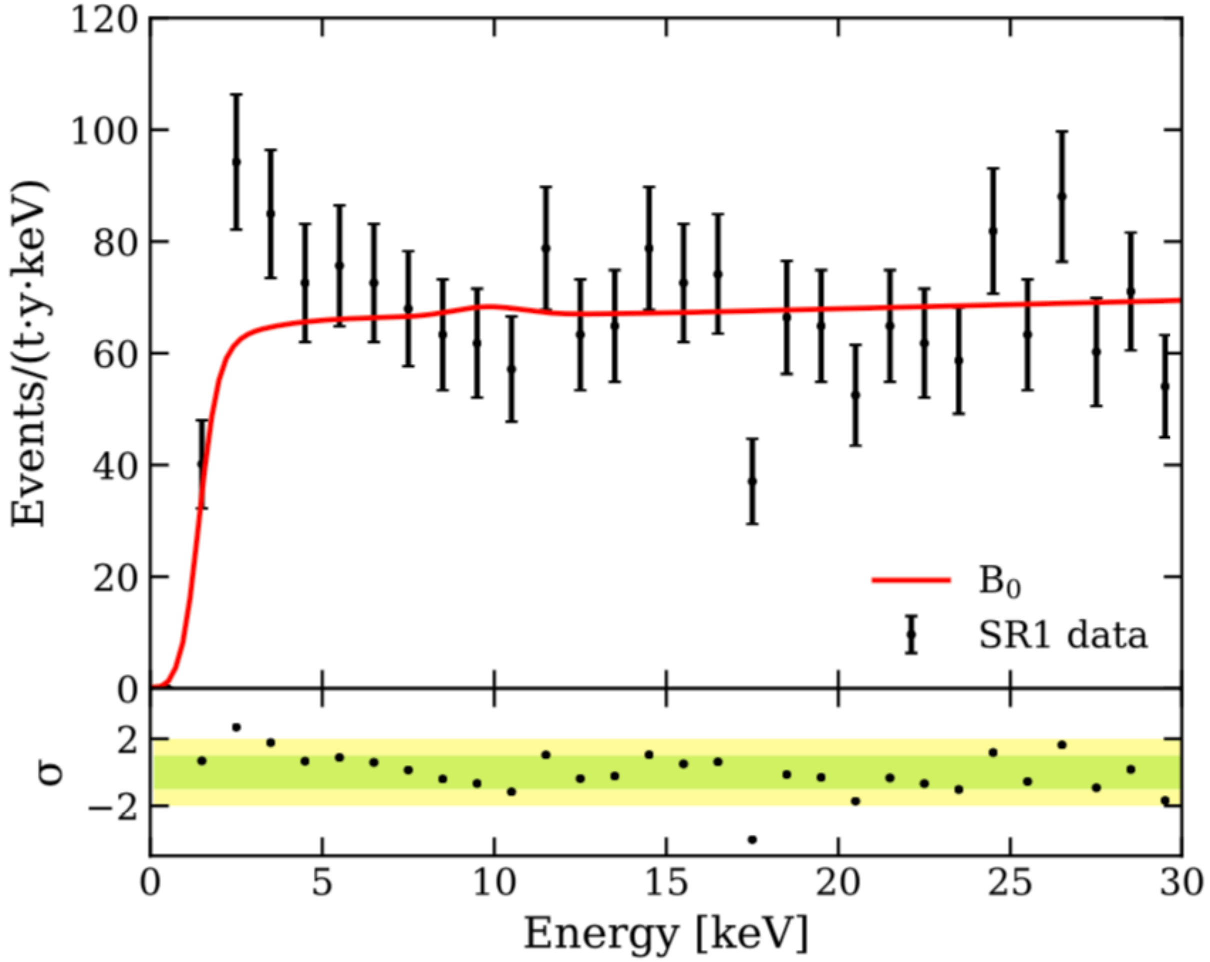


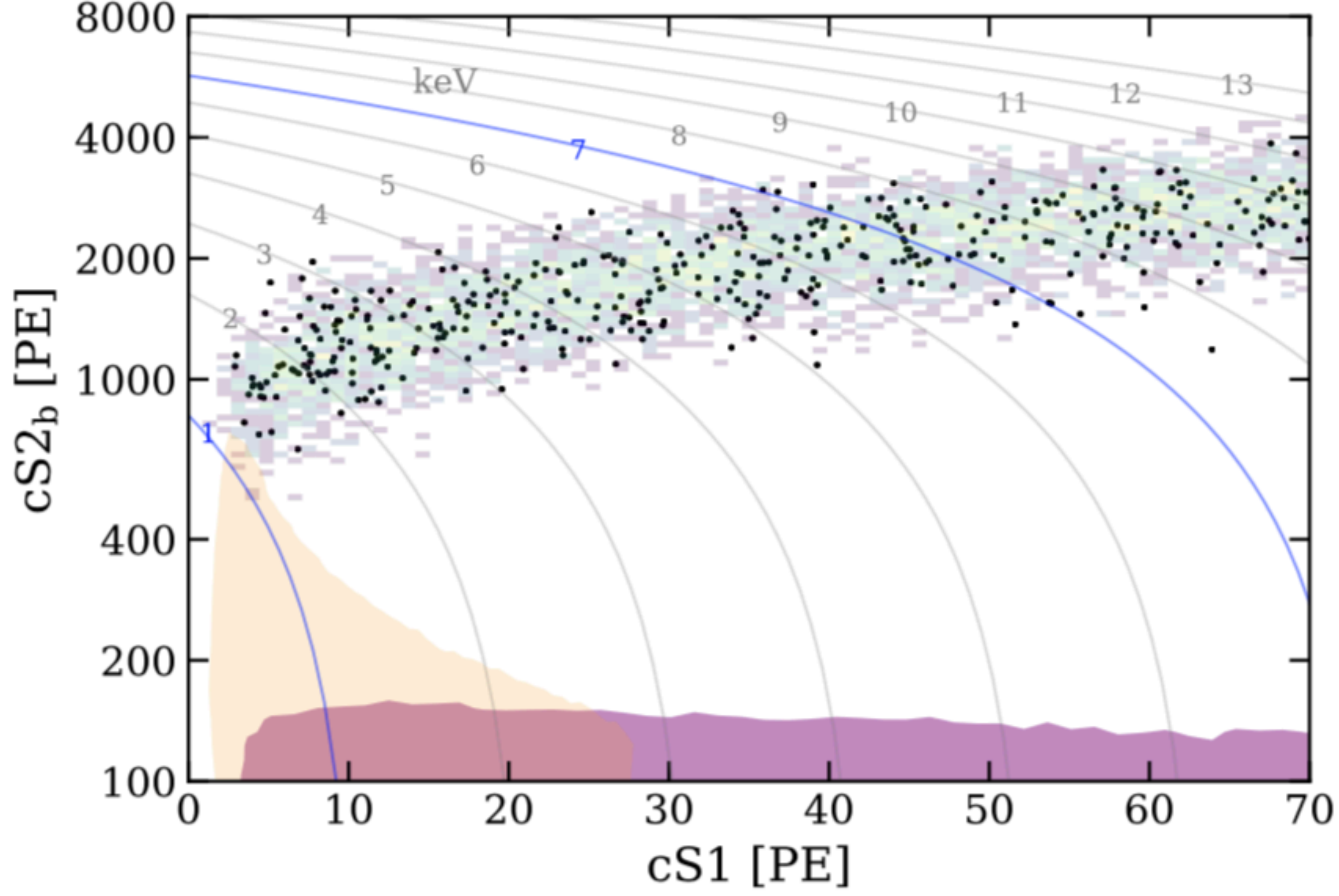
DM-electron scattering

XENON1T electron recoil

- Excess in electron recoil spectrum.

[XENON1T, 2006.09721]





E_R=1-7keV: 285 events observed,

232 ± 15 expected

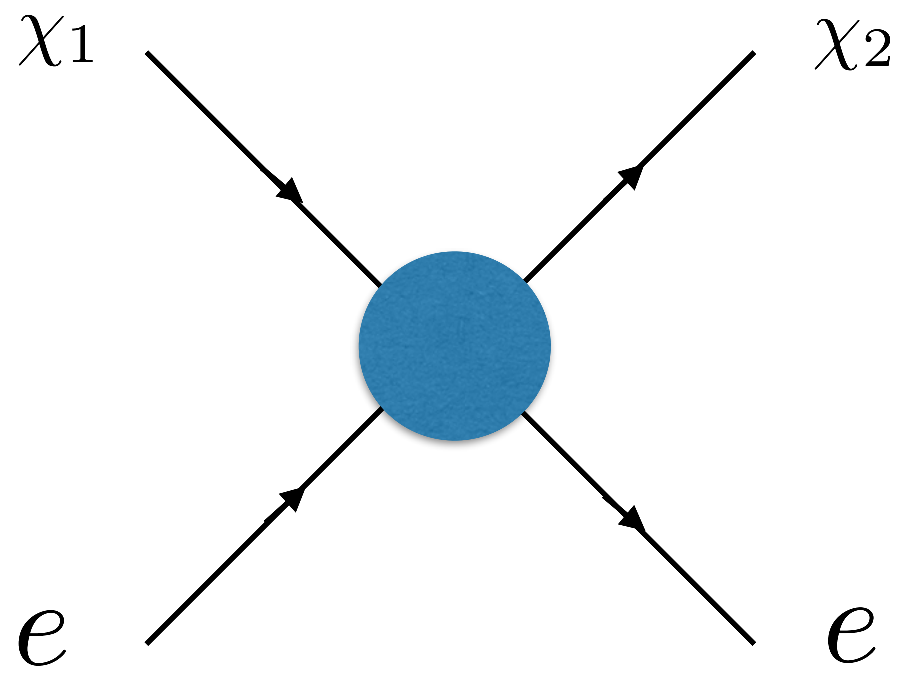
3.3σ deviation:

most significant at

E_R=2-3keV

cf. Other backgrounds: Unknown Tritium, Ar37

Exothermic dark matter



[K. Harigaya et al; HML; J. Bramante et al; Essig et al;S. Choi, HML, B. Zhu]

$$\Delta m = m_{\chi_1} - m_{\chi_2} \gg m_e v^2$$

$$E_R \sim \Delta m \sim 2.5\,\mathrm{keV}$$

"Exothermic dark matter"

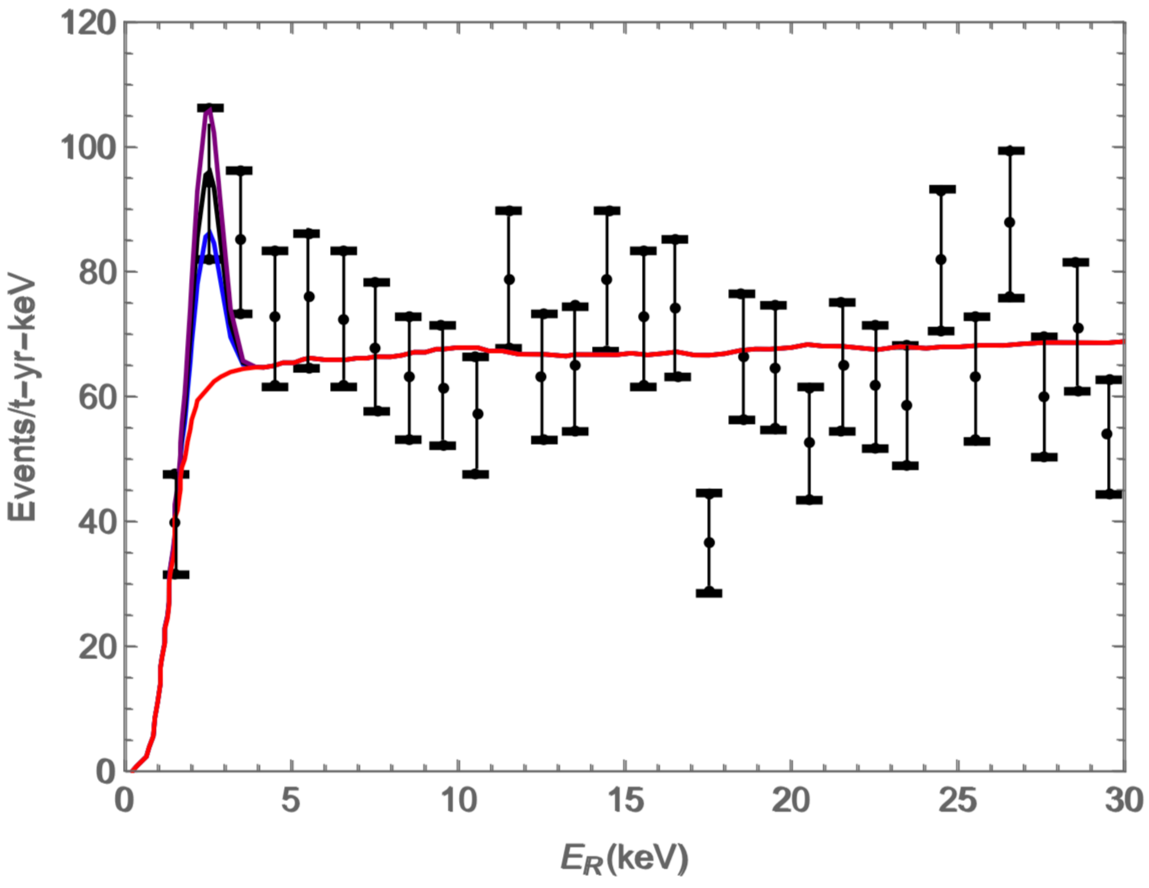
Monochromatic e-recoil energy

$$E_R \simeq \Delta m \left(1 - \frac{2}{\sqrt{\kappa}}\cos\theta\right)$$

$$\kappa = \frac{2\Delta m}{m_e v^2} \gg 1$$

Cross section

$$\bar{\sigma}_e / m_{\chi_1} \simeq 10^{-43}\mathrm{cm}^2\,/\mathrm{GeV}$$



Model for exothermic DM

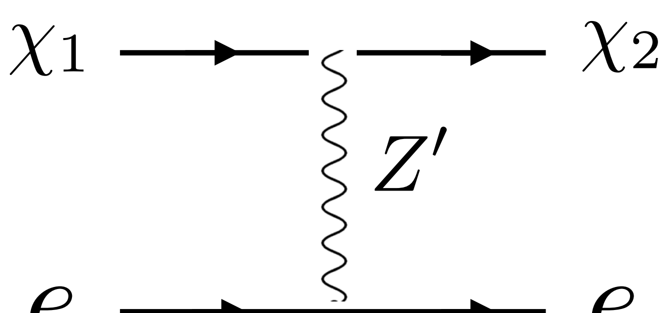
- Two DM states and electron with Z’ mediator:

$$\begin{aligned}\mathcal{L}_{\rm eff} &= \left(g_{Z'} Z'_\mu\, \bar\chi_2\gamma^\mu(v_\chi + a_\chi\gamma^5)\chi_1 + \text{h.c.}\right) + g_{Z'} Z'_\mu\, \bar e(v_e + a_e\gamma^5)e \\ &\quad + g_{Z'} Z'_\mu\, \bar\nu\gamma^\mu(v_\nu + a_\nu\gamma^5)\nu\end{aligned}$$

[HML, 2020]

- DM-electron inelastic cross section:

$$\begin{aligned}\bar\sigma_e &\simeq \frac{v_\chi^2 v_e^2 g_{Z'}^4 \mu_1^2}{\pi m_{Z'}^4} \\ &\simeq \left(\frac{v_\chi g_{Z'}}{0.6}\right)^2 \left(\frac{v_e g_{Z'}}{10^{-4} e}\right)^2 \left(\frac{600\,\text{MeV}}{m_{Z'}}\right)^4 \left(\frac{\mu_1}{m_e}\right)^2 \times 10^{-43}\,\text{cm}^2\end{aligned}$$

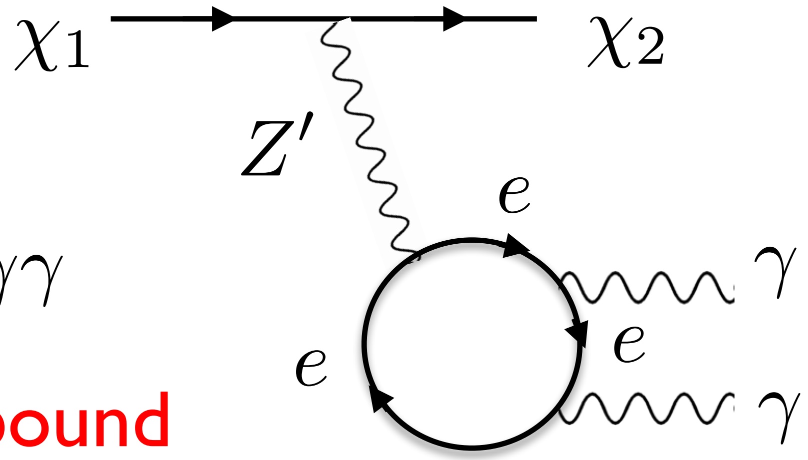


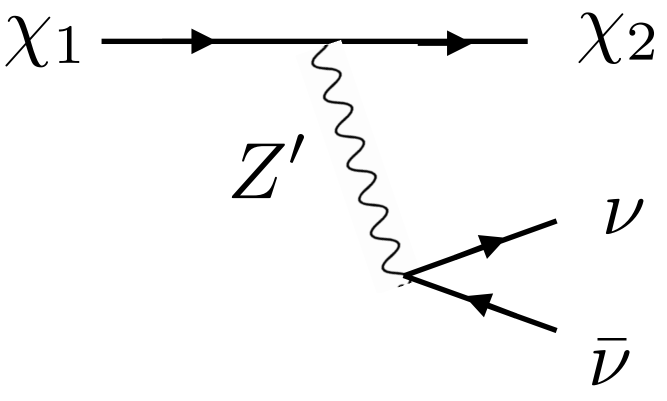
- Long-lived heavy DM state:

$a_e = 0$

$\chi_1 \not\to \chi_2\gamma\gamma$

No X-ray bound



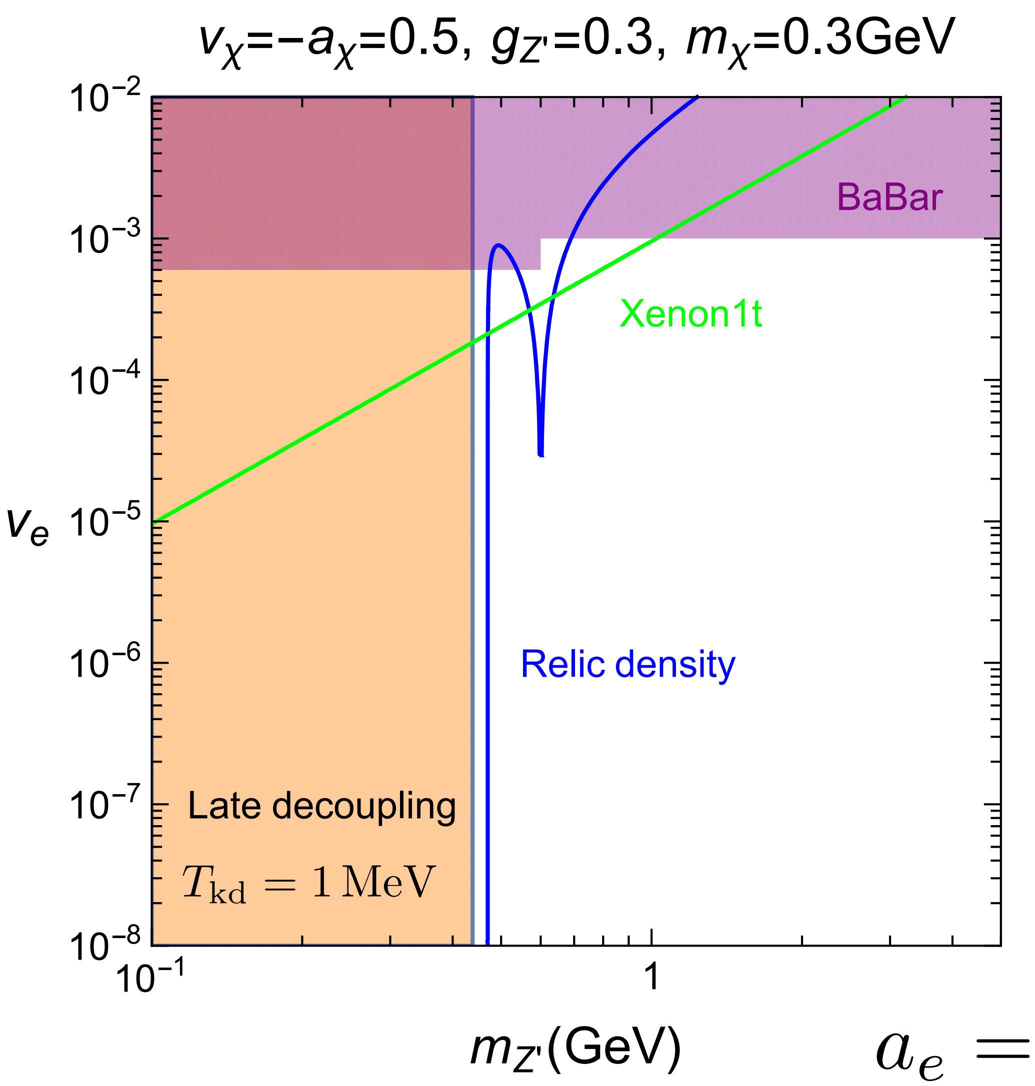


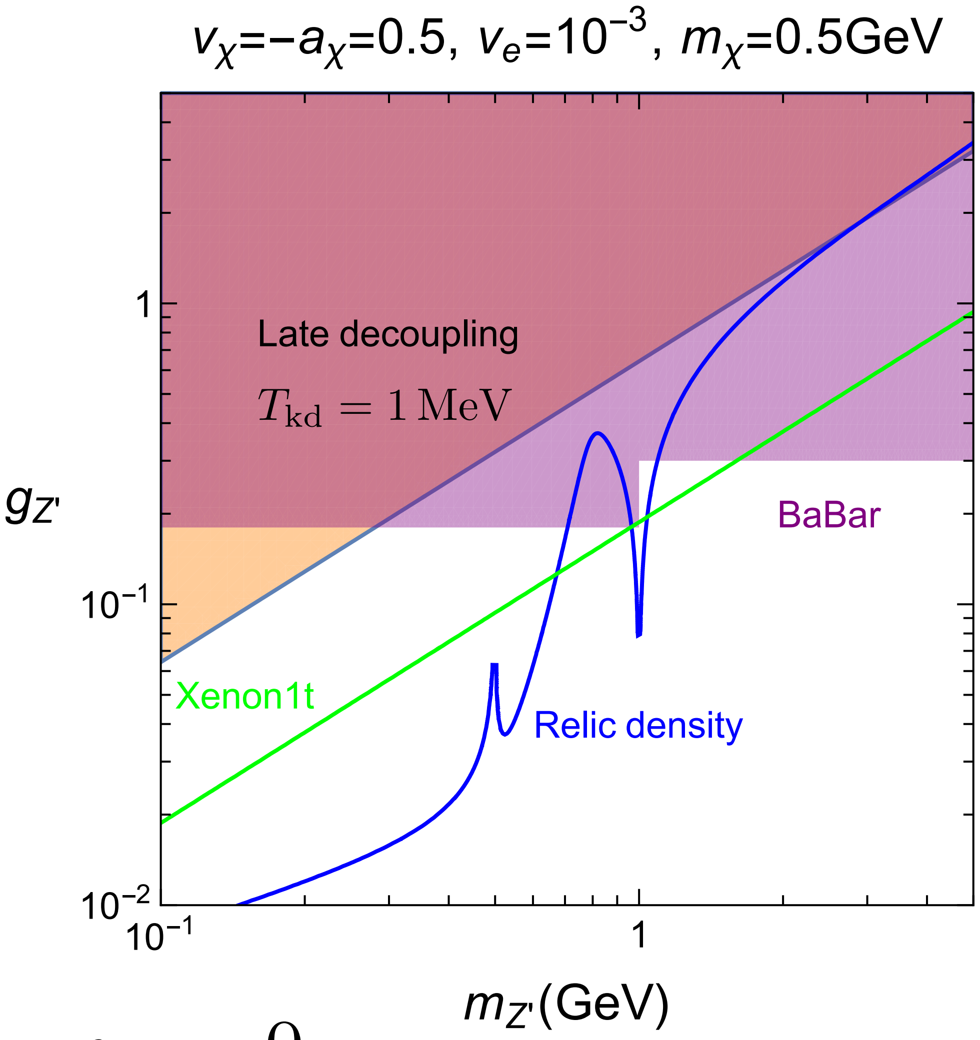
Long-lived

XENON1T + DM relic

- Electron couplings are constrained by visible/invisible searches at BaBar, beam dump, meson decays, Belle-2.

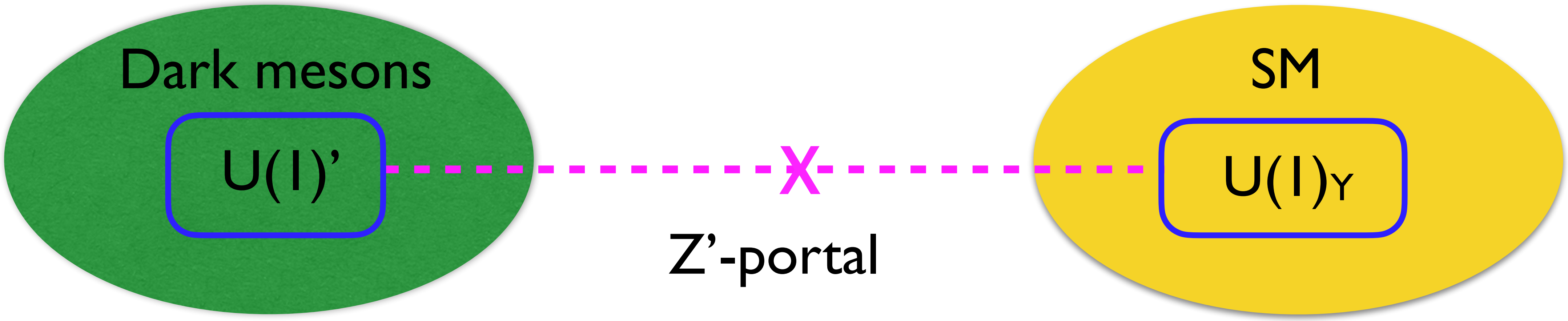
$m_{Z'} \lesssim 10\,\mathrm{GeV}$ → $|v_e|\,g_{Z'} \lesssim (10^{-4} - 10^{-3})\,e$





$$a_e = v_\nu = a_\nu = 0$$

Dark mesons & Z'-portal



- Dark mesons from hidden QCD = dark matter

  "Dark flavor violation" split dark meson masses.

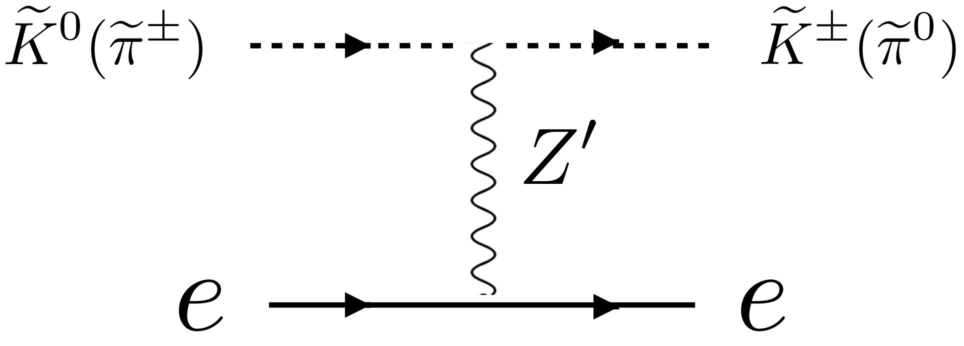
$$\mathcal{L}_{\rm mix} = -y_{12}\,\phi\,\bar{u}'d' - y_{13}\,\phi\,\bar{u}'s' - {\rm h.c.}$$

[HML, M. Seo, 2015;
S.Choi, HML, B. Zhu, 2012.03713]

$$\Longrightarrow \quad m_{\widetilde{K}^0} - m_{\widetilde{K}^\pm} \simeq \Delta m\,, \quad m_{\widetilde{\pi}^\pm} - m_{\widetilde{\pi}^0} \simeq \frac{1}{\sqrt{3}}\,\Delta m$$

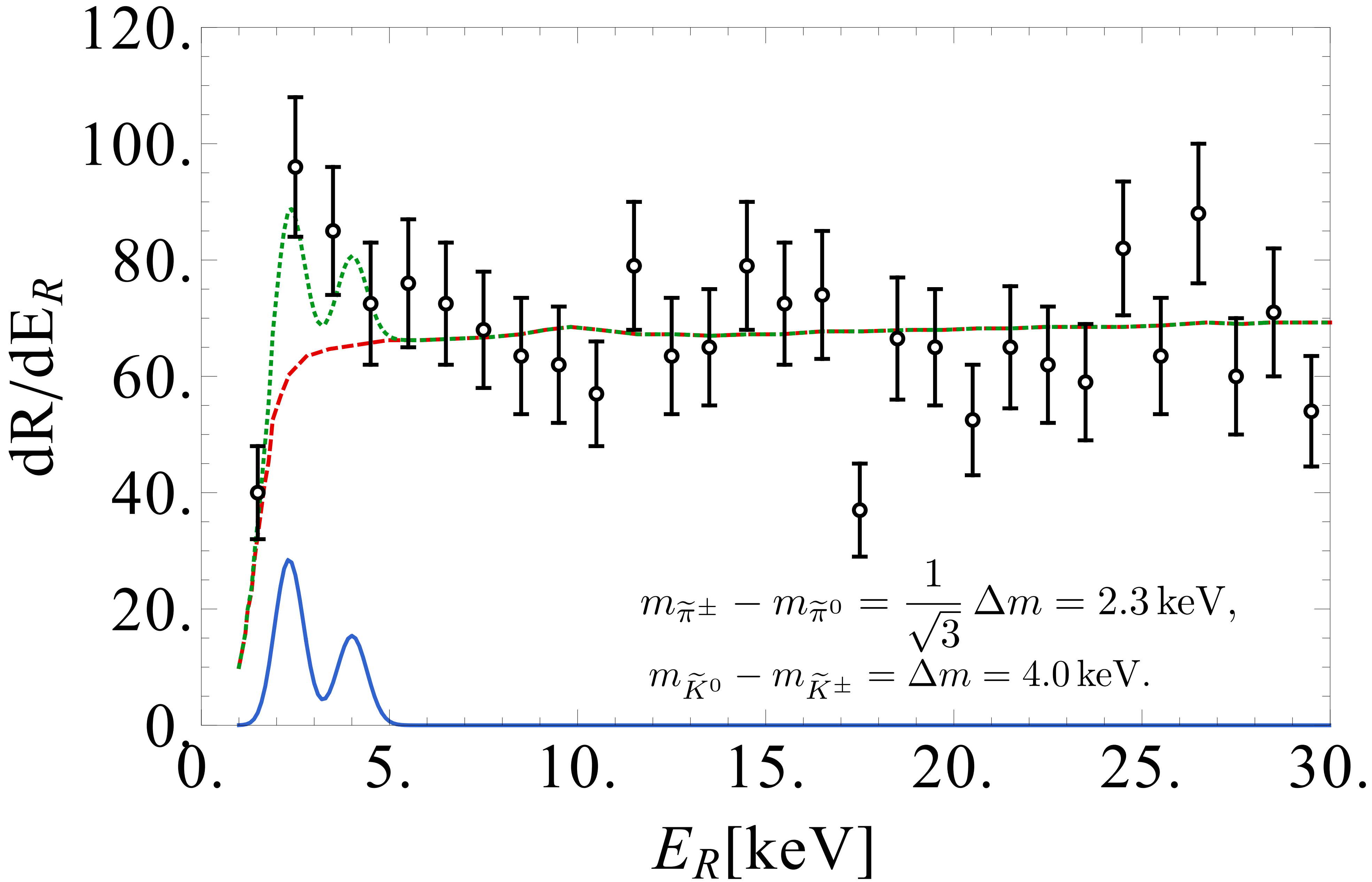
- Non-universal Z' portal:

  Dark meson-changing Z'
  => exothermic dark matter



Electron E_R from dark mesons

[S.Choi, HML, B. Zhu, 2012.03713]



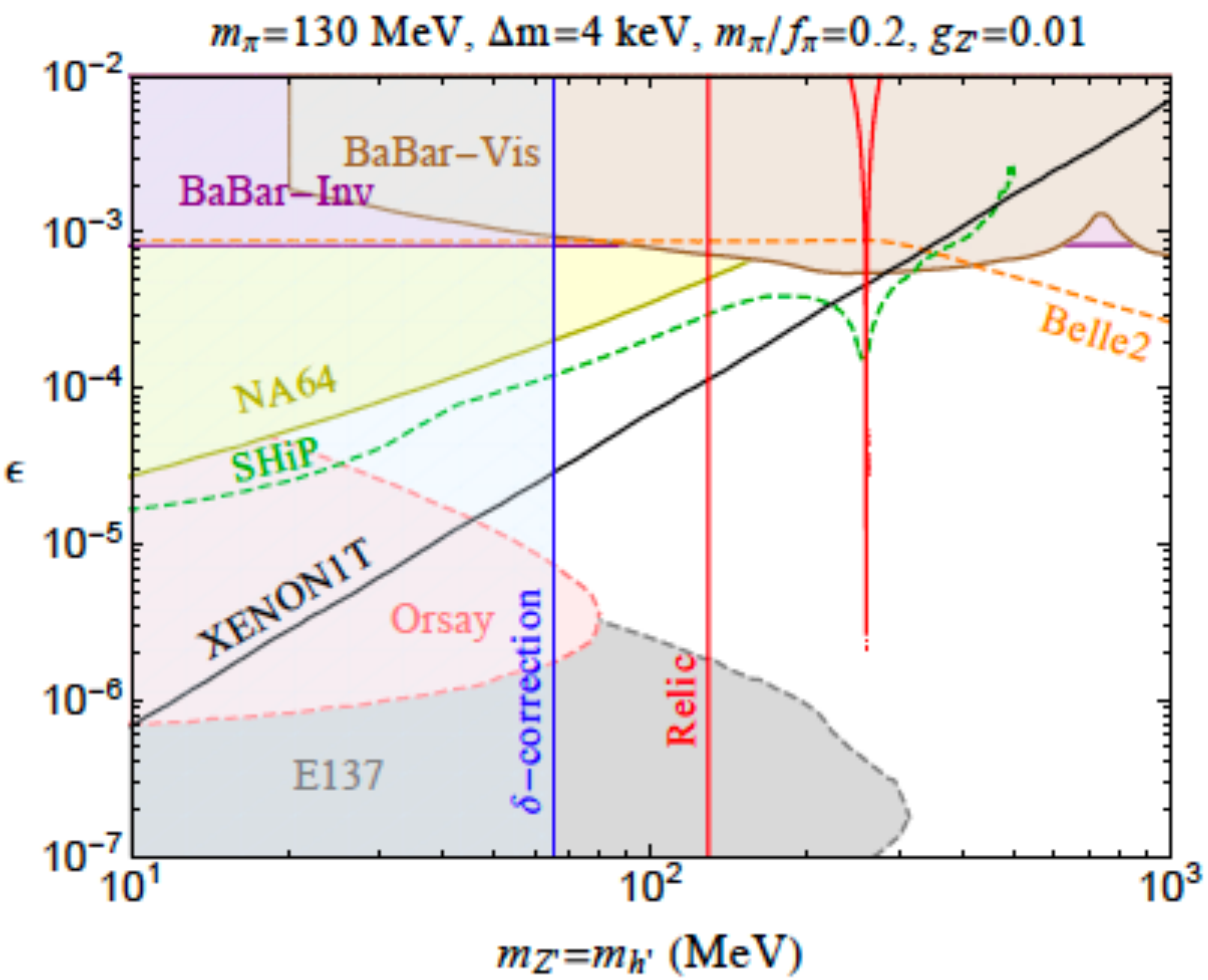
Double-peak case fits better than one-peak case.

Dark mesons & XENON1T

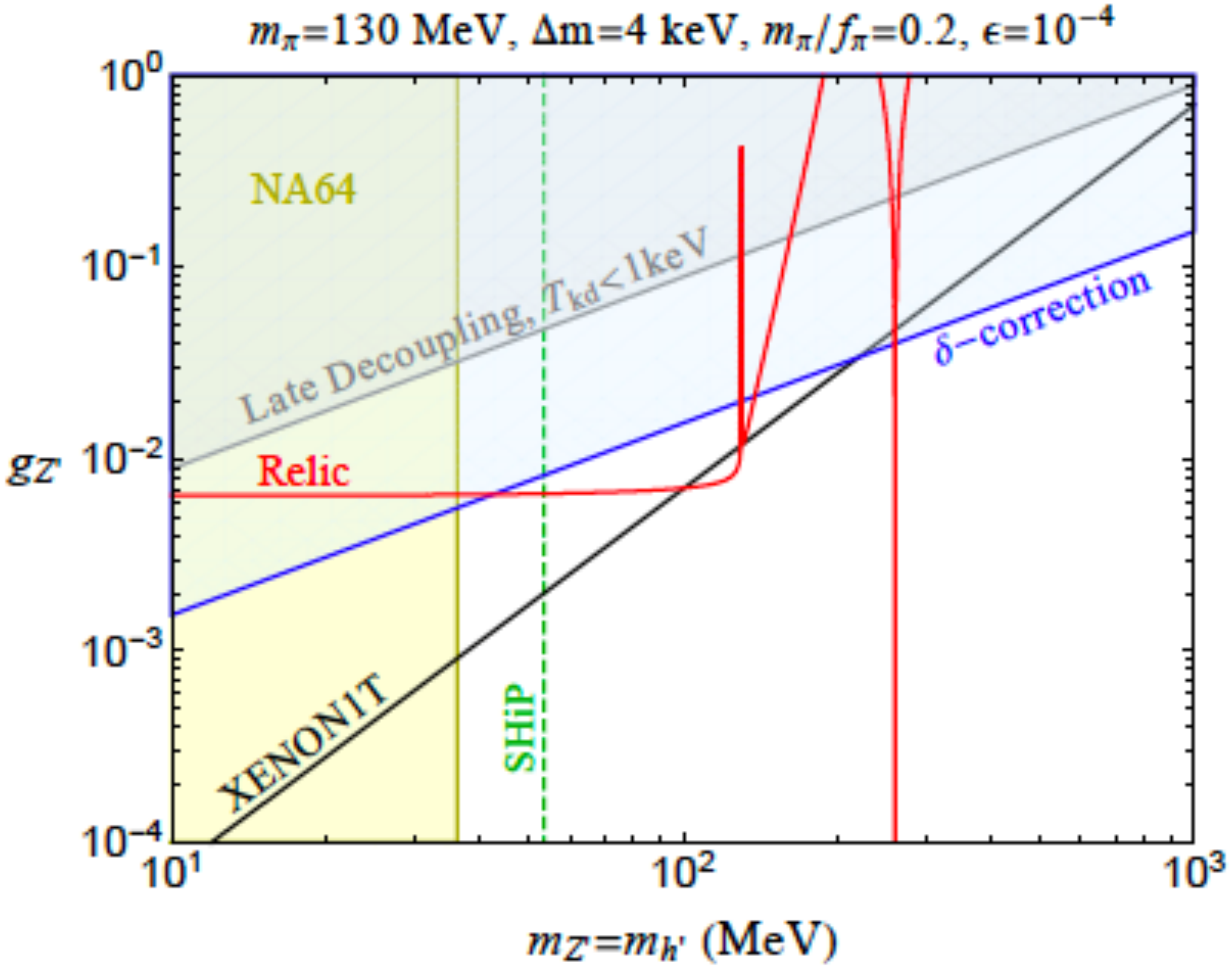
- Almost degenerate dark Higgs/Z' masses can be searched in intensity experiments such as Belle-2.

[S.Choi, HML, B. Zhu, 2020]

$m_\pi=130$ MeV, $\Delta m=4$ keV, $m_\pi/f_\pi=0.2$, $g_{Z'}=0.01$



$m_\pi=130$ MeV, $\Delta m=4$ keV, $m_\pi/f_\pi=0.2$, $\epsilon=10^{-4}$



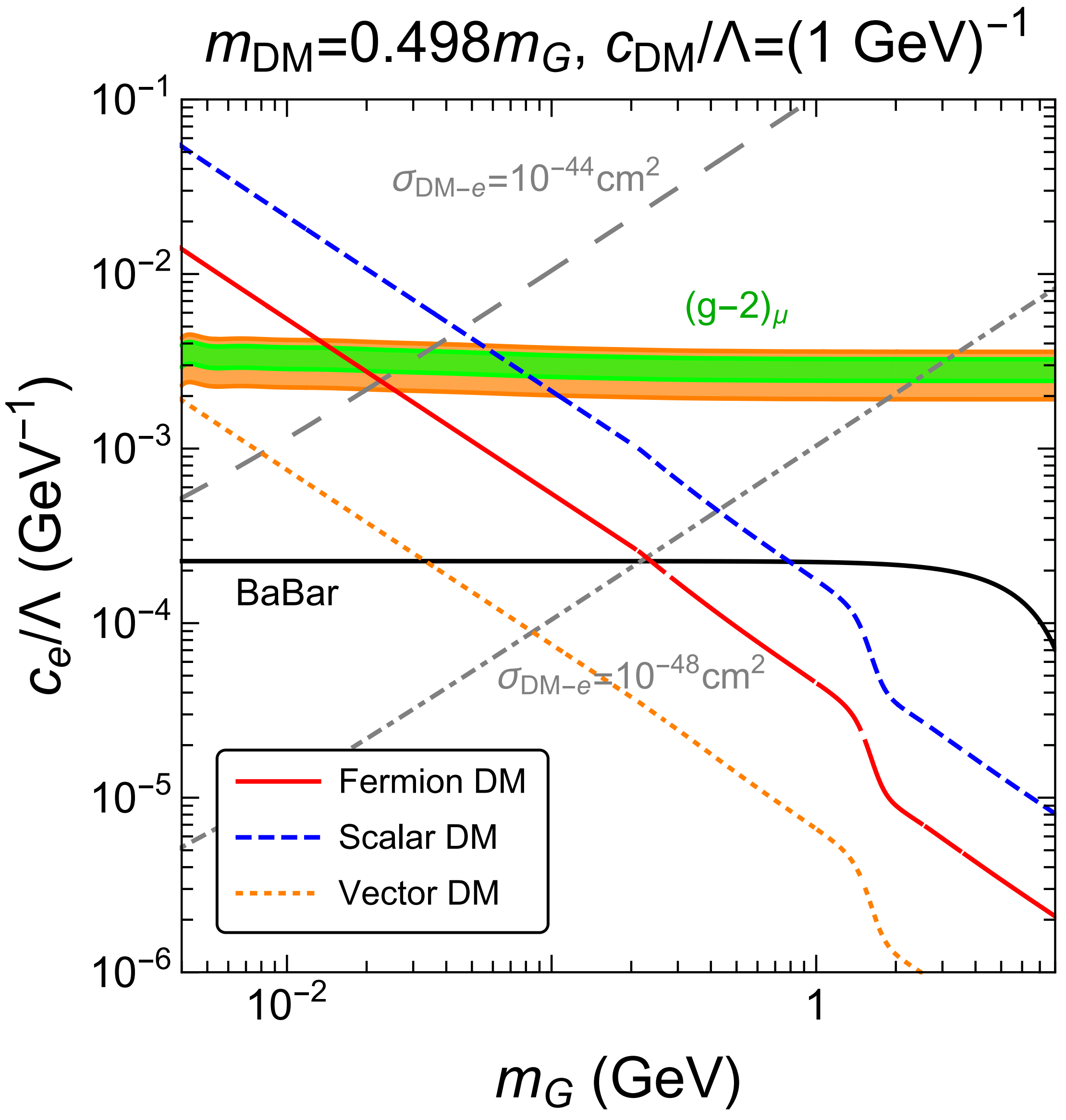
Exothermic dark matter with larger mass splitting can lead to displaced vertices at Belle-2.

cf. M. Duerr et al, 2012.08595;
D.W. Kang et al, 2101.02503

Other portals to light DM

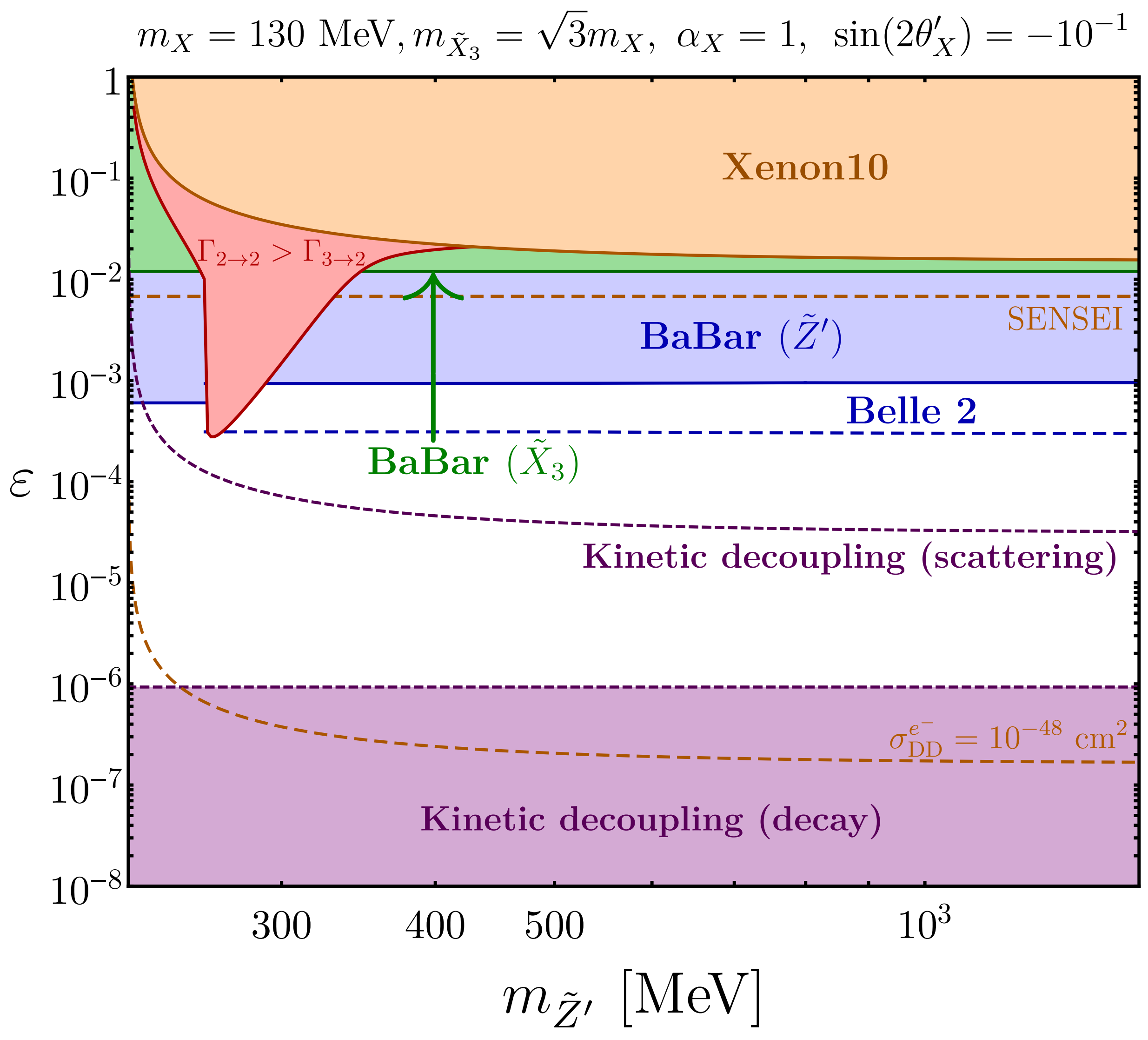
- Other portals such as spin-2, axion, …; DM spins

Spin-2 mediator



[Y. Kang, HML, 2020]

Non-abelian DM



[S. Choi, HML, Y. Mambrini, M. Pierre, 2019]

B-meson anomalies and new physics

Flavors and new physics

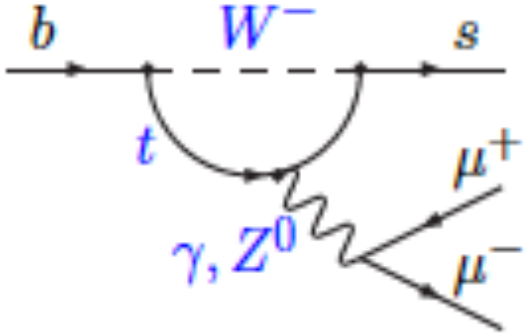
- “Charged currents” induce flavor violating processes at tree level, while FCNCs are induced at loop level.

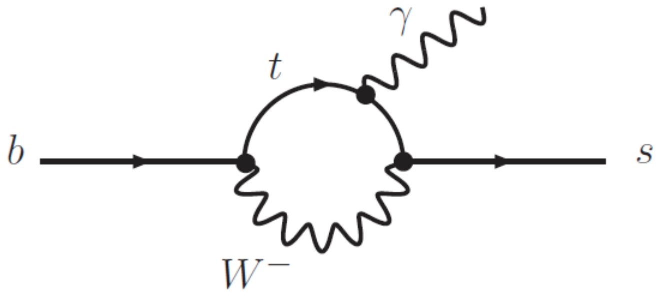
$$\frac{-g}{\sqrt{2}}(\overline{u_L}, \overline{c_L}, \overline{t_L})\gamma^\mu W_\mu^+ V_{\rm CKM} \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix} + \text{h.c.}, \qquad V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}.$$

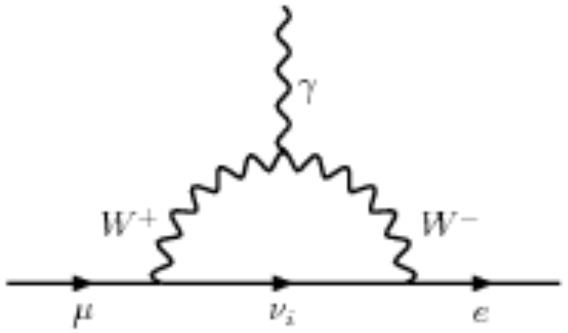
- Lepton universality is well tested in the SM.

$$\frac{\Gamma_{Z\to\mu^+\mu^-}}{\Gamma_{Z\to e^+e^-}} = 1.0009 \pm 0.0028\,, \quad \frac{\mathcal{B}(W^-\to e^-\overline{\nu}_e)}{\mathcal{B}(W^-\to \mu^-\overline{\nu}_\mu)} = 1.004 \pm 0.008\,. \quad \frac{\Gamma_{K^-\to e^-\overline{\nu}_e}}{\Gamma_{K^-\to \mu^-\overline{\nu}_\mu}} = (2.488 \pm 0.009) \times 10^{-5}$$

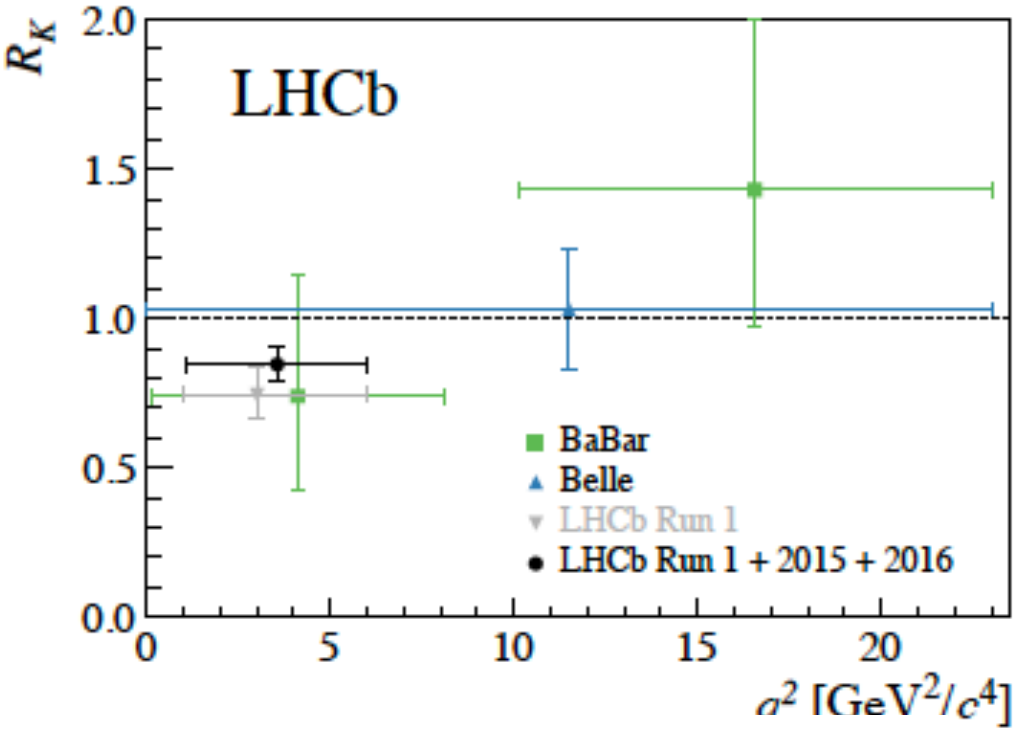
- “FCNC processes” and lepton universality are sensitive probes of new physics.

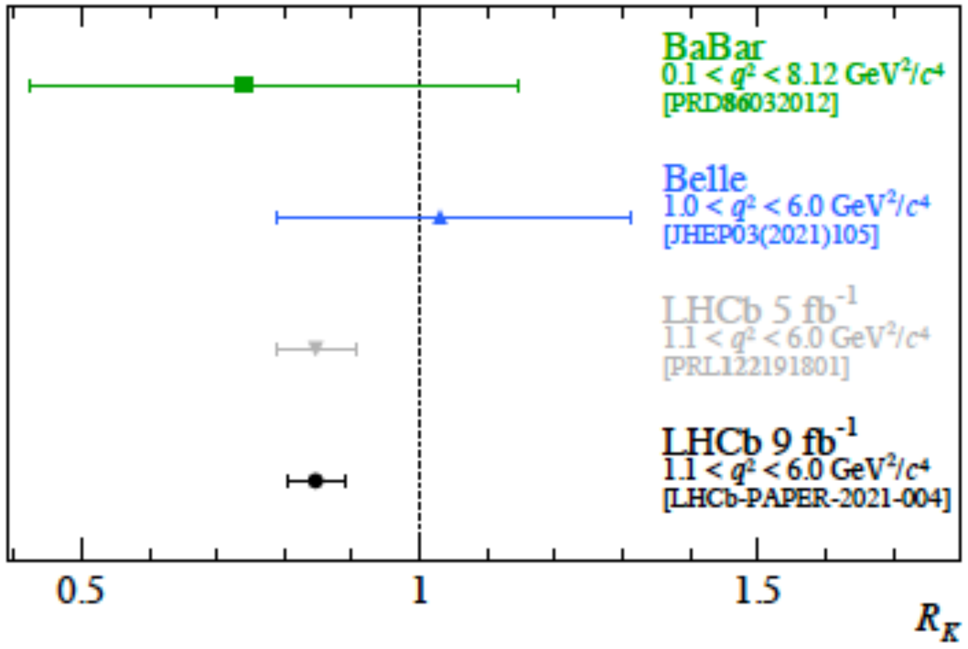






B-anomalies at LHCb





$$R_K = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\Gamma[B^+ \to K^+\mu^+\mu^-]}{dq^2} dq^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\Gamma[B^+ \to K^+e^+e^-]}{dq^2} dq^2}$$

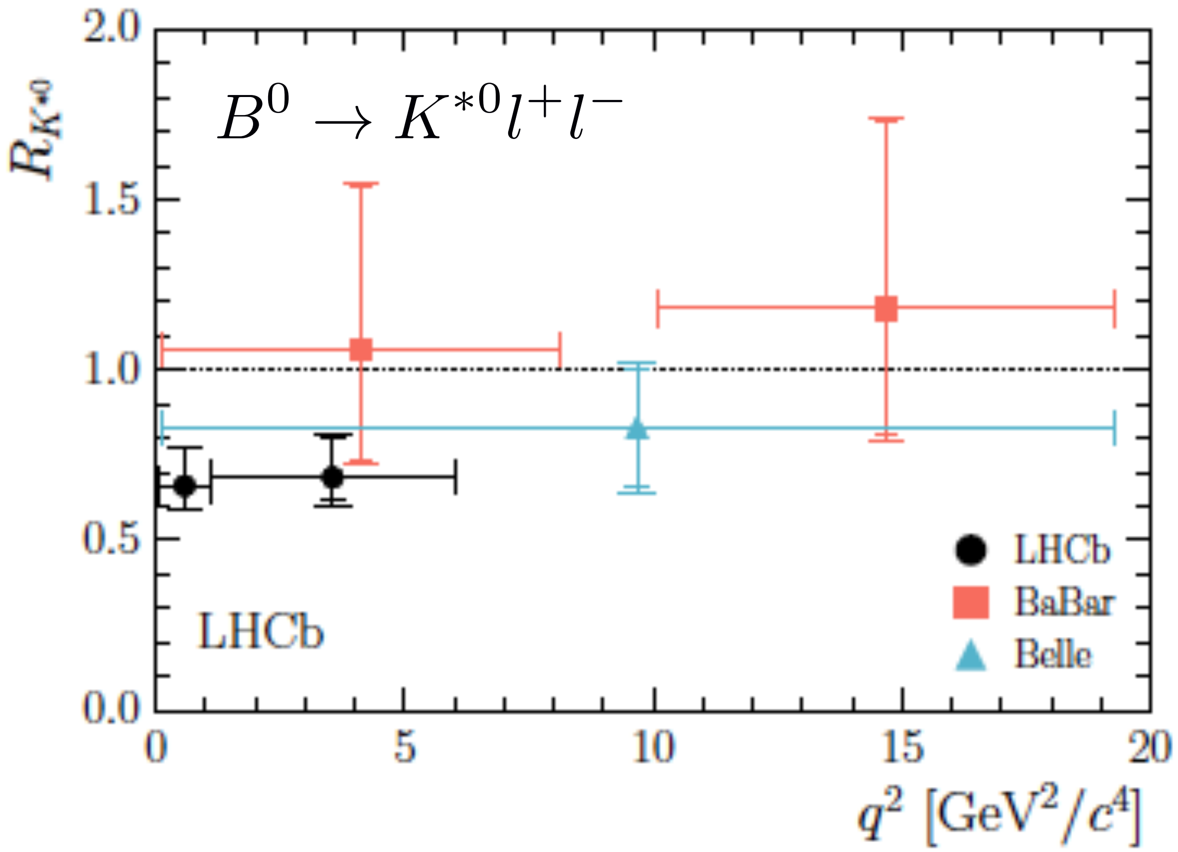
$$R_K^{[1.1,6.0]} = 1.00 \pm 0.01 \quad \text{(SM)}$$

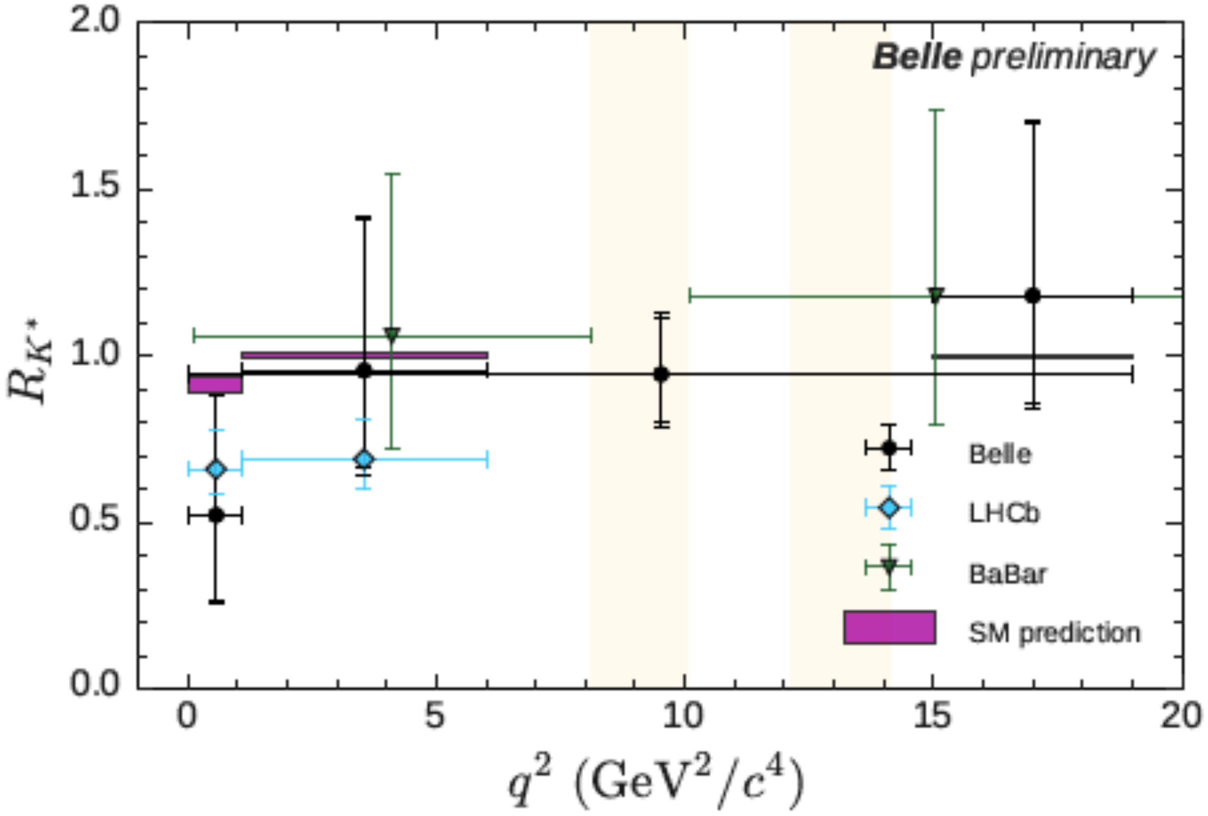
Hadronic uncertainties cancelled → Clean test of LFU

LHCb: 2011~2016 data $R_K = \mathbf{0.846}\ ^{+0.060}_{-0.054}\,(\text{stat.})\ ^{+0.016}_{-0.014}\,(\text{syst.})$ ~2.5σ

2017~2018 data → $R_K = 0.846\ ^{+0.042}_{-0.039}\ (\text{stat})\ ^{+0.013}_{-0.012}\ (\text{syst})$ ~3.1σ

B-anomalies at LHCb





LHCb Preliminary	**low-q^2**	**central-q^2**
$\mathcal{R}_{K^{*0}}$	$0.660\ ^{+\ 0.110}_{-\ 0.070} \pm 0.024$	$0.685\ ^{+\ 0.113}_{-\ 0.069} \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]
99.7% CL	[0.454–1.042]	[0.462–1.100]

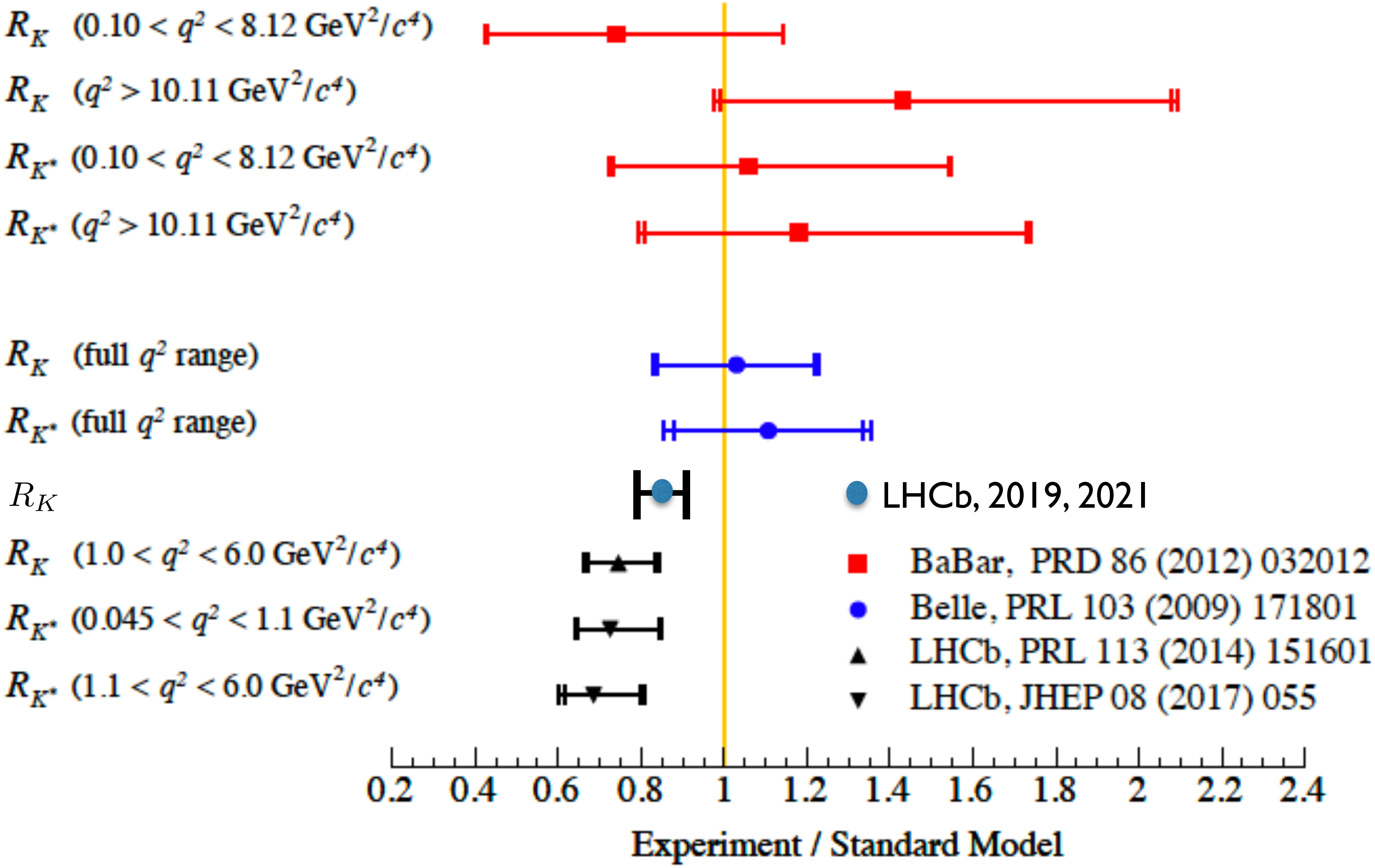
$$R_{K^*}^{[1.1,6.0]} = 1.00 \pm 0.01 \quad \text{(SM)}$$

$$R_{K^*}^{[0.045,1.1]} = 0.906 \pm 0.028 \quad \text{(SM)}$$

- R_{K^*}: 2.2-2.4σ deviation and 2.4-2.5σ deviation.

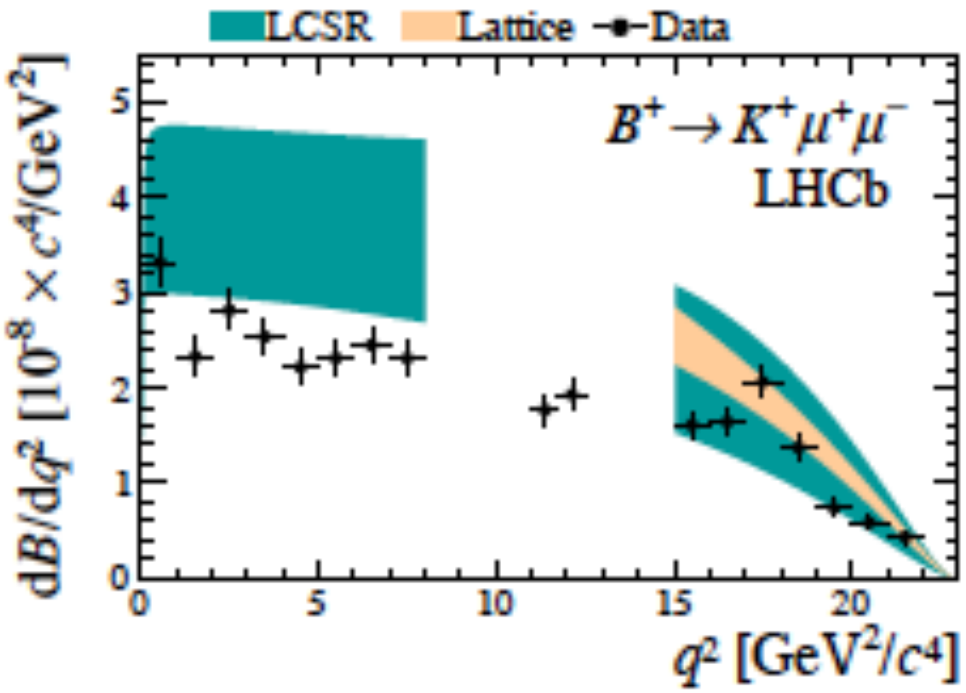
⇨ Hints for lepton flavor non-universality?

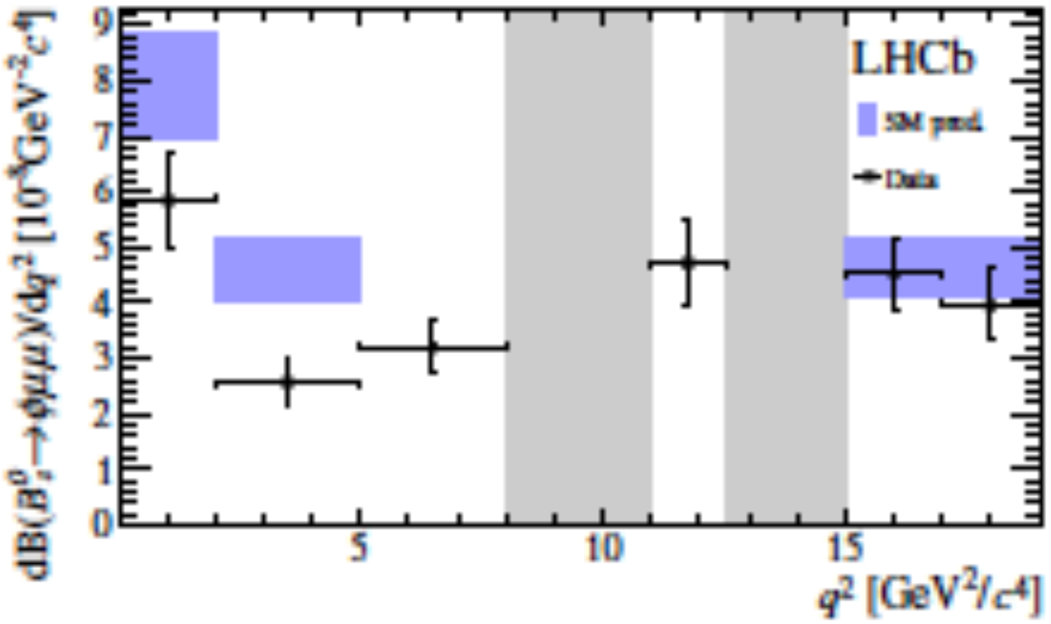
Summary of B-anomalies

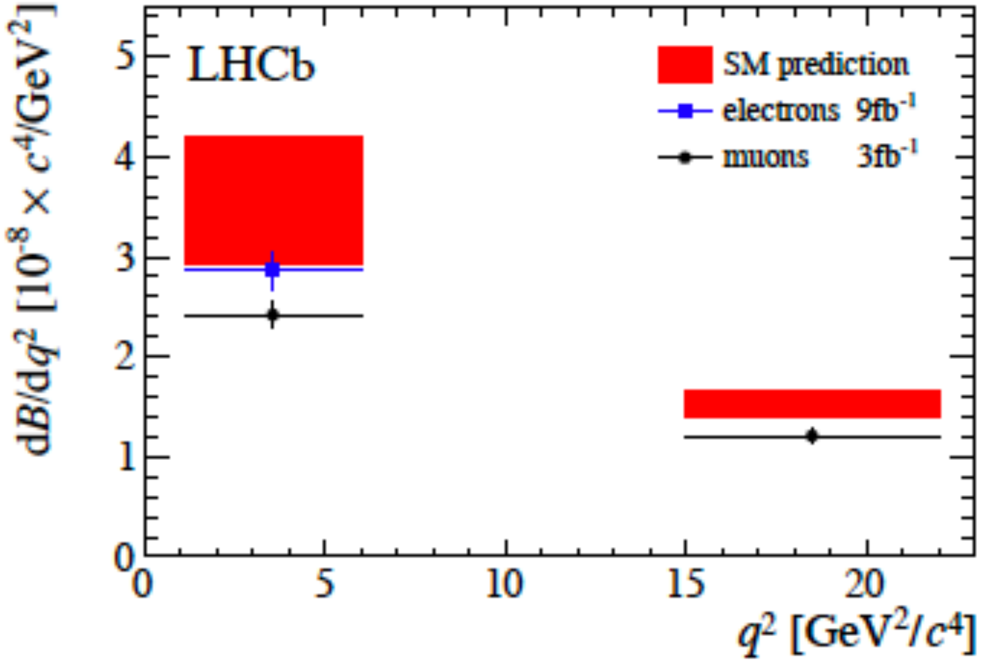


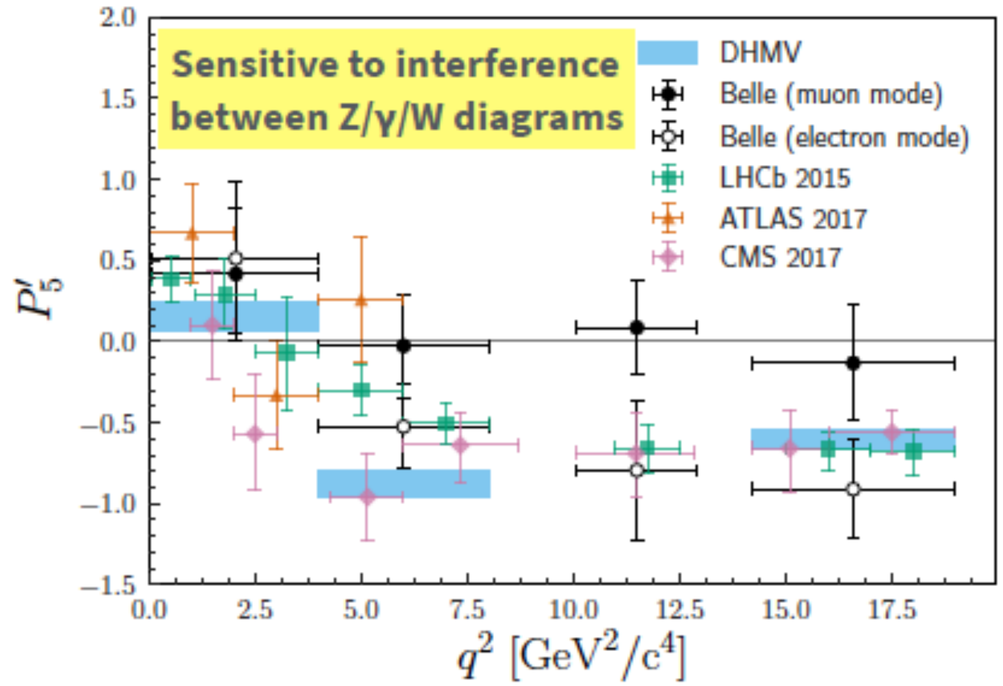
[S. Bifani et al, 1809.06229 + updates]

Muon less SM than electron





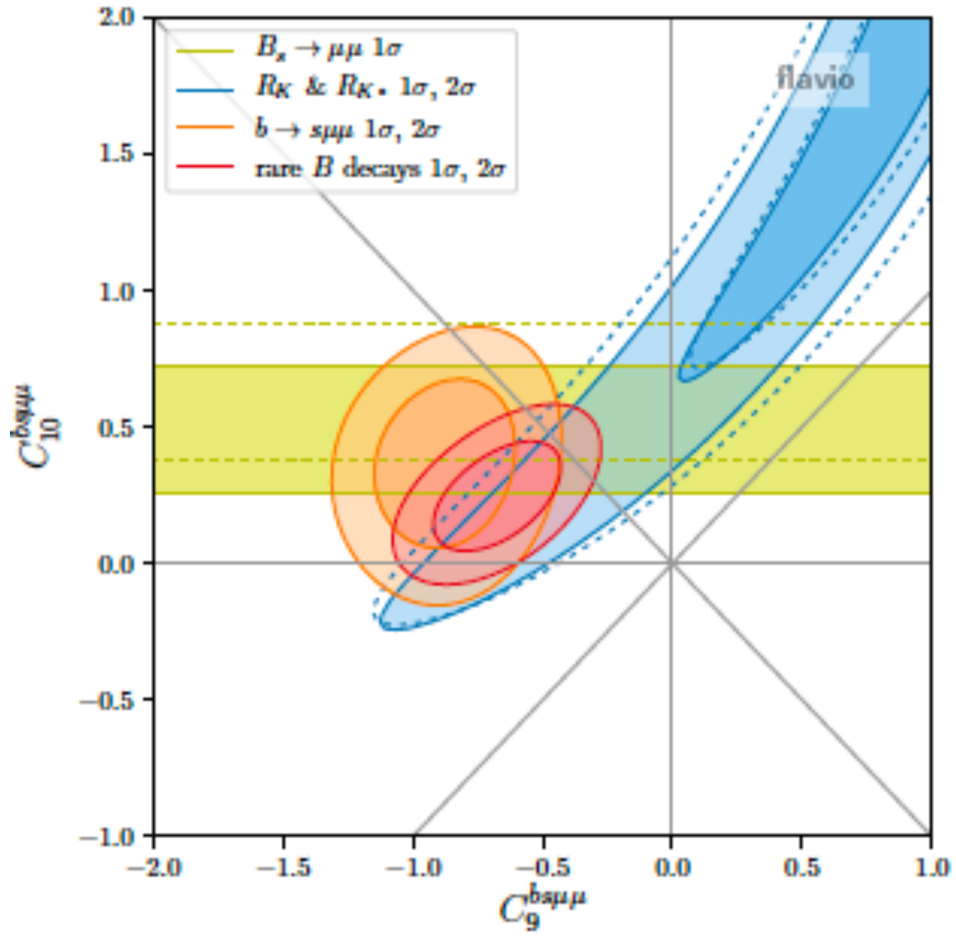



Sensitive to interference between Z/γ/W diagrams

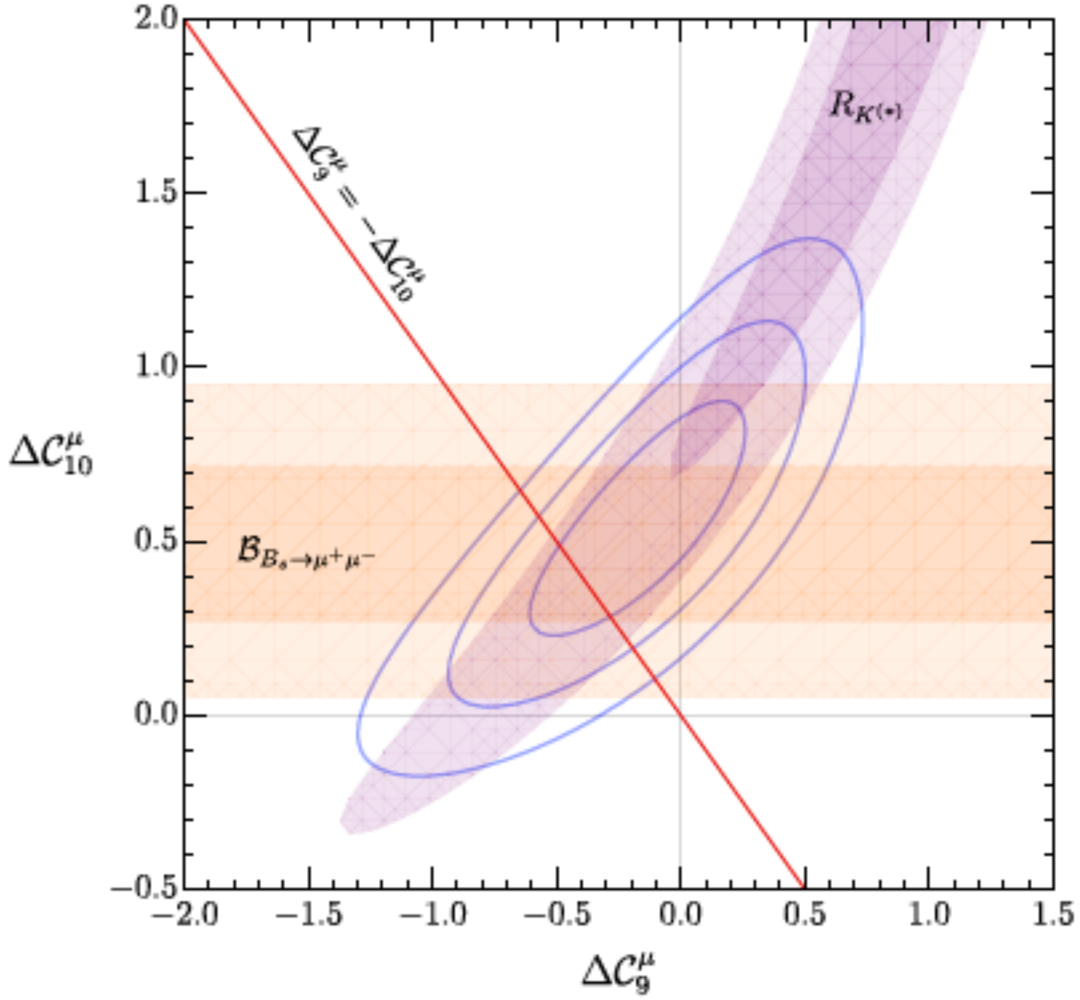
- Differential branching fractions & angular distribution are consistently lower than the SM values in muon channels.

Global fits

[Altmannshofer, Stangl, 2021]



[Cornella et al, 2021]



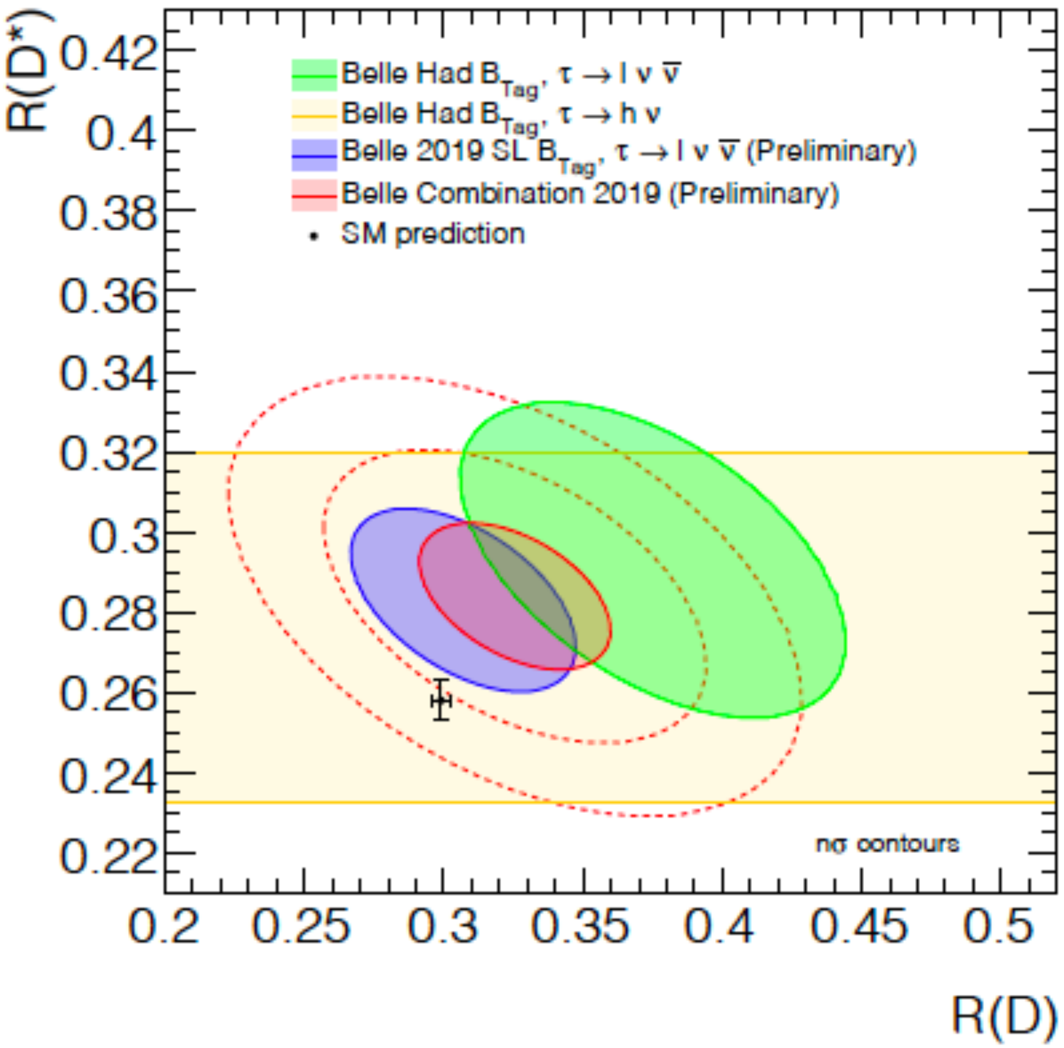
Best fit: ~6.1σ from SM (Consistent with $B_s \to \mu^+\mu^-$)

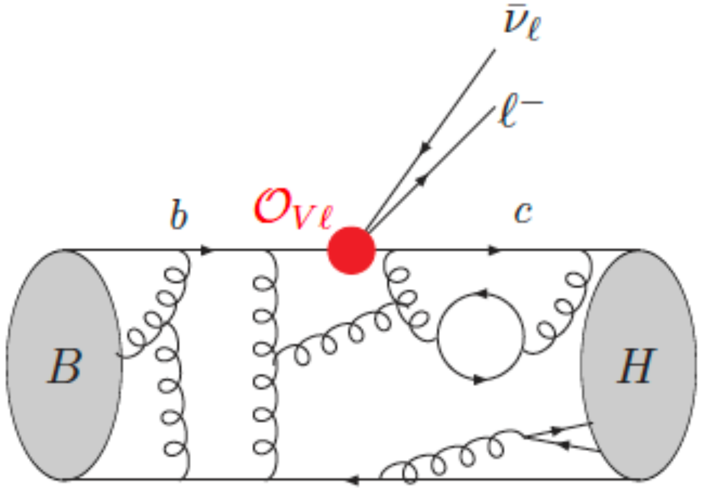
$C_9^{bs\mu\mu} \simeq -0.82$ Z’ models

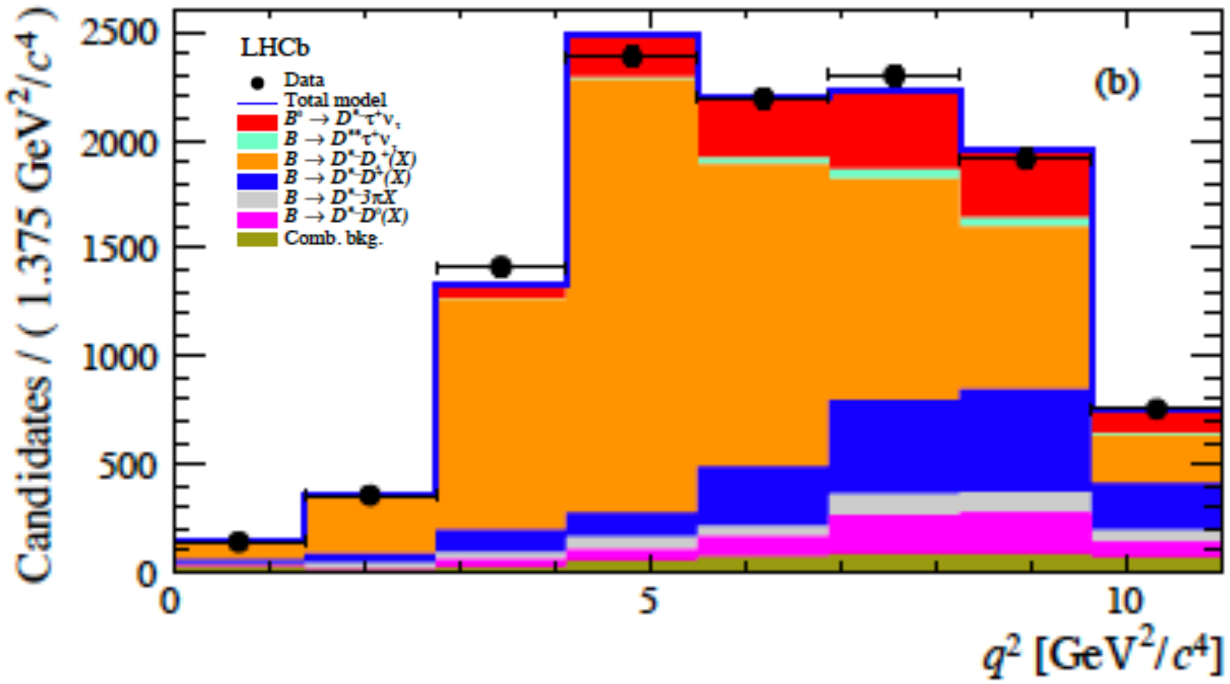
$C_9^{bs\mu\mu} = -C_{10}^{bs\mu\mu} \simeq -0.43$ Leptoquark models

B→D$^{(*)}\tau\nu$

$R_{D^*} = \mathcal{B}(B \to D^*\tau\nu)/\mathcal{B}(B \to D^*l\nu)$







[Belle-II,1808.10567]

$R_D = \mathcal{B}(B \to D\tau\nu)/\mathcal{B}(B \to Dl\nu)$

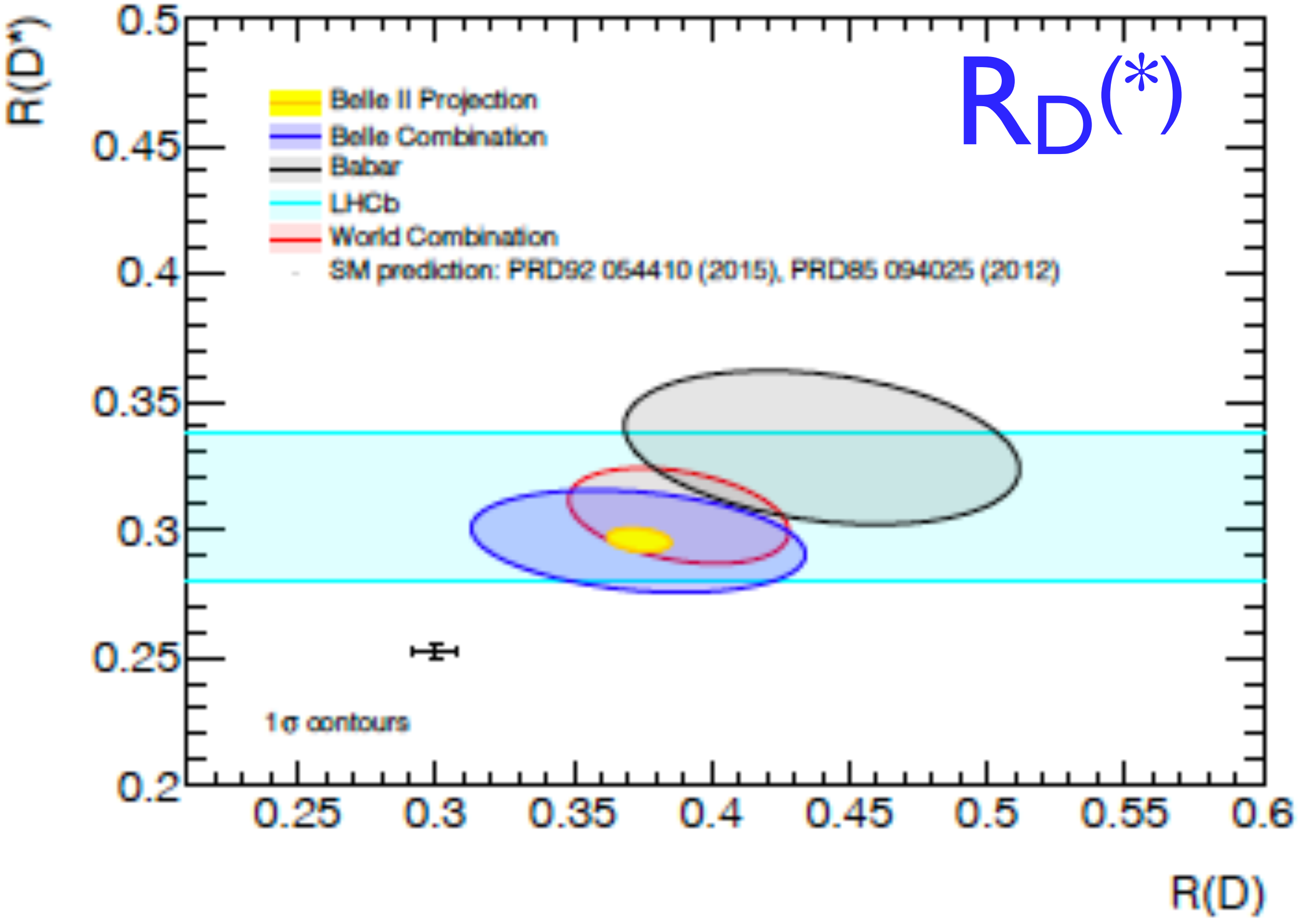
$$R_D^{\rm SM} = 0.299 \pm 0.003,$$
$$R_{D^*}^{\rm SM} = 0.257 \pm 0.003.$$

$$\begin{aligned} R_D^{\rm exp} &= 0.403 \pm 0.040 \pm 0.024, \\ R_{D^*}^{\rm exp} &= 0.310 \pm 0.015 \pm 0.008. \end{aligned}$$

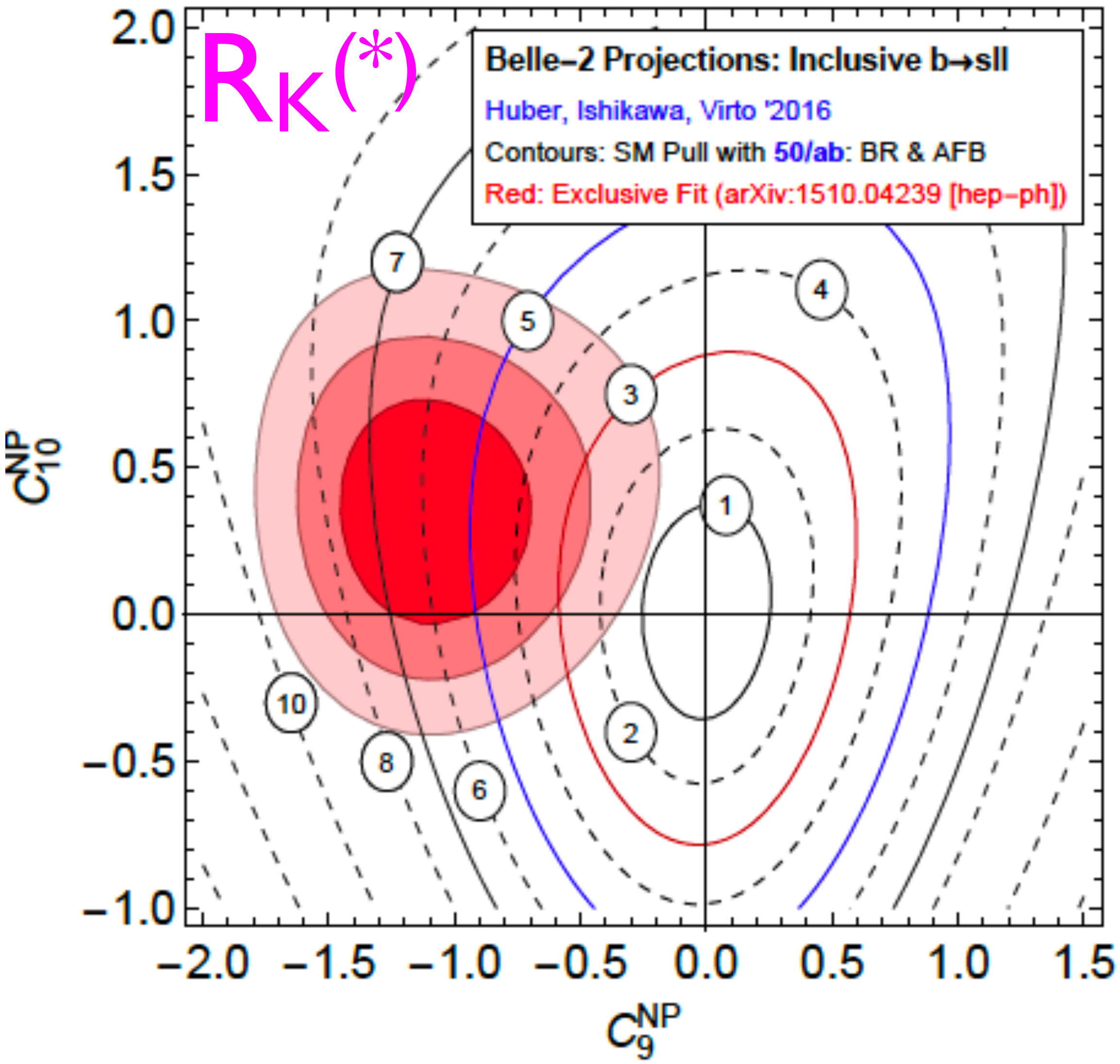
- 3.8σ anomalies in B→D$^{(*)}\tau\nu$.

3.1σ after Belle (Moriond 2019)

Belle II for B-anomalies



[Belle-II,1808.10567]



- Starting in 2019, Belle II can test LFUV in B-meson decays to few % accuracy with data of 5 ab^{-1}.

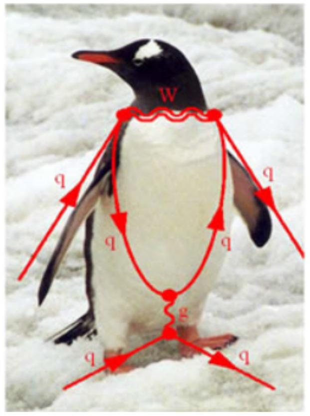
EFT for B-decays

Effective Hamiltonian for b→$s\mu\mu$:

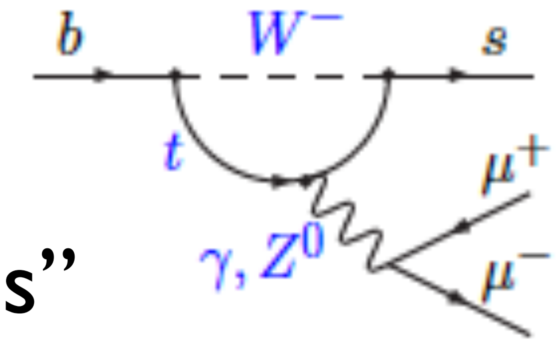
$$\mathcal{H}_{\text{eff},\bar{b}\to\bar{s}\mu^+\mu^-} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \frac{\alpha_{em}}{4\pi} \left(C_9^\mu \mathcal{O}_9^\mu + C_{10}^\mu \mathcal{O}_{10}^\mu + C_9'^\mu \mathcal{O}_9'^\mu + C_{10}'^\mu \mathcal{O}_{10}'^\mu\right) + \text{h.c.}$$

$$\mathcal{O}_9^\mu \equiv (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu \mu),\ \mathcal{O}_{10}^\mu \equiv (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu\gamma^5 \mu), \qquad C_9^{\mu,\text{SM}}(m_b) = -C_{10}^{\mu,\text{SM}}(m_b) = 4.27$$

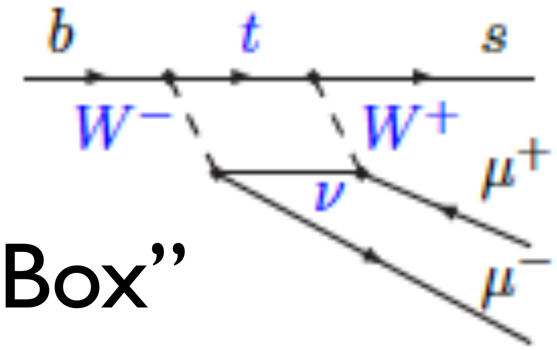
$$\mathcal{O}_9'^\mu \equiv (\bar{s}\gamma^\mu P_R b)(\bar{\mu}\gamma_\mu \mu),\ \mathcal{O}_{10}'^\mu \equiv (\bar{s}\gamma^\mu P_R b)(\bar{\mu}\gamma_\mu\gamma^5 \mu) \qquad C_9'^{\mu,\text{SM}}(m_b) \approx -C_{10}'^{\mu,\text{SM}}(m_b) \approx 0.$$



“Penguins”



“Box”

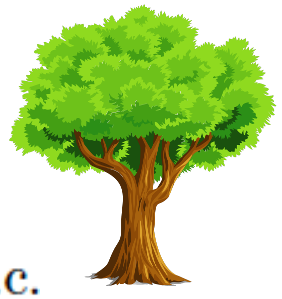


$$R_K[1,6] \simeq 1 + 0.24\left(C_{LL}^{\text{NP}\mu} + C_{RL}^\mu\right), \quad R_{K^*}[1,6] \simeq 1 + 0.24\left(C_{LL}^{\text{NP}\mu} - C_{RL}^\mu\right) + 0.07\, C_{RL}^\mu,$$

$$C_{LL}^{\text{NP}\ell} = C_9^{\text{NP}\ell} - C_{10}^{\text{NP}\ell}, \qquad C_{RL}^\ell = C_9'^\ell - C_{10}'^\ell$$

Effective Hamiltonian for b→cτν:

“Tree”

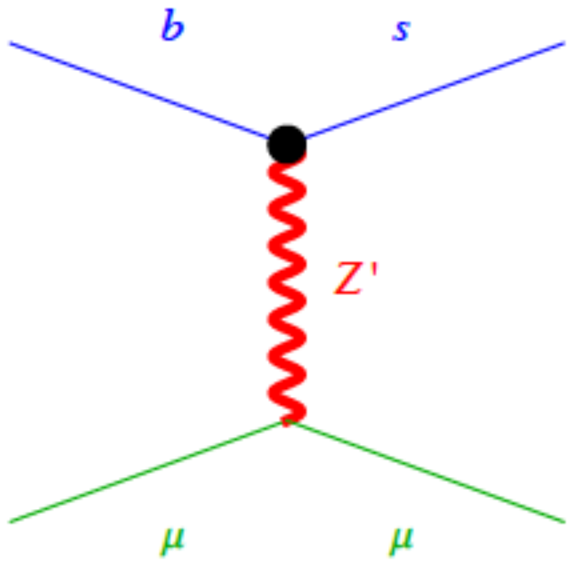


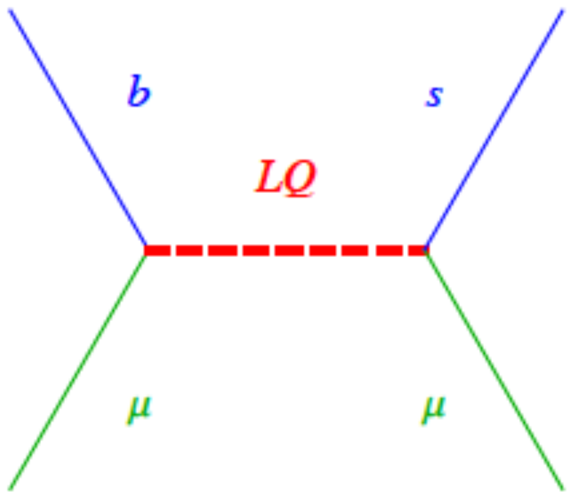
$$\mathcal{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{cb}\Big[C_V\,(\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\tau) + C_S\,(\bar{c}P_L b)(\bar{\tau}P_L\nu_\tau) + C_T(\bar{c}\,\sigma^{\mu\nu}P_L b)(\bar{\tau}\sigma_{\mu\nu}P_L\nu_\tau)\Big] + \text{h.c.}$$

$C_V = 1$ and $C_S = C_T = 0$ in the SM

New physics for B-anomalies

New physics for $R_{K^{(*)}}$ anomalies:





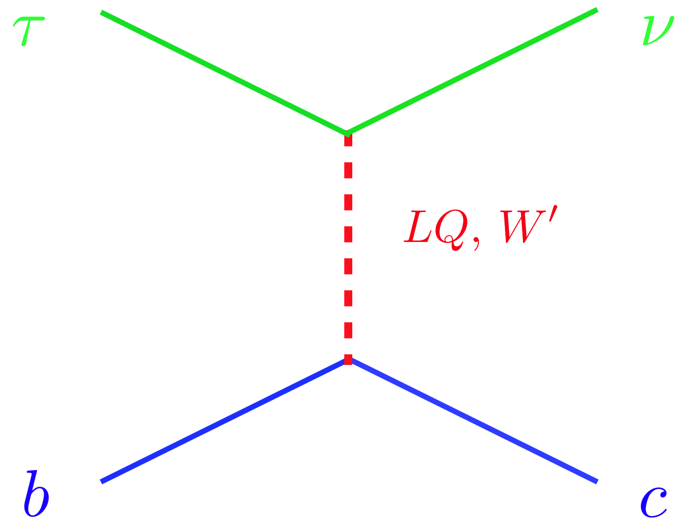
Leptoquarks

Z', leptoquarks, loops, etc.

$$\mathcal{L}_{\rm eff} = \frac{1}{\Lambda_{\rm NP}^2} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu \mu),$$

⇒ $\Lambda_{\rm NP} \simeq 30\ {\rm TeV}.$

New physics for $R_{D^{(*)}}$ anomalies:



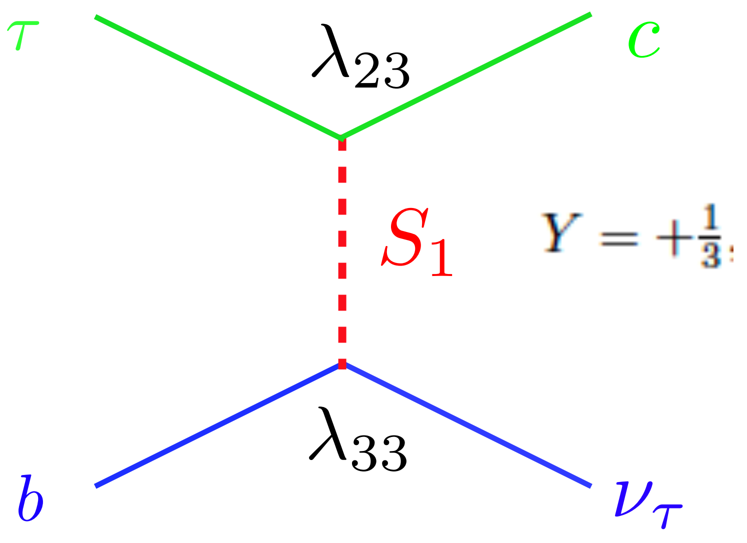
Leptoquarks, W', charged Higgs, etc.

$$\mathcal{L}_{\rm eff} = \frac{1}{\Lambda_{\rm NP}^2} (\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\tau),$$

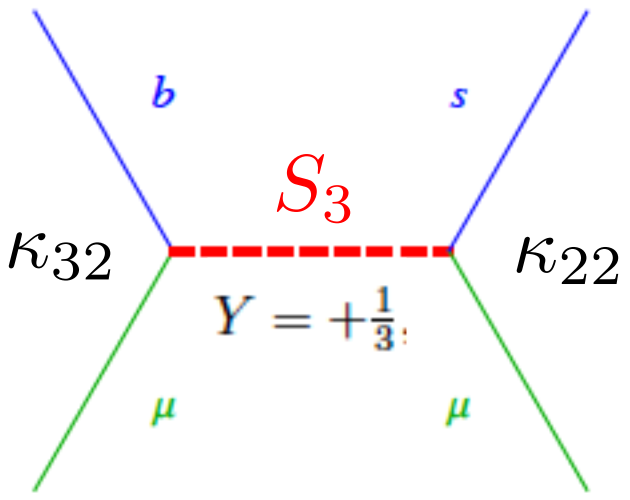
⇒ $\Lambda_{\rm NP} \simeq 3.5\ {\rm TeV}.$

Scalar leptoquarks

$R_{D^{(*)}}$: Singlet leptoquark



$R_{K^{(*)}}$: Triplet leptoquark



$$\mathcal{L}_{S_1} = -\lambda_{ij}\overline{(Q^C)^a_{Ri}}\,(i\sigma^2)_{ab}\,S_1\,L^b_{Lj} - \lambda'_{ij}\overline{(u^C)_{Li}}S_1 e_{jR} + \text{h.c.}$$

$$\mathcal{L}_{S_3} \;=\; -\kappa_{ij}Q^a_{Li}\Phi_{ab}L^b_{Lj} + \text{h.c.}$$

$B - \bar{B}$ mixing : loop-suppressed, unlike Z' case.

$B_s \to \mu^+\mu^-$: constrains the triplet leptoquark.

$B \to K^{(*)}\nu\bar{\nu}$: tree-level corrections due to singlet leptoquark.

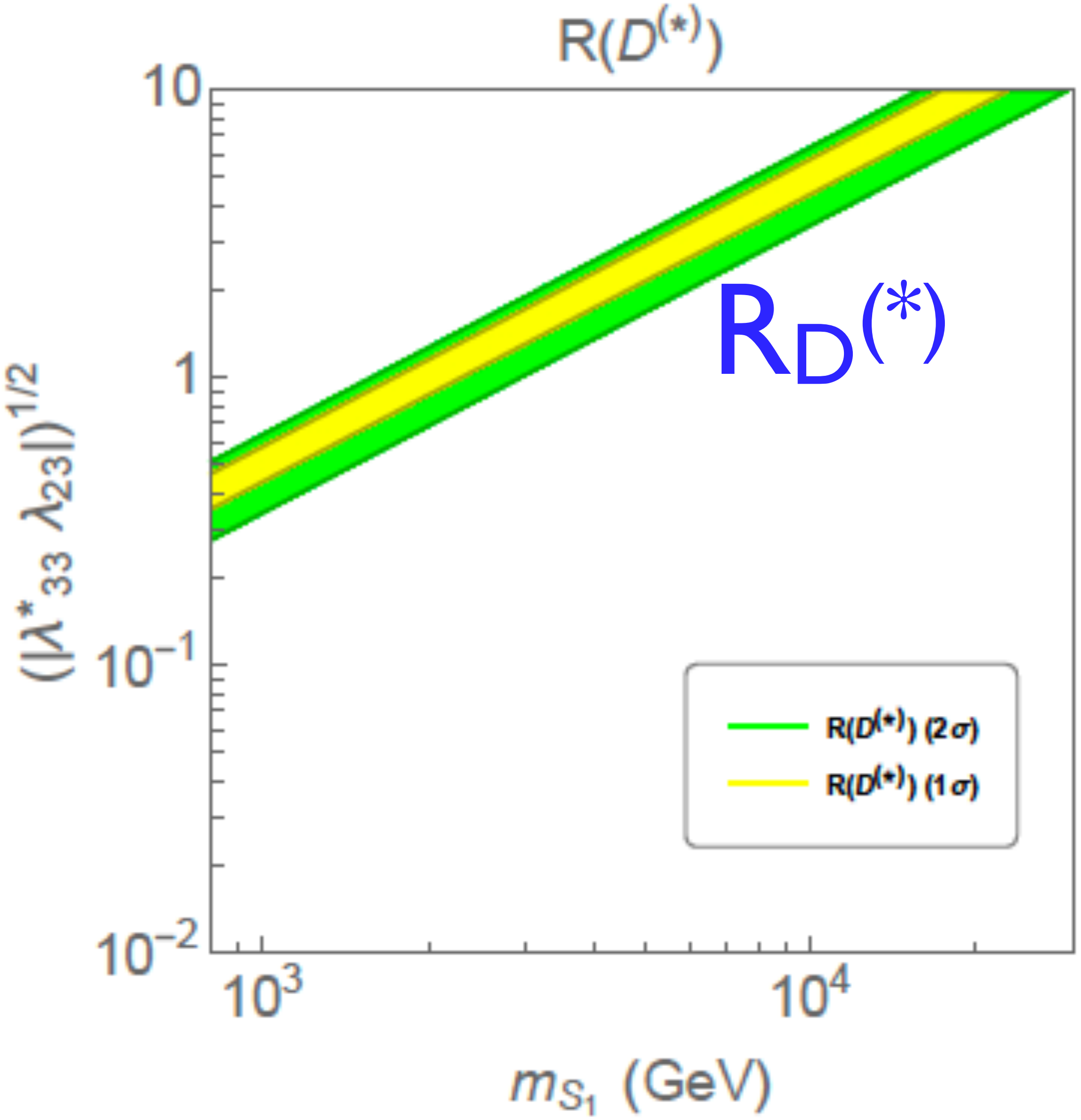
$$B(B \to K\nu\bar{\nu})\Big|_{\text{SM}} = (3.98 \pm 0.43 \pm 0.19) \times 10^{-6}, \quad B(B \to K^*\nu\bar{\nu})\Big|_{\text{SM}} = (9.19 \pm 0.86 \pm 0.50) \times 10^{-6}$$

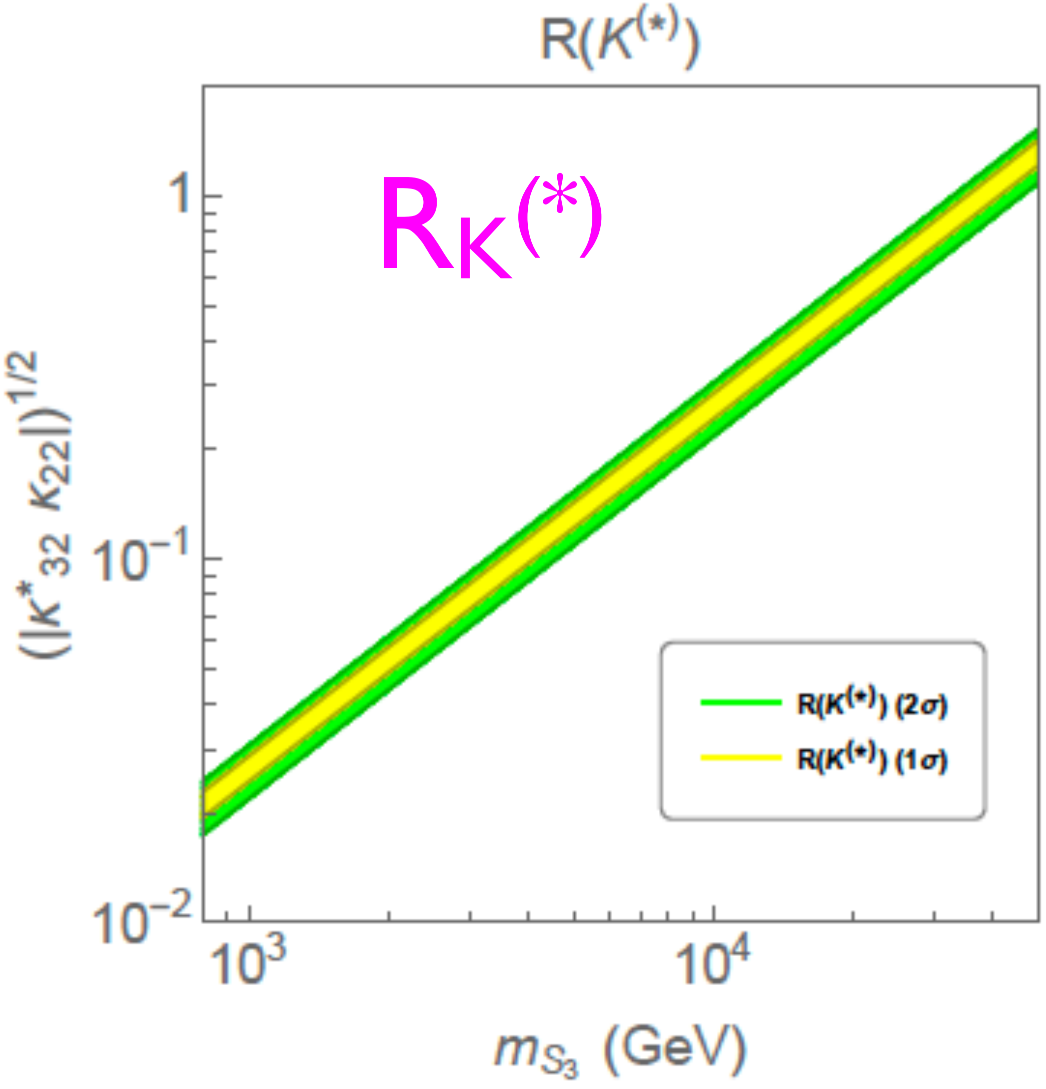
$$B(B \to K\nu\bar{\nu}) < 1.6 \times 10^{-5},$$ [Belle] $$B(B \to K^*\nu\bar{\nu}) < 2.7 \times 10^{-5}$$

Belle-2 at 10% level => strong constraints on leptoquark models.

Scalar leptoquarks

[Choi, Kang, HML, Ro, 2018]





Minimal flavor:

$$\lambda = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & \boxed{\lambda_{23}} \\ 0 & \lambda_{32} & \boxed{\lambda_{33}} \end{pmatrix}, \quad \kappa = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \boxed{\kappa_{22}} & \kappa_{23} \\ 0 & \boxed{\kappa_{32}} & \kappa_{33} \end{pmatrix}$$

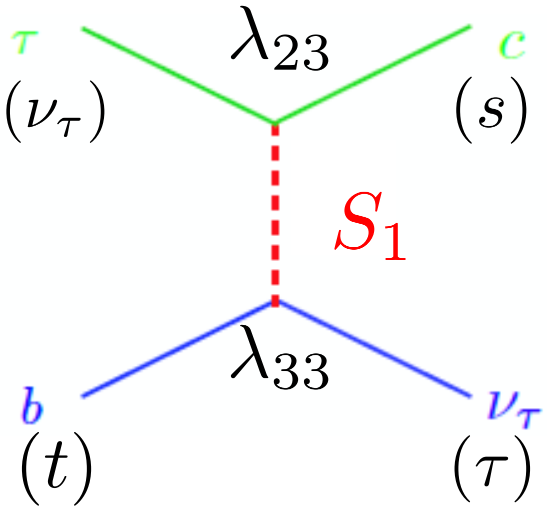
leptons →

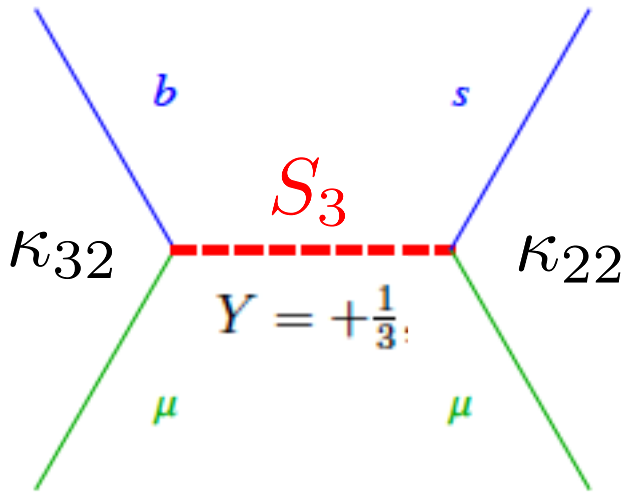
quarks ↓

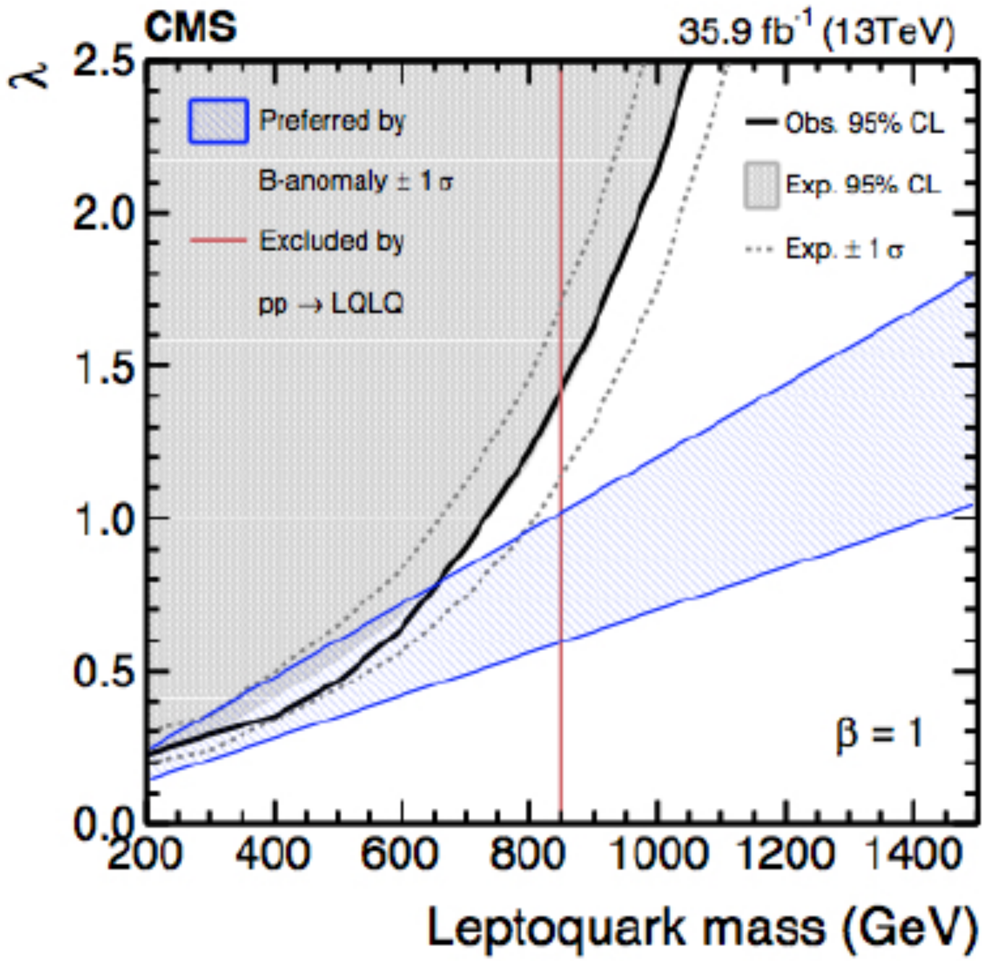
$$\frac{|\kappa^*_{33}\kappa_{23}|}{|\lambda^*_{33}\lambda_{23}|} \approx \frac{|\kappa^*_{32}\kappa_{23}|}{|\lambda^*_{32}\lambda_{23}|} \approx \frac{m^2_{S_3}}{m^2_{S_1}}$$

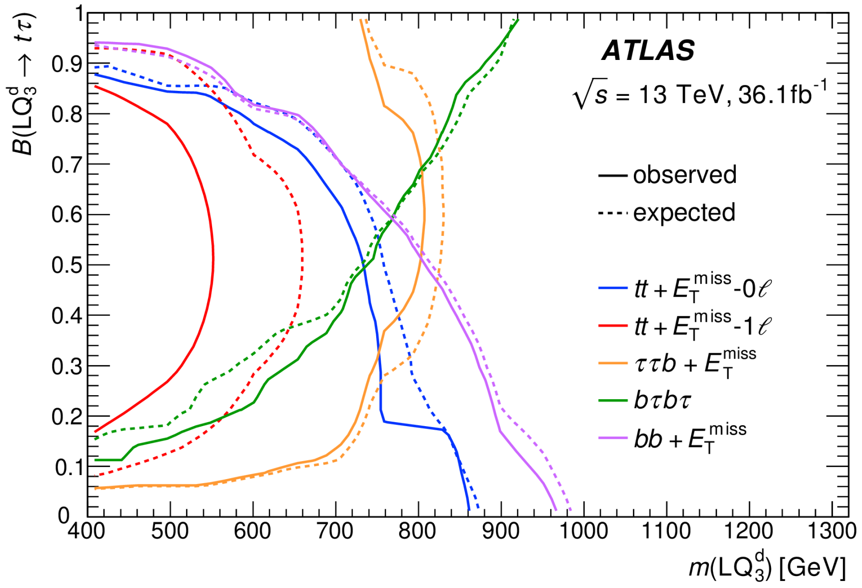
for $B \to K^{(*)}\nu\bar{\nu}$

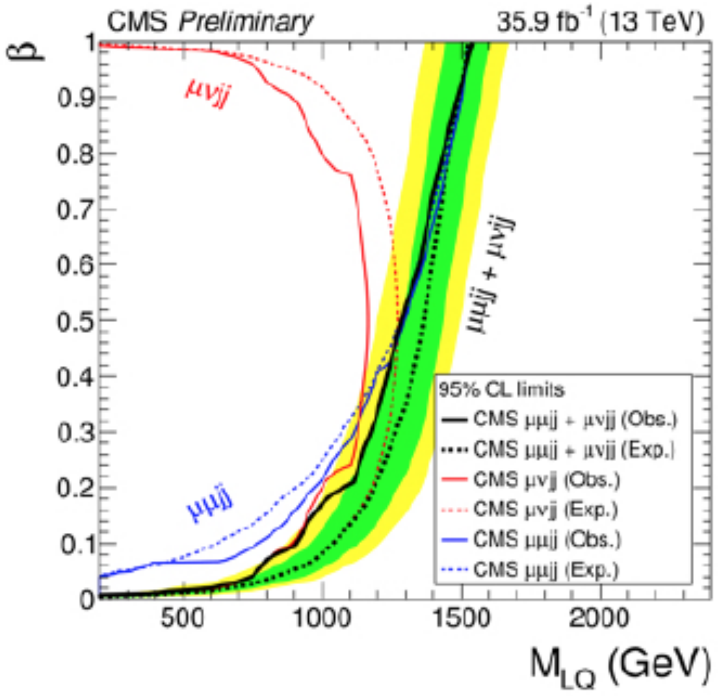
Hunting leptoquarks











[Choi, Kang, HML, Ro, 2018]

LQs	BRs	$m_{LQ,\min}$	BRs	$m_{LQ,\min}$
S_1	$B(\bar t\bar\tau/b\nu_\tau)=\frac{1}{2}\beta$	1.22 TeV ($b\nu_\tau$) [32]	$B(\bar c\bar\tau/s\nu_\tau)=\frac{1}{2}(1-\beta)$	950 GeV ($\nu_\tau j$) [33]
$S_3(\phi_1)$	$B(\bar b\bar\mu)=\gamma$	1.4 TeV [34]	$B(\bar s\bar\mu)=1-\gamma$	1.08 TeV ($\bar\mu j$) [35]
$S_3(\phi_2)$	$B(\bar t\bar\mu/\bar b\bar\nu_\mu)=\frac{1}{2}\gamma$	1.45 TeV ($\bar t\bar\mu$) [36]	$B(\bar c\bar\mu/\bar s\bar\nu_\mu)=\frac{1}{2}(1-\gamma)$	850 GeV ($\bar\mu\bar\nu_\mu jj$) [37]
$S_3(\phi_3)$	$B(\bar t\bar\nu_\mu)=\gamma$	1.12 TeV [38]	$B(\bar c\bar\nu_\mu)=1-\gamma$	950 GeV ($\bar\nu_\mu j$) [33]

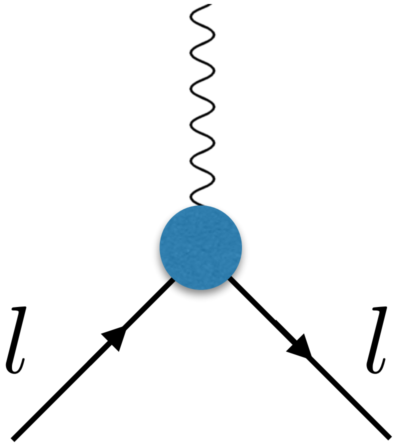
"Decay BRs"

$$\beta\equiv\lambda_{33}^2/(\lambda_{33}^2+\lambda_{23}^2)$$

$$\gamma\equiv\kappa_{32}^2/(\kappa_{32}^2+\kappa_{22}^2)$$

Lepton g-2, LFV, EDM

- Lepton g-2 and lepton flavor violation are important precision tests of the SM.



Muon g-2: $a_\mu(E821) = 116592089(63) \times 10^{-11}$

$$a_\mu(\mathrm{FNAL}) = 116\,592\,040(54) \times 10^{-11}$$

$$a_\mu(\mathrm{Exp}) = 116\,592\,061(41) \times 10^{-11}$$

$$a_\mu(\mathrm{Exp}) - a_\mu(\mathrm{SM}) = (251 \pm 59) \times 10^{-11}$$

4.2σ from SM

Electron g-2: $\Delta a_e = a_e^{\mathrm{exp}} - a_e^{\mathrm{SM}} = -89(36) \times 10^{-14}$ [Cs] -2.5σ

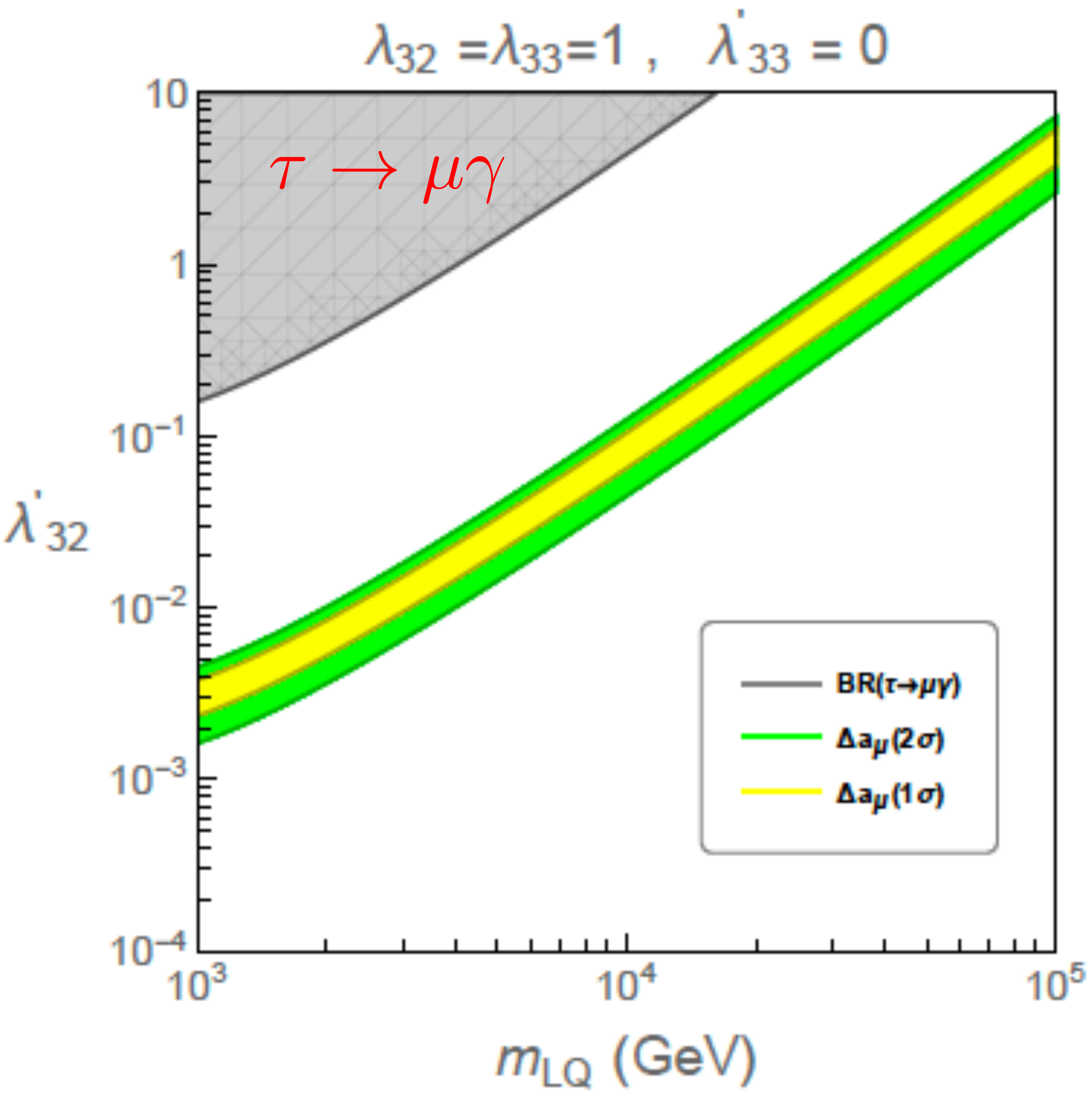
$\Delta a_e = a_e^{\mathrm{exp}} - a_e^{\mathrm{SM}} = 47(30) \times 10^{-14}$ [Rb] 1.6σ

Bounds on LFV: $\mathrm{BR}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ [MEG]

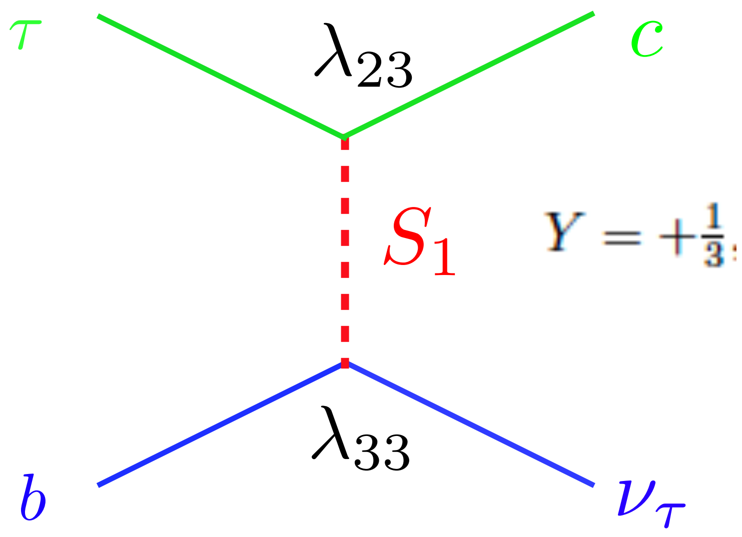
$\mathrm{BR}(\tau \to e\gamma) < 3.3 \times 10^{-8}$ $\mathrm{BR}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$

EDM: $d_e < 1.1 \times 10^{-29}\,e\,\mathrm{cm}$ [ACMEII] $d_\mu < 1.5 \times 10^{-19}\,e\,\mathrm{cm}$

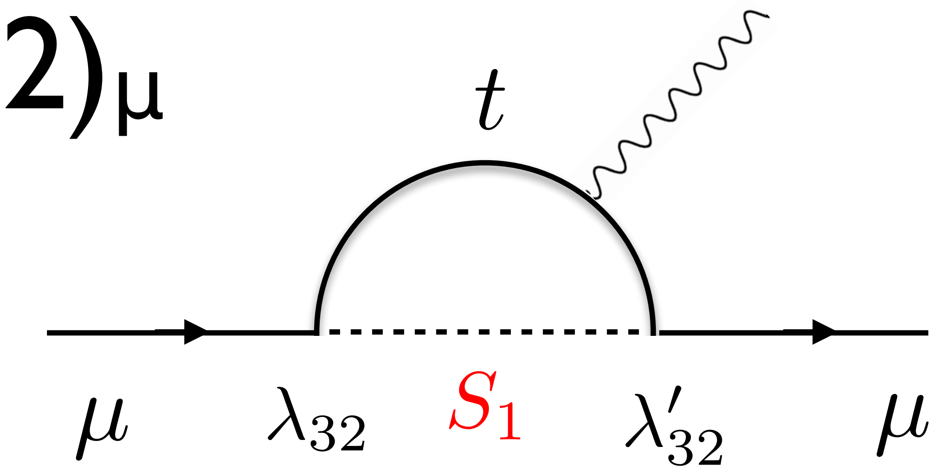
Lepton g-2 from top loops



$R_{D^{(*)}}$



$(g\text{-}2)_\mu$



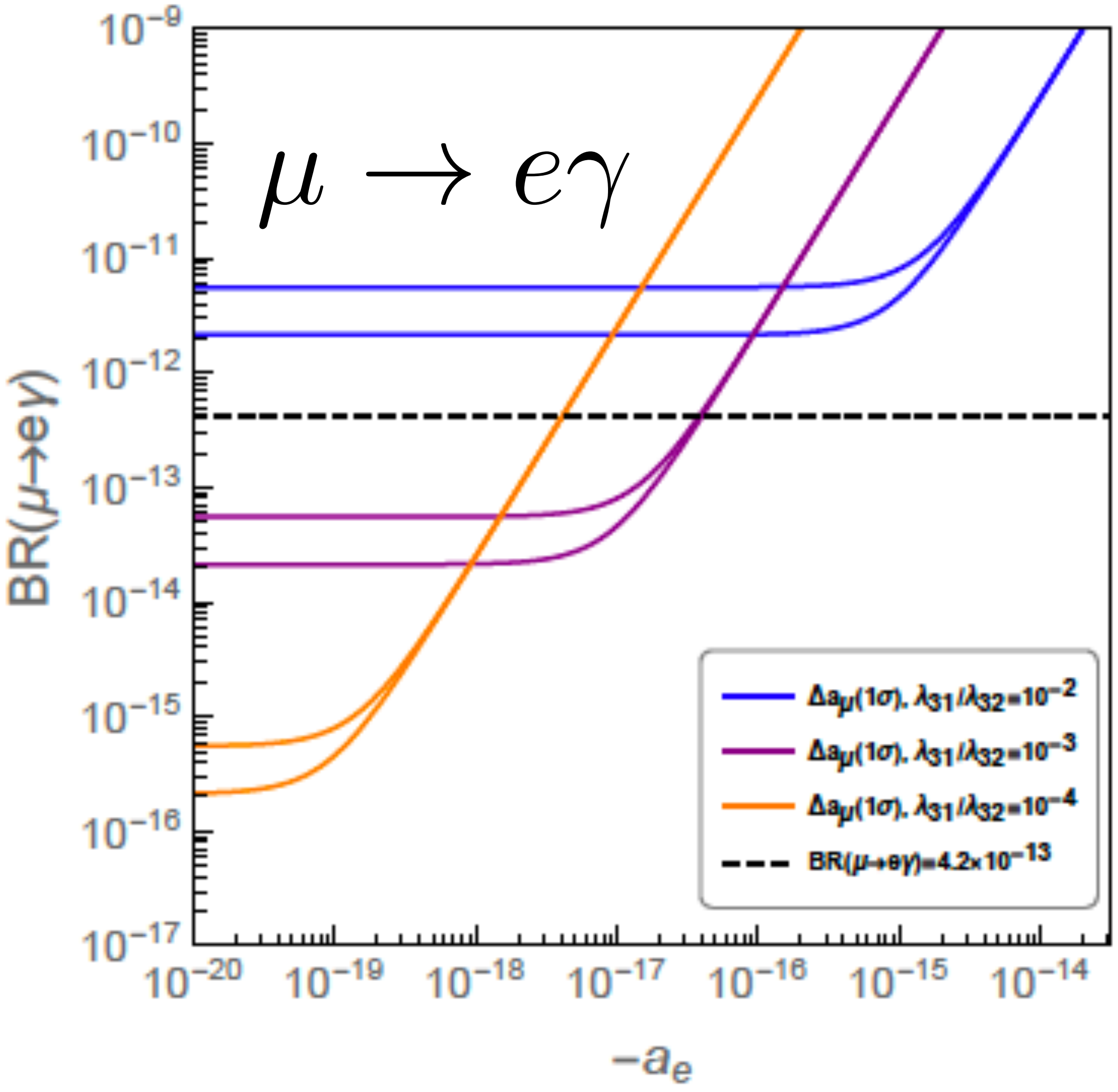
Minimal flavor: Top + Singlet leptoquark loops

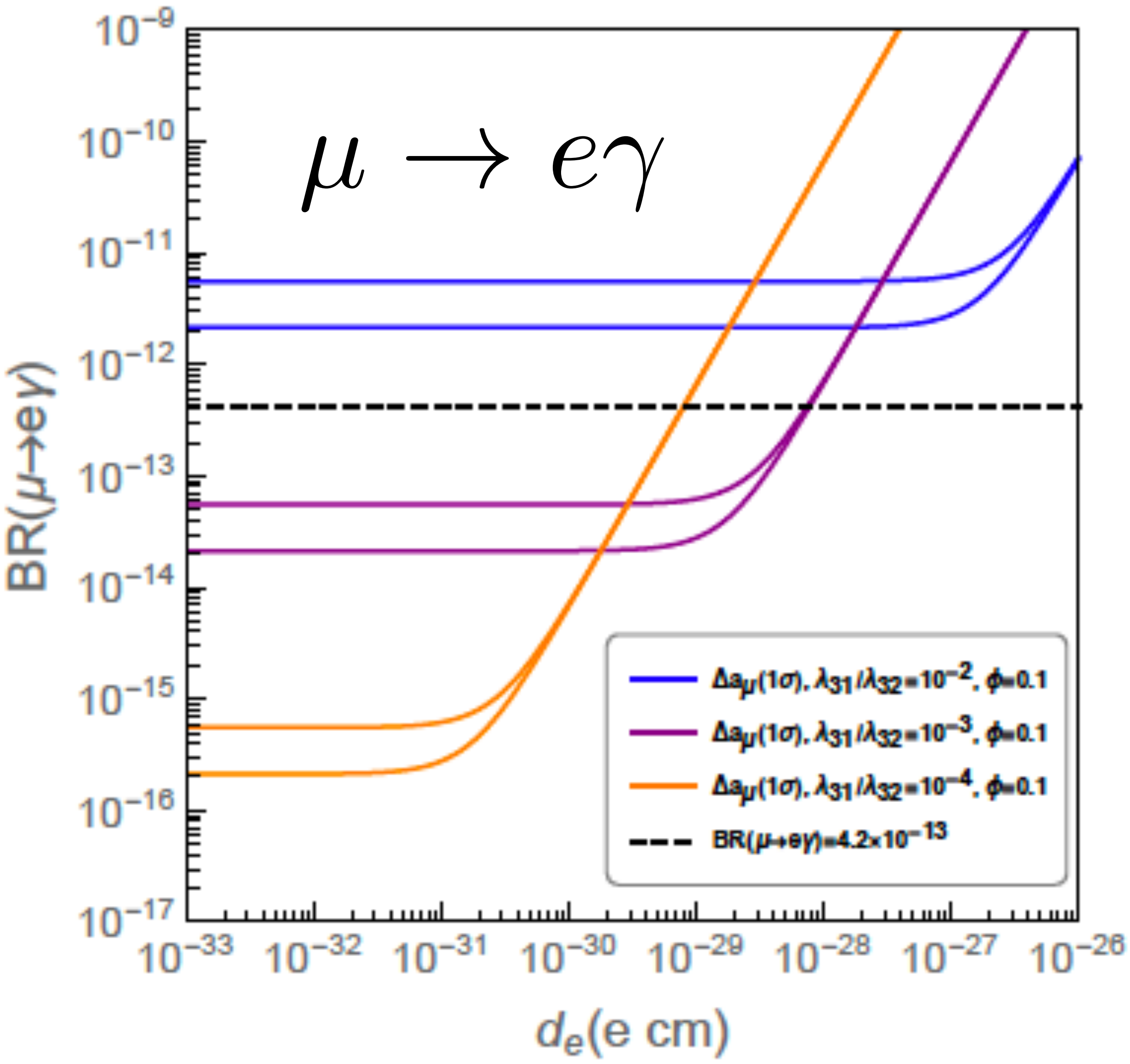
[Choi, Kang, HML, Ro, 2018]

$a_\mu\,,\;\; a_e$

Leptonic signatures

[HML, 2021]

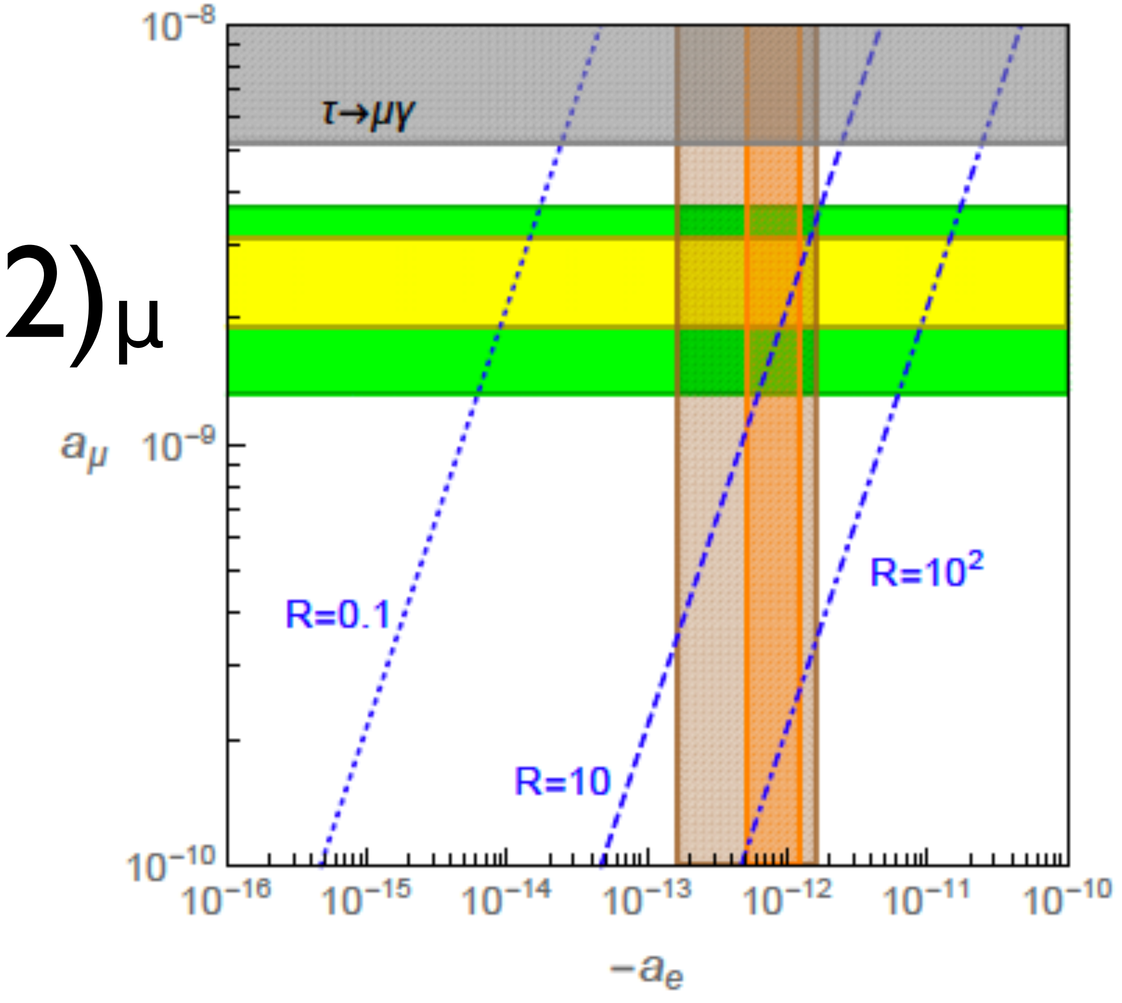




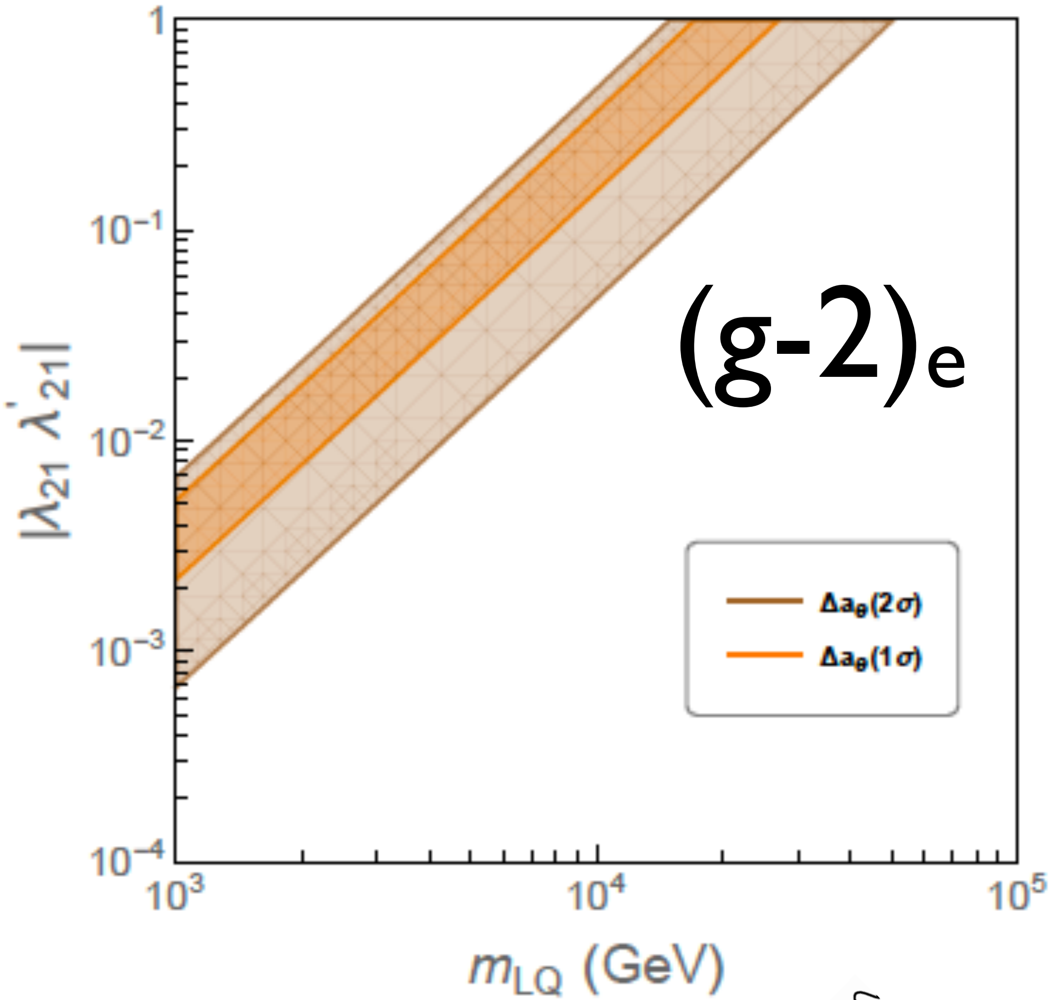
Strong constraint from $\mu \to e\gamma$ → Small electron g-2

But, electron EDM is detectable for a sizable CP phase.

Muon g-2 from charm loops



(g-2)$_\mu$



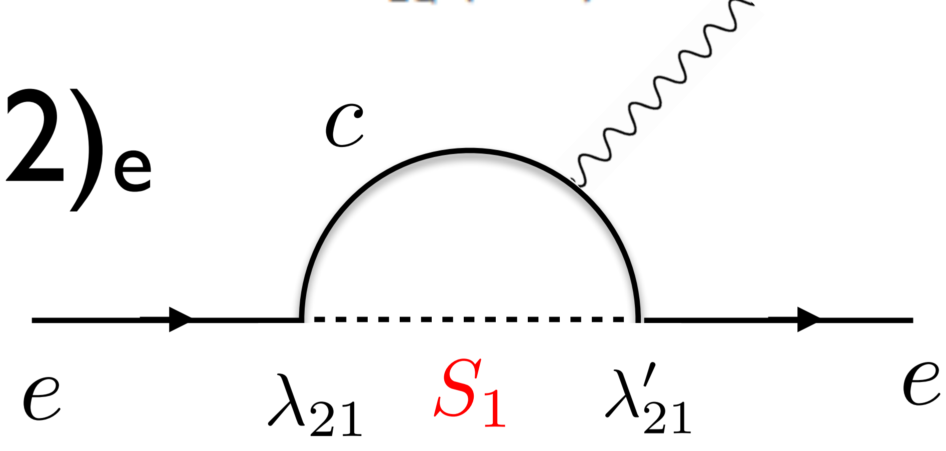
Electron g-2 specific flavor:

[HML, 2021]

Top loops → a_μ

Charm loops → a_e

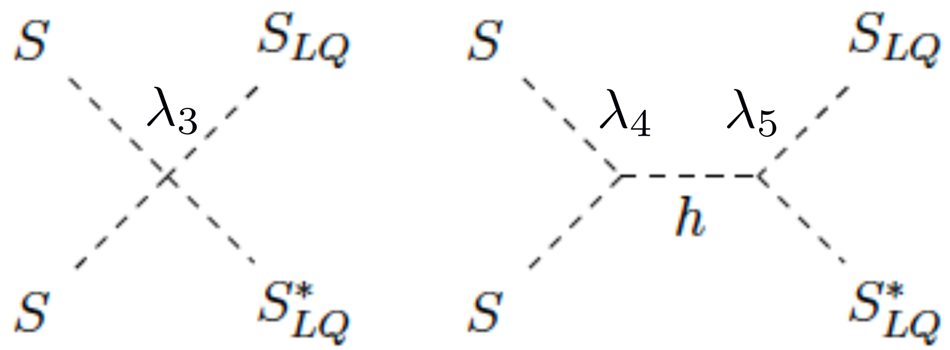
(g-2)$_e$



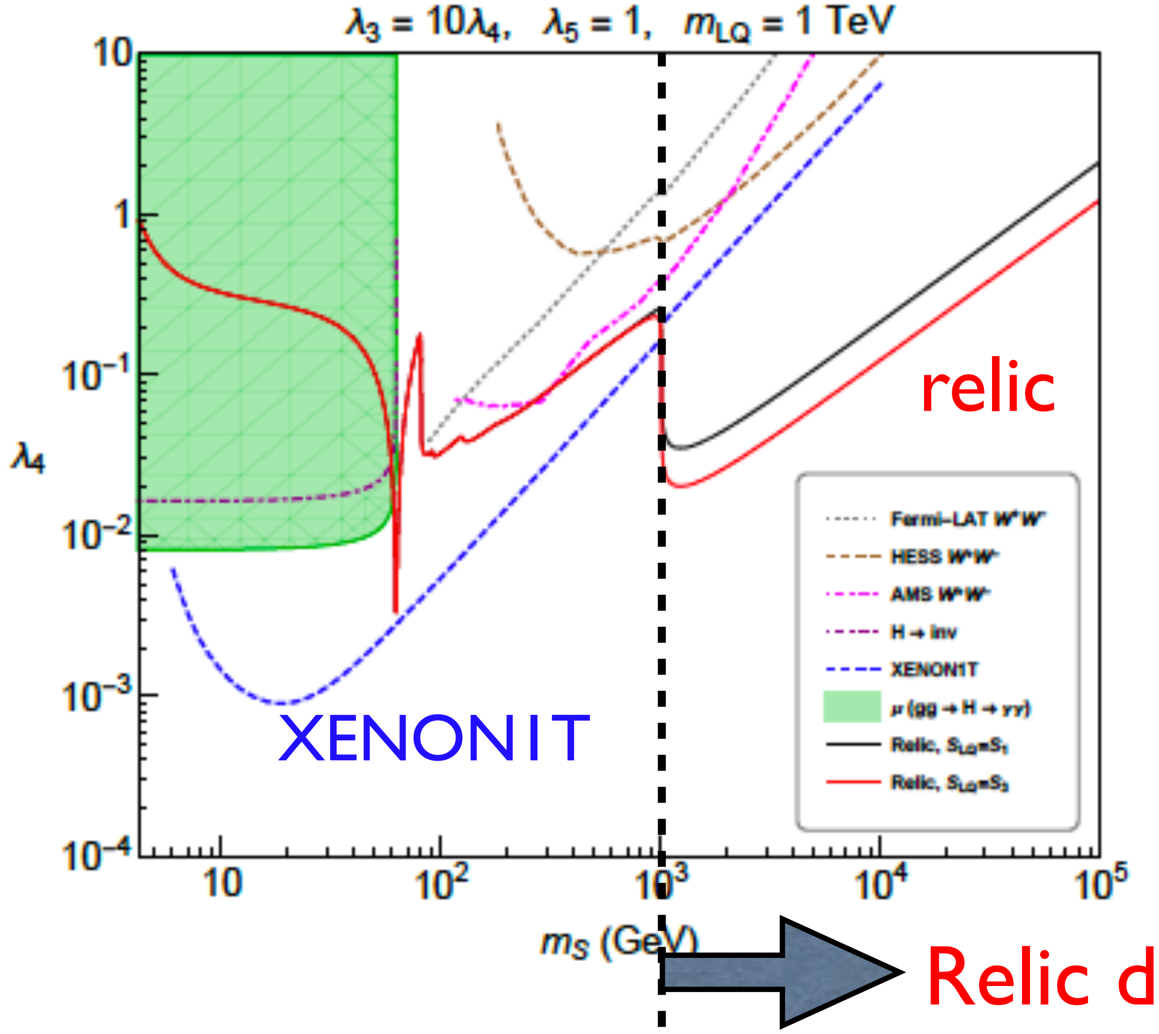
$$\boxed{\frac{a_e^{S_1}}{a_\mu^{S_1}} = \frac{m_e m_c}{m_\mu m_t} \cdot R, \qquad R = \frac{\mathrm{Re}(\lambda_{21}\lambda'^{*}_{21})}{\mathrm{Re}(\lambda_{32}\lambda'^{*}_{32})}}$$

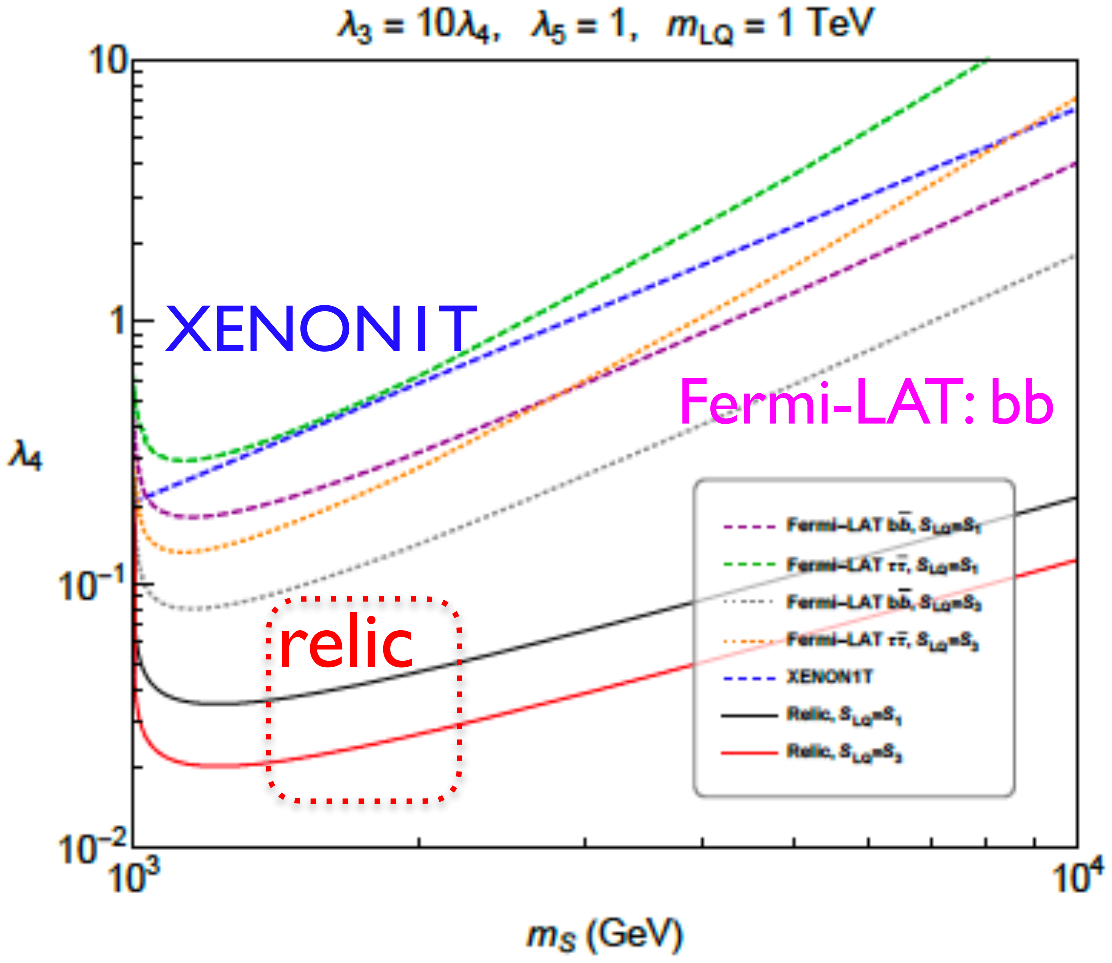
LQ-portal dark matter

[Choi, Kang, HML, Ro, 2018]



Annihilation into a LQ pair make Higgs-portal dark matter consistent.





Relic density is ok; DM indirect signals!

$R_{D^{(*)}}$: $\lambda_{33} \gg \lambda_{23}$ $\quad \mathrm{B}(\bar{t}t\,\bar{\tau}\tau) : \mathrm{B}(\bar{b}b\,\bar{\nu}_\tau\nu_\tau) : \mathrm{B}(\bar{t}b\,\bar{\tau}\nu_\tau + \mathrm{h.c.}) = \frac{1}{2} : \frac{1}{2} : 1$

$R_{K^{(*)}}$: $\kappa_{32} \gg \kappa_{22}$ $\quad \mathrm{B}(\bar{b}b\,\bar{\mu}\mu) : \mathrm{B}(\bar{t}t\,\bar{\mu}\mu) : \mathrm{B}(\bar{b}b\,\bar{\nu}_\mu\nu_\mu) : \mathrm{B}(\bar{t}b\,\bar{\mu}\nu_\mu + \mathrm{h.c.}) : \mathrm{B}(\bar{t}t\,\bar{\nu}_\mu\nu_\mu)$

$$= 1 : \frac{1}{4} : \frac{1}{4} : \frac{1}{2} : 1.$$

Conclusions

- Light dark matter and mediators can be probed at Belle-II and LHCb, in addition to direct and indirect detections.
- Flavor puzzles in B-meson decays may call for new forces or extra colored particles, thus opening a window for complementary between energy and intensity frontiers.
- Searches for light dark sector and B-meson decays at Belle-II and LHCb would lead to a crucial guideline for flavor physics in next decades.
- Existing anomalies in muon g-2 might be related to B-meson and XENON1T anomalies, and testable at Belle-II.