Scalar dark matter interacting through an extra U (1) gauge interaction

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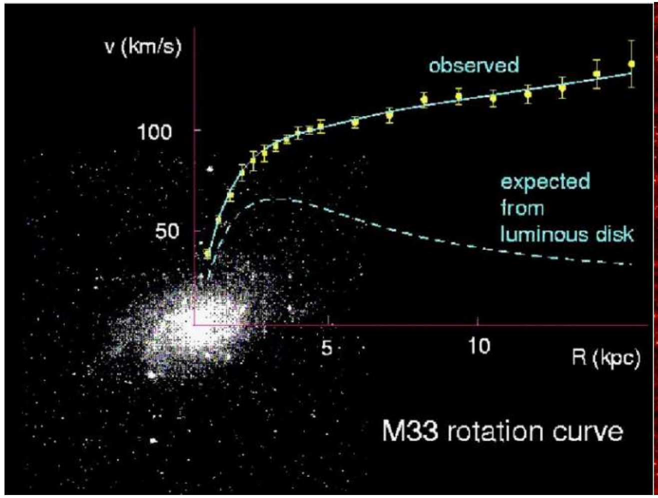
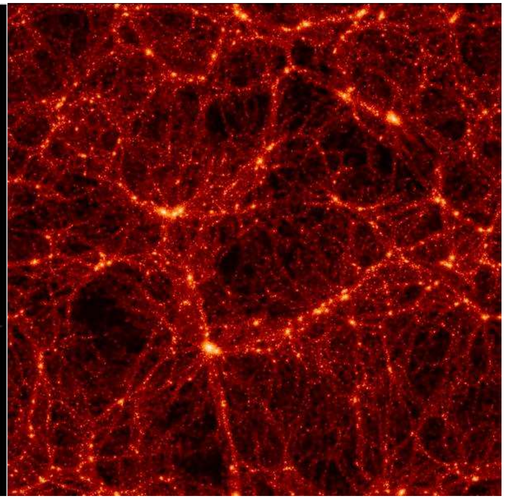
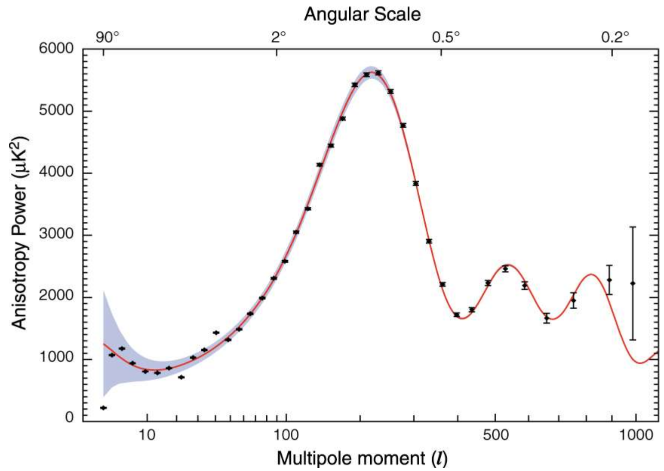
Refs : 1908.09277

§ Introduction

Dark matters are everywhere!



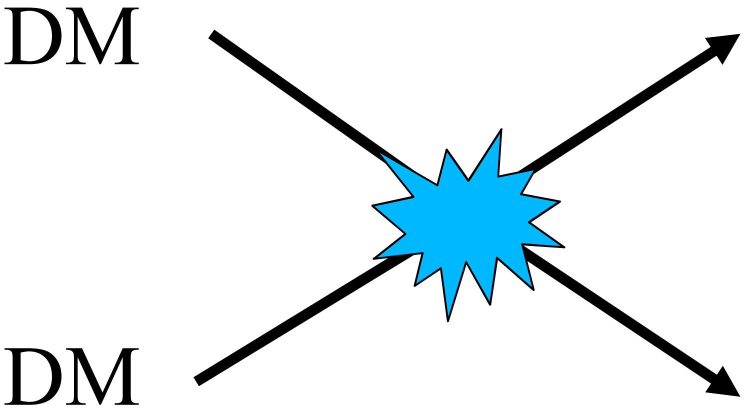




- Its identification (Mass, …) and properties are unknown

§ Introduction

If DM is WIMP with mass of about 100 GeV,
why haven't we discovered yet?



↑ $\sigma \ll 1$ pb

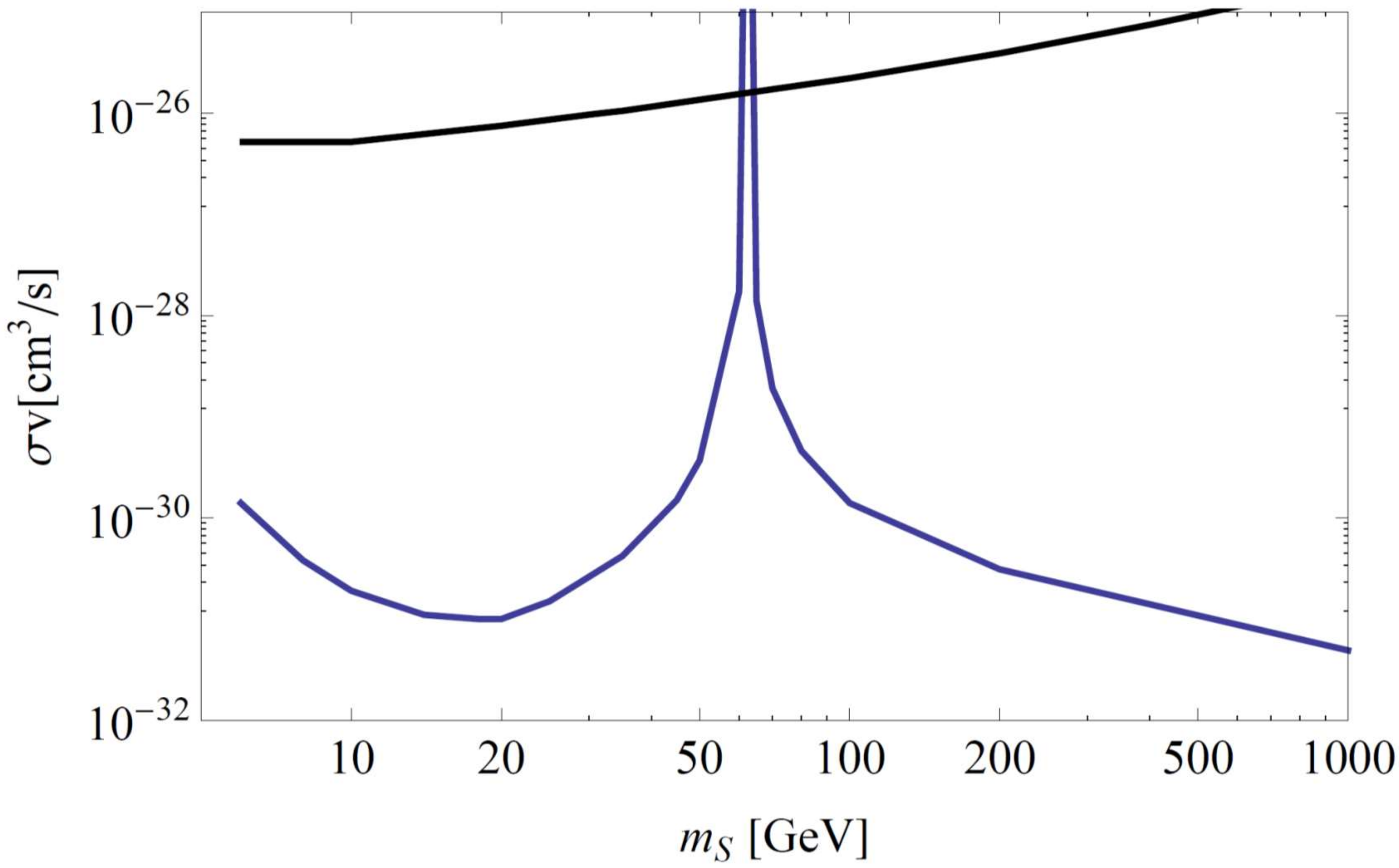
∵ Higgs and quarks?

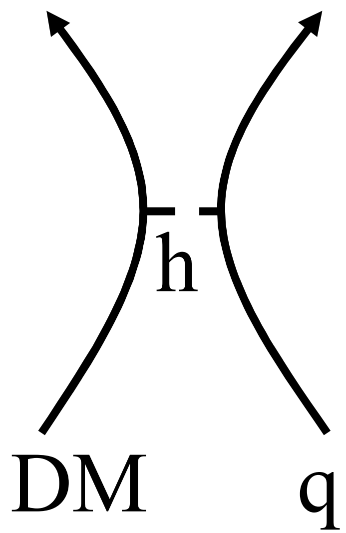
$\sigma v \backsim 1$ pb   by Ωh^2

$\sigma v < 1$ pb   by Fermi-LAT

§ Introduction

Singlet scalar DM interpretation of direct search null results into the present annihilation into *bb*





§ Introduction

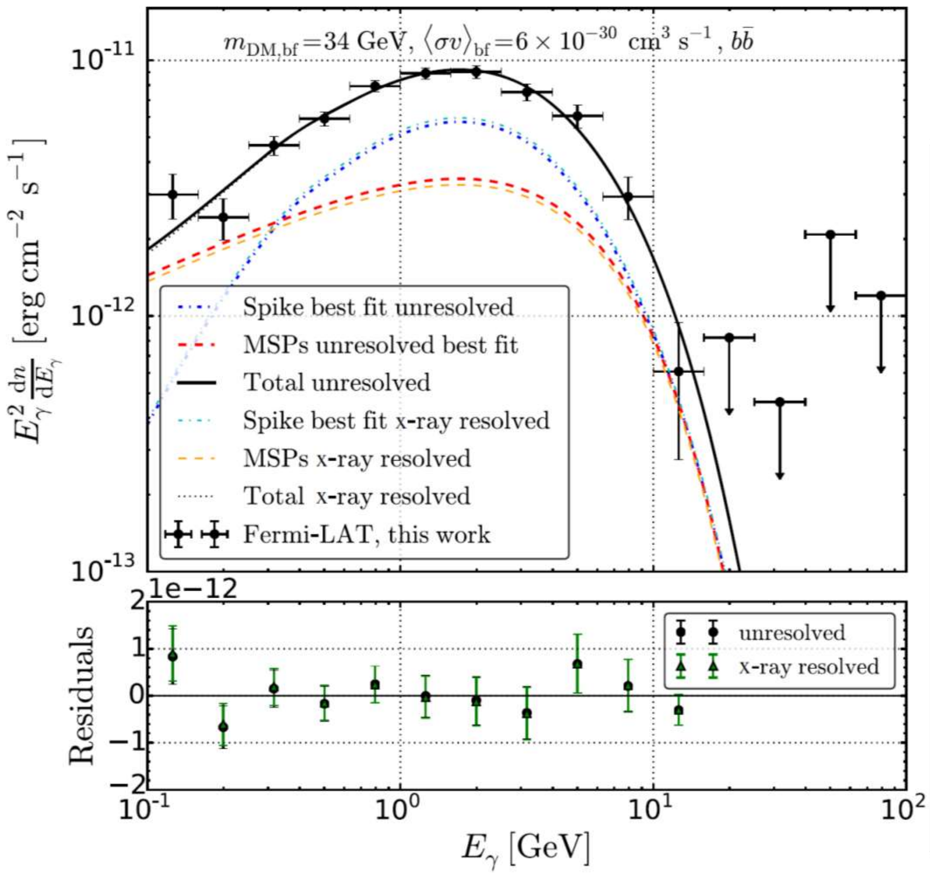
- Why is DD cross section so small?
  - Leptophilic DM [Krauss et al (2003), …]
  - Pseudo scalar mediator [Ipek et al (2014), …]
  - Pseudo NG dark matter [Gross et al (2017), …]
  - …
- Small DD cross section → Small annihilation as well
  - Then, how to reconcile with thermal abundance?
  - What if DM annihilation signal with a very small cross section were reported in future?

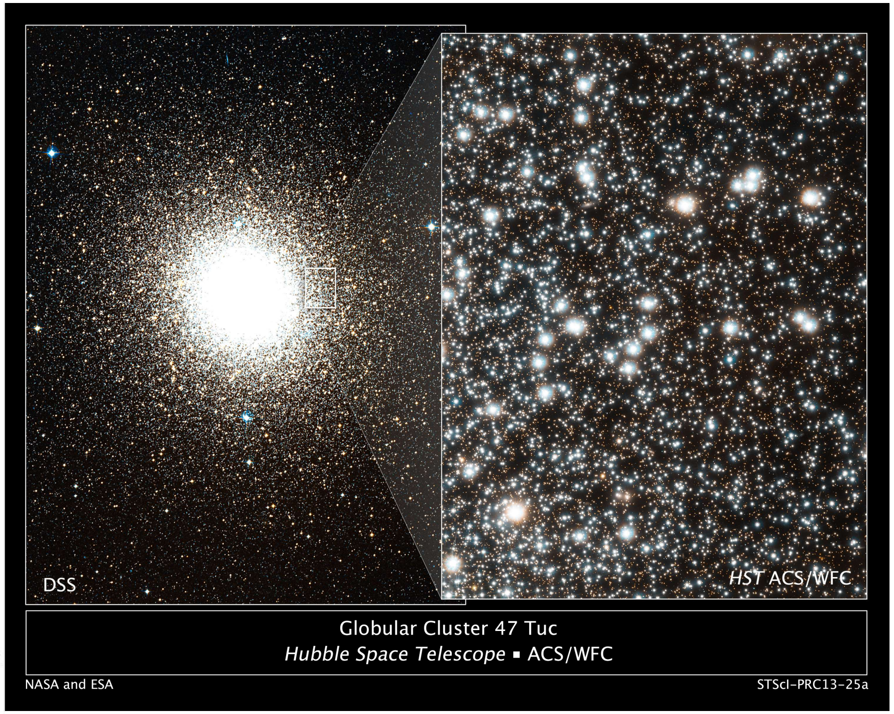
§ § Excess in globular cluster 47 Tuc

Understanding the γ-ray emission from the globular cluster 47 Tuc: Evidence for dark matter?

Anthony M. Brown,[1,*] Thomas Lacroix,[2] Sheridan Lloyd,[1] Céline Bœhm,[3,4,5,6] and Paula Chadwick[1]
[1]*Centre for Advanced Instrumentation, Department of Physics, University of Durham, South Road, Durham, DH1 3LE, United Kingdom*

[Brown et al (2018)]





§ § Excess in globular cluster 47 Tuc

mass is found to be 34 GeV, which is essentially the same as the best-fit DM explanation for the Galactic center "excess" when assuming DM annihilation into b quarks [37,38]. However, the value of our best-fit annihilation cross section is too small to account for the observed cosmological DM

[Brown et al (2018)]

- Few attention paid because of too small σv

- 30 GeV mass for annihilation into bb
- Several GeV mass for annihilation into $\tau\tau$??

§ Gauged U(1) scalar DM Model

§ Gauged U(1) scalar DM Model

- Particle content

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)$
Q^i	$\mathbf{3}$	$\mathbf{2}$	$1/6$	q_{Q^i}
u_R^i	$\mathbf{3}$	$\mathbf{1}$	$2/3$	q_{u^i}
d_R^i	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	q_{d^i}
L^i	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	q_{L^i}
e_R^i	$\mathbf{1}$	$\mathbf{1}$	-1	q_{e^i}
Φ	$\mathbf{1}$	$\mathbf{2}$	$1/2$	0
N_R^i	$\mathbf{1}$	$\mathbf{1}$	0	q_{N^i}
ϕ_1	$\mathbf{1}$	$\mathbf{1}$	0	$+1$
ϕ_2	$\mathbf{1}$	$\mathbf{1}$	0	$+2$

- q_X to be anomaly free

- Dark matter with the fixed charge so that it interacts with the U(1) breaking Higgs field.

C.f. [Rodejohann and Yaguna (2015), Biswas et al (2016, 2018), Singirala et al (2016), Bandyopadhyay et al (2018)]

§ § Masses and interactions

- Scalar potential

$$
\begin{aligned}
V(\Phi,\phi_1,\phi_2) =& -M_\Phi^2|\Phi|^2 + \frac{\lambda}{2}|\Phi|^4 + M_{\phi_1}^2\phi_1\phi_1^\dagger - M_{\phi_2}^2\phi_2\phi_2^\dagger \\
&+ \frac{1}{2}\lambda_1(\phi_1\phi_1^\dagger)^2 + \frac{1}{2}\lambda_2(\phi_2\phi_2^\dagger)^2 + \lambda_3\phi_1\phi_1^\dagger(\phi_2\phi_2^\dagger) \\
&+ (\lambda_4\phi_1\phi_1^\dagger + \lambda_5\phi_2\phi_2^\dagger)|\Phi|^2 - A(\phi_1\phi_1\phi_2^\dagger + \phi_1^\dagger\phi_1^\dagger\phi_2)
\end{aligned}
$$

- Mases of DM and Higgs bosons

$$
\begin{aligned}
\mathcal{L}_{\rm mass} =& -\frac{1}{2}(\varphi\ \varphi_2)\begin{pmatrix} -M_\Phi^2 + \frac{3}{2}\lambda v^2 + \frac{1}{2}\lambda_5 v_2^2 & \lambda_5 v v_2 \\ \lambda_5 v v_2 & -M_{\phi_2}^2 + \frac{3}{2}\lambda_2 v_2^2 + \frac{1}{2}\lambda_5 v^2 \end{pmatrix}\begin{pmatrix}\varphi \\ \varphi_2\end{pmatrix} \\
&- \frac{1}{2}\left(M_{\phi_1}^2 + \frac{1}{2}\lambda_3 v_2^2 + \frac{1}{2}\lambda_4 v^2 - \sqrt{2}Av_2\right)S^2 \\
&- \frac{1}{2}\left(M_{\phi_1}^2 + \frac{1}{2}\lambda_3 v_2^2 + \frac{1}{2}\lambda_4 v^2 + \sqrt{2}Av_2\right)P^2
\end{aligned}
$$

§ § Masses and interactions

- Interactions
  - Gauge interactions

$$\mathcal{L}_{\rm int} = g' Z'^{\mu} \left((\partial_\mu S) P - S \partial_\mu P \right)$$

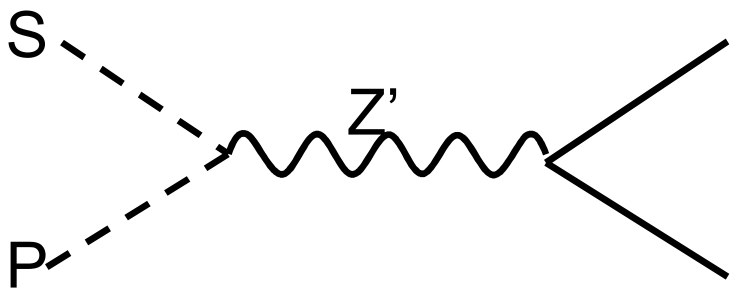
    - Absence of DM-DM-Z': Inelastic
  - Scalar interactions

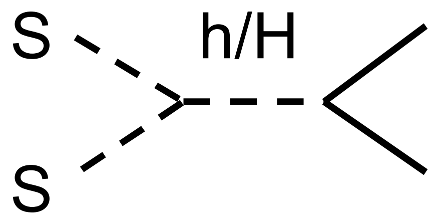
$$\mathcal{L}_{\rm int} \supset \frac{1}{2}\left(\left(\lambda_4 v \cos\alpha - (\lambda_3 v_2 - \sqrt{2}A)\sin\alpha\right) h + \left(\lambda_4 v \sin\alpha + (\lambda_3 v_2 - \sqrt{2}A)\cos\alpha\right) H\right) S^2$$
$$+ \frac{1}{2}\left(\left(\lambda_4 v \cos\alpha - (\lambda_3 v_2 + \sqrt{2}A)\sin\alpha\right) h + \left(\lambda_4 v \sin\alpha + (\lambda_3 v_2 + \sqrt{2}A)\cos\alpha\right) H\right) P^2$$

    - The direct DM search bound for Higgs bosons exchange processes is avoidable by taking those very small
    - Not used in freeze-out annihilation.

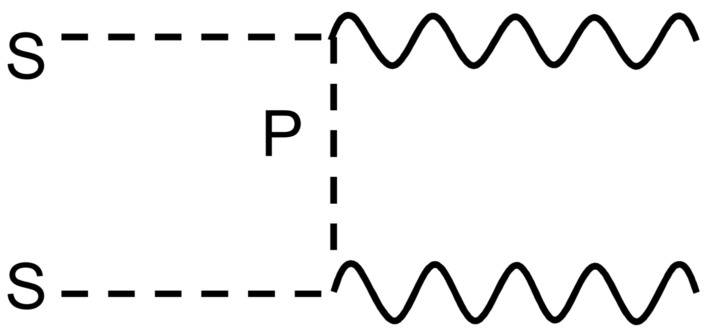
§ § Annihilation

- Annihilation modes
  - Co-annihilation





  - Into Z’ pair



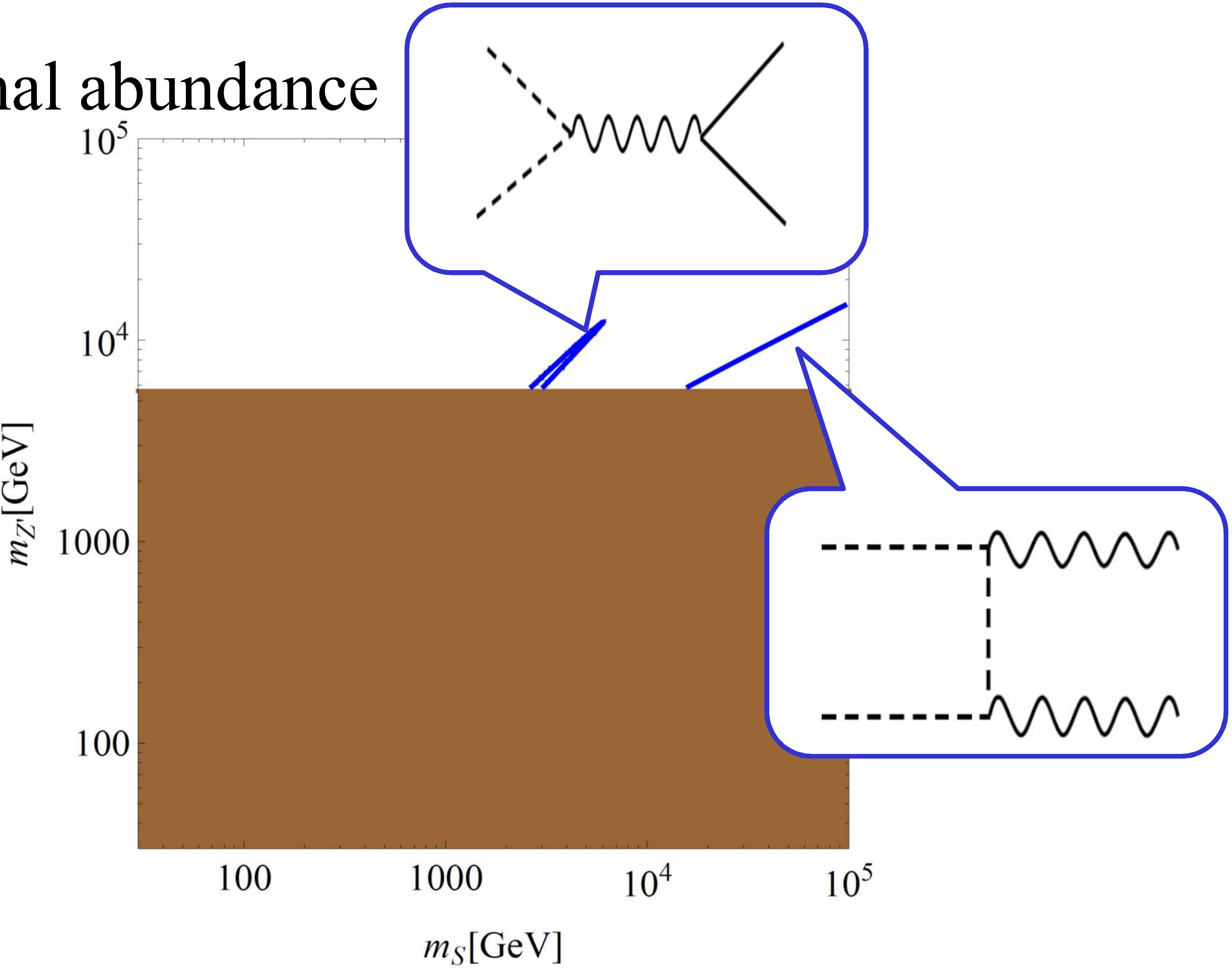
§ For specific U(1) models

- $U(1)_{B\text{-}L}$
  - At TeV scale
- $U(1)_{(B\text{-}L)3}$
  - At the weak scale
- $U(1)_{L\mu-L\tau}$
  - From MeV to the weak scale

§ § $U(1)_{B\text{-}L}$

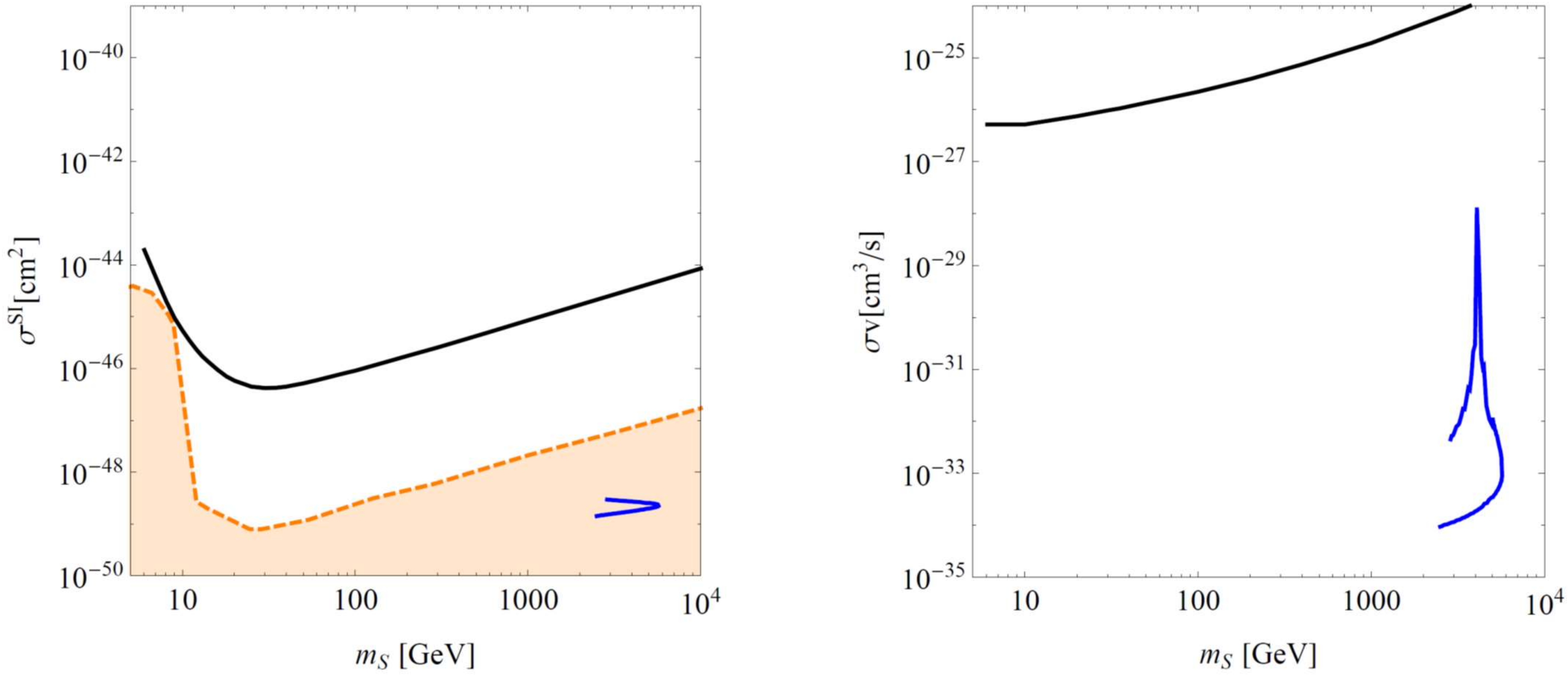
- Thermal abundance

g = 0.5



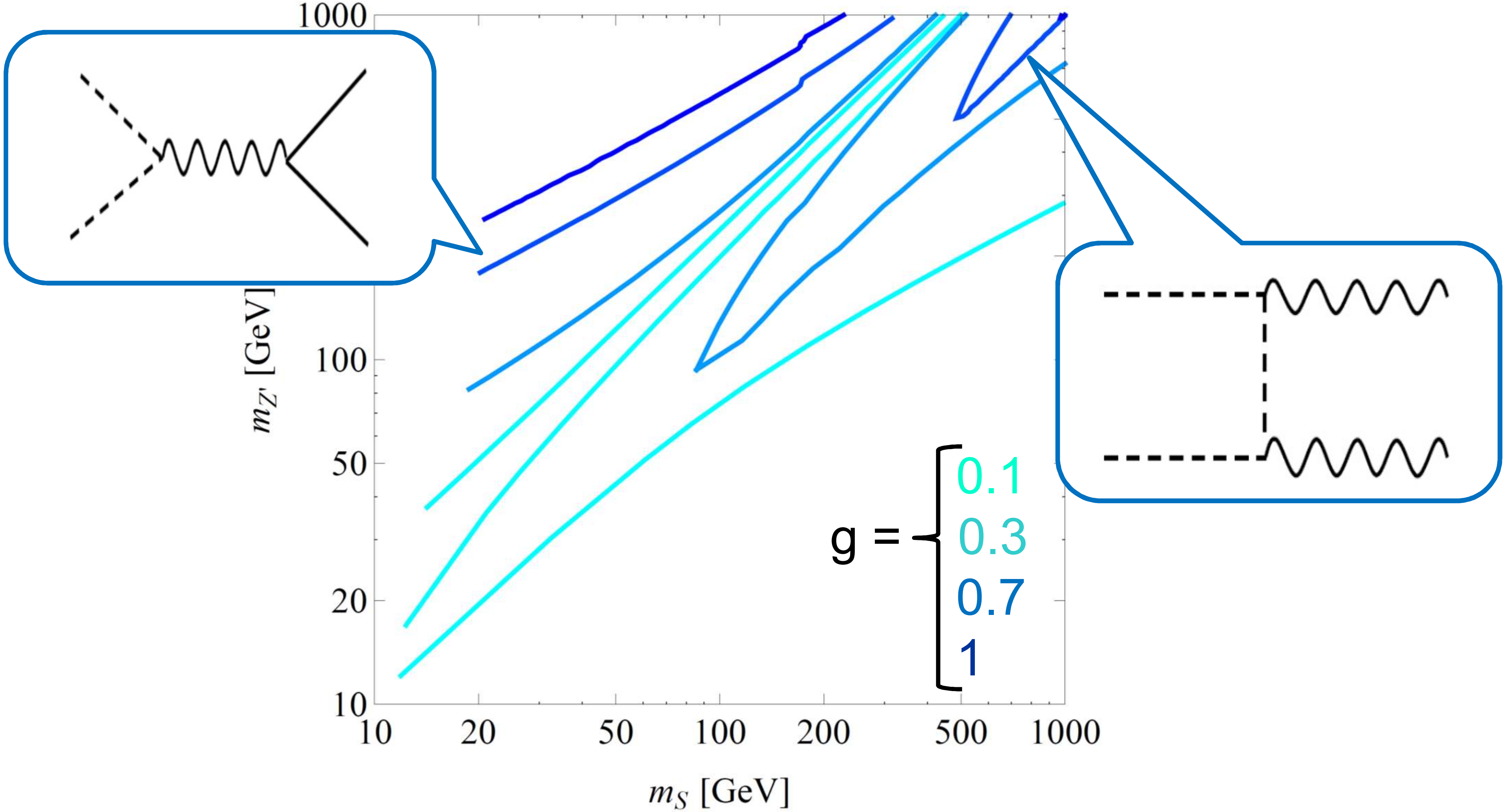
§ § $U(1)_{B\text{-}L}$

- Prospects for direct and indirect detection



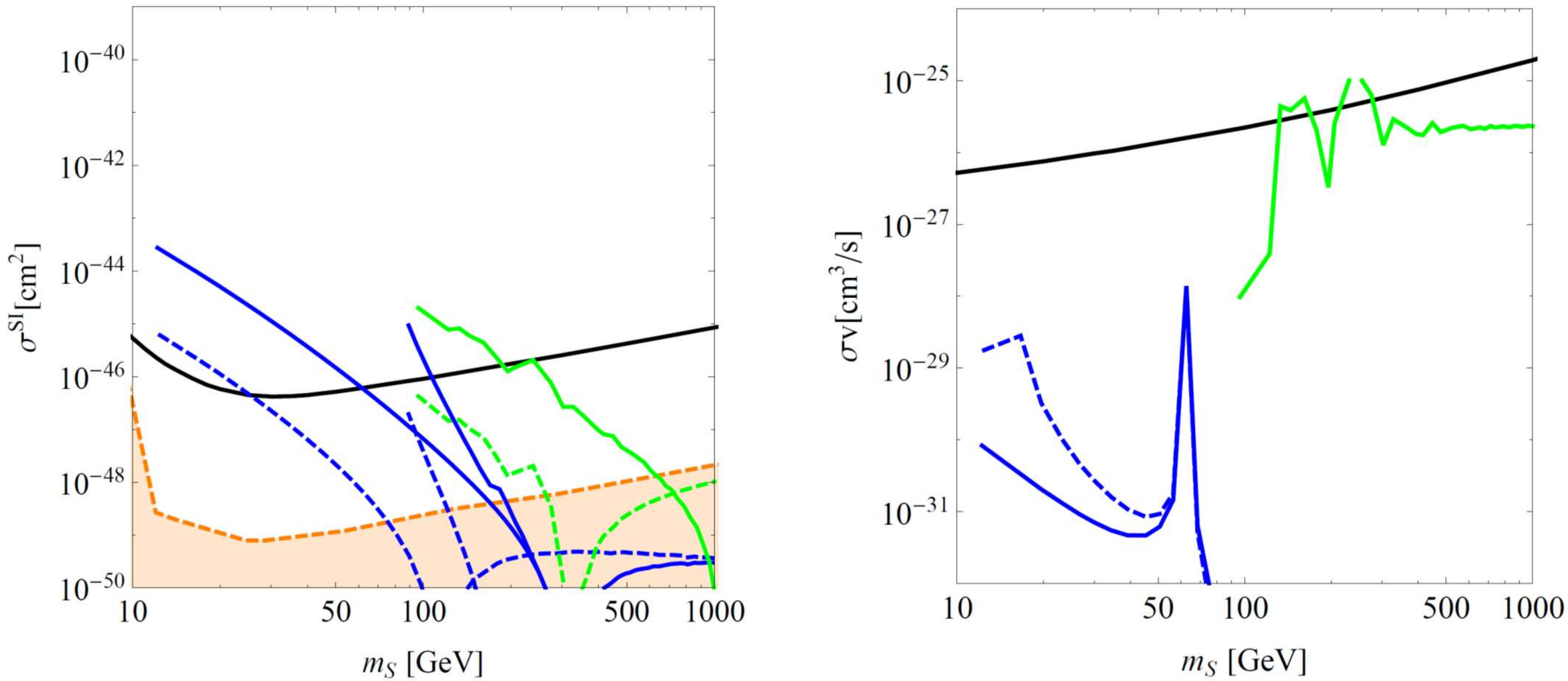
§ § $U(1)_{(B-L)3}$

- Thermal abundance



§ § $U(1)_{(B\text{-}L)3}$

- Prospects for direct and indirect detection

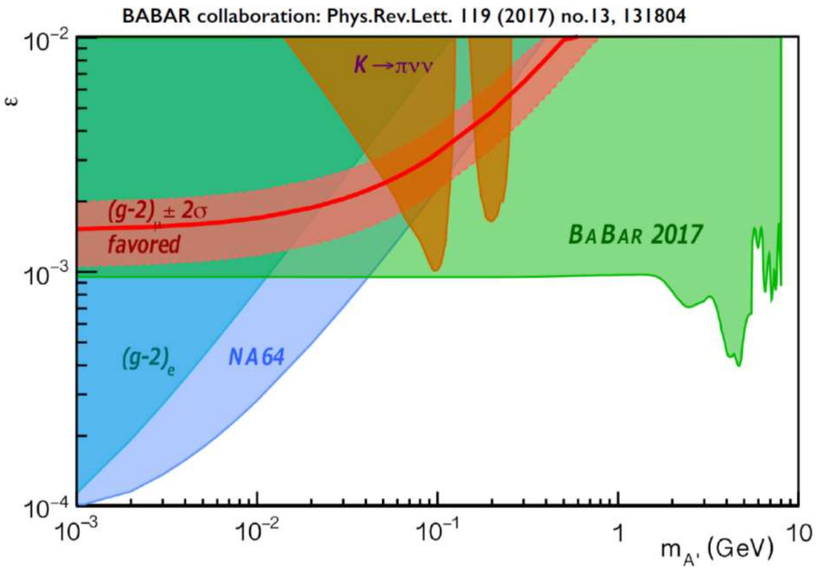


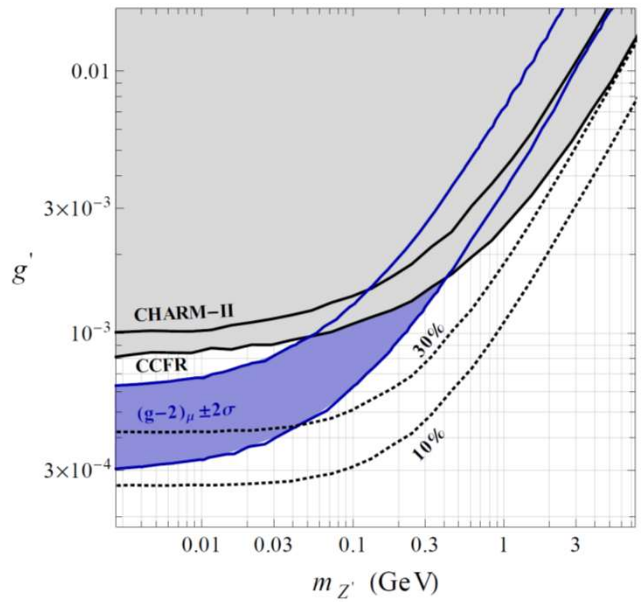
g = 0.3

§ $U(1)_{L\mu - L\tau}$ models

§ § g-2 in muon

- Anomalous magnetic moment of muon [Brown et al (2001), Bennet et al (2006)]
- Dark photon interpretation

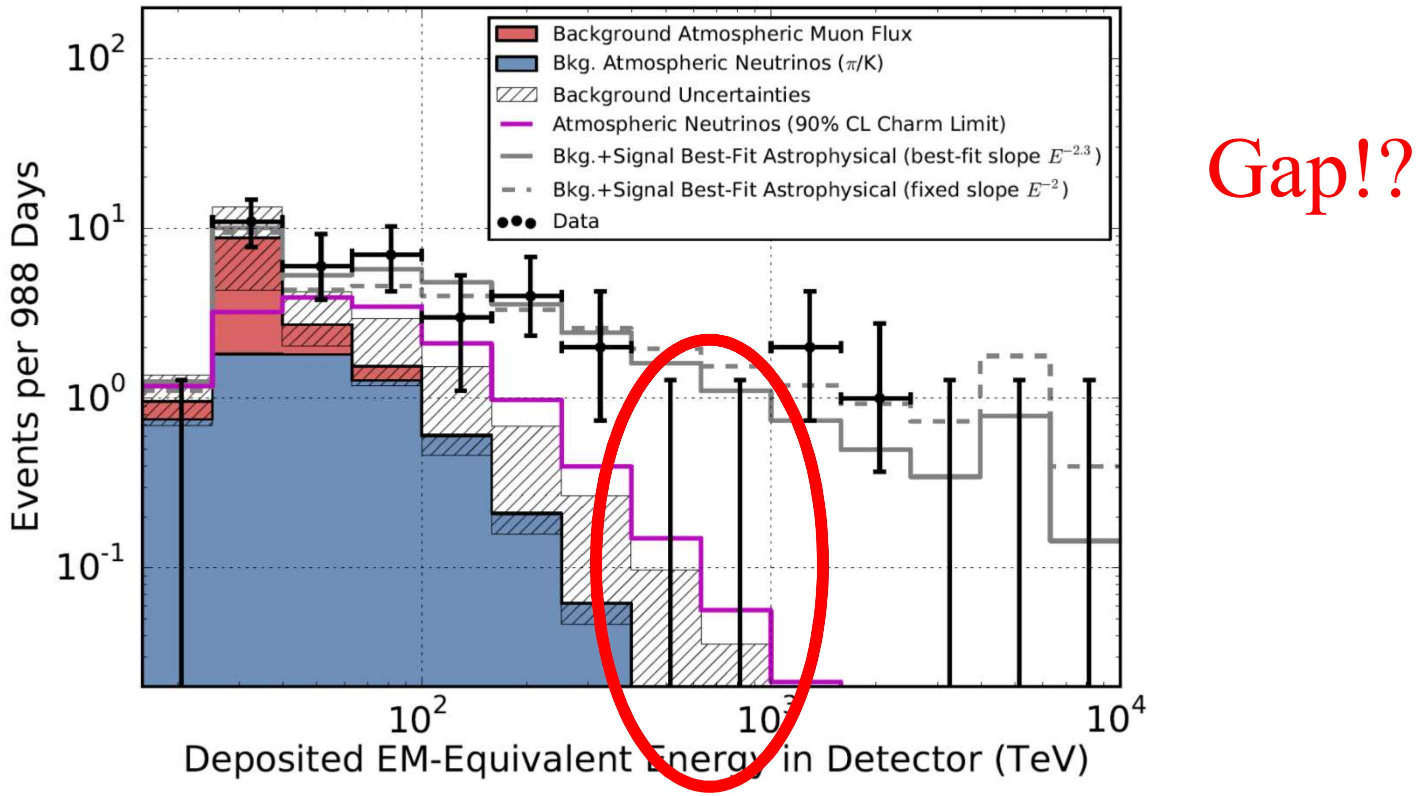




  – $U(1)_{L\mu\text{-}L\tau}$ interpretation [Ma et al (2002), …] is still viable [Altmannshofer et al (2014)]

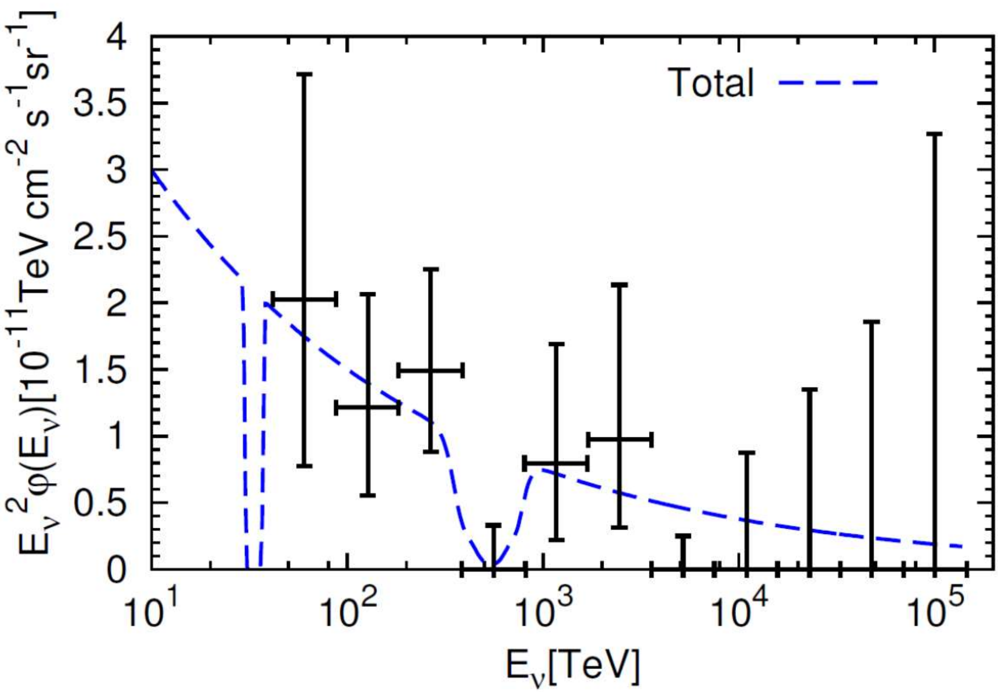
§ § A gap in IceCube?

- High energy neutrino spectrum measured by IceCube [IceCube (2014)]



§ § A gap in IceCube?

- High energy neutrino spectrum measured by IceCube [IceCube (2014)]
- New physics interpretation
  - Z' interpretation in $U(1)_{L\mu-L\tau}$ model [Araki et al (2015)]



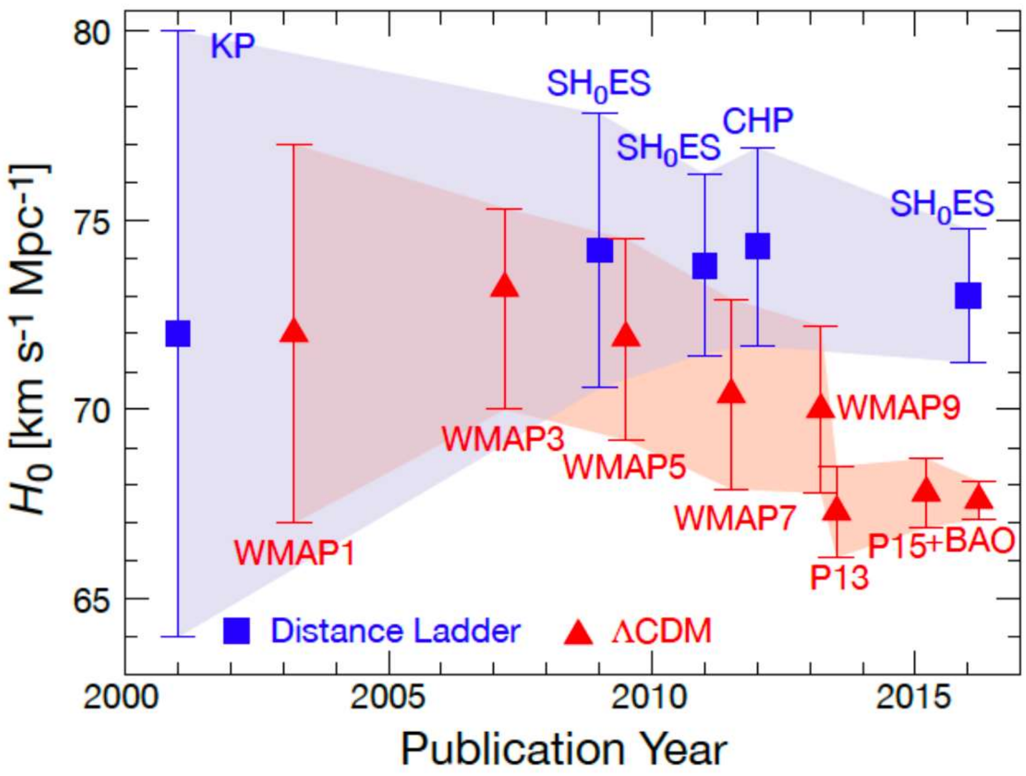
$m_{Z'} = 1.9$ MeV

$g' = 0.0005$

$\nu_{CR} + \nu_{C\nu B} \rightarrow Z'$

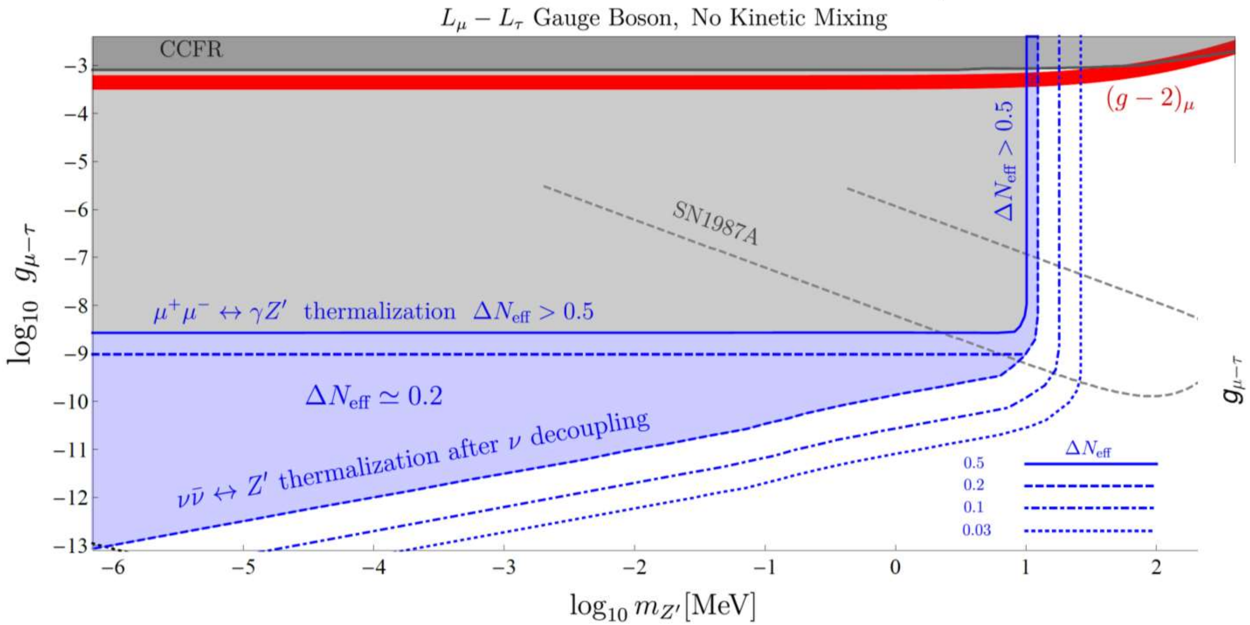
§ § Hubble tension

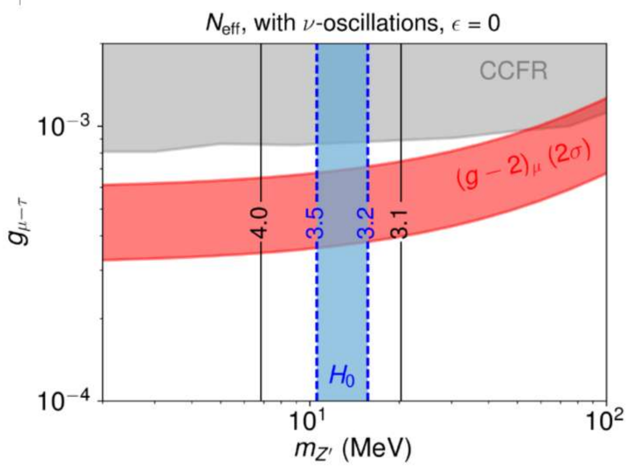
- Hubble parameter



§ § Hubble tension

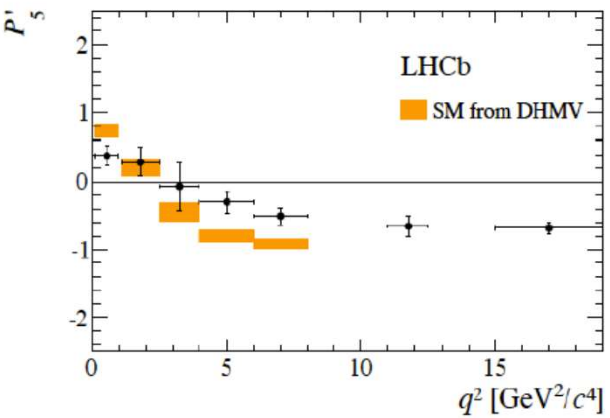
- Hubble parameter
- New physics interpretation
  - $\Delta N_{\rm eff}$ relaxes Hubble tension [D'Eramo et al (2018), Planck (2018), …]
  - Z' interpretation in $U(1)_{L\mu - L\tau}$ model [Escudero et al (2019)]





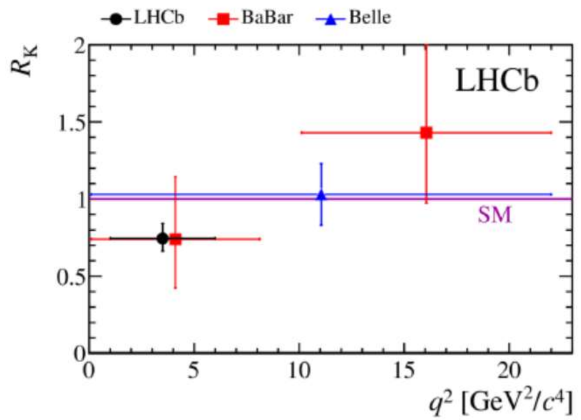
§ § B anomaly

- $B \to K\, ll$ anomaly at LHCb [(2013), …] and Belle [(2016)]



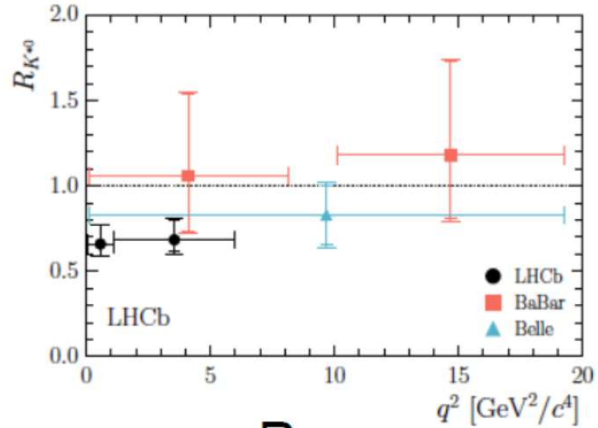
P'_5

LHCb, JHEP 1602 (2016) 104



R_K

LHCb, PRL 113 (2014) 151601

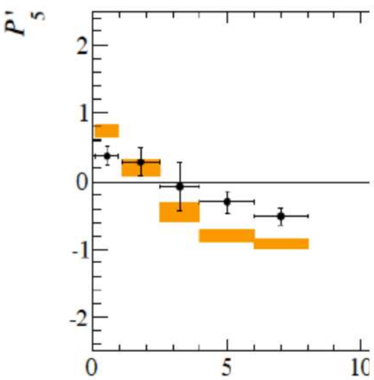


R_{K^*}

LHCb, JHEP 1708 (2017) 055

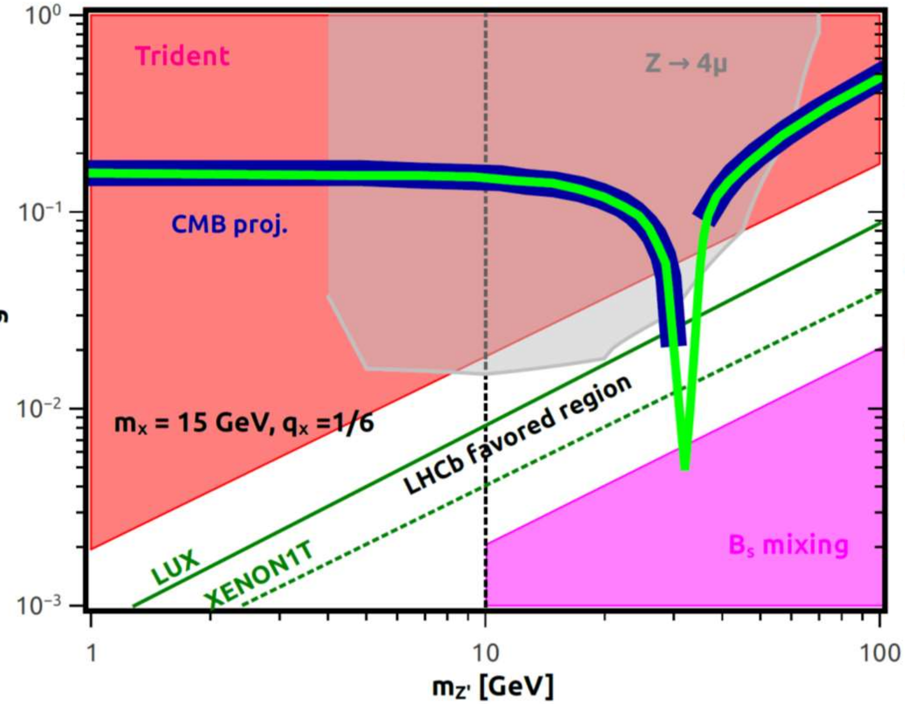
§ § B anomaly

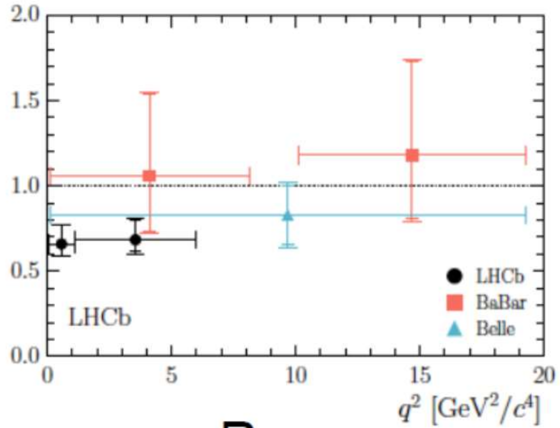
- *B* →*K ll* anomaly at LHCb [(2013), …] and Belle [(2016)]



P'$_5$

LHCb, JHEP 16





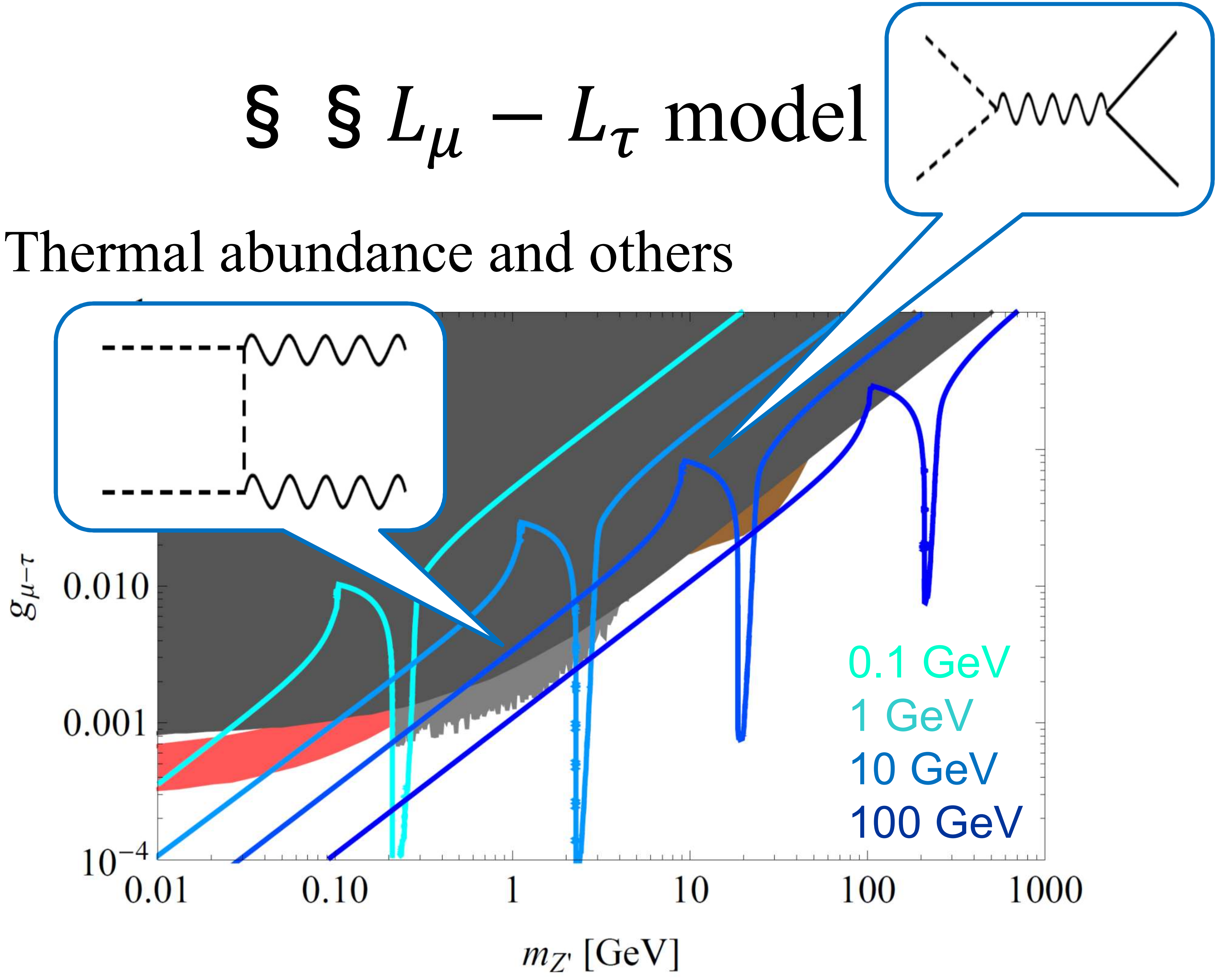
R_{K^*}

LHCb, JHEP 1708 (2017) 055

- Light U(l)$_{L\mu\text{-}L\tau}$ gauge boson interpretation [Altmannshofer et al (2014, 2016)]

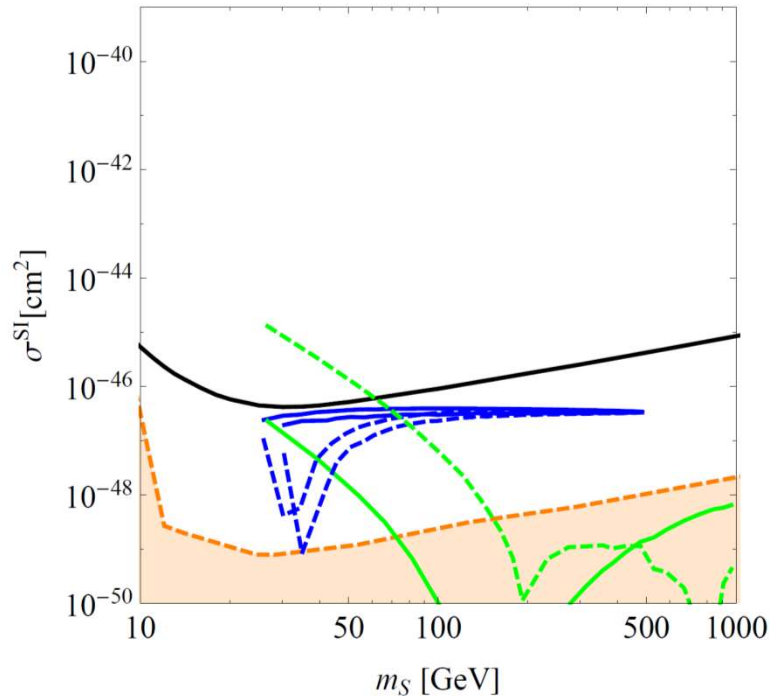
§ § $L_\mu - L_\tau$ model

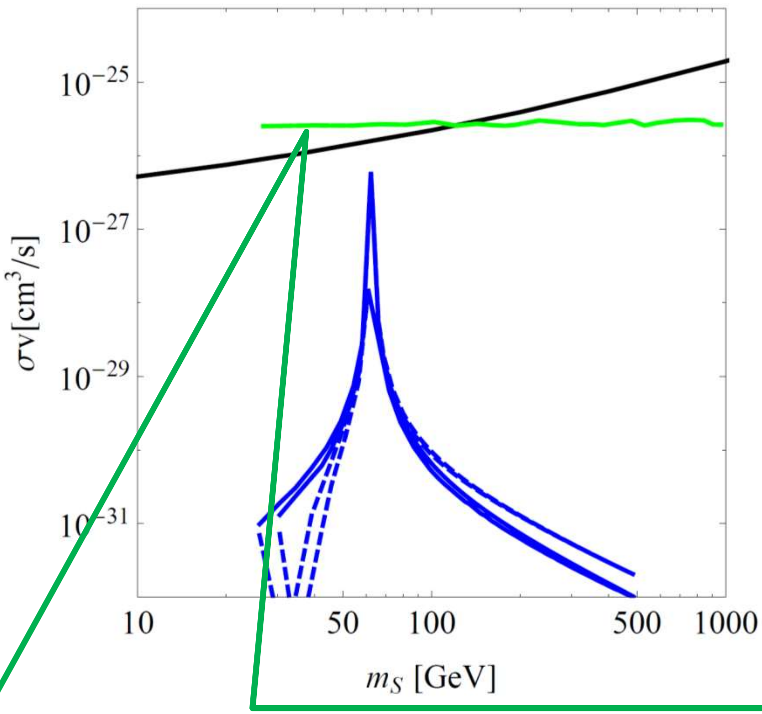
- Thermal abundance and others



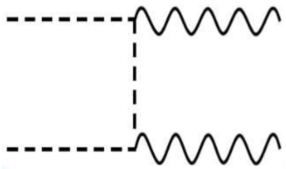
§ § $L_\mu - L_\tau$ model

- Constraints from and prospect for direct and indirect DM searches





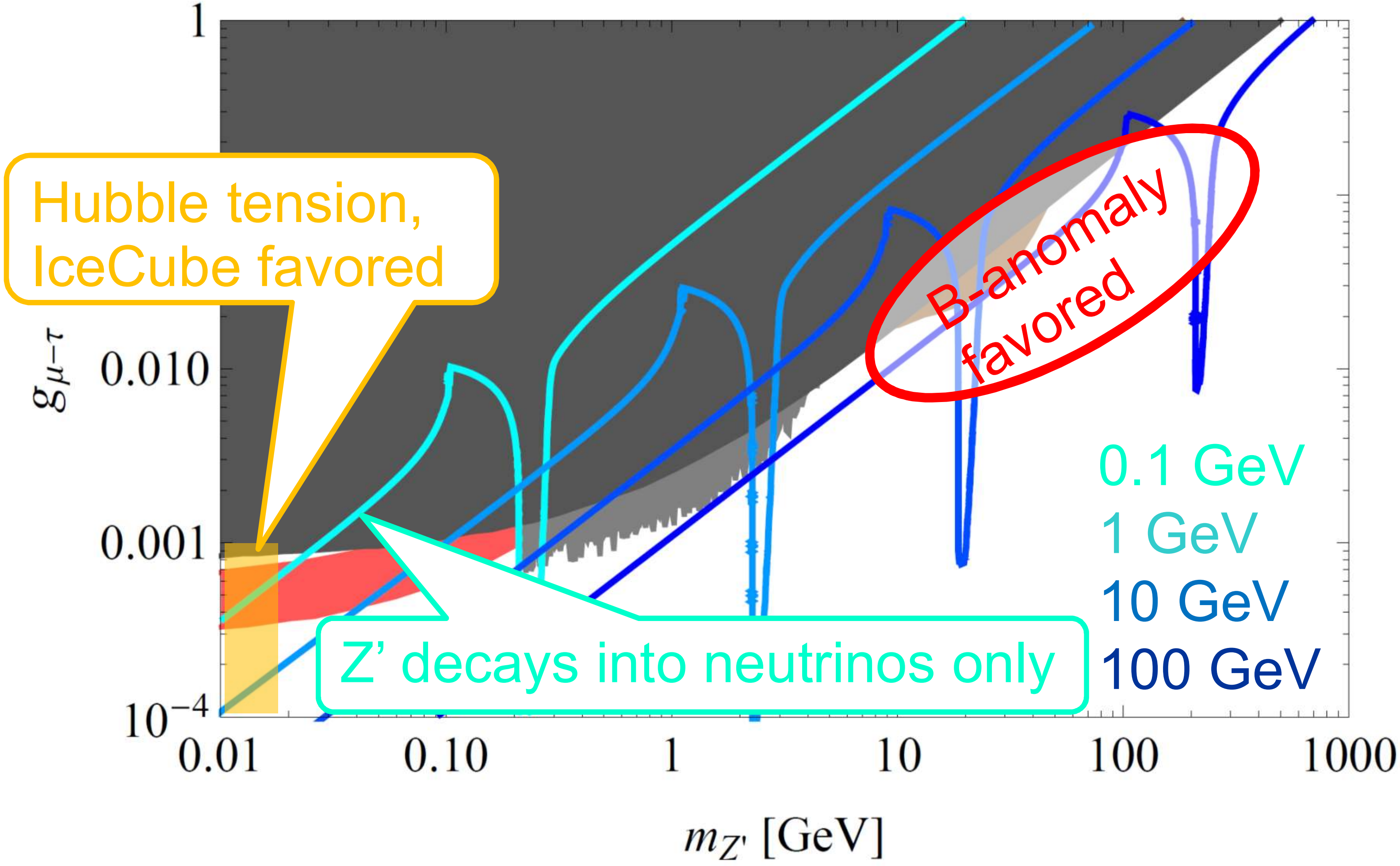
for $g_{\mu-\tau} = 0.03$



followed by Z' → $\tau\tau$ or $\mu\mu$ is constrained

§ § $L_\mu - L_\tau$ model

- Thermal abundance and others



§ Summary

- Gauged U(1) scalar DM model
  - with DM-DM-U(1) Higgs coupling
- Possible hierarchy between freeze out and today
  - E.g., 47 Tuc excess
- *B*-*L*, 3rd gen. *B*-*L*, and $L_\mu - L_\tau$ have been studied
- Gauged $L_\mu - L_\tau$ is anomaly friendly
  - g-2 of muon, IceCube, Hubble tension, B-anomaly…