Dark matter, Flavor, and LHC physics in DM models with bottom partner

Yuji Omura (KMI, Nagoya)

Based on 1601.07396 with J. Kawamura (Waseda)
and 1612.01643 with J.Kawamura, T. Abe and S. Okawa (Nagoya)

Introduction

WIMP dark matter scenario is very interesting,

because DM can be related to TeV-scale new physics, which could be discovered near future.

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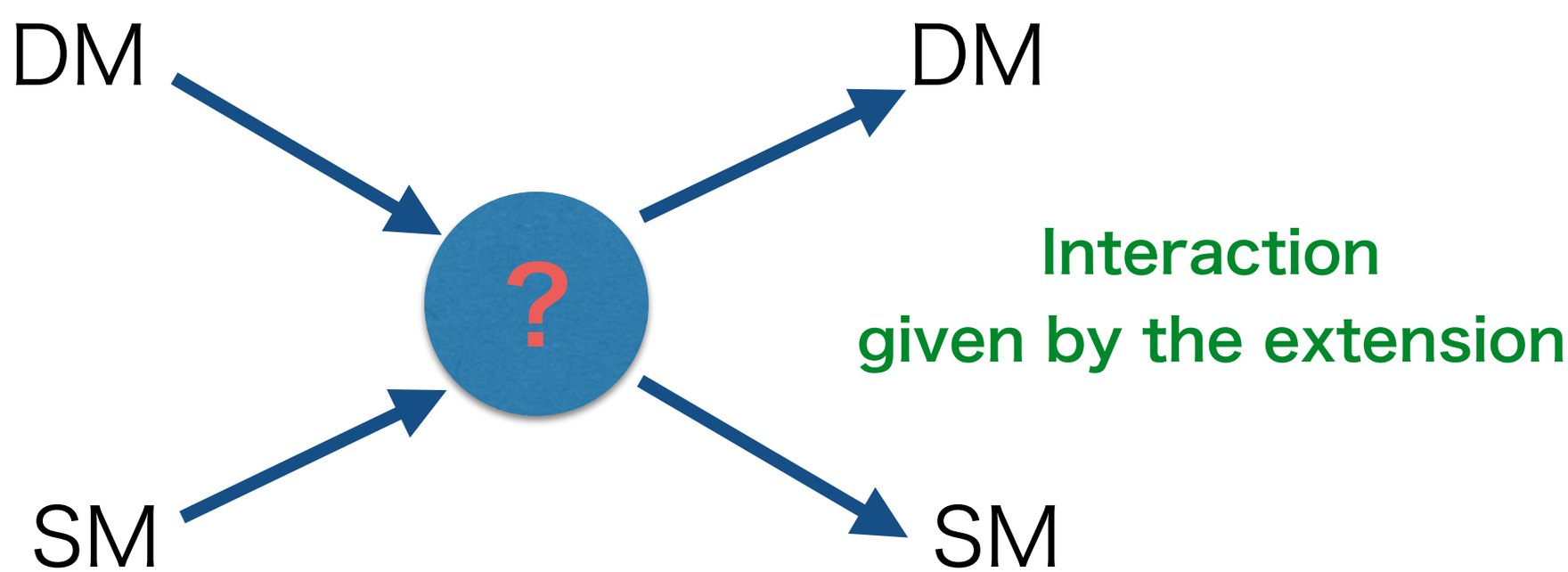
There are many possibilities of setups and many motivations



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There are many possibilities for the BSMs, but BSM may be very SM-like at TeV scale.

"Let's consider possible and simple setups with DM, that do not break the SM predictions so much."

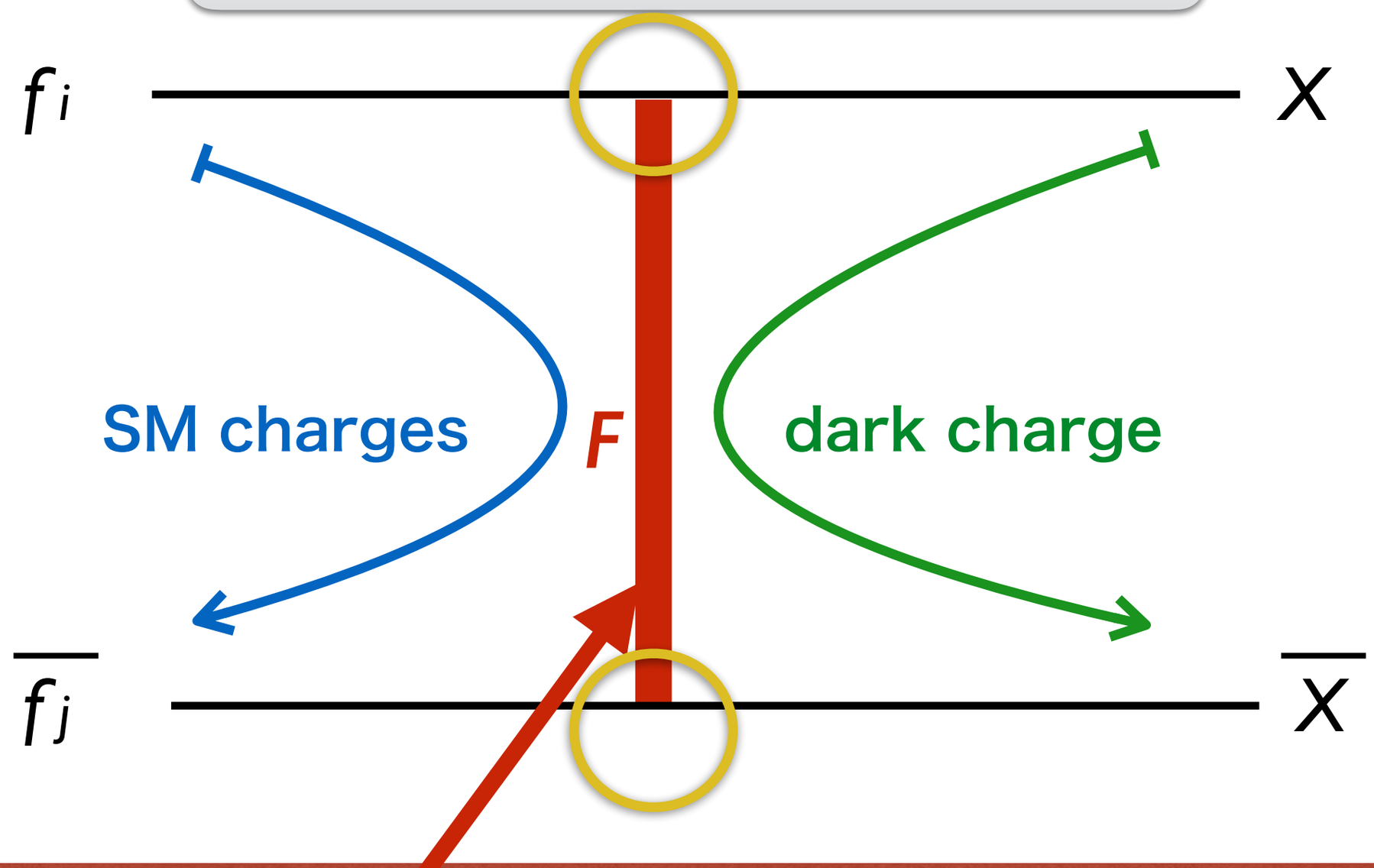
In particular, we discuss "*Fermion portal DM*".

(with J.Kawamura, T. Abe and S. Okawa)

Interaction between SM particle (f_i) and DM (X) in Fermion Portal Dark Matter Model

(Bai, Berger. 1308.0612;Wise, Perez 1303.1452;etc.)

$$\lambda_j \overline{F} X^\dagger f_j$$ flavor-dependent

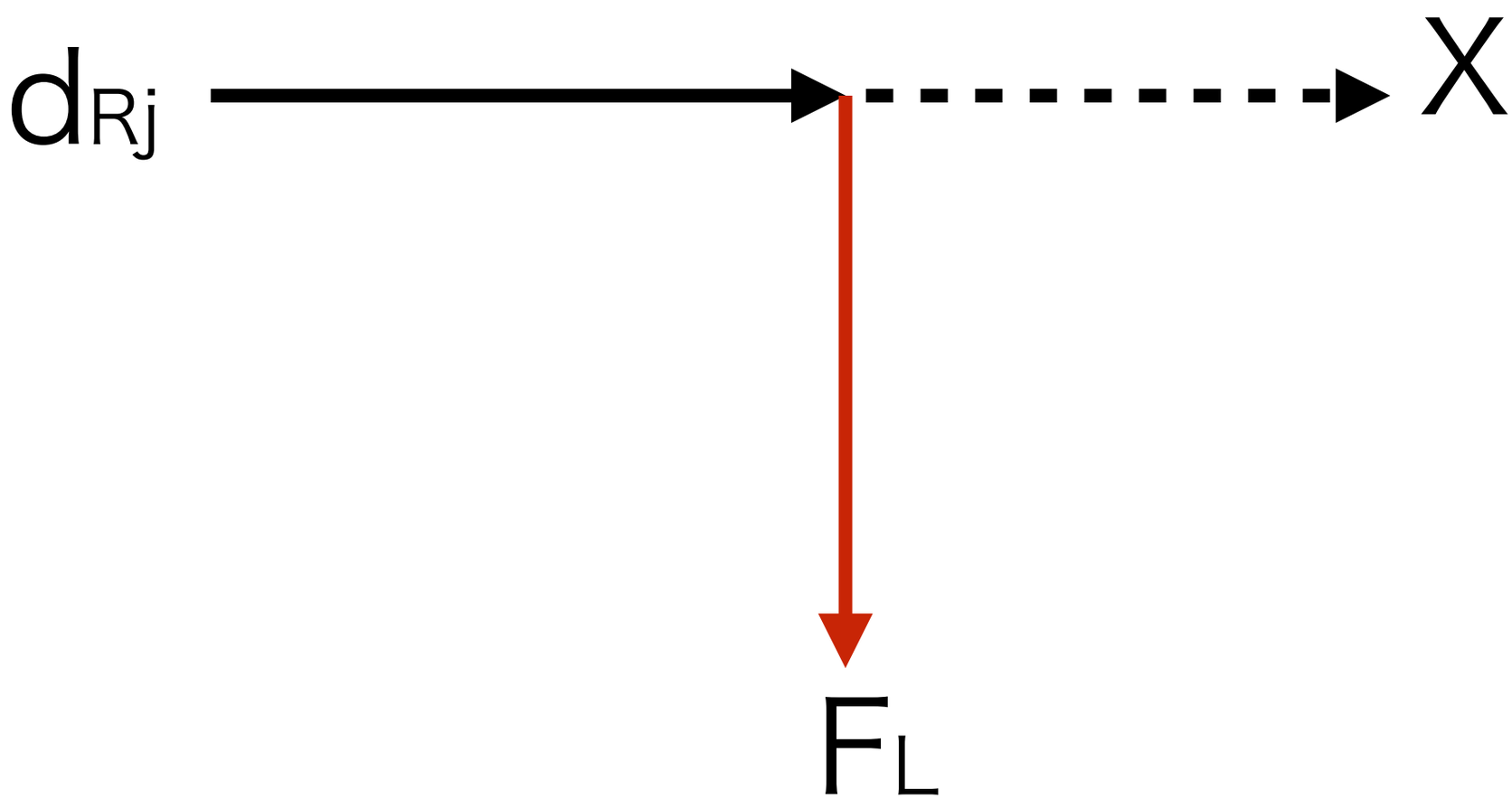


Extra particle with SM charges and dark charge

Interesting and good points of this model

$$\lambda_b \overline{F_L} X^\dagger b_R + \lambda_s \overline{F_L} X^\dagger s_R + \lambda_d \overline{F_L} X^\dagger d_R + h.c.$$

1. simple!



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2. No tree-level FCNCs

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4. There are candidates for the underlying theory:

flavor symmetric model (E. Ma, 1311.3213; Okawa, YO, work in progress)

GUT (P.Ko, C.Yu, YO, 1601.00586)

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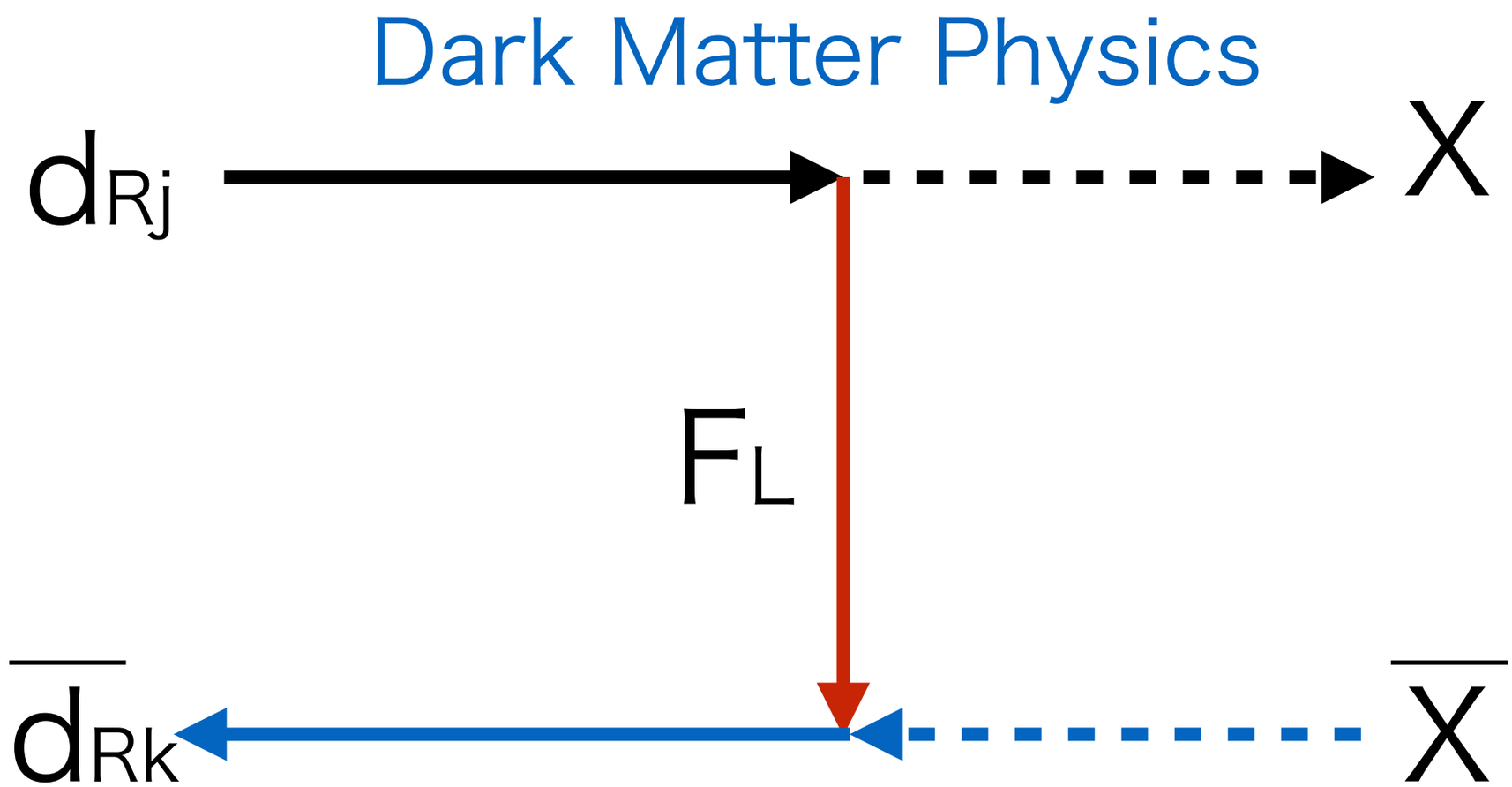
$$\lambda_b \overline{F_L} X^\dagger b_R + \lambda_s \overline{F_L} X^\dagger s_R + \lambda_d \overline{F_L} X^\dagger d_R + h.c.$$

5. many observables relate each other!



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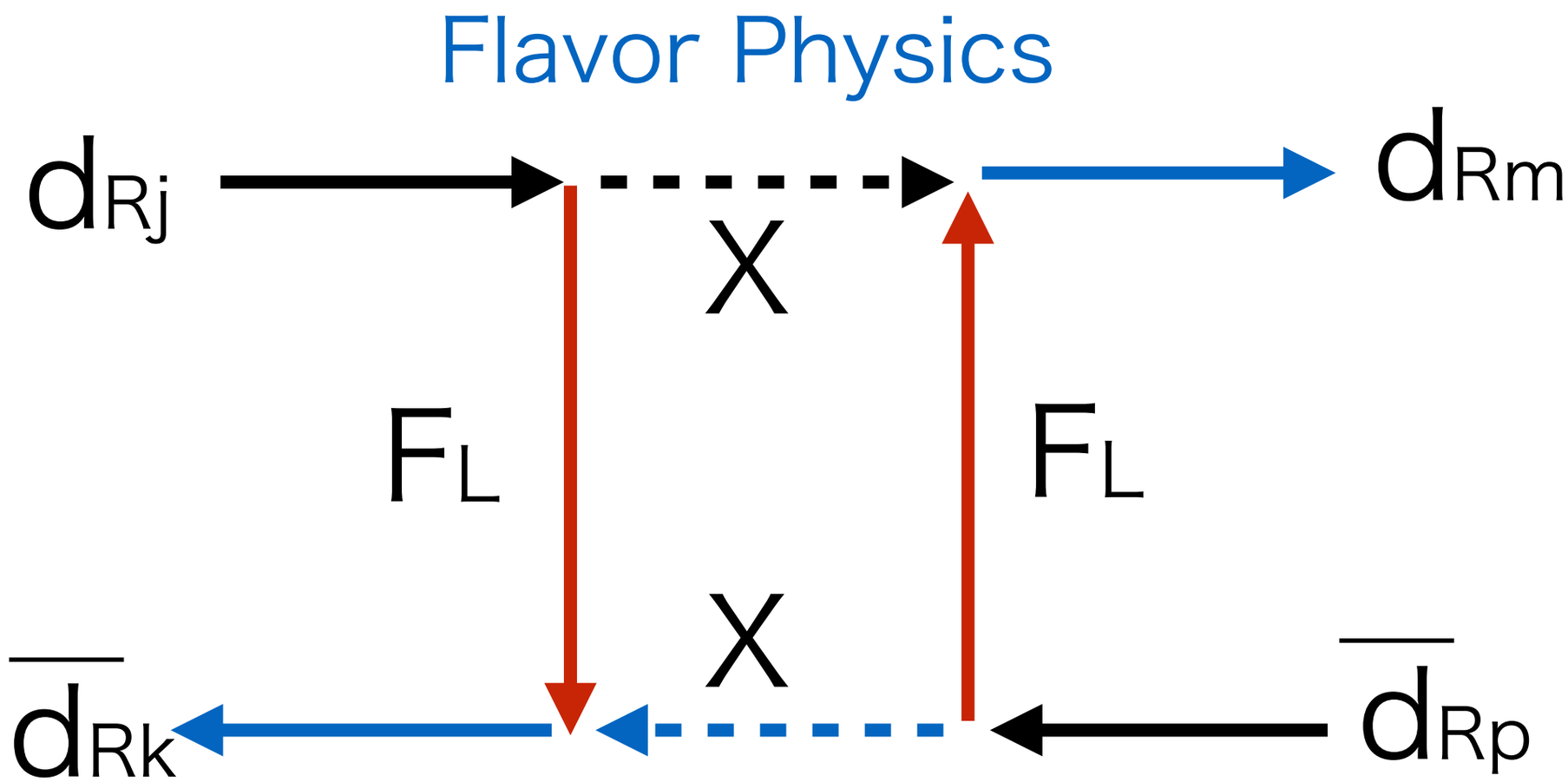

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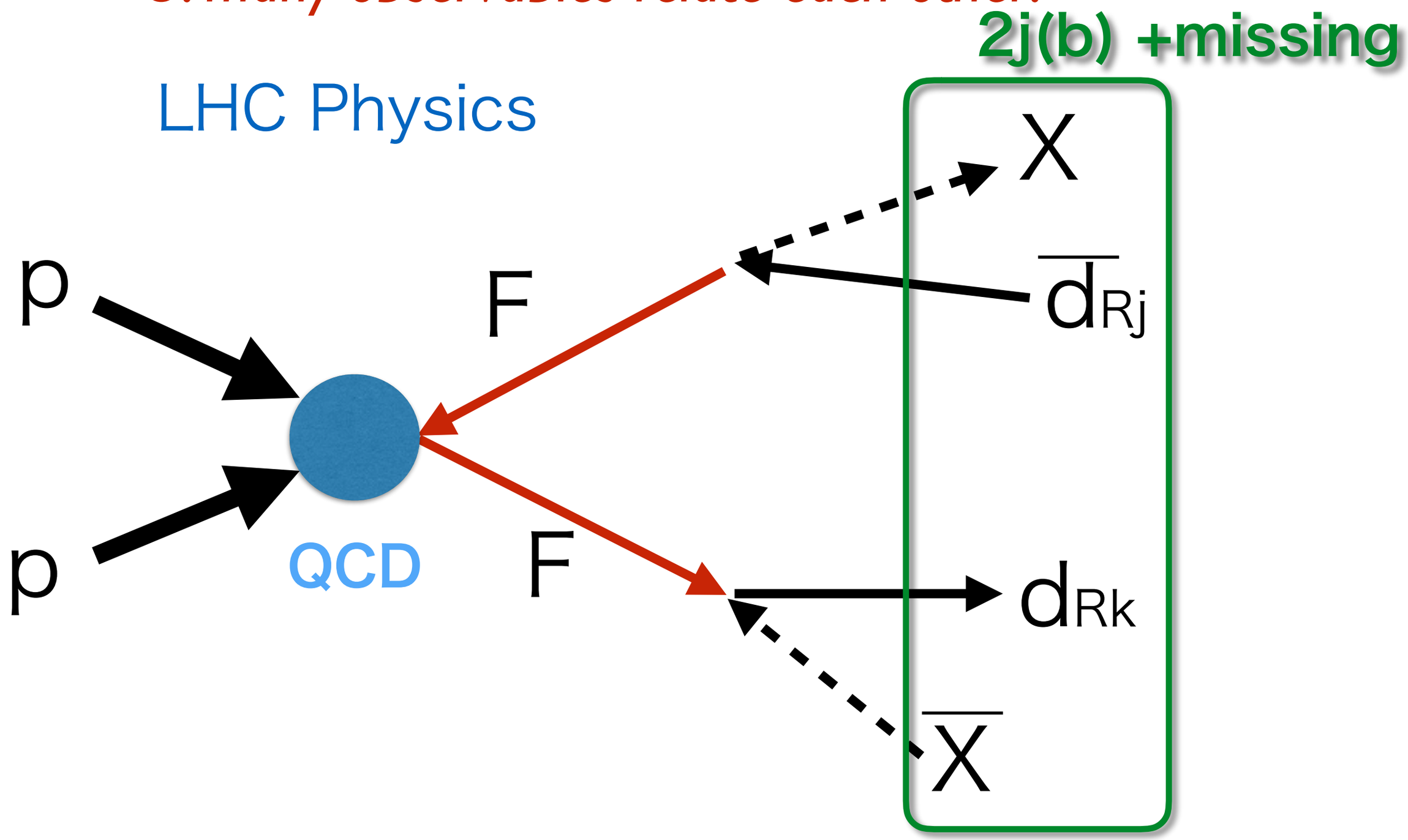
LHC Physics

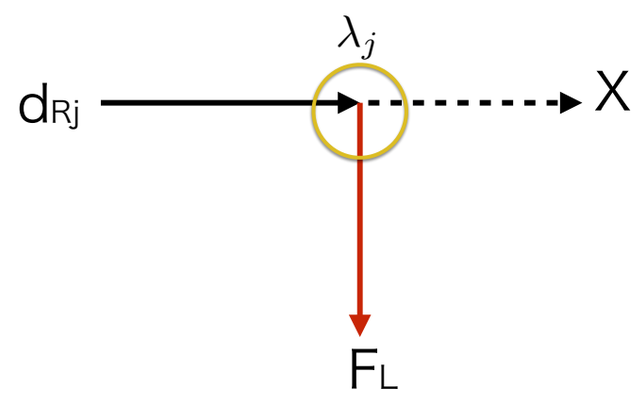


We can find correlations!

Dark Matter Physics

LHC Physics

$$\lambda_b \overline{F_L} X^\dagger b_R + \lambda_s \overline{F_L} X^\dagger s_R + \lambda_d \overline{F_L} X^\dagger d_R + h.c.$$

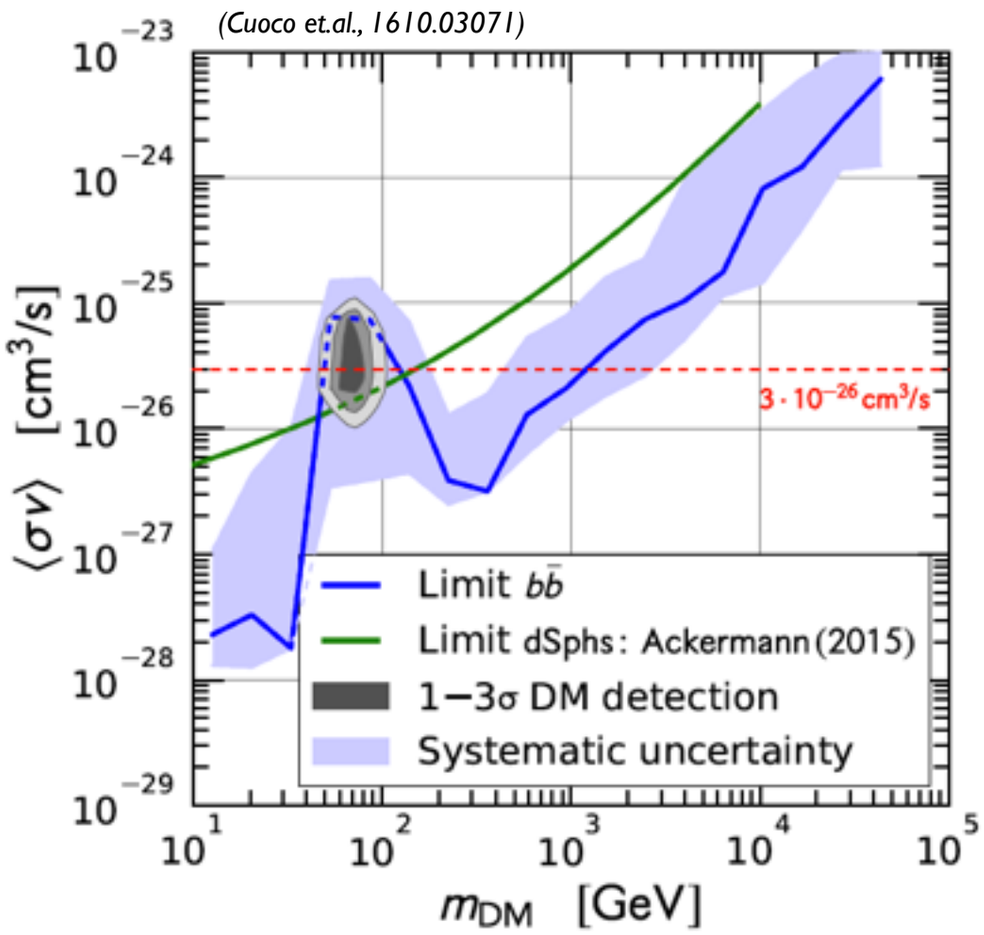


Flavor Physics

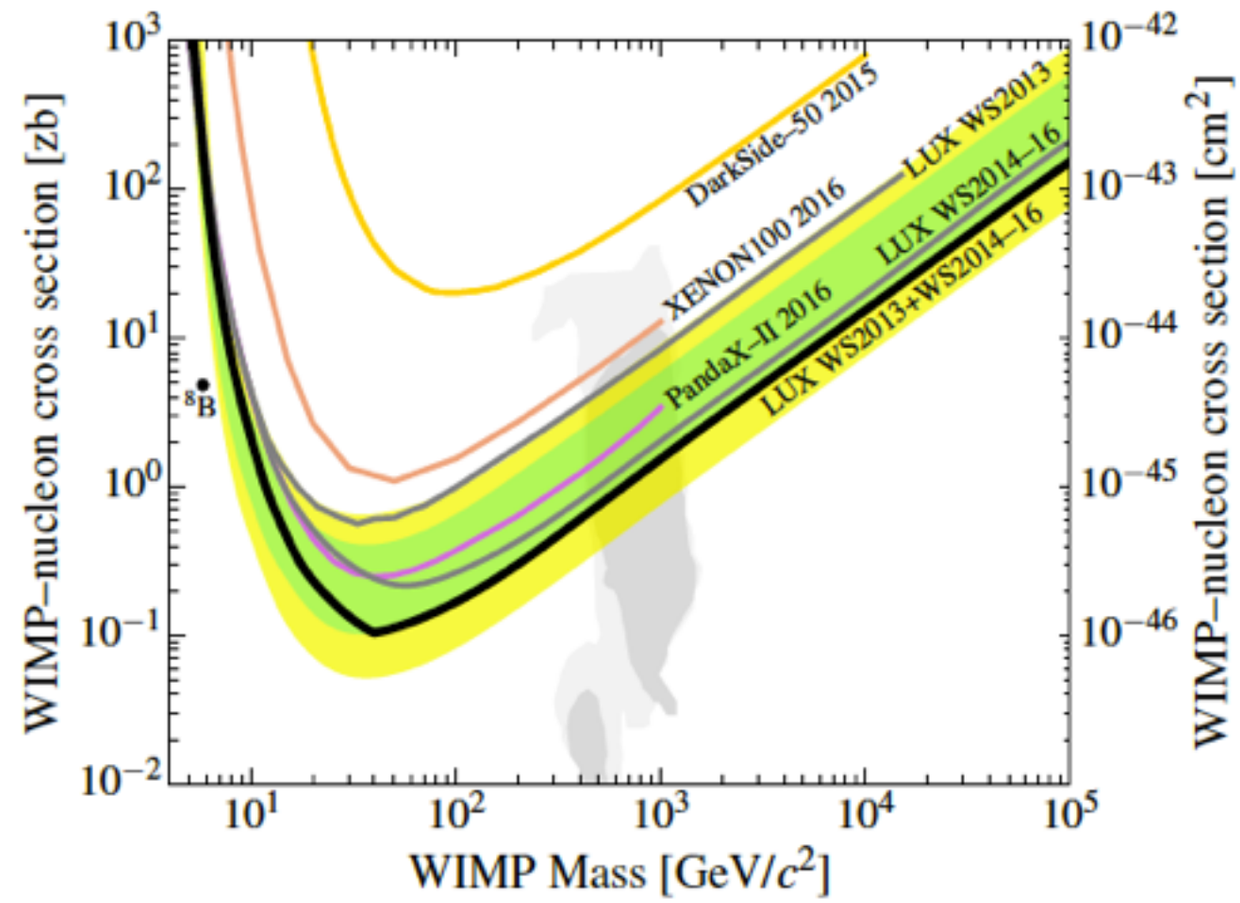
Theory

Recently, DM constraints getting very strong!

Indirect detection



direct detection



(Refs. Cui, etl.al.1610.03840; Cuoco et.al., 1610.03071)

We consider complex scalar DM and fermionic F, which mainly couples to bottom quark.

(1612.01643 with J.Kawamura, T.Abe, S. Okawa, YO)

SETUP

a simple DM model with a down-type partner

Extra down-type quark and DM

Fields	spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
F_L	$1/2$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	1
F_R	$1/2$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$	1
X	0	$\mathbf{1}$	$\mathbf{1}$	0	-1

Yukawa couplings

$$y^u_{ij}\overline{Q_L}\widetilde{H}u^j_R + y^d_{ij}\overline{Q_L}Hd^j_R + h.c.$$

$$+m_F\overline{F_L}F_R + \lambda_i\overline{F_L}X^\dagger d^i_R + h.c.$$

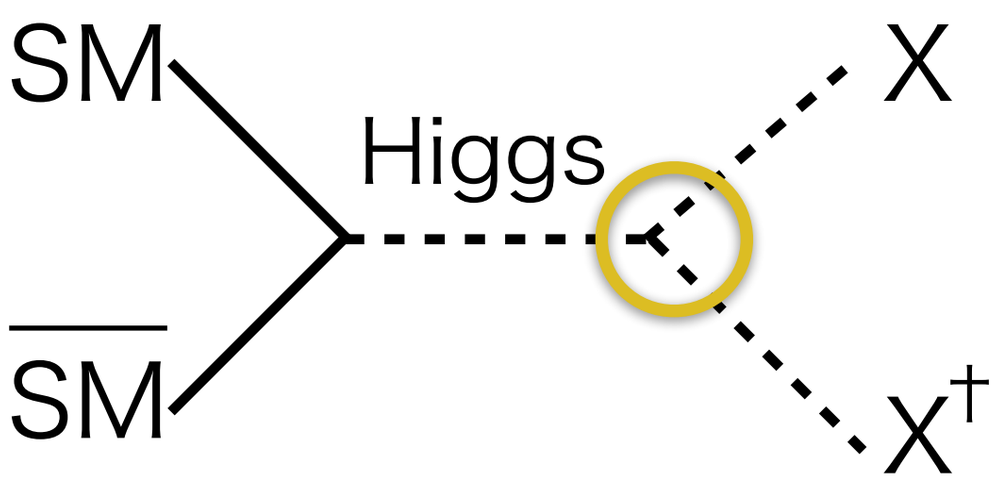
scalar potential

$$V_{\rm scalar} = m_X^2|X|^2 + \lambda_H|X|^2|H|^2 + \lambda_X|X|^4 - m_H^2|H|^2 + \lambda|H|^4$$

DM(X) interactions with SM particles through

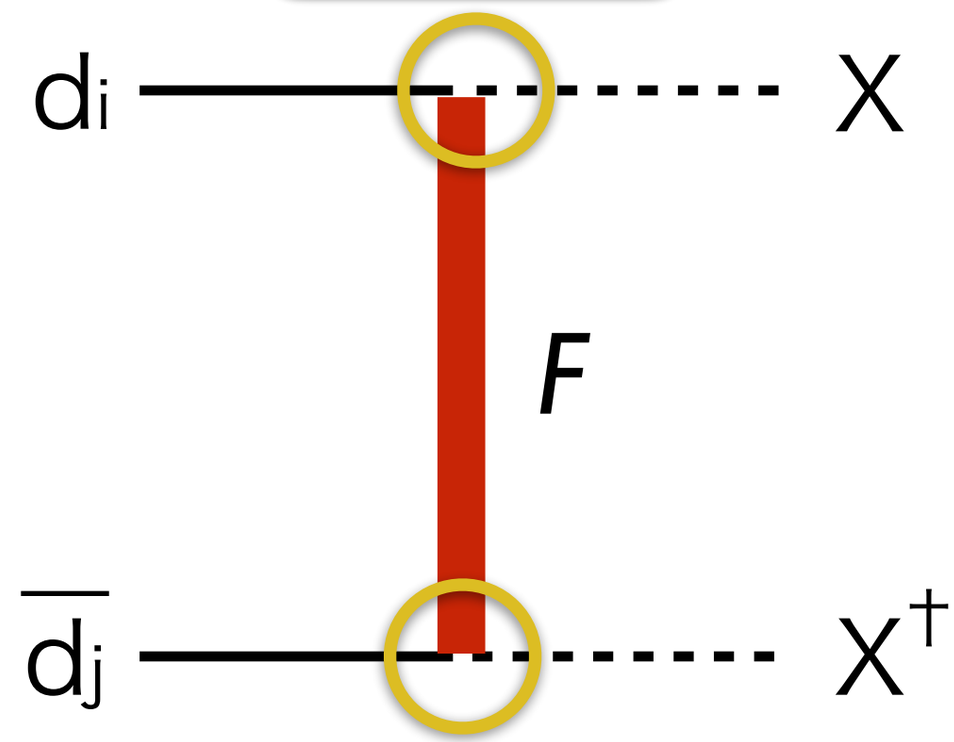
Higgs exchanging

$$\lambda_H |X|^2 |H|^2$$



extra quark exchanging

$$\lambda_i \overline{F_L} X^\dagger d_R^i$$
$$(i = d,\ s,\ b)$$



Phenomenology

8 parameters are fixed by observables.

F mass:	m_F
DM mass:	m_X
$\lambda_i \overline{F_L} X^\dagger d_R^i$ $(i = d,\, s,\, b)$	λ_b
	$Re(\lambda_s)$
	$Im(\lambda_s)$
	$Re(\lambda_d)$
	$Im(\lambda_d)$
$\lambda_H \lvert X\rvert^2 \lvert H\rvert^2$	λ_H

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F mass: m_F

DM mass: m_X

relevant to direct search@LHC

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λ_b

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relevant to direct search@LHC

DM physics fix λ_b and λ_X

See difference with Higgs portal DM

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relevant to direct search@LHC

DM physics fix λ_b and λ_X

$Re(\lambda_s)$

$Im(\lambda_s)$

$Re(\lambda_d)$

$Im(\lambda_d)$

Even if λs and λd are small,
flavor physics is sensitive to new physics!

$\lambda_H |X|^2 |H|^2$ λ_H

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$\lambda_i \overline{F_L} X^\dagger d_R^i$
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λ_b

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$Re(\lambda_s)$

$Im(\lambda_s)$

Bs-Bs mixing

K-K mixing

$Re(\lambda_d)$

$Im(\lambda_d)$

Bd-Bd mixing

$\lambda_H |X|^2 |H|^2$

λ_H

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Bd-Bd mixing

We will find predictions!

$\lambda_H |X|^2 |H|^2$

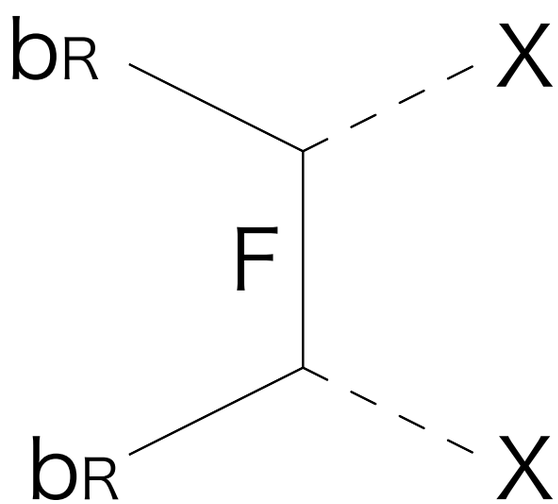
λ_H

See difference with Higgs portal DM

Dark Matter Physics

Relic density (DM annihilation)

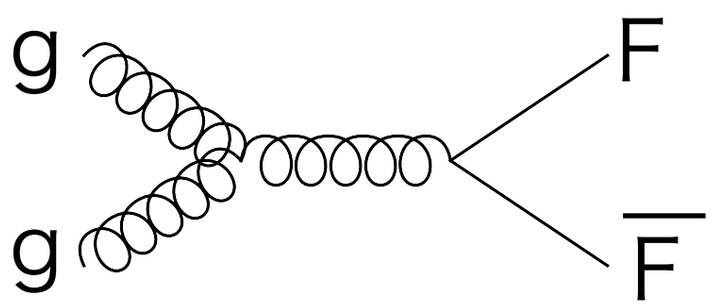
s-wave in t-channel (XX→bb) is suppressed by b-quark mass

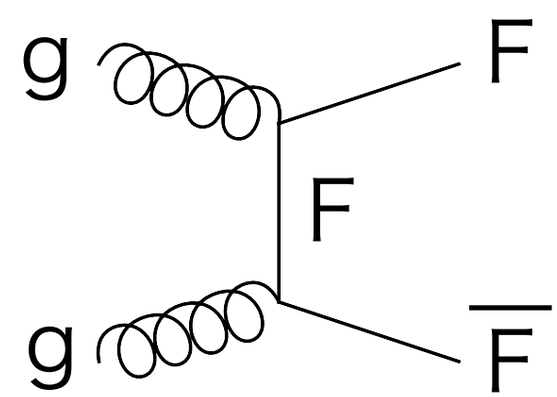


$$\langle \sigma v \rangle \approx \lambda_b^4 \left(a_0 \frac{m_b^2}{m_F^2} + b v^2 \right)$$

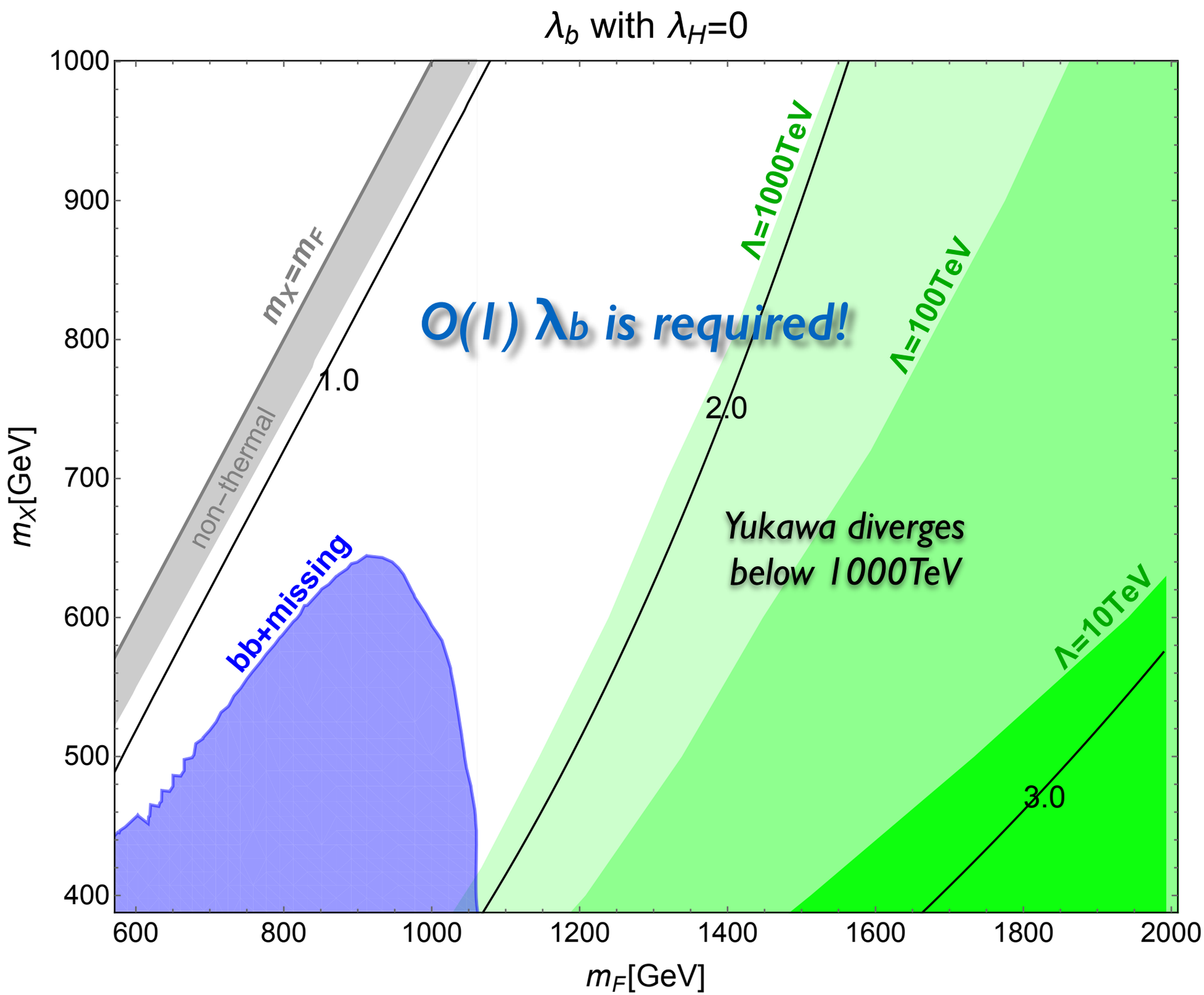
Large Yukawa required

coannihilation is also important in compressed regions: $m_F \approx m_X$



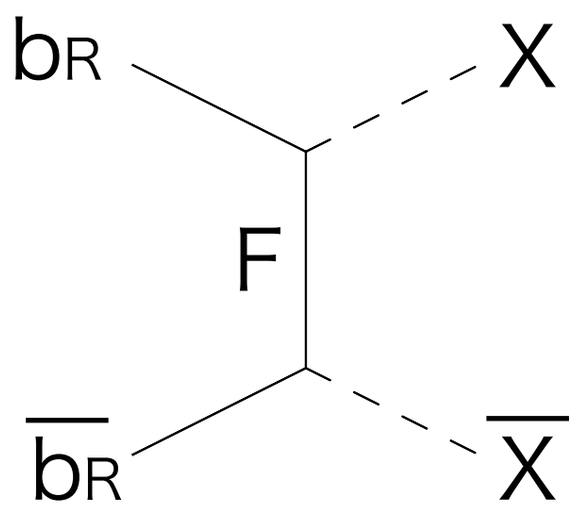


λ_b for the relic density wo "Higgs portal "

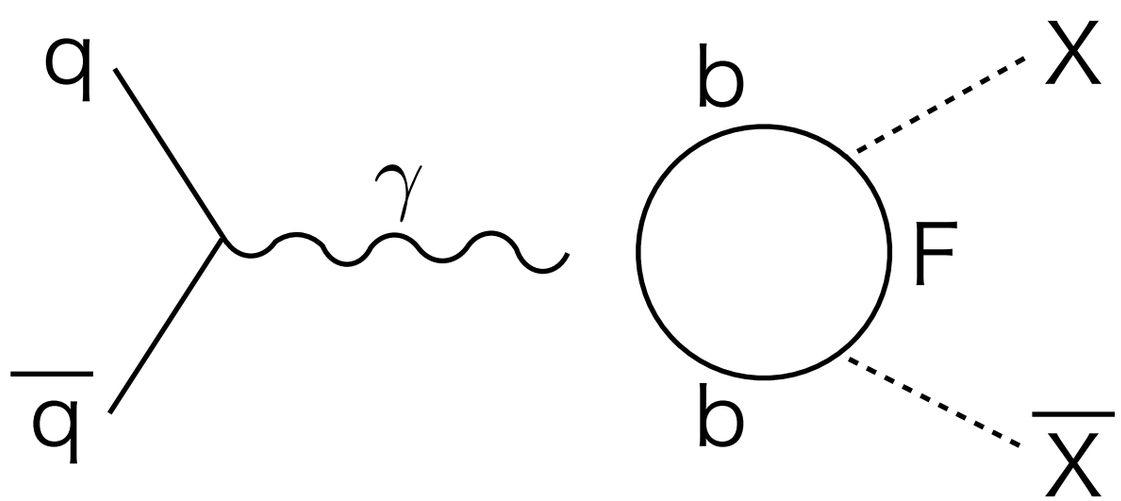


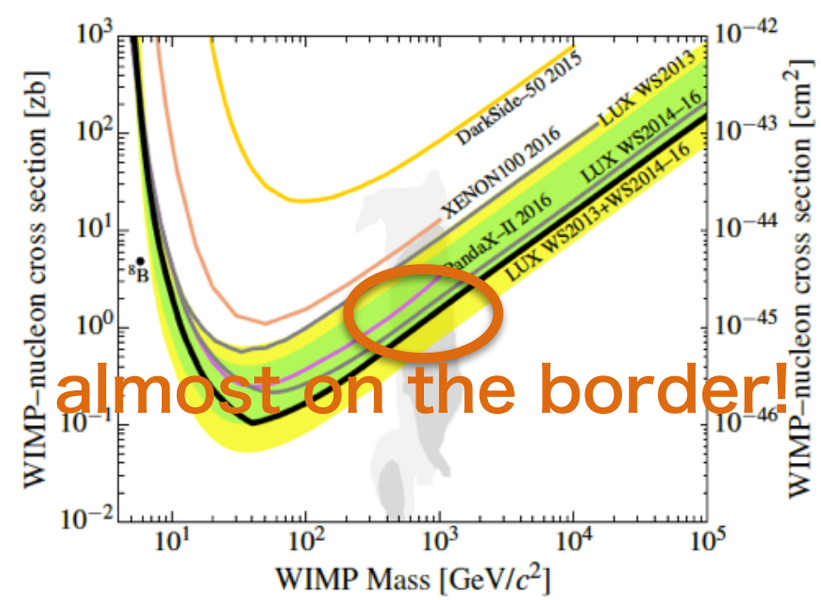
Direct Detection of X

DM interacts with b quarks at the tree-level.



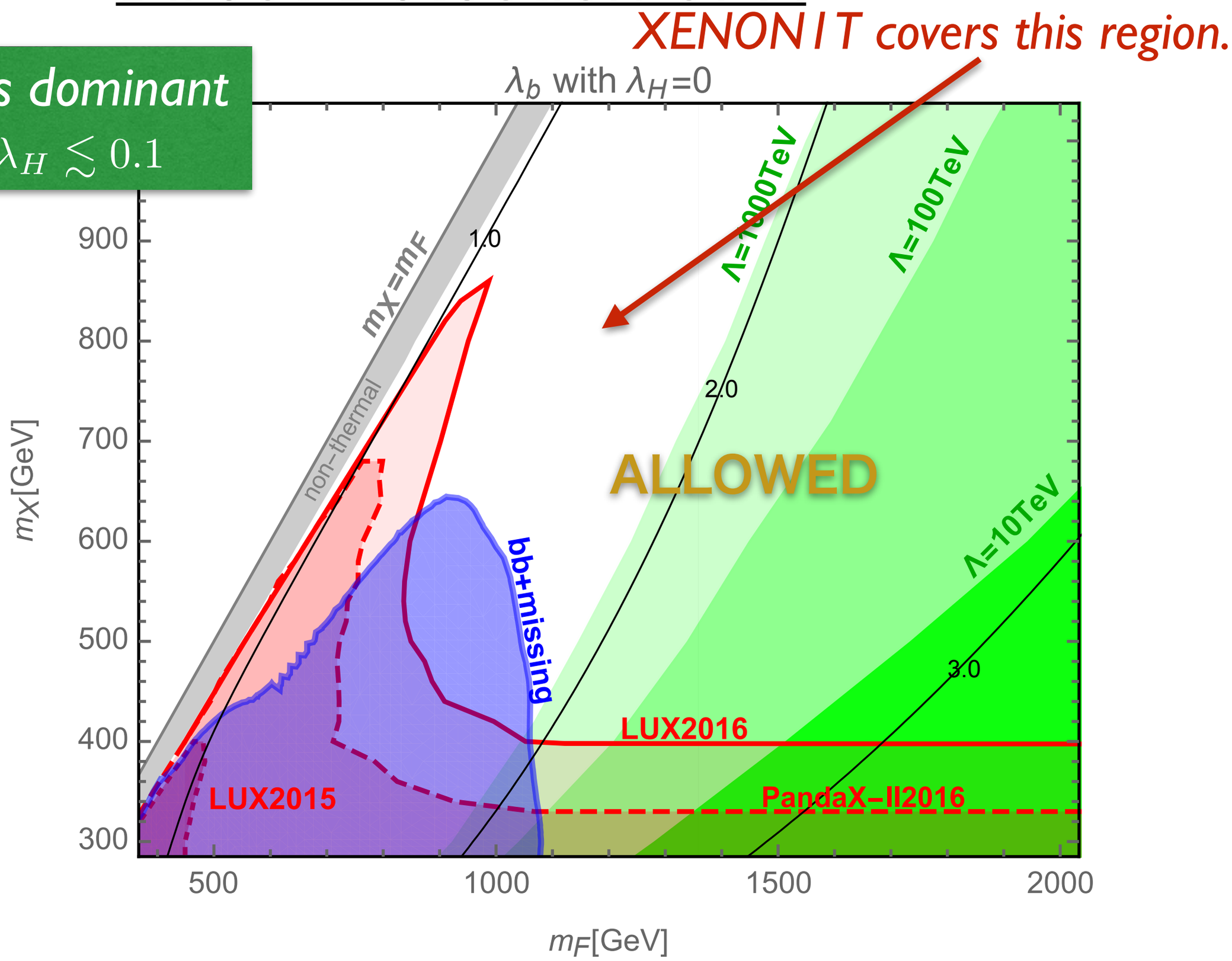
But large λ_b predicts enough large cross section even at the one-loop level.





Direct Detection of X

t-channel is dominant as far as $\lambda_H \lesssim 0.1$

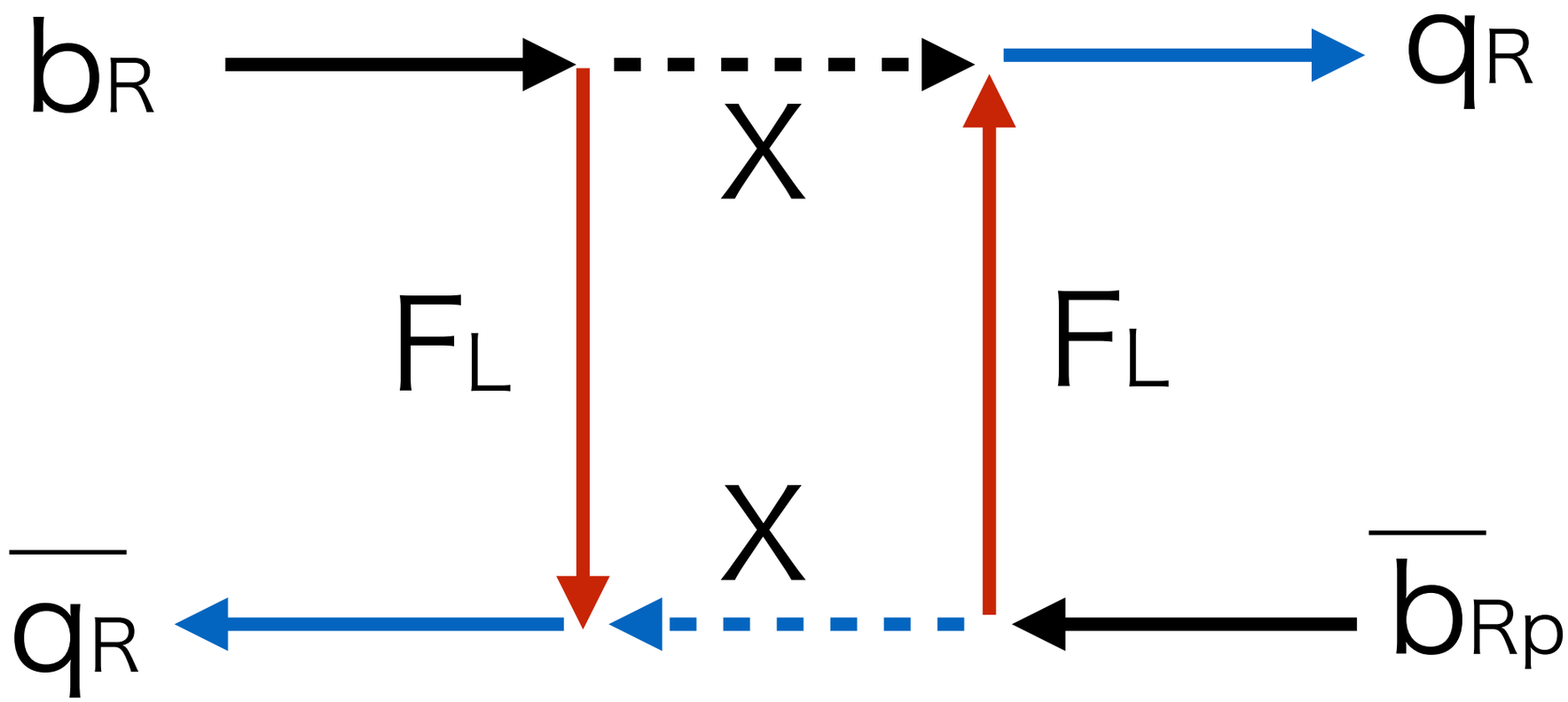


Flavor Physics

The most important processes are ΔF=2 processes

$B_d - \overline{B_d}$ mixing

$B_s - \overline{B_s}$ mixing



Observables in the ΔF=2 processes

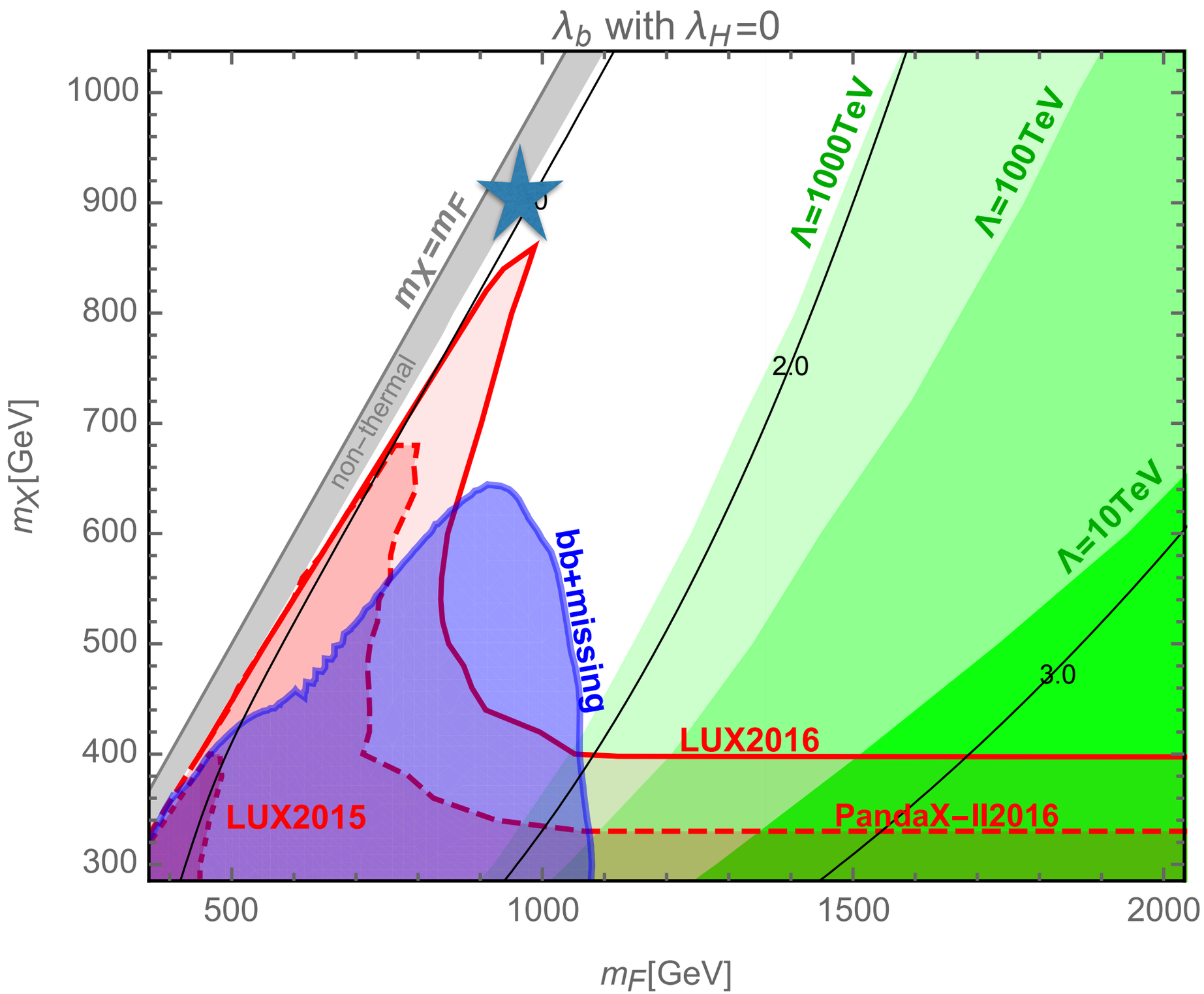
$B_d - \overline{B_d}$ mixing	$B_s - \overline{B_s}$ mixing	$K_0 - \overline{K_0}$ mixing
ΔM_d $\quad S_{\psi K}$	ΔM_s $\quad S_{\psi\phi}$	ΔM_K $\quad \epsilon_K$

If DM and F are observed, there are only 4 parameters in our scenario.

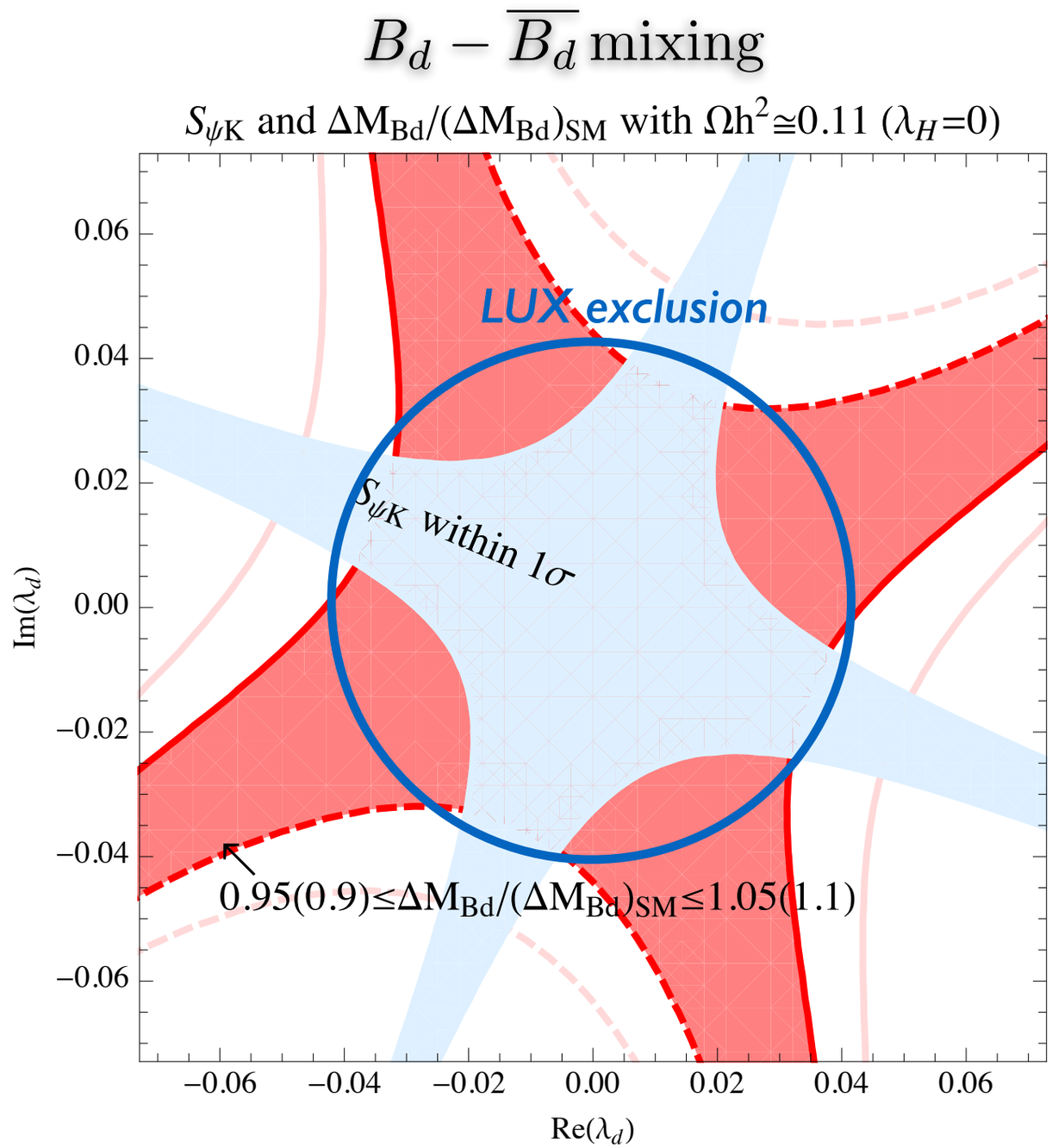
$Re(\lambda_d)$ $Im(\lambda_d)$ $\quad$ $Re(\lambda_s)$ $Im(\lambda_s)$

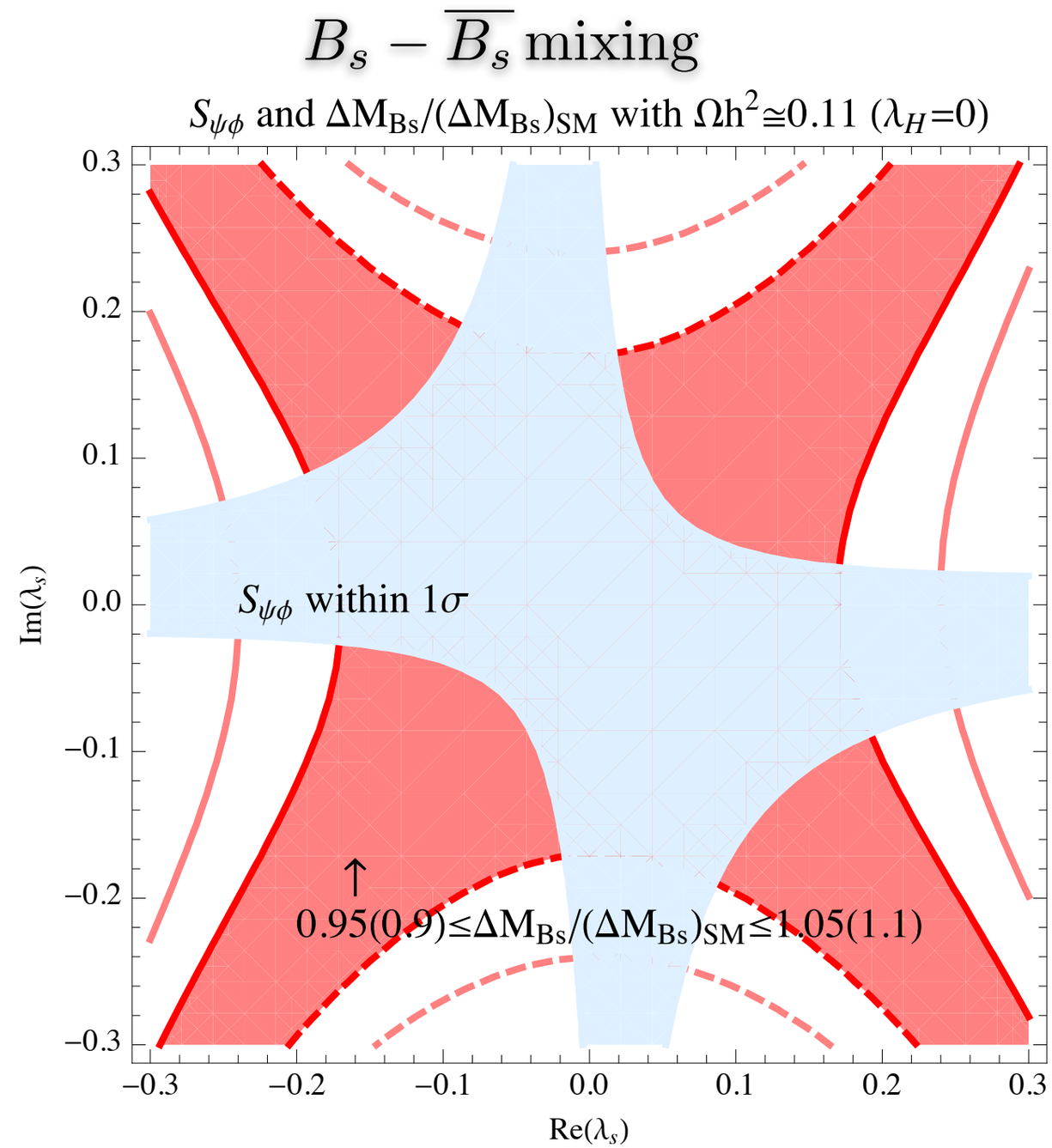
I expect that this model can be tested by flavor physics.

Let's see a sample point!



ΔF=2 processes in the compressed region: $(m_X,\, m_F,\, \lambda_b) = (900\mathrm{GeV},\, 964\mathrm{GeV},\, 0.66)$





~10 % error still exist. *(CKMfitter,1309.2293,1501.05013)*

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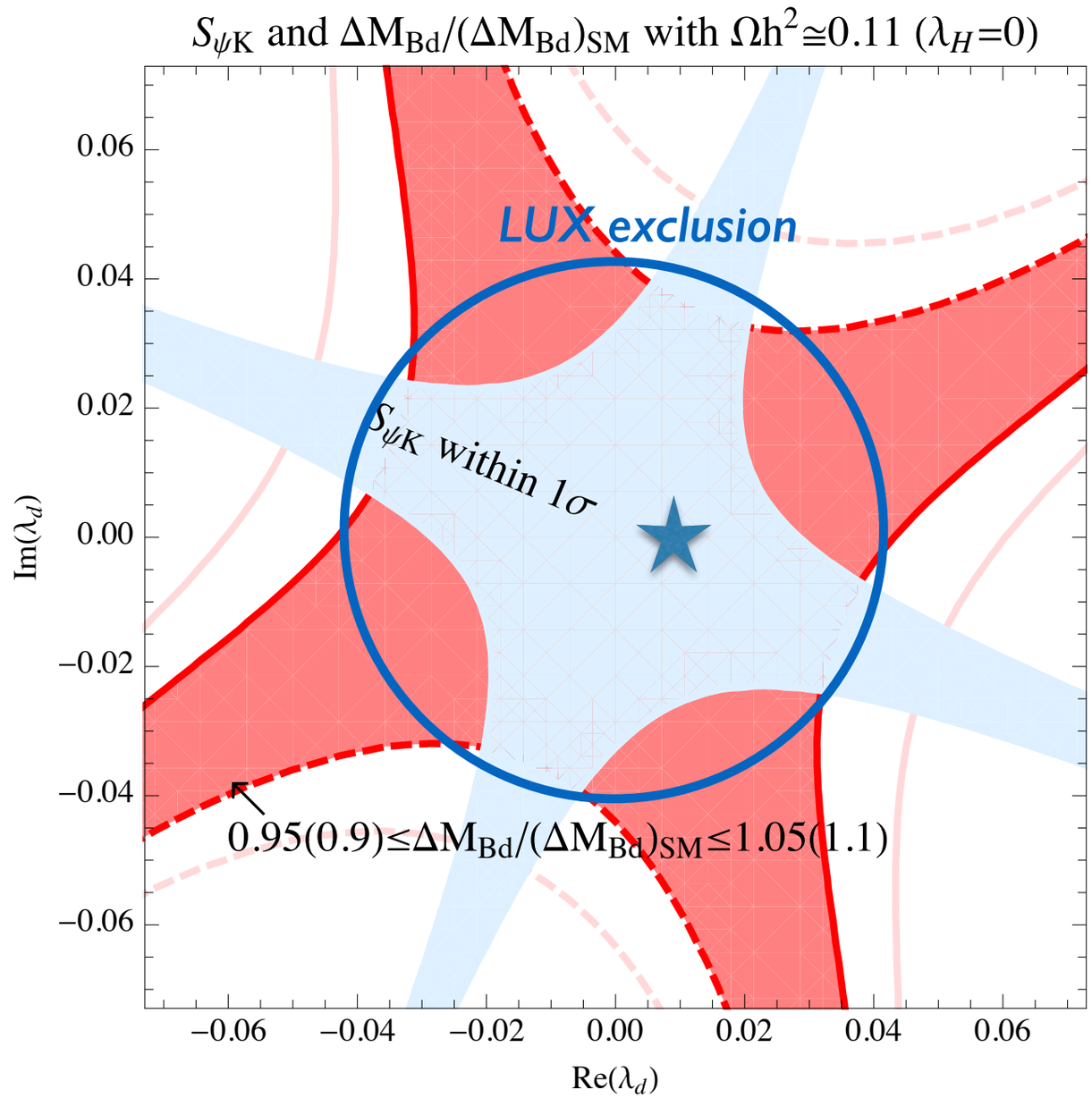

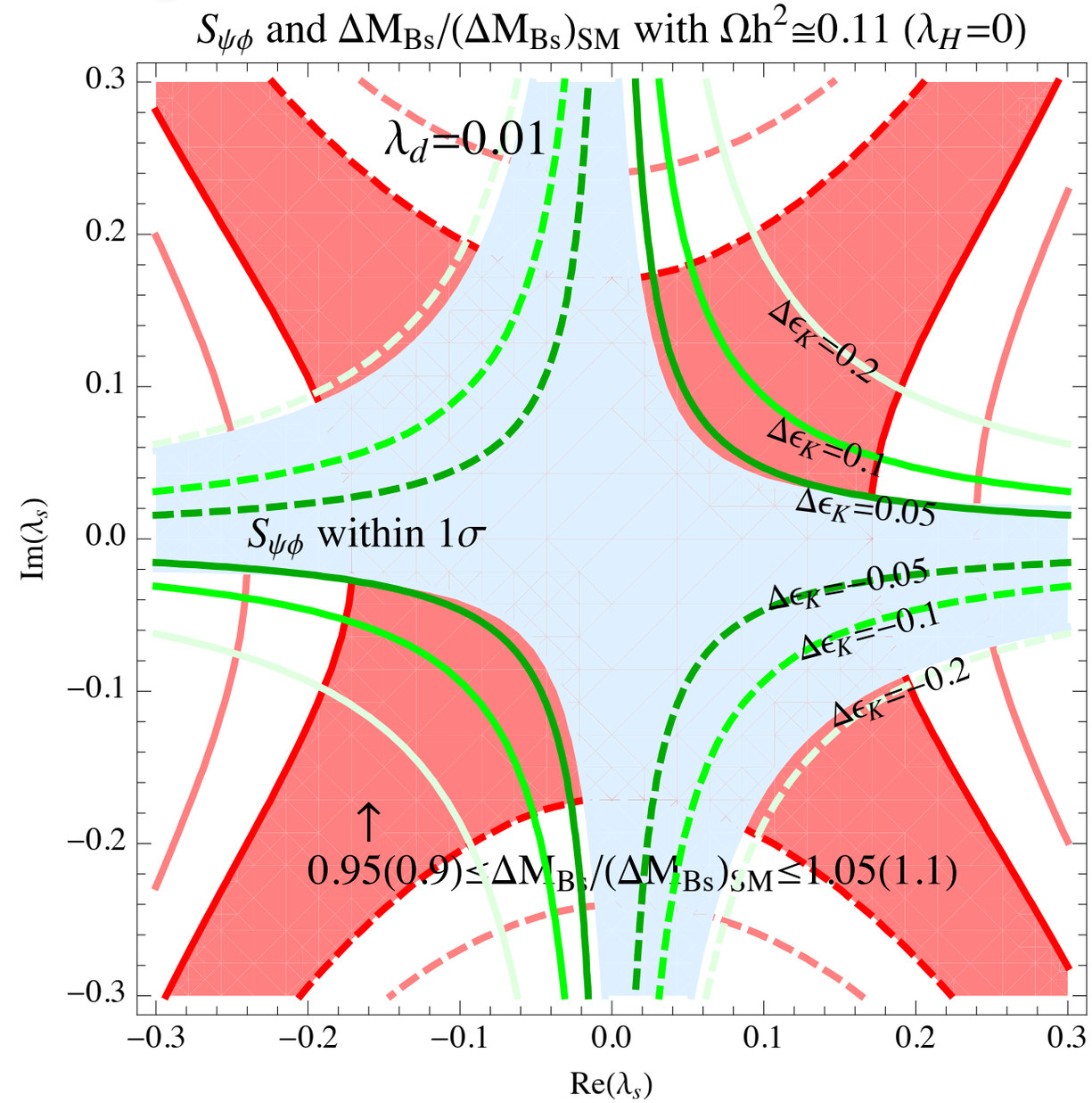

~10 % error still exist. *(CKMfitter,1309.2293,1501.05013)*

We find predictions for the deviations of meson mixings.

Summary

- Experimental results are very consistent with SM.

  ➡ There are many candidates for BSMs motivated by DM, mysteries of SM, but we need consider SM-like BSM around 1TeV.

- I'm discussing simple DM models with extra vector-like.

$$\lambda_i^f \overline{F_L^f} X^\dagger f_{R\,i} + \lambda_i^{f'} \overline{F_R^{f'}} X^\dagger f'_{L\,i} \, (f = e,\, d,\, u;\; f' = Q,\, L)$$

These can avoid constraints from EWPOs, tree-level FCNCs and direct detection of DM.

・In particular, we focus on scalar DM model with “bottom partner.”

・This setup can evade the strong bound from the indirect detection, but will be severely constrained by the new results of the direct detections.

We are looking forward to XENON1T results!

・The constraints and predictions for the $\Delta F=2$ processes are shown. →We can find correlations and prove our model.

END

Backup

List of DM (X) models with partners (F)

	Dark Matter (X)	DM mainly couples	Structure of Yukawa	Other Refs.
"Fermion Portal DM" (Bai, Berger. 1308.0612)	Fermion, complex scalar	up quark	$\lambda_u \overline{F_L^u} X^\dagger u_R$	"Effective WIMPS" (Chang,et.al. 1307.8120) Ko,Baek,Wu, 1606.00072; Toma,1307.6181; Giacchino,1307.6480; etc.
"Vector-like Portal" (Wise, Perez 1303.1452)	Complex scalar	quarks, leptons	$\lambda_u \overline{F_L^f} X^\dagger f_R$ $(f = u,\, d,\, e)$	
"Flavored DM" (Bhattacharya,London,et.al, 1509.04271)	Flavor-charged scalar	all quarks	$\lambda_f^{ij} \overline{F_L^f} X_i^\dagger f_{R\,j}$ $(i,\, j = \text{flavor index})$	Kile, Soni,1104.5239; Batell, et.al,1105.1781; Kamenic, et.al,1107.0623; Argrawal,et.al,1109.3516; etc.
Ibarra, Wild et.al,1511.04452	Real scalar	light quarks	$\lambda_q \overline{F^q} X_r q_R$	
This talk	Complex Scalar	bottom quark	$\lambda_i \overline{F_L^d} X^\dagger d_R^i$ $(\lambda_b \gg \lvert\lambda_s\rvert,\, \lvert\lambda_d\rvert)$	

Result including "Higgs Portal"