

# **Anomaly-cancellation on a leptophobic Z'-mediator with axially coupled DM**

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# Motivation

# Introduction

Simplest WIMP models: DM particle coupled to H, Z  
Under pressure by experiments, especially DD

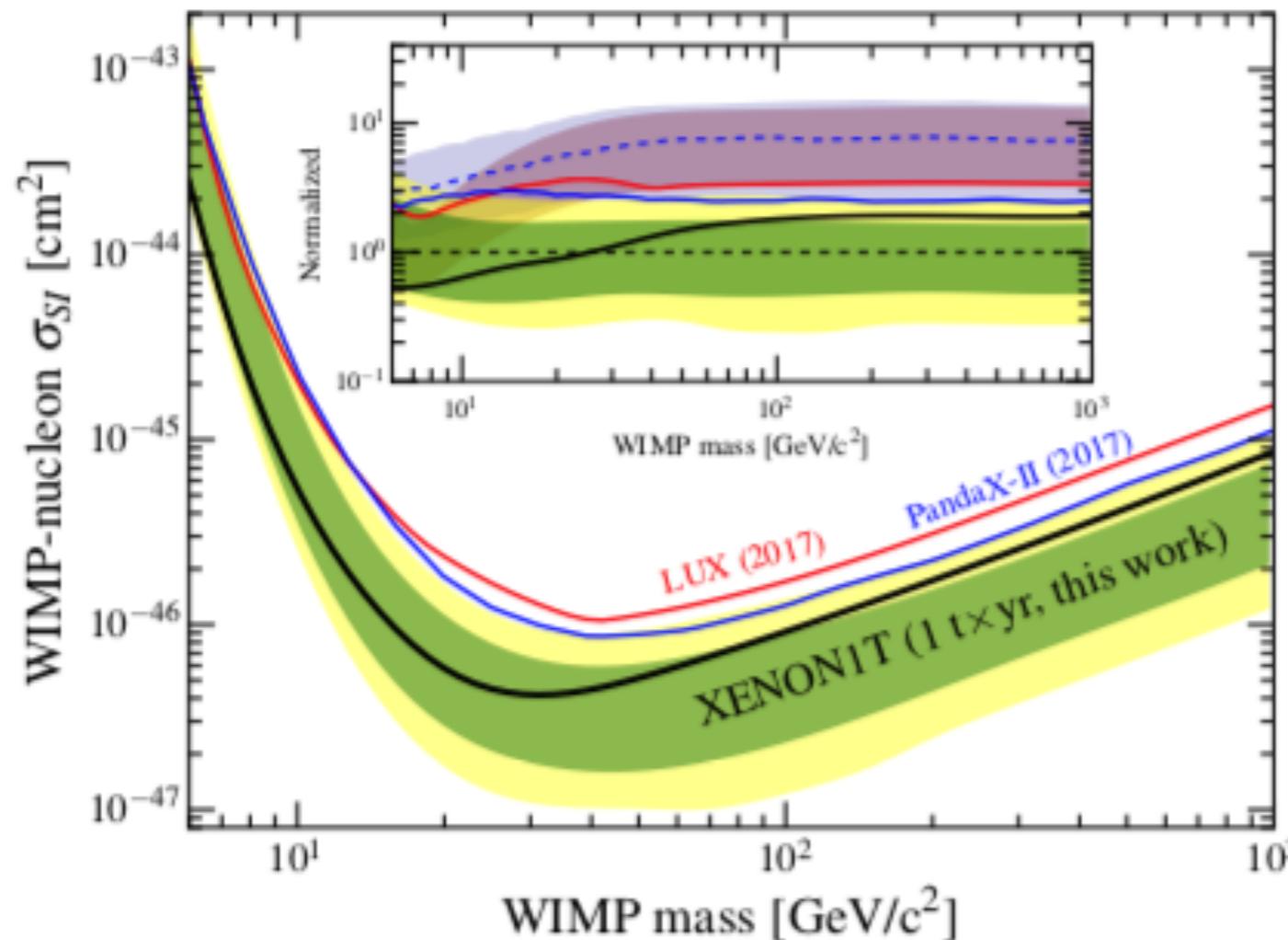
Over-simplified idea: larger DM sector and new mediators

Extra symmetries (in this work  $U(1)'$ ) produce new vector boson mediators but these models are also very constraint in the case of simplified dark matter sector

Two of the strongest constraints come from DD experiments and di-lepton searches

# DM coupling: Axial coupling

Strong direct detection constraints on SI cross-section



XENON Collaboration  
arXiv:1805.12562

Solution: Axial coupling

$$Y'_{\chi_L} = -Y'_{\chi_R}$$

# SM couplings: Leptophobia

Strong constraints by di-lepton searches

Solution: leptophobia       $Y'_{L_i} = Y'_{e_i} = 0$

From the lepton yukawas     $y_i^e \bar{L}_i H e_i$ :       $Y'_H = 0$

From the quark yukawas     $y_i^u \bar{Q}_i \bar{H} u_i$        $y_i^d \bar{Q}_i H d_i$ :  
 $Y'_{Q_i} = Y'_{u_i} = Y'_{d_i}$

Same  $Y'$  for the three generations:     $U(1)' \equiv U(1)_B$

$$Y'_{Q_i} = Y'_{u_i} = Y'_{d_i} = 1/3$$

## Anomalies

Usually SDMM are no self-consistent

The addition of an extra symmetry can contain anomalies that don't cancel with just one fermion in the dark sector

In many models these anomalies are supposed to cancel by extra particles at higher energy

In this work we attempt to build a UV-complete model, anomaly free, leptophobic and with an axial DM coupling and study the phenomenology

# Anomaly cancellation

# Anomaly cancellation

New symmetry group  $SU(3)_C \times SU(2)_W \times U(1)_Y \times U(1)'$

## Anomaly equations

$$SU(3)_C^2 \times U(1)' \text{ anomaly} \longrightarrow \text{Tr}[\{\mathcal{T}_i, \mathcal{T}_j\} Y'] = 0$$

$$SU(3)_C^2 \times U(1)_Y \text{ anomaly} \longrightarrow \text{Tr}[\{T_i, T_j\} Y] = 0$$

$$SU(2)_W^2 \times U(1)' \text{ anomaly} \longrightarrow \text{Tr}[\{T_i, T_j\} Y'] = 0$$

$$SU(2)_W^2 \times U(1)_Y \text{ anomaly} \longrightarrow \text{Tr}[\{T_i, T_j\} Y] = 0$$

$$U(1)_Y^2 \times U(1)' \text{ anomaly} \longrightarrow \text{Tr}[Y^2 Y'] = 0$$

$$U(1)_Y \times U(1)'^2 \text{ anomaly} \longrightarrow \text{Tr}[YY'^2] = 0$$

$$U(1)'^3 \text{ anomaly} \longrightarrow \text{Tr}[Y'^3] = 0$$

Similar analysis by Ellis et al.  
arXiv:1704.03850

$$U(1)_Y^3 \text{ anomaly} \longrightarrow \text{Tr}[Y^3] = 0$$

$$\text{Gauge gravity} \longrightarrow \text{Tr}[Y] = \text{Tr}[Y'] = 0$$

# Anomaly equations for a leptophobic U(1)'

Anomaly equations

$$SU(2)_W^2 \times U(1)' \text{ anomaly } 9Y'_q + \sum_{f \in SU(2)_W} (Y'_{f,L} - Y'_{f,R}) = 0 \quad Y'_{L_i} = Y'_{e_i} = 0$$

$$U(1)_Y^2 \times U(1)' \text{ anomaly } \rightarrow -\frac{9}{2}Y'_q + \sum_f (Y_{f,L}^2 Y'_{f,L} - Y_{f,R}^2 Y'_{f,R}) = 0 \quad Y'_{Q_i} = Y'_{u_i} = Y'_{d_i} = 1/3$$

Minimal particle content

$SU(2)_W$  doblet  $\psi$  with  $Y_\psi \neq 0$ ,  $SU(2)_W$  singlet  $\eta$  with  $Y_\eta \neq 0$   
and a SM singlet  $\chi$

458 solutions but only 4 solutions with an axial DM coupling

$$\{Y_\psi, Y_\eta\} = \left\{ \pm \frac{1}{2}, \pm 1 \right\}, \quad \left\{ \pm \frac{7}{2}, \pm 5 \right\}$$

$$\{Y'_{\psi_L}, Y'_{\psi_R}, Y'_{\eta_L}, Y'_{\eta_R}, Y'_{\chi_L}, Y'_{\chi_R}\} = \left\{ -\frac{3}{2}, \frac{3}{2}, \frac{3}{2}, -\frac{3}{2}, \frac{3}{2}, -\frac{3}{2} \right\}$$

# **Minimal content model: phenomenology**

# Particle content

## Fermionic content

$$\psi_L \left( 2, -\frac{1}{2}, -\frac{3}{2} \right)$$

$$\psi_R \left( 2, -\frac{1}{2}, \frac{3}{2} \right)$$

$$\eta_L \left( 1, -1, -\frac{3}{2} \right)$$

$$\eta_R \left( 1, -1, \frac{3}{2} \right)$$

$$\chi_L \left( 1, 0, \frac{3}{2} \right)$$

$$\chi_R \left( 1, 0, -\frac{3}{2} \right)$$

Only 1 complex scalar to give masses to the three fermions

$$S \left( 1, 0, -3 \right)$$

which takes a VEV that also gives mass to the new boson Z'

Non axial model by Duerr and Fileviez  
arXiv:1409.8165

# Lagrangian

## Lagrangian

$$\mathcal{L}_{gauge} \supset \frac{1}{4} F^{B\mu\nu} F_{\mu\nu}^B + \frac{\epsilon_B}{2} F^{\mu\nu} F_{\mu\nu}^B$$

$$\begin{aligned} \mathcal{L}_{\text{fer}} \supset & \mathcal{L}_{\text{kin}} - y_1 \bar{\psi}_L H \eta_R - y_2 \bar{\psi}_L \bar{H} \chi_R - y_3 \bar{\psi}_R H \eta_L - y_4 \bar{\psi}_R \bar{H} \chi_L \\ & - \lambda_\psi \bar{\psi}_L \psi_R S - \lambda_\eta \bar{\eta}_R \eta_L S - \lambda_\chi \bar{\chi}_R \chi_L S + (\text{h.c.}) \quad \text{No majorana masses} \end{aligned}$$

$$\mathcal{L}_{\text{scal}} \supset \mathcal{L}_{\text{kin}} - m_S^2 |S|^2 - \lambda_S^2 |S|^4 - \lambda_{HS}^2 |H|^2 |S|^2$$

First approx. at tree level  $\epsilon_B = \lambda_{HS} = 0$

Radiatively  $\epsilon_B = \frac{eg_q}{2\pi^2 \cos \theta_W} \log \frac{\Lambda'}{\mu} \simeq 0.02 g_q \log \frac{\Lambda'}{\mu}$

## Integration out

$$\begin{aligned}\mathcal{L}_{\text{fer}} \supset \mathcal{L}_{\text{kin}} &- y_1 \bar{\psi}_L H \eta_R - y_2 \bar{\psi}_L \bar{H} \chi_R - y_3 \bar{\psi}_R H \eta_L - y_4 \bar{\psi}_R \bar{H} \chi_L \\ &- \lambda_\psi \bar{\psi}_L \psi_R S - \lambda_\eta \bar{\eta}_R \eta_L S - \lambda_\chi \bar{\chi}_R \chi_L S + (\text{h.c.})\end{aligned}$$

If  $\psi, \eta$  are more massive than  $\chi$  we can integrate them out.

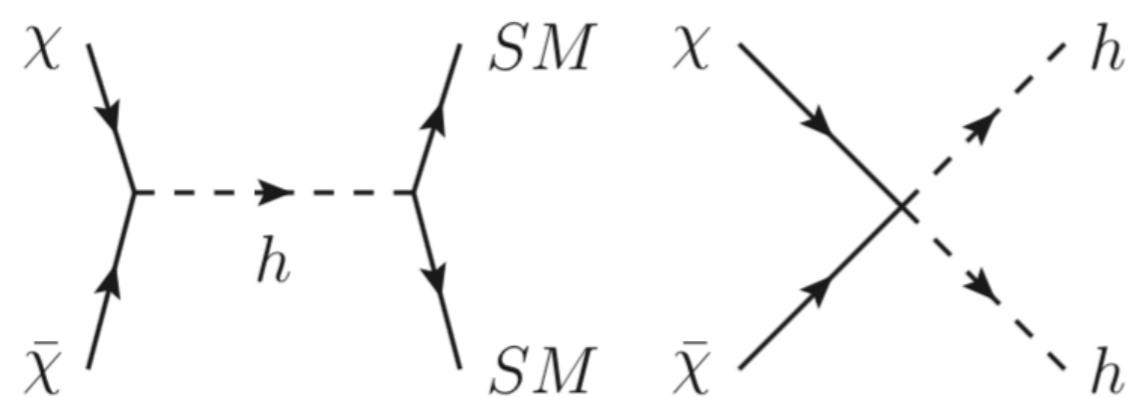
$$\mathcal{L}_{\text{eff}}^{\text{DM}} = \mathcal{L}_{\text{kin}} - \lambda_\chi \bar{\chi}_R \chi_L S + \frac{1}{\Lambda} \bar{\chi}_R \chi_L |H|^2 + \dots + (\text{h.c.})$$

2 annihilation channels: Z' portal and H portal

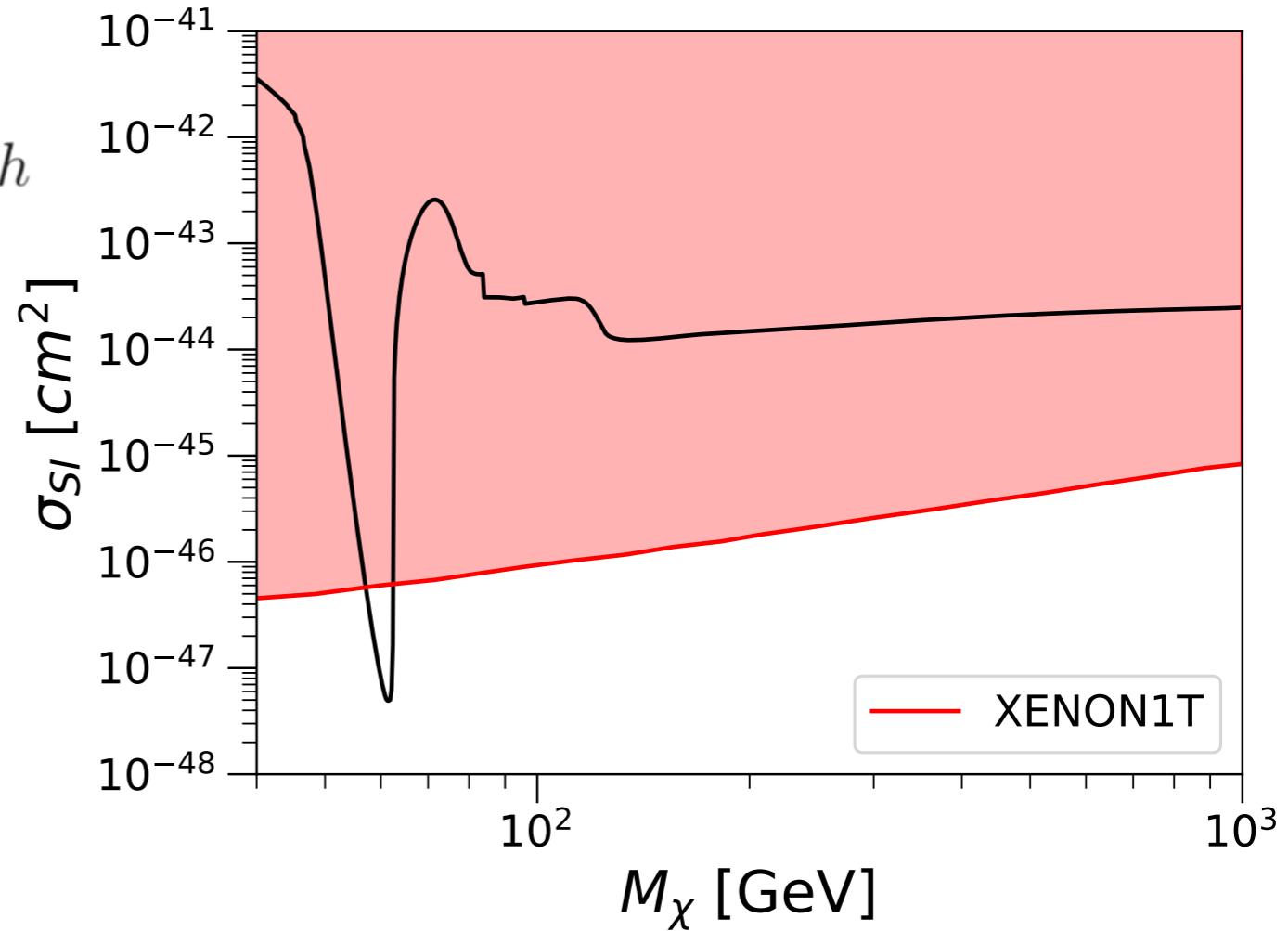
# Higgs channel: Relic density and DM constraints

Annihilation through the Higgs channel

$$\mathcal{L}_{\text{eff}}^{\text{DM}} = \mathcal{L}_{\text{kin}} - \lambda_{\chi} \bar{\chi}_R \chi_L S + \boxed{\frac{1}{\Lambda} \bar{\chi}_R \chi_L |H|^2} + \dots + (\text{h.c.})$$



2 d.o.f:  $m_{\chi}, \frac{1}{\Lambda}$

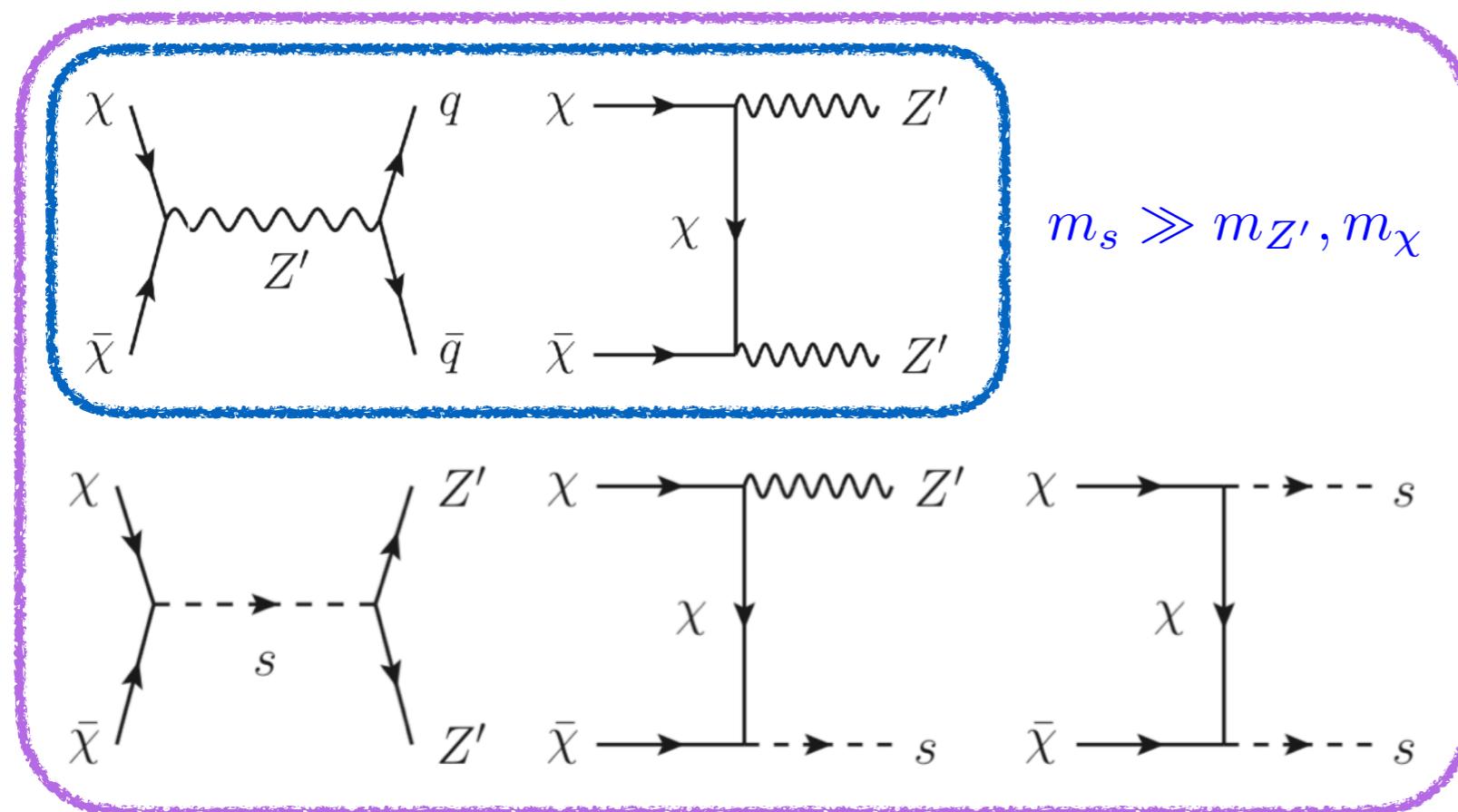


Excluded except  
the resonance

# Z' channel: Relic density

Annihilation through the Z' channel

$$\mathcal{L}_{\text{eff}}^{\text{DM}} = \boxed{\mathcal{L}_{\text{kin}} - \lambda_{\chi} \bar{\chi}_R \chi_L S} + \frac{1}{\Lambda} \bar{\chi}_R \chi_L |H|^2 + \dots + (\text{h.c.})$$



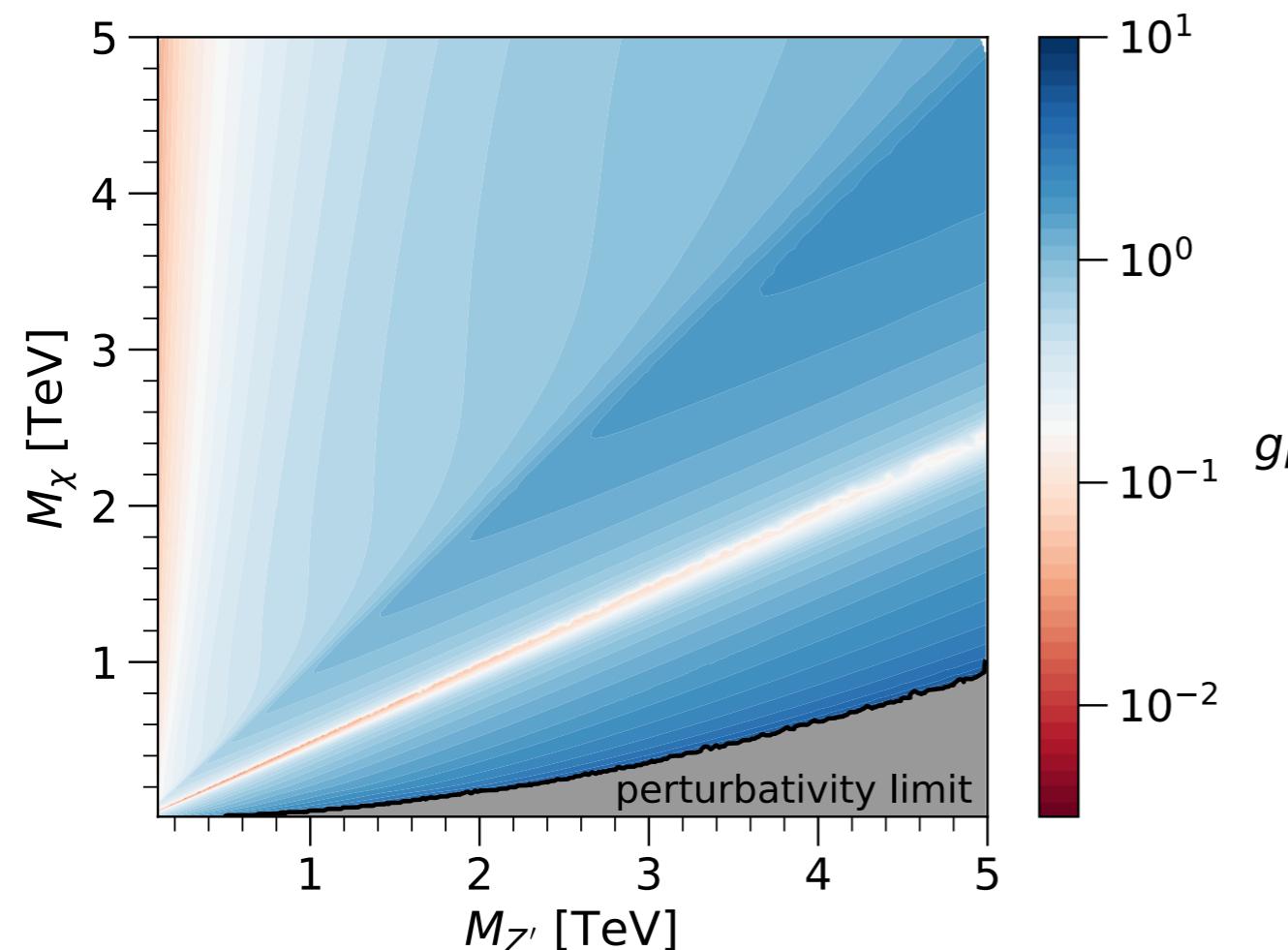
2 regimes:  $m_s = 15$  TeV and  $m_s = 2$  TeV

# Z' channel: Relic density

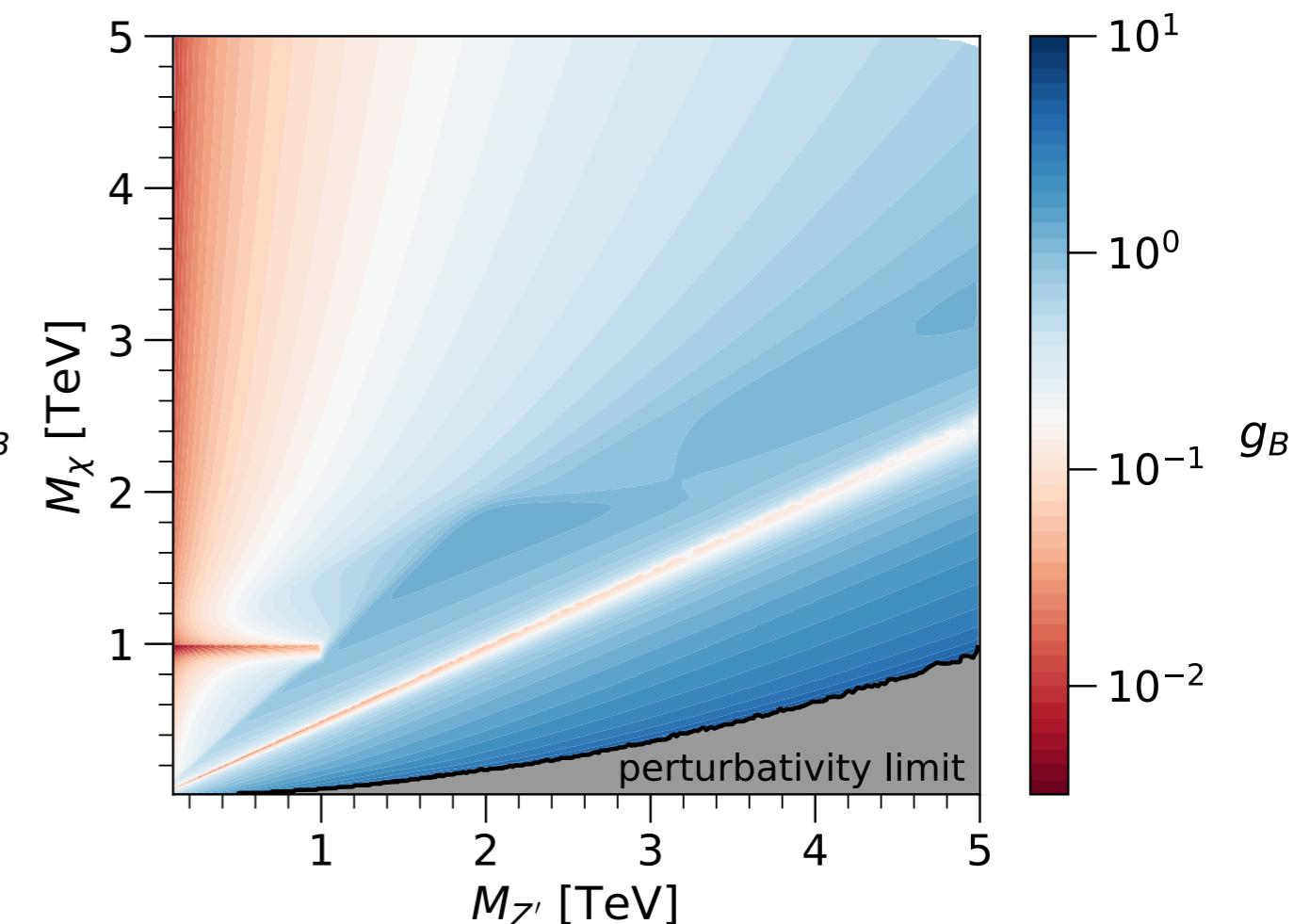
Annihilation through the Z' channel

4 d.o.f:  $m_\chi, g_B, m_{Z'}, m_s$

$m_s = 15 \text{ TeV}$



$m_s = 2 \text{ TeV}$



The Z' channel is strong enough to carry  
the annihilation in the early universe

## Z' channel: DM constraints

Axial DM coupling  $\longrightarrow$  SD cross section

Vector coupling to quarks  $\bar{q}\gamma_\mu q \bar{\chi}\gamma_5\gamma^\mu\chi$

Velocity suppression in the cross section

$$\sigma_{SD} \sim 0$$

$$\langle\sigma v\rangle_{ann} \sim 10^{-30} cm^3/s$$

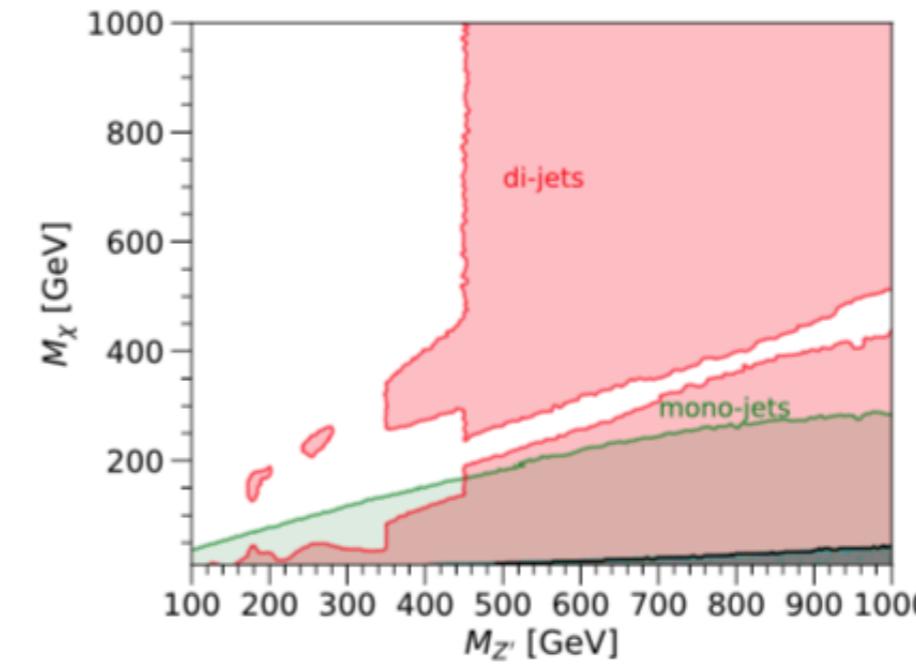
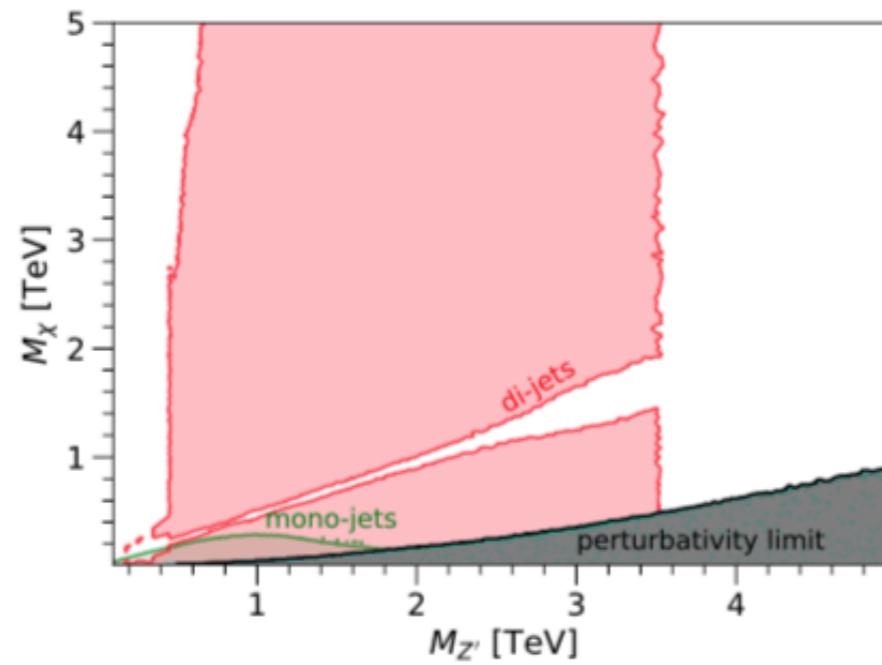
No constraints from DD or ID experiments

We have to check collider constraints.

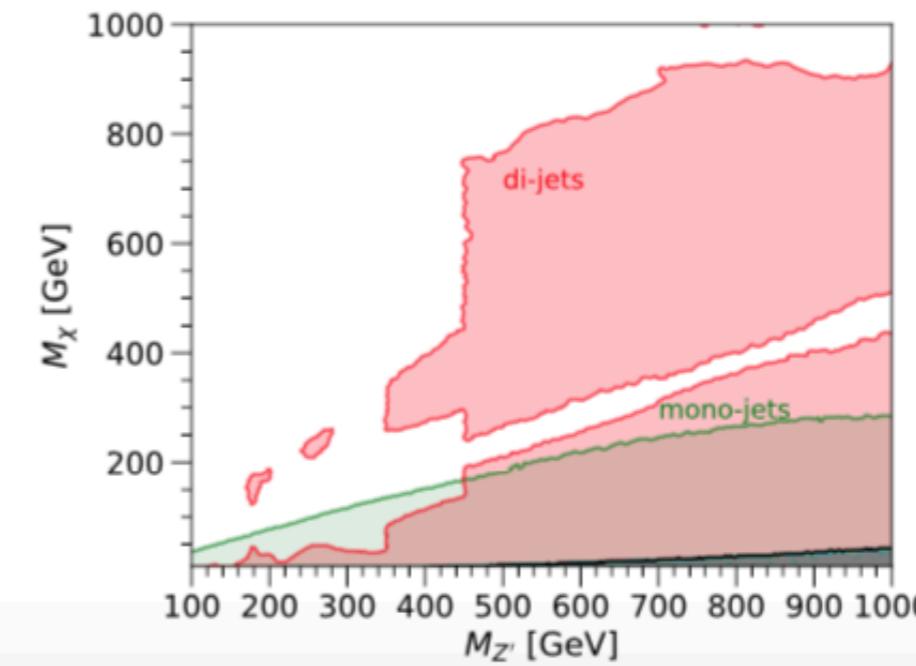
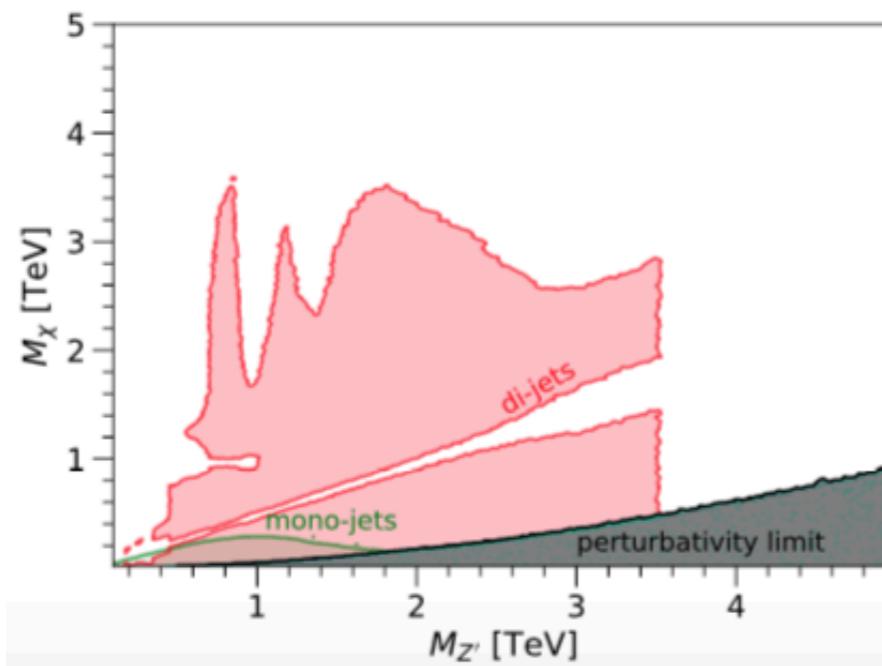
# Z' channel: Results

$$\log(\Lambda'/m_{Z'}) = 1$$

$m_s = 15 \text{ TeV}$



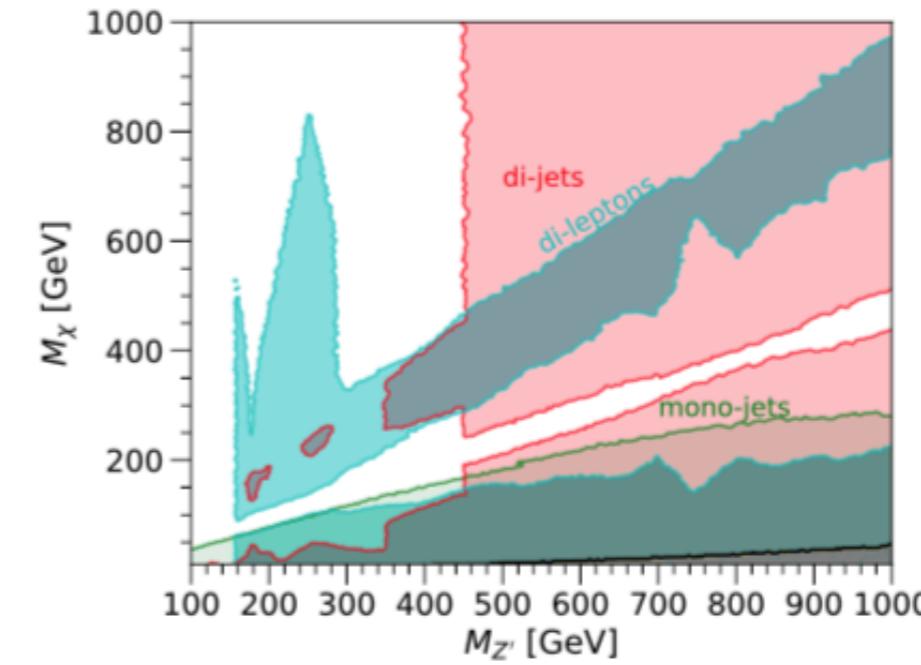
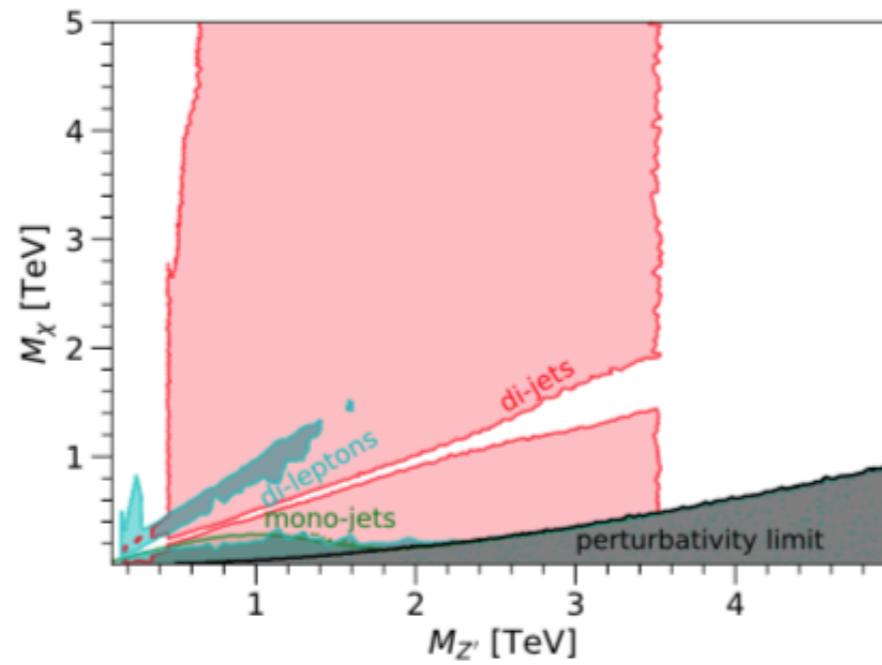
$m_s = 2 \text{ TeV}$



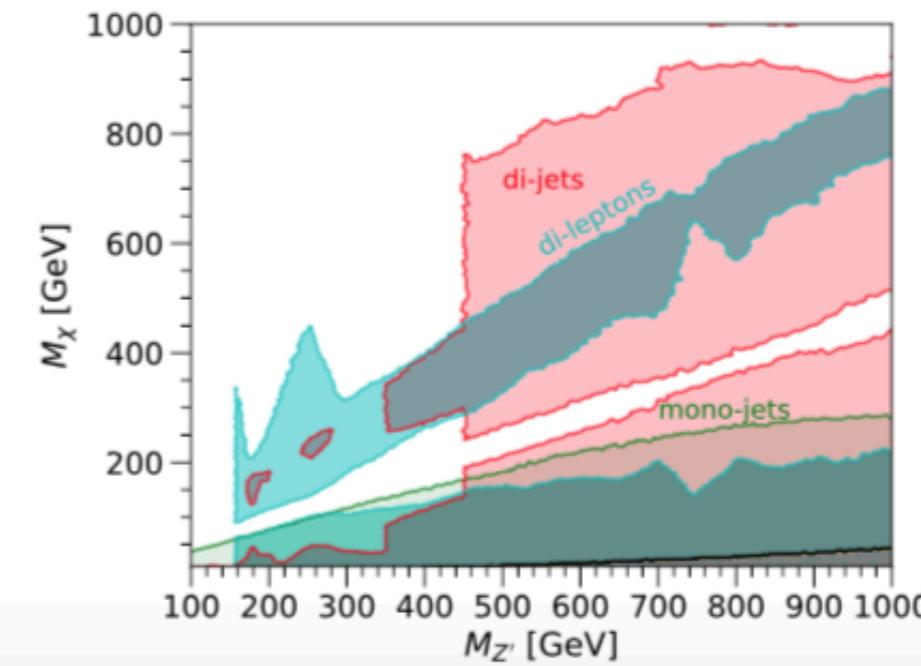
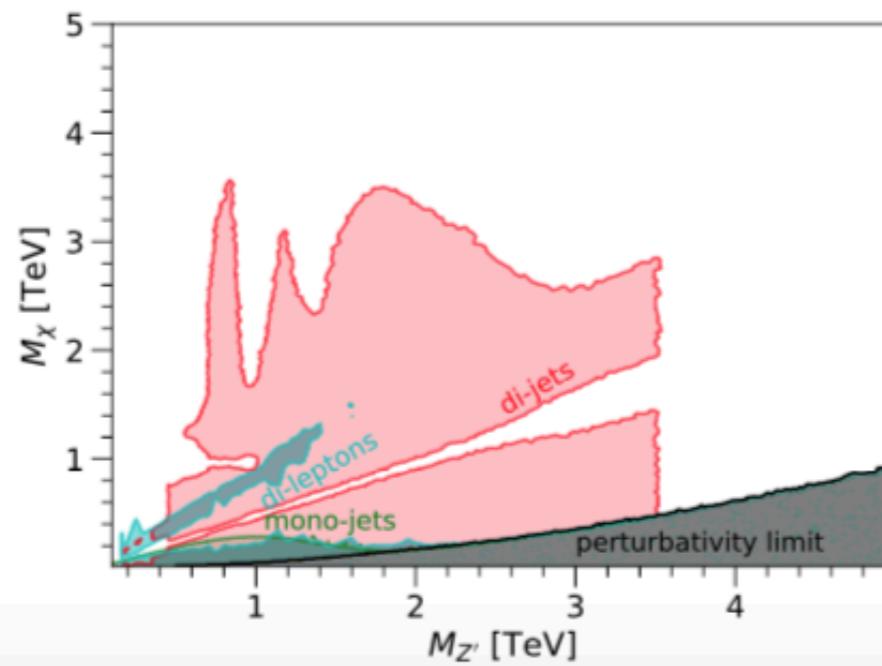
# Z' channel: Results

$$\log(\Lambda'/m_{Z'}) = \log(100m_{Z'}/m_{Z'}) = 4.6$$

$m_s = 15 \text{ TeV}$



$m_s = 2 \text{ TeV}$



# Summary

## Summary

SDMM are very constraint by experiments, especially DD and di-lepton searches

Leptophobic U(1) symmetry yields to BN symmetry, anomalous in the SM. The anomaly-cancellation is not trivial.

The vector coupling to the quarks combined with the axial DM coupling ends up with a velocity suppressed SD cross section. No DD or ID limits.

Due to the relation between the quark and DM coupling, collider searches can constraint the parameter's space of this kind of models.