# Scalar Dark Matter with a $\mu\tau$ Flavored Mediator

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Higgs as a Probe of New Physics

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Based on:

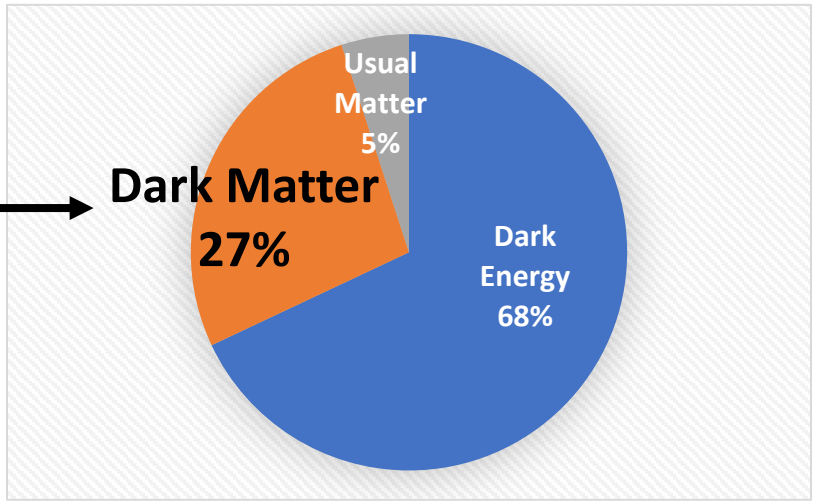
[1] K. Asai, C. Miyao, S. Okawa, K. Tsumura, Phys. Rev. D **106**, 035017(2022).

# Contents

- Introduction
- Our Model
- Analysis Results of Our Model
- Conclusion

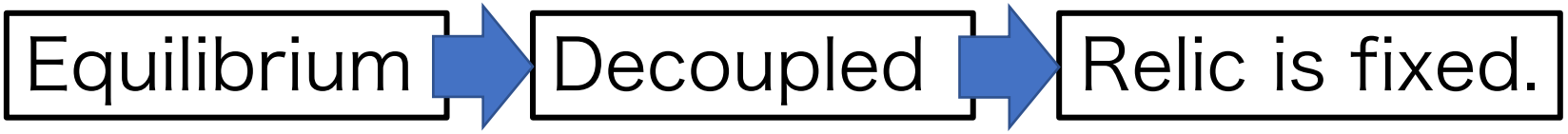
# Dark Matter (DM)

- Energy density ≈ 27%.
- Evidence of DM existence;
  rotation speed of galaxies,
  gravitational lens effect, ….
- Unknown Identities.



# Relic Abundance of DM

- DM is produced through thermal process.




- Theoretical value of relic abundance of thermal produced DM.

$$\Omega \mathrm{h}^2 \sim \frac{10^{-28}}{< \sigma v >_{\mathrm{ann}}}$$

- Observation value of relic abundance.

$$\Omega h^2_{\mathrm{obs}} \simeq 0.12$$

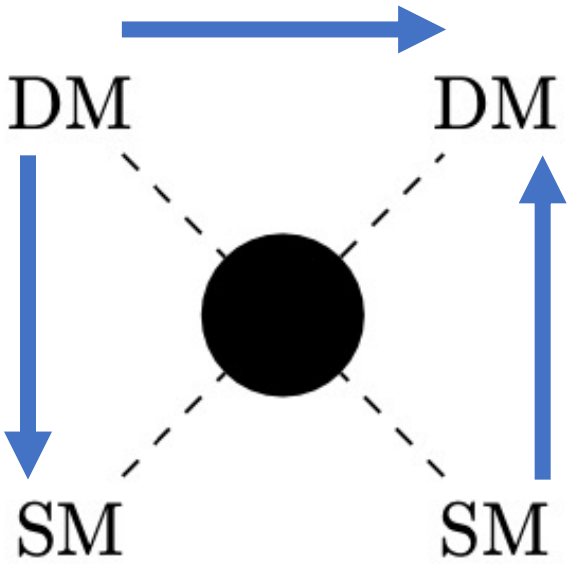
# Detection of DM

## Direct Detection (DD)

Observation of DM-SM scattering.

## Indirect Detection (ID)

Observation of cosmic ray from DM annihilation.



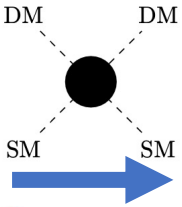

## Collider Search (CS)

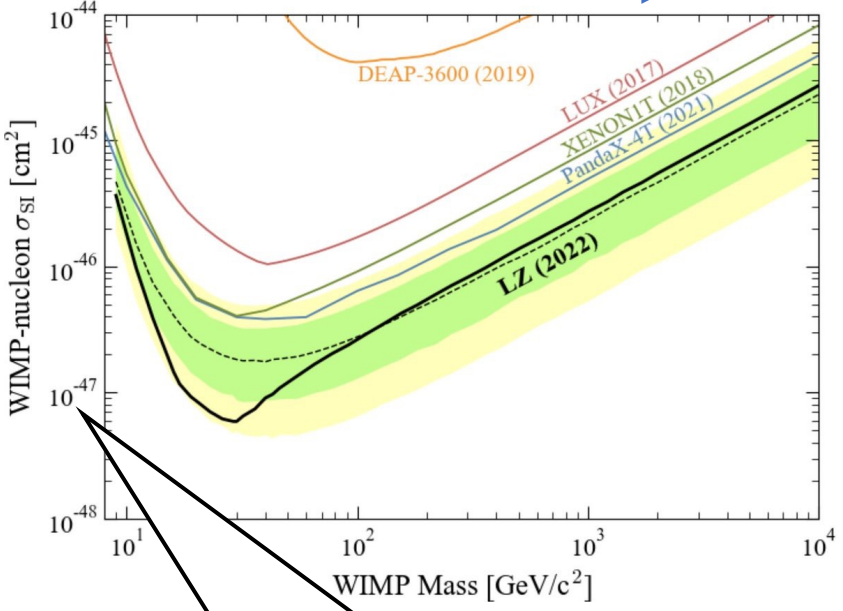
Observation of missing momentum through SM-SM collision process.

# The Latest Result of DD

## Result of DD

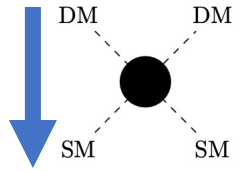
Cited from [4] LZ Collaboration, J. Aalbers et al., arXiv: 2207.03764 (hep-ex) (2022).




$\sigma_{\mathrm{sct}} \sim 10^{-47}\mathrm{cm}^2$

## Relic of DM




Observed value :

$$\Omega h^2_{\mathrm{obs}} \simeq 0.12$$

Theoretical value :

$$\Omega \mathrm{h}^2 \sim \frac{10^{-28}}{< \sigma v >_{\mathrm{ann}}}$$

$$< \sigma v >_{\mathrm{ann}} \sim 10^{-26}\ \mathrm{cm}^3/s$$

Some ideas are needed for explanation.

# Model of Previous Work

[5] I. Golon, A. Kawa and P. Tenedo, JHEP03, 064 (2017).

- Effective theory with flavor violation.

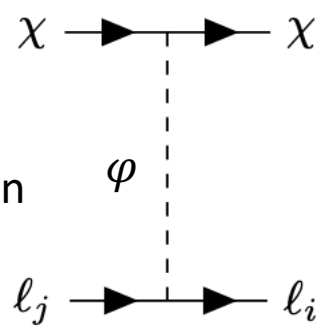
$$\mathcal{L}_{\varphi\chi} \propto \frac{1}{2} y_S \varphi \bar{\chi}\chi + \frac{i}{2} y_P \varphi \bar{\chi}\gamma^5 \chi$$

$$\mathcal{L}_{\varphi SM} = g_{ij}\varphi \bar{l}_i P_L l_j + g^*_{ji}\varphi^* \bar{l}_j P_R l_i$$

$\chi$: DM

$l_i$: charged lepton

$\varphi$: mediator




- DM interacts with an only pair of charged leptons which have different flavors each other mediated by $\varphi$.
- DM cannot interact with quarks.
  →DD is suppressed.
- DM can annihilate enough.

However, origin of interaction is unknown.

# Our Model

[1]Phys. Rev. D **106**, 035017(2022)

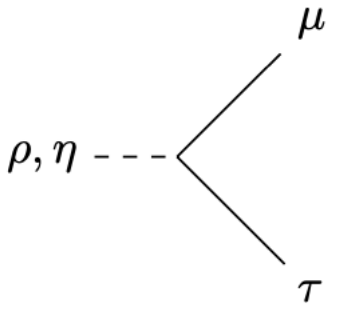
- SM + mediator:$\Phi = \begin{pmatrix} \phi^+ \\ \frac{\rho+i\eta}{\sqrt{2}} \end{pmatrix}$+Complex scalar DM: $\Sigma$.

| particle | $(L_e, L_\mu, L_\tau)$ | $(e_R, \mu_R, \tau_R)$ | $H$ | $\Phi$ | $\Sigma$ |
|---|---|---|---|---|---|
| SM | $(1,2)_{-1/2}$ | $(1,1)_{-1}$ | $(1,2)_{1/2}$ | $(1,2)_{1/2}$ | $(1,1)_0$ |
| $Z_4$ | $(1, i, -i)$ | $(1, i, -i)$ | $1$ | $-1$ | $i$ |

Nortation of SM charge : $(SU(3)_C, SU(2)_L)_{U(1)_Y}$

- $Z_4$ lepton flavor symmetry. = Origin of the interaction.

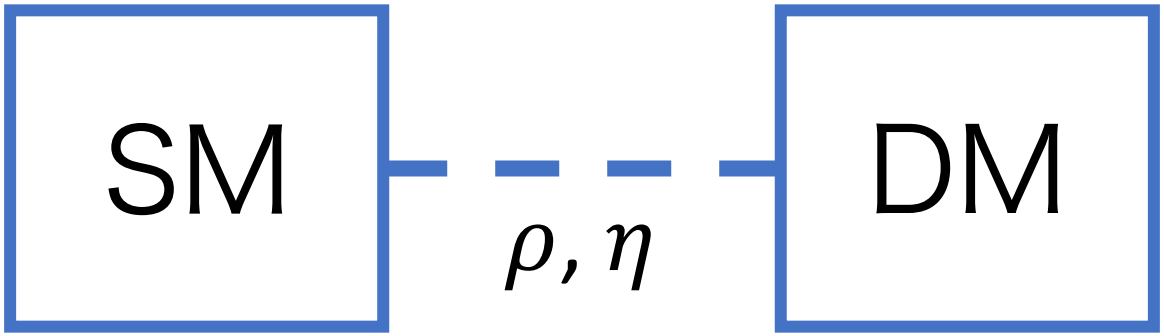
$$-\mathcal{L}_{Yukawa} = \overline{l_R} \begin{pmatrix} y_e H^\dagger & & \\ & y_\mu H^\dagger & y_{\mu\tau}\Phi^\dagger \\ & y_{\tau\mu}\Phi^\dagger & y_\tau H^\dagger \end{pmatrix} L + \text{H.c.}$$




- Flavor off-diagonal interaction.
- Renormalizable Model. → Highly prediction avirity.

# DM in Our Model

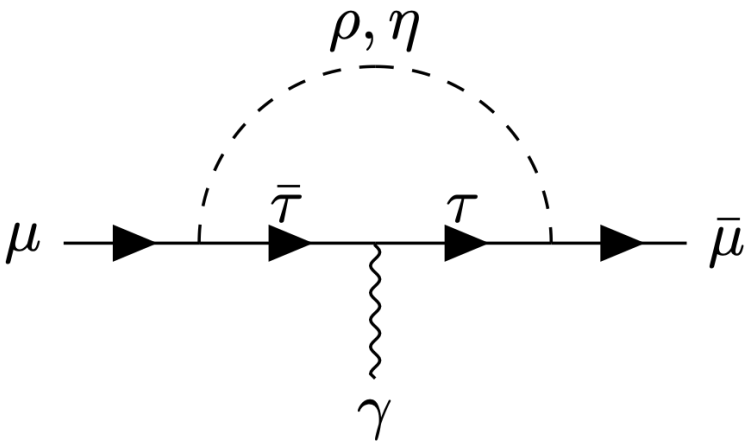
[1]Phys. Rev. D **106**, 035017(2022)




- Stabilized by flavor symmetry.
- DM interacts with SM only mediated by $\rho$ and $\eta$.
- DM interacts only with $\mu$ and $\tau$ about SM fermion.
  → DM-Nucleon scattering is suppressed at tree level.
- DM can interact quarks at loop level.
  → Prediction to the direct detection.

# Muon g-2 and Mediator

[6] Y, Abe, T. Toma and K. Tsumura, JHEP 06, 142 (2019).




- Muon g-2 has the discrepancy between SM theoretical value and experimental value.
- $\boldsymbol{\rho, \eta}$ give a correction to muon g-2.

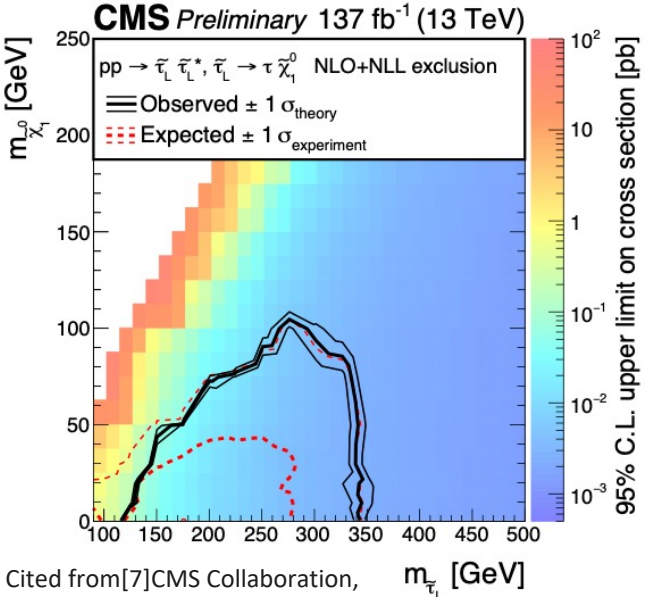
  → We set constraints for mediator.

# Constraint from Collider

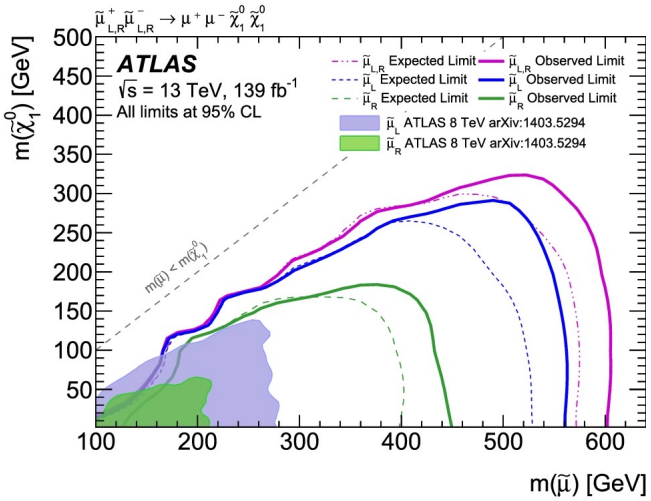
- $\phi^{\pm} \to \nu_{\tau}\tau^{\pm}, \nu_{\mu}\mu^{\pm}$ decay processes exist.

  →Constraints from slepton search is available.

We consider in cases of $m_{\phi} = 100, 700$ GeV.



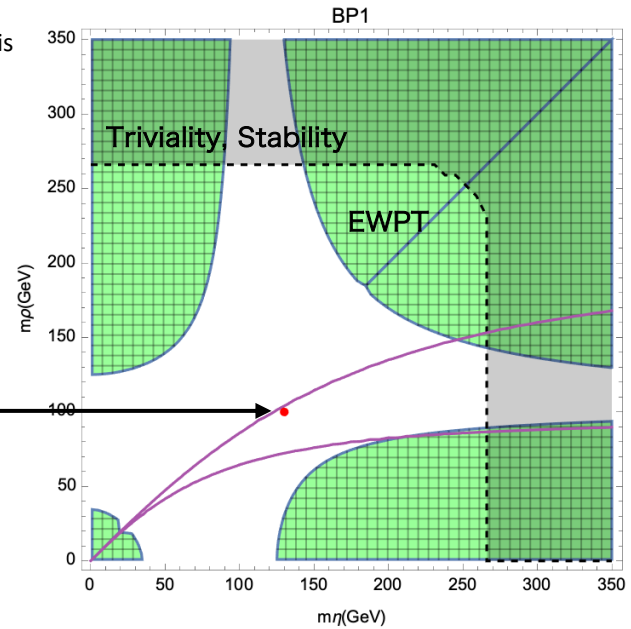

Cited from[7]CMS Collaboration, Report No. CMS-SUS-21-001, CERN-EP-2022-032 (2022).



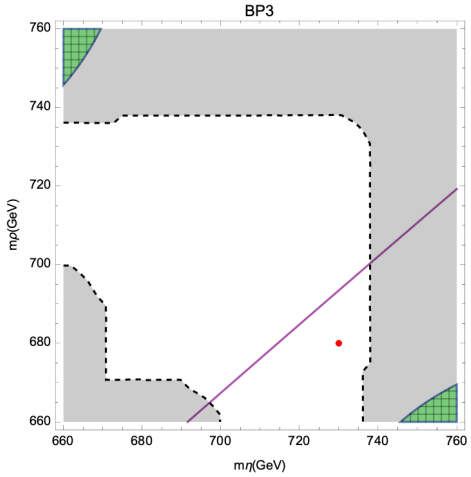

Cited from [8]ATLAS Collaboration, Eur. Phys. J. C 80, 123 (2020).

# Benchmark Point (BP)

Cited from [2]master thesis




BP3 : $(m_\phi, m_\rho, m_\eta, y_{\mu\tau}, y_{\tau\mu})$
$= (700\ \text{GeV}, 680\ \text{GeV}, 730\ \text{GeV}, 0.7, 0.7)$




BP1: $(m_\phi, m_\rho, m_\eta, y_{\mu\tau}, y_{\tau\mu}) = (100\ \text{GeV}, 100\ \text{GeV}, 130\ \text{GeV}, 0.07, 0.07)$

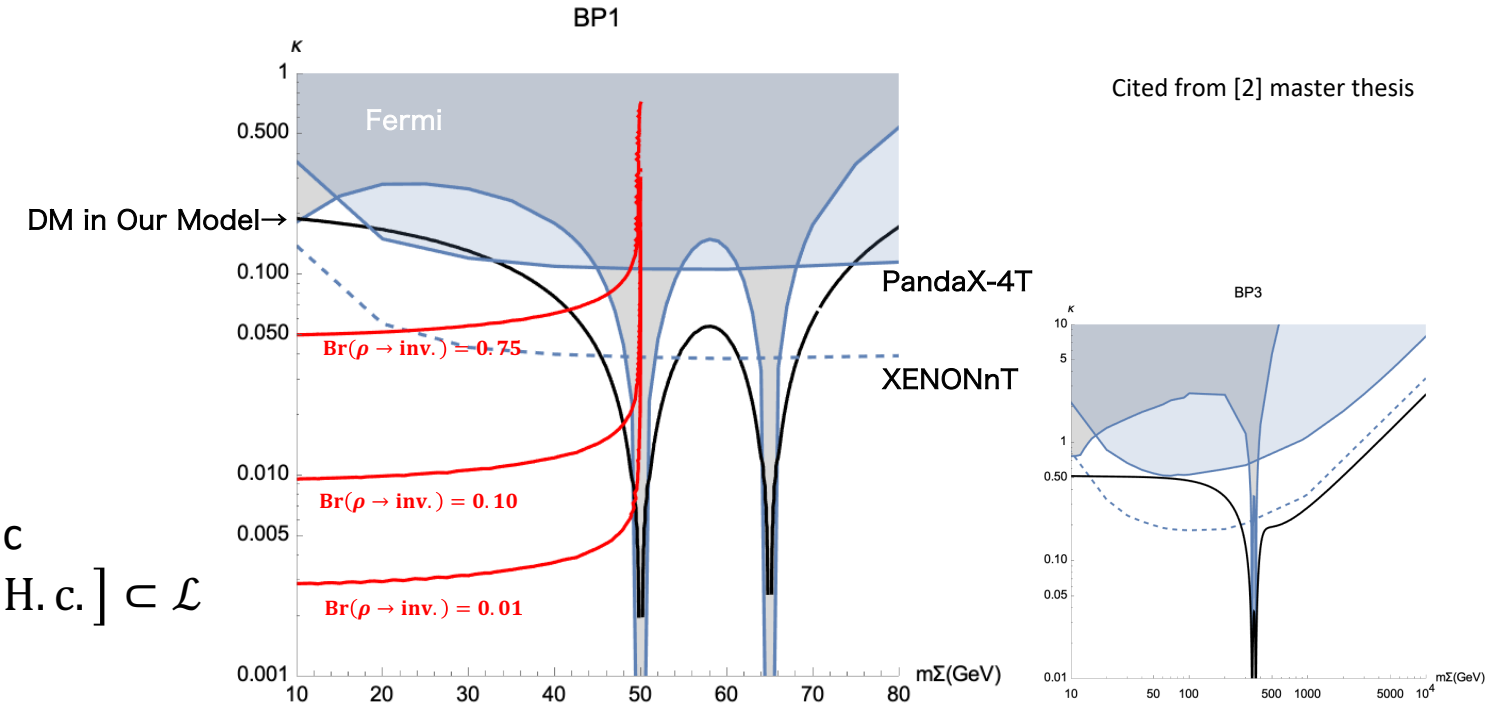
- Region between purple lines show mediators which give muon g-2 correction to within $2\sigma$.

We choose such mediator for BP and got prediction for the DM direct detection.

# Prediction from Our Model

$\kappa$ :scalar quartic

$\kappa\left[\left(H^{\dagger}\Phi\right)\Sigma^{2}+\mathrm{H.c.}\right]\subset\mathcal{L}$




- Black line show prediction from our model.
- Blue and grey region is excluded by experiments.
- Upside of dashed line is testable by XENONnT.

# Conclusion

- Direct detection of DM is suppressed by flavor structure.
- Our model can explain DM physics and muon g-2 at the same time.
- Our model is testable at loop level in future.

# Reference


[1] K. Asai, C. Miyao, S. Okawa, K. Tsumura, Phys. Rev. D **106**, 035017(2022).

[2] C. Miyao, Master Thesis(2023).

[3] Muon g-2 Collaboration, Phys. Rev. Lett.126, 141802 (2021).

[4] LZ Collaboration, J. Aalbers et al., arXiv: 2207.03764 [hep-ex] (2022).

[5] I. Golon, A. Kawa and P. Tenedo, JHEP03, 064 (2017).

[6] Y, Abe, T. Toma and K. Tsumura, JHEP 06, 142 (2019).

[7] CMS Collaboration, Report No. CMS-SUS-21-001, CERN-EP-2022-032 (2022).

[8] ATLAS Collaboration, Eur. Phys. J. C 80, 123 (2020).