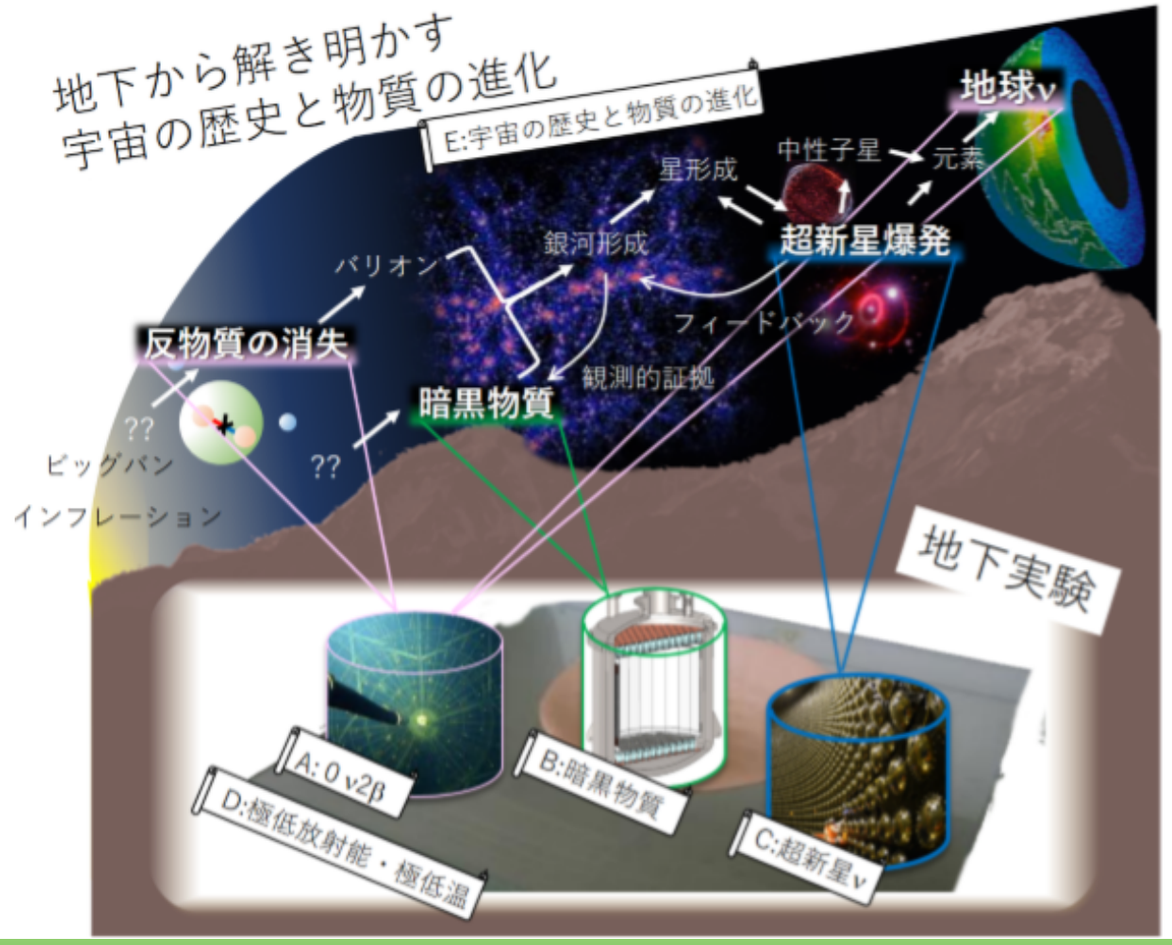
# 各種暗黒物質探索実験データと素粒子模型を系統的に照合するための枠組構築

新学術領域研究「地下宇宙研究」





馬渡 健太郎

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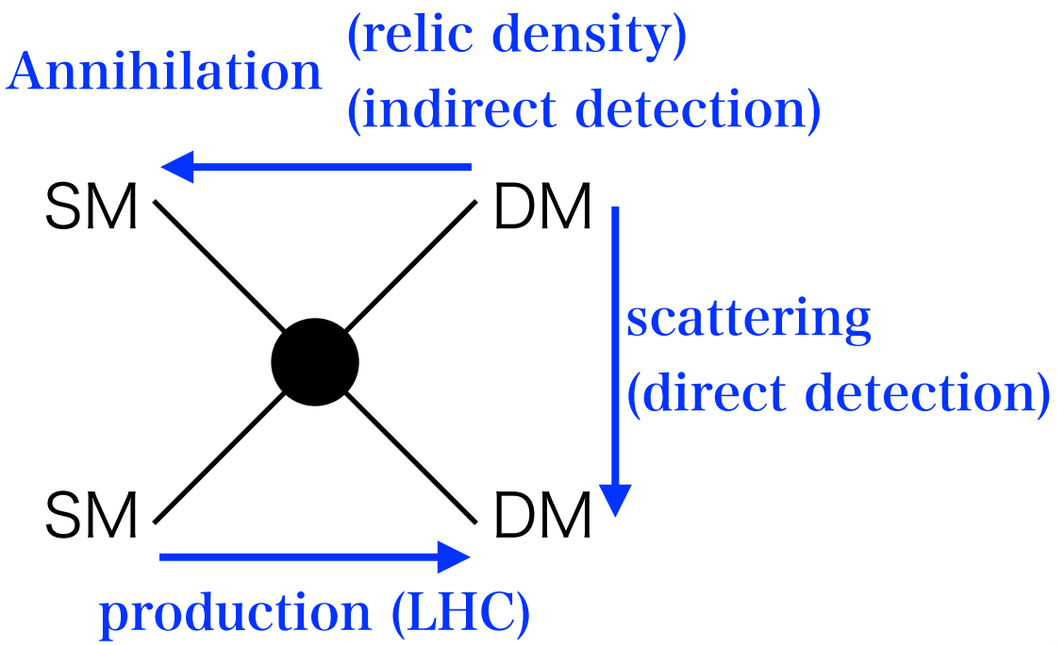
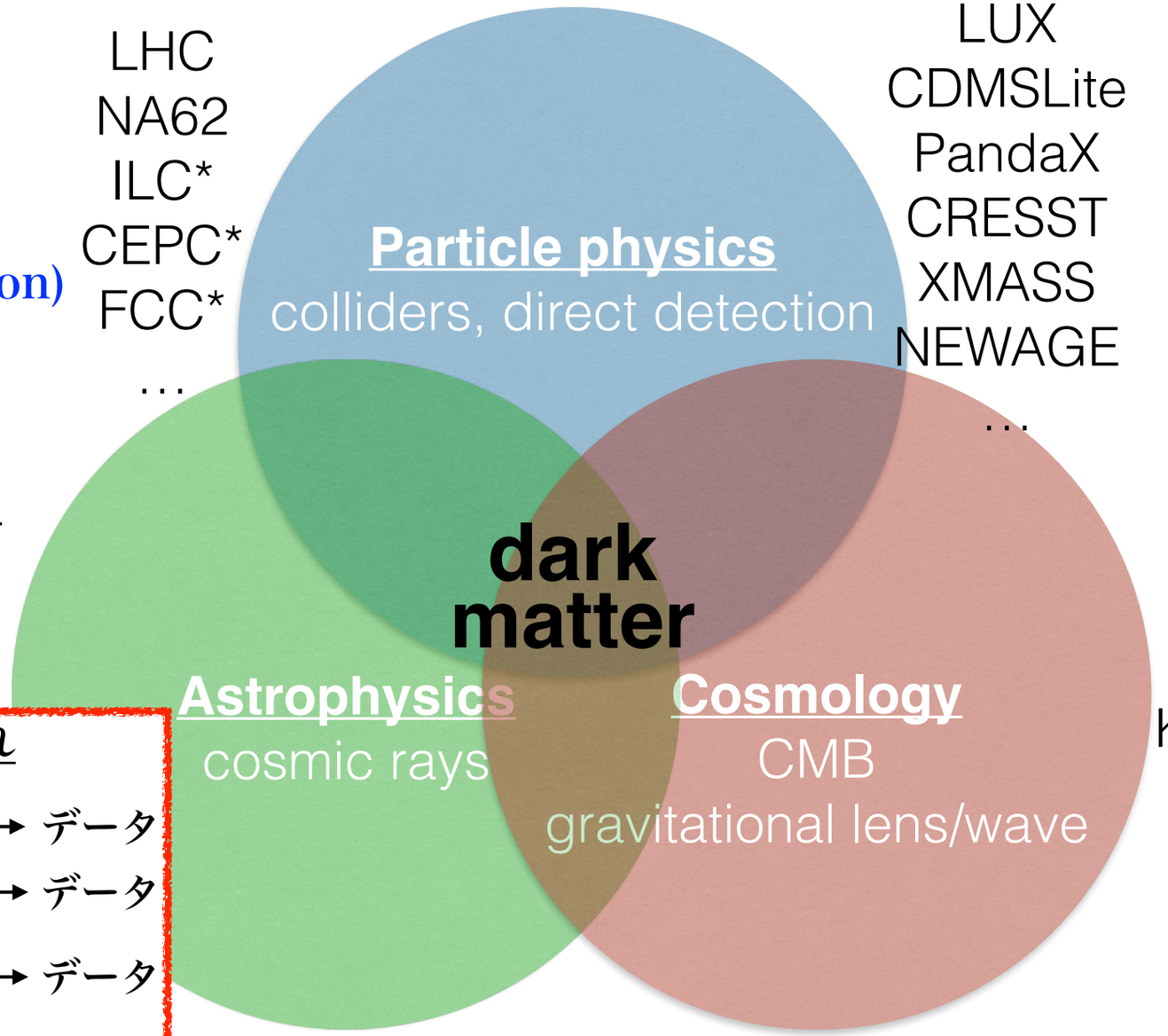
E01: 物質の起源を解明する新たな素粒子模型と初期宇宙進化の理論研究

# Various dark matter searches




LHC
NA62
ILC*
CEPC*
FCC*
…

LUX
CDMSLite
PandaX
CRESST
XMASS
NEWAGE
…



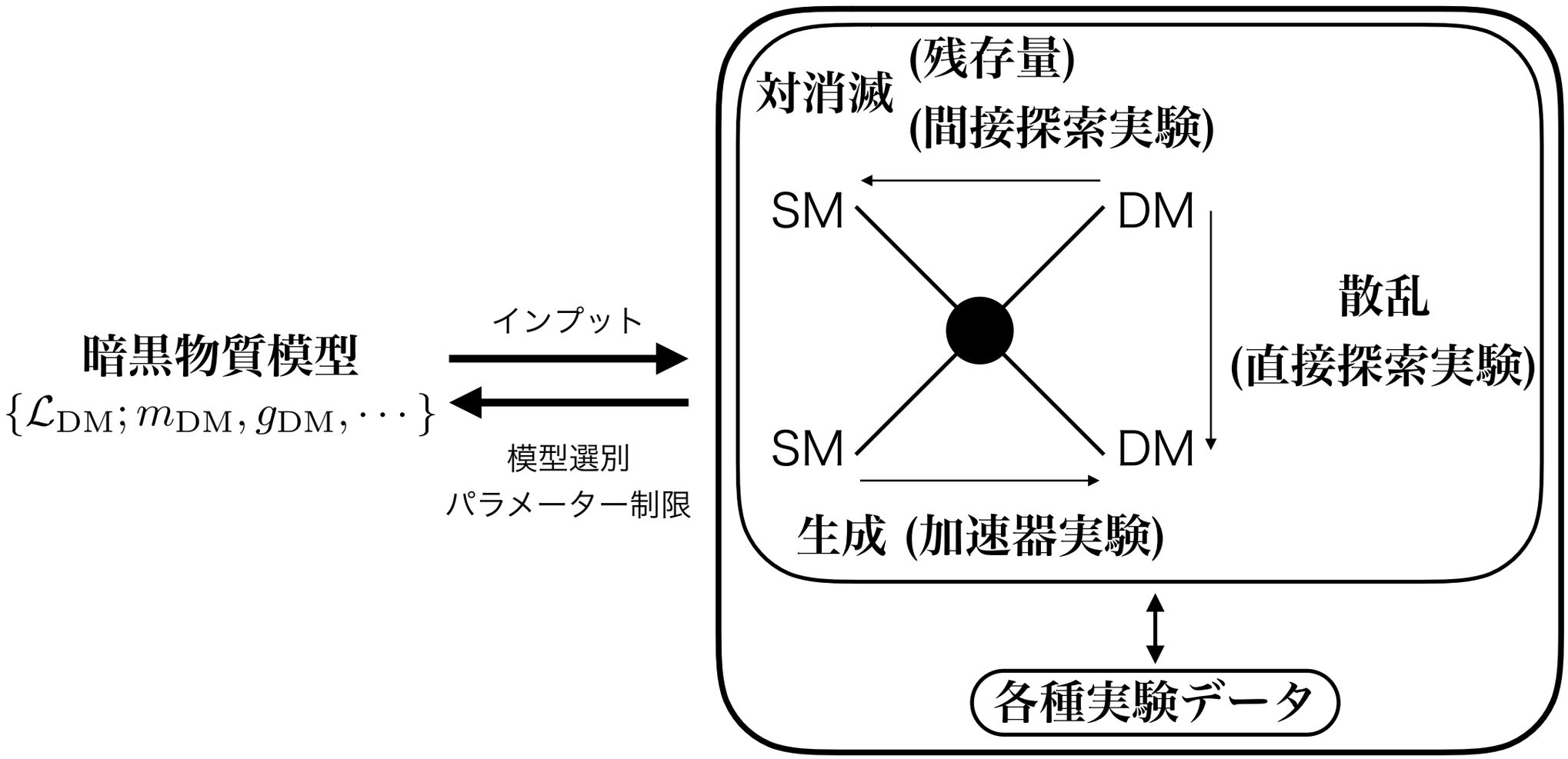

Fermi-LAT
AMS-02
Super-K

WMAP
Planck
LIGO
KAGRA*
LISA*
…

**従来の暗黒物質模型の研究の流れ**

暗黒物質模型
- 対消滅 (残存量) ⟷ データ
- 対消滅 (間接探索実験) ⟷ データ
- 散乱 (直接探索実験) ⟷ データ
- 生成 (加速器実験) ⟷ データ

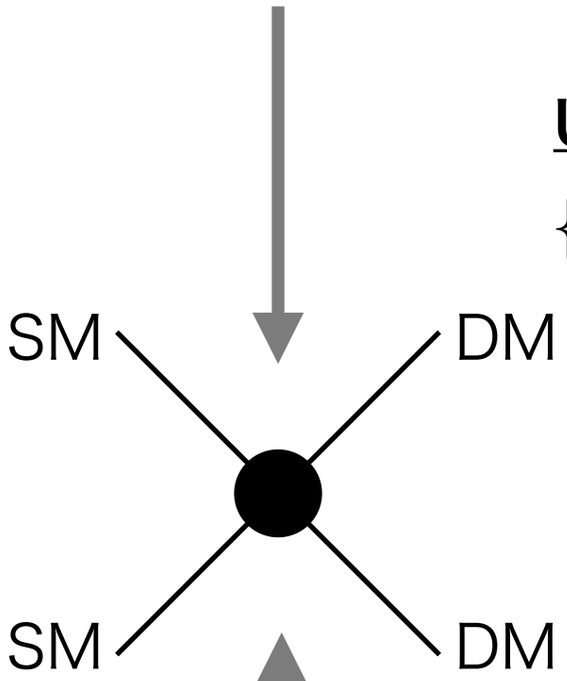
# Goal: building an analysis framework of DM searches




1. 暗黒物質模型のラグランジアンを共通のインプット
2. 各種探索実験に必要な物理量を計算
3. 各種実験データとの比較

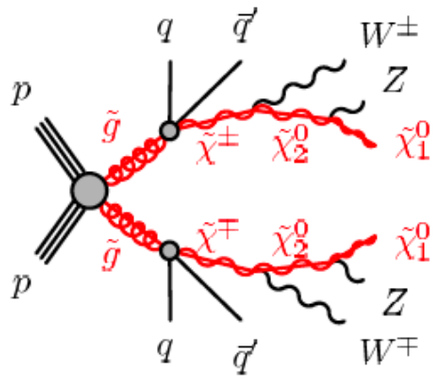
# DM (or MET) searches at LHC Run-I

Top-down approach



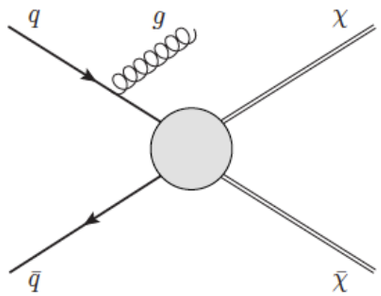

**UV model** : SUSY, ExtraDim, ⋯

$\{\mathcal{L}; m_{\rm DM}, m_1, m_2, \cdots, g_1, g_2, \cdots\}$




**EFT** : SM + DM particles

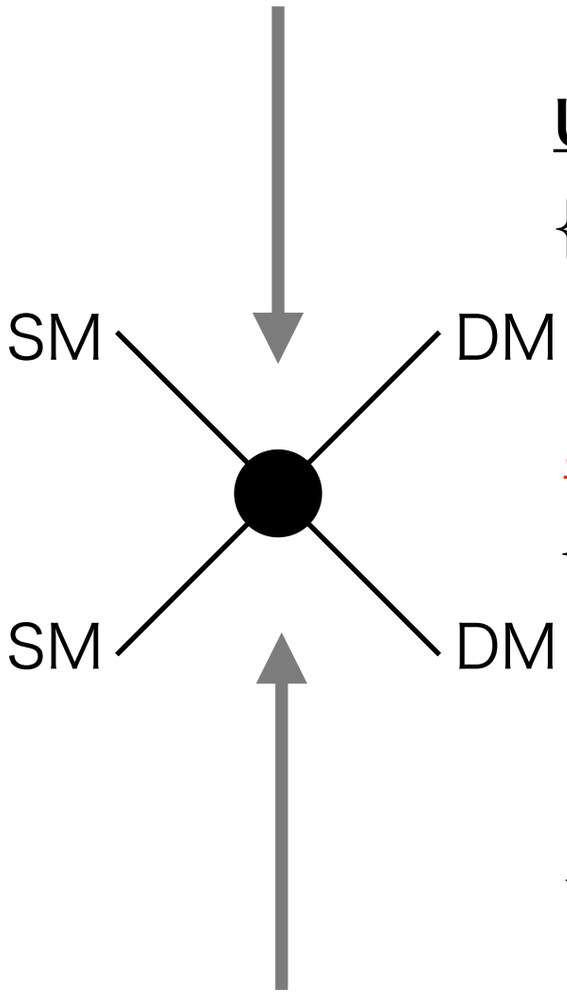
$\{\mathcal{L}; m_{\rm DM}, M_*\}$ $\quad \mathcal{L} = \frac{1}{M_*^2} \bar{\chi} \Gamma^\mu \chi \, \bar{q} \Gamma_\mu q$




Bottom-up approach

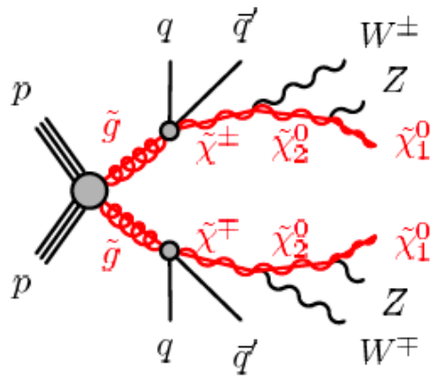
# DM (or MET) searches at LHC Run-II

Top-down approach



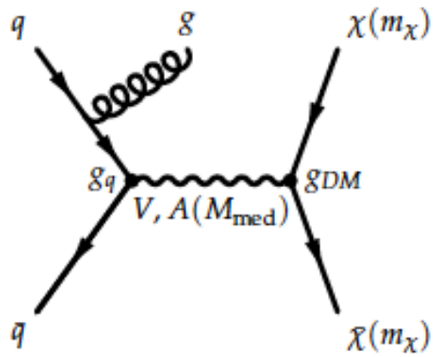

**UV model** : SUSY, ExtraDim, ⋯

$\{\mathcal{L}; m_{\rm DM}, m_1, m_2, \cdots, g_1, g_2, \cdots\}$



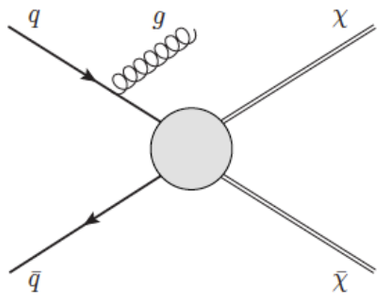

**Simplified model** : SM + DM + Mediator particles

$\{\mathcal{L}; m_{\rm DM}, m_{\rm med}, g_{\rm DM}, g_q\}$ $\mathcal{L} = g_{\rm DM} Z'_\mu \bar{\chi}\gamma^\mu\chi + g_q Z'_\mu \bar{q}\gamma^\mu q$




**EFT** : SM + DM particles

$\{\mathcal{L}; m_{\rm DM}, M_*\}$ $\mathcal{L} = \frac{1}{M_*^2}\bar{\chi}\Gamma^\mu\chi\,\bar{q}\Gamma_\mu q$

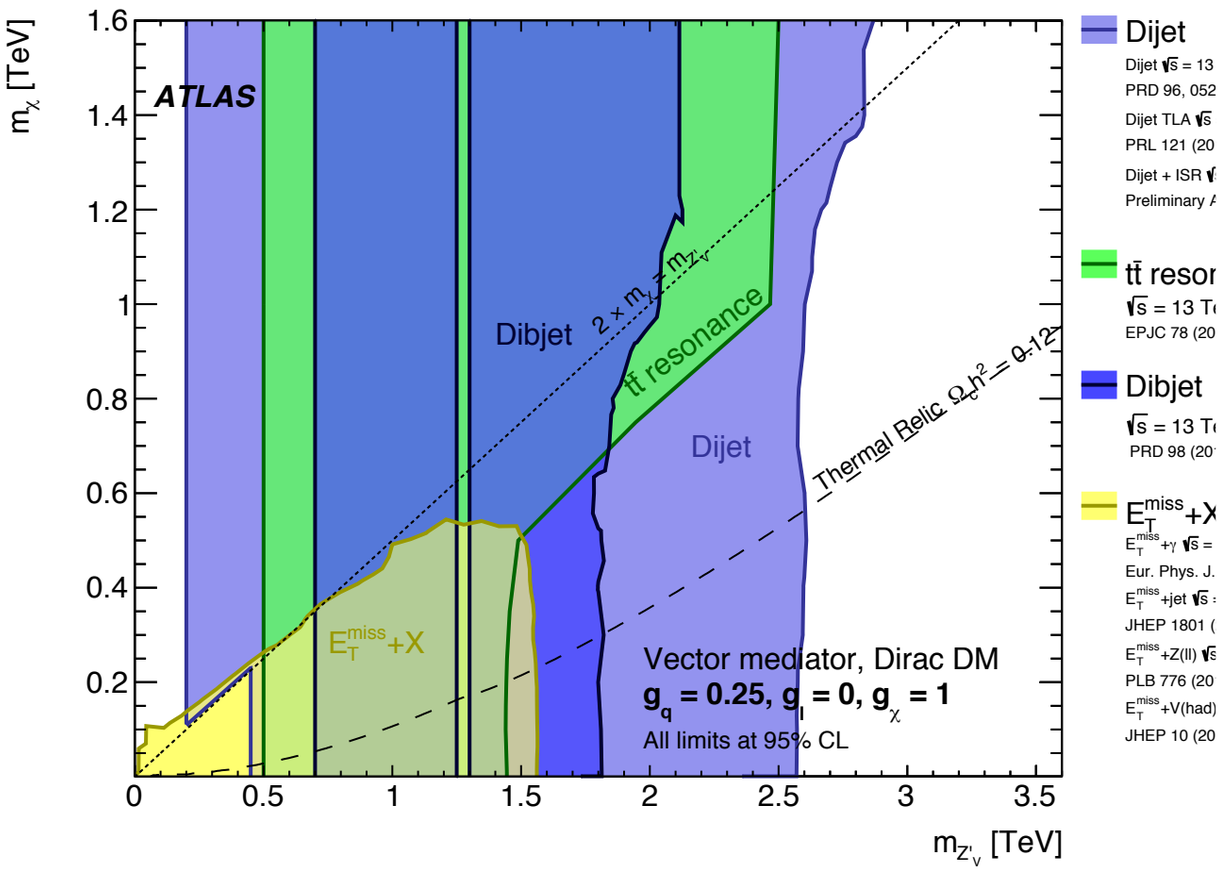



Bottom-up approach

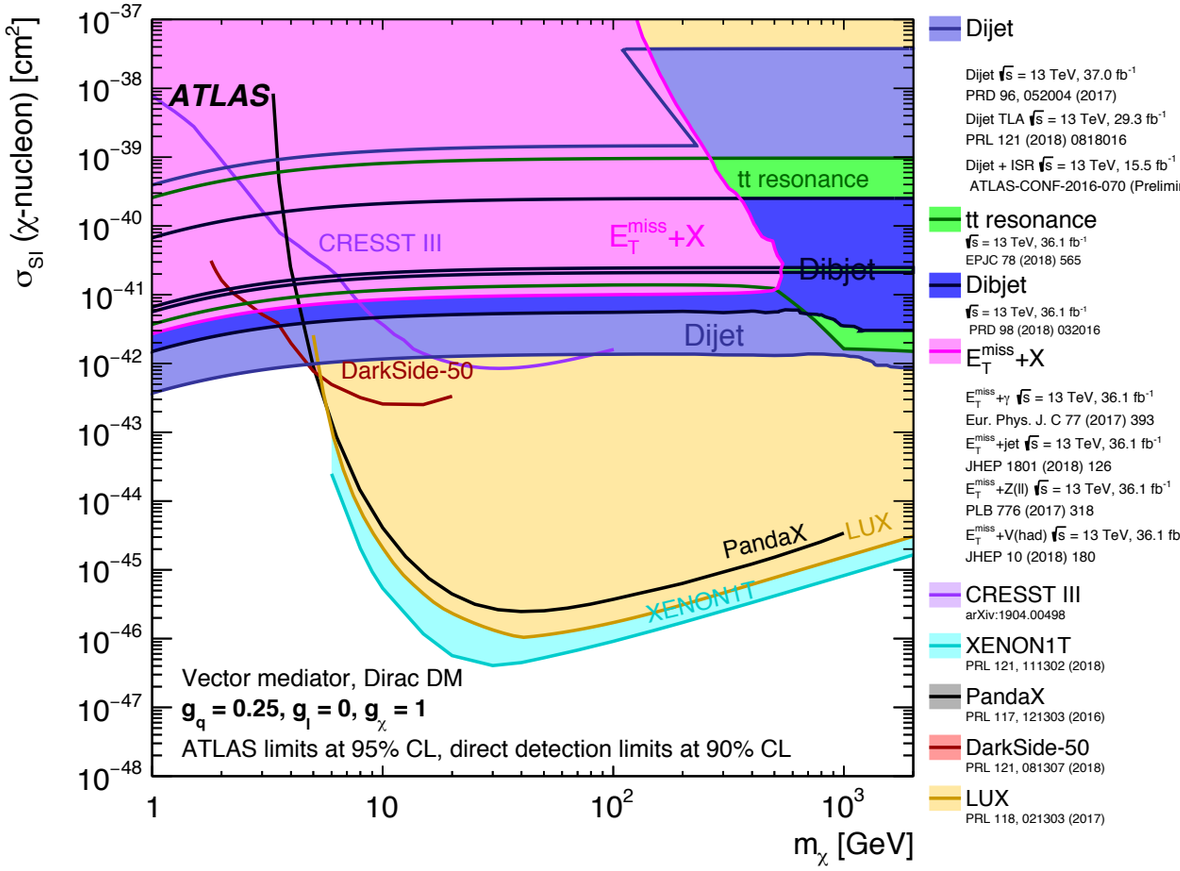
ATLAS [1903.01400, JHEP]

# Constraints on mediator-based dark matter and scalar dark energy models using $\sqrt{s} = 13$ TeV $pp$ collision data collected by the ATLAS detector

The ATLAS Collaboration




missing E vs. resonance searches




collider vs. direct searches

ATLAS [1903.01400, JHEP]

# Constraints on mediator-based dark matter and scalar dark energy models using $\sqrt{s} = 13$ TeV $pp$ collision data collected by the ATLAS detector

The ATLAS Collaboration

Table 4: Details of the generation setup and Universal FeynRules Output (UFO) model used for the spin-1 mediator simplified models, for each signature considered in this paper.

| Model and Final State | UFO | Generator and Parton Shower | Cross-section | Additional details |
|---|---|---|---|---|
| $Z'(\chi\bar{\chi}) + j$ | DMV [26, 215] | POWHEG-BOX v2 [216] + PYTHIA 8.205 [217] | NLO | Particle-level rescaling of leptophobic $Z'_A$ scenario of Ref. [26] (see Appendix A.1) |
| $Z'(\chi\bar{\chi}) + \gamma$ | DMSimp [116, 218] | MG5_aMC@NLO 2.4.3 (NLO) [213] + PYTHIA 8.212 | NLO | Leptophobic $Z'_A$ scenario simulated, other scenarios obtained by cross-section rescaling (see Appendix A.1) |
| $Z'(\chi\bar{\chi}) + V$ | DMSimp | MG5_aMC@NLO 2.5.3 (NLO) + PYTHIA 8.212 | NLO | Particle-level rescaling of LO samples of Ref. [20] to each of the four NLO scenarios (see Appendix A.1) |
| $Z'(qq)$ or $Z'(qq)$+ISR | DMSimp | MG5_aMC@NLO 2.2.3 (NLO) + PYTHIA 8.210 | NLO | Leptophobic $Z'_A$ scenario simulated, other scenario obtained by Gaussian resonance limits and cross-section rescaling [214] |
| $Z'(b\bar{b})$ | DMSimp | MG5_aMC@NLO 2.2.3 (NLO) + PYTHIA 8.210 | NLO | Leptophobic $Z'_A$ scenario simulated, other scenario obtained by Gaussian resonance limits and cross-section rescaling [214] |

# DMsimp: Simplified dark matter models

## Authors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## Description of the model

This is simplified dark matter models for NLO.

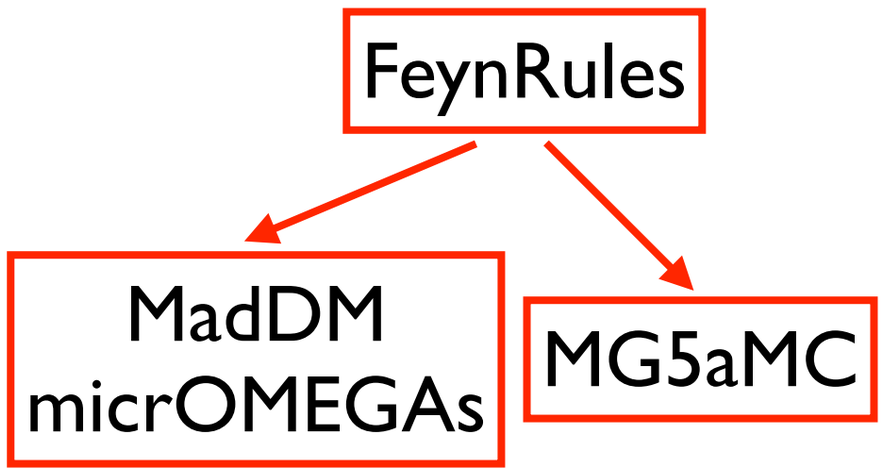
The mixed spin-0 mediator model is a LO model for MadDM with the inclusion of effective ggY and aaY couplings.

Our lagrangian consists of different types of DM:

- Xr (real scalar DM)
- Xc (complex scalar DM)
- Xd (Dirac spinor DM)
- Xm (Majorana spinor DM) [to be done.]
- Xv (vector DM)
- ...

and different types of mediators:

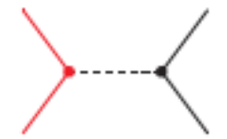
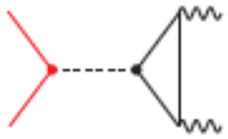
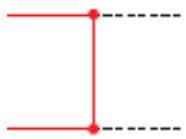
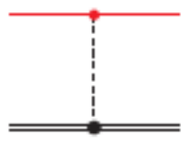
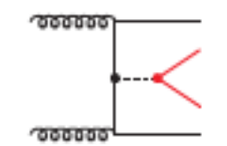
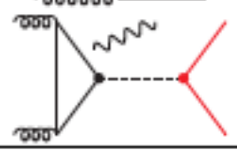
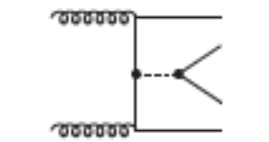
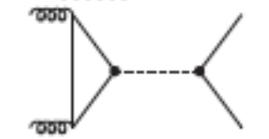
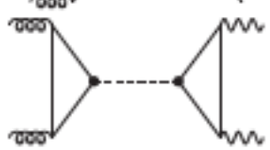
- s-channel
  - Y0 (spin-0)
  - Y1 (spin-1)
  - Y2 (spin-2)
  - ...
- t-channel [to be done.]




See more details in

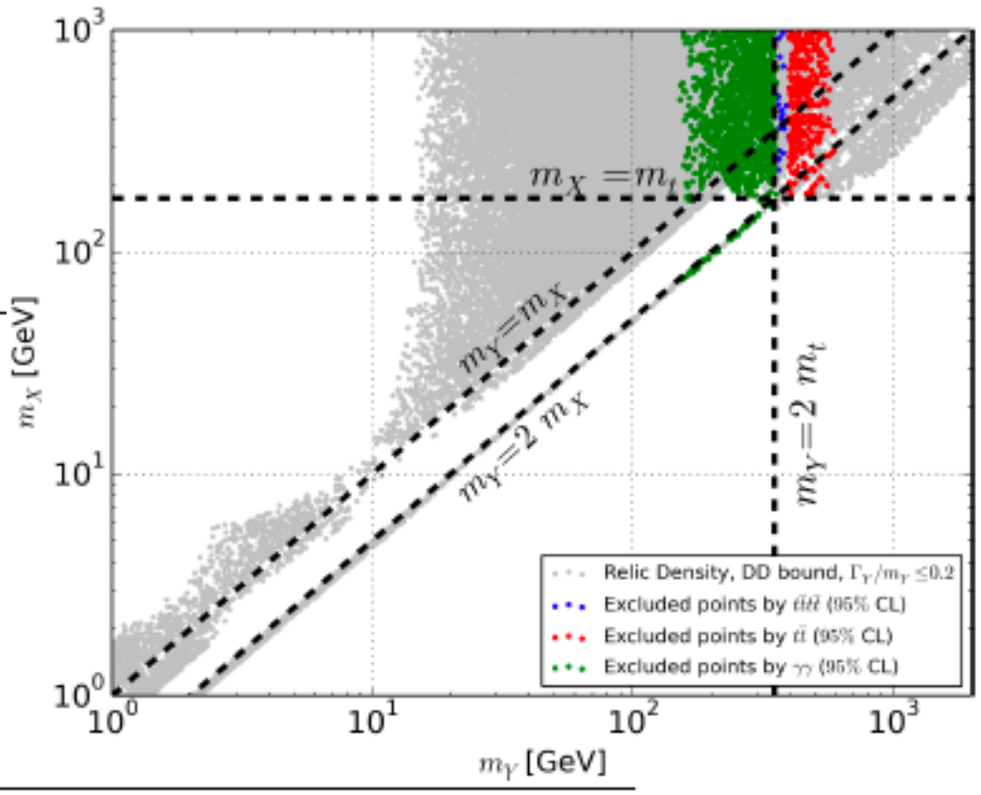

- 1508.00564 : O. Mattelaer, E. Vryonidou, "Dark matter production through loop-induced processes at the LHC: the s-channel mediator case" (EPJC75(2015)436).
- 1508.05327 : M. Backovic, M. Kramer, F. Maltoni, A. Martini, K. Mawatari, M. Pellen, "Higher-order QCD predictions for dark matter production at the LHC in simplified models with s-channel mediators" (EPJC75(2015)482).
- 1509.05785 : M. Neubert, J. Wang, C. Zhang, "Higher-order QCD predictions for dark matter production in mono-Z searches at the LHC"

# A comprehensive simplified DM study: s-channel spin-0

| | | | | |
|---|---|---|---|---|
| Cosmology | relic |  | $m_X > m_t$ | Arina, Backovic, Conte, Fuks, Guo, Heisig, Hespel, Kraemer, Maltoni, Martini, KM, Pellen, Vryonidou [1605.09242, JHEP] |
| | |  | $m_X < m_t$ | Planck, FermiLAT |
| Astrophysics | indirect |  | $m_X > m_Y$ | |
| | direct |  | $m_X > 1$ GeV | LUX, CDMSLite |
| Colliders | $\not{E}_T$ |  | $m_Y > 2m_X$ | |
| | |  | $m_Y > 2m_X$ | |
| | no $\not{E}_T$ |  | $m_Y > 2m_t$ | |
| | |  | $m_Y > 2m_t$ | |
| | |  | $m_Y < 2m_X$, | |

$$\mathcal{L}_{t,X}^{Y_0} = -\left(g_t \frac{y_t}{\sqrt{2}} \bar{t}t + g_X \bar{X}X\right) Y_0$$

X=DM
Y=mediator



# Spin-2 model: MET vs. resonance searches

Kraml, Laa, KM, Yamashita [1701.07008, EPJC]

$$\mathcal{L}_X^{Y_2} = -\frac{1}{\Lambda} g_X^T T_{\mu\nu}^X Y_2^{\mu\nu} \qquad \mathcal{L}_{\rm SM}^{Y_2} = -\frac{1}{\Lambda} \sum_i g_i^T T_{\mu\nu}^i Y_2^{\mu\nu}$$

$$g_{\rm SM} \equiv g_H^T = g_q^T = g_\ell^T = g_g^T = g_W^T = g_B^T$$

$$\{m_X,\, m_Y,\, g_X/\Lambda,\, g_{\rm SM}/\Lambda\}$$