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The Search for Dark Matter at Colliders

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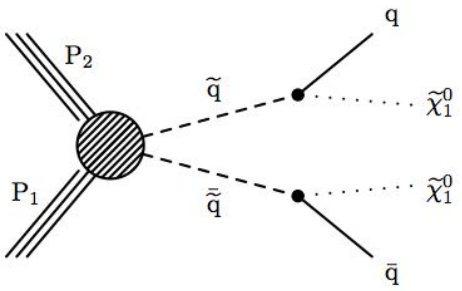
On behalf of MasterCode collaboration

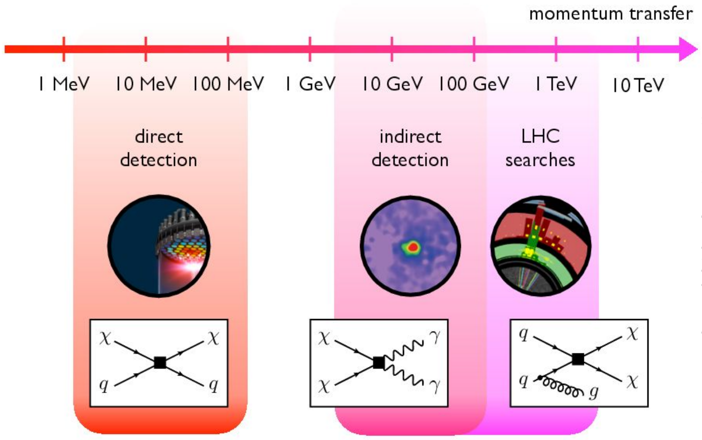
LHC (re)interpretation workshop
03 April 2019

Dark Matter Simplified Models

- The nature of Dark Matter (DM) is one of the most pressing issues in contemporary physics
- Weakly-interacting massive particles (WIMPs)
    - Weigh $\mathcal{O}$(TeV)
    - It could be produced at the LHC
- Several approaches to DM searches at the LHC
    - Models that predict WIMPs capable of providing the cold DM
    - SUSY
    - Production of heavier new particles
    - Direct production of DM particles in association with a single SM particle (mono-X signature).

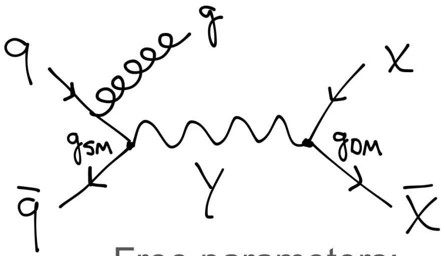


Dark Matter Simplified Models



arXiv: 1810.09420

- Effective Field Theory (EFT)
  - Focus on the mono-X signatures
  - Drawback: DM/SM interactions are likely to be mediated by particles in the TeV mass range
  - LHC might be capable of producing the mediator particle directly.
- Dark Matter Simplified Models (DMSMs)
  - Effective Lagrangians that include explicitly the mediator particle and its interactions with both DM and SM particles.
  - Mediators of spin one (vector and axial-vector) Y (this work)
  - Interactions are leptophobic
  - DM particle is a neutral Dirac fermion χ
  - Y-quark interactions are generation-independent



Free parameters:

$$m_Y\,,\,m_\chi\,,\,g_{SM}\,,\,g_{DM}$$

MasterCode framework

- Experimental results are often interpreted for fixed values of the couplings
- A more general approach is desirable for combining the direct DM constraints with those from the LHC
  - Obtaining the preferred cosmological value of $\Omega_\chi h^2$ requires values of g_{DM} and g_{SM} that depend on m_χ and m_Y.

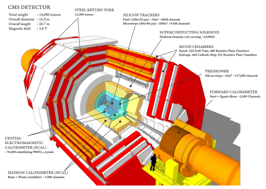
micrOMEGAS

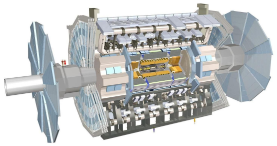
Madgraph5_aMC@NLO

DMSIMP

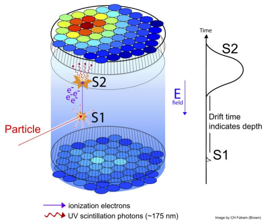
MultiNest

$$\chi^2 = \sum_{i}^{N_{meas}} \left(\frac{P_i - C_i}{\sigma_i} \right)^2$$





Collider data



Direct Detection

DM density

Astrophysical and LHC Constraints

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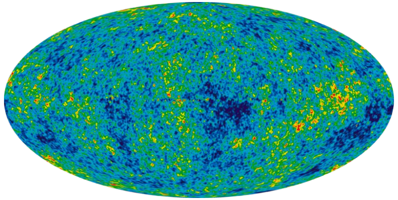
Dark Matter density



Density of cold DM in the Universe is constrained by Planck measurements of the cosmic microwave background:

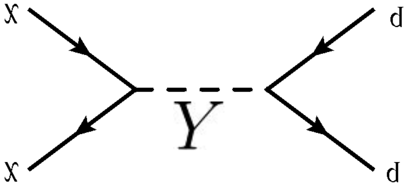
$$\Omega_{CDM}h^2 = 0.120 \pm 0.001$$

If dominant source is the WIMP:

$$\Omega_\chi h^2 \simeq \Omega_{CDM}h^2$$

$$\Omega_\chi h^2 \propto \frac{1}{\langle \sigma v \rangle}$$

Annihilation cross-section

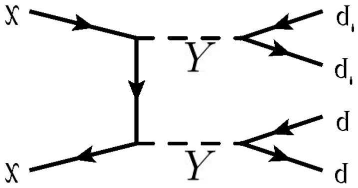


s-channel

$$\chi\chi \to Y^* \to SM$$

Resonant region

$$m_Y \simeq 2m_\chi$$



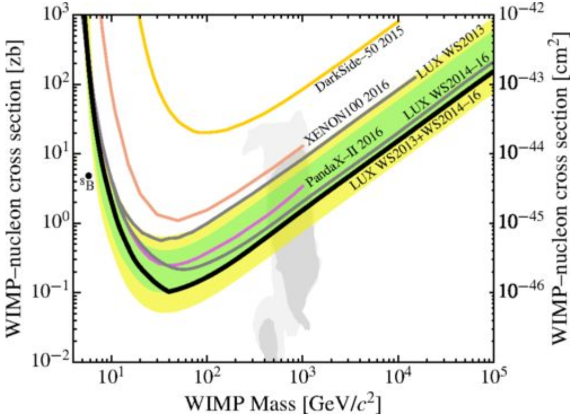
t-channel

$$\chi\chi \to YY$$

$$m_\chi > m_Y$$

Spin-dependent and -independent DM scattering

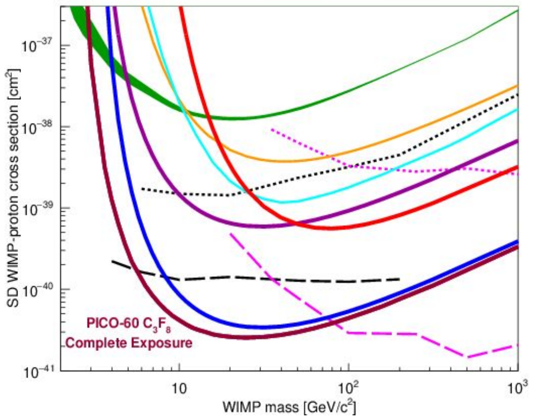
σ_p^{SI}



arXiv:1608.07648

LUX + PandaX-II + XENON1T

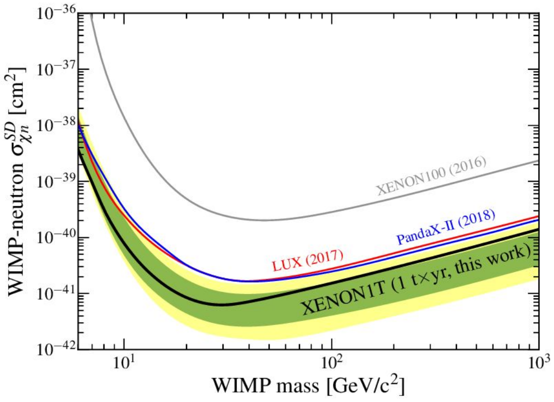
σ_p^{SD}



arXiv:1902.04031

PICO-60

σ_n^{SD}



arXiv:1902.03234

XENON1T

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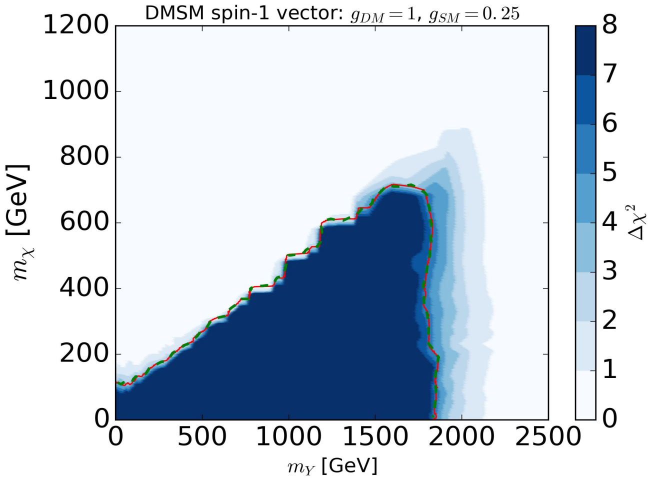
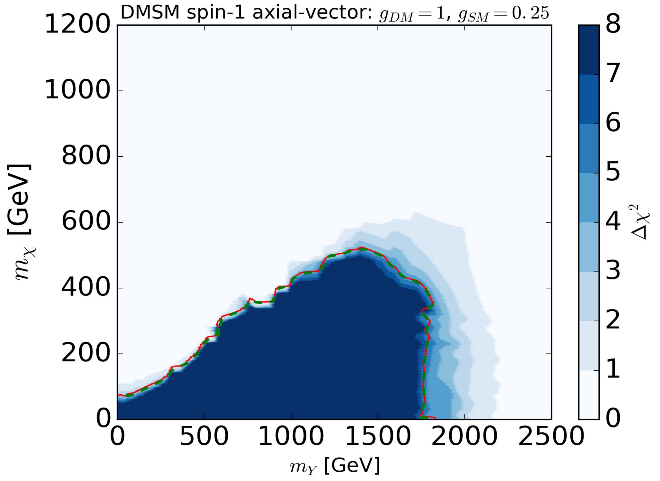
Monojet Constraints

CMS 35.9/fb of data from collisions @ 13 TeV
Signal regions targeting monojet final states





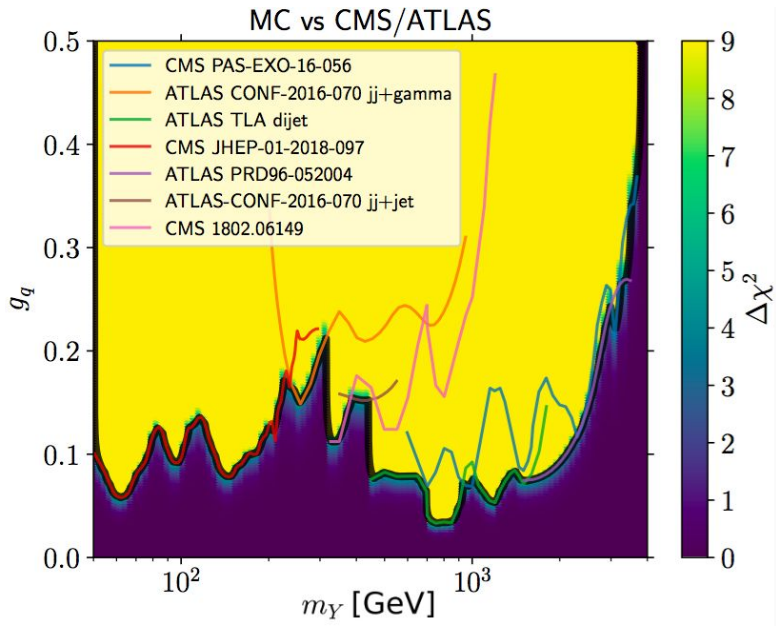
$$\Delta\chi^2 = 5.99 \times \left(\frac{1}{R_i^{\mathrm{UL}}(\mathbf{m})} \frac{\sigma_{\mathrm{MG}}(\mathbf{m})}{\sigma_{\mathrm{MG}}^{\mathrm{fix}}(\mathbf{m})} \right)^2$$

Dijet Constraints

ATLAS and CMS

constraints from dijet invariant distributions on *Z'* resonances.

$$\Delta\chi^2 = 4 \times \left(\left[\frac{g_{SM}^4}{\Gamma_q + \Gamma_\chi} \right] / \left[\frac{(g_{SM}^*)^4}{\Gamma_q(g_{SM}^*) + \Gamma_\chi} \right] \right)^2$$



Preliminary results

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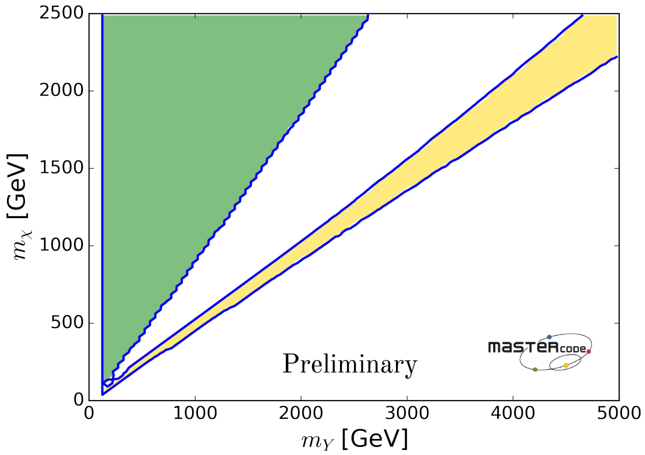
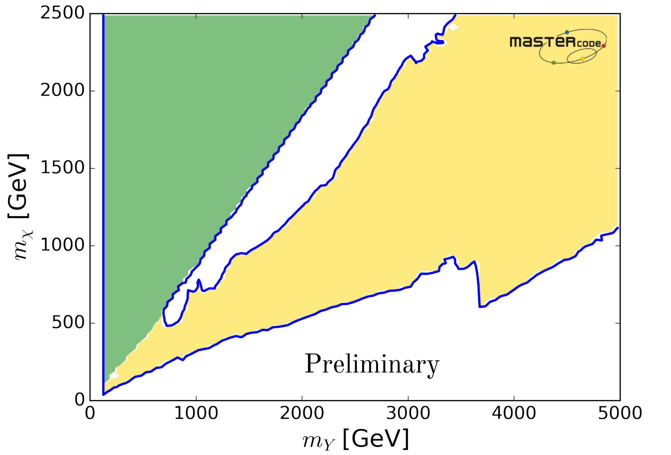
Mass plane

DMSM spin-1 Vector



DMSM spin-1 Axial-Vector



blue contours: 95% CL

t-channel $\chi\chi \to YY$

s-channel $\chi\chi \to Y^* \to SM$

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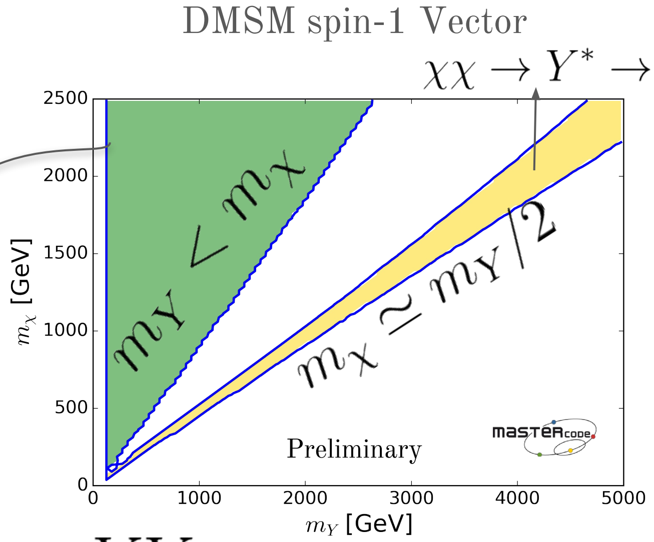
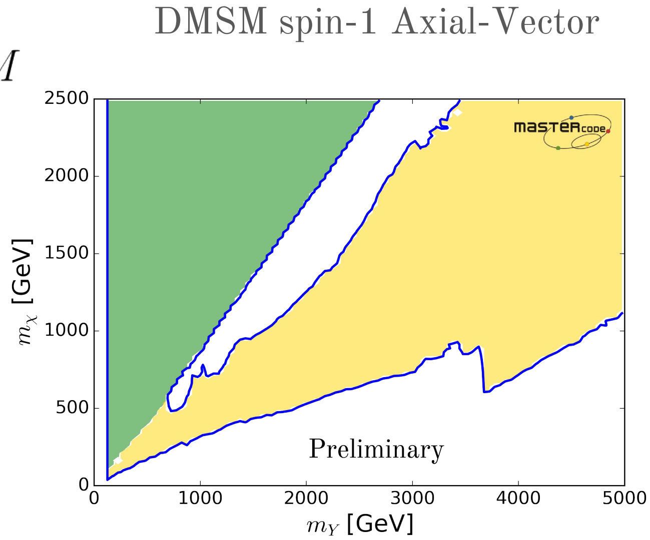
Mass plane

$\chi\chi \to Y^* \to SM$





$\chi\chi \to YY$

Annihilation cross-section

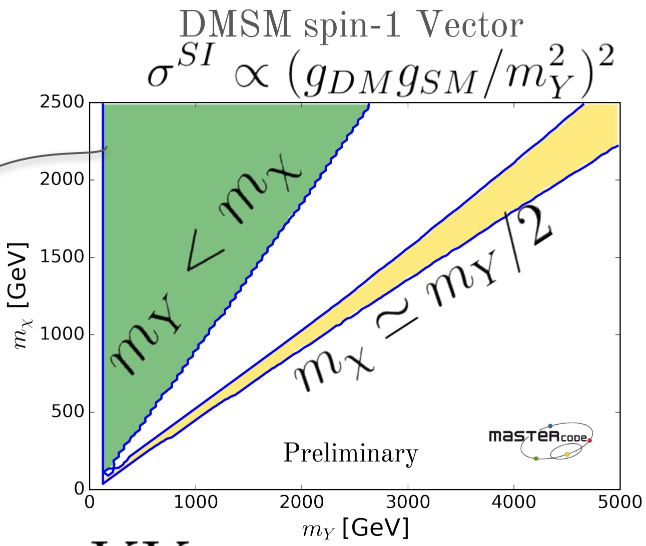
Proportional to g_{DM}^4

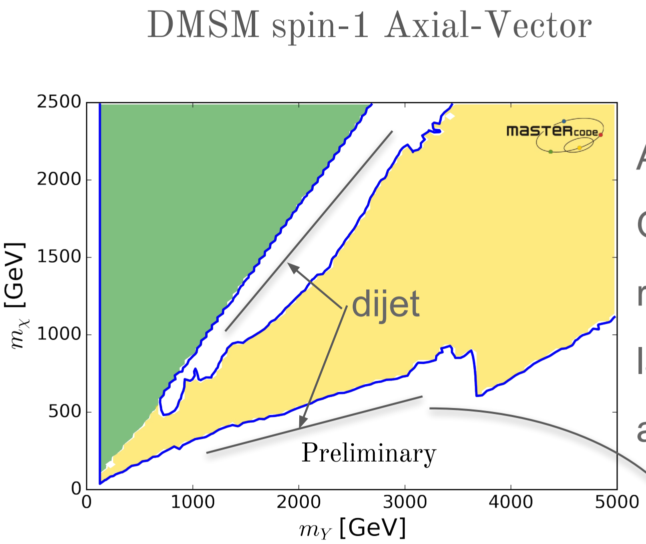
Independent of g_{SM}

t-channel

s-channel

Mass plane





Absent σ_p^{SI}

Off-resonance regions with larger $g_{DM} g_{SM}$ allowed

$\chi\chi \rightarrow YY$

Annihilation cross-section

Proportional to g_{DM}^4

Independent of g_{SM}

t-channel

s-channel

$m_Y > 2m_\chi$

$Y \rightarrow \chi\chi$

$BR(Y \rightarrow jj) < 100\%$

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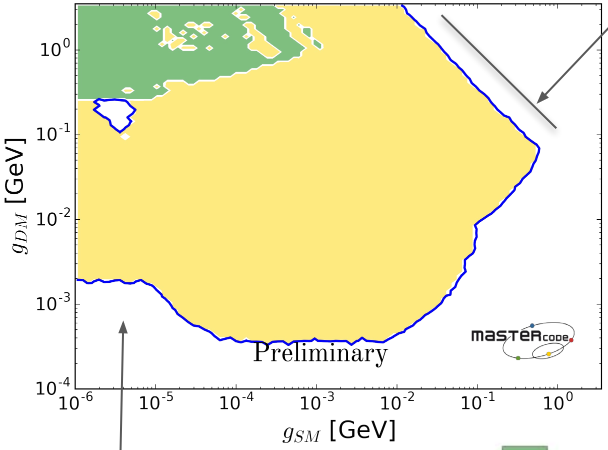
Coupling plane

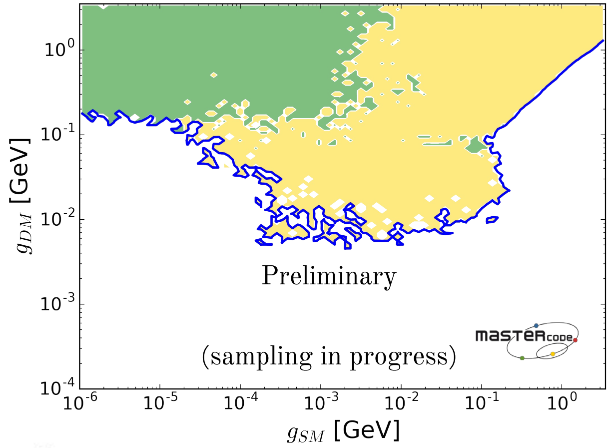
DMSM spin-1 Vector

$$\sigma^{SI} \propto (g_{DM} g_{SM}/m_Y^2)^2$$



overdense

DMSM spin-1 Axial-Vector

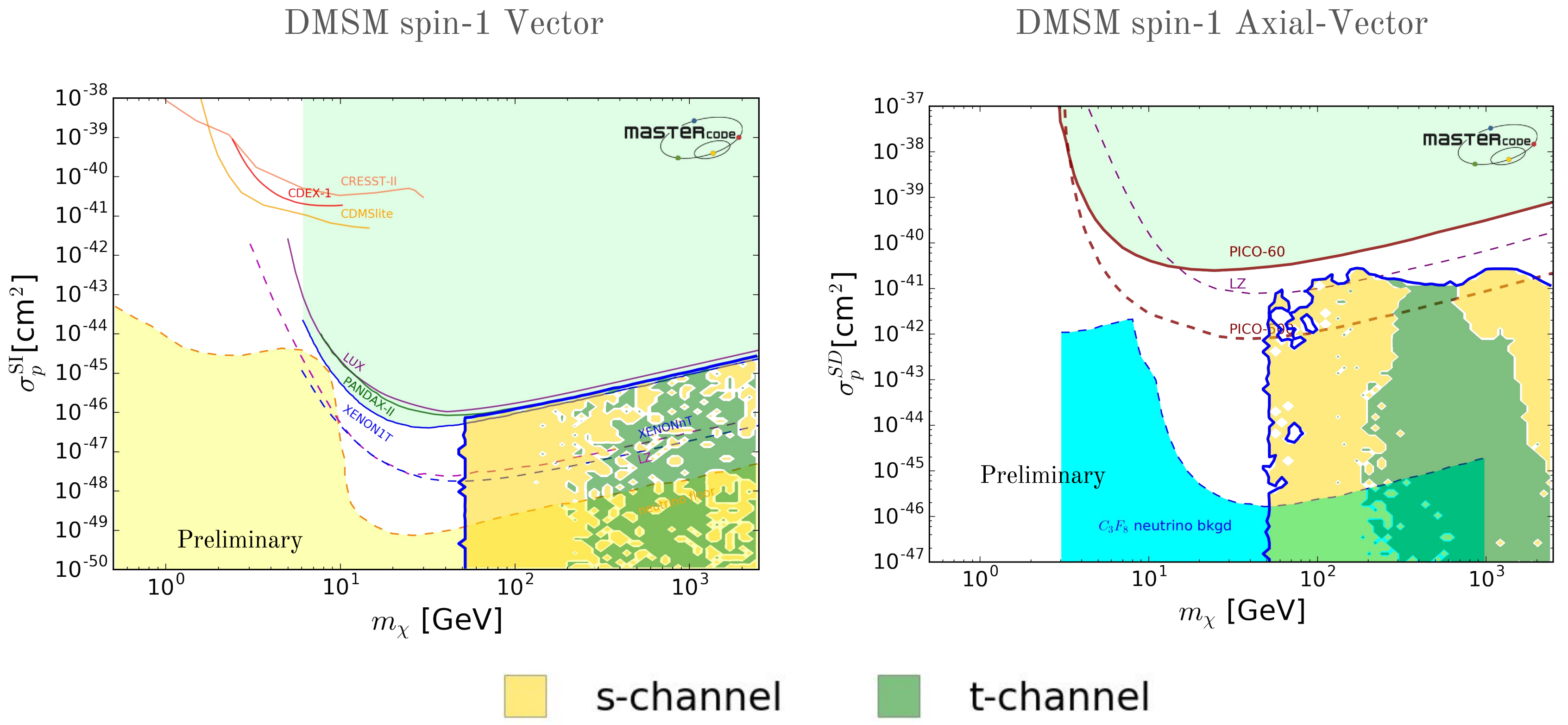


t-channel

s-channel

$$\Omega_\chi h^2 \propto m_Y^2/g_{DM}^2$$

Direct Detection



Summary

- Global analysis of DMSMs using MasterCode
  - Vector and axial-vector mediators
  - Four free parameters: $m_Y, m_\chi, g_{SM}, g_{DM}$
- Astrophysical and LHC constraints
  - Monojet and Dijet (LHC)
  - Cosmological constraint on DM density
  - Upper limits on spin-independent and -dependent scattering on nuclei.
- Two main mechanisms to bring the cosmological DM density into the allowed region:
  - Annihilation via t-channel X exchange and annihilation via Y boson in the s-channel
- σ_p^{SI} within the range accessible to the upcoming LZ and XENONnT experiments (may be also be below the neutrino floor)
- σ_p^{SD} within reach of upcoming PICO-500 and LZ experiments.

Thank you

cern.ch/mastercode