
ALEXIS

Global Fit to Dark Matter with Leptophobic Mediators

Sven Heinemeyer, IFT/IFCA (CSIC, Madrid/Santander)

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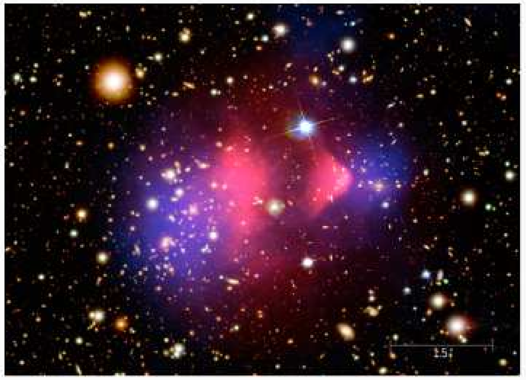
1. Introduction
2. Set-up and validation
3. General Results
4. Towards UV completions
5. Conclusions

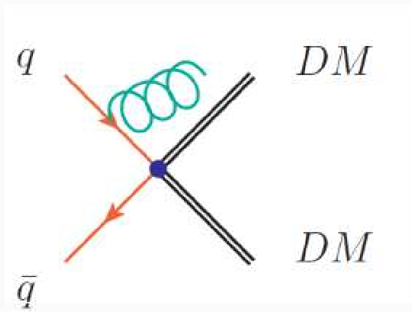
Dark Matter @ LHC

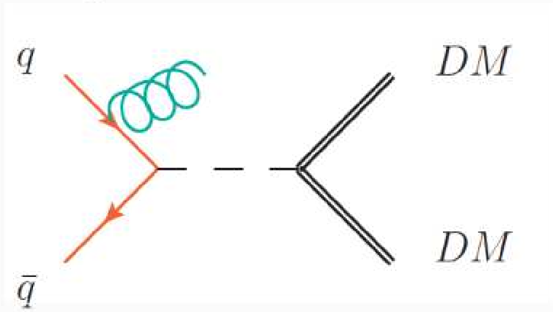
- We infer the existence of Dark Matter (DM) from indirect observations (cosmological, astrophysical).
- Can we probe DM at the LHC? Yes, if we assume that it couple sufficiently strongly to the SM (freeze-out points to that). *Unknown: the mass.*
- DM searches at the LHC fully underway.



How to predict the signals and interpret the results? Different possibilities have been studied:

1. EFT approach.
2. *Dark Matter Simplified Models*
3. Complete models (e.g. SUSY).

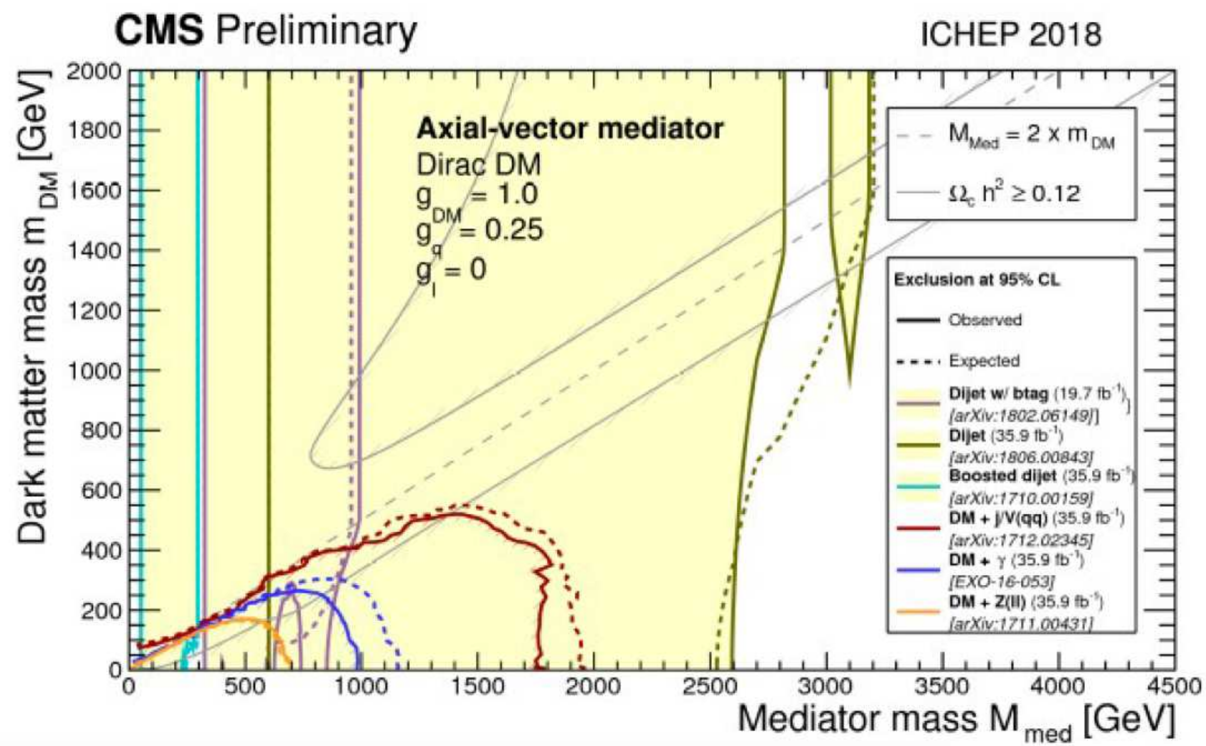




[*taken from E. Bagnaschi*]

Spin-1 mediator

- Interaction Lagrangian mediator-DM
  $\mathcal{L}_{X_D}^{Y_1} = \bar{X}_D \gamma_\mu \left(g_{X_D}^V + g_{X_D}^A \gamma_5 \right) X_D Y_1^\mu .$
- Interaction Lagrangian mediator-quarks
  $\mathcal{L}_{quarks}^{Y_1} = \sum_{i,j} \left[\bar{d}_i \gamma_\mu \left(g_{d_{i,j}}^V + g_{d_{i,j}}^A \gamma_5 \right) d_j + \bar{u}_i \gamma_\mu \left(g_{u_{i,j}}^V + g_{u_{i,j}}^A \gamma_5 \right) u_j \right] Y_1^\mu$
- Interaction Lagrangian mediator-leptons
  $\mathcal{L}_{leptons}^{Y_1} = \sum_{i,j} \left[\bar{l}_i \gamma_\mu \left(g_{l_{i,j}}^V + g_{l_{i,j}}^A \gamma_5 \right) l_j \right] Y_1^\mu$

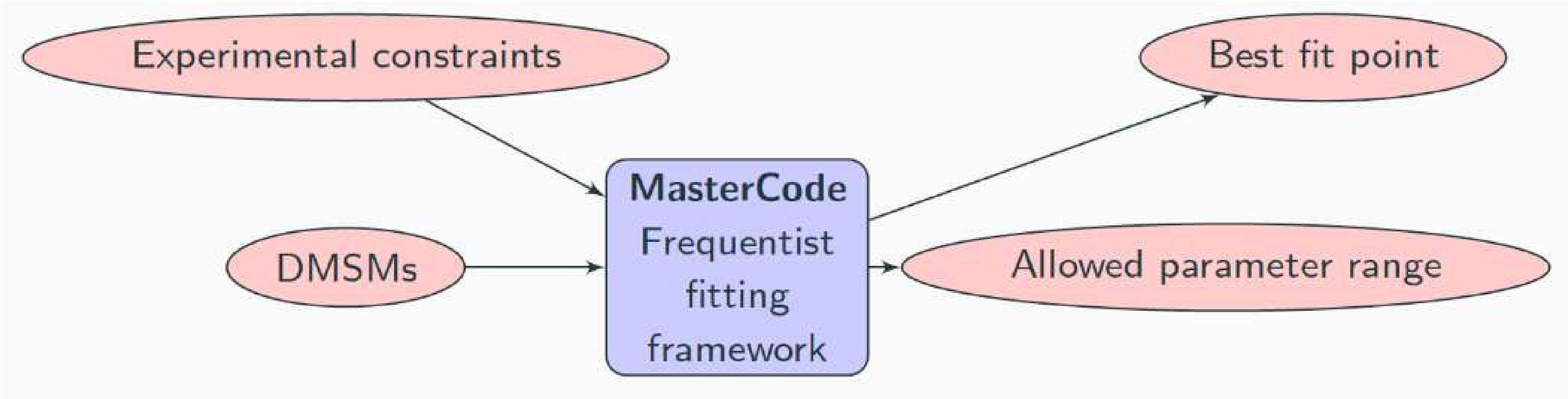


- simplifying assumptions on the Lagrangian (more soon)
- Results for fixed values of $m_{\rm med}$, $m_{\rm DM}$, $g_{\rm SM}$, $g_{\rm DM}$
- overlay results from mono-jet search
- overlay results from di-jet searches
- . . .

MasterCode approach

[2019]

Fit to the full Lagrangian (some simplifying assumptions)



Included into the fit:

– DM relic density
– DM direct detection limits
– LHC mono-jet searches
– LHC di-jet searches

⇒ global picture of status and prospects

2. Set-up and validation

Lagrangian according to LHC-DM-WG recommendation:

The Lagrangians

- We consider DMSMs with a spin-1 (Y_1) s-channel mediator.
- The dark matter candidate is a Dirac fermion (X_D).
- We use the model files provided by the `DMSIMP` package for our implementation.

Spin-1 mediator

- Interaction Lagrangian mediator-DM
  $\mathcal{L}^{Y_1}_{X_D} = \bar{X}_D \gamma_\mu \left(g^V_{X_D} + g^A_{X_D} \gamma_5 \right) X_D Y_1^\mu.$
- Interaction Lagrangian mediator-quarks
  $$\mathcal{L}^{Y_1}_{quarks} = \sum_{i,j} \Big[\bar{d}_i \gamma_\mu \left(g^V_{d_{i,j}} + g^A_{d_{i,j}} \gamma_5 \right) d_j + \bar{u}_i \gamma_\mu \left(g^V_{u_{i,j}} + g^A_{u_{i,j}} \gamma_5 \right) u_j \Big] Y_1^\mu$$
- Interaction Lagrangian mediator-leptons
  $$\mathcal{L}^{Y_1}_{leptons} = \sum_{i,j} \Big[\bar{l}_i \gamma_\mu \left(g^V_{l_{i,j}} + g^A_{l_{i,j}} \gamma_5 \right) l_j \Big] Y_1^\mu$$

Scenarios

- Leptophobic, $g^V_{l_{i,j}} = g^A_{l_{i,j}} = 0$ (no constraints from dilepton searches).
- Flavor diagonal, $g^{V/A}_{u/d_{i,j}} = 0$ if $i \neq j$.
- Flavor blind, $g^{V/A}_{u_{i,j}} = g^{V/A}_{d_{i,j}}$.

1. $g^V_{X_D} \equiv g_{DM}$ $\quad g^V_{X_D} = 0$
   $g^V_{u/d} \equiv g_{SM}$ $\quad g^A_{u/d} = 0,$
   pure vector.
2. $g^V_{X_D} = 0$ $\quad g^V_{X_D} \equiv g_{DM}$
   $g^V_{u/d} = 0$ $\quad g^A_{u/d} = g_{SM},$
   pure axial-vector.

[taken from E. Bagnaschi]

MasterCode set-up :

- Frequentist fitting framework written in Python/Cython and C++
- Multinest algorithm is used to sample the parameter space
- udocker used for deployment

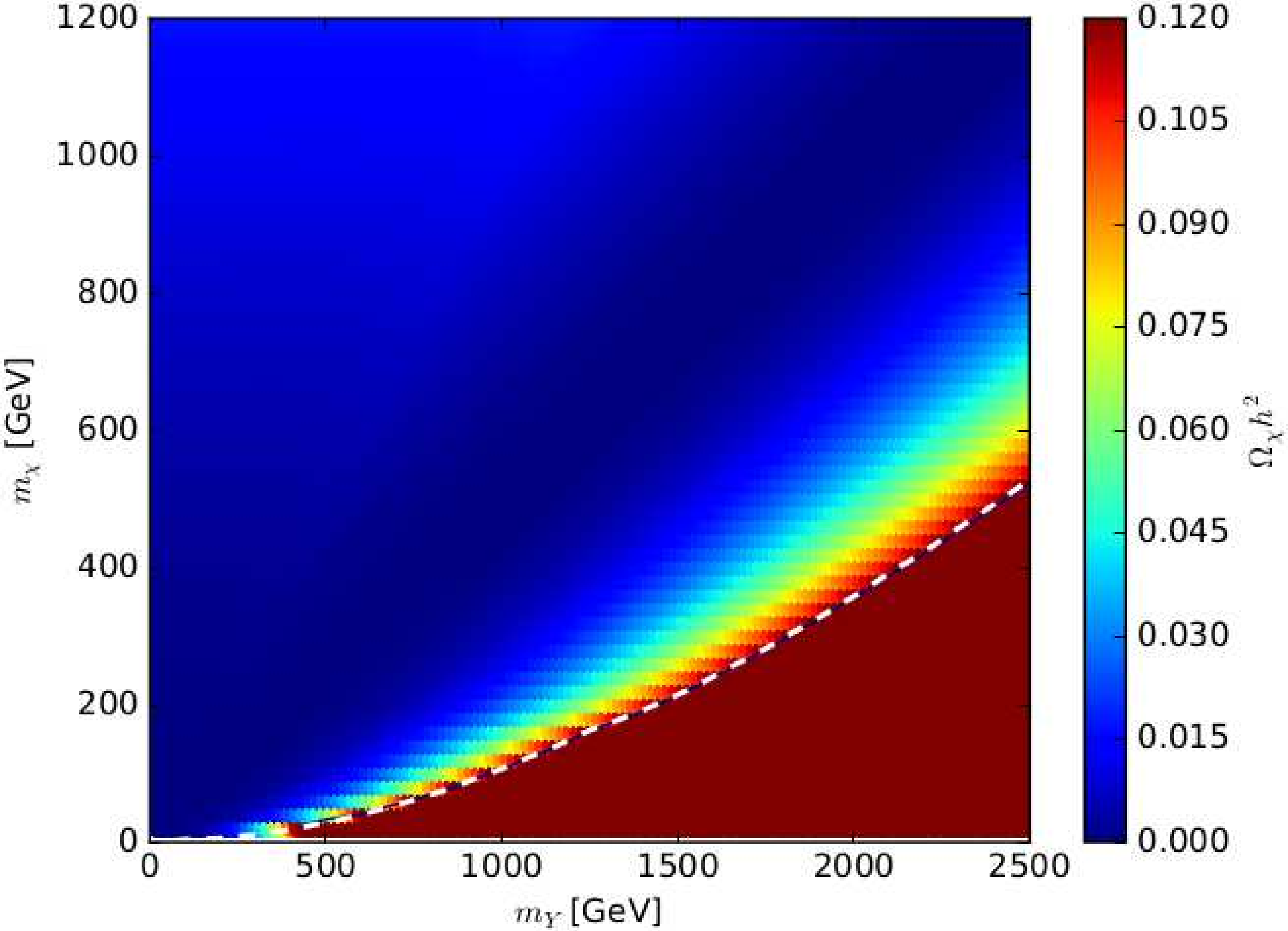
Scan ranges:

Parameter	Range	# of Segments
m_Y (mediator)	$(0.1, 5)$ TeV	10
m_χ (DM)	$(0, 2.5)$ TeV	8
$g_{\rm SM}$	$(10^{-6}, \sqrt{4\pi})$	2
$g_{\rm DM}$	$(10^{-6}, \sqrt{4\pi})$	2
Total # of segments		320

DM constraints:

[PRELIM.]

⇒ micrOMEGAs for relic density and DD cross sections

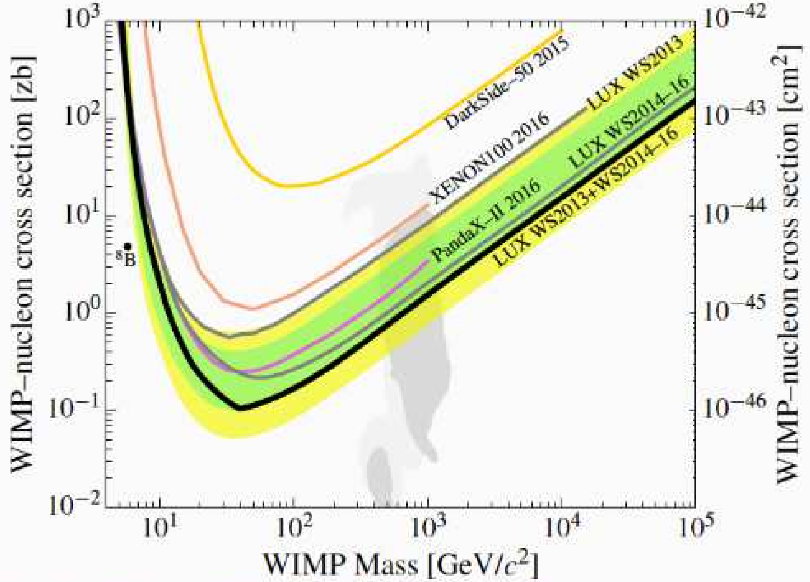


⇒ full agreement with ATLAS/CMS results (here: vector model)

Non-LHC constraints

Dark matter

- Relic density constraints from Planck.
- Direct detection constraints on σ_p^{SI} from LUX, XENON1T and PANDAX.
- Direct detection constraints on σ_p^{SD} from PICO60.



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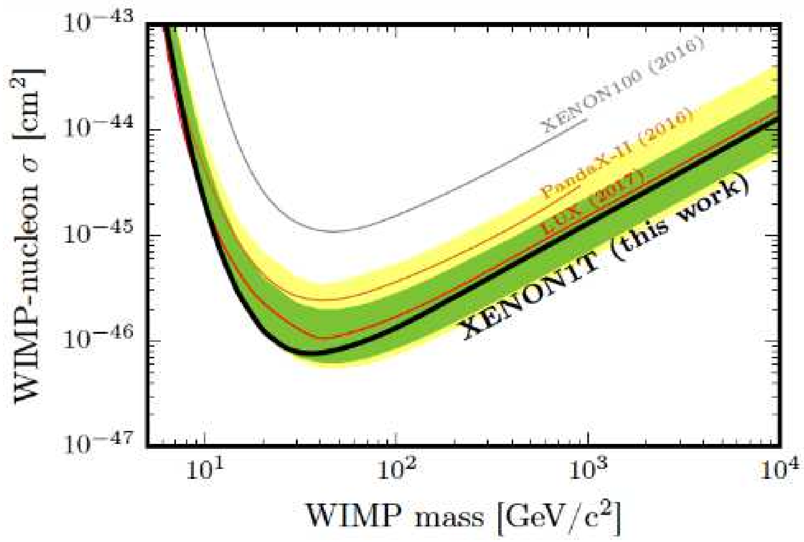
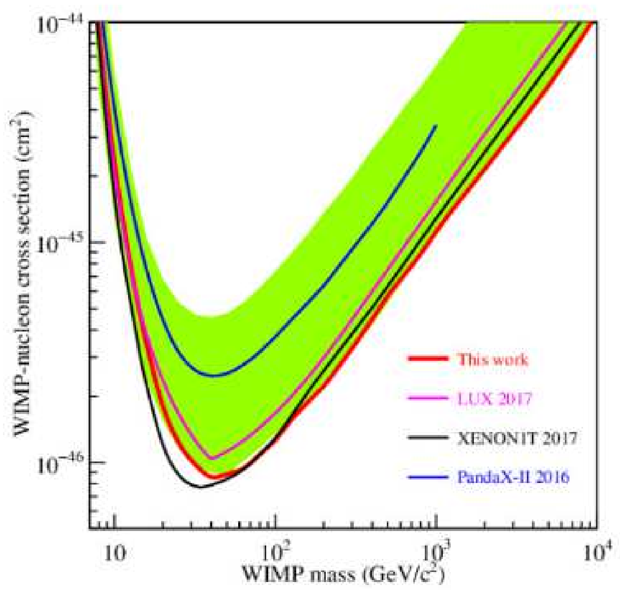


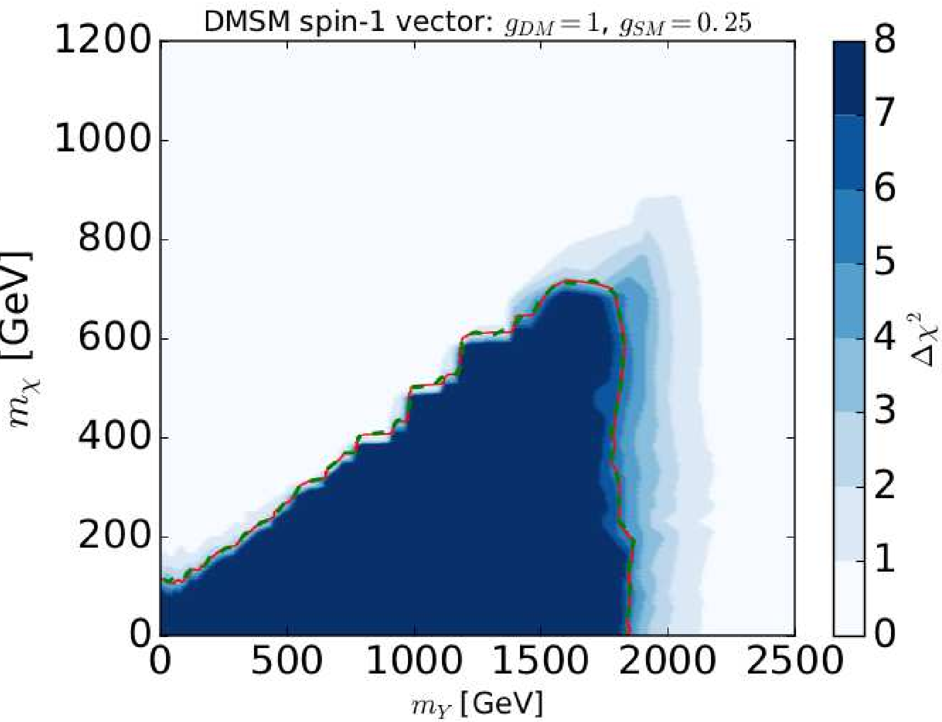


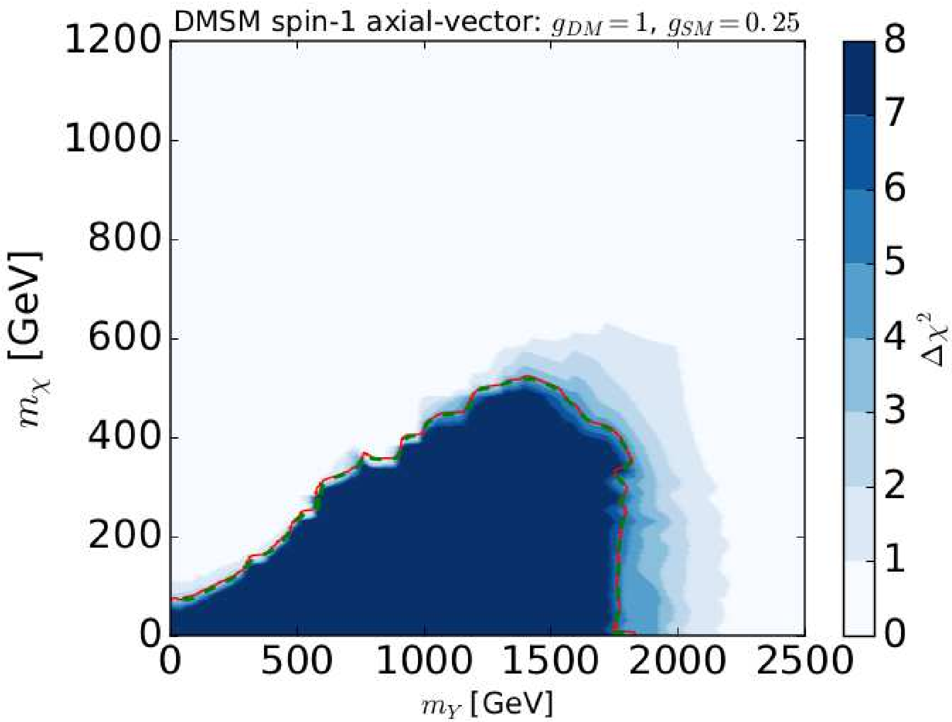
[*taken from E. Bagnaschi*]

Mono-jet constraints

[PRELIM.]

⇒ MG5 aMC(N)LO, Fastlim approach



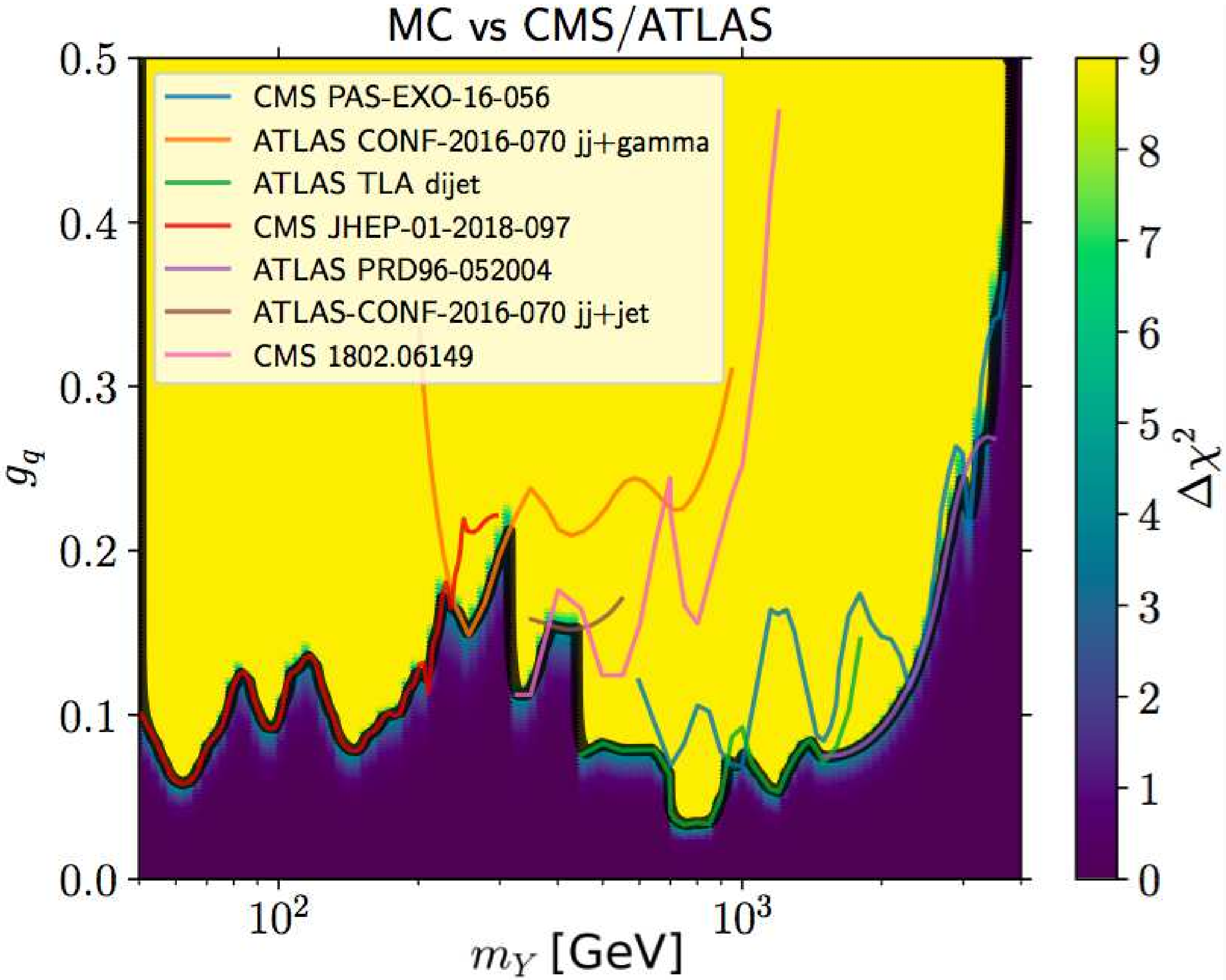


⇒ full agreement with ATLAS/CMS (red-dashed)

Di-jet constraints

[PRELIM.]

⇒ MG5 aMC(N)LO, Fastlim approach



⇒ full agreement with ATLAS/CMS

3. General Results

[PRELIM.]

– Results for vector mediator model

– Results for axial-vector mediator model

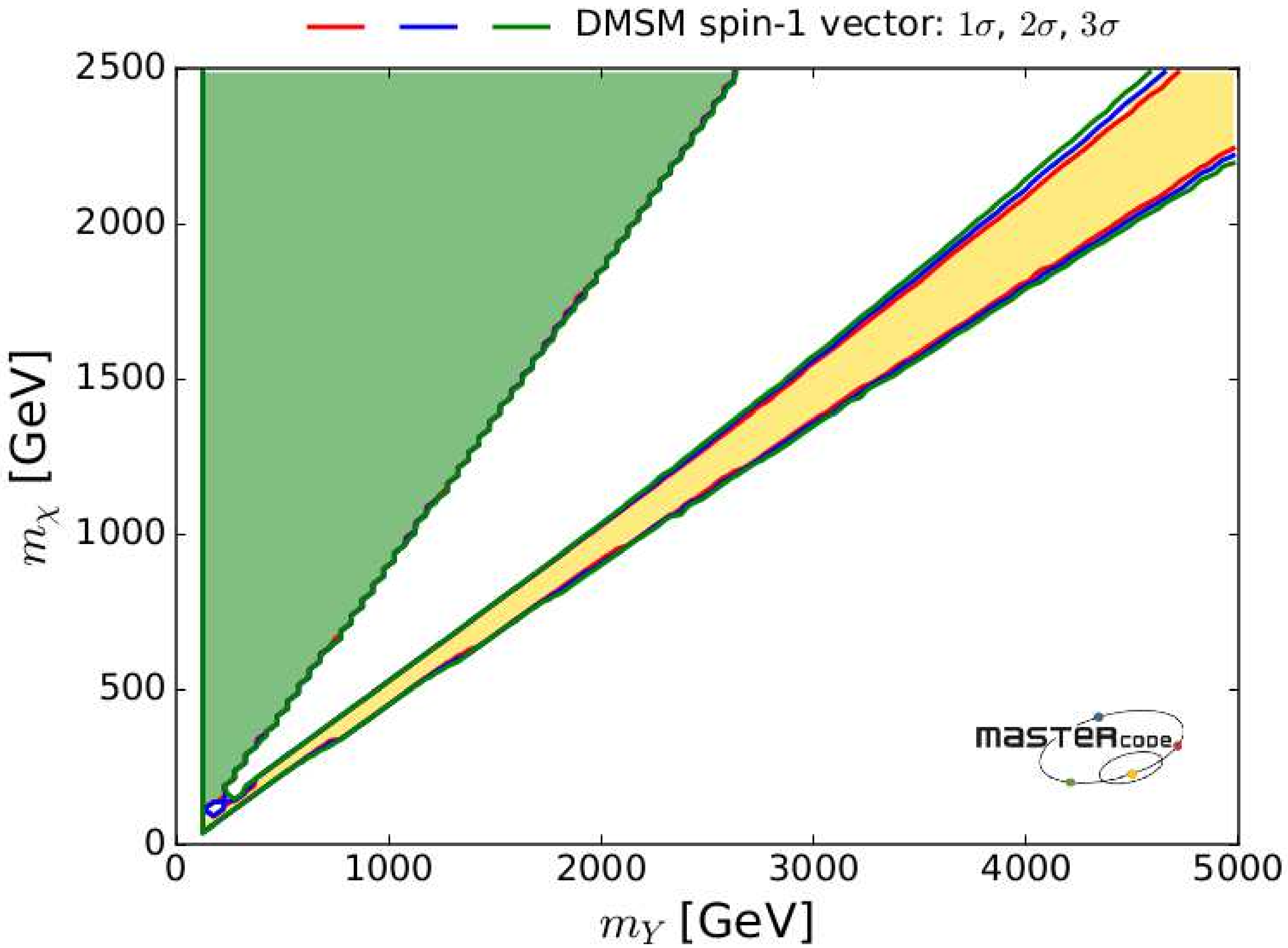
– No restrictions on couplings or masses

– Color coding:

green: annihilation via t-channel χ exchange
into pairs of mediator particles Y that subsequently decay
into SM particles

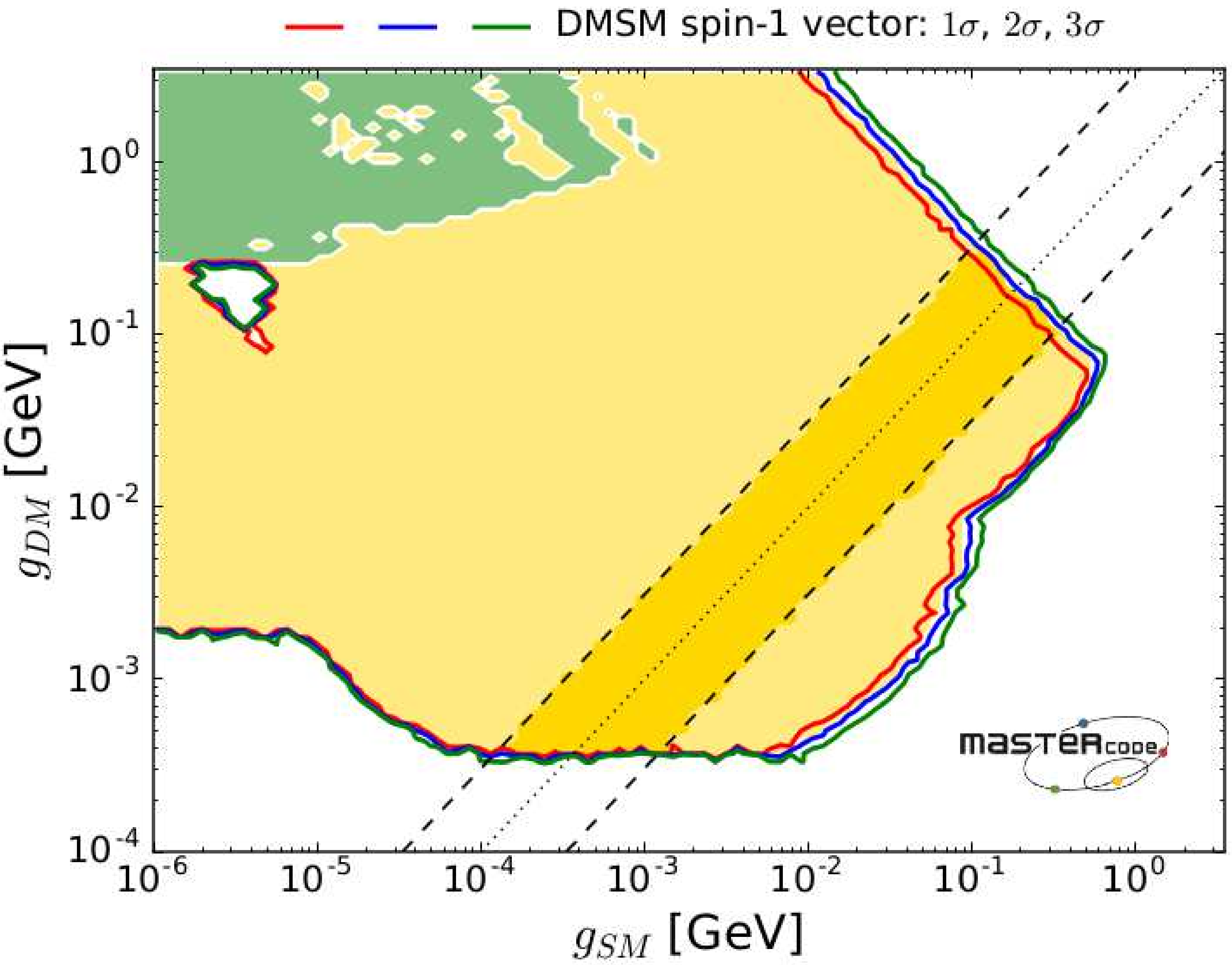
yellow: rapid annihilation directly into SM particles
via the s-channel Y resonance

Vector mediator (I): [PRELIM.]



$\Rightarrow$ clear separation between s- and t-channel

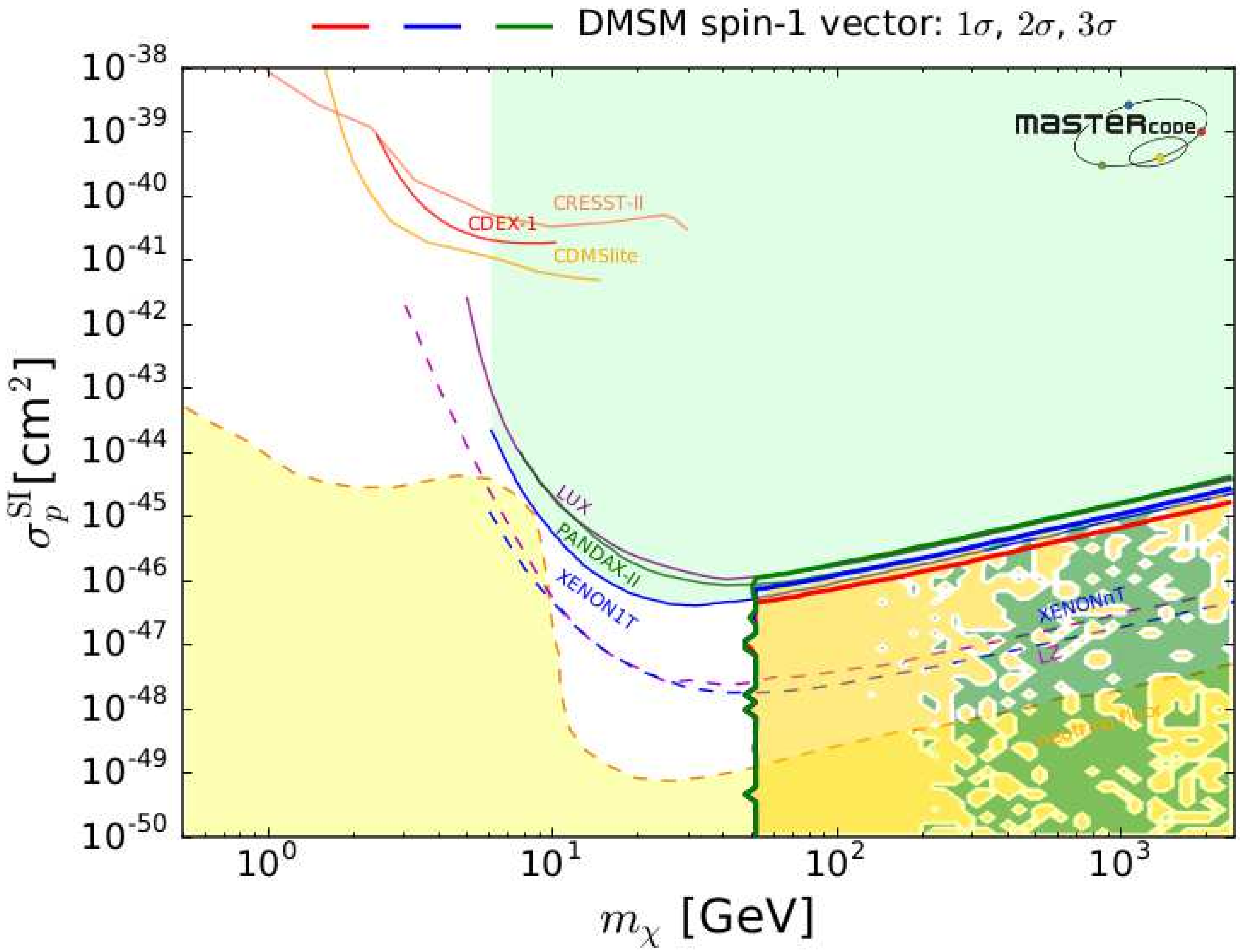
Vector mediator (II): [PRELIM.]



$\Rightarrow$ large ranges allowed, t-channel only for $g_{\rm DM} \gg g_{\rm SM}$

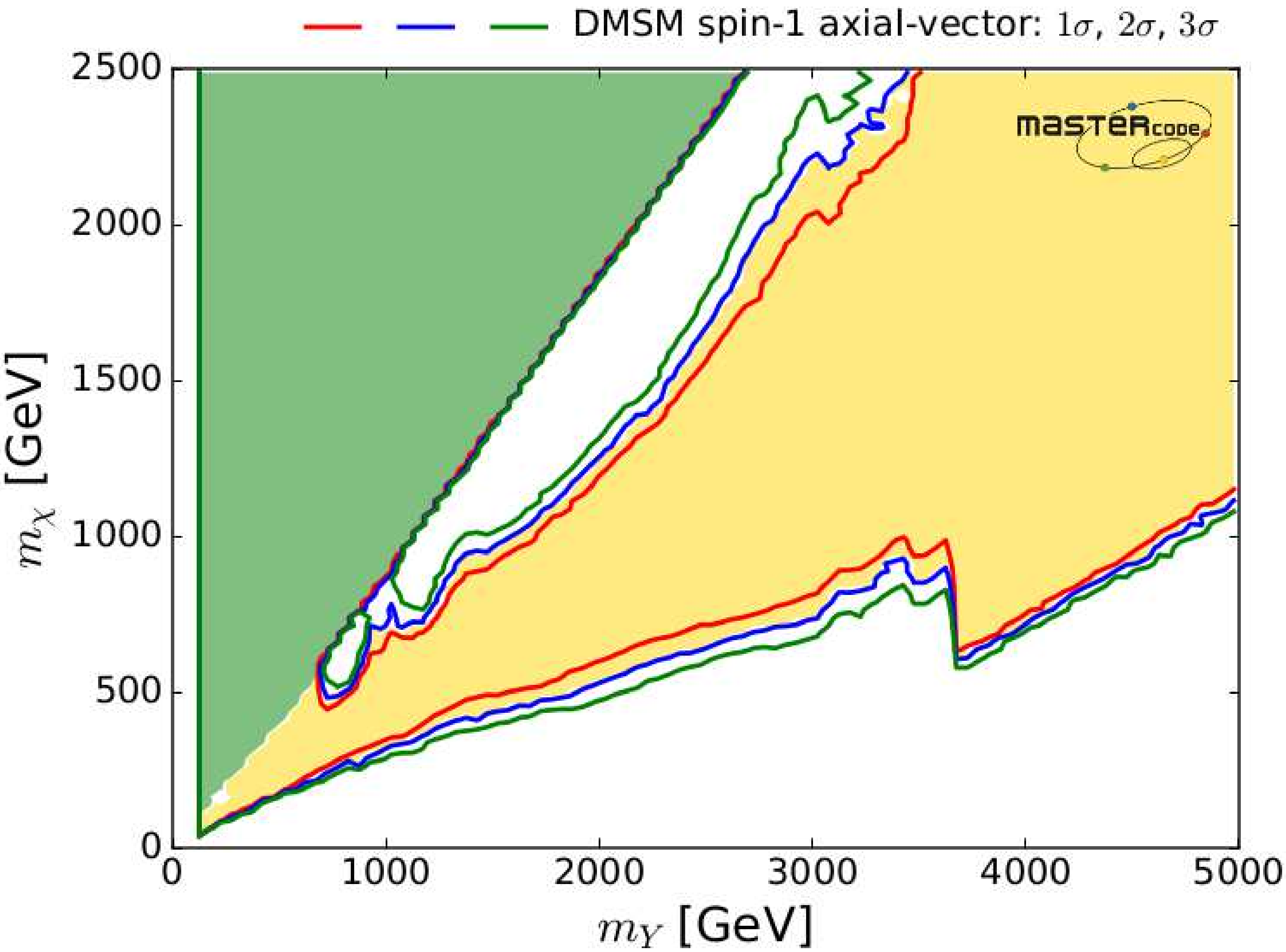
Vector mediator (III):

[PRELIM.]



⇒ mixed prospects, both for s- and t-channel case

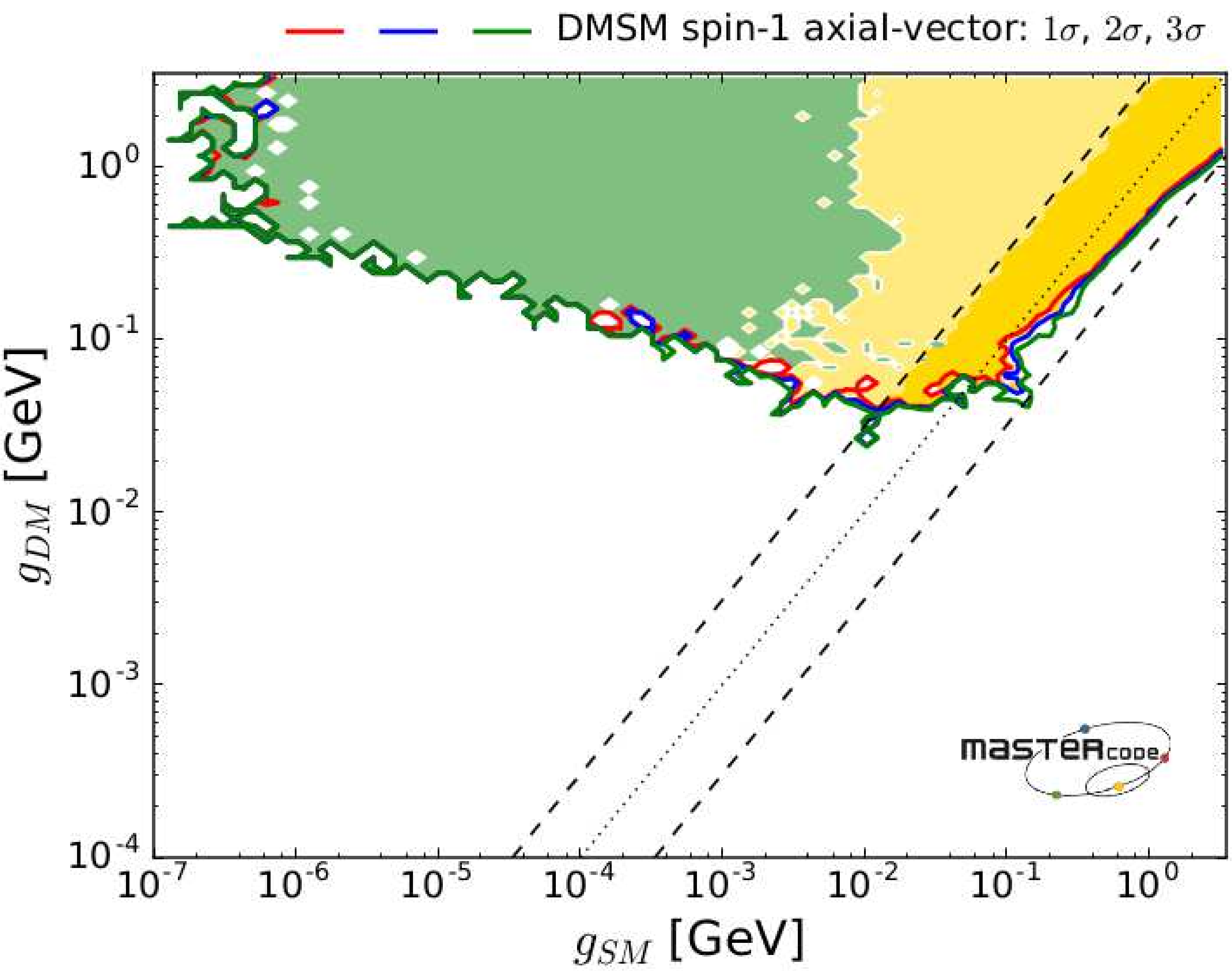
Axial-vector mediator (I): [PRELIM.]



⇒ Larger s-channel region, continous with t-channel

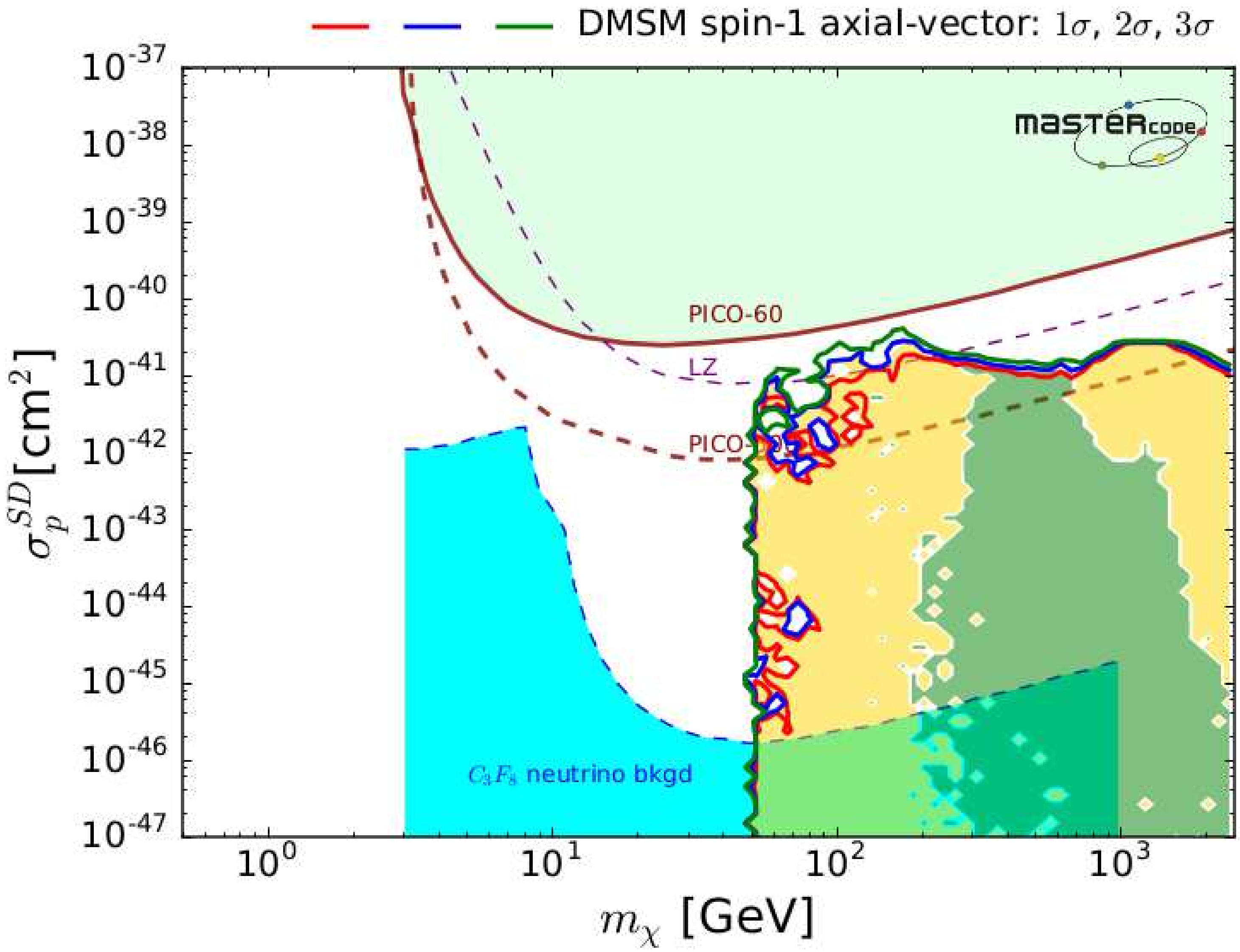
Axial-vector mediator (II):

[*PRELIM.*]



$\Rightarrow t$- (s-)channel for $g_{\rm SM} \lesssim (\gtrsim) 10^{-2}$

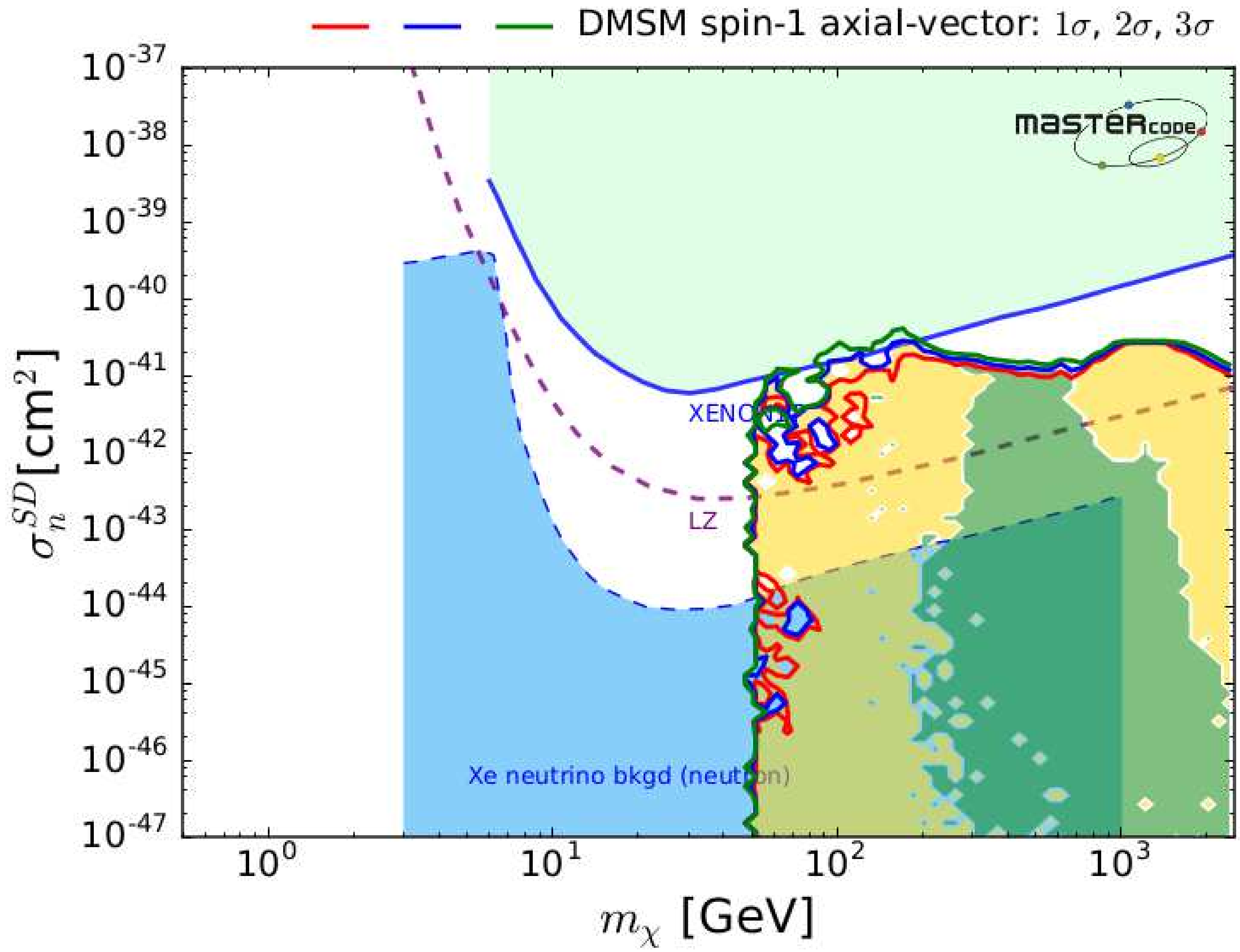
Axial-vector mediator (III): [PRELIM.]



$\Rightarrow$ will not be easy for PICO!

Axial-vector mediator (III):

[PRELIM.]



⇒ neither for LZ!

4. Towards UV completions

So far no UV completion considered!

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In any UV completion the spin-one boson could be expected to have comparable couplings to SM and DM particles, modulo possible group-theoretical factors and mixing angles!

$$g_{\text{DM}}/g_{\text{SM}} = \mathcal{O}(1)$$

4. Towards UV completions

So far no UV completion considered!

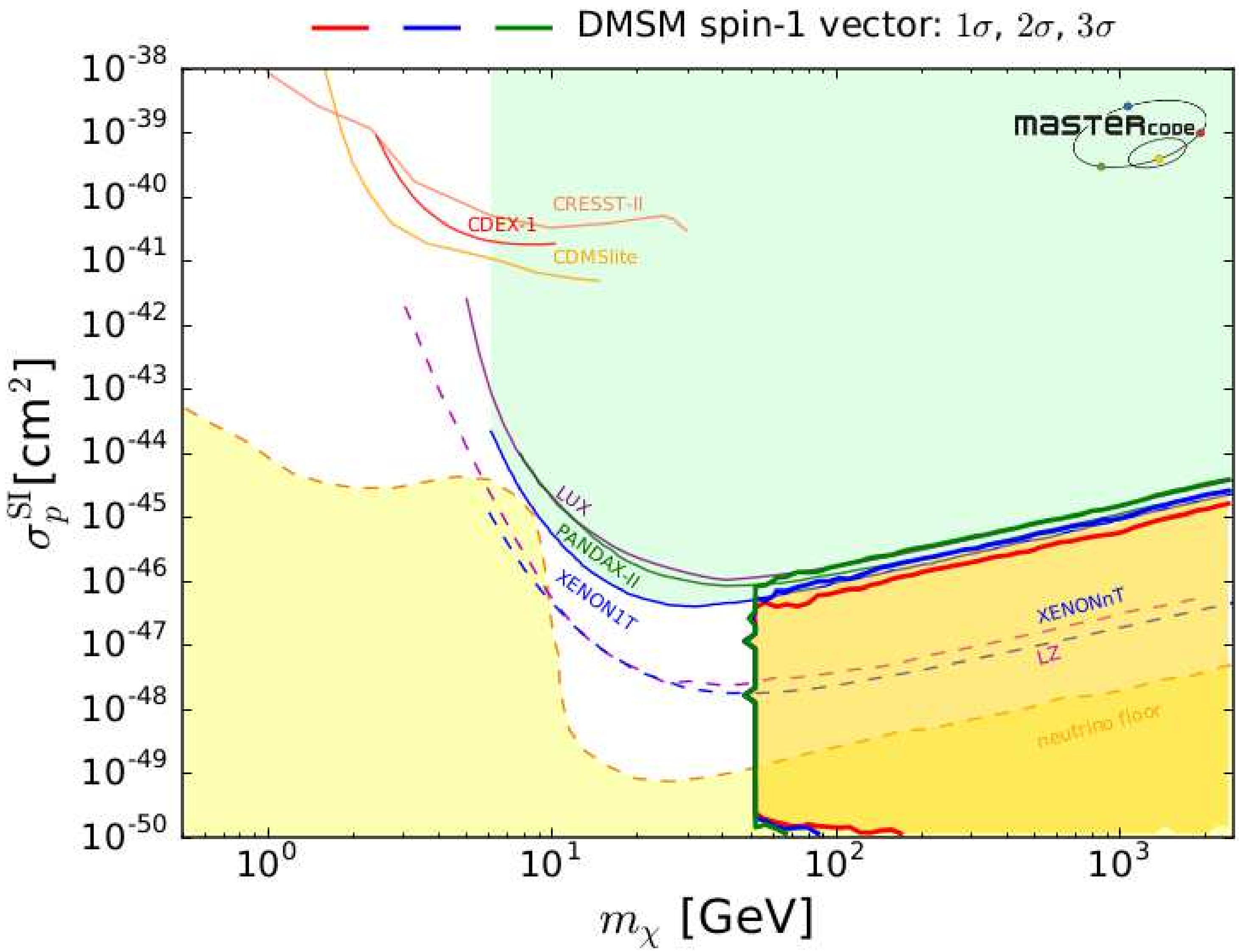
In any UV completion the spin-one boson could be expected to have comparable couplings to SM and DM particles, modulo possible group-theoretical factors and mixing angles!

$$g_{\mathrm{DM}}/g_{\mathrm{SM}} = \mathcal{O}(1)$$

$$1/3 < g_{\mathrm{DM}}/g_{\mathrm{SM}} < 3$$

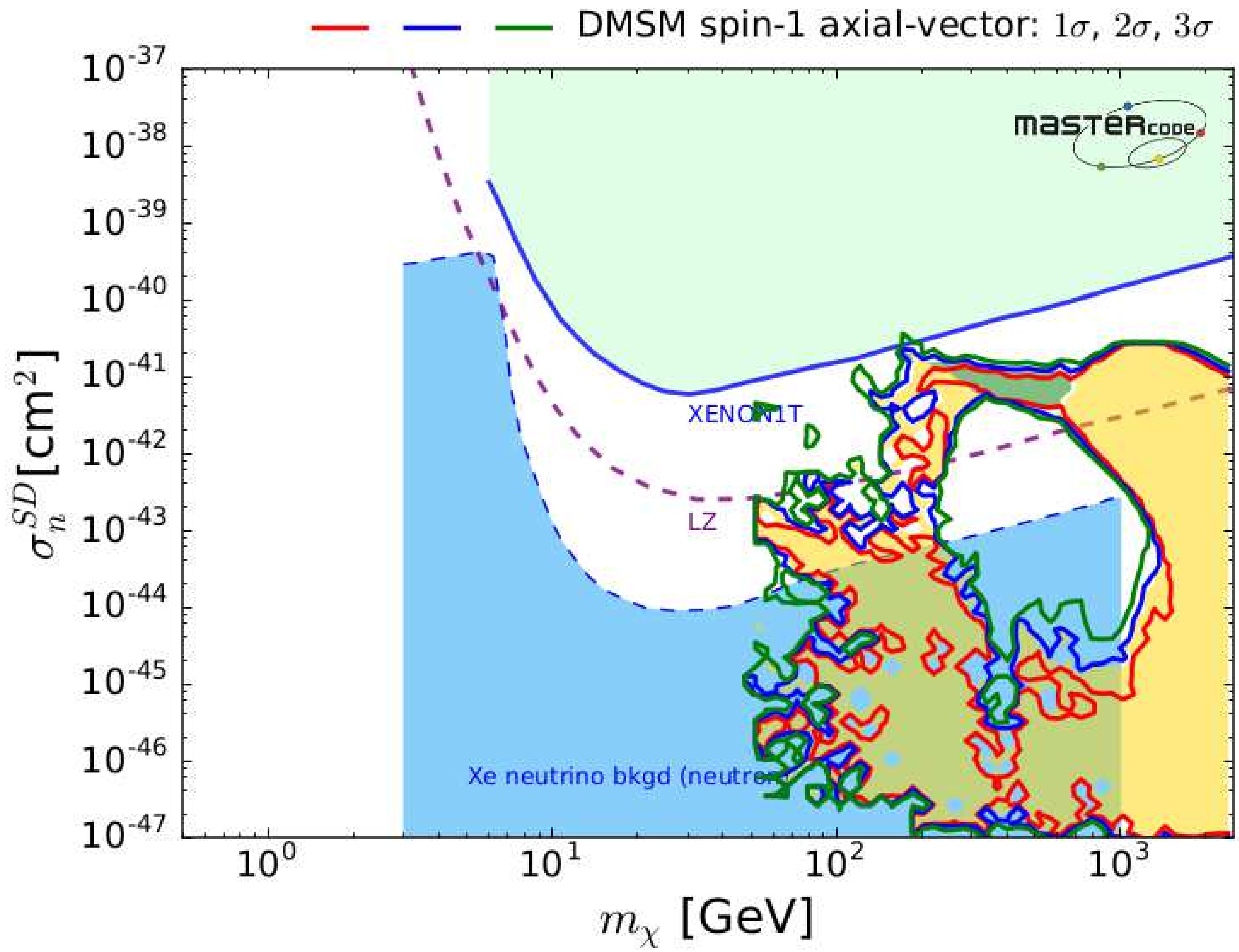
$\Rightarrow$ dark yellow regions

$\Rightarrow$ s-channel favored!



⇒ mixed prospects for discovery

Axial-vector mediator: towards UV completions [PRELIM.]



⇒ t-channel can fully be probed, s-channel only partially

5. Conclusions

- EFT vs. DMSM vs. full theories

- Lagrangian for vector or axial-vector mediator

- So far results presented for fixed values for some of $g_{\rm SM}$, $g_{\rm DM}$, $m_{\rm med}$, $m_{\rm DM}$ and other constraints (mono-jet, di-jet) overlaid

- MasterCode approach: full fit of the model, including
  - DM relic density
  - DM direct detection limits
  - LHC mono-jet searches
  - LHC di-jet searches

- Vector mediator: s- and t-channel separated, mixed prospects for DD

- Axialvector: s- and t-channel continous, mixed prospects for DD

- UV-completions: $1/3 < g_{\rm SM}/g_{\rm DM} < 3 \Rightarrow s$-channel preferred
  $\Rightarrow$ prospects for DD not improved


Further Questions?