Global perspectives on dark matter simplified models

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Work in progress
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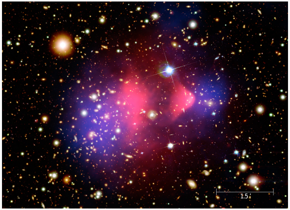
Introduction

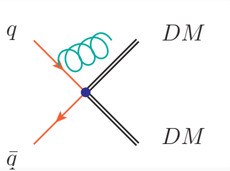
Dark Matter @ LHC

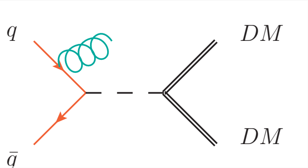
- We infer the existence of Dark Matter (DM) from indirect observations (cosmological, astrophysical).
- Can we probe DM at the LHC? Yes, if we assume that it couple sufficiently strongly to the SM (freeze-out points to that). *Unknown: the mass.*
- DM searches at the LHC fully underway.



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).





1st gen. dark matter simplified models

- Bottom-up approach.
- Introduce a mediator with a mass scale accessible at the LHC.
- Relatively light mediators allow more easily to recover the observed value of the relic density.

Various flavor of Dark Matter Simplified Models (DMSM) – 1st generation

- s-channel mediator: spin-0, spin-1.
    - MFV: spin-0 interactions proportional to the Yukawas.
- t-channel mediator: vertex with one quark and DM-particle:
    - Colored; phenomenology similar to SUSY squarks.
    - MFV: the mediator carries flavor index; equal coupling strength.

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 $\mathcal{L}_{X_D}^{Y_1} = \bar{X}_D \gamma_\mu \left(g_{X_D}^V + g_{X_D}^A \gamma_5 \right) X_D Y_1^\mu$.
- Interaction Lagrangian mediator-quarks

$$\mathcal{L}_{quarks}^{Y_1} = \sum_{i,j} \Big[\bar{d}_i \gamma_\mu \left(g_{d_{i,j}}^V + g_{d_{i,j}}^A \gamma_5 \right) d_j + \bar{u}_i \gamma_\mu \left(g_{u_{i,j}}^V + g_{u_{i,j}}^A \gamma_5 \right) u_j \Big] Y_1^\mu$$

- Interaction Lagrangian mediator-leptons

$$\mathcal{L}_{leptons}^{Y_1} = \sum_{i,j} \left[\bar{l}_i \gamma_\mu \left(g_{l_{i,j}}^V + g_{l_{i,j}}^A \gamma_5 \right) l_j \right] Y_1^\mu$$

Scenarios

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

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

Why going global?

- Interpretation of experimental results is usually given for fixed values of the couplings.
- Informative but we might want to condense into a single result the exclusion power of the LHC.
- Include consistently Ωh^2 and constraints from (in)direct-detection searches; allow to study the interplay with LHC searches.

- Build a likelihood from the different observables and find the regions where it is minimized.

Caveat

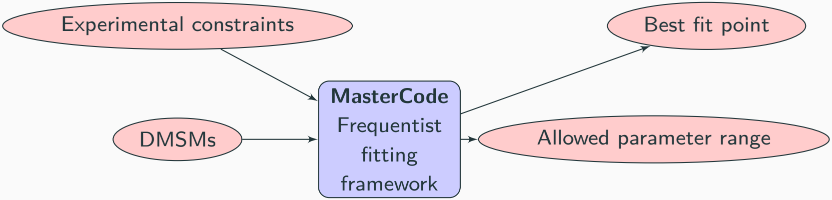
Use the framework to study correlations between simplified model parameters and not performing a complete fit as in the MSSM.

The framework

Global analyses

Global likelihood analyses

- Global-fit frameworks such as `MasterCode`, have been used for years to study BSM extensions of the SM. In our case, up to now we focused our attention to SUSY models (see the other MC talks on SUSY-DM and SUSY @ LHC later today).
- Dark Matter Simplified Models are not complete models, not meaningful to compute p-values. Use the framework with the aim of correlating different sectors and finding still allowed regions.



The framework

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

Parameter	Range	Number of segments
M_{Y_1}	(0 , 2.5) TeV	6
M_{DM}	(0 , 1.2) TeV	2
g_{SM}	(0 , $\sqrt{4\pi}$)	1
g_{DM}	(0 , $\sqrt{4\pi}$)	1
Total number of boxes		144

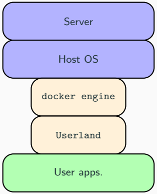
Codes

Mediator properties
`Analytic/MadGraph_aMC@NLO`
Collider
`MadGraph_aMC@NLO (DMSIMP models)`
Dark matter
`MicrOMEGAs`

- Sampled up to $\mathcal{O}(300M)$ points.

Docker and udocker

- As suggested by the name, `udocker` uses `docker` containers.
- `Docker`: software framework to automatize the deployment of application inside Linux containers.
- Other options, such as `LXC`, are available to use the Linux container infrastructure.



- Middleware suite developed in the context of the `INDIGO data-cloud` project to run `docker` containers in userspace, without requiring root privileges (both for installation and execution).

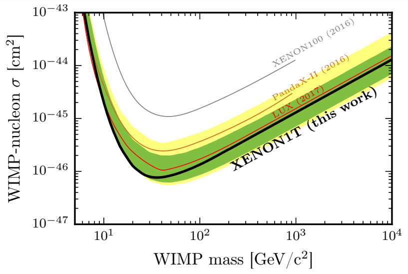
[Gomes at al., 1711.01758, submitted to CPC]

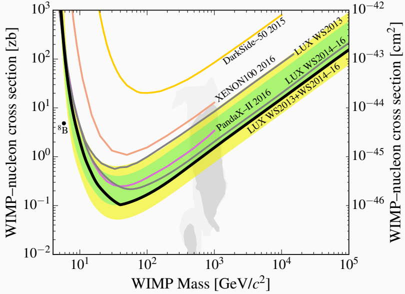
The constraints

Non-LHC constraints

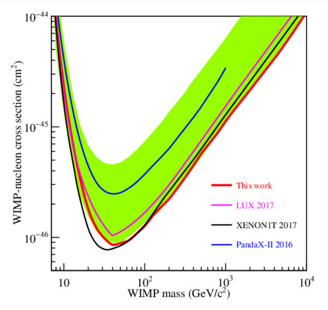
Dark matter

- 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.

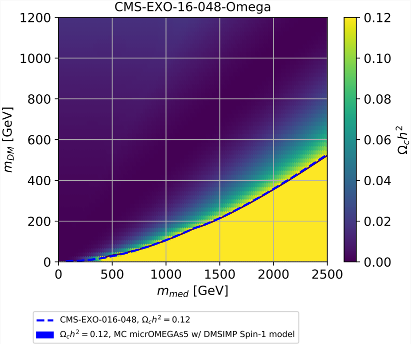


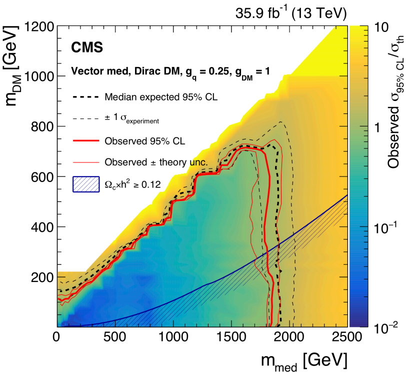


[1608.07648, 1705.06655, 1708.06917]



Validation Ωh^2



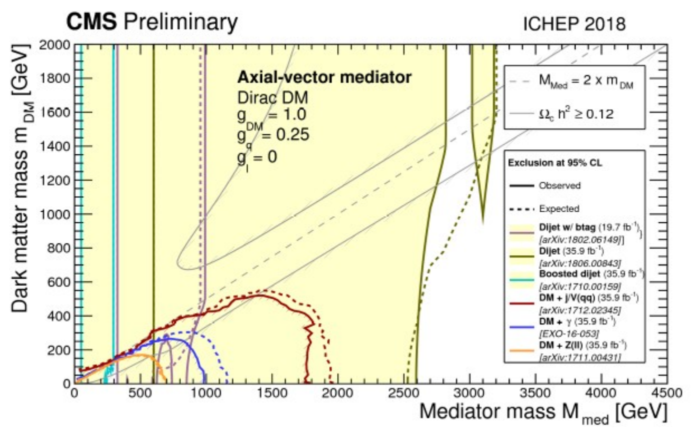


- Left: `MasterCode`; Right: CMS prediction from CMS-EXO-16-048.
- Agreement in the prediction for the $\Omega h^2 = 0.12$ line.

Collider constraints

DM simplified models are characterized by a variety of experimental signatures.

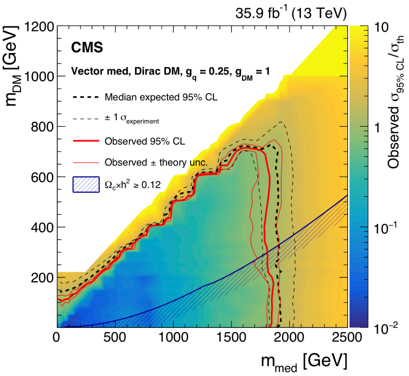
- Mono-jet signals.
- Mono-V/h
- Dijet, Dijet + X (to reduce gluon-induced background).



[CMS ICHEP '18]

Monojet constraint

- We use the monojet constraints from CMS [1712.02345]
- We model the likelihood à la `FastLim`, $\Delta\chi^2 = 5.99 \times (\sigma_{point}/\sigma_{UL,CMS,95\%})^2$
- Calculation of the cross-section through reweighting or via `MG5_aMC@(N)LO`.



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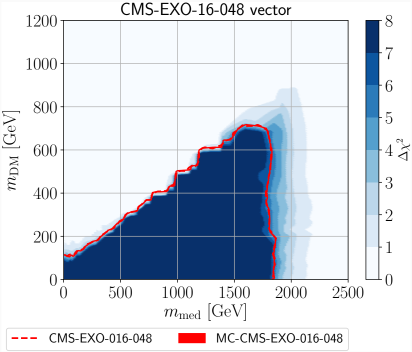

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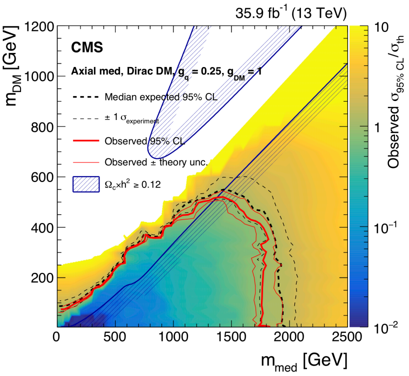

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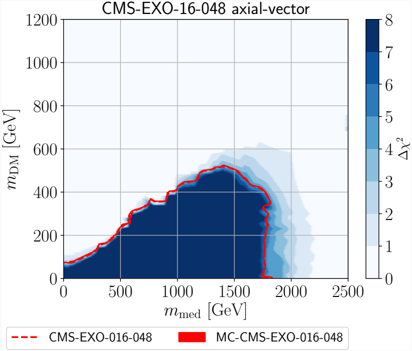
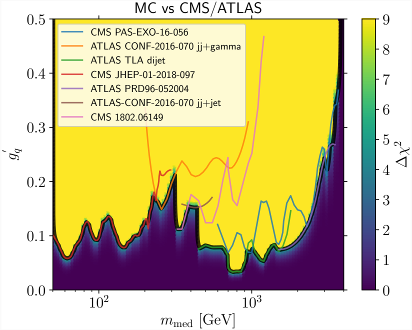


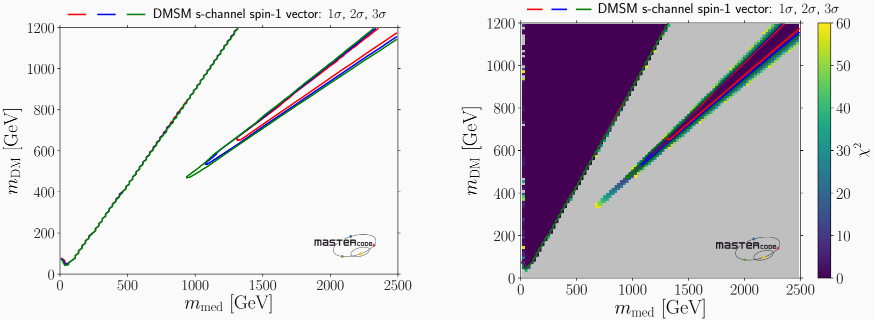
Dijet constraint

- We use the constraints from dijet and dijet+X searches on vector resonances.
- We recast the analysis using the limits on the coupling g_q given by the experiments on Z' resonances.
- $(g_{SM})^2 = (g_q^{exp})^2/2 \left(1 + \sqrt{1 + 4\Gamma_{DM}/\Gamma_q(g_q^{exp})}\right)$
- $\Delta\chi^2 = 4 \times (\sigma_{point}/\sigma_{lim})^2$.
- Hold in the limit of small width.
- $\sigma \simeq g_{SM}^4/\Gamma$.
- Cross-checked with MC-recasting for CMS dijet result.



Results

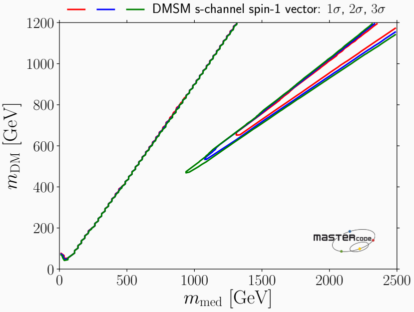
Vector mediator

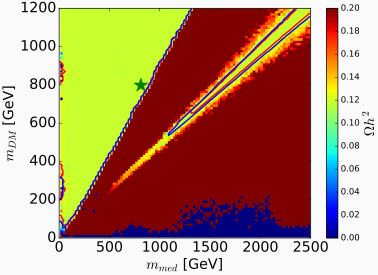


PRELIMINARY

- Two separated regions where the DM constraint can be completely satisfied.
- Low-masses allowed by going to very small couplings.

Vector mediator





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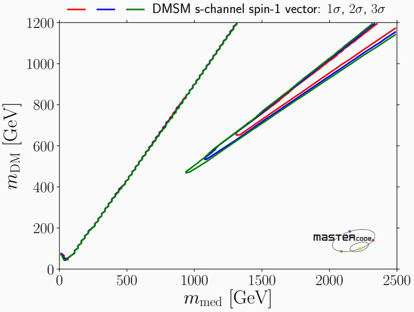

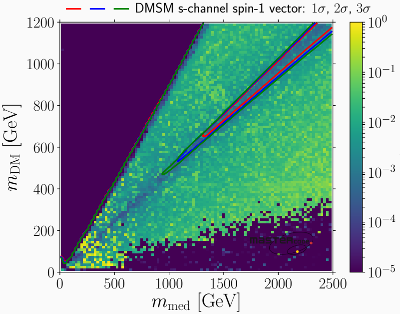

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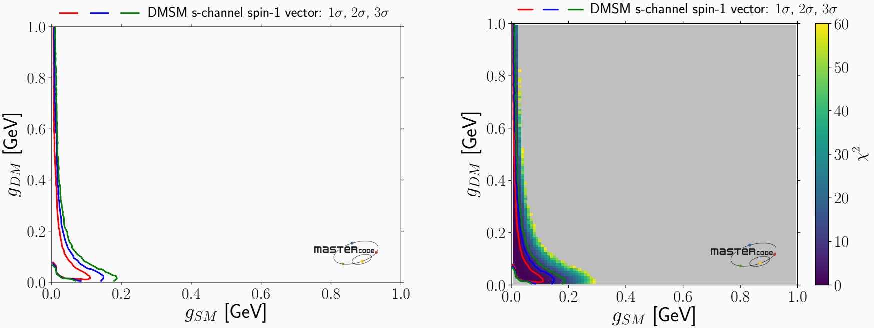

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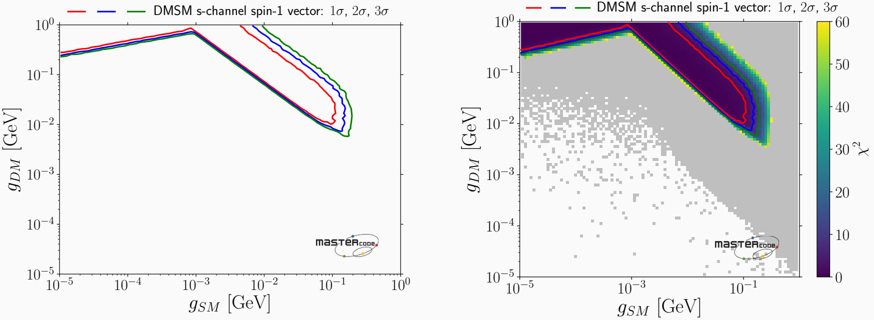

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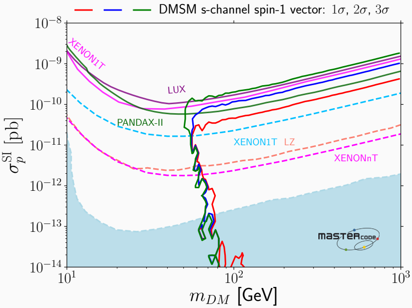
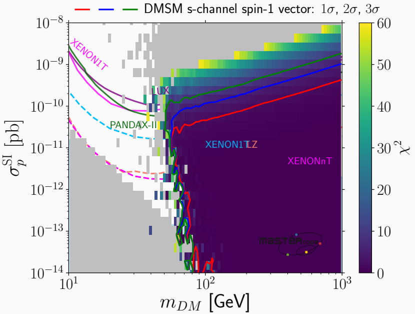
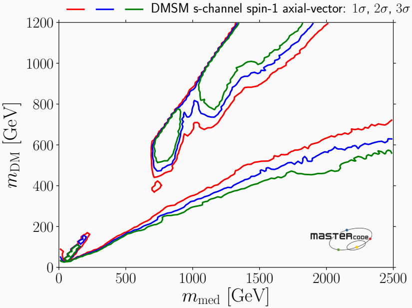
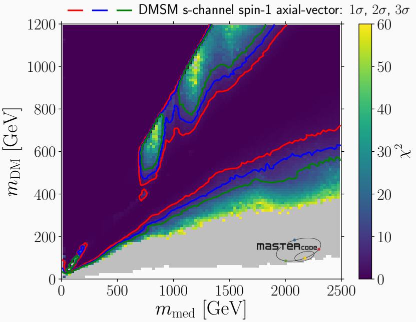




PRELIMINARY

Axial-vector mediator

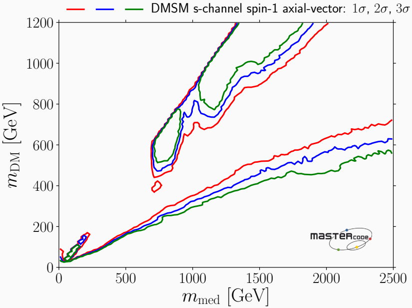


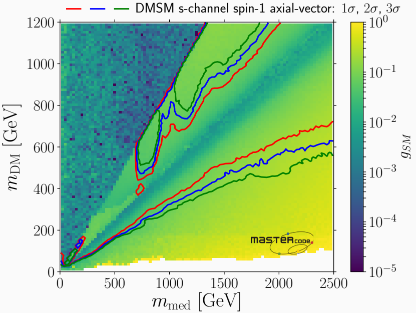


PRELIMINARY

- DM relic density drives the shape of the regions.

Axial-vector mediator





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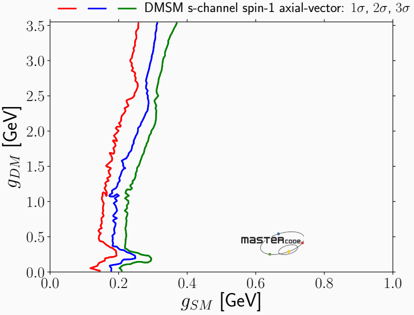

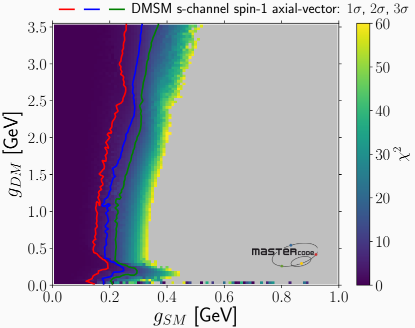

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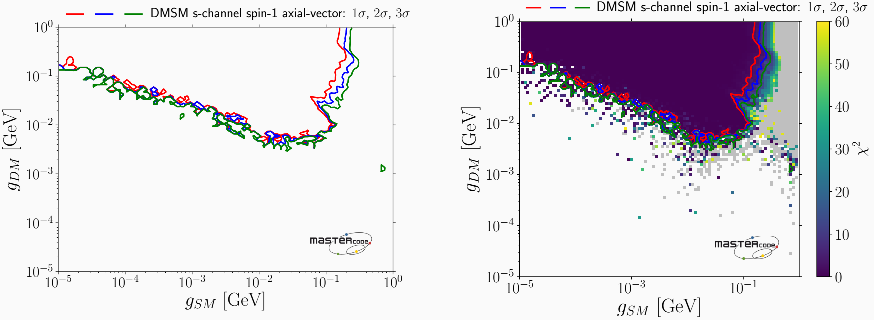

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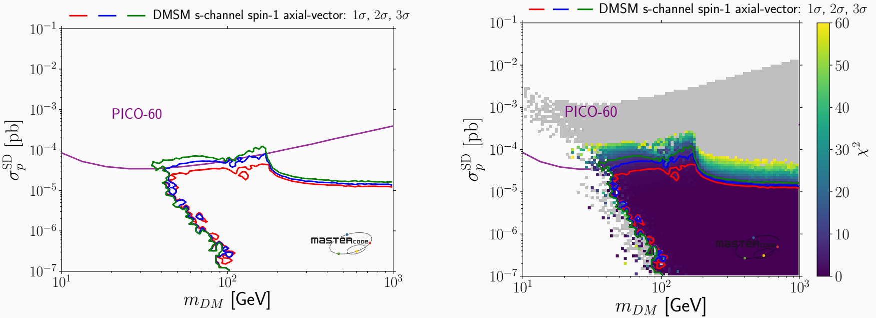

PRELIMINARY

- Allowed region defined both by direct detection and relic density constraints.

Conclusions and perspectives

- We have started studying DMSM from a global perspectives.
- For simplicity we have begun with 1^{st} generation DMSM.
- Allowed parameter space depends strongly on the choice of allowing smallish couplings.
- Concerning s-channel spin-1 vector and axial-vector:
    - Initial study underway, planning to allow heavier mediator/DM masses.
    - Inclusion of theory-oriented constraints.
    - Thorough comparison with other results.
- We plan to look at s-channel spin-0 models and to t-channel/more complex models in the future.

Backup slides