T-channel models and astro/cosmo bounds: using MadDM

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Hands-on session
LHC DM WG Spring WS 2020

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Based on:
C. Arina, B. Fuks and L. Mantani, arXiv:2001.05024 [hep-ph]
C. Arina, B. Fuks, J. Heisig, M. Kraemer, L. Mantani, K. Mawatari, H. Meis, L. Panizzi and J. Salko, work in progress

Outline

AIM of the tutorial: provide the basic knowledge with MadDM to study complementarity to LHC studies of cosmology and direct detection

- Running MadDM* for relic density (direct detection) predictions
- Running grid scan in MadDM in the plane M_{dm} - M_{med} (fixed coupling)
- Reading output files
- Provide the basic knowledge to run indirect detection processes
- Summary and outlook

* F. Ambrogi et al., Phys.Dark Univ. 24 (2019), arXiv:1804.00044 [hep-ph]

Installing MadDM

- Pre-requisite: have MG5 with python 2 (not 3) installed
- in tool_files there are the files for maddm (maddm.zip) and the NLO and LO model files needed for the tutorial
- Go into your MG5 main directory and put into the PLUGIN directory the zip file maddm.zip from the tool_files directory
- Put the maddm.py executable into the bin directory of MG5 and make it executable by typing

```
> chmod 770 maddm.py
```

- If you type

```
> ./bin/maddm.py
```

- MadDM should work and open up a hell environment similar to MG5
- Actually most of the feature of MG5 works for MadDM

Get UFO LO model files for MadDM

- Go to http://feynrules.irmp.ucl.ac.be/wiki/DMsimpt
- Download the dmsimpt_v1.2_s3mur.ufo.tar.gz file (UFO file at LO for Majorana DM coupling to uR only)
- Go into your MG5/models directory and unpack it there
- You are done with installing the LO file for most of this tutorial

- NOTICE: The UFO NLO model files used for collider pheno work perfectly fine within MadDM
- CAVEAT: The UFO NLO model files are generated with zero quark masses except for the top quark. This engenders a 10%-15% difference in the astro/cosmo predictions with respect to UFO model files with all quarks massive.
- For light dark matter (GeV scale) the quark masses are important for its astro/cosmo phenomenology

- We can provide others LO massive quarks UFO files (for scalar and vector DM) JUST ASK!

- (These can also be obtained with the feynrules main files)

Running MadDM for a single point in param space

- Open in you preferred editor a new file called maddm_singlerun_S3M_uR

```
import model UFO_S3M_uR
define darkmatter xm
define coannihilator ur~
generate relic_density
add direct_detection
output test_singlerun
```

- Run the script by typing into your MG5 main directory:

```
> ./bin/maddm.py maddm_singlerun_S3M_uR
```

- This script will generate a directory test_singlerun where all the outputs will be stored
- This can be done once as long as you do not want to change the physics (i.e. add indirect detection constraints etc…)

Relic density screen output

```
INFO: Trying process: ur ur~ > g a DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 3 diagrams
INFO: Trying process: ur ur~ > g z DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 3 diagrams
INFO: Trying process: ur ur~ > g h DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur ur~ > g ~sdm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur ur~ > g fsdm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur ur~ > g ~vdm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur ur~ > g fvdm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur ur~ > a a DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 3 diagrams
INFO: Trying process: ur ur~ > a z DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 3 diagrams
INFO: Trying process: ur ur~ > a h DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
```

YY co-annihilation processes

```
INFO: Trying process: ur ur~ > ta- ta+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 2 diagrams
INFO: Trying process: ur xm > g u DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 2 diagrams
INFO: Trying process: ur xm > g c DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g t DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g yf3qu1 DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g yf3qu2 DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g yf3qu3 DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g yf3u1 DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g yf3u2 DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > g yf3u3 DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: ur xm > a u DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Process has 2 diagrams
INFO: Trying process: ur xm > a c DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=
INFO: Trying process: ur xm > a t DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=
```

XY co-annihilation processes

Relic density and direct detection screen output

```
INFO: Trying process: xm xm > e- e+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > e- mu+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > e- ta+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > mu- e+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > mu- mu+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > mu- ta+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > ta- e+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > ta- mu+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
INFO: Trying process: xm xm > ta- ta+ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1999
39 processes with 86 diagrams generated in 26.917 s
Total: 39 processes with 86 diagrams
INFO: Trying process: xm xm > ur ur~ DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1998
INFO: Process has 2 diagrams
INFO: Trying process: xm xm > xm xm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1998
1 processes with 2 diagrams generated in 0.011 s
Total: 40 processes with 88 diagrams
INFO: Trying process: xm ur > ur xm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1998
INFO: Process has 2 diagrams
INFO: Crossed process found for xm ur~ > ur~ xm, reuse diagrams.
2 processes with 4 diagrams generated in 0.015 s
Total: 42 processes with 92 diagrams
INFO: Trying process: ur ur > ur ur DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1998
INFO: Process has 6 diagrams
INFO: Crossed process found for ur ur~ > ur ur~, reuse diagrams.
INFO: Trying process: ur ur~ > xm xm DMT<=2 QED<=4 SDEFFF=0 SDEFFV=0 SIEFFF=0 SIEFFS=0 SIEFFV=0 @1998
INFO: Process has 2 diagrams
INFO: Process ur~ ur > ur ur~ added to mirror process ur ur~ > ur ur~
INFO: Process ur~ ur > xm xm added to mirror process ur ur~ > xm xm
INFO: Crossed process found for ur~ ur~ > ur~ ur~, reuse diagrams.
4 processes with 20 diagrams generated in 0.048 s
Total: 46 processes with 112 diagrams
```

relic density tag (you can alternatively use @DM2SM)

XX annihilation processes

```
add direct_detection
INFO: Generating X Nucleon > X Nucleon diagrams from the full lagrangian...
INFO: Generating X Nucleon > X Nucleon diagrams from the effective lagrangian...
INFO: INFO: Generating X Nucleon > X Nucleon diagrams from the effective+full lagrangian...
INFO: Doing the spin dependent part...
INFO: Generating X Nucleon > X Nucleon diagrams from the effective lagrangi
INFO: Generating X Nucleon > X Nucleon diagrams from the effective + full l
```

DD is @LO
for SI NLO effects are important
python file provided

Launch MadDM for a single point in param space

- Open in you preferred editor a new file called launch_maddm_singlerun_S3M_uR

```
launch test_singlerun
direct = direct      ——> turns out the default directional detection
set Mxm   800.
set Mxv1e9
set Mxd    1e9
set Mxs1e9
set Mys3u1 1000.
set lams3u1x1 1.
set wys3u1 AUTO
```

- Run the script by typing into your MG5 main directory:

```
> ./bin/maddm.py launch_maddm_singlerun_S3M_uR
```

- This script sets the value of masses and coupling and the mediator width to AUTO in the param_card.dat file (in the test_singlerun/Cards dir)

Output of the single run

```
>
INFO: Computing the width set on auto in the param_card.dat
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles l- / j / vl / l+ / p / vl~ unchanged
Defined multiparticle all = g a ve vm vt ve~ vm~ vt~ ul cl t1 dl sl b1 ur cr t2 dr sr b2 ul~ cl~ t1~ dl~ sl~ b1~ ur~ cr~ t2~ dr~ sr~ b2~ u c t d s b yf3qu1 yf3qu2 yf3qu3 yf3qd1 yf3qd2 yf3qd3 yf3u1 yf3u2 yf3u3 yf3d1 yf3d2 yf3d3 u~ c~ t~ d~ s~ b~ yf3qu1~ yf3qu2~ yf3qu3~ yf3qd1~ yf3qd2~ yf3qd3~ yf3u1~ yf3u2~ yf3u3~ yf3d1~ yf3d2~ yf3d3~ z w+ h xs xv ~sdm fsdm ~vdm fvdm w- e- mu- ta- xm xd e+ mu+ ta+ xd~
Please note that the automatic computation of the width is
    only valid in narrow-width approximation and at tree-level.
INFO: load particles
INFO: load vertices
INFO: The model has interaction violating the charge: Y
INFO: Get two body decay from FeynRules formula
Results written to /Users/arina/Documents/physics/software/MG5_aMC_v2_7_2/test_singlerun/Cards/param_card.dat
INFO: Start computing relic,direct
maddm_card missed argument print_sigmas. Take
INFO: compilation done
INFO: MadDM Results
INFO:
**** Relic Density
OMEGA IS  0.590525585581
INFO: Relic Density       = 5.91e-01      EXCLUDED
INFO: x_f                 = 2.10e+01
INFO: sigmav(x_f)         = 5.10e-10
INFO: xsi                 = 1.00e+00
INFO:
***** Direct detection [cm^2]:
INFO: SigmaN_SI_p         All DM = 2.15e-49    ALLOWED    Xenon1ton ul    = 1.02e-45
INFO: SigmaN_SI_n         All DM = 1.10e-49    ALLOWED    Xenon1ton ul    = 1.02e-45
INFO: SigmaN_SD_p         All DM = 1.12e-40    ALLOWED    Pico60 ul       = 3.17e-40
INFO: SigmaN_SD_n         All DM = 2.87e-41    ALLOWED    Lux2017 ul      = 1.94e-40
INFO: Results written in: /Users/arina/Documents/physics/software/MG5_aMC_v2_7_2/test_singlerun/output/run_01/MadDM_results.txt
quit
MadDM>
```

Value of relic density, in this case larger than the Planck value so point is excluded

Theoretical values for SI and SD for proton and neutron

DD exclusion bounds for the tested model point: Xenon1T for SI and Pico for SD

Performing a grid scan

- Open in you preferred editor a new file called maddm_gridscan_S3M_uR

```
import model UFO_S3M_uR
define darkmatter xm
define coannihilator ur~
generate relic_density
add direct_detection
output test_gridscan
```

- Open in you preferred editor a new file called launch_maddm_gridscan_S3M_uR

```
launch test_gridscan
direct = direct
set Mxm scan:[10*x for x in range(1,100,10)]
set Mys3u1 scan:[10*x for x in range(1,100,10)]
set Mxv 1e9
set Mxd 1e9
set Mxs1e9
set lams3u1x1 1.
set wys3u1 AUTO
```

Performing a grid scan

- Run both scripts sequentially:

```
> ./bin/maddm.py maddm_gridscan_S3M_uR
> …
> ….. output of maddm…
> …
> ./bin/maddm.py launch_maddm_gridscan_S3M_uR
```

- Output folders are in ~/mydir/MG5_aMC_v2_7_2/test_gridscan/output

- File scan_run_01.txt (into useful_files) contains all data of the grid scan as listed

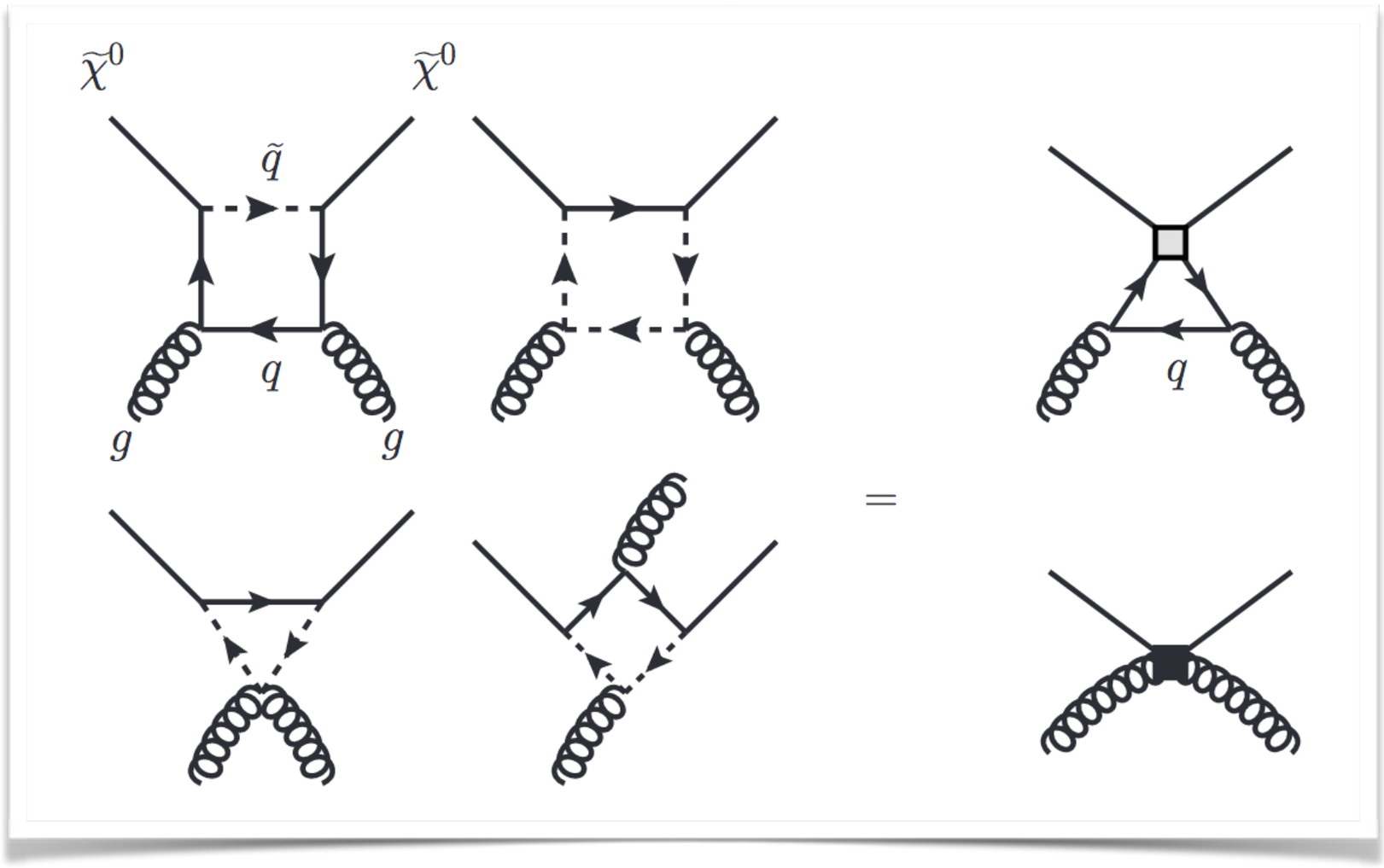
```
# [01] : run
# [02] : mass#52
# [03] : mass#2000002
# [04] : Omegah^2
# [05] : xf
# [06] : sigmav(xf)
# [07] : xsi
# [08] : sigmaN_SI_p
# [09] : lim_sigmaN_SI_p
# [10] : sigmaN_SI_n
# [11] : lim_sigmaN_SI_n
# [12] : sigmaN_SD_p
# [13] : lim_sigmaN_SD_p
# [14] : sigmaN_SD_n
# [15] : lim_sigmaN_SD_n
```

$$\xi = \frac{\Omega h^2_{\rm model}}{\Omega h^2_{\rm Planck}}$$

DD values on proton (p) and neutron (n)
+ exclusion limits
SI —> limit XENON1T
SD —> limit Pico-60

*Correcting the SI at NLO**

S3M_uR model is similar to wino neutralino coupling to up right squark



- Provided python file S3M_ur_NLO.py into useful_files, simple python file with the functions for SI@NLO
- See the example in the next slide on how to get SI@NLO (modify column 6 and 8 of the output scan file)

* SI@NLO from: J. Hisano, R. Nagai, N. Nagata, JHEP 05 37, arXiv:1502.02244 [hep-ph].

Python scripts for plotting

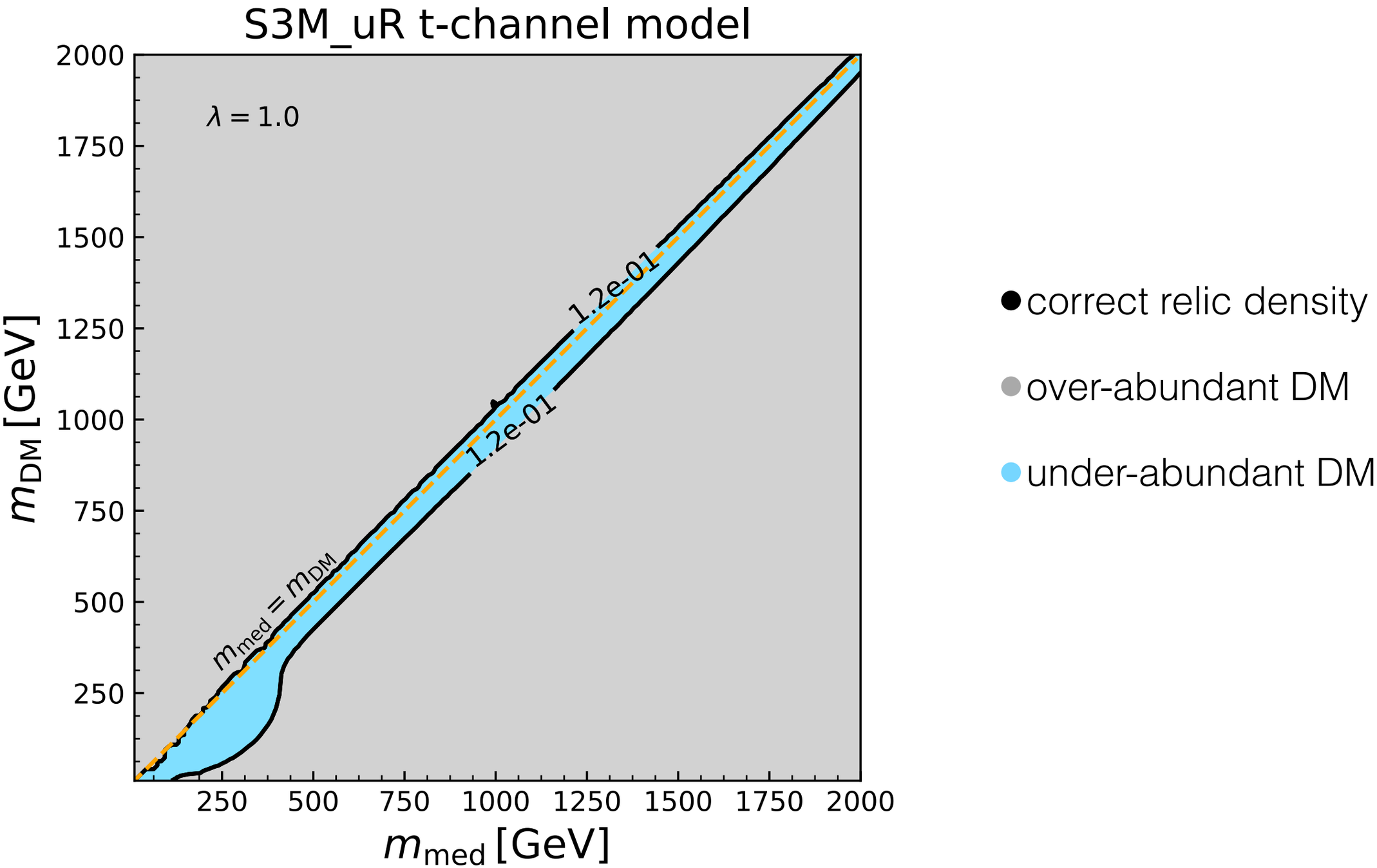
- The python files are in main directory
- First run reader_writer_SI_NLO.py
- This files reads scan output of maddm scan_run_01.txt (my file is generated with a much finer grid to get a nice plot) in the same directory, computes SI@NLO and output the signal strength (mu = sigma^SI/sigma^XENON1T) for SI and SD:

```
> python reader_writer_SI_NLO.py >  output_scan_NLO.txt
```

- Then run plotter_grid_scans_relic.py to get the two plots of the tutorial

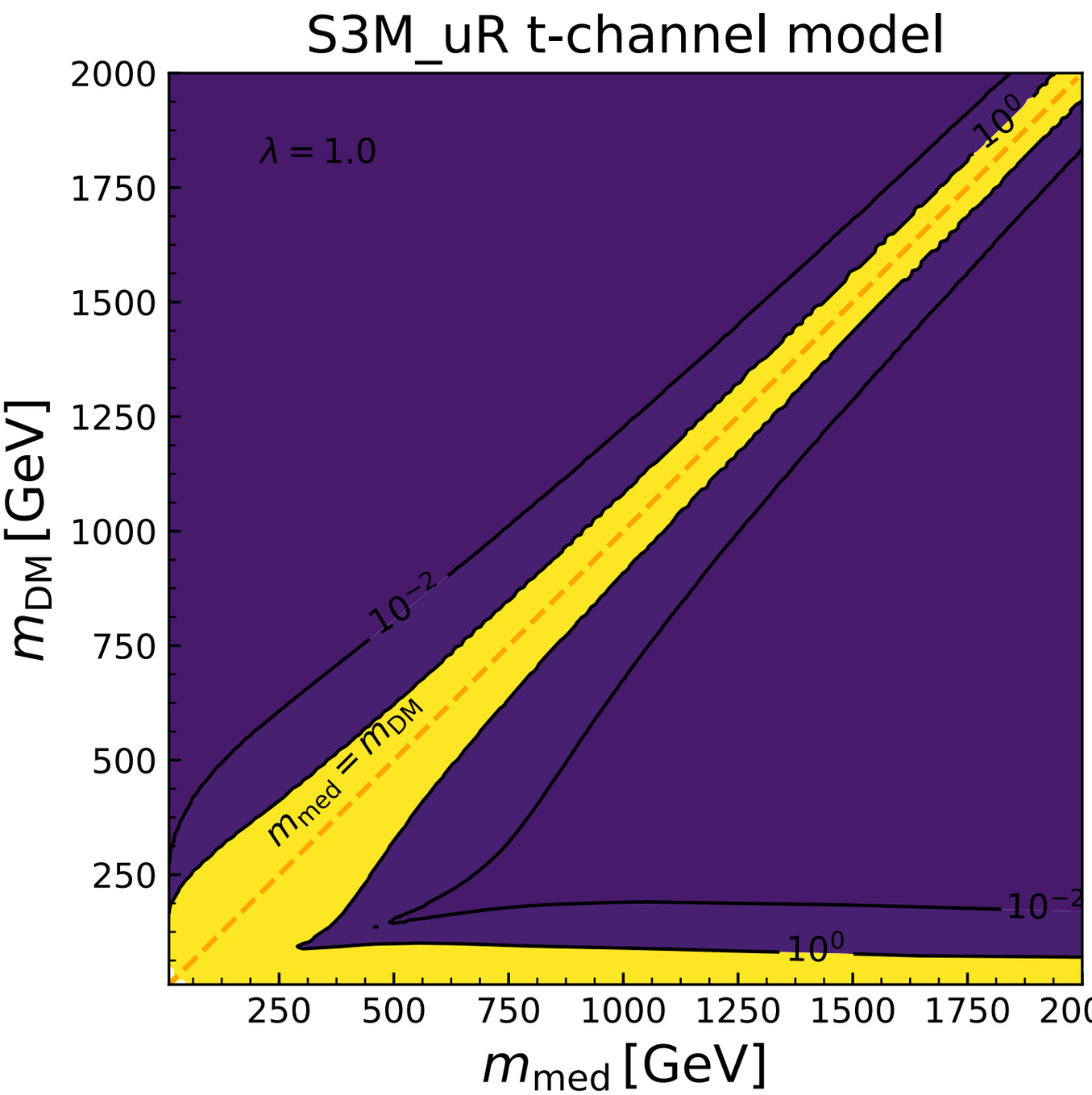
```
> python plotter_grid_scans_relic.py
```

*Relic density plot for the 2D grid scan**



* 3D scans will be shown in the talk by Luca Mantani

*Regions excluded from XENON1T of the 2D grid scan**



Color code for the signal strength

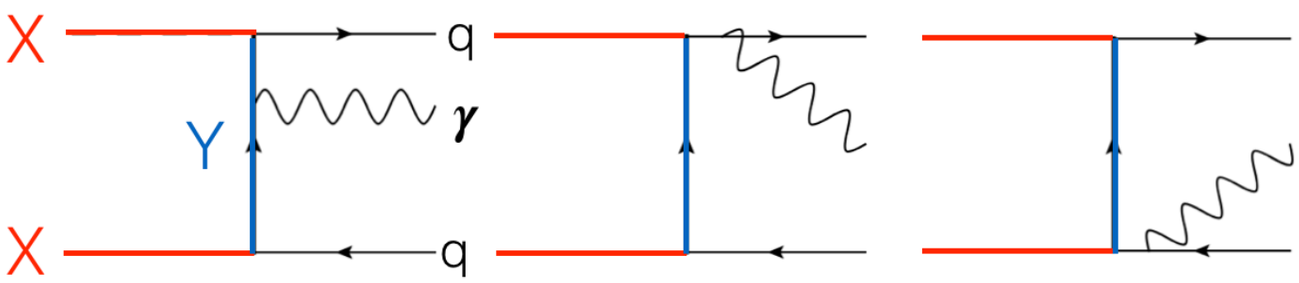
$$\mu_{\rm SI} = \frac{\sigma^{SI}_{\rm model}}{\sigma^{SI}_{\rm XENON1T}}$$

- Excluded by XENON1T@90%CL
- Allowed by XENON1T@90%CL

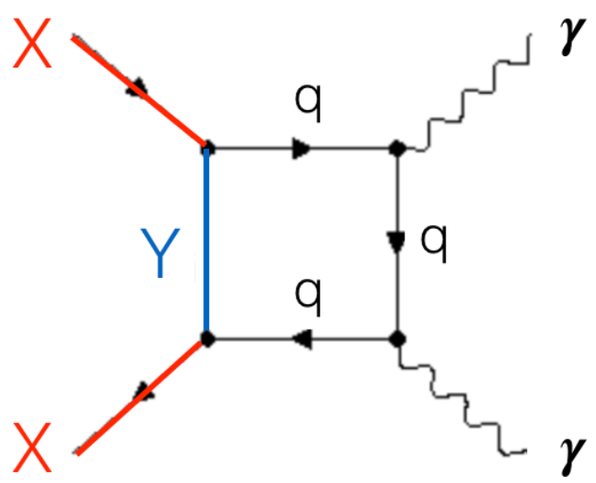
Indirect detection processes

- S3M_ur model involves a Majorana fermion hence its annihilation cross-section is suppressed by the velocity of DM particle at present time, which is v/c=10^-3
- Two ways of uplifting suppression:
  1. virtual internal bremsstrahlung (VIB), which is the emission of a photon + qq pair
  2. consider diphoton final state (loop-induced process)

Virtual internal bremsstrahlung (VIB)



Loop-induced diphotons



- Notice that Dirac and Vector DM are not suppressed by velocity while scalar DM is

Basic for VIB process

- Run manually the process generation to avoid having tools for ID installed (not need)

```
> ./bin/maddm.py
MadDM > import model UFO_S3M_uR
MadDM > define darkmatter xm
MadDM > define coannihilator ur~
MadDM > generate indirect_detection u u~ a
INFO: First time that you asked for indirect detection. Now asking for
dependency tool:
For indirect detection, MadDM relies on some external tools.You can decide here
which one you want to include.Not installing all the dependencies will limit
functionalities.
Which one do you want to install? (this needs to be done only once)
1. pythia8    shower (precise mode) [1410.3012]   : will be installed
2. PPPC4DMID all (fast mode) [1012.4515]   : will be installed
3. dragon    propagation (precise mode) [0807.4730]   : will be installed
4. dragon_data_from_galprop input for dragon [1712.09755]  : will be installed
You can:
 -> hit 'enter' to proceed
 -> type a number to cycle its options
 -> enter the following command:
    {tool_name} [install|noinstall|{prefixed_installation_path}]
If you are unsure about what this question means, just type enter to proceed.
[300s to answer]
MadDM > 1
MadDM > 2
MadDM > 3
MadDM > 4
MadDM > enter
MadDM > output test_VIB
```

Running VIB process

- Write the script run_VIB

```
launch test_VIB
indirect = sigmav   —-> compute of the annihilation cross section only
set sigmav_method madevent  —-> choice of the integration method
set Mxm 100.
set Mxv1e9
set Mxd1e9
set Mxs1e9
set Mys3u1 200.
set lams3u1x1 1.
set wys3u1 AUTO
set vave_indirect 1e-3
```

Gamma-ray line signal, use the velocity of DM in the Milky Way same for the VIB process

- Run the script run_VIB

```
./bin/maddm.py run_VIB
```

Output for the VIB process

- After some time, you get this VIB output:

```
INFO: load configuration from /Users/arina/Documents/physics/software/MG5_aMC_v2_7_2/test_VIB/Indirect/Cards/me5_configuration.txt
INFO: load configuration from /Users/arina/Documents/physics/software/MG5_aMC_v2_7_2/input/mg5_configuration.txt
INFO: load configuration from /Users/arina/Documents/physics/software/MG5_aMC_v2_7_2/test_VIB/Indirect/Cards/me5_configuration.txt
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
INFO: Computing sigmav with method: madevent
WARNING: no gamma spectrum since in sigmav mode
ERROR: The DM velocity in the dwarfs halo is not in the [3*10^-6 - 1.5*10^-4]/c range - will not calculate Fermi limits!
ERROR: Please rerun with the correct velocity to re-calculate the correct sigmav for Fermi limits.
INFO: MadDM Results
INFO: Define xsi = Relic density/Planck measurement for thermal scenarios.
INFO: Rescaling theory prediction for xsi(direct det.) and xsi^2(indirect det.) for thermal scenarios.

INFO:
***** Relic Density
OMEGA IS  0.0337728205179
INFO: Relic Density       = 3.38e-02       ALLOWED
INFO: x_f                 = 2.20e+01
INFO: sigmav(xf)          = 6.78e-09
INFO: xsi                 = 2.82e-01
INFO:
****** Indirect detection [cm^3/s]:
INFO: <sigma v> method: madevent
INFO: DM particle halo velocity: 0.001/c
WARNING: Printing only <sigma*v>: Fermi limits cannot be calculated since DM halo velocity not compatible with dwarfs.
INFO: xmxm_uuxa           Thermal = 1.27e-30      NO LIMIT      All DM = 1.59e-29       NO LIMIT
INFO:
INFO: Results written in: /Users/arina/Documents/physics/software/MG5_aMC_v2_7_2/test_VIB/output/run_02/MadDM_results.txt
quit
quit
```

Output loop-induced process

- For this process the NLO QCD files are needed (same used in the pheno tutorial)
- In MadDM loop-induced processes are still tested
- The process can be obtained with MG5

```
./bin/mg5
MG5_aMC > import model DMSimpt_NLO_v1_2_UFO-S3M_uR
MG5_aMC > generate xm xm > g g [QCD]
MG5_aMC > output
MG5_aMC > launch
MG5_aMC > 2
```

- Modify the run card to set the energy of each bin to xm + 1/2 mv^2, where v^2 is the dark matter velocity v/c=10^-3 in the Milky Way
- Each beam has energy = 100.00005 GeV (for Xm=100 GeV)

Output for loop-induced processes

- After some time, you get this output for the xm xm > gg process

```
=== Results Summary for run: run_01 tag: tag_1 ===

   Cumulative sequential time for this run: 1h03m18s
   Cross-section :   1.432e-08 +- 4.435e-11 pb
   Nb of events :  10000
```

- Trick to get the diphoton instead of di-gluons: rescale by the ratio between QCD and QED couplings which is a factor of

$$< \sigma v >_{\gamma\gamma} = \frac{8\alpha_e^2}{9\alpha_s^2} < \sigma v >_{gg} \simeq 0.0034 < \sigma v >_{gg}$$

- Total conversion factor from pb to cm^3/s is 0.0034*3e-29
- The cross-section for the diphoton process is 0.0146e-37 cm^3/s

Summary for indirect detection calculations

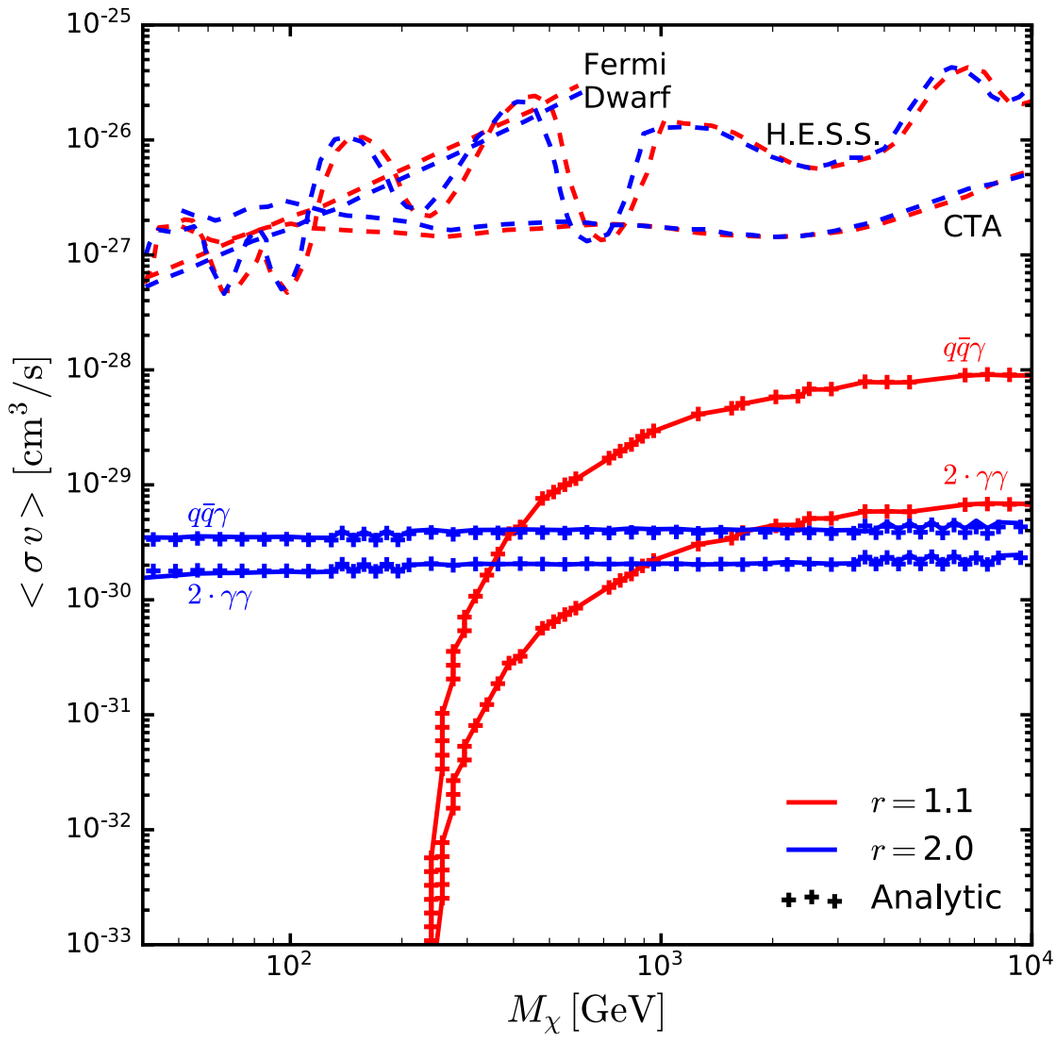
- It is possible to make scans for VIB and loop-induced processes the same way we did for relic density and direct detection (but it makes much longer…)

- The experimental constrains are given by gamma-ray lines searchers by e.g. Fermi-LAT and HESS (for DM masses above TeV)

- Example of plot (not provided in the tutorial):

  - There is no recasting of bounds from MadDM yet for this processes, it should be done by hand

  - Typically these probes are less sensitive than direct detection for a complementarity plot



Conclusions

<u>After the tutorial you are able to:</u>

- compute relic density observables for model points
- compute direct detection and SI@NLO for Majorana DM (ask us for the other cases)
- perform scans in the model parameter space to plot exclusions from direct detection or plank satellite for the model in the typical LHC search plane M_{med}-M_{dm} for complementarity purposes
- basic of indirect detection for higher order processes (VIB and diphoton)

The procedure is the same for all DM and mediators of the über-UFO model files

Do not hesitate to contact us for any numerical or physics issue!

Back up slides

Usual way of installing MadDM

- Pre-requisite: have MG5 with python 2 (not 3) installed
- Run the following command in a shell:

```
> ./bin/mg5
```

- Now install the latest version of MadDM by typing

```
MG5_aMC>install maddm
   You are installing 'maddm', please cite ref(s): arXiv:1804.00444.
Downloading http://madgraph.phys.ucl.ac.be/Downloads/maddm/maddm_V3.0.7.tar.gz
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
100  552k  100  552k    0     0  1110k      0 --:--:-- --:--:-- --:--:-- 1125k
compile maddm. This might take a while.
no compilation needed for plugin. Loading plugin information
Plugin maddm correctly interfaced. Latest official validition for MG5aMC version 2.6.8.
To use this module, you need to quit MG5aMC and run the executable bin/maddm.py
Installation succeeded
MG5_aMC>
```