t-channel dark matter and Madanalysis 5

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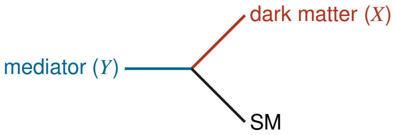
UNIVERSITÀ DELLA CALABRIA

Dark Tools - Torino 16-19 June 2025

Motivation

Study of scenarios based on the schematic interaction



Why is this important?

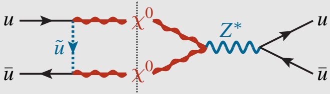
Representative of classes of theoretical scenarios

MSSM	**UED**	**FPVDM**
		

Complementary to s-channel

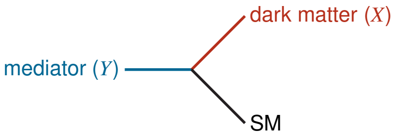
t-channel	**s-channel**
mediator always heavier than DM	mediator can also be lighter than DM
even number of mediator+DM in interactions	odd mediators allowed in interactions

But interferences can happen in non-minimal/full models. . .

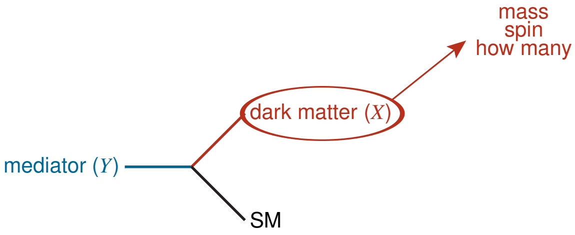


coloured mediators interesting at a hadron collider

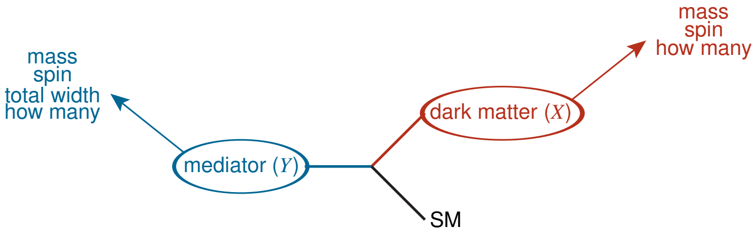
Guiding phenomenological questions



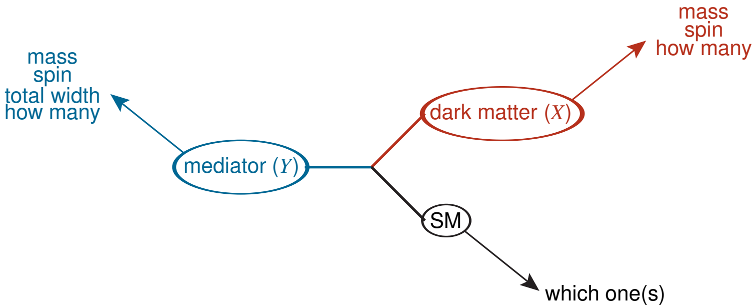
Guiding phenomenological questions



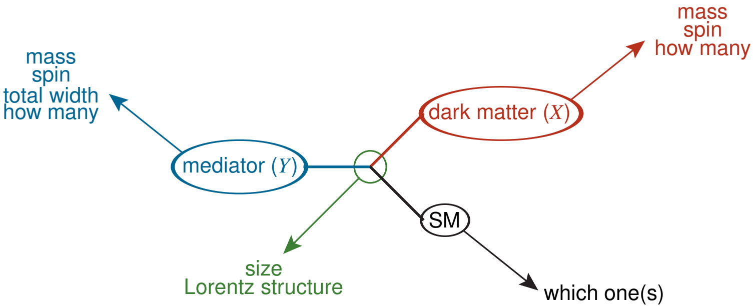
Guiding phenomenological questions



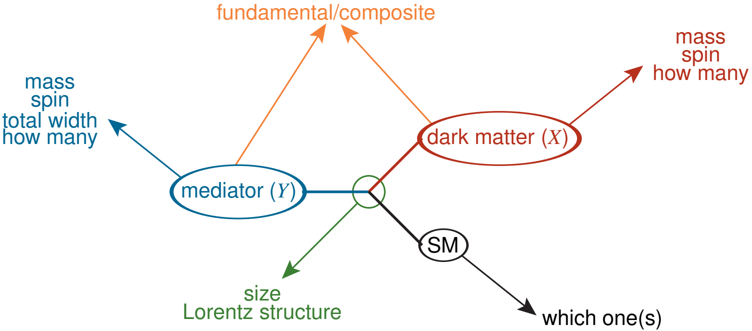
Guiding phenomenological questions



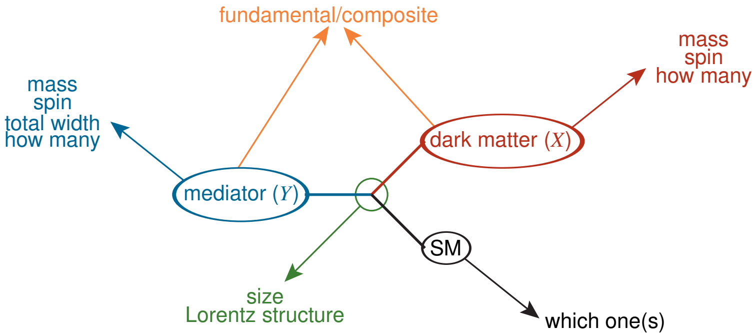
Guiding phenomenological questions



Guiding phenomenological questions



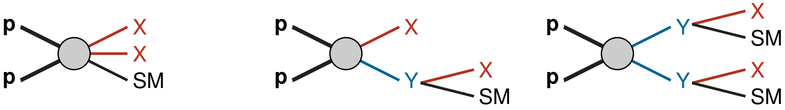
Guiding phenomenological questions



Depending on the possibilities:

- Can we observe a signal? And how?
- How does cosmology constrain the parameters?
- How do we reinterpret results?
- Can we define benchmarks for LHC to cover the widest range of possibilities?

Which signatures

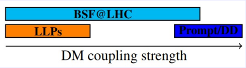


Not all processes might be possible at tree-level

depending on coupling or mass splitting

Long-lived mediators

Bound states
Displaced vertices
Delayed jets/photons



Mediators with prompt decay

MET+SM

depending on which SM particle

quark-philic — { 1st generation, 2st generation, 3st generation, universal, ... } — **lepto-philic**

Interacting with SM gauge bosons (Z/W) or the Higgs boson

I will focus on quark-philic scenarios with prompt-decay mediators

Putting our hands on it

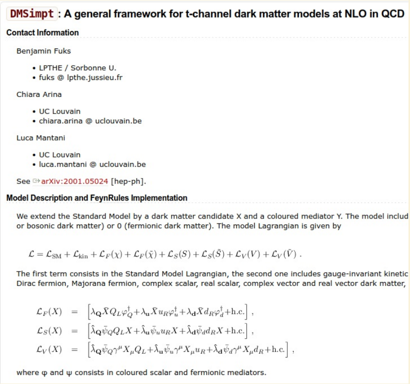
what do we need?

1. A numerical model to perform MC simulations (see Benjamin's talk)

Numerical models

Simplified models suitable for performing MC simulations at NLO in QCD
and testing against cosmological observables

Coloured mediators


DMSimpt : A general framework for t-channel dark matter models at NLO in QCD

Contact Information

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- fuks @ lpthe.jussieu.fr

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- chiara.arina @ uclouvain.be

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- UC Louvain
- luca.mantani @ uclouvain.be

See arXiv:2001.05024 [hep-ph].

Model Description and FeynRules Implementation

We extend the Standard Model by a dark matter candidate X and a coloured mediator Y. The model includ
or bosonic dark matter) or 0 (fermionic dark matter). The model Lagrangian is given by

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm kin} + \mathcal{L}_F(\chi) + \mathcal{L}_F(\tilde\chi) + \mathcal{L}_S(S) + \mathcal{L}_S(\tilde S) + \mathcal{L}_V(V) + \mathcal{L}_V(\tilde V)\ .$$

The first term consists in the Standard Model Lagrangian, the second one includes gauge-invariant kinetic
Dirac fermion, Majorana fermion, complex scalar, real scalar, complex vector and real vector dark matter,

$$\begin{aligned}
\mathcal{L}_F(X) &= \Big[\lambda_{\mathbf{Q}}\bar X Q_L \varphi_Q^\dagger + \lambda_{\mathbf{u}}\bar X u_R \varphi_u^\dagger + \lambda_{\mathbf{d}}\bar X d_R \varphi_d^\dagger + \text{h.c.}\Big]\ ,\\
\mathcal{L}_S(X) &= \Big[\hat\lambda_{\mathbf{Q}}\bar\psi_Q Q_L X + \hat\lambda_{\mathbf{u}}\bar\psi_u u_R X + \hat\lambda_{\mathbf{d}}\bar\psi_d d_R X + \text{h.c.}\Big]\ ,\\
\mathcal{L}_V(X) &= \Big[\hat\lambda_{\mathbf{Q}}\bar\psi_Q \gamma^\mu X_\mu Q_L + \hat\lambda_{\mathbf{u}}\bar\psi_u \gamma^\mu X_\mu u_R + \hat\lambda_{\mathbf{d}}\bar\psi_d \gamma^\mu X_\mu d_R + \text{h.c.}\Big]\ ,
\end{aligned}$$

where φ and ψ consists in coloured scalar and fermionic mediators.

V1: http://feynrules.irmp.ucl.ac.be/wiki/DMsimpt
V2: https://github.com/BFuks/DMSimpt.git

Dark sector particle	Spin	
Mediator	0	1/2
Dark matter	1/2	0 or 1

- DM real or complex
- Couplings with any SM quark (V1/V2) and lepton (V2)
- Restrictions to select representations or coupling hierarchies: only one generation, universal couplings. . . (available in V1, in progress for V2)

C. Arina, B. Fuks and L. Mantani, Eur. Phys. J. C **80** (2020) no.5, 409, arXiv:2001.05024 [hep-ph].
C. Arina, B. Fuks, **LP** *et al.*, arXiv:2504.10597 [hep-ph].

Putting our hands on it

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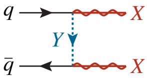
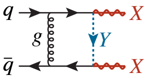
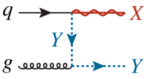
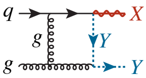
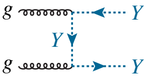
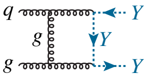
2. Tools to perform the MC simulations (see Olivier's and Sasha's talks)

The processes to simulate

Accurate kinematical description of the signal

Process	LO	NLO
XX		
XY		
YY		

Double-counting between real emission and tree-level processes
Removed through suitable algorythm in MadGraph (MadSTR)

beware of limitations: **narrow width approximation** $\Gamma_Y \ll m_Y$

Putting our hands on it

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3. **Tools to process the simulation results**

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   $\longrightarrow$ Reinterpret experimental data to **constrain** the parameter space of t-channel models

Putting our hands on it

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3. **Tools to process the simulation results**

$\longrightarrow$ Reinterpret experimental data to **constrain** the parameter space of t-channel models
$\longrightarrow$ Determine relevant kinematical distributions to optimize targeted analyses and **discriminate** different scenarios

Classification of simplified scenarios

Real DM

		Mediator spin		
		0	$1/2$	1
DM spin	0	×	**F3S**	×
	1/2	**S3M**	×	to be done
	1	×	**F3V**	×

Complex DM

		Mediator spin		
		0	$1/2$	1
DM spin	0	×	**F3C**	×
	1/2	**S3D**	×	to be done
	1	×	**F3W**	×

Examples of theories which can be described by these simplified models

S3M	SUSY: squarks+neutralino (Majorana fermion)
S3D	Right-handed neutrino portals with extended scalar sectors
F3S	UED: KK quark partners + KK photon (real scalar)
F3C	SUSY: sleptons+sneutrinos (not aware of quark-philic models)
F3V	?
F3W	FPVDM: vector-like quark + vector DM (non-abelian gauge boson)

Complex DM scenarios excluded by cosmology for interactions with light quarks

Is it true also for non-minimal models?

Is it true also for bottom and top?

Putting our hands on it

what do we need?

1. A numerical model to perform MC simulations (see Benjamin's talk)
2. Tools to perform the simulations (see Olivier's and Sasha's talks)
3. **Tools to process the simulation results**

    ⟶ Reinterpret experimental data to **constrain** the parameter space of t-channel models
    ⟶ Determine relevant kinematical distributions to optimize targeted analyses and **discriminate** different scenarios

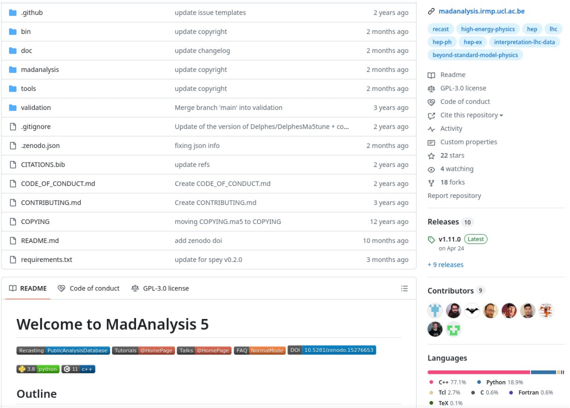
one of such tools is

MadAnalysis 5

MadAnalysis 5

❶ Clone

```
$ git clone https://github.com/MadAnalysis/madanalysis5.git
```



MadAnalysis 5

1. Clone

```
$ git clone https://github.com/MadAnalysis/madanalysis5.git
```

2. Set python virtual environment (optional)

```
$ python3 -m venv py3_env
$ source py3_env/bin/activate
$ pip3 install -upgrade pip
```

MadAnalysis 5

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$ git clone https://github.com/MadAnalysis/madanalysis5.git
```

2. Set python virtual environment (optional)

```
$ python3 -m venv py3_env
$ source py3_env/bin/activate
$ pip3 install -upgrade pip
```

3. Install required packages (be sure that ROOT is already installed)

```
$ python3 -m pip install -r ./madanalysis5/requirements.txt
```

Now MadAnalysis 5 is ready for parton-level analysis

t-channel example

multiple samples / multiple processes

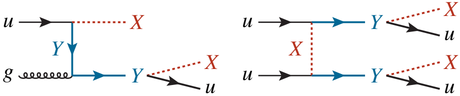
Let's assume the DM is a **real scalar** interacting with the **right-handed up quark**

t-channel example

multiple samples / multiple processes

Let's assume the DM is a **real scalar** interacting with the **right-handed up quark**

1. Open MG5_aMC and simulate just two processes: XY and YY with $Y \to Xu$




```
MG5_aMC> import model DMSimpt_v2_0_4FNS --modelname
MG5_aMC> define excluded = yf3u2 yf3u3 yf3qu1 yf3qu2 yf3qu3 yf3d1 yf3d2
yf3d3 yf3qd1 yf3qd2 yf3qd3
MG5_aMC>
MG5_aMC> generate p p > xs yf3u1, yf3u1 > xs u / excluded
MG5_aMC> output DMtsimp/XY
MG5_aMC>
MG5_aMC> generate p p > yf3u1 yf3u1, yf3u1 > xs u / excluded
MG5_aMC> output DMtsimp/YYt
```

t-channel example

multiple samples / multiple processes

Let's assume the DM is a **real scalar** interacting with the **right-handed up quark**

1. Open MG5_aMC and simulate just two processes: XY and YY with $Y \to Xu$
2. Enter in the simulation folders and run `./bin/madevent`, in each of them

```
XY> launch XY_coup1 # or any name, or blank
XY> shower = off
XY> detector = off
XY> analysis = off # we are using MA5 externally
XY> madspin = off
XY> reweight = off
XY> done
XY> set lamf3u1x1 1
XY> set mxs 1000 # and set mxv, mxw and mxc higher than 2000
XY> set myf3u1 2000
XY> set wyf3u1 auto
XY> done
```

For XY let's have two separate samples

```
XY> launch XY_coup1_2 -f
```

And do the same for a coupling $\lambda = 0.1$

t-channel example

multiple samples / multiple processes

Let's assume the DM is a **real scalar** interacting with the **right-handed up quark**

1. Open MG5_aMC and simulate just two processes: XY and YY with $Y \to Xu$
2. Enter in the simulation folders and run `./bin/madevent`, in each of them
3. Now let's run `./bin/ma5` in the MadAnalysis 5 folder

```
ma5> define invisible = invisible 51 52 53 56 57 58
ma5> define_region nocuts
ma5> define_region sdPHIpi
ma5> select sdPHI(j[1] met)>3.14 or sdPHI(j[1] met)<-3.14 {sdPHIpi}
ma5> import <MG path>/DMtsimp/XY/Events/XY_coup1/unweighted_events.lhe.gz as
XY_coup1
ma5> import <MG path>/DMtsimp/XY/Events/XY_coup1_2/unweighted_events.lhe.gz
as XY_coup1 # merging two samples in one dataset
ma5> import <MG path>/DMtsimp/XY/Events/XY_coup1/unweighted_events.lhe.gz as
XY_coup1
ma5> import <MG path>/DMtsimp/XY/Events/XY_coup01/unweighted_events.lhe.gz
as XY_coup0_1
ma5> import <MG path>/DMtsimp/XY/Events/XY_coup01/unweighted_events.lhe.gz
as XY_coup0_1
ma5> set main.graphic_render = matplotlib
ma5> set main.stacking_method = superimpose
ma5> set main.normalize = lumi_weight
ma5> set main.lumi=300
ma5> plot MET 75 0 1500 {nocuts} [logY]
ma5> plot MET 75 0 1500 {sdPHIpi} [logY]
ma5> submit <MG path>/DMtsimp/PartonAnalysis
```

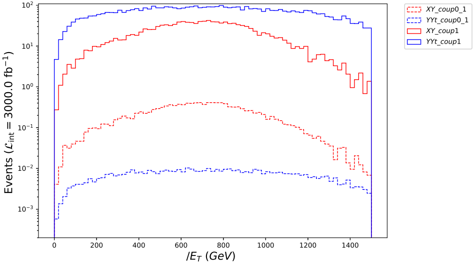
t-channel example

multiple samples / multiple processes

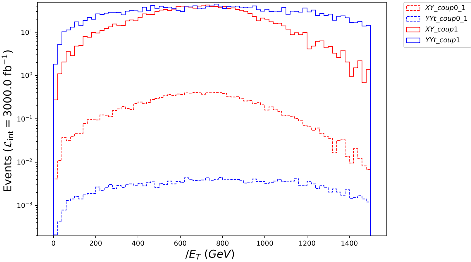
Let's assume the DM is a **real scalar** interacting with the **right-handed up quark**

1. Open MG5_aMC and simulate just two processes: XY and YY with $Y \to Xu$
2. Enter in the simulation folders and run `./bin/madevent`, in each of them
3. Now let's run `./bin/ma5` in the MadAnalysis 5 folder
4. Analyse results

no cuts



$|d\phi(j, MET)| > \pi$



Notice how XX and XY **scale differently** with the coupling
and how cuts affect distributions in different ways

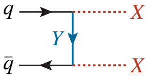
Relevance of the different processes

Master equation to reconstruct signal for any flavour hypothesis

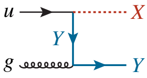
$$\begin{aligned}\sigma^{eff}_{\text{Tot}}(\lambda; M_Y, M_X) = &\ \lambda^0\ \hat{\sigma}_{Y\bar{Y}_{QCD}}(M_Y) \quad \epsilon_{Y\bar{Y}_{QCD}}(M_Y, M_X) \\ &+ \lambda^4\ \hat{\sigma}_{YY_t}(M_Y, M_X)\ \epsilon_{YY_t}(M_Y, M_X) \\ &+ \lambda^4\ \hat{\sigma}_{Y\bar{Y}_t}(M_Y, M_X)\ \epsilon_{Y\bar{Y}_t}(M_Y, M_X) \\ &+ \lambda^4\ \hat{\sigma}_{\bar{Y}\bar{Y}_t}(M_Y, M_X)\ \epsilon_{\bar{Y}\bar{Y}_t}(M_Y, M_X) \\ &+ \lambda^2\ \hat{\sigma}_{Y\bar{Y}_i}(M_Y, M_X)\ \epsilon_{Y\bar{Y}_i}(M_Y, M_X) \\ &+ \lambda^4\ \hat{\sigma}_{XX}(M_Y, M_X)\ \epsilon_{XX}(M_Y, M_X) \\ &+ \lambda^2\ \hat{\sigma}_{XY}(M_Y, M_X)\ \epsilon_{XY}(M_Y, M_X)\end{aligned}$$

$\hat{\sigma}$ are the cross-sections after factorizing the new coupling
ϵ are the efficiencies associated with a given experimental signal region

Example with XX and XY (decays are factorised via branching ratios)



$\mathcal{M} \propto \lambda^2 \rightarrow \sigma \propto \lambda^4$



$\mathcal{M} \propto \lambda \rightarrow \sigma \propto \lambda^2$

The kinematic properties are driven **only** by the masses
λ just **rescales** the cross-sections without affecting the shape of distributions

Relevance of the different processes

Master equation to reconstruct signal for any flavour hypothesis

$$
\begin{aligned}
\sigma^{eff}_{\rm Tot}(\lambda; M_Y, M_X) = & \lambda^0 \, \hat{\sigma}_{Y\bar{Y}_{QCD}}(M_Y) \quad \epsilon_{Y\bar{Y}_{QCD}}(M_Y, M_X) \\
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& + \lambda^2 \, \hat{\sigma}_{Y\bar{Y}_i}(M_Y, M_X) \, \epsilon_{Y\bar{Y}_i}(M_Y, M_X) \\
& + \lambda^4 \, \hat{\sigma}_{XX}(M_Y, M_X) \, \epsilon_{XX}(M_Y, M_X) \\
& + \lambda^2 \, \hat{\sigma}_{XY}(M_Y, M_X) \, \epsilon_{XY}(M_Y, M_X)
\end{aligned}
$$

$\hat{\sigma}$ are the cross-sections after factorizing the new coupling
ϵ are the efficiencies associated with a given experimental signal region

Now let's deal with the efficiencies

1. We need to include parton-showering and hadronization/fragmentation

```
XY> launch XY_coup1 # or any name, or blank
XY> shower = Pythia8
XY> ...
```

Relevance of the different processes

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2. Now we need to reconstruct the objects in the final state and pass them through the detector before applying the experimental selections and cuts

Relevance of the different processes

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& + \lambda^4 \ \hat{\sigma}_{Y\bar{Y}_t}(M_Y, M_X) \ \epsilon_{Y\bar{Y}_t}(M_Y, M_X) \\
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& + \lambda^2 \ \hat{\sigma}_{Y\bar{Y}_i}(M_Y, M_X) \ \epsilon_{Y\bar{Y}_i}(M_Y, M_X) \\
& + \lambda^4 \ \hat{\sigma}_{XX}(M_Y, M_X) \ \epsilon_{XX}(M_Y, M_X) \\
& + \lambda^2 \ \hat{\sigma}_{XY}(M_Y, M_X) \ \epsilon_{XY}(M_Y, M_X)
\end{aligned}
$$

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XY> ...
```

2. Now we need to reconstruct the objects in the final state and pass them through the detector before applying the experimental selections and cuts
3. Let's use analyses for which a **recast** is already available (or do our own recast)

MadAnalysis 5

1. Clone

```
$ git clone https://github.com/MadAnalysis/madanalysis5.git
```

2. Set python virtual environment (optional)

```
$ python3 -m venv py3_env
$ source py3_env/bin/activate
$ pip3 install -upgrade pip
```

3. Install required packages (be sure that ROOT is already installed)

```
$ python3 -m pip install -r ./madanalysis5/requirements.txt
```

4. Install the Public Analysis Database (PAD) in MadAnalysis 5

```
ma5> install PAD
```

this should install automatically Fastjet and Delphes, otherwise do it manually

```
ma5> install fastjet
ma5> install delphes
```

Now MadAnalysis 5 is ready to recast

Recasting with MadAnalysis 5

1. Now let's run `./bin/ma5 -R` in the MadAnalysis 5 folder, to enter in the reconstructed-level mode

```
ma5> set main.recast = on
ma5> set main.recast.store_events = False
ma5> define invisible = invisible 51 52 53 56 -56 57 -57 58 -58
ma5> import <your filename>.hepmc.gz as DMtsimp
ma5> set DMtsimp.xsection = <cross-section value>
ma5> set main.recast.card_path = <your path>/recasting_card.dat ma5> submit
<name of your run>
```

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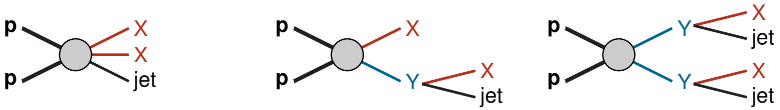
<name of your run>
```

What is inside the recasting_card.dat?

```
#  AnalysisName              PADType    Switch     DetectorCard
#  Detector cards must be located in the PAD(ForMA5tune/ForSFS) directory
#  Switches must be on or off
atlas_susy_2018_17           v1.2       on     delphes_card_atlas_susy_2018_17.tcl          # ATLAS - 13 TeV - At least 8 jets + met (139/fb)
cms_exo_20_004               v1.2       on     delphes_card_cms_exo_20_004.tcl              # CMS   - 13 TeV - Mono-jet (137/fb)
cms_sus_19_006               v1.2       on     delphes_card_cms_sus_19_006.tcl              # CMS   - 13 TeV - SUSY in the HT / missing HT channel (137/fb)
atlas_conf_2019_040          vSFS       on     sfs_card_atlas_susy_2016_07.ma5              # ATLAS - 13 TeV - multijet + met (139/fb)
atlas_exot_2018_06           vSFS       on     sfs_card_atlas_exot_2018_05.ma5              # ATLAS - 13 TeV - multijet + met [inclusive] (139/fb)
```

A list of searches (among those available) targeting final states with jets and MET
Why? Because our DM is quark-philic



The list depends on the final state

The longer the list, the longer it takes to do the recast
(large statistics takes several hours, choose wisely)

Recasting with MadAnalysis 5

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<name of your run>
```

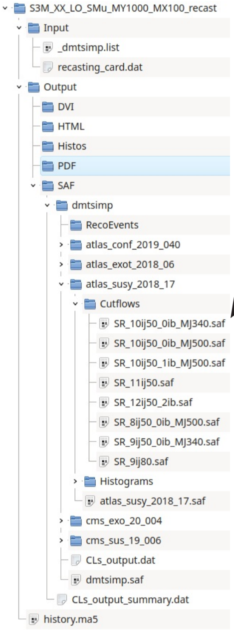
2. Let's look at the result

MA5 recasting output

the main parts at least

- S3M_XX_LO_SMu_MY1000_MX100_recast
  - Input
    - _dmtsimp.list
    - recasting_card.dat
  - Output
    - DVI
    - HTML
    - Histos
    - PDF
    - SAF
      - dmtsimp
        - RecoEvents
        - atlas_conf_2019_040
        - atlas_exot_2018_06
        - atlas_susy_2018_17
          - Cutflows
            - SR_10ij50_0ib_MJ340.saf
            - SR_10ij50_0ib_MJ500.saf
            - SR_10ij50_1ib_MJ500.saf
            - SR_11ij50.saf
            - SR_12ij50_2ib.saf
            - SR_8ij50_0ib_MJ500.saf
            - SR_9ij50_0ib_MJ340.saf
            - SR_9ij80.saf
          - Histograms
          - atlas_susy_2018_17.saf
        - cms_exo_20_004
        - cms_sus_19_006
        - CLs_output.dat
        - dmtsimp.saf
      - CLs_output_summary.dat
  - history.ma5

MA5 recasting output



- The cutflows

the main parts at least

```
<SAFheader>
</SAFheader>

<InitialCounter>
"Initial number of events"       #
300000          0                # nentries
1.504815e-03    0.000000e+00     # sum of weights
7.548232e-12    0.000000e+00     # sum of weights^2
</InitialCounter>

<Counter>
">= 4 pt_50 jets"                # 1st cut
91              0                # nentries
4.564607e-07    0.000000e+00     # sum of weights
2.289630e-15    0.000000e+00     # sum of weights^2
</Counter>

<Counter>
"no leptons with pt >= 10"       # 2st cut
91              0                # nentries
4.564607e-07    0.000000e+00     # sum of weights
2.289630e-15    0.000000e+00     # sum of weights^2
</Counter>

<Counter>
">= 11 pt_50 jets"               # 3st cut
0               0                # nentries
0.000000e+00    0.000000e+00     # sum of weights
0.000000e+00    0.000000e+00     # sum of weights^2
</Counter>
```

With this information we can investigate which cuts are killing or keeping the signal and/or the background

MA5 recasting output

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  - Output
    - DVI
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            - SR_12ij50_2ib.saf
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</Counter>
```

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The CLs summary

# dataset name	analysis name	signal region	best?	sig95(exp)	sig95(obs)	1-CLs	||	efficiency	stat	
dmtsimp	atlas_susy_2018_17	SR-8ij50-0ib-MJ500	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-9ij50-0ib-MJ340	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-10ij50-0ib-MJ340	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-10ij50-0ib-MJ500	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-10ij50-1ib-MJ500	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-11ij50	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-12ij50-2ib	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_susy_2018_17	SR-9ij80	0	-1	-1	0.0000000000	||	0.0000000	0.0000000	0.0000000
dmtsimp	atlas_exot_2018_06	IM0	0	35.8406065	45.4360687	0.0000000000	||	0.0157900	0.2725750	0.0000000
dmtsimp	atlas_exot_2018_06	IM1	0	24.1427386	30.3295550	0.0000132638	||	0.0093833	0.2108058	0.0000000
dmtsimp	atlas_exot_2018_06	IM2	0	20.9770386	28.7532502	0.0002287806	||	0.0054000	0.1602405	0.0000000
dmtsimp	atlas_exot_2018_06	IM3	0	18.4955612	27.3896549	0.0000000000	||	0.0030600	0.1207665	0.0000000
dmtsimp	atlas_exot_2018_06	IM4	0	18.4812883	29.4397034	0.0010372435	||	0.0017767	0.0920806	0.0000000

With this information we can reinterpret our results for any value of the DM coupling*

* conditions apply, do not exceed recommended doses of approximation

Some results

based on

t-channel dark matter models – a whitepaper

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Linda M. Carpenter,[28] Xabier Cid Vidal,[29] Emanuele Copello,[17] Louie Corpe,[30] Francesco D'Eramo,[18,19] Aldo Deandrea,[6,11]
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Philip Coleman Harris,[37] Julia Harz,[17] Alejandro Ibarra,[35] Alberto Orso Maria Iorio,[38,39] Felix Kahlhoefer,[22]
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Laura Lopez-Honorez,[48,49] Alberto Mariotti,[50,49] Vasiliki A. Mitsou,[51] Kirtimaan Mohan,[52] Chang-Seong Moon,[34]
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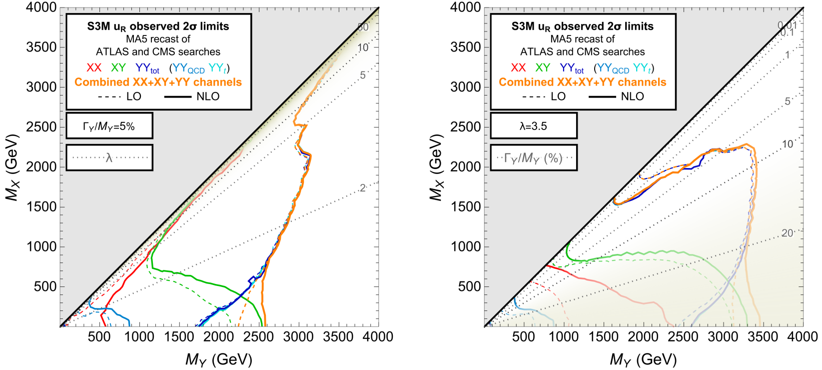
arXiv:2504.10597

Different coupling assumptions

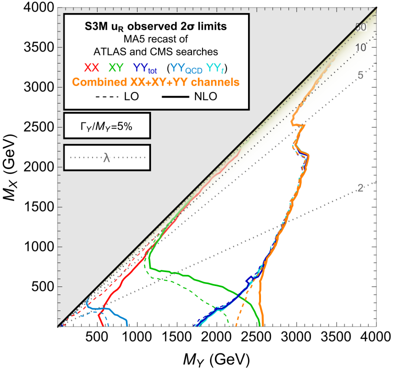
DM interacting with the up quark



- Validity of narrow width approximation
- Different functional dependence of coupling-dependent constraints
- Mild differences NLO vs LO

Different spin configurations

DM interacting with the up quark

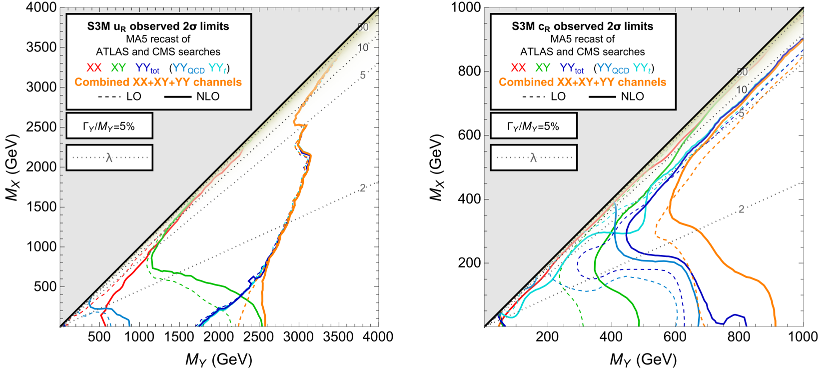


- Different reach (depending on degrees of freedom)
- Different dependence on masses (related to the structure of the amplitudes)

(see Phys. Rev. D **108** (2023) no.11, 115007 for details)

Different quark interactions

same spin configuration



- Huge role of valence quarks in same-charge mediator production
- Completely different interplay of contributions
- Different NLO/LO K-factors

Conclusions

Extremely flexible analysis for t-channel DM models through MA5

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around 6.5 GB of data for all quarks and all spin combinations
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We are **generalising** the treatment to s-channel and its interplay with t-channel