Searching for t-channel mediated dark matter

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The simplified model

- Dark matter is a spin-1/2 particle
- Dark matter couples universally to righthanded quarks
- The dark mediators are degenerate

$$\mathcal{L}_\chi = \lambda \bar{\chi}_L q_R \phi^* + \text{h.c.}$$

This model includes SUSY as a special case

coupling

Dark matter, can be Dirac or Majorana
Important differences in the signal.

quark

Dark mediator, (colored) complex scalar

The UFO files

- We provide the UFO files for both the Dirac DM model and the Majorana DM model. (Thanks to my postdoc Daneng Yang)

The Lagrangian implemented in an explicit form:

$$\begin{aligned}\mathcal{L}_{DM} &= \lambda\bar{\chi}P_R u_{R,i,a}\phi^*_{i,a} + \lambda\bar{u}_{R,i,a}P_L\chi\phi_{i,a} + \\ &\quad \lambda\bar{\chi}P_R d_{R,i,a}\phi^*_{i,a} + \lambda\bar{d}_{R,i,a}P_L\chi\phi_{i,a}\end{aligned} \tag{1}$$

where i is the flavor index, a is the color index. We leave the spin index implicit and assume repeated indices need to be summed over.

Field and couplings in the coding language:

```
DM field: Xd,                        "PDG" number: 7777
Mediator field: SOU={su,sc,st}       "PDG" number: {88881,88882,88883}
                SOD={sd,ss,sb}       "PDG" number: {99991,99992,99993}
Coupling: lmd0
```

The UFO files

- The parameter card

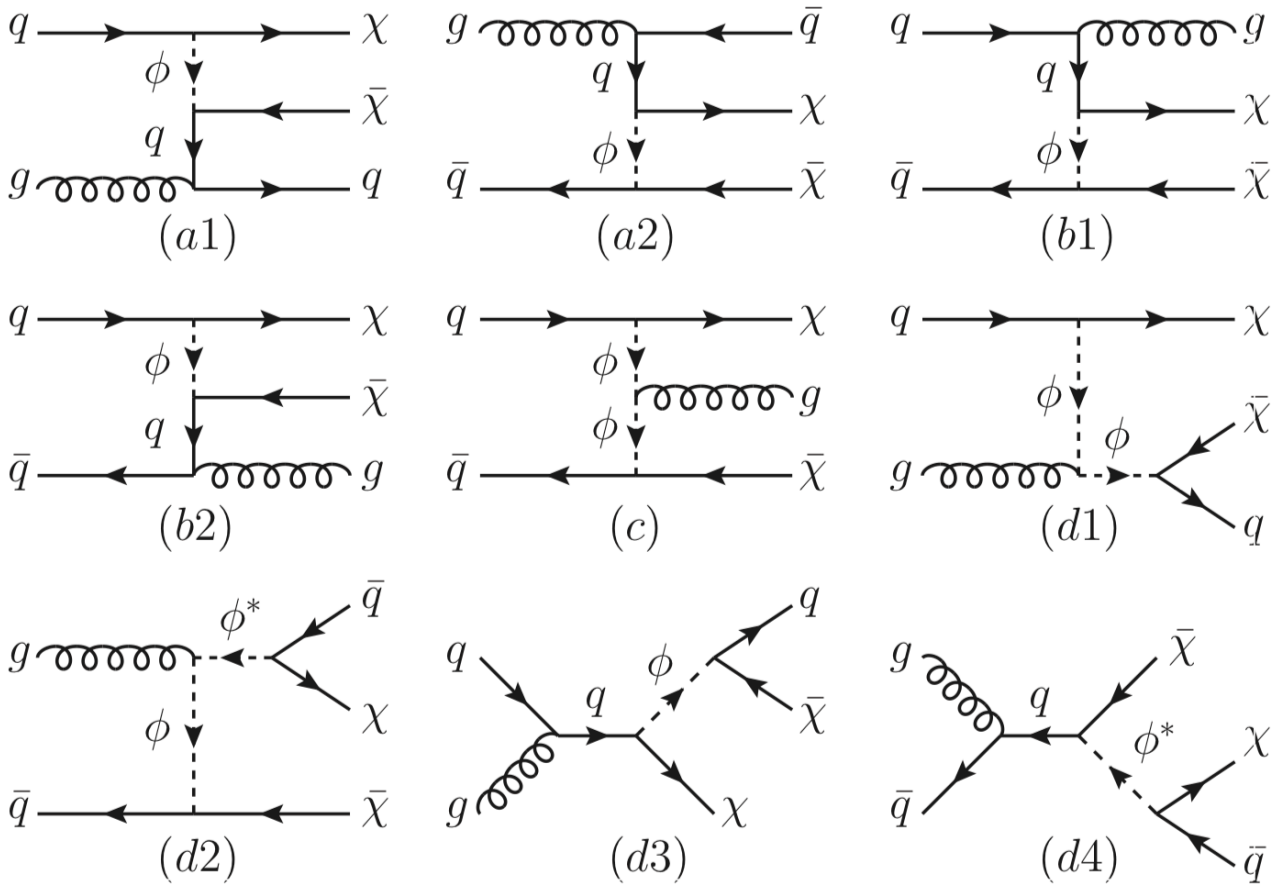
```
###################################
## INFORMATION FOR DMINPUTS
###################################
Block dminputs
    1 1.000000e-01 # lmd0

###################################
## INFORMATION FOR MASS
###################################
Block mass
    6 1.720000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # MH
 7777 2.000000e+02 # MXd1
 88883 8.000000e+02 # MS0U
 99993 8.000000e+02 # MS0D

 88881 800.000000 # su : MS0U
 88882 800.000000 # sc : MS0U
 99991 800.000000 # sd : MS0D
 99992 800.000000 # ss : MS0D
```

```
###################################
## INFORMATION FOR DECAY
###################################
DECAY   6 1.508336e+00 # WT
DECAY  23 2.495200e+00 # WZ
DECAY  24 2.085000e+00 # WW
DECAY  25 4.070000e-03 # WH
DECAY 88881 1.000000e+00 # WS0U1
DECAY 88882 1.000000e+00 # WS0U2
DECAY 88883 1.000000e+00 # WS0U3
DECAY 99991 1.000000e+00 # WS0D1
DECAY 99992 1.000000e+00 # WS0D2
DECAY 99993 1.000000e+00 # WS0D3
```

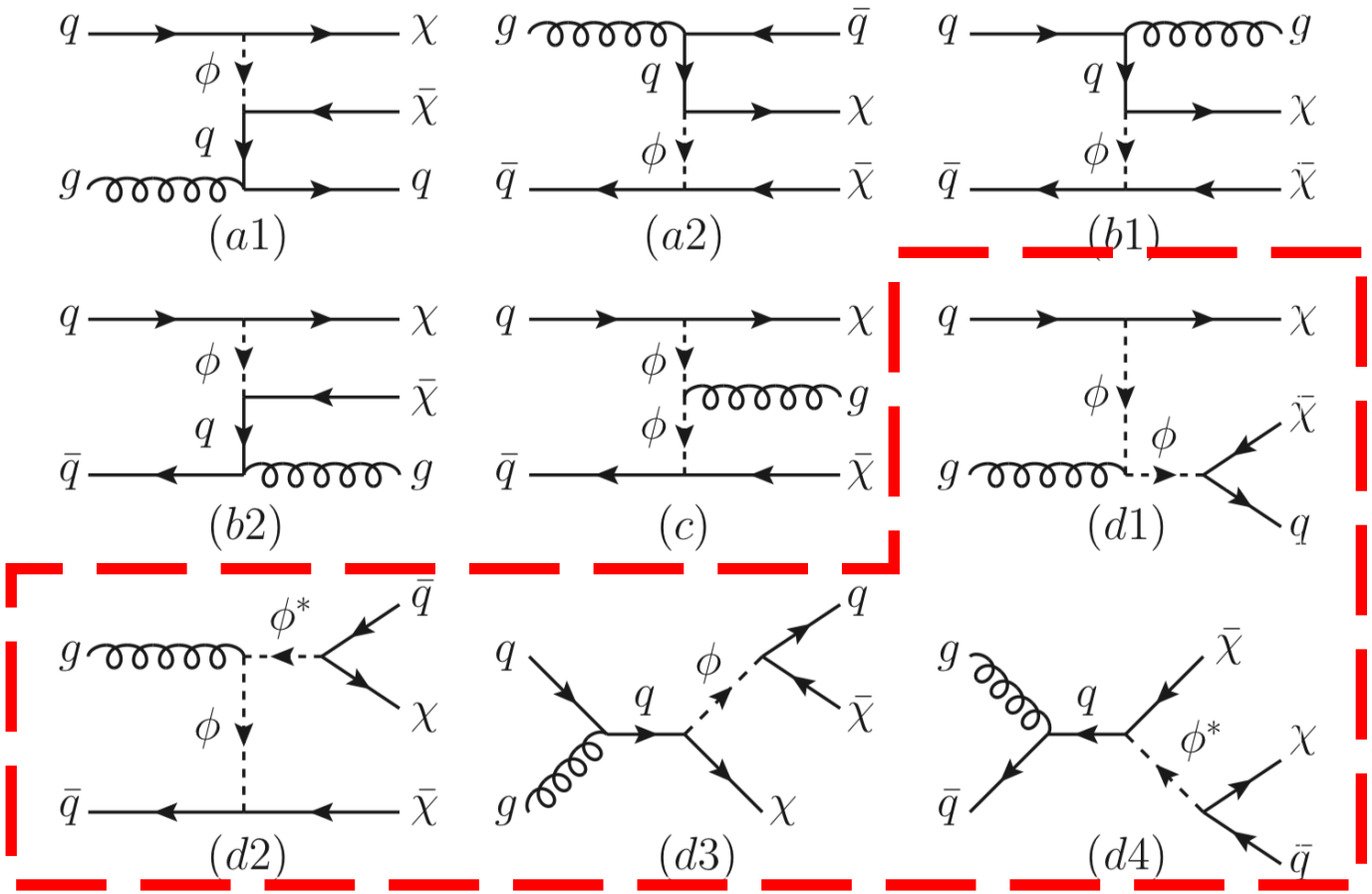
Two type of signals

- Mono-jet
  - ISR and single mediator production.
  - Harder jet from mediator production.
- Di-jet+MET
  - Similar to SUSY squark pair production.

Monojet+MET at parton level diagrams



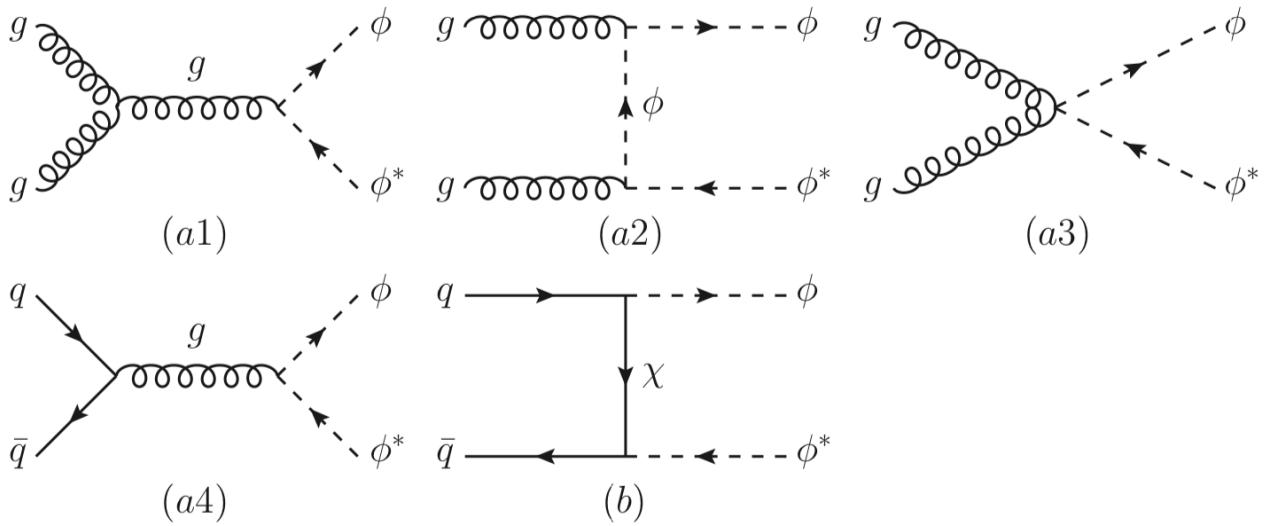
Monojet+MET at parton level diagrams



- ϕ can be produced on shell and then decay into MET and jet.
- 2→3 becomes 2→ 2
- Dominate when ϕ can be produced on-shell

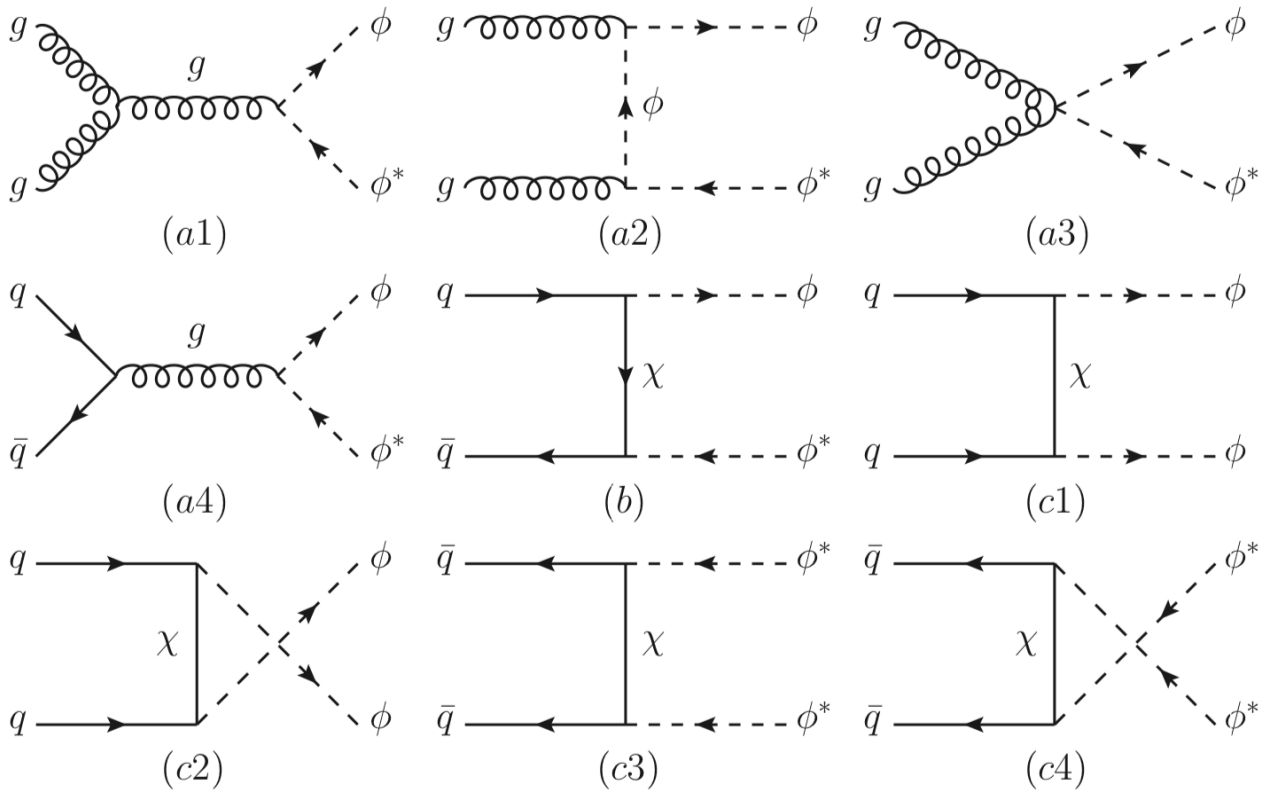
Dijet+MET at parton level

- Dijet+MET is important when a pair of ϕ can be produced on-shell
- If χ is Dirac



Dijet+MET at parton level

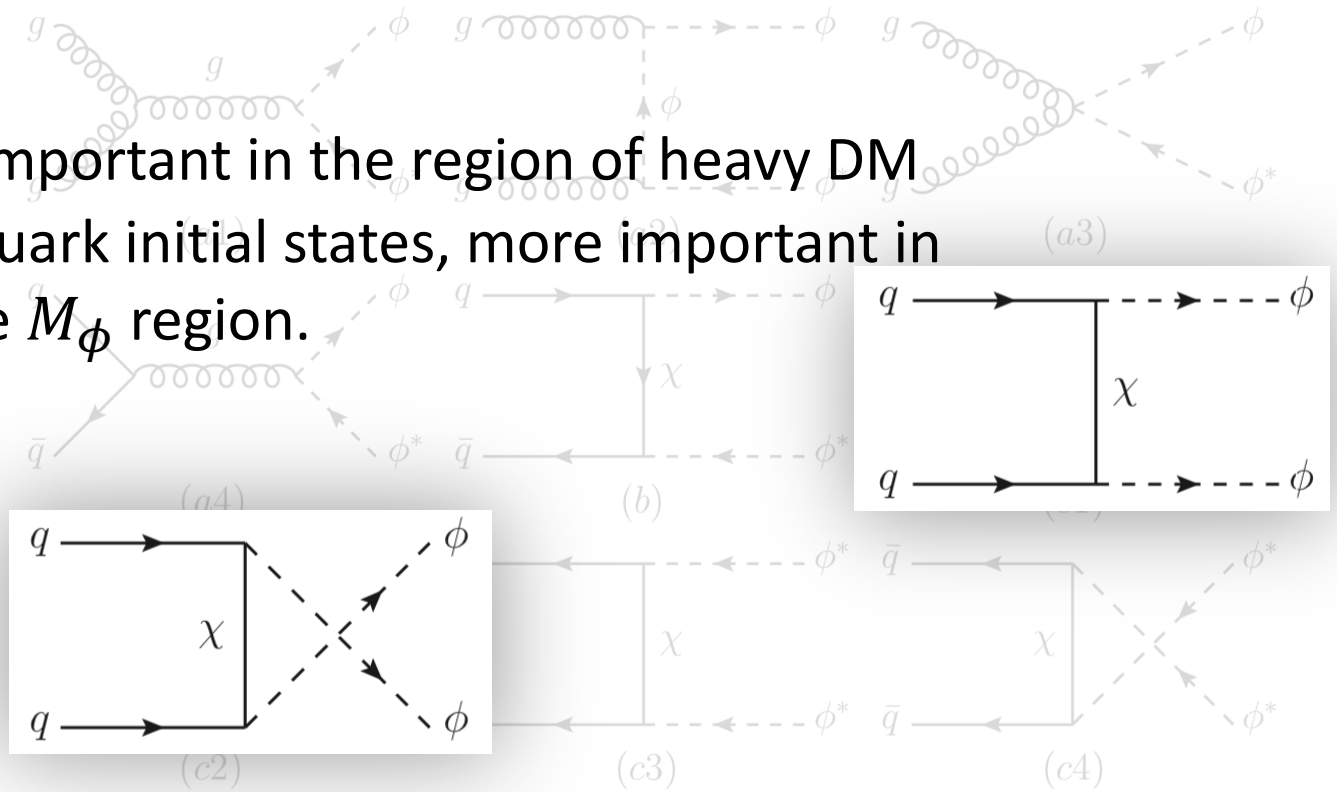
- Dijet+MET is important when a pair of ϕ can be produced on-shell
- If χ is Majorana



Dijet+MET at parton level

- Dijet+MET is important when a pair of ϕ can be produced on-shell
- If χ is Majorana

1. $\propto M_\chi$, important in the region of heavy DM
2. Valent quark initial states, more important in the large M_ϕ region.

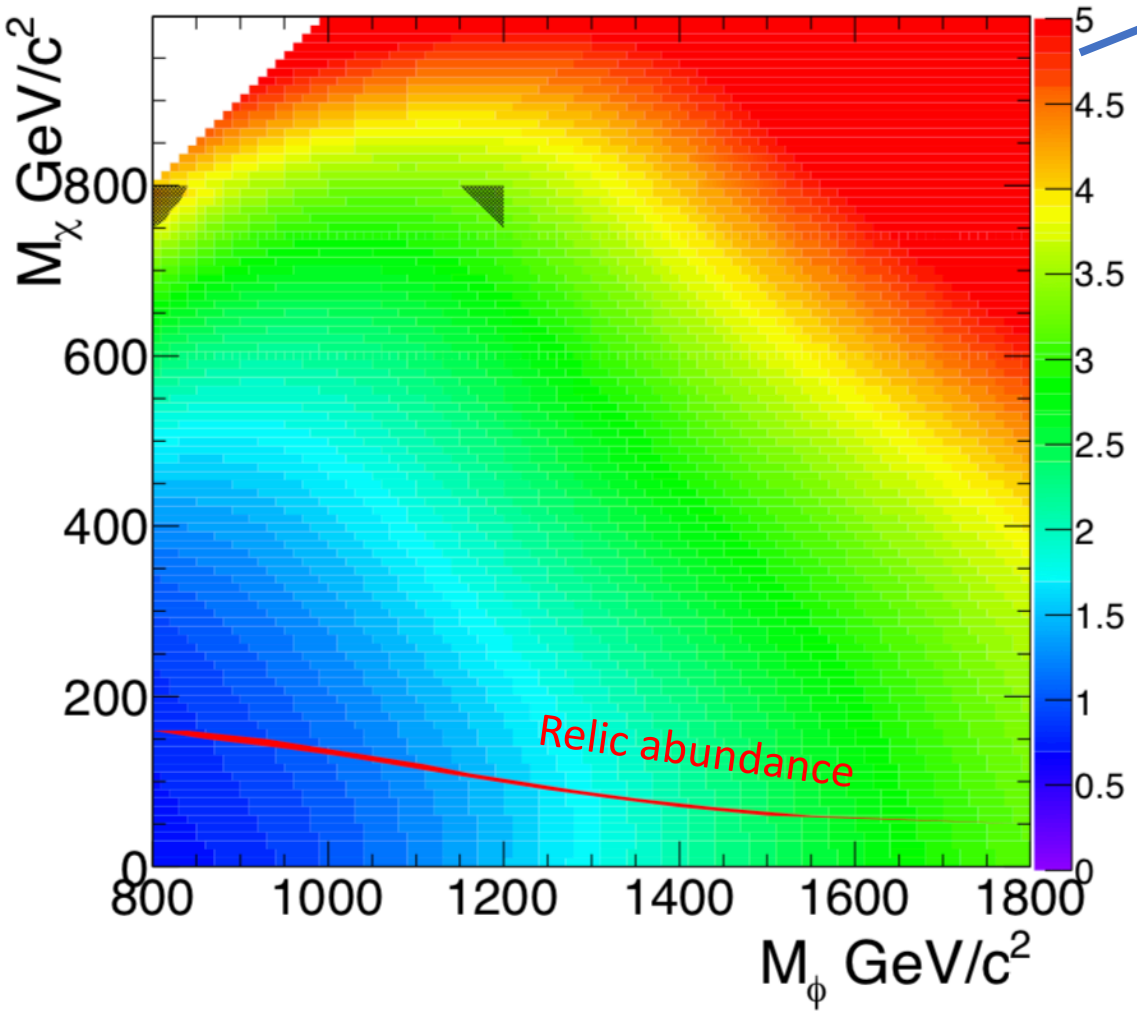


Monojet constraints

- Event generation
  - MG5+ME+Pythia6.4+FASTJET3 for signals
  - MG5+ME+Pythia6.4+PGS4 for background
  - CTEQ6L1
  - anti-KT

Constraints (Dirac case)

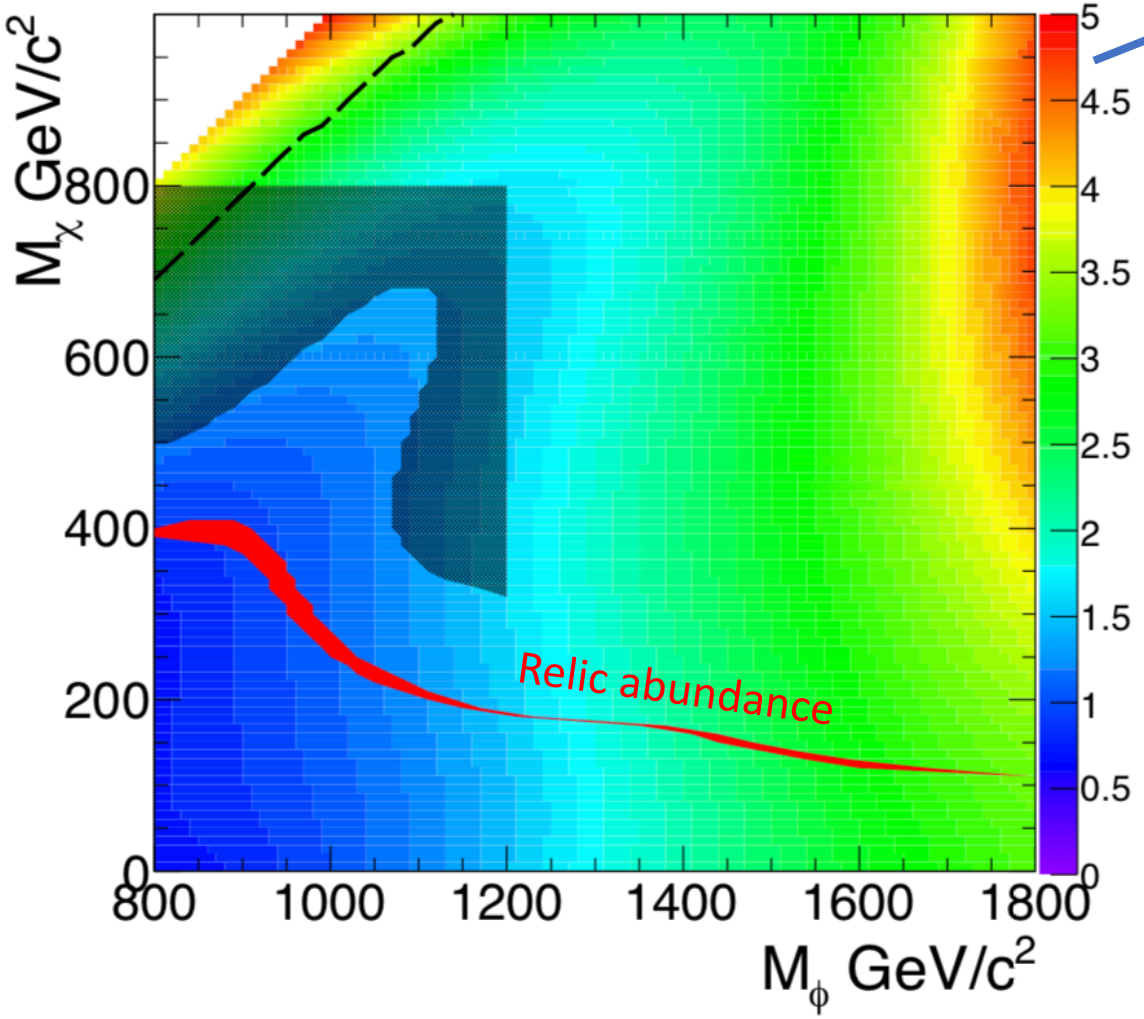
$$\mathcal{L}_\chi = \lambda \bar{\chi}_L q_R \phi^* + \text{h.c.}$$



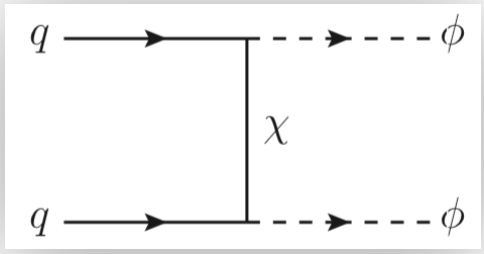
- With fixed M_χ, constraint on coupling becomes weaker with larger M_ϕ, since the production rate of phi becomes smaller.
- With fixed M_ϕ, constraint on coupling becomes weaker with larger M_χ, since the jet becomes softer.

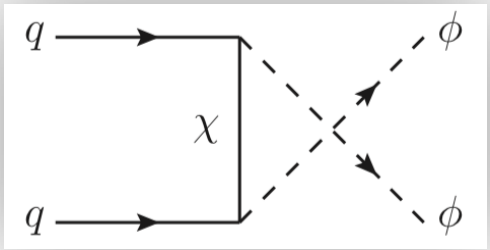
Constraints (Majorana case)

$$\mathcal{L}_\chi = \lambda \bar{\chi}_L q_R \phi^* + \text{h.c.}$$



- With fixed M_χ, constraint on coupling becomes weaker with larger M_ϕ, since the production rate of phi becomes smaller.
- With fixed M_ϕ, the constraint on coupling changes very little with M_χ, event becomes stronger in some region.

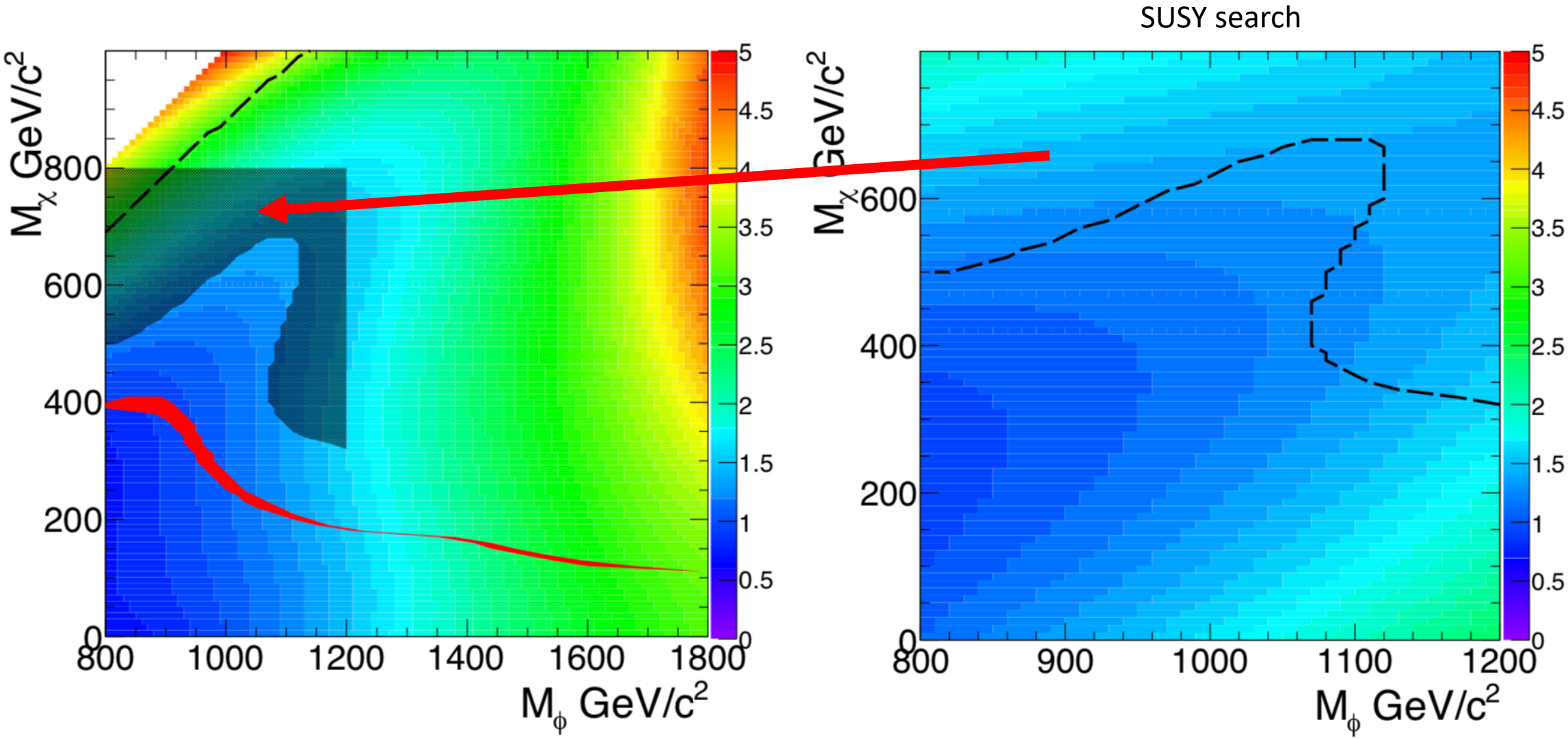




Constraints (Majorana case)

- The dijet+MET contribution is important in the large Mchi region, it may be important to consider “more professional” dijet +MET searches. (The SUSY squark search)
- Tech. Rep. CMS-PAS-SUS-13-012
- CalcHEP is used to calculate the total cross section
- K-factor is small and neglected

Constraints (Majorana case)



Summary

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- The model $\mathcal{L}_\chi = \lambda \bar{\chi}_L q_R \phi^* + \text{h.c.}$ χ: fermionic DM, ϕ: mediator
  - DM can be Dirac or Majorana, with important difference in signal
  - SUSY as a special case, itself is a UV complete model too.
- Parameters
  - Coupling λ, mass of messenger M_ϕ, and mass of DM M_χ. (same for Dirac and Majorana)
- Signals: monojet + MET and dijet + MET
  - In the case that χ is Dirac, monojet + MET search is more important in most of the parameter space.
  - In the case that χ is Majorana, the dijet + MET search is more important in the large M_χ region.

Mono-jet search

- 8 TeV LHC, 19.5 fb-1 CMS, (Tech. Rep. CMS-PAS-EXO-12-048)
  - At least one central jet with pT > 450 GeV, $|\eta|$ < 2.4
  - At most two jets with pT > 30 GeV, $|\eta|$ < 4.5
  - No isolated electrons with pT > 10 GeV, $|\eta|$ < 1.44 or 1.56<$|\eta|$<2.5
  - No isolated muons with pT > 10 GeV, $|\eta|$ < 2.1
  - MET > 450 GeV
  - For events with a second jet, $\Delta\phi(j1, j2)$< 2.5

Mono-jet search

- 8 TeV LHC, 19.5 fb-1 CMS, (Tech. Rep. CMS-PAS-EXO-12-048)
  - At least one central jet with pT > 110 GeV, $|\eta|$ < 2.4
  - At most two jets with pT > 30 GeV, $|\eta|$ < 4.5

Allowing a second hard jet.
Including both the monojet+MET and the dijet+MET events

  - No isolated electrons with pT > 10 GeV, $|\eta|$ < 1.44 or 1.56<$|\eta|$<2.5
  - No isolated muons with pT > 10 GeV, $|\eta|$ < 2.1
  - MET > 450 GeV
  - For events with a second jet, $\Delta\phi(j1, j2)$< 2.5

Comparison with dark matter direct detection