Monojet searches for simplified models of dark matter: The *Z'* portal case

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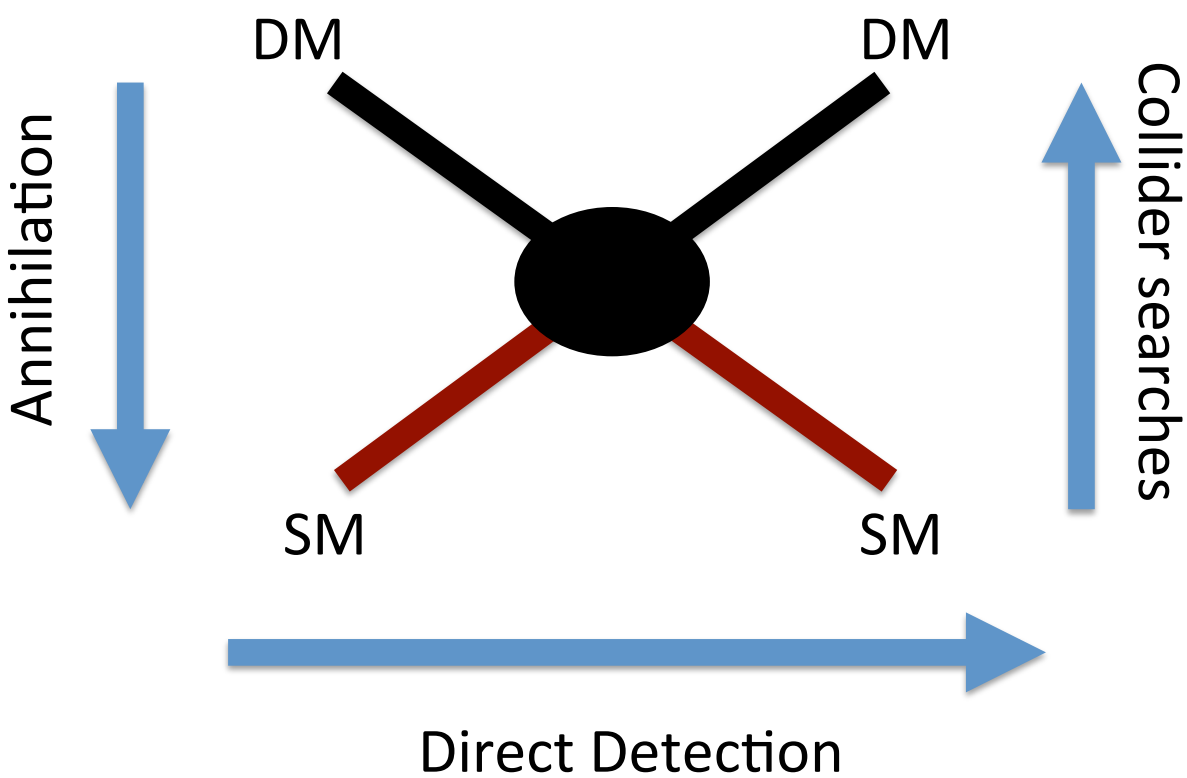
1202.2894, 1212.2221

Motivations



Outline

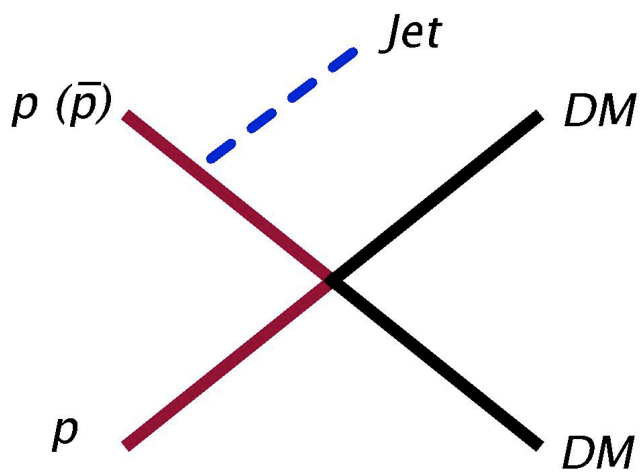
- Why we need UV complete models
- Monojet + MET constraint on the Z’ model
- Broad resonance case
- Dijet search

Motivations

- For low mass dark matter, $M_D \sim \mathcal{O}(10)\ \mathrm{GeV}$

$$\mathcal{O} = \frac{1}{\Lambda^2}\bar{\chi}_D \chi_D \bar{\psi}_{SM} \psi_{SM}$$

- *Monojet + MET* process



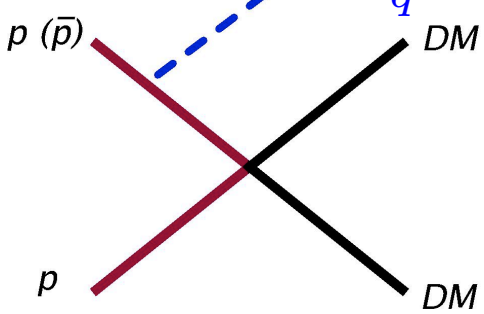
.....
Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu (2010);
Bai, Fox, Harnik (2010);
Shoemaker, Vecchi, (2011);
.....

CMS-PAS-EXO-12-048 (8 TeV, 19.5 fb^{-1})
ATLAS-CONF-2012-147 (8TeV, 10 fb^{-1})
CDF, PRL101 (2008)181602 (1.96 TeV, 1 fb^{-1})
Shalhout, Schwartz, Erbacher, Conway, Fox, Harnik, Bai,
CDF Note 10709 (1.96 TeV, 6.7 fb^{-1})
.....

Motivations

- $\mathcal{L}_{\rm eff}$: $\frac{1}{\Lambda_{jet}^2}\sum_q \bar{\chi}\gamma_\mu\chi\bar{q}\gamma^\mu q$ $\quad \Lambda < 900\ \mathrm{GeV}$

  CMS-PAS-EXO-12-048



Three body final state

$$\sigma \sim \frac{P_T^2}{\Lambda^4}$$

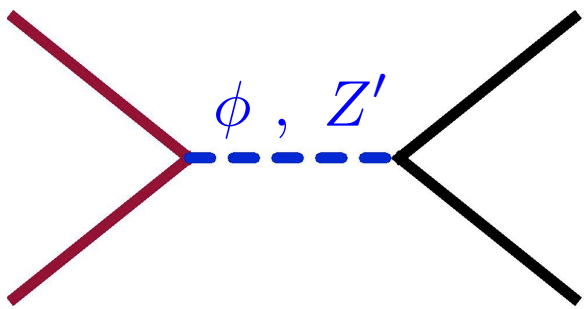
- $\Lambda \sim M^2/g^2$
  - Can be produced on shell → conservative bound
  - M < P_T and cannot be produced on shell

    → $\sigma \sim g^4/P_T^2 < P_T^2/\Lambda^4$

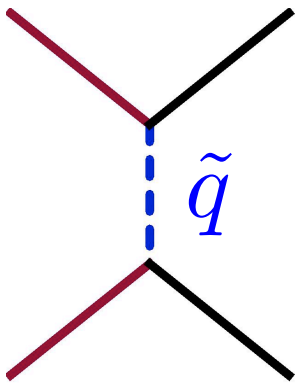
    → The constraint from effective theory is stronger.

Simple UV complete models

- S-channel mediator:



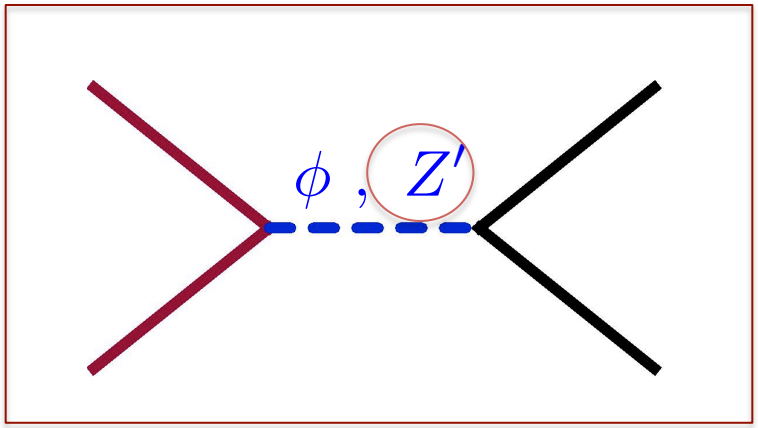
- T-channel mediator:



Simple UV complete models

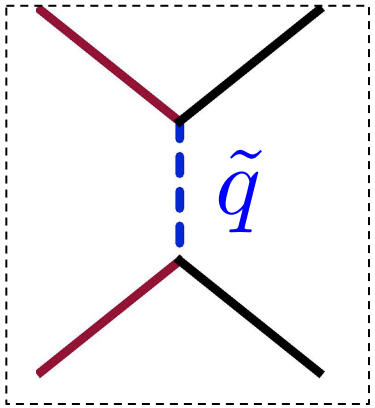
- S-channel mediator:

This talk



- T-channel mediator:

Hao Zhang's talk



Z' portal

- We consider a vector boson
  - Leptophobic
  - Universal coupling to quarks
  - The dark matter can be a Dirac spinor or Majorana spinor
- The most general Lagrangian

$$\mathcal{L} = Z'_\mu (g_{Z'} \bar{q} \gamma^\mu q + g_{Z'5} \bar{q} \gamma^\mu \gamma_5 q + g_D \bar{\chi} \gamma^\mu \chi + g_{D5} \bar{\chi} \gamma^\mu \gamma_5 \chi)$$

Z' portal

- Direct Detection

	Operator	Structure	DM-nucleon Cross Section
O_1	$\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\chi$	SI, MI	$\frac{9g_{Z'}^2 g_D^2 M_N^2 M_\chi^2}{\pi M_{Z'}^4 (M_N+M_\chi)^2}$
O_2	$\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\gamma_5\chi$	SI, MD	$\sim v^2$
O_3	$\bar{q}\gamma^\mu\gamma_5 q\bar{\chi}\gamma_\mu\chi$	SD, MD	$\sim v^2$
O_4	$\bar{q}\gamma^\mu\gamma_5 q\bar{\chi}\gamma_\mu\gamma_5\chi$	SD, MI	$\frac{3g_{Z'_5}^2 g_{D5}^2 (\Delta\Sigma)^2 M_N^2 M_\chi^2}{\pi M_{Z'}^4 (M_N+M_\chi)^2}$

Z' portal

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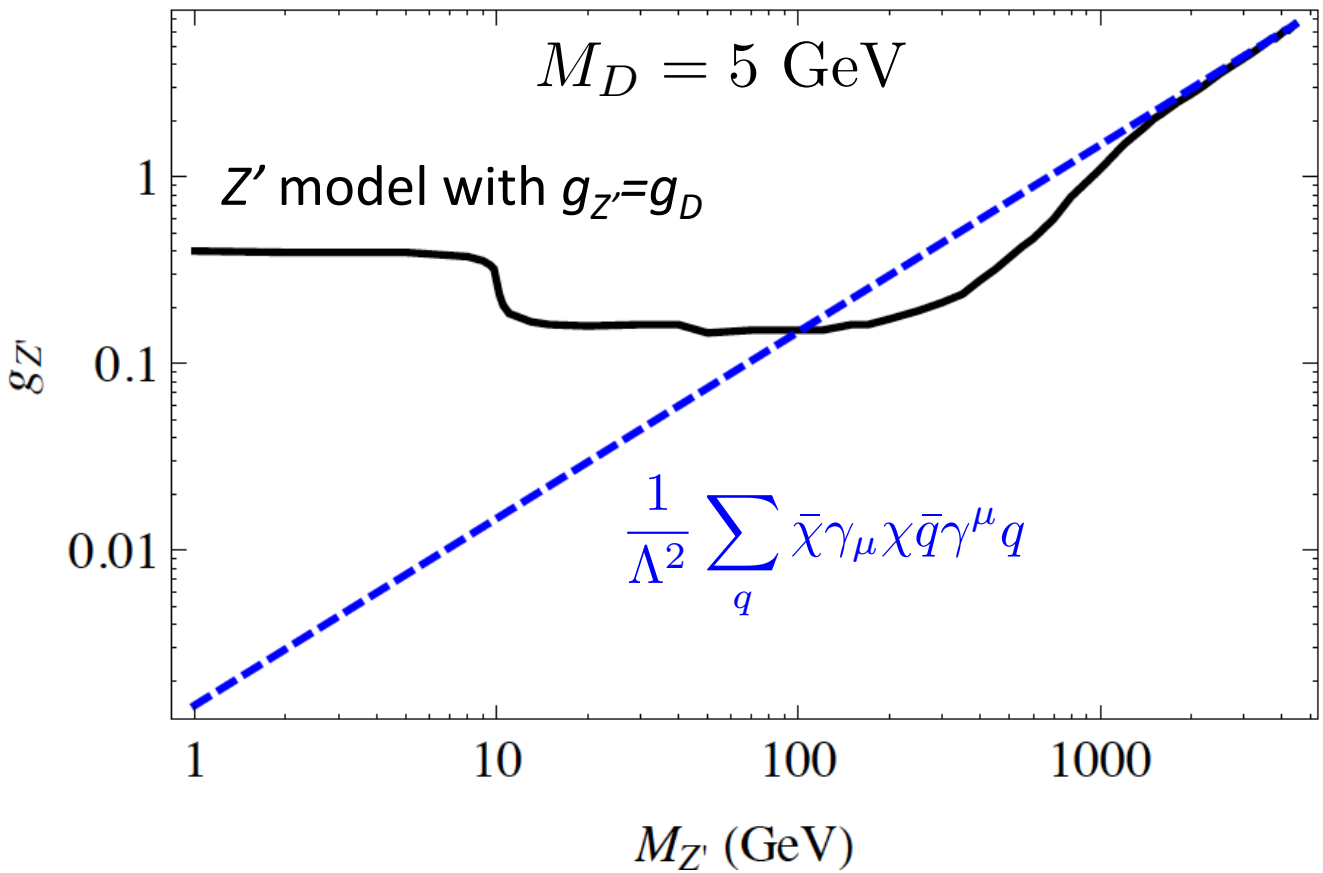
O_4	$\bar{q}\gamma^\mu \gamma_5 q \bar{\chi}\gamma_\mu \gamma_5 \chi$	SD, MI	$\frac{3 g_{Z'_5}^2 g_{D5}^2 (\Delta\Sigma)^2 M_N^2 M_\chi^2}{\pi M_{Z'}^4 (M_N + M_\chi)^2}$

In the case of O2, O3 and O4, since the direct detection signal is suppressed, collider constraints are much stronger if the dark matter can be produced inside the collider.

Monojet constraint

- ATLAS 7 TeV 1 fb^{-1} ($PT(j_1)$ > 300 GeV, MET > 350 GeV)



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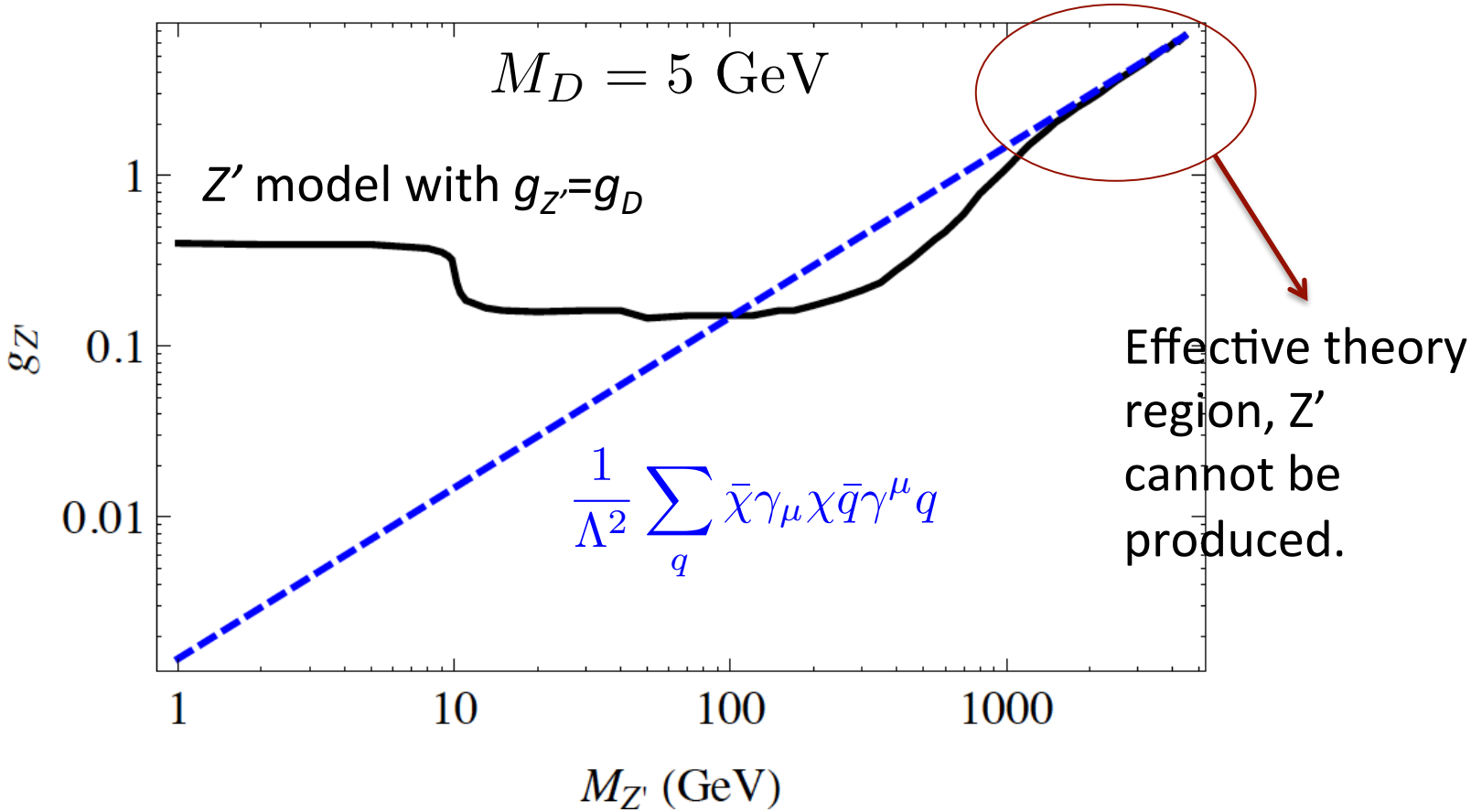

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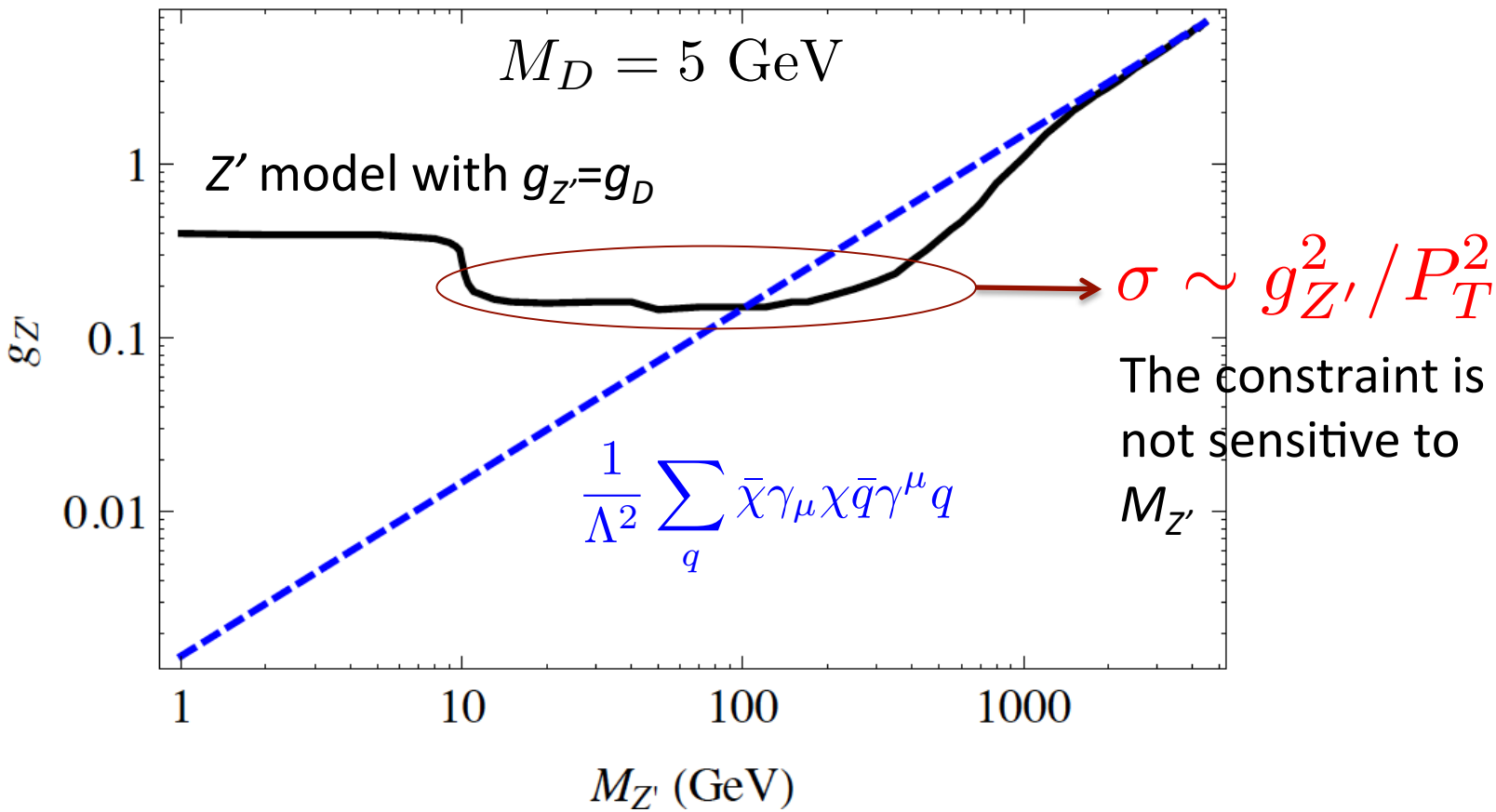

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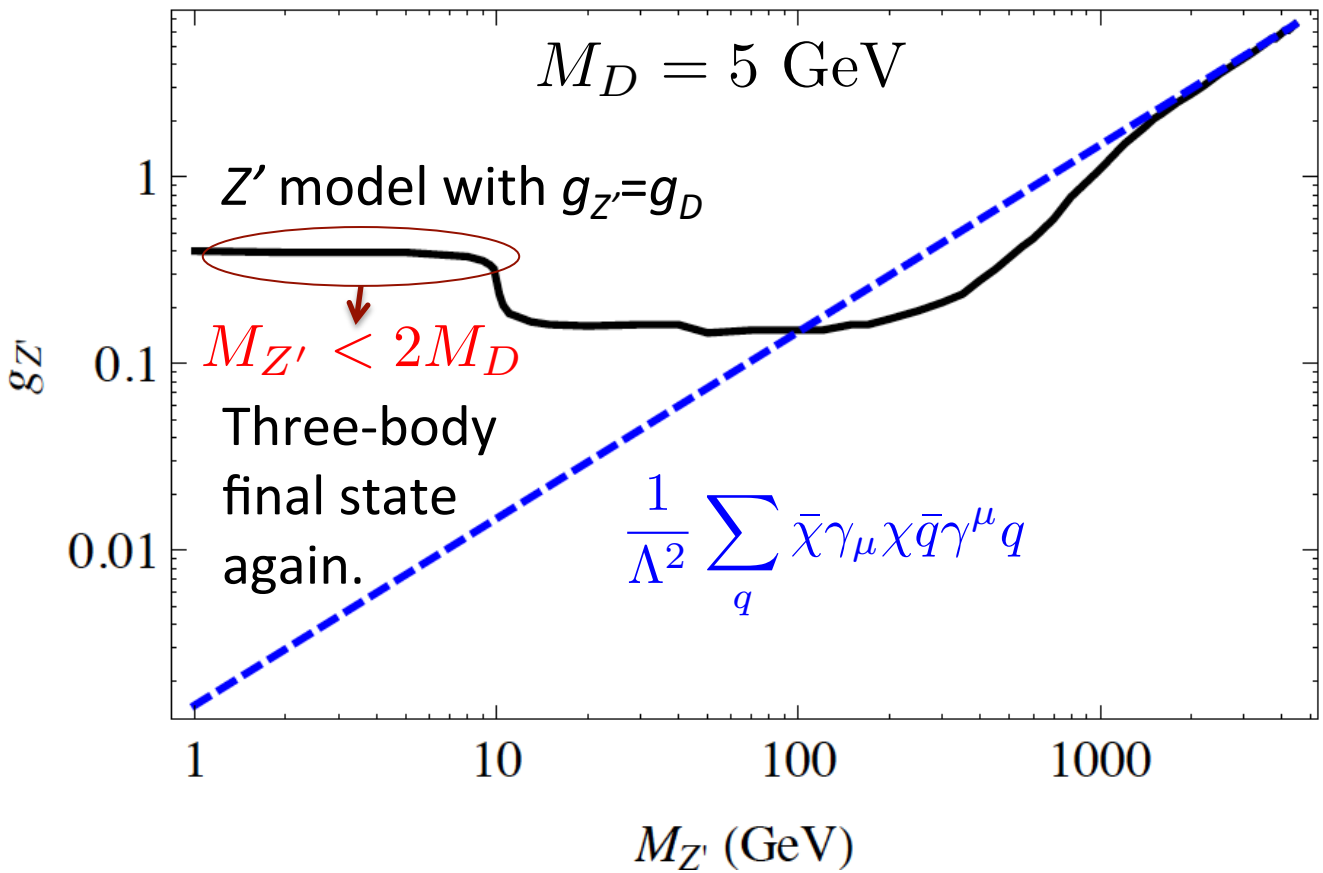

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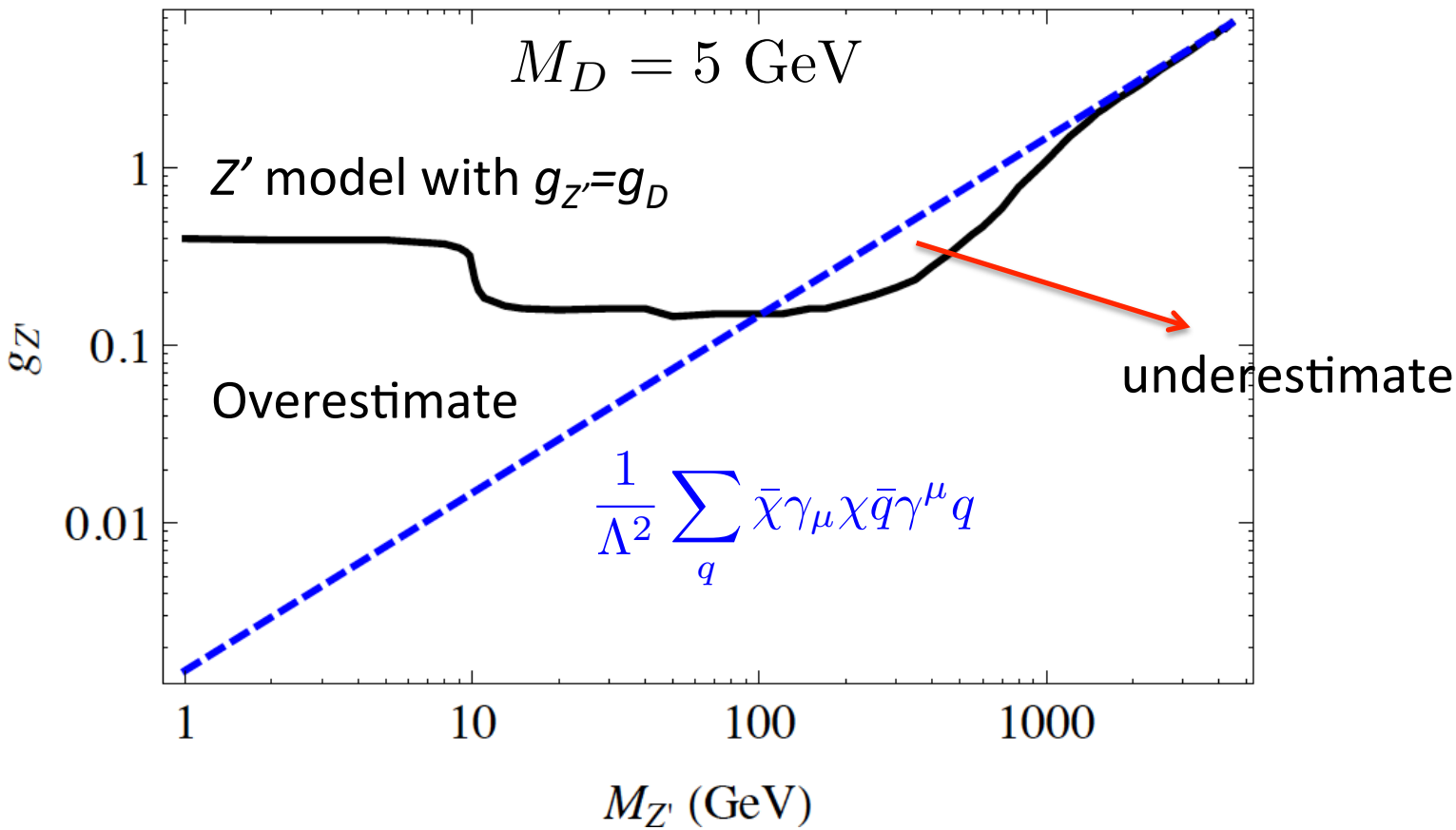


Broad resonance case

- Kinetic width:

$$\sigma \propto \frac{1}{(s - M_{Z'}^2)^2 + s\boxed{\Gamma_{Z'}^2(\sqrt{s})}}$$

Width of Z' as if its mass is $\sqrt{s}$

In the narrow width region using Breit-Wigner approximation

$$\frac{1}{(s - M_{Z'}^2)^2 + M_{Z'}^2\Gamma_{Z'}^2(M_{Z'})}$$

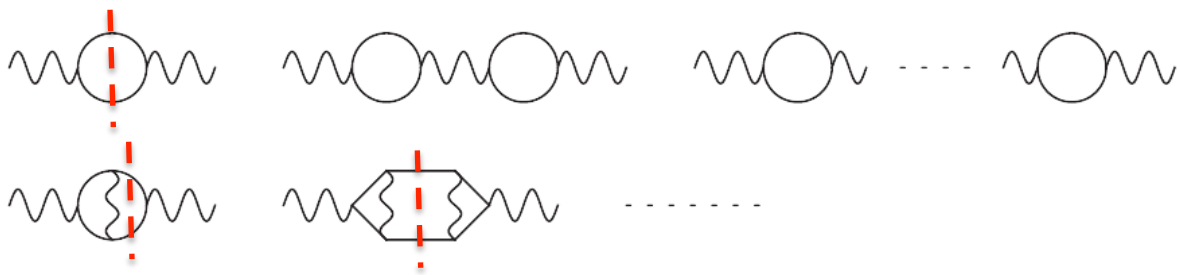
being used by most of the simulation codes!!

- In the Z' model $\Gamma_{Z'} \propto N_f N_C$

  with $g_{Z'}$ ~ O(1), $\Gamma_{Z'} \sim M_{Z'}$

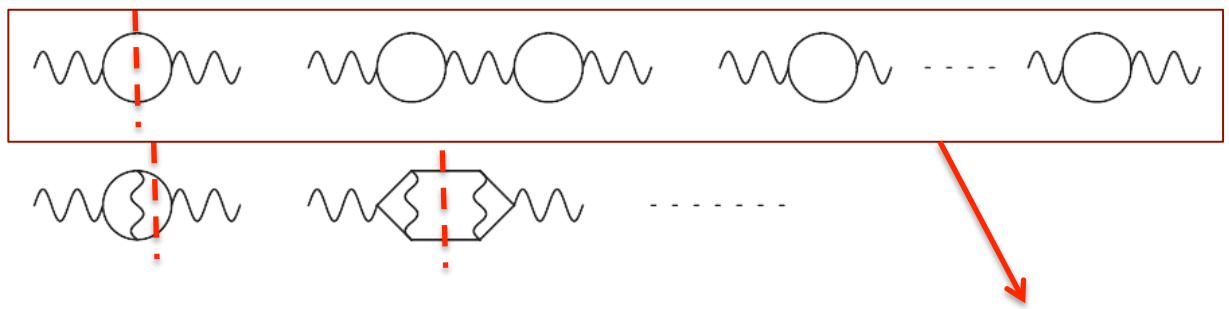
Broad resonance case

- Kinetic width:



Broad resonance case

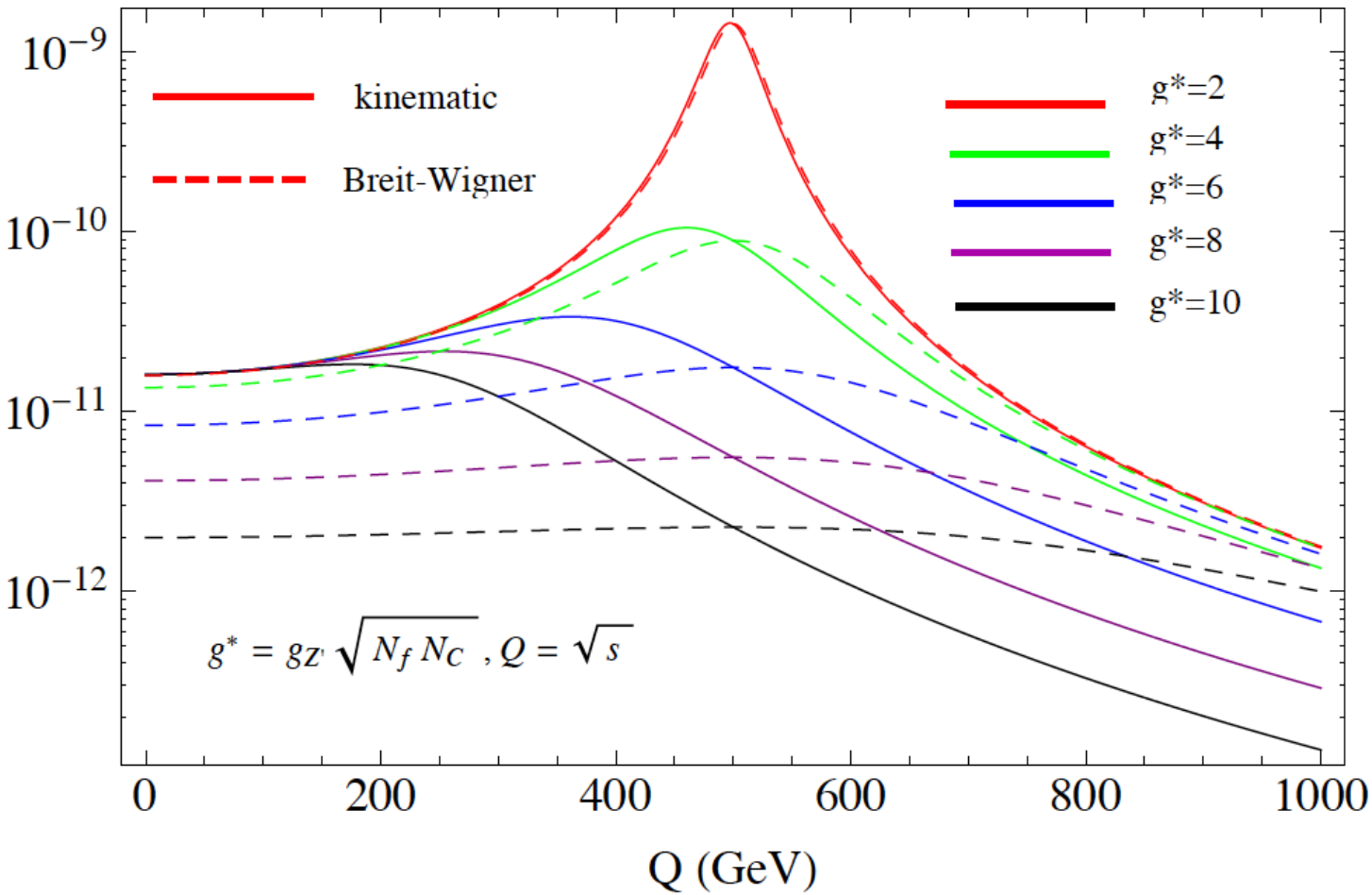
- Kinetic width:



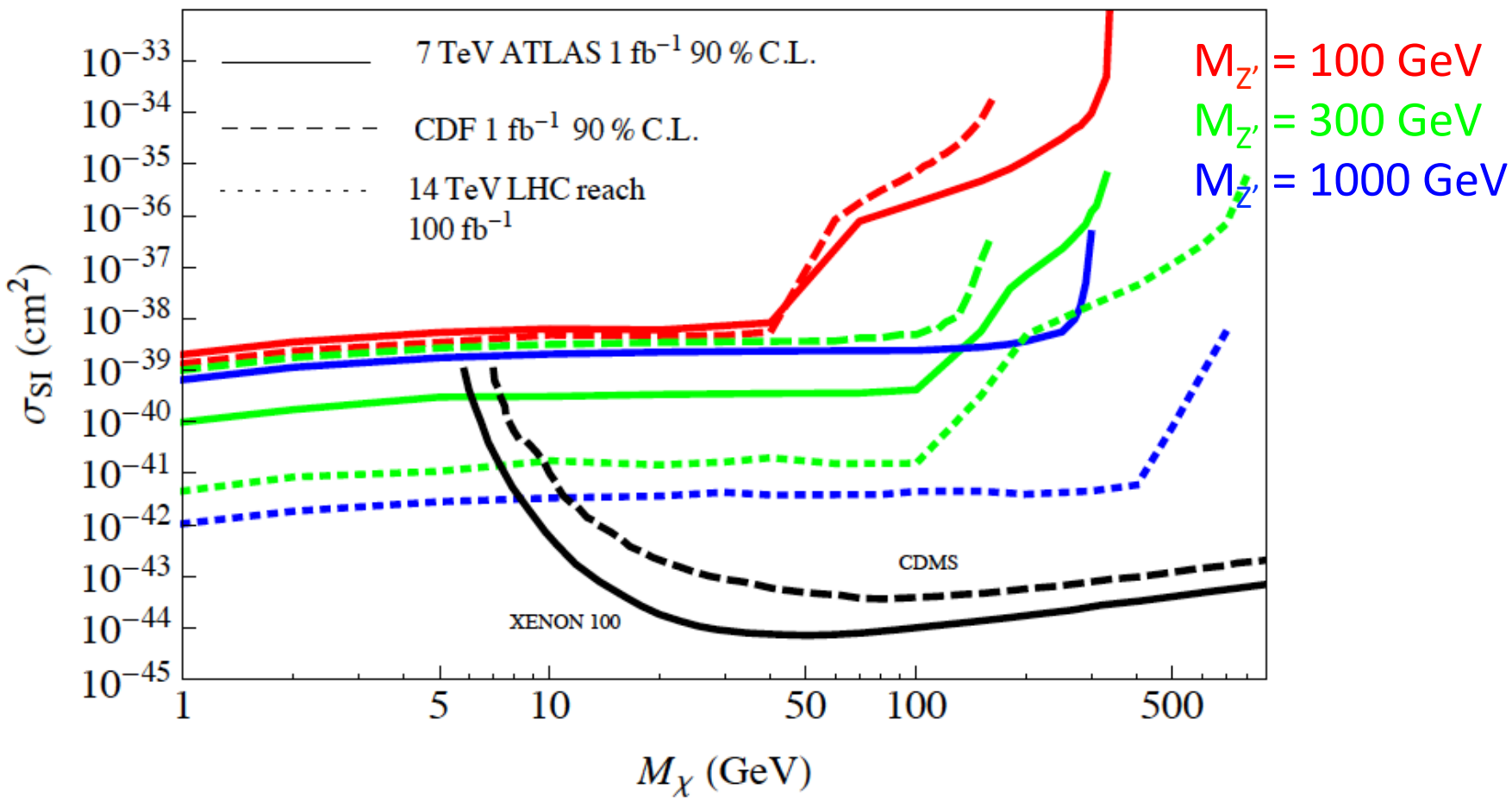
enhanced by $N_F \times N_C$.

$$\Gamma(\sqrt{s}) \approx \frac{\sqrt{s}}{M_{Z'}} \Gamma(M_{Z'})$$

Broad resonance case

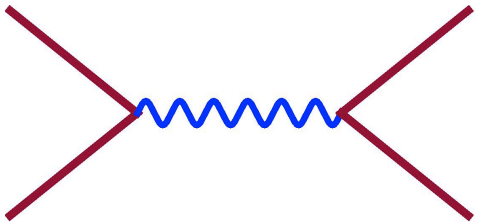


Constraints



Search for Z'

- Dijet bump searches:
  - Depends only on $g_{Z'}$;
  - Not sensitive to M_D ;
  - Suffers from large QCD background, difficult to go to small mass.



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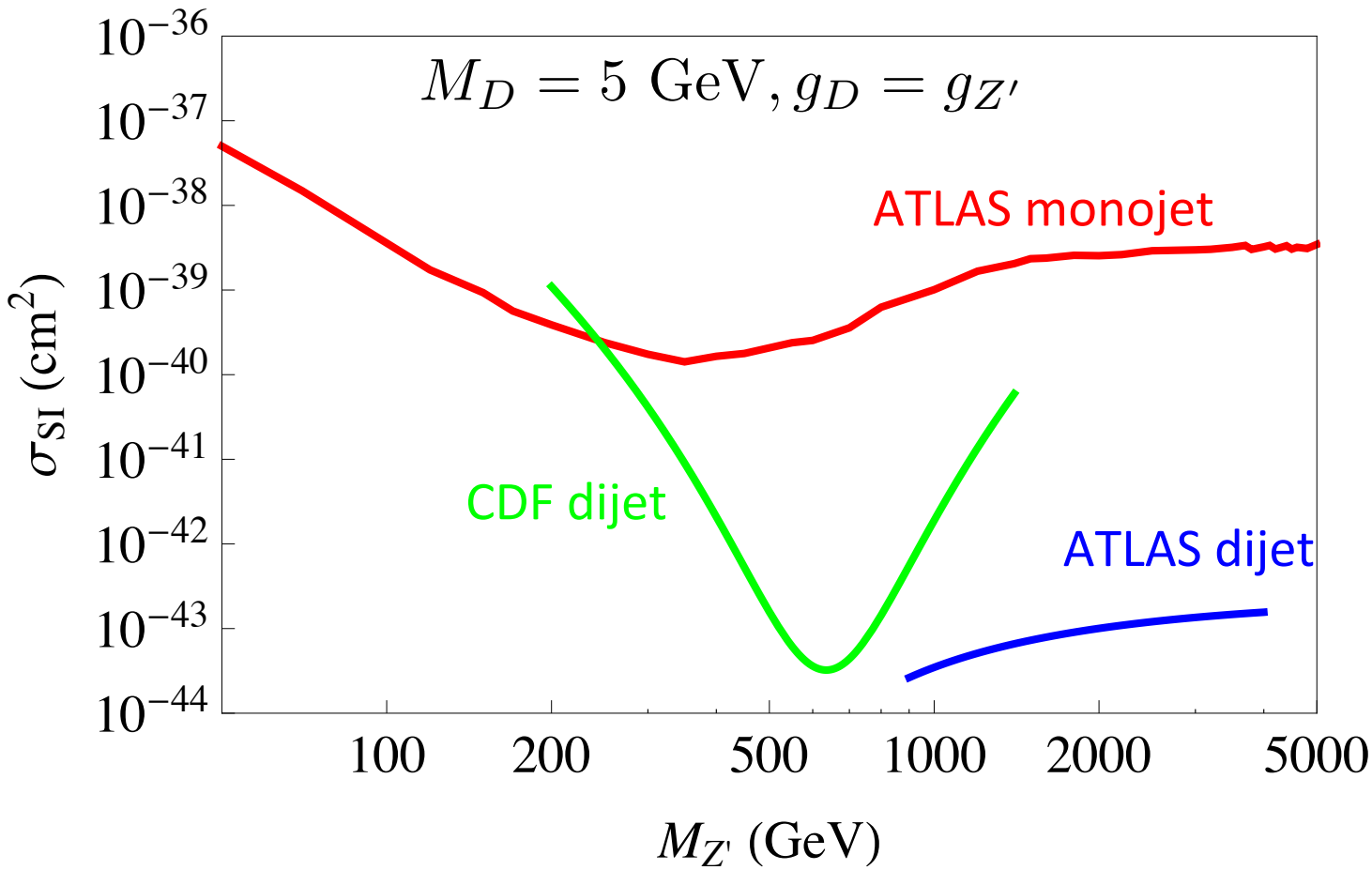

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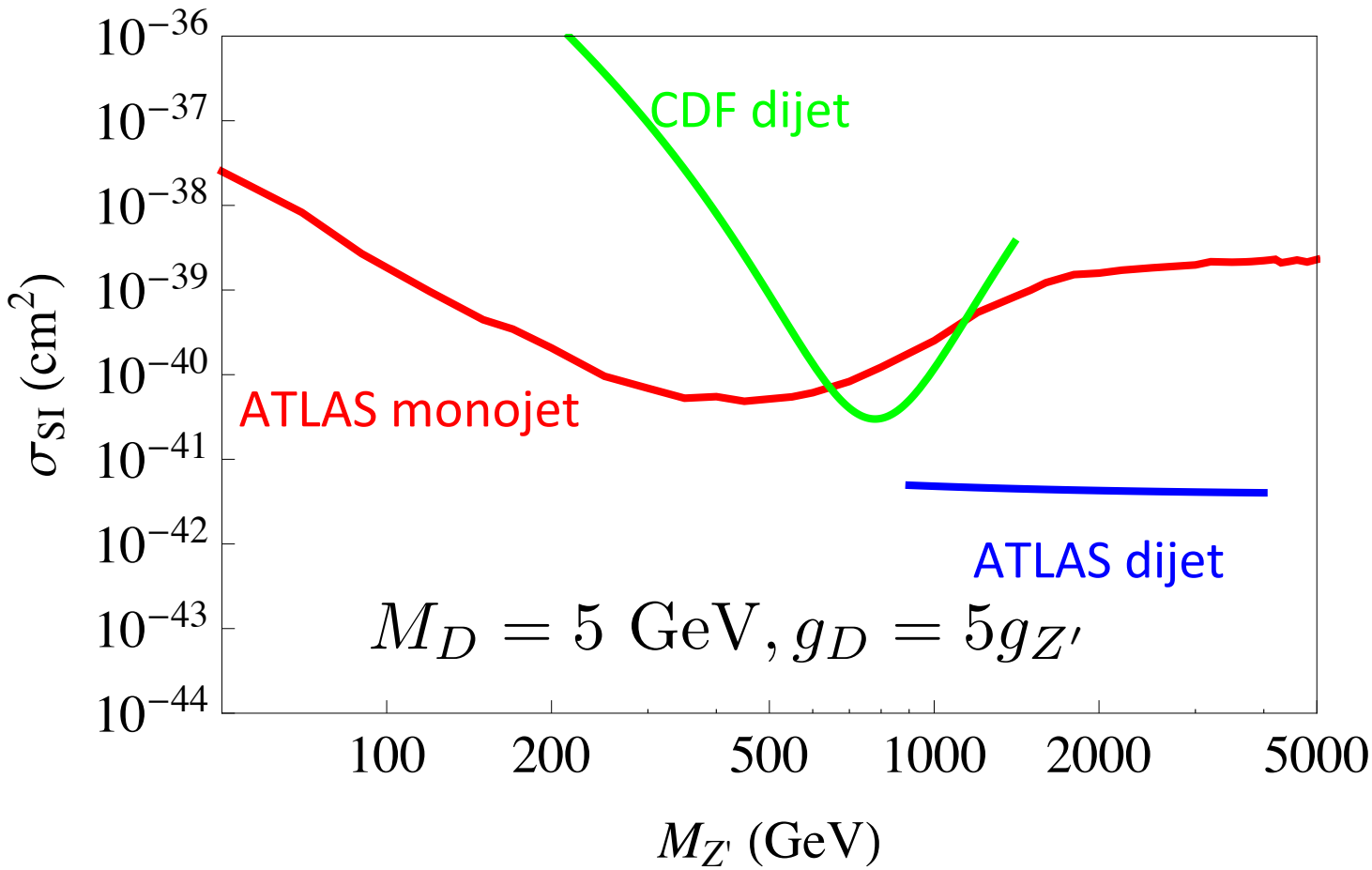
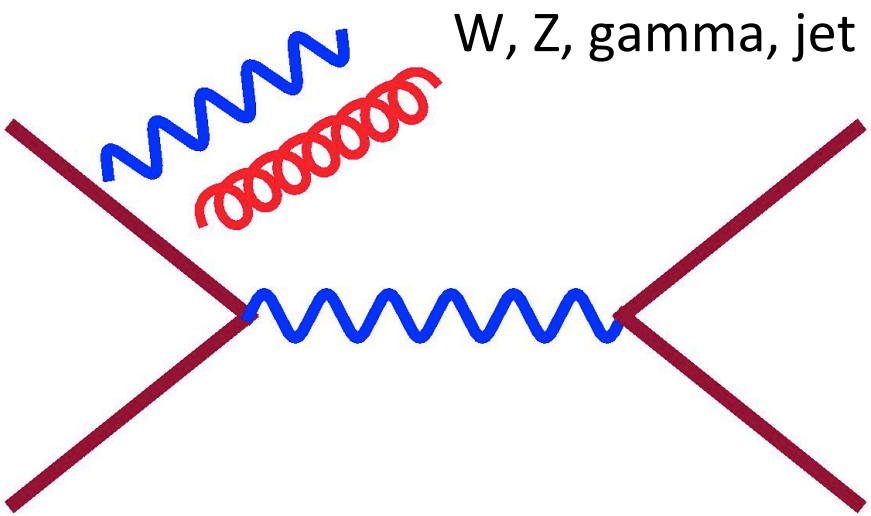


Extend dijet search to smaller $M_{Z'}$

- For smaller $M_{Z'}$ the jets produced from Z' decay is too soft, so that the trigger efficiency is too small.

- Instead of using only dijet bump search, we trigger another hard object.



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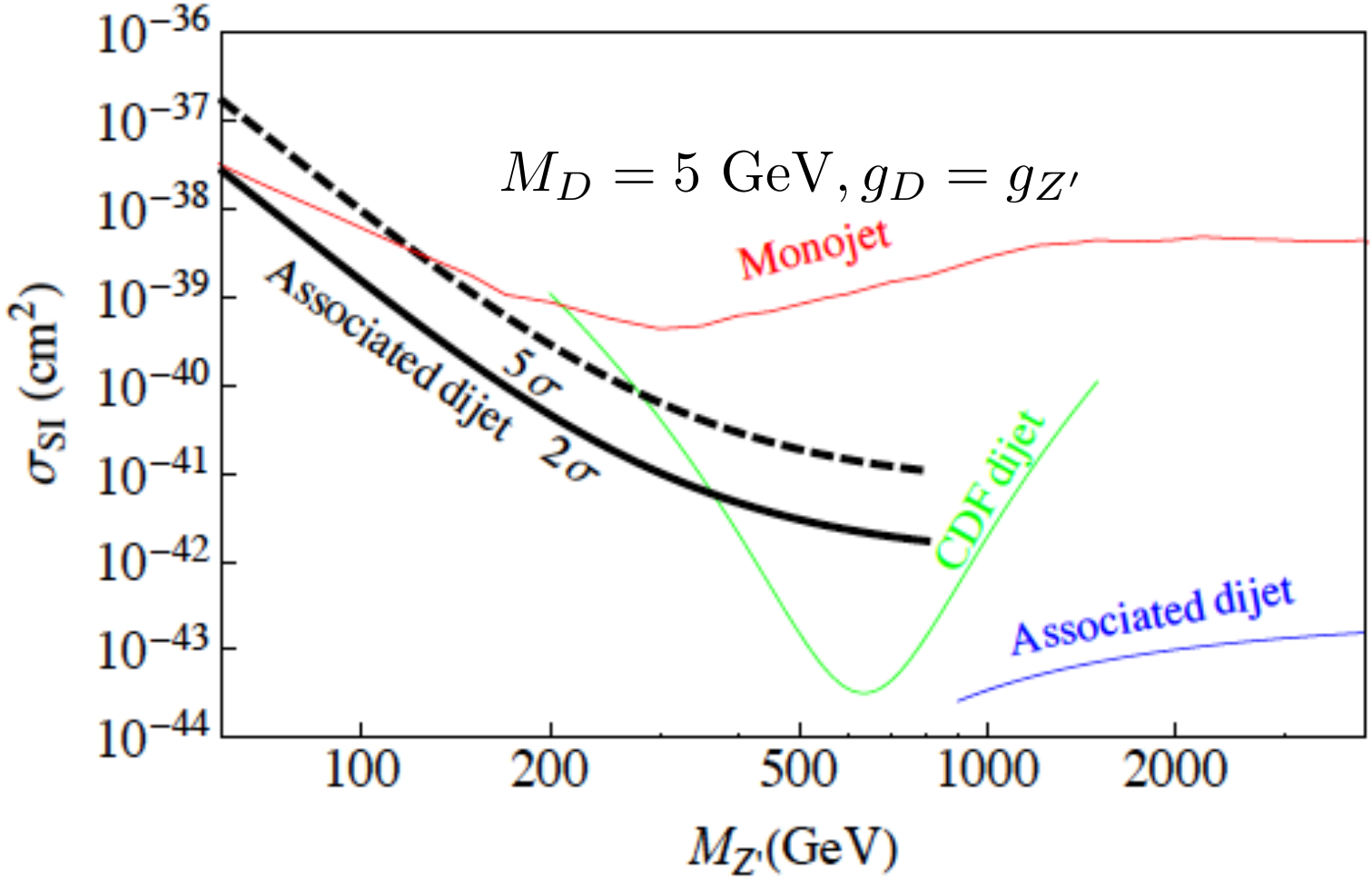

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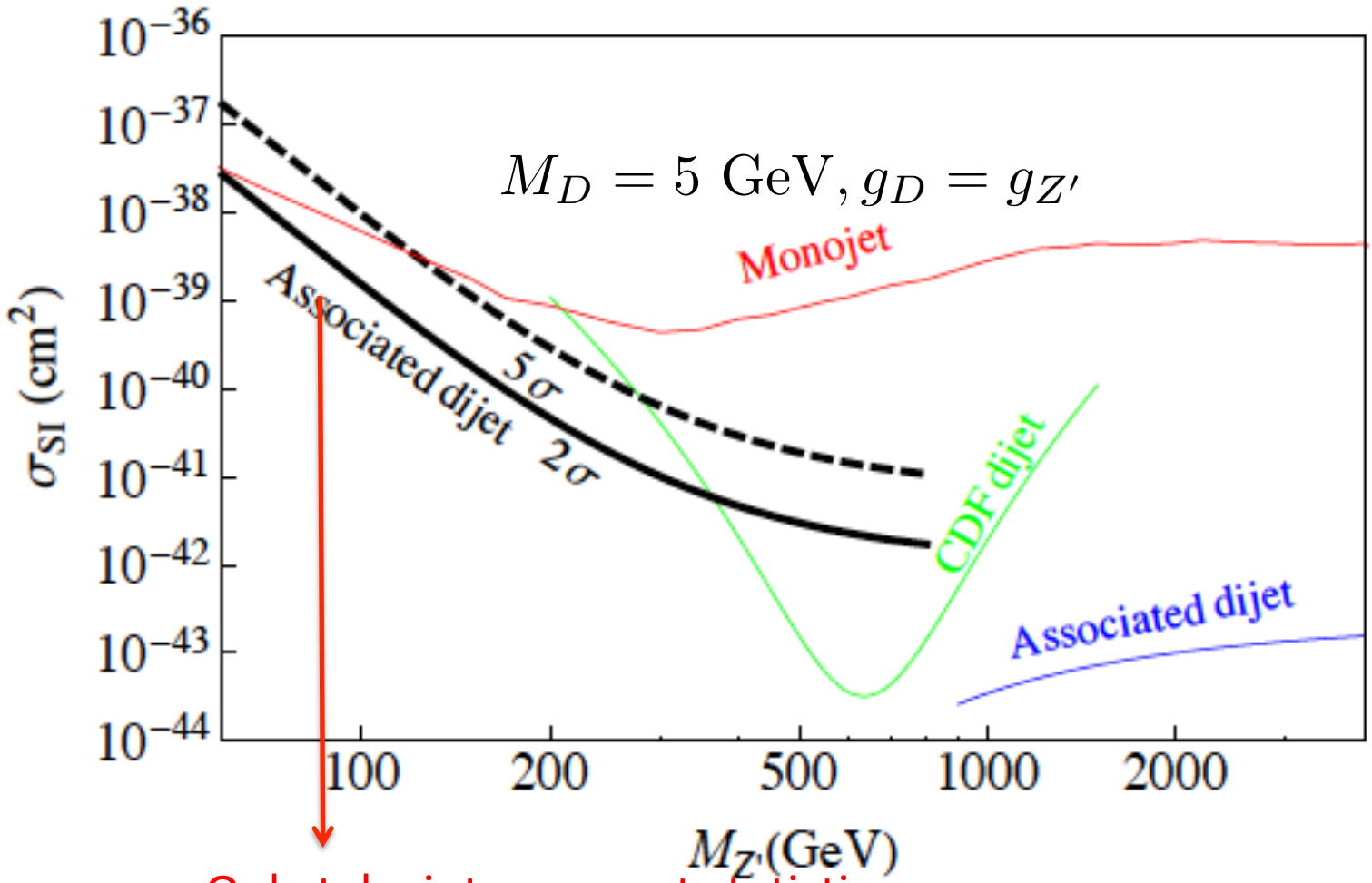

Only take into account statistic uncertainties!!

Summary

- In different parameter spaces, the effective theory estimation may either underestimate or overestimate the constraints on dark matter models, so it is important to consider UV complete theories.
- In the broad resonance case, it is important to use the kinetic width.
- In large $M_{Z'}$ region, the constraint from dijet bump search is stronger than from monojet search if $g_{Z'} \approx g_D$
- By triggering extra hard objects, we may be able to extend the dijet bump search to smaller $M_{Z'}$.