Dark Matter at colliders: Theory.

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Dark Matter.

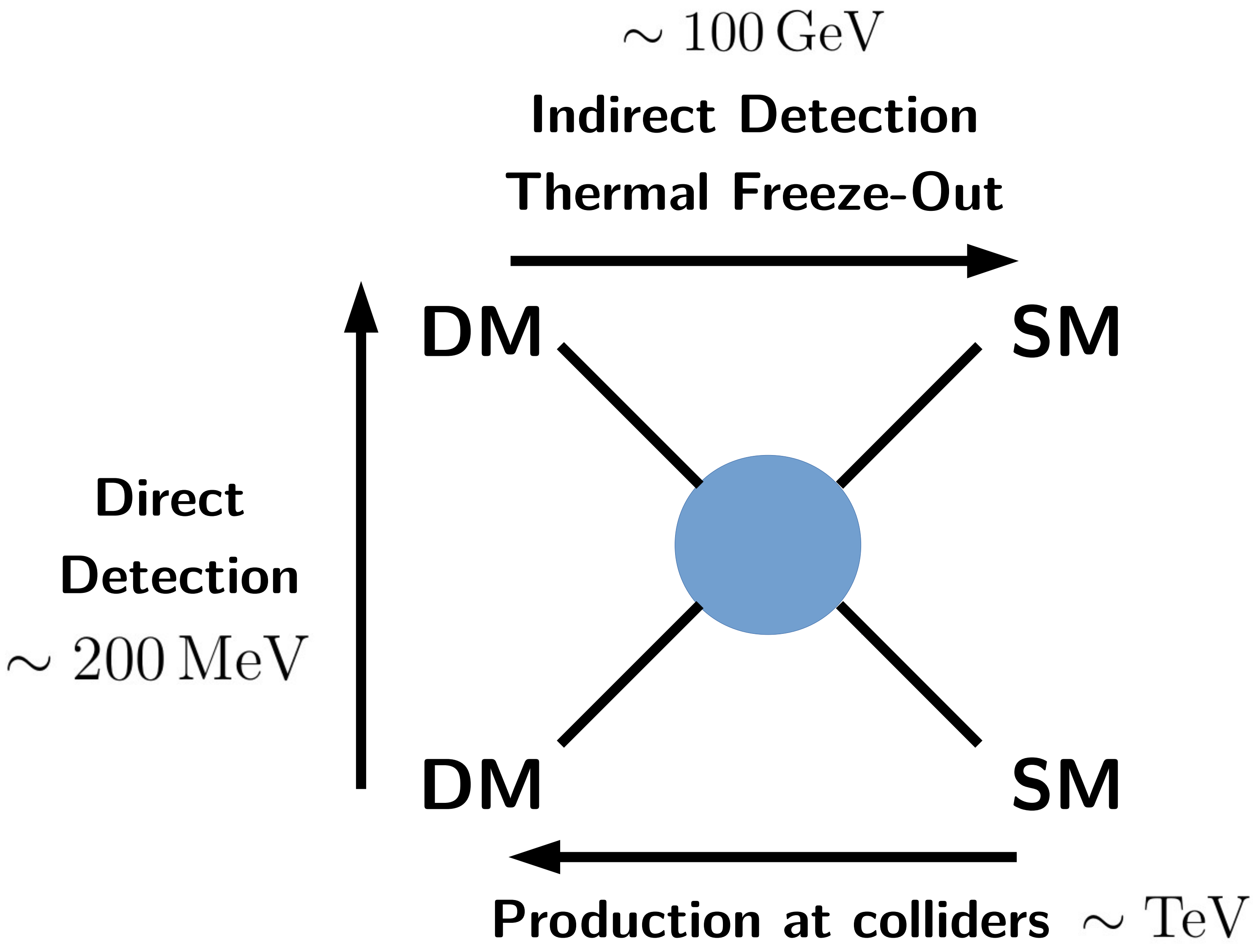
-There is clear observational evidence of the existence of Dark Matter (DM) in gravitational interactions.

-DM could consist of particles that lie Beyond the Standard Model.

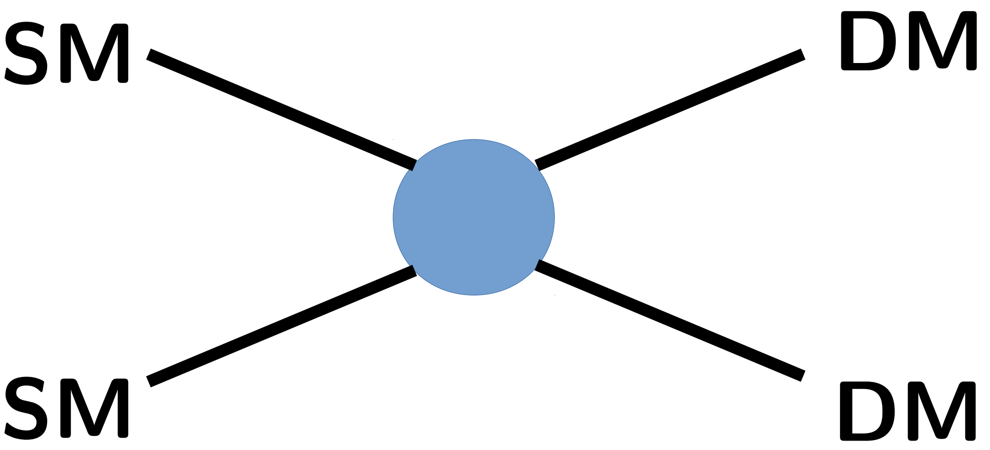
-If DM is a particle then it could be searched for at colliders!

-However, if there are several ways/models to incorporate DM into the SM, how can we test it in the LHC?

Dark Matter.

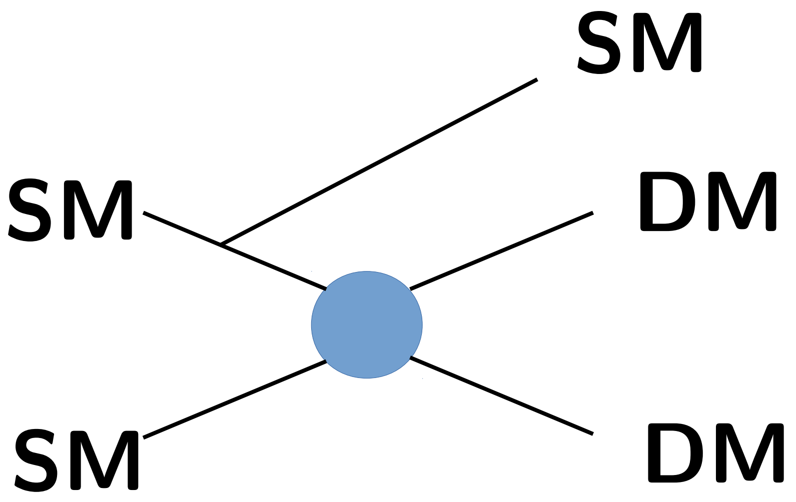

$\sim 100\,\mathrm{GeV}$
Indirect Detection
Thermal Freeze-Out
DM
SM
Direct
Detection
$\sim 200\,\mathrm{MeV}$
DM
SM
Production at colliders $\sim \mathrm{TeV}$

Dark Matter at colliders.

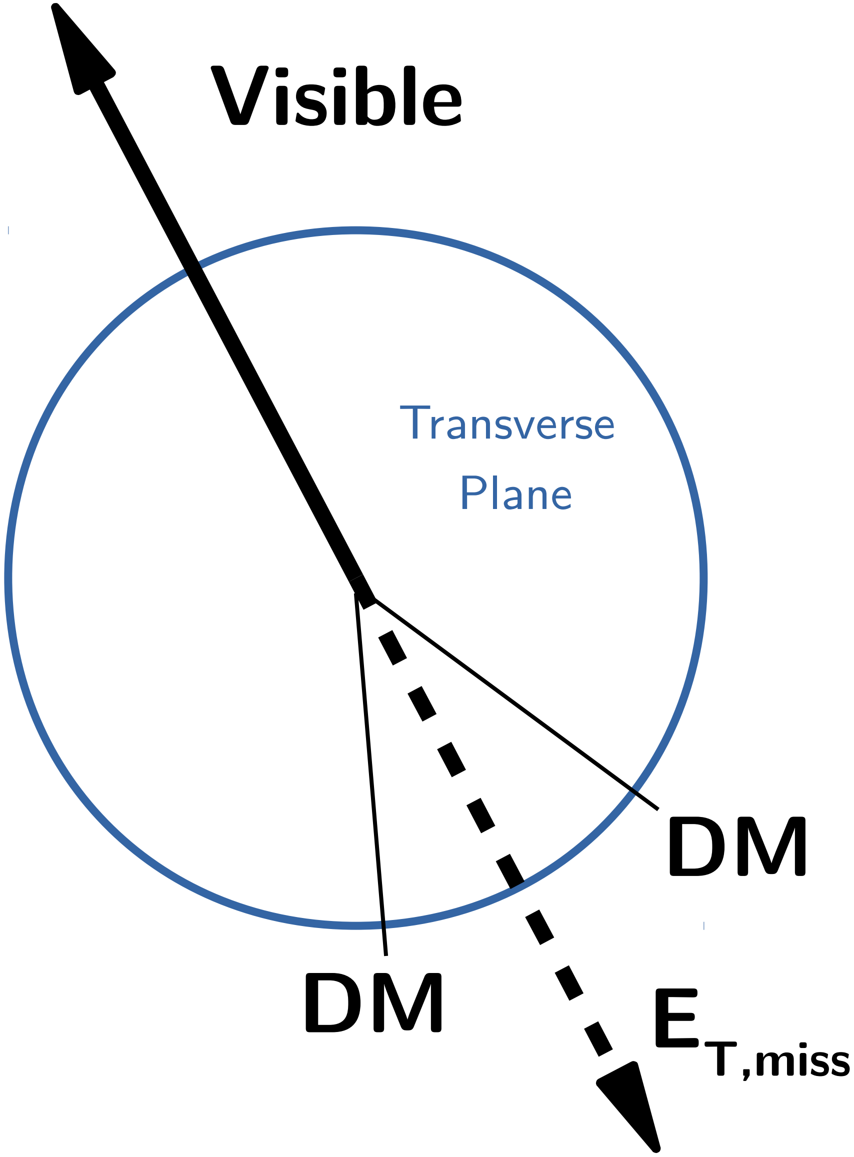


This diagram is invisible to the detectors. Something should be used to tag the dark matter production.

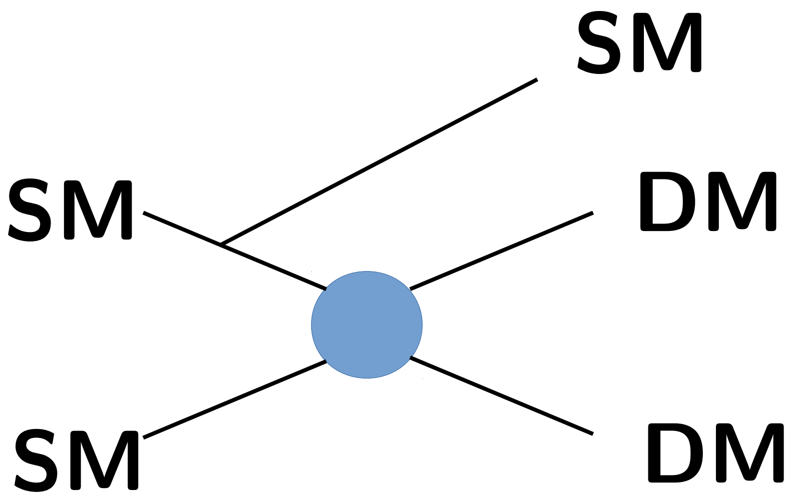
Dark Matter at colliders.

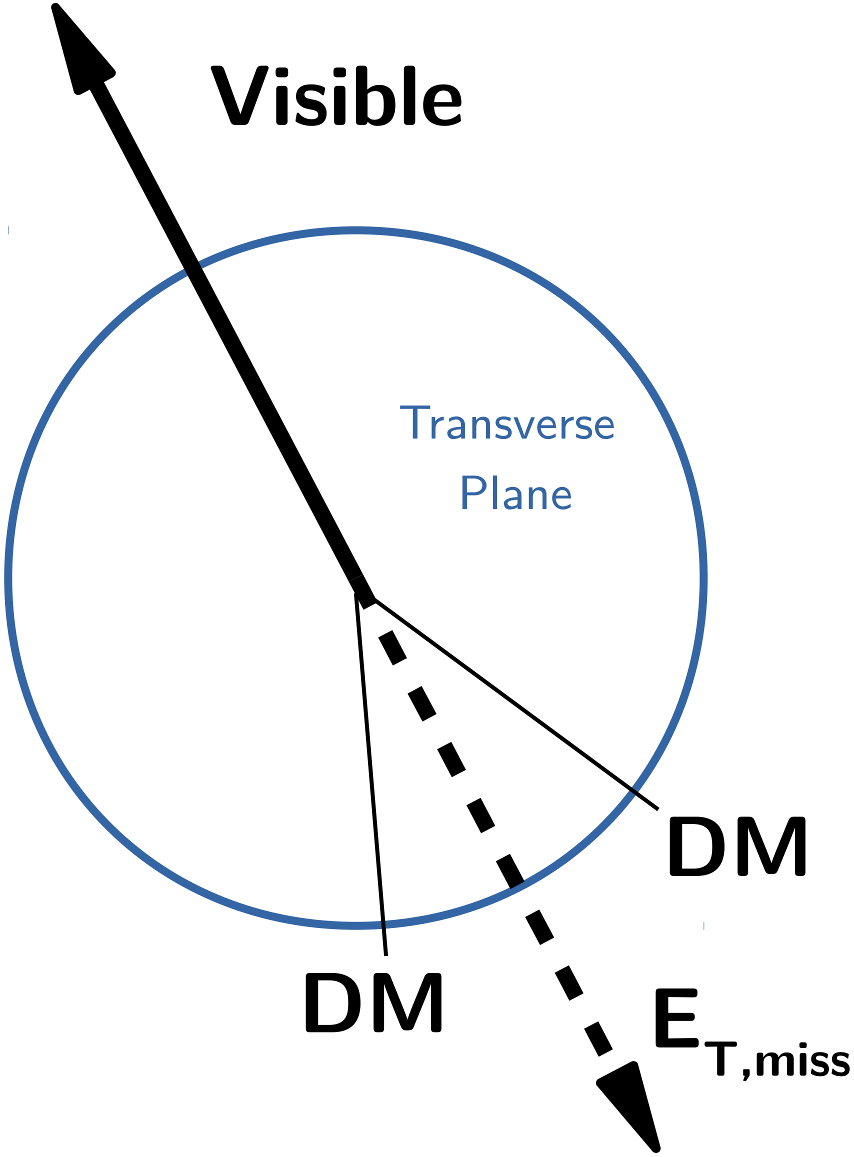


We can make use of the initial state radiation. A SM particle is radiated so we can tag it and it can produce a balance in the transverse momentum.



Dark Matter at colliders.

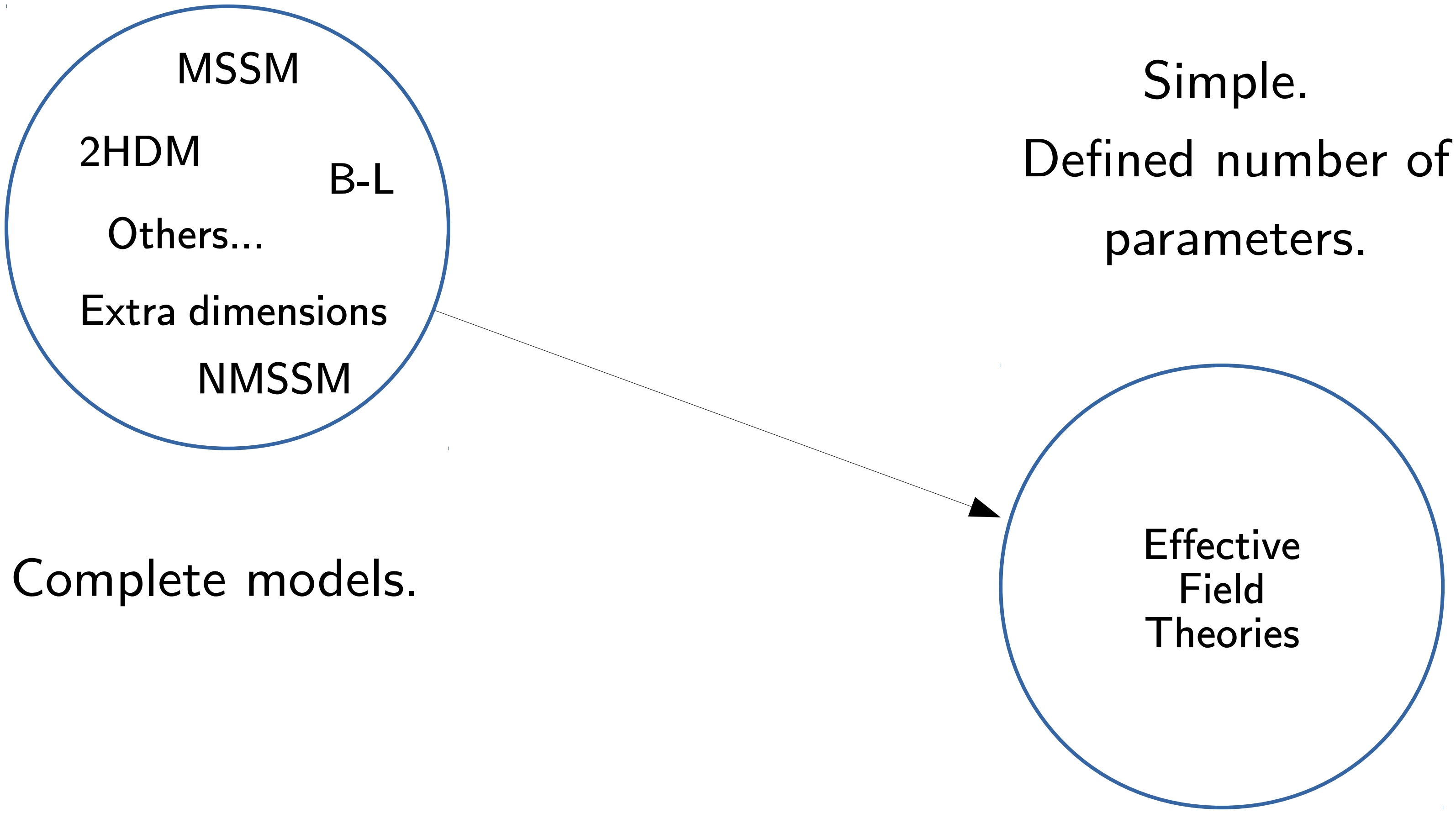




In order to estimate the dark matter production we need input from theory.

Dark Matter description.

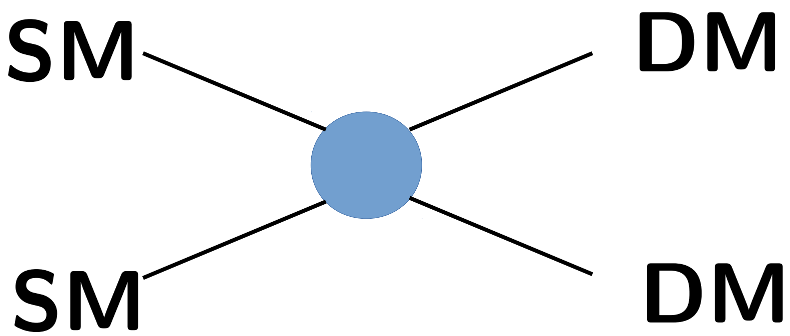
Simple.
Defined number of parameters.



Complete models.

EFT approach.

(Fox, Harnik, Kopp, Tsai, 1109.4398)



$$\mathcal{O}_V = \frac{(\bar{q}\gamma_\mu q)(\bar{\chi}\gamma^\mu \chi)}{\Lambda^2}$$

$$\mathcal{O}_A = \frac{(\bar{q}\gamma_\mu \gamma_5 q)(\bar{\chi}\gamma^\mu \gamma_5 \chi)}{\Lambda^2}$$

$$\mathcal{O}_S = \frac{(\bar{q}q)(\bar{\chi}\chi)}{\Lambda^2}$$

$$\frac{1}{\Lambda^2} = \frac{g_q g_\chi}{M^2}$$

$$\frac{g_q g_\chi}{Q^2 - M^2} = -\frac{g_q g_\chi}{M^2}\left(1 + \frac{Q^2}{M^2} + \mathcal{O}\left(\frac{Q^4}{M^4}\right)\right)$$

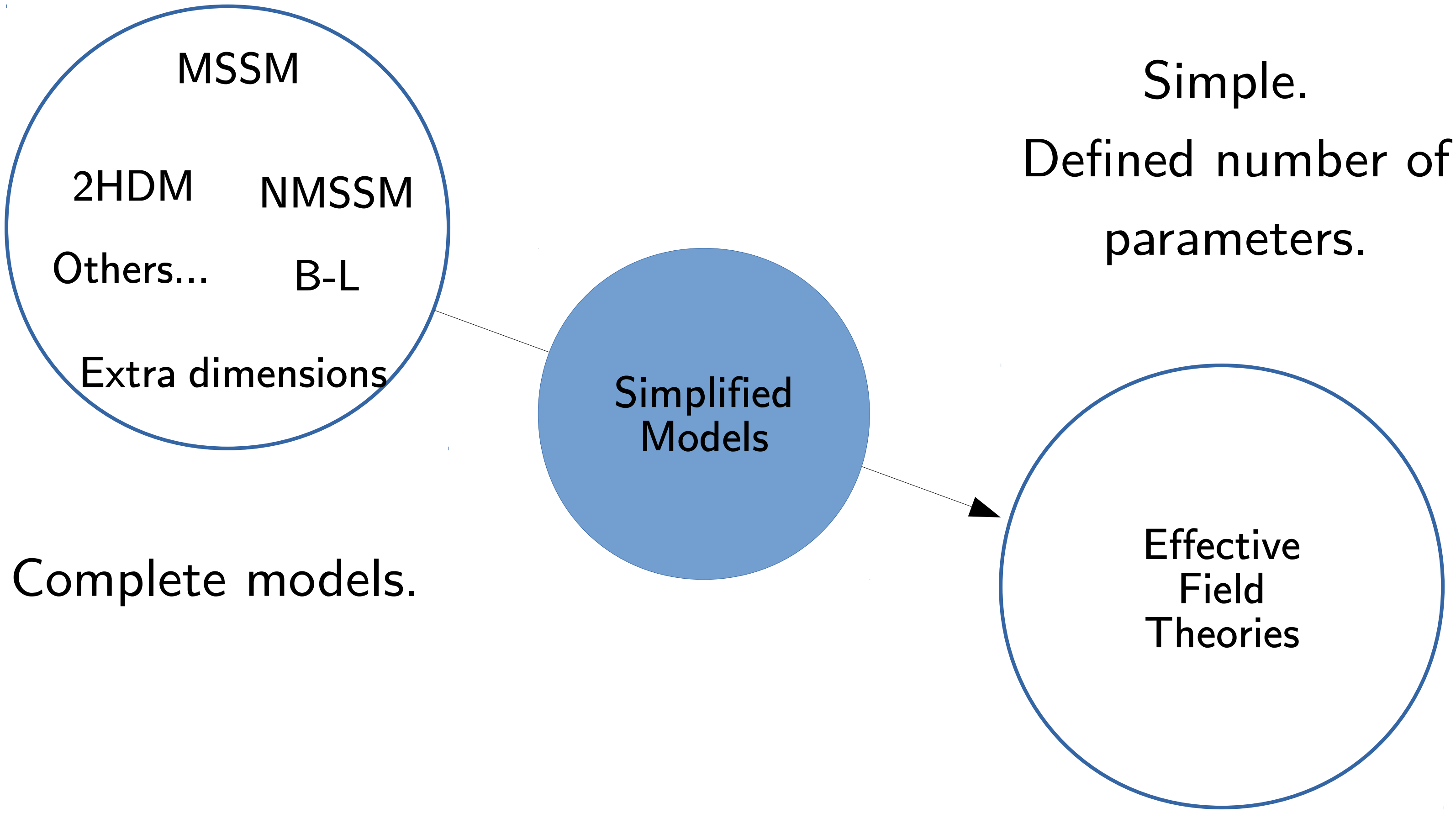
$$Q^2 > \Lambda^2$$

The EFT is not a good description.

$\Gamma_{\rm med} \geq M_{\rm med}$ usually in the regions where the EFT is valid.

(Buchmuller, Dolan, McCabe, 1308.6799)
(Buchmuller, Dolan, Malik, McCabe, 1407.8257)

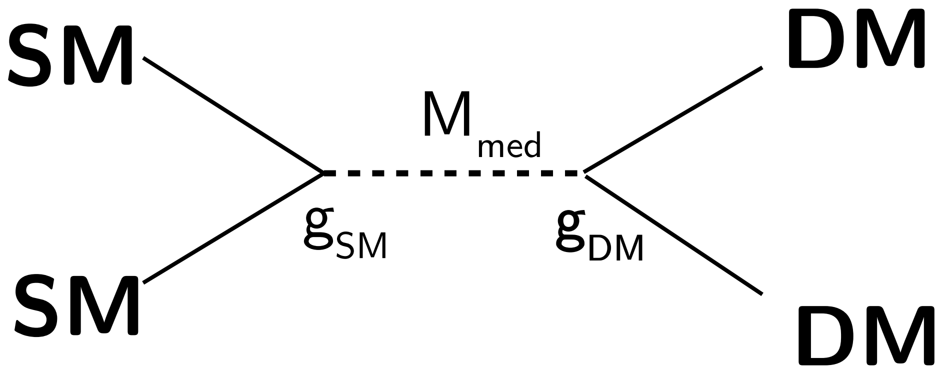
Dark Matter description.



Simple.
Defined number of parameters.

Complete models.

Simplified Models.



(LHC Dark Matter Working Group 1603.04156)

-The presence of the mediator allows to cover all the parameter space.

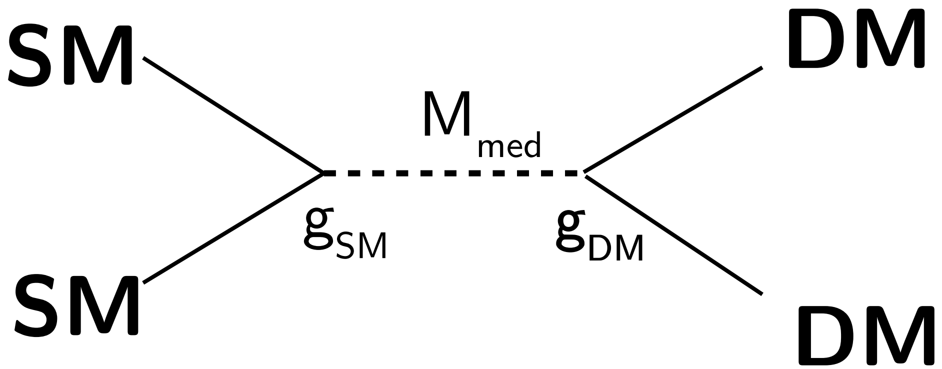
-Additional signatures are present (searches for the mediator itself).

-It allows a better comparison with direct detection experiments.

(Buchmuller, Dolan, Malik, McCabe, 1407.8257)

(LHC Dark Matter Working Group, 1603.04156)

Simplified Models.



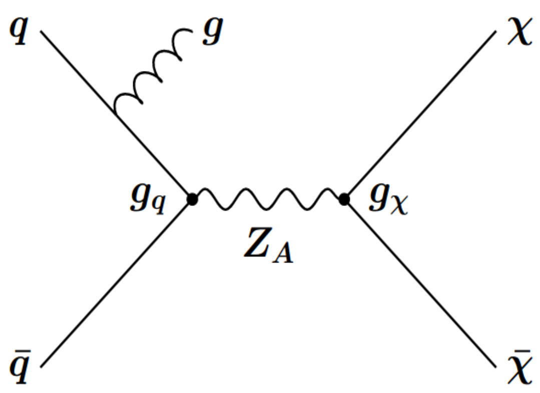
Parameters of the model:
(minimum content)
-Mediator mass (M_{med})
-DM mass (M_{DM})
-SM coupling (g_{SM})
-DM coupling (g_{DM})

Mediator Nature: Vector, Axial-Vector, Scalar, Pseudoscalar

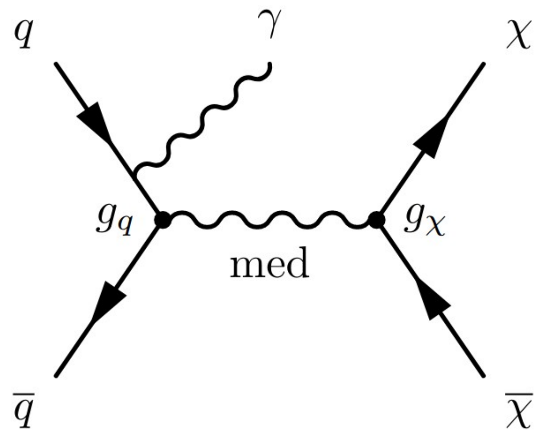
DM Nature: Dirac Fermion, Majorana Fermion, Real Scalar, Complex Scalar

Mono-X searches.

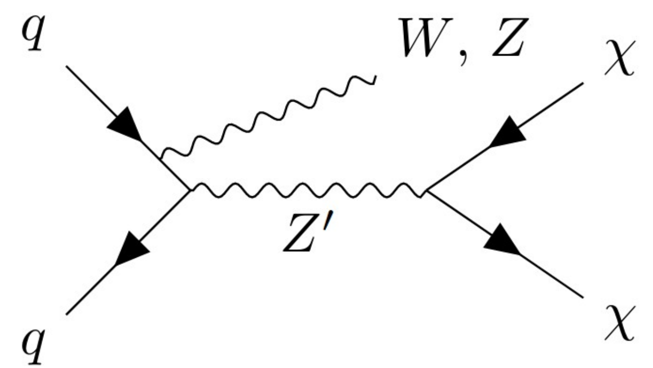
Mono-jet



Mono-photon

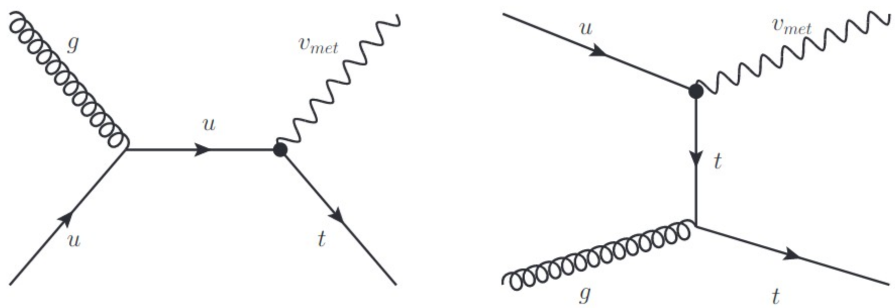


Mono-Z/W

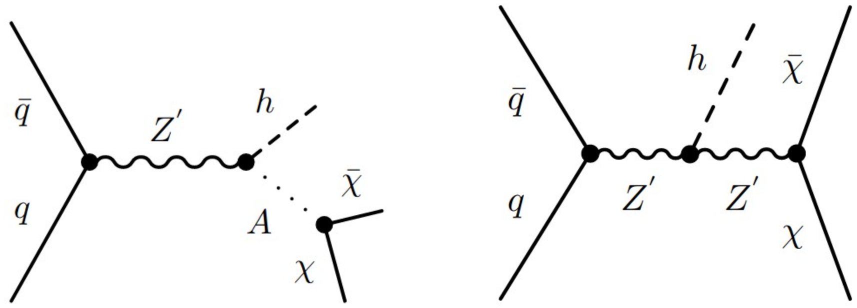


(See Varum Sharma's talk)

Mono-top

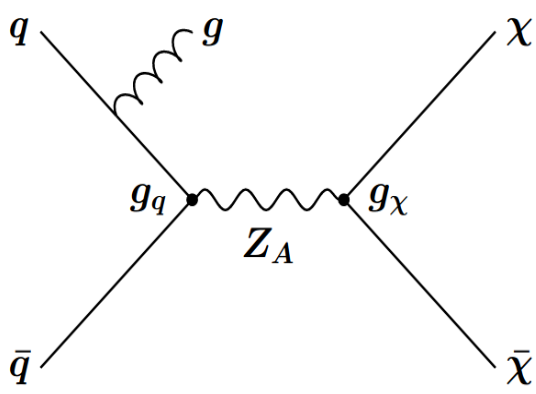


Mono-Higgs



(See Mariana Toscani's talk)

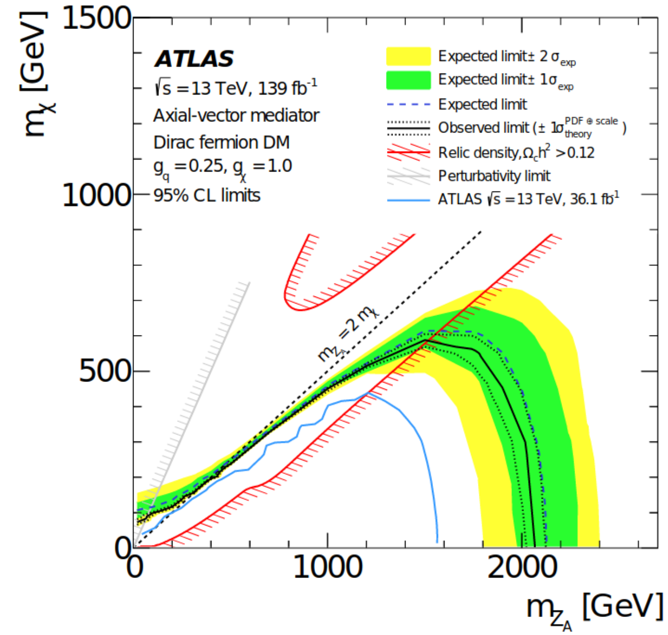
Mono-jet searches.

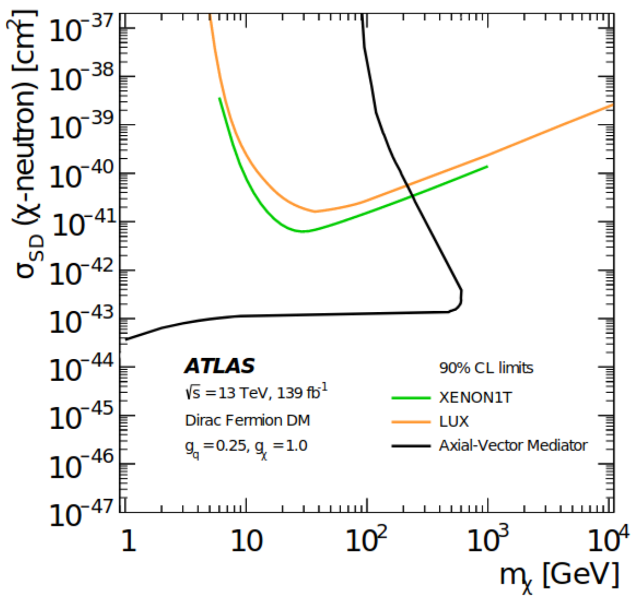


Complementarity between monojet and direct detection Dark Matter searches. (Buchmuller, Dolan, Malik, McCabe, 1407.8257)

Easy to compare with simplified models but also with complex models. (For example: Schwaller, Zurita 1312.7350)

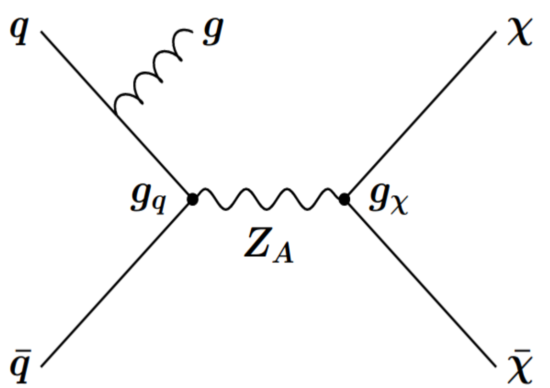
(ATLAS, 2102.10874)

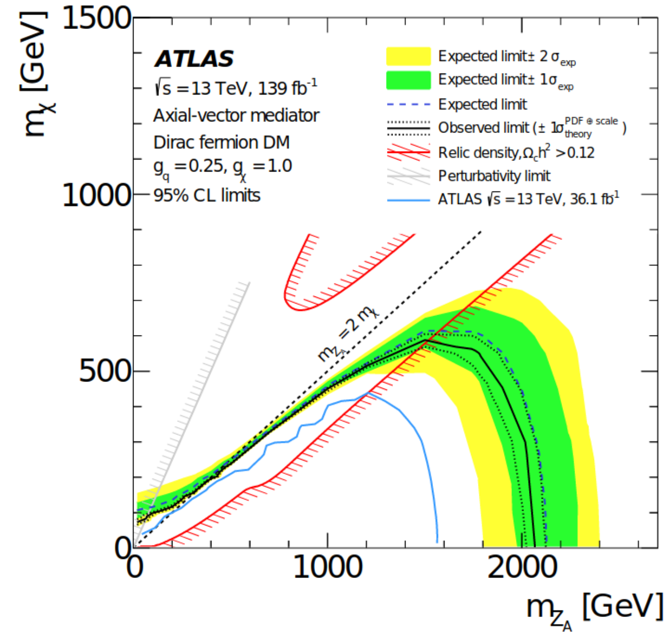


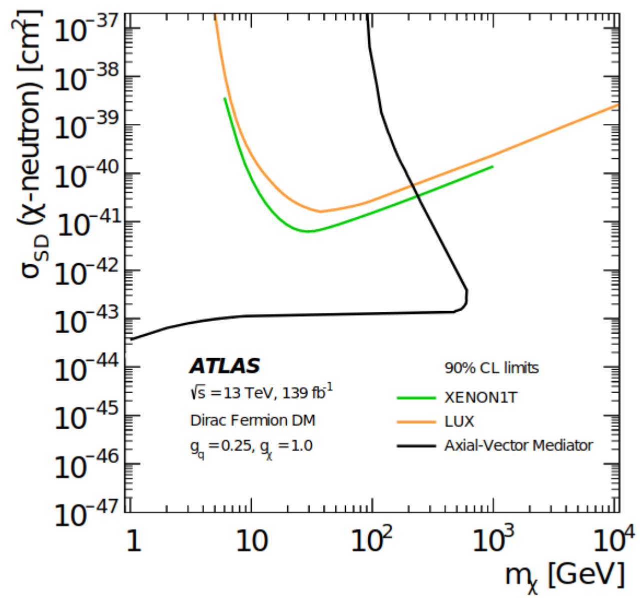


Mono-jet searches.

(ATLAS, 2102.10874)







Theory: Search recast available in CheckMate, MadAnalysis and Z' Explorer 2.0 (soon).

One can also use DeepLearning to test against LHC data. (Arganda, Medina, Perez, Szynkman, 2105.12018)

Mediator searches (Z’).

Mediator searches in SM decays.

One can set limits on the mediator mass and its couplings to SM particles.

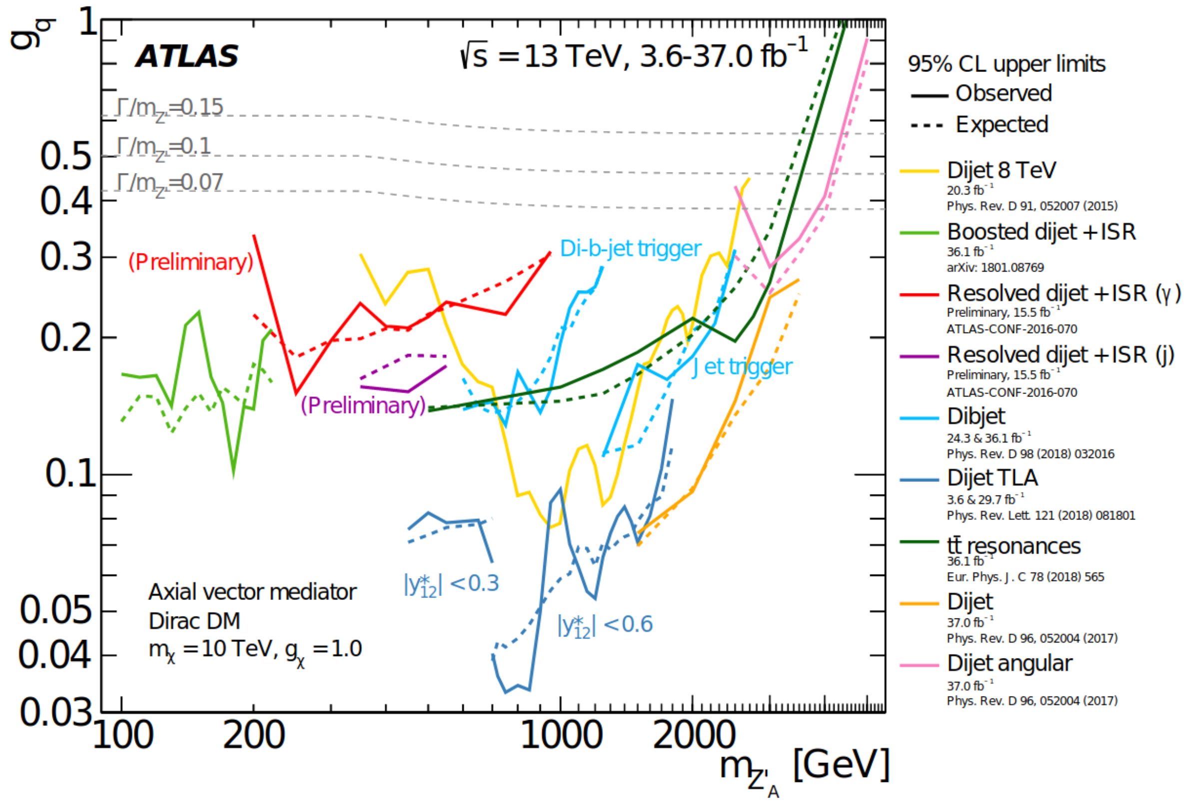
Dedicated searches to low mass and high mass regions.

(Low mass: see Silvio Donato’s talk)

(High mass: see Claudio Quaranta’s talk)

Direct comparison with the theoretical input.

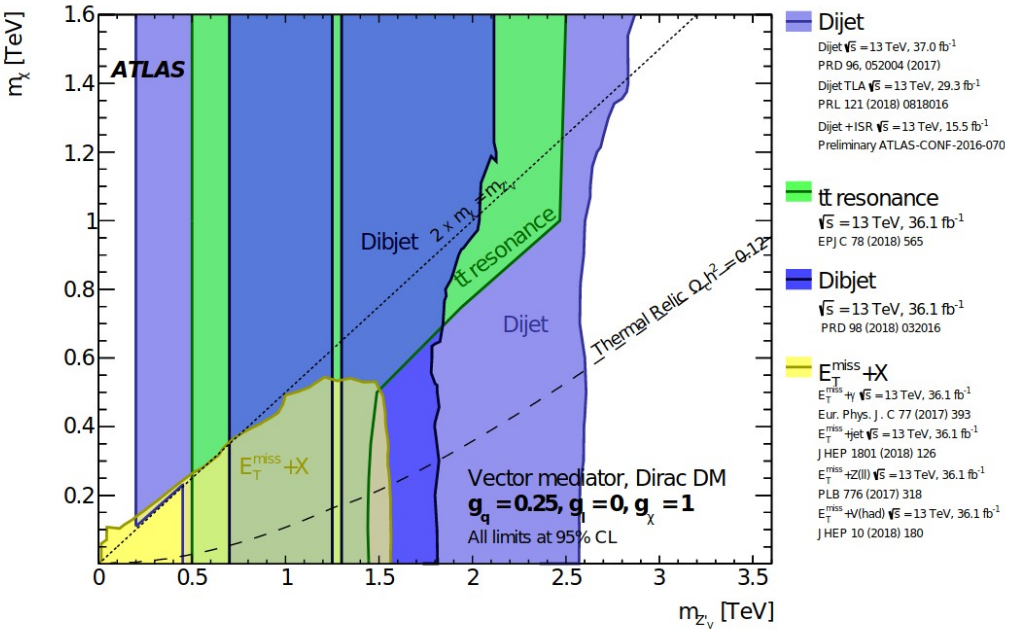
(Z’ Explorer: Alvarez, Estevez, Sanda-Seoane, 2005.05194)

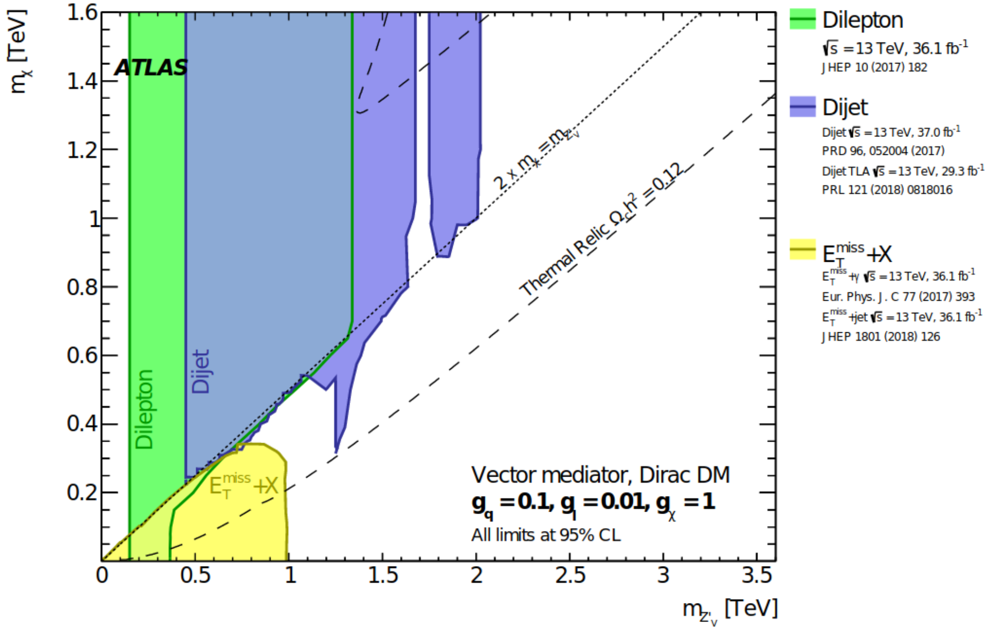


(ATLAS, 1903.01400)

Mediator + Mono-X searches.

Vector Mediator

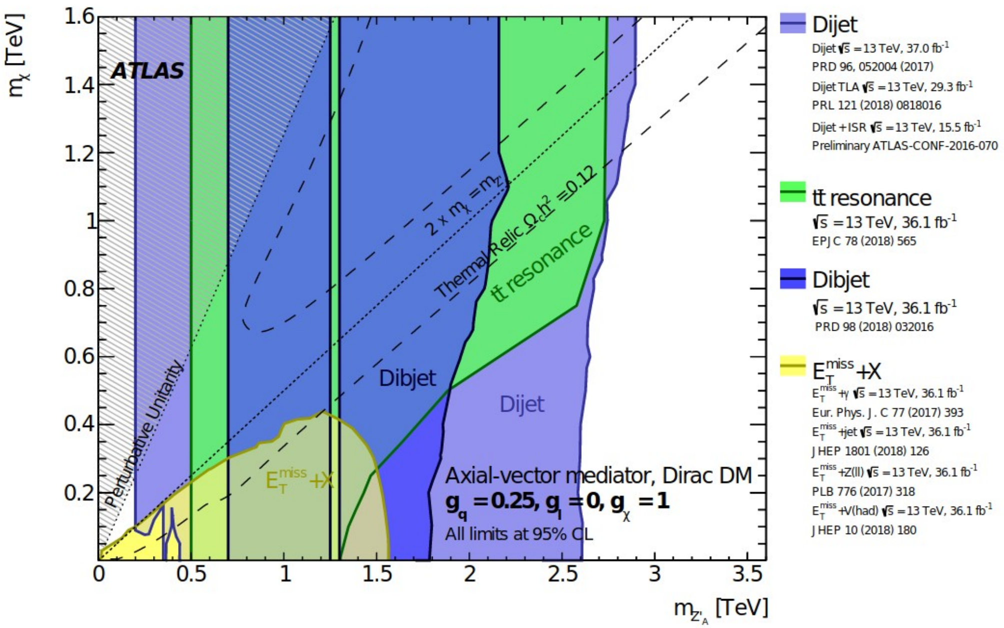


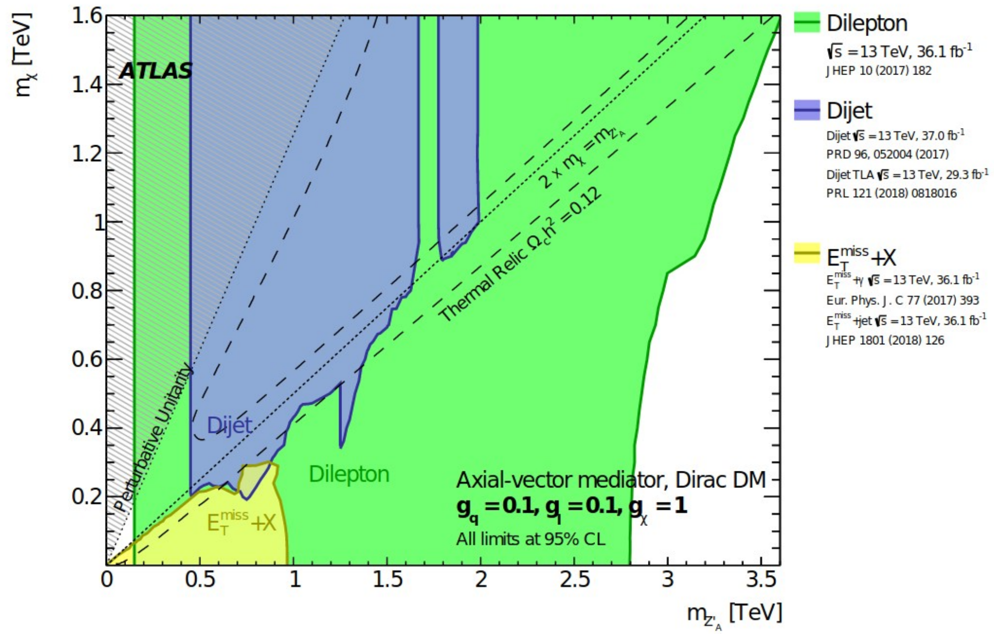


(ATLAS, 1903.01400)

Mediator + Mono-X searches.

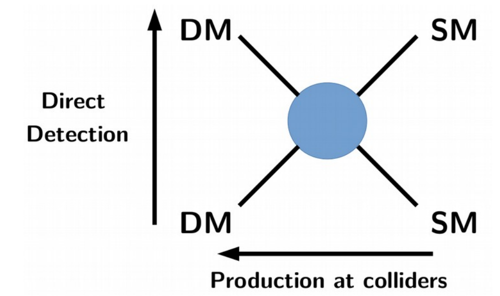
Axial-Vector Mediator





(ATLAS, 1903.01400)

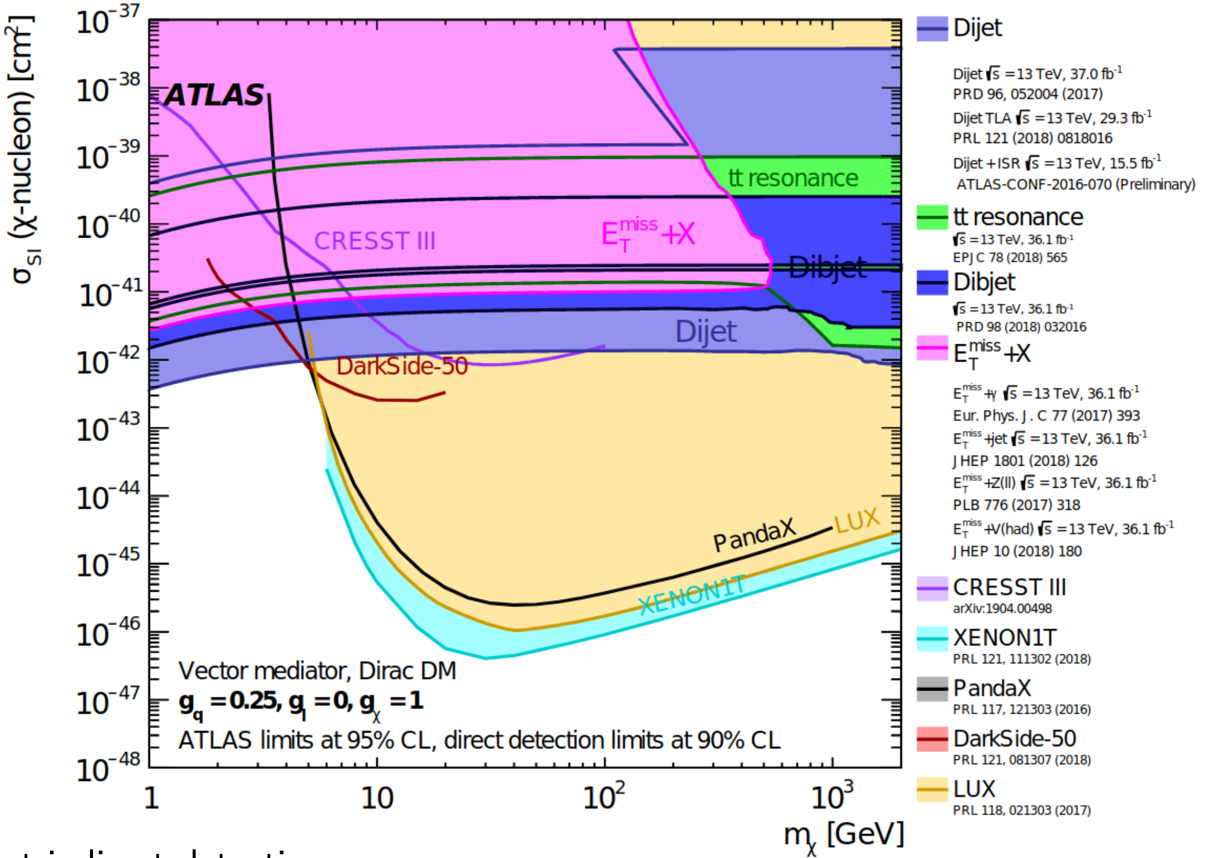
Collider vs. Direct Detection.



Complementarity:

- Collider searches:
  - ~Almost independent on DM mass.
  - ~Better performance for low DM masses.
- Direct detection searches:
  - ~Better performance for DM masses > 10 GeV.
- Complementarity between collider searches and direct detection searches

(ATLAS, 1903.01400)



It is also possible to compare the limits against indirect detection searches. (Buchmuller, Malik, McCabe, Penning, 1505.07826)

Conclusions.

-If DM particle exists it could be produced in colliders.

-Collider searches for Dark Matter:

~Complete models (SUSY, 2HDM, axions, etc)

~UV model independent searches:

*EFT: Physical limitations.

*Simplified Models: Improvement over EFT, additional signatures, better comparison against other DM searches.

-Complementarity between colliders and direct detection. Collider searches present better perfomance at low DM masses.

Thank you!