Theory Overview of Dark Matter Searches

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Theory Overview of Dark Matter Searches

- Theory:
  - Dark matter exists.
- Overview:
  - We should search for it.

How do we look for Dark Matter?

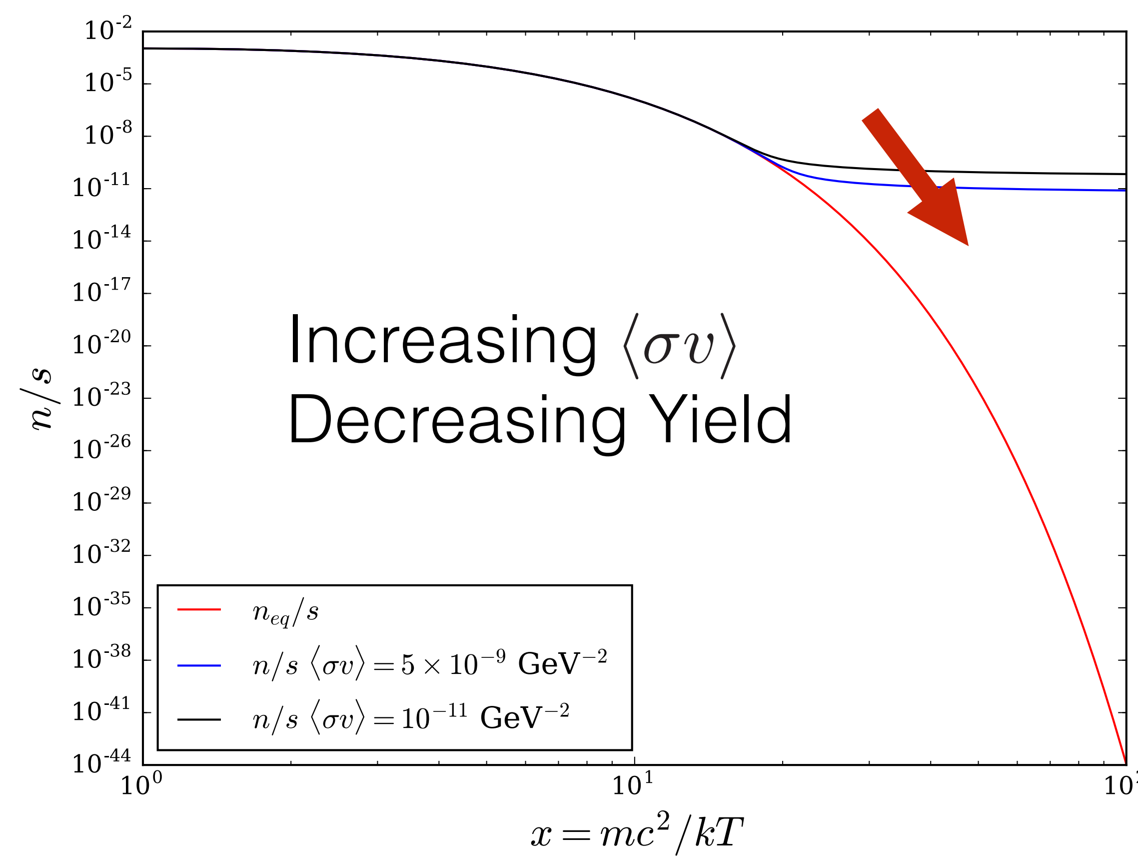
- What do we think dark matter *is*?
- What tools do we have available?

A thermal relic of the Early Universe
(Important: this is a *guess*)

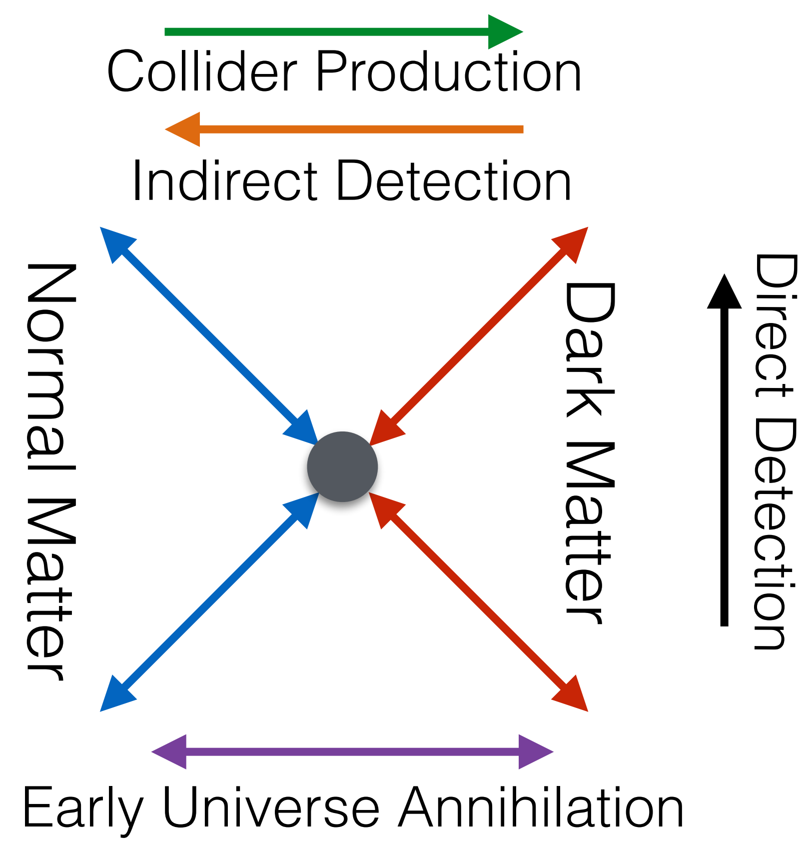
Detectors capable of measuring
weak-scale interactions with SM

Thermal Dark Matter

- *Assume* dark matter was in equilibrium with the thermal bath of Standard Model particles
  - Then need annihilation avoid overclosure
  - Sets a minimum $\langle\sigma v\rangle$
    - Approximately the Weak Scale
  - We can look for this!



Thermal Dark Matter

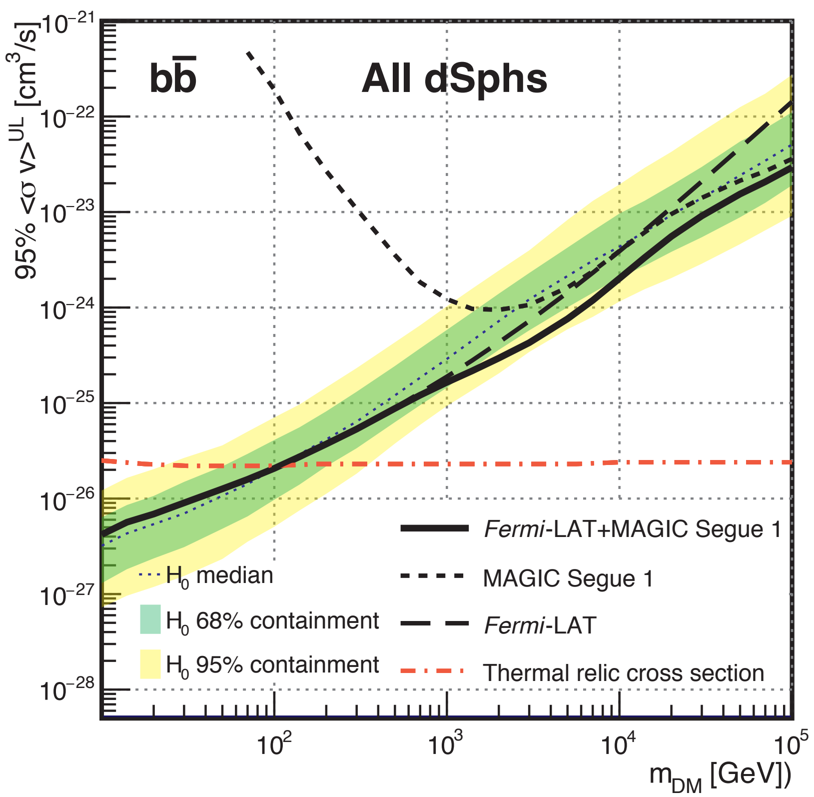


- The Thermal Dark Matter *ansatz* gives us a reason to expect interactions at the detectors we have available at the rates we can detect.

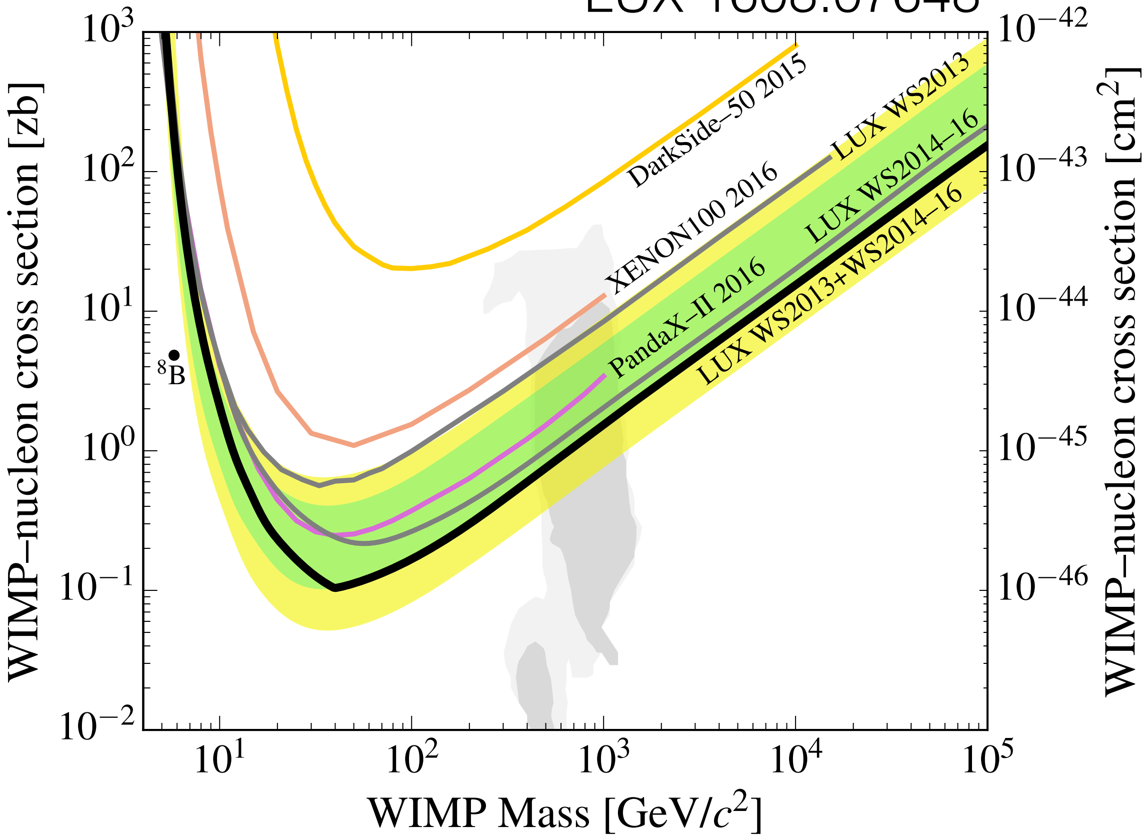
How's that Working out for Us?

- So far, only negative results.
- Definitely probing the parameter space of interest.

Fermi+MAGIC 1601.06950

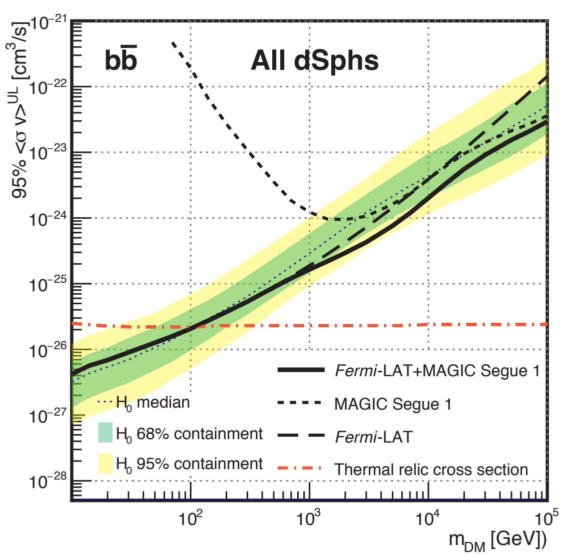


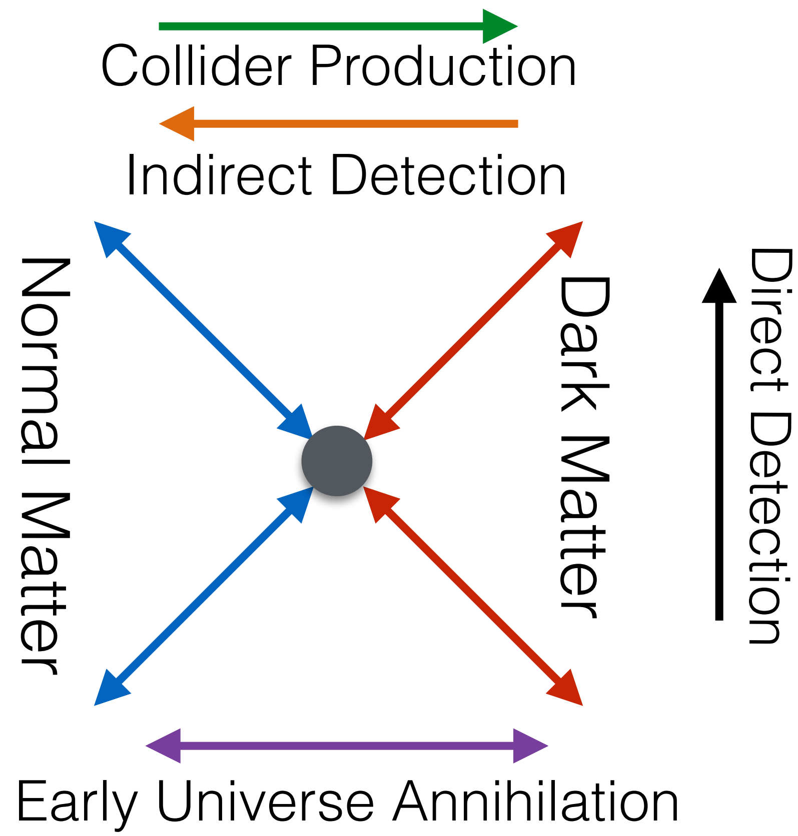
LUX 1608.07648



Is Thermal Dark Matter Dead?

Fermi+MAGIC 1601.06950





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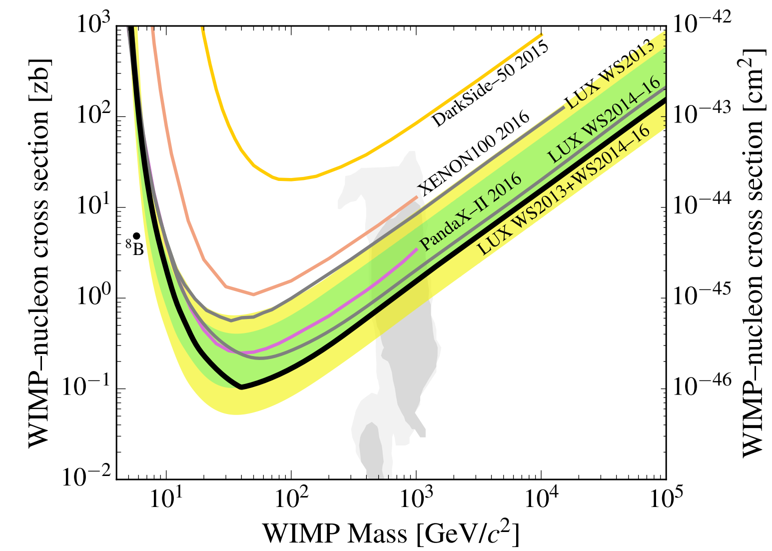
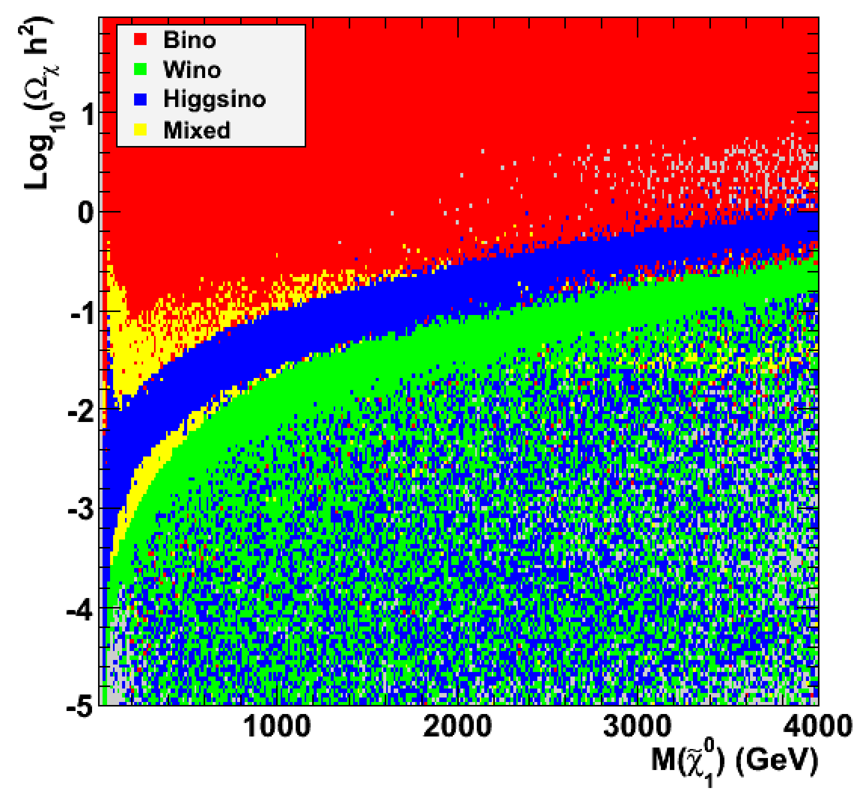


- Translation between annihilation cross section and experimental rates very model-dependent.
- Can’t (easily) kill “thermal dark matter.”
  - Can only eliminate specific models.

Supersymmetry

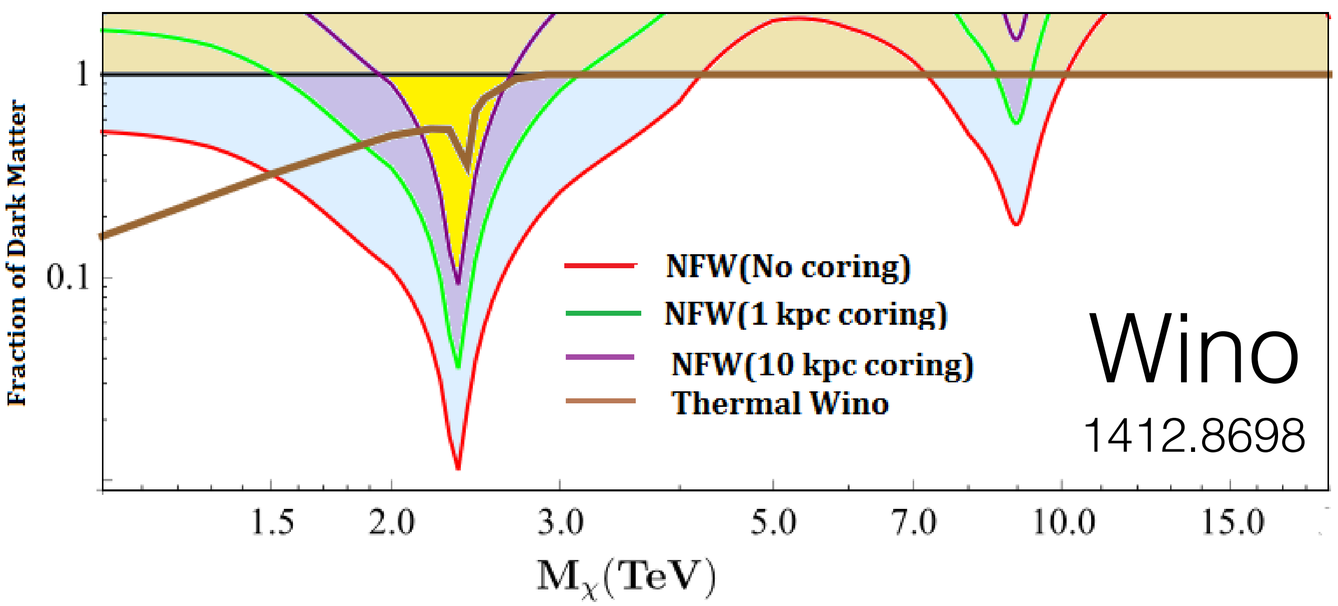
- Natural dark matter candidate:
$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{h}_u^0 + N_{14}\tilde{h}_d^0$$
- For LHC-accessible dark matter $\mathcal{O}(100\ \mathrm{GeV})$:
  - $\tilde{B}$ has too little annihilation, $\tilde{W}^3/\tilde{h}_u^0/\tilde{h}_d^0$ have too much
- Good news!
  - Successful SUSY dark matter often requires some new particles around
  - stau coannihilation, *A*-funnel, *etc.*
- Non-discovery of MSSM at LHC suggests theory needs modification

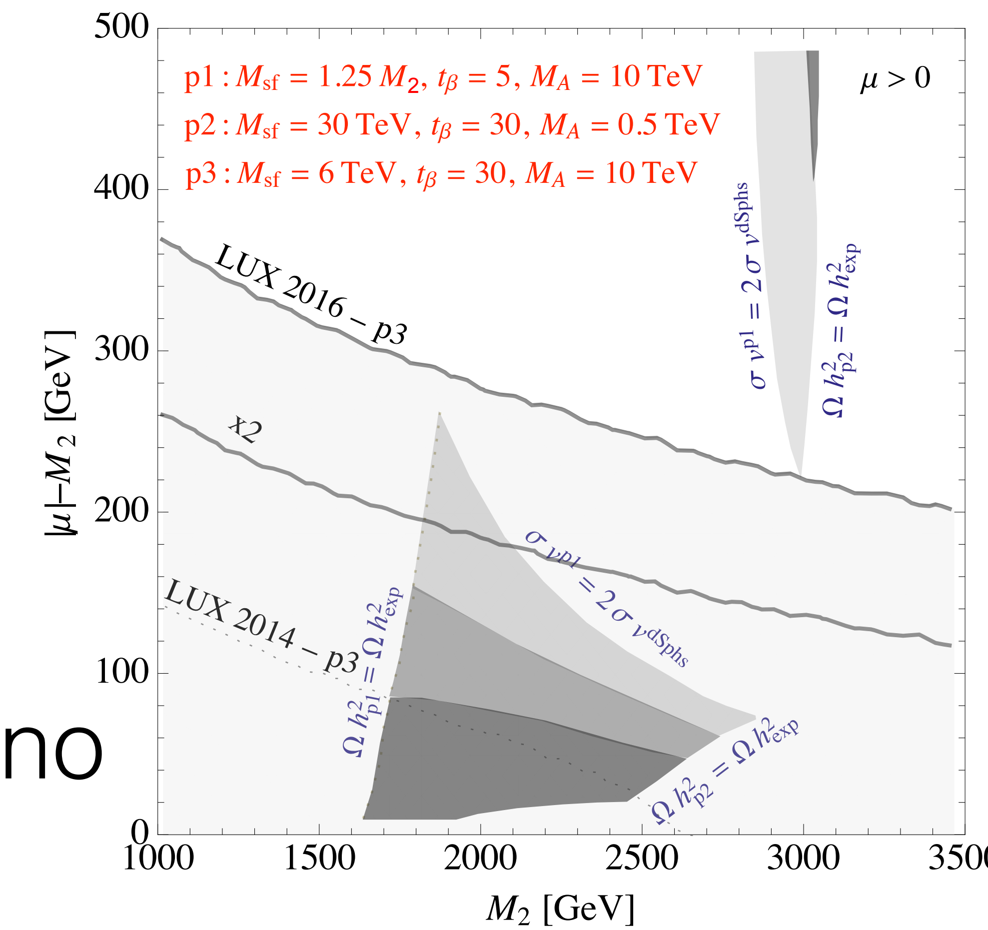


Arbey, Battaglia, and Mahmoudi 1504.05091

Supersymmetry

- Pure Winos or Higgsinos are too heavy to be seen at the LHC
  - Need to look via direct and indirect detection

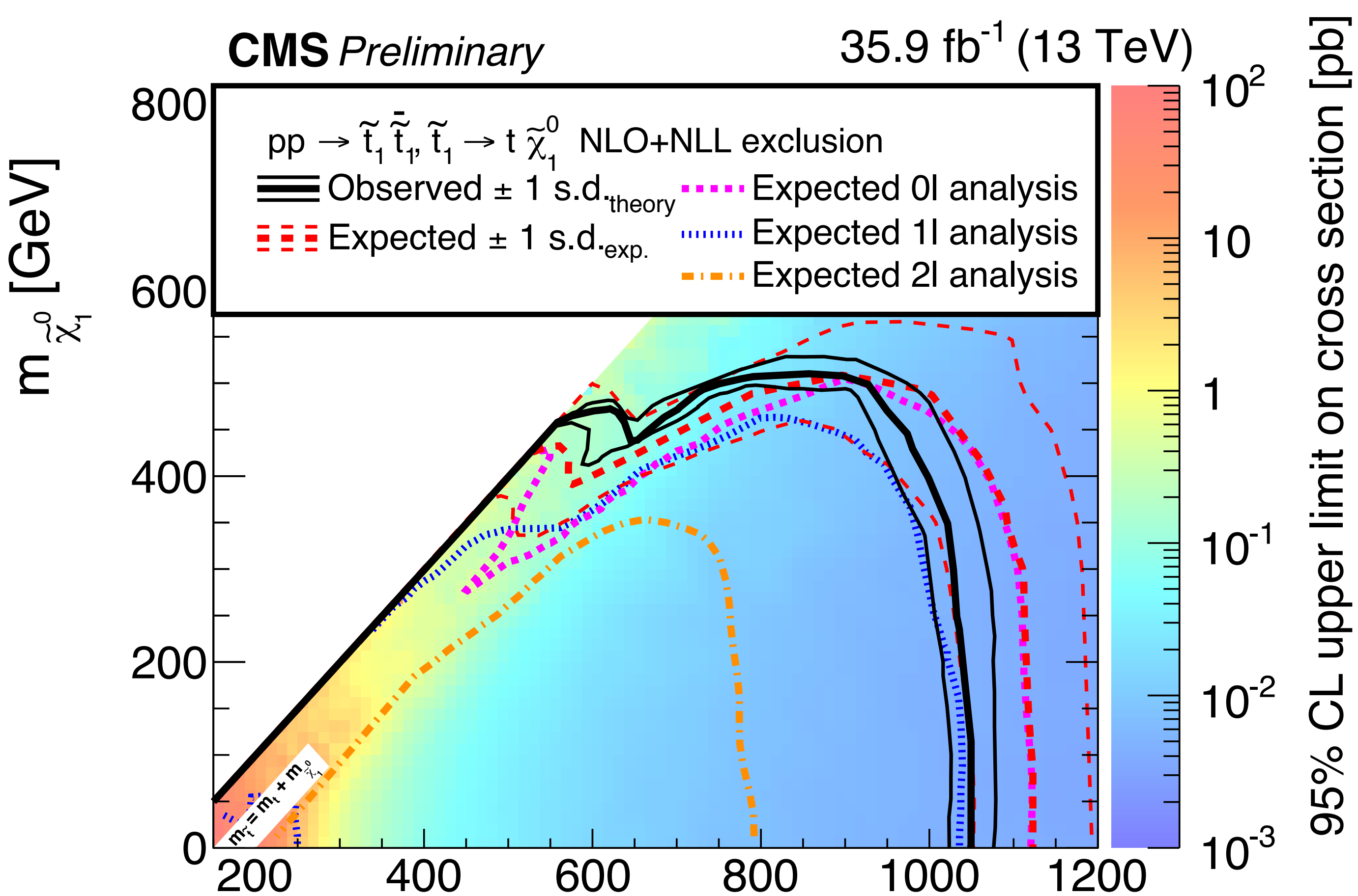




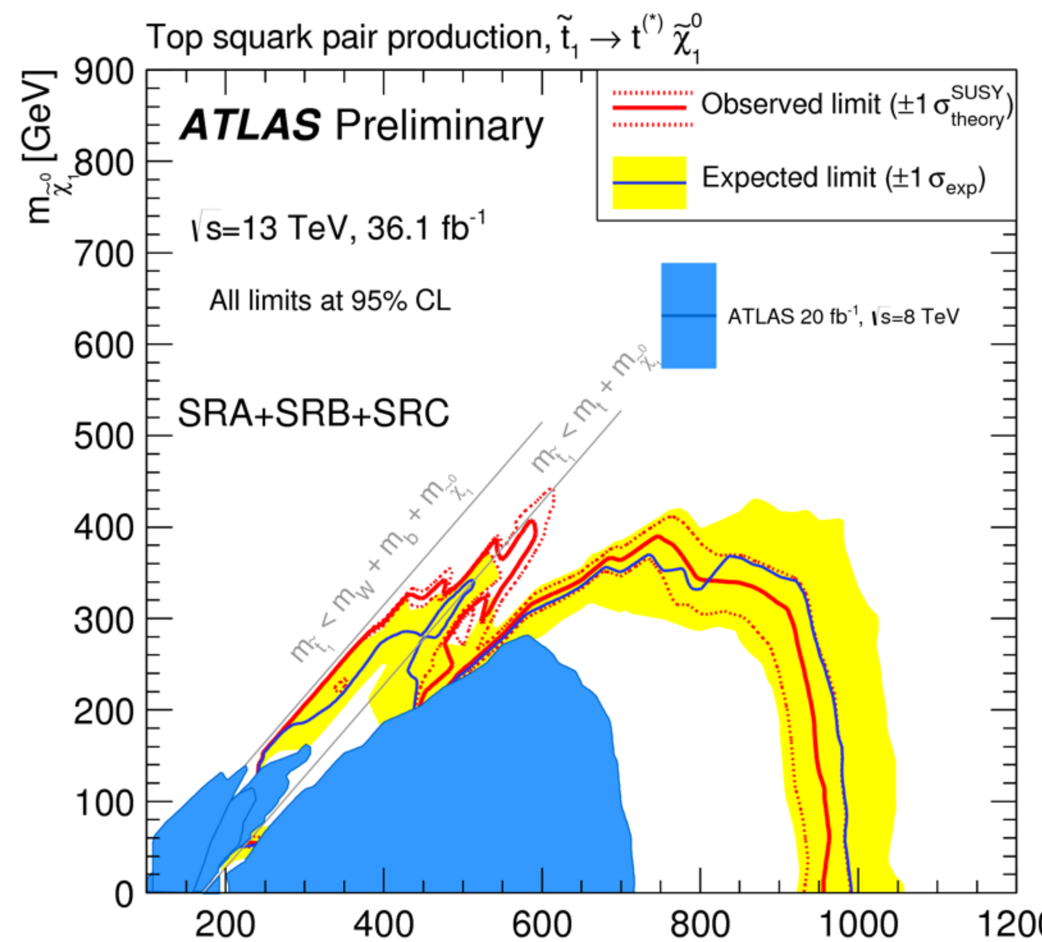
Wino/Higgsino
1611.00804

Supersymmetry

- For mixed neutralinos, tend to need other “light” particles around to annihilate with/through.



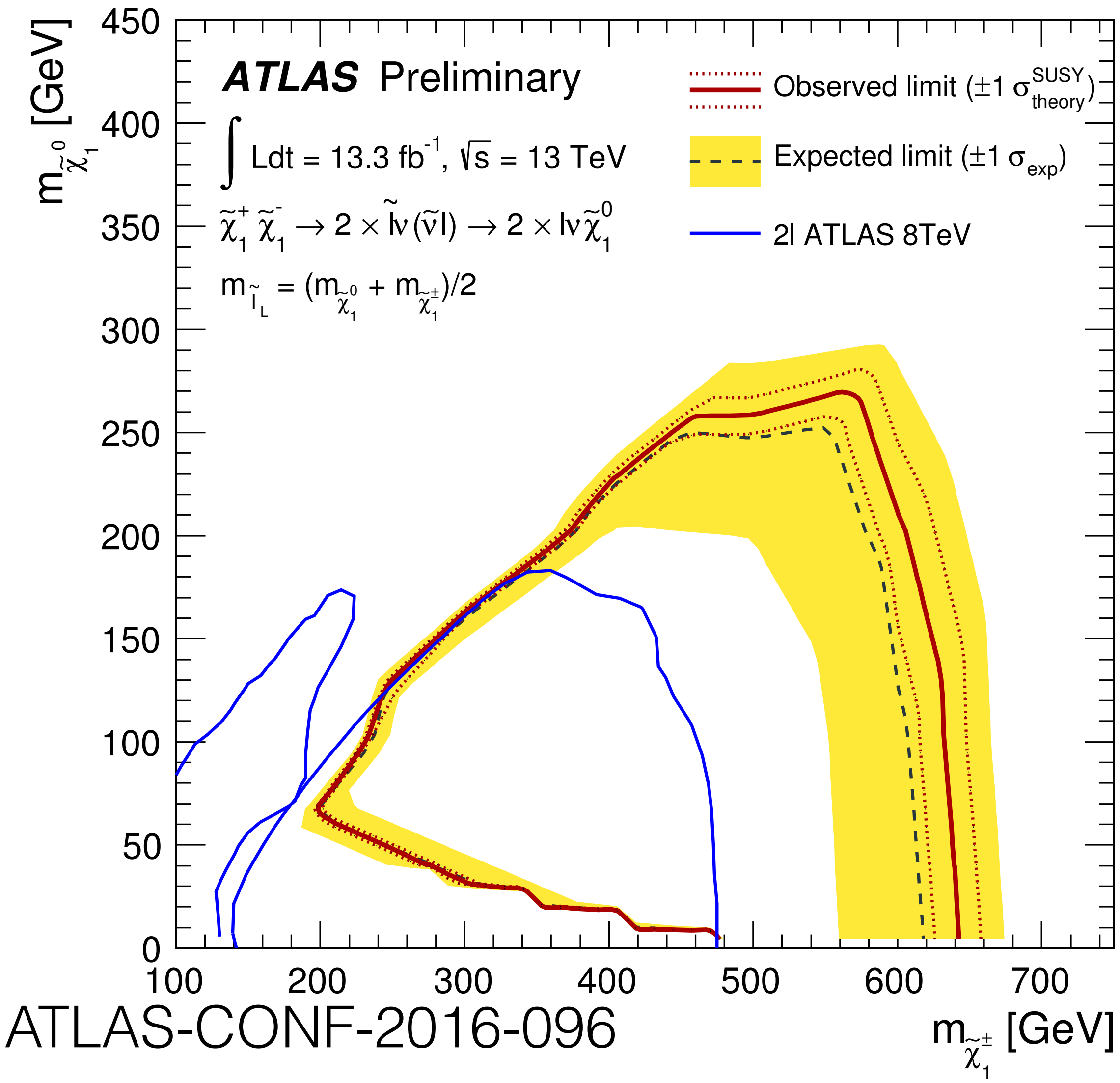
Patel, Moriond 2017



ATLAS-CONF-2017-020

Supersymmetry

- Hard to find electroweakinos with small splittings
  - Generalizes to $SU(2)_L$-multiplet WIMPs



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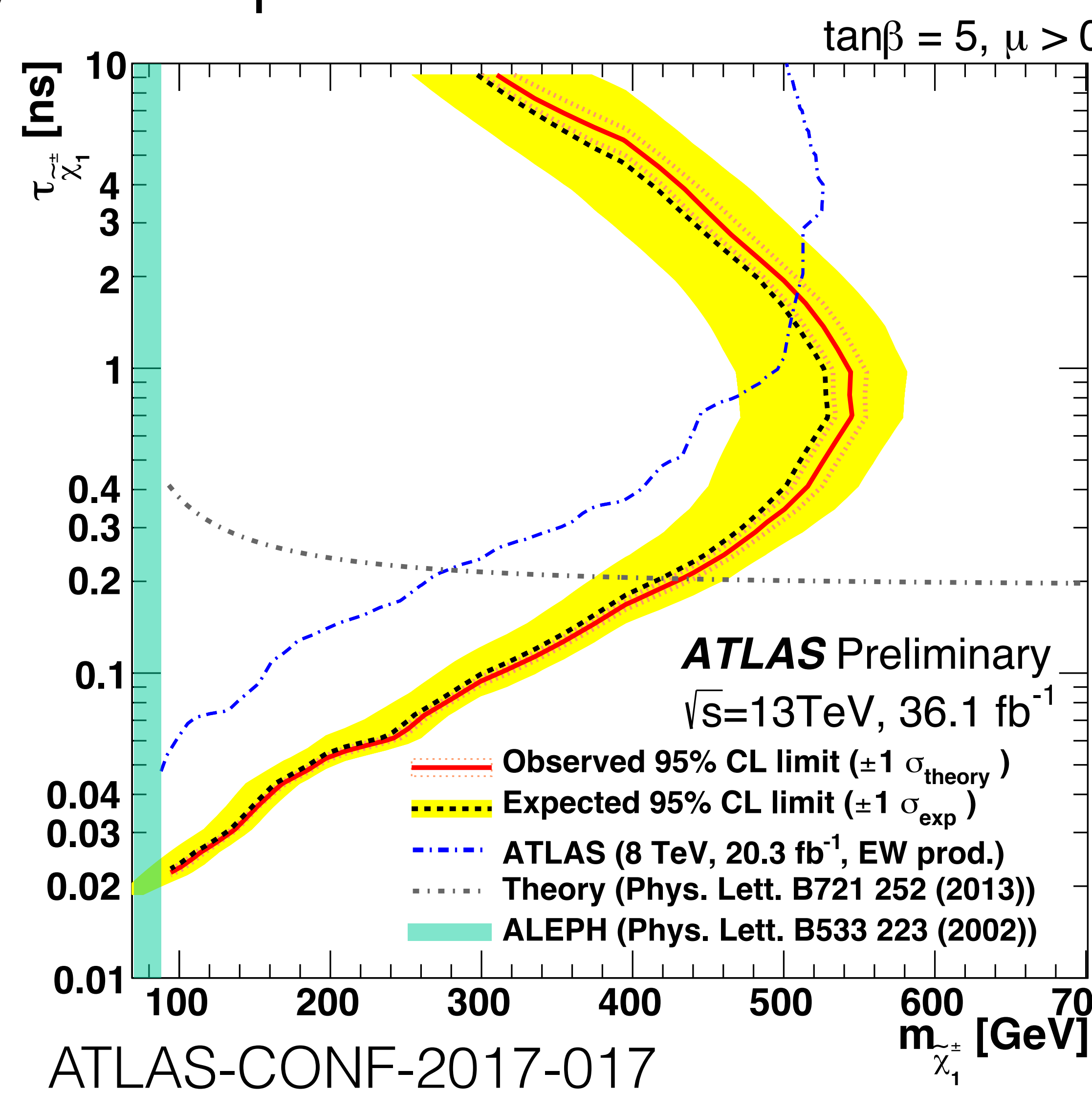


ATLAS-CONF-2017-017

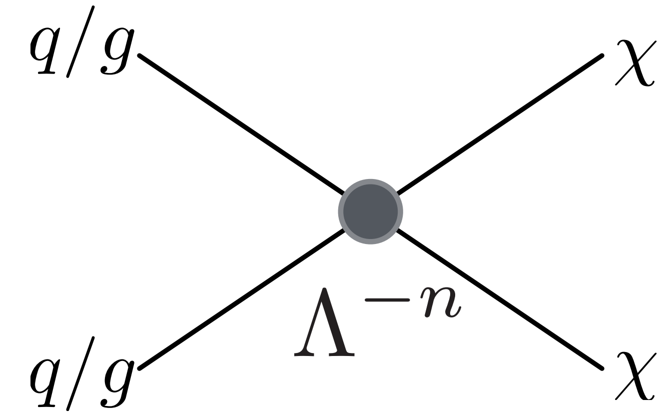
Effective Operators

- Supersymmetry is great for naturalness (and dark matter), but we don't care about naturalness here.
    - So free to build new models which aren't natural.

- Effective theory is only valid if

$$Q_{\text{transfer}} < M = \sqrt{g_\chi g_q}\Lambda < 4\pi\Lambda$$

- At the LHC $Q_{\text{transfer}} \propto p_{T,\text{jet}}$



~~Effective Operators~~ Simplified Models

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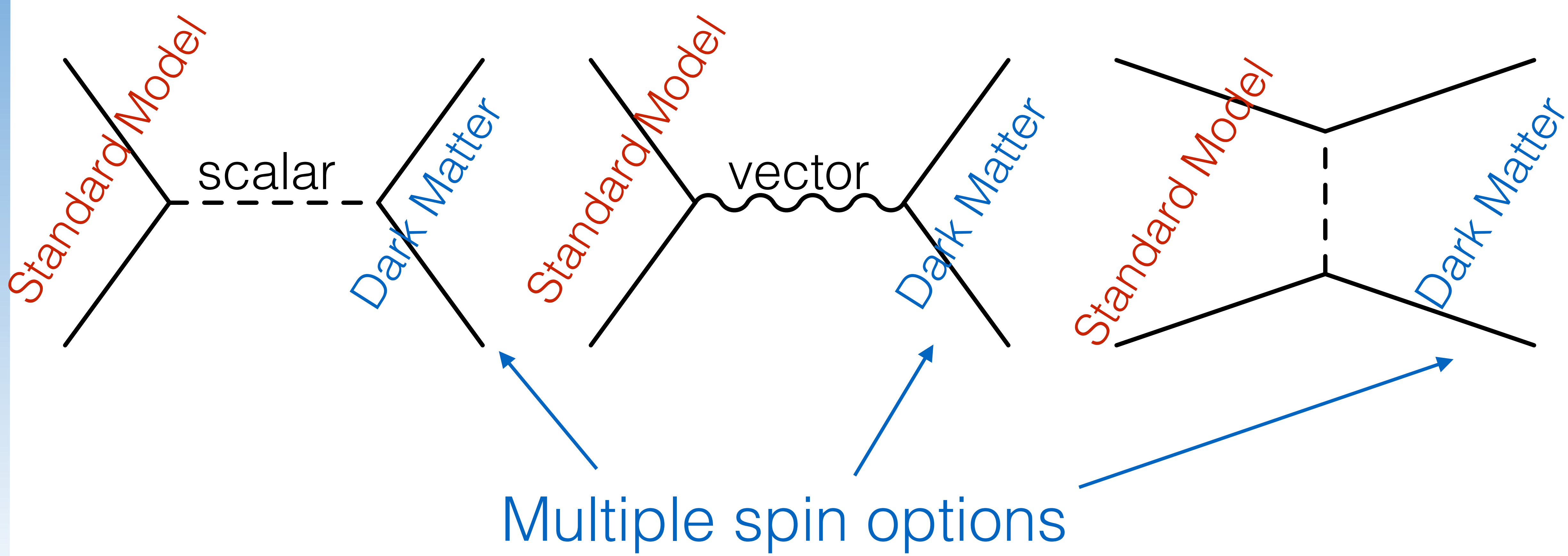
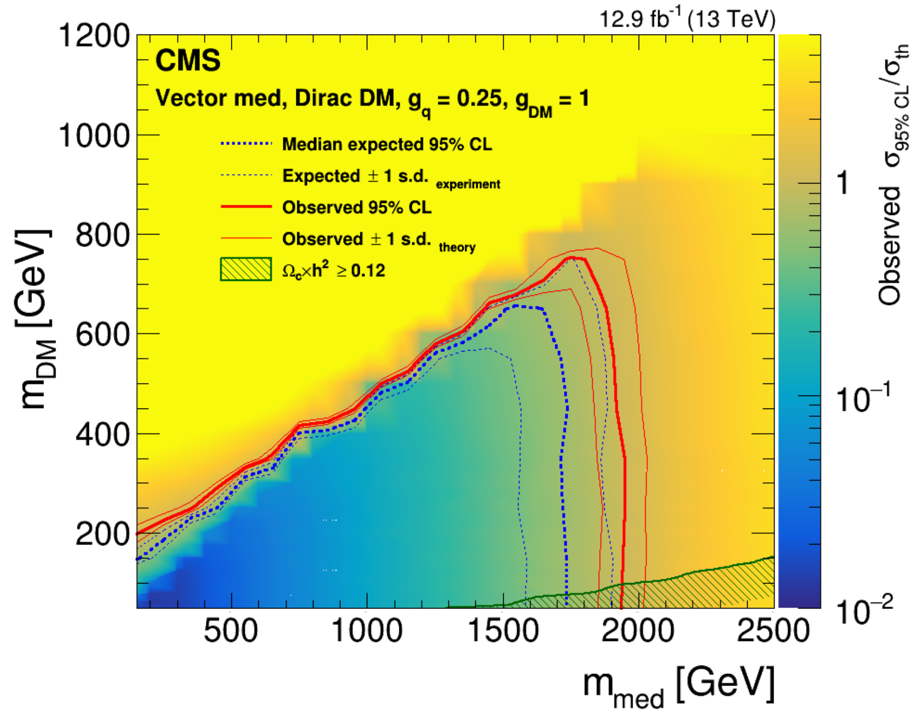
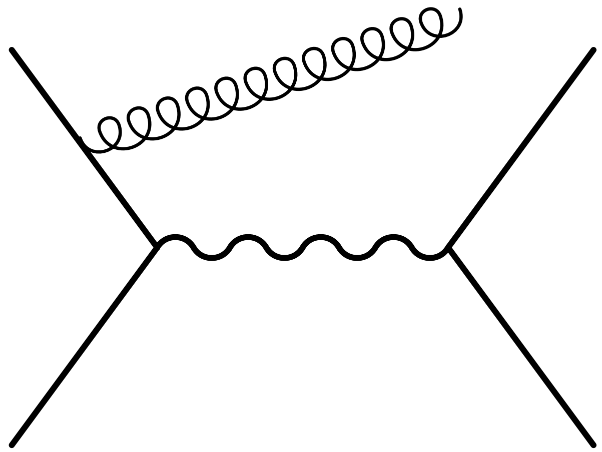
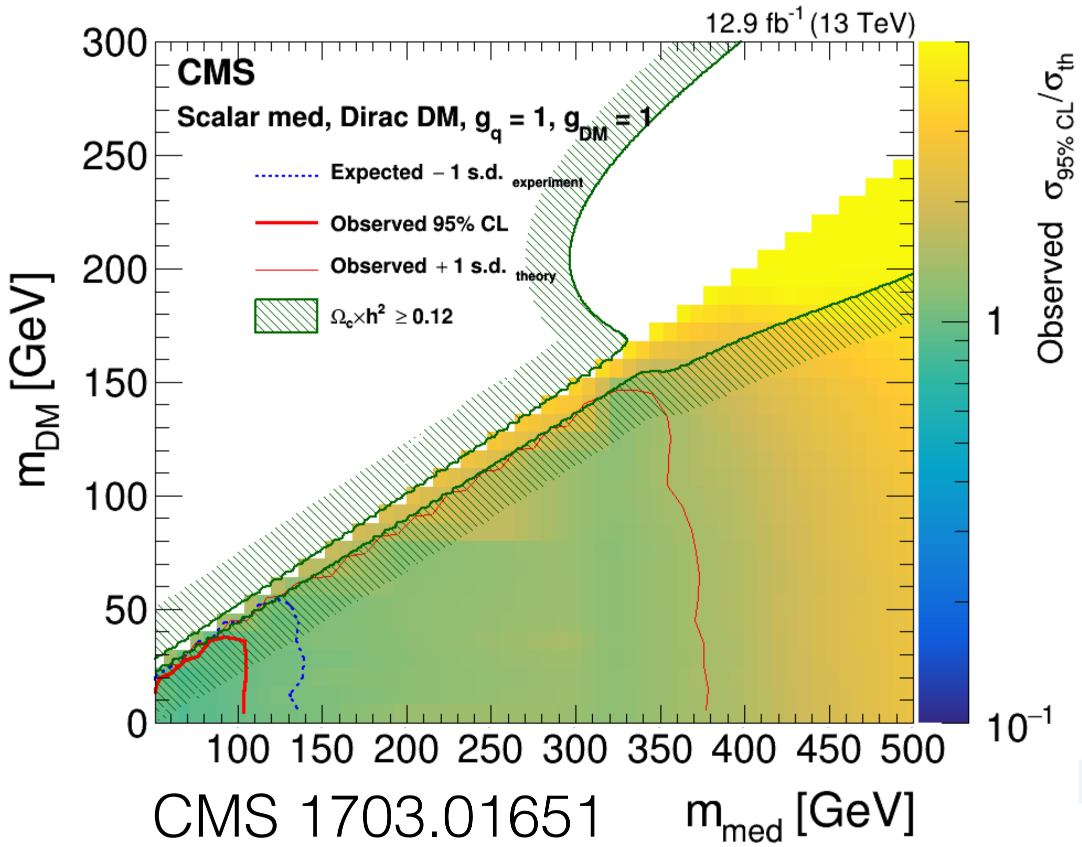


Monojets/Mono-X

- Probes a combination of visible-invisible couplings



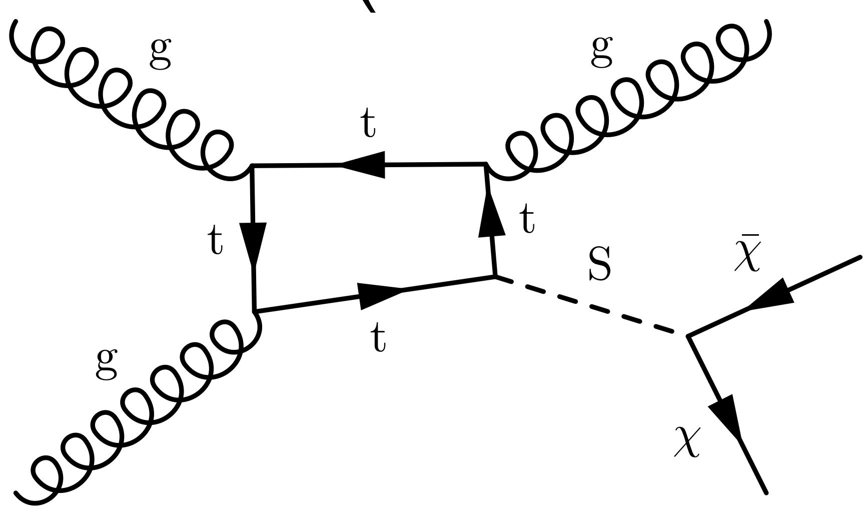


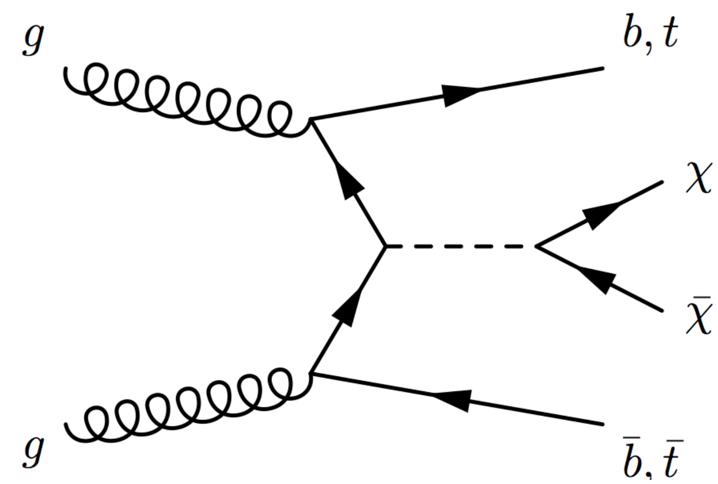


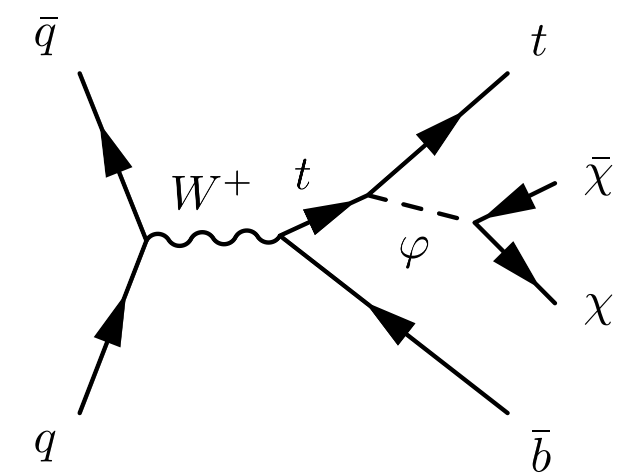
CMS 1703.01651

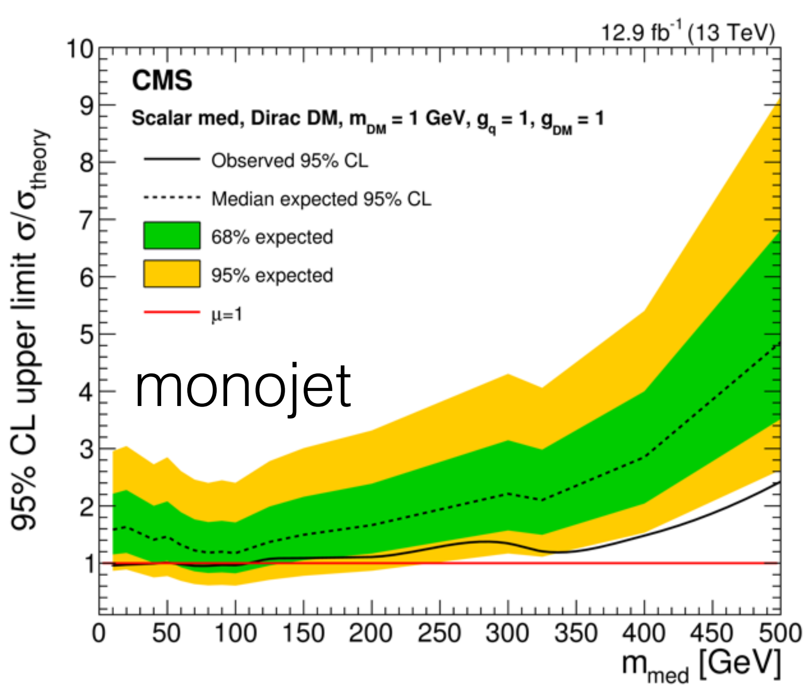
Associated Channels

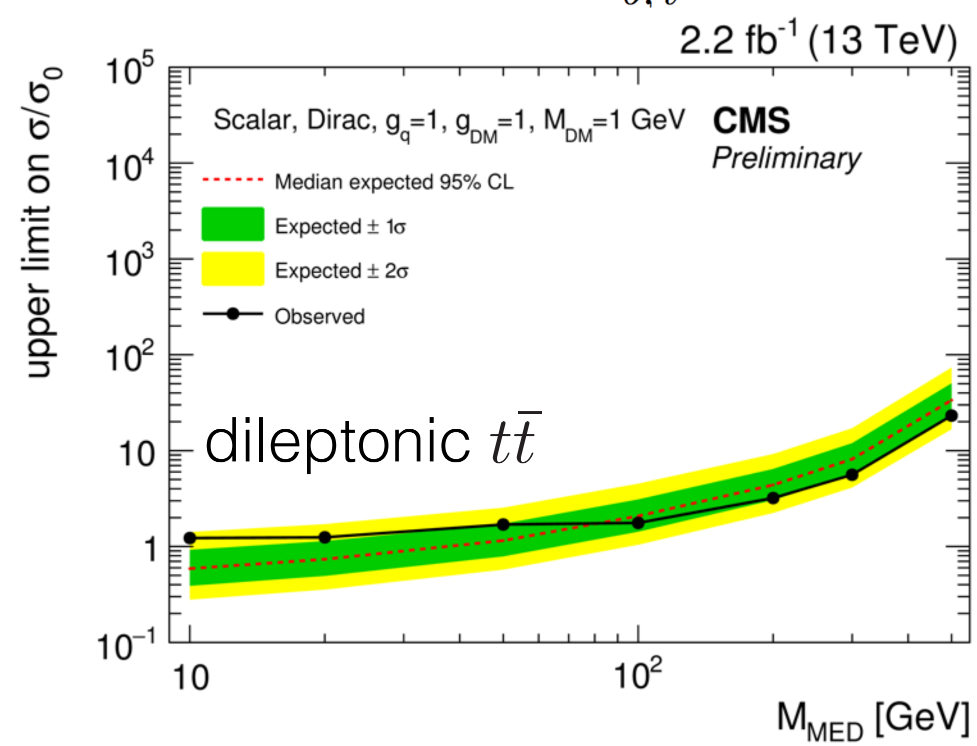
- A single model can result in multiple correlated final states (remember to include all of them)







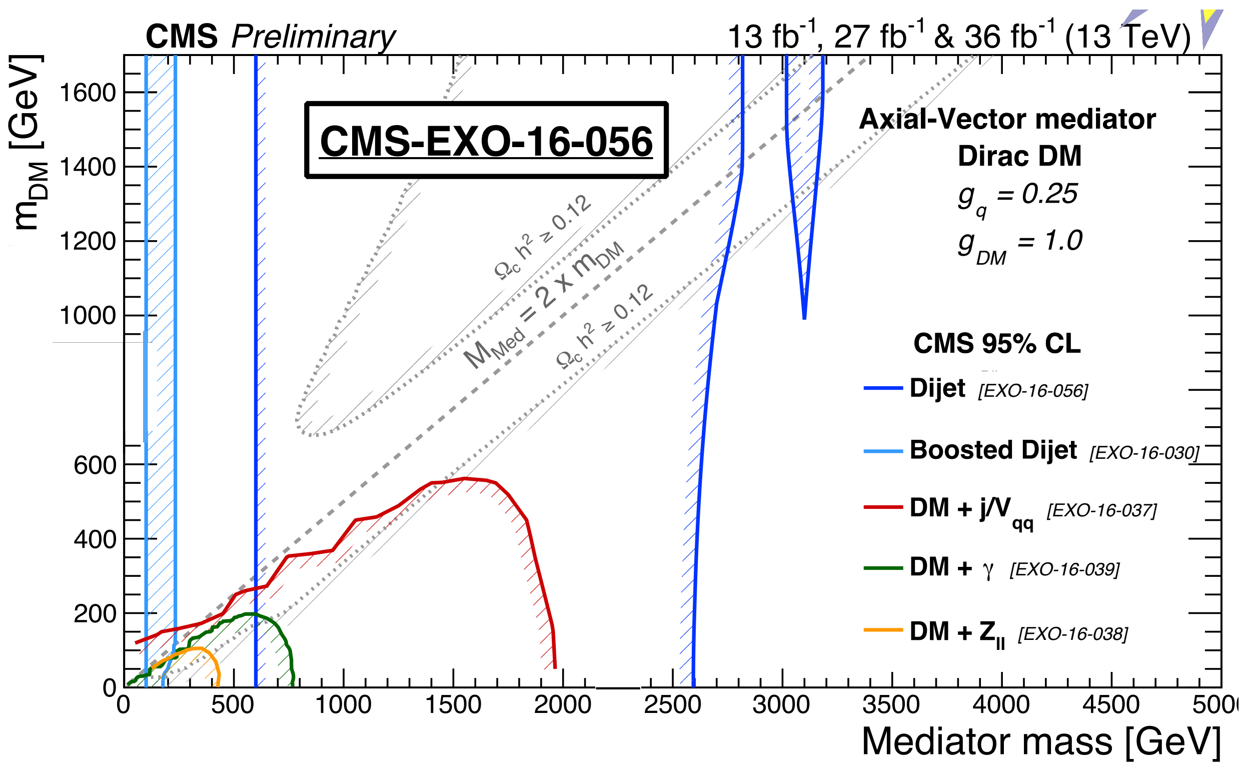




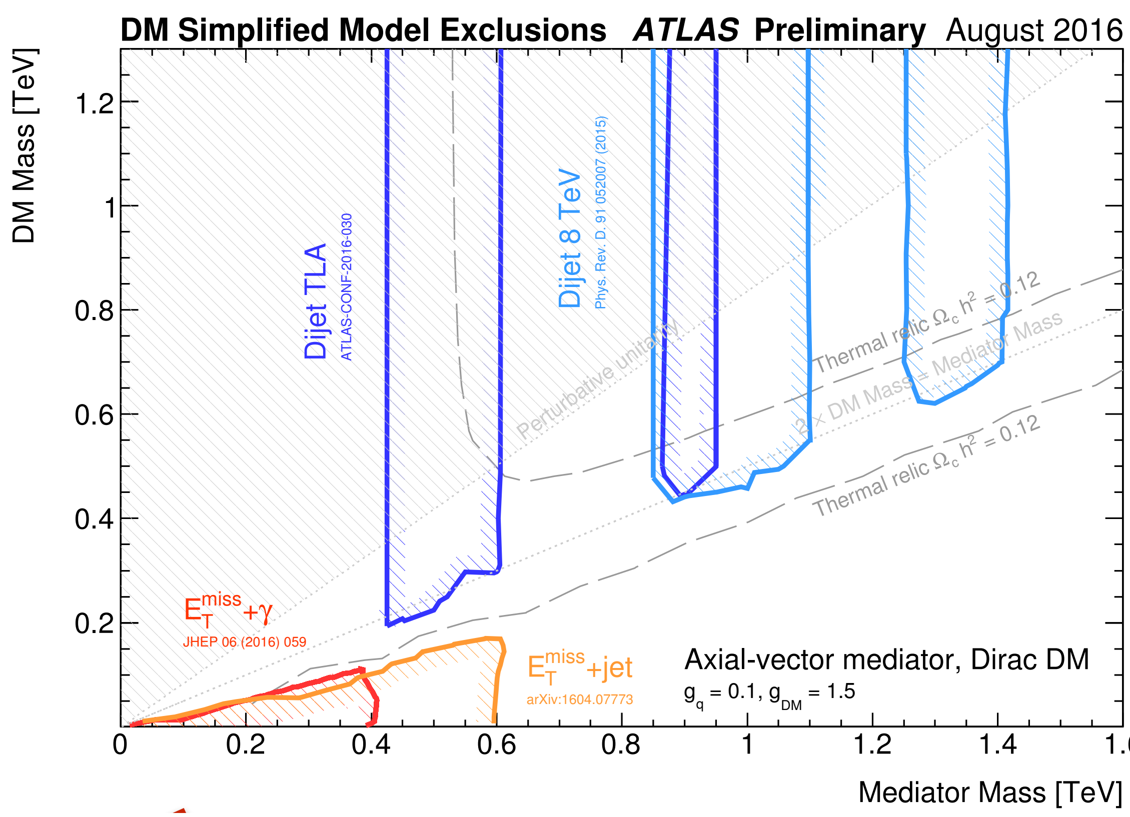
(Pinna et al. 1701.05195)

Visible vs. Invisible

- Mediators connected to Standard Model can decay back into Standard Model



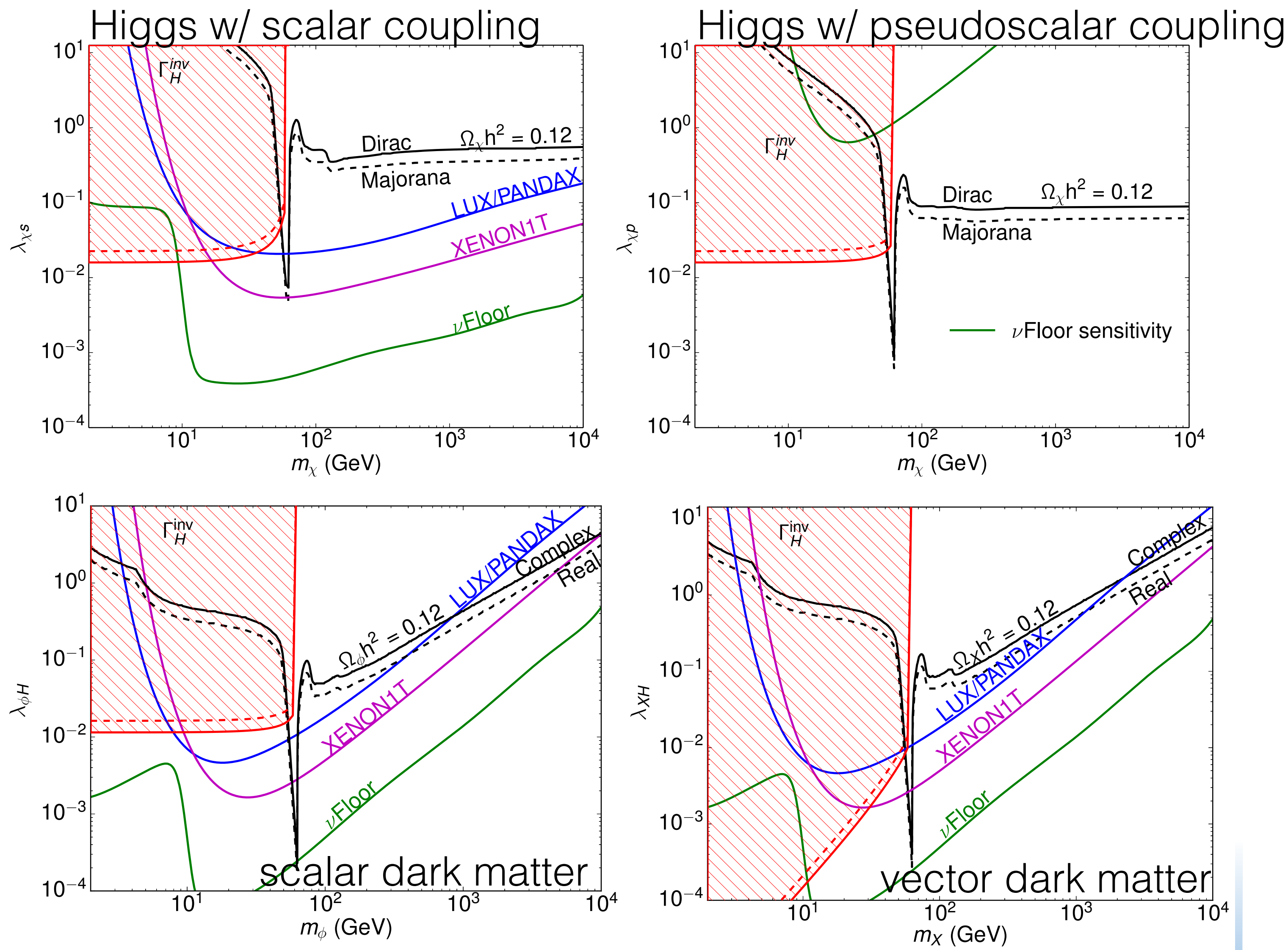
Importance depends on relative size of g_v, g_χ



Gerosa, Moriond 2017

Higgs Portal

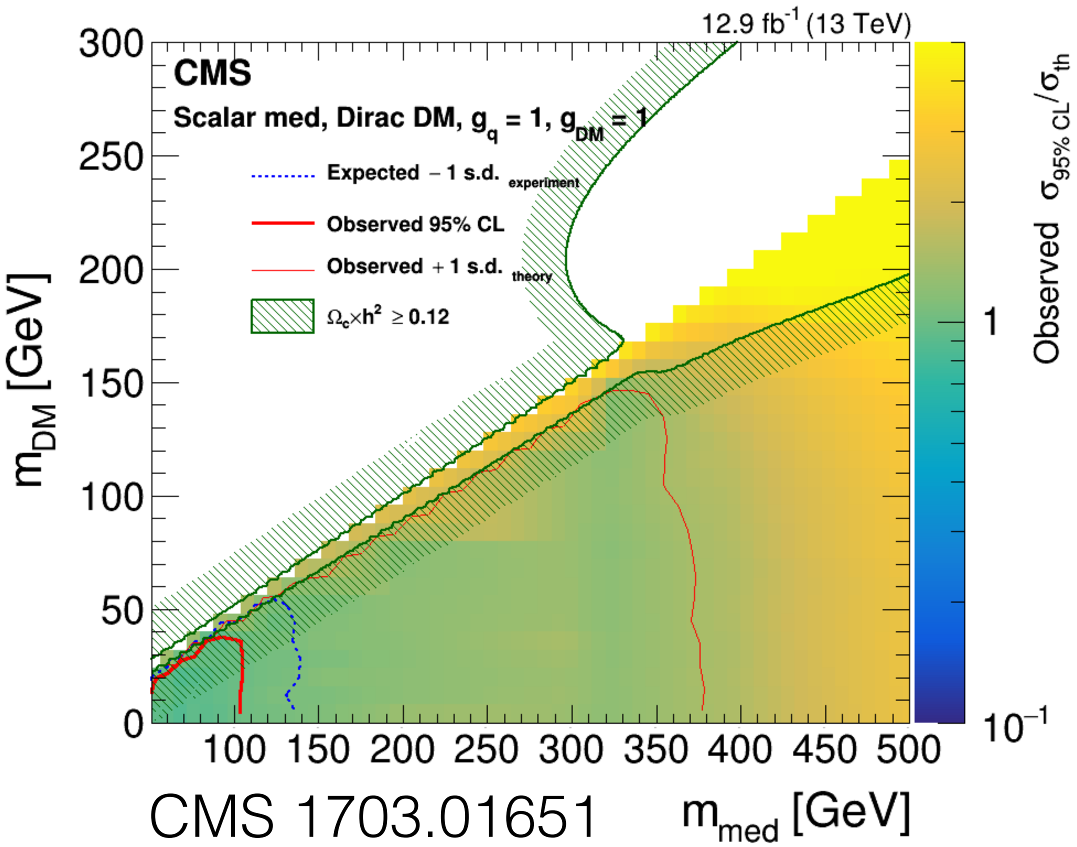
- Naturalness is not our motivating goal
- Nevertheless, EWSB is interesting.
- Can the Higgs be our mediator?
  - Maybe, but it's difficult.



Escudero et al 1609.09079

Spin-0 Portals

- Generalize the Higgs sector: new scalars and pseudoscalars
  - Expect minimal flavor violating-couplings



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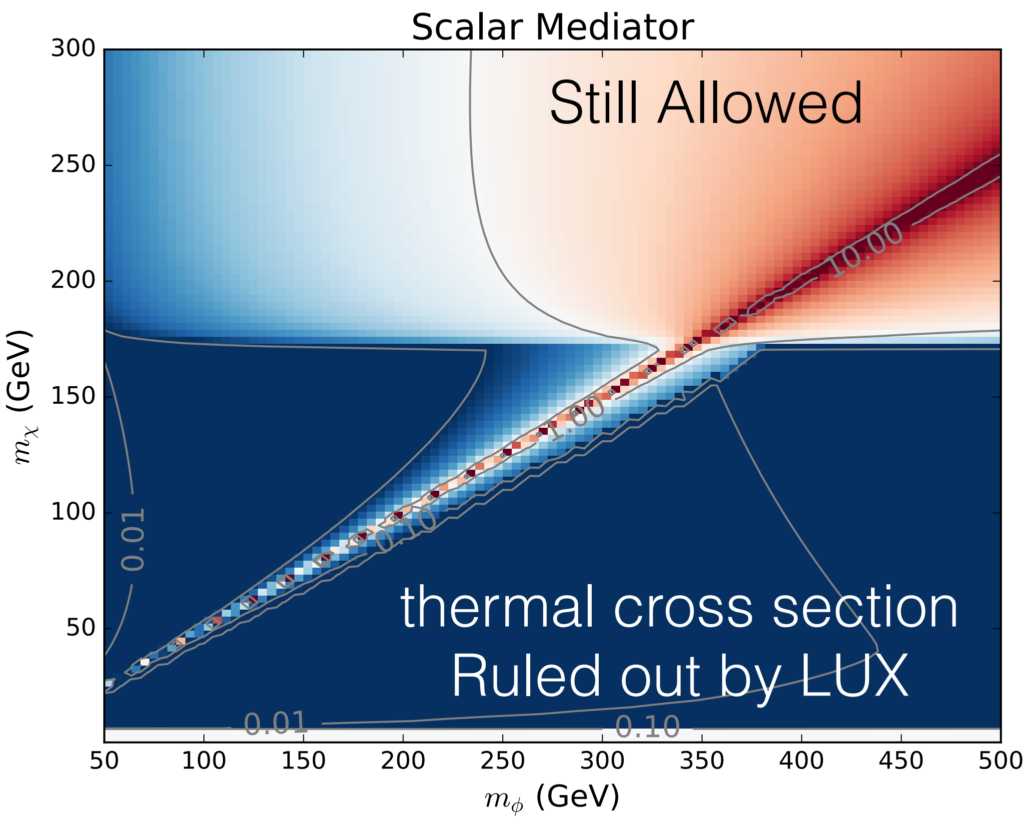

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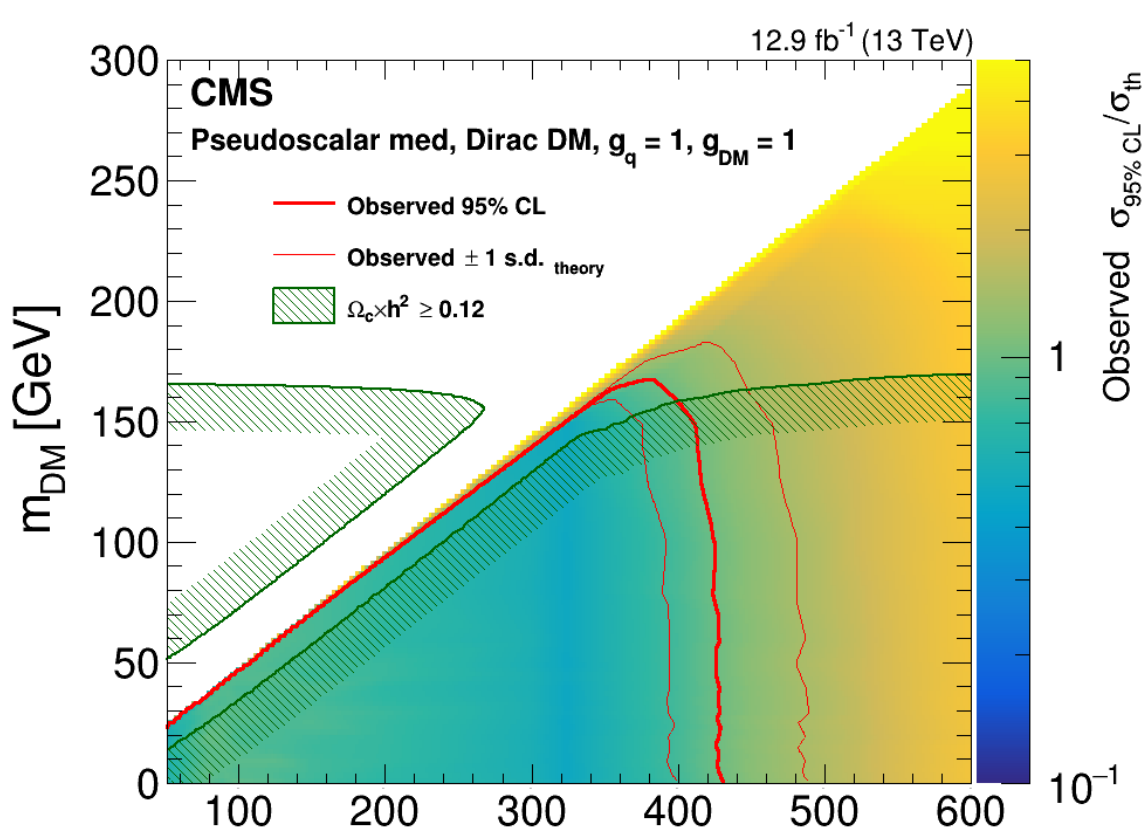

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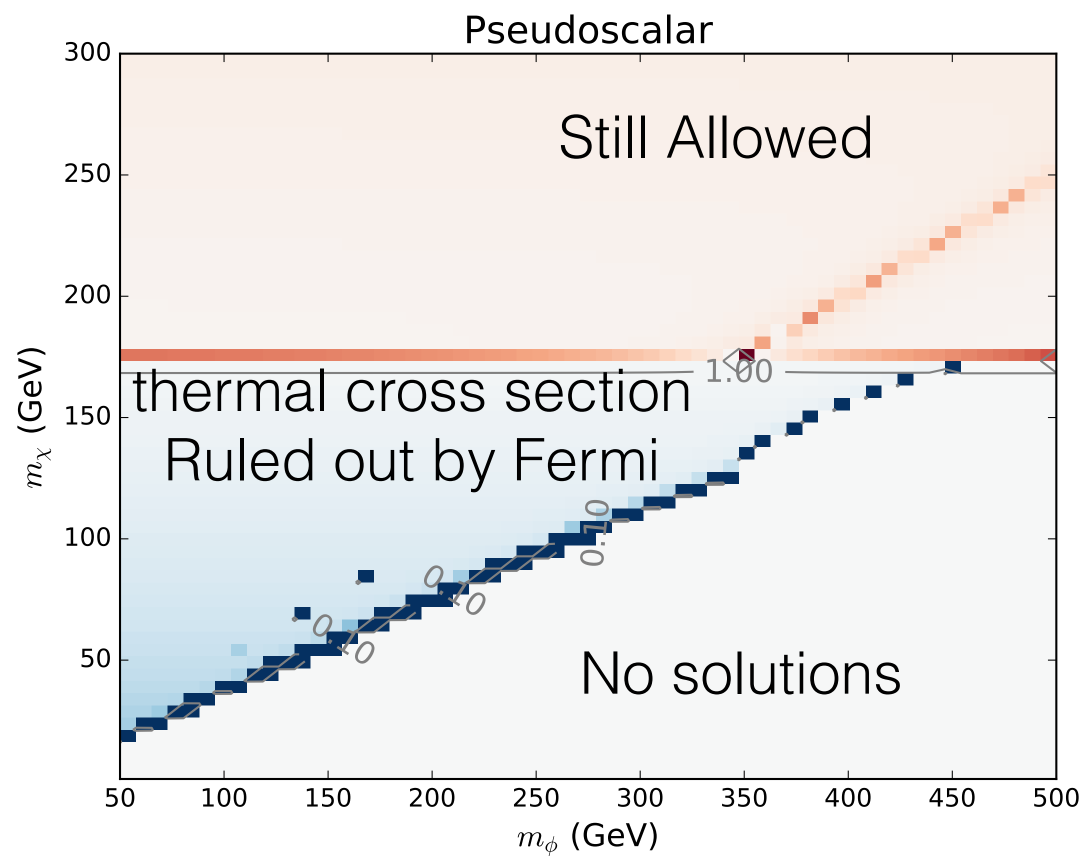
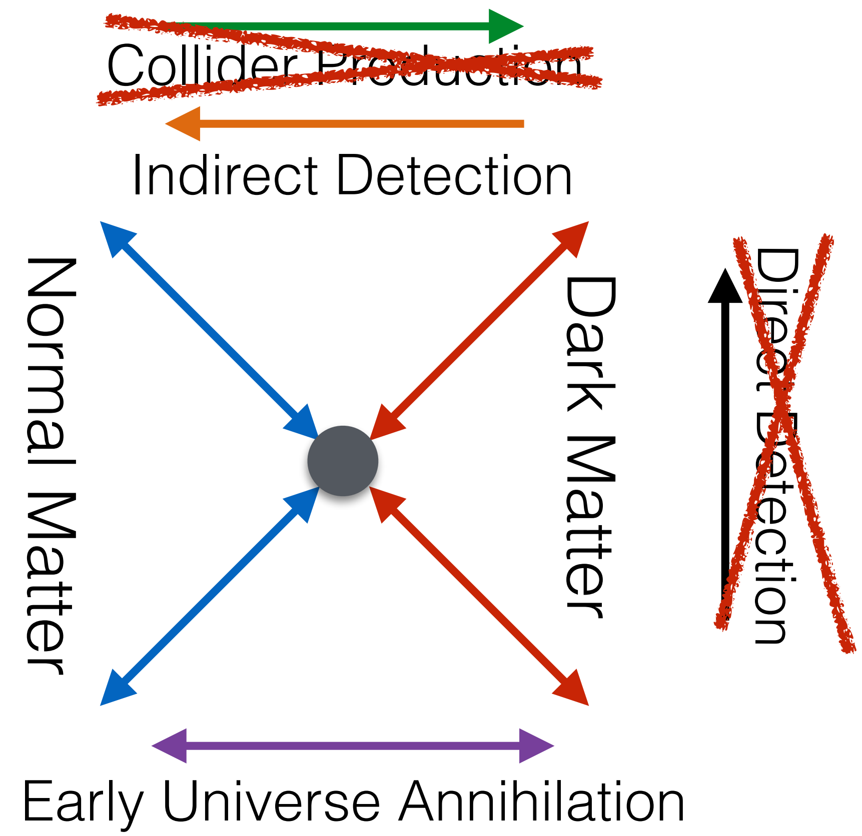


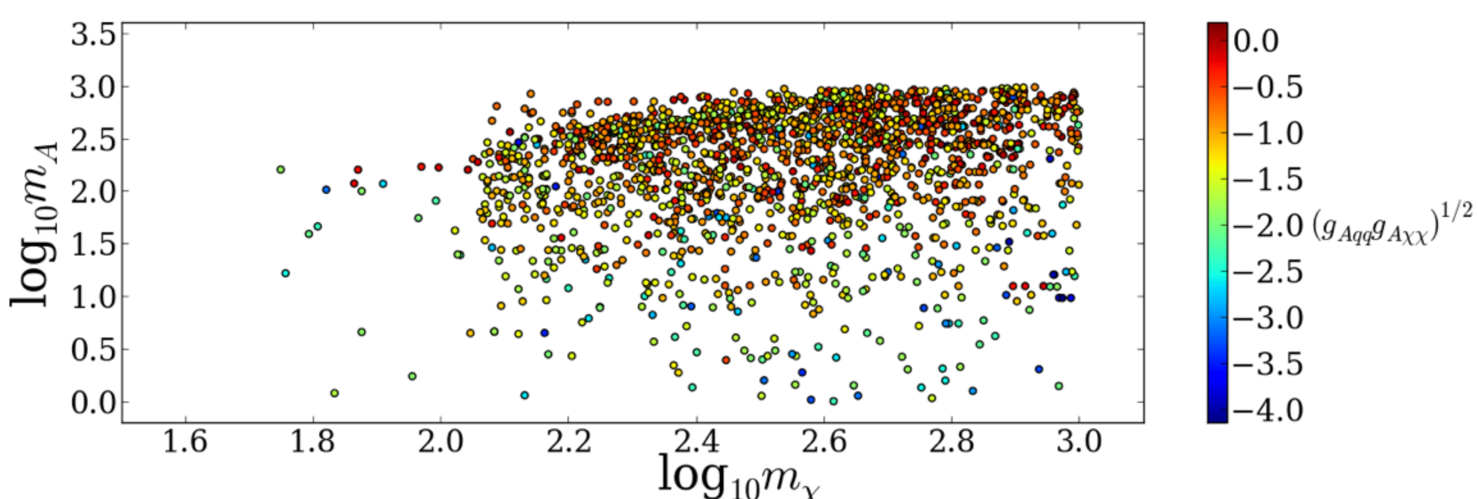
Leptophilic Dark Matter



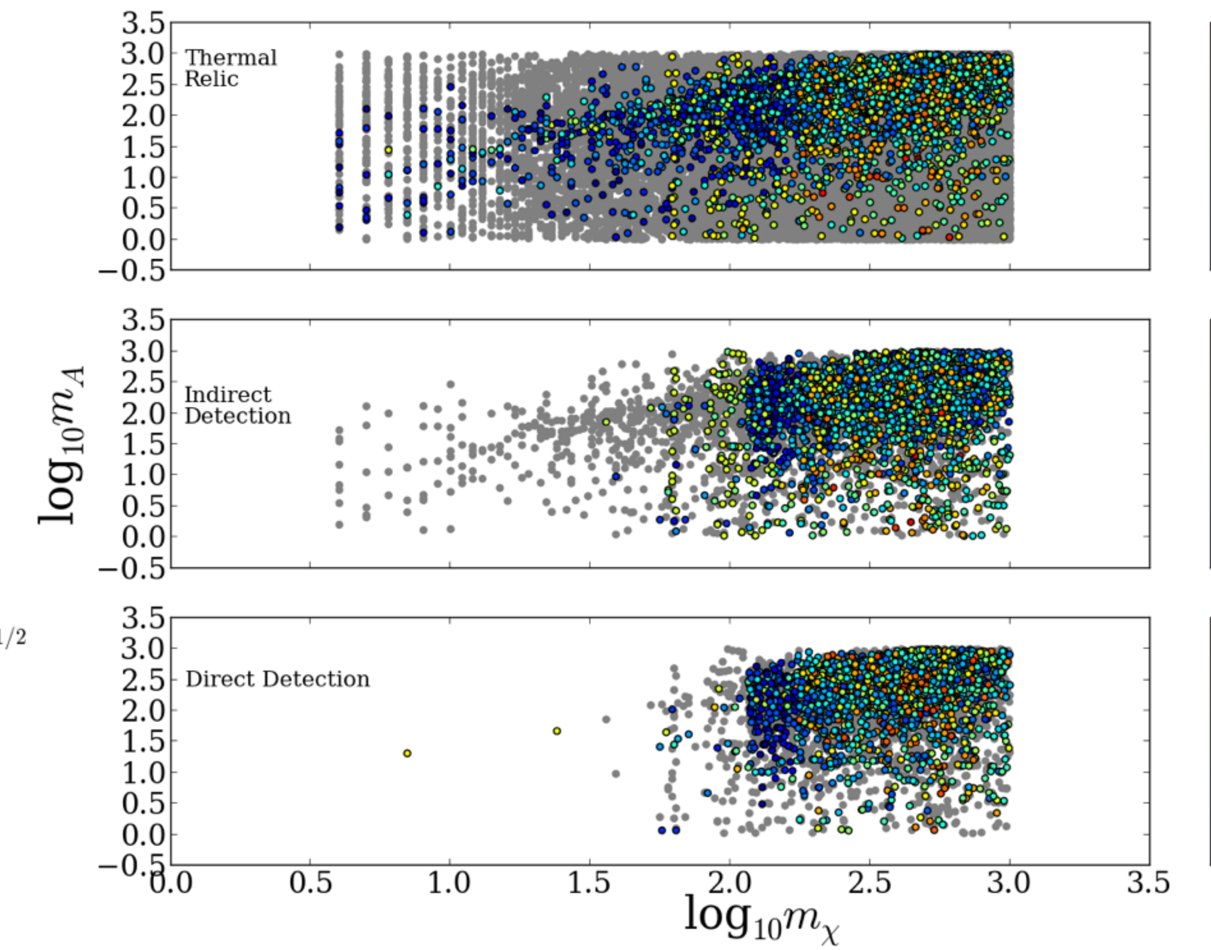
- An example I've been thinking about
  - Spin-0 mediators between dark matter and leptons seem "maximally bad."
  - Impossible to rule out?

Not so Simple Simplified Models

- But a generic leptophilic spin-0 mediator isn't leptophilic after EWSB.
  - Can start applying other experimental constraints



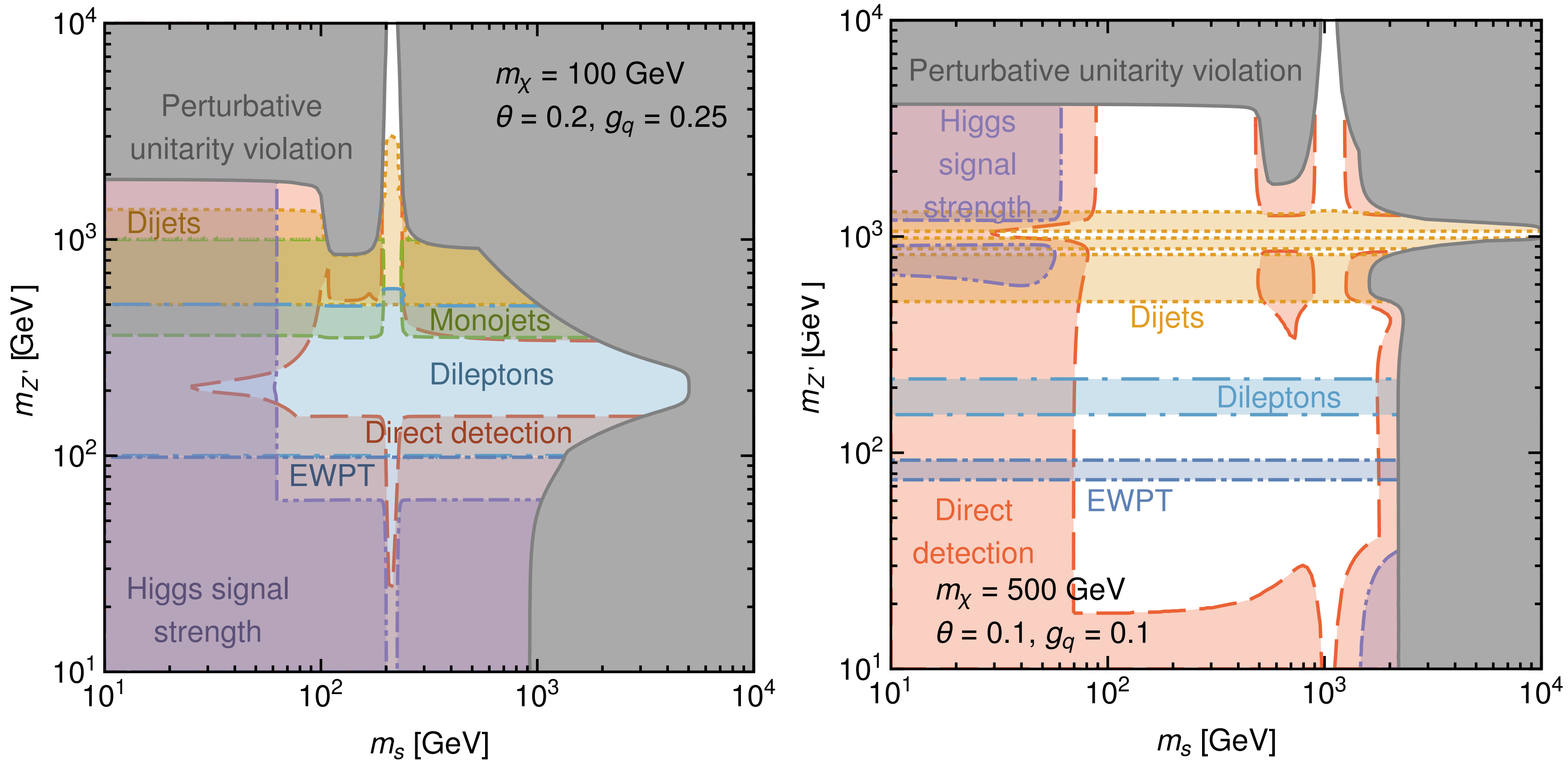
MRB and Feld *in prep*



Vector Portals

- Massive vector mediators must have their own symmetry breaking.
- New Higgses, new mixings. New constraints

Duerr et al 1606.07609



What's Left?

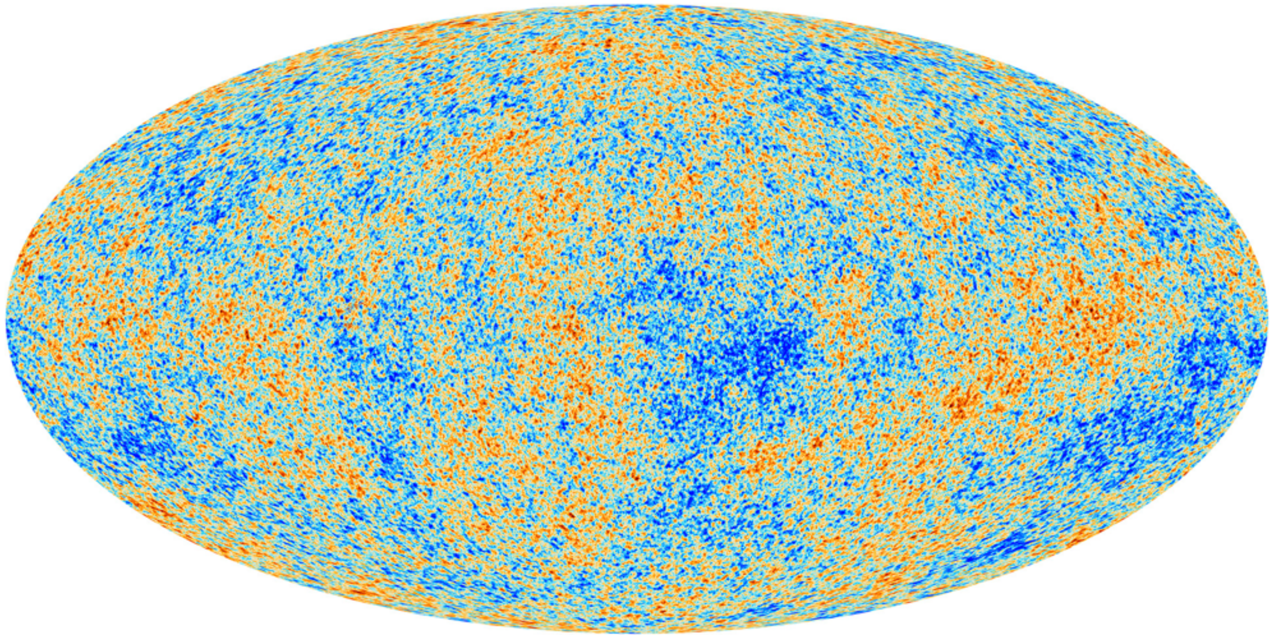
- Need to continue asking:
  - What can we be missing in simplified models?
  - Are the new particles:
    - Too Heavy? quark-phobic? Hidden in background?
  - Are we making unwarranted assumptions about particle widths/couplings?
  - Are the models too simple?
    - Overlooking some essential phenomenology?

Beyond Thermal Dark Matter

- We don't know dark matter has $\langle \sigma v \rangle \gtrsim 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$
- Coming up with new mechanisms for dark matter production is an industry for theorists.
- What does this mean for experiments?
    - New models may not *need* to have a significant interaction with Standard Model.
    - Removes much of the "predictivity"
- Bottom Line:
    - Experimentalists should take notice of new signatures proposed by theorists. Don't worry if a model is invisible to your experiments.

Look to the Skies

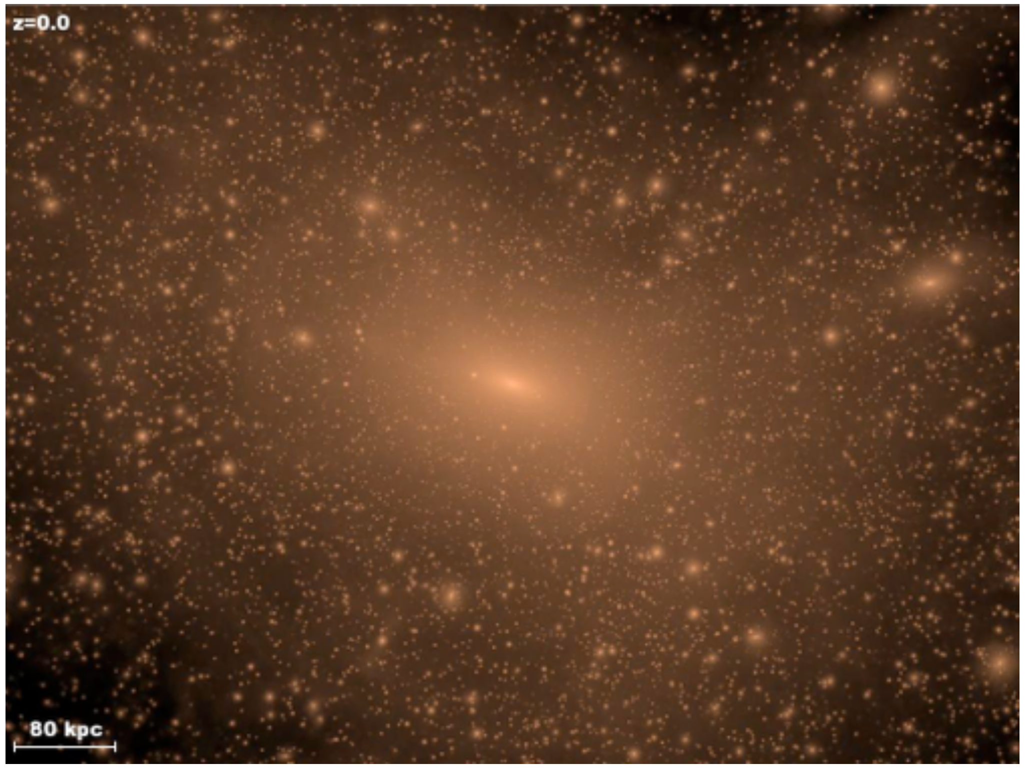
- Our only source for positive statements about dark matter comes from gravity.



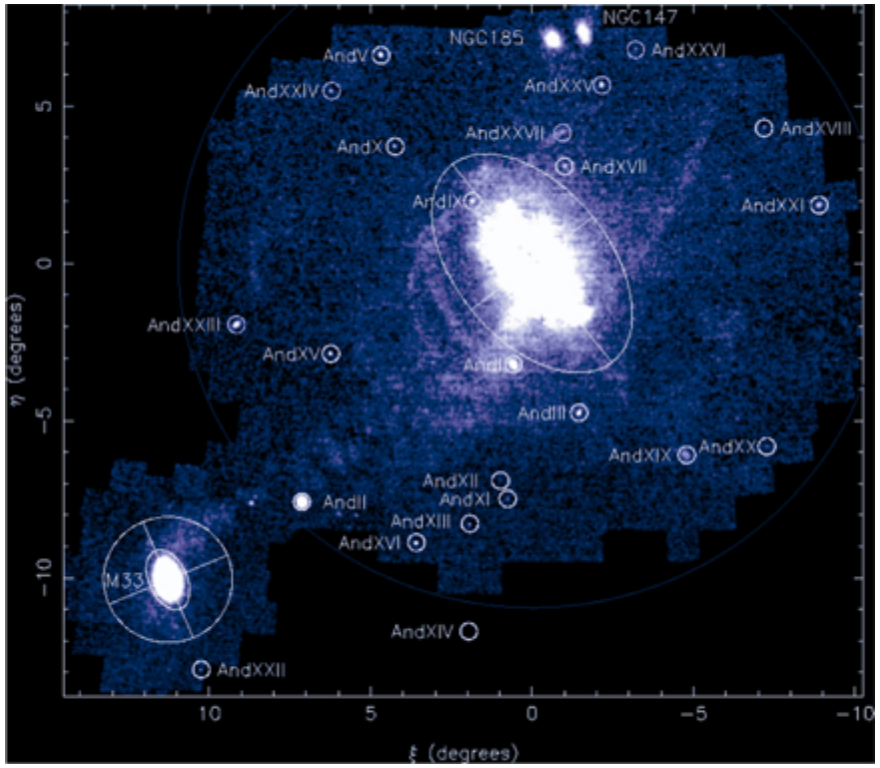
- Dark Matter parameters measured by the "classic" experimental triad are often orthogonal to what we learn from cosmology/astrophysics.

Is Dark Matter Boring?

- Early Universe consistent with ΛCDM.
- But there are some wrinkles around the edges.
- “Crisis in small scale structure”



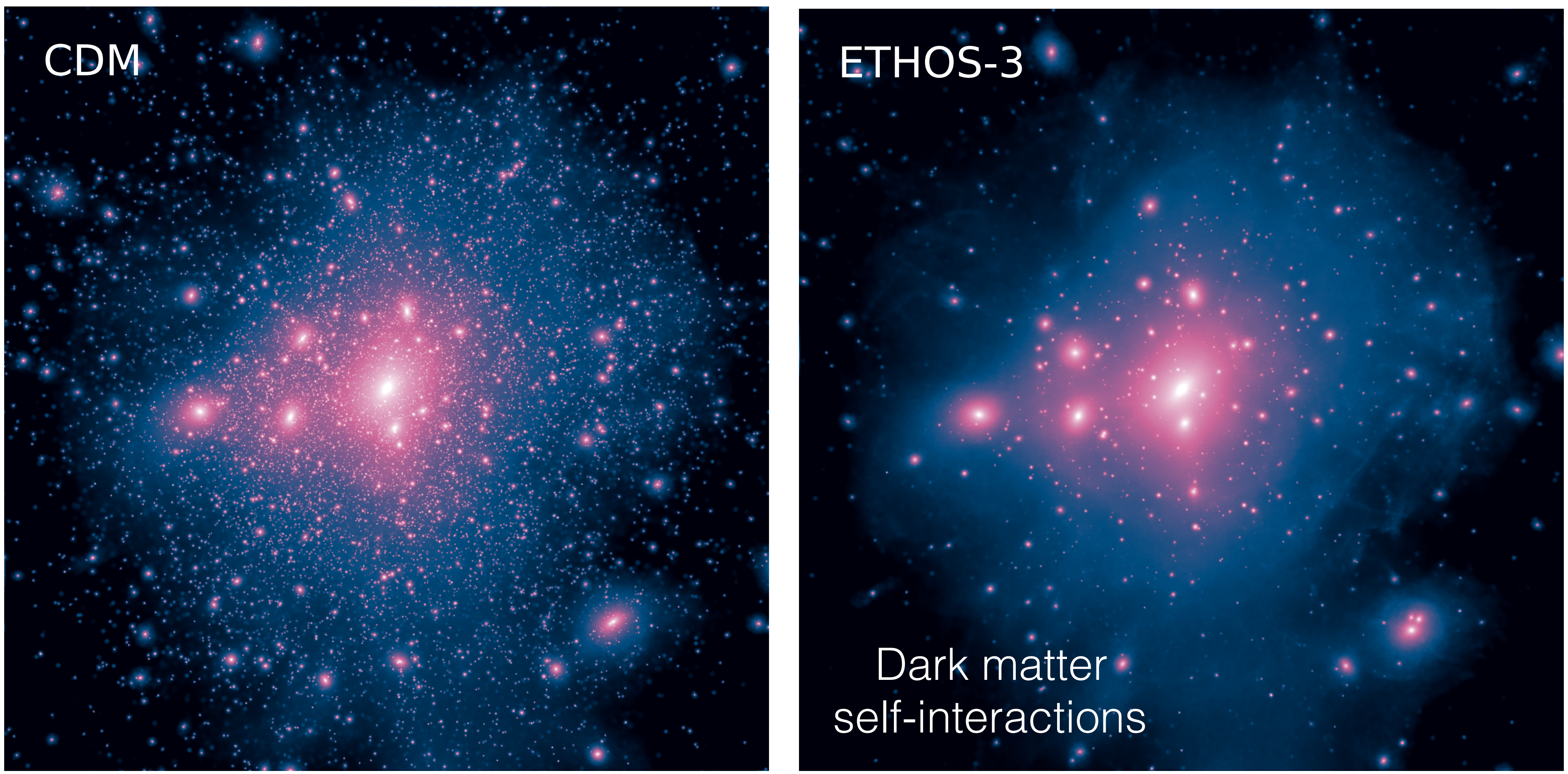
Via Lactea
100’s of dwarf galaxies



PAndAS
dozens seen

Is Dark Matter Boring?

- Evidence of interactions internal to the dark sector?
  - If so, these are not likely to be seen at LHC *etc*.



Vogelsberger et al 1512.05349

Astrophysical Probes

- What do we think dark matter *is*?
- What tools do we have available?

A thermal relic of the Early Universe

Detectors capable of measuring weak-scale interactions with SM

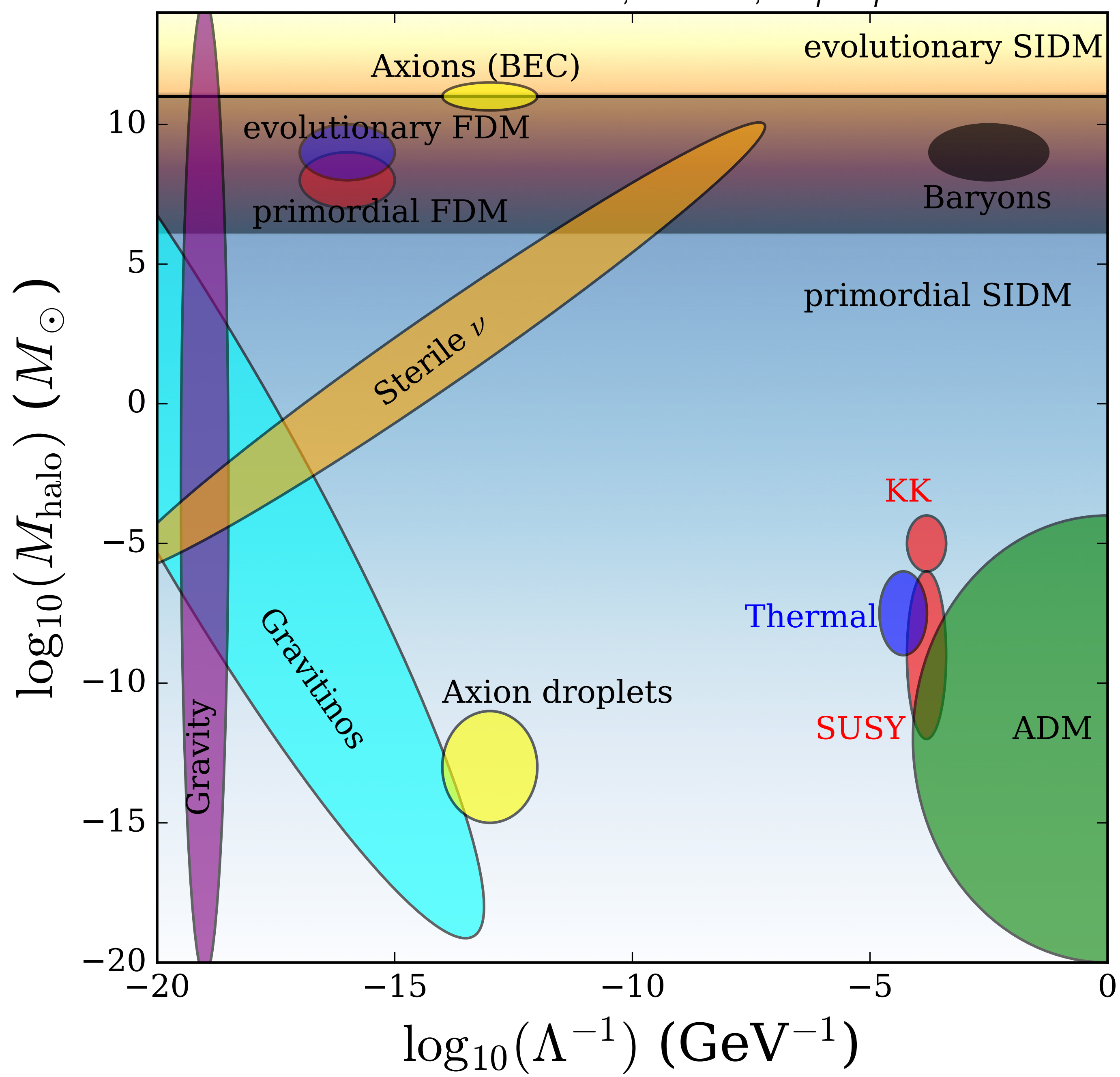
These are not exclusive hypotheses!

Part of an extended sector with non-trivial physics

Astrophysical/cosmological studies of dark matter structure

A Simple Parameterization

MRB, Peters, *in prep*



Halo size where "something interesting" happens

How much dark matter interacts with us

Conclusions

- Thermal dark matter is a well-motivated idea.
  - Rumors of its demise are greatly exaggerated.
  - We *can* catch non-thermal DM in this dragnet
  - Need to continually fine-tune the balance between

Generality (Simplified Models) ⟷ Unique Phenomenology (UV Complete Models)

- If you're an experimentalist, look for new theories that predict new signatures. If you're a theorist, work to make those new signatures understandable.

Conclusions

- Remember: we don't know what dark matter *is*
- Many good ideas out there. How can we prove or disprove them?
- Don't forget the experiments that the Universe has kindly run for us over the last 13.7 gigayears.