DARK DYNAMICS IN THEORY SPACE AND THEIR SIGNALS IN ANOMALY SPACE

Neal Weiner
CCPP - NYU
DM Aspen
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work w/ Dan Hooper, Jia Liu, Brian Shuve, Wei Xue, Itay Yavin

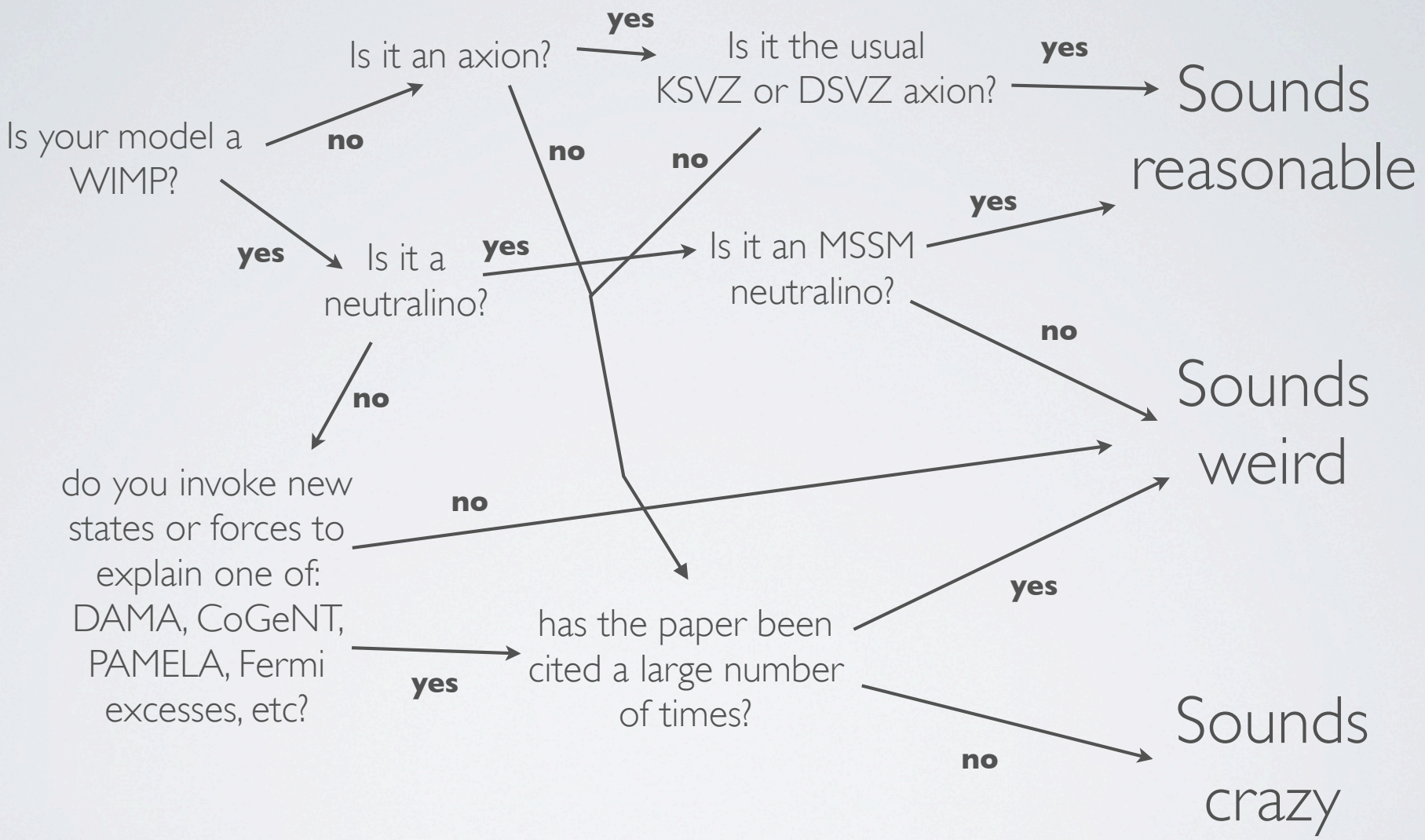
THE ZOOLOGY OF DARK MATTER

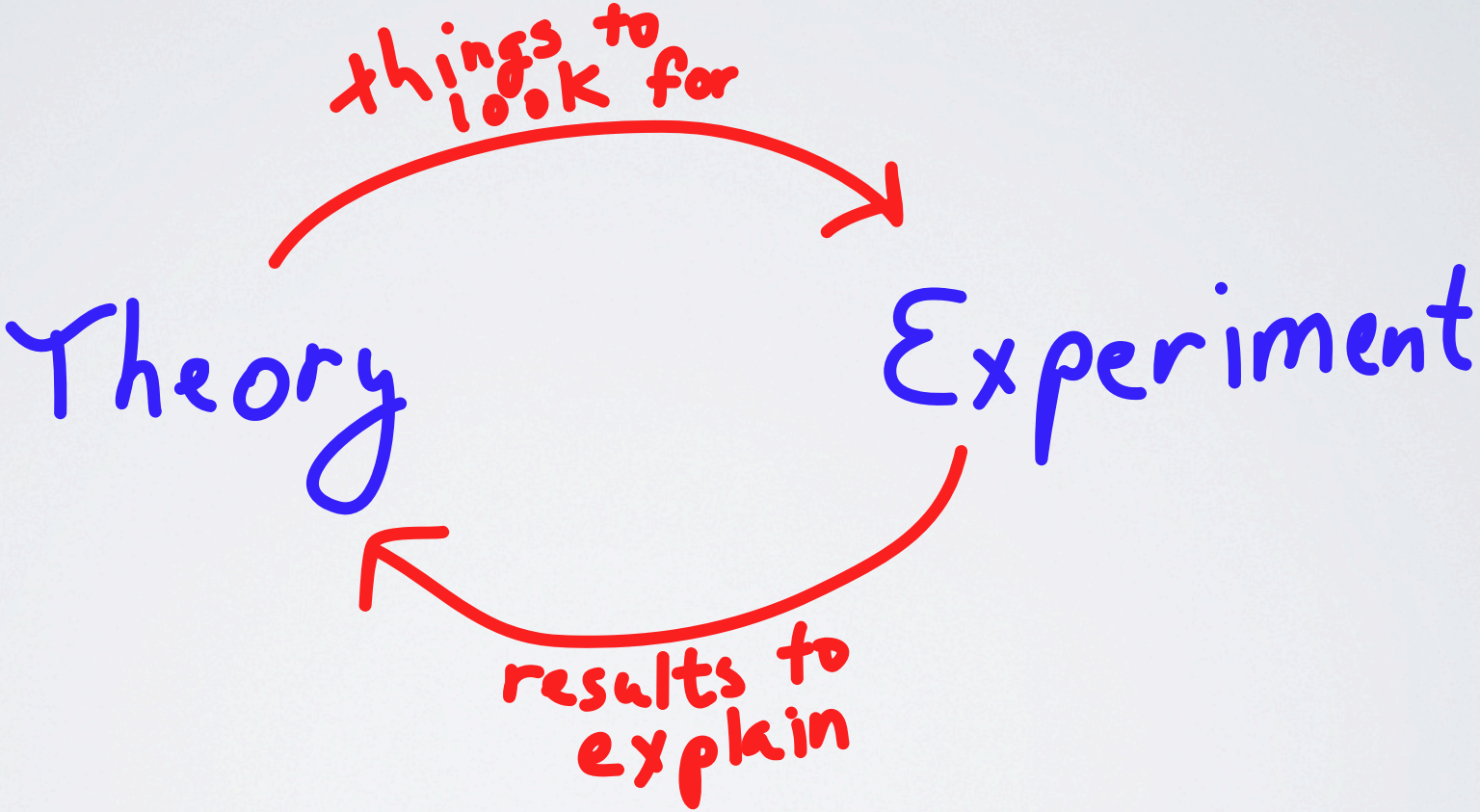
Three basic categories of dark matter:

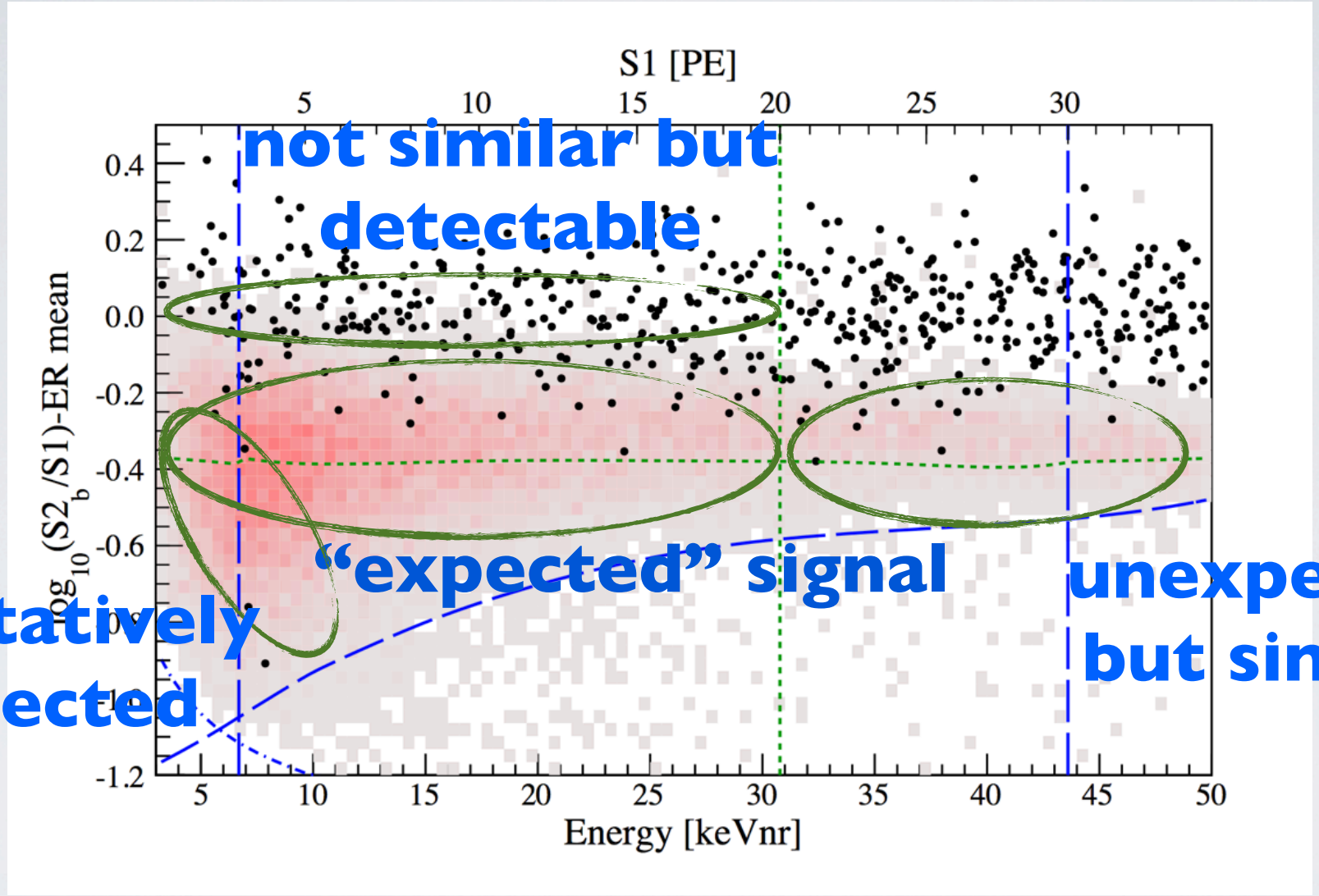
Reasonable Weird Crazy

sometimes also called "normal"

(also "wrong")


Is your model a WIMP?
no
yes
Is it an axion?
yes
Is it the usual KSVZ or DSVZ axion?
yes
Sounds reasonable
no
no
Is it a neutralino?
yes
Is it an MSSM neutralino?
yes
no
Sounds weird
no
do you invoke new states or forces to explain one of: DAMA, CoGeNT, PAMELA, Fermi excesses, etc?
yes
has the paper been cited a large number of times?
yes
no
Sounds crazy


things to look for
Theory
Experiment
results to explain


S1 [PE]
5
10
15
20
25
30
0.4
0.2
0.0
-0.2
-0.4
-0.6
-1.2
log10(S2b/S1)-ER mean
5
10
15
20
25
30
35
40
45
50
Energy [keVnr]
not similar but detectable
"expected" signal
qualitatively expected
unexpected but similar
unexpected, not detectable

HOW DO WE DECIDE WHEN A SIGNAL IS *NOT* DARK MATTER

- No easy answer
- One element: theoretical understanding of models for signal
- anomalies push the envelope of what dark matter could be and make new predictions

HOW TO APPROACH AN ANOMALY

I don't care about your stinking model!

effective field theorist hat

effective field theory hat

$$\frac{\chi\chi \times \text{Your Detector}}{\Lambda^n}$$

your model

HOW TO APPROACH AN ANOMALY

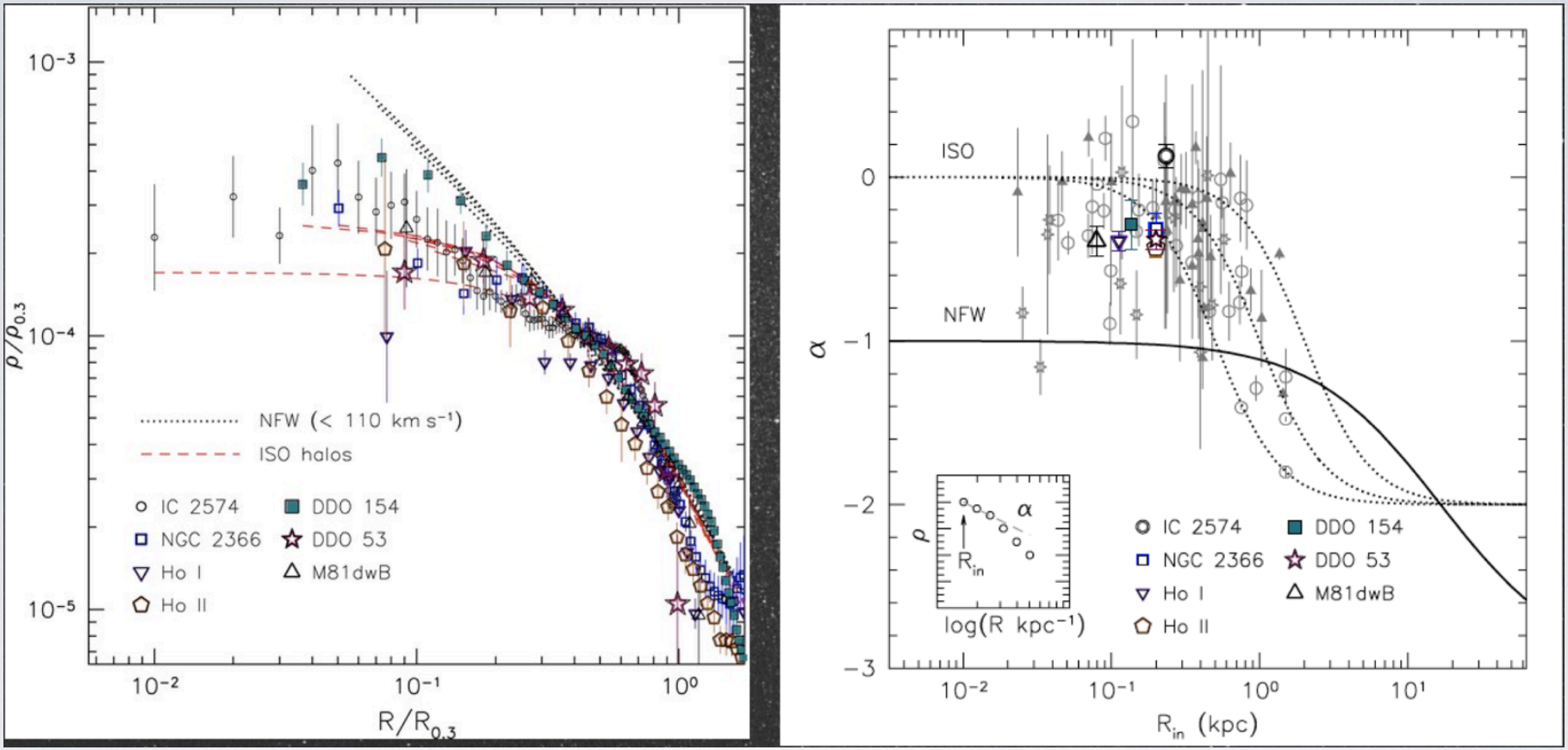
I don't care about your stinking model!

effective field theory hat

model is important for complementarity of searches

details matter

EXAMPLE 1: INTERACTING DM



dwarfs have cores - interacting dark matter?

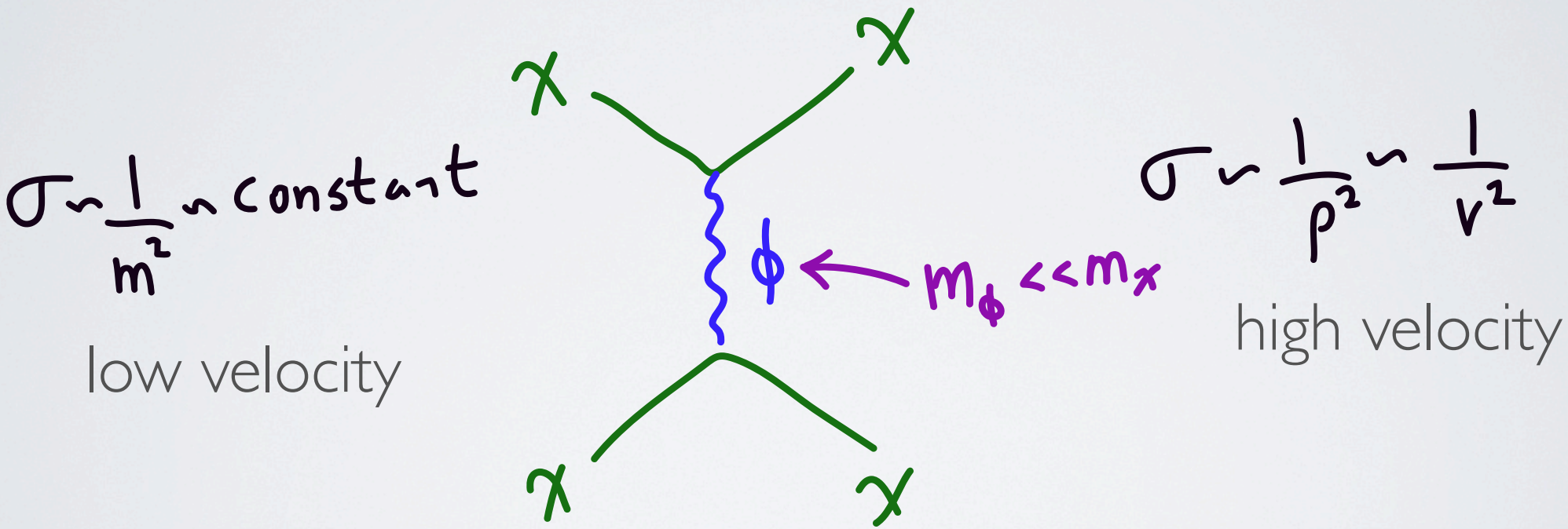
need $\sigma/m \sim 10^{-24}\text{cm}^2 \sim$ strong scale

constant $\sigma \Rightarrow \sigma$ v goes up for high velocity

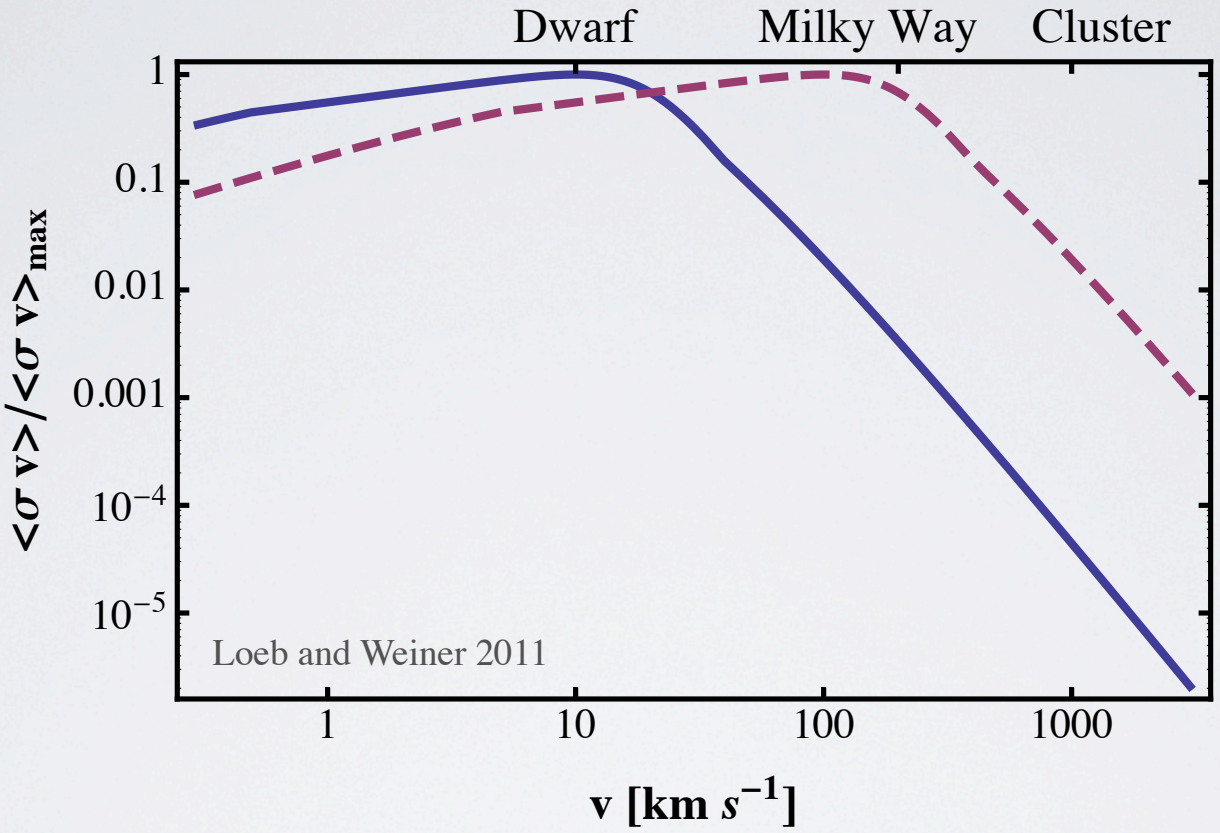
$\sigma \sim 1/v^p = \sigma$ v goes up for low velocity

a realistic model: note SIDM ≠ SIDM

self int ≠ strong int

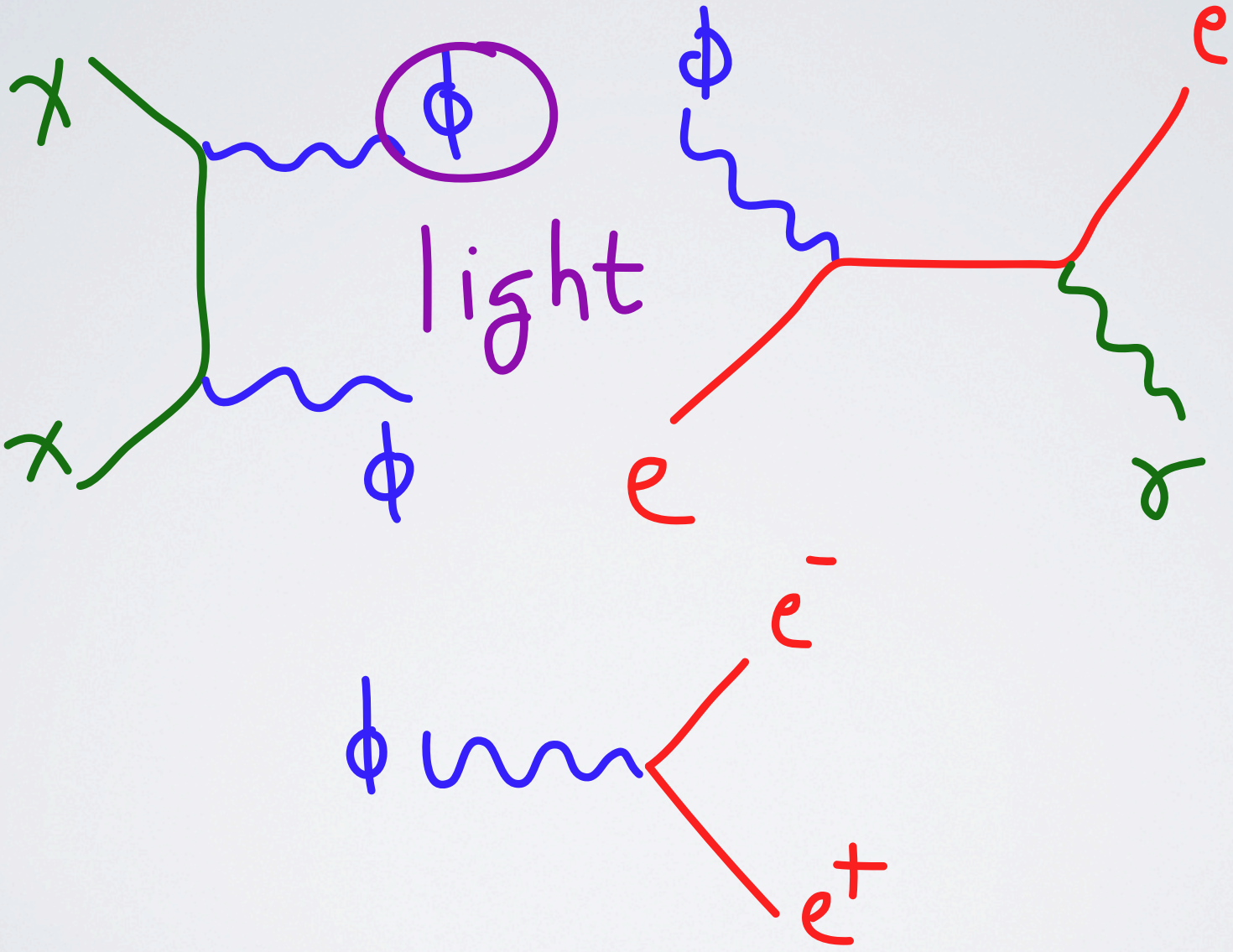


Spergel+Steinhardt '99; Hogan+Dalcanton '00; Feng, Kaplinghat+ Yu '09; Buckley+Fox '09; Loeb+NW '10



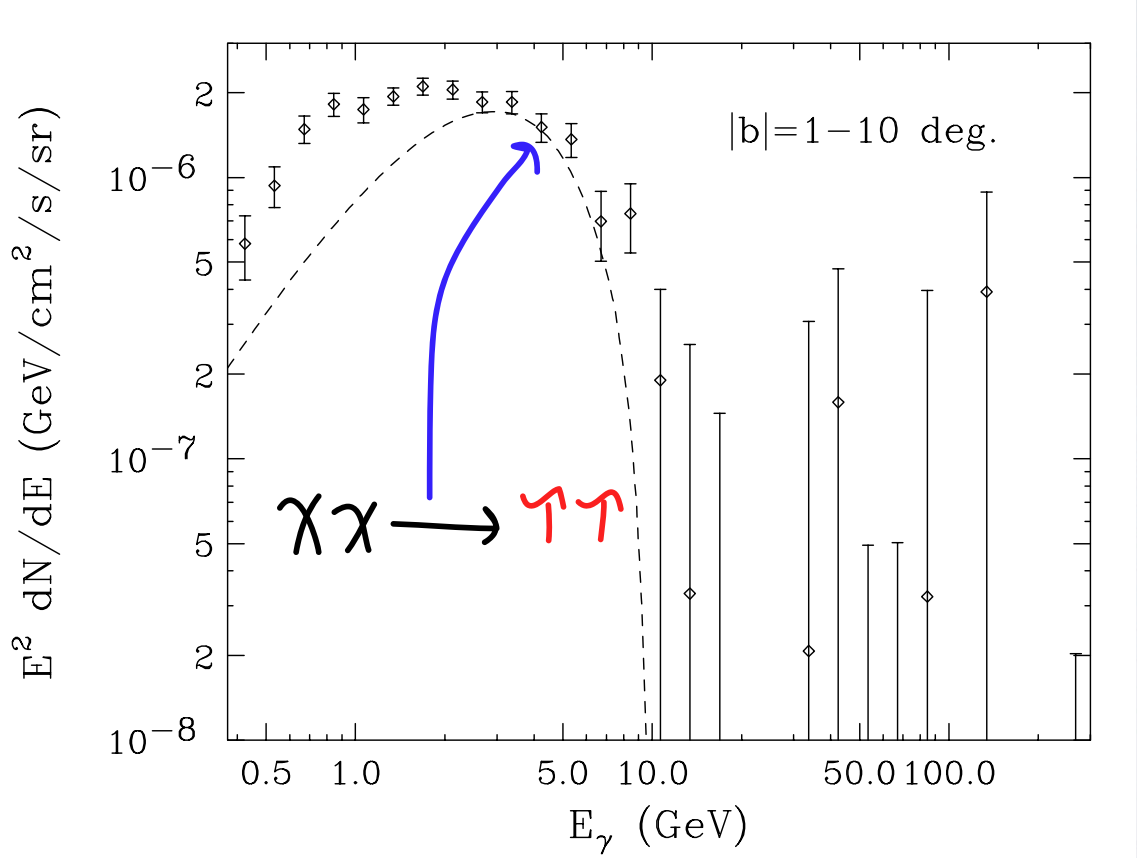
Spergel+Steinhardt '99; Hogan+Dalcanton '00; Feng, Kaplinghat+ Yu '09; Buckley+Fox '09; Loeb+NW '10

"DARK FORCE" MODELS



Finkbeiner, NW '08; Pospelov, Ritz, Voloshin '09; Arkani-Hamed et al '09; Pospelov, Ritz '09

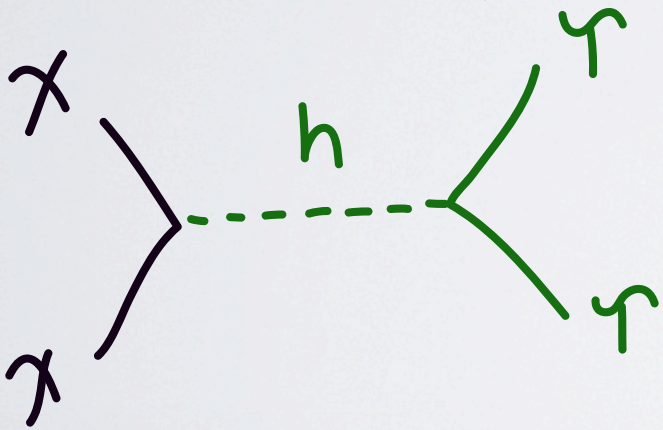
EXAMPLE II: LEPTONICALLY ANNIHILATING DM

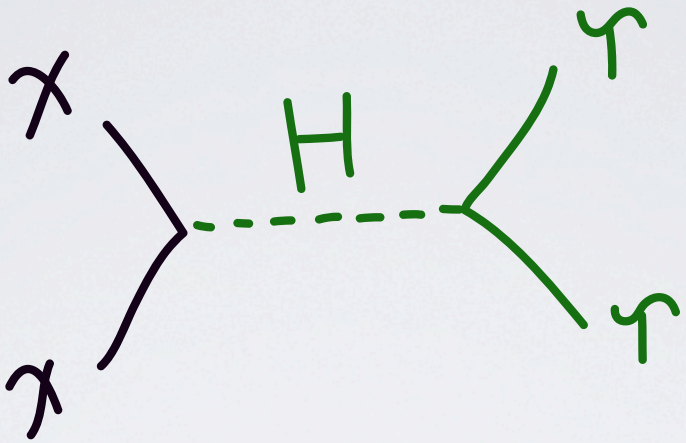


MODELS

Invisible Higgs decay

Higgs portal?



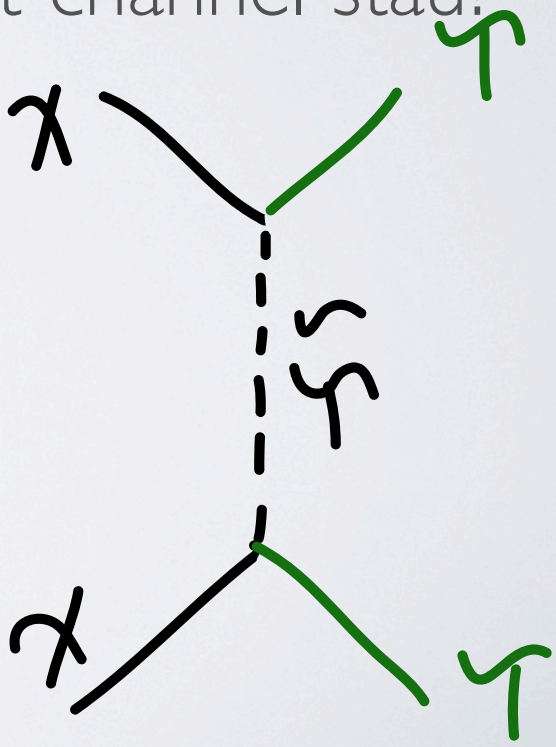


2nd Higgs portal?

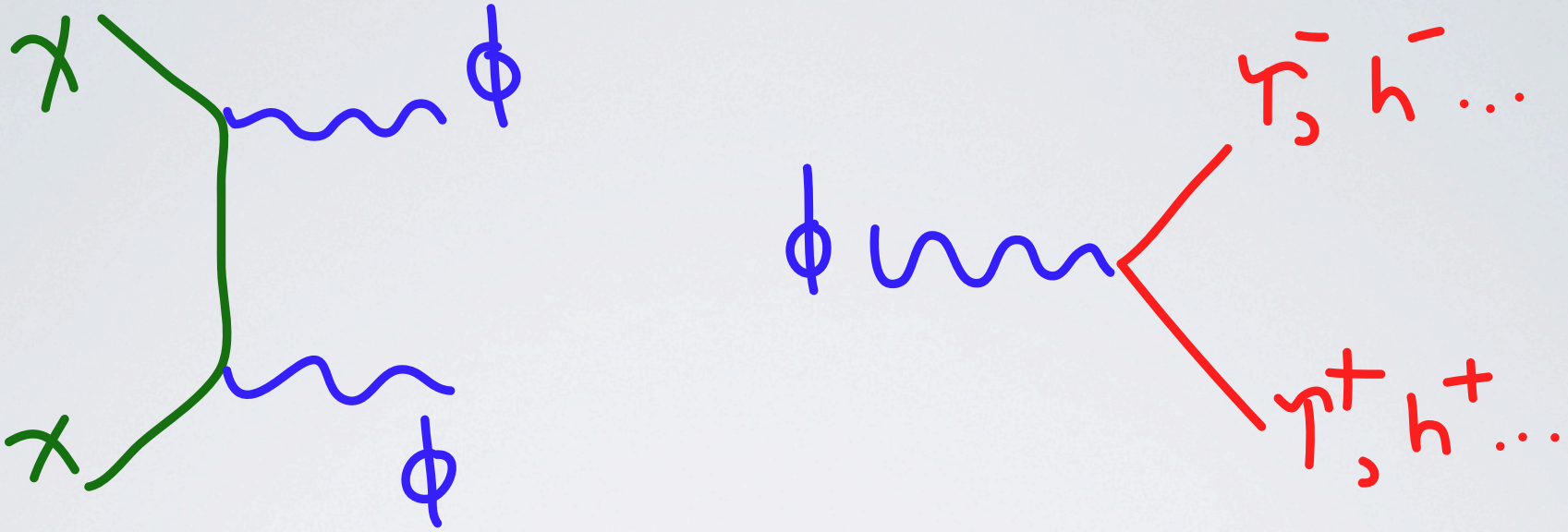
B-physics?
Leptonic Higgs?

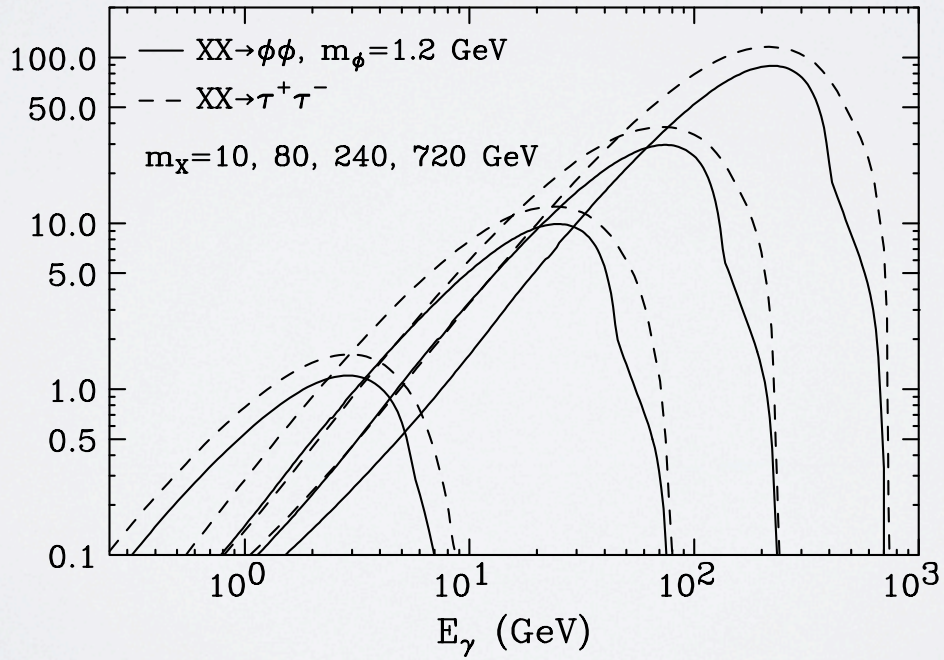
SUSY?

t-channel stau?



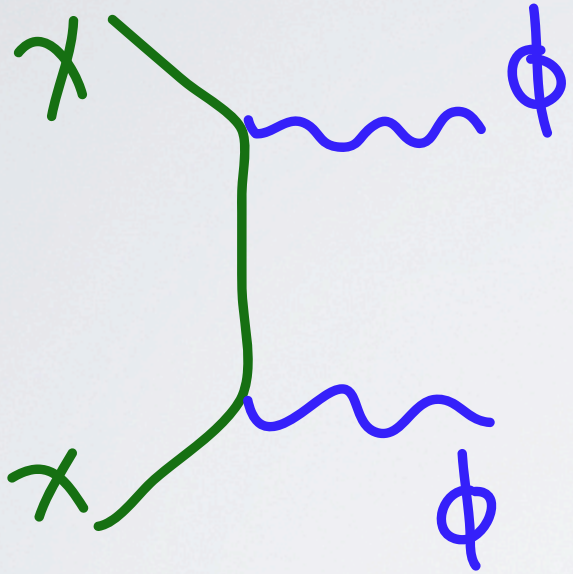
MODELS



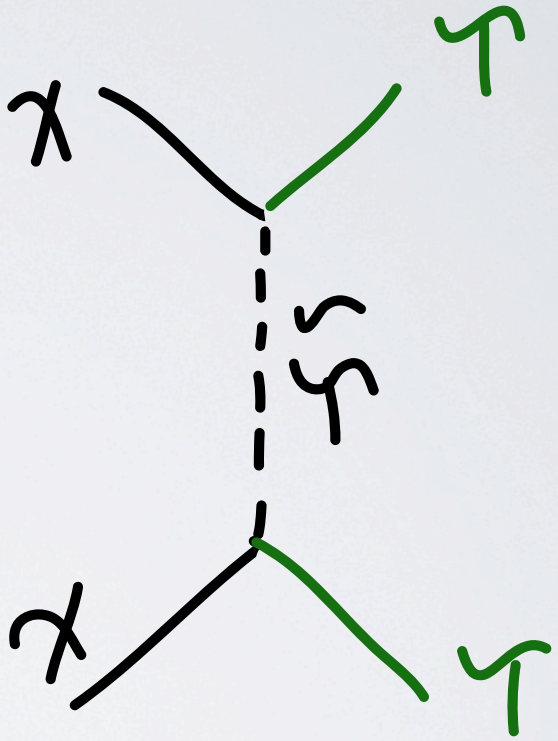


Hooper, NW, Xue '12

COMPLEMENTARITY

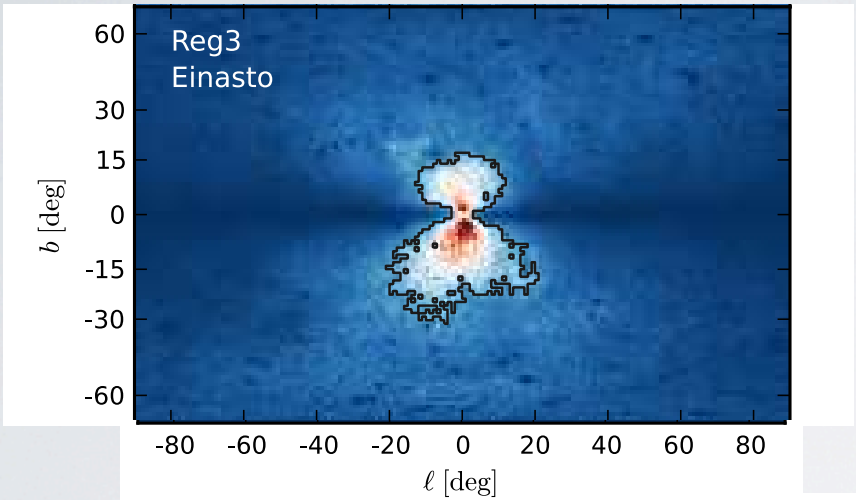


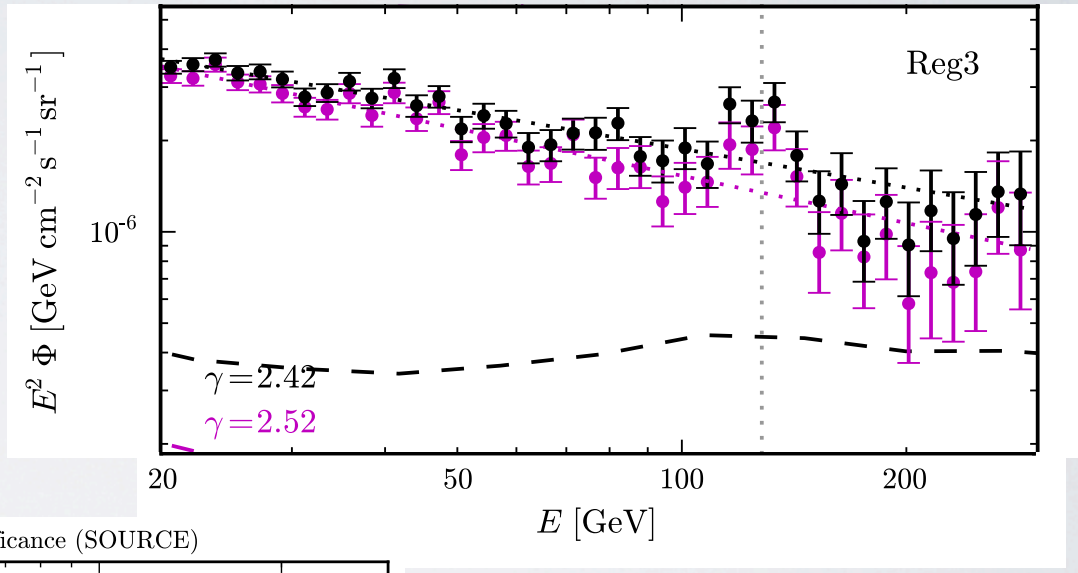
APEX/HPS/DarkLight
lepton jets @ LHC

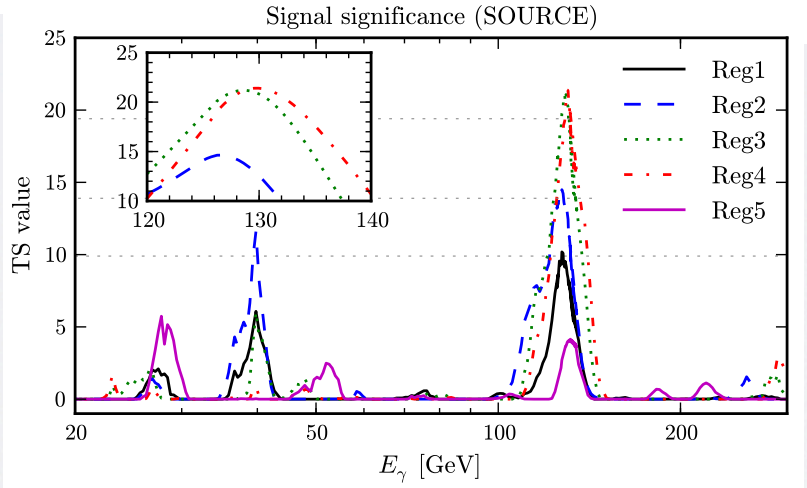


LHC

EXAMPLE III: A FERMI LINE



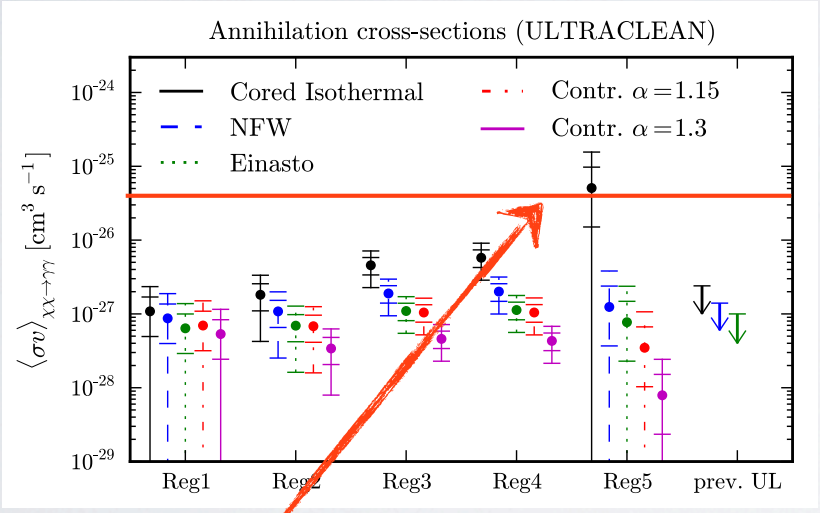




Weniger, '12; Bringmann et al '12; Finkbeiner + Su '12

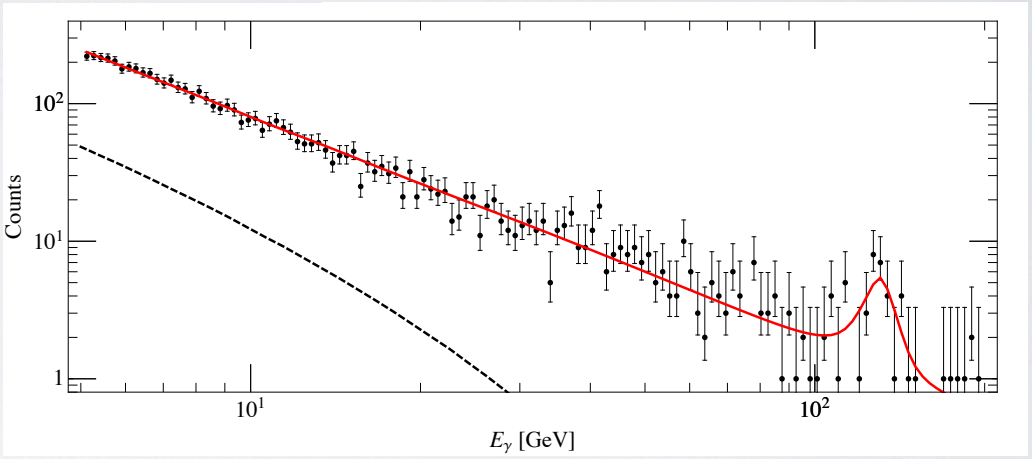
MODEL REQUIREMENTS

photon σ



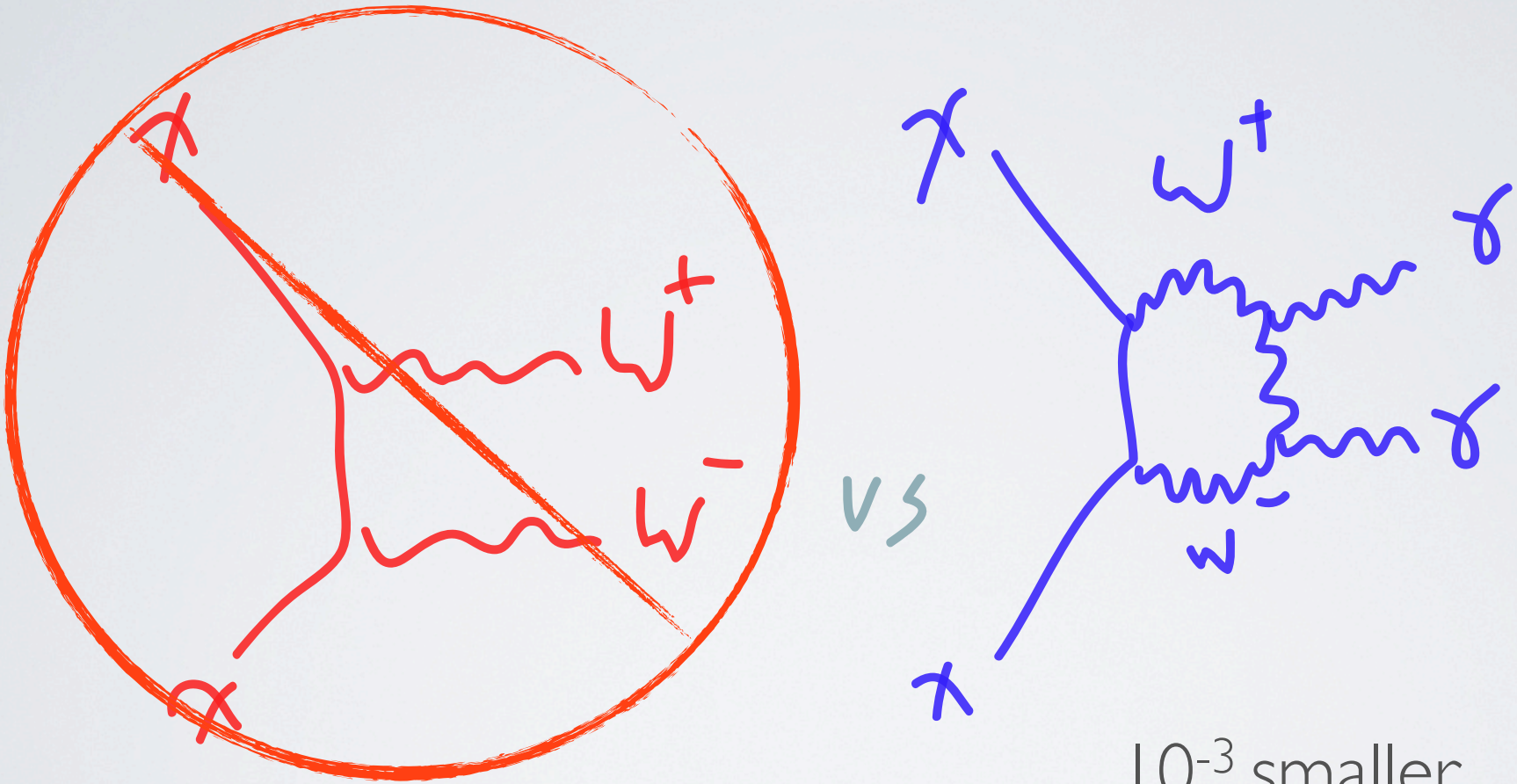
Relic Abundance

"other" σ (continuum)



Buchmuller, Garny; Cohen, Lisanti, Slatyer, Wacker; Cholis, Tavakoli, Ulio

CONTINUUM



10^{-3} smaller

these are really the same question

LESSON

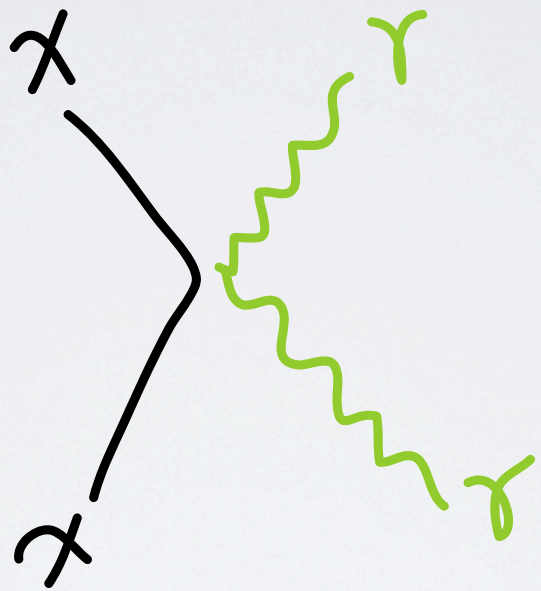
- There is not a lot of tree-level continuum annihilation if this is Dark Matter
- (I.e., the things in the loop are heavier than the WIMP)

MODELS FOR THE LINES

- ***Lots*** of models (Weniger - 116 citations)
- Simple approach: effective theory

SIMPLEST MODEL: RAYDM

$$\frac{1}{4\Lambda_R^3}\bar{\chi}\gamma_5\chi\left(c_1 B^{\mu\nu}\tilde{B}_{\mu\nu} + c_2 W^{\mu\nu}\tilde{W}_{\mu\nu}\right)$$



scale Λ_R ~ 500 GeV (really 300 GeV w/ EM coupling)

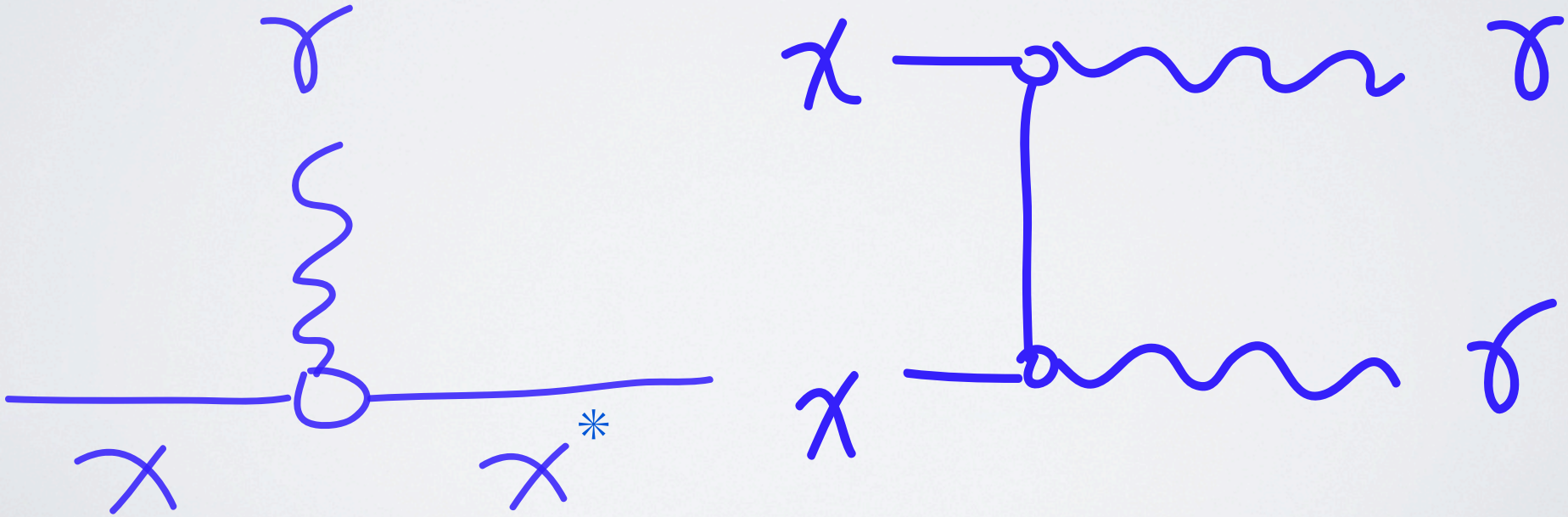
continuum not a problem

probably shouldn't be using the effective theory

2ND SIMPLEST: MIDM

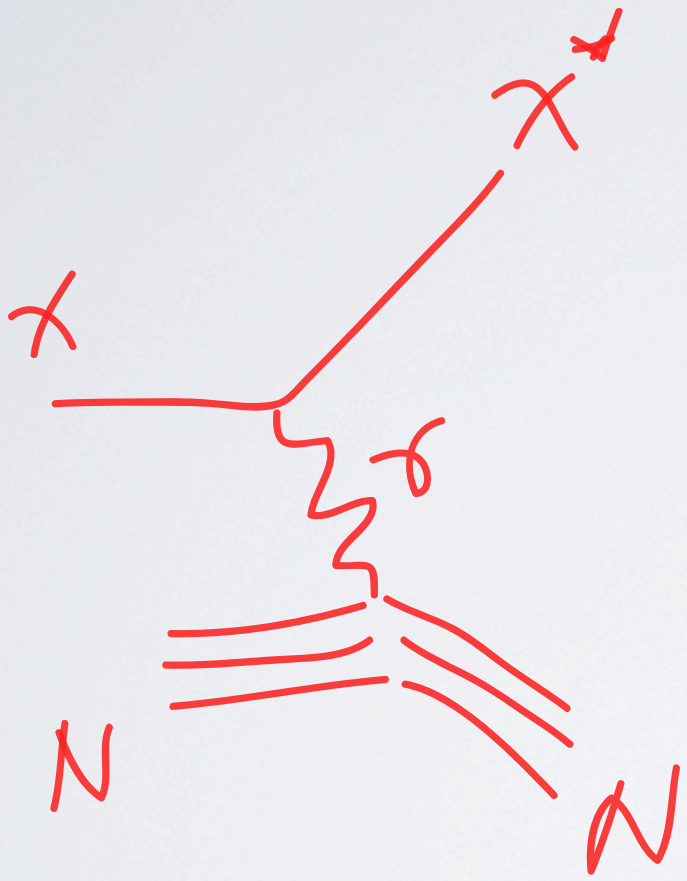
Chang, NW, Yavin '10

$$\frac{1}{\Lambda}\,\chi\,\sigma^{\mu\nu}\chi^{*}\,B_{\mu\nu}$$

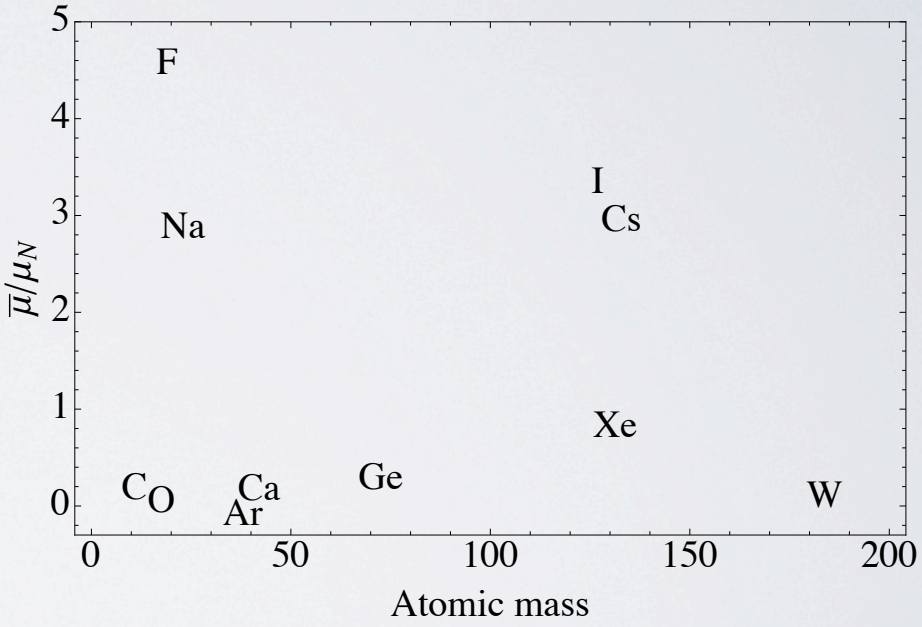


Goodman et al '10

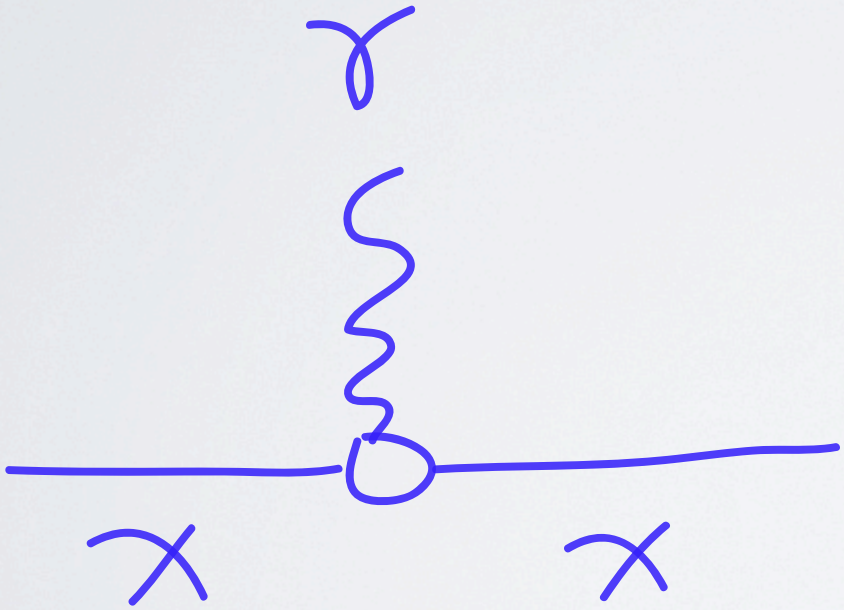
MAGNETIC INELASTIC DM

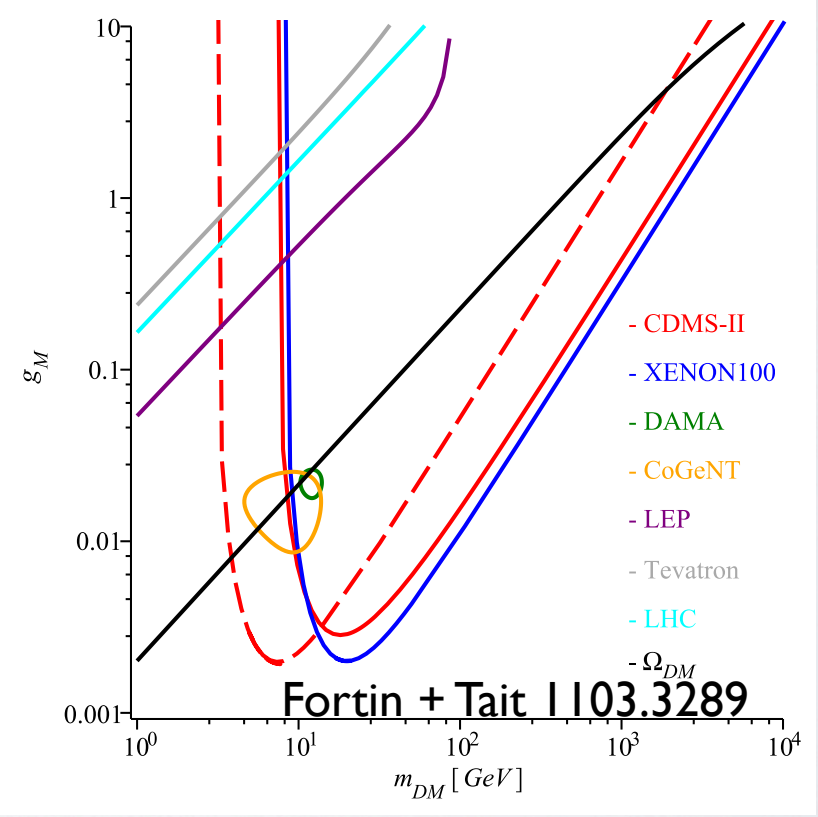


$$\frac{\mu_{\chi N} v^2}{2} > \delta$$



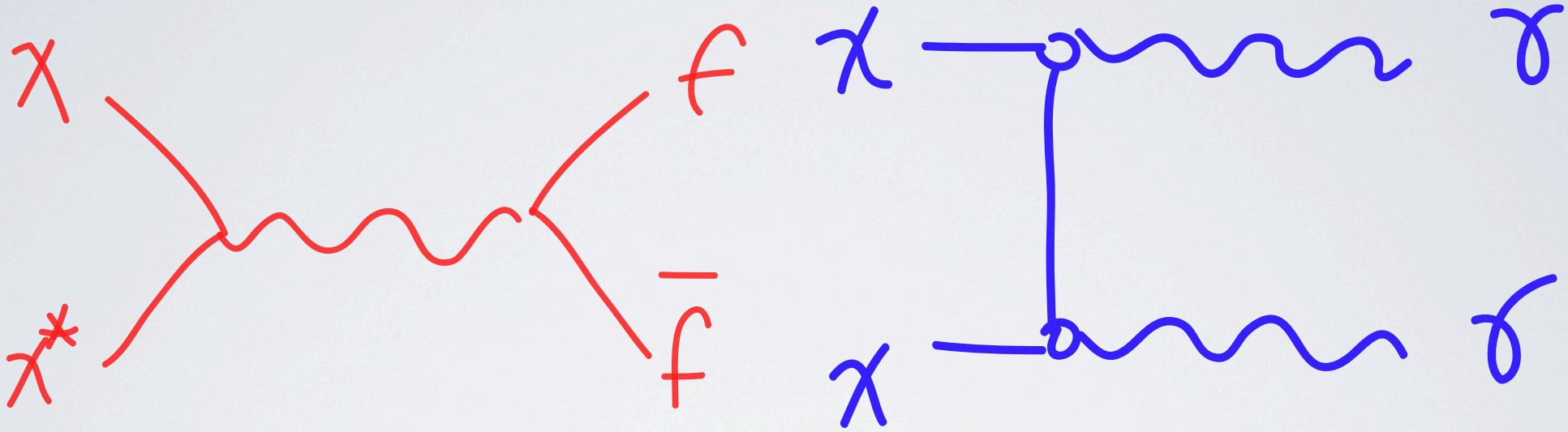
MUST BE INELASTIC





(pseudo) Dirac fermion with magnetic dipole

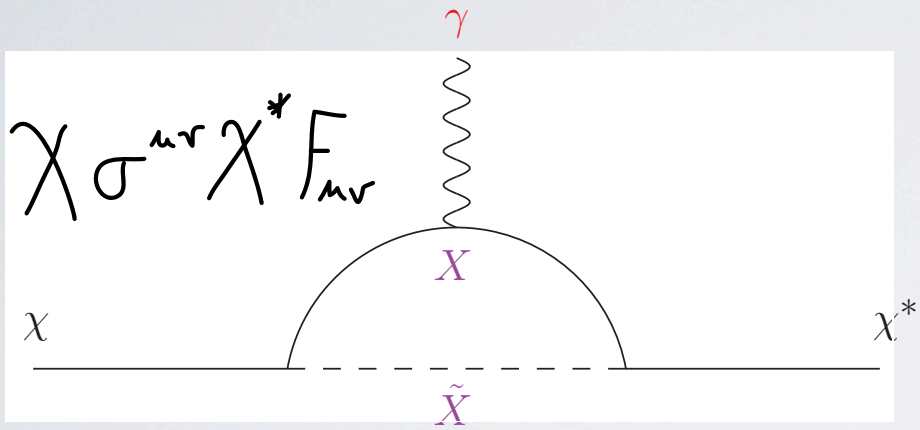
DIPOLE FREEZEOUT



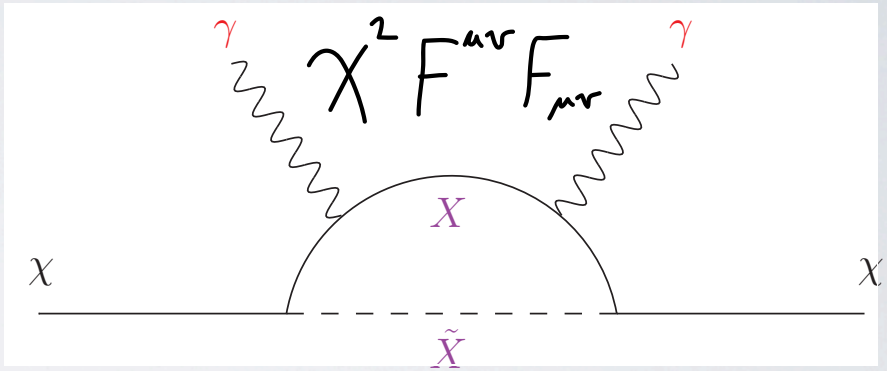
Want dipole ~ 1/TeV for relic abundance
Rate O(10) too low

Option: tune splitting of excited state (~20 GeV)
to suppress early universe Tulin, Yu, Zurek 1208.0009

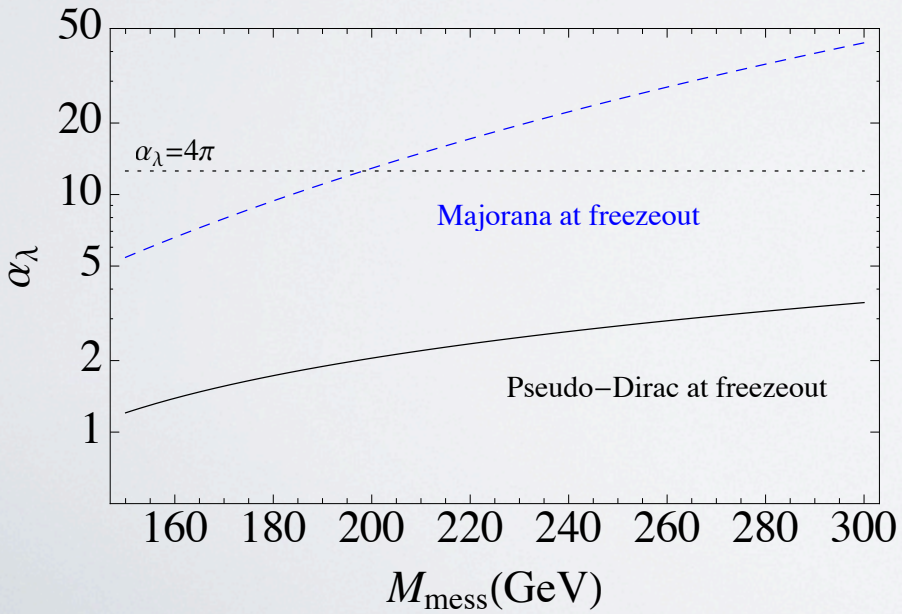
UV COMPLETIONS

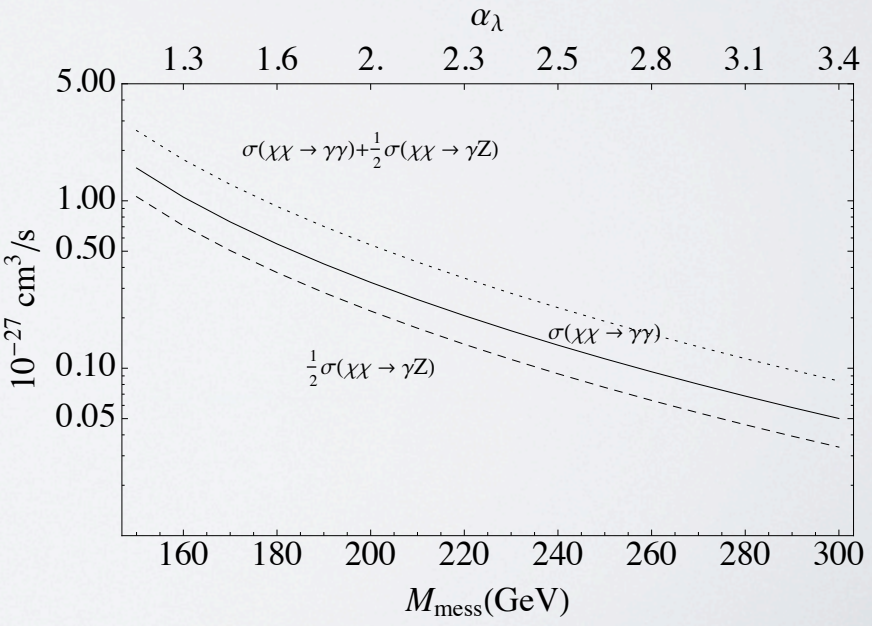


(a)

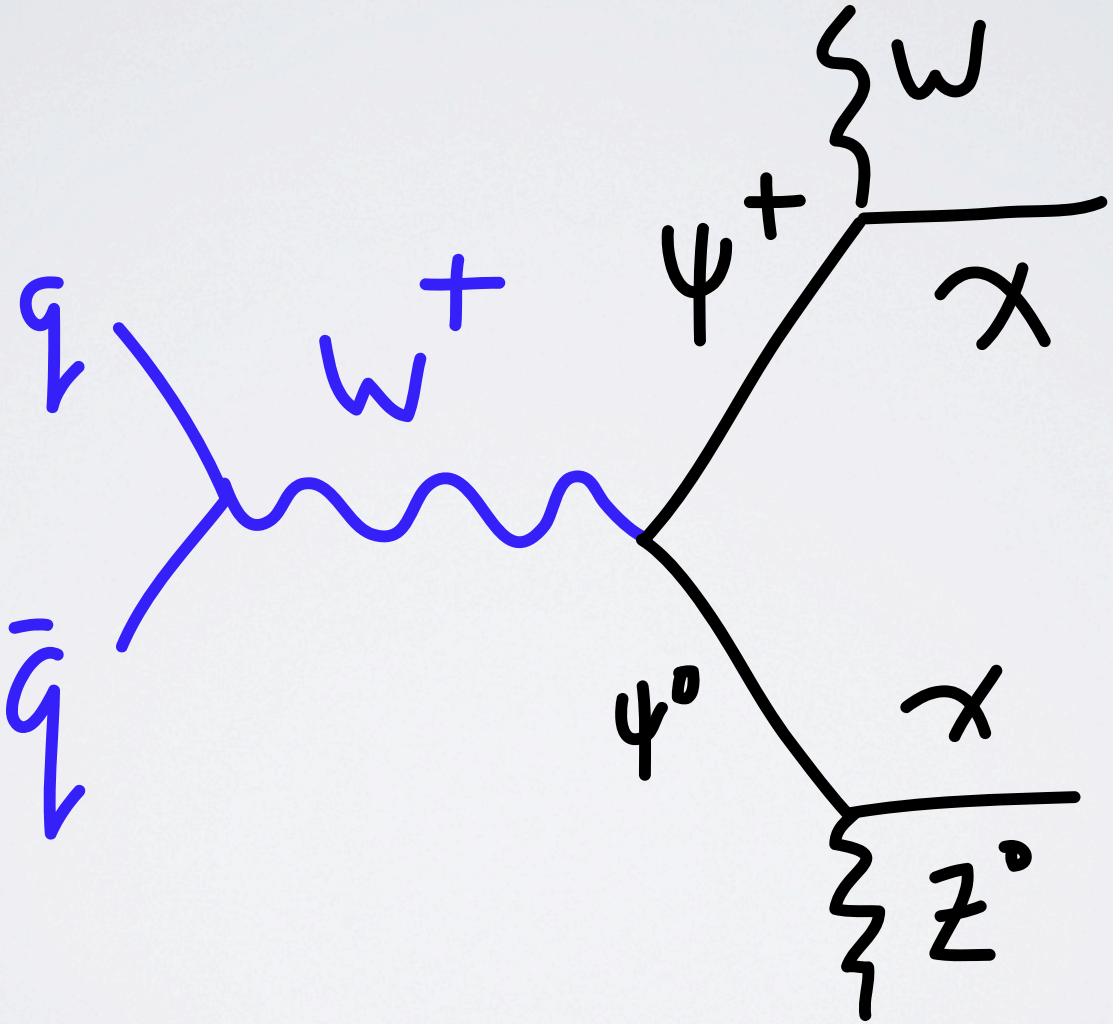


(b)

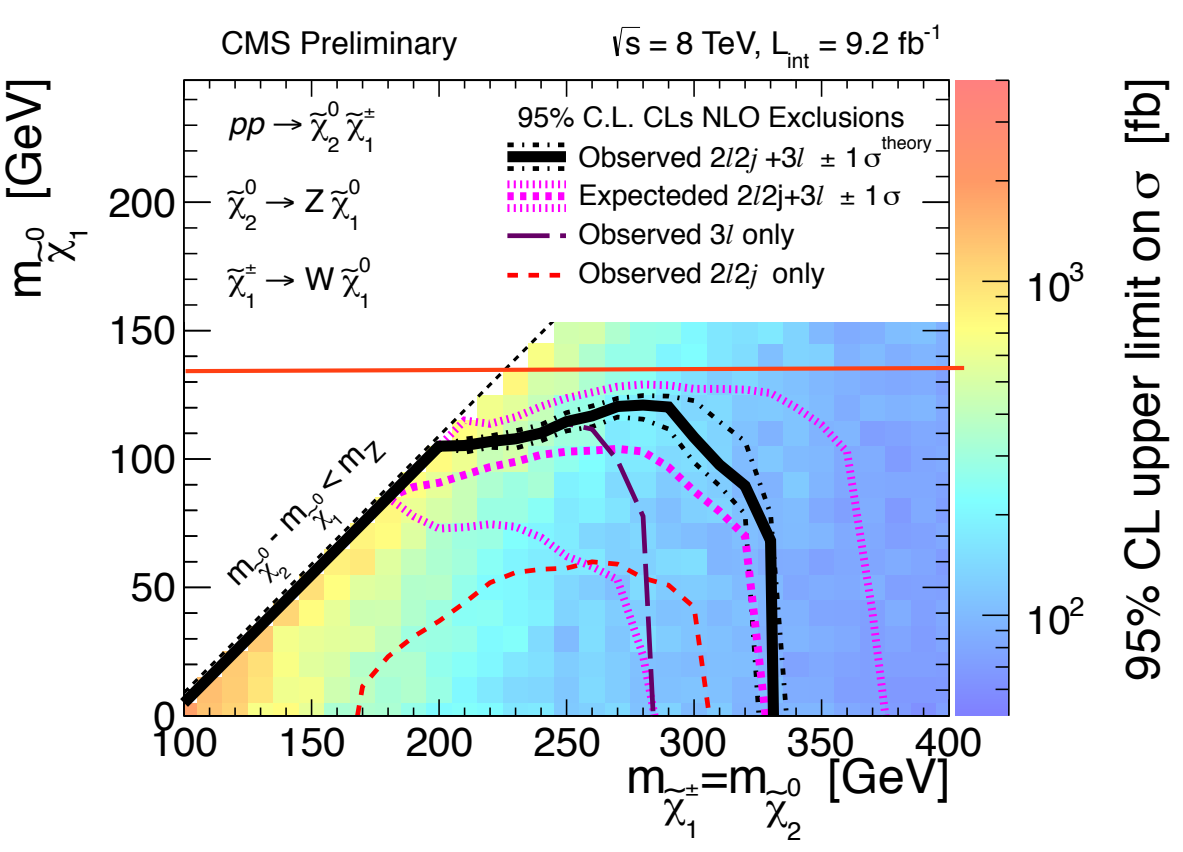




HOW TO LOOK?



DISCOVERING LIGHT CHARGED STATES

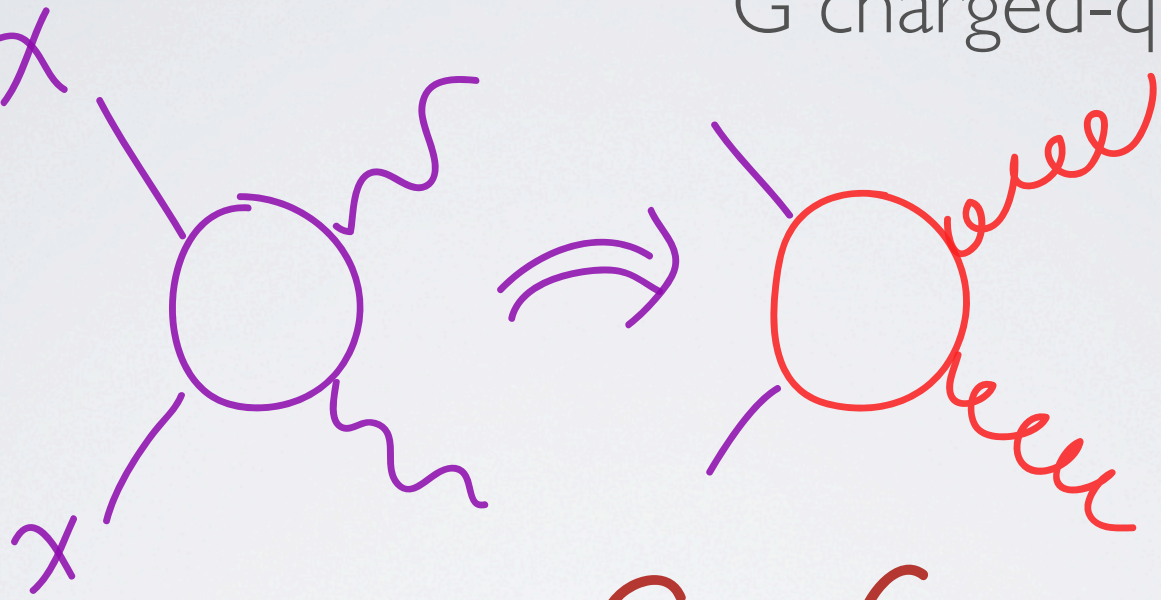


(If ψ stable then only stubs)

ELASTIC WIMPS

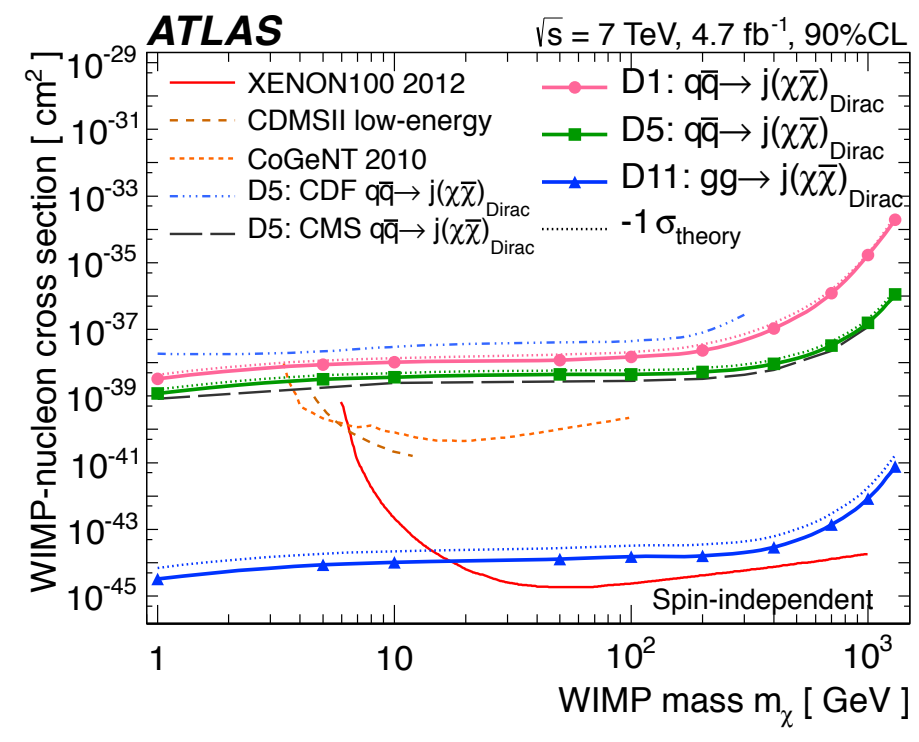
G charged-EW fields

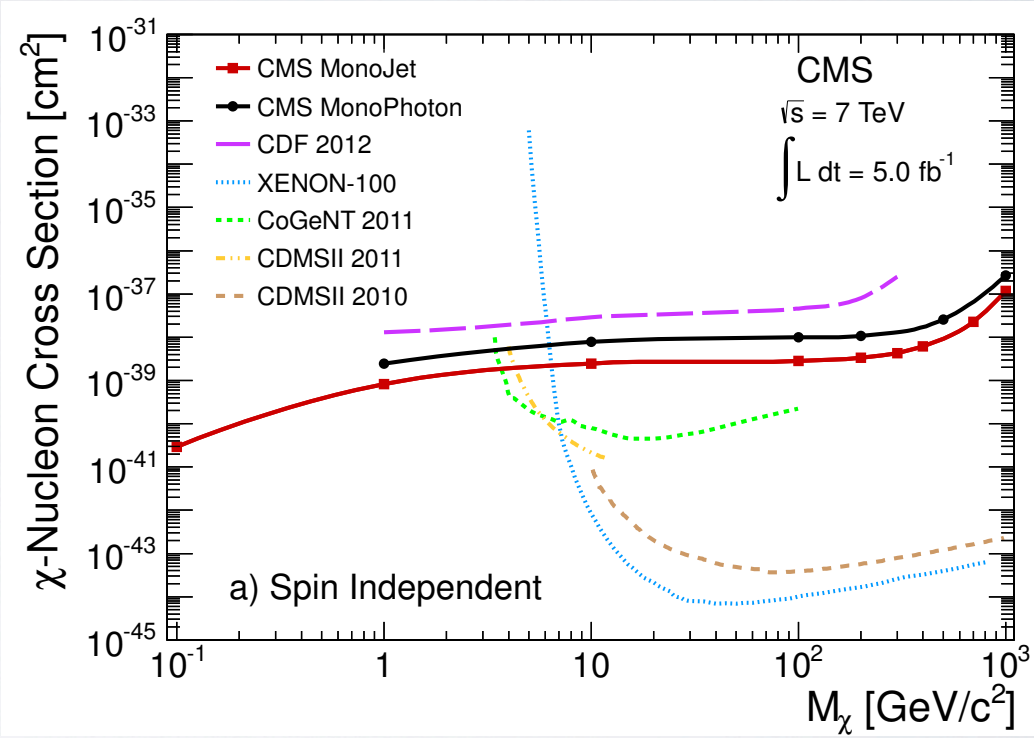
G charged-quarks



$$\frac{\alpha_s}{\Lambda^3}\chi\chi G_{\mu\nu}G_{\mu\nu}$$

MONOJETS FROM G-QUARKS





should be ~x2 heavier

CONCLUSIONS

- The theory ⇔ experiment interplay is very healthy in the DM community
- "Normal" models of DM are an excellent jumping off point, but we should understand our prejudices
  - If you are more flexible, gymnastics becomes merely stretching
- Model details matter: complementarity, extensions to broader parameters, tensions with other experiments often require going beyond EFT
- Need to stop knocking down straw man models

CONCLUSIONS

- Don't fear crazy models - they may provide guidance of how to look for DM (what if it isn't a WIMP?)
- The craziest thing would be to get too confident that we actually know what we're talking about

Thanks!

Don’t fear crazy looking models!