New Priors in Hidden Physics

Neal Weiner
Cosmic Visions Workshop
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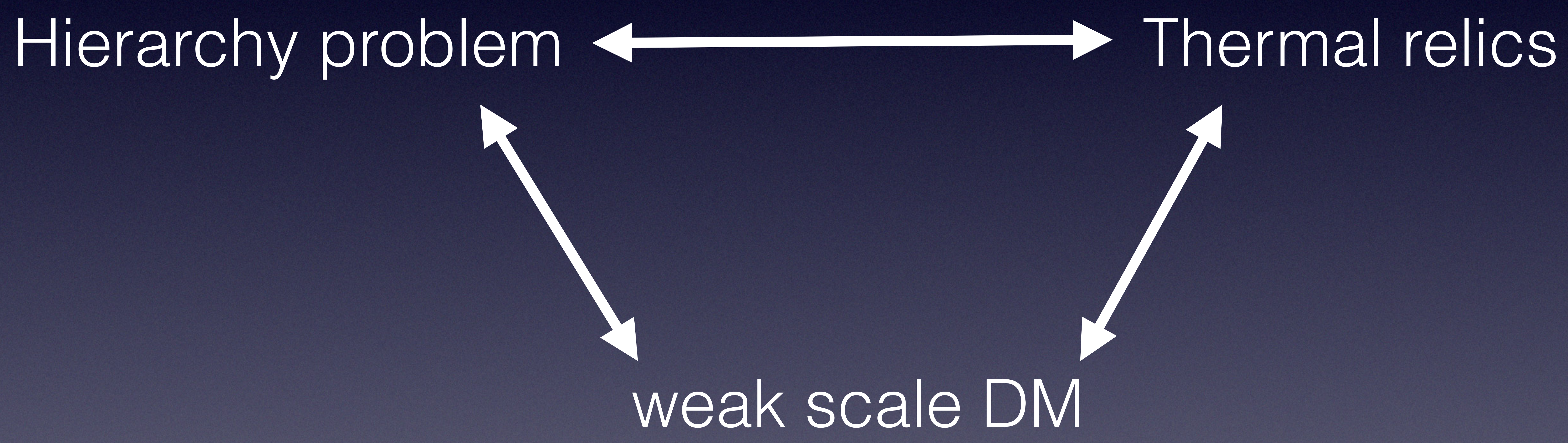
The era of strong priors 199x~2016

- Hierarchy problem
- Weak scale DM
- Questions of the SM (unification, neutrino mass, strong CP…)

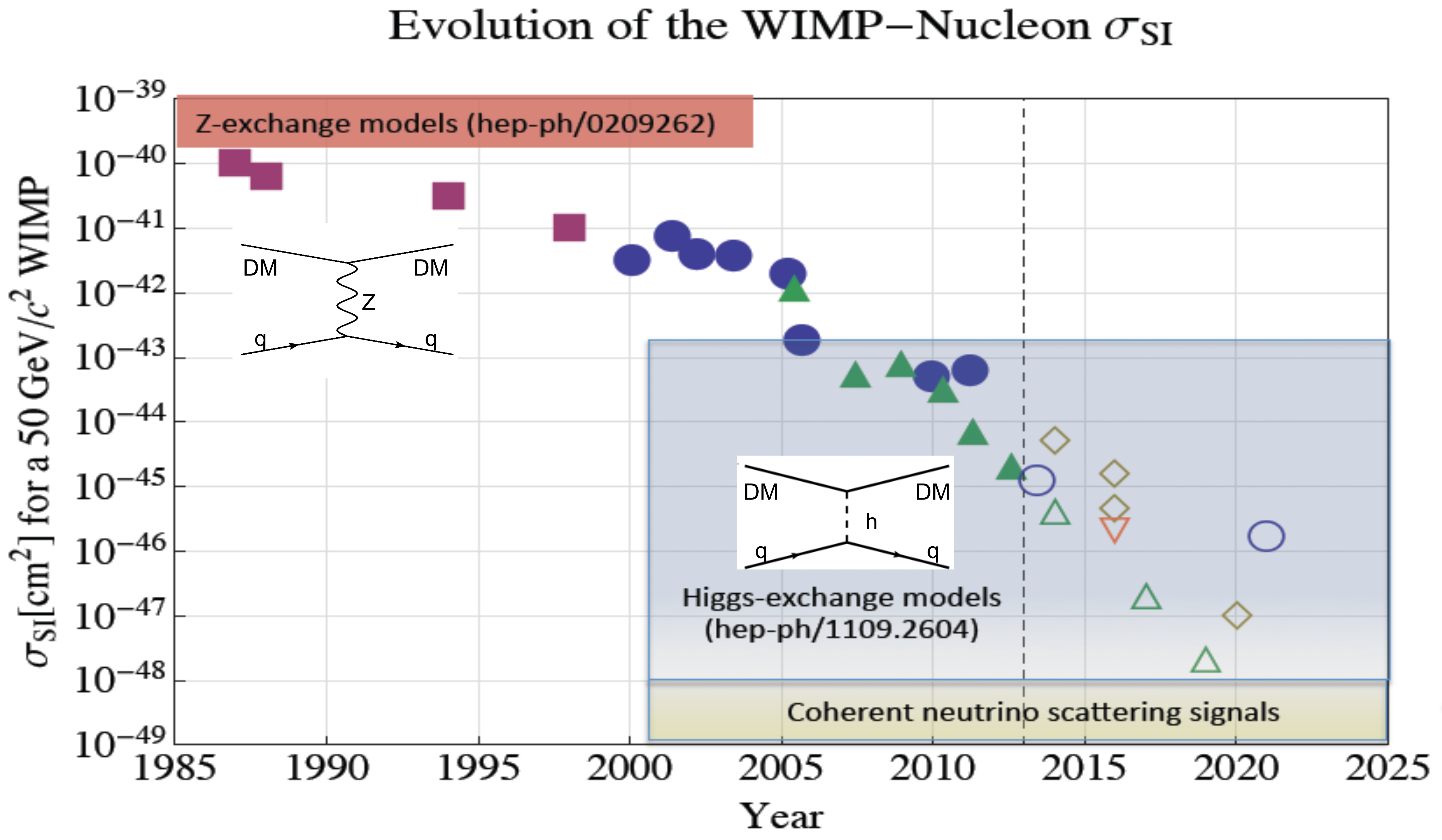
Dark matter in the era of strong priors



“WIMP” miracle made (and makes) a motivating case

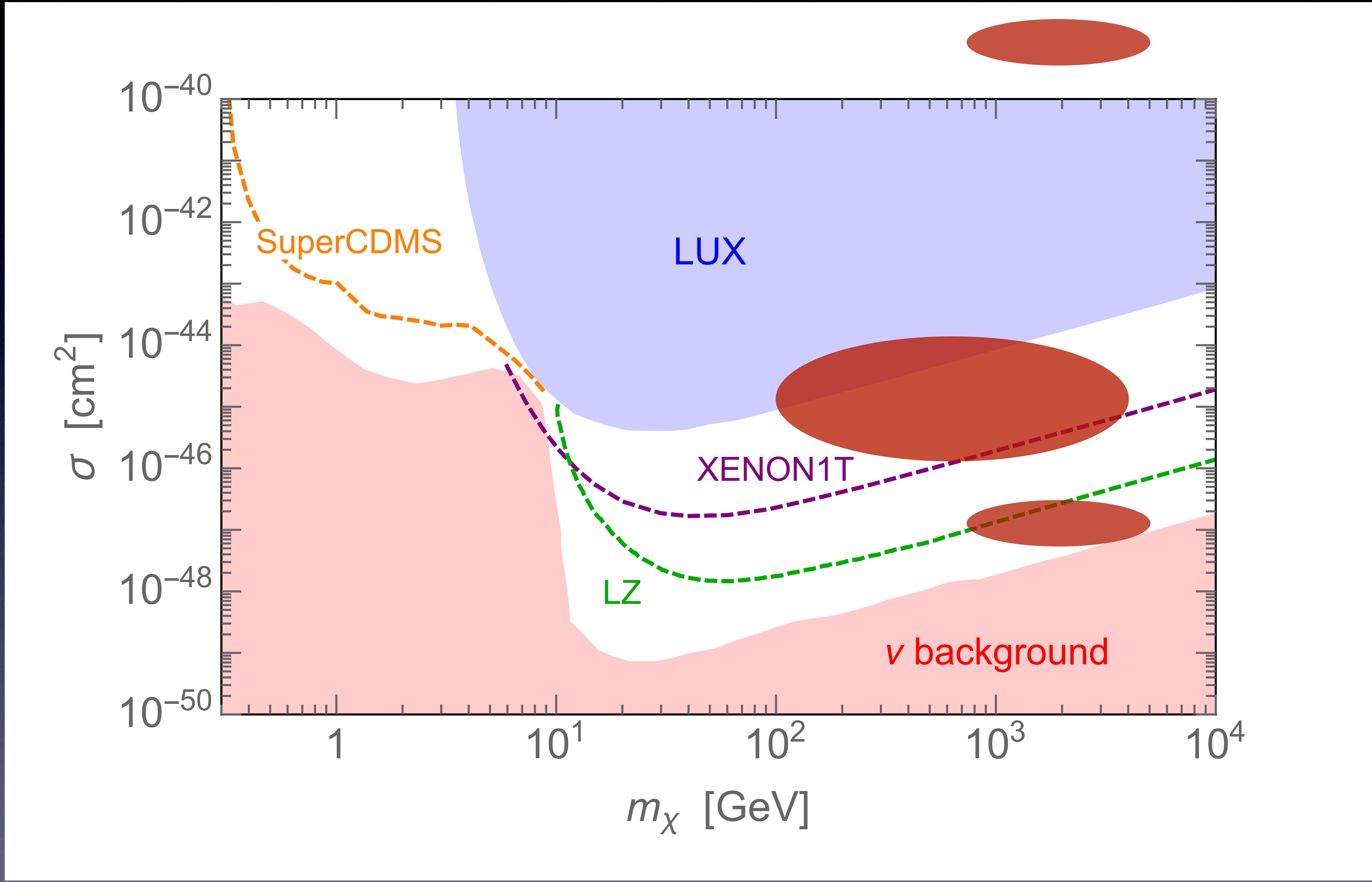
breaking down priors

rapid progress in WIMP search



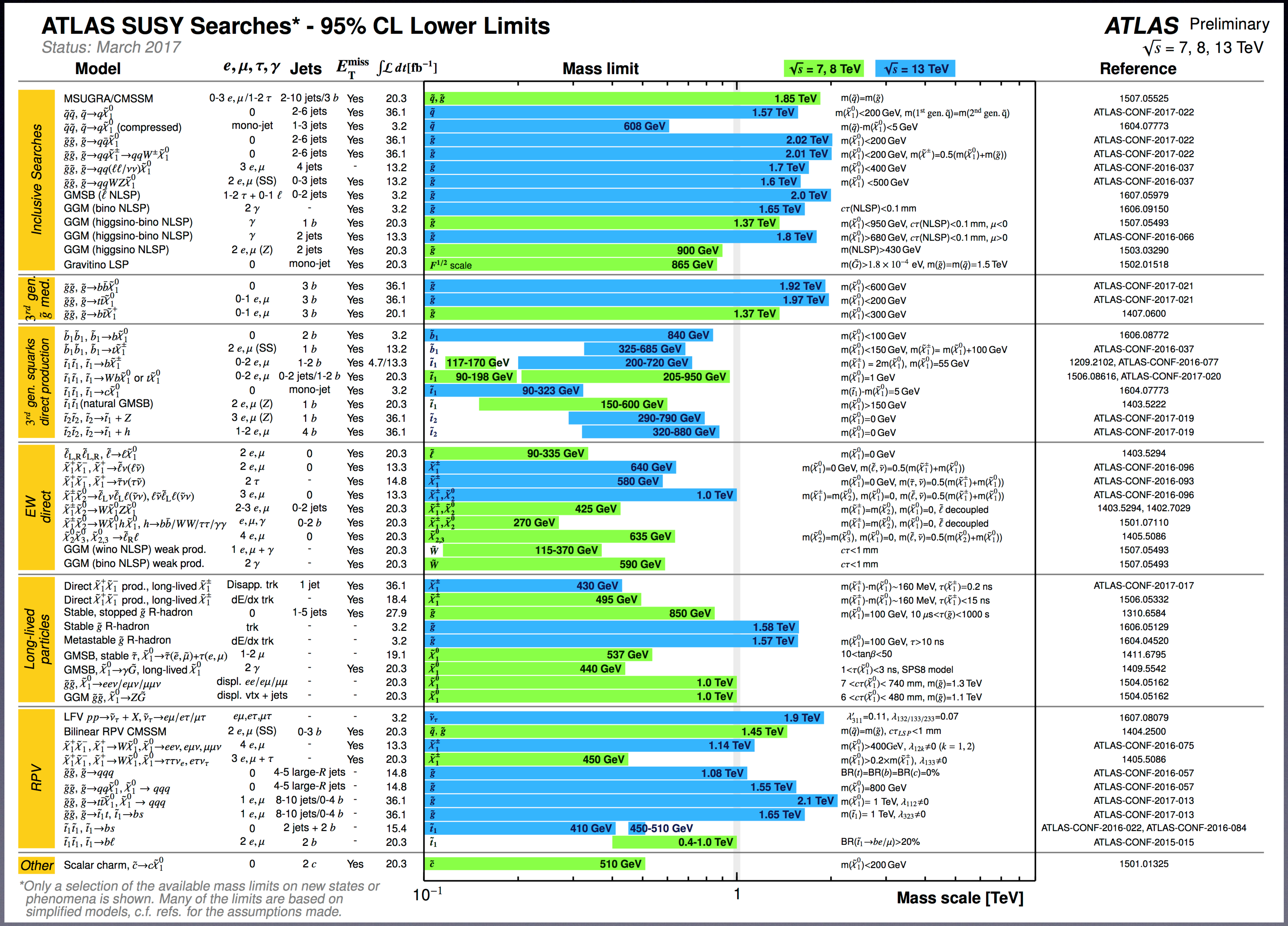
slide from J Feng

Plot from Josh Ruderman



No sign of WIMPs so far

LHC - no sign of weak scale BSM



Neutrinos/GUTs

- Neutrino mass guess: few x 10^{-3}
- Neutrino mixing guess: small (CKM)
- Proton decay?

We have pursued scenarios under very strong assumptions

- Where do we go from here?

Moving beyond the era of strong priors

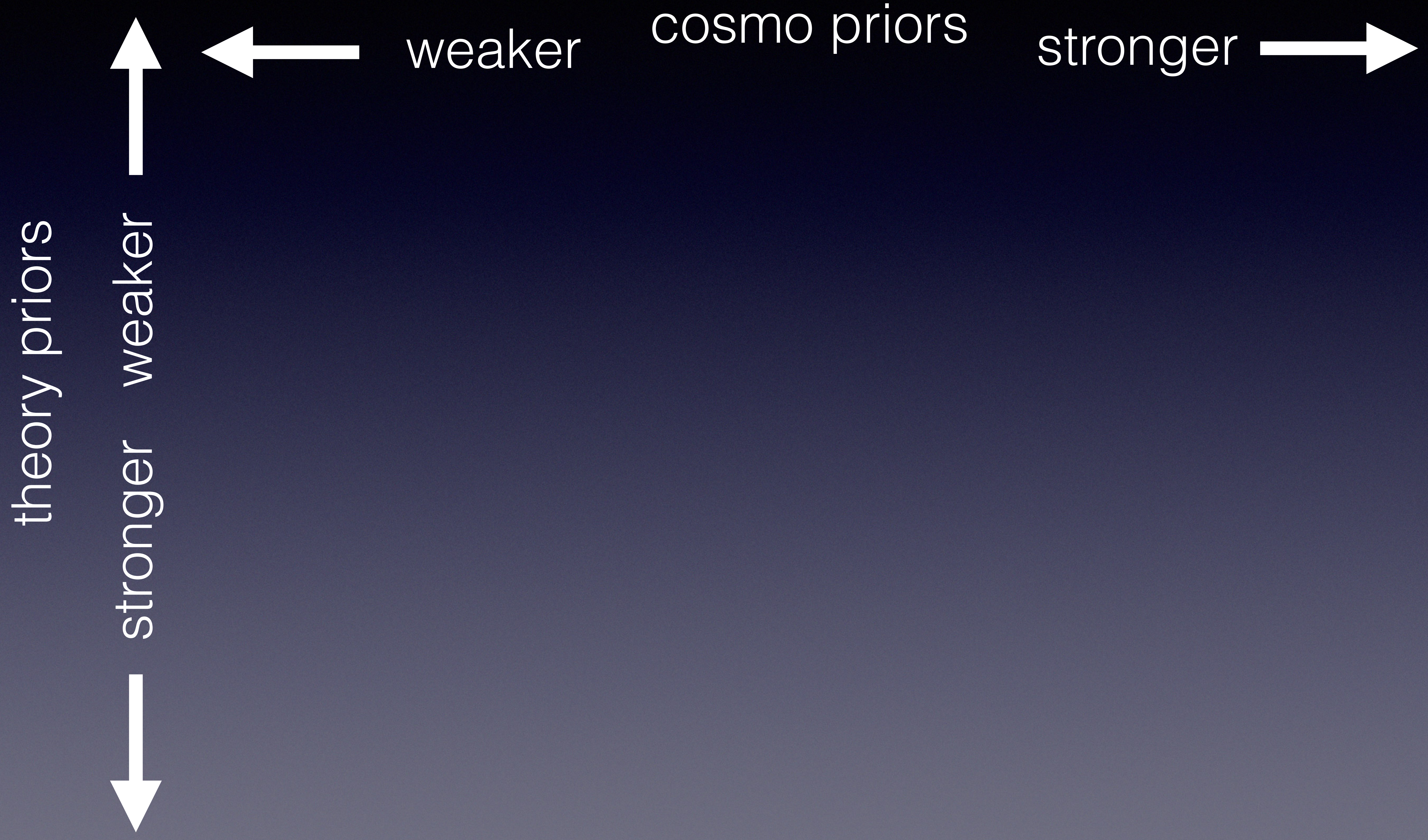
- No priors?
- Weak priors?
- New priors?

We know there is physics beyond the standard model (DM)!

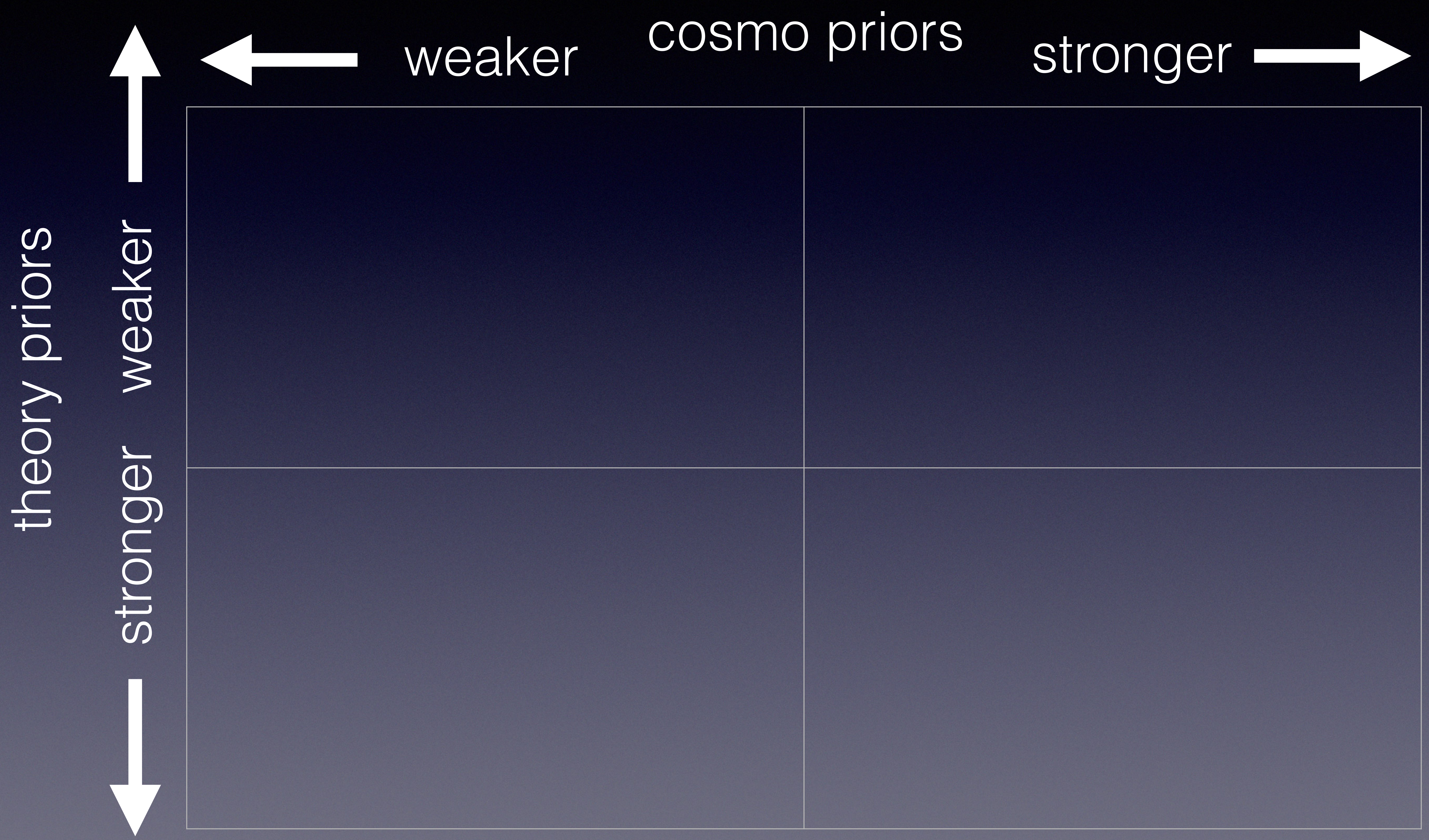
Example: axion

- weak priors: EFT of scalars and pseudoscalars coupling to SM
- moderate priors: QCD axion
- strong priors: QCD axion + standard cosmology

The Priorhedron



The Priorhedron



The Priorhedron

cosmo priors: weaker ← → stronger

theory priors: weaker ↑ ↓ stronger

	cosmo priors: weaker	cosmo priors: stronger
theory priors: weaker	EFT couplings to new physics	
theory priors: stronger		

The Priorhedron

theory priors \ cosmo priors	weaker	stronger
weaker	EFT couplings to new physics	thermal and quasi thermal relics, scalars from EUPT
stronger		

The Priorhedron

cosmo priors: ← weaker | stronger →

theory priors: ↑ weaker | stronger ↓

theory priors \ cosmo priors	weaker	stronger
weaker	EFT couplings to new physics	thermal and quasi thermal relics, scalars from EUPT
stronger	QCD axions w/o cosmology; scale-free DM	

The Priorhedron

← weaker — cosmo priors — stronger →

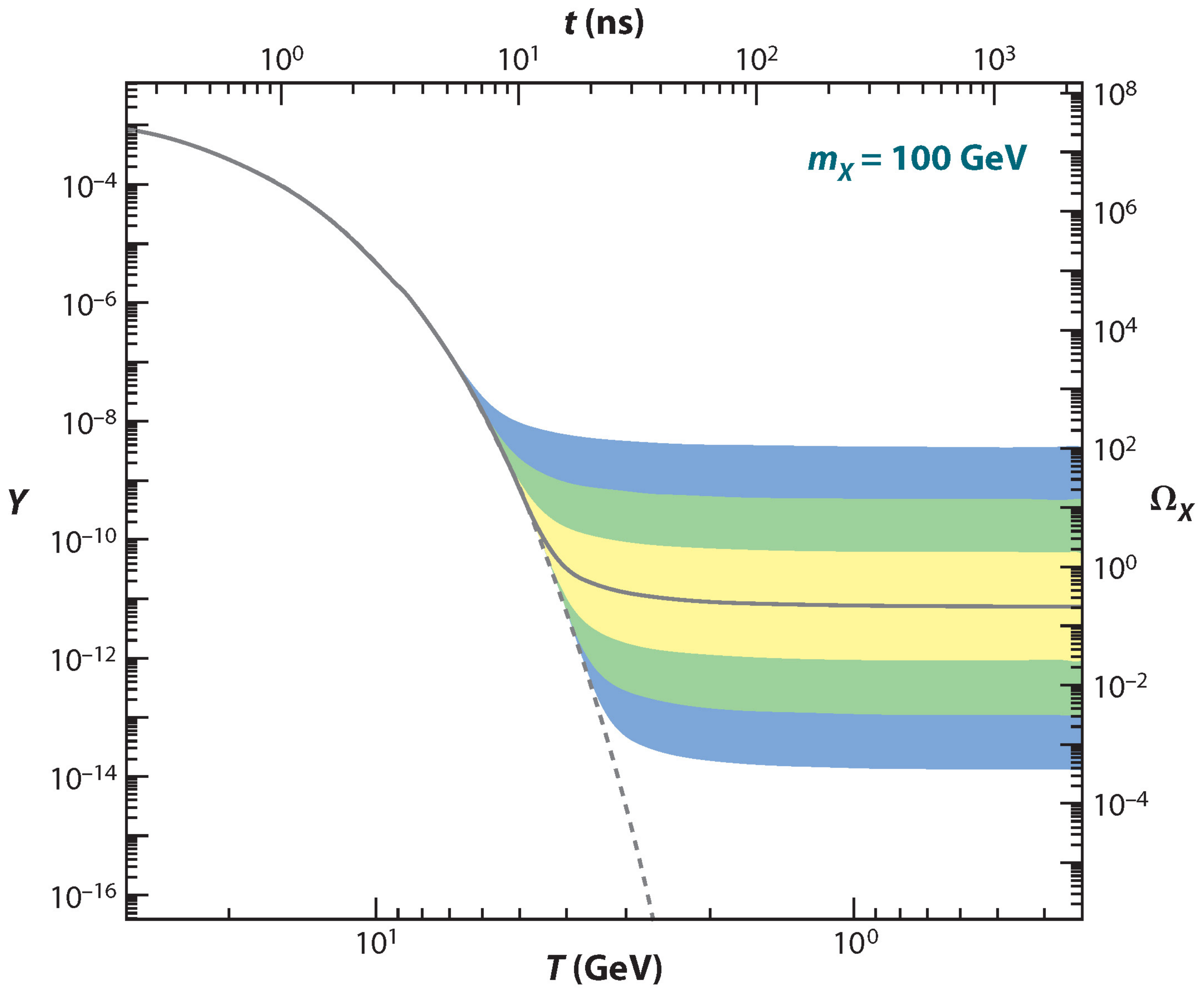
theory priors: ↑ weaker / stronger ↓

theory priors \ cosmo priors	weaker	stronger
weaker	EFT couplings to new physics	thermal and quasi thermal relics, scalars from EUPT
stronger	QCD axions w/o cosmology; scale-free DM	WIMPs; "classic" PQ axions

BSM in the era of moderate priors

- Opportunity to ask broader questions
- Can't simply be fishing expedition (although IMHO a certain amount of cost effective fishing is important)
- Take one step back on some prior axis and find target regions
    - e.g., consider a thermally connected particle
    - a broader class of axion like particles

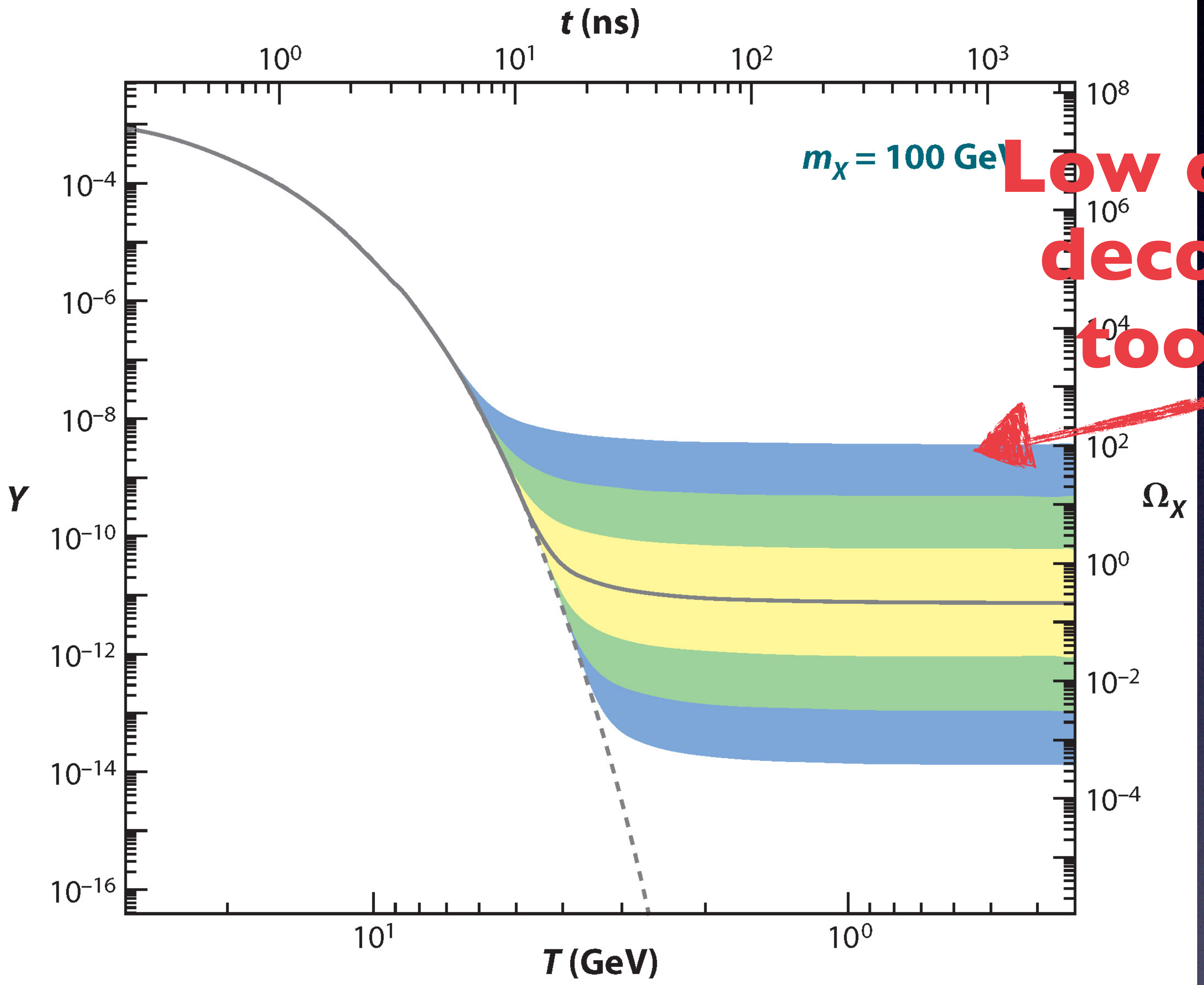
The story of the WIMP



For a thermal relic, you learn precisely one number, namely the annihilation cross section

$$< \sigma v >_{ann} \approx 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{sec}^{-1} \approx \frac{\alpha^2}{(200\mathrm{GeV})^2}$$

The story of the WIMP



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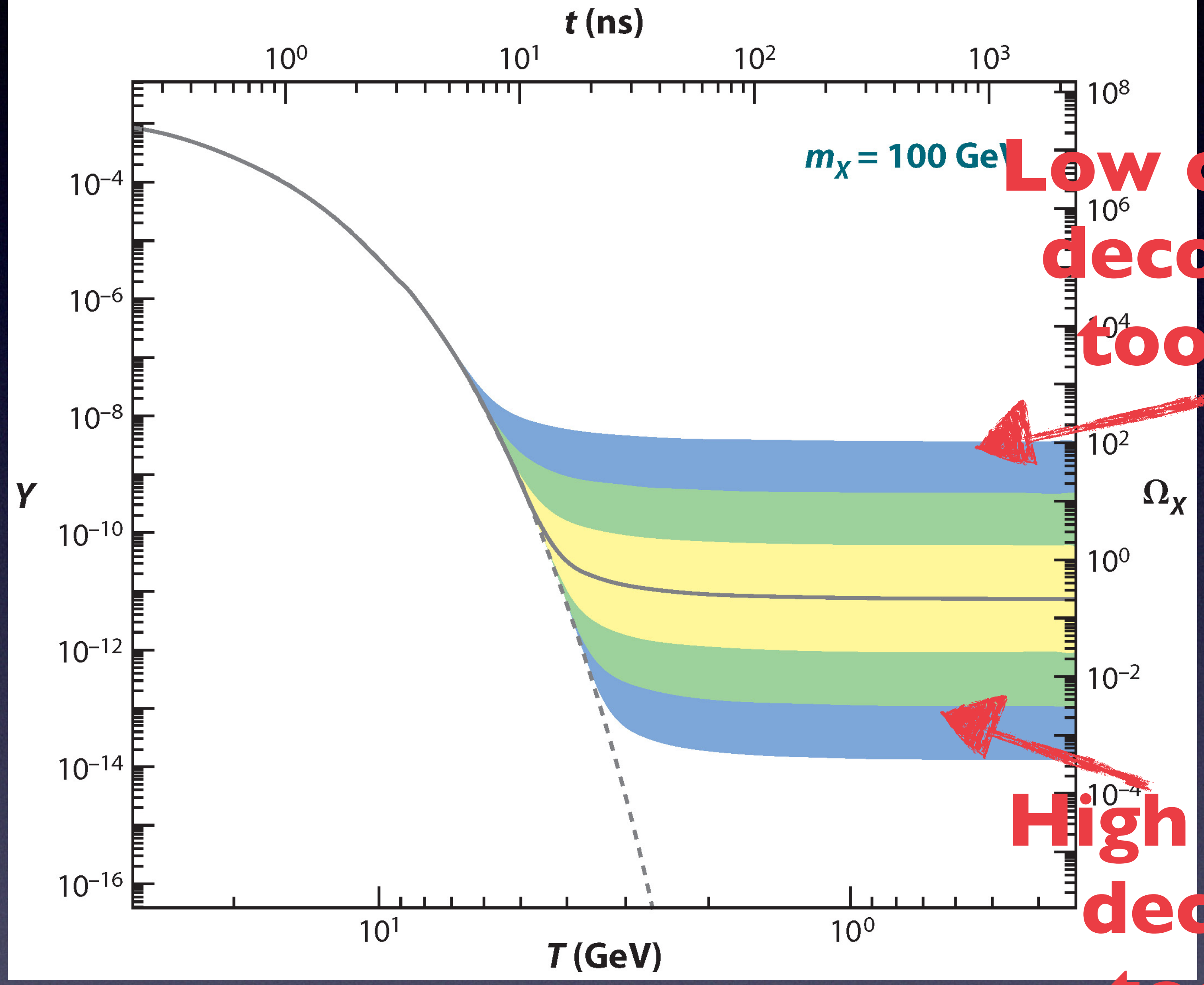
$$
\begin{aligned}
< \sigma v >_{ann} &\approx 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{sec}^{-1} \\
&\approx \frac{\alpha^2}{(200 \mathrm{GeV})^2}
\end{aligned}
$$

The story of the WIMP



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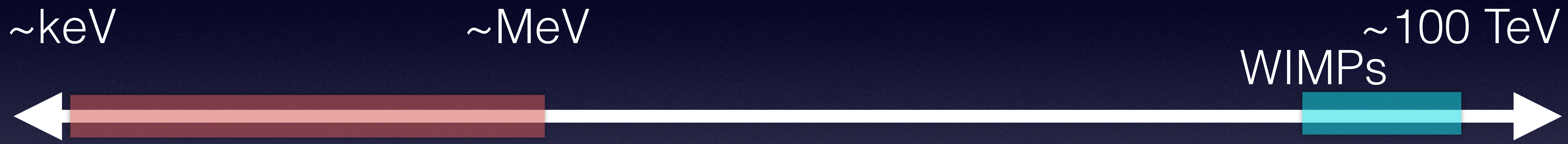
Broadening the scope



structure "bound":
DM not enough SSS
if $T_{DM} \sim T_{SM}$

BBN "bound"
no new relativistic
DOF at BBN
if $T_{DM} \sim T_{SM}$

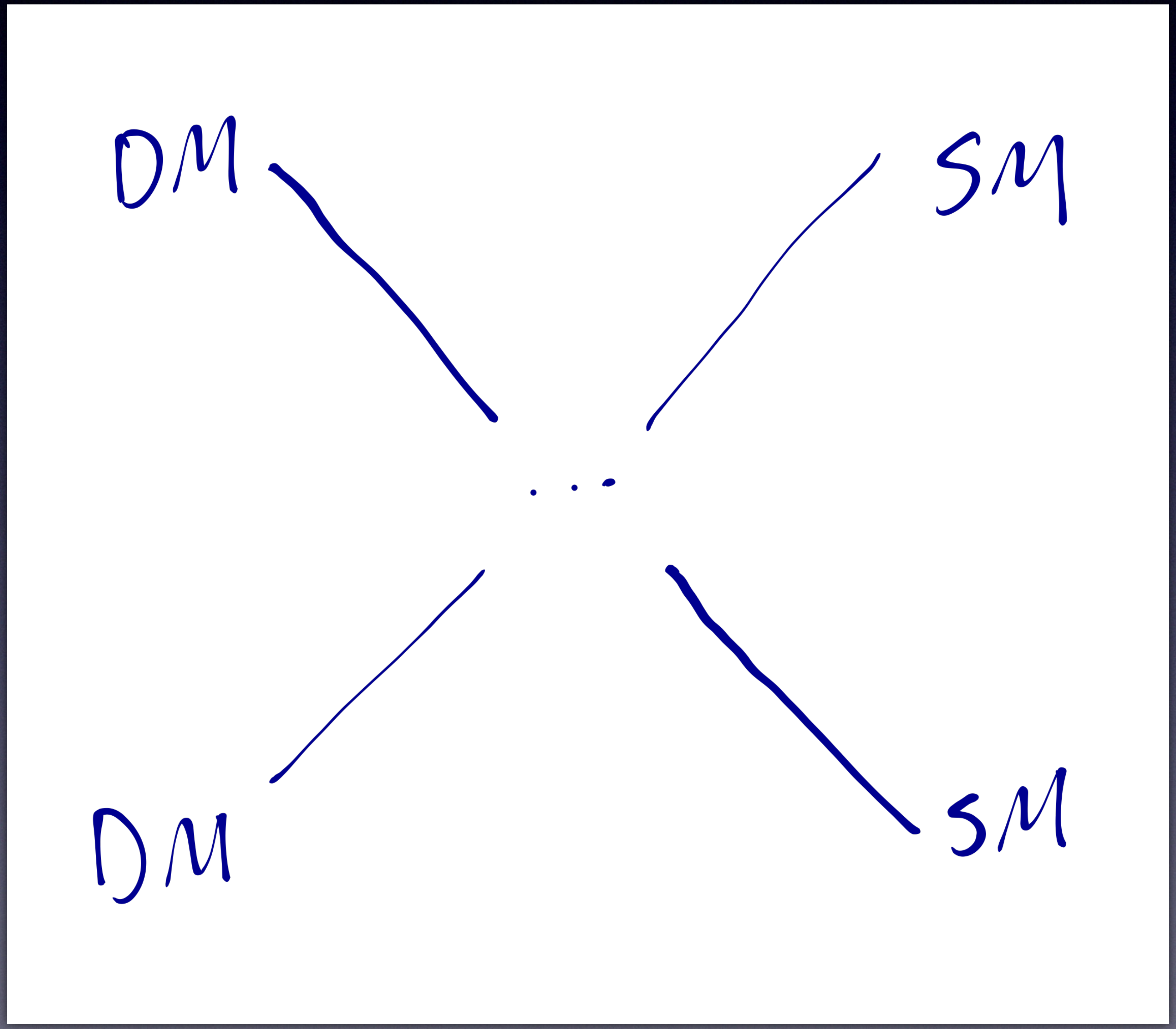
unitarity bound:
too much DM

Huge range of possibilities from keV to GeV scale

WIMP complementarity

cosmic rays (indirect)

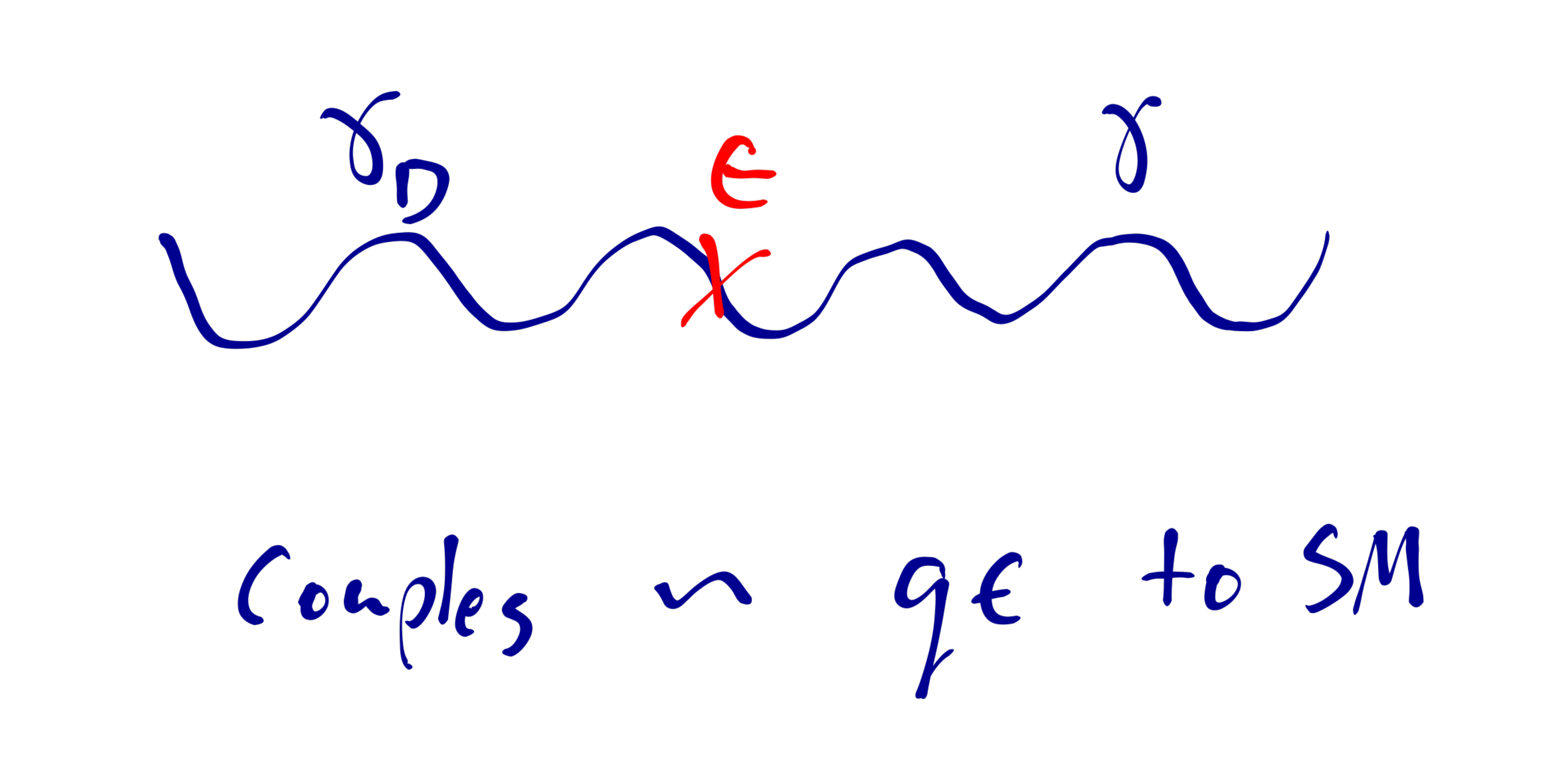
nuclear recoils (direct)



colliders (production)

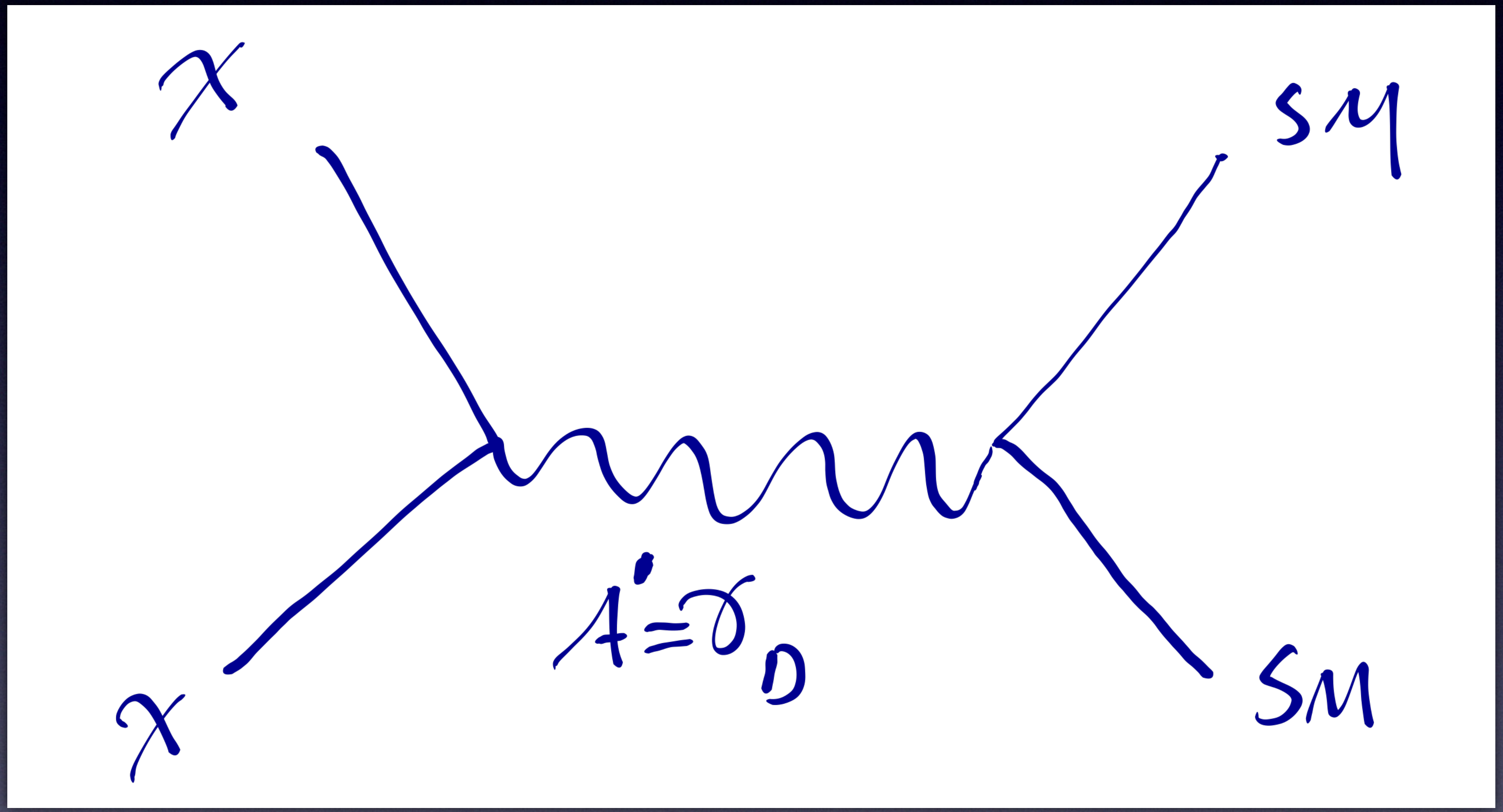
Coupling and decoupling a light particle

A light DM particle needs a new interaction to stay in equilibrium

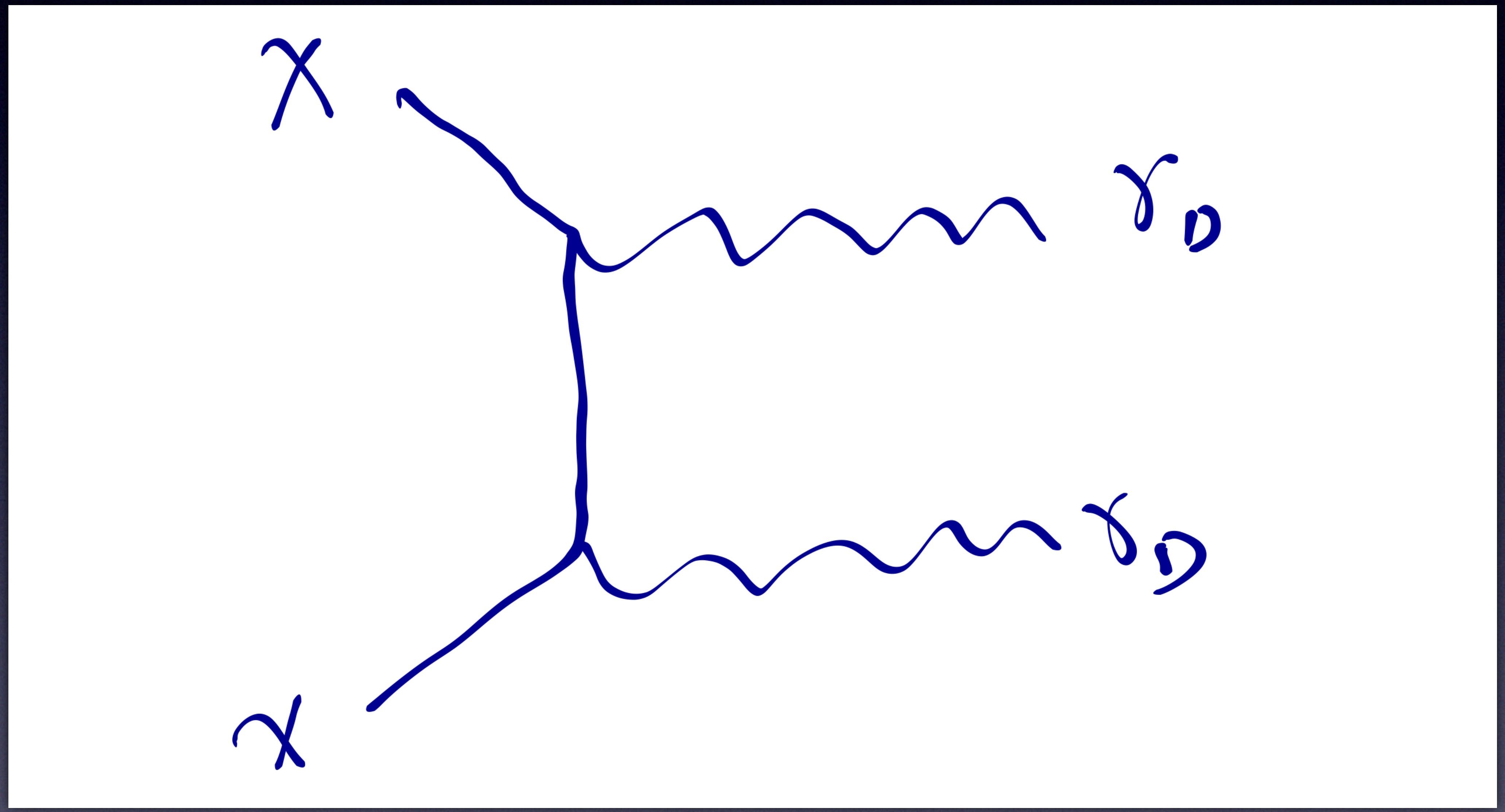


Simple example a “dark photon” - can naturally be very weakly mixed

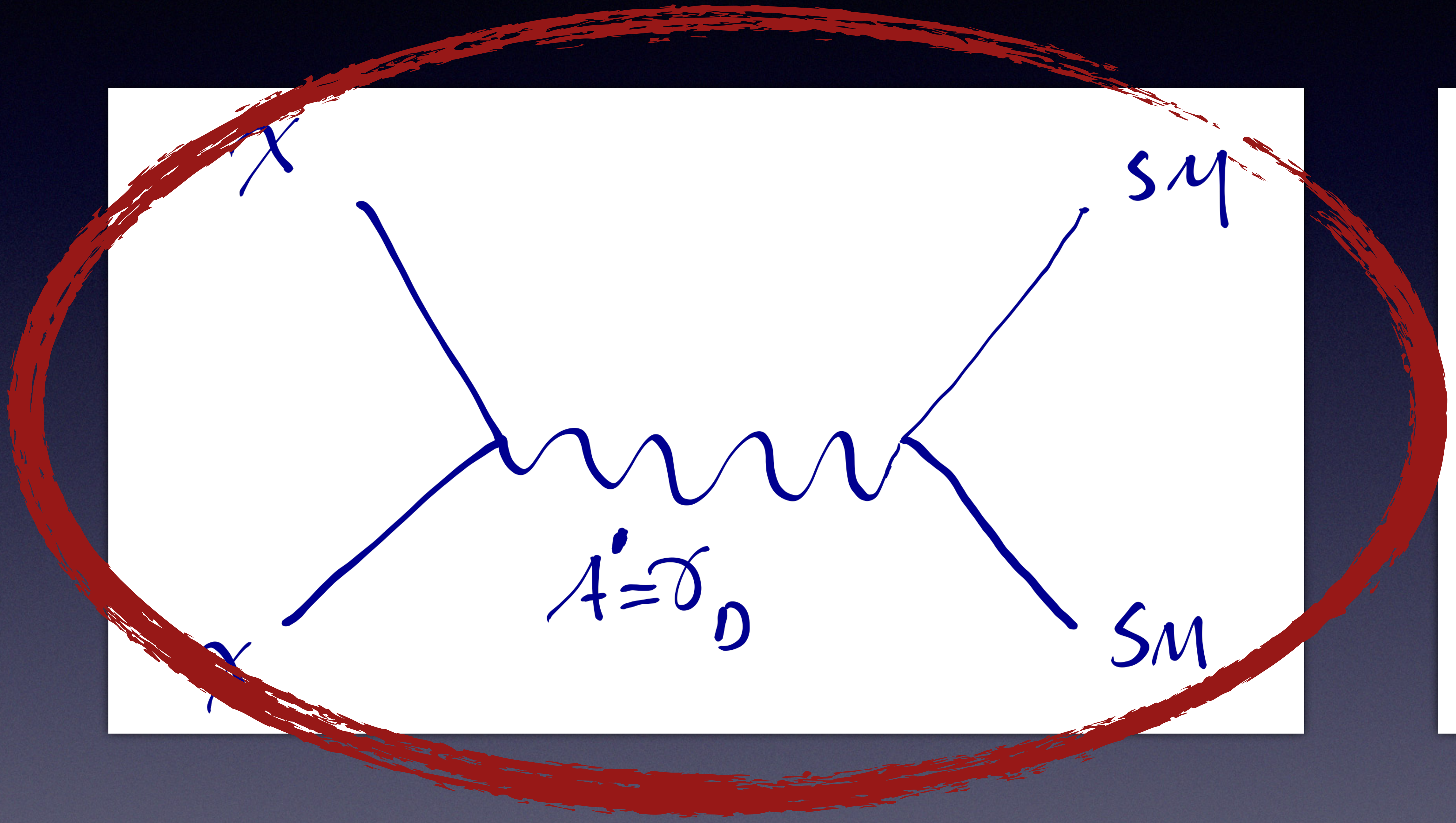
Holdom; Boehm + Fayet



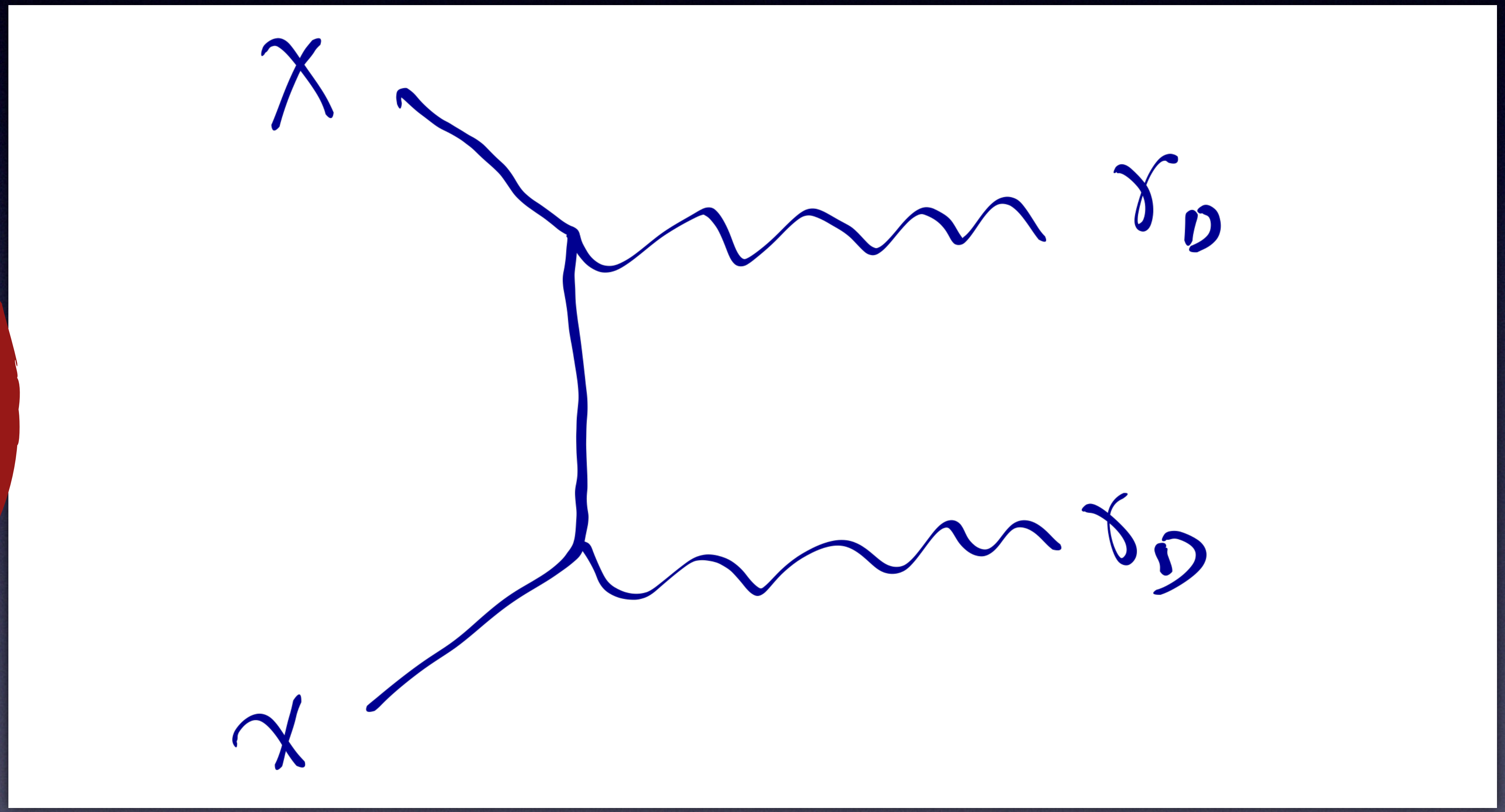
SM Annihilation



Hidden Sector Annihilation



SM Annihilation

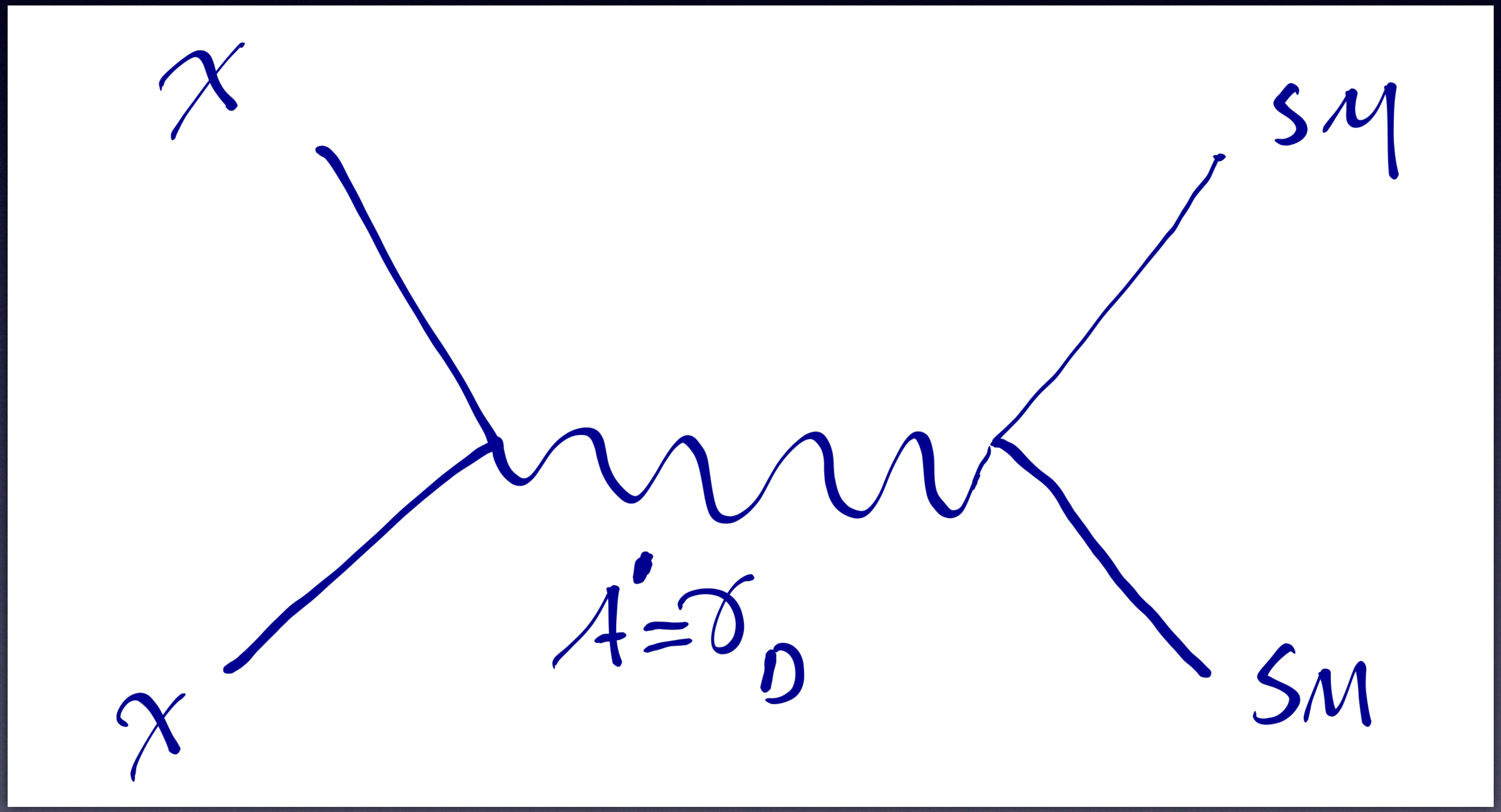


Hidden Sector Annihilation

Complementarity “Classic”

cosmic rays (indirect)

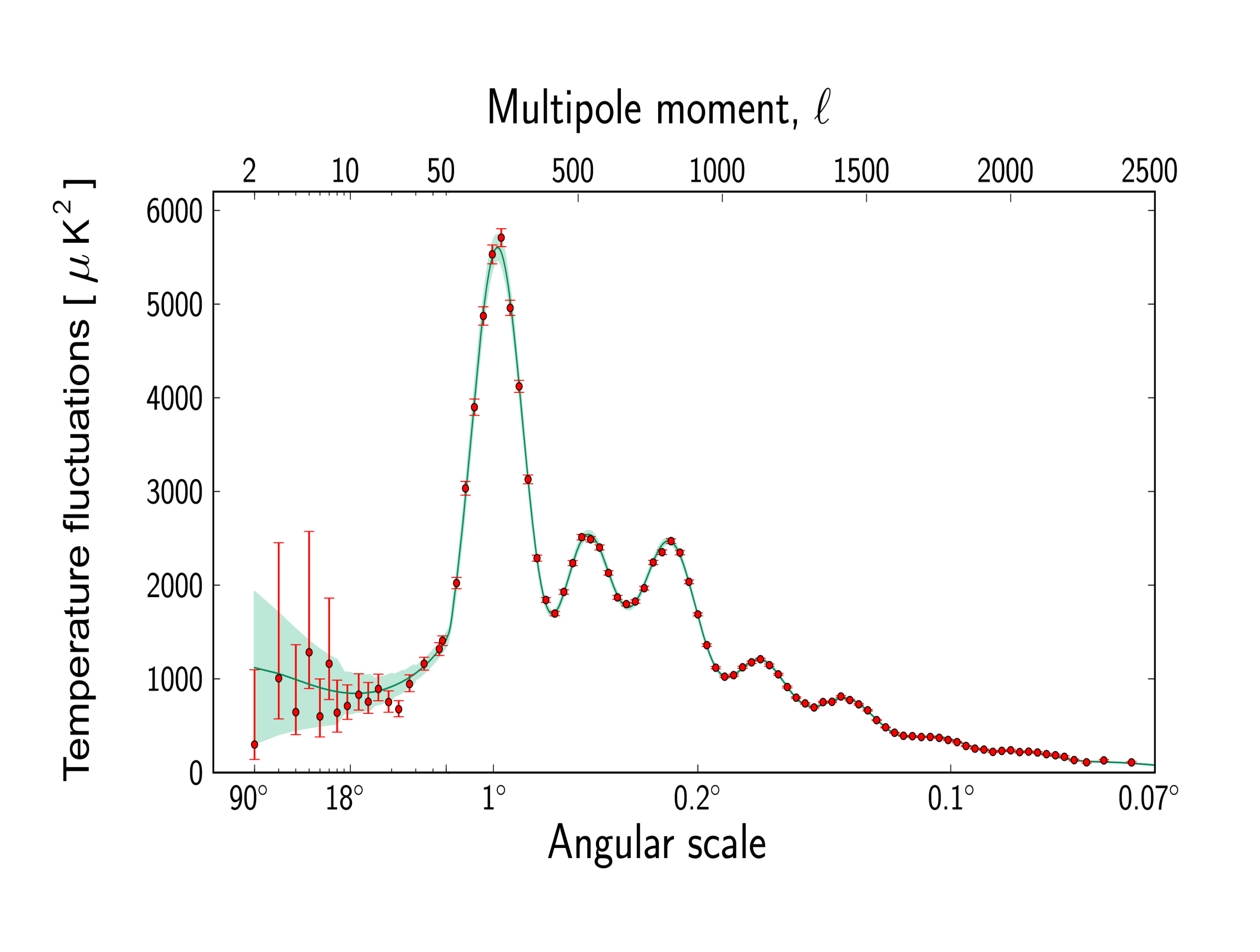
SM recoils (direct)

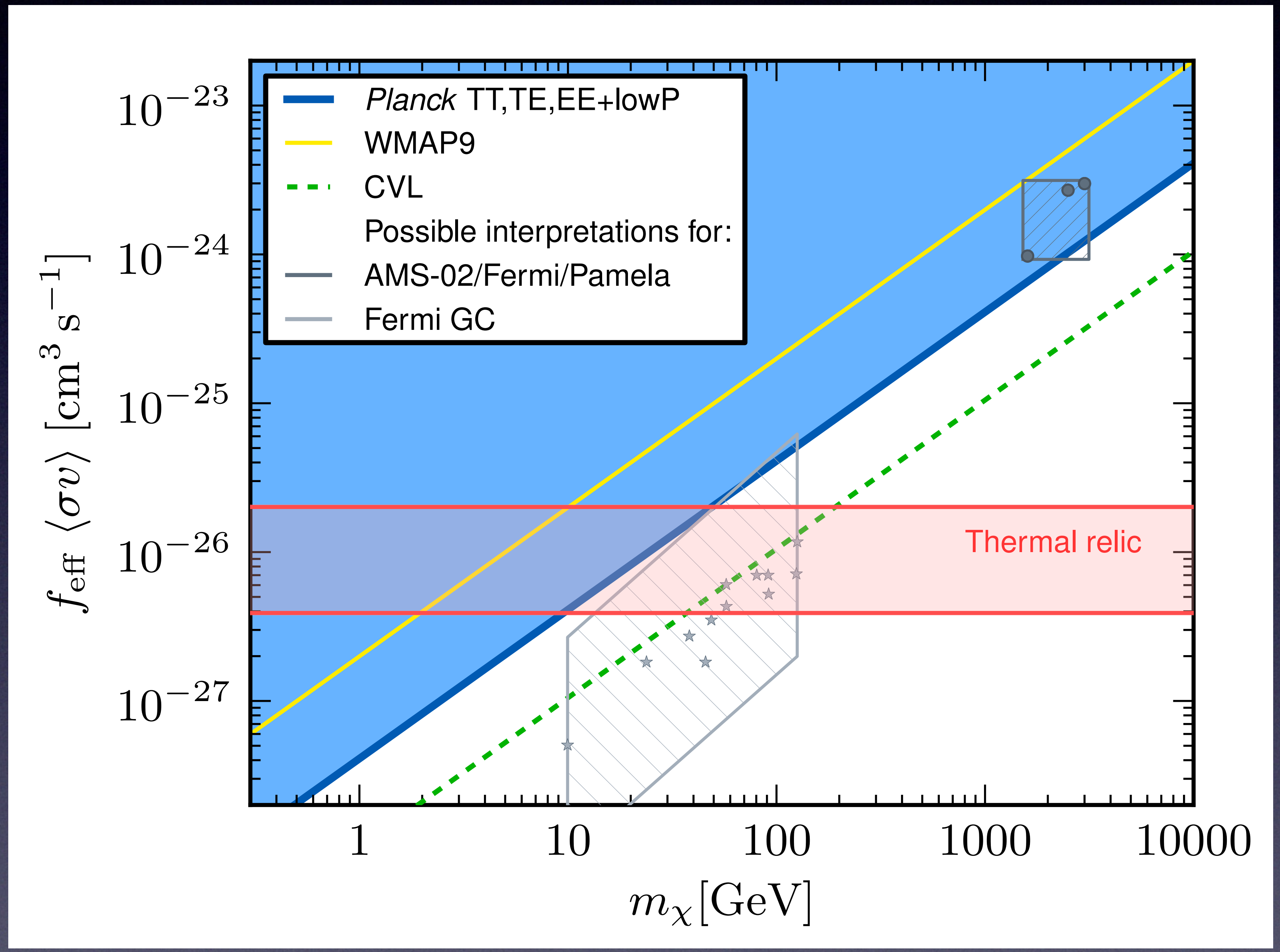


colliders (production)

Limited final states so complementarity is more robust

Cosmology: already powerful





- CMB, LSS much more advanced than in 90's
- CMB constraints light relics more effectively

A signal from z=1100

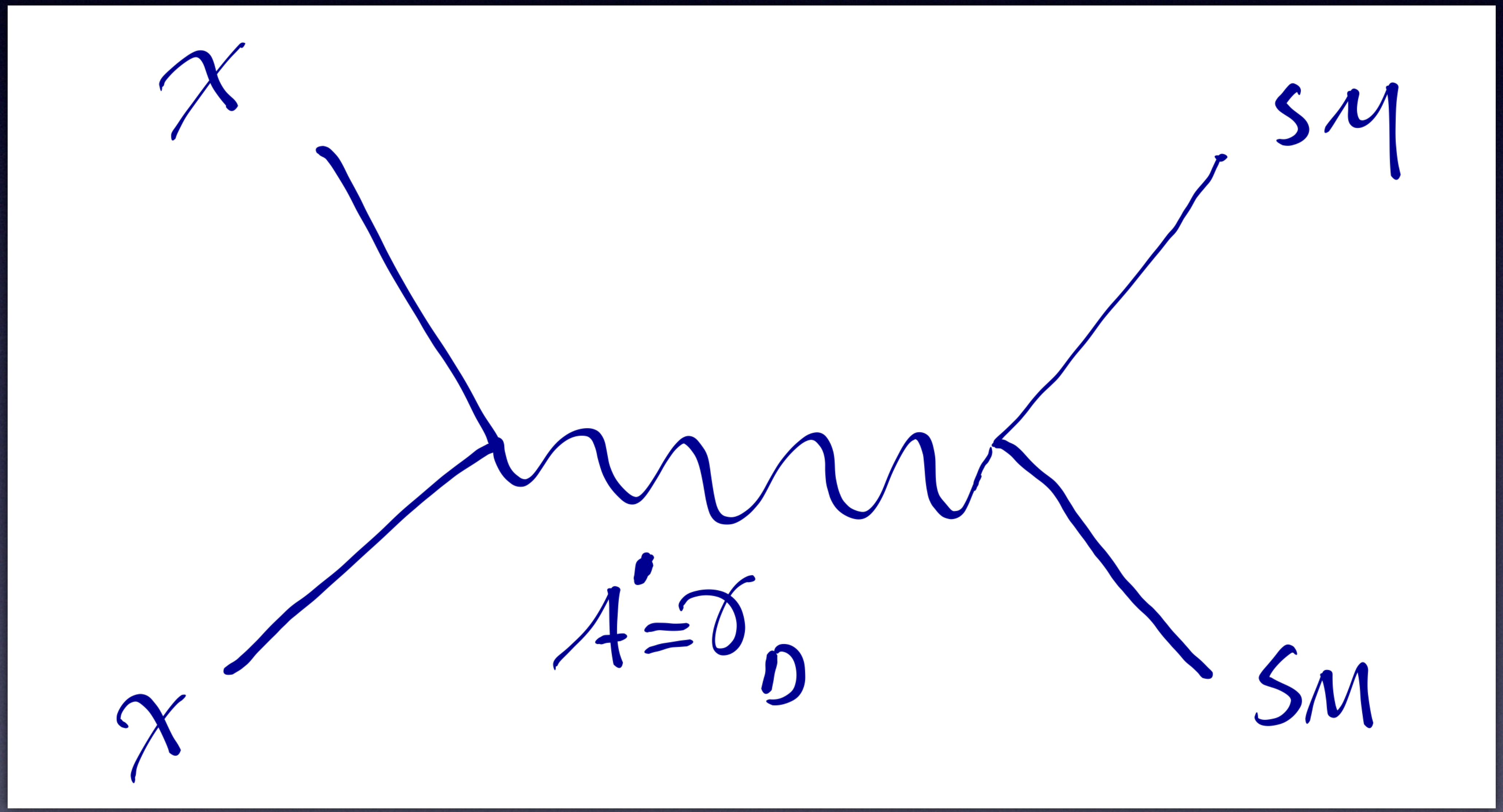
$$E/\mathrm{vol} \sim n_\chi^2 \langle \sigma v \rangle m_\chi$$

$$\sim \frac{\rho_\chi^2 \langle \sigma v \rangle}{m_\chi}$$

- Need to turn off annihilation at recombination
  - Annihilation is p-wave (velocity suppressed) [scalar]
  - Mass splitting between Majorana states [pseudo-Dirac fermion]

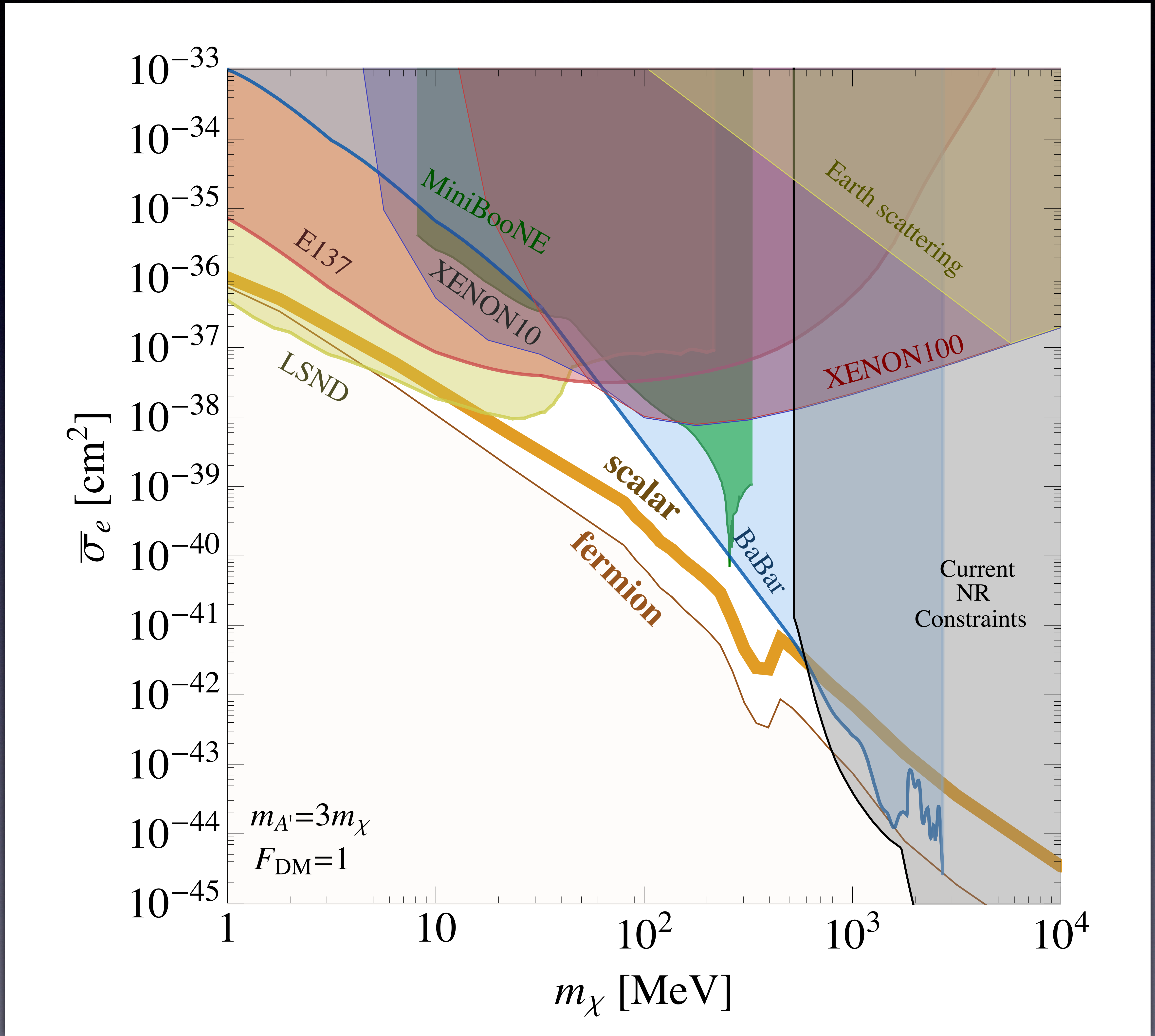
Direct detection

SM recoils (direct)



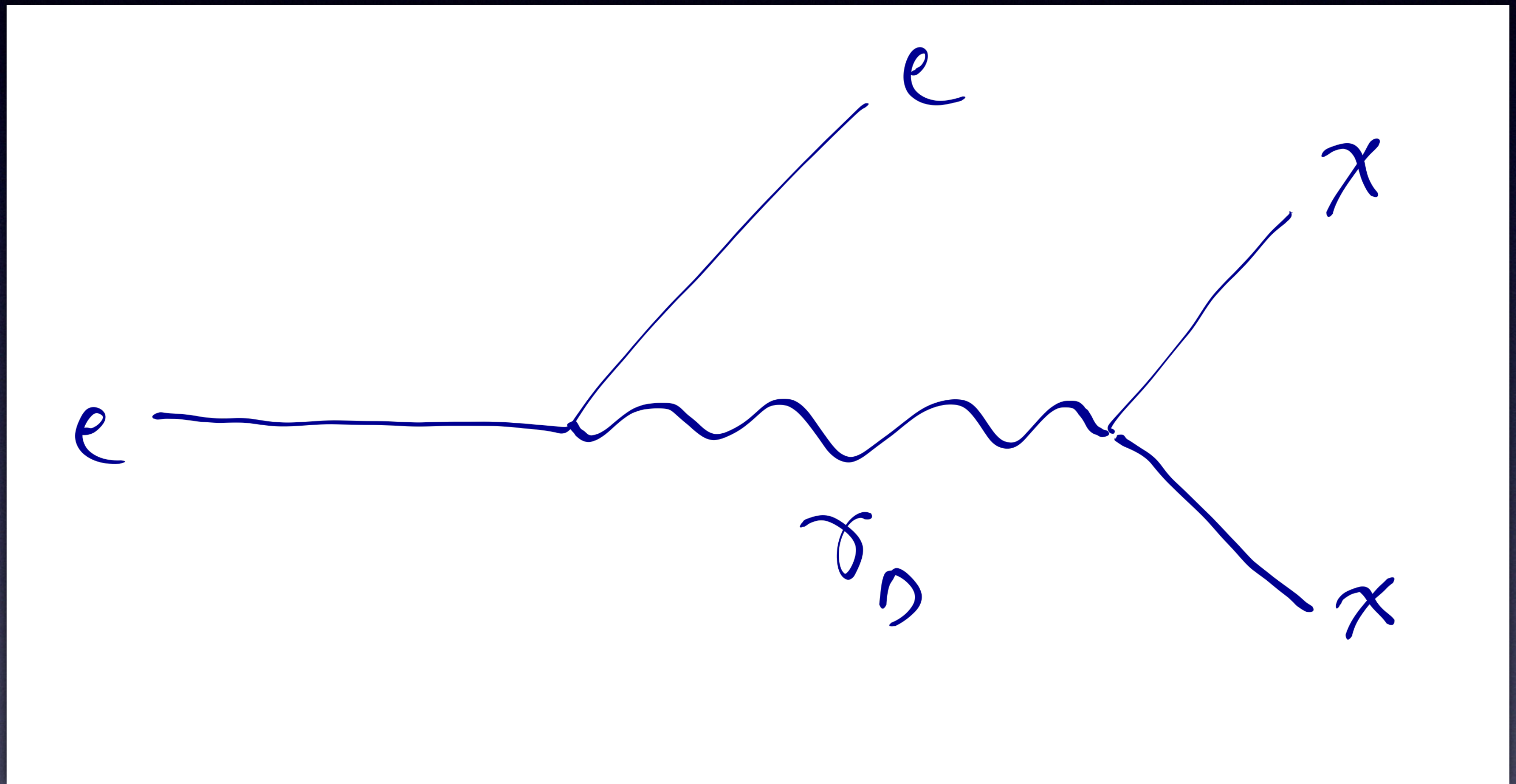
Not just nuclear anymore

The Thermal Target

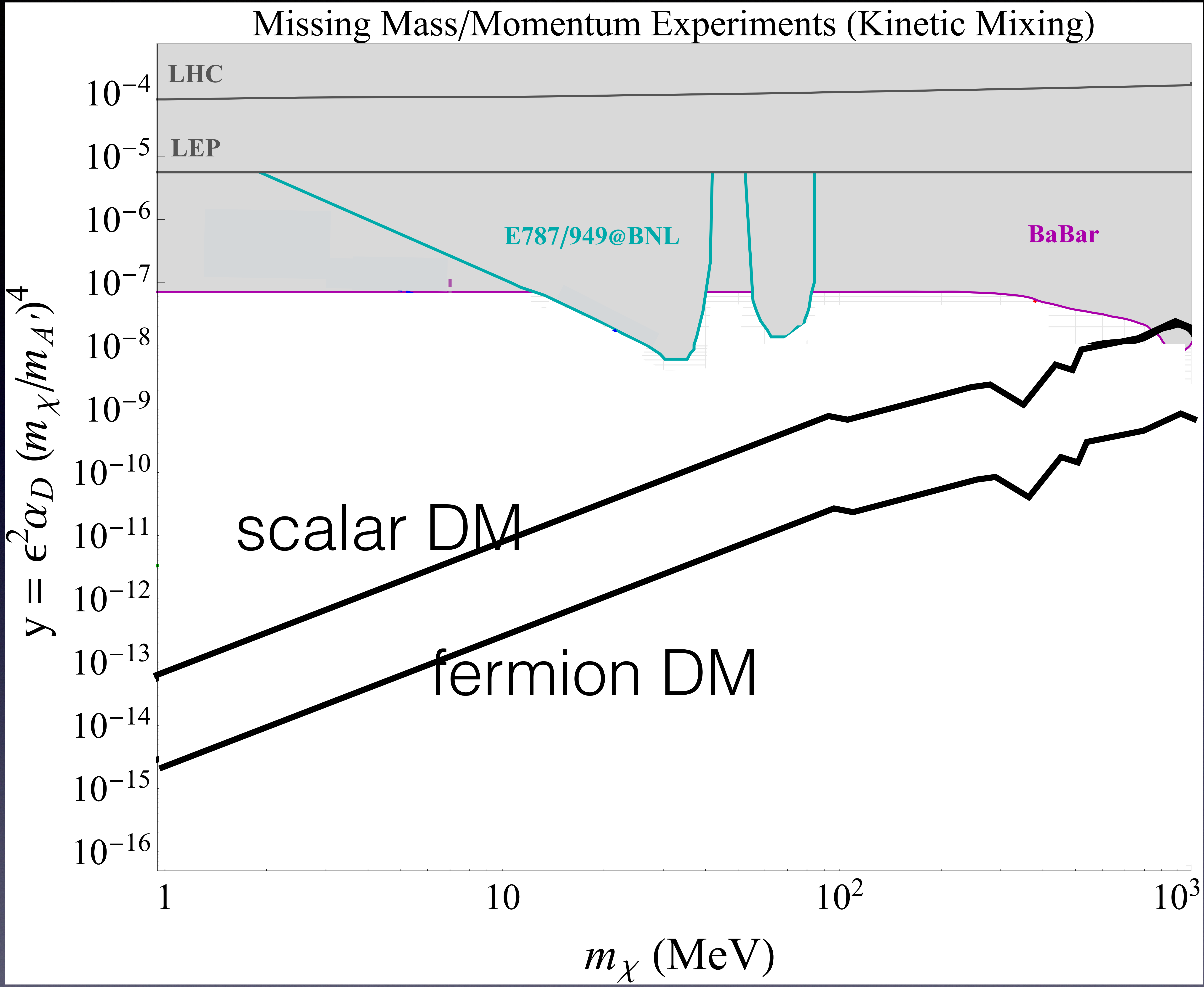


Plot from Essig

“New” Complementarity

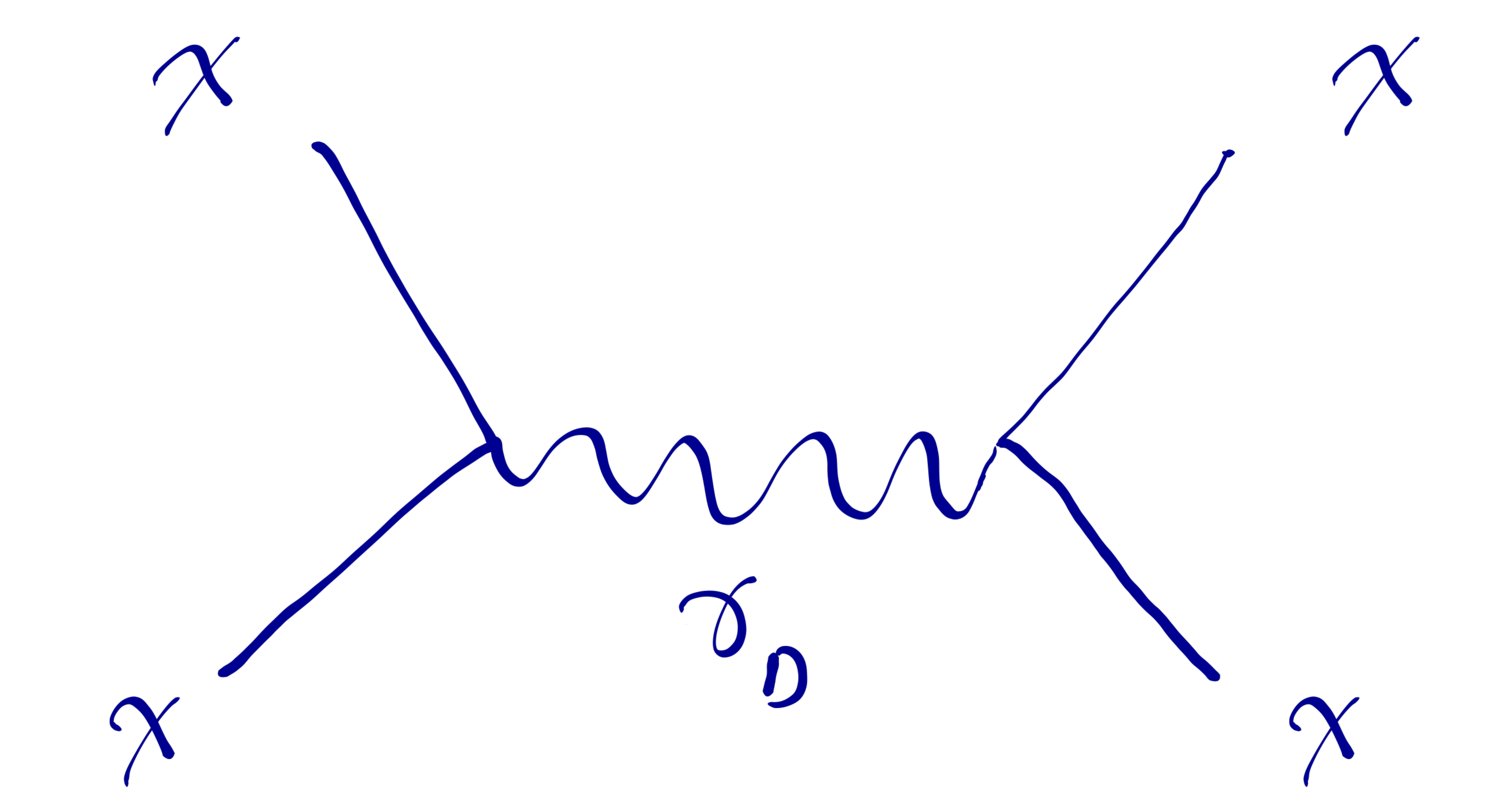


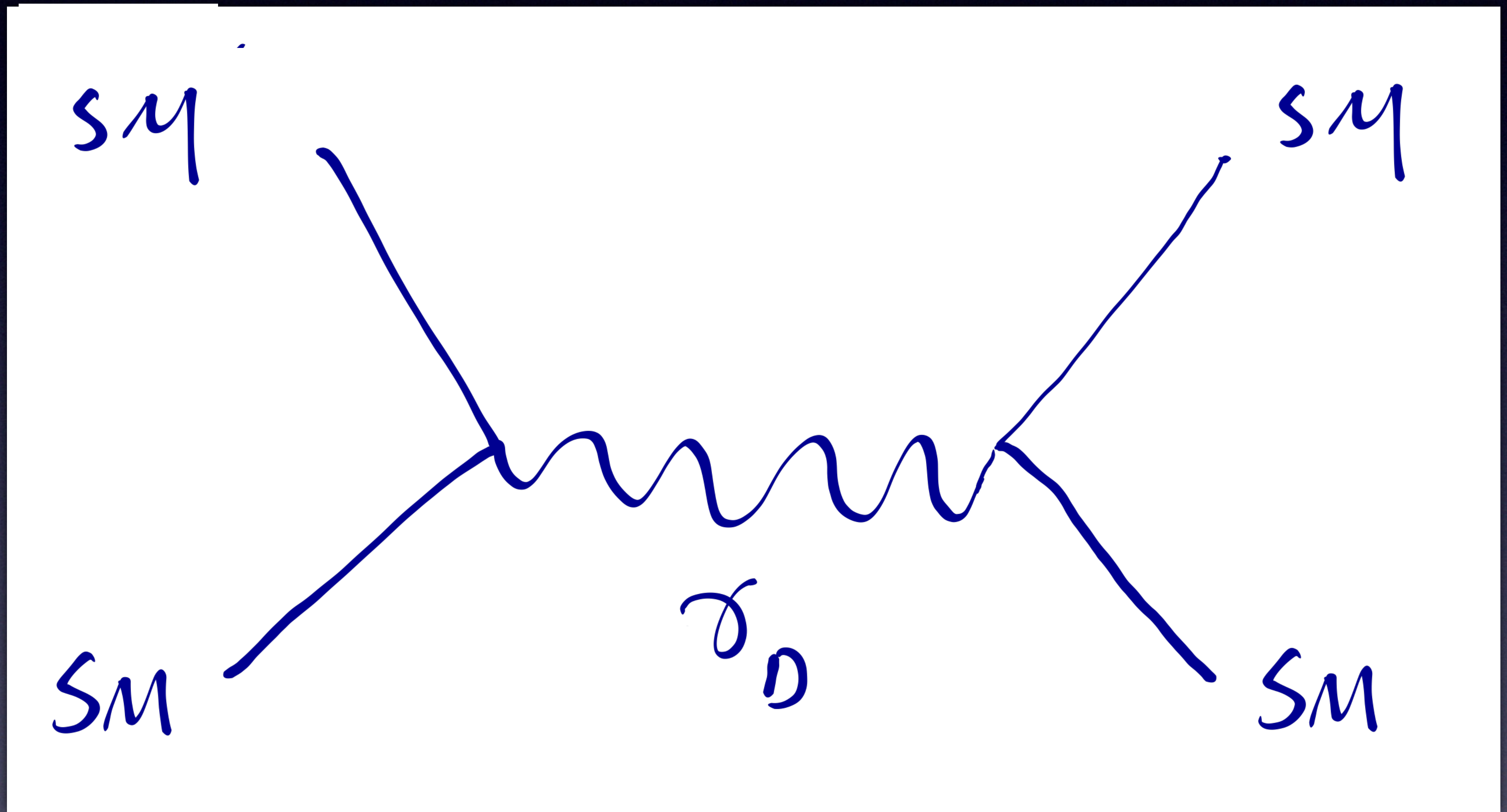
Parametrically linked tightly to thermal diagram



Missing Mass/Momentum Experiments (Kinetic Mixing)
LHC
LEP
E787/949@BNL
BaBar
scalar DM
fermion DM
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
$y = \epsilon^2 \alpha_D (m_\chi/m_{A'})^4$
1
10
10^2
10^3
m_χ (MeV)

“New” Complementarity





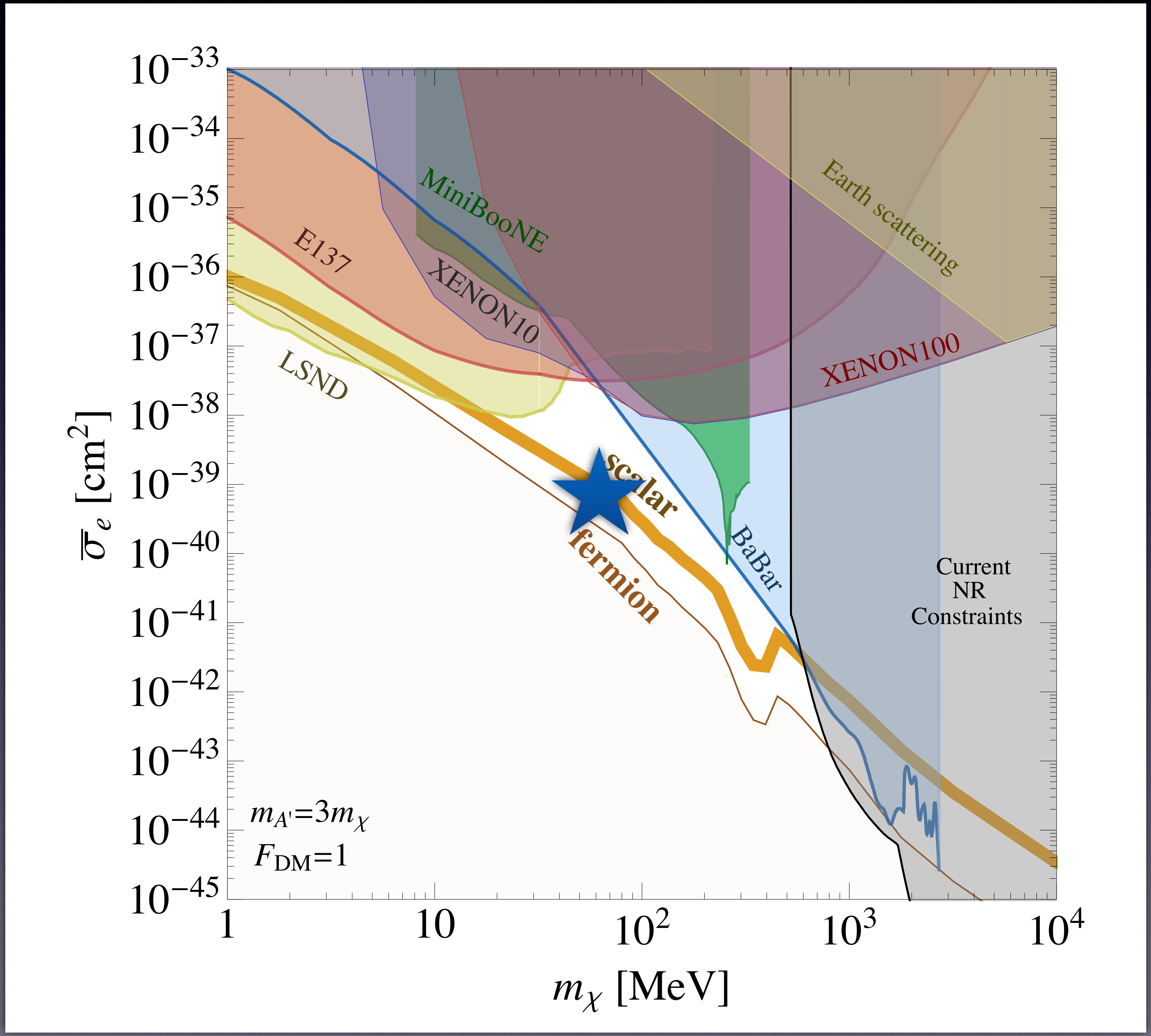
Parametrically linked more weakly to thermal diagram

DM self interaction? Anomalies like 8Be?

Asking general questions

- This needn't be ***the*** DM to be interesting
- Are there any particles leftover from "late" (sub TeV) thermal contact?

Scaling of signals



Scaling arguments

$\rho \sim \frac{1}{\sigma}$ i.e. $\rho \sim \rho_0 \frac{\sigma_0}{\sigma}$

but $n \sigma v \sim \frac{\rho}{m} \sigma v \sim \frac{\rho_0 \sigma_0}{m \sigma} \sigma v \sim \mathrm{const}$

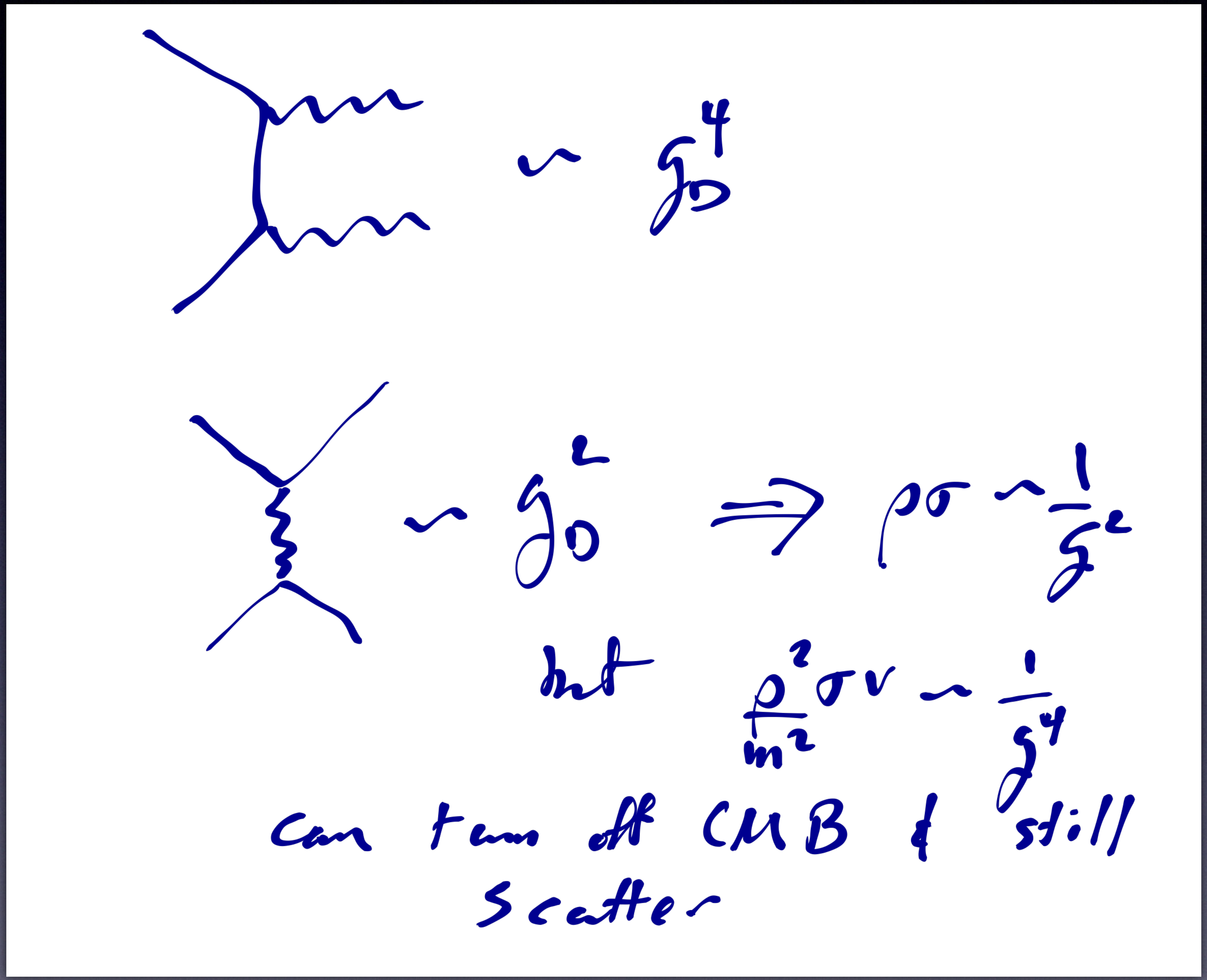
$n^2 \sigma v \sim \frac{\rho_0^2 \sigma_0^2}{m^2 \sigma^2} \sigma \sim \frac{1}{\sigma}$ decreases for large σ

direct signal stable

indirect signal decreases

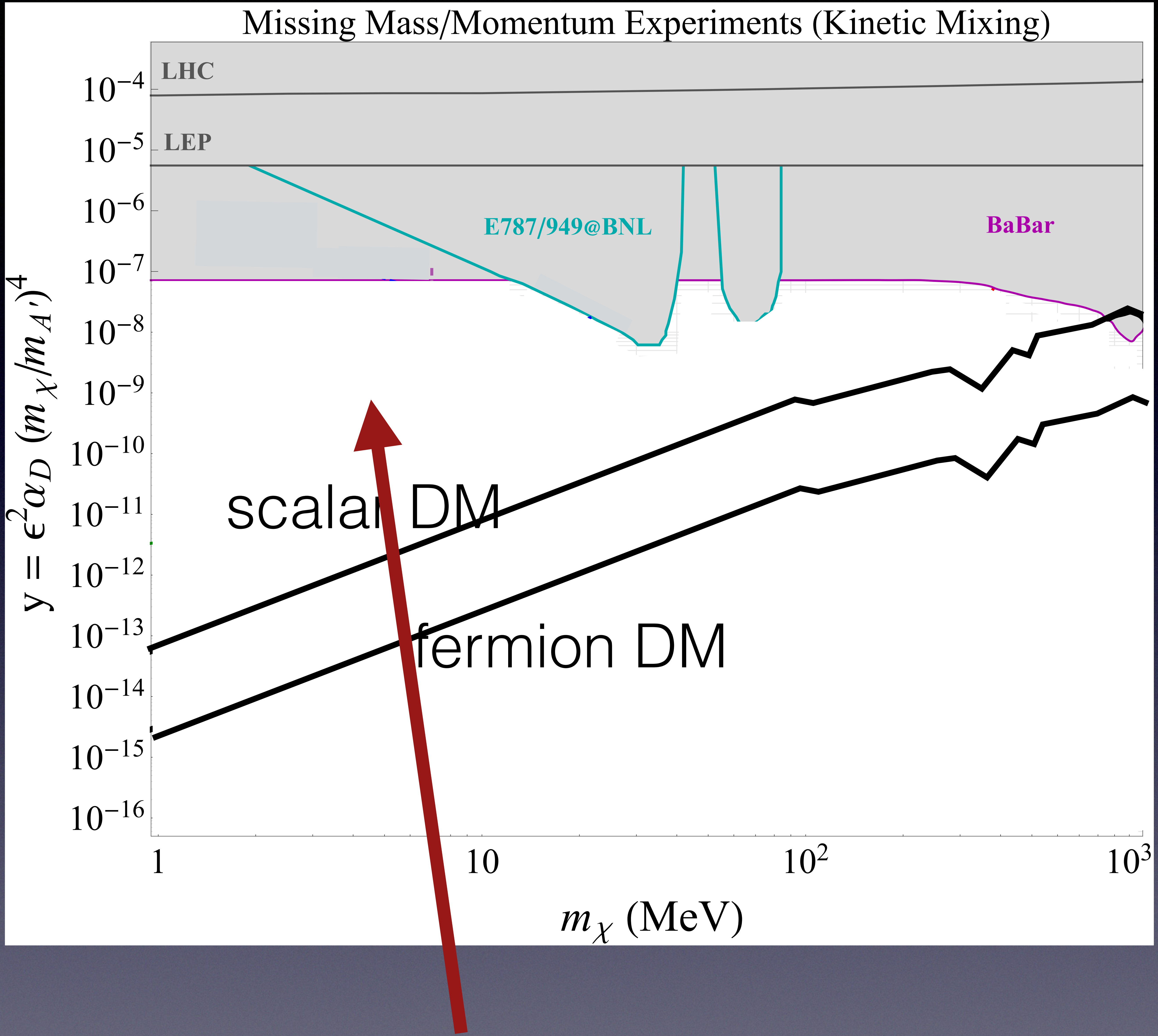
The thermal target here is *more* robust

Scaling arguments



direct signal decreases

indirect signal decreases faster



qualitative physics information here, too

Moving away from priors changes questions

- Looking for the DM is critical, but finding cosmologically “relevant” hidden physics would be profound
- A WIMP was motivated to be *the* DM, but hidden physics may or may not be
- Broadening the question changes how we think about targets, how robust they are and *changes the implications of complementarity*

Generalizations of thermal history

- Freeze-in (signal arises later)
- SIMPS (new “miracle” at 100 MeV)
- ELDERS
- Forbidden DM
- Dynamical DM
- …
- Major theoretical advancement has been in rethinking “generic” thermal particles

Still need labs for new ideas

Rebalancing our priorhedron