Dark Sectors

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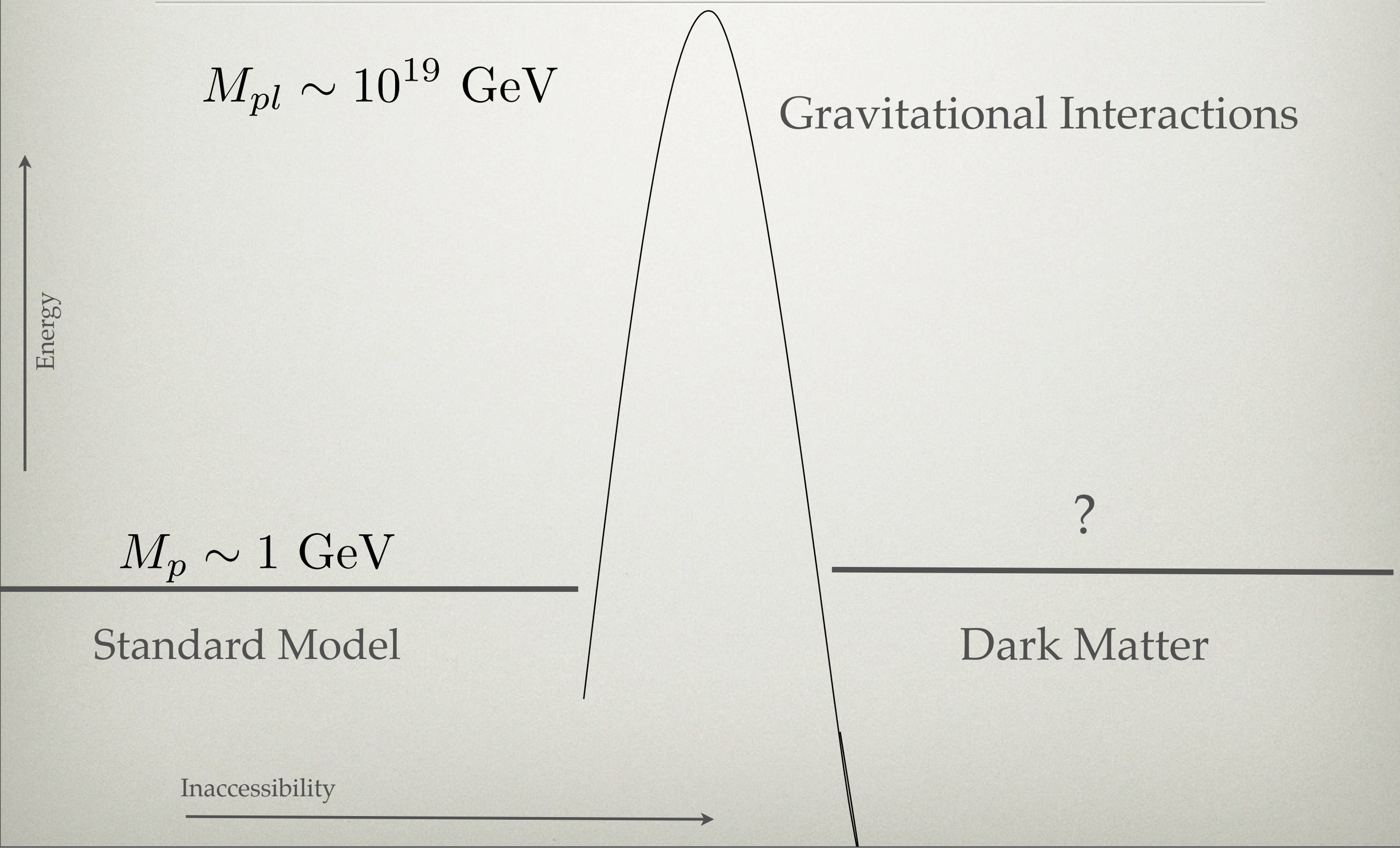
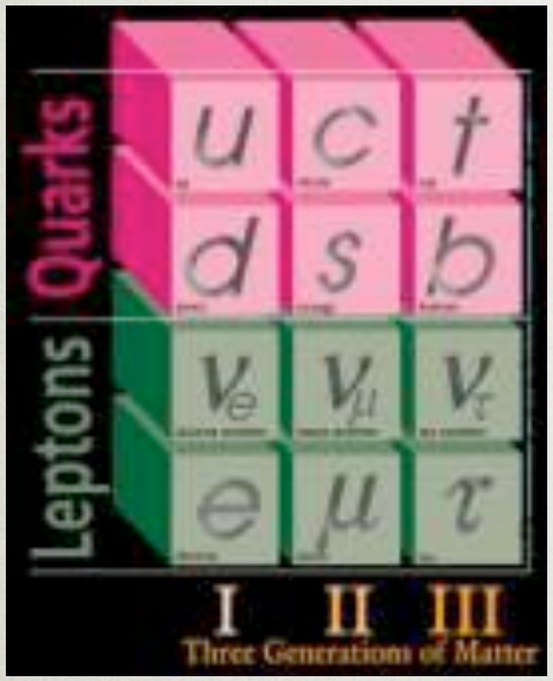
Super-Weakly Interacting



Dark Sectors

Our thinking has shifted

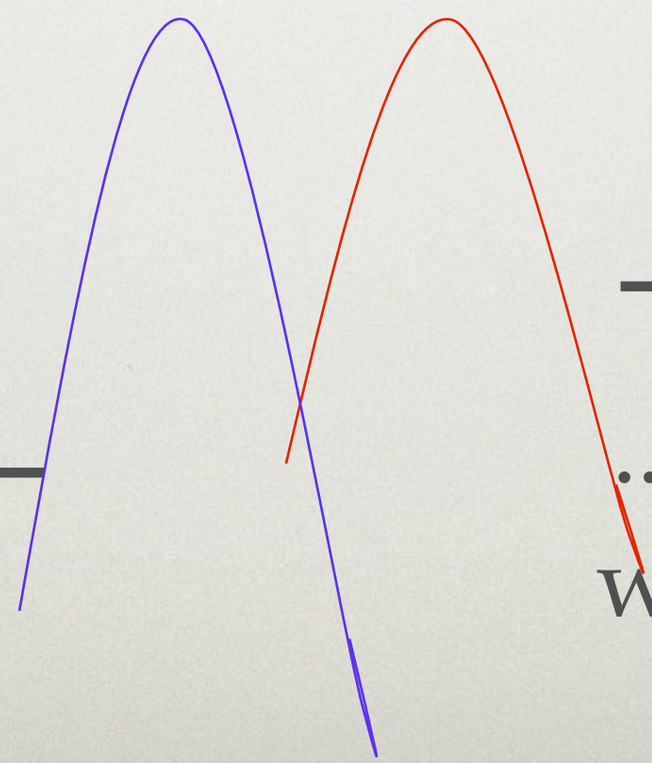


From a single, stable very weakly interacting particle .....
(WIMP, axion)

?

$M_p \sim 1$ GeV

Standard Model

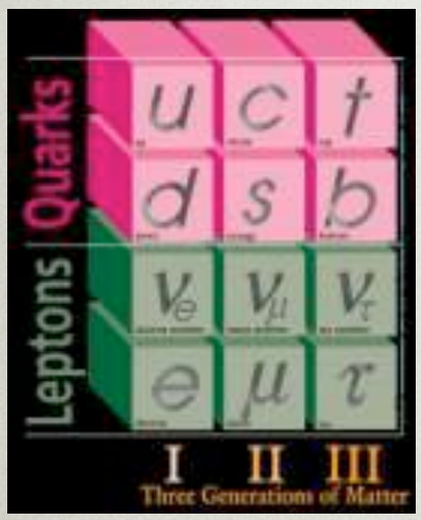


...to a hidden world with multiple states, new interactions

Intervention of Data

DAMA, PAMELA, Fermi, CoGeNT ....

Data has helped us think about the dark sector in a fundamentally new way

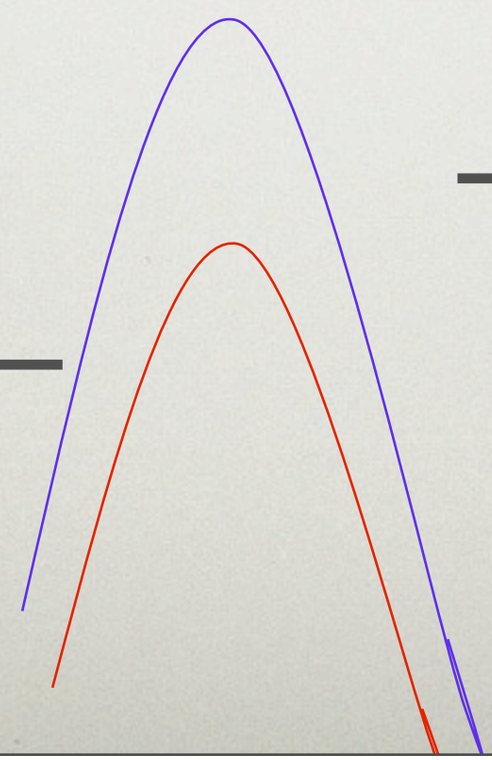


?

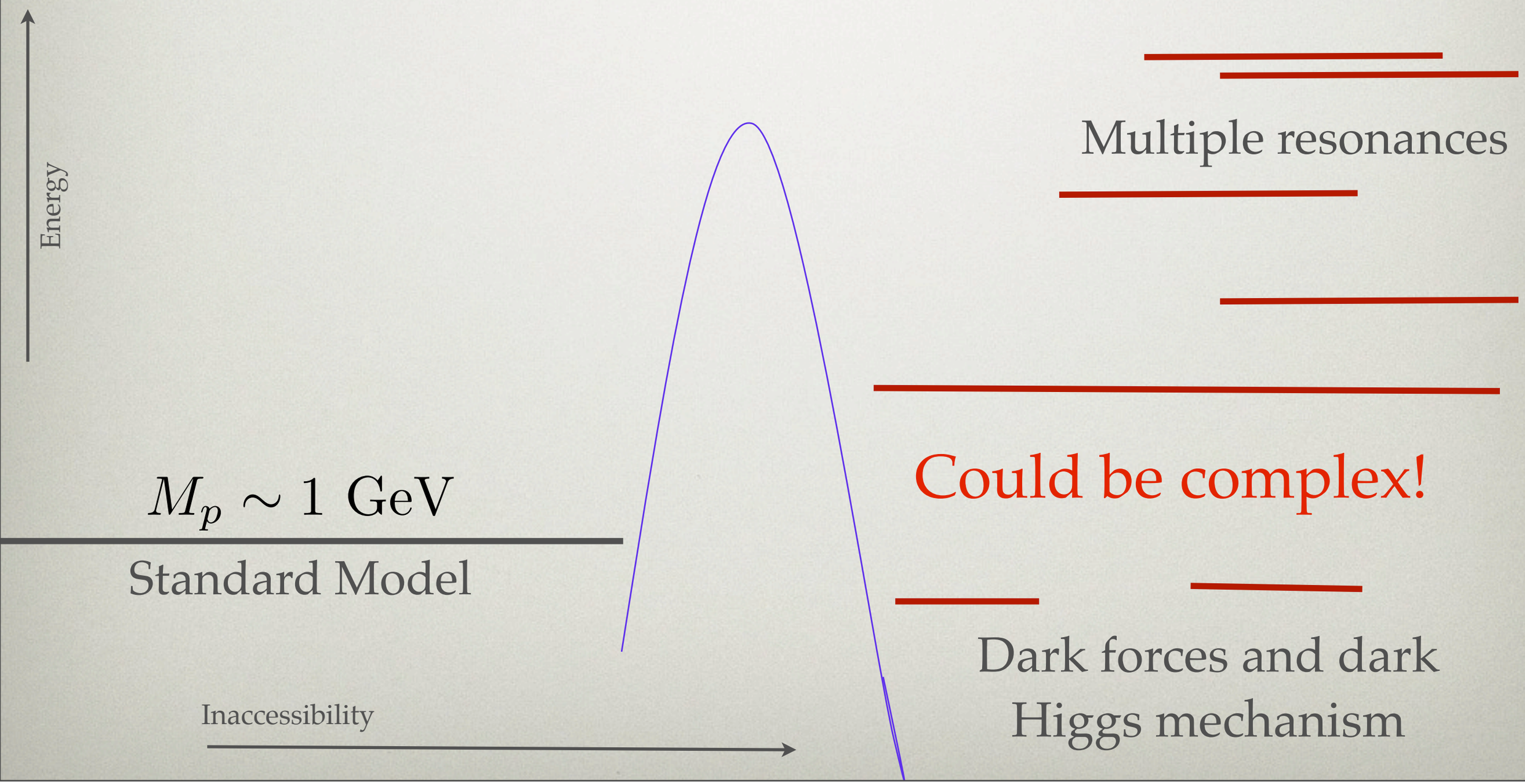
Complex!

$$M_p \sim 1 \text{ GeV}$$

Standard Model

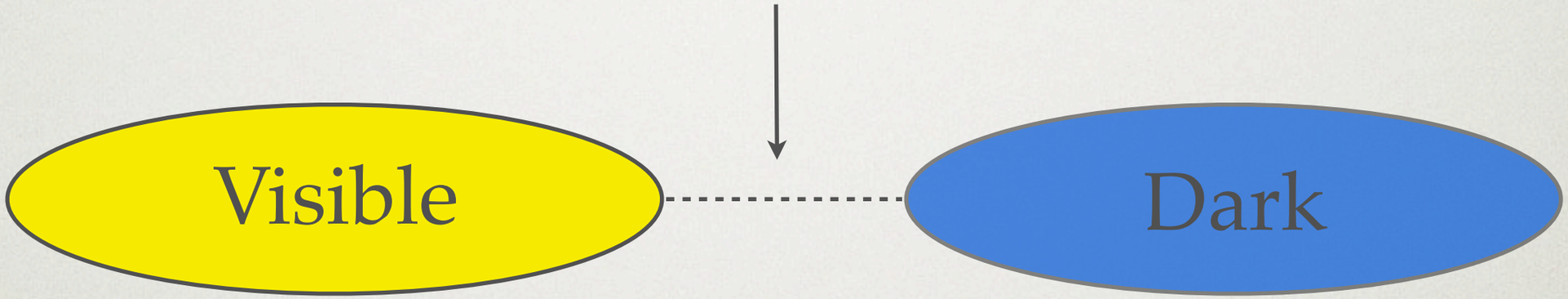


STRUCTURE!


Energy
Multiple resonances
$M_p \sim 1$ GeV
Standard Model
Could be complex!
Dark forces and dark Higgs mechanism
Inaccessibility

Access

Heavy or Weakly Coupled



Higgs	Energy, cosmic
New electroweak states	Energy, intensity, cosmic
New light, weakly coupled mediators	Intensity, cosmic
Heavier than electroweak states	Intensity, cosmic

Anything!

Perhaps we should make many fishing expeditions?

Fishing Expeditions

- Of course, they should be *well-motivated*
- Well-motivated physics need not lie along the line of a few ideas
- *What are the top few priorities in each frontier for fishing expedition type explorations?*

What is Meant by a Fishing Expedition?

- Not simply going to higher energies, more intense beams, bigger DM detectors (though these existing projects can have some fishing sub-expeditions)
- Many smaller scale experiments designed to improve sensitivity by many orders of magnitude on qualitatively different types of physics, with a clear discovery capability

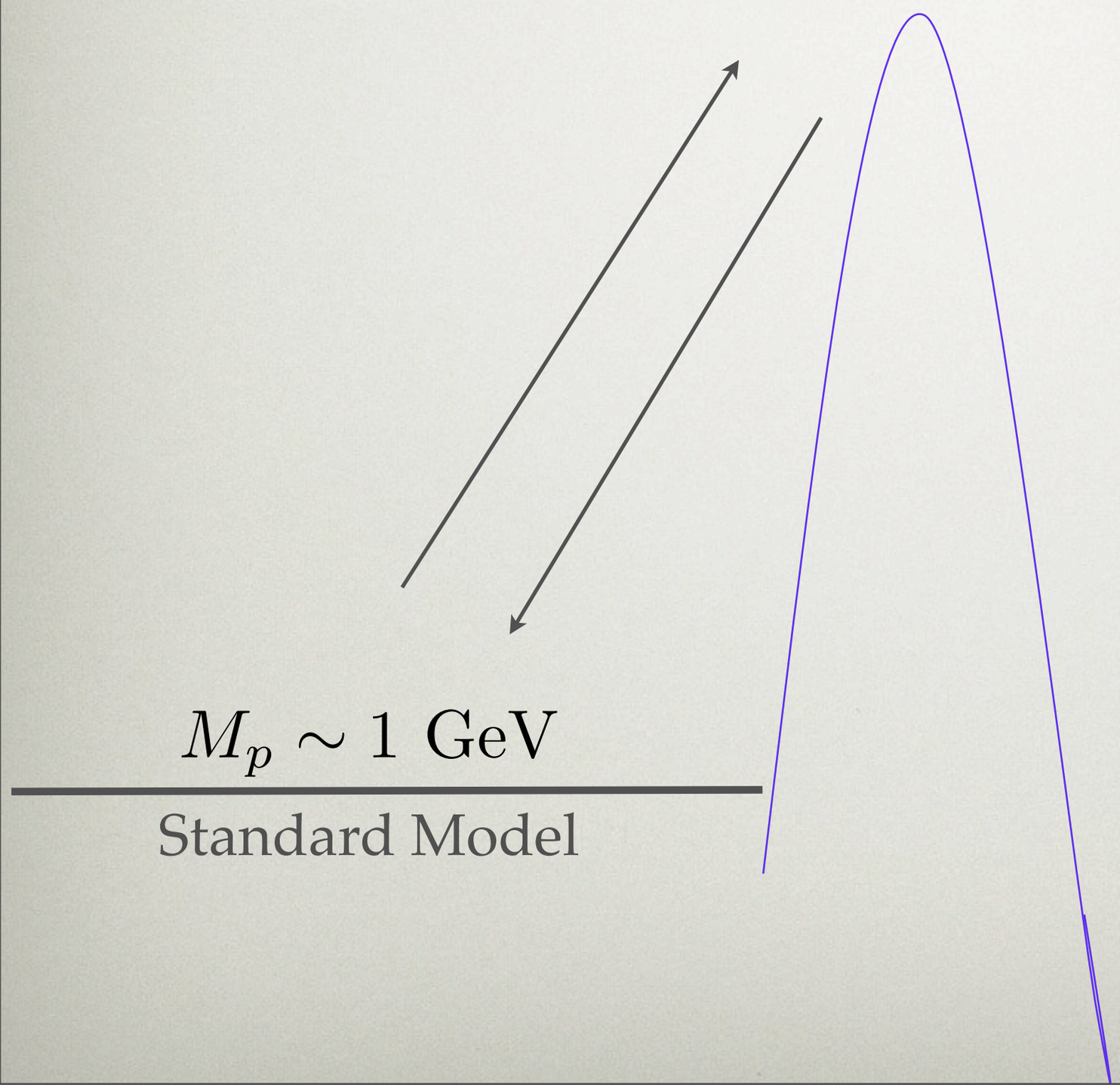
Fishing Expeditions

- Characterized by creativity and entrepreneurial emphasis
- Such expeditions exist, and I will review *a few* of the efforts in each frontier
- Often lost by focus on large programs
- Is this a important piece of revitalizing the US program?

Fishing Expeditions

- Note that dividing things into “energy, cosmic, and intensity” frontiers can be antithetical to this way of thinking if we focus only on a couple of big programs
- Nevertheless, some things manage to survive
- More should be supported
- Examples from “the frontiers”

1. Energy

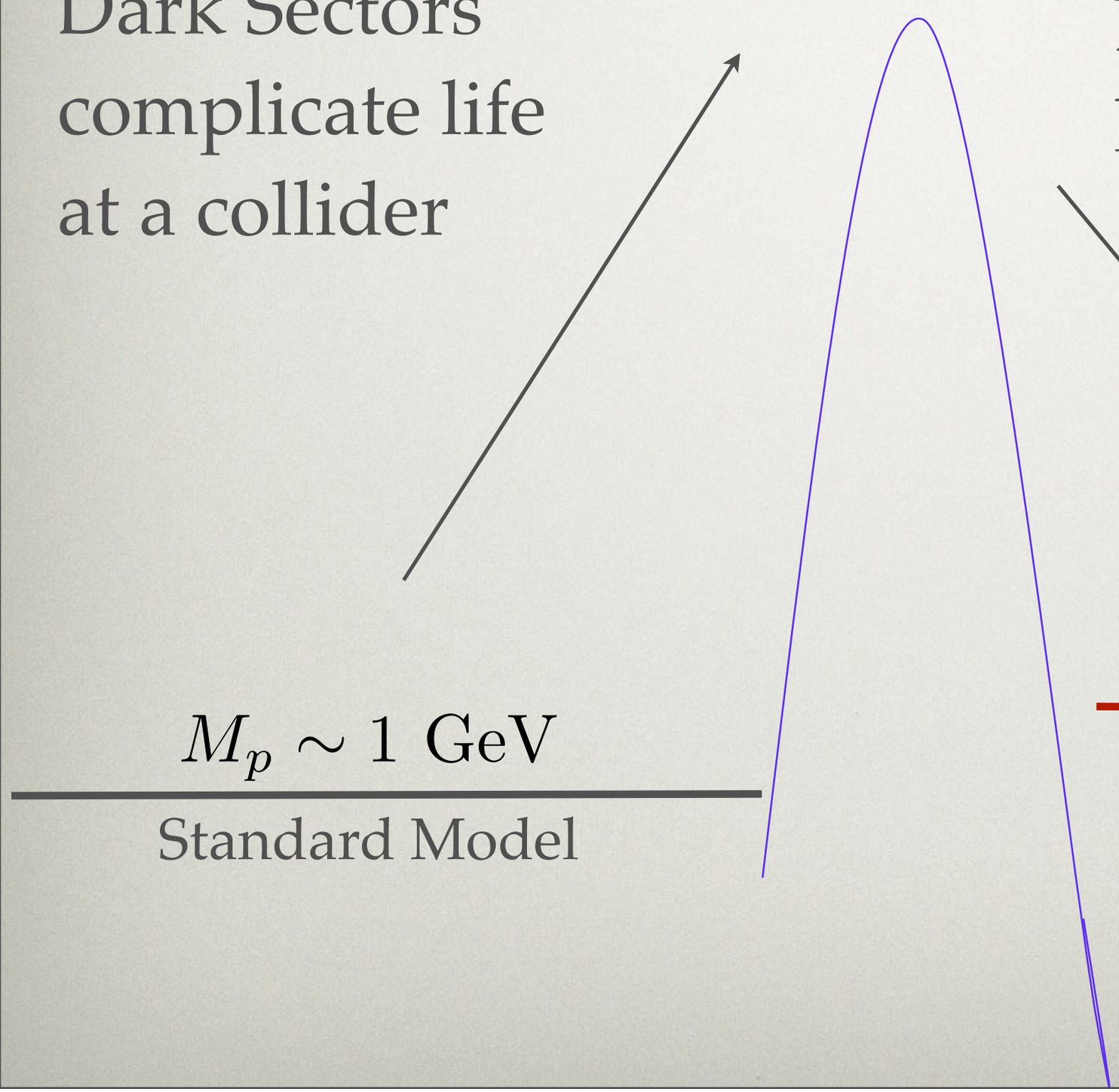


Only worry about
Production rates

1. Energy

Dark Sectors complicate life at a collider

Dark Sectors make life rich at a collider!



Multiple resonances

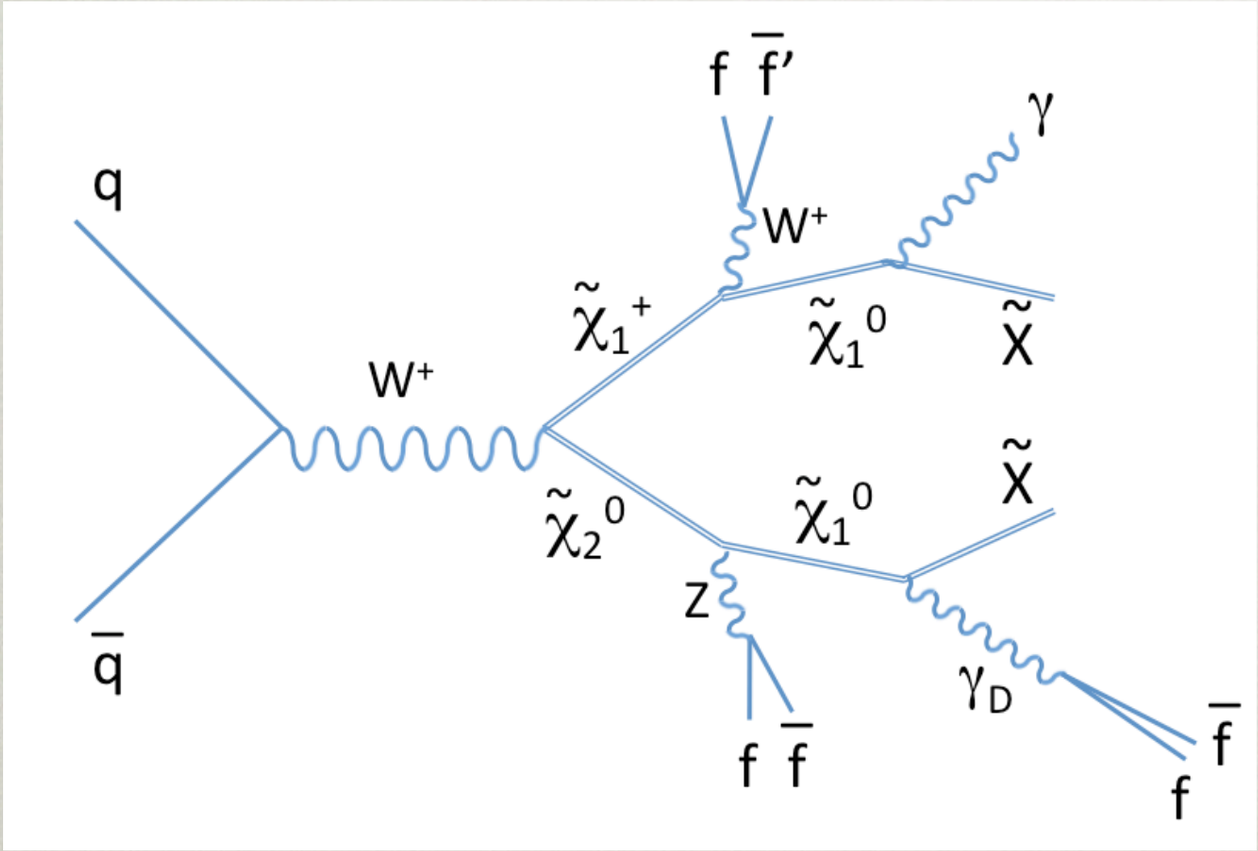
$M_p \sim 1$ GeV

Standard Model

Hidden Valley
Could be complex!

1. Energy

- Targeted searches with simplified topologies

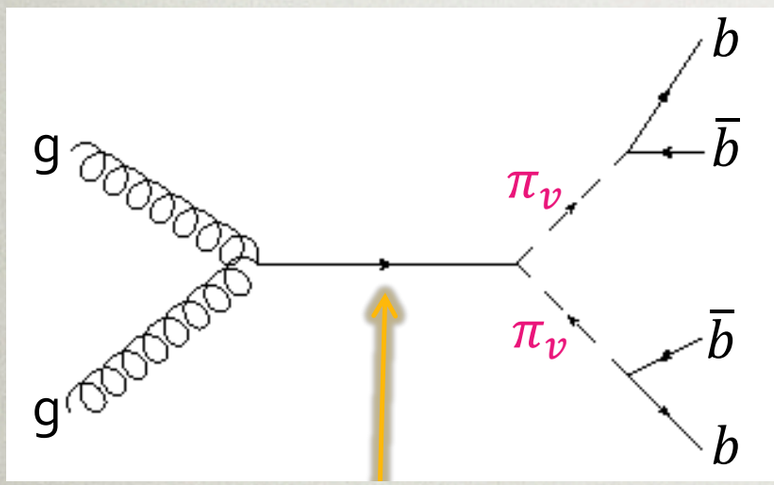


High multiplicities
Low mass resonances

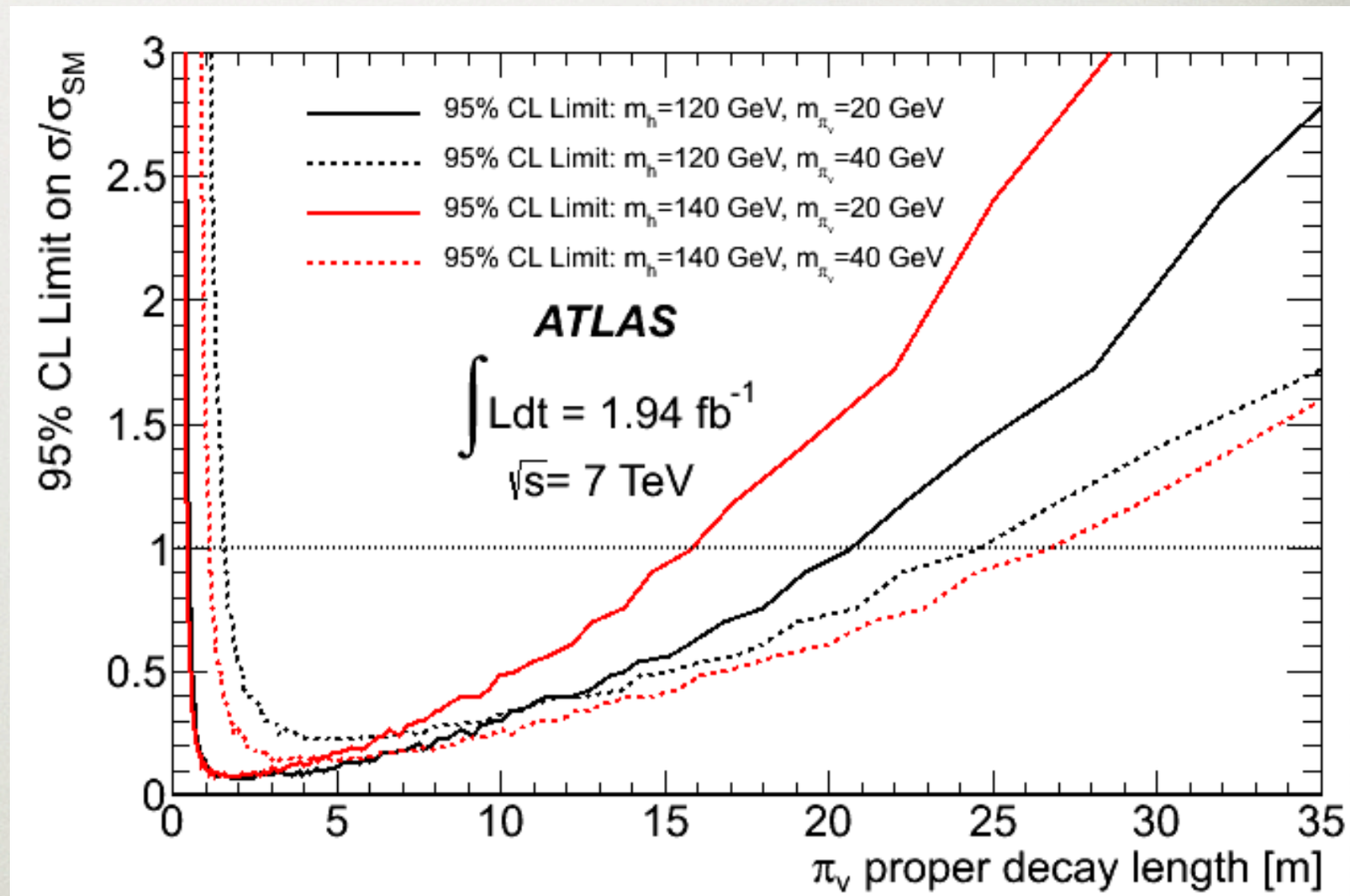
CDF: "Search for Dark Photons from SUSY Hidden Valleys"

1. Energy

- Specialized techniques: displaced vertices



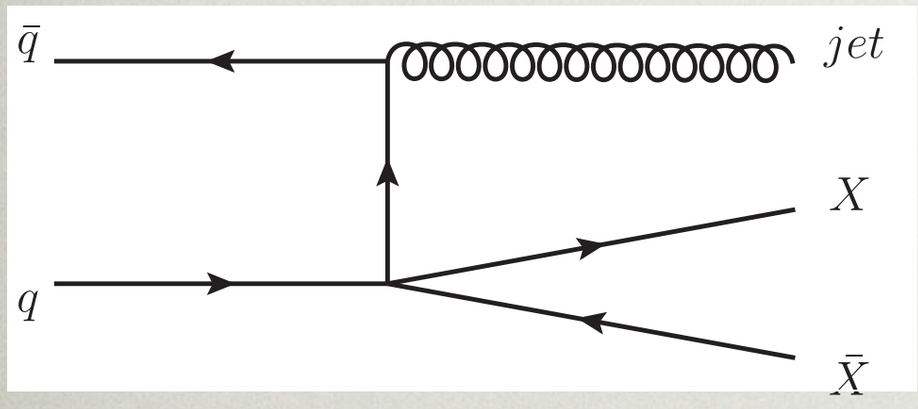
Decays in EM calo
Decays in hadronic calo
Decays in muon spect

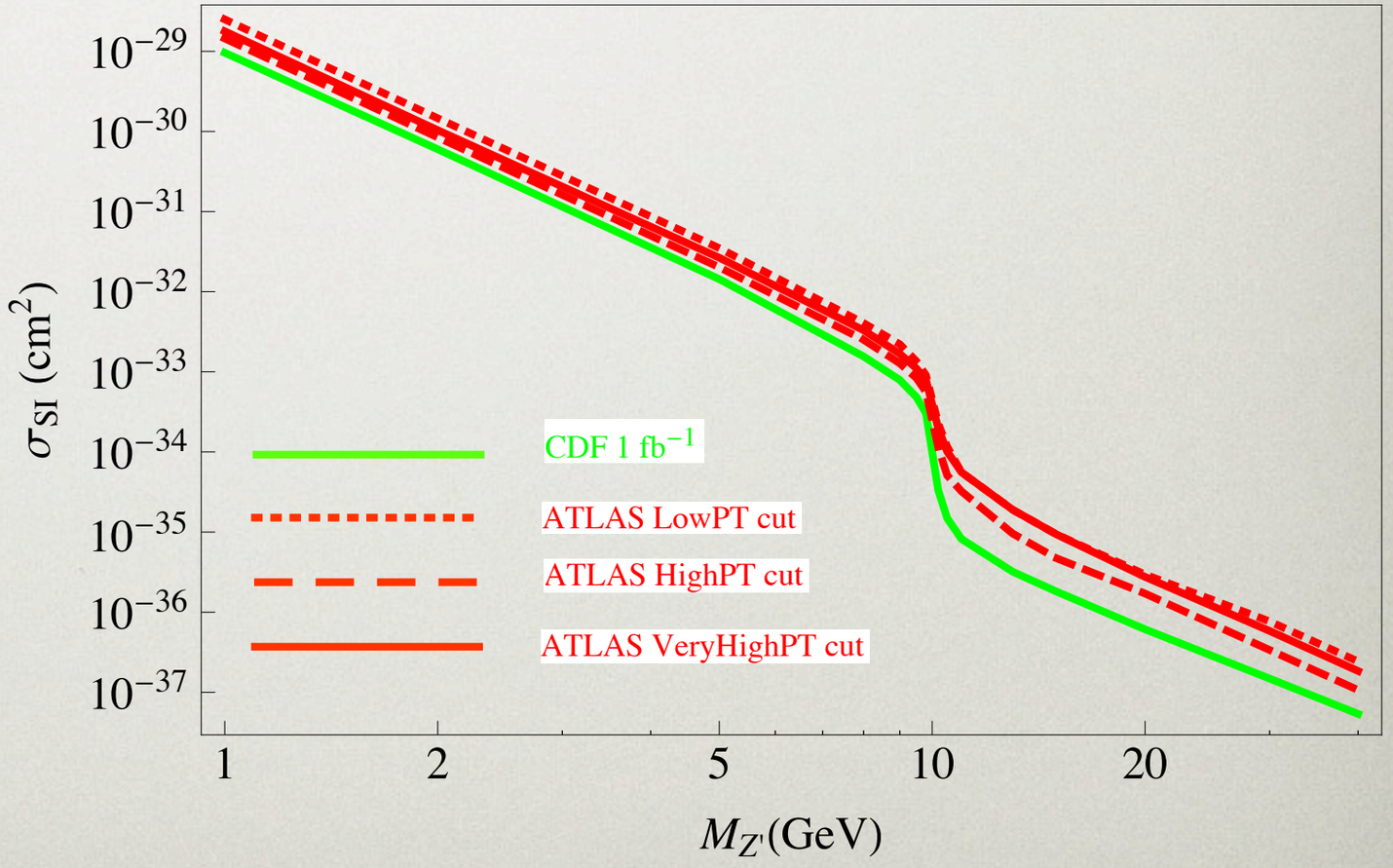


Search for long-lived neutral particles

But sometimes it's not effective ....

- Monojet searches assume an EFT and don't consider direct constraints

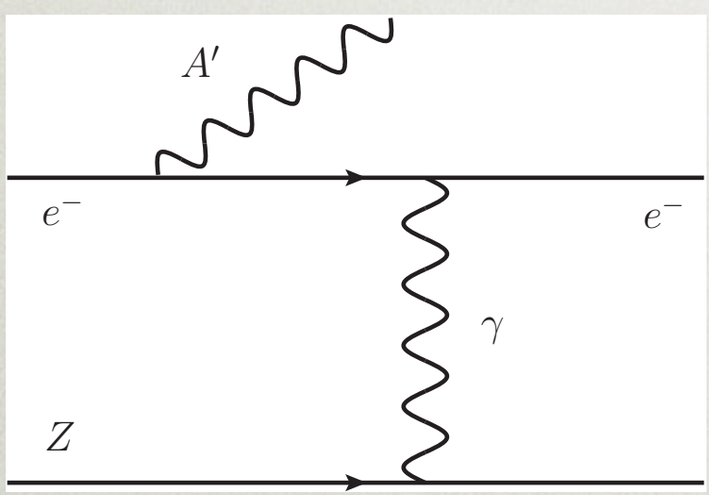




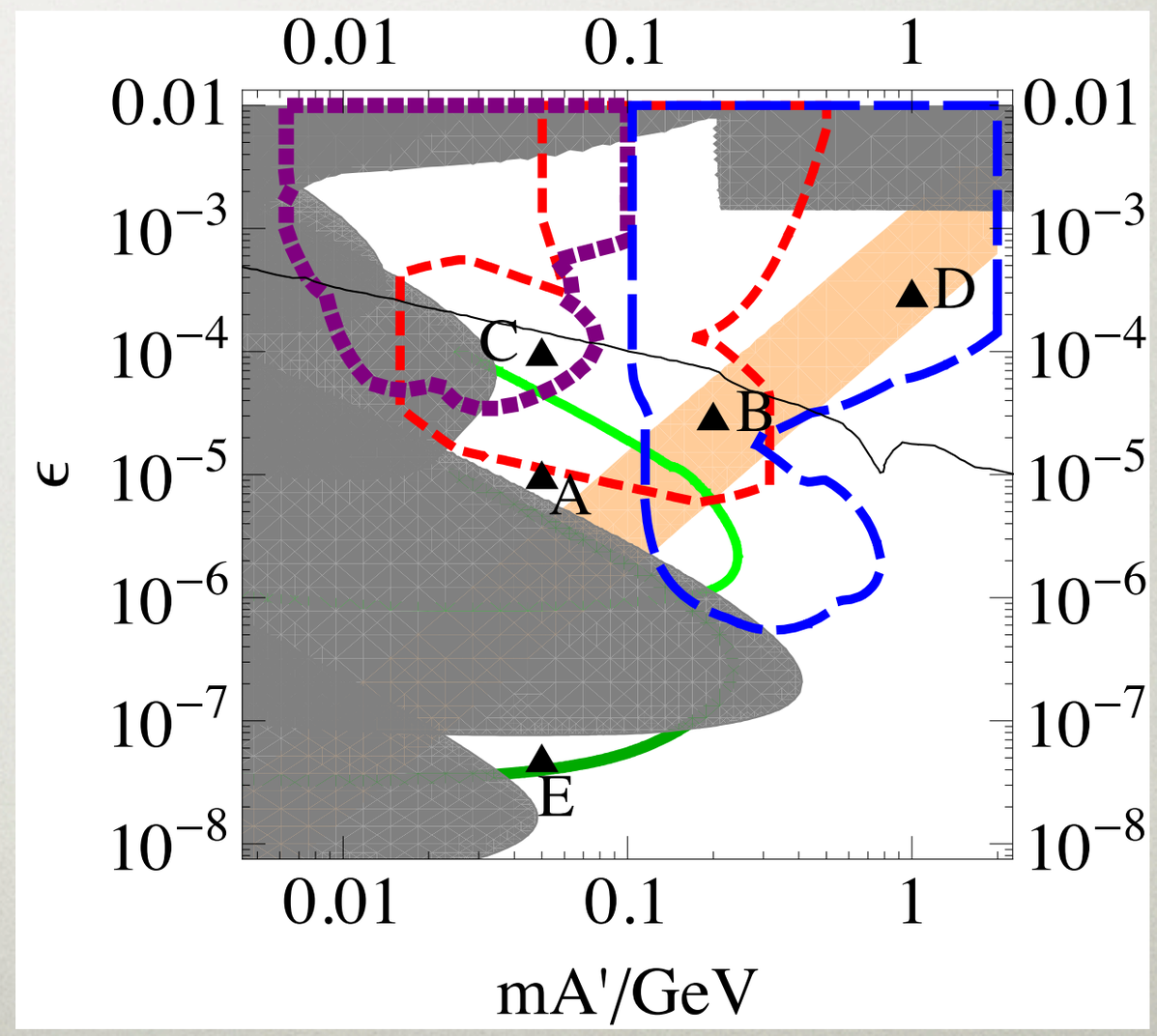
Wang and An

2. Intensity

- Light, weakly coupled objects

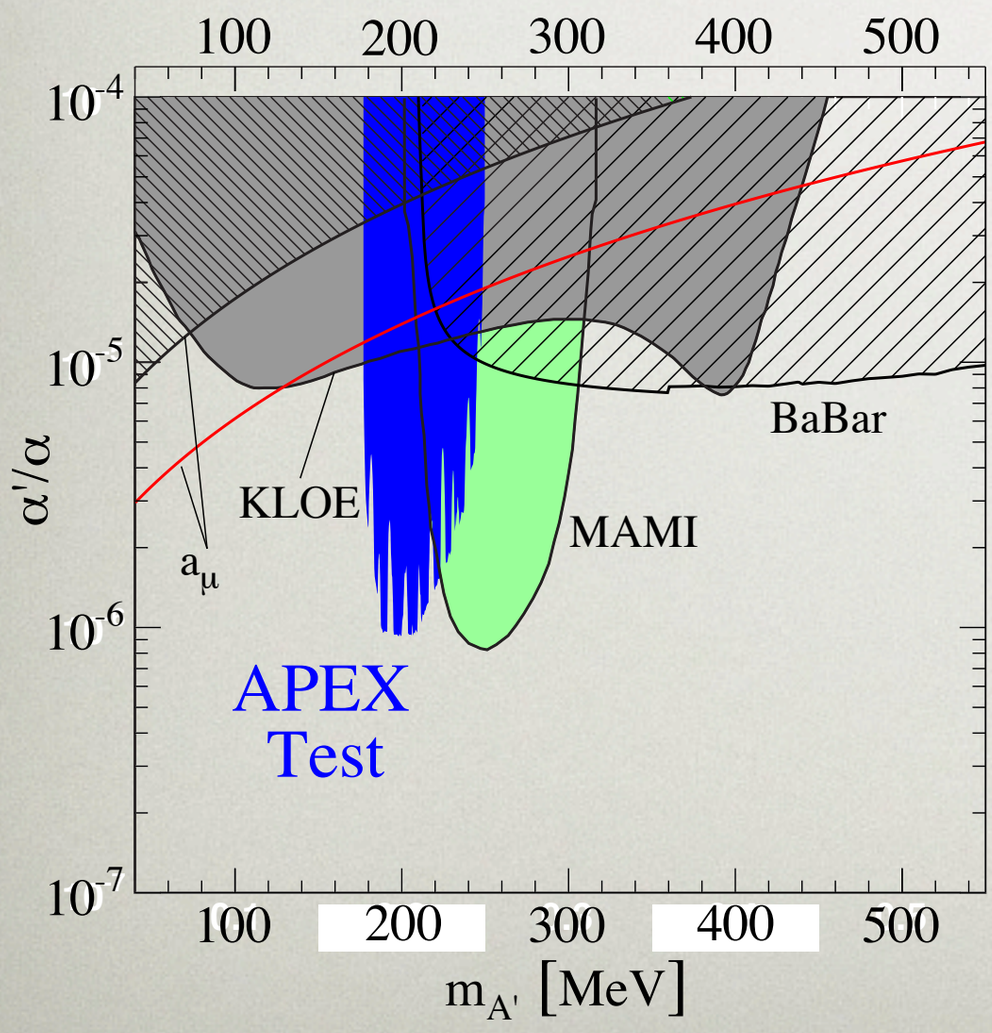


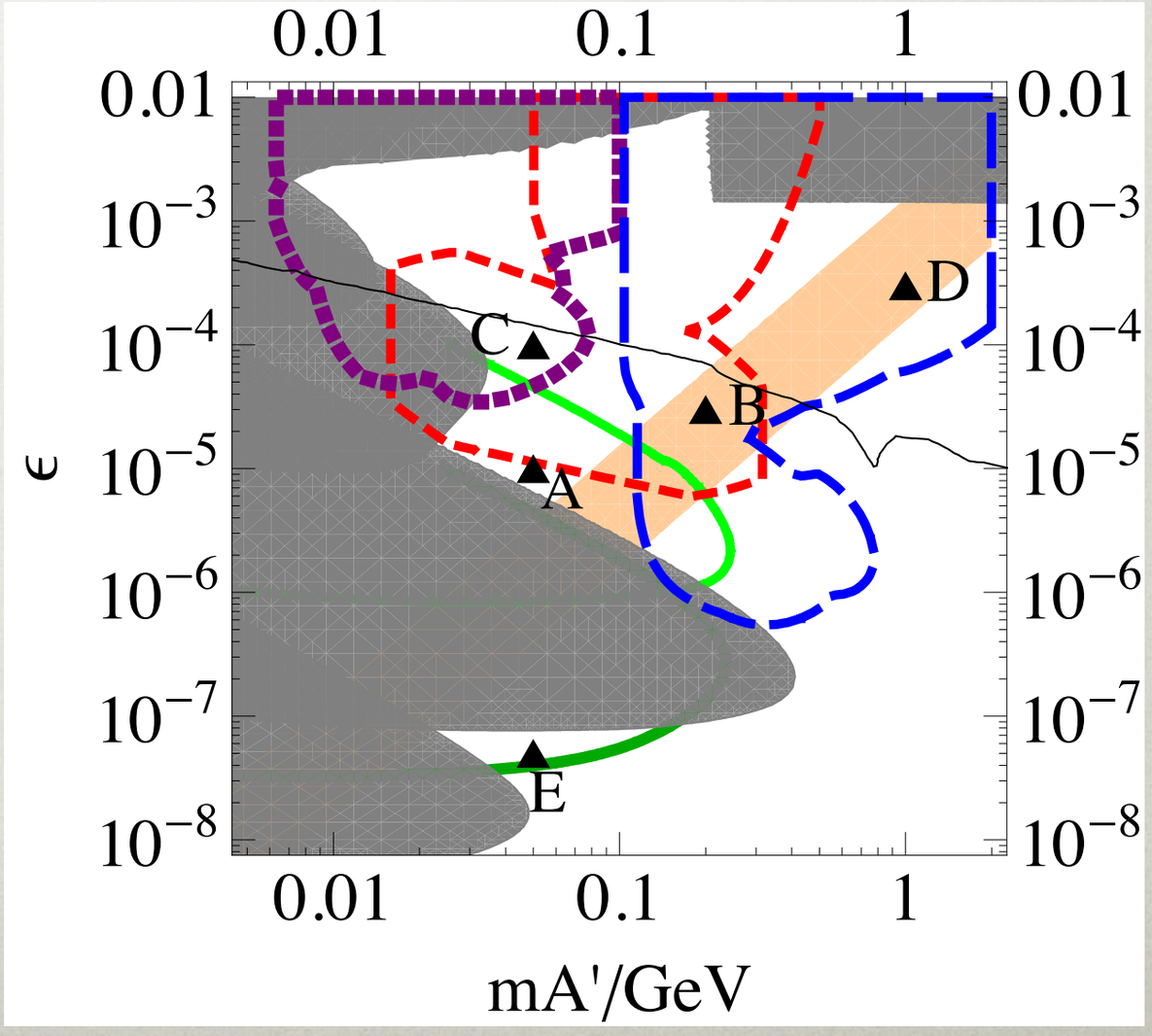
Bjorken, Essig, Schuster, Toro



2. Intensity

- Light, weakly coupled objects

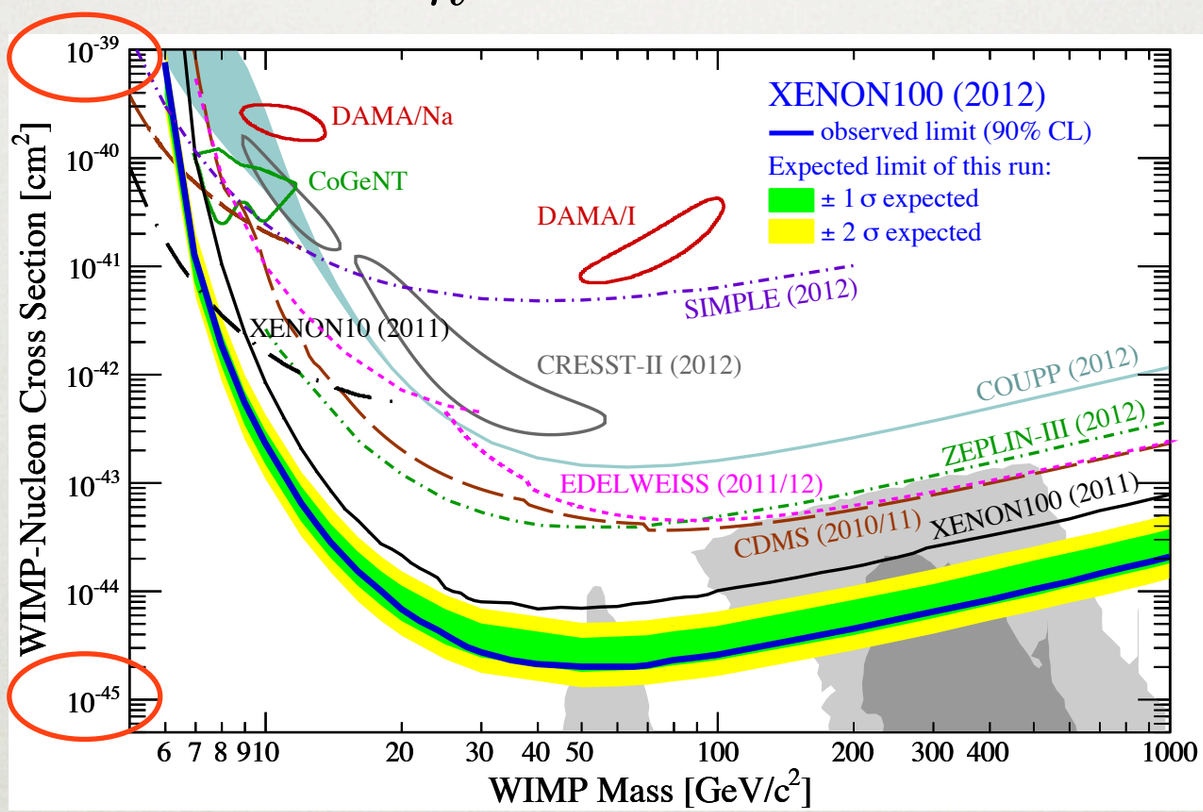




3. Direct Detection is Cosmic Intensity Frontier

Scattering through the Z boson: ruled out

$$\sigma_n \sim 10^{-39}\ \mathrm{cm}^2$$

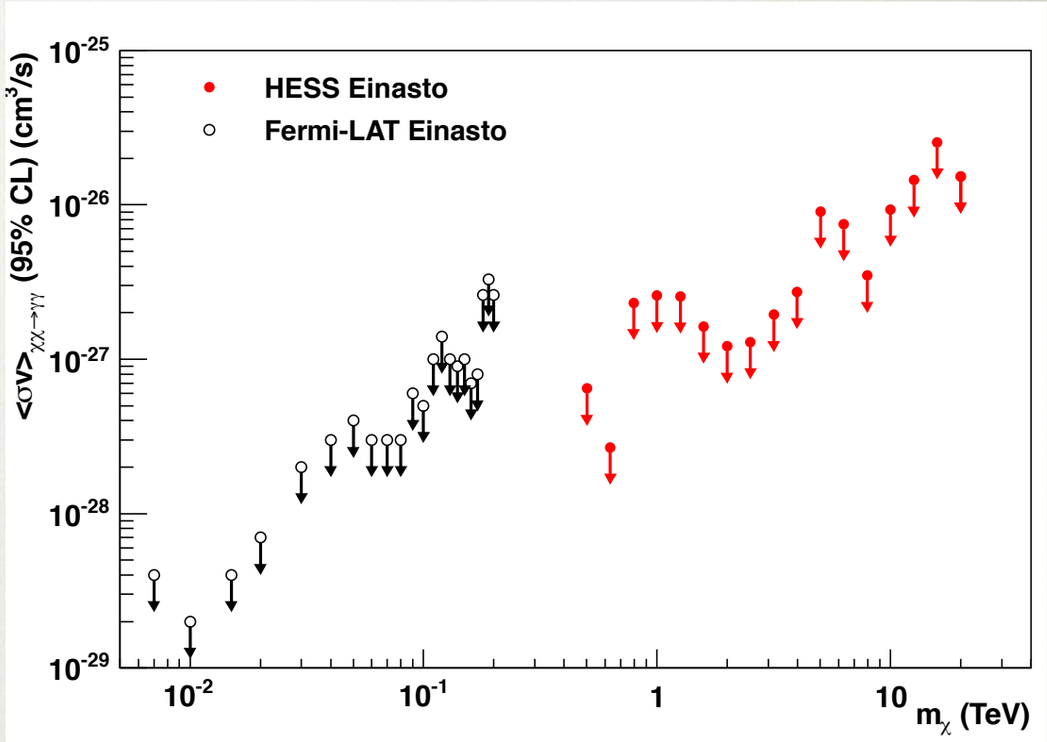


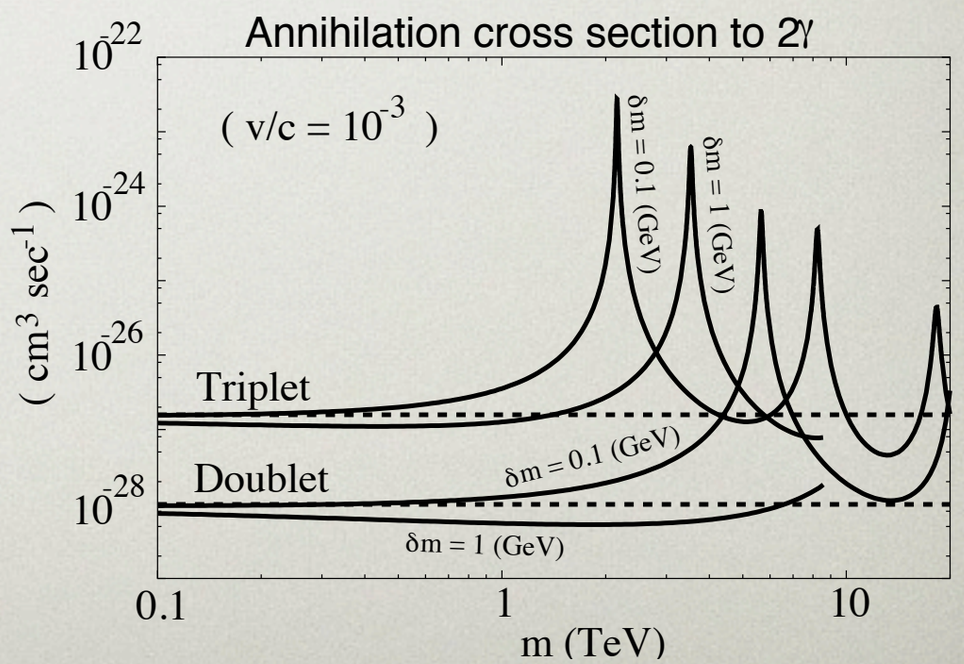
Next important benchmark:
Scattering through the Higgs

$$\sigma_n \sim 10^{-45-46}\ \mathrm{cm}^2$$

Cosmic Intensity Frontier for Neutralino

- Make the Neutralino a pure state -- coupling to Higgs vanishes
- However, Wino and Higgsino pure states can be probed by indirect detection





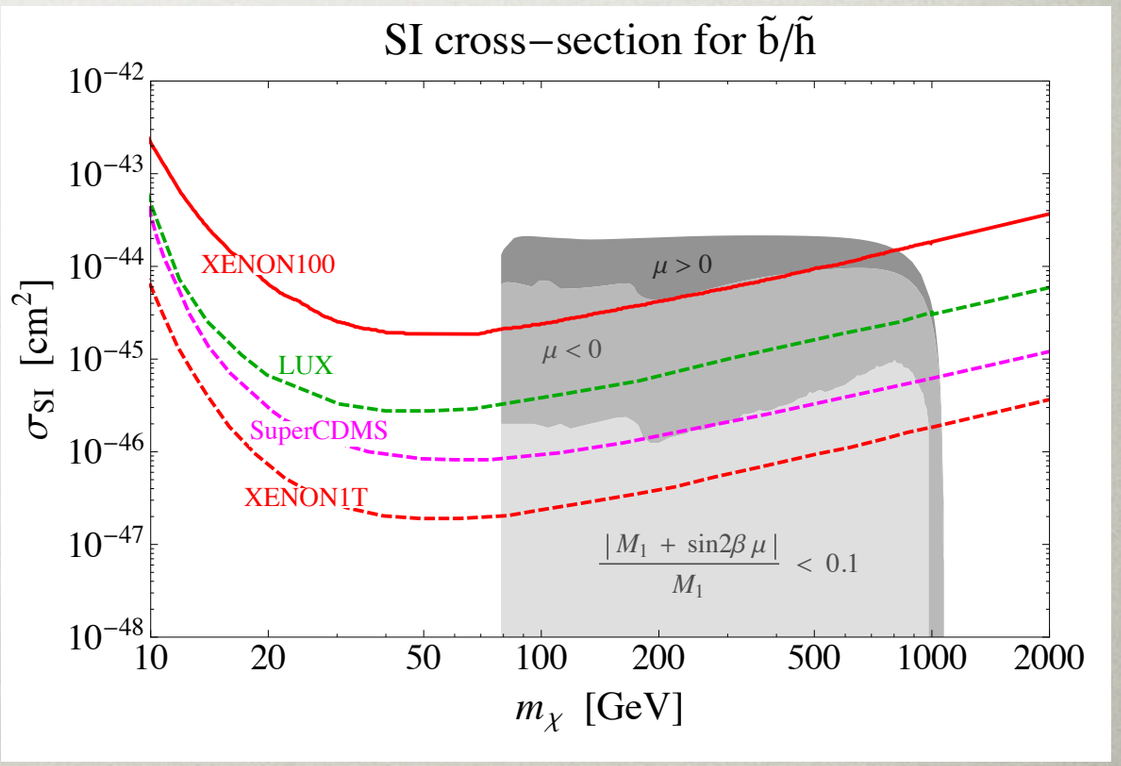
Hisano, Matsumoto, Nojiri, Saito

Always a Way Around

- Tune away the coupling to the Higgs
- Smaller cross-sections correspond to more tuning in the neutralino components

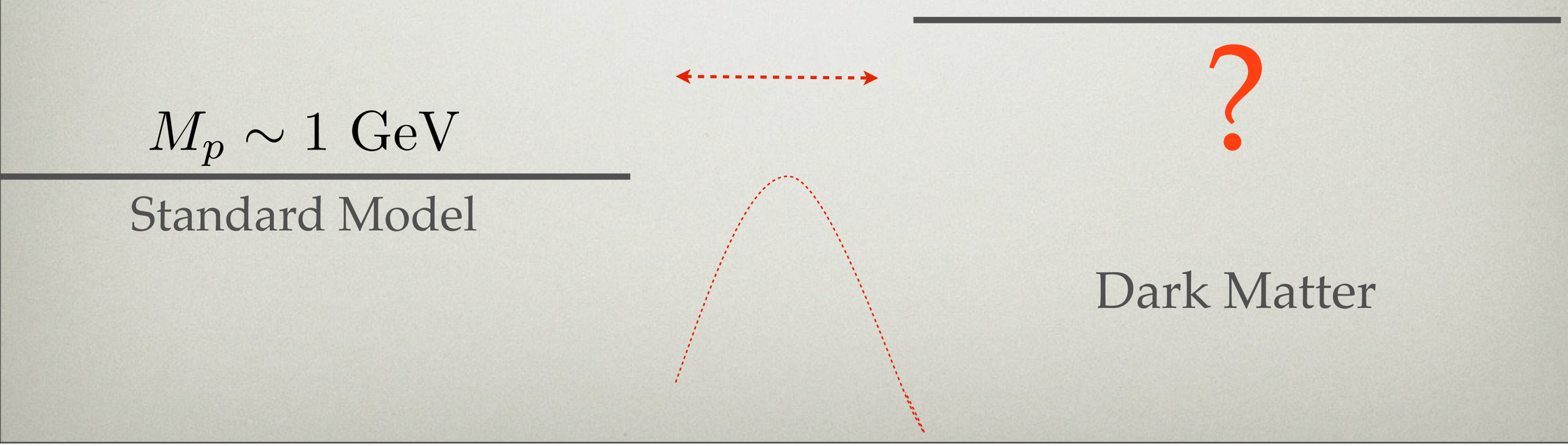
$\mathbf{m}_\chi$	**condition**
M_1	$M_1 + \mu \sin 2\beta = 0$
M_2	$M_2 + \mu \sin 2\beta = 0$
$-\mu$	$\tan\beta = 1$
M_2	$M_1 = M_2$

Cheung, Hall, Pinner, Ruderman



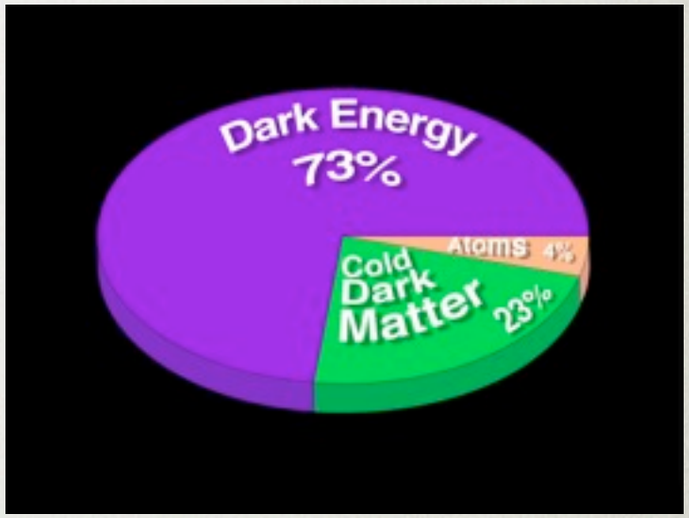
3. Direct Detection is Cosmic Intensity Frontier

- Light, weakly coupled hidden sectors
- Applies to both mass of DM particle and the nature of the scattering process



Light WIMPs: Asymmetric Dark Matter

- Standard picture: freeze-out of annihilation; baryon and DM number unrelated
- Accidental, or dynamically related?

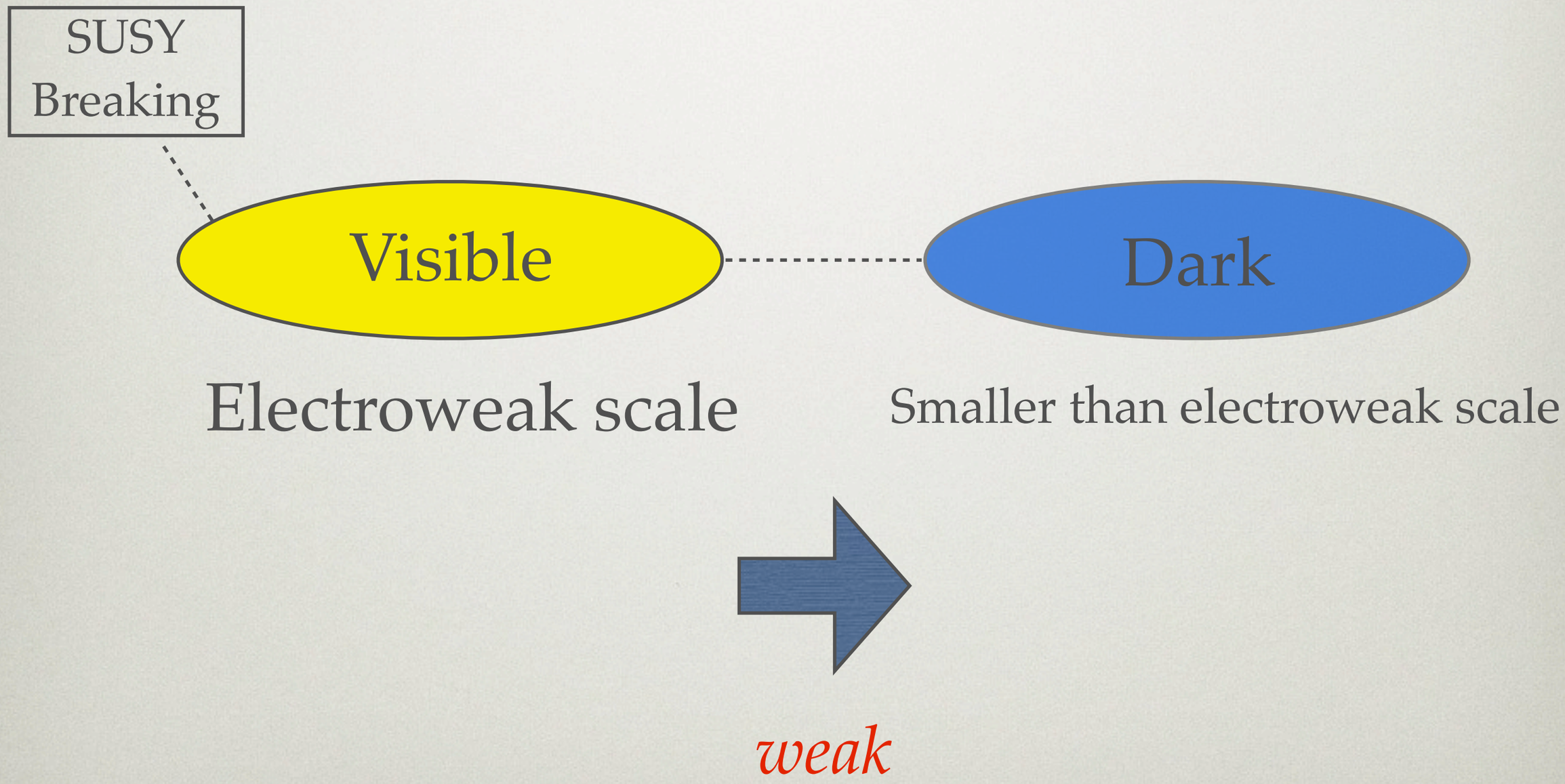


Experimentally, $\Omega_{DM} \approx 5\Omega_b$

Mechanism $n_{DM} \approx n_b$

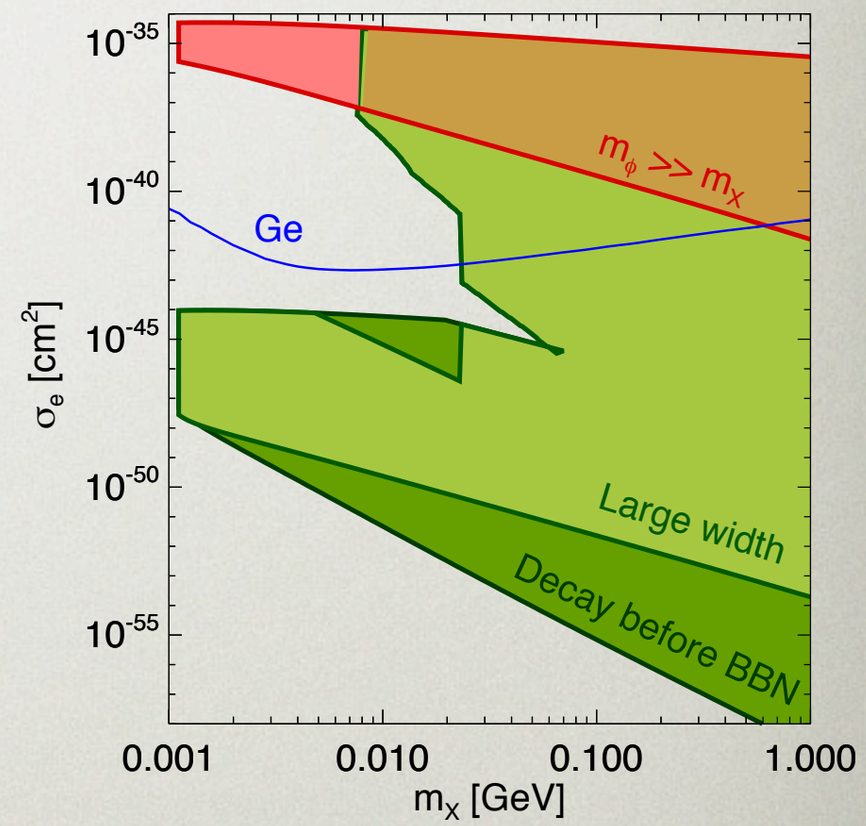
$\Rightarrow$ $m_{DM} \approx 5m_p$

Light WIMPs: Hidden Supersymmetric DM



Light WIMPs: Good and Bad for Direct Detection

- Good: definite mass predictions
- Bad: prediction for scattering cross-section in direct detection model dependent
- For very light DM, scattering off electrons is most important process



Lin, Yu, KZ
Ge line from Essig, Mardon, Volansky

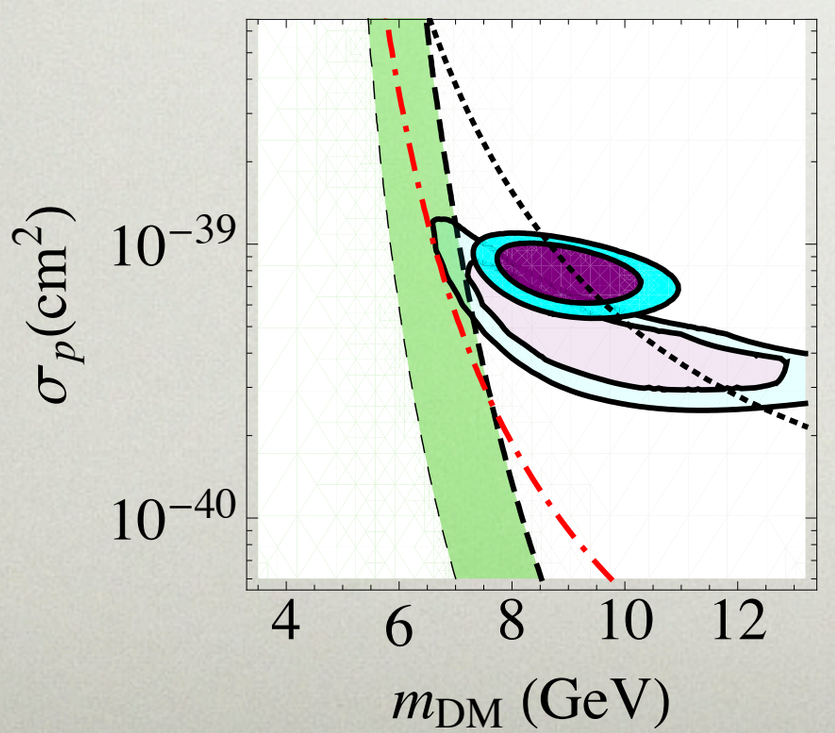
3. Cosmic Frontier and Light DM

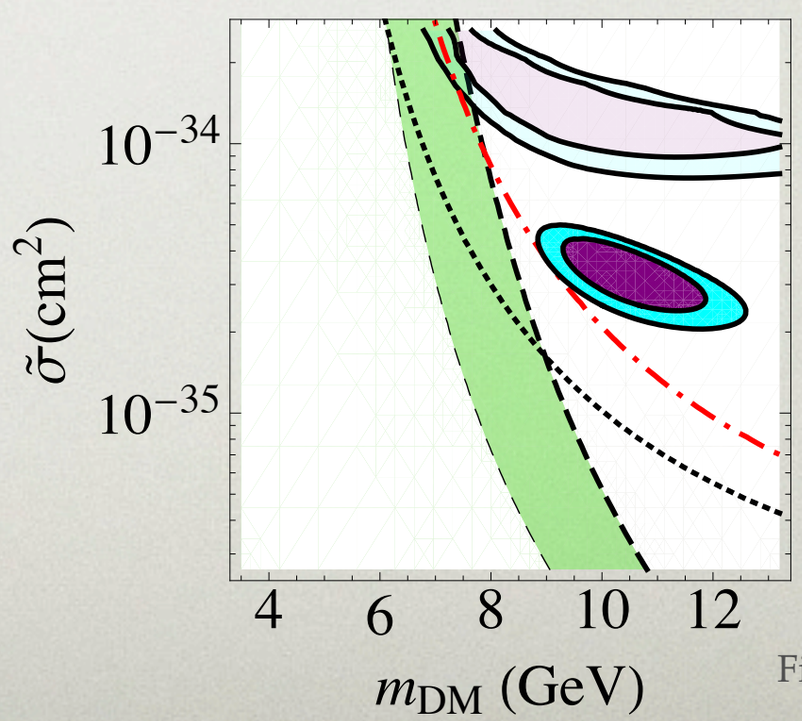
- CDMSLite
- CDMS Low Threshold
- Modified configurations of Xenon detectors for more light collection?
- CoGeNT
- COUPP
- DAMIC
- DM Ice
- Helium Targets
- DNA Detectors
- .....
- How do we get to lower thresholds?

Let many flowers bloom!

3. Cosmic

- Simplest case: non-standard momentum dependence in scattering cross-section due to light mediator
- *Dynamics* in direct detection



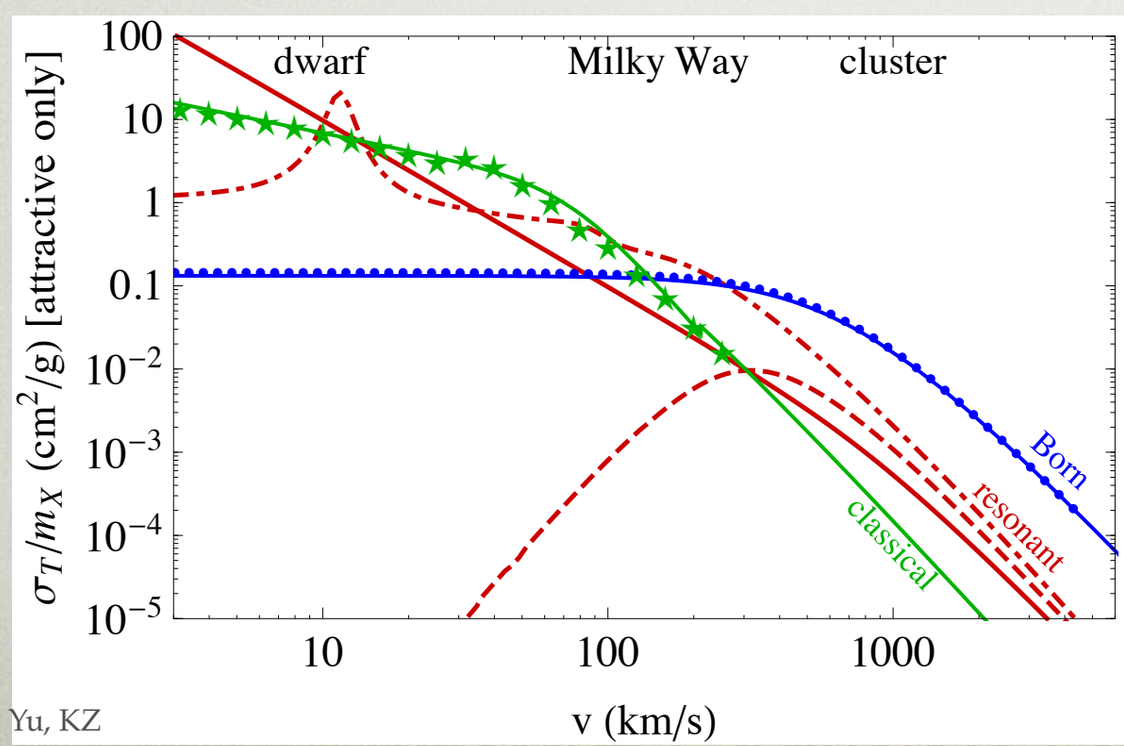


Fitzpatrick, KZ

3. Cosmic

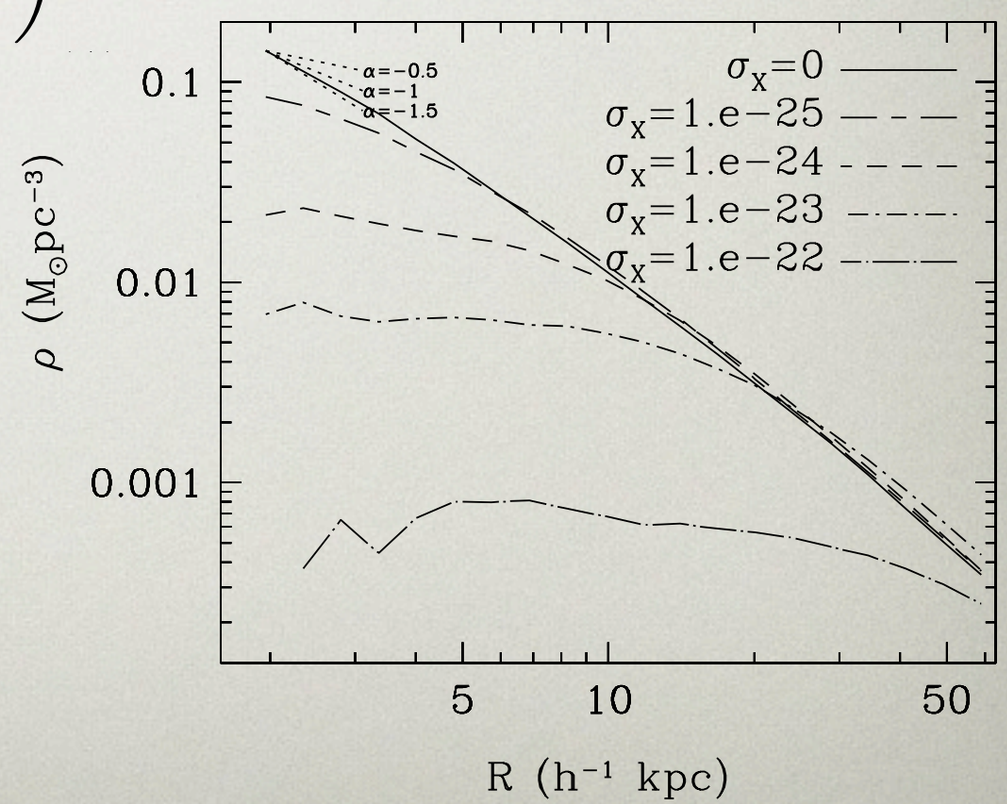
- *Dynamics* in astrophysical objects
- Self-interacting DM

$$\sigma_T \approx 5 \times 10^{-23}\,\mathrm{cm}^2 \left(\frac{\alpha_X}{0.01}\right)^2 \left(\frac{m_X}{10\,\mathrm{GeV}}\right)^2 \left(\frac{10\,\mathrm{MeV}}{m_\phi}\right)^4$$



Tulin, Yu, KZ

Dave, Spergel, Steinhardt, Wandelt



Questions?

- How much of the domestic program should be invested here?
- Is this a (partial) solution to investing all resources in large international collaborations on the energy frontier?
- What is the suite of small to medium scale experiments that can have a big impact on “crazy” physics?