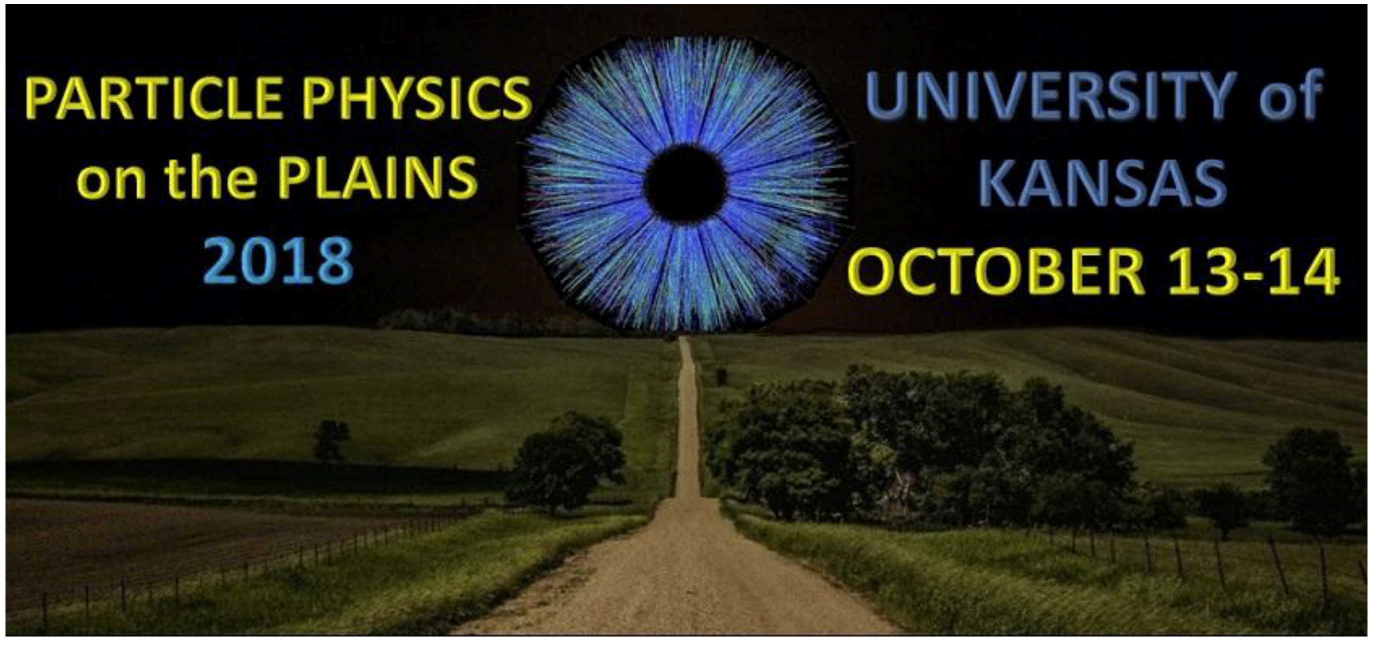
GeV-Scale Messengers of Planck-Scale Dark Matter

Gopolang Mohlabeng

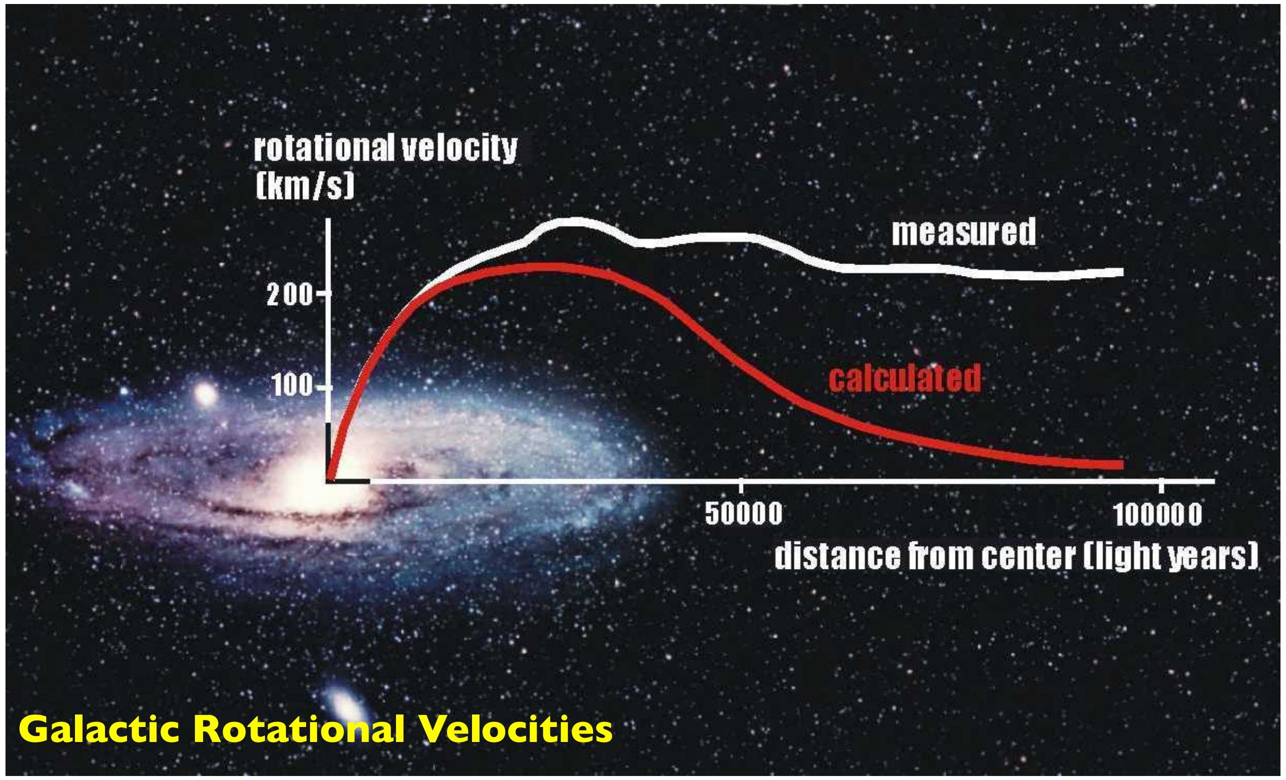
BROOKHAVEN NATIONAL LABORATORY

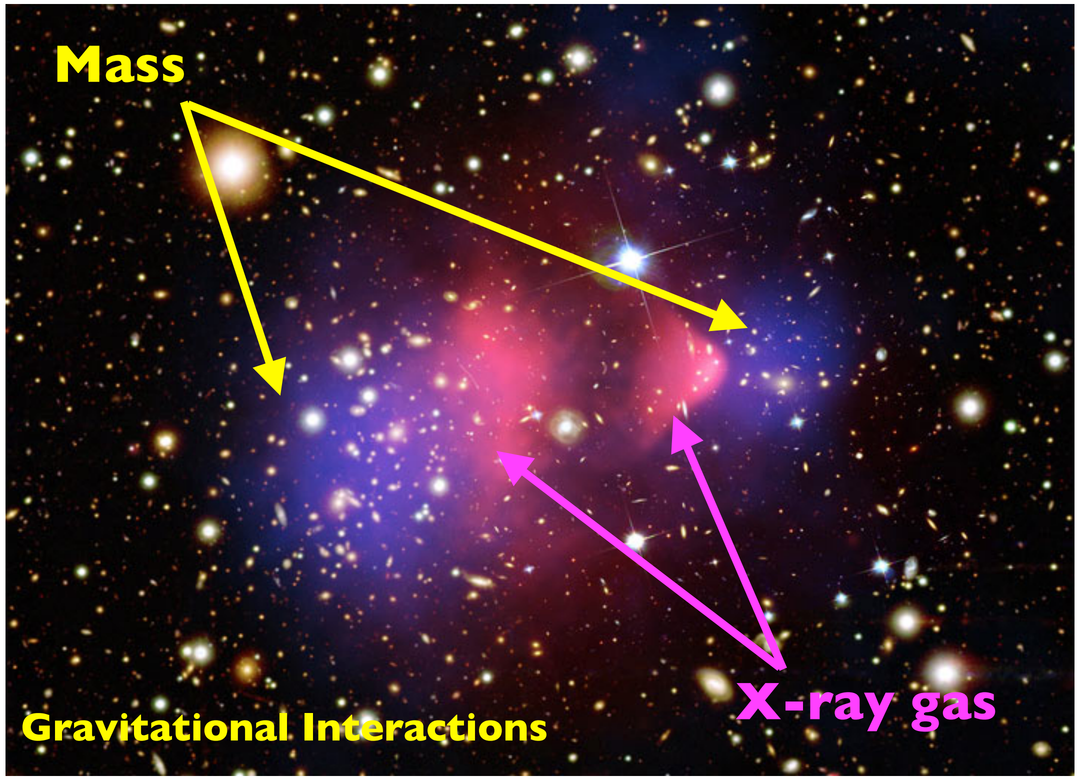
+ Hooman Davoudiasl

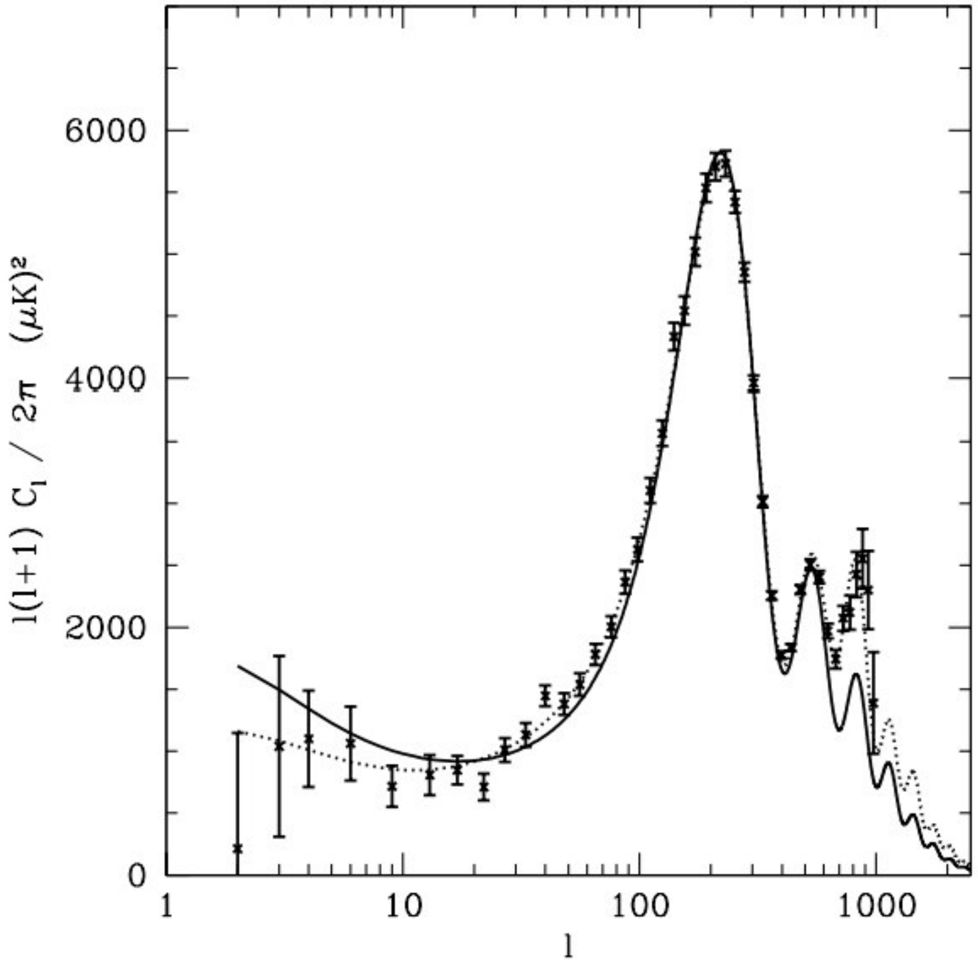
Based on arXiv:1809.07768



Various observations point to existence of Dark Matter in our Universe







Primordial Fluctuations

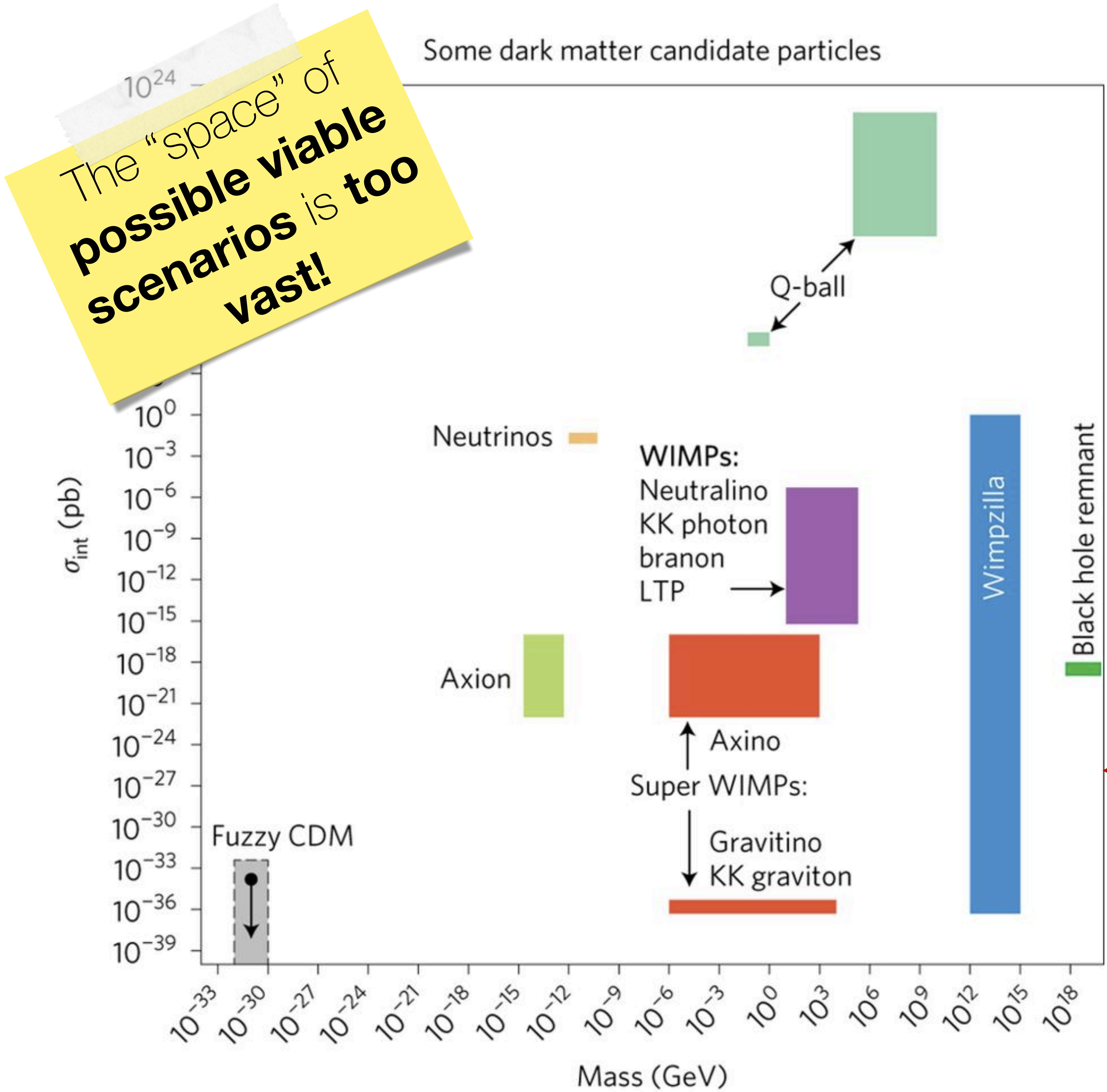
+ Many more .....

The (Inconvenient) Truth about DM

If particle DM exists, **we don't know much about it**

1. Mass = ???
2. Spin = ???
3. Decays = ???
4. Interactions = ***Gravity***, ???
5. Elementary = ???
6. …

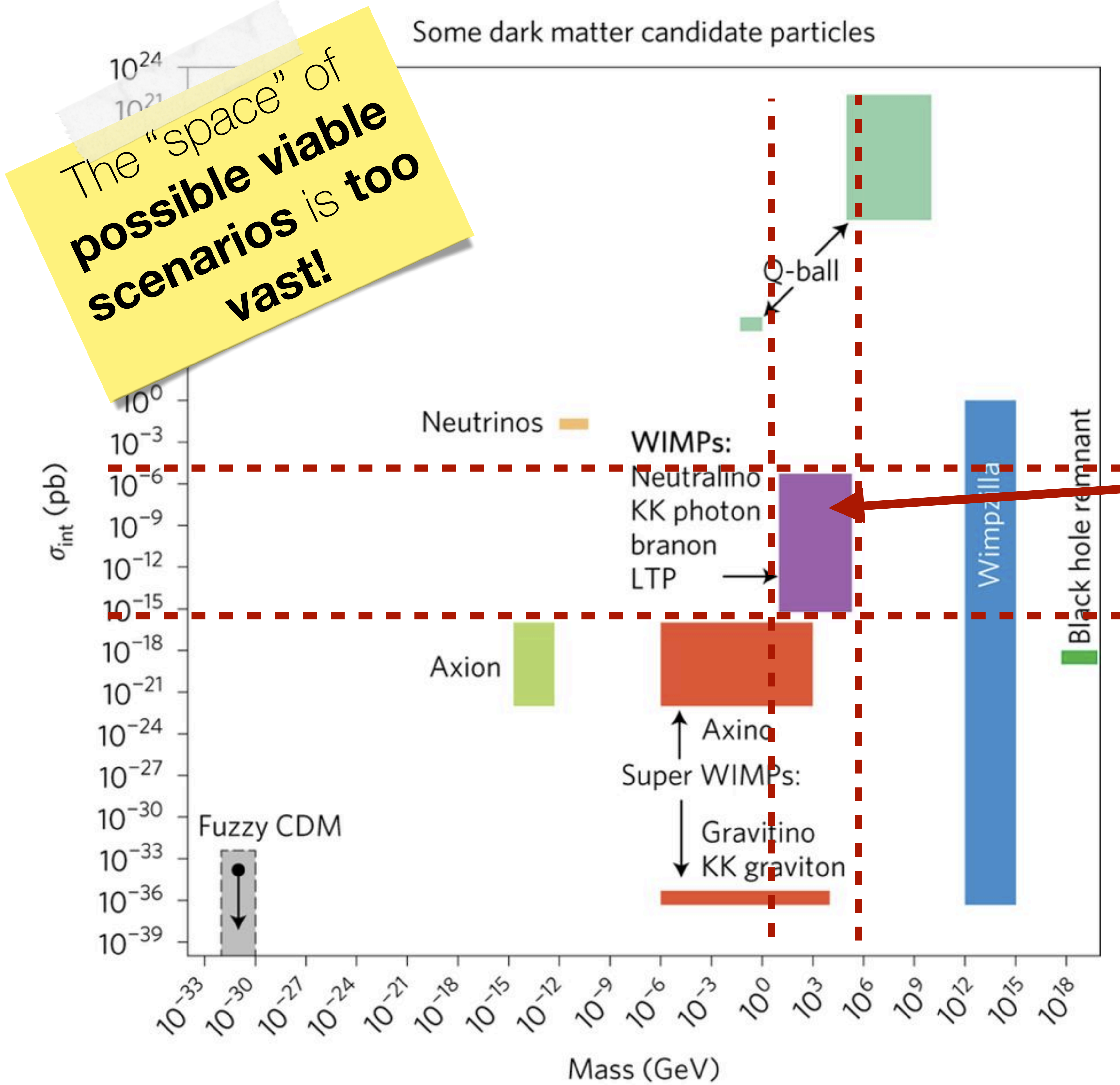
We have no sense of the scale at which DM resides



DM models alone span many orders of magnitude in energy scales

All guided by theoretical motivation

e.g WIMP DM



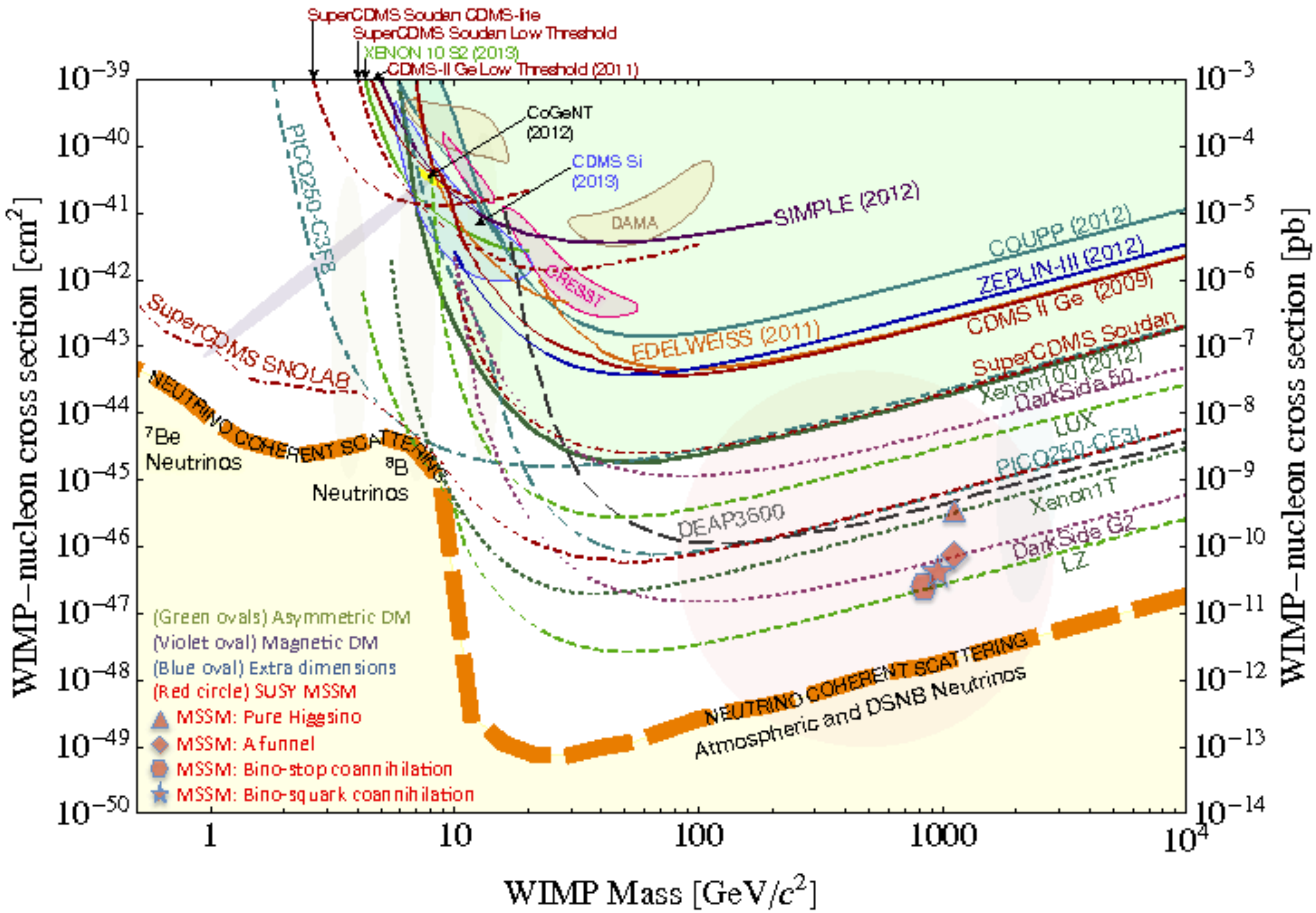
Even if you only consider **WIMPs**, they span:

6 orders of magnitude in mass and

9 orders of magnitude in interaction cross section

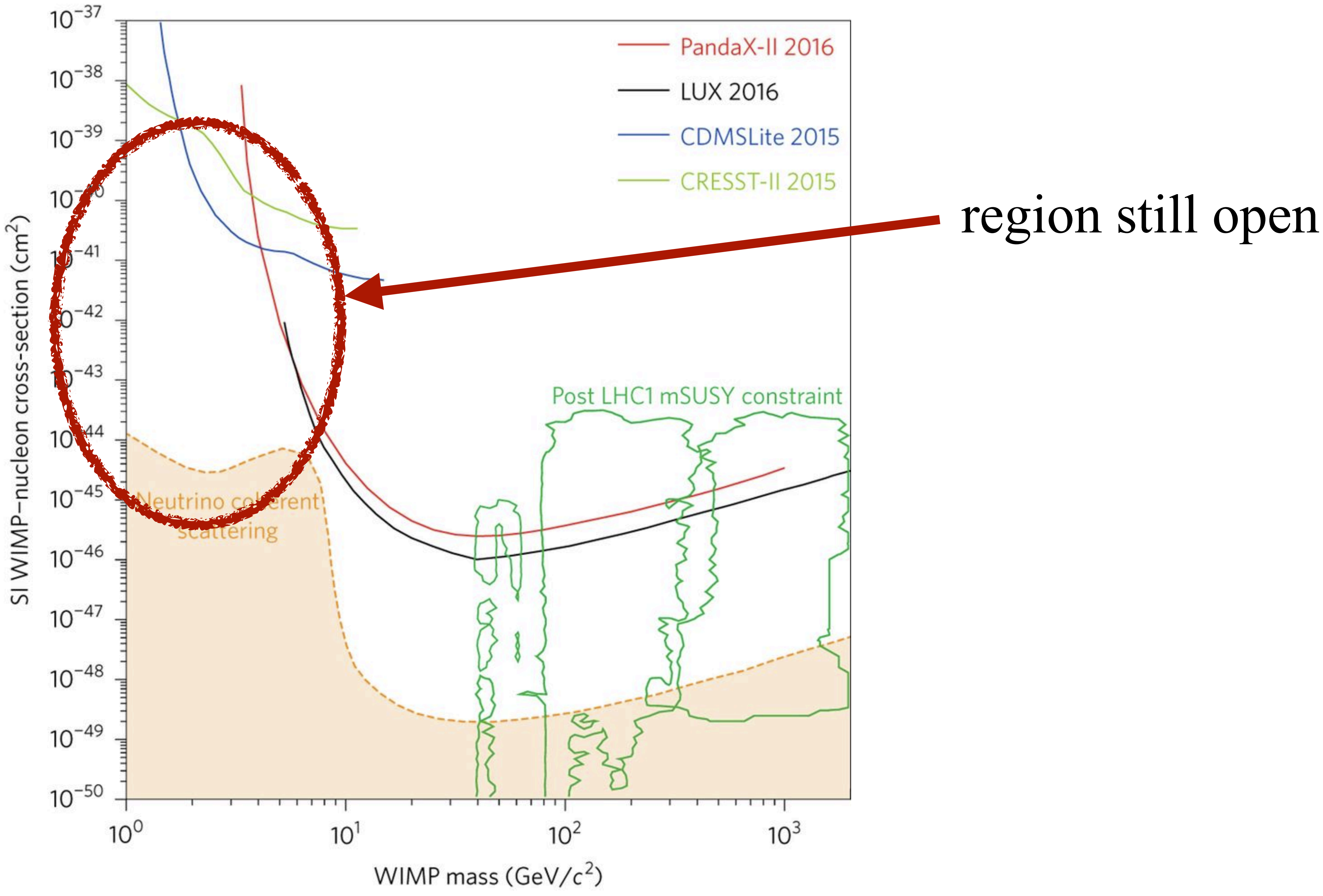
Searches motivated by potential connection to EW physics

e.g. Direct detection searches for DM in this range

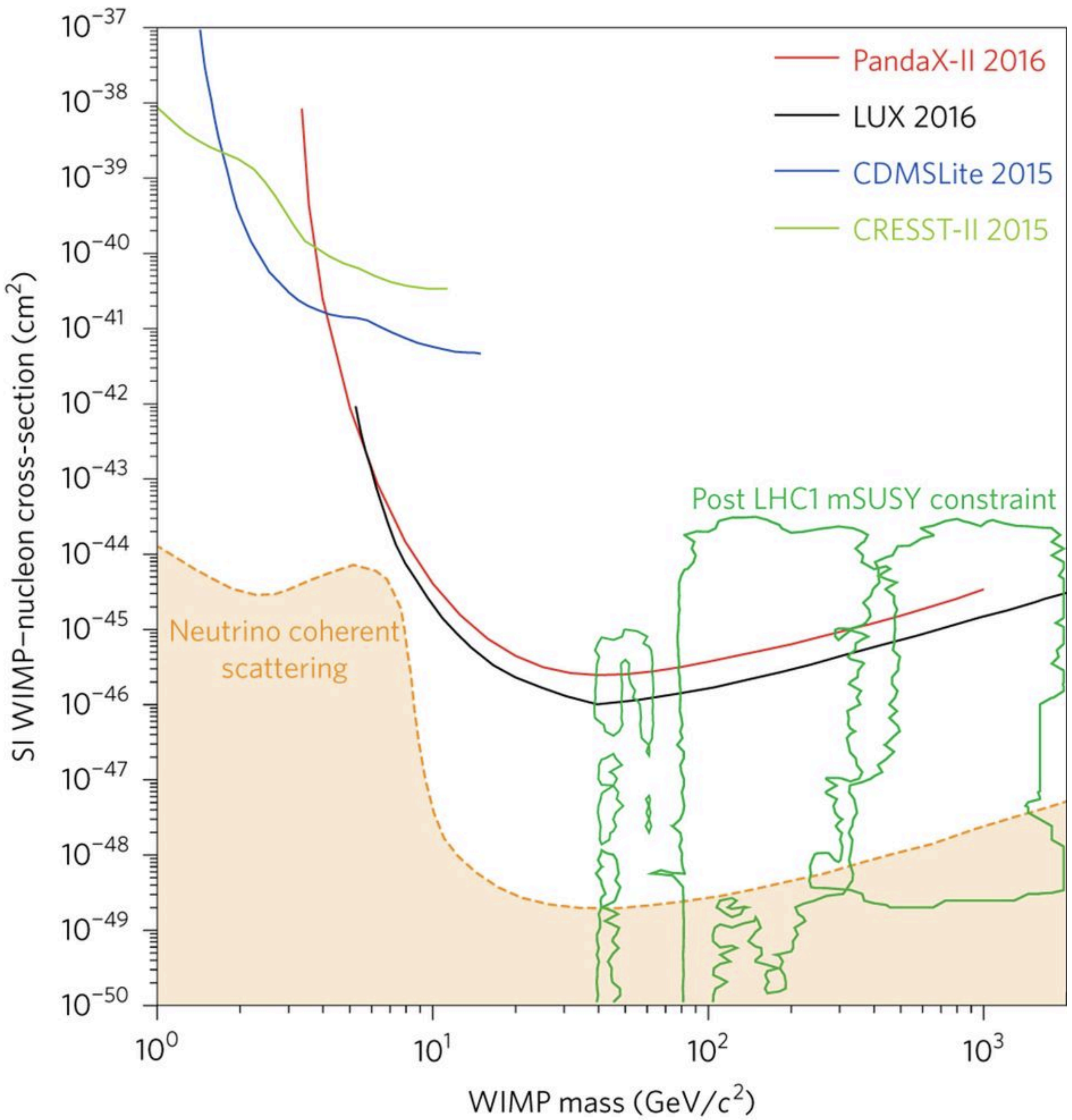


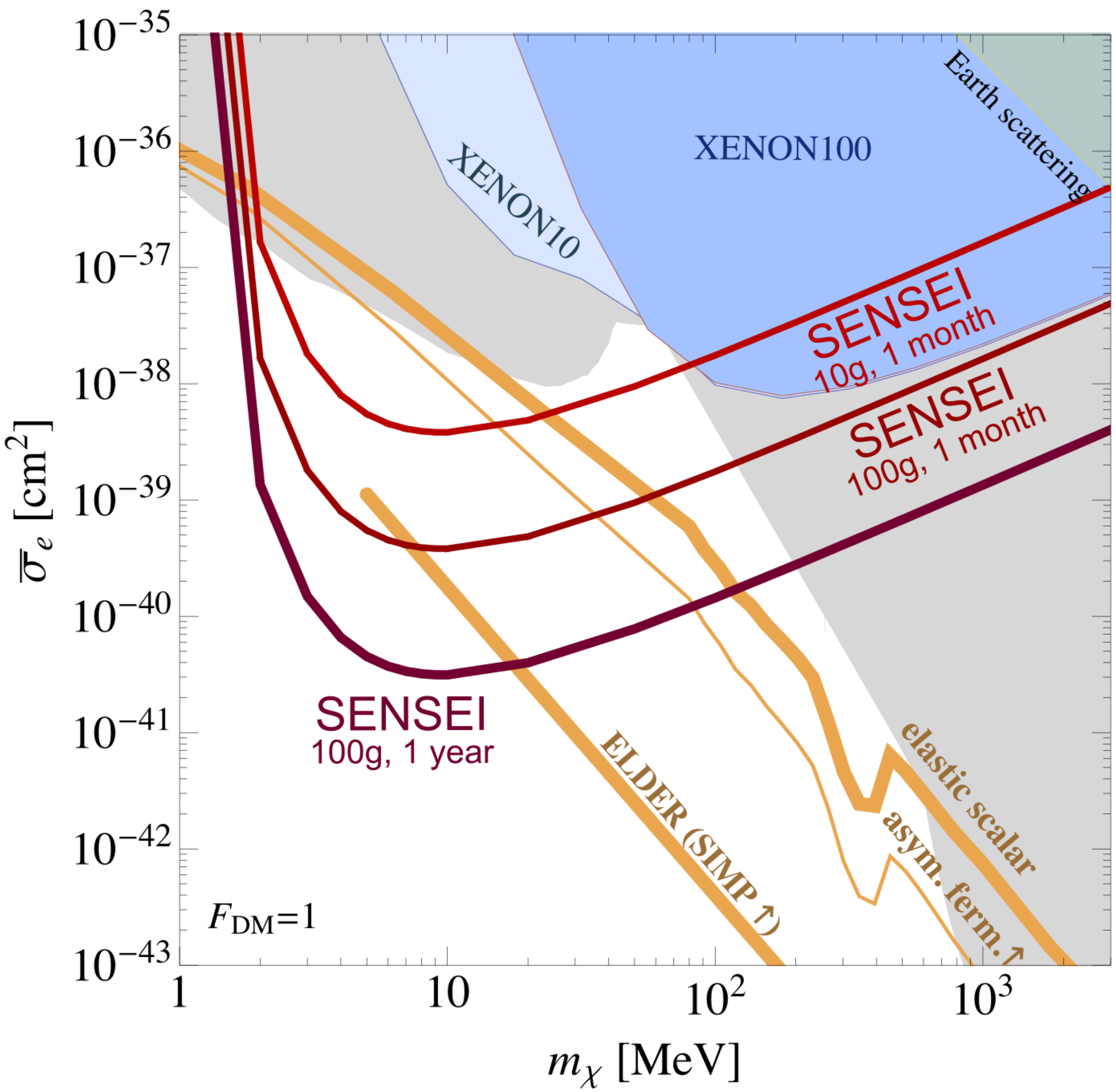
However DM at this scale is heavily constrained

Motivated Searches away from the weak scale, mainly toward sub-GeV scale



Motivated Searches away from the weak scale, mainly toward sub-GeV scale





Electron recoil allows for probing lower energy thresholds and accessing lower mass

Also experiments designed to search for Axions and ALPs, much lower masses

Nothing stops us from searching above weak scale

How far above the weak scale?

- Planck Mass
- Scale of quantum gravity
- GUT scale

← reasonable targets

Masses of order $10^{15} - 10^{19}$ GeV

Lets call this Planck Scale DM (PSDM)

Outline

- I will give motivation for PSDM

- I will introduce a possible model for PSDM

- Discuss the model constraints

- Give some brief conclusions

Potential Problems of PSDM

$n_{DM} \sim \dfrac{1}{M_{DM}}$: Number density of larger particles is smaller

$M_{DM} > 100\ \mathrm{TeV}$: Leads to overclosure of Universe if produced <u>thermally</u>

Cannot produce such heavy particles at a collider

unless collider is size of solar system

But….

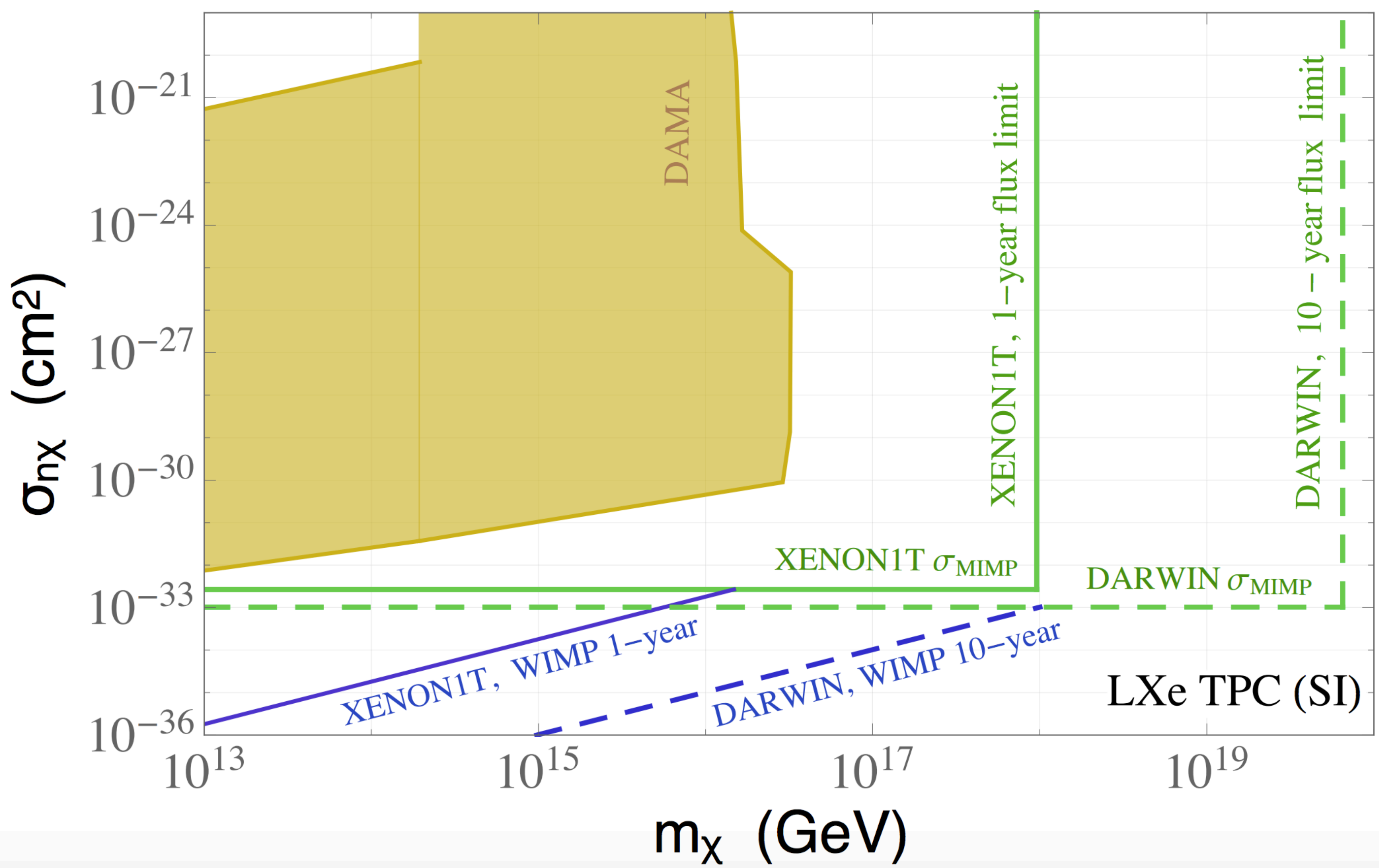
Lower number density $\Rightarrow$ experiments not very sensitive to PSDM

$\Rightarrow$ PSDM may interact stronger with SM than weak scale DM

May scatter multiple times in detector

Multiple scattering signature would be a "smoking gun"

Multiple scattering can be searched for at current experiments



Bramante, Broerman, Lang & Raj, arXiv:1803.08044

DD limits extrapolated to include Multi-Scattering and Single Scattering

Cross-sections of order $10^{-36} - 10^{-30}\text{cm}^2$

What kind of physics can give these kind of cross-sections?

- Simplest possibility is to consider very light mediators between these very large scales and the SM

- Vector bosons associated with gauge symmetries well motivated

- To keep vector light compared to Planck scale, need resilient gauge symmetry, not easily broken

Simplest gauge group $U(1)$ enjoys this property

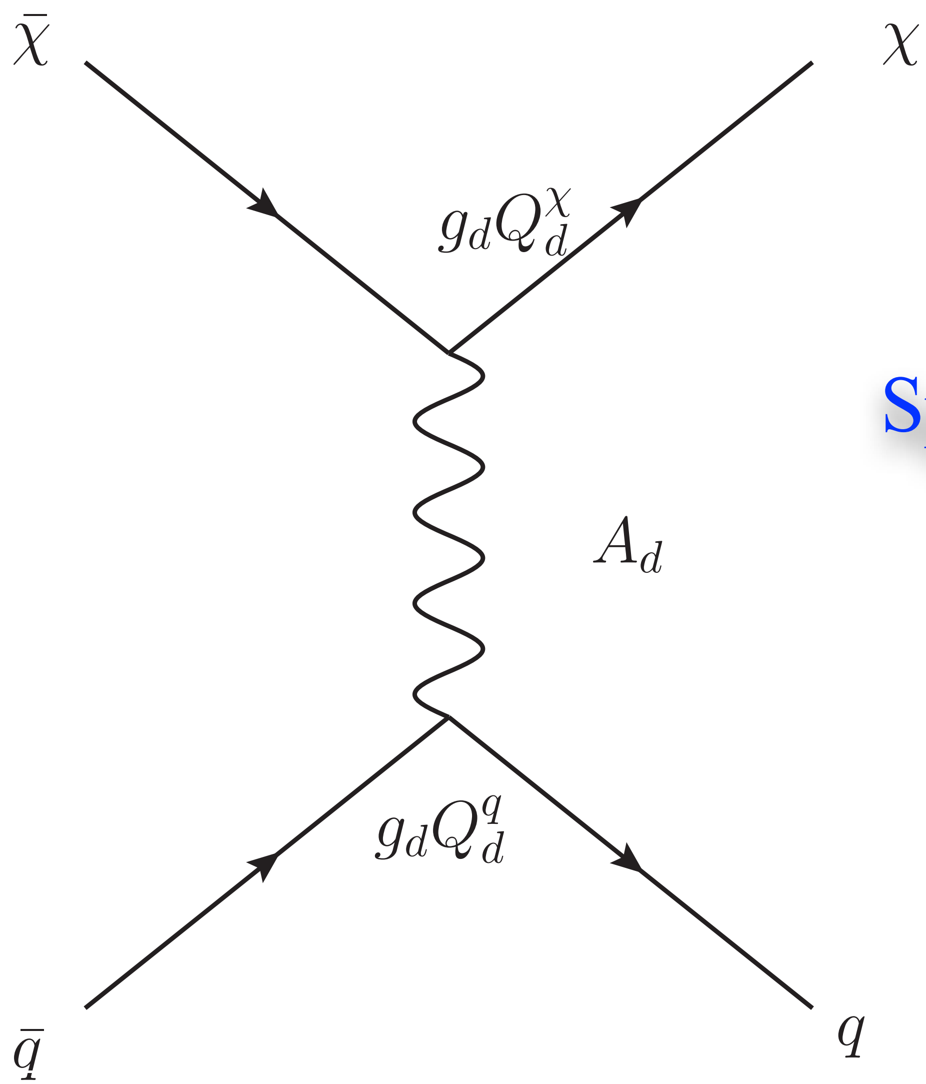
Halverson & Langacker, arXiv:1801.03503

We propose a "dark" gauge group $U(1)_d$ which has vector A_d

We want to connect PSDM to nucleons via new vector

$U(1)_d \Rightarrow$ gauged baryon number with

$$\mathcal{L} \supset g_d(Q_d^q \bar{q}\gamma_\mu q + Q_d^\chi \bar{\chi}\gamma_\mu \chi)A_d^\mu + \epsilon.e(\bar{q}\gamma_\mu q + \bar{l}\gamma_\mu l)A_d^\mu$$



Spin Independent PSDM-nucleon cross-section

$$\sigma_{\chi n} \sim \frac{16\pi \mu_{\chi n}^2 (Q_d^n Q_d^\chi)^2 \alpha_d^2}{m_{A_d}^4}$$

$U(1)_B$ is anomalous, i.e. not a consistent gauge theory

Anomaly cancelation requires heavy fermions that are:

- Vector-like under SM
- Chiral under dark sector

Heavy fermions would get mass from U(1) breaking by dark Higgs

Scale of spontaneous symmetry breaking $\gtrsim$ 100 GeV

Dobrescu & Frugiuele, Phys. Rev. Lett. 113, 061801 (2014)

However….

Breaking $U(1)_B$ & preserving EWS results in non-zero Wess-Zumino terms

Giving non-decoupling longitudinal mode of vector showing up in low energy processes

Dror, Lasenby & Pospelov, Phys. Rev. Lett. 119, 141803 (2017)

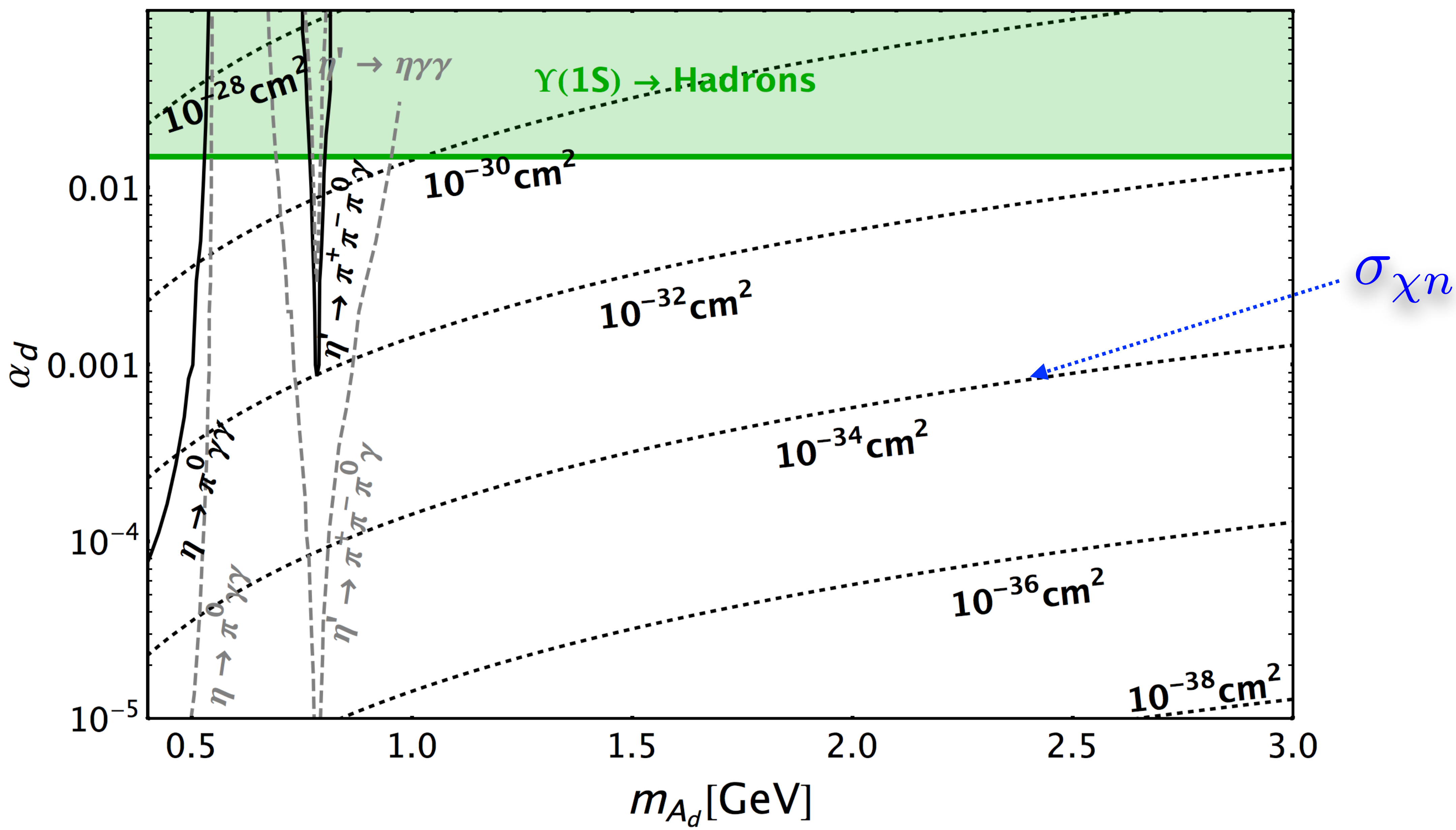
Effects show up in:
- B-meson decays
- Z-boson decays

If $U(1)_B$ breaking is different i.e. not EWS preserving

No longitudinal mode effects

PSDM may show up through multiple scattering in detector

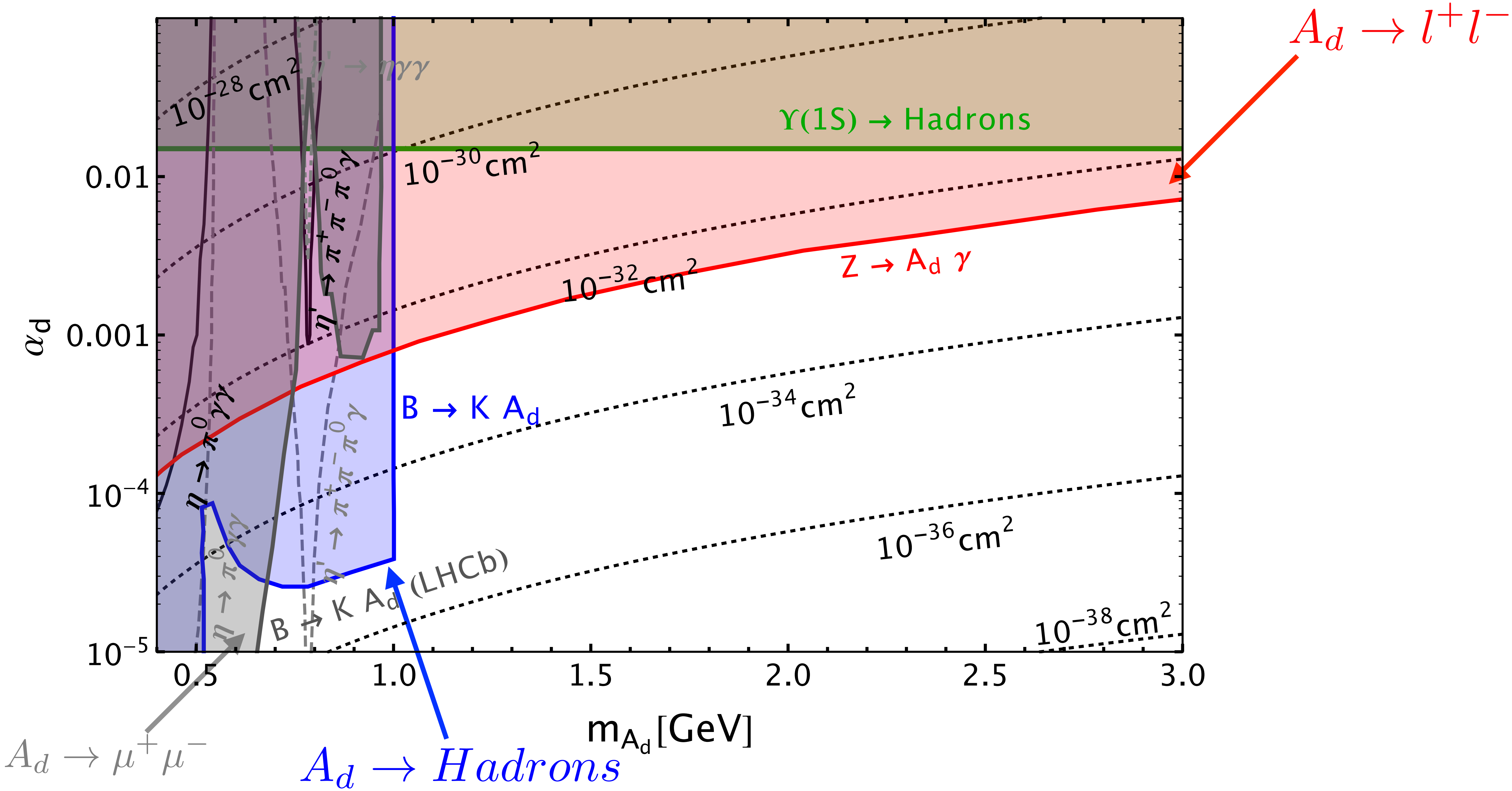
Messenger particle maybe searched for in complementary manner at low energy experiments



Davoudiasl & G.M, arXiv:1809.07768

Including longitudinal mode enhancements

Were made assuming: $\epsilon = \frac{e g_d}{(4\pi)^2}$

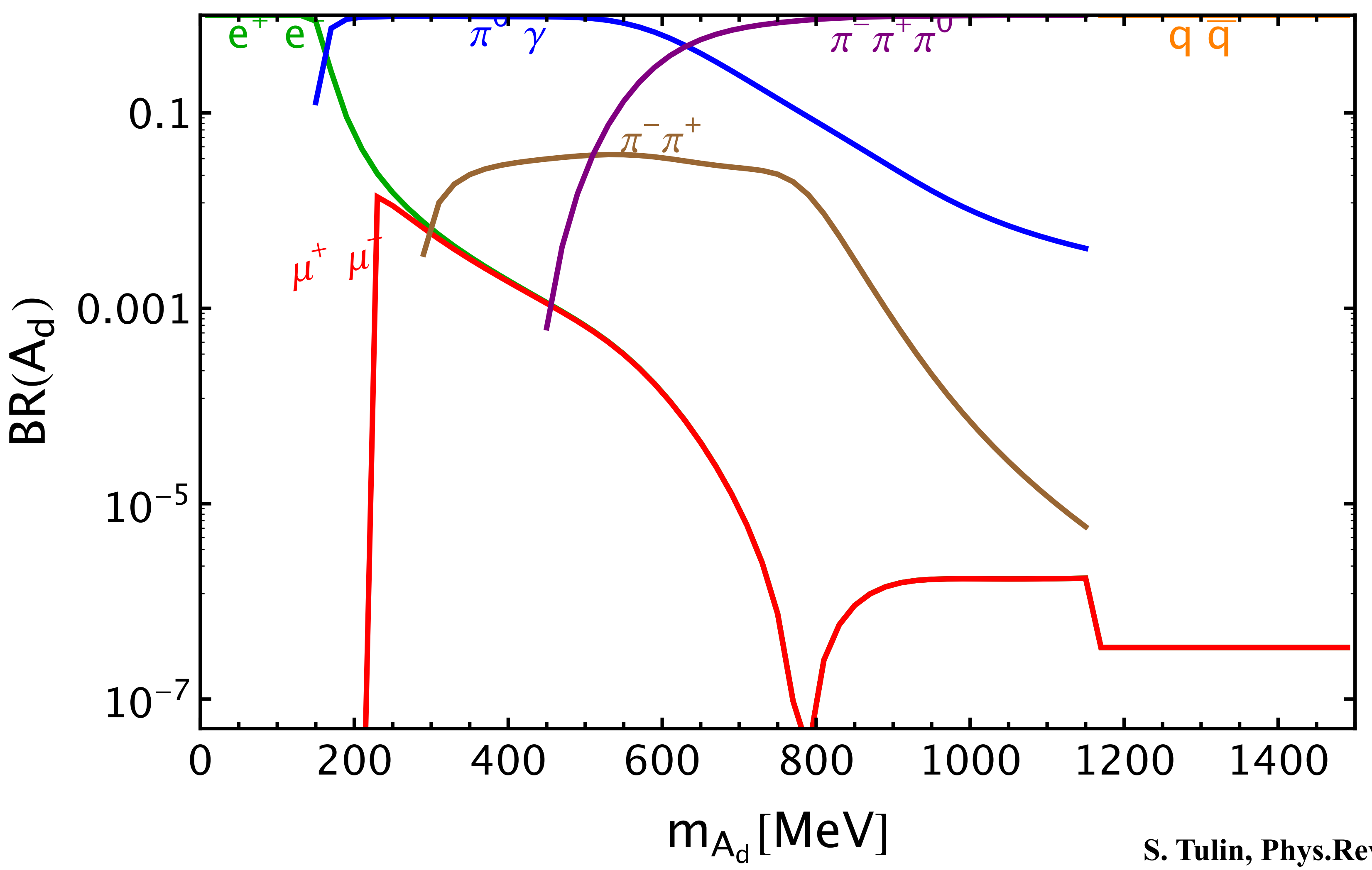


can still get: $\sigma_{\chi n} \sim 10^{-33} - 10^{-38}\text{cm}^2$

$$\mathcal{L} \supset g_d(Q_d^q \bar{q}\gamma_\mu q + Q_d^\chi \bar{\chi}\gamma_\mu \chi)A_d^\mu + \epsilon.e(\bar{q}\gamma_\mu q + \bar{l}\gamma_\mu l)A_d^\mu$$

$BR(A_d \to l^+l^-)$ suppressed by $\left(\frac{\epsilon e}{g_d Q_d^q}\right)^2 \lesssim 10^{-2}$

Experiments like BaBar searching for $A' \to l^+l^-$ less sensitive to A_d



Assume A_d has similar quantum numbers to ω-meson

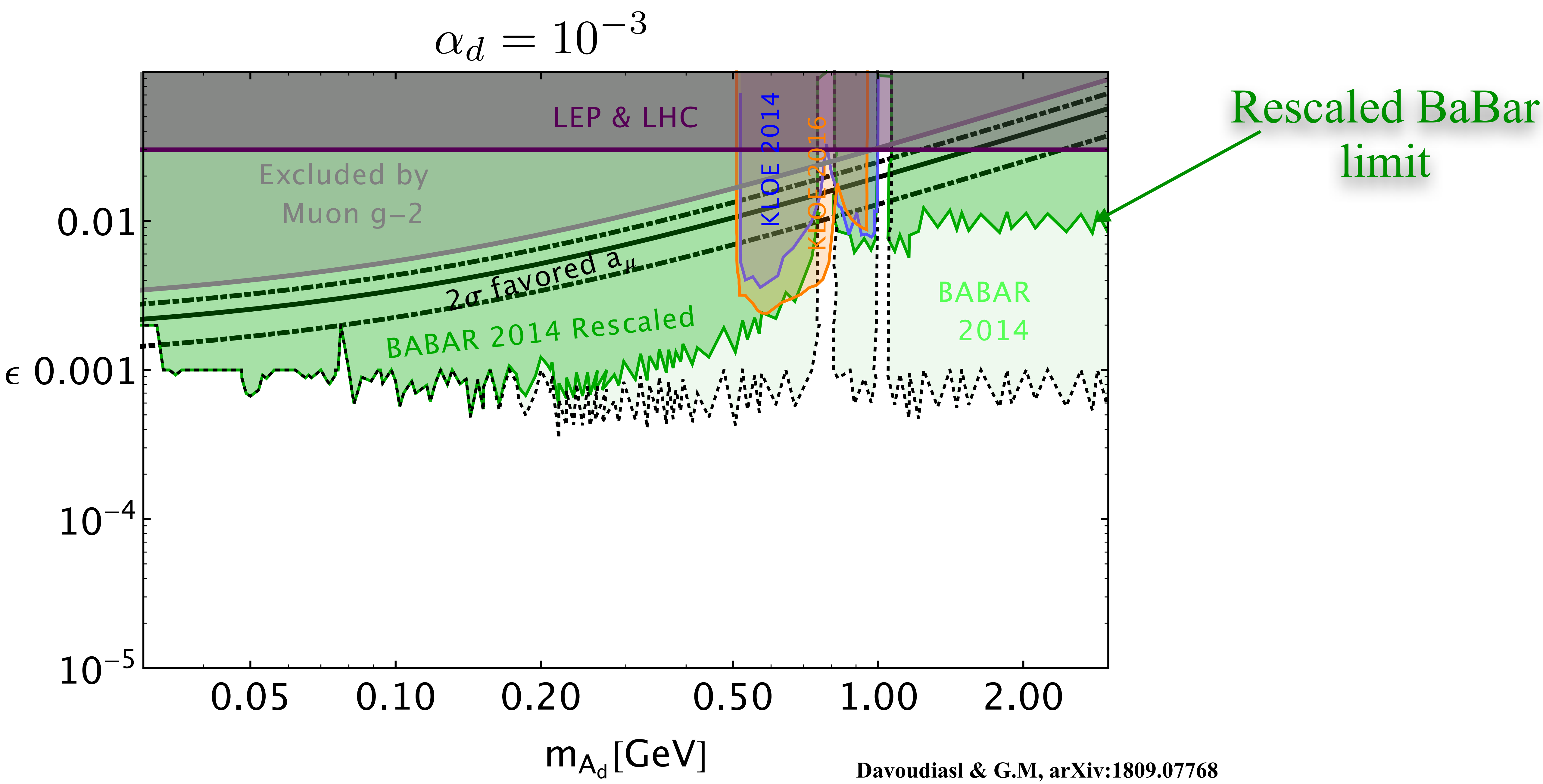
Above m_π threshold A_d goes to hadrons

S. Tulin, Phys.Rev. D89 (2014) no.11, 114008

We can recast the BaBar visible decay limit using

$$N_{A_d} = \sigma_{A_d\gamma} BR(A_d \to l^+ l^-)\mathcal{L}$$

Assuming $N_{A_d} \approx N_{BaBar}$



Davoudiasl & G.M, arXiv:1809.07768

Conclusions

- We need to look at many avenues in our search for Dark Matter

DM at the Planck Scale is one possibility

- We propose a model of gauged baryon number connecting low energy physics to Planck scale

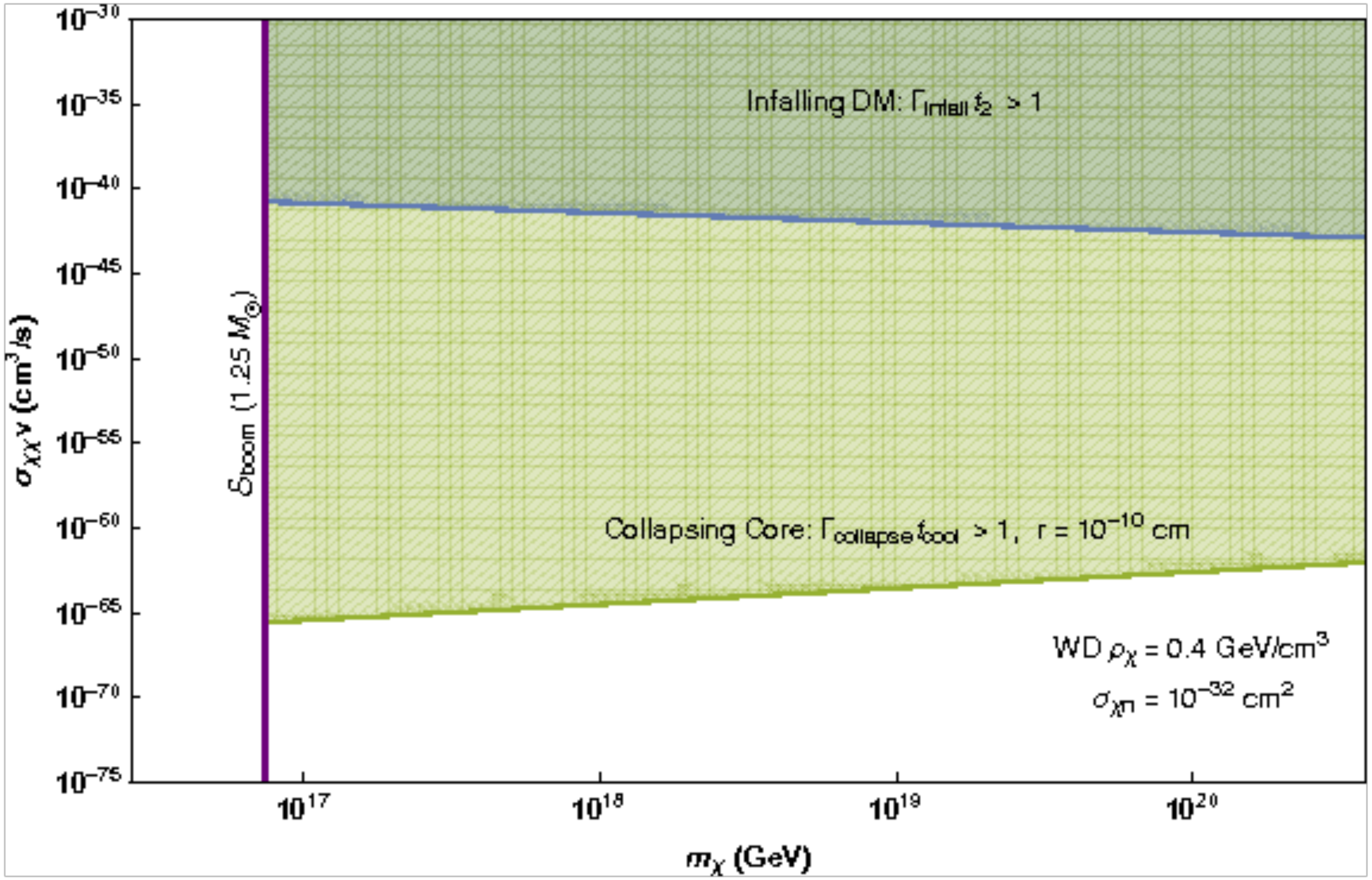
- We calculate the DD cross-sections needed for multiple scattering and provide low energy constraints on messenger particle

- We argue that baryon number maybe be the best way to connect PSDM to SM while maintaining potential for “smoking gun” signals

DM may be at Planck Scale, we just have to be open to the idea

Back up Slides

White Dwarf constraints on PSDM



$$\sigma_{\chi\chi} v_\chi \sim \frac{4\pi\alpha_d^2}{m_\chi^2}$$

$$\sim 10^{-54}\mathrm{cm}^3/\mathrm{s}$$

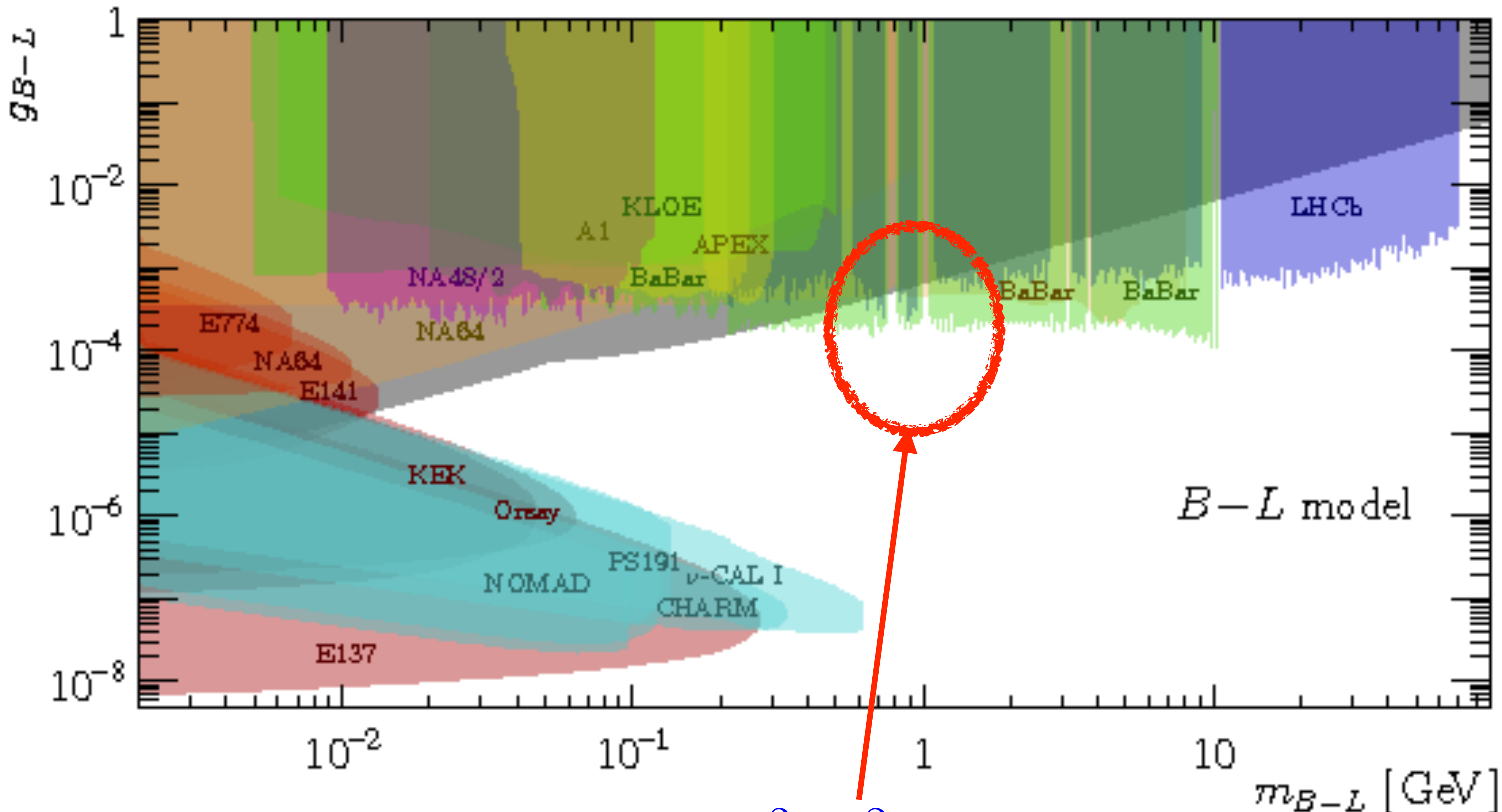
for $m_\chi \sim 10^{17}\mathrm{GeV}$

& $\alpha_D \sim 10^{-2}$

Graham, Janish, Narayan, Rajendran & Riggins, arXiv:1805.07381

What about other mediators?

How about gauged B-L?



$$\sigma_{\chi n} \sim \frac{\mu_{\chi n}^2 \alpha_{B-L}^2}{m_{A_{B-L}}^4}$$

$$\sim 10^{-44}\text{cm}$$

What about other mediators?

How about a low mass scalar?

- May lead to different, less constrained pheno

- May have to worry about stability of low mass against large quantum corrections

- Leading to question of "Naturalness"

However detection of scalar mediator in conjunction with PSDM could have implications for "Naturalness"

$$m_{A_d} \sim g_d Q_d^{\Phi} < \Phi >$$

$$m_F \sim y < \Phi >$$

$$\mathcal{L} \supset y \bar{F}_L F_R \Phi$$

If $< \Phi > \quad \lesssim \ 100 \ \mathrm{GeV}$ Fermions F would have been seen at LEP/LHC

$$\Rightarrow 100 \ \mathrm{GeV} \ \lesssim \ < \Phi >$$

For $m_{A_d} \sim 1 \ \mathrm{GeV} \quad \Rightarrow \quad Q_d^{\Phi} << 1$

$$\Rightarrow \quad Q_d^{F} << 1$$

Many fermions at TeV scale to cancel anomalies