GeV-Scale Messengers of Planck-Scale Dark Matter

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Based on **Phys.Rev. D98 (2018) no.11, 115035**

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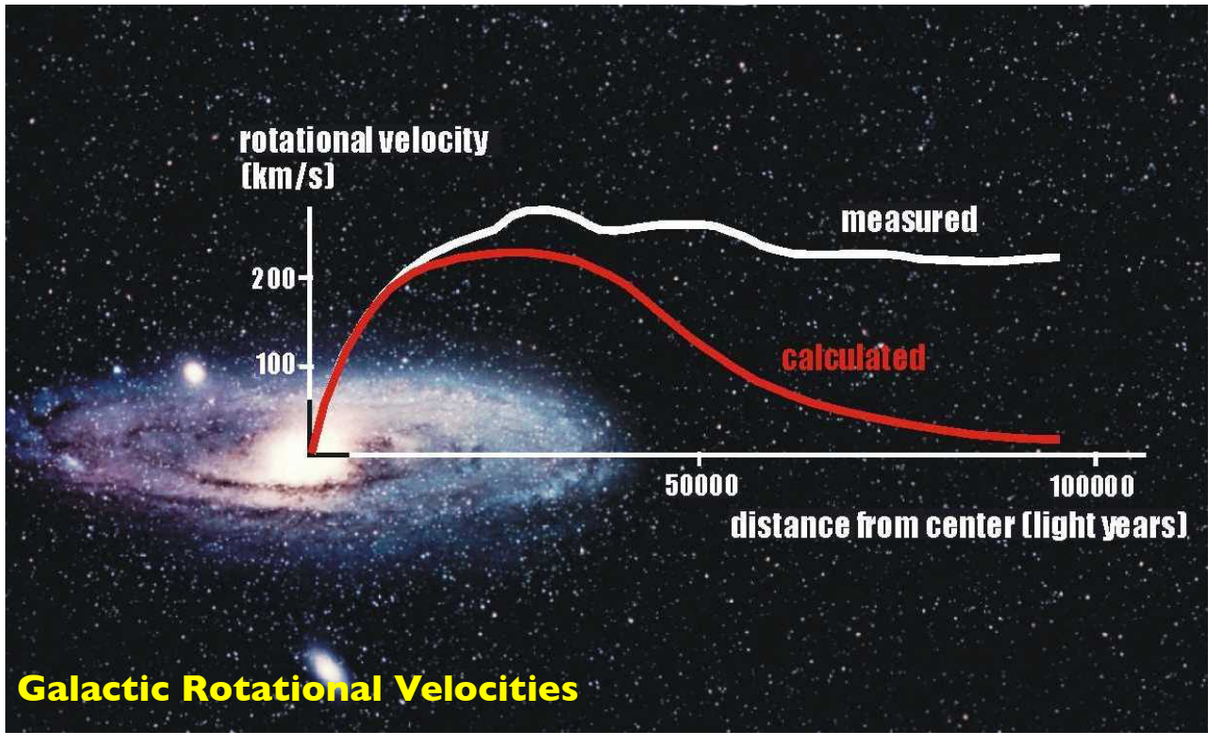
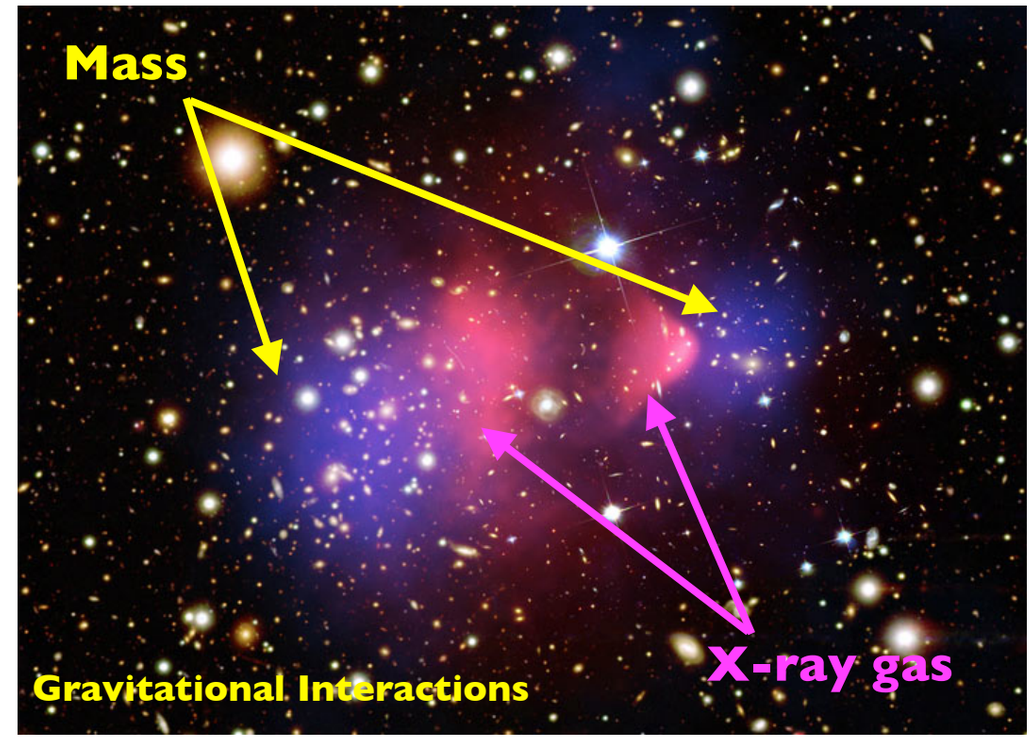
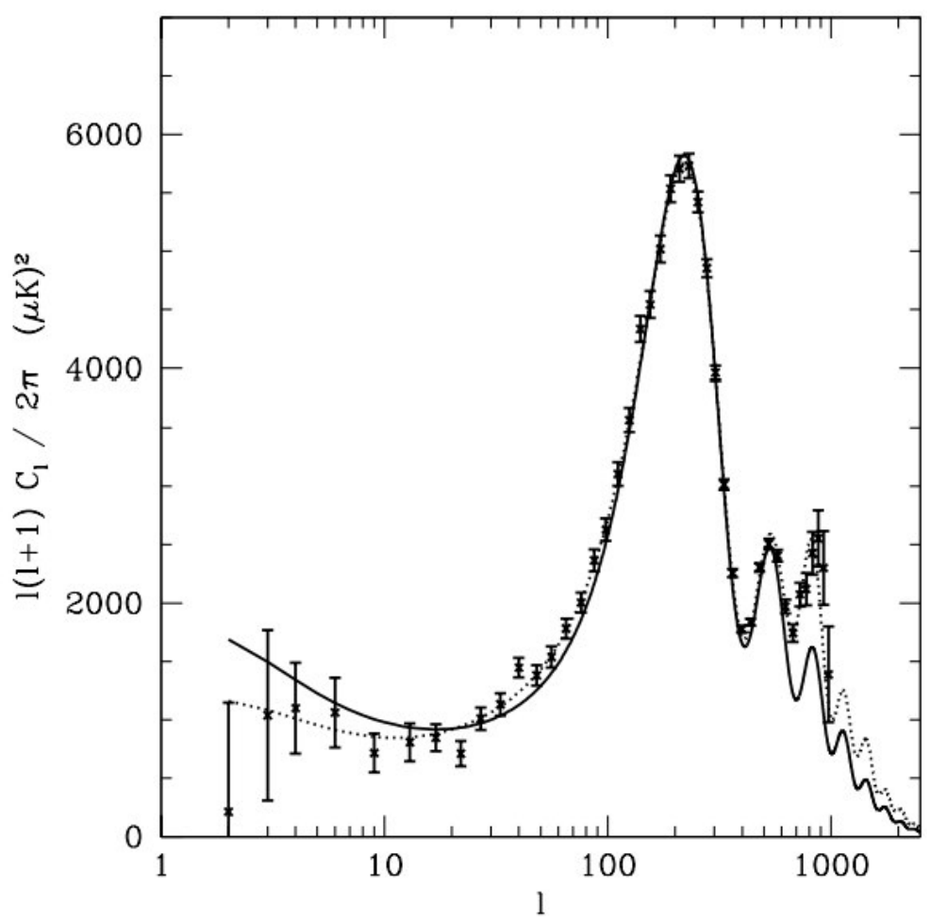
Various observations point to existence of Dark Matter in our Universe







Primordial Fluctuations

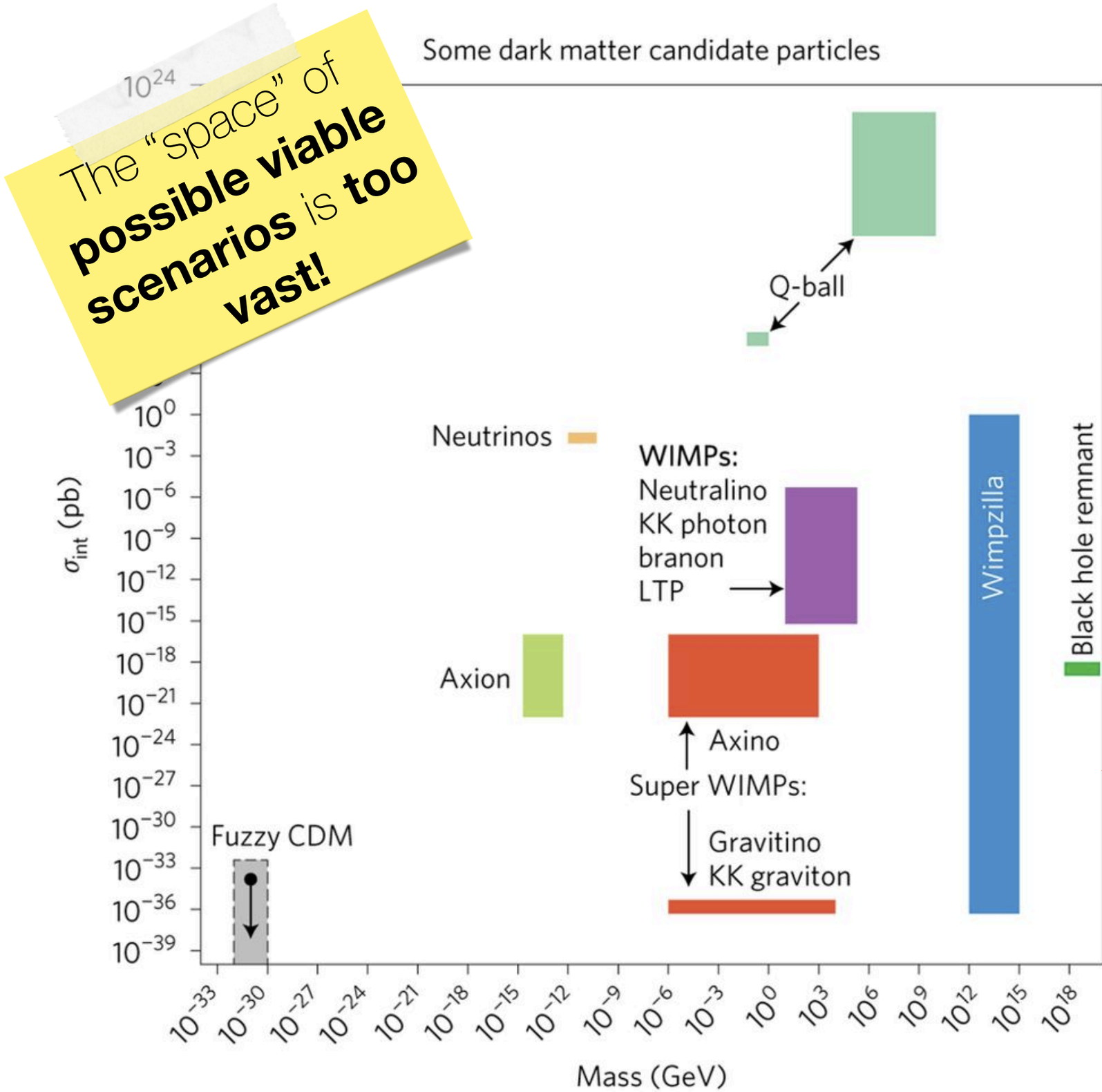
+ Many more .....

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. …

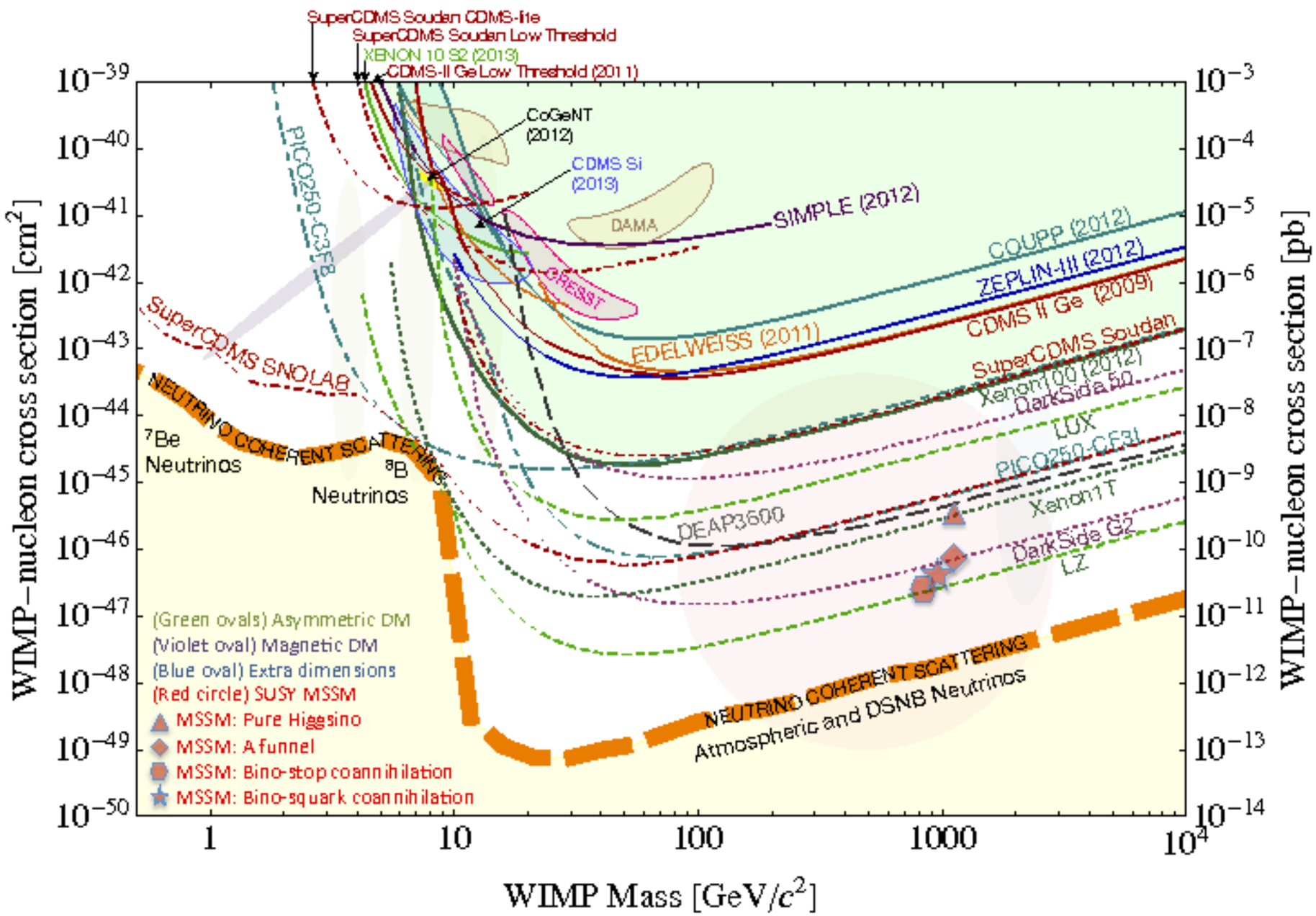
We have no sense of the scale at which DM resides



DM models alone span many orders of magnitude in energy scales

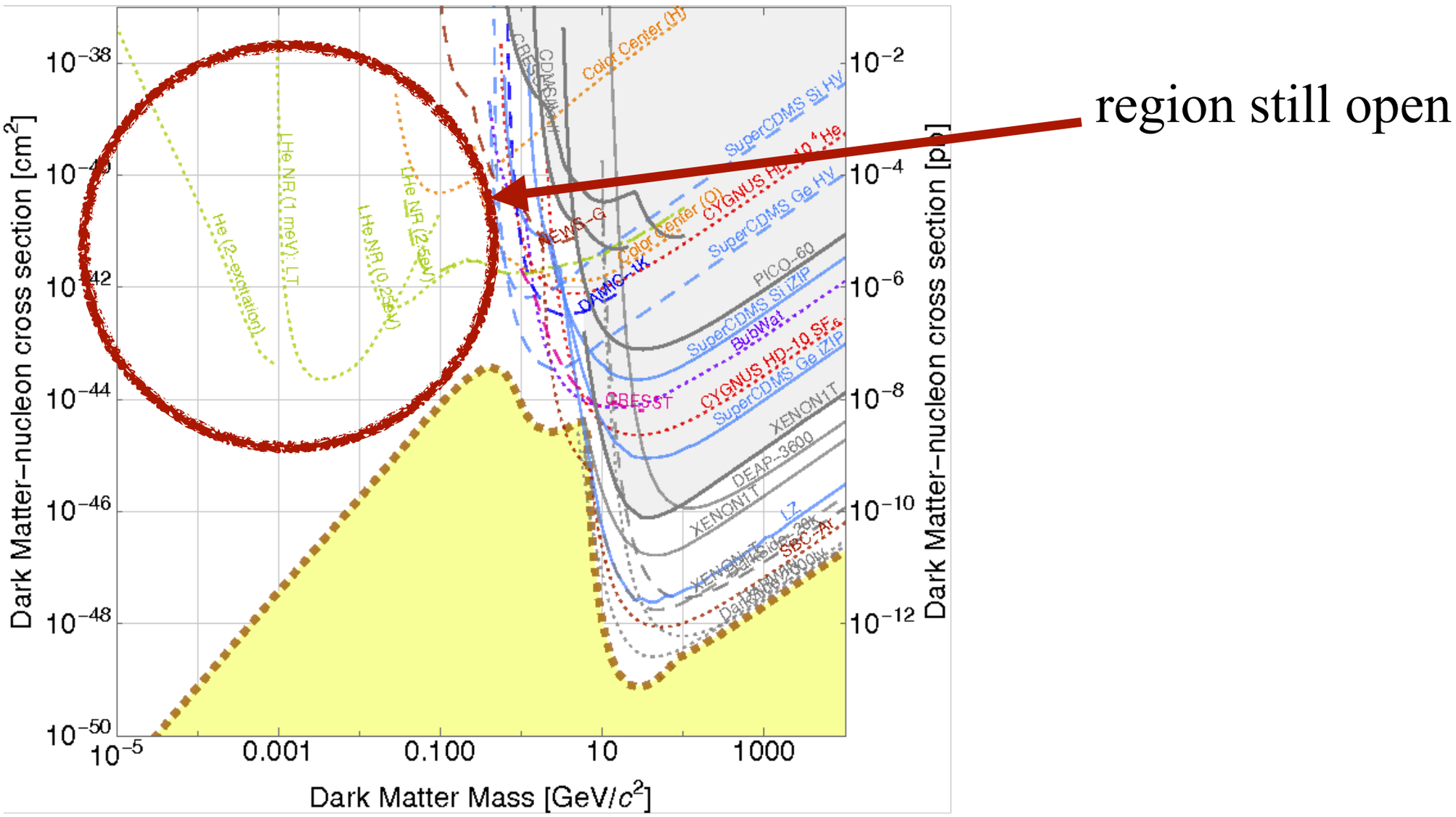
All guided by theoretical motivation

e.g. 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



US Cosmic Visions Report: **arXiv:1707.04591**

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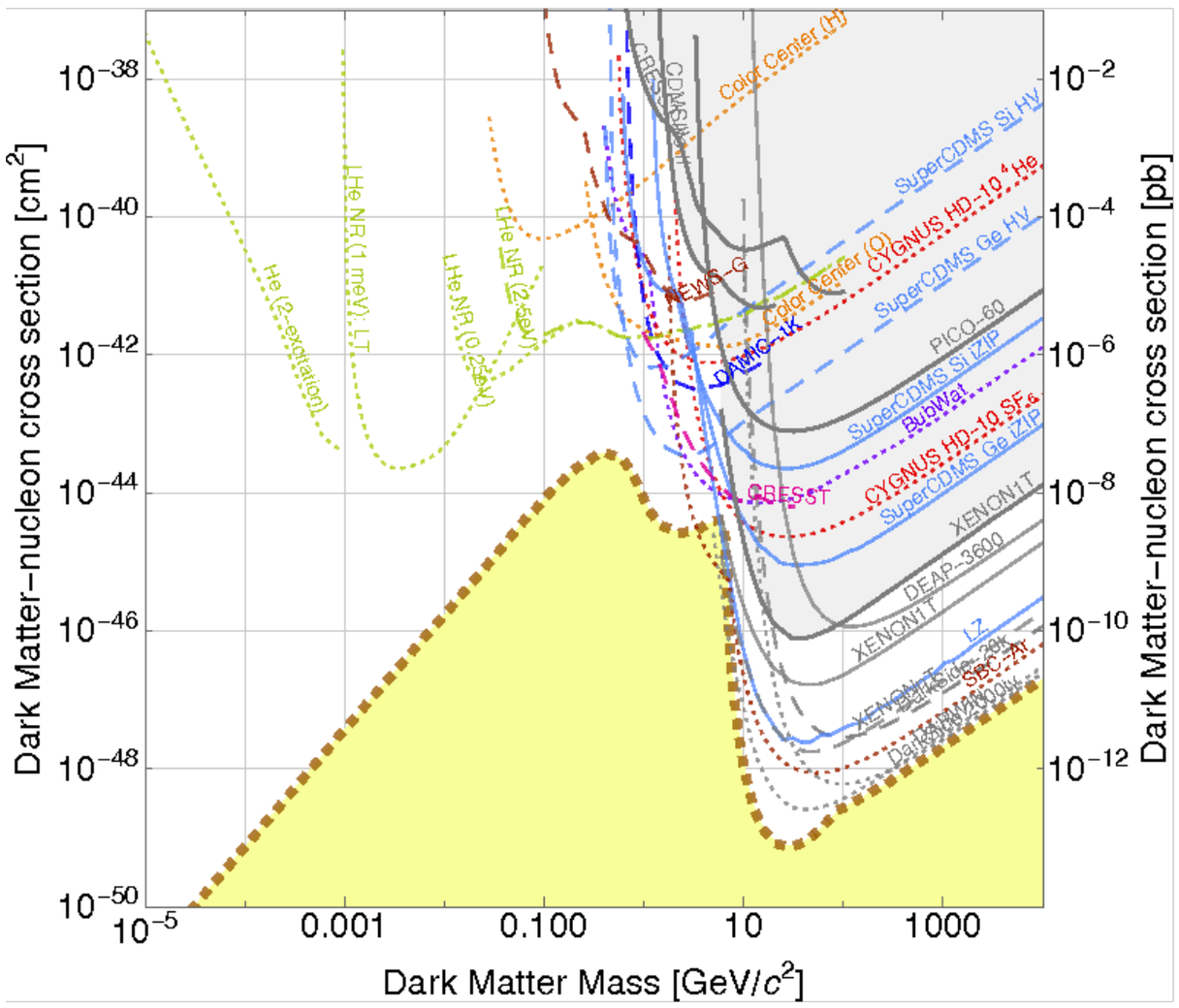

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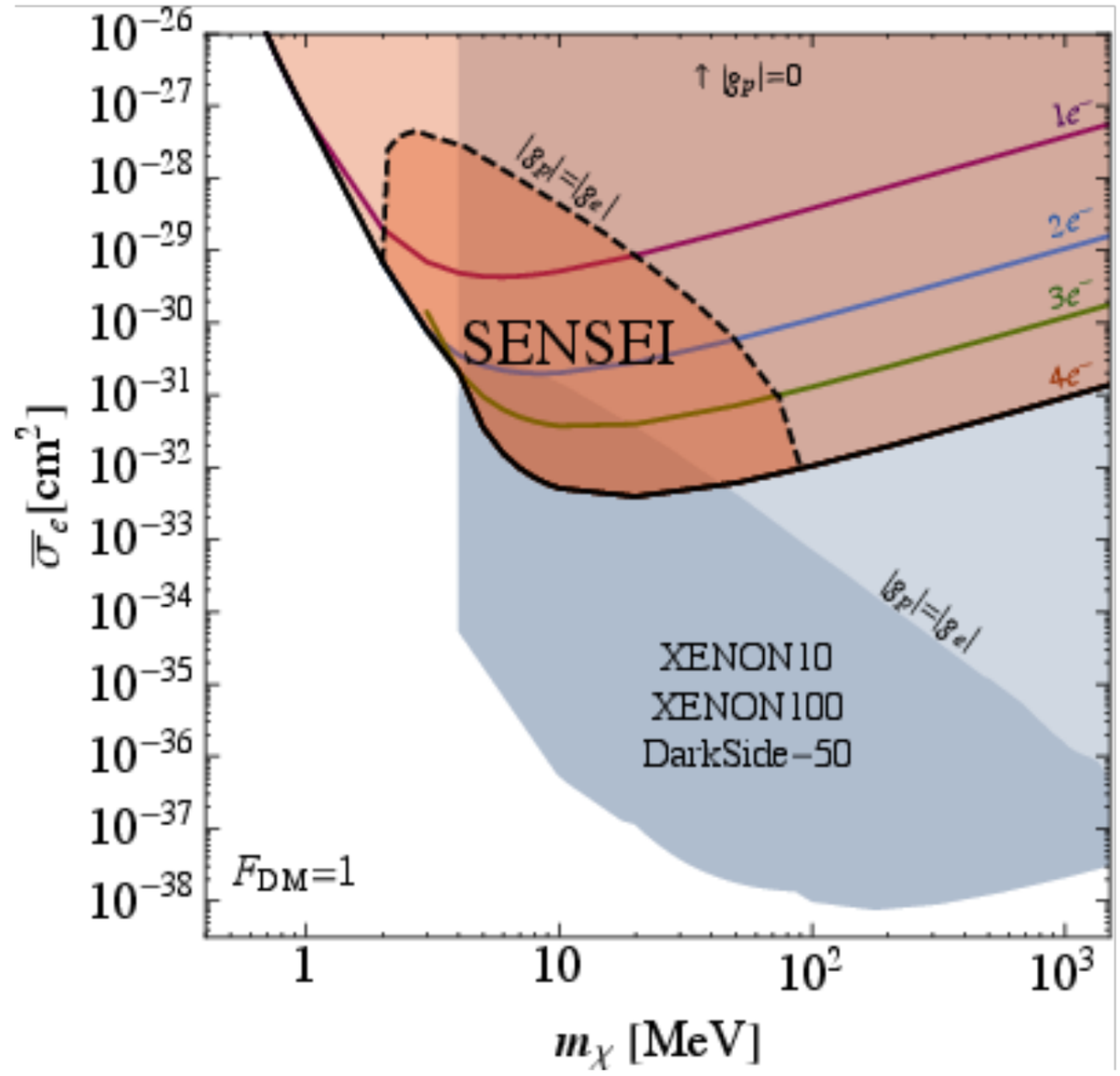


Sensei Collaboration: **Phys.Rev.Lett. 121 (2018) no.6, 061803**

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

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

Disadvantages

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

$M_{DM} > 100 \text{ TeV}$: 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

Advantages

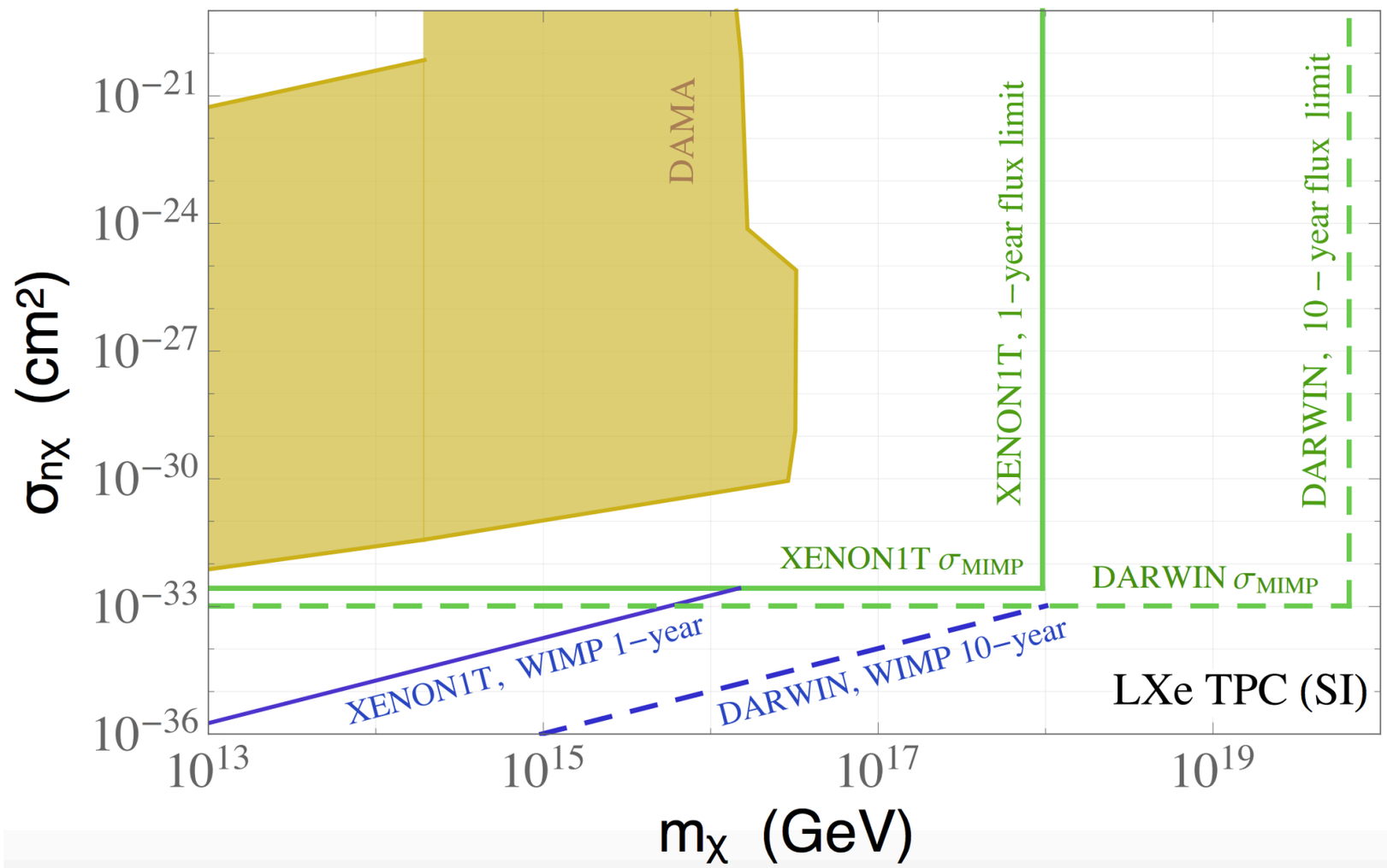
Lower number density $\Rightarrow$ experiments not very sensitive to PSDM

$\Rightarrow$ 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



DD limits extrapolated to include Multi-Scattering and Single Scattering

Bramante, Broerman, Lang & Raj: **Phys.Rev. D98 (2018) no.8, 083516**

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

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

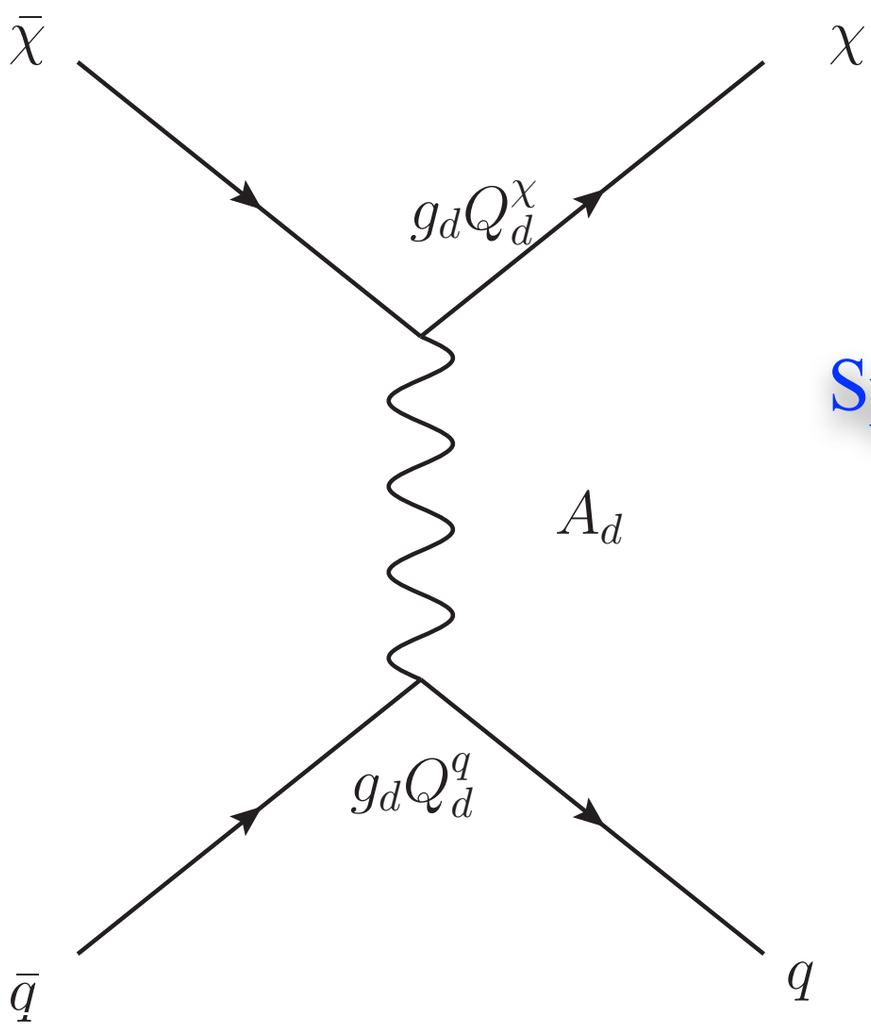
Halverson & Langacker: **arXiv:1801.03503**

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

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

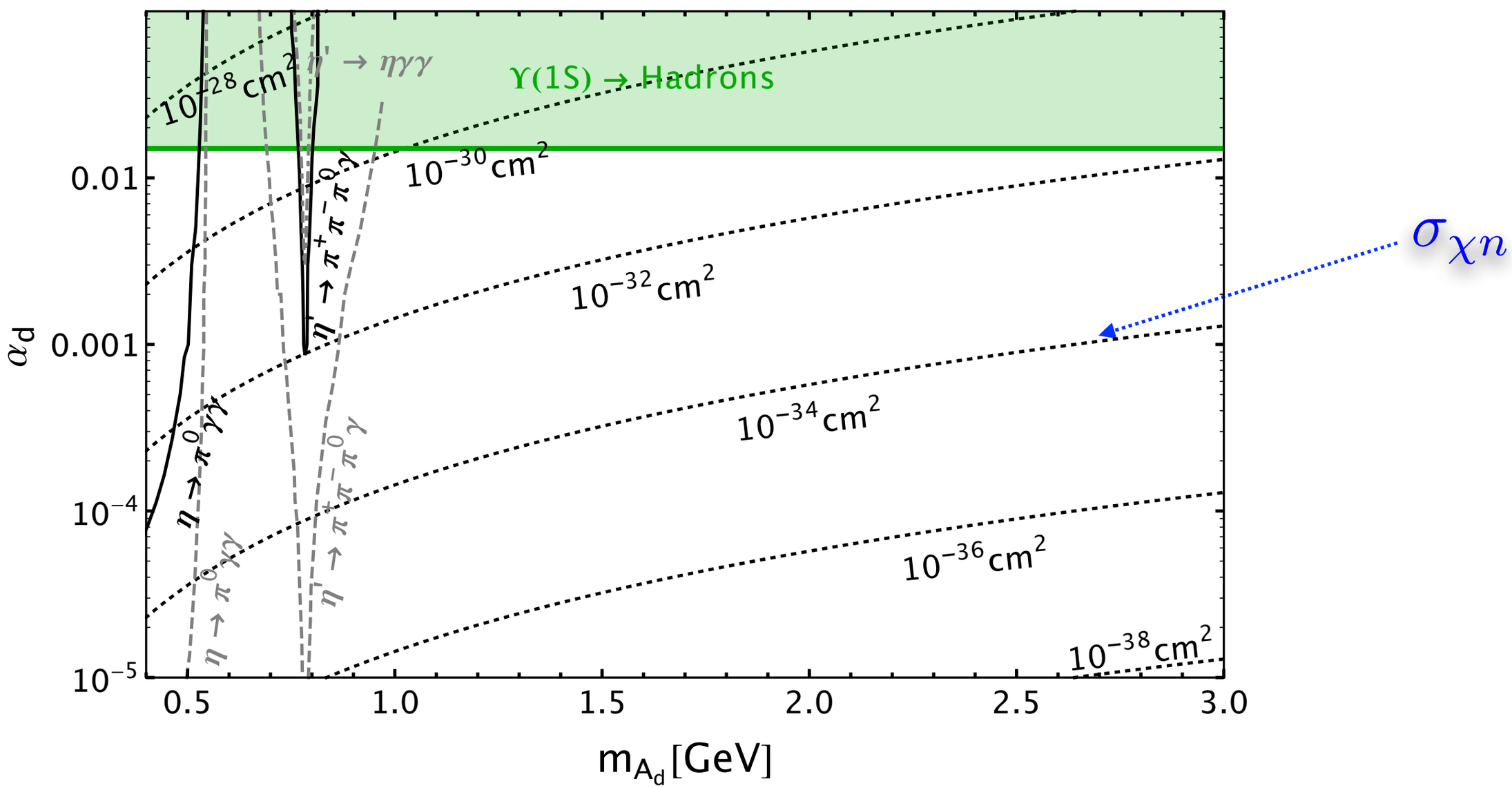


Spin Independent PSDM-nucleon cross-section

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

PSDM may show up through multiple scattering in detector

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

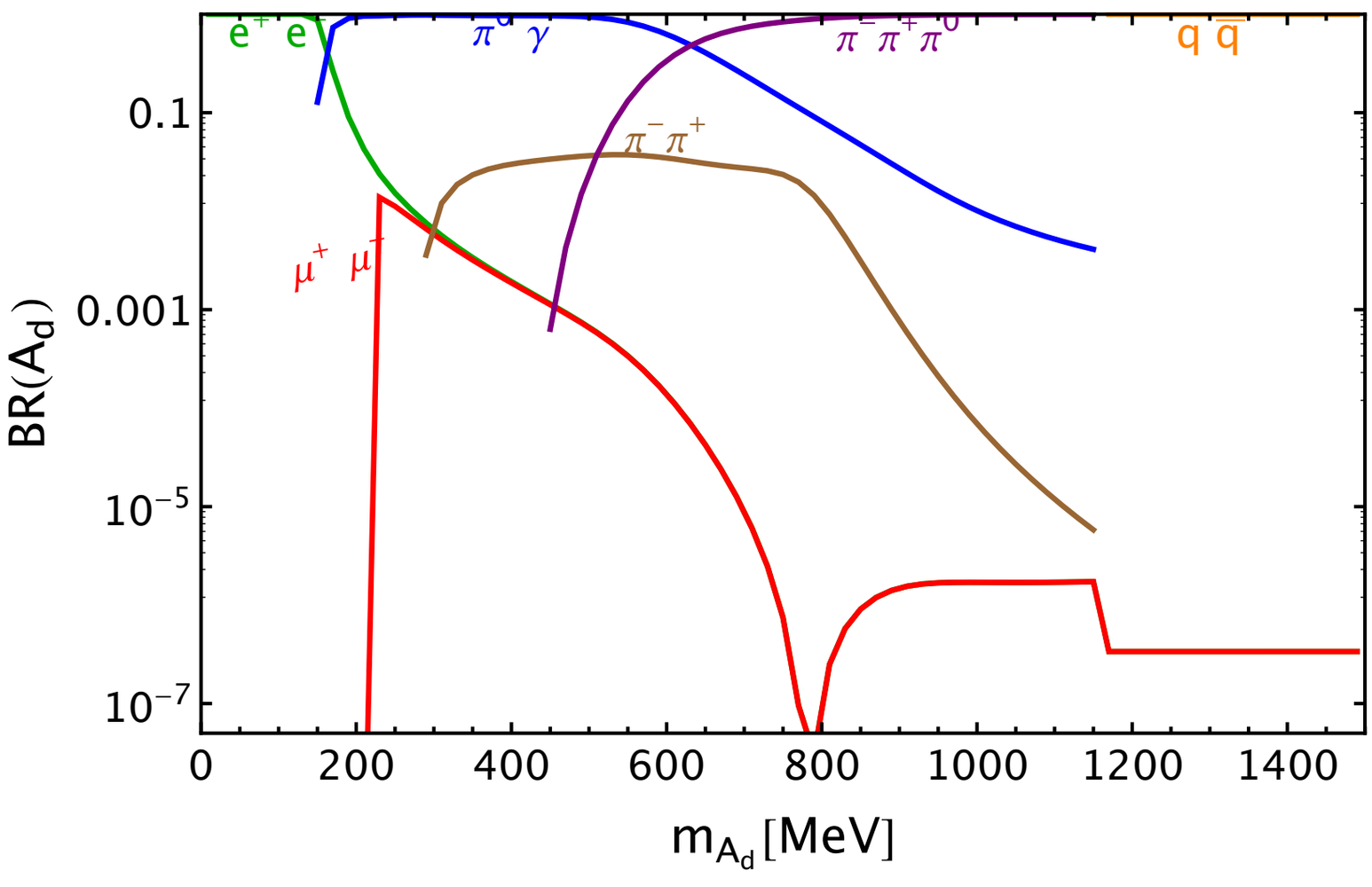


Davoudiasl & Mohlabeng: **Phys.Rev. D98 (2018) no.11, 115035**

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

$BR(A_d \to l^+l^-)$ 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



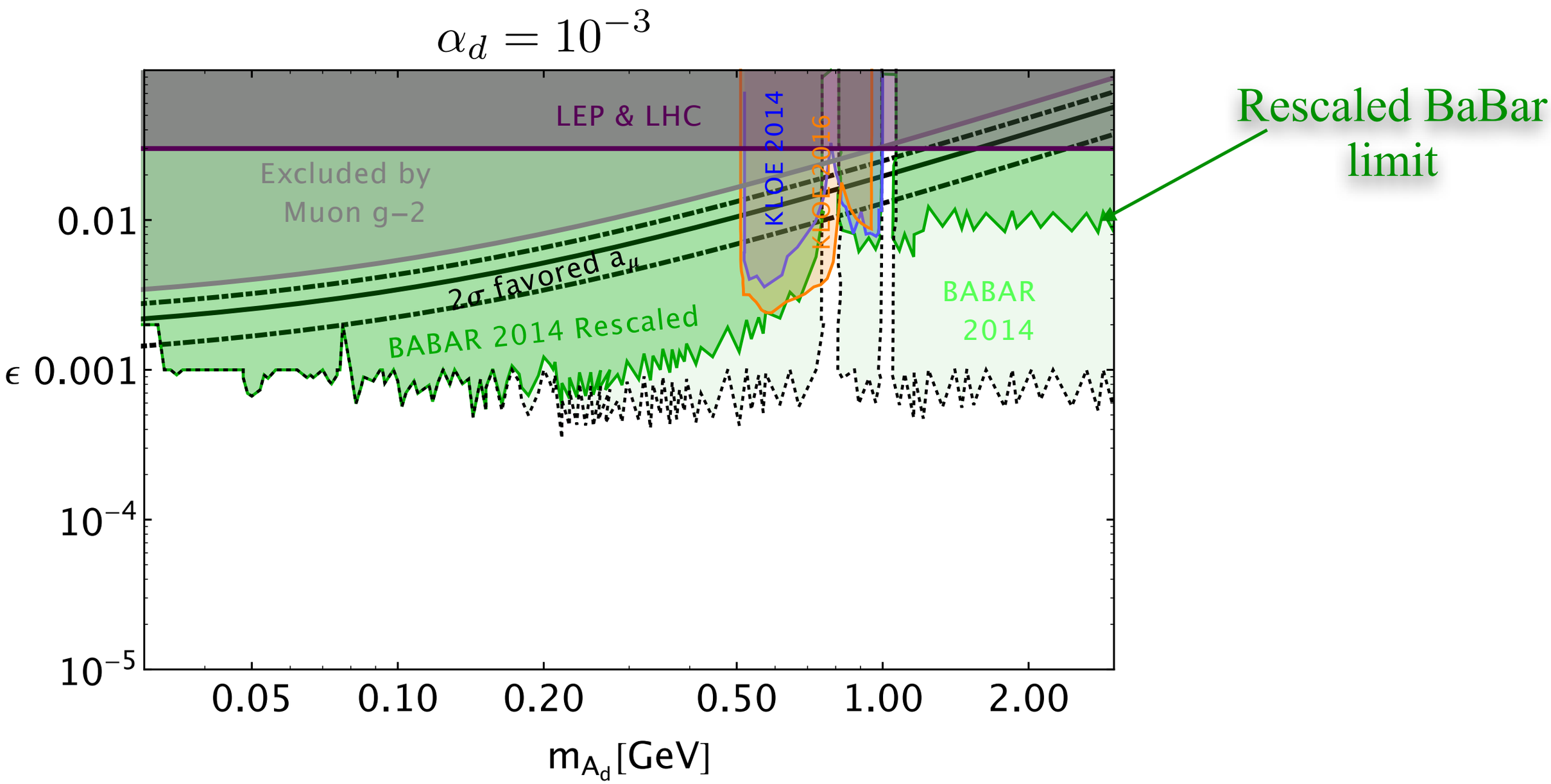
Assume A_d has similar quantum numbers to ω-meson

Above m_π threshold A_d goes to hadrons

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 & Mohlabeng: **Phys.Rev. D98 (2018) no.11, 115035**

Conclusions

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

PSDM is one possibility

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

- We can probe $10^{-38} - 10^{-33}\mathrm{cm}^2$ cross-section & $m_\chi \lesssim 10^{16-17}\mathrm{GeV}$

- 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

Thanks

Back up Slides

$U(1)_B$ 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

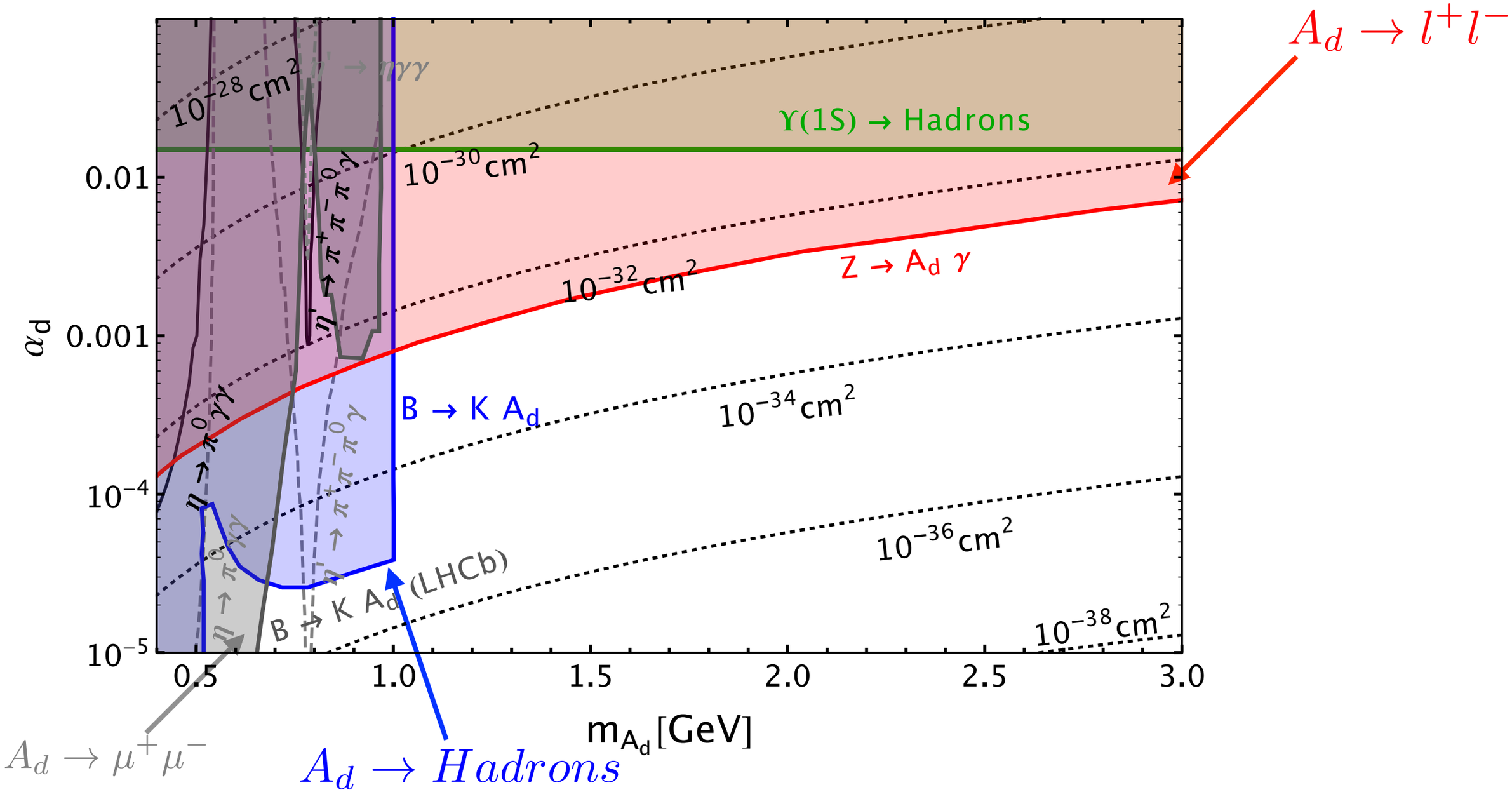
- Z-boson decays

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

No longitudinal mode effects

Including longitudinal mode enhancements

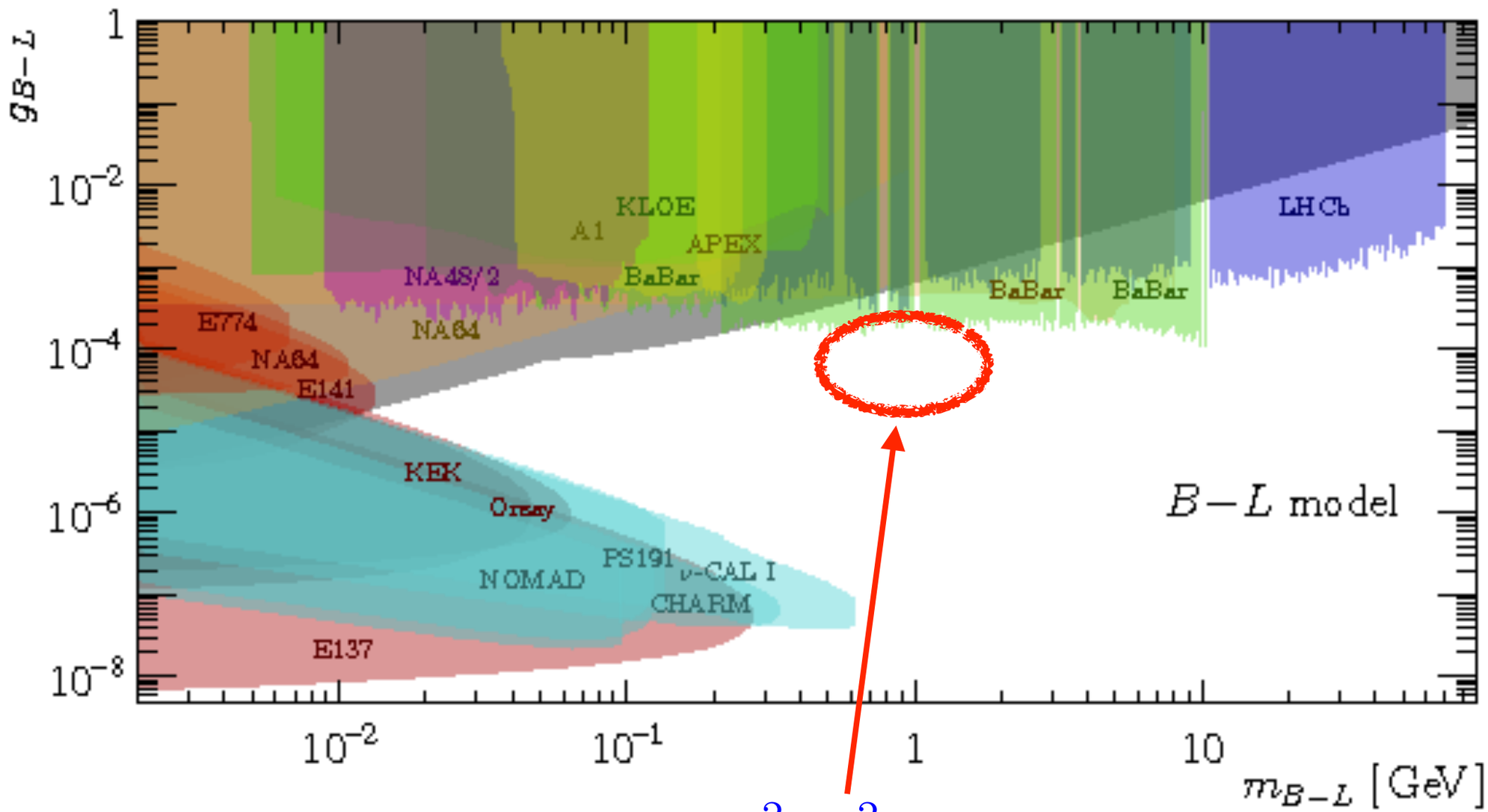
Were made assuming: $\epsilon = \dfrac{e g_d}{(4\pi)^2}$



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

Consider other mediators?

How about gauged B-L?



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

Ilten, Soreq, Williams & Xue, JHEP 1806 (2018) 004

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

Other mediators

How about a low mass scalar?

- May lead to different, less constrained pheno

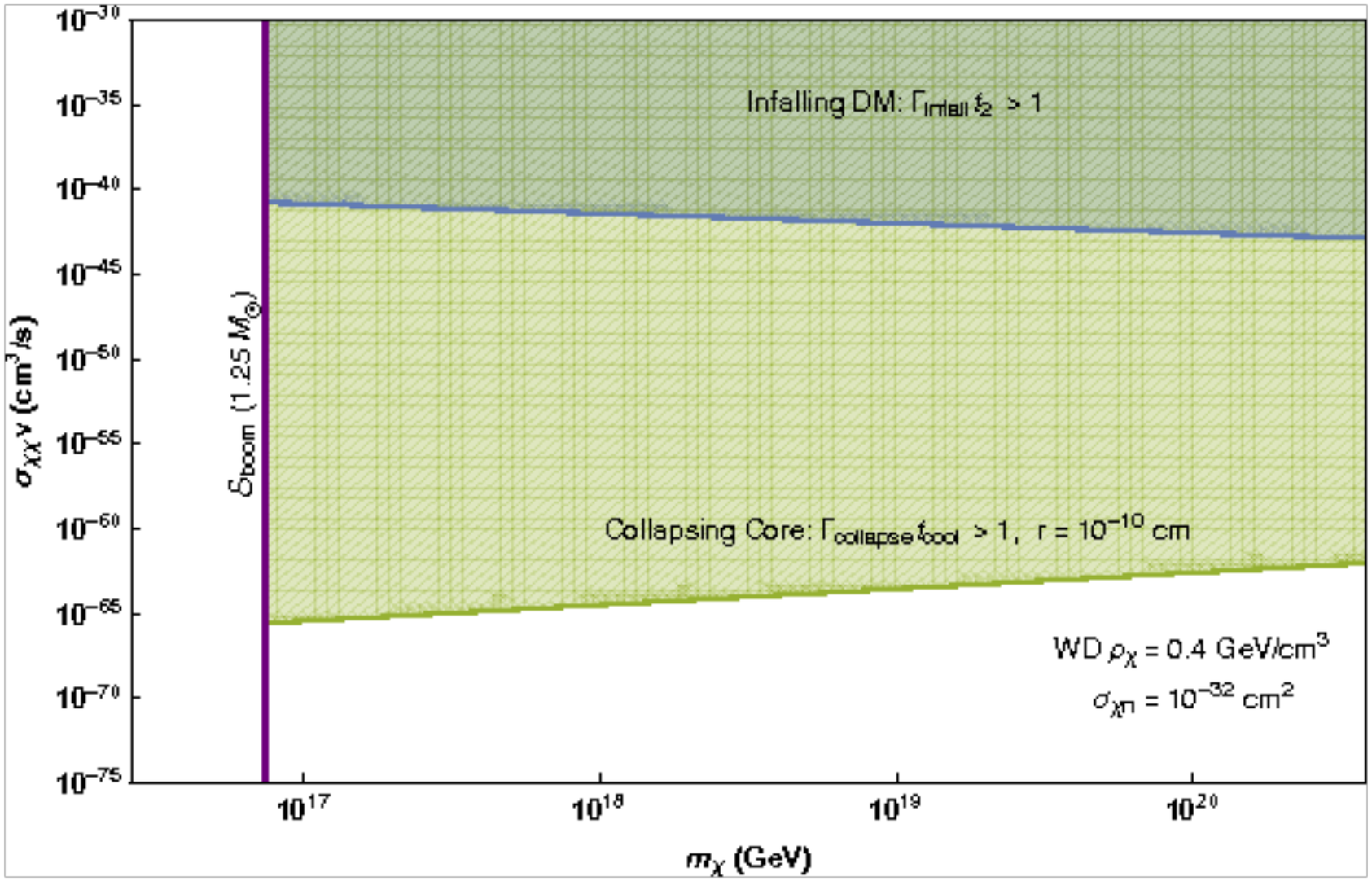
- May have to worry about stability of low mass against large quantum corrections

- Leading to question of "Naturalness"

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

Further constraints

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

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

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

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

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

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

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

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

Many fermions at TeV scale to cancel anomalies