

New States from Simple Dark Sector

Yue Zhang
Caltech

SLAC Dark Sector Workshop 2016

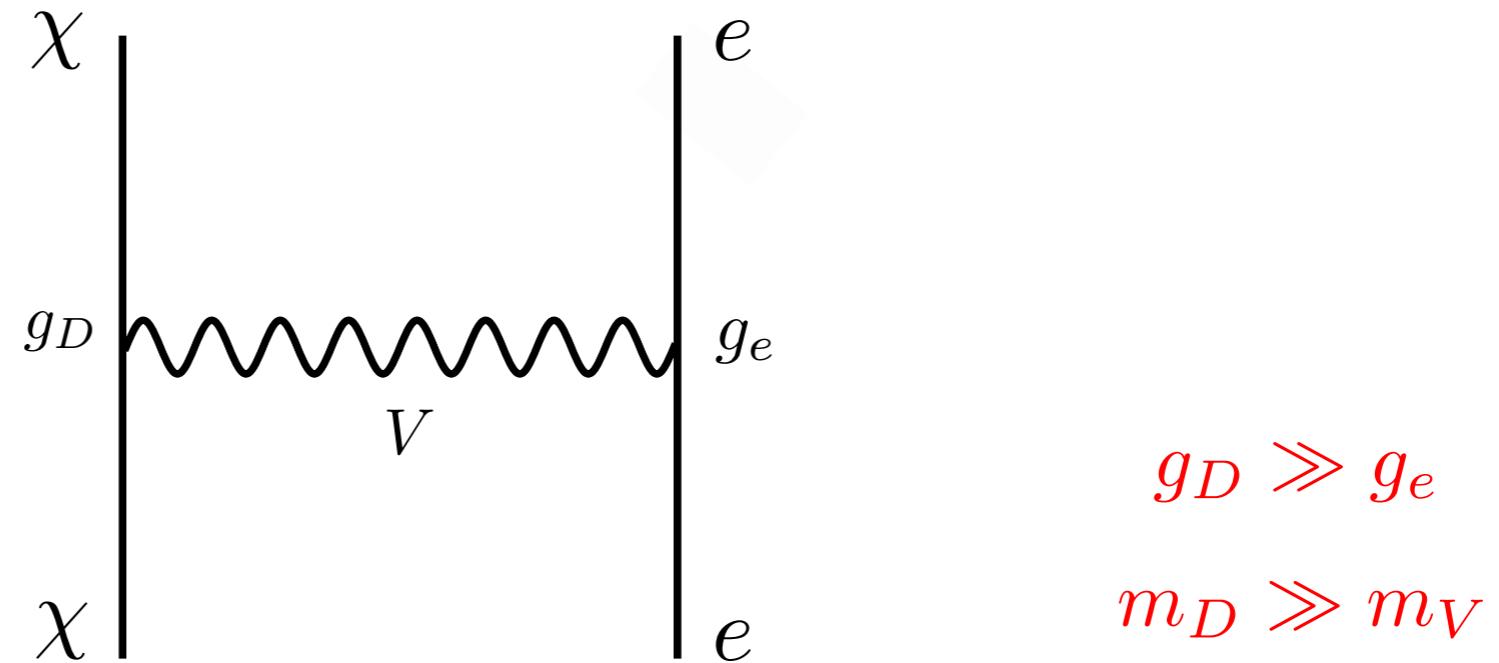
I will talk about

Dark sector containing

- Vector mediator
- Scalar mediator
- Non-abelian gauge symmetry

Vector Mediator Portal

Consider a vector dark force portal between electron and DM

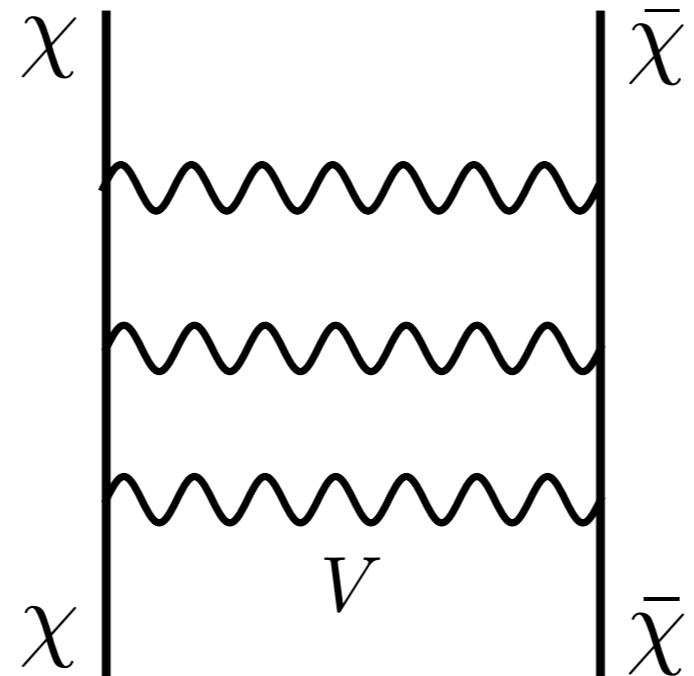


Traditional searches: prompt and displaced decay of V ,
DM direct detection using electron recoil.

Dark Force and Bound States

Traditional searches: DM and dark force as elementary particles.

DM bound states could exist if $\alpha_D m_D \gtrsim 1.66 m_V$

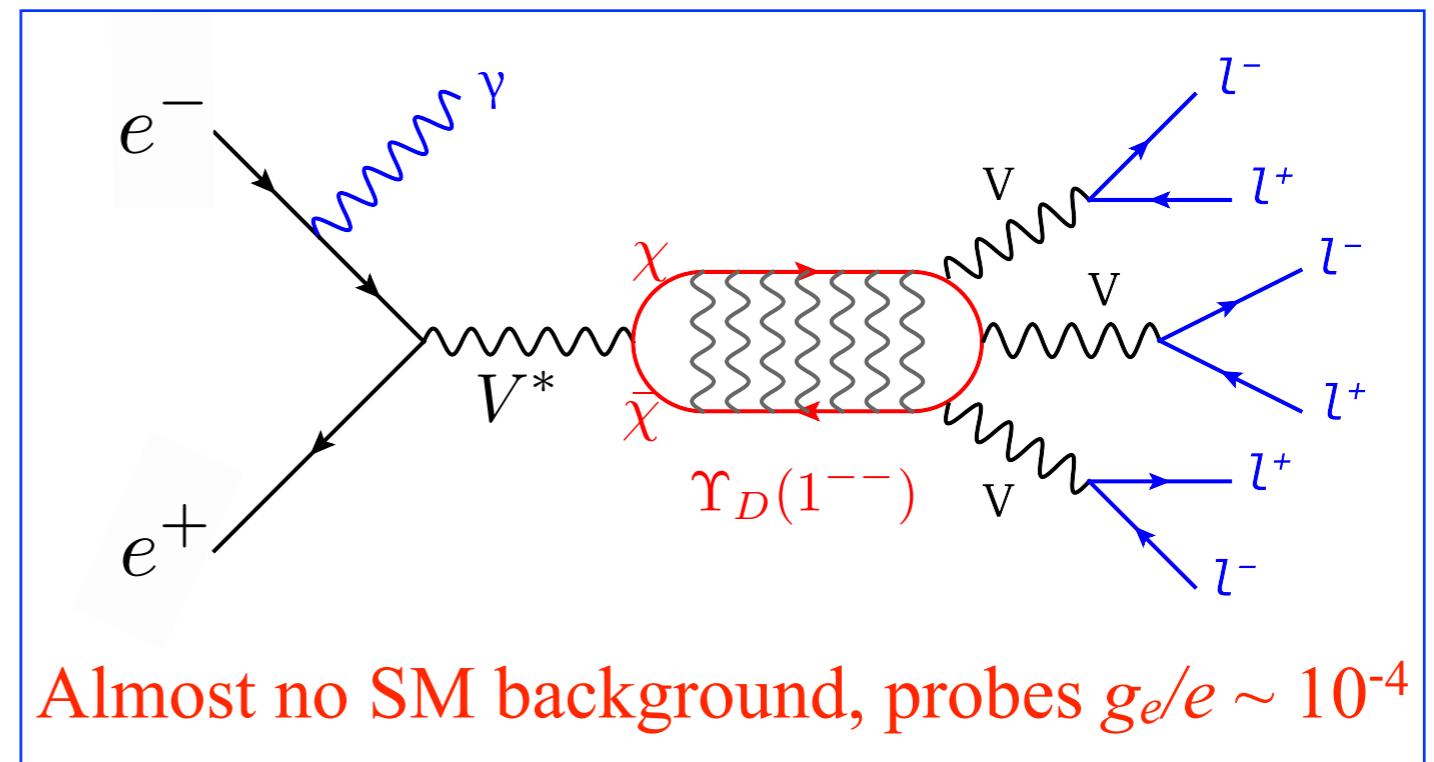
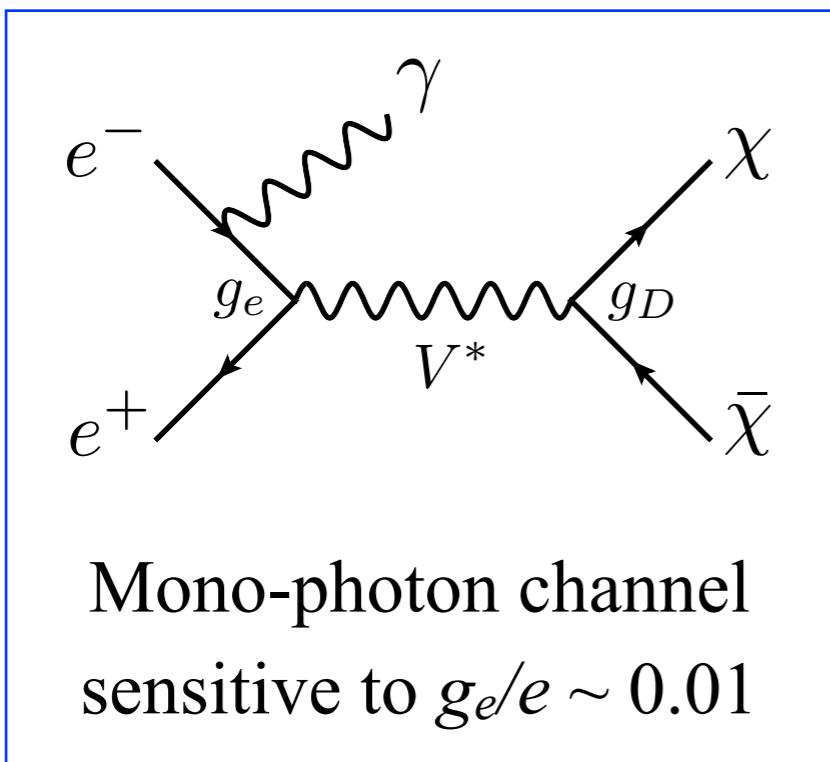


(unstable dark matter bound states)

DM Bound States at B-factory

In analogy to studying the heavy quarks:

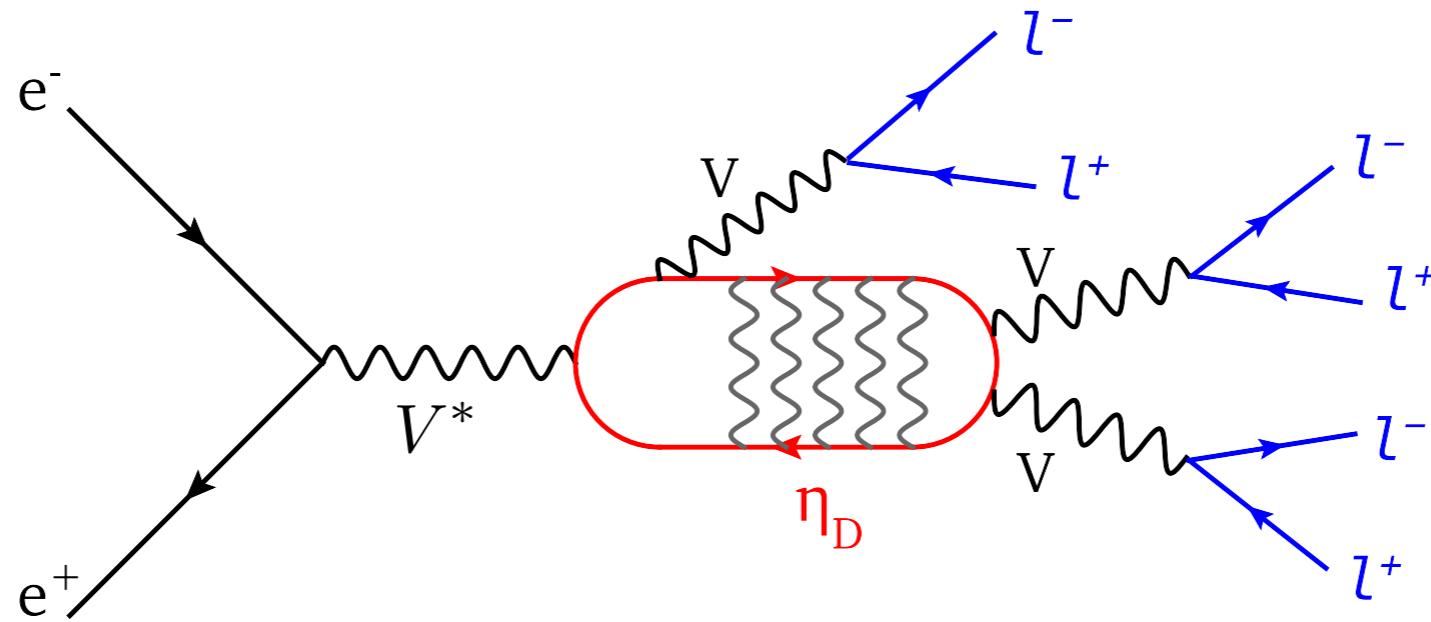
- open dark flavor (missing energy).
- hidden dark flavor (darkonium resonances).



Essig, Mardon, Papucci, Volansky,
Zhong (JHEP 2013)

An, Echenard, Pospelov, **YZ** (PRL 2016)

Another Channel



I assume fermionic DM here, two states with $L=0$

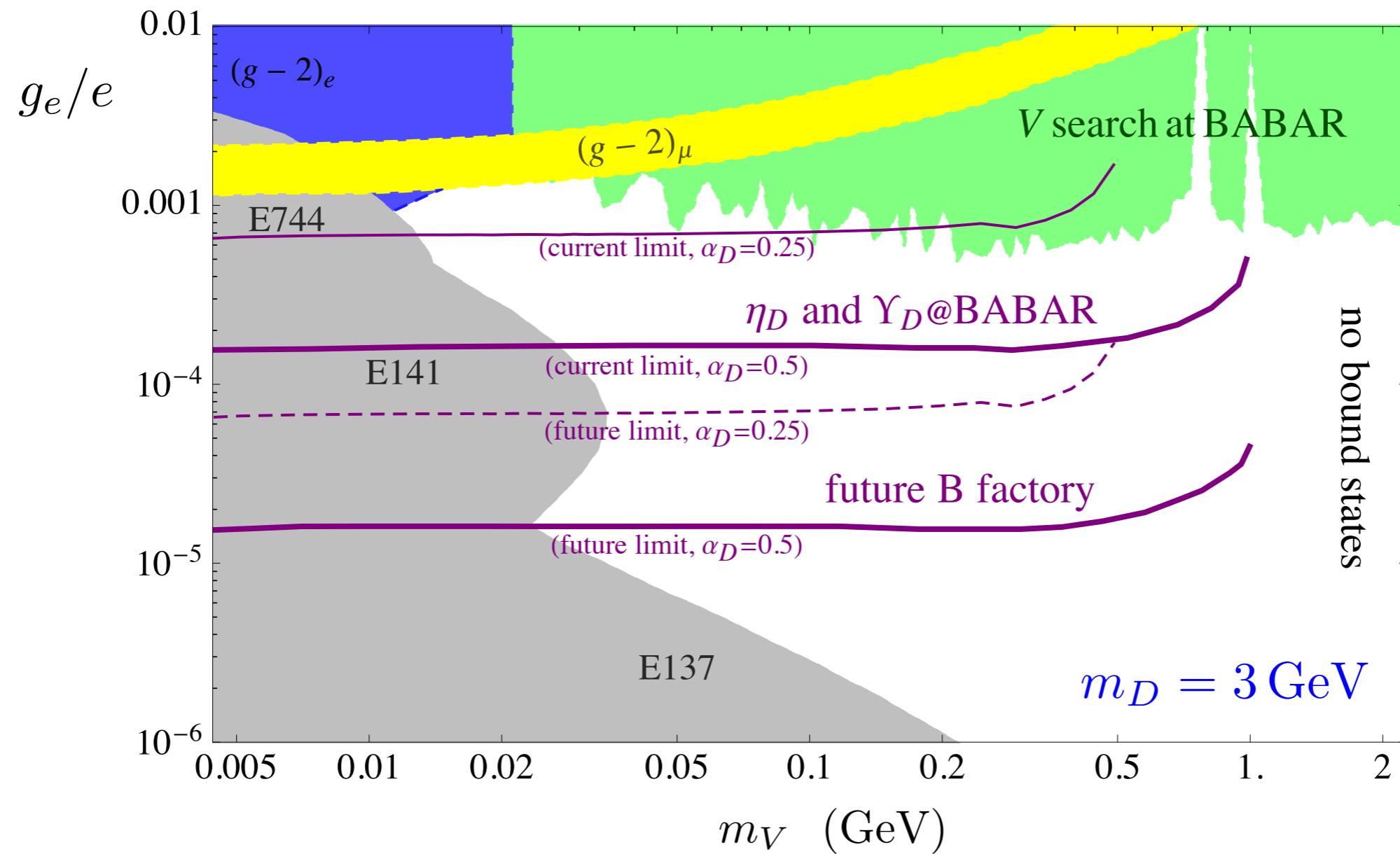
$$\Upsilon_D \ (J^{PC} = 1^{--})$$

$$\eta_D \ (J^{PC} = 0^{-+})$$

An, Echenard, Pospelov, **YZ** (PRL 2016)

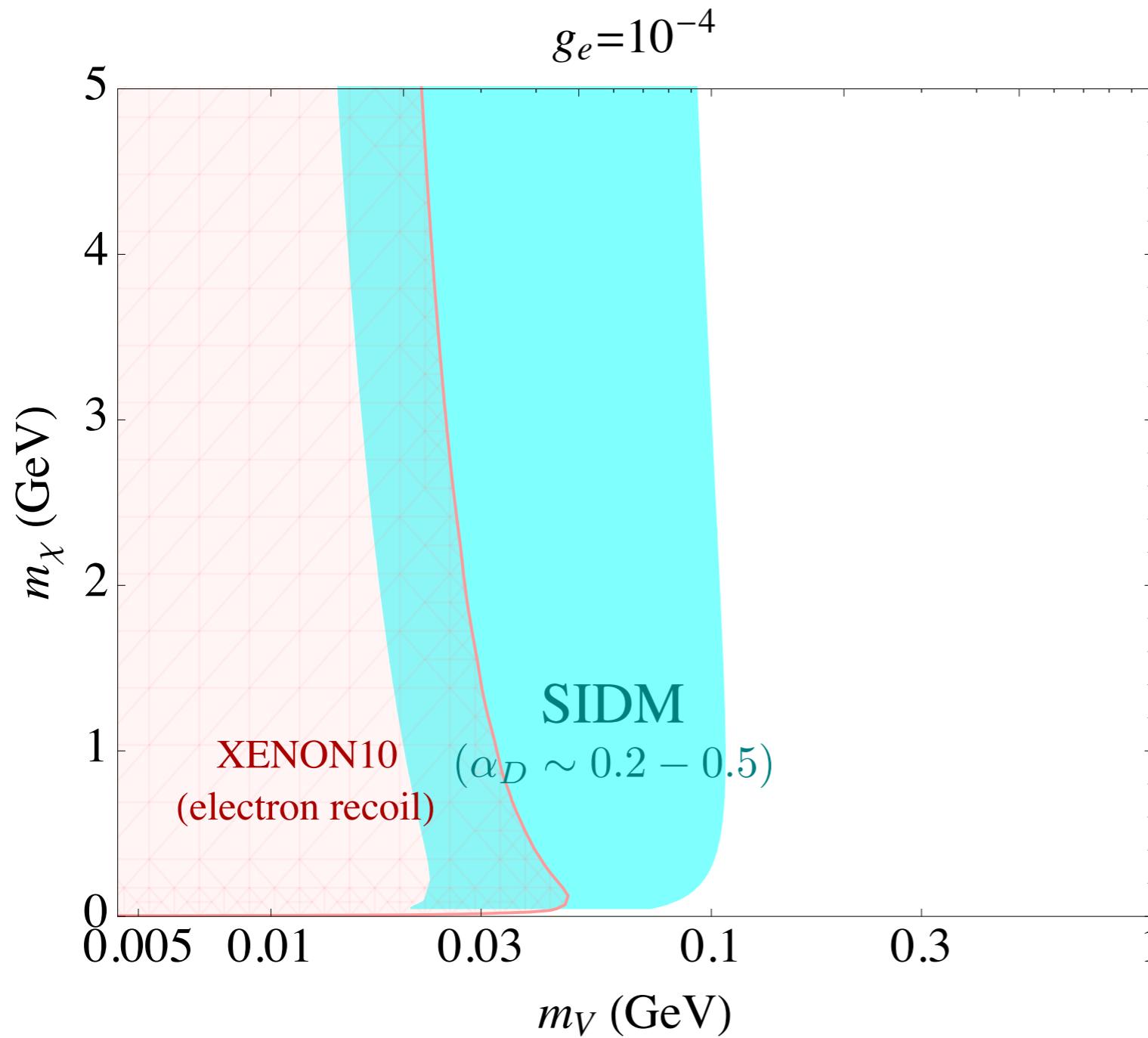
Better Limits

Stronger limit from bound state channel (6ℓ resonance), for $\alpha_D > 0.25$.



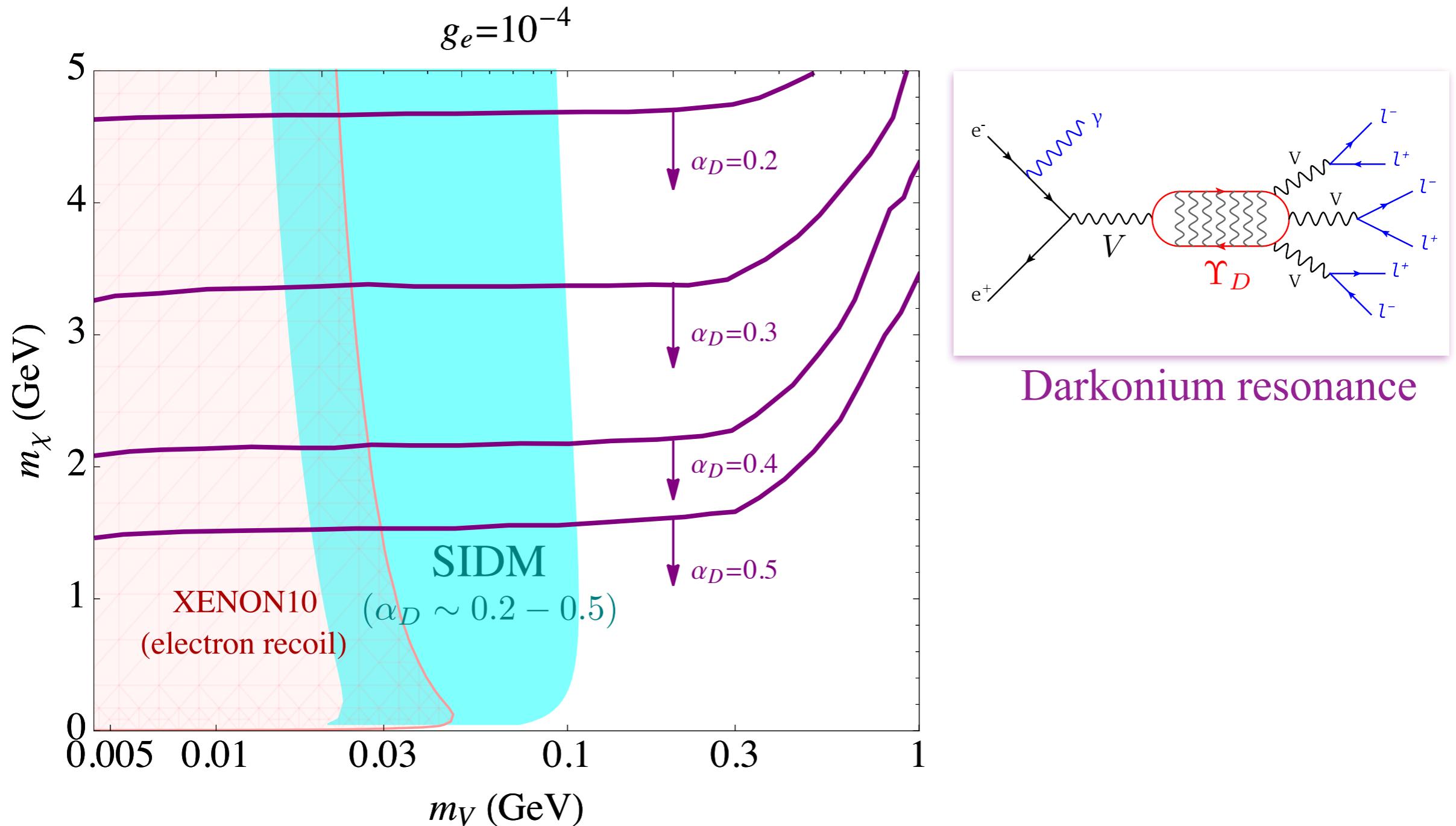
An, Echenard, Pospelov, YZ (PRL 2016)

Implications for Self-interacting DM



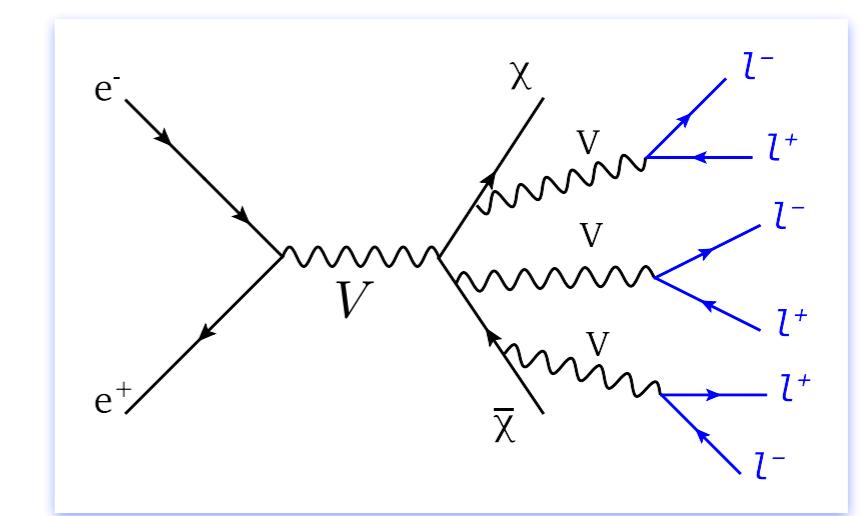
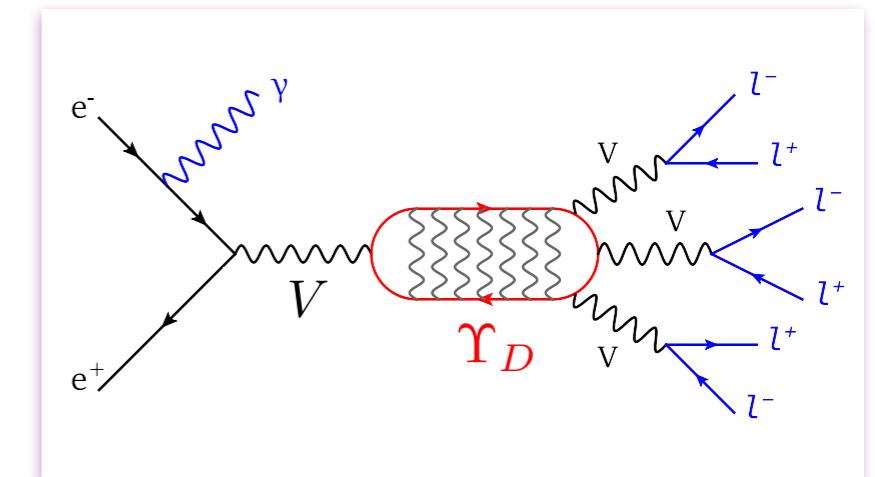
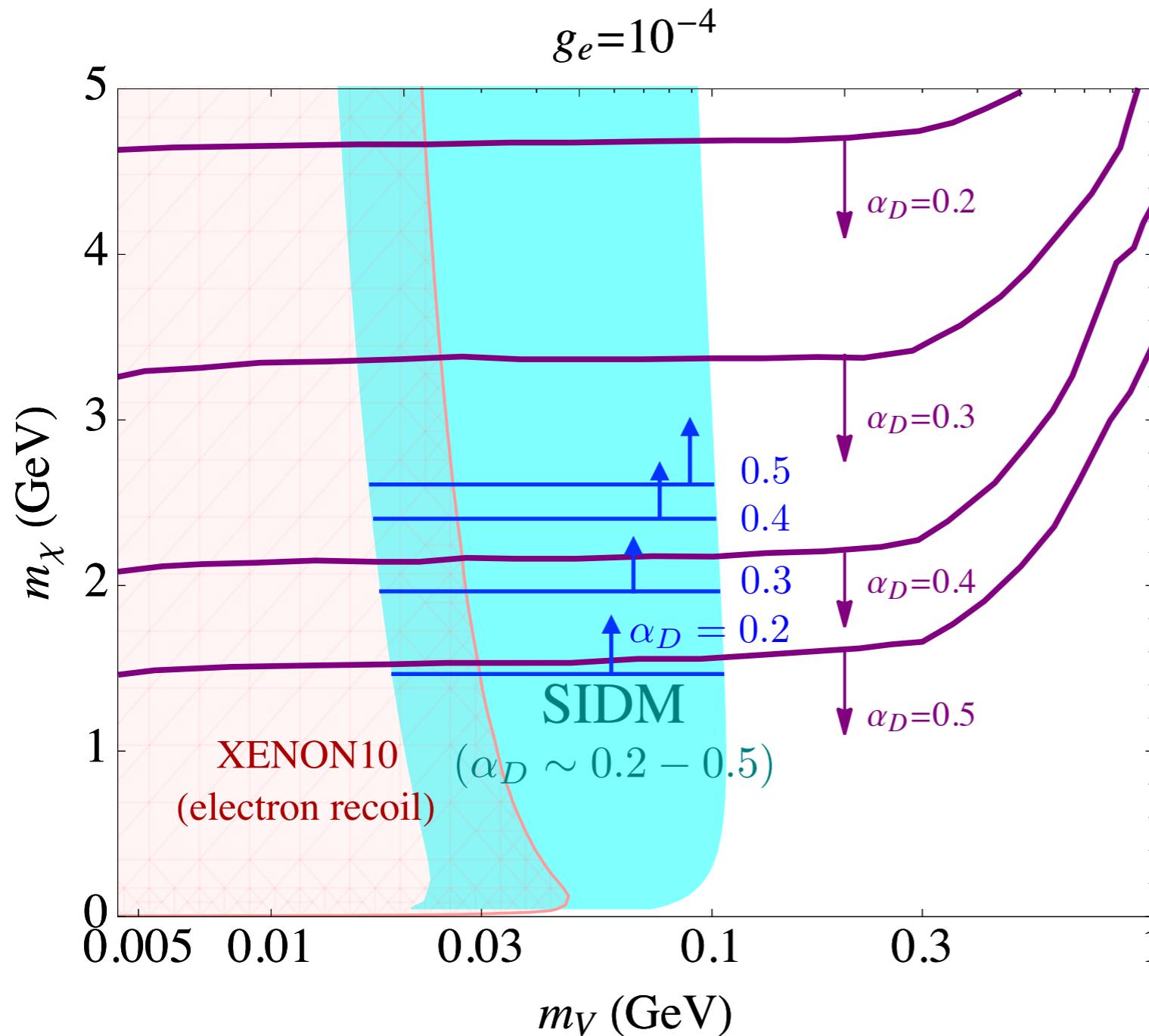
An, Echenard, Pospelov, YZ (PRL 2016)

Implications for Self-interacting DM



An, Echenard, Pospelov, YZ (PRL 2016)

Implications for Self-interacting DM

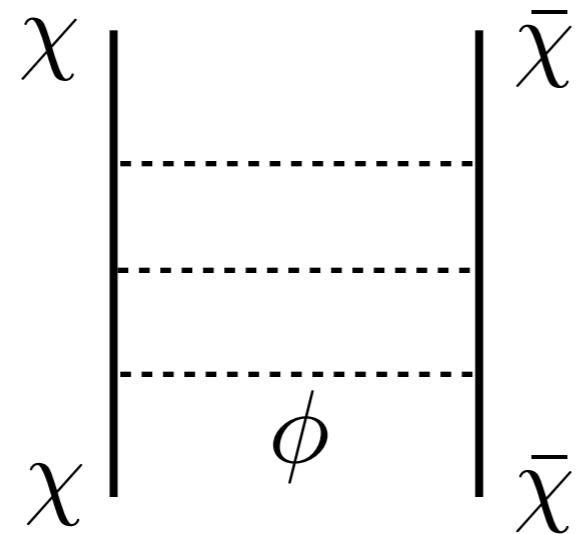


An, Echenard, Pospelov, YZ (PRL 2016)

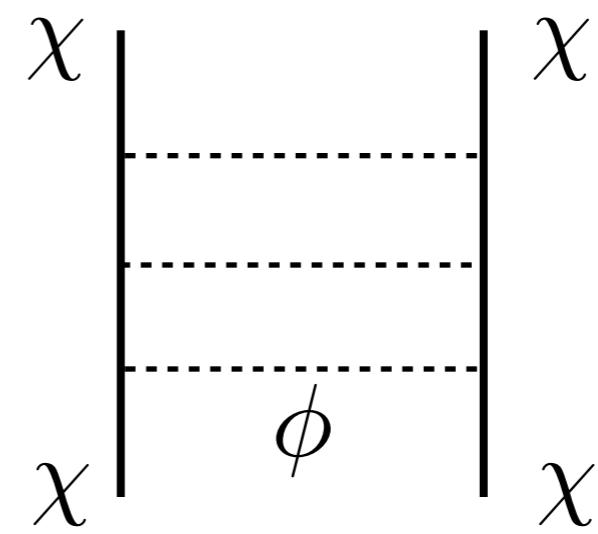
Scalar Mediator Portal

Proton beam dump experiments can serve as powerful probes.

Dark Yukawa $g_D \bar{\chi} \chi \phi + \mu \phi H^\dagger H$ Scalar force always attractive



(unstable)

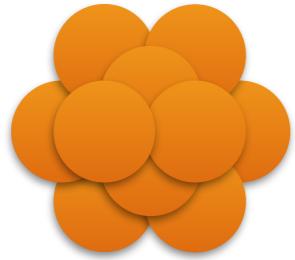


(stable)

Stable bound states may exist in nature: bind more χ 's together

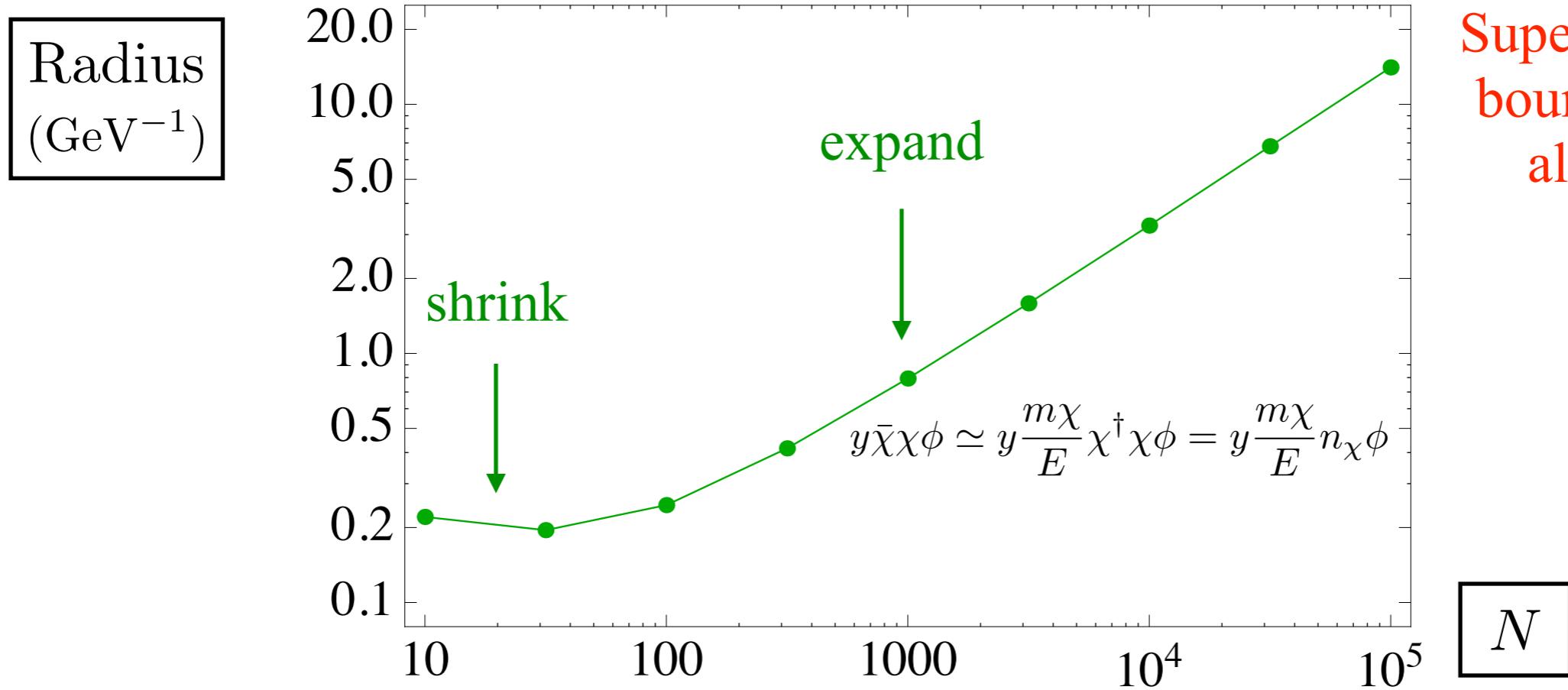
Wise, YZ (JHEP 2015)

N-body DM Bound States



degenerate Fermi gas, hydrostatic equilibrium

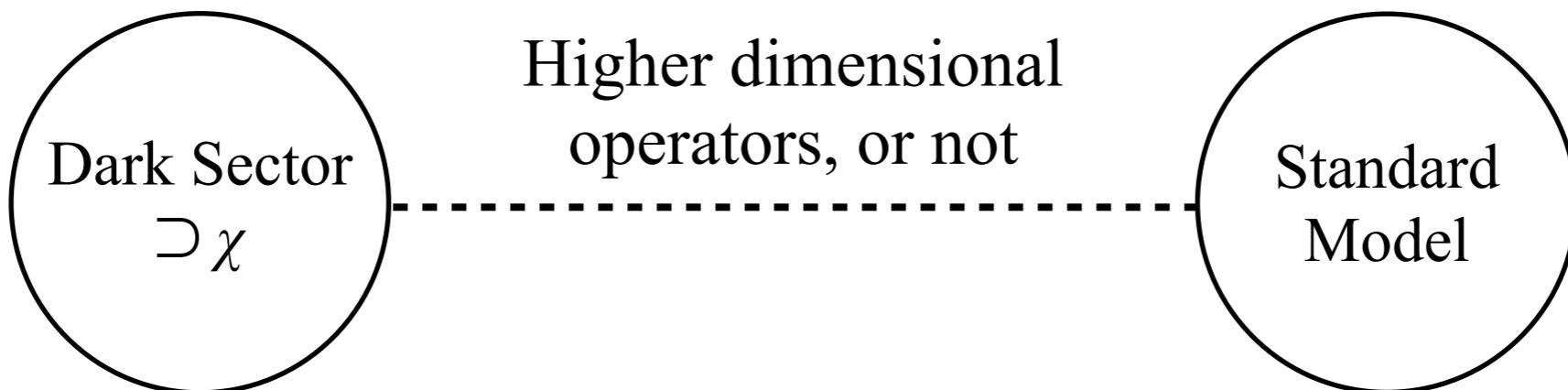
$$m_\chi = 100 \text{ GeV}, \alpha_\chi = 0.1$$



Dark form factors for direct detection

Wise, YZ (JHEP 2015)

Non-Abelian Dark Sector



Pure gauge $SU(N)$: Lightest glueball state as DM candidate.

Only two fundamental parameters:

Intrinsic scale: Λ , number of colors: N

Soni, YZ (1602.00714)

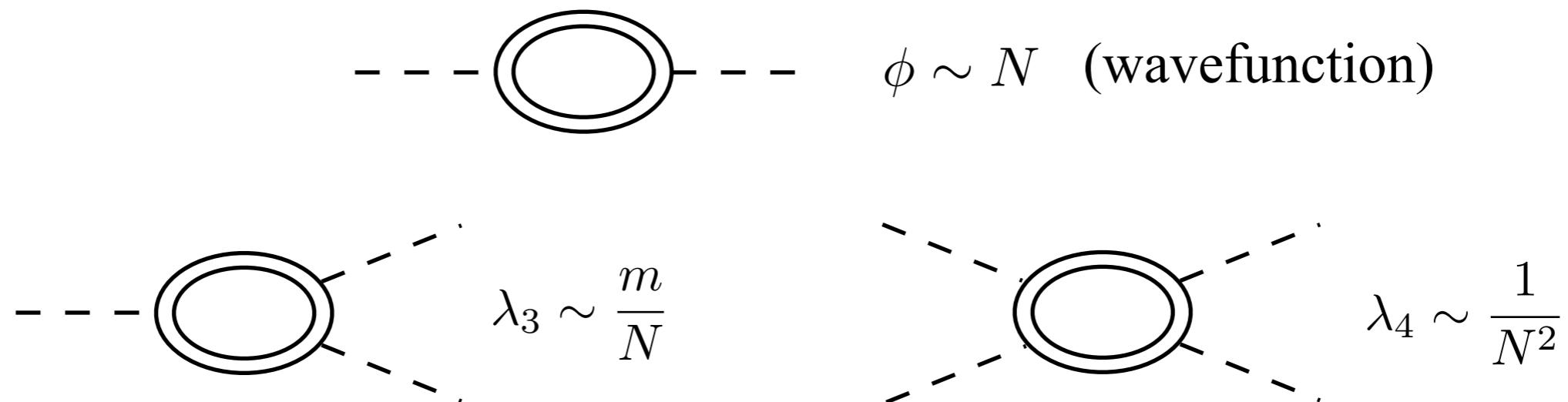
Dark Glueball Interactions

Scalar glueball potential: $V(\phi) = \frac{1}{2}m^2\phi^2 + \frac{1}{3!}\lambda_3\phi^3 + \frac{1}{4!}\lambda_4\phi^4 + \dots$

From lattice studies: $m \simeq c\Lambda + \mathcal{O}(1/N^2)$

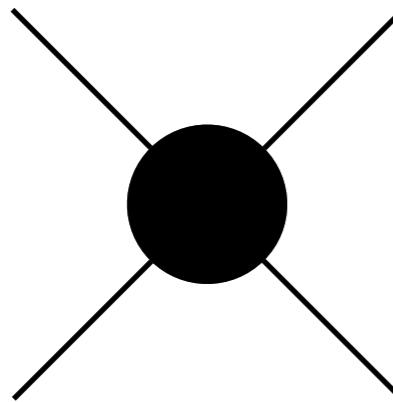
Lucini, Rago, Rinaldi (1007.3879)

Power counting in the large N limit

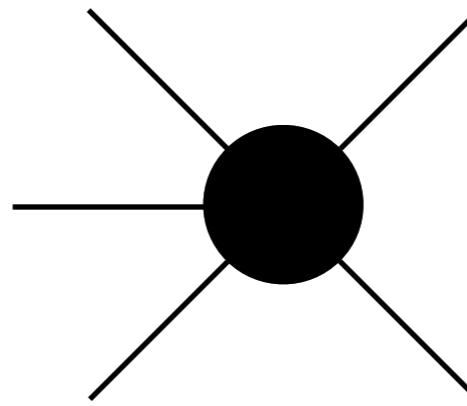


Effects on Structure Formation

2→2 scattering from $\lambda_4\phi^4$ term



3→2 annihilation also allowed



$$T \simeq \frac{T_0}{1 + \frac{3T_0}{m} \ln \frac{a}{a_0}}$$

Self-interaction

Bullet cluster constraint

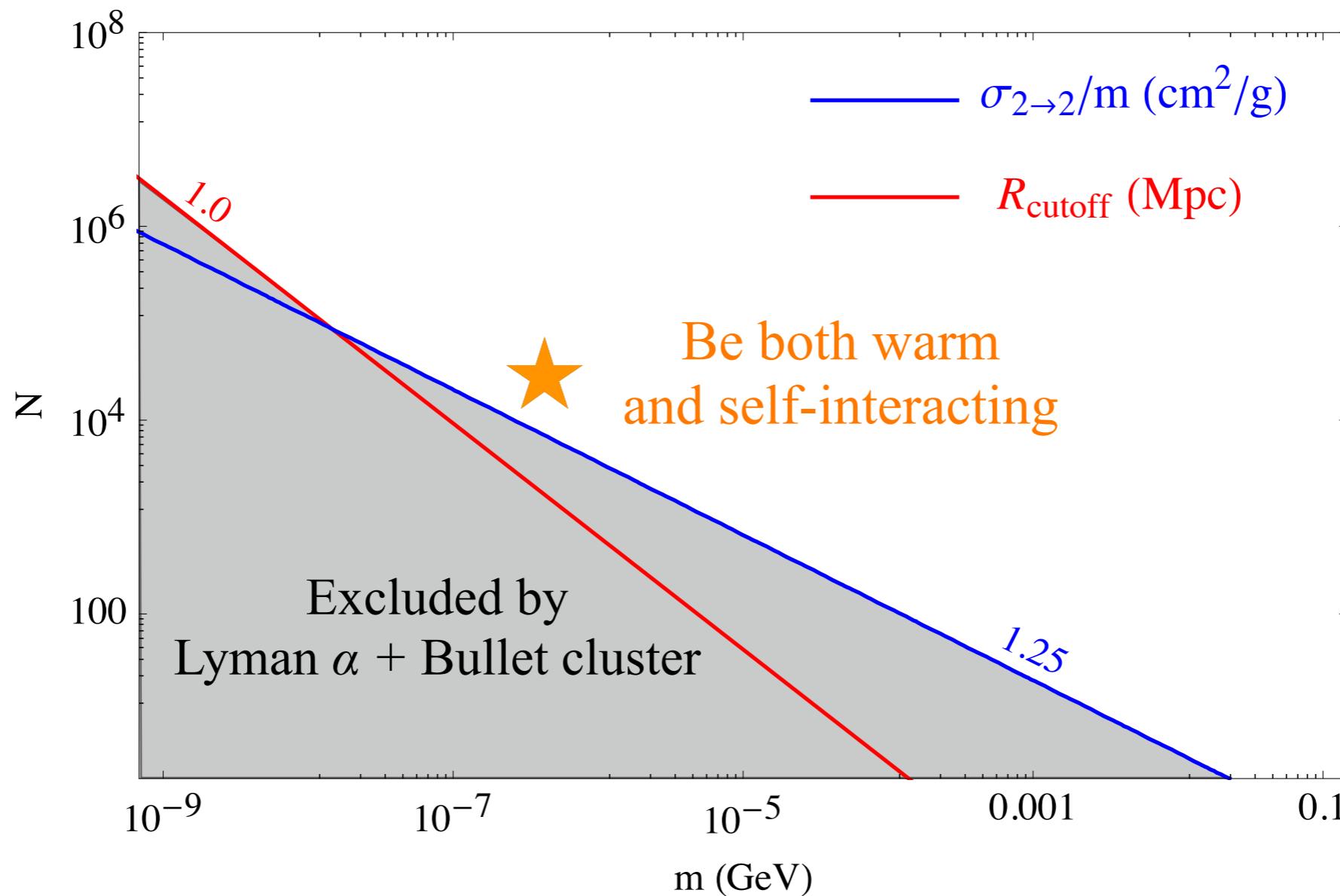
collisional damping

Lyman- α forest constraint

note: $T \sim 1/a$ (radiation), $T \sim 1/a^2$ (matter)

Carlson, Machacek, Hall (1992); Soni, YZ (1602.00714)

Constraints on Parameter Space

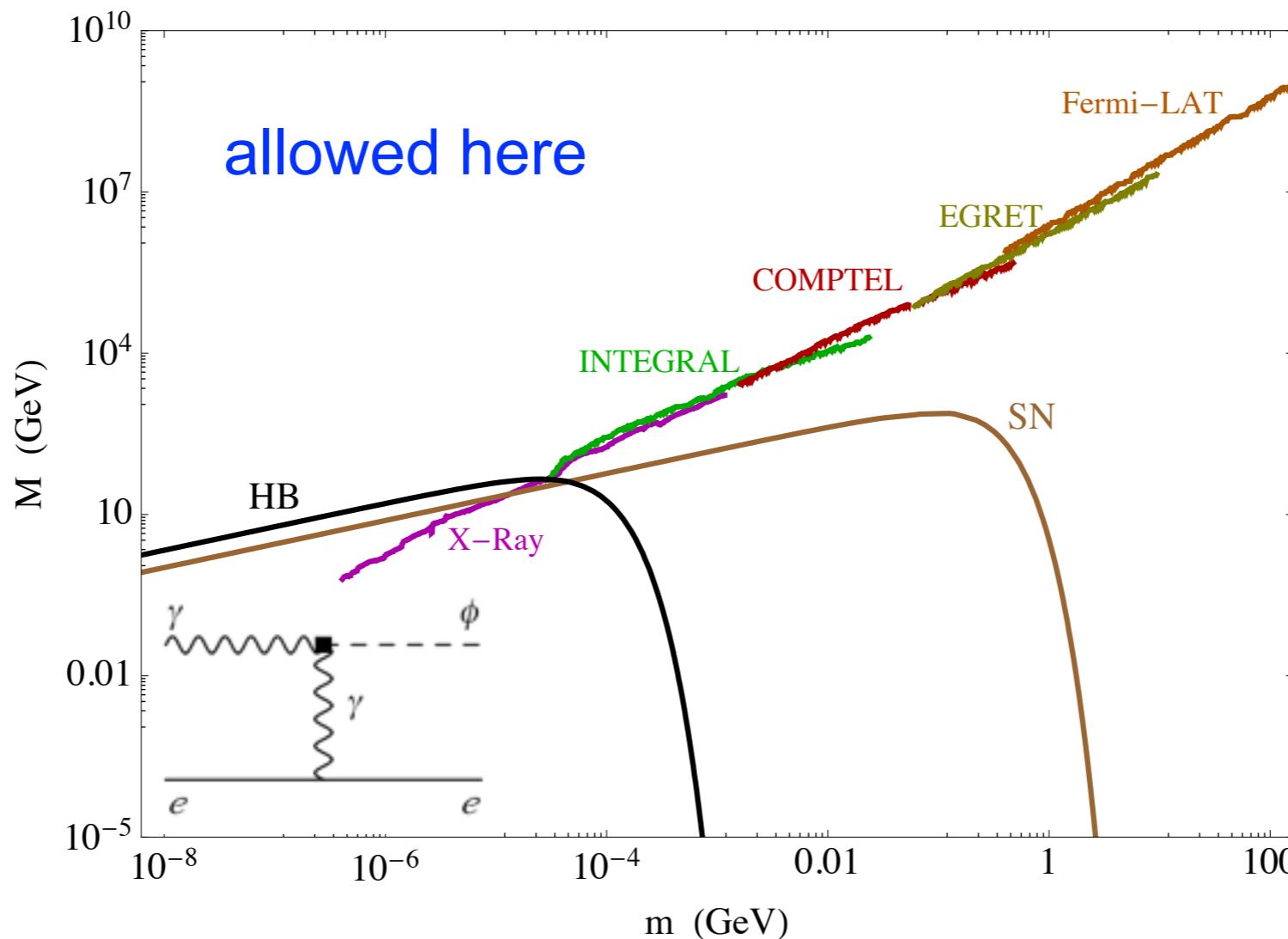


Soni, YZ (1602.00714)

Higher Dimensional Operators

Any HD operator would make dark glueball a decaying DM.

$$O = \frac{1}{M^4} H^{\mu\nu} H_{\mu\nu} (F^{\alpha\beta} F_{\alpha\beta}) \rightarrow \frac{Nm^3}{M^4} \phi F^{\alpha\beta} F_{\alpha\beta}$$



Soni, YZ (1602.00714)

The Message

Simple models could offer rich new states

Future experiments are territories to test these possibilities