WG 1:
New avenues in direct detection

Conveners:

Rouven Essig (Stony Brook)
Juan Estrada (Fermilab)
Dan McKinsey (Berkeley)

DoE Charge

- Workshop is in response to P5 report recommendations to maintain a diversity of new, small projects for dark matter searches in areas of parameter space not currently being (or on track to be) explored
- Show the existence of a (organized and well motivated) community
- Show we have a strong physics case with clear targets in the parameter space
- Show we have a clear roadmap (experimental program) to address the physics case:
  - ready to start project funding FY19 (generation 1)
  - complementary or more sensitive follow-up (generation 2) in ~5-7y (?)
  - an R&D activity for a long term program (generation 3) in >7y (?)

DoE would like to know about projects that…

- are <$10 million
- can be mostly DoE funded
- targeting new parameter space

we will want to make a clear summary
for close-out plenary and white paper

White paper

- Authorship is to be determined, but likely anyone supportive of this science and who contributes to white paper
- 1-page contributions will help conveners summarize all ideas — please send to us asap

We will collect info in a table (discuss)

Name of Experiment	Target Material	Readout	Parameter space	Project Budget	Timescale/Status
xenon TPCs (Xenon100/1T/ nT, LUX, LZ)	Xe	TPC	~5 MeV (ER) ~500 MeV (NR+B) 1 GeV (NR)		many results + R&D ongoing
...					

Important goal: explain why science case is strong

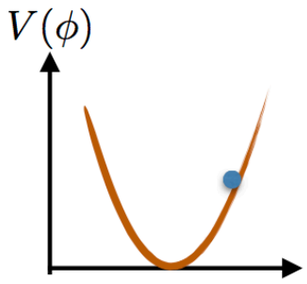
To make a clear and simple case in close-out plenary, we may want to:

- Decide which parameter space we want to focus on
- Provide 1 or 2 benchmark models w/ sharp targets in this parameter space

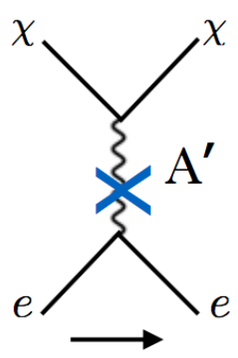
Parameter space

from Tongyan's talk:

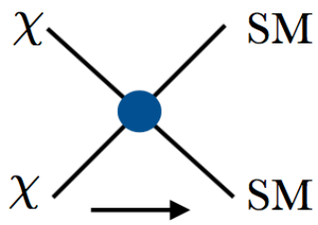
Bosonic DM

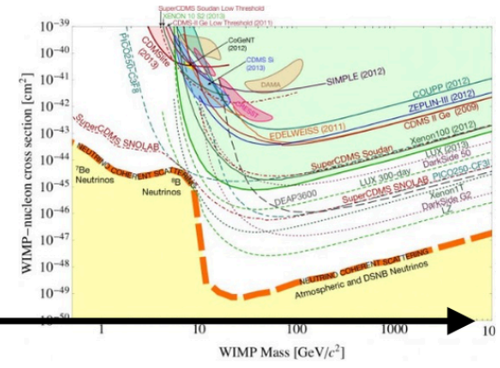


Light DM +
light mediators



WIMP





Absorption | Scattering

meV eV keV MeV GeV TeV

Dark matter mass

Parameter space

from Tongyan's talk:

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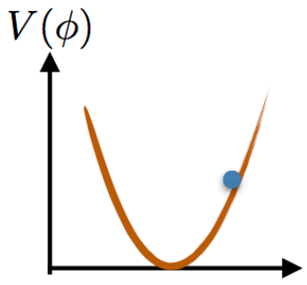

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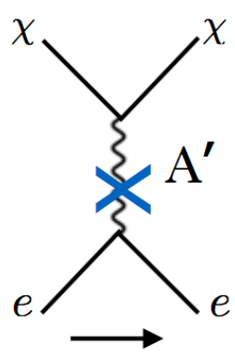

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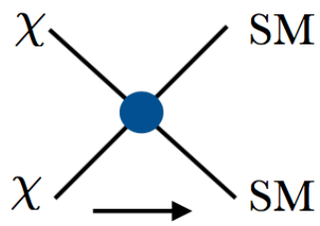

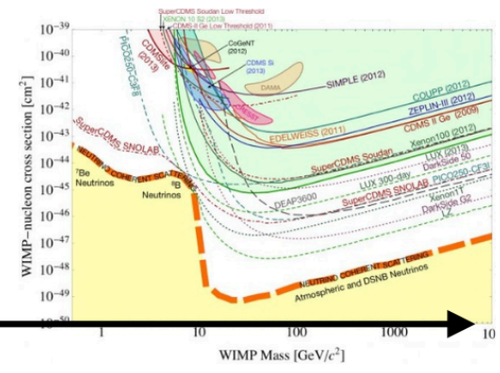

Absorption | Scattering

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Dark matter mass

focus on < GeV?

Parameter space for scattering

- σ_e vs m_{DM}, or σ_N vs m_{DM}, or <u>both</u>

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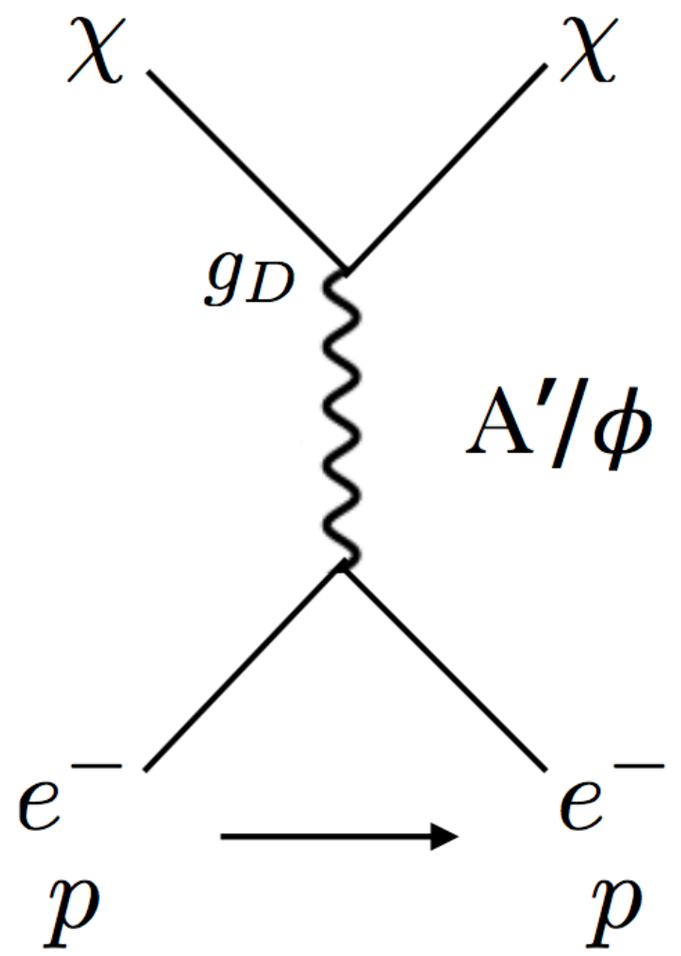
mediator between DM & SM could be e.g.

- vector (e.g. dark photon), coupling to leptons & quarks
- vector, coupling predominantly to quarks only or leptons only
- scalar (via Higgs mixing)



all are viable and interesting possibilities!

(+others exist too!)

Parameter space for scattering

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- vector, coupling predominantly to quarks only or leptons only ← as above (but is model building less pleasant?)
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in Tongyan's talk, but let's review

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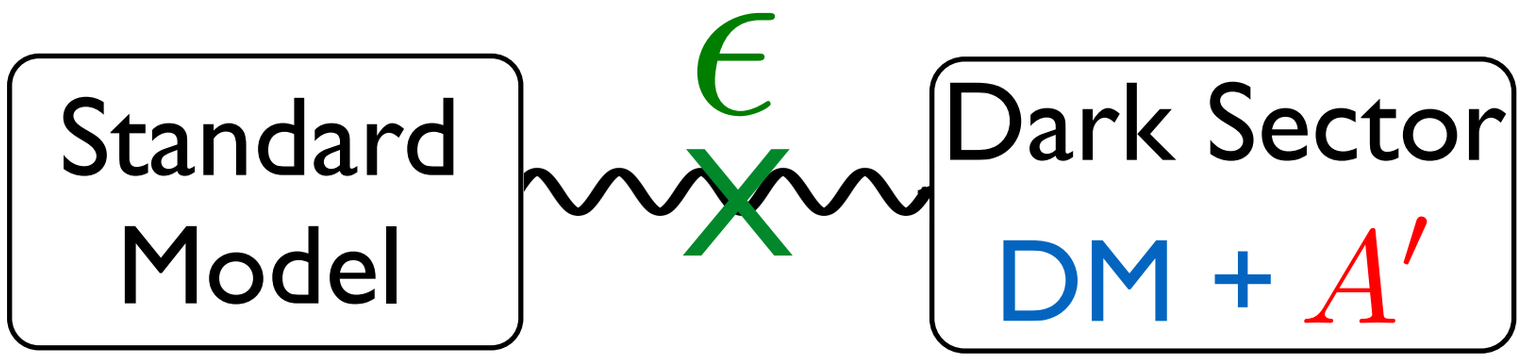

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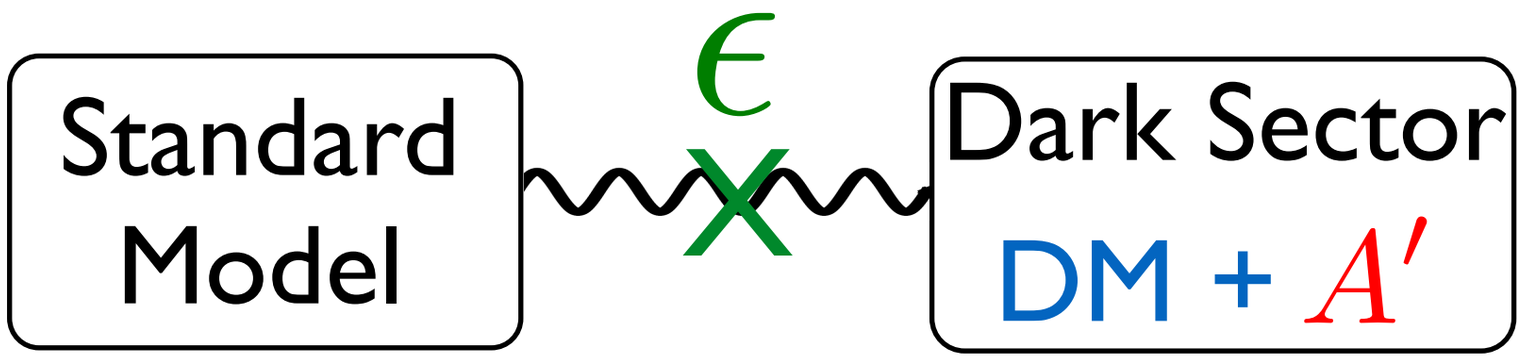

- light A′ (~m_{DM})
- ultra-light A′ ($\ll$ keV)

simple & predictive

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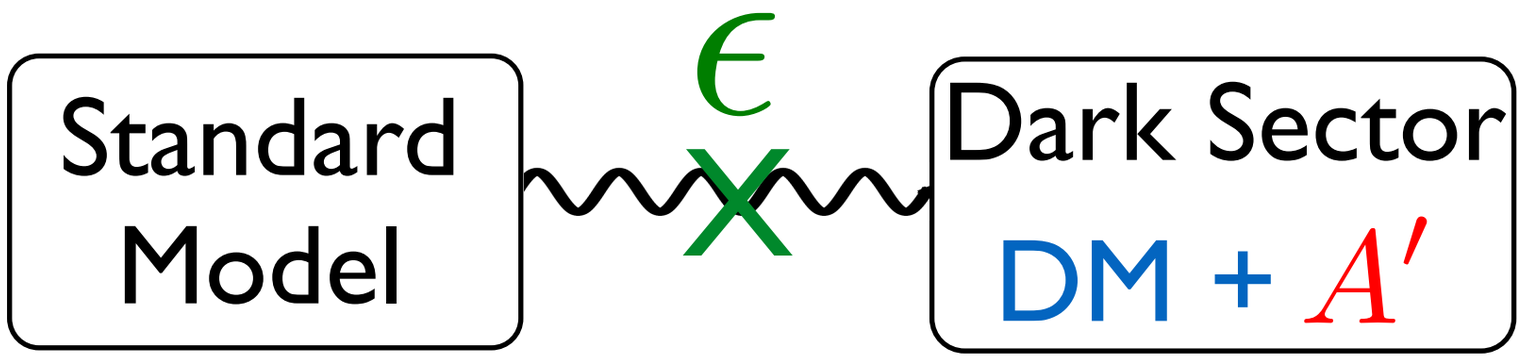

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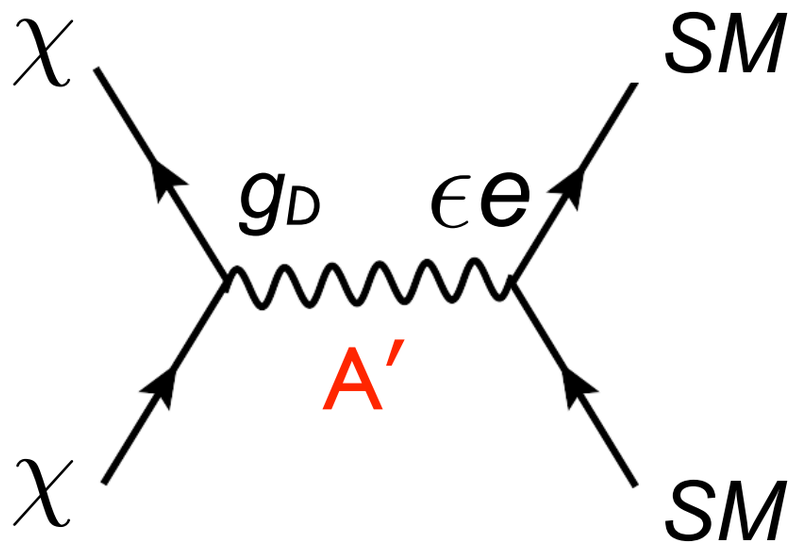
see e.g. Arkani-Hamed et.al.; Weiner et.al.; Pospelov & Ritz; RE, Kaplan, Schuster, Toro; RE, Mardon, Volansky; Lin, Yu, Zurek; Chu, Hambye, Tytgat; Hall, Jedamzik, March-Russell, West; Boehm, Fayet; Borodatchenkova, Choudhury, Drees; Pospelov, Ritz, Voloshin; Batell, Pospelov, Ritz; Izaguirre, Krnjaic, Schuster, Toro; RE, Fernandez-Serra, Mardon, Soto, Volansky, Yu; …

Targets



$m_{A'} > 2m_\chi$

(very predictive)

e.g. Boehm & Fayet (2003); Borodatchenkova, Choudhury, Drees (2005); Lin, Yu, Zurek (2011); Izaguirre, Krnjaic, Schuster, Toro (2015); RE, Fernandez-Serra, Mardon, Soto, Volansky, Yu (2015)

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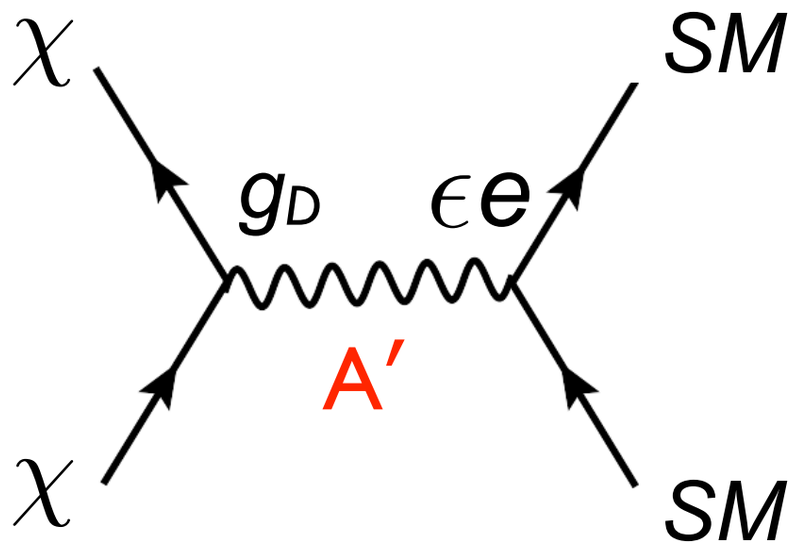

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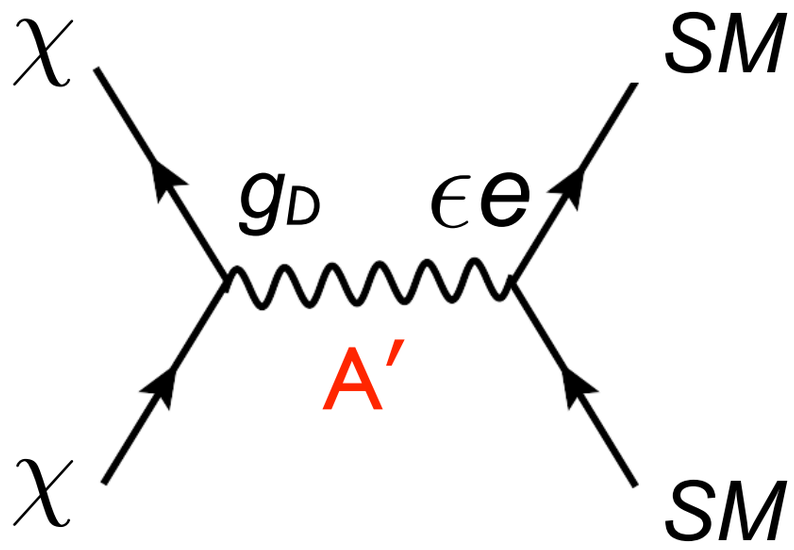

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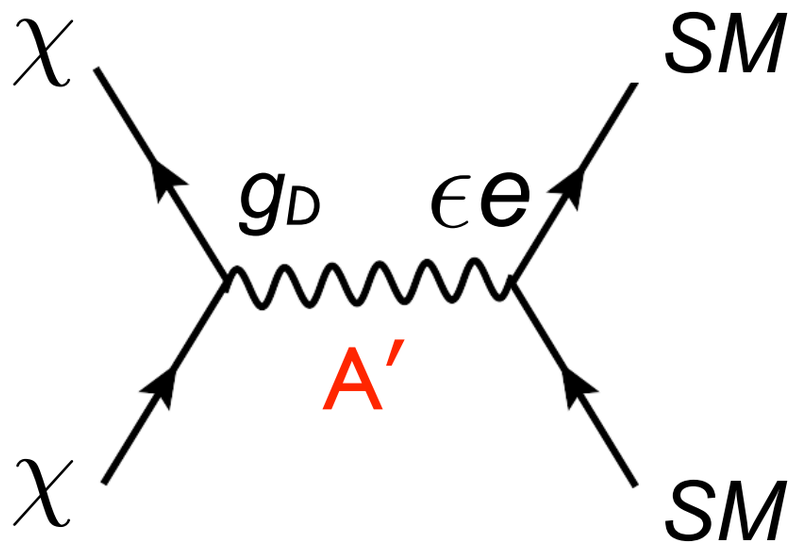

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unconstrained by CMB

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s-wave

$\Longrightarrow$ asymmetric

CMB sets *lower* bound on σv

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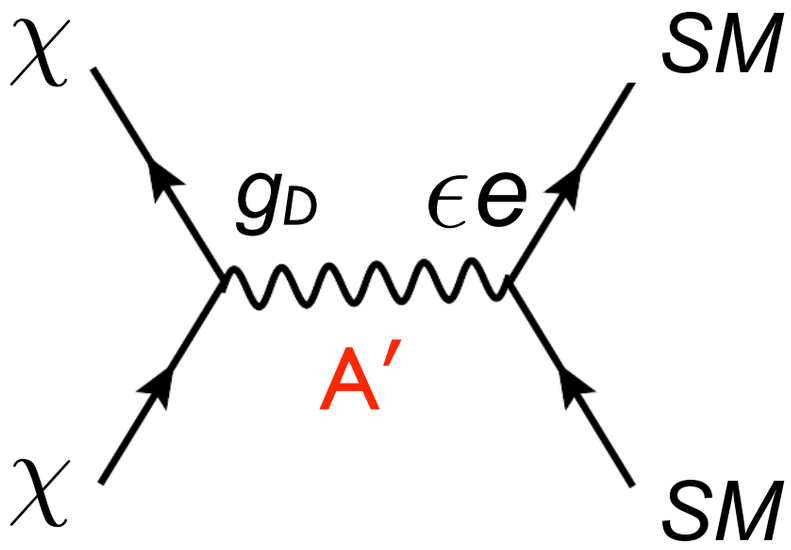

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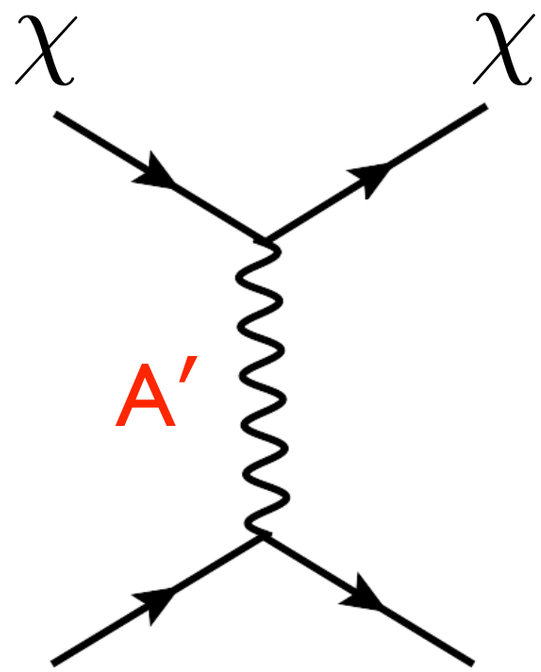
provides nice targets for direct detection experiments!

CMB sets *lower* bound on σv

Direct Detection



$$\bar{\sigma}_e \propto \frac{\epsilon^2 \alpha_D}{m_{A'}^4} \mu_{\chi e}^2$$

$$F_{\rm DM} = 1$$

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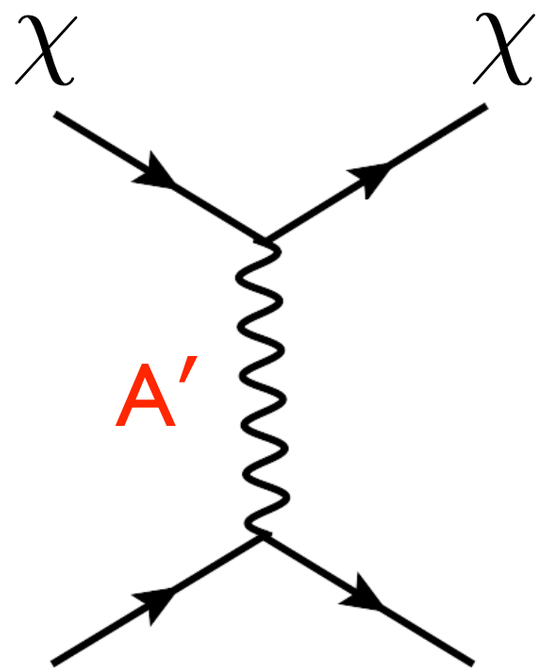
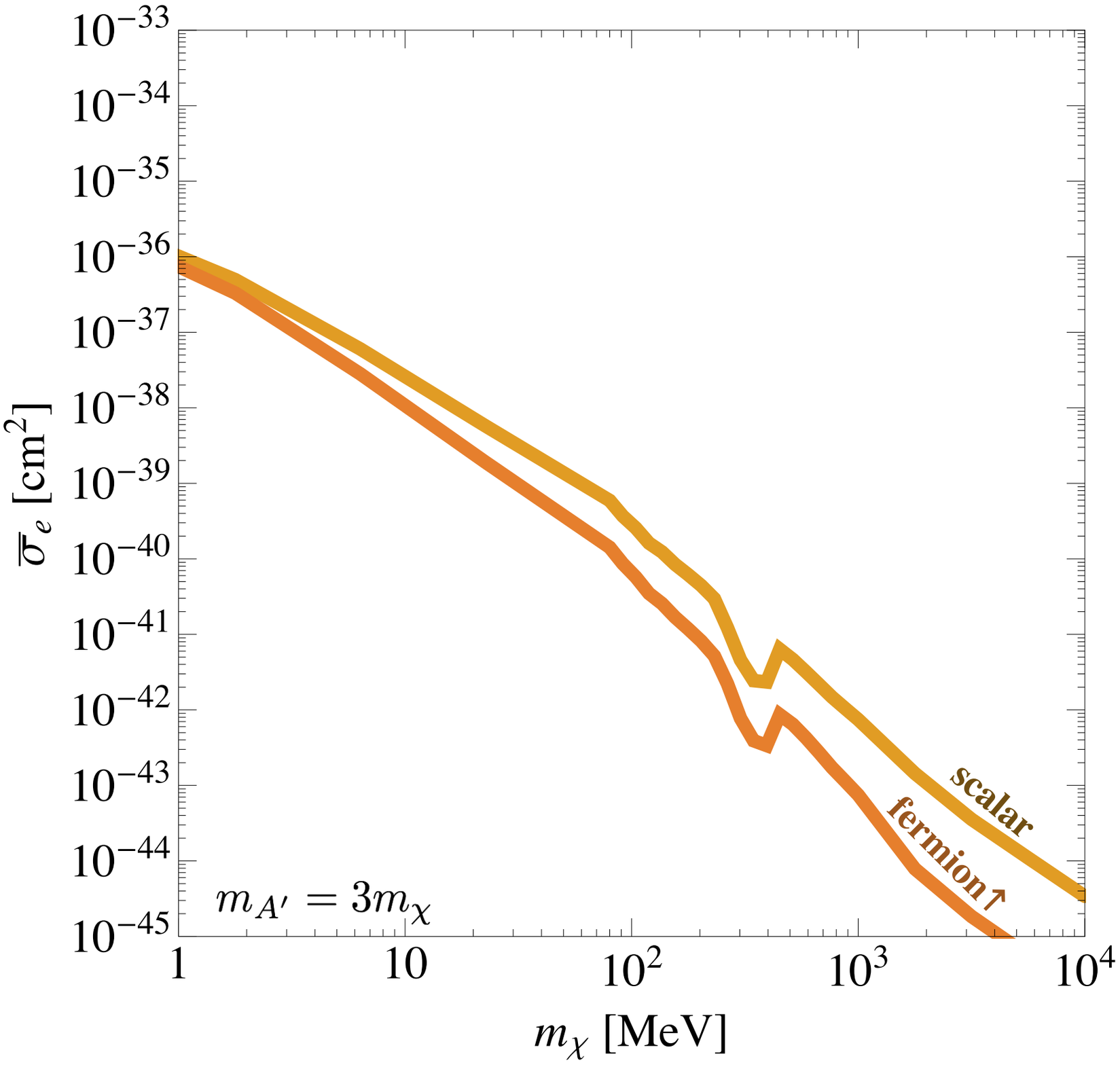


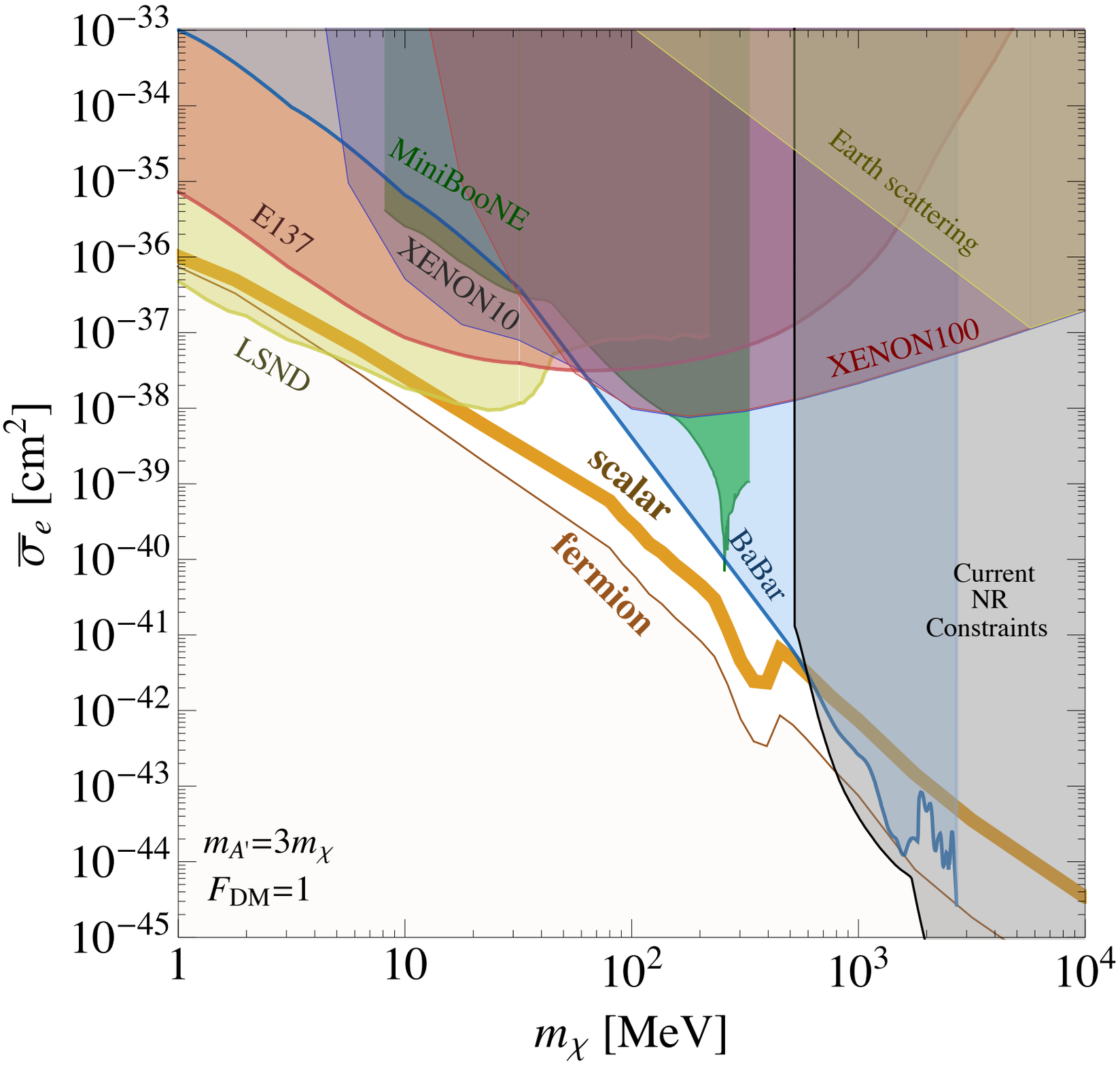
$$\bar{\sigma}_e \propto \frac{\epsilon^2 \alpha_D}{m_{A'}^4} \mu_{\chi e}^2 \qquad F_{\rm DM} = 1$$

similar combination as freeze-out parameters!

Freeze-out & Asymmetric DM targets

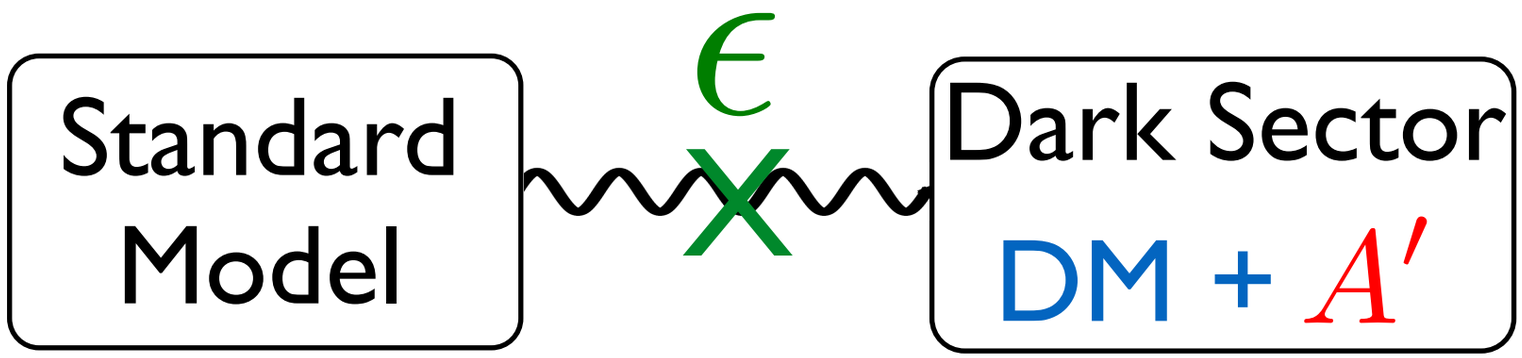


Current constraints



exciting complementarity with collider & beam-dump probes

DM w/ dark photon (A′) mediator



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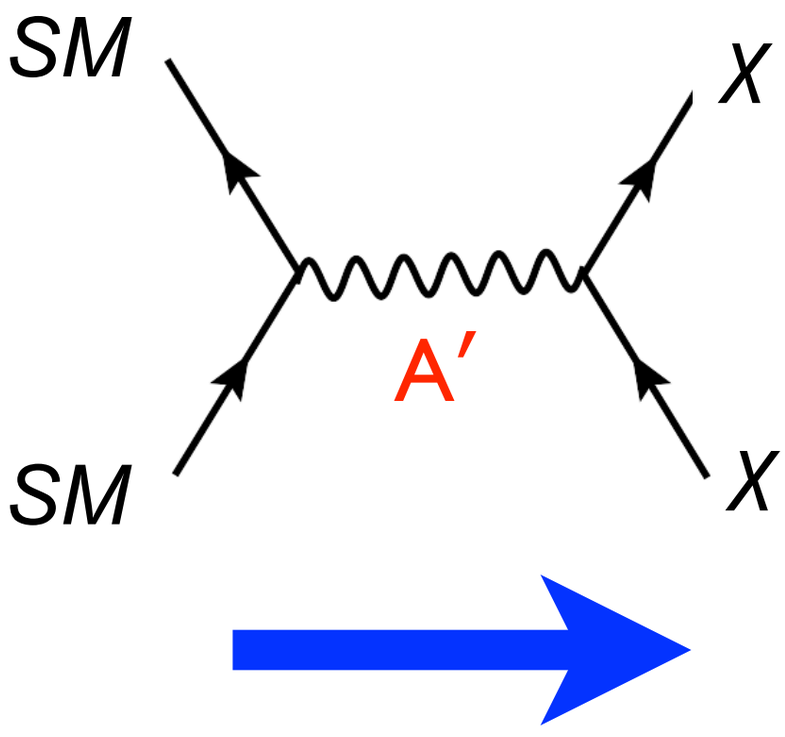
"Freeze-in"

can generate correct DM relic density by "freeze-in"

Hall et.al. (0911.1120)



build up DM abundance as Universe cools

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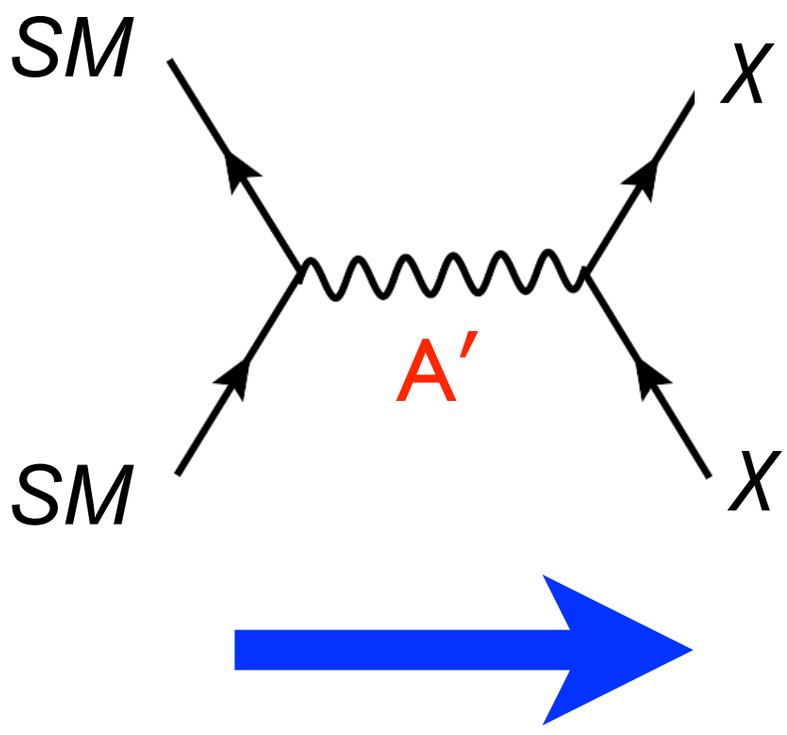


build up DM abundance as Universe cools

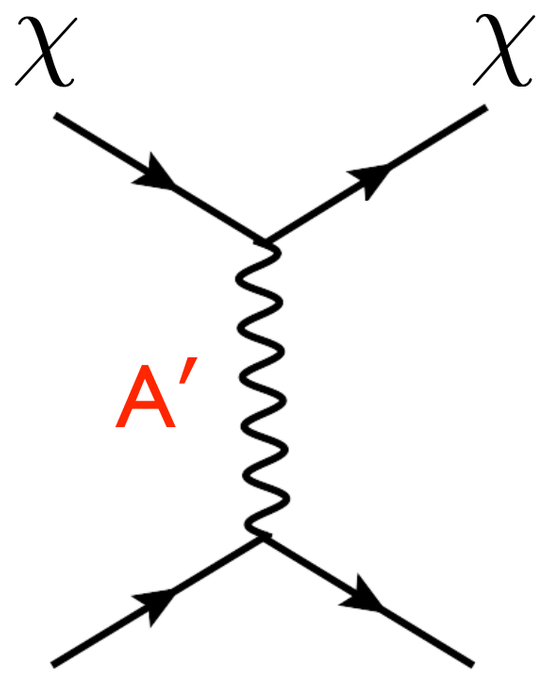
e.g. m_χ = 100 MeV, correct relic abundance for $\alpha_D \epsilon^2 \sim 5 \times 10^{-24}$

(~independent of $m_{A'}$)

RE, Mardon, Volansky
Chu, Hambye, Tytgat

(calculated w/ thermal effects by Jae Hyeok Chang)

Direct Detection w/ ultralight A′ (≪ keV)



enhanced at low q^2

$$\sigma \propto \frac{16\pi\mu_{\chi e}^2 \alpha \alpha_D \epsilon^2}{q^4}$$

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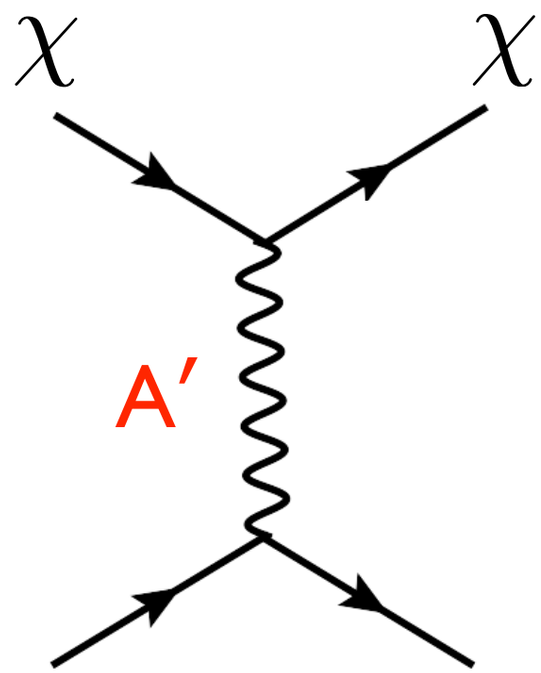

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SM *SM*

$$\sigma \propto \frac{16\pi\mu_{\chi e}^2 \alpha \alpha_D \epsilon^2}{q^4} = \frac{16\pi\mu_{\chi e}^2 \alpha \alpha_D \epsilon^2}{(\alpha^2 m_e^2)^2} \times \left(\frac{\alpha^2 m_e^2}{q^2}\right)^2$$

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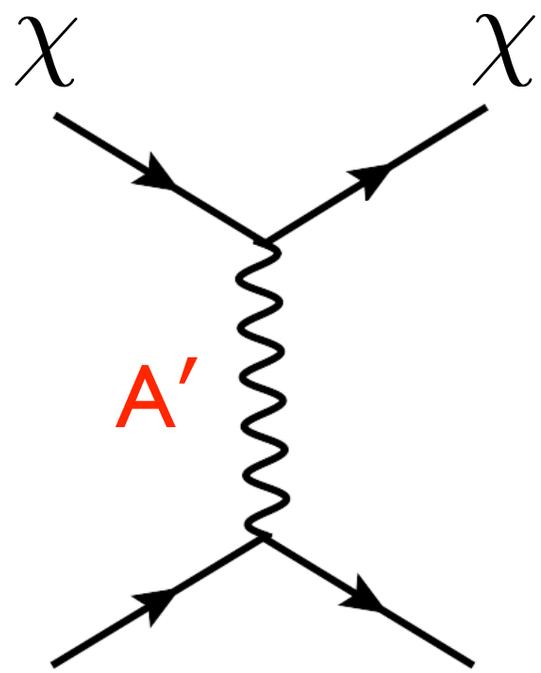

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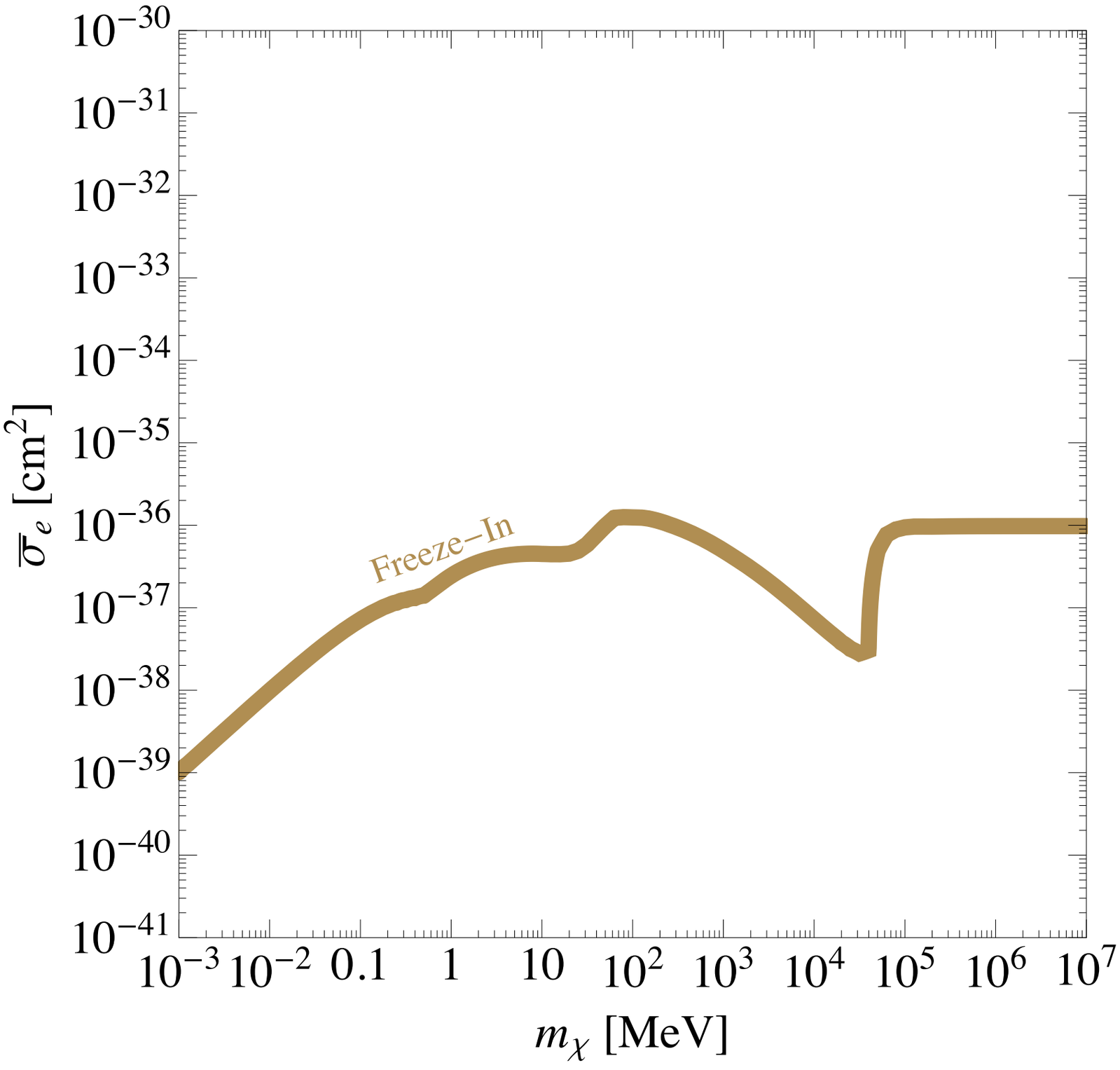
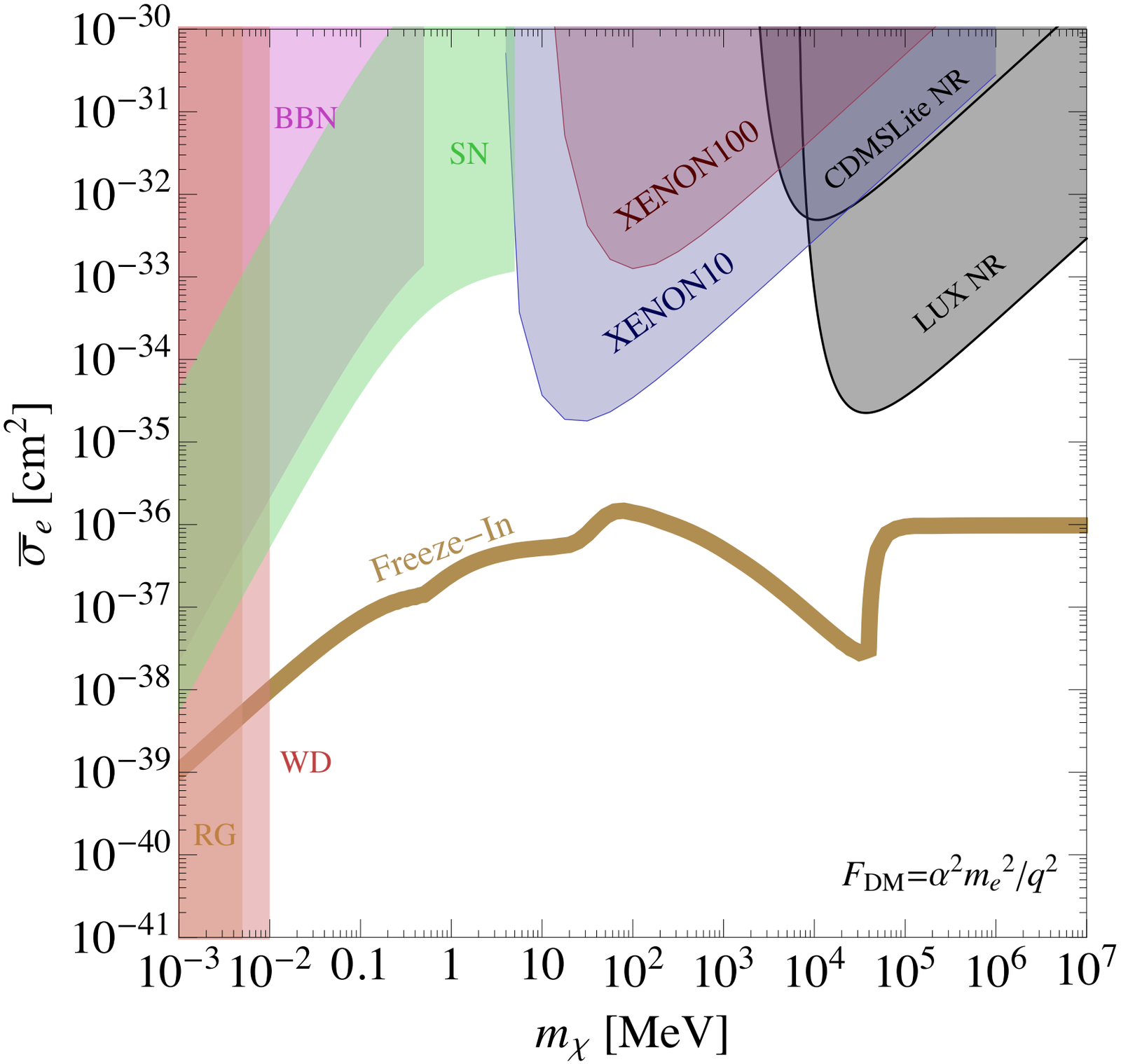
$$\equiv \bar{\sigma}_e \times (F_{\rm DM}(q))^2$$

Freeze-in target



Current Constraints



collider & beam-dump constraints irrelevant

light mediator scenario is uniquely probed by Direct Detection

Summary of Possible Theory Targets for DM scattering

- "Thermal Freeze-out"
- "Asymmetric freeze-out"

} closely related, count as 1 target?

- "Freeze-in"

Discussion of Benchmark Models

- clear, simple targets
- DM can scatter off both electrons and nuclei:

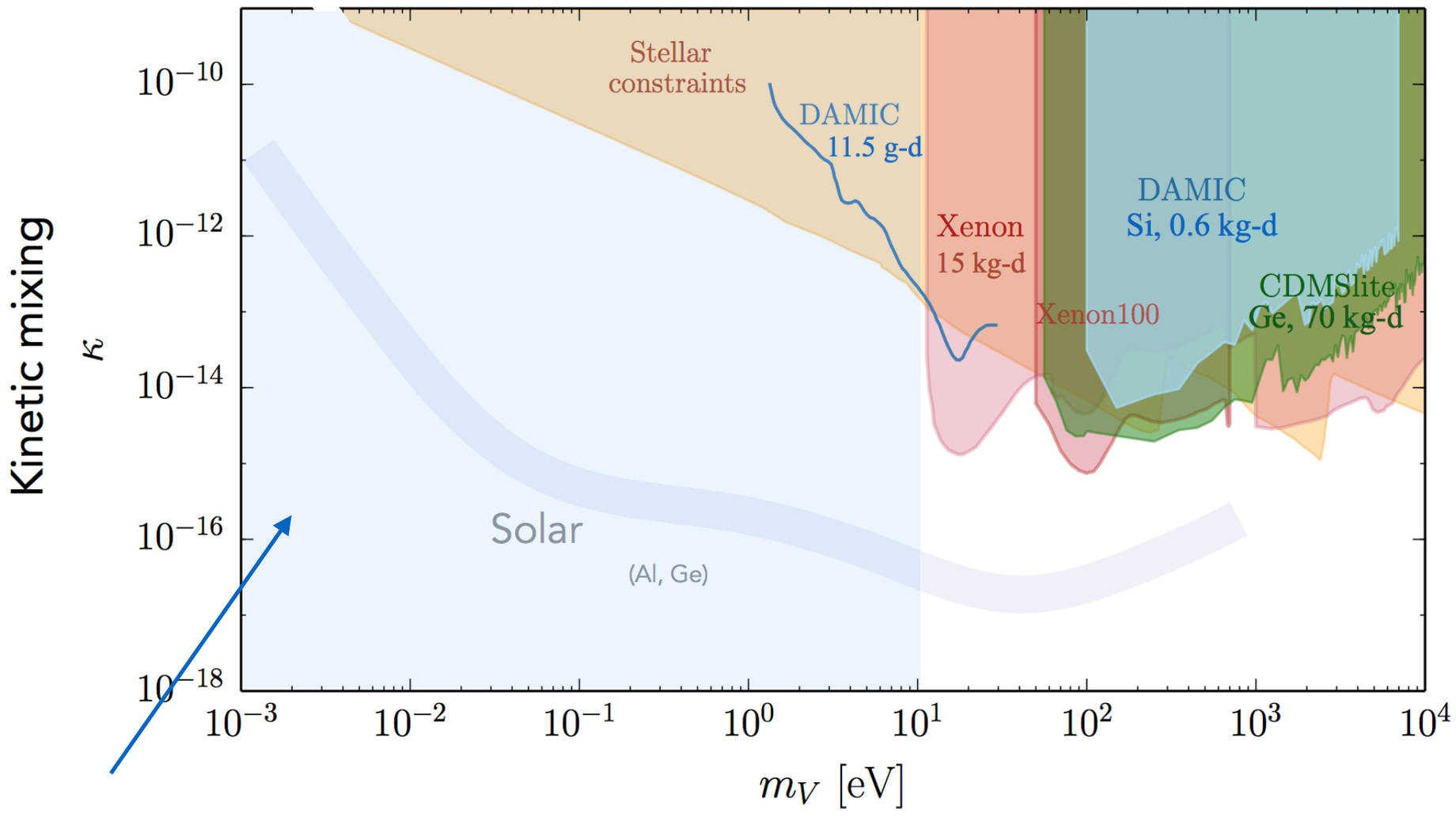
$$\bar{\sigma}_n \simeq \frac{Z^2}{A^2}\frac{\mu_{\chi,n}^2}{\mu_{\chi,e}^2}\bar{\sigma}_e \simeq \frac{1}{4}\frac{m_\chi^2}{m_e^2}\bar{\sigma}_e$$

- But benchmarks have shortcomings: since A′ couples to electrically charged particles, some proposed detection techniques won't be very sensitive to this model
- In white paper, do we want to add other models (e.g. where DM couples preferentially to quarks)?

Benchmark Models for DM absorption?

- No sharp targets, only "areas of interest"
- But comes along for free when probing scattering

Hidden photon



$10^{12.5}\ \mathrm{GeV} < H_I < 10^{13.5}\ \mathrm{GeV}$

Dark matter mass

plot from Tongyan's talk today

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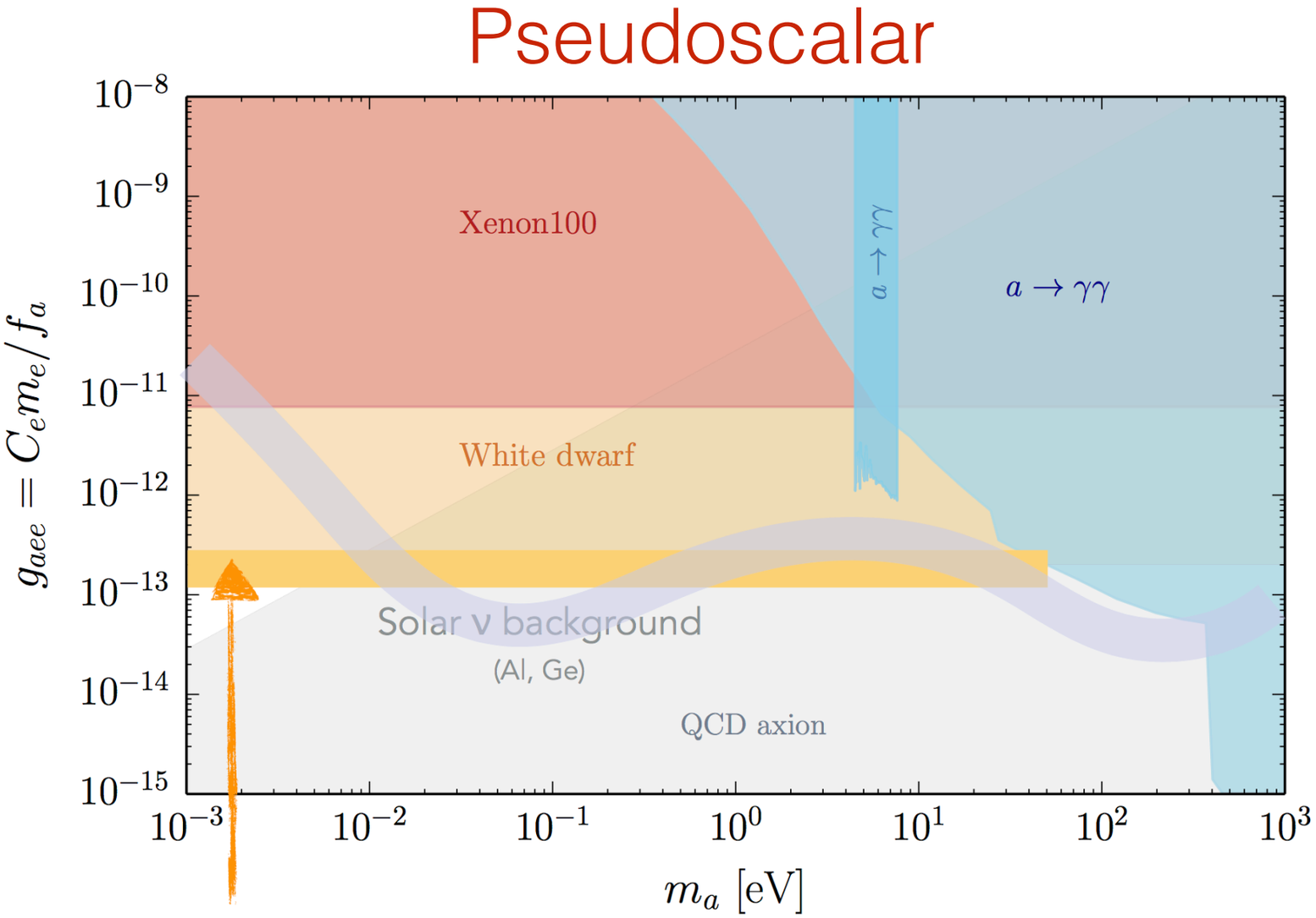


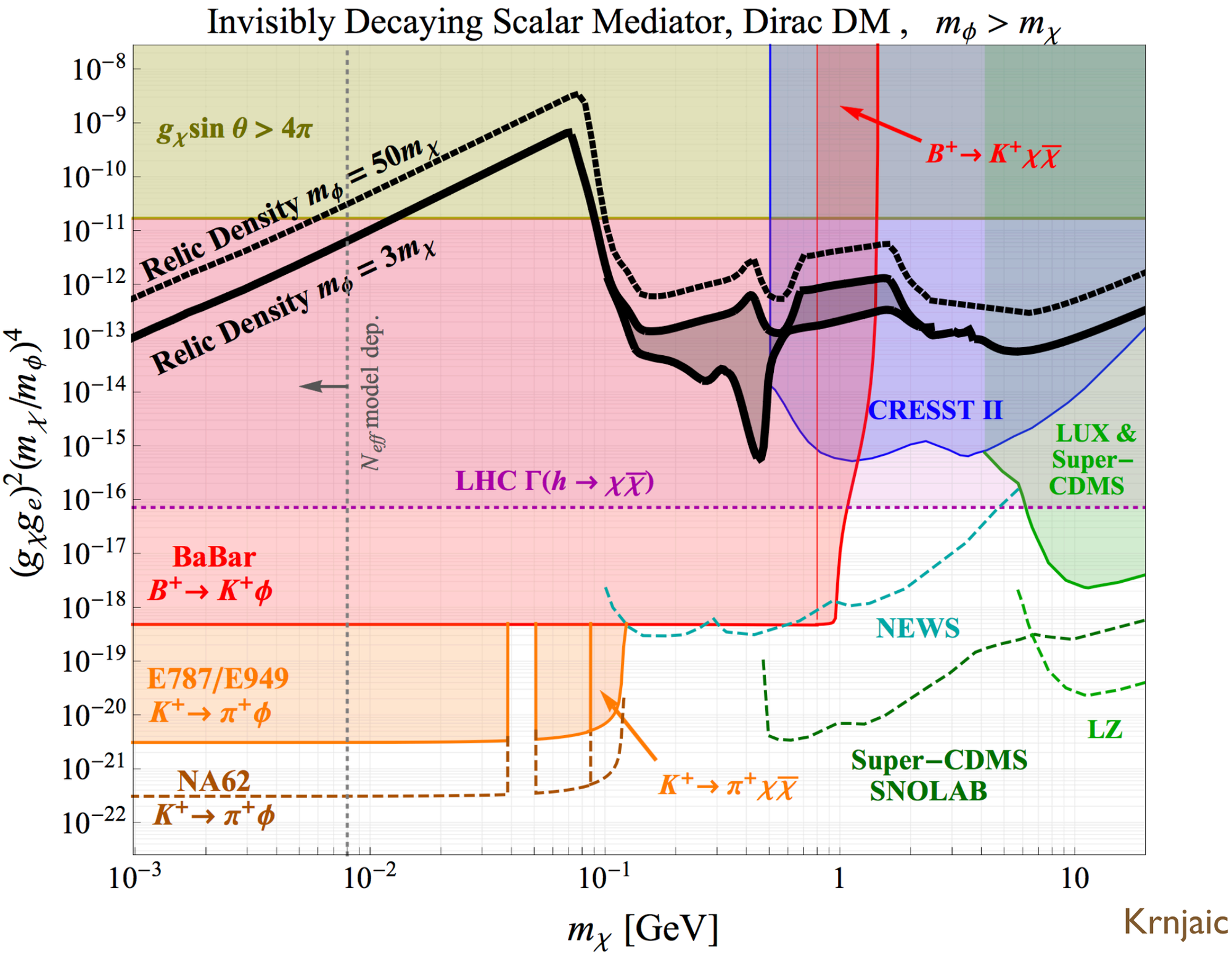
White dwarf cooling hint

Isern et al. 2008;
Giannotti et al. 2015

plot from Tongyan's talk today

Backup

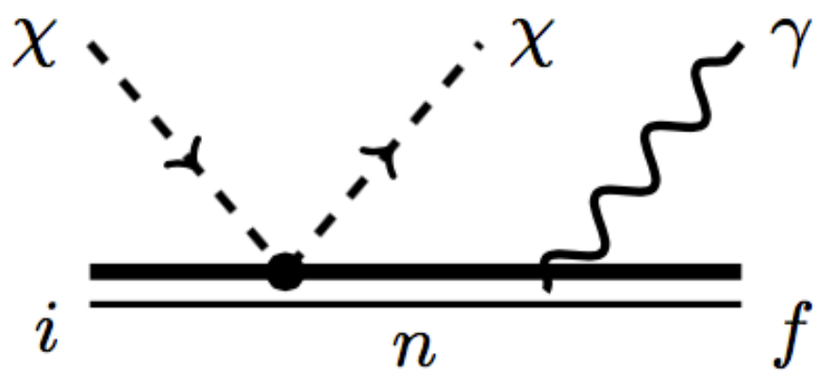
Scalar mediator

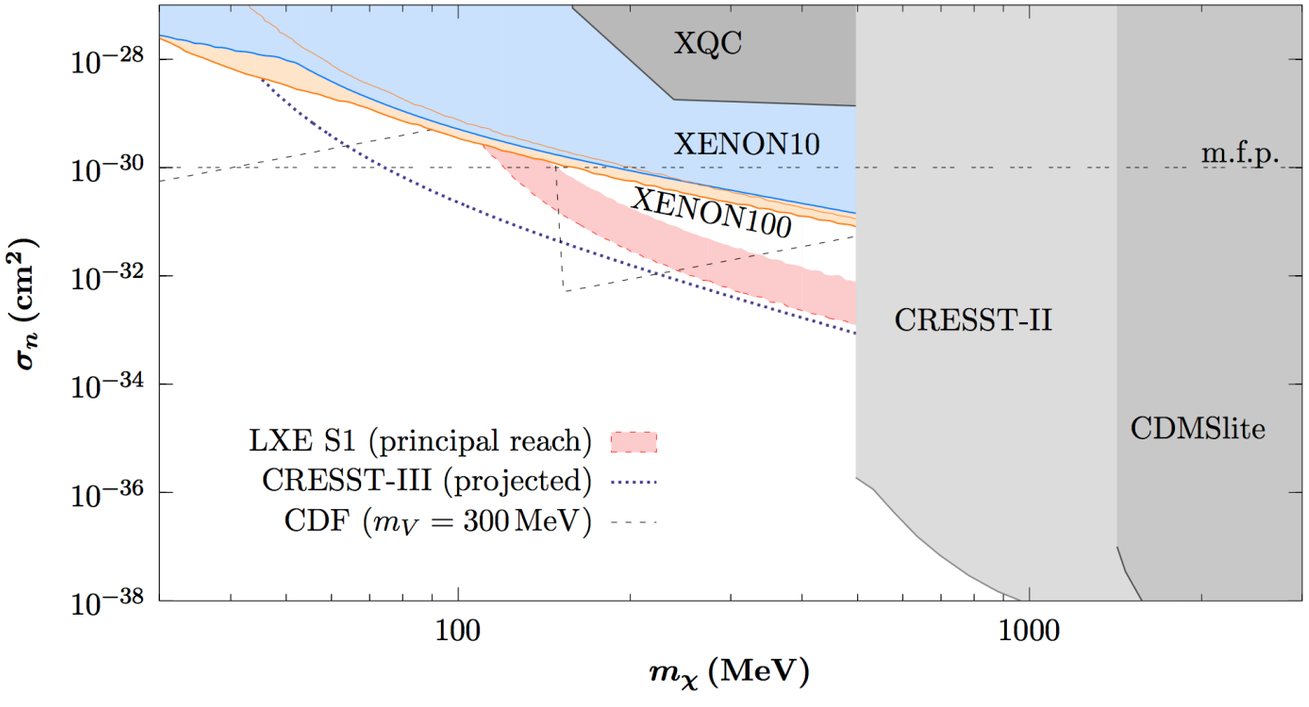


Krnjaic

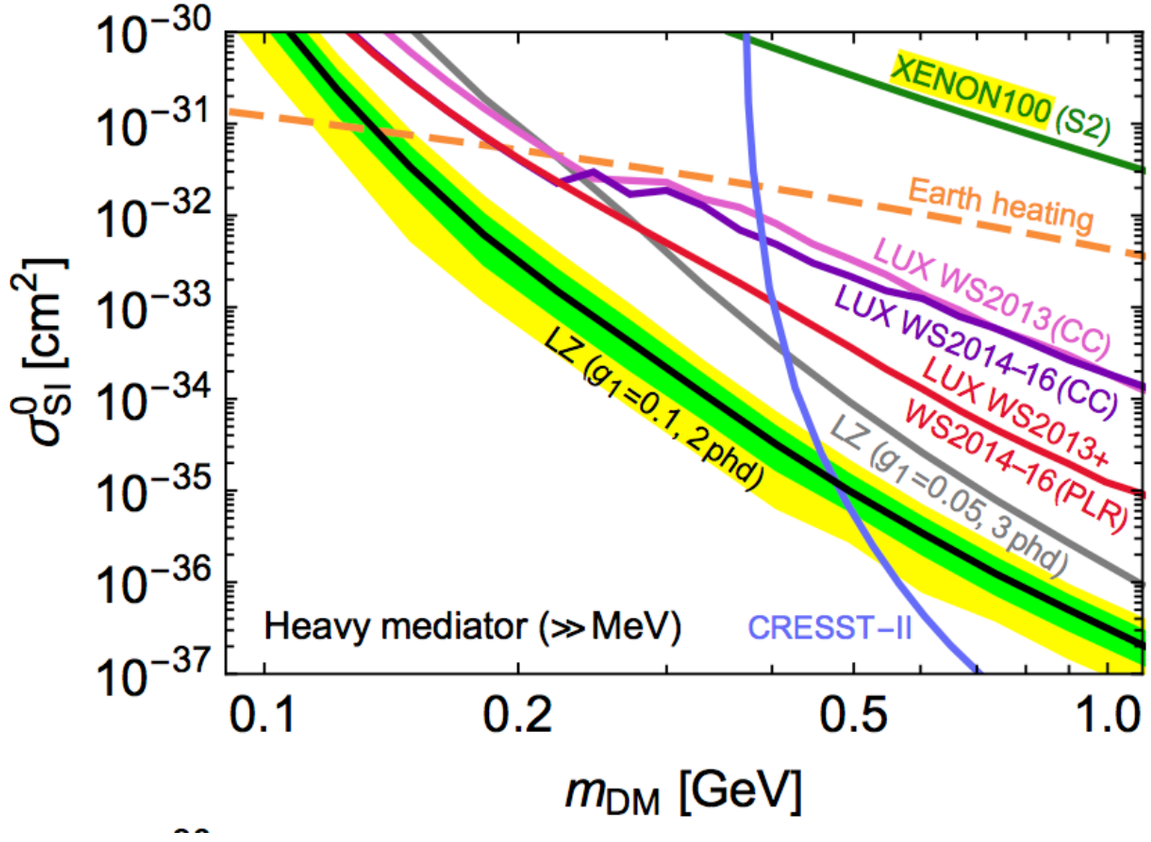
Bremsstrahlung in DM-Nucleus scattering

Kouvaris, Pradler



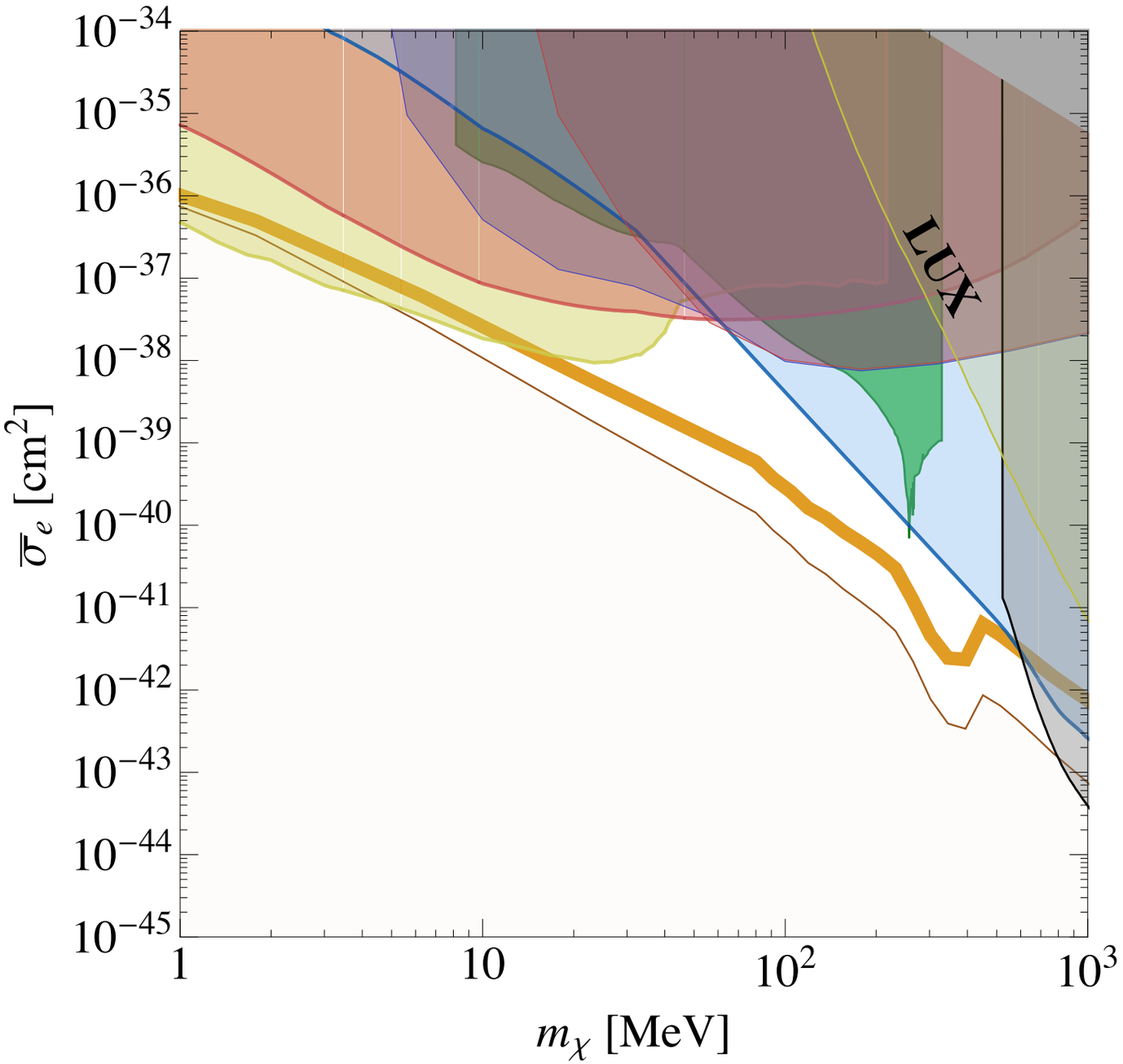


Kouvaris, Pradler



McCabe

LUX constraint for A′ mediated model



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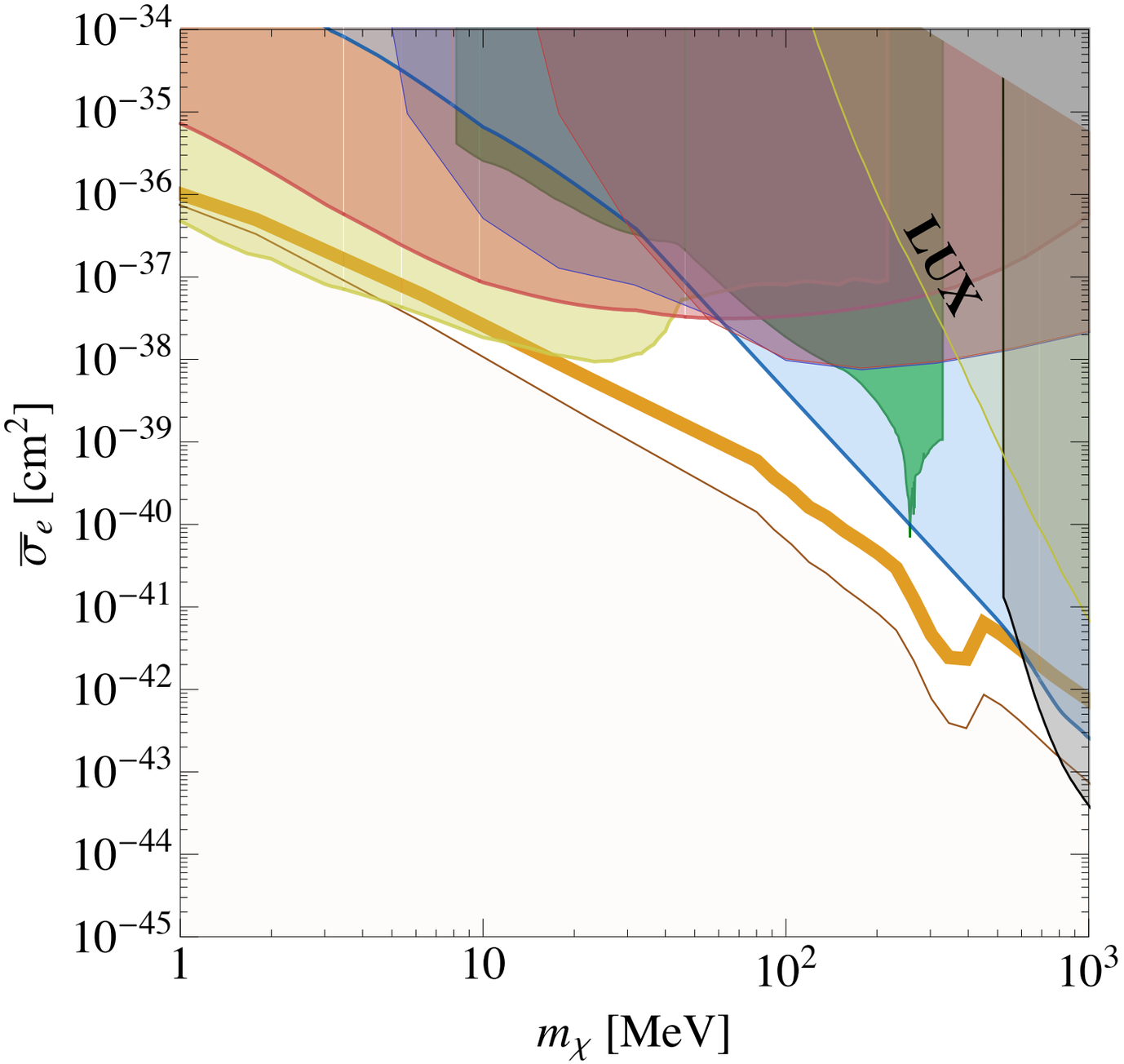


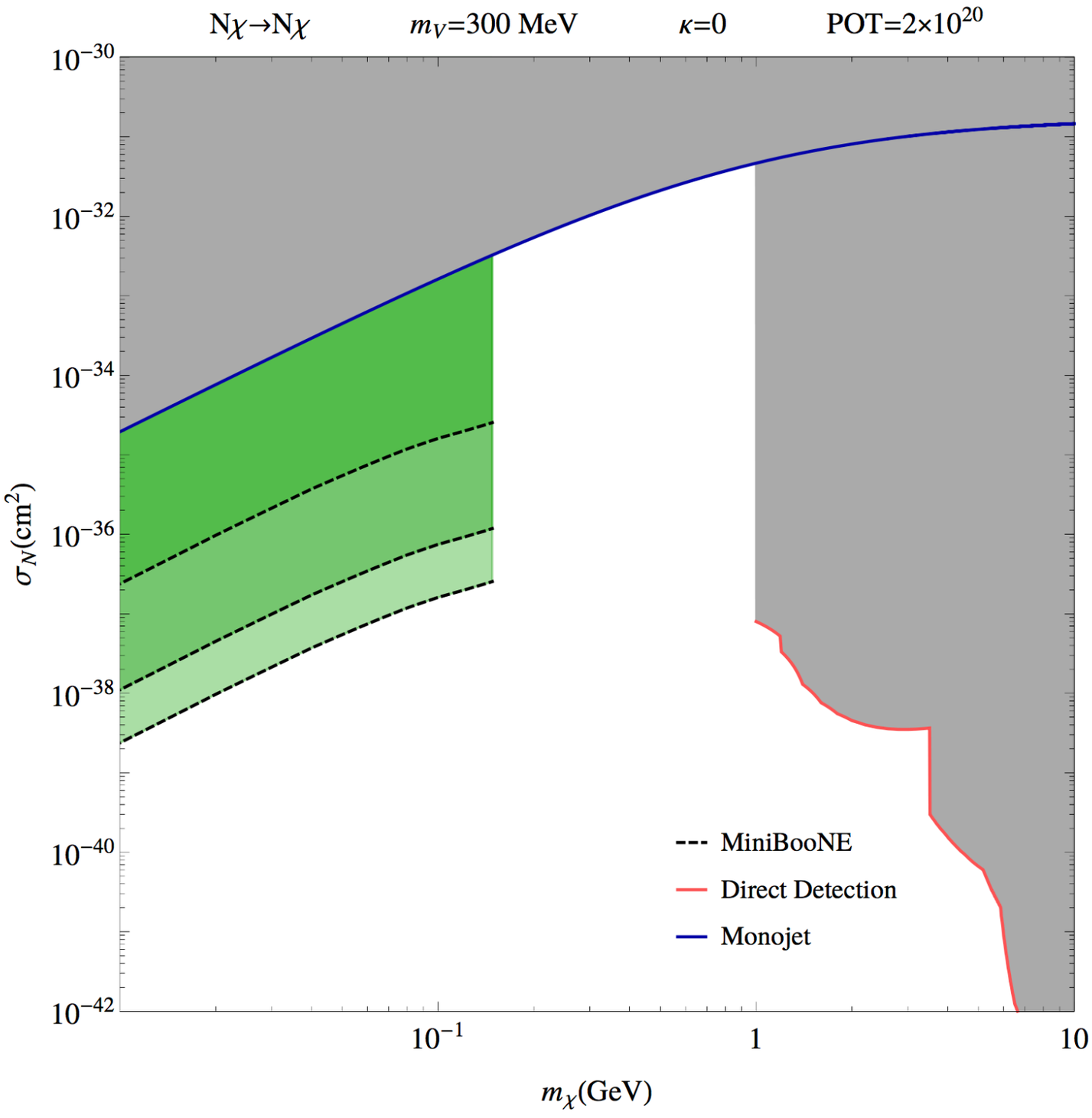
can consider instead
new vector mediator
that couples dominantly
to quarks
("leptophobic DM")

(gauge $U(1)_B$ symmetry)

also has thermal targets

see e.g. Batell, Deniverville, McKeen, Pospelov, Ritz

Leptophobic DM



see e.g. Batell, Deniverville, McKeen, Pospelov, Ritz