Why we need to search for Dark Photons

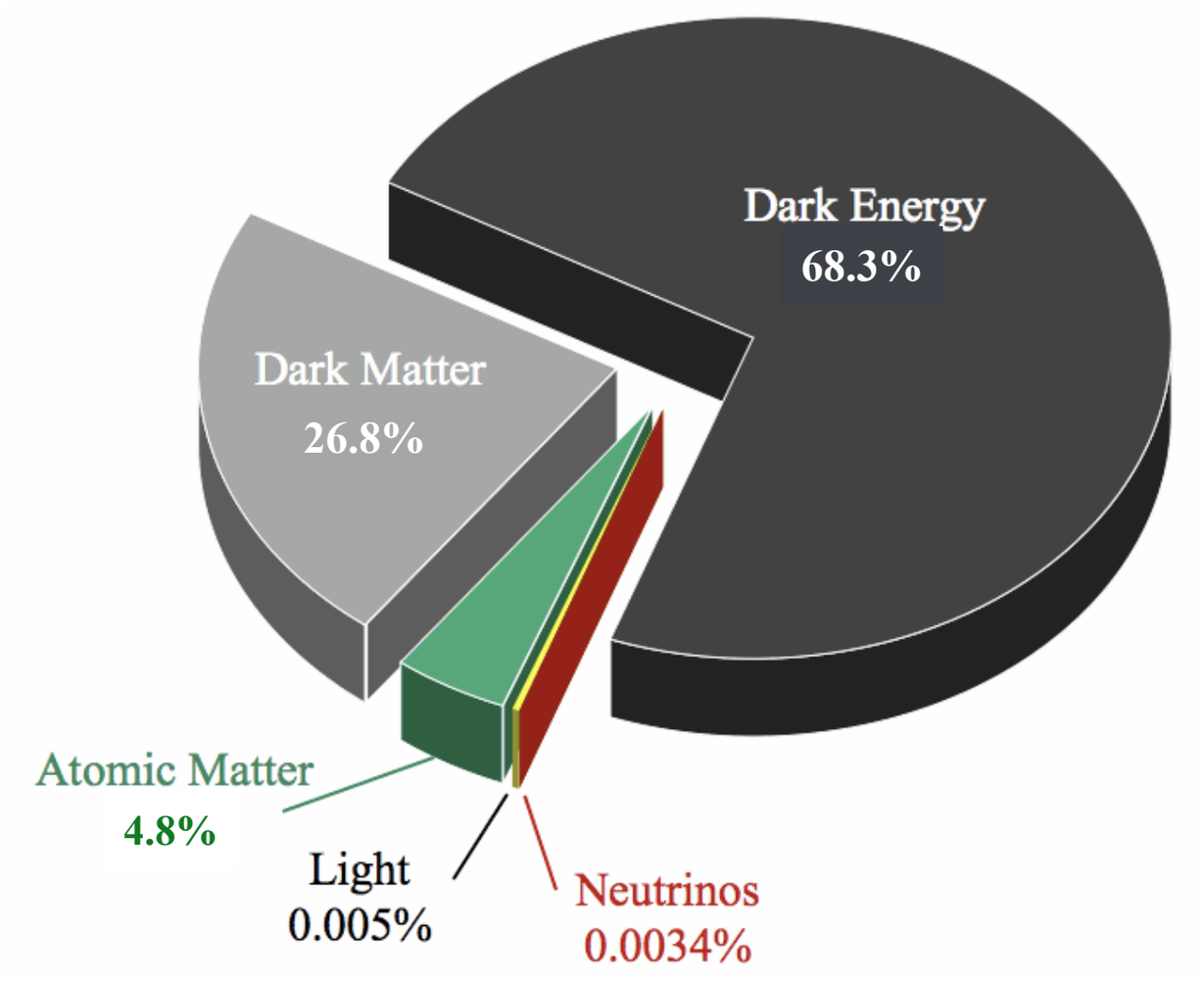
Rouven Essig

Yang Institute for Theoretical Physics

Stony Brook University

HPS Collaboration Meeting, JLab 10/26/2015

What is Dark Matter?

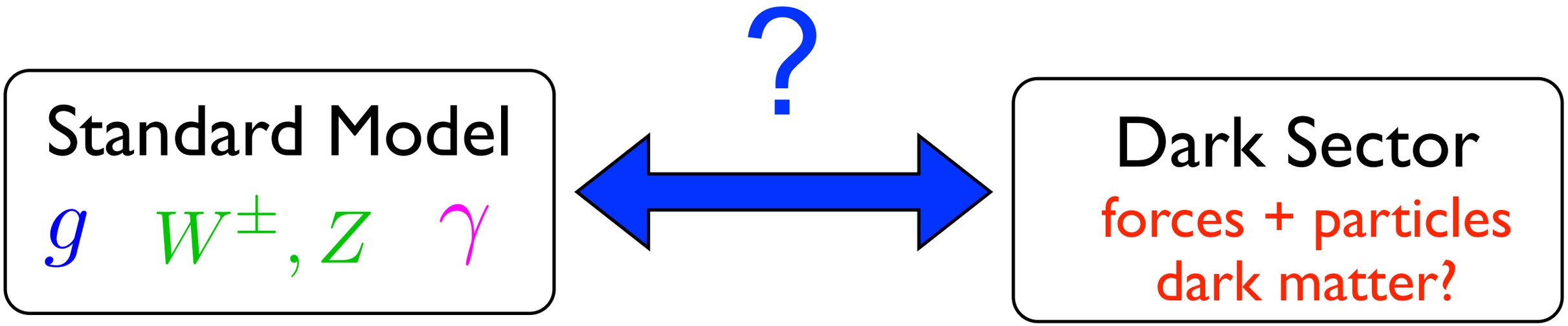


Suggestive of a *dark sector*,

neutral under all Standard Model forces

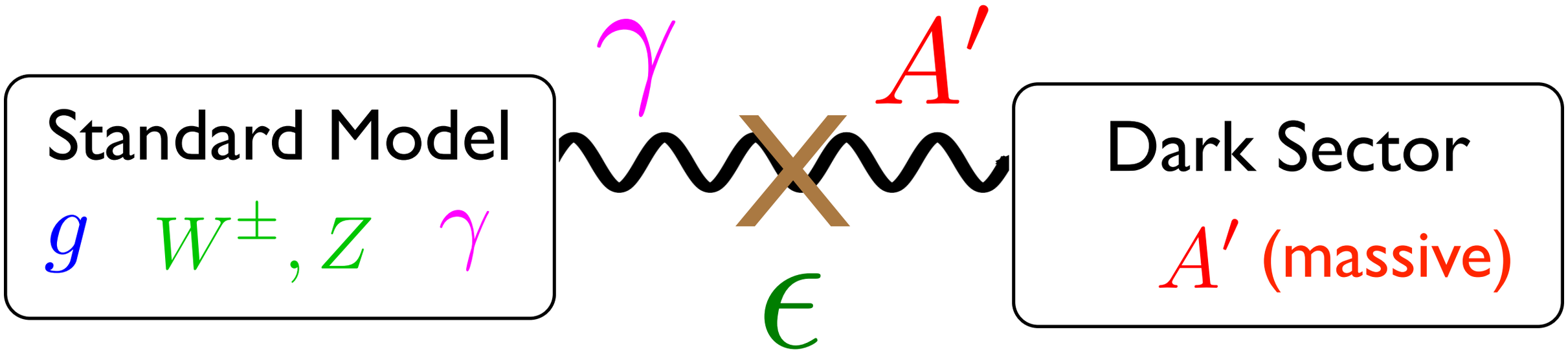
Portals to a dark sector?

only a few important interactions exist that are allowed by Standard Model symmetries



HPS built to probe the
dark photon portal

Dark Photons



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

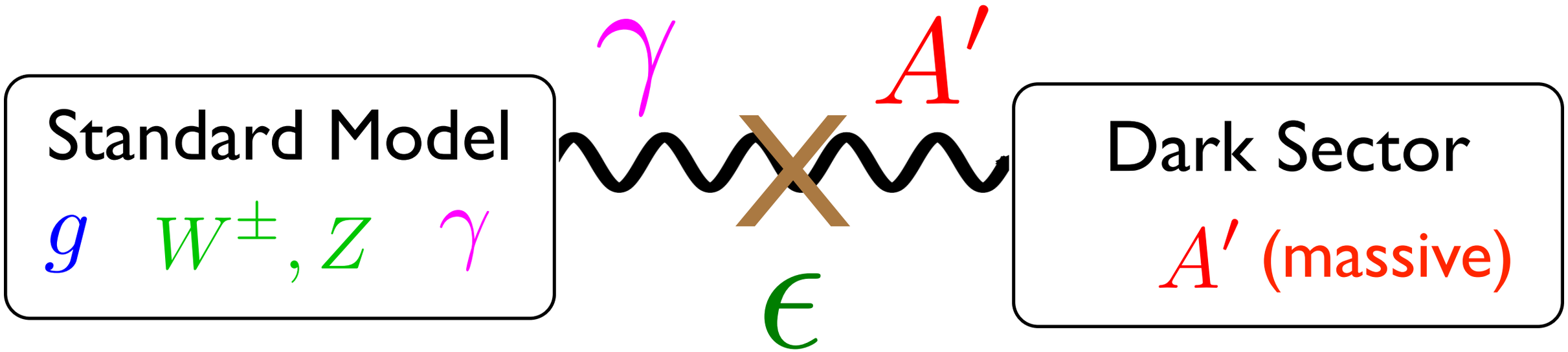
"Kinetic Mixing"

Holdom

Galison, Manohar

a special portal: not suppressed by a mass scale!

Dark Photons



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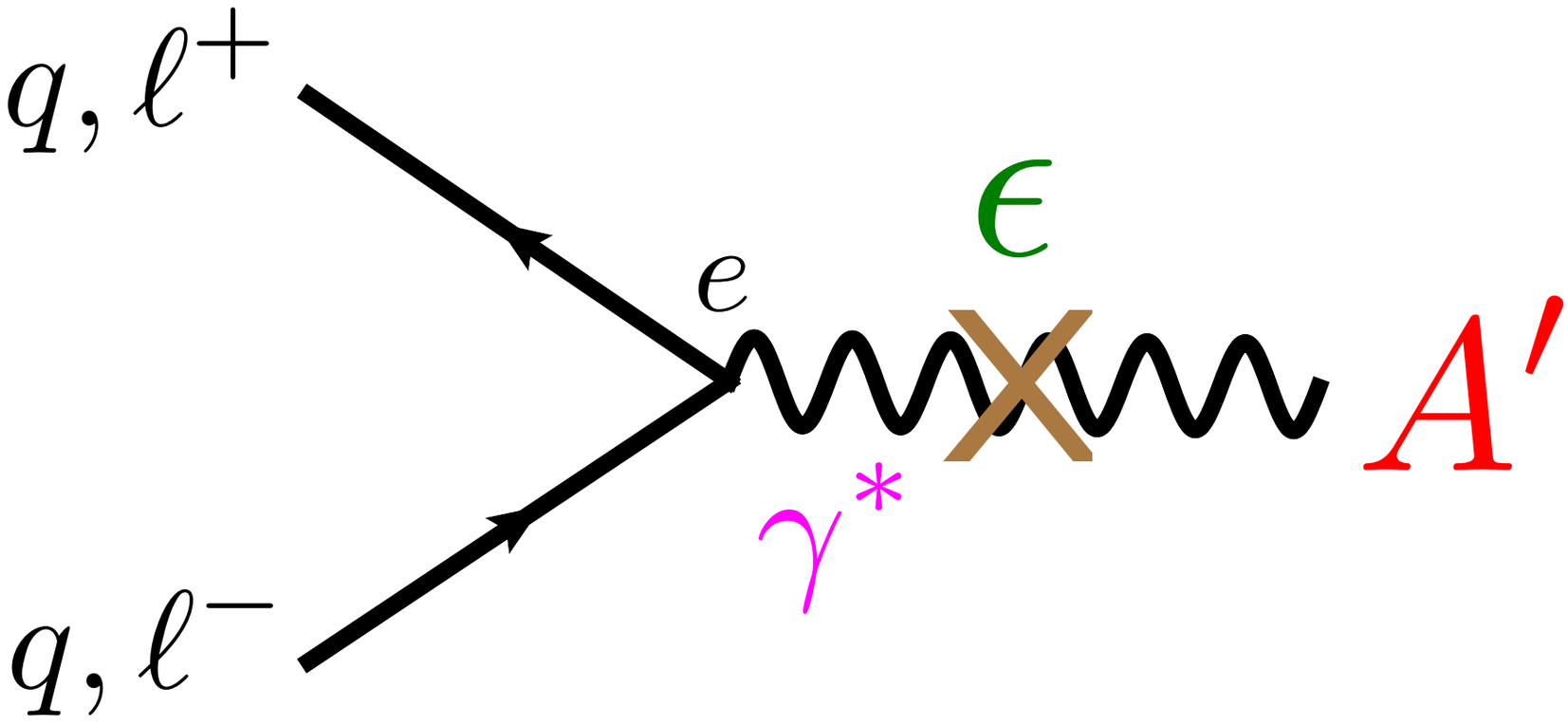
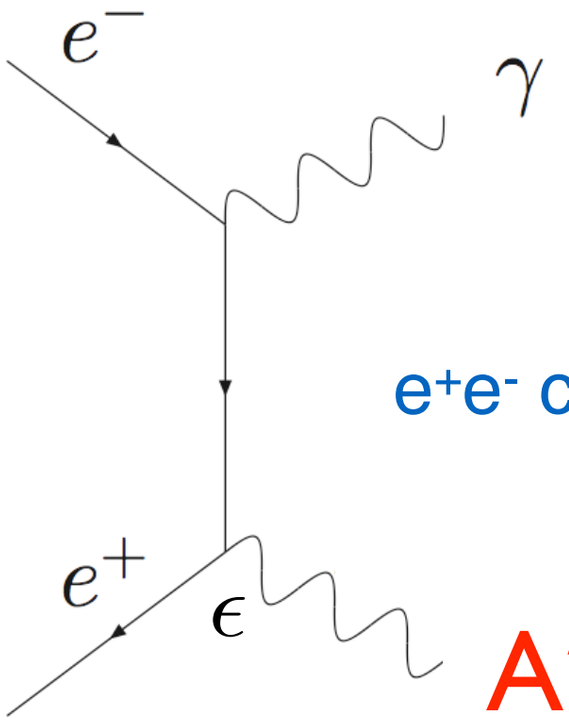
simplest Dark Sector consists of just an A′,
but dark sector could be much richer

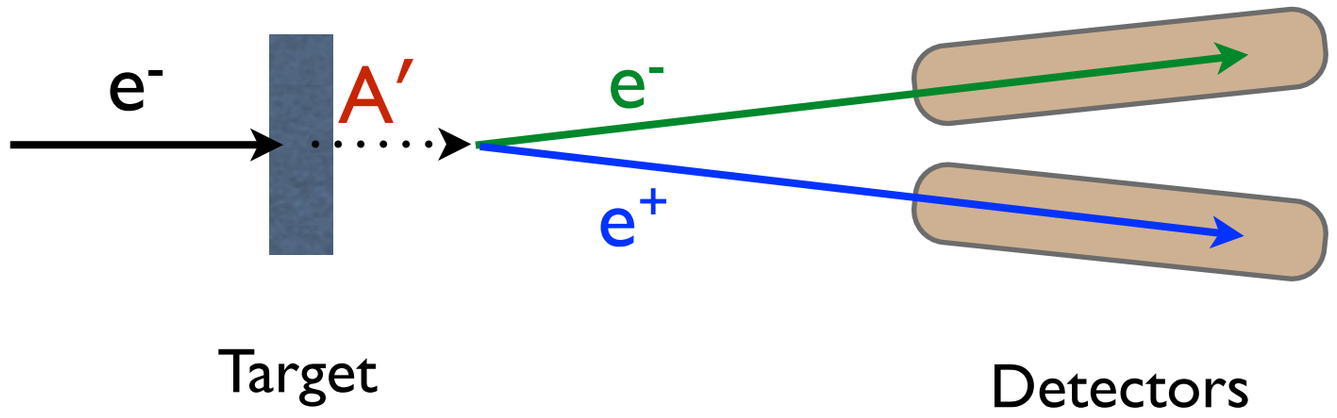
A′ couples to quarks & charged leptons



Examples of A′ Production



e+e- collision



electron fixed target/beam dump

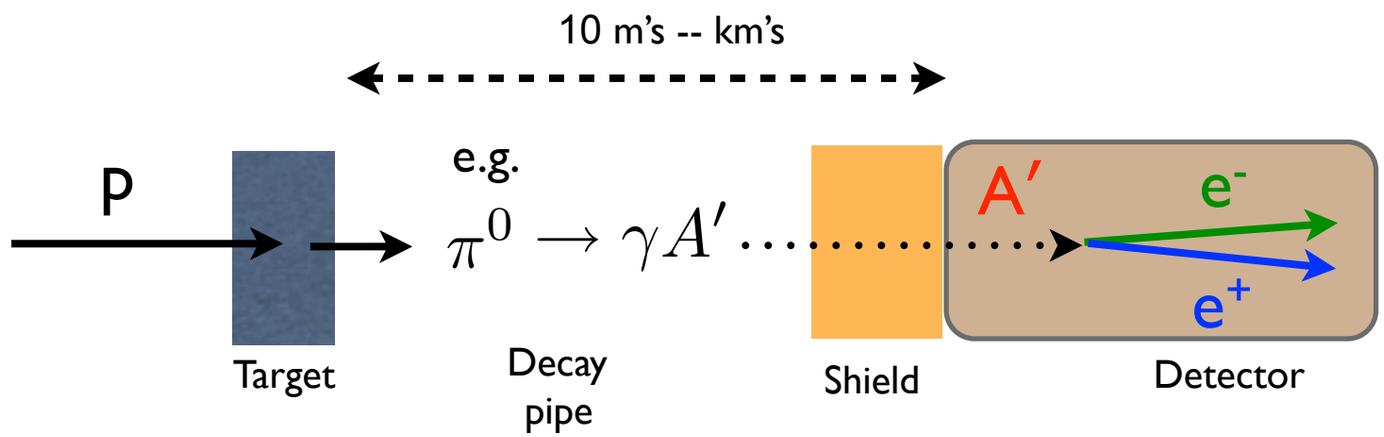
rare meson decays

$$\pi^0 \to \gamma A'$$

$$\phi \to \eta A'$$

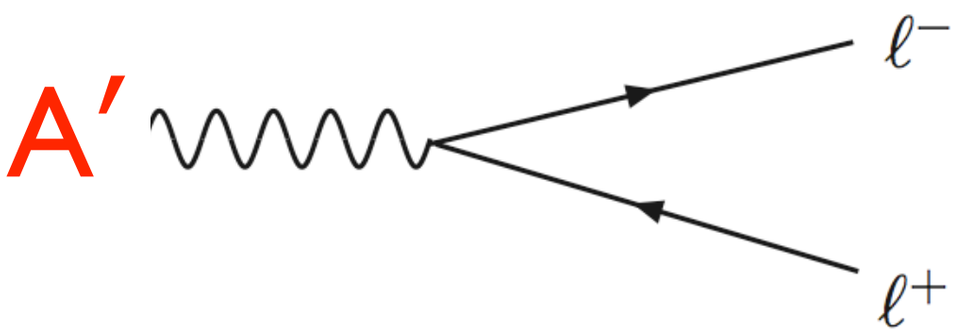
rare Higgs decays

$$h \to Z A'$$



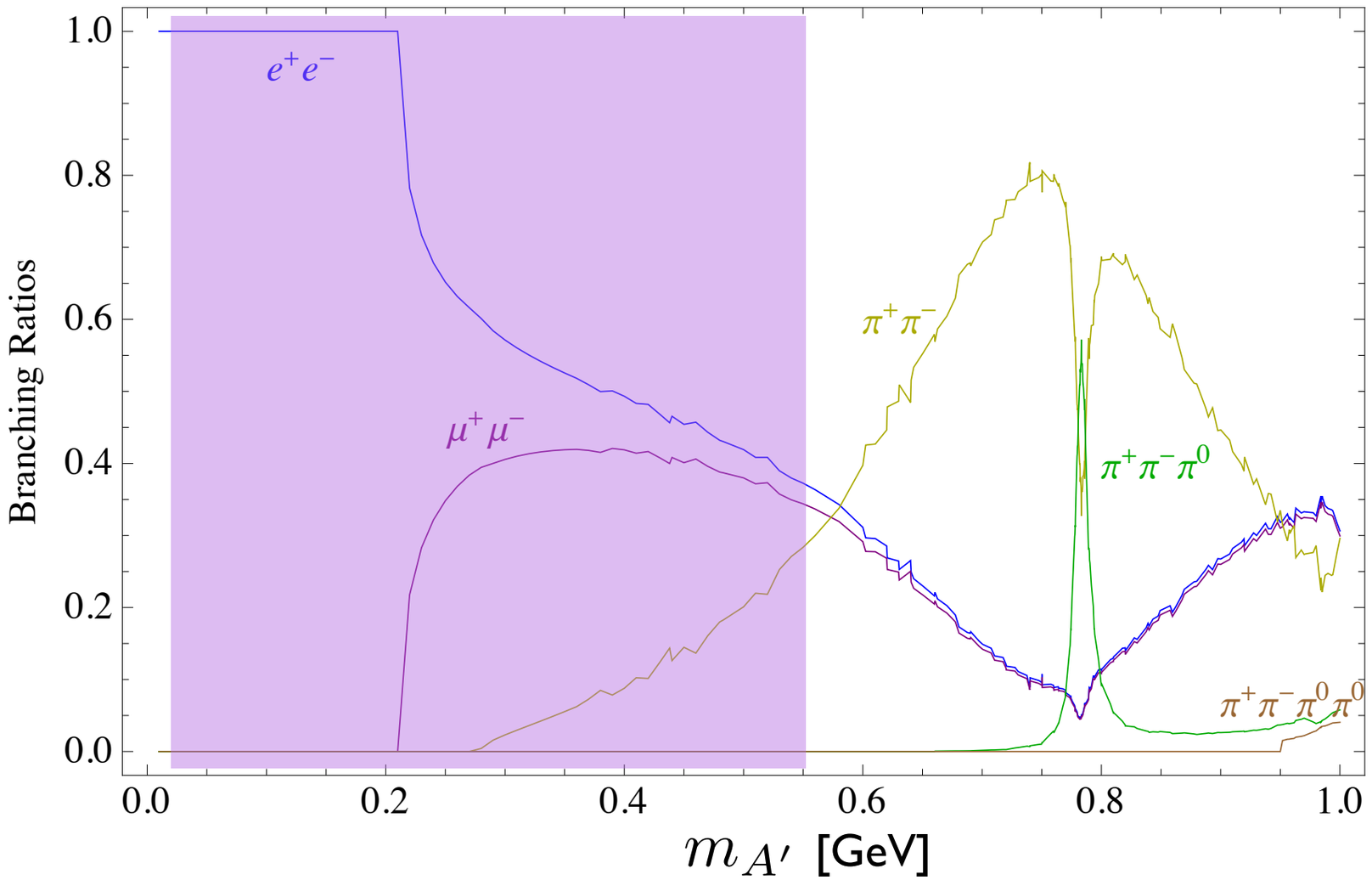
proton fixed target

A′ Decays

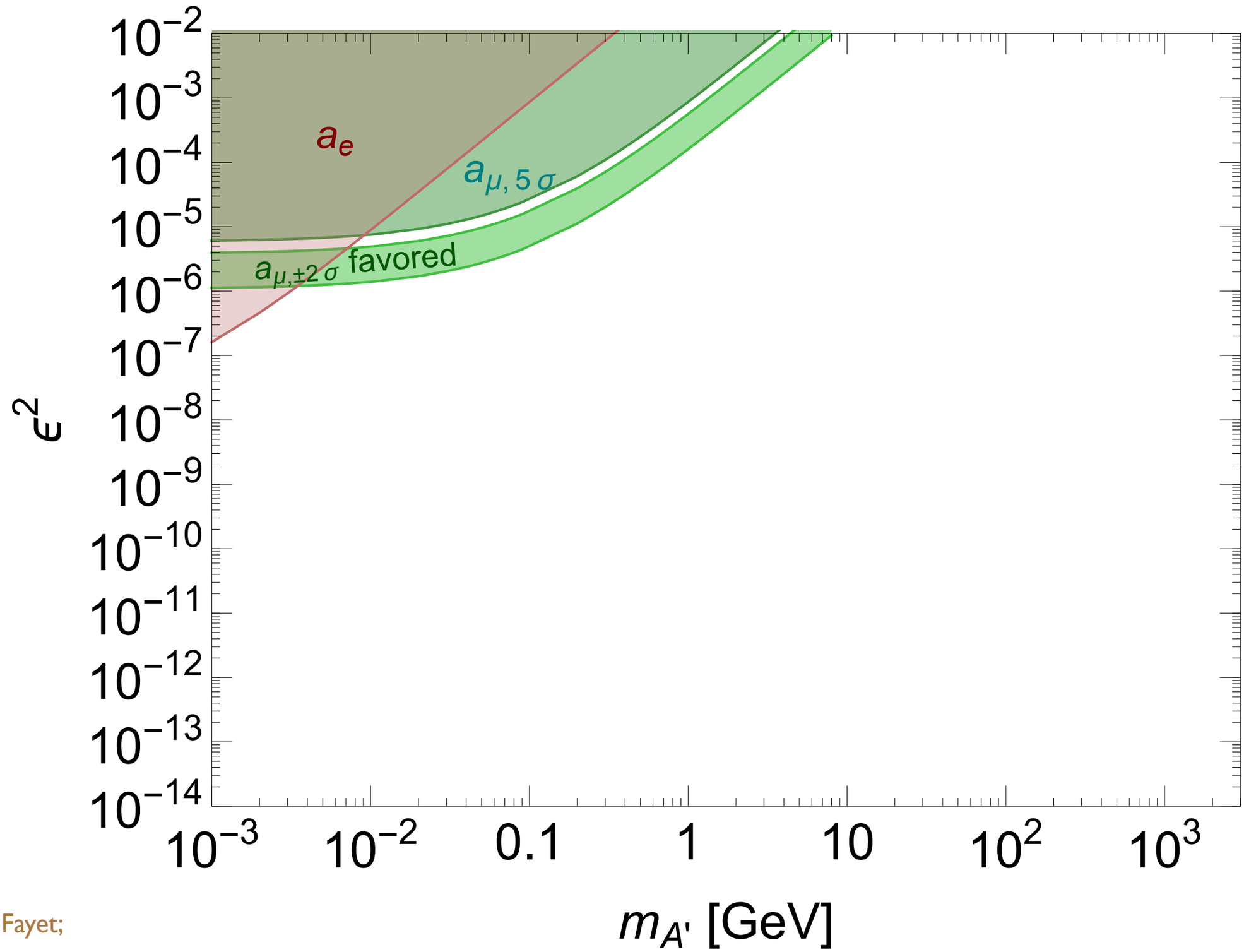


($A' \rightarrow$ other states also possible)

HPS mass range



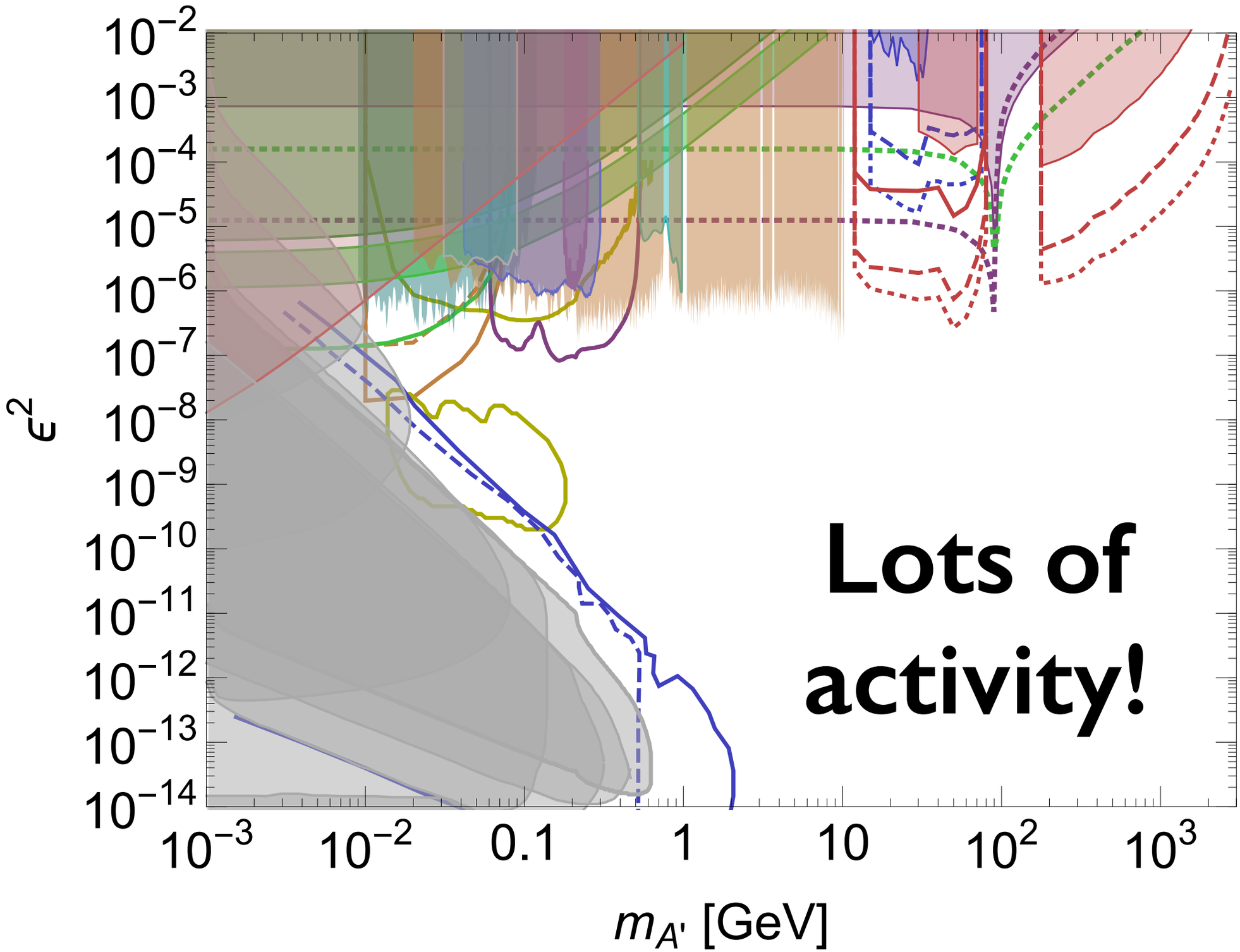
A′ Status 2008



Pospelov; Fayet;

A′ Status Today

from Curtin, RE, Gori, Shelton



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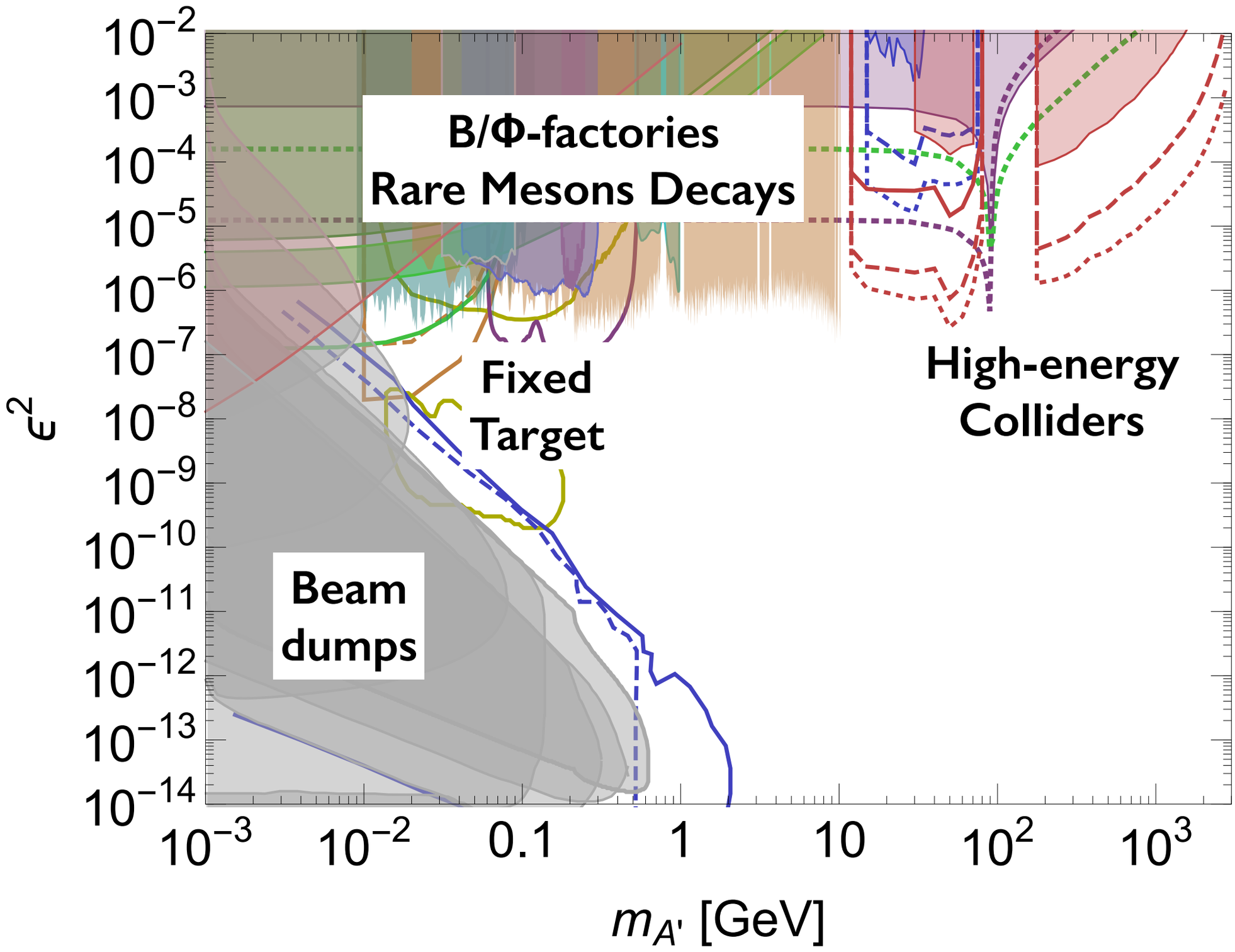
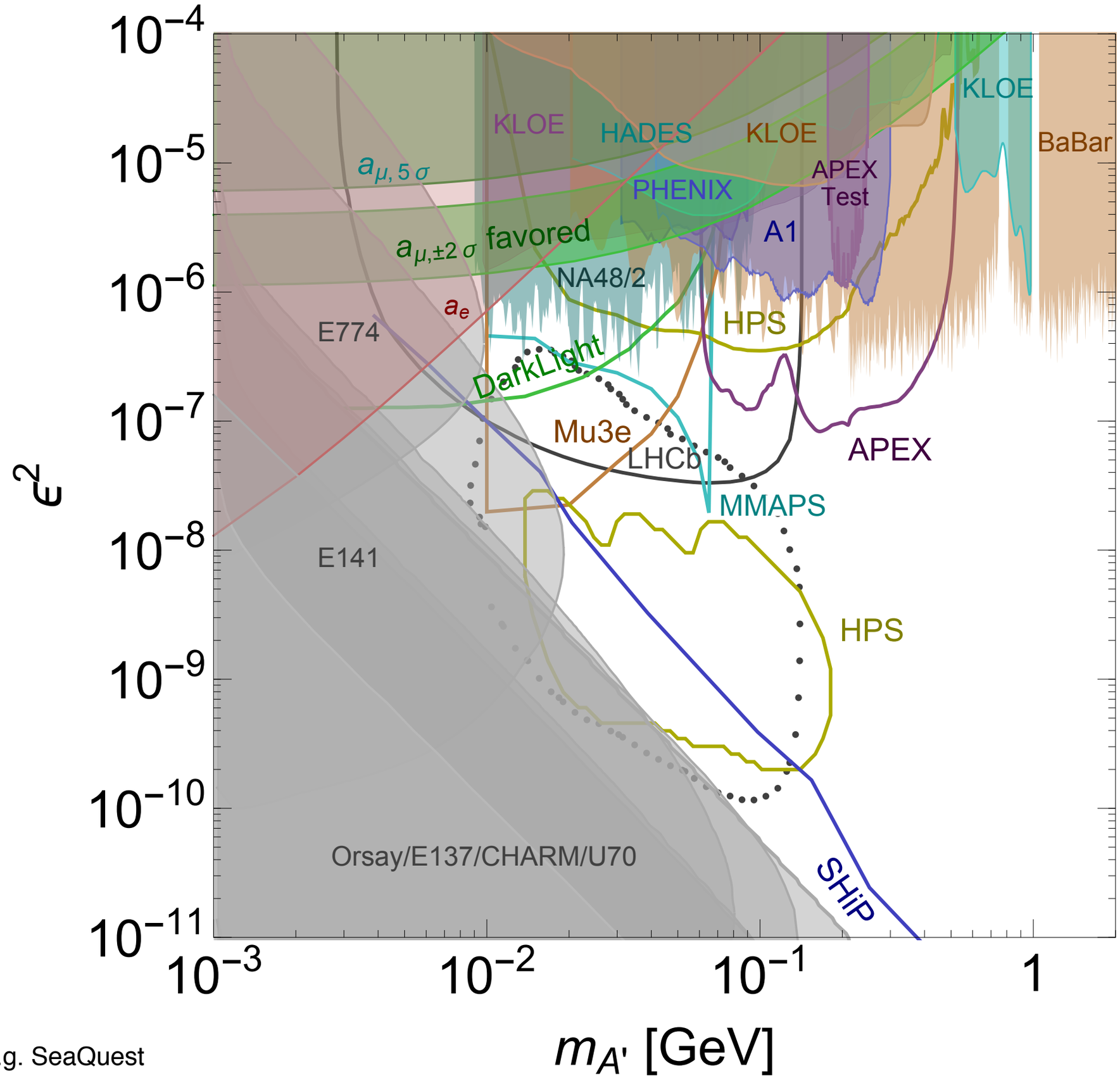


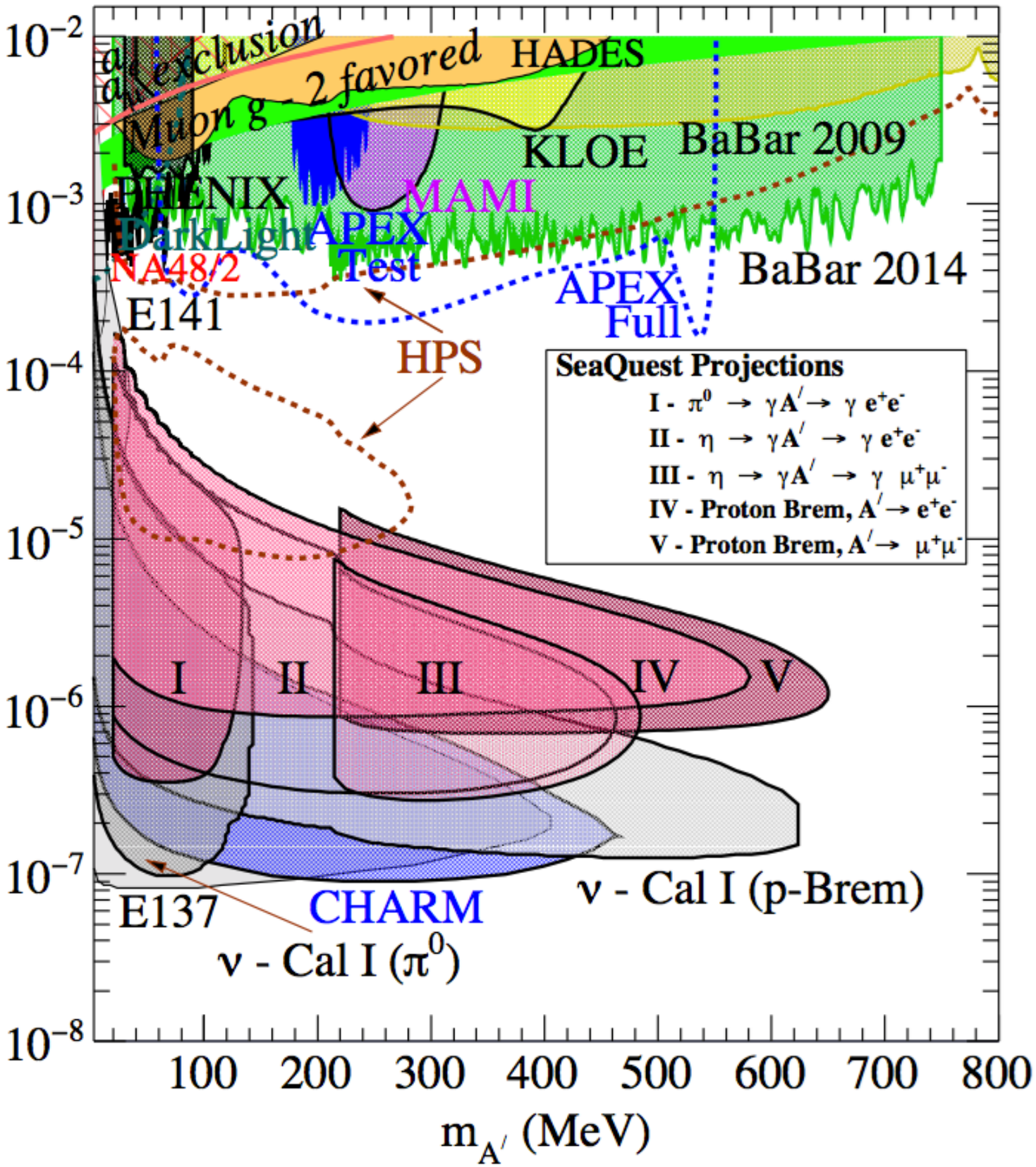
A′ Status Today: MeV-GeV



not shown: e.g. SeaQuest

Comment on SeaQuest

plot from Gardner, Holt, Tadepalli (1509.00050)



Some old plots shown by SeaQuest are "optimistic"… so please keep thinking about how to probe high mass region

(TBC)

Why search for Dark Photons?

- Simple and ubiquitous in Beyond SM scenarios; dark photon portal could easily be most accessible portal — theoretically, ε could be O(1)!

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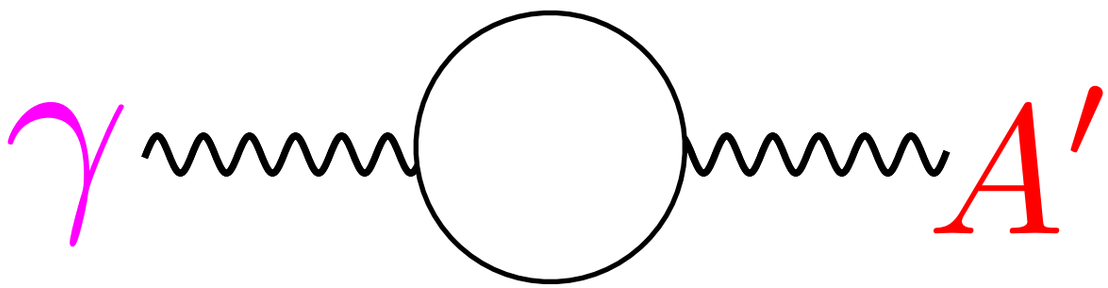
Some scenarios give preferred values of ε

GUT: ε from one-loop versus two loop

if $U(1)_Y$ embedded in a Grand Unified Theory (GUT), generate ε below GUT scale



$$\epsilon \sim \frac{g_Y g_D}{16\pi^2} \ln\left(\frac{M}{M'}\right)$$

$$\sim 10^{-3} - 10^{-1}$$

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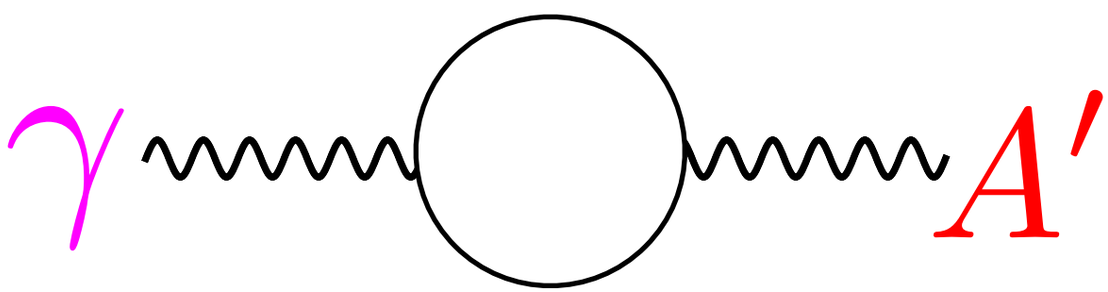

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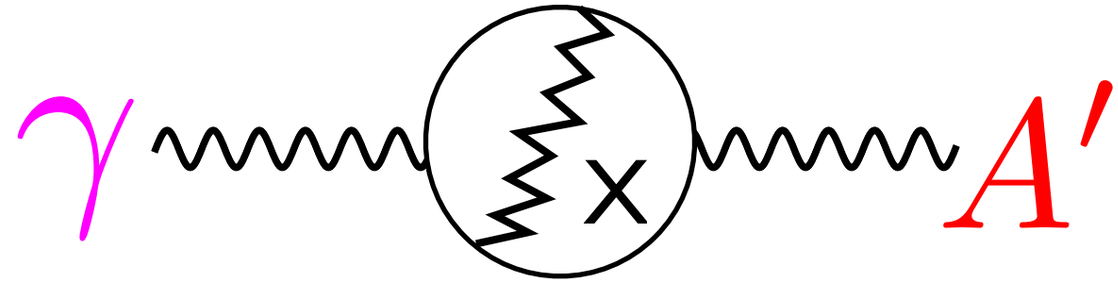
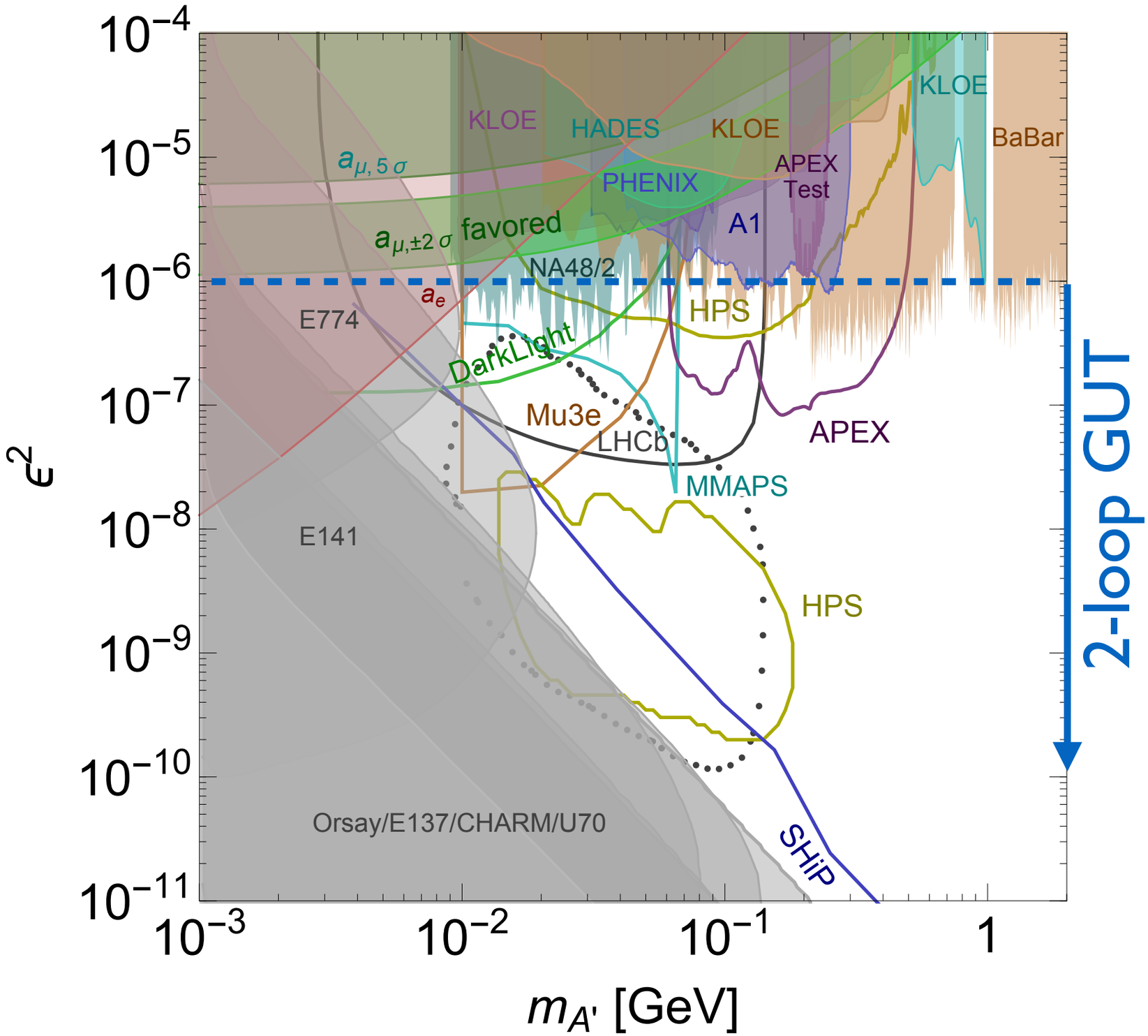


$$\epsilon \sim 10^{-5} - 10^{-3}$$

HPS, APEX etc can probe GUT ε values



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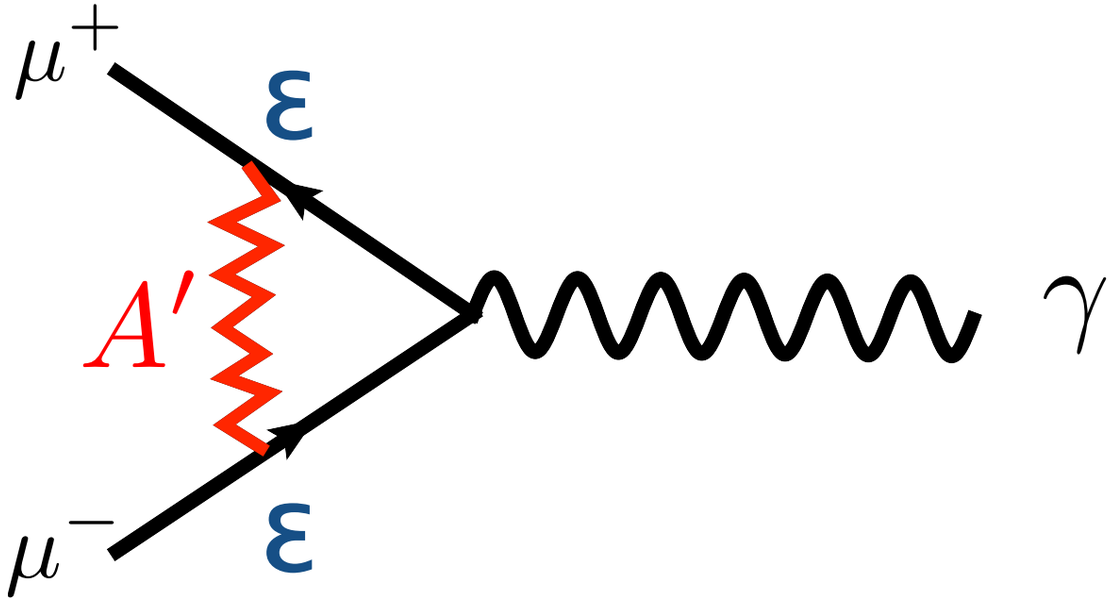
- muon g-2

A′ can explain muon g-2

Standard Model
$(g_s - 2)_\mu$ versus Data

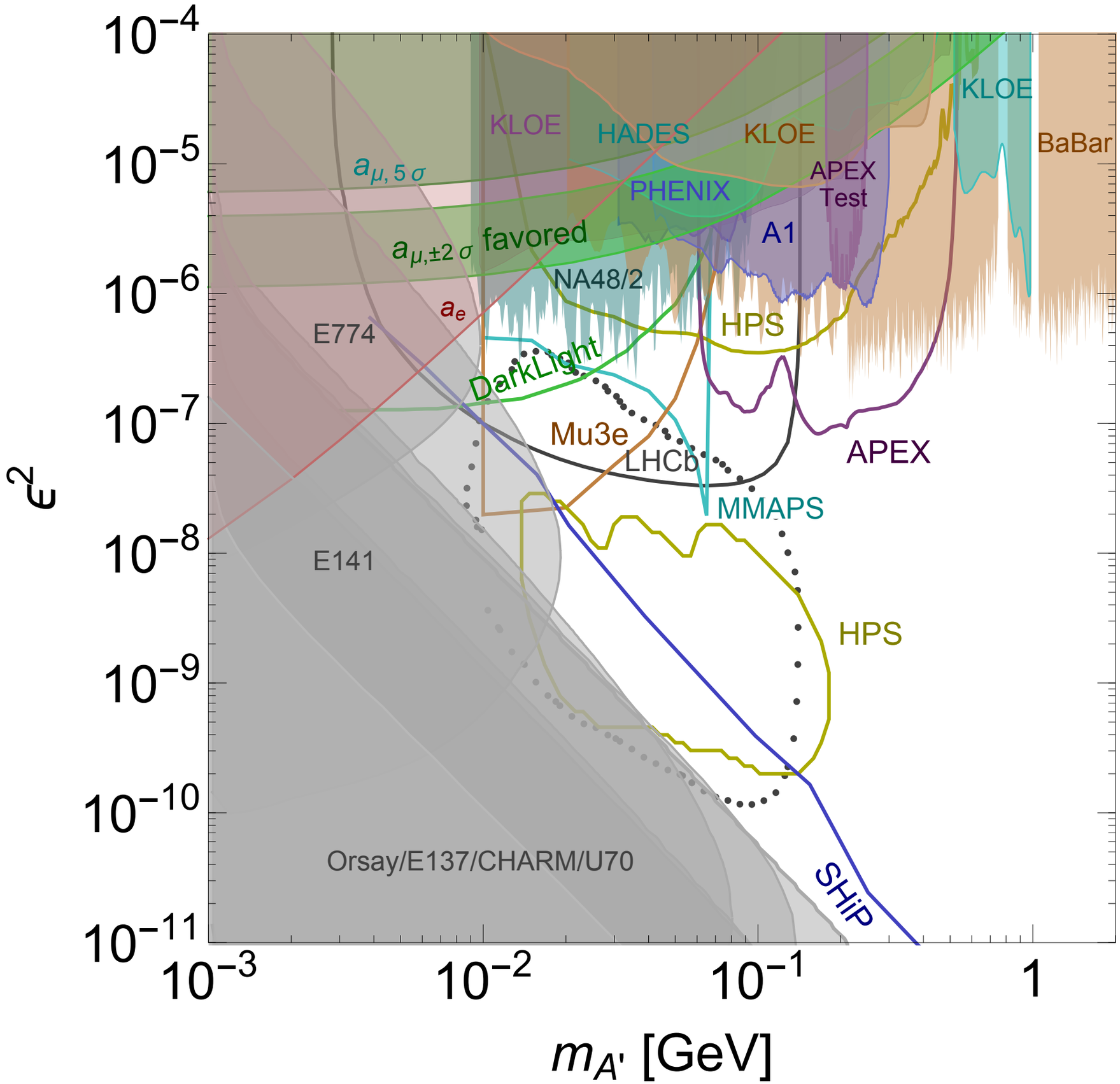
$\sim 3.6\ \sigma$ discrepancy



Boehm, Fayet
Pospelov

independent of A′ decay modes!

HPS, APEX… can probe g-2 for $\mathrm{Br}(A' \to \mathrm{SM}) \ll 100\%$



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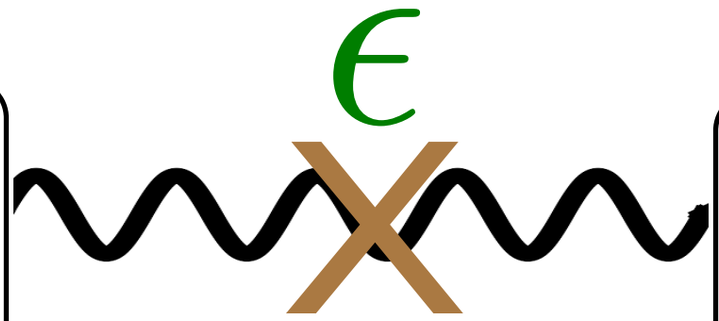
- A′ could couple to dark matter, leading to an amazing variety of possible signatures:
  - data "anomalies" can guide specific scenarios

Dark Matter & Dark Photons

Standard Model

$g \quad W^{\pm}, Z \quad \gamma$



Dark Sector

DM + A'

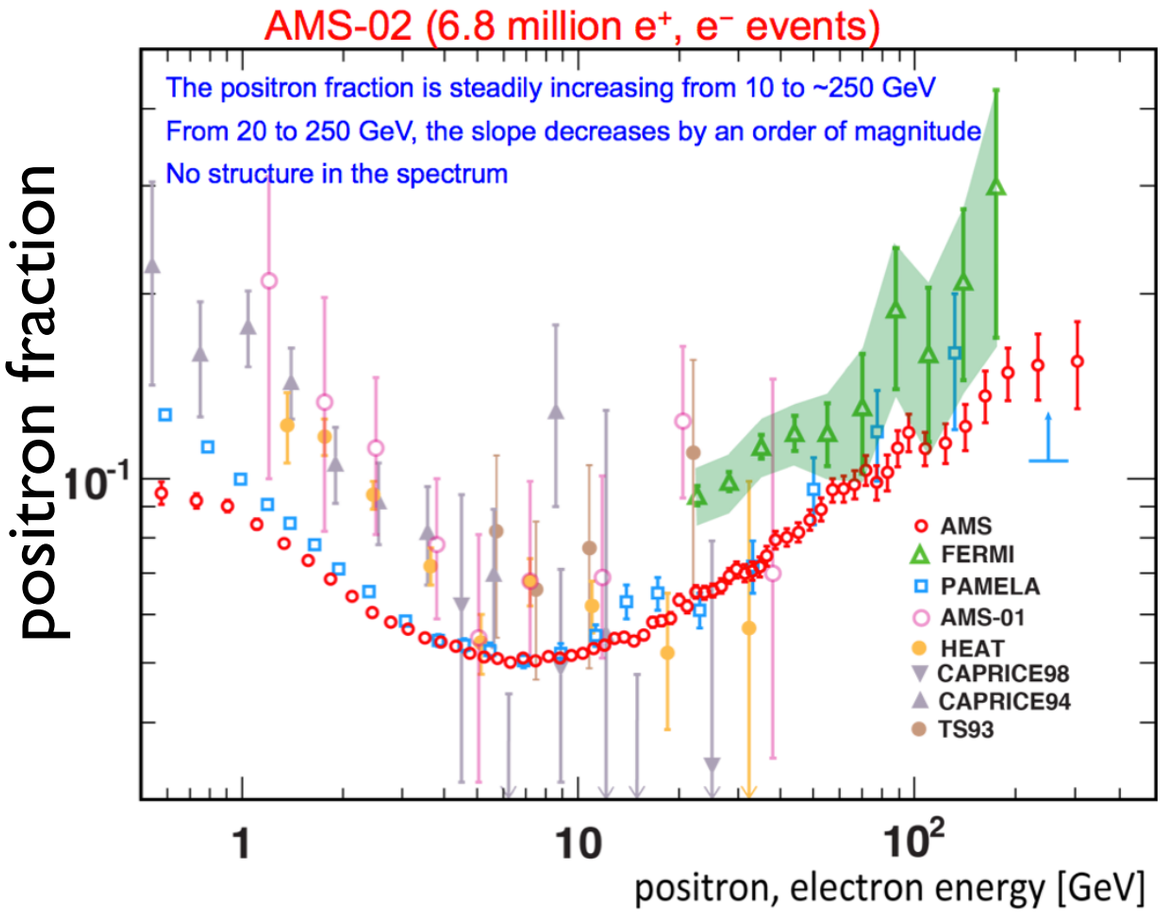
“Old” hints

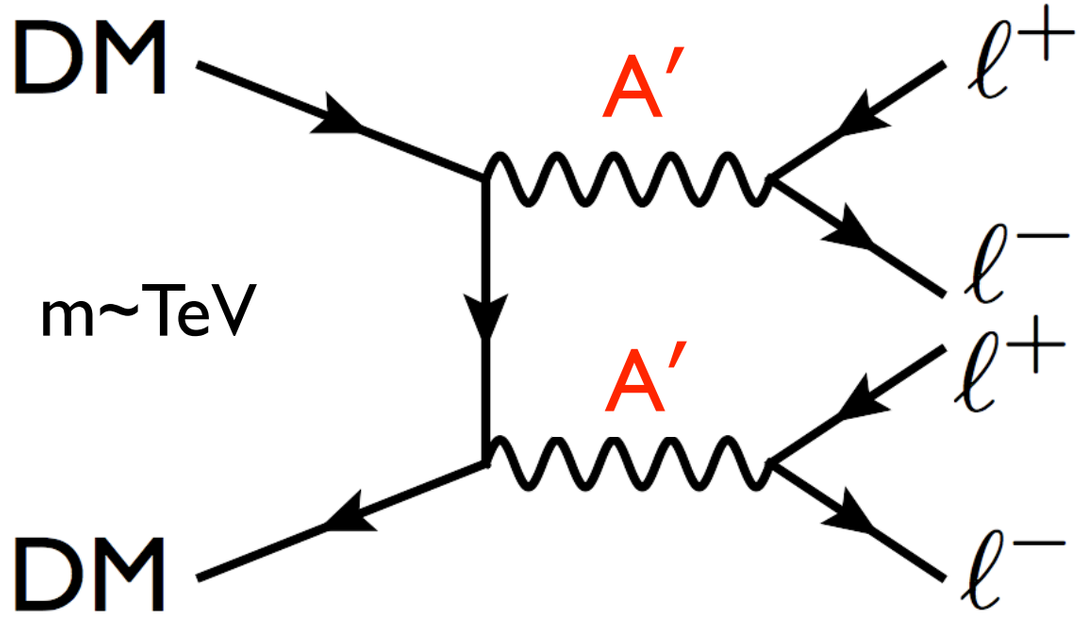
- cosmic-rays e^+ & e^- (PAMELA, …)
- direct detection (DAMA, …)

(now unlikely to be DM)

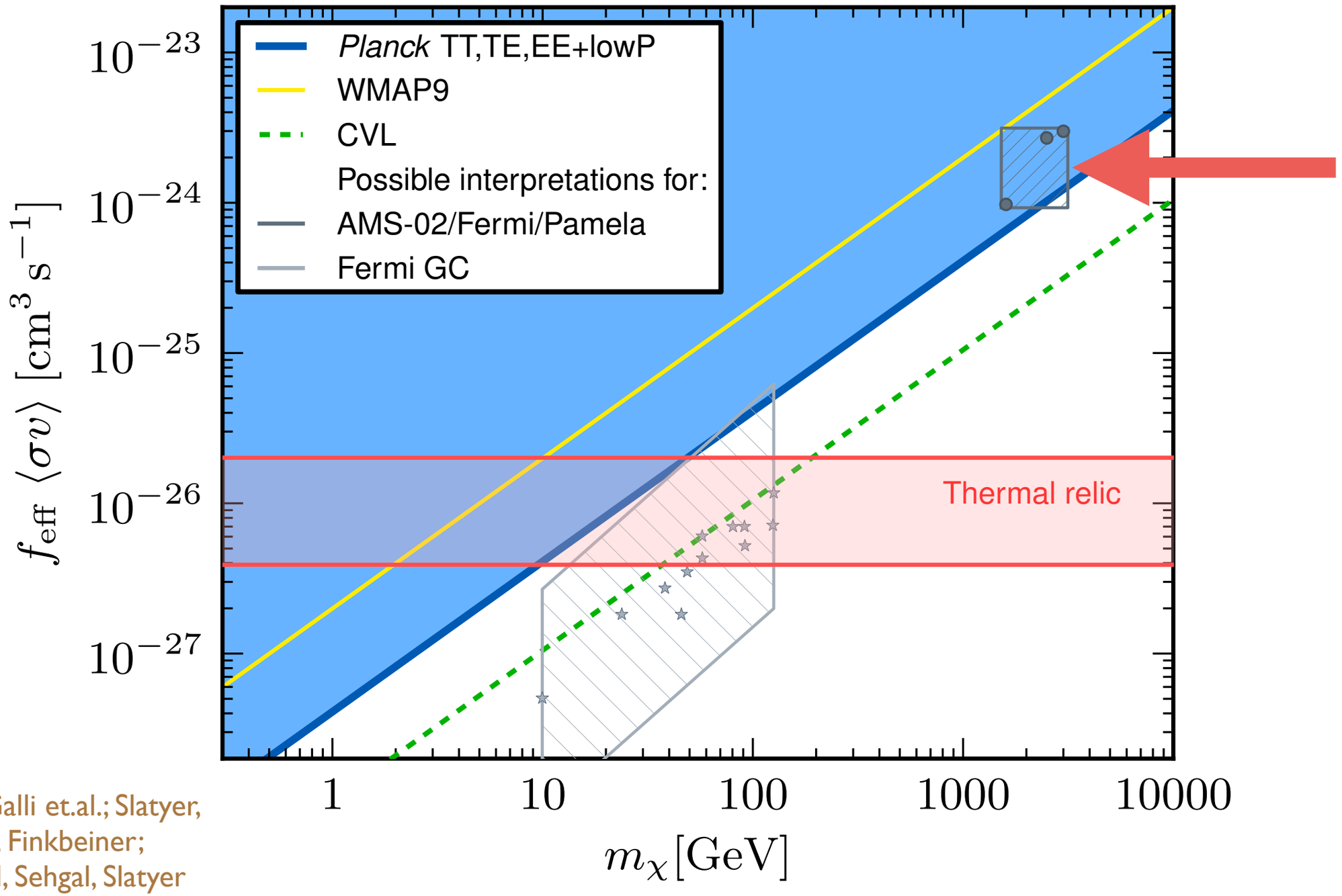
“Old” hint from cosmic-rays

Arkani-Hamed et.al.; Cholis et.al.; Pospelov & Ritz





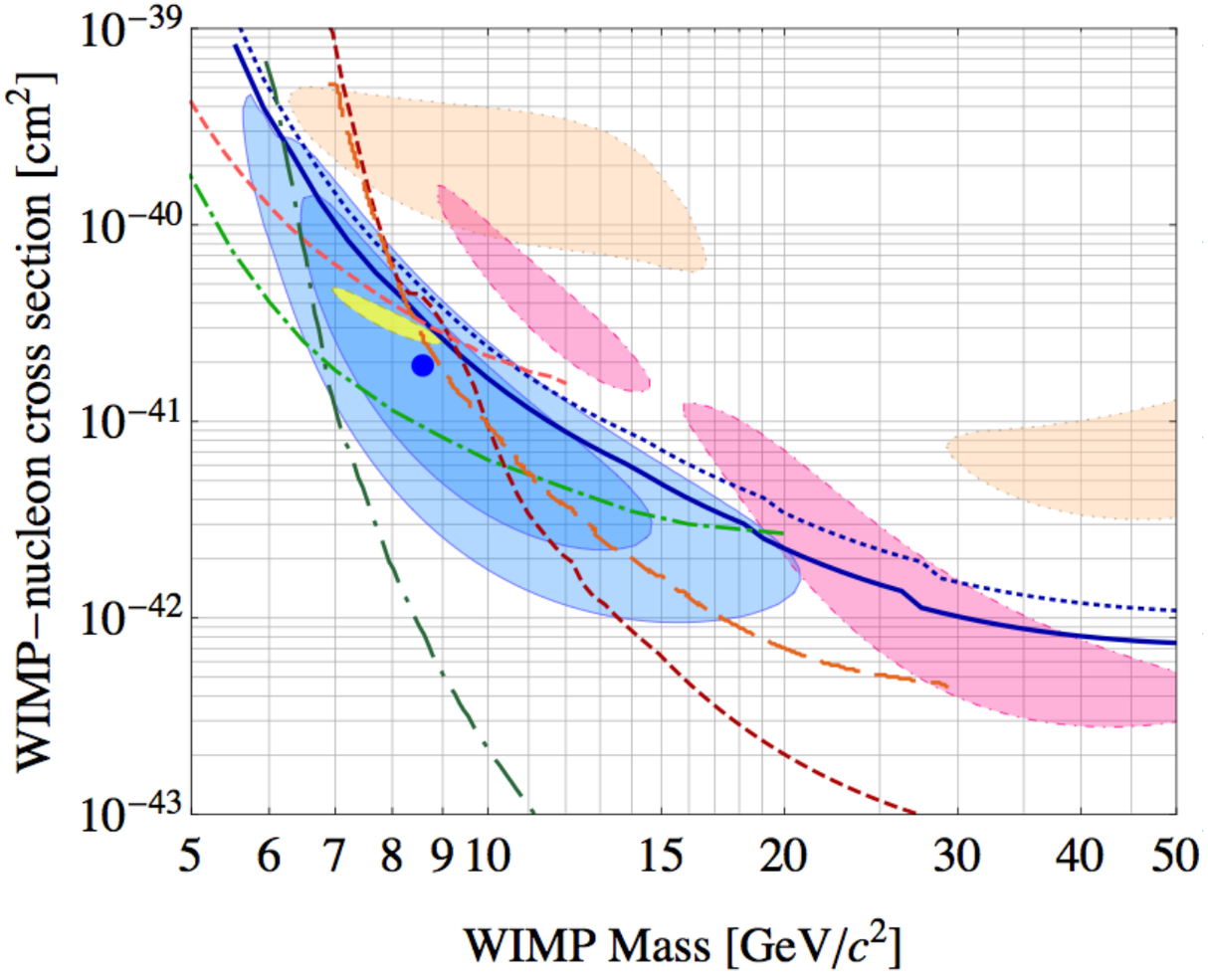
Strong constraints from CMB, Fermi, …



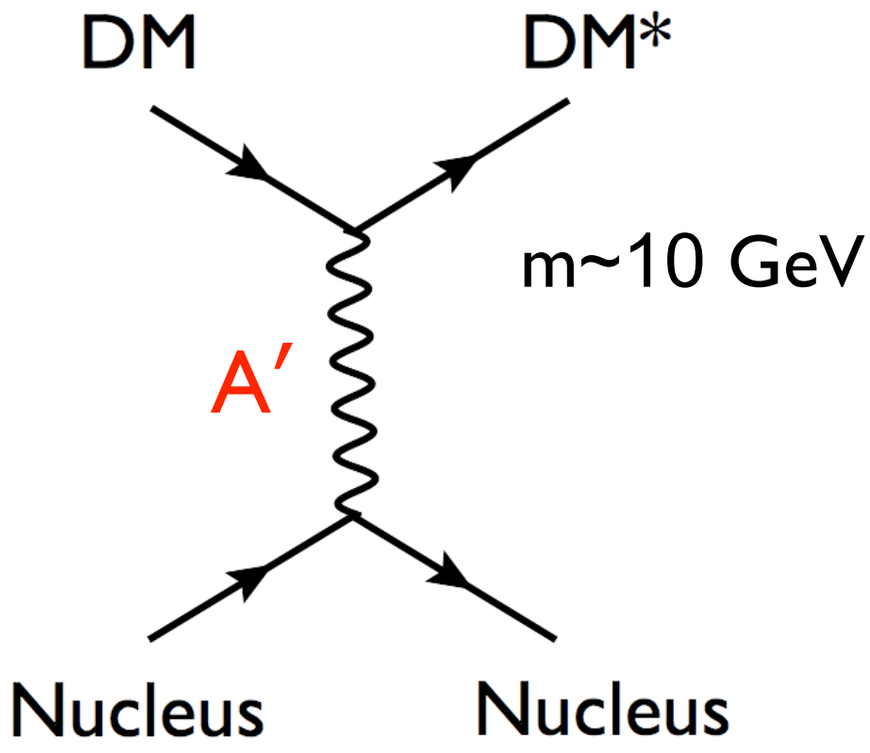
Planck

see also e.g. Galli et.al.; Slatyer, Padmanabhan, Finkbeiner; Madhavacheril, Sehgal, Slatyer

"Old" hint from direction detection

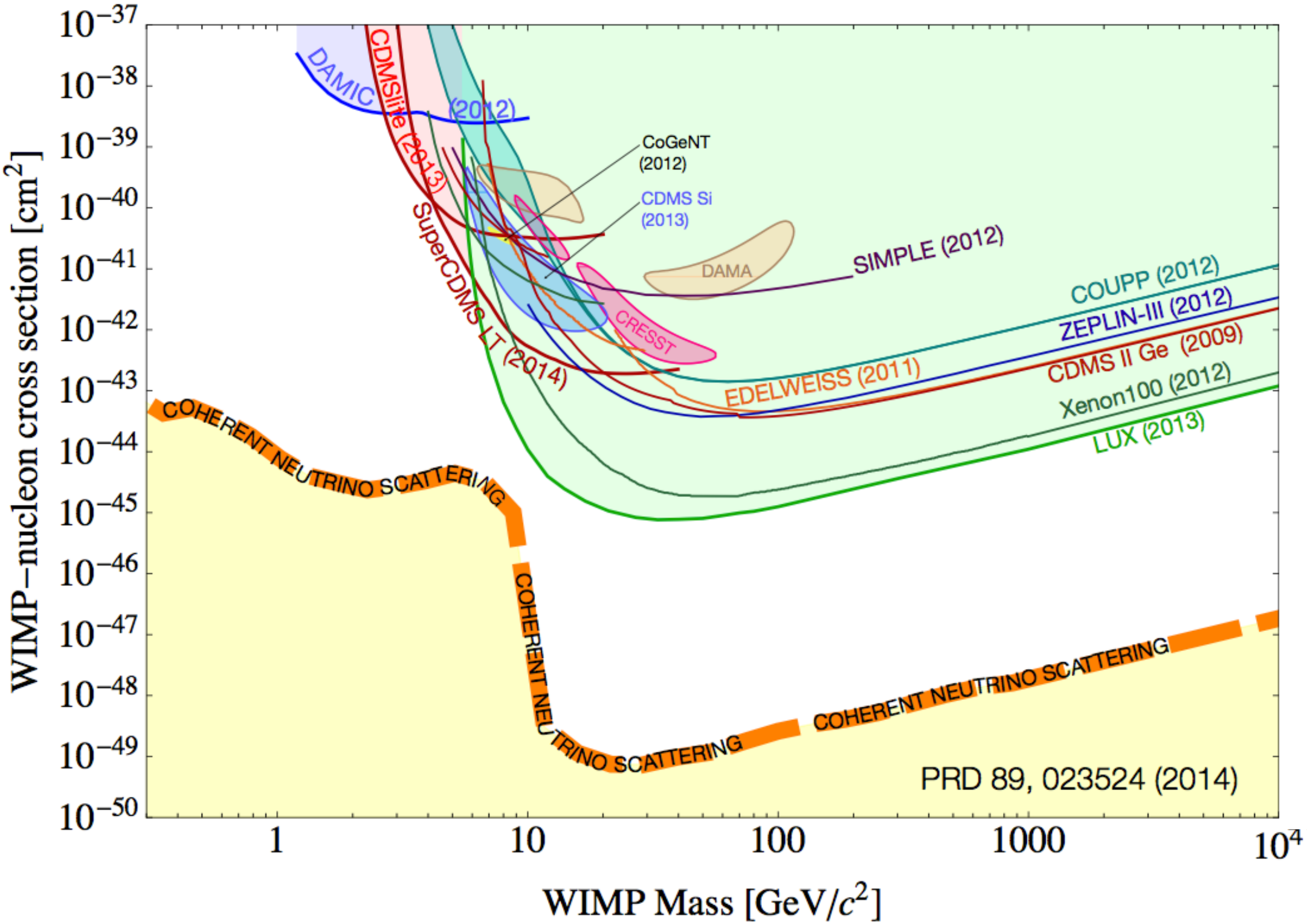


DAMA, CoGeNT, CRESST, CDMS-Si



hard for SM mediators,
easier for light mediators

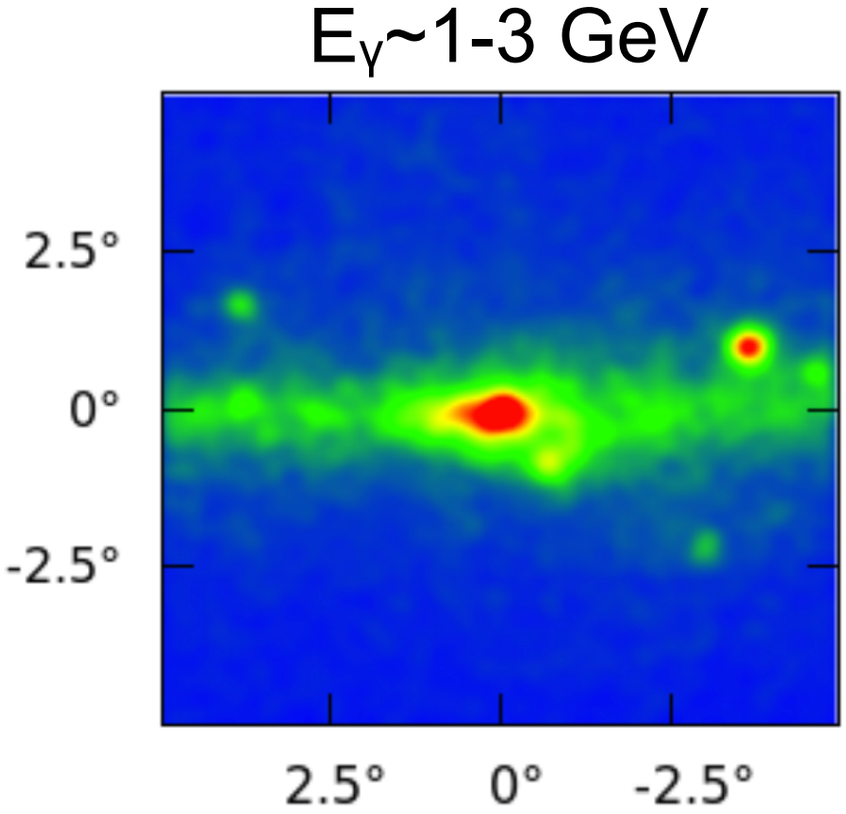
Severe constraints from other experiments



"Newer" hints, e.g.

- ~GeV gamma-ray excess near Galactic Center
- 3.5 keV "line"
- "small-scale crisis" of cold, collisionless DM

Galactic Center Gamma-ray Excess



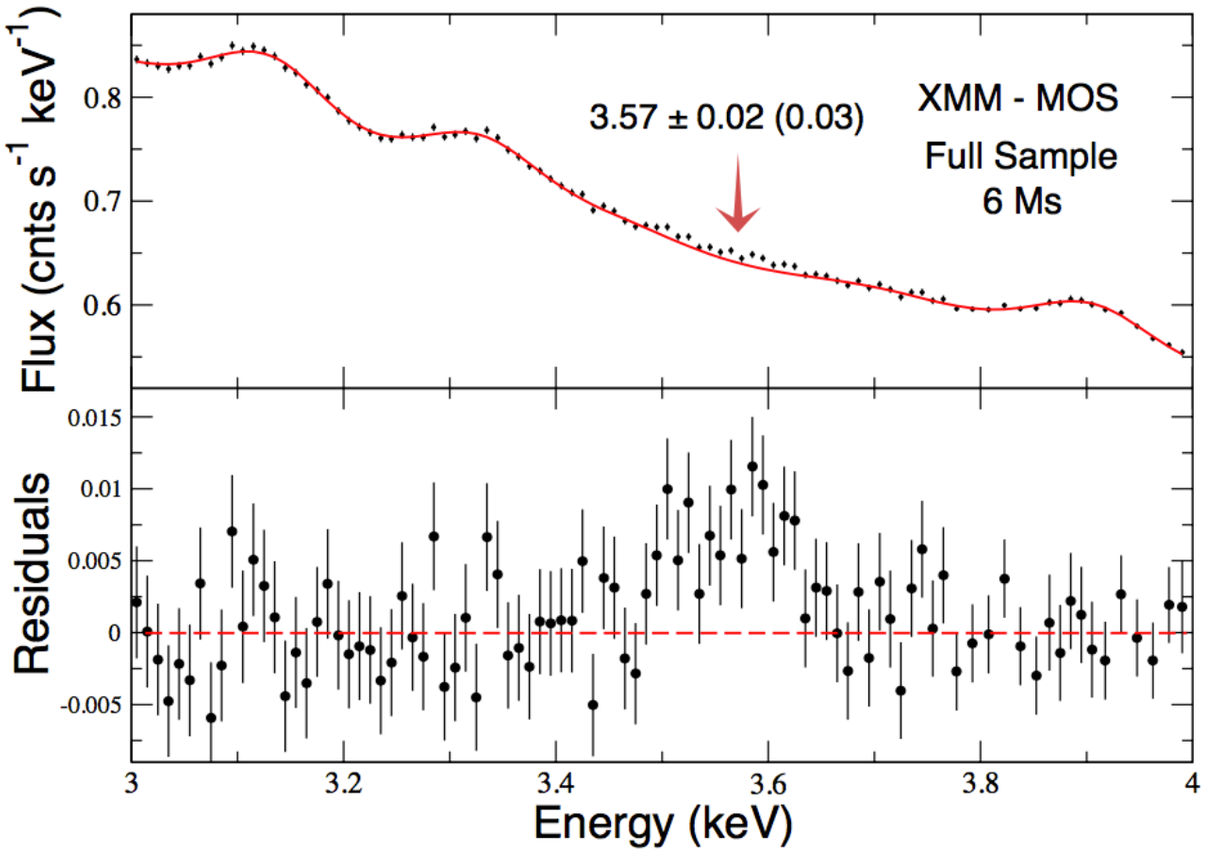
m_{DM} = 10 GeV

$m_{A'}$ = 100 MeV

Hooper, Weiner, Xue

3.5 keV γ-ray line

observed in e.g. galaxy clusters by X-ray satellites



Bulbul et.al.

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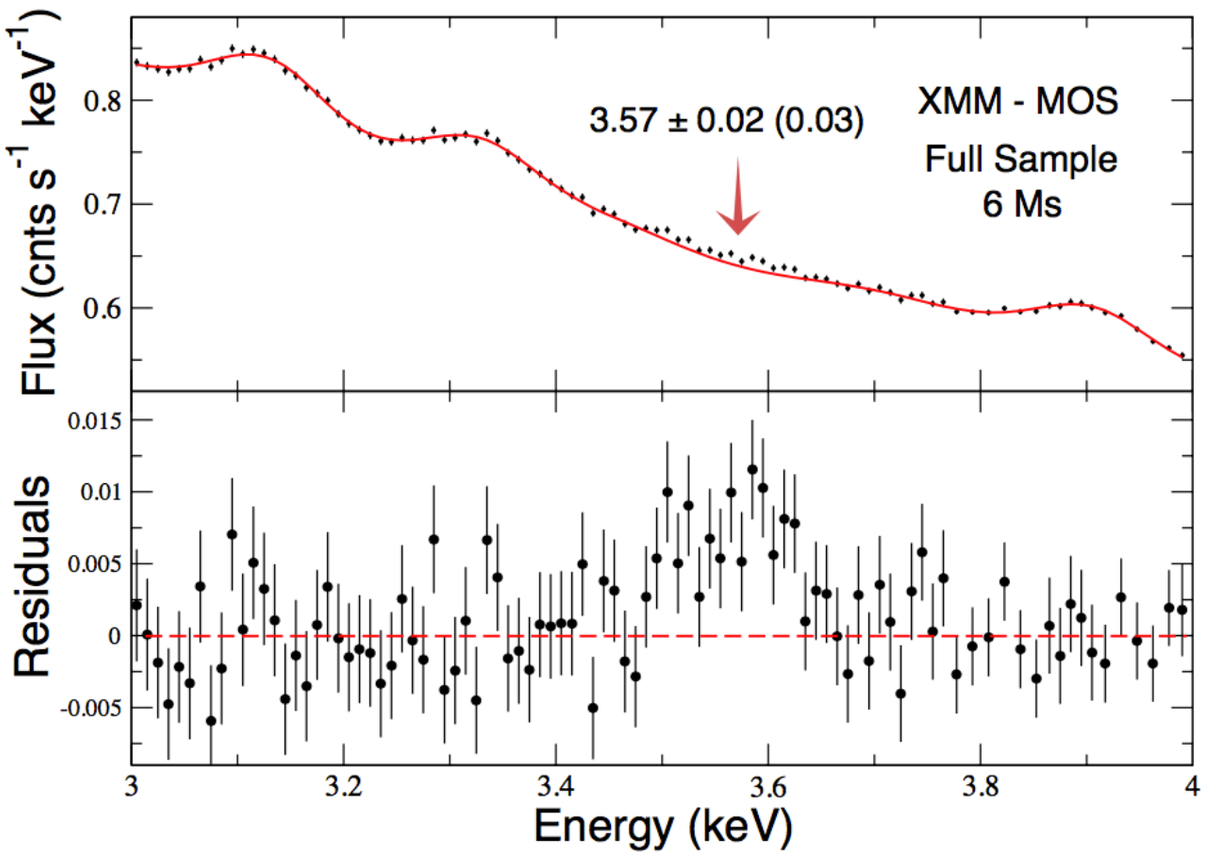
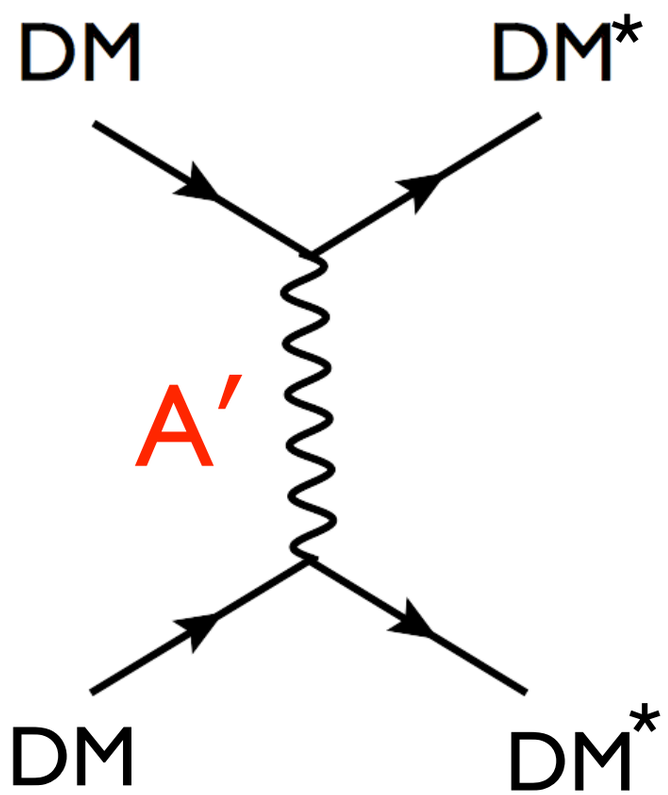
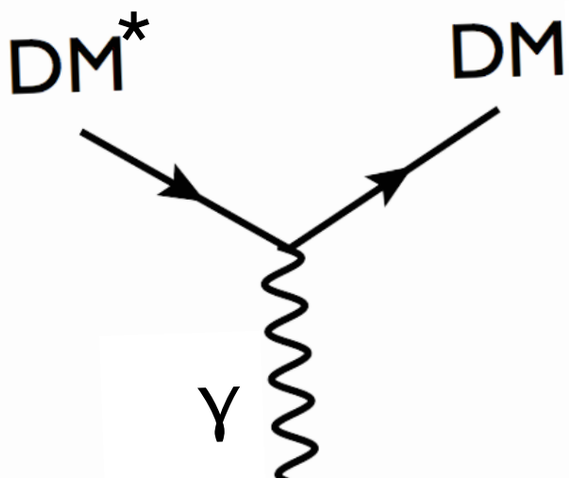


Bulbul et.al.



followed by



Finkbeiner, Weiner

“Small-scale crisis” of CDM

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some galaxies have less DM in the center than predicted by simulations

e.g. Navarro et al. 1997

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simulations predict too many low-mass subhalos & dozens of “dark” satellites more massive than the dwarf spheroidals

e.g. Klypin et al. 1999; Moore et.al. 1999

Boylan-Kolchin et.al. 2011

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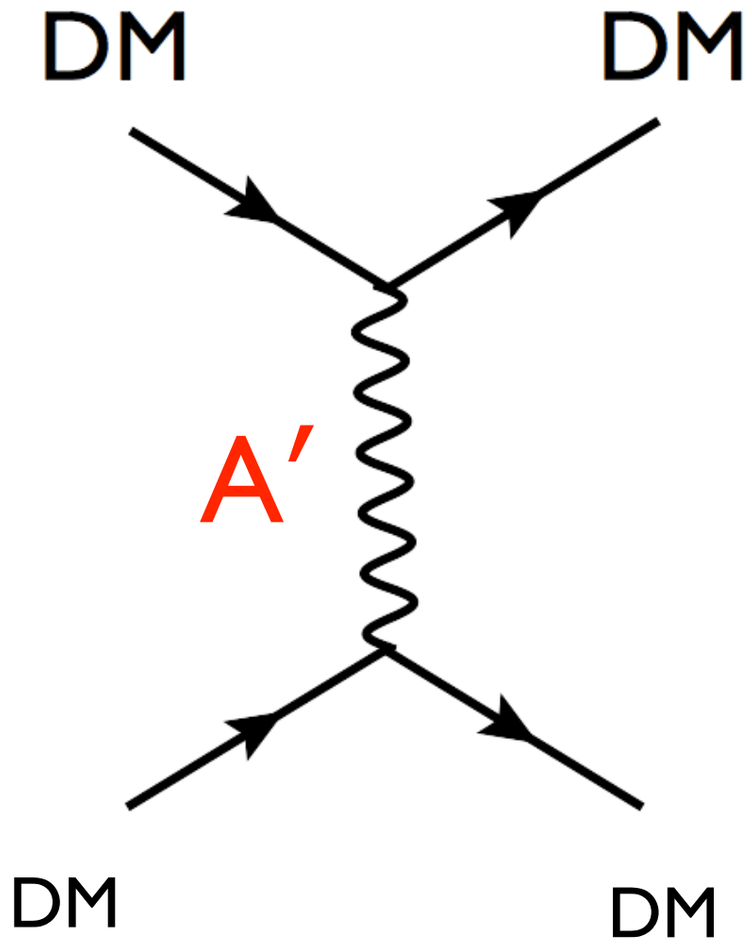
Boylan-Kolchin et.al. 2011

- Resolution?
  - baryonic physics?
  - warm dark matter? (e.g. ~keV sterile neutrino?)
  - self-interacting dark matter?

Spergel, Steinhardt 1999

  - …

DM self-interactions through A′?



e.g. Spergel & Steinhardt; Loeb & Weiner; Kaplinghat, Tulin, Yu

could resolve some of the "small-scale crises"

Rough estimate for size of DM self-interactions

want $\gtrsim 1$ DM collision over age of Galaxy

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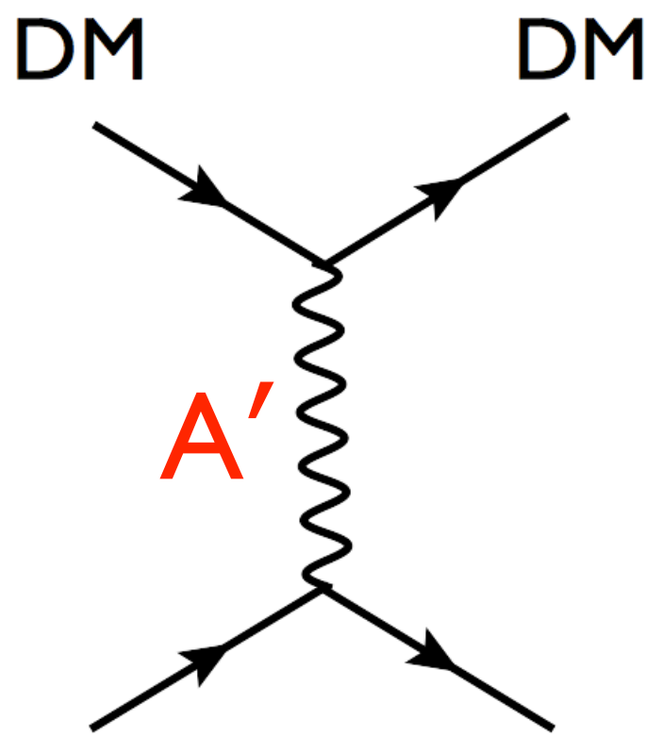
~QCD scale!

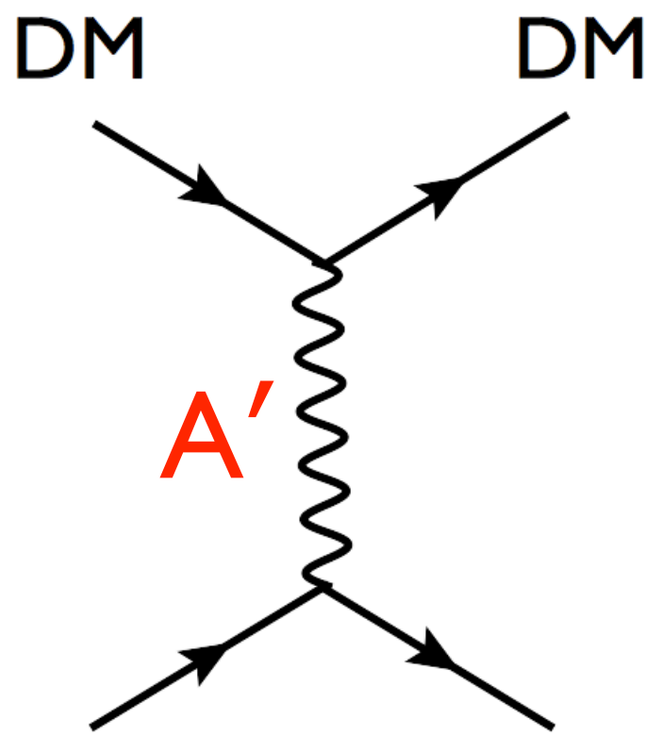
Large σ/m is easy w/ light mediators



$$\frac{\sigma}{m_\chi} \sim 0.1 \ \frac{\text{barn}}{\text{GeV}} \left(\frac{\alpha_D}{0.005}\right)^2 \left(\frac{m_\chi}{1\ \text{GeV}}\right) \left(\frac{10\ \text{MeV}}{m_{A'}}\right)^4$$

Born approximation

Large σ/m is easy w/ light mediators



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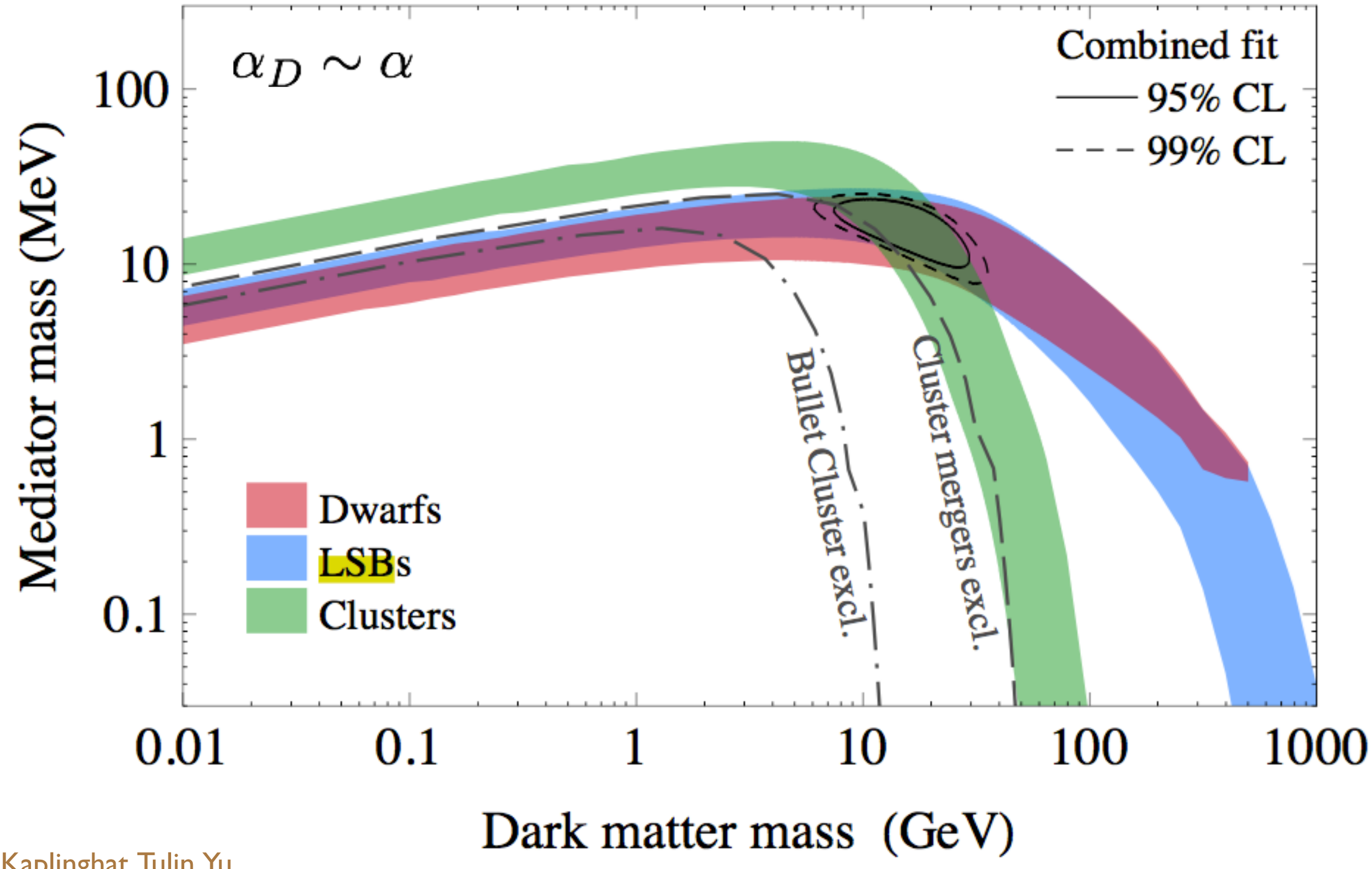
Born approximation

$\Longrightarrow$ light mediators!

(but doesn't constrain ε)

Obtaining cores in dwarfs, galaxies, & clusters



Kaplinghat, Tulin, Yu

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- Simple and ubiquitous in Beyond SM scenarios; dark photon portal could easily be most accessible portal — theoretically, ε could be O(1)!

- muon g-2

- A′ could couple to dark matter, leading to an amazing variety of possible signatures:
  - data "anomalies" can guide specific scenarios
  - simple, well-motivated DM models (e.g. sub-GeV DM) motivate new searches/interpretations

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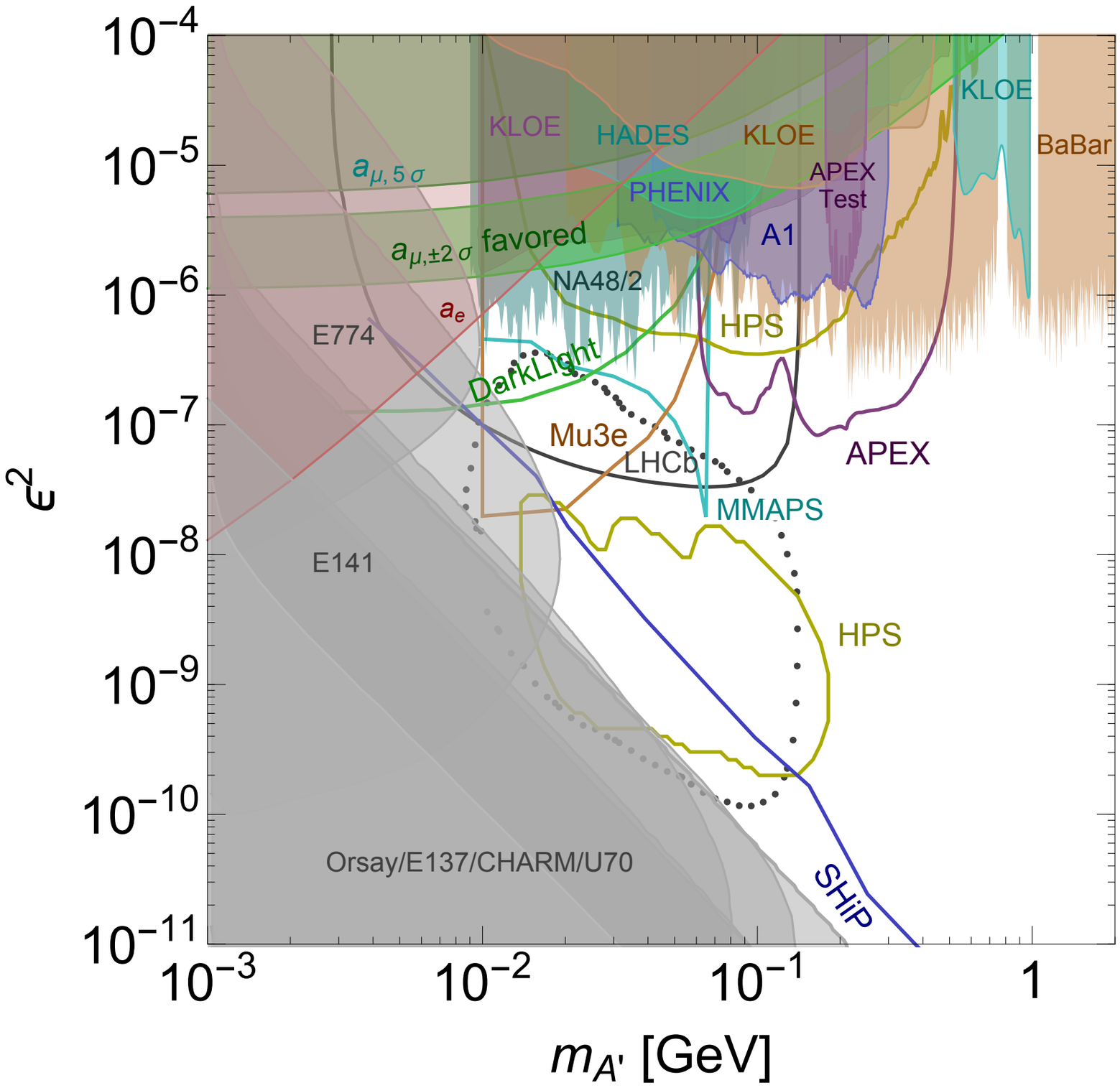
(only mention 3 examples)

Assume A′ → Dark Matter is possible



Then many constraints here weaken/disappear!

But ε value to explain muon g-2 is unchanged!

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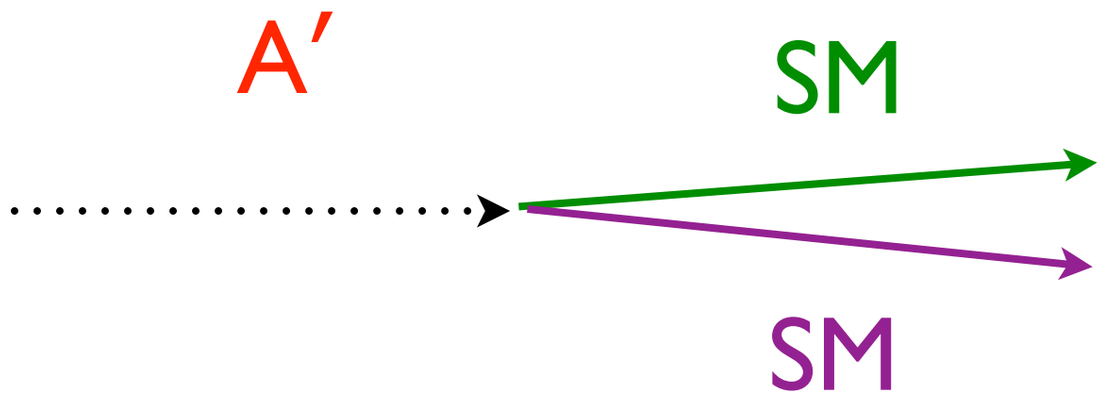
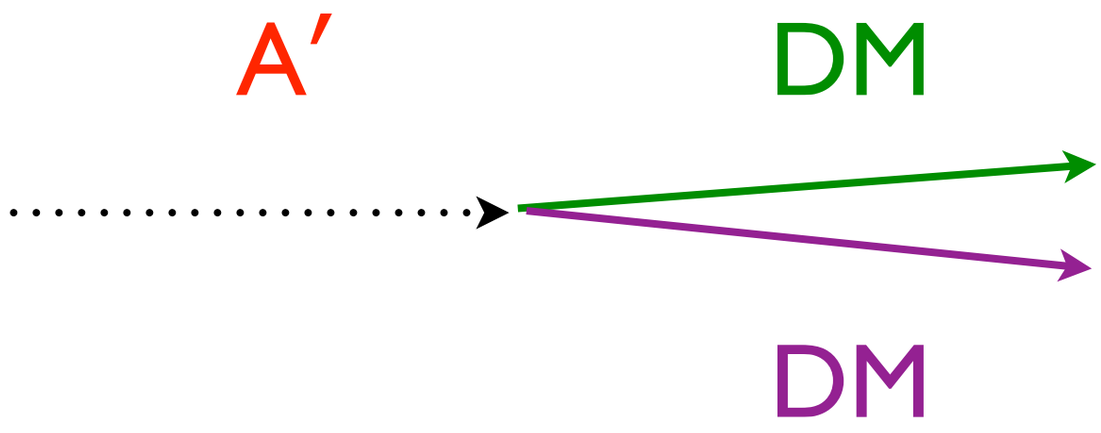


Controlled by ε^2



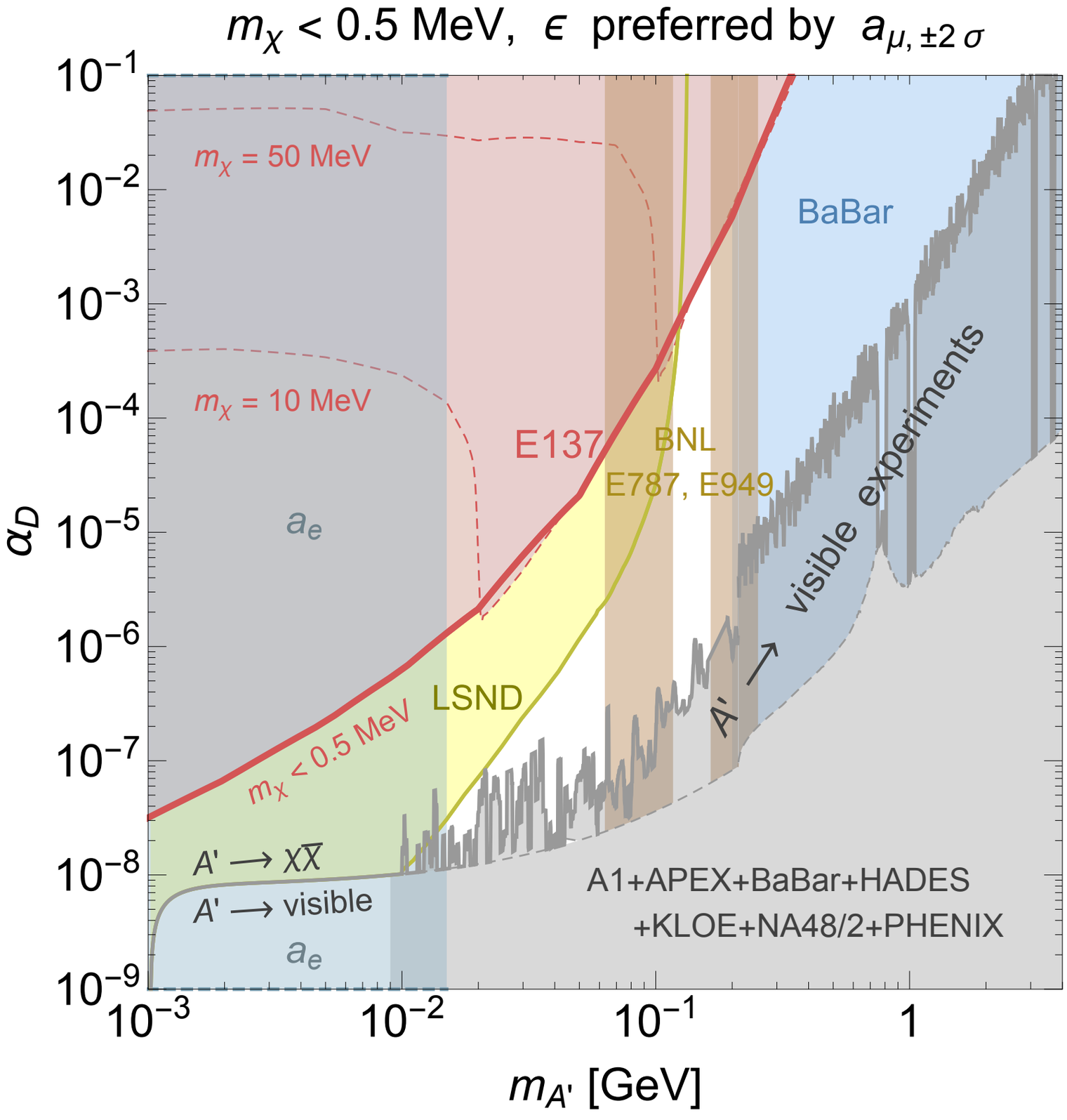
Controlled by α_D

now fix ε to explain g-2…

Constraint on g-2 region

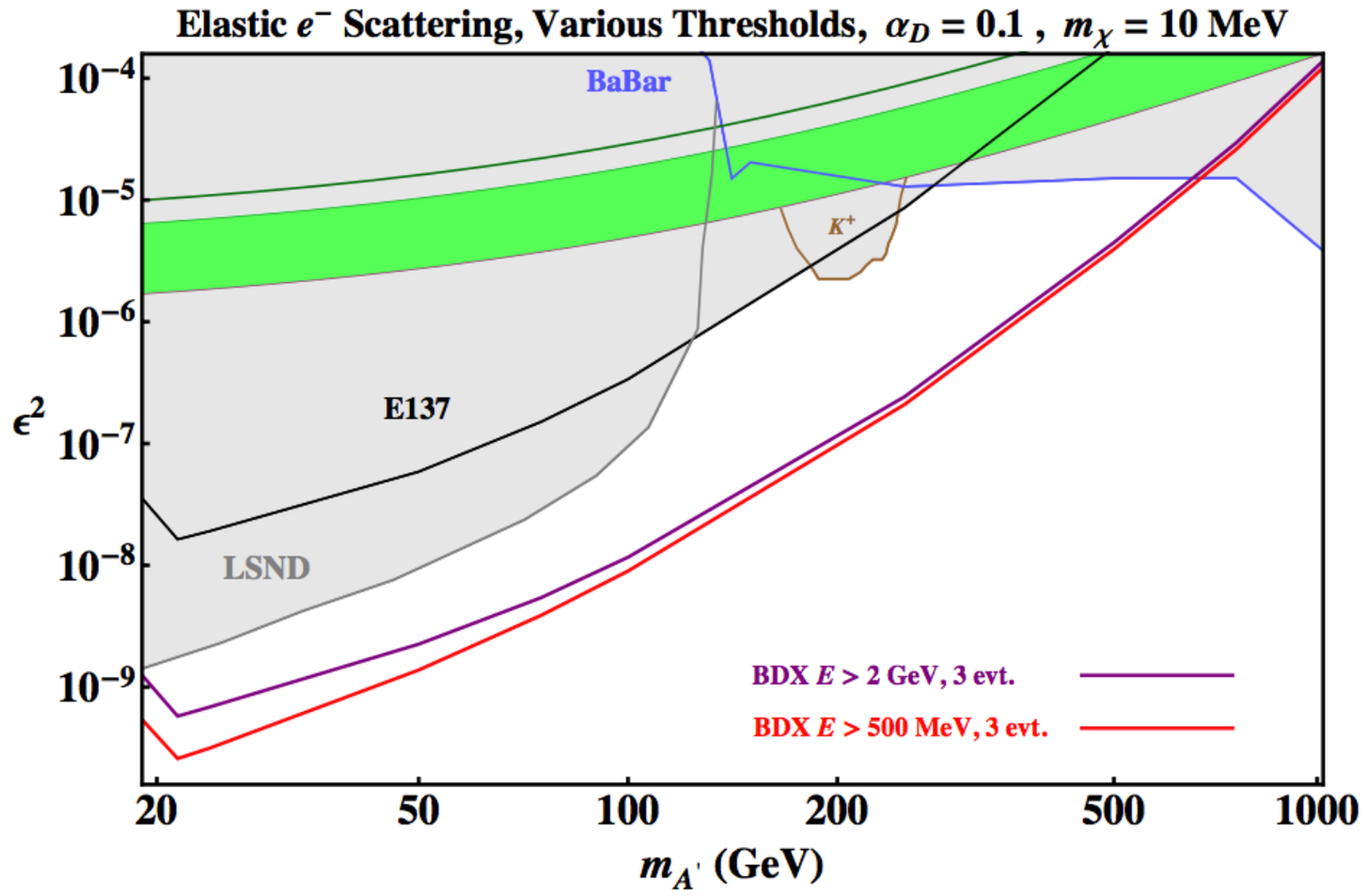
Batell, RE, Surujon

Izaguirre, Krnjaic, Schuster, Toro



New proton/electron beam dumps for sub-GeV DM

MiniBooNE, BDX,
missing momentum, …



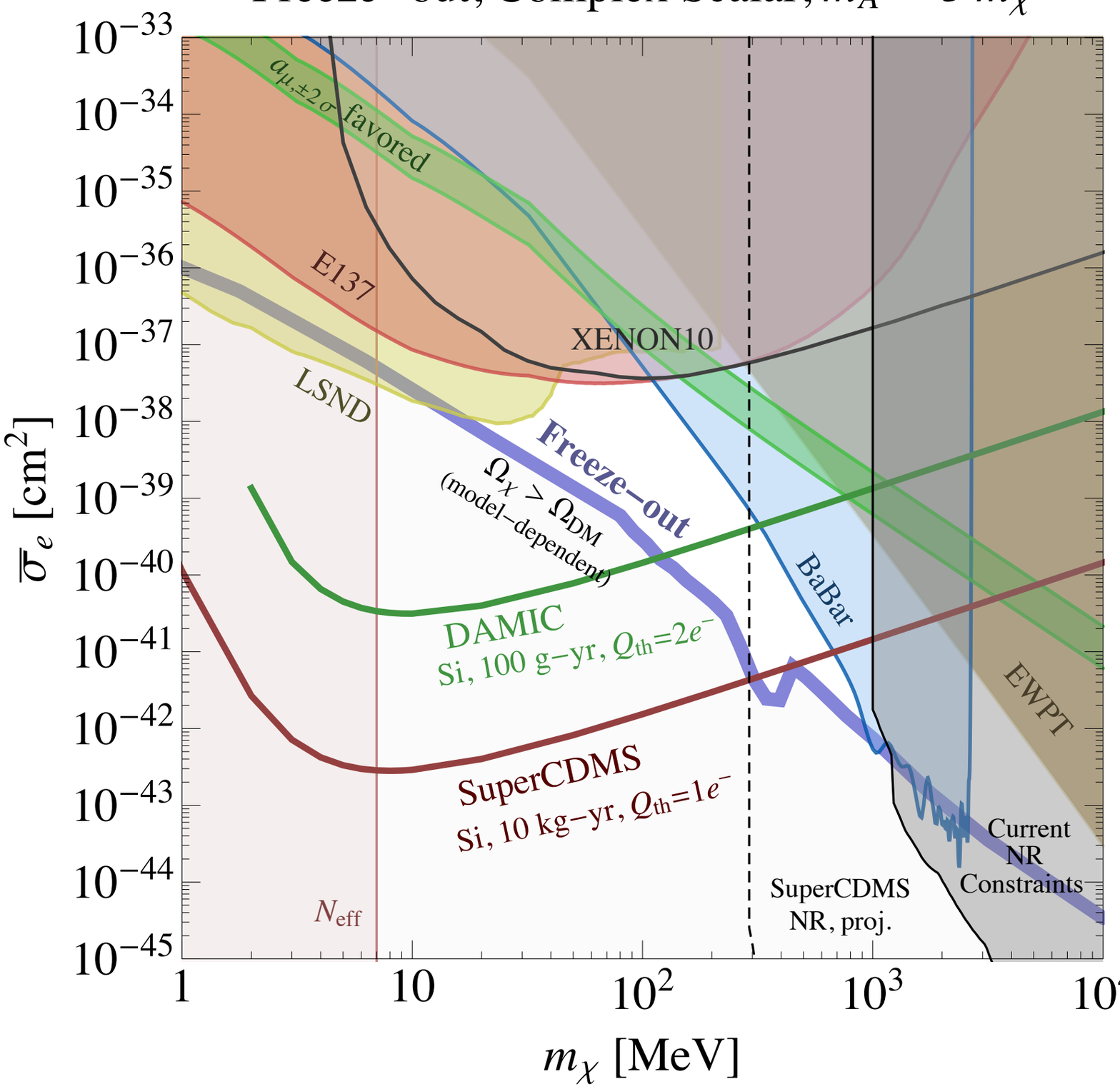
BDX proposal
(Battaglieri et.al.)

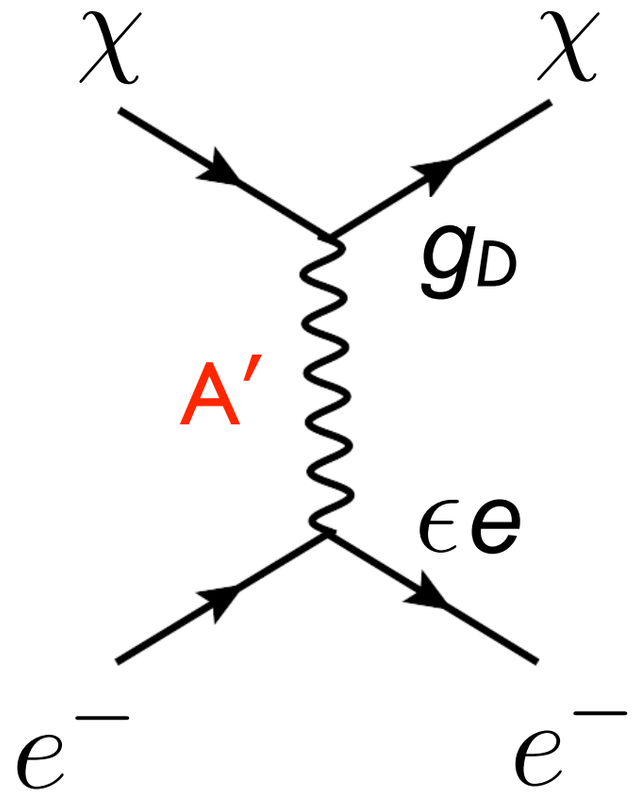
e.g.
Batell, Pospelov, Ritz
Deniverville, Pospelov, Ritz
Deniverville, McKeen, Ritz
Aguilar-Arevalo et.al.
Izaguirre, Krnjaic, Schuster, Toro (several)
Diamond, Schuster
Batell, RE, Surujon
BDX Collaboration
…

New Direct Detection Experiments for sub-GeV DM

RE, Mardon, Volansky

RE, Fernandez-Serra, Mardon, Soto, Volansky, Yu





Conclusions

- Dark photon portal is special: simple, ubiquitous, easily dominant over other portals
- HPS (and others) can probe e.g.:
  - muon g-2 for $\mathrm{Br}(A' \to \mathrm{SM}) \ll 1$
  - ε expected from GUT symmetry
  - mediator of DM interactions, motivated by e.g.:
    - small-scale crisis of cold, collisionless DM
    - 3.5 keV line
    - GC excess
    - simple sub-GeV DM models