A′ Motivation & Status, APEX's role

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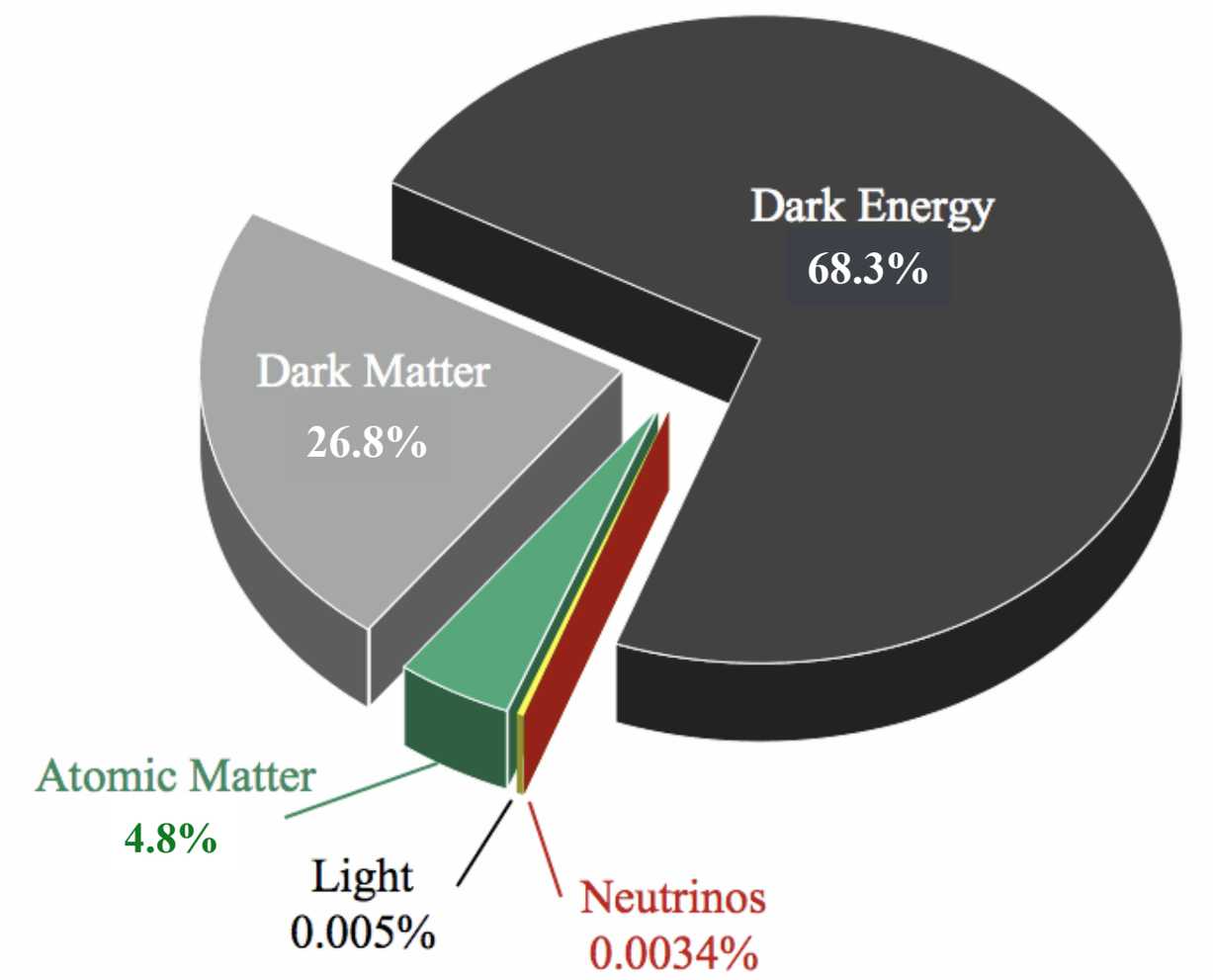
APEX Collaboration Meeting, JLab 4/19/2015

Outline

- A′ physics, status, motivation
- APEX and its unique role
- Comments on Dark Matter "Anomalies"

Dark Matter: powerful evidence for New Physics

Planck

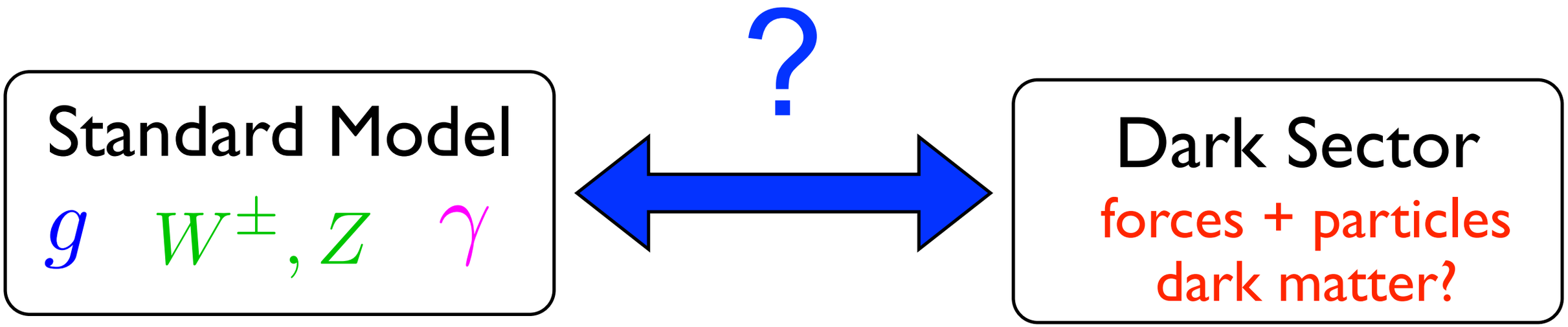


But what does it consist of?

Dark matter suggests the presence of a *dark sector*, neutral under all Standard Model forces

Portals to a dark sector?

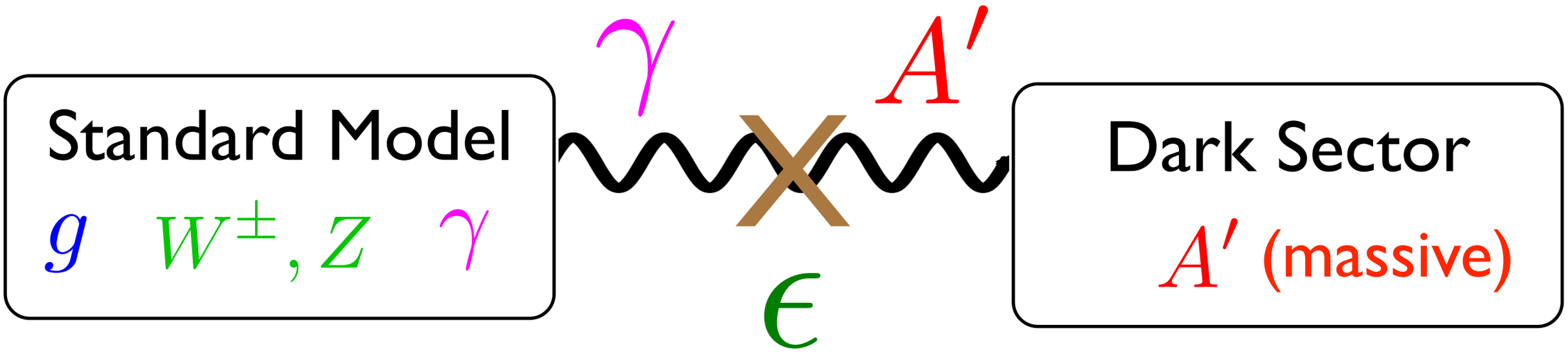
only a few important interactions exist that are allowed by Standard Model symmetries



APEX built to probe the
dark photon portal

Dark Photons

ordinary photon & A′ can mix



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

"Kinetic Mixing"

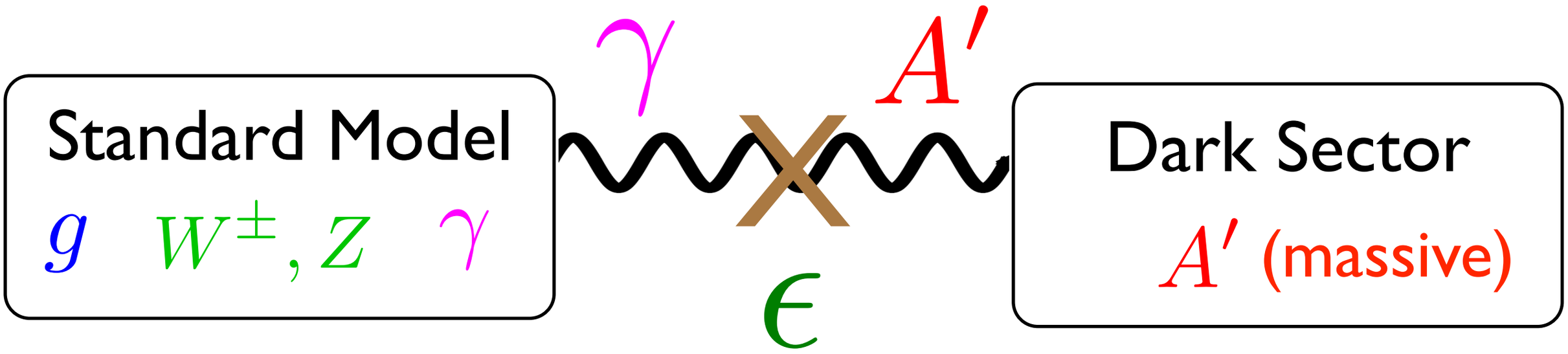
Holdom

Galison, Manohar

a special portal: not suppressed by a mass scale!

Dark Photons

ordinary photon & A′ can mix



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

"Kinetic Mixing"

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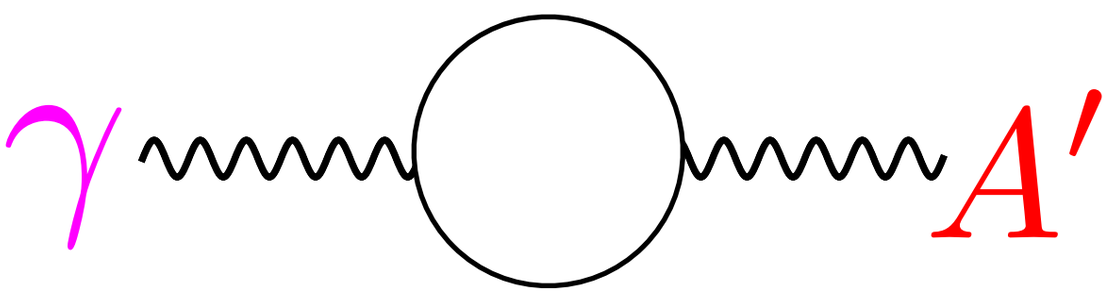
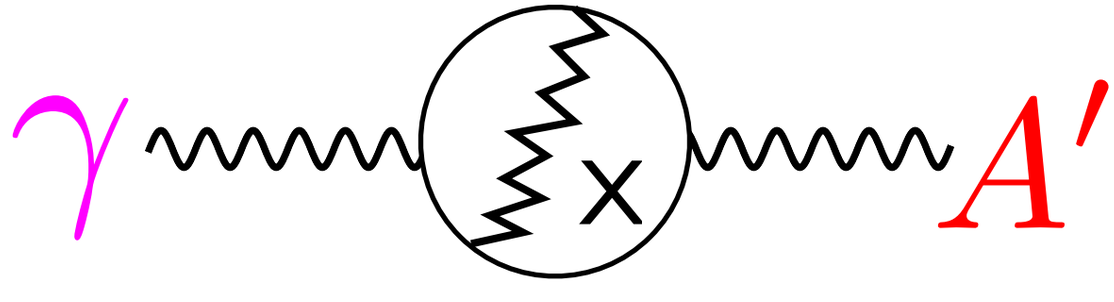
Galison, Manohar

simplest Dark Sector consists of just an A′

GUT: ε from one-loop versus two loop

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





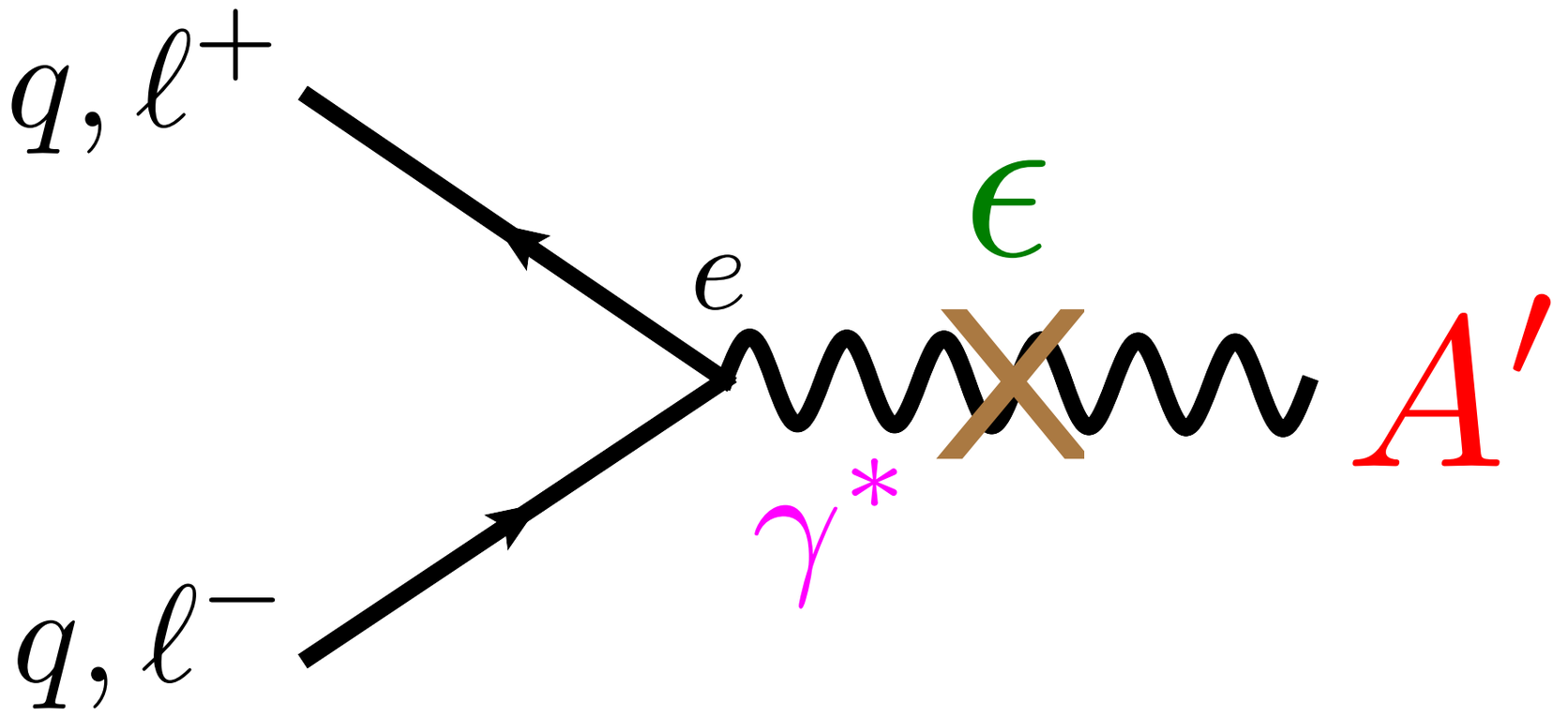
$$\epsilon \sim \frac{g_Y g_D}{16\pi^2} \ln\left(\frac{M}{M'}\right)$$

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

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

APEX and HPS can be first to probe ε from 2-loop GUT!

A′ couples to quarks & charged leptons



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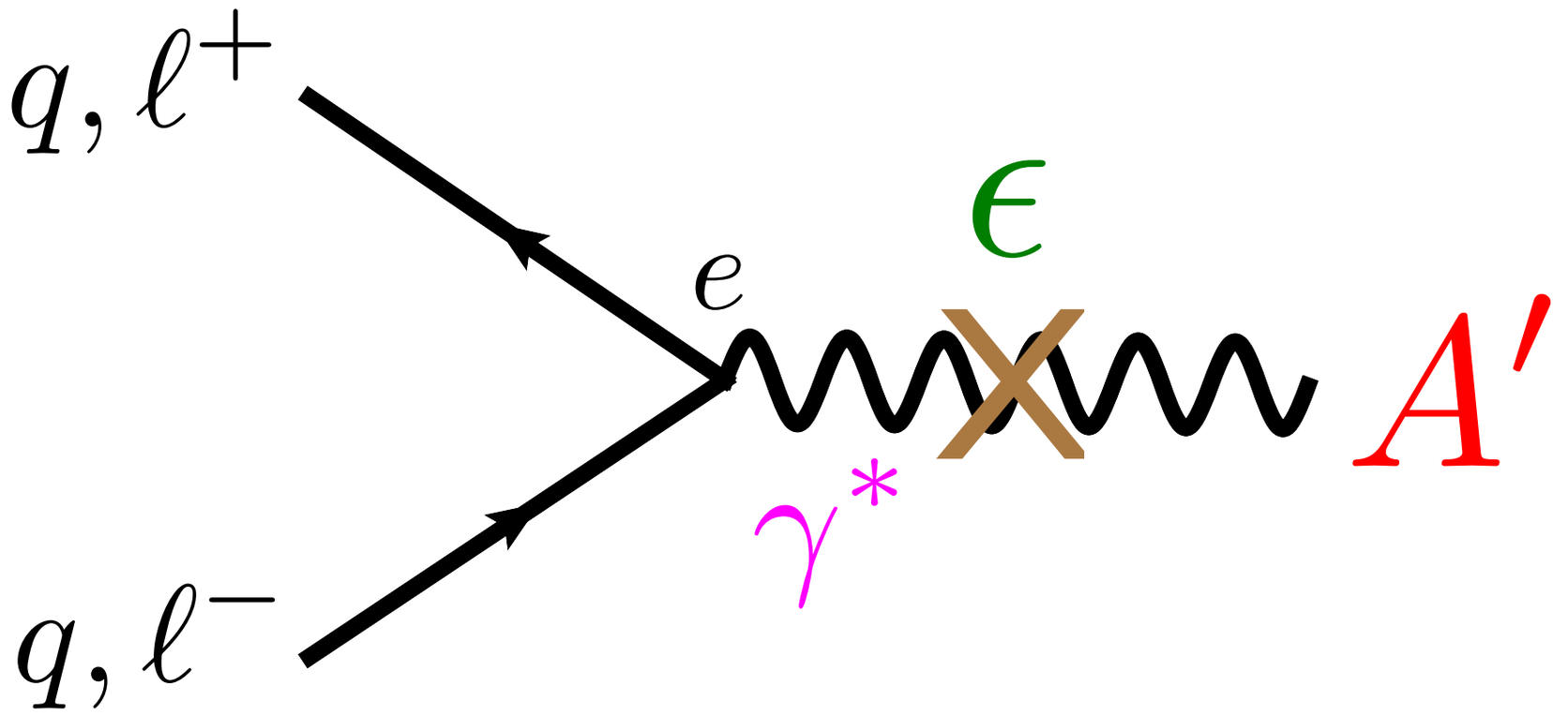

allows production of A' at colliders, beam dumps etc.

allows decay: $A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \ldots$

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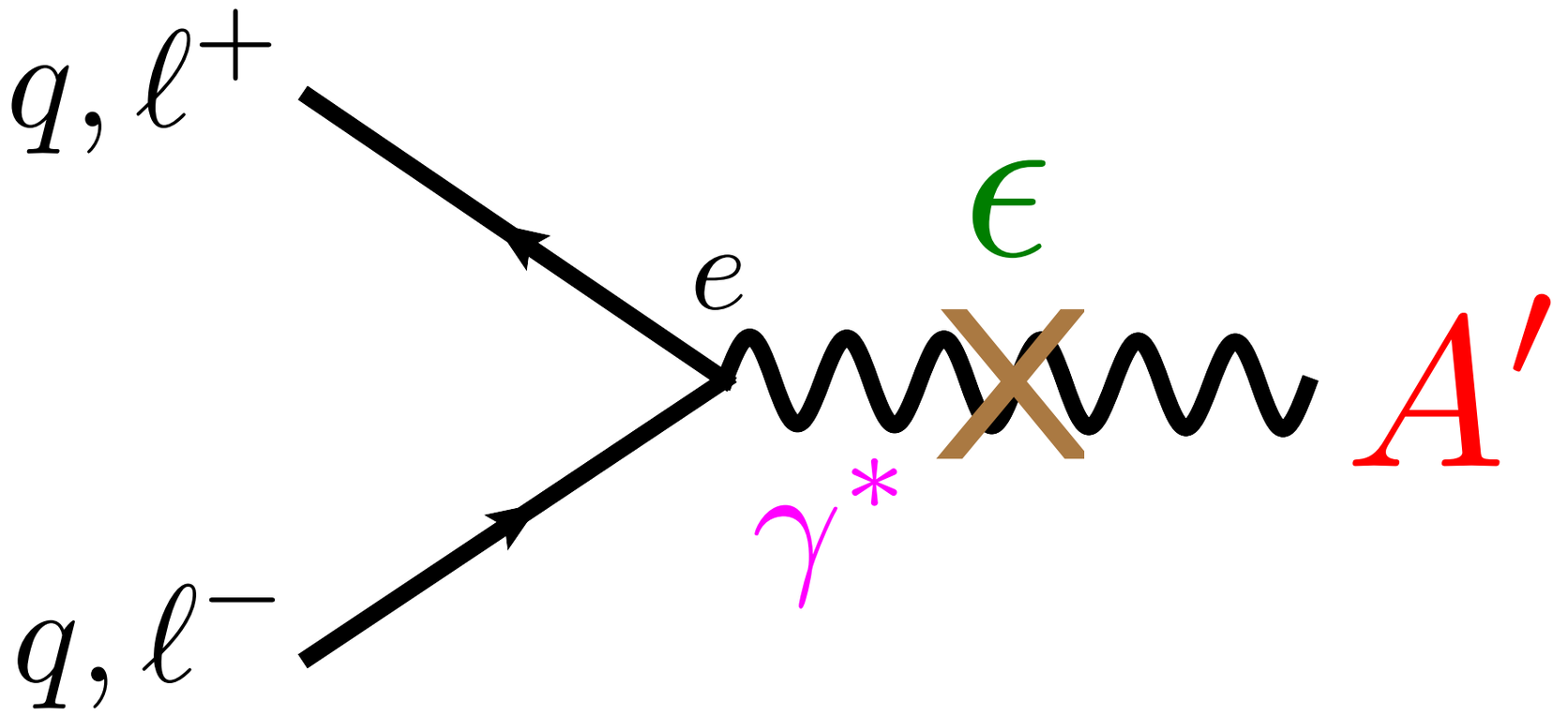

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(A' → Dark Sector also possible!)

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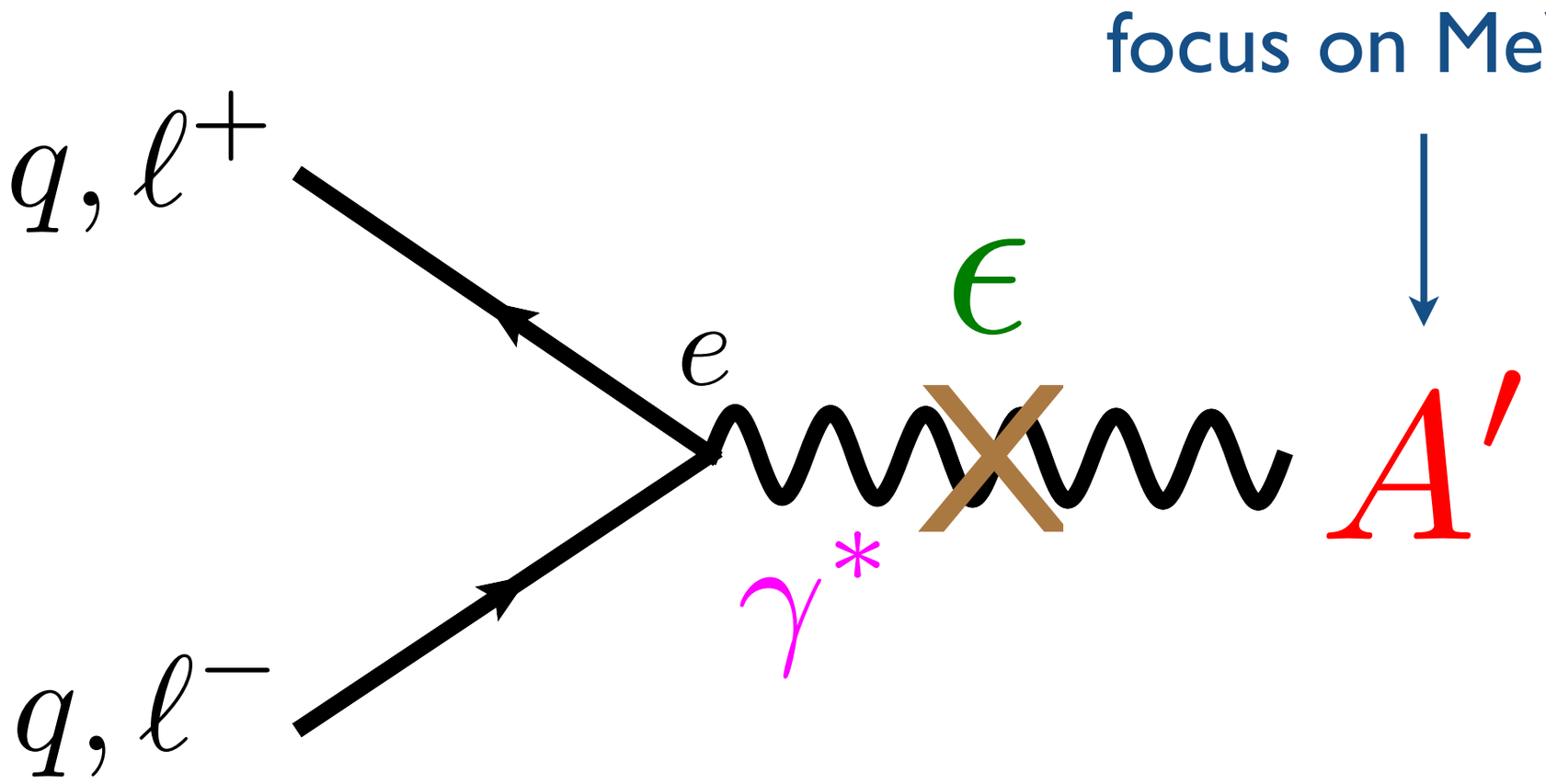

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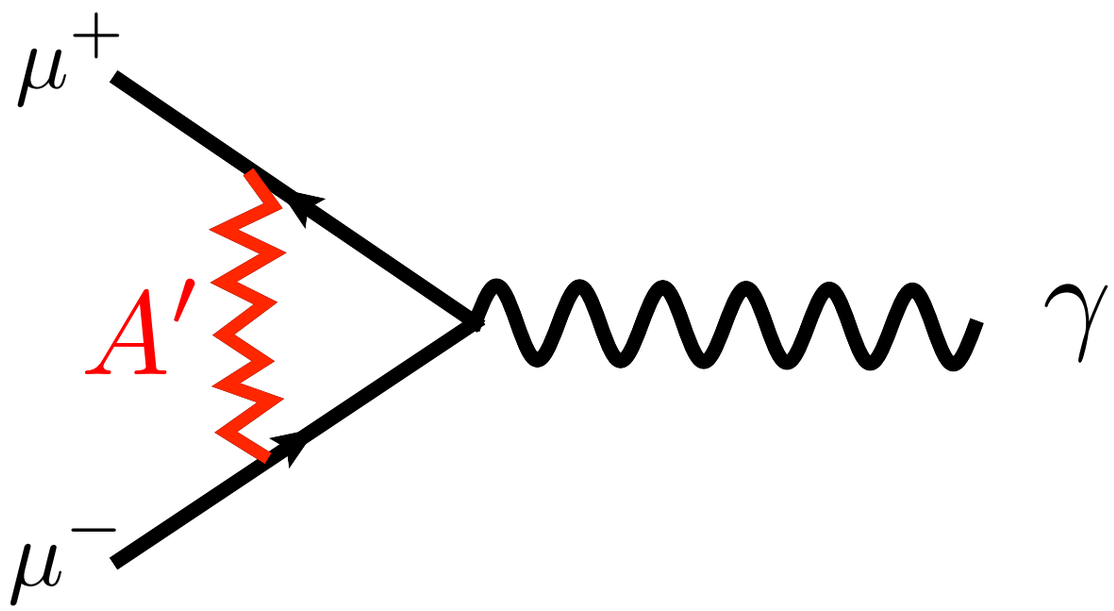
Hint for A′ from anomalous muon g-2?

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

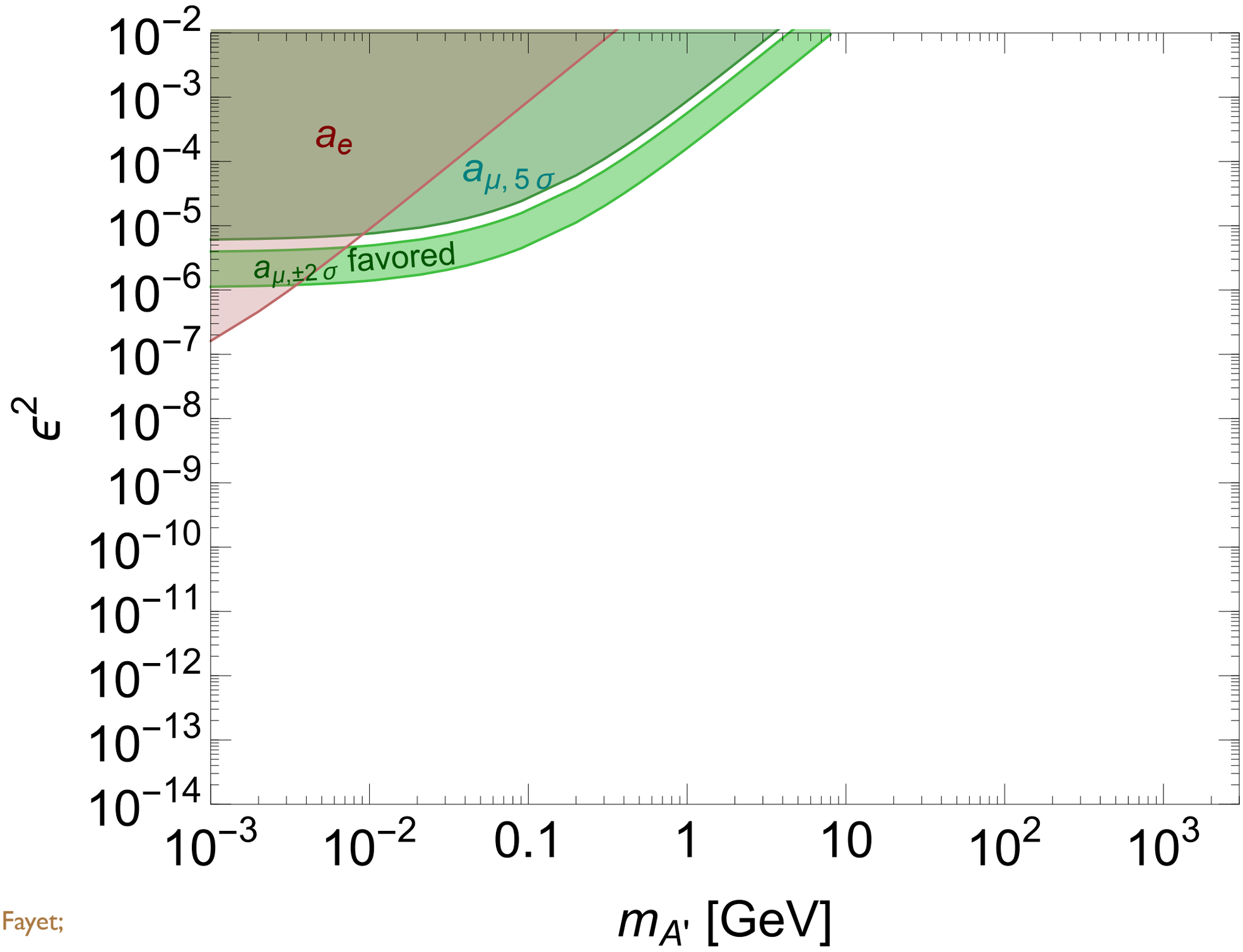
$\sim 3.6\ \sigma$ deviation



A′ may explain
observed $(g_s - 2)_\mu$!

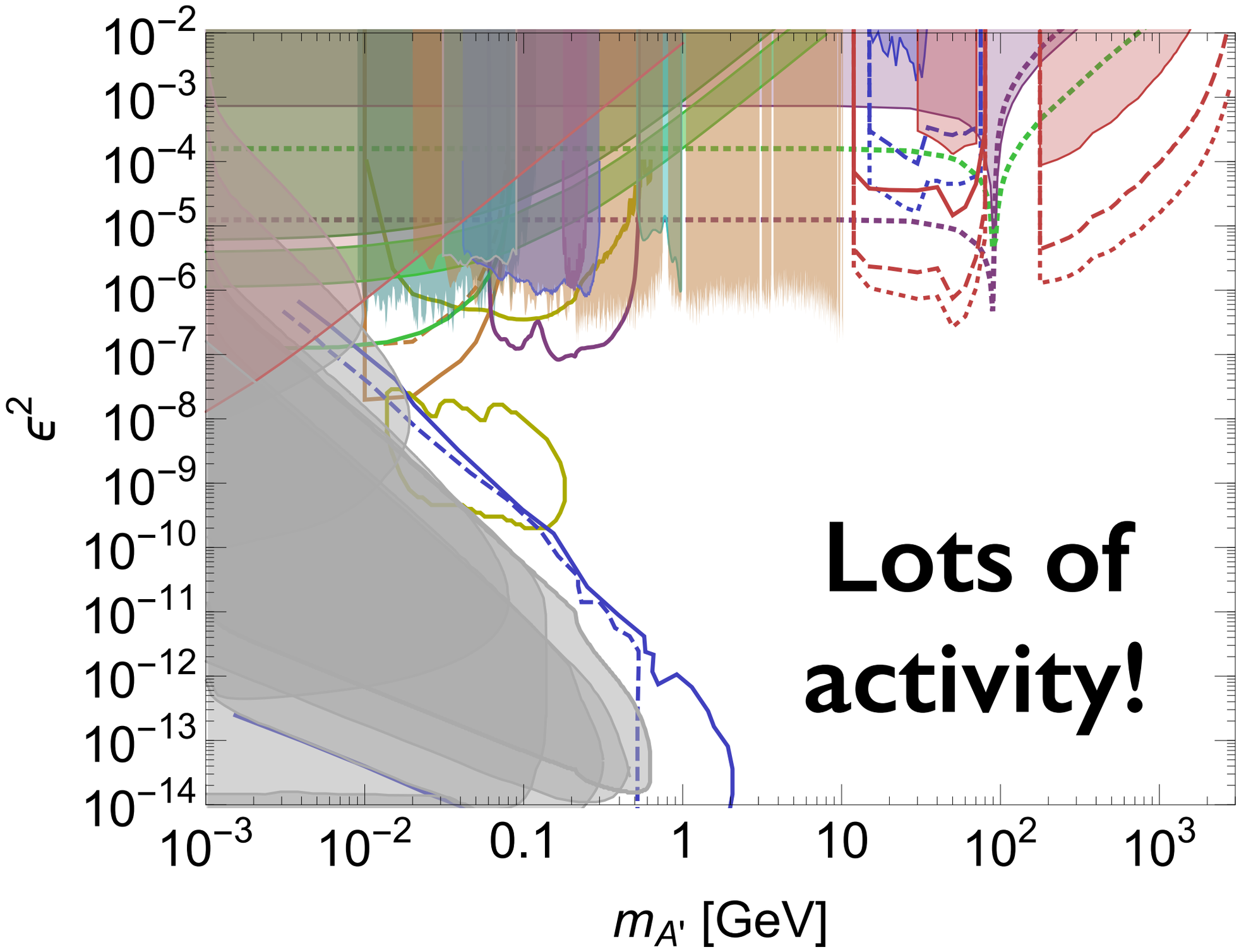
Boehm, Fayet
Pospelov

A′ Status 2008

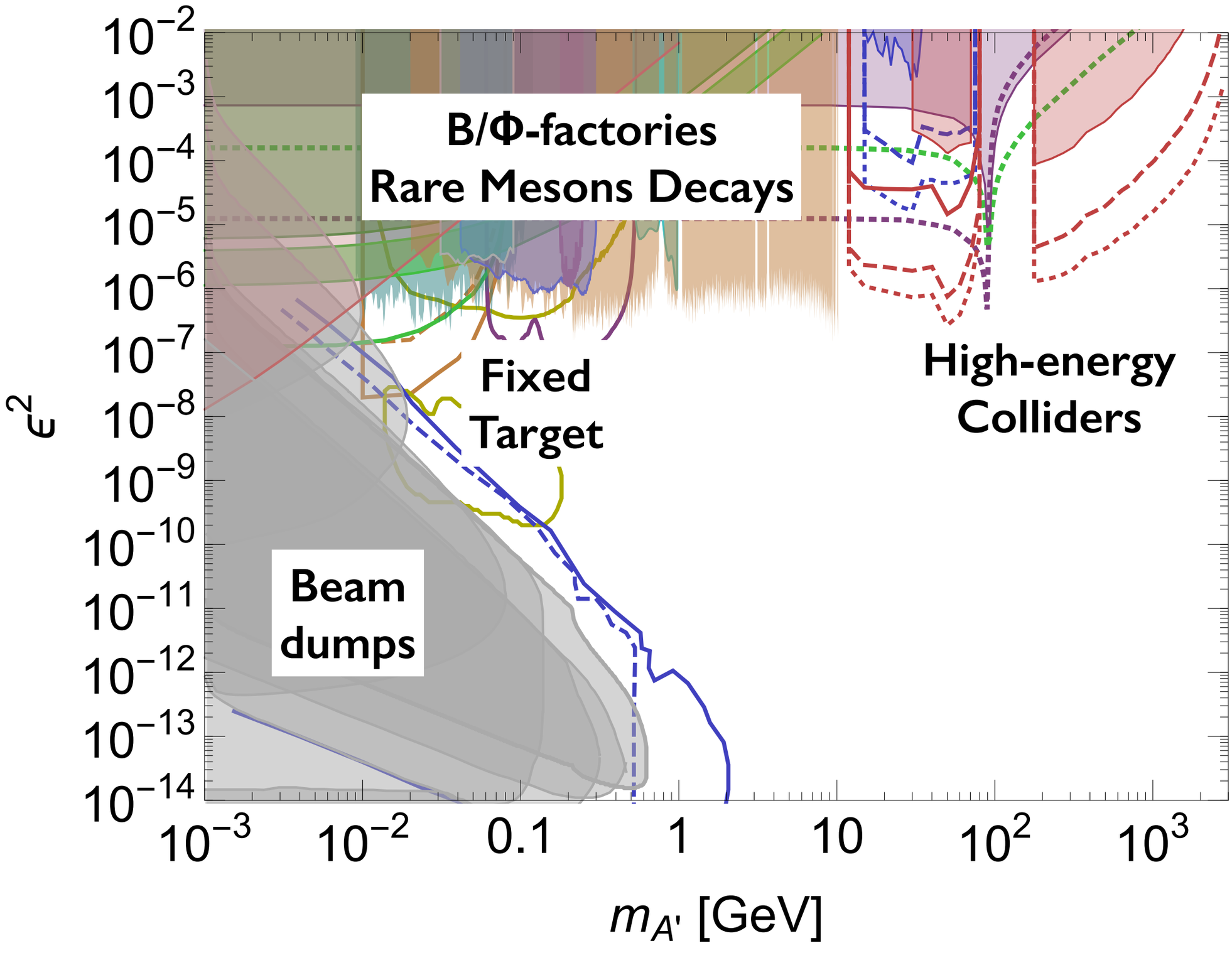


Pospelov; Fayet;

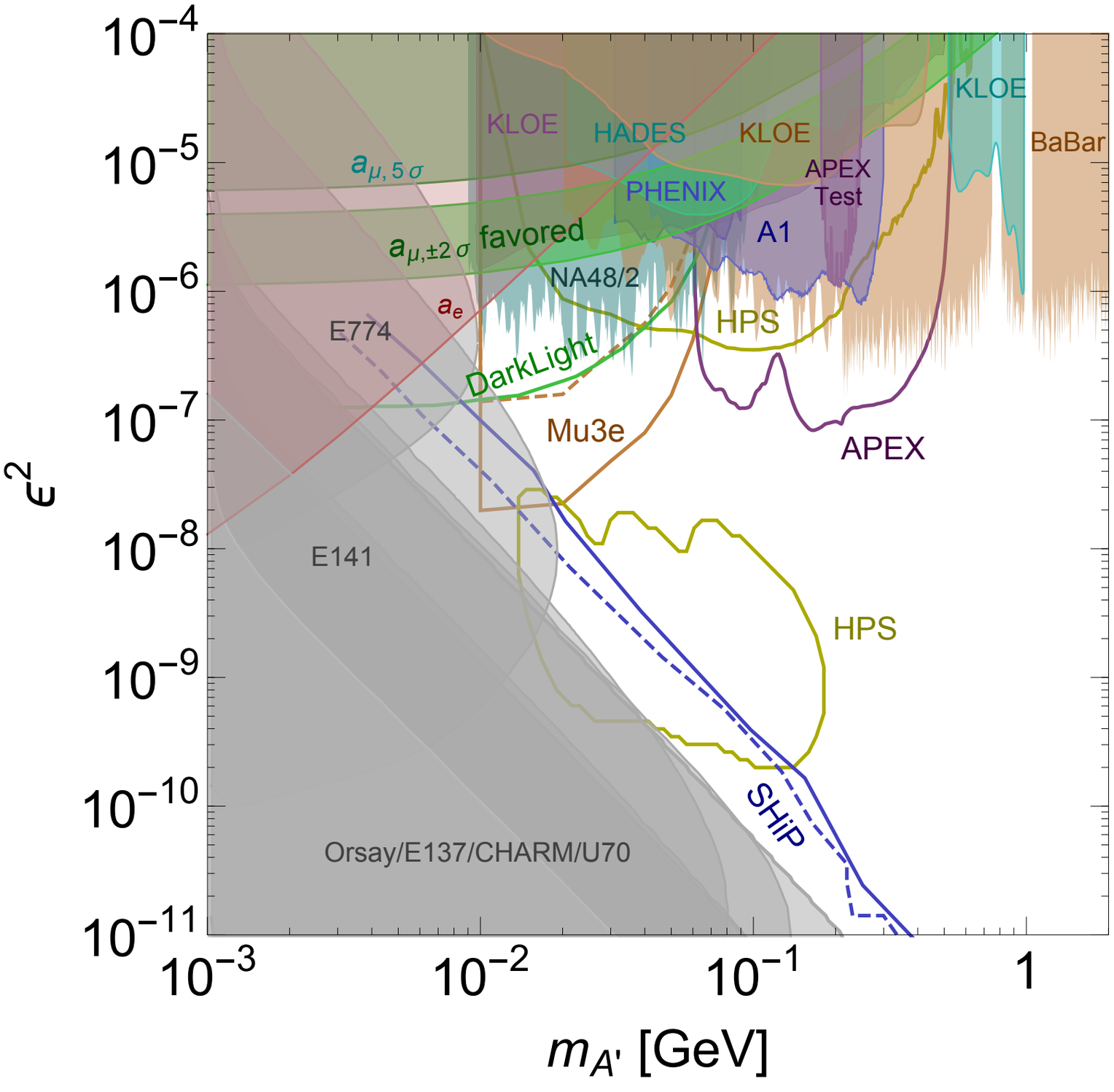
A′ Status Today



A′ Status Today



A′ Status Today: MeV-GeV



Many new searches
in last year
+ new proposals!

+ Cornell e^+ experiment (not shown)

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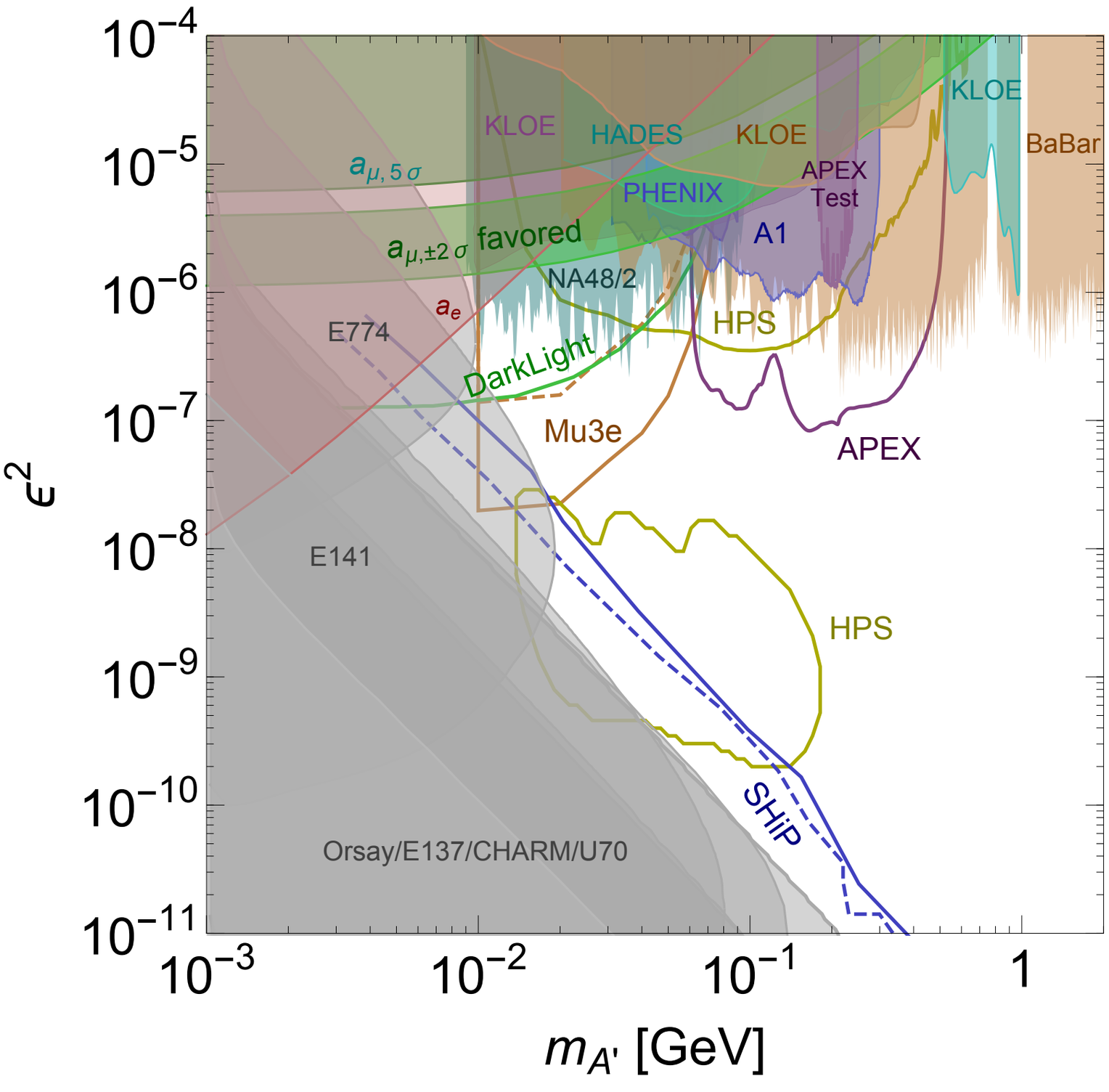

Many new searches in last year + new proposals!

Recent result: Muon g-2 region disfavored, for A′ decaying directly to Standard Model

+ Cornell e^+ experiment (not shown)

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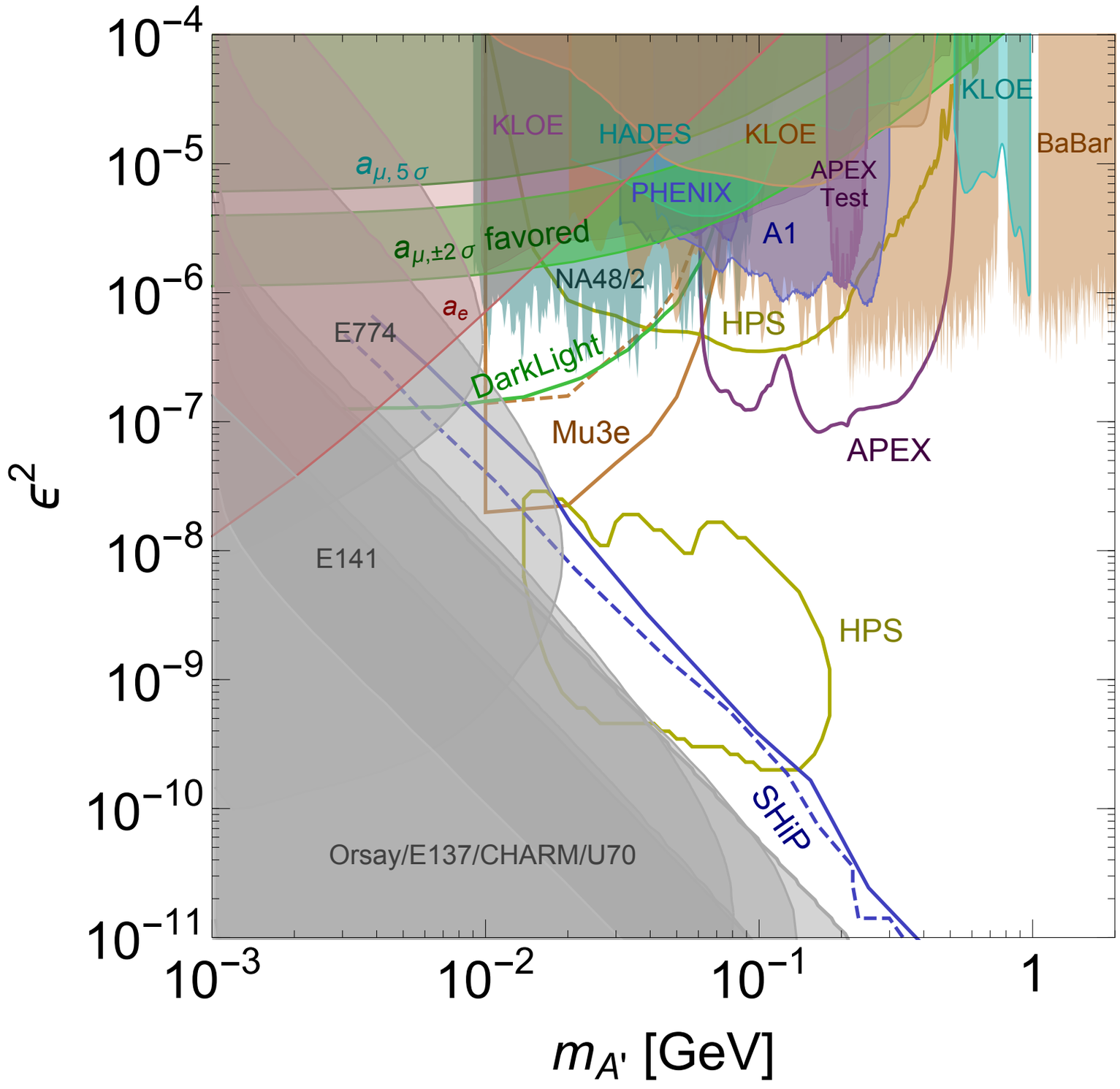
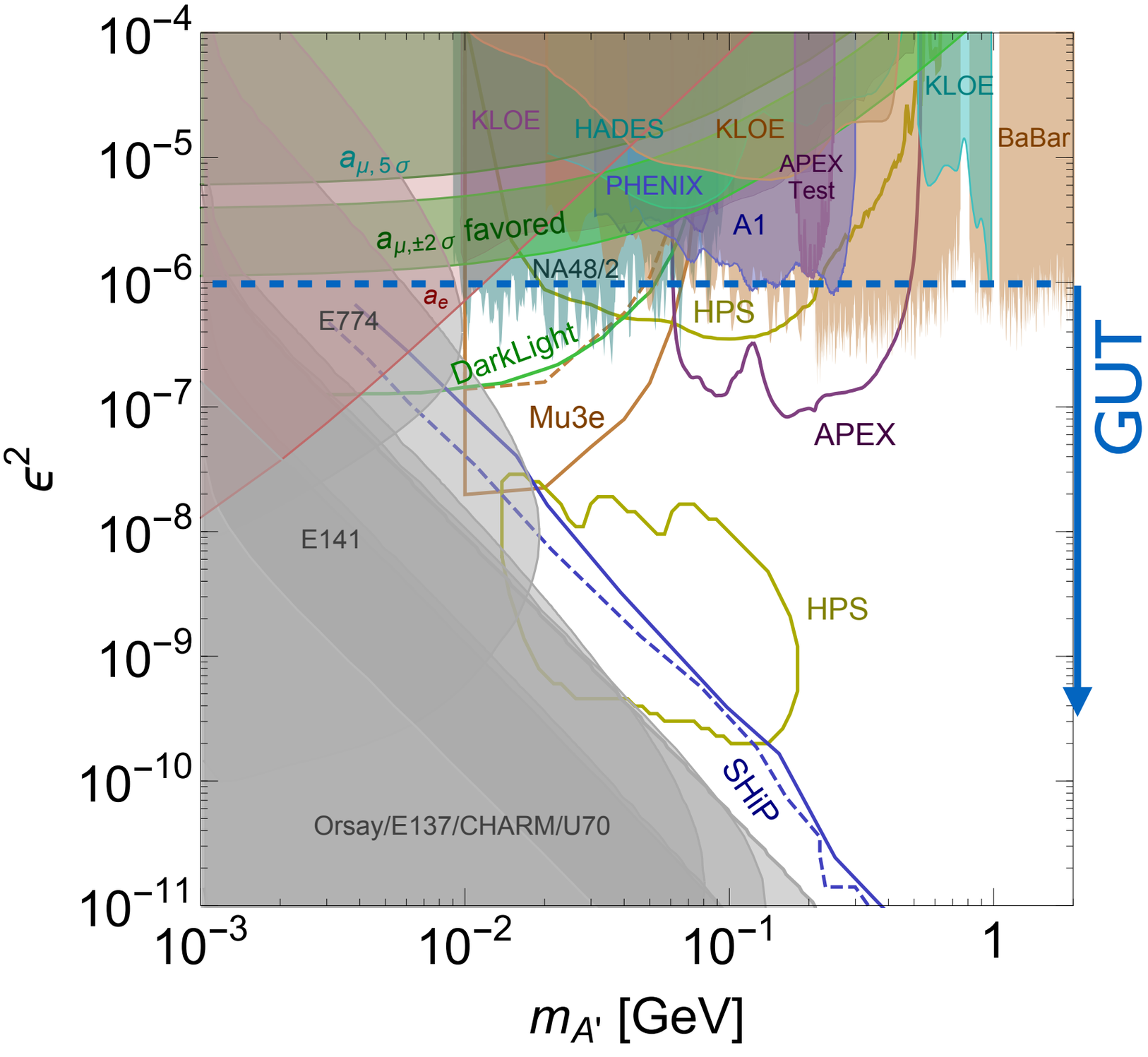
APEX: unique + important reach



unique reach
at high masses

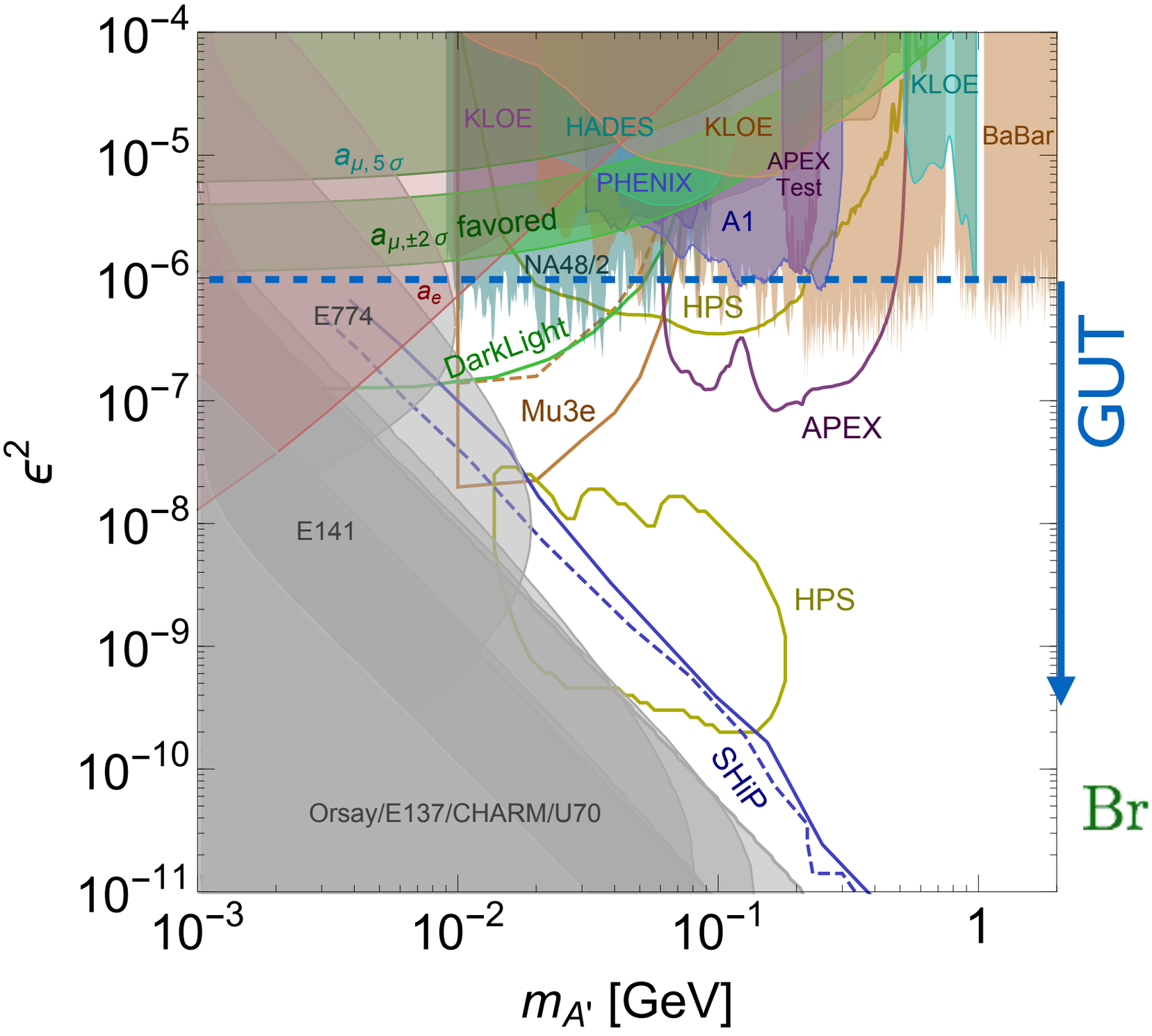
APEX: unique + important reach



unique reach at high masses

reach ε region expected from GUT symmetry

APEX: unique + important reach



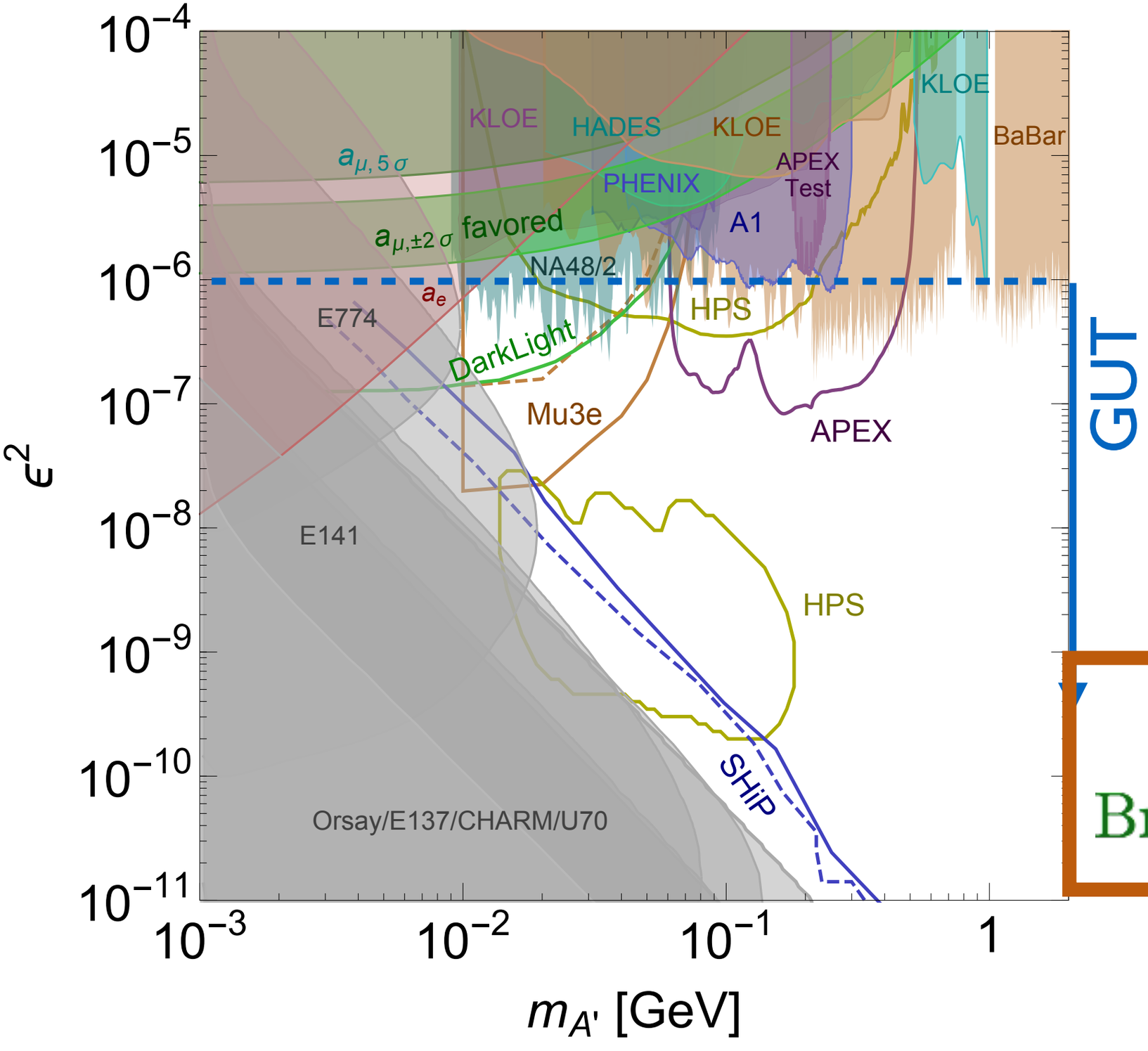
unique reach at high masses

reach ε region expected from GUT symmetry

can probe g-2 for

$\mathrm{Br}(A' \to \text{visible}) \gtrsim 1\%$!

APEX: unique + important reach



unique reach at high masses

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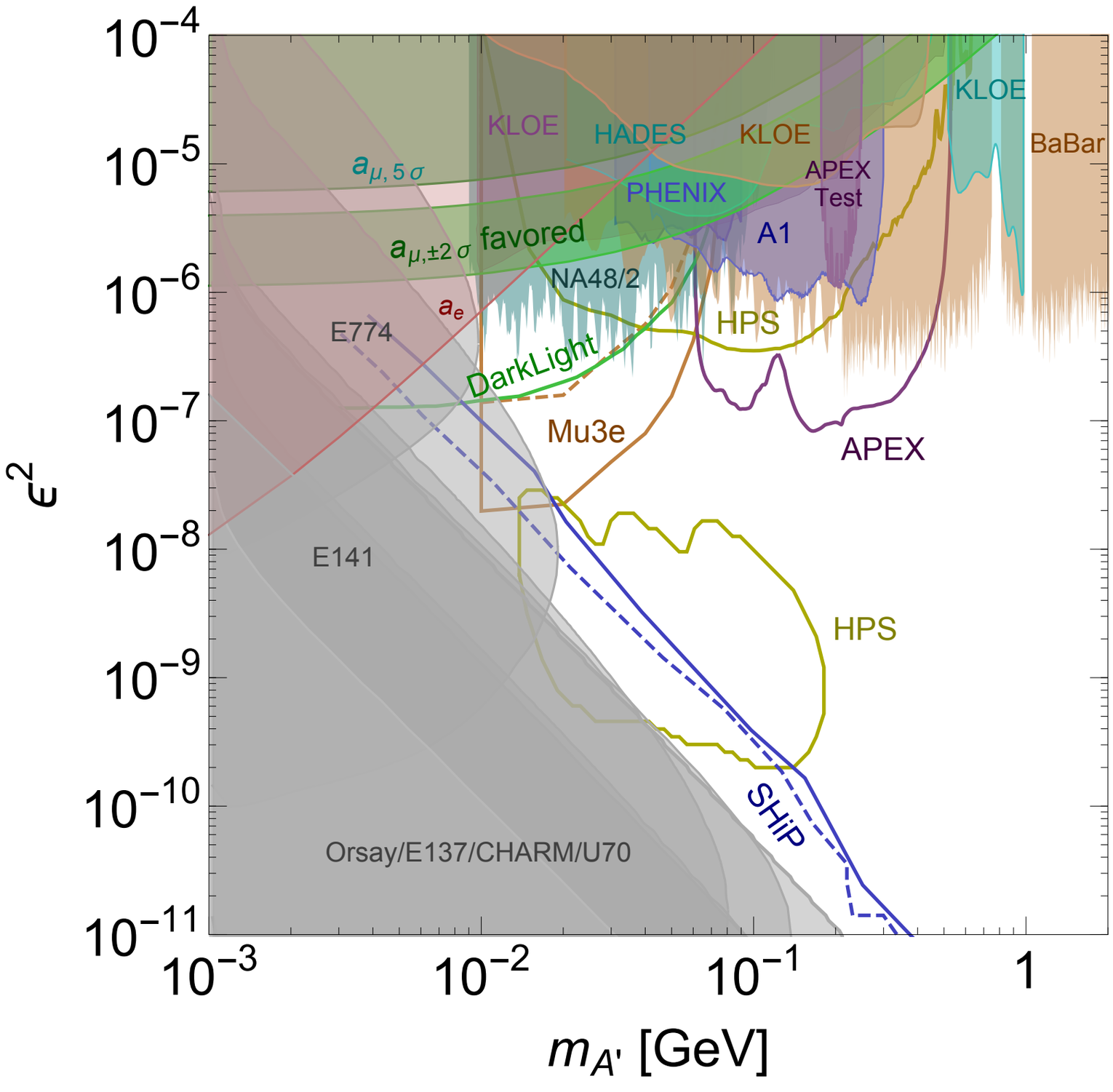
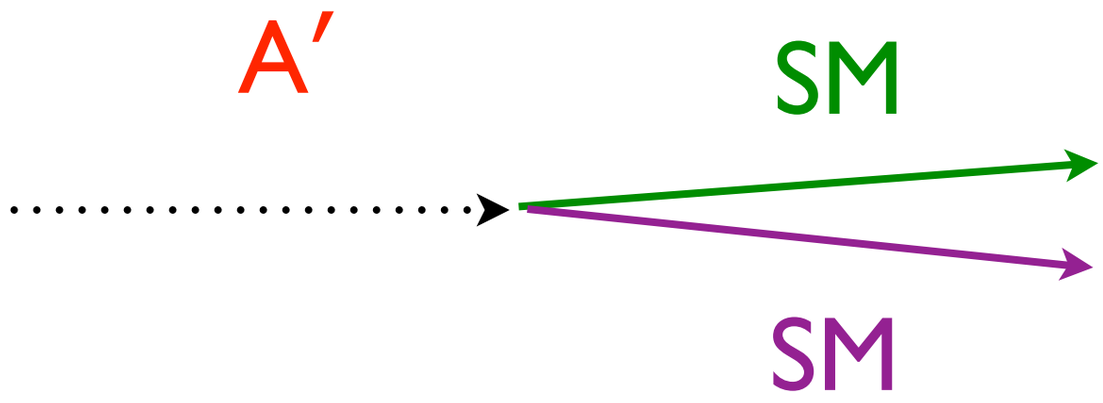
interesting possibility!

Assume A′ → Dark Matter is possible

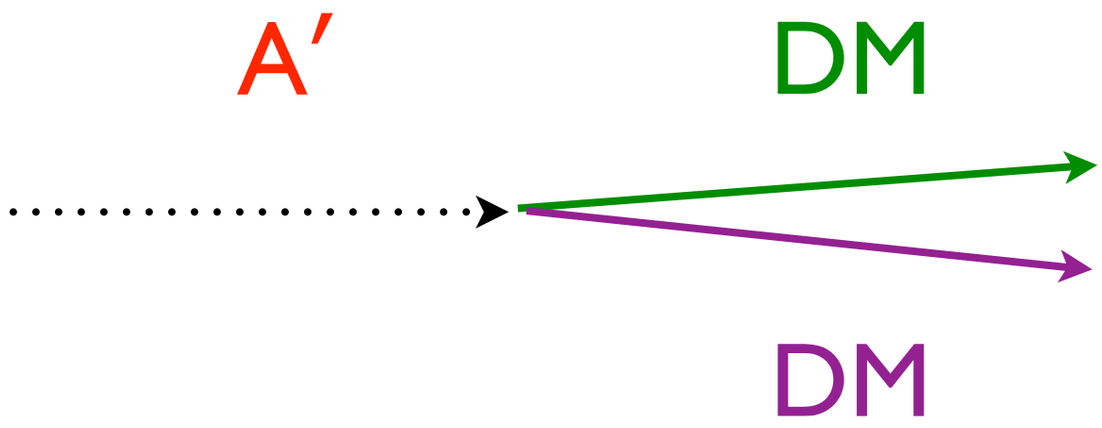


Then many constraints here weaken/ disappear!

Assume A′ → Dark Matter is possible



Controlled by ε



Controlled by α_D

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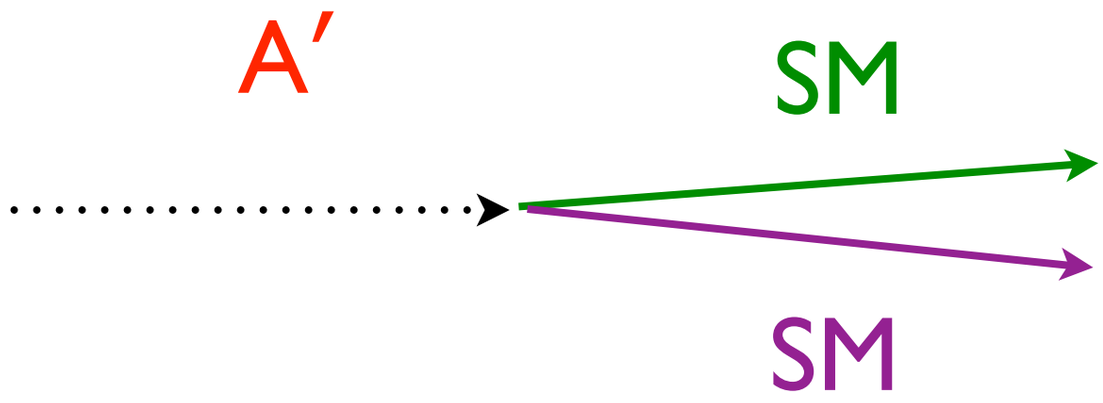
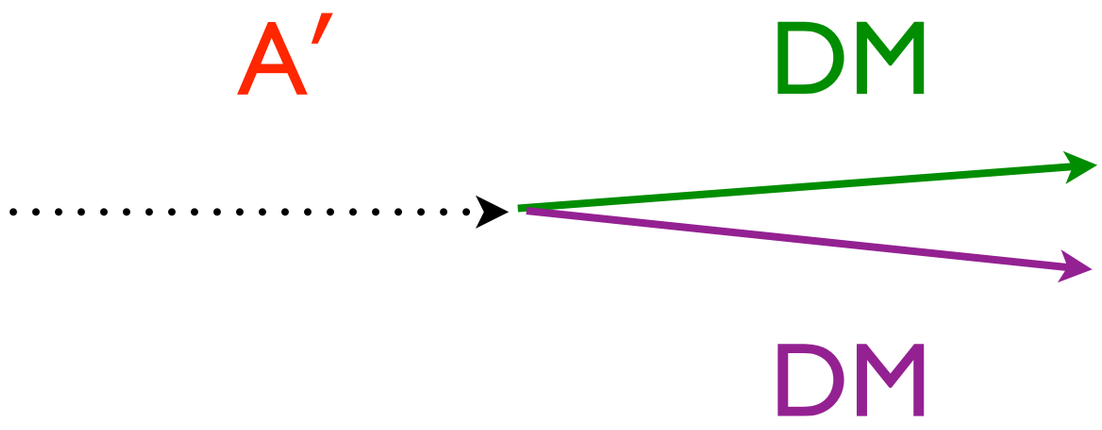


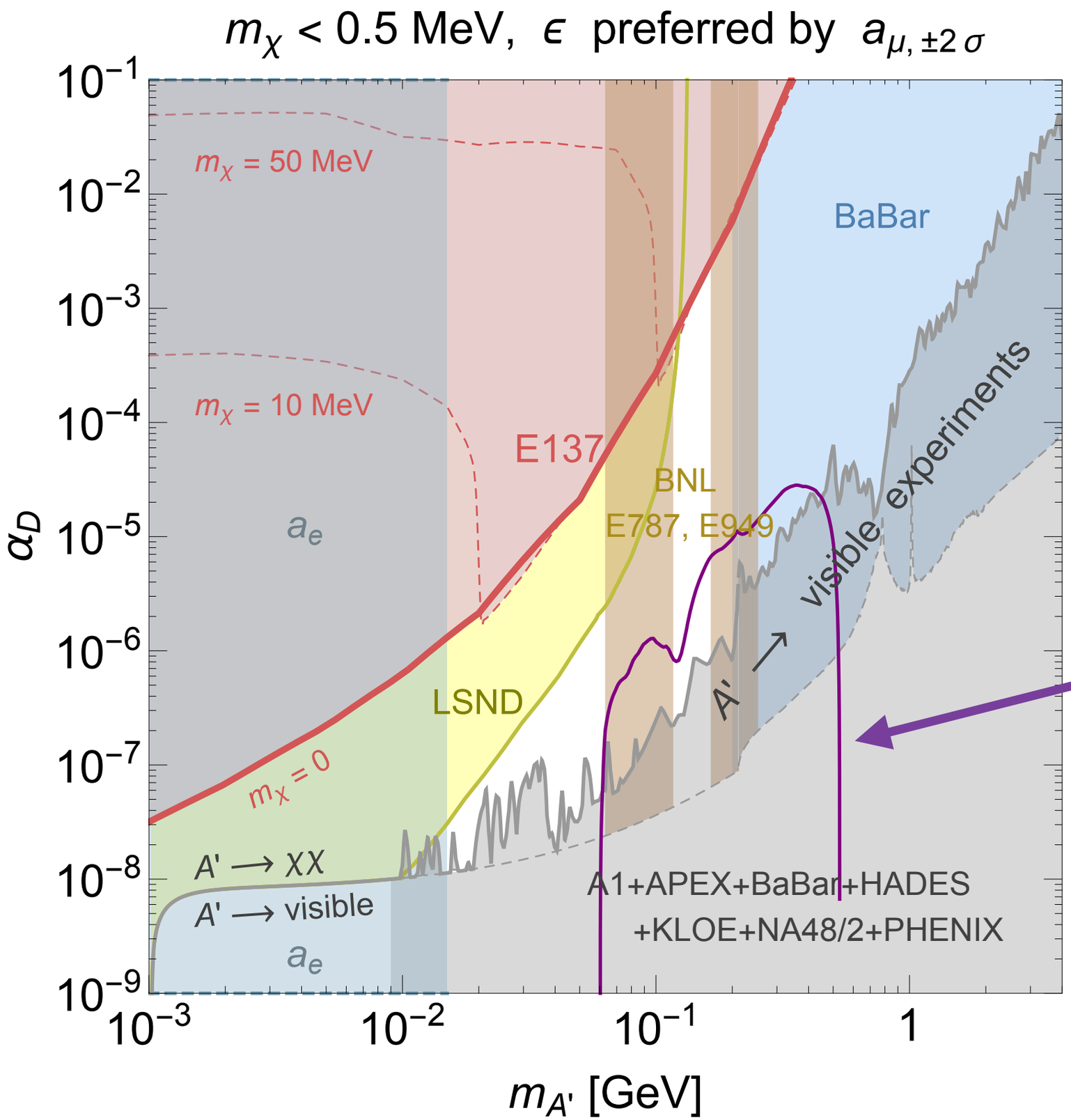
Controlled by ε



Controlled by α_D

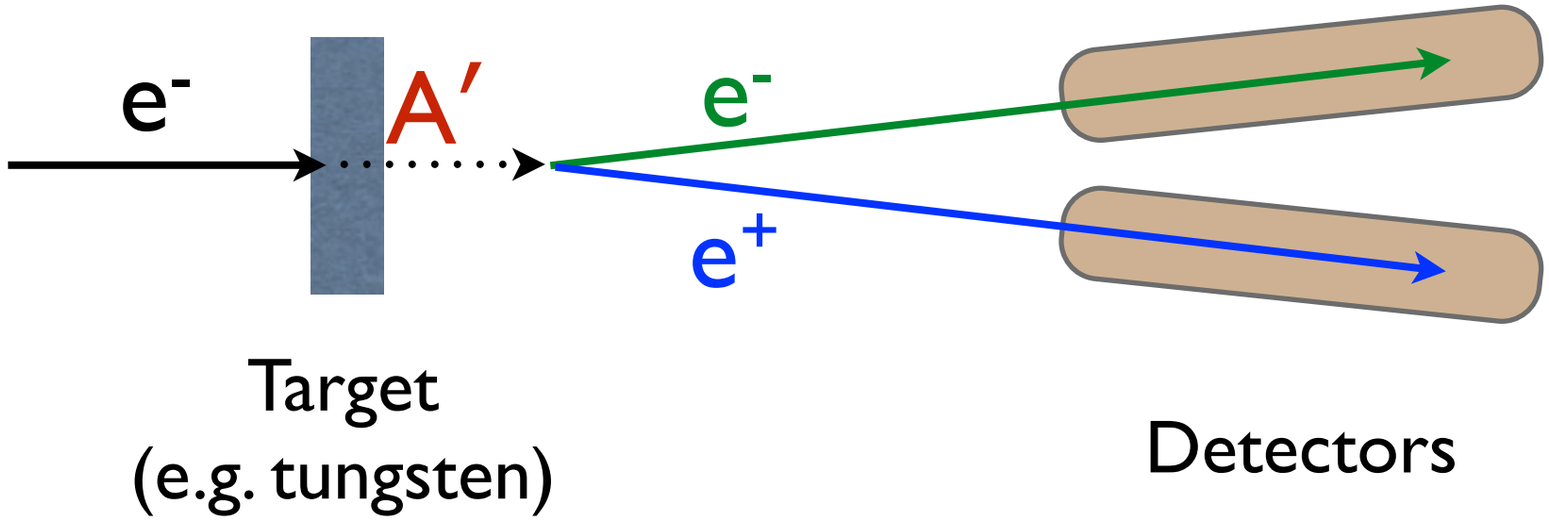
now fix ε to explain g-2…

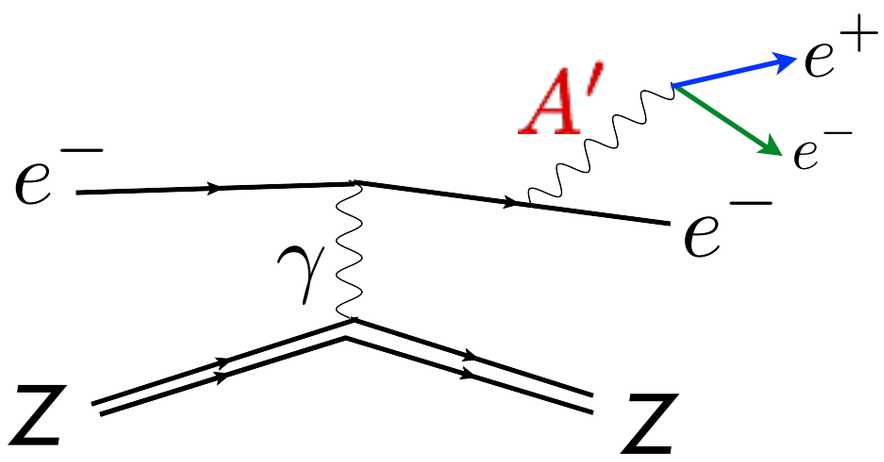
Constraint on g-2 region



APEX

Electron-beam Fixed-Target Concept

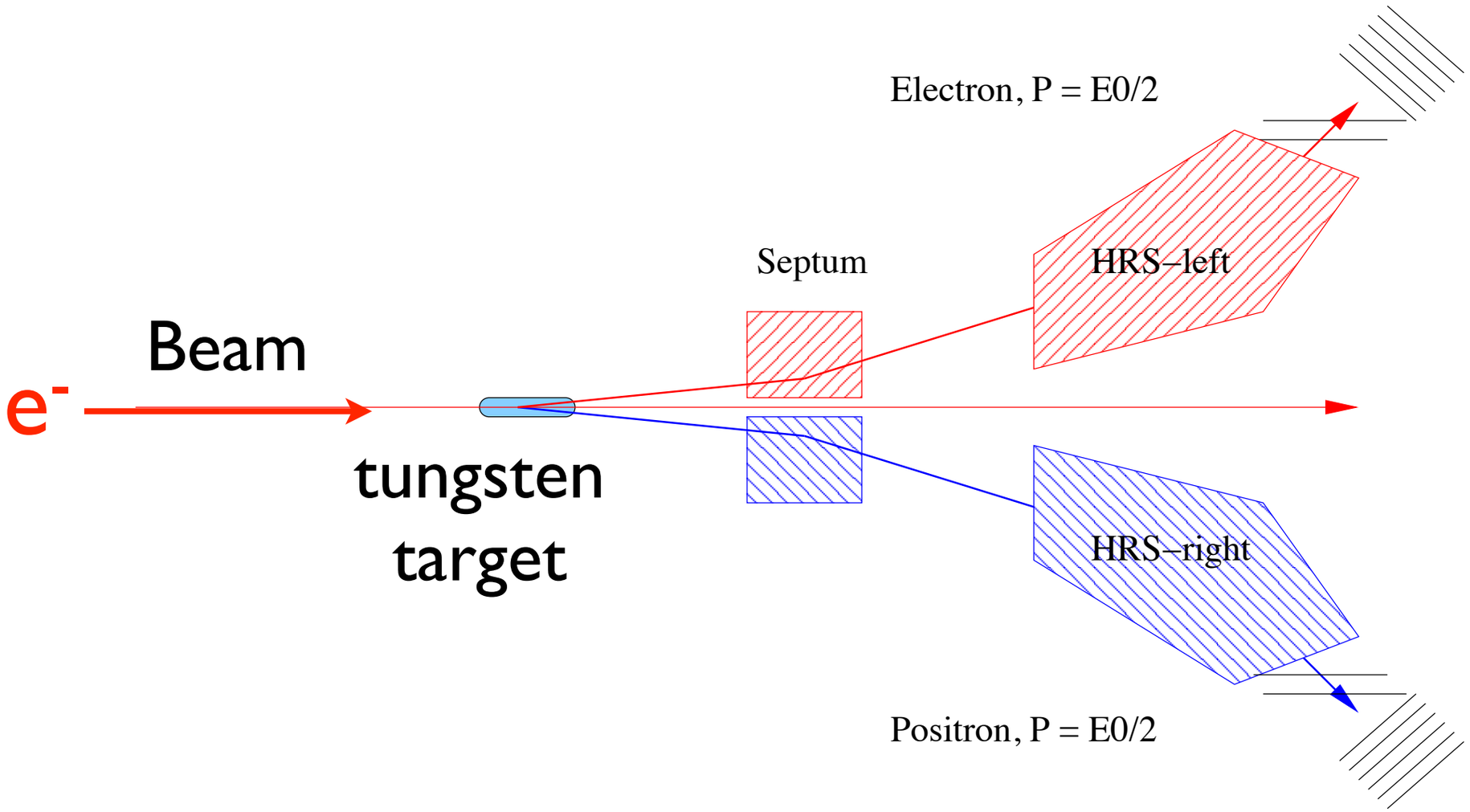




look for $A' \rightarrow e^+e^-$
resonance ("bump hunt")
or **displaced vertex**

existing (beam dump) constraints & strategies outlined in
Bjorken, RE, Schuster, Toro *PRD, 2009*

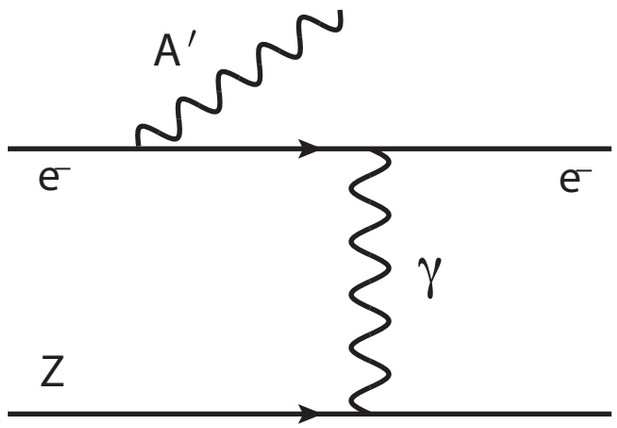
APEX Experimental Setup



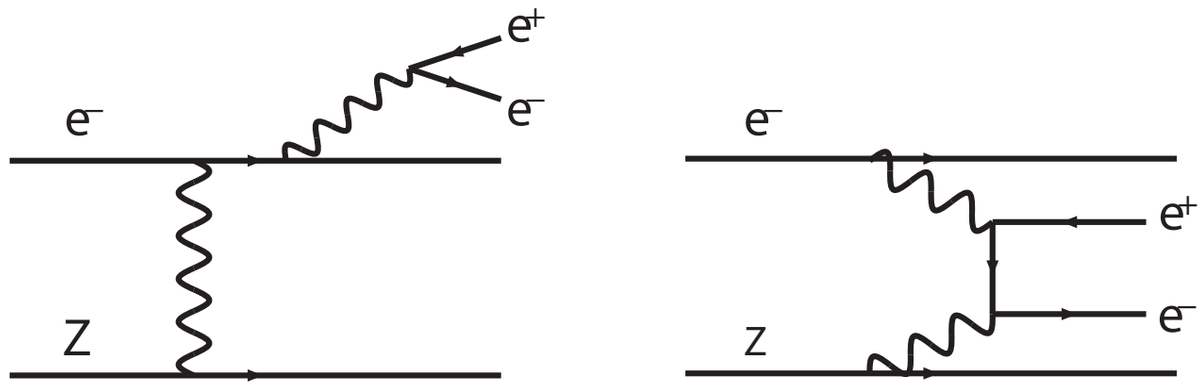
septum magnet crucial to maximize S/B

choose symmetric configuration (angles and energy)

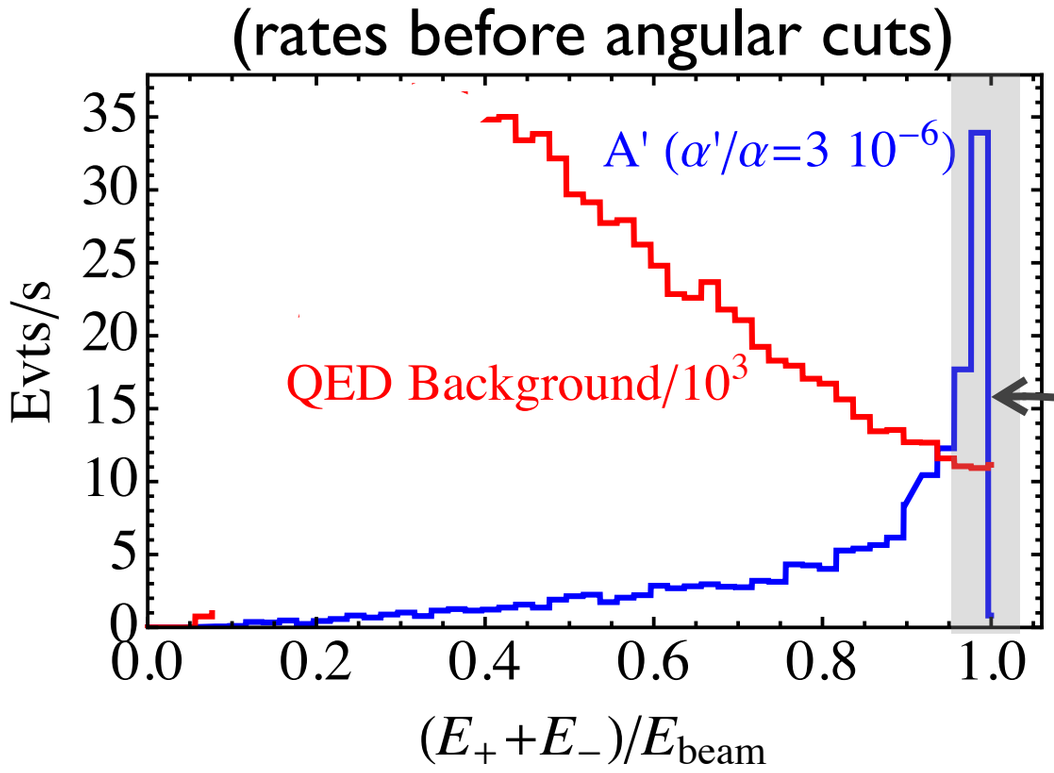
Symmetric configuration maximizes signal over background



A′ signal



Backgrounds



A′ products carry (almost) full beam energy

Symmetric energy, angles in two arms optimize A′ acceptance

$E^+ \approx E^- \approx E_{beam}/2$

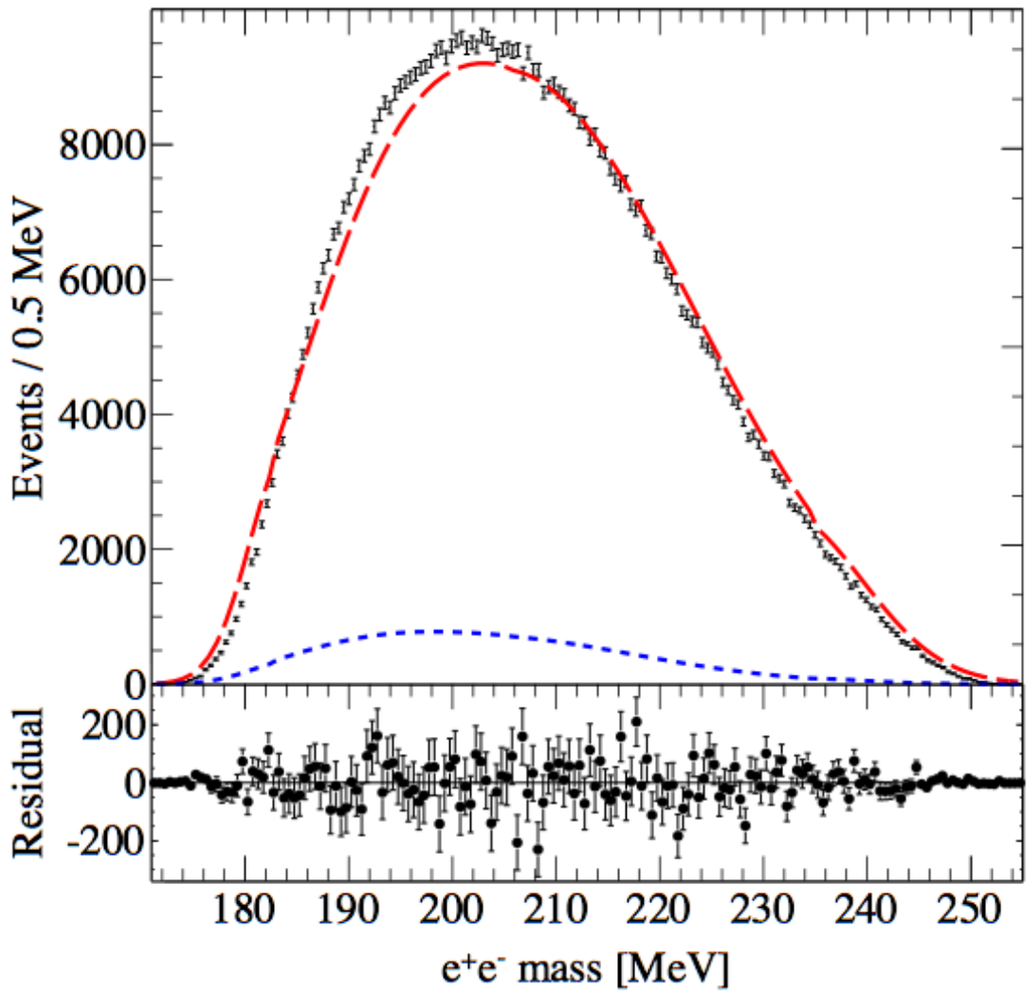
19

APEX Test Run in July 2010

- Demonstrated many key elements for full experiment including
  - mass resolution
  - understanding of backgrounds
  - resonance search (on 700,000 good trident events)

- Results published in PRL 107 (2011) 191804

Invariant Mass Spectrum →



APEX run plan and timeline

- Full experiment: ~1 Month Beam Time split between 1, 2, 3, and 4 GeV
- main “back-up” experiment in Hall A for Spring 2016
- More likely to run in Fall 2017/Spring 2018

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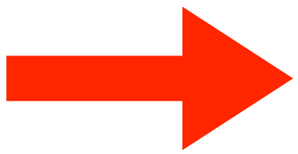
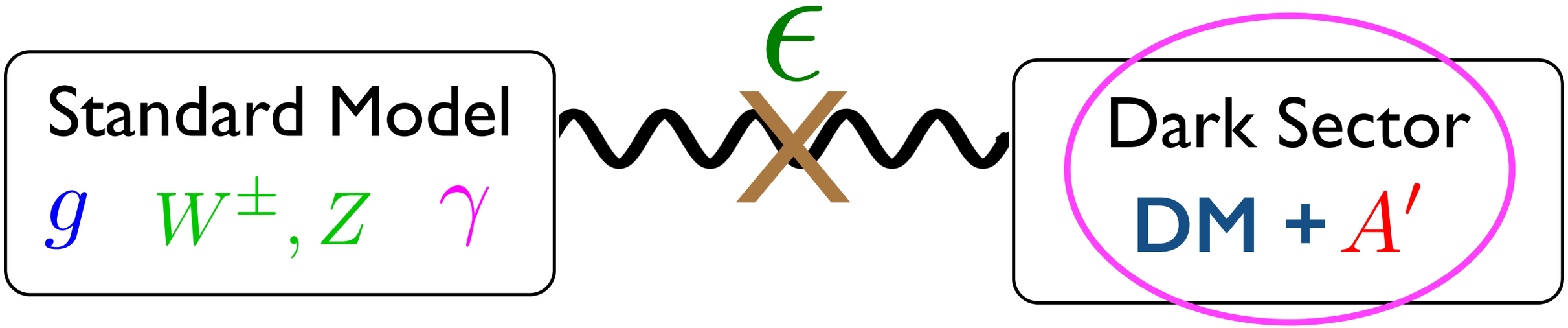


- Comments on Dark Matter "Anomalies"

Dark Matter & Dark Photons



Why consider DM interactions w/ A′?

- DM does not have to be a WIMP!
- small-scale crisis of cold, collisionless DM
- cosmic-ray positron excess
- direct detection anomalies

“Small-scale crisis” of CDM

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- “Cusp-core problem”:

some galaxies appear less dense in the center than predicted by simulations

e.g. Navarro et al. 1997

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- "Missing satellites problem" & "Too big too fail problem":

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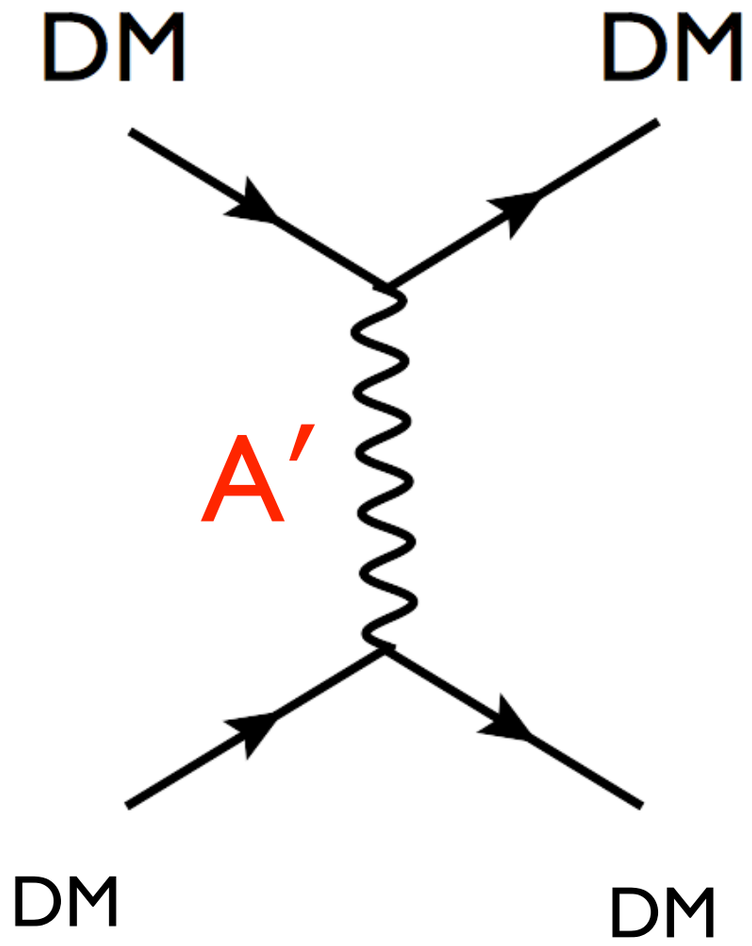
- Resolution?
  - baryonic physics?
  - warm dark matter? (e.g. ~keV sterile neutrino?)
  - self-interacting dark matter?

Spergel, Steinhardt 1999

  - …

DM self-interactions through A′?

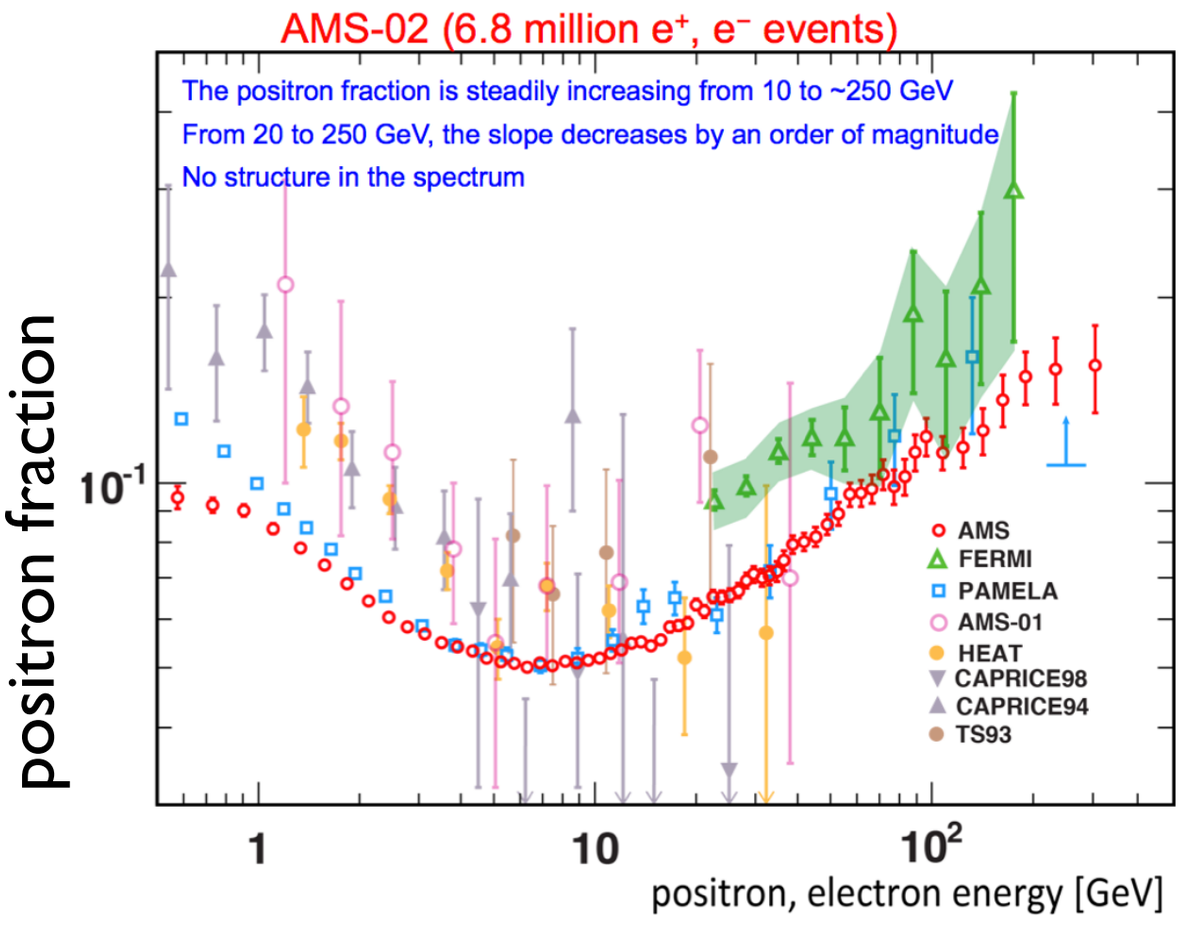


e.g. Spergel & Steinhardt; Loeb & Weiner; Kaplinghat, Tulin, Yu

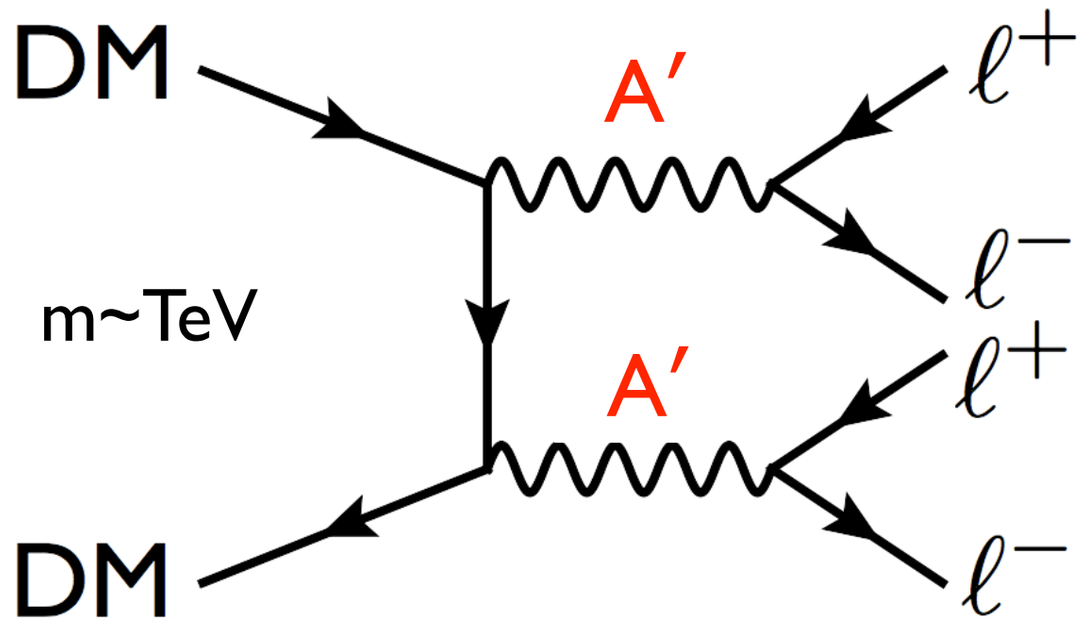
could resolve some of the "small-scale crises"

"Old" motivation from 2008

New dark matter interactions?



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



cosmic-ray e^+, e^- excesses?

PAMELA, Fermi, AMS2…

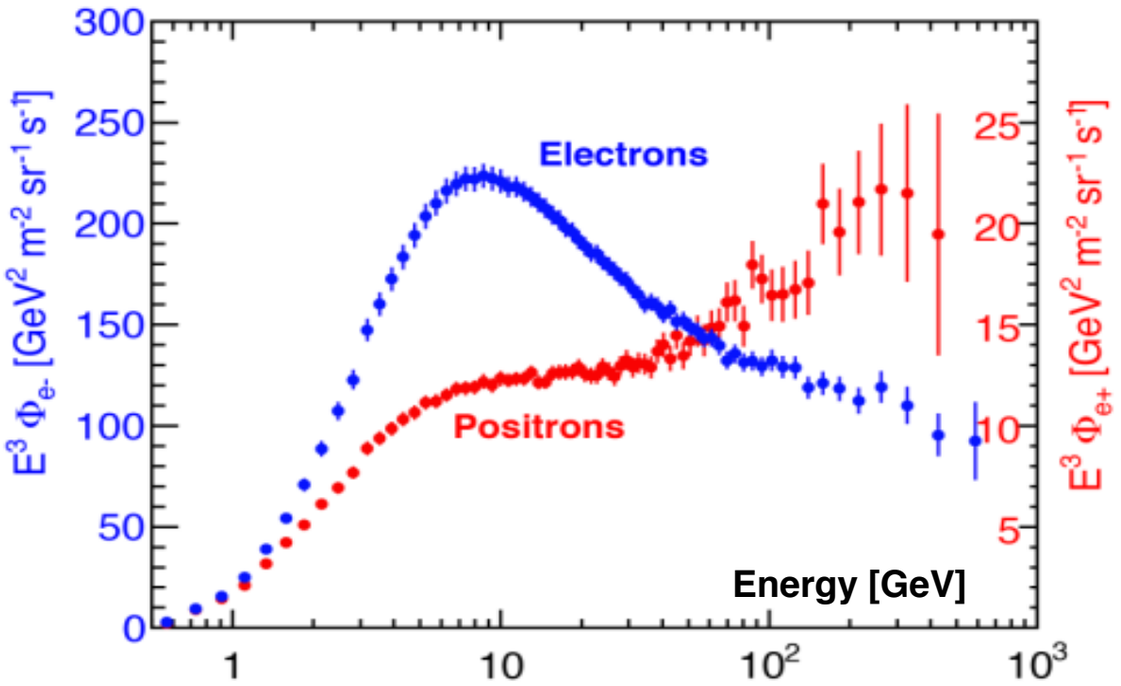
(*decays* involving A′ also possible)

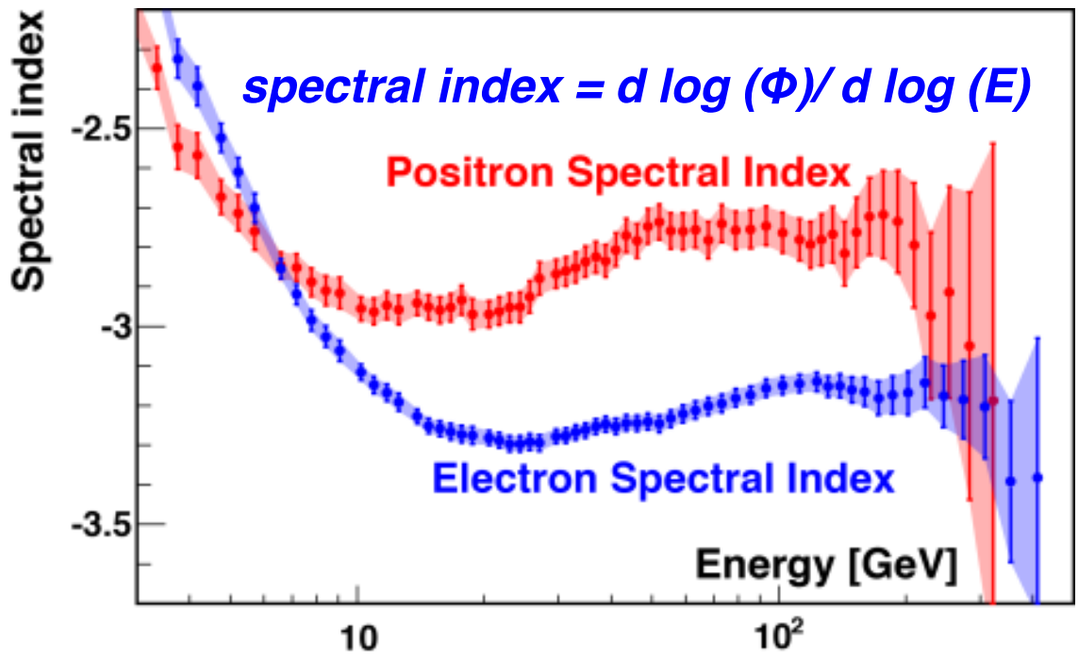
Many constraints (from e.g. CMB, Fermi gamma-rays)

New results from AMS-02

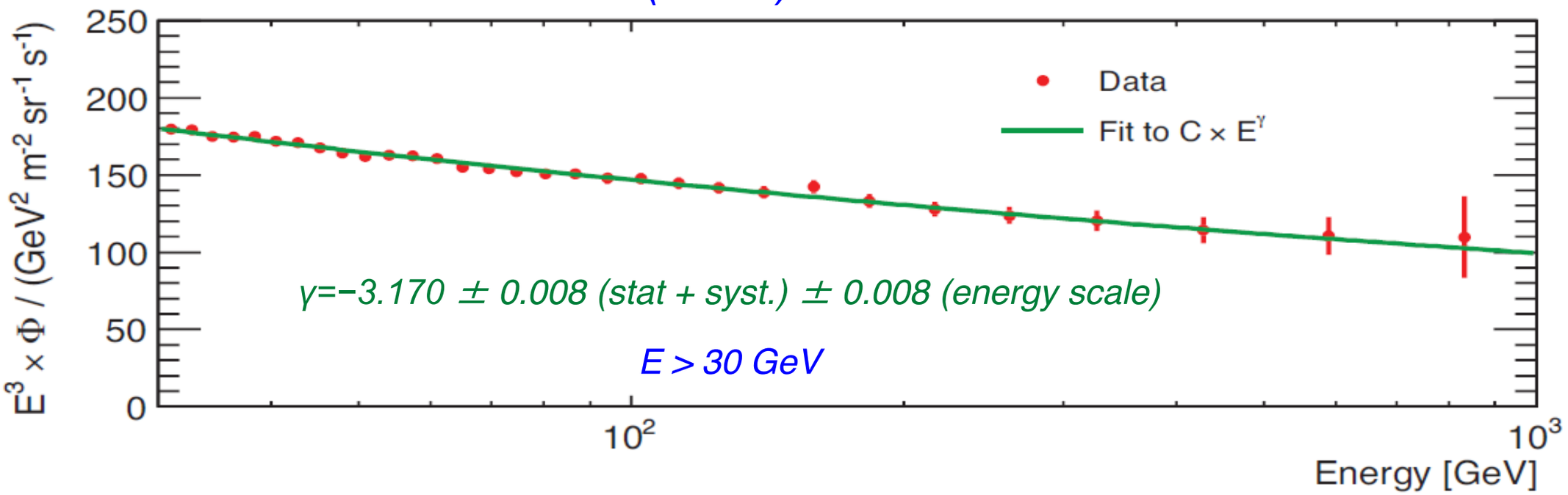
slide from Sam Ting, 4/15/2015

The Electron Flux and the Positron Flux





$\Phi(e^+ + e^-) = C\, E^{\gamma}$



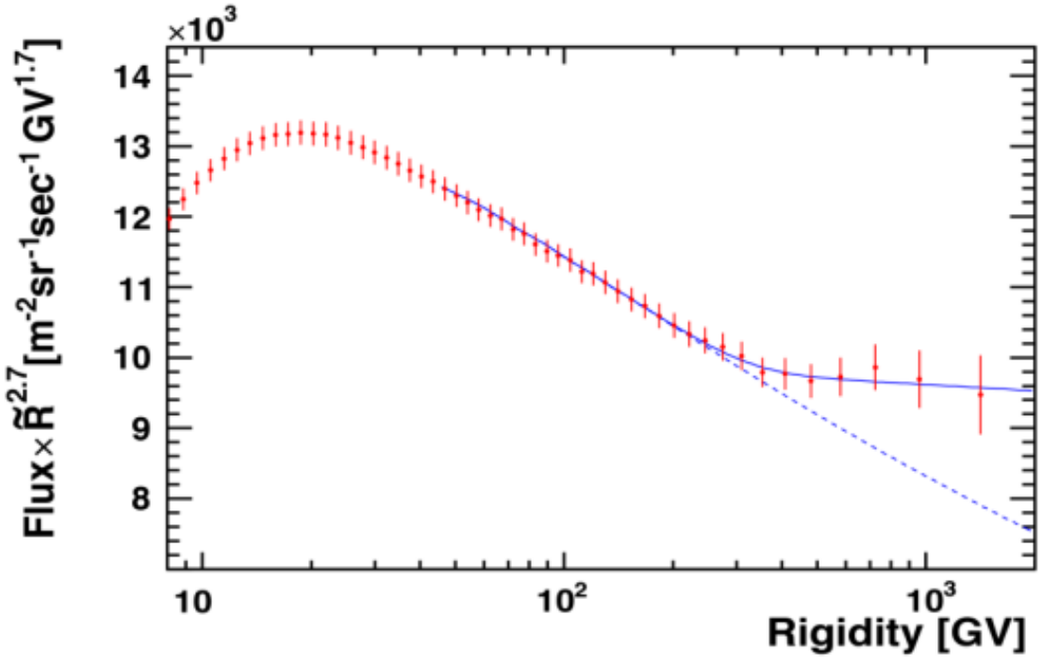
$\gamma = -3.170 \pm 0.008$ (stat + syst.) ± 0.008 (energy scale)

$E > 30$ GeV

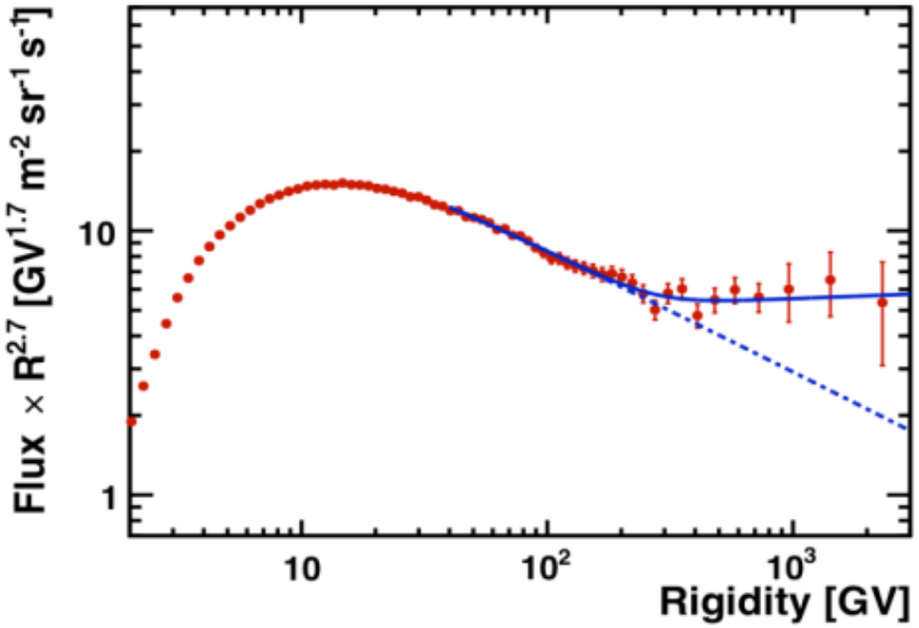
New results from AMS-02

slide from Sam Ting, 4/15/2015

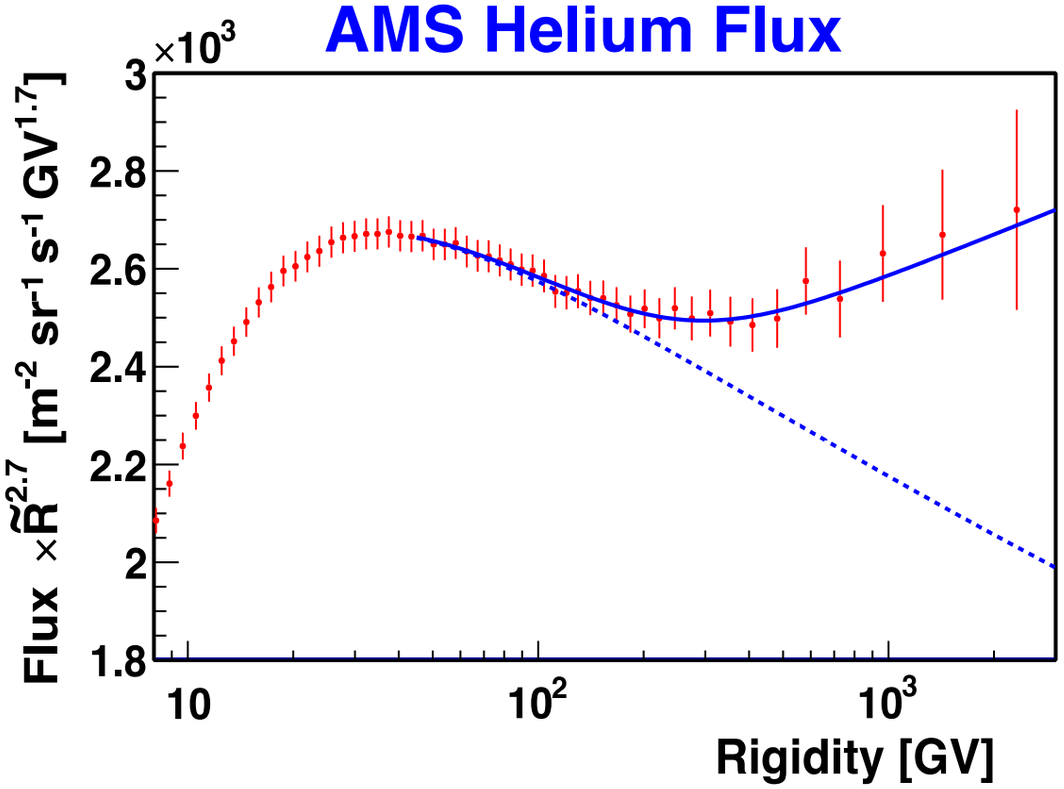
AMS proton flux



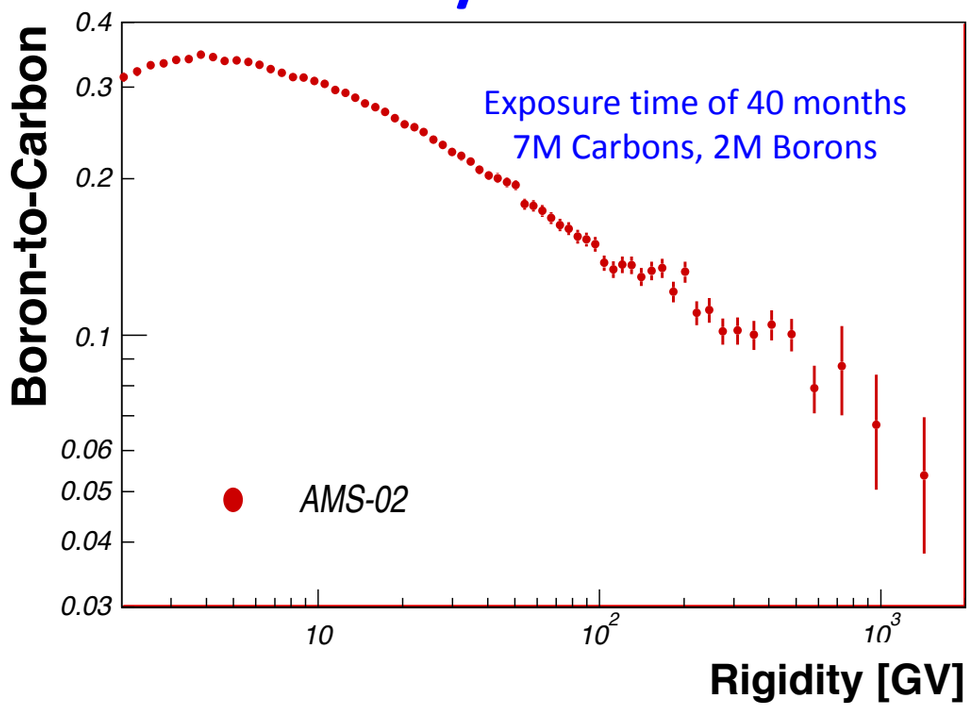
Lithium flux



AMS Helium Flux



B/C Ratio



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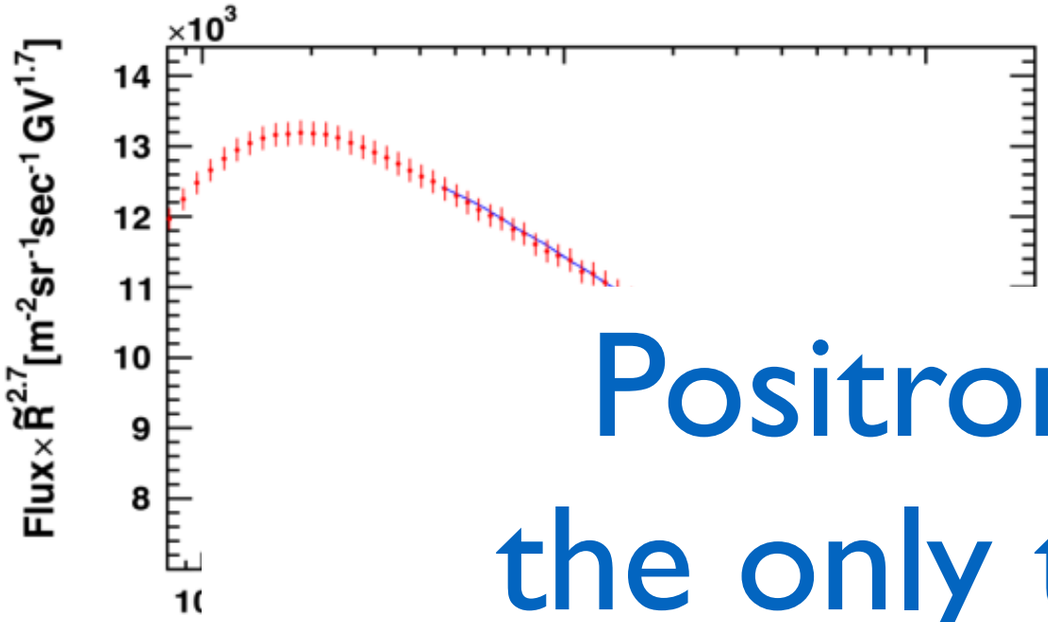
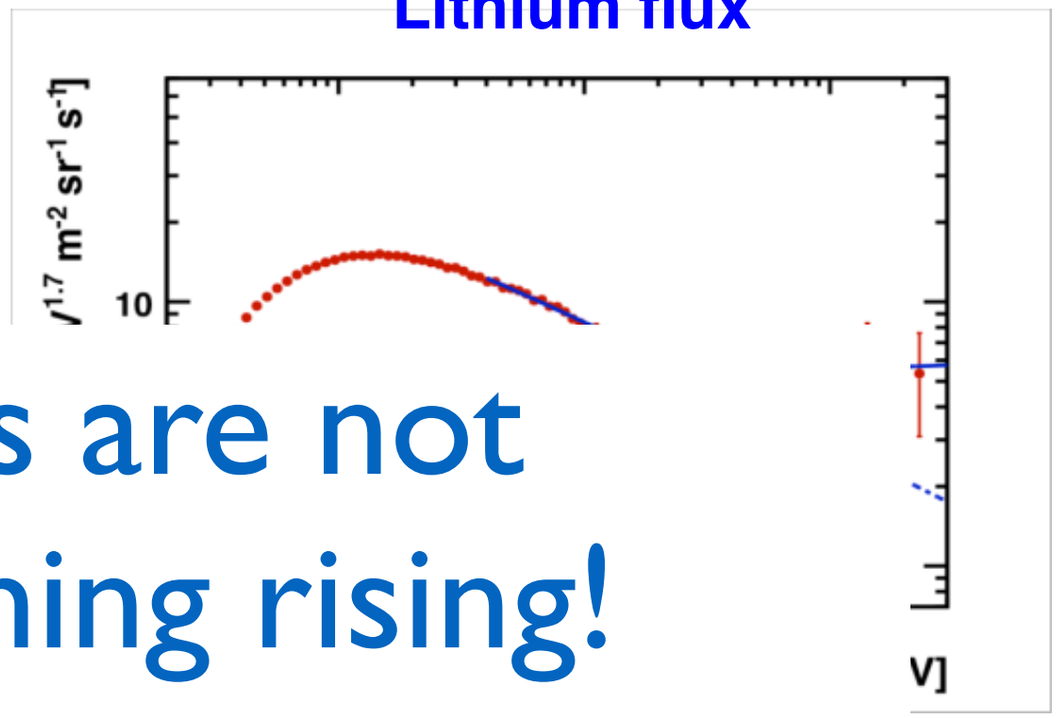
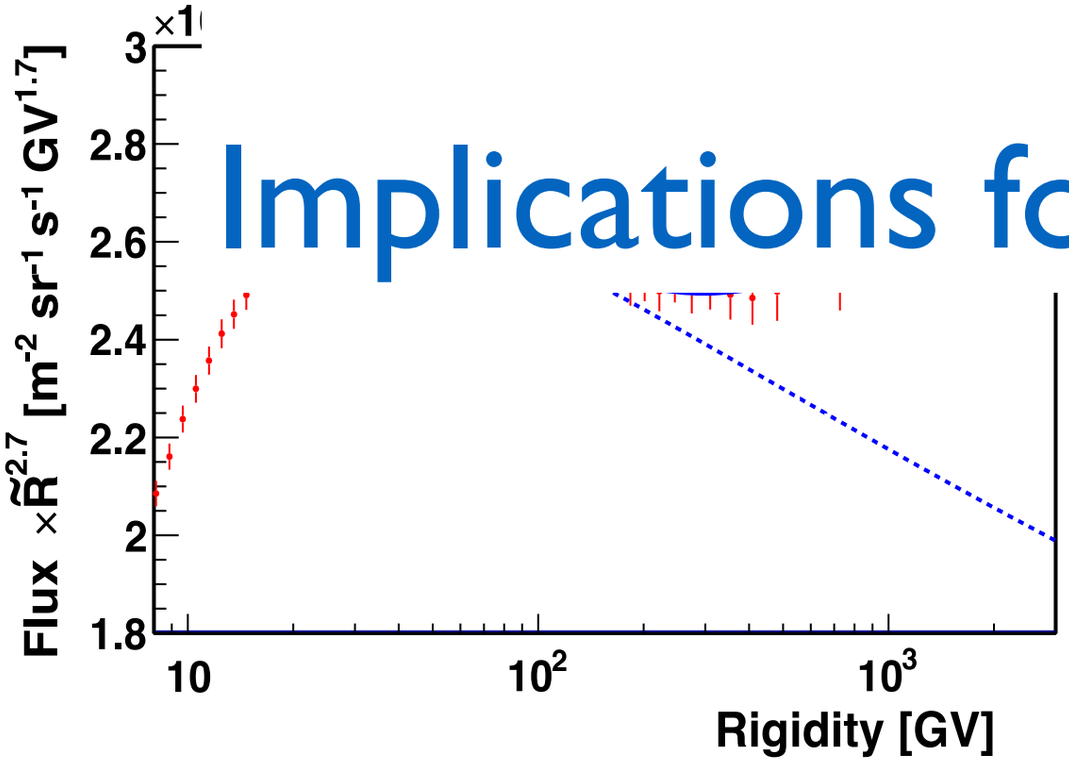


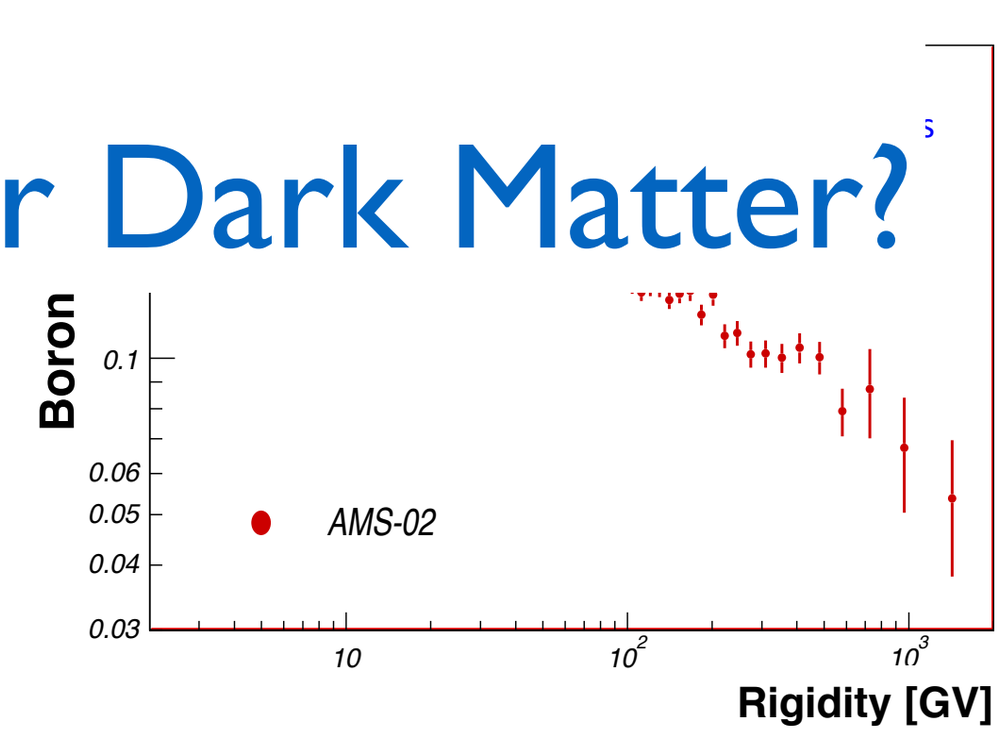
Lithium flux



Positrons are not the only thing rising!

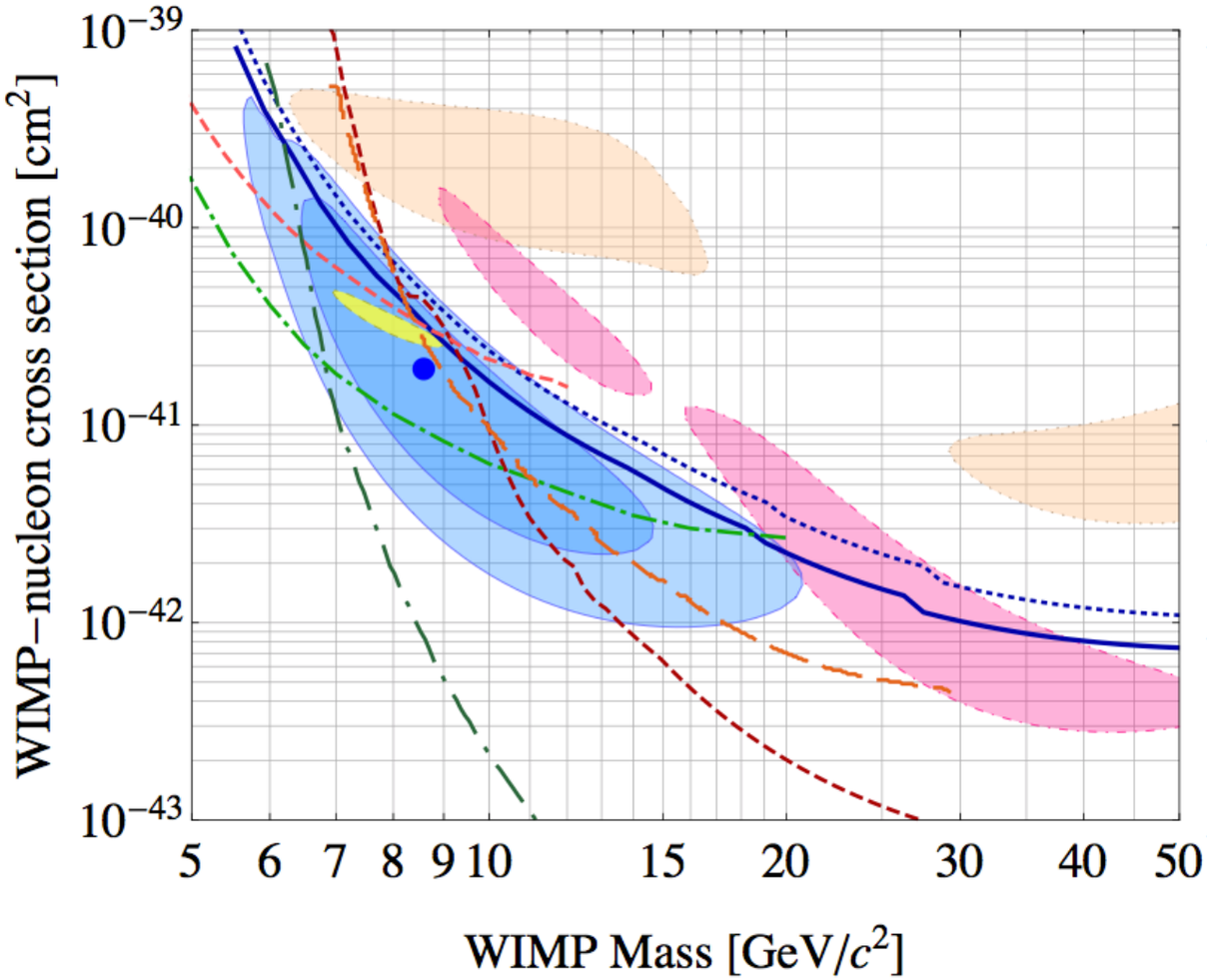
Implications for Dark Matter?





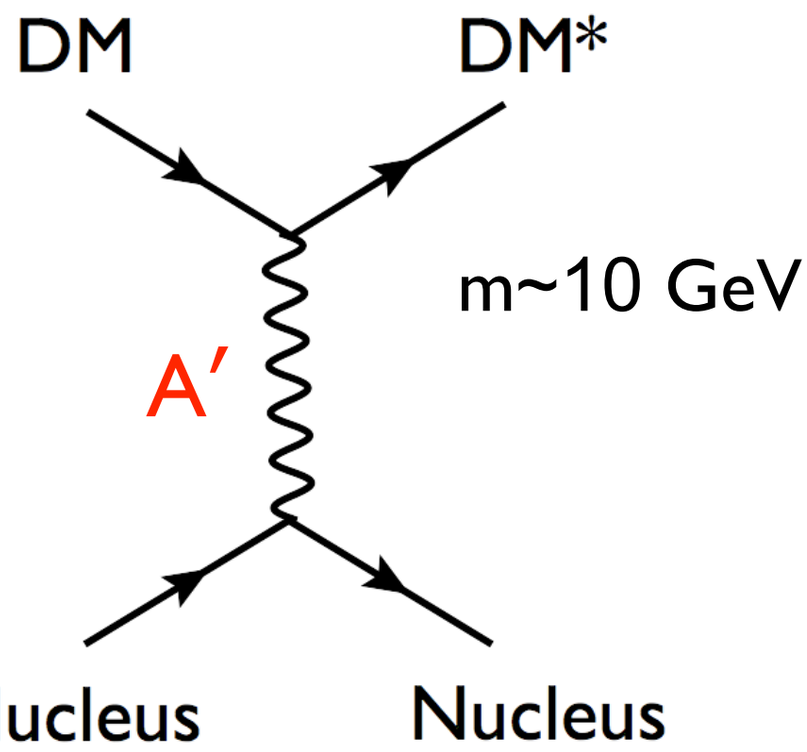
"Old" motivation from 2008

New dark matter interactions?



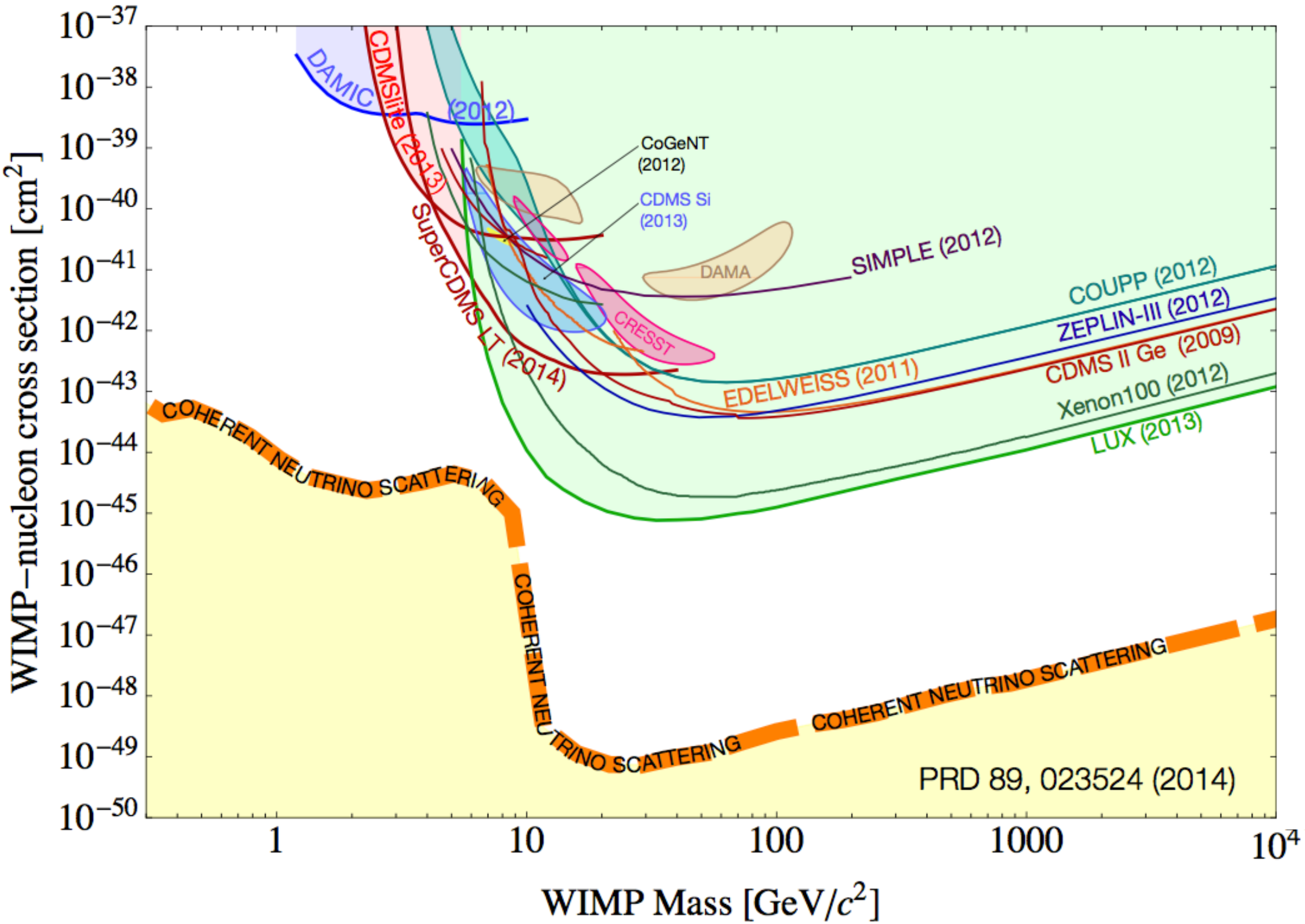
direct detection hints?

DAMA, CoGeNT, CRESST, CDMS-Si



hard for Standard Model mediators, easier for light mediators

Severe constraints from other experiments



Conclusions

- Dark photons searches are well-motivated and actively pursued worldwide
- APEX motivation:
    - probe muon g-2 for Br(A' → SM) < 1
    - probe ε expected from GUT symmetry
    - probe for possible mediator of DM interactions
- APEX has unique reach among A' experiments
- APEX can be ready by Spring 2016

Please sign up for Group Dinner

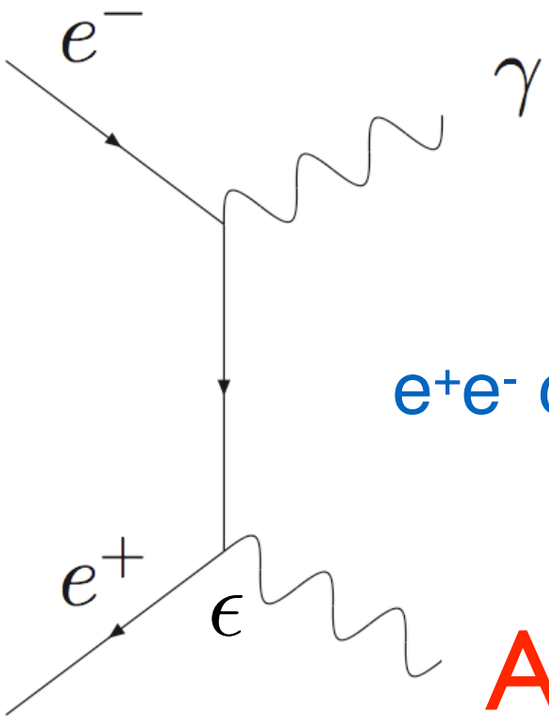
Bonefish Grill, Sunday, 7pm

Group photo

Monday 10:15am

Backup

A′ Production



e^+e^- collision

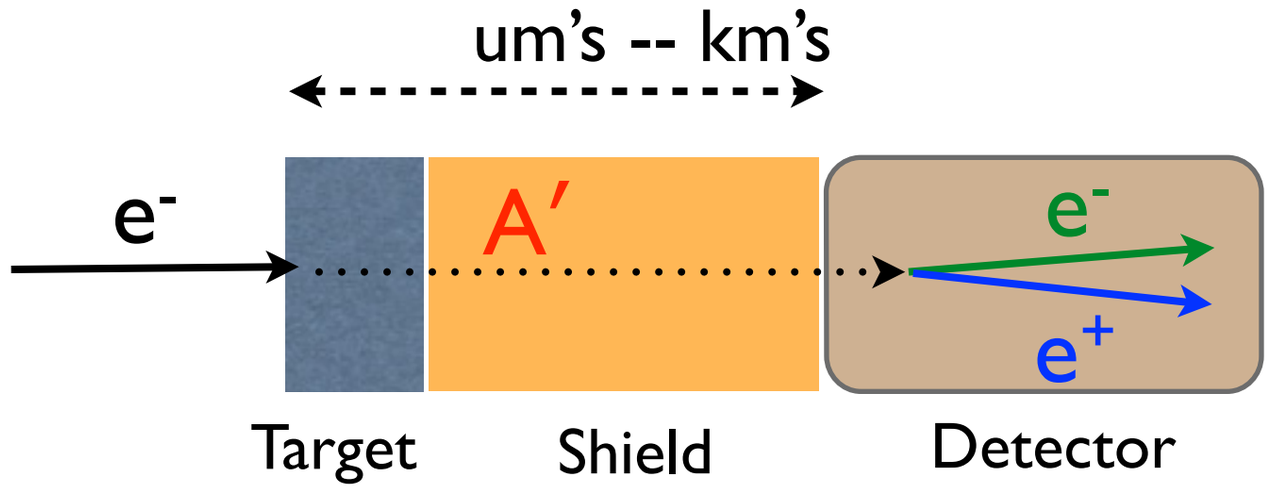
rare meson decays

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

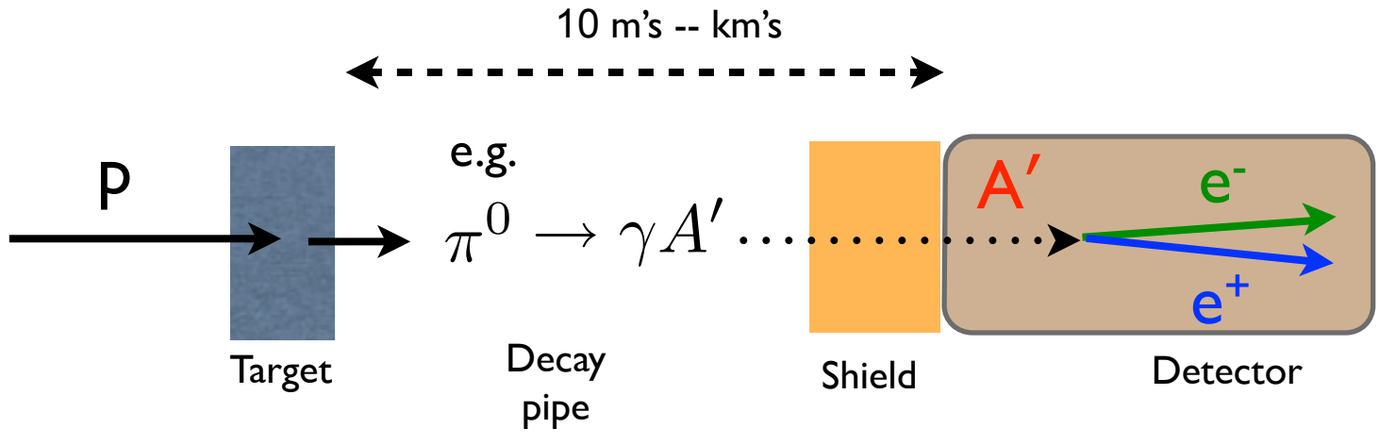
$$\phi \to \eta A'$$

rare Higgs decays

$$h \to Z A'$$

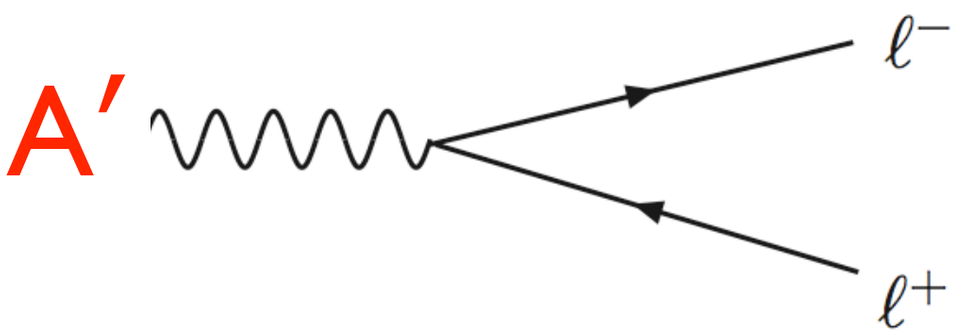


electron fixed target/beam dump



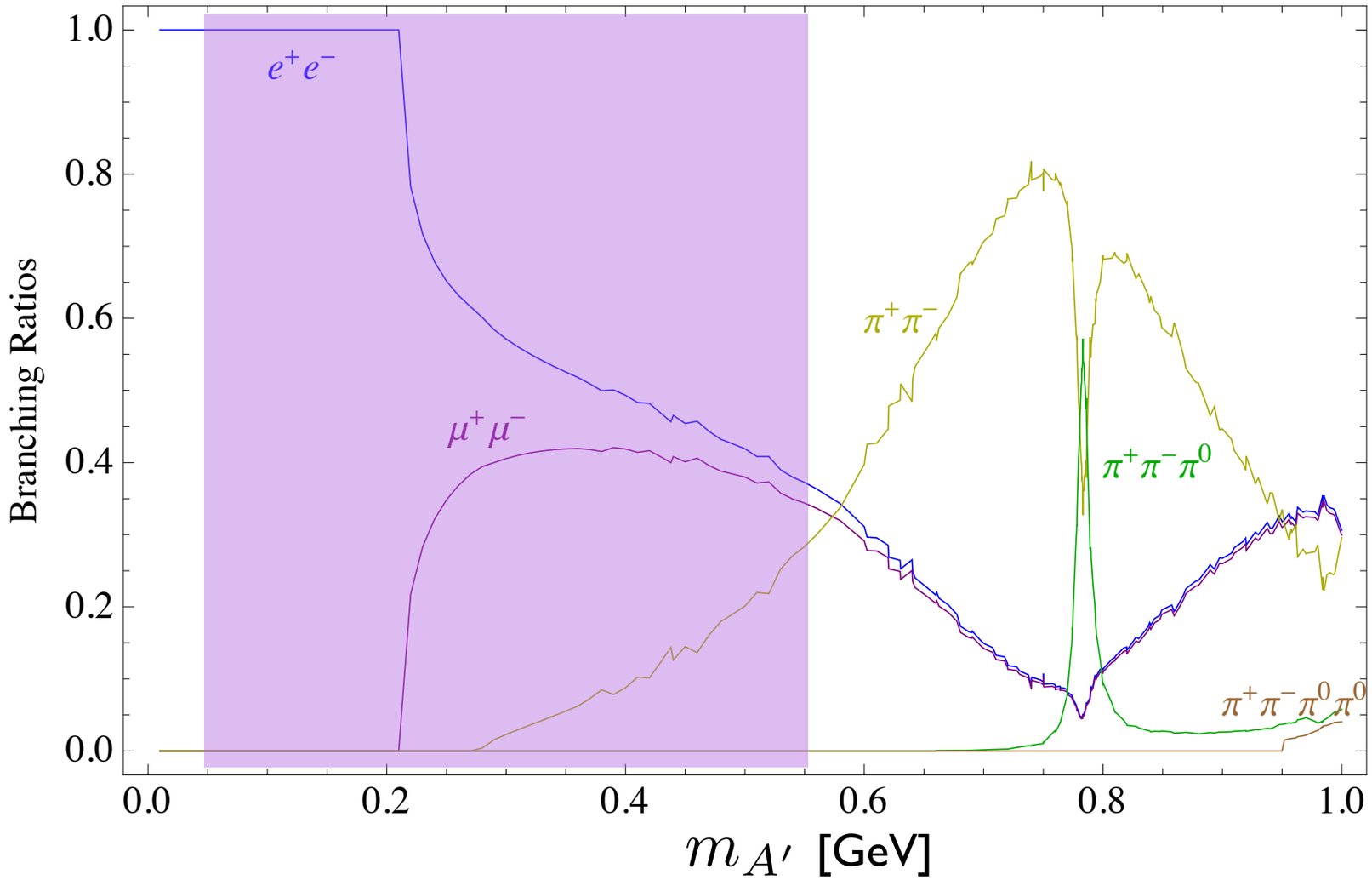
proton fixed target

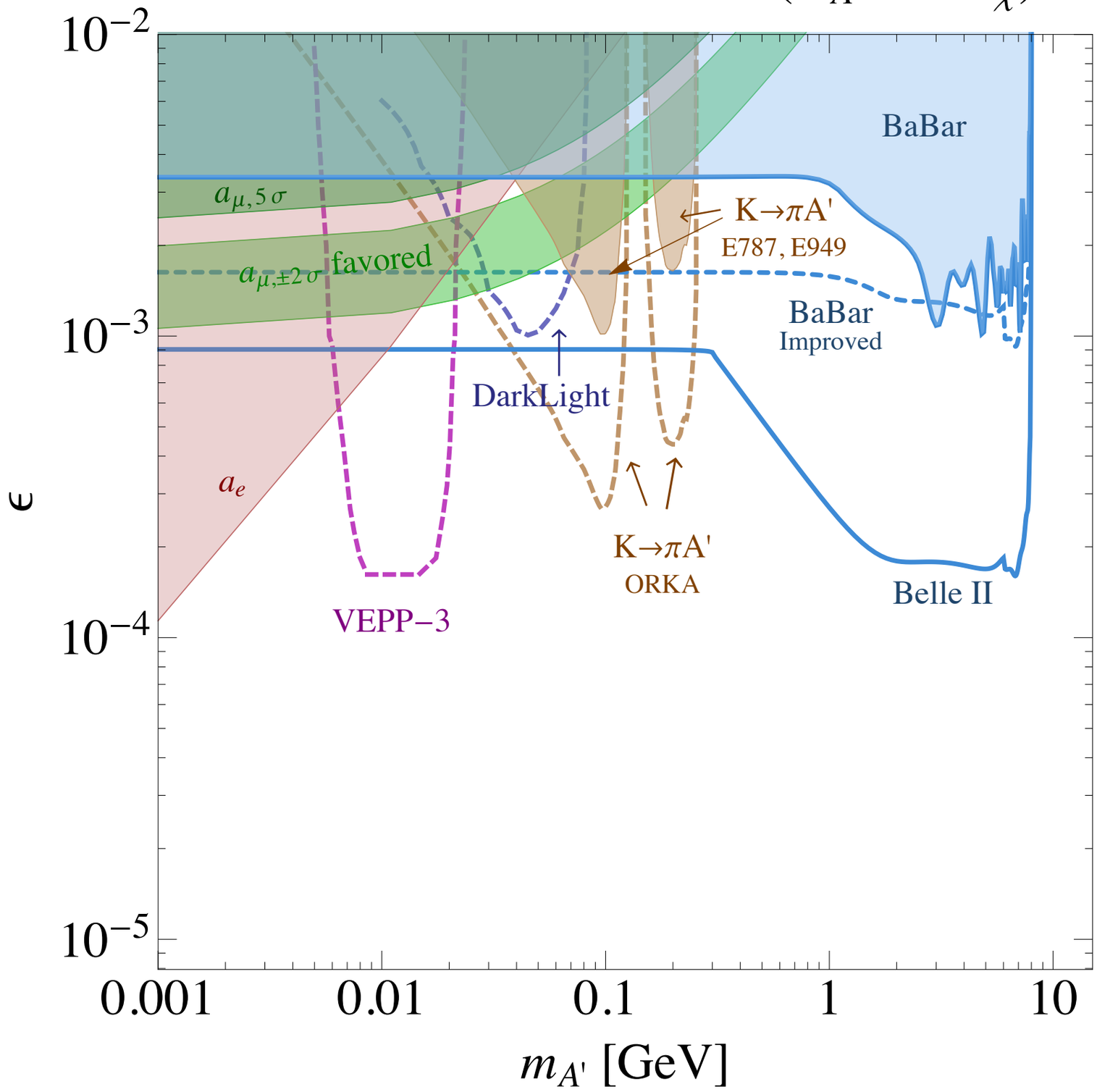
A′ Decays



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

APEX mass range



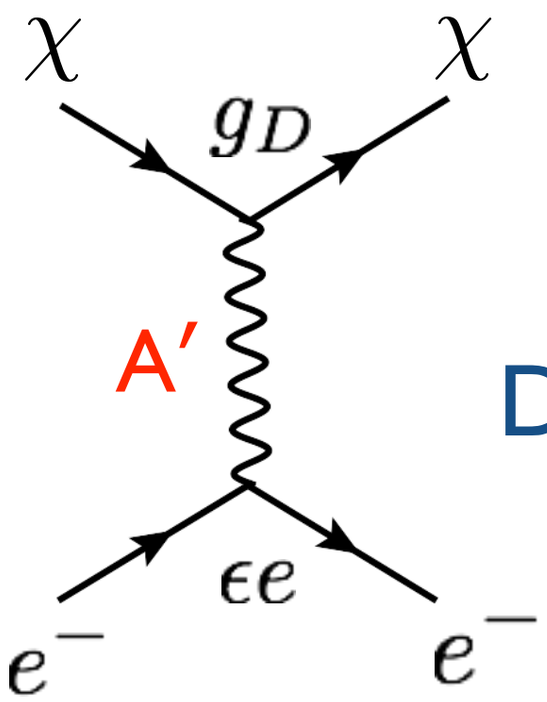

Hidden Photon → invisible ($m_{A'} > 2\, m_\chi$)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
ϵ
$a_{\mu,5\,\sigma}$
$a_{\mu,\pm 2\,\sigma}$ favored
a_e
BaBar
K→πA'
E787, E949
BaBar
Improved
DarkLight
K→πA'
ORKA
VEPP−3
Belle II
0.001
0.01
0.1
1
10
$m_{A'}$ [GeV]

MeV-to-GeV mass DM w/ A′

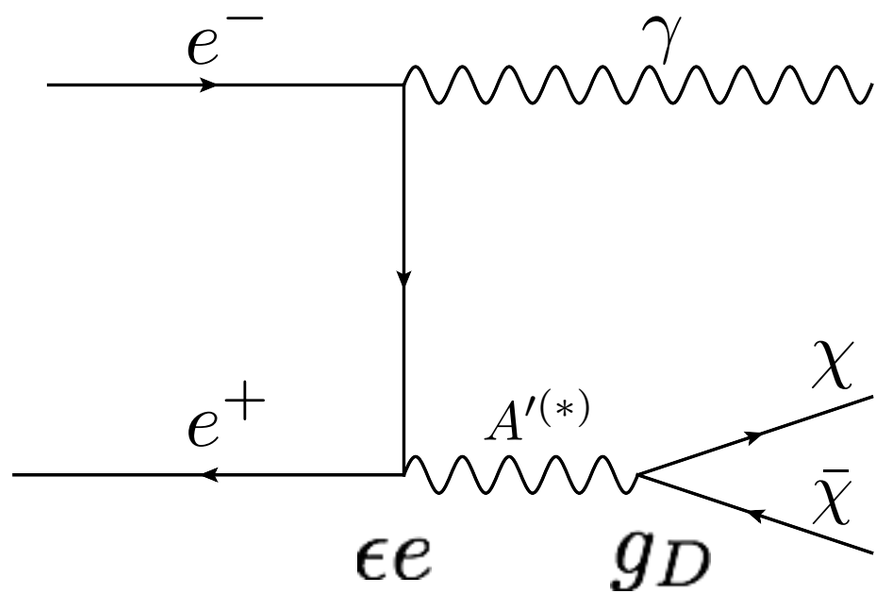
very rich phenomenology

- direct detection
- fixed-target
- colliders
- indirect detection

Examples

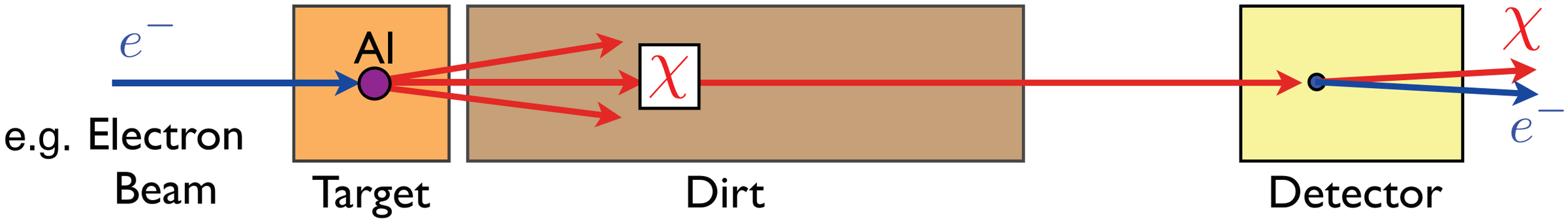


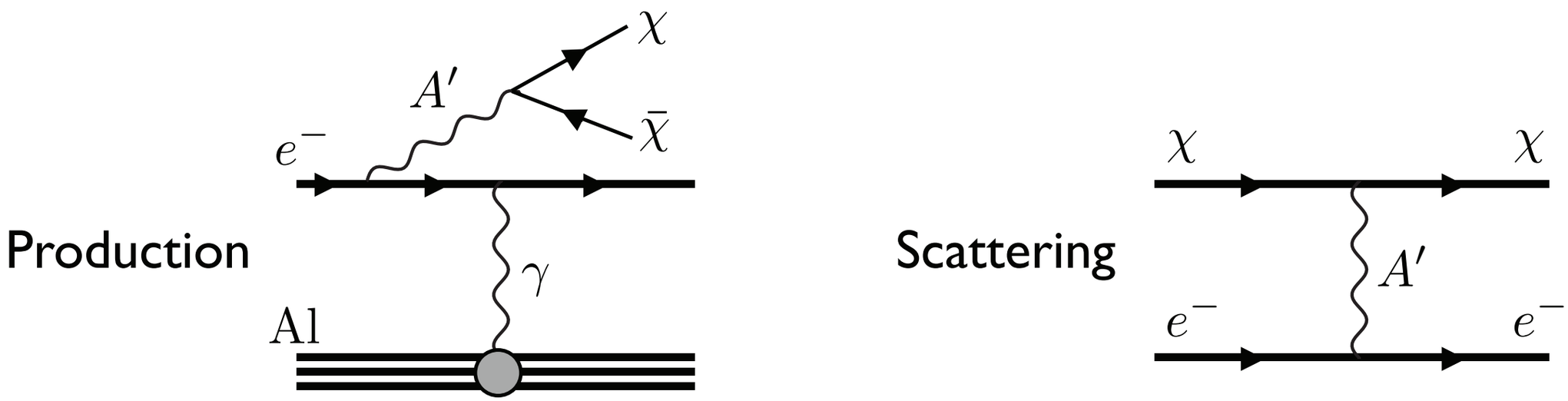
Direct Detection



BaBar/ Belle-2

Beam Dump Searches

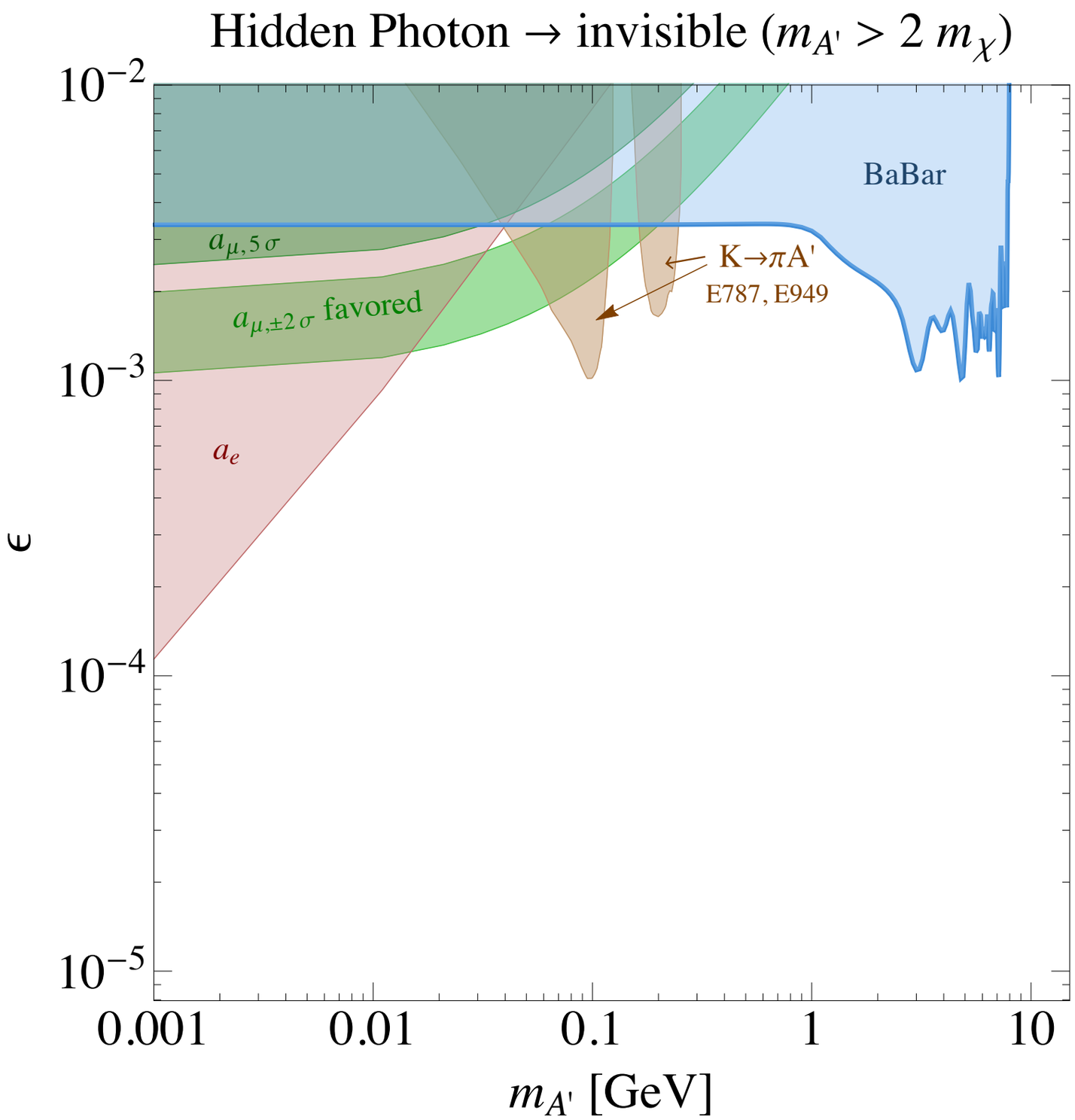




Note: depends on α_D!

see e.g. Batell, Pospelov, Ritz; Deniverville, Pospelov, Ritz; Deniverville, McKeen, Ritz; Aguilar-Arevalo et.al.; Krnjaic, Izaguirre, Schuster, Toro; Diamond, Schuster; Batell, RE, Surujonl; BDX Collaboration

Model-independent constraints



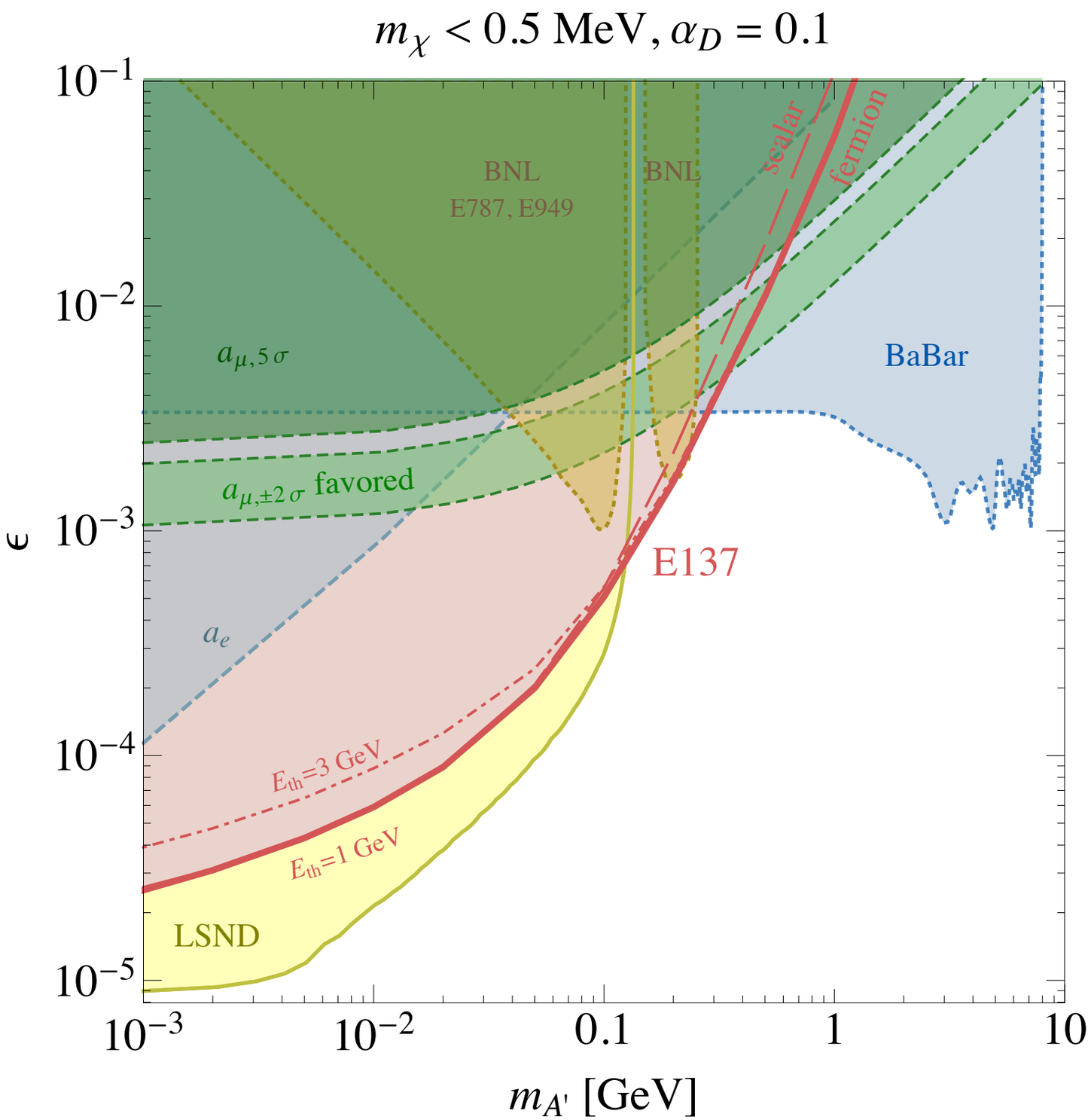
looks for

A′ → "invisible"

(missing energy)

Model-dependent constraints

from Batell, RE, Surujon



e.g. LSND, E137, SLAC mQ (not shown) depend on α_D!

Constraint on muon g-2 region from visible+invisible searches