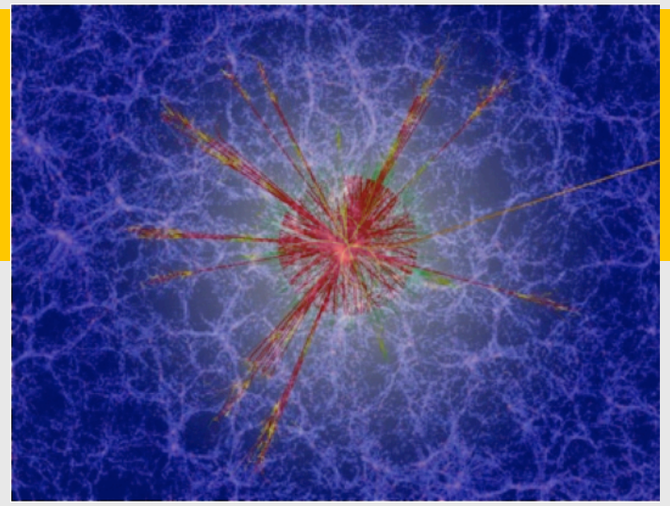
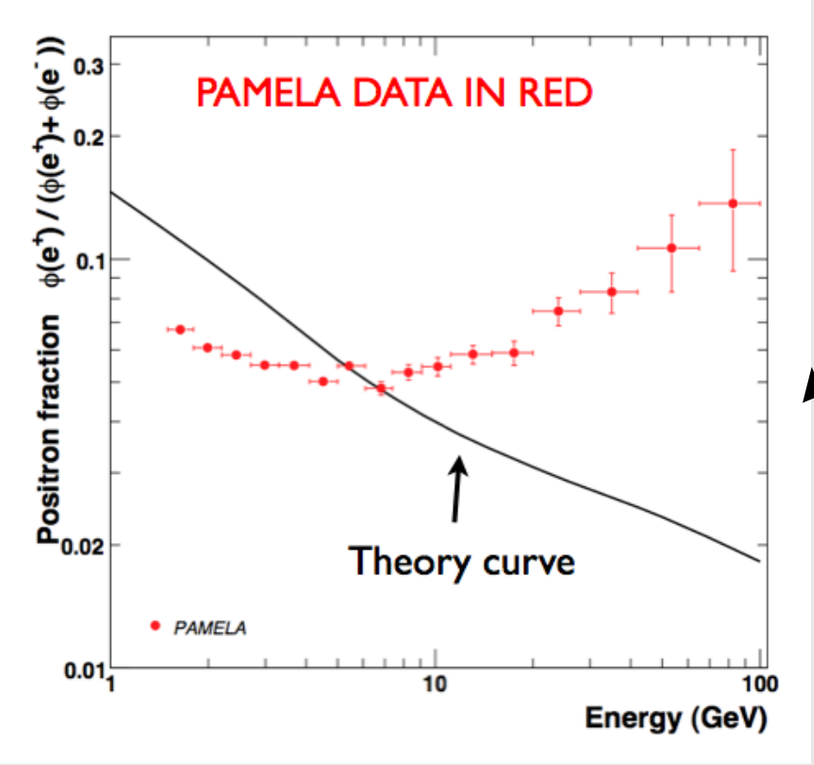


Dark Forces & SuperB: ***Introduction & Rare Decays***

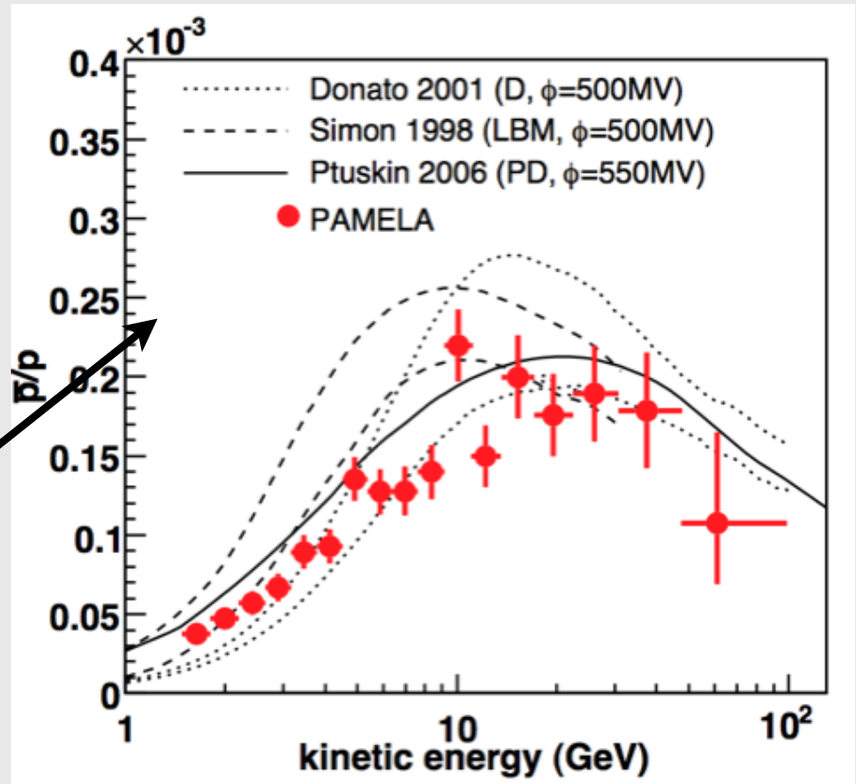
Matt Graham
SLAC
May 31, 2011

Hints from Astrophysics



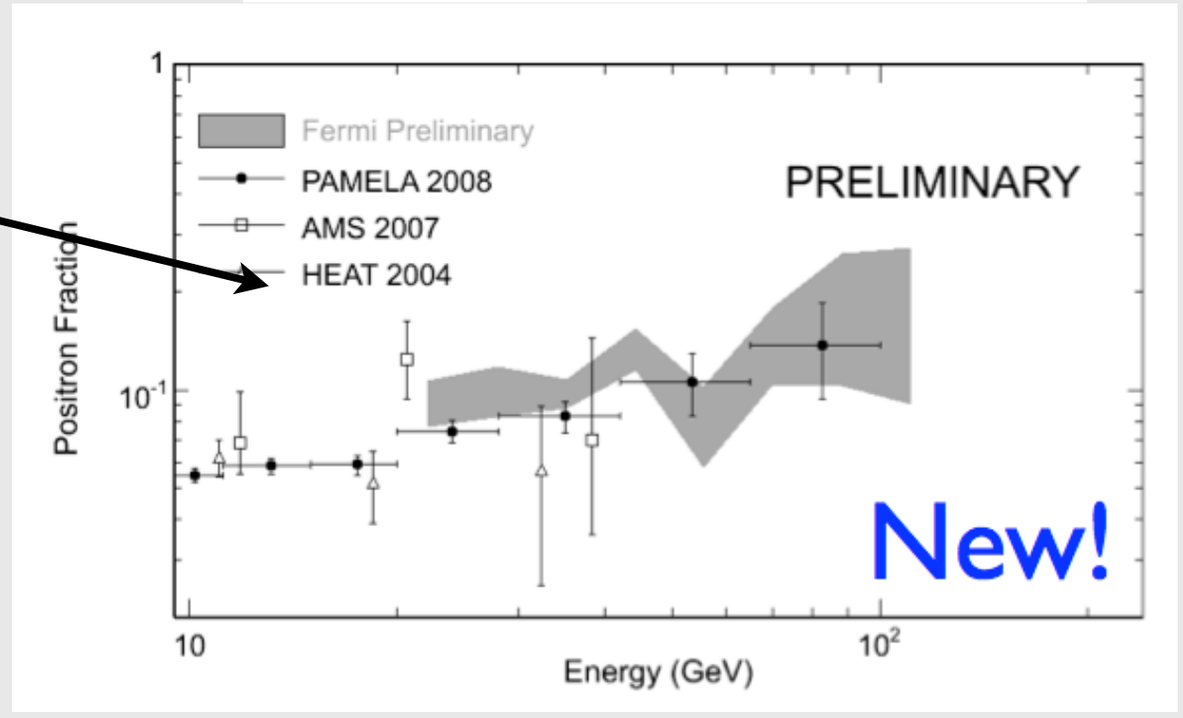
excess in e^+/e^- ratio

...but not in $\overline{p}/p$ ratio



- FERMI sees it too!

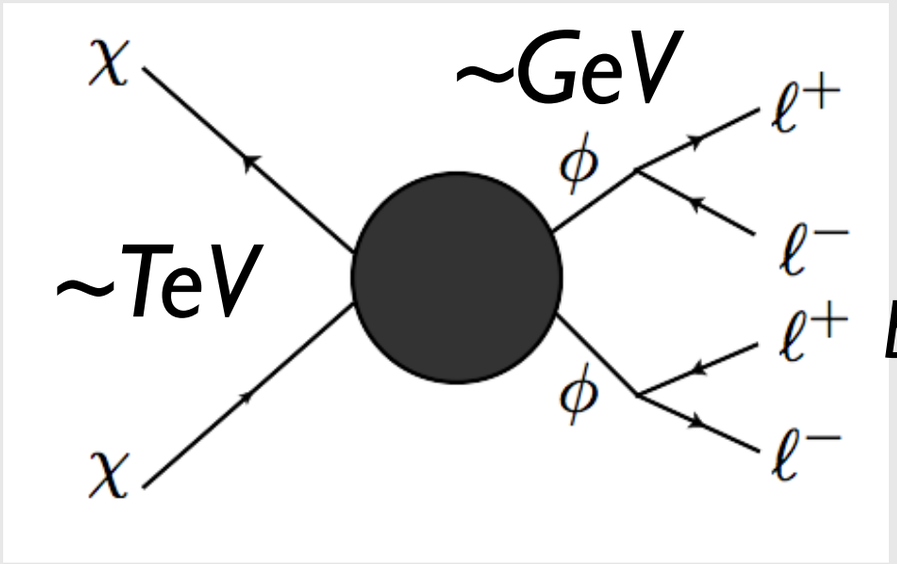
Is this astrophysics or particle physics?



Dark Matter Annihilations

Arkani-Hamed, Finkbeiner, Slatyer, Weiner (hep-ph/0810.0713)

Pospelov, Ritz (hep-ph/0810.1502)



highly boosted

- new "dark force" with gauge boson φ~ GeV while the dark matter particle is ~TeV scale...leading to highly boosted e^+e^- pairs

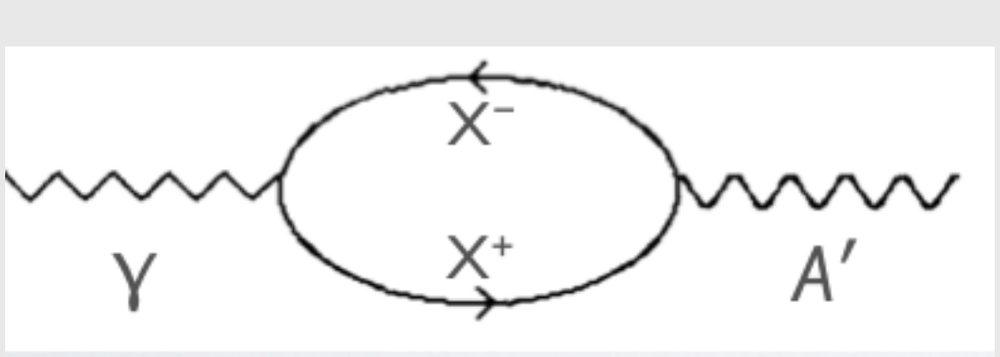
- gauge boson decays to lepton pairs (e^+e^-, $\mu^+\mu^-$) but not pp because φ is below pp threshold (2GeV)

- the φ couples to the SM photon...we might see something in the B-Factories!

U(1)′ and Kinetic Mixing

...an extremely general conclusion ➪ if there is another U(1) symmetry in nature, it will mix with the SM U(1): *Holdom, Phys. Lett.B166, 1986*

$$\mathcal{L}_{U(1)'} = -\frac{1}{4}V_{\mu\nu}^2 - \boxed{\frac{\epsilon}{2}V_{\mu\nu}F^{\mu\nu}} + |D_\mu\phi|^2 - V(\phi)$$

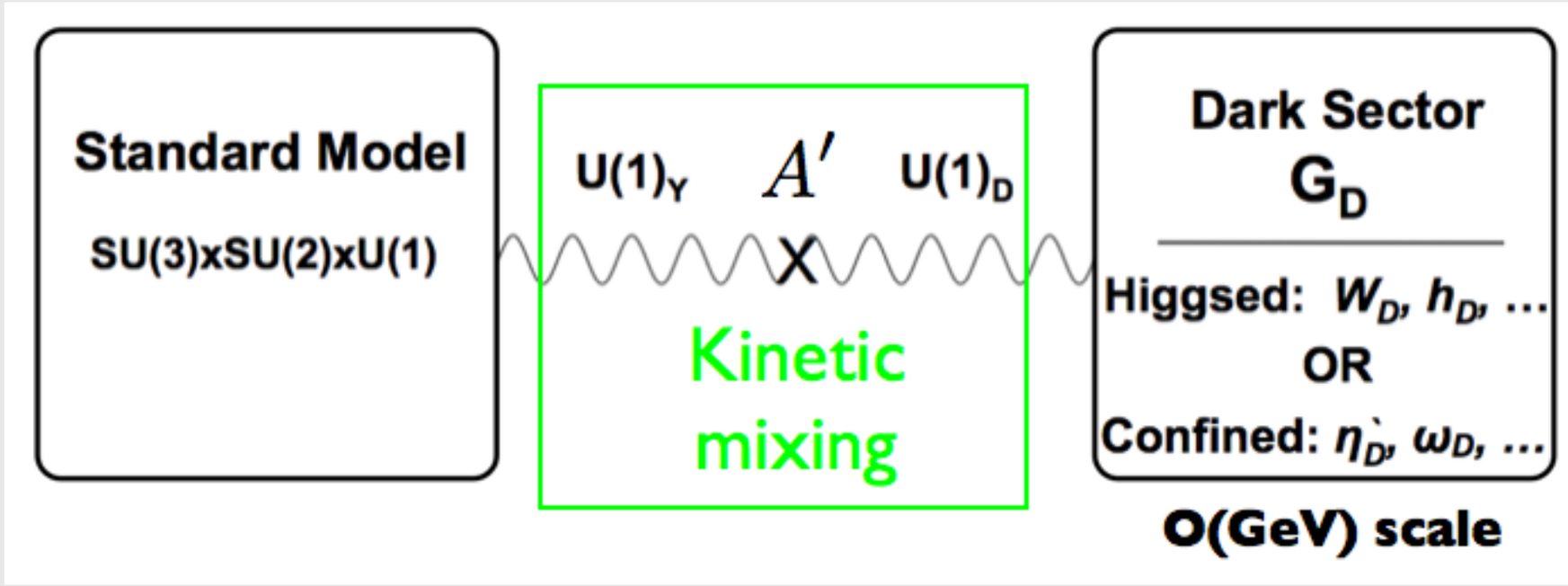


"kinetic mixing"

$$\epsilon \sim 10^{-3} - 10^{-2} \xrightarrow[\text{symmetry}]{\text{enhanced}} \epsilon_{GUT} \sim 10^{-5} - 10^{-3}$$

$$m_{A'} \sim \sqrt{\epsilon}\sqrt{\frac{g_D g_Y}{g_2^2}} m_W \sim MeV - GeV$$

The Dark Sector



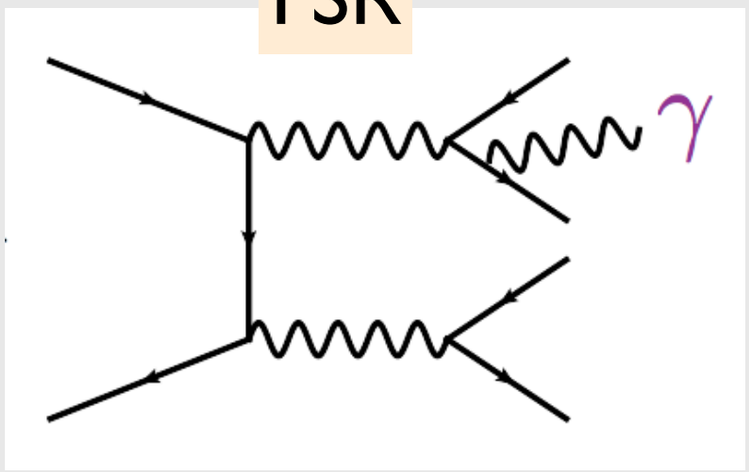
- Abelian $U(1)_D$ common to all models...mixes with SM hypercharge with coupling ε (or κ depending on the paper); "dark higgs" to give mass
- Structure in the dark sector is wide open...
  - could have nothing interesting: just the U(1)´ (still pretty interesting!)
  - Higgsed non-abelian SU(2): "dark EW"
  - Confined non-abelian SU(N): "dark color"
    - Alves, Behbahani, Schuster, Wacker (hep-ph/0903.3945)

B-Factories are good place to look for Abelian dark forces..but are probably the best place to look for non-Abelian case

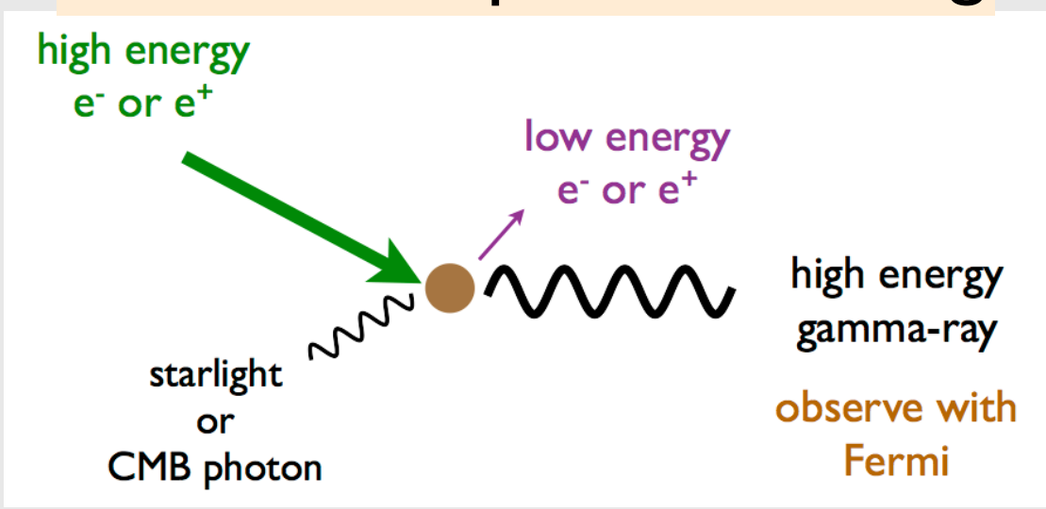
If this is true, what else should we see?

- gamma-rays guaranteed...

FSR



Inverse Compton Scattering



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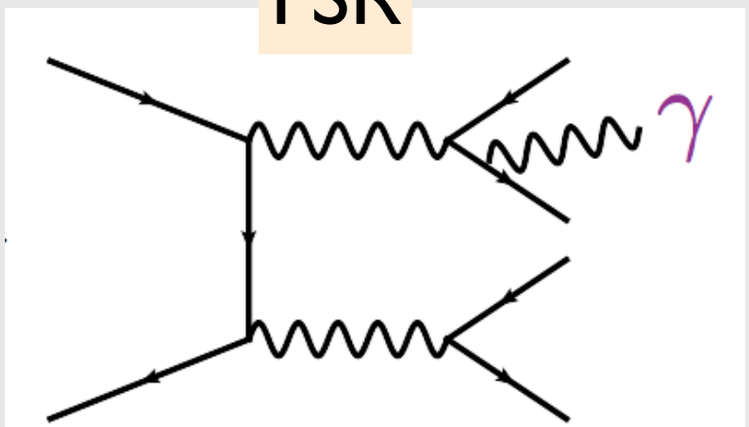

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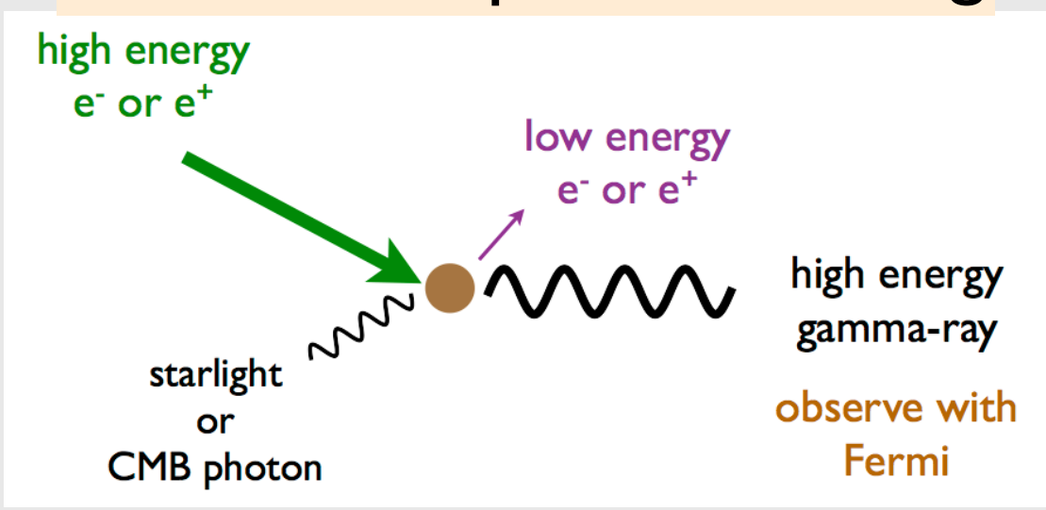
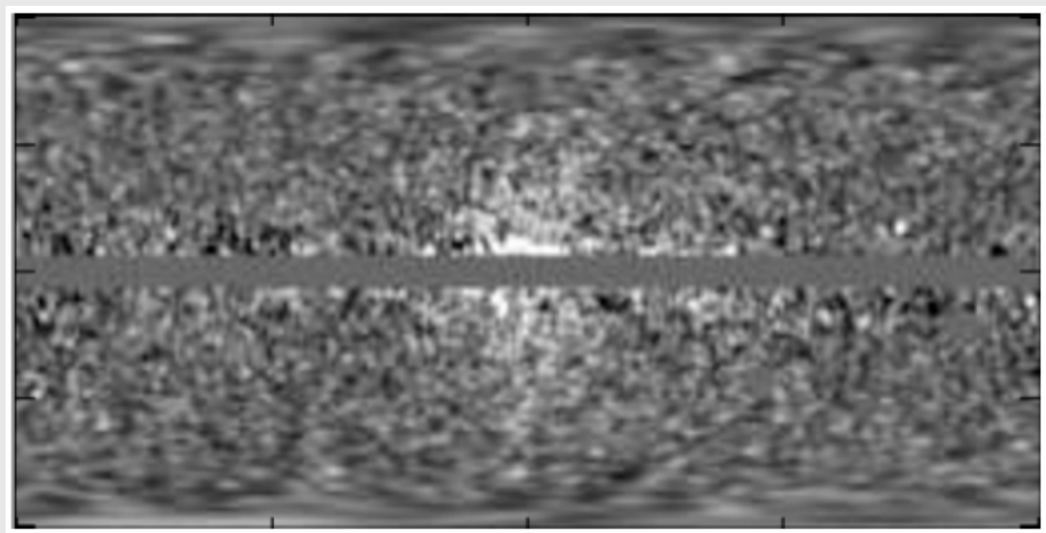


"Fermi Haze"???

Unknown excess of gammas radiating from galactic center...more recent analysis hints it may be a "bulge"

(Su. et. al.,Astrophys.J.724:1044-1082,2010.)

Warning...still controversial

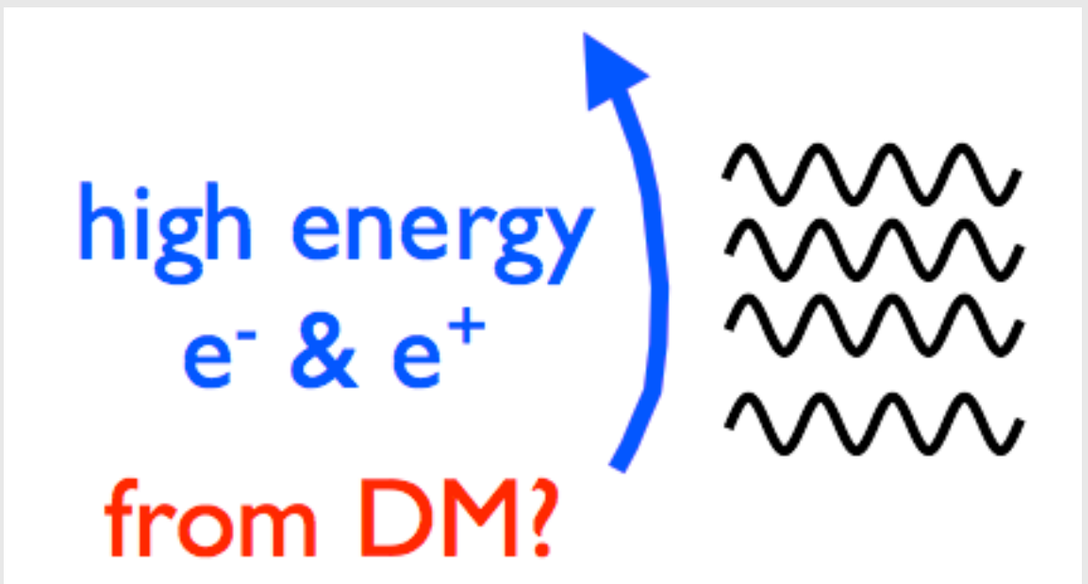


Dobler et. al., astro-ph/0907.3953

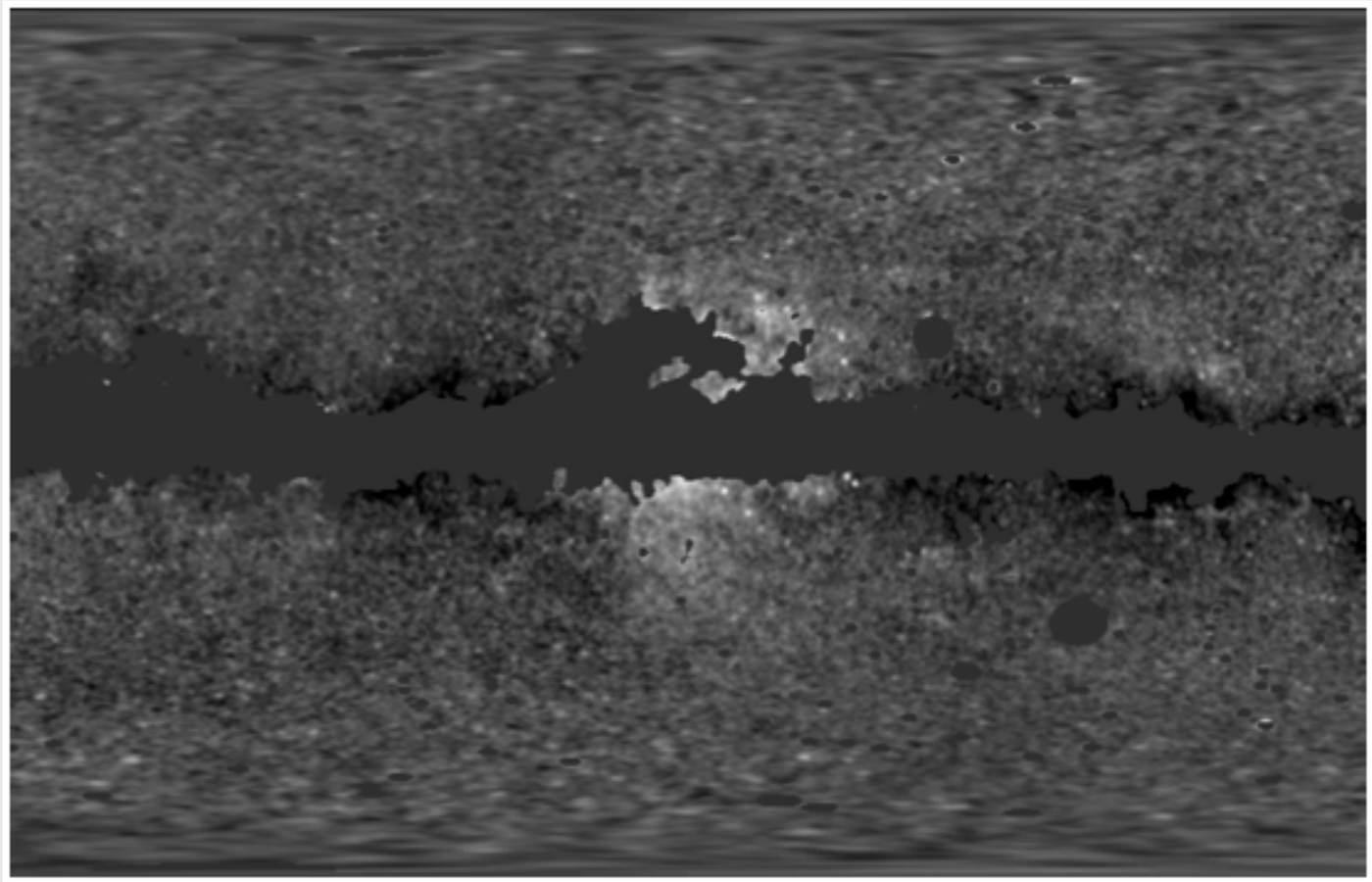
If this is true, what else should we see?

- gamma-rays guaranteed...
- microwave excess...

Synchrotron radiation from bending in galactic magnetic field



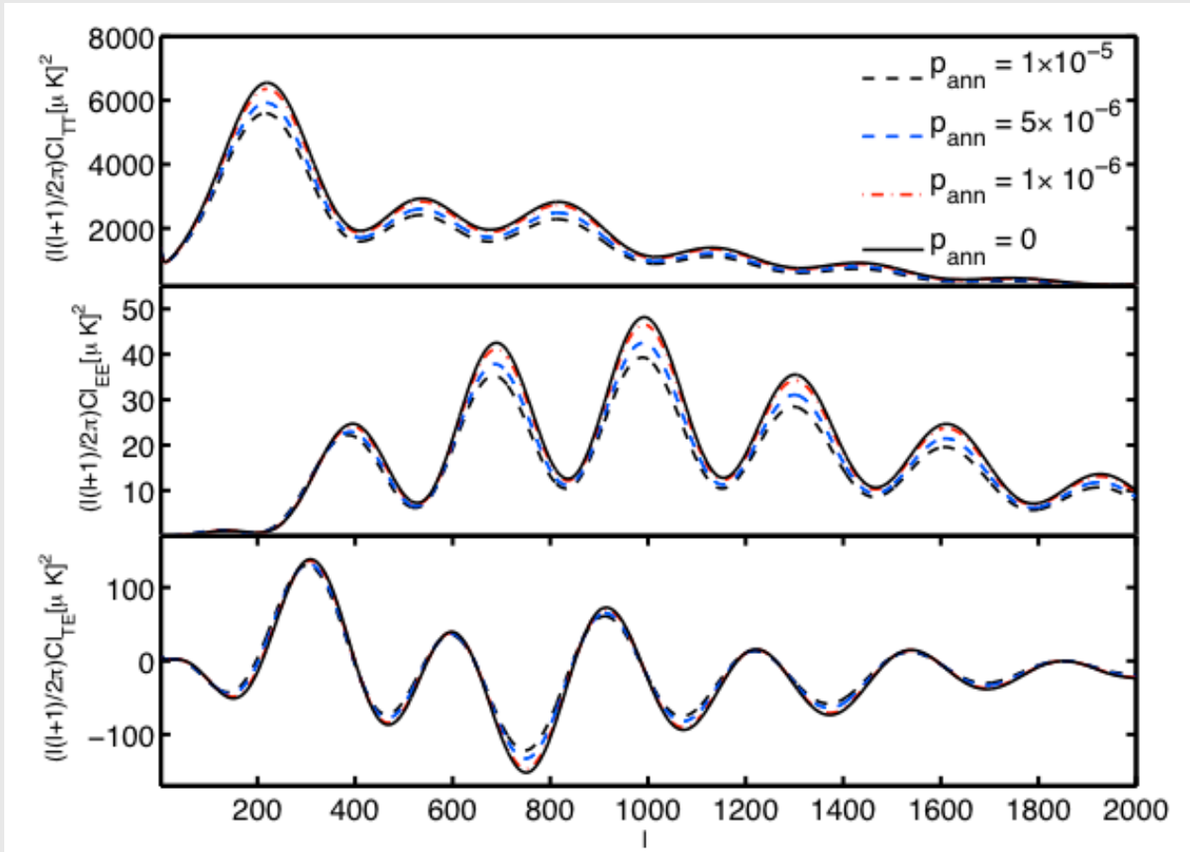
"WMAP Haze"



If this is true, what else should we see?

- gamma-rays guaranteed...
- microwave excess...
- anisotropies in the CMB

DM annihilation at the time of recombination slightly changes the CMB power spectra...Plank should be decisive



If this is true, what else should we see?

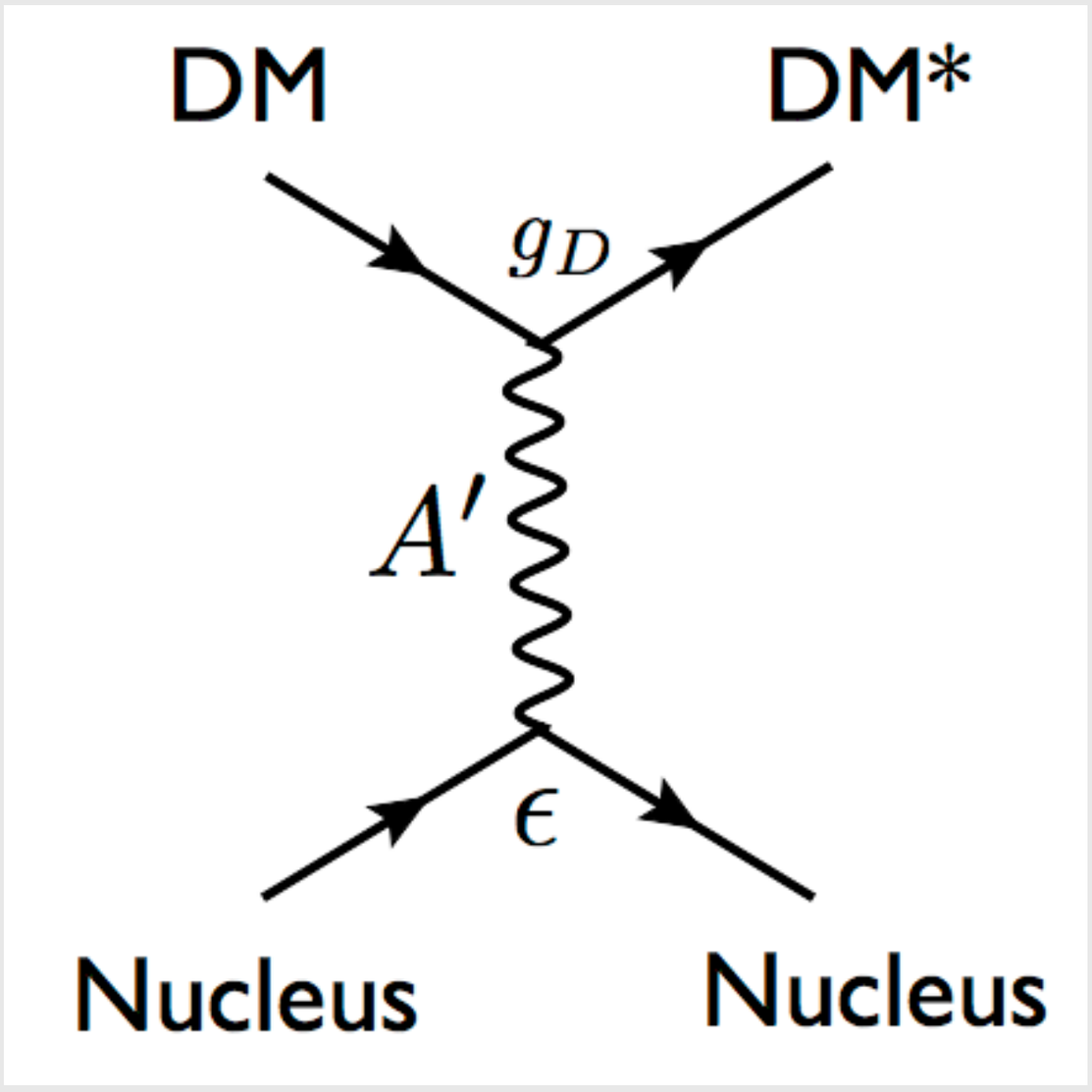
- gamma-rays guaranteed...
- microwave excess...
- anisotropies in the CMB

There are many ways for DM annihilation (or decay) to show up in astro experiments...but it's not clear that any will allow us to say conclusively we are seeing DM an not something else (pulsars!).

...and teasing the particle physics details (the interesting part!) out of these experiments is even harder.

What about direct detection?

- The connection between dark forces and direct detection experiments ➪ "inelastic dark matter"



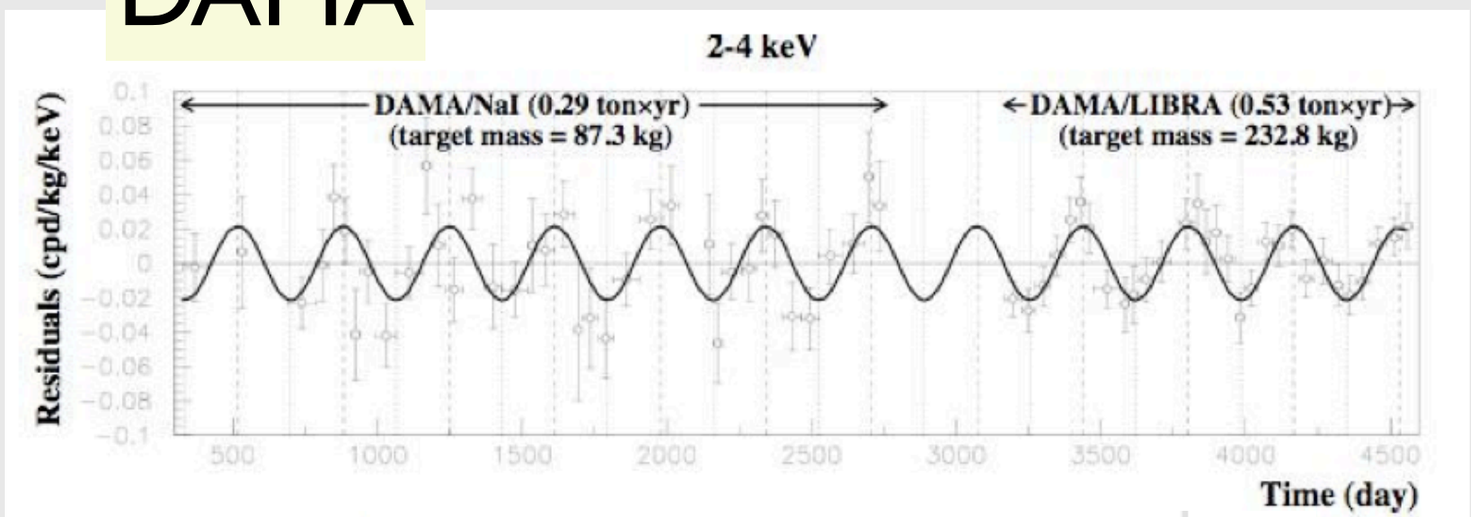
$$\sigma = 16\,\pi\,c_W^2\,\mu_{DM,p}^2\,\frac{\alpha\alpha_D\epsilon^2}{m_{A'}^4}$$

...must be an excited state in the dark sector ➪ non-Abelian dark force

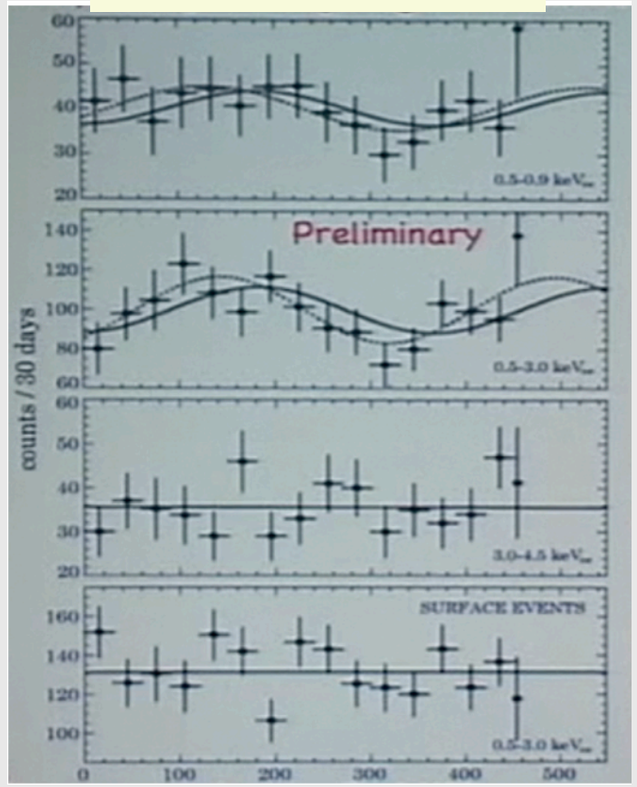
What about direct detection?

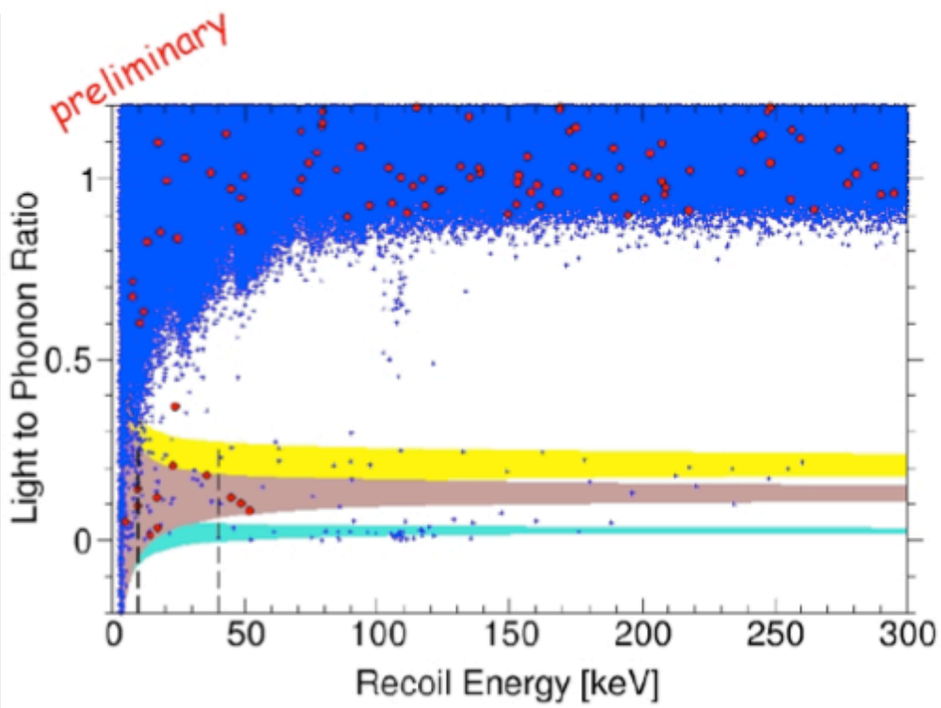
- The current message from DM direct detection experiments is...confusing.
- DAMA, CoGeNT (?), CREST (?) see...something...

DAMA



CoGeNT



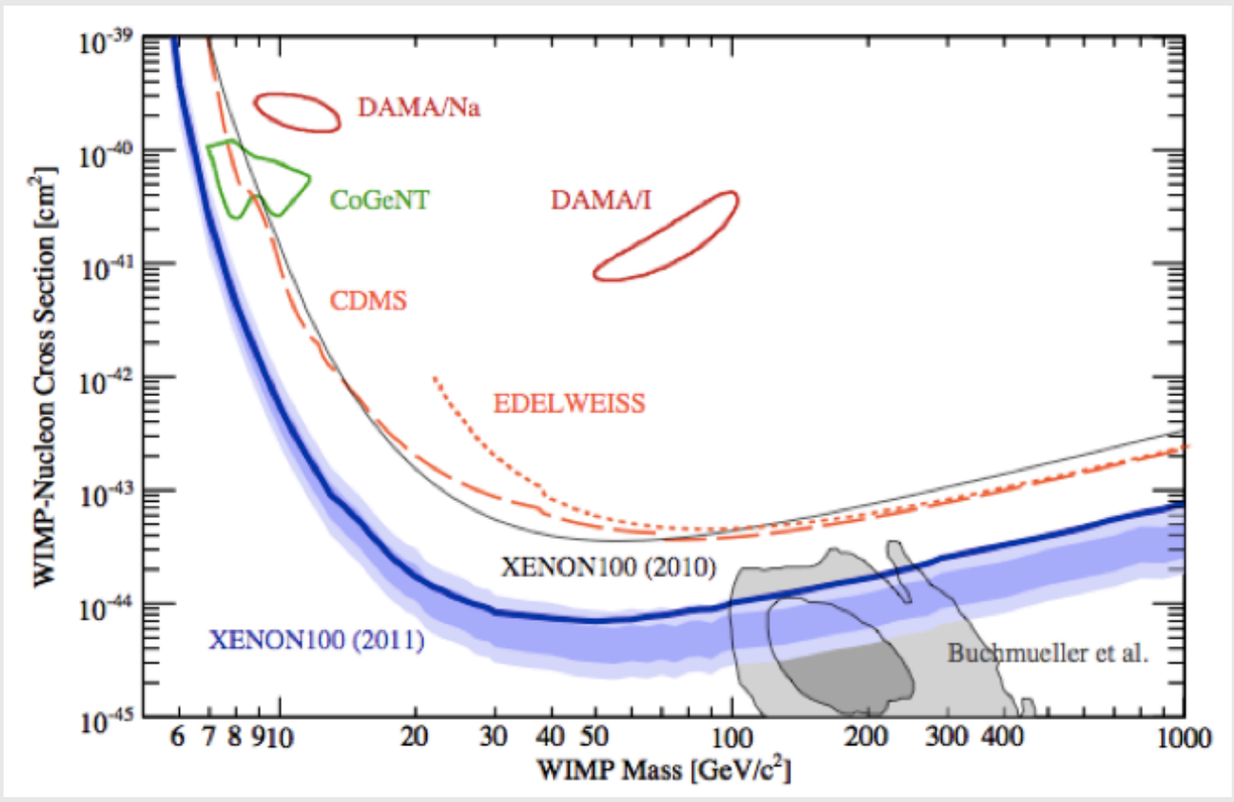


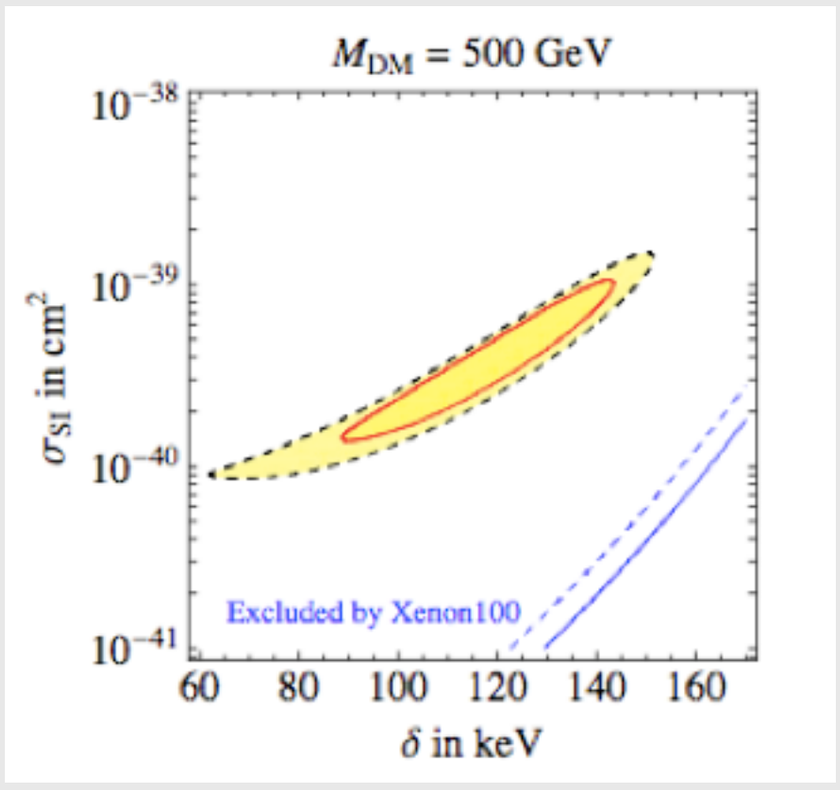
CREST

α-band
Oxygen
Tungsten

What about direct detection?

- The current message from DM direct detection experiments is...confusing.
- DAMA, CoGeNT (?), CREST (?) see...something...
- But XENON10/100 and CDMS sees nothing

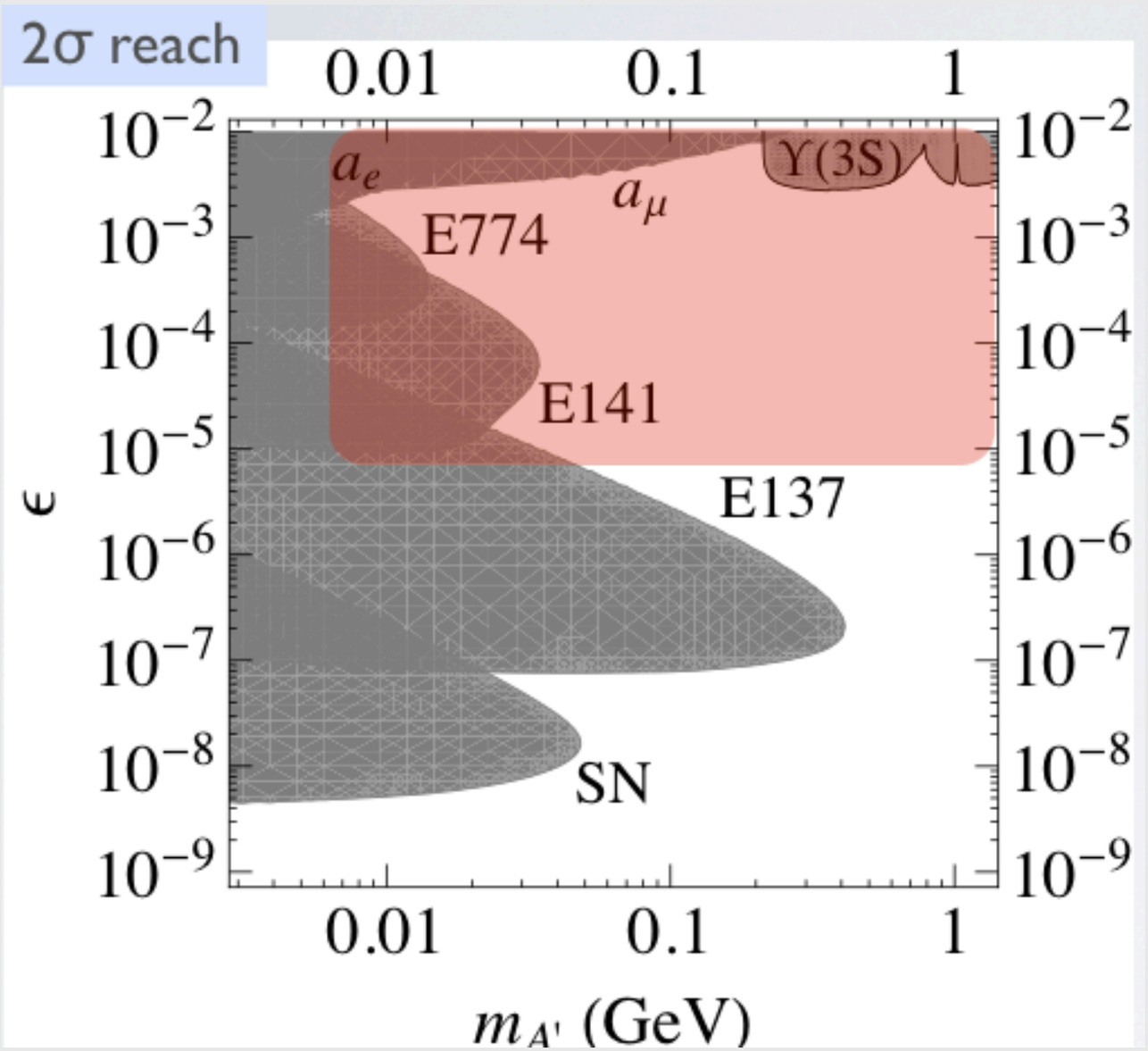




What about direct detection?

- The current message from DM direct detection experiments is...confusing.
- DAMA, CoGeNT (?), CREST (?) see...something...
- But XENON10/100 and CDMS sees nothing
- There are a few ways to reconcile these results (isospin violating, inelastic DM; two DM components)...need some creativity though.

*The Dark Photon Sweet Spot****

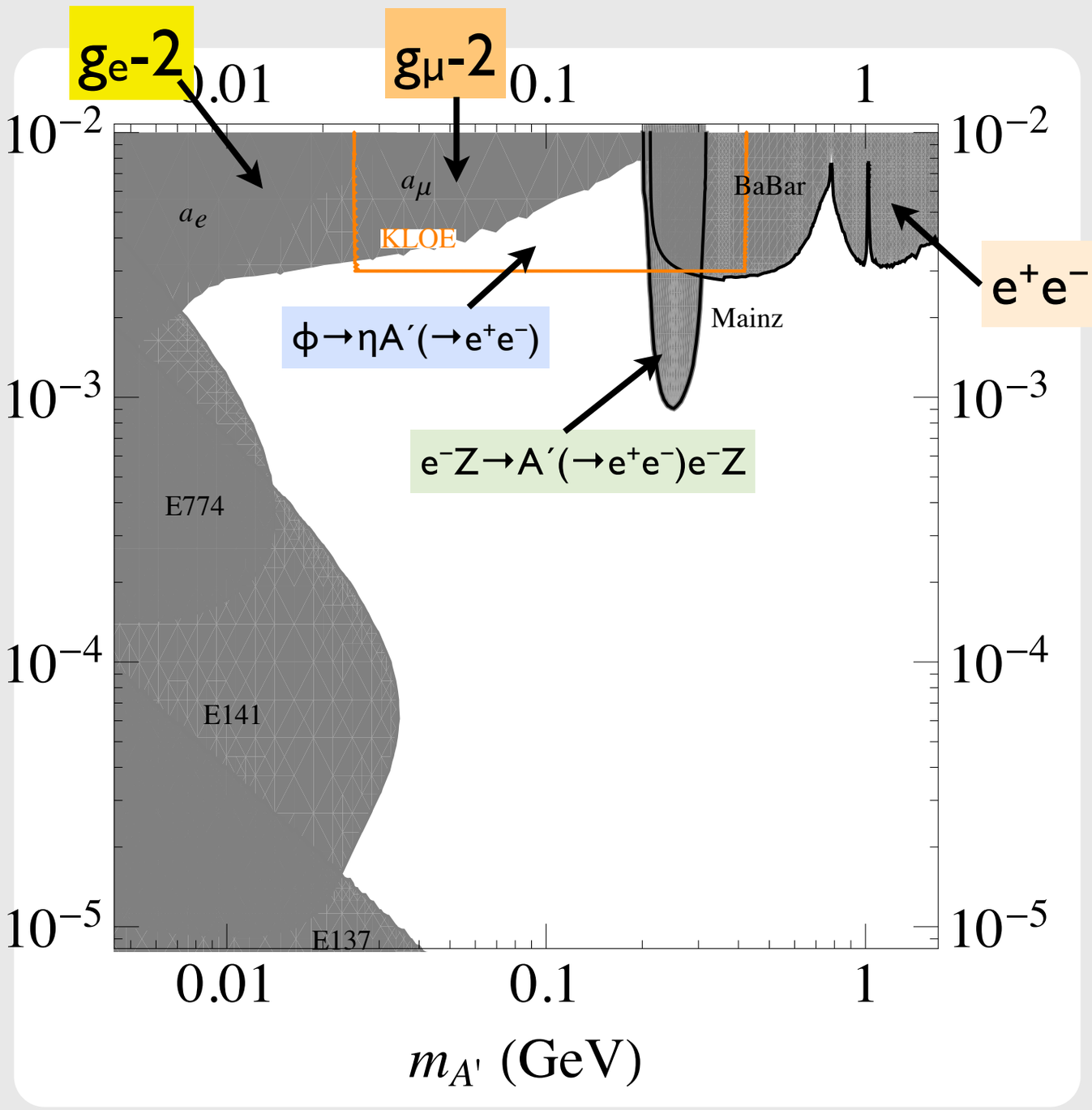


Both "naturalness" arguments and hints from astrophysics block out the same region in mass-coupling space:

$$\epsilon \sim 10^{-2} - 10^{-5}$$

$$m_{A\prime} \sim \mathrm{MeV} - \mathrm{GeV}$$

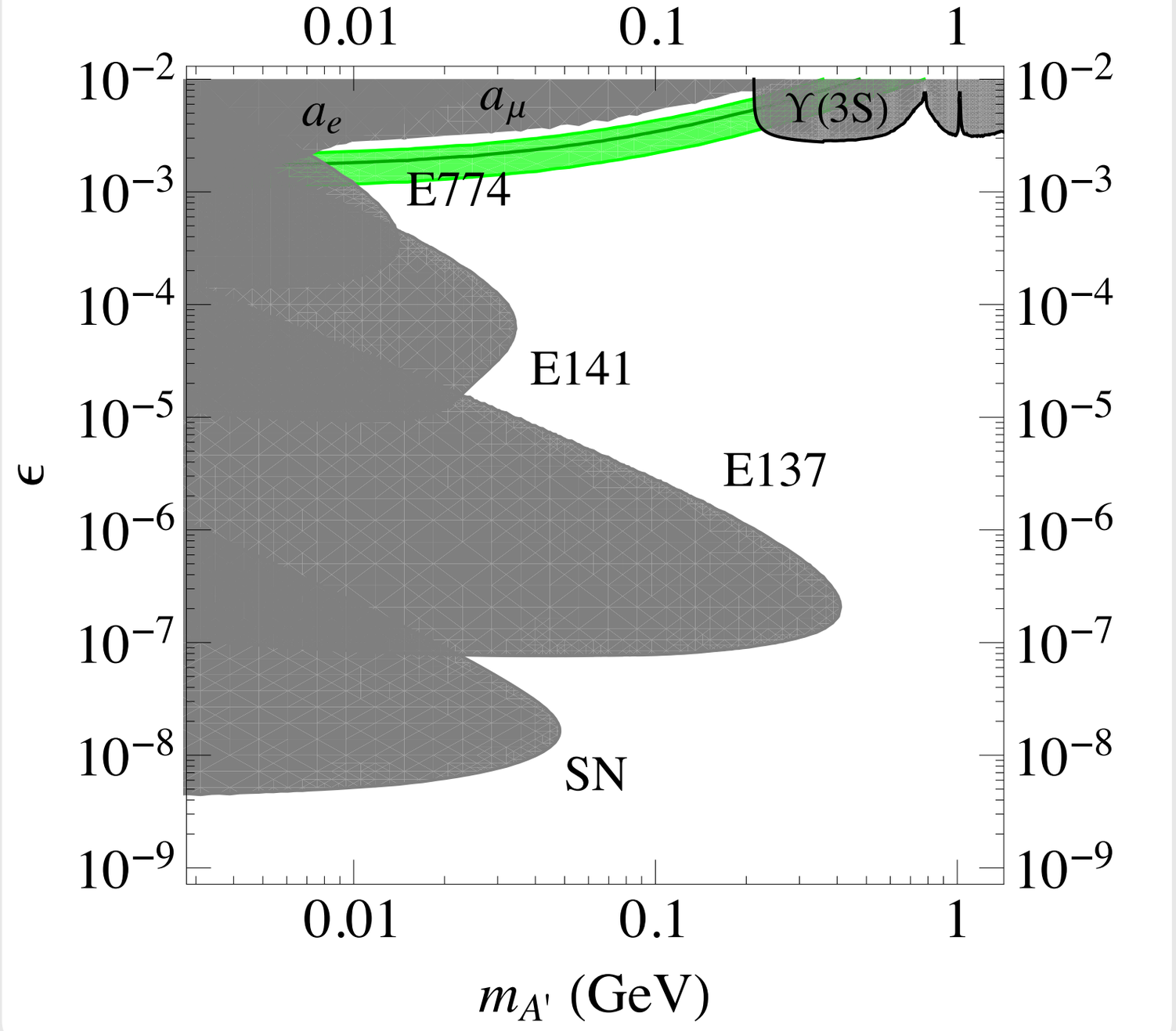
Existing Constraints



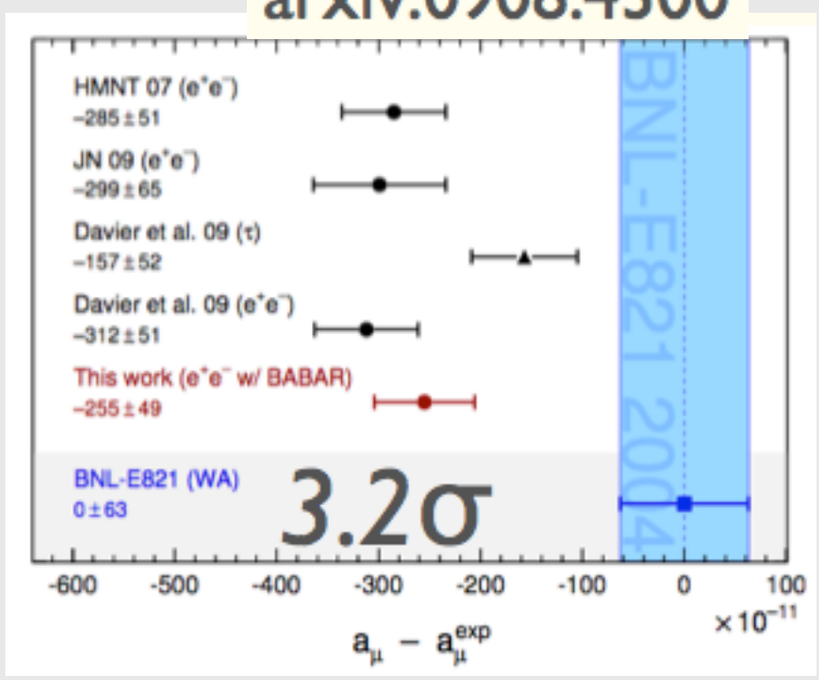
	Shield (m)	E_{beam} (GeV)	Lumi (e^-)
E137	200	20	10^{20}
E141	0.12	9	2×10^{15}
E774	0.3	275	5×10^{9}

Dark photons and the g-2 anomaly

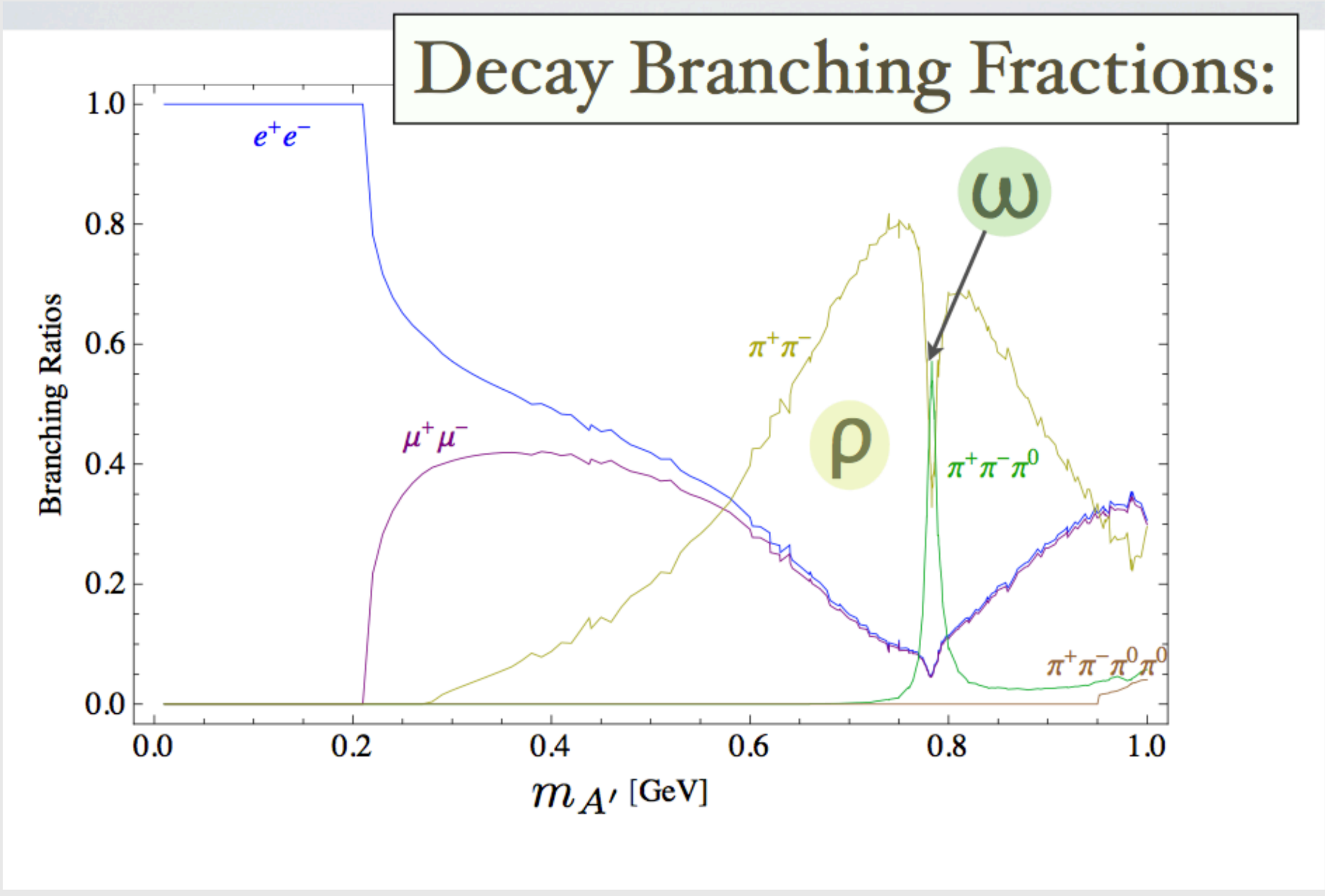
If the g-2 anomaly is due to a heavy photon



Davier *et al.*, arxiv:0908.4300



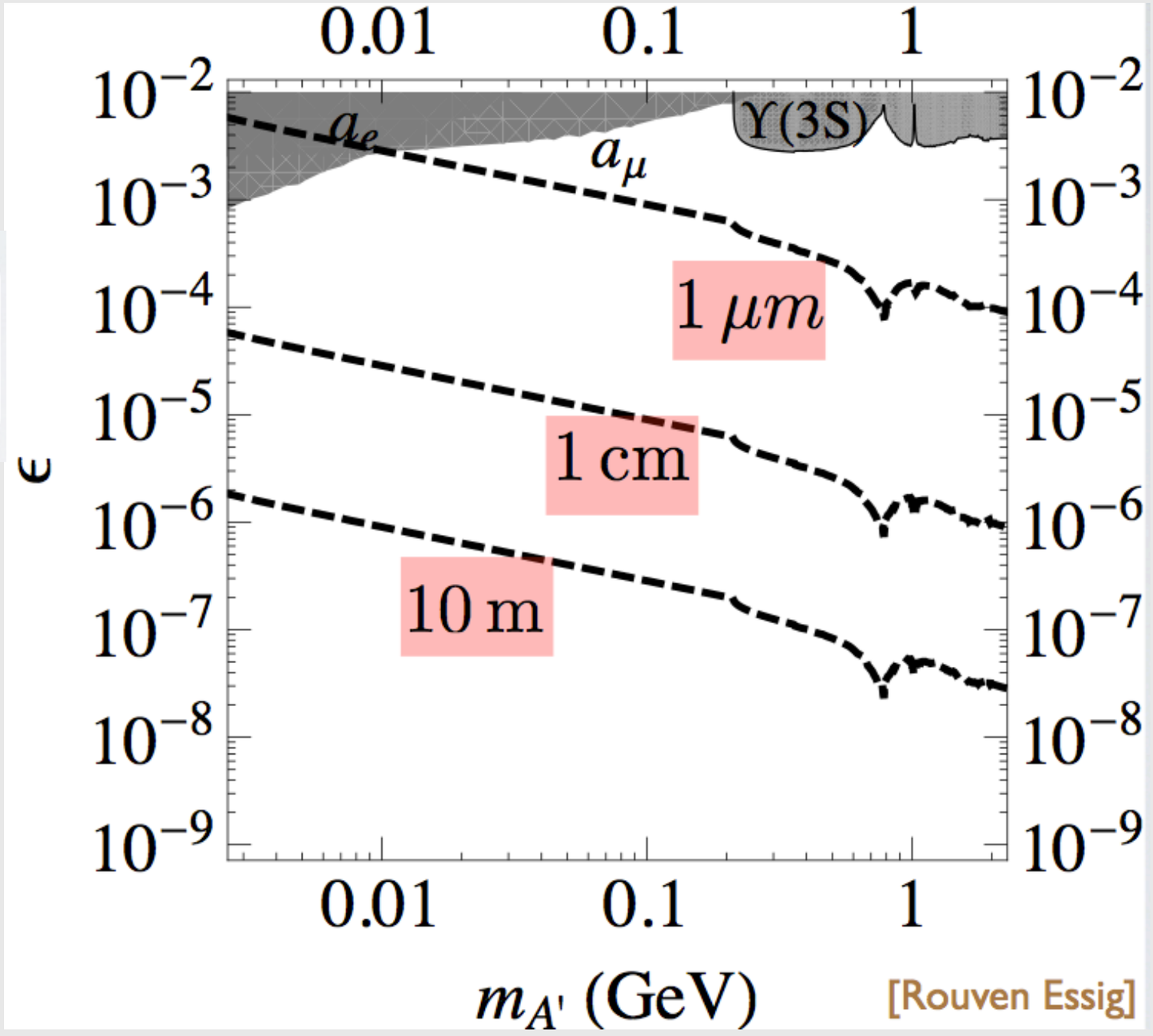
A´ Decay Products



A´ Lifetime

$$\gamma c\tau \propto \left(\frac{10^{-4}}{\epsilon}\right)^2 \left(\frac{100\ \mathrm{MeV}}{m_{A'}}\right)^2$$

lower ε, lower mass
→ longer lifetime



Rare (light) meson decays

SuperB will be a meson factory...

$\pi^0 \to \gamma U$ ~ expect ~10^{11} in 100ab; $\epsilon < 10^{-4}$?

$X \to YU$	n_X	$m_X - m_Y$ (MeV)	BR($X \to Y + \gamma$)	BR($X \to Y + \ell^+\ell^-$)	$\epsilon \leq$
$\eta \to \gamma U$	$n_\eta \sim 10^7$ 10^{10}	547	$2 \times 39.8\%$	6×10^{-4}	2×10^{-3}
$\omega \to \pi^0 U$	$n_\omega \sim 10^7$	648	8.9%	7.7×10^{-4}	5×10^{-3}
$\phi \to \eta U$	$n_\phi \sim 10^{10}$	472	1.3%	1.15×10^{-4}	1×10^{-3}
$K_L^0 \to \gamma U$	$n_{K_L^0} \sim 10^{11}$	497	$2 \times (5.5 \times 10^{-4})$	9.5×10^{-6}	2×10^{-3}
$K^+ \to \pi^+ U$	$n_{K^+} \sim 10^{10}$	354	-	2.88×10^{-7}	7×10^{-3}
$K^+ \to \mu^+ \nu U$	$n_{K^+} \sim 10^{10}$	392	6.2×10^{-3}	$7 \times 10^{-8\,a}$	2×10^{-3}
$K^+ \to e^+ \nu U$	$n_{K^+} \sim 10^{10}$	496	1.5×10^{-5}	2.5×10^{-8}	7×10^{-3}

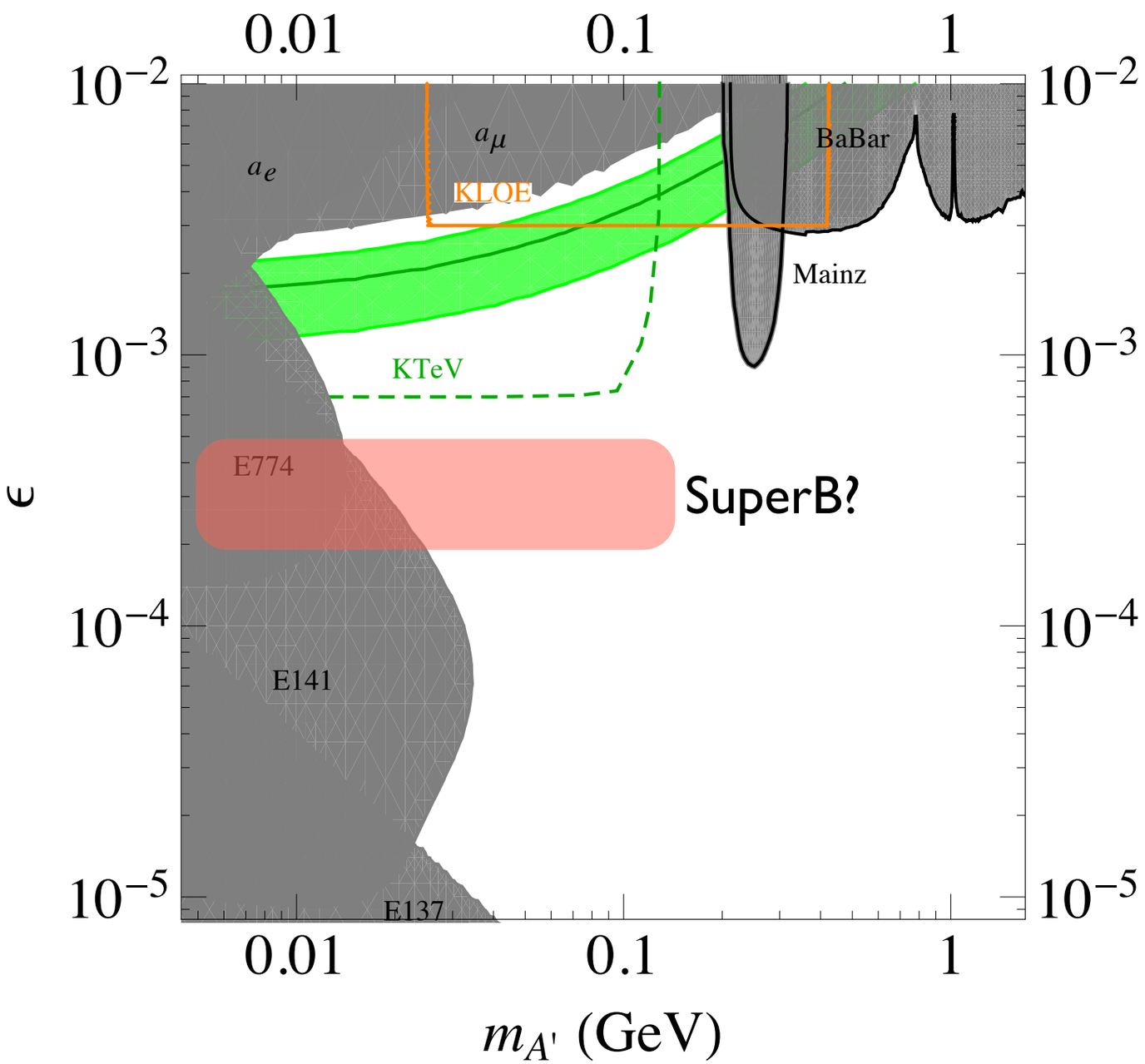
few $\times 10^{-4}$

Reece & Wang 2009

Summary of estimates from existing samples...most of these are from fixed target experiments.

→SuperB will have a huge number of these and other meson decays from J/ψ, D, ϒ, and B...

Potential of π^0 decays

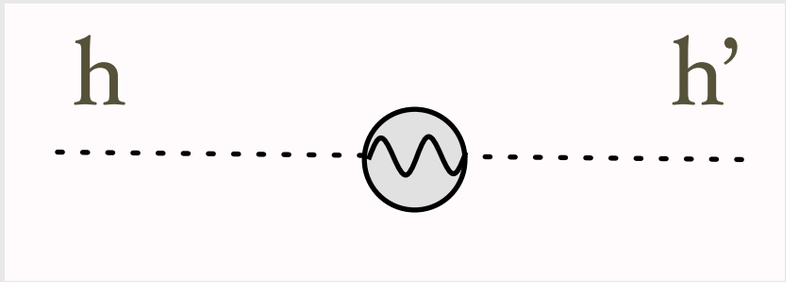


π^0 decays are particularly interesting since they cover the g-2 favored region

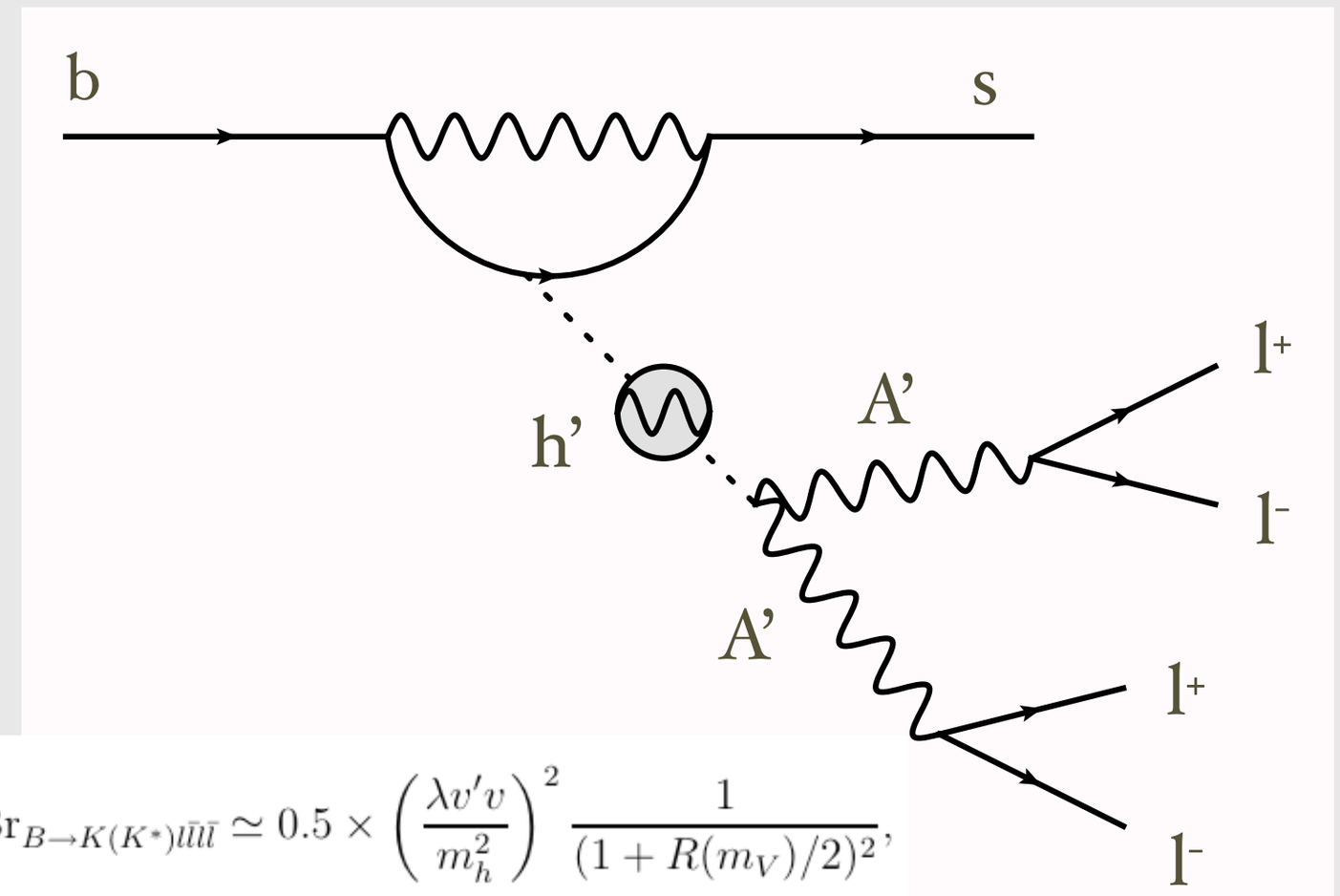
KTeV has a large π^0 sample on disk ready to be analyzed...SuperB should be able to improve upon this (but it's a tough analysis)

Rare B-Decays

- Vector portal: $\mathcal{L} = -\frac{\kappa}{2} V^{\mu\nu} B_{\mu\nu}$
- Higgs portal: $\mathcal{L} = (-\lambda S^2 + \xi S) H^\dagger H$

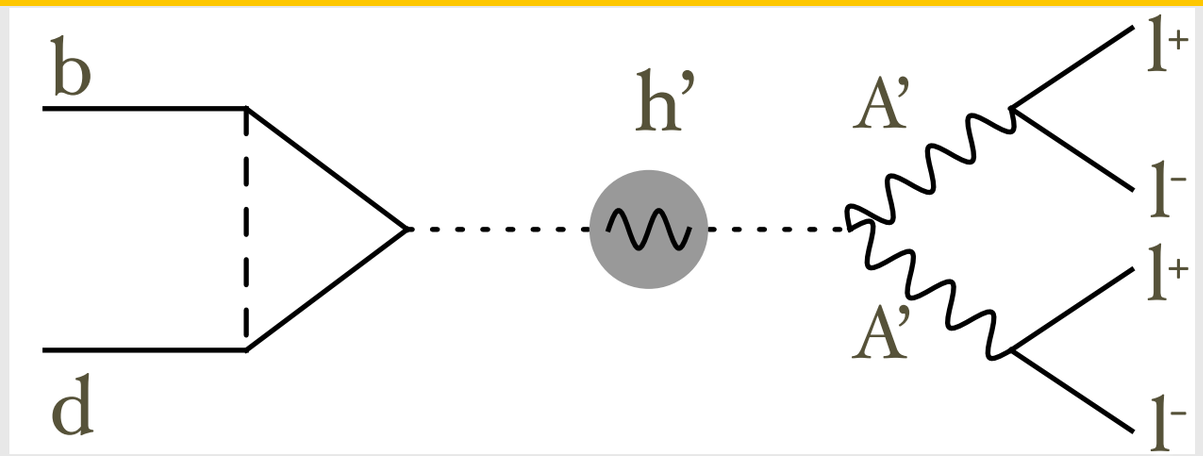


- In addition to kinetic mixing ("vector portal") there must also be a higgs portal.
- Because of the top dominating the loop, FCNC decays may be an interesting place to look for this...
  - Look for dilepton resonance in $K^{(*)}ll$
  - modes like $B \to K^{(*)}4l$ or $B^0 \to 4l$ should be very clean



$$\mathrm{Br}_{B\to K(K^*)l\bar{l}l\bar{l}} \simeq 0.5 \times \left(\frac{\lambda v' v}{m_h^2}\right)^2 \frac{1}{(1+R(m_V)/2)^2},$$

Multilepton B-Decays

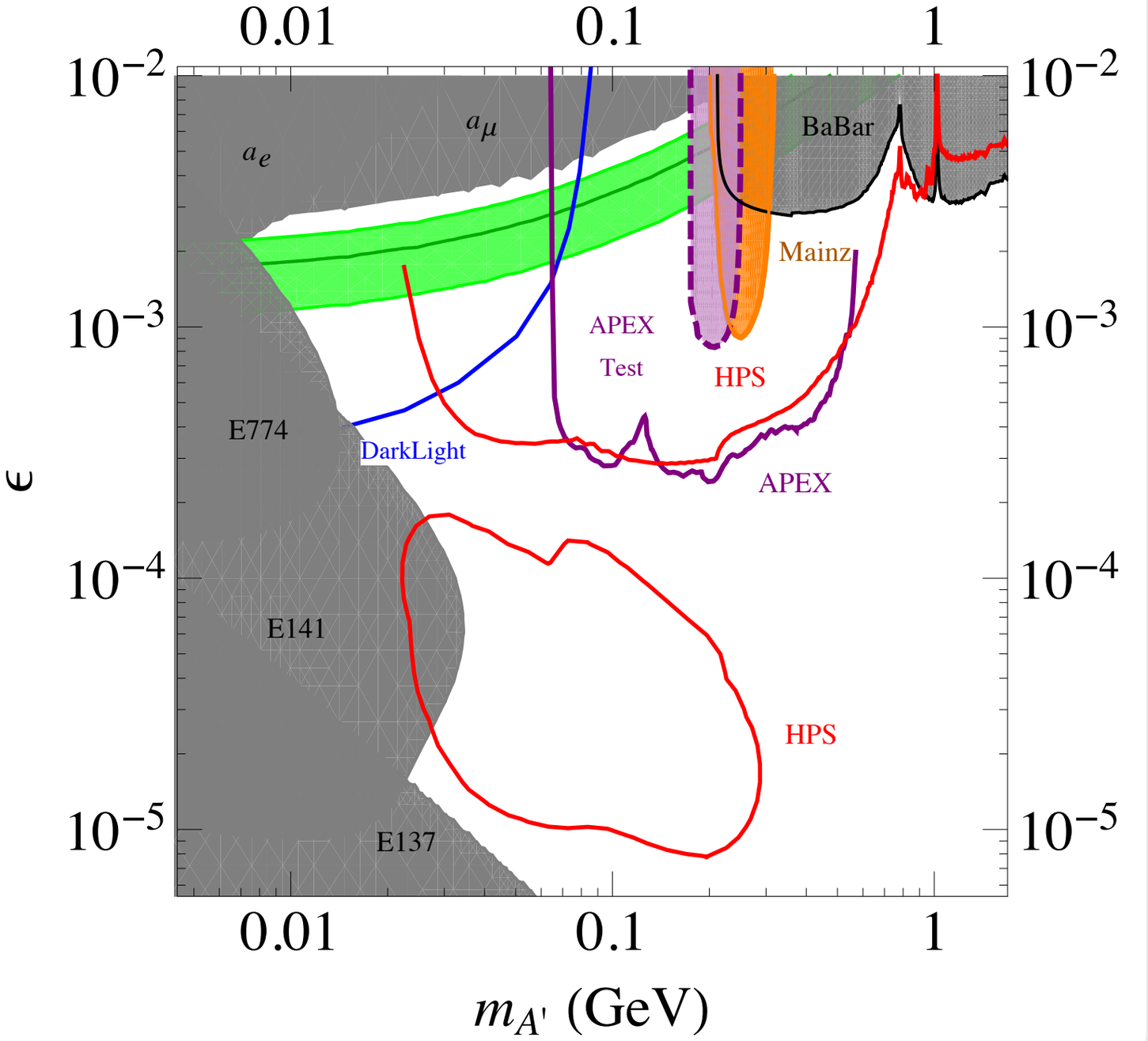


Vector A'

$$\mathrm{Br}_{B_s\to VV} = 4\times 10^{-5}\times \lambda^2\lambda_{VV}^{1/2}\times \frac{1-4m_V^2/m_B^2+12m_V^4/m_B^4}{(1-m_{h'}^2/m_B^2)^2},$$

- here, λ gives the mixing strength of the higgs-dark higgs and λ_{VV} is a phase space term
- reasonable to have BR~10^{-9}-10^{-11}
  - note that this eqn is for B_s decays...multiply by $|V_{td}/V_{ts}|$

Not the only game in town...



Many experiments in the works to look for Dark Forces:

Mainz and APEX (JLab) ~ forward spectrometers

HPS (JLab)~ compact Si-based vertex-tracker

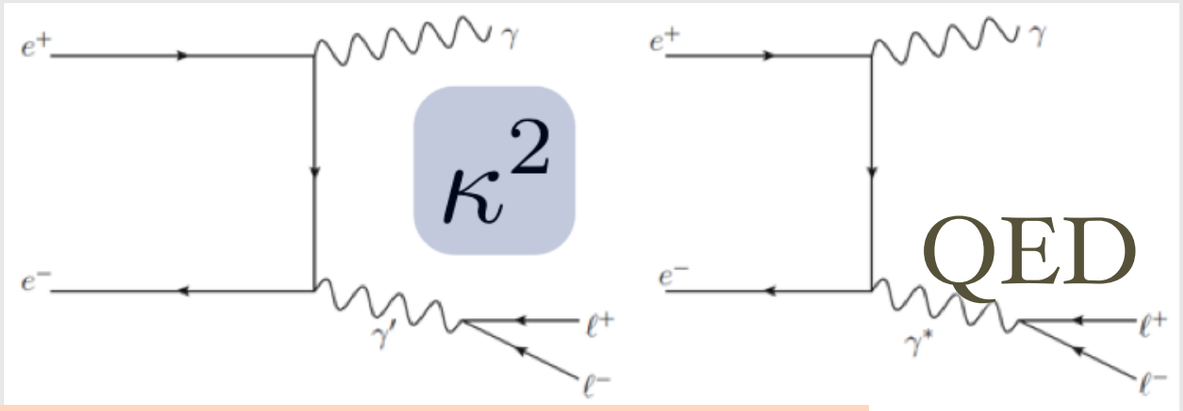
DarkLight (JLab FEL) ~ high acceptance, H_2 gas target

KTeV ~ π^0 decays

LHC/Tevatron ~ "lepton jets"

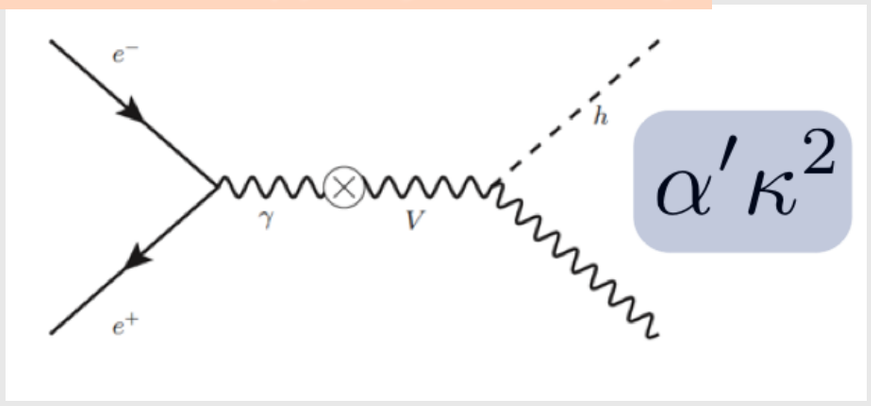
More to come!

- The basic theory is very simple...a new U(1)´➪ heavy "photon" linking to a hidden, "dark" sector
- Intriguing hints are intriguing...
- Dark forces are hot, hot, hot! Many papers from the theory community exploring possible scenarios
- luminosity + acceptance + clean environment = SuperB will be a very good place to look
- see next talks for more details!



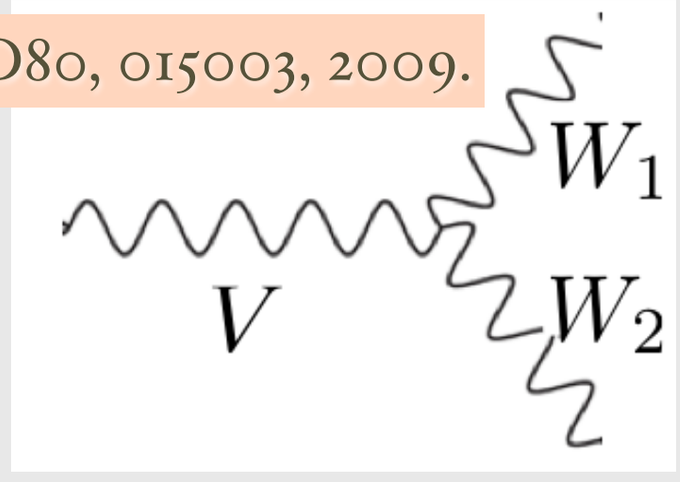
Batell et al., PRD79, 115008, 2009.

generic: $\gamma l^+ l^-$
look for a bump in ll mass
huge QED background



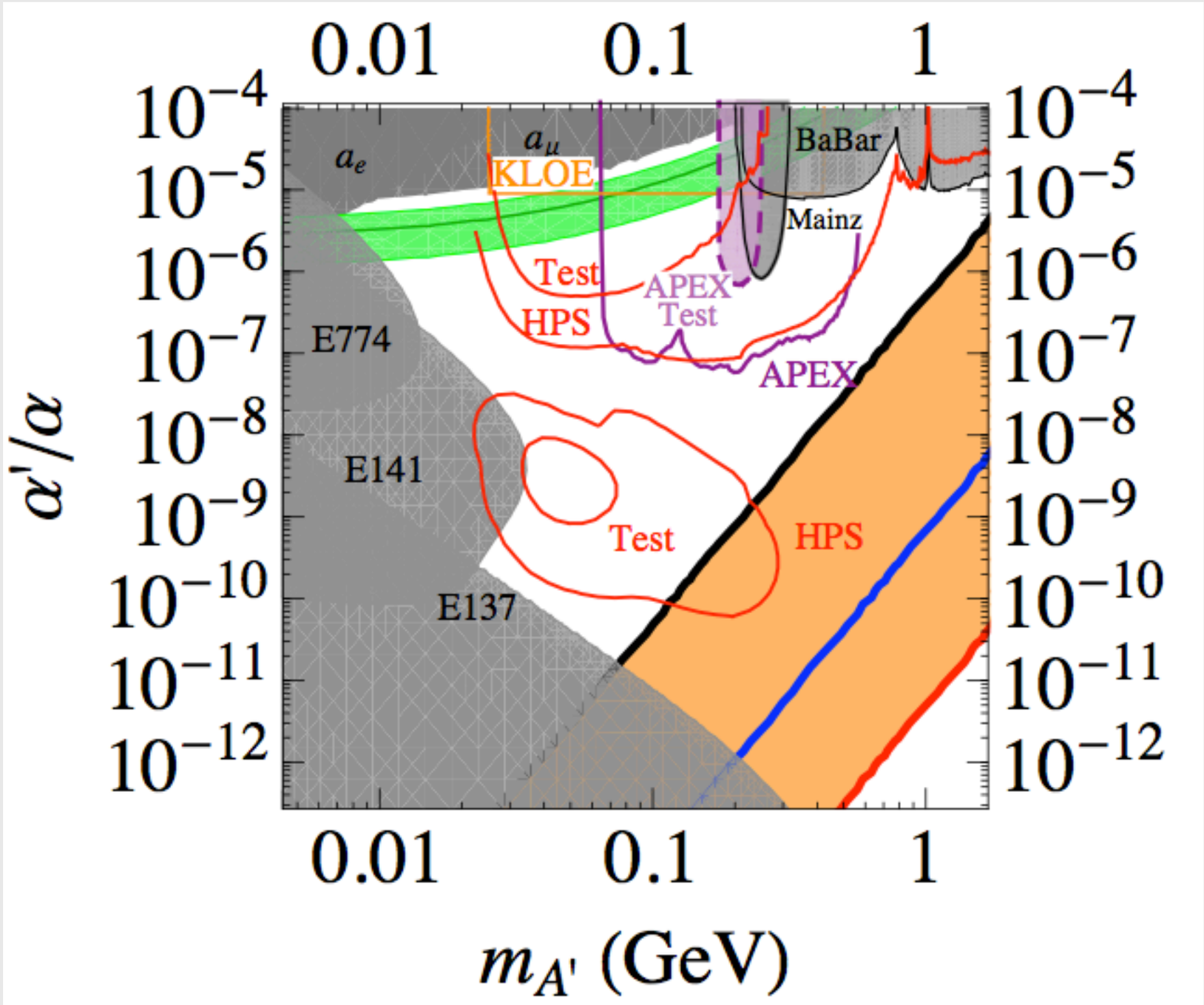
Essig et al., PRD80, 015003, 2009.

generic+Higgs: 6l or 2l+$\not{E}$
small QED background



generic non-Abelian: 4l
small QED background

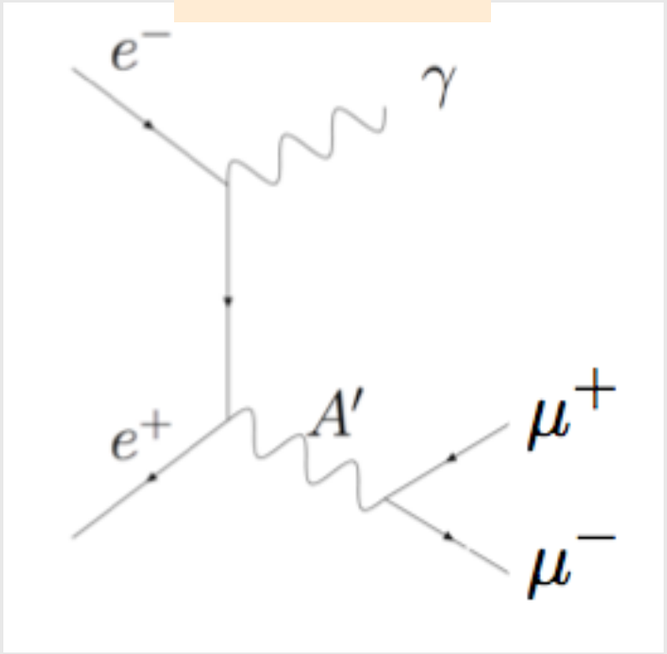
...if you believe DAMA



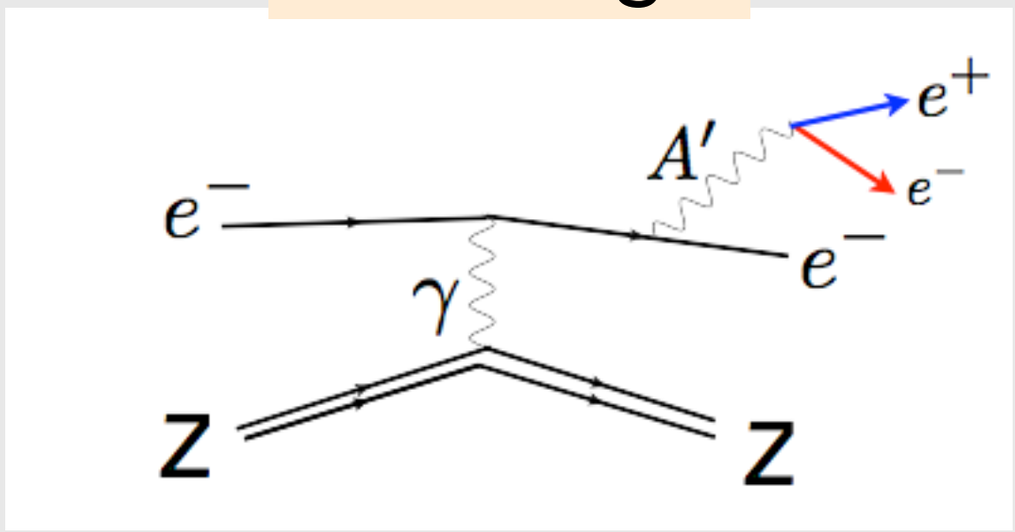
Collider vs. Fixed Target

Wherever there is a photon there is a dark photon...

Collider



Fixed Target



$$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$$

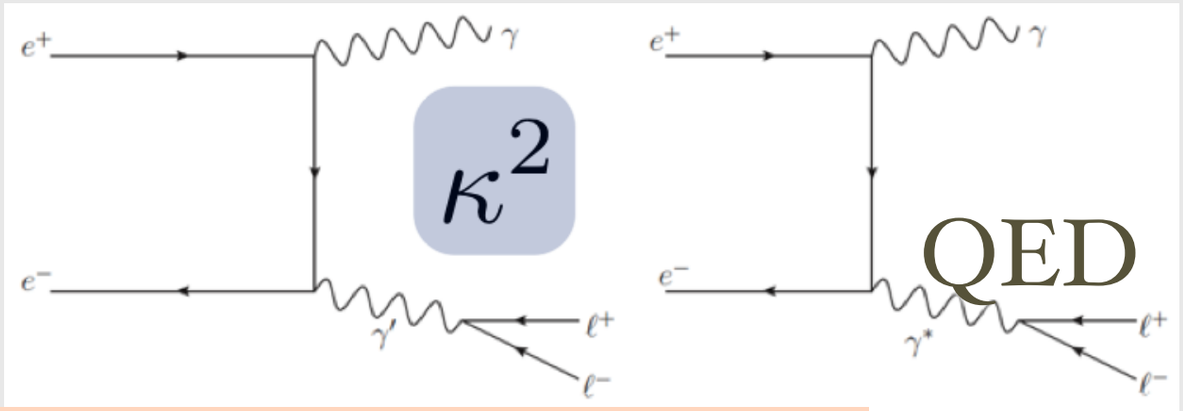
$O\ ab^{-1}$ per ~~decade~~ month

$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

$O\ ab^{-1}$ per day

...much higher backgrounds

Direct A´ Production



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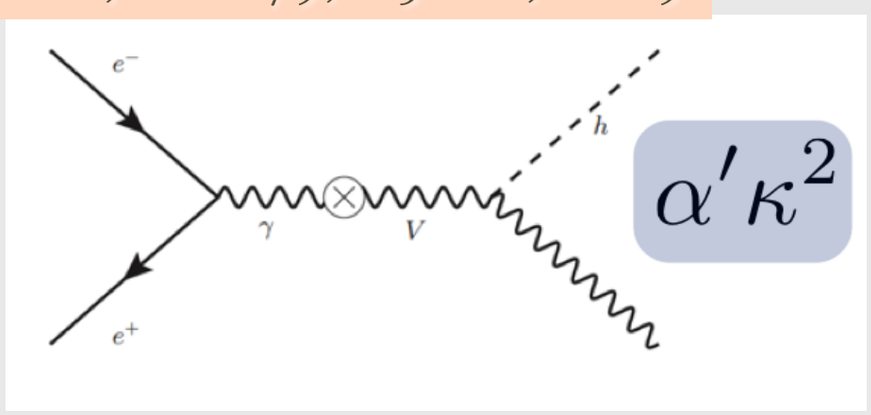
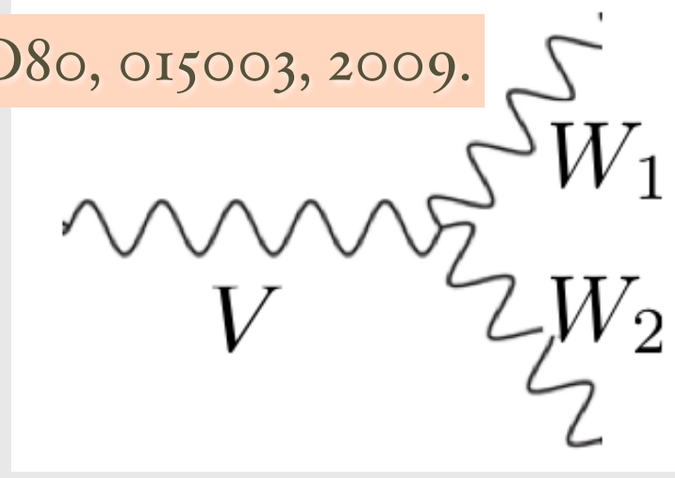


generic+Higs: 6l or 2l+E
small QED background

Essig et al., PRD80, 015003, 2009.



generic non-Abelian: 4l
small QED background