Implications of and Search for a Heavy Photon: a new gauge force, dark photon, dark matter …

part I

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HUGS-2012, JLAB

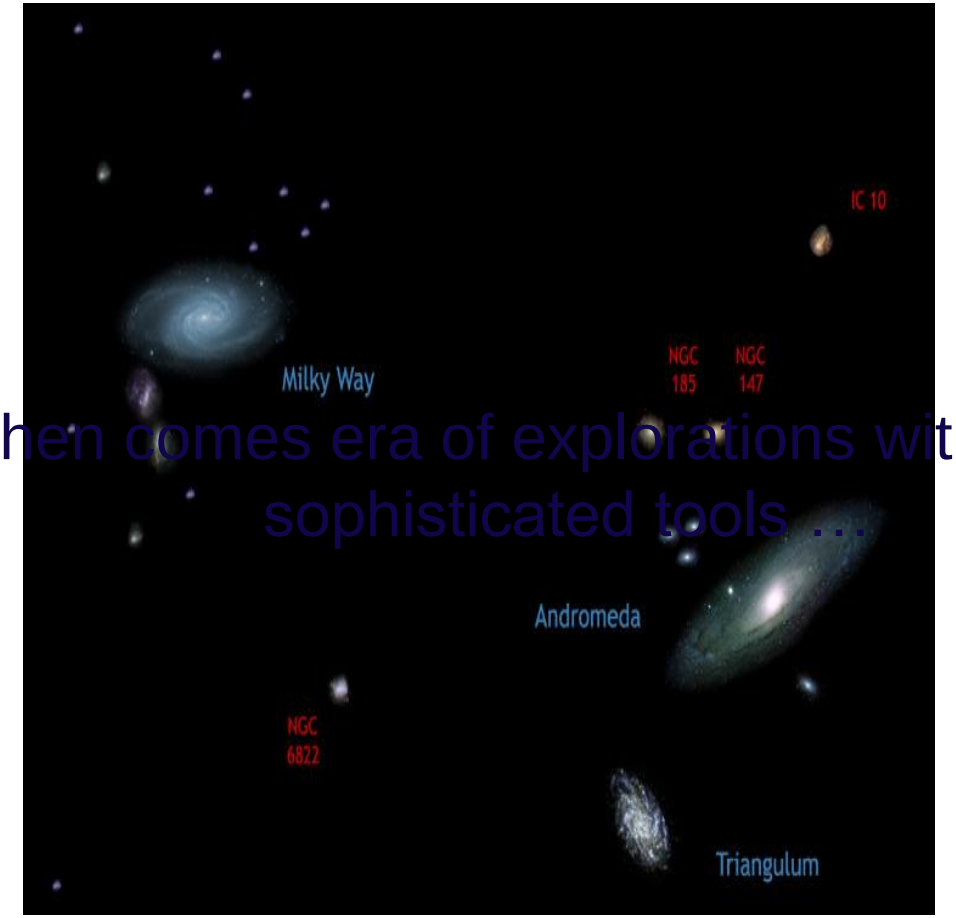
Outline

- Introduction
- Matter in the Universe
- Standard Model and extra U(1)
- Evidence from cosmological observations
- Couplings, masses, decays
- Limits on coupling and the mass
- Possibilities with accelerator based experiments
- Summary – *part-I*

Preamble

- Interest in the possibility that a massive photon-like particle could exist and play a role in dark matter annihilation emerged in 2009, and has generated considerable activity since then
- Such a particle could account for the striking evidence in the cosmic rays of an excess of high energy electrons and a rising positron fraction and is natural on very general theoretical grounds as well
- A heavy photon could also account for dark matter interactions with regular matter, and so bear on dark matter direct detection experiments
- It will be a mediator of an additional U(1) as suggested in String theories and if so it will mix kinetically to the Standard Model photon (Holdom ‘86)
- The heavy photon would be produced in electron bremsstrahlung off heavy targets, albeit at rates strongly suppressed compared to production of virtual photons of the same mass

A little *detour* -

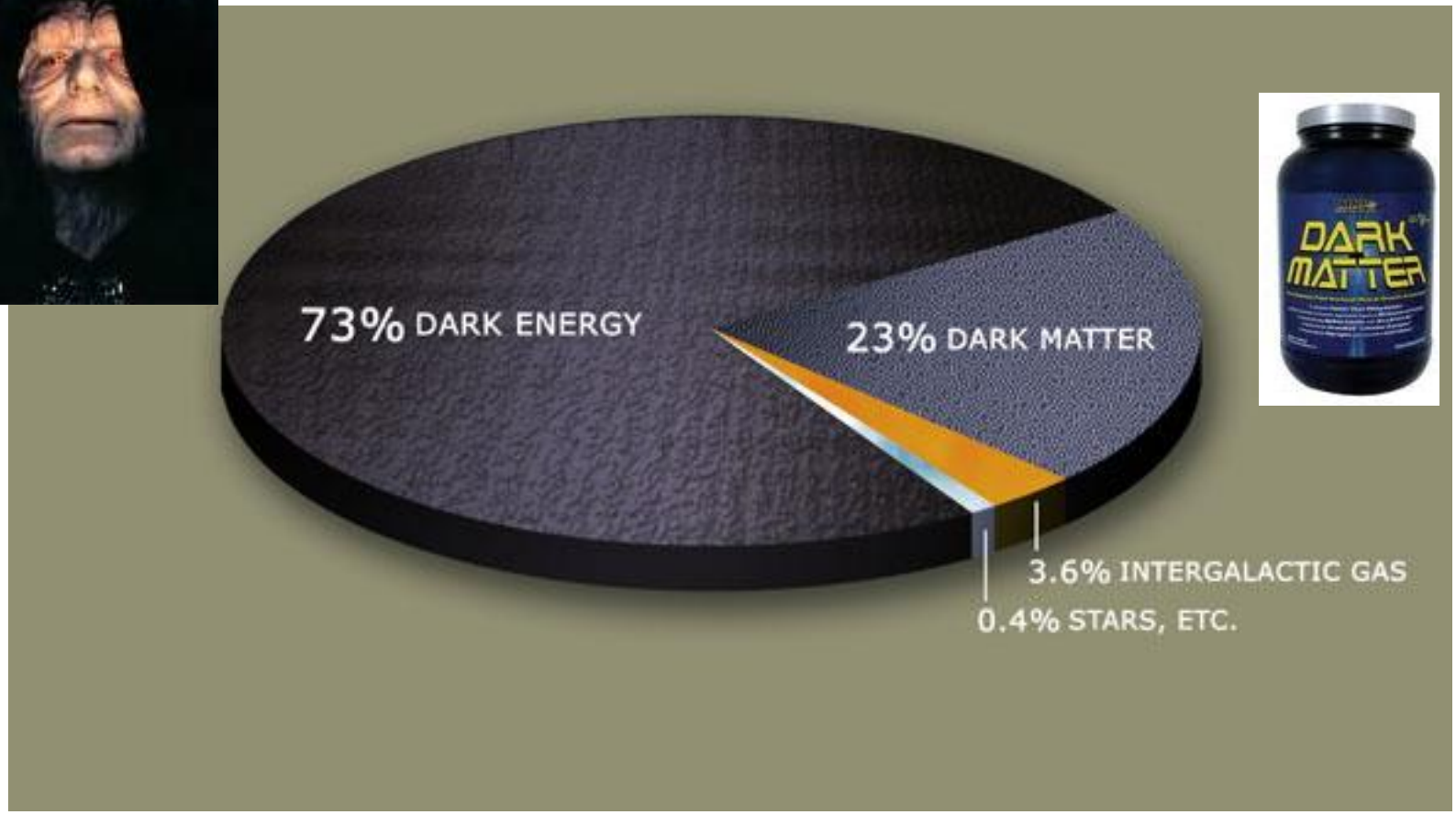


to the 20th century with
to 16th century's
Copernican revolution,
the Heliocentric model
observations

Under 20th century our place
in the Universe goes from a
flat Earth and the geocentric
model

then comes era of explorations with more sophisticated tools …

Distribution of matter in Universe



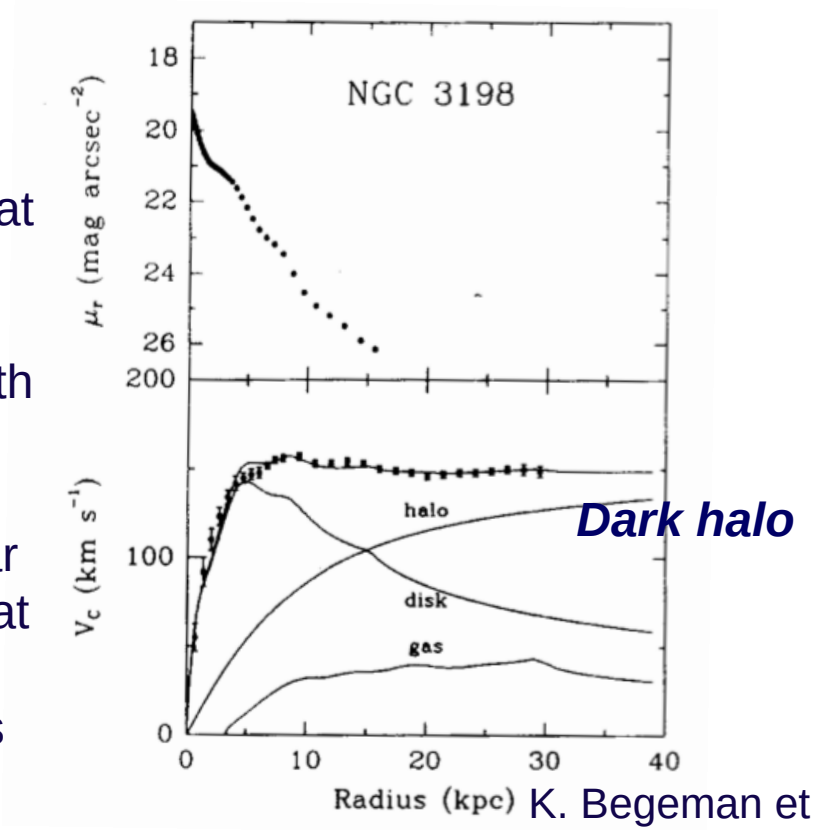
“Missing mass” of the Universe

- Two cosmological observations played an important role in “dark matter” scenario of the Universe – *rotational speed of spiral galaxies* and *the gravitational lensing*

$V^2(r) = G*M(r)/r$
V should decrease with M decreasing at large r, G is the gravitational constant

Optical observations seems agreed with above dependence

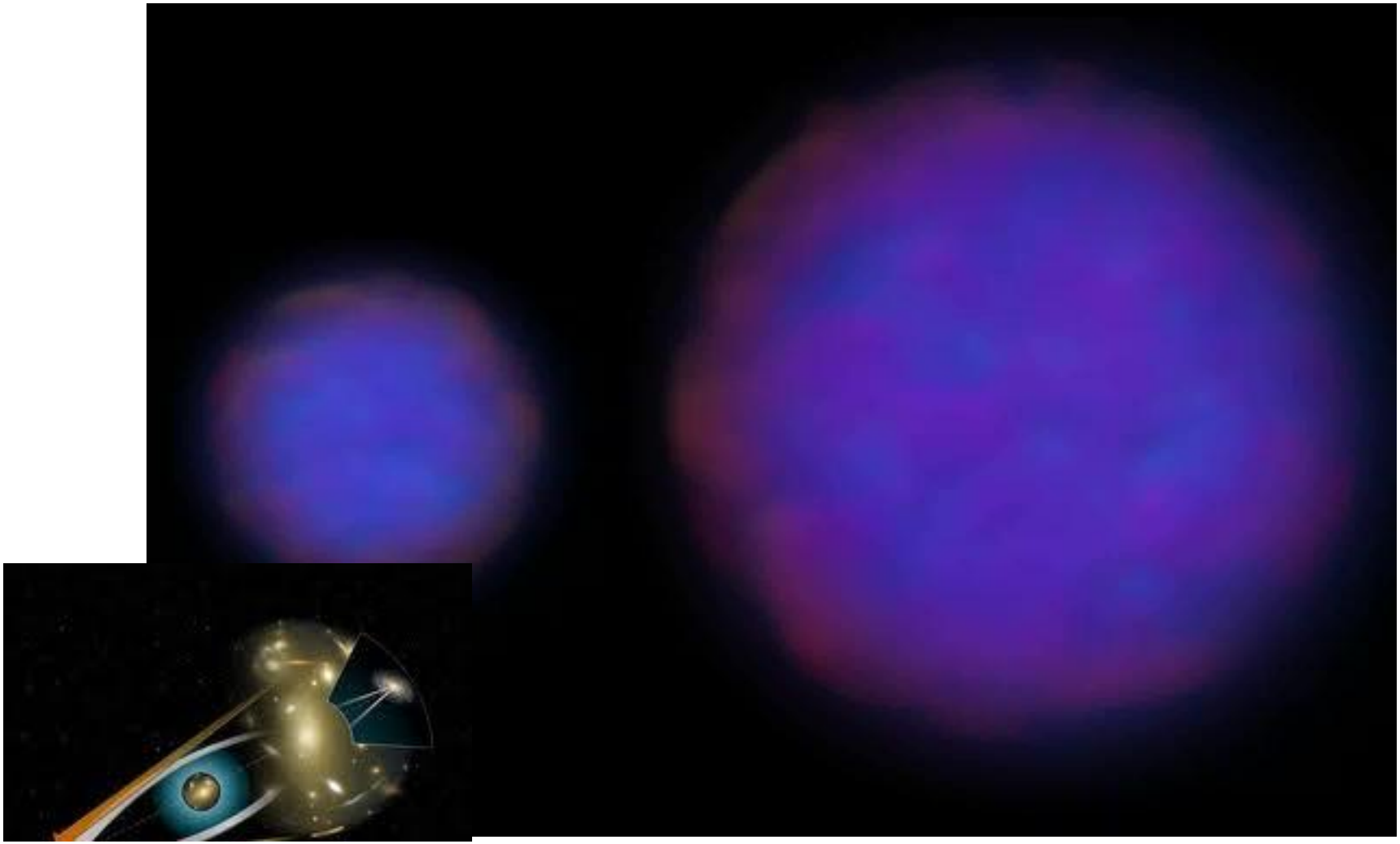
Radio-telescopes pushed the radius far beyond the starlight (HI, EM radiation at 1420.40575177 MHz) and often found constant velocity out to the radial limits



Dark halo

K. Begeman et al.

Gravitational lensing – Abell 2744, Pandora's Cluster

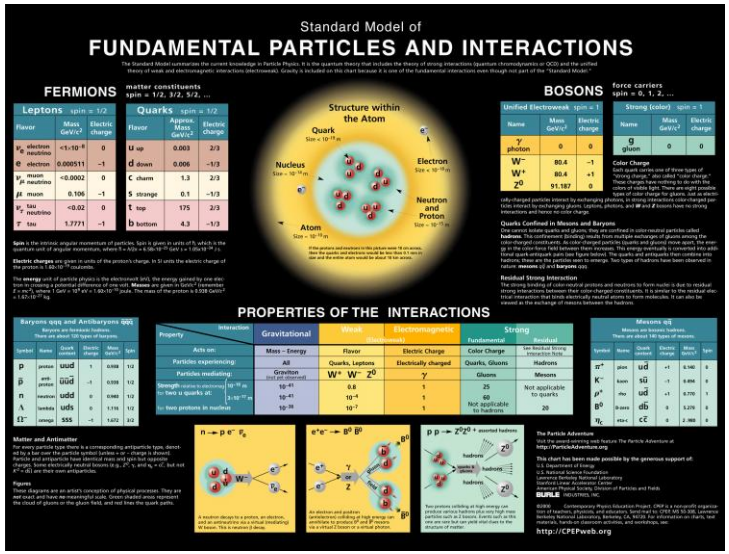


Dark Matter

- The quest for the identification of the missing mass of the universe has been with us since many decades now
- While explanations in terms of modifications of Newtonian gravity or General Relativity become more and more contrived, evidence for the particle nature of such Dark Matter (DM) now comes from many astrophysical and cosmological observations
- Non-baryonic new particles that may fulfill the rôle of DM have emerged in the latest decades within many Beyond the Standard Model (SM) theories

The Standard Model

Almost all known particle physics phenomena are well described within the SM, but … it does not explain the complete picture



- neutrino finite mass
- gravitation
- dark matter, dark energy

and the Higgs boson, has yet to be found

Standard Model

strong g

weak $W^{\pm}, Z$

electromagnetic γ

Hidden Sector?

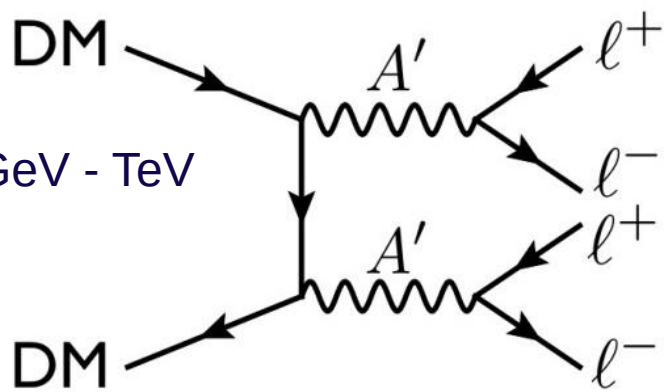
new force? A'

Extra U(1) below the weak scale

New Physics behind the SM

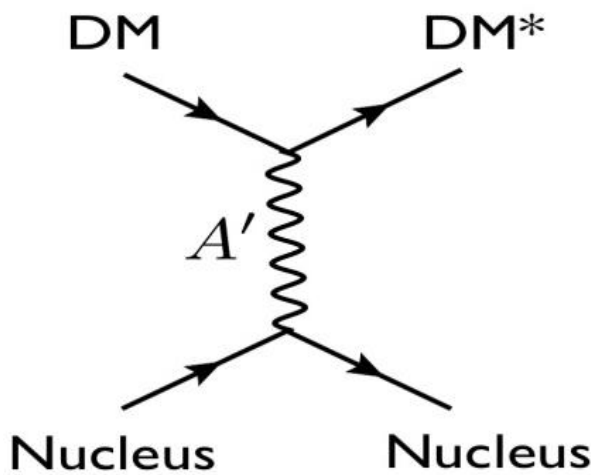
A new hidden sector with sub-GeV gauge bosons can explain several particle physics anomalies, e.g *g-2* of the muon, the flavor oscillations of neutrinos (associated with their small but finite masses)

This new gauge boson, called as heavy photon, dark photon, A' …, can be our way to reach to the dark sector



GeV - TeV

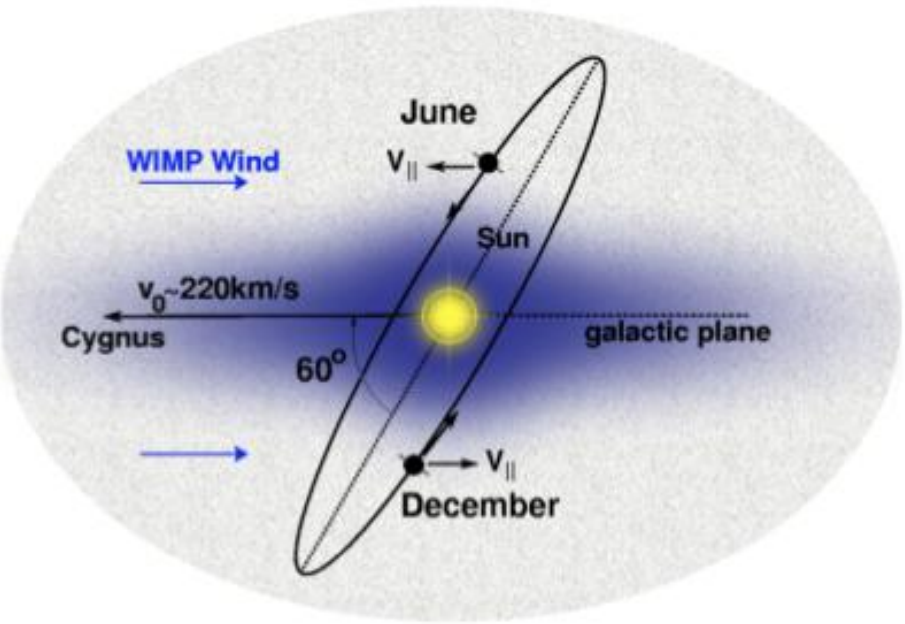
MeV - GeV

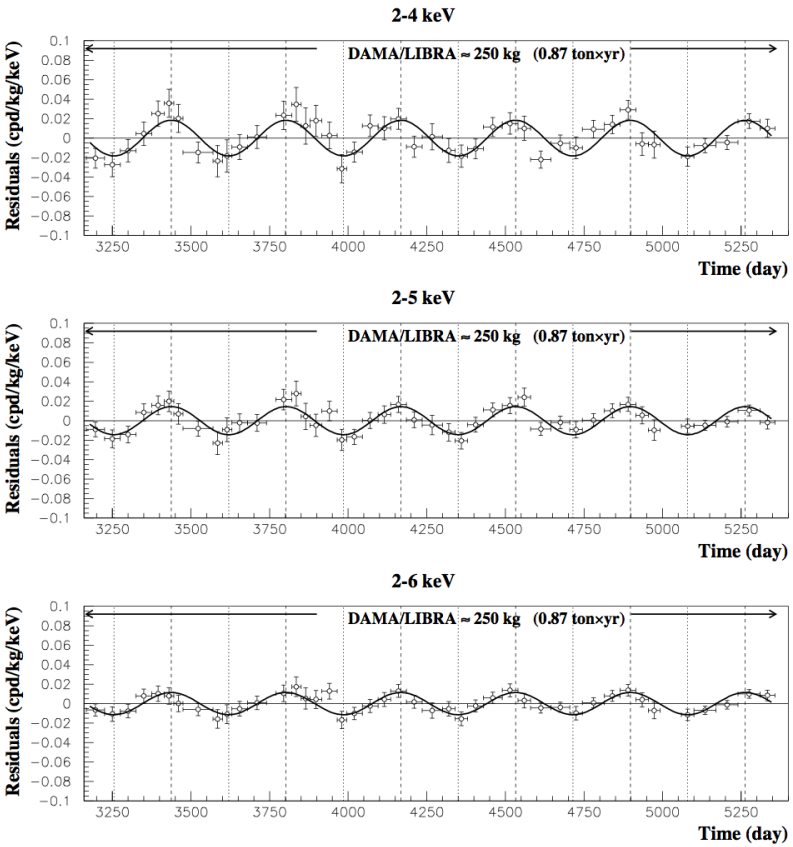


Arkani-Hamed, Finkbeiner, Slatyer, Weiner
Pospelov & Ritz

Dark matter coupling to the A' can explain DM annihilation into e^+e^-
Inelastic scattering via A' can account for direct detection results

DAMA/LIBRA





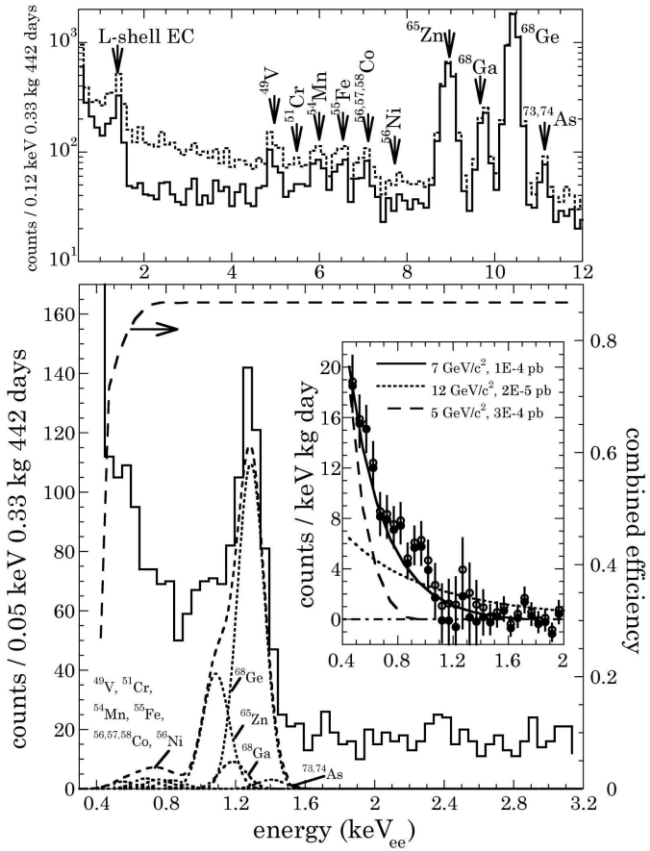
A*cos[ω(t-t0)] (continuos line)

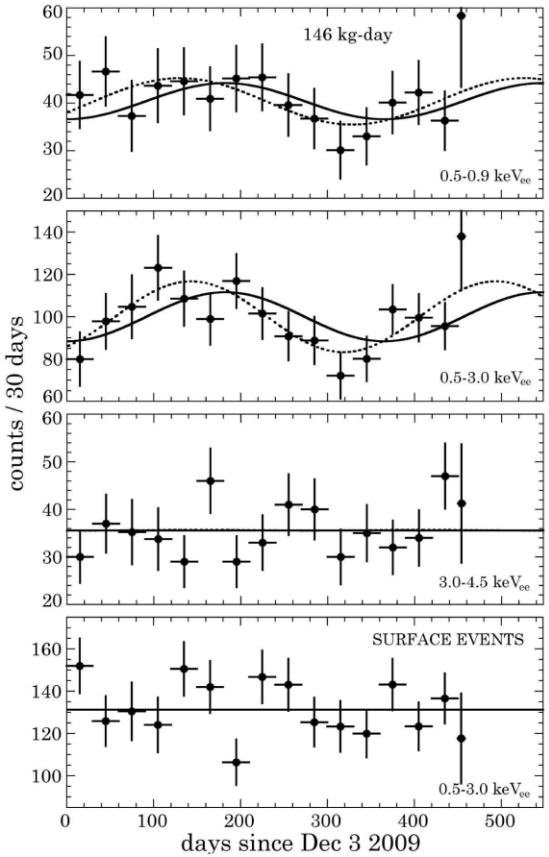
t_0 = 152.5 d, T = 1.00 y

250 kg NaI detector for rare processes in Gran Sasso

CoGeNT Modulation

- Similar annual oscillation have been observed by CoGent [440g Germanium crystal cooled to LN temperatures in Soudan Underground Laboratory]

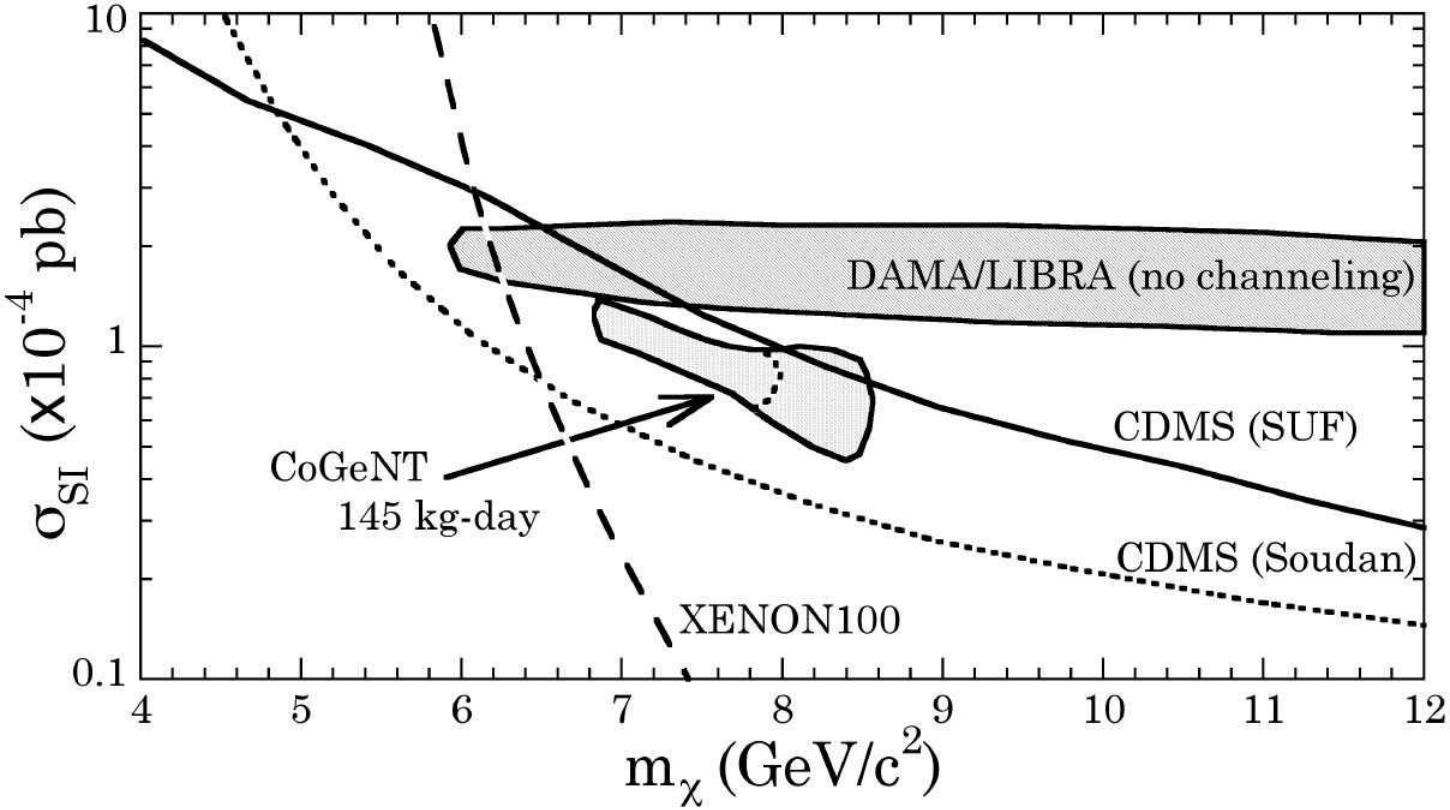




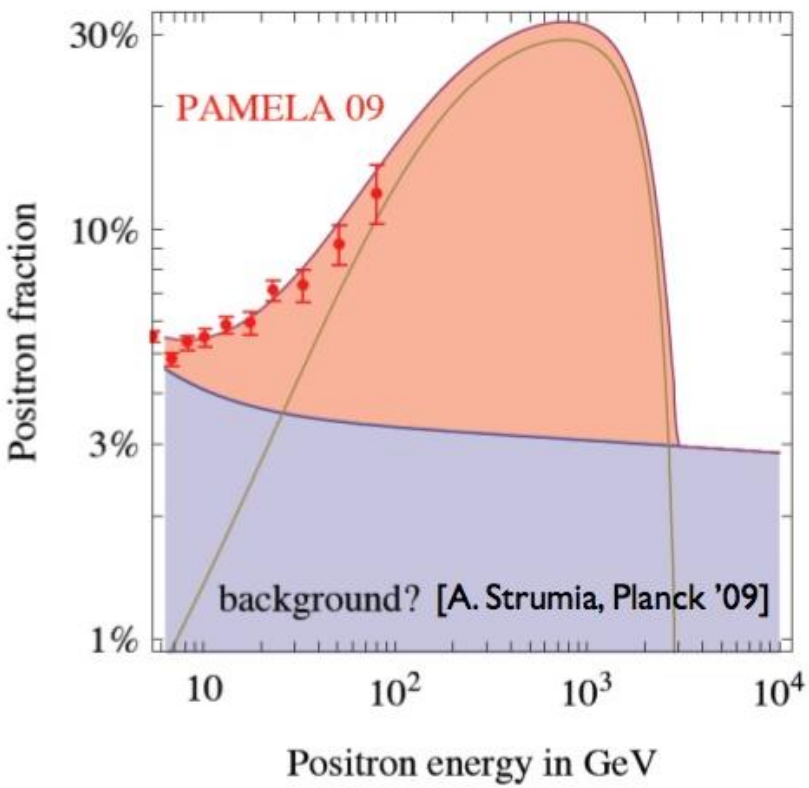
arXiv:1106.0650v3 [astro-ph.CO] 4 Oct 2011

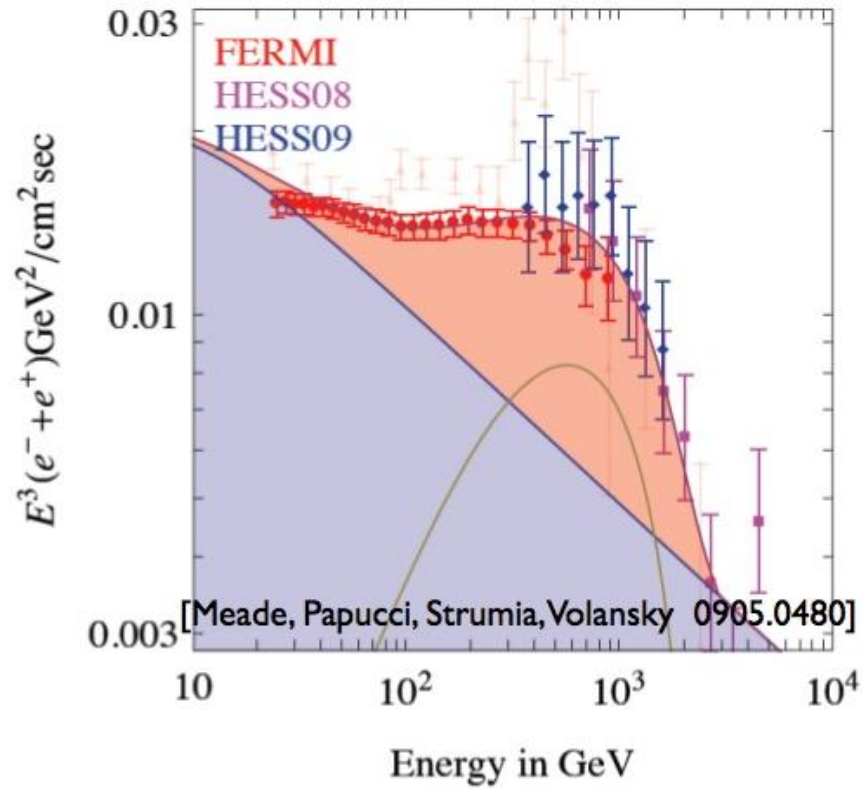
Hint for WIMPs

However, two other experiments CDMS-II and XENON100 have found no evidence for dark matter in their detectors.



PAMELA/FERMI

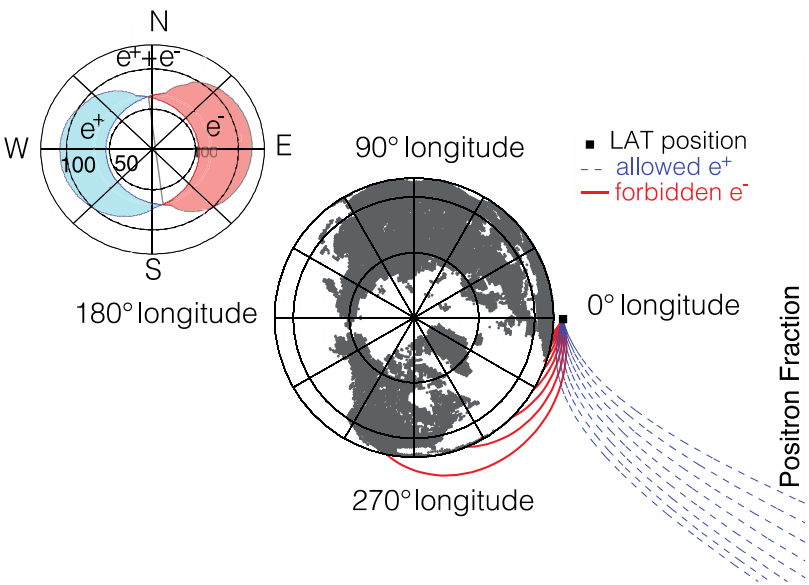


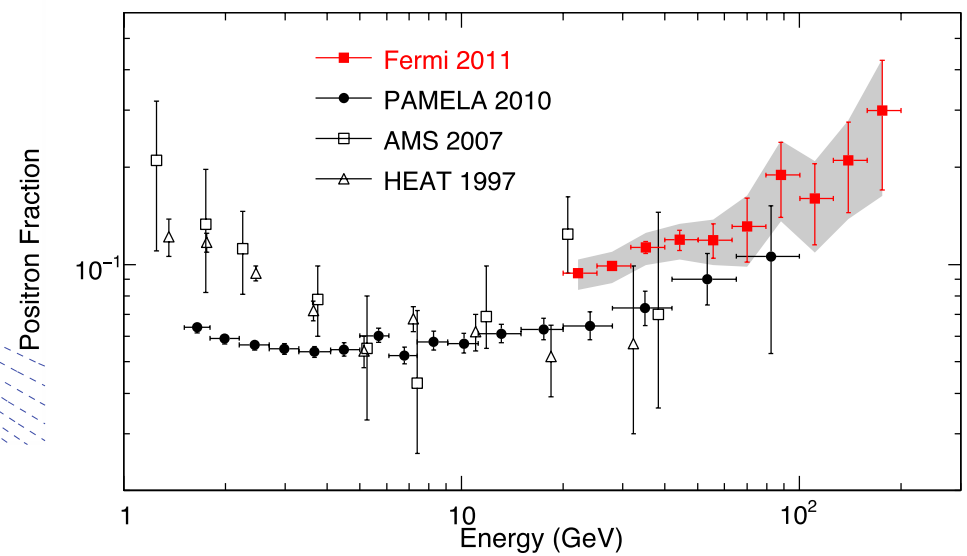


There is seemingly a need for a new source of positrons!

FERMI: New Results

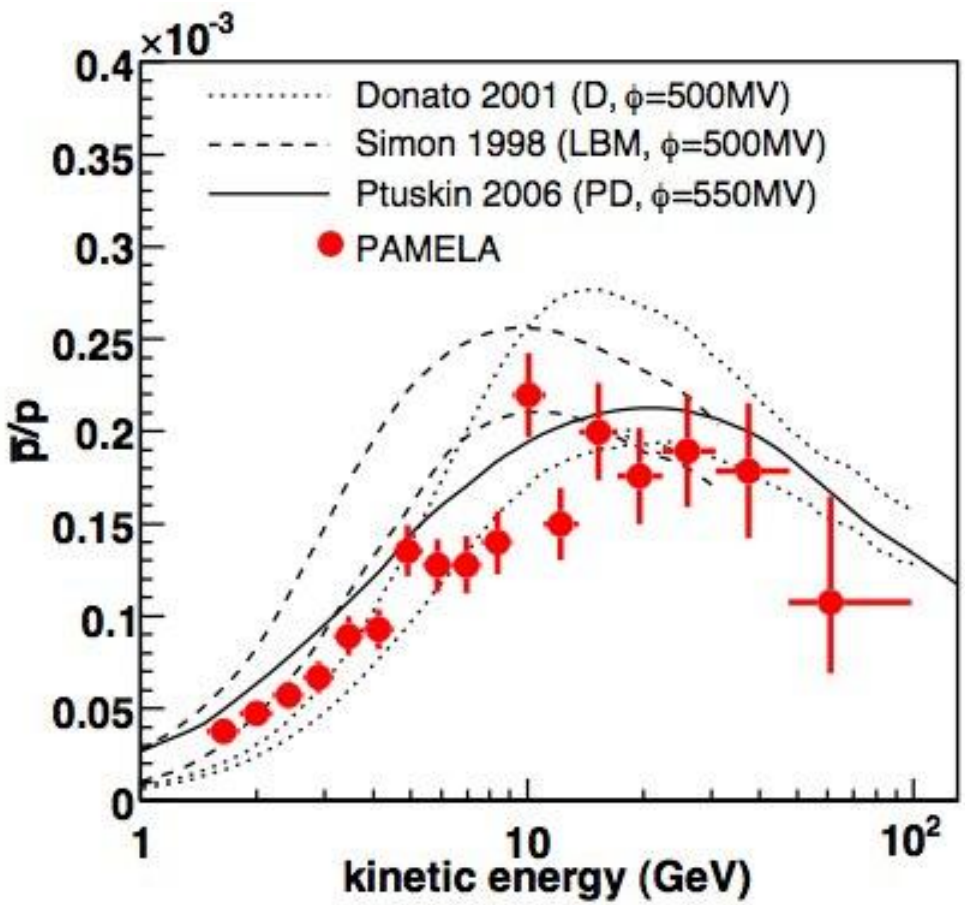
Using Earth's magnetic field and the shadow imposed, energy spectra were measured separately for e^+ and e^-





arXiv:1109.0521v2 [astro-ph.HE] 27 Mar 2012

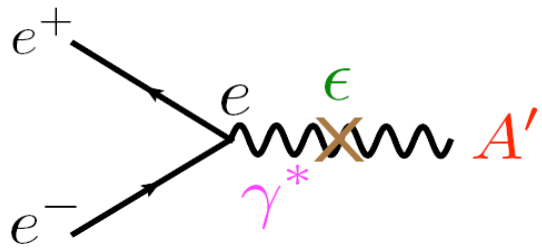
PAMELA – anti-protons



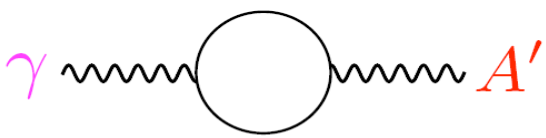
- No excess in anti-proton spectrum
- A new gauge force that is broken at relatively low energies

Coupling of the SM to Hidden sector

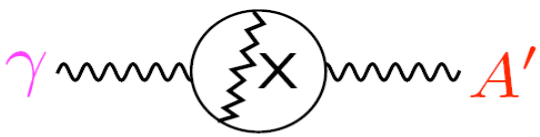
Through the kinetic mixing couples to the Standard Model photon (Holdom '86)



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



$$\epsilon \sim 10^{-4} - 10^{-2}$$



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

(if SM unifies in a GUT)

$$e^2 = \frac{a¢}{a}$$

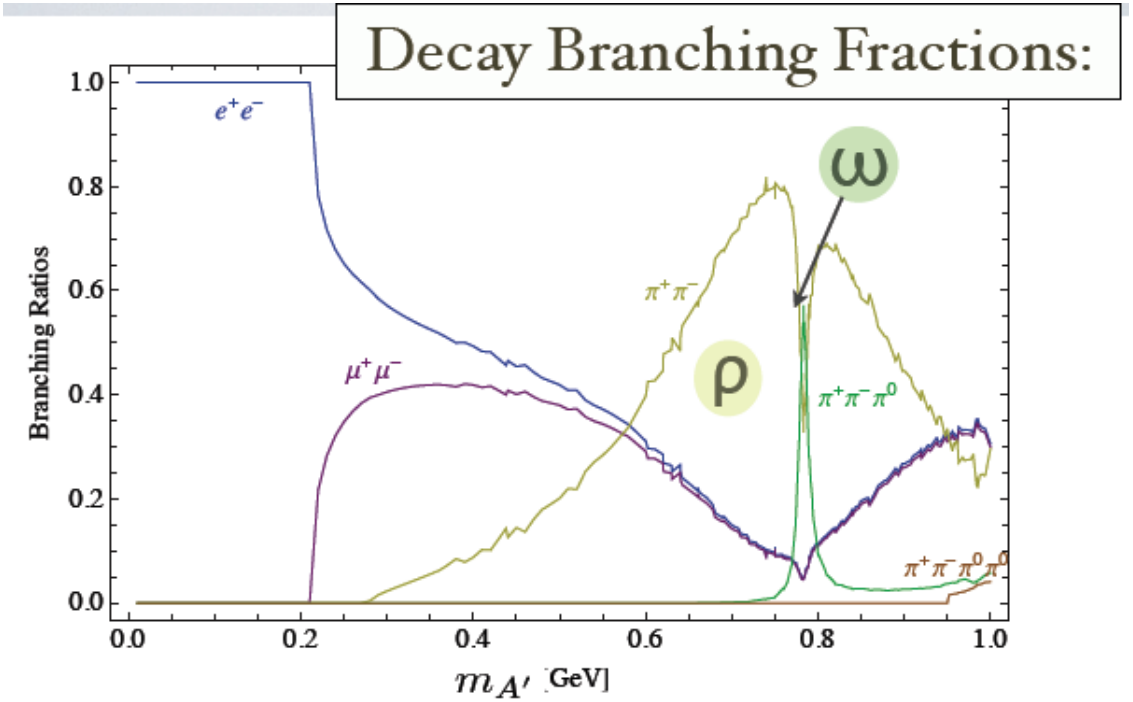
α is the fine-structure constant

Where and how to search for dark photons

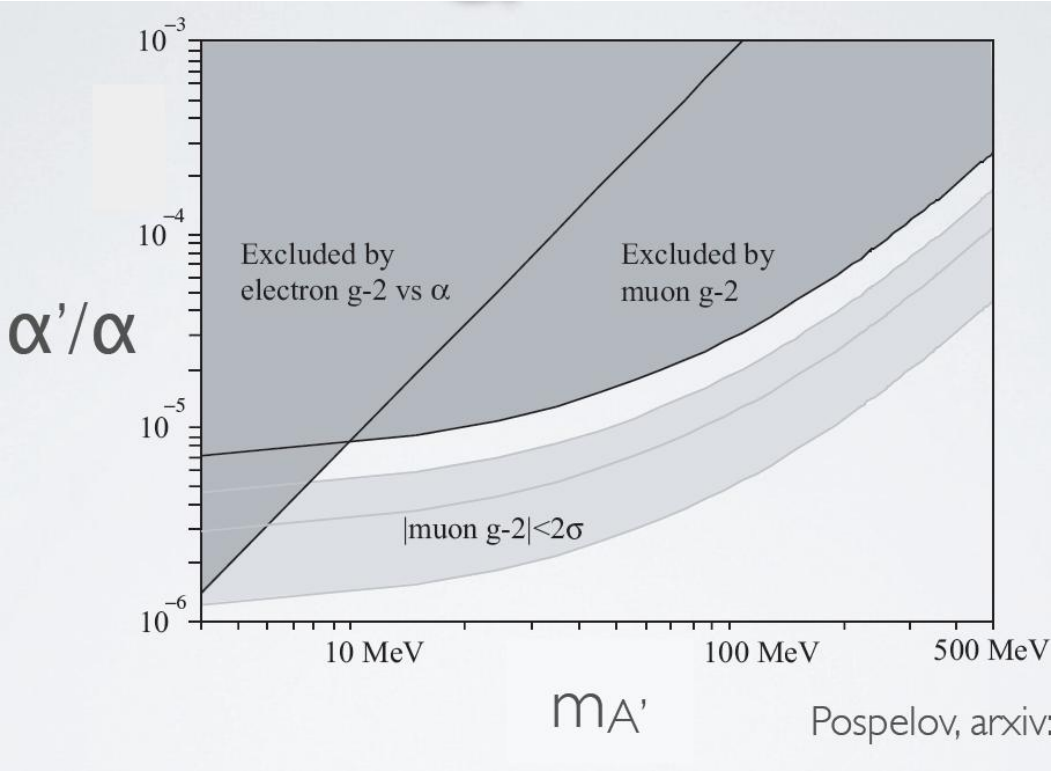
Both "naturalness" arguments and fits to astrophysical data suggest

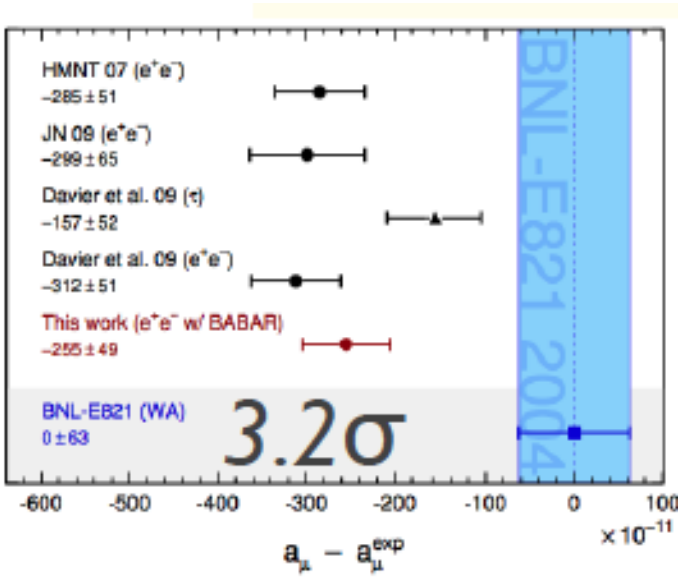
$$\alpha' / \alpha \equiv \varepsilon^2 \sim 10^{-4} - 10^{-10}$$

$$m_{A'} \sim \text{MeV - GeV}$$



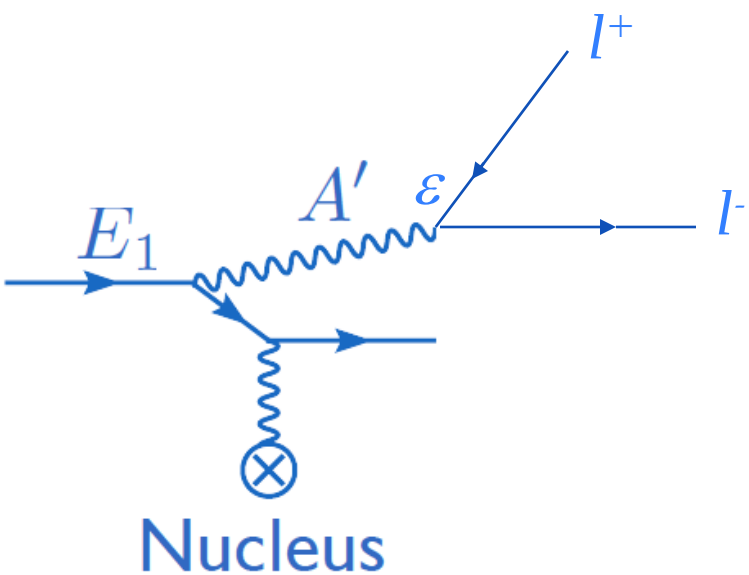
Limits from g_μ-2

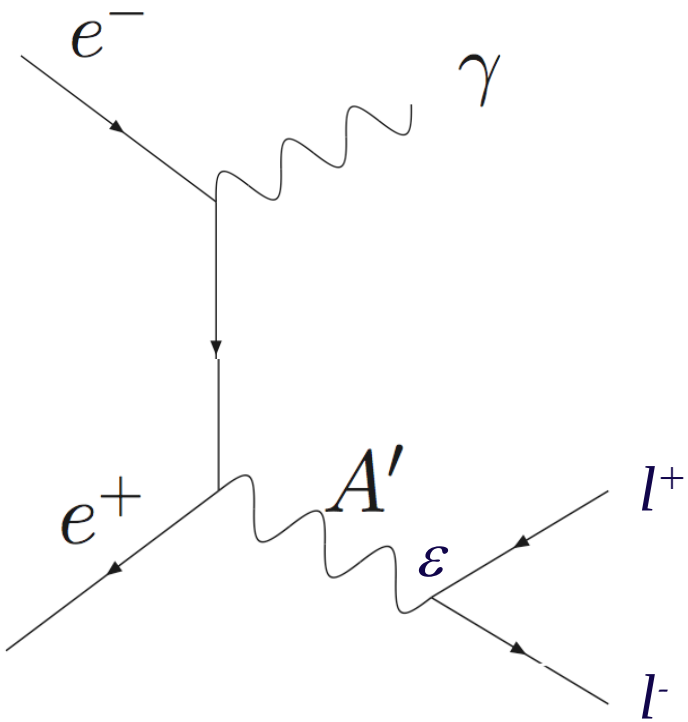




Paspelov, arxiv:0811.1030

Direct searches: l^+l^-





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

J. D. Bjorken, R. Essig, Ph. Schuster, N. Toro (0906.0580)
R. Essig, Ph. Schuster, N. Toro (0903.3941)

Summary for today …

- There is mounting evidence for dark matter in the Universe
- There is also intriguing evidence that particle dark matter annihilation may be responsible for some of striking cosmological observations, linked to the hidden sector photon
- Potential of a hidden sector linked to the SM by a new U(1) gauge boson is exciting:
  - theoretically, there are only a few ways for a new force to manifest itself...parameter space should be explored!
  - possibly explains a number of recent experimental results

The quest for the identification of the missing mass of the universe has began

Tomorrow, review of the Heavy (dark) Photon search experiments will be presented