Searching for Heavy Photons Using TREK

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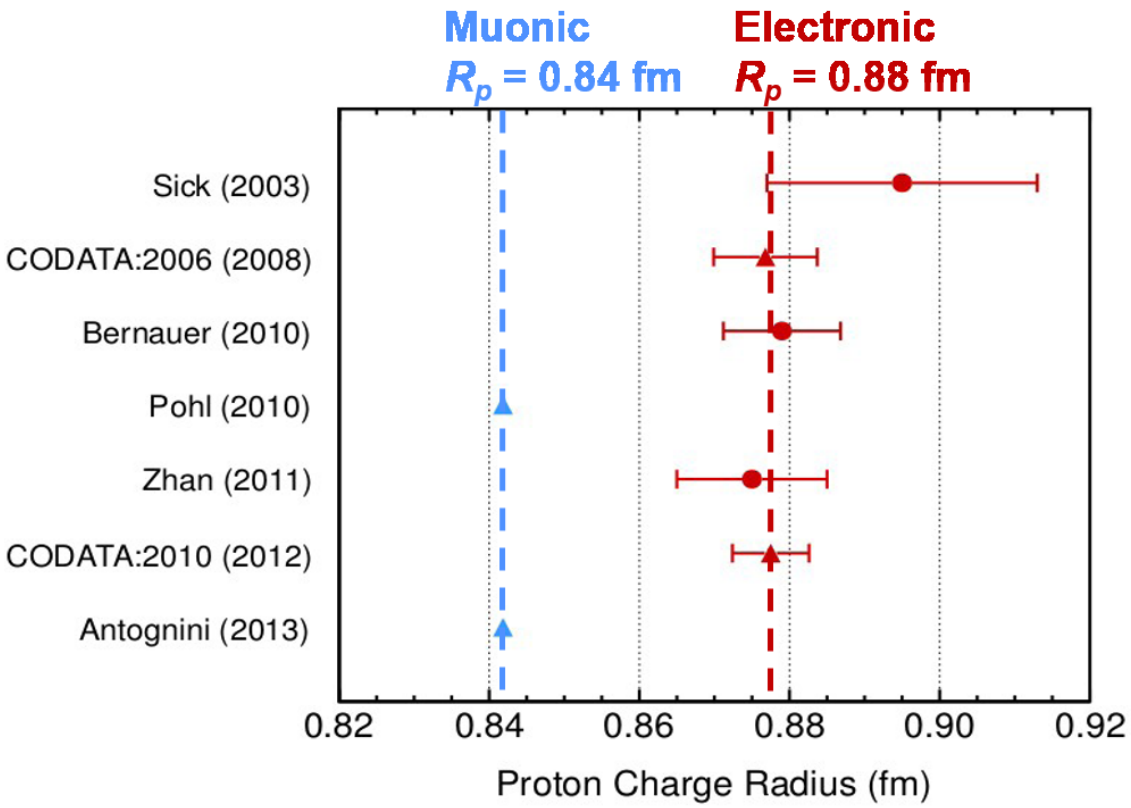
Search for a Light Gauge Boson, A′

- Astrophysical motivation for dark matter annihilation: positron excess observed by PAMELA, FERMI and AMS-2 experiments.
- Muon anomalous magnetic moment, g_μ-2
  → Kinetic mixing model (Holdom 1986, Pospelov 2009)
- Beyond kinetic mixing → the Proton Radius puzzle
- Lepton-flavor non-universal coupling → preferred coupling to muons
  → Coupling to right-handed muons (Batell, McKeen, Pospelov)
  → Fine-tuned non-universal couplings (Carlson, Rislow)

The Proton Radius Puzzle

- $> 7\sigma$ discrepancy between muonic and electronic hydrogen measurements



▲ Spectroscopy

● Scattering data

R_P = 0.84184(67) fm

R_P = 0.875(10) fm

R_P = 0.8758(77) fm

R_P = 0.84087(39) fm

Dark Photons & Proton Radius Puzzle

- Jaeckel, Roy (Phys. Rev. **D82**, 125020 (2010))
  → Hidden U(1) photon can decrease charge radius for muonic hydrogen, however even more so for regular hydrogen
- Tucker-Smith, Yavin (Phys. Rev. **D83**, 101702 (2011))
  → Can solve proton radius puzzle
  → MeV particle coupling to p and μ (not e) consistent with g_μ-2
- Batell, McKeen, Pospelov (Phys. Rev. Lett. **107**, 011803 (2011))
  → Can solve proton radius puzzle
  - new e/μ differentiating force consistent with g_μ-2
  - < 100 MeV vector or scalar gauge boson → dark photon?
- Carlson, Rislow (Phys. Rev. **D89**, 035003 (2014))
  → Can solve proton radius puzzle
  - new e/μ differentiating force consistent with g_μ-2
  - fine tune the coupling for gauge boson
- Barger, Chiang, Keung, Marfatia (Phys. Rev. Lett. **108**, 081802 (2012))
  - Constrained by K → μν decay

Selective e/μ Coupling via Rare Kaon Decays

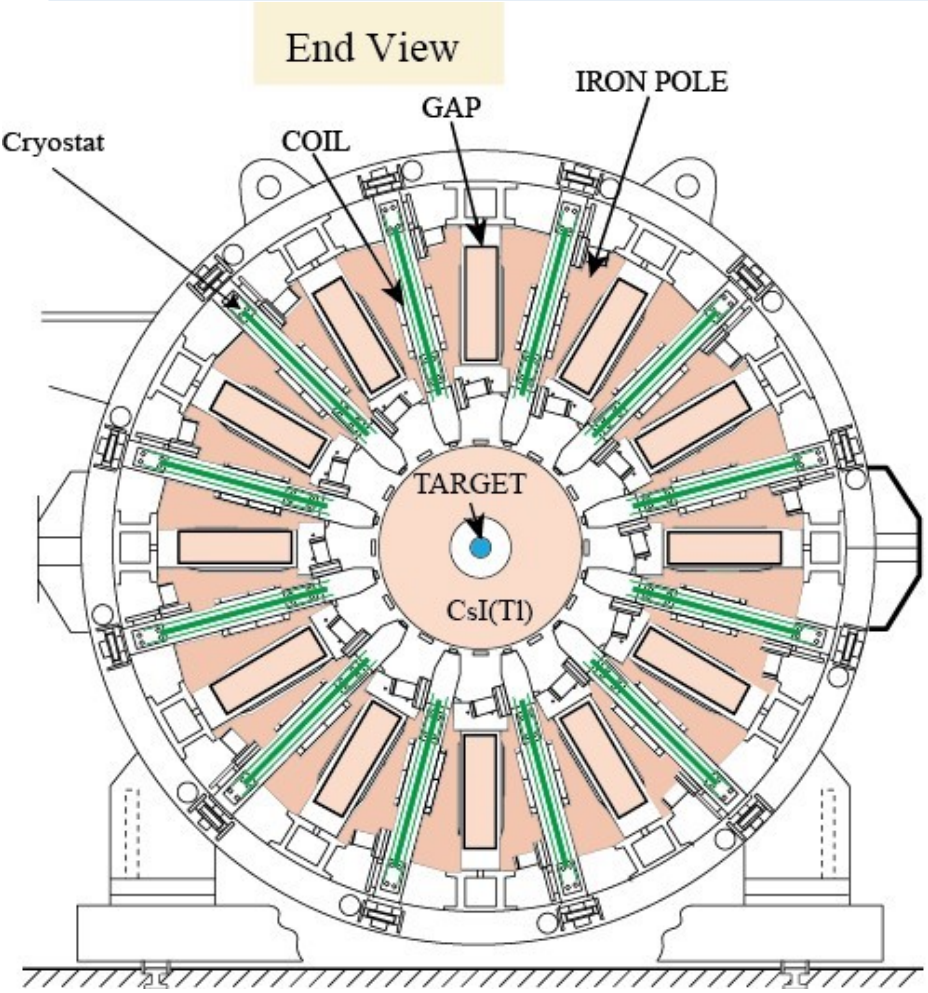
- Require selective e/μ coupling to explain the proton radius puzzle
- Kaon decay channels can constrain the non-universal coupling
  - → Use TREK to detect the kaon decay products
  - → Scheduled to run beginning in 2015
  - → See website: http://trek.kek.jp

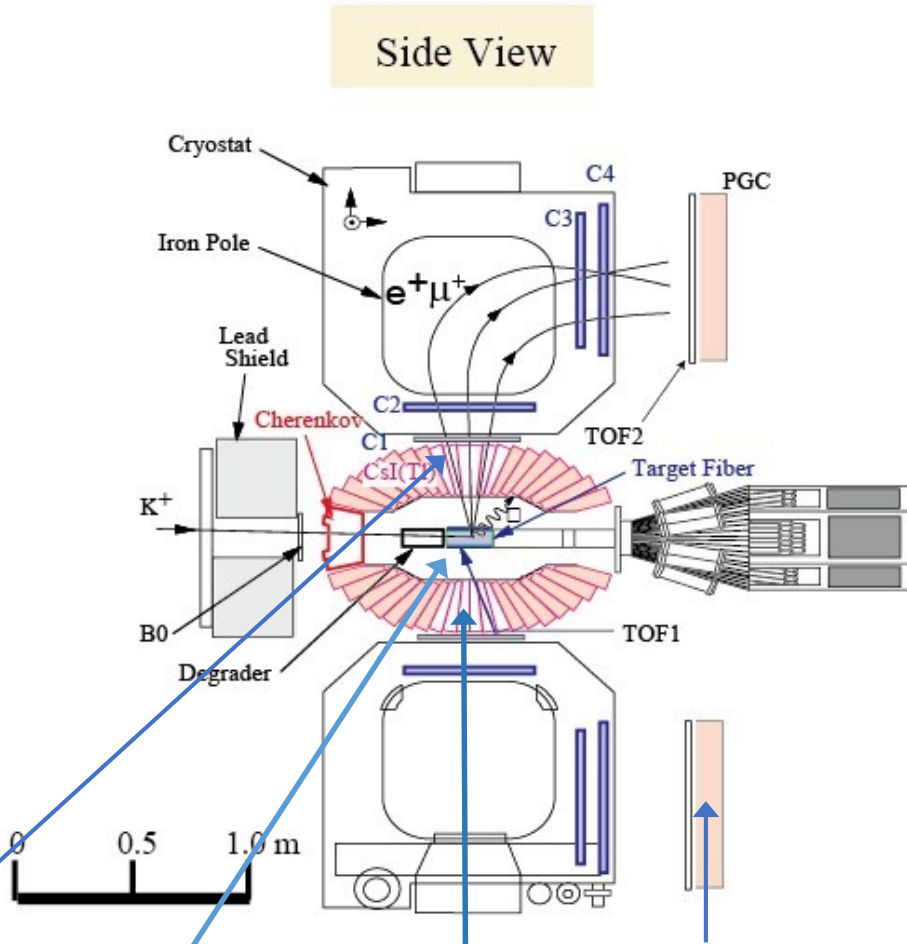
K^+ decays ~ 10^{10}

Signal: $K^+ \rightarrow \mu^+ \nu A'$, $A' \rightarrow e^+ e^-$

Background: (QED) BR($K^+ \rightarrow \mu^+ \nu\ e^+ e^-$) ~ 2.5 x 10^{-5} ~ 250,000 ev.
Add. background from $K^+ \rightarrow \mu^+ \nu \pi^0 \rightarrow \mu^+ \nu\ e^+ e^- (\gamma)$

TREK Detector System





- C1 GEM
- Aerogel Cherenkov

- TOF, Leadglass
- CsI calorimeter

Determination of Mixing Parameter, ε^2

- $\epsilon^2 = \alpha'/\alpha$ describes dark photon coupling strength to the electromagnetic current.
- Based on cross section ratio derived in eqn. 19 of Bjorken *et al.*, Phys. Rev. **D80**, 075018 (2009)
- Requires signal > 2*(background fluctuation)

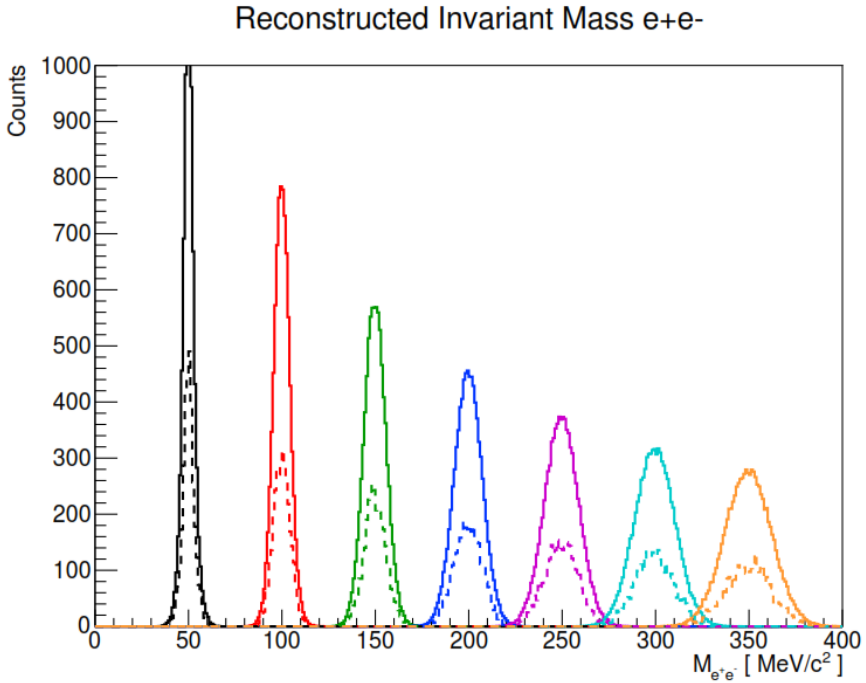
$$\varepsilon^2 = \frac{2}{\sqrt{BR\left(K^+_{\mu^+\nu_\mu l^+ l^-}\right)(m_{\gamma'}) \times N_{K^+}}} \frac{2N\alpha}{3\pi} \frac{\delta m}{m_{\gamma'}}$$

$BR\left(K^+_{\mu^+\nu_\mu l^+ l^-}\right)(m_{\gamma'}) \times N_{K^+}$ = total number of events in mass bin at $m_{\gamma'}$ with width δm

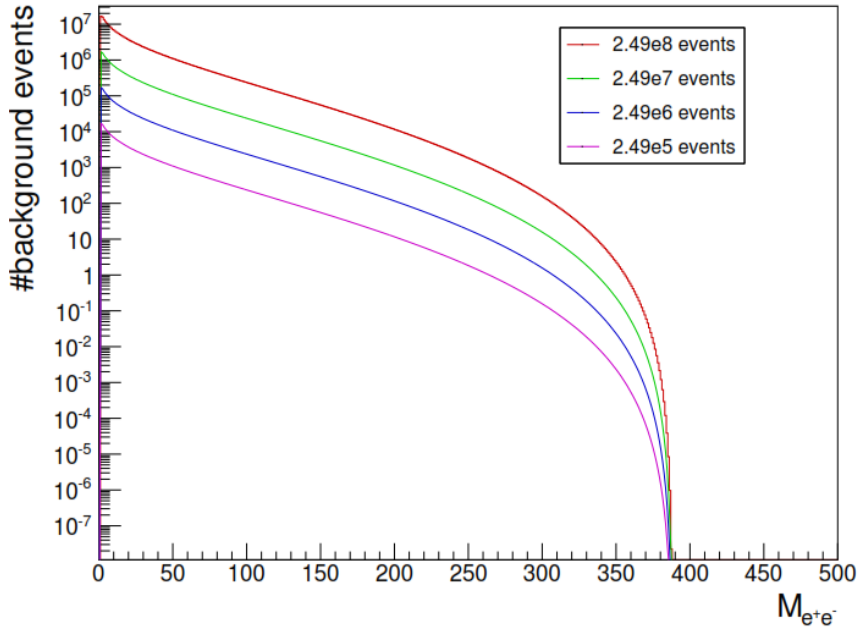
$\frac{\delta m}{m_{\gamma'}}$ ← mass cut

$m_{\gamma'}$ ← Chosen heavy photon mass

Reconstructed Invariant Mass



- Solid line is before acceptance cut
- Dashed line is after CsI acceptance cut applied.
- Use sigma for mass cut with $\delta m = 2*\sigma$

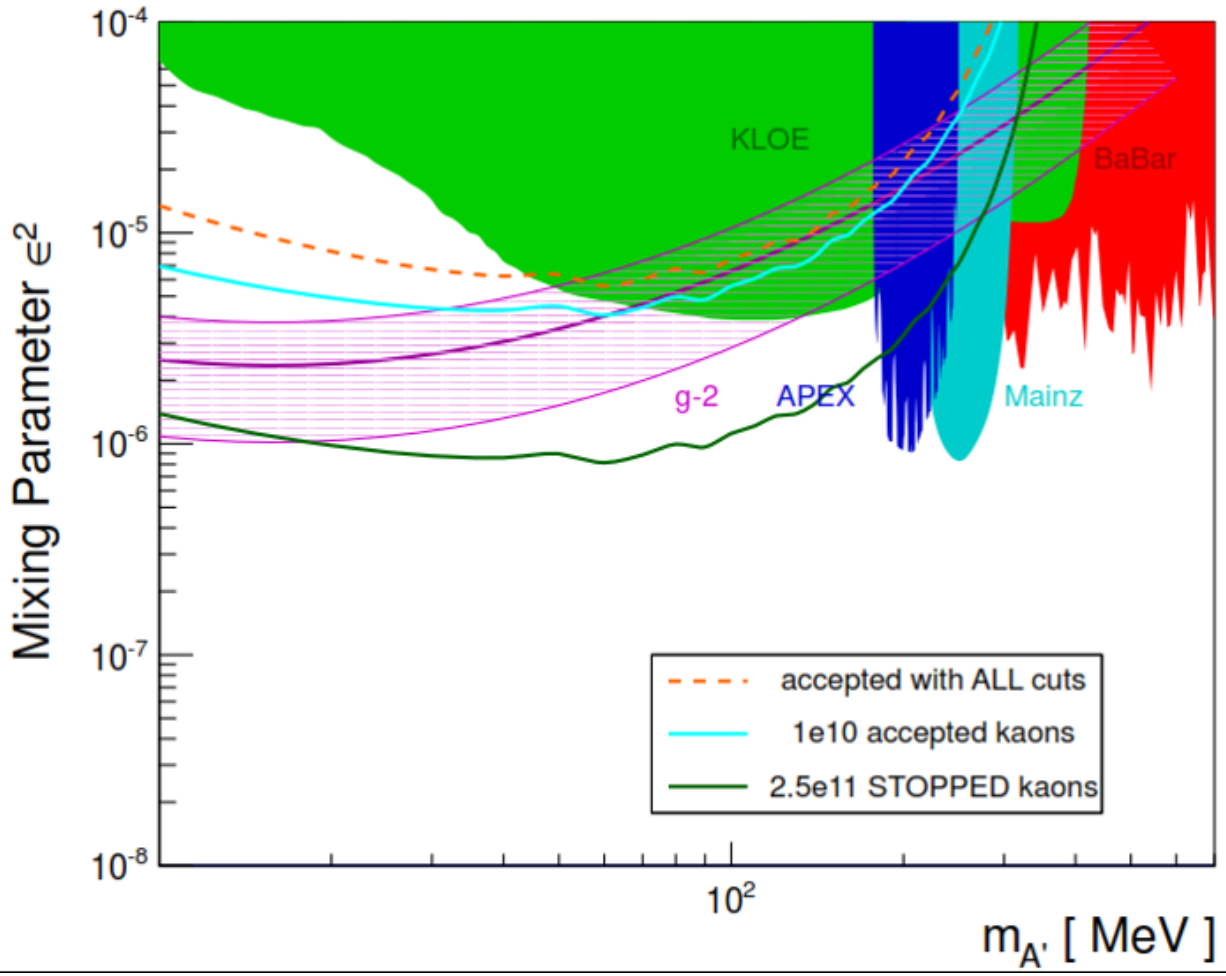


- Renormalise to account for Bijnens B.R. = 2.49e-5
- Total integral should be the number of expected events given by,

$$N_{kaons} \times \text{Total B.R.}$$

- Use distributions to evaluate ε^2

Simulated ε^2



- δm cut varies
- depends on width found in signal simulations
- Use δm = 2*σ
- σ ~ 2.5 – 11 MeV
- Rescaled to take account of the acceptance
- Apply detector acceptance cuts
- more stopped kaons → ε^2 curve probes lower

Search for a new particle in $K^+ \to \mu^+ \nu e^+ e^-$

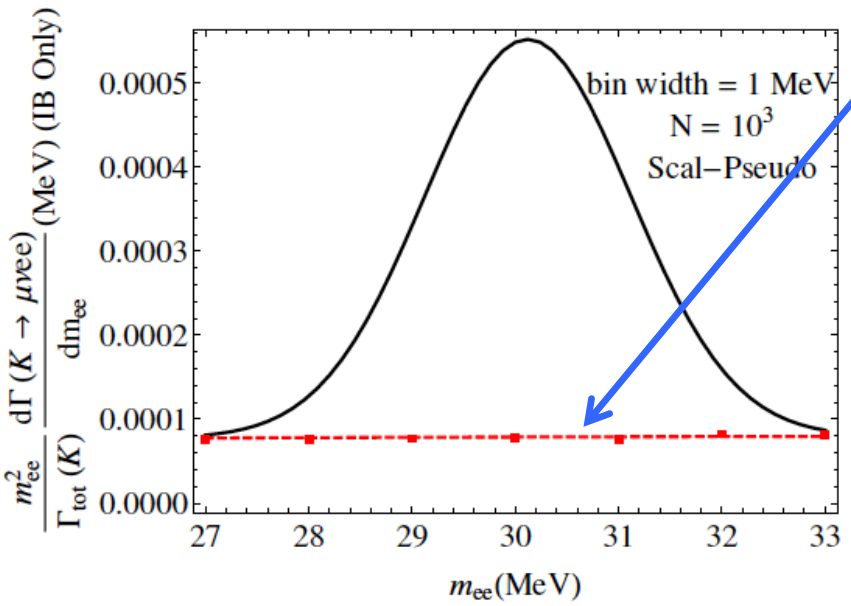
QED background: $K^+ \to \mu^+ \nu e^+ e^-$

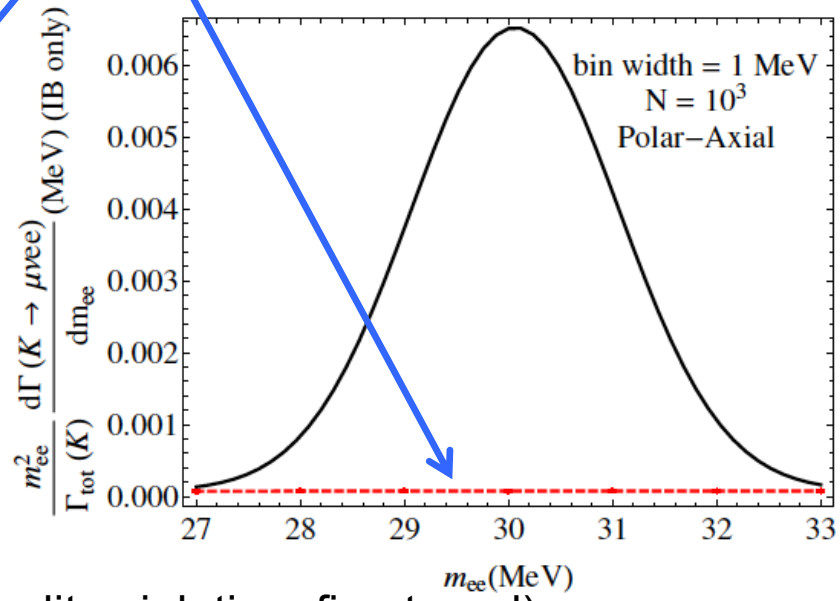
- $\Gamma(K^+ \to \mu^+ \nu ee) \sim 2.5 \times 10^{-5}$
- Expect 10^{10} stopped K^+ in E36
- 250k QED evts or ~1000 / MeV

Signal: $K^+ \to \mu^+ \nu A'$, $A' \to e^+ e^-$

Carlson & Rislow
(Phys. Rev. **D89**, 035003 (2014))

same background!





Carlson&Rislow model (universality-violating, fine tuned)

HUGE signals predicted, E36 very stringent test

Summary

- Many experiments searching for heavy photons
- Using rare kaon decay channel, can probe parameter space for dark photon model – universal coupling.
- TREK/E36 specifications lend to an exclusion curve in the g-2 region
- Simulations presented are a first step
- Other background decay channels to be investigated
- If other models (e.g. right-handed muon) are correct, then exclusion region for those signals should be straightforward to measure.
- TREK/E36 can rule out any new physics explanation of the proton radius puzzle involving light bosons with preferred couplings to muons.