g-2 Revisited

The Dark Z Strikes Back

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BNL Lunch Discussion

May 21, 2021

Based on H. Davoudiasl, H.-S. Lee, and W. J. Marciano. 2012-2015

+

M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, and E. Picciau

HEP-PH April 21, 2021

Recent Fits g-2, Q_W(Cs), Q_W(P) for Z_d Model

BROOKHAVEN
NATIONAL LABORATORY

Magnet Leaves BNL (Summer 2013)

Fermilab + Storage Ring at Night

Status of Muon & Electron SM g-2 Values

$a^{exp}(\mu) = 116\ 592\ 061(41)\times10^{-11}$ Recent BNL + Fermilab

$\Delta a(\mu) = a^{exp}(\mu) - a^{SM}(\mu) = 251(59)\times10^{-11}$ 4.2 sigma deviation

$\Delta a(e) = a^{exp}(e) - a^{SM}(e) = 48(30)\times10^{-14}$ 1.6 sigma deviation using $\alpha(Rb)$

Expect for heavy "new physics" $\Delta a(\mu)/\Delta a(e) = m^2_\mu/m^2_e \approx 4\text{x}10^4$

off by a factor of 8

New Physics Scale M: $m_e < M < m_\mu$ $\Delta a(\mu)$ & $\Delta a(e) = \frac{\alpha}{2\pi}\varepsilon^2 F\left(\frac{m_l^{\,2}}{m_d^{\,2}}\right)$

$new\ physics\ mass$ & coupling

Dark Photon mass ~ 30-100MeV

Kinetic Mixing $\varepsilon \approx 2x10^{-3}$

Dark Symmetry & Our World

***1. Kinetic $U(1)_Y$ x $U(1)_d$ Mixing (B. Holdom): $B_{\mu\nu}D^{\mu\nu}$**

***2. Z-γ_d mass mixing (DLM)**

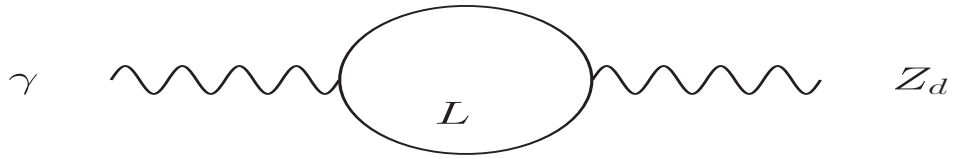
***3. $U(1)_d$ = B-L, L_μ-L_τ, L_e-L_μ, L_e-L_τ… Dark Symmetry**

***(some particles have dark charge & ordinRT)**

***(P. Fayet) Very Small Couplings $U(1)_d$)**

Example

One Loop gamma-γ_d Kinetic Mixing
(Through Heavy Charged Leptons)
That also carry $U(1)_d$ charge
Expect $\varepsilon \sim e g_d Q Q_d / 8\pi^2 \leq O(10^{-3})$

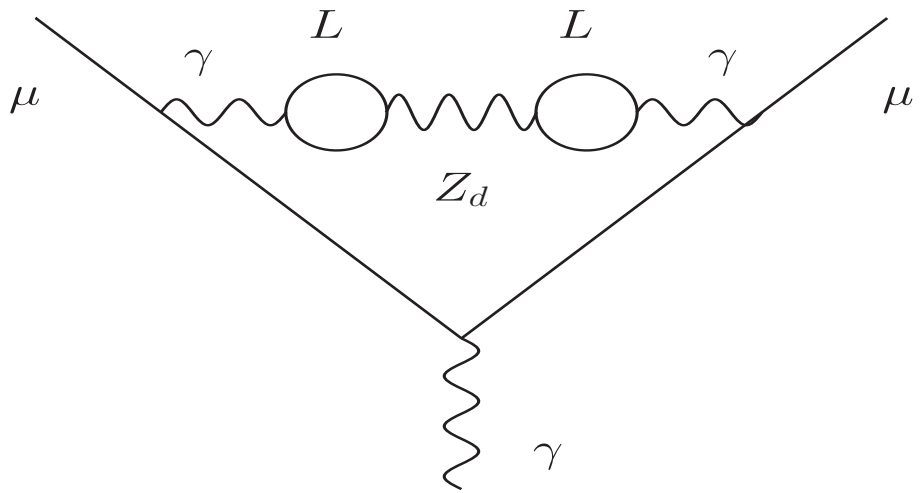


Muon Anomalous Magnetic Moment

$a_\mu^{Zd}=\alpha/2\pi\varepsilon^2 F(m_{Zd}/m_\mu)$, $F(0)=1$

solves $(g_\mu-2)/2$ discrepancy $\approx 288(80)\times10^{-11}$

for $\varepsilon^2\approx10^{-6}$-$10^{-4}$ & $m_{Zd}\approx$10-300MeV (see figure)

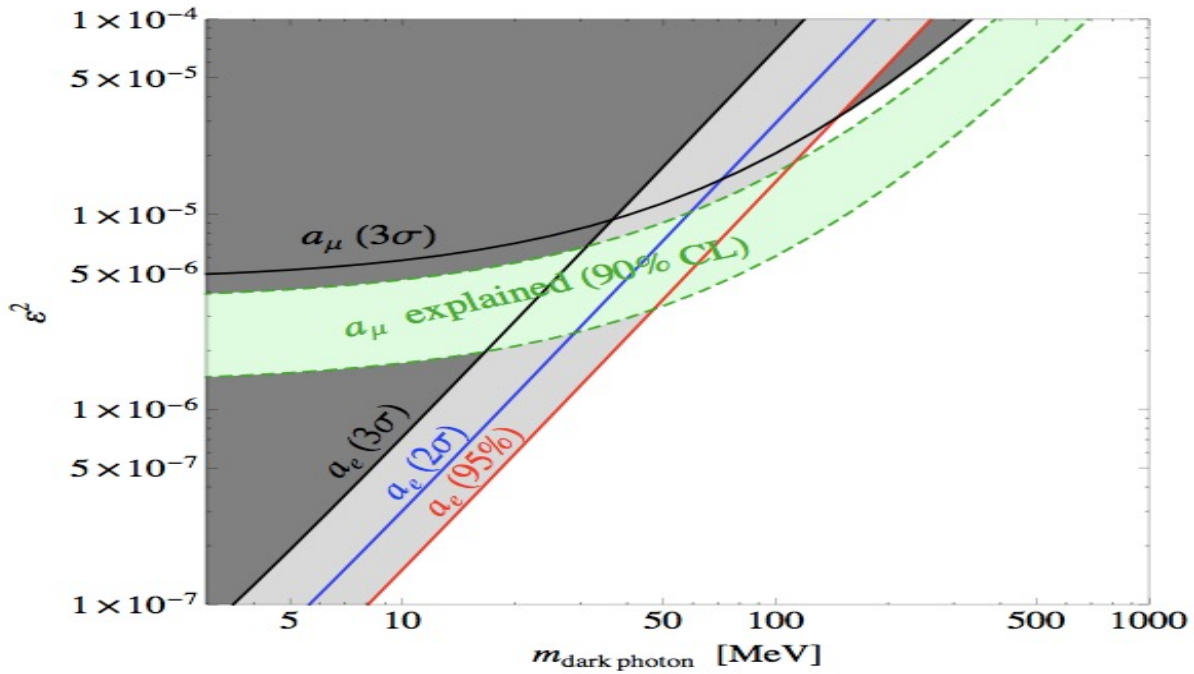


Lepton Magnetic Moment Constraints on the Dark Photon

Green Band Corresponds to $a_\mu^{exp}-a_\mu^{SM}=288(63)(49)\times10^{-11}$ 90% CL

g_e-2 Constraint DAVOUDIASL, LEE, MARCIANO

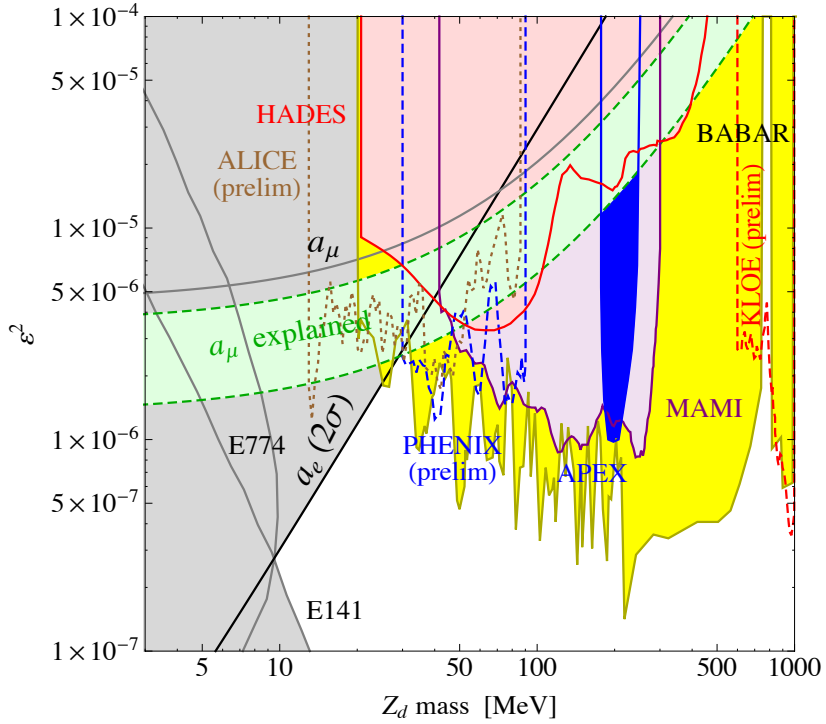
$a_e(\text{exp}) - a_e(\text{theory}) = 0.48\ (0.30) \times 10^{-12}$

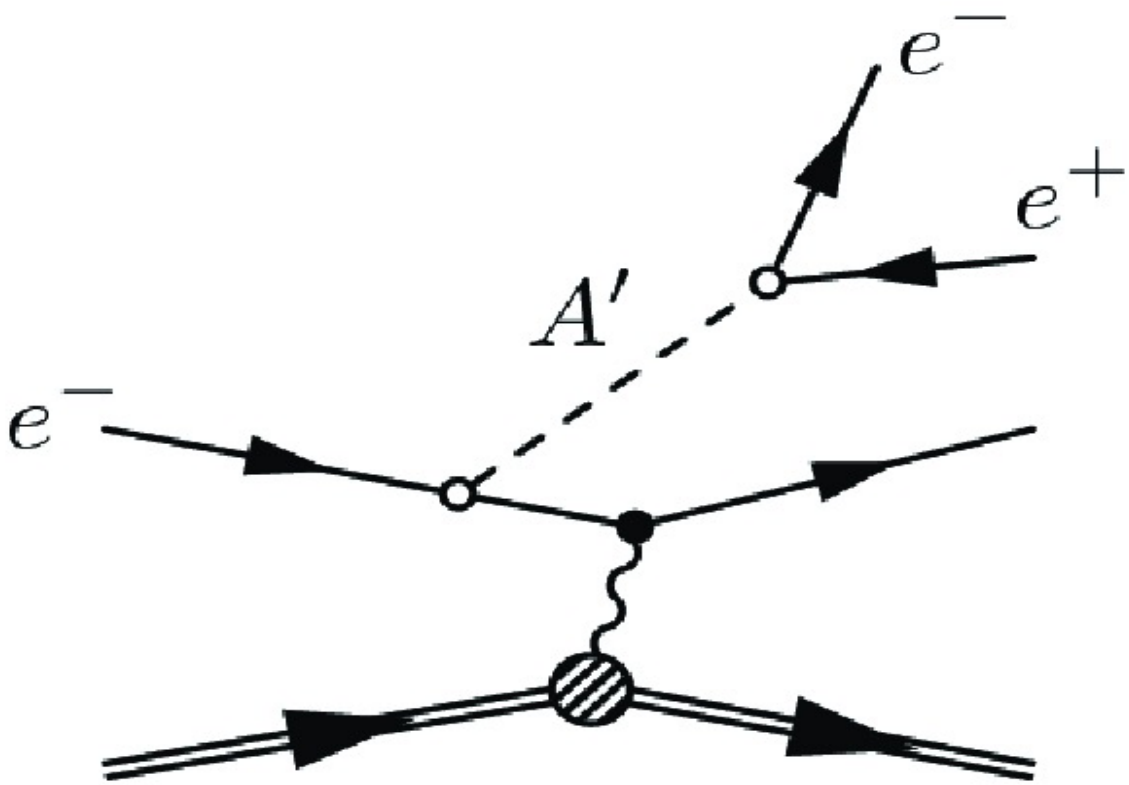


Current Dark Photon Constraints

Assuming BR(Z_d➔ e+e-) ~1. (ruled out)

Require Z_d decays to light dark matter Most bounds go away




e^-
e^+
A'
e^-

Near Term Sensitivity Improvements

MAMI 2013 **$\varepsilon^2 \geq 10^{-6}$ for m_{Z_d} >40MeV explored**

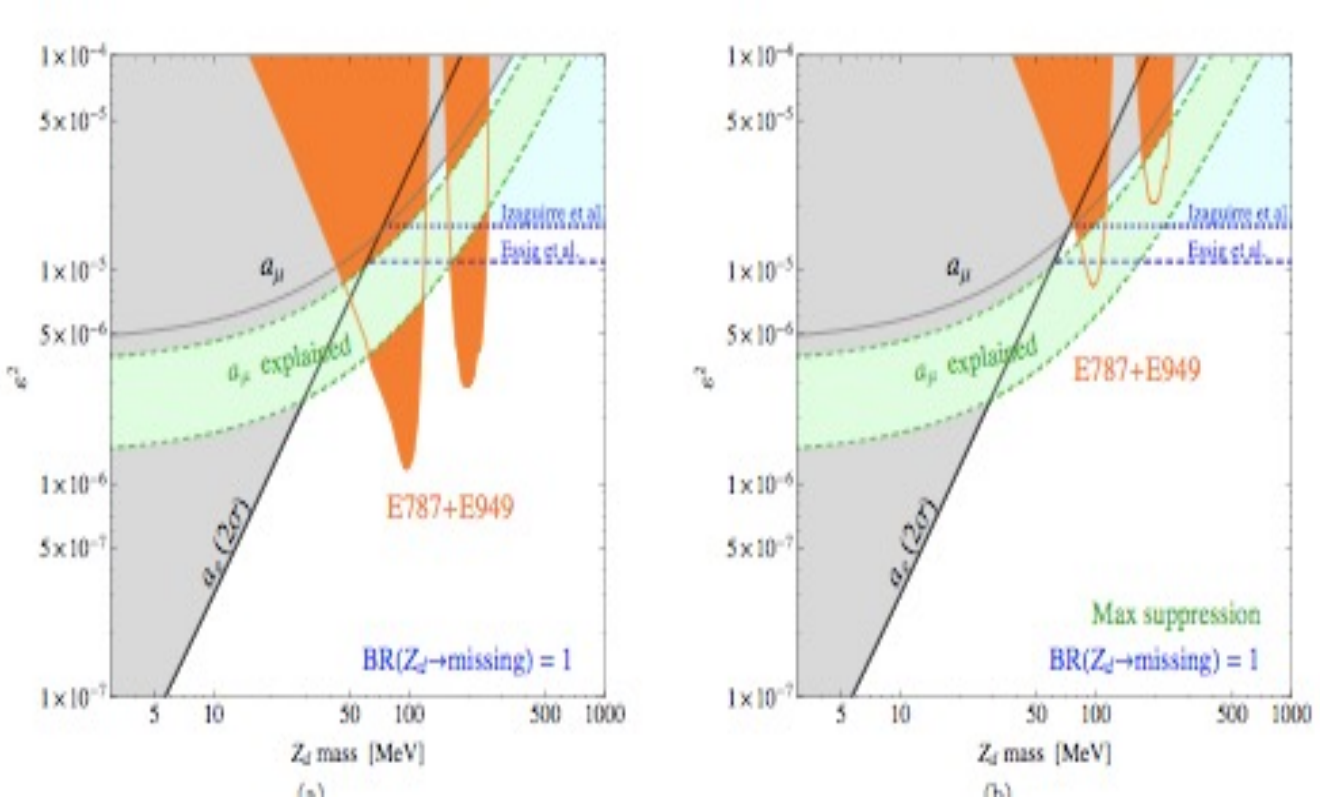
NA48 DATA $\varepsilon^2 \geq 10^{-6}$ for m_{Z_d} >10-20MeV explored
Using $\pi^0 \rightarrow \gamma Z_d$ $Z_d \rightarrow e^+e^-$

The g_μ-2 scenario may soon be ruled out for $Z_d \rightarrow e^+e^-$

Very light dark matter allows $Z_d \rightarrow$ dark matter (invisible)

New scenario eliminates many constraints but allows
$K \rightarrow \pi Z_d$ $Z_d \rightarrow K$ +"missing energy" constraints

K➔$\pi^+ Z_d$ Constraints for BR(γ_d (*dark matter)~1*
m_{Zd}=100, 200MeV ruled out?



Dark Parity Violation (needs study of $O(\varepsilon^2)$)

H. DAVOUDIASL, H-S LEE, W. MARCIANO

Effect of ε & ε_Z together: (at low $Q^2 \ll m_Z^2$)

$\Delta\sin^2\theta_W(Q^2) = -0.42\varepsilon\delta m_Z m_{Zd}/(Q^2+m_{Zd}^2)$

For $\delta \approx m_{Zd}/m_Z$, $\Delta\sin^2\theta_W(Q^2) = \pm 0.42\varepsilon m_{Zd}^2/(Q^2+m_{Zd}^2)$

Shift largest at small $Q^2 \ll m_{Zd}^2$ (≈O(1%)! Eg APV)

(1.5 sigma APV deviation) fit ⟨ ***$\varepsilon\delta = 4\times10^{-6}$***

or $\varepsilon \approx \delta \approx 2\times10^{-3}$ for (g_μ-2) & APV ⟨ ***$m_{Zd} \approx 50$MeV region***

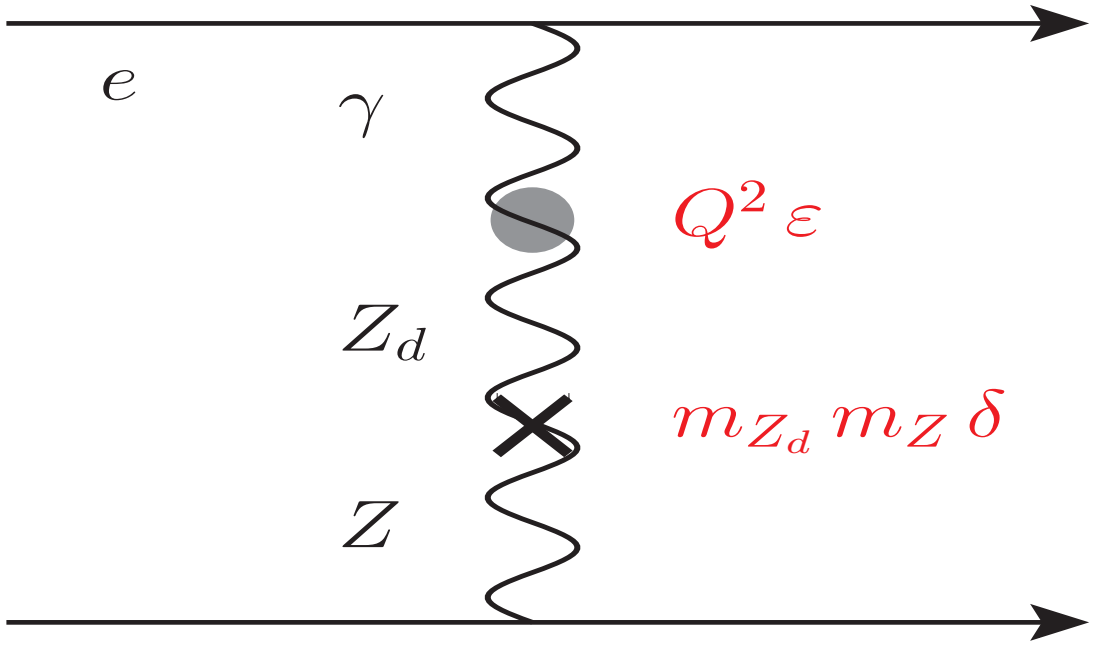
$\sin^2\theta_W(Q \approx 75\text{MeV})$ shift by ±O(0.5-1%)!!

δ down to $\approx 10^{-3}$ Potentially Observable

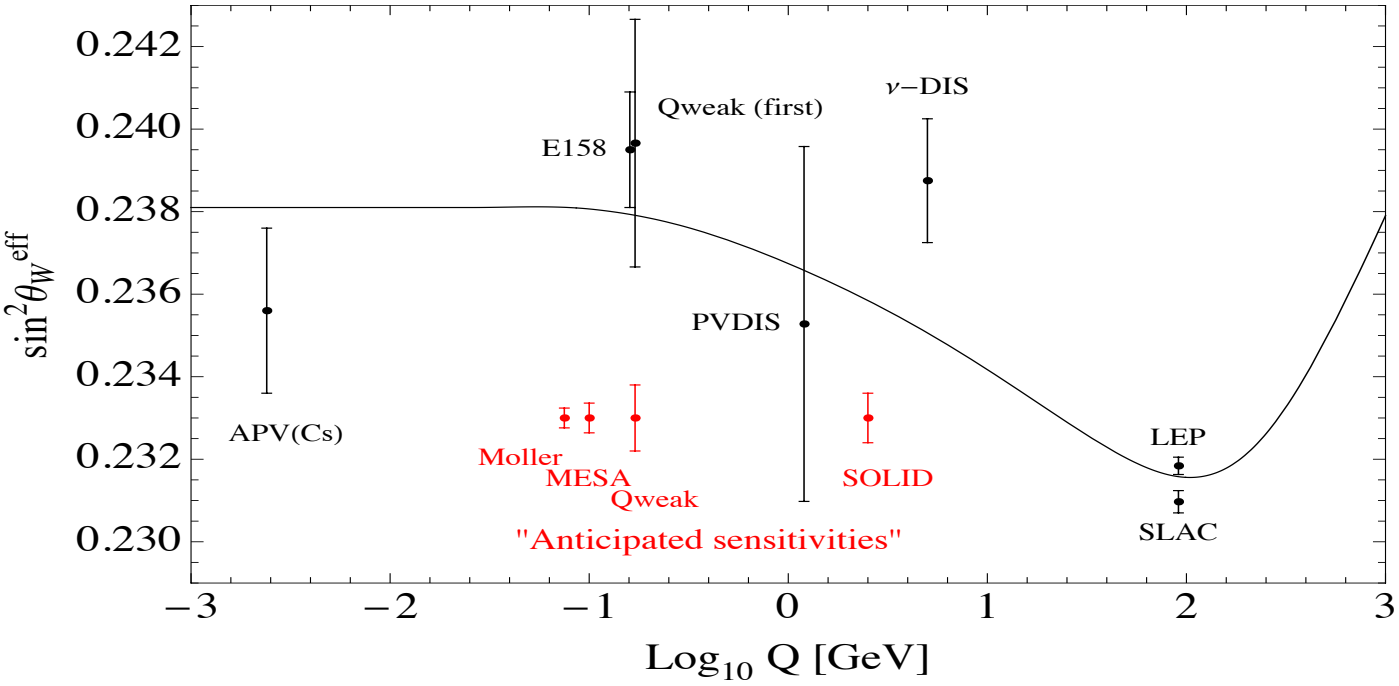
A_{RL}(ee) & A_{RL}(eC) at low Q^2 Potentially Important

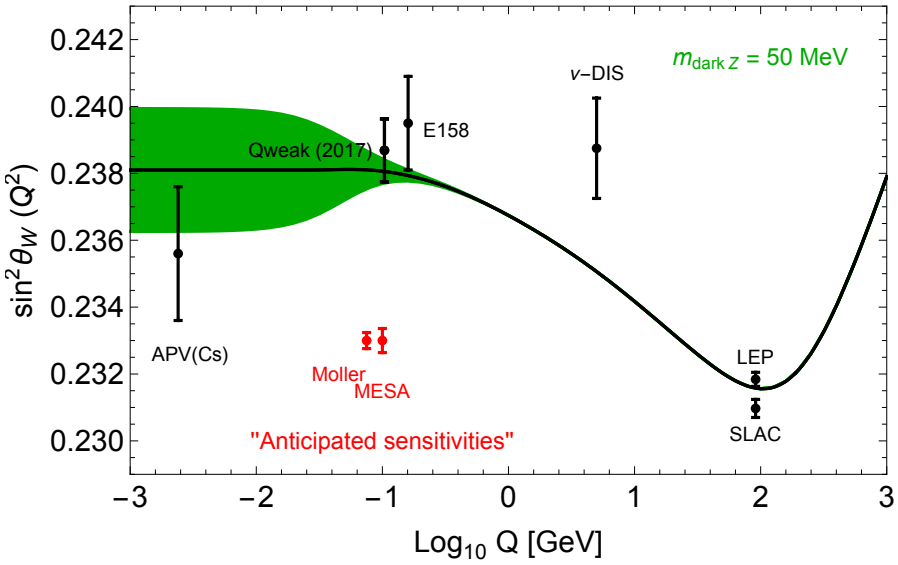
Negligible effect at the Z Pole!

Dark Z Effect on electron scattering
Photon-Z Mixing through Z_d
from H-S Lee



$\sin^2\theta_W(Q^2)$ Measurements & expected Future Sensitivities




0.242
0.240
0.238
0.236
0.234
0.232
0.230
$\sin^2\theta_W$ (Q^2)
−3
−2
−1
0
1
2
3
Log_{10} Q [GeV]
$m_{\mathrm{dark}\,Z}$ = 50 MeV
Qweak (2017)
E158
ν−DIS
APV(Cs)
Moller
MESA
LEP
SLAC
"Anticipated sensitivities"

Light dark Z solution to g-2 is Viable with mass apprx 50MeV
Decays to light dark matter

- Possible Exp. Consequences: mixing (10^{-3})
- Electron g-2 Exp. Improve muon g-2 theory & exp.
- Parity Violation at Jlab (under investigation)
- K decay to pi + missing energy