Parity Violating Polarized eC Scattering Asymmetry A_{RL}(eC) & New Physics

1) eC(±0.3%) vs ±25% Bates
2) New Physics Sensitivity

Q_W(C) vs Q_W(Cs), Q_W(e), Q_W(p)

i) Short-Distance Phys.
ii) Dark Parity Violation

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For a recent review containing much of this material see:

"<u>Low-Energy Measurements of the Weak Mixing Angle</u>"

Annual Review of Nuclear and Particle Science (2013)
K. Kumar, S. Mantry, W. Marciano & P. Souder

<u>Elastic Polarized PV eC➔eC</u>

$A_{RL} \equiv \sigma_R - \sigma_L / \sigma_R + \sigma_L$,

- ***<u>G. Feinberg(1975)</u>***: Simple 0^+➔0^+ Amplitude

$A_{RL}(eC) = -2^{1/2} G_F Q^2 / 48\pi\alpha \times Q_W(^{12}C)$

$Q_W(^{12}C) = -24 \sin^2\theta_W$

Hadronic Effects Cancel at low Q^2 (*<u>see Donnelly Talk</u>*)

Robust Carbon Target can take high current

No Solenoid Spectrometer Polarized Target Issue for 0^+

A_{RL}(eC) (historical comparison)

BATES EXP A_{RL}(eC) (1978-1990)

P. Souder et al. PRL65, 694(1990) (Pioneering Effort)

($0^+ \rightarrow 0^+$ Elastic Scattering)

Very Modest Effort by today's standards

E_e=0.25GeV, P_e=0.37±0.02, I=30-60μA, <Q>=150MeV, T=150hrs

$A_{RL}(eC)^{SM} = G_\mu Q^2 \sin^2\theta_W / \sqrt{2}\pi\alpha$ $P_e A_{RL}(eC)^{exp} = 0.60 \pm 0.14 \pm 0.02 \times 10^{-6}$

Measured $\sin^2\theta_W = 0.20 \pm 0.05$

Current ±25% can be improved (statistically) to ±0.2% or better!

P_e=0.85, I=150-500μA, T=1500-5000hrs, 20xAcceptance→±0.2%!

Roughly Equivalent to 3xAPV(Cs) Sensitivity but no Atomic Theory

Main Issue: Polarization ±0.2%, (Very Challenging!)

Note, if only ±0.4% Pol. Attainable, that will be ≈ uncertainty

Elastic eC vs ep F.O.M

Statistical Figure of Merit ≈ A^2 x # scattering events

±0.2% eC compared to ±1% ep (requires **25x** larger F.O.M.)

All else equal (Pol., I, Target, Acceptance, Q^2(small)…)

$\frac{\text{F.O.M.(eC)}}{\text{F.O.M.(ep)}} = [(4s^2/(1-4s^2)]^2 x36 \approx$ **5500**! ➔ eC takes ≈**1/200 time!**

Alternative lower <Q>≈40MeV in eC statistically ***easy!***

A_{RL}(eC) good exp at Mainz or JLAB (limited by Pol. Unc.)

Polarization: ***Needs R&D Effort ±0.2% - ±0.4%***

Standard Model Predictions

- m_{Higgs}=125-126GeV   SM Now Complete!

  Combined with other fundamental parameters
- α^{-1} = 137.035999173(35)
- G_F = 1.1663787(6) × 10^{-5} GeV^{-2}
- m_Z = 91.1876(21) GeV
- m_t=173.3(8) GeV

  And Electroweak Radiative Corrections

Precise Predictions Possible – Test **"New Physics"**

Eg. S & T Loop Effects: 4^{th} Generation, Technicolor..

Zχ from SO(10), Contact Interactions…

m_W & $\sin^2\theta_W(m_Z)_{MS}$ Predictions

$m_W = 80.362(6)\text{GeV}[1 - 0.0036S + 0.0056T]$

$m_W = 80.385(15)\text{GeV}$ (experiment) *somewhat high*

$\sin^2\theta_W(m_Z)_{MS} = 0.23124(6)[1 + 0.0157S - 0.0112T]$

$\sin^2\theta_W(m_Z)_{MS} = 0.23125(16)$ (Z pole experimental ave.)

$S = 0.07 \pm 0.09$ and $T = 0.10 \pm 0.09$

Very dependent on $\sin^2\theta_W(m_Z)_{MS}$ value!

Significantly Constrains: 4th Generation, Technicolor, SUSY…

Low Q^2 Measurements of $\sin^2\theta_W(m_Z)_{MS}$

$\sin^2\theta_W(m_Z)_{MS}$ =0.2283(20) Cs APV at ⟨Q⟩ ≃ 2.4 MeV

Dzuba, Berengut, Flambaum, Roberts 2012 PRL

$Q_W(Cs) \rightarrow -72.58(29)(32)_{th}$ Update vs SM -73.24(5)

(1.5 sigma APV deviation)

$\sin^2\theta_W(m_Z)_{MS}$ =0.2329(13) Møller A_{PV} at ⟨Q⟩≃160 MeV

$A_{RL}(ee)=-131(14)(10)\times10^{-9} \propto (1-4\sin^2\theta_W)$

Measured to ±12% $\rightarrow \sin^2\theta_W$ to ±0.6%

$\sin^2\theta_W(m_Z)_{MS}$ =0.2356(16) $\nu_\mu N$ at ⟨Q⟩ ≃ 5 GeV

Needs Reanalysis

Future Expectations

QWEAK exp at JLAB (Under Analysis)

$A_{RL}(ep \rightarrow ep) \approx -3\times10^{-7}$ E=1.165GeV, <Q>≈160MeV, Pol≈89±1%

$\Delta\sin^2\theta_W(m_Z)_{MS}=0.0008$ via ±4% measurement of A_{RL}

Polarized Moller at JLAB E=11GeV <Q>=75MeV

$A_{RL}(ee \rightarrow ee)$ to ±2.5% $\Delta\sin^2\theta_W(m_Z)_{MS}=\pm0.00025!$

P2 MESA Flagship Experiment $A_{RL}(ep \rightarrow ep)$

Like ***JLAB QWEAK*** but Lower Energy & More Running Time

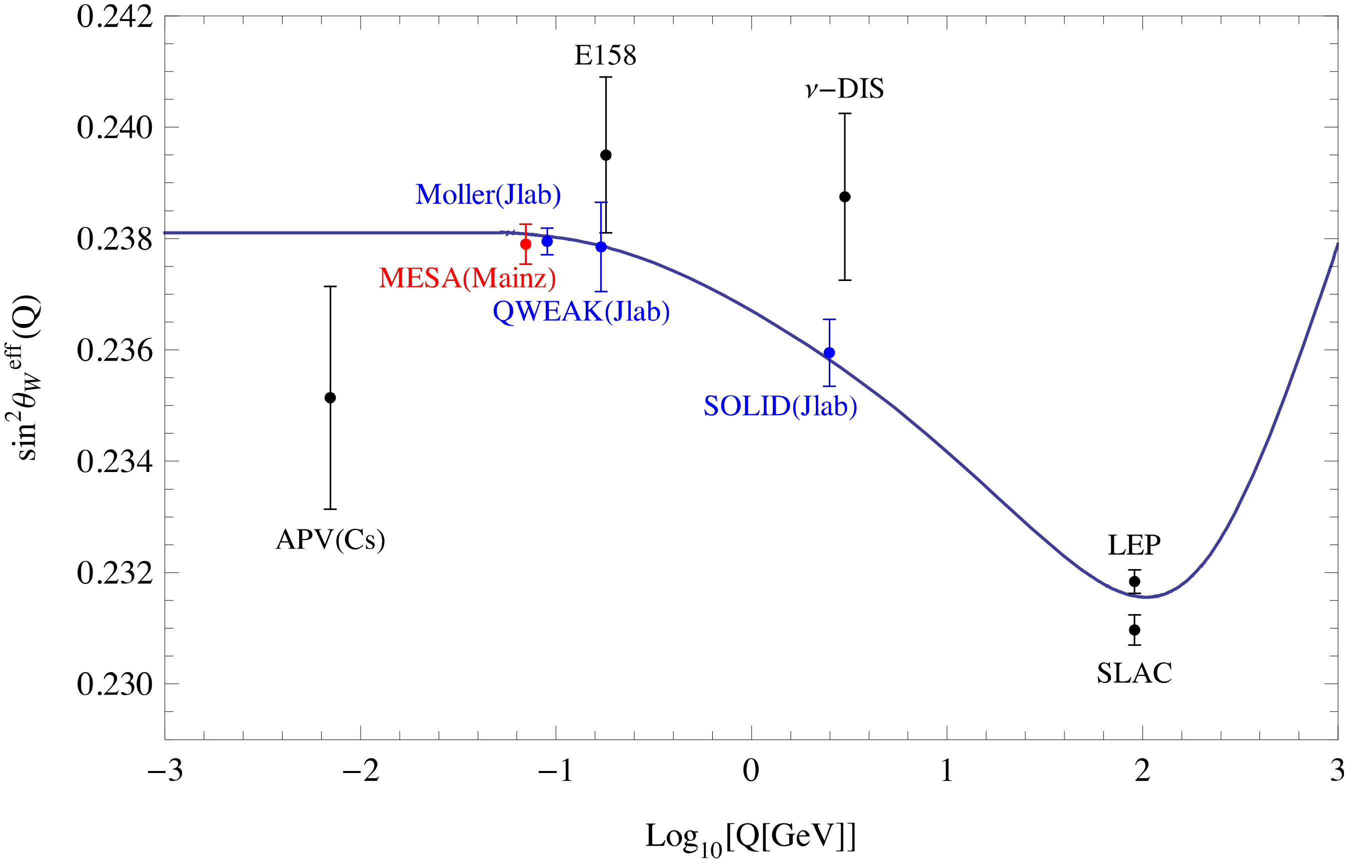
E_e =1.1GeV➔0.14GeV(?) (Reduces Theory Unc.) <Q>~100MeV?

$\Delta\sin^2\theta_W=\pm0.00018$ *(stat) ± (syst. 2 loop, pol.,)*

Pol. ±0.5% + 2loop unc.➔ $\Delta\sin^2\theta_W=\pm0.00020_{syst}$

Overall ±0.0003-0.0004

APV Update & Possible A_{RL} Measurements



Comparison of (static) weak charges

$Q_W(e)=-0.0435(9)[1+0.25T-0.34S+0.7X(Q^2)+7m^2_Z/m^2_{Z\chi}]$

$Q_W(p)=0.0707(9)[1+0.15T-0.21S+0.43X(Q^2)+4.3m^2_Z/m^2_{Z\chi}]$

$Q_W(^{133}Cs)=-73.24(5)[1+0.011S-0.023X(Q^2)-0.9m^2_Z/m^2_{Z\chi}]$

$Q_W(^{12}C)=-5.510(5)[1-0.003T+0.016S-0.033X(Q^2)-m^2_Z/m^2_{Z\chi}]$

Exp. Goals: $Q_W(e)$ ±2.5%, $Q_W(p)$ ±1.5%, $Q_W(^{12}C)$ ±0.3%

Observations

A_{RL}(eC) at ±0.3% about 3xmore sensitive to new physics than current Q_W(Cs) (now1.5 sigma deviation from SM)

A_{RL}(eC) at ±0.3% about the same or better than A_{RL}(ee) at ±2.5% and A_{RL}(ep) at ±1.5% for m_{Z_X} (2TeV) and some contact int.

A_{RL}(eC) at ±0.3% about 2-2.5x worse than A_{RL}(ep) & A_{RL}(ee) for $\sin^2\theta_W$, S (lower <Q> ➔ better $X(Q^2)$ sensitivity).

A_{RL}(eC) negligible 2 loop uncertainty

A_{RL}(ep) & A_{RL}(ee) currently 2 loop unc. ±1.3% & ±2%

Polarized ee, ep, eC Asymmetries

- $A_{RL}=\sigma_R-\sigma_L/\sigma_R+\sigma_L$ Parity Violating α Q^2 very small

Experiment	<Q>MeV	$\Delta\sin^2\theta_W$	Measurement
Cs APV	2.4	±0.0020	Atomic Theory
E158 SLAC	160	±0.0013	ee Completed
Q_{weak} JLAB	160	±0.0008	ep in analysis
Moller JLAB	75	±0.00029	ee approved
MESA (ep) P2	100?	±0.00037	ep Low Energy
eC (±0.3%)	40-120?	±0.0007?	Pol. & Syst.

Do Both P2 and A_{RL}(eC) at MESA (Complementary)

Dark Parity Violation

- **$U(1)_d$ gauge symmetry from the Dark Sector**

  *Dark Photon, U Boson, Secluded … **Dark Z (Z_d)***

Interaction with our world:

Induced by heavy fermion loops & extended Higgs

1) **Kinetic Mixing $U(1)_Y x U(1)_d$** $\varepsilon e Z_d^{\mu} J_{\mu}^{em}$ $\varepsilon \approx \alpha/\pi \approx 2x10^{-3}$

2) **Z-Z_d Mass Mixing** $\varepsilon_Z g/2\cos\theta_W Z_d^{\mu} J_{\mu}^{NC}$

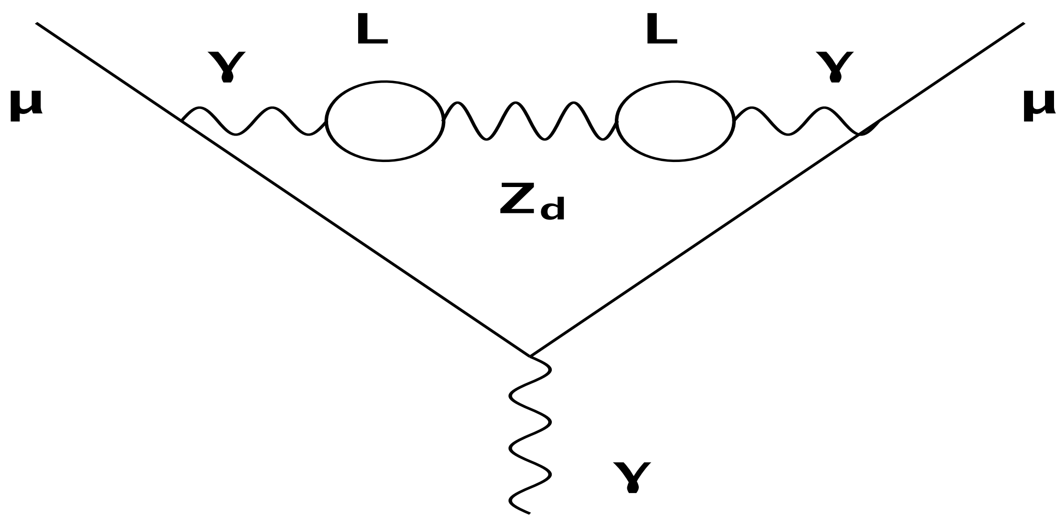
   $\varepsilon_Z = m_{Zd}/m_Z \delta = O(m_{Zd}/m_Z)^2 \approx \underline{10^{-6}}$

$\Delta a_\mu = a_\mu^{exp} - a_\mu^{SM} = 286(80)x10^{-11}$ (*3.6σ discrepancy!*)

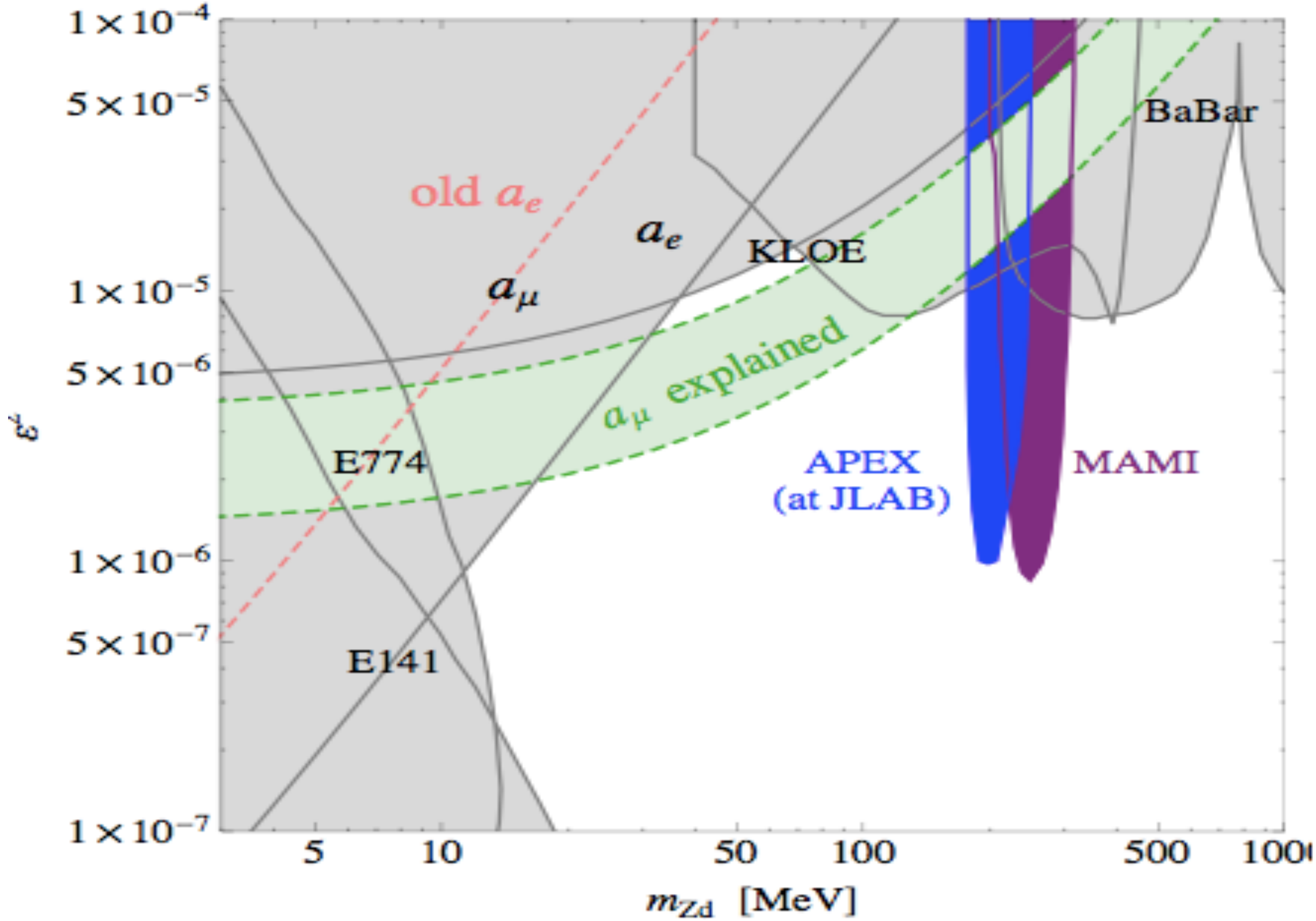
$\approx \frac{1}{4}(\alpha/\pi)^3$ **(Effective 3 loop physics?)**

Effective 3 loop g_μ-2 Diagram

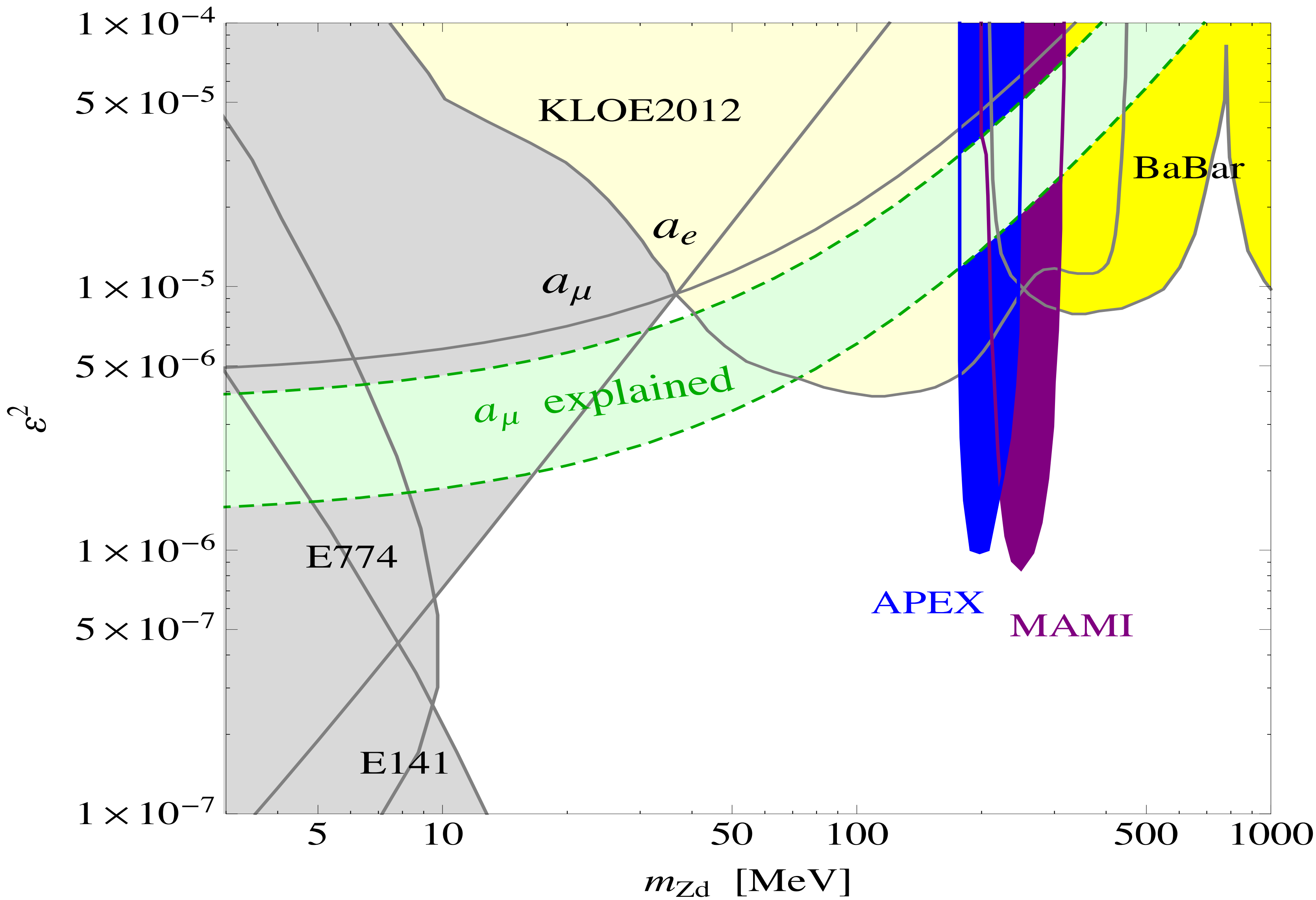
$a_\mu^{Zd} = \alpha/2\pi\varepsilon^2 F(m_{Zd}/m_\mu)$, F(0)=1 solves g_μ-2 discrepancy
for $\varepsilon^2 \approx 3\text{-}5\times10^{-6}$ & $m_{Zd} \approx 20\text{-}60$MeV (see figure)



Old a_e vs Recent a_e (3 sigma bound)
(Davoudiasl, Lee & WJM)



+2012 KLOE Update PL



Dark Parity Violation

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 $Q^2 < m_{Zd}^2$ ($\approx$O(1%)! Eg APV)

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

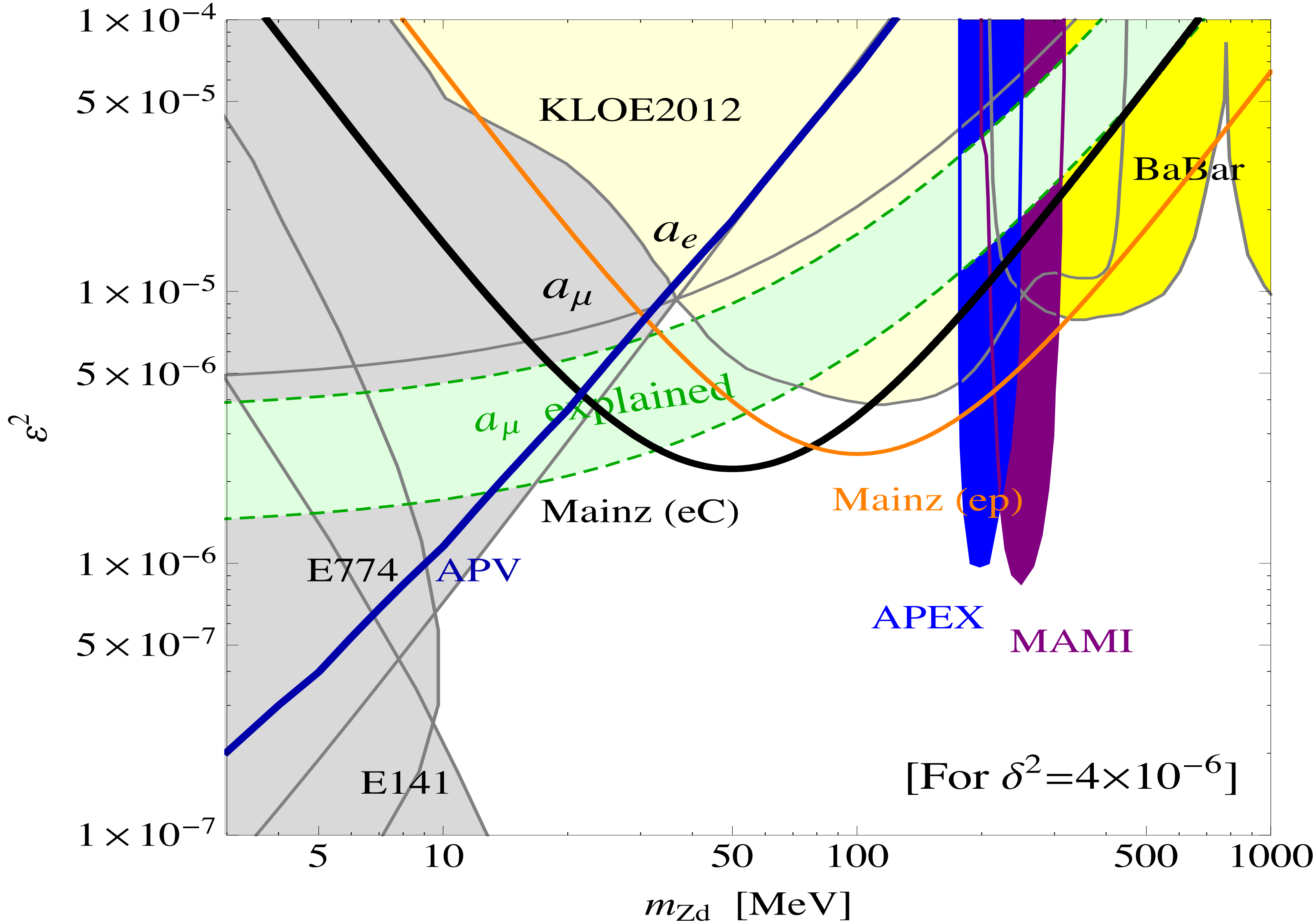
or $\varepsilon \approx \delta \approx 2\times10^{-3}$ for $(g_\mu - 2)$ & APV → $m_{Zd} \approx 50$MeV region

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

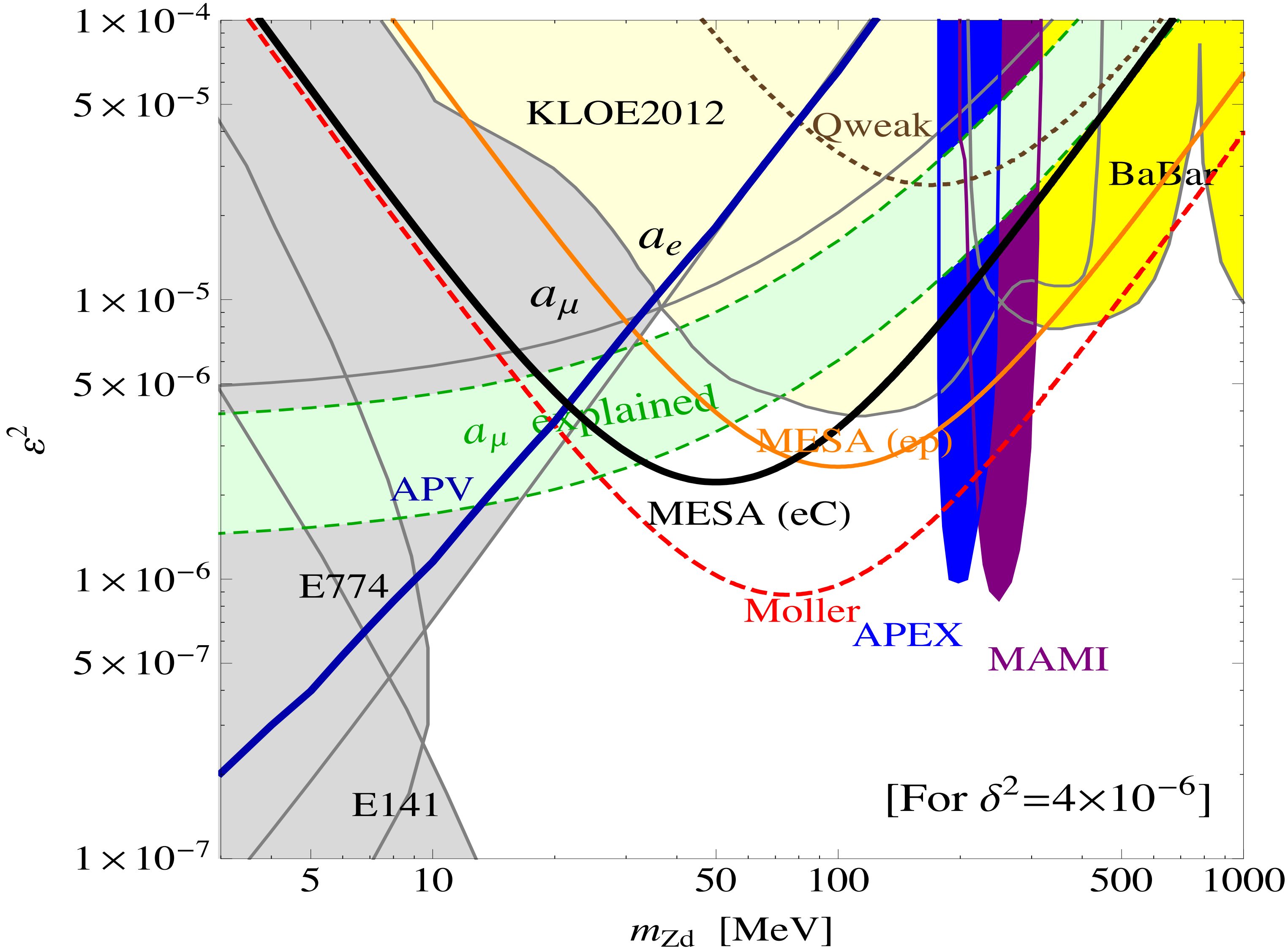
δ down to $\approx 10^{-3}$ Potentially Observable

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

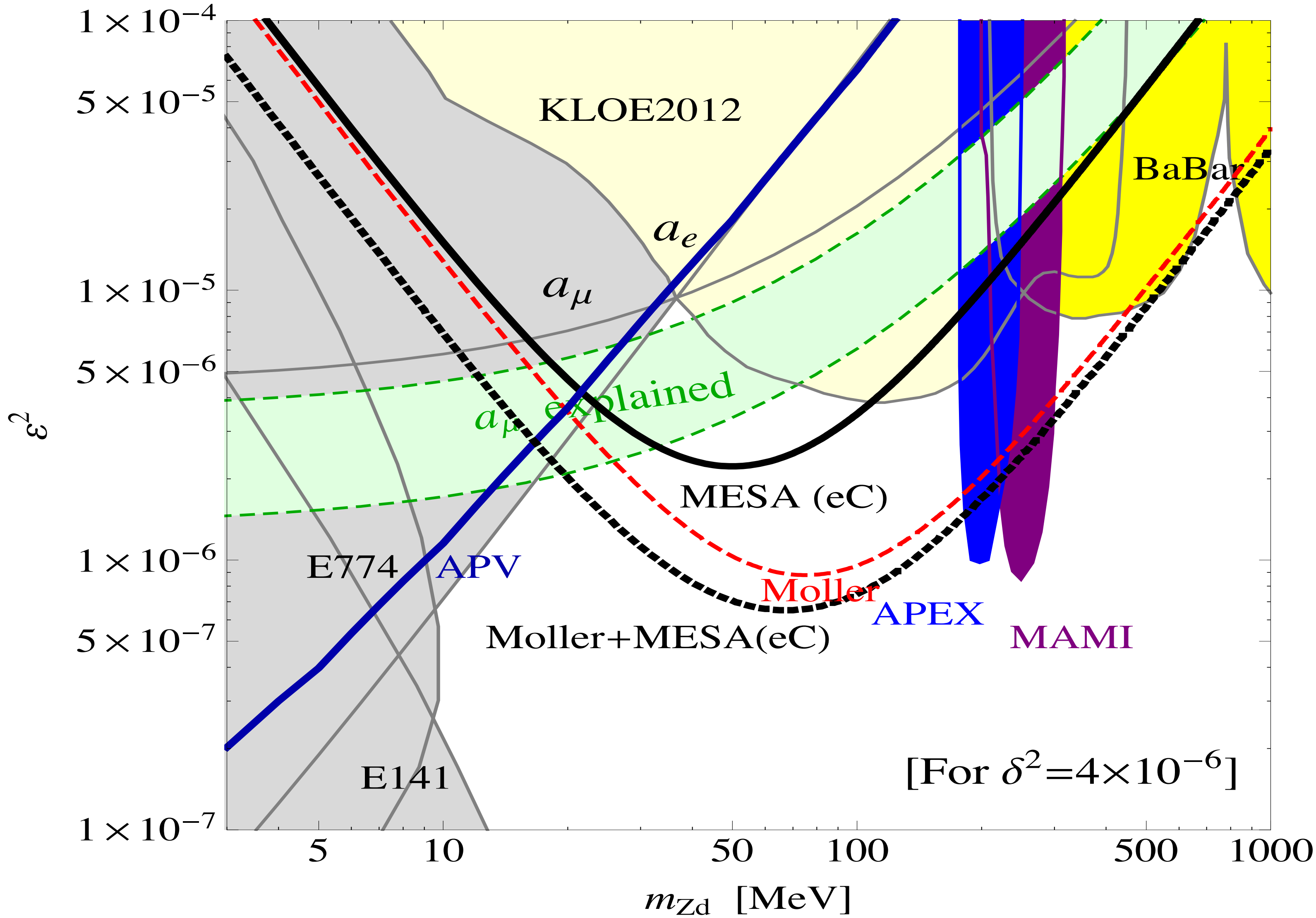
A_{RL}(eC) at <Q>=50MeV vs A_{RL}(ep) at <Q>=100MeV



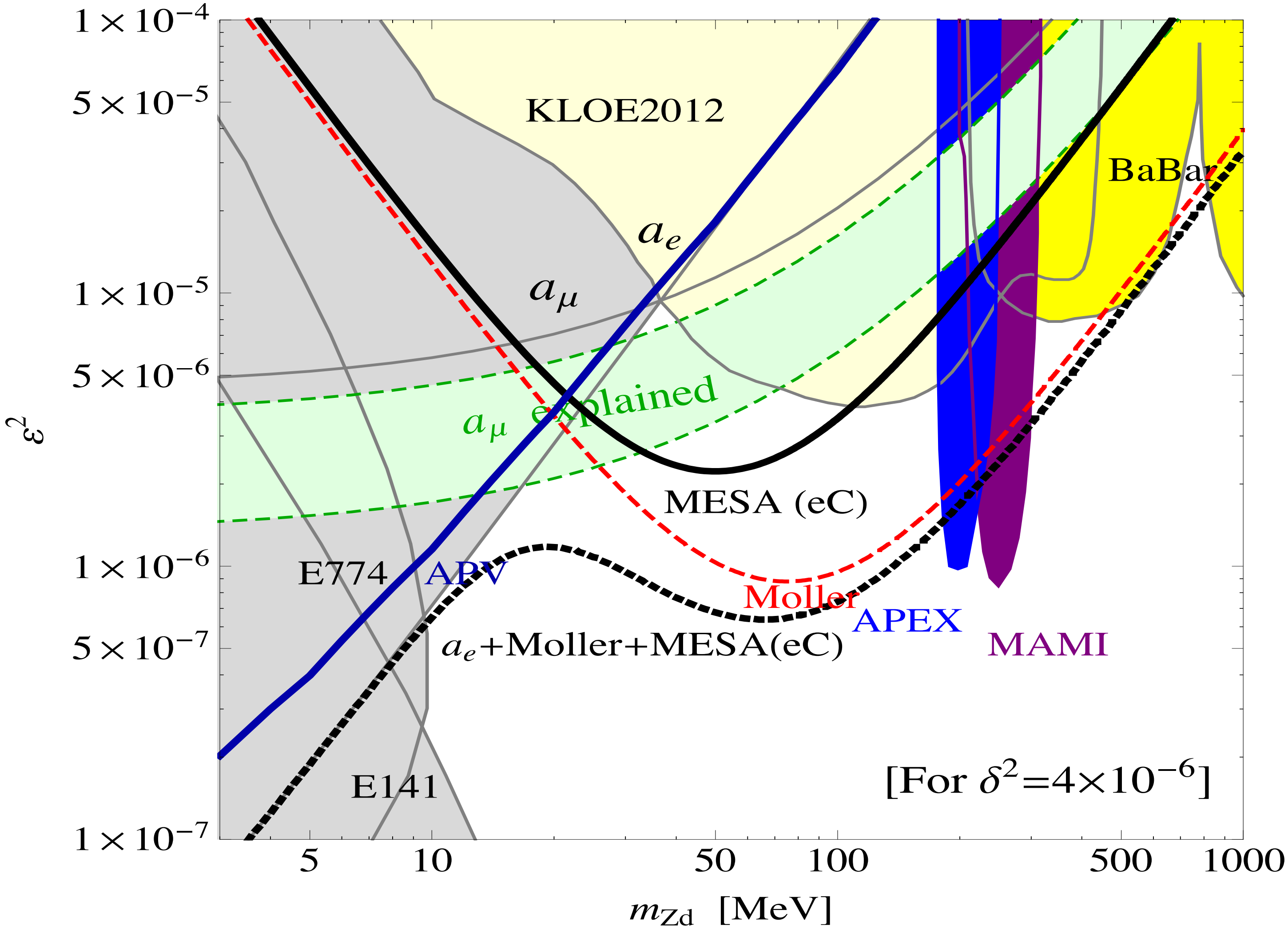
+Moller A_{RL}(ee) at <Q>=75MeV



Moller <Q>=75MeV + A_{RL}(eC) <Q>=50MeV



Combined Constraints



<u>Conclusion</u>

A_{RL}(eC) at ±0.3% about 3x sensitivity of Q_W(Cs) ***<u>1.5σ deviation?</u>***
No Atomic Theory Unc. But Polarization Unc. (Dominant?)

Statistically A_{RL}(eC) much easier than A_{RL}(ep) at low energy
Complementary. Motivates improved (±0.2-0.4%) polarimetery

If "dark photon" (20-60MeV) evidence emerges in direct searches➔motivation for low Q^2 A_{RL}(eC)
Do <Q>≈40-120MeV look for ***<u>relative</u>*** $\sin^2\theta_W(Q^2)$ change
Overcomes pol. Uncertainty!

Deserves Further Study