“Dark Z boson” and Low-Energy New Physics Searches

based on the works with H. DavoudiasI and W. Marciano at BNL
[PRD85 (2012), PRL109 (2012), PRDxx (2012)]

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(William and Mary / Jefferson Lab)

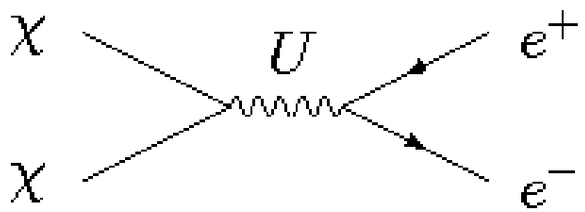
Cake Seminar at Jefferson Lab Theory Center
October 24, 2012

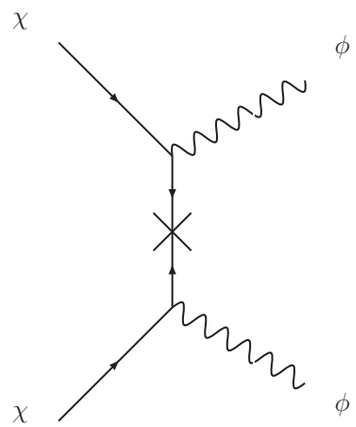
It is a Light Z' gauge boson ($m_{Z'} \approx O(1)$ GeV)

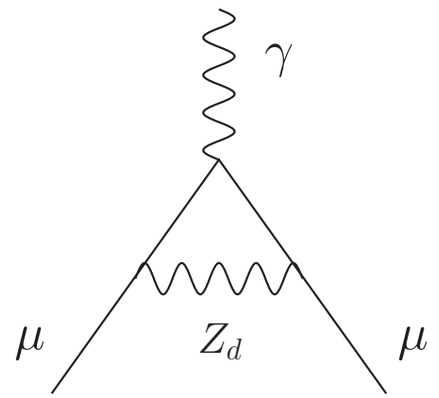
Typical motivations of Light Z' are from DM explanations of excess in the astrophysical signals from our galactic center.

DM annihilation with "GeV-scale gauge boson" can explain anomalies such as

(1) 511 keV gamma-ray (INTEGRAL) [Fayet (2004)]
(2) Positron excess (ATIC, PAMELA) [Arkani-Hamed,Finkbeiner,Slatyer, Weiner (2008)]







Also, $(g\text{-}2)_\mu$ anomaly, if real, can be explained [Fayet (2007); Pospelov (2008)].

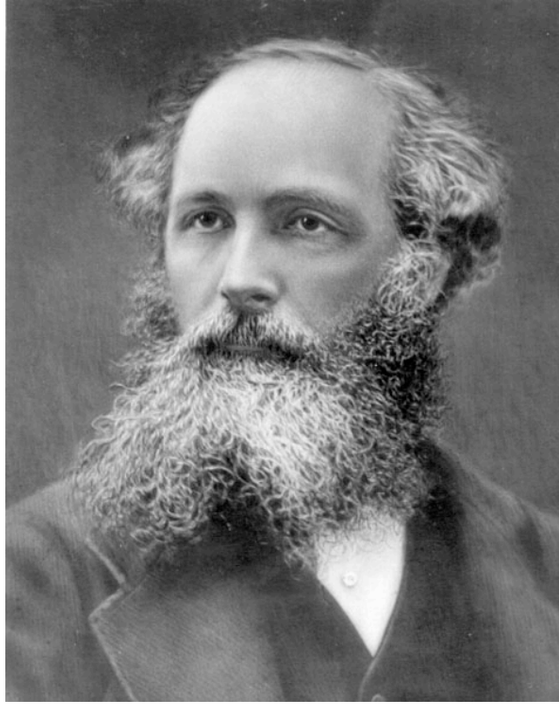
Cf. Many pioneering works on Light Z' (called "U boson") in a rather general setup was done by [P. Fayet (since 1980)].

Light Z' is one of the New Physics scenarios that can be tested with existing (and upcoming) Low-Energy experimental facilities (at JLab, Mainz, etc).

We consider a very weakly interacting Z' in roughly "10 MeV < $m_{Z'}$ < 10 GeV".

We start from "Dark Photon" (well-established model) and extend it to "Dark Z".

New gauge boson means New force



Fundamental forces (interactions) known to us:
(1) Gravity [I. Newton, ... in 17C]
(2) Electromagnetic force [J. Maxwell, ... in 19C]
(3) Weak nuclear force [S. Weinberg, ... in 20C]
(4) Strong nuclear force [M. Gell-Mann, ... in 20C]

Each and every fundamental force made huge impact in understanding physical world.

Discovery of another fundamental force will do the same.

Outline

1. Dark Photon (brief, updated review)

2. Dark Z

3. Dark Z Implications for Parity-Violating Experiments

4. Dark Z Implications for Rare Meson Decays

5. Dark Z Implications for Higgs Physics (very briefly)

1. Dark Photon

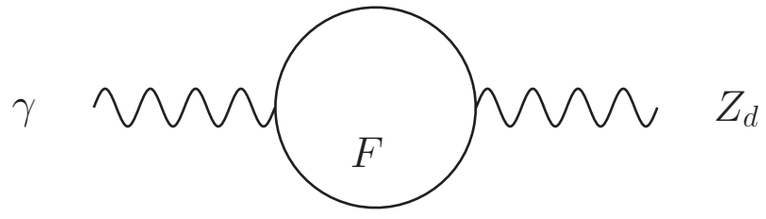
Dark U(1)

Consider a U(1)' gauge symmetry -- Dark U(1) or Secluded U(1) -- which may interact with DM or Hidden sector particles. SM particles have zero charges.

Z' couples to SM particles through kinetic mixing of $U(1)_Y$ & U(1)'. [Holdom (1986)]

$$\mathcal{L}_{\rm kin} = -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} + \frac{1}{2} \frac{\varepsilon}{\cos\theta_W} B_{\mu\nu} Z'^{\mu\nu} - \frac{1}{4} Z'_{\mu\nu} Z'^{\mu\nu}$$
$$({\rm with}\ F_{\mu\nu} \equiv \partial_\mu F_\nu - \partial_\nu F_\mu)$$

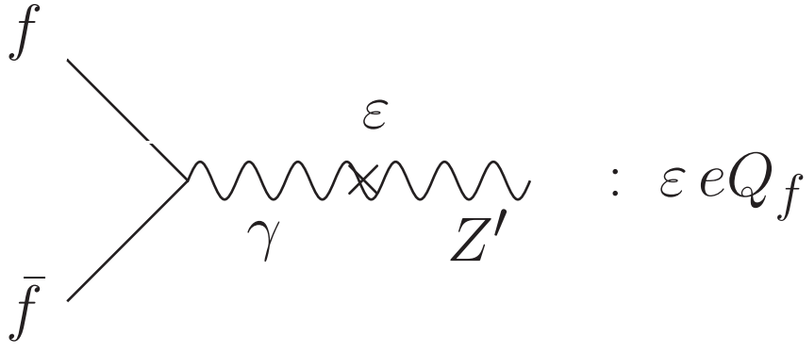
Expected size of kinetic mixing from loops of heavy fermions: $\varepsilon \sim (g_Y g_{Z'})/(16\pi^2) \lesssim 10^{-3}$



Dark Photon

Typical phenomenology of the $U(1)_Y$ & U(1)' kinetic mixing is carried out in the setup that Z' couples only to EM Current (vector coupling).

$$\mathcal{L}_{\rm int} = -\varepsilon\, e J^{\mu}_{em} Z'_{\mu} \qquad\qquad J^{\mu}_{em} = Q_f \bar{f} \gamma^{\mu} f$$



(coupling) = ε (photon coupling)
Thus, named as "Dark Photon"

Puzzling at the first glance since $B = \cos\theta_W A - \sin\theta_W Z$

Higgs structure matters

Dark Photon is justified in the simplest Higgs structure

"SM Higgs doublet + Higgs singlet"

(Higgs singlet to break U(1)' and give a mass to Z').

Z-Z' kinetic mixing part is cancelled by Z-Z' mass mixing (which is "induced by kinetic mixing") at Leading order, and leaves γ-Z' mixing only.
Neglecting $O(\varepsilon^2)$ terms,

$$\mathcal{L}_{\rm int} \sim -eJ^{\mu}_{em}A_{\mu} - (g/\cos\theta_W)J^{\mu}_{NC}Z_{\mu} \qquad \text{(kinetic mixing diagonalization)}$$
$$\rightarrow -eJ^{\mu}_{em}[A_{\mu} + \varepsilon Z'_{\mu}] - (g/\cos\theta_W)J^{\mu}_{NC}[Z_{\mu} + O(\varepsilon)Z'_{\mu}]$$
$$\rightarrow -eJ^{\mu}_{em}[A_{\mu} + \varepsilon Z'_{\mu}] - (g/\cos\theta_W)J^{\mu}_{NC}Z_{\mu} \qquad \text{(Z-Z' mass matrix diagonalization)}$$

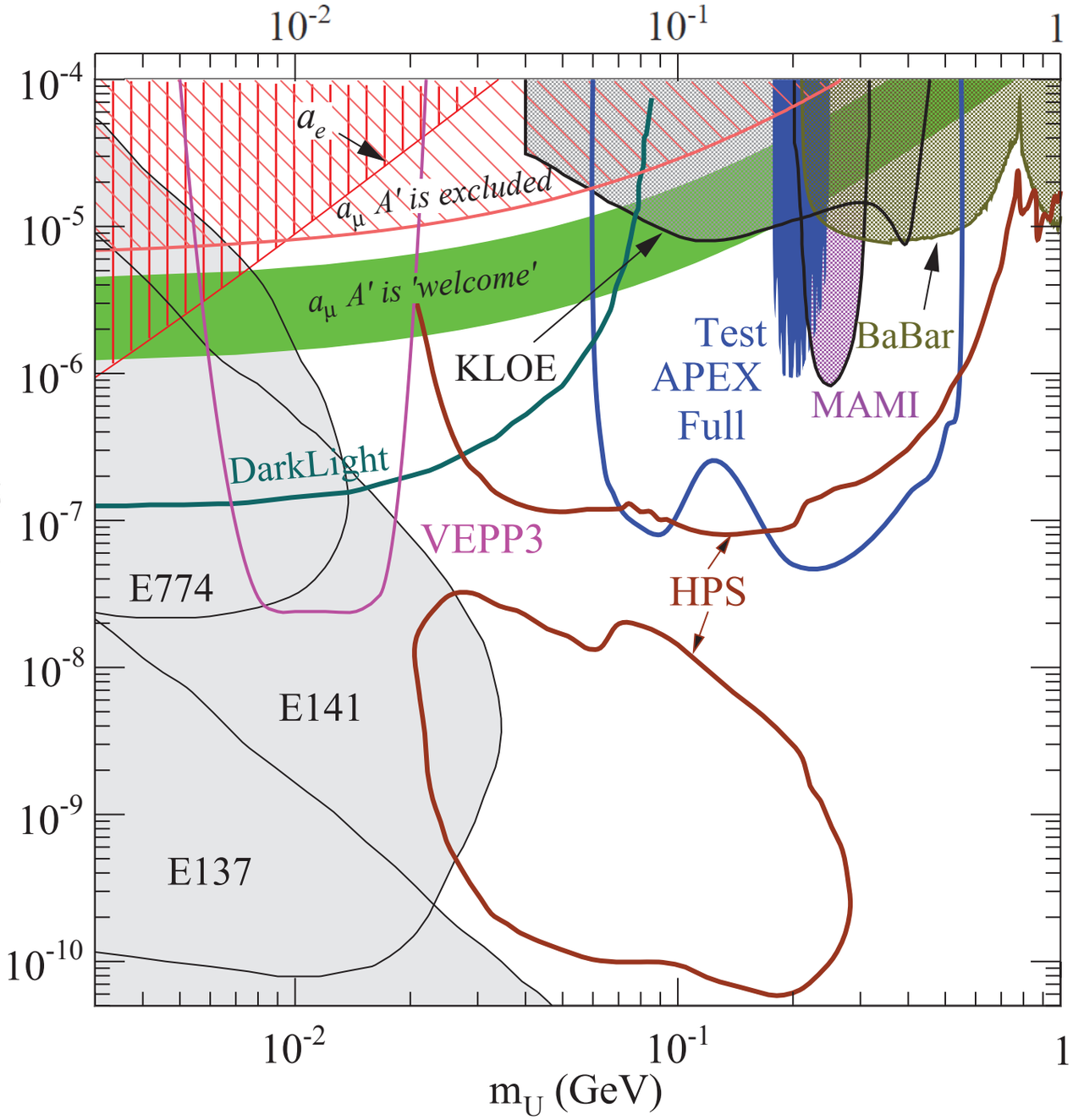
for 1 Higgs doublet + singlet

Z' coupling to weak Neutral Current (containing axial coupling) appears only at Higher order of ε, and it can be neglected in most cases (for $\varepsilon < 10^{-3}$).

Caveat: Z-Z' mass matrix is sensitive to the Higgs sector.

(We will use this to introduce "Dark Z" which couples to NC later.)

Typical implications for Dark Photon

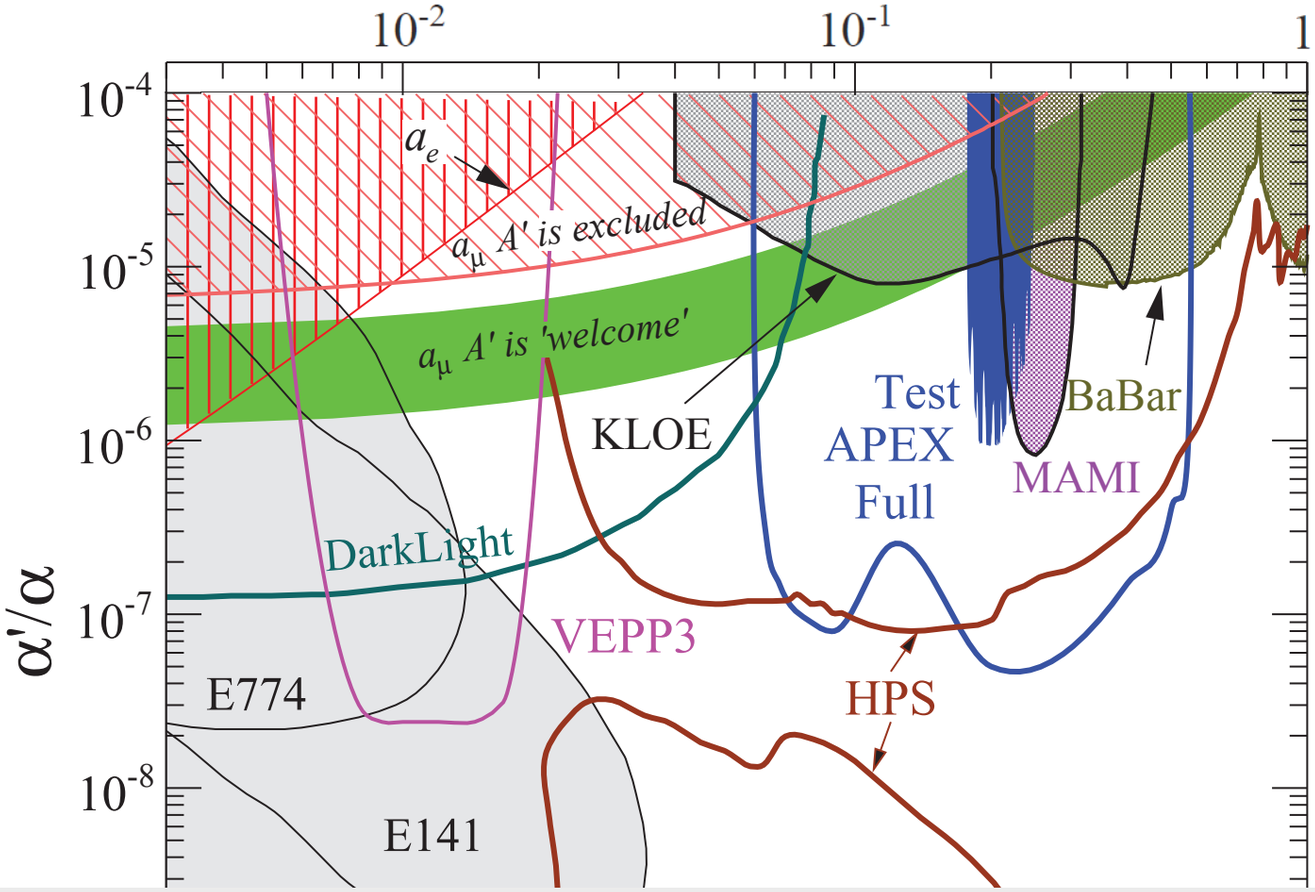


Numerous studies of Dark Photon phenomenology

[Pospelov,Ritz (2008)]
[Reece,Wang (2009)]
[Bjorken,Essig,Schuster,Toro (2009)]
[Freytsis,Ovanesyan,Thaler (2009)]
and many more ...

Constraints/Sensitivity in the ($m_{Z'}$, ε^2) plane [from R. McKeown (arXiv:1109.4855)]

Typical implications for Dark Photon



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and many more ...

1. g-2 (for electron, muon)
   (Deviation in muon g-2 [green band] can be an early hint of Dark Photon.)

2. Electron beam-dump experiments (E137, E141 at SLAC; E774 at Fermilab)

3. $\Upsilon(3S) \rightarrow \gamma\, Z' \rightarrow \gamma\, \mu^+\mu^-$ (BaBar); $\phi \rightarrow \eta\, Z' \rightarrow \eta\, \ell^+\ell^-$ (KLOE in Italy)

5. Fixed target experiments: New experiments designed for Dark Photon search
   (APEX at JLab; MAMI in Mainz; ...)

Light Z' search examples (JLab experiments)

Free Electron Laser

FEL: DarkLight

Linac

Linac

Electron Source

A

B

C

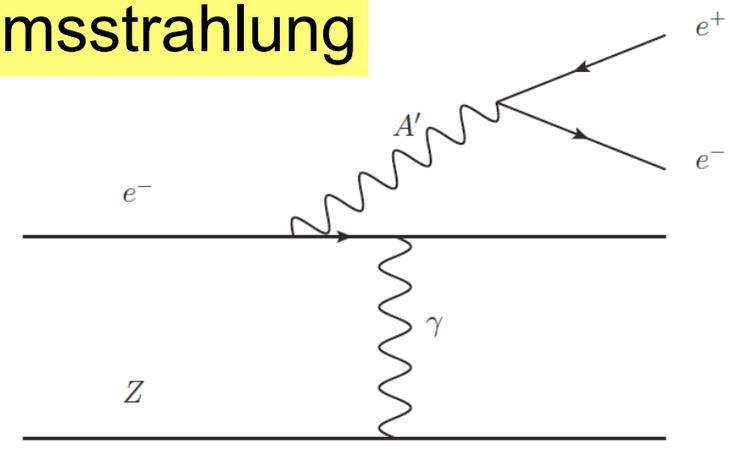
Hall A: APEX

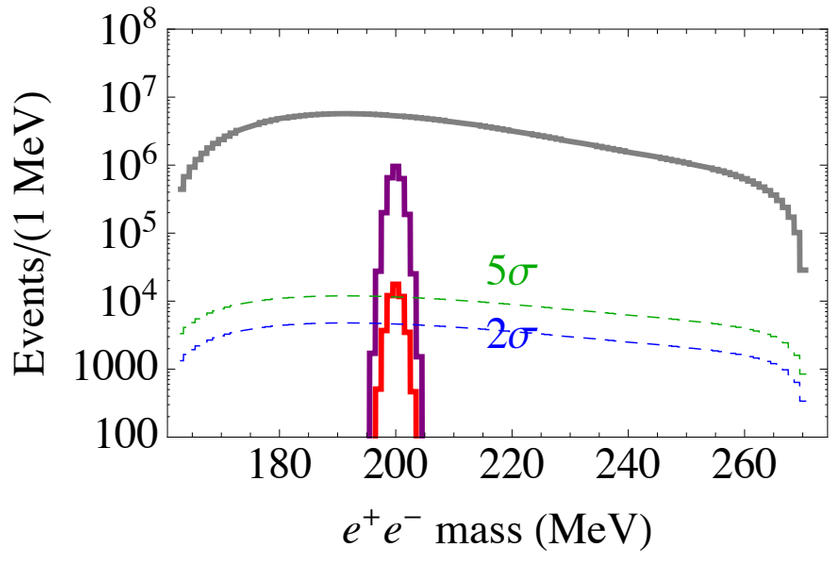
Hall B: HPS

Example: A' Experiment (APEX) at JLab - Hall A

[APEX Collaboration: Essig,Schuster,Toro,Wojtsekhowski, et al]

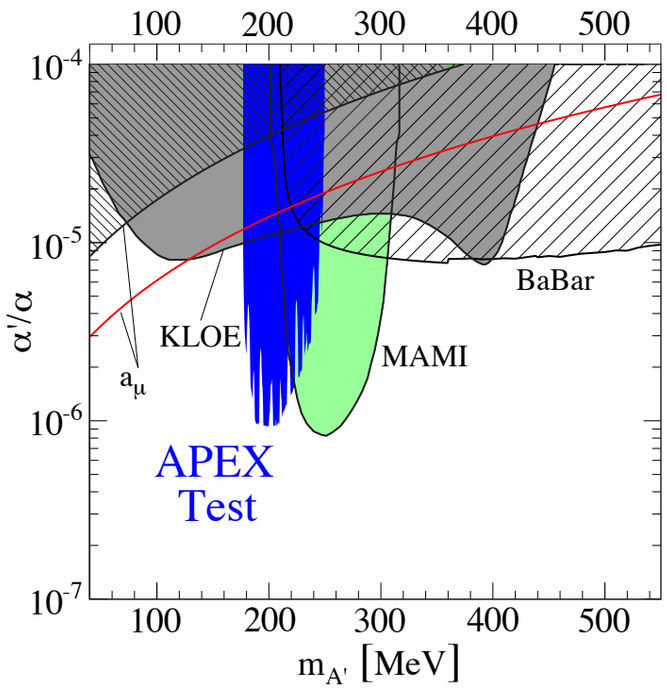
Dark Photon Bremsstrahlung





New Fixed target (Tantalium Z=73) experiment designed for direct Dark Photon production/detection. (Z' → e^+e^- narrow resonance search using HRS)

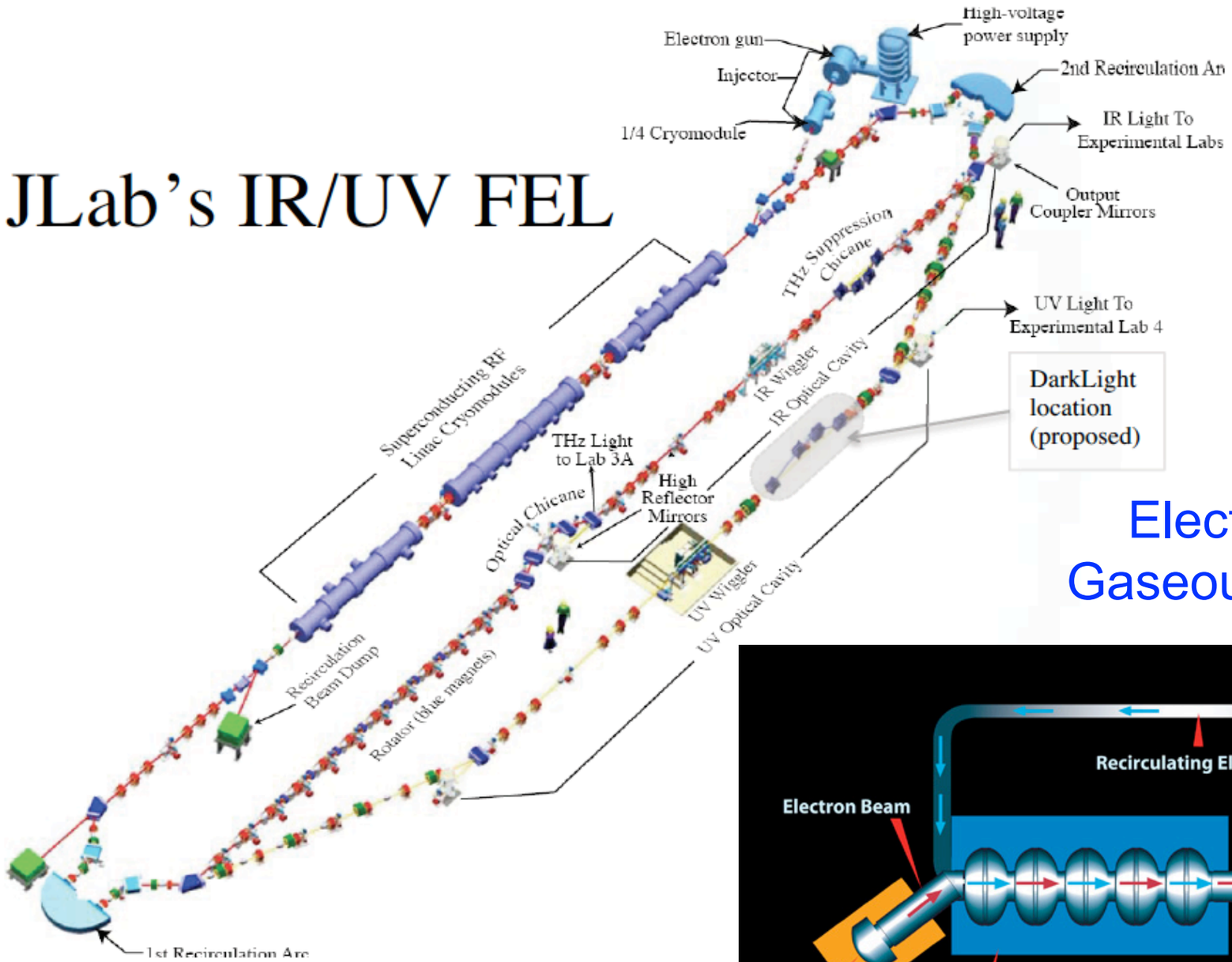
[APEX test-run result (2011)]



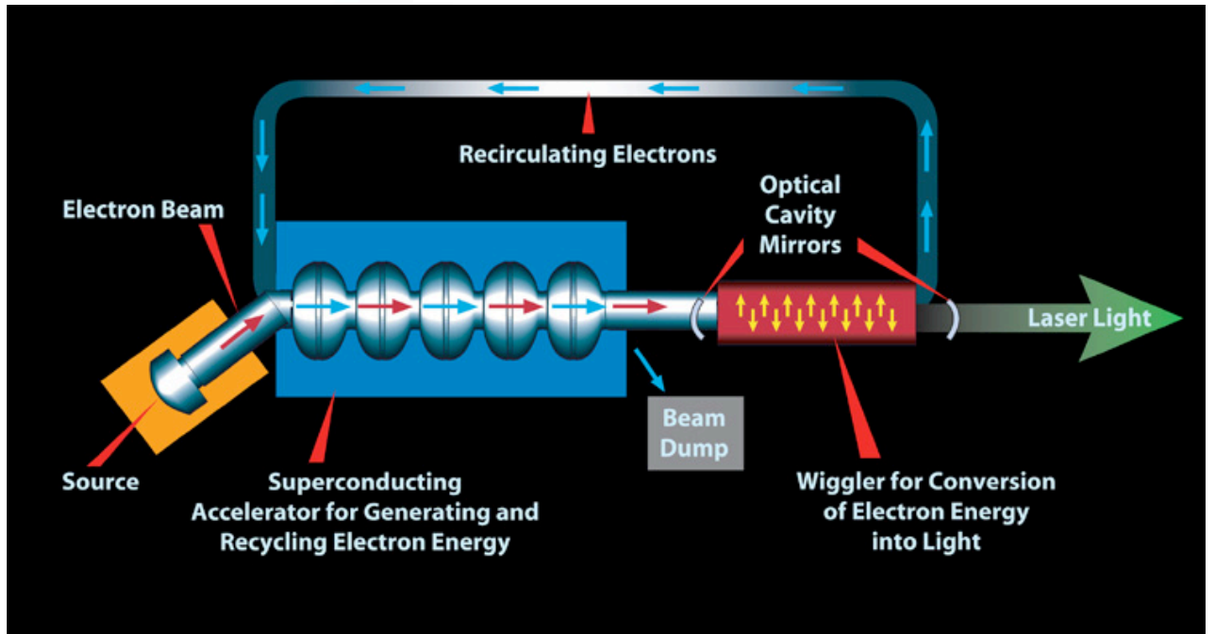
Example: DarkLight experiment (using JLab - Free Electron Laser facility)

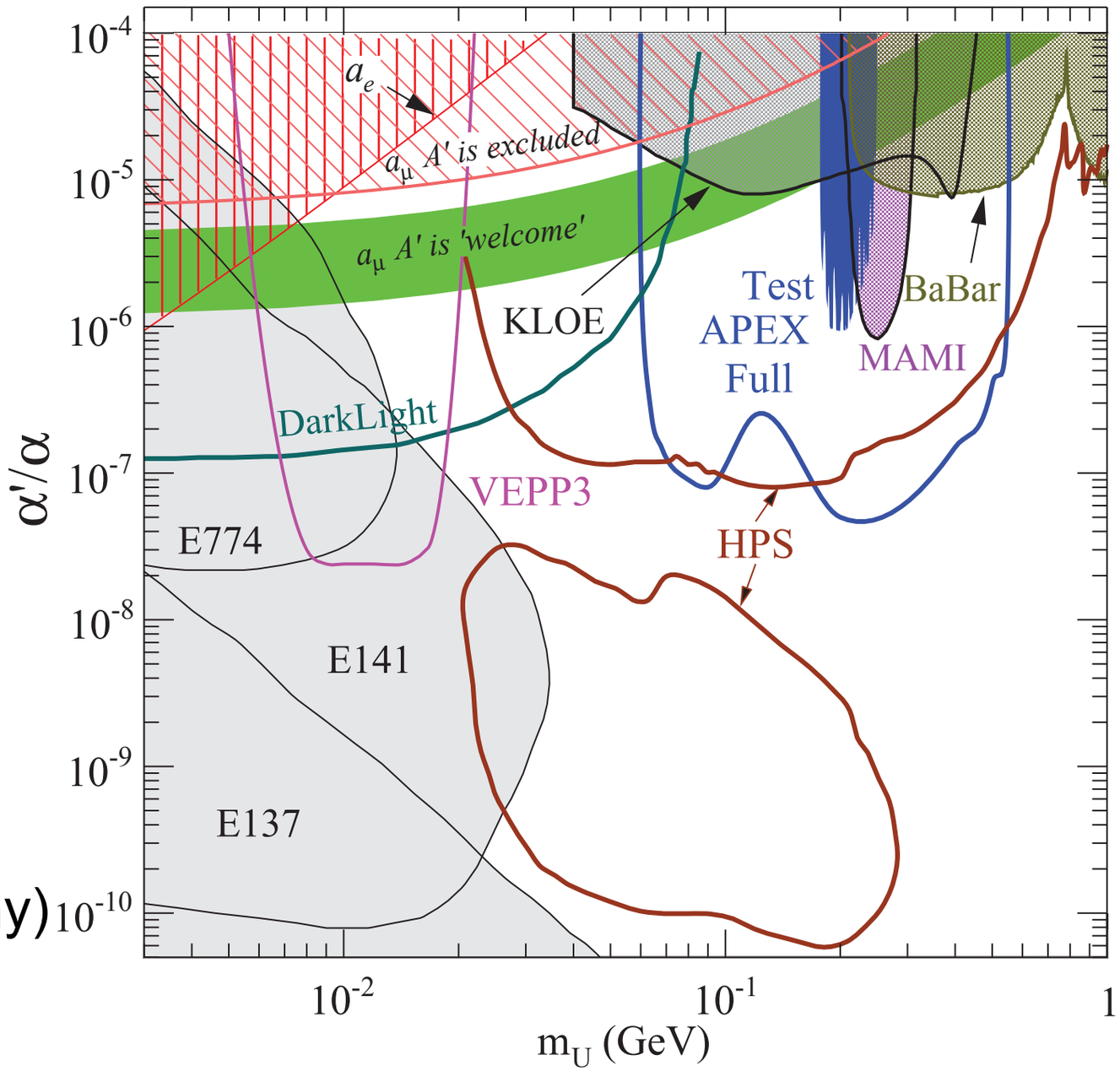
[DarkLight Collaboration]

JLab's IR/UV FEL



Electrons incident on Gaseous Hydrogen Target





Ongoing and proposed experiments
for “direct” Dark Photon search:

(1) MAMI (Microtron in Mainz, Germany)
(2) APEX (at JLab - Hall A)
(3) DarkLight (at JLab - FEL)
(4) Heavy Photon Search (at JLab - Hall B)
(5) VEPP3 (at Budker in Russia)

Hunting for this Little particle (Light Z’) is becoming a Big industry.

One of the Fastest-developing New fields

In 2009, New experiments suggested by theorists

New Fixed-Target Experiments to Search for Dark Gauge Forces.
James D. Bjorken, Rouven Essig, Philip Schuster (SLAC), Natalia Toro (Stanford U., ITP). Jun 2009. 20 pp.
Published in **Phys.Rev. D80 (2009) 075018**
SLAC-PUB-13650, SU-ITP-09-22
DOI: 10.1103/PhysRevD.80.075018
e-Print: **arXiv:0906.0580** **[hep-ph]** PDF
1 References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
2 Journal Server; ADS Abstract Service; SLAC Document Server
Detailed record - Cited by 123 records

In 2010, APEX experiment proposal (JLab)

An Electron Fixed Target Experiment to Search for a New Vector Boson A' Decaying to e+e-.
Rouven Essig, Philip Schuster (SLAC), Natalia Toro (Stanford U., Phys. Dept.), Bogdan Wojtsekhowski (Jefferson Lab). Jan 2010. 19 pp.
Published in **JHEP 1102 (2011) 009**
SLAC-PUB-13882, SU-ITP-10-01
DOI: 10.1007/JHEP02(2011)009
e-Print: **arXiv:1001.2557** **[hep-ph]** PDF
1 References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
2 Journal Server; ADS Abstract Service; SLAC Document Server
Detailed record - Cited by 41 records

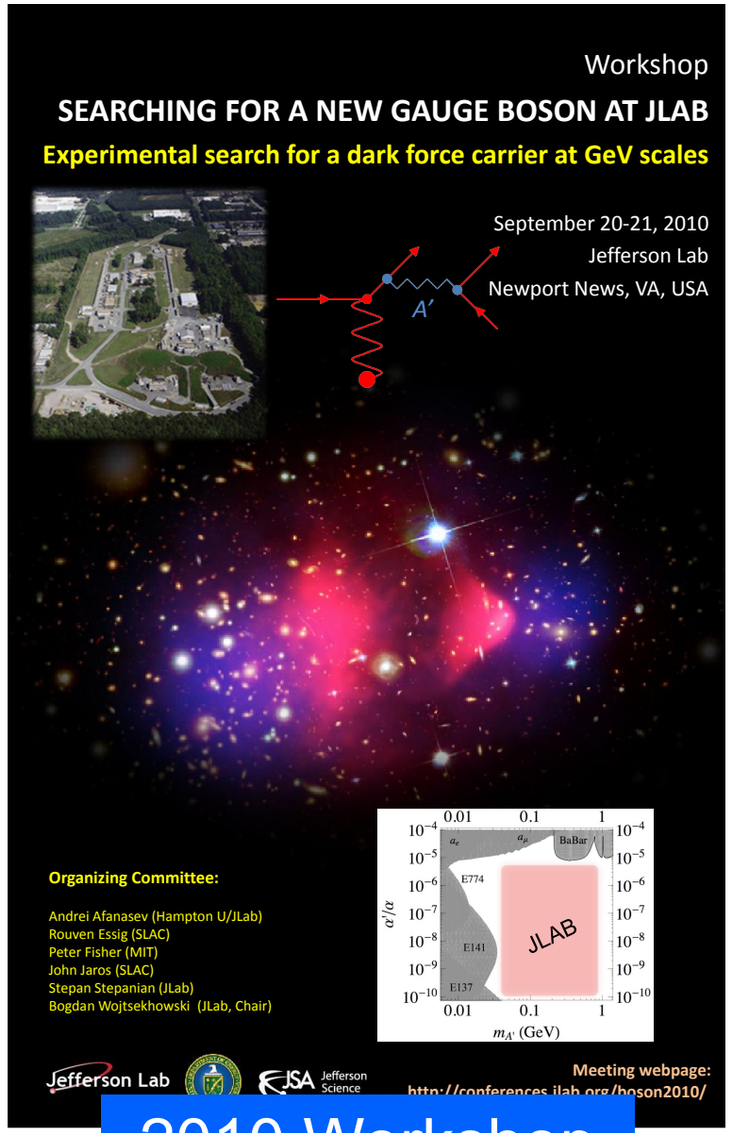
In 2011, First results published

Search for a New Gauge Boson in Electron-Nucleus Fixed-Target Scattering by the APEX Experiment.
APEX Collaboration (S. Abrahamyan (Yerevan Phys. Inst.) *et al.*). Aug 2011. 5 pp.
Published in **Phys.Rev.Lett. 107 (2011) 191804**
JLAB-PHY-11-1406-SLAC-PUB-14491
DOI: 10.1103/PhysRevLett.107.191804
e-Print: **arXiv:1108.2750** **[hep-ex]** PDF
1 References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
2 Journal Server; ADS Abstract Service; JLab Document Server
Detailed record - Cited by 35 records

Amazing speed for modern BSM physics experiments!

Dark Force Workshops (Worldwide Activity)

2009 Workshop at SLAC

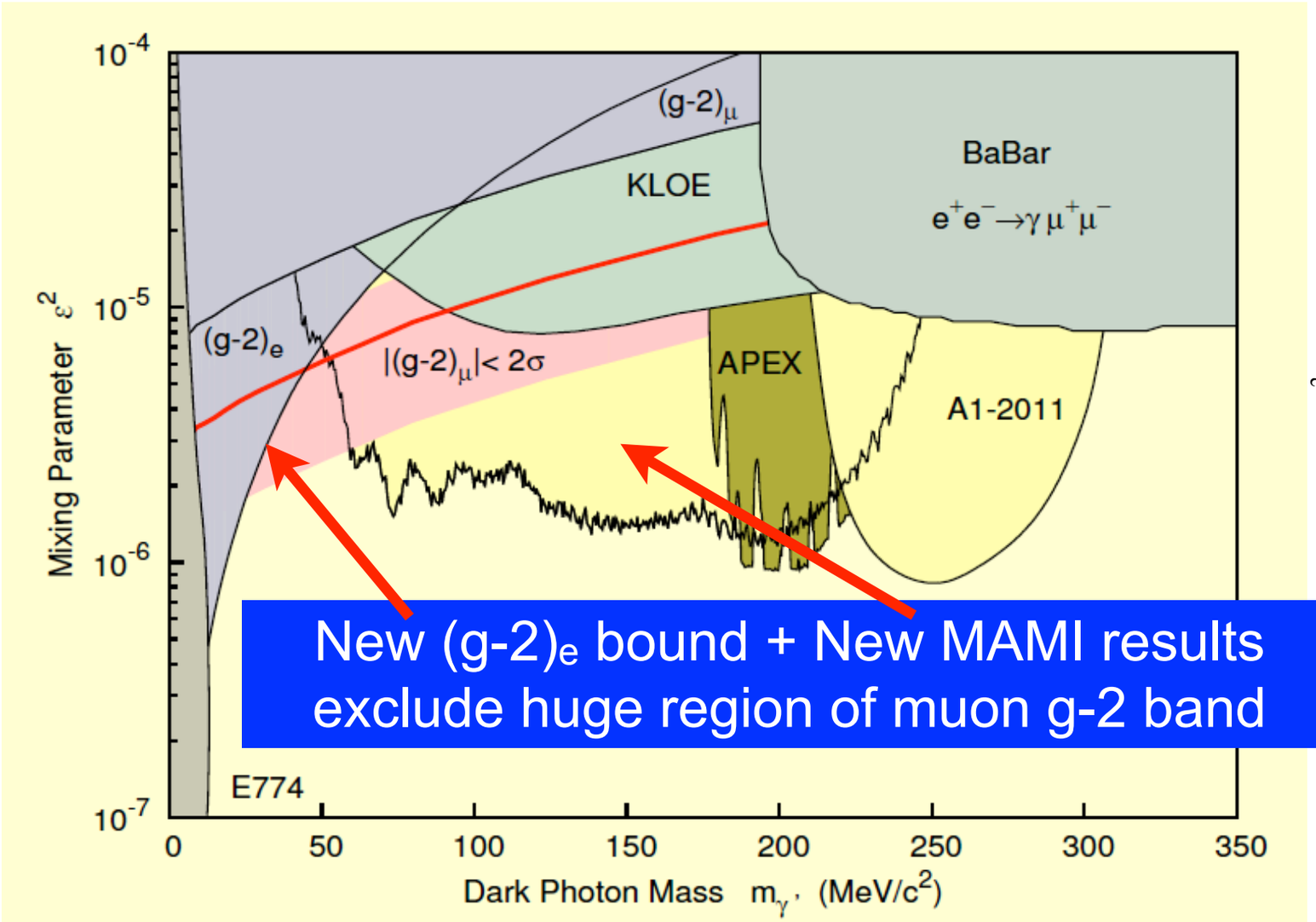


2010 Workshop at JLab

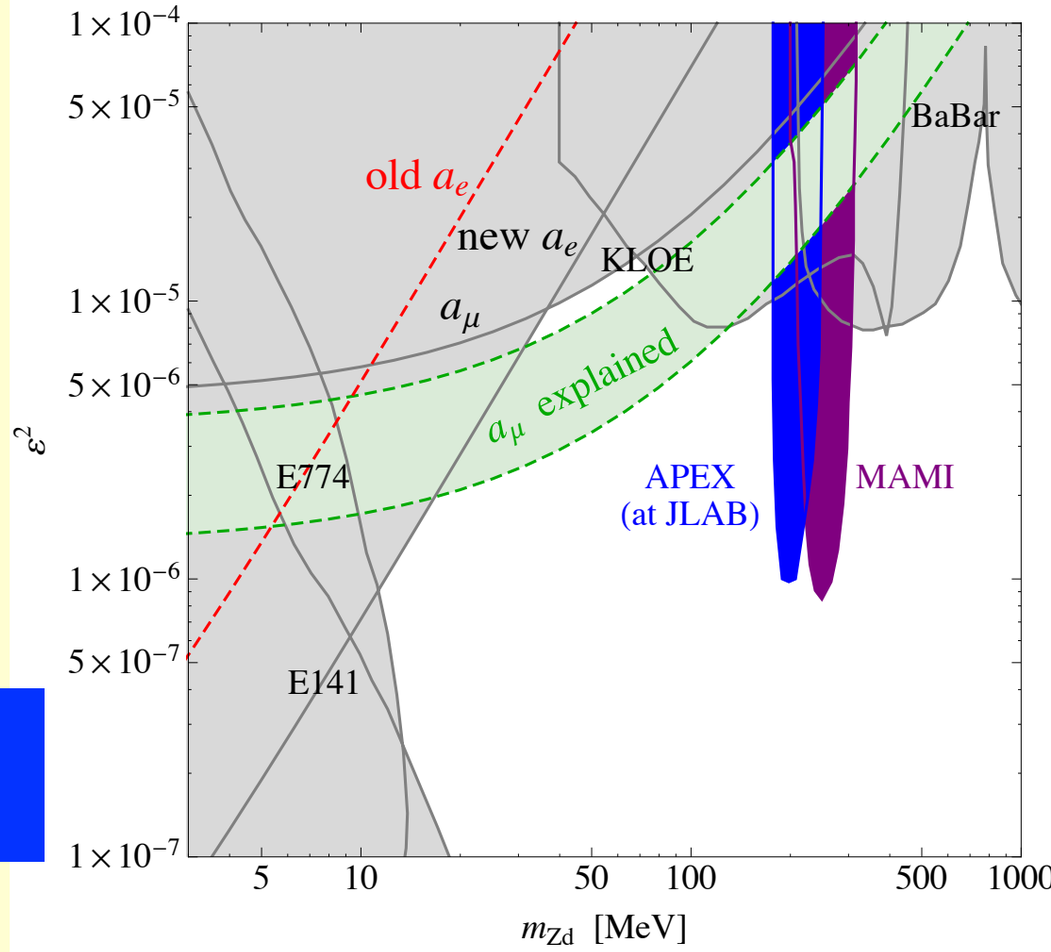
2012 Workshop at INFN (Rome)

Last week
(Many new results!)

New results presented at the Last week's Workshop!



[MAMI 2012 preliminary (Oct 2012)]



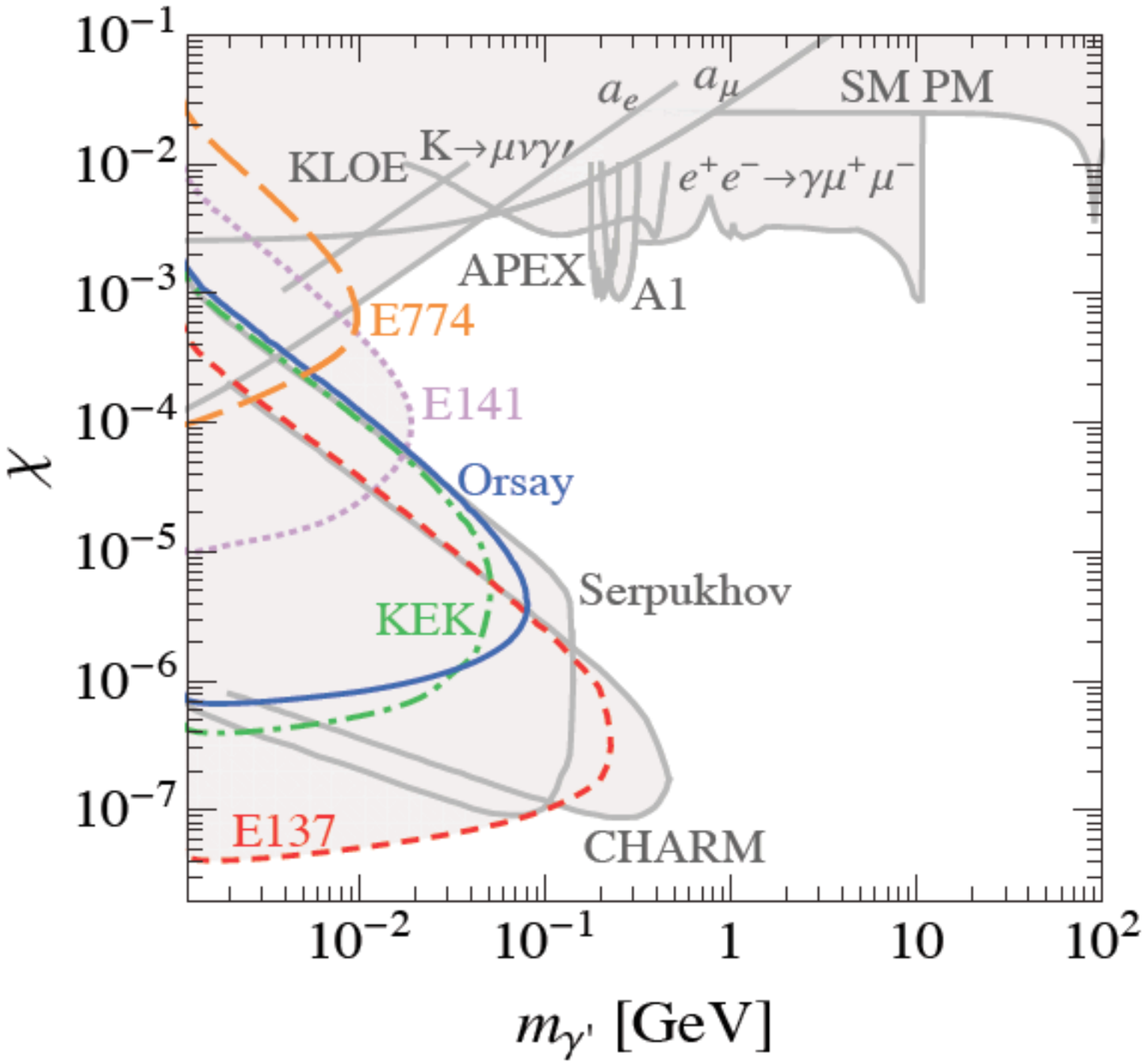
[Davoudiasl,HL,Marciano (Aug 2012)]

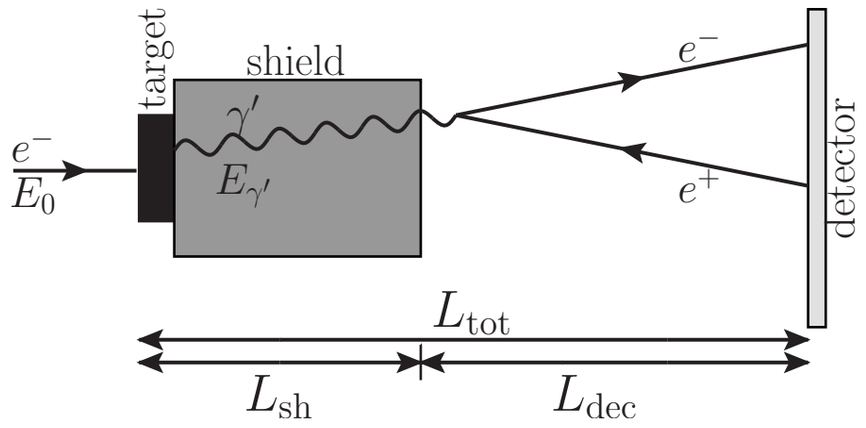
Before, muon g-2 band was bounded mostly by beam-dump experiments (E774).

Now, it is bounded by new $(g-2)_e$ bound

-- based on the recent α measurement [Bouchendira et al (2011)] and improved calculation on $(g-2)_e$ up to $O(\alpha^5)$ [Kinoshita et al (May 2012)].

Updated beam dump bounds





[Andreas,Niebuhr,Ringwald (Sep 2012)]

Constrained parameter space change fast from new experiments or new analysis.

2. Dark Z

: a variant of Dark Photon containing “axial coupling”

[Davoudiasl, HL, Marciano (2012)]

General Higgs sector

Z-Z' mixing (from kinetic mixing) vanished in the simplest Higgs model [Dark Photon]. Consider the same setup as Dark Photon case (kinetic mixing), but with a more general Higgs sector.

The Z-Z' mass matrix (with $m_{Z'} << m_Z$) can be written as, in $\varepsilon=0$ limit,

$$M^2_{ZZ'} \simeq m_Z^2 \begin{pmatrix} 1 & -\varepsilon_Z \\ -\varepsilon_Z & m^2_{Z'}/m^2_Z \end{pmatrix}$$

with Z-Z' mixing angle ε_Z given by $\varepsilon_Z = \dfrac{m_{Z'}}{m_Z}\delta$
where δ is a small model-dependent quantity.

We do not specify the Higgs sector, but it can be realized with, for example, 2HDM (type-I) with U(1)' instead of $\mathbf{Z_2}$.

H_1 w/ zero U(1)' charge → SM fermions couple to only this Higgs.
H_2 w/ nonzero U(1)' charge → It breaks U(1)'.
(+ optional Higgs singlet H_d)

$$\delta = \sin\beta \sin\beta_d \quad (\text{with } \tan\beta \equiv v_2/v_1 \ , \ \tan\beta_d \equiv v_2/v_d)$$

Dark Z

With a general Higgs sector (like 2HDM), Z-Z' mixing does not vanish.

Now, the Z' couples to EM Current (∝ ε: kinetic mixing) as well as the weak Neutral Current (∝ ε_Z: Z-Z' mass mixing).

$$\mathcal{L}_{\rm int}^{\rm SM} = -eJ_{em}^{\mu}A_{\mu} - (g/\cos\theta_W)J_{NC}^{\mu}Z_{\mu}$$

$$\mathcal{L}_{\rm int}^{Z'} = -\left[\varepsilon\, eJ_{em}^{\mu} + \varepsilon_Z\,(g/\cos\theta_W)J_{NC}^{\mu}\right]Z'_{\mu}$$

$$J_{\mu}^{NC} = (\frac{1}{2}T_{3f} - Q_f\sin^2\theta_W)\bar{f}\gamma_{\mu}f - \frac{1}{2}T_{3f}\bar{f}\gamma_{\mu}\gamma_5 f \qquad \frac{\mathrm{BR}(Z'\to e^+e^-)}{\mathrm{BR}(Z'\to 3\nu\bar{\nu})} \simeq \frac{1}{6} + \frac{1}{2}\left(\frac{\varepsilon}{\varepsilon_Z}\right)^2$$

To emphasize the difference from Dark Photon (coupling only to EM Current), we refer our Z' to "Dark Z boson". (In ε→0 limit, Z' couples only to Neutral Current.)

In a rough sense, Dark Photon = Heavy photon; Dark Z boson = Light Z boson.

New features due to Neutral Current

Since Dark Z couples to weak Neutral Current (containing axial coupling), it implies some new features that Dark Photon (vector coupling only) does not show.

(i) Parity violation

(ii) Enhancement from Goldstone Boson Equivalence Theorem (boosted Dark Z)

(iii) Coupling to electrically neutral particles (such as neutrinos)

As examples, we explore Dark Z implications for Low-Q^2 parity violation, rare meson decays, Higgs physics in this talk.

3. Dark Z Implications for Parity-Violating Experiments

Dark Z effects on Neutral Current experiments

Dark Z effect comes to the “Neutral Current phenomenology” as

$$G_F \to \left(1 + \delta^2 \frac{1}{1 + Q^2/m_{Z'}^2}\right) G_F$$

$$\sin^2\theta_W \to \left(1 - \varepsilon\delta \frac{m_Z}{m_{Z'}} \frac{\cos\theta_W}{\sin\theta_W} \frac{1}{1 + Q^2/m_{Z'}^2}\right) \sin^2\theta_W$$

1. Sensitive only to Low-Q^2 (momentum transfer). (Effect negligible for $Q^2 >> m_{Z'}^2$)
2. Unless ε is extremely small, $\Delta\sin^2\theta_W$ (Weinberg angle shift) is more sensitive.

[Weinberg angle measures Vector vs. Axial couplings ratio of the Neutral Current. Thus, it depends on both δ and ε. (If ε=0, Dark Z couples just like SM Z, and $\sin^2\theta_W$ does not change.)]

“Low-Q^2 Parity-Violating experiments (measuring Weinberg angle)” seem to be a right place to look: (i) Atomic parity violation, (ii) Polarized electron scattering experiments.

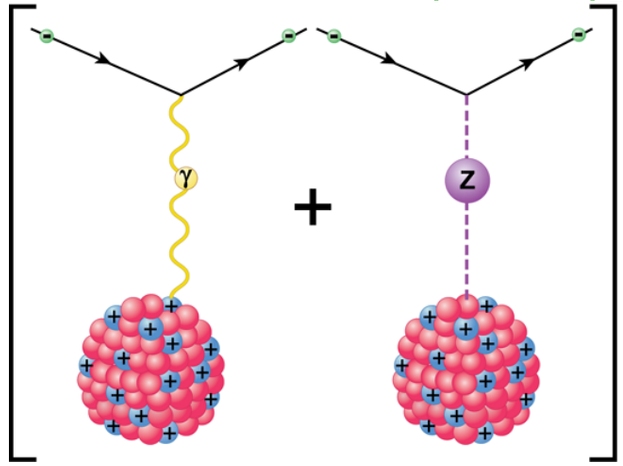
Low-Q^2 Parity-Violating Experiments

Atomic Parity Violation [Weak nuclear charge $Q_W(Z,N) \simeq -N+Z(1-4\sin^2\theta_W)$]:

$Q_W(^{133}Cs) = -72.58(43)$ in Cesium Experiment [C. Wieman et al (1985-1988)]

$Q_W(^{133}Cs) = -73.23(2)$ in SM [reflecting new result by Flambaum et al (2012)]2

in a reasonable agreement (1.5σ).

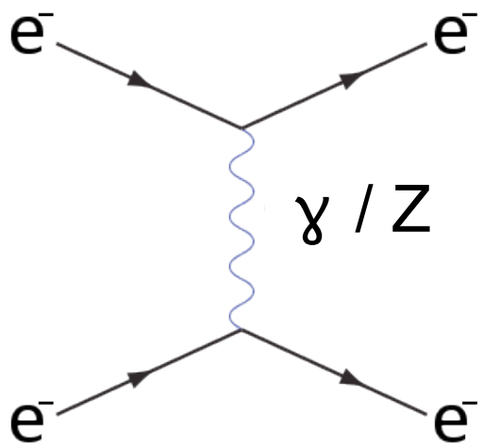


Polarized Electron Scattering [Left-Right asymmetry $A_{LR} = \sigma_L-\sigma_R / \sigma_L+\sigma_R$]:

$\sin^2\theta_W(m_Z)=0.2329(13)$ SLAC E158 (e^-e^- Moller scattering; Q≈160 MeV) (2005)

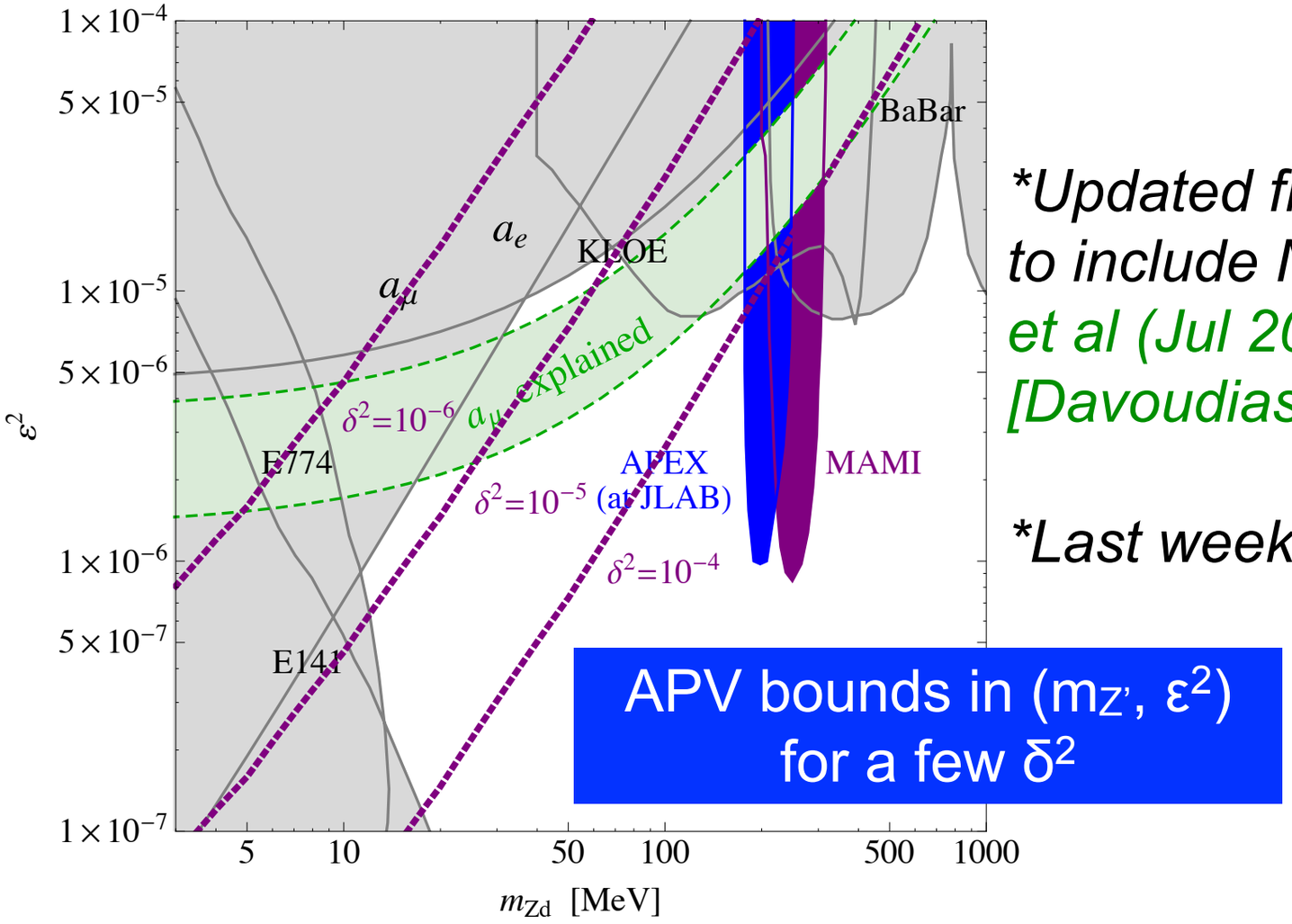
$\sin^2\theta_W(m_Z)=0.23125(16)$ at Z-pole average (LEP, SLC)

in good agreement.



$$\Delta \sin^2\theta_W \simeq -0.42\varepsilon\delta\frac{m_Z}{m_{Z'}}f(Q^2/m^2_{Z'})$$

Bounds from APV experiments



**Updated from the publication (PRL, Jul 2012) to include New APV calculation by [Flambaum et al (Jul 2012)] and New $(g-2)_e$ bound [Davoudiasl,HL,Marciano (Aug 2012)].*

**Last week's new MAMI results not included!*

Working assumption: the muon g-2 anomaly is due to Dark Z (green band).
APV (no deviation) gives a bound $\delta^2 < 10^{-4}$. (curves in 90% CL)
Can polarized electron scattering give better bounds on δ^2 (or test the Dark Z explanation to muon g-2 anomaly)?

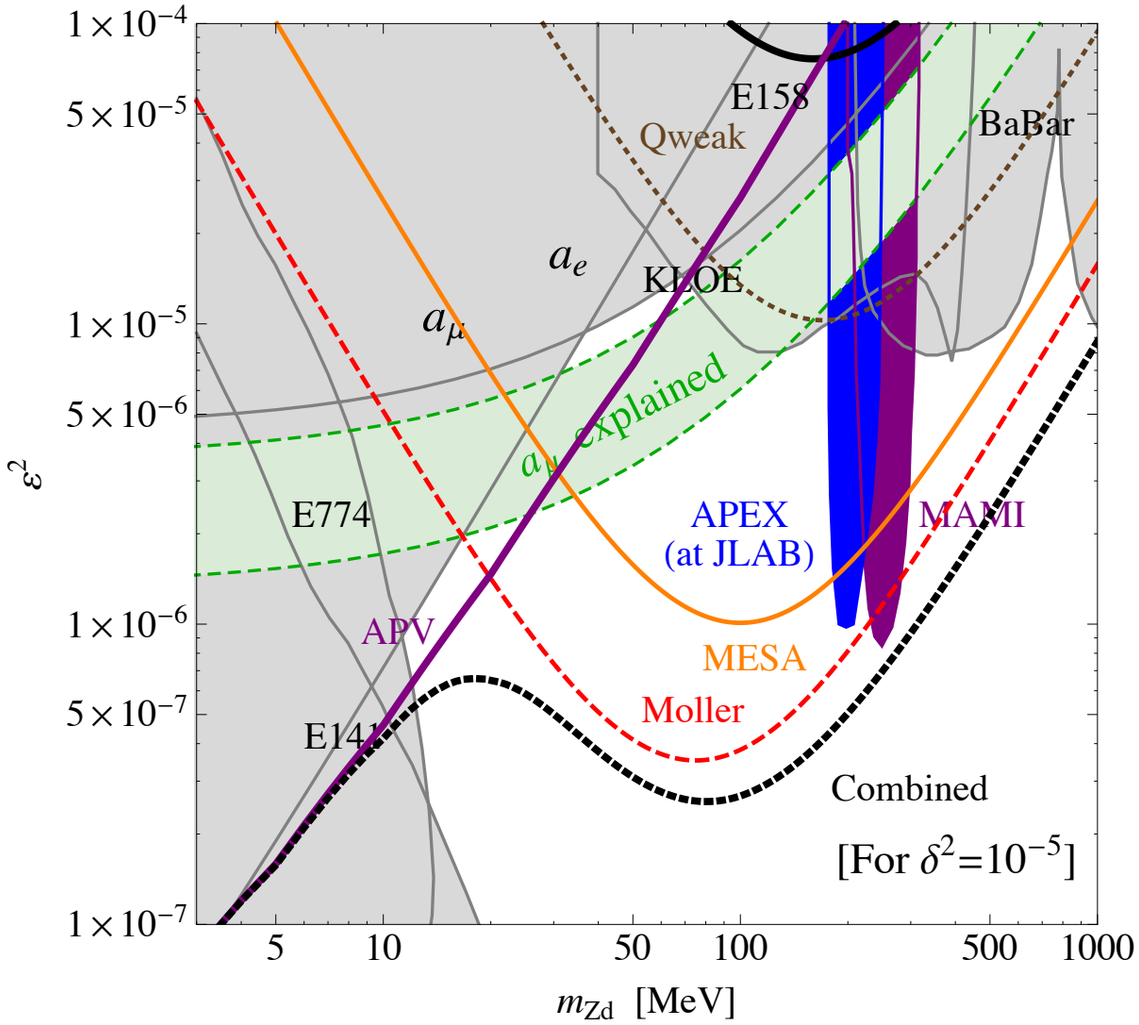
APV & Polarized electron scattering experiments

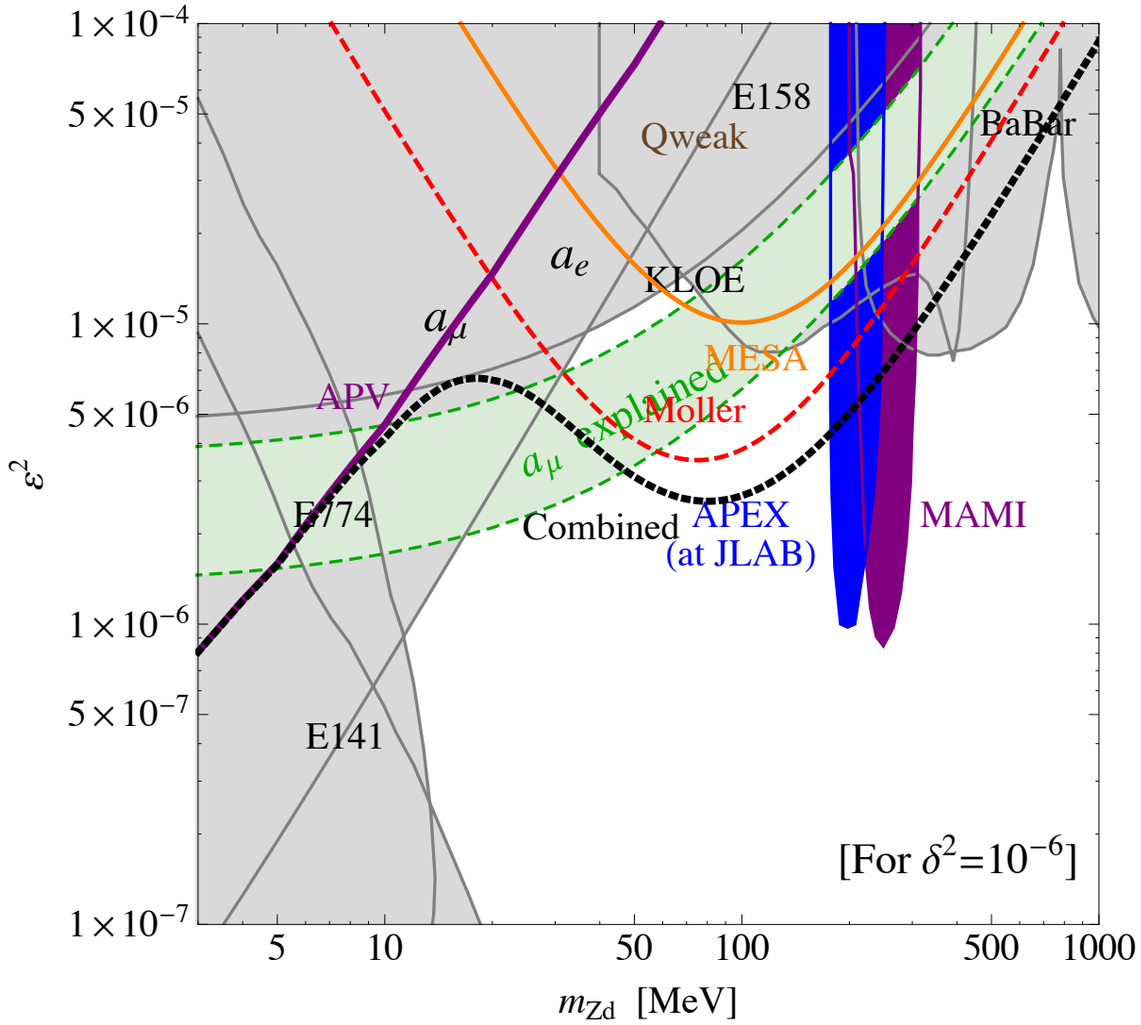
Experiment	$\langle Q \rangle$	$\sin^2\theta_W(m_Z)$	Bound on dark Z (90% CL)
Cesium APV	2.4 MeV	0.2313(16)	$\varepsilon^2 < \frac{39\times10^{-6}}{\delta^2}\left(\frac{m_{Z_d}}{m_Z}\right)^2 \frac{1}{K(m_{Z_d})^2}$
E158 (SLAC)	160 MeV	0.2329(13)	$\varepsilon^2 < \frac{62\times10^{-6}}{\delta^2}\left(\frac{(160\ \mathrm{MeV})^2+m_{Z_d}^2}{m_Z\, m_{Z_d}}\right)^2$
Qweak (JLAB)	170 MeV	±0.0007	$\varepsilon^2 < \frac{7.4\times10^{-6}}{\delta^2}\left(\frac{(170\ \mathrm{MeV})^2+m_{Z_d}^2}{m_Z\, m_{Z_d}}\right)^2$
Moller (JLAB)	75 MeV	±0.00029	$\varepsilon^2 < \frac{1.3\times10^{-6}}{\delta^2}\left(\frac{(75\ \mathrm{MeV})^2+m_{Z_d}^2}{m_Z\, m_{Z_d}}\right)^2$
MESA (Mainz)	50 MeV	±0.00037	$\varepsilon^2 < \frac{2.1\times10^{-6}}{\delta^2}\left(\frac{(50\ \mathrm{MeV})^2+m_{Z_d}^2}{m_Z\, m_{Z_d}}\right)^2$
Combined		±0.00021	$\varepsilon^2_{\mathrm{comb}} < \frac{1}{\sum_i (1/\varepsilon_i^2)}$

TABLE I: Existing and possible future constraints on dark Z from various parity violating experiments

APV bound changed.
MESA parameters not fixed yet.

Polarized electron scattering experiments





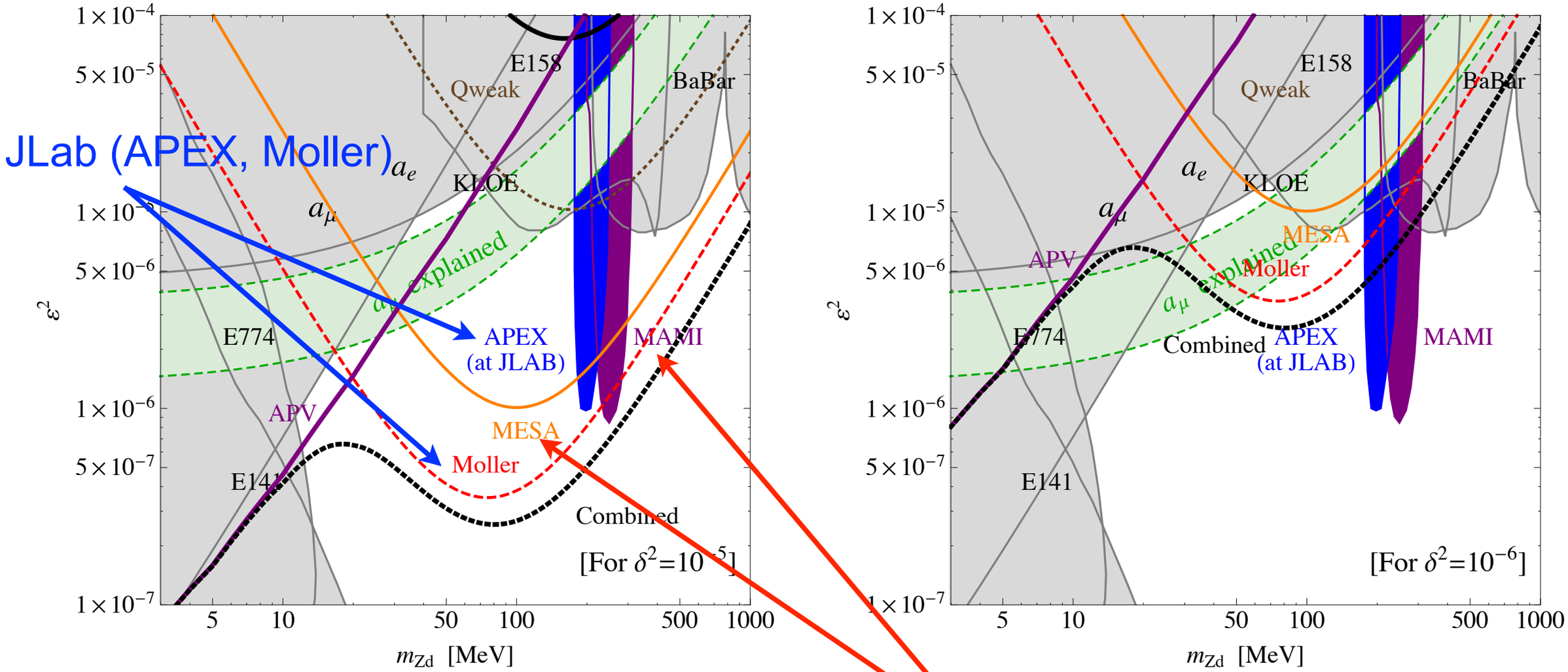
SLAC E158 and JLab Qweak (expected) bounds are weak, but proposed similar experiments (Moller at JLab, MESA at Mainz), combined with APV result, can test Dark Z explanation of muon g-2 anomaly up to δ^2 = (few)×10^{-6}. (curves in 90% CL)

If Dark Z is there, it will result in $\sin^2\theta_W$ shift.

(Ex) ($m_{Z'}$=75GeV, $\varepsilon^2=10^{-5}$) point will give $\Delta\sin^2\theta_W$ = 0.0015 (for $\delta^2=4\times10^{-6}$)

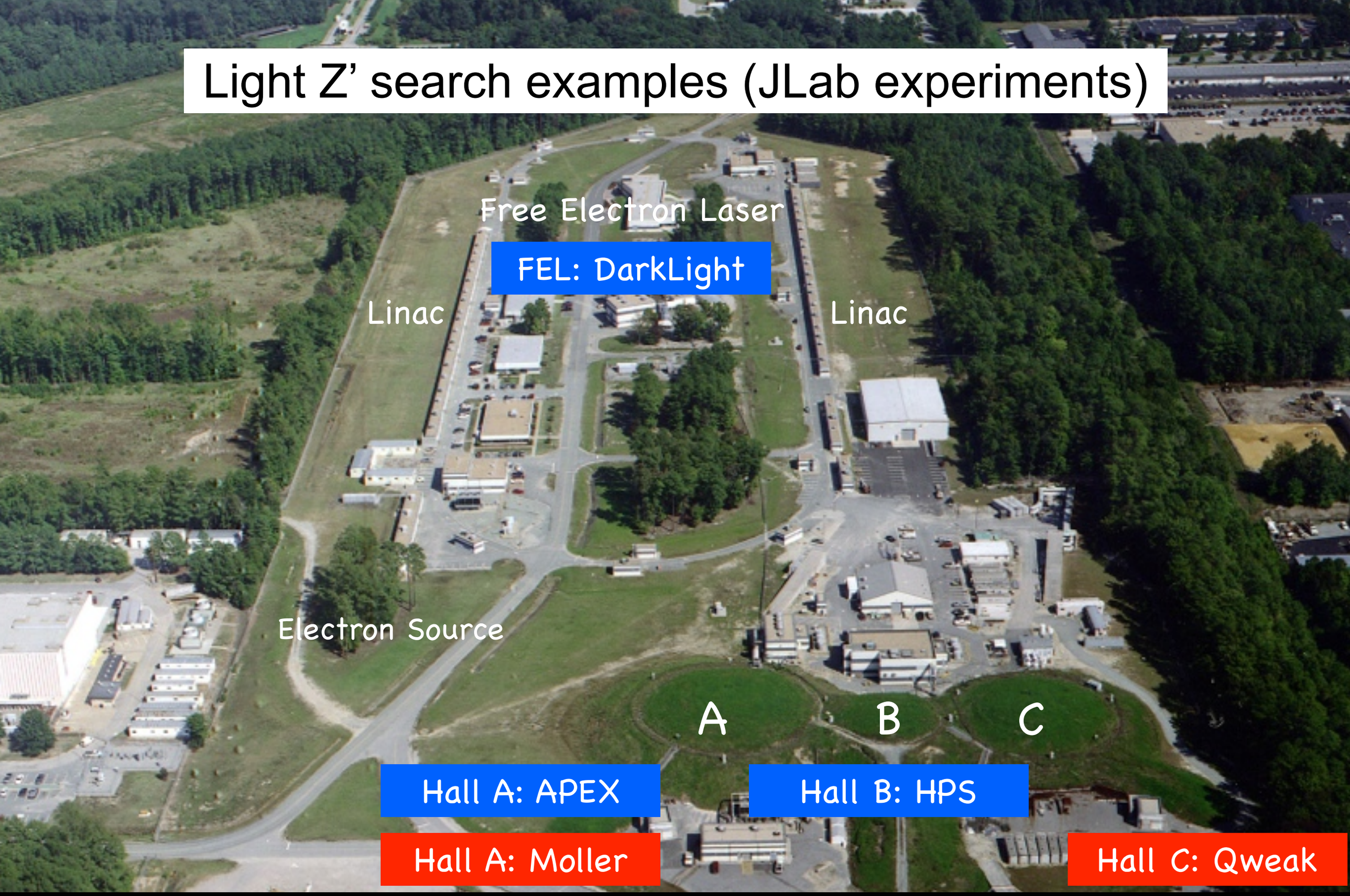
that can be measured by Moller with 5σ CL. (Not a good BP since last week.)

Polarized electron scattering experiments



Direct Dark Photon search places (JLab, Mainz) are also running complementary polarized electron scattering experiments that can be used for Dark Z search.

Light Z' search examples (JLab experiments)



Low-Q^2 Parity-Violating experiments are complementary "Dark Force" searches (for those with axial couplings)!

4. Dark Z Implications for Rare Meson Decays

Goldstone Boson Equivalence Theorem

Another advantage of Dark Z (with axial coupling) shows up in the boosted case.

Textbook (Peskin & Schroeder) example in SM: Consider top decay width (t→bW).

Naive expectation is $\Gamma(t \to bW) \sim g^2 m_t$

In reality, $\Gamma(t \to bW) \sim g^2 m_t \left(\frac{m_t}{m_W}\right)^2 \approx Y_t^2\, m_t \quad (\text{for } m_t \gg m_W)$

(larger than a naive expectation because of large Y_t)

Boosted W gets longitudinally polarized, and its production is that of associated Goldstone boson (pseudoscalar part of Higgs), up to $O(m_W^2/m_t^2)$.

Goldstone Boson Equivalence Theorem (GBET):
[Gauge boson emission/absorption] in High-E limit ≈ [Associated pseudoscalar (longitudinal component of gauge boson) emission/absorption]

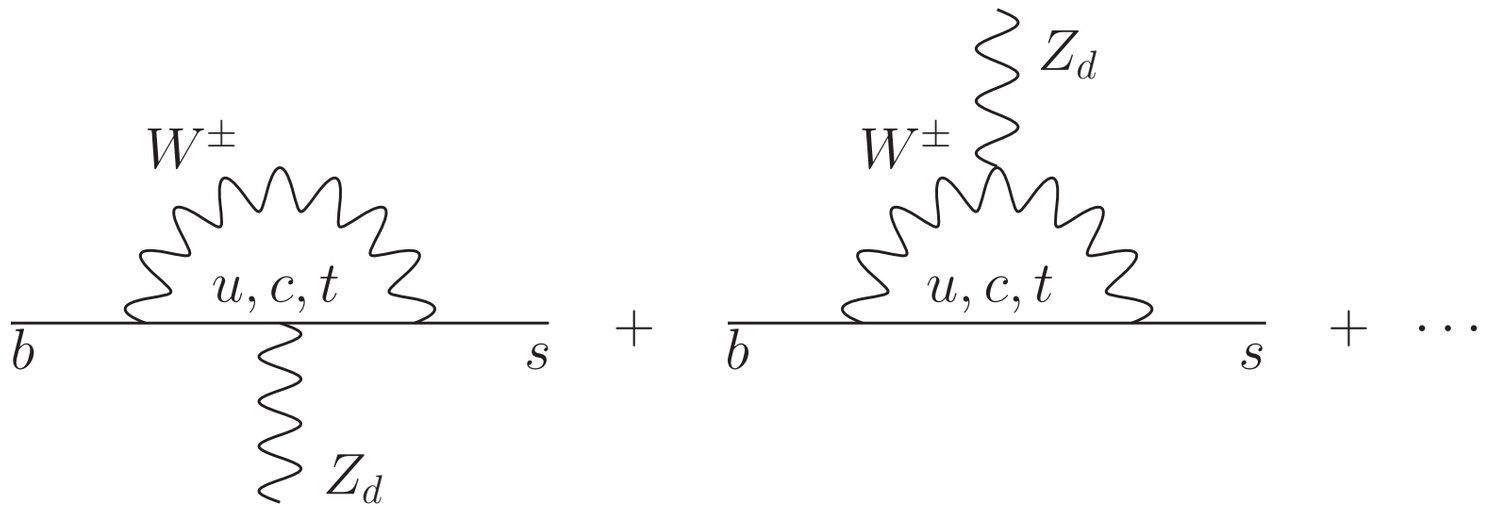
If the latter has larger coupling, the gauge boson production is enhanced.

Rare meson decays

Expect similar effect in rare meson decays into Dark Z:

$K \to \pi Z'$, $B \to K Z'$ (2-body decays)

$b \to s Z'$:
(FCNC through loop)



For $m_{Z'} << m_K, m_B$, Dark Z is boosted (longitudinally polarized), and GBET tells us

(Z' production) ≈ (Axion production)

light pseudoscalar

Cf. Decaying branching ratio is not axion-like.

BR(Z' → ee) = BR(Z' → μμ) (up to phase space)

Rare meson decays

For Dark Z, we adopt existing calculation on s-d-Axion, b-s-Axion coupling as a good approximation.
[Hall, Wise (1981)] [Frere, Vermaseren, Gavela (1981)] [Freytsis, Ligeti, Thaler (2009)]

$$\mathrm{BR}(K^+ \to \pi^+ Z')|_{\mathrm{longitudinal}} \simeq 4 \times 10^{-4}\, \delta^2$$

$$\mathrm{BR}(B \to K Z')|_{\mathrm{longitudinal}} \simeq 0.1\, \delta^2 \quad [\mathrm{large}\ m_t\ \mathrm{and}\ V_{tb}]$$

Compare this to Dark Photon case [no GBET enhancement because it couples only to conserved current], which is not very promising (for typical size of $\varepsilon \lesssim 10^{-3}$) [Batell, Pospelov, Ritz (2009)].

$$\mathrm{BR}(B \to K Z') \sim 6 \times 10^{-7}\, \varepsilon^2 \quad (\mathrm{for}\ m_{Z'} \simeq 1\ \mathrm{GeV})$$

$K \to \pi Z'$

Compare to the experimental values (which agree to the SM expectation)

$$\mathrm{BR}(K^+ \to \pi^+ e^+ e^-)_{\mathrm{Exp}} = (3.00 \pm 0.09) \times 10^{-7}$$
$$\mathrm{BR}(K^+ \to \pi^+ \mu^+ \mu^-)_{\mathrm{Exp}} = (9.4 \pm 0.6) \times 10^{-8}$$
$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})_{\mathrm{Exp}} = (1.7 \pm 1.1) \times 10^{-10}$$

to get bounds

$$|\delta| < 0.01/\sqrt{\mathrm{BR}(Z' \to e^+ e^-)}$$
$$|\delta| < 0.001/\sqrt{\mathrm{BR}(Z' \to \text{missing energy})}$$

In the future, with enough data and fine bins, $Z' \to \ell^+\ell^-$ (ℓ=e,μ) can give a bump in the dilepton invariant mass plot.

(Caveat: Acceptance cuts are used in experimental values. For example, $M_{ee} > 140$ MeV to avoid $\pi \to ee\gamma$ Dalitz decay BKG.)

B → K Z'

Similarly, from B decay results, we get

$$|\delta| < 0.001/\sqrt{\mathrm{BR}(Z' \to e^+e^-)}$$

$$|\delta| < 0.01/\sqrt{\mathrm{BR}(Z' \to \text{missing energy})}$$

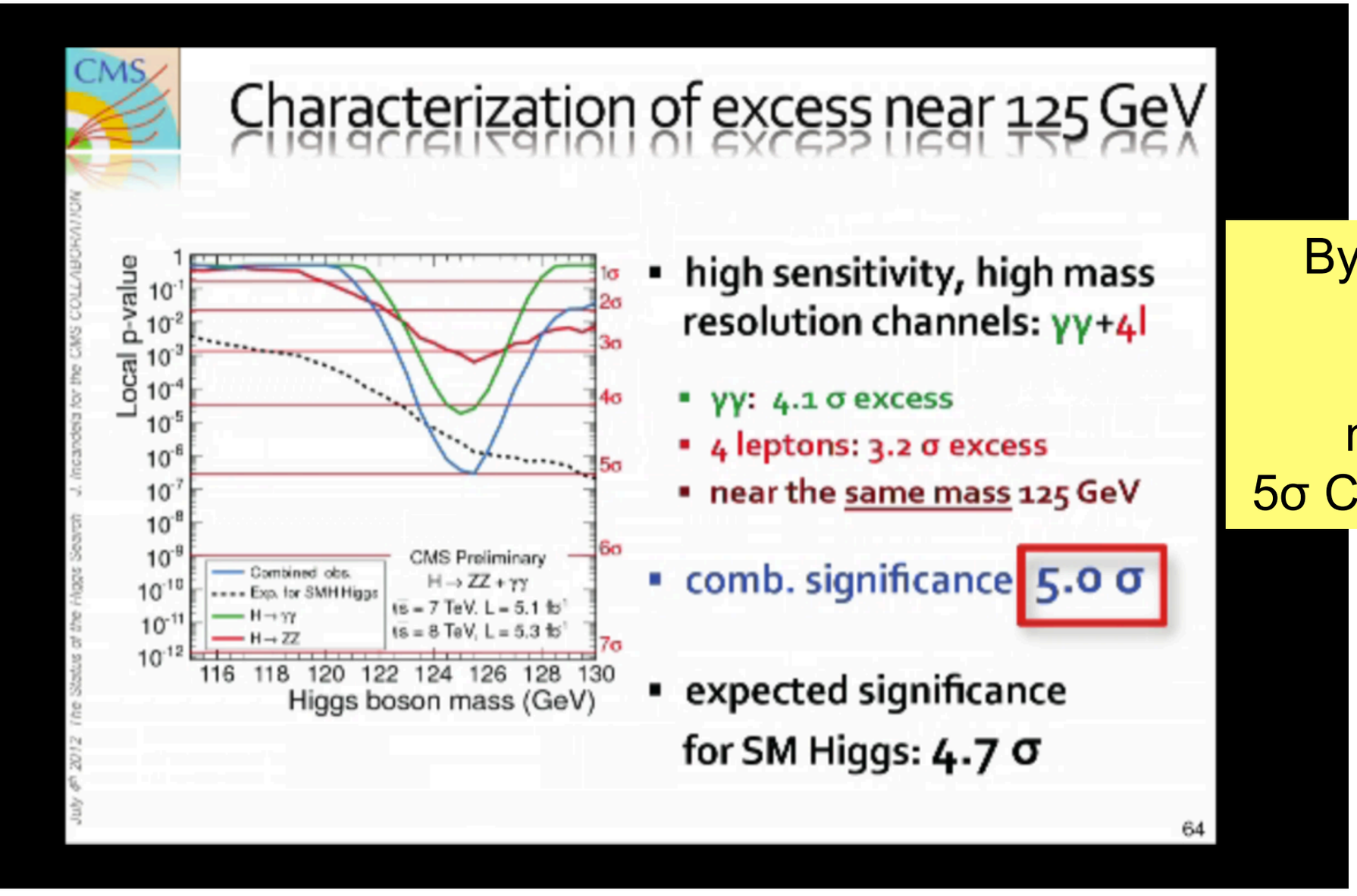
Overall, rare K and B meson decays provide, depending on Z' BR,

$|\delta| < 0.01\text{-}0.001$ (for $m_{Z'} << m_K, m_B$).

5. Dark Z Implications for Higgs Physics

(Connection of High-E and Low-E physics)

Higgs (or something similar) was discovered.



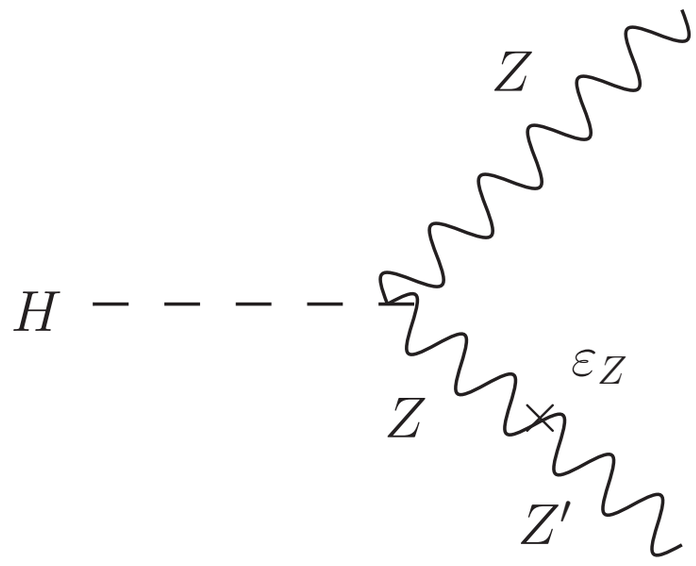
By both ATLAS and CMS
(July 4, 2012)

mass = 125-126 GeV
5σ C.L. (γγ and 4ℓ combined)

About time to do precision Higgs study.
We consider the SM-like Higgs decay into light Z' particle at the LHC.

SM-like Higgs → Z Z'

For Dark Photon (kinetic mixing only), Z-Z' net mixing vanishes, but for Dark Z, it does not.

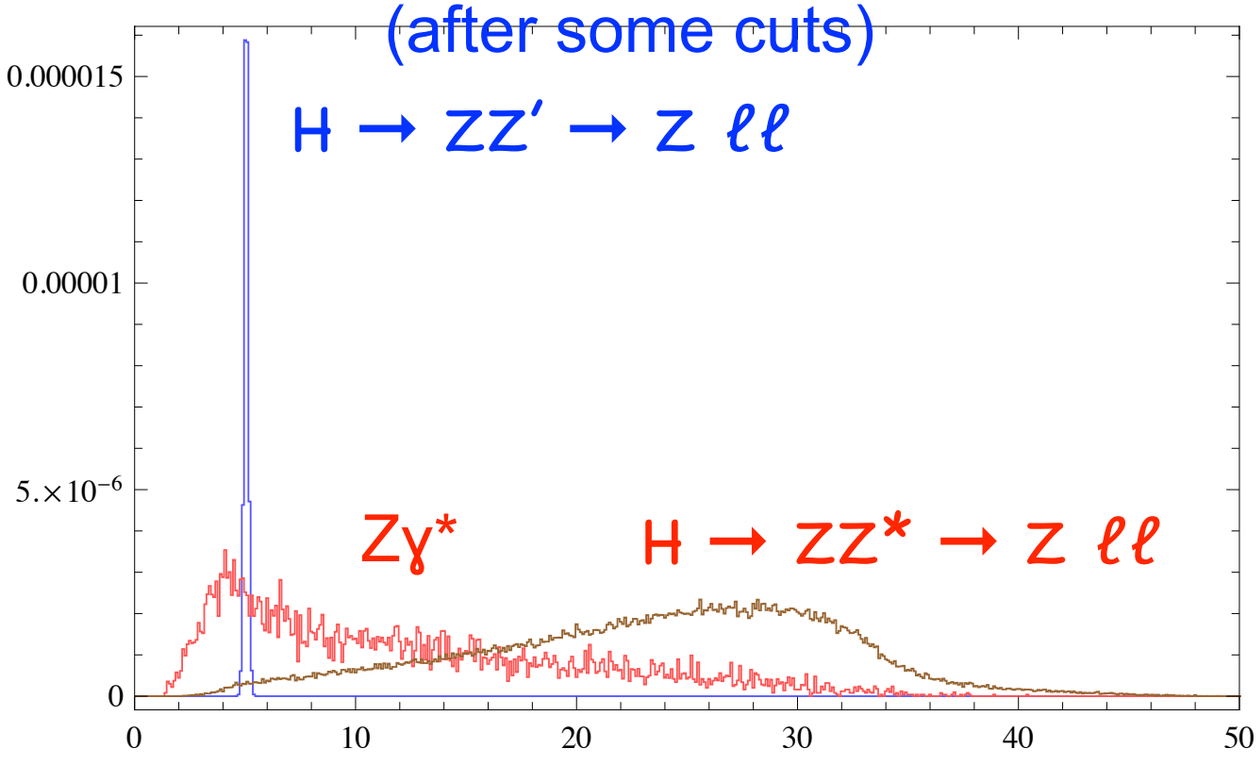


(HZZ' coupling) = ε_Z (HZZ coupling)

Also GBET provides an enhancement (in a similar way to meson decay B → K Z').

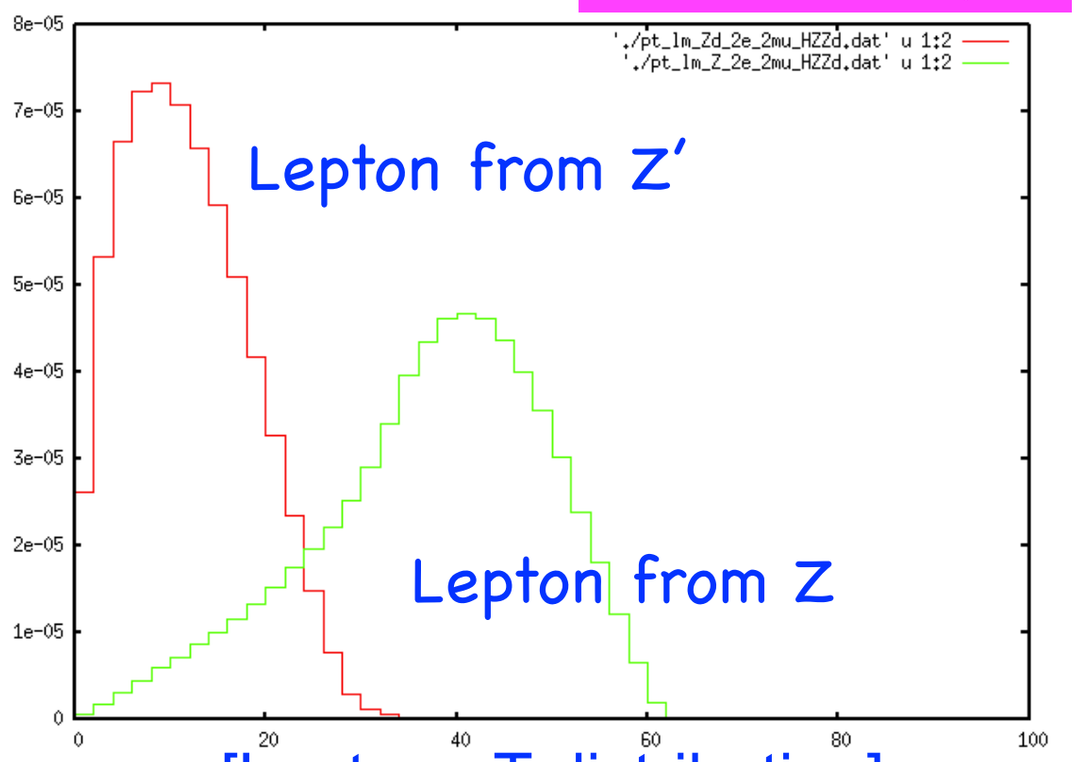
Monte Carlo study (Higgs → ZZ' → 4-leptons)

Expect a "spike" in low invariant mass (after some cuts)



[Dilepton Invariant Mass]

[Preliminary]



[Lepton pT distribution]

(pT spread to large values due to boosted Z')

Typical 4-lepton search at ATLAS/CMS [H → ZZ$^{(*)}$]: Impose $M_{\ell\ell} \gtrsim$ 15-20 GeV to reduce BKG (such as Zγ*).

But "$M_{\ell\ell}$ ~ several GeV" could be a sweet spot for Light Z' bump hunting.
(For sub-GeV range, LHC is not sensitive. Complementary to JLab/Mainz or B/K.)

Monte Carlo analysis for feasibility study is underway [with I. Lewis at BNL].

Summary

Summary

In the dark/secluded U(1)' picture (SM particles have zero charges), it can still communicate with the SM through kinetic mixing $U(1)_Y$ X U(1)'.

Z' coupling depends on details of Higgs sector.
(i) Dark Photon: couples to EM Current (simplest Higgs sector case)
(ii) Dark Z: couples to Neutral Current as well (more general Higgs sector)

Dark Z is a natural way to introduce axial coupling to "Dark Photon"-related study.

New features of Dark Z: Low-Q^2 parity violation, Enhancement from Goldstone Boson Equivalence Theorem (in rare meson/Higgs decays), ...

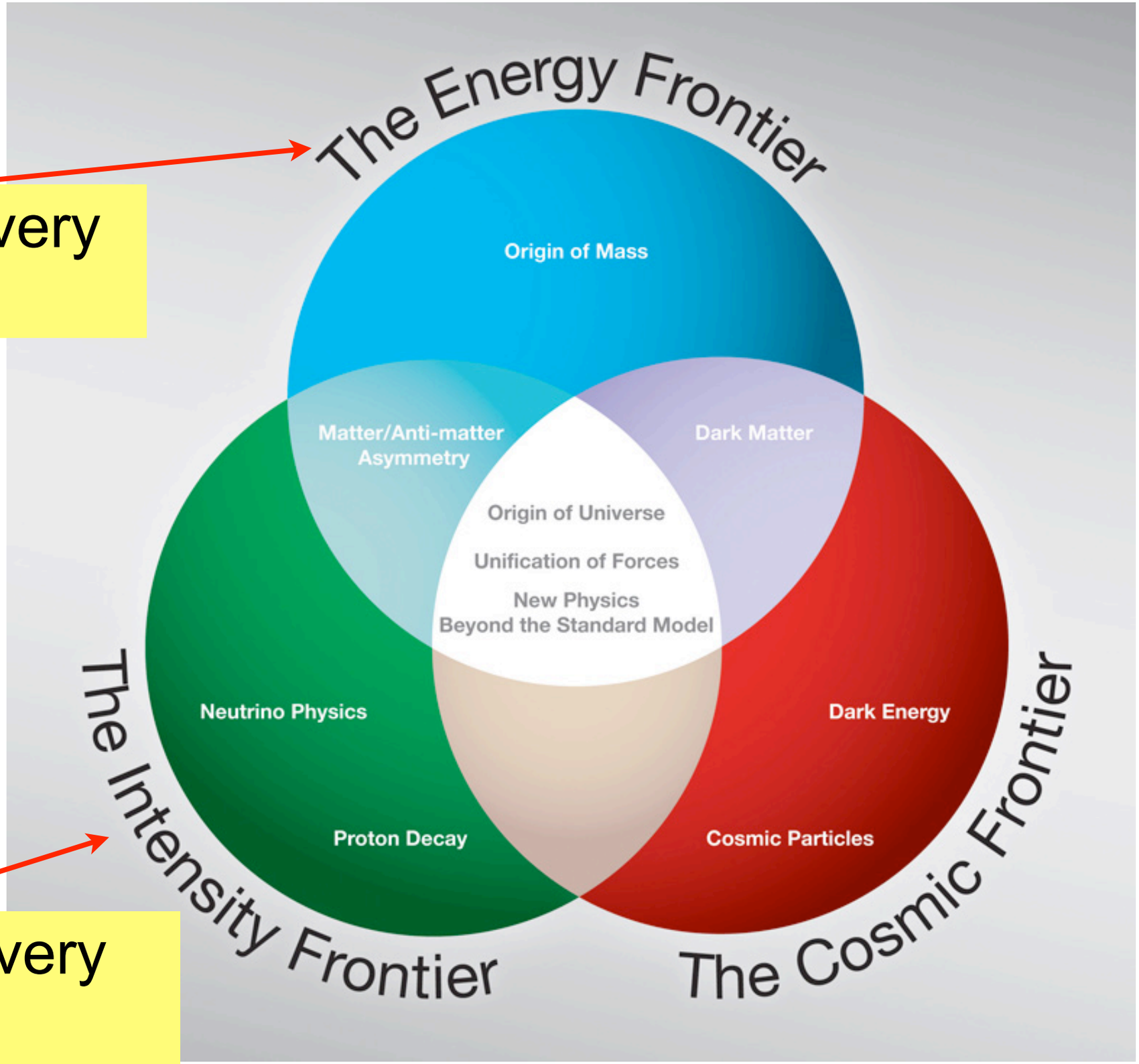
In hunting for a Light and very weakly-interacting Z', various Low-E experiments (JLab, B-factories, ...) and High-E experiments (LHC, ...) are all relevant and complementary.

Rosy possibility: First New Physics discovery may take place in Newport News in a couple of years!

- Thank you -

Backup Slides

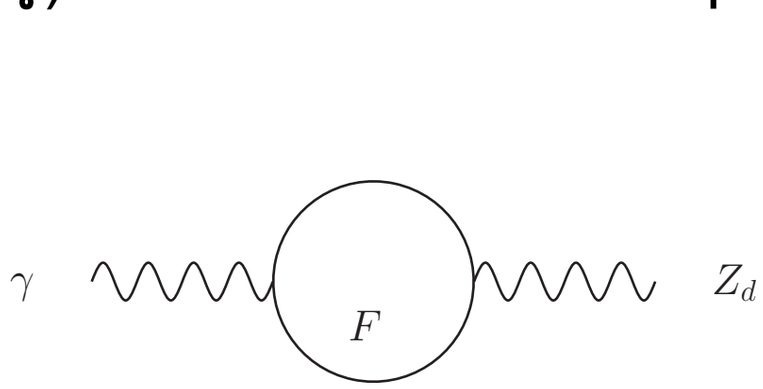
Traditional Discovery Frontier

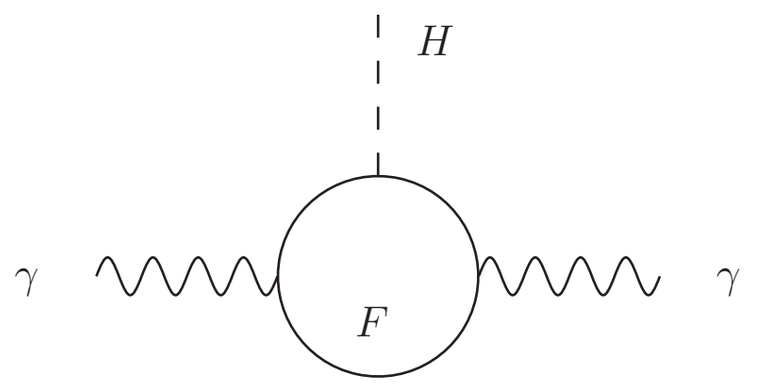
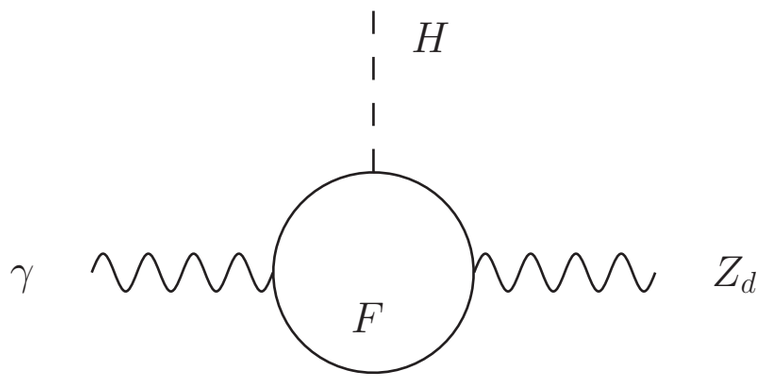
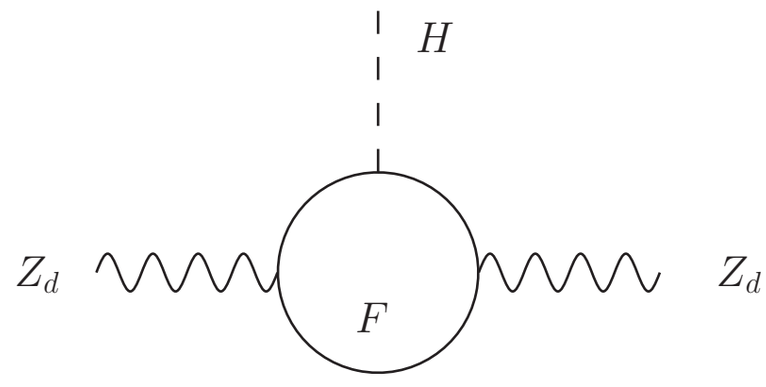


Emerging Discovery Frontier!
(with Dark sector picture)

Diphoton excess and Dark Photon?

If kinetic mixing is mediated by a heavy vector-like lepton (F), it can explain the diphoton excess in the recently observed 125 GeV Higgs.
BR(H → ɣ ɣ) ~ 1.5-2 times the SM prediction.





It predicts H → ɣ Z’ and Z’ Z’ at the rate below H → ɣ ɣ, but potentially observable rate. (Z’ → ee would look like a converted photon)