Looking for New Physics in the low energy experiments

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arXiv: 1810.11028, 2001.06522

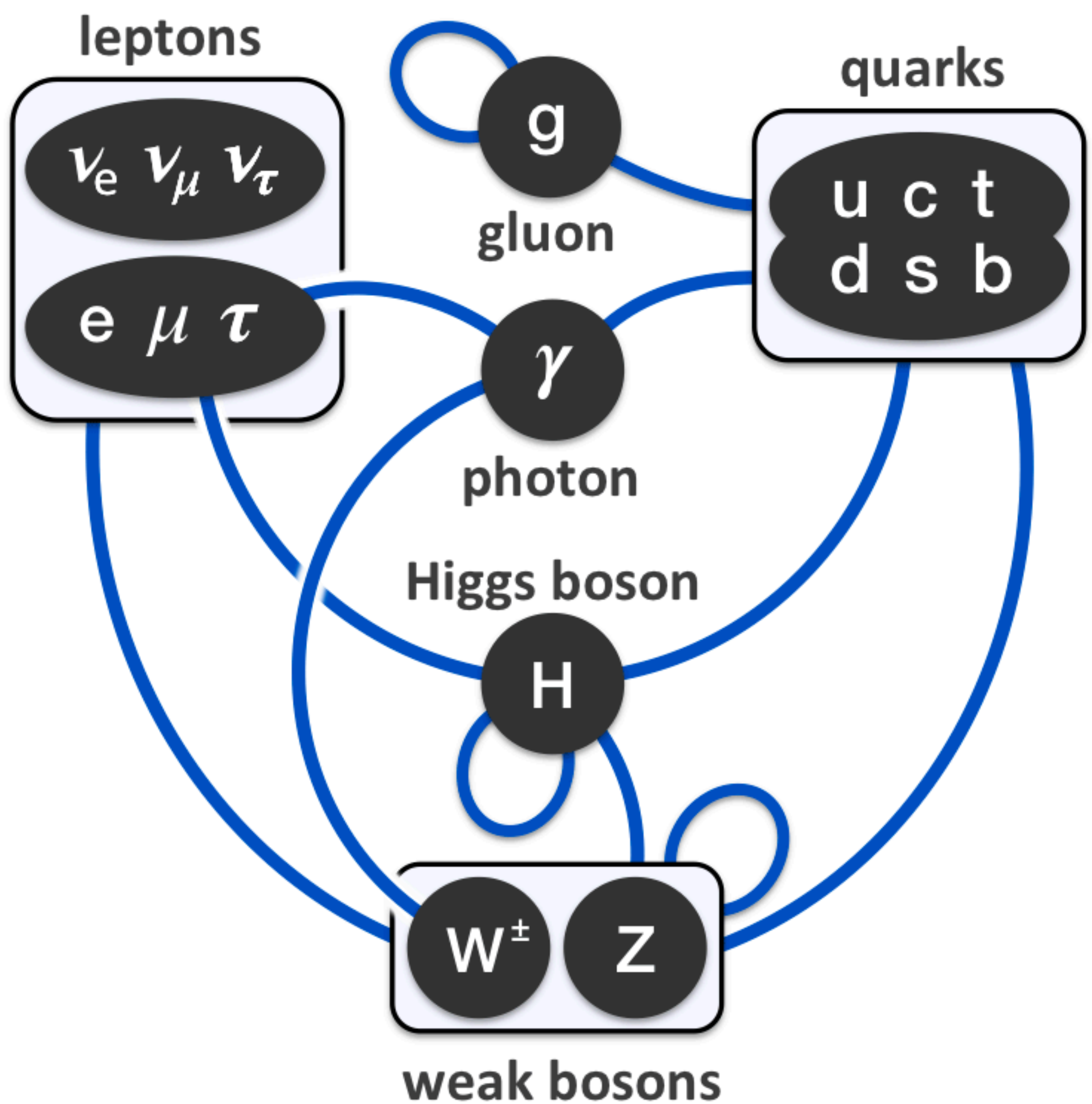
04/02/2020 Fermilab Seminar

The outline

- The motivation for new physics in the low energy
- The lepton g-2
- The KOTO experiment
- Summary

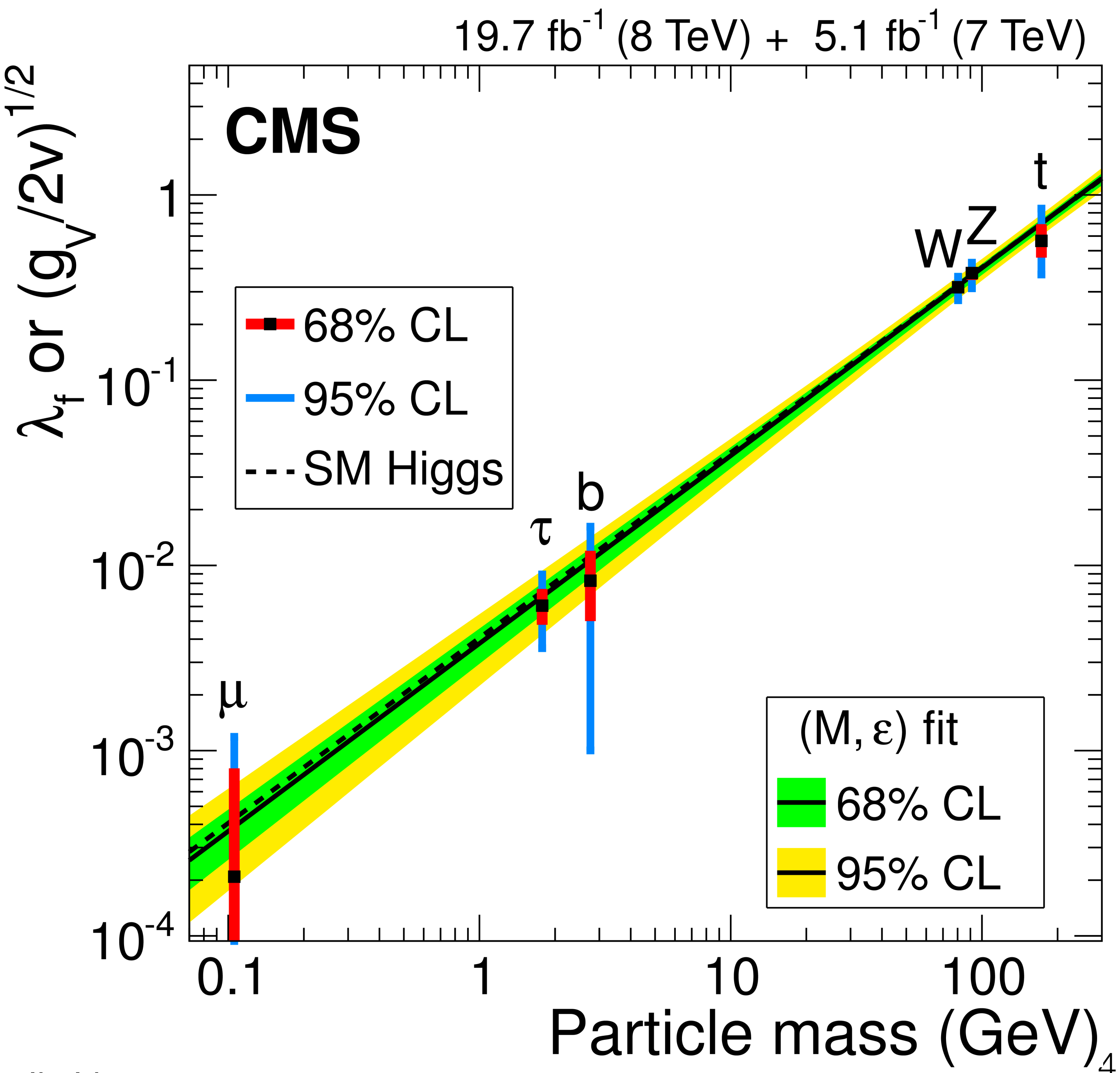
The Standard Model

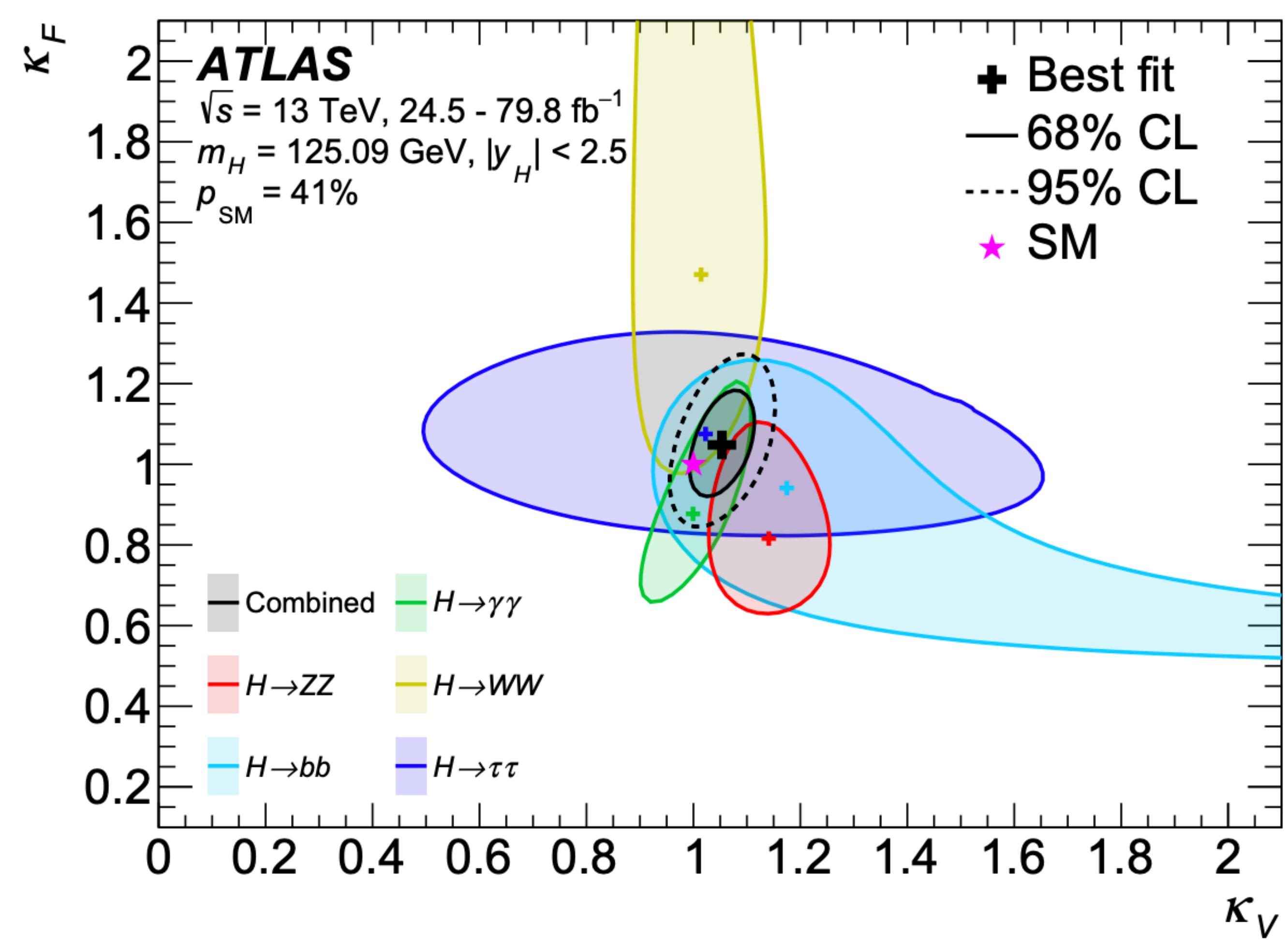
- A unified story for strong, weak and electromagnetic interactions.



The 125 GeV Higgs

- Its properties are very close to the SM predictions.





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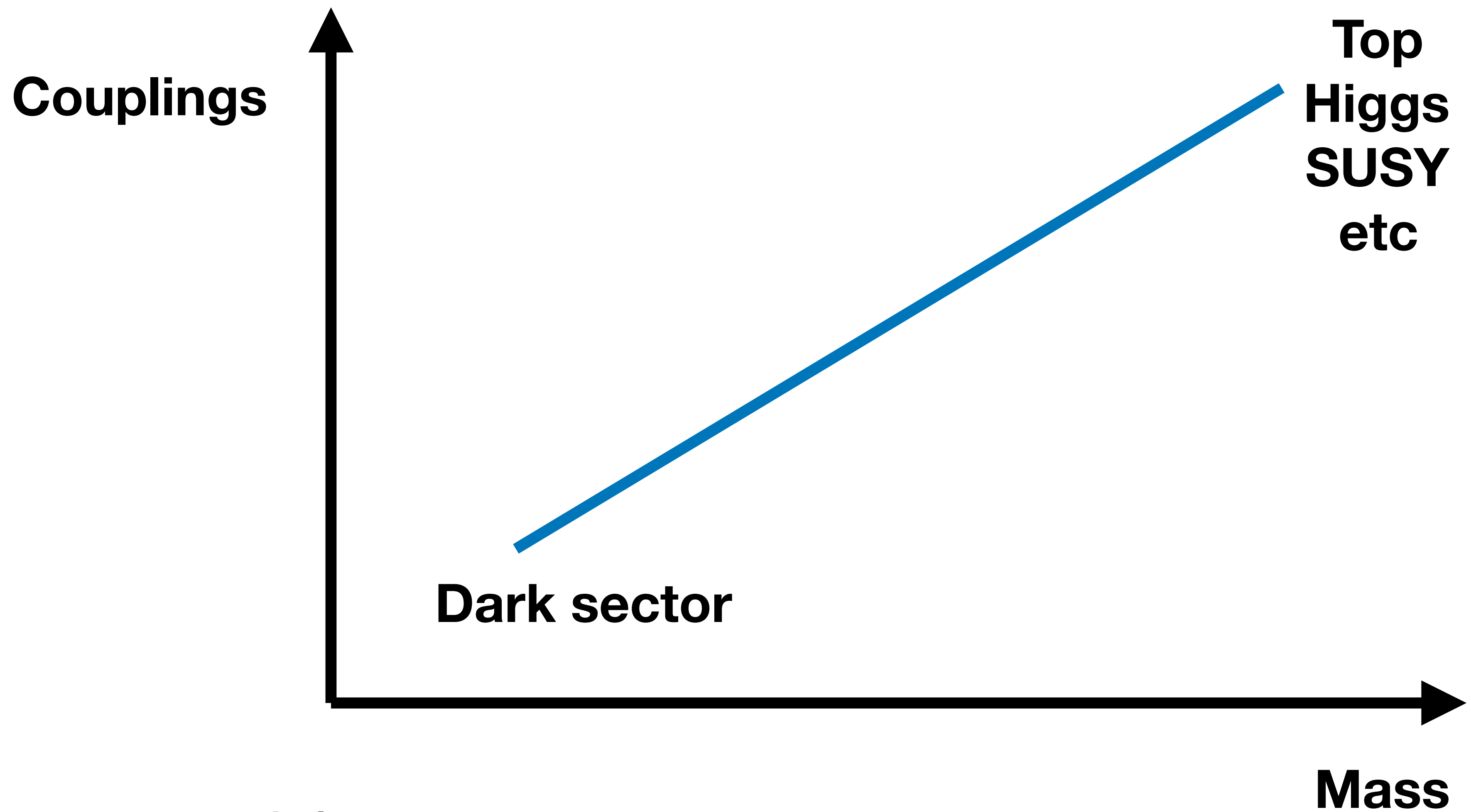
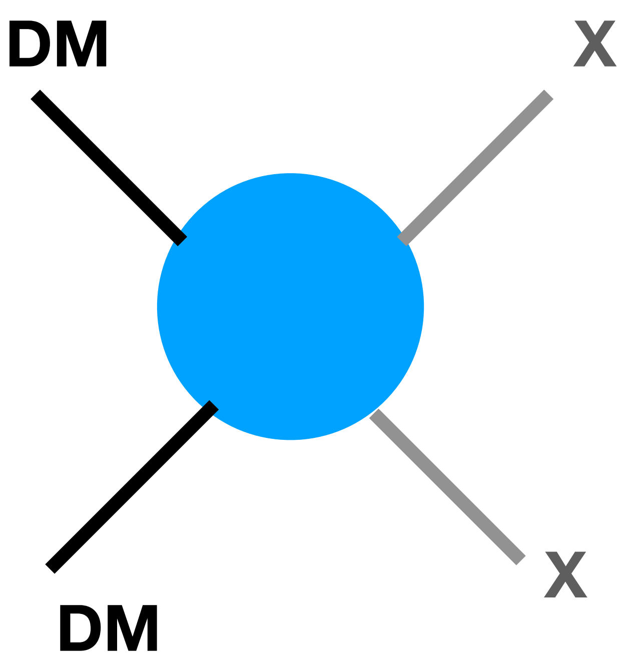
The heavy and the light

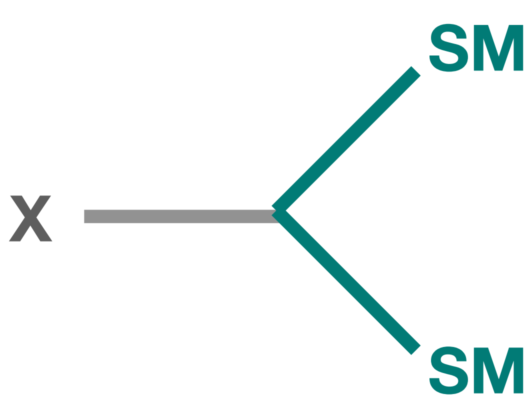


- Dark sector particles
  - New light weakly coupled particles
  - Do not interact with the known strong, weak, or electromagnetic forces

The motivation for dark sector particles

- 1. Existence of dark matter
    - do not interact with strong, weak, or electromagnetic forces
    - A zoo of similar particles in the dark sector as in the visible sector
- 2. The null detection of dark matter
    - Secluded annihilation: DM + DM → X + X
    - X is light and weakly coupled to visible sector





The motivation for dark sector particles

- 3. The experiment status
  - Technically difficult to increase E
  - Easier to accumulate higher luminosity
- 4. The low energy experiment hints
  - Lepton e/mu g-2 (light scalar at ~100 MeV) 1806.10252 Davoudiasl et al …
  - KOTO: neutral K decay into pi0 + MET (light scalar < 200 MeV) 1909.11111 Kitahara et al …
  - MiniBooNE: (dark neutrino/boson at 10~100MeV) 1807.09877 Bertuzzo et al …
  - Atomki: Be8/He4 decay into a 17 MeV ee resonance 1604.07411 Feng et al …

Dark sector models via gauge singlet portals

- Kinetic mixing portal $B_{\mu\nu}F'^{\mu\nu}$
- Neutrino portal LH
- Higgs portal $H^\dagger H$
- Higher dimensional operators $\frac{a}{\Lambda}\tilde{F}F, \frac{a}{\Lambda}\tilde{G}G$

The Higgs portals

- SM Higgs portal model $H^\dagger H\phi^2,\ H^\dagger H\phi$

$$\mathscr{L}_{\text{int}} \supset \sin\theta \times \phi \left(\sum_q \frac{m_q}{v}\bar{q}q + \sum_\ell \frac{m_\ell}{v}\bar{\ell}\ell + \cdots \right)$$

- More structures with multiple Higgs doublets
  - CP-even scalar mixing

$$H_1^\dagger H_1\phi,\ H_2^\dagger H_2\phi \cdots$$

  - CP-odd/even scalar mixing

$$H_1^\dagger H_2\phi + h.c. \cdots$$

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Lepton magnetic dipole moments

The classical relation between the magnetic moment and the orbital momentum of leptons in classical (quantum) theory

$$\overrightarrow{\mu} = -\frac{e}{2m_\ell}\overrightarrow{L}$$

is slightly modified the case of Spin. Actually, from the low energy limit of the relativistic Dirac equation, we have

$$\overrightarrow{\mu} = -\frac{e}{2m_\ell} g_\ell \overrightarrow{S}$$

Schwinger realized that this g-factor is modified under quantum corrections

$$a_\ell \equiv \frac{g_\ell - 2}{2} = \frac{\alpha}{2\pi} + \cdots$$

Today, the electromagnetic corrections are known up to five loops, and the agreement between theory and experiments is one of the greatest triumphs of science and the SM.

The direct measurement of MDM

- For a lepton in a uniform magnetic field, the cyclotron frequency (momentum rotation) is

$$\omega_c = \frac{eB}{m_\ell \gamma_\ell}$$

- For an electron in a uniform magnetic field, the spin rotation frequency is

$$\omega_s = \frac{eB}{m_\ell \gamma_\ell} + a_\ell \frac{eB}{m_\ell}$$

- The spin precision frequency accounted the rotation frame and inertial frame difference

$$\omega_a = \omega_s - \omega_c = a_\ell \frac{eB}{m_\ell}$$

Precision has no γ dependence!

Experiments practice clever ways to measure the precision frequency.

hep-ex/0308064

The direct measurement of MDM

- In the experiment, adding a uniform B field and electrostatic quadrupole focusing

$$\vec{\omega}_a = \frac{e}{m_\ell}\left[a_\ell \vec{B} - \left(a_\ell - \frac{1}{\gamma_\ell^2 - 1}\right)\vec{\beta}_\ell \times \vec{E}\right]$$

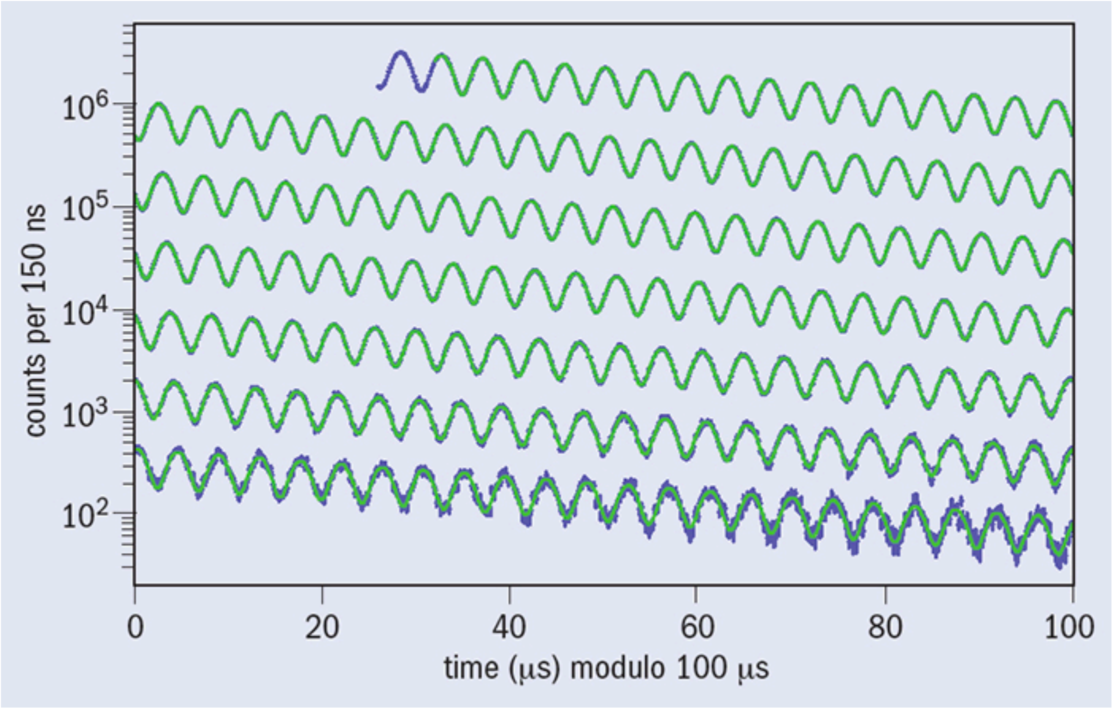
- For muon lepton, there is a magic momentum

$$\left(a_\ell - \frac{1}{\gamma_\ell^2 - 1}\right) = 0 \Rightarrow p_m^\mu = 3.09\text{GeV}$$

- BNL measurement of muon g-2

$$a_\mu^{\exp} = (11659208.0 \pm 6.3) \times 10^{-10}$$

hep-ex/0308064

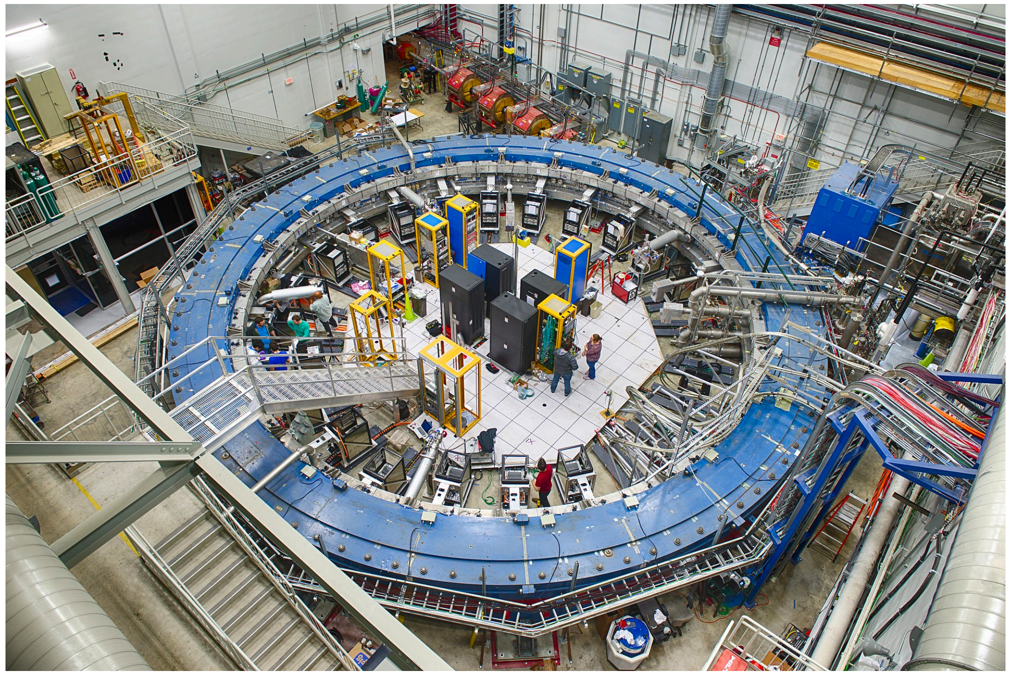


The direct measurement of MDM

- BNL measurement of muon g-2

$$a_\mu^{\rm exp} = (11659208.0 \pm 6.3) \times 10^{-10}$$

- Waiting for the cross-check from Fermilab Muon g-2



- Electron g-2 is measured by Single-Electron Quantum Cyclotron with cavity control

$$a_e^{\rm exp} = (115965218073 \pm 28) \times 10^{-14}$$

1009.4831

The theory calculation of MDM

- The electron g-2 calculation

$$a_e^{\rm th} = a_e^{\rm QED} + a_e^{\rm Had} + a_e^{\rm EW}$$

  - QED up to 10th order

$$(\alpha/\pi)^5 \sim 7 \times 10^{-14}$$

  - EW and Had (light-light) are small due to small m_e

$$a_e^{\rm th} = (115965218164.3 \pm \mathbf{2.5} \pm \mathbf{2.3} \pm \mathbf{1.6} \pm \mathbf{76.3}) \times 10^{-14}$$

QED **Had (l-l)+EW** α

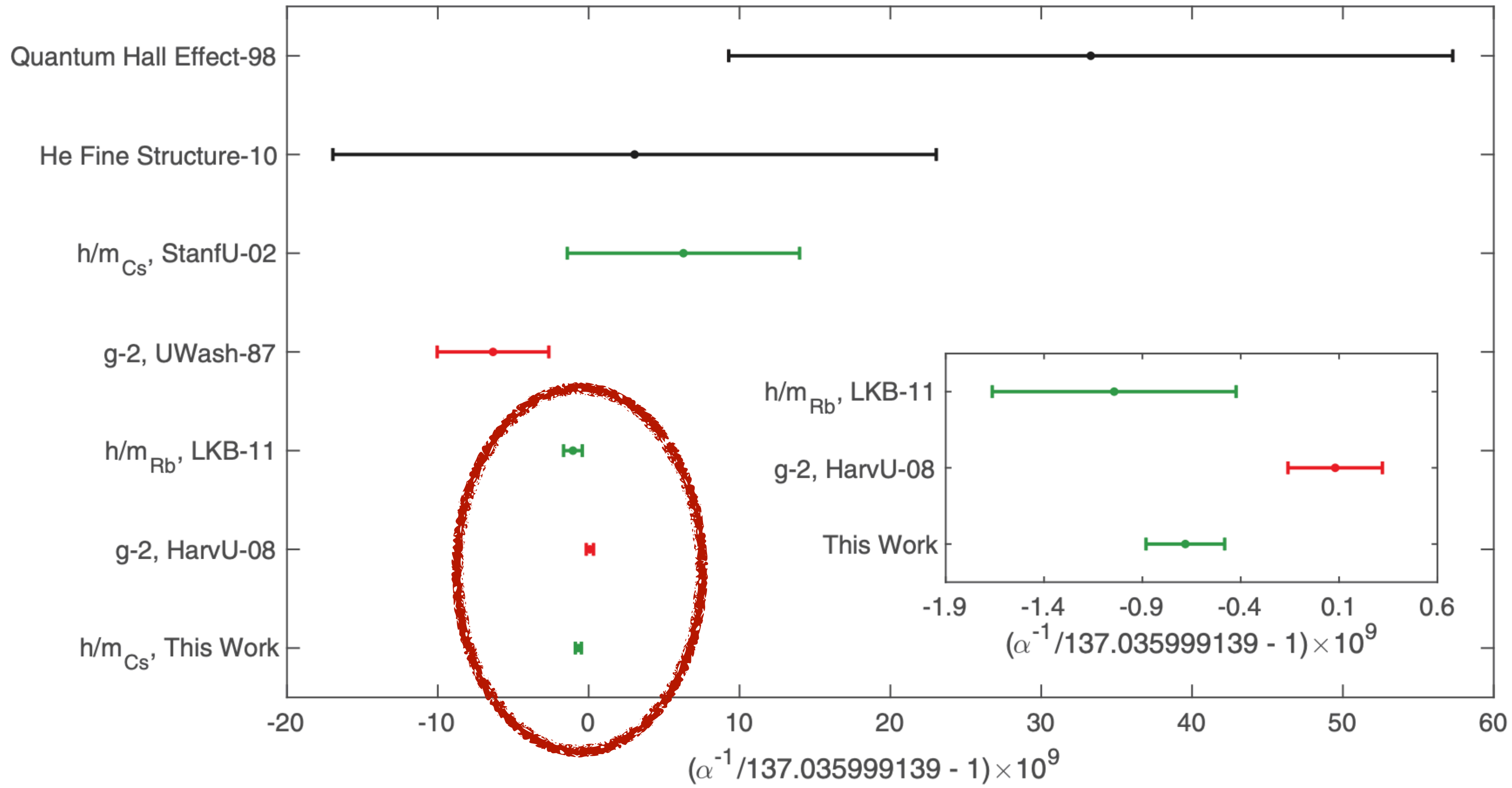
Aoyama et al 1412.8284, old fine structure constant from Rb measurement

- Fine structure constant induces the largest uncertainty for a_e
- Fine structure constant calculated via a_e has better uncertainty than direct measurement.

The theory calculation of MDM

- The most recent fine structure constant measurement

Parker et al., Science 360, 191–195 (2018)



$$a_e^{\rm th} = (115965218161 \pm 23) \times 10^{-14}$$

$$\Delta a_e = a_e^{\rm exp} - a_e^{\rm th} = (-88 \pm 36) \times 10^{-14}$$

- Negative value and a 2.4 σ discrepancy

The theory calculation of MDM

- The muon g-2 calculation

$$a_\mu^{\rm th} = a_\mu^{\rm QED} + a_\mu^{\rm Had} + a_\mu^{\rm EW}$$

  - Hadronic uncertainty dominated

$$a_\mu^{\rm Had}(\text{vac pol}) = (688 \pm 4) \times 10^{-10}$$

$$a_\mu^{\rm Had}(\gamma \times \gamma) \simeq 10 \times 10^{-10}$$

  - EW uncertainty

$$a_\mu^{\rm EW} = (15.1 \pm 0.4) \times 10^{-10}$$

- Positive value and a 3.7 σ

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm th} = (27.4 \pm 7.3) \times 10^{-10}$$

- The difference is close to EW contribution suggesting New Physics at the Weak scale: SUSY etc

A combined explanation for e/mu g-2?

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm th} = (27.4 \pm 7.3) \times 10^{-10}$$

$$\Delta a_e = a_e^{\rm exp} - a_e^{\rm th} = (-88 \pm 36) \times 10^{-14}$$

- A naive estimate $\frac{m_e^2}{m_\mu^2}\Delta a_\mu \approx 6.4 \times 10^{-14}$

- Possible solutions for negative and sizable a_e correction
  - Higher order operator: 2-loop Barr-Zee 1806.10252, 2003.09781, 2003.03386
  - Threshold correction 1906.08768
  - Heavy leptons 1910.10734, 2003.07638
  - Charged Higgs 1907.08109
  - Chargino-sneutrino/bino-slepton 1908.03607
  - Leptoquark with mixed chirality 2002.12544

Scalar explanations for e/mu g-2

- Scalar ϕ_R and pseudo-scalar ϕ_I coupling to leptons

$$\mathscr{L}_{\text{int}} = i g_I \phi_I \bar{\ell} \gamma_5 \ell + g_R \phi_R \bar{\ell} \ell$$

- 1-loop contribution to g-2

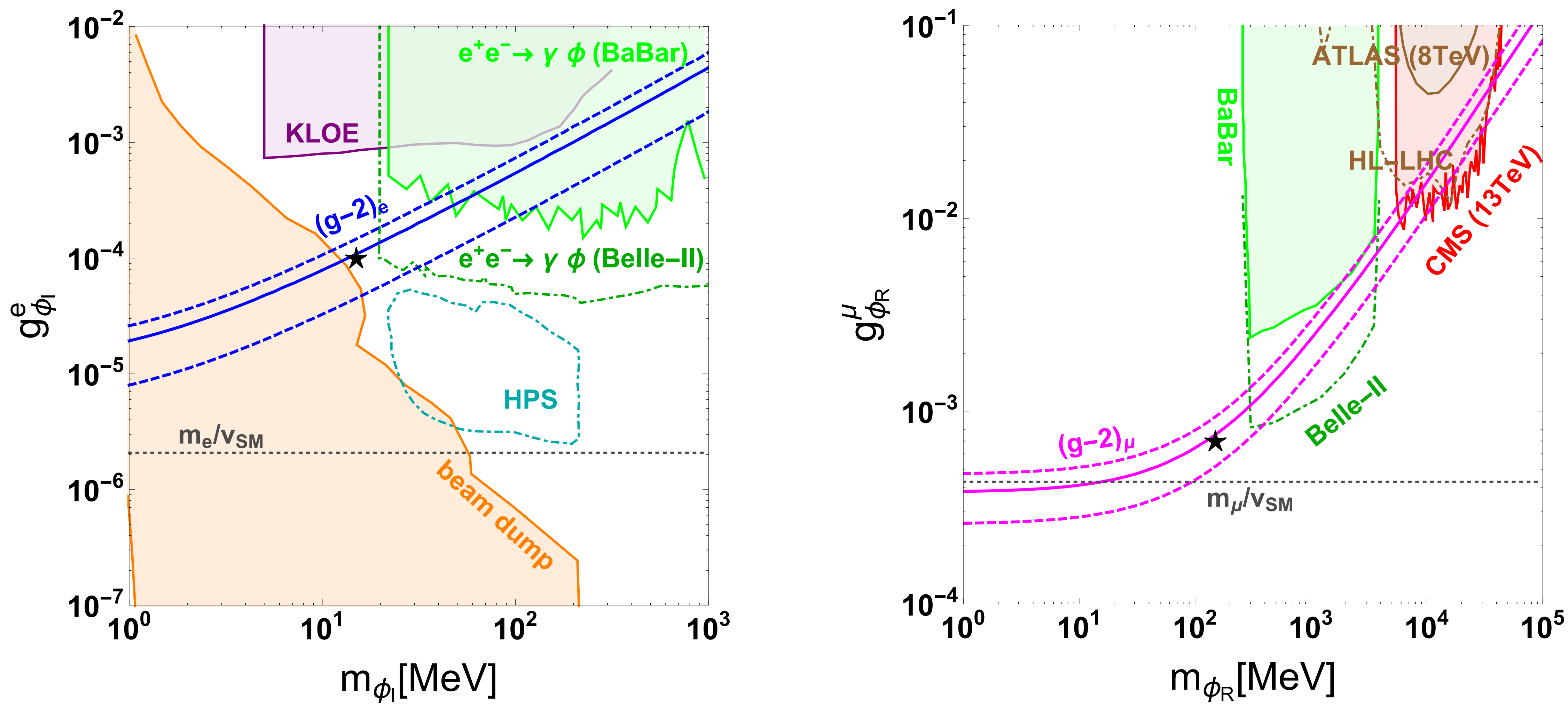
$$\Delta a_\ell = \frac{1}{8\pi^2} \int_0^1 dx \frac{(1-x)^2\left((1+x)g_R^2 - (1-x)g_I^2\right)}{(1-x)^2 + x\left(m_\phi / m_\ell\right)^2} .$$

- Scalar leads to positive contribution, while pseudo-scalar leads to negative contribution

Scalar explanations for e/mu g-2

- If we have $$\mathscr{L}_{\text{int}} = i g^e_{\phi_I} \phi_I \bar{e} \gamma_5 e + g^\mu_{\phi_R} \phi_R \bar{\mu} \mu$$

J. Liu, C.E.M.Wagner, X.Wang, arXiv:1810.11028



The e/mu g-2 discrepancies can be solved!
The sign difference backed up by CP symmetry!

One complex story instead of two simple stories?

A complex scalar EFT story

- We assume the scalar and pseudo-scalar originated from the real and imaginary components of a complex singlet scalar

- Due to flavor symmetry, it can couple to e linearly, while mu quadratically

$$\mathscr{L}_{\rm EFT} = \frac{\phi^*}{\Lambda_e}\bar{L}_e H e_R + y_\mu \bar{L}_\mu H \mu_R + \frac{\phi^*\phi}{\Lambda_\mu^2}\bar{L}_\mu H \mu_R + H.c.$$

- After the scalars got vevs

$$H = \frac{1}{\sqrt{2}}\left(v + h + iG^0\right), \quad \phi = \frac{1}{\sqrt{2}}\left(v_\phi + \phi_R + i\phi_I\right)$$

- We obtain

$$m_e = \frac{v v_\phi}{2\Lambda_e}, \quad m_\mu = \frac{y_\mu v}{\sqrt{2}} + \frac{v v_\phi^2}{2\sqrt{2}\Lambda_\mu^2},$$

$$g_{\phi_R}^{e,\rm EFT} = -g_{\phi_I}^{e,\rm EFT} = \frac{v}{2\Lambda_e} = \frac{m_e}{v_\phi}, \quad g_{\phi_R}^{\mu,\rm EFT} = \frac{v_\phi v}{\sqrt{2}\Lambda_\mu^2}$$

- Pseudo-scalar couples to e only, providing negative a_e
- Scalar couples to e with same coupling, provides positive a_e but is heavier to suppress positive contribution
- Only scalar couples to mu, leading to positive a_μ

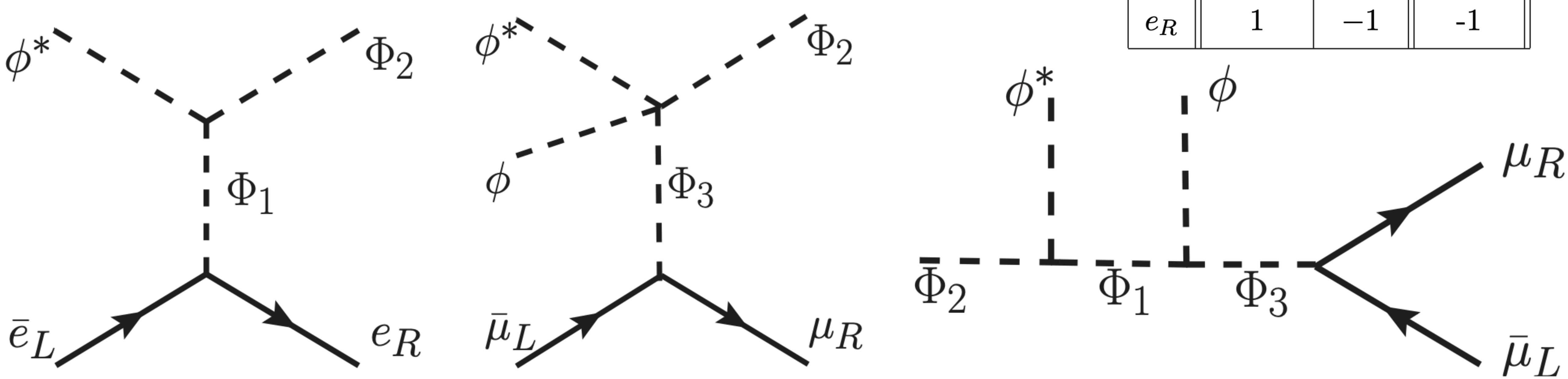
A complex scalar UV story

J. Liu, C.E.M.Wagner, X.Wang, arXiv:1810.11028

- One can obtain EFT model with SM extension with Higgs doublets
- PQ-like symmetry broken softly

filed	$SU(2)_L$	$U(1)_Y$	$U(1)^e_{\rm PQ}$
Φ_1	2	$\frac{1}{2}$	2
Φ_2	2	$\frac{1}{2}$	0
Φ_3	2	$\frac{1}{2}$	0
ϕ	1	0	-2
L_e	2	$\frac{1}{2}$	1
e_R	1	-1	-1

- Scalar portals: $\phi^*\Phi_1^\dagger\Phi_2,\ \phi^*\Phi_1^\dagger\Phi_3,\ \phi\phi^*\Phi_2^\dagger\Phi_3$



- Integrating out heavy scalars leads to EFT $\mathscr{L}_{\rm EFT} \supset \frac{\phi^*}{\Lambda_e}\bar{L}_e H e_R + \frac{\phi^*\phi}{\Lambda_\mu^2}\bar{L}_\mu H \mu_R + H.c.$

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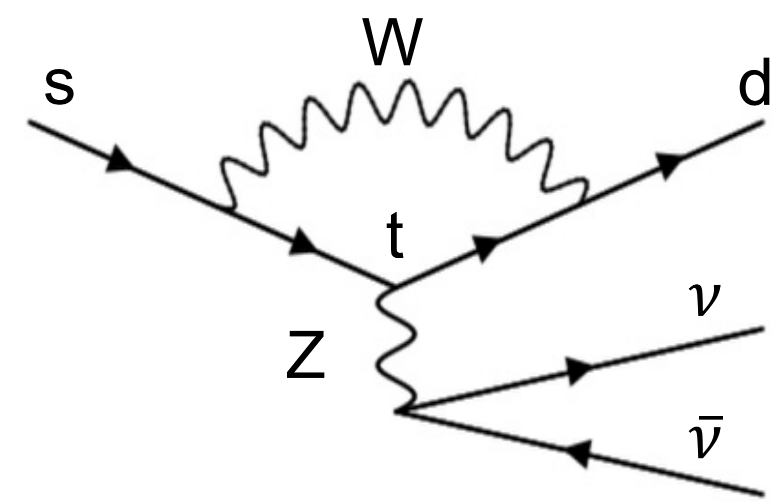
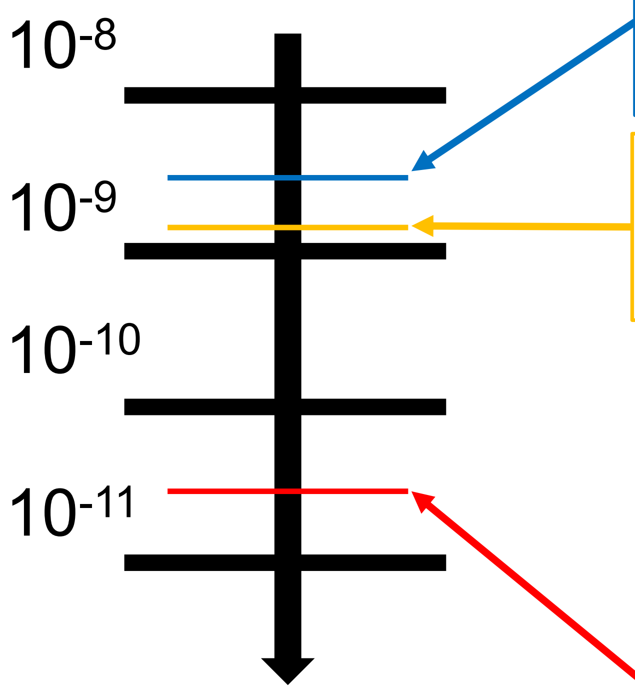
$K_L \to \pi^0 \nu \bar{\nu}$ decay



- Direct CPV
- FCNC : highly suppressed decay
  - BR (SM) : 3×10^{-11}
- Small theoretical uncertainty (~2%)

  → Good probe for new physics search



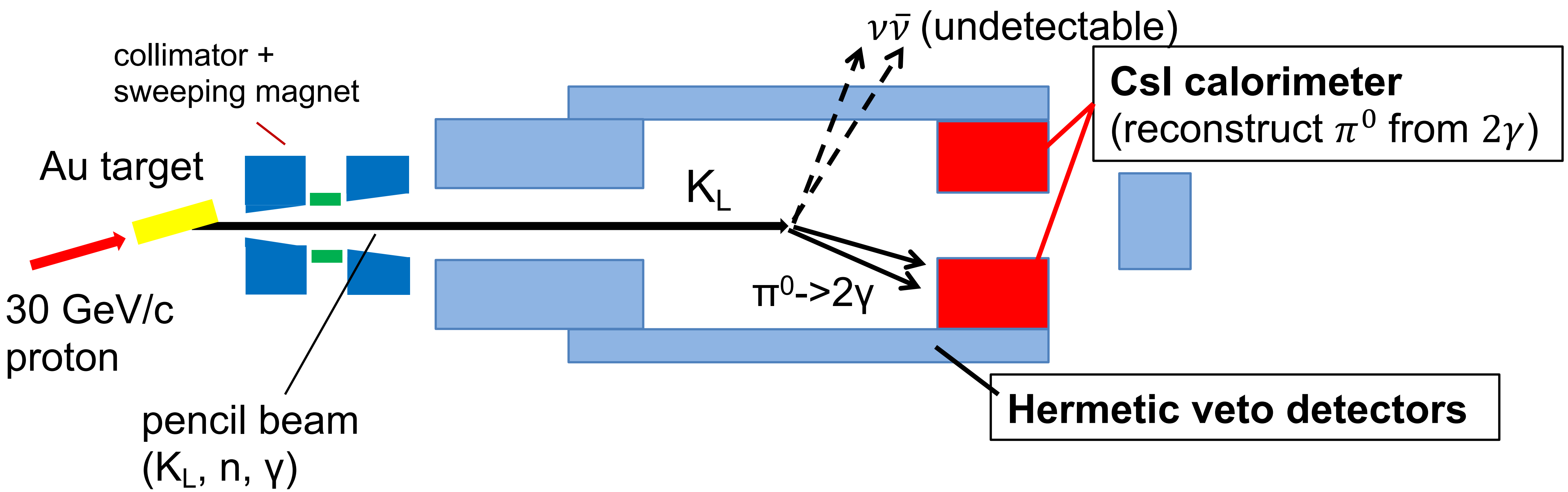
direct limit (KOTO 2015 result, Phys.Rev.Lett. 122 (2019) no.2, 021802)
3.0×10^{-9} (90% C.L.)

indirect limit (Grossman-Nir bound)
1.5×10^{-9}

SM prediction
3.0×10^{-11}

KOTO experiment setup

$K_L \to \pi^0 \nu\bar{\nu}$: $(\pi^0 \to)$ 2γ + nothing



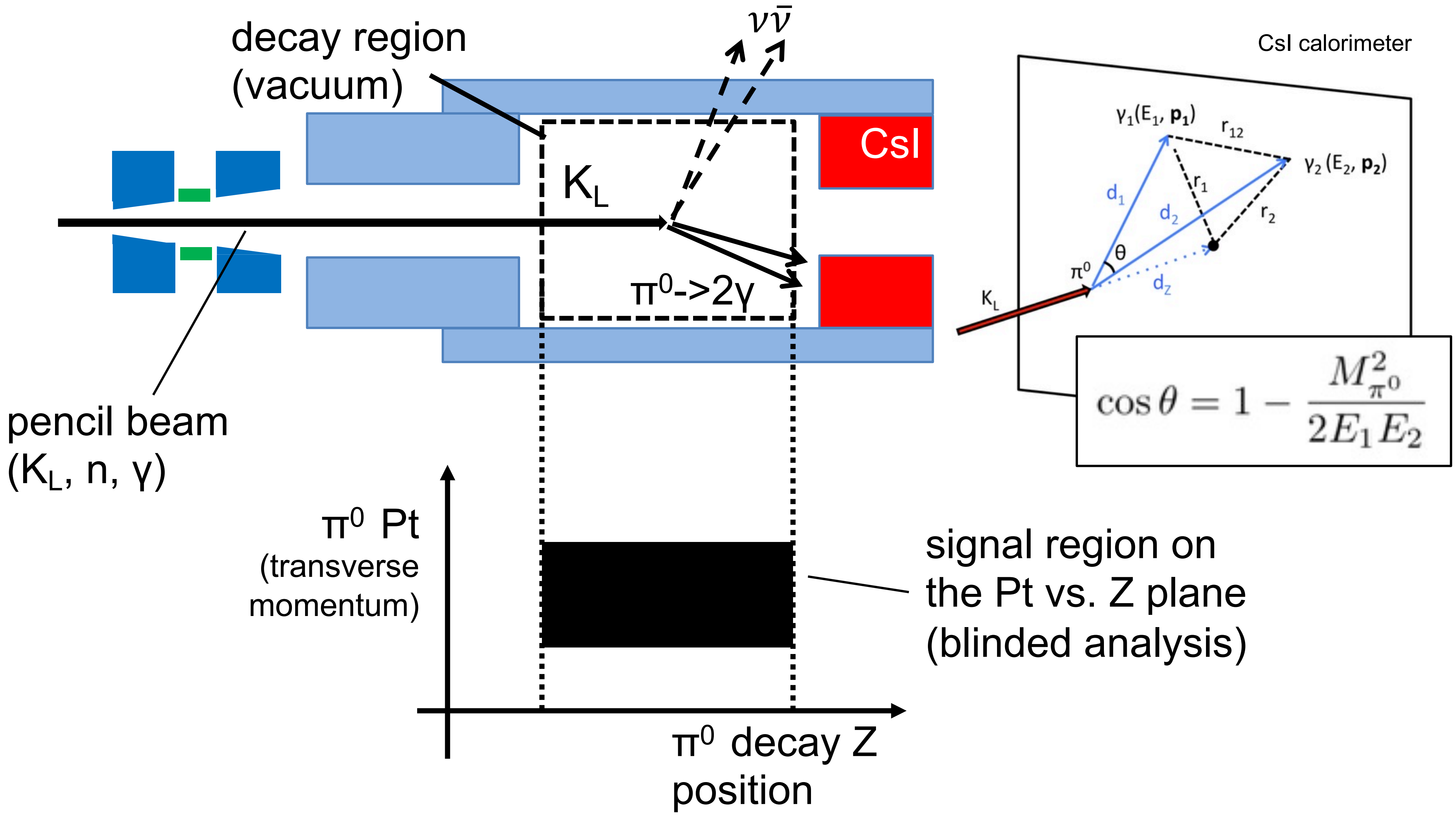
- Neutrinos are not detected

- A new weakly-coupled particle X either stable or decay outside of detector can mimic missing energy

$$K_L \to \pi^0 X$$

Reconstruction in the experiment

Missing transverse momentum → finite π^0 p_t

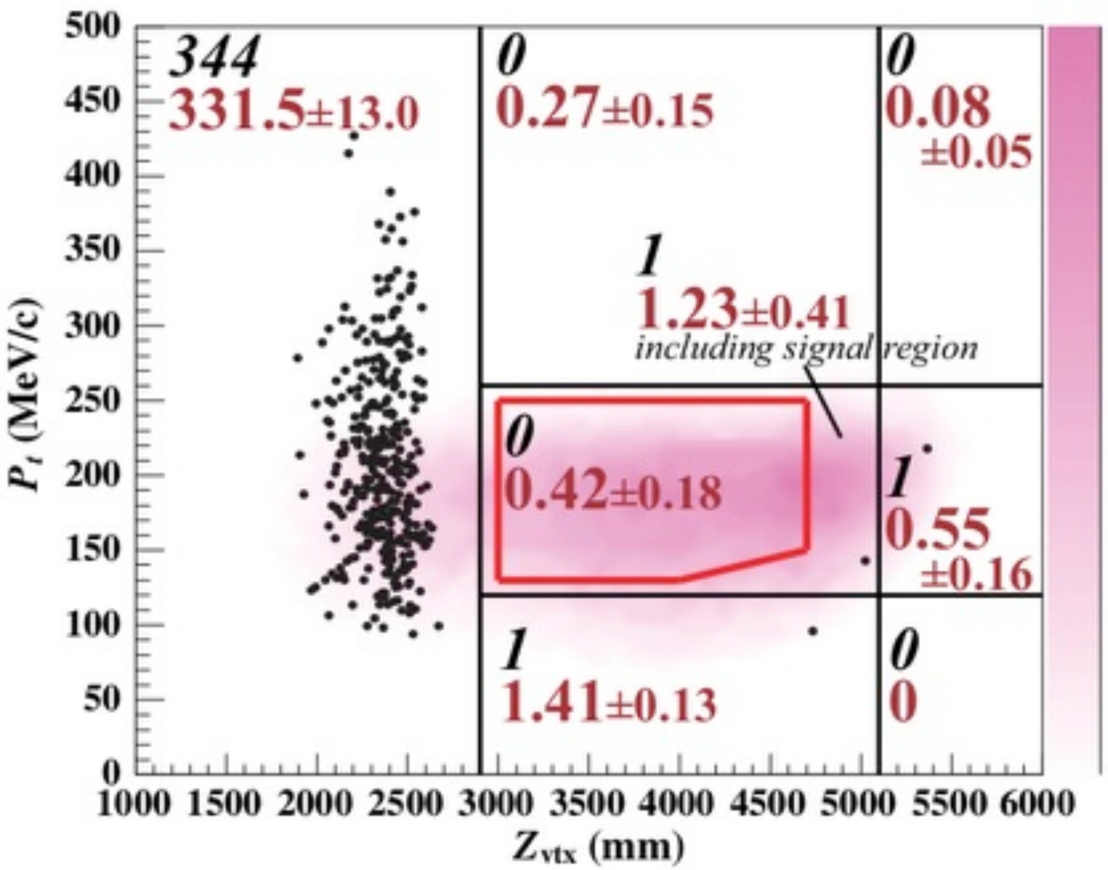


- Assumptions: π0 decays at beam axis
- π0 (Pt vs. Z) can be calculated

Slides from Satoshi Shinohara

Result of 2015 physics run

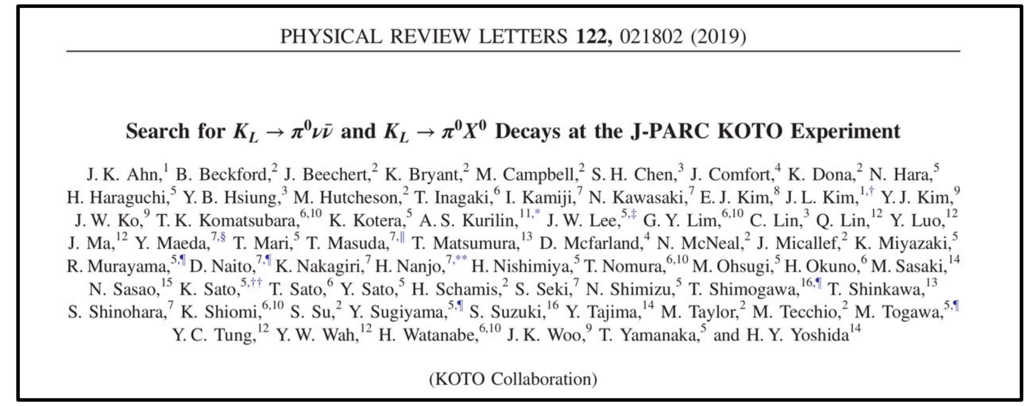
Phys. Rev. Lett. 122, 021802



observed

expectation

contour : $K_L \to \pi^0 \nu\bar{\nu}$ (MC)



PHYSICAL REVIEW LETTERS **122,** 021802 (2019)

Search for $K_L \to \pi^0 \nu\bar{\nu}$ and $K_L \to \pi^0 X^0$ Decays at the J-PARC KOTO Experiment

J. K. Ahn,[1] B. Beckford,[2] J. Beechert,[2] K. Bryant,[2] M. Campbell,[2] S. H. Chen,[3] J. Comfort,[4] K. Dona,[2] N. Hara,[5] H. Haraguchi,[5] Y. B. Hsiung,[3] M. Hutcheson,[2] T. Inagaki,[6] I. Kamiji,[7] N. Kawasaki,[7] E. J. Kim,[8] J. L. Kim,[1,†] Y. J. Kim,[9] J. W. Ko,[9] T. K. Komatsubara,[6,10] K. Kotera,[5] A. S. Kurilin,[11,*] J. W. Lee,[5,‡] G. Y. Lim,[6,10] C. Lin,[3] Q. Lin,[12] Y. Luo,[12] J. Ma,[12] Y. Maeda,[7,§] T. Mari,[5] T. Masuda,[7,‖] T. Matsumura,[13] D. Mcfarland,[4] N. McNeal,[2] J. Micallef,[2] K. Miyazaki,[5] R. Murayama,[5,¶] D. Naito,[7,¶] K. Nakagiri,[7] H. Nanjo,[7,**] H. Nishimiya,[5] T. Nomura,[6,10] M. Ohsugi,[5] H. Okuno,[6] M. Sasaki,[14] N. Sasao,[15] K. Sato,[5,††] T. Sato,[6] Y. Sato,[5] H. Schamis,[2] S. Seki,[7] N. Shimizu,[5] T. Shimogawa,[16,¶] T. Shinkawa,[13] S. Shinohara,[7] K. Shiomi,[6,10] S. Su,[2] Y. Sugiyama,[5,¶] S. Suzuki,[16] Y. Tajima,[14] M. Taylor,[2] M. Tecchio,[2] M. Togawa,[5,¶] Y. C. Tung,[12] Y. W. Wah,[12] H. Watanabe,[6,10] J. K. Woo,[9] T. Yamanaka,[5] and H. Y. Yoshida[14]

(KOTO Collaboration)

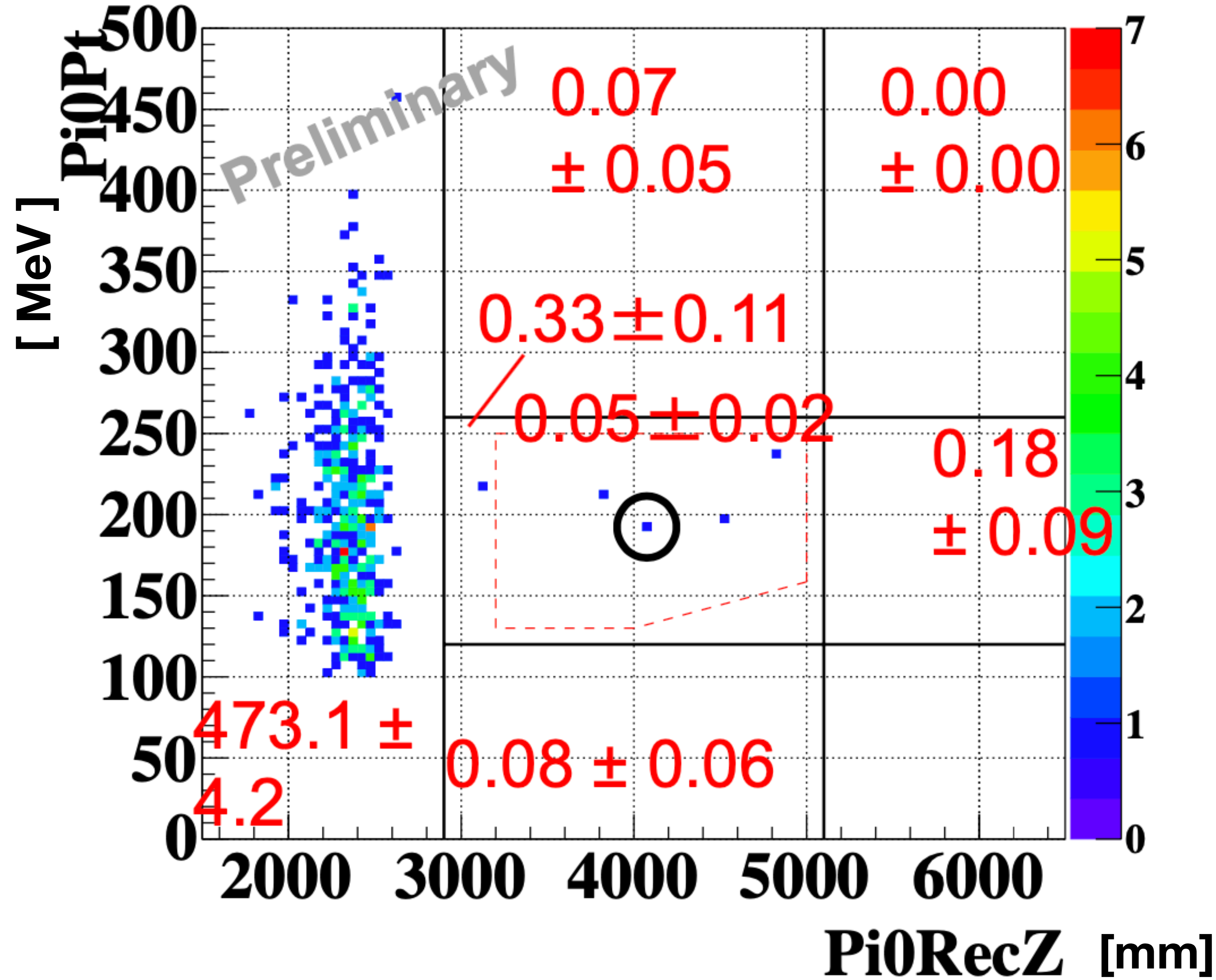
- Single event sensitivity :
  $(1.30 \pm 0.01_{stat} \pm 0.14_{syst}) \times 10^{-9}$
  - No event in the signal region

➡ Upper limit (90% C.L.) :
Br($K_L \to \pi^0 \nu\bar{\nu}$) < 3.0 × 10^{-9}

× 10 improvement from previous limit (KEK E391a)

Slides from Satoshi Shinohara

Results from 2016 to 2018 runs



Satoshi Shinohara at KAON2019, 10-13 September, 2019, Perugia, Italy.

Problem to generate a model: Nir-Grossman bound

- KOTO signal
  - Bkg = 0.05(0.02), obs= 3 → BR($K_L \to \pi^0 \nu\nu$)~ $2\mathrm{x}10^{-9}$
- NA62/E949 constraints
  - BR($K^+ \to \pi^+ \nu\nu$) < $1.85\mathrm{x}10^{-10}$
- Nir-Grossman bound
  - isospin symmetry $\Gamma\left(K_L(\bar{s}d) \to \pi^0(\bar{d}d)\nu\nu\right) \approx \Gamma\left(K^+(\bar{s}u) \to \pi^0(\bar{d}u)\nu\nu\right)$
  - Using lifetime of charged and neutral Kaons, BR($K^0 \to \pi^0 \nu\nu$) < 4.3 BR($K^+ \to \pi^+ \nu\nu$)

The constraint contradicts with observed BRs!

Solution: long-lived particle

- A light particle (m< 200 MeV) from Kaon decay

$$K_L \to \pi^0 X, \quad K^+ \to \pi^+ X$$

- If it is long-lived enough to escape KOTO detector (few meters), it can mimic the missing energy
- But an isospin symmetric model is constrained by charged Kaon experiment (Nir-Grossman bound)
- The way out: charged Kaon experiments veto the region when X mass close to pion mass, due to large bkg from

$$K^+ \to \pi^+ \pi^0$$

- Therefore, long lived particle with mass ~ 140 MeV is viable

George W.S. Hou 2016

Solution: short-lived particle

- A light particle (m< 200 MeV) from Kaon decay

$$K_L \to \pi^0 X, \quad K^+ \to \pi^+ X$$

- If it is long-lived enough to escape KOTO detector (few meters), it can mimic the missing energy
- The way out: it is short-lived to decay inside the charged Kaon experiment, thus vetoed in measurement of

$$K^+ \to \pi^+ \bar{\nu} \nu$$

- KOTO detector scale ~ 3 m, NA62 detector ~ 150 m
- X lifetime has to be 0.1 nano-seconds $\sim$ 3 cm

Kitahara et al, 1909.11111

Model building: long-lived scalar with simple mixing to SM Higgs

- SM Higgs portal

$$\mathscr{L}_{\rm int} \supset \sin\theta \times \phi \left(\sum_q \frac{m_q}{v} \bar{q} q + \sum_\ell \frac{m_\ell}{v} \bar{\ell}\ell + \frac{2m_W^2}{v} \phi W_\mu^+ W^{\mu -} + \cdots \right)$$

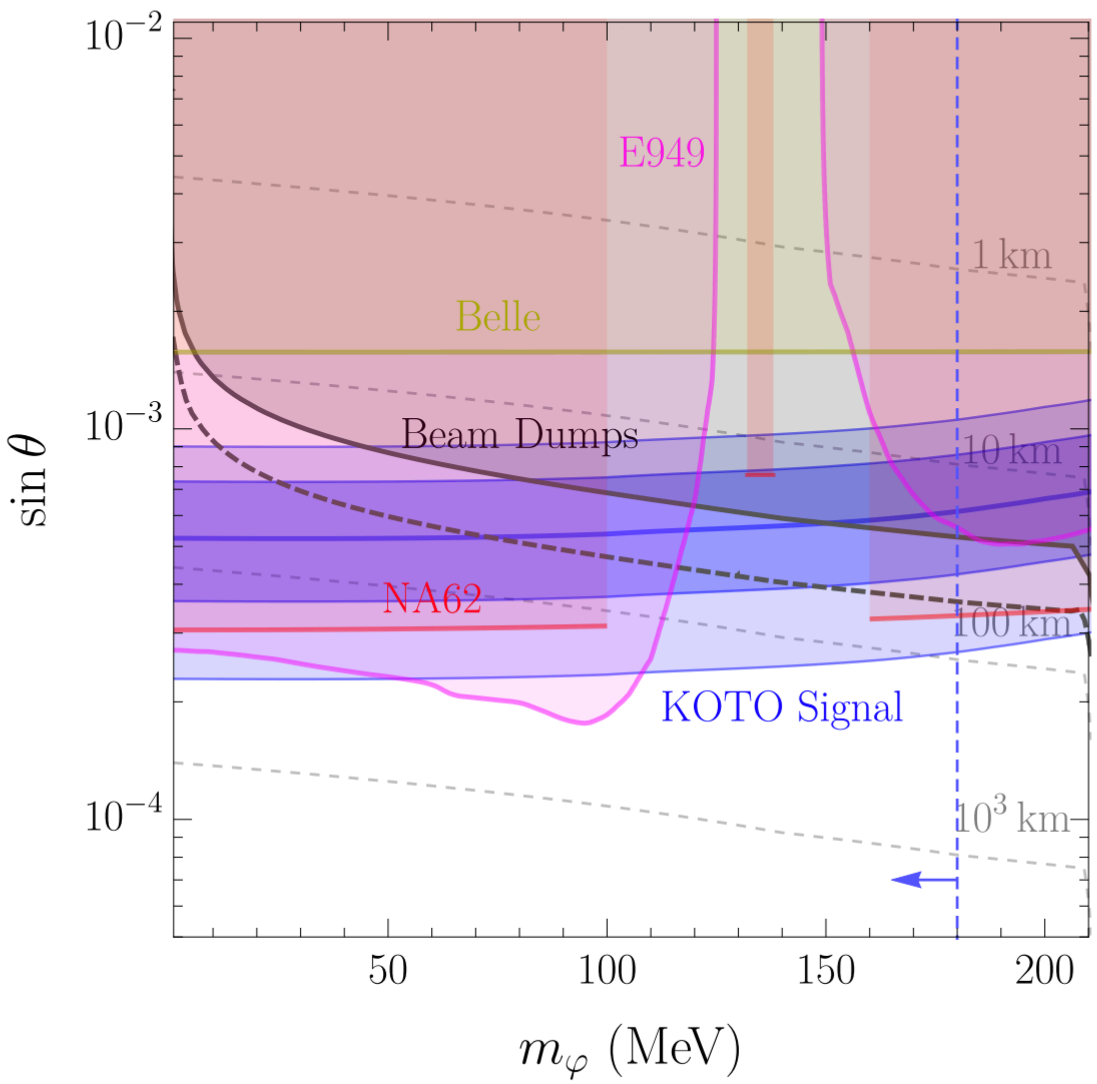
- The rates for the Kaon decay into ϕ and π from 1-loop

$$\Gamma(K_L \to \pi^0 \phi) = \frac{\left(\textbf{Re}\left[g(\sin\theta)\right]\right)^2}{16\pi m_K^3} \lambda^{1/2}(m_K^2, m_\pi^2, m_\phi^2),$$

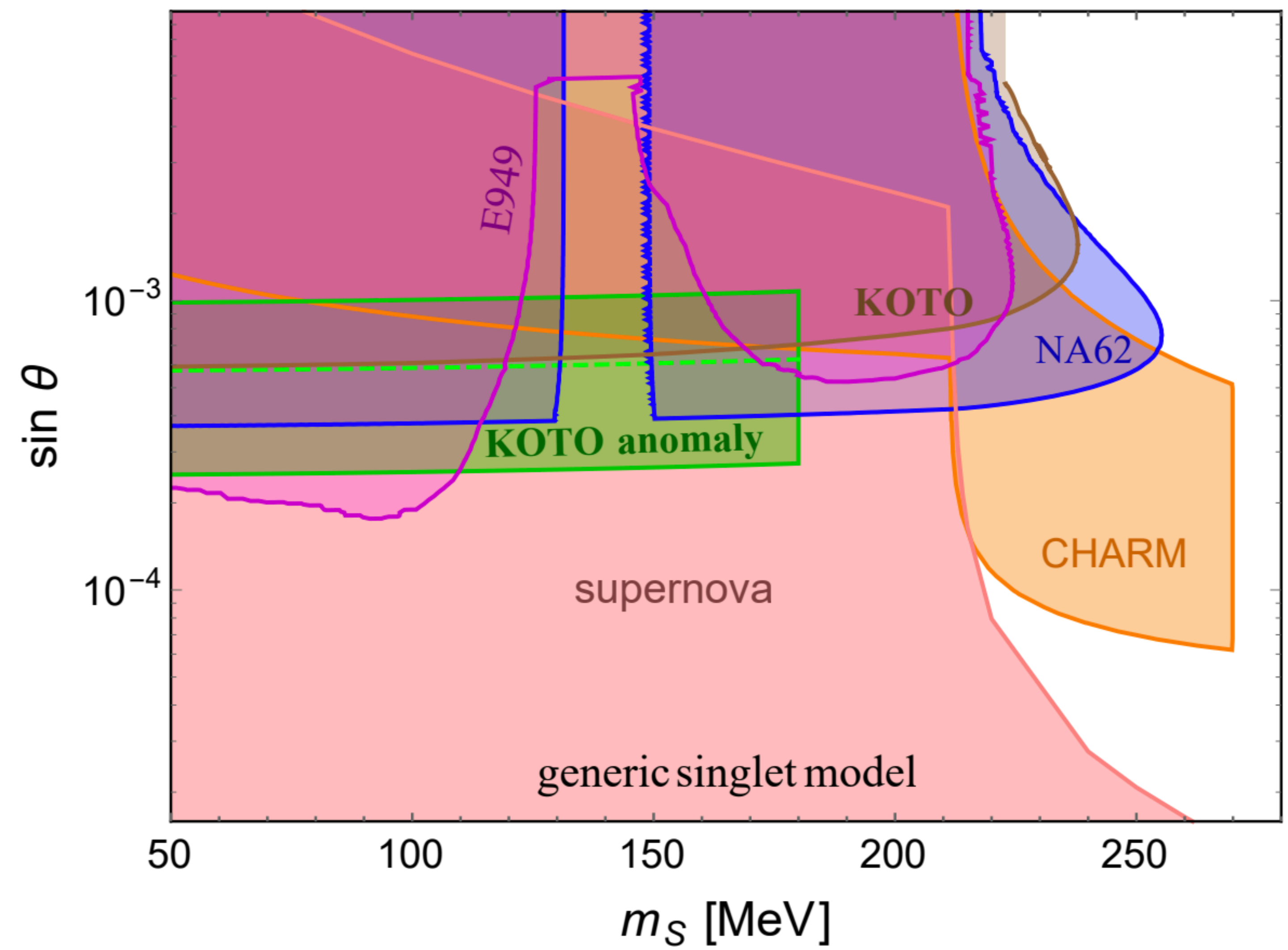
$$g(\sin\theta) = \frac{3m_K^2}{32\pi^2 v^3} \sin\theta \sum_{q=u,c,t} m_q^2 V_{qd}^* V_{qs},$$

Long-lived scalar mediator fits to KOTO

- Charged Kaon exp forced mass ~ 140 MeV
- But highly constrained by astrophysical bounds



Patrick Meade et al, 1911.10203



R. Mohapatra et al, 1911.12334

Our Model building: short-lived scalar mixing with extended Higgs sector

- Type-X 2HDM: one SM-like doublet coupling to quarks and one doublet coupling to leptons

$$\mathscr{L}_{\rm yuk} = -\lambda_u \bar{Q}\tilde{\Phi}_2 u_R - \lambda_d \bar{Q}\Phi_2 d_R - \lambda_e \bar{L}\Phi_1 e_R + h.c.$$

- The light scalar mixing independently with two doublets

$$\mathscr{L}_{\rm eff} \supset \epsilon_q \sum_q \frac{m_q}{v}\phi\bar{q}q + \epsilon_\ell \sum_\ell \frac{m_\ell}{v}\phi\bar{\ell}\ell + \epsilon_W \frac{2m_W^2}{v}\phi W_\mu^+ W^{\mu-}$$

- The coupling to gauge boson is not independent

$$\epsilon_q \simeq \frac{\sin\theta_{2\phi}}{\sin\beta}, \quad \epsilon_\ell \simeq \frac{\sin\theta_{1\phi}}{\cos\beta}$$

- In the large tanβ limit, we obtain a simple relation

$$\epsilon_W \simeq \left(\sin\theta_{1\phi}\cos\beta + \sin\theta_{2\phi}\sin\beta\right)$$

$$\approx \epsilon_\ell \cos^2\beta + \epsilon_q \sin^2\beta \approx \epsilon_q,$$

Liu, McGinnis, Wagner., Wang, arXiv:2001.06522

Fixing the model parameters

$$\mathscr{L}_{\rm eff} \supset \epsilon_q \sum_q \frac{m_q}{v}\phi\bar{q}q + \epsilon_\ell \sum_\ell \frac{m_\ell}{v}\phi\bar{\ell}\ell + \epsilon_q \frac{2m_W^2}{v}\phi W_\mu^+ W^{\mu-}$$

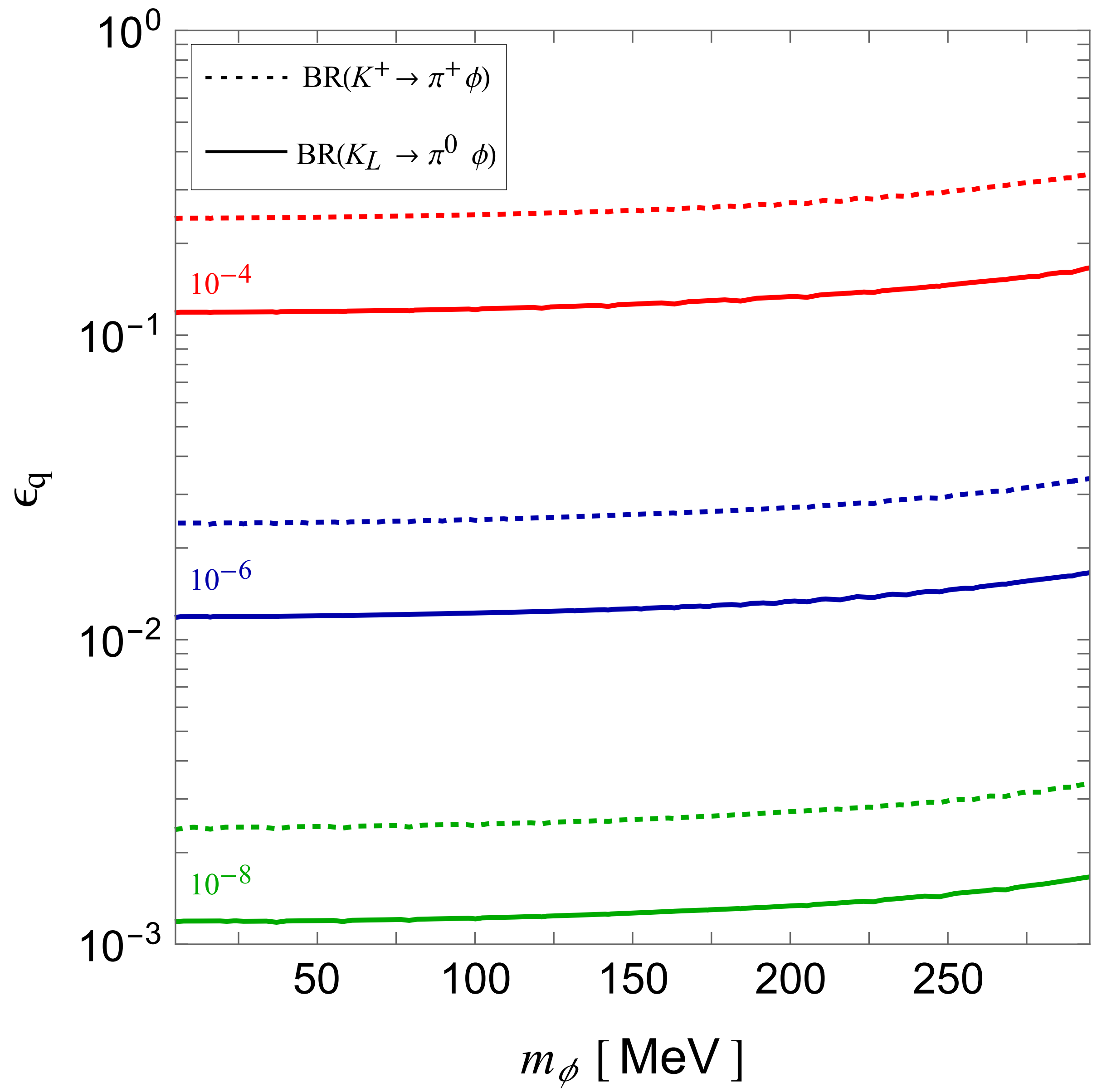
- Three free parameters ϵ_q ϵ_ℓ m_ϕ
- Two requirements:
  - Muon g-2 fixes ε_l
  - Branching ratio of neutral Kaon decay to ϕ fixes ε_q
- Only mass parameter is free

Liu, McGinnis, Wagner., Wang, arXiv:2001.06522

The Kaon decay branching ratio

- The effective BR fitted to KOTO experiment

$$\mathrm{BR}(K_L \to \pi^0 \phi; \mathrm{KOTO}) = \epsilon_{\mathrm{eff}} \mathrm{BR}(K_L \to \pi^0 \phi) e^{-\frac{L}{p_\phi}\frac{m_\phi}{\tau_\phi}}$$



- The true BR for neutral Kaon and charged Kaon decay
- BR(KOTO) ~ $2\text{x}10^{-9}$ according to 3 obs events, relying on both quark coupling and lifetime
- Check charged Kaon BR to avoid constraints

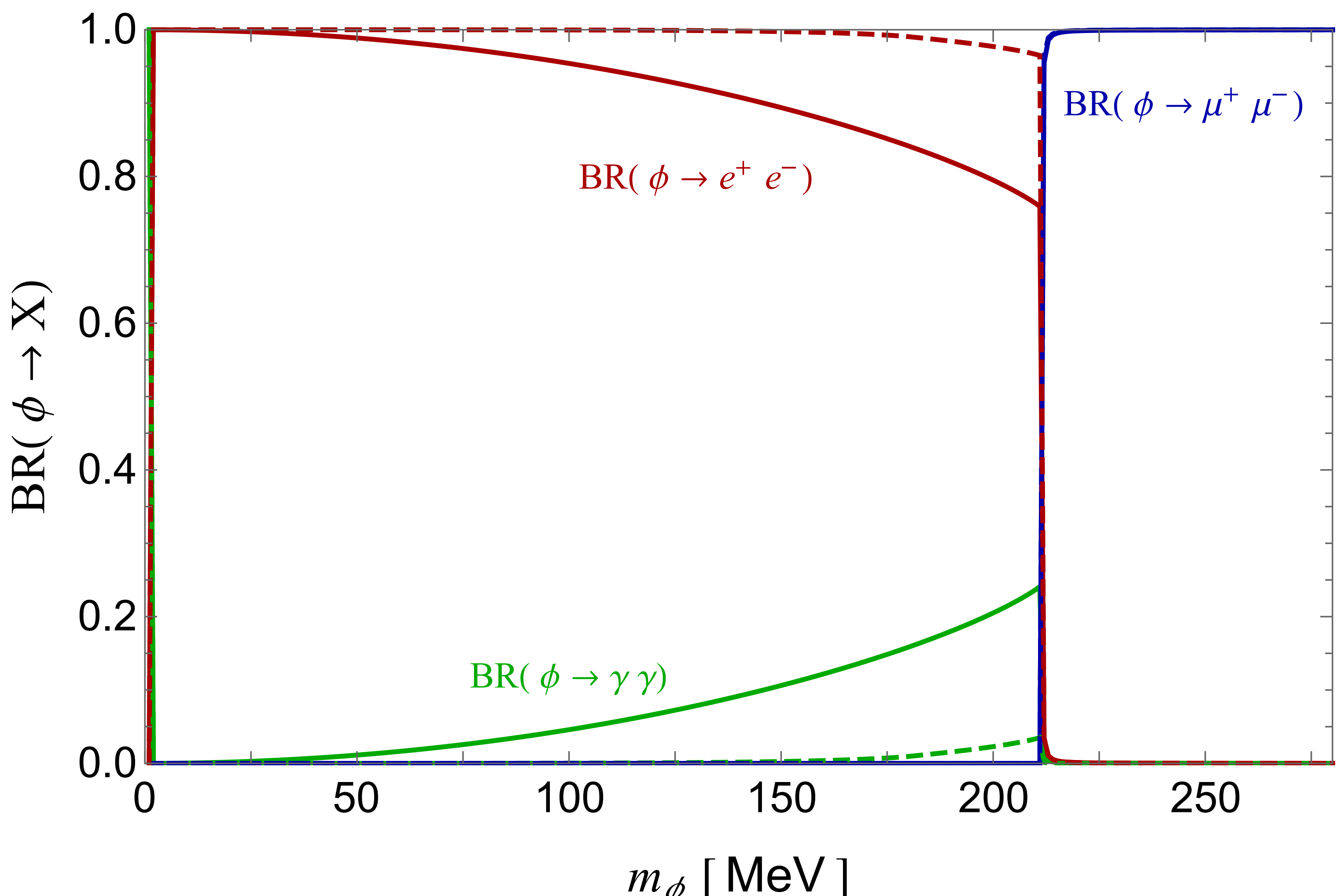
Jia Liu

The lifetime of ϕ

- The decay width for a light ϕ

$$\Gamma(\phi \to \ell\ell) = \frac{\epsilon_\ell^2 m_\ell^2}{8\pi v^2} m_\phi (1-\tau_\ell)^{3/2}\theta(m_\phi^2 - 4m_\ell^2)$$

$$\Gamma(\phi \to \gamma\gamma) = \frac{\alpha^2 m_\phi^3}{1024\pi^3}\left|\sum_q \frac{6\epsilon_q}{v} Q_q^2 A_{1/2}(\tau_q) + \sum_\ell \frac{2\epsilon_\ell}{v} A_{1/2}(\tau_\ell) + \frac{2\epsilon_W}{v} A_1(\tau_W)\right|^2$$

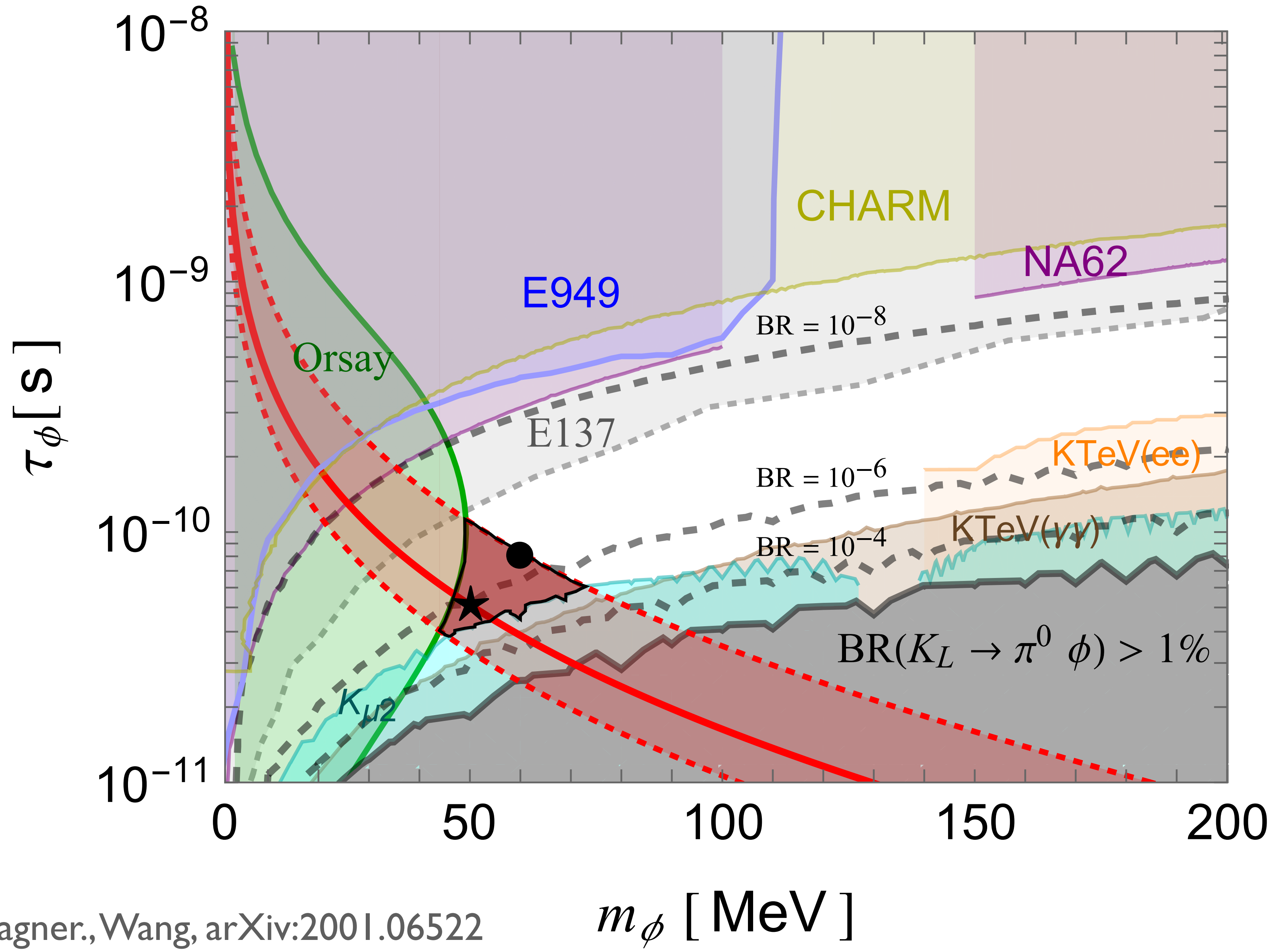


- Our model: $\epsilon_l \sim 1 >> \epsilon_q \sim 0.01$
- Dashed line for simple mixing model (with accidental cancellation in γγ)
- solid line for our model.
- In region of interest, the lifetime depends dominantly on ϵ_l and the decay into ee.

Experimental constraints

- Proton beam dump
  - E949 and NA62: looking for $K^+ \to \pi^+ \bar{\nu}\nu$
  - CHARM: looking for displaced decay (480 m) from $K \to \pi + (ee/\gamma\gamma/\mu\mu)$
  - Kμ2: using stopped charged Kaon looking for $K^+ \to \pi^+ \phi$
  - KTeV/E799: looking for ee but requires $m_{ee} > 140$ MeV $K^0 \to \pi^0 e^+ e^-$
- Electron beam dump
  - Orsay: looking for the radiation of light particles decaying into electron pairs $eN \to eN\phi,\ \phi \to e^+e^-$
  - Similar experiment E137, although analysis was done for a dark photon, mixing with the photon and have to be reinterpreted in the scalar framework.
- B physics and collider constraints: like $B \to K\phi,\ \phi \to e^+e^-$ avoided due to relative long lifetime

The results

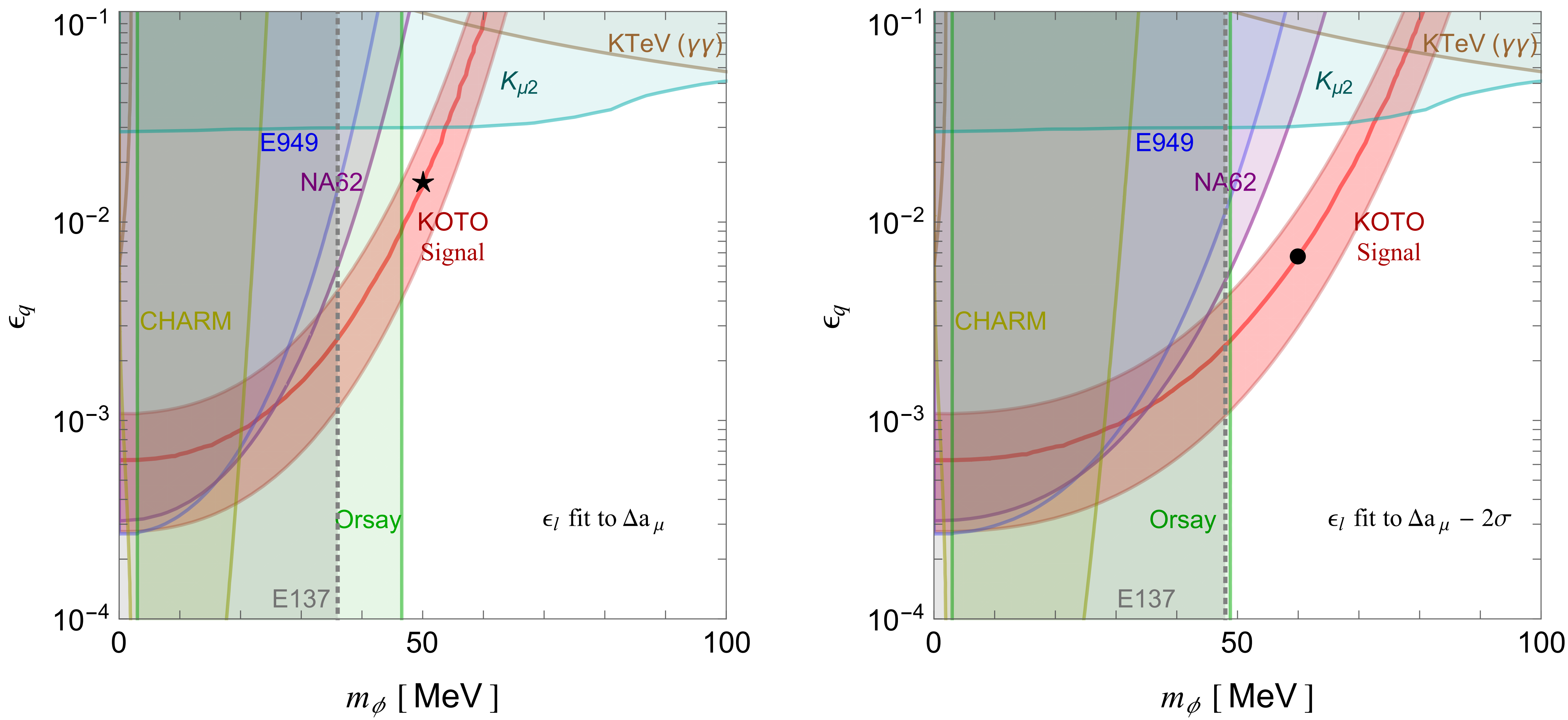


Liu, McGinnis, Wagner., Wang, arXiv:2001.06522

m_ϕ [MeV]	ϵ_q	ϵ_ℓ	BR($K_L \to \pi^0 \phi$)	τ [s]	$\tan\beta$	$\sin\alpha$	$\sin\theta_{1\phi}$	$\sin\theta_{2\phi}$
50	1.6×10^{-2}	1.22	1.7×10^{-6}	5.1×10^{-11}	100	−0.01	0.0122	1.6×10^{-2}
60	6.8×10^{-3}	0.87	3.2×10^{-7}	8.25×10^{-11}	100	−0.01	0.0087	6.8×10^{-3}

The results

- The mass v.s. quark coupling plane



- Each m_ϕ corresponds to a ϵ_l, in accordance with Muon g-2
- The red shaded band is for KOTO 95% C.L.

Liu, McGinnis, Wagner., Wang, arXiv:2001.06522

Comments

- Main difference between short-lived scalar (cm) and long-lived scalar (100 km): Supernova bound applies if ϕ escapes the neutrino sphere (40 km)

- B physics measurement at LHCb

$$\mathrm{BR}(B^0 \to K^{*0} e^+ e^-) = 3.1^{+0.94}_{-0.88} \times 10^{-7}, \quad \mathrm{BR}(B^0 \to K^{*0} e^+ e^-)^{\mathrm{th}} = (2.3 \pm 0.6) \times 10^{-7}$$

  - Our benchmark model

$$\mathrm{BR}(B \to K^* \phi) \simeq 10^{-4}, \quad \mathrm{BR}(\phi \to e^+ e^-) \approx 100\,\%$$

  - However, LHCb requires a good quality vertex: ee pair vertex coincide with K* vertex, within vertex resolution L~ 5 mm

  - The probability of ϕ decay within L is

$$P = 1 - e^{-m_\phi L/(p_\phi \tau_\phi)} \sim m_\phi L/(p_\phi \tau_\phi)$$
$$= \frac{50\ \mathrm{MeV}}{40\ \mathrm{GeV}} \times \frac{5\ \mathrm{mm}}{1.5\ \mathrm{cm}} \approx 4 \times 10^{-4}$$

Safe from LHCb constraints.

The outline

- The motivation for new physics in the low energy
- The lepton g-2
- The KOTO experiment
- Summary

Summary

- Light dark sector particles can be motivated by dark matter property and its null detection
- Recent low energy anomalies might hint new light particles, but require further cross-checks from independent experiments
- We show the light scalars can be related to lepton g-2 and KOTO exp
- The less likely to remain is the electron g-2, but if a pseudo-scalar of about 17 MeV is its explanation, it may also address the Atomki nuclear transition anomaly.
- The muon g-2 could be explained by a scalar of mass of about 50 MeV and couplings to muons of the order of the SM Higgs ones.
- Such a scalar can also lead to an explanation of the KOTO excess, for appropriate values of the quark couplings
- Let's hope for a bright future for particle physics !

Thank you!