Radiative Charged Seesaw Mechanism and Implications to ILC

Kei Yagyu（Osaka U.）

Kai-Feng Chen, Cheng-Wei Chiang, KY, 2006.07929 [hep-ph] (JHEP)

Cheng-Wei Chiang, KY, 2104.00890 [hep-ph]

71st general meeting of ILC physics subgroup

12th May, KEK (Online)

Last participated Gen. ILC Meeting

Testing Higgs models via the $H^{\pm}W^{\mp}Z$ vertex by a recoil method at the ILC

Kei Yagyu (Univ. of Toyama)

Collaborators

Shinya Kanemura, Kazuya Yanase

Physical Review D83, 075018

KEK, 14th May, 2011

Last participated Gen. ILC Meeting

Testing Higgs models via the $H^{\pm}W^{\mp}Z$ vertex by a recoil method at the ILC

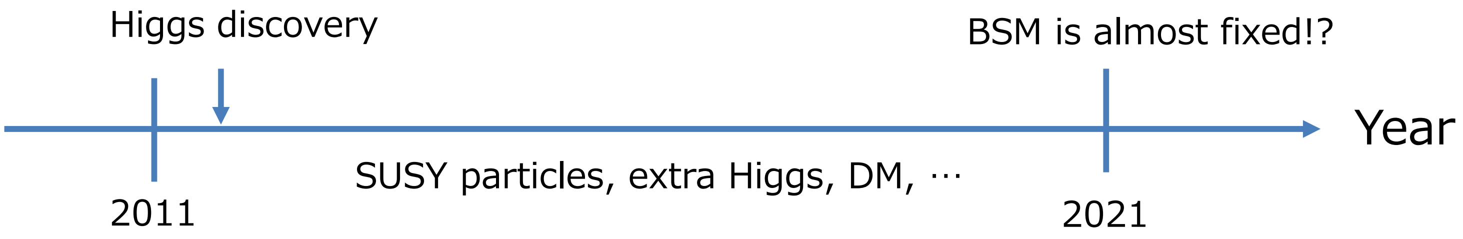
Kei Yagyu (Univ. of Toyama)

Collaborators

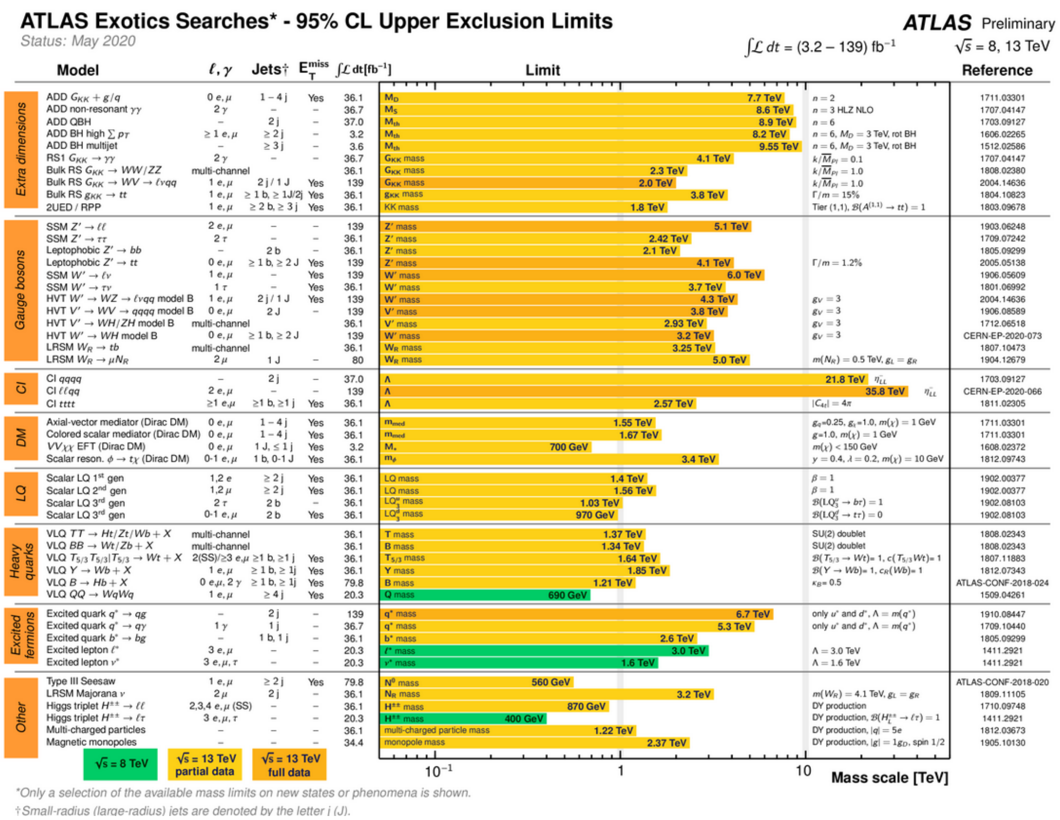
Shinya Kanemura, Kazuya Yanase

Physical Review D83, 075018

KEK, 14th May, 2011

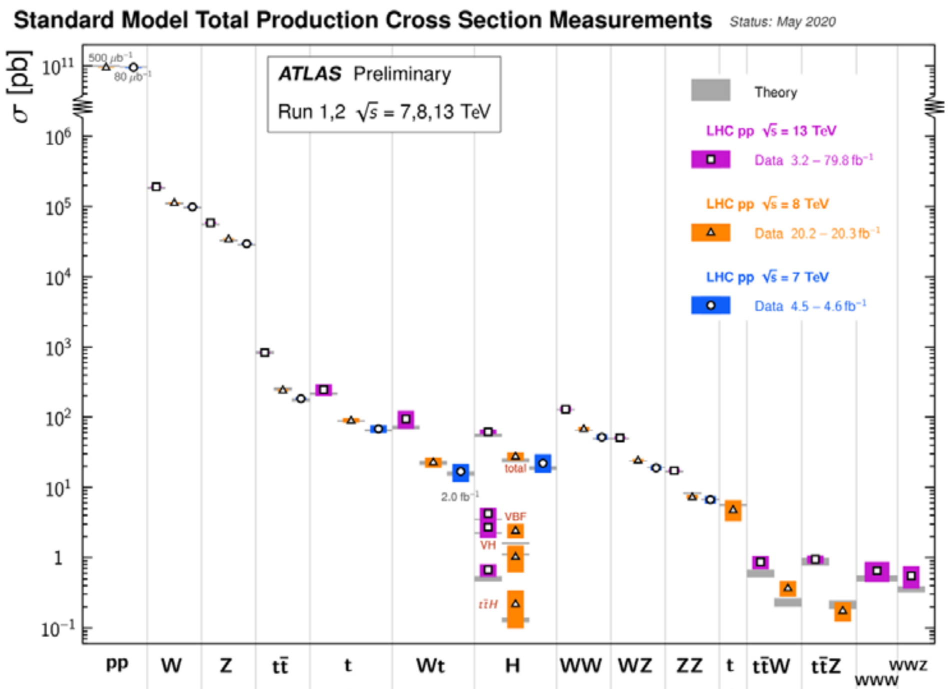


Actual current situation



So far, no SUSY, no extra Higgs and

no DM have been observed.



SM predictions are good agreement.

Still, the SM is very good….

Recently, there was exciting news which could indicate the evidence of NP.

7th Apr., US CT 10:00 (JST 0:00)

Fermilab

Home | About | Science | Jobs | Contact | Phone Book

Newsroom | DUNE at LBNF | Come visit us | Resources for

News

Newsroom

- News and features
- Press releases
- Fermilab in the news
- Fact sheets and brochures
- DUNE at LBNF newsroom
- Photo, video and graphics galleries
- Search photo, video and graphics
- Social media

First results from Fermilab's Muon g-2 experiment strengthen evidence of new physics

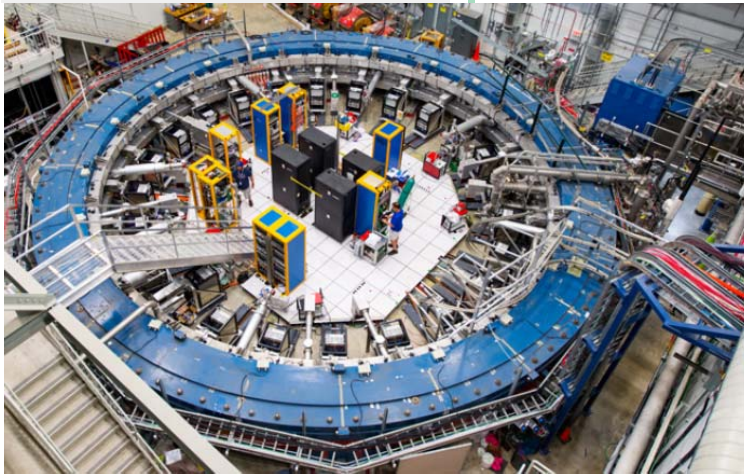
April 7, 2021

Share | Tweet | Email

Media contact

- Tracy Marc, Fermilab, media@fnal.gov, 224-290-7803

The long-awaited first results from the Muon g-2 experiment at the U.S. Department of Energy's Fermi National Accelerator Laboratory show fundamental particles called muons behaving in a way that is not predicted by scientists' best theory, the Standard Model of particle physics. This landmark result, made with unprecedented precision, confirms a discrepancy that has been gnawing at researchers for decades.



Special Seminar

Seminar agenda:

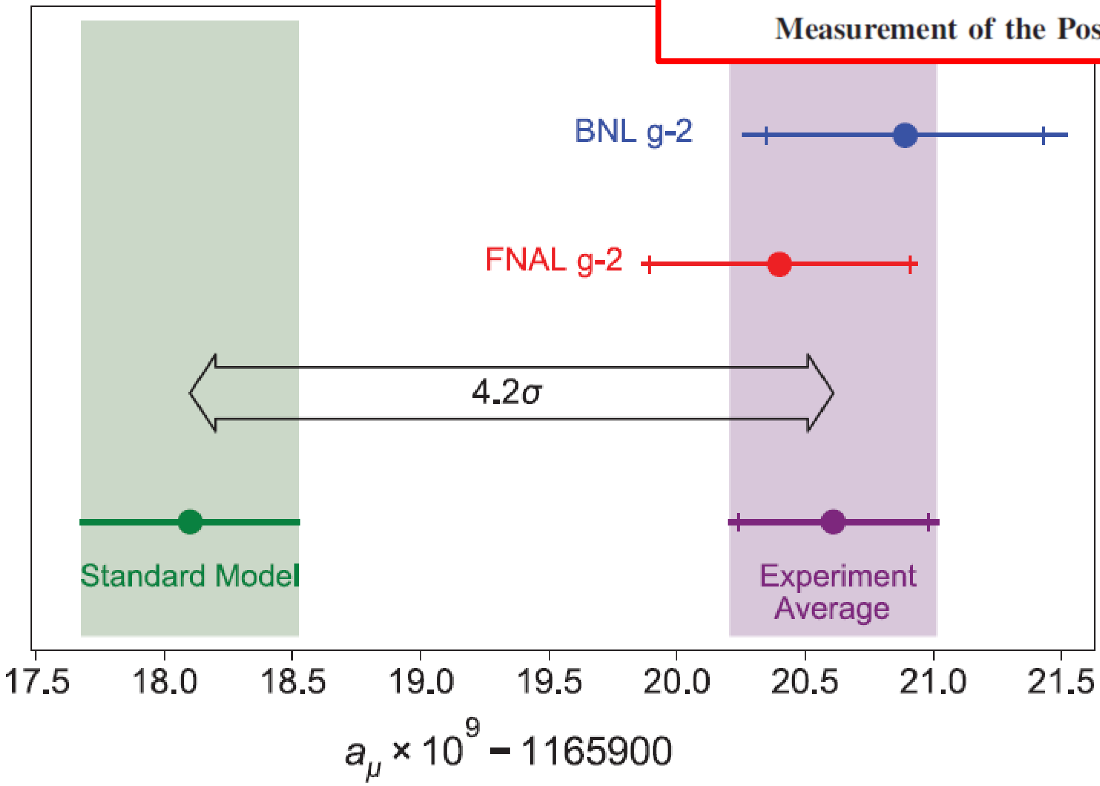
10:00 – 10:05 Introduction — Kevin Pitts, Fermilab chief research officer
10:05 – 10:20 Theory overview — Aida El-Khadra, UIUC theoretical physicist
10:20 – 11:00 Muon g-2 results — Chris Polly, Fermilab experimental physicist
11:00 – 11:20 Question & Answer

PRL126, 141801 (2021)

PHYSICAL REVIEW LETTERS **126,** 141801 (2021)

Editors' Suggestion **Featured in Physics**

Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm



$$\Delta a_\mu \equiv a_\mu^{\mathrm{Exp}} - a_\mu^{\mathrm{SM}}$$

Before: $\Delta a_\mu = (2.79 \pm 0.76) \times 10^{-9}$ (3.7σ)

After: $\Delta a_\mu = (2.51 \pm 0.59) \times 10^{-9}$ **(4.2σ!!)**

Festival on arXiv

[16] arXiv:2104.03217 [pdf, other]
Supersymmetric Interpretation of the Muon $g-2$ Anomaly
Motoi Endo, Koichi Hamaguchi, Sho Iwamoto, Teppei Kitahara

[17] arXiv:2104.03223 [pdf, other]
Wino-Higgsino dark matter in the MSSM from the $g-2$ anomaly
Sho Iwamoto, Tsutomu T. Yanagida, Norimi Yokozaki

[18] arXiv:2104.03227 [pdf, other]
Lepton-specific inert two-Higgs-doublet model confronted with the new results for muon and electron g-2 anomaly and multi-lepton searches at the LHC
Xiao-Fang Han, Tianjun Li, Hong-Xin Wang, Lei Wang, Yang Zhang

[19] arXiv:2104.03228 [pdf, other]
Muon $g-2$ and B-anomalies from Dark Matter
Giorgio Arcadi, Lorenzo Calibbi, Marco Fedele, Federico Mescia

[20] arXiv:2104.03231 [pdf, other]
Confronting spin-3/2 and other new fermions with the muon g-2 measurement
Juan C. Criado, Abdelhak Djouadi, Niko Koivunen, Kristjan Müürsepp, Martti Raidal, Hardi Veermäe

[21] arXiv:2104.03238 [pdf, other]
Probing light dark matter with scalar mediator: muon $(g-2)$ deviation, the proton radius puzzle
Bin Zhu, Xuewen Liu

[22] arXiv:2104.03239 [pdf, other]
Heavy Bino and Slepton for Muon g-2 Anomaly
Yuchao Gu, Ning Liu, Liangliang Su, Daohan Wang

[23] arXiv:2104.03242 [pdf, other]
Revisiting the μ-τ-philic Higgs doublet in light of the muon $g-2$ anomaly, τ decays, and multi-lepton searches at the
Hong-Xin Wang, Lei Wang, Yang Zhang

・・・

[46] arXiv:2104.03302 [pdf, other]
The Tiny (g-2) Muon Wobble from Small-μ Supersymmetry
Sebastian Baum, Marcela Carena, Nausheen R. Shah, Carlos E. M. Wagner

31 papers (8$^{\text{th}}$ April)

- SUSY
- Extended Higgs
- WIMP DM
- Axion-like particles
- Extended gauge sym.

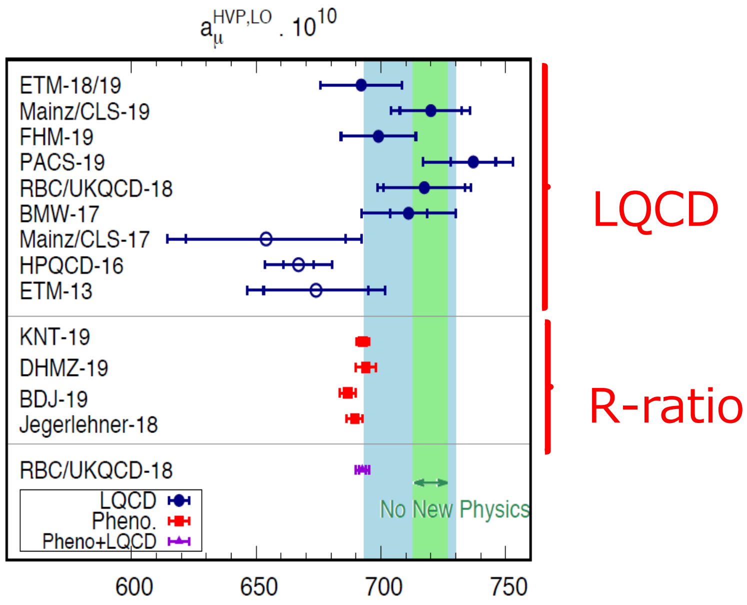
…

Several issues

- The deviation is 4.2σ < 5σ, so it is still "anomaly", not established.

  (cf. 750 diphoton excess ~4σ @ATLAS and CMS)
- LQCD result is consistent with experiments ⋯ .

Recent review: 2006.04822

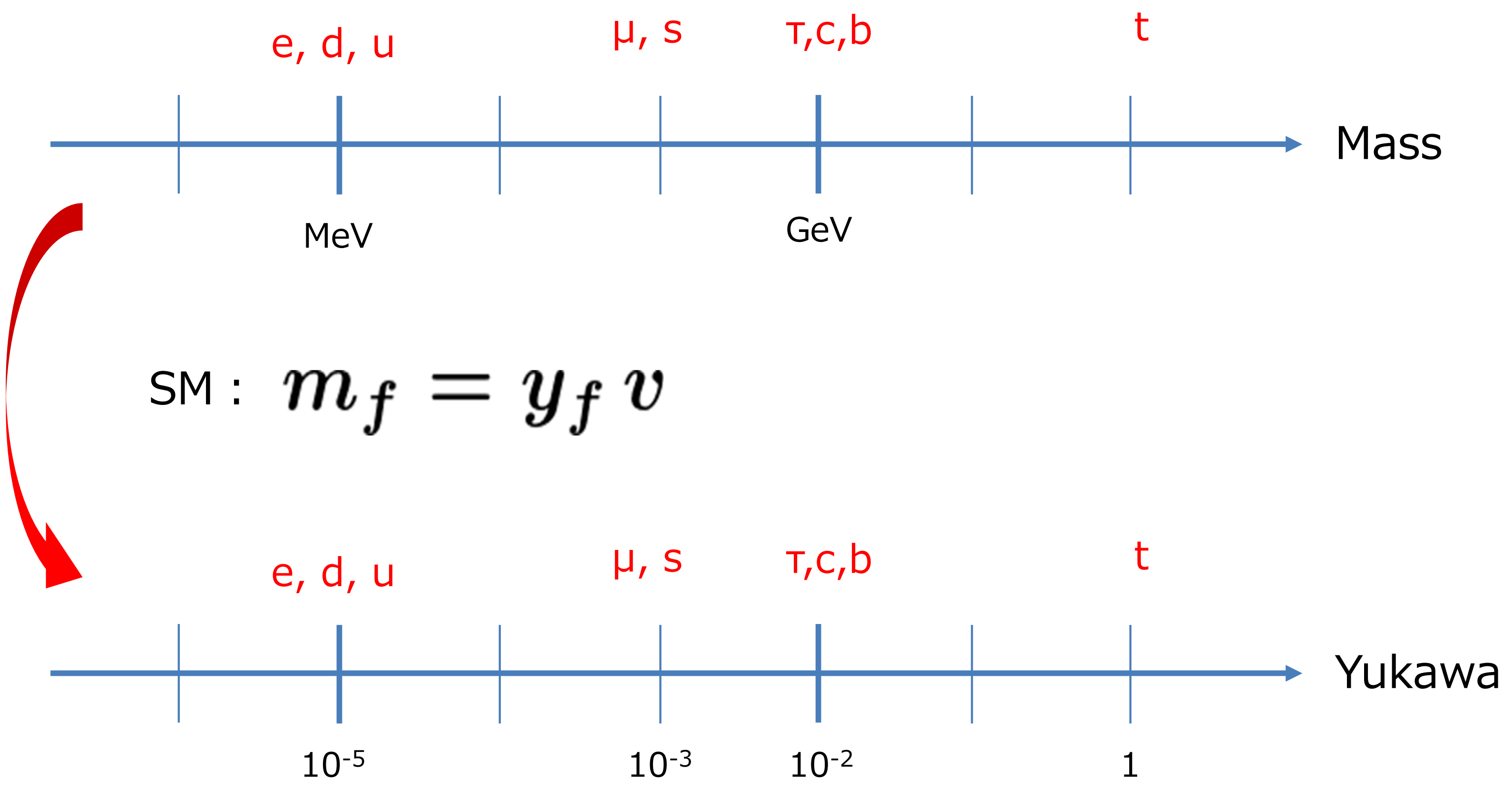


We need to wait more data and improving the SM calculation.

But, it would be worth to more seriously consider the anomaly as a hint of BSM!

Contents

Fermion Mass Hierarchy



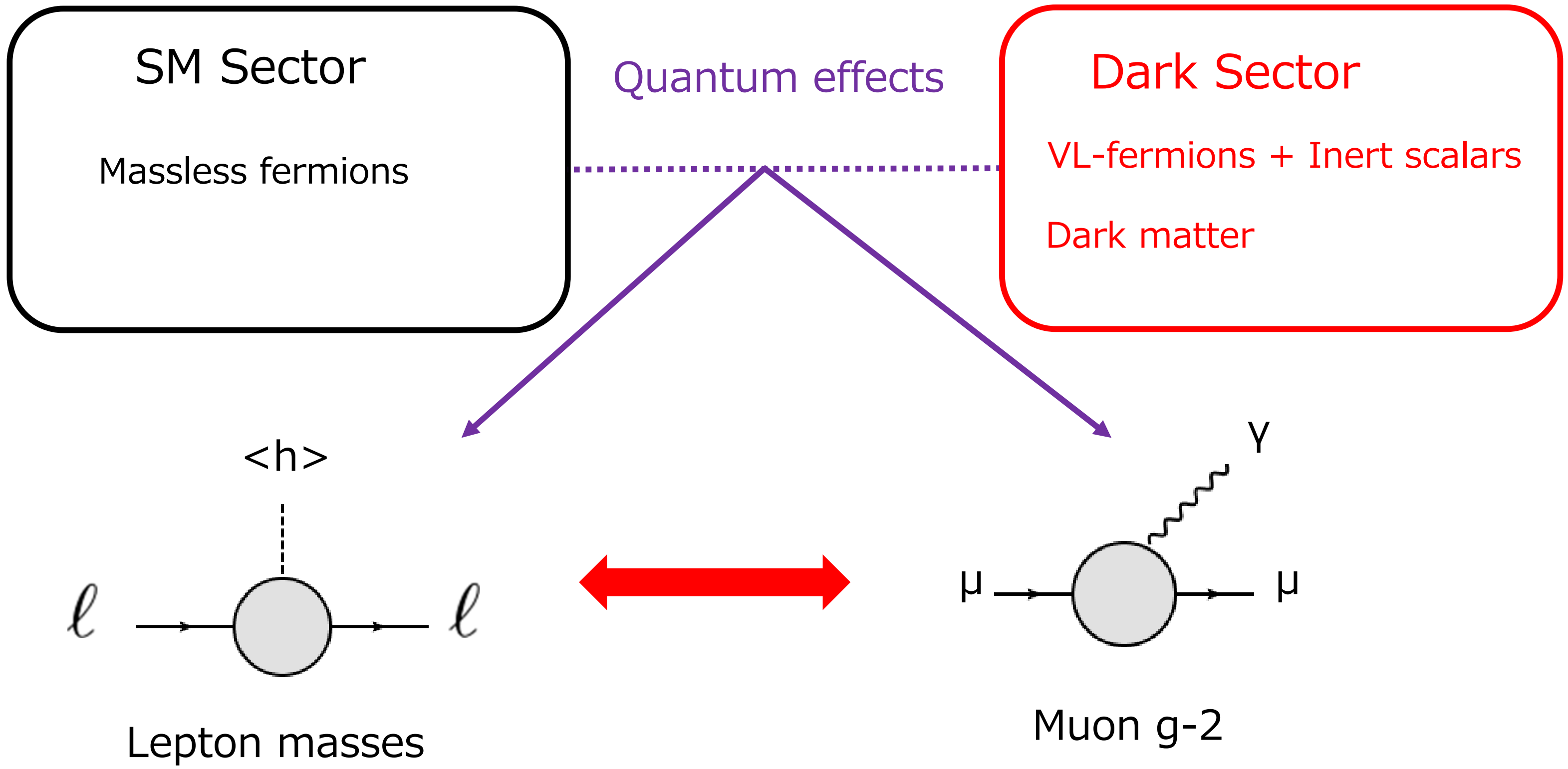
SM : $m_f = y_f\, v$

Can we explain the mass hierarchy with O(1) couplings?

Also, can we explain the muon (g-2) anomaly?

Dark sector as origin of lepton masses

- Introduction of "dark sector" to the SM



$$\sim \left(\frac{1}{16\pi^2}\right)^N \times \left(\frac{v}{M}\right) \times Y_{\rm New}$$

"Radiative Charged Seesaw"

Dark sector simultaneously explains tiny lepton masses and $(g\text{-}2)_\mu$ anomaly.

Model

- We consider the case with the tree level tau mass and 1-loop induced μ/e masses.

	Fermions				Scalars		
Fields	$(L_L^e, L_L^\mu, L_L^\tau)$	(e_R, μ_R, τ_R)	(F_L^e, F_L^μ)	(F_R^e, F_R^μ)	H	Φ_L	Φ_R
$U(1)_\ell$ (exact)	$(q_e, q_\mu, 0)$	$(q_e, q_\mu, 0)$	(q_e, q_μ)	(q_e, q_μ)	0	0	0
Z_2 (exact)	$(+,+,+)$	$(+,+,+)$	$(-,-)$	$(-,-)$	$+$	$-$	$-$
Z_2' (soft-breaking)	$(+,+,+)$	$(-,-,+)$	$(+,+)$	$(-,-)$	$+$	$-$	$-$

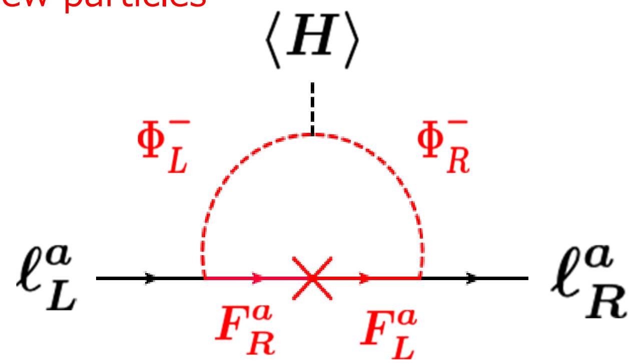
New particles

Forbid LFVs

Forbid tree level mixing

Stabilize the DM candidate

Forbid tree level Yukawa



- Lagrangian for the lepton sector

$$\mathcal{L} = -y_\tau \bar{L}_L^\tau H \tau_R - \sum_{a=e,\mu} \left(M^a \overline{F_L^a} F_R^a + f_L^a \overline{L_L^a} \Phi_L F_R^a + f_R^a \overline{\ell_R^a} \Phi_R F_L^a \right) - \mu H \Phi_L \Phi_R + \text{h.c.}$$

Charge assignment under $SU(2)_I \times U(1)_Y$

- We list the possible sets of the $SU(2)_I \times U(1)_Y$ charge.

$$F \sim (I_F, Y_F) \qquad \Phi_{L,R} \sim (I_{L,R}, Y_{L,R}) \qquad \bar{L}_L \Phi_L F_R$$

$$\text{with} \quad Y_L = -1/2 - Y_F, \quad Y_R = -1 - Y_F \qquad \bar{\ell}_R \Phi_R F_L$$

(I_F, Y_F)	(I_L, Y_L)	(I_R, Y_R)	Sign of Δa_ℓ
$(\mathbf{1}, 0)$	$(\mathbf{2}, -1/2)$	$(\mathbf{1}, -1)$	$+$
$(\mathbf{1}, -1)$	$(\mathbf{2}, 1/2)$	$(\mathbf{1}, 0)$	$-$
$(\mathbf{2}, 1/2)$	$(\mathbf{1} \text{ or } \mathbf{3}, -1)$	$(\mathbf{2}, -3/2)$	$+$
$(\mathbf{2}, -1/2)$	$(\mathbf{1} \text{ or } \mathbf{3}, 0)$	$(\mathbf{2}, -1/2)$	$-$ or $\pm$
$(\mathbf{2}, -3/2)$	$(\mathbf{1} \text{ or } \mathbf{3}, 1)$	$(\mathbf{2}, 1/2)$	$-$
$(\mathbf{3}, 1)$	$(\mathbf{2}, -3/2)$	$(\mathbf{3}, -2)$	$+$
$(\mathbf{3}, 0)$	$(\mathbf{2}, -1/2)$	$(\mathbf{3}, -1)$	$\pm$
$(\mathbf{3}, -1)$	$(\mathbf{2}, 1/2)$	$(\mathbf{3}, 0)$	$-$
$(\mathbf{3}, -2)$	$(\mathbf{2}, 3/2)$	$(\mathbf{3}, 1)$	$-$

E. Ma, 1311.3213 (PRL)

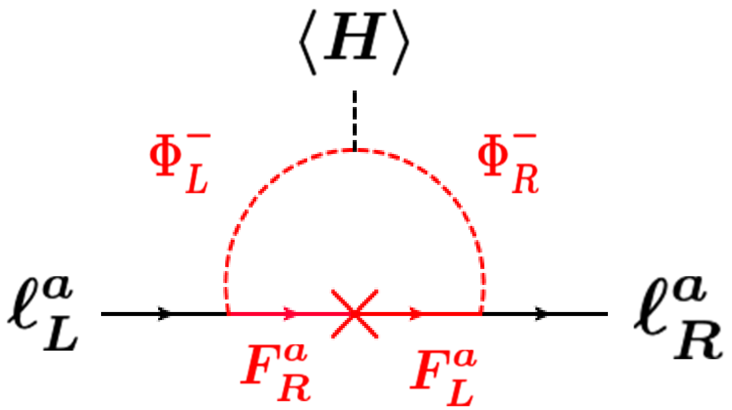
Common dark sector contributes to mass and $(g\text{-}2)_\mu$ → Sign of $(g\text{-}2)_\mu$ is fixed.

Let us focus on the simplest case with F ~ (**1**, 0).

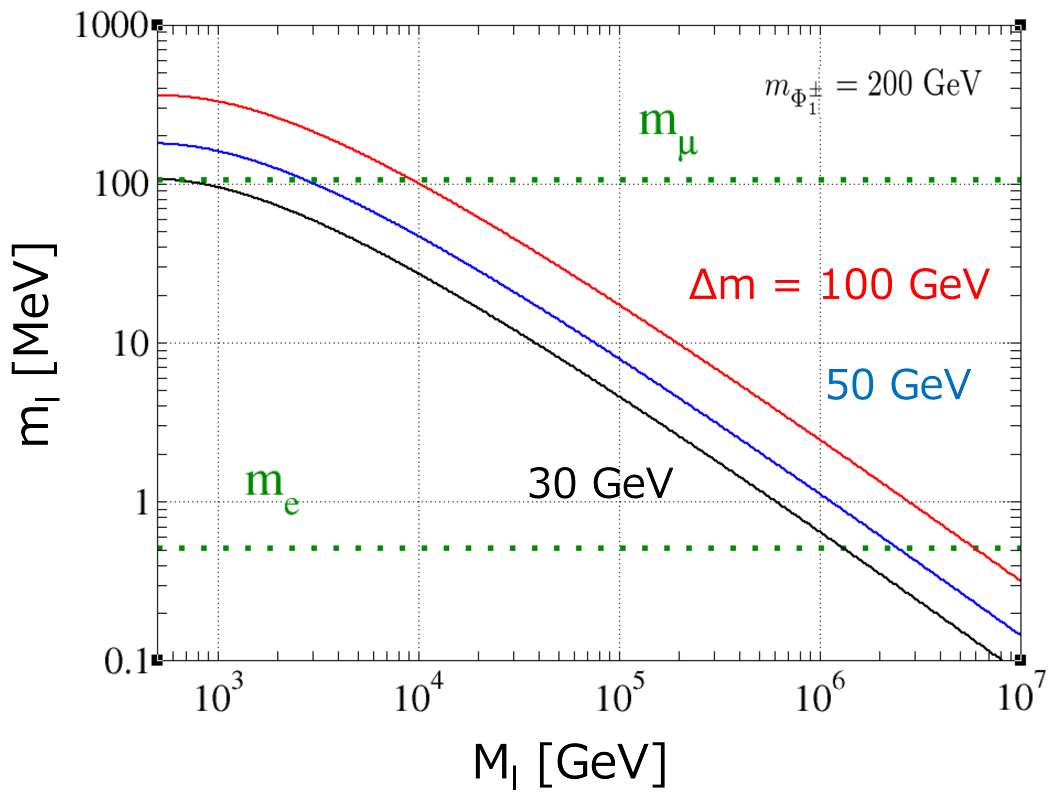
Charged lepton masses

$$m_\ell \simeq \frac{f_L^\ell f_R^\ell s_{2\theta}}{16\pi^2}\frac{m_{\Phi_1^\pm}}{M_\ell}(m_{\Phi_2^\pm} - m_{\Phi_1^\pm})\left(1 + \ln\frac{m^2_{\Phi_1^\pm}}{M_\ell^2}\right)$$

$$\begin{pmatrix}\Phi_L^\pm \\ \Phi_R^\pm\end{pmatrix} = \begin{pmatrix}\cos\theta & -\sin\theta \\ \sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}\Phi_1^\pm \\ \Phi_2^\pm\end{pmatrix}$$



$f_L f_R s_{2\theta} = 1$



- Case with an O(1) coupling :

  Muon mass → M ~ O(1) TeV

  Electron mass → M ~ O(1) PeV

Anomalous magnetic moments

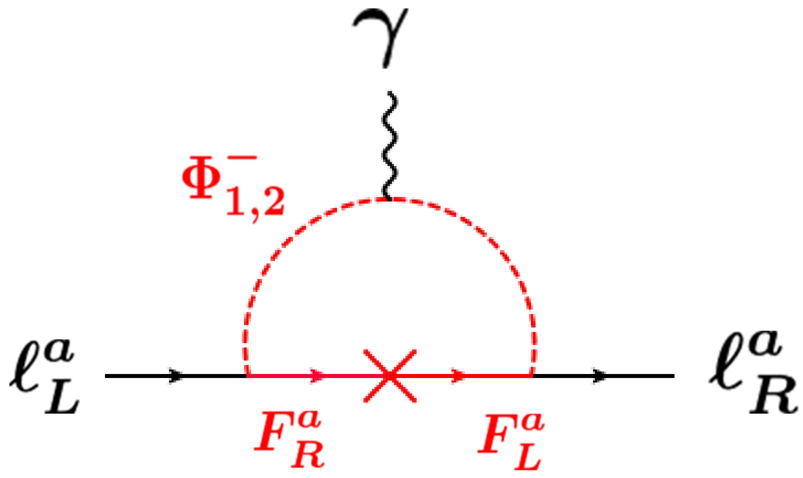
$$\Delta a_\ell \equiv a_\ell^{\rm exp} - a_\ell^{\rm SM}$$

FNAL (2021)

$$\Delta a_\mu = (251 \pm 59) \times 10^{-11}$$ 4.2σ

Nature, 588 (2020)

$$\Delta a_e = (4.8 \pm 3.0) \times 10^{-13}$$ 1.6σ



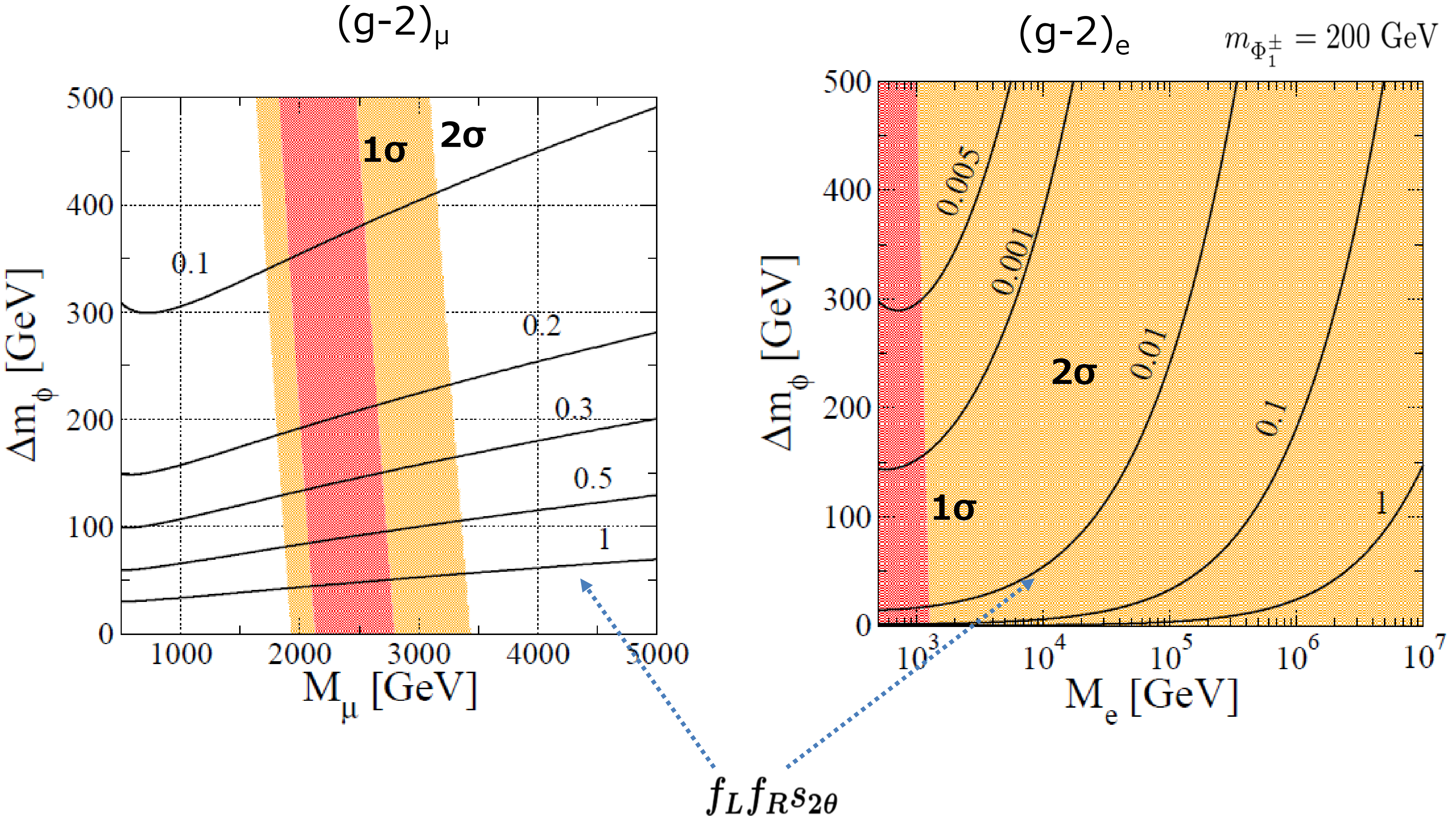
$$\boxed{\Delta a_\ell \simeq +\frac{m_\ell^2}{M_\ell^2}\frac{5+\ln(m_{\Phi_1}^2/M_\ell^2)}{1+\ln(m_{\Phi_1}^2/M_\ell^2)}}$$

For $M_l \gg m_{\Phi 1}$

- It gives a positive contribution to $(g-2)_l$.
- The dependence of the new Yukawa couplings does not explicitly appear.
- The magnitude is mainly determined by $(m_l/M_l)^2$.

Anomalous magnetic moments

Cheng-Wei Chiang, KY, 2104.00890 [hep-ph]

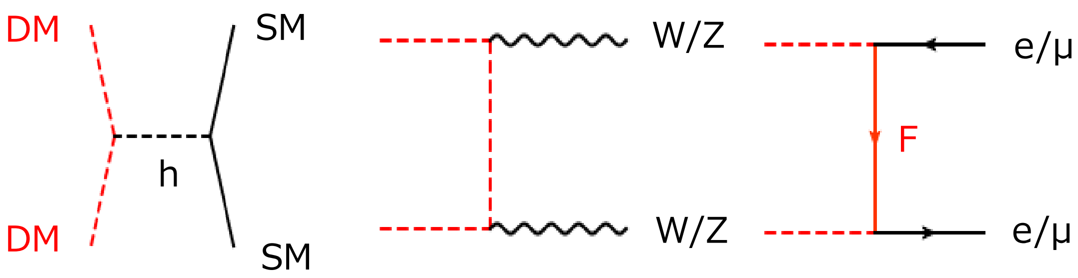


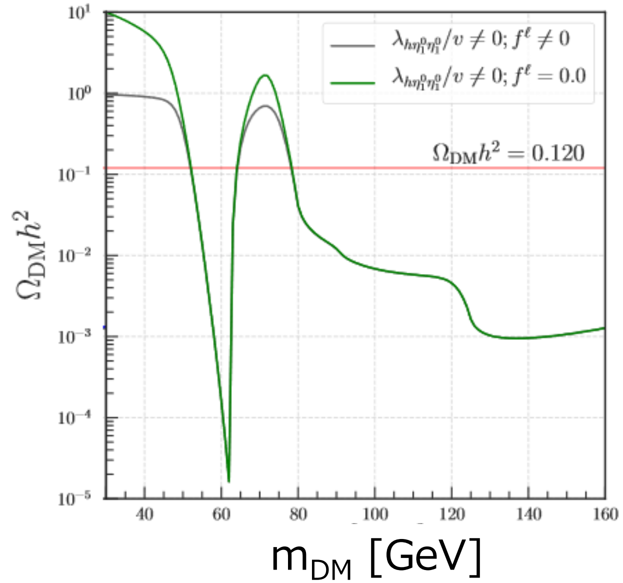
Dark matter

Kai-Feng Chen, Cheng-Wei Chiang, KY, 2006.07929 (JHEP)

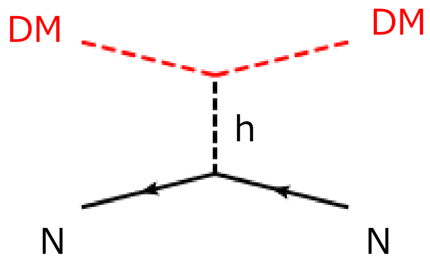
- DM = Re (Φ_L^0)

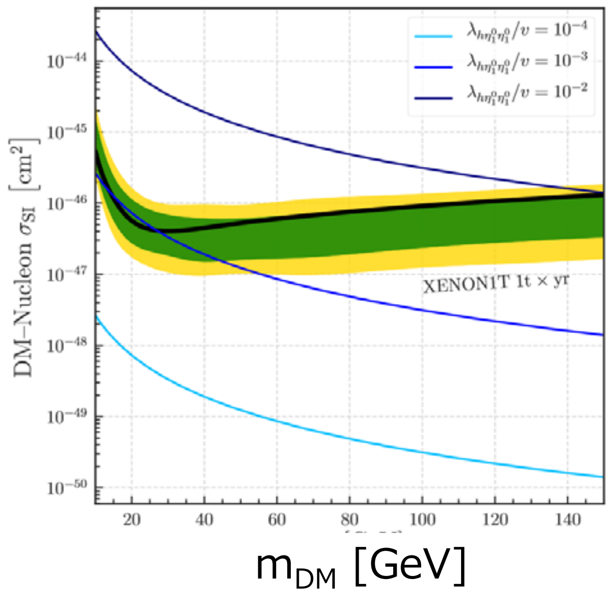
- Annihilation processes





- Direct searches



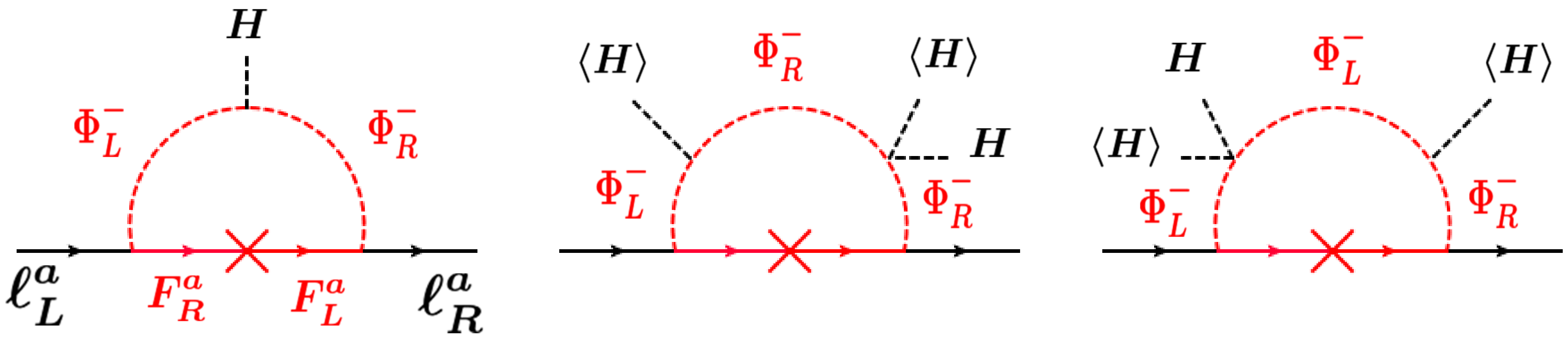


- There are solutions at m_{DM} ~ 63 GeV and 80 GeV.
- We need $|\lambda_{DM}| < 10^{-3}$ to avoid direct search constraint.

Contents

Yukawa coupling

- Yukawa coupling does not simply obey $y_f = m_f/v$.



$$y_\ell \simeq \frac{m_\ell}{v} \underbrace{\frac{1}{|1+\ln(m_{\Phi_1}^2/M_\ell^2)|}\left[\left|2+\ln\left(\frac{m_{\Phi_1}^2}{M_\ell^2}\right)\right| + \frac{v^2\lambda_0}{m_{\Phi_1^\pm}^2}\right]}_{\equiv\ \kappa_\ell}$$

For $M_l \gg m_{\Phi 1}$

$$\lambda_0 = \frac{m_{\rm DM}^2}{v^2} + \lambda_{\rm DM} - \frac{\lambda_{HR}}{2}$$

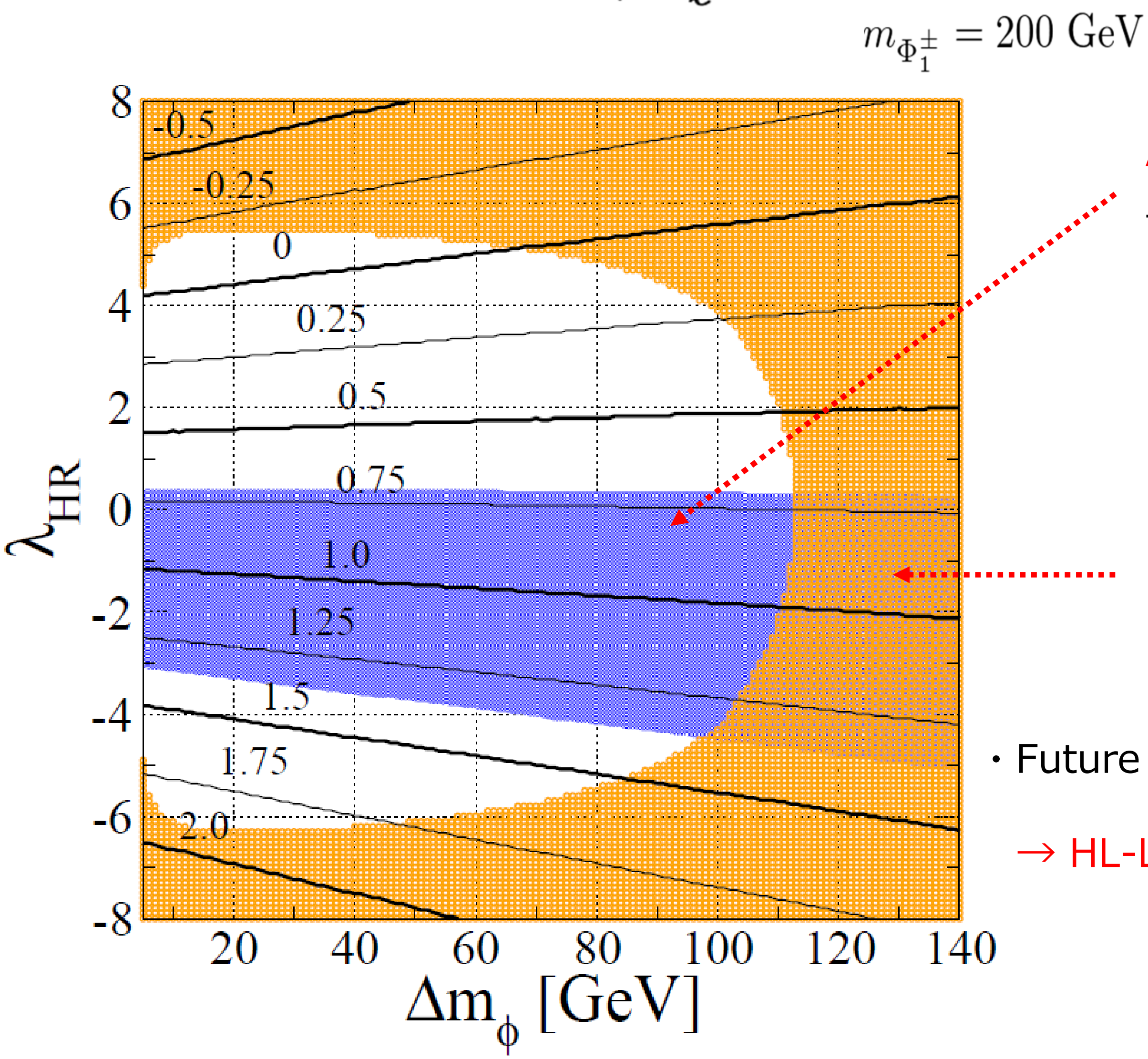
$$V = \lambda_{HR}(H^\dagger H)(\Phi_R^*\Phi_R) + \cdots$$

・The deviation is not suppressed by the loop factor, and it can be sizable.

Yukawa coupling

Cheng-Wei Chiang, KY, 2104.00890 [hep-ph]

- Contours for $\kappa_\ell = y_\ell / y_\ell^{\mathrm{SM}}$



Allowed (95%CL) by the signal strength for pp → h → μμ.

ATLAS, 2007.07830 [hep-ex]

CMS-PAS-HIG-19-006

Excluded by perturbativity bound by using 1-loop RGEs.

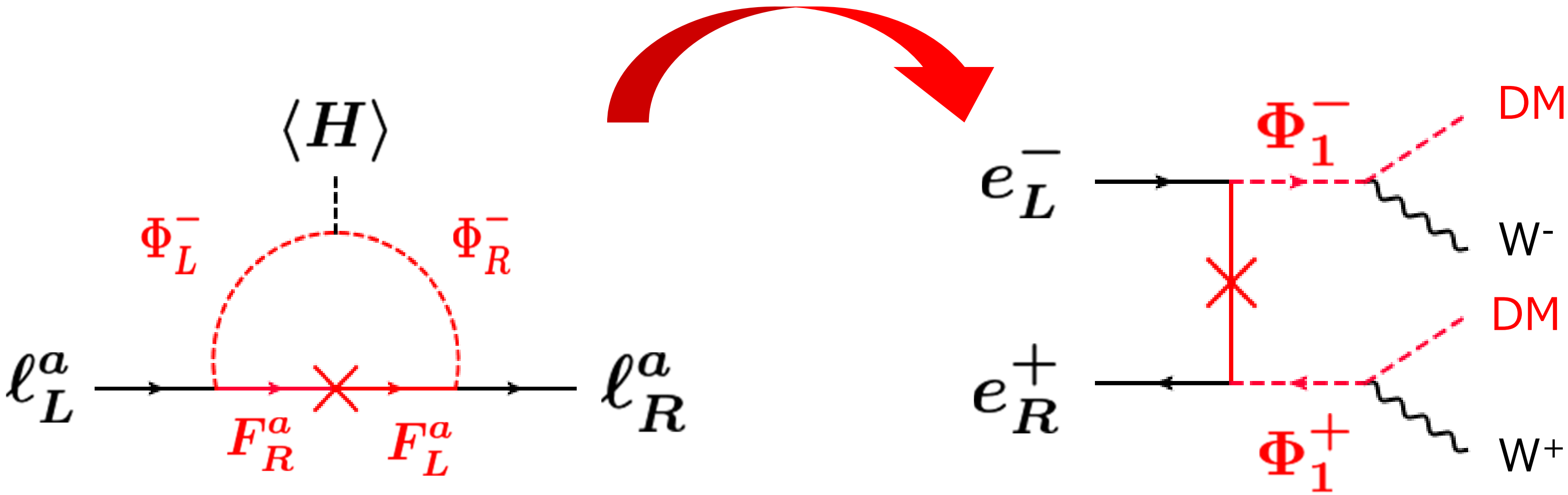
- Future measurements of the μ-Yukawa:

→ HL-LHC ~ 7%, ILC(250) ~5%

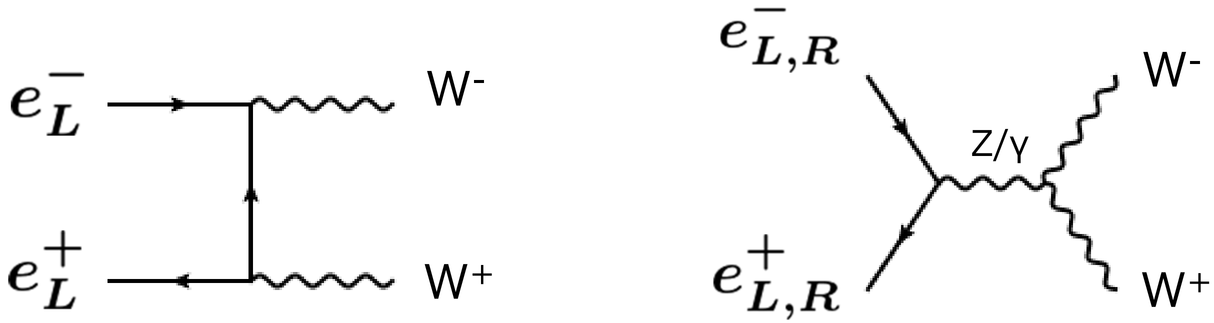
Direct searches at the ILC

Cheng-Wei Chiang, Ryomei Obuchi, KY, work in progress

Rotating by 90°



SM background

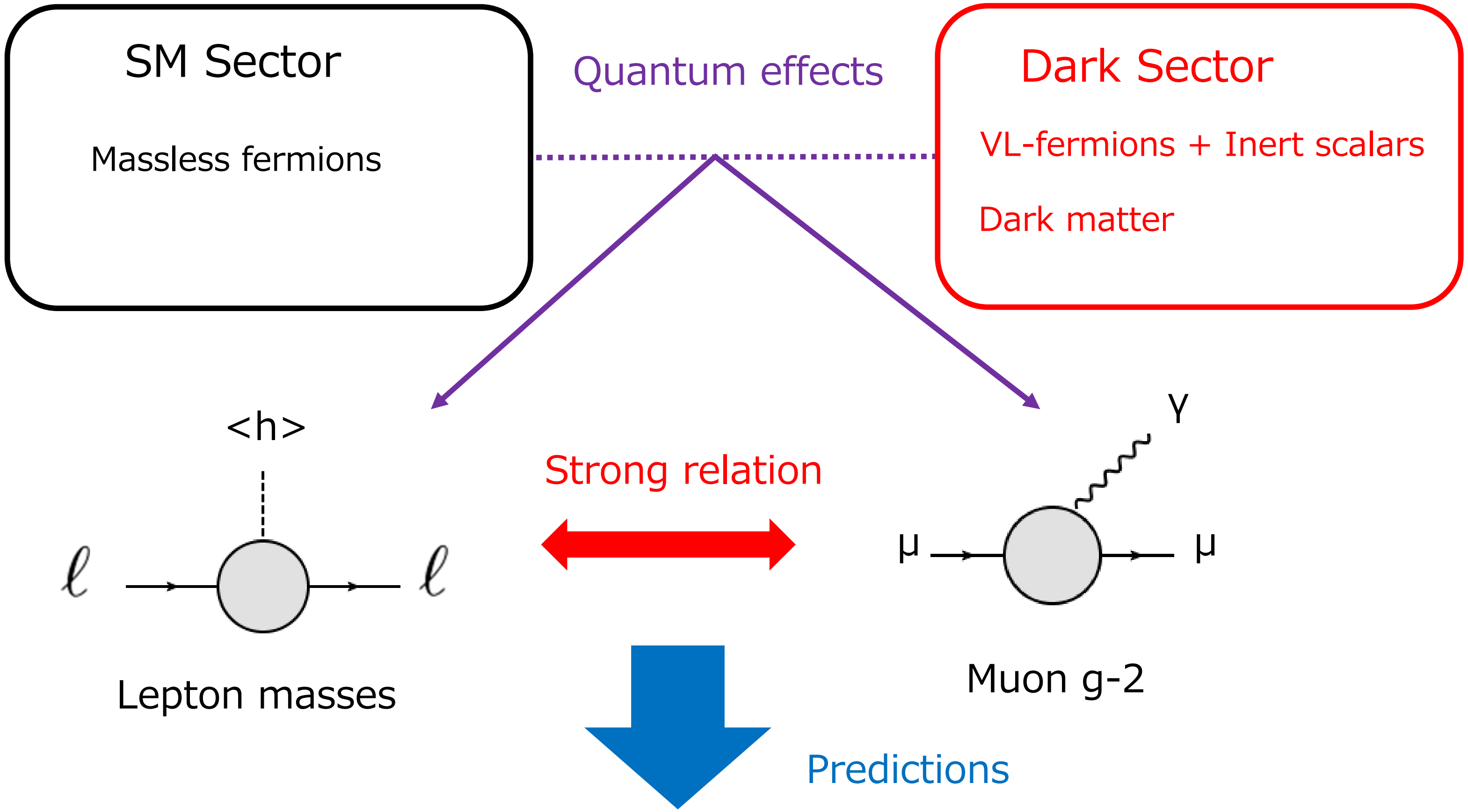


Chirality structure of the initial electron/positron is clearly different.

Beam polarization would be crucially important!

Summary

Radiative charged seesaw scenarios can naturally solve DM and $(g\text{-}2)_\mu$.



(1) Large deviations in the muon Yukawa coupling and

(2) characteristic chiral structure in the signature at the ILC.