National Center for Theoretical Sciences
Physics Division 國家理論科學研究中心 物理組

The Future is Flavourful, 2024

Oral Presentation

Probing lepton-flavor-violating processes in e^+e^- colliders

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Based on work done with

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NYCU Institute of Physics

Jun 04, 2024

Outline

1. Introduction
2. The lepton-flavor-violating scalar mediator
3. Probing the LFV model at Belle II experiment
4. The discrimination of the scalar boson from the vector boson portal in LFV processes
5. Conclusions

1. Introduction

- Lepton Flavor Conservation:

In Standard Model of particle physics, lepton flavors are expected to be conserved.

however

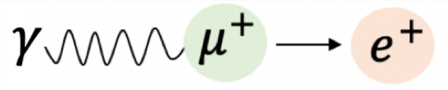
✓ No fundamental symmetry is associated with this conservation.

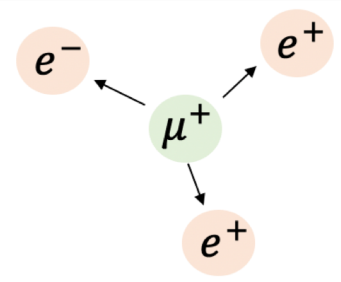
✓ Some theories of **physics BSM** still incorporate lepton flavor violating processes.

For example,

Lepton colliders

✓ Rare decays of the muon: $\mu \to e\gamma$ and $\mu \to 3e$.





Belle II

BaBar

✓ The charge-changing $\mu^- \to e^+$ conversion in muonic atoms: $\mu^- + (Z, A) \to e^+ + (Z-2, A)$

- **Lepton Flavor Violation**: "Charged leptons can change their flavor during interactions."

Why is Lepton Flavor Violation interesting?

- A clear signal of new physics.
- One of attractive explanations for the muon anomalous magnetic moment.

✓ Prominently, **muon-related** LFV processes are of current interest

$e^+e^- \to e^+\boldsymbol{\mu}^-\phi$ and $e^+e^- \to \boldsymbol{\mu}^+e^-\phi$

→ solution for
- → 4.2σ $(g_\mu - 2)$ anomaly [1].
- → 1.5σ $(g_\mu - 2)$ anomaly [2] with leading hadronic contribution to a_μ from lattice QCD.

[1] Stephan Narison, Nuclear Physics A 1039, 122744 (2023).

[2] Sz. Borsanyi *et al.*_ Nature volume 593, pages51–55 (7 April 2021).

2. The lepton-flavor-violating mediator

A **real scalar** mediator ϕ interacts with a pair of **oppositely-charged**, **different-flavored** leptons ($e^{\pm}\mu^{\mp}$) in the limit of GeV-scale ϕ masses [3],

$$\mathcal{L}_{\phi e\mu} = \sum_{\ell=e,\mu,\tau} \boldsymbol{y_{\ell}}\bar{\ell}_L\phi\ell_R + \boldsymbol{y_{e\mu}}\bar{e}_L\phi\mu_R + y_{\mu e}\bar{\mu}_L\phi e_R + \mathrm{h.c.}, \tag{1}$$

where y_ℓ and $y_{e\mu(\mu e)}$ are CLFC and CLFV coupling constants, respectively.

Here, ϕ comes from an extra leptophilic second Higgs doublet assumed to couple to only leptons.

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Here, ϕ comes from an extra leptophilic second Higgs doublet assumed to couple to only leptons.

Assuming that:

- The flavor diagonal terms with y_ℓ are vanishing.
- Only involving LFV nondiagonal terms of e and μ.

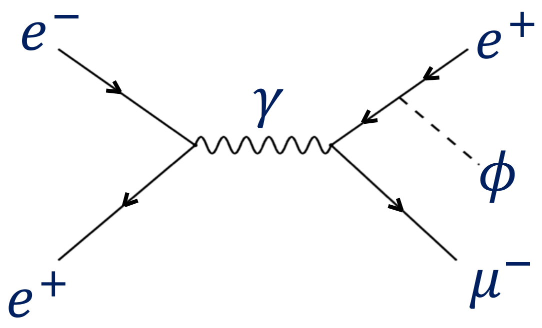
(1) rewritten as

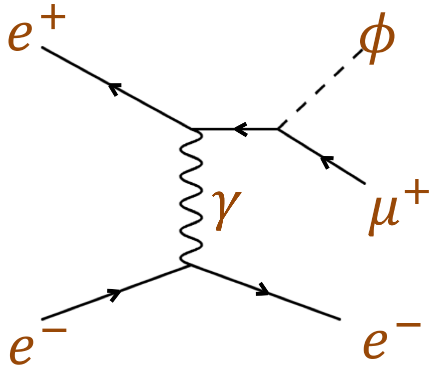
$$\mathcal{L}_{\phi e\mu} = \phi \bar{e}(g_{e\mu} + h_{e\mu}\gamma^5)\mu + \phi \bar{\mu}(g_{e\mu}^* - h_{e\mu}^*\gamma^5)e \quad (2)$$

where $g_{e\mu} = (y_{e\mu} + y_{\mu e}^*)/2$ and $h_{e\mu} = (y_{e\mu} - y_{\mu e}^*)/2$

[3] J. Lorenzo Diaz-Cruz, J. J. Toscano, PhysRevD.62.116005.

Lagrangian: $\mathcal{L}_{\phi e\mu} = \phi\bar{e}\left(\boldsymbol{g_{e\mu}} + \boldsymbol{h_{e\mu}}\gamma^5\right)\mu + \phi\bar{\mu}\left(g_{e\mu}^* - h_{e\mu}^*\gamma^5\right)e$ (3)





- Both LFV processes $e^+e^- \to e^+\mu^-\phi$ and $e^+e^- \to \mu^+e^-\phi$ will only depend on $\left(|g_{e\mu}|^2 + |h_{e\mu}|^2\right)$.

taking

$\boldsymbol{g_{e\mu}} = \boldsymbol{h_{e\mu}} = \boldsymbol{f}$ a positive real number

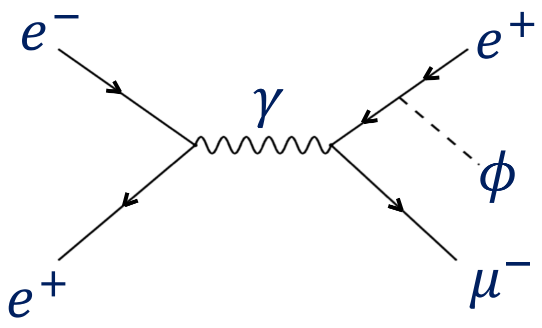
(3)

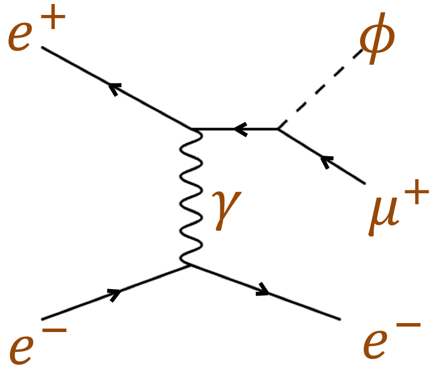
$\mathcal{L}_{\phi e\mu} = \boldsymbol{h_{e\mu}}\phi\bar{e}(1+\gamma^5)\boldsymbol{\mu} + \boldsymbol{h_{e\mu}}\phi\boldsymbol{\bar{\mu}}(1-\gamma^5)e$

probing

interpretation of anomaly in $g_\mu - 2$.

Lagrangian: $\mathcal{L}_{\phi e\mu} = \phi\bar{e}(\boldsymbol{g_{e\mu}} + \boldsymbol{h_{e\mu}}\gamma^5)\mu + \phi\bar{\mu}(g^*_{e\mu} - h^*_{e\mu}\gamma^5)e$ (3)





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$$\mathcal{L}_{\phi e\mu} = \boldsymbol{h_{e\mu}}\phi\bar{e}(1+\gamma^5)\boldsymbol{\mu} + \boldsymbol{h_{e\mu}}\phi\bar{\boldsymbol{\mu}}(1-\gamma^5)e$$

probing

interpretation of anomaly in $g_\mu - 2$.

Approximation [4] → $\Delta a_\mu = \frac{\boldsymbol{h^2_{e\mu}}}{8\pi^2}\left[2x_a^2 \log\left(\frac{x_a}{x_a - 1}\right) - 1 - 2x_a\right]$ (4)

for $m_\phi > m_\mu$ where $x_a = \boldsymbol{m^2_\phi}/m^2_\mu$.

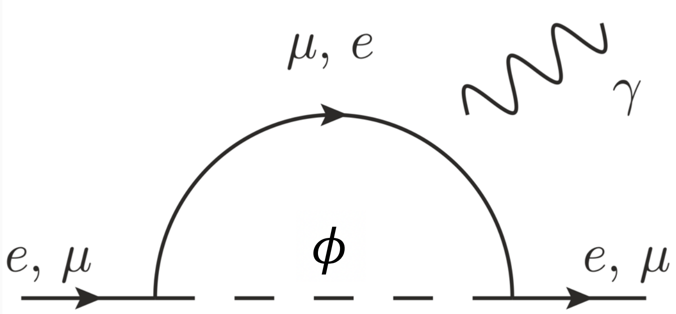


Fig. 1: The contribution of one-loop diagram to a_μ mediated by the scalar ϕ in the LFV model.

[4] M. Endo, S. Iguro and T. Kitahara, *JHEP* 06 (2020) 040.

Existing constraints on the coupling $h_{\mu e}$ in **LFV scalar** search

→ depending on the relative strength of CLFC and CLFV couplings of the boson to leptons.

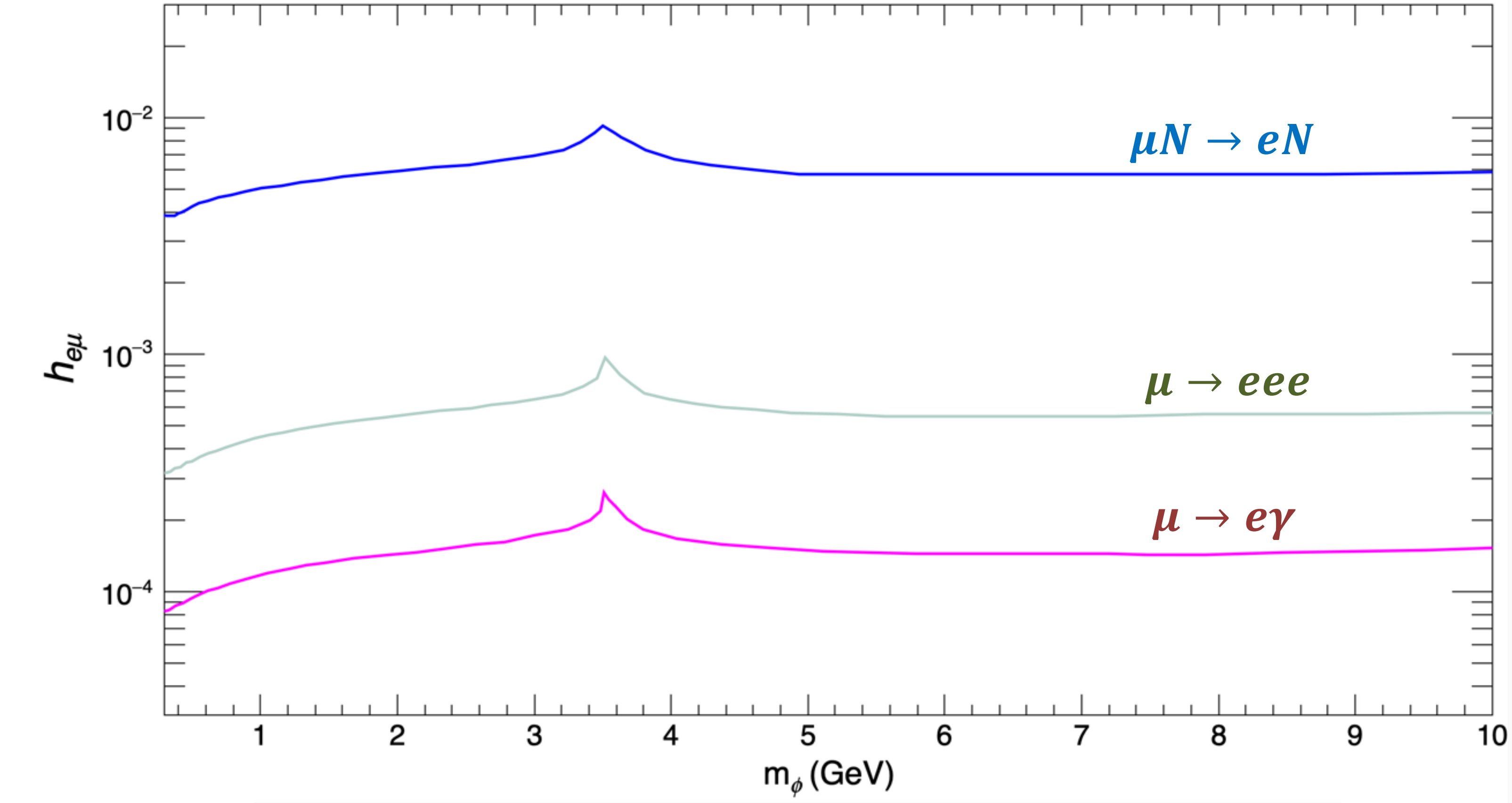


Fig. 2: The CLFV coupling is taken to $h_{e\mu}/g_{\ell\ell}$ = 10^3 [5].

[5] M. Bauer, M. Neubert, S. Renner, M. Schnubelb, JHEP 09 (2022) 056.

3. Probing the LFV model at Belle II experiment

Belle II experiment An energy asymmetric detector of 7 GeV e^- and 4 GeV e^+ with $E_{C.M}$ = 10.58 GeV.

LFV processes: $e^+e^- \to e^\pm\mu^\mp\phi$

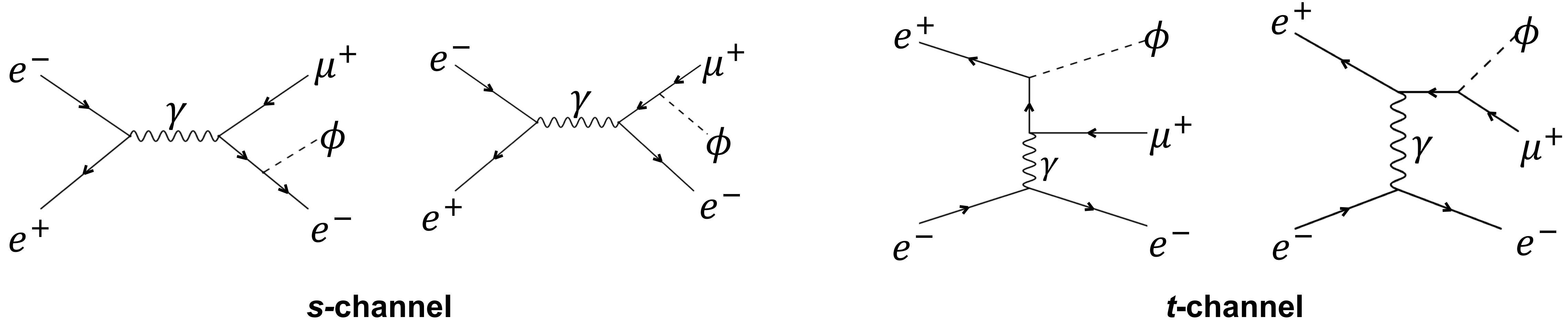


Fig. 3: Feynman diagrams for process $e^+e^- \to e^-\mu^+\phi$

Visible decay: Two pair of same-sign final-state electrons and muons

$$e^+e^- \to e^+\mu^-\phi \to e^+\boldsymbol{\mu}^-\boldsymbol{\mu}^-e^+$$
$$e^+e^- \to e^-\mu^+\phi \to e^-\boldsymbol{\mu}^+\boldsymbol{\mu}^+e^-$$

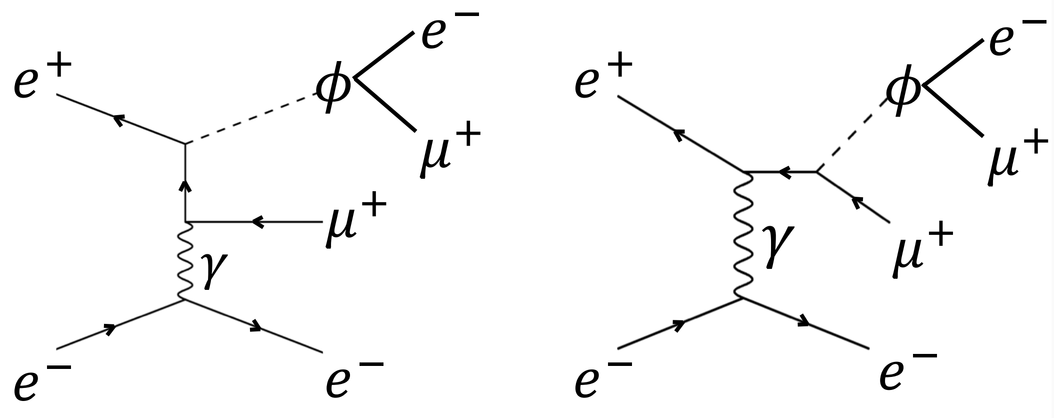
In the range: $1 \leq m_\phi/\mathrm{GeV} \leq 8$

Visible decay mode

$$e^+e^- \to e^-\mu^+\boldsymbol{\phi} \to e^-\mu^+\boldsymbol{\mu}^+\boldsymbol{e}^-$$

and $e^+e^- \to e^+\mu^-\boldsymbol{\phi} \to e^+\mu^-\boldsymbol{\mu}^-\boldsymbol{e}^+$

same-sign lepton pairs are essentially **background free** [4].



***t*−channel**

[4] M. Endo, S. Iguro and T. Kitahara, *JHEP* 06 (2020) 040.

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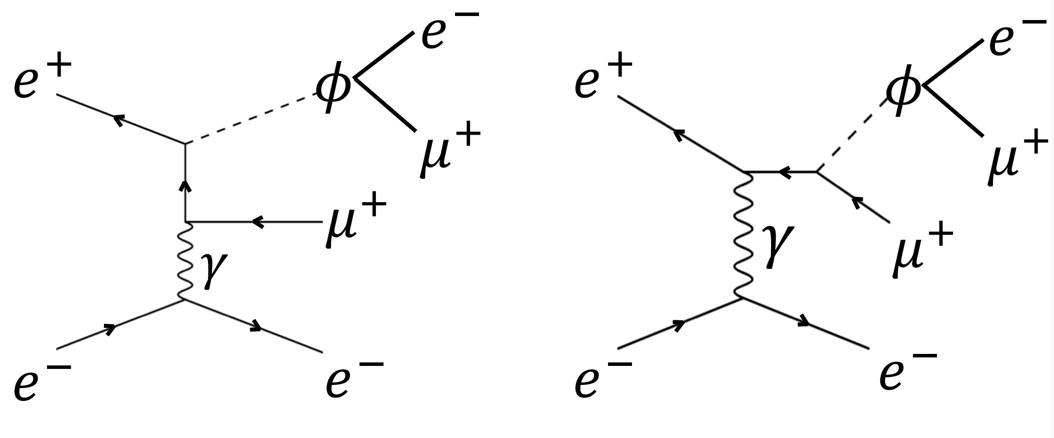


Using

- **Background free selection** with $N_{95\%\mathrm{up}}$ of 3 events for a Poisson signal.
- Assuming Br($\phi \to e^+\mu^-$) = Br($\phi \to e^-\mu^+$) = 0.5.
- The simulation package MadGraph5 and CalcHEP.
- A cut of *CleanedTracks* selection criteria for the **kinematical cuts** and **lepton tagging efficiencies** for the final-state leptons [6].

At $\mathcal{L} = 1\ \mathrm{fb}^{-1}$, Belle II limit on $h_{e\mu}$ for $1 \leq m_\phi/\mathrm{GeV} \leq 8$

[4] M. Endo, S. Iguro and T. Kitahara, *JHEP* 06 (2020) 040.
[6] Belle-II collaboration, The Belle II Physics Book, PTEP (2020) 123C01.

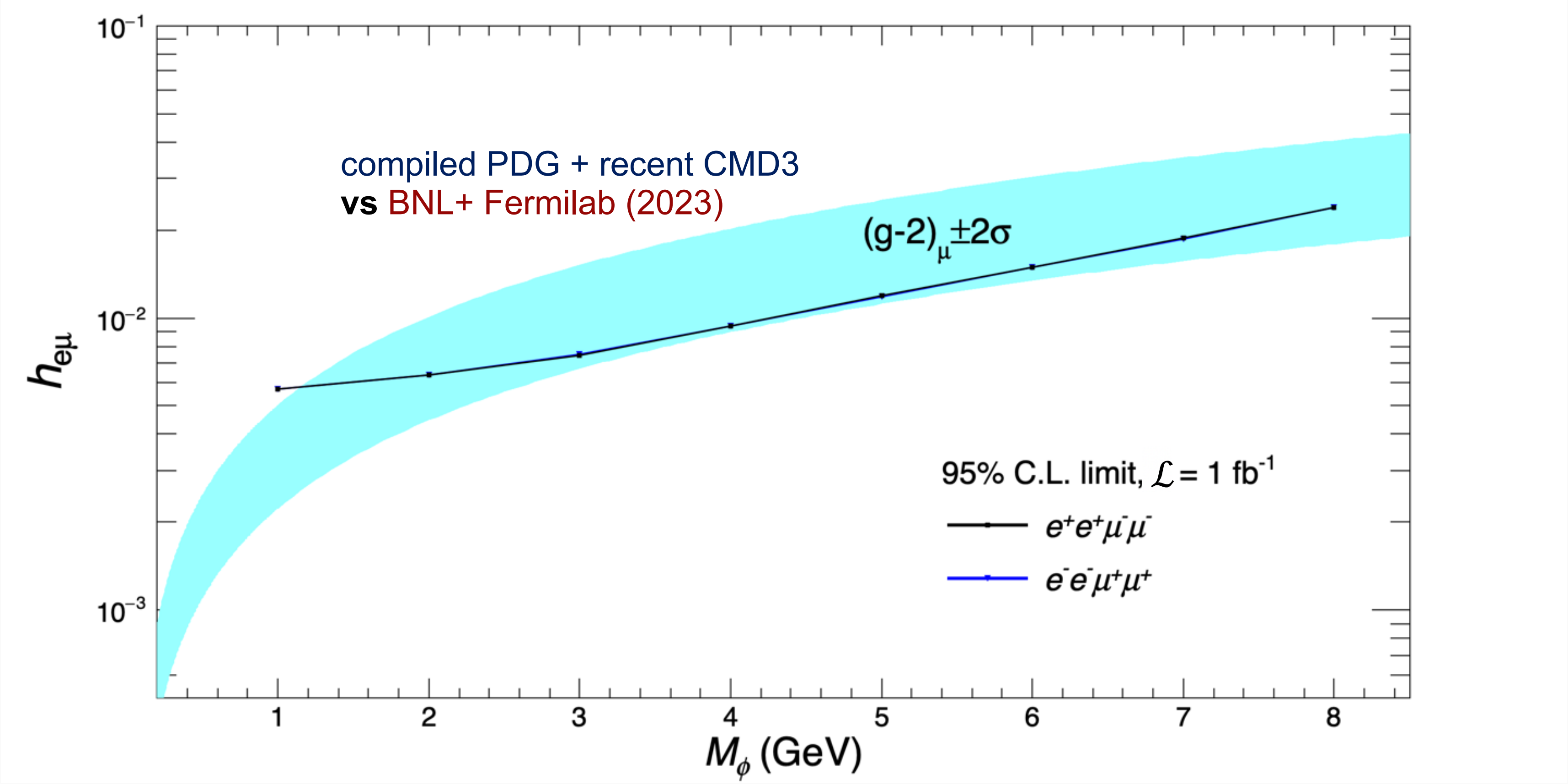
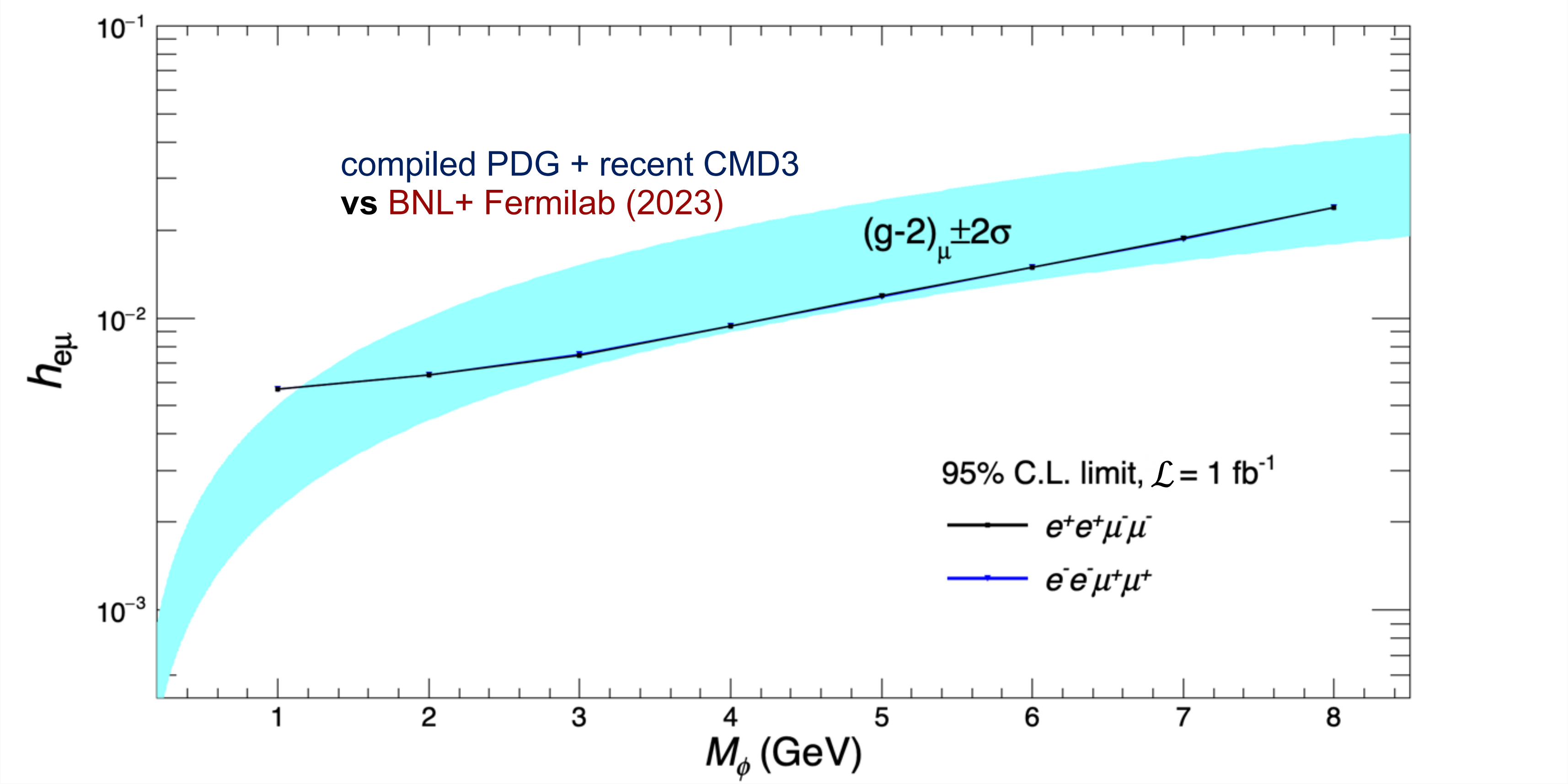


Fig. 4: The sensitivity to $h_{e\mu}$ as a function of m_ϕ expected for LFV scalar search at Belle II.

- At $\mathcal{L} = 1\ \mathrm{fb}^{-1}$, the Belle II limit on $h_{e\mu}$ for 1 ≤ m_ϕ/GeV ≤ 8 already touches the 2σ parameter region favored by $g_\mu - 2$.

$$h_{e\mu} \sim \frac{1}{\sqrt{\mathcal{L}}}$$



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- At $\mathcal{L} = 1\ \text{fb}^{-1}$, the Belle II limit on $h_{e\mu}$ for $1 \leq m_\phi/\text{GeV} \leq 8$ already touches the 2σ parameter region favored by $g_\mu - 2$.

At Belle II full luminosity $\mathcal{L} = 50\ \mathrm{ab}^{-1}$

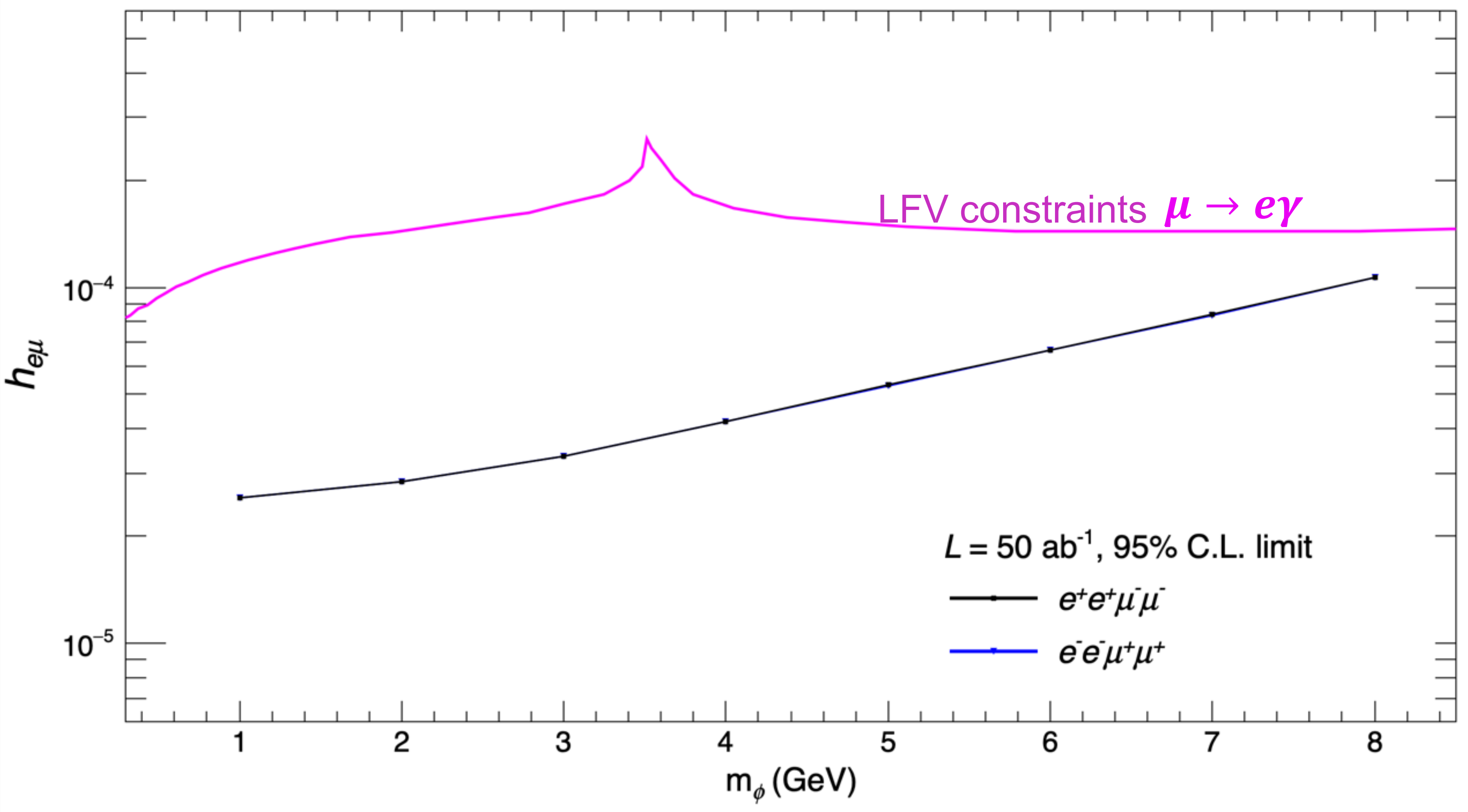

Fig. 5: The sensitivity to $h_{e\mu}$ as a function of m_ϕ expected for LFV scalar search at Belle II.

Visible decay mode

$$e^+e^- \to e^-\mu^+\phi \to e^-\mu^+\mu^+e^-$$

and $$e^+e^- \to e^+\mu^-\phi \to e^+\mu^-\mu^-e^+$$

Existing constraints to the **LFV vector search** → (motivated) $Z - Z'$ mixing

↓

extra $U(1)'$ gauge symmetry + adopting a model-independent approach

Z [7]

Z DECAY MODES		Fraction (Γ_i/Γ)		Scale factor/ Confidence level	p (MeV/c)
$e^{\pm}\mu^{\mp}$	LF	[j] $<$ 7.5	$\times 10^{-7}$	CL=95%	45594
$e^{\pm}\tau^{\mp}$	LF	[j] $<$ 5.0	$\times 10^{-6}$	CL=95%	45576
$\mu^{\pm}\tau^{\mp}$	LF	[j] $<$ 6.5	$\times 10^{-6}$	CL=95%	45576

μ

μ^- DECAY MODES		Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$e^-\gamma$	LF	$<$ 4.2	$\times 10^{-13}$	90%	53
$e^-e^+e^-$	LF	$<$ 1.0	$\times 10^{-12}$	90%	53
$e^-2\gamma$	LF	$<$ 7.2	$\times 10^{-11}$	90%	53

[7] R.L. Workman et al. (PDG), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

Existing constraints to the **LFV vector** search

- The mass Lagrangian for the interaction of massive neutral gauge bosons after EW symmetry breaking:

$$\mathcal{L}_{\text{mass}} = \frac{1}{2}\begin{pmatrix}\hat{Z}^{\lambda} & \hat{Z}'^{\lambda}\end{pmatrix}\begin{pmatrix}M_Z^2 & \Delta \\ \Delta & M_{Z'}^2\end{pmatrix}\begin{pmatrix}\hat{Z}_{\lambda} \\ \hat{Z}'_{\lambda}\end{pmatrix} \tag{5}$$

where $M_{Z,Z'}$ denote masses of the gauge bosons and Δ represents the mixing between them.

↓ containing both kinetic- and mass-mixing contributions

➢ In the presence of kinetic mixing, $M_{Z'}$ is not identical to the original mass of the $U(1)'$ gauge boson.

The squared-mass matrix in $\mathcal{L}_{\text{mass}}$ can be diagonalized using

$$\begin{pmatrix}Z \\ Z'\end{pmatrix} = \begin{pmatrix}\cos\xi & \sin\xi \\ -\sin\xi & \cos\xi\end{pmatrix}\begin{pmatrix}\hat{Z} \\ \hat{Z}'\end{pmatrix} \quad \text{with } \tan 2\xi = \frac{2\Delta}{M_Z^2 - M_{Z'}^2} \tag{6}$$

with mass eigenvalues $$m_{Z,Z'}^2 = \frac{1}{2}(M_Z^2 + M_{Z'}^2) \pm \frac{1}{2}\sqrt{(M_Z^2 - M_{Z'}^2)^2 + 4\Delta^2} \tag{7}$$

Existing constraints to the LFV vector coupling

- The Lagrangian describes the interactions of $\hat{Z}$ and $\hat{Z}'$ with charged leptons,

$$\mathcal{L}_{\text{int}} = -g_Z J_Z^\lambda \hat{Z}_\lambda - h_{Z'} J_{Z'}^\lambda \hat{Z}'_\lambda \quad (8)$$

and the currents $g_Z J_Z^\lambda = \bar{\hat{\ell}} \gamma^\lambda (g_L P_L + g_R P_R) \hat{\ell}$, $h_{Z'} J_{Z'}^\lambda = \bar{\hat{\ell}} \gamma^\lambda (h'_L P_L + h'_R P_R) \hat{\ell}$,

where $\hat{\ell} = (\hat{e} \quad \hat{\mu} \quad \hat{\tau})^T$, $P_{L,R} = \frac{1}{2}(1 \mp \gamma^5)$ and $\hat{Z}$ coupling constants $g_{L,R}$ are family universal.

whereas $\hat{Z}'$couplings are not assumed to be family universal according to

$$h'_L = \text{diag}\left(L'_e, L'_\mu, L'_\tau\right), \qquad h'_R = \text{diag}\left(R'_e, R'_\mu, R'_\tau\right)$$

The interaction eigenstates in $\hat{\ell}$ are related to the mass eigenstates in ℓ by: $\hat{\ell}_{L,R} = \boldsymbol{P}_{L,R}\, \hat{\ell} = \boldsymbol{V}_{L,R} \ell_{L,R}$ (9)

with $\boldsymbol{V}_{L,R}$ are unitary matrices which diagonalize the lepton mass matrix $\widehat{M}_\ell$ in the Yukawa Lagrangian

$$\text{diag}\left(m_e, m_\mu, m_\tau\right) = V_L^\dagger \widehat{M}_\ell V_R$$

In terms of the mass eigenstates, Z, Z' and ℓ, we can then write

$$\mathcal{L}_{\rm int} = -\bar{\ell}_i\gamma^\lambda\left(\boldsymbol{\beta}_L^{\ell_i\ell_j}P_L + \boldsymbol{\beta}_R^{\ell_i\ell_j}P_R\right)\ell_j Z_\lambda - \bar{\ell}_i\gamma^\lambda\left(\boldsymbol{b}_L^{\ell_i\ell_j}P_L + \boldsymbol{b}_R^{\ell_i\ell_j}P_R\right)\ell_j Z'_\lambda \tag{10}$$

with

$$\left.\begin{aligned}\boldsymbol{\beta}_{L,R}^{\ell_i\ell_j} &= \left(\boldsymbol{\beta}_{L,R}^{\ell_j\ell_i}\right)^* = \boldsymbol{\delta_{ij}\cos\xi\, g_{L,R} + \sin\xi\left(B_{L,R}\right)_{ij}} \\ \boldsymbol{b}_{L,R}^{\ell_i\ell_j} &= \left(\boldsymbol{b}_{L,R}^{\ell_j\ell_i}\right)^* = \boldsymbol{-\delta_{ij}\sin\xi\, g_{L,R} + \cos\xi\left(B_{L,R}\right)_{ij}}\end{aligned}\right\} \Rightarrow \boxed{\boldsymbol{\beta}_{L,R}^{\ell_i\ell_j} = \delta_{ij}\frac{g_{L,R}}{\cos\xi} + \tan\xi\, \boldsymbol{b}_{L,R}^{\ell_i\ell_j}} \tag{11}$$

where $\ell_{i(j)} = e, \mu, \tau$ and $\boldsymbol{B}_{L,R} = V_{L,R}^\dagger h'_{L,R} V_{L,R}$ are nondiagonal 3×3 matrices.

Weak mixing angle ξ ⟷ Electroweak $\boldsymbol{\rho_0}$ parameter deduced from a global fit to Z physics data.

Since Z-Z' mixing alters the Z mass, $\rho_0 \equiv \frac{m_W^2}{c_W^2 m_Z^2} = \frac{m_W^2}{c_W^2 M_Z^2}\left[1 - \frac{(m_{Z'}^2 - M_Z^2)\tan^2\xi}{M_Z^2}\right]^{-1}$ (12)

For $\xi \ll 1$, $\tan\xi \simeq \sin\xi \simeq \xi \Rightarrow$ $\boxed{\rho_0 \simeq 1 + \frac{(m_{Z'}^2 - m_Z^2)\xi^2}{m_Z^2}}$ (13)

The numerical results with two-loop corrections to the ρ_0 parameter [7]: $\rho_0 = 1.0002 \pm 0.0009$

[7] R.L. Workman et al. (PDG), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

Existing constraints to the LFV vector coupling

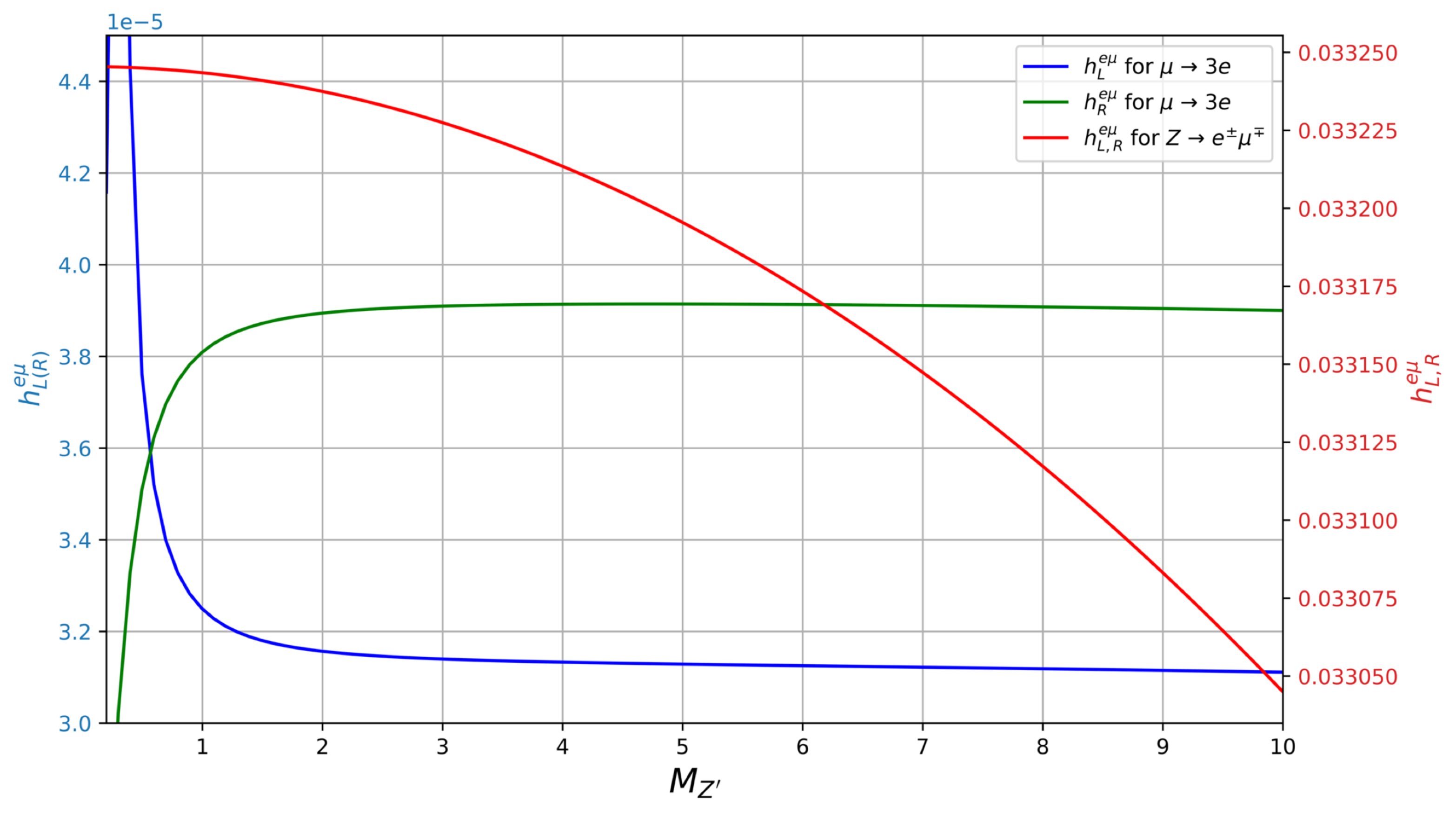

Fig. 6: Constraints on the coupling $h^{e\mu}_{L,R}$ (in red, right axis) of process $Z \to e^{\pm}\mu^{\mp}$ and $h^{e\mu}_{L(R)}$ of process $\mu \to e^- e^+ e^-$ (with $h^{e\mu}_{L(R)}/h^{\ell\ell}_{L(R)}$ = 10^3) in LFV vector search [8].

⇩

depending on the relative strength of CLFC and CLFV couplings of the boson to leptons

[8] Cheng-Wei Chiang, Yi-Fan Lin, Jusak Tandean, JHEP 11 (2011) 083.

4. The discrimination of the scalar boson from the vector boson portal in LFV processes

- To discriminate the scalar boson from the vector boson scenarios:
  - ✓ Probing differential cross section $d\sigma/d\boldsymbol{M}(\boldsymbol{e}^-\boldsymbol{\mu}^+)$ or $d\sigma/d\boldsymbol{M}(\boldsymbol{e}^+\boldsymbol{\mu}^-)$

→ exhibiting **distinct shapes**

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    → exhibiting **distinct shapes**

LFV processes:

$$e^+e^- \to \boldsymbol{e}^-\boldsymbol{\mu}^+\phi \to \boldsymbol{e}^-\boldsymbol{\mu}^+\mu^+e^-$$
$$e^+e^- \to \boldsymbol{e}^+\boldsymbol{\mu}^-\phi \to \boldsymbol{e}^+\boldsymbol{\mu}^-\mu^-e^+$$

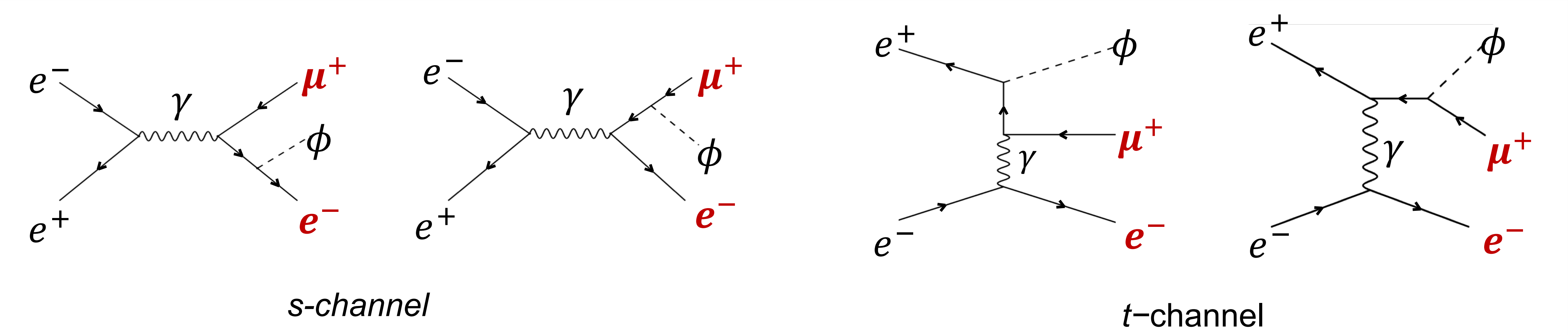

Fig. 3: Feynman diagrams for process $e^+e^- \to e^-\mu^+\phi$

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depend on **spin** of boson → exhibiting **distinct shapes**

depend on

→ Events number

→ Boson mass (recoil against $e^{\mp}\mu^{\pm}$ system).

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depend on **spin** of boson → exhibiting **distinct shapes**

depend on
→ Events number
→ Boson mass (recoil against $e^\mp\mu^\pm$ system).

- **Cumulative mass distribution** [8]: → calculating the area under each of the cumulative mass distributions.

$$K^i(M_{e^\mp\mu^\pm}) = \frac{\sum_i N^i_{e^\mp\mu^\pm B}}{N^{\text{total}}_{e^\mp\mu^\pm B}}$$

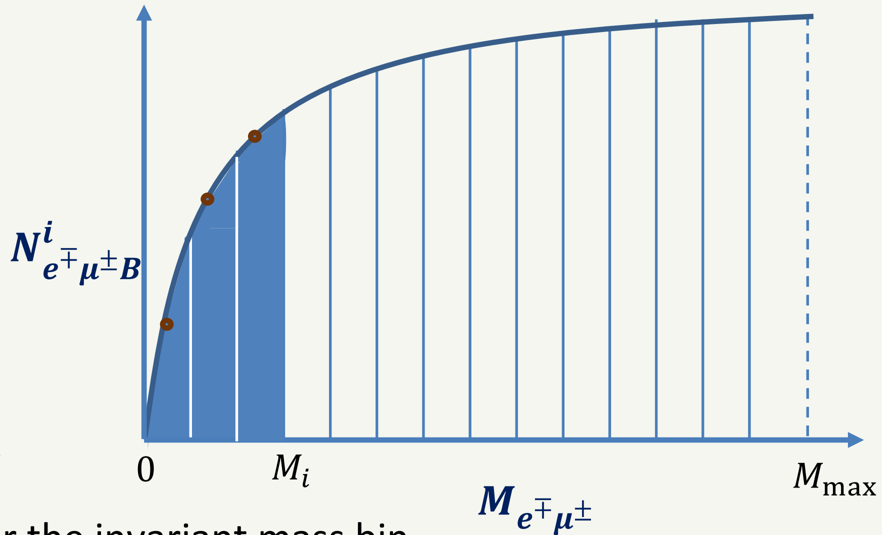
$\sum_i N^i_{e^\mp\mu^\pm B}$ → Event number within $0 \le M_{e^\mp\mu^\pm} \le M_i$

$N^{\text{total}}_{e^\mp\mu^\pm B}$ → Total event number within $0 \le M_{e^\mp\mu^\pm} \le M_{\max}$

↓

$0 \le K^i(M_{e^\mp\mu^\pm}) \le 1$

LFV boson B → scalar ϕ / vector V



➢ $K^i(M_{e^\mp\mu^\pm})$ is useful due to the **significant** differences between **peak event rates** in different scenarios.

i: index for the invariant mass bin

[9] Kwang-Chang Lai, C. S. Jason Leung, and Guey-Lin Lin, Phys. Rev. D 107, 043017 (2023).

- The **statistical uncertainty** of the measurement follows Poisson distribution [9]:

Cumulative mass distribution

$$\boldsymbol{\sigma}_{\boldsymbol{K}(\boldsymbol{M}_{e^{\mp}\mu^{\pm}})} = K^{i}(M_{e^{\mp}\mu^{\pm}}) \times \sqrt{\frac{1}{N^{i}_{e^{\mp}\mu^{\pm}B}} - \frac{1}{N^{\text{total}}_{e^{\mp}\mu^{\pm}B}}} \qquad (14)$$

Events number in a certain mass interval

Total event number

⇒ LFV scalar and vector boson scenarios can be distinguished with statistical uncertainties taken into account.

Considering the case of $M_B = 1$ GeV

[9] Kwang-Chang Lai, C. S. Jason Leung, and Guey-Lin Lin, Phys. Rev. D 107, 043017 (2023).

M_B = 1 GeV

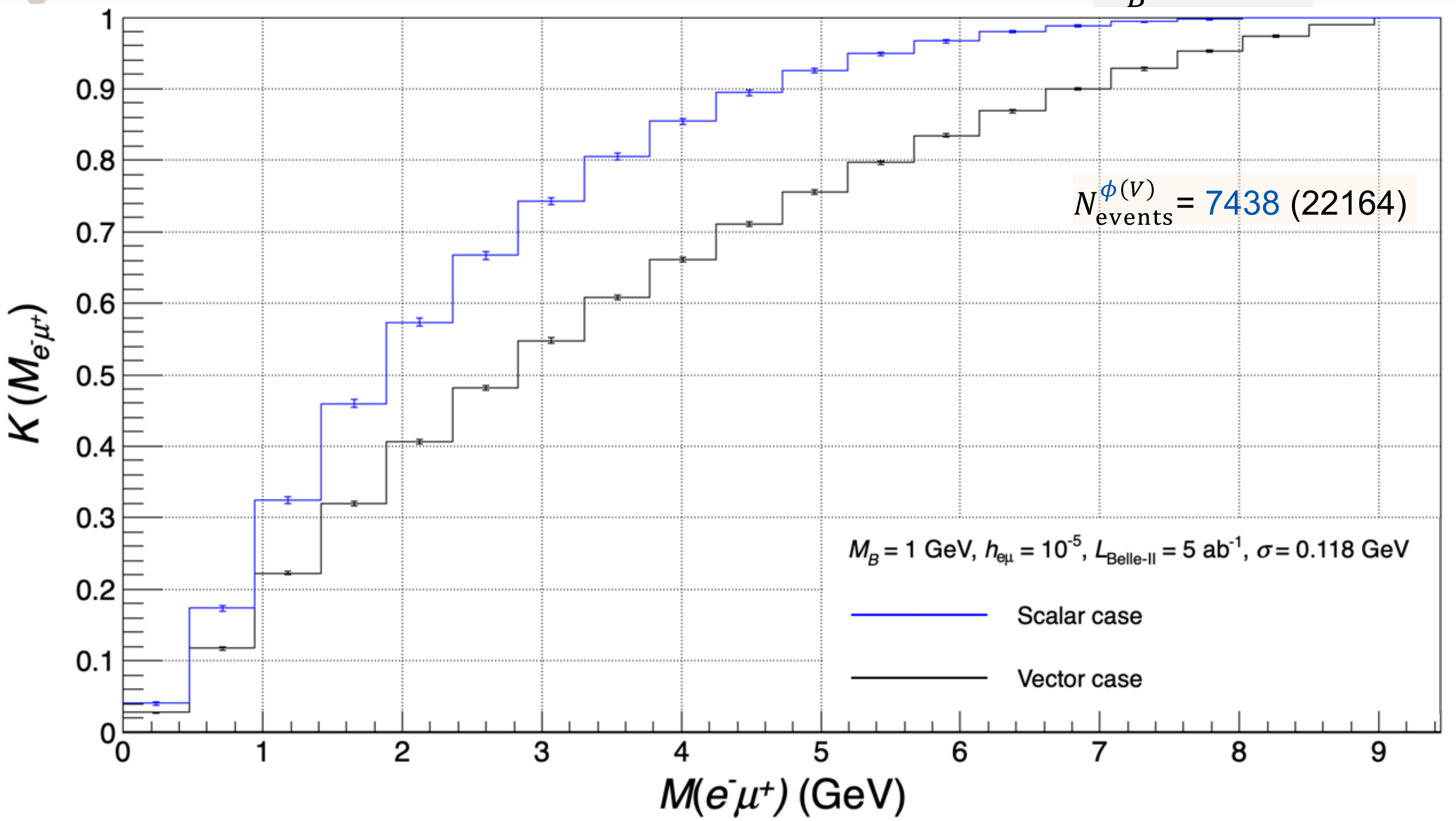


Fig. 7. Cumulative mass distribution $K^i(M_{e^\mp\mu^\pm})$ of LFV search $e^+e^- \to e^-\mu^+B$ ($B = \phi, V$).

- At $\mathcal{L} = 5\,\text{ab}^{-1}$, taking $h_{e\mu} = 10^{-5}$

  ↓

  satisfying current experimental **constraints**

- Statistical errors in binned histograms, each with a **bin width of** $\pm 2\sigma$, where σ = 0.118 GeV is the *recoil mass resolution* at $M_B = 1$ GeV.

M_B = 1 GeV

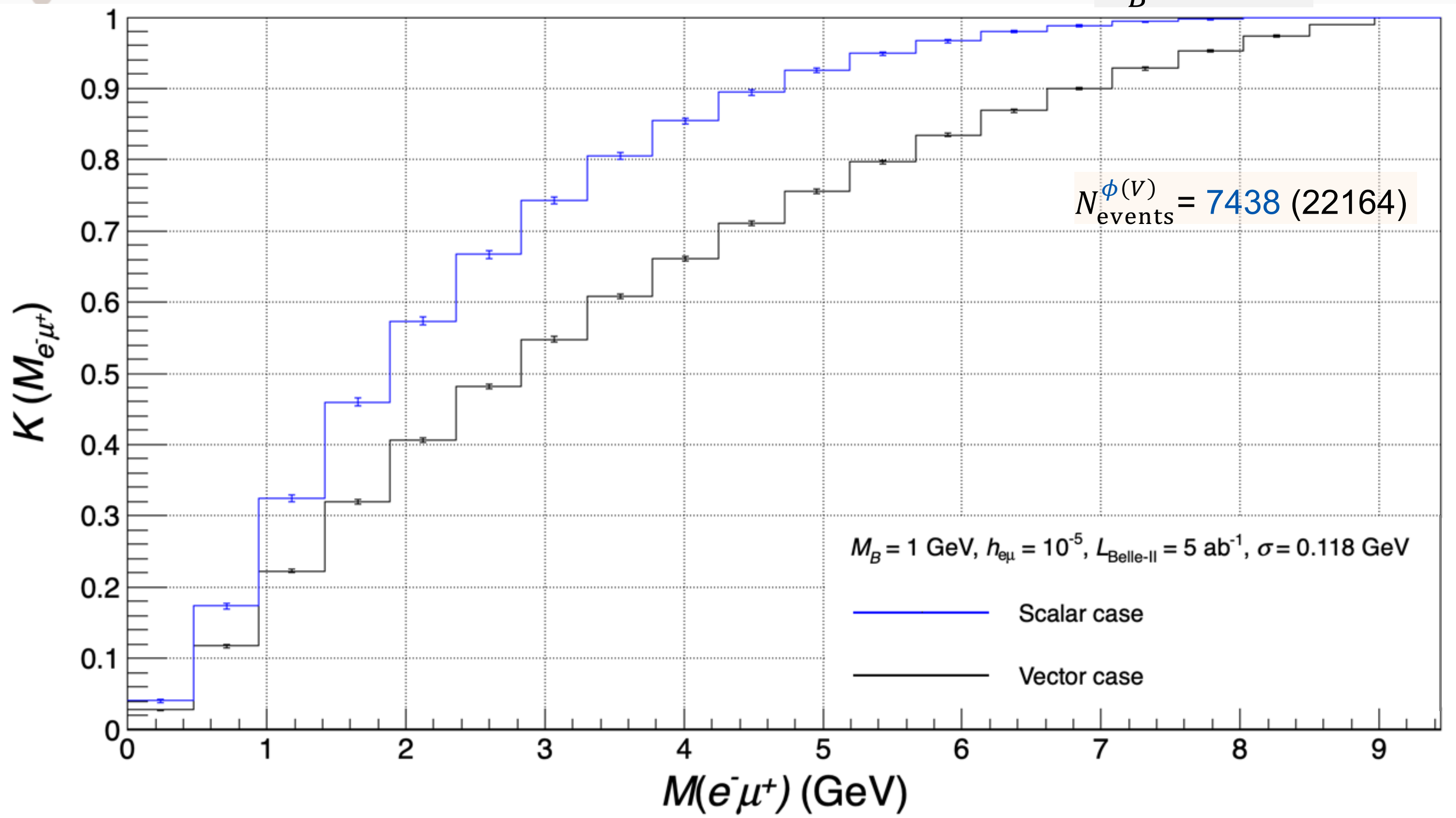


Fig. 8. Cumulative mass distribution $K^i(M_{e^\mp\mu^\pm})$ of LFV search $e^+e^- \to e^-\mu^+ B$ ($B = \phi, V$).

- At $\mathcal{L} = 5\,\text{ab}^{-1}$, taking $h_{e\mu} = 10^{-5}$

  ↓

  satisfying current experimental **constraints**

- Statistical errors in binned histograms, each with a **bin width of** $\pm 2\sigma$, where σ = 0.118 GeV is the *recoil mass resolution* at $M_B = 1$ GeV.

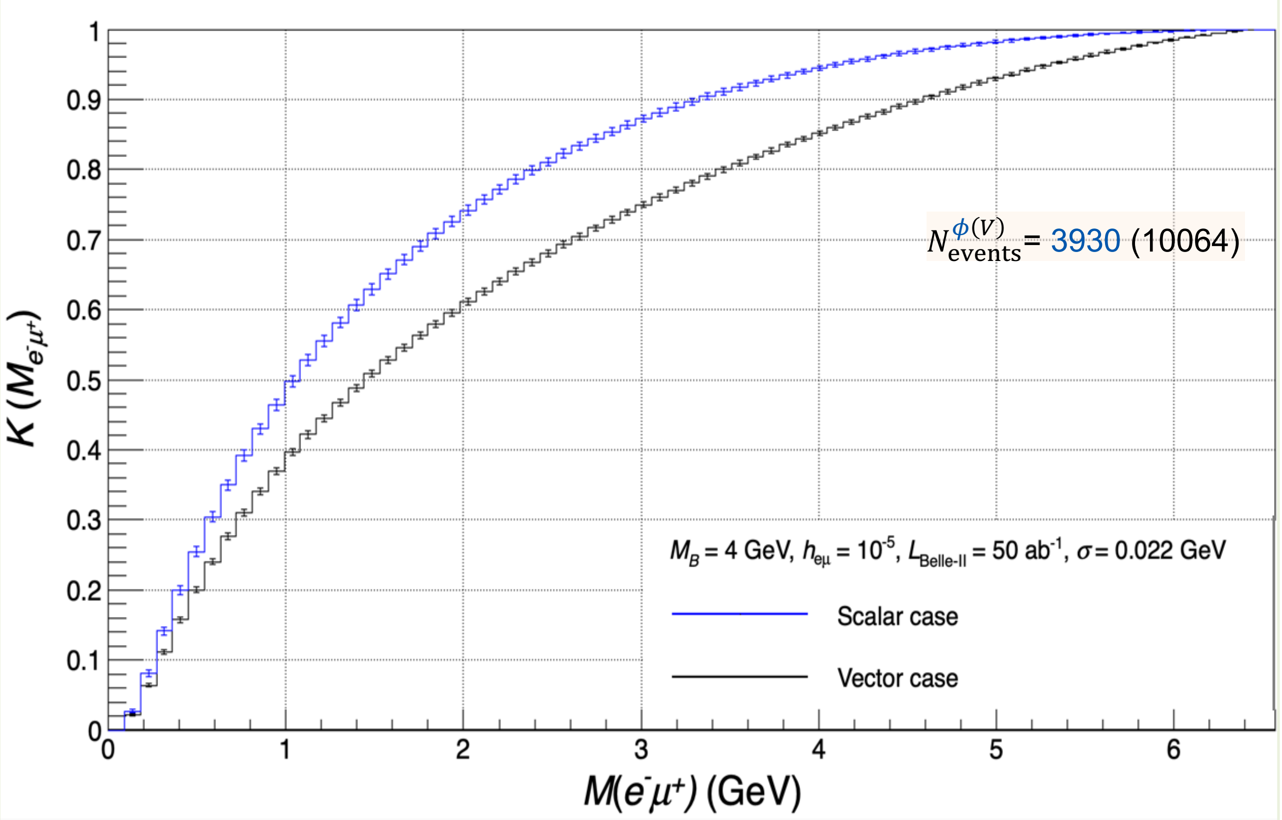
✓ Quantitatively, the ordering $K^\phi\left(M_{e^\mp\mu^\pm}\right) > K^V\left(M_{e^\mp\mu^\pm}\right)$ holds in the considered simulation.

✓ $K^\phi\left(M_{e^\mp\mu^\pm}\right)$ increase faster in the range of $1 \le M_{e^\mp\mu^\pm} \le 5$ GeV since LFV event rate of scalar boson case increases the fastest in this mass range.

⇒ LFV scalar boson scenario is found to be distinguishable from that of vector boson case in Belle II detector provided only statistical uncertainties are considered in simulations.

4. The discrimination of the scalar boson from the vector boson portal in LFV processes

M_B = 4 GeV



- At $\mathcal{L} = 50\ \mathrm{ab}^{-1}$, taking $h_{e\mu} = 10^{-5}$

  ↓

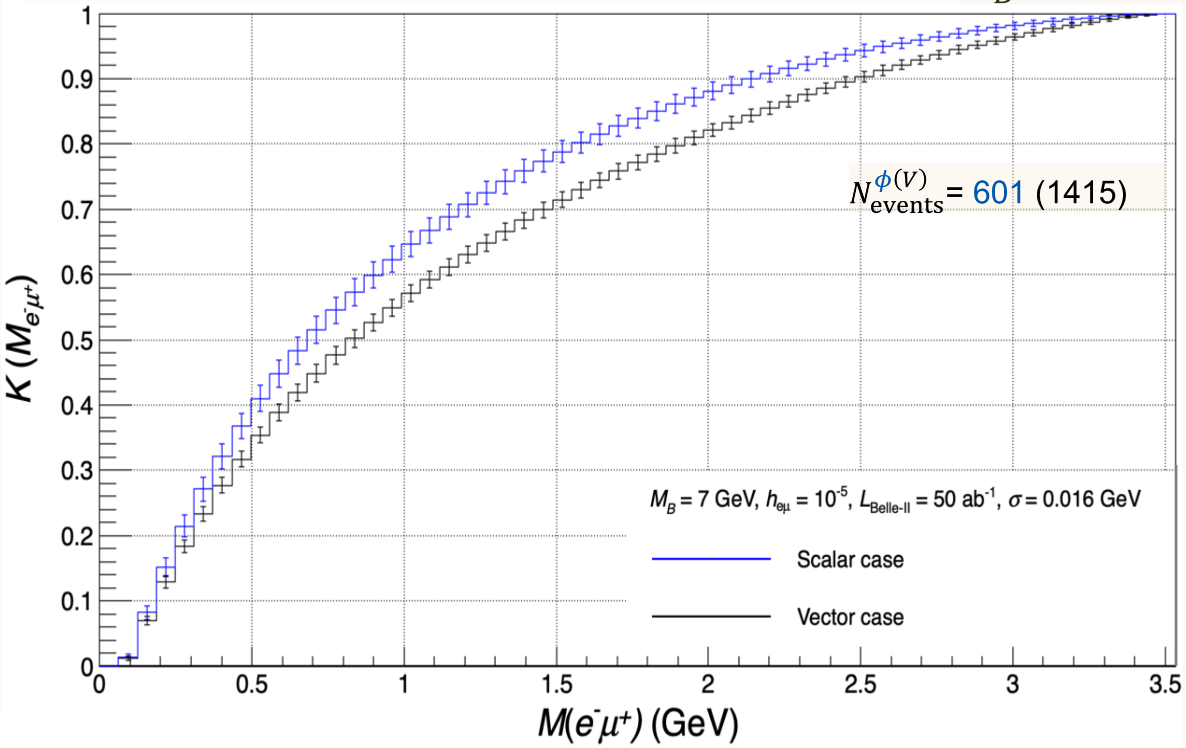
  satisfying current experimental constraints
- Statistical errors in binned histograms, each with a **bin width of** $\pm 2\sigma$, where $\sigma = 0.022$ GeV.

- At $\mathcal{L} = 50\ \mathrm{ab}^{-1}$, taking $h_{e\mu} = 10^{-5}$

  ↓

  satisfying current experimental constraints
- Statistical errors in binned histograms, each with a **bin width of** $\pm 2\sigma$, where $\sigma = 0.016$ GeV.

M_B = 7 GeV



5. Conclusions

- We have studied Belle II sensitivity to probe $e\mu$ flavor-violating scalar model.

  ✓ Sensitivities to LFV Yukawa coupling $h_{e\mu}$ of processes $e^+e^- \to e^\pm\mu^\mp\phi \to e^\pm e^\pm\mu^\mp\mu^\mp$ for $\mathcal{L} = 1\ \text{fb}^{-1}$ at Belle II experiment can already touch the favorable parameter range accounting for the measured $g_\mu - 2$ in the range $1 \leq m_\phi/\text{GeV} \leq 8$.

  ✓ At high luminosity, we could potentially search for new physics. Particularly, the sensitivity for Belle II full luminosity to $h_{e\mu}$ is still quite below the LFV current constrain for $\mu \to e\gamma$.

- We also propose a method to discriminate the scalar scenario from LFV interaction with a vector boson exchange.

  ✓ By carefully analyzing the cumulative mass distribution $K^i(M_{e^\mp\mu^\pm})$ for both the LFV scalar and vector bosons with statistical uncertainties taken into account.

  → LFV scalar and vector boson scenarios are distinguished.


THANK
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