Mar. 2 2017, HPNP 2017 @ Toyama University

A search for a light $L_\mu - L_\tau$ gauge boson at Belle-II

Shihori Hoshino (Saitama University), T. Araki, T. Ota, J. Sato, and T. Shimomura

This work is based on arXiv: 1702.01497 [hep-ph]

★Muon $g-2$ discrepancy

The discrepancy between theory(SM) and experiment is summarized as [1] $a=(g-2)/2$

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (26.1 \pm 8.0)\cdot 10^{-10} \sim 3\sigma \ .$$

We need new physics beyond the SM and have searched for them.
Any significant signal has not been observed yet at high energy colliders...

We focus on models including a new **"light"** gauge boson with **"feeble interactions"** !

★New gauged U(1)$_{L_\mu - L_\tau}$ model [2]

$$\mathcal{L}_{\rm int} = g_{Z'}(+\bar{\nu}_\mu \gamma^\rho P_L \nu_\mu - \bar{\nu}_\tau \gamma^\rho P_L \nu_\tau + \bar{\mu}\gamma^\rho \mu - \bar{\tau}\gamma^\rho \tau) Z'_\rho$$

New gauge coupling constant

Contribution to $g_\mu-2$

New gauge boson (MeV〜GeV)

The opposite charges are assigned to μ and τ leptons.

No quantum gauge anomalies.
No CLFV couplings.

For $M_{Z'} \sim$ MeV, $g_{Z'} \sim 10^{-4}$,

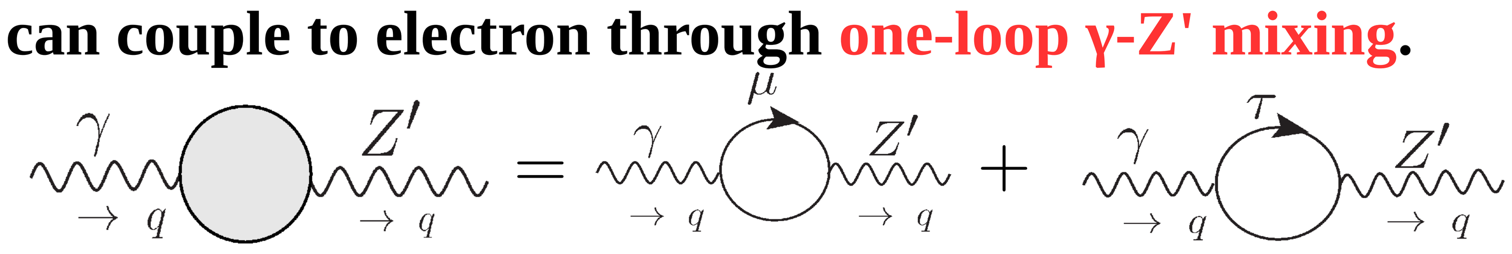
this model can explain muon $g-2$ discrepancy.

We use the **minimal** **U(1)$_{L_\mu - L_\tau}$ model**.

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} Z'_{\rho\sigma} Z'^{\rho\sigma} - \frac{\varepsilon}{4} Z'_{\rho\sigma} B^{\rho\sigma} + \frac{M_{Z'}{}^2}{2} Z'_\rho Z'^\rho$$
$$+ g_{Z'}(+\bar{\nu}_\mu \gamma^\rho P_L \nu_\mu - \bar{\nu}_\tau \gamma^\rho P_L \nu_\tau + \bar{\mu}\gamma^\rho \mu - \bar{\tau}\gamma^\rho \tau) Z'_\rho$$

- New particle is only Z'.
- No tree-level kinetic mixing between $U(1)_Y$ and $U(1)_{L_\mu - L_\tau}$
- 2 parameters, $g_{Z'}$ and $M_{Z'}$.

In the minimal U(1)$_{L_\mu - L_\tau}$ model,
Z' can couple to electron through one-loop γ-Z' mixing.



$$\equiv \Pi(q^2) = \frac{8 e g_{Z'}}{(4\pi)^2} \int_0^1 x(1-x) \ln \frac{m_\tau^2 - x(1-x)q^2}{m_\mu^2 - x(1-x)q^2}\, dx$$

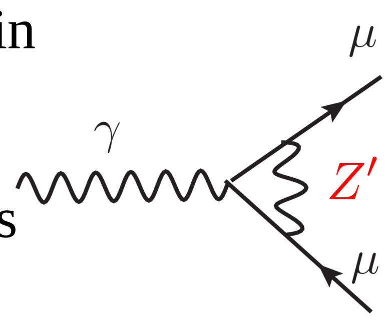
The mixing **depends on injection momentum q.**

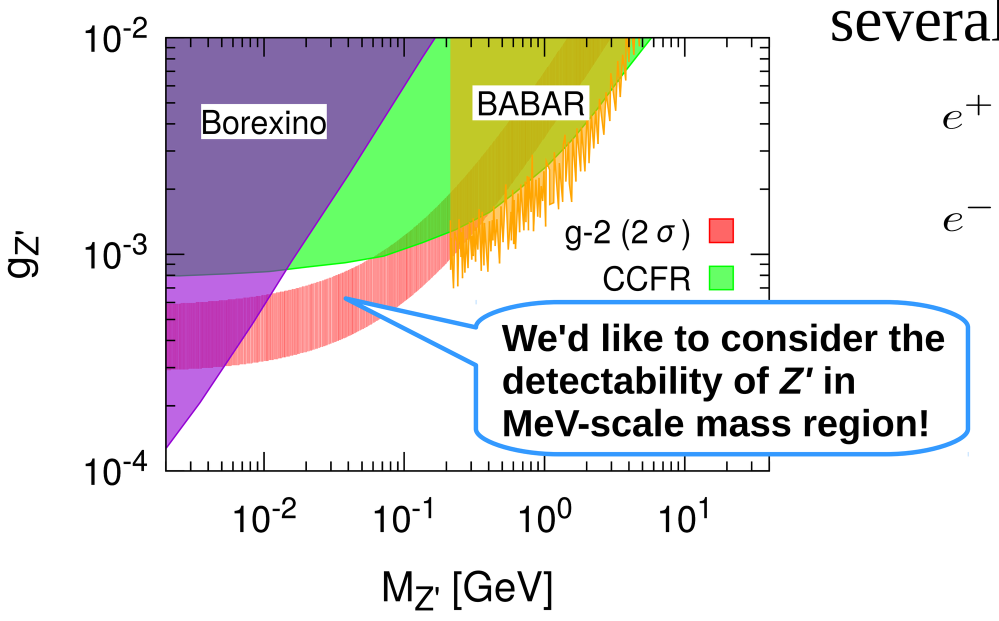
★Motivation and Constraints

Z' contribution to muon $g-2$

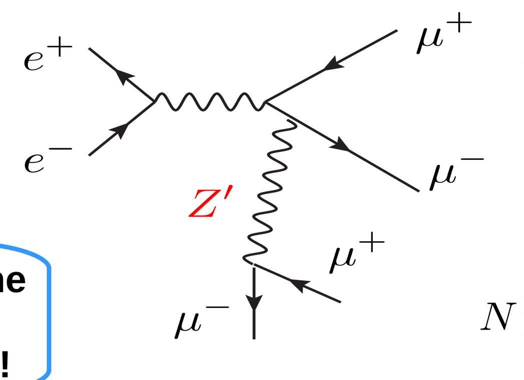
In $L_\mu - L_\tau$ models, we have an additional contribution to g_μ-2.

The parameter region in which the discrepancy of $g_\mu - 2$ can be Explained with in 2σ is shaded in red [3].

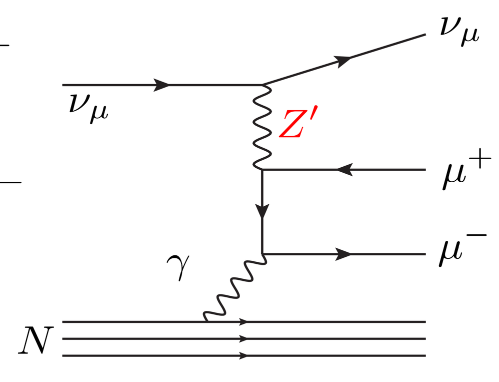




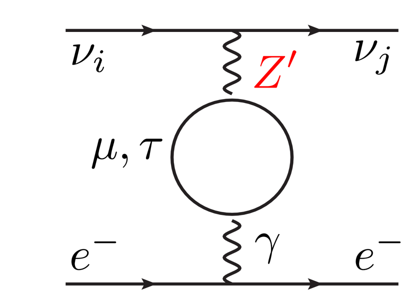
The minimal U(1)$_{L_\mu - L_\tau}$ model is strictly constrained by several experiments.



$e^+e^- \to 4\mu$ at BABAR (orange [4]).



Neutrino trident production at CCFR (green [5]).



Neutrino-electron elastic scattering at Borexino (purple [6]).

★Detectability of a light $L_\mu - L_\tau$ gauge boson at Belle-II

Target : A $L_\mu - L_\tau$ gauge boson Z' which lies on the parameter region

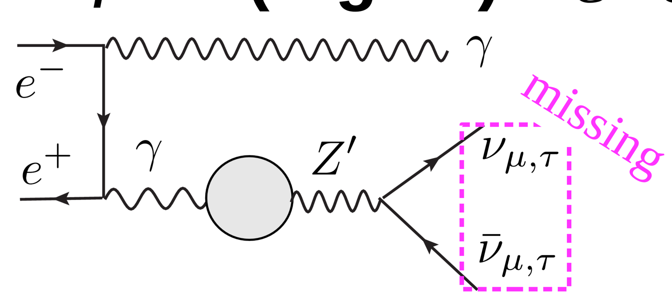
$M_{Z'} \sim$ MeV   : Suitable for low energy experiments.

$g_{Z'} \sim 10^{-4} - 10^{-3}$: High luminosity is necessary.

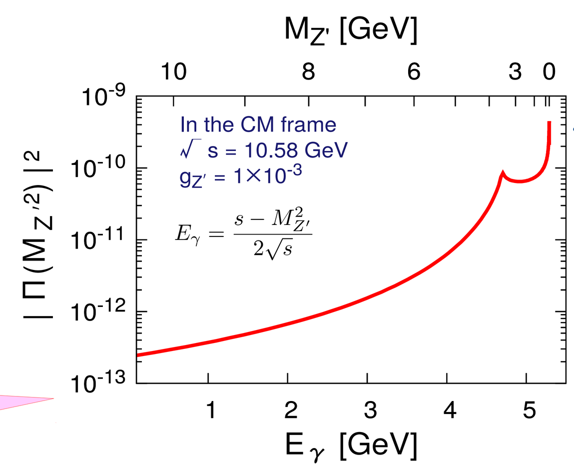
Belle-II is expected to be suitable !!
$\sqrt{s}$ (the CM energy) $= 10.58$ GeV [7]
L (Integrated luminosity) $= 50\ {\rm ab}^{-1}$

We would like to discuss the detectability of Z' through the **one photon + missing** process at Belle-II.

$L_\mu - L_\tau$ (Signal) : $e^+e^- \to \gamma Z'$, $Z' \to \nu\bar{\nu}$



The Z' is produced on its mass shell and subsequently decays into a pair of neutrinos.



The mixing depending on momentum is enhanced in low mass region!

The cross section is given as

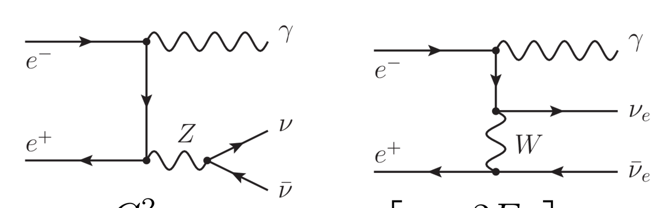
$$\sigma_{\gamma Z'} = \frac{2\pi\alpha^2 |\Pi(M_{Z'}^2)|^2}{s}\left[1-\frac{M_{Z'}^2}{s}\right] \times \left[\left[1+\frac{2sM_{Z'}^2}{(s-M_{Z'}^2)^2}\right]\ln\frac{(1+\cos\theta_{\rm max})(1-\cos\theta_{\rm min})}{(1-\cos\theta_{\rm max})(1+\cos\theta_{\rm min})} - \cos\theta_{\rm max} + \cos\theta_{\rm min}\right],$$

which is multiplied by the branching ratio of $Z' \to \nu\bar{\nu}$.

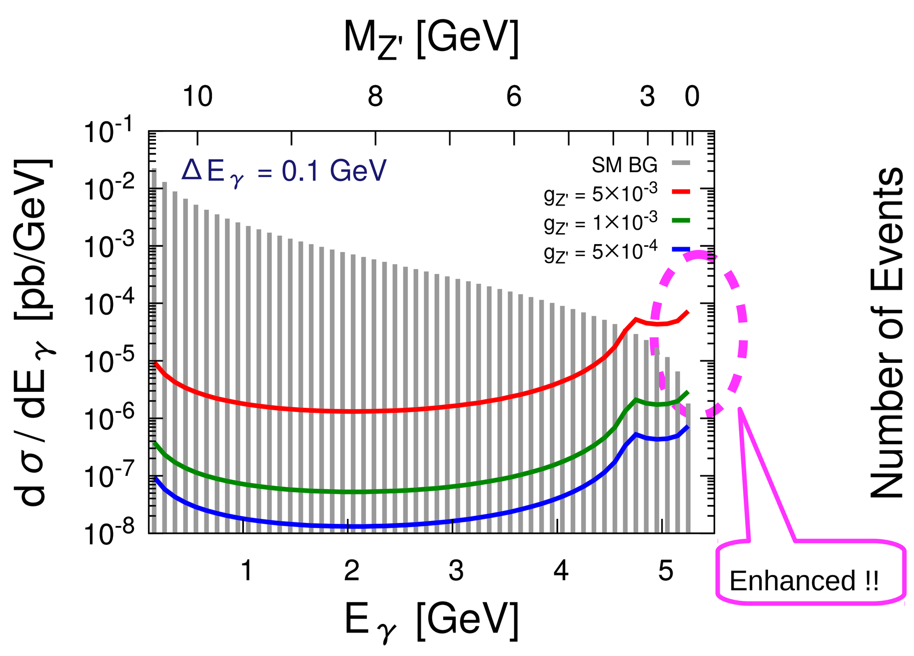
$\theta_{\rm max} < \theta < \theta_{\rm min}$: The range of coverage of the EM calorimeter.

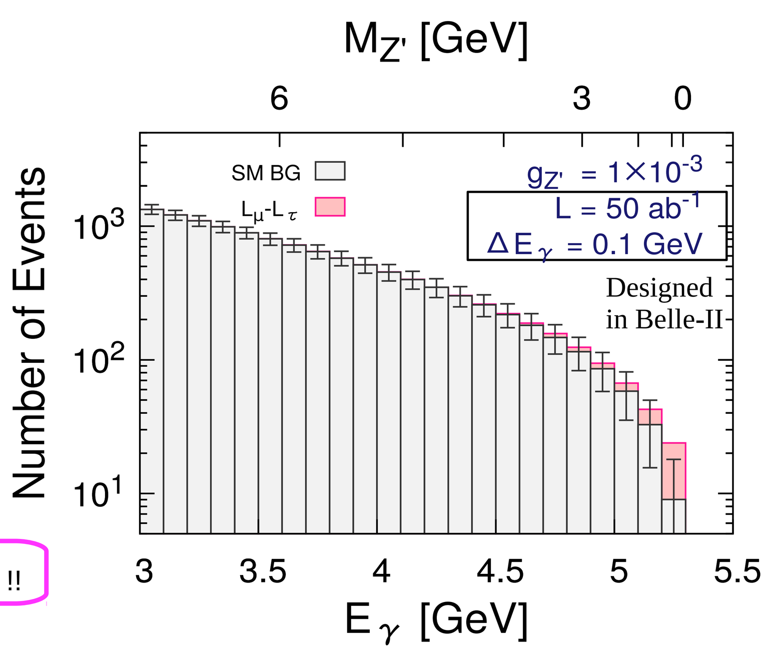
SM (BG) : $e^+e^- \to \gamma\nu\bar{\nu}$

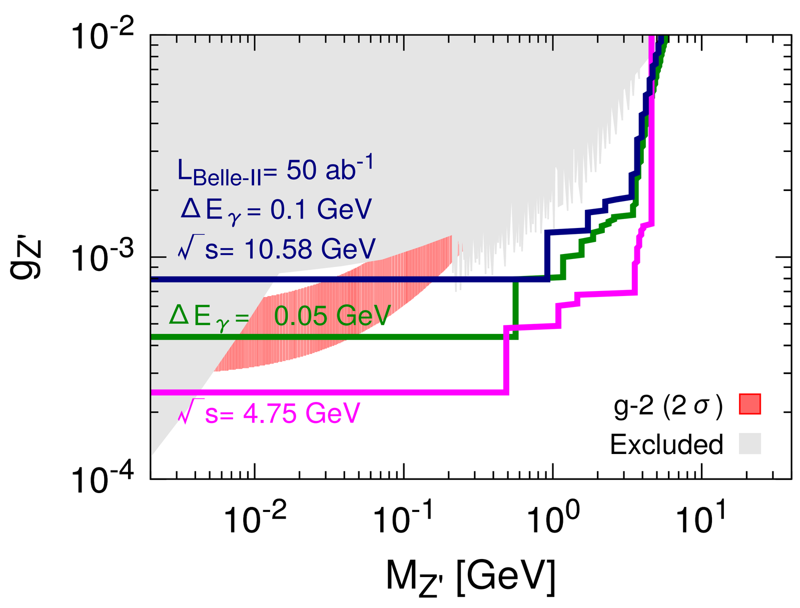
mediated by off-shell weak boson



$$\frac{d\sigma_{\rm SM}}{dE_\gamma} = \frac{\alpha G_F^2}{3\pi^2}(g_L^2 + g_R^2)E_\gamma\left[1-\frac{2E_\gamma}{\sqrt{s}}\right] \times \left[\left[1-\frac{\sqrt{s}}{E_\gamma}+\frac{s}{2E_\gamma^2}\right]\ln\frac{(1+\cos\theta_{\rm max})(1-\cos\theta_{\rm min})}{(1-\cos\theta_{\rm max})(1+\cos\theta_{\rm min})} - \cos\theta_{\rm max} + \cos\theta_{\rm min}\right]$$







- We require $\dfrac{N_{\rm sig}}{\sqrt{N_{\rm BG}}} > 3$ to claim the detection of the Z'.
- In the region above these lines, Belle-II can detect the Z'.
- We found that Belle-II will be able to cover some of the unconstrained parameter region for the muon $g-2$ discrepancy.

★References

[1] K. Hagiwara *et al*. J.Phys.**G38** (2011) 085003. [2] X. He *et al*. Phys. Rev. **D43**, 22 (1991). [3] S. Baek *et al*. Phys. Rev. **D64 ,** 055006 (2001). [4] J. P. Lees *et al*. (BaBar), Phys. Rev. **D94**(1), 011102 (2016).
[5] W. Altmannshofer *et al*. Phys. Rev. Lett. 113, 091801 (2014). [6] T. Araki *et al*.Phys. Rev. **D93**(1), 013014 (2016). [7] T. Abe et al. (Belle-II) (2010), 1011.0352.