Overview of tau physics

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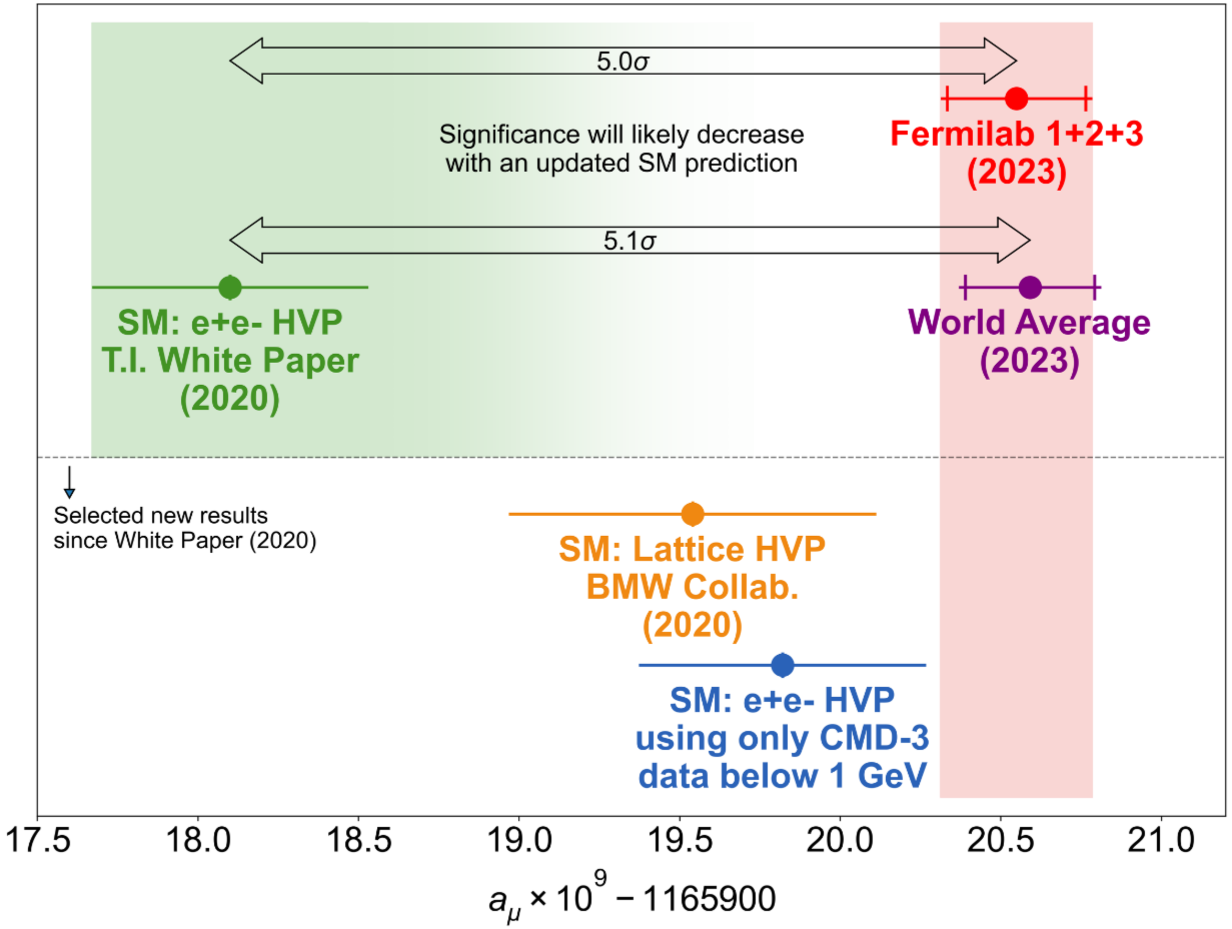
Muon g-2 (Lepton Universality)



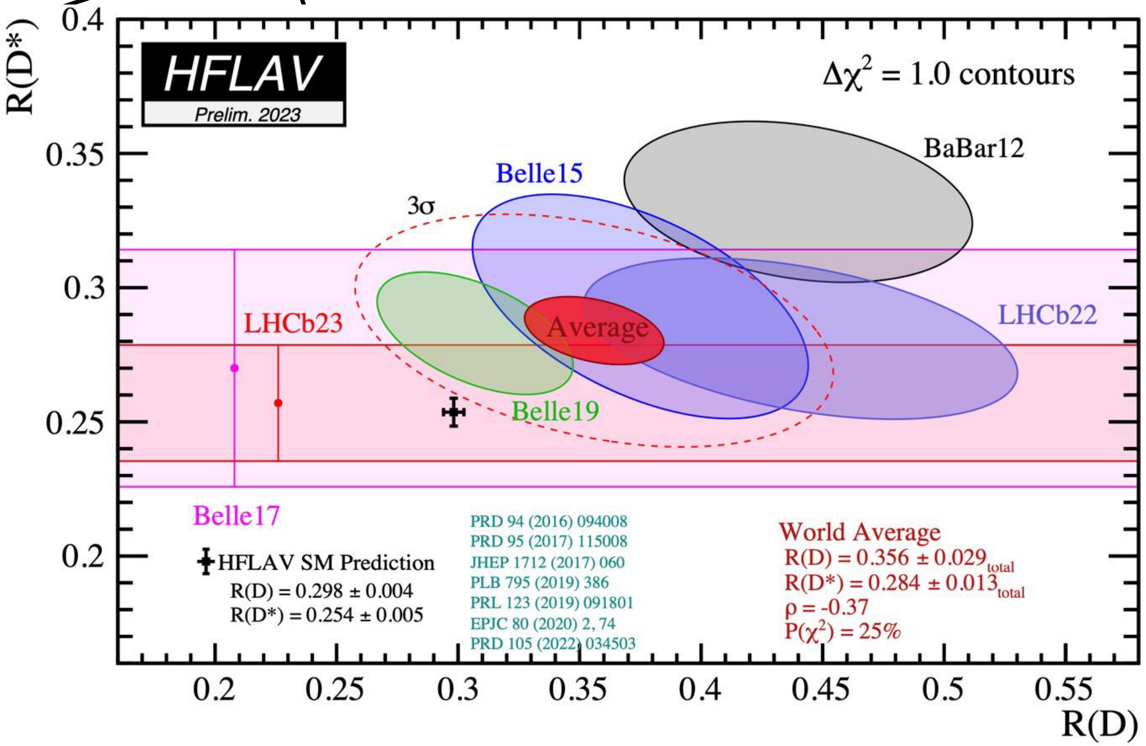
Anyway, muon g-2 gives us some hint to violate the lepton universality. For example, Lμ-Lτ model explains this discrepancy. So, muon g-2 may Indicates deep relation between τ and μ.

We may need to consider tau g-2 more seriously.

Lepton Universality in B decays

$$R\left(D^{(*)}\right) = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}\ell\nu)}$$

Belle, BaBar LHCb update this these 10 years.
This also may be a big indication for the new physics.
This is a trigger to make the discussion of the Lepto-Quark model active.
Belle II evaluates R(D*).



In addition, Belle II also evaluates

$$R(X) = \frac{Br(B \to X\tau\nu)}{Br(B \to X\ell\nu)},$$

where X means everything except signal t decay products and tag side B's decay products.

Lepton Universality in τ decay

$$\Gamma(\alpha \to \nu_\alpha \beta \overline{\nu}_\beta(\gamma)) = \frac{\mathcal{B}(\alpha \to \nu_\alpha \beta \overline{\nu}_\beta)}{\tau_\alpha} = \frac{G_\alpha G_\beta m_\alpha^5}{192\pi^3} f\left(\frac{m_\beta^2}{m_\alpha^2}\right) R_W^{\alpha\beta} R_\gamma^\alpha , \qquad (325)$$

where

$$G_\beta = \frac{g_\beta^2}{4\sqrt{2}M_W^2} , \qquad f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x , \qquad (326)$$

$$R_W^{\alpha\beta} = 1 + \frac{3}{5}\frac{m_\alpha^2}{M_W^2} + \frac{9}{5}\frac{m_\beta^2}{M_W^2} \ [1647\text{–}1649], \qquad R_\gamma^\alpha = 1 + \frac{\alpha(m_\alpha)}{2\pi}\left(\frac{25}{4} - \pi^2\right) . \qquad (327)$$

HFLAV report (arXiv:2206.07501 [hep-ex])

$$\left(\frac{g_\mu}{g_e}\right)_\tau = 1.0019 \pm 0.0014 .$$

$$\left(\frac{g_\tau}{g_\mu}\right)_h^2 = \frac{\mathcal{B}(\tau \to h\nu_\tau)}{\mathcal{B}(h \to \mu\overline{\nu}_\mu)} \frac{2m_h m_\mu^2 \tau_h}{(1 + \delta R_{\tau/h}) m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2/m_h^2}{1 - m_h^2/m_\tau^2}\right)^2 , \qquad (331)$$

where $h = \pi$ or K. The radiative corrections $\delta R_{\tau/\pi}$ and $\delta R_{\tau/K}$ have been recently updated with an improved estimation of their uncertainties and their values are $(0.18 \pm 0.57)\%$ and $(0.97 \pm 0.58)\%$ [1581], respectively. We obtain:

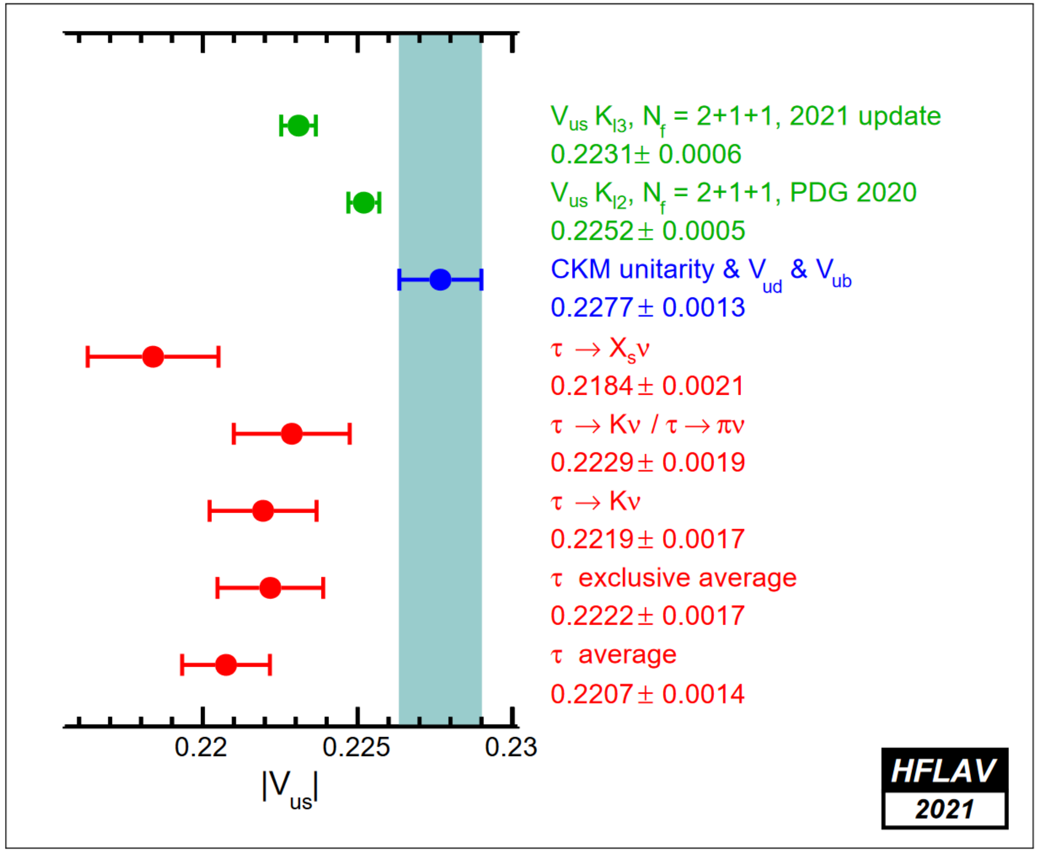
$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9959 \pm 0.0038 , \qquad \left(\frac{g_\tau}{g_\mu}\right)_K = 0.9855 \pm 0.0075 . \qquad (332)$$

The new physics can sneak into these discrepancies?

It is to important to suppress systematics coming from PID, tracking and so on.
Belle could not achieve it.
Recently, Belle II has a result.
→Paul's talk

Vus using τ decays

Vus can be evaluated by several ways using τ decays.

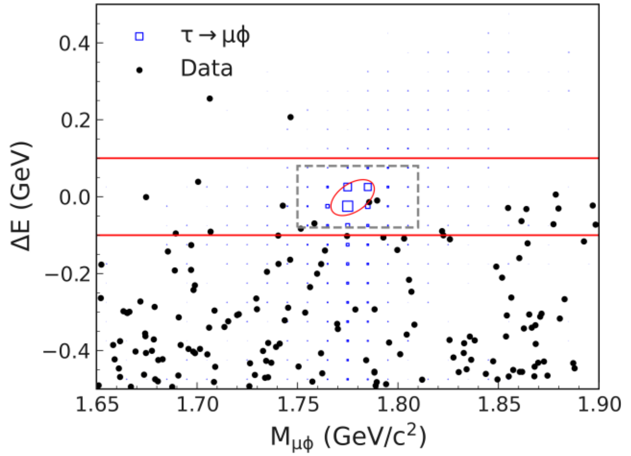


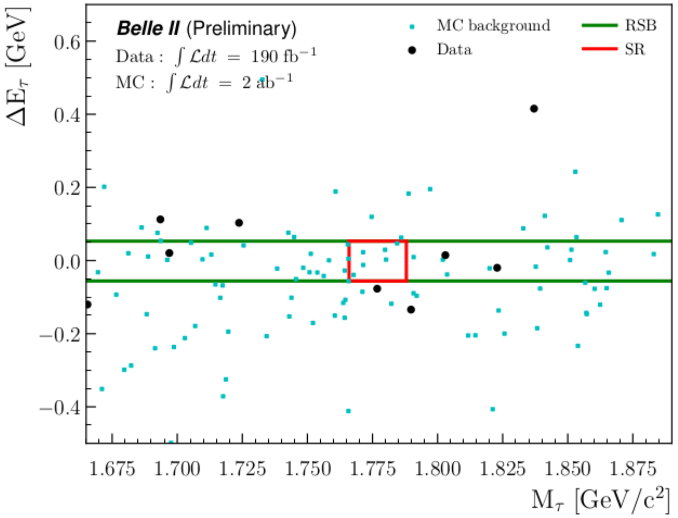
$$\frac{\mathcal{B}(\tau^- \to K^-\nu_\tau)}{\mathcal{B}(\tau^- \to \pi^-\nu_\tau)} = \frac{f_{K\pm}^2 |V_{us}|^2}{f_{\pi\pm}^2 |V_{ud}|^2} \frac{(m_\tau^2 - m_K^2)^2}{(m_\tau^2 - m_\pi^2)^2} (1 + \delta R_{\tau K/\tau\pi})$$

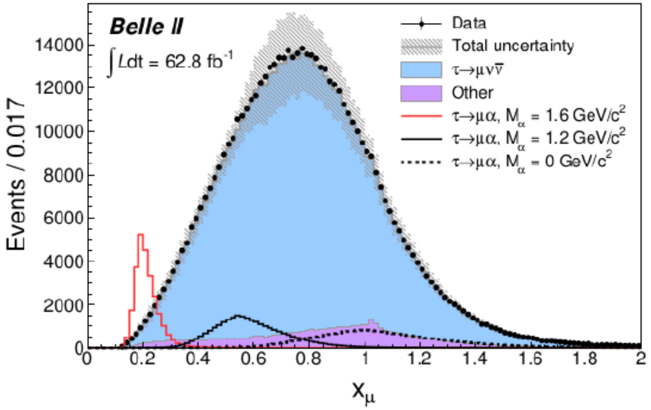
$$\mathcal{B}(\tau^- \to K^-\nu_\tau) = \frac{G_F^2}{16\pi\hbar} f_{K\pm}^2 |V_{us}|^2 \tau_\tau m_\tau^3 \left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{EW}(1 + \delta R_{\tau K})$$

Dividing any partial width Γ_x by the electronic partial width, Γ_e, we obtain partial-width ratios R_x, which satisfy $R_{\text{had}} = R_s + R_{\text{VA}}$. In terms of such ratios, $|V_{us}|$ can be measured as [1651, 1652]

$$|V_{us}|_{\tau s} = \sqrt{R_s \Big/ \left[\frac{R_{\text{VA}}}{|V_{ud}|^2} - \delta R_{\text{theory}}\right]}\,, \qquad (340)$$







Lepton Flavor Violating τ decays

$\tau \to \ell V^0$ searches have been performed with Belle's full data. ($\ell = e, \mu, V^0 = \rho^0, K^*,\ \phi, \omega$)

Machine Learning technique increase the sensitivity more than expected. (JHEP 06 (2023) 118)

At Belle II, $\tau \to \ell\phi$ searches have been performed newly introducing 'no tag' method, which deals with the other τ inclusively. It successfully increase the detection efficiency as well as the sensitivity.(arXiv:2305.04759 [hep-ex])

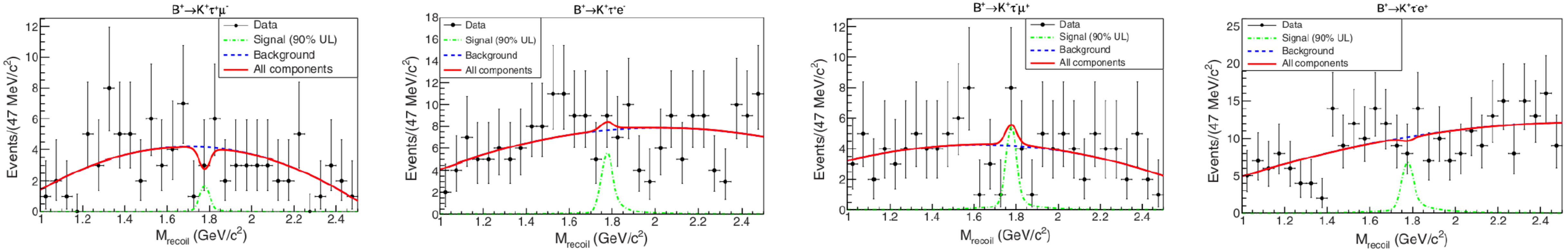
Also, at Belle II, $\tau \to \ell\alpha$ searches have been performed. (α is an undetectable neutral boson, which does not decay within the detector.)(Phys. Rev. Lett. 130, 181803 (2023))

After ARGUS's search, no update have been reported.

→Alberto's talk

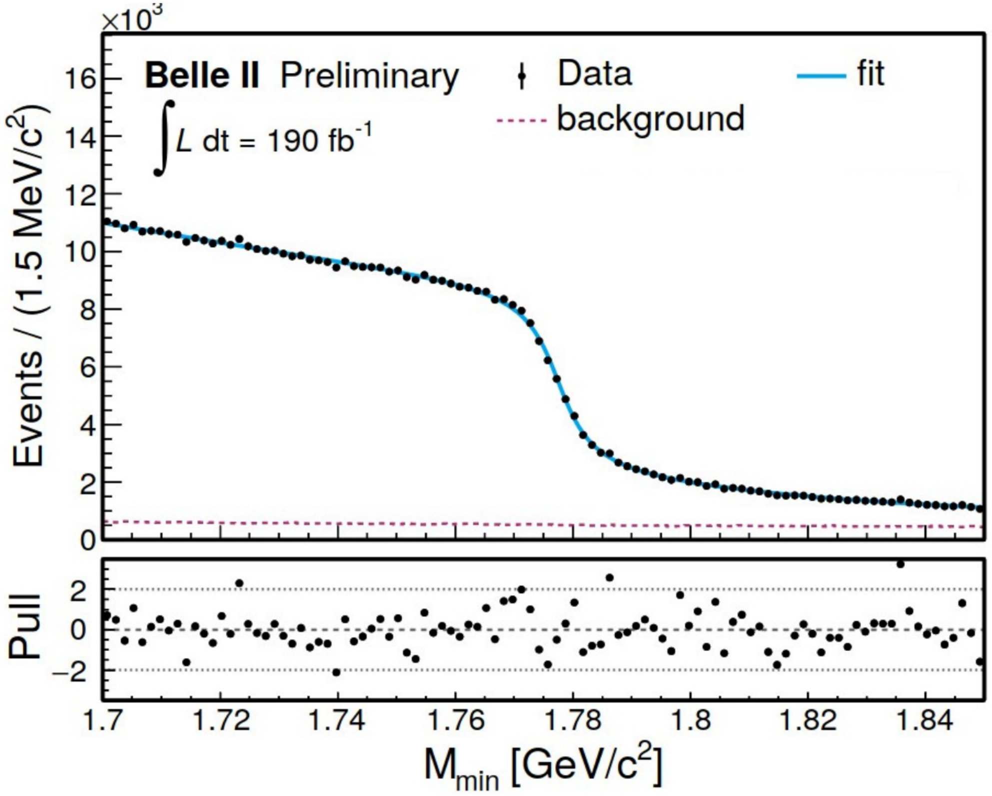
Lepton Flavor Violation including τ

Several searches from B, D, ϒ, J/ψ have been performed by Belle, BaBar, BES III such as ϒ,J/ ψ →τℓ, $B \to K\tau\ell$, D→Xeμ.



Phys, Rev. Lett. 130, 261802 (2023), PRD 86, 012004(2012), Phys. Rev. D 101, 112003, Phys. Rev. Lett. 124, 071802

Tau mass measurement



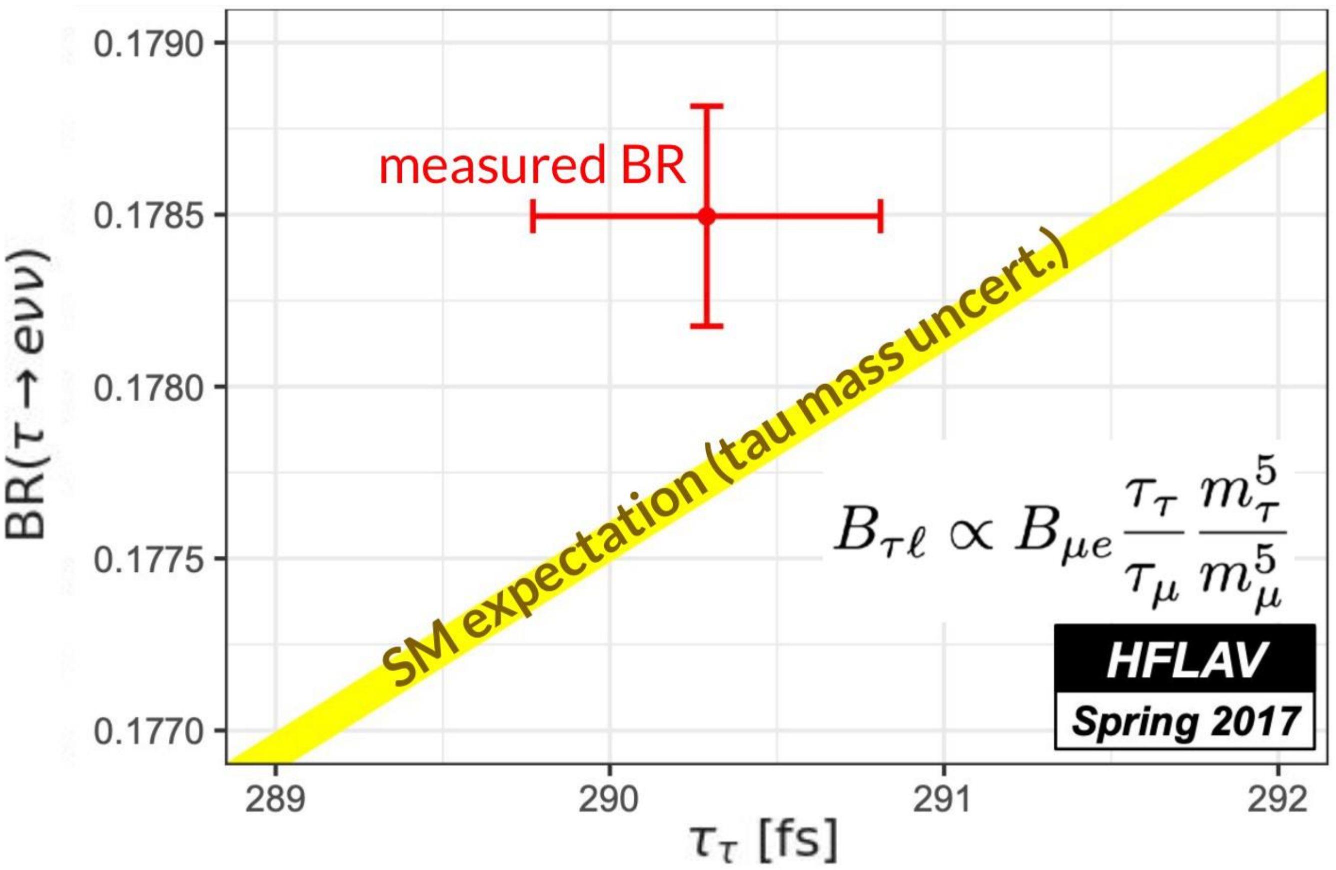
Phys. Rev. D 108, 032006 (2023)

There are 2 ways to measure τ mass:
Threshold method→tau-pair production
Pseudo-mass method→tau decay

$$M_{min} = \sqrt{M_{3\pi}^2 - 2(\frac{\sqrt{s}}{2} - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} < m_\tau$$

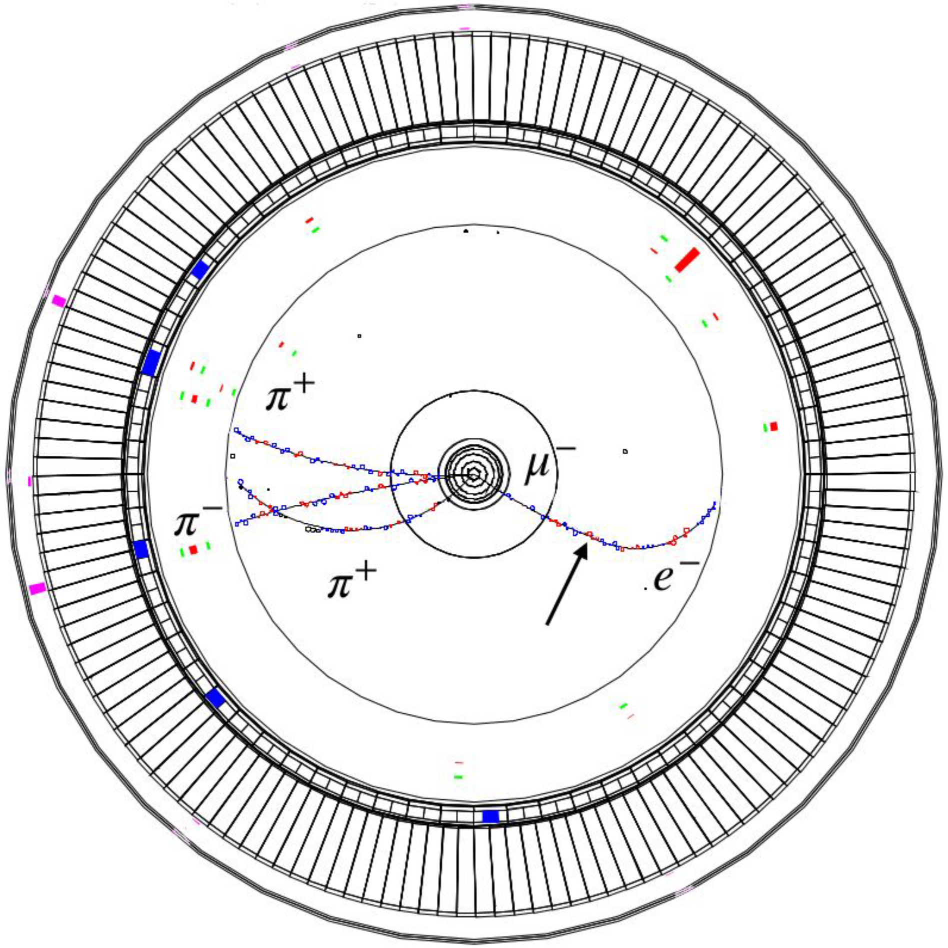
Before Belle II result, BESIII (Threshold) gave the most Precise result.
Thanks to Belle II good momentum resolution and the effort to reduce the systematics, Belle II result get the most precise with less statistics than BaBar’s.
→Radek’s talk

Tau mass, lifetime and Br. of $\tau \to e\nu\nu$



The precise measurement of the basic properties are also important for the new physics search.

Michel Parameter Measurement

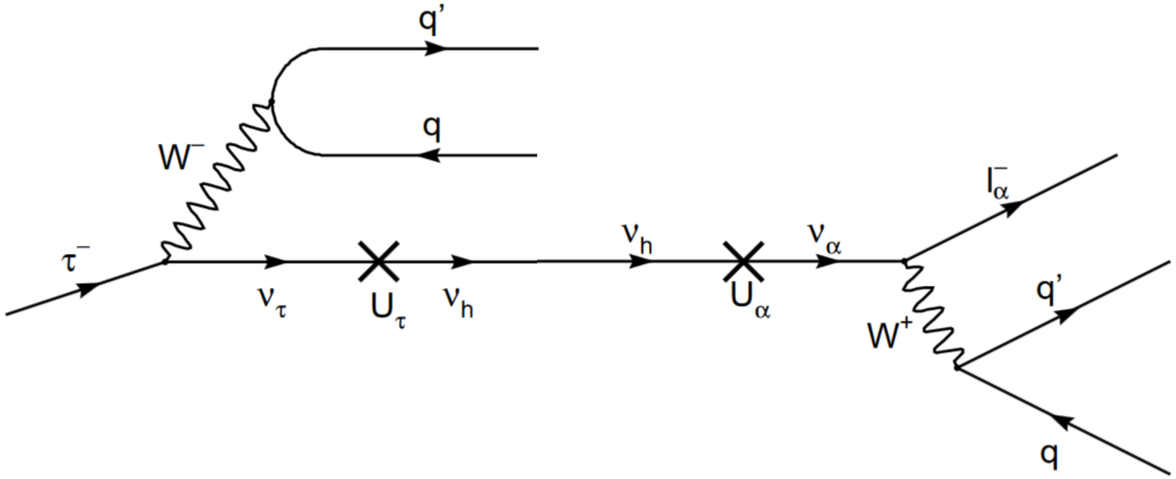


Michel Parameters of τ make us to understand the Lorentz structure of τ decays.
Depending on the used τ decay, different parameter will be evaluated.

At Belle, Michel Parameter ξ' is evaluated using τ→μ(→eνν)νν with 'kink' trajectory.
Very challenging trial but succeeded.

arXiv:2303.10570 [hep-ex]
→Paul's talk

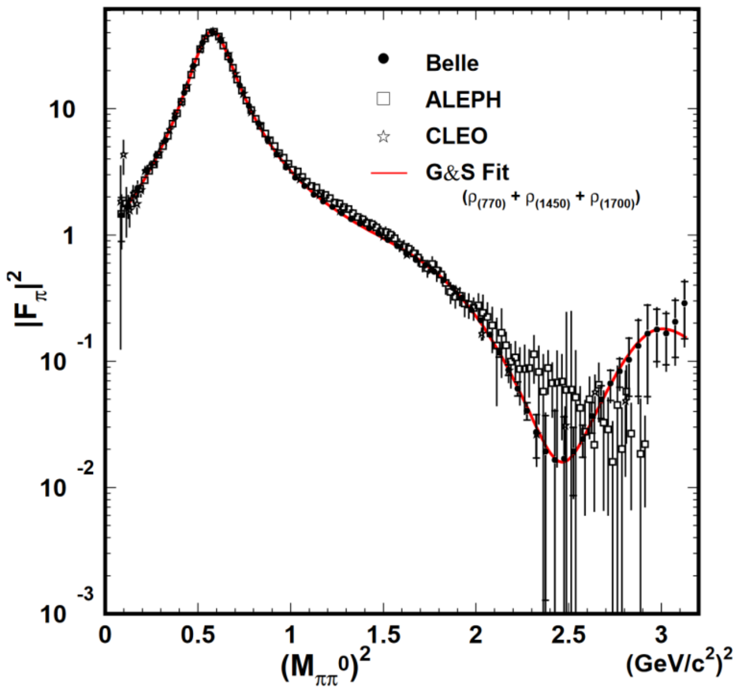
Heavy Neutrino Search in τ decay



Belle recently has searched for heavy neutrino.
In this case, heavy neutrino has long lifetime.
Not at collision point, but within the detector,
the heavy neutrino decays and displaced vertex
would be observed. (arXiv:2212.10095 [hep-ex])
Differently from Belle's assumption, in the BaBar
analysis, the heavy neutrino does not decay in the
detector. The heavy neutrino is produced with the
hadronic system. By evaluating the energy distribution
Heavy neutrino existence is evaluated. →Sophie's talk

Hadronic τ decay

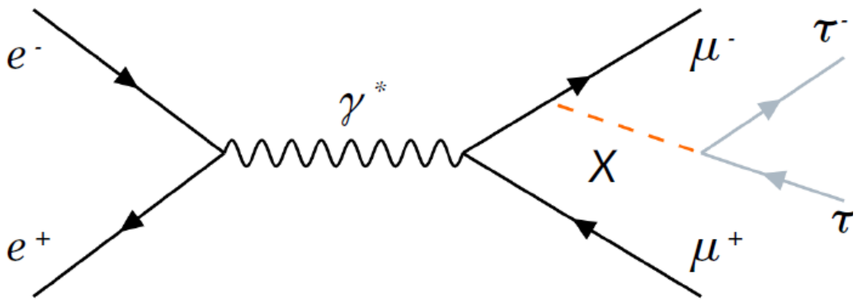
Hadronic τ decay provides a good stage to study low energy (~1GeV) QCD such as resonance structure, CVC and so on. Around 10 years ago, COMPASS has observed a new resonance $a_1(1420)$. Should it be found in $\tau\to3\pi\nu$? In this decay, mainly 3π comes from $a_1(1260)$.→Andrei's talk

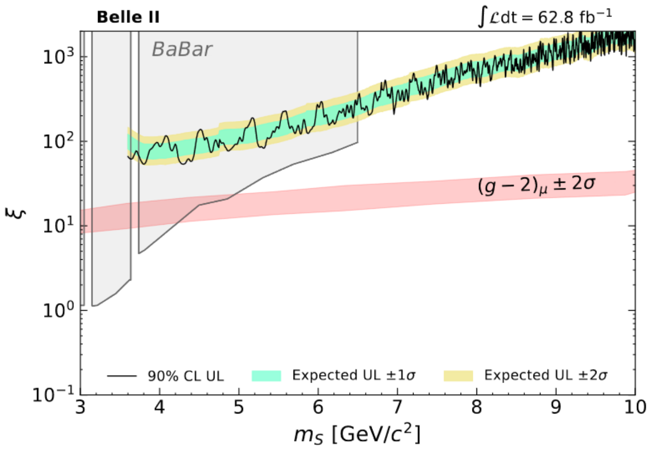


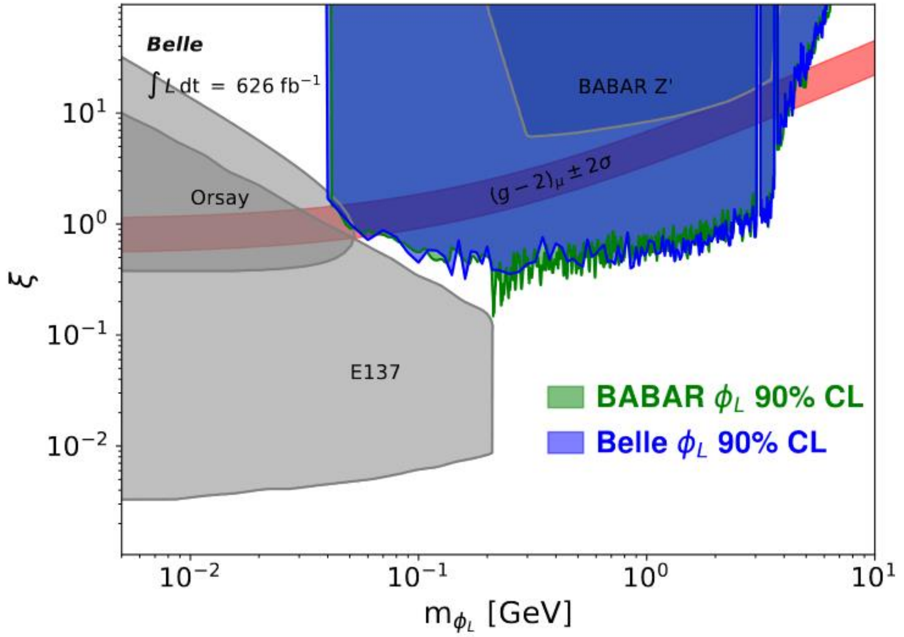
Recently, HVP evaluation using $\tau\to2\pi\nu$ is again focused on. It can be translated via CVC to ee→ππ.

$$\sigma^{I=1}_{e^+e^-\to X^0}(s) = \frac{4\pi\alpha^2}{s} v_{1,X^-}(s)$$

Resonance search using ee→μμττ







Using ττ and μμ, we can search for new resonance producing τ-pair.

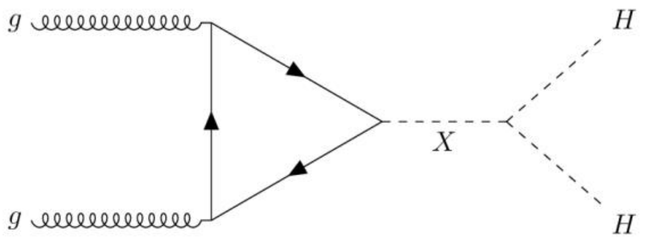
Also, we can interpretate the result for Lμ-Lτ model.

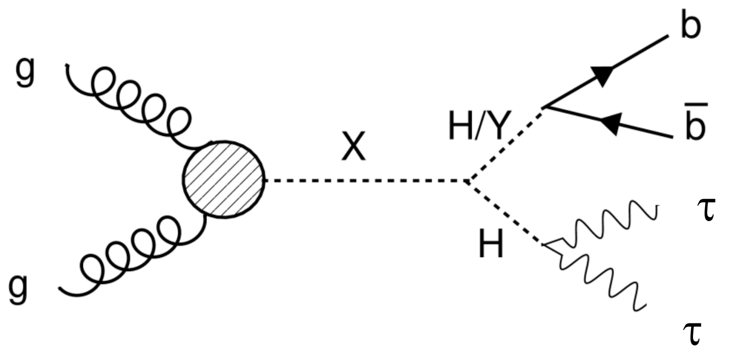
As a similar signature, Belle and BaBar have searched for $e^+e^- \to \tau^+\tau^-\phi_L,\ \phi_L \to \ell^+\ell^-$, ϕ is called leptophilic scalar.

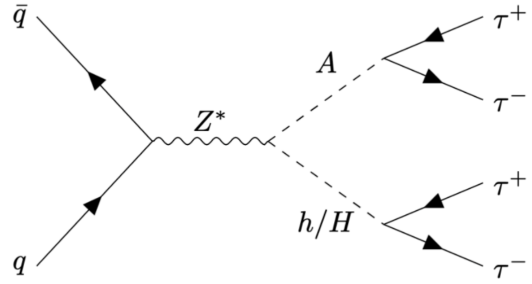
(arXiv:2207.07476v2 [hep-ex] , Phys. Rev. Lett. 125, 181801 (2020))

Higgs study relating τ

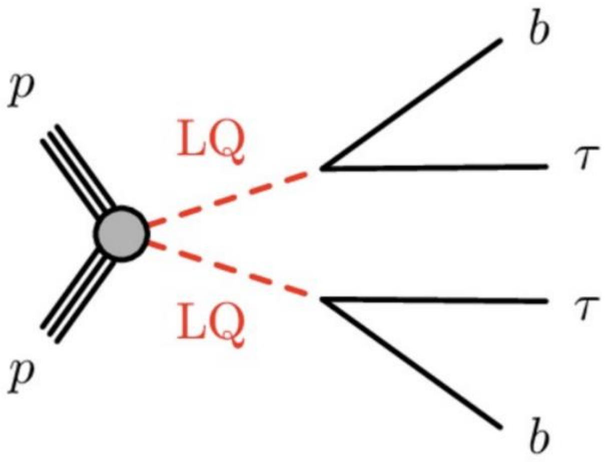
Now, tau is a good probe for Di-higgs search and so on at LHC.

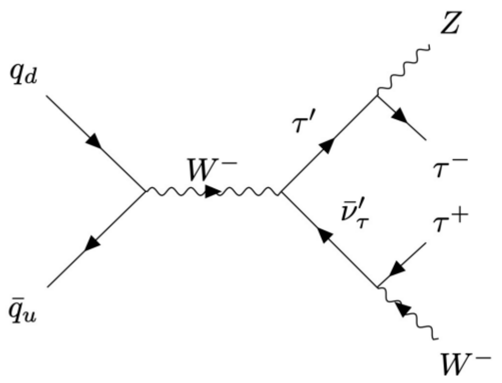


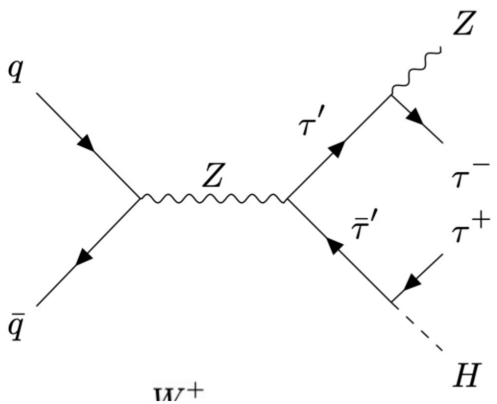


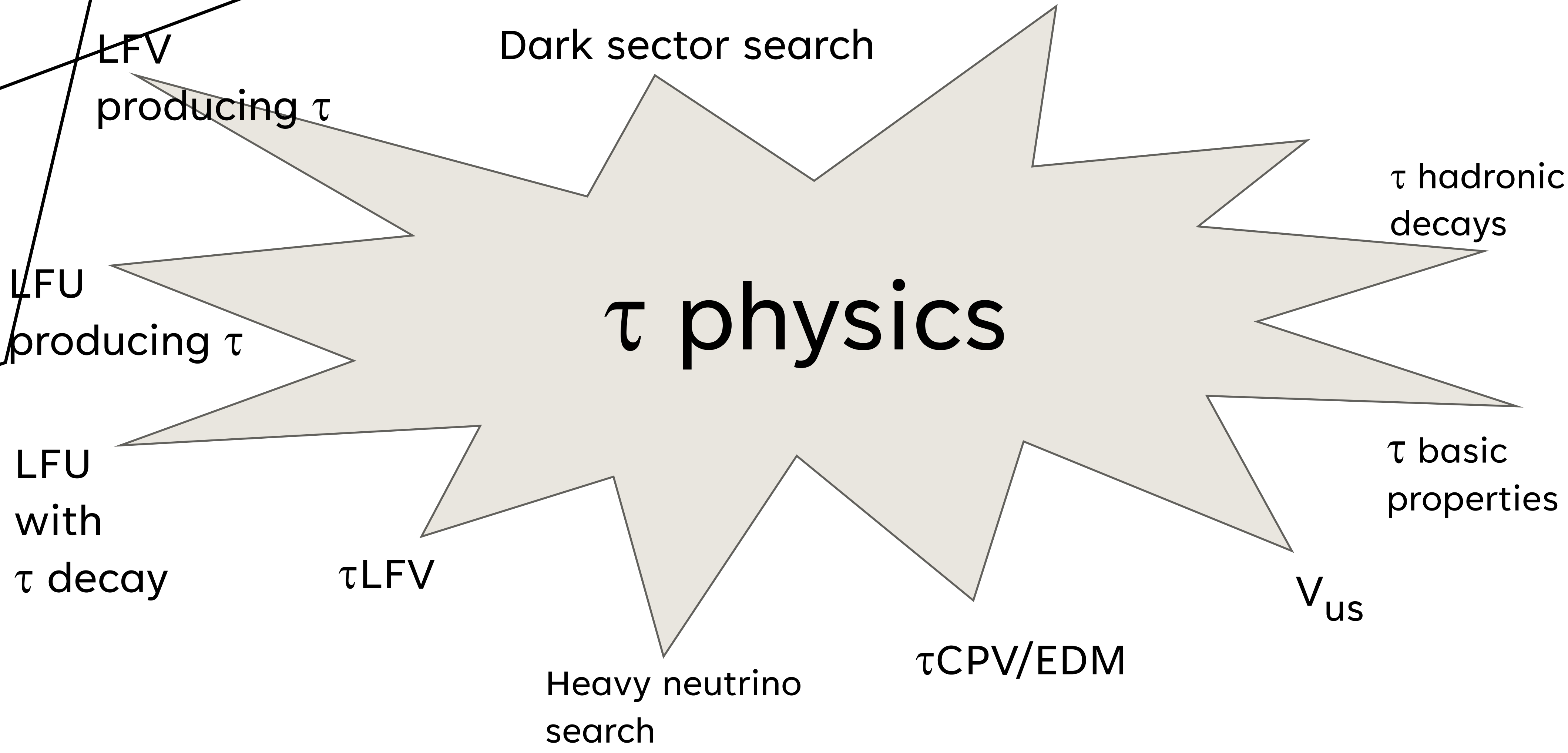


Also, as a decay product, t is used to search for exotic particle such as Lepto-Quark, vector-like fermion and so on at LHC.









τ Physics must be a key to open the window for the New Physics.
Not only the increase of statistics but also new method development enable us to get better results.