New physics searches through τ decays at Belle

Sourav Patra
(Belle Collaboration)
IISER Mohali, India

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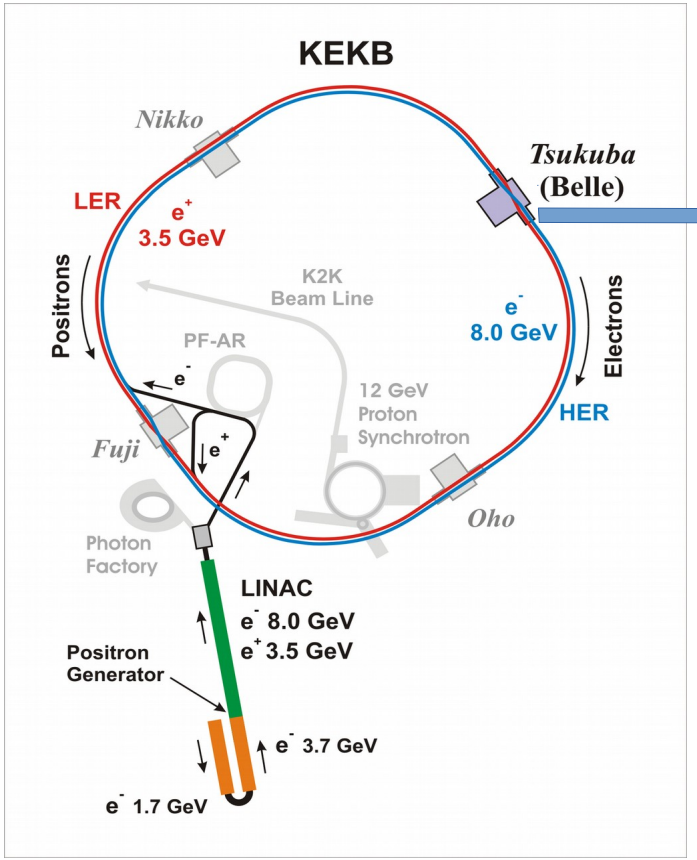
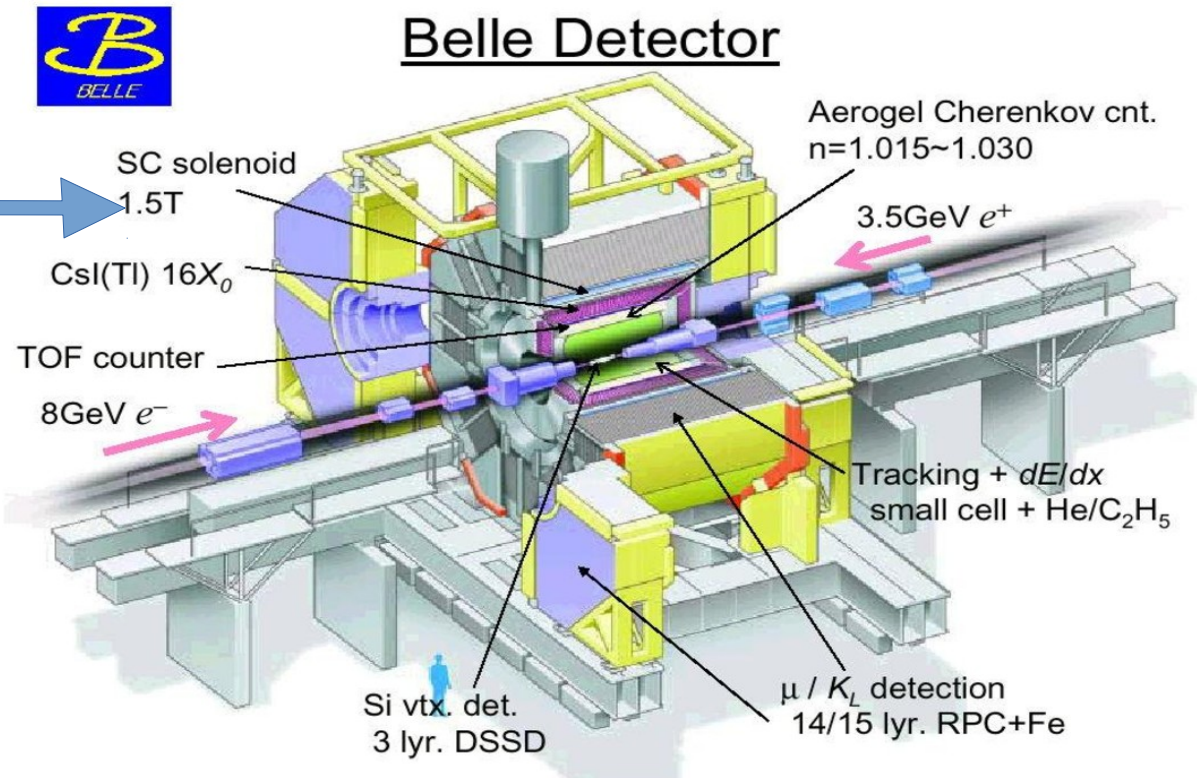
Overview

- Search for lepton-flavor-violating tau lepton decays to $\ell\gamma$ at Belle [*submitted to JHEP*]

- Improved search for the electric diople moment of the tau lepton [*to be submitted to PRD*]

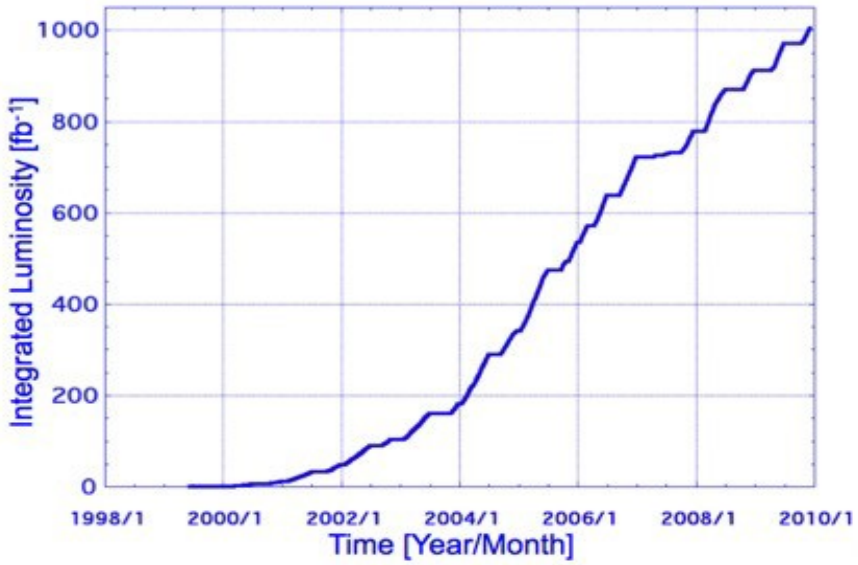
Belle Experiment





NP searches in τ decays at Belle

- Tau is the heaviest known lepton till date and sensitive to NP searches in the lepton decays.
- Belle was NOT only a *B*-factory, but it was also a tau-factory.
- Low background and full event reconstruction make Belle ideal place for tau studies.
- **Efficient NP searches in τ decays :**
  - LFV in $\tau \to \ell\gamma$, $\tau \to 3\ell$ [ℓ=e, μ]
  - Measurement of EDM
  - LNV, BND in $\tau \to p\ell\ell'$ [ℓ,ℓ'=e, μ]
  - CPV in $\tau \to K^0_S \pi \nu$

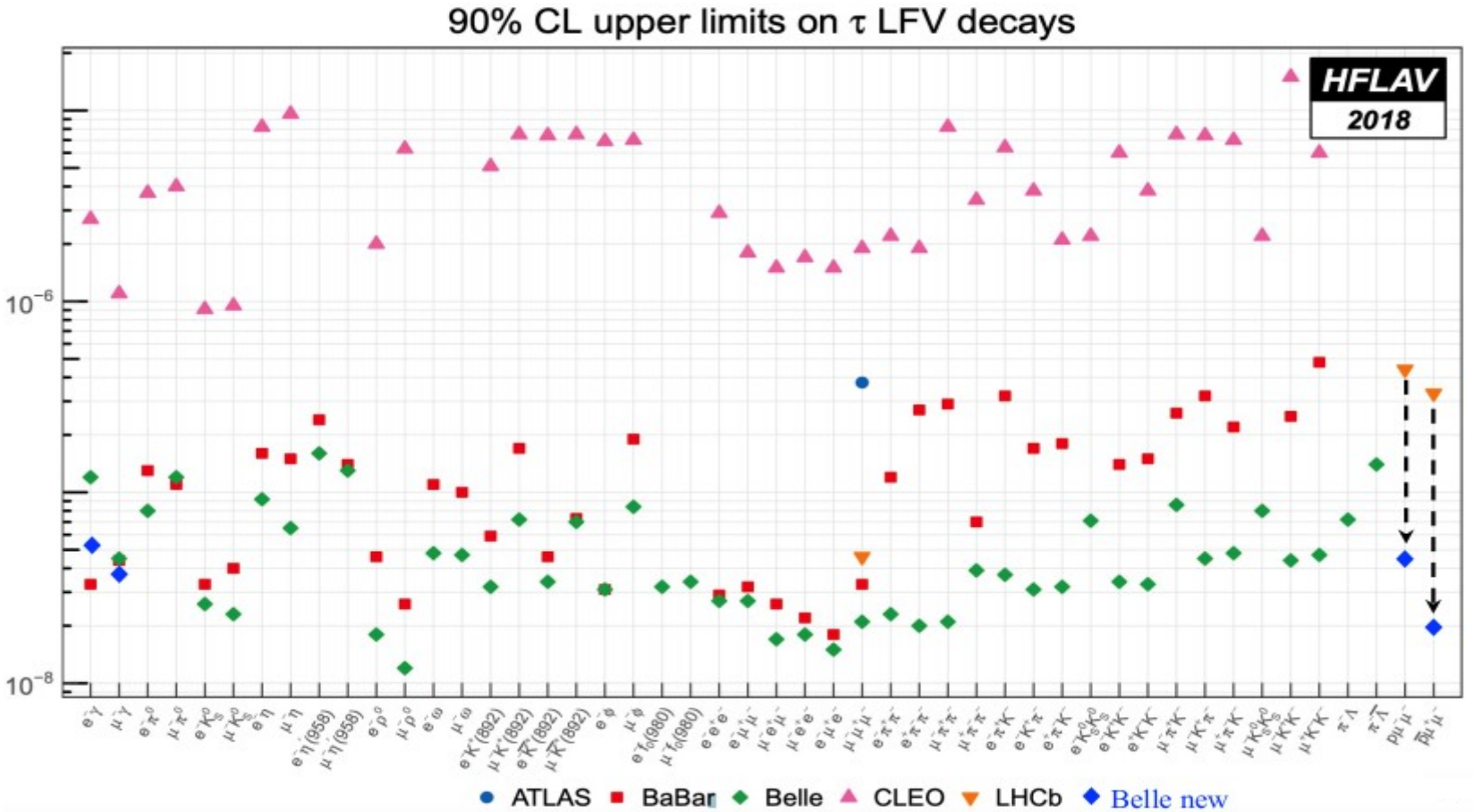


$\sigma(B\bar{B}) = 1.1$ nb $\quad \sigma(\tau\tau) = 0.9$ nb

$N_{B\bar{B}} = 772 \times 10^6 \quad N_{\tau\tau} = 918 \times 10^6$

B-factory ⇒ τ-factory

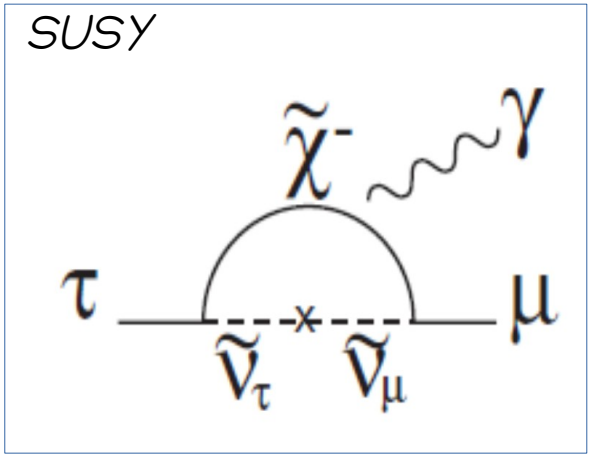
Experimental status on LFV in τ decays



G. Mohanty, PASCOS 2021

LFV : Overview of $\tau \to \ell\gamma$

- Neutrino oscillation suggests that the LFV may already present.
- LFV decays are deeply suppressed in the SM.
- Couple of NP models inspired by GUT predict the higher decay rates for the LFV transitions up to the sensitivity of the present accelerators.
- $\tau \to \mu\gamma$ mode is the one of the highly sensitive modes to search for LFV transition.



- Previous measurements :

Belle
$\mathcal{B}(\tau^\pm \to \mu^\pm\gamma) < 4.5 \times 10^{-8}$
$\mathcal{B}(\tau^\pm \to e^\pm\gamma) < 1.2 \times 10^{-7}$
PLB 666, 16 (2008)

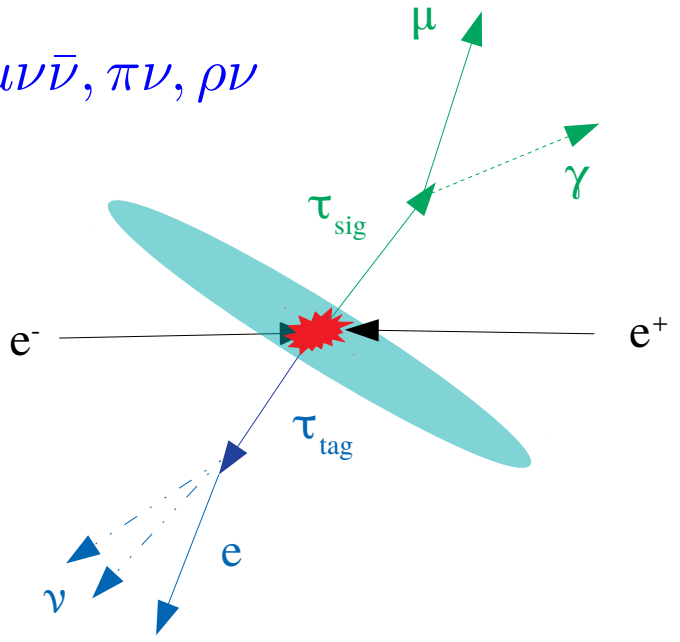
BaBar
$\mathcal{B}(\tau^\pm \to \mu^\pm\gamma) < 4.4 \times 10^{-8}$
$\mathcal{B}(\tau^\pm \to e^\pm\gamma) < 3.3 \times 10^{-8}$
PRL 104, 021802 (2010)

Model	$\tau \to \mu\gamma$	Reference
SM + ν oscillation	10^{-40}	EPJ C8(1999) 513
SUSY Higgs	10^{-10}	PLB 566 (2003) 217
SM + heavy Maj ν	10^{-9}	PRD 66 (2002) 034008
Non-universal Z'	10^{-9}	PLB 547 (2002) 252
SUSY SO(10)	10^{-8}	RPD 68 (2003) 033012
MSUGRA + seesaw	10^{-7}	PRD 66 (2002) 115013

LFV : Event selection

- **Decay channel :**

$$e^+e^- \to \tau_{\rm sig}\tau_{\rm tag} \qquad \tau_{\rm sig} \to \ell\gamma \qquad \tau_{\rm tag} \to e\nu\bar{\nu}, \mu\nu\bar{\nu}, \pi\nu, \rho\nu$$



- **Selections criteria:**
  - Net charge of an event ⇒ 0 with $p^T > 0.1$ GeV/c for each of the track.
  - Only one photon in signal side identified in the ECL barrel with $E_\gamma > 0.5$ GeV.
  - Fraction of visible energy < 0.93(e,μ), < 0.86(π) and < 0.94(ρ).
  - $|\vec{p}_{\rm miss}| > 0.4$ GeV/c

LFV : Background suppression

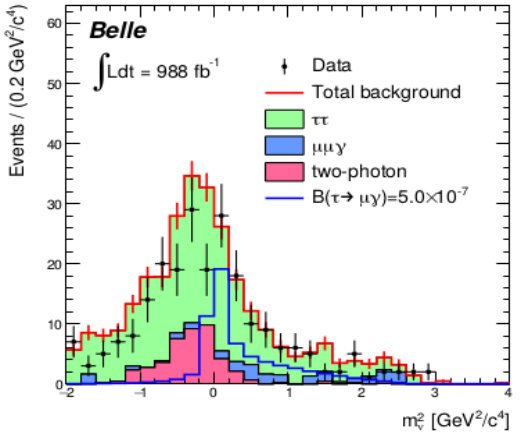
$$m_\nu^2 = (E_{\ell\gamma}^{\rm CM} - E_{\rm tag}^{\rm CM})^2 - |\vec{p}_{\rm miss}^{\,\rm CM}|^2$$

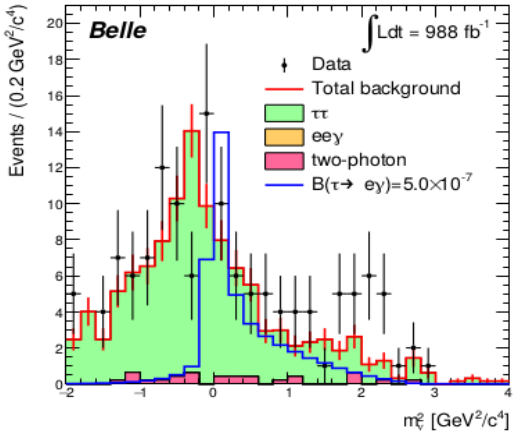
- **Potential backgrounds:**
  - Leptonic decays of τ ($\tau \to \ell\nu\nu$).
  - Bhabha and di-muon sample.
  - ISR or beam backgrounds have been misidentified as signal photon.

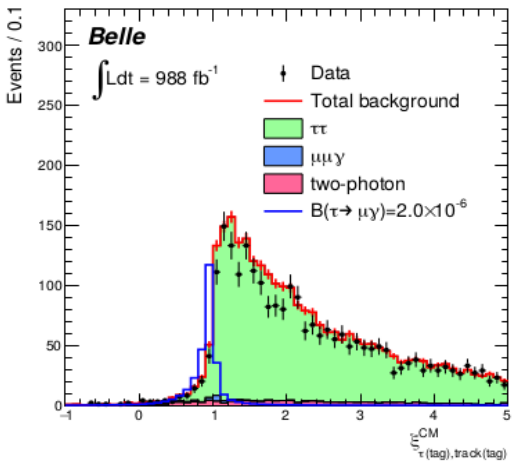
- **New Variable :**

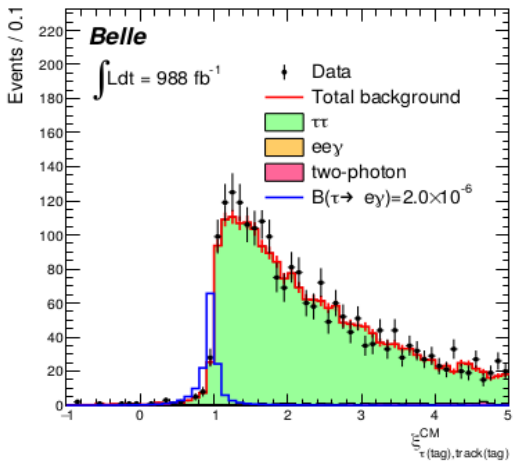
$$\xi_{\tau({\rm tag}).{\rm track(tag)}}^{\rm CM} = \frac{\vec{p}_{\tau({\rm tag})}^{\,\rm CM} \cdot \vec{p}_{\rm track(tag)}^{\,\rm CM}}{|\vec{p}_{\tau({\rm tag})}^{\,\rm CM}||\vec{p}_{\rm track(tag)}^{\,\rm CM}|}$$

$$0 < \xi_{\tau({\rm tag}).{\rm track(tag)}}^{\rm CM} < 1$$









LFV : Result

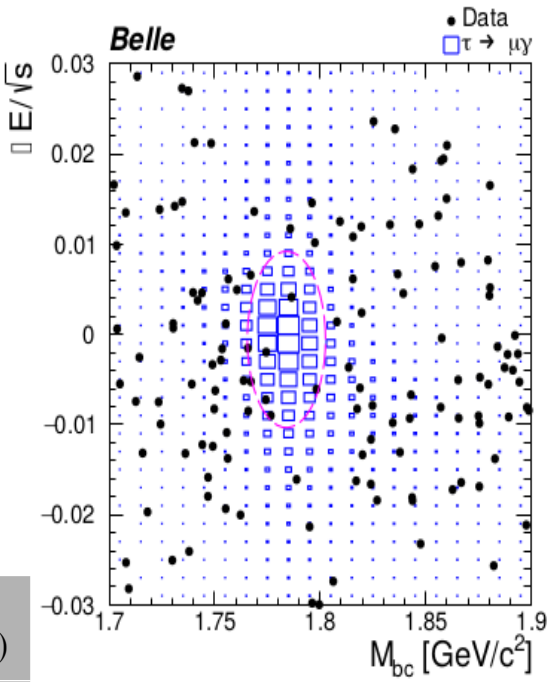
$$M_{\rm bc} = \sqrt{E_{\rm beam}^{\rm CM} - |\vec{p}_{\ell\gamma}^{\,\rm CM}|}$$

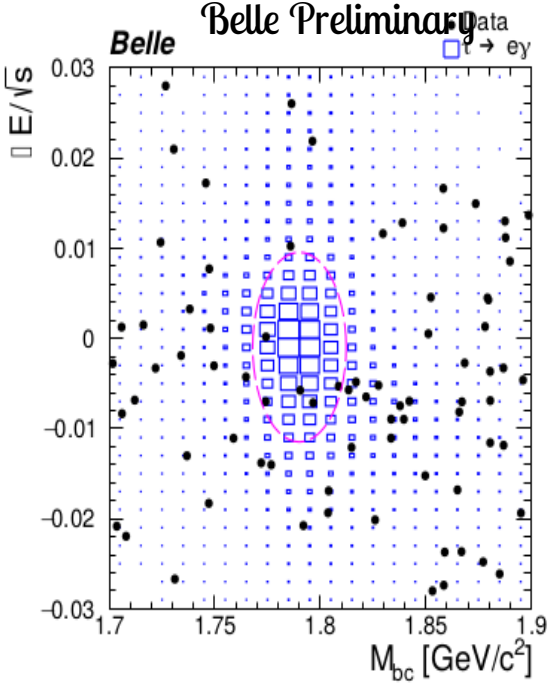
$$\Delta E/\sqrt{s} = (E_{\ell\gamma}^{\rm CM} - \sqrt{s}/2)/\sqrt{s}$$

- ULs are estimated with an ensemble of pseudo experiments.

$$\mathcal{B}(\tau^{\pm} \to \ell^{\pm}\gamma) < \frac{N_{\rm sig}^{\rm UL}}{2N_{\tau\bar{\tau}}\epsilon}$$

Decay	ϵ (%)	N_{bkg}	N_{obs}	N_{sig}^{UL}	UL (90% CL)
$\tau\to\mu\gamma$	3.7	5.8 $\pm$0.4	5.0	2.8	4.2 x10^{-8}
$\tau\to e\gamma$	2.8	5.1 $\pm$0.4	5.0	3.0	5.6 x10^{-8}





$$\left(\frac{M_{\rm bc} - \mu_{M_{\rm bc}}}{2\sigma_{M_{\rm bc}}}\right)^2 + \left(\frac{\Delta E/\sqrt{s} - \mu_{\Delta E/\sqrt{s}}}{2\sigma_{\Delta E/\sqrt{s}}}\right)^2 < 1.0$$

Our result for $\tau\to\mu\gamma$ is the most stringent to date.

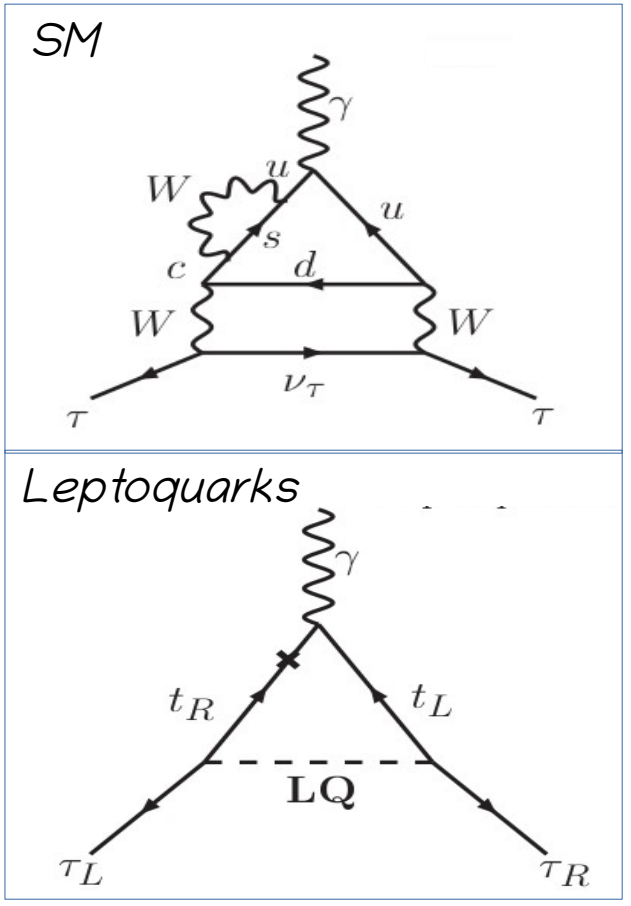
EDM : Theoretical predictions

- CP violation arises from the single irreducible phase of CKM matrix.
- Electric dipole moment of τ parameterizes T/CP violation.
- Non vanishing EDM of $\tau \Rightarrow$ Sign of NP.
- Theoretical Predictions :
  - Standard Model $\Rightarrow \sim 10^{-34}$ ecm.
  - Scalar Leptoquarks $\Rightarrow \sim 10^{-19}$ ecm.

PRD54, 3377 (1996), Phys

- Previous Belle measurement :
  - $\mathrm{Re}(d_\tau) = (1.15 \pm 1.70) \times 10^{-17}$ ecm.
  - $\mathrm{Im}(d_\tau) = (-0.83 \pm 0.86) \times 10^{-17}$ ecm.

PLB391 413 (1997)



EDM : Measurement technique

- **Effective Lagrangian :**

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{EDM}}; \quad \mathcal{L}_{\text{EDM}} = -id_\tau \bar{\tau}\sigma^{\mu\nu}\gamma_5 \partial_\mu A_\nu \tau$$

- **Squared spin density matrix :**

$$\mathcal{M}^2_{e^+e^-\to\tau^+\tau^-} = \mathcal{M}^2_{\text{SM}} + \text{Re}(d_\tau)\mathcal{M}^2_{\text{Re}} + \text{Im}(d_\tau)\mathcal{M}^2_{\text{Im}} + O(d_\tau^2)$$

- **Using optimal observable :**

$$\mathcal{O}_{\text{Re}} = \frac{\mathcal{M}^2_{\text{Re}}}{\mathcal{M}^2_{\text{SM}}} \qquad \mathcal{O}_{\text{Im}} = \frac{\mathcal{M}^2_{\text{Im}}}{\mathcal{M}^2_{\text{SM}}}$$

- **Effective EDM can be extracted by averaging the observable :**

$$\langle \mathcal{O}_{\text{Re}} \rangle = a_{\text{Re}}\text{Re}(d_\tau) + b_{\text{Re}} \qquad \langle \mathcal{O}_{\text{Im}} \rangle = a_{\text{Im}}\text{Im}(d_\tau) + b_{\text{Im}}$$

Phys. Lett. B551, 16 (2003)

EDM : Analysis strategy

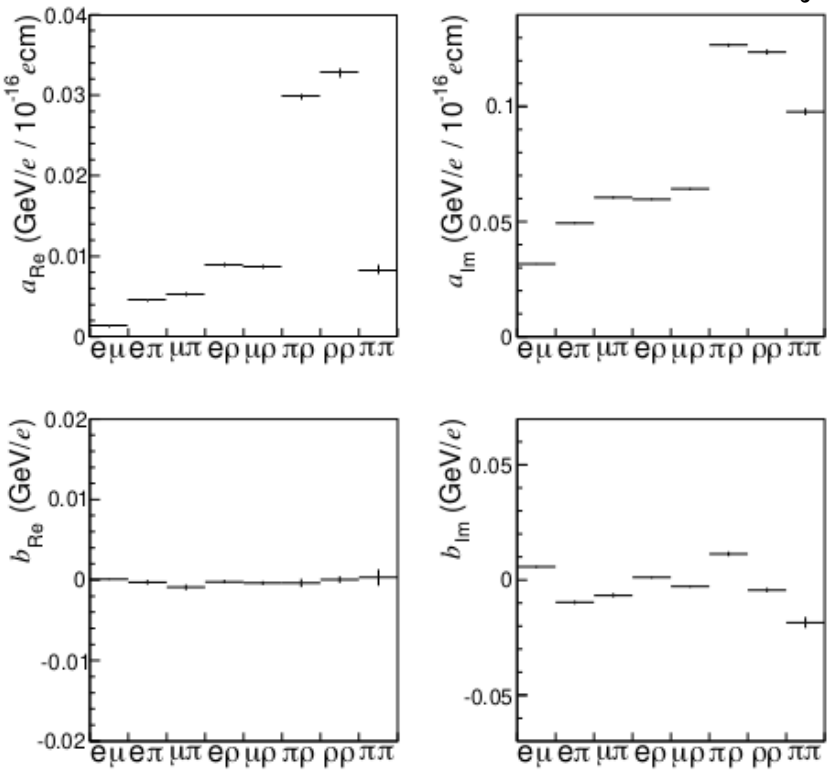
- **Decay channels :**

$$e^+e^- \to \tau^+\tau^-(\to e\mu, e\pi, e\rho, \mu\pi, \mu\rho, \pi\rho, \pi\pi, \rho\rho)$$

- **Selection criteria :**
  - Net charge $\Rightarrow 0$
  - Leptons are identified in the barrel region.
  - Sum of charged tracks momentum < 9 GeV/c.
  - $p_e > 0.5$ GeV/c, $p_{\mu/\pi} > 1.2$ GeV/c, $p_\rho > 1.0$ GeV/c.
  - Missing momentum not directed along the beam pipe.

- Values of $a_{\mathrm{Re/Im}}$ and $b_{\mathrm{Re/Im}}$ have been estimated from the Monte-Carlo simulation.

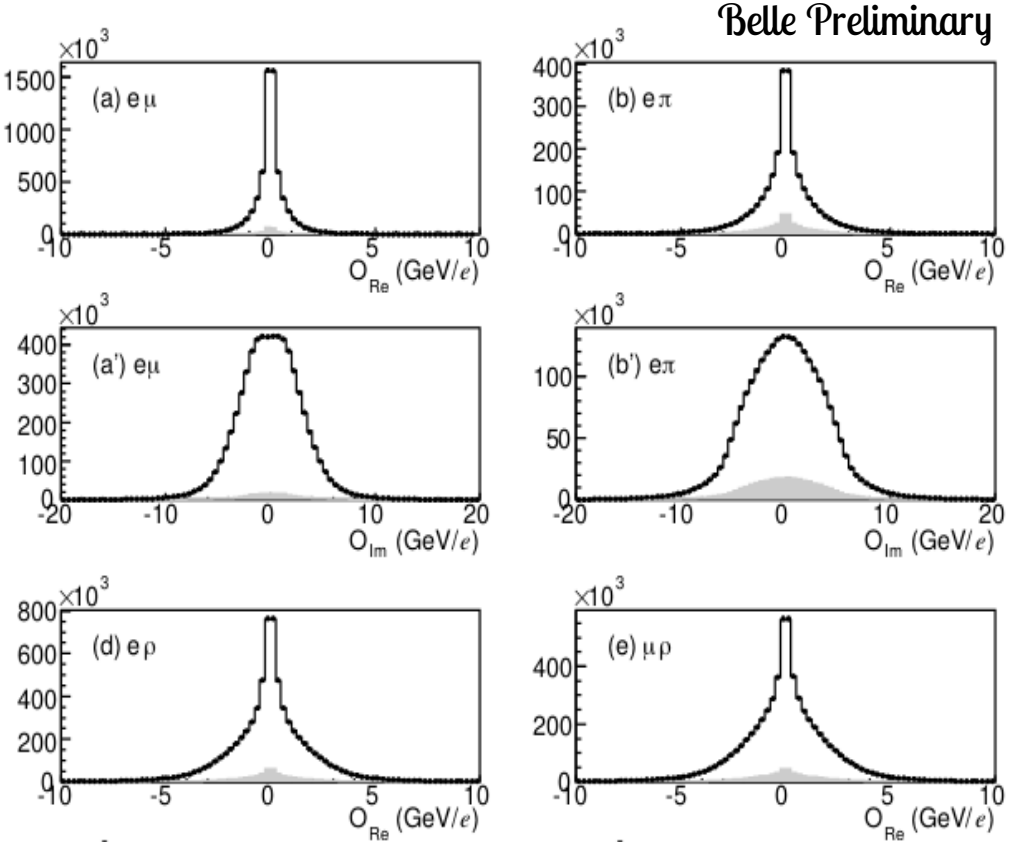
Belle Preliminary



Obtained values of $a_{\mathrm{Re/Im}}$ and $b_{\mathrm{Re/Im}}$ (MC)

EDM : Result

- Obtained results :
  - Re(d_τ) = (-6.2 ±6.3) x10^{-18} ecm.
  - Im(d_τ) = (-4.0 ±3.2) x10^{-18} ecm.
- New results are one magnitude order more stringent than the previous results.



Distribution $\mathcal{O}_{Re}$ and $\mathcal{O}_{Im}$

Summary

- In absence of any signal for LFV decays, we set the ULs of branching fractions at 90% CL ($\tau^{\pm}\to\mu^{\pm}\gamma$ <4.2x10^{-8} and $\tau^{\pm}\to e^{\pm}\gamma$< 5.6x$10^{-8}$). Our limit for $\mu\gamma$ mode is most stringent to date.
- Also, the measured values of CP odd (Re(d_τ) = (-6.2$\pm$6.3) x10^{-18} ecm) and CP even (Im(d_τ) = (-4.0$\pm$3.2) x10^{-18} ecm) parameters of the EDM are more one magnitude order more strict than the previous measurement by the Belle.

Thanks for your attention