Tau physics at super cτ factories (SCTF/STCF): Standard Model & New Physics searches

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The overall framework for τ phenomenology

- Standard Model provides unprecedented description of nature, including tau physics
- Quantum Field Theory with few ingredients
  - Local Symmetry: $\underbrace{SU(3)_C}_{\text{Gluons}} \times \underbrace{SU(2)_L \times U(1)_Y}_{\gamma, Z, W}$

$$l_N = \begin{pmatrix} \nu_L \\ l_L \end{pmatrix}_N , \quad e_N = l_{R,\,N} , \quad \varphi = \begin{pmatrix} \phi^{(+)} \\ \phi^{(0)} \end{pmatrix} , \qquad \text{N=1,2,3; Family}$$

$$q_{\alpha N} = \begin{pmatrix} u_L \\ d_L \end{pmatrix}_{\alpha N} , d_{\alpha N} = d_{R,\,\alpha N} , \quad u_{\alpha N} = u_{R,\,\alpha N} . \qquad \alpha = 1, 2, 3; \text{ Color}$$

  - Symmetry Breaking through vev of φ: $SU(2)_L \times U(1)_Y \to U(1)_{\rm em}$

The τ in the Standard Model

- In a sense, τ in the SM is practically identical to e or μ
- All gauge interactions (Z, W, γ, G) of τ are exactly the same (Lepton Flavor Universality)
- Interaction with the Higgs has the same functional form. Yukawa eigenvalues (and then masses) can and happen to be different

$$Y_\tau \sim 3500\, Y_e \to m_\tau \approx 1.777\,\mathrm{GeV}$$

- Rich phenomenology emerging from this single numerical difference

τ production at super cτ factory

- Number of $\tau^+\tau^-$ events comparable to huge Belle II statistics ($> 10^{10}$ at STCF)
- Different energy region, different potential. Eg see talk by Sun
- Runs near the $\tau^+\tau^-$ threshold: better controlled background can beat better luminosity. Examples
  - Mass measurement
  - Two-body decays
  - True tauonium
- Polarized tau observables at SCTF can open an extra window to fundamental physics

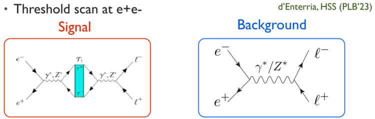
Fundamental properties: the τ mass and the tauonium

m_τ

- Until last year $m_\tau = (1776.86 \pm 0.12)\,\mathrm{MeV}$ PDG
- New measurements from KEDR and Belle-II: $m_\tau = (1776.93 \pm 0.09)\,\mathrm{MeV}$
- Super $c\tau$ factory can reduce uncertainty (by a factor of 100!? Jing-Hang Fu et al.)
- One of the few fundamental SM parameters (interesting per se), complementarity with next generation (FCC/CEPC) lifetime measurement

Tauonium

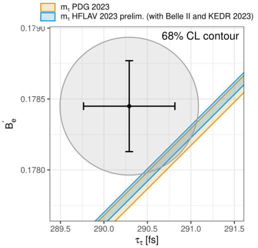
- QED confinement: two leptons can bind together to form bound states

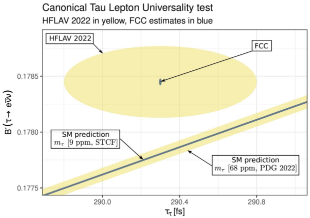


- Ortho-ditauonium can be discovered at STCF/SCTF! d'Enterria, Shao, Jing-Hang Fu et al.
- Important interplay with mass measurement

Fundamental properties: the lifetime

- Tau has a (relatively...) long lifetime: $\tau_\tau = (290.29 \pm 0.53) \cdot 10^{-15}\,\mathrm{s}$ HFLAV
- Input for canonical universality test Lusiani ICHEP 2024





- Perhaps SCTF/STCF can improve/complement current measurement
- τ mass improvement will become more relevant looking further ahead

Fundamental properties: Lepton Flavor Universality (LFU)

- SM calculation gives us $\Gamma_{\ell\to\ell'\nu_\ell\bar{\nu}'_\ell} \propto g_\ell g_{\ell'} G_F^2\, m_\ell^5 f(\frac{m_\ell}{m'_\ell})$ with $g_\ell = g_{\ell'} = 1$
- Within the SM, ratios between the following quantities can be predicted

1. $\Gamma(\tau \to e) = \mathcal{B}(\tau \to e)/\tau_\tau$
2. $\Gamma(\tau \to \mu) = \mathcal{B}(\tau \to \mu)/\tau_\tau$
3. $\Gamma(\mu \to e) = \mathcal{B}(\mu \to e)/\tau_\mu$

Lepton Flavour Universality: coupling ratios

$$\left(\frac{g_\tau}{g_\mu}\right) = \sqrt{\frac{\mathcal{B}_{\tau e}\tau_\mu m_\mu^5 f_{\mu e} R_\gamma^\mu R_W^{\mu e}}{\mathcal{B}_{\mu e}\tau_\tau m_\tau^5 f_{\tau e} R_\gamma^\tau R_W^{\tau e}}} = 1.0016 \pm 0.0014 \qquad \left(\frac{g_\tau}{g_e}\right) = \sqrt{\frac{\mathcal{B}_{\tau\mu}\tau_\mu m_\mu^5 f_{\mu e} R_\gamma^\mu R_W^{\mu e}}{\mathcal{B}_{\mu e}\tau_\tau m_\tau^5 f_{\tau\mu} R_\gamma^\tau R_W^{\tau\mu}}} = 1.0018 \pm 0.0014$$

$$\left(\frac{g_\mu}{g_e}\right) = \sqrt{\frac{\mathcal{B}_{\tau\mu} f_{\tau e} R^{\tau e}}{\mathcal{B}_{\tau e} f_{\tau\mu} R^{\tau\mu}}} = 1.0002 \pm 0.0011$$

improved by Belle II recent prelim. measurement of $\mathcal{B}_{\tau\mu}/\mathcal{B}_{\tau e}$ [Adachi et al., 2024], was 1.0019 ± 0.0014

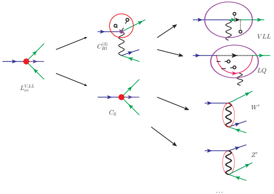
$$\left(\frac{m_\rho^2}{m_\lambda^2}\right) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x \quad \text{with} \quad x = \frac{m_\rho^2}{m_\lambda^2}, \quad \lambda, \rho = \text{lepton flavours}$$

R_γ^λ, $R_W^{\lambda\rho}$ radiative corrections [Pich, 2014]

- Canonical test: $B'_e \equiv \left\{\mathcal{B}(\tau \to e), \frac{\Gamma(\tau\to e)}{\Gamma(\tau\to\mu)}\mathcal{B}(\tau \to \mu)\right\} = \left(\left[\frac{\Gamma(\tau\to e)}{\Gamma(\mu\to e)}\right] \frac{\mathcal{B}(\mu\to e)}{\tau_\mu}\right)\tau_\tau$

Lusiani ICHEP 24

- BSM: from EFTs to UV $\mathcal{O}(10\,\mathrm{TeV})$ models. SCTF/STCF may provide a valuable input



Fundamental Properties: Magnetic moment and EDM

Anomalous magnetic moment

- Tau response to weak magnetic field?
- Linear term in (soft) photon momentum of $\langle \tau^-_{p',\sigma'} | J^\mu_{\rm EM} e^{iS_{\rm int}} | \tau^-_{p,\sigma} \rangle$
- $S_{\rm int} \approx 0 \to g_\tau \approx 2, \quad a_\tau^{\rm SM} \equiv \frac{g_\tau^{\rm SM} - 2}{2} = 0.00117721(5)$ Eidelman, Passera
- STCF, together with Belle-II, with a potential precision of $\Delta a_\tau \sim 10^{-5}$, could discover and precisely measure the anomalous magnetic moment of the heaviest lepton Tchen, Wu

Electric dipole moment

- Bounds can be improved up to $d_\tau^\gamma \sim 10^{-18}\,\rm e\ cm$ at STCF Xulei, Sun, Zhou
- Polarized electron beam at SCTF suitable to test ${\rm Re}\, d_\tau$ Obraztsov, Milstein
- It can probe some BSM scenarios Tchen, Wu

Lorentz structure in Leptonic τ decays

- Generalized lagrangian

$$\mathcal{H} = 4\frac{G_{\ell'\ell}}{\sqrt{2}} \sum_{n,\epsilon,\omega} g^n_{\epsilon\omega} \left[\overline{\ell'_\epsilon}\Gamma^n(\nu_{\ell'})_\sigma\right] \left[\overline{(\nu_\ell)_\lambda}\Gamma_n \ell_\omega\right]$$

$n = S, V, T$. Is it really $V - A$?

- Disentangle them using distributions with polarized leptons Pich 2013
- Traditional Michel parameters can be re-expressed in term of these couplings.
- STCF and SCTF (polarized τ!) can perform quite well and complement Belle-II

Parameter	SM value	$\mu^- \to e^-\bar{\nu}_e\nu_\mu$	$\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$
ξ'	1	1.00 ± 0.04	$? \pm 0.006$
ξ''	1	0.98 ± 0.04	$? \pm 0.03$
α'/A	0	-0.010 ± 0.020	$? \pm 0.014$
β'/A	0	0.002 ± 0.007	$? \pm 0.007$

Bodrov, Pakhlov

- Extra valuable information from extra photon and multi-lepton decays (no strong interactions)

CPV in tau decays

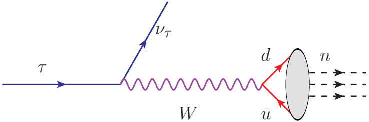
- CP violation never observed in lepton decays
- CPV asymmetry $A_\tau(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau)$ in the SM: same flavor amplitudes, but kaon mixing $|\langle K_0|K_S\rangle| \neq \langle|\bar{K}_0|K_S\rangle|$

$$A_\tau^{\rm SM}(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) \approx (3.6 \pm 0.1) \cdot 10^{-3}$$

Bigi-Sanchda, Grossman-Nir, Pich

- SCTF/STCF, together with Belle-II, can discover CP violation in lepton decays and probe it with the SM accuracy. Complex measurement. Different set-ups, backgrounds, not redundant
- $A_\tau^{\rm BaBar}$ tension $\to$ $\rm BSM$ heavy? Cirigliano et al, Rendon et al
  - Given other sectors, it should be direct CP. A_τ requires strong phase-shift
  - But BSM EFT study shows that the only one, $\delta_T - \delta_V$, happens to be too small
- Alternative proposal by SCTF: use polarized τ to define CP asymmetries not requiring $\Delta\delta$. It motivates quantitative phenomenological analysis
- More generally, using polarized taus SCTF (or STCF at second stage) can accurately test many distributions including other CP-violating observables in τ decays never studied before

Hadronic τ decays in the SM



$$\frac{d\Gamma}{ds\, d\Omega_\nu} = \frac{\pi}{m_\tau}\left(1 - \frac{s}{m_\tau^2}\right) G_F^2 |V_{uD}|^2 \left(\sum_{s_\nu} L^{\alpha\beta}\right) \delta^4(q - p_H) d\phi_n \, H^\alpha H^{\beta,\dagger}$$

- $\sum_{s_\nu} L^{\alpha\beta} = p_\nu^\alpha L_\tau^\beta + p_\nu^\beta L_\tau^\alpha - g^{\alpha\beta} p_\nu \cdot L_\tau + i\epsilon^{\alpha\beta\gamma\delta} p_\gamma^\nu L_\delta^\tau$
  $L_\tau^\mu \equiv \bar{u}(p_\tau, s_\tau)\gamma^\mu P_L u(p_\tau, s_\tau)$ related to polarization vector. Unpolarized τ? $L_\tau^\mu \to p_\tau^\mu$
- $H_\mu = \langle n | \bar{d}_L \gamma_\mu u | 0 \rangle$. Many modes, energies, distributions
  Summing, $H^{\alpha\beta}(q) = (-g^{\alpha\beta} q^2 + q^\alpha q^\beta) H^1(q^2) + q^\alpha q^\beta H^{(0)}(q^2) \equiv (2\pi)^3 \int d\phi_n \delta^4(q - p_H) H^\alpha H^{\beta,\dagger}$
- Polarized τ distributions can be predicted from unpolarized ones. Potential for SCTF
- Unpolarized case. Beyond per-cent level requires radiative beyond S_{EW}!

$$\frac{d\Gamma_\tau}{ds} = \frac{m_\tau^3}{4\pi} G_F^2 |V_{uD}|^2 \left(1 - \frac{s}{m_\tau^2}\right)^2 \left[H^{(0)} + H^{(1)}\left(1 + 2\frac{s}{m_\tau^2}\right)\right]$$

Hadronic τ decays: one meson

$$\frac{d\Gamma_\tau}{ds} = \frac{m_\tau^3}{4\pi} G_F^2 |V_{uD}|^2 \left(1 - \frac{s}{m_\tau^2}\right)^2 \left[H^{(0)} + H^{(1)}\left(1 + 2\frac{s}{m_\tau^2}\right)\right]$$

$$H^{\alpha\beta}(q) = (-g^{\alpha\beta}q^2 + q^\alpha q^\beta)H^1(q^2) + q^\alpha q^\beta H^{(0)}(q^2) \equiv (2\pi)^3 \int d\phi_n \delta^4(q - p_H) H^\alpha H^{\beta,\dagger}$$

$$H^\mu = -i\frac{f_P}{2} p_H^\mu \to H^{\alpha\beta} = \frac{1}{4}\delta(q^2 - m_H^2) q^\alpha q^\beta$$

$$\Gamma(\tau \to H\nu_\tau) = \frac{m_\tau^3 f_H^2 G_F^2 |V_{uD}|^2}{16\pi}\left(1 - \frac{m_H^2}{m_\tau^2}\right)^2 (1 + \delta_{RC}^{(H)})$$

$\Gamma(\tau \to \pi\nu_\tau)_{\rm SM} = 2.458(34) \times 10^{-13}\,\mathrm{GeV}$ $\quad$ $\Gamma(\tau \to \pi\nu_\tau)_{\rm exp} = 2.453(12) \times 10^{-13}\,\mathrm{GeV}$

$\Gamma(\tau \to K\nu_\tau)_{\rm SM} = 1.584(24) \times 10^{-14}\,\mathrm{GeV}$ $\quad$ $\Gamma(\tau \to \mathrm{K}\nu_\tau)_{\rm exp} = 1.578(23) \times 10^{-14}\,\mathrm{GeV}$ $\quad$ Cirigliano '21

But much better predictive power for ratios.

- $(\tau \to K)/(\tau \to \pi)$: Precise determination of V_{us}
- $(\tau \to P)/(P \to \ell)$: Different test of LFU

- SCTF/STCF can improve BRs
- SCTF/STCF (and lattice) can help with RCs

Talk by Haolin Li

Hadronic τ decays: Two mesons

$$\frac{d\Gamma_\tau}{ds} = \frac{m_\tau^3}{4\pi} G_F^2 |V_{uD}|^2 \left(1 - \frac{s}{m_\tau^2}\right)^2 \left[H^{(0)} + H^{(1)} \left(1 + 2\frac{s}{m_\tau^2}\right)\right]$$

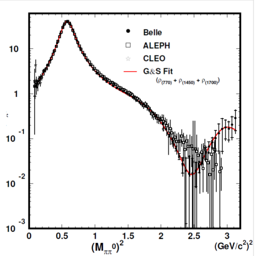
$$\langle P^- P'^0 | \bar{D}\gamma^\mu u |0\rangle = C_{PP'} \left\{ \left(p_- - p_0 - \frac{\Delta_{PP'}}{s} q\right)^\mu F_V^{PP'}(s) + \frac{\Delta_{PP'}}{s} q^\mu F_S^{PP'}(s) \right\}$$

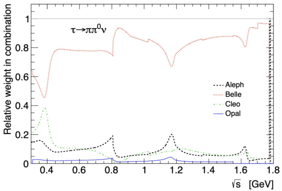
$$\left[\frac{d\Gamma}{ds}\right]_{\rm SM} = \frac{G_\mu^2 |V_{uD}|^2 m_\tau^3}{768\pi^3} S_{EW}^{\rm had} C_{PP'}^2 \left(1 - \frac{s}{m_\tau^2}\right)^2 \times \left\{ \left(1 + 2\frac{s}{m_\tau^2}\right) \lambda_{PP'}^{3/2} |F_V^{PP'}(s)|^2 + 3\frac{\Delta_{PP'}^2}{s^2} \lambda_{PP'}^{1/2} |F_S^{PP'}(s)|^2 \right\}$$

$\lambda_{PP'} \equiv \lambda(s, m_{P^-}^2, m_{P'0}^2)/s^2$, $\Delta_{PP'} = m_{P^-}^2 - m_{P'0}^2$

Hadronic τ decays: Two mesons

- $\pi\pi$, KK determined by F_V. From χpT to resonances. $\pi\pi$ at the core of muon g-2 debate





Experiment	$a_\mu^{\rm had,LO}[\pi\pi,\tau]$ (10^{-10}) $2m_{\pi^\pm} - 0.36$ GeV	$0.36 - 1.8$ GeV
ALEPH	$9.80 \pm 0.40 \pm 0.05 \pm 0.07$	$501.2 \pm 4.5 \pm 2.7 \pm 1.9$
CLEO	$9.65 \pm 0.42 \pm 0.17 \pm 0.07$	$504.5 \pm 5.4 \pm 8.8 \pm 1.9$
OPAL	$11.31 \pm 0.76 \pm 0.15 \pm 0.07$	$515.6 \pm 9.9 \pm 6.9 \pm 1.9$
Belle	$9.74 \pm 0.28 \pm 0.15 \pm 0.07$	$503.9 \pm 1.9 \pm 7.8 \pm 1.9$
Combined	$9.82 \pm 0.13 \pm 0.04 \pm 0.07$	$506.4 \pm 1.9 \pm 2.2 \pm 1.9$

Hayashi, Malaescu, Miniworkshop on tau decays

For KK see eg Gonzalez-Solis-Roig

- $K\pi$. Main contribution to Cabibbo-suppressed continuum. See eg 0803.1786, 1304.8134
- $\eta\pi$. Suppressed in the SM due to G-parity. Not yet observed
- Perhaps STCF/SCTF can provide experimental information, either in BR or distributions

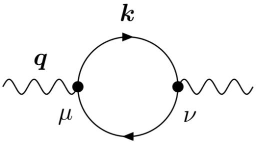
Hadronic τ decays: inclusive SM

$$\frac{d\Gamma_\tau}{ds} = \frac{m_\tau^3}{4\pi} G_F^2 |V_{uD}|^2 \left(1 - \frac{s}{m_\tau^2}\right)^2 \left[H^{(0)} + H^{(1)} \left(1 + 2\frac{s}{m_\tau^2}\right)\right]$$

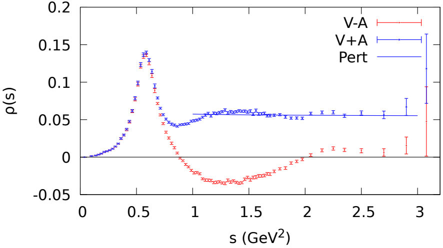
$$H^{\alpha\beta}(q) = (-g^{\alpha\beta} q^2 + q^\alpha q^\beta) H^1(q^2) + q^\alpha q^\beta H^{(0)}(q^2) \equiv (2\pi)^3 \int d\phi_n \delta^4(q - p_H) H^\alpha H^{\beta,\dagger}$$

Sum over all possible $n \Rightarrow H^{(i)}(s) \to \rho^{(i)}(s) \equiv \frac{1}{\pi} \,\mathrm{Im}\, \Pi_J^{(i)}(s)$ (e.g. 9802448)

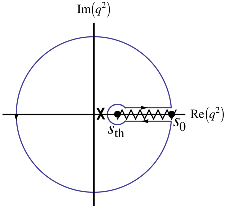
$$\Pi_J^{\mu\nu}(q) \equiv i \int d^4x\, e^{iqx} \langle 0| T[J^\mu(x) J^{\nu\dagger}(0)] |0\rangle$$



- Transition region between perturbative and non-perturbative QCD
- $V - A$ is a probe of spontaneous chiral symmetry breaking
- Can STCF/SCTF help?



Hadronic τ decays: inclusive SM



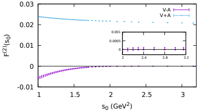
$$\underbrace{\int_{s_{\rm th}}^{s_0} \frac{ds}{s_0}\,\omega(s)\,\frac{1}{\pi}\,\mathrm{Im}\,\Pi(s)}_{\rm data} + \underbrace{\frac{1}{2\pi i}\oint_{|s|=s_0}\frac{ds}{s_0}\,\omega(s)\,\Pi(s)}_{\sim \rm OPE} = 2\frac{F_\pi^2}{s_0}\,\omega(M_\pi^2)$$

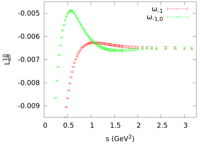
Rich phenomenology: α_s, V_{us}, Weinberg Sum Rules, $\Pi(0)$

Method & Eq. (#)	$\alpha_s(m_\tau^2)$		
	CIPT	FOPT	Average
ALEPH moments	$0.339^{+0.019}_{-0.017}$	$0.319^{+0.017}_{-0.015}$	$0.329^{+0.020}_{-0.018}$
Modified ALEPH moments	$0.338^{+0.014}_{-0.012}$	$0.319^{+0.013}_{-0.010}$	$0.329^{+0.016}_{-0.014}$
$A^{(2,m)}$ moments	$0.336^{+0.018}_{-0.016}$	$0.317^{+0.015}_{-0.013}$	$0.326^{+0.018}_{-0.016}$
s_0 dependence	0.335 ± 0.014	0.323 ± 0.012	0.329 ± 0.013
Borel transform	$0.328^{+0.014}_{-0.013}$	$0.318^{+0.015}_{-0.012}$	$0.323^{+0.015}_{-0.013}$

$$\alpha_s(m_\tau^2)^{\rm CIPT} = 0.335 \pm 0.013$$
$$\alpha_s(m_\tau^2)^{\rm FOPT} = 0.320 \pm 0.012$$
$$\alpha_s(m_\tau^2) = 0.328 \pm 0.013$$
$$\alpha_s^{(n_f=5)}(M_Z^2)\Big|_\tau = 0.1197 \pm 0.0015$$

Pich. R-S '16, '22





Gonzalez-Alonso,...,R-S '16, Pich,R-S '21

- In the $SU(3)_V$ limit $\frac{R_{\tau,V+A}}{|V_{ud}|^2} - \frac{R_{\tau,s}}{|V_{us}|^2} = 0$
- $SU(3)_V$ breaking by $m_s \neq m_d$
- $\frac{R_{\tau,V+A}}{|V_{ud}|^2} - \frac{R_{\tau,s}}{|V_{us}|^2} = \delta R_{th} \to |V_{us}|^2$
  Gamiz '07 '13, ETMC '23
- Tension with other V_{us}!

Hadronic τ decays: BSM

$$
\begin{aligned}
\mathcal{L}_{\text{eff}} \;=\; & -\frac{G_F V_{ud}}{\sqrt{2}} \Bigg[\left(1+\epsilon_L^{d\tau}\right) \bar{\tau}\gamma_\mu (1-\gamma_5)\nu_\tau \cdot \bar{u}\gamma^\mu (1-\gamma_5) d \\
& + \epsilon_R^{d\tau}\; \bar{\tau}\gamma_\mu (1-\gamma_5)\nu_\tau \;\; \bar{u}\gamma^\mu (1+\gamma_5) d \\
& + \bar{\tau}(1-\gamma_5)\nu_\tau \cdot \bar{u}\left[\epsilon_S^{d\tau} - \epsilon_P^{d\tau}\gamma_5\right] d \\
& + \epsilon_T^{d\tau}\; \bar{\tau}\sigma_{\mu\nu}(1-\gamma_5)\nu_\tau \cdot \bar{u}\sigma^{\mu\nu}(1-\gamma_5) d \Bigg] + \text{h.c.}
\end{aligned}
$$

Cirigliano '10

Minimal assumptions

- Not light ($\mathcal{O}(\mathrm{GeV})$) nonstandard particles
- SM interactions dominate
- Lorentz and $U(1)_{\text{EM}} \times SU(3)_C$ invariance

Hadronic τ decays: BSM

$$\frac{d\Gamma^{(n)}}{dq^2} \sim \sum \underbrace{\mathrm{KIN}_{ij}(q^2)\cdot\rho_{ij}^{(n)}(q^2)}_{\mathrm{SM}}(1+c_A\epsilon_A) + \sum \epsilon_A \cdot \mathrm{KIN}'_{ij}(q^2)\cdot\rho_{ij}'^{(n)}(q^2)$$

$$\epsilon_A = c_A \cdot \underbrace{\frac{q^2}{M_{\mathrm{BSM}}^2}}_{\mathrm{BSM\ suppression}} \Big/ \underbrace{\frac{q^2}{M_W^2}}_{\mathrm{SM\ suppression}} = c_A \cdot \frac{M_W^2}{M_{\mathrm{BSM}}^2}\ ,\ \text{Eg } c_A \sim 1, \epsilon_A \lesssim 10^{-2} \to M_{\mathrm{BSM}} \gtrsim 1\,\mathrm{TeV}$$

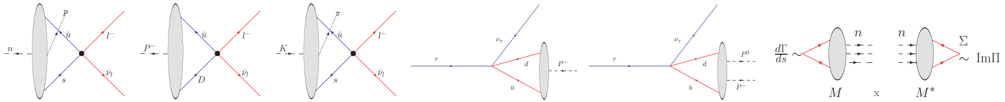
BSM sensitivity? Two possibilities

- SM Suppression. $\tau \to \eta\pi\nu_\tau$. $|\epsilon_S| \lesssim 10^{-2}$ JHEP 12 (2017) 027, inclusive $V-A$
- SM and experiment precisely known: $\tau \to \pi\nu_\tau$, $\tau \to \pi\pi\nu_\tau$, inclusive $V+A$

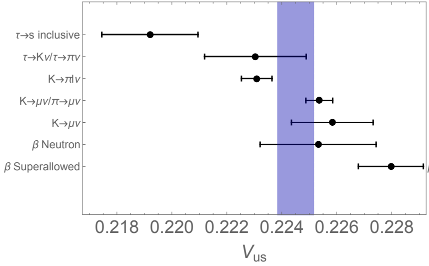
$$\begin{pmatrix} \epsilon_L^{d\tau/e} + \epsilon_R^{d\tau} - \epsilon_R^{de} \\ \epsilon_R^{d\tau} \\ \epsilon_P^{d\tau} \\ \hat{\epsilon}_T^{d\tau} \\ \epsilon_L^{s\tau/e} - \epsilon_R^{s\tau} - \epsilon_R^{se} - \frac{m_{K^\pm}^2}{m_\tau(m_u+m_s)}\epsilon_P^{s\tau} \\ \epsilon_L^{s\tau/e} - 0.03\epsilon_R^{s\tau} - \epsilon_R^{se} + 0.08(1)\epsilon_S^{s\tau} - 0.38\epsilon_P^{s\tau} + 0.40(13)\hat{\epsilon}_T^{s\tau} \end{pmatrix} = \begin{pmatrix} 2.4 \pm 2.6 \\ 0.7 \pm 1.4 \\ 0.4 \pm 1.0 \\ -3.3 \pm 6.0 \\ -0.2 \pm 1.0 \\ -1.3 \pm 1.2 \end{pmatrix} \times 10^{-2}$$

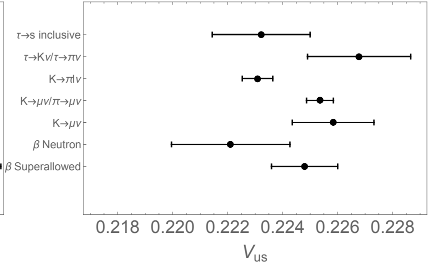
Cirigliano,...,R-S

Interplay with other observables



- Mediated by same kind of charged current lagrangian
- Common inputs: V_{ud}, V_{us}. Additionally related by unitarity

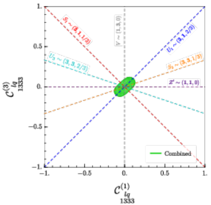


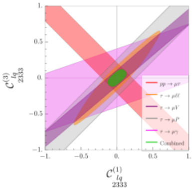


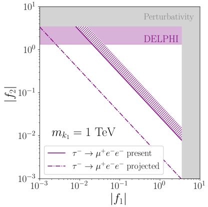
- Further interplay with other EWPOs and LHC Cirigliano . . . R-S STCF/SCTF may help

Charged Lepton Flavor Violation (cLFV)

- Forbidden in the $m_\nu = 0$ SM, too small to be observed in trivial generalization
- Current best bounds: Belle, BaBar. Belle-II will improve them, STCF may compete
- It can test BSM scenarios beyond the reach of other experiments







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- Prospects for $\tau \to \mu\gamma$ (eg S_1 and $R_2 > 100\,\mathrm{TeV}$ leptoquarks). Also for $\tau \to \mu\alpha(\gamma)$ at SCTF

Conclusions

STCF/SCTF have significant potential to contribute to the study of fundamental tau physics

- Mass measurement at STCF/SCTF may become the most precise for decades
- Discovery of (orthodi-)tauonium at STCF/SCTF
- Tau anomalous magnetic moment and EDM
- CPV in tau decays
- Novel tests with polarized taus: leptonic (Michel-like parameters) and hadronic decays
- Improvements on new-physics bounds, Cabibbo anomalies, LFU and cLFV
- Hadronization of quark currents