Minimal New Physics Explanation for Anomalies in Hadronic tau decays

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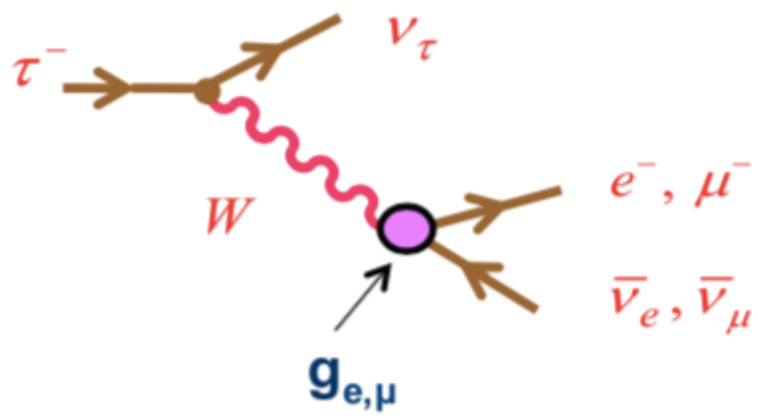
In collaboration with **Subhajit Ghosh, Amol Dighe,** and **Tuhin Roy**

Based on **1902.09561 (hep-ph)**

Tau decays as probes of SM & beyond

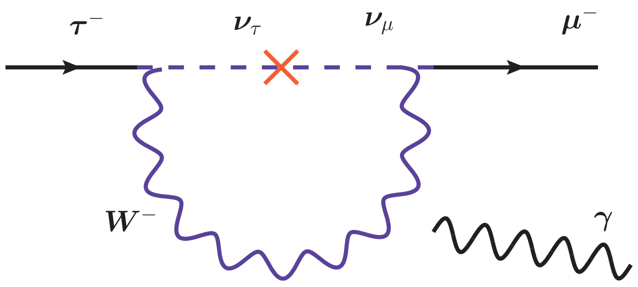
Lepton flavor universality



Charged lepton flavor violation

eg $\tau \to \mu\gamma$

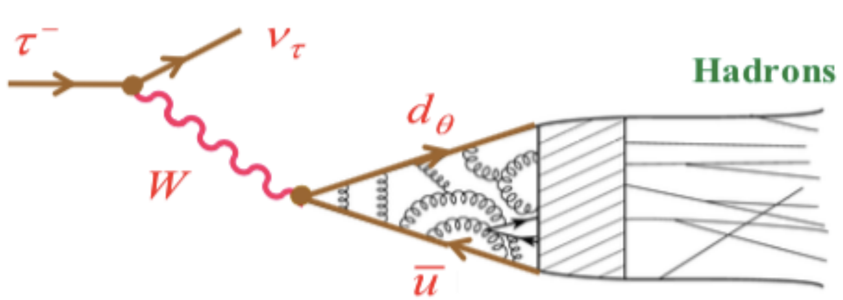
No SM background



$$\mathscr{L}_{\rm SM} \supset \frac{g_2}{\sqrt{2}}(\bar{\tau}_L \gamma^\mu \nu_{\tau,L}) W_\mu^- + \mathrm{h.c.}$$

Determination of the SM parameters

V_{us} , α_s, m_s



$d_\theta = V_{ud}\, d + V_{us}\, s$

Tests of CP violation

CP Violation in tau decays

$$A^{\tau}_{CP} = \frac{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}$$

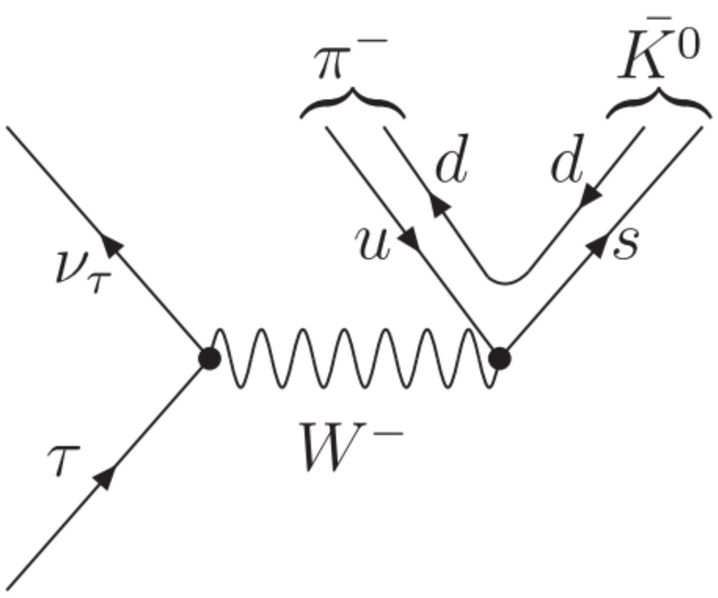
Bigi, Sanda, PLB 625, 2005

This asymmetry is nonzero is the SM, and comes from CPV in **neutral kaon mixing**

Using

$$|K_{S,L}\rangle = p\,|K^0\rangle \pm q\,|\overline{K}^0\rangle\,, \quad \frac{|p|^2 - |q|^2}{|p|^2 + |q|^2} \approx 2\,\mathrm{Re}(\epsilon)$$

Indirect CPV paramater
($\sim 10^{-3}$)



The SM prediction is $\quad A^{\tau}_{CP}(\mathrm{SM}) \approx 2\,\mathrm{Re}(\epsilon)$

$$= (0.33 \pm 0.01)\,\%$$

CP Violation in tau decays

$\sim 3\sigma$ disagreement between theory and experiment

$$A_{CP}^{\tau}(\mathrm{SM}) = (0.36 \pm 0.01)\,\%\,, \qquad A_{CP}^{\tau}(\mathrm{Exp}) = (-0.33 \pm 0.21 \pm 0.10)\,\%$$

After taking into account exp. conditions and time efficiencies

BABAR Collab., 1109.1527

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BABAR Collab., 1109.1527

After taking into account exp. conditions and time efficiencies

A sidenote :

The same dynamics also yields **CPV for D meson decays**

$$A_D \equiv \frac{\Gamma(D^+ \to K_S \pi^+) - \Gamma(D^- \to K_S \pi^-)}{\Gamma(D^+ \to K_S \pi^+) + \Gamma(D^- \to K_S \pi^-)} \approx -2\,\mathrm{Re}(\epsilon)$$

Experimental and SM values for CP asymmetry in D meson are **consistent** with each other

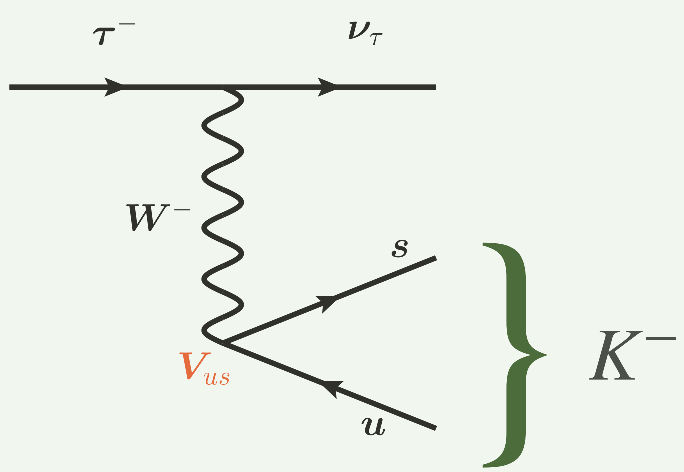
$$A_D(\mathrm{SM}) = (-0.332 \pm 0.006)\,\% \,, \qquad A_D(\mathrm{Exp}) = (-0.41 \pm 0.09)\,\%$$

Extraction of Vus

Branching fraction	HFLAV Spring 2017 fit (%)
$K^- \nu_\tau$	0.6960 ± 0.0096
$K^- \pi^0 \nu_\tau$	0.4327 ± 0.0149
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	0.0640 ± 0.0220
$K^- 3\pi^0 \nu_\tau$ (ex. K^0, η)	0.0428 ± 0.0216
$\pi^- \overline{K}^0 \nu_\tau$	0.8386 ± 0.0141
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	0.3812 ± 0.0129
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. K^0)	0.0234 ± 0.0231
$\overline{K}^0 h^- h^- h^+ \nu_\tau$	0.0222 ± 0.0202
$K^- \eta \nu_\tau$	0.0155 ± 0.0008
$K^- \pi^0 \eta \nu_\tau$	0.0048 ± 0.0012
$\pi^- \overline{K}^0 \eta \nu_\tau$	0.0094 ± 0.0015
$K^- \omega \nu_\tau$	0.0410 ± 0.0092
$K^- \phi \nu_\tau$ ($\phi \to K^+ K^-$)	0.0022 ± 0.0008
$K^- \phi \nu_\tau$ ($\phi \to K_S^0 K_L^0$)	0.0015 ± 0.0006
$K^- \pi^- \pi^+ \nu_\tau$ (ex. K^0, ω)	0.2923 ± 0.0067
$K^- \pi^- \pi^+ \pi^0 \nu_\tau$ (ex. K^0, ω, η)	0.0410 ± 0.0143
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	0.0001 ± 0.0001
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	0.0001 ± 0.0001
$X_s^- \nu_\tau$	2.9087 ± 0.0482

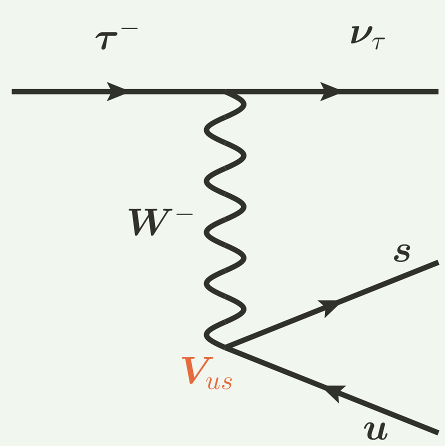
via exclusive mode:

$$\mathrm{BR}(\tau \to K\nu_\tau)/\mathrm{BR}(\tau \to \pi\nu_\tau)$$

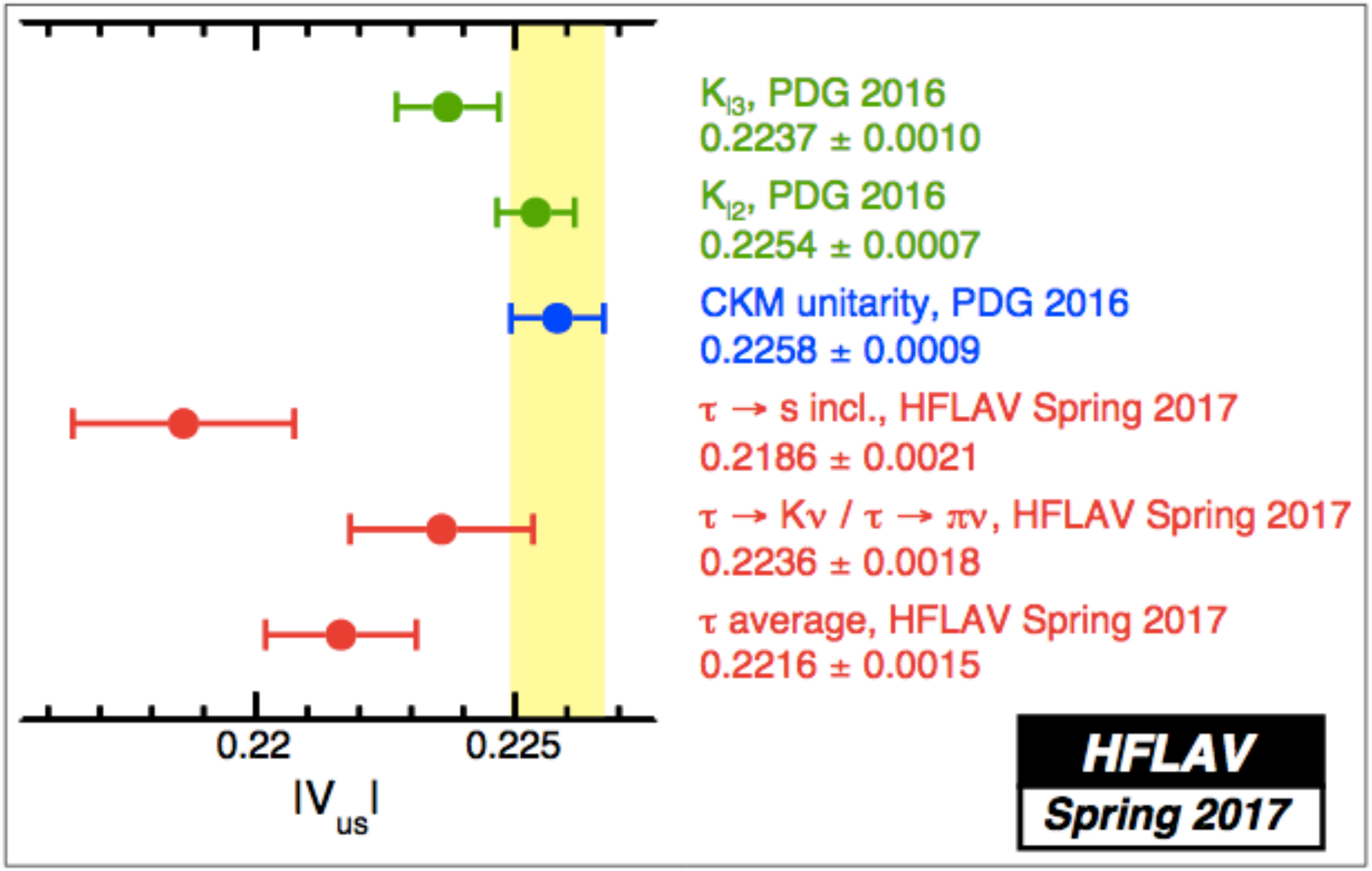


via inclusive mode:

$$\tau \to X_s + \nu_\tau$$



Status of Vus



$|V_{us}|_{uni} = 0.22582(89)$ from $\sqrt{1-|V_{ud}|^2}$ (CKM unitarity)

$|V_{us}|_{\tau s} = 0.2186(21) \quad -3.1\sigma$ from $\Gamma(\tau^- \to X_s^- \nu_\tau)$

$|V_{us}|_{\tau K/\pi} = 0.2236(18) \quad -1.1\sigma$ from $\Gamma(\tau^- \to K^- \nu_\tau)/\Gamma(\tau^- \to \pi^- \nu_\tau)$

New physics in $\tau \to s$?

The low-energy effective Lagrangian

$$\mathscr{L}^{\Delta S=1} \supset -\frac{4G_F}{\sqrt{2}} V_{us} \Big[c_L^V\, \bar{\tau}_L \gamma^\mu \nu_{\tau L} \cdot \bar{u}_L \gamma_\mu s_L + c_R^V\, \bar{\tau}_L \gamma^\mu \nu_{\tau L} \cdot \bar{u}_R \gamma_\mu s_R \quad \text{Vector}$$

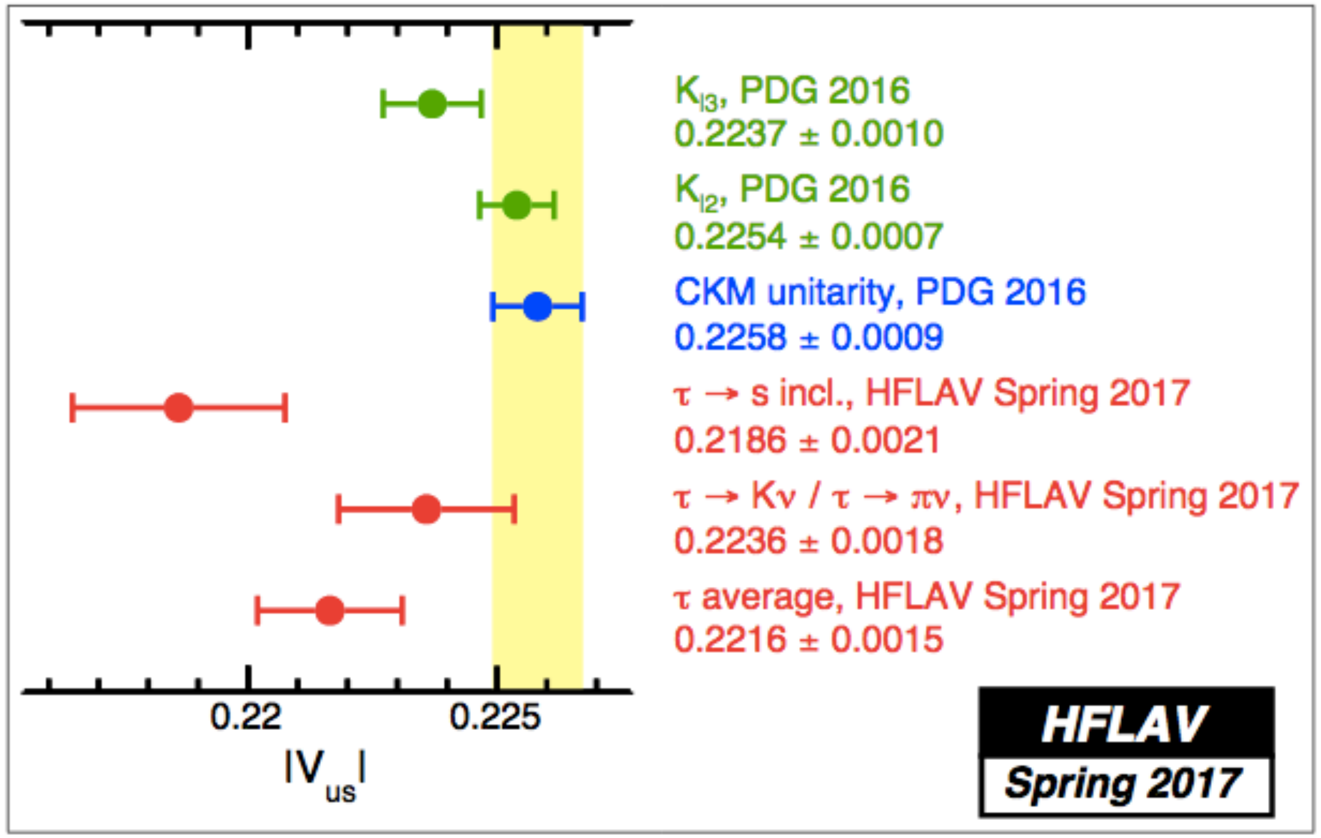
$$+ c_L^S\, \bar{\tau}_R \nu_{\tau L} \cdot \bar{u}_R s_L + c_R^S\, \bar{\tau}_R \nu_{\tau L} \cdot \bar{u}_L s_R \quad \text{Scalar}$$

$$+ c_T\, \bar{\tau}_R \sigma_{\mu\nu} \nu_{\tau L} \cdot \bar{u}_R \sigma_{\mu\nu} s_L \Big] + \text{h.c.} \quad \text{Tensor}$$

In the SM : $c_L^V = 1$ and rest coefficients are zero

Nature of NP interaction?

Vus extraction from *EXCLUSIVE* mode is almost consistent



Vus extraction from *INCLUSIVE* mode is anomalous

NP keeps two body decay unaffected, but modifies inclusive rate

Tensors !! →

$$\langle K^-(q)\,|\,\bar{s}\sigma_{\mu\nu}u\,|\,0\rangle = 0$$ For $\tau \to K\nu$

No antisymmetric structure is possible

Nature of NP interaction?

Need interference of two amplitudes to yield non-zero CP asymmetry

$$A_{CP} \propto |A_1 + A_2|^2 - |\bar{A}_1 + \bar{A}_2|^2$$
$$= -4|A_1||A_2| \sin(\delta_1^{\mathrm{S}} - \delta_2^{\mathrm{S}}) \sin(\delta_1^{\mathrm{W}} - \delta_2^{\mathrm{W}})$$

$A_j = |A_j| e^{i\delta_j^{\mathrm{S}}} e^{i\delta_j^{\mathrm{W}}}, \ (j = 1,2)$

Both strong and weak phases are necessary

$\tau \to K_S \pi^- \nu_\tau$:

$$\frac{d\Gamma}{ds} \propto \left| f_0(s)\left(c_V + \frac{s}{m_\tau(m_s - m_u)} c_S \right) \right|^2 ,$$

No strong phase in scalar-vector interference

$$\left| f_+(s) c_V - T(s) \right|^2$$

Relative strong phase in tensor-vector interference

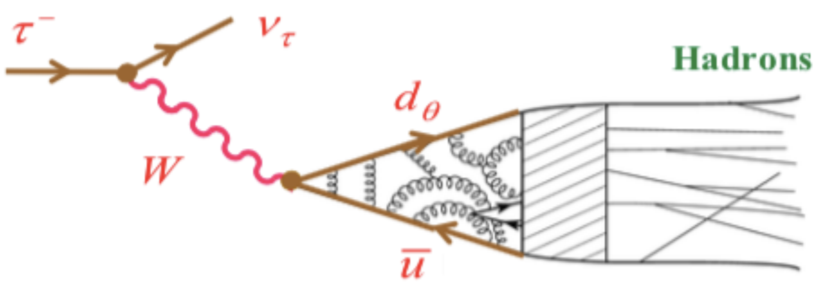
Only tensor operator can generate direct CPV !

Inclusive Hadronic Tau decay

$$\mathscr{L}_{\rm NP} \supset -\frac{4G_F}{\sqrt{2}} V_{us}\, c_T \left[\, \bar\tau_R \sigma_{\mu\nu} \nu_{\tau L} \cdot \bar u_R \sigma_{\mu\nu} s_L \right]$$

Key observable is

$$R_\tau = \frac{\Gamma(\tau \to \nu_\tau + \text{hadrons})}{\Gamma(\tau \to \nu_\tau e^- \bar\nu_e)}$$



$d_\theta = V_{ud}\, d + V_{us}\, s$

SU(3) breaking quantity

$$\delta R_\tau \equiv \frac{R_\tau^{NS}}{|V_{ud}|^2} - \frac{R_\tau^{S}}{|V_{us}|^2}$$

Correction from :

$m_s \leftrightarrow m_u$, $\langle \bar s s \rangle \leftrightarrow \langle \bar u u \rangle$

$$\delta R_\tau^{\rm SM} = 0.242(32)$$

E. Gamiz et. al, PRL 94 (2005) 011803

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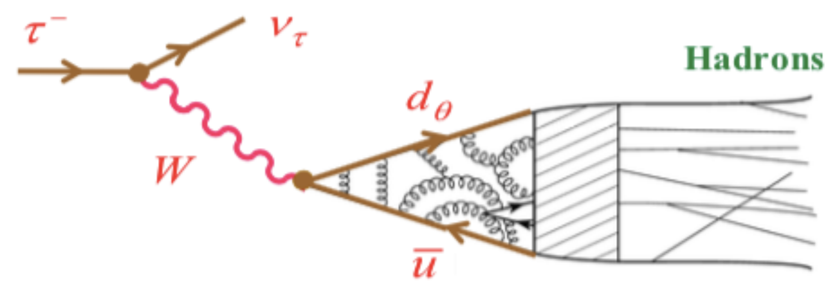

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In presence of tensor contribution:

Pure tensor term

$$\delta R_{\tau,\rm theory} \simeq \delta R_\tau^{\rm SM} - 288\pi^2 {\rm Re}[C_T] \frac{\langle 0 | \frac{1}{2}(\bar{u}u + \bar{s}s) | 0 \rangle}{m_\tau^3} - 18 |C_T|^2$$

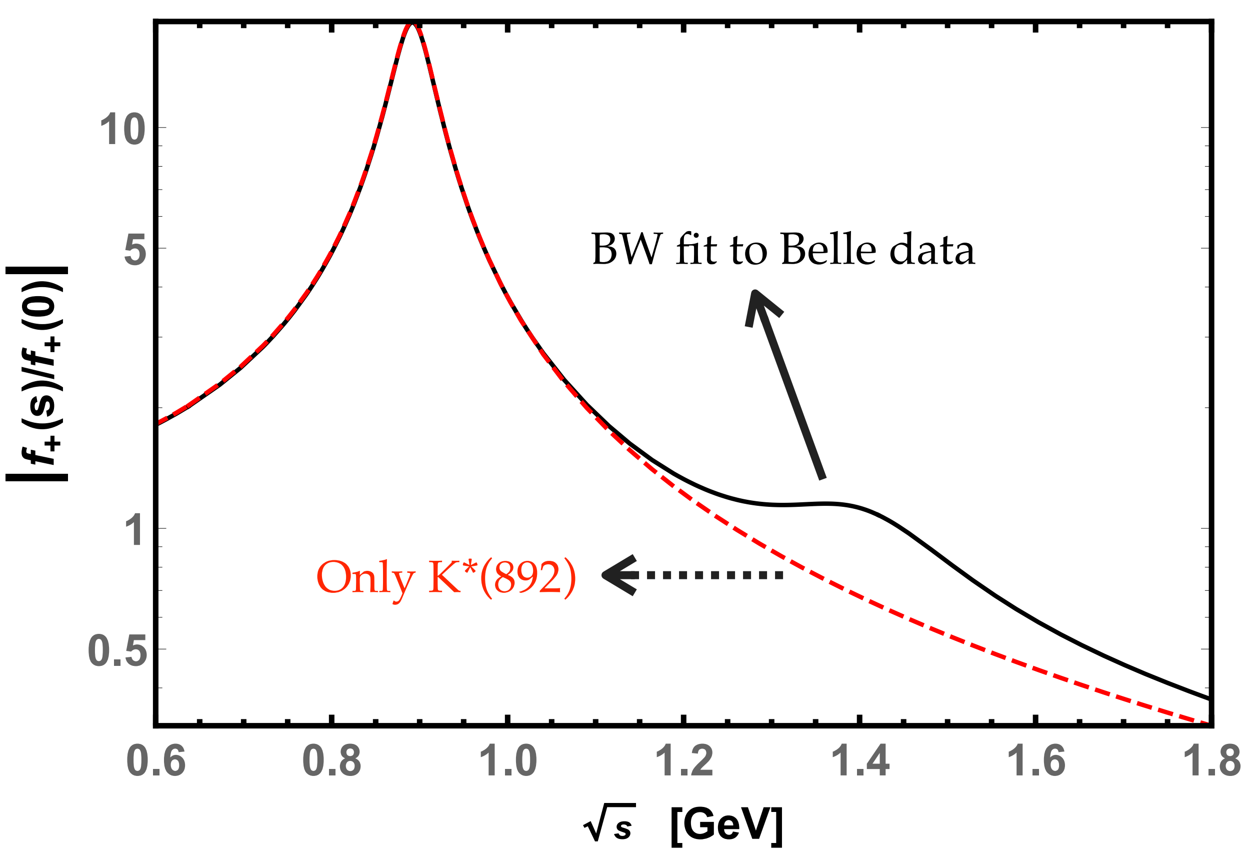
V-T interference term

CPV in $\tau \to K_S \pi^- \nu_\tau$

$$A_{CP}^{\tau} = \frac{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}$$

Devi, Dhargyal, Sinha, PRD 90, 013016 (2014)

$$A_{CP}^{\tau,\mathrm{BSM}} = \frac{\sin \delta_T^W \, |c_T|}{\Gamma_\tau \mathrm{BR}(\tau \to K_S \pi \nu_\tau)} \times \int_{s_{\pi K}}^{m_\tau^2} ds' \, \kappa(s) \, |f_+(s')| \, |B_T(s')| \sin\left[\delta_+(s') - \delta_T(s')\right]$$



Vector and Tensor Form factors :

Contribution from K*(892) and K*(1410), dominated by elastic K*(892) resonance

Can be parametrised by **Omnes function**

$$\Omega(s) = \exp\left\{ \frac{s}{\pi} \int_{s_{\pi K}}^{\infty} \frac{\delta(s')}{s'(s'-s)} \right\}$$

In elastic region: Watson final state theorem

Phys. Rev. 95 (1954) 228

$$\delta_+(s) = \delta_T(s) = \delta_1^{1/2}(s)$$

CPV in $\tau \to K_S \pi^- \nu_\tau$

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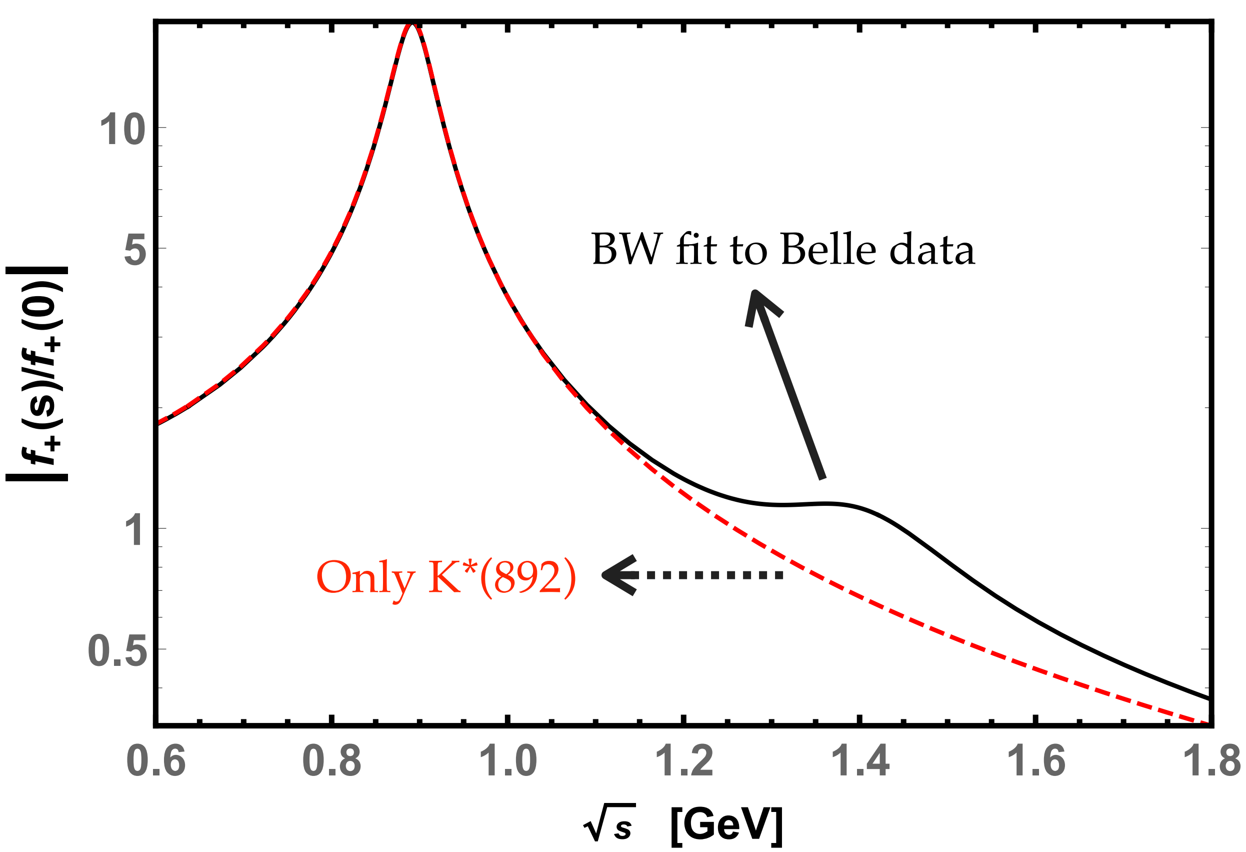

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$$\delta_+(s) = \delta_T(s) = \delta_1^{1/2}(s)$$

Vector-Tensor interference vanishes up to inelastic corrections!!

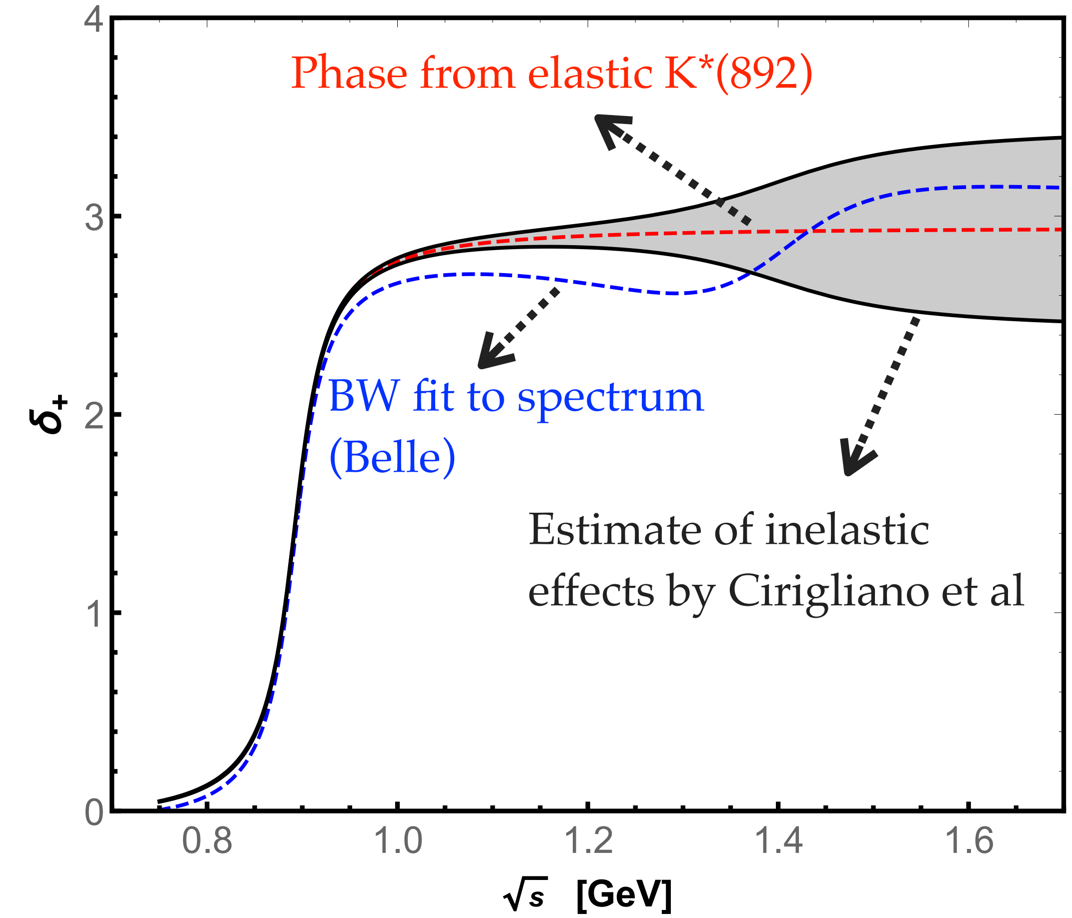
CPV in $\tau \to K_S \pi^- \nu_\tau$

Inelastic effects start around K*(1410) resonance

Inelastic phase shifts can't be extracted from experimental fits

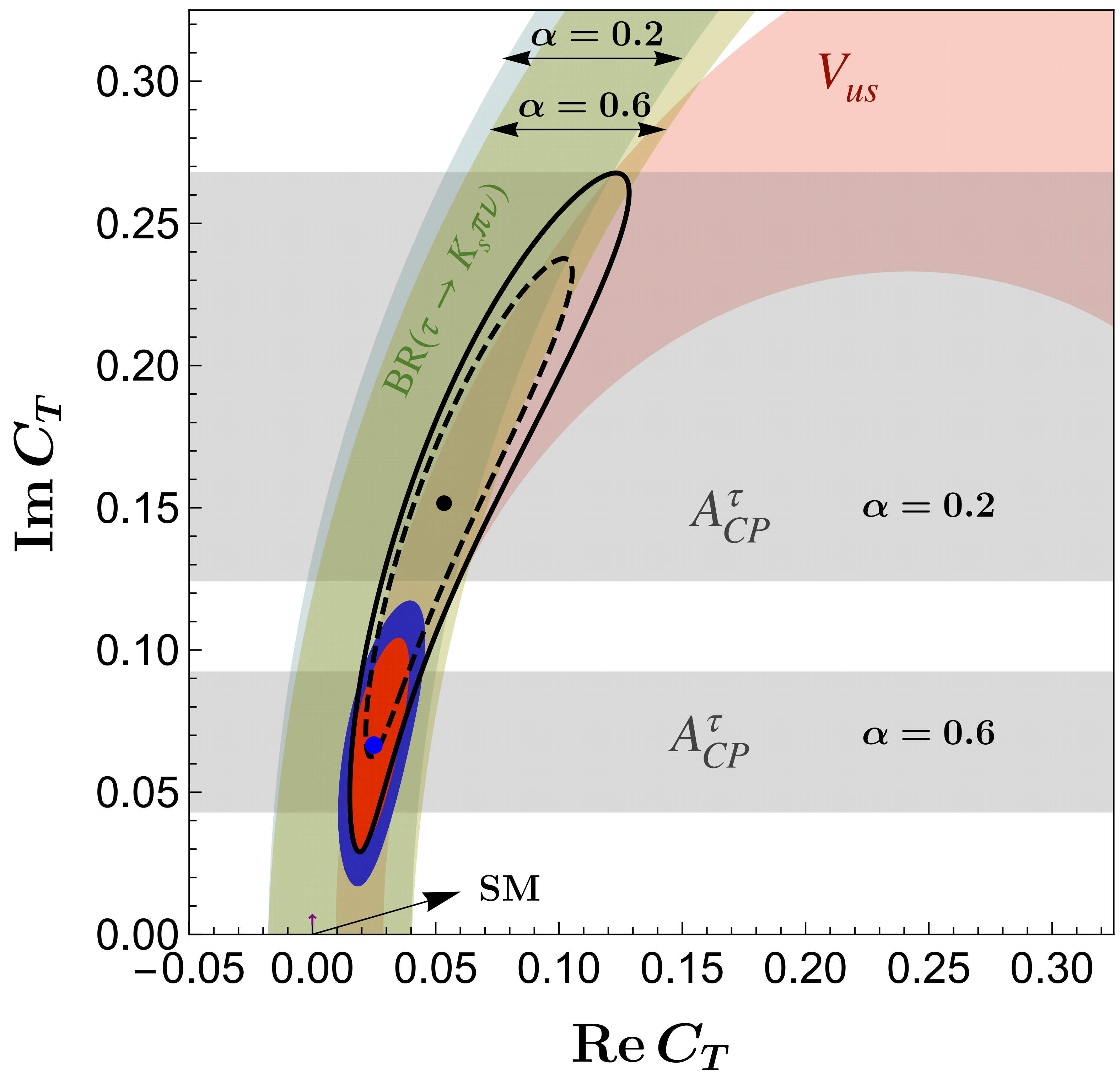
We take the following assumption:

$$\delta_T(s) - \delta_+(s) = \alpha \times \text{Arg}[\text{BW}\,(K^*(1410))]$$



Belle collab., PLB 654, 65 (2007)
Cirigliano et al, PRL 120, 141803 (2018)

Combined NP resolution



Implications from SM Gauge Invariance

$$\mathscr{L}_{eff}^{\mathrm{Low-energy}} \supset c_T\, \bar{\tau}_R \sigma_{\mu\nu} \nu_{\tau L} \cdot \bar{u}_R \sigma_{\mu\nu} s_L \qquad m_\tau \ll v < \Lambda$$

↓ **EW gauge inv.**

$$\ell_3 = \begin{pmatrix} \nu_\tau \\ \tau_L \end{pmatrix} \qquad q_2 = \begin{pmatrix} c_L \\ s_L \end{pmatrix}$$

$$\mathscr{L}_T \supset \frac{C}{\Lambda^2}\, \bar{\ell}^i \sigma_{\mu\nu} e_R\, \epsilon^{ij}\, \bar{q}_L^j \sigma^{\mu\nu} u_R + \mathrm{h.c.}$$

$$= \frac{C}{\Lambda^2}\left[(\bar{\nu}_{\tau,L}\sigma_{\mu\nu}\tau_R)(\bar{s}_L\sigma^{\mu\nu}u_R) - V_{us}(\bar{\tau}_L\sigma_{\mu\nu}\tau_L)(\bar{u}_L\sigma^{\mu\nu}u_R)\right] + \mathrm{h.c.}$$

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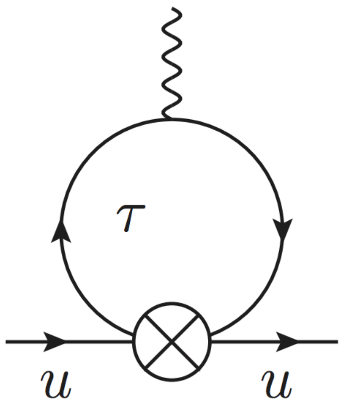
$$= \frac{C}{\Lambda^2} \left[(\bar{\nu}_{\tau,L} \sigma_{\mu\nu} \tau_R)(\bar{s}_L \sigma^{\mu\nu} u_R) - V_{us} (\bar{\tau}_L \sigma_{\mu\nu} \tau_L)(\bar{u}_L \sigma^{\mu\nu} u_R) \right] + \mathrm{h.c}$$



Bound from **neutron EDM** $\quad |\mathrm{Im}\, c_T| \lesssim 10^{-5}$

Cirigliano et al, PRL 120, 141803 (2018)

No heavy BSM explanation is possible for A_{CP} anomaly ??!!

Breaking the no-go theorem !!

Matching of low energy EFT operator to Gauge invariant operator is not unique

Breaking the no-go theorem !!

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$$-\frac{4G_F}{\sqrt{2}} V_{us}\, C_T \left[(\bar{\nu}_{\tau L}\, \sigma_{\mu\nu}\, \tau_R)\, (\bar{s}_L\, \sigma^{\mu\nu}\, u_R)\right] \xrightarrow{\text{EW gauge invariance}} \frac{\mathscr{K}}{\Lambda^4}\left[(\bar{\ell}_3 H^\dagger)\, \sigma_{\mu\nu}\, \tau_R\right]\, \left[(\bar{q}_2 H)\, \sigma^{\mu\nu}\, u_R\right]$$

$$\downarrow$$

$$\frac{\mathscr{K} v^2}{2\Lambda^4}\left[(\bar{\nu}_{\tau,L}\, \sigma_{\mu\nu}\, \tau_R)\, (\bar{s}_L\, \sigma^{\mu\nu}\, u_R)\right]$$

No Neutron EDM operator
(Thanks to the Higgses)

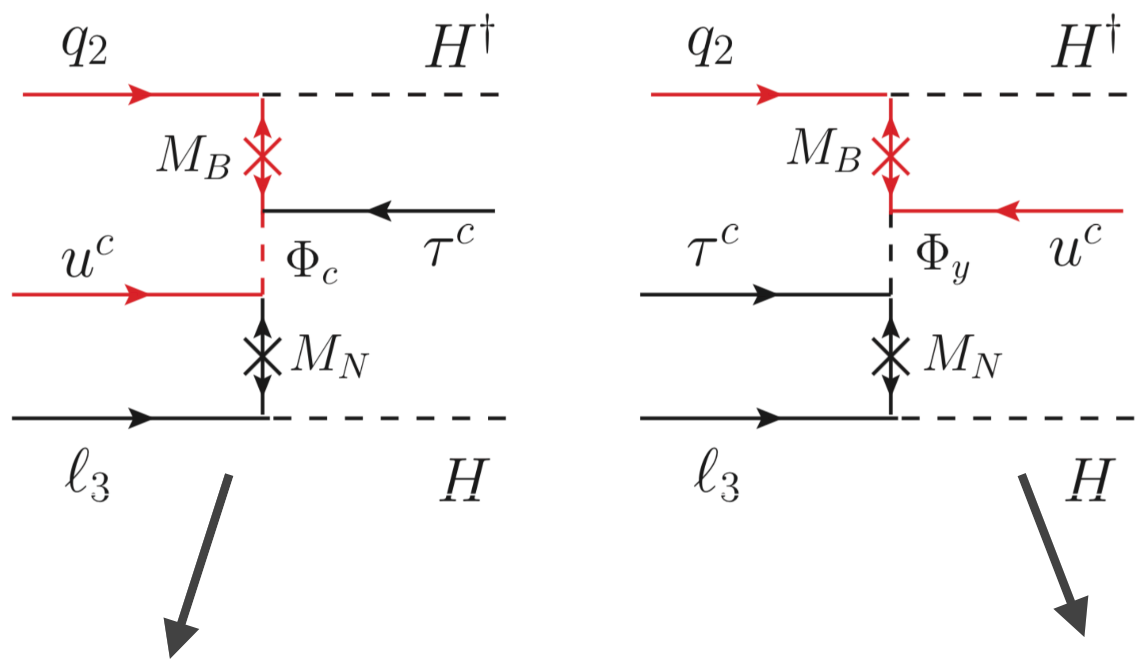
Heavy BSM explanation is possible for A_{CP} anomaly

A toy UV model

	$(SU(3)_C, SU(2)_W)_Y$	$U(1)_{q_2}$	$U(1)_{u_1}$	$U(1)_{\ell_3}$	$U(1)_{e_3}$
B	$(3,1)_{-1/3}$	0	1	0	0
B^c	$(\bar{3},1)_{1/3}$	-1	0	0	0
N	$(1,1)_0$	0	0	-1	0
N^c	$(1,1)_0$	0	0	0	1
Φ_c	$(3,1)_{2/3}$	0	+1	0	-1
Φ_y	$(1,1)_1$	0	0	0	0

$$\mathscr{L} \supset k_1\, H^\dagger q_2 B^c + k_2\, H\ell_3 N + k_3\, \Phi_c u_1^c N^c$$

$$+k_4\, \Phi_c^\dagger e_3^c B + k_5\, \Phi_y u_1^c B + k_6\, \Phi_y^\dagger e_3^c N^c$$



$$\frac{4k_1k_2k_3k_4}{M_N M_B m_c^2}\left[\left(q_2 H^\dagger e_3^c\right)\left(\ell_3 H u_1^c\right)\right]$$

$$\frac{4k_1k_2k_6k_7}{M_N M_B m_y^2}\left[\left(q_2 H^\dagger u_1^c\right)\left(\ell_3 H e_3^c\right)\right]$$

Fierz Transformation

$$-\frac{1}{2}\left(q_2 H^\dagger u_1^c\right)\left(\ell_3 H e_3^c\right) - \frac{1}{2}\left(q_2 H^\dagger \sigma^{\mu\nu} u_1^c\right)\left(\ell_3 H \sigma_{\mu\nu} e_3^c\right)$$

Summary

Tau decays offer unique possibilities to test the SM and beyond.

We have explored the possibility of addressing the anomalies in **Vus** and **CP asymmetry** in tau decays via NP in a model-independent analysis.

A single effective tensor operator can account for both CP asymmetry and V_{us} anomaly.

EW gauge invariance implied constraints from neutron EDM are not general and arise only in particular class.

As a proof-of-principle, the UV model demonstrates how to generate the dim-8 gauge invariant operator, avoiding the dim-6 one that contributes to neutron EDM.

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Thank you

Back-up

τ : The Heaviest Lepton

Mass : 1776.86(12) MeV PDG 2018

Lifetime : 290.3(5) fs PDG 2018

The only known lepton heavy enough to decay into **both leptons and hadrons**

PDG 2018 lists 244 various decay modes of the tau

Decays to lighter leptons $\tau \to \ell \bar{\nu}_\ell \nu_\tau (\ell = e, \mu)$: 17 % each

Decays to hadrons $\tau \to \text{hadrons} + \nu_\tau$: 65 %

Largest BR $\tau^- \to \pi^- \pi^0 \nu_\tau$: 25 %

NP in Hadronic Tau decay

$$\mathscr{L}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{us} \left[\bar{s}_L \gamma^\mu u_L \cdot \bar{\nu}_{\tau L} \gamma_\mu \tau_L \right] + \frac{Dv^2}{2\Lambda^4} \left[\bar{s}_L \sigma_{\mu\nu} u_R \cdot \bar{\nu}_{\tau L} \sigma^{\mu\nu} \tau_R \right]$$

$$c_T = \left(\frac{v}{\Lambda} \right)^4 \frac{D}{4V_{us}},$$

c_T is a complex number

$\mathrm{Im}\, c_T$: Contributes to CP asymmetry

$\mathrm{Re}\, c_T$ & $\mathrm{Im}\, c_T$: Contributes to $\tau \to X_s \nu_\tau$

Calculation of R_τ

$$\sum_n \Gamma(\tau \to \nu_\tau n) = \frac{1}{2m_\tau}\int \frac{d^3p_\nu}{(2\pi)^3 2E_\nu}\frac{1}{2}\sum_{s,s'}\sum_n \int d\phi_n \left|\langle \nu_\tau n | \mathscr{H} | \tau\rangle\right|^2 (2\pi)^4\delta^4(q-p_n)$$

Can be written in term of spectral functions using:

$$\rho^{\mu\nu}_{ij,VV} \equiv \int d\phi_n (2\pi)^3\delta^4(q-p_n)\sum_n \langle 0 | V^\mu_{ij} | n\rangle\langle n | V^{\nu\dagger}_{ij} | 0\rangle$$

$$= (q^\mu q^\nu - g^{\mu\nu}q^2)\rho^{(1)}_{ij,VV}(q^2) + q^\mu q^\nu \rho^{(0)}_{ij,VV}(q^2)$$

Spectral functions are equal to imaginary part of the associated correlators

Optical theorem

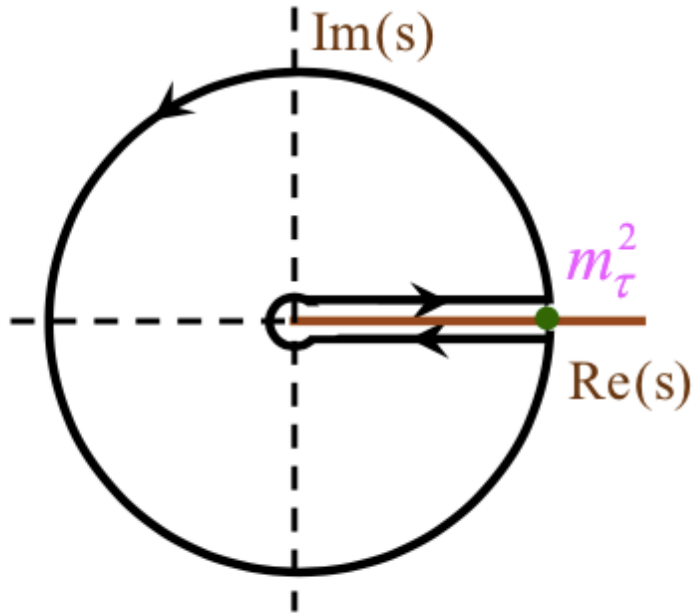
$$\Pi^{\mu\nu}_{ij,VV}(q) \equiv i\int d^4x e^{iqx}\langle 0 | T\{V^\mu_{ij}(x)V^{\nu\dagger}_{ij}(0)\} | 0\rangle$$

$$= (q^\mu q^\nu - g^{\mu\nu}q^2)\Pi^{(1)}_{ij,VV}(q^2) + q^\mu q^\nu \Pi^{(0)}_{ij,VV}(q^2)$$

Calculation of R_τ

$$R_\tau^{S\,(NS)} = 12\pi |V_{us(d)}|^2 S_{EW} \int_0^{m_\tau^2} \frac{ds}{m_\tau^2}\left(1-\frac{s}{m_\tau^2}\right)\left[\left(1+2\frac{s}{m_\tau^2}\right)\mathrm{Im}\Pi^{(1)}(s) + \mathrm{Im}\Pi^{(0)}(s)\right]$$

Braaten, Narison, Pich'92



Analyticity of Π : making use of Cauchy theorem

$$R_\tau^{S\,(NS)} = 6i\pi |V_{us(d)}|^2 S_{EW} \oint_{|s|=m_\tau^2} \frac{ds}{m_\tau^2}\left(1-\frac{s}{m_\tau^2}\right)\left[\left(1+2\frac{s}{m_\tau^2}\right)\Pi^{(1)}(s) + \Pi^{(0)}(s)\right]$$

Use of OPE:

$$\Pi^J(s) = \sum_{D=2,4,..} \frac{1}{(-s)^{D/2}} \sum_{\mathrm{dim}O=D} C^{(J)}(s,\mu)\langle O_D(\mu)\rangle$$

New Physics in R_τ^S

The tensor contribution:

Vector-tensor interference term

$$R^S_{\tau,BSM} = 6\pi i\,|V_{us}|^2 \oint_{|s|=m_\tau^2} \frac{ds}{m_\tau^2}\left(1-\frac{s}{m_\tau^2}\right)\left[-12\,\mathrm{Re}[C_T]\frac{\Pi_{TV}}{m_\tau}\right.$$

$$\left. + 16\,|C_T|^2\left(1+\frac{s}{2m_\tau^2}\right)\left(\Pi_{TT}^{(Q)}+\Pi_{TT}^{(R)}\right)\right]$$

Pure tensor term

Using

$$\Pi_{TV}(-Q^2) \simeq -\frac{2}{Q^2}\langle 0\,|\,\bar{q}q\,|\,0\rangle$$

$$\Pi_{TT}^{(Q)} = \Pi_{TT}^{(R)} = -\frac{N_C}{24\,\pi^2}\log(Q^2)$$

Ignored mass and α_s corrections

Craigie, Stern, PRD 26, 1982

Calculation of Vus in SM

$$\delta R_\tau \equiv \frac{R_\tau^{NS}}{|V_{ud}|^2} - \frac{R_\tau^{S}}{|V_{us}|^2}$$: SU(3) breaking quantity, depend on m_s

$$\delta R_\tau \approx 24\, S_{EW} \frac{m_s^2(m_\tau^2)}{m_\tau^2} \Delta(\alpha_s)$$

$$|V_{us}| = \sqrt{\frac{R_\tau^S}{\frac{R_\tau^{NS}}{|V_{ud}|^2} - \delta R_\tau}}$$

S_{EW} : EW corrections, $\Delta(\alpha_s)$: known upto $\mathcal{O}(\alpha_s^3)$

$\delta R_\tau = 0.242(32)$ Gamiz et al, hep-ph/0612154

Experimental information

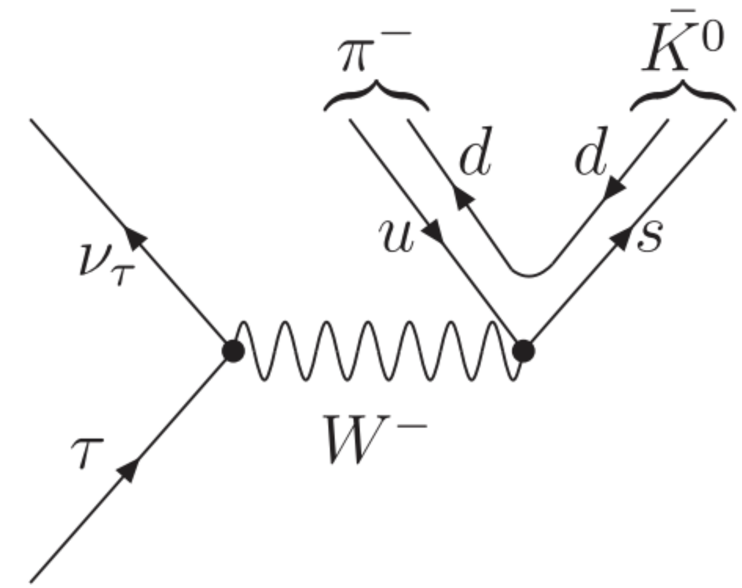
$R_\tau^S = 0.1633(27)$ $R_\tau^{NS} = 3.4718(72)$ $|V_{ud}| = 0.97417(21)$ HFLAV report 2017

$$|V_{us}|_{\tau s} = 0.2186 \pm 0.0018_{\text{exp}} \pm 0.0010_{\text{theory}}$$

$-3.1\,\sigma$ away from unitarity!

CP Violation in tau decays

In the SM, $\tau^+ (\tau^-)$ decay first into a $K^0 (\bar{K}^0)$ state



In experiments, intermediate K_s is not observed directly, rather defined via a final $\pi^+\pi^-$ state with $m_{\pi\pi} \approx m_K$ and decay time τ_S

Therefore, CP asymmetry depends on the integrated decay times and can be expressed as (reconstructed over a time interval $t_1 < \tau_S < t_2$)

$$A^{\tau}_{CP}(t_1, t_2) = \frac{\int_{t_1}^{t_2} dt[\Gamma(K^0(t) \to \pi\pi) - \Gamma(\overline{K}^0(t) \to \pi\pi)]}{\int_{t_1}^{t_2} dt[\Gamma(K^0(t) \to \pi\pi) + \Gamma(\overline{K}^0(t) \to \pi\pi)]}$$

Grossman, Nir, JHEP 04 (2012) 002

Form factors for $\tau \to K_S \pi^- \nu_\tau$

Vector and Tensor form factors are parametrized by **Omnés function**

$$\Omega(s) = \exp\left\{ \frac{s}{\pi} \int_{s_{\pi K}}^{\infty} \frac{\delta(s')}{s'(s'-s)} \right\}$$

with phase taken from Belle's fit

$$f_+(s) = f_+(0)\, \Omega(s),$$

$$B_T(s) = B_T(0)\, \Omega(s),$$

Cirigliano et al, PRL 120, 141803 (2018)

Decay Rate CP Asymmetry

BABAR result reanalysis

Measured asymmetry $A = \dfrac{f_1 A_1 + f_2 A_2 + f_3 A_3}{f_1 + f_2 + f_3}$

$A = (-0.27 \pm 0.18 \pm 0.08)\,\%$

$f_1 \; : \; \tau^- \to \pi^- K^0_S \nu_\tau$ (signal)

$f_2 \; : \; \tau^- \to K^- K^0_S \nu_\tau$

$f_3 \; : \; \tau^- \to \pi^- K^0 \bar{K}^0 \nu_\tau$

BABAR: $A_1 = -A_2 = A_Q$ (valid in SM)

$A_Q = (-0.36 \pm 0.23 \pm 0.11)\,\%$

$A_Q = (0.33 \pm 0.01)\,\%$

BABAR correction factor = 1.08

Correct extraction of asymmetry assuming NP in the signal :

Put $A_2 = (-0.33 \pm 0.01)\,\%$ and extract $A_1 = (-0.33 \pm 0.21 \pm 0.10)\,\%$