Université Claude Bernard Lyon 1

Probing short-distance physics with Kaons

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3rd mini workshop

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Rare kaon decays

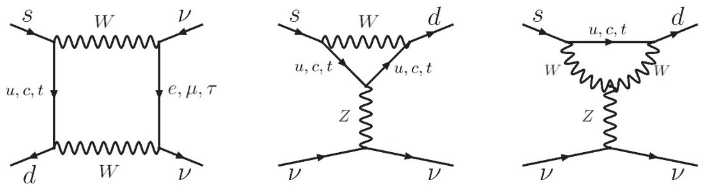
Rare Kaon decays take place via $s \to d$ FCNC and are strongly suppressed in the SM

- Historical tools to study FCNC
- Interesting probe of New Physics → Requires reliable prediction in the SM

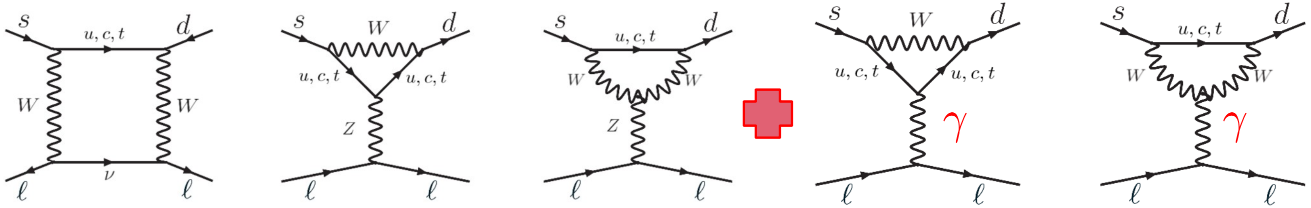
Weak effective Hamiltonian: $\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{td} \frac{\alpha_e}{4\pi} \sum_k C_k^\ell O_k^\ell$

$$O_L^\ell = (\bar{s}\gamma_\mu P_L d)(\bar{\nu}_\ell \gamma^\mu (1-\gamma_5)\nu_\ell), \quad O_9^\ell = (\bar{s}\gamma_\mu P_L d)(\bar{\ell}\gamma^\mu \ell), \quad O_{10}^\ell = (\bar{s}\gamma_\mu P_L d)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$ + other operators

- SD dominated
  - $K^+ \to \pi^+ \nu\nu$ and $K_L \to \pi^0 \nu\nu$ (*golden channels*)



- LD dominated
  - $K_L \to \mu\mu$, $K_S \to \mu\mu$, $K^+ \to \pi^+ \ell\ell$ and $K_L \to \pi^0 \ell\ell, \ldots$



$K^+ \to \pi^+ \nu\nu$

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \frac{\kappa_+ (1+\Delta_{\mathrm{EM}})}{\lambda^{10}} \frac{1}{3} s_W^4 \sum_{\ell} \left[\mathrm{Im}^2 \left(\lambda_t C_L^\ell \right) + \mathrm{Re}^2 \left(-\frac{\lambda_c X_c}{s_w^2} + \lambda_t C_L^\ell \right) \right]$$

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})_{\mathrm{SM}} = (7.86 \pm 0.61) \times 10^{-11}$$

[D'Ambrosio, Iyer, Mahmoudi, SN '22]

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})^{16-18}_{\mathrm{NA62}} = (10.6^{+4.0}_{-3.5} \pm 0.9) \times 10^{-11}$$

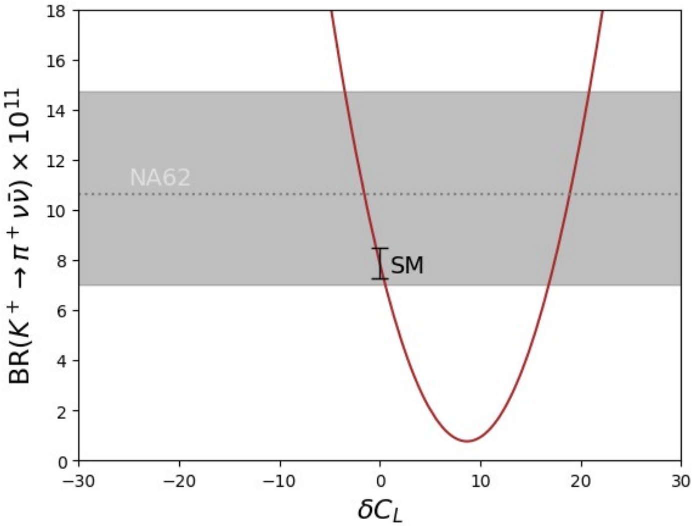
[NA62 Coll., Cortina Gil et al. '21]

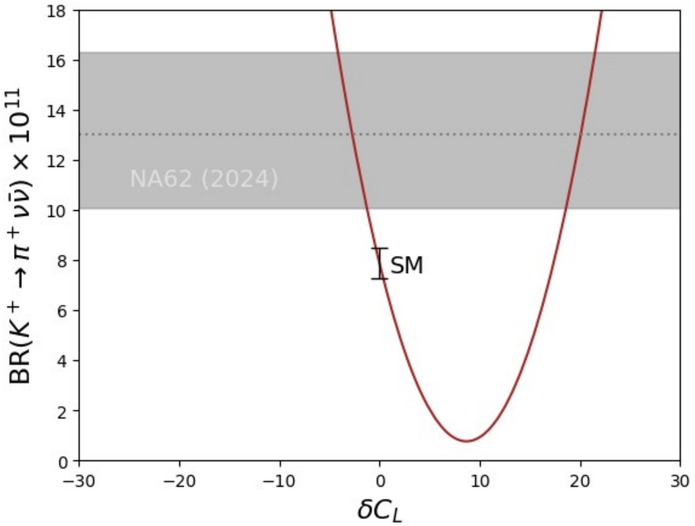
$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})^{16-22}_{\mathrm{NA62}} = \left(13.0^{+3.7}_{-2.7}{}^{+1.3}_{-1.2}\right) \times 10^{-11}$$

[NA62 Coll., J. Swallow talk at CERN]

New Physics effects:

Lepton flavour universal





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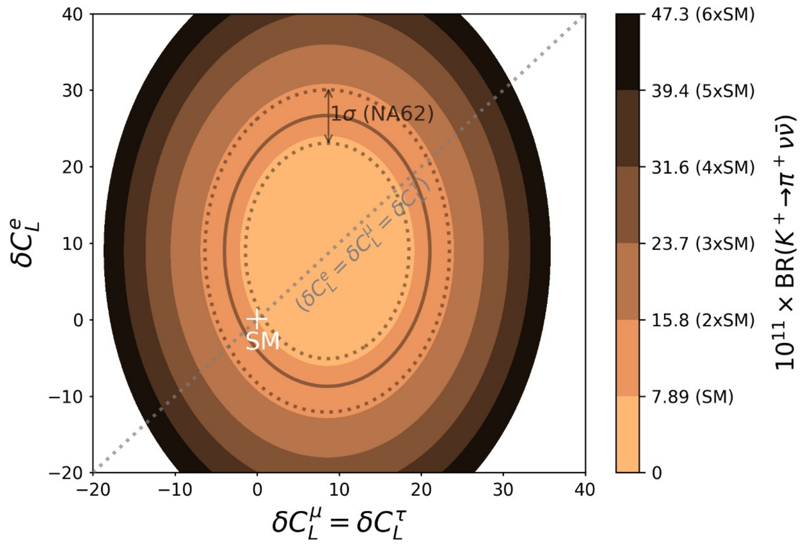
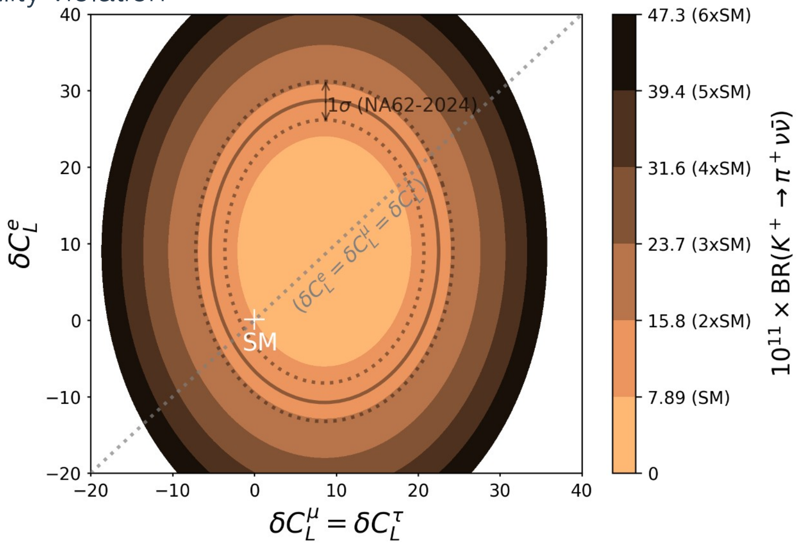
New Physics effects:

Lepton flavour universality violation





$K_L \to \pi^0 \nu\nu$

$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu}) = \frac{\kappa_L}{\lambda^{10}} \frac{1}{3} s_w^4 \sum_\ell \mathrm{Im}^2 \left(\lambda_t C_L^\ell\right)$$

$$\mathrm{BR}(K_L \to \pi^0 \nu\nu)_{\mathrm{SM}} = (2.68 \pm 0.30) \times 10^{-11}$$

[D'Ambrosio, Iyer, Mahmoudi, SN '22]

$$\mathrm{BR}(K_L \to \pi^0 \nu\nu)^{16-18}_{\mathrm{KOTO}} < 3.0 \times 10^{-9} \text{ at } 90\%\mathrm{CL}$$

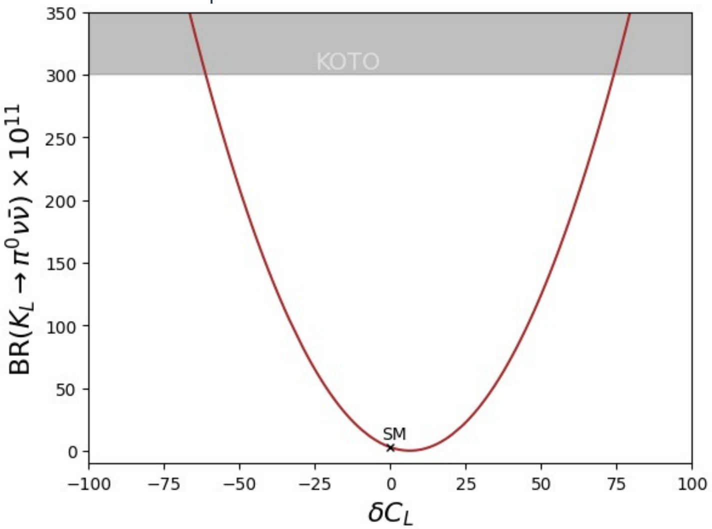
[KOTO Coll., Ahn et al. '18]

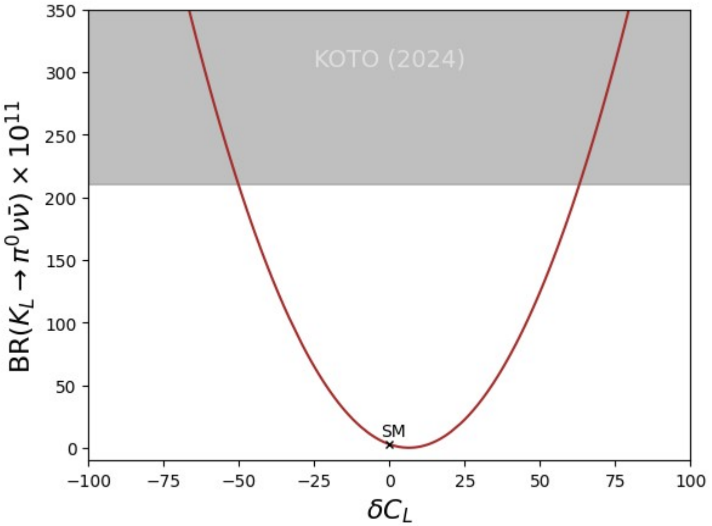
$$\mathrm{BR}(K_L \to \pi^0 \nu\nu)^{21}_{\mathrm{KOTO}} < 2.1 \times 10^{-9} \text{ at } 90\%\mathrm{CL}$$

[KOTO Coll., J. Redeker talk at ICHEP24]

New Physics effects:

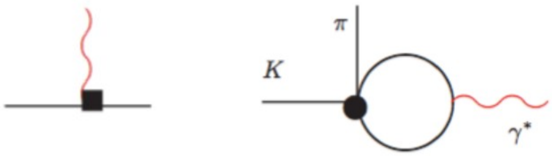
Lepton flavour universal



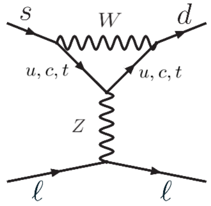


LFUV in $K^+ \to \pi^+ \ell \ell$

$K^+ \to \pi^+ \ell \ell$ is long distance dominated, mediated by single photon exchange $K^+ \to \pi^+ \gamma^*$



LD >> SD



$\Longrightarrow$ precise SM prediction not yet possible

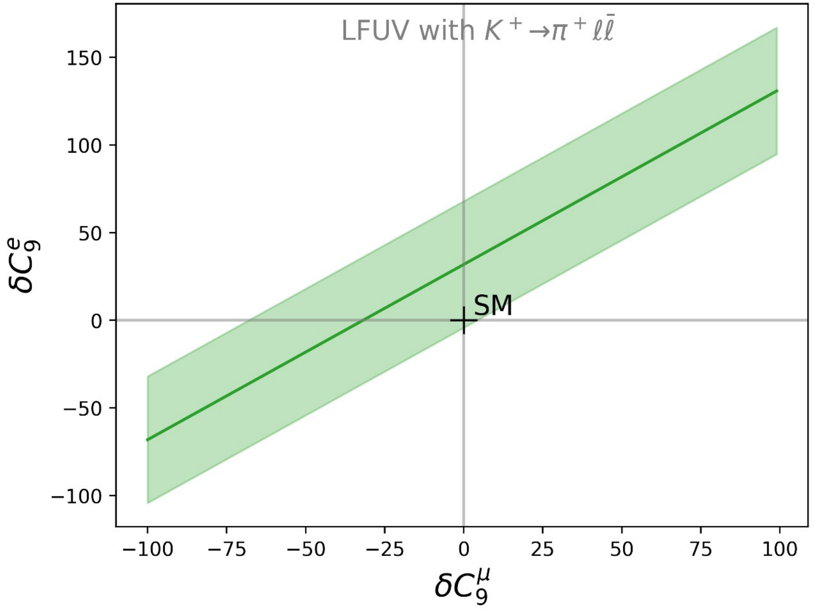
$$\mathcal{A}(z) \propto G_F M_K^2 (a + bz) + W^{\pi\pi}(z) \qquad z = m^2(\ell\ell) / M_K^2$$

form factors (a, b) — loop term ($W^{\pi\pi}$)

LFU predicts the same a for $\ell = e, \mu$ and similarly for b

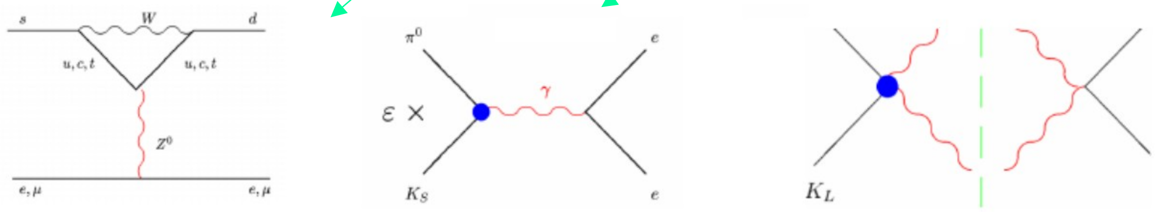
$a^{ee} \neq a^{\mu\mu}$ indicates LFUV NP: $a_+^{\mu\mu} - a_+^{ee} = -\sqrt{2}\,\mathrm{Re}\,[V_{td}V_{ts}^*(C_9^\mu - C_9^e)]$
[Crivellin et al. '16]

Channel	a_+	b_+	Reference
ee	-0.561 ± 0.009	-0.694 ± 0.040	E865 '99 and NA48/2 '09 comb. [D'Ambrosio, Greynat, Knecht '18]
$\mu\mu$	-0.575 ± 0.013	-0.722 ± 0.043	NA62 Coll. '22



$K_L \to \pi^0 \ell\ell$

$$\mathrm{BR}(K_L \to \pi^0 \ell\bar{\ell}) = \left(C^\ell_{\rm dir} \pm C^\ell_{\rm int}|a_S| + C^\ell_{\rm mix}|a_S|^2 + C^\ell_{\gamma\gamma}\right) \cdot 10^{-12}$$

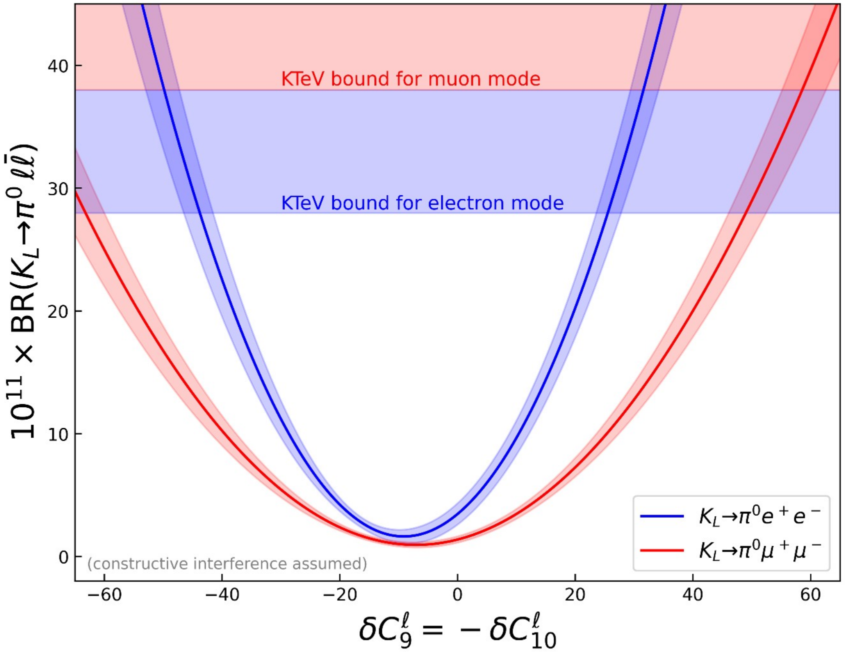


[Dambrosio et al. '98;Isidor et al. '04;Mescia, Smith, Trine '06]

	$C^\ell_{\rm dir}$	$C^\ell_{\rm int}$	$C^\ell_{\rm mix}$	$C^\ell_{\gamma\gamma}$
$\ell = e$	$(4.62 \pm 0.24)(w_{7V}^2 + w_{7A}^2)$	$(11.3 \pm 0.3) w_{7V}$	14.5 ± 0.5	≈ 0
$\ell = \mu$	$(1.09 \pm 0.05)(w_{7V}^2 + 2.32 w_{7A}^2)$	$(2.63 \pm 0.06) w_{7V}$	3.36 ± 0.20	5.2 ± 1.6

[Mescia, Smith, Trine '06]

$$w_{7V} = \frac{1}{2\pi} \mathrm{Im}\left[\frac{\lambda_t^{sd}}{1.407 \times 10^{-4}} C_9\right], \quad w_{7A} = \frac{1}{2\pi} \mathrm{Im}\left[\frac{\lambda_t^{sd}}{1.407 \times 10^{-4}} C_{10}\right]$$



$$\mathrm{BR}^{\rm SM}(K_L \to \pi^0 e\bar{e}) = 3.46^{+0.92}_{-0.80}\,(1.55^{+0.60}_{-0.48}) \times 10^{-11}$$

$$\mathrm{BR}^{\rm SM}(K_L \to \pi^0 \mu\bar{\mu}) = 1.38^{+0.27}_{-0.25}\,(0.94^{+0.21}_{-0.20}) \times 10^{-11}$$

[D'Ambrosio, Iyer, Mahmoudi, SN '22]

$$\mathrm{BR}^{\rm exp}(K_L \to \pi^0 e\bar{e}) < 28 \times 10^{-11} \quad \text{at 90\% CL}$$

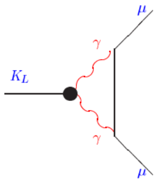
$$\mathrm{BR}^{\rm exp}(K_L \to \pi^0 \mu\bar{\mu}) < 38 \times 10^{-11} \quad \text{at 90\% CL}$$

[KTeV '00 and '03]

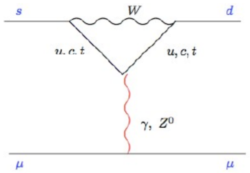
$K_L \to \mu\,\mu$

$K_L \to \mu\,\mu$ is long distance dominated, mediated by two photons via $K_L \to \gamma^* \gamma^*$

$$\mathrm{BR}(K_L \to \mu\bar{\mu}) = \tau_L \frac{f_K^2 m_K^3 \beta_\mu}{16\pi} \left| N_L^{\mathrm{LD}} - \left(\frac{2m_\mu}{m_K} \frac{G_F \alpha_e}{\sqrt{2}\pi}\right) \mathrm{Re}\left[-\lambda_c \frac{Y_c}{s_W^2} + \lambda_t C_{10}^{\ell}\right]\right|^2$$



LD >> SD



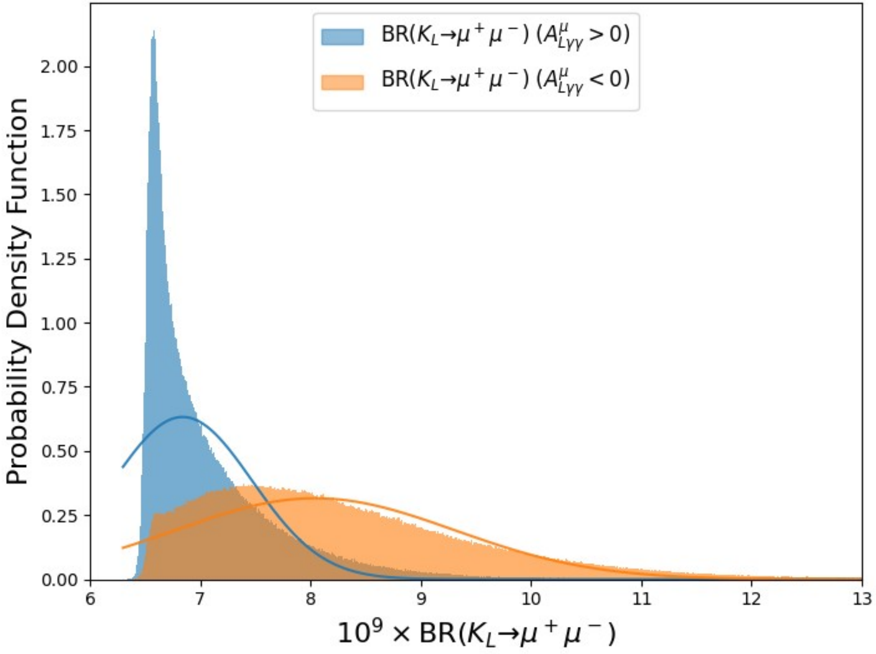
$$N_L^{\mathrm{LD}} \propto (\chi_{\mathrm{disp}} + i\chi_{\mathrm{abs}}) \longrightarrow N_L^{\mathrm{LD}} = \pm\,[0.54(77) - 3.95i] \times 10^{-11}\,(\mathrm{GeV})^{-2}$$

[D'Ambrosio et al. '86 '97 Isidori, Unterdorfer '03;D'Ambrosio et al. '17]

- Prediction depends on the sign of $A(K_L \to \gamma\gamma)$ contribution
- Uncertainty highly asymmetric

$$\mathrm{BR}(K_L \to \mu\bar{\mu})_{\mathrm{SM}} = \begin{cases} \mathrm{LD}(+):\ (6.82^{+0.77}_{-0.24} \pm 0.04) \times 10^{-9} \\ \mathrm{LD}(-):\ (8.04^{+1.46}_{-0.97} \pm 0.09) \times 10^{-9} \end{cases}$$

[D'Ambrosio, Iyer, Mahmoudi, SN '22]



$K_L \to \mu\,\mu$

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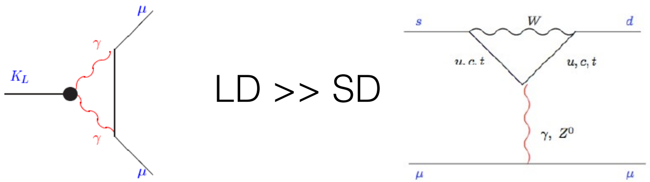

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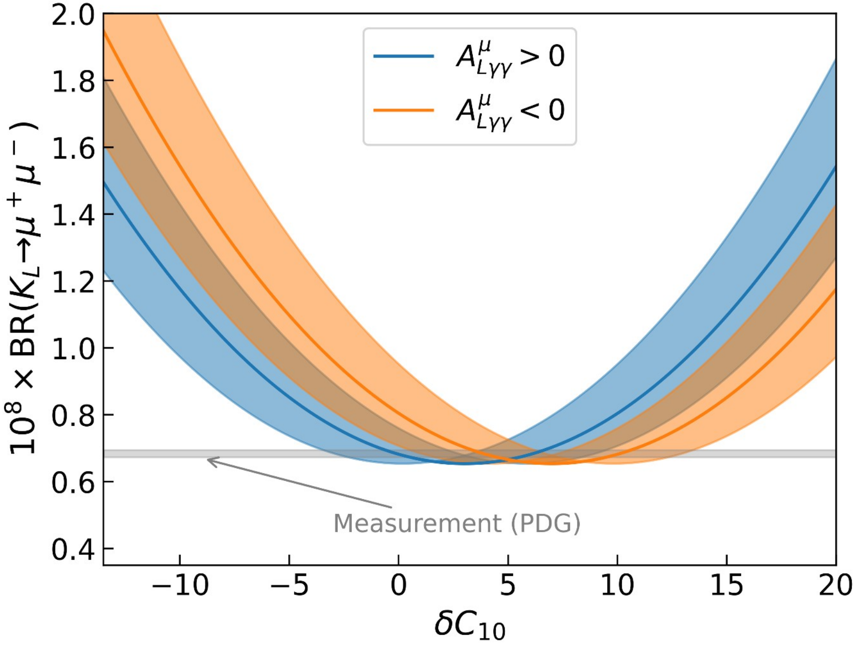

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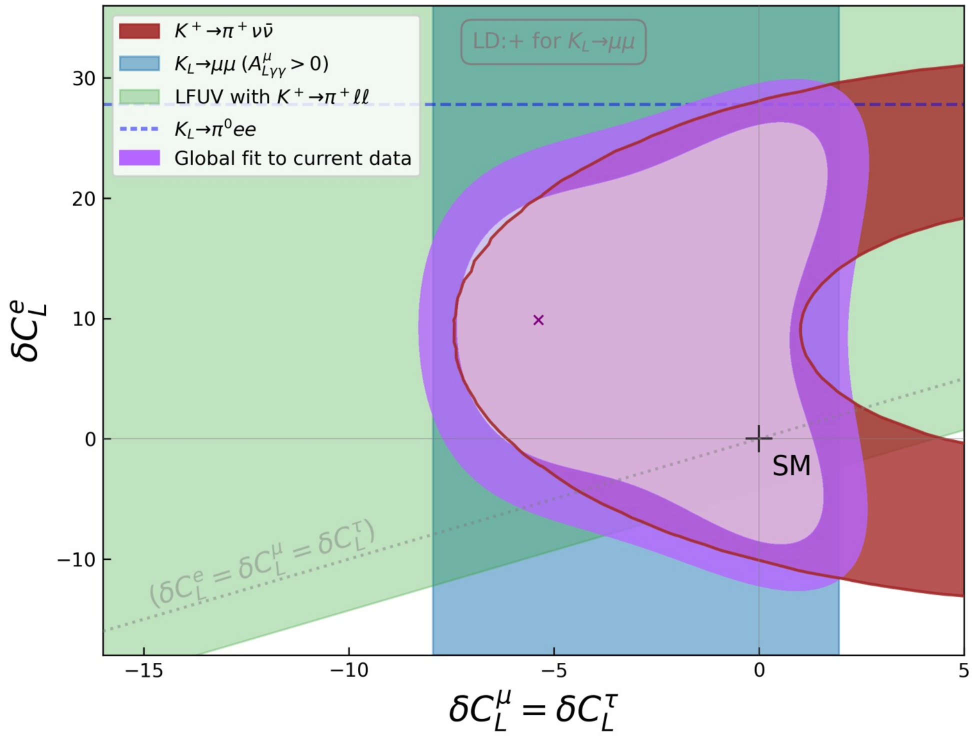
[D'Ambrosio, Iyer, Mahmoudi, SN '22]

$$\mathrm{BR}(K_L \to \mu\bar{\mu})_{\mathrm{exp}} = (6.84 \pm 0.11) \times 10^{-9}$$ [PDG]

All observables / Global fit

Fit with SuperIso (considering positive LD+ for $K_L \to \mu\mu$ and positive interference for $K^+ \to \pi^+ \ell\ell$)



We assume:

- only vectorial and axial NP contributions
- NP contributions of the charged and neutral leptons related to each other by the SU(2)$_L$ gauge symmetry and we work in the chiral basis

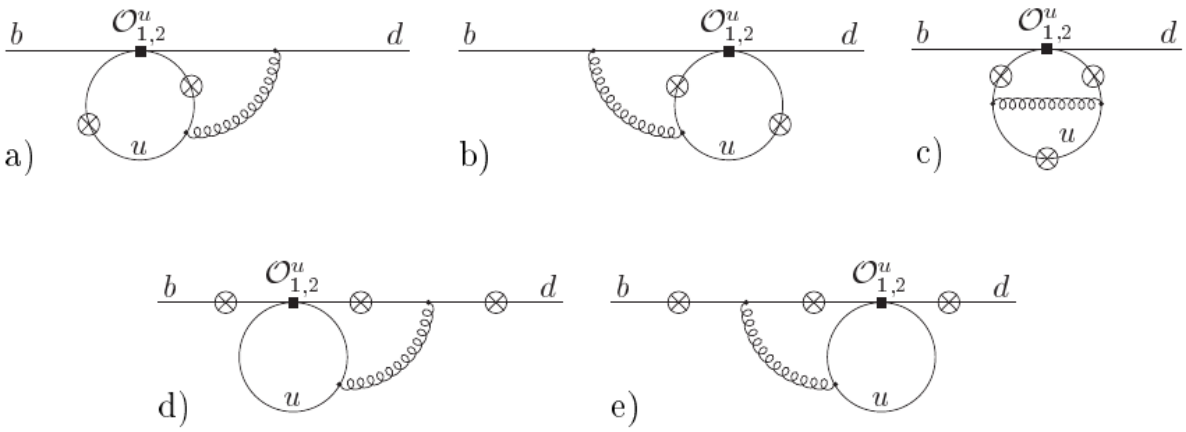
$$\delta C_L^\ell \equiv \delta C_9^\ell = -\delta C_{10}^\ell$$

Lighter / **darker** purple region: **68%** / **95%** CL of global fit

Some issues to consider for SuperIso

- How to treat asymmetric uncertainty inputs
- How to treat asymmetric uncertainty for a calculated observable
- Is there a meaningful way of considering asymmetric uncertainties in fits

Loop functions

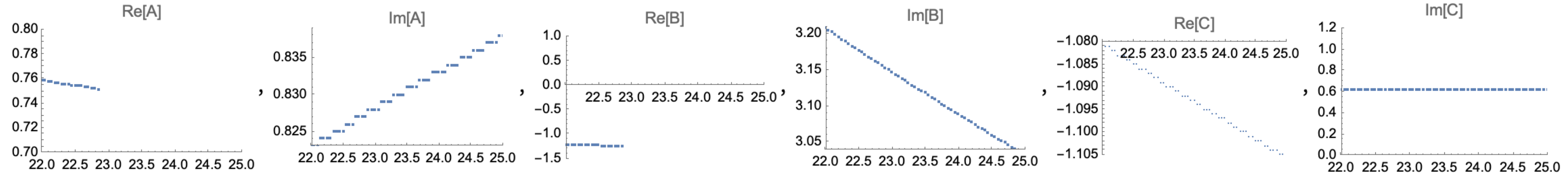


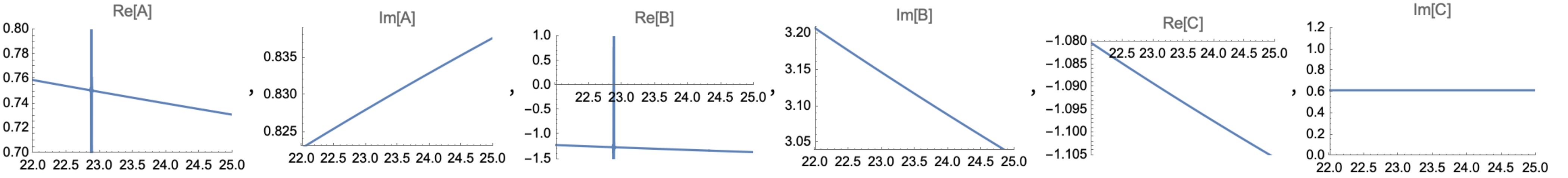
[Seidel '04]

$$\langle d\ell^+\ell^-|\mathcal{O}_i^u|b\rangle_{\substack{\text{non-fact.}\\ \text{two-loop}}} = \frac{\alpha_s}{4\pi}\left(F_{i,u}^{(7)}\langle\tilde{\mathcal{O}}_7\rangle_{\text{tree}} + F_{i,u}^{(9)}\langle\tilde{\mathcal{O}}_9\rangle_{\text{tree}}\right)$$

$$\begin{aligned} F_{1,u}^{(7)} &= A(s), \\ F_{2,u}^{(7)} &= -6A(s), \\ F_{1,u}^{(9)} &= B(s) + 4C(s), \\ F_{2,u}^{(9)} &= -6B(s) + 3C(s), \end{aligned}$$

Loop functions





$$A(s) = -\frac{104}{243}\ln\left(\frac{m_b^2}{\mu^2}\right) + \frac{4\hat{s}}{27(1-\hat{s})}\left[\mathrm{Li}_2(\hat{s}) + \ln(\hat{s})\ln(1-\hat{s})\right]$$
$$+\frac{1}{729(1-\hat{s})^2}\left[6\hat{s}\left(29-47\hat{s}\right)\ln(\hat{s}) + 785 - 1600\hat{s} + 833\hat{s}^2 + 6\pi i\left(20 - 49\hat{s} + 47\hat{s}^2\right)\right]$$
$$-\frac{2}{243(1-\hat{s})^3}\left[2\sqrt{z-1}\left(-4+9\hat{s}-15\hat{s}^2+4\hat{s}^3\right)\mathrm{arccot}(\sqrt{z-1}) + 9\hat{s}^3\ln^2(\hat{s}) + 18\pi i\hat{s}\left(1-2\hat{s}\right)\ln(\hat{s})\right]$$
$$+\frac{2\hat{s}}{243(1-\hat{s})^4}\left[36\,\mathrm{arccot}^2(\sqrt{z-1}) + \pi^2\left(-4+9\hat{s}-9\hat{s}^2+3\hat{s}^3\right)\right] \qquad (29)$$

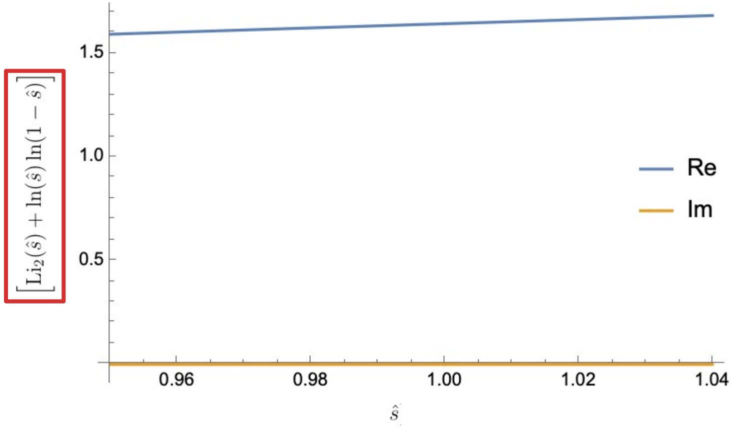
$$B(s) = \frac{8}{243\hat{s}}\left[(4-34\hat{s}-17\pi i\hat{s})\ln\left(\frac{m_b^2}{\mu^2}\right) + 8\hat{s}\ln^2\left(\frac{m_b^2}{\mu^2}\right) + 17\hat{s}\ln(\hat{s})\ln\left(\frac{m_b^2}{\mu^2}\right)\right]$$
$$+\frac{(2+\hat{s})\sqrt{z-1}}{729\hat{s}}\left[-48\ln\left(\frac{m_b^2}{\mu^2}\right)\mathrm{arccot}(\sqrt{z-1}) - 18\pi\ln(z-1) + 3i\ln^2(z-1)\right.$$
$$-24i\,\mathrm{Li}_2(-x_2/x_1) - 5\pi^2 i + 6i\Big(-9\ln^2(x_1) + \ln^2(x_2) - 2\ln^2(x_4)$$
$$+6\ln(x_1)\ln(x_2) - 4\ln(x_1)\ln(x_3) + 8\ln(x_1)\ln(x_4)\Big)$$
$$\left.-12\pi\Big(2\ln(x_1) + \ln(x_3) + \ln(x_4)\Big)\right]$$
$$-\frac{2}{243\hat{s}(1-\hat{s})}\left[4\hat{s}\left(-8+17\hat{s}\right)\left(\mathrm{Li}_2(\hat{s}) + \ln(\hat{s})\ln(1-\hat{s})\right)\right. + \ldots$$

Logarithm and the Dilogarithm have a branch cut:

When $s > 1$ for small $\epsilon > 0$:

- $\mathrm{Im}[\mathrm{Li}_2(s + \pm i\epsilon)] = \mp\pi\,\mathrm{Log}(s)$
- $\mathrm{Log}(1 - s + \pm i\epsilon)] = \mathrm{Log}(s-1) \pm i\pi$

$$\Longrightarrow \mathrm{Im}[\mathrm{Li}_2(s + \pm i\epsilon) + \mathrm{Log}(s + \pm i\epsilon)\mathrm{Log}(1 - s + \pm i\epsilon)]$$
$$= \mp\pi\,\mathrm{Log}(s) + \mathrm{Log}(s)\,(\pm\pi) = 0$$



But they must be treated in the same way

- Care needs to taken when dealing with log and DiLog, etc. functions
- For future calculations one might need them for non-physical regions $q^2 \equiv s < 0$

Backup

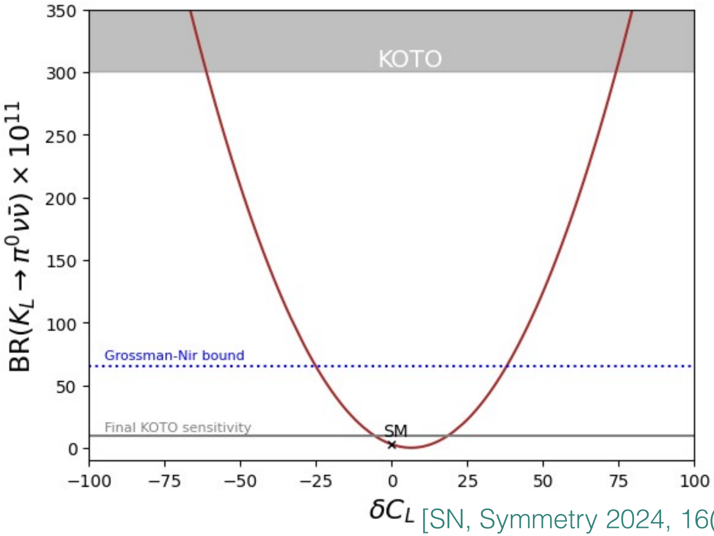
$K_L \to \pi^0 \nu\nu$

Matrix elements of $K_L \to \pi^0 \nu\nu$ and $K^+ \to \pi^+ \nu\nu$ are related via isospin resulting in the Grossman-Nir bound [Grossman, Nir '97]

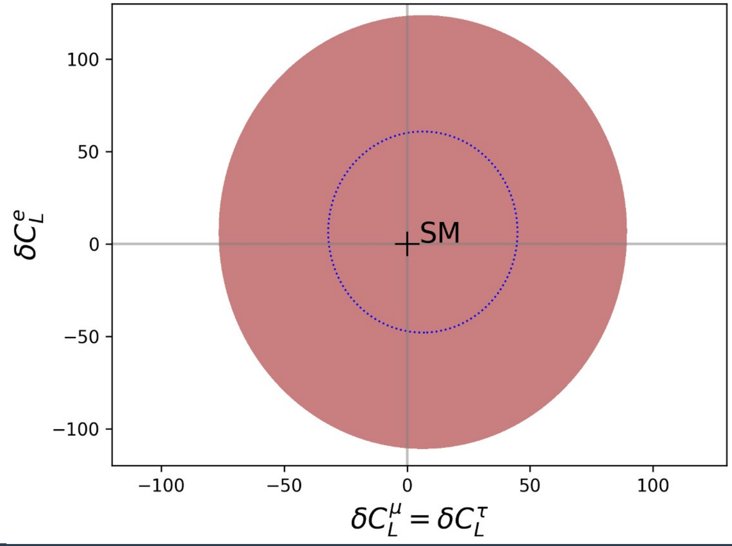
$$\mathrm{BR}(K_L \to \pi^0 \nu\nu) \leq 4.3 \times \mathrm{BR}(K^+ \to \pi^+ \nu\nu)$$

valid in the presence of most NP models

Considering the 2021 results of NA62 for $\mathrm{BR}(K^+ \to \pi^+ \nu\nu)$



[SN, Symmetry 2024, 16(8), 946]



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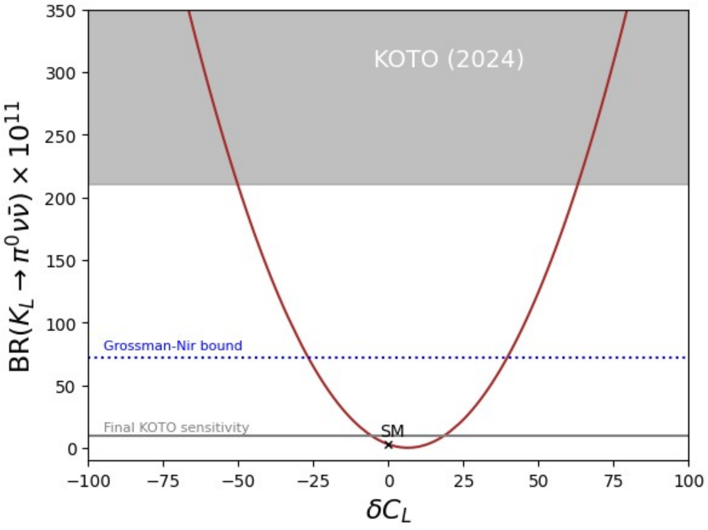
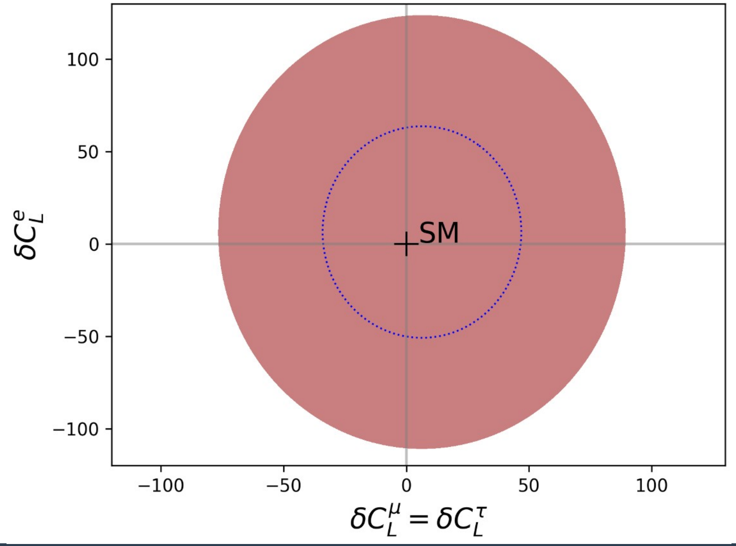
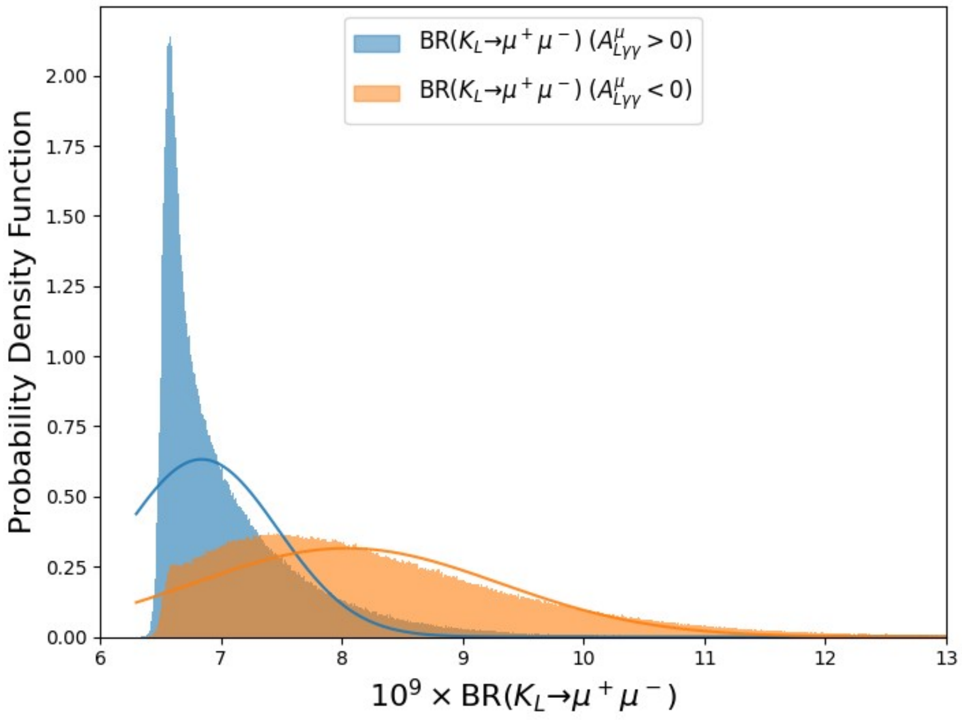
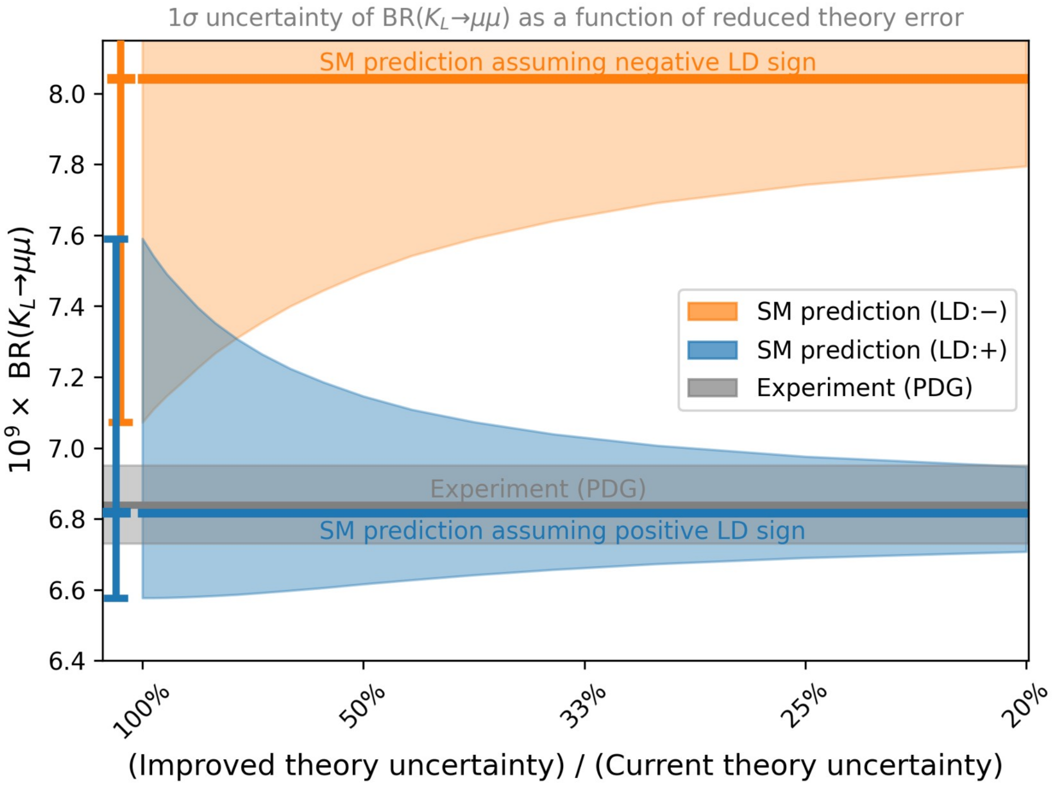




Backup

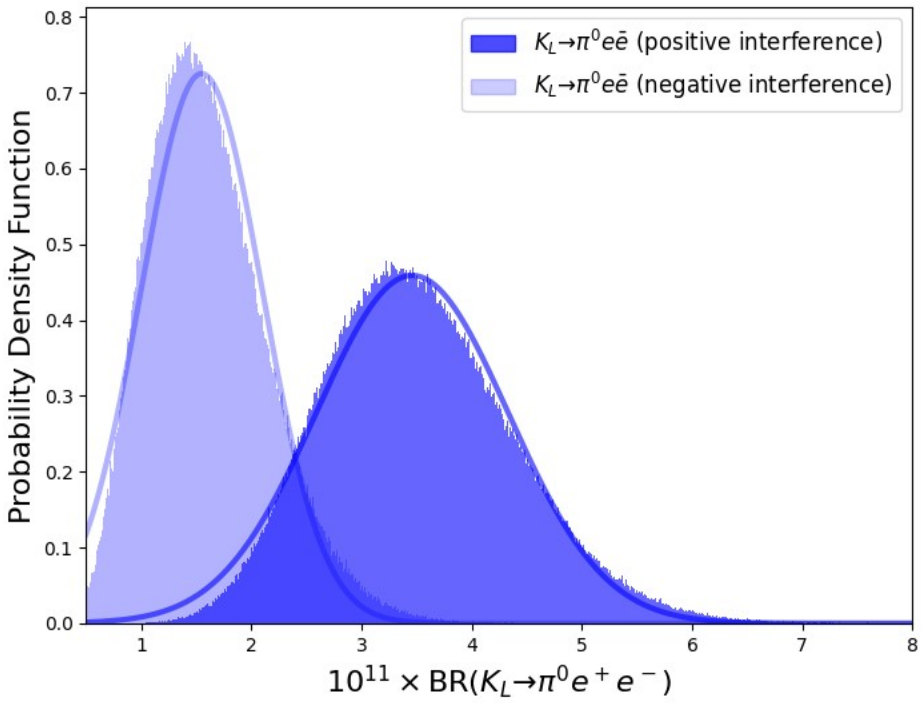
Asymmetric theoretical uncertainty of $K_L \to \mu\mu$

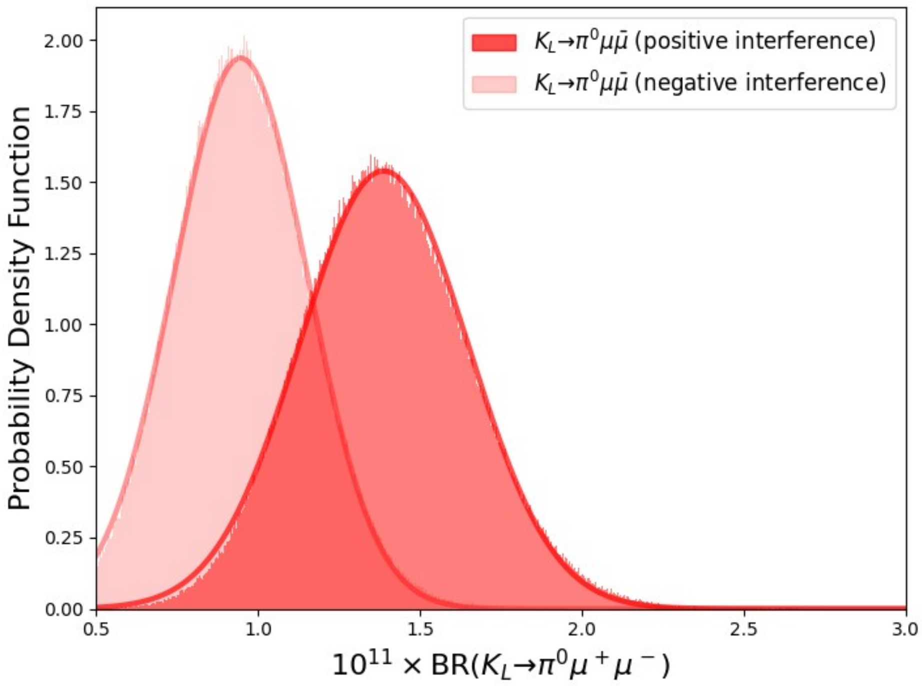




Backup

Asymmetric theoretical uncertainty of $K_L \to \pi^0 \ell\ell$





$K_S \to \mu\,\mu$

$$\mathrm{BR}(K_S \to \mu\bar{\mu}) = \tau_S \frac{f_K^2 m_K^3 \beta_\mu}{16\pi} \left\{ \beta_\mu^2 \left| N_S^{\mathrm{LD}} \right|^2 + \left(\frac{2m_\mu}{m_K} \frac{G_F \alpha_e}{\sqrt{2}\pi} \right)^2 \mathrm{Im}^2 \left[-\lambda_c \frac{Y_c}{s_W^2} + \lambda_t C_{10}^\ell \right] \right\}$$

The long-distance contribution is cleaner, as the leading $O(p^4)$ chiral contribution of $K_S \to \pi^+\pi^- \to \gamma\gamma \to \mu^+\mu^-$ is theoretically under better control [Ecker, Pich '91]

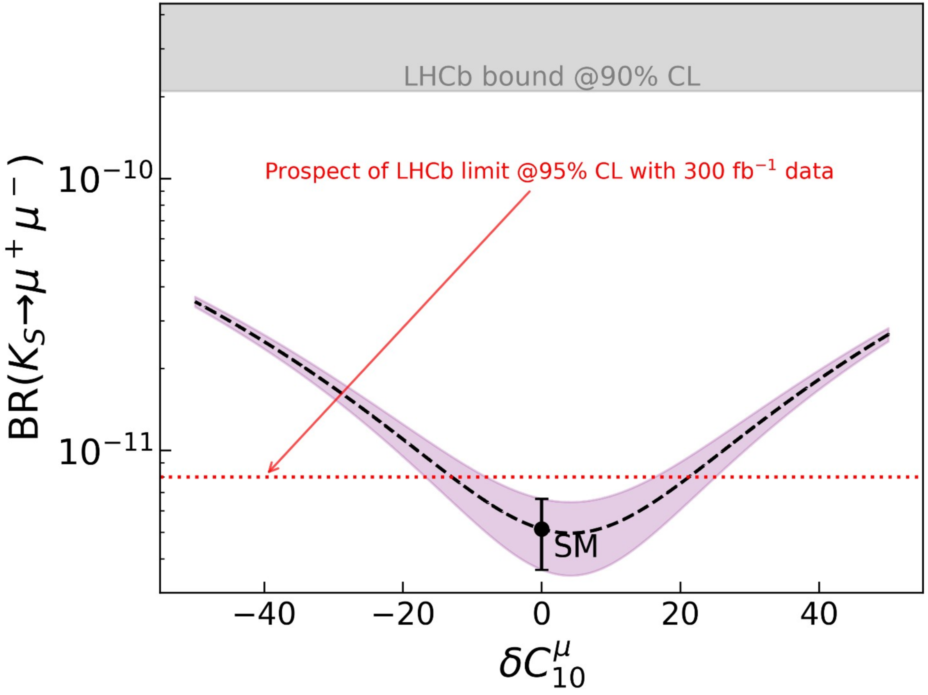
$$\mathrm{BR}(K_S \to \mu\bar{\mu})^{\mathrm{SM}} = (5.15 \pm 1.50) \times 10^{-12}$$

[D'Ambrosio, Iyer, Mahmoudi, SN '22]

$$\mathrm{BR}(K_S \to \mu\bar{\mu})^{\mathrm{LHCb}} < 2.1(2.4) \times 10^{-10} \;\; @90(95)$$

[LHCb '20]

- $K_S \to \mu\mu$ not very sensitive to axial currents
- Sensitive to new physics scenarios involving scalar and pseudoscalar contributions



Scalar and pseudoscalar contributions in $K_S \to \mu\,\mu$

Adding scalar contributions

$$\mathcal{H}_{\text{eff}}^{\text{scalar}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{td} \frac{\alpha_e}{4\pi} \left[C_S^\ell O_S^\ell + C_P^\ell O_P^\ell\right]$$

$$O_S^\ell = (\bar{s} P_R d)(\bar{\ell}\ell), \quad O_P^\ell = (\bar{s} P_R d)(\bar{\ell}\gamma_5 \ell)$$

$$\text{BR}(K_S \to \mu\bar{\mu}) = \tau_S \frac{f_K^2 m_K^3 \beta_\mu}{16\pi} \left\{ \beta_\mu^2 \left| N_S^{\text{LD}} - m_K \frac{G_F \alpha_e}{\sqrt{2}\pi} \text{Re}\left[\frac{\lambda_t C_S}{m_s + m_d}\right] \right|^2 + \left(\frac{G_F \alpha_e}{\sqrt{2}\pi}\right)^2 \left| \frac{2m_\mu}{m_K} \text{Im}\left[-\lambda_c \frac{Y_c}{s_W^2} + \lambda_t C_{10}\right] + m_K \text{Im}\left[\frac{\lambda_t C_P}{m_s + m_d}\right] \right|^2 \right\}$$

[Chobanova et al. ‘17]

- $K_S \to \mu\mu$ measurement currently two orders of magnitude above SM
- What does current data of other modes say about scalar and pseudoscalar contributions?

Scalar contributions in $K^+ \to \pi^+ \ell \ell$

Looking again into $K^+ \to \pi^+ \ell^+ \ell^-$ in the presence of scalar contributions

$$\mathcal{M} = \frac{\alpha G_F}{4\pi} f_V(z)(p_K + p_\pi)^\mu \bar{\ell}\gamma_\mu \ell + G_F m_K f_S \bar{\ell}\ell$$

$$\frac{d\Gamma}{dz} = \frac{2}{3}\frac{G_F^2 M_K^5}{2^8\pi^3}\beta_\ell \lambda^{1/2}(z) \times \left\{ |f_V|^2\, 2\frac{\alpha^2}{16\pi^2}\lambda(z)\left(1 + 2\frac{r_\ell^2}{z}\right) + |f_S|^2\, 3\, z\beta_\ell^2 \right\}$$

$r_\ell = m_\ell / m_K,$

$r_\pi = m_\pi / m_K,$

$\beta_\ell = \sqrt{1 - 4 r_\ell^2 / z},$

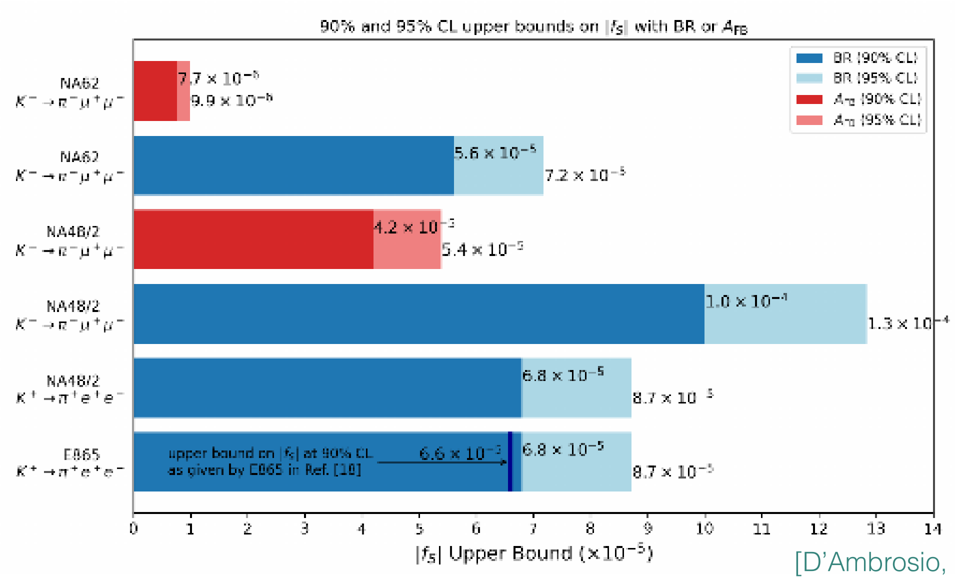
$\lambda(z) = 1 + z^2 + r_\pi^4 - 2(z + r_\pi^2 + z r_\pi^2)$

$$A_{\rm FB}(z) = \frac{\alpha_e G_F^2 m_K^5}{2^8\pi^4} r_\ell \beta_\ell^2 \lambda(z) \mathrm{Re}[f_V^* f_S] \Big/ \left(\frac{d\Gamma(z)}{dz}\right)$$

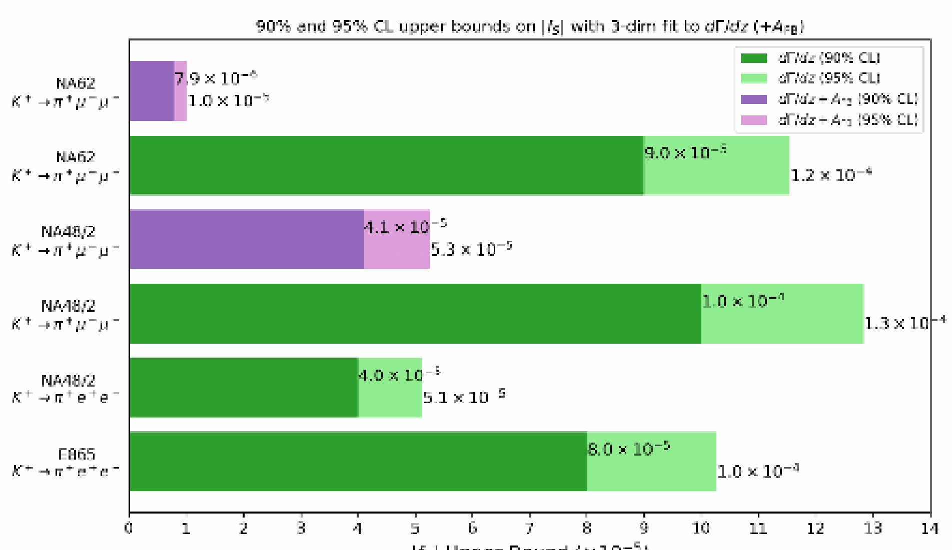
[Chen et al. ‘03, Gao '03]

- If assumed SM-like only f_V contributes
- $A_{\rm FB}$ only non-zero in case $f_S \neq 0$; for electron mode always suppressed by electron mass
- Both the the various bins of the differential decay width and the integrated (BR) can probe f_S

Scalar and pseudoscalar contributions in $K_S \to \mu\,\mu$



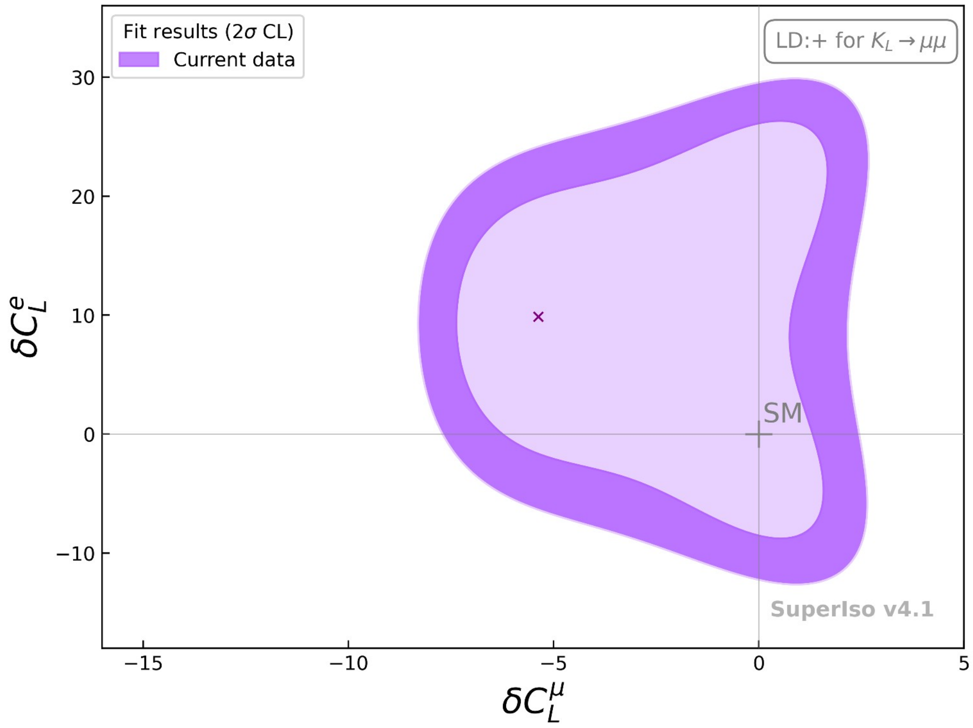
[D'Ambrosio, Iyer, Mahmoudi, SN '24]



- Previous bound on f_S via $\mathrm{BR}(K^+ \to \pi^+ e^+ e^-)$ from E865 data $|f_S| < 6.6 \times 10^{-5}$ at 90% CL
- In the muon mode also A_{FB} be considered
- ~one order of magnitude stronger bound by analyzing simultaneously BR and $d\Gamma/dz$ with $|f_S| < 7.9 \times 10^{-6}$ at 90% CL

Prospects for future measurements

Prospects for KOTO-II



Current situation

Scenario 1

- NA62 final precision for $K^+ \to \pi^+ \nu\nu$
- KOTO-II final precision for $K_L \to \pi^0 \nu\nu$

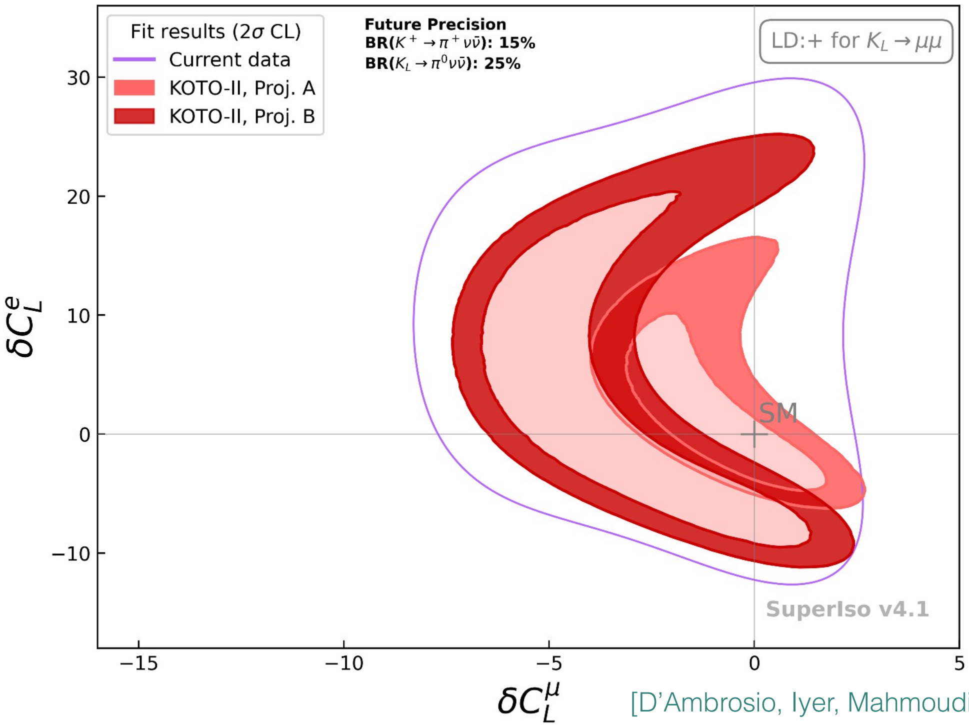
Projection A

Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

Projection B

All measurements give current best-fit point with target precision of KOTO-II

Prospects for KOTO-II



[D'Ambrosio, Iyer, Mahmoudi, SN '24]

Current situation

Scenario 1

- NA62 final precision for $K^+ \to \pi^+ \nu\nu$
- KOTO-II final precision for $K_L \to \pi^0 \nu\nu$

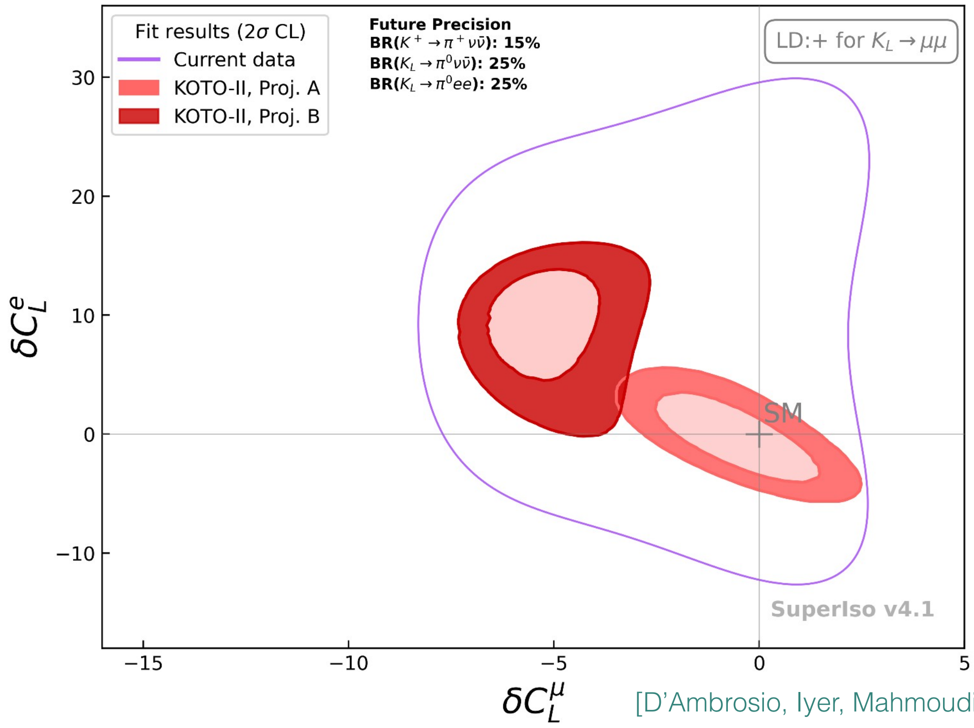
Projection A

Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

Projection B

All measurements give current best-fit point with target precision of KOTO-II

Prospects for KOTO-II



[D'Ambrosio, Iyer, Mahmoudi, SN '24]

— Current situation

Scenario 2

- NA62 final precision for $K^+ \to \pi^+ \nu\nu$
- KOTO-II final precision for $K_L \to \pi^0 \nu\nu$
- KOTO-II measurement of $K_L \to \pi^0 e^+ e^-$

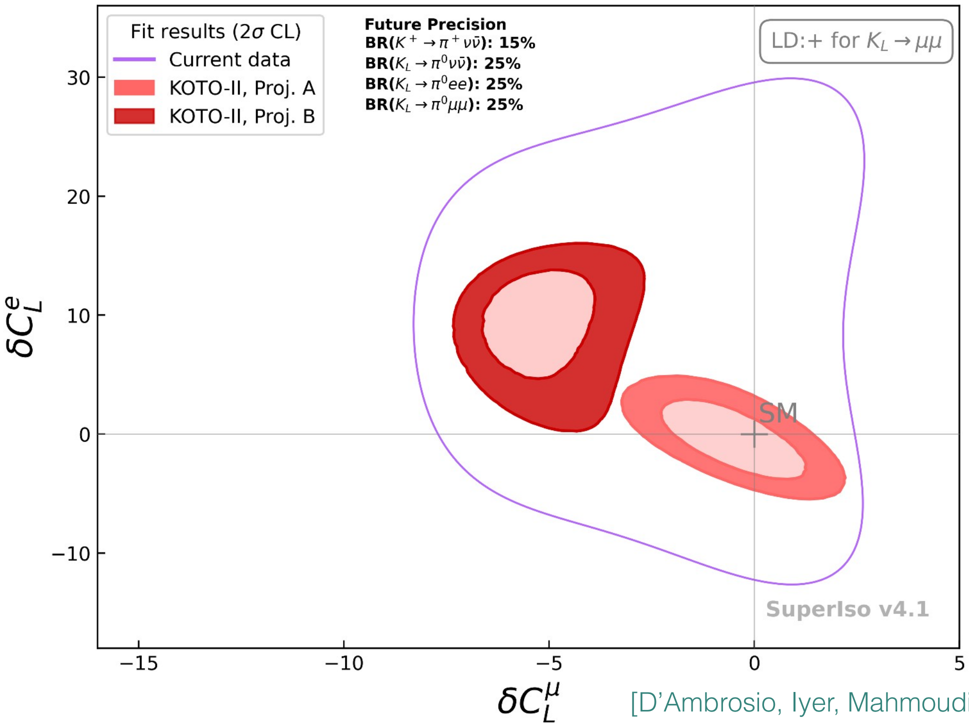
Projection A

Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

Projection B

All measurements give current best-fit point with target precision of KOTO-II

Prospects for KOTO-II



[D'Ambrosio, Iyer, Mahmoudi, SN '24]

Current situation

Scenario 3

- NA62 final precision for $K^+ \to \pi^+ \nu\nu$
- KOTO-II final precision for $K_L \to \pi^0 \nu\nu$
- KOTO-II measurement of $K_L \to \pi^0 e^+ e^-$
- KOTO-II measurement of $K_L \to \pi^0 \mu^+ \mu^-$

Projection A

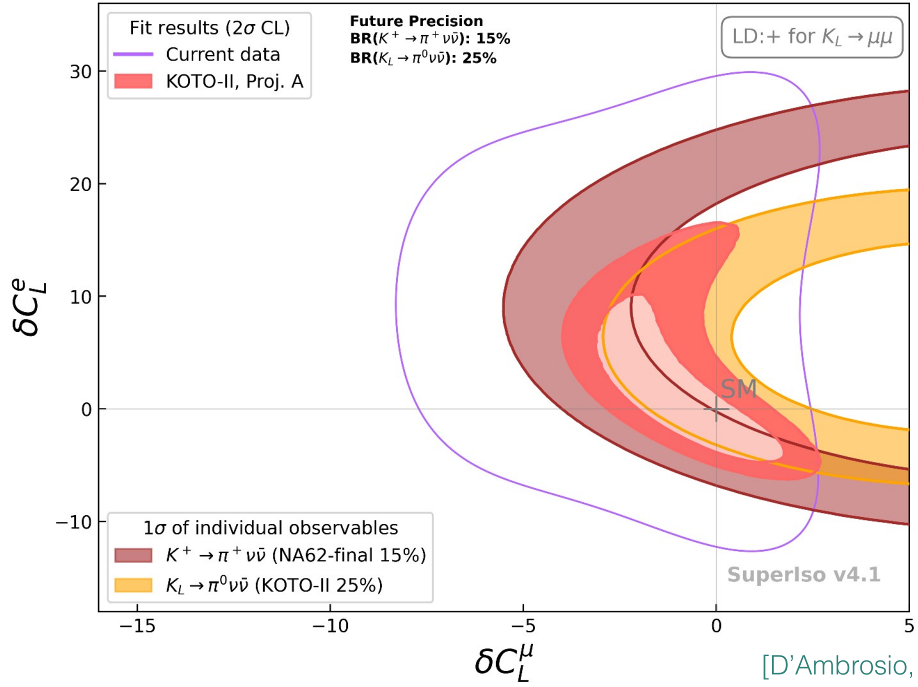
Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

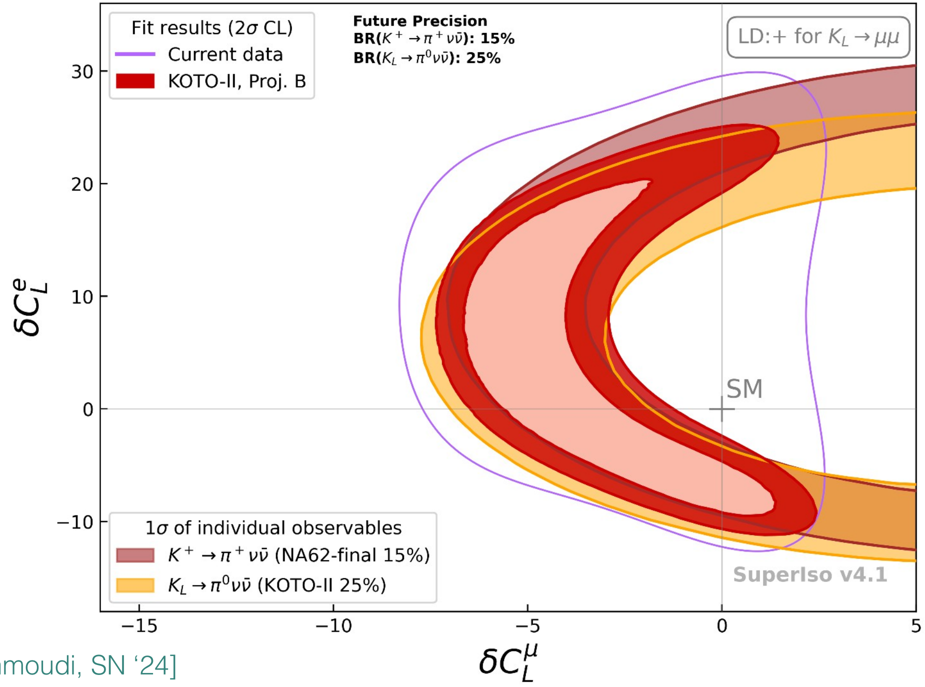
Projection B

All measurements give current best-fit point with target precision of KOTO-II

Impact of projected measurements

Scenario 1





[D'Ambrosio, Iyer, Mahmoudi, SN '24]

Projection A

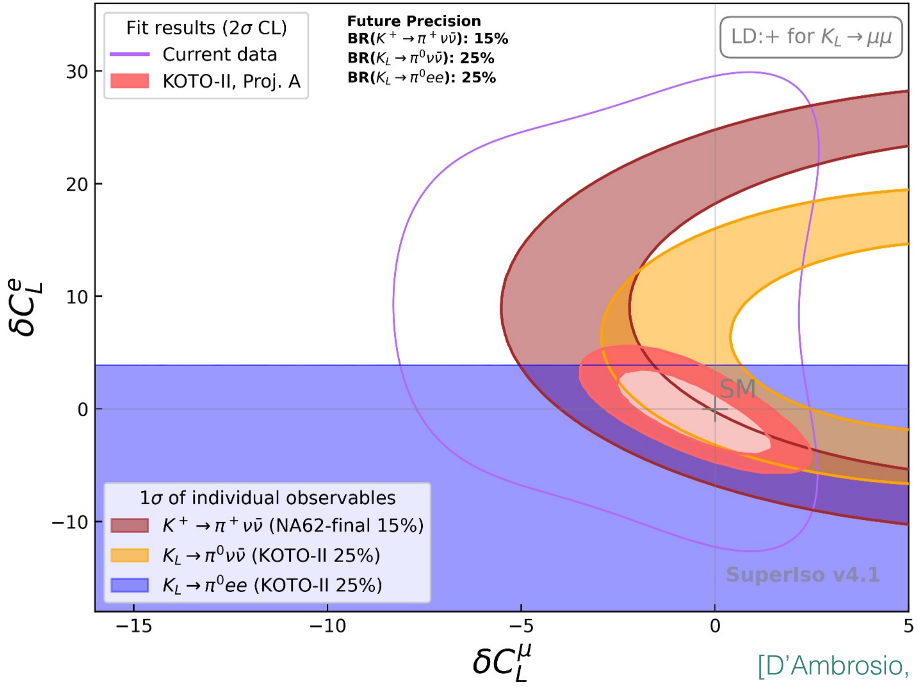
Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

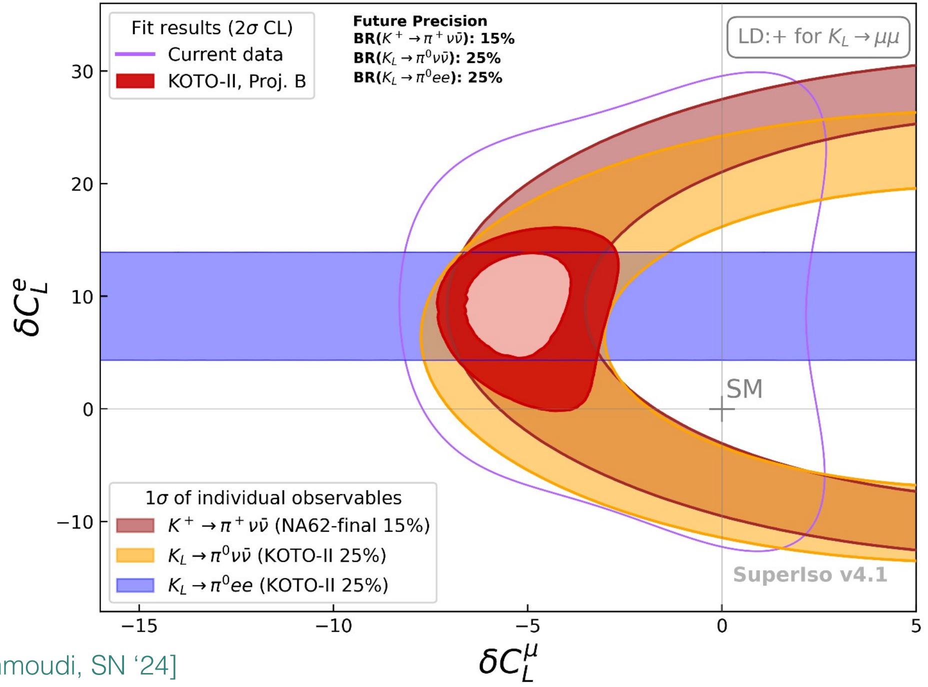
Projection B

All measurements give current best-fit point with target precision of KOTO-II

Impact of projected measurements

Scenario 2





[D'Ambrosio, Iyer, Mahmoudi, SN '24]

Projection A

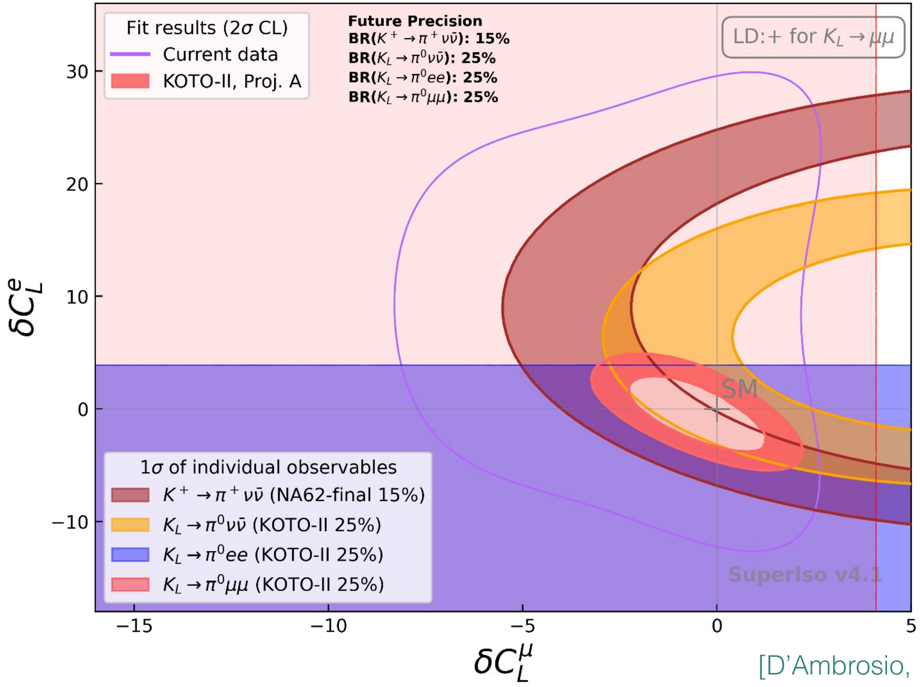
Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

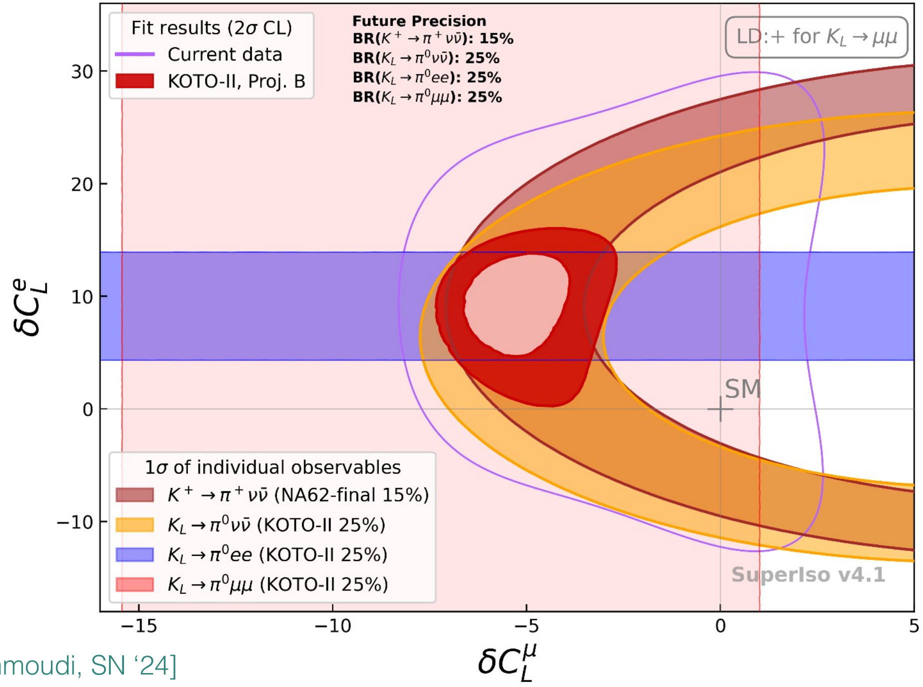
Projection B

All measurements give current best-fit point with target precision of KOTO-II

Impact of projected measurements

Scenario 3





[D'Ambrosio, Iyer, Mahmoudi, SN '24]

Projection A

Observables already measured are kept, others assumed to match SM, with target precision of KOTO-II

Projection B

All measurements give current best-fit point with target precision of KOTO-II