

Lepton Flavor Universality Violation: the Experimental View. PASCOS 2024, ICISE, Quy Nhon, Vietnam, July 9, 2024

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Outline

- What is LFUV and why it is relevant
- Experiments and data sets
- Low energy
	- Light mesons decays
	- Tau decays
- High energy:
	- W and Z decays
	- TeV scale
- Heavy flavour transitions
	- c->s l nu transitions
	- b->s l l transitions
	- b->c l nu transitions
- Conclusions

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What is LFUV and why it matters $U(3)_{L_L}\times U(3)_{E_R}$ $\begin{array}{c} \nint \text{m of } t \text{ and } \n\end{array}$ r antistributions interactions are less energy, believed to cause the accelerating expansion of the Universe, is another source of mystery $\sim g \,\delta_{ij}$

 $\overline{\smash{\bigcup_{i=1}^{N}}\,}$

Li

- SM: 3 generations of leptons with the same gauge couplings win tune tuning of $\Delta V E \overline{I}^t E^j I$ $\mathcal{L}_{\mathrm{SM}} \supset Y_{ij}^E \overline{L}_L^i E_R^j H + \overline{\hbar} c$ new physics (NP) and is usually called \mathbf{u} . $\begin{array}{ccc} \hline \text{I} & \text{I} &$ • Yukawa sector breaks the universality in two ways $m_e \neq m_\mu \neq m_\tau$
	- Difference in masses and Higgs coupling $\begin{array}{|c|c|}\hline \textbf{L} & \textbf{$
- SM fields do mix: The Standard Model is Lepton μ μ μ and μ and μ and μ and μ and μ H_2 Non Universal tlenus but it is NOT Lepton \parallel corrections could be much smaller. There are, however, many observations that are not explained $\ell_{\rm max}$ $\mu_{\rm max}$ τ • The Standard Model is Lepton Flavour Non Universal (LFNU) but it is NOT Lepton
	- Quarks \rightarrow CKM matrix Violating (LFV)
	- Neutrinos \rightarrow PMNS, matrix \mathcal{L} the SM, and with gravity, as we know. Consider the size of the size v_{e} e μ^{max} $\mathbb{E}\left[\mathbf{y}, \tau \to 3\mu_{\nu} \mathbf{B}_{\mu}, \mathbf{b}_{\mu} \right]$ forbidden because of $\mathcal{U}^{(1)}$ _{*e*} × $U^{(1)}$ _{*u*} \leq King \int
- For charged leptons the matrix seems purely diagonalies in flavour physics suggest a pattern similar to SM (LFNU without duen because or $\mathcal{O}(1)_e \times U(1)_\mu$ s king r μ_{0} , Sorbidden because of $\mathcal{B}(1)_{e} \times U(1)_{\mu}$ s king r T is the relative size values of the relative sizes of the relati is the matrix and new physics suggest a pattern similar to SM (LFNU without LFV)
- Lepton Flavor Violation of physics solf a possible link with the anomalies?) b
- Lepton Flavor Universality Violation: diagonal terms not all equal
	- Sensitive to physics beyond the standard model
	- Tensions or anomalies observed in various channels
- Accidental symmetry, not coming from first principles

Figure 1: (left) Sizes of the the the the CKM matrix elements for \mathcal{A}

 $e \sim$ s \sim 10 \sim

R

 $\left\{\begin{array}{cc}L^T & \mu & L^T & R^T\end{array}\right\}$

Possible sources of

How can we observe LFUV tiquark (s) and a lepton (` = *µ* or e) pair is forbidden at tree level and only proceeds via loop A.Knue \mathbb{R}^n are very small (\mathbb{R}^n) are very small \mathbb{R}^n • Measure ratios of processes with different \bullet Measure ratios of processes with differ leptons to reduce systematics available phase space for the two decays (B⁺ ! ^K+*µ*+*µ* and B⁺ ! ^K+e+e) is the same to an excellent approximation, which makes the ratio of these branching fractions very close to $\begin{array}{c|c|c|c|c} \hline \multimap b & & \multicolumn{2}{c|}{\text{Leptonic decays of}} \ \hline \end{array}$ $\begin{array}{c|c}\n\hline\n\end{array}$ $\begin{array}{c|c}\n\hline\n\end{array}$ $\begin{array}{c|c}\n\hline\n\end{array}$ w and Z decays $\begin{array}{c|c}\n\hline\n\end{array}$ strange, charm, beauty W and Z decays $\mathcal{U} \longrightarrow \mathcal{V}$ in the case of a lepton coupling in the coup hadrons, and tau \sum_{ℓ} in a recent review of various, and $\mathbf{c_1}$ and ref. [8] and $\mathbf{c_2}$ LFU with b \sim left with b \sim LFUV μ) and couplings to all charged leptons are universal in μ K^+ B^+ W^+ W^{\dagger} Semileptonic decays and paradoc \bar{u} , \bar{c} , \bar{u} Rare decays of beauty of strange, charm and the decays of beaut hadrons $D_a^{(*)}$ **beauty hadrons**

 ϵ implied test of ϵ and ϵ and ϵ and ϵ and ϵ to differential Figure 1: Representative Feynman diagrams for the decay of a B+ meson conjugated processes implied a lepton pair in the SM (left) and in a left in a lepton processes implied in a lepton \mathcal{L} Charge conjugated processes implied

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● Hadronic uncertainties mostly cancel in the ratio

Experiments and data sets α periments and dat her trirettop of the grou **a**.

or whether there are no sector whether there are no sector whether the sector whether the sector whether the s

Channel Belle BaBar

 $\begin{array}{c|cc}\n\overrightarrow{BB} & 7.7 \times 10^8 & 4.8 \times 10^8 \\
\hline\n\overrightarrow{B_s^{(*)}B_s^{(*)}} & 7.0 \times 10^6 & -\n\end{array}$

 $\Upsilon(1S)$ 1.0×10^8
 $\Upsilon(2S)$ 1.7×10^8 0.9×10^7 $\begin{array}{c|cc}\n\Upsilon(2S) & 1.7 \times 10^8 & 0.9 \times 10^7 \\
\Upsilon(3S) & 1.0 \times 10^7 & 1.0 \times 10^8\n\end{array}$ 1.0×10^{7}

 $\tau \tau$ 1.0 × 10⁹ 0.6 × 10⁹

 $\sum_{i=1}^n \frac{1}{i} \sum_{j=1}^n \frac{1}{j} \sum_{j=1}^n \frac{$

 3.6×10^7 –

 $\frac{B_{s}^{(*)}\bar{B}_{s}^{(*)}}{\Upsilon(1S)}$ 7.0 × 10⁶ -

e+*e*[−] Υ(4*S*)

 A over \mathcal{A} over \mathcal{A}

Low Energy

μ/e :Light meson d $\frac{1}{\sqrt{2}}$ μ/e :Light meson d experiments done at TRIUMF (57–59) and the Paul Scherrer Institute (60), is the Paul Scherrer Institute (60), i
Institute (60), is the Paul Scherrer Institute (60), is the Paul Scherrer Institute (60), is the Paul Scherrer *Q* ∼ *m*π, *^K*, *µ/*\$χ , where \$χ ∼ 4π*F*^π ∼ 1.2 GeV (*F*^π ≃ 92.4 MeV is the π decay constant), and the electromagnetic coupling *e*. In this setup, one can write

• Pseudo scalars leptonic decays $R_{e/\mu}^P = \frac{1}{\Gamma}$

• $P = \pi/K$ \bullet $P = \frac{n}{N}$ \bullet *P* = 1

- Helicity suppressed because of V-A **P** Prelicity suppressed because of V-A \bullet Helicity suppressed because of V-A \quad $\,$
	- Can be calculated at 10-4 level with radiative corrections $\frac{1}{2}$ $\frac{1}{2}$ o Can
- Recast in terms of ratios of coupling constants 2Even though the ratios *R*(*D*) and *R*(*D*∗) point toward NP as they show deviations from *µ*–τ LFU, we do Here we have the NP effects required are so large that the terms needed the NP effects required are so large t
Here we have the completing $I_{CC} = A_{\ell} \bar{u}_{\ell} v^{\mu} P_L d \bar{v}_{\ell} v_{\ell} P_L \ell$ Therefore, effects in two-quark–two-lepton operators are required in order to explain *R*(*D*) and *R*(*D*∗), which $L_{\text{CC}} = A_{\ell} |\bar{u}\gamma^{\mu} P_{L} d\bar{\nu}_{\ell} \gamma_{\mu} P_{L} \ell,$ *L* additive corrections $I_{CC} = \overline{A_{v}}\overline{u}\nu^{\mu}P_{L}d\overline{\nu}_{v}\nu_{v}P_{L}\ell$ √ $\text{LCC} = \frac{\text{Lpc}}{\text{Lpc}}$ $\frac{1}{\mu}$ *e* $\frac{1}{\mu}$ *e* $\frac{1}{\mu}$ *i g real*
Pratios of counling constants $I_{cc} = \frac{1}{4} \int_{\overline{u}}^{\overline{u}} \nu^{\mu} P_{\overline{u}} d\overline{v}_{\mu} \nu^{-} P_{\overline{u}} \ell$

$$
\left(\frac{A_{\mu}}{A_{e}}\right)_{R_{e/\mu}^{\pi}}=1.0010\pm0.0009,\quad\left(\frac{A_{\mu}}{A_{e}}\right)_{R_{e/\mu}^{K}}=0.9978\pm0.001
$$

• Compatible with SM !*A^µ Ae* " **Compatible with SM** PDG Averages, sequently for a deviation of $\frac{PDS\text{ A}}{ANN}$ Δ originate from various mechanisms. In the literature it is common to interpret deviations from α

which case *A*^ℓ ∝ *g*ℓ.We discuss this scenario in detail in Section 3.1.1.We note that, in the context

 $f(x)$ $f(x)$ 41) can also have an impact on the tests of LFUV studied in this review; these effects are searched for in π, *K*, quality is the number of colors) (17, 48) and found to contribute negligible negligible negligible negligible n

and found to the error of the e = 1*.*0010 ± 0*.*0009, 8. *^e/µ* has been discussed by the FLAVIAnet Annu. Rev. Nucl. Part. Sci. 2022. 72:69–91 **1.** Pion decays. In the matrice of $\frac{1}{2}$, one usually properties the ratio to be fully properties the ratio to be fully properties the ratio of $\frac{1}{2}$

'[*P* → *e*ν¯*e*(γ)]

their expressions are well known (54). The hadronic structure dependence frst appears through

 \bar{R}

 $\frac{1}{\Gamma}$

μ/e : semileptonic decays s *^e/µ* . Therefore, in the SM this ratio is determined entirely by phase-space

• The SM ratio is determined entirely by phase-space factors and long-distance radiative corrections factors and long-distance radiative corrections (64–67). The ratios for *KL* and *K* [±] are consistent, !*A^µ* וט
נו $corrections$

http://www.scholarp

The numbers given above correspond to the recent and the recent analysis in Reference 61, which uses the reference h and h uses h and h uses h and h uses h and h and h and h and h and h and h and imental internation into the contract of the charged in Referrence 63 with reduced to the charged errors in the Annu. Rev. Nucl. Part. Sci. 2022. 72:69–91

modes) and theoretical input on *K*ℓ³ radiative corrections from References 66 and 67, which in-

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$\mu/e:$ more $c \rightarrow s \ell \nu$

\overline{D} lentoni

 $B(D_s^+ \rightarrow \tau^+ \nu)$ (%)

 $= 10.05 \pm 0.35$, consistent with the SM prediction 9.75

D_s leptonic decays D_s semileptonic decays

$\mathcal{R}_{\mu/e}$ obtained by measuring BFs

17 Consistent with SM predictions

 $R_{\tau/\mu} = \frac{\mathcal{B}[D_{\mathcal{S}}^+ \rightarrow \tau^+ \nu]}{\mathcal{B}[D^+ \rightarrow \mu^+ \nu]}$ $\mathcal{B}[D_S^+]$

LFUV, Beta Decays, and Cabibbo . beta decays. The most recent survey (78) of experimental and theoretical input leads to *Vud* = $W = \frac{1}{2} \sum_{i=1}^{N} \frac{1}{i} \sum_{j=1}^{N} \frac{1}{j} \sum_{j=1}$ LFUV, Beta Decays, and Cabibbo T to the lifetime (84) and beta asymmetry (84) and beta asymmetry (85) (for asy

 σ

expansion parameters *ϵ*IsoB ∼ (*mu* − *md*)*/*'QCD and *ϵ*EM ∼ α*/*π, respectively (α ∼ 1*/*137 is the

/; / : decays • In *, → *,one can separate the event in two hemispheres: tag and signal Jul 9, 2024 F.Forti, LFUV 13 former can test only τ–*µ* universality effciently, the latter allow us to assess *µ*–*e*, τ–*e*, and τ–*µ* universality. If we defne *R*τ *µ/^e* ⁼ Br(^τ [−] [→] *^µ*−ν¯ *^µ*ντ) Br(^τ [−] [→] *^e*−ν¯*e*ντ) , 18. *R*τ π(*K*) ^τ */µ* ⁼ Br[^τ [→] ^π(*K*)ντ] Br[π(*K*) → *µ*ν*µ*] , 19. ^τ */µ* ⁼ Br(^τ [−] [→] *^e*−ν¯*e*ντ) Br(*µ*[−] → *e*−ν¯*e*ν*µ*) , and 20. *R*τ ^τ */^e* ⁼ Br(^τ [−] [→] *^µ*−ν¯ *^µ*ντ) Br(*µ*[−] → *e*−ν¯*e*ν*µ*) , 21. then the LFU ratios can be expressed in terms of experimentally measured rates and theoretical input. For *µ*–*e* universality, we have !*A^µ Ae* " τ = # *R*τ *µ/e f* (*m*² *^e /m*² τ) *f* (*m*² *µ/m*² τ) , 22. where *^f* (*x*) ⁼ [−]8*^x* ⁺ ⁸*x*³ [−] *^x*⁴ [−] ¹²*x*2log *^x*. The above expression receives radiative corrections of *O*(α*/*π) × (*mµ/m*^τ) ² (95), which are therefore suppressed. For τ–*µ* universality, we have⁸ former can test only τ–*µ* universality effciently, the latter allow us to assess *µ*–*e*, τ–*e*, and τ–*µ R*τ *µ/^e* ⁼ Br(^τ [−] [→] *^µ*−ν¯ *^µ*ντ) Br(^τ [−] [→] *^e*−ν¯*e*ντ) , 18. *R*τ π(*K*) ^τ */µ* ⁼ Br[^τ [→] ^π(*K*)ντ] Br[π(*K*) → *µ*ν*µ*] , 19. *R*τ ^τ */µ* ⁼ Br(^τ [−] [→] *^e*−ν¯*e*ντ) Br(*µ*[−] → *e*−ν¯*e*ν*µ*) , and 20. *R*τ ^τ */^e* ⁼ Br(^τ [−] [→] *^µ*−ν¯ *^µ*ντ) Br(*µ*[−] → *e*−ν¯*e*ν*µ*) , 21. then the LFU ratios can be expressed in terms of experimentally measured rates and theoretical input. For *µ*–*e* universality, we have *µ/e f* (*m*² *^e /m*² τ) *f* (*m*² *µ/m*² τ) , 22. former can test only τ–*µ* universality effciently, the latter allow us to assess *µ*–*e*, τ–*e*, and τ–*µ* universality. If we defne *R*τ *µ/^e* ⁼ Br(^τ [−] [→] *^µ*−ν¯ *^µ*ντ) Br(^τ [−] [→] *^e*−ν¯*e*ντ) , 18. ^τ */µ* ⁼ Br[^τ [→] ^π(*K*)ντ] Br[π(*K*) → *µ*ν*µ*] , 19. *R*τ ^τ */µ* ⁼ Br(^τ [−] [→] *^e*−ν¯*e*ντ) Br(*µ*[−] → *e*−ν¯*e*ν*µ*) , and 20. *R*τ ^τ */^e* ⁼ Br(^τ [−] [→] *^µ*−ν¯ *^µ*ντ) Br(*µ*[−] → *e*−ν¯*e*ν*µ*) , 21. then the LFU ratios can be expressed in terms of experimentally measured rates and theoretical input. For *µ*–*e* universality, we have !*A^µ Ae* " τ = # *R*τ *f* (*m*² *^e /m*² τ) *f* (*m*² *µ/m*² τ) where *^f* (*x*) ⁼ [−]8*^x* ⁺ ⁸*x*³ [−] *^x*⁴ [−] ¹²*x*2log *^x*. The above expression receives radiative corrections of *O*(α*/*π) × (*mµ/m*^τ) ² (95), which are therefore suppressed. For τ–*µ* universality, we have⁸ boundary between those hemispheres is the plane perpendicular to the ⌧ flight direction, which is experimentally approximated by the thrust axis. The thrust axis is the unit vector *t* ^ˆ that maximizes the thrust value ^P*|^t* final state particle in the *e*+*e* centre-of-mass frame [38, 39]. Throughout this paper, quantities in the *e*+*e* centre-of-mass frame are indicated by an asterisk. We define the *signal* hemisphere as the one containing a charged particle originating either from ⌧ ! *e*⌫¯*e*⌫⌧ or ⌧ ! *µ*⌫¯*µ*⌫⌧ decays. We also require that the opposite hemisphere, labelled with *tag*, contains only one charged particle and at least one neutral pion. Thus, the tag side contains predominantly ⌧ ⁺ ! *^h*+*n*⇡0⌫¯⌧ decays with multiplicity *n* = 1*,* 2. We select ⌧ -pair candidates by requiring the event to contain exactly two charged particles with zero total charge, each having a trajectory displaced from the average in- Tests of LFU are precise measurements for which, in addition to sizable quantities of data, one needs to control systematic effects when determining the BRs. In the most recent results from BaBar, for example, *R*^τ *µ/^e* and (*Aµ/Ae*)^τ were determined with a precision of 0*.*4%(0*.*16%stat ⊕ 0*.*36%syst) and 0*.*2% (96), respectively, where the leading systematic uncertainty (0.32%) originated from particle identifcation. Similarly, *R*^π ^τ */µ* and (*A*^τ */Aµ*)^π were determined with a precision of 0*.*63%(0*.*14%stat ⊕ 0*.*61%syst) and 0*.*57%, where again the dominant systematic source originated from particle identifcation. The results from BaBar and CLEO have also been used to obtain the latest Heavy Flavor Averaging Group combination, which includes 176 measurements and 89 constraints in τ processes (98). For purely leptonic τ decays, these are ! *A*^τ *A^µ* " τ = 1*.*0010 ± 0*.*0014, 25. !*A*^τ *Ae* " τ = 1*.*0029 ± 0*.*0014, and 26. !*A^µ Ae* " τ = 1*.*0018 ± 0*.*0014*.* 27. During the preparation of this review, new values of (*A*^τ */Aµ*)*^h* (*h* = π, *K*) that were obtained by computing radiative corrections, including the lightest multiplets of spin-1 heavy states in ChPT, were reported (99). These new values are ! *A*^τ *A^µ* " π = 0*.*9964 ± 0*.*0038, and 28. ! *A*^τ *A^µ* " *K* = 0*.*9857 ± 0*.*0078*.* 29. These values have the correlation coeffcients (98) Tests of LFU are precise measurements for which, in addition to sizable quantities of data, one needs to control systematic effects when determining the BRs. In the most recent results from *µ/^e* and (*Aµ/Ae*)^τ were determined with a precision of 0*.*4%(0*.*16%stat ⊕ 0*.*36%syst) and 0*.*2% (96), respectively, where the leading systematic uncertainty (0.32%) originated from particle identifcation. Similarly, *R*^π ^τ */µ* and (*A*^τ */Aµ*)^π were determined with a precision of 0*.*63%(0*.*14%stat ⊕ 0*.*61%syst) and 0*.*57%, where again the dominant systematic source originated from particle identifcation. The results from BaBar and CLEO have also been used to obtain the latest Heavy Flavor Averaging Group combination, which includes 176 measurements and 89 constraints in τ processes ! *A*^τ *A^µ* τ = 1*.*0010 ± 0*.*0014, 25. !*A*^τ *Ae* " τ = 1*.*0029 ± 0*.*0014, and 26. !*A^µ Ae* " τ = 1*.*0018 ± 0*.*0014*.* 27. During the preparation of this review, new values of (*A*^τ */Aµ*)*^h* (*h* = π, *K*) that were obtained by computing radiative corrections, including the lightest multiplets of spin-1 heavy states in ChPT, were reported (99). These new values are ! *A*^τ *A^µ* " π = 0*.*9964 ± 0*.*0038, and 28. ! *A*^τ *A^µ* " *K* = 0*.*9857 ± 0*.*0078*.* 29. These values have the correlation coeffcients (98) (*A*^τ */Ae*)^τ 0*.*51 1 (*Aµ/Ae*)^τ −0*.*50 0*.*49 1 (*A*^τ */Aµ*)^π 0*.*23 0*.*25 0*.*02 1 30. • New Belle II analysis • 362 fb−1 • Purity 96% and 92% for electron and muon channel. • Systematics dominated by electron ID and trigger *Belle* -&+* () 0 ()\$"%"&). +  ⁴ 43 ⁴ 2 3  2 +!) +), +!) # &)+"&+. + + % '\$ Figure 6. Observed momentum distribution for muon (left) and electron (right) candidates with fit results overlaid. The lower panel shows the ratio between data and fit results. The hatched area indicates the possible variation of the fitted yields due to systematic e↵ects, with the constraints of the nuisance parameters reduced to their fit uncertainties and correlations taken into account. !  !  !  !  ! -&+* () 0 ()\$"%"&). +  ⁴ 43 ⁴ 2 3  2 +!) +), +!) # &)+"&+. + + % '\$ Figure 6. Observed momentum distribution for muon (left) and electron (right) candidates with fit results overlaid. The lower panel shows the ratio between data and fit results. The hatched area indicates the possible variation of the fitted yields due to systematic e↵ects, with the constraints of the nuisance parameters reduced to their fit uncertainties and correlations taken into account. !  !  !  !  ! Figure 7. Determinations of *R^µ* (left) and *|gµ/ge|*⌧ (right) from previous individual measure-Annu. Rev. Nucl. Part. Sci. 2022. 72:69–91 Consistent with the SM at 1.4 From BF to couplings

where *^f* (*x*) ⁼ [−]8*^x* ⁺ ⁸*x*³ [−] *^x*⁴ [−] ¹²*x*2log *^x*. The above expression receives radiative corrections of

High Energy

 $R(Z^0 \rightarrow \tau^+ \tau^- / Z^0 \rightarrow e^+ e^-)$

 $R(Z^0 \rightarrow \tau^+ \tau^- / Z^0 \rightarrow \mu^+ \mu^-)$

 $R(Z^0\rightarrow \mu^+\mu^-/Z^0\rightarrow e^+e^-)$

 $R(W^{-}\rightarrow \tau^{-} \bar{\nu}_{u}/W^{-}\rightarrow e^{-} \bar{\nu}_{e})$

- Existing tension from LEP in $W \to \tau \nu / W \to (e, \mu) \nu$)
- Very precise Z measureme[nts from LE](https://doi.org/10.1103/PhysRevD.105.072008)P/SLD *Rµ/e ^W* (ATLAS) = *^Rµ/e E-mail:* cms-publication-committee-chair@cern.ch
- CMS and ATLAS can use *tt* events Abstract A search is presented for physics being the standard model (SM) using elec-

- Reduce lepton ID systematics ,! have one power of e!ciencies: better cancellation of uncertainties by the CMS experiment at the LHC at √*s* = 13 TeV from 2016 to 2018 corresponding to **P** LEPTSLC [2005] **With double rational expectations** a total integrated luminosity of up to the up to 140 fb−1 is analyzed. No significant deviation is analyzed. N
- **•** Get final value *u* measurement *W Z* (ATLAS) = 0*.*9990 *±* 0*.*0022 (stat.) *±* 0*.*0036 (syst.) stringent lower limits to date on the masses for various spin-1 particles, spin-2 gravitons in on the ratio of the production cross section cross section cross section and the branching fraction and the branching fraction cross section and the branching fraction and the branching fraction and the branching fraction to different of a new narrow resonance to the most of the most version of the most

Rµ/e Phys.Rept.427:

 $257-151$

in data (black dots with statistical uncertainties) and expected from the SM processes (stacked f

Heavy Flavor Transitions

As D.Buttazzo explained, this is were the interesting stuff lies

$\mathcal{O}(1\%)$ decay modes, a total shift on *RK* is computed for each of the vari-

$b → s \ell \ell$ signal or a computation of particles such as $p \rightarrow s k$ *pK*[−]. The ratio of branching fractions, *RH* (refs. 9,10), is defined in the $b \rightarrow s \ell \ell$ signals are observed from $b \rightarrow s \ell \ell$ signals is subserved from s *B*⁺→*ψ*(2*S*)*K*⁺ decays. The double ratio of branching fractions, *Rψ*(2*^S*), **b** busing the normalisation

$$
q_{\min}^2 < q^2 < q_{\max}^2
$$

• Forbidden at tree level, very sensitive to New Physics signals $\frac{1}{2}$ ry sensitive to New Physics signals 0*.*1 *< q*² *<* 6 GeV² */c*⁴ and *m*(*pK*−) *<* 2600 MeV/*c*² is

\n- Forbidden at tree level, very sensitive to New Physics is
$$
R
$$
\n- R
\n- $W = \frac{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(B \to H\mu^+ \mu^-)}{dq^2} dq^2}{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(B \to H e^+ \mu^-)}{dq^2} dq^2} \quad B = B^+, B^0, B_s, A_b$
\n- $H = K^+, K^{*0}, K_S, pK^-$
\n- Measure double ratio using J/ψ resonance to reduce sys
\n- $R = \frac{P(A^+, B^+)}{P(A^+, B^+)} \quad R = \frac{P(A^+, B^+, B^+)}{P(A^+, B^+)} \quad R = \frac{P(A^+, B^+, B^+)}{P(A^+, B^+)} \quad R = \frac{P(A^+, B^+, B^+)}{P(A^+, B^+)} \quad R = \frac{P(A^+, B^$

• Measure double ratio using J/ψ resonance to reduce systematic $R(R^+ \rightarrow K^+ \mu^+ \mu^-)$ $R(R^+ \rightarrow K^- \mu^-)$ $R_K = \frac{\mathcal{B} (B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B} (B^+ \to K^+ \mu^+ \mu^-) \mathcal{K}^+ \mu^+ \mu^-) \mathcal{B} (B^+ \to K^+ e^+ e^-)}$ provides a independent value of the double-ratio and η is ρ is the double-ratio analysis of the double-ratio and ρ is ρ i $\mu^+\mu^-$ *p*⁺ *R*⁺ *R*⁺ *B* (*B*⁺ \rightarrow *K*⁺ *e*⁺ *e*⁻) $\sin \theta$ *I l*₁ μ resonance to reduce systematic.

$$
R_K = \frac{B(B \to K \mu^+ \mu^-)}{B(B^+ \to J/\psi (\to \mu^+ \mu^-) K^+)} / \frac{B(B \to K \ e^+ e^-)}{B(B^+ \to J/\psi (\to e^+ e^-) K^+)}
$$
\n• LHCB 2019 showed 24 σ and 25 σ for R_{∞} in two bins (B.1011:5)

• LHCB 2019 showed 2.4 σ and 2.5 σ for $R_{K^{*0}}$ in two bins (Run1: 3fb-1) \bullet FULLER SILOMED STOWED 2.40 and 2.30 for K^{k0} in • LHCB 2019 showed 2.40 and 2.50 for $R_{K^{*0}}$ in two **Fig. 4 | Comparison between** *RK* **measurements.** In addition to the LHCb \mathbf{p} :

$$
R_{K^{*0}} = \begin{cases} 0.66 \frac{+}{-0.07} \text{(stat)} \pm 0.03 \text{(syst)} & \text{for } 0.045 < q^2 < 1.1 \text{ GeV}^2/c^4\\ 0.69 \frac{+}{-0.07} \text{(stat)} \pm 0.05 \text{(syst)} & \text{for } 1.1 < q^2 < 6.0 \text{ GeV}^2/c^4 \end{cases} \frac{\text{HEP } 08/20}{\text{HEP } 08/20} \frac{1}{\text{HEP }
$$

- \bullet _ΛμHB 2020 measured R_{pK} in $\Lambda_b \to pK^- \ell \ell$ respective SM experimentally S_{max} $\cdot \Lambda_b^{\text{bHB}}$ 2020 measured R_{pK} in $\Lambda_b\to pK^- \ell\ell$ example R_{nk} in Δ_{nk} of R_{nk} of R_{nk} μ and μ up-type quarks *ū*, ¯*c* and ¯*t*. Right: a possible new physics contribution to the decay with a hypothetical leptoquark (*LQ*) which, unlike the electroweak \bullet , LHB 2020 measured $R_{n,k}$ in $\Lambda_h \to pK^- \ell \ell$ $R_{pK}|_{0,1}$ Λ_b^{ν} is one good Λ_b^{ν} is one good quality, and the value of Λ_b^{ν} \bullet \bullet LHB 2020 measured R_{pK} in $\Lambda_b\to pK^- \ell\ell$ and $R_{pK}|_{0.1 < q^2 < 6~{\rm GeV^2/c^4}} = 0.8$ $\ell \ell \qquad R_{pK}|_{0.1 \leq q^2 \leq 6 \text{ GeV}^2/c^4} = 0.8$
- LHCB 2022 result showed a 3.1σ tension for R_K and $1.4 1.5\sigma$ These decays form proved with $b \rightarrow \overline{s}$ $R_{\rm tr}(1 \ 1 < a^2 < 6.0 \ {\rm GeV}^2 \ c^{-4}) = 0.846 \pm 0.042 \pm 0.013$ $\ln_{\mathcal{N}}(1.1 \times q \times 0.6 \text{ GeV } e) = 0.616 - 0.039 - 0.012$ \overline{AB} 2022 result showed a 3 1 σ tension for R _r and 1 4 \overline{AB} $\begin{array}{r} \bullet \ \ \text{LHCB} \text{ 2022} \text{ result showed a } 3.1\sigma \text{ tension for } R_K \text{ and } 1.4\ \text{} \ b \to \bar s \end{array}$ a $R_{K^0} = 0.6$ or $R_{K^0} = 0.6$ is similar to that of its corresponding $R_{K^0} = 0.6$ $R_K(1.1 < q^2 < 6.0 \,\mathrm{GeV}^2 \, c^{-4}) = 0.846^{+0.042+0.013}_{-0.039-0.012} \hspace{1.5cm} R_{K^0_S} = 0.66^{+0.20}_{-0.14} \, .$ bosons, could have different interaction strengths with the different types r_{b}
• LHCB 2022 result showed a 3.1σ tension for R_{ν} and 1.4 − 1.5σ **Nat. Phys. 18 (2022) 277-282**
 NATURE PHYS. 18 (2022) 277-282
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 R_K 0.846 0.944
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 P where $\frac{2}{3}$ at 2.1–2.1–2.1–2.3 stated deviations for the low- $b\rightarrow \bar{s}$ \mathbf{p} $R_{K^0_S} = 0.66^{+0.20}_{-0.14}$ $R_{K^{*+}}=0.70^{+0.18}_{-0.13}$ wed a 3.1 σ tension for $R_{\scriptscriptstyle{K}}$ and 1.4 $-$ 1.5 σ $\mathcal S$ and $\mathcal D$ of the rare decay $\mathcal D$ $+0.20$ $n_0 = 0.846^{+0.042+0.013}_{-0.030-0.012}$ 0.032 0.012

<u>Nat. Phys. 18 (2022) 277-282</u> $R_{K^{*+}} = 0.70^{+0.18}_{-0.13}$ yields observed in the ratios observed in the ratios of efficiency modes and the ratios of efficiency α $\frac{1}{2}$ fractions for the dielectron final states is obtained states is obtained states is obtained states in $\frac{1}{2}$

most precise measurement to date and is consistent with the SM

 $\begin{array}{cc} \textbf{INFN} & \text{Jul } 9, 2024 & \textbf{R}_K & \textbf{0.846} & \text{0.044} \end{array}$ F.Forti, LFUV R_K 0.846 $_{0.041}$ R_K = 0.846 $^{+0.044}_{-0.041}$ F.Forti, LFUV $\frac{1}{10}$ dominated uncertainties. As detailed below. tions in the central to predictions for **R**_A×^{0.044} regions for the central-area region to the central-are similar to the central-are similar to the central-are similar to the central-are similar to the central-are sim **v** dues, 2024 **b** R_K **0.846** $_{0.041}$ **c**. The larger data set currently depend at $_{0.041}$

$b \rightarrow s \ell \ell$ updat The nonresonant electron candidate samples have a more \mathbb{Z}^n by \mathbb{Z}^n \overline{D} background they contain resonance \overline{D} \overline{d} LU OU

$b\to s\ell\ell$ status and h

INFN

Jul 9, 2024 F.Forti, LFUV

● Differ[ences only drive](https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.131.111802)n by lepton masses $b \rightarrow c \ell \nu$ *R*(*D*(⇤) ⌧*/µ*) = *^B*(*^B* ! *^D*(⇤) \mathcal{P} ^{*y*}

- Any deviations from LFU is a key signature of physics **8** Measure the rati[os of rates](https://journals.aps.org/prd/abstract/10.1103/PhysRevD.108.012018) to different lepton $\frac{1}{2}$ and $\frac{1}{2}$ in the ratio *^R*(*Hc*) = *^B*(*H^b* ! *^Hc*⌧⌫⌧) Φ
	- \bullet Hadronic uncertainties mostly cancel in the ratio Φ
B **B E***z*
	- *A* Beduced experi[mental system](https://arxiv.org/abs/2406.03387)atic uncertainties

$$
R(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau \nu_\tau)}{\mathcal{B}(H_b \to H_c \mu \nu_\mu)} \qquad H_b = B^0, B^+_{(c)}, \Lambda^0_B, B^-_{(c)}, \Lambda^0_B, B^-_{(d)}, \Lambda^0_B, B^-_{(e)}, B^+_{(f)}, B^-_{(g)}, B^+_{(g)}, B
$$

• Angular analysis adds extra power and sensit

Complementary approaches **Complementary approaches** B Factories: LHCb: **Complementary approaches**

B Factories

- Full reconstruction of both signal and tagging B meson (low efficiency) accompanying B mesons (low efficiency) ● Full reconstruction of both signal and α and α mesons in α
- Closed event kinematics (missing energy) $\frac{1}{k}$ is now stice (missing energy)
- π^0 and neutrals reconstruction a control die die die oorlog door rals reconstruction
- Simple normalization; high efficiency for both μ and e

LHC_b $L₁$

- Large cross section ● Large cross section
- Exploit vertexing for B, D, τ reconstruction .
onstructio
	- Reliance on all-charged modes and μ -ID
- Normalization of signal relative to similar decay processes similar decay processes \overline{N} • Normalization of signal relative to

$R(D)$ and $R(D^{\ast})$ from $R(D)$ and $R(D^*)$ from $P(T)$ and $P(T)$ $T_0(D)$ and $T_0(D)$ $\mathbb{I} \cap (\mathbb{R}^d)$ *µ* $\mathbf{p}(n)$ systematic $\mathbf{p}(n)$ in $\mathbf{p}(n)$ \overline{D} $\overline{D$ *J* IFOII $U_{\text{C}}^{(0)}$ muonic the muonic the discrepancy between the discrepancy betwe $\mathbf{u}(\mathbf{D})$ and $\mathbf{u}(\mathbf{D})$ and $\mathbf{u}(\mathbf{D})$ $\boldsymbol \Omega$

$$
R(D^{(*)+}) = \frac{B(D^{(*)+})}{B(B-)}
$$

$$
R(D^{(*)+}) = \frac{\mathcal{B}(B - B)}{\mathcal{B}(B - B)}
$$

- First LHCb measurement using the D^+ ground state
	- B momentum at LHC: exploit B flight direction and boost approximation results
Results

 $\gamma\beta_{z,\text{total}} = \gamma\beta_{z,\text{visible}}$

$$
\mathrm{R}(\mathrm{D}^{\scriptscriptstyle +})\,\,=\,\, \overline{\mathit{B}}{}^{\scriptscriptstyle 0}\,\overline{\mathit{E}}{}^{\scriptscriptstyle 1}
$$

LHCb-PAPER-2024-007 $R(D^+)$

PERD 1.8 Compatible with SM ^{Eugev²/c⁴ Main systematic unc} $\frac{1}{2}$ background modeling ון
. \mathbf{r} Uncertainty on ratio

> See also talk by. Universality in t W1P4, Wed $@8.3$

c distribution $q^2 = (p_{B} - p_D)^2$

M.Rotondo, FPCP 2024

$R(D^*)$ from Bell Exclusively reconstruct the hadronically-decaying tag $\mathbb{E} \left(\mathbb{D}^* \right)$ irom Bell $\sqrt{2}$ H **Here we report the first measurement of** H $Belle I\overline{I}$

- Exclusively reconstruct the hadronically-decaying tag B using "Full Event Interpretation" (FEI) method **Pthod** Comput Softw Big Sci 3, 6 (2019) g B using "Full Event Interpretation" (FEI) Phys.Rev.D 97, 012004 (2018). bative physics of the *B* ! *D*⇤ transition are also included in the decay rate and are described by hadronic matrix (198*.*⁰ *[±]* ³*.*0) ⇥ ¹⁰⁶ *BB* pairs, collected at the ⌥(4S) res-
	- Similar methodology to previous BABAR and Belle publications *PHITHE THUMOUDUS* **by** to **previous** DADAIT and Defice publications *PRL* 109,101802 (2012). *n*icanously to previous DA Similar methodology to previous BABAR and Belle
	- Fully reconstructed D* _{seonetpucted D*
• Propetpucted D*} signal, *B* ! *D*⇤⌧ ⌫⌧ , and normalization mode decays,
	- Leptonic tau decay **B Exercise (2018)**
- PRD 88, 072012 (2013). PRL 118,211801 (2017). PRD 97, 012004 (2018).

Exclusively reconstruct the hadronically-decaying tag

 \bar{f}

publications

*D** signal modes:

● Similar methodology to previous *BABAR* and Belle

- Require that there are no additional charged tracks or π⁰ candidates left over
- To extract the signal, use the residual calorimeter **charged the signal, use the residual calorificer** energy E_{ECL} and the beam-constrained missing mass

 $E_{\text{beam}}^* - E_{D^*}^* - E_{\ell}^*$ ² - $\left(-\vec{p}_B^* - \vec{p}_{D^*}^* - \vec{p}_{\ell}^*\right)^2$ **M2 miss = (pe+e- - pB -pD* -p***l***) 2** used to $M_{\rm miss}^2 = (E^*_{\rm beam} - E^*_{D^*} - E^*_\ell)^2 - (-\vec{p}^*_{B_{\rm tag}} - \vec{p}^*_{D^*} - \vec{p}^*_\ell)^2$

• Primary experimental challenge is to understand the significant (and poorly known) backgrounds ${\rm from~}B \rightarrow D^{**}N$ $\frac{1}{2}$ \overline{c} سسسسس
Aha cid ary experimental challenge is to understand
Anificant (and poorly known) backgrounds $\frac{1}{2}$

space factor, and hence *R*(*D*) and *R*(*D*⇤) are expected

• Consistent with SM and previous results, but still fai where the first values, which we have the second term is $\frac{1}{2}$

Jul 9, 2024 F.Forti, LFUV 27 across all *D* α modes from 0.000 to 200 to

$R(D)$ & $R(D^*)$ measurements and predictions

 $R(D) & R(D^*)$ EPS 2015

 $R(D)$ & $R(D^*)$ Winter 2016

$R(D)$ & $R(D^*)$ Moriond 2017

$R(D) & R(D^*)$ FPCP 2017

$R(D)$ & $R(D^*)$ Summer 2018

$R(D)$ & $R(D^*)$ Fall 2022

$R(D)$ & $R(D^*)$ Summer 2023

$R(D) & R(D^*)$

• $R(D)$ and $R(D^*)$ combined average • 3.31 σ tension with the SM prediction considering the correlation • Is the SM prediction stable?

- R(D): predictions consistent
- $R(D^*)$: tensions between some of the calculations

Inclusive R(X) Inclusive R(X) **Inclusive R(X)**

- Possible to compare the inclusive rates
- Tag B reconstructed using FEI method uping 1 111 inounce
- Search for the signal B in the rest of the event
	- Leptonic $\tau \to e/\mu \bar{\nu} \nu$ decay
	- Remaining reconstructed particles in the event form the hadronic system "X" $\frac{1}{\sqrt{2}}$
	- "Tag B" reconstruction using FEI $rac{1}{\sqrt{2}}$ • Additional experimental challenge due to unspecified hadronic "X" system $\frac{1}{2}$ *τ* → *eνν*, *τ* → *μνν*
- e signal b decay in the signal b modelling/ characterizing backgrounds: • Primary experimental challenge is *pT*, *pT*,
	- B \rightarrow Xlv (l=e,µ)decays
	- $\sqrt{2}$ signal electron or muon from $\sqrt{2}$ *π* events with this-t.eq • Generic $B\bar{B}$ events with mis-reconstruction
	- Continuum $q\bar{q}$ events

 $D^{\mathbf{0}}$)

 \mathbb{R}^n

Hadr

 π^+

Inclusive R(X) Starting Grant No. 947006 "InterLeptons"; Natural \mathbf{V} $\blacktriangle\mathbf{\Sigma}$, Program of China under Contract No. 2022YFA1601903, value (red), compared to the world average of R and the standard model is the standard model in the standard model in the standard model in the standard model describe the constraint Γ

- Signal determined from 2D distribution of p_ℓ^B vs M_{miss}^2 We find RðXτ=lÞ for electrons and muons of $R_{\rm{max}}=0.222$ \pm 0.237 \pm 0.232 \pm 0.037 \pm 0.037 \pm 0.037 \pm \overline{r} $\overline{\mathbf{v}}$
- Data-driven $X\ell\nu$ modelling and reweighting using M_X distribution in $p_\ell^B > 1.4$ GeV sideband region <u>rodening and reweign</u> \mathbf{r} antre n Council, Seventh Framework PIEF-GA-2013-622527,
- Systematics dominated by data-driven corrections to background and signal modelling
- Life is hard:

Jul 9, 2024 **F.Forti, LFUV Example 38 F.Forti** 3884 This Letter started as a blind analysis. Unblinding of an earlier version exposed a significant correlation of the results with the lepton momentum threshold, attributed to a biased selection applied in an early data-processing step and to insufficient treatment of low-momentum backgrounds. We reblinded, removed the problematic selection, tightened lepton requirements, and introduced the leptonsecondary and muon-fake reweightings. The results are now independent of the lepton momentum threshold, and are consistent between subsets of the full dataset when split by lepton charge, tag flavor, lepton polar angle, and data collection period. We verify that the reweighting uncertainties cover mismodeling of D-meson decays by varying the branching ratio of each decay $D \to K$ (anything) within its uncertainty as provided in Ref. [35] while fixing the total event normalization.

of Science and Technology, and UPES SEED funding

$$
R(X_{\tau/\ell})
$$
\nThe
lusive R(X) results

$$
R(X_{e/\mu}) = 1.007 \frac{\text{M}}{\text{N}} 0.009 \text{(stat)} \pm 0.019 \text{(syst)}
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We find an Robert Communication of the energy of the

$$
R(X_{\tau/\mu}) = 1.007 \text{ mJy.009 (stat)} \pm 0.017 \text{(syst)}
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R(X_{\tau/\mu}) = 0.222 \pm 0.020 \text{(stat)} \pm 0.037 \text{(syst)}
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R(X_{\tau/\mu}) = 0.222 \pm 0.027 \text{(stat)} \pm 0.050 \text{(syst)}
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R(X_{\tau/\ell}) = 0.228 \pm 0.016 \text{(stat)} \pm 0.036 \text{(syst)}
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R(X_{\tau/\ell}) = 0.228 \pm 0.016 \text{(stat)} \pm 0.036 \text{(syst)}
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R(X_{\tau/\ell}) = 0.228 \pm 0.016 \text{(stat)} \pm 0.036 \text{(syst)}
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Limited by $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ are $\frac{1}{2}$ and $\frac{1}{2}$ are $\frac{1}{2}$ are smallish data^sset $\text{I}}$ I $\text{I$ lower threshold on participants and participants on participants on participants of the change of the change of \mathcal{L} $\frac{1}{2}$ $\frac{1}{2}$ biased selection applied in an early data-processing step I imited by gystematics even with $\frac{1}{\text{max}}$ and $\frac{1}{\text{max}}$ of $\frac{1}{\text{max}}$ \mathcal{W} stematics, even $\mathcal{Y}^\text{pr}_{l}$ th o.4% shared events), the total correlation between this correlation betw $\frac{1}{N}$ ited by $\frac{1}{N}$ stematics, even $\frac{1}{N}$, $\frac{1}{N}$. $\frac{1}{N}$

Main sources of syst. uncertainties: $X_c \ell \nu$ M_X shape: 7.1%, $\mathscr{B}(\ell)$ Physique Nucl´eaire et de Physique des Particules $\frac{1}{2}$ graduaria ded de problematic selection, removement de problematic selection, V β M \pm α tight sources of system between reflection A_c or μ μ $_{X}$ shape: 7.1% \mathbf{p} $\frac{1}{\sqrt{2}}$ $F19/(\overline{O}(D))$ $R(1,1,0)$, $O_0(D)$ / 2 $\bm{\mathsf{Main}}$ sources of syst. uncertainties: $X_c\ell\nu$ M_X shape: 7.1%, $\mathscr{B}(B\to X)$

 \overline{a}

uncertainties arising from coupling between signal and

Belle II

 $s = s \cos \theta$

CH Angular analys distributions of the spin-1 charged spin-1 charmed spin-1 charmed mesons. We measure finally spin-1 charmed spinangular-asymmetry observables as functions of the decay recoil that are sensitive to lepton-universality-sensitive to lepton-universality-sensitive to lepton-universality-sensitive to lead that are sensitive to lead that \blacksquare **B And B h** $\mathbf{A} \mathbf{D}$ $F_{\text{Belle II}}$ as Λ \mathcal{D} and symmetric to LUV, say \mathcal{D} The forward-backward asymmetry AFB measures the ten- \mathcal{L} dency for the same direction to the same direction to the same direction of \mathcal{L}

- Rich phenomenology due to different decay amplitudes encoded in angular distributions (3 angles) as a function o $\frac{1}{2}$ the recoil energy of the D^* violations. We use events we use the settlement of the new tests when ϵ and ϵ α data corresponding to 189 fb α integration-position-position-position-position-position collisions collection α • Rich phenomenology due to different decay an the alternative coupled and D momentum and D momentum of the orientation of the O momentum of the O momentum of the O momentum of the D momentum of the O momentum of the D momentum of the D momentum of the D momentum of th with respect to the D . We redefine the D The recoil energy of the D^*
- $\bullet\,$ measure 5 angular asymmetries and $\,$ compare them for $e/$ in 2 bins of w (1 $\leq w_{low} \leq 1.275$, 1.275 $< w_{high} \leq 1.503$) $\bullet\,$ measure 5 angular a terms of one-dimensional integrals

$$
A_x(w) = \left(\frac{d\Gamma}{dw}\right)^{-1} \left[\int_0^1 - \int_{-1}^0 \right] dx \frac{d^2\Gamma}{dw dx} \qquad w = \frac{m_{B^0}^2 + m_{D^*}^2 - q^2}{2m_B m_{D^*}}
$$

with $x = \cos \theta_e$ for A_{FB} , $\cos 2\chi$ for S_3 , $\cos \chi \cos \theta_V$ for S_5 , $\frac{1}{\sin \chi} \cos \theta_V$ for S_7 , and $\sin 2\chi$ for S_9 , as illustrated in the \sum_{λ} cos \sum_{λ} for \sum_{λ} , and sin \sum_{λ} for \sum_{λ} , as indicated $\sin \chi \cos \theta_V$ for S_7 , and $\sin 2\chi$ for S_9 , as illustrated in the

evidence for the lepton-to-travel along the W direction (LUV) in the four-vector of the lepton-to-transferred to the μ α_{FB} , definency of the repton to travel along the w direction
 S_2 , S_0 : sensitive to alignment of lepton and D^* direction 1.8 reconstructions by \mathcal{L} \mathfrak{so} A_{FB} : tendency of the lepton to travel along the $\mathcal I$ S_3, S_9 : sensitive to alignment of lepton and D^* d \mathbf{S} supplemental material determination of the \mathbf{M} dimension t_F , condency of the repton to traver along the widnesday.
 λ , consitive to elignment of lenton and D^* dipection. $A_{FB}\text{: tendency of the lepton to travel along the W direction}$ \mathcal{S}_3 , \mathcal{S}_9 : sensitive to alignment of lepton and D* direction

- S_5, S_7 ; measure coupled alignments in the orientation of the D wrt the D^{*} between the direction of the charged lepton in the virtual W S_5, S_7 : measure coupled alignments in the orier y_1, y_9 : behbrare coupled alignments in the orientation of t accounting for experimental effects such as $\frac{1}{2}$ $\mathcal{S}_5, \mathcal{S}_7$: measure coupled alignments in the <u>orientation of the D wrt the D</u>*
- $\overline{}$. All asymmetry measurements are statistics limited. t 0 direction in the D 0 direction in the D t 3.05 finition α . • All asymmetry measurements are statistics limited.
- $\begin{array}{ccc} \bullet & \bullet & \bullet & \bullet \\ \bullet^{\bullet} & \bullet^{\bullet} & \bullet^{\bullet} & \bullet^{\bullet} & \bullet^{\bullet} \end{array}$ - Compatible with SM, no evidence for LFU violation.

The expression depends on Fermi's coupling constant *G*F,

Angular coefficie

- The differential decay rate can be decomposed in functions with 12 coefficients J_i all dependent on
	- Measure J_i in four bins of w
	- Reconstruct D meson in different modes: D^{*}*b* KK D

 D ifference between electron an

Jul 9, 2024 F.Forti, LFUV 41

Aside: determination of|*V* using CLN and BGL parametrizations and lattice data from [1-2-3]: *cb* |

Conclusions

- Lepton Flavour Universality Violation provides powerful tools for exploration of physics beyond standard model
- Experimentally challenging analyses, many channels tried
- Many new results, and more analyses ongoing, just scratching the surface
- Common effort with theory to improve the interpretation of the results and the SM expectations
- Tension with SM has been shrinking with more data and improved analysis

Conclusions • Lepton Flavour University Violation provides powerful tools for exploration of \blacksquare • Experimentally channels tried
• Many new results CALM scrips just • Many new results and more and m scratching the sur **AND** • Common effort with \bullet \bullet \bullet interpretation of the results and • Tension with SM $_{1}$ MORE DATA more data and improved analysis