Theory Ouverture

Federico Mescia

Theory Ouverture

- **Where do we stand?!"**
- **Recent developments in flavour observables:**
  - R_D-R_{D^*}, $B \to K^{(*)}\mu\mu$, and news from $B \to K\nu\nu$ & $K \to \pi\nu\nu$
- **What next?!**
  - HL-LHC (0.3 $\mathrm{ab}^{-1}_{\mathrm{LHCb}}$), Belle II-Upgrade … HE-LHC (27 TeV)?
  - Models of Flavour: MFV, $U(2)^5$, Rank-1-FV and interplay with DM

Introduction: Where do we stand?!

1. The Higgs boson has been found

   → *the SM is a d=4 renormalizable QFT*

2. The Higgs boson is light

   → m_h ~ 125 GeV → not the heaviest SM particle

3. There is a "mass-gap" above the SM spectrum

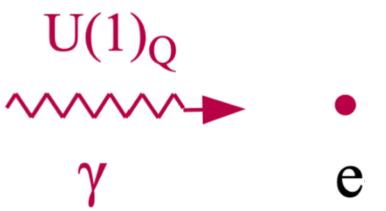
   → no unambiguous sign of NP up to ~ 1 TeV ☹
   → no clear UV cut-off where the SM fails

AHIME':

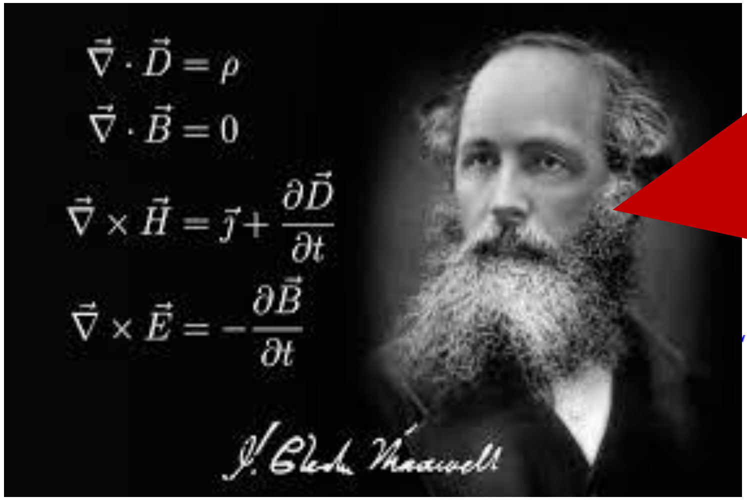
Pessimism based on indirect searches in the pre-LHC era:
EWPO + Flavor (*LEP Paradox*)

Persisting pessimism…

1861
simple scenario
at low-energies



Elegant
beautiful



Everything is clear

Interactions are unified

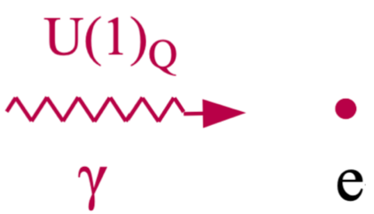
nothing up to the Gravity scale

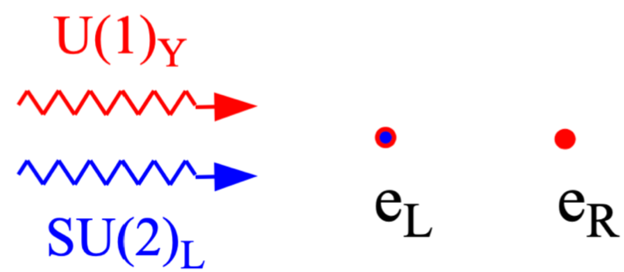
❖ *adapted from G. Isidori*

…persisting optimism!

1861
simple scenario
at low-energies

1971
more complex one
at high-energies
(new symmetries)





Elegant
beautiful
but not complete

Awful – che casino!

At high energy,
L=R → L≠R
γ is not a fundamental field

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Many open questions:

❖ All SM problems are still there

❖ Experimental issues:

- **Baryon Asymmetry→CPV**
- Neutrino Masses
- Dark Matter
- (Gravity)

❖ Theoretical puzzles:

- Hierarchy Problem
- Flavour Puzzle
- 3 Families
- Strong CP problem
- GUT

❖ Strong motivation to pursue search of New Physics at broad spectrum of energy

➢ Atlas/CMS/LHCb/BelleII/NA62/BESIII/Mu2e…

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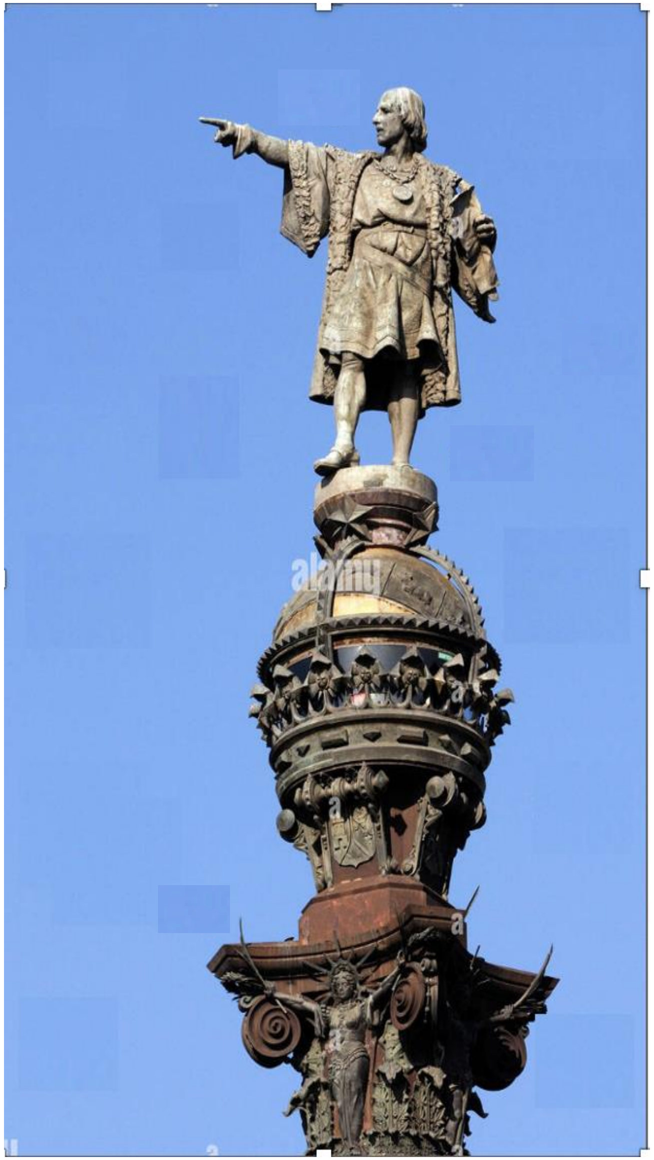
⇒ *Key role of* Flavour Physics @HL era

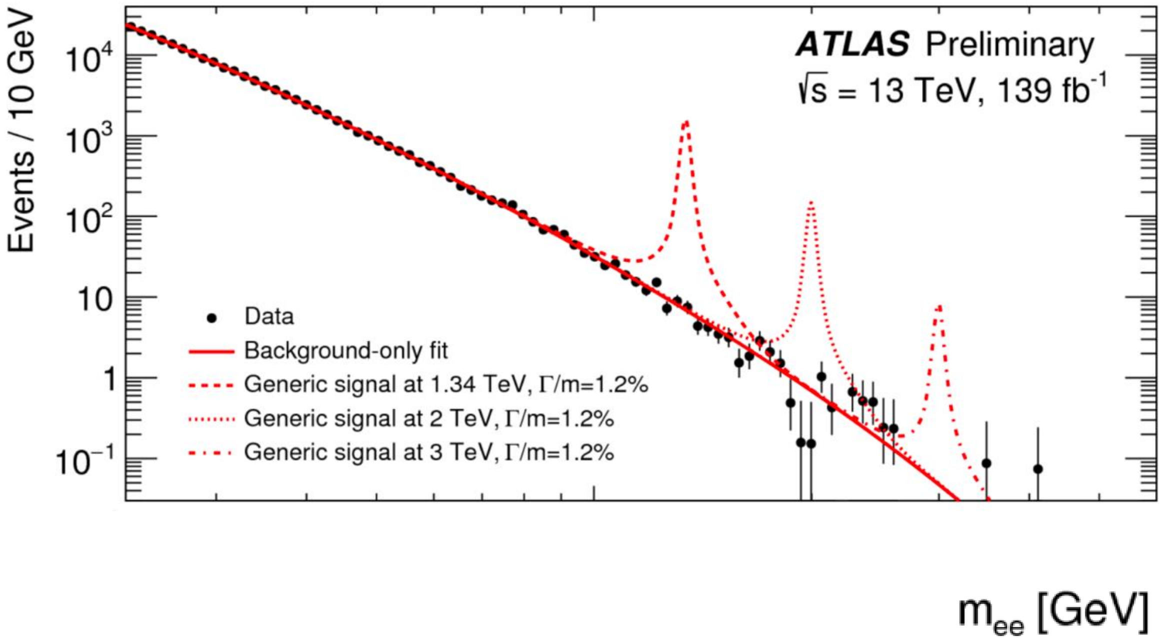
Direct vs indirect searches?

Let’s go and discover



Direct Searches for New Physics

- ❖ Searches for new particles in the spectrum
- ❖ Direct information on the mass of NP



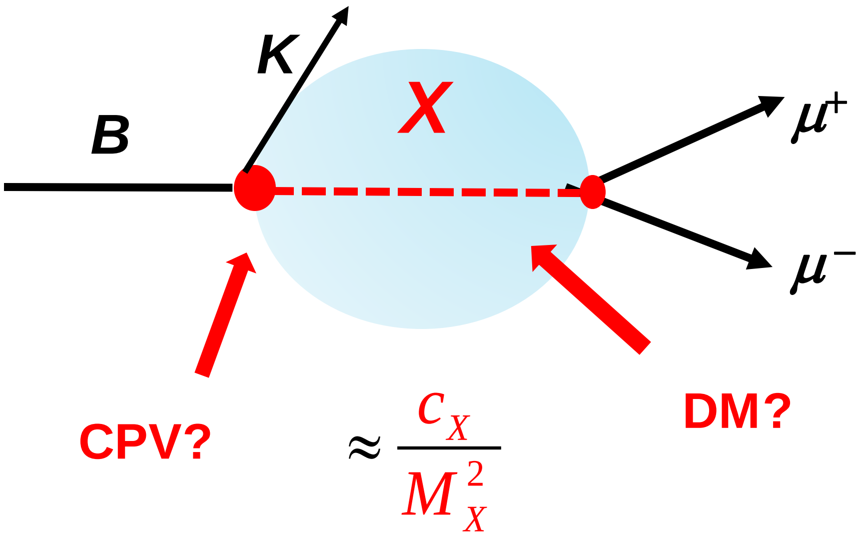
Limited by the available energy of the collider
HE-LHC 2040?

Indirect Searches for New Physics

FLAVOUR PHYSICS AS A DISCOVERY TOOL OF NEW PARTICLES

- for heavy M_X

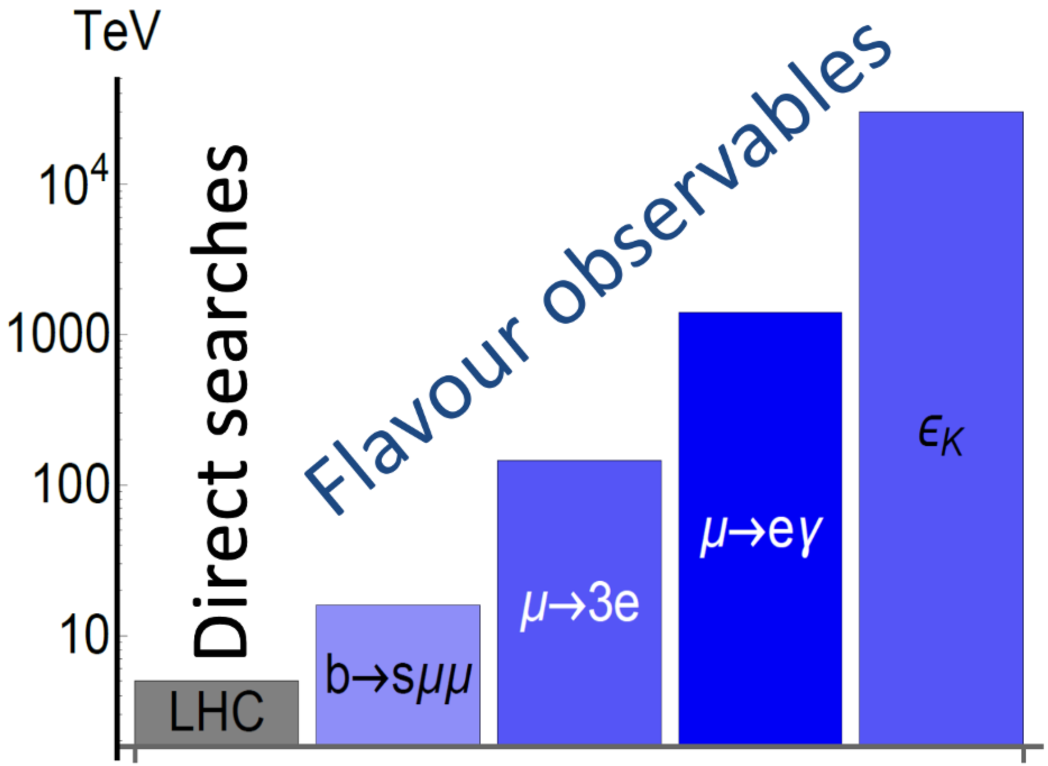
New particles *can be detected through loops of low-energy processes*



❖ $M_X > M_B$: **indirect probe of high-energy scale**

Flavour Physics: window to New Physics

Compare high-statistics measurements to high-precision SM predictions to search for the quantum effects of new particles



New intensity frontier opens up soon thanks to HL-LHC
(Belle-II and BES-III upgrades)

Flavour Physics: window to New Physics

For heavy M_{NP}

$$\boxed{\text{Measurement of flavour Transitions}} = \frac{c_{SM}}{M_W^2} + \frac{c_{NP}}{M_{NP}^2}$$

- ❖ $c_{SM} \approx 0$ *enhanced sensitivities to New Particles in rare hadron transitions, for example **b** $\rightarrow$ **s ll** processes at LHCb*

- ❖ **Specific advantage at HL-LHC:** huge increase in statistics

HL-LHC (NA62, KOTO, BES-III, Belle-II) good opportunity of improvement in flavor physics, covering unexplored regions of realistic NP models

Flavour Physics: window to New Physics

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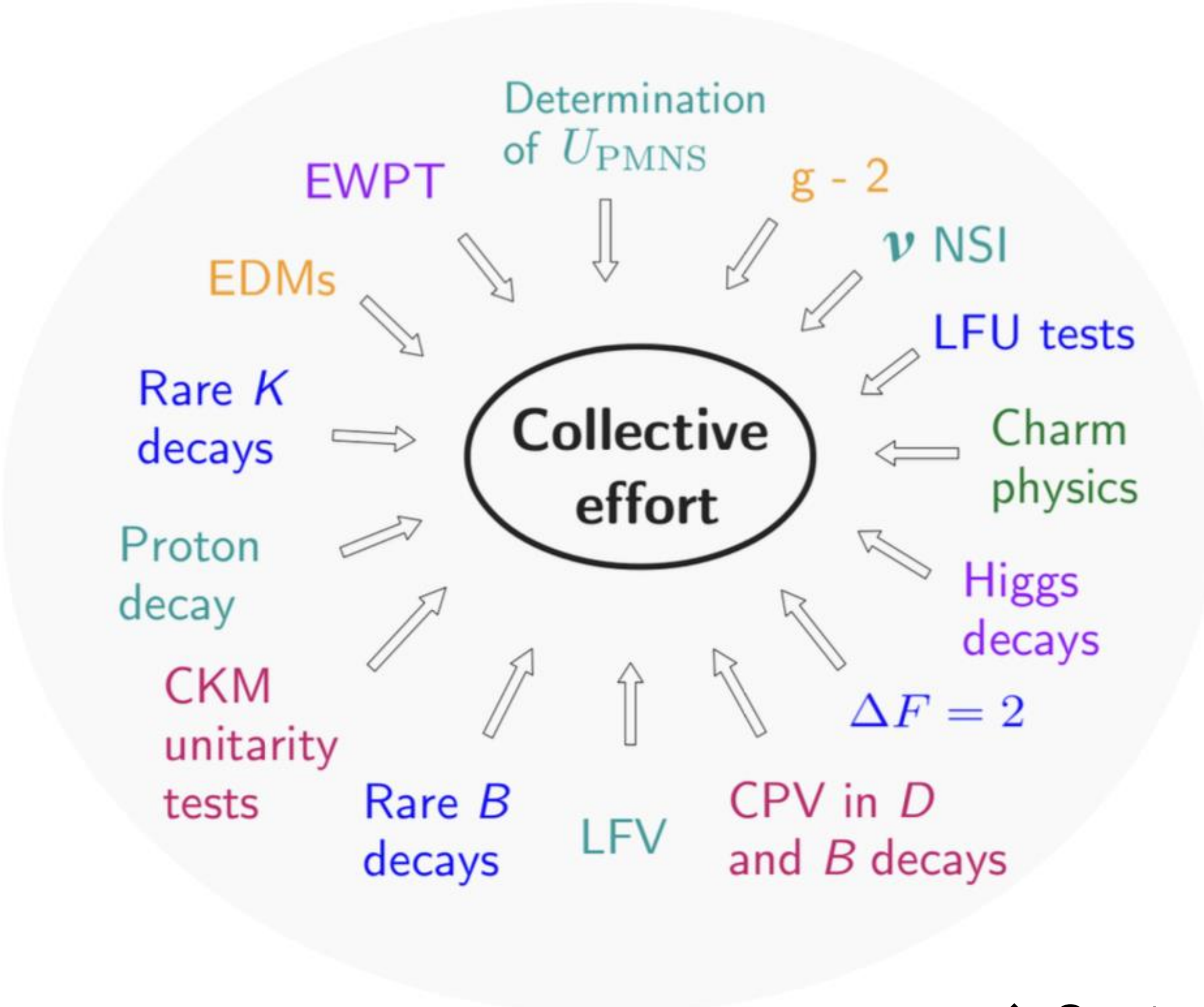
❖ **Specific advantage at HL-LHC**: huge increase in statistics

HL-LHC

	now		HL-LHC
Λ		$\longrightarrow$ $3\times\Lambda$	
c_{NP}		$0.1\times c_{NP}$	

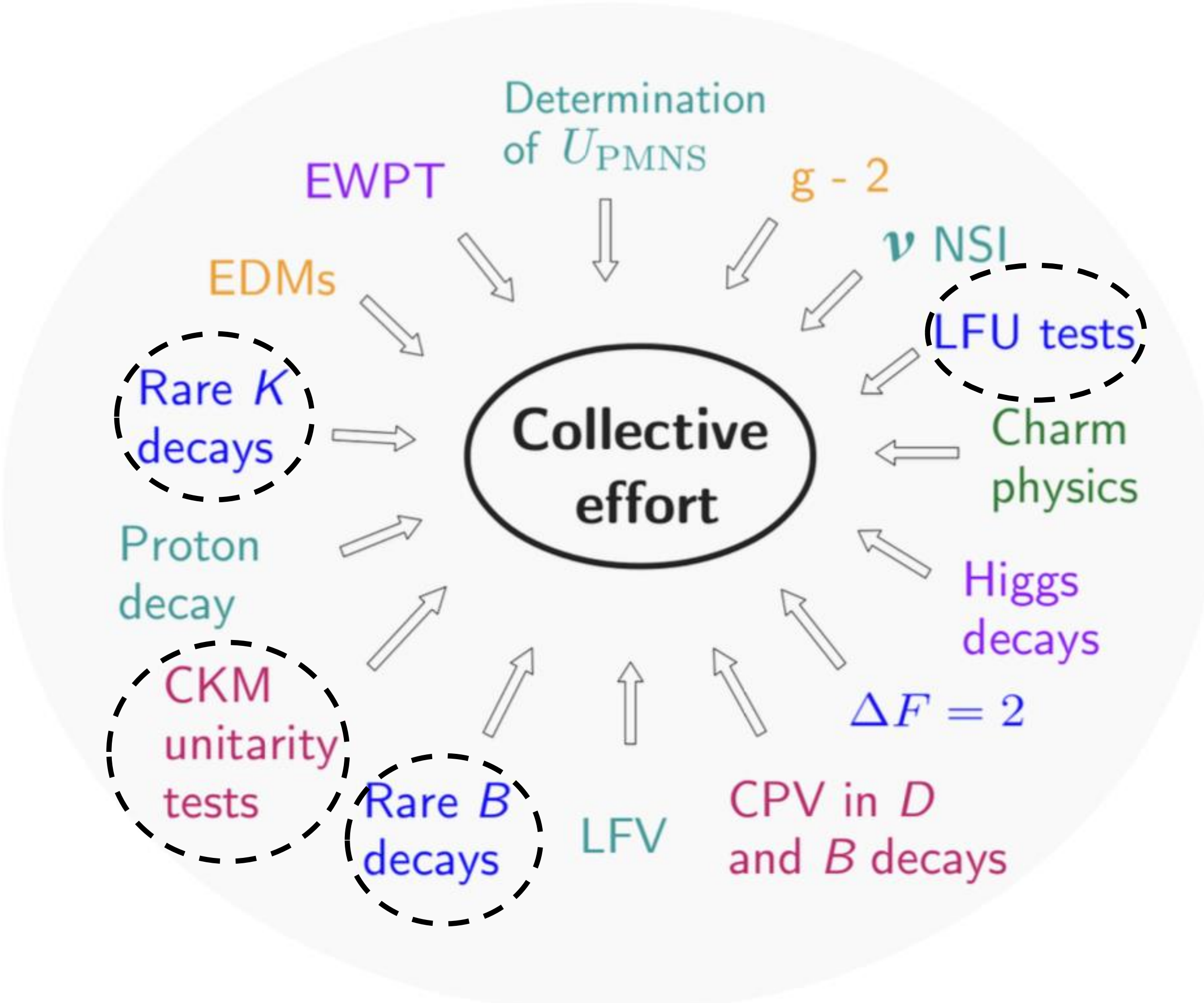
(for th. clean observables)



❖ Courtesy of O. Sumensari

For heavy $M_{NP}=\Lambda$

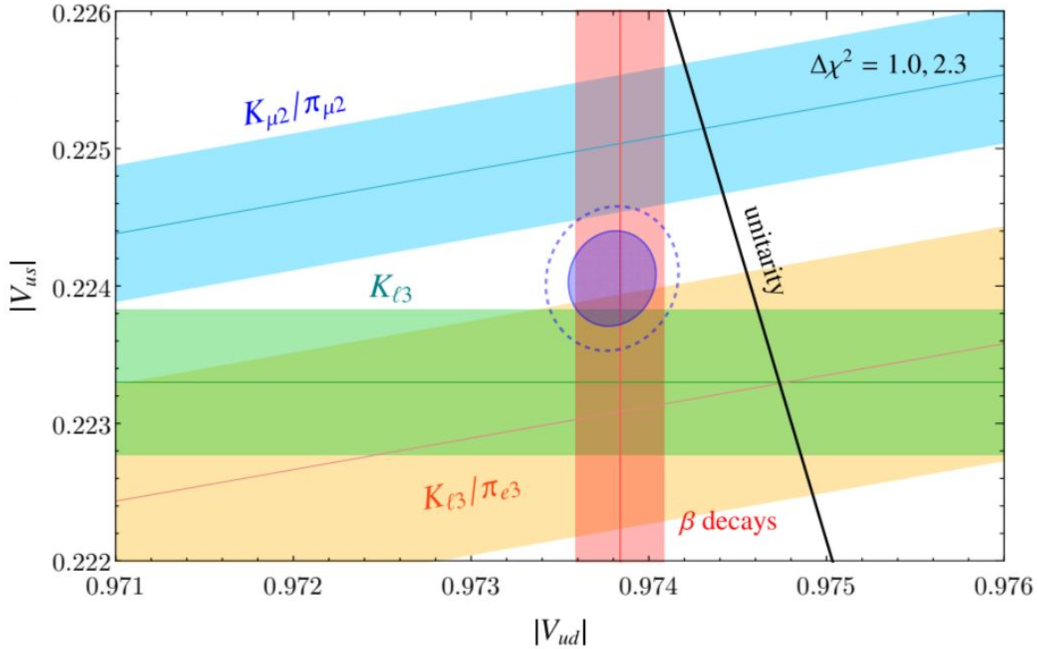
$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{\mathcal{C}^{(5)}}{\Lambda_L}\mathcal{O}^{(5)} + \sum_i \boxed{\frac{\mathcal{C}_i^{(6)}}{\Lambda^2}}\mathcal{O}_i^{(6)} + \dots$$



Determination of U_{PMNS}
EWPT
g - 2
EDMs
ν NSI
LFU tests
Rare K decays
Collective effort
Charm physics
Proton decay
Higgs decays
CKM unitarity tests
$\Delta F = 2$
Rare B decays
LFV
CPV in D and B decays

CKM Unitarity test:
Discrepancies in 1st row/column of CKM matrix

- Deficit of first row CKM unitarity
- Tension between V_{us} from K_{l3} vs K_{l2}



Both theory and experiments demands a closer scrutiny of systematic errors

$$\left|V_{ud}^2\right| + \left|V_{us}^2\right| + \left|V_{ub}^2\right| = 0.9985 \pm 0.0005,^*$$

$$\left|V_{ud}^2\right| + \left|V_{cd}^2\right| + \left|V_{td}^2\right| = 0.9970 \pm 0.0018^*$$

* see talk by S.Simula on Thursday for last updates.

Discrepancies in 1st row of CKM unitarity

- Deficit of first row CKM unitarity
- Tension between V_{us} from K_{l3} vs K_{l2}

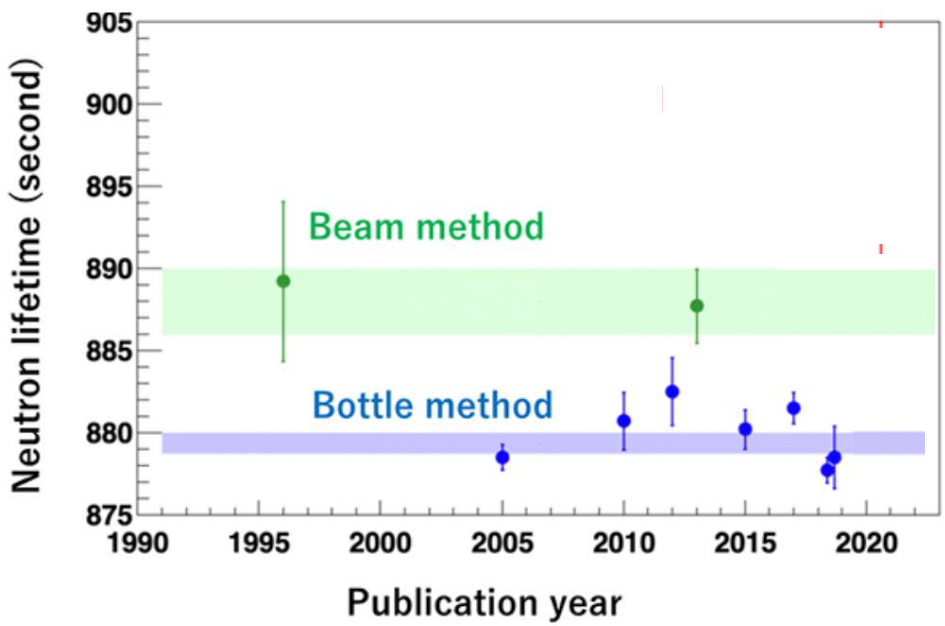
$$\left|V_{ud}^2\right| + \left|V_{us}^2\right| + \left|V_{ub}^2\right| = 0.9985 \pm 0.0005,$$

- Experiment: information to be improved

Systematic problems in β decays measurements?

❖ ***V_{ud}*: exp. Info unclear**

  ➢ Tension in neutron lifetime between beam vs bottle method (≈ 4σ)



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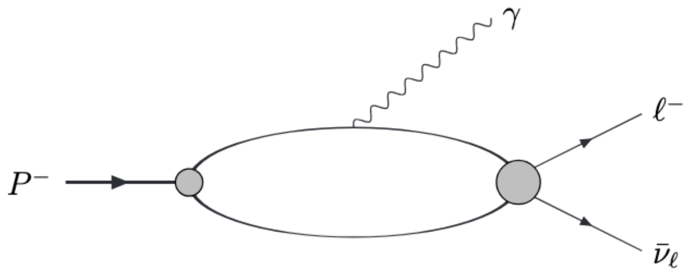


- Theory: radiative corrections on super-allowed β *and K* decays?

❖ ***V_{us}* : great progress in controlling radiative corrections from Lattice QCD**

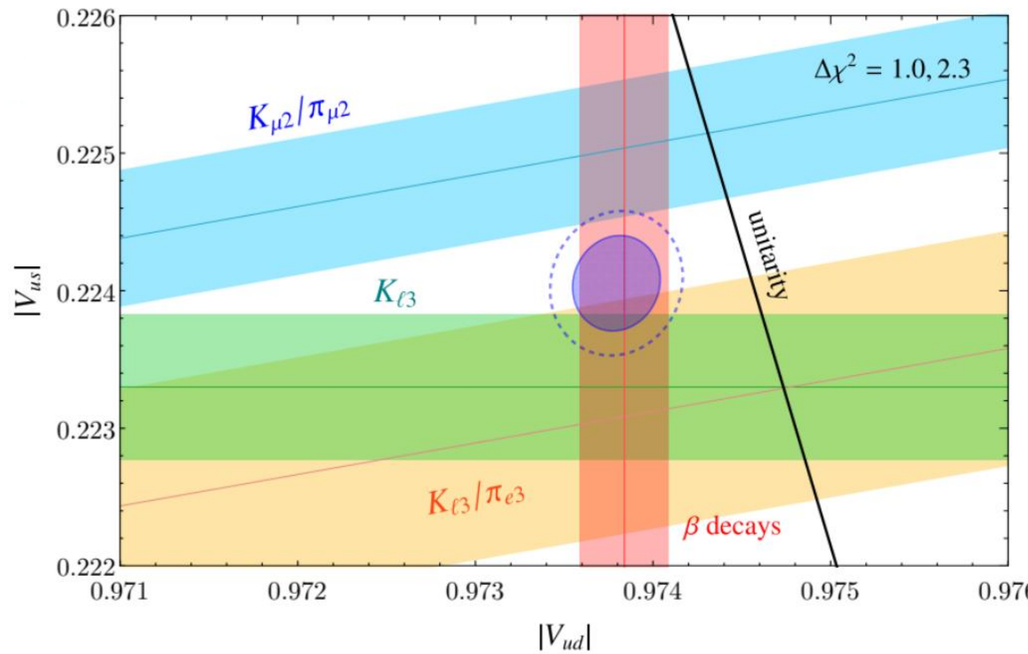
- ➢ Problem solved for $K_{l2\gamma}$ and correctly match with exp. cuts.
- ➢ K_{l3} small phase space: soft photon from $K_{l3\gamma}$ important for high-precision test**. Lattice calculation missing!**

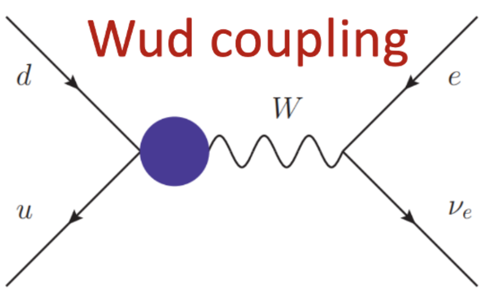
Gagliardi, Garofalo, Giusti, Frezzotti, Lubicz, Martinelli, Sachrajda, Tantalo, Tarantino, Sanfilippo, Simula, 2202.03833 ..

❖ ***V_{ud}* : radiative corrections on super-allowed β need further revision**

Discrepancies in 1st row of CKM unitarity

- Deficit of first row CKM unitarity
- Tension between V_{us} from K_{l3} vs K_{l2}
- Experiment/Theory information to be improved
- NP example: Vector-like quarks by modified coupling to W





$$\frac{\Lambda_{NP}}{g_{NP}} = 10\ \text{TeV}$$

$$\left|V_{ud}^2\right| + \left|V_{us}^2\right| + \left|V_{ub}^2\right| = 0.9985 \pm 0.0005,^*$$

*see talk by Simula on Thursday for last updates.

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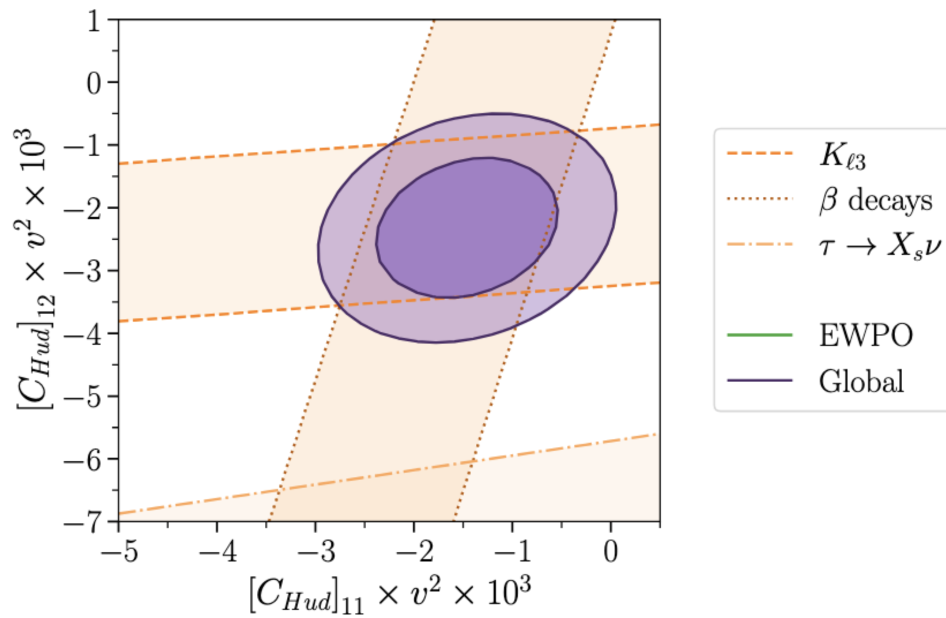
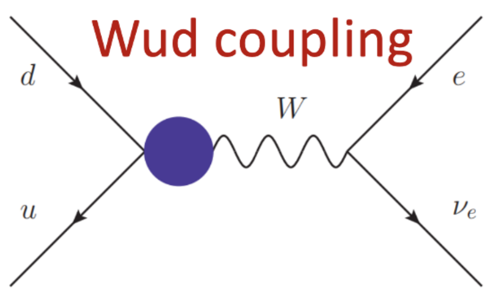




$$\frac{\Lambda_{NP}}{g_{NP}} = 10 \text{ TeV}$$

$$|V_{ud}^2| + |V_{us}^2| + |V_{ub}^2| = 0.9985 \pm 0.0005,^*$$

M. Kirk et al. 2212.06862.

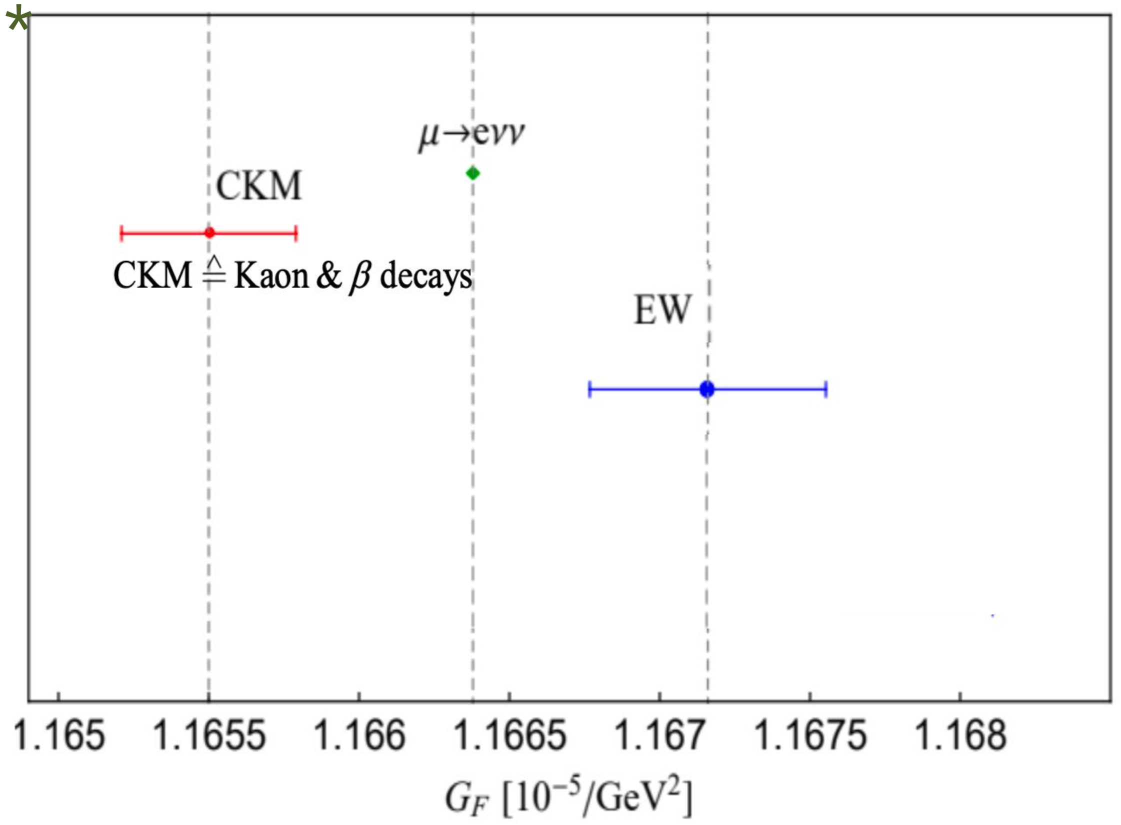
*see talk by Simula on Thursday for last updates.

Discrepancies in 1st row of CKM unitarity

The Fermi constant can be determined from

1. μ decay
2. Kaon and beta decays (assuming CKM unitarity)
3. The global EW fit (Z decays, α)

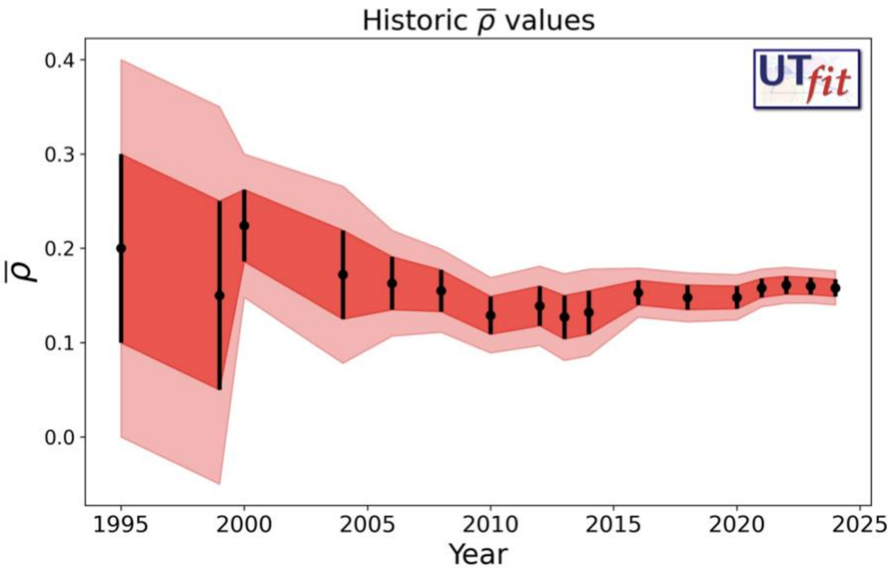
*

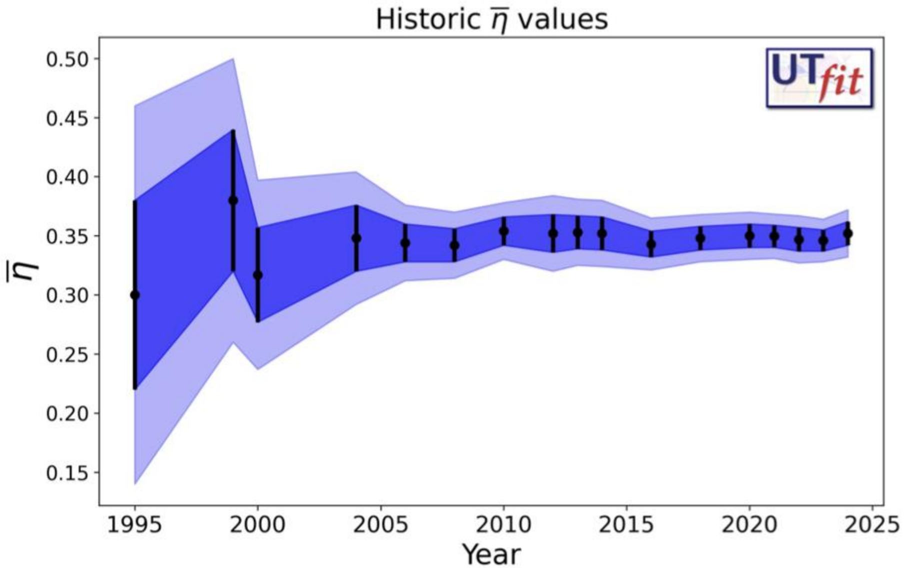


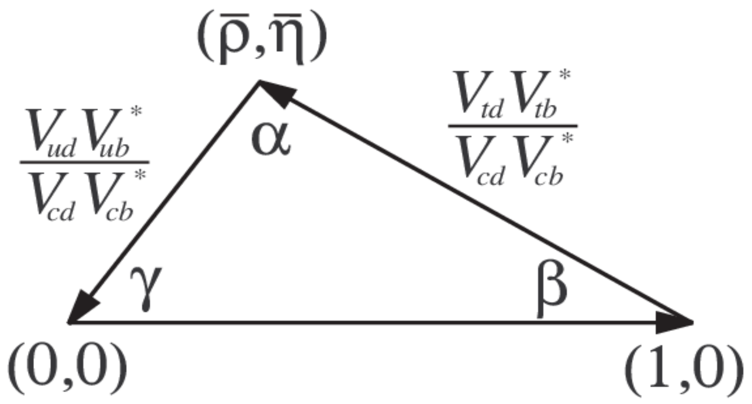
Some tensions between EW fit and determination of the Fermi constant

* smallish changes from the last improvement of M_W, see HEPfit for EWPT

Unitarity Triangle results over the years (3rd family)





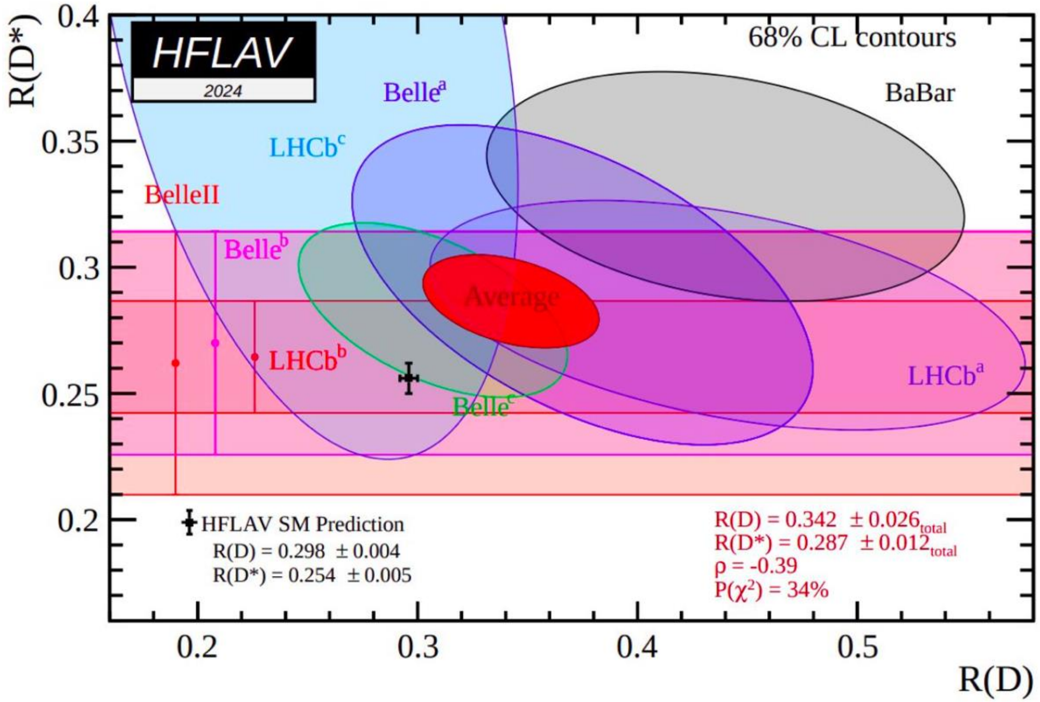


- CKM triangle well know now
- Huge progress thanks **to B-factories and Lattice QCD**
- First step towards high-precision flavour physics
- *Thanks to this improvement, we can look for NP in rare B and K decays*

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

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

- Discrepancy currently standing at **~ 3.1σ** for the combined $R(D)$ & $R(D^*)$;
- Test of lepton flavour universality between heavy τ leptons versus light e, μ leptons
- Clear signature of BSM couplings with the 3rd generation



- ***Long-standing discrepancies started from BaBar, Belle, then recently LHCb***

$R(D)$ & $R(D^*)$ news from Belle II

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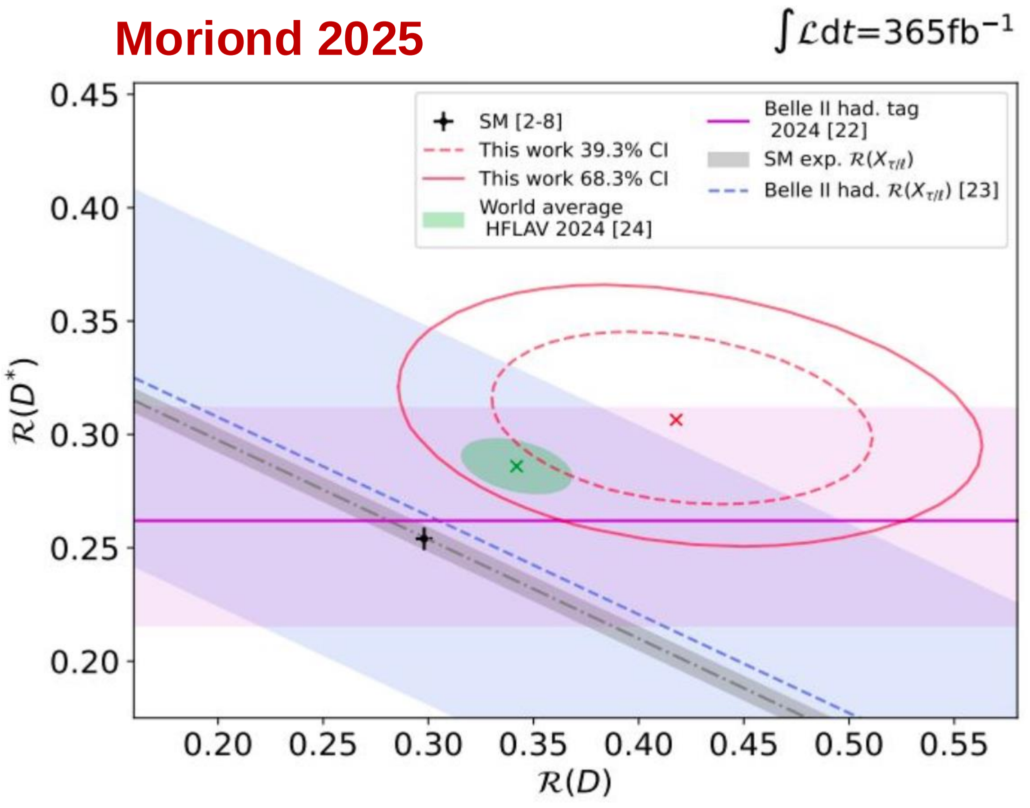
Moriond 2025



- ***Long-standing discrepancies started from BaBar, Belle, then recently LHCb and now seems confirmed by Belle II***

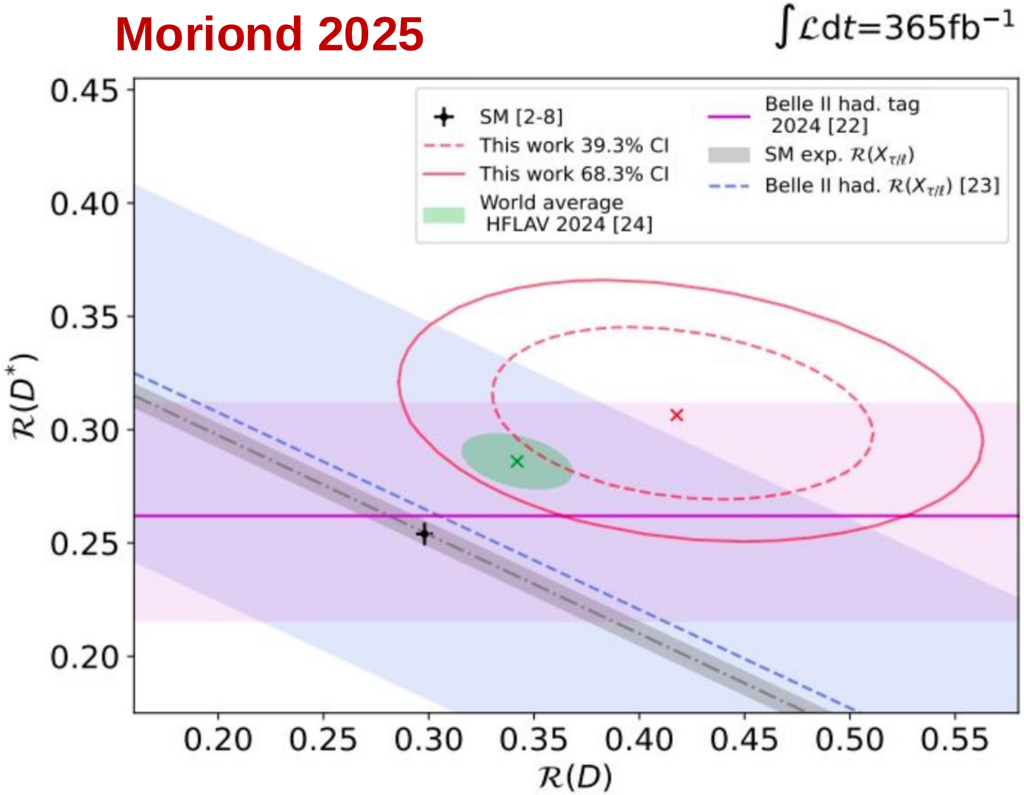
$R(D)$ & $R(D^*)$ theory

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

- Recently, developments in refining SM predictions (see talks by **M. Bordone, M. Fedele, L. Vittorio)**
- Lattice QCD results for B→D form factors are satisfactory ☺
- Instead for B→D[*] the situation is confusing: results with staggered do not agree with those obtained with Wilson discretization: (see talk by **A. Juttner)**

  - **A lot of activities will be reported at this workshop**

Moriond 2025



- *New Physics by tree-level exchange of W', LQ, …*

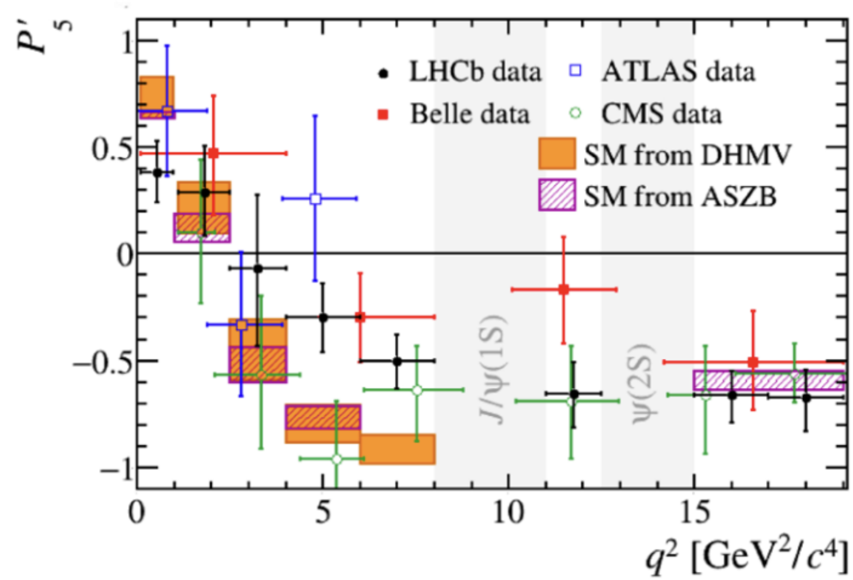
$$\frac{\Lambda_{NP}}{g_{NP}} = \text{a few TeV}$$

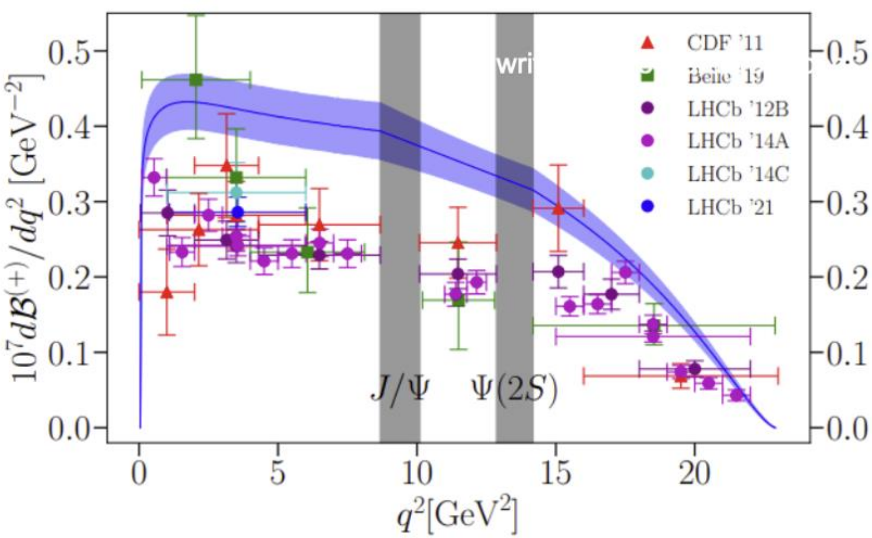
Di Luzio & Nardecchia, 1706.01868

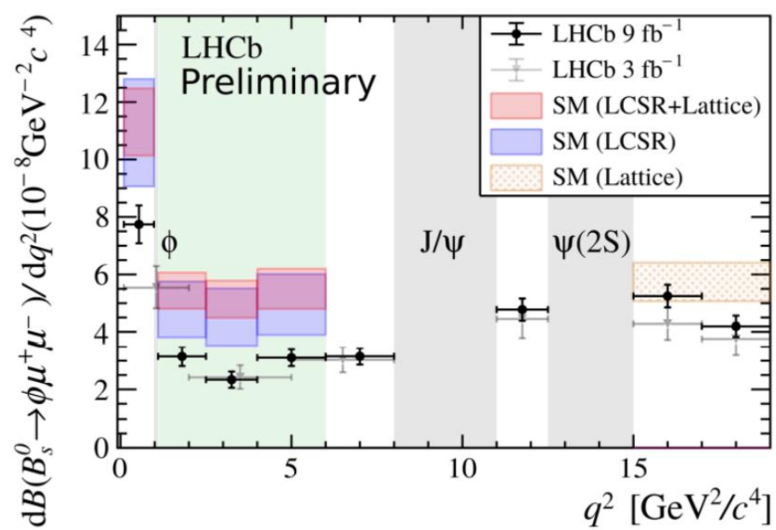
$B \to K^{(*)}\,\mu\mu$ & $B_s \to \phi\,\mu\mu$

- **~ 4σ** deficit in Br **using LCSR helped by Lattice QCD***
- Test of NP in angular observables, P'_5 ?

see talk by Quim Matias







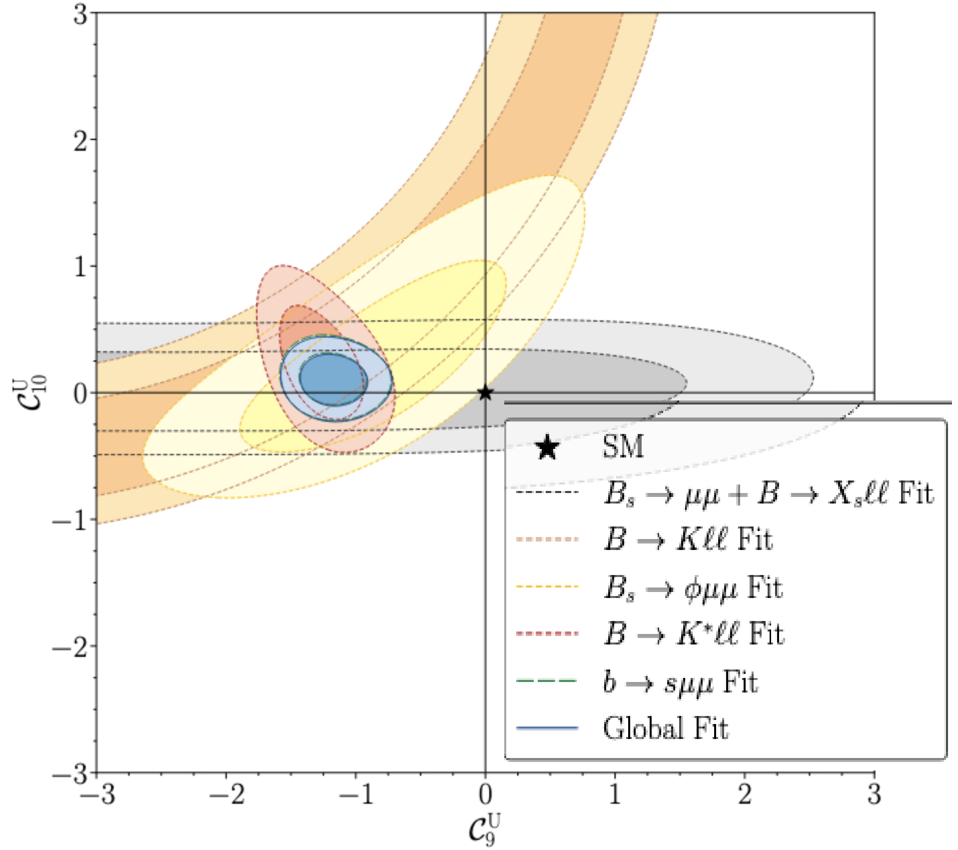
Br's ~ 20% below the SM expectations!!?

$b \to s\,\mu\mu$ global fit

- $B_s \to \mu\mu$ is now SM-like, C_{10}~0
- R_K, R_{K^*} & R_ϕ ~1 toward LFU NP
- **Good fit with**

$$C_9^U$$

$$C_9^U, C_{10}^U$$



Capdevila, Crivellin and Matias, 2309.01311

Global fit pointing to 5σ or 7σ deviation w.r.t the SM, depending on the choice of hadronic input.

Gubernari, Reboud, van Dyk, Virto, 2206.03797

Hurth, Mahmoudi and Neshatpour 2310.05585

$b \to s\,\mu\mu$ global fit

❖ $B_s \to \mu\mu$ is now SM-like, C_{10}~0

❖ R_K, R_{K^*} & R_ϕ ~1 toward LFU NP

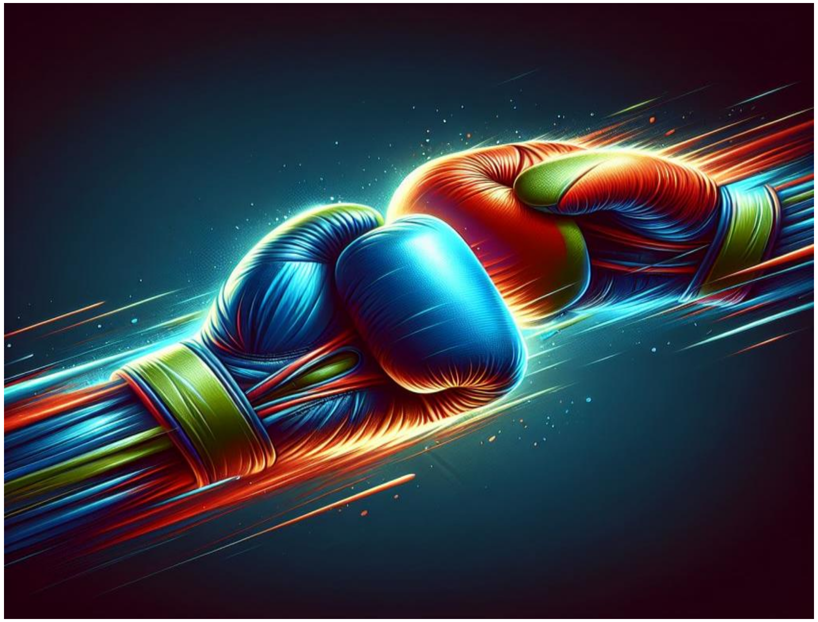
❖ **Good fit with**

Open question:

<u>Local</u> or non-local hadronic matrix elements (charm-loops)

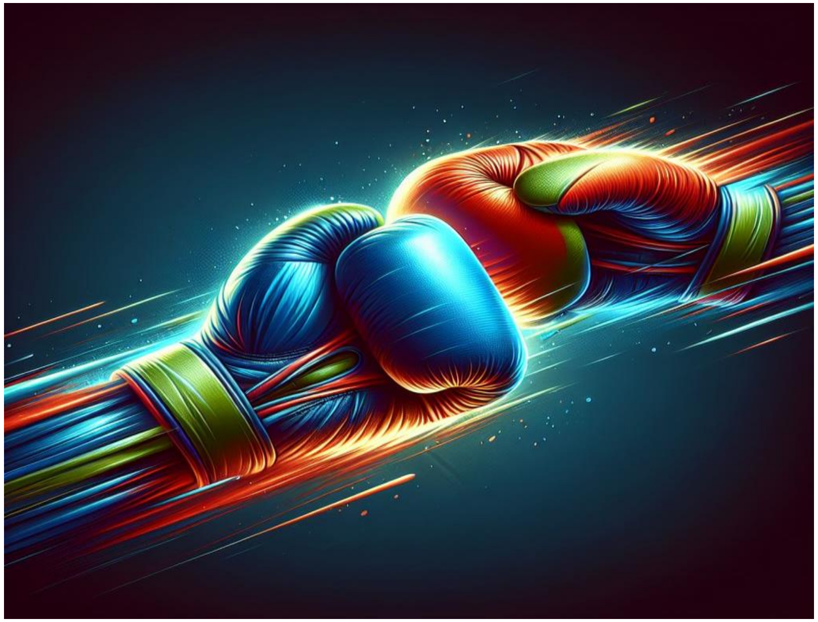
- *<u>local matrix elements</u> have not been computed on lattice recently: heavily dominated by LCSR.* ?!

Hadronic inputs - hot issues for discussions at all workshops



$b \to s\, \mu\mu$ global fit

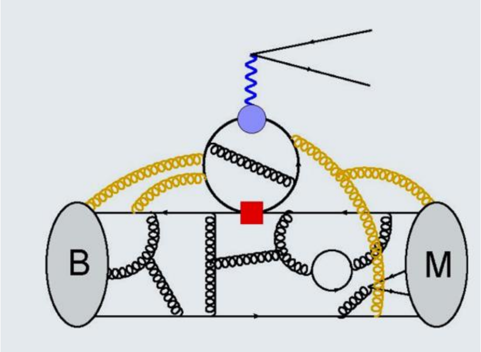
Hadronic inputs - hot issues for discussions at all workshops



- $B_s \to \mu\mu$ is now SM-like, C_{10}~0
- R_K, R_{K^*} & R_ϕ ~1 toward LFU NP
- **Good fit with**

Open question: charm-loops?

$$h_\lambda(q^2) = \frac{\epsilon^*_\mu(\lambda)}{m_B^2} \int d^4x e^{iqx} \langle \bar{K}^* | T\{ j^\mu_{\text{em}}(x) \mathcal{H}^{\text{had}}_{\text{eff}}(0) \} | \bar{B} \rangle$$



see talk by **A. Tinari**

$b \to s\,\mu\mu$ global fit

Hadronic inputs - hot issues for discussions at all workshops

- $B_s \to \mu\mu$ is now SM-like, C_{10}~0
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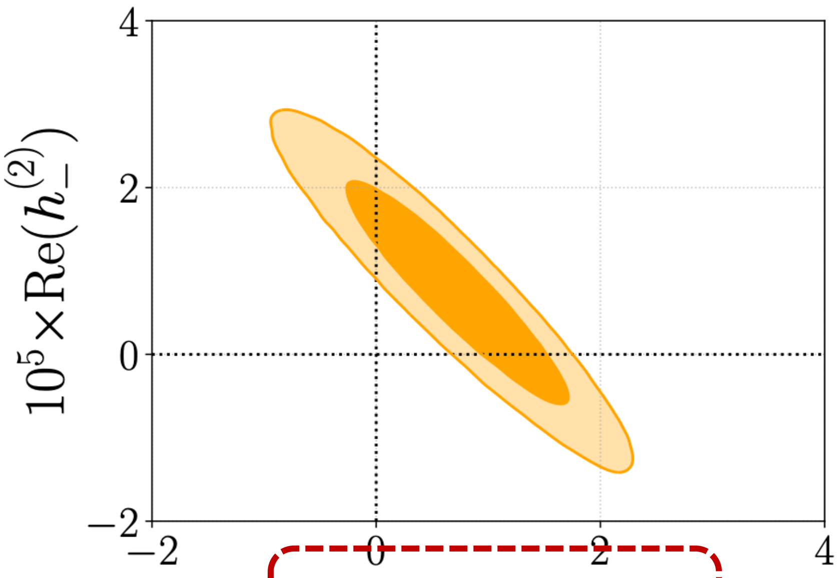
- **Good fit with**

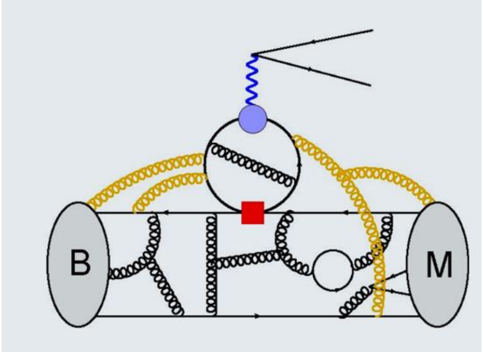


$$\mathrm{Re}(h_-^{(1)}) \simeq -C_{9,\mathrm{U}}^{\mathrm{NP}}$$

Open question: charm-loops?

M. Ciuchini, M. Fedele, E. Franco, M. Valli, L. Silvestrini, 2212.10516

$$H_V^- \propto \frac{m_B^2}{q^2}\left[\frac{2m_b}{m_B}\left(C_7^{\mathrm{SM}} + h_-^{(0)}\right)\widetilde{T}_{L-} - 16\pi^2 h_-^{(2)}\, q^4\right] + \boxed{\left(C_9^{\mathrm{SM}} + h_-^{(1)}\right)}\widetilde{V}_{L-}\,,$$

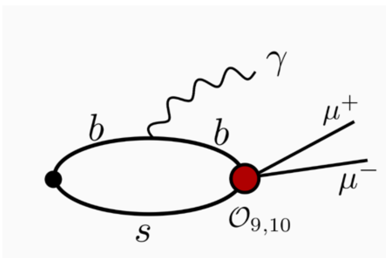


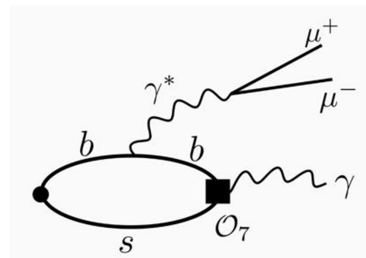
Looking for complementary $b \to s$ modes

Breakthrough from Lattice QCD

Frezzotti, Gagliardi, Lubicz, Martinelli, Sachrajda, Sanfilippo, Simula, Tantalo 2402.03262

$B_s \to \mu^+\mu^-\gamma$ at large q^2 from lattice QCD





G. GAGLIARDI

Comparison with current LHCb upper-bound for $x_\gamma^{\rm cut} \sim 0.166$.

$$\boxed{\mathcal{B}_{\rm SD}^{\rm LHCb}(0.166) < 2\times 10^{-9}\,, \qquad \mathcal{B}_{\rm SD}(0.166) = 6.9(9)\times 10^{-11}}$$

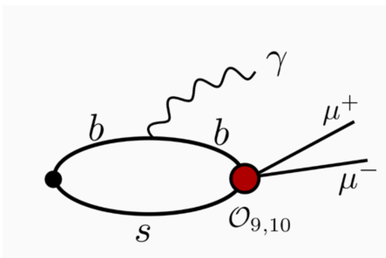
$B_s \to \mu\mu\gamma$ @ high-q2: same short-distance effects as those in *$B \to K^{(*)}$* $\boldsymbol{\ell\ell}$
but long-distance contributions are expected to be rather small

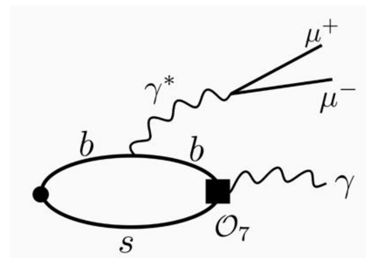
Looking for complementary $b \to s$ modes

Breakthrough from Lattice QCD

$B_s \to \mu^+\mu^-\gamma$ **at large q^2 from lattice QCD**

Frezzotti, Gagliardi, Lubicz, Martinelli, Sachrajda, Sanfilippo, Simula, Tantalo 2402.03262





G. GAGLIARDI

Comparison with current LHCb upper-bound for $x_\gamma^{\mathrm{cut}} \sim 0.166$.

$$\boxed{\mathcal{B}_{\mathrm{SD}}^{\mathrm{LHCb}}(0.166) < 2 \times 10^{-9}\ , \qquad \mathcal{B}_{\mathrm{SD}}(0.166) = 6.9(9) \times 10^{-11}}$$

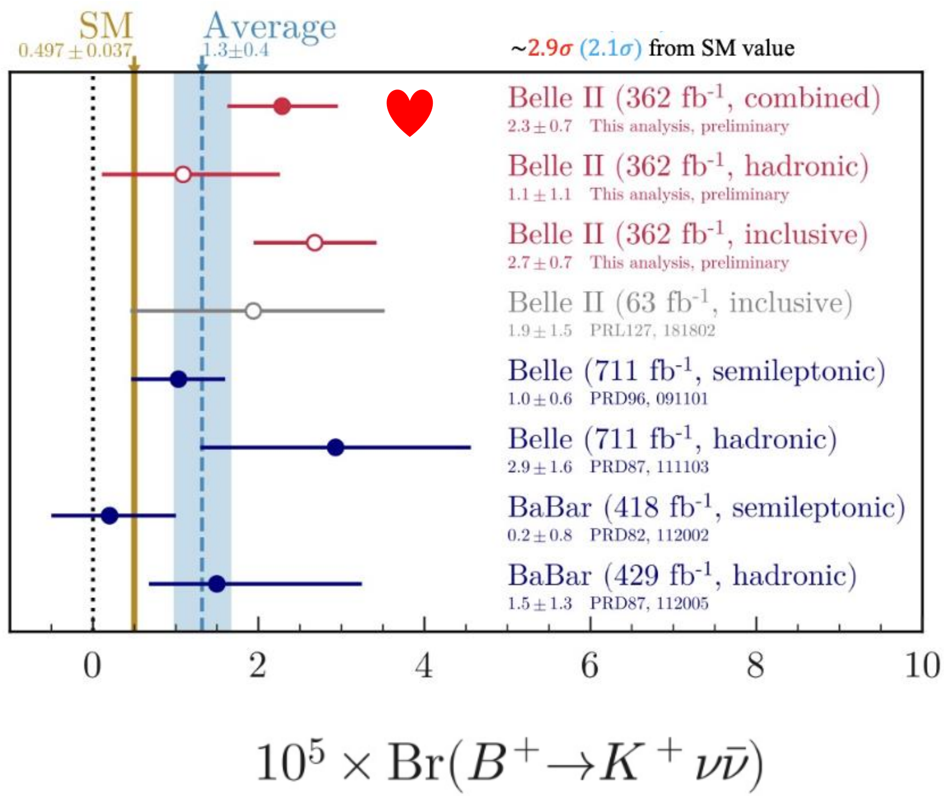
Is there a way to use the Hansen-Lupo-Tantalo method to estimate the contribution of $c\bar{c}$ to C_9?

(see talk by C. Sacrajada, G. Gagliardi)

$B \to K^{(*)} \nu\nu$ from Belle II

see talk by **L. Allwicher**

- ❖ First experimental evidence of $B \to K\nu\nu$!
- ❖ extremely theoretically clean probe of BSM:
  - ➢ they are significantly suppressed in SM
  - ➢ long-distance contributions are generally sub-leading



1. NP assumed to be heavy

$$\frac{\Lambda}{g_{NP}} = 10\ \mathrm{TeV}$$

$$\mathcal{L}_{\rm LEFT}^{\rm NP} = \sum_{ij\alpha\beta} \left[L_L^{ij\alpha\beta} (\bar{d}_L^i \gamma_\mu d_L^j)(\bar{\nu}_L^\alpha \gamma^\mu \nu_L^\beta) + L_R^{ij\alpha\beta} (\bar{d}_R^i \gamma_\mu d_R^j)(\bar{\nu}_L^\alpha \gamma^\mu \nu_L^\beta) \right]$$

1. $\tilde{R}_2 \sim (\mathbf{3}, \mathbf{2}, 1/6)$
2. $S_1 \sim (\bar{\mathbf{3}}, \mathbf{1}, 1/3)$

Marzocca, Nardecchia, Toni, Stanzione 2404.06533
Allwicher, Becirevic, Piazza, Sumensari 2309.02246
Becirevic, Fajfer, Kosnik, Pavicic 2419.23257
Allwicher, Becirevic, Piazza, Sumensari 2309.02246
Allwicher, Bordone, Isidori, Piazza and Stanzione, 2410.21444

$B \rightarrow K^{(*)} \nu\nu$ from Belle II

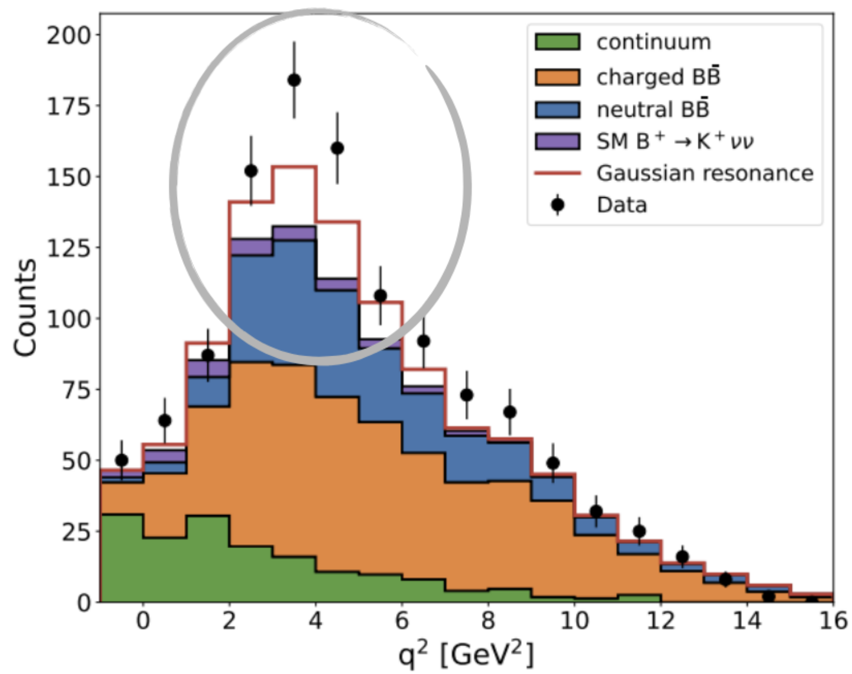
- First experimental evidence of $B \rightarrow K\nu\nu$!
- extremely theoretically clean probe of BSM:
  - they are significantly suppressed in SM
  - long-distance contributions are generally sub-leading

2. NP assumed to be light

- hint of new invisible particles: fermions or bosons

$$B \rightarrow K\, E_{\rm miss}$$

$10^5 \times \mathrm{Br}(B^+ \rightarrow K^+ \nu\bar{\nu})$



Bolton, Fajfer, Kamenik, Novoa-Brunet 2503.19025
Altmannshofer et al. '23

Good fit to Belle-II data too, since the excess is mostly localized

$m_\psi \sim 0.6$ GeV

$m_{V/\phi} \sim 2.1$ GeV

$K^+ \to \pi^+\nu\nu$ from NA62

$$\frac{\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\rm exp}}{\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\rm SM}} = \mathbf{1.65 \pm 0.30}$$

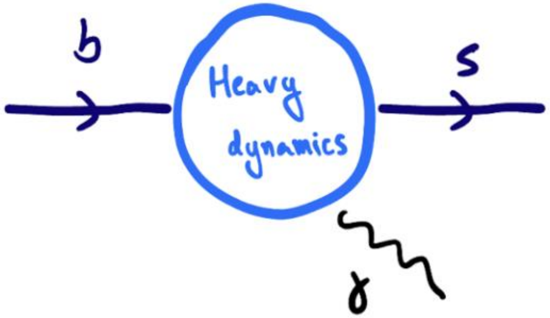
Compatible with the SM at 1.7 σ

- theoretically clean
- significant improvements expected in the next years:
  Belle II will measure $B \to K\nu\bar{\nu}$ @ 10%, and NA62 $K \to \pi\nu\bar{\nu}$ @ 15%(
- sensitive to a limited number of EFT operators: $C_{\ell q}^{(3)[3333]}$, $C_{\ell q}^{(1)[3333]}$
- **the present central values exceed the corresponding SM predictions**
- Sensitive to 3rd generation NP

Allwicher, Bordone, Isidori, Piazza and Stanzione, 2410.21444

Twofold role of Flavour Physics

I. Search of New Physics particles (via loops)



II. Identifying new symmetries

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \begin{pmatrix} c_L \\ s_L \end{pmatrix} \quad \begin{pmatrix} t_L \\ b_L \end{pmatrix}$$

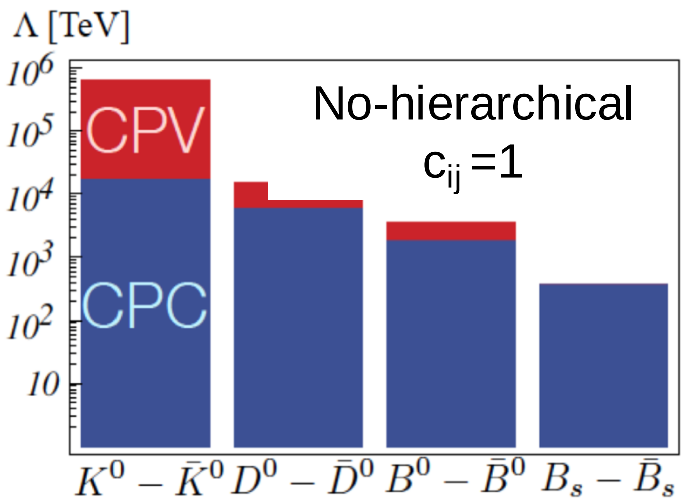
Gauge symmetry

Flavor symmetry?

Flavour Physics: window to new Symmetries

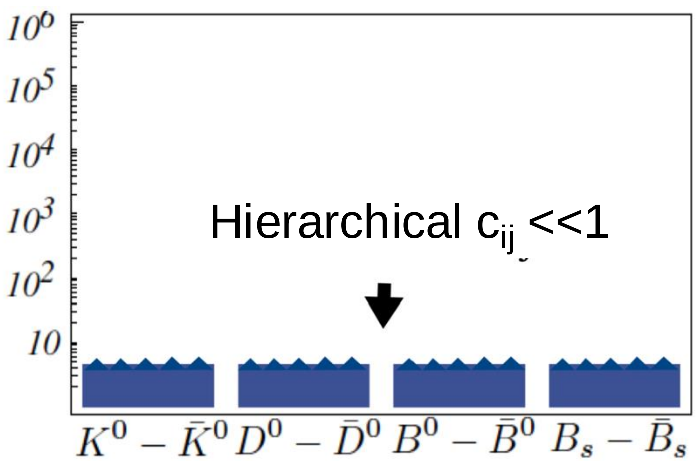
HL-LHC tasks: Is there a hierarchy of NP flavour?

With O(1) NP couplings, bounds on **flavour-violating** operators point to **huge scales higher than 10^4 TeV**



However**, hierarchical structures are already present** in the SM

c_{ij} = 1 is unnatural
due to Y_u and Y_d



With SM inspired assumptions about the NP flavour structure (Λ<10 TeV)

MFV vs **U(2)^5** vs **Rank-1 FV?**

Λ ~ 10 TeV, Λ ~ 1 TeV, Λ ~ 1-10 TeV

Flavour Physics: window to new Symmetries

MFV vs $U(2)^5$ vs Rank-1 FV?

- ***Flavour** could just be an accidental symmetry from more fundamental interactions: nothing forbids it to be badly violated in the UV.*

D'Ambrosio, Giudice, Isidori, Strumia, hep-ph/0207036
…
Glioti, Rattazzi, Ricci and Vecchi, 2402.09503.

I. MFV= $U(3)^5$ flavour breaking

Flavour violations = **a** $Y_{1=2=3}$

- one d.o.f
- **Λ ~ 10 TeV**

$$Y_{U/D} = \begin{pmatrix} x & x & x \\ x & x & x \\ x & x & x \end{pmatrix}$$

- For new physics interactions, e.g. $\mathcal{L}_{\rm NP} = C_{ij}(\overline{u}_{Ri}\gamma^\mu u_{Rj})\mathcal{O}_\mu$

$$\longrightarrow C_{ij} = c_0\,\delta_{ij} + \epsilon\, c_1 (Y_u^\dagger Y_u)_{ij} + \epsilon^2 \left[c_2 (Y_u^\dagger Y_u Y_u^\dagger Y_u)_{ij} + c_2' (Y_u^\dagger Y_d Y_d^\dagger Y_u)_{ij}\right] + \dots$$

Flavour Physics: window to new Symmetries

MFV vs U(2)^5 vs Rank-1 FV?

- ***Flavour*** *could just be an accidental symmetry from more fundamental interactions: nothing forbids it to be badly violated in the UV.*

  Marzia

II. U(2)^5 flavour breaking

Flavour violations = a $Y_{1=2}$ + $\varepsilon\, \tilde{Y}_3$

$$Y_{U,D} = y_{t/b} \begin{pmatrix} Y_{1=2} & \tilde{Y}_3 \\ 0 & 1 \end{pmatrix}$$

- 3rd familiy special!
- two d.o.f
- **Λ ~ 1 TeV**
- *Higgs mostly coupled to 3rd gen*

(could have escaped at Atlas/CMS)

Bordone, Isidori,Trifinopoulos, 1705.10729
Allwicher, Cornella, Isidori and Stefanek, 2311.00020

Flavour Physics: window to new Symmetries

MFV vs $U(2)^5$ vs Rank-1 FV?

III. Rank-1 flavour breaking;

New Physics coupled linearly to SM quarks, $\lambda_i \bar{q}^i \mathcal{O}_{\rm NP}$

Flavour violations = $a\, \hat{n}_i \hat{n}_j$

$$\hat{n}_i = \begin{pmatrix} \hat{n}_{1^{\rm st}} \\ \hat{n}_{2^{\rm nd}} \\ \hat{n}_{3^{\rm rd}} \end{pmatrix} = \begin{pmatrix} e^{i\alpha_{db}} \sin\theta \cos\phi \\ e^{i\alpha_{sb}} \sin\theta \sin\phi \\ \cos\theta \end{pmatrix}$$

- Five d.o.f
- **Λ ~ 1-10 TeV**

NP couples along a specific direction, $\hat{n}$
in the $U(3)_q$ *quark flavor space*

Marzocca, Nardecchia, Toni, Stanzione, 2404.06533

MFV and DM

NO-anomalies: No panic!

All interactions respect the MFV pattern

MFV hypothesis → Stability of flavored dark matter

$SU(3)_Q \times SU(3)_{u_R} \times SU(3)_{d_R}$	Stable?
$(\mathbf{1},\mathbf{1},\mathbf{1})$	
$(\mathbf{3},\mathbf{1},\mathbf{1})$, $(\mathbf{1},\mathbf{3},\mathbf{1})$, $(\mathbf{1},\mathbf{1},\mathbf{3})$	Yes
$(\bar{\mathbf{3}},\mathbf{1},\mathbf{1})$, $(\mathbf{1},\bar{\mathbf{3}},\mathbf{1})$, $(\mathbf{1},\mathbf{1},\bar{\mathbf{3}})$	Yes
$(\mathbf{6},\mathbf{1},\mathbf{1})$, $(\mathbf{1},\mathbf{6},\mathbf{1})$, $(\mathbf{1},\mathbf{1},\mathbf{6})$ $(\mathbf{3},\mathbf{3},\mathbf{1})$, $(\mathbf{3},\mathbf{1},\mathbf{3})$, $(\mathbf{1},\mathbf{3},\mathbf{3})$	Yes
$(\bar{\mathbf{6}},\mathbf{1},\mathbf{1})$, $(\mathbf{1},\bar{\mathbf{6}},\mathbf{1})$, $(\mathbf{1},\mathbf{1},\bar{\mathbf{6}})$ $(\bar{\mathbf{3}},\bar{\mathbf{3}},\mathbf{1})$, $(\bar{\mathbf{3}},\mathbf{1},\bar{\mathbf{3}})$, $(\mathbf{1},\bar{\mathbf{3}},\bar{\mathbf{3}})$	Yes

- Applied for any spin and EW representation of χ
- Only the lightest flavored particle is stable

Batell, Pradler, Spannowsky, 1105.1781
Lopez-Honorez and L. Merlo,1303.1087
F.M., Okawa, Keyun Wu 2408.16812

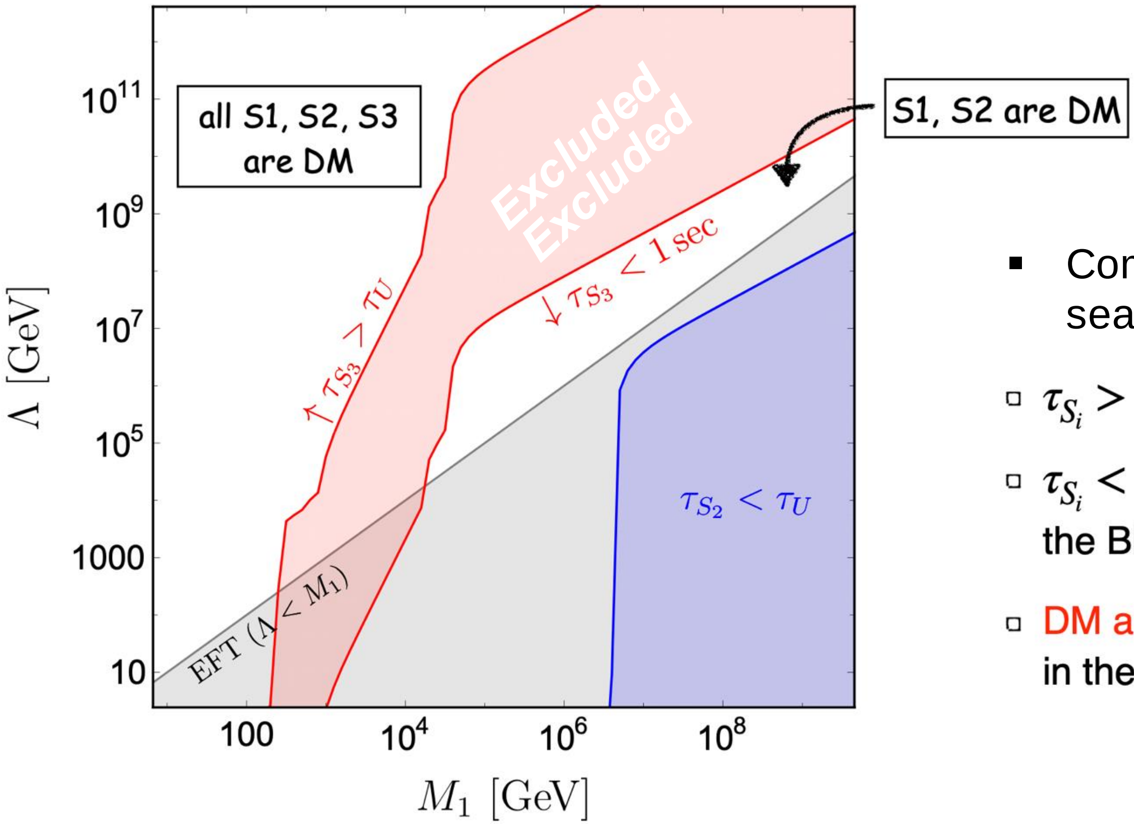
$$\boxed{(n_\chi - m_\chi) \bmod 3 \neq 0}$$ stability condition

$$\chi \sim (n_{q_L}, m_{q_L}) \times (n_{u_R}, m_{u_R}) \times (n_{d_R}, m_{d_R})$$

$$m_\chi = m_{q_L} + m_{u_R} + m_{d_R}$$
$$n_\chi = n_{q_L} + n_{u_R} + n_{d_R}$$

DM and Flavour Physics (MFV)

A gauge singlet scalar $S \sim (\mathbf{1}, \mathbf{3}, \mathbf{1})$



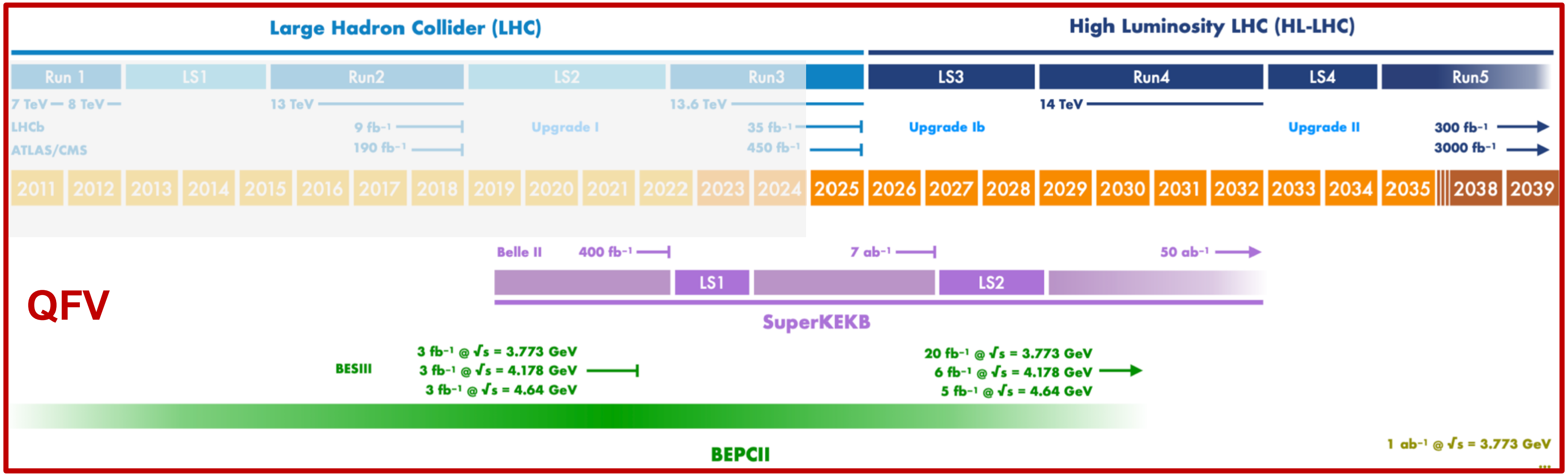
- Compatible with all direct and indirect searches
- $\tau_{S_i} > \tau_U \rightarrow$ DM
- $\tau_{S_i} < \tau_U \rightarrow$ not DM and have to decay prior to the BBN (we require $\tau_{S_i} < 1\,\mathrm{sec}$ in that case)
- DM are composed of two or three components in the white region

F.M., Okawa, Keyun Wu 2408.16812

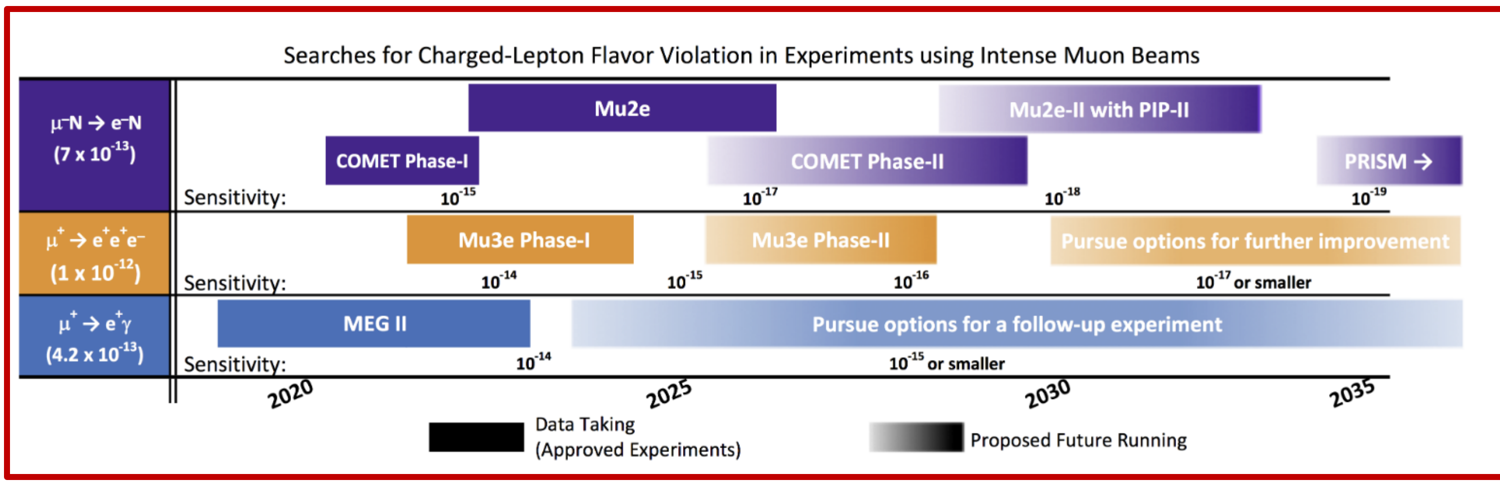
What next?!:

What next?!:

QFV



LFV



Plenty of new experiments on the next 10 years. **Ora et Labora.**

(LHCb, Belle-II, BES-III, NA62, KOTO, EDM, g-2, Mu2e, Legend-1000)

Conclusions

- **Intensity frontier**:
  Potential discovery of new d.o.f beyond the reach of direct productions, ATLAS/CMS

☹ ***Hadronic uncertainties:***
  QCD strong to kill – PIANO PIANO!

- **R_D and $b \to s\ \mu\mu$:**
  Theory and exp. progress is needed to solve this issue: new Exp. and LQCD data will be essential.

- **$B \to K\ \nu\nu$ and $K \to \pi\nu\nu$:**
  Better data are expected soon from NA62 and Belle II.

- **Model Building:**
  new ideas to tackle and correlate other open questions

Força, Equilibri, Valor i Seny

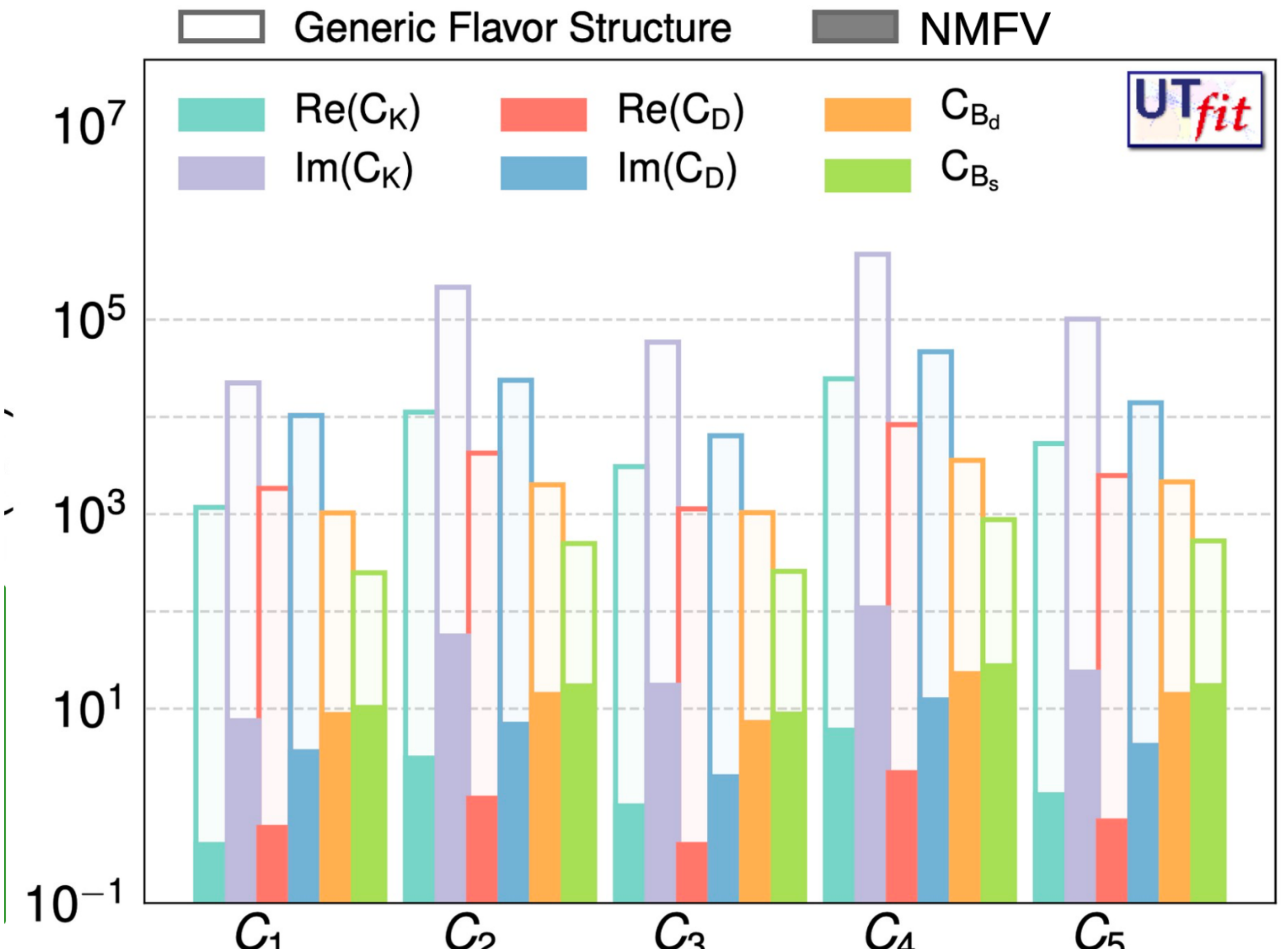
Força, Equilibri, Valor i Seny

Grazie

Bon voyage to Beyond Flavour Anomalies

Flavour Physics: window to New Physics

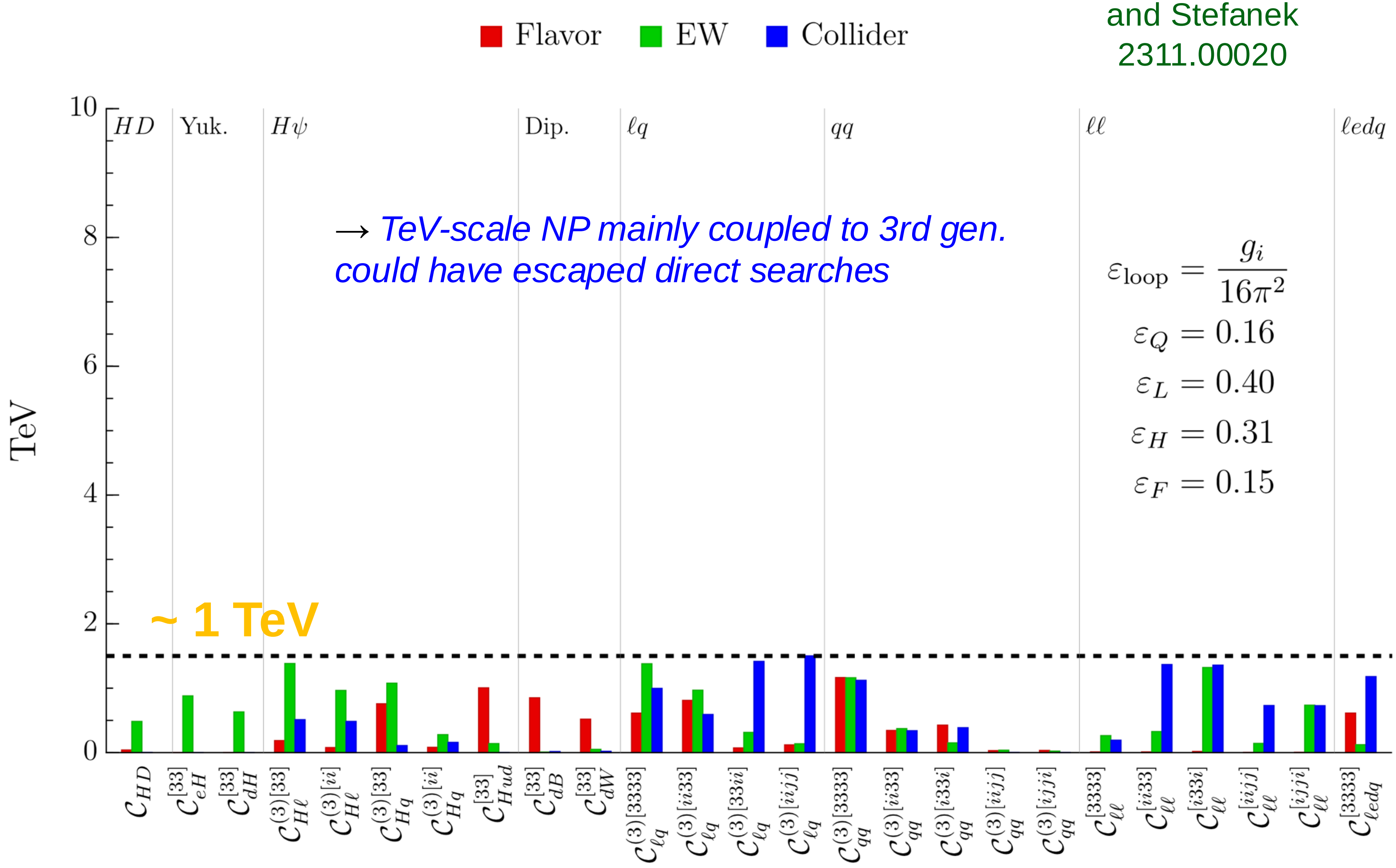
HL-LHC hints; “NP flavour to be or not to be hierarchical”?



Flavour Physics: NP in the 3rd generation

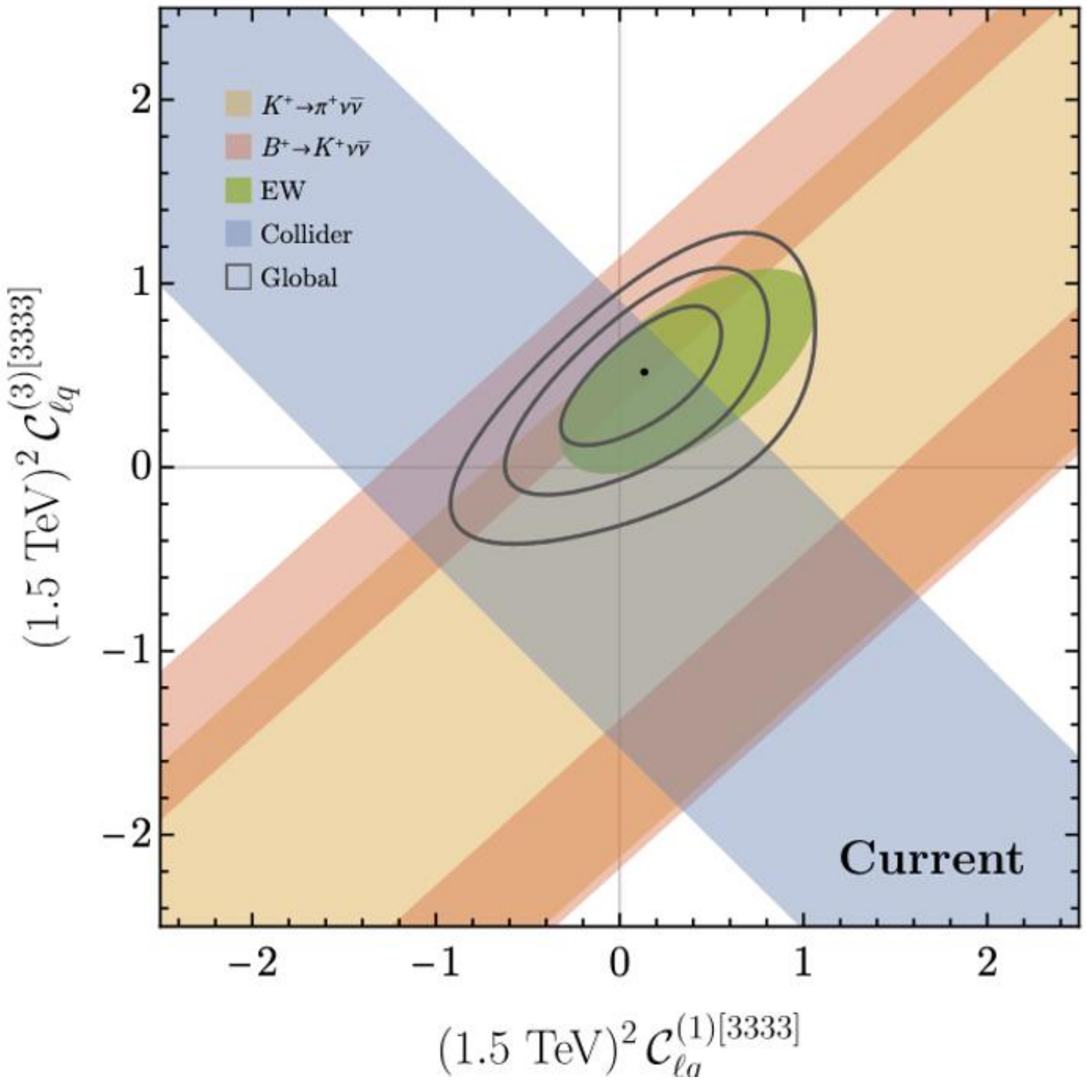
$U(2)^5 \equiv U(2)_q \times U(2)_u \times U(2)_d \times U(2)_\ell \times U(2)_e$

Allwicher, Cornella, Isidori and Stefanek
2311.00020



Flavour Physics: NP in the 3rd generation

$$U(2)^5 \equiv U(2)_q \times U(2)_u \times U(2)_d \times U(2)_\ell \times U(2)_e$$



Allwicher, Cornella, Isidori and Stefanek 2311.00020

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II
EW Penguins				
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05
CKM tests				
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°
γ, all modes	3° [167]	1.5°	1.5°	0.35°
$\sin 2\beta$, with $B^0 \to J/\psi K^0_{\mathrm{S}}$	0.013 [609]	0.011	0.005	0.003
ϕ_s, with $B_s^0 \to J/\psi\phi$	20 mrad [44]	14 mrad	–	4 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad
a^s_{sl}	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%
$\boldsymbol{B^0_s, B^0 \to \mu^+\mu^-}$				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B^0_s \to \mu^+\mu^-)$	90% [264]	34%	–	10%
$\tau_{B^0_s \to \mu^+\mu^-}$	22% [264]	8%	–	2%
$S_{\mu\mu}$	–	–	–	0.2
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**				
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002
$R(J/\psi)$	0.24 [220]	0.071	–	0.02
Charm				
$\Delta A_{CP}(KK - \pi\pi)$	2.9×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K^0_{\mathrm{S}}\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}

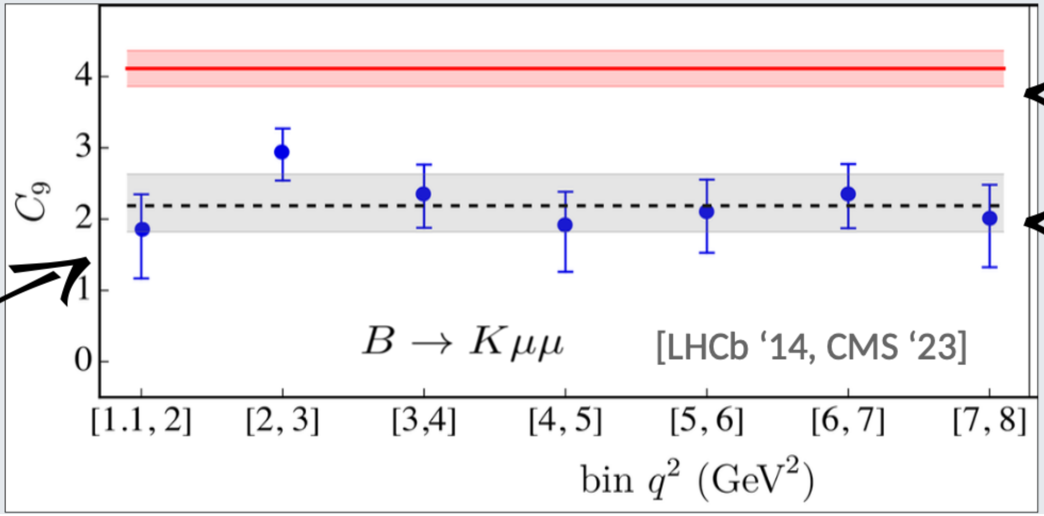
Long story short

1) The contribution is dominated by the charm loops due to O_{1c} and O_{2c}

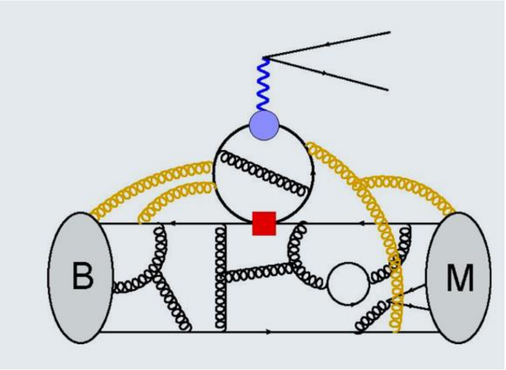
2) The contribution mimics new physics by shifting C_9

▹ No visible q^2 dependence for NP [Bordone, Isidori, Maechler, Tinari '24]

At low q^2:



Data from LHCb and CMS



	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

★★★ large effects
★★ visible but small effects
★ unobservable effects