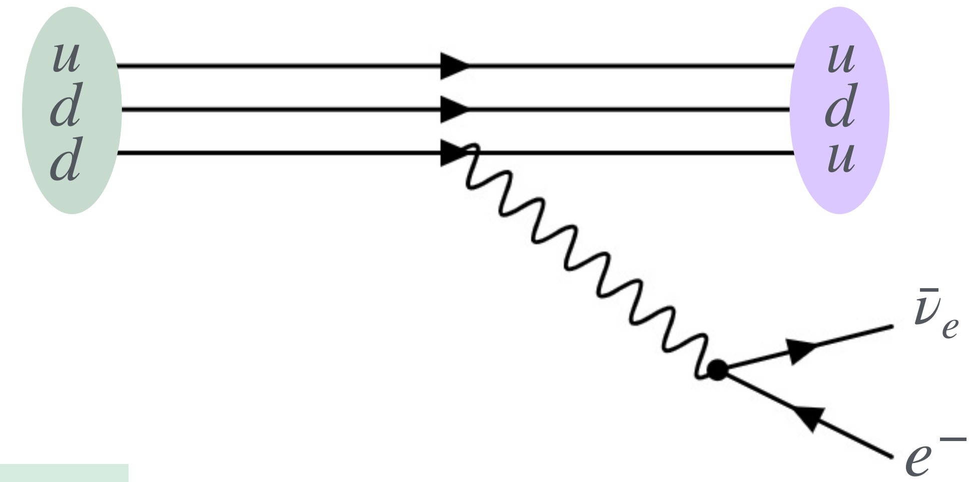
One-loop analysis of β decays in SMEFT

Maria Dawid

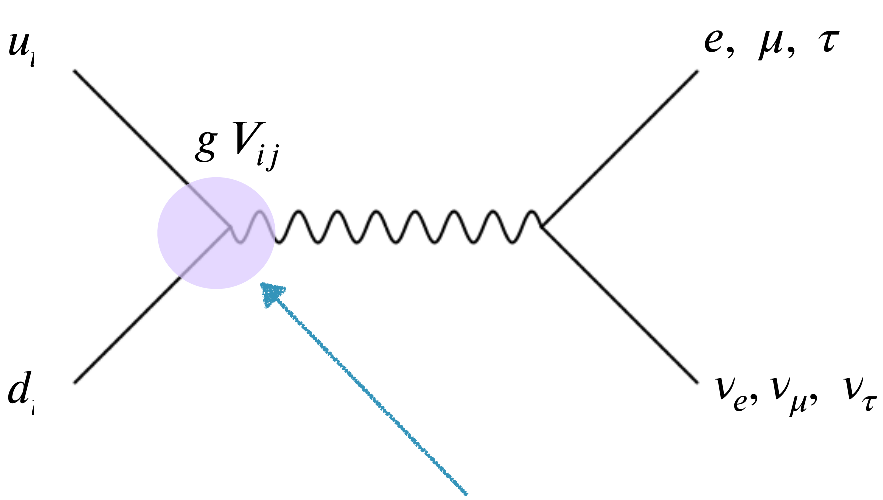
Based on
M.D, V. Cirigliano, W. Dekens
ArXiv: (2402.06723)

Beta decay



The Cabibbo-Kobayashi-Maskawa matrix

$$V_{\mathrm{CKM}} V^{\dagger}_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} V^*_{ud} & V^*_{cd} & V^*_{td} \\ V^*_{us} & V^*_{cs} & V^*_{ts} \\ V^*_{ub} & V^*_{cb} & V^*_{tb} \end{pmatrix} = 1 \ ,$$



$$\mathscr{L}_{EW} \subset \frac{g}{\sqrt{2}} W^+_\mu \, \bar{d}_{i_L} V_{ij} \gamma^\mu u_{j_L}$$

Unitarity

$$\Delta_{CKM} \equiv |V_{ud}|^2 + |V_{us}|^2 - 1 \approx 0$$

Global fit

$$\Delta_{CKM} = -1.48(53) \times 10^{-3}$$

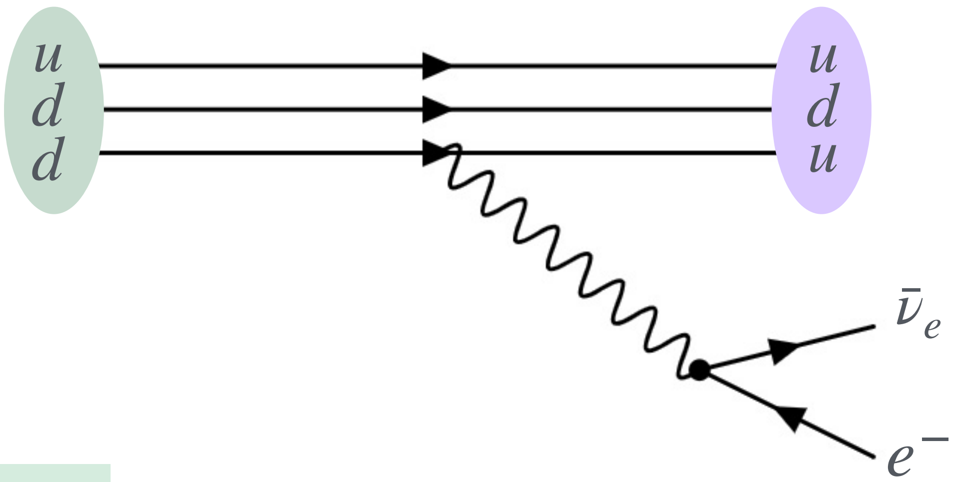
$$V_{ud} = 0.973670(25)$$

$$V_{us} = 0.22422(36)$$

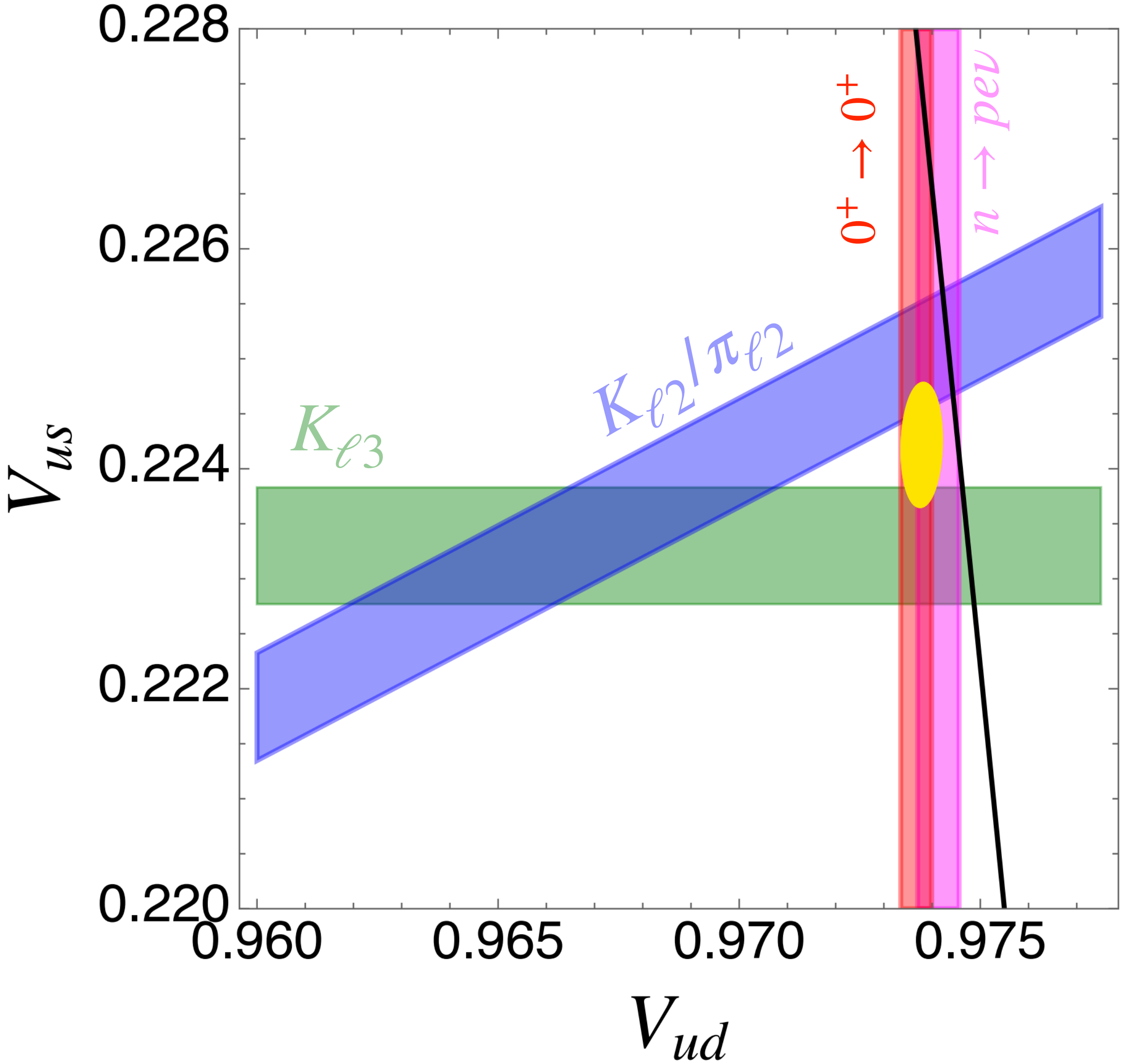
Discrepancy with SM

- Underestimated SM uncertainties?
- BSM physics?

The CKM unitarity test



The Cabibbo-Kobayashi-Maskawa matrix



Scrutinizing CKM unitarity with a new measurement of the $K_{\mu 3}/K_{\mu 2}$ branching fraction
V. Cirigliano et al. (arXiv: 2208.11707)

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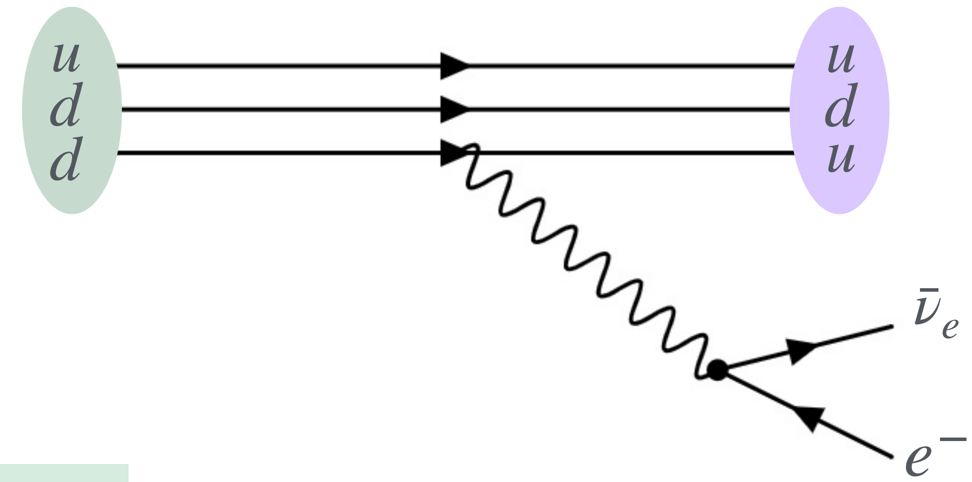

The Cabibbo-Kobayashi-Maskawa matrix

Probing physics beyond Standard Model

Work on three different fronts:

Enhancing the accuracy of experiments

Improving precision of SM calculations

Advancing theory for BSM physics

Standard Model Effective Field Theory

Unitarity

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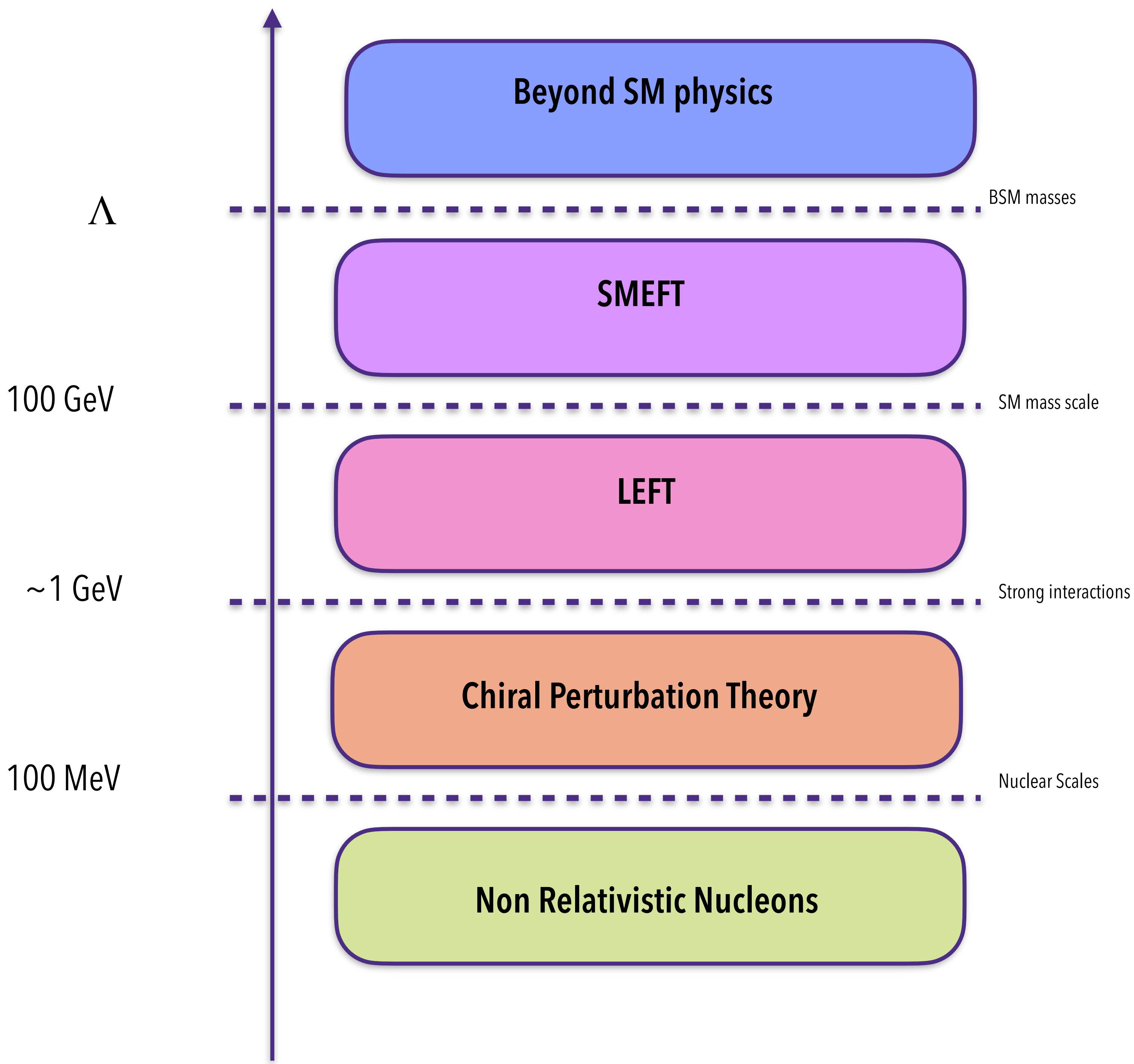
Effective Field Theories

To connect UV physics to beta decays, use EFT



Effective Field Theories

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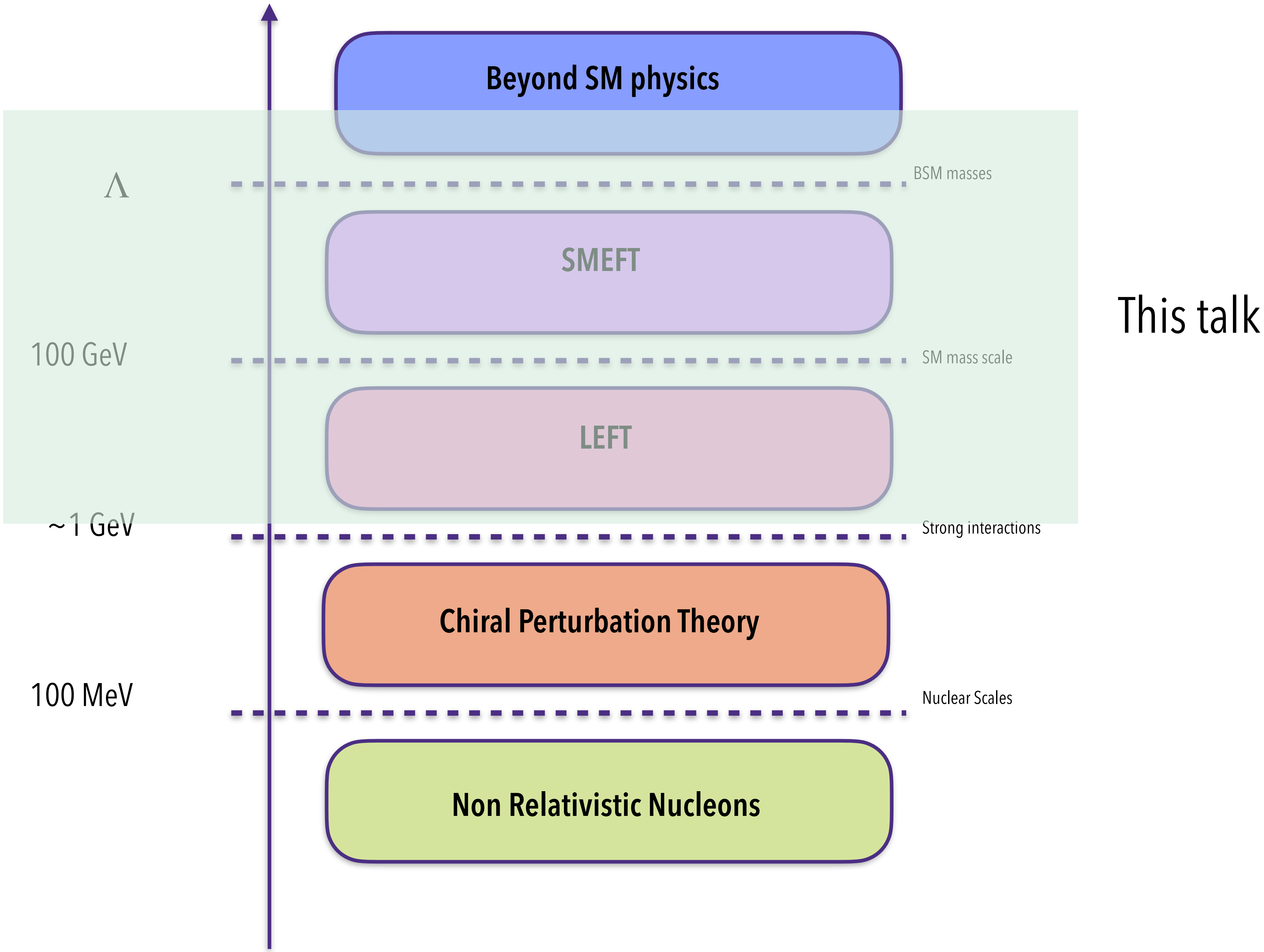


Standard Model EFT

The EFT constructed with Standard Model fields & symmetries

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \frac{1}{v} C^{(5)} Q^{(5)} + \frac{1}{v^2} \sum_k C_k^{(6)} Q_k^{(6)} + \mathcal{O}(\frac{1}{v^3}) + \ldots$$

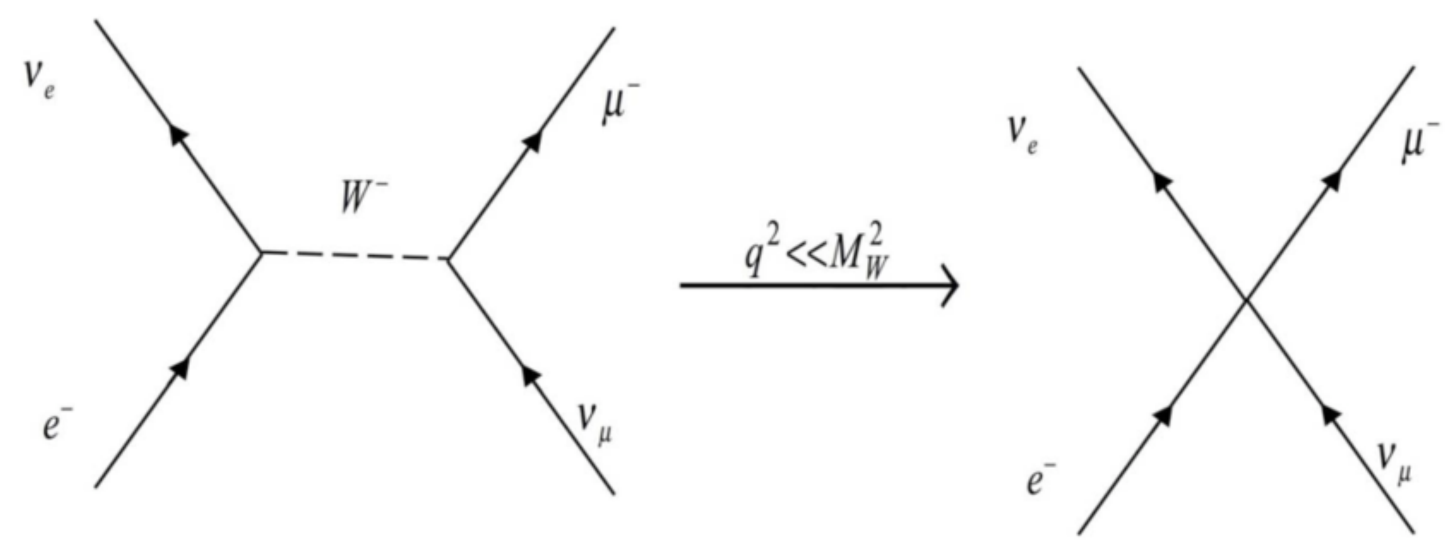
The Standard Model is a part of the leading order of SMEFT

With $C_k \sim v^2/\Lambda^2$

C - Wilson coefficients

Q - local interaction terms (operators)

Example of EFT: Fermi Theory



$$\frac{-g_{\mu\nu} + q_\mu q_\nu / M_W^2}{q^2 - M_W^2} \xrightarrow{q^2 << M_W^2} \frac{g_{\mu\nu}}{M_W^2}$$

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$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \frac{1}{v} C^{(5)} Q^{(5)} + \frac{1}{v^2} \sum_k C_k^{(6)} Q_k^{(6)} + \mathcal{O}(\frac{1}{v^3}) + \ldots$$

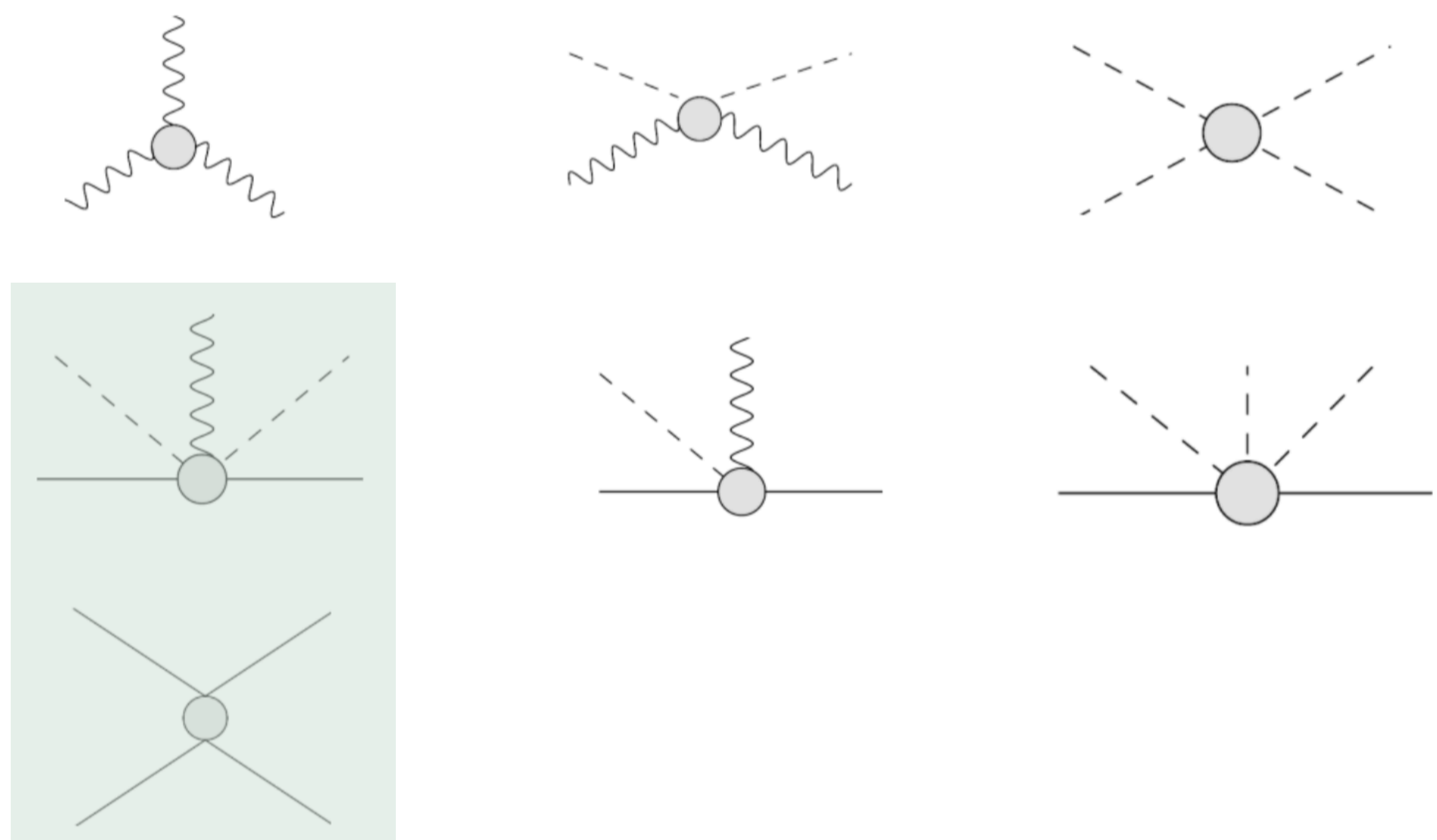
6-dim operators

With $C_k \sim v^2/\Lambda^2$

No fermions

Two fermions

Four fermions



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The Standard Model is a part of the leading order of SMEFT

With $C_k^i \sim v^{i-4}/\Lambda^{i-4}$

C - Wilson coefficients

Q - local interaction terms (operators)

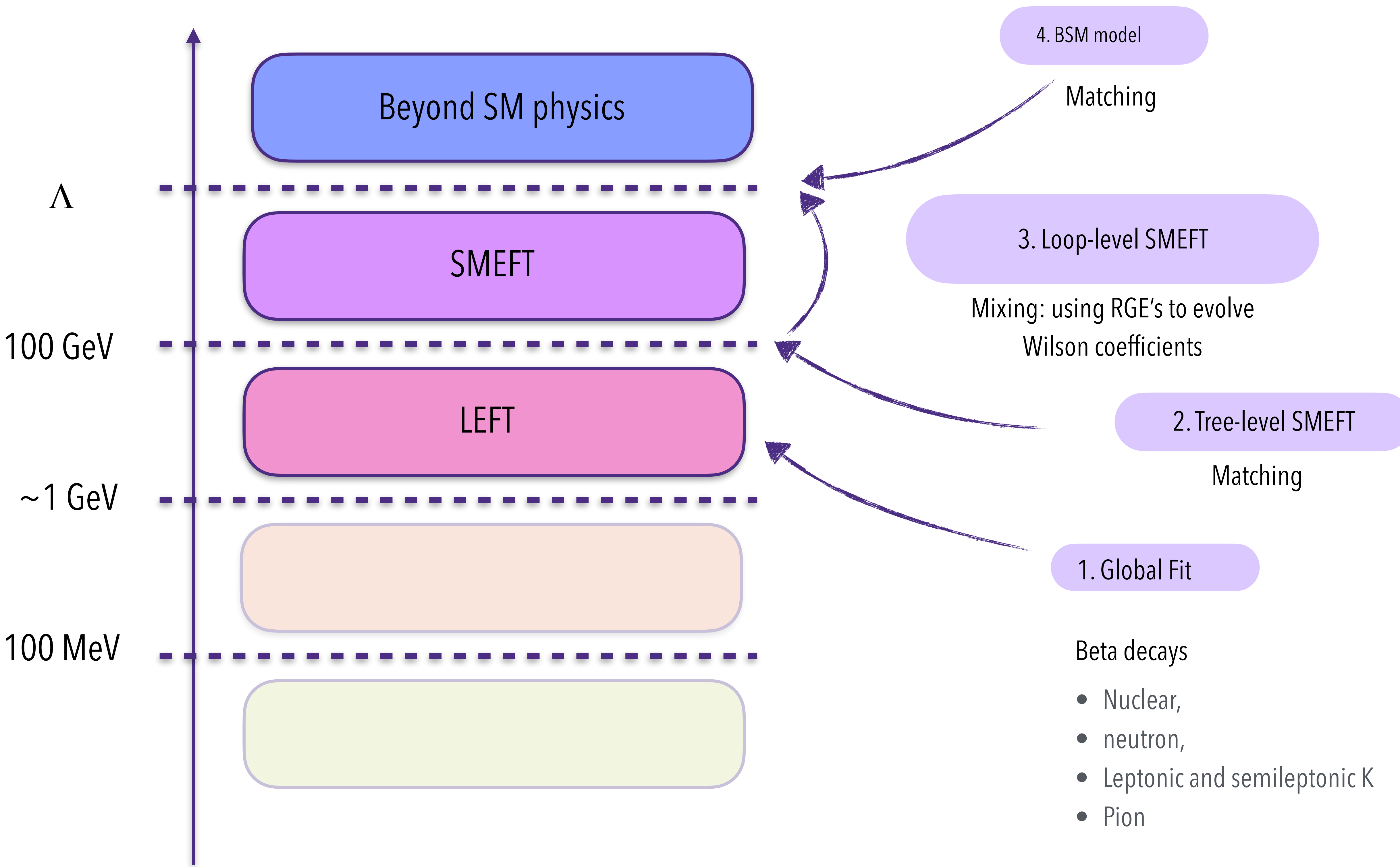
Operators that contain particles directly involved in a process

SMEFT contributions to beta decay are well-known at a tree level

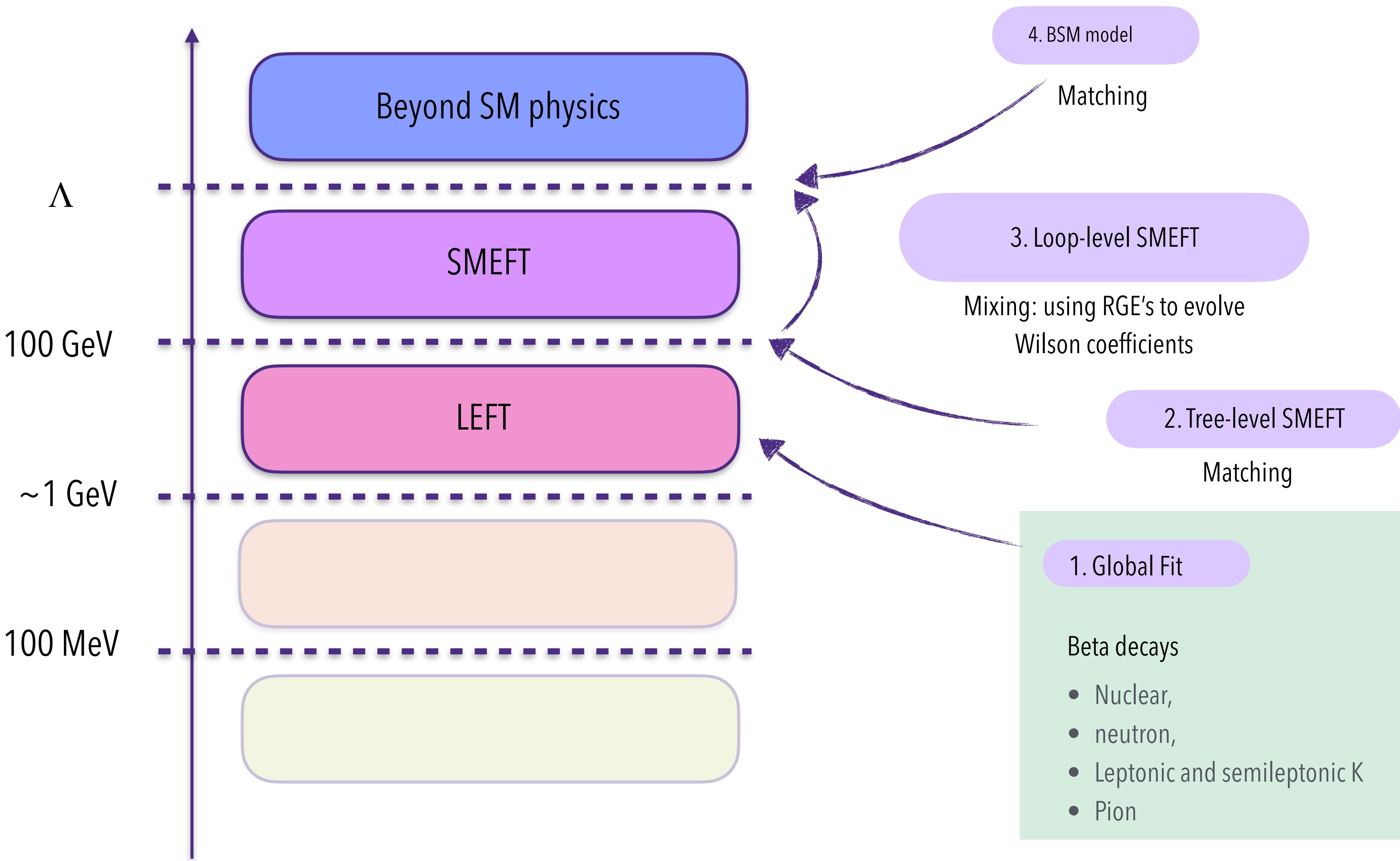
What about quantum fluctuations?

Goal of the work: identify leading contributions to beta decay at a one-loop level.

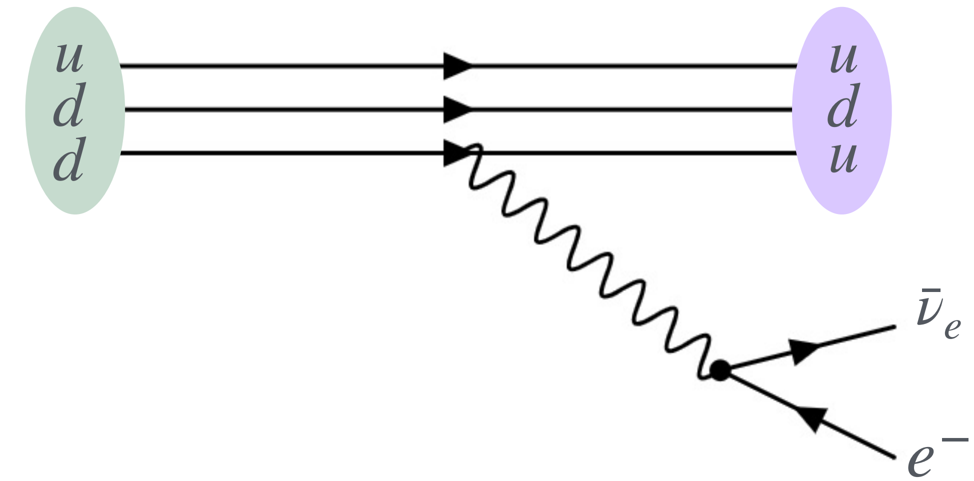
β-decay on loop level



β-decay on loop level



GeV scale effective Lagrangian



$$\boldsymbol{d \to u\, l^-\, \bar{\nu}_l}$$

From muon decay

$$\epsilon_L = \epsilon_L^\beta - \epsilon_L^\mu$$

$$\begin{aligned}
\mathscr{L}_{LEFT} = -\frac{G_F^0 V_{ud}}{\sqrt{2}} \, [&(1+\epsilon_L)\, \bar{e}\, \gamma_\mu (1-\gamma_5) \nu_l\, \bar{u} \gamma^\mu (1-\gamma_5) d && \text{left quarks} \\
&+ \epsilon_R\, \bar{e} \gamma_\mu (1-\gamma_5) \nu_l\, \bar{u} \gamma^\mu (1+\gamma_5) d && \text{right quarks} \\
&+ \epsilon_S\, \bar{e}\, (1-\gamma_5) \nu_l\, \bar{u} d && \text{scalar} \\
&- \epsilon_P\, \bar{e} (1-\gamma_5) \nu_l\, \bar{u} \gamma_5 d && \text{pseudo-scalar} \\
&+ \epsilon_T\, \bar{e} \sigma_{\mu\nu}\, (1-\gamma_5) \nu_l\, \bar{u} \sigma^{\mu\nu}\, (1-\gamma_5) d\ ] && \text{tensor}
\end{aligned}$$

ϵ_L^μ SMEFT correction to GF as extracted from muon decay

Anomalies in global SMEFT analyses. A case study of first-row CKM unitarity
V. Cirigliano, W. Dekens, J. de Vries, E. Mereghetti, T. Tong
(arXiv:2311.00021)

Global Fit

flavor-assumption-independent analysis

- Drell-Yan collider processes ('C')
- Low-energy charged current processes ('L')
  - – Neutron and nuclear β decays
  - – Kaon and pion decays ($\Gamma(K \to \mu\nu_\mu)$, $R_\pi = \Gamma(\pi \to e\nu_e)/\Gamma(\pi \to \mu\nu_\mu)$, $R_K = \Gamma(K \to e\nu_e)/\Gamma(K \to \mu\nu_\mu)$, $R_\mu = \Gamma(K \to \mu\nu_\mu)/\Gamma(\pi \to \mu\nu_\mu)$)
- electroweak precision observables ('EW')
  - – observables measured at the Z pole (decay widths, asymmetries, hadronic cross section obtained from $e + e^- \to Z \to \bar{q}q$, W mass

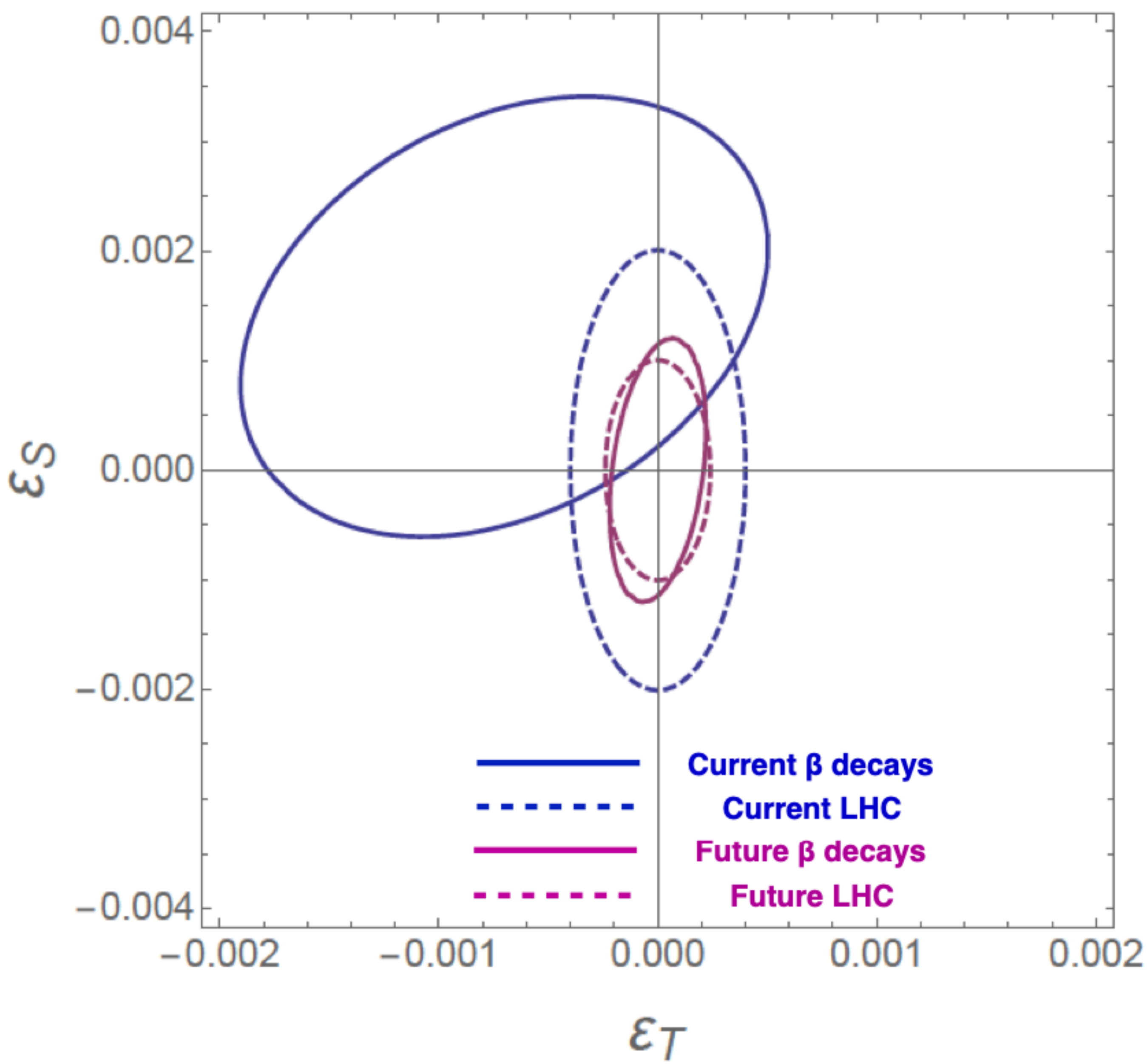
→ put constraints on ϵ_i's $\sim v^2/\Lambda^2$

$$\epsilon_L^{(\mu)}, \quad \epsilon_L^{(c)}, \quad \epsilon_L^{(v)} \approx -8.3 \pm 2.5 \times 10^{-4}$$

→ 20 TeV

Other fit:
A. Falkowski, M. González-Alonso, O. Naviliat-Cuncic
(arXiv:2010.1379))

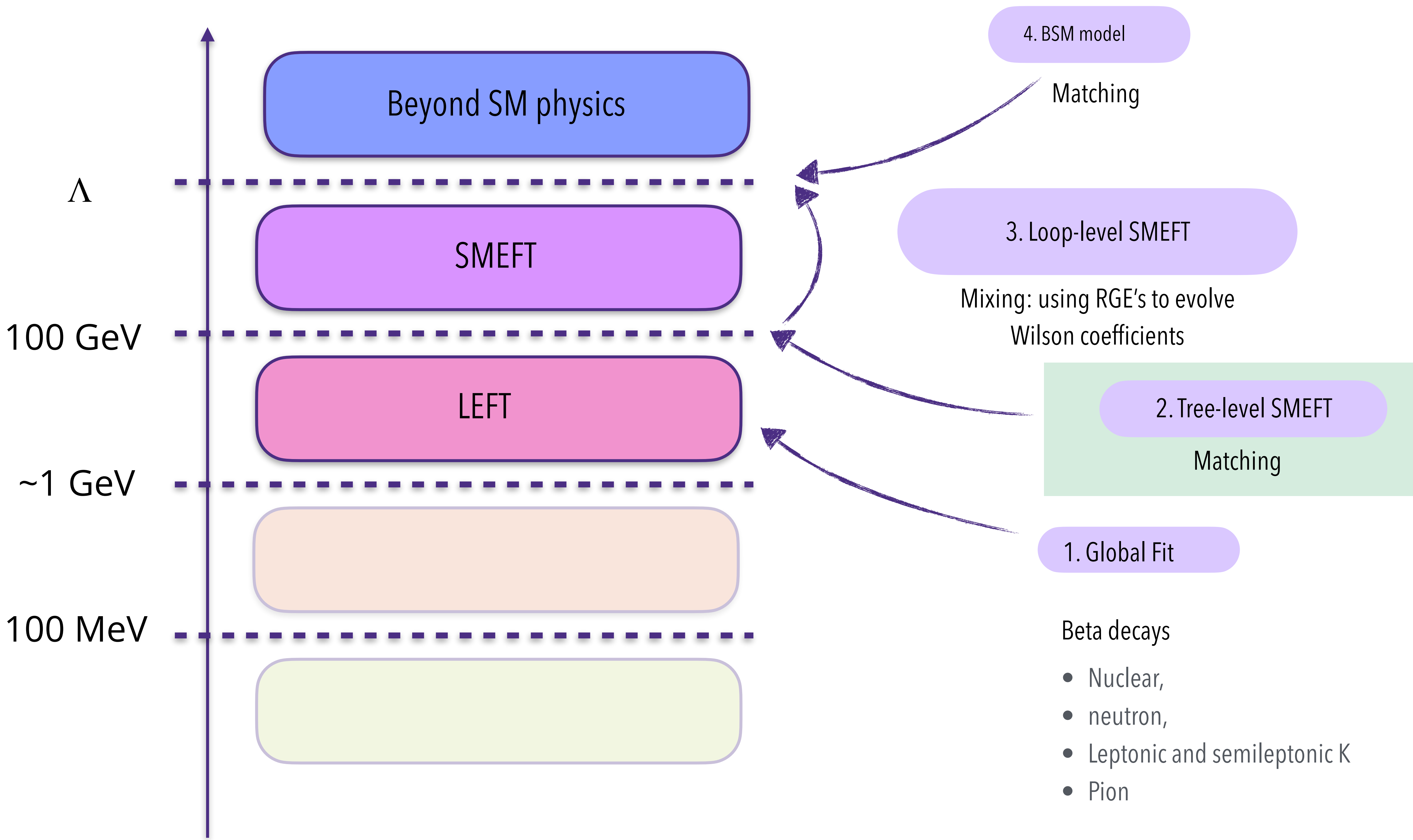
Global Fit



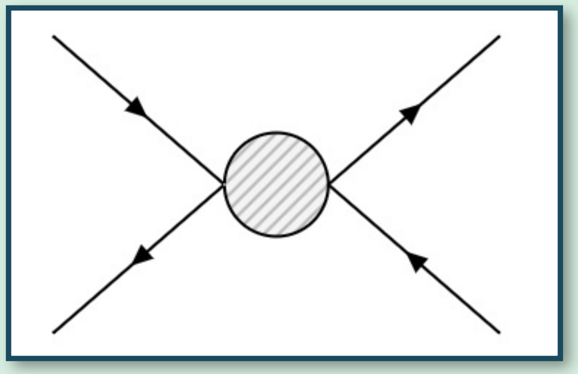
- Current and projected 90% C.L. constraints on ϵ_S and ϵ_T defined at 2 GeV in the MS bar scheme
- Beta decay:
  - The current analysis includes all existing neutron and nuclear decay measurements,
  - Future projection assumes measurements of the various decay correlations with uncertainty of 0.1%
- LHC:
  - Obtained from $pp \to e + MET + X$
  - ATLAS results at $\sqrt{s} = 13$ TeV
  - The projected future LHC bounds are obtained by assuming that no events are observed at transverse mass greater than 3 TeV
- LHC cannot constrain ϵ_L, and ϵ_R

Isovector and flavor diagonal charges of the nucleon from 2+1+1 flavor QCD
Rajan Gupta et al. (arXiv:1812.03573)

β-decay on loop level

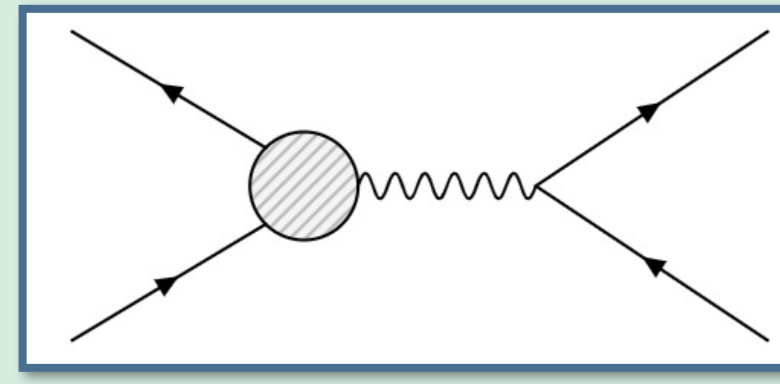


Beta Decay at the Tree Level



Four fermion operators

$$Q_{lq}^{(3)} = (\bar{l}_p \gamma_\mu \tau^I l_r)\,(\bar{q}_s \gamma^\mu \tau^I q_t),$$
$$Q_{ledq} = (\bar{l}_p e_r)\,(\bar{d}_s q_t),$$
$$Q_{lequ}^{(1)} = \left(\bar{l}_p^j e_r\right) \epsilon_{jk} \left(\bar{q}_s^k u_t\right),$$
$$Q_{lequ}^{(3)} = \left(\bar{l}_p^j \sigma_{\mu\nu} e_r\right) \epsilon_{jk} \left(\bar{q}_s^k \sigma^{\mu\nu} u_t\right),$$



Vertex correction

$$Q_{Hud} = i\left(H^\dagger D_\mu H\right)\left(\bar{u}_p \gamma^\mu d_r\right),$$
$$Q_{Hl}^{(3)} = \left(H^\dagger i \overleftrightarrow{D}_\mu^I H\right)\left(\bar{l}_p\, \tau^I \gamma^\mu l_r\right),$$
$$Q_{Hq}^{(3)} = \left(H^\dagger i \overleftrightarrow{D}_\mu^I H\right)\left(\bar{q}_p\, \tau^I \gamma^\mu q_r\right),$$

p , r , s, t are flavor indices
here all 1

We work in the weak eigenstate basis

$$M_u = diag\ (m_u, m_c, m_t),\ M_d = diag\ (m_d, m_c, m_t)\ V^\dagger$$

$$l^i = \begin{pmatrix} \nu_L^i \\ e_L^i \end{pmatrix},\quad q^i = \begin{pmatrix} u_L^i \\ V\, d_L^i \end{pmatrix},\quad H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix},$$

e, u, d – right-chiral fields,
$\tau - SU(2)$ generators,
D_μ - covariant derivative

Muon Decay

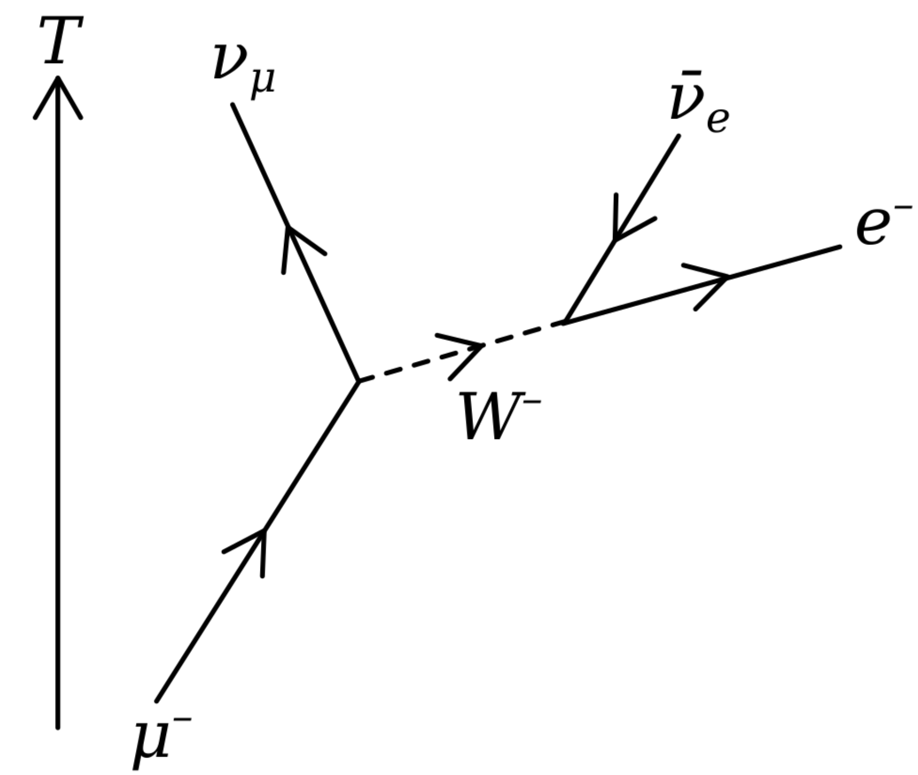
$\epsilon_L^{(\mu)}$ arises from the SMEFT correction to the Fermi constant extracted from muon decay and is given by

$$Q_{Hl}^{(3)} = \left(H^\dagger i \overleftrightarrow{D}_\mu^I H\right)(\bar{l}_p \tau^I \gamma^\mu l_r)$$

$$Q_{ll} = (\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma_\mu l_t)$$

flavour indices:

(1,2,2,1)



$$\epsilon_L^{(\mu)} = \left(C_{ll_{1221}} + C_{ll_{2112}}\right) - 2(C_{Hl_{11}}^{(3)} + C_{Hl_{22}}^{(3)}$$

$$l^i = \begin{pmatrix} \nu_L^i \\ e_L^i \end{pmatrix}, \quad q^i = \begin{pmatrix} u_L^i \\ V\, d_L^i \end{pmatrix}, \; H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix},$$

e, u, d – right-chiral fields,

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D_μ - covariant derivative

Matching at the Electro-Weak Scale

$$[\mathcal{T}_{LEFT} = \mathcal{T}_{SMEFT}]_{\mu_W}$$

Vector interactions for left quarks:

- $\epsilon_L = \epsilon_L^{(v)} + \epsilon_L^{(c)} - \epsilon_L^{(\mu)}$
- $\epsilon_L^{(v)} = 2\, C_{Hl}^{(3)} + 2\dfrac{\left[V C_{Hq}^{(3)}\right]_{11}}{V_{ud}} + 4\dfrac{[V C_{Hl}^{(3)}]_{11}}{V_{ud}},$
- $\epsilon_L^{(c)} = -2\dfrac{\left[V C_{lq}^{(3)}\right]_{11}}{V_{ud}},$
- $\epsilon_L^{(\mu)} = \left(C_{ll_{1221}} + C_{ll_{2112}}\right) - 2(C_{Hl_{11}}^{(3)} + C_{Hl_{22}}^{(3)})$

$$\epsilon_R = -\frac{\left[V C_{Hud}^{(3)}\right]_{11}}{V_{ud}},$$

$$\epsilon_s - \epsilon_P = -2\frac{\left[V C_{ledq}^{(3)}\right]_{11}}{V_{ud}},$$

$$\epsilon_s + \epsilon_P = -2\frac{\left[V C_{lequ}^{(1)}\right]_{11}}{V_{ud}},$$

$$\epsilon_T = -\frac{C_{lequ}^{(3)}}{V_{ud}}.$$

$\epsilon_L^{(v)}$ - vertex correction
$\epsilon_L^{(c)}$ - contact correction
$\epsilon_L^{(\mu)}$ - correction to muon decay

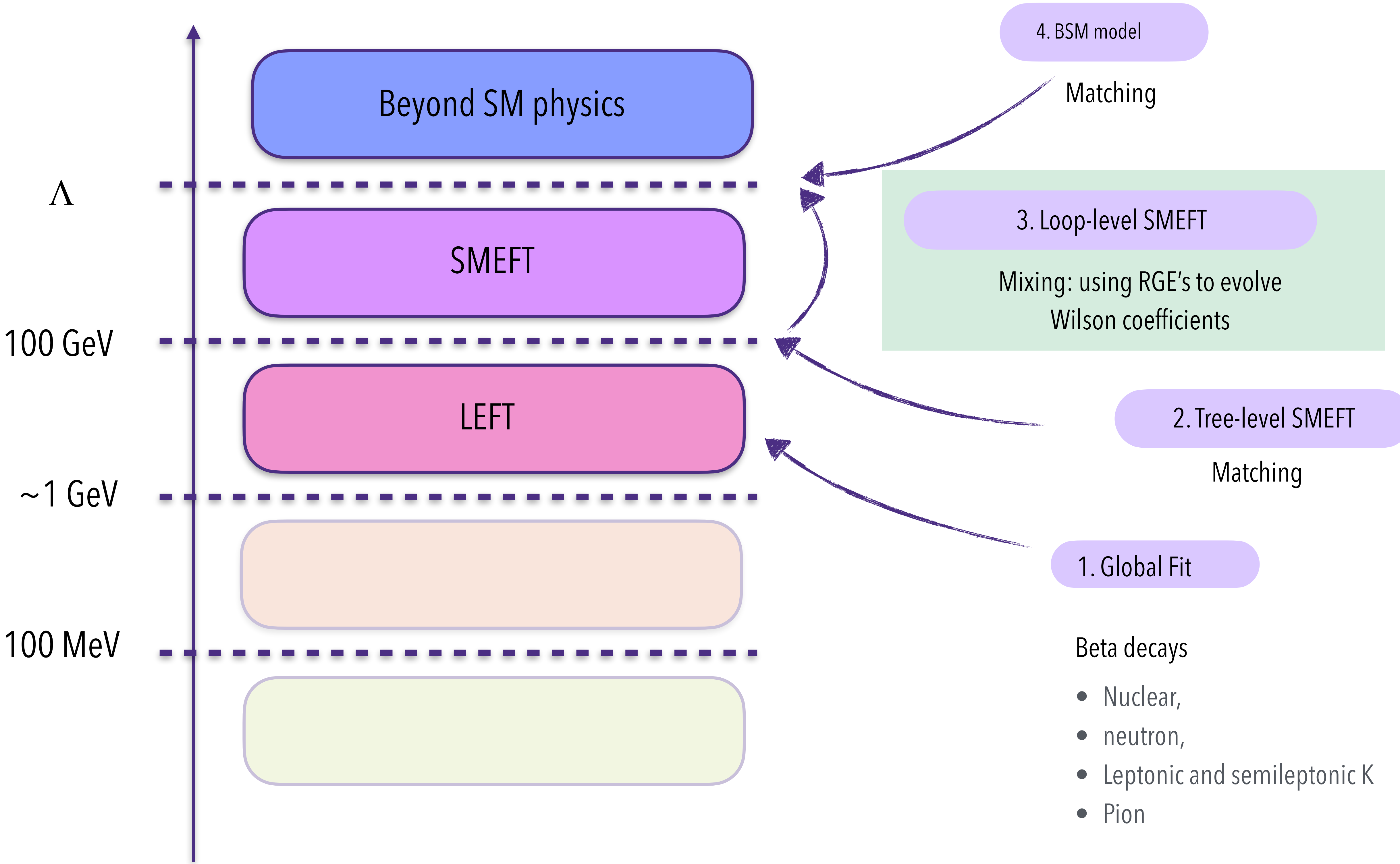
$$\left[V C_{Hq}^{(3)}\right]_{11} = \underset{11}{C_{Hq}^{(3)}} V_{11} + \underset{12}{C_{Hq}^{(3)}} V_{21} + \underset{13}{C_{Hq}^{(3)}} V_{31}$$

Bounds from beta decay (CKM unitarity)

$$\Delta_{CKM} = 2\left|V_{ud}\right|^2 \epsilon_L^d + 2\left|V_{us}\right|^2 \epsilon_L^s$$

$$\epsilon_L^{(\mu)},\quad \epsilon_L^{(c)},\quad \epsilon_L^{(v)} \approx -8.3 \pm 2.5 \times 10^{-4},$$

β-decay on loop level

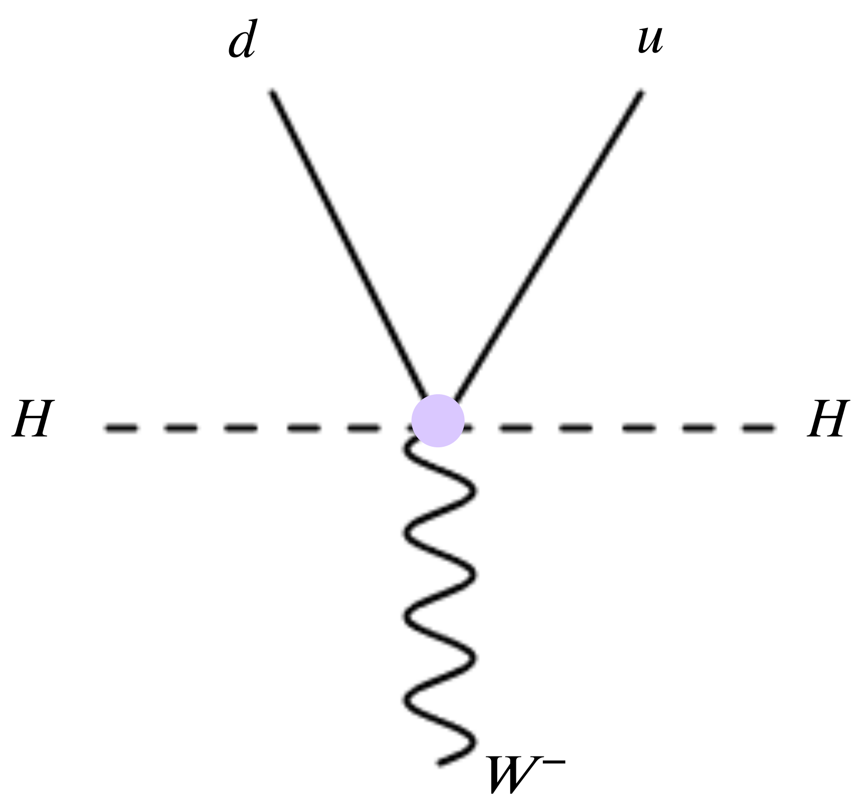


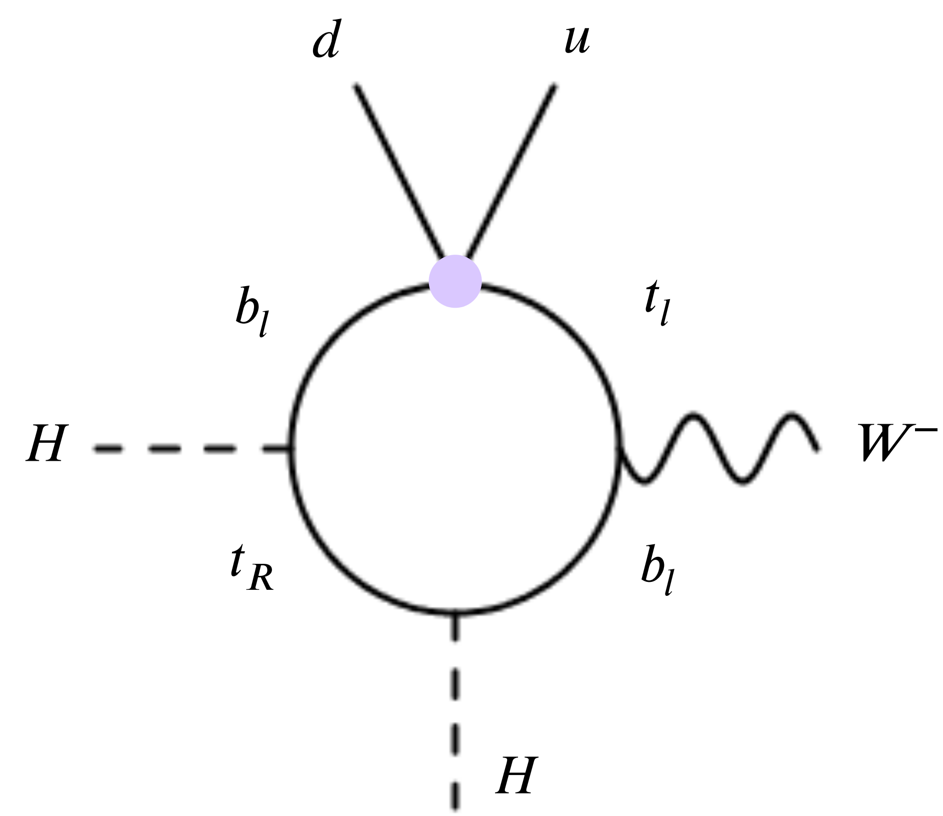
Beta decays

- Nuclear,
- neutron,
- Leptonic and semileptonic K
- Pion

Mixing Procedure

- SMEFT operator





$Q^{(3)}_{\substack{Hq\\11}}$

$Q^{(3)}_{\substack{qq\\1133}} \rightarrow Q^{(3)}_{\substack{Hq\\11}}$

Triplet

$$Q^{(3)}_{Hq} = (H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p \tau^I \gamma^\mu q_r)$$

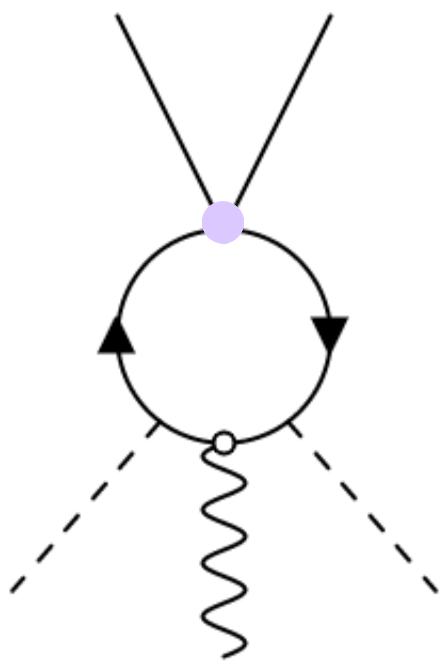
2 quarks and boson

$$Q^{(3)}_{qq} = (\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$$

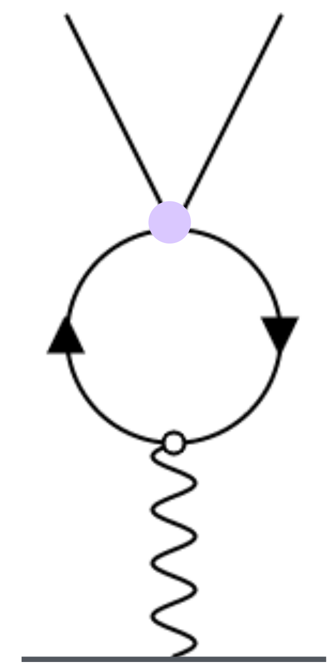
4 quarks

More Examples

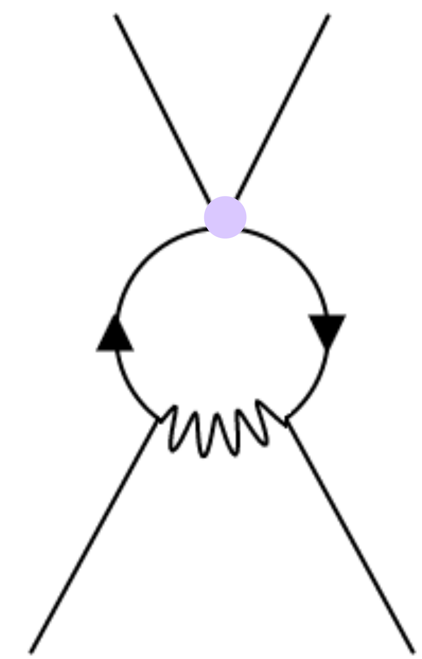
- SMEFT operator



Contribution to $Q_{Hl}^{(3)}$ and $Q_{Hq}^{(3)}$
from $Q_{qq}^{(3)}$, $Q_{qq}^{(1)}$, $Q_{lq}^{(3)}$



Contribution to $Q_{lq}^{(3)}$
from $Q_{qq}^{(3)}$, $Q_{qq}^{(1)}$



Contribution to Q_{ll}
from Q_{ll}

Renormalization Group Equations

RGE

Tree level

Loop level

$$\begin{pmatrix} \dot{C}_\beta \\ \dot{C}_x \end{pmatrix} = \begin{pmatrix} \gamma_{\beta\beta} & \gamma_{\beta x} \\ \gamma_{x\beta} & \gamma_{xx} \end{pmatrix} \begin{pmatrix} C_\beta \\ C_x \end{pmatrix}$$

Mixing of operators

$$C_{\beta j}(\mu_W) = \sum_k U_{jk}(\mu_W, \Lambda) C_{xk}(\Lambda)$$

$$|\epsilon| = |\kappa_i \, C_i| \le \bar{\epsilon}_L$$

mixing parameter from RGE's

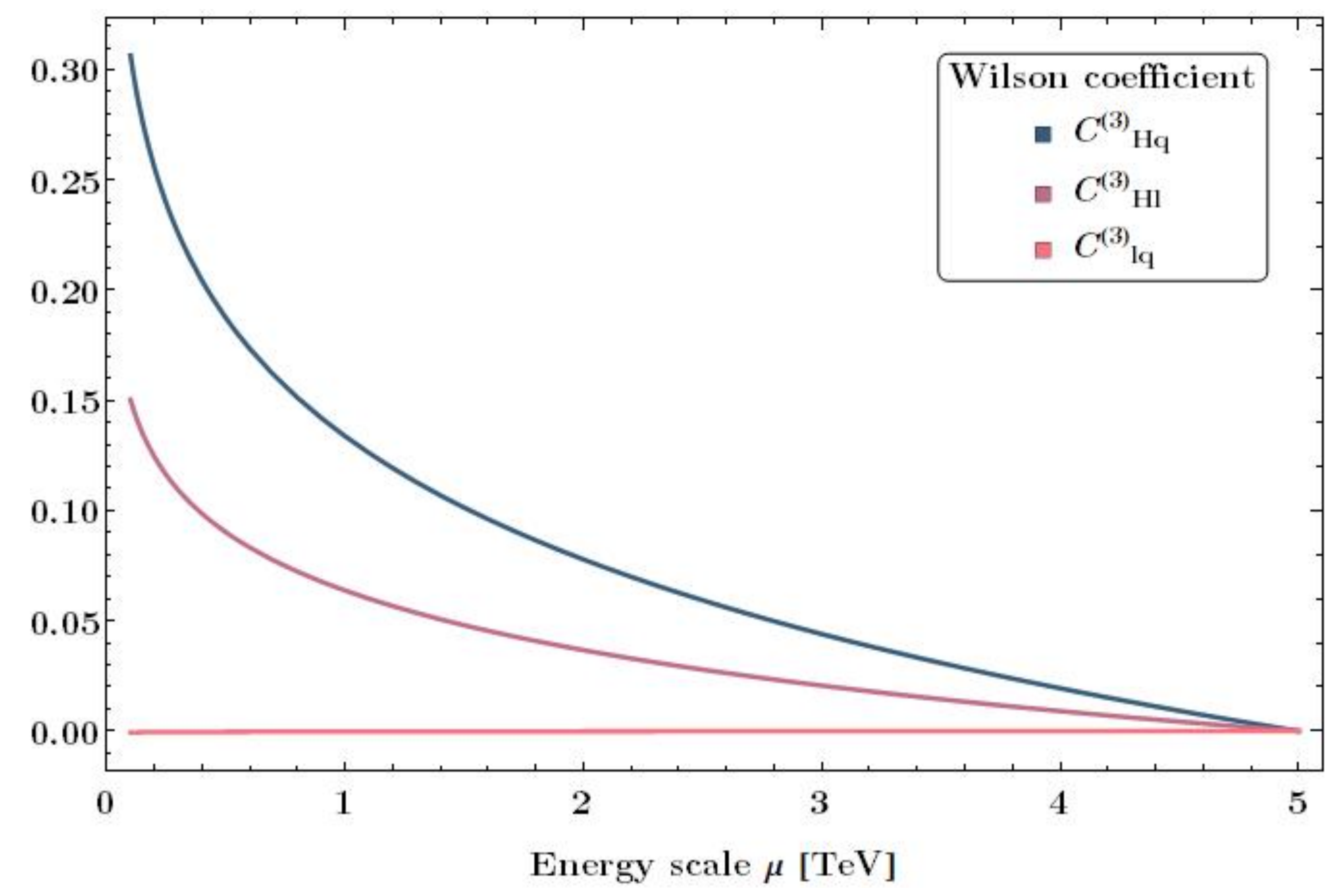
bound from the experiment

Initial conditions for $\Lambda = 5$ TeV

$$C_\beta(\Lambda) = 0$$

$$C_x(\Lambda) = 1$$

Example of solutions of RGE's for $C^{(3)}_{Hq}$, $C^{(3)}_{Hl}$ and $C^{(3)}_{lq}$



RH, Scalar, Pseudoscalar, and Tensor Terms

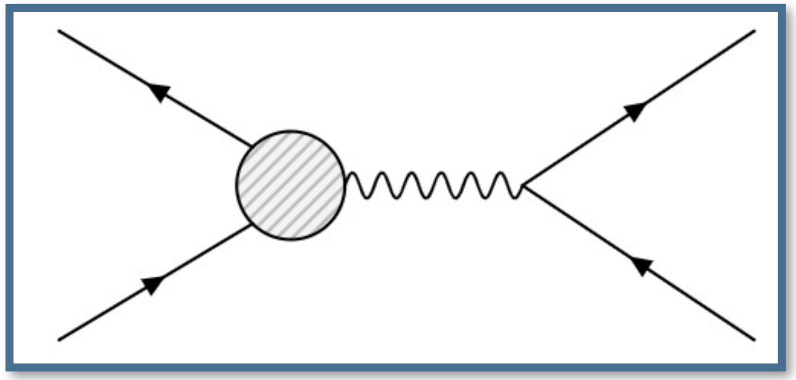
This class of couplings are suppressed by y_b

Example:

$$\dot{C}_{\underset{11}{Hud}} \subset 4\left(C^{(1)}_{\underset{1331}{ud}} + \frac{4}{3}C^{(8)}_{\underset{1331}{ud}}\right)\left[Y_u Y_d^\dagger\right]_{33} \xrightarrow{\text{Solving RGE}} \text{bounds of } \mathcal{O}(1)$$

Results for ϵ_i at $\mu_W = 246$ GeV in terms of C_β and C_x at $\Lambda = 5$ Tev

$$\epsilon_R = 0.950\, \boldsymbol{C_{Hud}} - 0.001\, C^{(1)}_{ud} - 0.0011\, C^{(8)}_{ud}\,,$$
$$\epsilon_P = 0.603\, \boldsymbol{C^{(1)}_{lequ}} - 0.600\, \boldsymbol{C_{ledq}} + 0.143\, C^{(3)}_{lequ}$$
$$\epsilon_S = -\,0.603\, \boldsymbol{C^{(1)}_{lequ}} - 0.600\boldsymbol{C_{ledq}} + 0.143\, C^{(3)}_{lequ}$$
$$\epsilon_T = 0.003\, C^{(1)}_{lequ} - 0465\, \boldsymbol{C^{(3)}_{lequ}}$$



Coefficienents in blue are matched to a given ϵ_i at a tree level

LH Currents

The largest contribution to ϵ_i at a loop level ($\kappa_{ij} > 10^{-2}$):

$$Q_{\beta_L}: \{Q_{ll}, Q^{(3)}_{lq}, Q^{(3)}_{Hl}, Q^{(3)}_{Hq},\ Q^{(1)}_{qq}, Q^{(3)}_{qq}, Q_{H\Box}\}$$

$$Q^{(1)}_{qq} = \left(\bar{q}_p \gamma_\mu q_r\right)\left(\bar{q}_s \gamma^\mu q_t\right)$$
$$Q^{(3)}_{qq} = \left(\bar{q}_p \gamma_\mu \tau^I q_r\right)\left(\bar{q}_s \gamma^\mu \tau^I q_t\right)$$
$$Q_{H\Box} = \left(H^\dagger H\right)\Box\left(H^\dagger H\right)$$

Results for ϵ_L at $\mu_W = 246$ GeV in terms of C_β and C_x at $\Lambda = 5$ Tev

$$\left.\begin{aligned}
\epsilon_L^{(d)} &= 0.946\, C^{(3)}_{\substack{Hq\\11}} - 1.052\, C^{(3)}_{\substack{lq\\1111}} + 1.012\, C_{\substack{ll\\1221}} - 0.965\, C^{(3)}_{\substack{Hl\\22}} \\
&+ 0.198\, C^{(3)}_{\substack{qq\\1133}} - 0.026\, C^{(3)}_{\substack{qq\\1331}} + 0.026\, C^{(1)}_{\substack{qq\\1331}} - 0.0471\, C_{\substack{ll\\1122}} - 0.100\, C^{(3)}_{\substack{lq\\2233}},
\end{aligned}\right\}\ \text{Beta decay}$$

$$\left.\begin{aligned}
\epsilon_L^{(s)} &= \frac{0.942}{\lambda} C^{(3)}_{\substack{Hq\\12}} - \frac{1.052}{\lambda} C^{(3)}_{\substack{lq\\1112}} + 1.010\, C_{\substack{ll\\1221}} - 0.960\, C^{(3)}_{\substack{Hl\\22}} \\
&+ \frac{0.198}{\lambda} C^{(3)}_{\substack{qq\\1233}} - \frac{0.028}{\lambda} C^{(3)}_{\substack{qq\\1332}} + \frac{0.026}{\lambda} C^{(1)}_{\substack{qq\\1332}} - 0.099\, C^{(3)}_{\substack{lq\\2233}} - 0.047\, C_{\substack{ll\\1122}} \\
&+ 0.0144\left(C^{(3)}_{\substack{Hq\\11}} + C^{(3)}_{\substack{Hq\\22}} + C^{(3)}_{\substack{Hq\\33}}\right) - 0.016\left(C^{(3)}_{\substack{lq\\1111}} + C^{(3)}_{\substack{lq\\1122}} + C^{(3)}_{\substack{lq\\1133}}\right).
\end{aligned}\right\}\ \text{Kaon decay}$$

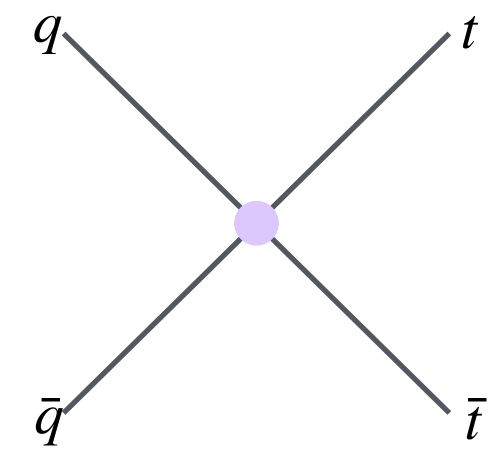
M.D, V. Cirigliano, W. Dekens
ArXiv: (2402.06723)

Results

With $C_k \sim v^2/\Lambda^2$

$C_x(\Lambda = 5\,\text{TeV})$	Constraint from β decays	Strongest constraints from other processes	Process
$C^{(3)}_{\substack{qq\\1133}}$	-0.004 ± 0.0013	$-0.0073 \pm 0.006^{(1)}$ $\pm 0.00002^{(2)}$	Top production $K \to \pi\nu\bar{\nu}$
$C^{(3)}_{\substack{lq\\2233}}$	0.008 ± 0.0025	$-0.00024 \pm 0.00021^{(2)}$	B decays (R_K)
$C_{\substack{ll\\1122}}$	0.018 ± 0.005	-0.0018 ± 0.0029	Muon pair production
$C^{(1)}_{\substack{qq\\1331}}$	-0.031 ± 0.009	$-0.035 \pm 0.027^{(1)}$ $\pm 0.0009^{(2)}$	Top production Δm_K
$C^{(3)}_{\substack{qq\\1331}}$	0.03 ± 0.009	$-0.042 \pm 0.024^{(1)}$ $\pm 0.00004^{(2)}$	Top production $K \to \pi\nu\bar{\nu}$

Example of tree level process, $t\bar{t}$ production at the LHC



Result: Stronger constraints on BSM operators from loop-level processes than those achievable in other channels at tree level.

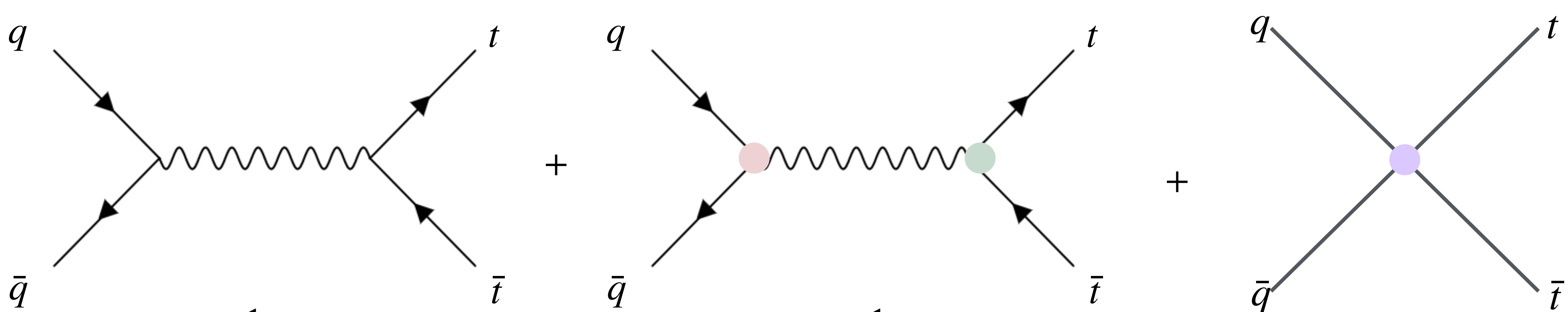
(1) indicates that the fit was performed assuming $U(3)_l \times U(3)_e \times U(3)_d \times U(2)_u \times U(2)_q$ symmetry

(2) indicates that the constraint would disappear if one used the weak basis in which the down-type quark mass matrix M_d is diagonal.

Results vs LHC

Transverse mass distributions for events satisfying all selection criteria in the electron channels.

SM $\qquad\qquad\qquad\qquad$ $SMEFT$



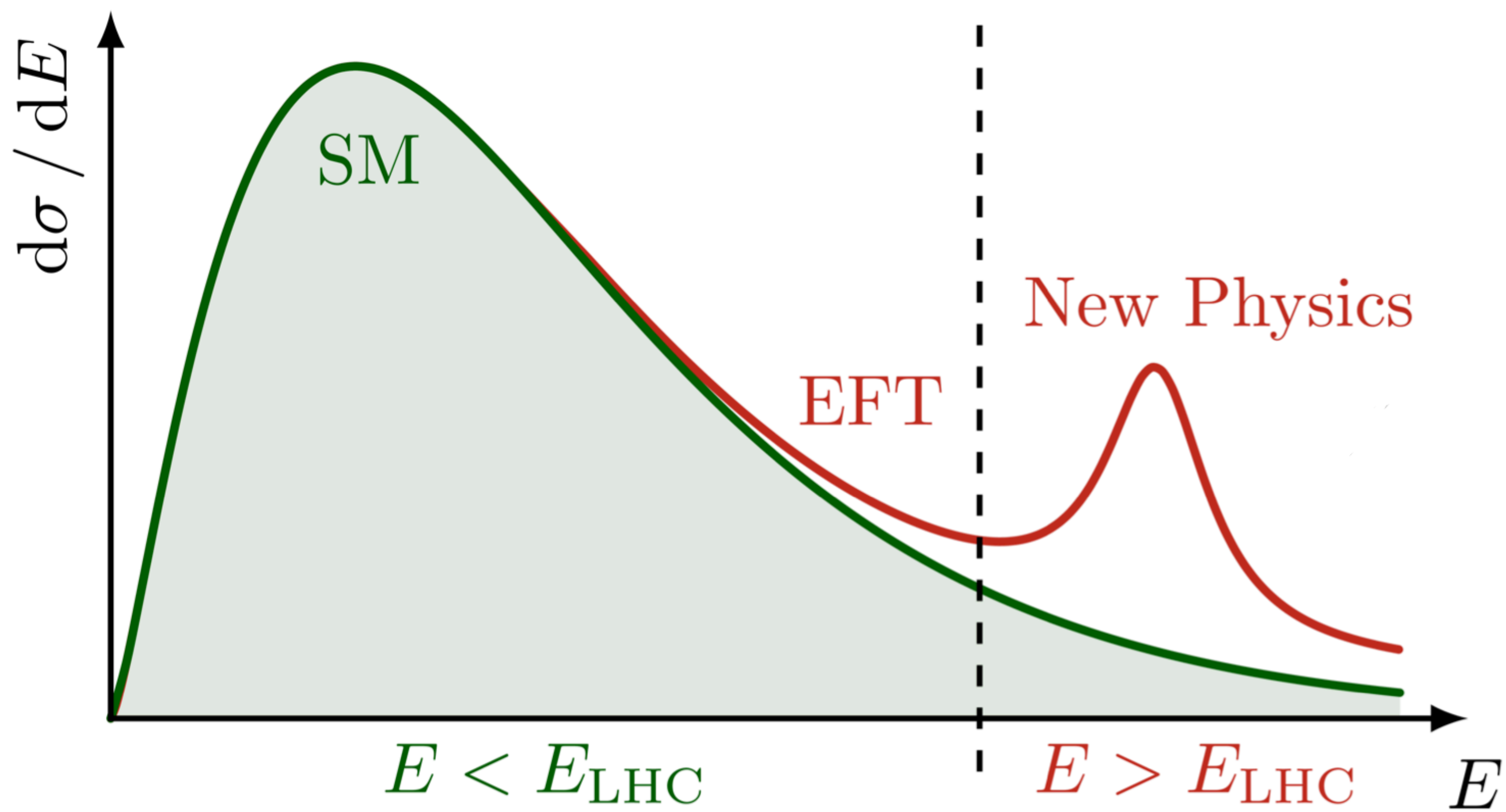
$\mathscr{T}$ $\quad \sim \dfrac{1}{s} \qquad\qquad \sim \dfrac{1}{s} \qquad\qquad \sim 1$

Scattering amplitude $\quad \mathscr{T} = \mathscr{T}_{SM} + \mathscr{T}_{SMEFT}$

Cross-section $\quad \sigma = \left|\mathscr{T}_{SM}\right|^2 + 2Re\left[\mathscr{T}_{SM} \times \mathscr{T}_{SMEFT}\right] + \left|\mathscr{T}_{SMEFT}\right|^2$

Results vs LHC

Transverse mass distributions for events satisfying all selection criteria in the electron channels.

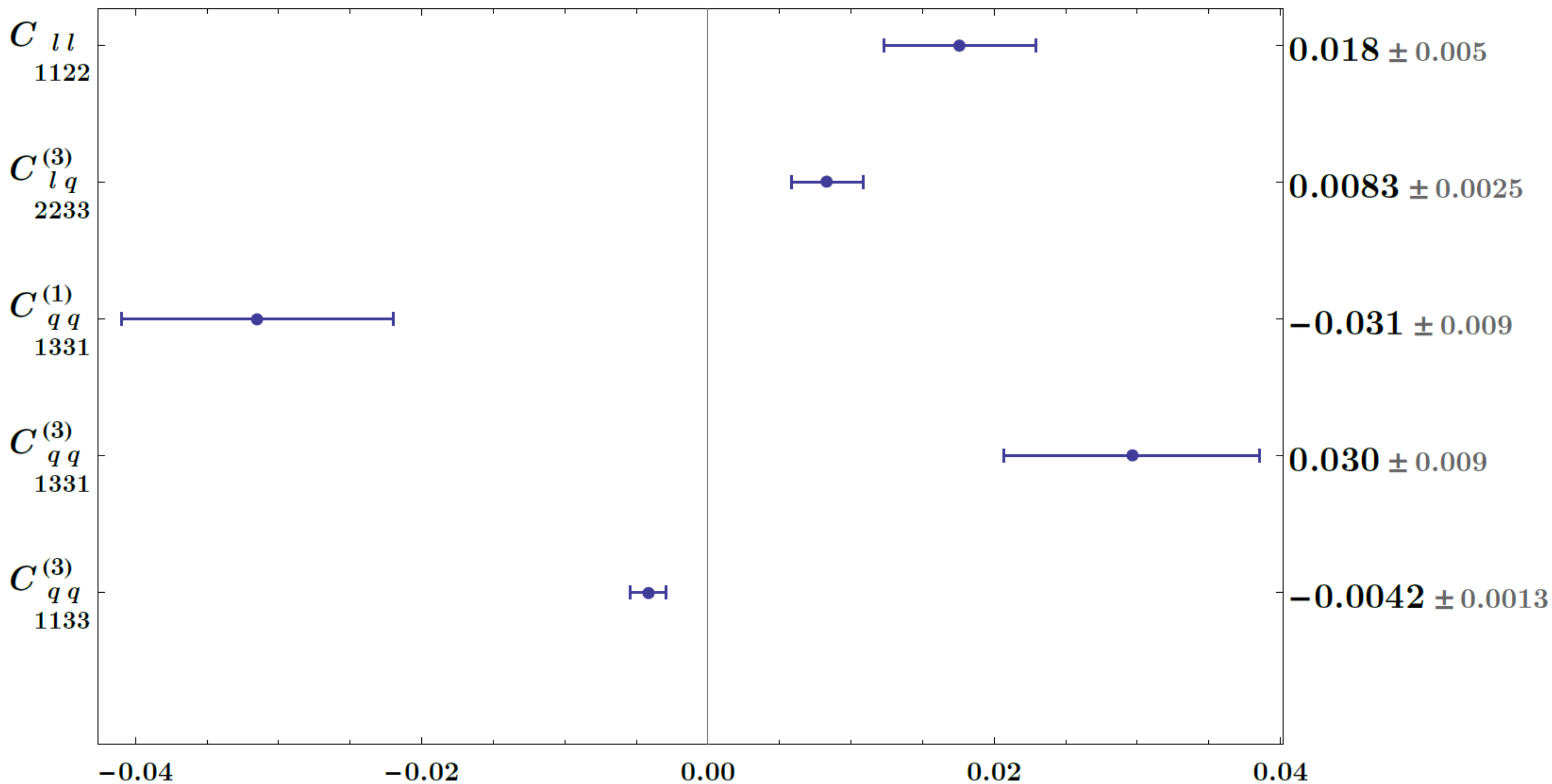


Search for a new heavy gauge boson resonance decaying into a lepton and missing transverse momentum in 36 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS experiment

M.D, V. Cirigliano, W. Dekens
ArXiv: (2402.06723)

Results

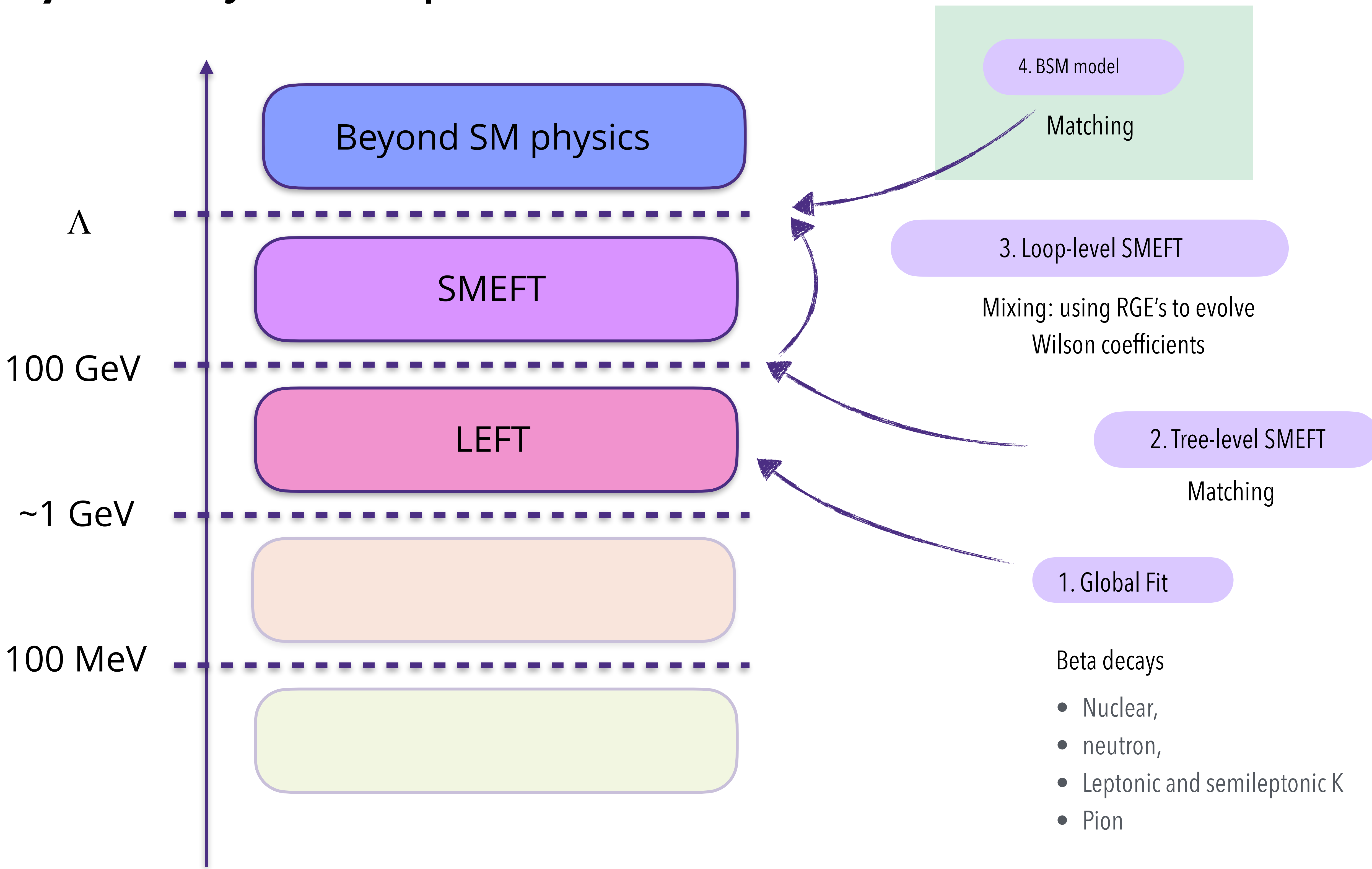
$$C \sim \frac{v^2}{\Lambda^2}$$



$\Lambda \sim 8$ TeV

Result: Beta decay at loop level can probe higher energies (that correspond to masses of BSM particles) than other processes, e.g., from LHC

β-decay on loop level



Beyond the SM: a model above the high-energy scale

Assumption of BSM above the Λ scale

1. $\mathscr{L}_{BSM}$ is invariant under linearly-realized $SU(3)_C \times SU(2)_L \times U(1)_Y$.
2. $\mathscr{L}_{BSM}$ containts only particles of spin ≤ 1.
3. Adding one new particle at a time.

Q_x operator	Heavy field						
$Q_{qq}^{(3)}$ Irrep	ω_1 $(3,1)_{-\frac{1}{3}}$	ζ $(3,3)_{-\frac{1}{3}}$	Ω_1 $(6,1)_{\frac{1}{3}}$	Υ^* $(6,3)_{\frac{1}{3}}$	$\mathcal{W}$ $(1,1)_0$	$\mathcal{G}$, $(8,1)_0$	$\mathcal{H}^*$ $(8,3)_0$
$Q_{qq}^{(1)}$ Irrep	ω_1 $(3,1)_{-\frac{1}{3}}$	ζ $(3,3)_{-\frac{1}{3}}$	Ω_1 $(6,1)_{\frac{1}{3}}$	Υ^* $(6,3)_{\frac{1}{3}}$	$\mathcal{B}$ $(1,3)_0$	$\mathcal{G}$, $(8,1)_0$	$\mathcal{H}^*$ $(8,3)_0$
$Q_{lq}^{(3)}$ Irrep	ω_1 $(3,1)_{-\frac{1}{3}}$	ζ $(3,3)_{-\frac{1}{3}}$	$\mathcal{W}$ $(1,3)_0$	$\mathcal{U}_2$ $(3,1)_0$	$\mathcal{X}$ $(3,3)_{\frac{2}{3}}$		
Q_{ll} Irrep	$\mathcal{S}_1$ $(1,1)_1$	Ξ $(1,3)_1$	β $(1,1)_0$	$\mathcal{W}$ $(1,3)_0$			

J. De Blas, J.C. Criado at al.
(1711.10391)

Summary

- The CKM unitarity test is important for constraining ϵ_L and ϵ_R
- Beta decay probes BSM physics at a tree-level at ~ 20 TeV (needs experimental and theoretical scrutiny!)
- We put constraints on New Physics operators that include **top quarks** at ~ 8 TeV at a loop-level, which exceeds the LHC results!
- We connect these operators to the BSM model

FLAVOR-CHANGING NEUTRAL CURRENT OPERATORS

- At a loop level ($\Delta F = 2$):
  $\dot{C}_\beta = \gamma_{\beta x} C_x,$
  $\dot{C}_{FCNC} = \gamma_{FCNC} C_x$
- Rotation to the mass basis

The strongest constraints arise from the rare
$\Delta S = 1$ proces $K \to \pi \nu \bar{\nu}$

$$[\mathrm{L}^{\nu d}_{VLL}] < 0.97 \times 10^{-5}\ \text{TeV}$$

$$v^2[\mathrm{L}^{\nu d}_{VLL}] = \widetilde{C}_{ll12} + \lambda\left(\widetilde{C}_{ll11} - \widetilde{C}_{ll22}\right) +$$

$$\widetilde{C}_{llij} = \underset{llij}{C^{(1)}_{lq}} - \underset{llij}{C^{(3)}_{lq}} + \delta_{ll}\underset{ij}{C^{(1)}_{Hq}} + \delta_{ll}\underset{ij}{C^{(3)}_{Hq}}$$

$\underset{1133}{C^{(1)}_{lq}} < 2.0 \times 10^{-5},$ $\quad \underset{1331}{C^{(1)}_{qq}} < 0.57 \times 10^{-3}$

$\underset{1133}{C^{(3)}_{lq}} < 2.0 \times 10^{-5},$ $\quad \underset{1331}{C^{(3)}_{qq}} < 0.37 \times 10^{-4}$

With $C_k \sim v^2/\Lambda^2$