

Everything You Always Wanted to Know About Model-Independent Analyses in Flavor Physics* (*But Were Afraid To Ask)

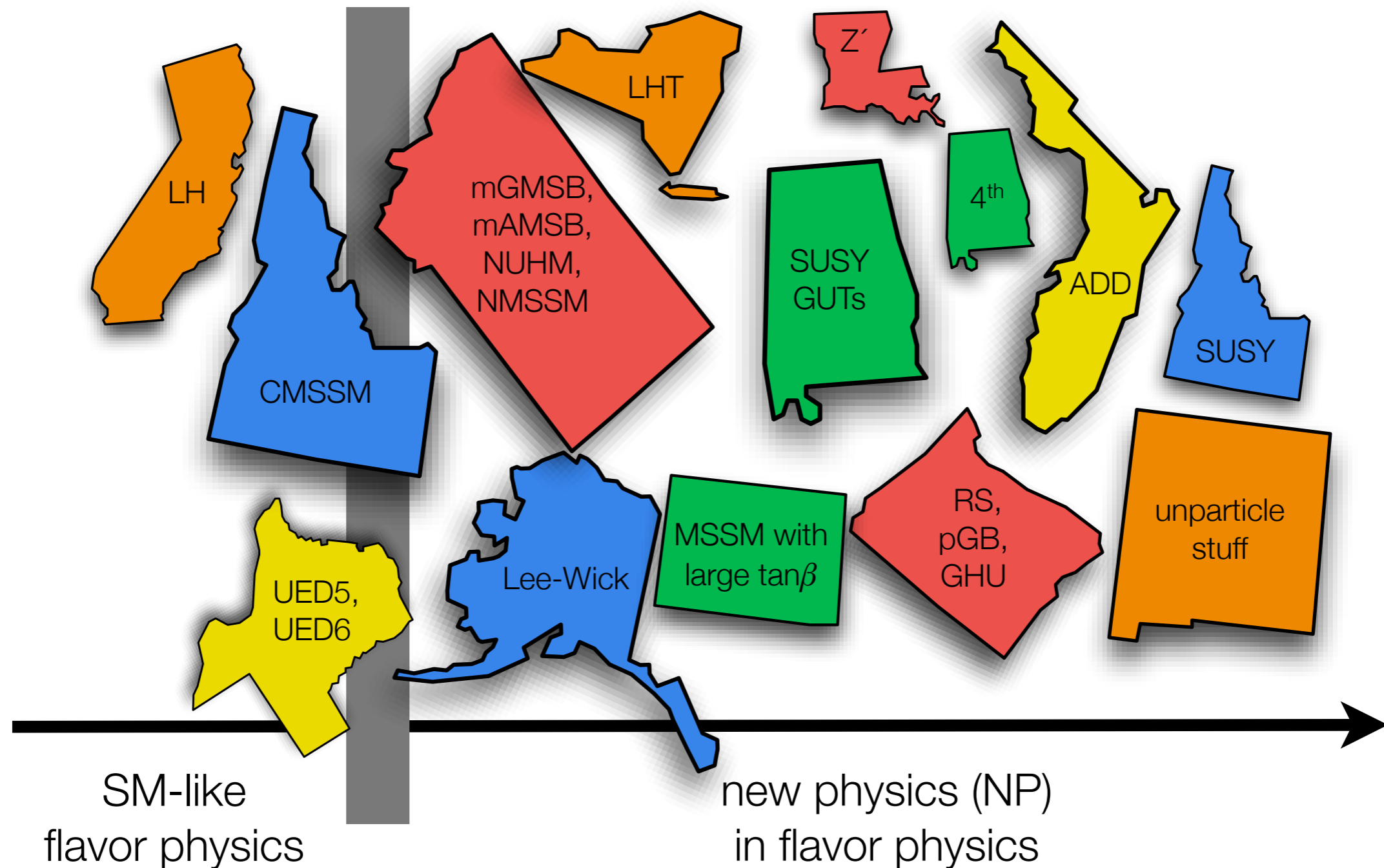
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CERN TH Flavour Institute,
10th of June 2008

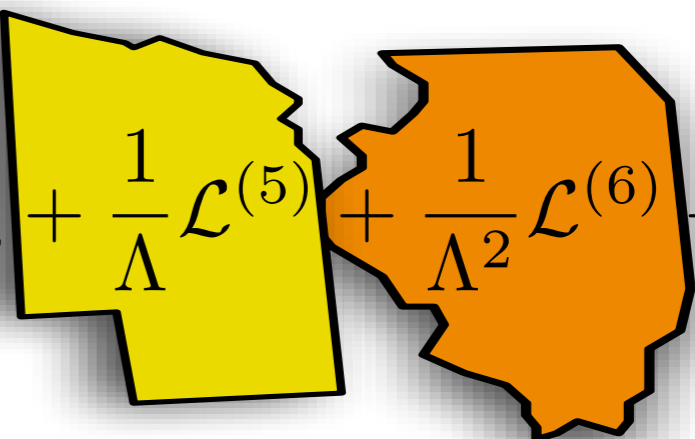
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Frederic Ronga
IFCA (Santander) and ETH Zurich

presented by Gudrun Hiller
Technical University Dortmund (TPP)

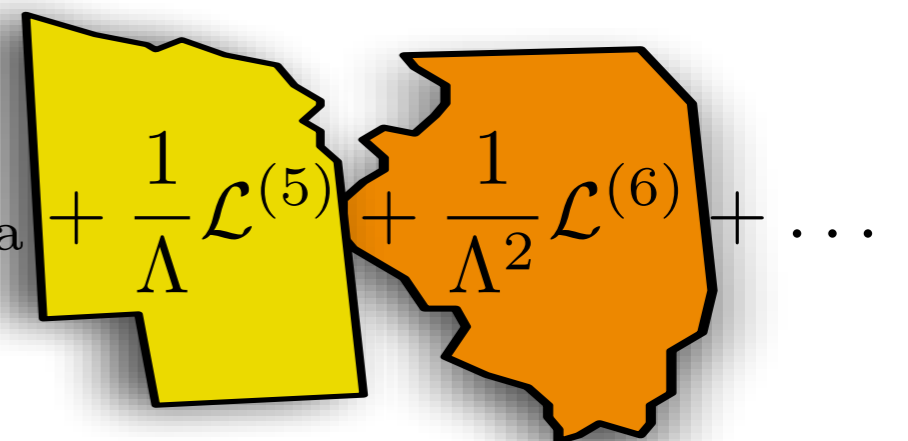
If I look at all this mess, I get seriously confused ...



while I feel more comfortable looking at this:

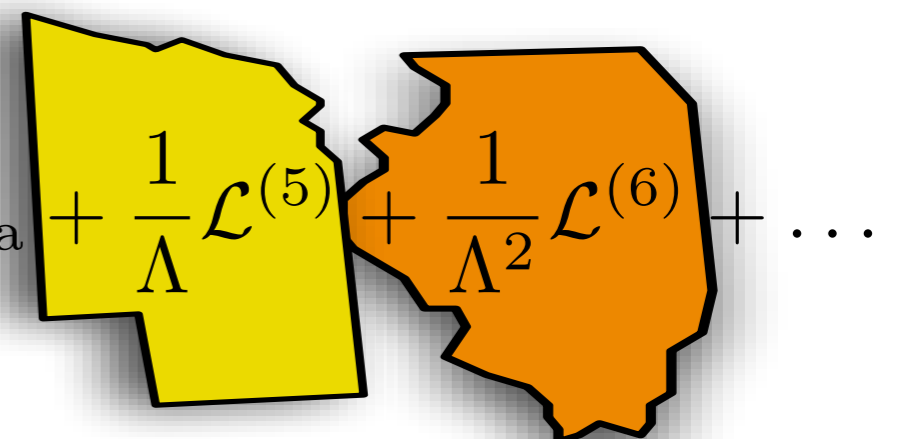
$$\mathcal{L}_{\text{eff}} = \Lambda^2 H^\dagger H + \lambda (H^\dagger H)^2 + \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{Yukawa}} + \frac{1}{\Lambda} \mathcal{L}^{(5)} + \frac{1}{\Lambda^2} \mathcal{L}^{(6)} + \dots$$
The diagram consists of two overlapping, irregular, hand-drawn shapes. The left shape is yellow and contains the term $\frac{1}{\Lambda} \mathcal{L}^{(5)}$. The right shape is orange and contains the term $\frac{1}{\Lambda^2} \mathcal{L}^{(6)}$. The shapes overlap in the middle, and the entire expression is followed by an ellipsis \dots .

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$$\mathcal{L}_{\text{eff}} = \Lambda^2 H^\dagger H + \lambda (H^\dagger H)^2 + \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{Yukawa}} + \frac{1}{\Lambda} \mathcal{L}^{(5)} + \frac{1}{\Lambda^2} \mathcal{L}^{(6)} + \dots$$


- model-specific analyses: derive bounds on masses of new heavy degrees of freedom and additional flavor- and CP -violating parameters
- model-independent analyses: derive constraints on coefficients of higher-dimensional operators thereby gaining information on scale Λ of NP
- helpful to think of model-independent analyses in flavor physics of small sister of fits to electroweak precision data leading for example to S - T ellipse

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- analogy makes clear that model-independent analyses are very sensitive to multiplicity and quality of available experimental data
- due to plethora of higher-dimensional flavor-violating operators and fact that neither multiplicity nor quality of experimental data is “yet there”, in many cases strong theoretical assumptions like reduction of operator basis are still necessary to “get something out” of model-independent analyses of Wilson coefficients; but there are high hopes that this situation will improve in future

Model-independent analyses in flavor physics:

- Buchalla et al., Z -couplings in exclusive $b \rightarrow s/\ell^+/\ell^-$, hep-ph/0006136
- Ali et al., Semileptonic and radiative rare B -decays, hep-ph/0112300
- D'Ambrosio et al., B - and K -decays in MFV, hep-ph/0207036
- Hiller and Krüger, Scalar and pseudoscalar operators in $b \rightarrow s$ transitions, hep-ph/0310219
- Gambino et al., Determination of sign of $b \rightarrow s\gamma$ amplitude, hep-ph/0410155
- Buchalla et al., CP asymmetries in $b \rightarrow s$ transitions, hep-ph/0503151
- Matias and Krüger, Transverse amplitudes in $B \rightarrow K^*/\ell^+/\ell^-$, hep-ph/0502060
- Bobeth et al., Correlations of B - and K -decays in CMFV, hep-ph/0505110
- Lee et al., Short-distance information from $b \rightarrow s/\ell^+/\ell^-$, hep-ph/0612156
- Fox et al., Correlations between flavor-changing bottom and top decays, arXiv:0704.1482
- Haisch and Weiler, Determination of sign of Z -penguin amplitude, arXiv:0706.2054
- UTfit Collaboration, $\Delta F = 2$ transitions in MFV, NMFV, and beyond, arXiv:0707.0636
- Dassinger et al., Lepton flavor-violating tau decays, arXiv:0707.0988
- Bobeth et al., Angular distributions in $B \rightarrow K/\ell^+/\ell^-$, arXiv:0709.4174
- Grzadkowski and Misiak, Anomalous Wtb couplings from $B \rightarrow X_s\gamma$, arXiv:0802.1413
- Bobeth et al., CP asymmetries in exclusive $b \rightarrow s/\ell^+/\ell^-$, arXiv:0805.2525

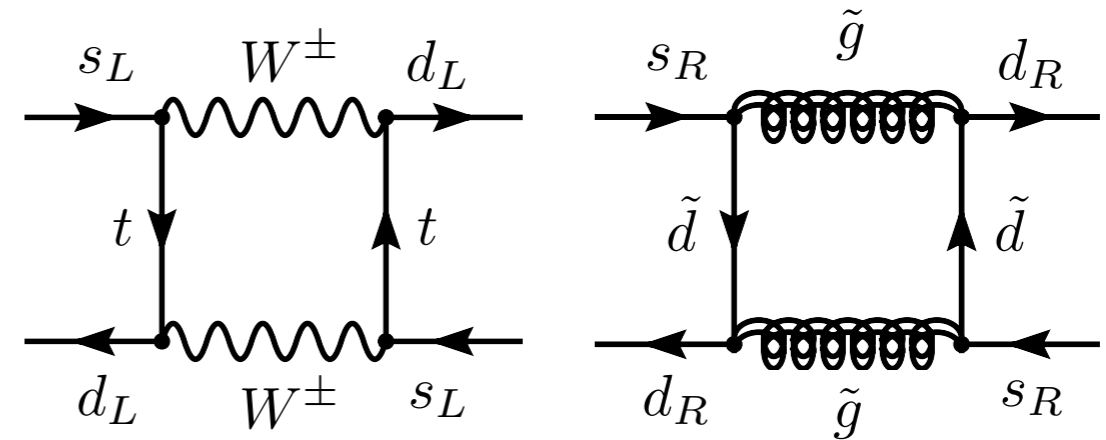
Let's have a closer look at three random examples:

- Buchalla et al., Z -couplings in exclusive $b \rightarrow s/\ell^+ \ell^-$, hep-ph/0006136
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Constraining $\Delta F = 2$: $K-\bar{K}$, $B-\bar{B}$, and $D-\bar{D}$ mixing

$$\mathcal{H}_{\text{eff}}^{\Delta S=2} = \sum_{i=1}^5 C_K^i Q_i + \sum_{i=1}^3 \tilde{C}_K^i \tilde{Q}_i$$

$$C_K^i = \frac{1}{\Lambda^2} \left\{ 1, \dots, \frac{g^2 (V_{ts}^* V_{td})^2}{(4\pi)^2} \right\}, \dots$$



$$Q_1 = (\bar{d}_L^a \gamma_\mu s_L^a)(\bar{d}_L^b \gamma^\mu s_L^b)$$

$$Q_2 = (\bar{d}_R^a s_L^a)(\bar{d}_R^b s_L^b)$$

$$Q_3 = (\bar{d}_R^a s_L^b)(\bar{d}_R^b s_L^a)$$

$$Q_4 = (\bar{d}_R^a s_L^a)(\bar{d}_L^b s_R^b)$$

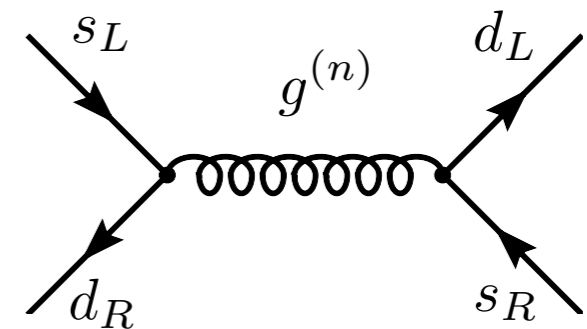
$$Q_5 = (\bar{d}_R^a s_L^b)(\bar{d}_L^b s_R^a)$$

...

- due to enhancement in renormalization group evolution and chiral factors in matrix elements non-standard operators Q_{2-5} and \tilde{Q}_{1-3} are more severely constrained than coefficient of SM operator Q_1
- scale Λ of NP in models that generate $\Delta F = 2$ operators beyond minimal flavor-violation typically pushed to scales that lie beyond reach of direct searches at LHC

Constraining $\Delta F = 2$: $K-\bar{K}$, $B-\bar{B}$, and $D-\bar{D}$ mixing

parameter	limit on Λ^*	suppression in RS**
$\text{Re } C_K^1$	$1 \times 10^3 \text{ TeV}$	$23 \times 10^3 \text{ TeV}$
$\text{Re } C_K^4$	$12 \times 10^3 \text{ TeV}$	$22 \times 10^3 \text{ TeV}$
$\text{Re } C_K^5$	$10 \times 10^3 \text{ TeV}$	$38 \times 10^3 \text{ TeV}$
$\text{Im } C_K^1$	$15 \times 10^3 \text{ TeV}$	$23 \times 10^3 \text{ TeV}$
$\text{Im } C_K^4$	$160 \times 10^3 \text{ TeV}$	$22 \times 10^3 \text{ TeV}$
$\text{Im } C_K^5$	$140 \times 10^3 \text{ TeV}$	$38 \times 10^3 \text{ TeV}$
$ C_{B_d}^1 $	$0.21 \times 10^3 \text{ TeV}$	$1.2 \times 10^3 \text{ TeV}$
$ C_{B_d}^4 $	$1.7 \times 10^3 \text{ TeV}$	$3.1 \times 10^3 \text{ TeV}$
$ C_{B_d}^5 $	$1.3 \times 10^3 \text{ TeV}$	$5.4 \times 10^3 \text{ TeV}$
$ C_{B_s}^1 $	30 TeV	270 TeV
$ C_{B_s}^4 $	230 TeV	780 TeV
$ C_{B_s}^5 $	150 TeV	1400 TeV
$ C_D^1 $	$1.2 \times 10^3 \text{ TeV}$	$25 \times 10^3 \text{ TeV}$
$ C_D^4 $	$3.5 \times 10^3 \text{ TeV}$	$12 \times 10^3 \text{ TeV}$
$ C_D^5 $	$1.4 \times 10^3 \text{ TeV}$	$21 \times 10^3 \text{ TeV}$



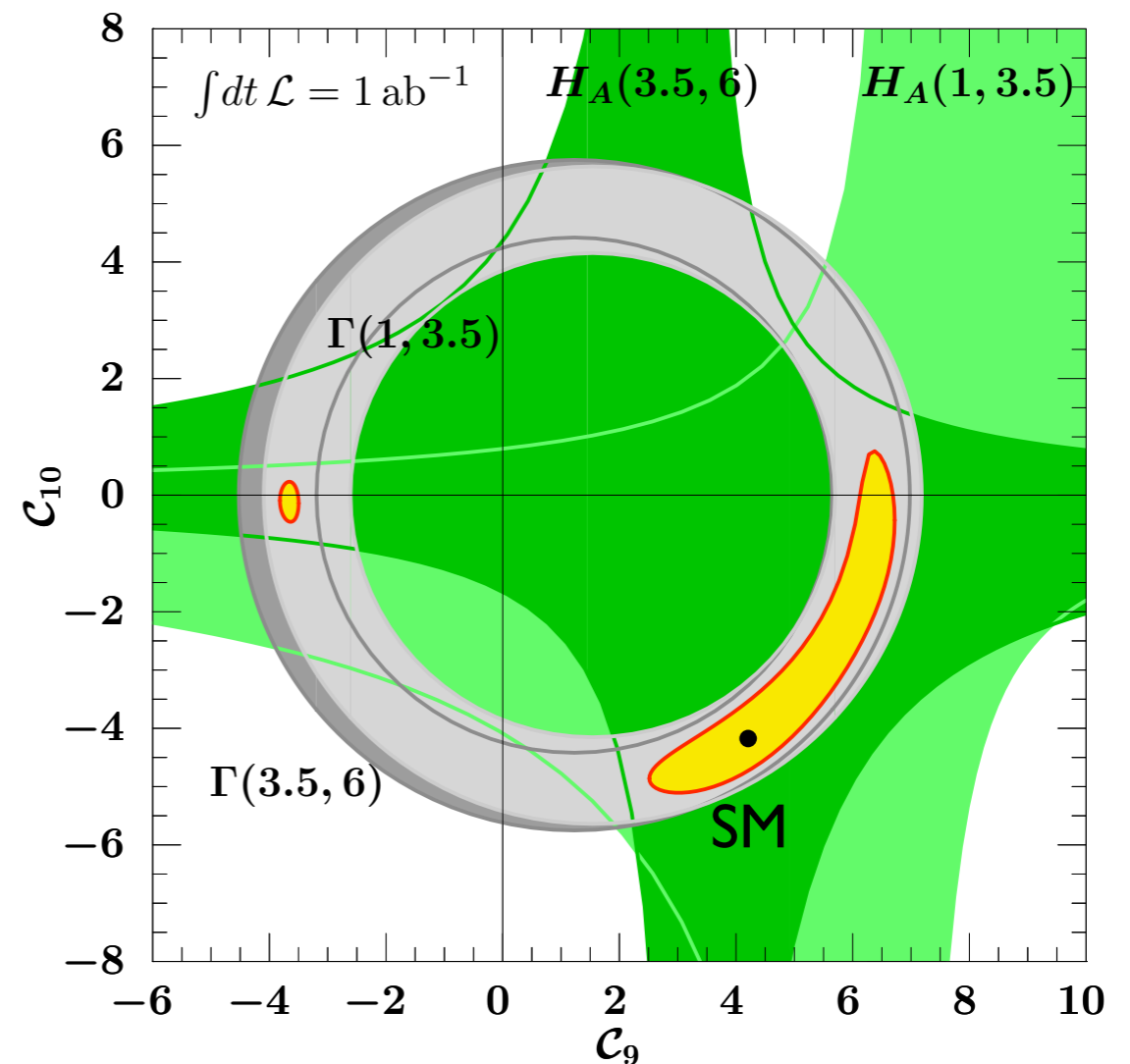
- in Randall-Sundrum scenario model-independent limit on $\text{Im } C_K^{4,5}$ following from $|\epsilon_K|$ imply that Kaluza-Klein gluon mass has to be generically larger than 20 TeV
- model-independent bounds on $\Delta F = 2$ Wilson coefficients allow for first “sanity check” in flavor sector when building NP models

Learning effectively from $b \rightarrow s l^+ l^-$

- angular decomposition:

$$\begin{aligned} \frac{d^2\Gamma}{dsdz} &\sim \left\{ (1+z^2) \left[\left(C_9 + \frac{2}{s} C_7 \right)^2 + C_{10}^2 \right] \right. \\ &\quad \left. + (1-z^2) \left[(C_9 + 2C_7)^2 + C_{10}^2 \right] \right. \\ &\quad \left. - 4zsC_{10} \left(C_9 + \frac{2}{s} C_7 \right) \right\} \\ &\equiv \underbrace{H_T + H_L}_{\sim \Gamma} + \underbrace{H_A}_{\sim A_{\text{FB}}} \end{aligned}$$

$$(s = q^2/m_b^2, z = \cos \theta, \theta : \angle b, l^+)$$



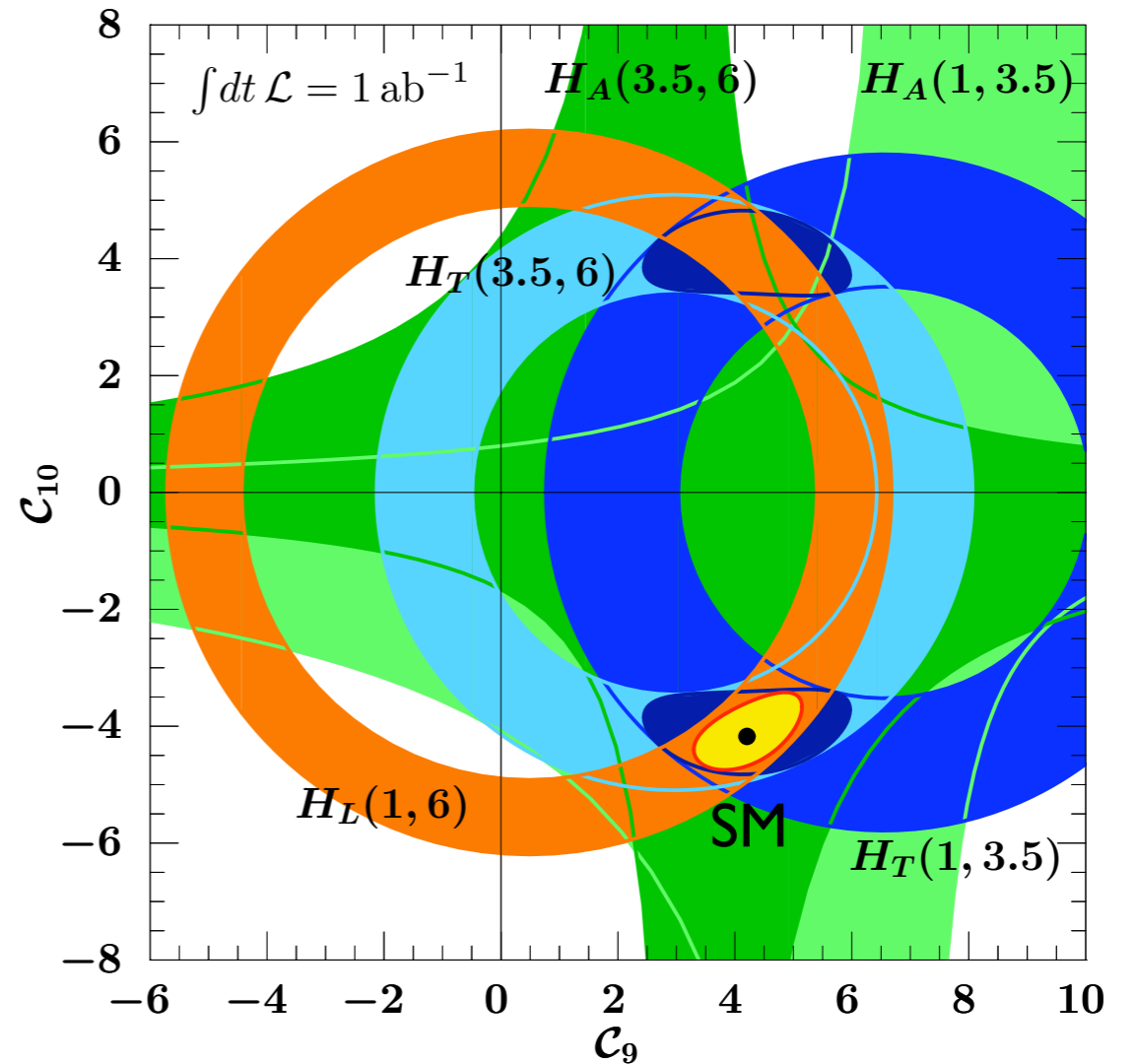
$$H_{T,L,A}(q_1^2, q_2^2) \equiv \int_{q_1^2}^{q_2^2} dq^2 H_{T,L,A}(q^2)$$

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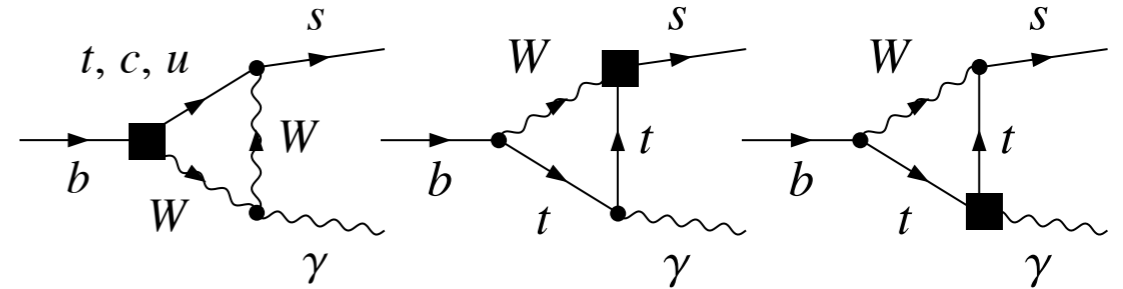
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Learning effectively from $b \rightarrow s/\ell^+\ell^-$

- take away messages:
 - ▶ design $b \rightarrow s/\ell^+\ell^-$ observables that are “simple” to measure, theoretically clean and at same time have highest possible sensitivity to magnitudes and phases of different combinations of Wilson coefficients
 - ▶ implement all experimental cuts into theory predictions and agree to use optimized cuts in $b \rightarrow s/\ell^+\ell^-$ measurements; for example avoid region close to photon pole which does not add any information with respect to $b \rightarrow s\gamma$
 - ▶ combine all available experimental information on inclusive and exclusive $b \rightarrow s/\ell^+\ell^-$ channels and other $b \rightarrow s$ processes, to allow for complementary and more complex tests of underlying theory
 - ▶ don't forget that experiments measure decay distributions not Wilson coefficients; considerable care should be expended to make extractions of Wilson coefficients as model-independent as possible, so that meanings of experiment and theory remain distinct

Anomalous Wtb couplings from $B \rightarrow X_s \gamma$

$$\begin{array}{c} q \uparrow \\ \text{---} \text{---} \text{---} W_\mu^a \\ \text{---} \text{---} \text{---} \\ t \quad b \end{array} = -\frac{ig_W}{\sqrt{2}} \left[\gamma_\mu (\textcolor{red}{v}_L P_L + \textcolor{orange}{v}_R P_R) + \frac{i\sigma_{\mu\nu} q^\nu}{M_W} (\textcolor{blue}{g}_L P_L + \textcolor{green}{g}_R P_R) \right]$$



95% CL bound	δv_L	v_R	g_L	g_R	$\text{Re } C_7^{(p)}$	$\text{Re } C_8^{(p)}$
upper	0.03	0.0025	0.0004	0.57	0.04	0.15
lower	-0.13	-0.0007	-0.0015	-0.15	-0.14	-0.56

- ATLAS measurements should allow to put stronger bound of few 10^{-2} on g_R , while expected bounds on v_R and g_L are weaker than $B \rightarrow X_s \gamma$ limits by more than order of magnitude due to chiral m_t/m_b enhancement in $b \rightarrow s \gamma$
- Single top production measurement at Tevatron imply $\delta v_L = 0.3 \pm 0.2$. Around order of magnitude better bounds are expected at LHC which would overcome current $B \rightarrow X_s \gamma$ constraint on NP contribution to v_L

Road to NP via model-independent flavor analyses

- develop strategies to extract all measurable Wilson coefficients from experimentally visible but theoretically clean measurements
- use all available experimental information with goal to over-constrain Wilson coefficients following example of unitarity triangle fit
- mimic experimental set-up concerning cuts and include theory uncertainties into model-independent analyses
- more communication between experimentalists and theorists is needed to exploit full potential of expected plethora of data
- build explicit NP models that correlate and explain observed model-independent effects to make sure that class of models is not empty