A view of flavour physics in 2021

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SNS, Pisa

Mainz, Feb 9, 2021

- Introduction and the basic picture

in

- Higgs compositeness

and/or - B-anomalies (if LFV confirmed)

or - An Intermezzo

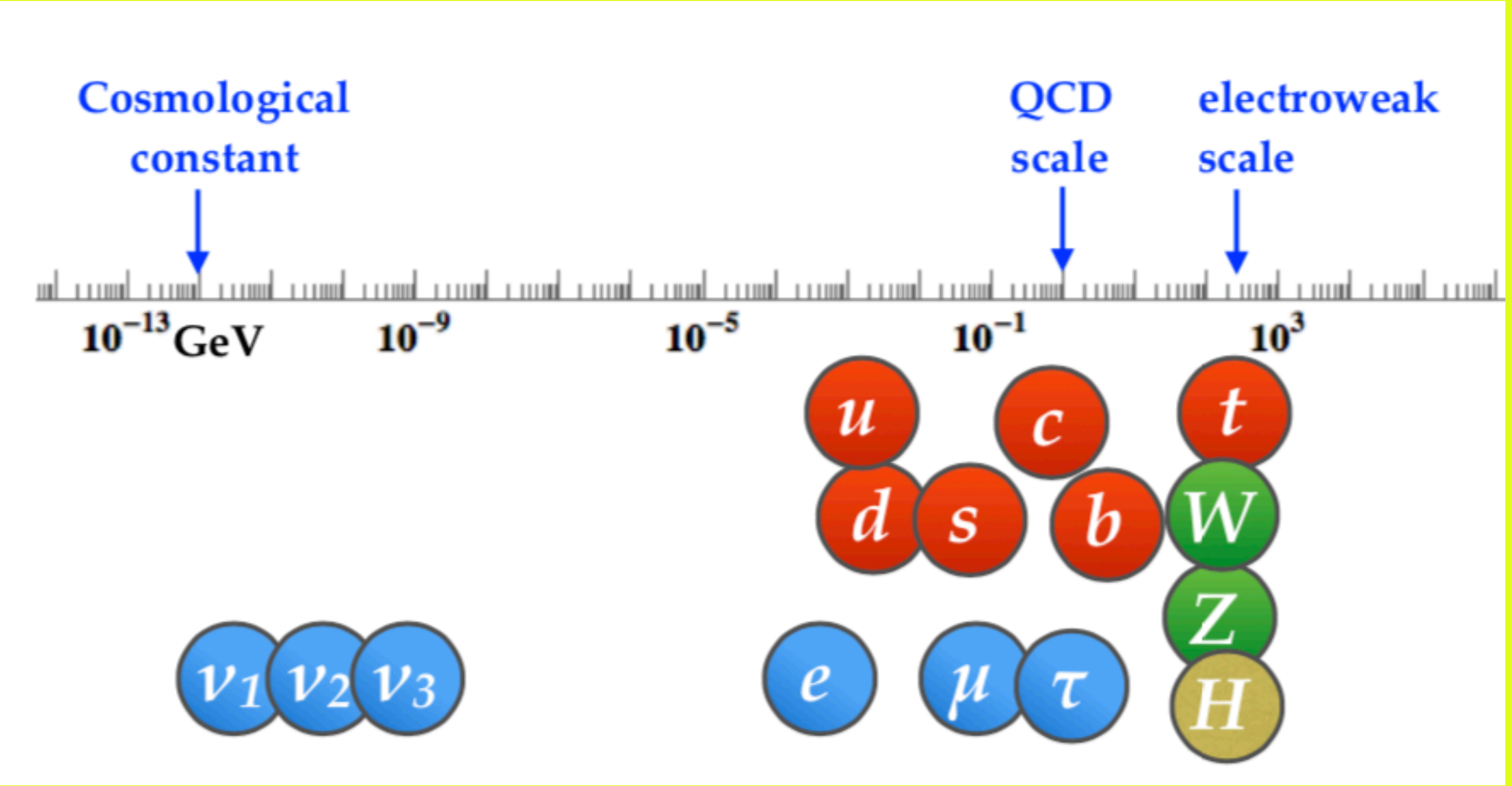
and - Supersymmetry

Introduction 1

In spite of its successes, the SM is NOT a complete theory

None of its 15=17-2 masses predicted by the theory

(though with a number of observables correlated by m_W, m_Z and m_H, m_t)



Among which masses one, m_H, sensitive to all the UV scales coupled to the Higgs: the hierarchy problem

Introduction 2

Where could some light come from?

1.A theory breakthrough → 1a BSM; 1b Foundations (FT, QM)

1a Not that one hasn't tried, sometimes with great ideas (GUT, susy, axion,...)

2.Astrophysics, Cosmology → 2a DM; 2b B-asymmetry

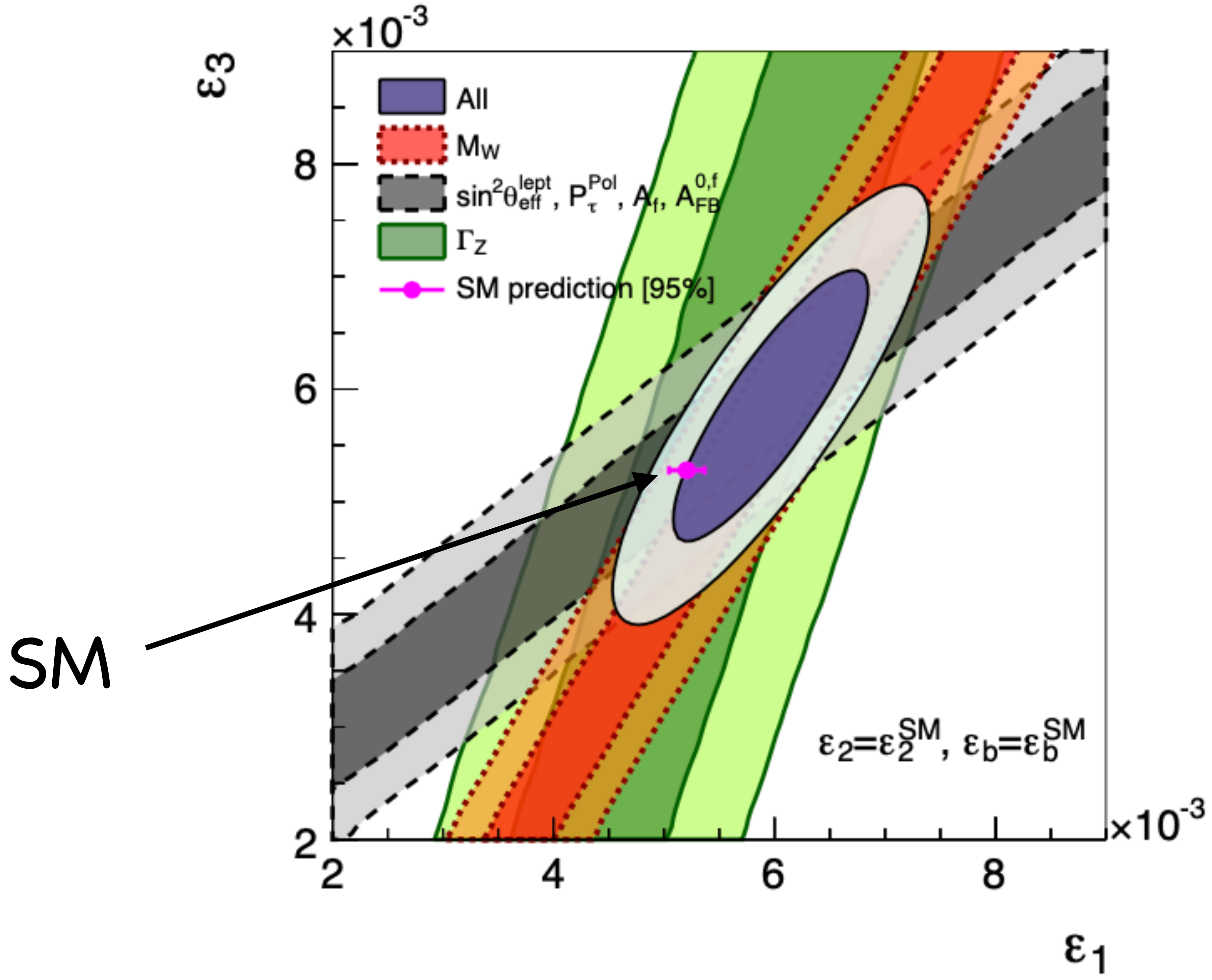
Fundamental questions. Related to the structure of the SM of PP?

3.An experimental deviation from the SM → 3a New particles; 3b Precision

Focus on 3b, assuming (which requires) new physics in the MultiTeV, as made likely (?) by the hierarchy problem, still pending

EWPT versus FCNC: a significant comparison

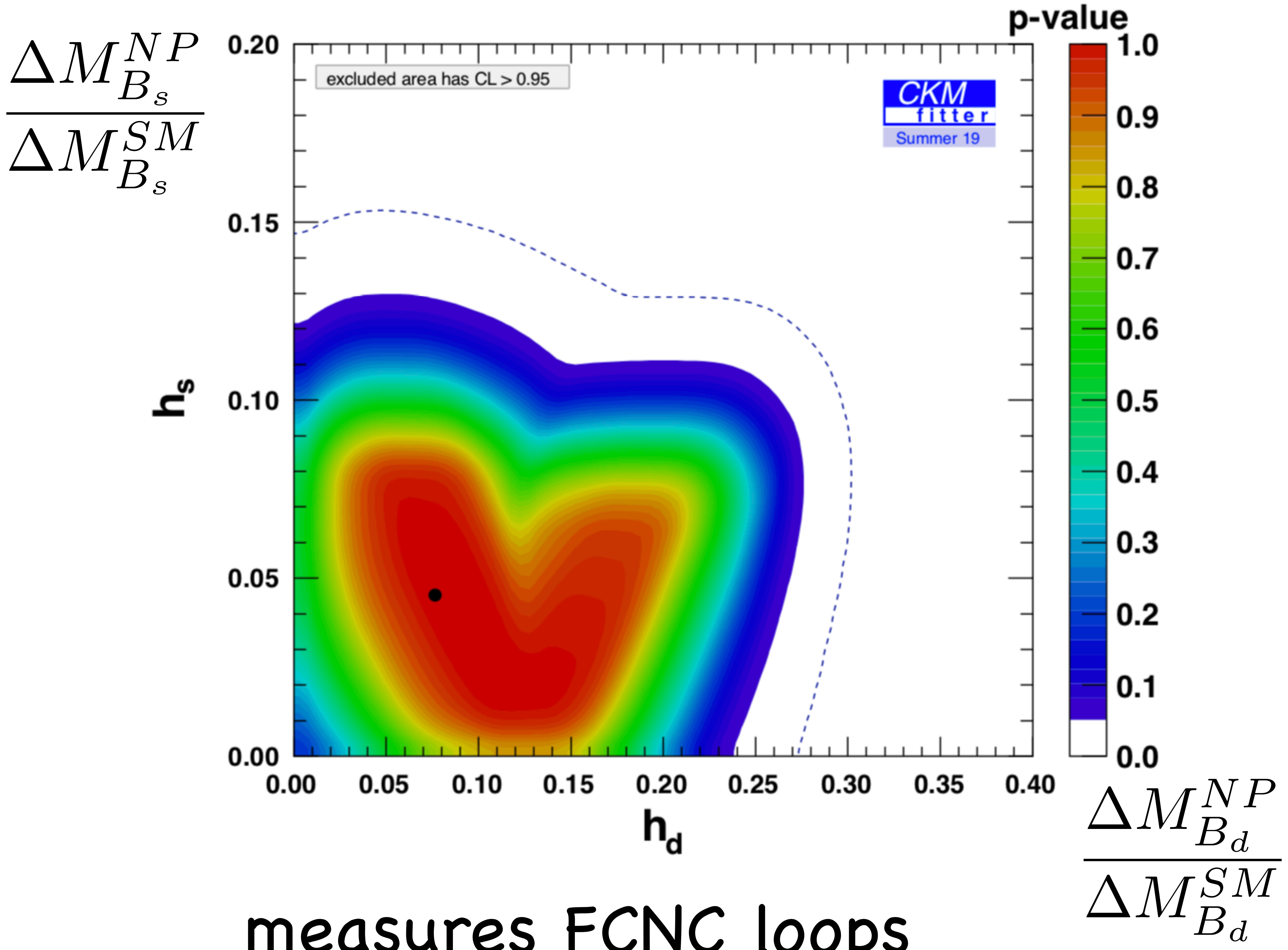
De Blas et al, 2019



measures EW loops
at about 20% level

A future facility (FCCee, ...)
could go to 2% level

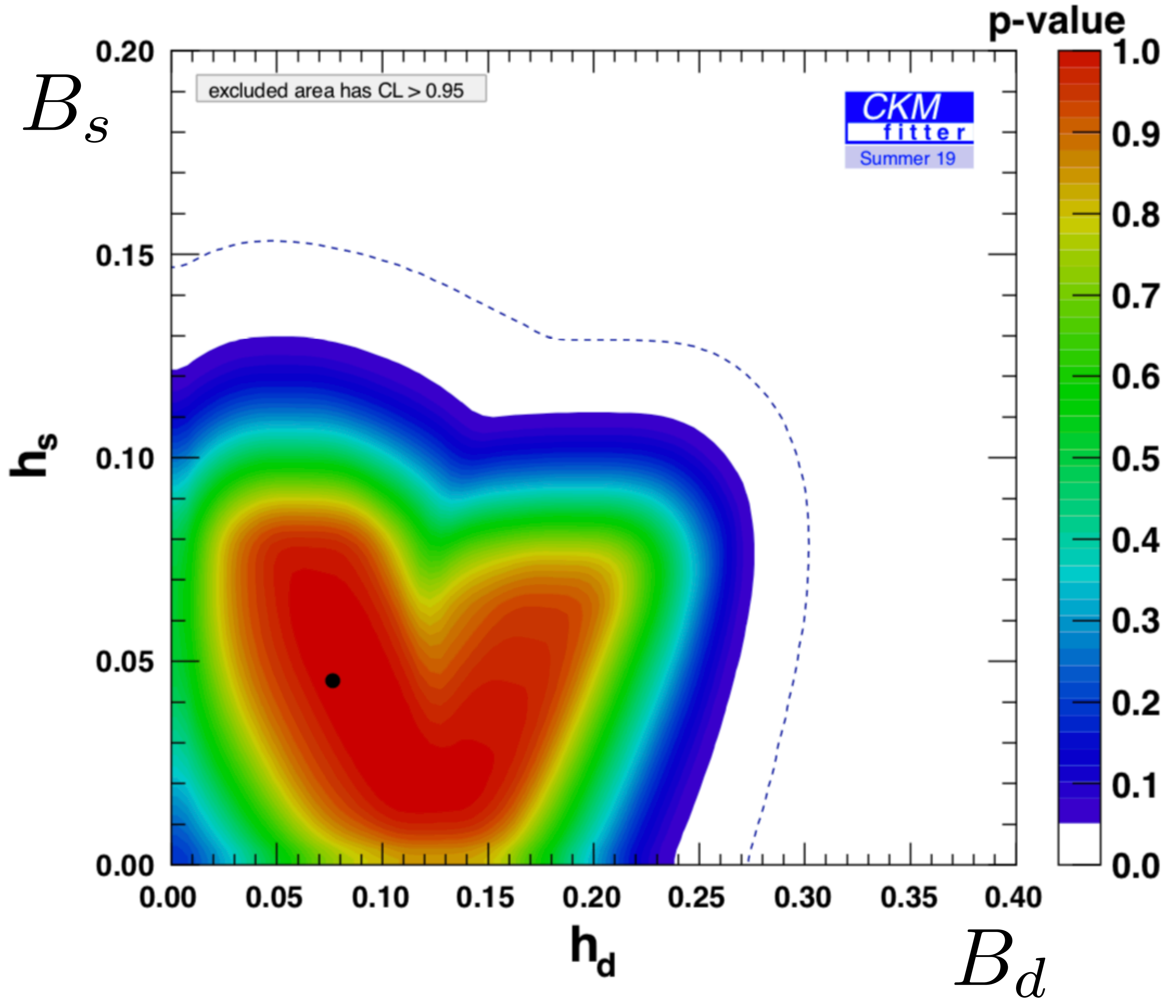
Charles et al, 2020



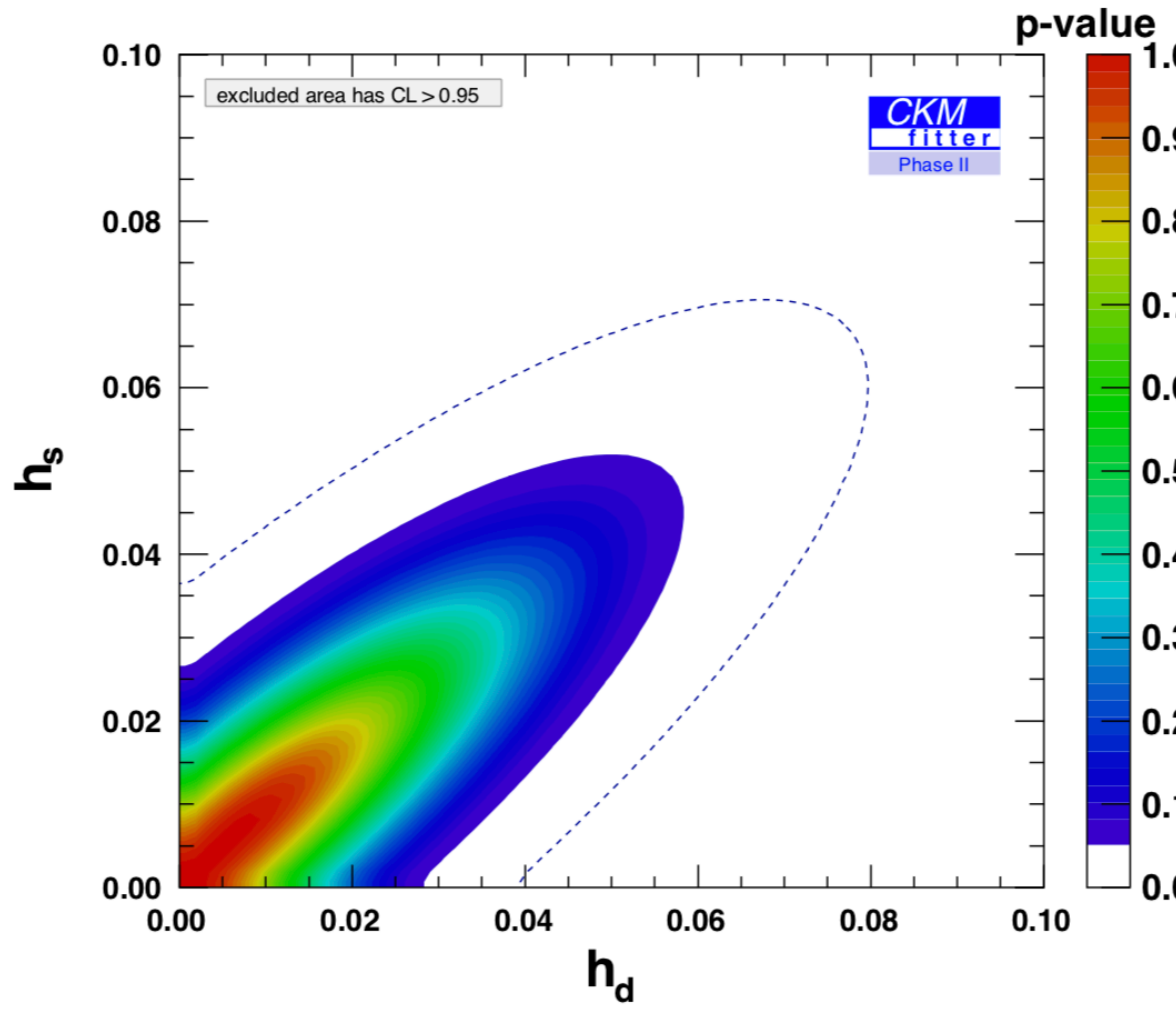
measures FCNC loops
at about 20% level

An "aggressive" flavour program
could go to 2-4% level

current



"phase II"



Phase II: LHCb 300/fb, Belle II 250/ab

$$M_{12} = (M_{12})_{\rm SM} \times (1 + h_{d,s} e^{2i\sigma_{d,s}})$$

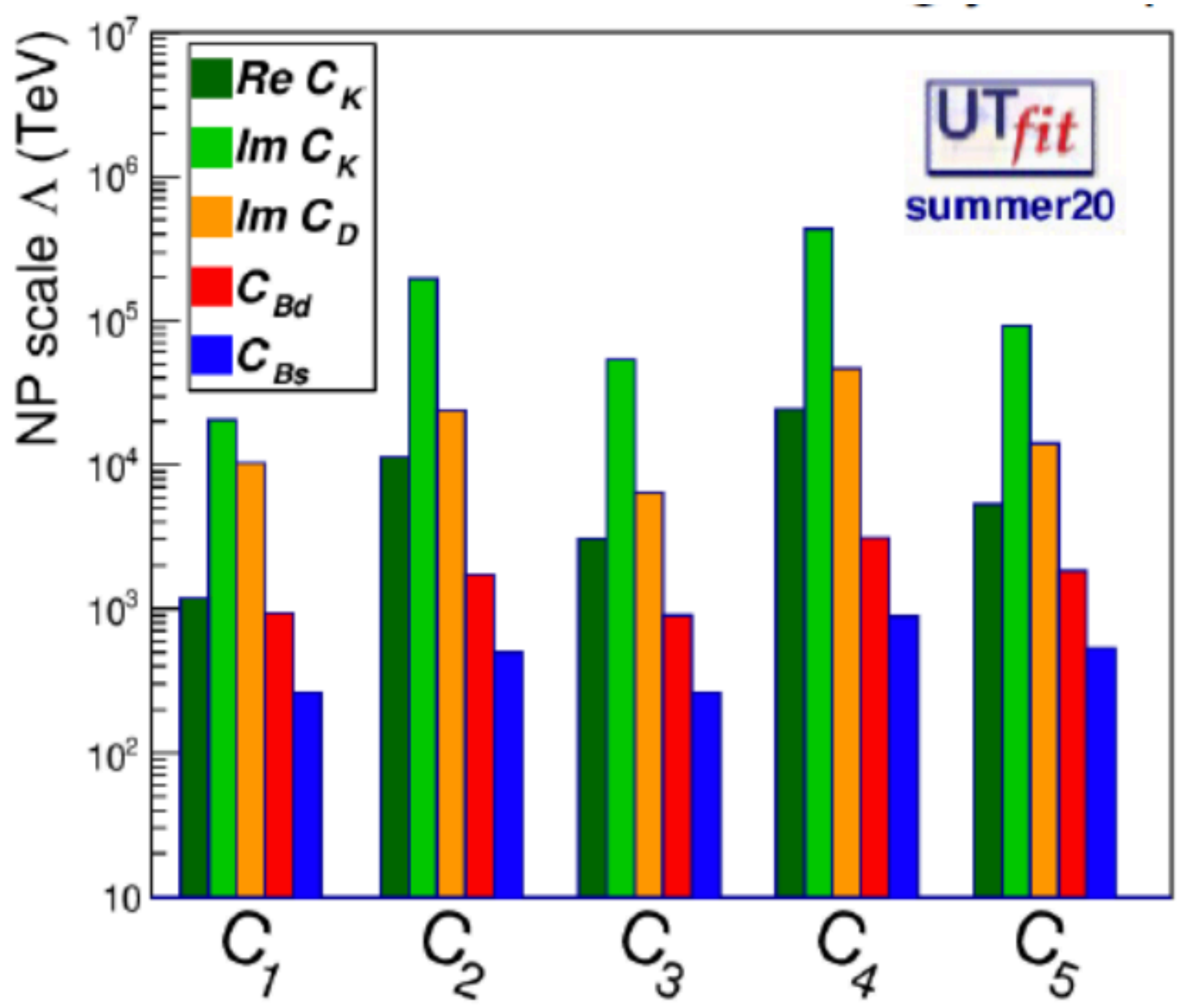
Charles et al, 2020

Which scales involved in flavour physics?

$$\mathcal{L} = \mathcal{L}_{SM} + \Sigma_i \frac{C_i}{\Lambda_i^2} \mathcal{O}_i$$

$\Delta F = 2$

$$\begin{aligned}
\mathcal{O}_1 &= [\bar{s}^\alpha \gamma_\mu (1-\gamma_5) d^\alpha][\bar{s}^\beta \gamma_\mu (1-\gamma_5) d^\beta] \\
\mathcal{O}_2 &= [\bar{s}^\alpha (1-\gamma_5) d^\alpha][\bar{s}^\beta (1-\gamma_5) d^\beta] \\
\mathcal{O}_3 &= [\bar{s}^\alpha (1-\gamma_5) d^\beta][\bar{s}^\beta (1-\gamma_5) d^\alpha] \\
\mathcal{O}_4 &= [\bar{s}^\alpha (1-\gamma_5) d^\alpha][\bar{s}^\beta (1+\gamma_5) d^\beta] \\
\mathcal{O}_5 &= [\bar{s}^\alpha (1-\gamma_5) d^\beta][\bar{s}^\beta (1+\gamma_5) d^\alpha]
\end{aligned}$$



ImC=CPV

Flavour determined by very HE physics (as such, not easy to clarify by exp.s?!?)

1

Any new MultiTeV scale, if any, is flavour independent

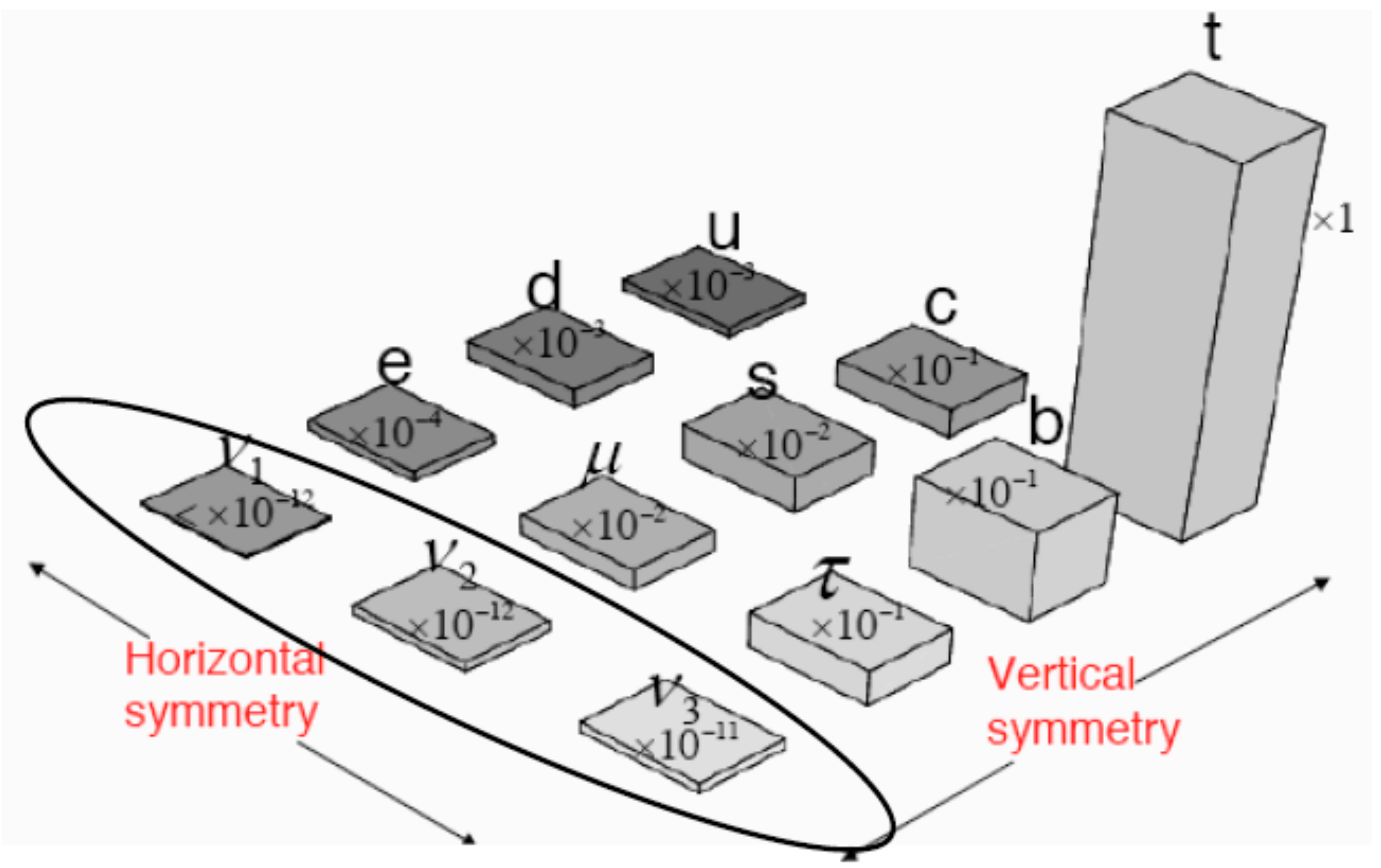
The hierarchy problem is NOT related to flavour physics

Or

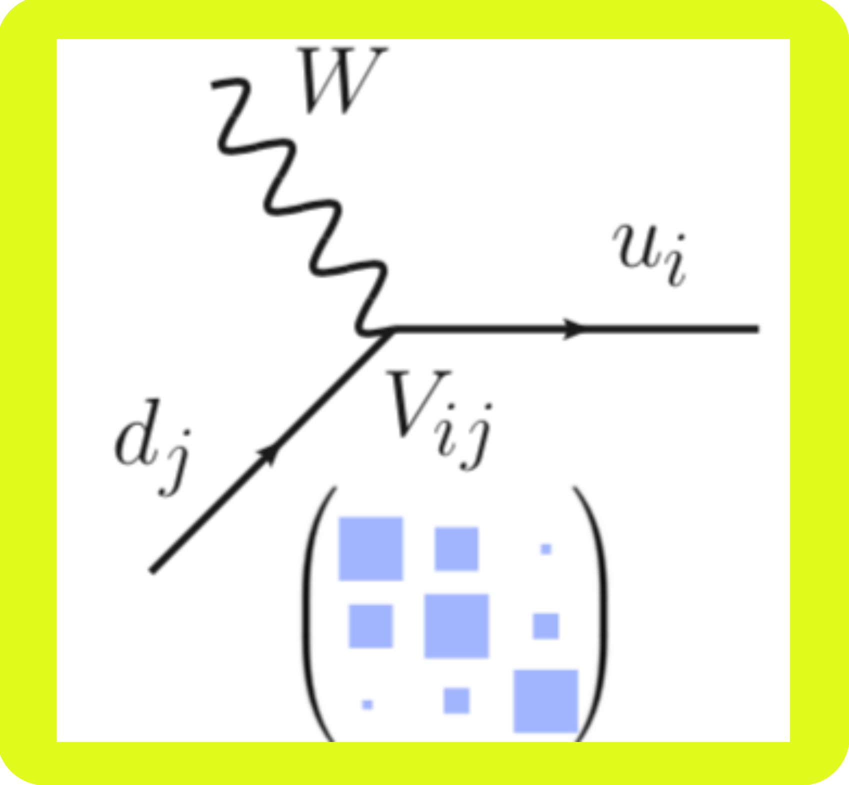
2 The basic picture (ETC, branes in extra-D, ...)

recently:
Panico, Pomarol 2016
Bordone et al 2017

Masses

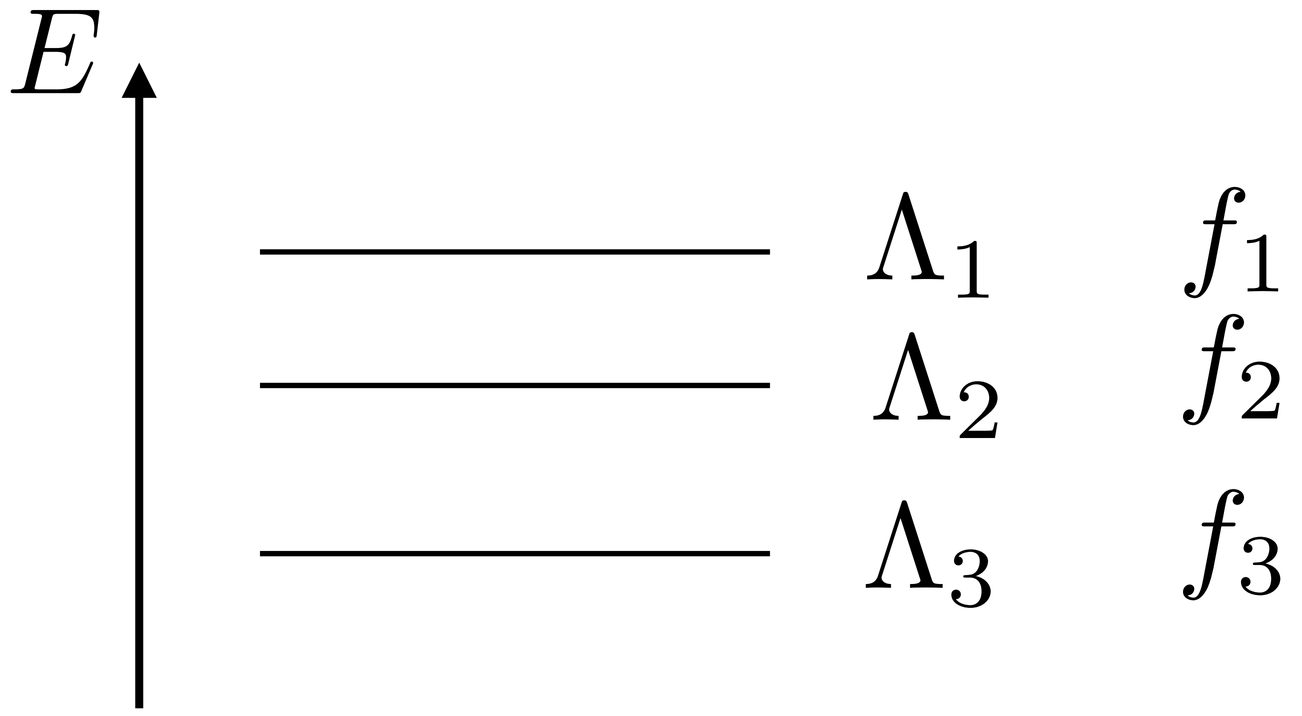


and mixings



suggest:

The different families are distinguished by new interactions at different scales, responsible for their masses,

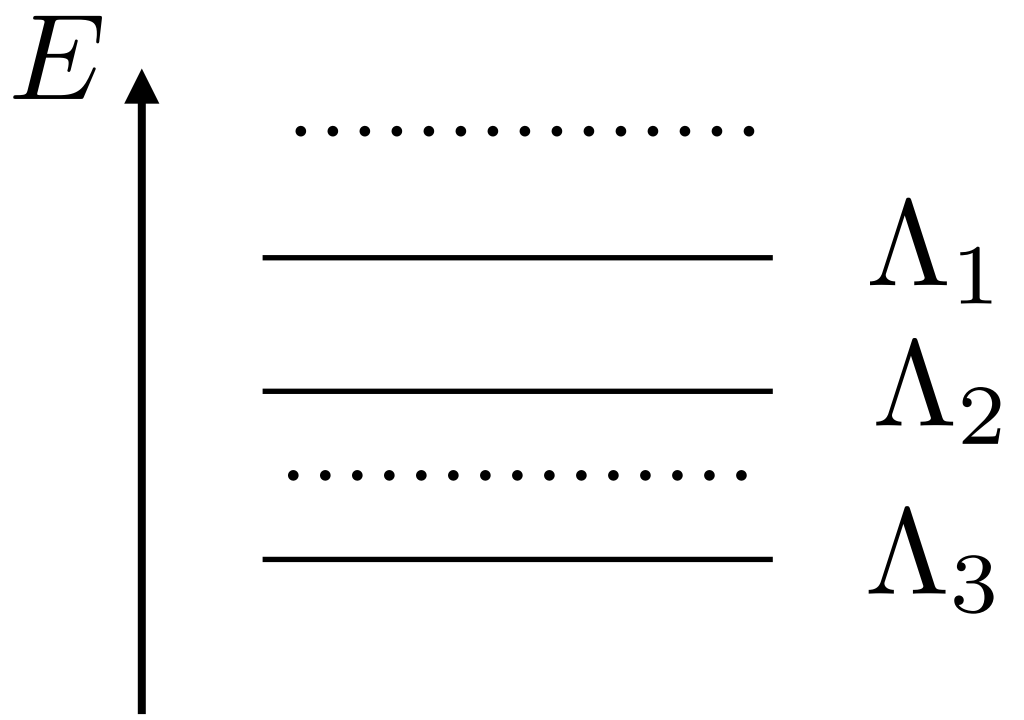


so that at low energy $E \lesssim \Lambda_3$:

- A dominant new interaction at Λ_3 involves (part of) the third family only

- An accidental $U(2)^n$ symmetry, under which $f_3 = \mathbf{1}, \quad f_{1,2} = \mathbf{2}$, progressively broken at Λ_2, Λ_1 , controls the full Yukawa couplings (and the communication of $f_{1,2}$, in the mass basis, with the int.s at Λ_3)

Uncertainties



1. From $y_t \approx 1$, q_3, u_3 feel the interaction at Λ_3 .
   What about $d_3,\ l_3,\ e_3$? Some $U(2)$-factors more relevant than others

2. $V_{CKM} = U_L D_L^+$ Separately U_L, D_L ? $Y_U = U_L^+ Y_U^{diag} U_R$ $Y_{D,E}$

3. $U_R, D_R,\ E_{L,R}$?

When needed, take minimally broken $U(2)^n$ "Weak MFV"

$$Y_u = y_t \left(\begin{array}{c|c} \Delta Y_u & x_t V \\ \hline 0 & 1 \end{array} \right) \qquad Y_d = y_b \left(\begin{array}{c|c} \Delta Y_d & x_b V \\ \hline 0 & 1 \end{array} \right)$$

q_3 only present at Λ_3
($q_3 \to -q_3$ at $\Lambda_{2,1}$)

$\Rightarrow$ Every element of D_L, U_L fixed but for $|V_{cb}| \approx |U_{23}^L - D_{23}^L|$

$\Rightarrow$ $U_R \sim D_R \sim \mathbf{1}$

B, Isidori et al, 2011

Weak MFV

$$Y_u = y_t \left(\begin{array}{c|c} \Delta Y_u & x_t V \\ \hline 0 & 1 \end{array}\right) \qquad Y_d = y_b \left(\begin{array}{c|c} \Delta Y_d & x_b V \\ \hline 0 & 1 \end{array}\right)$$

And, when need, Y_e

q_3 only present at Λ_3 ($q_3 \to -q_3$ at $\Lambda_{2,1}$)

So that:

$$U_R \sim D_R \sim \mathbf{1}$$

$$U_L = \begin{pmatrix} c_u & s_u\, e^{i\alpha_u} & -s_u s_t e^{i(\alpha_u+\phi_t)} \\ -s_u\, e^{-i\alpha_u} & c_u c_t & -c_u s_t e^{i\phi_t} \\ 0 & s_t e^{-i\phi_t} & c_t \end{pmatrix} \qquad D_L =$$

$$V_{CKM} \approx \begin{pmatrix} c_u c_d + s_u s_d\, e^{i(\alpha_d-\alpha_u)} & -c_u s_d\, e^{-i\alpha_d} + s_u c_d\, e^{-i\alpha_u} & s_u s e^{-i(\alpha_u-\xi)} \\ c_u s_d\, e^{i\alpha_d} - s_u c_d\, e^{i\alpha_u} & c_u c_d + s_u s_d\, e^{i(\alpha_u-\alpha_d)} & c_u s e^{i\xi} \\ -s_d s\, e^{i(\alpha_d-\xi)} & -s c_d e^{-i\xi} & 1 \end{pmatrix}$$

$$s = |V_{cb}|, \quad \frac{s_u}{c_u} = \left|\frac{V_{ub}}{V_{cb}}\right|, \quad s_d = -(0.22 \div 0.27)$$

$$s e^{i\xi} = s_b e^{-i\phi_b} - s_t e^{-i\phi_t}$$

Flavour in composite Higgs

What is the radius of Higgs compositeness, if any? $l_H = 1/m_*$

Flavour in composite Higgs

m_* = scale of Higgs compositeness

f = scale of symmetry breaking

H = pNGB

$m_* = g_* f$

f

m_H

$+ \; q_i, l_i, V_\mu^a$

1. At $\Lambda_3 \approx m_*$ only q_3, u_3 involved

(If $\Lambda_3 > m_*$, $y_t \approx (\frac{m_*}{\Lambda_3})^{(d_H-1)>1}$)

$$\mathcal{L}_Y^{(3)} = g^* x_L x_R \bar{q}_{L3} \mathcal{O}_H u_{R3}, \qquad x_{L,R} \leq 1 \qquad y_{u3} = g^* x_L x_R \qquad \mathcal{O}_H : \quad <0|\mathcal{O}_H|H> \neq 0$$

$$\mathcal{L}_{d>4}^{(3)}(q_3, u_3, H) = \frac{y_t^2}{\Lambda_3^2} x_t^2 (\bar{q}_{L3}\gamma_\mu q_{L3})^2 + \ldots$$

(See next slide) $\quad \frac{y_t}{g^*} < x_t = \frac{x_L}{x_R} < \frac{g^*}{y_t}$

2. Neglect the int.s at $\Lambda > \Lambda_3$ other than for their effects on $\mathcal{L}_Y$

$\Rightarrow$ In the mass basis, $\mathcal{L}_{d>4}^{(3)} \Rightarrow \mathcal{L}_{d>4}$ controlled by D_L, U_L

Main constraints in composite Higgs

(in the previous scheme)

Bounds rescaled by D_L or $U_L = V_{cb}$

How m_* scales with g_*

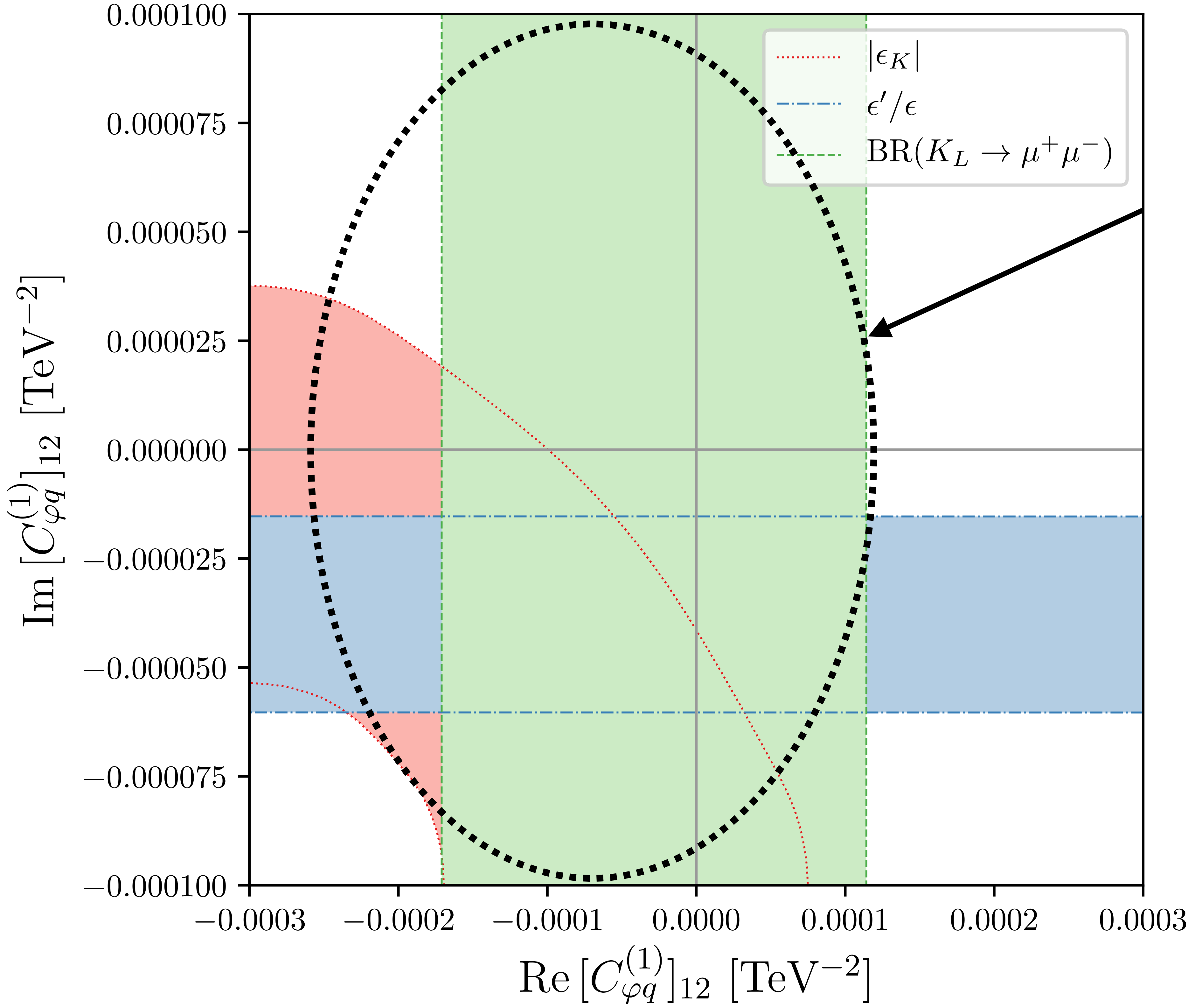
$Observable$	$Operator$	$\Lambda/TeV\,(pres)$	$\Lambda/TeV\,(fut)$	m_*/Λ
ϵ_K	$Q_1^{sd} = (\bar{s}_L\gamma_\mu d_L)^2$	7	13	x_t
ΔM_{B_d}	$Q_1^{bd} = (\bar{b}_L\gamma_\mu d_L)^2$	8	18	x_t
ΔM_{B_s}	$Q_1^{bs} = (\bar{b}_L\gamma_\mu s_L)^2$	9	20	x_t
$\Delta M_D, p/q$	$Q_1^{cu} = (\bar{c}_L\gamma_\mu u_L)^2$	3	10	x_t
$b \to s\, \bar{l}l$	$(\bar{s}_L\gamma_\mu b_L)H^+ i\mathcal{D}_\mu H$	4.5	12	$\sqrt{g^* x_t}$
$s \to d\, \bar{l}l(\bar{q}q)$	$(\bar{d}_L\gamma_\mu s_L)H^+ i\mathcal{D}_\mu H$	1.7	5	$\sqrt{g^* x_t}$
$neutron EDM\ (*)$	$\approx m_t(\bar{t}_L\sigma_{\mu\nu}T^a t_R)g_S G_a^{\mu\nu}$	≈ 5.5	16	$g^*/4\pi$
$electron EDM\ (*)$	$\approx m_t(\bar{t}_L\sigma_{\mu\nu}t_R)eF^{\mu\nu}$	≈ 50	?	$\sqrt{g^* x_t}/(4\pi)$

$$\frac{y_t}{g_*} < x_t < \frac{g_*}{y_t}$$

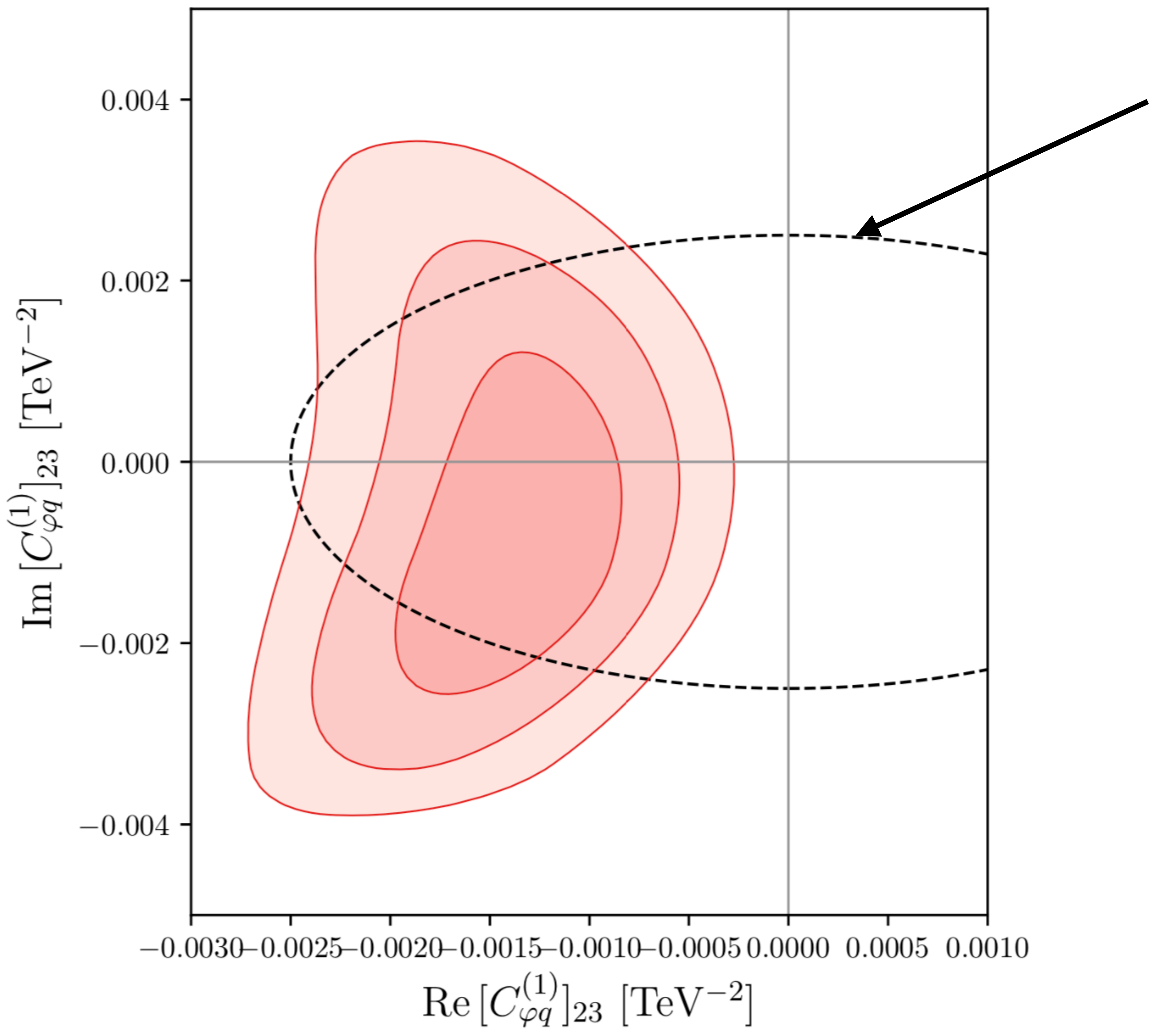
(*) = assuming maximal phases

an estimate of future sensitivity

$(\bar{d}_L \gamma_\mu s_L) H^+ i\mathcal{D}_\mu H$



$(\bar{s}_L \gamma_\mu b_L) H^+ i\mathcal{D}_\mu H$



Straub, 2018

If $K^+ \to \pi^+ \nu\nu$ at 10%, important

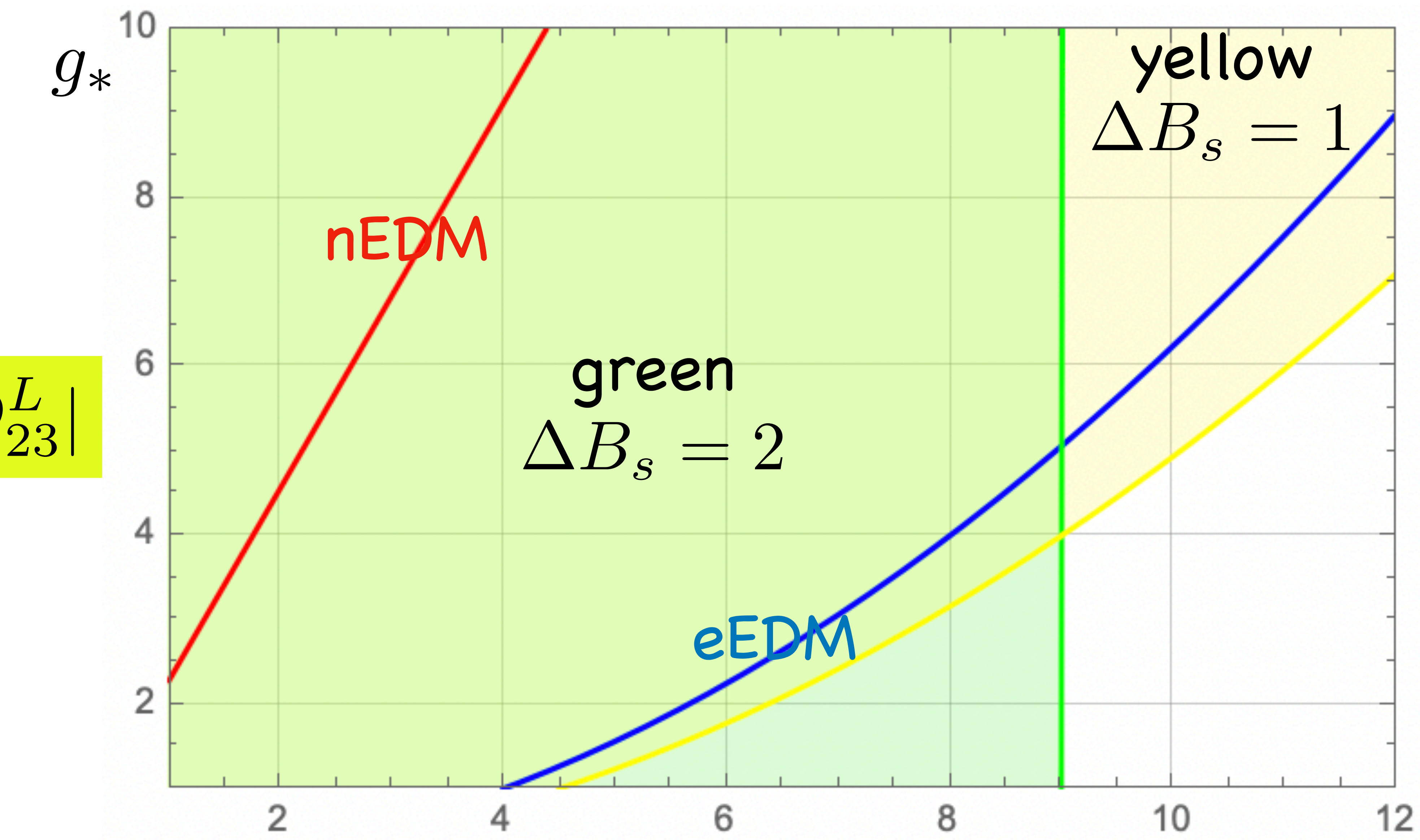
mainly

$B_s \to \mu^+\mu^-$ $B \to K^* \mu^+\mu^-$

Current (main) flavour bounds with weak MFV

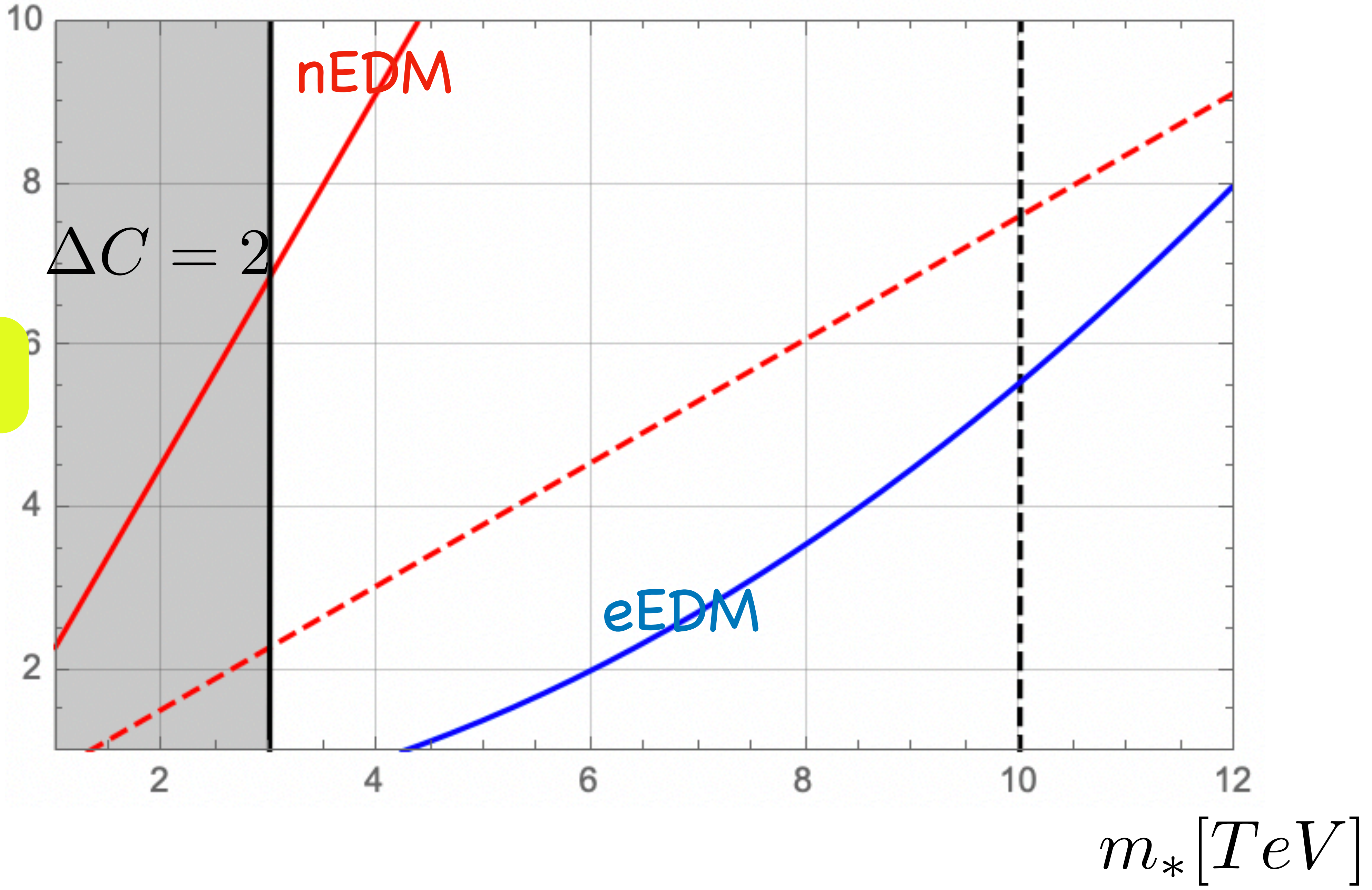
Exclusion plots $x_t = 1$

$|V_{cb}| \approx |D^L_{23}|$



- sensitivity on $\Delta B_s = 1, 2$ improvable by a factor of 2
  - maximal phases assumed for the EDMs

$|V_{cb}| \approx |U^L_{23}|$



- dotted lines = estimated future sensitivity
  - maximal phases assumed for the EDMs

Precision in composite Higgs

m_* = scale of Higgs compositeness

f = scale of symmetry breaking

H = pNGB

$m_* = g_* f$

f

m_H

$+ \; q_i, l_i, V_\mu^a$

- Higgs couplings — $c_\phi \sim g_*^2/m_*^2$ "On-shell"

- flavour-less ElectroWeak observables

Pole observables: $m_W, sin\theta^l_{eff}$ — $c_W \sim 1/m_*^2$

DiBoson production: Wh, Zh, WZ, WW — $c_W \sim 1/m_*^2$

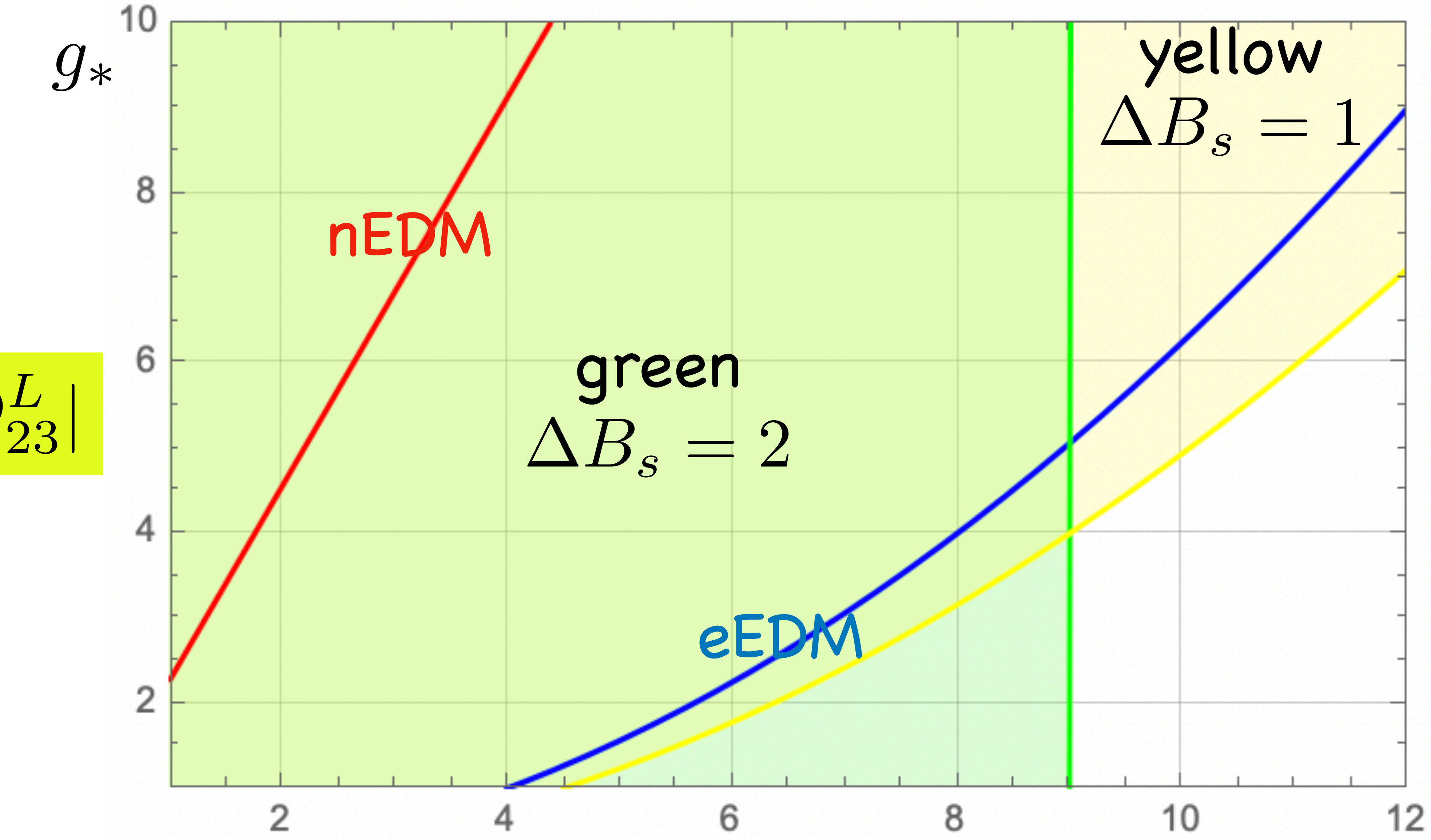
Drell-Yan $l^+l^-, l\nu$ at high m_{ll}, m^T_{ll} — $c_{2W} \sim 1/g_*^2 m_*^2$

"Off-shell"

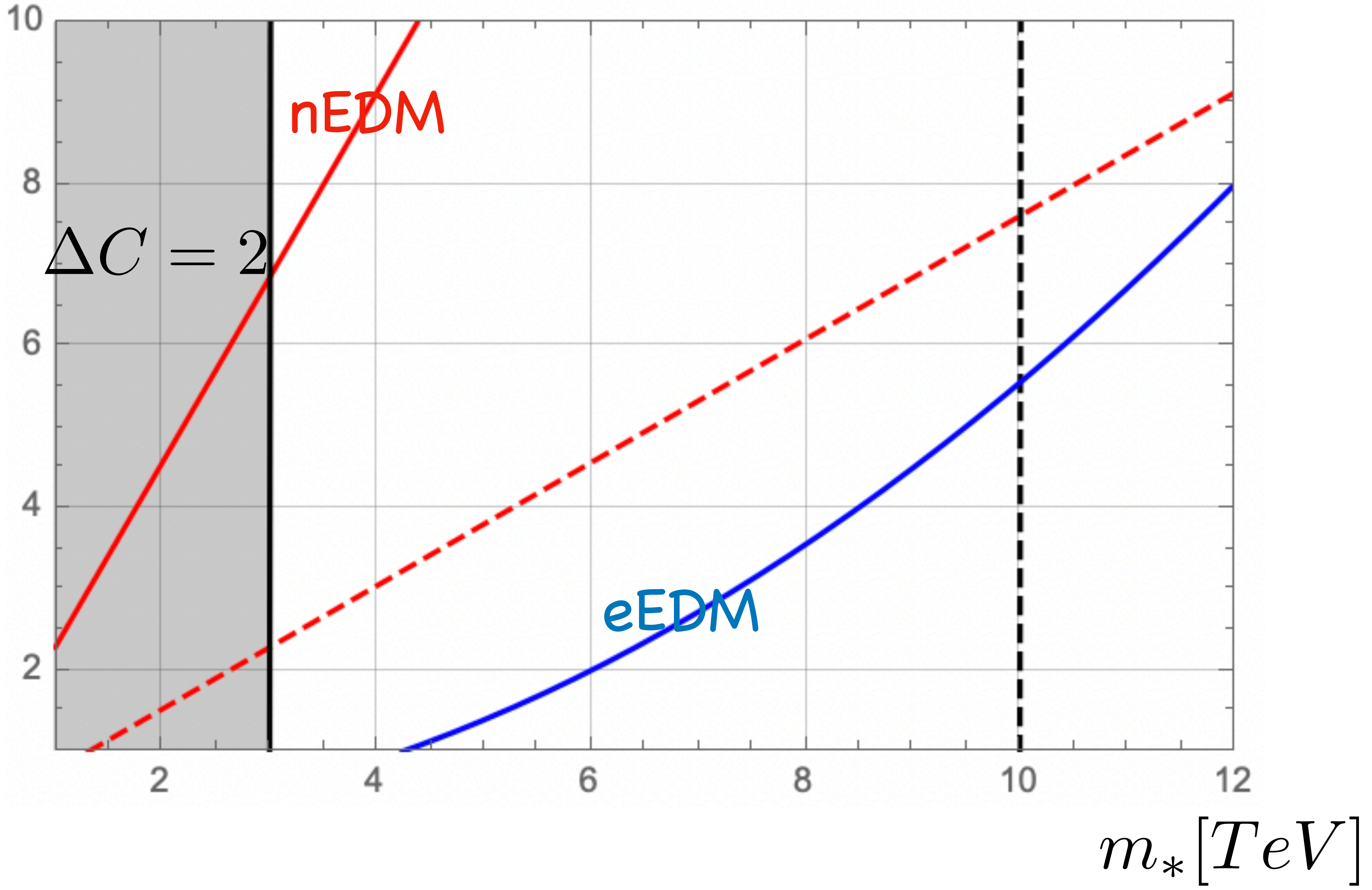
- flavour observables

Exclusion plots: flavour versus Higgs/EWPT

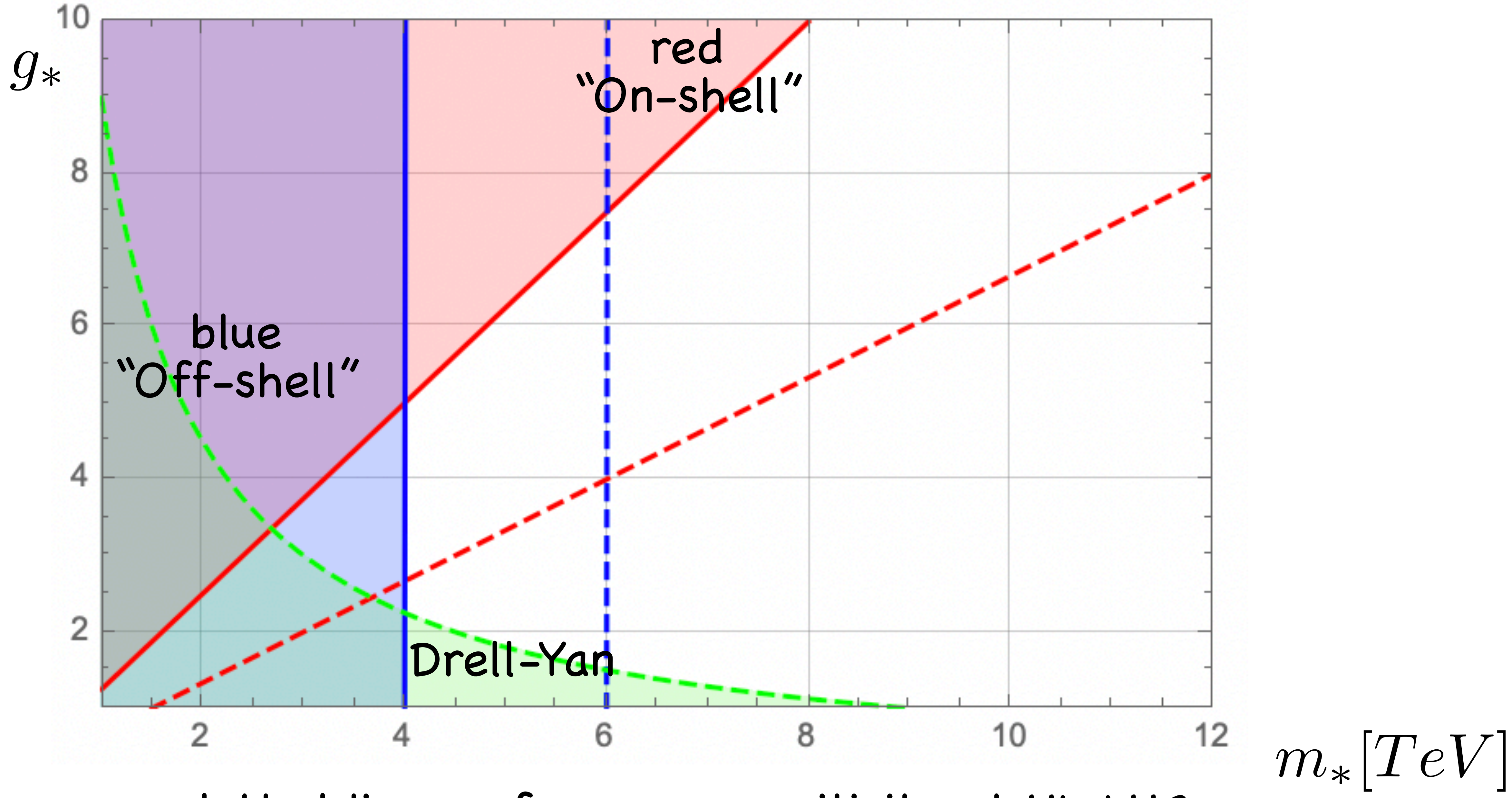
$|V_{cb}| \approx |D^L_{23}|$



$|V_{cb}| \approx |U^L_{23}|$



Higgs/EWPT



dotted lines = foreseen sensitivity at HL-LHC

Highly complementary!

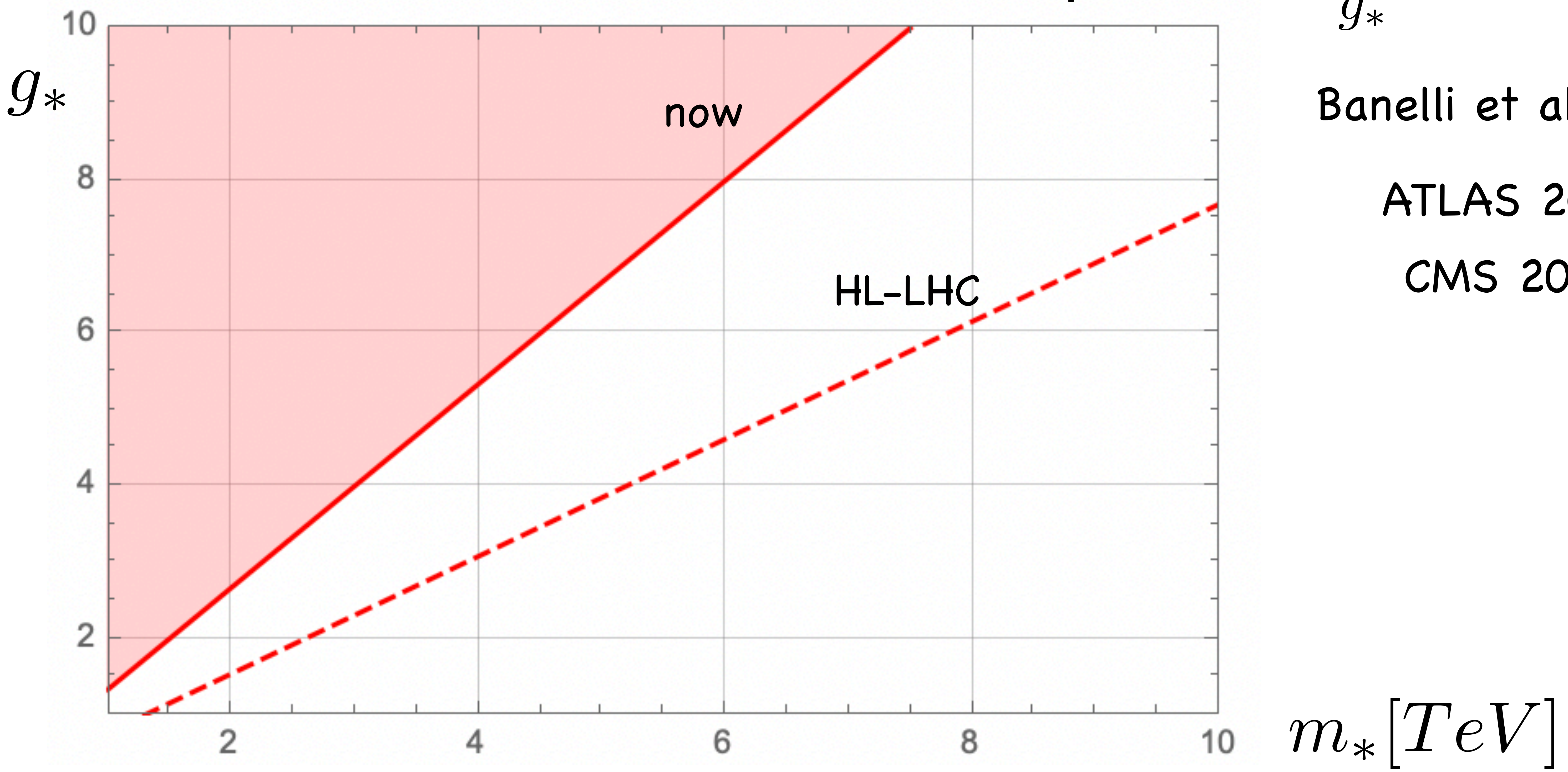
$\sqrt{\mathcal{O}(1)}$-factors possible in either direction

Four tops $pp \to t\bar{t}t\bar{t}$ in weak MFV

$$\mathcal{L}^{4top} = \frac{y_t^2}{m_*^2}[x_t^2(\bar{q}_{L3}\gamma_\mu q_{L3})^2 + (\bar{q}_{L3}t_R)(\bar{t}_R q_{L3}) + \frac{1}{x_t^2}(\bar{t}_R\gamma_\mu t_R)^2]$$

$$\frac{y_t}{g_*} < x_t = \frac{x_L}{x_R} < \frac{g_*}{y_t}$$

Exclusion plot $x_t = \frac{y_t}{g_*}$ or $x_t = \frac{g_*}{y_t}$



Banelli et al 2020

ATLAS 2019

CMS 2019

(With some excesses in multilepton + jets in current data)

Comparable, but conceptually very different from Higgs, EWPT "on-shell"

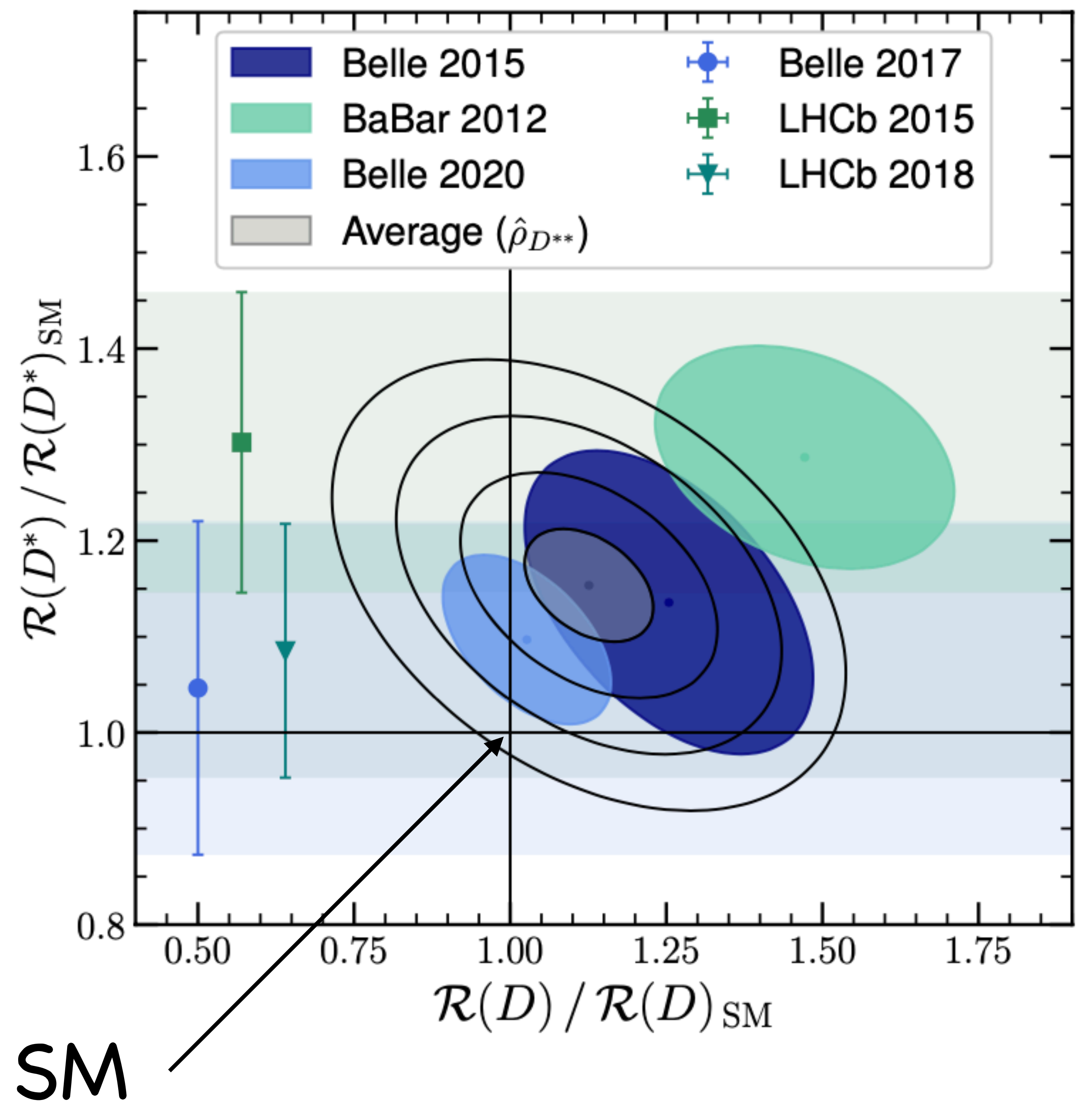
And/or

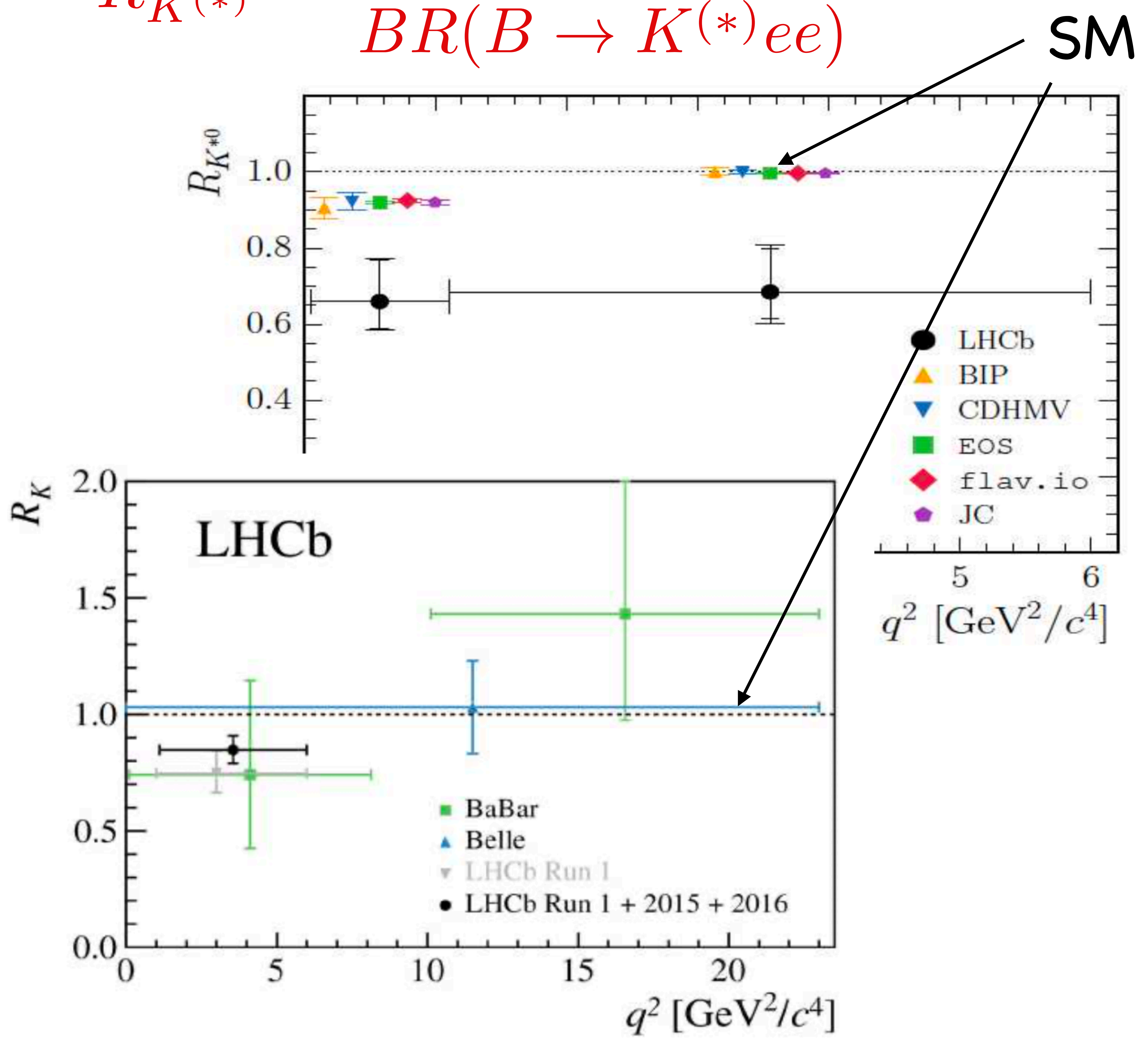
A violation of Lepton Flavour Universality?

$$R_{D^{(*)}} = \frac{BR(B \to D^{(*)}\tau\nu)}{BR(B \to D^{(*)}l\nu, l = \mu, e)}$$

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)}$$

Bernlochner et al 2021





$3.6\ \sigma$

$4.2\ \sigma$ together with other observables

Yet too early to say

Still in the limbo, but

Observable	Current LHCb	LHCb 2025	Upgrade II
EW Penguins			
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [4]	0.025	0.007
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [5]	0.031	0.008
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**			
$R(D^*)$	0.026 [15, 16]	0.0072	0.002
$R(J/\psi)$	0.24 [17]	0.071	0.02

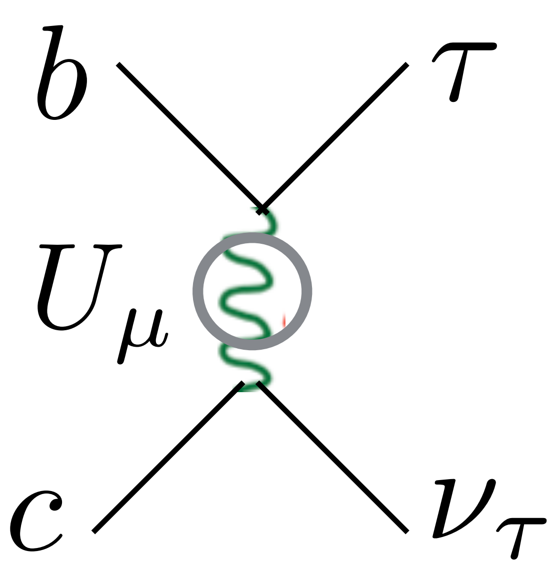
the expected future precision will settle the issue

A leptoquark interpretation of the anomalies 1

On top of the flavour picture as described above,

$U_\mu = (\mathbf{3},\mathbf{1})_{2/3}$ with mass $M_U \sim \Lambda_3$ and $\mathcal{L}_U^{(3)} = g_U U_\mu^a (\bar{q}_{3L}^a \gamma_\mu l_{3L}) + h.c.$

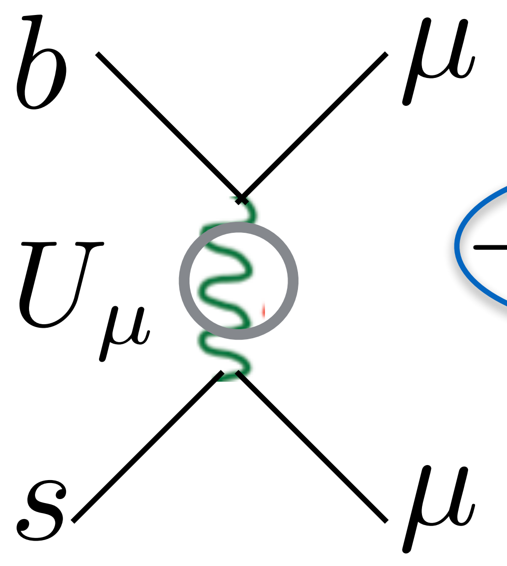
$\Rightarrow$ In the mass basis $\mathcal{L}_U^{(3)} \Rightarrow \mathcal{L}_U$ controlled by U_L, D_L, E_L



$b \to c\tau\nu$

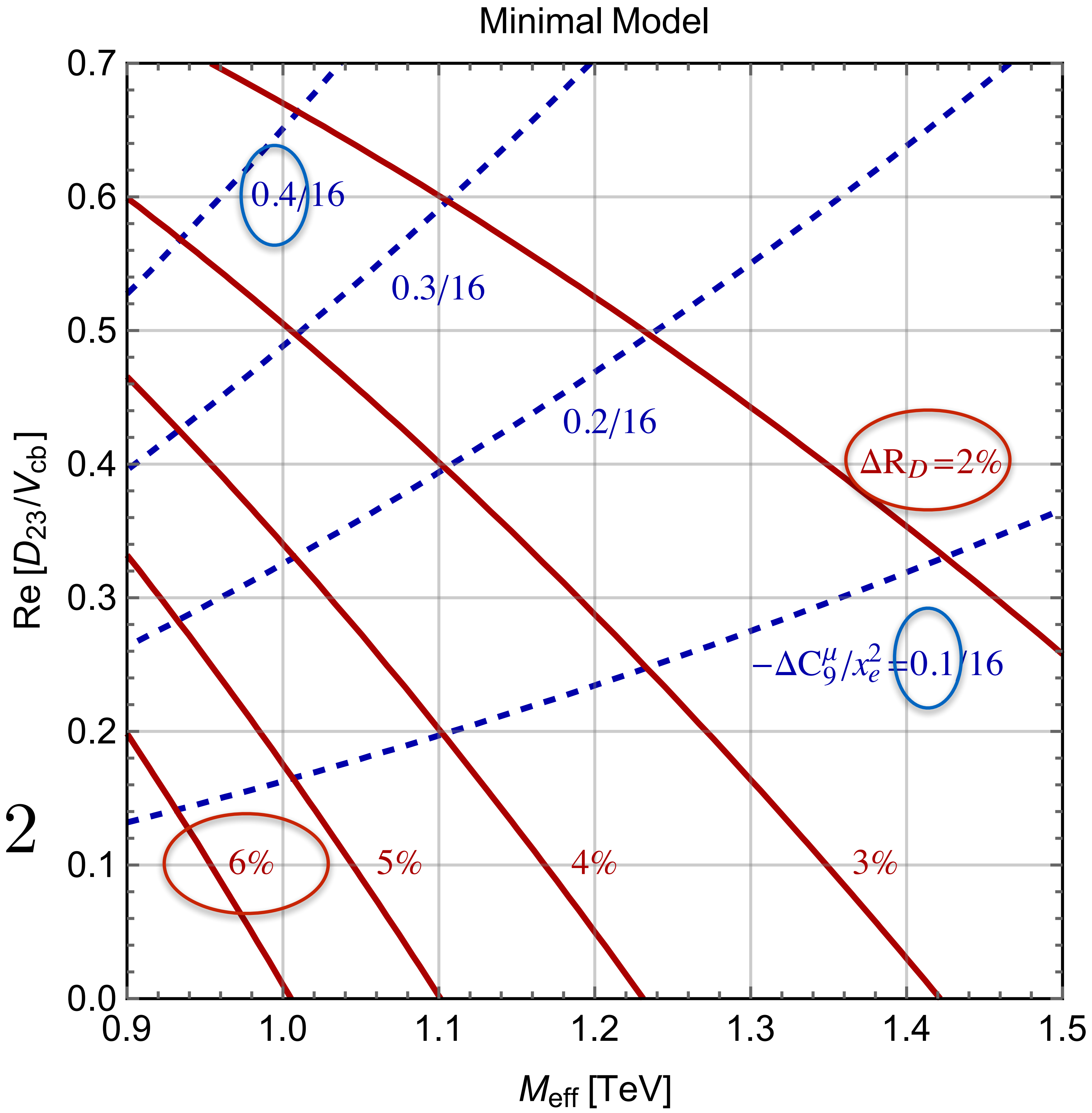
currently:

$\Delta R_D = (14 \pm 4)\%$



$b \to s\mu\mu$

$-\Delta C_9^\mu = 2.2\Delta R_K = 0.42 \pm 0.12$



B, Ziegler 2019

$$Re \frac{D_{23}^L - U_{23}^L}{V_{cb}} \approx 1$$

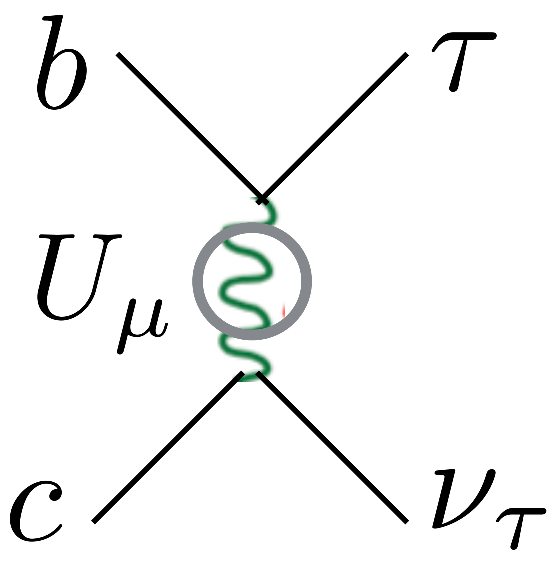
$$x_e = |E_{23}/V_{cb}|$$

$$M_{eff} = \frac{M_U}{g_U}$$

A leptoquark interpretation of the anomalies 2

Λ_2 affects not only $\mathcal{L}_Y$ but $\mathcal{L}_U$ as well, in a suppressed way

$$\Rightarrow \quad \mathcal{L}_U = \mathcal{L}_U^{(3)} + \mathcal{L}_U^{(3,2)} \qquad \mathcal{L}_U^{(3,2)} = g_U U_\mu^a \left(\epsilon_l (\bar{q}_{3L}^a \gamma_\mu l_{2L}) + \epsilon_q (\bar{q}_{2L}^a \gamma_\mu l_{3L}) + \epsilon_l \epsilon_q (\bar{q}_{2L}^a \gamma_\mu l_{2L})\right)$$



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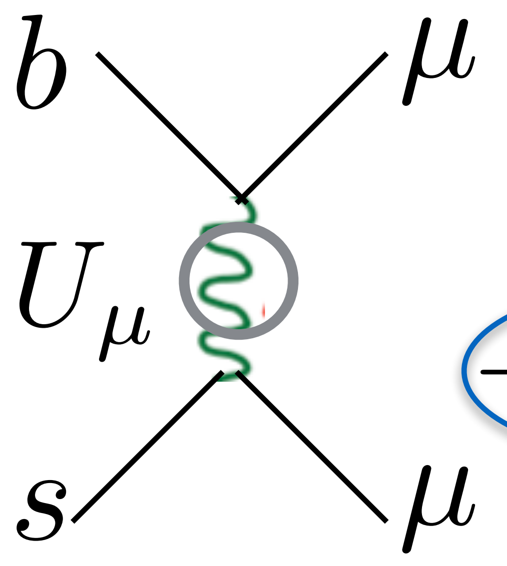

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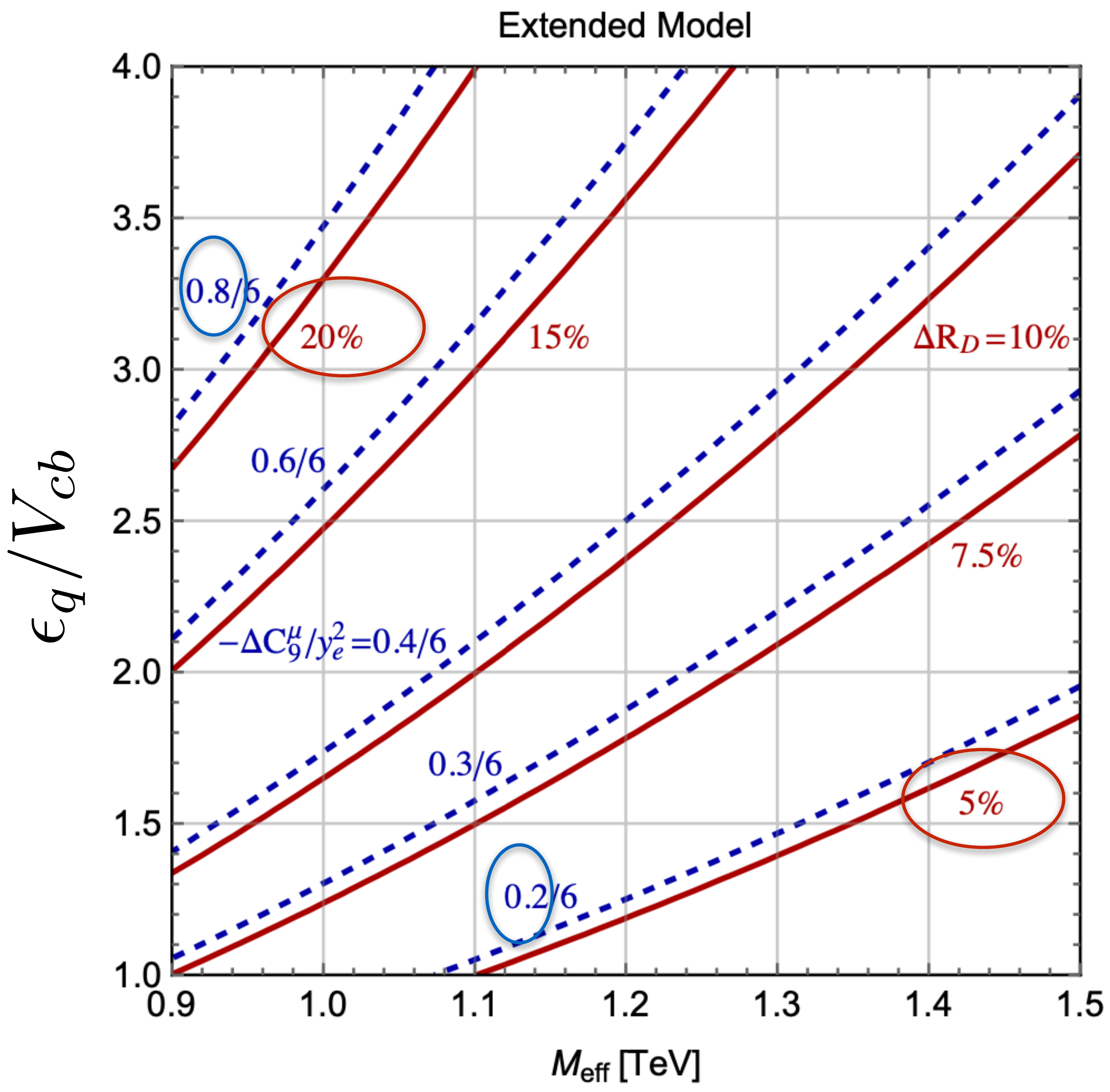


B, Ziegler 2019

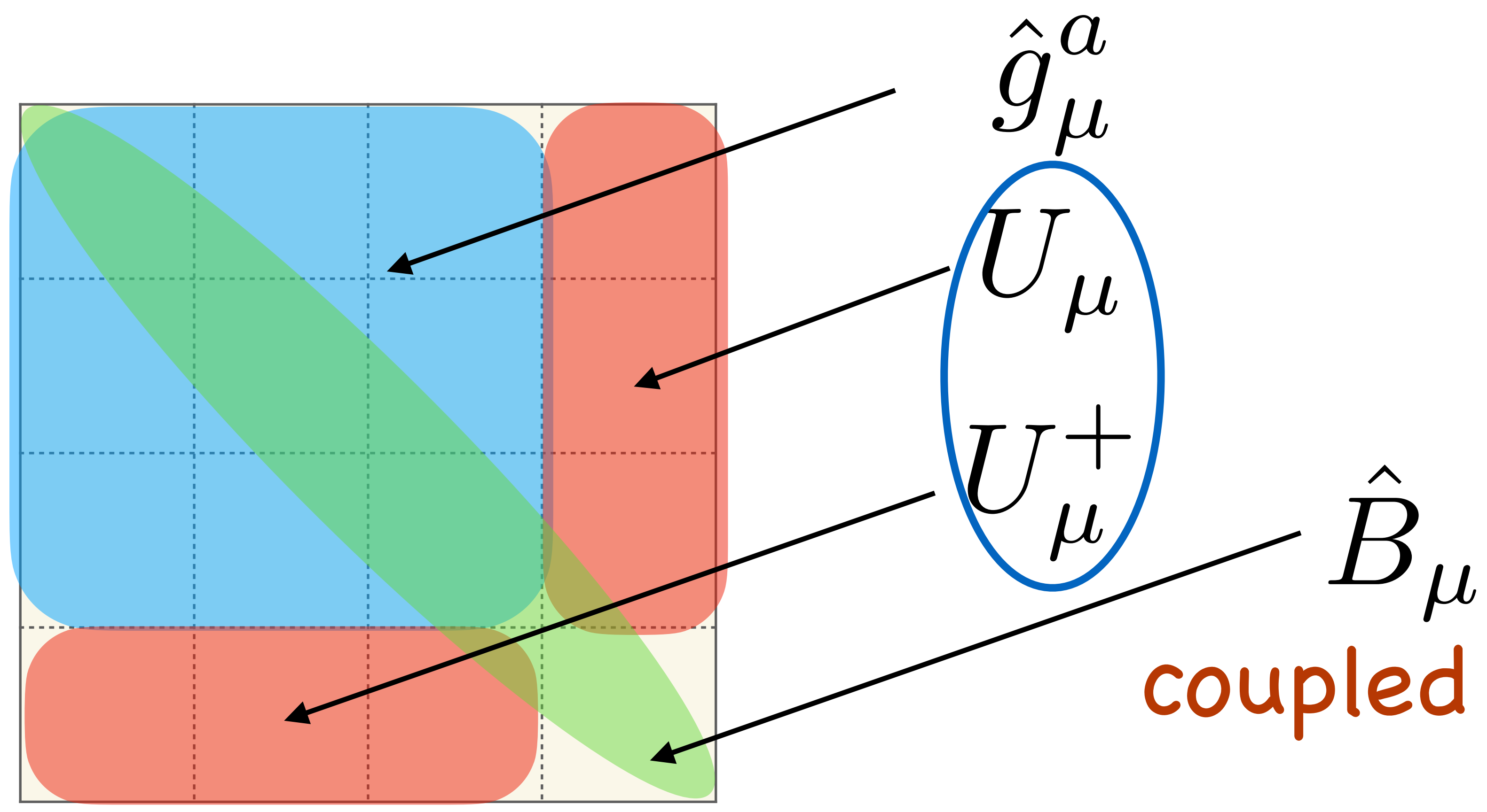
$$y_e = |\epsilon_l / V_{cb}|$$

$$M_{eff} = \frac{M_U}{g_U}$$

A step towards a "UV-completion" of U_μ

Pati-Salam SU(4): L as a fourth colour

Pati, Salam 1974

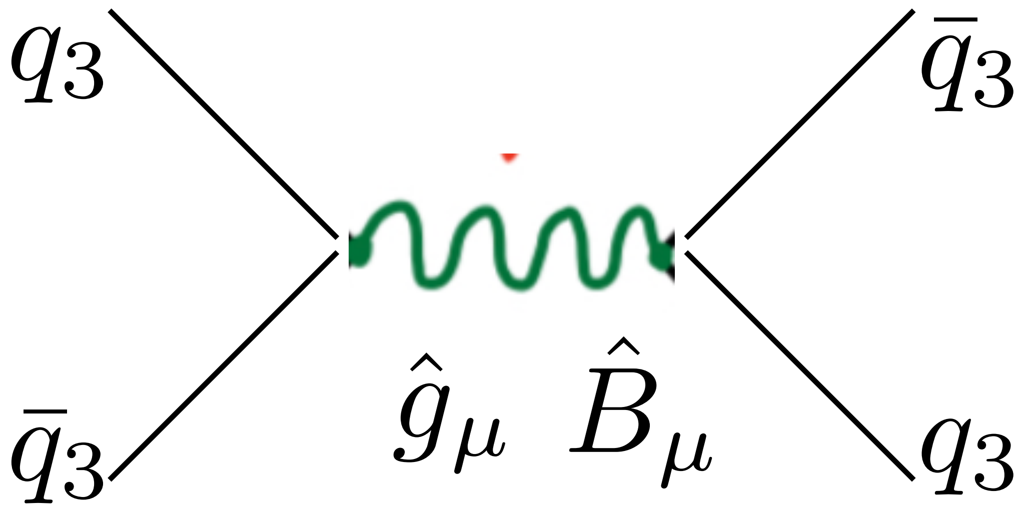


A global symmetry of a new strong interaction?

An extra gauge group?

Really alternative views? Extra-D?

B, Isidori et al 2015
B, Murphy et al 2016
Di Luzio et al 2017
Bordone et al 2017
Assad et al 2017
B, Tesi 2017
Blanke, Crivellin 2018
Fornal et al 2018



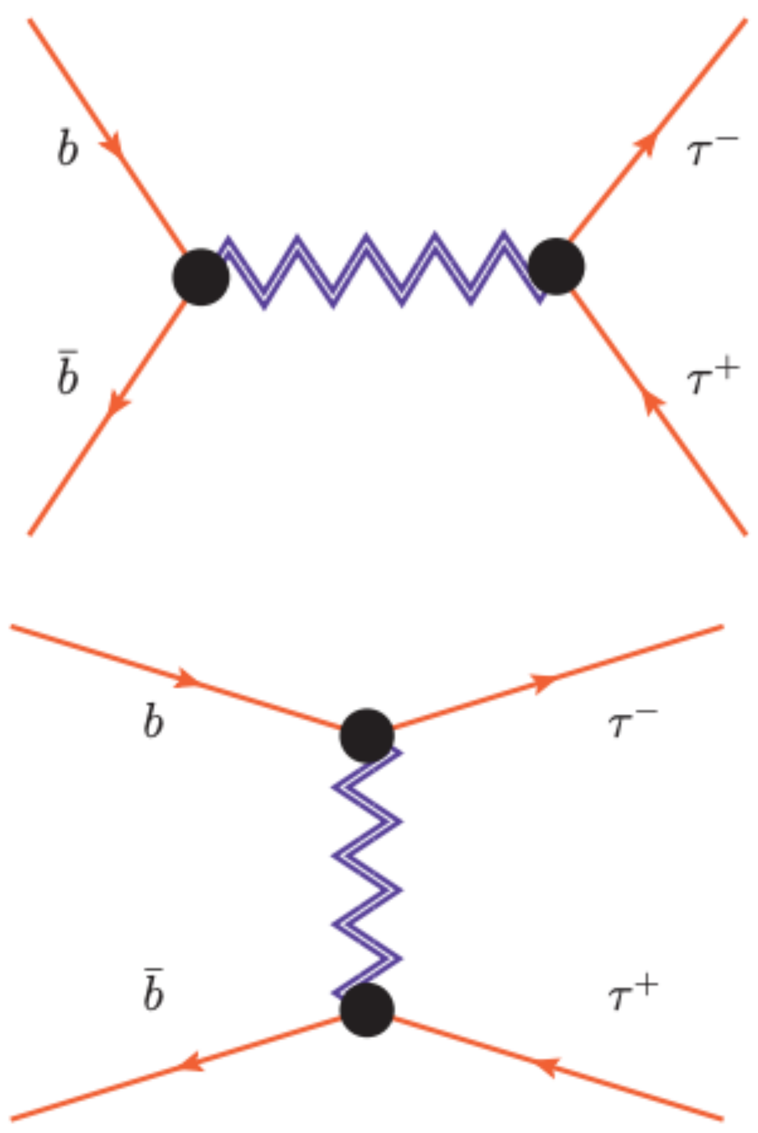
with $g/M \approx g_U/M_U$

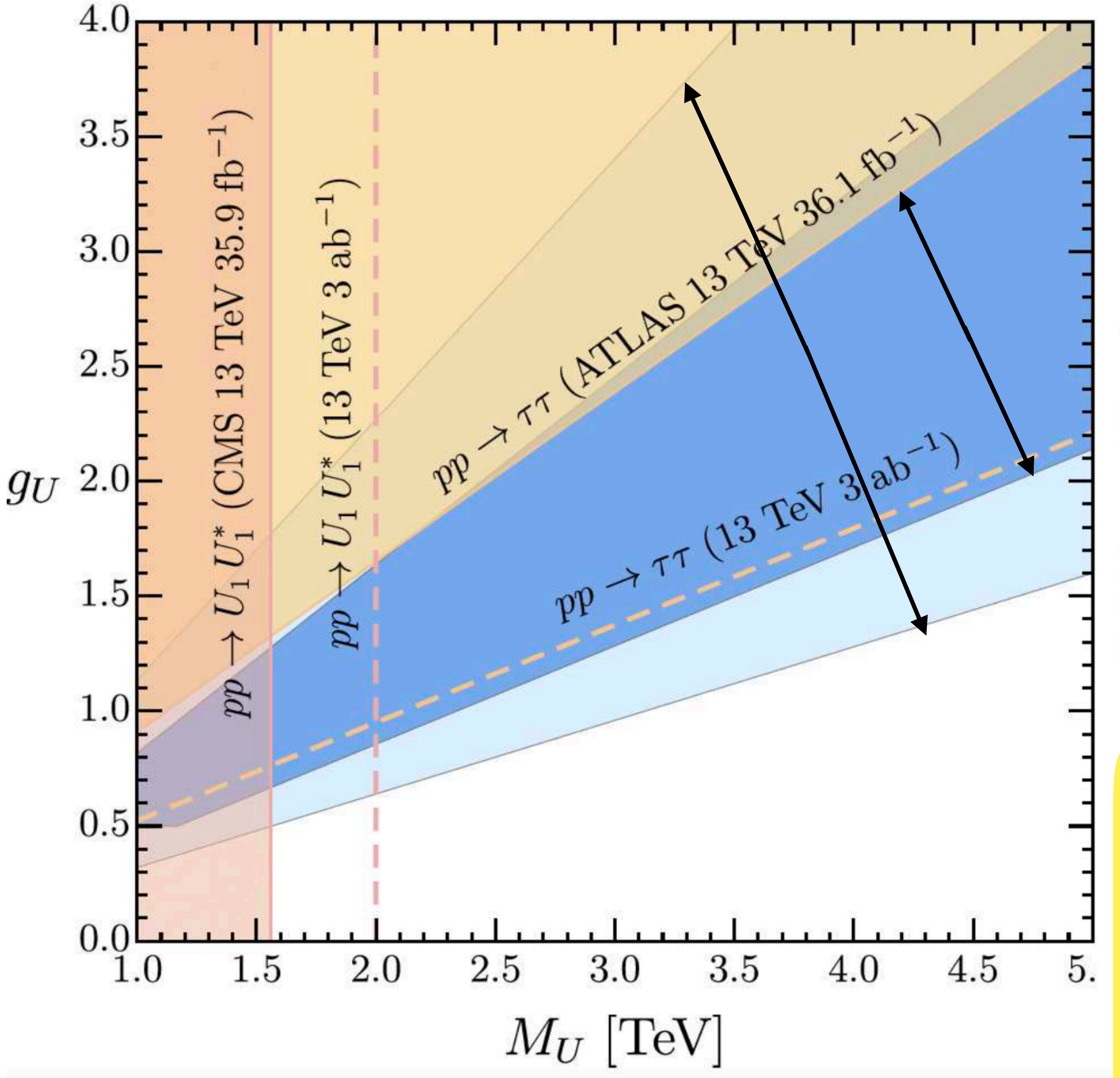
$\Rightarrow$ From $\Delta B_s = 2$ $\quad D^L_{23} \lesssim 0.1 V_{cb}$

$\Rightarrow$ $U^L_{23} \approx V_{cb}$ $\quad$ CPV in $\Delta C = 2$ crucial

Clear high-p_T signatures of U_μ

Faroughy et al, 2016
Baker et al, 2019





… as of many LE flavour observables
$B \to K\tau\mu, B_s \to \tau\mu, \ldots$

If compared with previous plots,
LFV compatible with Higgs compositeness provided:

1. $V_{cb} \approx U_{23}^L$

2. $M_U \approx m_* \gtrsim 4\ TeV,\ g^* \gtrsim 2$

or An Intermezzo

Mass-angle relations

If $$|\frac{m^{U,D}}{m_{33}^{U,D}}| = \begin{pmatrix} 0 & \epsilon' & 0 \\ \pm\epsilon' & \leq \epsilon & a\epsilon \\ 0 & b\epsilon & 1 \end{pmatrix}$$

Gatto, Sartori, Tonin 1968
Weinberg 1977
Fritzsch 1977
Hall, Rasin 1993

then

$$|V_{us}| = |\sqrt{\frac{m_d}{m_s}} - e^{i\phi}\sqrt{\frac{m_u}{m_c}}| = 0.19 \div 0.26 \quad \Leftrightarrow \quad V_{us} = 0.2243(5)$$

$$|\frac{V_{td}}{V_{cb}}| = \sqrt{\frac{m_d}{m_s}} = 0.224(13) \Leftrightarrow |\frac{V_{td}}{V_{cb}}| = 0.21(1)$$

$$|\frac{V_{ub}}{V_{cb}}| = |\sqrt{\frac{m_u}{m_c}}| = 0.045(5) \Leftrightarrow \begin{array}{l} |\frac{V_{ub}}{V_{cb}}|(low) = 0.061(6) \\ |\frac{V_{ub}}{V_{cb}}|(high) = 0.095(10) \end{array}$$

(up to corrections less than the uncertainty on $\frac{m_d}{m_s}$ and $\frac{m_u}{m_c}$)

Consider the diagonal $U(2)^{diag} \subset U(2)_Q \times U(2)_u \times U(2)_d$

B, Dvali, Hall 1995

1. Under U(2): $Q_{1,2} \equiv Q; \quad u_{1,2} \equiv u; \quad d_{1,2} \equiv d$ = $\mathbf{2}_1$
   $Q_3; \quad u_3; \quad d_3$ = $\mathbf{1}_0$

2. U(2) broken by $\quad U(2) \xrightarrow{\Sigma = \bar{\mathbf{2}}} U(1)_f \xrightarrow{\eta = \mathbf{1}} 0$

$$\mathcal{L}_Y = [\lambda_{33} Q_3 u_3 + \lambda_{23}(Q\Sigma)u_3 + \lambda_{32} Q_3(\Sigma u) + \lambda_{22}(Q\Sigma)(\Sigma u) + \lambda_{12}(Q\eta u)]H$$

(in full generality) $\quad <\Sigma>= \begin{pmatrix} 0 \\ \epsilon \end{pmatrix} \qquad <\eta>= \epsilon'$

$$\Rightarrow \quad Y^{U,D} = \begin{pmatrix} 0 & \lambda_{12}\epsilon' & 0 \\ -\lambda_{12}\epsilon' & \lambda_{22}\epsilon^2 & \lambda_{23}\epsilon \\ 0 & \lambda_{32}\epsilon & \lambda_{33} \end{pmatrix}$$

(with different λ's for Y^U and Y^D)

Still pending question: Why $Y^U \neq Y^D \quad (m_t >> m_b)$?

A possible answer $U(2) \equiv SU(2)_f \times U(1)_f$

1. Take $Q, u, d = \mathbf{2}_1, \quad Q_3, u_3 = \mathbf{1}_0$ and $d_3 = \mathbf{1}_1$

2. Replace $\eta = \mathbf{1}_{-2}$ with $\chi = \mathbf{1}_{-1}$ so that

$$d_3 \to \chi d_3, \quad \eta \to \chi^2$$

Dudas et al 2013

Linster, Ziegler 2018

i.e., up to O(1) factors,

$$Y^U = \begin{pmatrix} 0 & \epsilon' & 0 \\ -\epsilon' & \epsilon^2 & \epsilon \\ 0 & \epsilon & 1 \end{pmatrix} \Rightarrow Y^U = \begin{pmatrix} 0 & \epsilon_\chi^2 & 0 \\ -\epsilon_\chi^2 & \epsilon^2 & \epsilon \\ 0 & \epsilon & 1 \end{pmatrix}$$

$$Y^D = \begin{pmatrix} 0 & \epsilon' & 0 \\ -\epsilon' & \epsilon^2 & \epsilon \\ 0 & \epsilon & 1 \end{pmatrix} \Rightarrow Y^D = \begin{pmatrix} 0 & \epsilon_\chi^2 & 0 \\ -\epsilon_\chi^2 & \epsilon^2 & \epsilon\epsilon_\chi \\ 0 & \epsilon & \epsilon_\chi \end{pmatrix}$$

as in page 1 or 2 except for $\frac{Y^D_{23}}{Y^D_{33}} = tan\ \theta^R_d = \mathcal{O}(\frac{\epsilon}{\epsilon_\chi}) = ?$

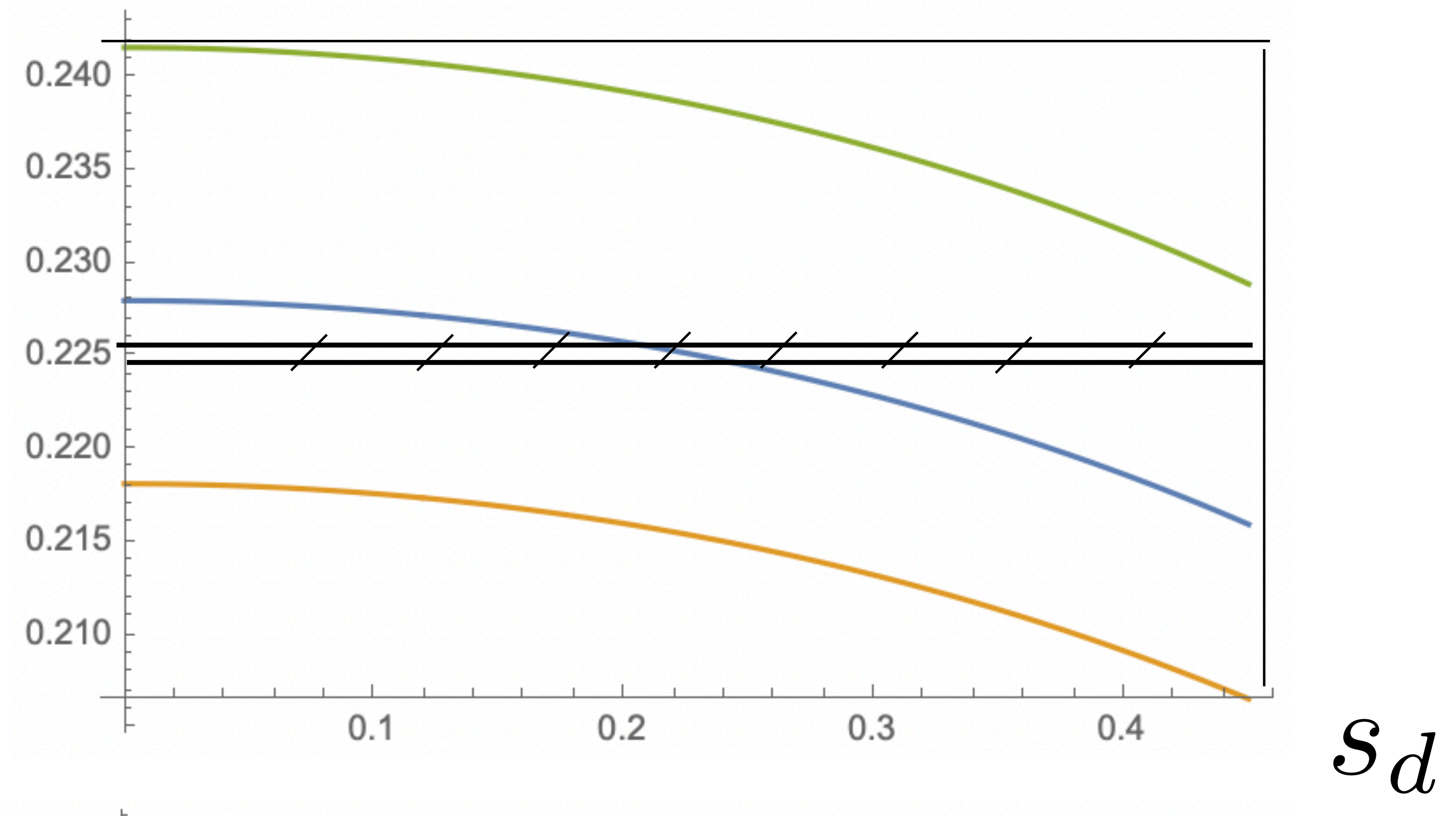
Mass-angle relations as functions of $sin\theta_d^R$

$$\frac{Y_{23}^D}{Y_{33}^D} = tan\ \theta_d^R$$

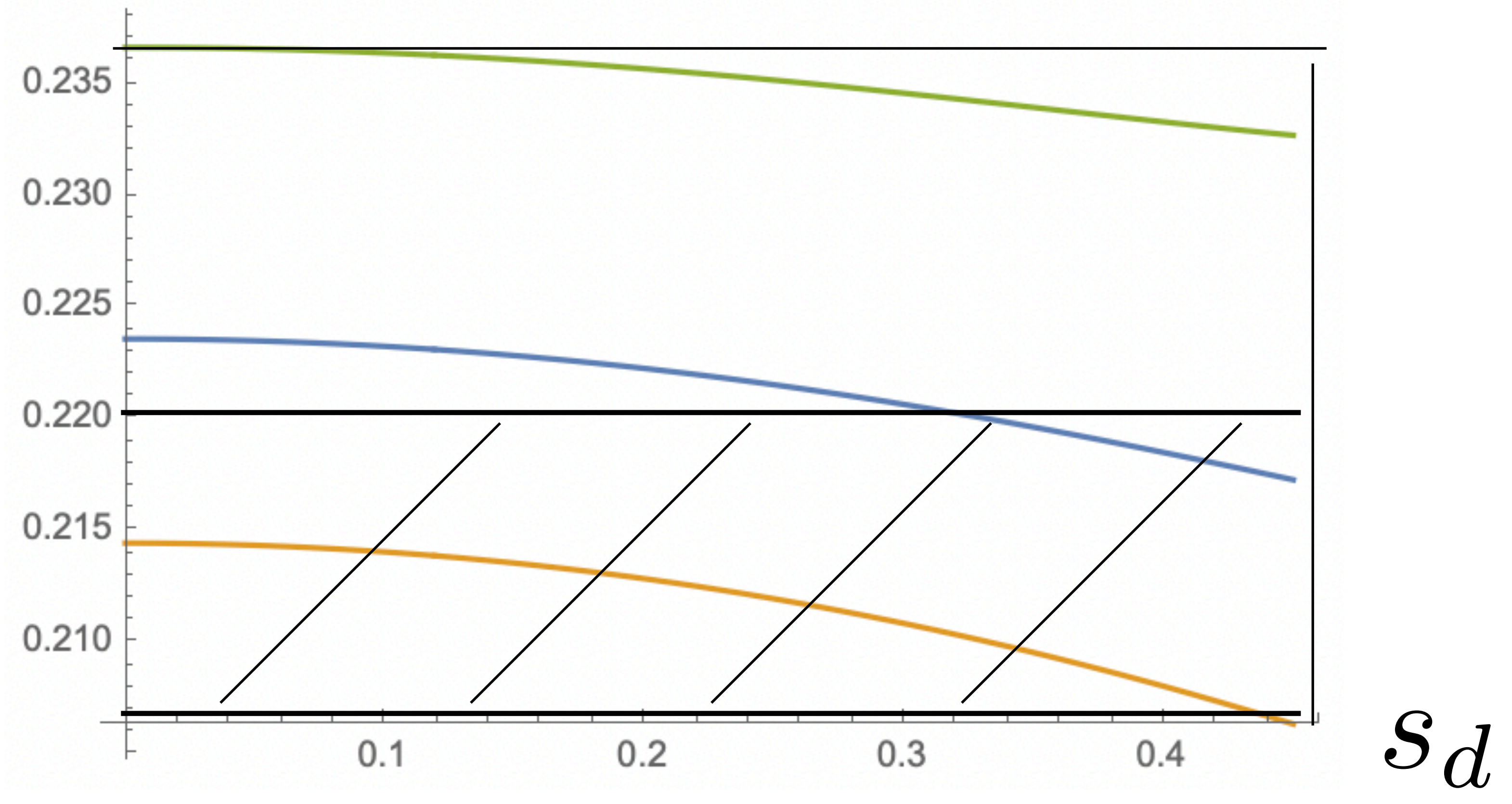
$$\alpha_1 = \alpha_2 = \pi/2$$

Roberts et al, 2001

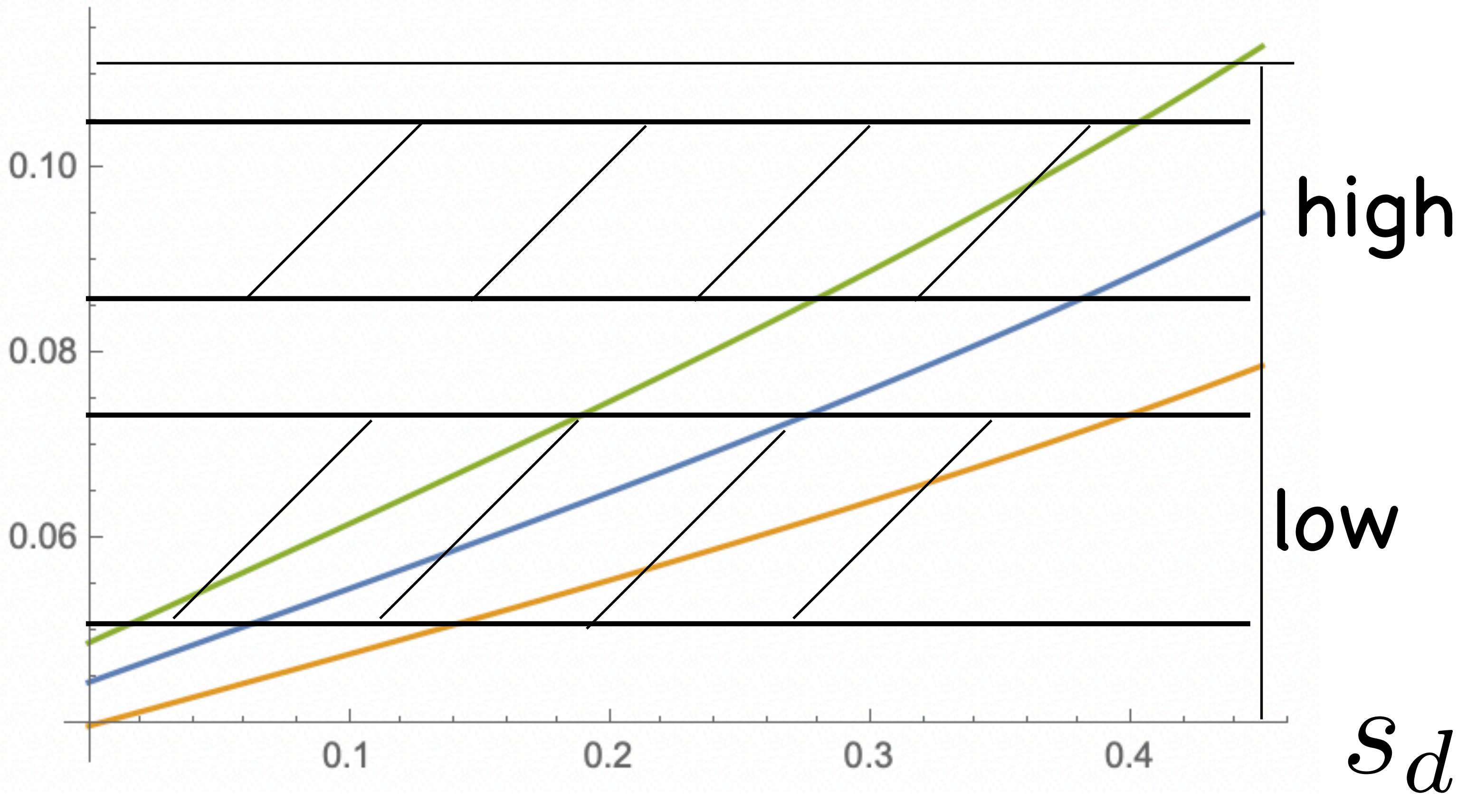
$$V_{us} = \left| \sqrt{\frac{m_d}{m_s}}\sqrt{c_d} - e^{i\alpha_1}\sqrt{\frac{m_u}{m_c}} \right|$$



$$\left|\frac{V_{td}}{V_{cb}}\right| = \left| \sqrt{\frac{m_d}{m_s}}\sqrt{c_d} - e^{i\alpha_2}R \right|$$



$$\left|\frac{V_{ub}}{V_{cb}}\right| = \left| \sqrt{\frac{m_u}{m_c}} - e^{-i(\alpha_1+\alpha_2)}R \right|$$



$$R = \frac{s_d}{\sqrt{c_d}}\sqrt{\frac{m_d}{m_s}}\frac{m_s}{m_b|V_{cb}|}$$

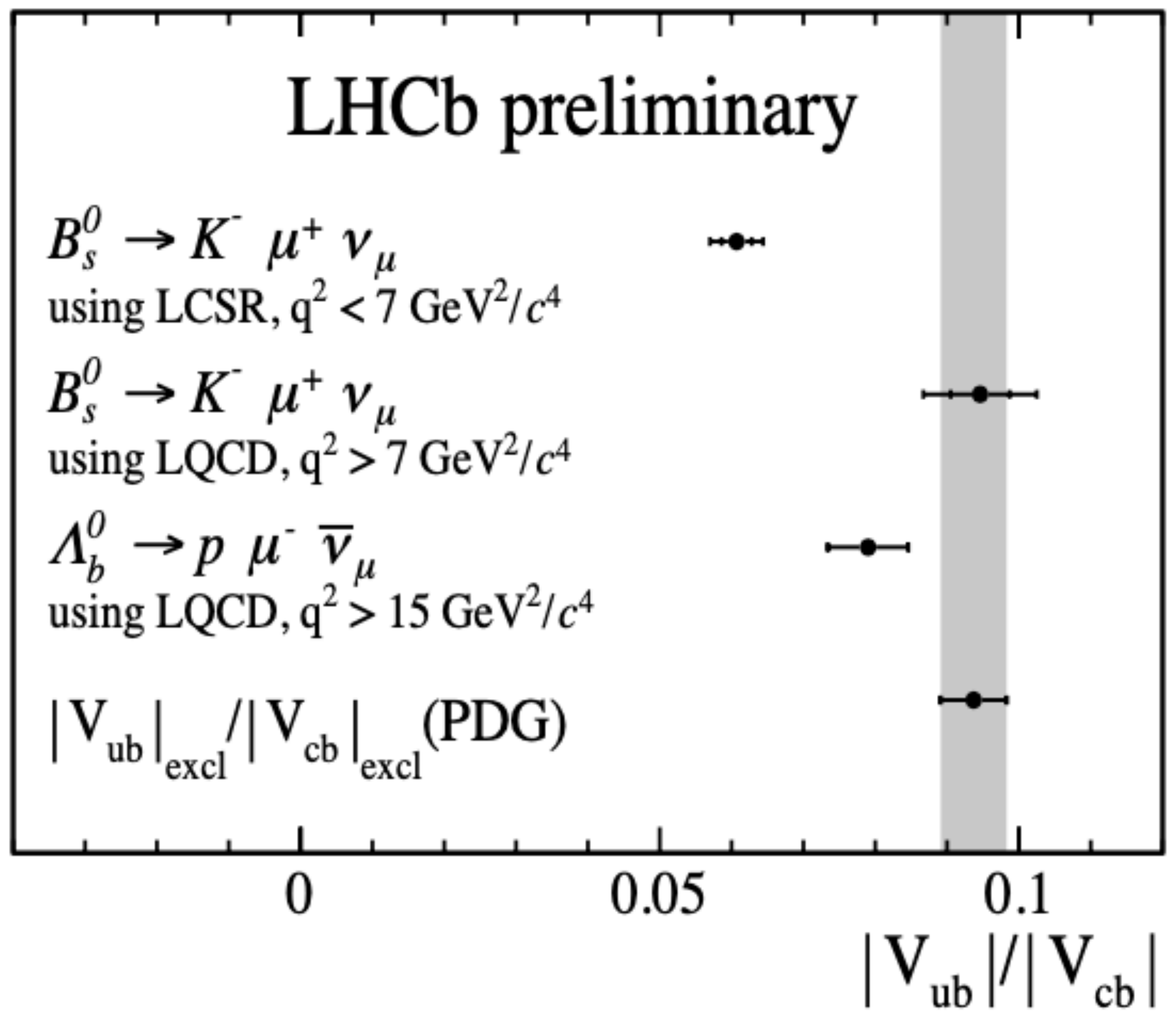
$$c_d = cos\theta_d^R,\ s_d = sin\theta_d^R$$

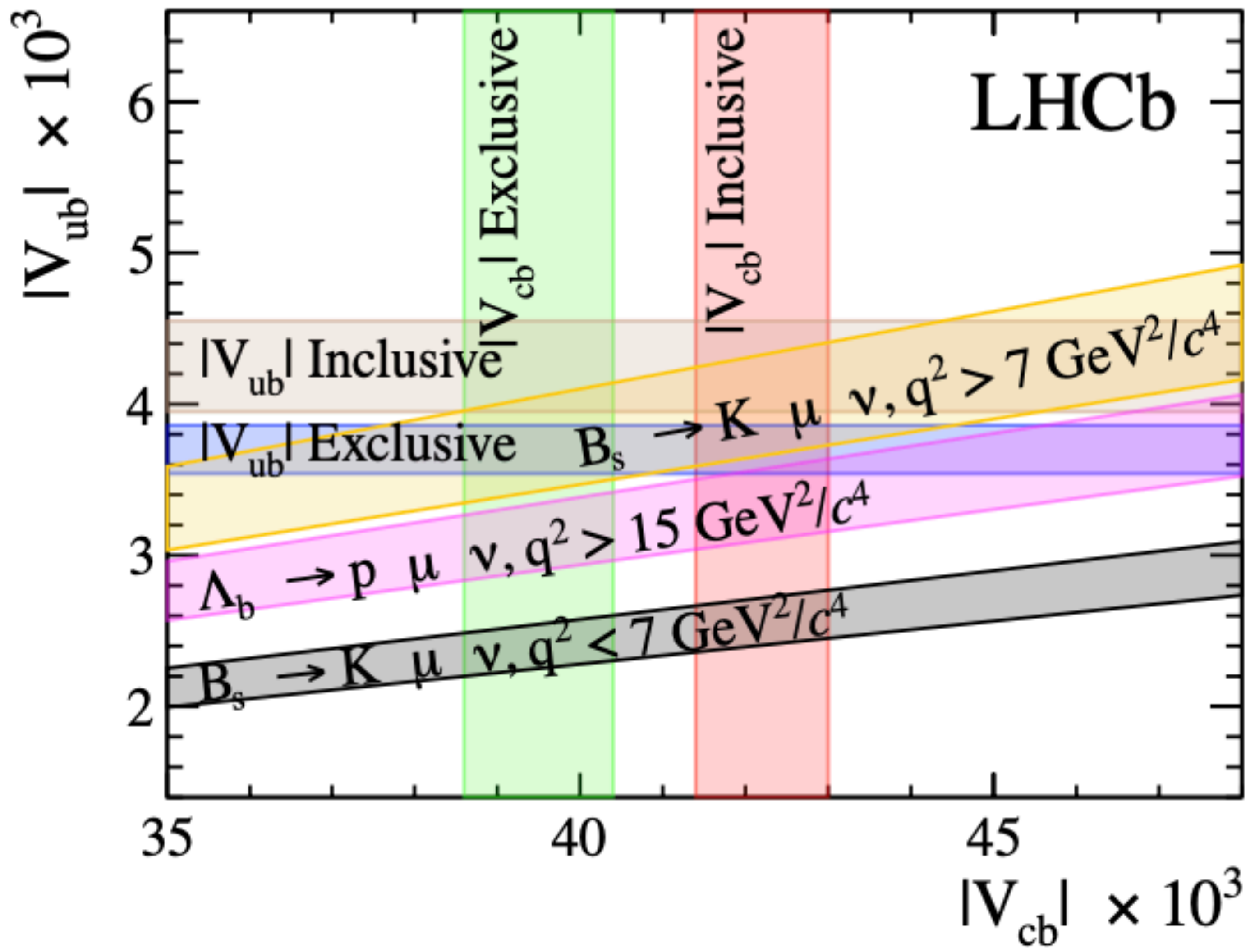
LHCb 2020

Results: $|V_{ub}|/|V_{cb}|$

$$|V_{ub}|/|V_{cb}|(\text{low}) = 0.0607 \pm 0.0015(\text{stat}) \pm 0.0013(\text{syst}) \pm 0.0008(\text{D}_s) \pm 0.0030(FF)$$

$$|V_{ub}|/|V_{cb}|(\text{high}) = 0.0946 \pm 0.0030(\text{stat})^{+0.0024}_{-0.0025}(\text{syst}) \pm 0.0013(\text{D}_s) \pm 0.0068(FF)$$





And

Flavour versus direct searches in weakly coupled theories

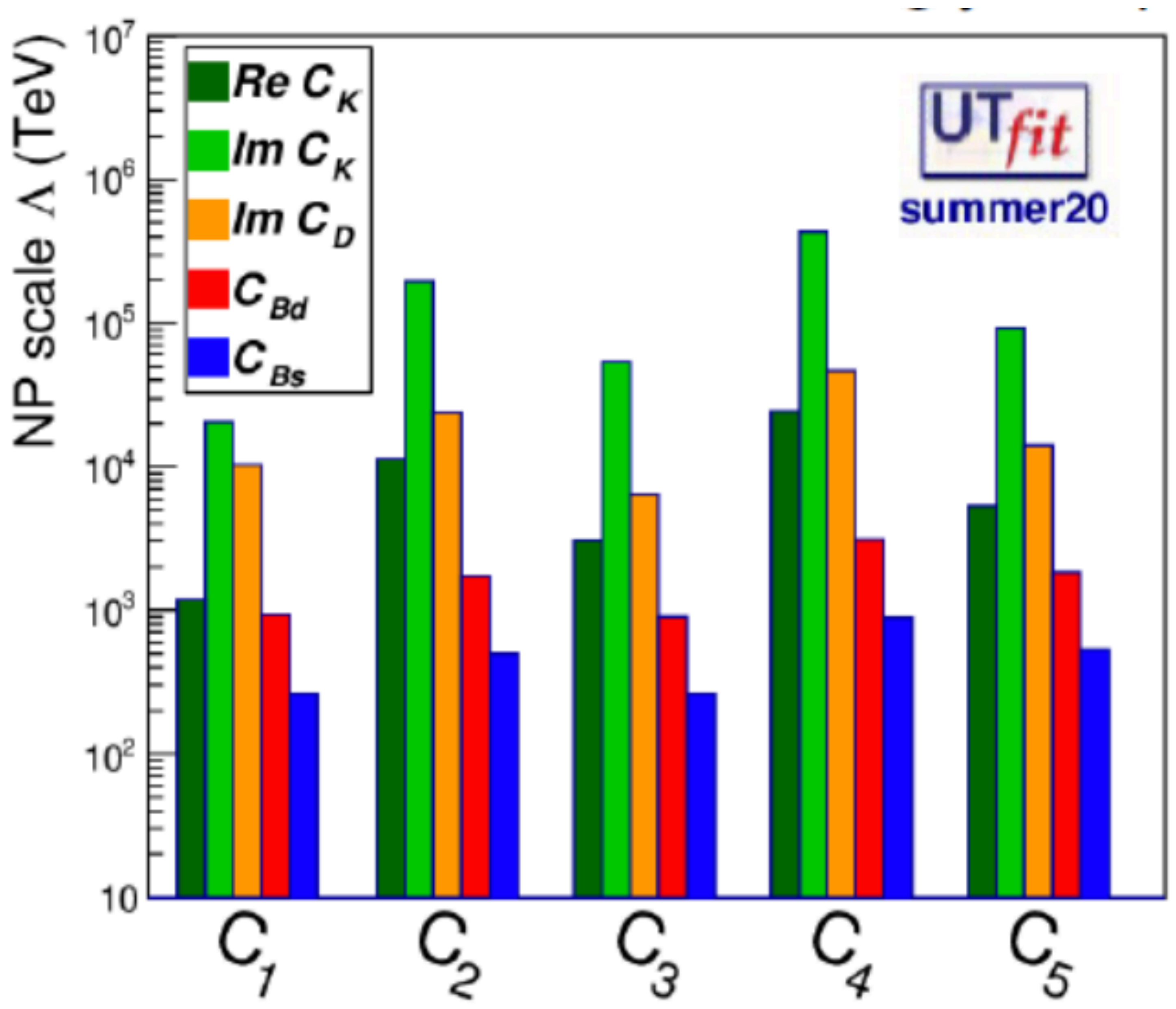
(like SUSY)

Weak MFV

Observable	$\Lambda/TeV\,(pres)$
ϵ_K	7
ΔM_{B_d}	8
ΔM_{B_s}	9
$\Delta M_D, p/q$	3
$b \to s\ \bar{l}l$	4.5
$s \to d\ \bar{l}l(\bar{q}q)$	1.7
$neutron EDM\ (*)$	≈ 5.5
$electron EDM\ (*)$	≈ 50

$\Leftarrow$ If rescaled by a loop factor, flavour hardly competitive with direct searches (LHC)

However $\Rightarrow$



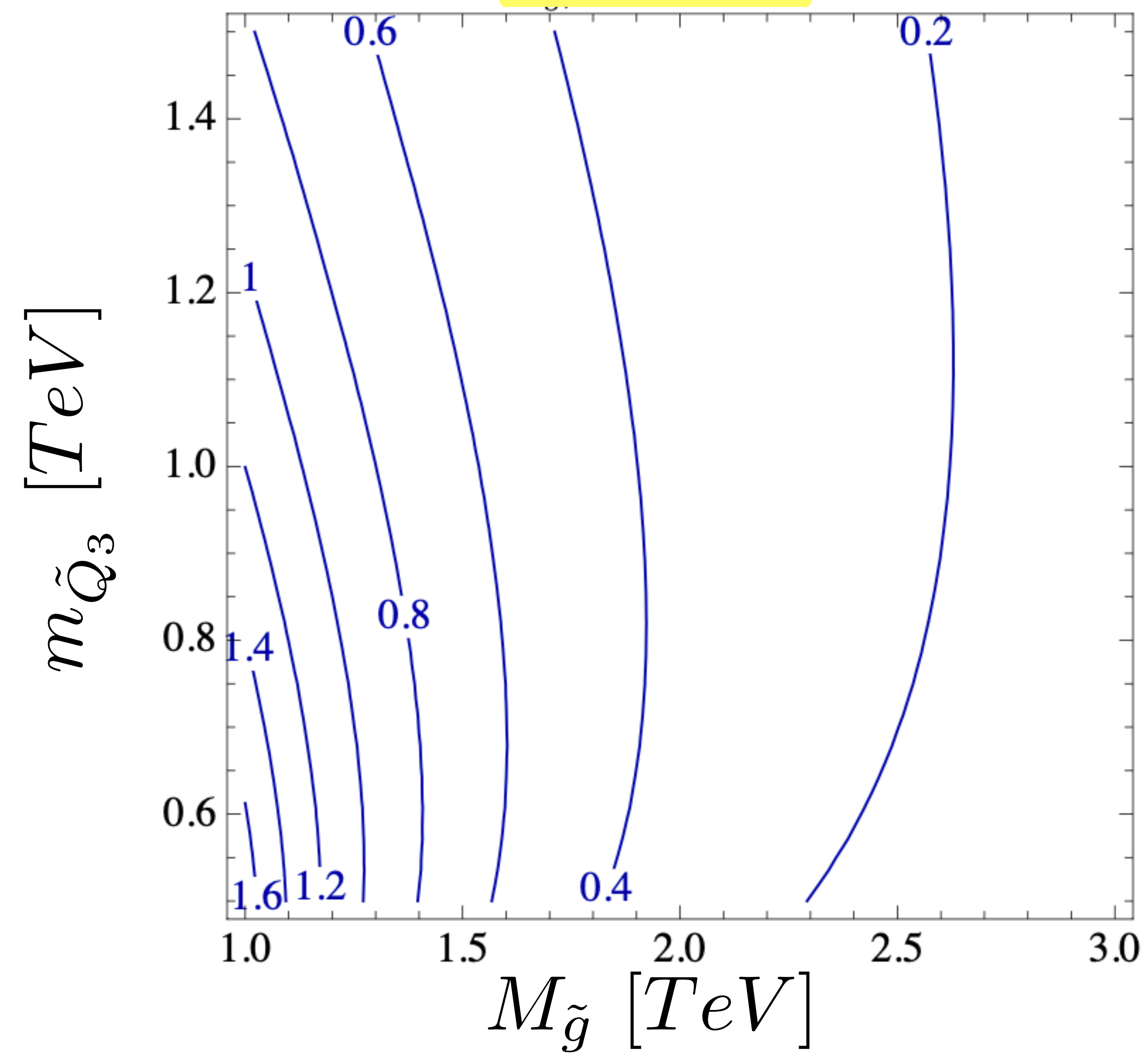
LL LR

SUSY with lighter $\tilde{Q}_3, \tilde{t}, \tilde{b}$ than all other $\tilde{f}$ and $U(2)^{diag}$

$$R \approx \frac{\Delta\epsilon_K^{susy}}{\epsilon_K^{SM}}$$ Now $R \lesssim 0.2$

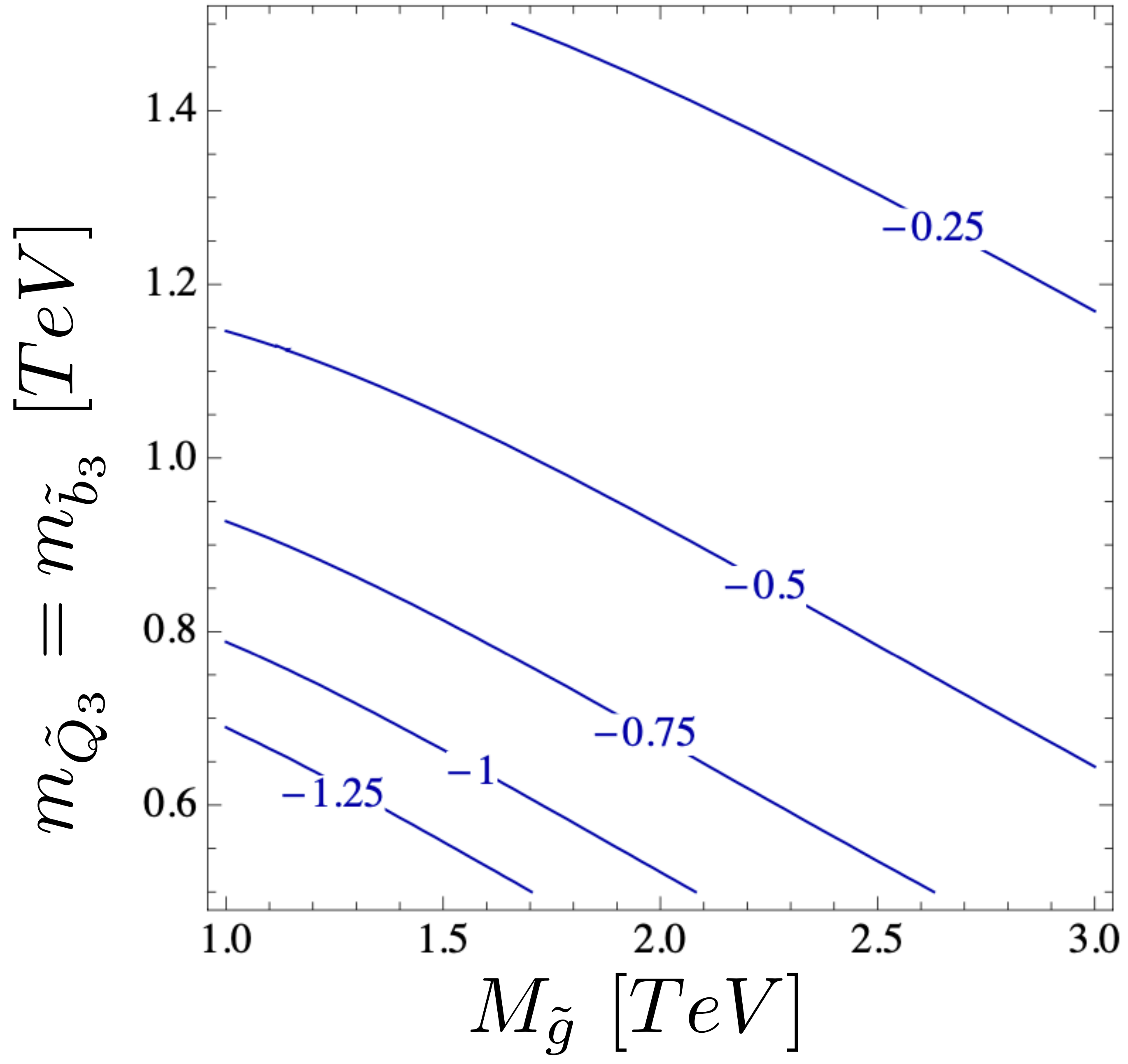
B, Buttazzo et al 2014

$100R$



LL gluino-sbottom box diagram

R with $s_d = V_{cb}$



$$R \approx \left(\frac{s_d/V_{cb}}{M}\right)^2$$

LR gluino-sbottom box diagram

and maximal phase

R dominates over other flavour observables due to LR enhancement
(except for the electron EDM with maximal phases)

Summary

- Where is the scale of flavour? 1 or 2 ?

It's up to experiments to decide

Solomonic but important, in my view

- If $m_*(H) \approx$ MultiTeV and/or LFV confirmed in B-decays 2 + weak MFV ($U(2)^n$) "unavoidable" in some form, offering an "indirect" discovery potential of NP before the next HE collider

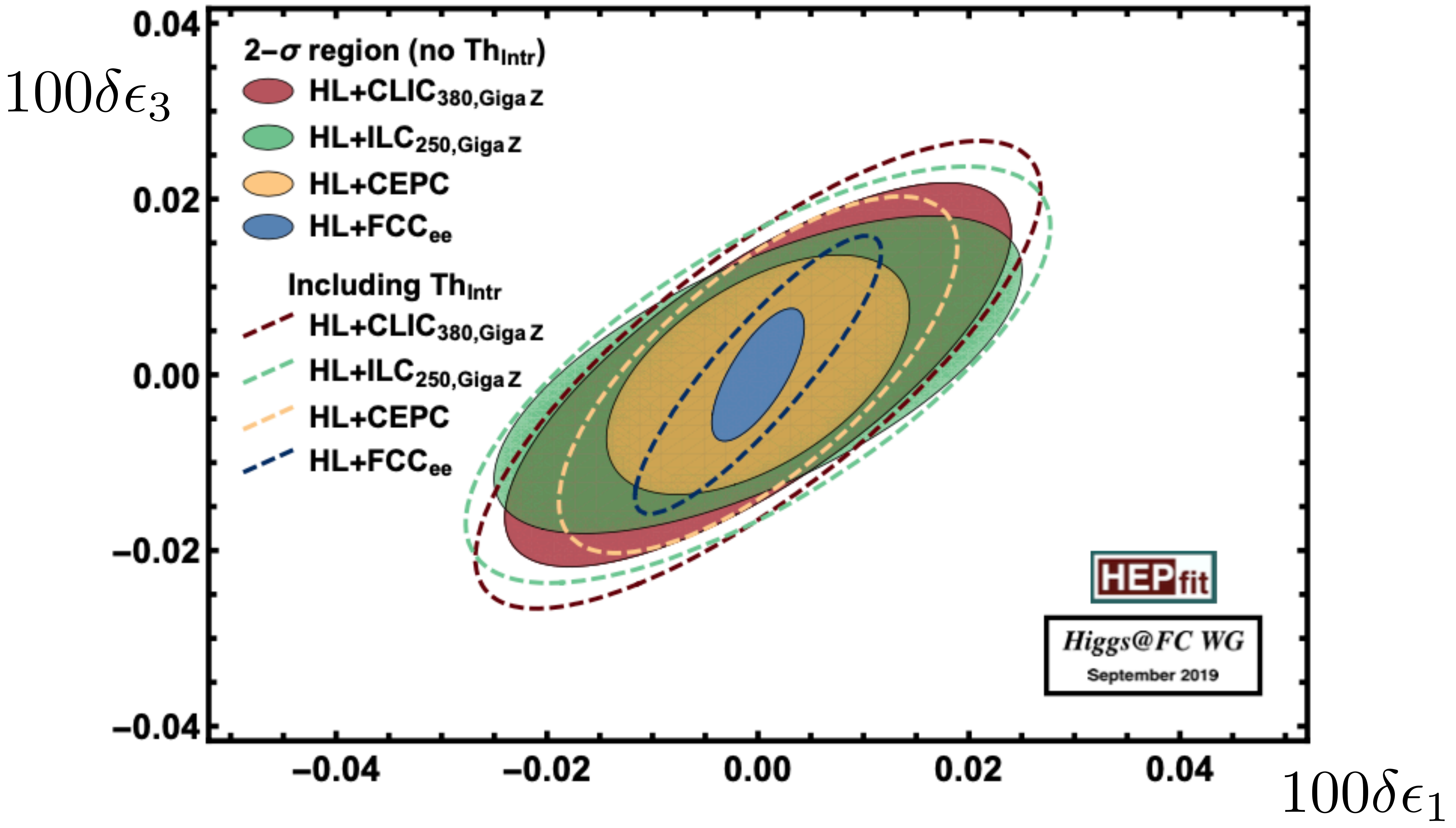
- Mass/angle relations suggestive, but not compelling enough

If relevant ($U(2)^{diag}$), ϵ_K from $(\bar{q}_L q_R)(\bar{q}_L q_R)$ dominant constraint for weakly coupled theories as well, like SUSY

Back up

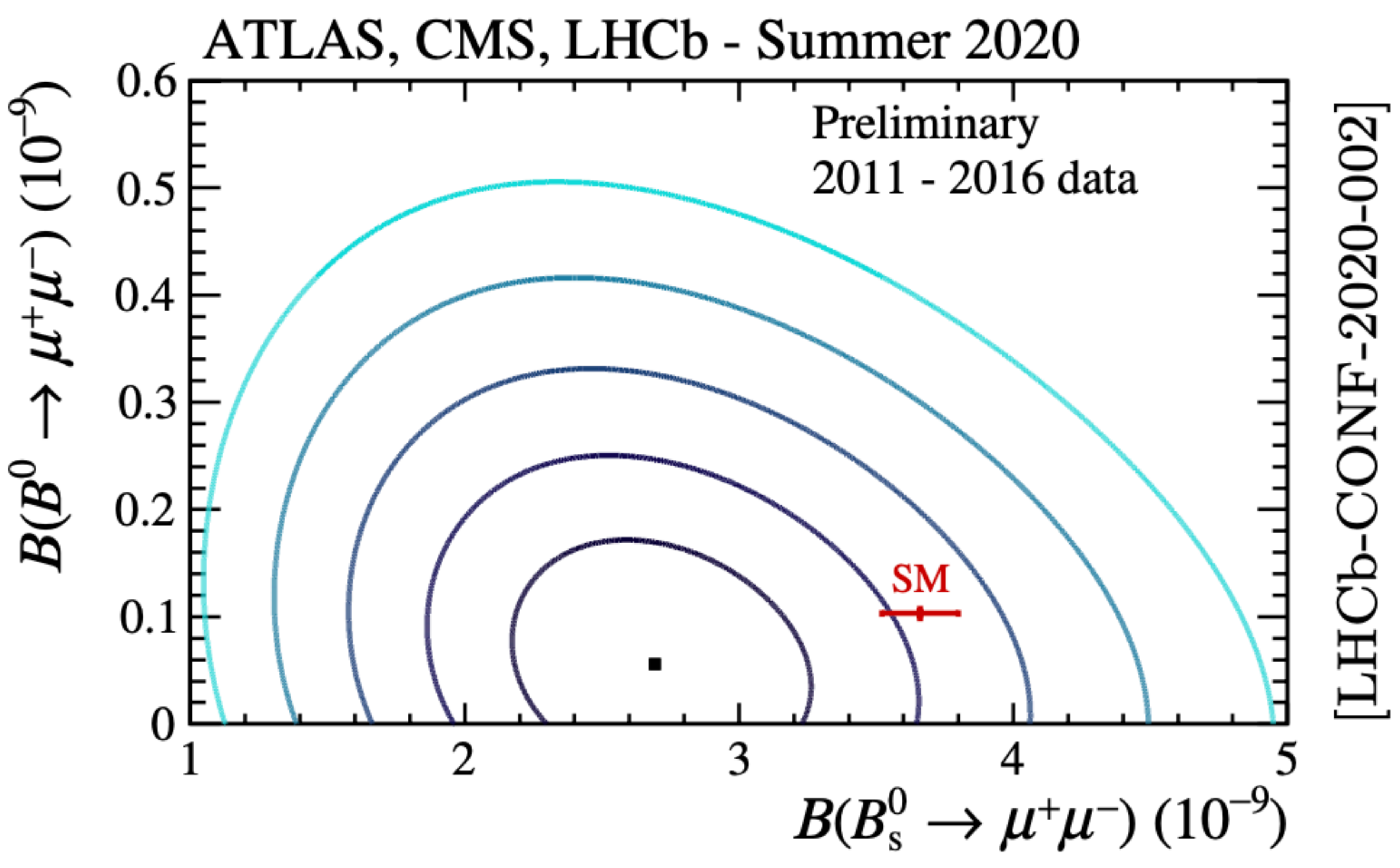
Foreseen precision on $\epsilon_{1,3}$

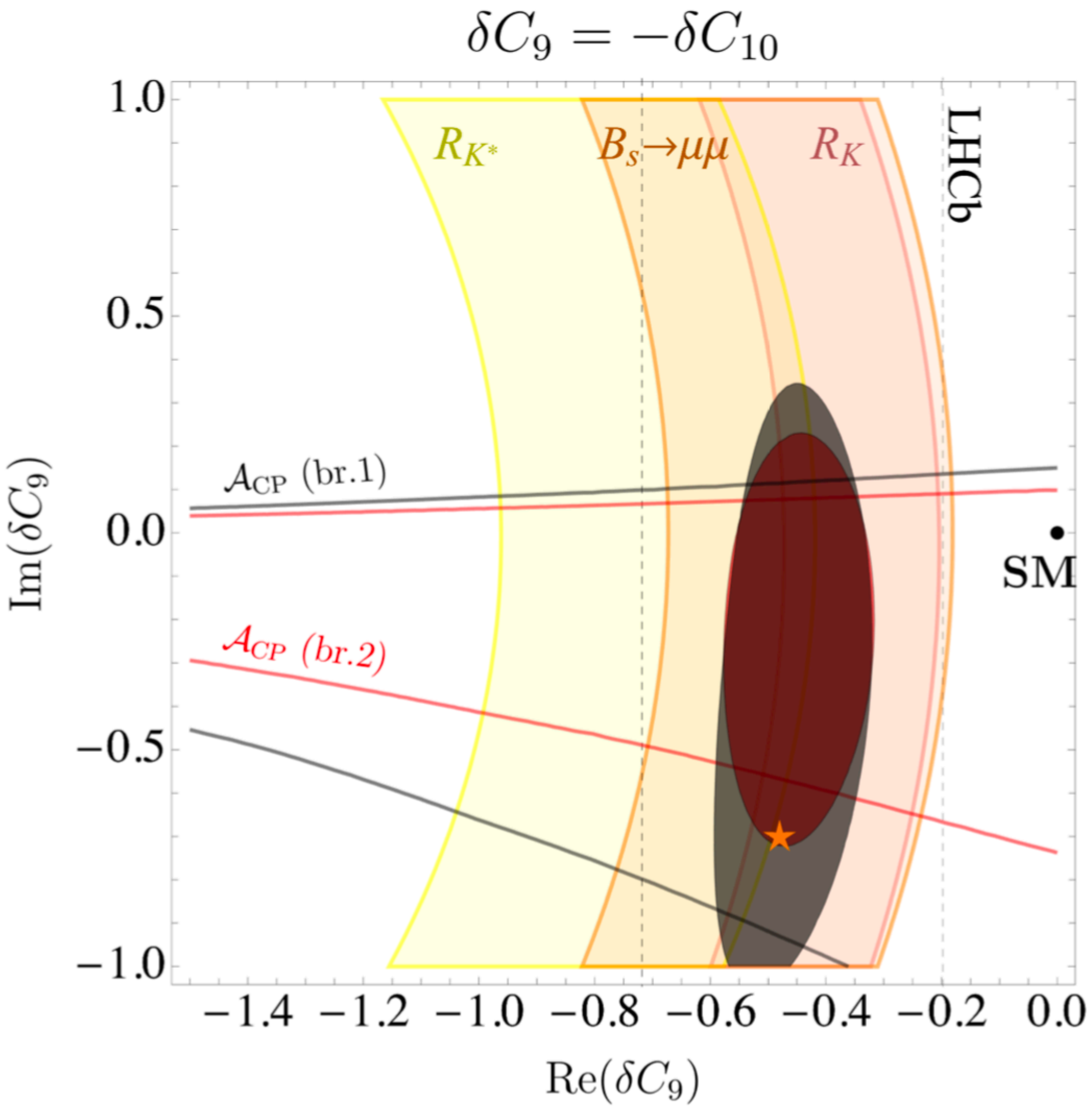
$$\epsilon_1^{SM} \approx \epsilon_3^{SM} \approx 5 \cdot 10^{-3}$$



De Blas et al, 2019

News on B-decay anomalies



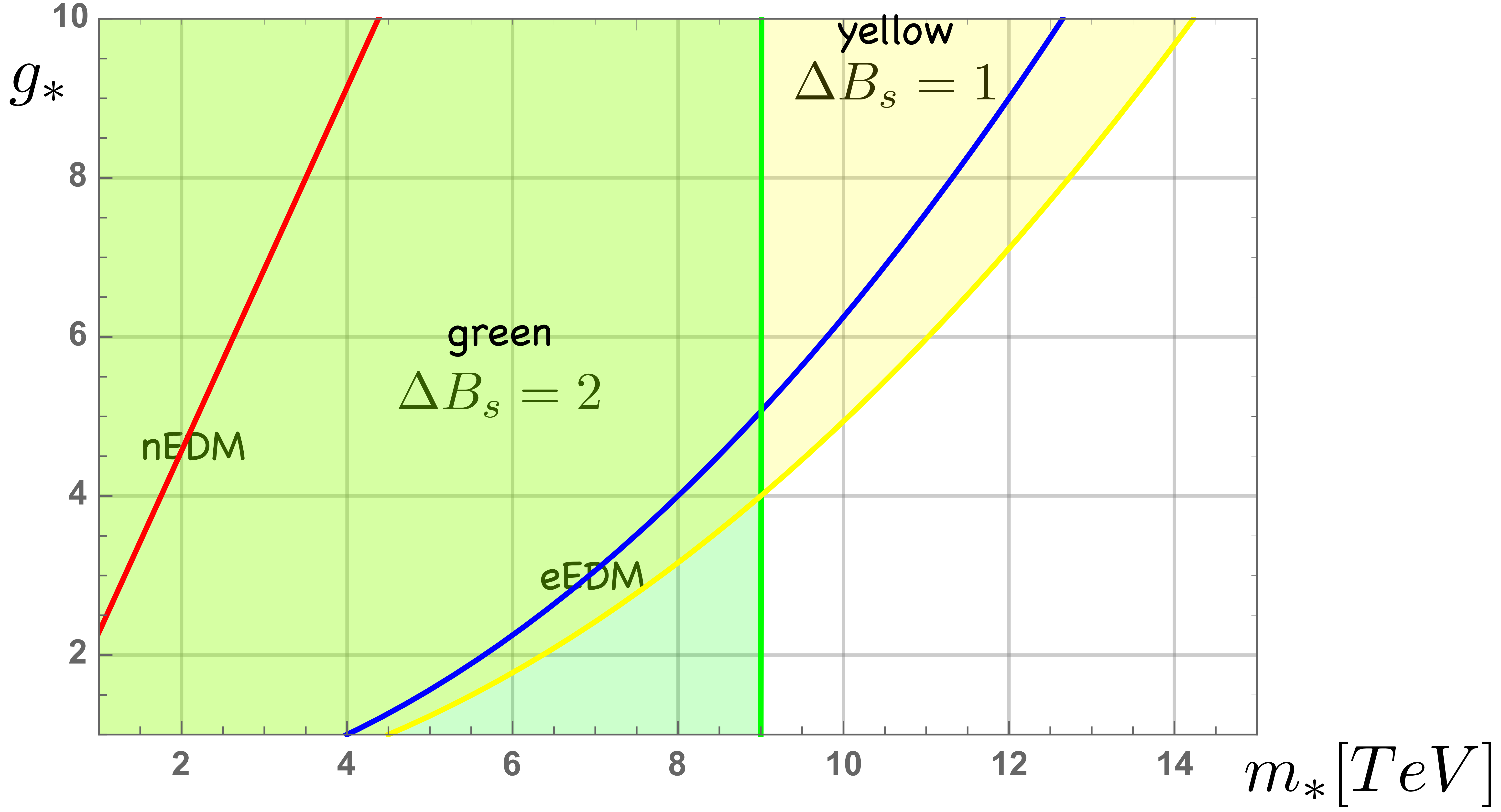


$$\mathcal{A}_{CP}^{K^{(*)}} = \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\mu\mu) - \mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\mu\mu) + \mathcal{B}(B \to K^{(*)}\mu\mu)}$$

Becirevic et al, 2020

Current (main) flavour bounds with weak MFV

Exclusion plot $x_t = 1$



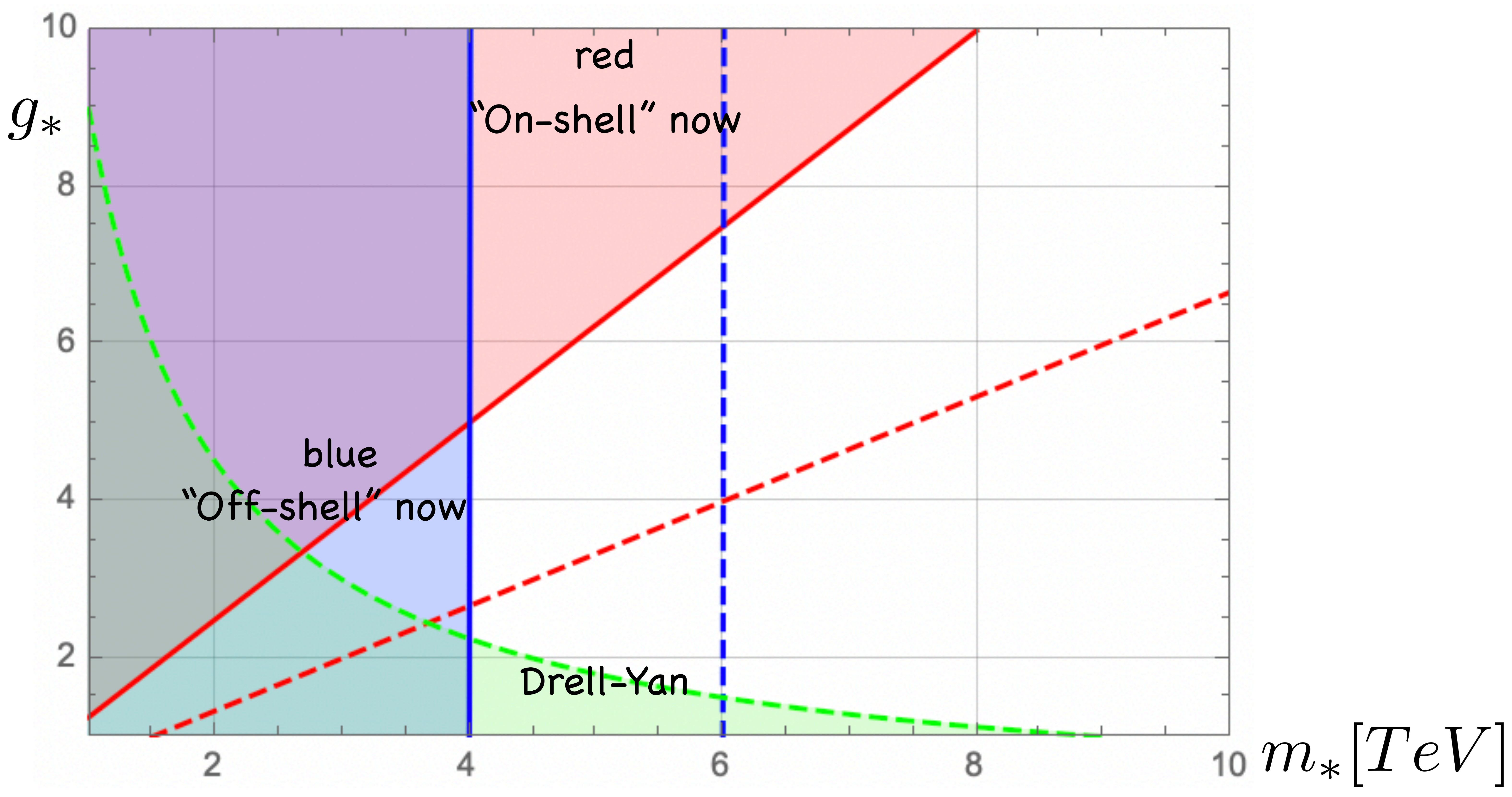
$\sqrt{\mathcal{O}(1)}$ -factors possible in either direction

- maximal phases for the EDMs and no cancellation among diff. op.s in $\Delta B = 1, 2$

- sensitivity on $\Delta B_s = 1, 2$ improvable by a factor of 2

Higgs couplings, EWPT summary

Exclusion plot



$\sqrt{\mathcal{O}(1)}$ -factors possible in either direction

- dotted lines = foreseen sensitivity at HL-LHC