Precision in the "near" future of BSM

Paolo Nason's Fest, Milano, September 15/16 2022

R. Barbieri (SNS, Pisa)

1. Introduction

My own "prejudices"

2. SM Effective Field Theory

Useful? How to use it?

3. How do precision measurements relate to BSM searches?

Current anomalies as examples

In inverse order of arrival:

$M_W \qquad (g-2)_\mu \qquad B - anomalies$

4. Any "definite goal"?

Observational

Problems of (questions for) the SM

Structural

0. Which rationale for matter quantum numbers?

$$|Q_p + Q_e - Q_n| < 10^{-21} e$$

1. Phenomena unaccounted for

neutrino masses

matter-antimatter asymmetry

Dark matter

inflation?

2. Why $\theta \lesssim 10^{-10}$?

$$\theta G_{\mu\nu} \tilde{G}^{\mu\nu}$$

Axions?

3. $\mathcal{O}_i : d(\mathcal{O}_i) \leq 4$ only?

neutrino masses

gravity?

Are the protons forever?

4. Lack of calculability

the hierarchy problem

the flavour problem

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; 2c Gravity

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,

A difference in the two sectors of the SM?

$$\mathcal{L}_{SM} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + i\bar{\Psi}\not{D}\Psi$$

The "gauge sector"

$$+|D_\mu\phi|^2 + M^2|\phi|^2 - \lambda|\phi|^4 + \Lambda + \lambda_{ij}\phi\bar{\Psi}_i\Psi_j$$

The "Higgs sector"
(where the Fermi scale originates)

the hierarchy problem — the CC problem — the flavour problem

In EFT they look much the same

No particle mass calculable (15=17-2)

To me: the relatively best motivation for BSM in the MultiTeV

Standard Model EFT

3. $\mathcal{O}_i : d(\mathcal{O}_i) \leq 4$ only?

$$\mathcal{L} = \mathcal{L}_{SM} + \Sigma_i \frac{E_i}{v^2} \mathcal{O}_i^{(d>4)}$$

To be used with a grain of salt (about 2500 op.s at d=6 only)

One relevant subset: "Universal theories"

0. NO new light particle (general for SMEFT to be meaningful at all)

1. Quark-lepton and flavour universality as in SM
   (Fermions involved in NP only via the SM currents)

2. NO CPV in new physics

D=6 operators (16)

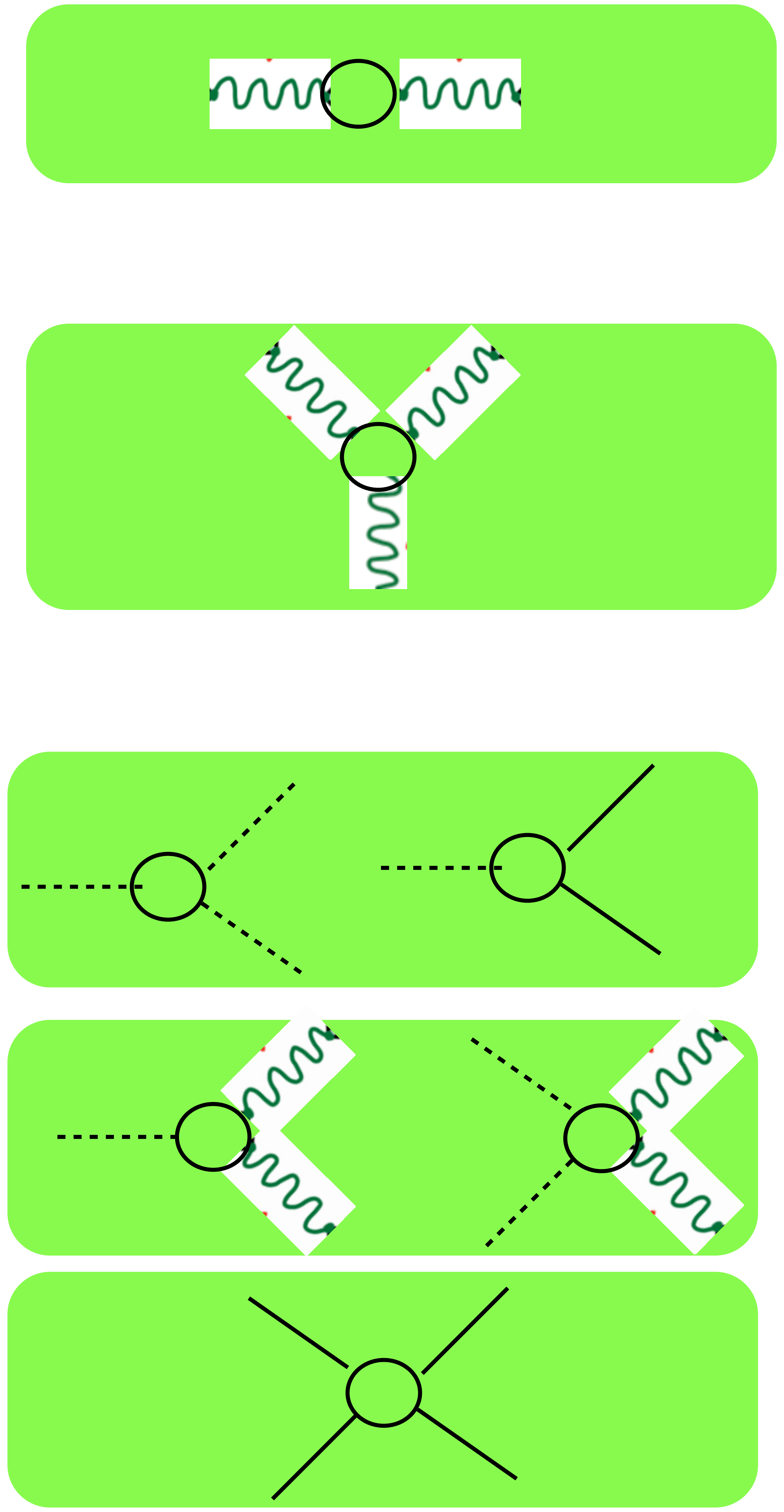
$$\mathcal{O}_W = \frac{ig}{2}(H^\dagger \sigma^a \overleftrightarrow{D}_\mu H) D^\nu W^a_{\mu\nu}$$
$$\mathcal{O}_B = \frac{ig'}{2}(H^\dagger \overleftrightarrow{D}_\mu H)\partial^\nu B_{\mu\nu}$$
$$\mathcal{O}_{WW} = g^2 |H|^2 W^a_{\mu\nu} W^{a\mu\nu}$$
$$\mathcal{O}_{WB} = gg' H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu}$$
$$\mathcal{O}_{BB} = g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu}$$
$$\mathcal{O}_{GG} = g_s^2 |H|^2 G^A_{\mu\nu} G^{A\mu\nu}$$
$$\mathcal{O}_{2W} = -\frac{1}{2}(D^\mu W^a_{\mu\nu})^2$$
$$\mathcal{O}_{2B} = -\frac{1}{2}(\partial^\mu B_{\mu\nu})^2$$
$$\mathcal{O}_{2G} = -\frac{1}{2}(D^\mu G^A_{\mu\nu})^2$$
$$\mathcal{O}_{3W} = \frac{g}{6}\epsilon^{abc} W^{a\nu}_\mu W^{b\rho}_\nu W^{c\mu}_\rho$$
$$\mathcal{O}_{3G} = \frac{g_s}{6} f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$$
$$\mathcal{O}_T = \frac{1}{2}(H^\dagger \overleftrightarrow{D}_\mu H)^2$$
$$\mathcal{O}_H = \frac{1}{2}(\partial_\mu |H|^2)^2$$
$$\mathcal{O}_6 = \lambda |H|^6$$
$$\mathcal{O}_y \approx |H|^2 (H \bar{q}_L Y_u u_R + h.c.)$$
$$\mathcal{O}_{2y} \approx (\bar{q}_L Y_u u_R)(\bar{u}_R Y_u^+ q_L)$$

'Basis dependent"
Only the number fixed

pseudo-observables (16)

Wells, Zhang 2015

	EGGM
$\hat{S}$	$g^2(E_{WB} + \frac{1}{4}E_W + \frac{1}{4}E_B)$
$\hat{T}$	E_T
W	$\frac{g^2}{4}E_{2W}$
Y	$\frac{g^2}{4}E_{2B}$
Z	$\frac{g^2}{4}E_{2G}$
$\Delta\bar{g}_1^Z$	$-\frac{g^2}{4c_\theta^2}E_W$
$\Delta\bar{\kappa}_\gamma$	$g^2 E_{WB}$
$\bar{\lambda}_\gamma$	$-\frac{g^2}{4}E_{3W}$
$\bar{\lambda}_g$	$-\frac{g^2}{4}E_{3G}$
$\Delta\kappa_3$	$-E_6 - \frac{3}{2}E_H$
$\Delta\bar{\kappa}_F$	$-E_y - \frac{1}{2}E_H$
$\Delta\bar{\kappa}_V$	$-\frac{1}{2}E_H$
f_{gg}	$4E_{GG}$
$f_{z\gamma}$	$2[2c_\theta^2 E_{WW} - 2s_\theta^2 E_{BB} - (c_\theta^2 - s_\theta^2)E_{WB}]$
$f_{\gamma\gamma}$	$4(E_{WW} + E_{BB} - E_{WB})$
c_{2y}	E_{2y}



At LHC

M_W

$pp \to ll, qq$

$pp \to dibosons$

Higgs couplings

Different subset of op.s for different subset of pseudo-ob.s and different models!!

D=6 operators (16)

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LEP

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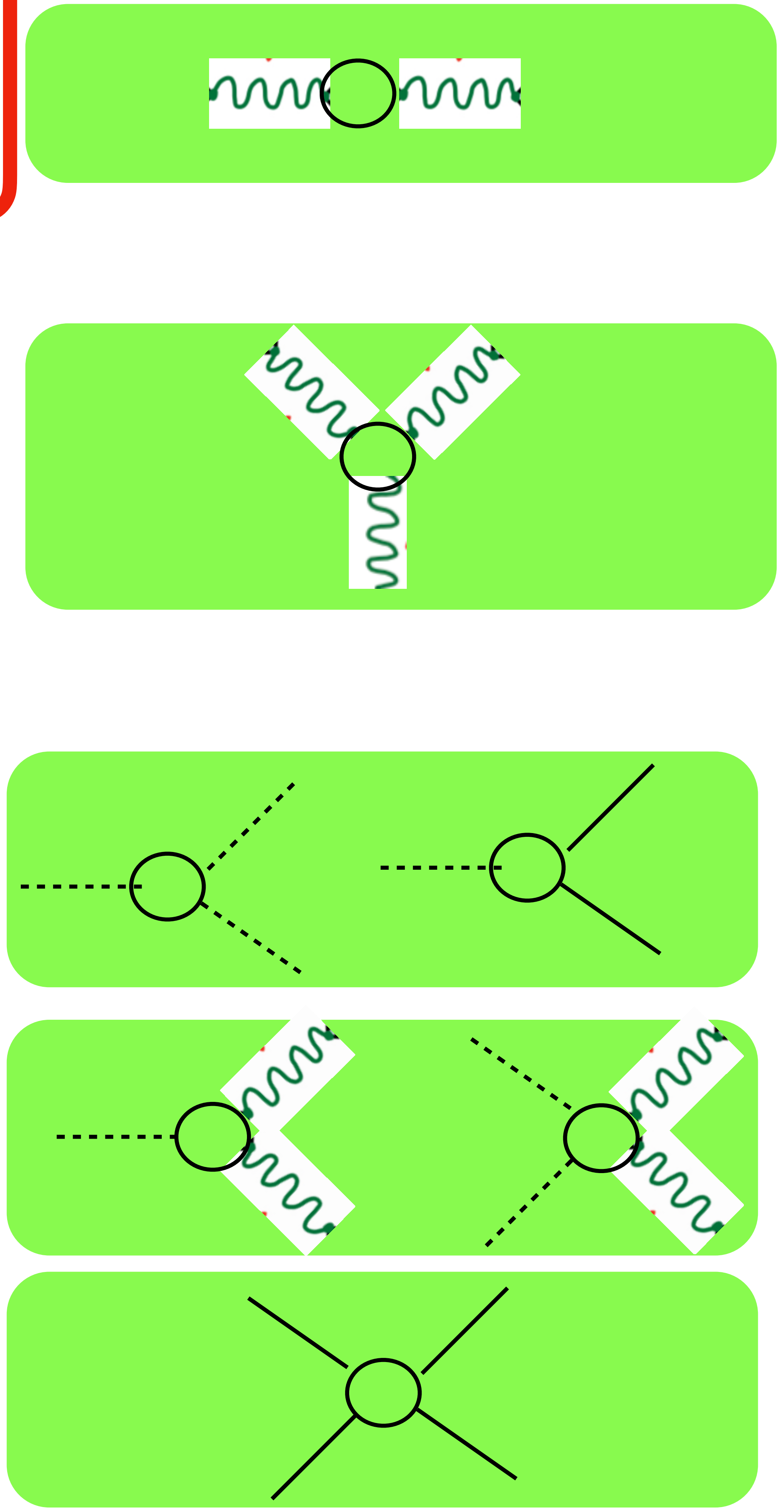
c_{2y}	E_{2y}



At LHC

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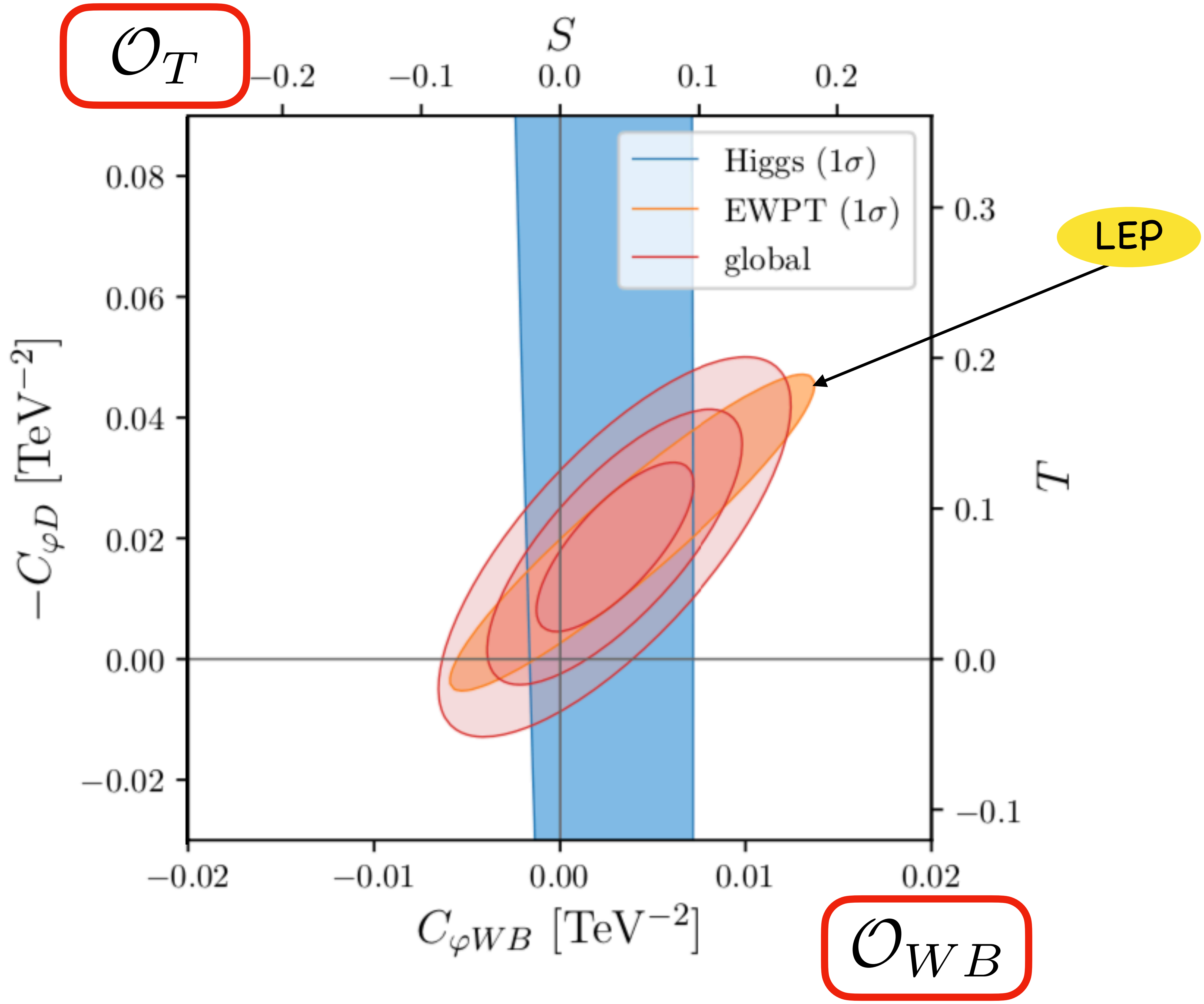
Different subset of op.s for different subset of pseudo-ob.s
and different models!!

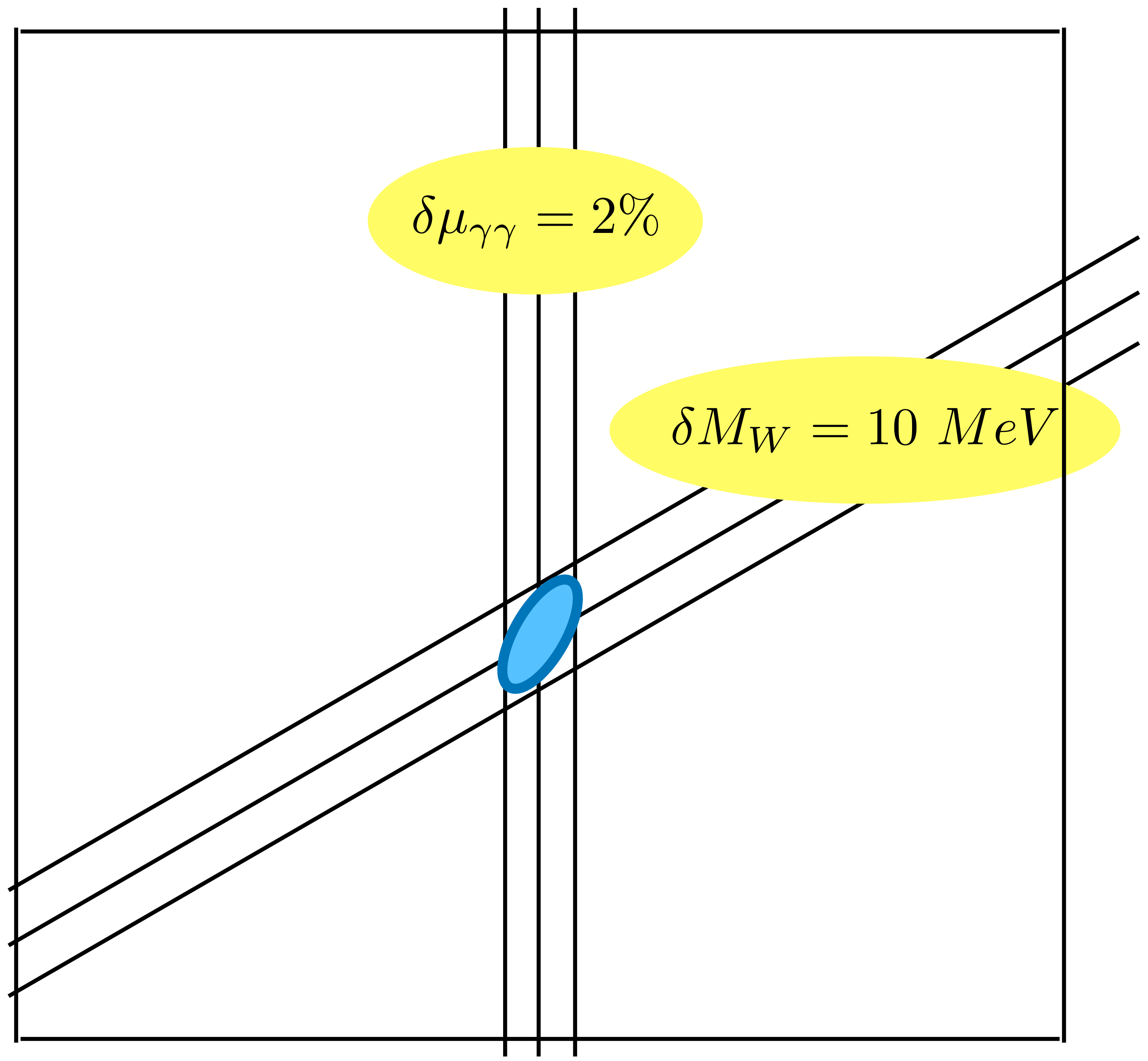
Three examples for the "best LEP" coefficients

1. On shell measurements

$H \to \gamma\gamma$



Projection with 2 observables only



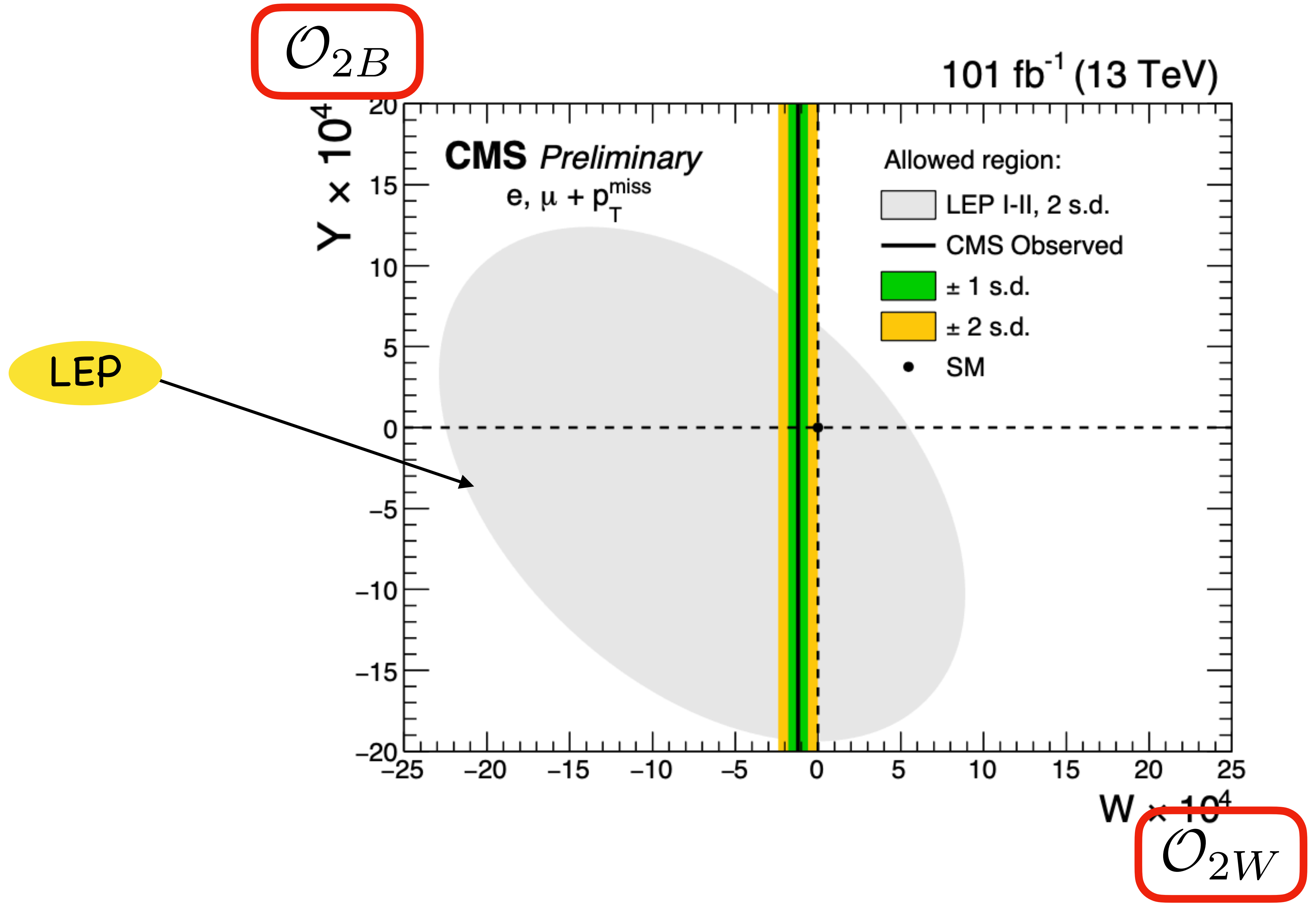
(On the same scale as the plot on the left)

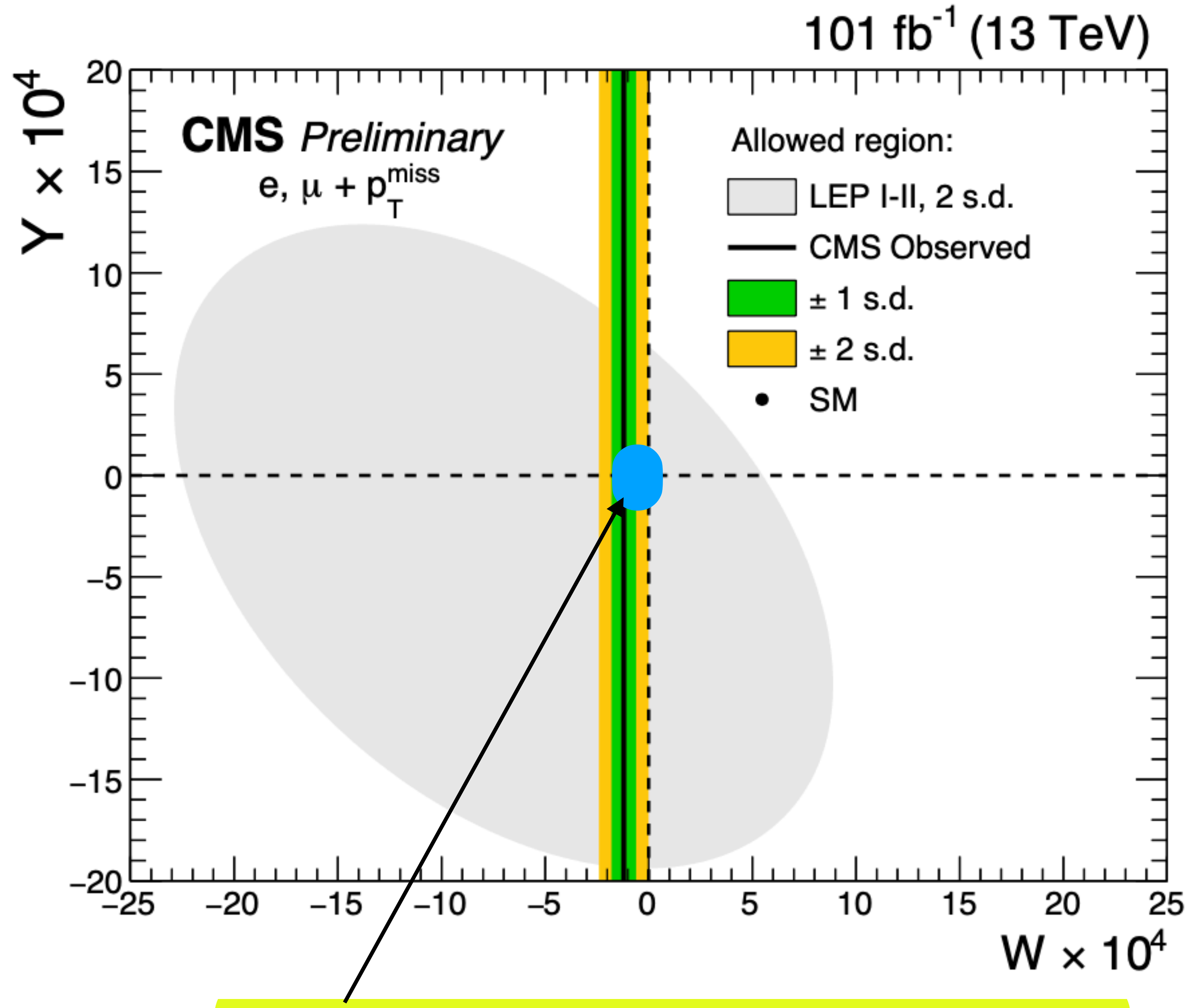
Falkowski, Straub 2019

Three examples for the "best LEP" coefficients

2. Off shell measurements

$$pp \to l\nu, ll$$





HL-LHC

$$W \to 4 \cdot 10^{-5}$$

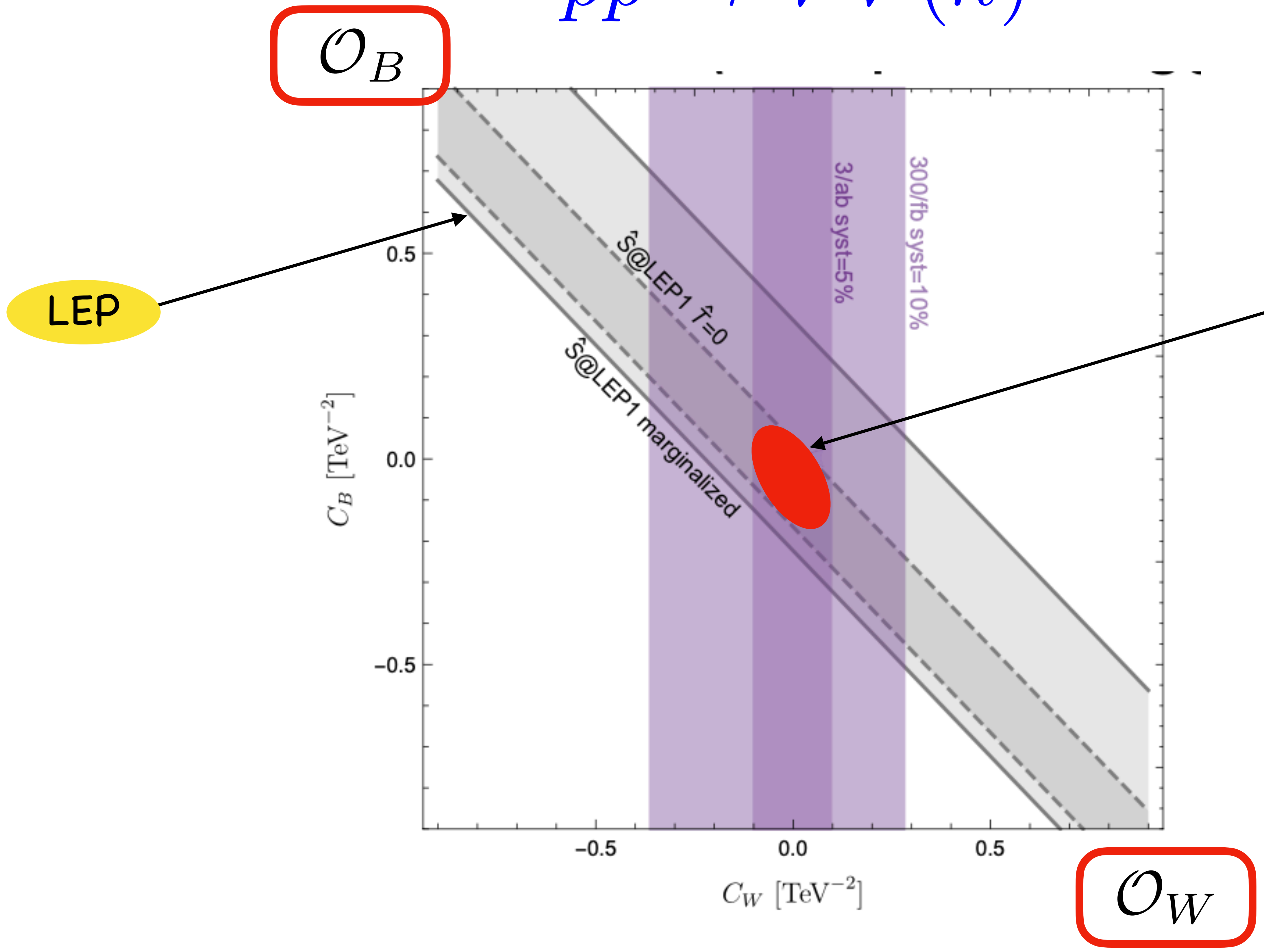
$$Y \to 8 \cdot 10^{-5}$$

Panico et al, 2021

Three examples for the "best LEP" coefficients

2. Off shell measurements

$pp \to VV(h)$



Franceschini et al, 2018

A definite goal: Precision in composite Higgs

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

A two-parameter "theory"

$m_* = g_* f$

f

m_H

H = pNGB

f = scale of symmetry breaking

m_* = scale of Higgs compositeness

- Higgs couplings — $c_H \sim g_*^2/m_*^2$

- flavour-less ElectroWeak observables

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

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

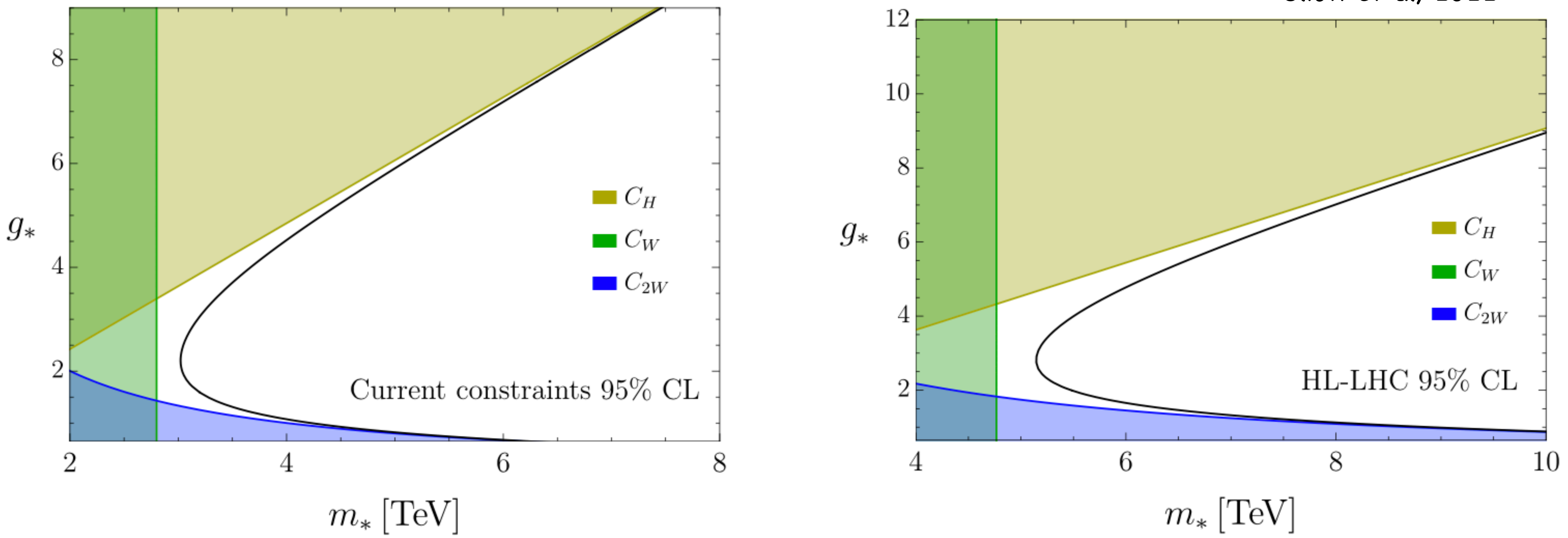
Drell-Yan $l^+l^-, l\nu$ at high m_{ll}, m^T_{ll} — $c_{2W} \sim 1/g_*^2 m_*^2$

- flavour observables — $g_*^2/m_*^2, g_*/m_*^2, 1/m_*^2$

flavour-less observables in composite Higgs

$$\mathcal{L}_{\rm EFT} = \frac{m_*^4}{g_*^2}\hat{\mathcal{L}}\left[\frac{\partial}{m_*}, \frac{g_* H}{m_*}, \frac{g_*\sigma}{m_*}, \frac{g_*\Psi}{m_*^{3/2}}, \frac{gA}{m_*}, \frac{\lambda\psi}{m_*^{3/2}}\right]$$

Glioti et al, 2022



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

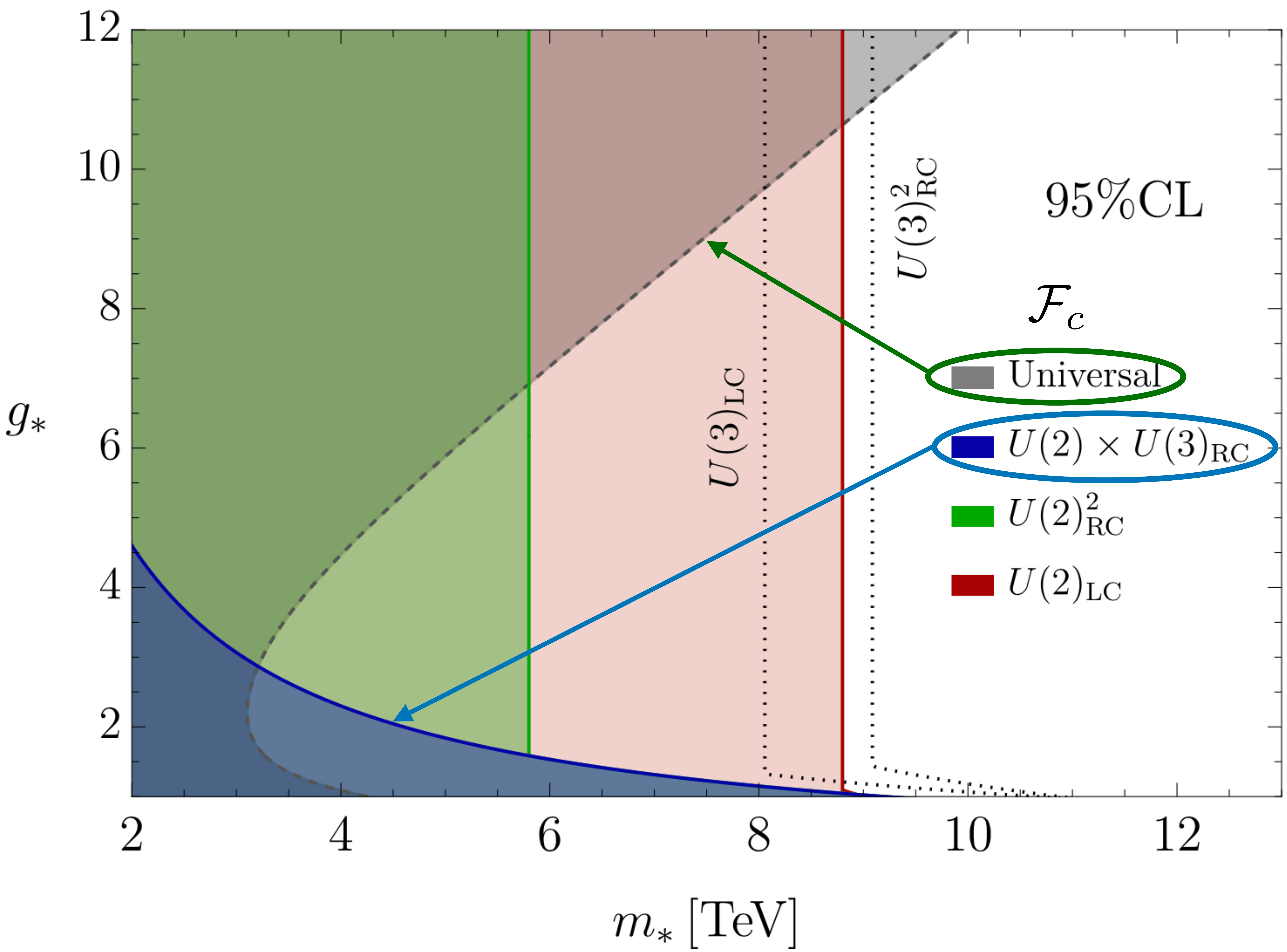
A projected gain of about 2 TeV in m_* for any value of g_*

Flavour in composite Higgs

Different flavour symmetries $\mathcal{F}_c$ of the strong sector

$$U(3)_q \times U(3)_u \times U(3)_d \times \mathcal{F}_c$$

(but no LFV)



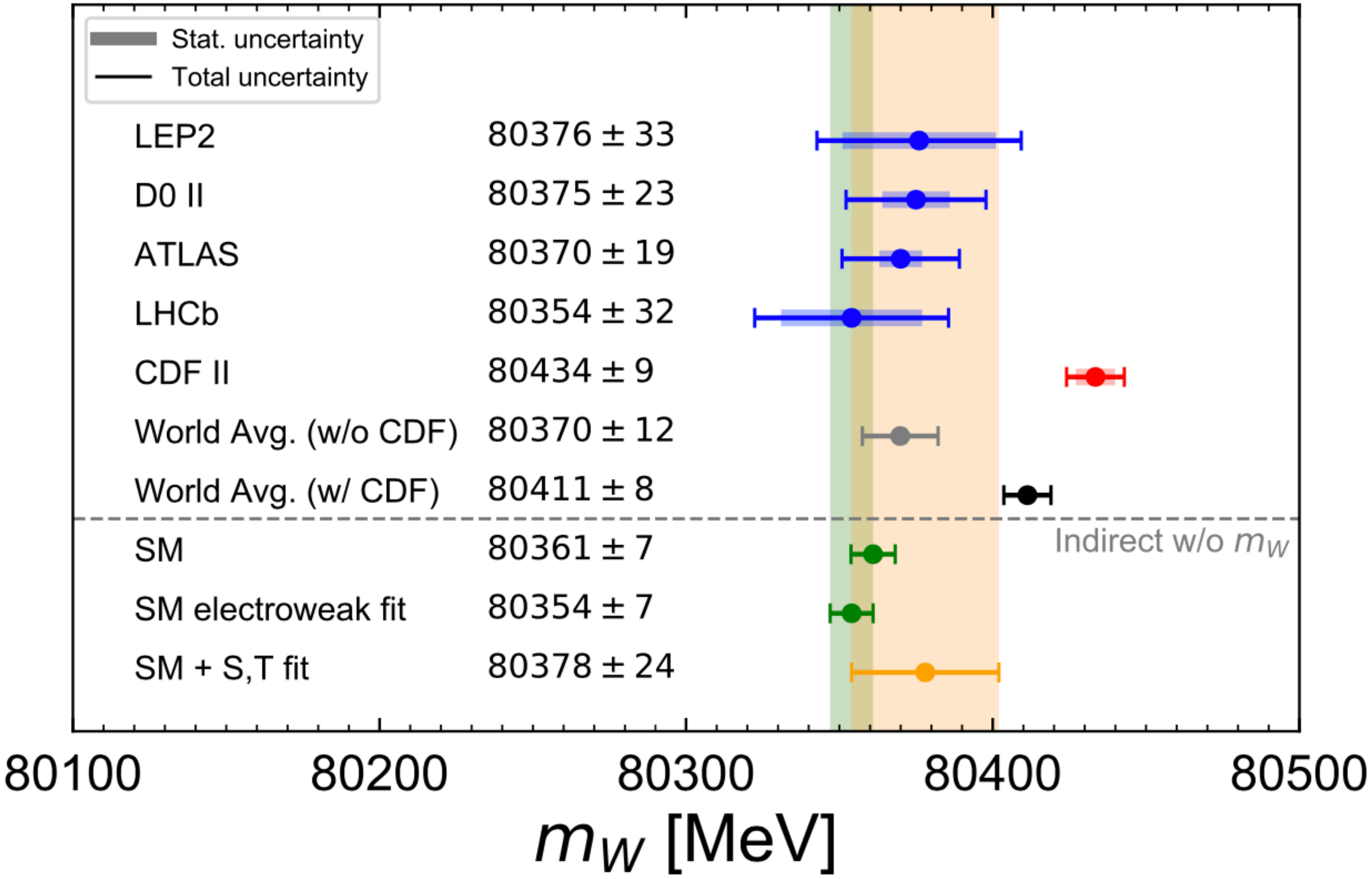
Current constraints

(more later)

Glioti et al, 2022

Example 1

M_W



Bagnaschi et al, 2022

$$\frac{\delta M_W}{M_W} = 0.7\hat{T} - 0.4\hat{S}$$

(2 more op.s in universal theories)

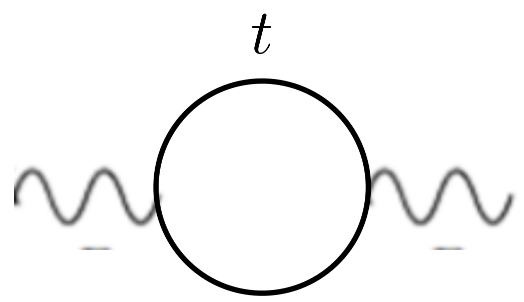
$$\left(\frac{\delta \sin^2_{eff}\theta}{\sin^2_{eff}\theta} = -1.4\hat{T}\right)$$

$$\frac{\delta \sin^2_{eff}\theta}{\sin^2_{eff}\theta}\Big|_{exp} = 10^{-3}$$

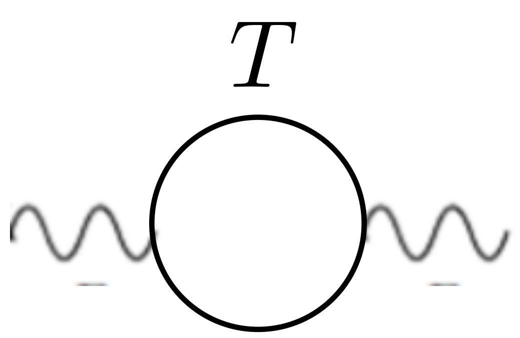
$$\frac{\delta M_W}{M_W}\Big|_{exp} = \frac{20\ MeV}{80\ GeV} = 2.5\cdot 10^{-4}$$

VectorLike Heavy top partners T

Ubiquitous in Composite Higgs



$y_t H \bar{q}_L t_R \qquad \hat{T}(top) = \frac{3m_t^2}{32\pi^2 v^2} = 9.5 \cdot 10^{-3}$

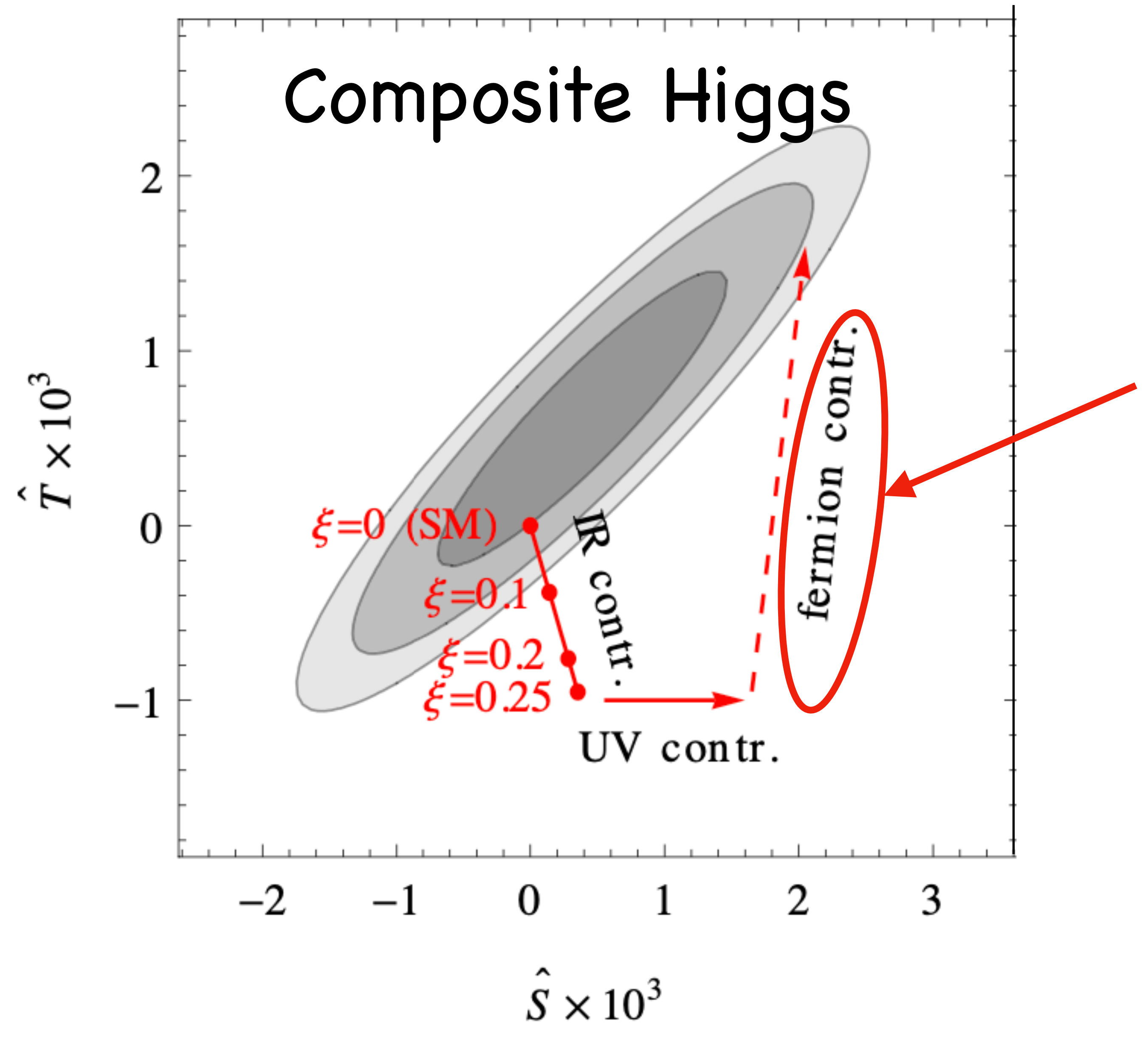


$Y_T H \bar{q}_L T_R \longrightarrow \hat{T}(T) \approx \frac{3Y_T^2}{16\pi^2} \frac{m_t^2}{M_T^2} \lg \frac{M_T^2}{m_t^2}$

$Y_t H \bar{Q}_L t_R, \quad Q = \begin{pmatrix} T \\ B \end{pmatrix} \longrightarrow \hat{T}(T) \approx \frac{3Y_t^2}{8\pi^2} \frac{m_t^2}{M_T^2} \lg \frac{M_T^2}{m_t^2}$

($\hat{S}, \delta g_b$ smaller)

	If CDF II	If $\delta M_W \lesssim 10\ MeV$
Singlet	$\frac{M_T}{Y_T} \approx (1.8 \div 2.2)\ TeV$	$\frac{M_T}{Y_T} \gtrsim (2.8 \div 3.5)\ TeV$
Doublet	$\frac{M_T}{Y_t} \approx (2.5 \div 3)\ TeV$	$\frac{M_T}{Y_t} \gtrsim (4 \div 5)\ TeV$

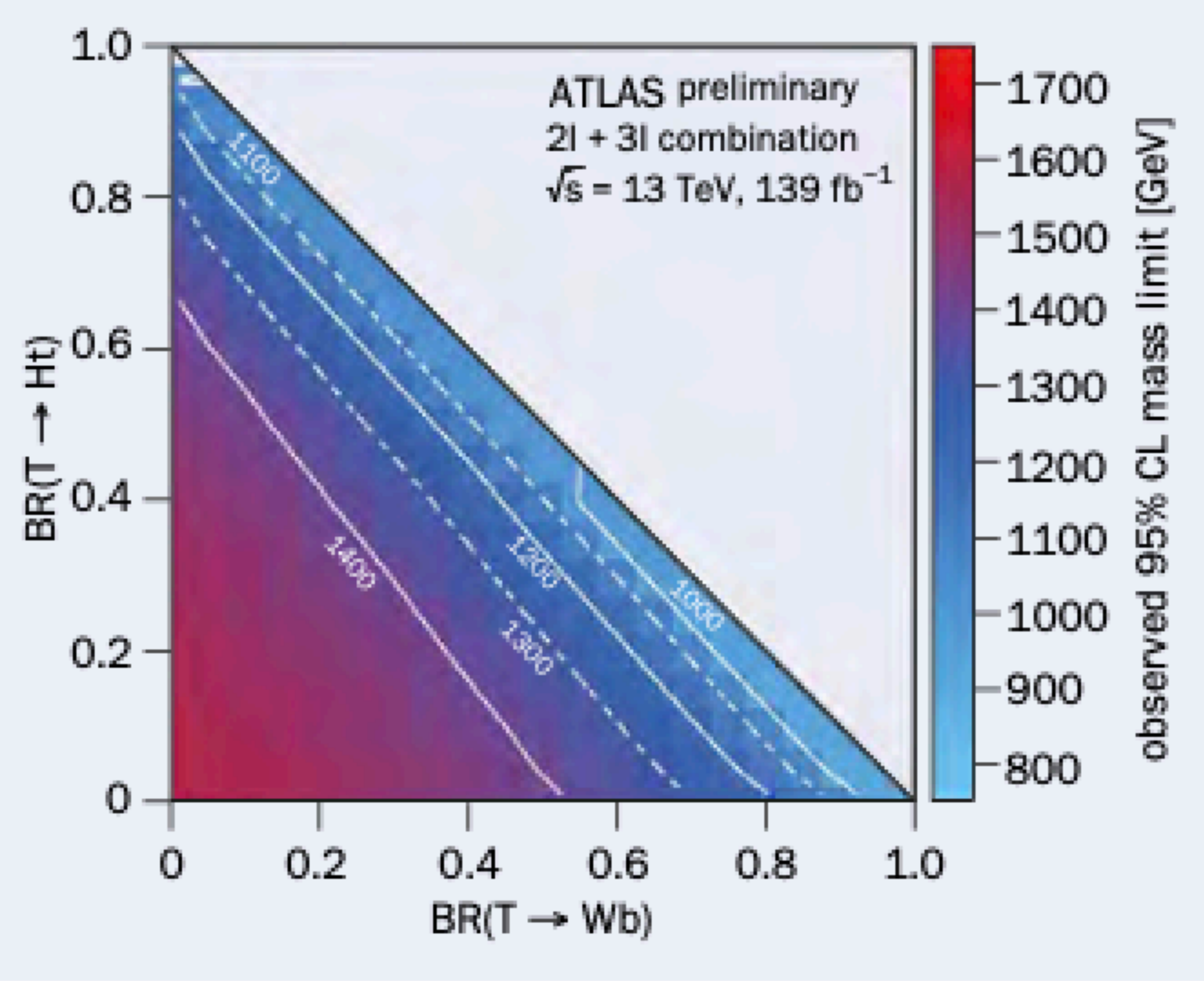


B,Bellazzini et al, 2007

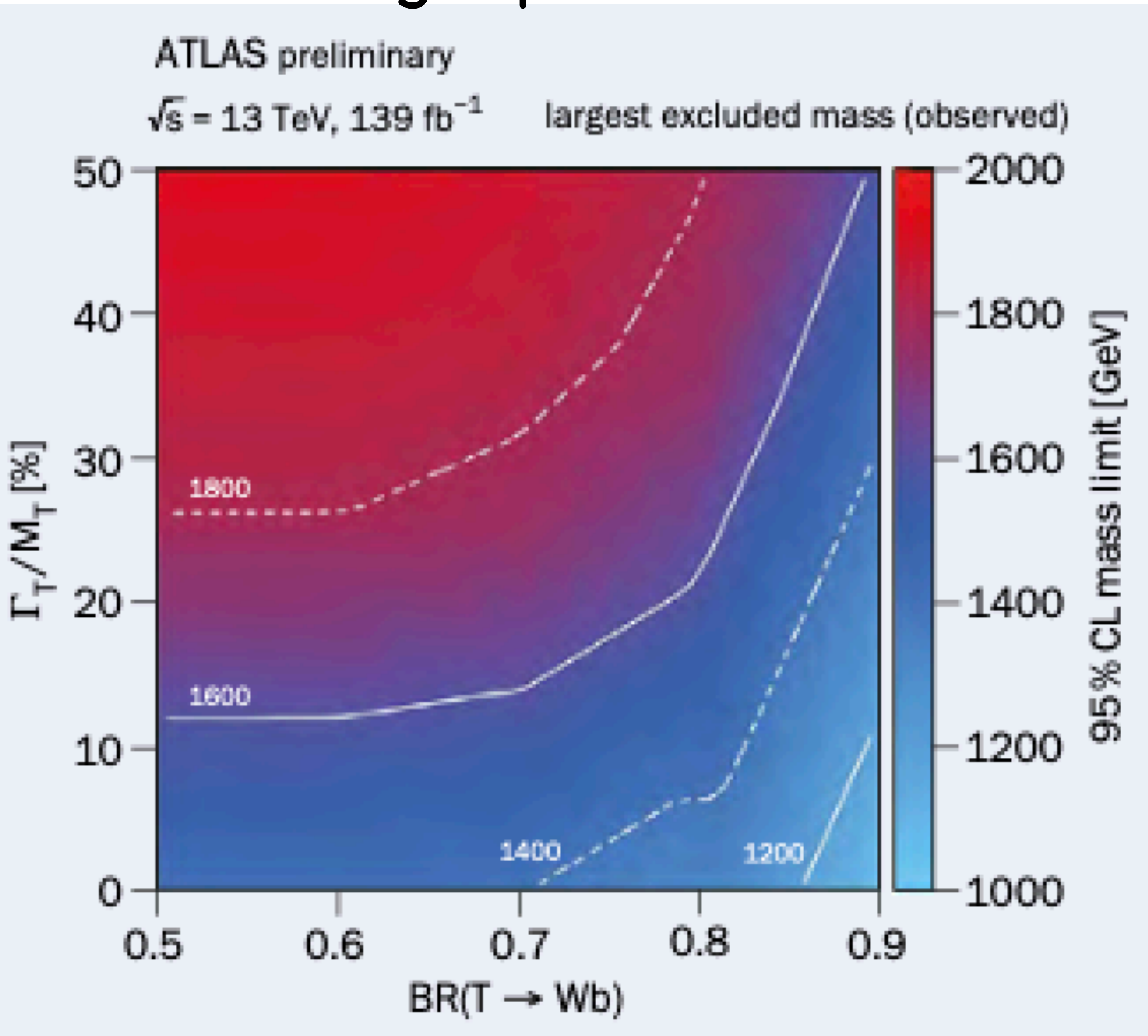
LHC searches of heavy T

$$T \to Ht, Wb$$

Pair production



Single production



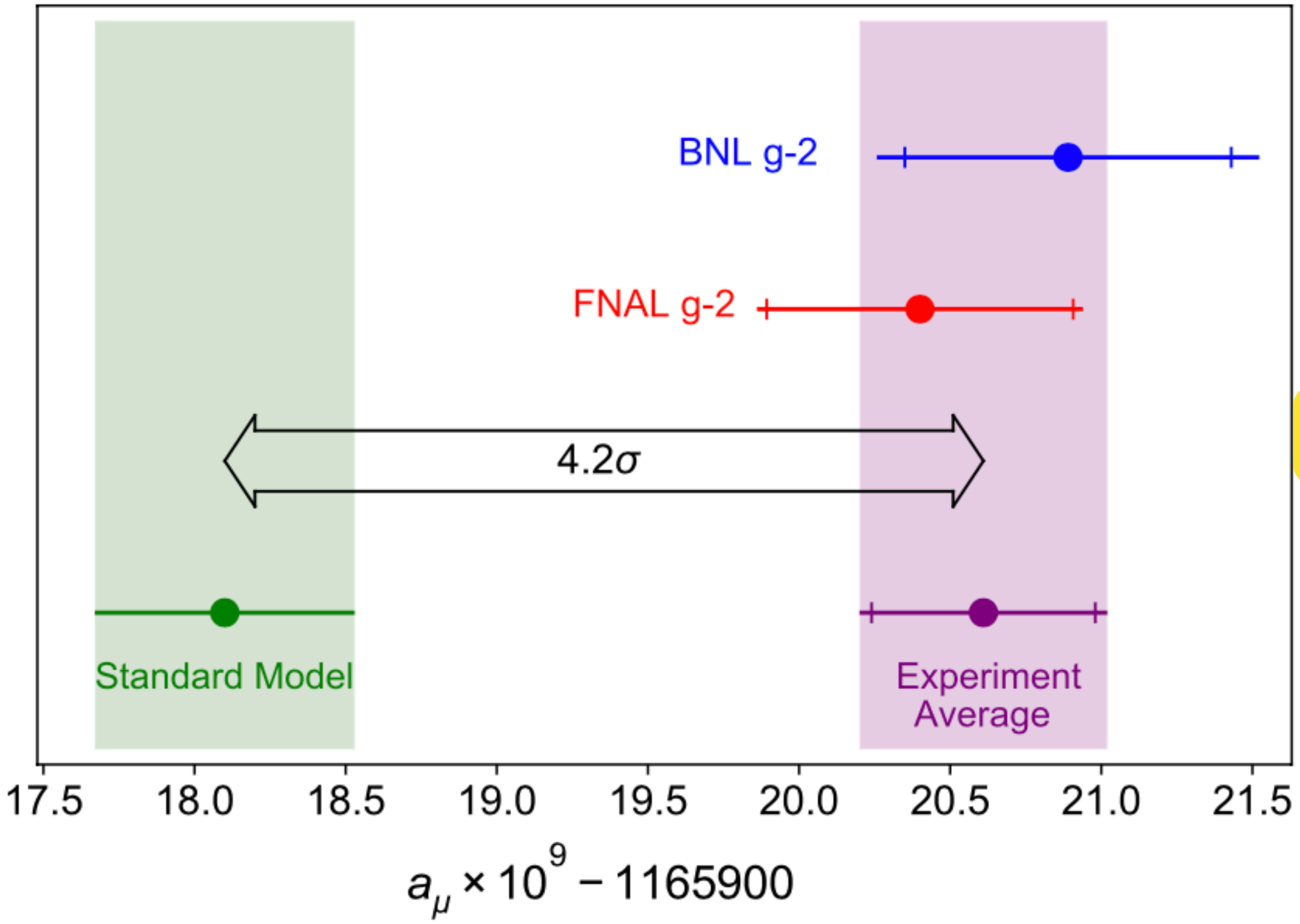
Example 2

$(g-2)_\mu$

$\Delta a_\mu|_{HVP} = 6845(40) \cdot 10^{-11}$

$\Delta a_\mu|_{Weak} = 153(1) \cdot 10^{-11}$

$\Delta a_\mu|_{HLbL} = 92(18) \cdot 10^{-11}$



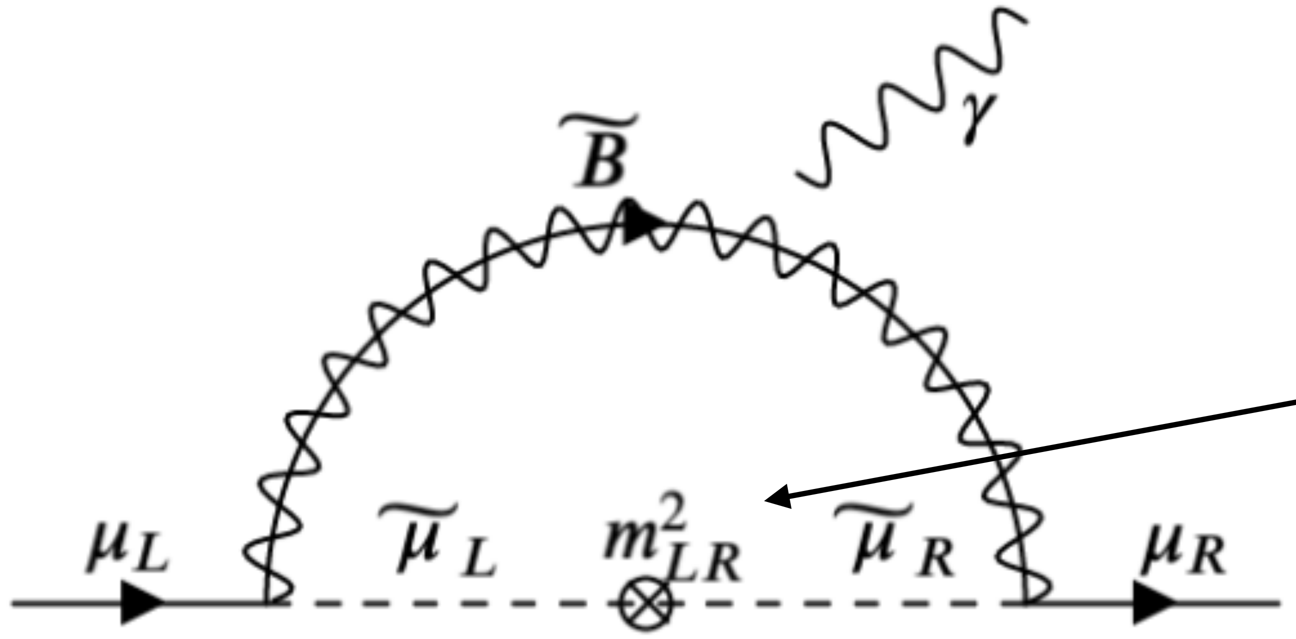
$a_\mu|_{exp} - a_\mu|_{th} = 250(60) \cdot 10^{-11}$

SUSY as an "EASY" and MOTIVATED interpretation

1. Relevant (low energy) parameters:

$$M_1 \tilde{b}\tilde{b}, \quad m_{\tilde{\mu}_L} \tilde{\mu}_L^+ \tilde{\mu}_L, \quad m_{\tilde{\mu}_R} \tilde{\mu}_R^+ \tilde{\mu}_R, \quad \mu H_1 H_2, \quad \tan\beta = \frac{< H_2 >}{< H_1 >}$$

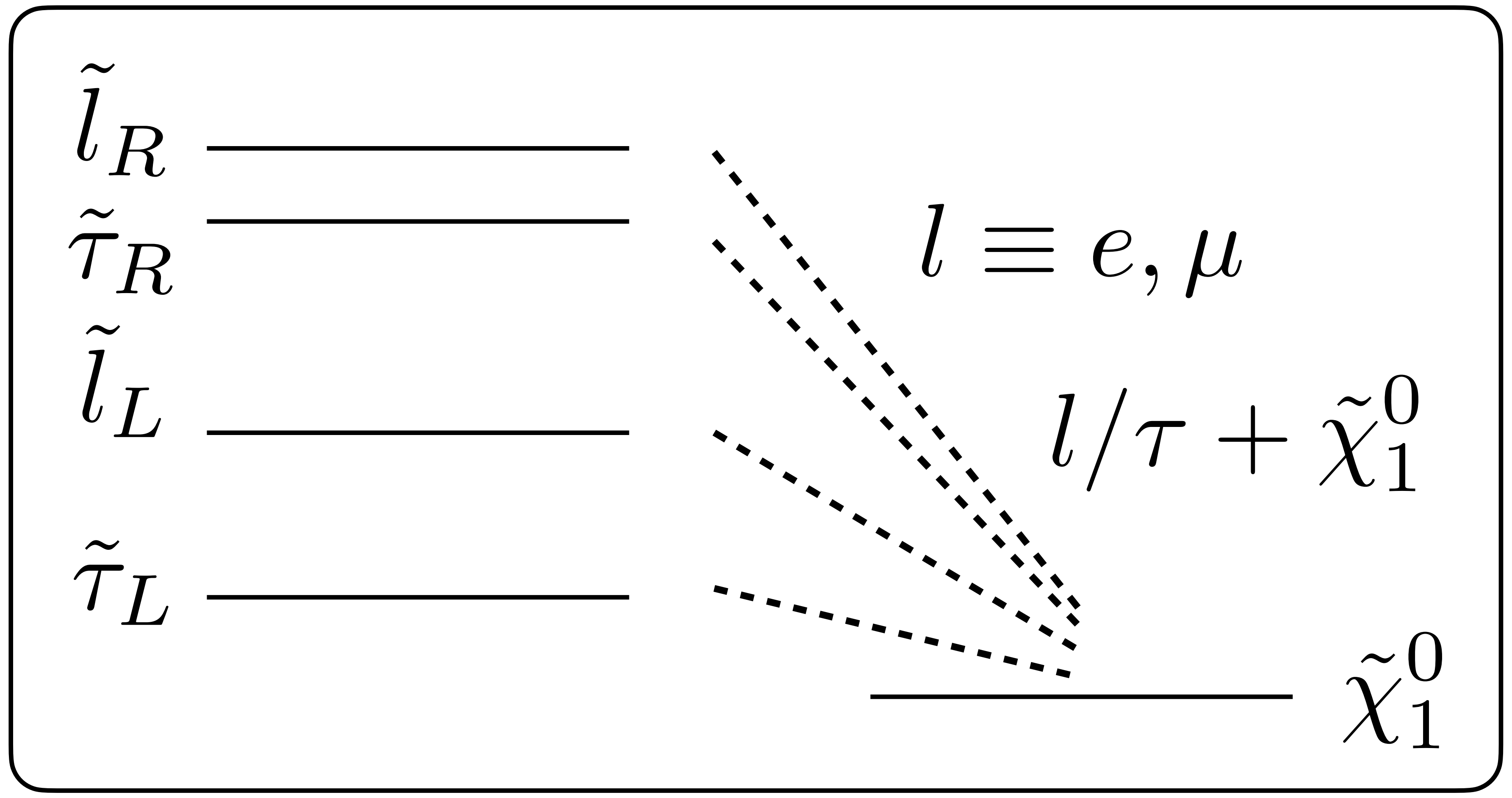
2. Size of the effect:



$$m^2_{LR} = m_\mu \mu \tan\beta$$

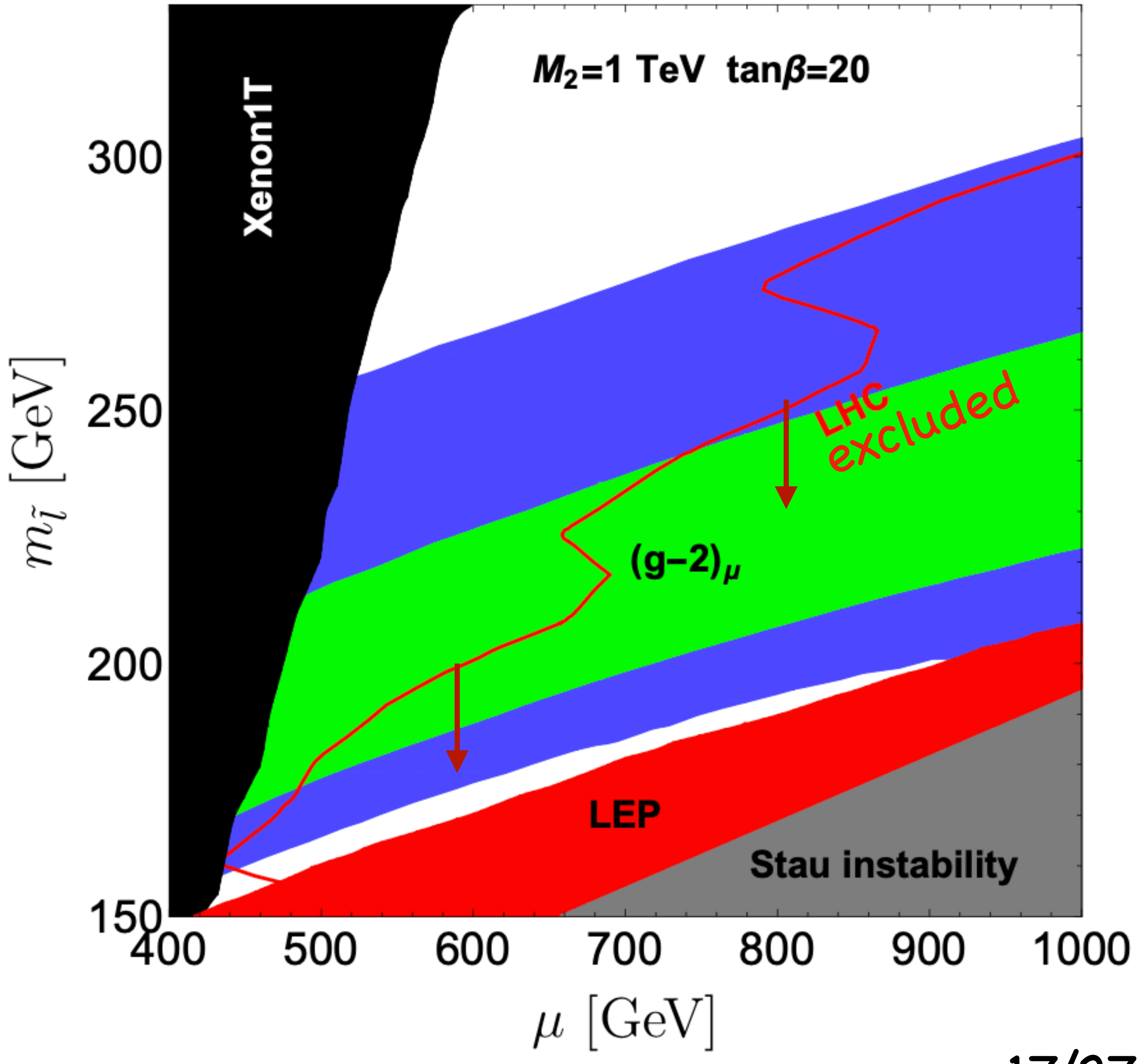
$$\Delta a_\mu|_{SUSY} \approx \frac{g_1^2}{16\pi^2} m_\mu^2 \frac{M_1 \mu \tan\beta}{m^2_{\tilde{\mu}_L} m^2_{\tilde{\mu}_R}} \approx 2.5 \cdot 10^{-9} (\frac{\tan\beta}{10})(\frac{\mu}{1\ TeV})(\frac{M_1}{100\ GeV})(\frac{200\ GeV}{m_{\tilde{\mu}_L}})^2(\frac{200\ GeV}{m_{\tilde{\mu}_R}})^2$$

4. Direct signals



$$M_1 < m_{\tilde{l}_L}, m_{\tilde{l}_R} < M_2 < \mu < M_3$$

Cox et al, 2021

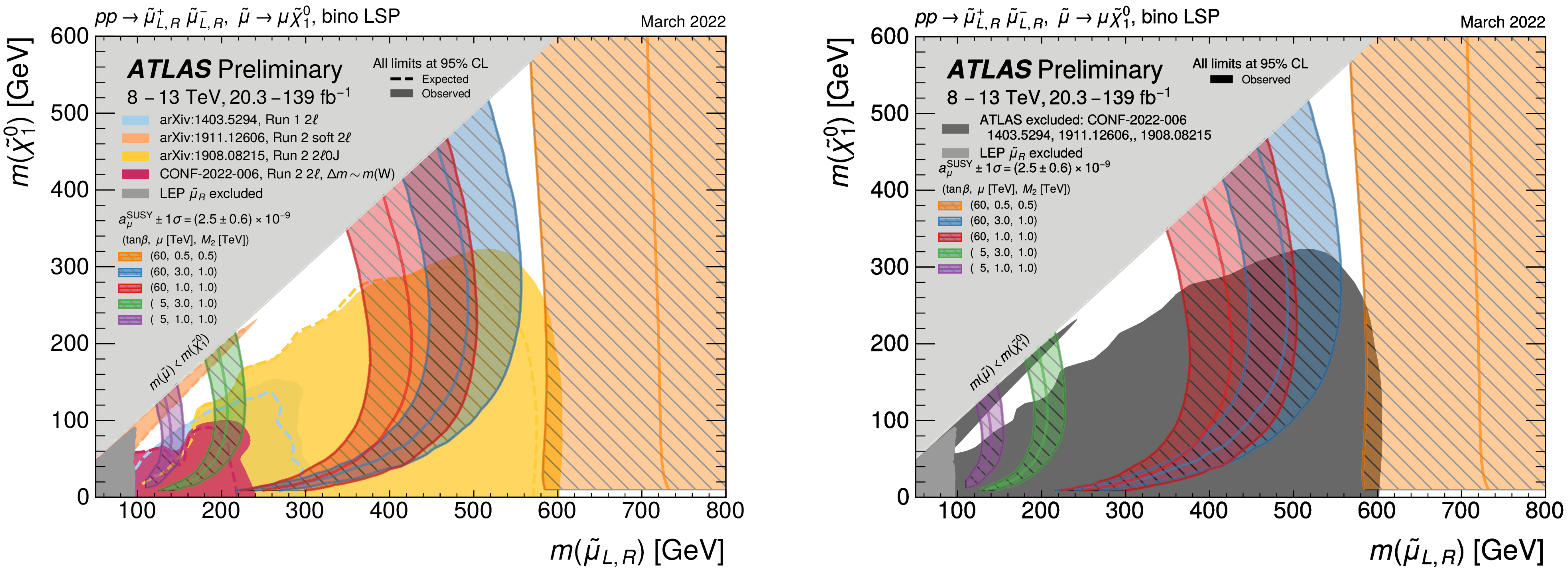


- **LHC** $\sigma(pp \to \tilde{l}\tilde{l}) \approx 1 \div 10 \; fb$

  backgrounds: $VV, \; V + jets, \; V^* \to l\bar{l}, \; t\bar{t}, \; t + V$

- **DM**

  $\tilde{\chi}_1^0 \tilde{\tau}$ co-annihilation $\Delta m \equiv m_{\tilde{\tau}} - m_{\tilde{\chi}_1^0} \lesssim 15 \; GeV$



$pp \to \tilde{\mu}^+_{L,R}\, \tilde{\mu}^-_{L,R},\ \tilde{\mu} \to \mu \tilde{\chi}^0_1$, bino LSP
March 2022
ATLAS Preliminary
8 – 13 TeV, 20.3 – 139 fb^{-1}
All limits at 95% CL
Expected
Observed
arXiv:1403.5294, Run 1 2ℓ
arXiv:1911.12606, Run 2 soft 2ℓ
arXiv:1908.08215, Run 2 2ℓ0J
CONF-2022-006, Run 2 2ℓ, $\Delta m \sim m(W)$
LEP $\tilde{\mu}_R$ excluded
$a_\mu^{SUSY} \pm 1\sigma = (2.5 \pm 0.6) \times 10^{-9}$
($\tan\beta$, μ [TeV], M_2 [TeV])
(60, 0.5, 0.5)
(60, 3.0, 1.0)
(60, 1.0, 1.0)
(5, 3.0, 1.0)
(5, 1.0, 1.0)
$m(\tilde{\mu}) < m(\tilde{\chi}^0_1)$
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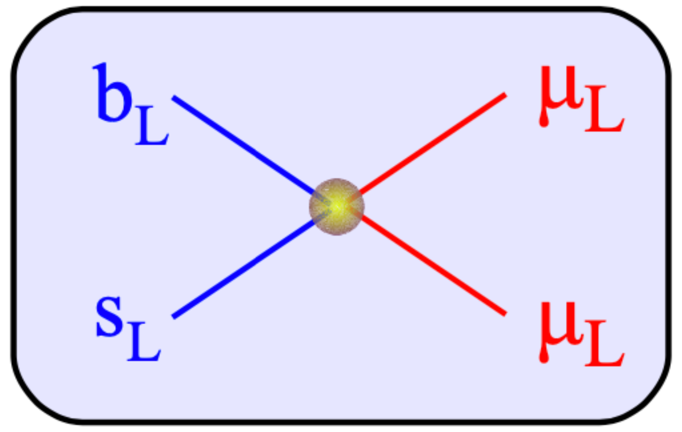
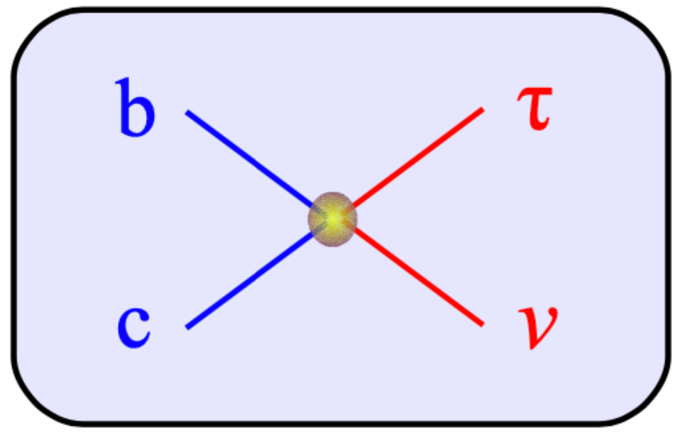
$m(\tilde{\chi}^0_1)$ [GeV]
$m(\tilde{\mu}_{L,R})$ [GeV]

Example 3: B-anomalies in semi-leptonic decays

Neutral



Charged



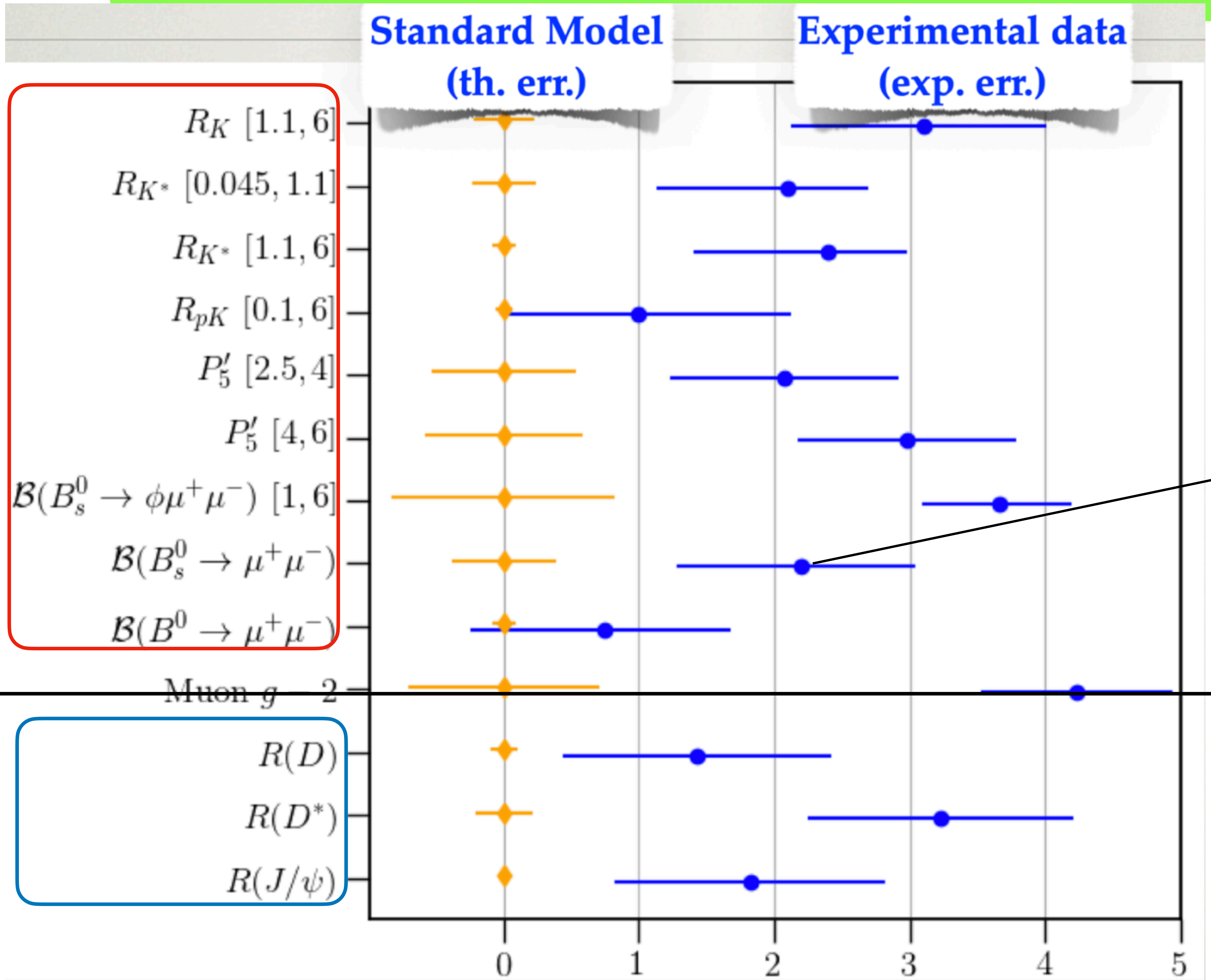
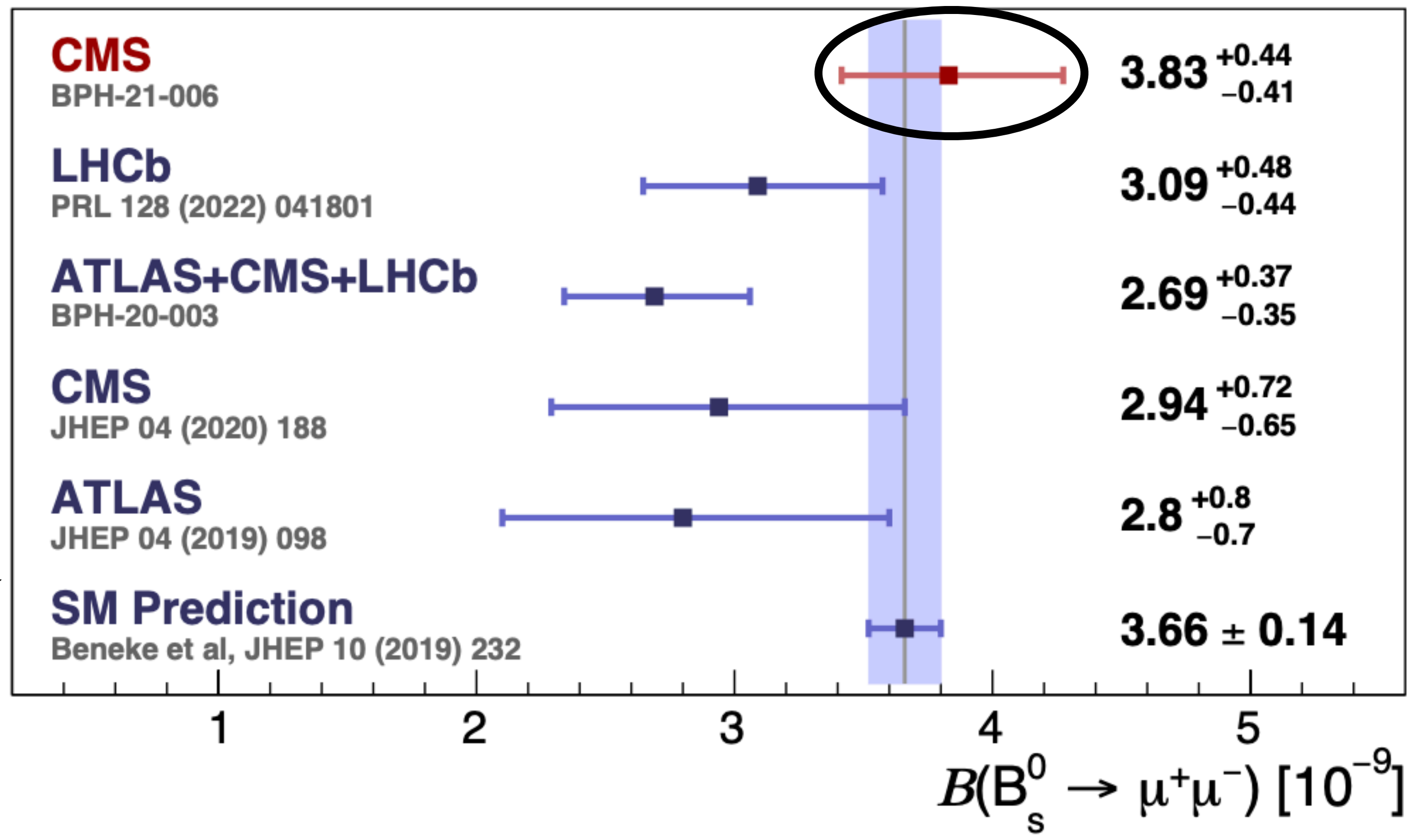


figure credit: Patrick Koppenburg

ICHEP 2022



- in many cases $\sigma_{th} << \sigma_{exp}$

Broad features

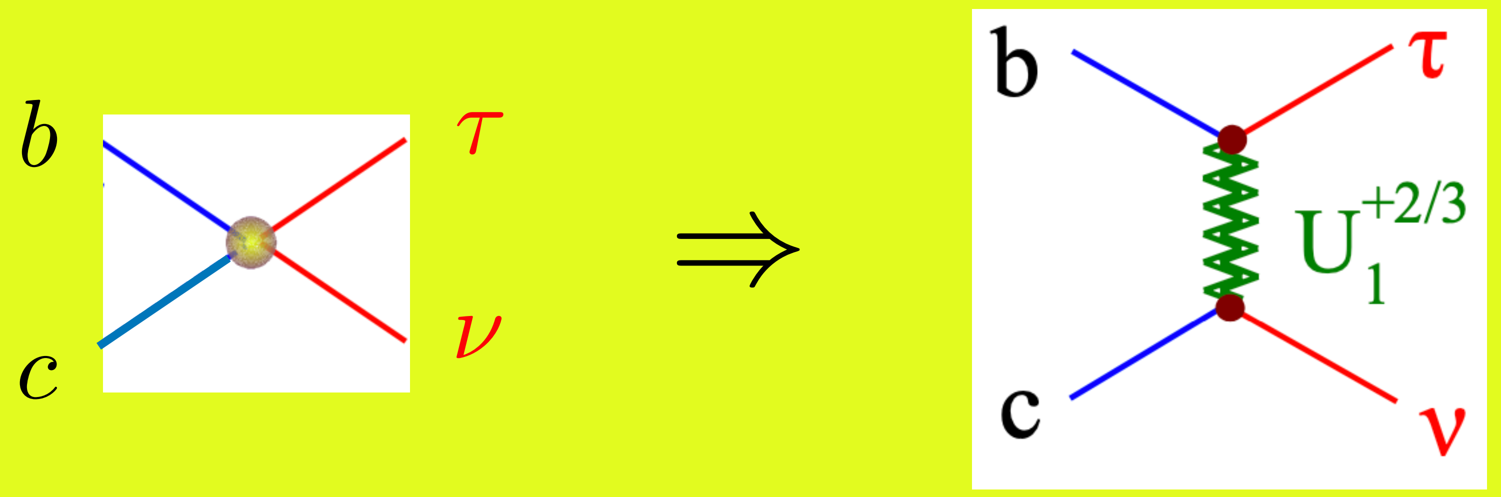
- Anomalies only seen in semi-leptonic op.s $(\bar{q}q\ \bar{l}l)$
  not in $\tau \to \mu\nu\nu$ $(\bar{l}l\ \bar{l}l)$ nor in $\Delta F = 2$ $(\bar{q}q\ \bar{q}q)$

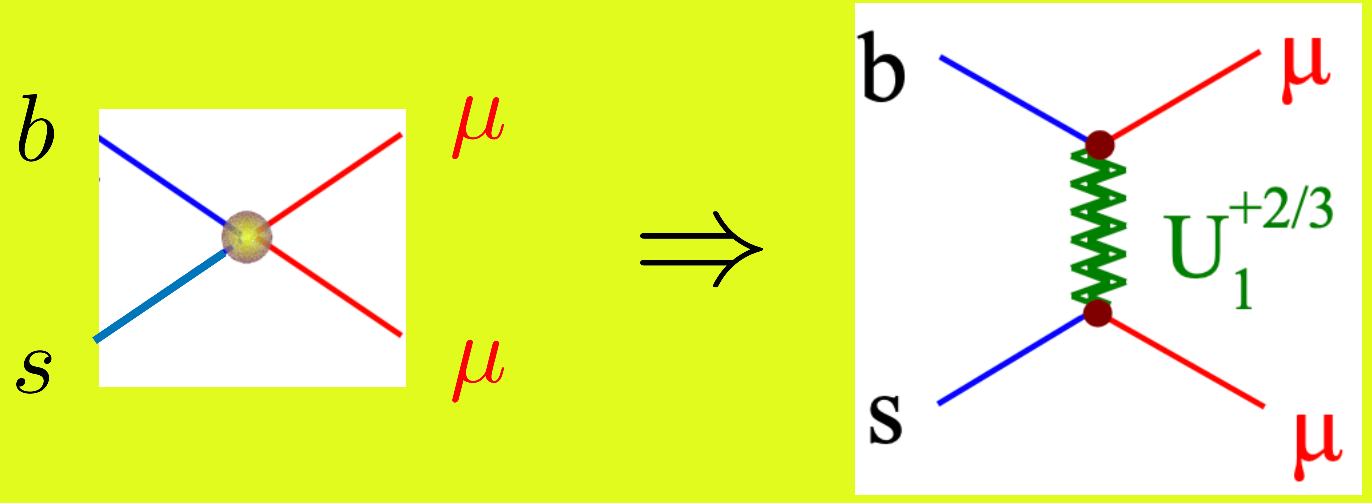
- Need left-handed ops. $(\bar{q}_L\gamma_\mu q_L\ \bar{l}_L\gamma_\mu l_L)$ to interfere with the SM

- A larger effect in CC [SM tree-level] $b(3)c(2) \to \tau(3)\nu_\tau(3)$
- A smaller effect in NC [SM loop-level] $b(3)c(2) \to \mu(2)\mu(2)$

A pattern similar to Yukawa couplings !?!?

A vector lepto-quark $U(1)_1^{2/3}$

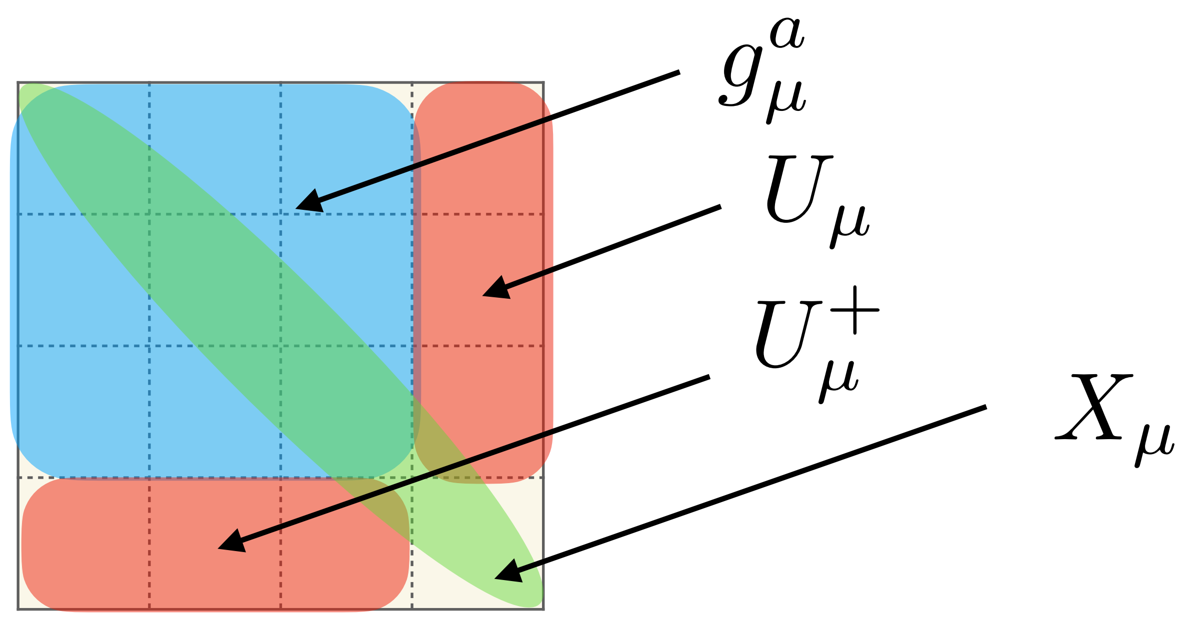




with hierarchical couplings to different generations

What if B-anomalies confirmed and interpreted by U_μ ?

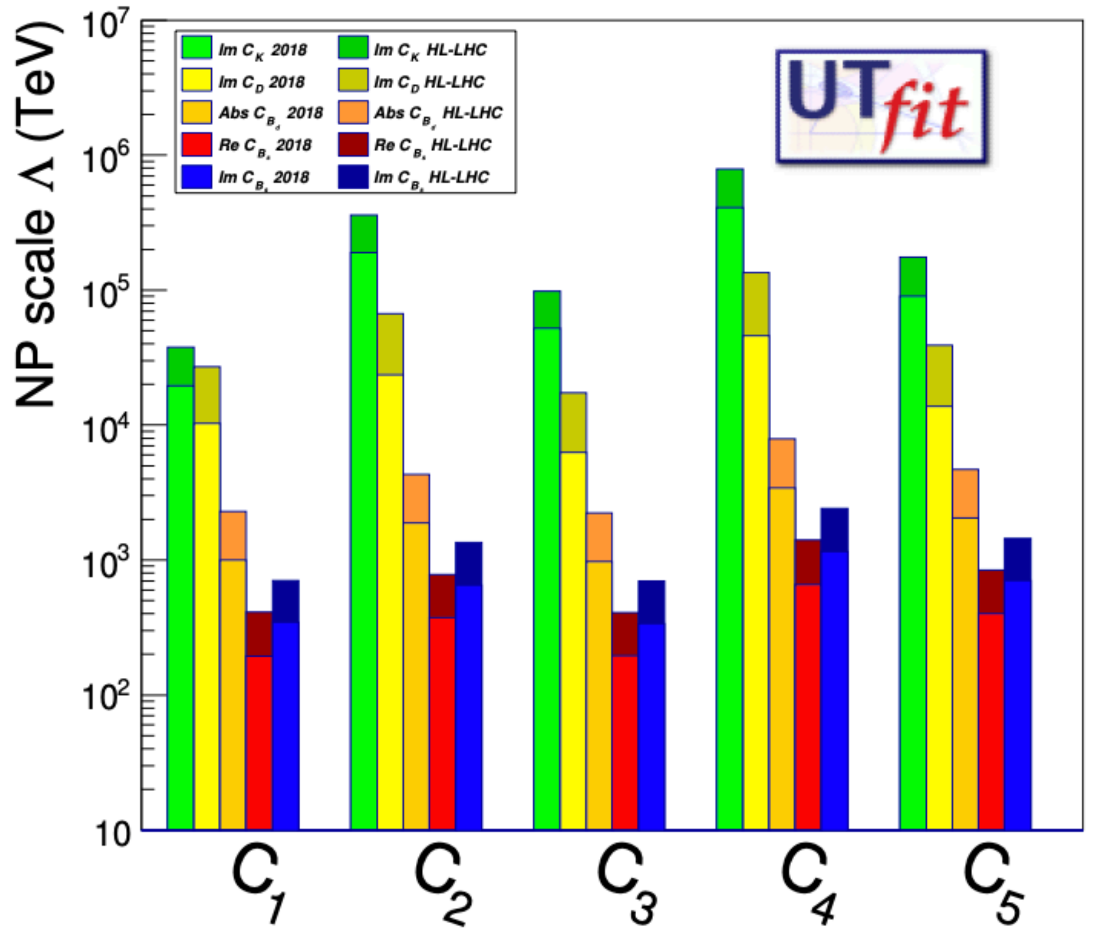
➡ 3 "necessities" and 1 question



1. $U^{2/3}_\mu \subset \mathcal{G}^A_\mu$ (S(4) Pati-Salam)
[gauged or ρ-like]

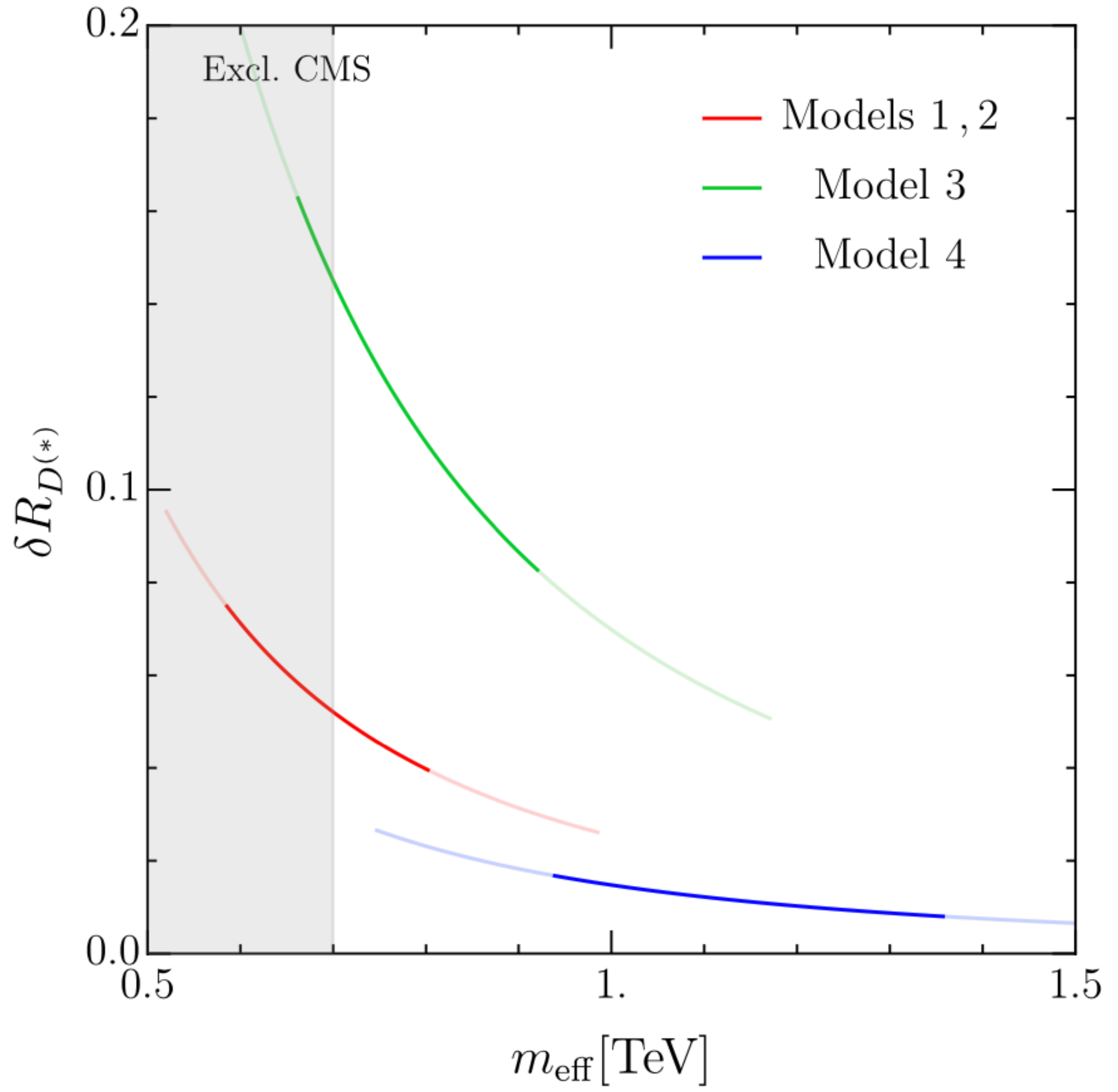
2. No direct coupling of $f_{1,2}$ to $\mathcal{G}^A_\mu$ but only via mixing to vector-like F_j

3. Approximate flavour-symmetry protection of low scale M_U



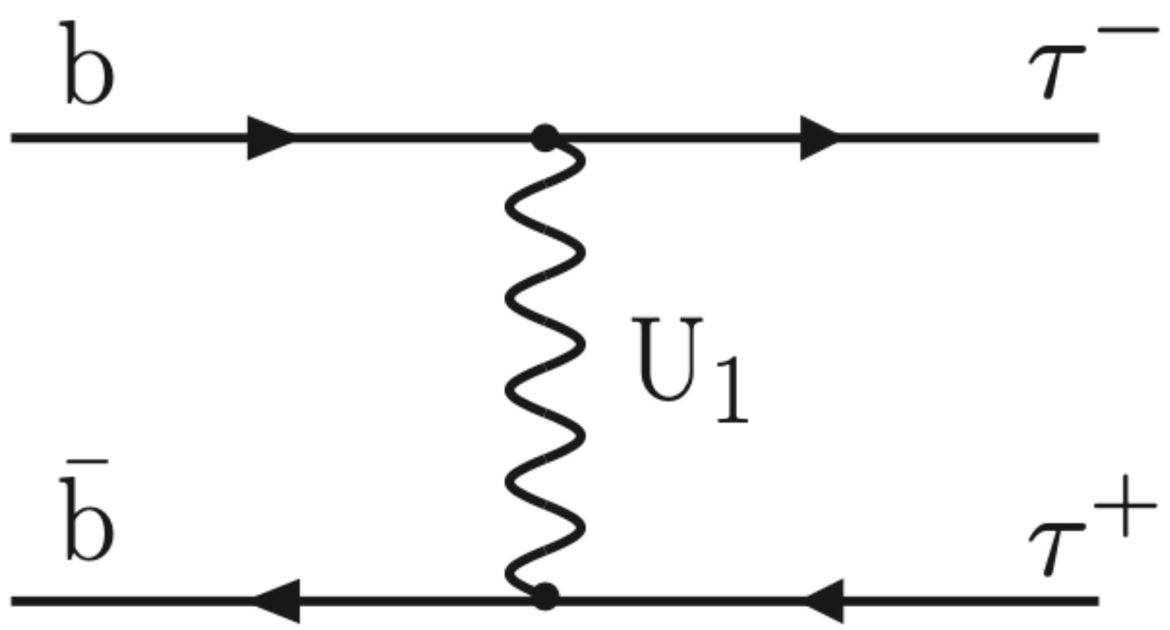
1. Can the $\mathcal{G}^A_\mu$ be related to Higgs compositeness? $[\rho, F_j]$

Range of $m_{eff} = \frac{M_U}{g_U}$ in 4 simplified SU(4) models to account for the anomalies



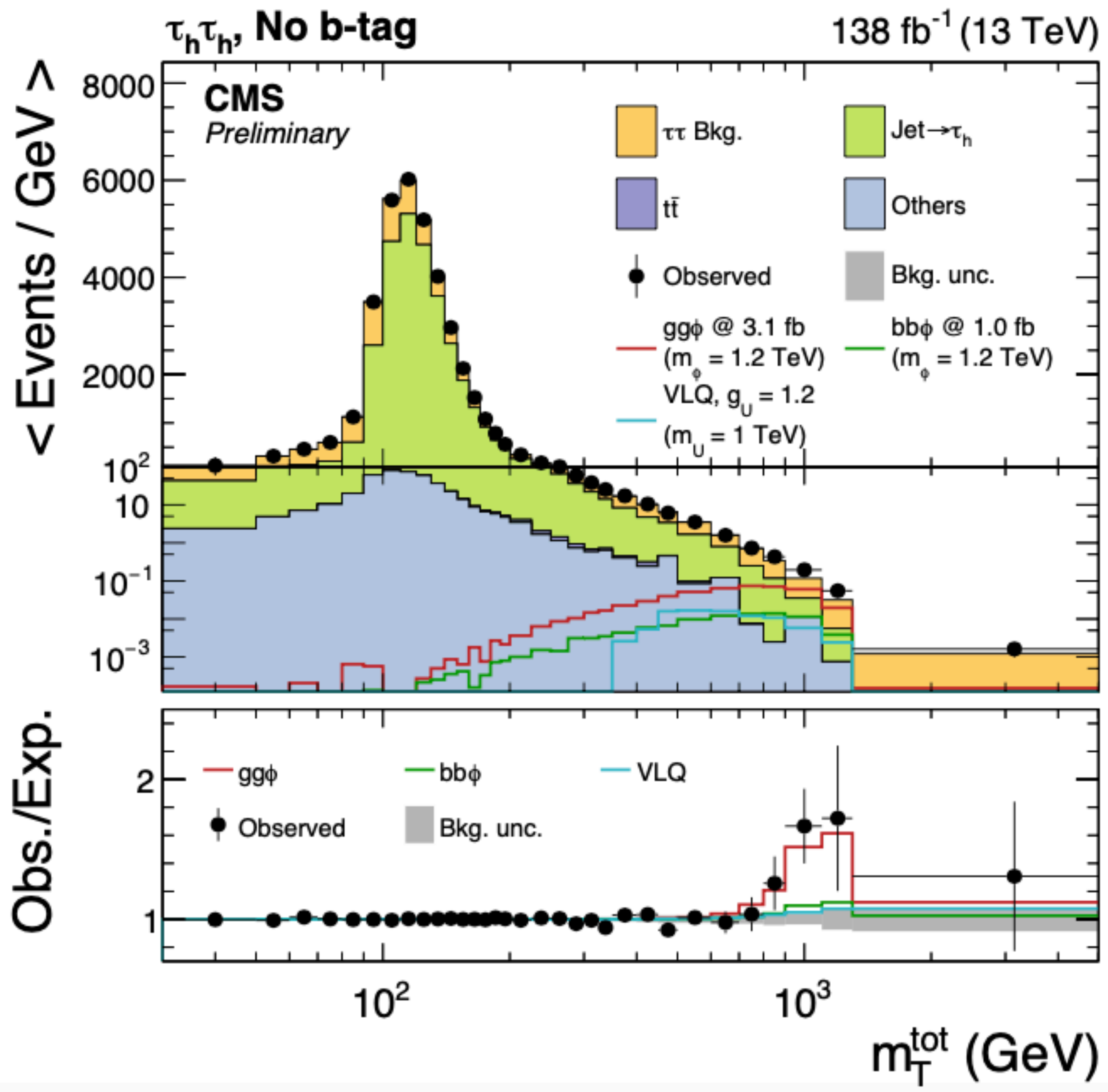
B, Isidori, Cornella, 2022

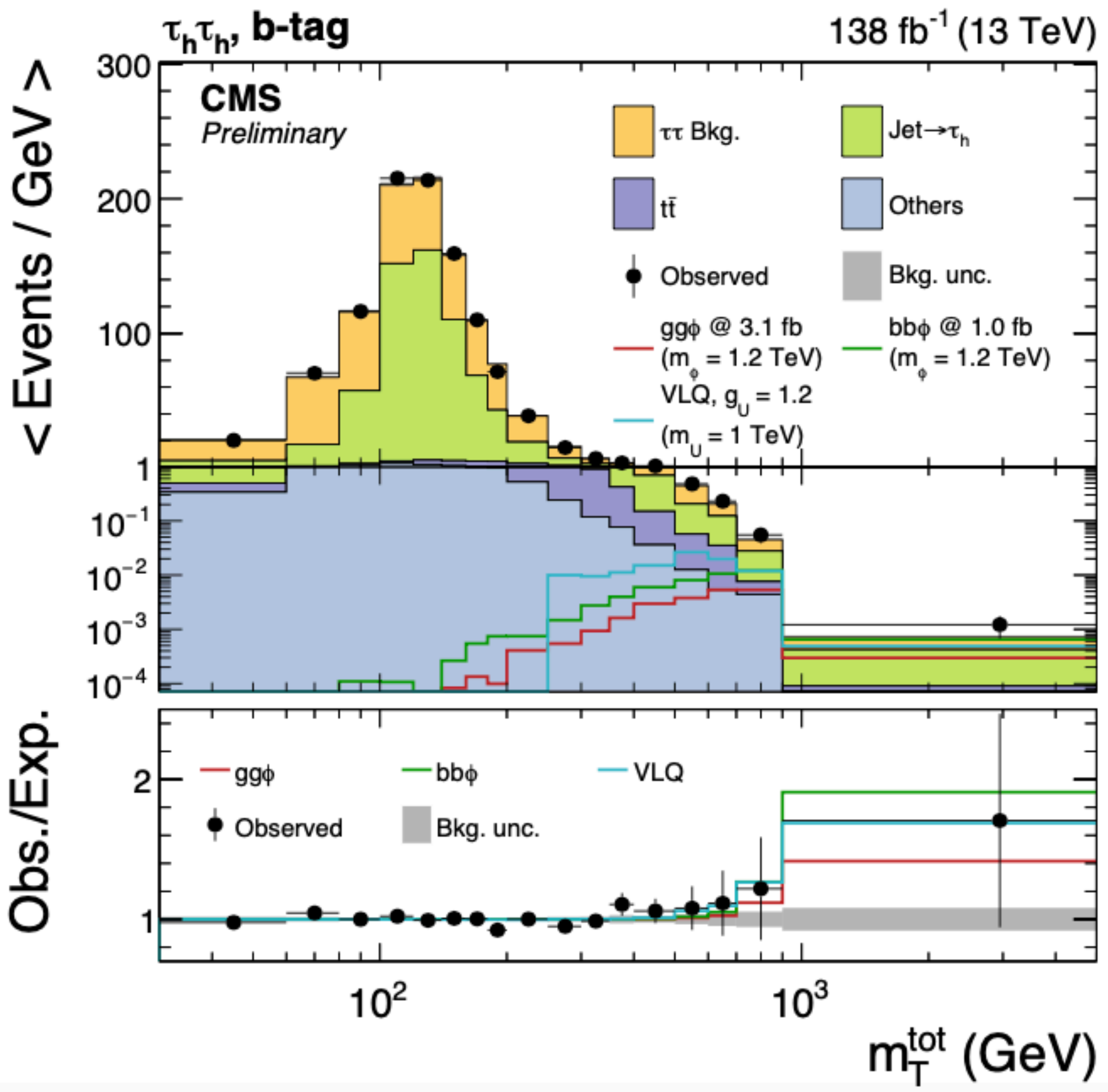
t-channel vector lepto-quark exchange

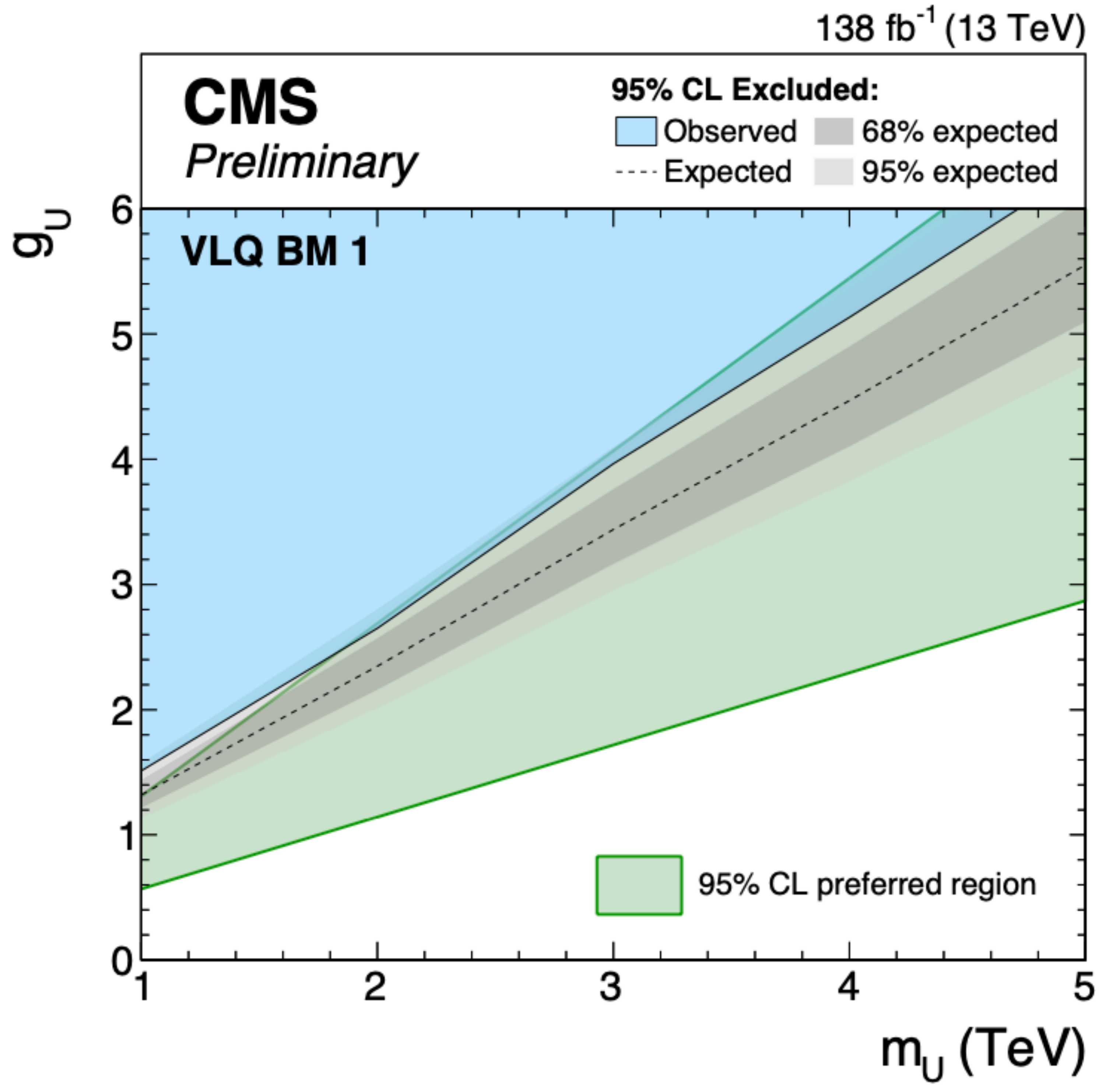


$$A \propto \left(\frac{g_U}{\sqrt{2}}\right)^2 \frac{1}{M_U^2}$$

($pp \to \tau\mu, \mu\mu$ weaker)







$$m_{eff} \equiv \frac{m_U(TeV)}{g_U} \approx 0.8 \div 1.5$$

Flavour in composite Higgs

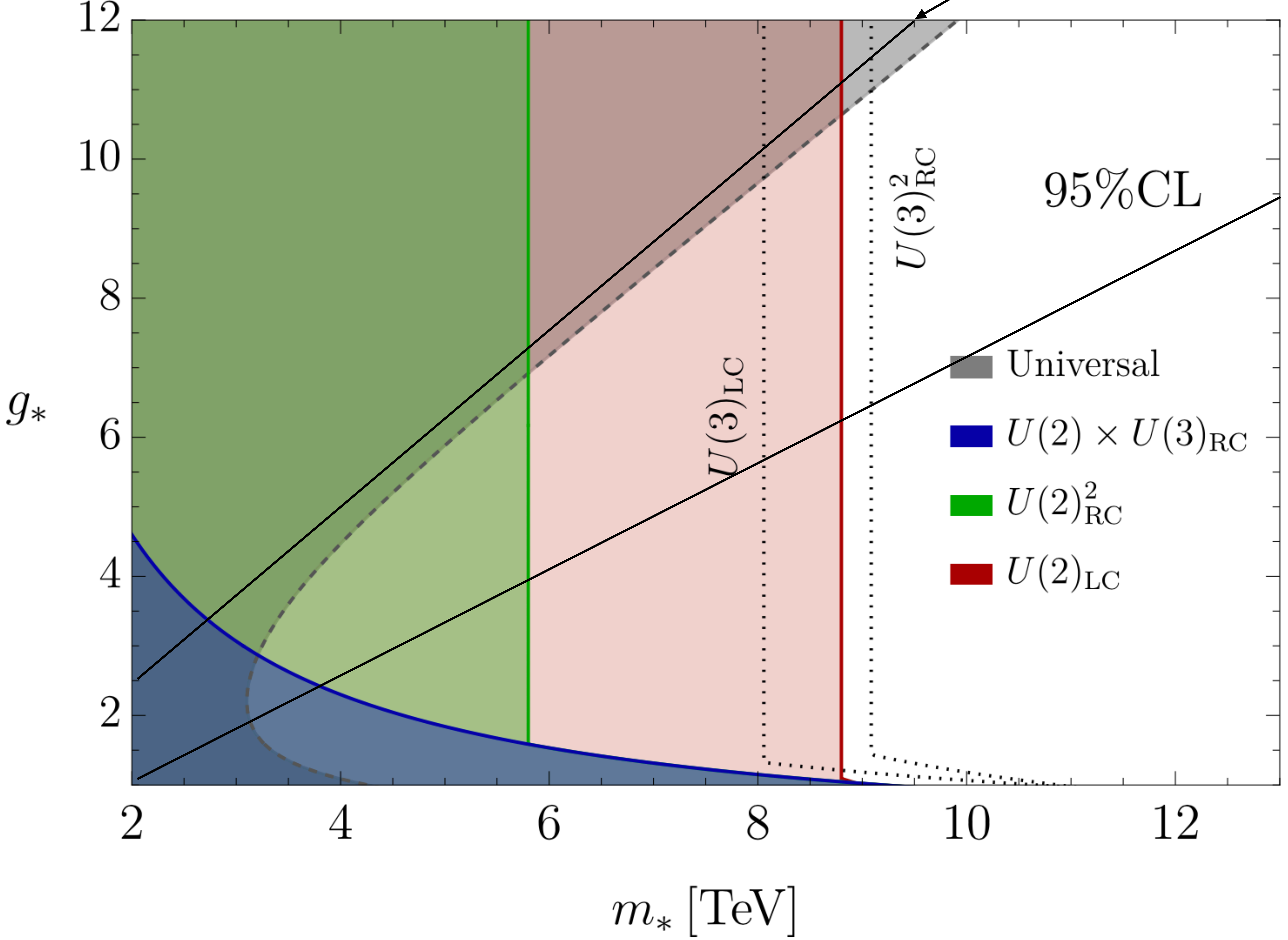
(but no LFV)

If $g_U \to g_*$ and $m_U \to m_*$

$m_{eff} = 0.8\ TeV$

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

$m_{eff} = 1.5\ TeV$



Glioti et al, 2022

A projection of the future sensitivity on some key observables from LHCb only

		$23\ fb^{-1}$	$300\ fb^{-1}$
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

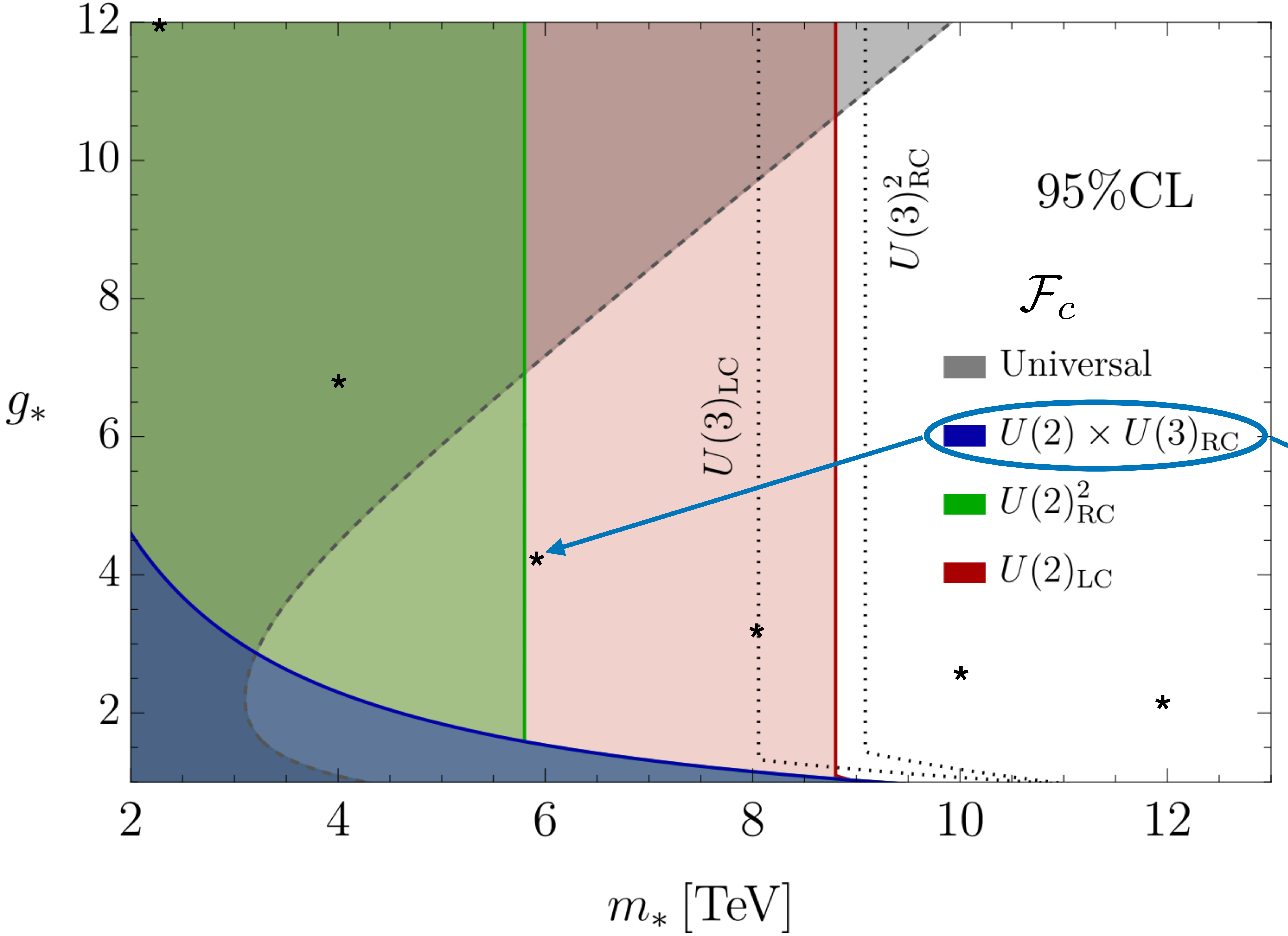
Statistical uncertainty

Flavour in composite Higgs

Different flavour symmetries $\mathcal{F}_c$ of the strong sector

$$U(3)_q \times U(3)_u \times U(3)_d \times \mathcal{F}_c$$

(but no LFV)



Current constraints

$b \to s\, ll$
Improvable by a factor of 10 in rate

Glioti et al, 2022

Summary

1. To turn the SM into a ST still premature,
   in spite of its empirical success
   (in my view mostly because of its unpredicted 15 masses)

2. Precision offers an indirect discovery potential of NP
   at MultiTeV, if any, before the next HE collider

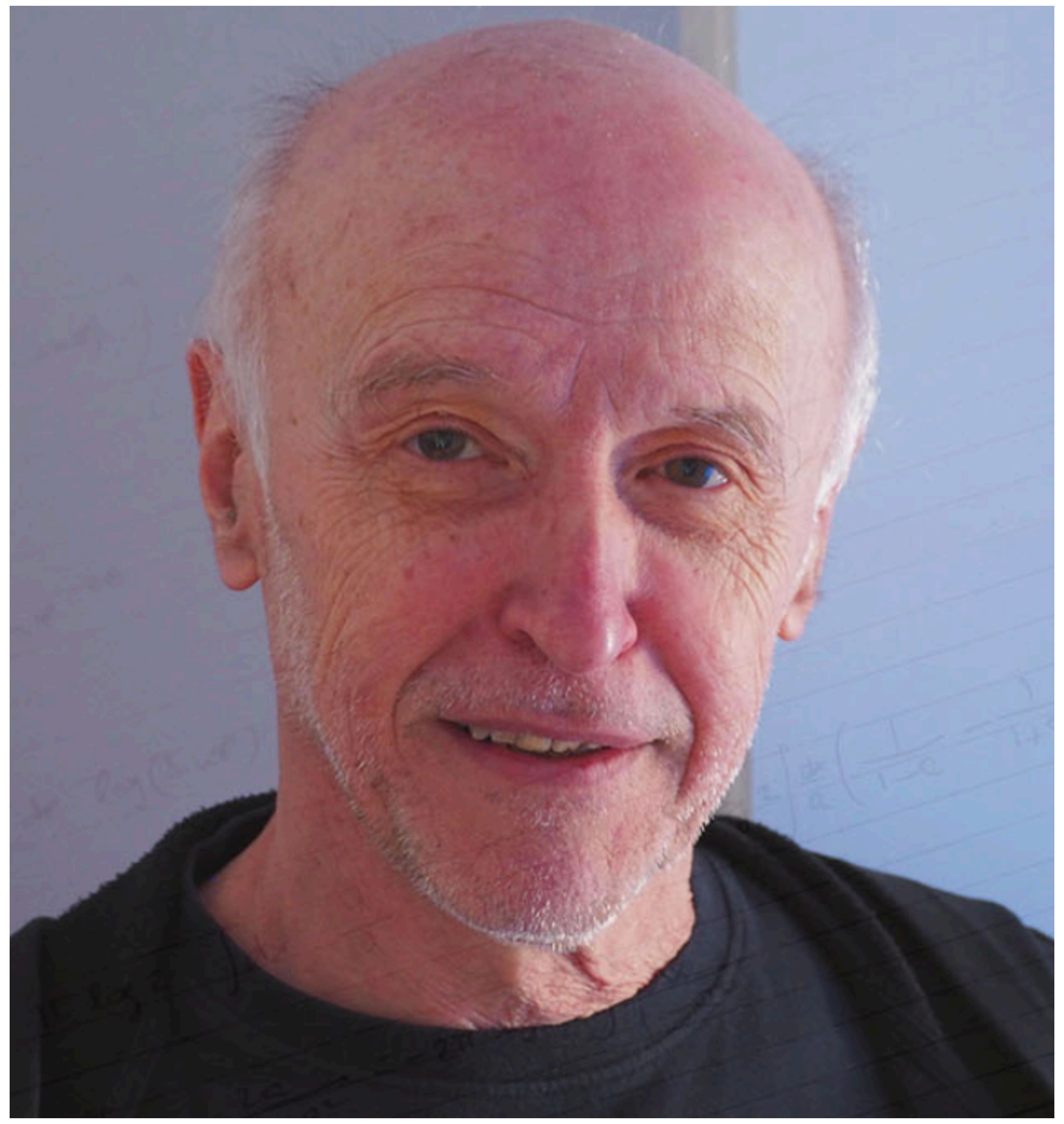
3. Worth to establish a BSM Precision Programme in depth
   and extension (Exp/QCD/EW/PDF/SMEFT/BSM)

4. The scale of Higgs compositeness explorable
   well beyond the reach of direct searches at LHC
   (with a key "unavoidable" role of flavour)

Last but not least

None of this would have been and will be possible at all without the fundamental contributions by people like

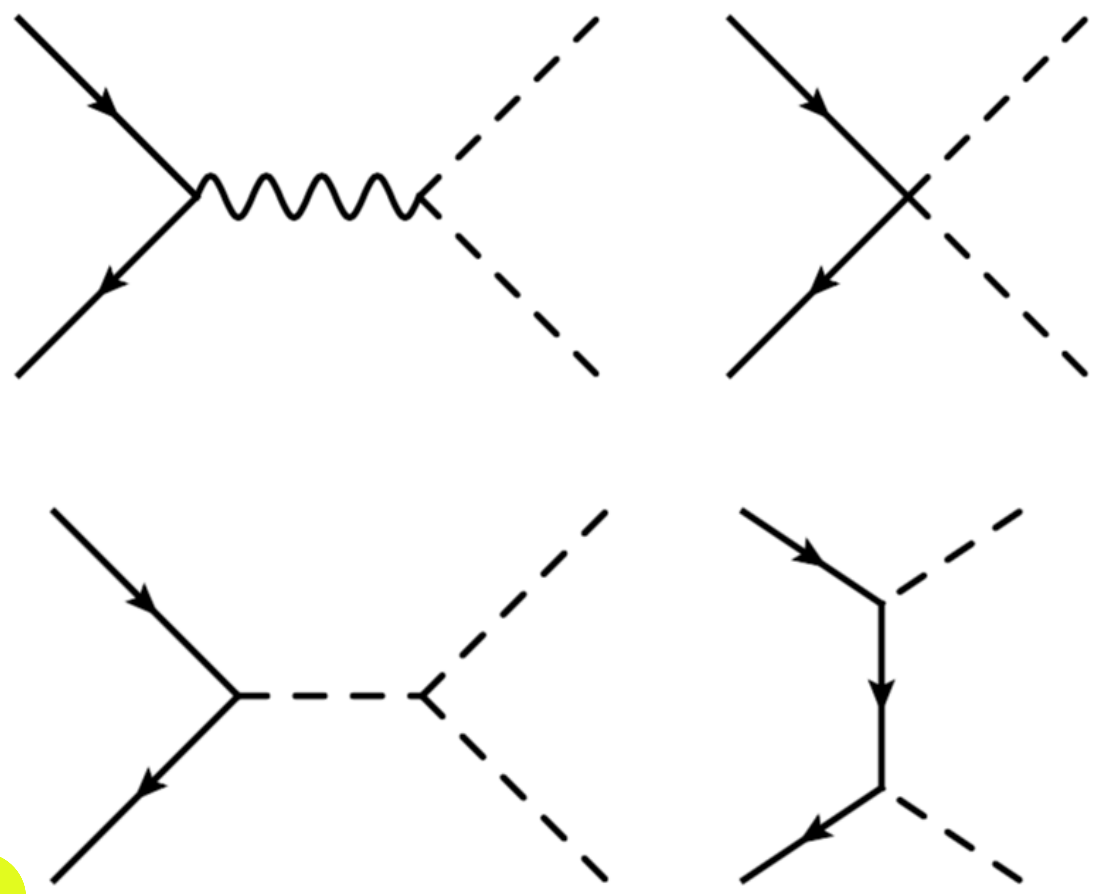
PAOLO



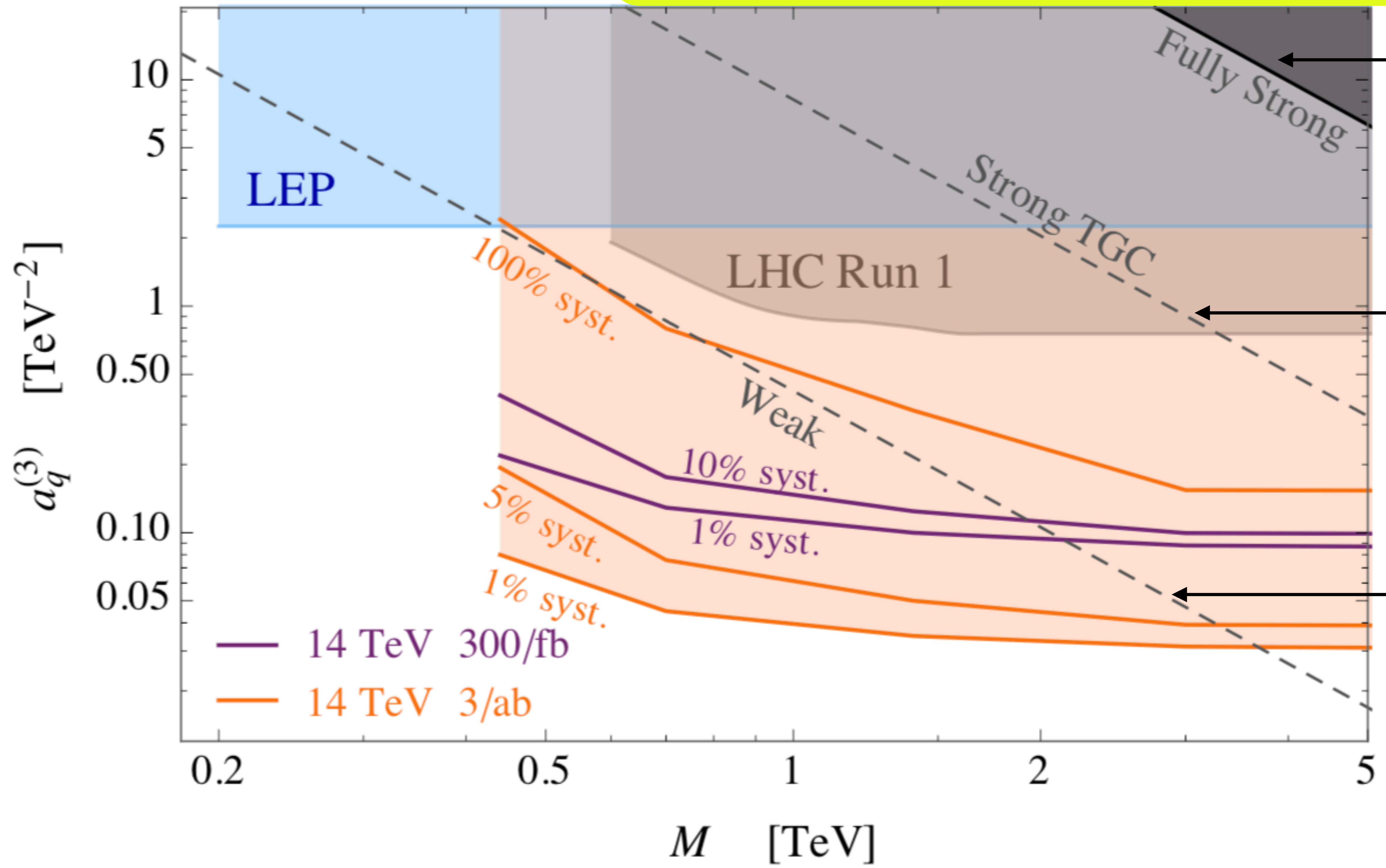
Backup

Energy growth of diBoson differential cross sections

	SM	BSM
$q_{L,R}\bar{q}_{L,R} \to V_L V_L(h)$	~ 1	$\sim E^2/M^2$
$q_{L,R}\bar{q}_{L,R} \to V_\pm V_L(h)$	$\sim m_W/E$	$\sim m_W E/M^2$
$q_{L,R}\bar{q}_{L,R} \to V_\pm V_\pm$	$\sim m_W^2/E^2$	$\sim E^2/M^2$
$q_{L,R}\bar{q}_{L,R} \to V_\pm V_\mp$	~ 1	~ 1



$$\delta A(\bar{q}q' \to WZ) \approx a_q^{(3)} E^2$$



$$a_q^{(3)} = \frac{16\pi^2}{M^2}$$

$$a_q^{(3)} = \frac{4\pi g}{M^2}$$

$$a_q^{(3)} = \frac{g^2}{M^2}$$

Franceschini et al 2018

3. Main constraints on parameter space

- No coloured partners below $1 \div 2\ TeV$

$$M_3 \tilde{g}\tilde{g}, \quad M_3 \gtrsim a\ few\ TeV$$

- No flavour violations $\mu \to e\gamma,\ \tau \to \mu\gamma, etc$

$$m_{\tilde{e}_L} = m_{\tilde{\mu}_L} = m_{\tilde{\tau}_L}$$ (and similarly for $m_{\tilde{l}_R}$)

Due to $m^2_{LR}(\tau) = m_\tau \mu \tan\beta \approx (150\ GeV)^2 \frac{\tan\beta}{10} \frac{\mu}{TeV}$ $\Rightarrow \tilde{\tau} =$ lightest s-lepton

(if not vacuum-unstable)

- Cancellations needed

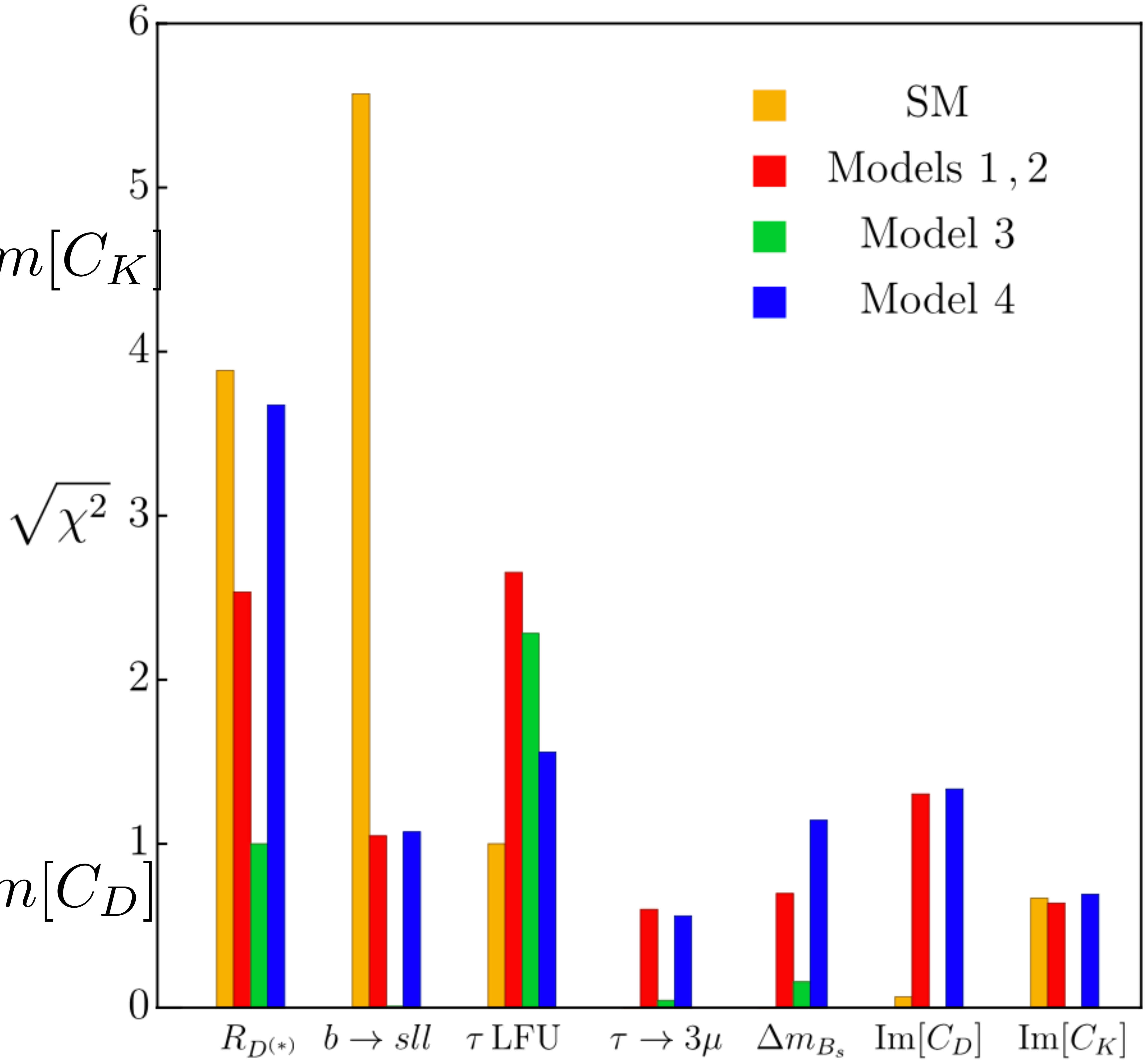
$$m_Z^2 = -2(m^2_{H_2} + |\mu|^2)$$

Low energy observables

(influenced by $\mathcal{G}_\mu^A$-exchanges at three level or in loops dominated by IR logs)

Class	Observable	Experiment/constraint	Correlation	SM prediction
I	$C^\mu_{9,\mathrm{NP}} = -C^\mu_{10,\mathrm{NP}}$	-0.39 ± 0.07 [29]	$-$	0
	R_D	0.340 ± 0.030 [30]	$\rho = -0.38$	0.298 ± 0.003 [30]
	R_{D^*}	0.295 ± 0.014 [30]		0.252 ± 0.005 [30]
II	$(g_\tau / g_{e,\mu})$	1.0012 ± 0.0012 [30]	$-$	1
III	$\tau \to 3\mu$	$< 2.1 \times 10^{-8}$ [34]	$-$	0
	$K_L \to \mu^\pm e^\mp$	$< 4.7 \times 10^{-12}$ [34]	$-$	0
IV	$\delta(\Delta m_{B_s})$	0.0 ± 0.1 [*]	$-$	0
	$\mathrm{Im}(\mathcal{C}^{\mathrm{NP}}_{uc})$ [GeV^{-2}]	$(-0.03 \pm 0.46) \times 10^{-14}$ [32, 33]	$-$	0
	$\mathrm{Im}(\mathcal{C}^{\mathrm{NP}}_{ds})$ [GeV^{-2}]	$(0.06 \pm 0.09) \times 10^{-14}$ [32, 33]	$-$	0

Overall fit



$Im[C_K]$

$Im[C_D]$

Δm_{B_s}

$R_{D^{(*)}}, b \to sll$ U_μ- exchange

τLFU $\approx U_\mu$- exchange at one loop

$\tau \to 3\mu$ X_μ- exchange

$\Delta m_{B_s}, Im[C_D], Im[C_K]$ $\approx g^a_\mu$- exchange

B, Isidori, Cornella, 2022

Cox et al, 2021

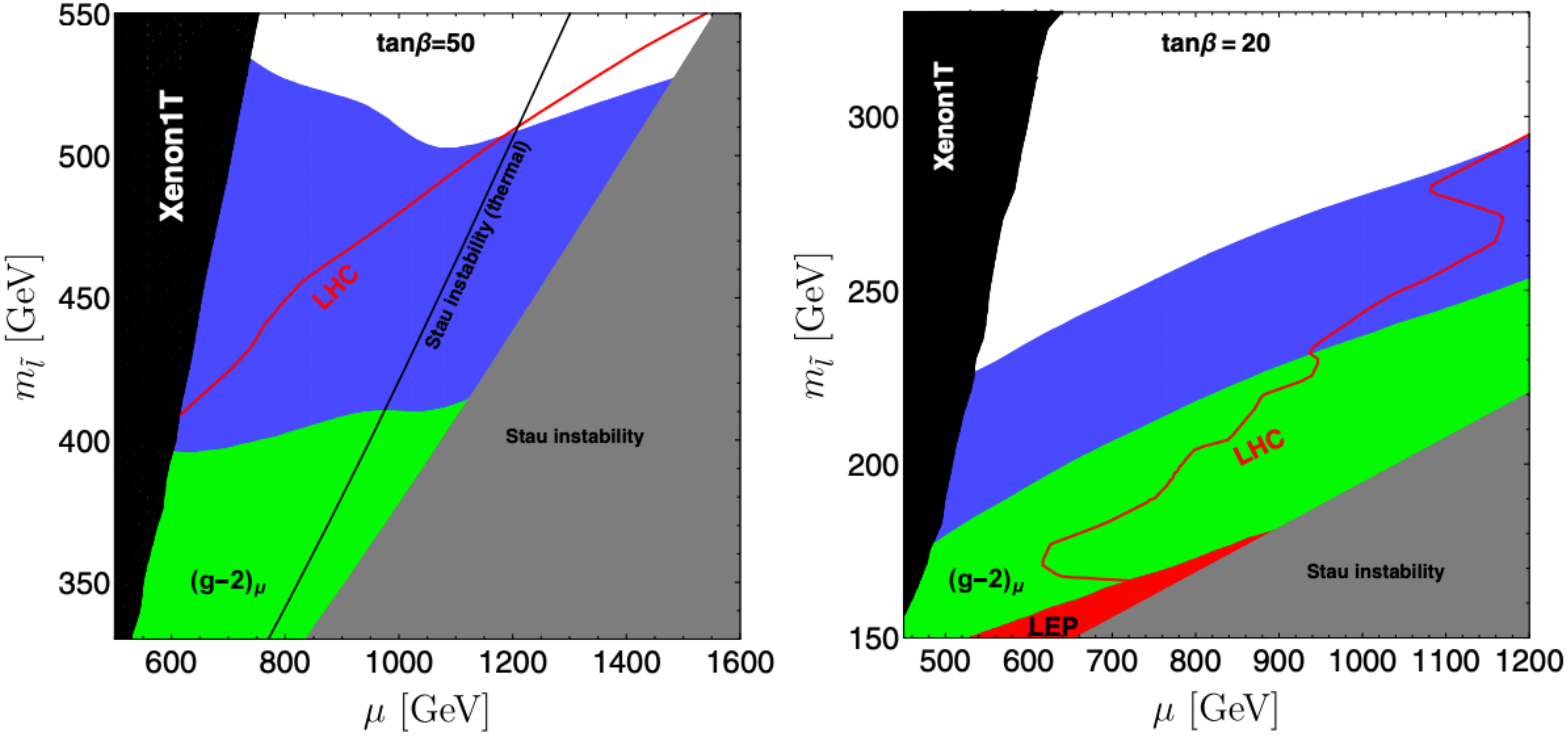


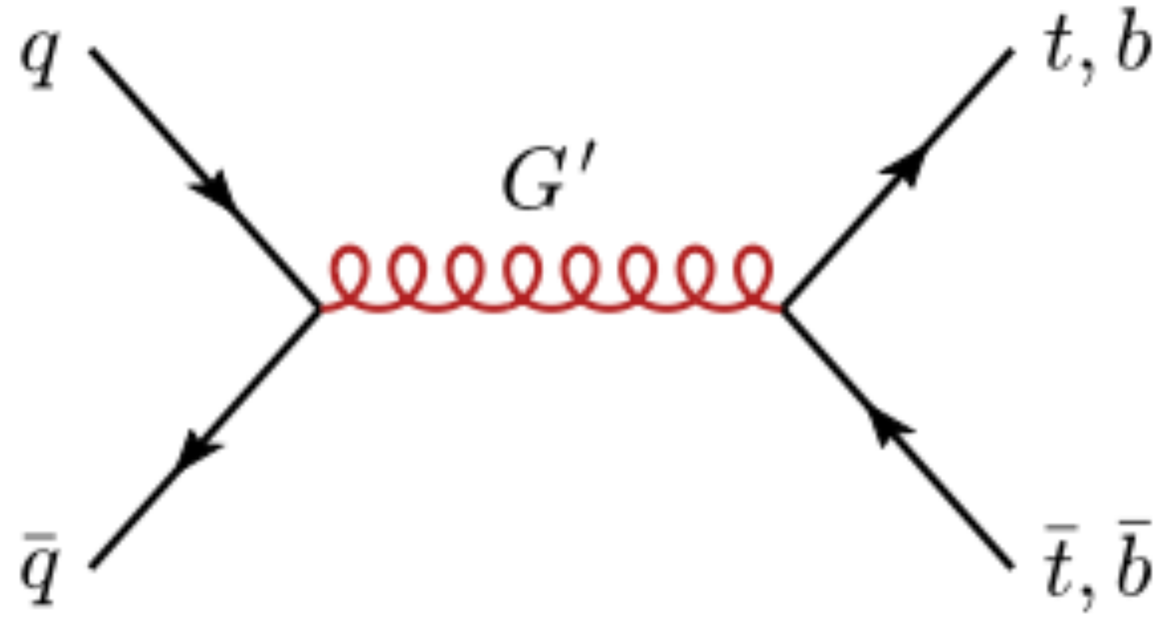
FIG. 1. Bino–stau coannihilation. M_1 has been adjusted to obtain the correct relic abundance, and we fix $M_2 = 1$ TeV. The green (blue) region is consistent with a_μ at 1σ (2σ). The black region is excluded by XENON1T [24]. The region to the right of the red line is excluded by the ATLAS slepton search with 139 fb^{-1} [22], and the red region is excluded by slepton searches at LEP [25]. The grey region is excluded by vacuum instability. Left: $\tan\beta = 50$. Right: $\tan\beta = 20$.

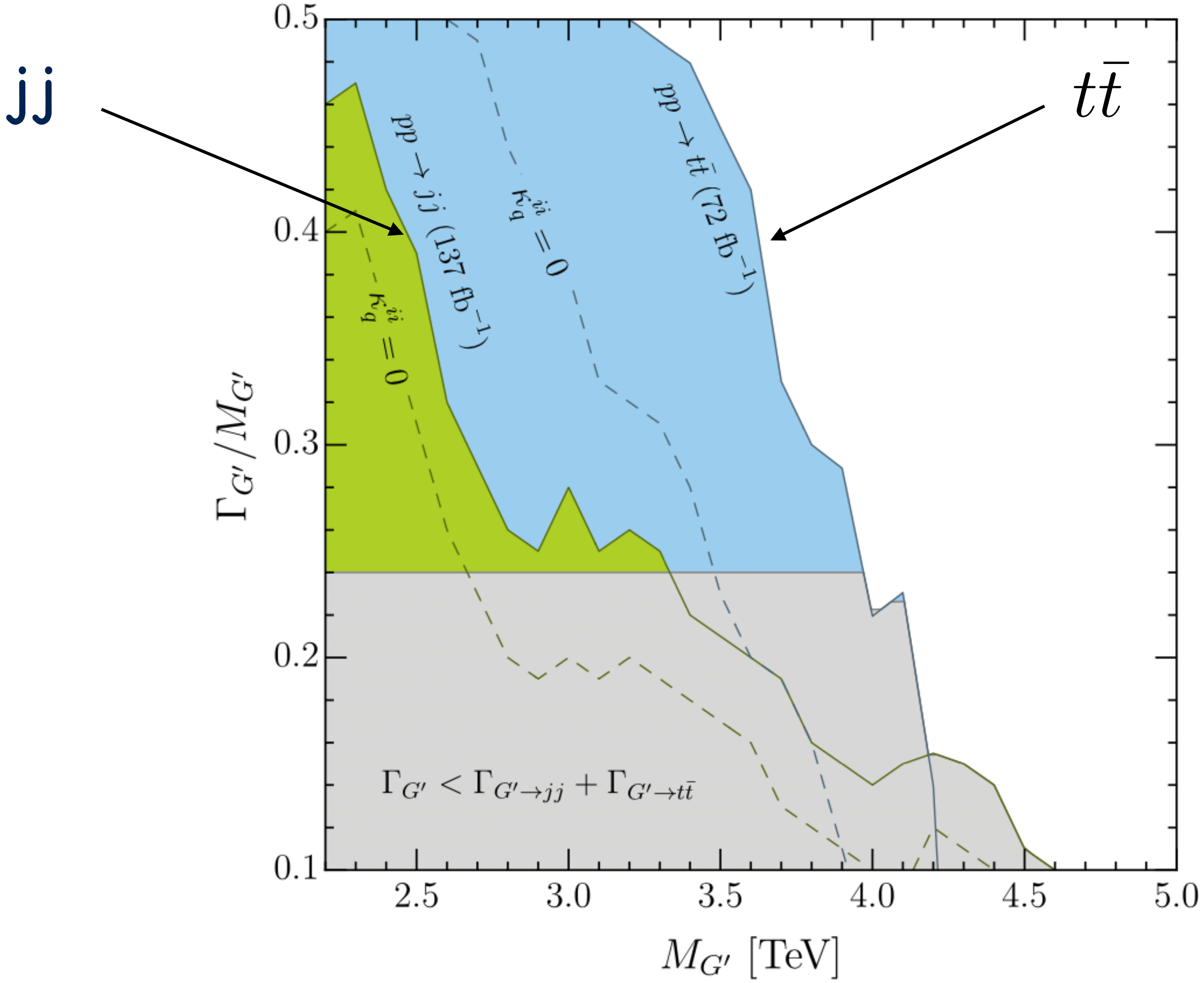
A vector lepto-quark living inside Pati-Salam $SU(4)$

A recast of large-Γ dijet and $t\bar{t}$ searches

at fixed $g_{G'} \approx g_U = 3$ where $\Gamma(G' \to t\bar{t}, b\bar{b}) \gtrsim 0.24 m_{G'}$

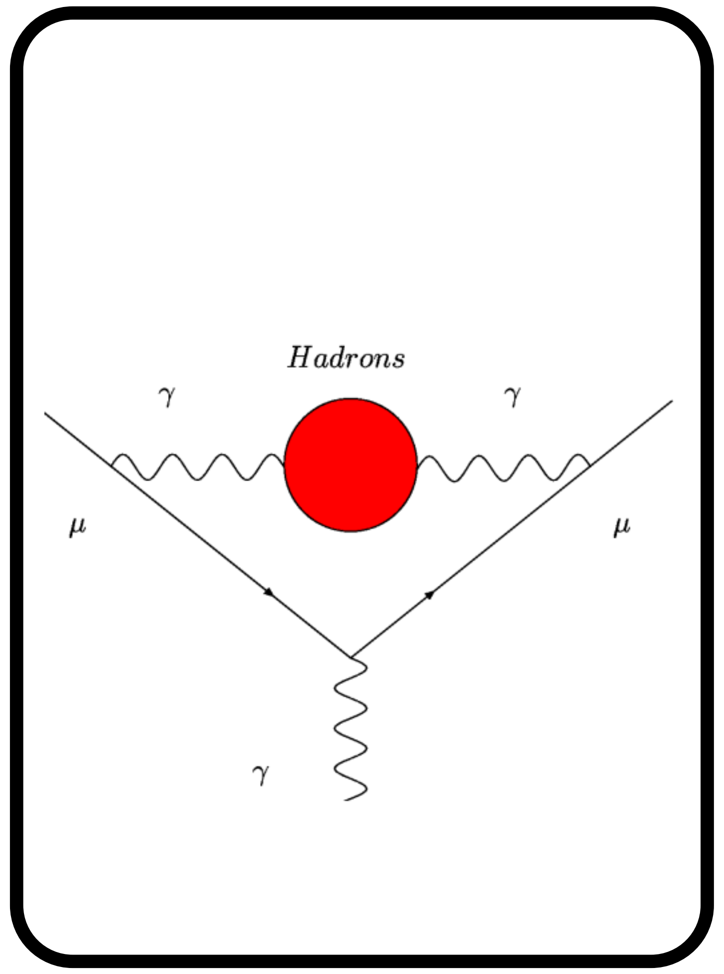
A heavy gluon



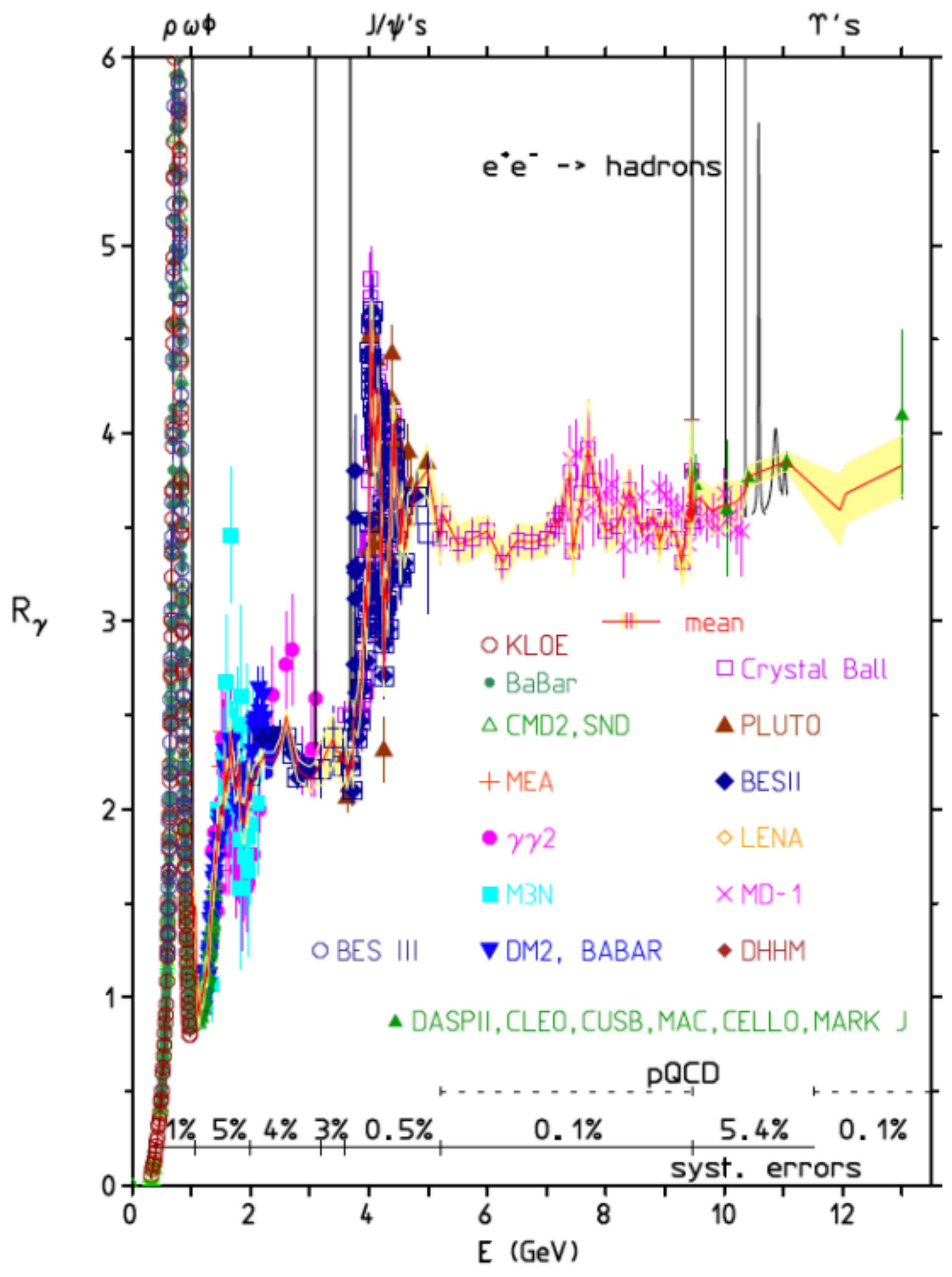


Cornella et al 2021

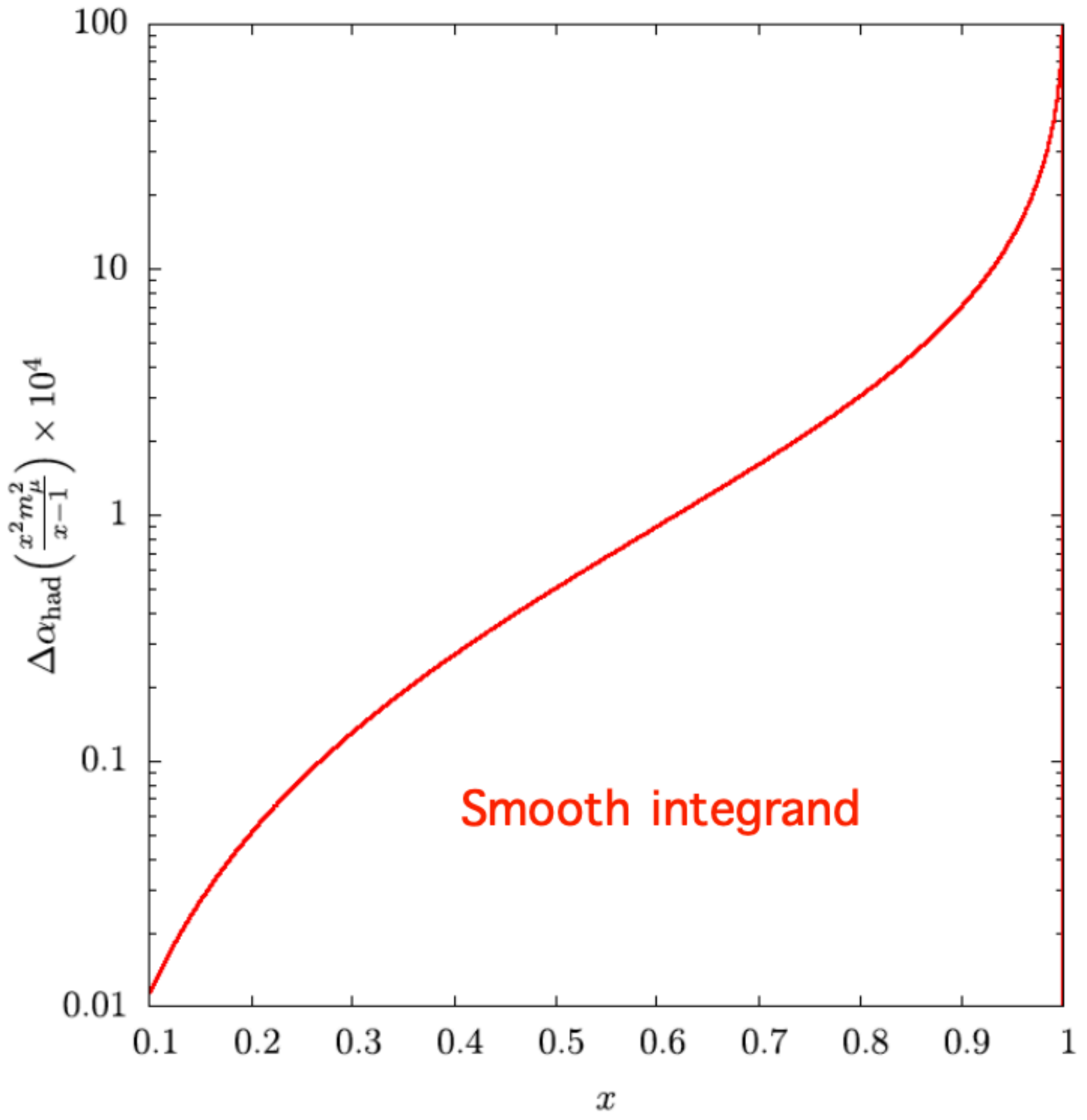
with a significant dependence on the coupling to the light quarks



Timelike → Spacelike

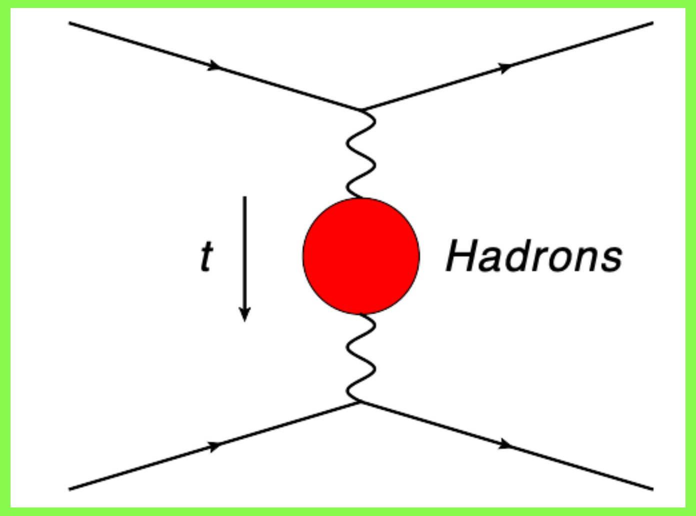


F. Jegerlehner, arXiv:1511.04473



Carloni Calame, MP, Trentadue, Venanzoni, PLB 2015

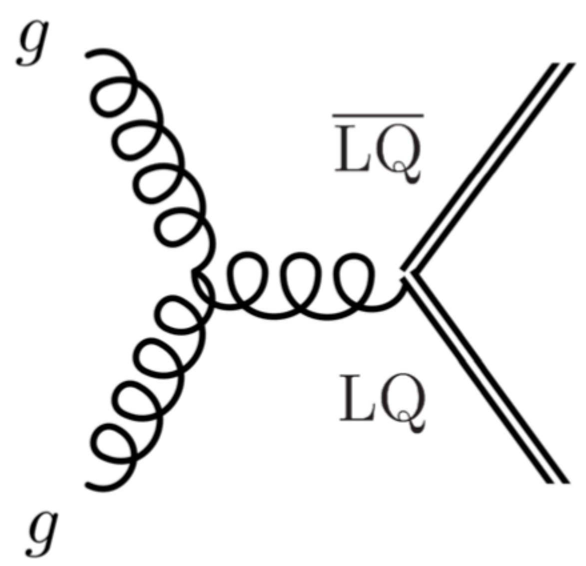
MUonE

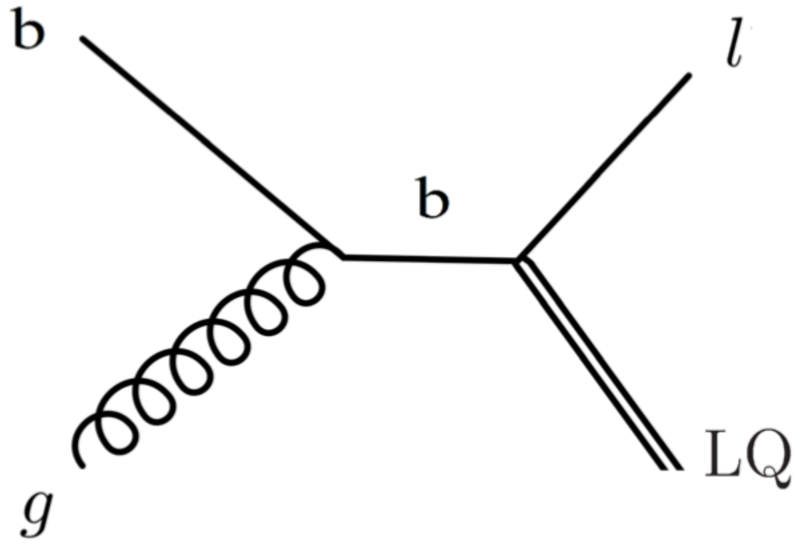


- ☑ **Inclusive measurement**
- ☑ **Smooth integrand**
- ☑ **Direct interplay with lattice QCD**

If the needed precision can be reached

Direct production of vector lepto-quark





$$BR(U_1 \to b\tau) \approx 1/2$$