The rise of Particle Physics

Rome, 23-24 Sept 2024

Riccardo Barbieri
SNS, Pisa

1. A brief appendix to Alvaro's talk (also in memory of Raul Gatto)

2. Flavour in the "mid term" of BSM

After Appelquist, Politzer

DeRujula, Glashow (1975)

DeRujula, Georgi, Glashow

MESON HYPERFINE SPLITTINGS AND LEPTONIC DECAYS

R. BARBIERI *, R. GATTO **, R. KÖGERLER * and Z. KUNSZT *

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***Instituto di Fisica and Instituto Nazionale di Fisica Nucleare, Roma, Italy*

Received 3 May 1975

MESON MASSES AND WIDTHS IN A GAUGE THEORY WITH LINEAR BINDING POTENTIAL

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and

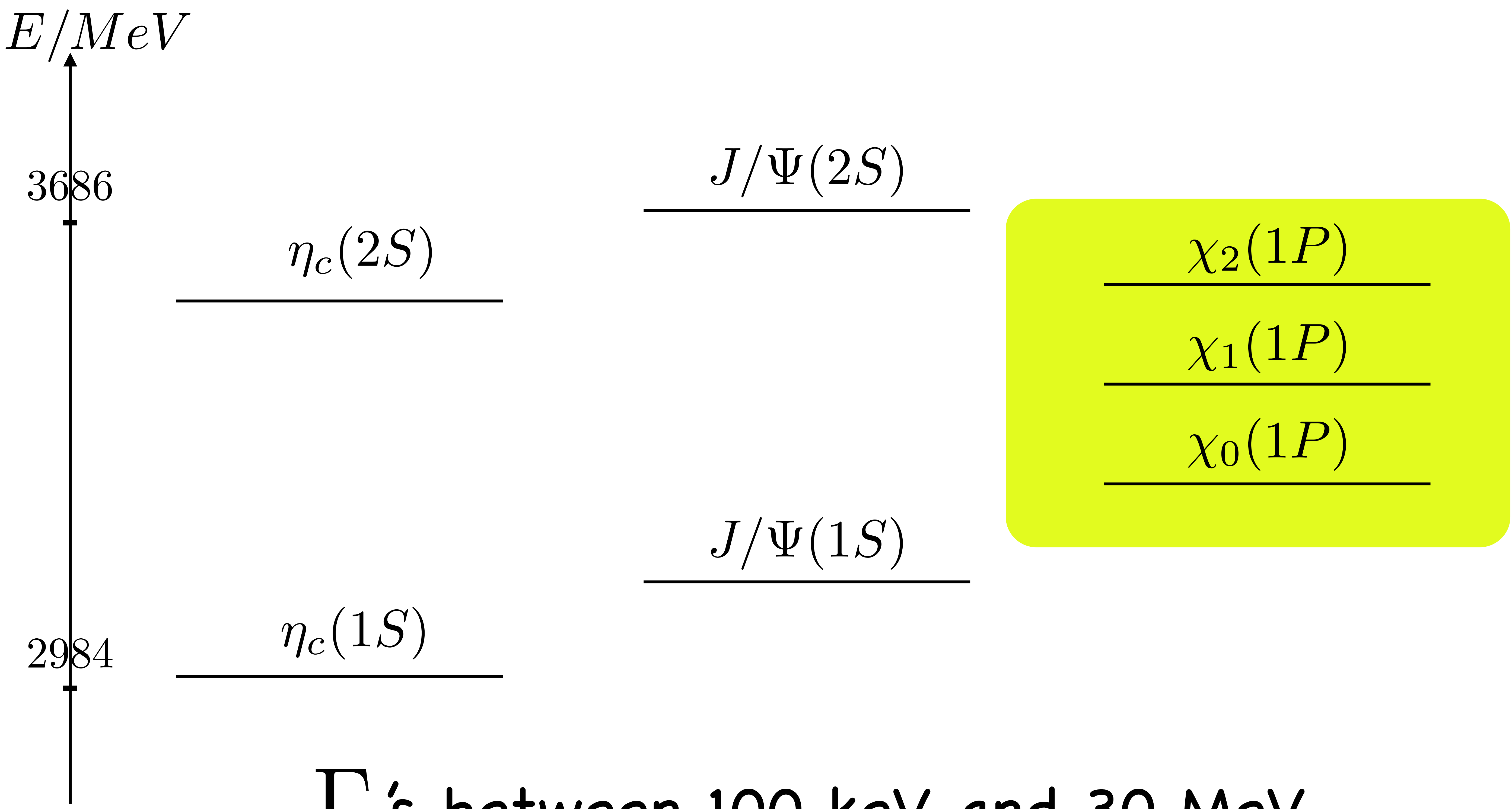
R. GATTO

Istituto di Fisica dell'Università, Roma

Received 1 July 1975

The November Revolution

$e^+e^- \to J/\Psi \to e^+e^-$ Discovery: Nov 1974



Γ's between 100 keV and 30 MeV

What about the P waves?

CALCULATION OF THE ANNIHILATION RATE OF P WAVE QUARK-ANTIQUARK BOUND STATES

R. BARBIERI, R. GATTO* and R. KÖGERLER
CERN, Geneva, Switzerland

Received 27 October 1975

$$\Gamma_{\text{ann}}(0^{++}) = \frac{96\alpha_s^2}{M^4} |\phi_p'(0)|^2, \qquad \Gamma_{\text{ann}}(2^{++}) = \frac{128}{5}\frac{\alpha_s^2}{M^4} |\phi_p'(0)|^2$$

SINGULAR BINDING DEPENDENCE IN THE HADRONIC WIDTHS OF 1^{++} AND 1^{+-} HEAVY QUARK ANTIQUARK BOUND STATES

R. BARBIERI and R. GATTO*
CERN, Geneva, Switzerland

and

E. REMIDDI
Istituto di Fisica dell'Università, Bologna,
Istituto Nazionale di Fisica Nucleare, Sezione di Bologna, Italy

Received 10 February 1976

$$\Gamma_{\text{ann}}(1^{++}) \approx \frac{n}{3}\frac{128}{3\pi}\frac{\alpha_s^3}{M^4} |\phi_1'(0)|^2 \lg \frac{4m^2}{4m^2 - M^2}$$

The annihilation rates into hadrons of P-wave heavy quark-antiquark bound states are calculated within SU(3) colour gauge theory (in particular for the charm scheme). An interesting feature we find is a logarithmic divergence for small binding for the states 1^{++} and 1^{+-}. Implications for the asymptotic freedom approach to the decay rates of the new particles are discussed. An attempt to use quantitatively the obtained results for all the *C*-even P-waves gives $\Gamma_{\text{ann}}(0^{++}) : \Gamma_{\text{ann}}(2^{++}) : \Gamma_{\text{ann}}(1^{++}) \approx 15 : 4 : 1$.

$^3P_{0,1,2}$ parameter measurements

ELSEVIER

Physics Letters B 533 (2002) 237–242

PHYSICS LETTERS B

www.elsevier.com/locate/npe

E760

New measurements of the resonance parameters of the $\chi_{c0}(1^3P_0)$ state of charmonium

Available online at www.sciencedirect.com

SCIENCE DIRECT

ELSEVIER

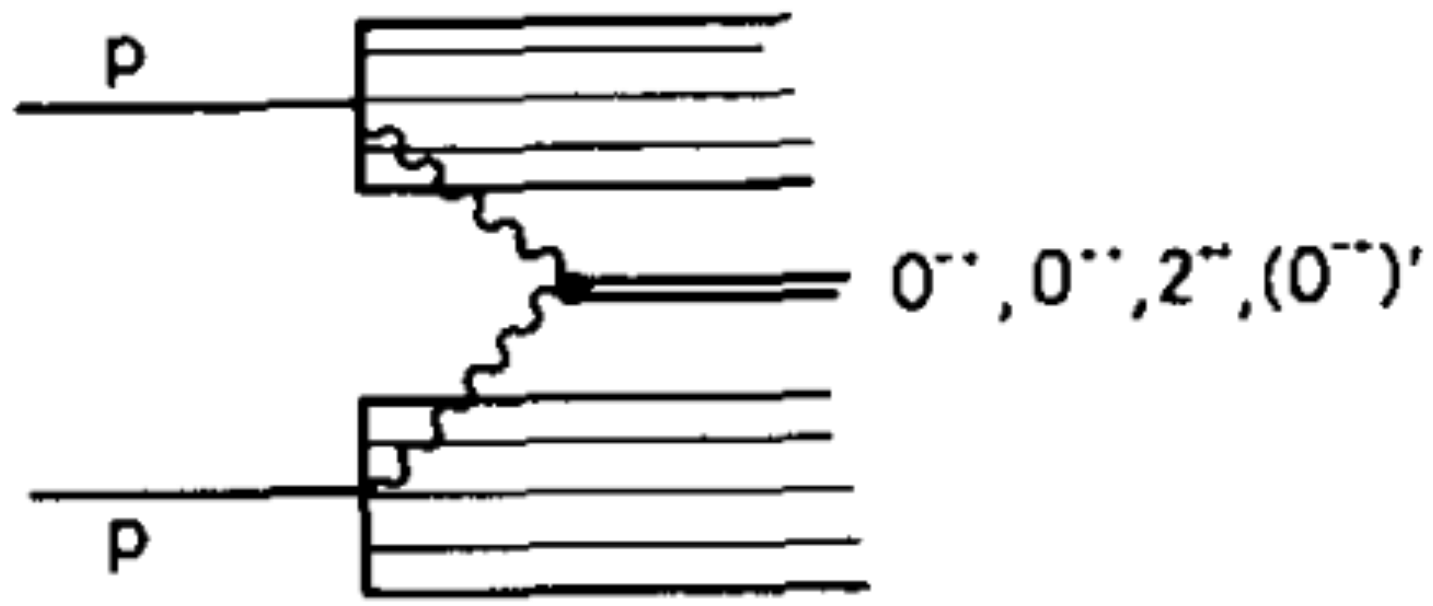
Nuclear Physics B 717 (2005) 34–47

NUCLEAR PHYSICS B

E385

Measurement of the resonance parameters of the $\chi_1(1^3P_1)$ and $\chi_2(1^3P_2)$ states of charmonium formed in antiproton–proton annihilations

Fermilab



About 30 years after the November revolution

CALCULATION OF THE ANNIHILATION RATE OF P WAVE QUARK-ANTIQUARK BOUND STATES

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R. BARBIERI and R. GATTO*
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First measured in 1986 at Crystal Ball (SLAC)

Now:

$$\Gamma(\chi_{c0}) = 10.5 \pm 0.6 \qquad \Gamma(\chi_{c2}) = 1.93 \pm 0.11 \qquad \Gamma(\chi_{c1}) = 0.84 \pm 0.04 \qquad MeV$$

$$\Gamma(0^{++}) : \Gamma(2^{++}) : \Gamma(1^{++}) = 12 : 2.4 : 1$$

Needed refinements

$\Rightarrow$ "Colour-singlet" model (+ NLO) $2m$

Relativistic, colour-octet, binding corrections

NRQCD $mv, \Lambda_{QCD}, mv^2, \ldots$

Strong Radiative Corrections to Annihilations of Quarkonia in QCD

Riccardo Barbieri (Pisa, Scuola Normale Superiore and INFN, Pisa), E. d'Emilio (Pisa, Scuola Normale Superiore and INFN, Pisa), G. Curci (CERN), E. Remiddi (Bologna U.) (Jan, 1979)

Published in: *Nucl.Phys.B* 154 (1979) 535-546

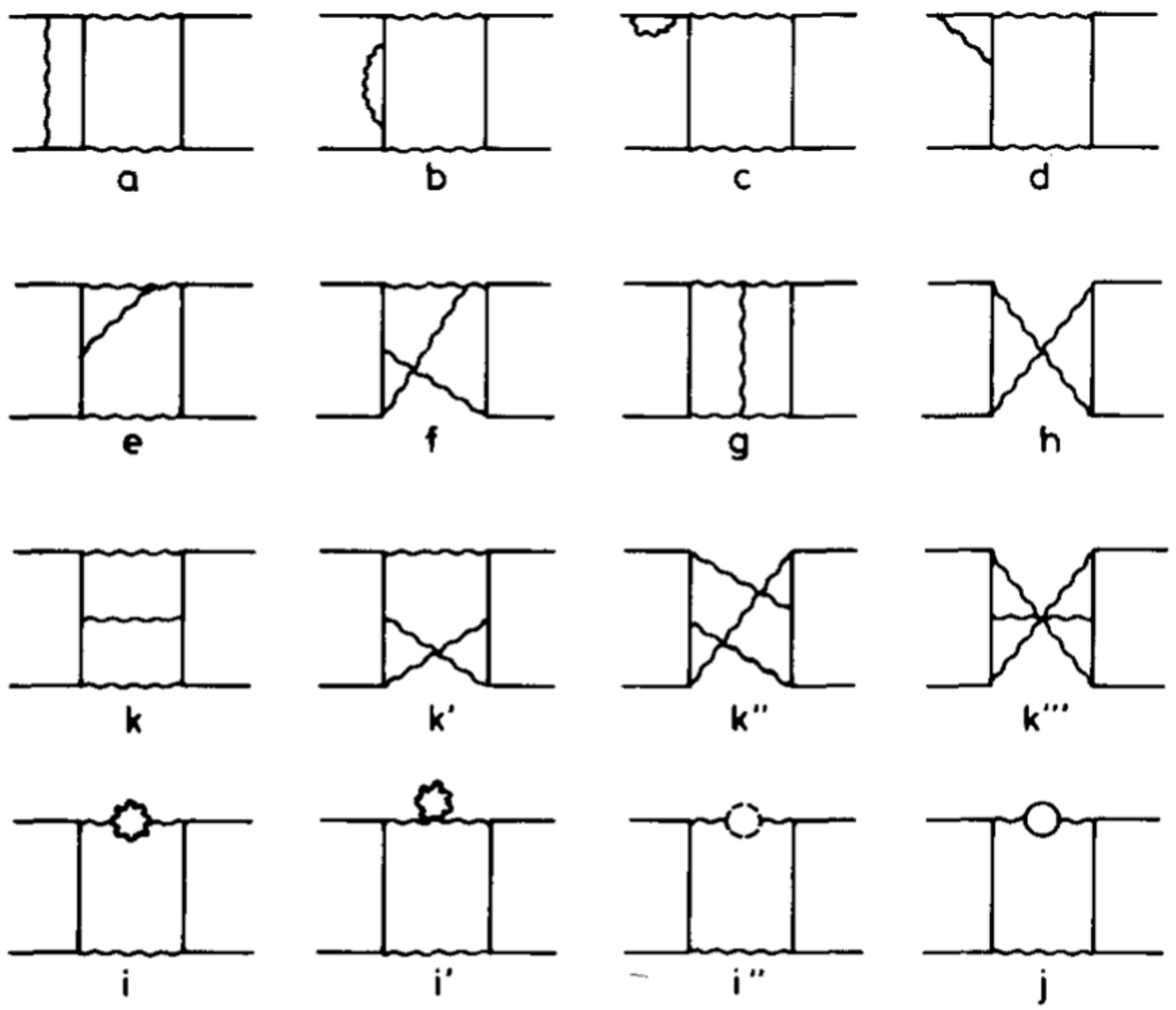
η_c

Strong QCD Corrections to p Wave Quarkonium Decays

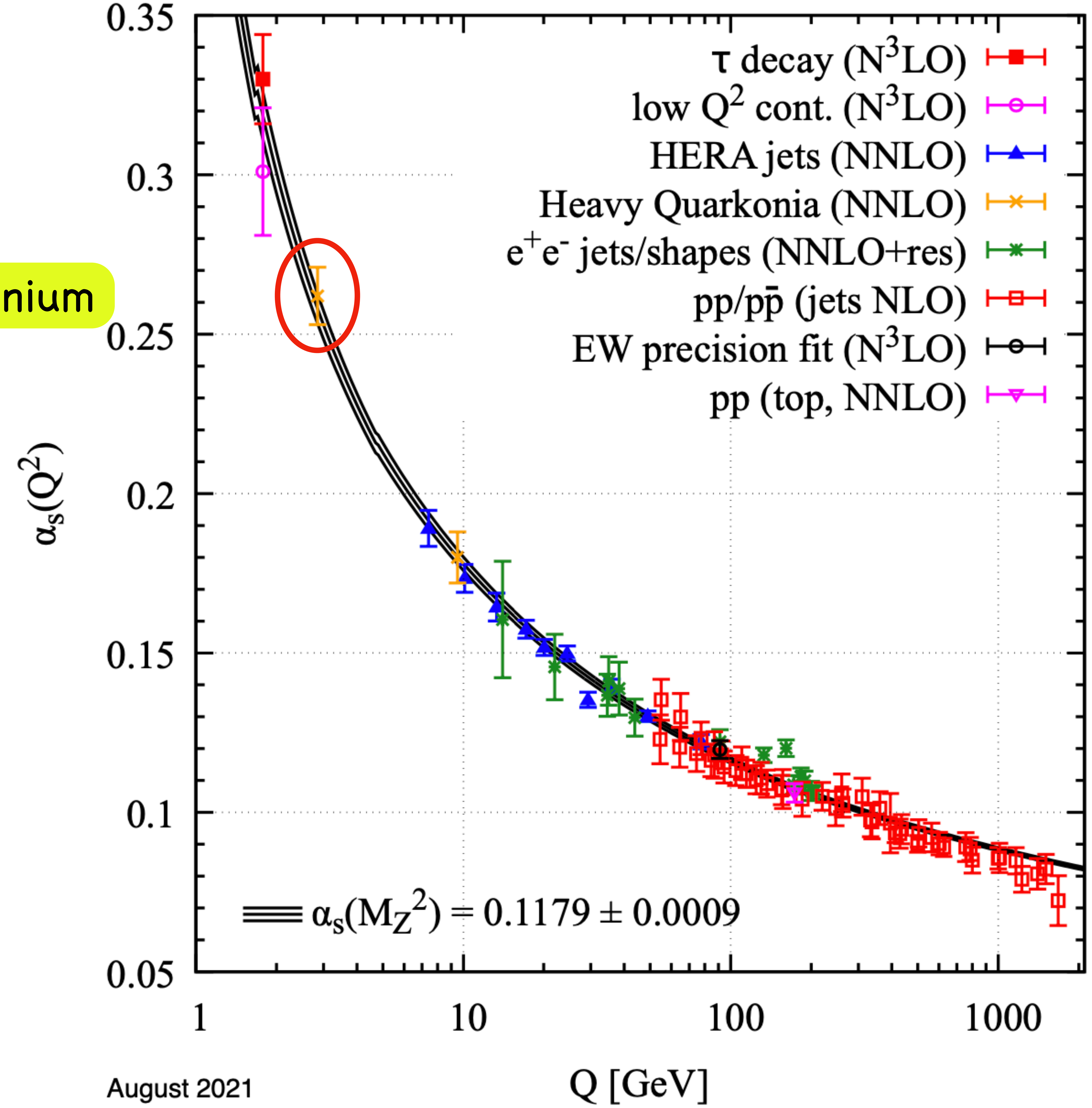
Riccardo Barbieri (CERN and Pisa, Scuola Normale Superiore), Michele Caffo (INFN, Bologna), Raoul Gatto (Geneva U.), E. Remiddi (Geneva U. and Bologna U. and INFN, Bologna) (Jul, 1980)

Published in: *Phys.Lett.B* 95 (1980) 93-95

χ_0, χ_2



Charmonium



PDG, 2021

Flavour in the “mid term” of BSM

1. A brief view on BSM (my biases)

2. Minimal Flavour Deconstruction

Observational

Questions from (problems for) the SM

Structural

0. Which rationale for matter quantum numbers?

E.g.: $|Q_n - Q_p - Q_e| < 10^{-21} e$

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? A discrete space-time symmetry?

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

neutrino masses

Are the protons forever?

Gravity

What about individual L_i conservations?

4. Lack of calculability

the hierarchy problem

the flavour puzzle

none of the 15 masses predicted in the SM

Observational

Questions from (problems for) the SM

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neutrino masses

Are the protons forever?

Gravity

What about individual L_i conservations?

4. Lack of calculability

$\Rightarrow$ the hierarchy problem, the flavour puzzle $\Leftarrow$ none of the 15 masses predicted in the SM

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

(and a strong motivation for the next HE collider)

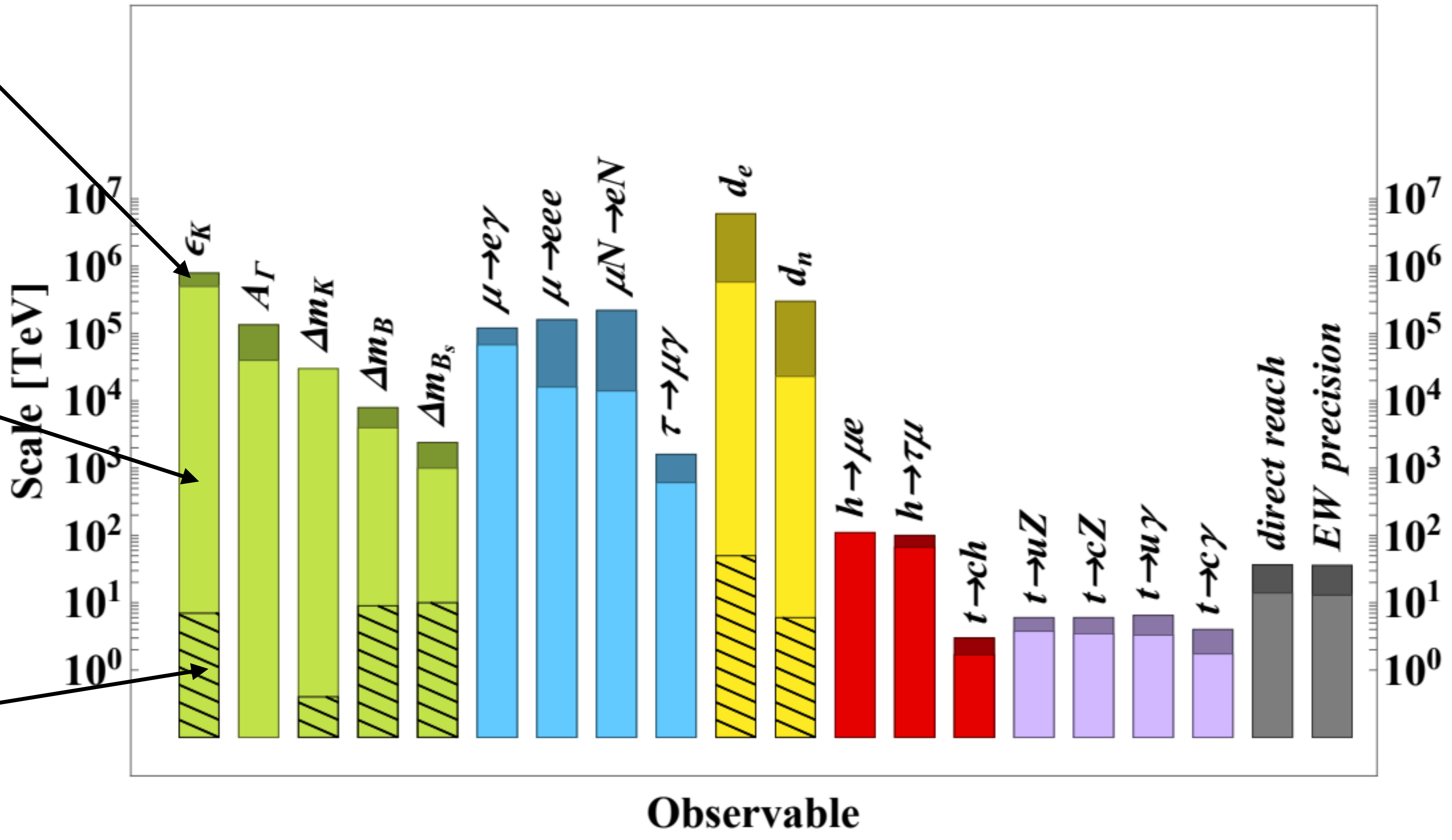
An extreme summary in precision measurements

(European Strategy for PP, 2020)

"Mid-term" prospects:
All approved exp.s + LHCb II

current
$$\mathcal{L} = \mathcal{L}_{SM} + \Sigma_i \frac{1}{\Lambda_i^2}\mathcal{O}_i$$

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



Flavour and EDMs (CPV) dominate

A more detailed plot

(from actually measured flavour quantities only)

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

$$Q_1^{q_iq_j} = \bar{q}_{jL}^{\alpha}\gamma_\mu q_{iL}^{\alpha}\bar{q}_{jL}^{\beta}\gamma^\mu q_{iL}^{\beta} \,,$$

$$Q_2^{q_iq_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jR}^{\beta} q_{iL}^{\beta} \,, \qquad Q_4^{q_iq_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha}\bar{q}_{jL}^{\beta} q_{iR}^{\beta} \,,$$

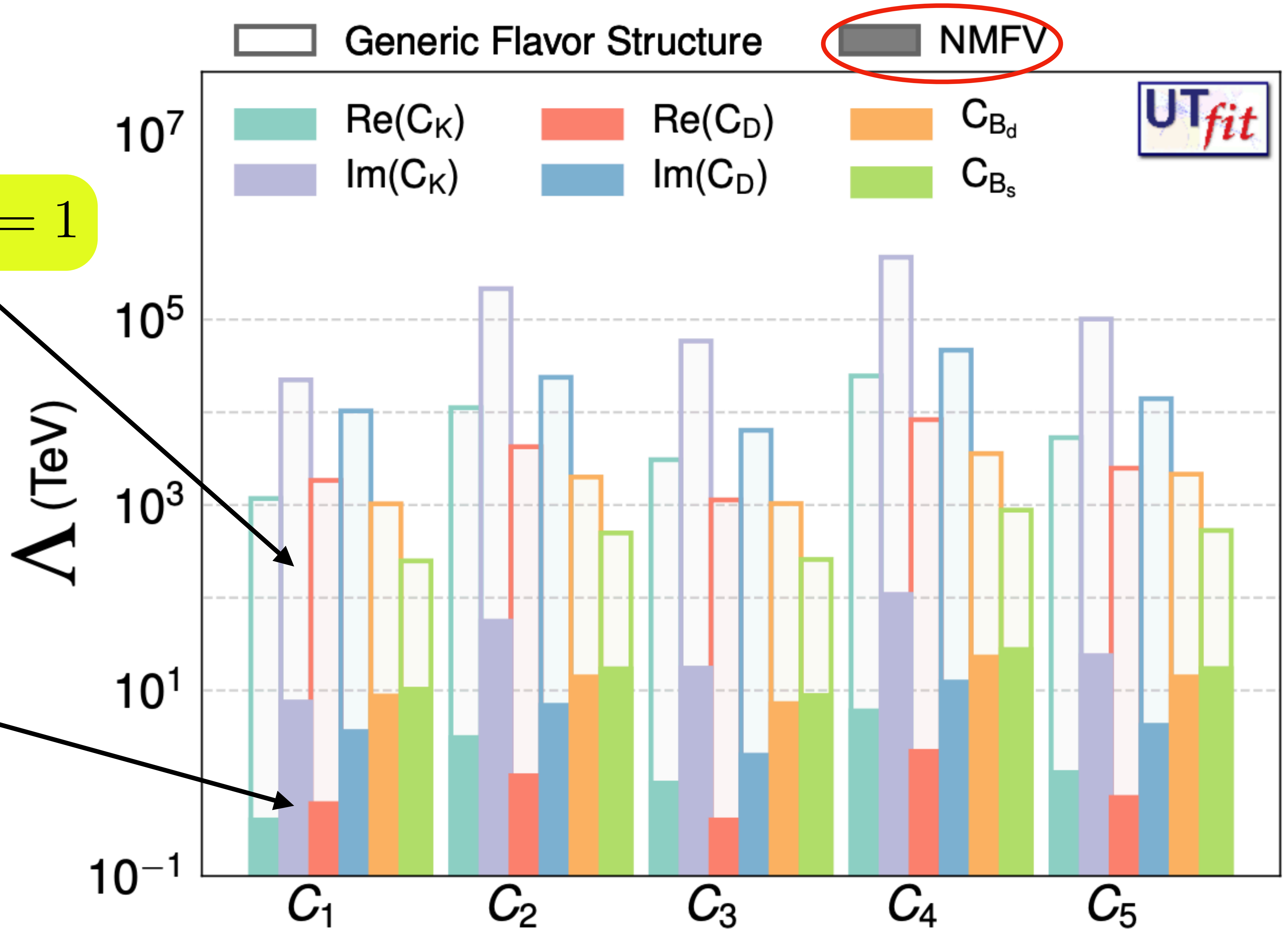
$$Q_3^{q_iq_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jR}^{\beta} q_{iL}^{\alpha} \,, \qquad Q_5^{q_iq_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\beta}\bar{q}_{jL}^{\beta} q_{iR}^{\alpha} \,.$$

$\mathcal{C}_i = 1$

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

$$F^{SM}(C_{K,D}) = (V_{td}V_{ts}^*)^2 e^{i\phi_{K,D}}$$

$$F^{SM}(C_{B_q}) = (V_{tq}V_{tb}^*)^2 e^{i\phi_{B_q}}$$



Pierini, 2023

Where is the actual scale of flavour physics Λ^f ?

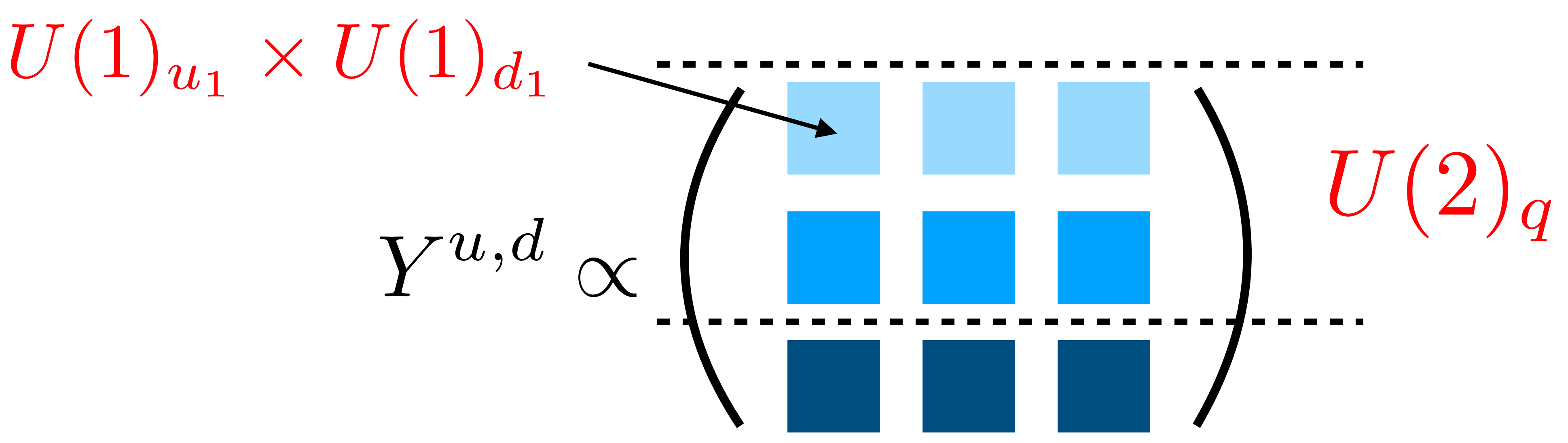
(approximate) symmetries of the Yukawa couplings

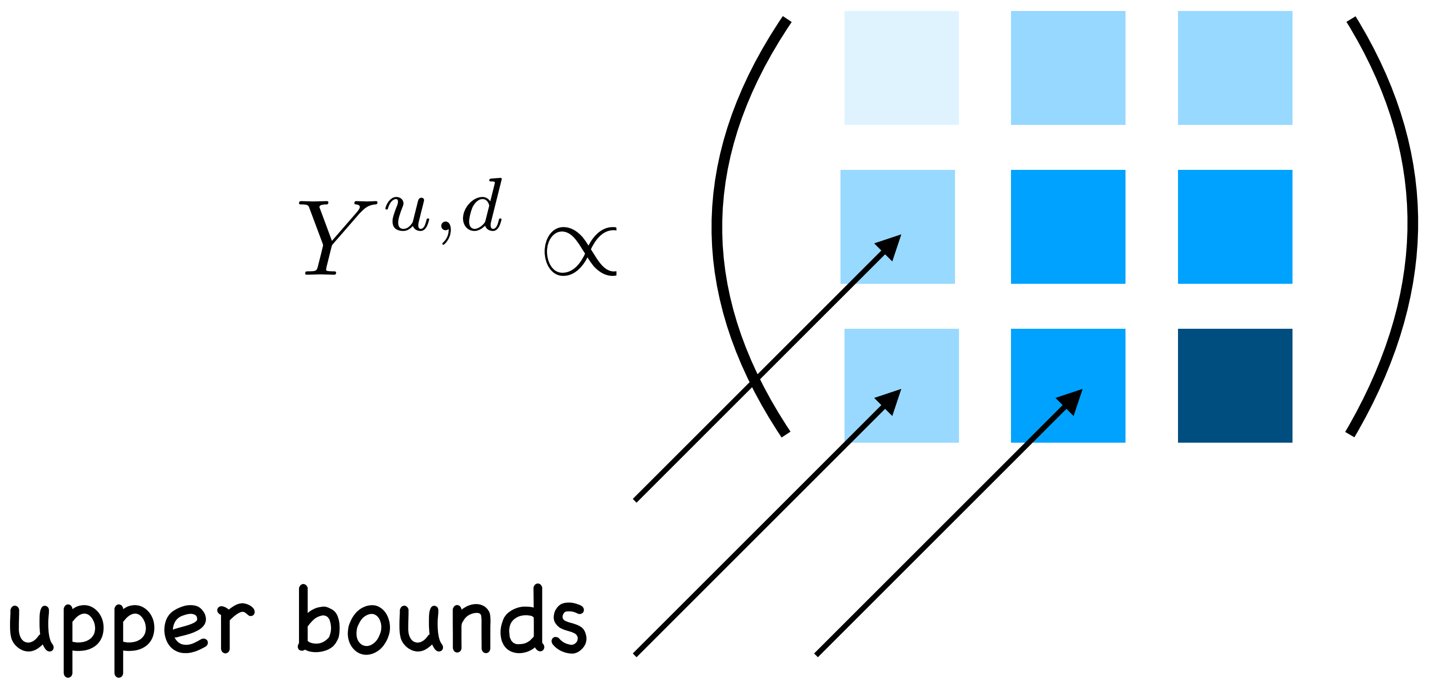
Charged fermion Yukawa couplings

$$Y \propto U_L^+ \begin{pmatrix} m_1/m_3 & 0 & 0 \\ 0 & m_2/m_3 & 0 \\ 0 & 0 & 1 \end{pmatrix} U_R \qquad m_1/m_3 << m_2/m_3 << 1 \qquad U_L^u (U_L^d)^+ = V_{CKM} \approx \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

1 IF $[U_L^{u,d}]_{i\neq j} \lesssim [V_{CKM}]_{i\neq j}$

2 IF 1 + $[U_R^{u,d}]_{i\neq j} \lesssim [U_L^{u,d}]_{i\neq j}$



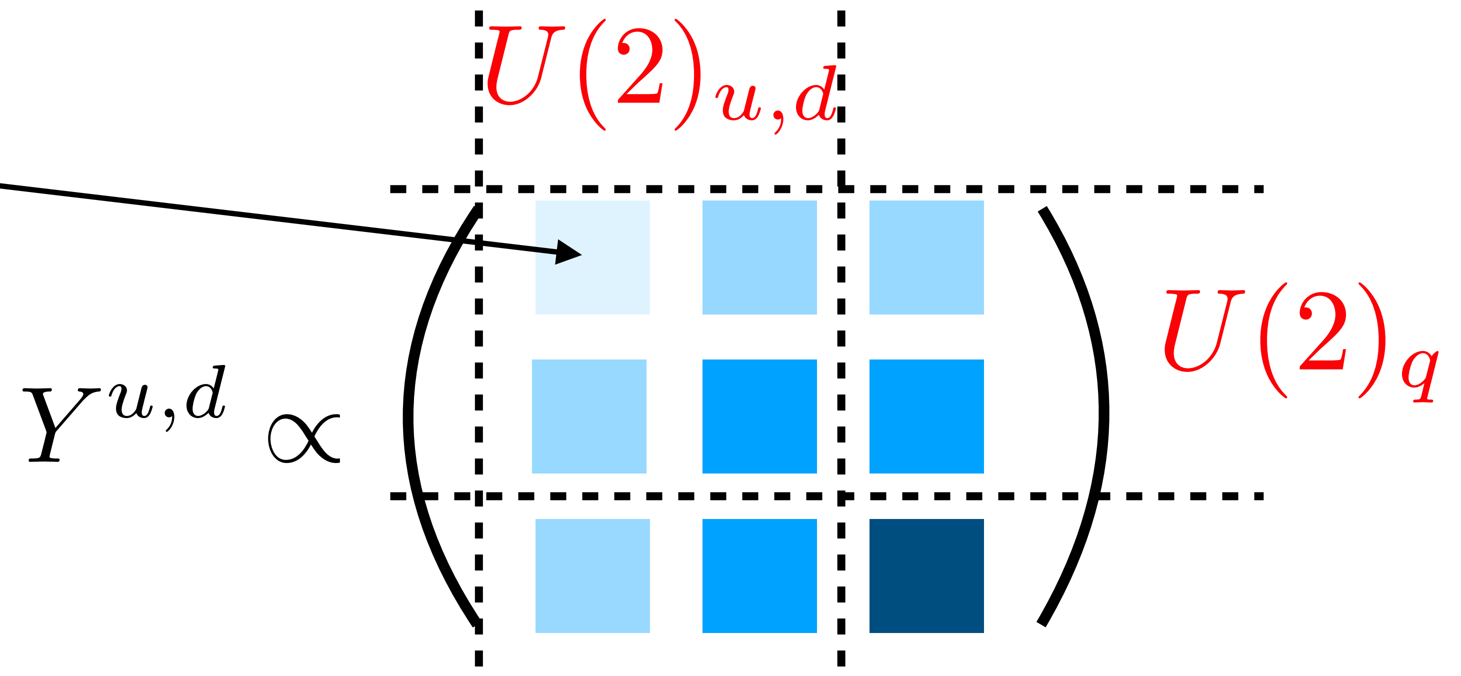


(approximate) symmetries of the Yukawa couplings

Charged fermion Yukawa couplings

IF $[U_L^{u,d}]_{i\neq j} \lesssim [V_{CKM}]_{i\neq j}$ and $[U_R^{u,d}]_{i\neq j} \lesssim [U_L^{u,d}]_{i\neq j}$

$U(1)_{u_1} \times U(1)_{d_1}$



B, Dvali, Hall, 1995

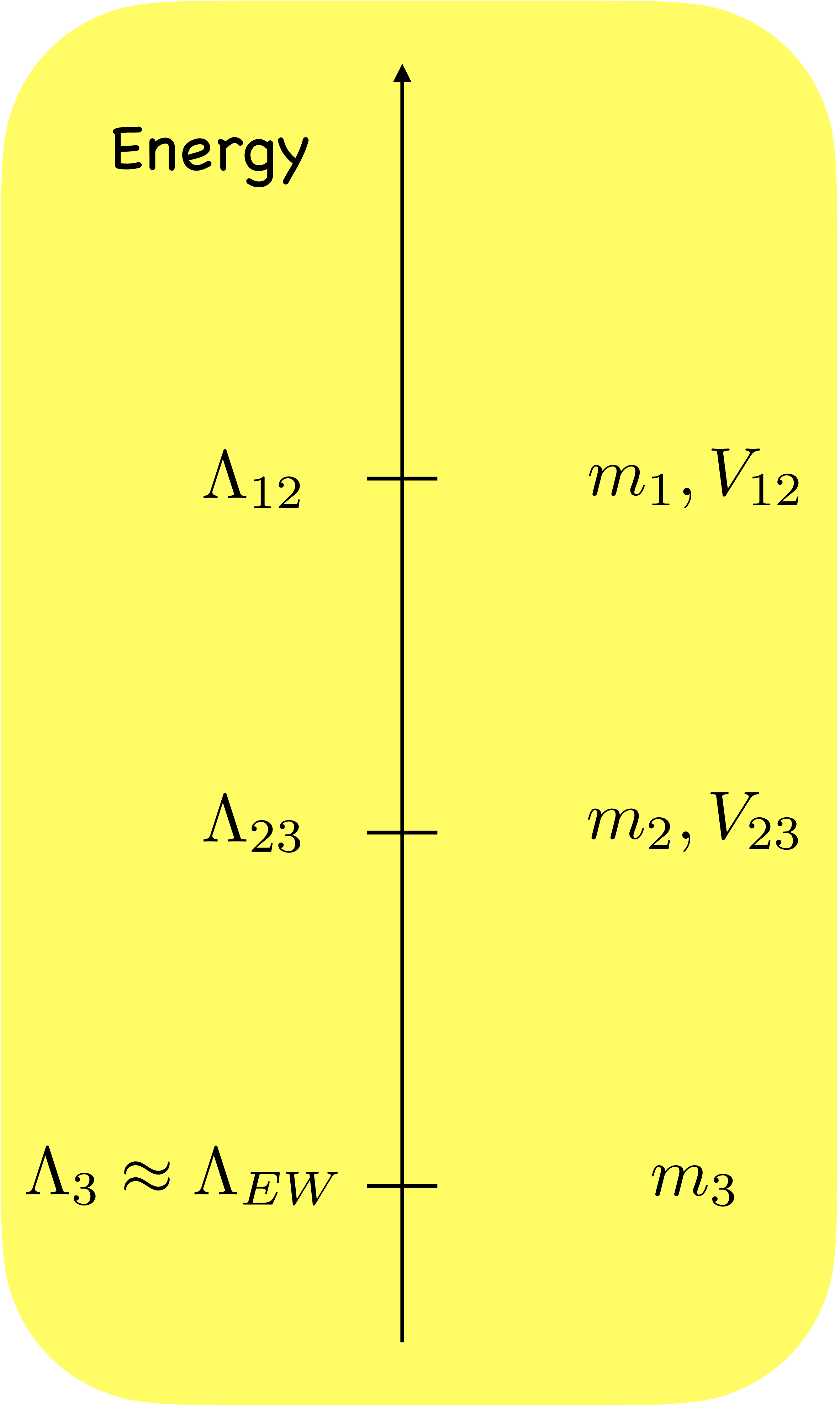
$\Rightarrow U(2)_q \times U(2)_u \times U(2)_d$

B, Isidori et al, 2011

Can $U(2)^n$ allow for Λ^f to be in the MultiTeV? YES, suitably broken

$\Rightarrow$ Can $U(2)^n$ and $U(1)^n$ emerge as accidental symmetries? What breaks them? $\Leftarrow$

Flavour non-universal interactions



A broad idea:

Lighter fermion masses generated at higher scales, protected by accidental symmetries due to

Flavour non-universal interactions

. . . .
Dvali, Shifman, 2000
. . . .
Panico, Pomarol, 2016
Bordone et al, 2017
B, 2021

In particular:

"Flavour Deconstruction" of the SM gauge symmetries

Davighi, Isidori, 2023
Davighi et al, 2023
Fernando-Navarro, King 2023

"Minimal Flavour Deconstruction" in 4d, explicit

B, Isidori, 2023

$$G = SU(3)\times SU(2)\times U(1)_Y^{[3]}\times U(1)_{B-L}^{[12]}\times U(1)_{T_{3R}}^{[2]}\times U(1)_{T_{3R}}^{[1]}$$

Scalars

Field	$U(1)_Y^{[3]}$	$U(1)_{B-L}^{[12]}$	$U(1)_{T_{3R}}^{[2]}$	$U(1)_{T_{3R}}^{[1]}$	$SU(3)\times SU(2)$
$H_{u,d}$	$-1/2$	0	0	0	$(\mathbf{1},\mathbf{2})$
χ^q	$-1/6$	$1/3$	0	0	$(\mathbf{1},\mathbf{1})$
χ^l	$1/2$	-1	0	0	$(\mathbf{1},\mathbf{1})$
ϕ	$1/2$	0	$-1/2$	0	$(\mathbf{1},\mathbf{1})$
σ	0	0	$1/2$	$-1/2$	$(\mathbf{1},\mathbf{1})$

VectorLike fermions

		$U(1)_Y^{[3]}$	$U(1)_{B-L}^{[12]}$	$U(1)_{T_{3R}}^{[2]}$	$U(1)_{T_{3R}}^{[1]}$	$SU(3)\times SU(2)$
light VL ($\alpha=1,2$)	U_α	$1/2$	$1/3$	0	0	$(\mathbf{3},\mathbf{1})$
	D_α	$-1/2$	$1/3$	0	0	$(\mathbf{3},\mathbf{1})$
	E_α	$-1/2$	-1	0	0	$(\mathbf{1},\mathbf{1})$
heavy VL	U_3	0	$1/3$	$1/2$	0	$(\mathbf{3},\mathbf{1})$
	D_3	0	$1/3$	$-1/2$	0	$(\mathbf{3},\mathbf{1})$
	E_3	0	-1	$-1/2$	0	$(\mathbf{1},\mathbf{1})$

(a 16-plet/generation with neutrinos)

Most general $d\leq 4$

$$\mathcal{L}_Y^u = (y_3^u\,\bar q_3 u_3 H_u + y_{i\alpha}^u\,\bar q_i U_\alpha H_u + y_\alpha^{\chi_u}\,\bar U_\alpha u_3\chi^q + y_{\alpha 2}^{\phi_u}\,\bar U_\alpha u_2\phi + y_{\alpha 3}^{\phi_u}\,\bar U_{R\alpha}U_{L3}\phi + \hat y_{\alpha 3}^{\phi_u}\,\bar U_{L\alpha}U_{R3}\phi + y_1^{\sigma_u}\,\bar U_3 u_1\sigma + \text{h.c.}) + M_{U_3}\,\bar U_3 U_3 + M_{U_\alpha}\,\bar U_\alpha U_\alpha$$

And similarly for $Y_{d,e}$ with $H_u\to H_d$

The overall picture

gauge

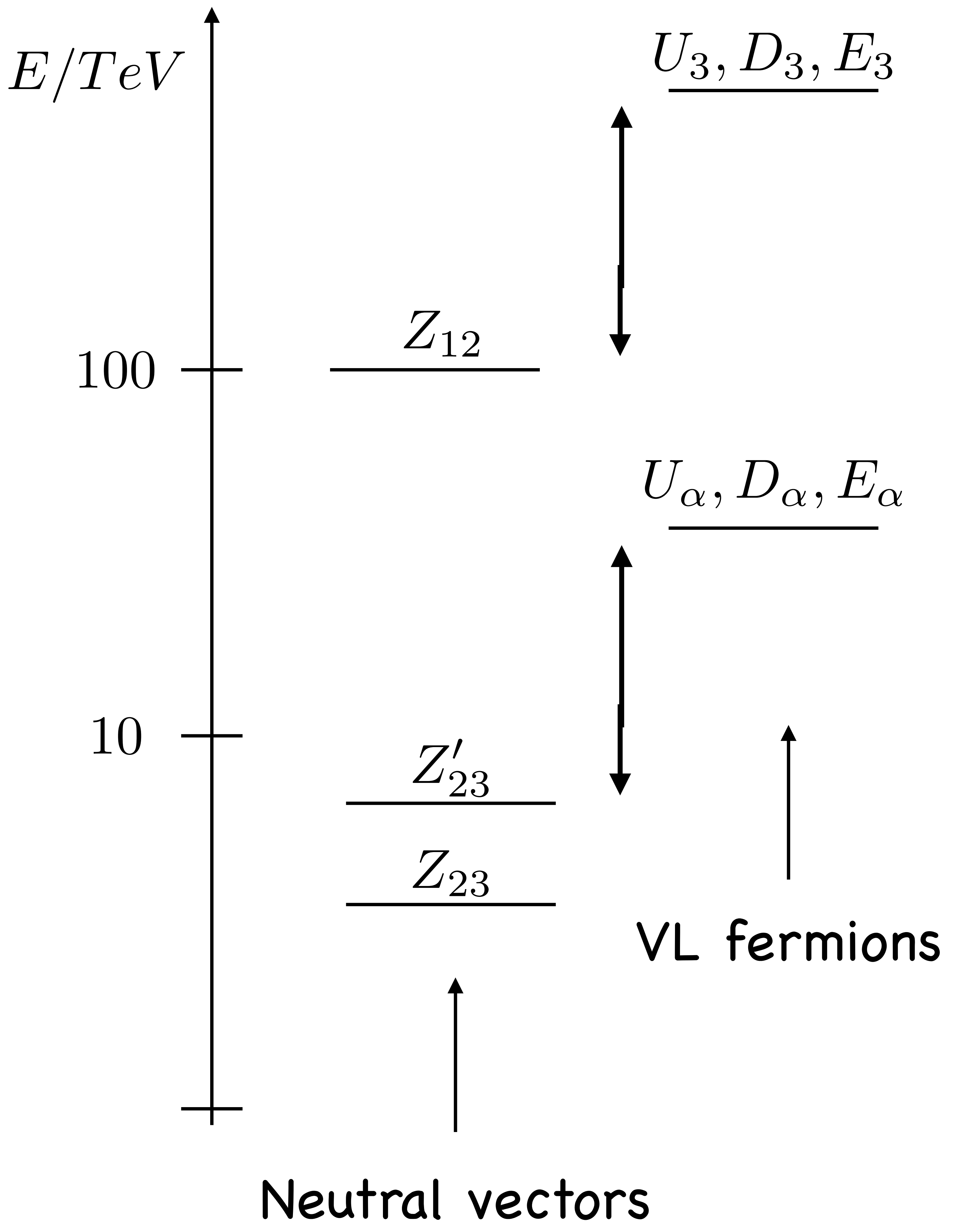
$U(1)_Y^{[3]} \times U(1)_{B-L}^{[12]} \times U(1)_{T_{3R}}^{[2]} \times U(1)_{T_{3R}}^{[1]}$

$U(1)_Y^{[3]} \times U(1)_{B-L}^{[12]} \times U(2)_{T_{3R}}^{[12]}$

$U(1)_Y$

Universal $SU(3) \times SU(2)$

left understood



global (accidental)

$U(1)_{u_1} \times U(1)_{d_1} \times U(1)_{e_1}$

$U(2)_q \times U(2)_u \times U(2)_d \times U(2)_l \times U(2)_e$

Universal $U(1)_B \times U(1)_L$

left understood

Yukawa couplings

Most general $d \leq 4$

$$\mathcal{L}_Y^u = (y_3^u \, \bar{q}_3 u_3 H_u + y_{i\alpha}^u \, \bar{q}_i U_\alpha H_u + y_\alpha^{\chi_u} \, \bar{U}_\alpha u_3 \chi^q + y_{\alpha 2}^{\phi_u} \, \bar{U}_\alpha u_2 \phi + y_{\alpha 3}^{\phi_u} \, \bar{U}_{R\alpha} U_{L3} \phi + \hat{y}_{\alpha 3}^{\phi_u} \, \bar{U}_{L\alpha} U_{R3} \phi + y_1^{\sigma_u} \, \bar{U}_3 u_1 \sigma + \text{h.c.}) + M_{U_3} \, \bar{U}_3 U_3 + M_{U_\alpha} \, \bar{U}_\alpha U_\alpha$$

By integrating out the VL fermions

$$\Rightarrow \quad Y_u \approx \begin{pmatrix} y_{1\alpha}^u \hat{y}_{\alpha 3}^{\phi_u} y_1^{\sigma_u} \epsilon_\sigma \epsilon_\phi & y_{1\alpha}^u y_{\alpha 2}^{\phi_u} \epsilon_\phi & y_{12}^u y_2^{\chi_u} \epsilon_\chi \\ y_{2\alpha}^u \hat{y}_{\alpha 3}^{\phi_u} y_1^{\sigma_u} \epsilon_\sigma \epsilon_\phi & y_{2\alpha}^u y_{\alpha 2}^{\phi_u} \epsilon_\phi & y_{22}^u y_2^{\chi_u} \epsilon_\chi \\ \approx 0 & \approx 0 & y_3^u \end{pmatrix}$$

$$\epsilon_\chi = \frac{\langle \chi \rangle}{M_\alpha} \qquad \epsilon_\phi = \frac{\langle \phi \rangle}{M_\alpha} \qquad \epsilon_\sigma = \frac{\langle \sigma \rangle}{M_3}$$

And similarly for $Y_{d,e}$

Yukawa couplings

$\Rightarrow$

$$Y_u \approx \begin{pmatrix} y^u_{1\alpha}\hat{y}^{\phi_u}_{\alpha 3} y^{\sigma_u}_1 \epsilon_\sigma \epsilon_\phi & y^u_{1\alpha} y^{\phi_u}_{\alpha 2}\epsilon_\phi & y^u_{12} y^{\chi_u}_2 \epsilon_\chi \\ y^u_{2\alpha}\hat{y}^{\phi_u}_{\alpha 3} y^{\sigma_u}_1 \epsilon_\sigma \epsilon_\phi & y^u_{2\alpha} y^{\phi_u}_{\alpha 2}\epsilon_\phi & y^u_{22} y^{\chi_u}_2 \epsilon_\chi \\ \approx 0 & \approx 0 & y^u_3 \end{pmatrix}$$

$$\epsilon_\chi = \frac{\langle\chi\rangle}{M_\alpha} \qquad \epsilon_\phi = \frac{\langle\phi\rangle}{M_\alpha} \qquad \epsilon_\sigma = \frac{\langle\sigma\rangle}{M_3}$$

And similarly for $Y_{d,e}$

All charged fermion masses and V_{CKM} reproduced with

$$\frac{v_u}{v_d} \approx 10 \qquad \epsilon_\chi, \epsilon_\phi, \epsilon_\sigma = (0.5 \div 2)\cdot 10^{-1} \quad \text{and} \quad y's = 0.1 \div 1$$

$\Rightarrow$ $U^{u,d,e}_L \approx V_{CKM} \quad (U^u_L U^{d+}_L = V_{CKM})$ $\qquad [U^{u,d,e}_R]_{i\neq j} << [U^{u,d,e}_L]_{i\neq j}$

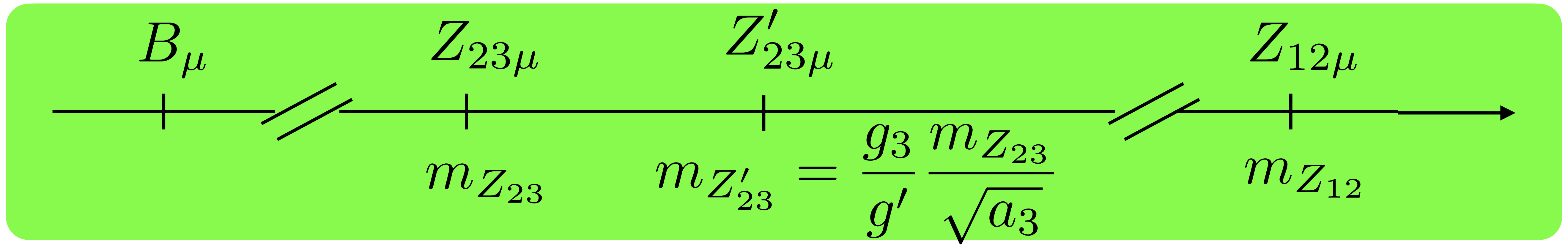
Vector masses and couplings

B, 2024

$$D_\mu \equiv \partial_\mu - i\left(g_3 Y^{[3]} A_{3\mu} + g_B \frac{(B-L)^{[12]}}{2} A_{B\mu} + g_2 T_{3R}^{[2]} A_{2\mu} + g_1 T_{3R}^{[1]} A_{1\mu}\right)$$

Take $\langle\sigma\rangle >> \langle\chi\rangle, \langle\phi\rangle \equiv \sqrt{b}\langle\chi\rangle$ and $g_3 >> g_B, g_2, g_1$ Define $\frac{g_B\sqrt{g_1^2+g_2^2}}{g_1 g_2} = \tan\alpha \equiv t_\alpha$

Before EWSB



$$a_3 = \frac{b(1+t_\alpha^2)^2}{t_\alpha^2(1+b)^2}$$

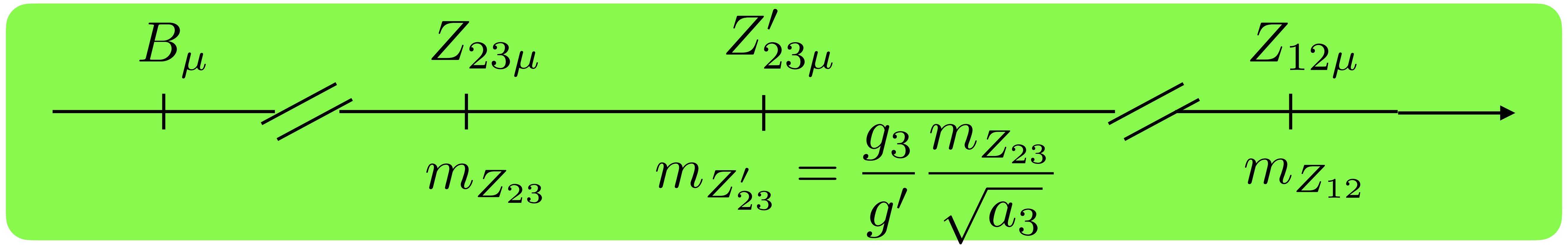
$$a_{23} = \frac{1-bt_\alpha^2}{t_\alpha(1+b)}$$

$$D_\mu(B, Z_{23}, Z'_{23}) = -i\left[g' B_\mu Y + g' Z_{23\mu}\left(a_{23} Y^{[3]} + \frac{1}{t_\alpha}\frac{(B-L)^{[12]}}{2} - t_\alpha T_{3R}^{[12]}\right) + g_3 Z'_{23\mu} Y^{[3]}\right]$$

Vector masses and couplings

B, 2024

Before EWSB



$$D_\mu(B, Z_{23}, Z'_{23}) = -i[g' B_\mu Y + g' Z_{23\mu}(a_{23} Y^{[3]} + \frac{1}{t_\alpha}\frac{(B-L)^{[12]}}{2} - t_\alpha T_{3R}^{[12]}) + g_3 Z'_{23\mu} Y^{[3]}]$$

$$a_3 = \frac{b(1+t_\alpha^2)^2}{t_\alpha^2(1+b)^2} \qquad a_{23} = \frac{1-bt_\alpha^2}{t_\alpha(1+b)}$$

After EWSB

$$\mathcal{L}_H^{gauge} = |(\partial_\mu - ig\vec{T}\cdot\vec{W}_\mu - ig_3 Y^{[3]} A_{3\mu})H|^2$$

$$\frac{\delta m_Z^2}{m_Z^2} \equiv s_W^2 \frac{m_Z^2}{m_{Z_{23}}^2}(a_{23}^2 + a_3)$$ and $$\delta D_\mu(Z) = -iZ_\mu g' s_W \frac{m_Z^2}{m_{Z_{23}}^2}[(a_{23}^2 + a_3)Y^{[3]} + a_{23}(\frac{1}{t_\alpha}\frac{(B-L)^{[12]}}{2} - t_\alpha T_{3R}^{[12]})]]$$

Parameters at the lowest new scale $m_{Z_{23}}; \quad t_\alpha, b$

Phenomenology at the lowest new scale 1

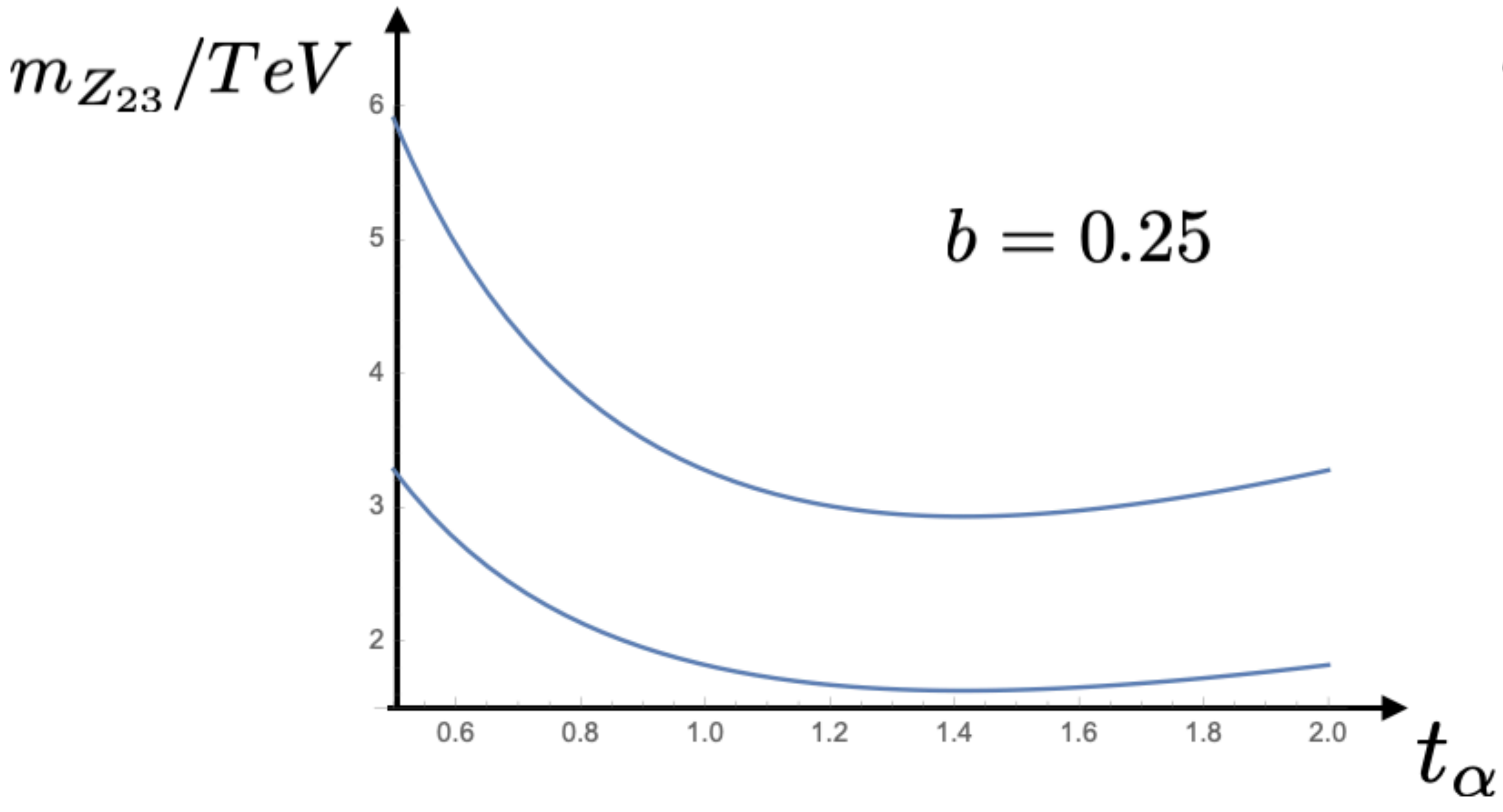
B, 2024

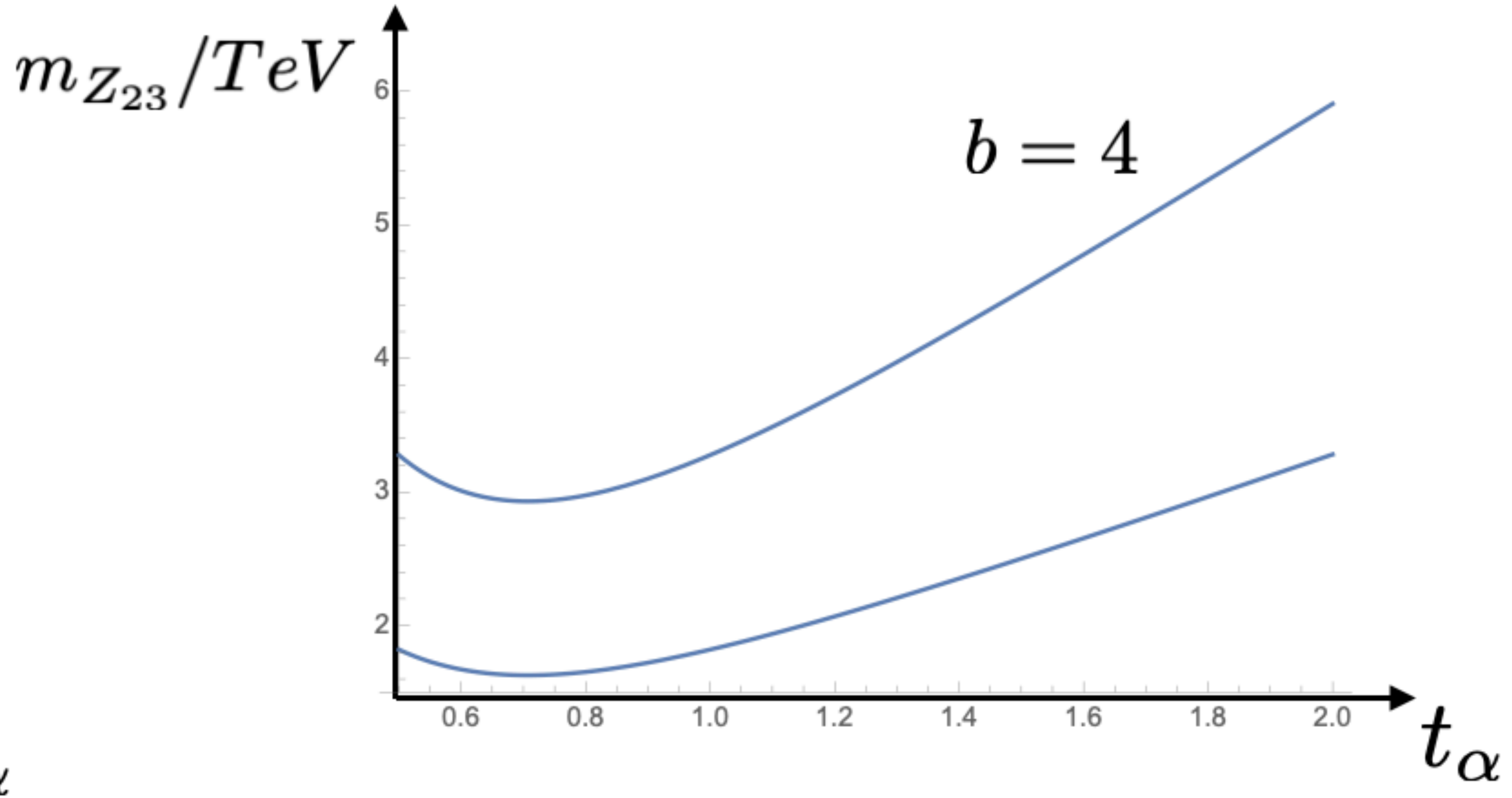
EWPT

$$\frac{\delta m_Z^2}{m_Z^2} \equiv s_W^2 \frac{m_Z^2}{m_{Z_{23}}^2}(a_{23}^2 + a_3) \qquad \frac{\delta m_Z^2}{m_Z^2} = (\frac{m_Z(SM)}{m_Z(exp)})^2 - 1 = (38 \pm 20) \cdot 10^{-5}$$

De Blas et al, 2022

To reproduce the 1σ interval above





Phenomenology at the lowest new scale 2

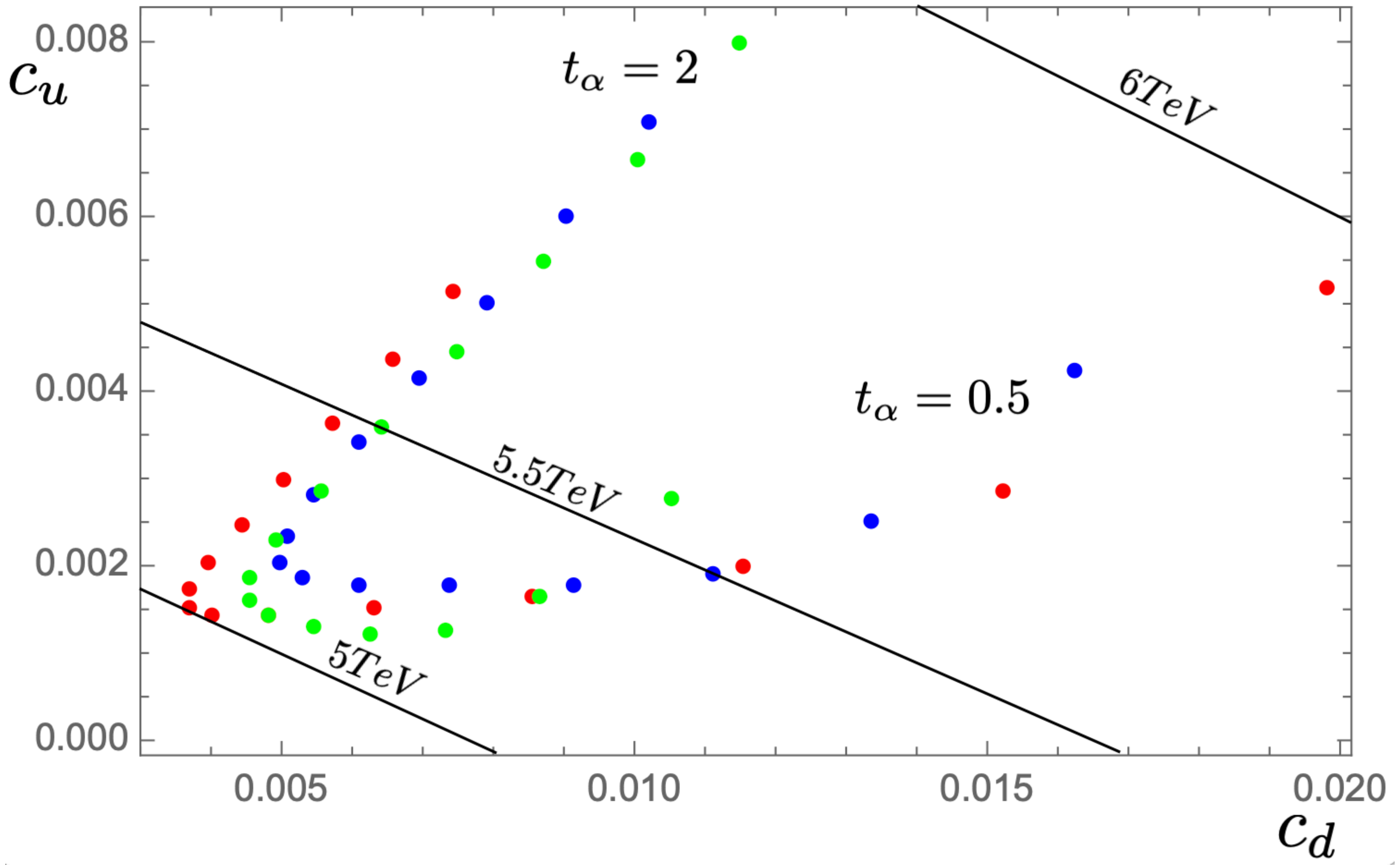
High-p_T Drell-Yan $pp \to l^+ l^-, \quad l = e, \mu$

Defining $c_u = g'^2 (g_L^{u2} + g_R^{u2}) Br_{Z_{23}}(l^+ l^-), \quad c_d = g'^2 (g_L^{d2} + g_R^{d2}) Br_{Z_{23}}(l^+ l^-)$

from Z_{23} exchange $c_u w_u + c_d w_d = \frac{6}{\pi} \sigma_{l^+ l^-}$

ATLAS, CMS $140 fb^{-1}$

Current lower bound on $m_{Z_{23}}$



b=0.25

b=1

b=4

Phenomenology at the lowest new scale 3

Flavour Changing effects $\Delta F = 2, b \to sll, K \to \pi\nu\nu, \tau \to 3\mu, \mu \to 3e, etc$

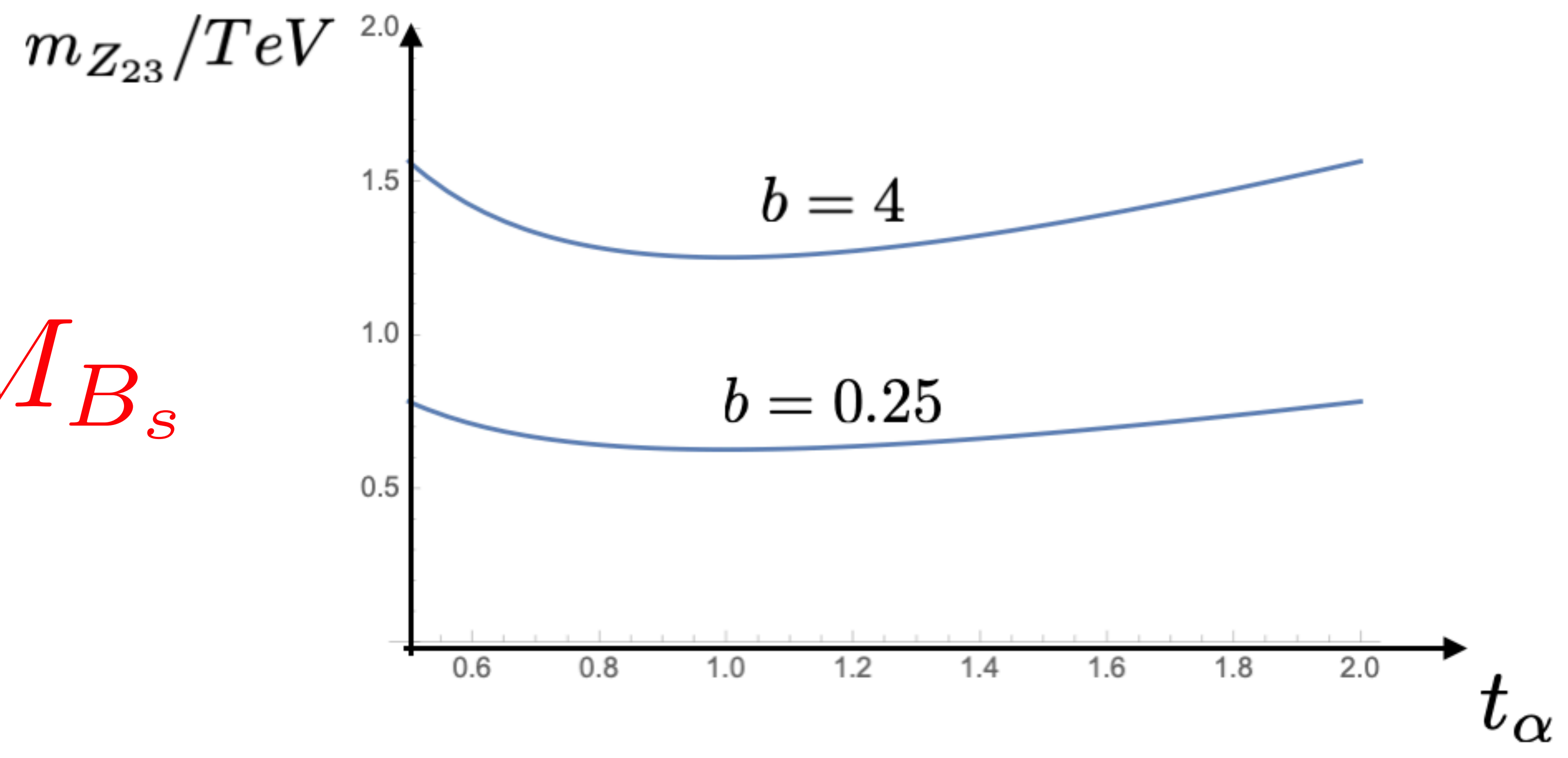
From the different couplings of Z, Z_{23}, Z'_{23} to the third generation versus the first two, after going to the mass basis: $f_L = U^f_L f^{(0)}_L, f_R \approx f^{(0)}_R$

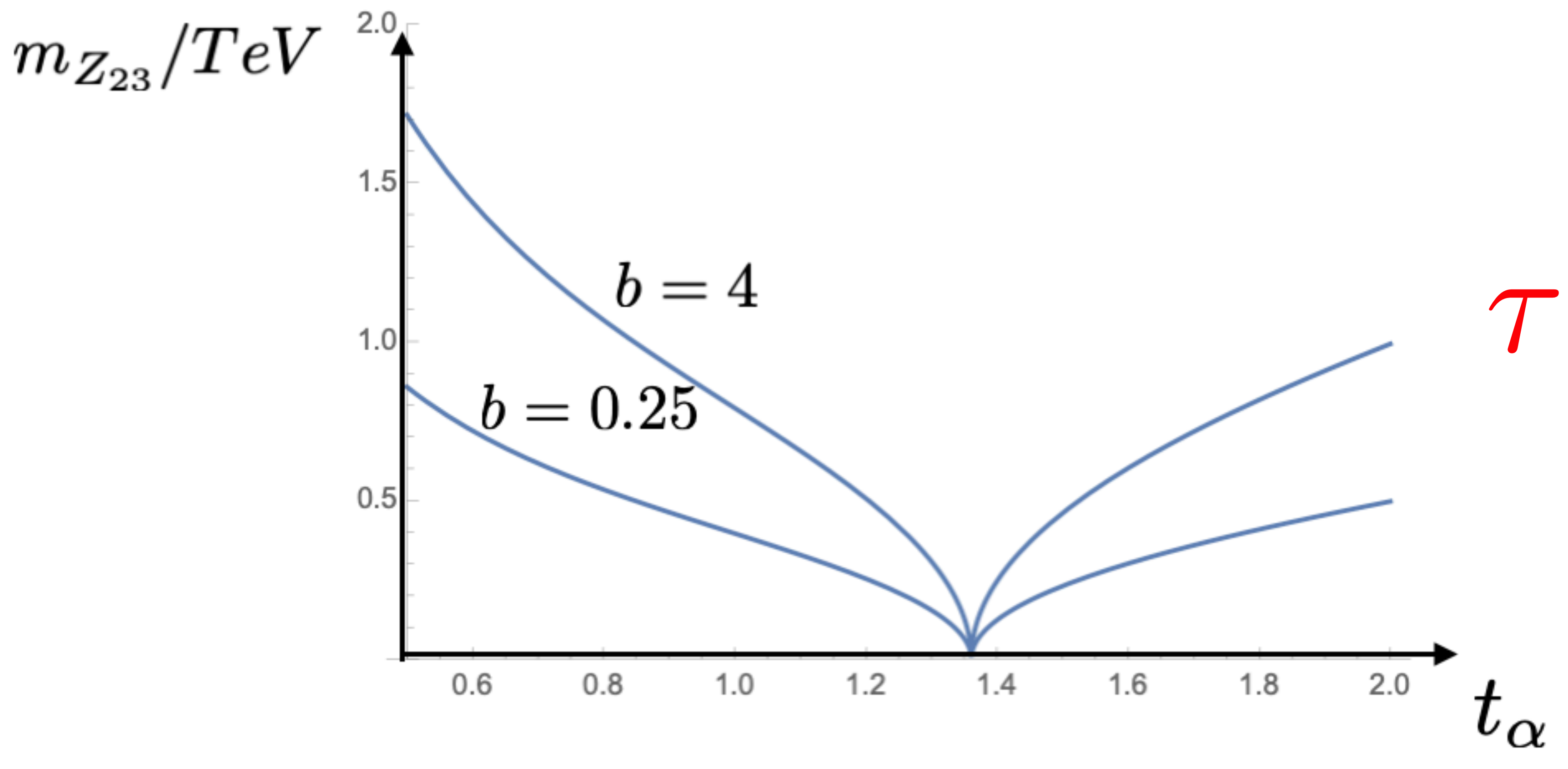
$$\mathcal{L}^{(FC)} = [g'(a_{23} - \frac{1}{t_\alpha})Z_{23\mu} + g_3 Z'_{23\mu} + s_W g' \frac{m^2_Z}{m^2_{Z_{23}}}(a^2_{23} - \frac{a_{23}}{t_\alpha} + a_3)Z_\mu]J^\mu,$$

$$J^\mu = \frac{1}{6}J^\mu_u + \frac{1}{6}J^\mu_d - \frac{1}{2}J^\mu_e, \qquad J^\mu_f = \Sigma_{i\neq j}[U^f_L]_{i3}[U^f_L]^*_{j3}\bar{f}_{Li}\gamma^\mu f_{Lj}$$

Current lower bounds on $m_{Z_{23}}$ with $U^e_L = U^d_L = V^+_{CKM}$

ΔM_{B_s}





$\tau \to 3\mu$

Flavour precision tests, a partial list (2022)

Input	Reference	Measurement	UT*fit* Prediction	Pull
$\sin 2\beta$	[22], **UT*fit***	0.688(20)	0.736(28)	−1.4
γ	[22]	66.1(3.5)	64.9(1.4)	+0.29
α	**UT*fit***	94.9(4.7)	92.2(1.6)	+0.6
$\varepsilon \cdot 10^3$	[38]	2.228(1)	2.00(15)	+1.56
$\lvert V_{ud}\rvert$	**UT*fit***	0.97433(19)	0.9738(11)	+0.03
$\lvert V_{ub}\rvert \cdot 10^3$ •	**UT*fit***	3.77(24)	3.70(11)	+0.25
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	[39]	3.74(17)		
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	[22]	4.32(29)		
$\lvert V_{cb}\rvert \cdot 10^3$ •	**UT*fit***	41.25(95)	42.22(51)	−0.59
$\lvert V_{cb}\rvert \cdot 10^3$ (excl)	**UT*fit***	39.44(63)		
$\lvert V_{cb}\rvert \cdot 10^3$ (incl)	[40]	42.16(50)		
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	[39]	0.0844(56)		
$\Delta M_d \times 10^{12}\,\mathrm{s}^{-1}$	[38]	0.5065(19)	0.519(23)	−0.49
$\Delta M_s \times 10^{12}\,\mathrm{s}^{-1}$	[38]	17.741(20)	17.94(69)	−0.30
$\mathrm{BR}(B_s \to \mu\mu) \times 10^9$	[38]	3.41(29)	3.47(14)	−0.14
$\mathrm{BR}(B \to \tau\nu) \times 10^4$	[38]	1.06(19)	0.869(47)	+0.96
$\mathrm{Re}\,(\varepsilon'/\varepsilon) \times 10^4$	[38]	16.6(3.3)	15.2(4.7)	+0.27
$(\lvert q/p\rvert_D - 1) \times 10^2$		0.05(2.50)	0.8(4.0)	−0, 15
$BR(B^+ \to K^+\nu\nu)10^6$		23(7)	5.58(37)	+2.5
$BR(K^+ \to \pi^+\nu\nu)10^{11}$		10.6(4.0)	9.31(76)	+0, 3
R_D		0.344(26)	0.298(4)	+1.7
R_{D^*}		0.285(12)	0.254(5)	+2.3

UTfit Collaboration

with some little integration

(No EDM's, $\mu \to e\gamma$, etc.)

Current precision

Input	Reference	Measurement	UTfit Prediction	Pull	current
$\sin 2\beta$	[22], **UT**fit	0.688(20)	0.736(28)	−1.4	4%th/exp
γ	[22]	66.1(3.5)	64.9(1.4)	+0.29	5%exp
α	**UT**fit	94.9(4.7)	92.2(1.6)	+0.6	5%exp
$\varepsilon \cdot 10^3$	[38]	2.228(1)	2.00(15)	+1.56	8%th
$\|V_{ud}\|$	**UT**fit	0.97433(19)	0.9738(11)	+0.03	0.1%th
$\|V_{ub}\| \cdot 10^3$ •	**UT**fit	3.77(24)	3.70(11)	+0.25	8%exp/th
$\|V_{ub}\| \cdot 10^3$ (excl)	[39]	3.74(17)			
$\|V_{ub}\| \cdot 10^3$ (incl)	[22]	4.32(29)			
$\|V_{cb}\| \cdot 10^3$ •	**UT**fit	41.25(95)	42.22(51)	−0.59	2%exp/th
$\|V_{cb}\| \cdot 10^3$ (excl)	**UT**fit	39.44(63)			
$\|V_{cb}\| \cdot 10^3$ (incl)	[40]	42.16(50)			
$\|V_{ub}\|/\|V_{cb}\|$	[39]	0.0844(56)			
$\Delta M_d \times 10^{12}\,\mathrm{s}^{-1}$	[38]	0.5065(19)	0.519(23)	−0.49	5%th/exp
$\Delta M_s \times 10^{12}\,\mathrm{s}^{-1}$	[38]	17.741(20)	17.94(69)	−0.30	4%th
$\mathrm{BR}(B_s \to \mu\mu) \times 10^9$	[38]	3.41(29)	3.47(14)	−0.14	9%exp
$\mathrm{BR}(B \to \tau\nu) \times 10^4$	[38]	1.06(19)	0.869(47)	+0.96	20%exp
$\mathrm{Re}\,(\varepsilon'/\varepsilon) \times 10^4$	[38]	16.6(3.3)	15.2(4.7)	+0.27	30%th
$(\|q/p\|_D - 1) \times 10^2$		0.05(2.50)	0.8(4.0)	−0, 15	100%th*
$BR(B^+ \to K^+\nu\nu)10^6$		23(7)	5.58(37)	+2.5	35%exp
$BR(K^+ \to \pi^+\nu\nu)10^{11}$		10.6(4.0)	9.31(76)	+0, 3	40%exp
R_D		0.344(26)	0.298(4)	+1.7	8%exp
R_{D^*}		0.285(12)	0.254(5)	+2.3	4%exp

Ciao.

Conceivable progress in the "mid-term" of flavour

Input	Reference	Measurement	UT*fit* Prediction	Pull	current	mid-term
$\sin 2\beta$	[22], **UT*fit***	0.688(20)	0.736(28)	−1.4	4%th/exp	0.6%
γ	[22]	66.1(3.5)	64.9(1.4)	+0.29	5%exp	0.8%
α	**UT*fit***	94.9(4.7)	92.2(1.6)	+0.6	5%exp	0.4%
$\varepsilon \cdot 10^3$	[38]	2.228(1)	2.00(15)	+1.56	8%th	
$\|V_{ud}\|$	**UT*fit***	0.97433(19)	0.9738(11)	+0.03	0.1%th	
$\|V_{ub}\| \cdot 10^3$ •	**UT*fit***	3.77(24)	3.70(11)	+0.25	8%exp/th	1%
$\|V_{ub}\| \cdot 10^3$ (excl)	[39]	3.74(17)				
$\|V_{ub}\| \cdot 10^3$ (incl)	[22]	4.32(29)				
$\|V_{cb}\| \cdot 10^3$ •	**UT*fit***	41.25(95)	42.22(51)	−0.59	2%exp/th	0.5%
$\|V_{cb}\| \cdot 10^3$ (excl)	**UT*fit***	39.44(63)				
$\|V_{cb}\| \cdot 10^3$ (incl)	[40]	42.16(50)				
$\|V_{ub}\|/\|V_{cb}\|$	[39]	0.0844(56)				
$\Delta M_d \times 10^{12}\,\mathrm{s}^{-1}$	[38]	0.5065(19)	0.519(23)	−0.49	5%th/exp	2%
$\Delta M_s \times 10^{12}\,\mathrm{s}^{-1}$	[38]	17.741(20)	17.94(69)	−0.30	4%th	1.5%
$\mathrm{BR}(B_s \to \mu\mu) \times 10^9$	[38]	3.41(29)	3.47(14)	−0.14	9%exp	4%
$\mathrm{BR}(B \to \tau\nu) \times 10^4$	[38]	1.06(19)	0.869(47)	+0.96	20%exp	4%
$\mathrm{Re}\,(\varepsilon'/\varepsilon) \times 10^4$	[38]	16.6(3.3)	15.2(4.7)	+0.27	30%th	
$(\|q/p\|_D - 1) \times 10^2$		0.05(2.50)	0.8(4.0)	−0, 15	100%th*	30%*
$BR(B^+ \to K^+\nu\nu)10^6$		23(7)	5.58(37)	+2.5	35%exp	10%
$BR(K^+ \to \pi^+\nu\nu)10^{11}$		10.6(4.0)	9.31(76)	+0, 3	40%exp	20%
R_D		0.344(26)	0.298(4)	+1.7	8%exp	4%
R_{D^*}		0.285(12)	0.254(5)	+2.3	4%exp	2.5%

with strong correlations!

(No EDM's, $\mu \to e\gamma$, etc.)

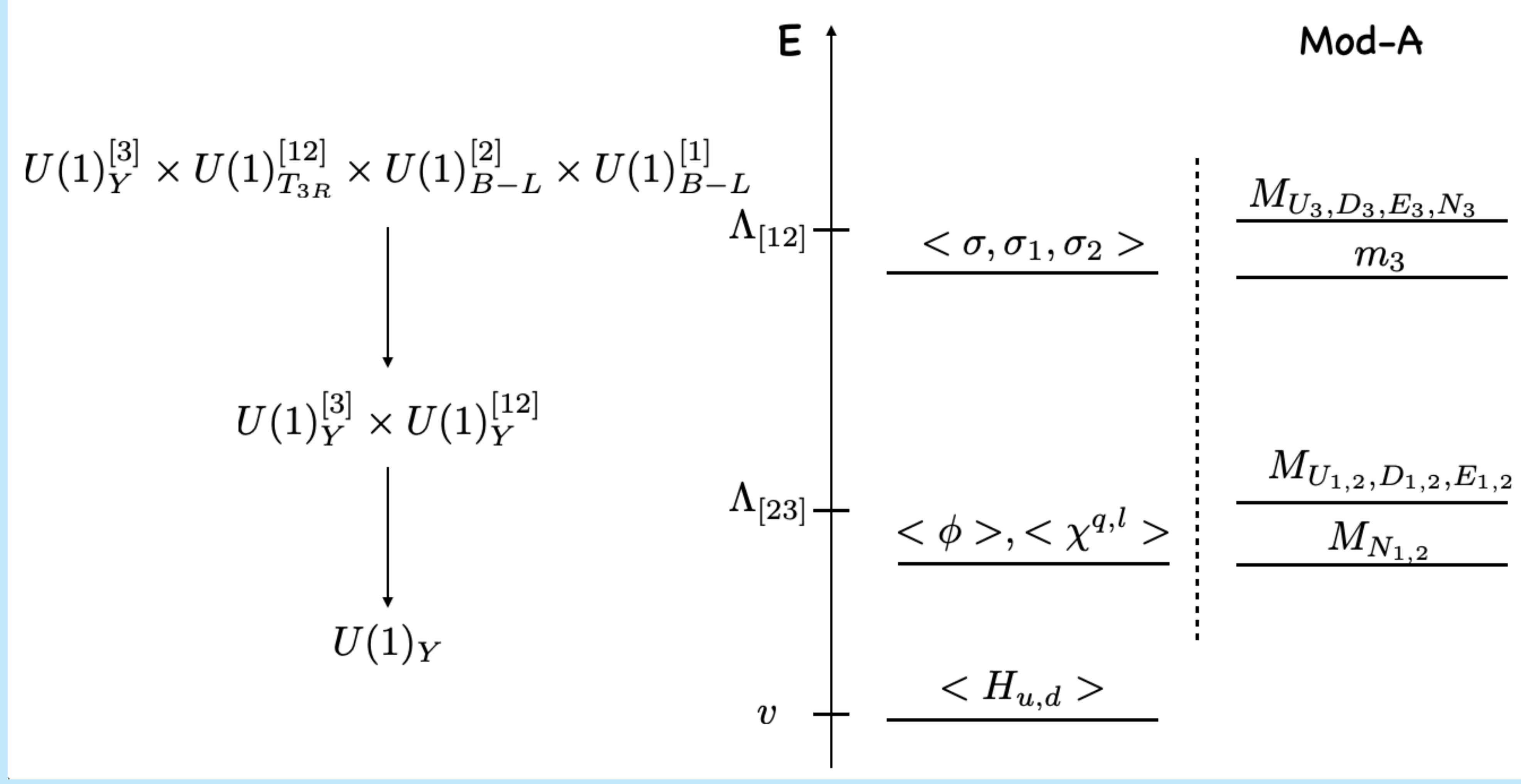
Summary

1. Flavour symmetries ($U(2)^n$) can:
   - allow for flavour changing $\frac{1}{\Lambda^{n-4}}\mathcal{O}^{n>4}$ with $\Lambda \approx$ MultiTeV
   - be related to the pattern of $Y^{u,d,e}$ and arise accidentally

2. In an explicit 4d gauge model, MFD, increased precision in the "mid term" of EWPT, Drell-Yan, flavour observables can in each case find evidence for motivated new physics in the MultiTeV

3. A convincing deviation from the SM in any of these areas would motivate an overall fit along the lines as described

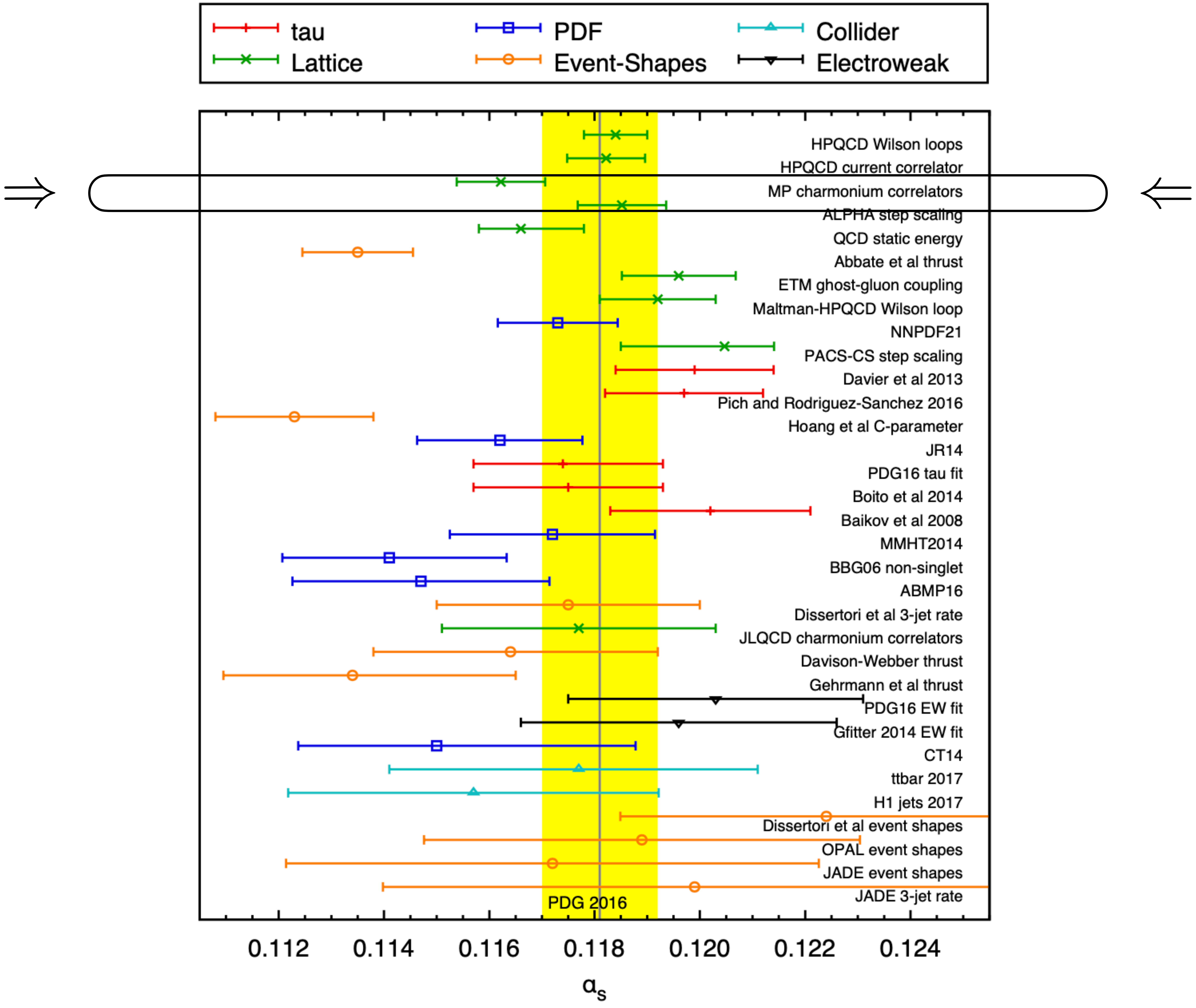
Extension to neutrinos

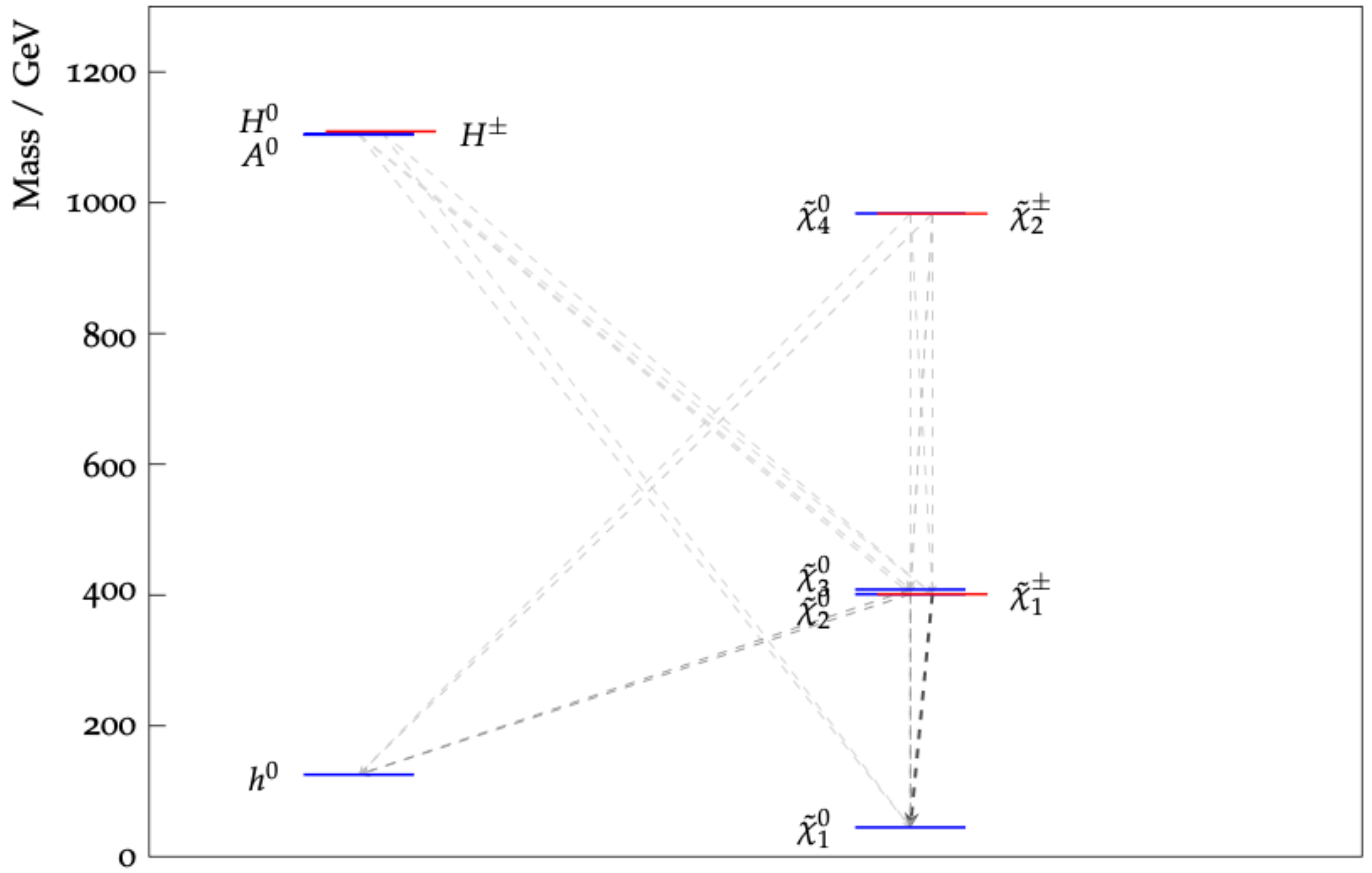


		$U(1)^{[3]}_Y$	$U(1)^{[12]}_{B-L}$	$U(2)^{[2]}_{T_{3R}}$	$U(1)^{[1]}_{T_{3R}}$	$SU(3) \times SU(2)$
light VL	$N_{1,2}$	$1/2$	-1	0	0	$(\mathbf{1}, \mathbf{1})$
heavy VL	N_3	0	-1	0	$1/2$	$(\mathbf{1}, \mathbf{1})$
scalars	σ_1	0	2	0	-1	$(\mathbf{1}, \mathbf{1})$
	σ_2	0	2	-1	0	$(\mathbf{1}, \mathbf{1})$

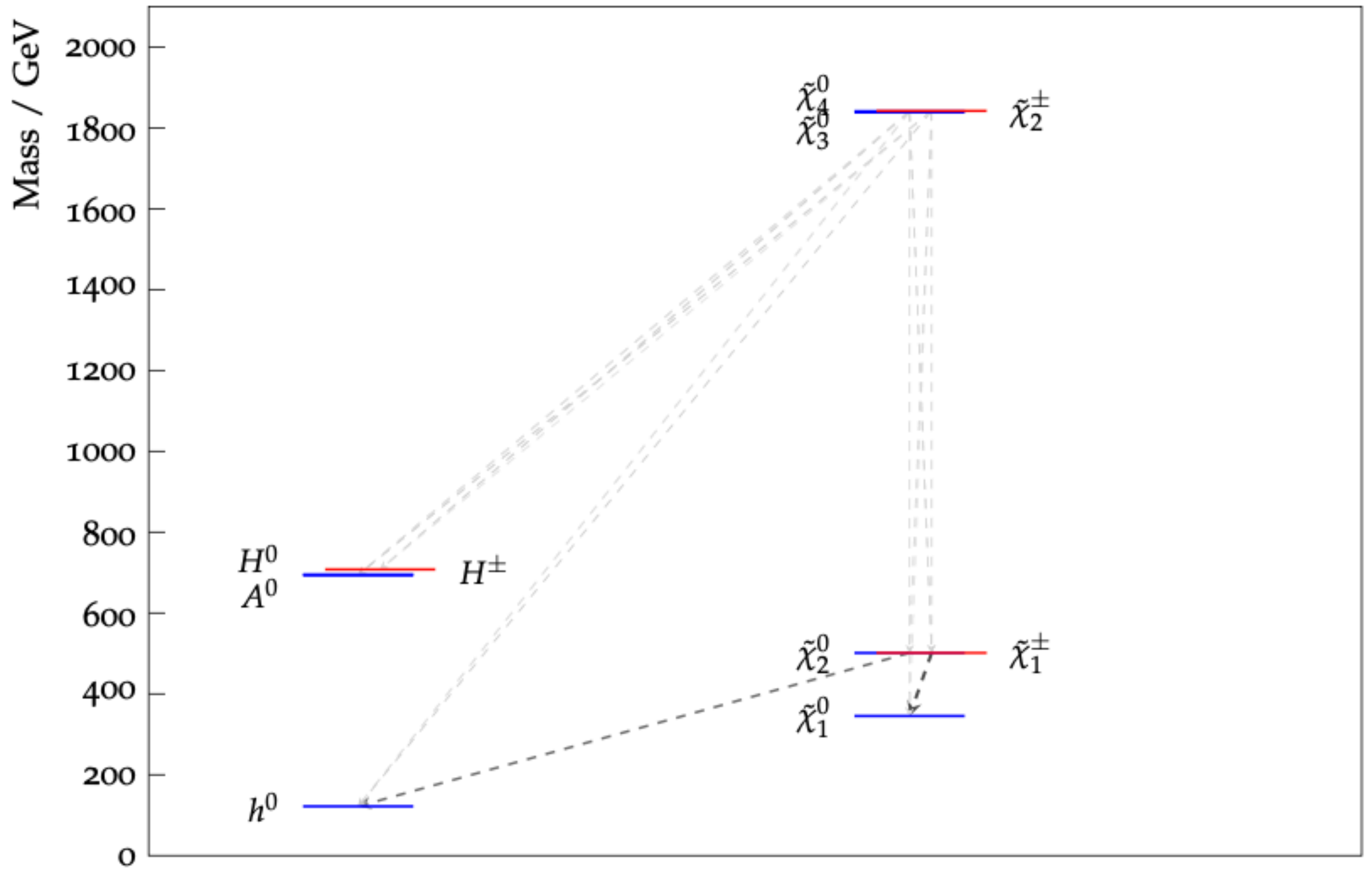
$$m^\nu_{LL}|_{\text{Mod. A}} \approx v_u^2 \begin{pmatrix} \frac{y^4}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^4}{m_3} & \frac{y^4}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^4}{m_3} & \frac{y^5}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^3}{m_3} \\ \frac{y^4}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^4}{m_3} & \frac{y^4}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^4}{m_3} & \frac{y^5}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^3}{m_3} \\ \frac{y^5}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^3}{m_3} & \frac{y^5}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^3}{m_3} & \frac{y^5}{y^{\sigma 2}\langle\sigma_2\rangle} + \frac{y^2}{m_3} \end{pmatrix}$$

$$\langle\sigma\rangle \approx (y^\nu_H)^2 \cdot 10^{14\div 15} GeV$$


tau
Lattice
PDF
Event-Shapes
Collider
Electroweak
HPQCD Wilson loops
HPQCD current correlator
MP charmonium correlators
ALPHA step scaling
QCD static energy
Abbate et al thrust
ETM ghost-gluon coupling
Maltman-HPQCD Wilson loop
NNPDF21
PACS-CS step scaling
Davier et al 2013
Pich and Rodriguez-Sanchez 2016
Hoang et al C-parameter
JR14
PDG16 tau fit
Boito et al 2014
Baikov et al 2008
MMHT2014
BBG06 non-singlet
ABMP16
Dissertori et al 3-jet rate
JLQCD charmonium correlators
Davison-Webber thrust
Gehrmann et al thrust
PDG16 EW fit
Gfitter 2014 EW fit
CT14
ttbar 2017
H1 jets 2017
Dissertori et al event shapes
OPAL event shapes
JADE event shapes
JADE 3-jet rate
PDG 2016
0.112
0.114
0.116
0.118
0.120
0.122
0.124
αs

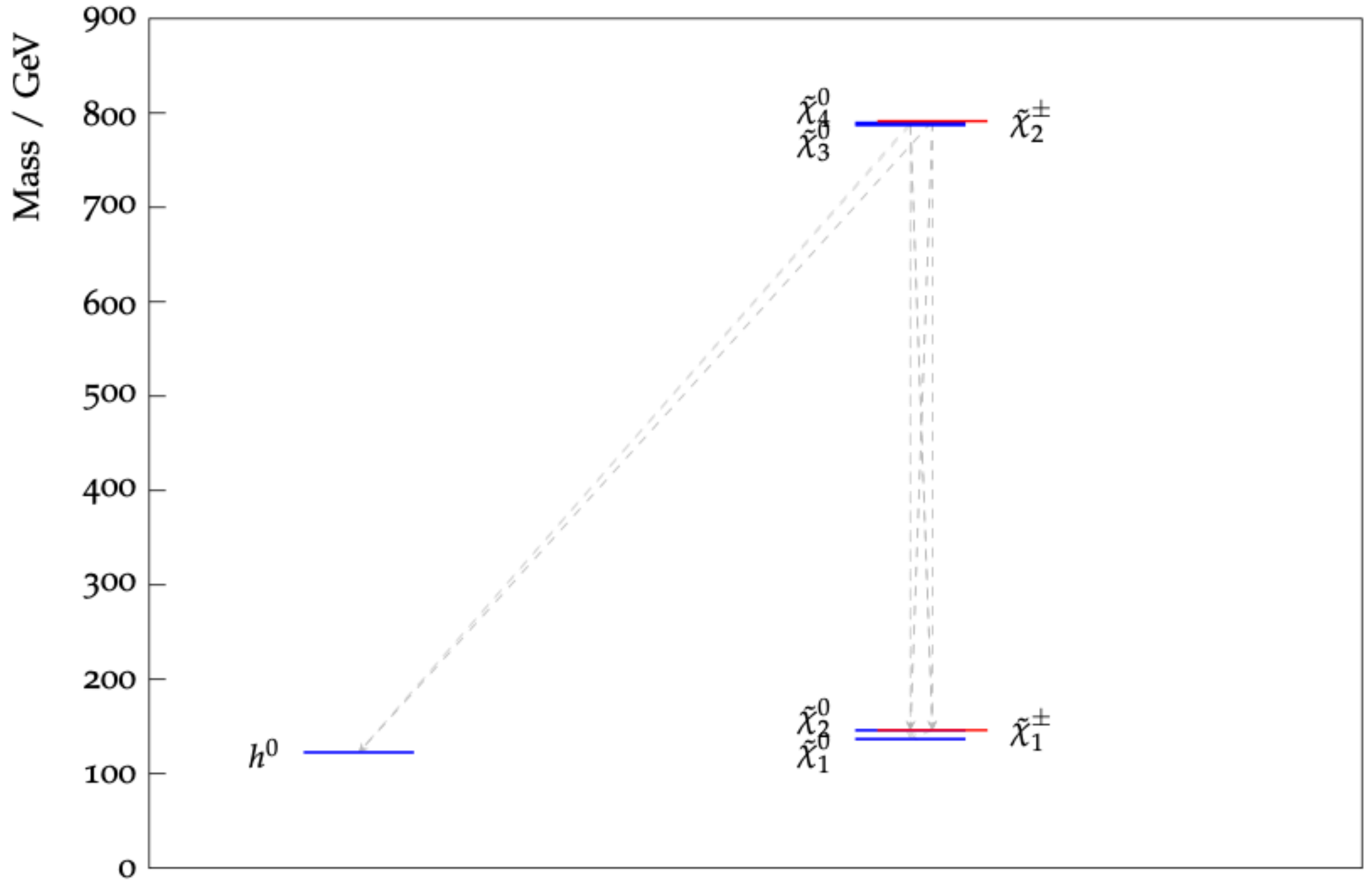


(a) Z/h funnel region

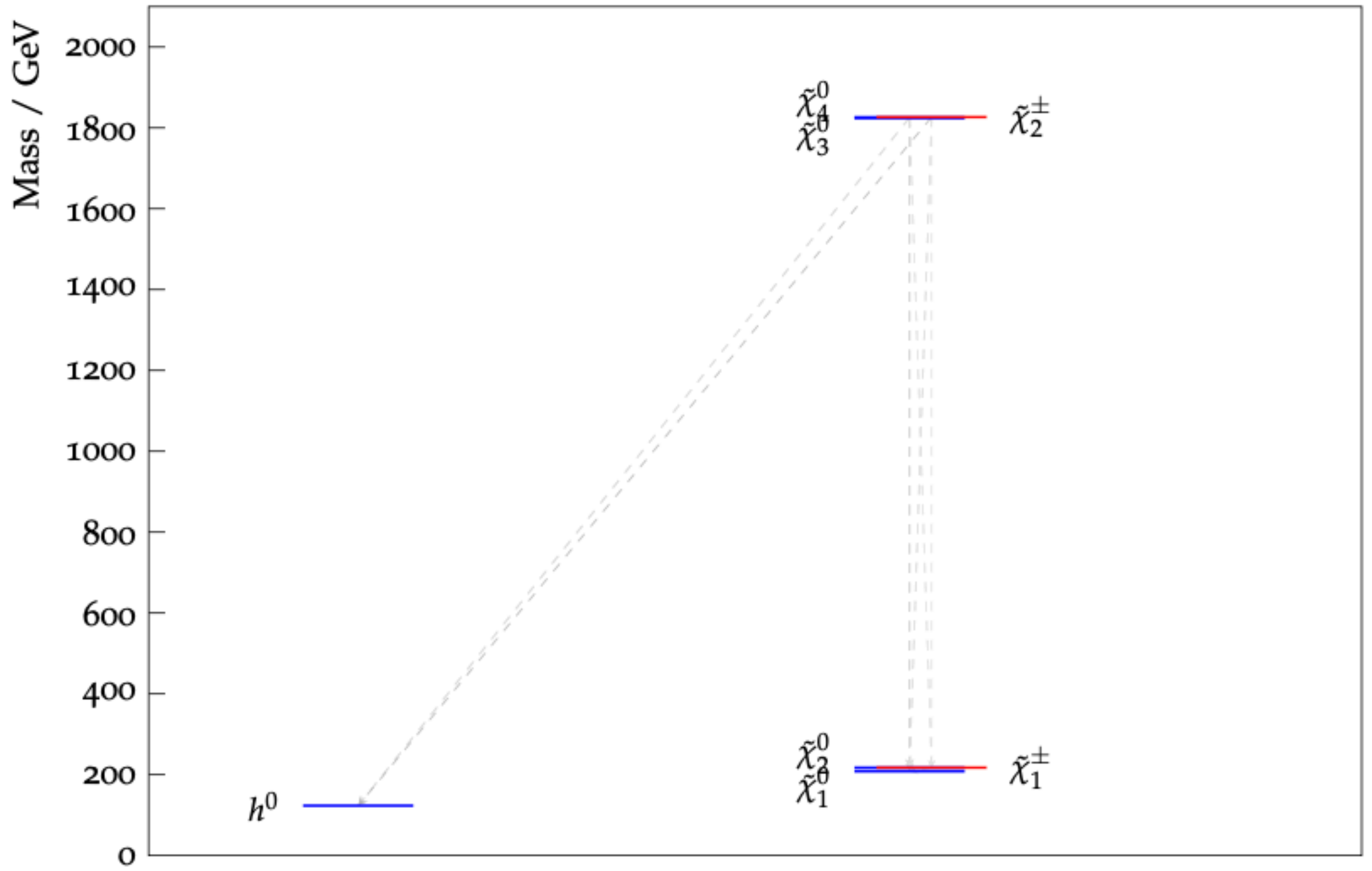


(b) A/H funnel region

ATLAS, 2024



(c) Compressed region



(d) Compressed region