Finding the flavon of $\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry

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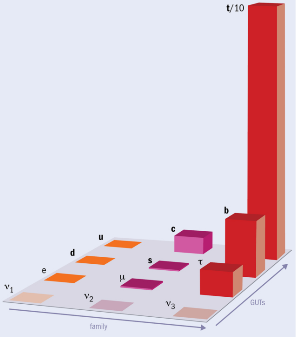
[Eur. Phys. J. C 83, 4, 305 (2023)], G. Abbas, V. Singh, R. Sain and N. Singh

[arXiv:2407.09255 [hep-ph]], G. Abbas, A. K. Alok, N. R. S. Chundawat, N. Khan and N. Singh

Outlines

1. Flavour problem of the Standard Model (SM)
2. $\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry
3. Constraints on the flavour scale
4. Collider signatures of the flavon
5. Summary

The SM flavour problem



Quark mixing angles: $\theta_{12} = 13.04^o \pm 0.05^o, \theta_{23} = 2.38^o \pm 0.06^o, \theta_{13} = 0.201^o \pm 0.011^o$[1]

Leptonic mixing angles: $\theta_{12} = 33.41^{\circ}{}^{+0.75^\circ}_{-0.72^\circ}, \theta_{23} = 49.1^{\circ}{}^{+1.0^\circ}_{-1.3^\circ}, \theta_{13} = 8.54^{\circ}{}^{+0.11^\circ}_{-0.12^\circ}$[1]

[1] PDG

$\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry

- The Froggatt-Nielsen (FN) mechanism is achieved through an abelian $U(1)$ symmetry by employing a flavon field (χ), which couples with the top quark at tree-level, and the masses of other fermions originate from the higher dimensional non-renormalizable operators of the following form,

$$\begin{aligned} \mathcal{O} &= y\left(\frac{\chi}{\Lambda}\right)^{(\theta_i+\theta_j)} \bar{\psi}\varphi\psi, \\ &= y\epsilon^{(\theta_i+\theta_j)} \bar{\psi}\varphi\psi = Y\bar{\psi}\varphi\psi, \end{aligned}$$

where $\epsilon = \frac{\langle\chi\rangle}{\Lambda} < 1$. [2]

- We introduce a framework based on discrete symmetry, $\mathcal{Z}_N \times \mathcal{Z}_M$, imposed on the SM, and employ a gauge singlet flavon field (χ). [3] [4]

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[2] Froggatt and Nielsen 1979
[3] Int. J. Mod. Phys. A 34, no.20, 1950104 (2019), G. Abbas
[4] Int. J. Mod. Phys. A 36, 2150090 (2021), G.Abbas

$\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry

- Employing the Principle of Minimum Suppression (PMS), the minimal realization of the $\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry turns out to be $\underline{\mathcal{Z}_2 \times \mathcal{Z}_5}$. [5]
- Other non-minimal forms are $\underline{\mathcal{Z}_2 \times \mathcal{Z}_9}$, $\underline{\mathcal{Z}_2 \times \mathcal{Z}_{11}}$, and $\underline{\mathcal{Z}_8 \times \mathcal{Z}_{22}}$ [6]that also provide the set-up to achieve FN mechanism.
- The charge-assignment to the SM and flavon fields under these symmetries are,

Fields	$\mathcal{Z}_2$	$\mathcal{Z}_5$
u_R, c_R, t_R	+	ω^2
$d_R, s_R, b_R, e_R, \mu_R, \tau_R$	-	ω
$\nu_{e_R}, \nu_{\mu_R}, \nu_{\tau_R}$	-	ω^3
ψ_L^1	+	ω
ψ_L^2	+	ω^4
ψ_L^3	+	ω^2
χ	-	ω
φ	+	1

Fields	$\mathcal{Z}_2$	$\mathcal{Z}_9$
u_R, t_R	+	1
c_R	+	ω^4
$d_R, s_R, b_R, e_R, \mu_R, \tau_R$	-	ω^3
ν_{e_R}, ν_{μ_R}	+	ω^6
ν_{τ_R}	+	ω^7
ψ_L^1	+	ω
ψ_L^2	+	ω^8
ψ_L^3	+	1
χ	-	ω
φ	+	1

[5]Eur. Phys. J. C 83, 4, 305 (2023), G. Abbas, V. Singh, R. Sain and N. Singh
[6]Phys.Rev.D 108 (2023) 11, 115035, G. Abbas, R. Adhikari and E. J. Chun

Masses and mixing patterns

- The masses of quarks and charged leptons in terms of the expansion parameter $\epsilon (< 1)$, up to leading-order are, [7]

masses	$\mathcal{Z}_2 \times \mathcal{Z}_5$	$\mathcal{Z}_2 \times \mathcal{Z}_9$
$\{m_t, m_c, m_u\}$	$\simeq \{\lvert y^u_{33}\rvert, \lvert y^u_{22}\rvert \epsilon^2, \lvert y^u_{11}\rvert \epsilon^4\} v/\sqrt{2}$	$\simeq \{\lvert y^u_{33}\rvert, \lvert y^u_{22}\rvert \epsilon^4, \lvert y^u_{11}\rvert \epsilon^8\} v/\sqrt{2}$
$\{m_b, m_s, m_d\}$	$\simeq \{\lvert y^d_{33}\rvert \epsilon, \lvert y^d_{22}\rvert \epsilon^3 \lvert y^d_{11}\rvert \epsilon^5\} v/\sqrt{2}$	$\simeq \{\lvert y^d_{33}\rvert \epsilon^3, \lvert y^d_{22}\rvert \epsilon^5, \lvert y^d_{11}\rvert \epsilon^7\} v/\sqrt{2}$
$\{m_\tau, m_\mu, m_e\}$	$\simeq \{\lvert y^l_{33}\rvert \epsilon, \lvert y^l_{22}\rvert \epsilon^3, \lvert y^l_{11}\rvert \epsilon^5\} v/\sqrt{2}$	$\simeq \{\lvert y^l_{33}\rvert \epsilon^3, \lvert y^l_{22}\rvert \epsilon^5, \lvert y^l_{11}\rvert \epsilon^7\} v/\sqrt{2}$

masses	$\mathcal{Z}_2 \times \mathcal{Z}_{11}$	$\mathcal{Z}_8 \times \mathcal{Z}_{22}$
$\{m_t, m_c, m_u\}$	$\simeq \{\lvert y^u_{33}\rvert, \lvert y^u_{22}\rvert \epsilon^6, \lvert y^u_{11}\rvert \epsilon^{10}\} v/\sqrt{2}$	$\simeq \{\lvert y^u_{33}\rvert \epsilon, \lvert y^u_{22}\rvert \epsilon^4, \lvert y^u_{11}\rvert \epsilon^8\} v/\sqrt{2}$
$\{m_b, m_s, m_d\}$	$\simeq \{\lvert y^d_{33}\rvert \epsilon^3, \lvert y^d_{22}\rvert \epsilon^7, \lvert y^d_{11}\rvert \epsilon^9\} v/\sqrt{2}$	$\simeq \{\lvert y^d_{33}\rvert \epsilon^3, \lvert y^d_{22}\rvert \epsilon^5, \lvert y^d_{11}\rvert \epsilon^7\} v/\sqrt{2}$
$\{m_\tau, m_\mu, m_e\}$	$\simeq \{\lvert y^l_{33}\rvert \epsilon^3, \lvert y^l_{22}\rvert \epsilon^7, \lvert y^l_{11}\rvert \epsilon^9\} v/\sqrt{2}$	$\simeq \{\lvert y^l_{33}\rvert \epsilon^3, \lvert y^l_{22}\rvert \epsilon^5, \lvert y^l_{11}\rvert \epsilon^9\} v/\sqrt{2}$

where $\epsilon = 0.1$ for $\mathcal{Z}_2 \times \mathcal{Z}_5$, $\epsilon = 0.23$ for $\mathcal{Z}_2 \times \mathcal{Z}_9$, $\epsilon = 0.28$ for $\mathcal{Z}_2 \times \mathcal{Z}_{11}$, and $\epsilon = 0.23$ for $\mathcal{Z}_8 \times \mathcal{Z}_{22}$ are used to produce the masses and mixing patterns of fermions.

[7] **[arXiv:2407.09255 [hep-ph]], G. Abbas, A. K. Alok, N. R. S. Chundawat, N. Khan and N. Singh**

Masses and mixing patterns

- The mixing angles of quarks are obtained as,

Quark mixing angles	$\mathcal{Z}_2 \times \mathcal{Z}_5$	$\mathcal{Z}_2 \times \mathcal{Z}_9$
$\sin\theta_{12} \simeq \lvert V_{us}\rvert$	$\simeq \left\lvert \frac{y_{12}^d}{y_{22}^d} - \frac{y_{12}^u}{y_{22}^u} \right\rvert \epsilon^2$	$\simeq \left\lvert \frac{y_{12}^d}{y_{22}^d} - \frac{y_{12}^u}{y_{22}^u} \right\rvert \epsilon^2$
$\sin\theta_{23} \simeq \lvert V_{cb}\rvert$	$\simeq \left\lvert \frac{y_{23}^d}{y_{33}^d} - \frac{y_{23}^u}{y_{33}^u} \right\rvert \epsilon^2$	$\simeq \left\lvert \frac{y_{23}^d}{y_{33}^d} \right\rvert \epsilon^2$
$\sin\theta_{13} \simeq \lvert V_{ub}\rvert$	$\simeq \left\lvert \frac{y_{13}^d}{y_{33}^d} - \frac{y_{12}^u y_{23}^d}{y_{22}^u y_{33}^d} - \frac{y_{13}^u}{y_{33}^u} \right\rvert \epsilon^4$	$\simeq \left\lvert \frac{y_{13}^d}{y_{33}^d} - \frac{y_{12}^u y_{23}^d}{y_{22}^u y_{33}^d} \right\rvert \epsilon^4$

Quark mixing angles	$\mathcal{Z}_2 \times \mathcal{Z}_{11}$	$\mathcal{Z}_8 \times \mathcal{Z}_{22}$
$\sin\theta_{12} \simeq \lvert V_{us}\rvert$	$\simeq \left\lvert \frac{y_{12}^d}{y_{22}^d} \right\rvert \epsilon^2$	$\simeq \left\lvert \frac{y_{12}^d}{y_{22}^d} - \frac{y_{12}^u}{y_{22}^u} \right\rvert \epsilon$
$\sin\theta_{23} \simeq \lvert V_{cb}\rvert$	$\simeq \left\lvert \frac{y_{23}^d}{y_{33}^d} - \frac{y_{23}^u}{y_{33}^u} \right\rvert \epsilon^4$	$\simeq \left\lvert \frac{y_{23}^d}{y_{33}^d} - \frac{y_{23}^u}{y_{33}^u} \right\rvert \epsilon^2$
$\sin\theta_{13} \simeq \lvert V_{ub}\rvert$	$\simeq \left\lvert \frac{y_{13}^d}{y_{33}^d} \right\rvert \epsilon^6$	$\simeq \left\lvert \frac{y_{13}^d}{y_{33}^d} - \frac{y_{12}^u y_{23}^d}{y_{22}^u y_{33}^d} - \frac{y_{13}^u}{y_{33}^u} \right\rvert \epsilon^3$

The scalar potential

- The scalar potential of the model can be written in the following form,

$$-\mathcal{L}_{\text{potential}} = -\mu^2\varphi^\dagger\varphi + \lambda(\varphi^\dagger\varphi)^2 - \mu_\chi^2\,\chi^*\chi + \lambda_\chi\,(\chi^*\chi)^2 + \lambda_{\varphi\chi}(\chi^*\chi)(\varphi^\dagger\varphi).$$

- The flavon field (χ) can be parametrized by excitations around its VEV,

$$\chi(x) = \frac{f + s(x) + i\,a(x)}{\sqrt{2}}.$$

Softly broken scalar potential

$$V_\rho = \rho\,\chi^2 + \mathrm{H.c.}$$

$$m_s = \sqrt{\mu_\chi - 2\rho} = \sqrt{\lambda_\chi} f \quad \text{and} \quad m_a = \sqrt{-2\rho}$$

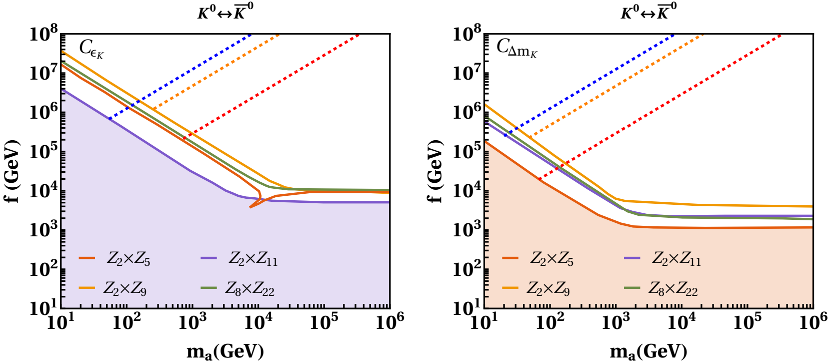
Symmetry conserving scalar potential

$$V_{\tilde{N}} = -\lambda\frac{\chi^{\tilde{N}}}{\Lambda^{\tilde{N}-4}} + \text{H.c.}$$

$$m_a^2 = \frac{1}{8}|\lambda|\tilde{N}^2\epsilon^{\tilde{N}-4}f^2$$

Quark flavour constraints on the flavour scale

$$C_{\epsilon_K} = \frac{\text{Im}\langle K^0|\mathcal{H}_{\text{eff}}^{\Delta F=2}|\bar{K}^0\rangle}{\text{Im}\langle K^0|\mathcal{H}_{\text{SM}}^{\Delta F=2}|\bar{K}^0\rangle} = 1.12^{+0.27}_{-0.25}\,{}^{8},\quad C_{\Delta m_K} = \frac{\text{Re}\langle K^0|\mathcal{H}_{\text{eff}}^{\Delta F=2}|\bar{K}^0\rangle}{\text{Re}\langle K^0|\mathcal{H}_{\text{SM}}^{\Delta F=2}|\bar{K}^0\rangle} = 0.93^{+1.14}_{-0.42}\,{}^{8}$$



[8] @95% C.L. , M. Bona et al. 2007, [UTFIT]

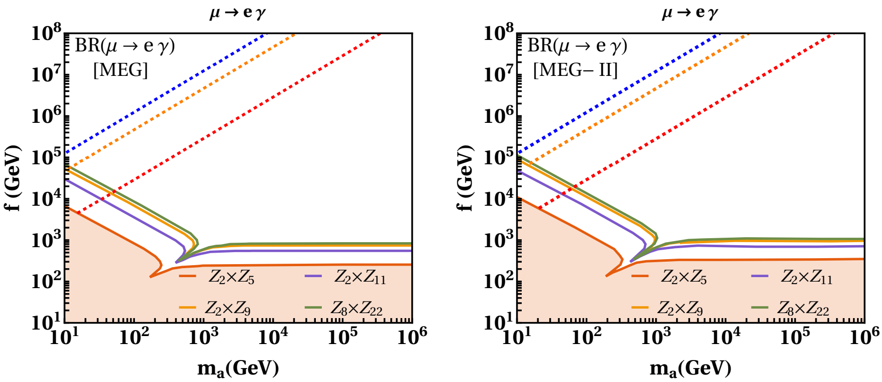
Leptonic flavour constraints

Observables	Current sensitivity	Ref.	Future projection	Ref.
$\text{BR}(\mu \to e\gamma)$	$< 4.2 \times 10^{-13}$	MEG	6×10^{-14}	MEG2
$\text{BR}(\mu \to e)^{\text{Au}}$	$< 7 \times 10^{-13}$	SINDRUM 2	–	–
$\text{BR}(\mu \to e)^{\text{Al}}$	–	–	3×10^{-15}	COMET Phase-1
$\text{BR}(\mu \to e)^{\text{Al}}$	–	–	6×10^{-17}	COMET Phase-2
$\text{BR}(\mu \to e)^{\text{Al}}$	–	–	6×10^{-17}	Mu2e
$\text{BR}(\mu \to e)^{\text{Al}}$	–	–	3×10^{-18}	Mu2e 2
$\text{BR}(\mu \to e)^{\text{Si}}$	–	–	2×10^{-14}	DeeMe
$\text{BR}(\mu \to e)^{\text{Ti}}$			$\sim 10^{-20} - 10^{-18}$	PRISM/PRIME
$\text{BR}(\mu \to 3e)$	$< 1.0 \times 10^{-12}$	SINDRUM	$\sim 10^{-16}$	Mu3e

Table: Experimental upper limits on various Leptonic flavour violation (LFV) processes.[9]

[9] Eur. Phys. J. C 83, 4, 305 (2023), G. Abbas, V. Singh, R. Sain, and N. Singh

Leptonic flavour constraints



Collider signatures of the flavon

$$pp \to a \to f_i \bar{f}_j / \gamma\gamma$$

m_a [GeV]	HL-LHC [14 TeV, 3 ab^{-1}] 500	1000	HE-LHC [27 TeV, 15 ab^{-1}] 500	1000	100 TeV, 30 ab^{-1} 500	1000
jet-jet [pb]		$4 \cdot 10^{-2}$		$3 \cdot 10^{-2}$		$4 \cdot 10^{-2}$
$\tau\tau$ [pb]	$7 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$4 \cdot 10^{-3}$	$7 \cdot 10^{-4}$	$5 \cdot 10^{-3}$	$8 \cdot 10^{-4}$
ee, $\mu\mu$ [pb]	$2 \cdot 10^{-4}$	$4 \cdot 10^{-5}$	$1 \cdot 10^{-4}$	$3 \cdot 10^{-5}$	$1 \cdot 10^{-4}$	$3 \cdot 10^{-5}$
μe [pb]	$9 \cdot 10^{-4}$	$7 \cdot 10^{-5}$	$7 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-4}$
$\mu\tau$ [pb]	$2 \cdot 10^{-3}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$2 \cdot 10^{-4}$	$2 \cdot 10^{-3}$	$3 \cdot 10^{-4}$
$e\tau$ [pb]	$1 \cdot 10^{-3}$	$2 \cdot 10^{-4}$	$8 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$3 \cdot 10^{-4}$
$b\bar{b}$ [pb]		$9 \cdot 10^{-3}$		$5 \cdot 10^{-3}$		$7 \cdot 10^{-3}$
$\gamma\gamma$ [pb]	$1 \cdot 10^{-4}$	$2 \cdot 10^{-5}$	$6 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$7 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
$t\bar{t}$ [pb]	4	$5 \cdot 10^{-2}$	3	$4 \cdot 10^{-2}$	8	0.1

Table: Estimated reach ($\sigma \times BR$) of the future colliders

	Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_5$		Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_9$		Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_{11}$		Benchmark $\mathcal{Z}_8 \times \mathcal{Z}_{22}$	
m_a [GeV]	500	1000	500	1000	500	1000	500	1000
jet-jet [pb]		$3.6 \cdot 10^{-2}$		$1.5 \cdot 10^{-6}$		$2.3 \cdot 10^{-7}$		$1.4 \cdot 10^{-3}$
$\tau\tau$ [pb]	$1.2 \cdot 10^{-3}$	$9.2 \cdot 10^{-5}$	$8.0 \cdot 10^{-5}$	$3.4 \cdot 10^{-6}$	$2.9 \cdot 10^{-5}$	$1.6 \cdot 10^{-6}$	$3.4 \cdot 10^{-3}$	$6.1 \cdot 10^{-5}$
$\mu\tau$ [pb]	$1.4 \cdot 10^{-3}$	$1.1 \cdot 10^{-4}$	$2.3 \cdot 10^{-4}$	$9.5 \cdot 10^{-6}$	$3 \cdot 10^{-5}$	$1.7 \cdot 10^{-6}$	$5.8 \cdot 10^{-3}$	$1 \cdot 10^{-4}$
$e\tau$ [pb]	$1.1 \cdot 10^{-3}$	$8.9 \cdot 10^{-5}$	$2.2 \cdot 10^{-4}$	$9.4 \cdot 10^{-6}$	$8.5 \cdot 10^{-5}$	$4.7 \cdot 10^{-6}$	$3.2 \cdot 10^{-4}$	$5.8 \cdot 10^{-6}$
$\mu\mu$ [pb]	$1.1 \cdot 10^{-6}$	$8.3 \cdot 10^{-8}$	$1.7 \cdot 10^{-6}$	$7.3 \cdot 10^{-8}$	$2.2 \cdot 10^{-7}$	$1.2 \cdot 10^{-8}$	$2.9 \cdot 10^{-5}$	$5.3 \cdot 10^{-7}$
ee [pb]	$2.5 \cdot 10^{-10}$	$2 \cdot 10^{-11}$	$3.4 \cdot 10^{-9}$	$1.4 \cdot 10^{-10}$	$6.7 \cdot 10^{-11}$	$3.7 \cdot 10^{-12}$	$1.7 \cdot 10^{-9}$	$3 \cdot 10^{-11}$
$\gamma\gamma$ [pb]	$1.3 \cdot 10^{-7}$	$3.6 \cdot 10^{-9}$	$8.2 \cdot 10^{-10}$	$1.2 \cdot 10^{-11}$	$1.5 \cdot 10^{-10}$	$3 \cdot 10^{-12}$	$6.6 \cdot 10^{-4}$	$1 \cdot 10^{-5}$
$b\bar{b}$ [pb]	$9.8 \cdot 10^{-3}$	$6.3 \cdot 10^{-4}$	$4.7 \cdot 10^{-4}$	$1.9 \cdot 10^{-5}$	$1.2 \cdot 10^{-4}$	$5.7 \cdot 10^{-6}$	$1.9 \cdot 10^{-2}$	$3.2 \cdot 10^{-4}$
$t\bar{t}$ [pb]							4.42	0.12

Table: Benchmark points at 14 TeV, $3ab^{-1}$ HL-LHC

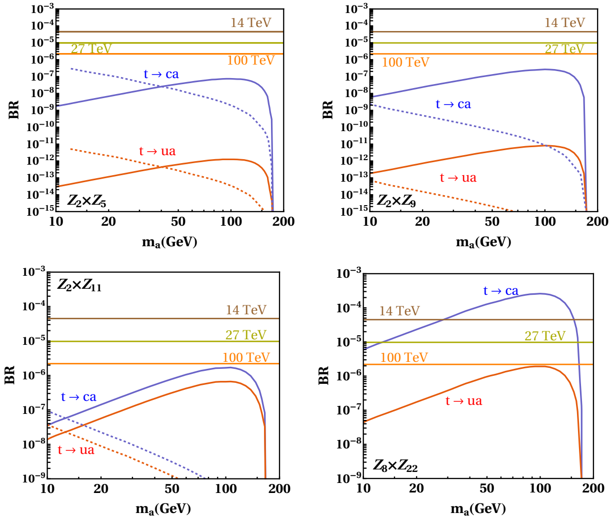
m_a [GeV]	Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_5$ 500	1000	Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_9$ 500	1000	Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_{11}$ 500	1000	Benchmark $\mathcal{Z}_8 \times \mathcal{Z}_{22}$ 500	1000
jet-jet [pb]		0.133		$8.2 \cdot 10^{-6}$		$9.4 \cdot 10^{-7}$		$9.8 \cdot 10^{-3}$
$\tau\tau$ [pb]	$2.6 \cdot 10^{-3}$	$2.8 \cdot 10^{-4}$	$2.9 \cdot 10^{-4}$	$1.7 \cdot 10^{-5}$	$8 \cdot 10^{-5}$	$5.6 \cdot 10^{-6}$	$1.5 \cdot 10^{-2}$	$4 \cdot 10^{-4}$
$\mu\tau$ [pb]	$3.2 \cdot 10^{-3}$	$3.5 \cdot 10^{-4}$	$8.3 \cdot 10^{-4}$	$4.8 \cdot 10^{-5}$	$8.4 \cdot 10^{-5}$	$5.8 \cdot 10^{-6}$	$2.5 \cdot 10^{-2}$	$6.8 \cdot 10^{-4}$
$e\tau$ [pb]	$2.6 \cdot 10^{-3}$	$2.8 \cdot 10^{-4}$	$8.2 \cdot 10^{-4}$	$4.8 \cdot 10^{-5}$	$2.3 \cdot 10^{-4}$	$1.6 \cdot 10^{-5}$	$1.4 \cdot 10^{-3}$	$3.8 \cdot 10^{-5}$
$\mu\mu$ [pb]	$2.4 \cdot 10^{-6}$	$2.6 \cdot 10^{-7}$	$6.4 \cdot 10^{-6}$	$3.7 \cdot 10^{-7}$	$6.2 \cdot 10^{-7}$	$4.3 \cdot 10^{-8}$	$1.3 \cdot 10^{-4}$	$3.5 \cdot 10^{-6}$
ee [pb]	$5.6 \cdot 10^{-10}$	$6.1 \cdot 10^{-11}$	$1.3 \cdot 10^{-8}$	$7.4 \cdot 10^{-10}$	$1.8 \cdot 10^{-10}$	$1.3 \cdot 10^{-11}$	$7.2 \cdot 10^{-9}$	$1.9 \cdot 10^{-10}$
$\gamma\gamma$ [pb]	$2.9 \cdot 10^{-7}$	$1.1 \cdot 10^{-8}$	$3 \cdot 10^{-9}$	$6.3 \cdot 10^{-11}$	$4.2 \cdot 10^{-10}$	$1.1 \cdot 10^{-11}$	$2.8 \cdot 10^{-3}$	$6.7 \cdot 10^{-5}$
$b\bar{b}$ [pb]	$2.7 \cdot 10^{-2}$	$2.3 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$	$1 \cdot 10^{-4}$	$3.8 \cdot 10^{-4}$	$2.3 \cdot 10^{-5}$	$8.8 \cdot 10^{-2}$	$2.2 \cdot 10^{-3}$
$t\bar{t}$ [pb]							20.46	0.83

Table: Benchmark points at 27 TeV, $15ab^{-1}$ HE-LHC

	Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_5$		Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_9$		Benchmark $\mathcal{Z}_2 \times \mathcal{Z}_{11}$		Benchmark $\mathcal{Z}_8 \times \mathcal{Z}_{22}$	
m_a [GeV]	500	1000	500	1000	500	1000	500	1000
jet-jet [pb]		0.95		$1.1 \cdot 10^{-4}$		$8.1 \cdot 10^{-6}$		0.18
$\tau\tau$ [pb]	$1.1 \cdot 10^{-2}$	$1.4 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$	$1.9 \cdot 10^{-4}$	$4.8 \cdot 10^{-4}$	$3.8 \cdot 10^{-5}$	0.14	$6.2 \cdot 10^{-3}$
$\mu\tau$ [pb]	$1.3 \cdot 10^{-2}$	$1.7 \cdot 10^{-3}$	$6.3 \cdot 10^{-3}$	$5.5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$3.9 \cdot 10^{-5}$	0.23	$1.0 \cdot 10^{-2}$
$e\tau$ [pb]	$1.1 \cdot 10^{-2}$	$1.4 \cdot 10^{-3}$	$6.2 \cdot 10^{-3}$	$5.4 \cdot 10^{-4}$	$1.3 \cdot 10^{-3}$	$1.1 \cdot 10^{-4}$	$1.3 \cdot 10^{-2}$	$5.9 \cdot 10^{-4}$
$\mu\mu$ [pb]	$9.9 \cdot 10^{-5}$	$1.3 \cdot 10^{-6}$	$4.8 \cdot 10^{-5}$	$4.2 \cdot 10^{-6}$	$3.7 \cdot 10^{-6}$	$2.9 \cdot 10^{-7}$	$1.2 \cdot 10^{-3}$	$5.4 \cdot 10^{-5}$
ee [pb]	$2.4 \cdot 10^{-9}$	$3.0 \cdot 10^{-10}$	$9.6 \cdot 10^{-8}$	$8.4 \cdot 10^{-9}$	$1.1 \cdot 10^{-9}$	$8.8 \cdot 10^{-11}$	$6.9 \cdot 10^{-8}$	$3.0 \cdot 10^{-9}$
$\gamma\gamma$ [pb]	$1.2 \cdot 10^{-6}$	$5.6 \cdot 10^{-8}$	$2.3 \cdot 10^{-8}$	$7.2 \cdot 10^{-10}$	$2.5 \cdot 10^{-9}$	$7.2 \cdot 10^{-11}$	$2.7 \cdot 10^{-2}$	$1 \cdot 10^{-3}$
$b\bar{b}$ [pb]	0.15	$1.7 \cdot 10^{-2}$	$1.7 \cdot 10^{-2}$	$1.3 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$	$2 \cdot 10^{-4}$	1.03	$4.1 \cdot 10^{-2}$
$t\bar{t}$ [pb]							241.4	15.4

Table: Benchmark points for a 100 TeV, $30ab^{-1}$ hadron collider

Anomalous top decays



Conclusions

- The $\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry in a unique and novel framework that can effectively address the flavour problem of the SM.
- We have investigated the bounds on the flavour scale of the minimal and non-minimal versions of this symmetry using the current as well as the future projected sensitivities of the quark and lepton flavour physics data.
- The HL-LHC will be able to probe the signatures of the flavon of $\mathcal{Z}_2 \times \mathcal{Z}_5$ and the $\mathcal{Z}_8 \times \mathcal{Z}_{22}$ flavour symmetries.
- In addition to the $\mathcal{Z}_2 \times \mathcal{Z}_5$ and the $\mathcal{Z}_8 \times \mathcal{Z}_{22}$, HE-LHC will be sensitive to $\mathcal{Z}_2 \times \mathcal{Z}_9$ flavour symmetry through few specific inclusive signatures.
- The future 100 TeV collider will be decisive to test all of these four $\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetries at the experimental frontiers.

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Thank you !