UV completion of Composite Higgs Models

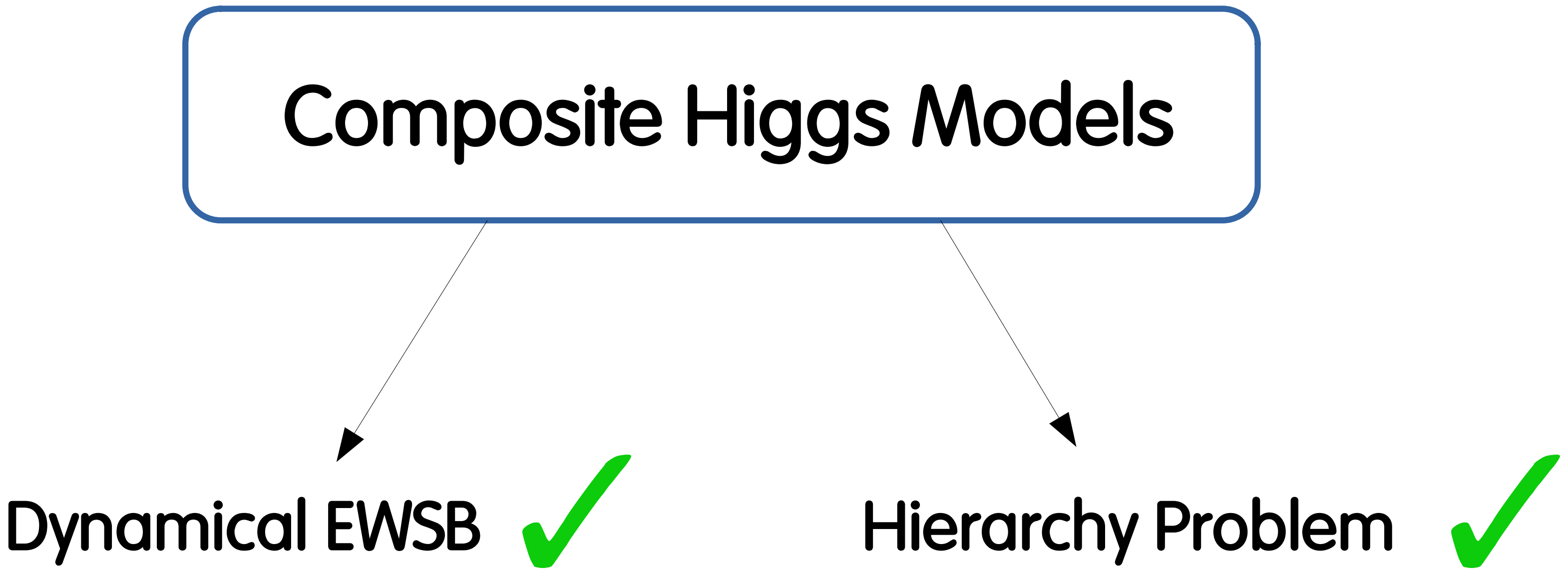
Shahram Vatani

Composite Higgs Models

Composite Higgs Models

Dynamical EWSB

Hierarchy Problem


Composite Higgs Models
Dynamical EWSB ✓
Hierarchy Problem ✓

Composite Higgs Models

Dynamical EWSB ✓

Hierarchy Problem ✓

$$\delta {m^2}_h \sim \Lambda^2$$

Composite Higgs Models

Dynamical EWSB ✓

Hierarchy Problem ✓

$$\delta {m^2}_h \sim \Lambda^2$$
$$\delta {m^2}_h \sim \frac{1}{\epsilon}$$

Composite Higgs Models

Dynamical EWSB ✓

Hierarchy Problem ✓

$$\delta {m^2}_h \sim \Lambda^2 \quad \rightarrow \quad \delta {m^2}_h \sim \Lambda^2 + {m^2}_{NP}$$
$$\delta {m^2}_h \sim \frac{1}{\epsilon} \quad \rightarrow \quad \delta {m^2}_h \sim \frac{1}{\epsilon} + {m^2}_{NP}$$

Composite Higgs Models

Dynamical EWSB ✓

Hierarchy Problem ✓

Up to now... « Effective Composite Higgs Models »

Composite Higgs Models

Underlying Theory

Composite Higgs Models

Underlying Theory

Large N

Composite Higgs Models

Underlying Theory

Large N

TPS

- 1 Composite Higgs
- 2 UV road
- 3 Alternatives

Composite Higgs

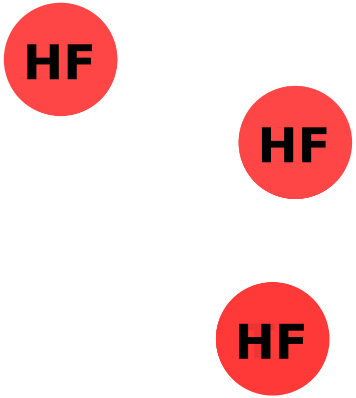
The Basic Idea

- New Fermions, **HyperFermions**

The Basic Idea

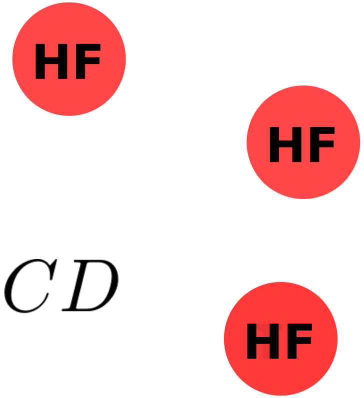
CH

- New Fermions, HyperFermions



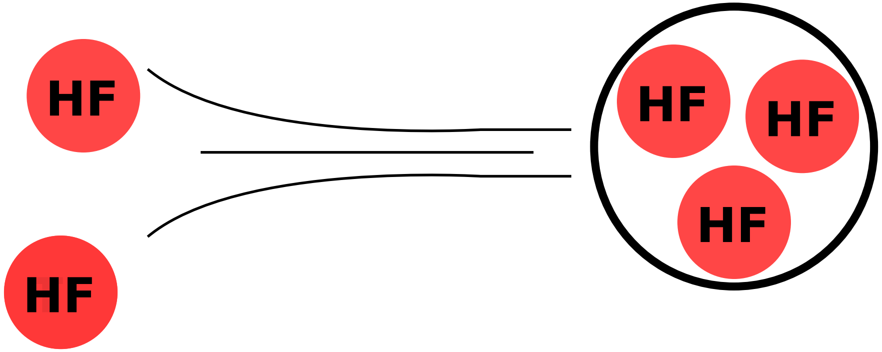
The Basic Idea

- New Fermions, **HyperFermions**
- New Interaction, **HyperColor** $\sim \quad QCD$

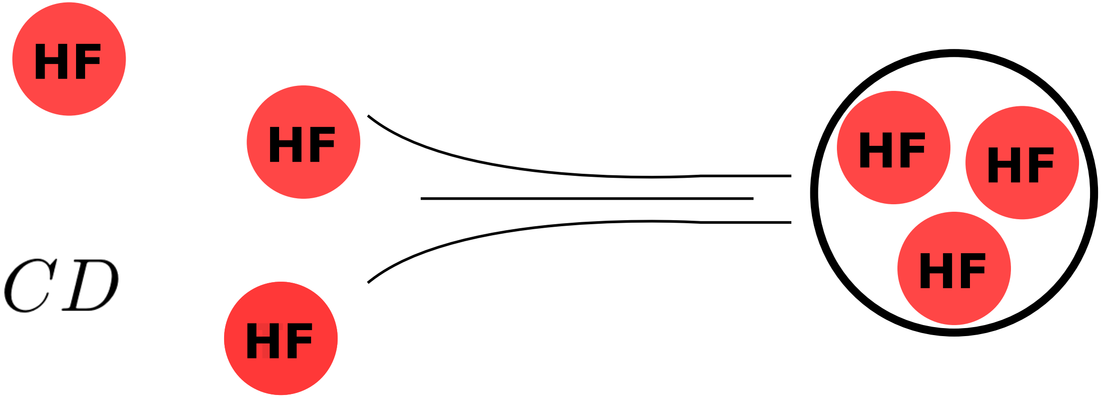


The Basic Idea

- New Fermions, **HyperFermions**
- New Interaction, **HyperColor** $\sim \quad QCD$



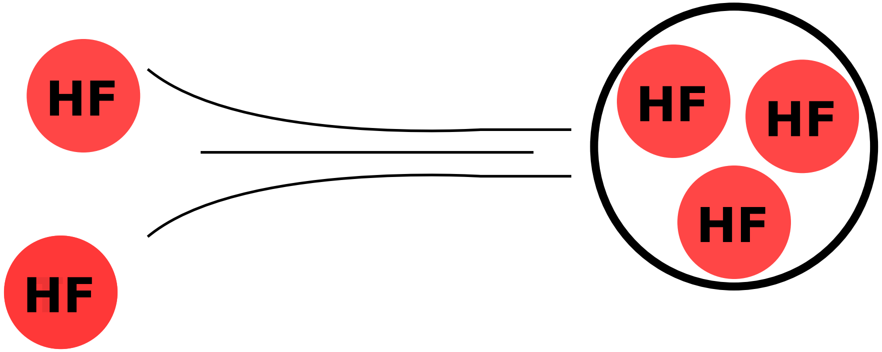
The Basic Idea



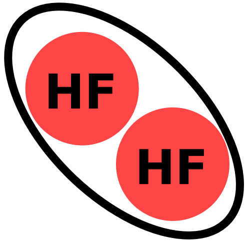
- New Fermions, **HyperFermions**
- New Interaction, **HyperColor** $\sim \quad QCD$
- Condensation
- Symmetry breaking pattern $\longrightarrow \quad G/H$
- Pions

The Basic Idea

- New Fermions, **HyperFermions**
- New Interaction, **HyperColor** $\sim \quad QCD$

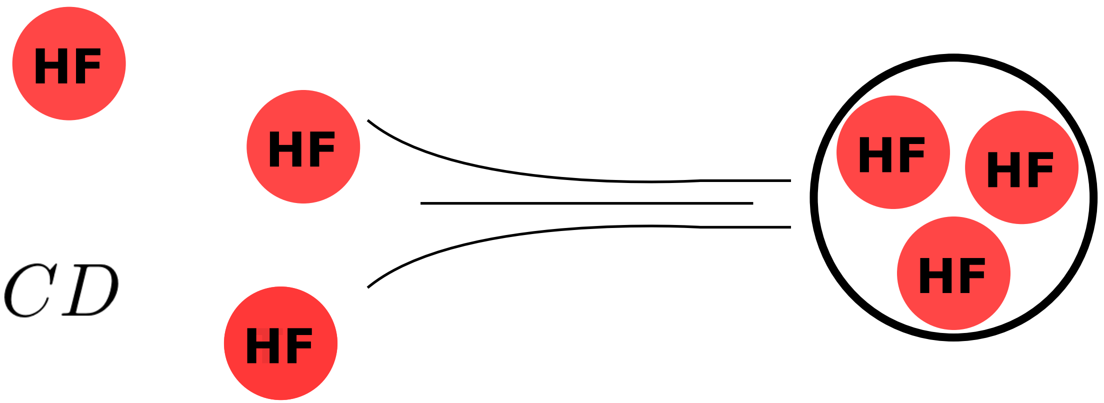


- Condensation
- Symmetry breaking pattern $\longrightarrow \quad G/H$
- Pions

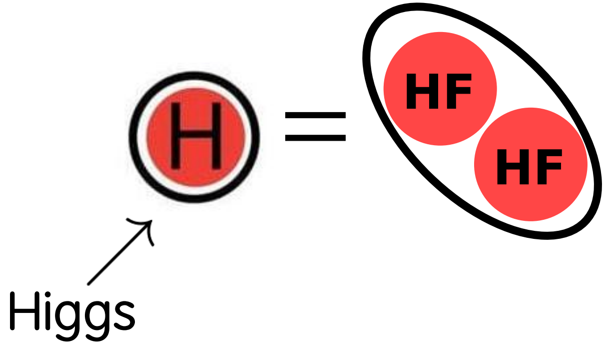


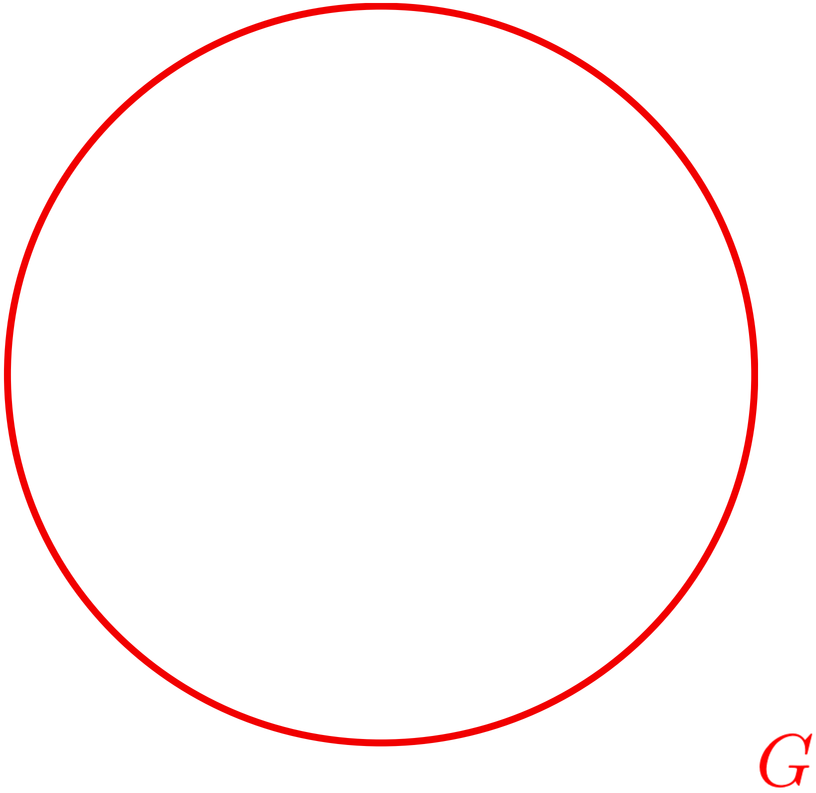
The Basic Idea

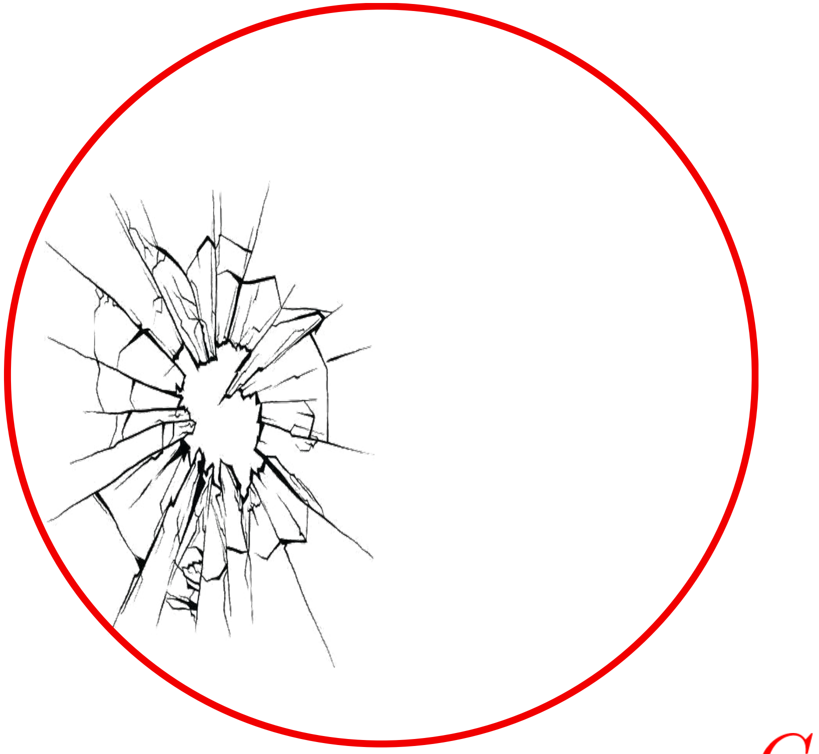
- New Fermions, **HyperFermions**
- New Interaction, **HyperColor** $\sim \quad QCD$

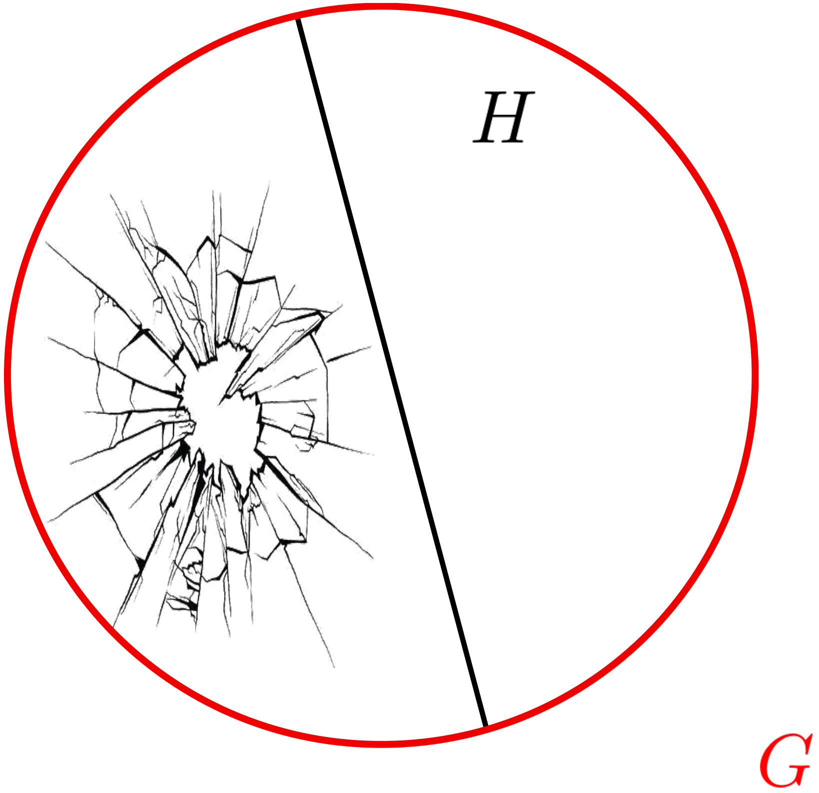


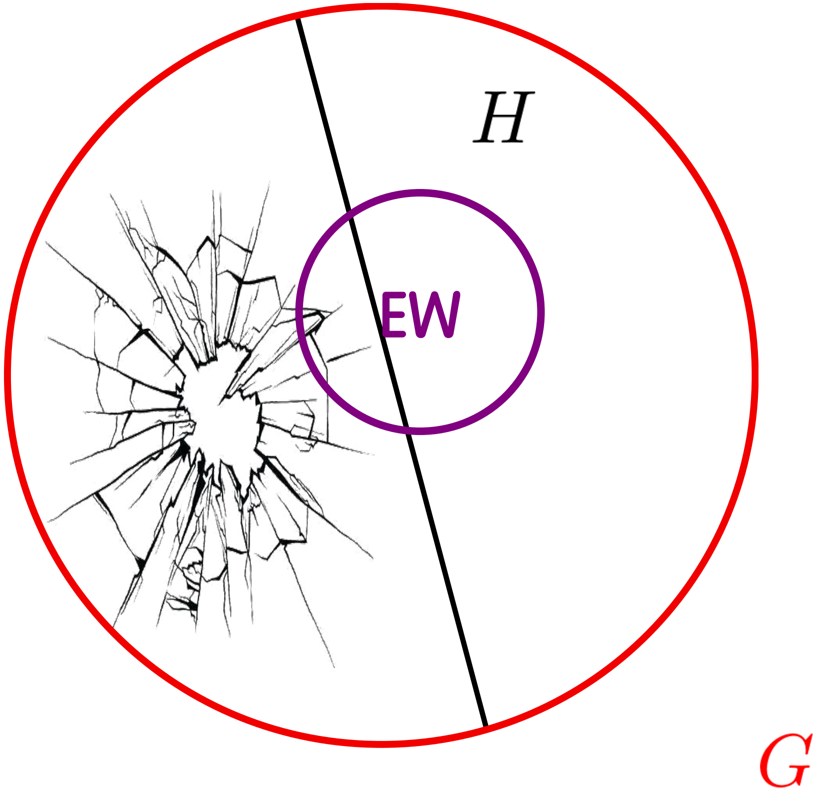
- Condensation
- Symmetry breaking pattern $\longrightarrow \quad G/H$
- Pions




G


G


H
G



H
EW
G

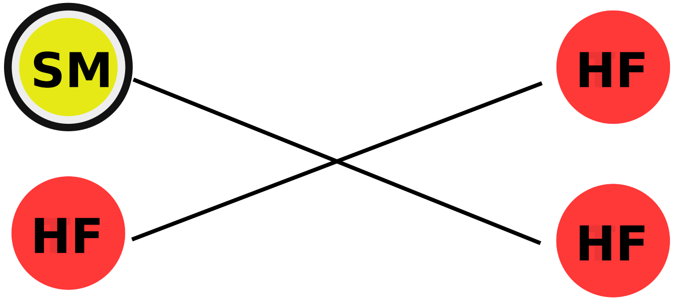
- How is this linked to the **rest of SM** ?
- **Mass** of the SM fermions ?

- How is this linked to the **rest of SM** ?
- **Mass** of the SM fermions ?

Effective 4-Fermion Interactions !

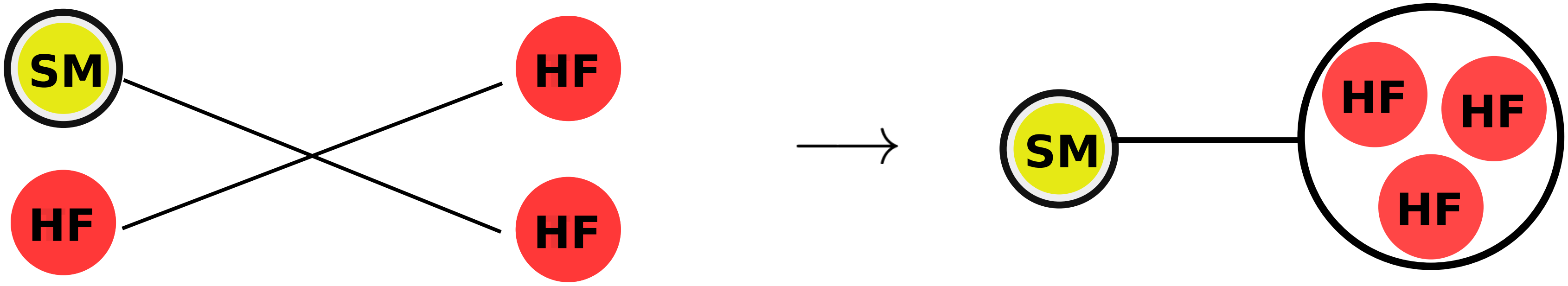
- How is this linked to the **rest of SM** ?
- **Mass** of the SM fermions ?

Effective 4-Fermion Interactions !



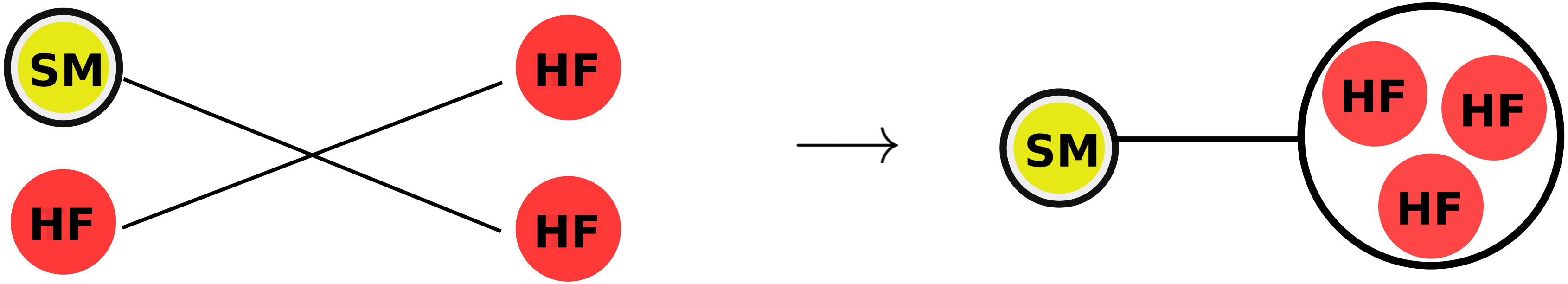
- How is this linked to the **rest of SM** ?
- **Mass** of the SM fermions ?

Effective 4-Fermion Interactions !

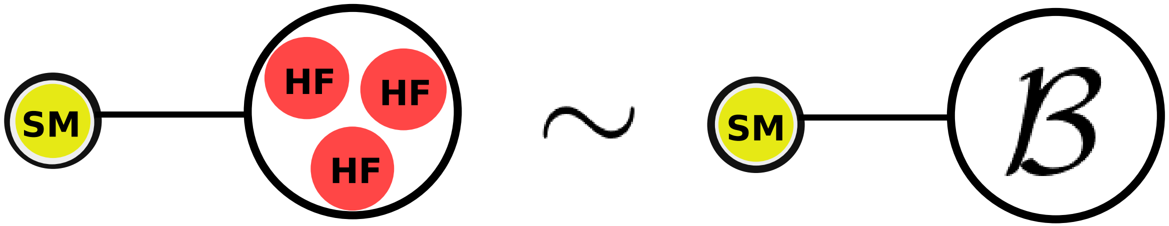


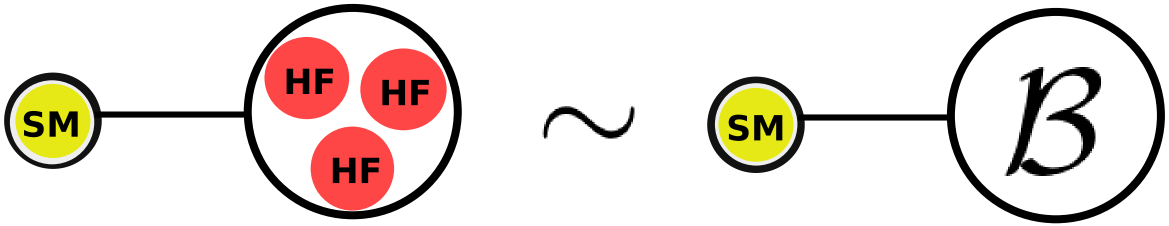
- How is this linked to the <u>rest of SM</u> ?
- <u>Mass</u> of the SM fermions ?

Effective 4-Fermion Interactions !

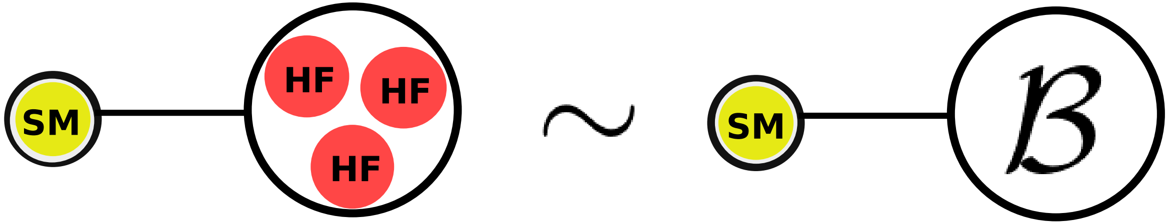


Partial Compositness

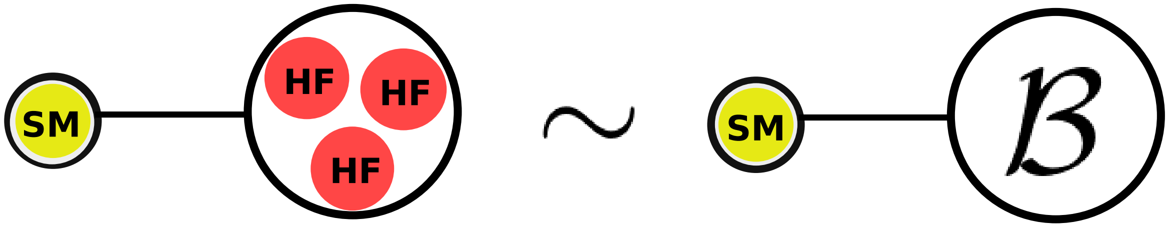

SM
HF
HF
HF
~
SM
$\mathcal{B}$



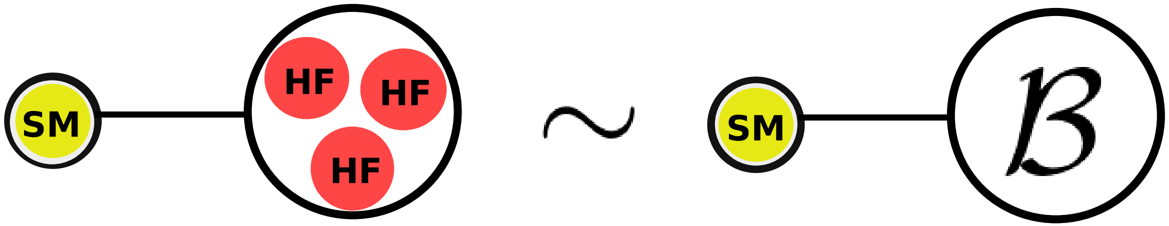
- Effective linear mixing between **SM** and a **baryon resonance** $\mathcal{B}$ (SM partner)



- Effective linear mixing between  and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F



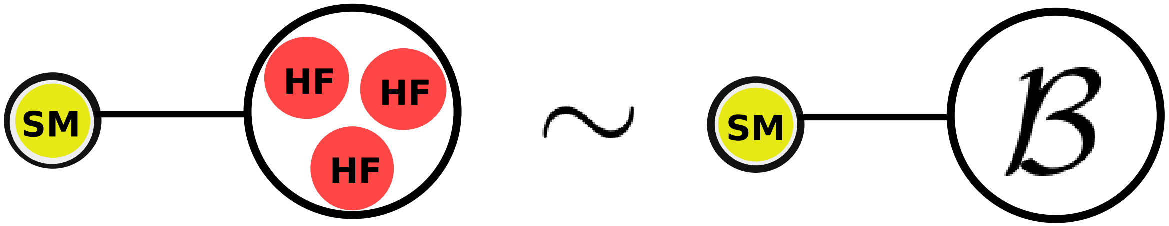
- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ (SM partner)
- The interaction needs to be generated at some scale Λ_F



- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

<u>Free Dynamic</u>

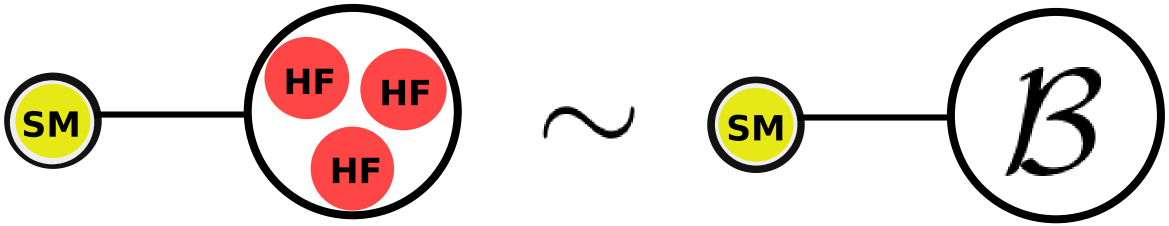
$$c\frac{t\mathcal{H}\mathcal{H}\mathcal{H}}{{\Lambda_F}^2}$$



- Effective linear mixing between SM and a **baryon resonnance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

<u>Free Dynamic</u>

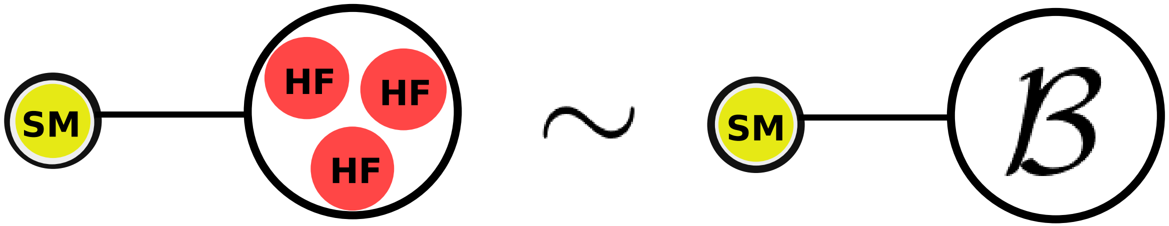
$$\left[\frac{c(\mu)}{\Lambda_F^2}\right] t\mathcal{H}\mathcal{H}\mathcal{H}$$



- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

<u>Free Dynamic</u>

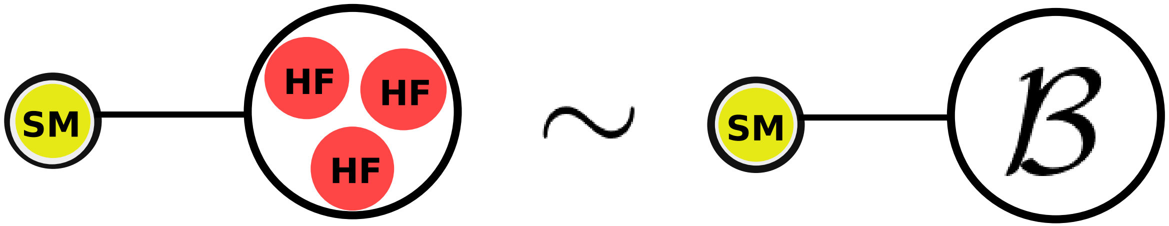
$$\left[c(\Lambda_{HC}) \frac{\Lambda_{HC}^3}{{\Lambda_F}^2} \right] t\mathcal{B}$$



- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

Free Dynamic

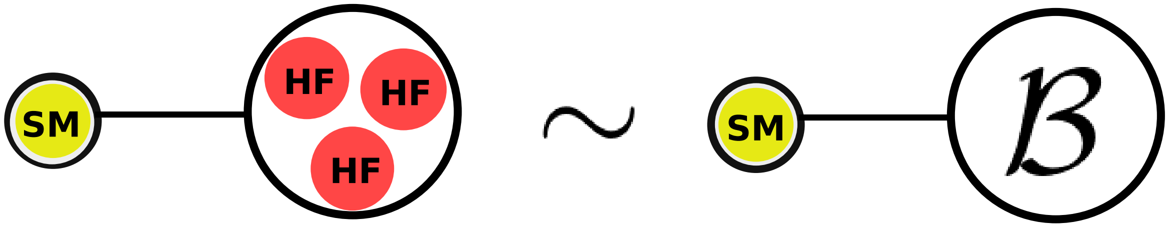
$$\left[c(\Lambda_{HC}) \frac{\Lambda_{HC}^3}{\Lambda_F{}^2} \right] t\mathcal{B}$$



- Effective linear mixing between **SM** and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

Free Dynamic

$$\sim c\frac{\Lambda_{HC}^3}{\Lambda_F{}^2}t\mathcal{B}$$

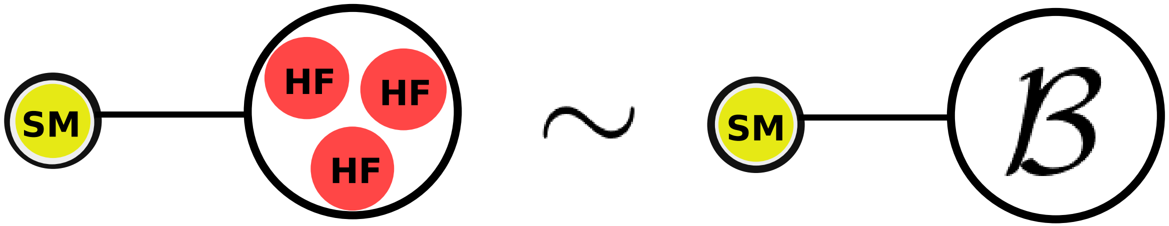


- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ (SM partner)
- The interaction needs to be generated at some scale Λ_F

Free Dynamic

$$\sim c\frac{\Lambda_{HC}^3}{\Lambda_F{}^2}t\mathcal{B}$$

Near Conformal Dynamic



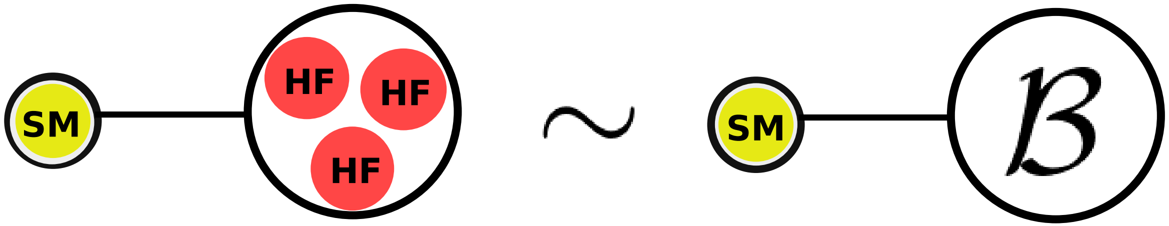
- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ (SM partner)
- The interaction needs to be generated at some scale Λ_F

Free Dynamic

$$\sim c\frac{\Lambda_{HC}^3}{{\Lambda_F}^2}t\mathcal{B}$$

Near Conformal Dynamic

$$\rightsquigarrow \left[c\left(\frac{\Lambda_F}{\Lambda_{HC}}\right)^{\gamma}\frac{\Lambda_{HC}^3}{\Lambda_F^2}\right]t\mathcal{B}$$



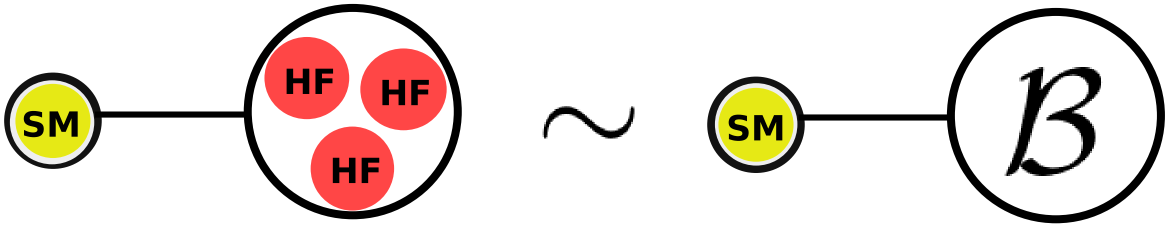
- Effective linear mixing between **SM** and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

Free Dynamic

$$\sim c\frac{\Lambda_{HC}^3}{\Lambda_F{}^2}t\mathcal{B}$$

Near Conformal Dynamic

$$\rightsquigarrow \left[c\left(\frac{\Lambda_F}{\Lambda_{HC}}\right)^{\gamma}\frac{\Lambda_{HC}^3}{\Lambda_F^2}\right]t\mathcal{B}$$



- Effective linear mixing between SM and a **baryon resonance** $\mathcal{B}$ **(SM partner)**
- The interaction needs to be generated at some scale Λ_F

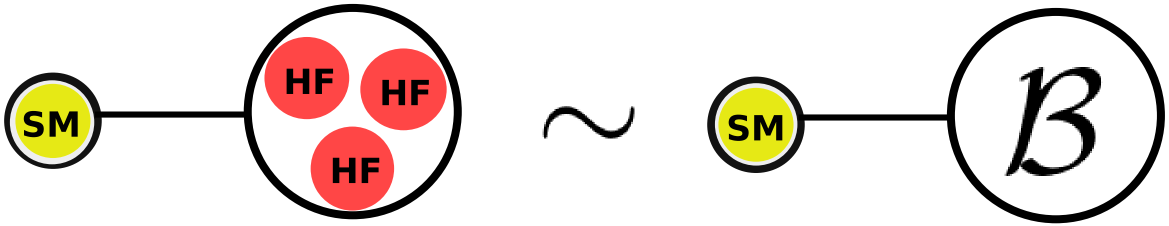
Free Dynamic

$$\sim c\frac{\Lambda_{HC}^3}{\Lambda_F{}^2} t\mathcal{B}$$

Near Conformal Dynamic

$$\rightsquigarrow \left[c\left(\frac{\Lambda_F}{\Lambda_{HC}}\right)^{\gamma}\frac{\Lambda_{HC}^3}{\Lambda_F^2}\right] t\mathcal{B}$$

$$\rightsquigarrow [c\,\Lambda_{HC}]\, t\mathcal{B} \qquad (\gamma = 2)$$

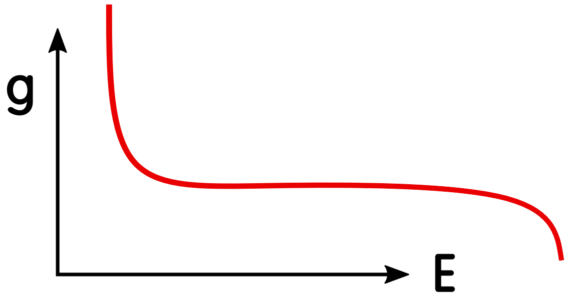


- Effective linear mixing between (SM) and a **baryon resonance** $\mathcal{B}$ (SM partner)
- The interaction needs to be generated at some scale Λ_F

Free Dynamic

$$\sim c\frac{\Lambda_{HC}^3}{\Lambda_F{}^2}t\mathcal{B}$$

Near Conformal Dynamic



What is Natural ?

What is Natural ?
A model dependant question ?

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order **1**
- Else, we need a **mechanism** (protecting symmetry…)

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order **1**
- Else, we need a **mechanism** (protecting symmetry…)

CH

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1
- Else, we need a **mechanism** (protecting symmetry…)

<u>(B)SM</u>

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1
- Else, we need a **mechanism** (protecting symmetry…)

(B)SM

- $y_t \sim 1$ Natural

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1
- Else, we need a **mechanism** (protecting symmetry…)

<u>(B)SM</u>

•$y_t \sim 1$	Natural
•$y_{b,c,s,d,u} \ll 1$	Need for a Mechanism

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1
- Else, we need a **mechanism** (protecting symmetry…)

(B)SM		HyperColor Theories
• $y_t \sim 1$	Natural	
• $y_{b,c,s,d,u} \ll 1$	Need for a Mechanism	

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1
- Else, we need a **mechanism** (protecting symmetry…)

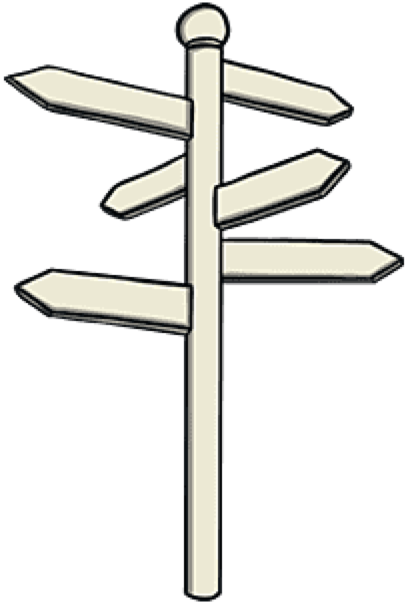
(B)SM		HyperColor Theories	
• $y_t \sim 1$	Natural	• $y_{b,c,s,d,u} \ll 1$	Natural
• $y_{b,c,s,d,u} \ll 1$	Need for a Mechanism		

What is Natural ?
A model dependant question ?

- **Coupling** are **expected** to be of order 1
- Else, we need a **mechanism** (protecting symmetry…)

(B)SM		HyperColor Theories	
• $y_t \sim 1$	Natural	• $y_{b,c,s,d,u} \ll 1$	Natural
• $y_{b,c,s,d,u} \ll 1$	Need for a Mechanism	• $y_t \sim 1$	Need for a Mechanism

Where do we go ?



Composite Higgs Models

- Higgs as pNGB
- SM partner as HyperBaryons
- Asymptotically Free Theory

Composite Higgs Models

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Real	Real	SU(5)/SO(5) $\times$ SU(6)/SO(6)				
$SO(N_{\rm HC})$	$5\times\mathbf{S}_2$	$6\times\mathbf{F}$	$N_{\rm HC}\geq 55$	$\frac{5(N_{\rm HC}+2)}{6}$	1/3	/	
$SO(N_{\rm HC})$	$5\times\mathbf{Ad}$	$6\times\mathbf{F}$	$N_{\rm HC}\geq 15$	$\frac{5(N_{\rm HC}-2)}{6}$	1/3	/	
$SO(N_{\rm HC})$	$5\times\mathbf{F}$	$6\times\mathbf{Spin}$	$N_{\rm HC}=7,9$	$\frac{5}{6}$, $\frac{5}{12}$	1/3	$N_{\rm HC}=7,9$	M1, M2
$SO(N_{\rm HC})$	$5\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\rm HC}=7,9$	$\frac{5}{6}$, $\frac{5}{3}$	2/3	$N_{\rm HC}=7,9$	M3, M4
	Real	Pseudo-Real	SU(5)/SO(5) $\times$ SU(6)/Sp(6)				
$Sp(2N_{\rm HC})$	$5\times\mathbf{Ad}$	$6\times\mathbf{F}$	$2N_{\rm HC}\geq 12$	$\frac{5(N_{\rm HC}+1)}{3}$	1/3	/	
$Sp(2N_{\rm HC})$	$5\times\mathbf{A}_2$	$6\times\mathbf{F}$	$2N_{\rm HC}\geq 4$	$\frac{5(N_{\rm HC}-1)}{3}$	1/3	$2N_{\rm HC}=4$	M5
$SO(N_{\rm HC})$	$5\times\mathbf{F}$	$6\times\mathbf{Spin}$	$N_{\rm HC}=11,13$	$\frac{5}{24}$, $\frac{5}{48}$	1/3	/	
	Real	Complex	SU(5)/SO(5) $\times$ SU(3)^2/SU(3)				
$SU(N_{\rm HC})$	$5\times\mathbf{A}_2$	$3\times(\mathbf{F},\overline{\mathbf{F}})$	$N_{\rm HC}=4$	$\frac{5}{3}$	1/3	$N_{\rm HC}=4$	M6
$SO(N_{\rm HC})$	$5\times\mathbf{F}$	$3\times(\mathbf{Spin},\overline{\mathbf{Spin}})$	$N_{\rm HC}=10,14$	$\frac{5}{12}$, $\frac{5}{48}$	1/3	$N_{\rm HC}=10$	M7
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4\times\mathbf{F}$	$6\times\mathbf{A}_2$	$2N_{\rm HC}\leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	2/3	$2N_{\rm HC}=4$	M8
$SO(N_{\rm HC})$	$4\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\rm HC}=11,13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\rm HC}=11$	M9
	Complex	Real	SU(4)^2/SU(4) $\times$ SU(6)/SO(6)				
$SO(N_{\rm HC})$	$4\times(\mathbf{Spin},\overline{\mathbf{Spin}})$	$6\times\mathbf{F}$	$N_{\rm HC}=10$	$\frac{8}{3}$	2/3	$N_{\rm HC}=10$	M10
$SU(N_{\rm HC})$	$4\times(\mathbf{F},\overline{\mathbf{F}})$	$6\times\mathbf{A}_2$	$N_{\rm HC}=4$	$\frac{2}{3}$	2/3	$N_{\rm HC}=4$	M11
	Complex	Complex	SU(4)^2/SU(4) $\times$ SU(3)^2/SU(3)				
$SU(N_{\rm HC})$	$4\times(\mathbf{F},\overline{\mathbf{F}})$	$3\times(\mathbf{A}_2,\overline{\mathbf{A}}_2)$	$N_{\rm HC}\geq 5$	$\frac{4}{3(N_{\rm HC}-2)}$	2/3	$N_{\rm HC}=5$	M12
$SU(N_{\rm HC})$	$4\times(\mathbf{F},\overline{\mathbf{F}})$	$3\times(\mathbf{S}_2,\overline{\mathbf{S}}_2)$	$N_{\rm HC}\geq 5$	$\frac{4}{3(N_{\rm HC}+2)}$	2/3	/	
$SU(N_{\rm HC})$	$4\times(\mathbf{A}_2,\overline{\mathbf{A}}_2)$	$3\times(\mathbf{F},\overline{\mathbf{F}})$	$N_{\rm HC}=5$	4	2/3	/	

Composite Higgs Models

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Real	Real	SU(5)/SO(5) × SU(6)/SO(6)				
$SO(N_{HC})$	$5 \times \mathbf{S}_2$	$6 \times \mathbf{F}$	$N_{HC} \geq 55$	$\frac{5(N_{HC}+2)}{6}$	1/3	/	
$SO(N_{HC})$	$5 \times \mathbf{Ad}$	$6 \times \mathbf{F}$	$N_{HC} \geq 15$	$\frac{5(N_{HC}-2)}{6}$	1/3	/	
$SO(N_{HC})$	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$N_{HC} = 7, 9$	$\frac{5}{6}, \frac{5}{12}$	1/3	$N_{HC} = 7, 9$	M1, M2
$SO(N_{HC})$	$5 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{HC} = 7, 9$	$\frac{5}{6}, \frac{5}{3}$	2/3	$N_{HC} = 7, 9$	M3, M4
	Real	Pseudo-Real	SU(5)/SO(5) × SU(6)/Sp(6)				
$Sp(2N_{HC})$	$5 \times \mathbf{Ad}$	$6 \times \mathbf{F}$	$2N_{HC} \geq 12$	$\frac{5(N_{HC}+1)}{3}$	1/3	/	
$Sp(2N_{HC})$	$5 \times \mathbf{A}_2$	$6 \times \mathbf{F}$	$2N_{HC} \geq 4$	$\frac{5(N_{HC}-1)}{3}$	1/3	$2N_{HC} = 4$	M5
$SO(N_{HC})$	$5 \times \mathbf{F}$	$6 \times \mathbf{Spin}$	$N_{HC} = 11, 13$	$\frac{5}{24}, \frac{5}{48}$	1/3	/	
	Real	Complex	$SU(5)/SO(5) \times SU(3)^2/SU(3)$				
$SU(N_{HC})$	$5 \times \mathbf{A}_2$	$3 \times (\mathbf{F}, \overline{\mathbf{F}})$	$N_{HC} = 4$	$\frac{5}{3}$	1/3	$N_{HC} = 4$	M6
$SO(N_{HC})$	$5 \times \mathbf{F}$	$3 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$	$N_{HC} = 10, 14$	$\frac{5}{12}, \frac{5}{48}$	1/3	$N_{HC} = 10$	M7
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{HC})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{HC} \leq 36$	$\frac{1}{3(N_{HC}-1)}$	2/3	$2N_{HC} = 4$	M8
$SO(N_{HC})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{HC} = 11, 13$	$\frac{8}{3}, \frac{16}{3}$	2/3	$N_{HC} = 11$	M9
	Complex	Real	$SU(4)^2/SU(4) \times SU(6)/SO(6)$				
$SO(N_{HC})$	$4 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$	$6 \times \mathbf{F}$	$N_{HC} = 10$	$\frac{8}{3}$	2/3	$N_{HC} = 10$	M10
$SU(N_{HC})$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$6 \times \mathbf{A}_2$	$N_{HC} = 4$	$\frac{2}{3}$	2/3	$N_{HC} = 4$	M11
	Complex	Complex	$SU(4)^2/SU(4) \times SU(3)^2/SU(3)$				
$SU(N_{HC})$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$3 \times (\mathbf{A}_2, \overline{\mathbf{A}}_2)$	$N_{HC} \geq 5$	$\frac{4}{3(N_{HC}-2)}$	2/3	$N_{HC} = 5$	M12
$SU(N_{HC})$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$3 \times (\mathbf{S}_2, \overline{\mathbf{S}}_2)$	$N_{HC} \geq 5$	$\frac{4}{3(N_{HC}+2)}$	2/3	/	
$SU(N_{HC})$	$4 \times (\mathbf{A}_2, \overline{\mathbf{A}}_2)$	$3 \times (\mathbf{F}, \overline{\mathbf{F}})$	$N_{HC} = 5$	4	2/3	/	

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4\times\mathbf{F}$	$6\times\mathbf{A}_2$	$2N_{\mathrm{HC}}\le 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	2/3	$2N_{\mathrm{HC}}=4$	M8
$SO(N_{\mathrm{HC}})$	$4\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\mathrm{HC}}=11,13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\mathrm{HC}}=11$	M9

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	2/3	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\mathrm{HC}} = 11$	M9

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\text{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\text{HC}} \leq 36$	$\frac{1}{3(N_{\text{HC}}-1)}$	$2/3$	$2N_{\text{HC}} = 4$	M8
$SO(N_{\text{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\text{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\text{HC}} = 11$	M9

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\rm HC} \leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	2/3	$2N_{\rm HC} = 4$	M8
$SO(N_{\rm HC})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\rm HC} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\rm HC} = 11$	M9

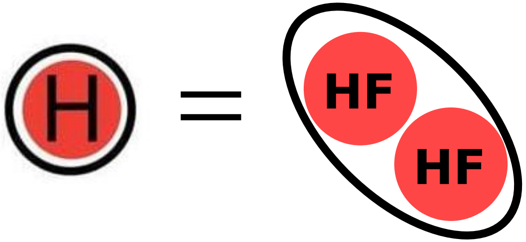
$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\rm HC} \leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	$2/3$	$2N_{\rm HC} = 4$	M8
$SO(N_{\rm HC})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\rm HC} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\rm HC} = 11$	M9

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	$2/3$	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\mathrm{HC}} = 11$	M9

$$EW \subset SU(4)$$

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\rm HC} \leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	$2/3$	$2N_{\rm HC} = 4$	M8
$SO(N_{\rm HC})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\rm HC} = 11, 13$	$\frac{8}{3}, \frac{16}{3}$	$2/3$	$N_{\rm HC} = 11$	M9

$$EW \subset SU(4)$$



$$= \langle \psi\psi \rangle$$

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	$2/3$	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\mathrm{HC}} = 11$	M9

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4)	SU(6)/SO(6)			
$Sp(2N_{\rm HC})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\rm HC} \leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	$2/3$	$2N_{\rm HC} = 4$	M8
$SO(N_{\rm HC})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\rm HC} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\rm HC} = 11$	M9

CH

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\text{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\text{HC}} \leq 36$	$\frac{1}{3(N_{\text{HC}}-1)}$	$2/3$	$2N_{\text{HC}} = 4$	M8
$SO(N_{\text{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\text{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\text{HC}} = 11$	M9

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\rm HC} \leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	2/3	$2N_{\rm HC} = 4$	M8
$SO(N_{\rm HC})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\rm HC} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\rm HC} = 11$	M9

CH

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	2/3	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\mathrm{HC}} = 11$	M9

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	$2/3$	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\mathrm{HC}} = 11$	M9

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\text{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\text{HC}} \leq 36$	$\frac{1}{3(N_{\text{HC}}-1)}$	$2/3$	$2N_{\text{HC}} = 4$	M8
$SO(N_{\text{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\text{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\text{HC}} = 11$	M9

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\text{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\text{HC}} \leq 36$	$\frac{1}{3(N_{\text{HC}}-1)}$	$2/3$	$2N_{\text{HC}} = 4$	M8
$SO(N_{\text{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\text{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\text{HC}} = 11$	M9

Those models are not UV Complete !

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	2/3	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\mathrm{HC}} = 11$	M9

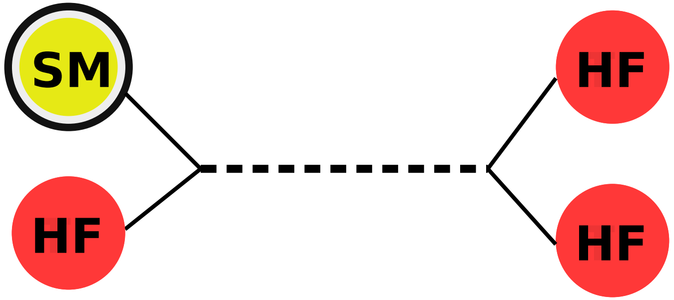
Those models are not UV Complete !

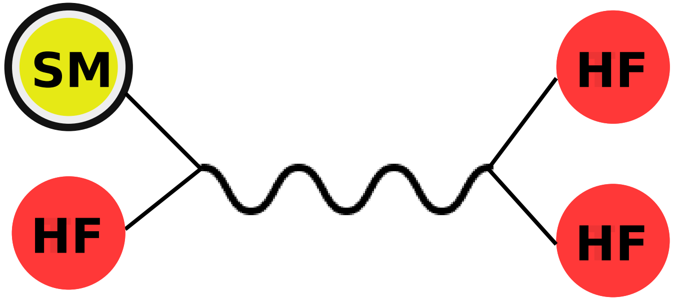
- Need well defined new strong sector
- Need to generate 4-F interactions

G_{HC}	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\mathrm{HC}})$	$4 \times \mathbf{F}$	$6 \times \mathbf{A}_2$	$2N_{\mathrm{HC}} \leq 36$	$\frac{1}{3(N_{\mathrm{HC}}-1)}$	$2/3$	$2N_{\mathrm{HC}} = 4$	M8
$SO(N_{\mathrm{HC}})$	$4 \times \mathbf{Spin}$	$6 \times \mathbf{F}$	$N_{\mathrm{HC}} = 11, 13$	$\frac{8}{3}, \frac{16}{3}$	$2/3$	$N_{\mathrm{HC}} = 11$	M9

Those models are not UV Complete !

- Need well defined new strong sector
- Need to generate 4-F interactions

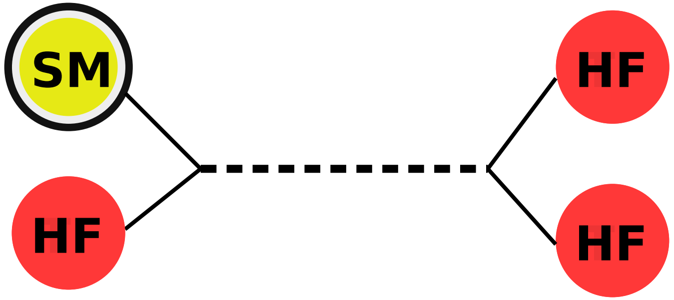


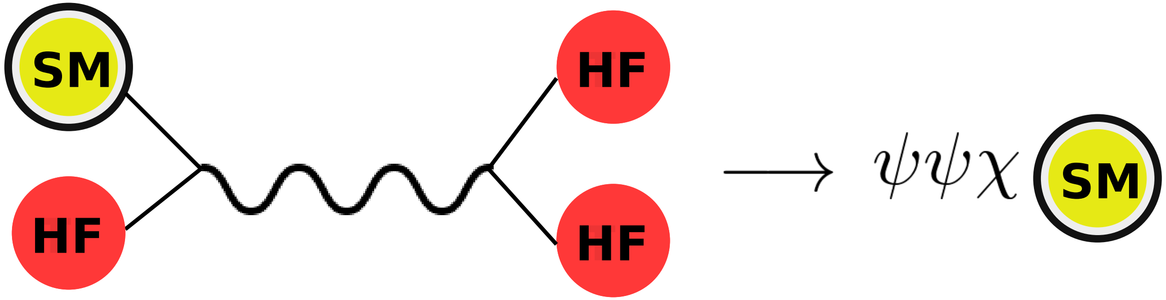


$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) $\times$ SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4\times\mathbf{F}$	$6\times\mathbf{A}_2$	$2N_{\rm HC}\leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	$2/3$	$2N_{\rm HC}=4$	M8
$SO(N_{\rm HC})$	$4\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\rm HC}=11,13$	$\frac{8}{3}$, $\frac{16}{3}$	$2/3$	$N_{\rm HC}=11$	M9

Those models are not UV Complete !

- Need well defined new strong sector
- Need to generate 4-F interactions





Historically

Historically

- Extended Technicolor ⇝ Tension with Flavor
- Bosonic Technicolor ⇝ Tension with Naturalness

Historically

- Extended Technicolor ⇝ Tension with Flavor
- Bosonic Technicolor ⇝ Tension with Naturalness

Partial Unification (PU)

Historically

- Extended Technicolor ⇝ Tension with Flavor
- Bosonic Technicolor ⇝ Tension with Naturalness

Partial Unification (PU)

- Partially unify HC and SM
- High scale scalars to break the gauge group
- 4-F are generated automatically (gauge + scalars)

Means

- Partially unify HC and SM
- High scale scalars to break the gauge group
- 4-F are generated automatically (gauge + scalars)

TPS

Means

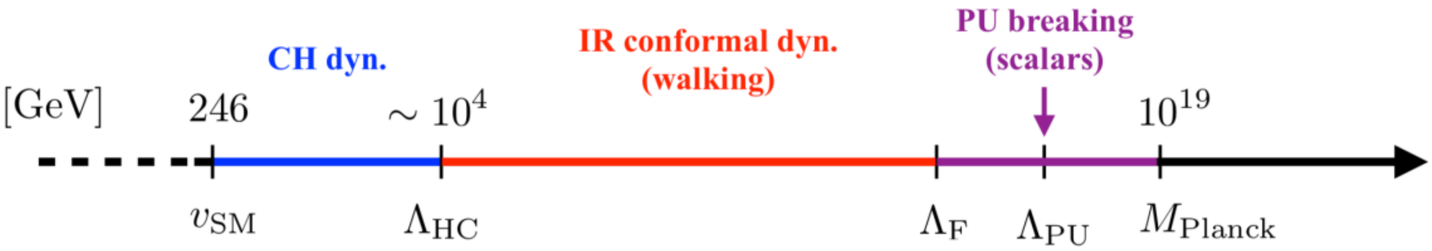
- Partially unify HC and SM
- High scale scalars to break the gauge group
- 4-F are generated automatically (gauge + scalars)

Goals

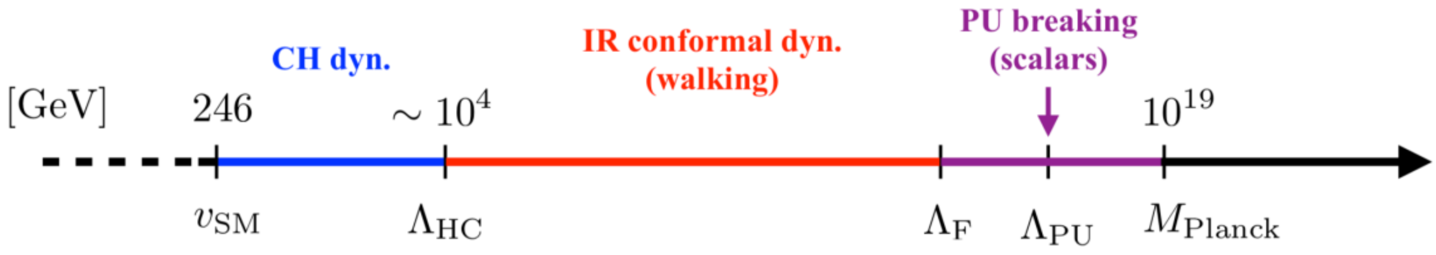
- Generate 4-F
- In a well defined theory
- Target at low energy a Composite Higgs scenario
- Realistic Flavor structure

The Techni-Pati-Salam
(TPS)
a possible UV completion

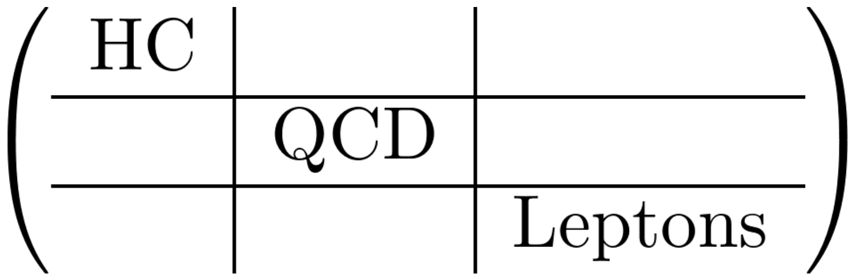
Set-Up


CH dyn.
IR conformal dyn. (walking)
PU breaking (scalars)
[GeV]
246
~ 10^4
10^19
v_SM
Λ_HC
Λ_F
Λ_PU
M_Planck

Set-Up



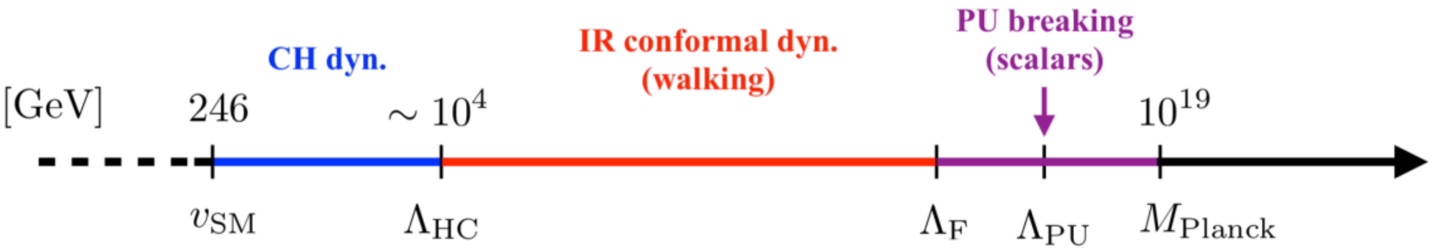
CH dyn.
IR conformal dyn. (walking)
PU breaking (scalars)
[GeV]
246
$\sim 10^4$
10^{19}
$v_{\rm SM}$
$\Lambda_{\rm HC}$
$\Lambda_{\rm F}$
$\Lambda_{\rm PU}$
$M_{\rm Planck}$

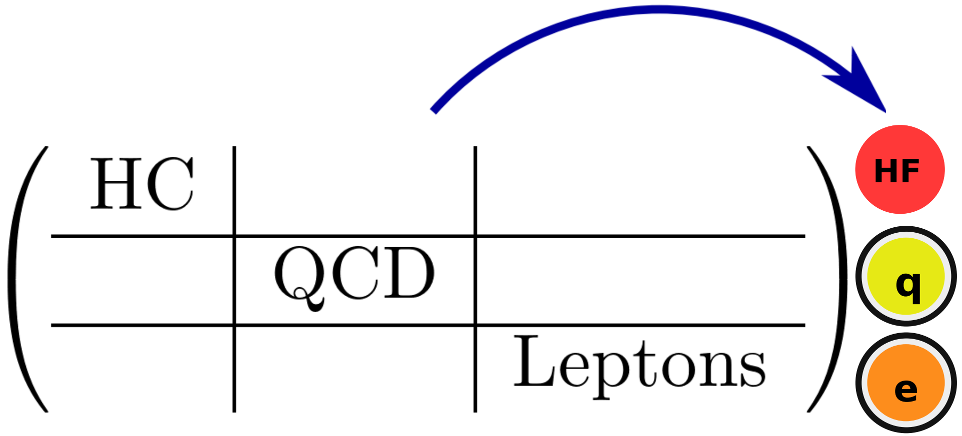


HC
QCD
Leptons

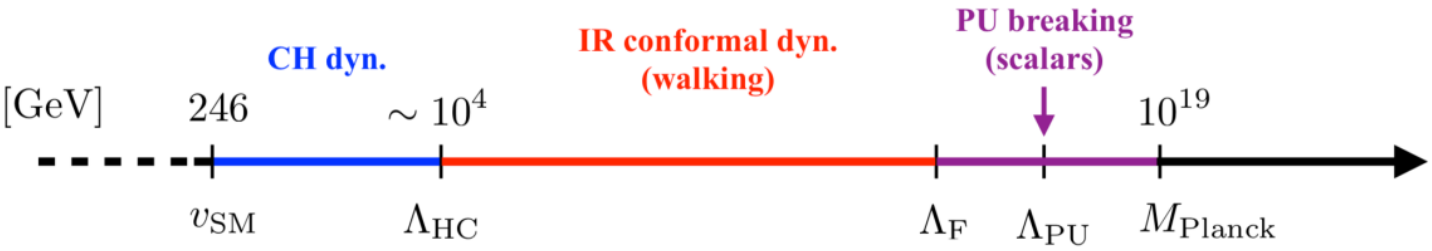
TPS

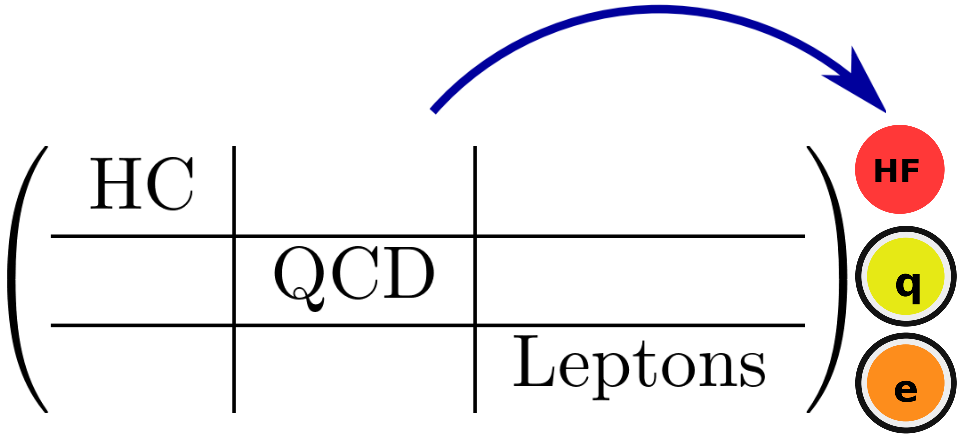
Set-Up


CH dyn.
IR conformal dyn. (walking)
PU breaking (scalars)
[GeV]
246
$\sim 10^4$
10^{19}
v_{SM}
Λ_{HC}
Λ_F
Λ_{PU}
M_{Planck}


HC
QCD
Leptons
HF
q
e

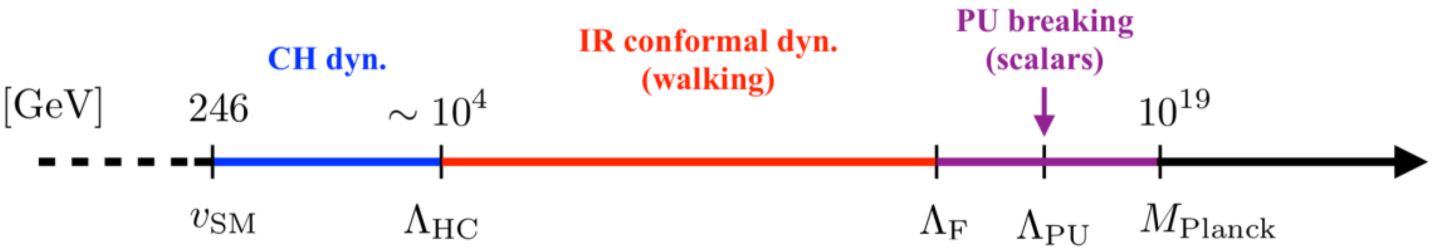
Set-Up

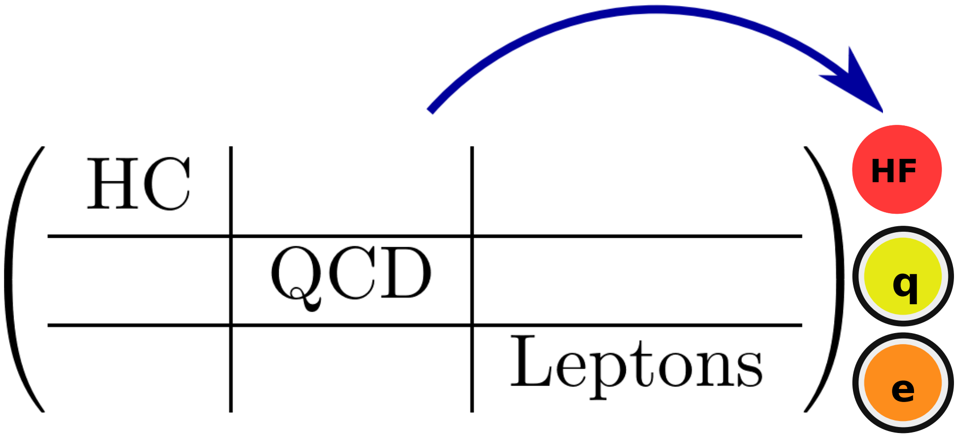




$$\mathrm{HC} \quad =$$

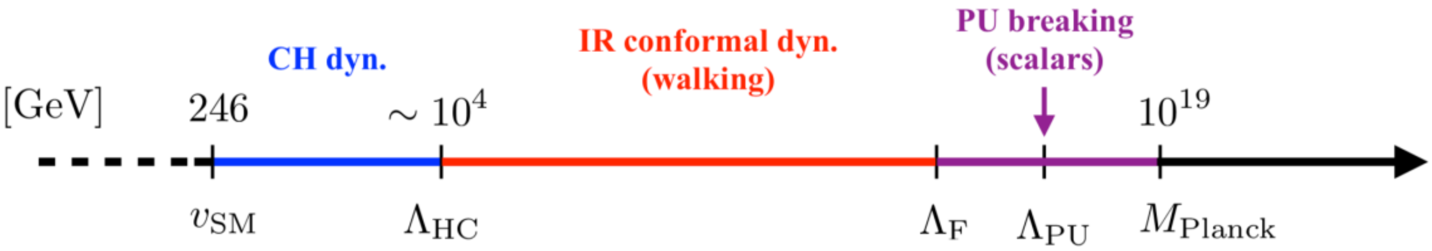
Set-Up

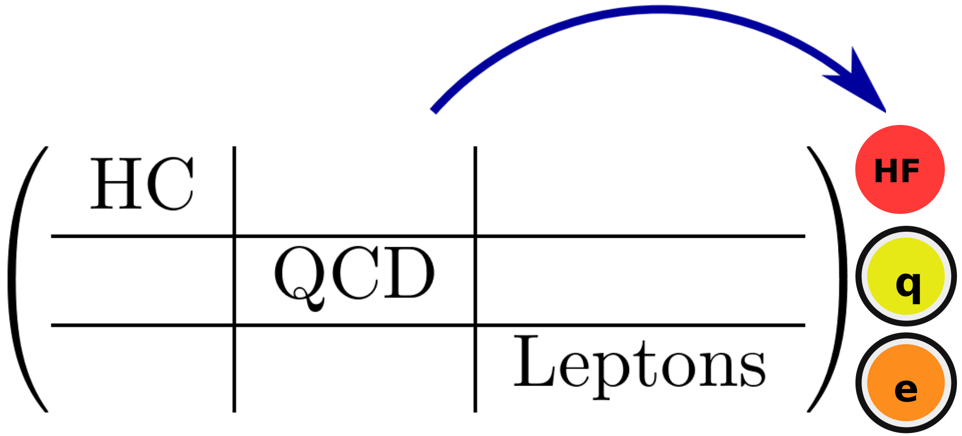




$$\mathrm{HC} = SU(N)$$

Set-Up

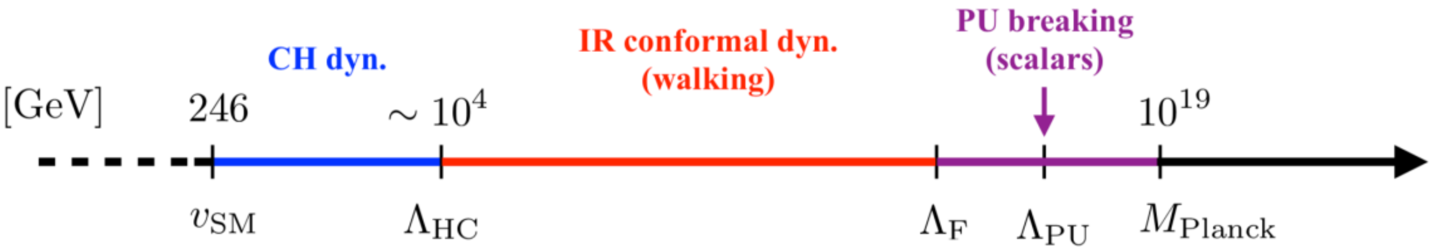


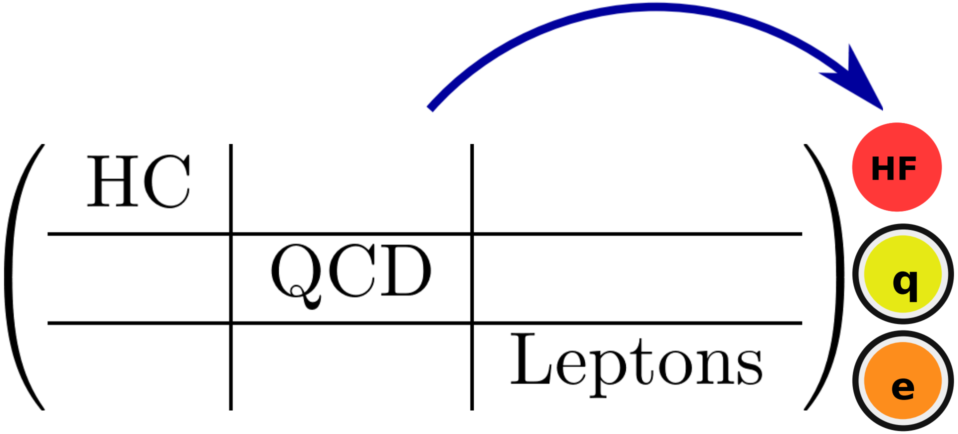


$$\mathrm{HC} = SU(N)$$

TPS

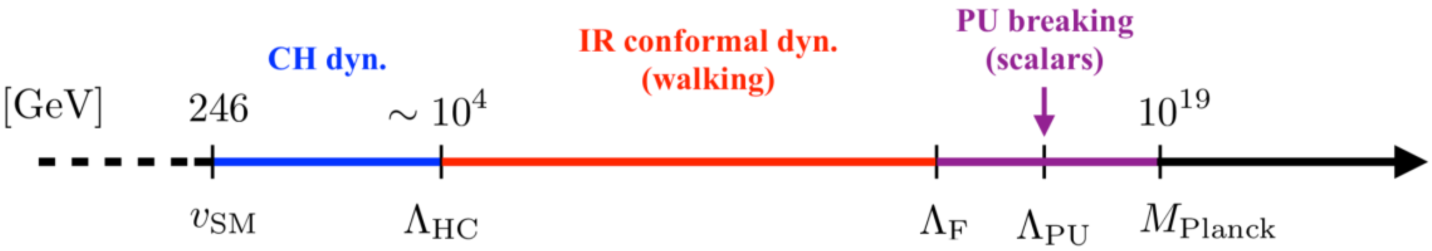
Set-Up

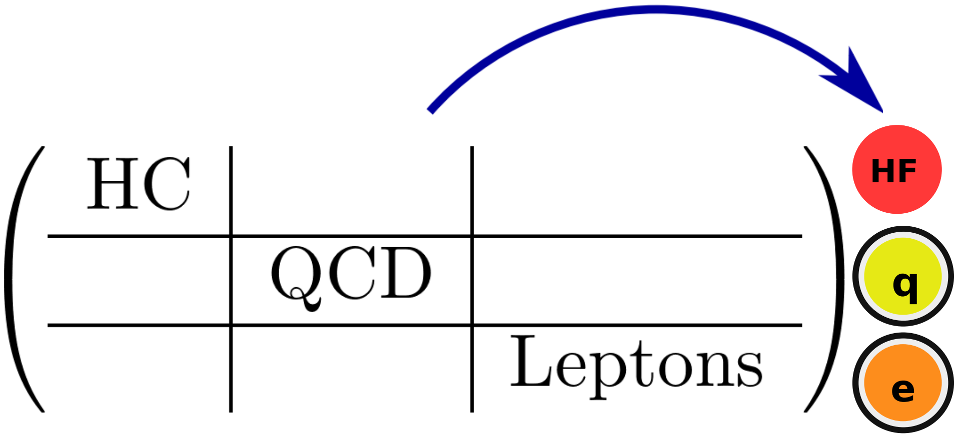




$$\mathrm{HC} = \cancel{SU(N)}\,,\quad SO(N)$$

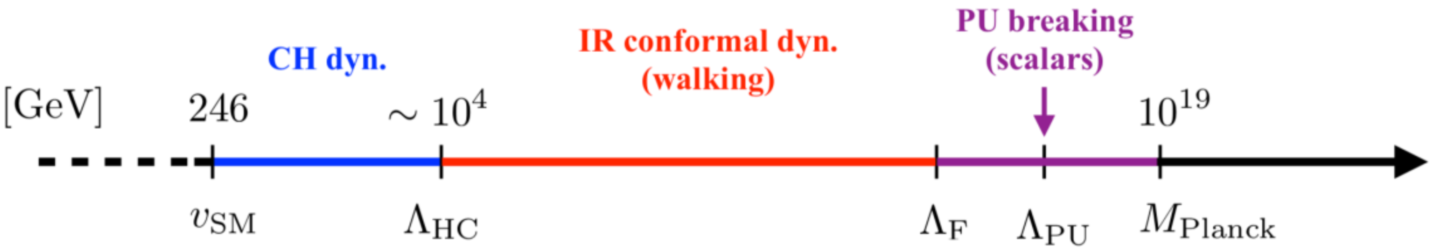
Set-Up

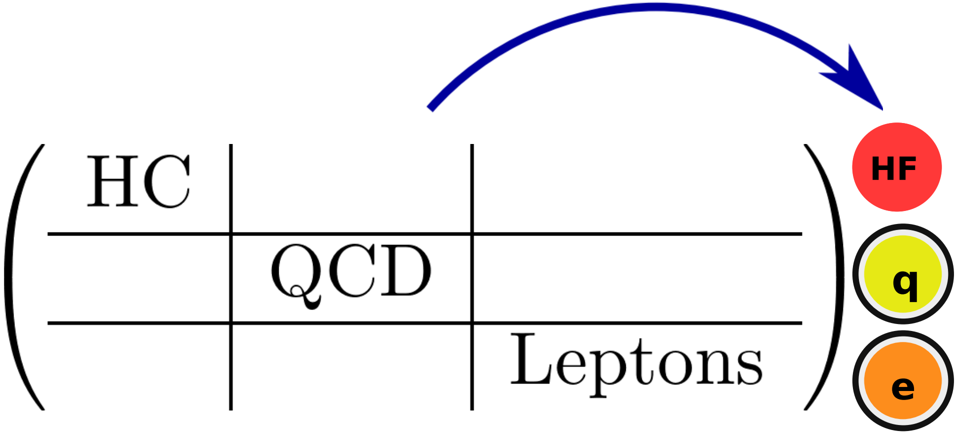




$$\mathrm{HC} = SU(N)\,,\quad SO(N)$$

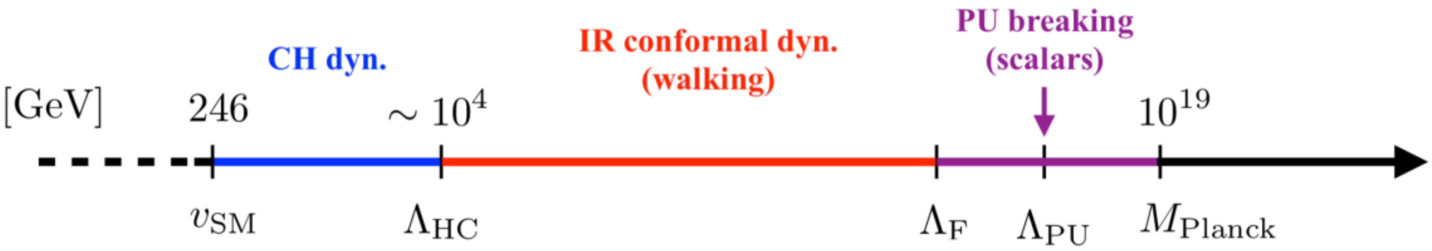
Set-Up

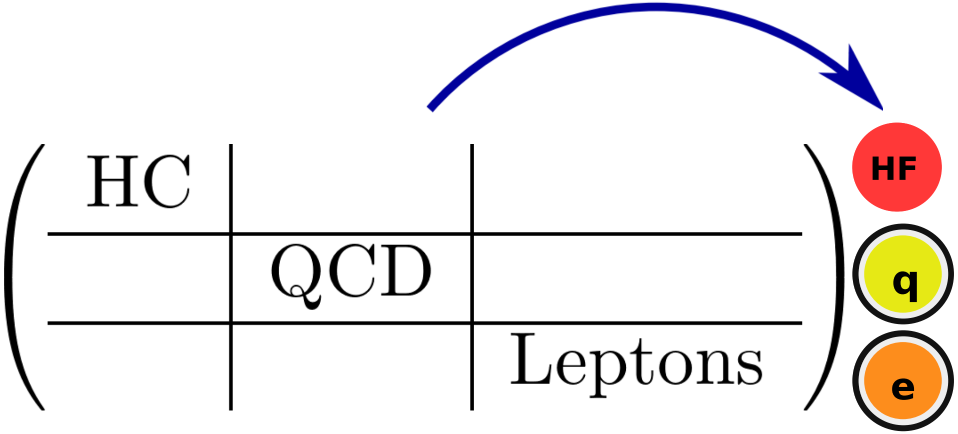




$$\mathrm{HC} = SU(N)\,,\quad SO(N)\,,\quad Sp(N)$$

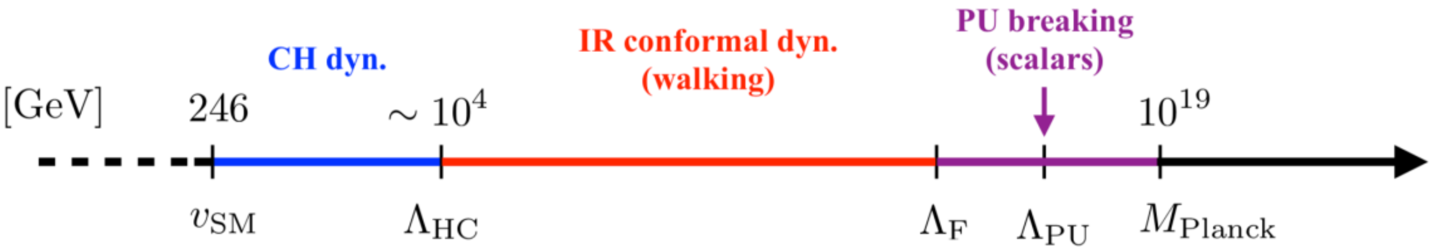
Set-Up





$$\mathrm{HC} = SU(N)\,,\quad SO(N)\,,\quad Sp(N)$$

Set-Up



$$SU(8)_{PS} \times SU(2)_R \times SU(2)_L$$

Scalars ... to do ... the breaking !

Scalars ... to do ... the breaking !

TPS

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$	vev
Φ	8	2	1	v_{PS}^{Φ}
Ψ	Adj	1	1	v_{EHC}^{Ψ}
Θ	A_2	1	1	v_{CHC}^{Θ}
Δ	A_3	2	1	

TPS

Scalars … to do … the breaking !

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$	vev
Φ	8	2	1	v^{Φ}_{PS}
Ψ	Adj	1	1	v^{Ψ}_{EHC}
Θ	A_2	1	1	v^{Θ}_{CHC}
Δ	A_3	2	1	

- $SU(8)_{PS} \times SU(2)_R \to SU(7)_{EHC} \times U(1)_E$ splits Leptons from Quarks

TPS

Scalars … to do … the breaking !

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$	vev
Φ	8	2	1	v^{Φ}_{PS}
Ψ	Adj	1	1	v^{Ψ}_{EHC}
Θ	A_2	1	1	v^{Θ}_{CHC}
Δ	A_3	2	1	

- $SU(8)_{PS} \times SU(2)_R \to SU(7)_{EHC} \times U(1)_E$ **splits Leptons from Quarks**
- $SU(7)_{EHC} \to SU(4)_{CHC} \times SU(3)_c \times U(1)_X$ **splits HF from Quarks**

Scalars ... to do ... the breaking !

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$	vev
Φ	8	2	1	v_{PS}^{Φ}
Ψ	Adj	1	1	v_{EHC}^{Ψ}
Θ	A_2	1	1	v_{CHC}^{Θ}
Δ	A_3	2	1	

- $SU(8)_{PS} \times SU(2)_R \to SU(7)_{EHC} \times U(1)_E$ splits Leptons from Quarks
- $SU(7)_{EHC} \to SU(4)_{CHC} \times SU(3)_c \times U(1)_X$ splits HF from Quarks
- $SU(4)_{CHC} \times U(1)_X \times U(1)_E \to Sp(4)_{HC} \times U(1)_Y$

TPS

Scalars ... to do ... the breaking !

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$	vev
Φ	8	2	1	v_{PS}^{Φ}
Ψ	Adj	1	1	v_{EHC}^{Ψ}
Θ	A_2	1	1	v_{CHC}^{Θ}
Δ	A_3	2	1	

- $SU(8)_{PS} \times SU(2)_R \to SU(7)_{EHC} \times U(1)_E$ **splits Leptons from Quarks**
- $SU(7)_{EHC} \to SU(4)_{CHC} \times SU(3)_c \times U(1)_X$ **splits HF from Quarks**
- $SU(4)_{CHC} \times U(1)_X \times U(1)_E \to Sp(4)_{HC} \times U(1)_Y$

Fermion Content

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$
Ω^p	8	1	2
Υ^p	$\bar{8}$	2	1
Ξ	$70 = A_4$	1	1
N^p	1	1	1

Fermion Content

TPS

Higgs Components

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$
$\Omega^p = \begin{pmatrix} L^p_{u/d} \\ q^p_L \\ l^p_L \end{pmatrix}$	8	1	2
$\Upsilon^p = \begin{pmatrix} U_d & D_u \\ d^{c\,p}_R & u^{c\,p}_R \\ e^{c\,p}_R & \nu^{c\,p}_R \end{pmatrix}$	$\bar{8}$	2	1
$\Xi = \begin{pmatrix} U_u & \chi & \rho & \eta & \omega \\ D_d & \tilde{\chi} & \tilde{\rho} & \tilde{\eta} & \tilde{\omega} \end{pmatrix}$	$70 = A_4$	1	1
N^p	1	1	1

Partial Compositness

4-F : Gauge Mediation

4-F : Gauge Mediation

TPS

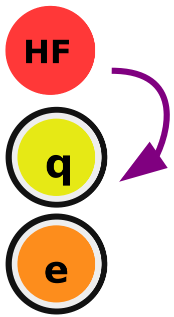
$$A^\mu = \left(\begin{array}{c|c|c} \text{HC} & & \\ \hline & \text{QCD} & \\ \hline & & \text{Leptons} \end{array}\right)$$

4-F : Gauge Mediation

$$A^\mu = \left(\begin{array}{c|c|c} \mathrm{HC} & \bullet & \\ \hline \bullet & \mathrm{QCD} & \\ \hline & & \mathrm{Leptons} \end{array}\right)$$

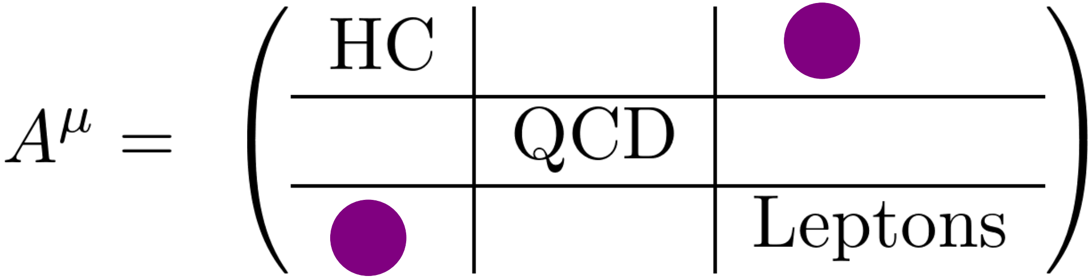
4-F : Gauge Mediation

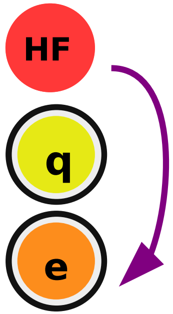
$$A^\mu = \left(\begin{array}{c|c|c} \text{HC} & \bullet & \\ \hline \bullet & \text{QCD} & \\ \hline & & \text{Leptons} \end{array}\right)$$



4-F : Gauge Mediation

TPS





Quark-Lepton mass splitting !

Scalar Mediation ?

Scalar Mediation ?

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon \Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi \Psi \Xi \\ - \lambda_{\Theta L} \Omega \Theta^* \Omega - \lambda_{\Theta R} \Upsilon \Theta \Upsilon - \lambda_\Delta \Upsilon \Delta \Xi + \text{c.c.}$$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\begin{aligned}\mathcal{L}_Y = &-\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi \\ &- \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}\end{aligned}$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi$$
$$- \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde\chi\tilde\eta)$	(χD_b) $(U_t\tilde\chi)$ $(\eta\tilde\chi)$ $(\chi\tilde\eta)$	-	$(U_t D_b)$ $(\eta\tilde\eta)$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t\nu_R^c)$ $(U_t\tau_R^c)$ $(\tilde\eta t_R^c)$ $(\tilde\eta b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta\nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta\tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde\chi b_R^c)$ $(\chi\tau_R^c)$	$(\tilde\chi t_R^c)$ $(\chi\nu_R^c)$	-	(χU_d^3) $(\tilde\chi D_u^3)$	(χD_u^3) $(\tilde\chi U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde\eta U_d^3)$	$(\tilde\eta D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon \Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi \Psi \Xi$$
$$- \lambda_{\Theta L} \Omega \Theta^* \Omega - \lambda_{\Theta R} \Upsilon \Theta \Upsilon - \lambda_\Delta \Upsilon \Delta \Xi + \text{c.c.}$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t \tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

We add Yukawa couplings:

$$
\begin{aligned}
\mathcal{L}_Y = & -\mu_N NN - \lambda_\Phi \Upsilon \Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi \Psi \Xi \\
& - \lambda_{\Theta L} \Omega \Theta^* \Omega - \lambda_{\Theta R} \Upsilon \Theta \Upsilon - \lambda_\Delta \Upsilon \Delta \Xi + \text{c.c.}
\end{aligned}
$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$		-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t \tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi \\ - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_{0}$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_{0}$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-		-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon \Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi \Psi \Xi \\ - \lambda_{\Theta L} \Omega \Theta^* \Omega - \lambda_{\Theta R} \Upsilon \Theta \Upsilon - \lambda_\Delta \Upsilon \Delta \Xi + \text{c.c.}$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon \Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi \Psi \Xi \\ - \lambda_{\Theta L} \Omega \Theta^* \Omega - \lambda_{\Theta R} \Upsilon \Theta \Upsilon - \lambda_\Delta \Upsilon \Delta \Xi + \text{c.c.}$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_{0}$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_{0}$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t \tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_4}^2} c_4 \; (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon \Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi \Psi \Xi - \lambda_{\Theta L} \Omega \Theta^* \Omega - \lambda_{\Theta R} \Upsilon \Theta \Upsilon - \lambda_\Delta \Upsilon \Delta \Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_4}^2} c_4 \, (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t \tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_4}^2} c_4 \; (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi 4}^2} c_4 \; (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

$$\frac{\lambda_\Delta^2}{M_{\varphi 5}^2} c_5 \; (\overline{U}_t \overline{D}_u^3)(\chi t_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi \\ - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi 4}^2} c_4 \; (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

$$\frac{\lambda_\Delta^2}{M_{\varphi 5}^2} c_5 \; (\overline{U}_t \overline{D}_u^3)(\chi t_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_{0}$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_{0}$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

TPS

Scalar Mediation ?

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi 4}^2} c_4 \;(\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

$$\frac{\lambda_\Delta^2}{M_{\varphi 5}^2} c_5 \;(\overline{U}_t \overline{D}_u^3)(\chi t_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t\tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

TPS

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi$$
$$- \lambda_{\Theta L} \Omega\Theta^*\Omega - \lambda_{\Theta R} \Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_4}^2} c_4 \; (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_5}^2} c_5 \; (\overline{U}_t \overline{D}_u^3)(\chi t_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t \tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

We add Yukawa couplings:

$$\mathcal{L}_Y = -\mu_N NN - \lambda_\Phi \Upsilon\Phi N - \mu_\Xi \Xi\Xi - \lambda_\Psi \Xi\Psi\Xi - \lambda_{\Theta L}\Omega\Theta^*\Omega - \lambda_{\Theta R}\Upsilon\Theta\Upsilon - \lambda_\Delta \Upsilon\Delta\Xi + \text{c.c.}$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_4}^2} c_4 \; (\overline{U}_t \overline{U}_d^3)(\chi b_R^c)$$

$$\frac{\lambda_\Delta^2}{M_{\varphi_5}^2} c_5 \; (\overline{U}_t \overline{D}_u^3)(\chi t_R^c)$$

	1 SM field							0 SM field						
φ_i	$(\mathbf{4},\mathbf{1})_{-\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{4},\mathbf{1})_{\frac{1}{2}}$	$(\mathbf{4},\mathbf{3})_{\frac{1}{6}}$	$(\mathbf{4},\mathbf{3})_{-\frac{5}{6}}$	$(\mathbf{5},\mathbf{1})_0$	$(\mathbf{5},\mathbf{1})_{-1}$	$(\mathbf{5},\mathbf{3})_{\frac{2}{3}}$	$(\mathbf{5},\mathbf{3})_{-\frac{1}{3}}$
$\Omega\Theta^*\Omega$	$(L^3 l_L)$	$(L^3 q_L)$	-	-	-	-	-	-	-	-	$(L^3 L^3)$	-	-	-
$\Upsilon\Theta\Upsilon$	$(U_d^3 \nu_R^c)$ $(D_u^3 \tau_R^c)$	$(U_d^3 t_R^c)$ $(D_u^3 b_R^c)$	- -	- -	- -	- -	- -	- -	- -	- -	$(U_d^3 D_u^3)$	- -	- -	- -
$\Xi\Psi\Xi$	-	-	-	-	-	-	-	$(\chi\eta)$ $(\tilde{\chi}\tilde{\eta})$	(χD_b) $(U_t \tilde{\chi})$ $(\eta\tilde{\chi})$ $(\chi\tilde{\eta})$	-	$(U_t D_b)$ $(\eta\tilde{\eta})$	-	-	-
$\Upsilon\Delta^*\Xi$	$(U_t \nu_R^c)$ $(U_t \tau_R^c)$ $(\tilde{\eta} t_R^c)$ $(\tilde{\eta} b_R^c)$	$(D_b t_R^c)$ (ηb_R^c) $(\eta \nu_R^c)$	$(D_b b_R^c)$ (ηt_R^c) $(\eta \tau_R^c)$	(χb_R^c)	(χt_R^c)	$(\tilde{\chi} b_R^c)$ $(\chi \tau_R^c)$	$(\tilde{\chi} t_R^c)$ $(\chi \nu_R^c)$	-	(χU_d^3) $(\tilde{\chi} D_u^3)$	(χD_u^3) $(\tilde{\chi} U_d^3)$	$(U_t U_d^3)$	$(U_t D_u^3)$	$(\tilde{\eta} U_d^3)$	$(\tilde{\eta} D_u^3)$

Scalar Mediation ?

TPS

- **We can have top-bottom mass splitting !**

Scalar Mediation ?

- We can have top-bottom mass splitting !
- Masses and mixing of the scalars

Scalar Mediation ?

- **We can have top-bottom mass splitting !**
- **Masses and mixing of the scalars** $\rightarrow$ complete study of the potential $\cdots$

Scalar Mediation ?

- **We can have top-bottom mass splitting !**
- **Masses and mixing of the scalars** $\rightarrow$ complete study
  of the potential $\cdots$

- **Size of the Yukawa couplings**

Scalar Mediation ?

- **We can have top-bottom mass splitting !**
- **Masses and mixing of the scalars** $\rightarrow$ complete study of the potential $\cdots$

- **Size of the Yukawa couplings** $\rightarrow$ constraints from HF masses

HyperFermion Masses

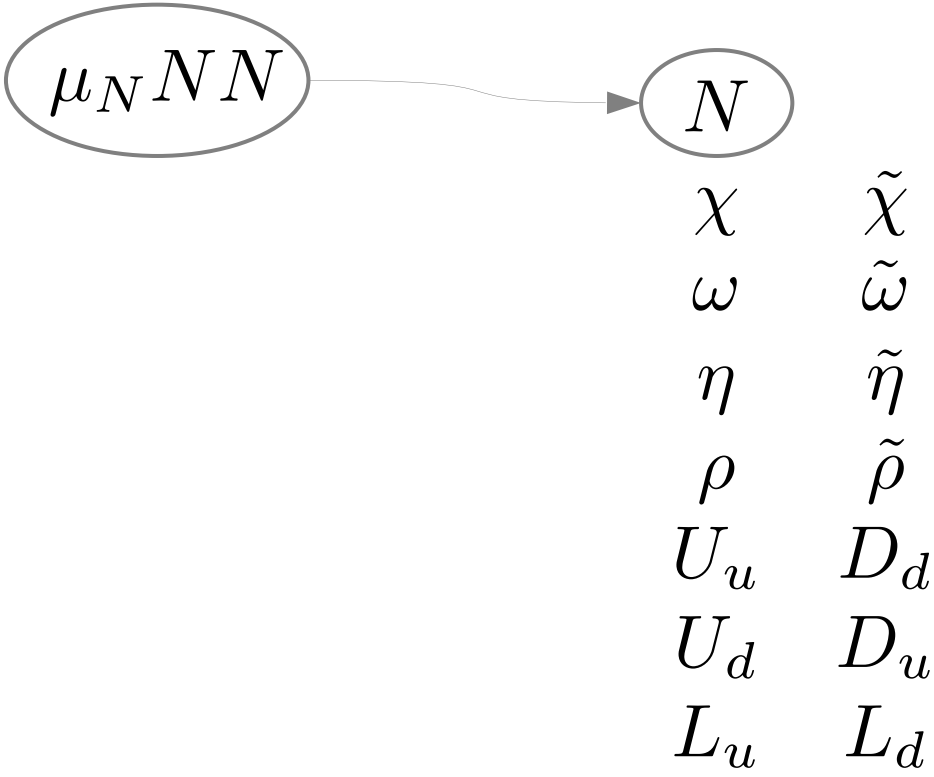
- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**

$$
\begin{array}{cc}
N & \\
\chi & \tilde{\chi} \\
\omega & \tilde{\omega} \\
\eta & \tilde{\eta} \\
\rho & \tilde{\rho} \\
U_u & D_d \\
U_d & D_u \\
L_u & L_d
\end{array}
$$

HyperFermion Masses

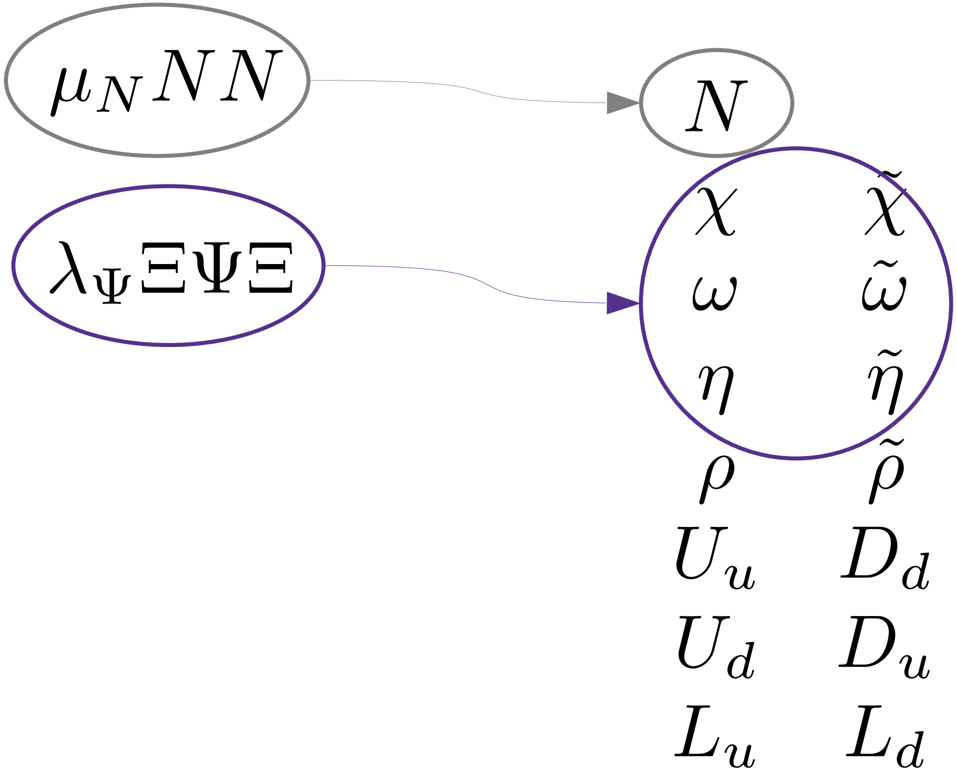
TPS

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



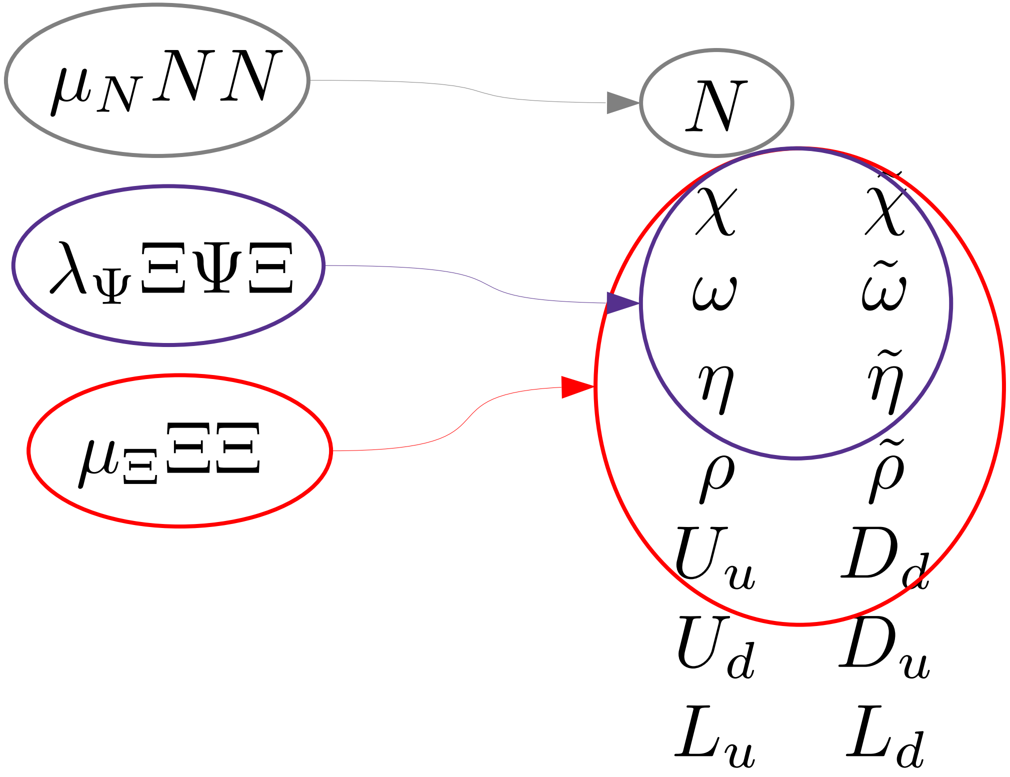
HyperFermion Masses

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



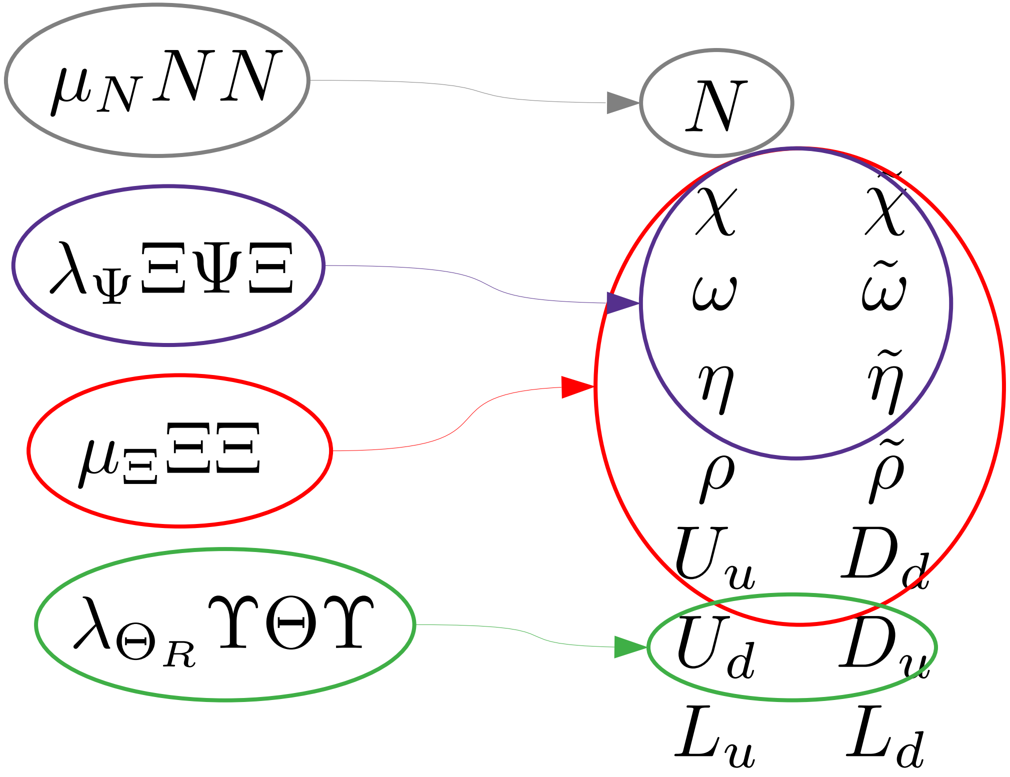
HyperFermion Masses

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



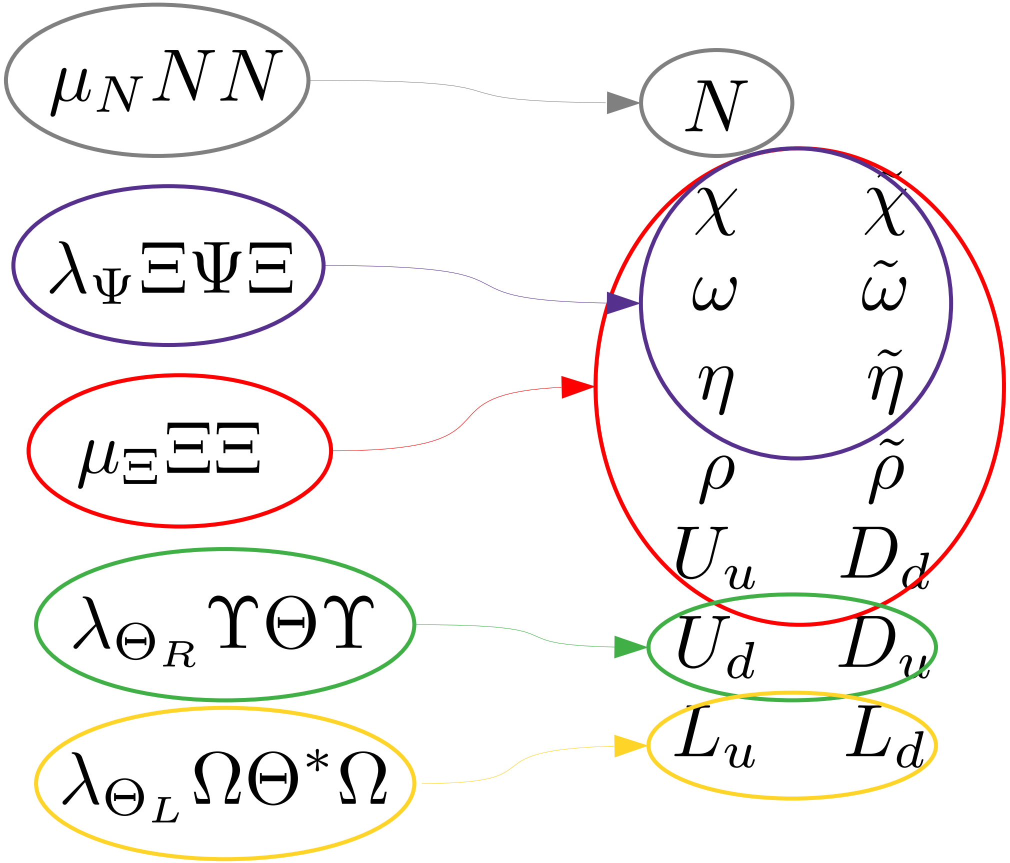
HyperFermion Masses

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



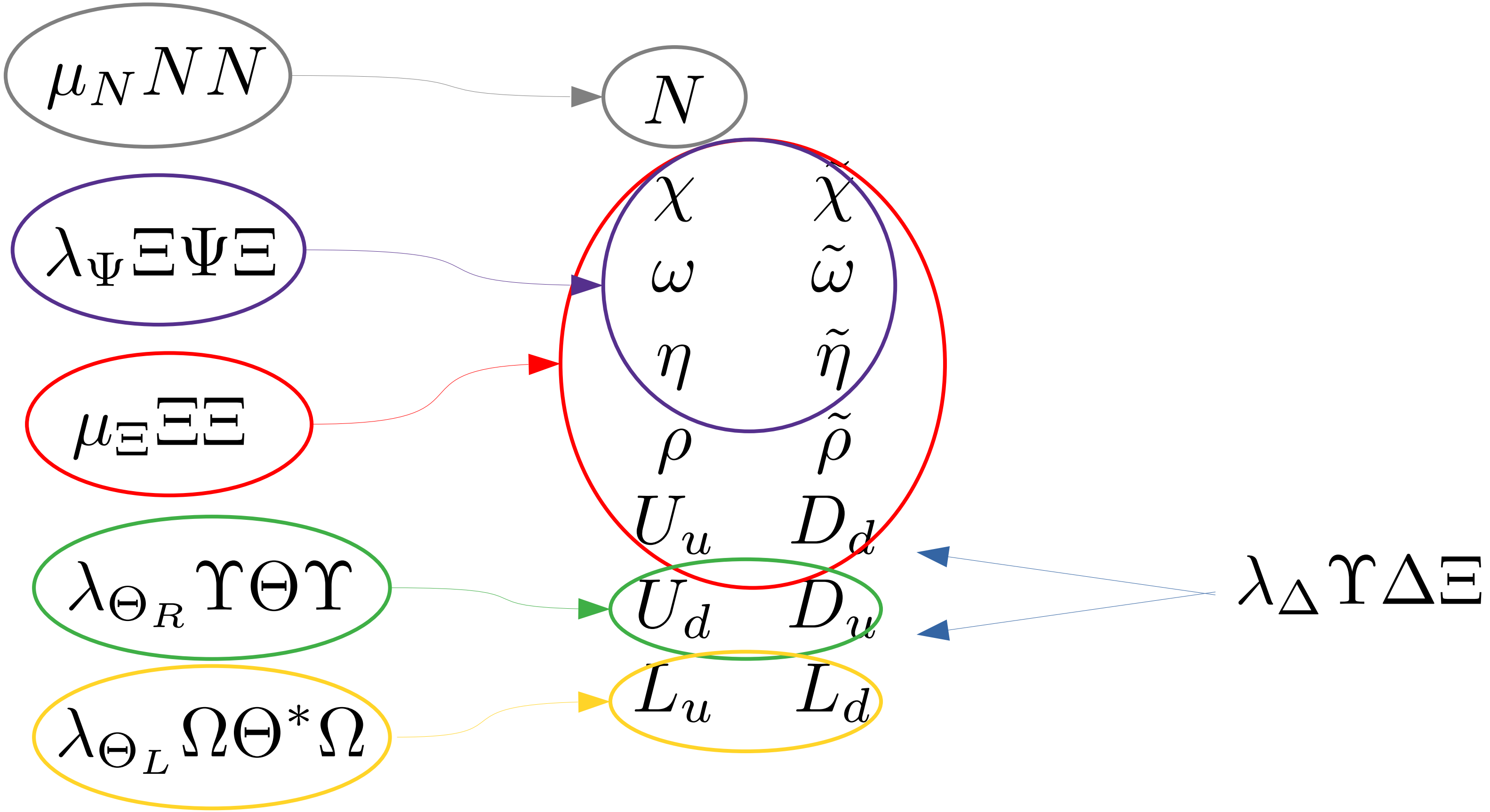
HyperFermion Masses

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



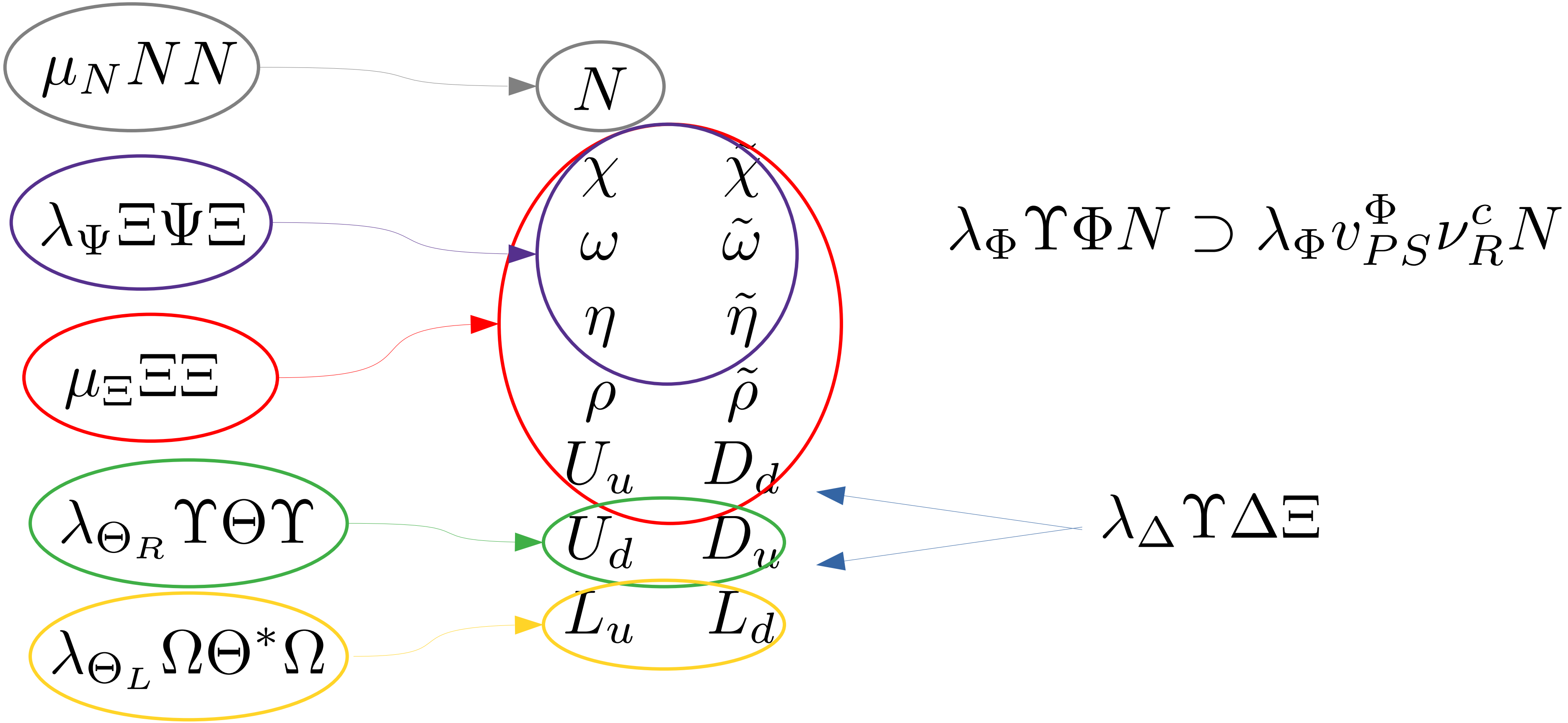
HyperFermion Masses

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



HyperFermion Masses

- Relevant for **HyperColor Dynamics**, low energy **symmetry breaking pattern**



Fermion Masses

- Quark-Lepton $\rightarrow$ masses of HF / massive gauge bosons

Fermion Masses

- Quark-Lepton $\rightarrow$ masses of HF / massive gauge bosons
- Top – Bottom $\rightarrow$ Different running 4F-Operator / Scalar Mediation

Fermion Masses

TPS

- Quark-Lepton $\rightarrow$ masses of HF / massive gauge bosons
- Top – Bottom $\rightarrow$ Different running 4F-Operator / Scalar Mediation
- What about neutrinos ?

Fermion Masses

- Quark-Lepton $\rightarrow$ masses of HF / massive gauge bosons
- Top – Bottom $\rightarrow$ Different running 4F-Operator / Scalar Mediation
- Neutrinos $\rightarrow$ Inverse seesaw mechanism

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get **Conformal Dynamics ?**

So far so good

TPS

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get **Conformal Dynamics ?**

Need Lattice Input !!

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get **Conformal Dynamics ?** ✓

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get **Conformal Dynamics**

So far so good

TPS

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get **Conformal Dynamics**

How can we generalize that for the 3 families ?

Fermion Content

TPS

	$SU(8)_{PS}$	$SU(2)_R$	$SU(2)_L$
$\Omega^p = \begin{pmatrix} L^p_{u/d} \\ q^p_L \\ l^p_L \end{pmatrix}$	8	1	2
$\Upsilon^p = \begin{pmatrix} U_d & D_u \\ d^{c\ p}_R & u^{c\ p}_R \\ e^{c\ p}_R & \nu^{c\ p}_R \end{pmatrix}$	$\bar{8}$	2	1
$\Xi = \begin{pmatrix} U_u & \chi & \rho & \eta & \omega \\ D_d & \tilde{\chi} & \tilde{\rho} & \tilde{\eta} & \tilde{\omega} \end{pmatrix}$	$70 = A_4$	1	1
N^p	1	1	1

Rank of the Mass Matrix

Rank of the Mass Matrix

TPS

- Each species of fermion, $t,\ b,\ \tau,\ \nu_\tau$ gets its own mass matrix :

Rank of the Mass Matrix

TPS

- Each species of fermion, $t,\ b,\ \tau,\ \nu_\tau$ gets its own mass matrix :

$$\begin{pmatrix} \langle O_{R1} O_{L1} \rangle & \langle O_{R1} O_{L2} \rangle & \langle O_{R1} O_{L3} \rangle \\ \langle O_{R2} O_{L1} \rangle & \langle O_{R2} O_{L2} \rangle & \langle O_{R2} O_{L3} \rangle \\ \langle O_{R3} O_{L1} \rangle & \langle O_{R3} O_{L2} \rangle & \langle O_{R3} O_{L3} \rangle \end{pmatrix}$$

Rank of the Mass Matrix

TPS

- Each species of fermion, $t,\ b,\ \tau,\ \nu_\tau$ gets its own mass matrix :

$$\begin{pmatrix} \langle O_{R1}O_{L1}\rangle & \langle O_{R1}O_{L2}\rangle & \langle O_{R1}O_{L3}\rangle \\ \langle O_{R2}O_{L1}\rangle & \langle O_{R2}O_{L2}\rangle & \langle O_{R2}O_{L3}\rangle \\ \langle O_{R3}O_{L1}\rangle & \langle O_{R3}O_{L2}\rangle & \langle O_{R3}O_{L3}\rangle \end{pmatrix}$$

- 3 families if rank 3 !

Rank of the Mass Matrix

TPS

- Each species of fermion, $t,\ b,\ \tau,\ \nu_\tau$ gets its own mass matrix :

$$\begin{pmatrix} \langle O_{R1}O_{L1}\rangle & \langle O_{R1}O_{L2}\rangle & \langle O_{R1}O_{L3}\rangle \\ \langle O_{R2}O_{L1}\rangle & \langle O_{R2}O_{L2}\rangle & \langle O_{R2}O_{L3}\rangle \\ \langle O_{R3}O_{L1}\rangle & \langle O_{R3}O_{L2}\rangle & \langle O_{R3}O_{L3}\rangle \end{pmatrix}$$

- 3 families if rank 3 !

$$\mathcal{O}_{L,a} \ = \ y_{L,a}\mathcal{O}_L \qquad \mathcal{O}_{R,a} \ = \ y_{R,a}\mathcal{O}_R$$

Rank of the Mass Matrix

TPS

- Each species of fermion, $t,\ b,\ \tau,\ \nu_\tau$ gets its own mass matrix :

$$\begin{pmatrix} \langle O_{R1}O_{L1}\rangle & \langle O_{R1}O_{L2}\rangle & \langle O_{R1}O_{L3}\rangle \\ \langle O_{R2}O_{L1}\rangle & \langle O_{R2}O_{L2}\rangle & \langle O_{R2}O_{L3}\rangle \\ \langle O_{R3}O_{L1}\rangle & \langle O_{R3}O_{L2}\rangle & \langle O_{R3}O_{L3}\rangle \end{pmatrix}$$

- 3 families if rank 3 !

$$\mathcal{O}_{L,a} = y_{L,a}\mathcal{O}_L \qquad \mathcal{O}_{R,a} = y_{R,a}\mathcal{O}_R \quad \rightarrow \quad \text{rank 1}$$

Rank of the Mass Matrix

- Each species of fermion, $t,\ b,\ \tau,\ \nu_\tau$ gets its own mass matrix :

$$\begin{pmatrix} \langle O_{R1} O_{L1} \rangle & \langle O_{R1} O_{L2} \rangle & \langle O_{R1} O_{L3} \rangle \\ \langle O_{R2} O_{L1} \rangle & \langle O_{R2} O_{L2} \rangle & \langle O_{R2} O_{L3} \rangle \\ \langle O_{R3} O_{L1} \rangle & \langle O_{R3} O_{L2} \rangle & \langle O_{R3} O_{L3} \rangle \end{pmatrix}$$

- 3 families if rank 3 !

$$\mathcal{O}_{L,a} \ = \ y_{L,a} \mathcal{O}_L \qquad \mathcal{O}_{R,a} \ = \ y_{R,a} \mathcal{O}_R \quad \rightarrow \quad \text{rank 1}$$

- We need different Baryonic Operators. How can we generate them ?

3 Flavors

3 Flavors

- Gauge mediation +1

3 Flavors

TPS

- Gauge mediation +1
- Scalar mediation

3 Flavors

TPS

- Gauge mediation +1
- Scalar mediation + 0

3 Flavors

• Gauge mediation	+1
• Scalar mediation	+ 0
• New Θ , scalar mediation	+1

3 Flavors

TPS

- Gauge mediation +1
- Scalar mediation + 0
- New Θ , scalar mediation +1
- New Δ_L , or Loops induced +1

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get a **Conformal Dynamic**

So far so good

- **UV completed the 4F** (with scalars and gauge bosons)
- Generate mass for the **entire family**
- **Mass Hierarchy** between the fermions
- Large window to get a **Conformal Dynamic**
- Enough ingredients for a **Flavor Structure**

What is next ?

- Study of the complete potential
- Lattice input
- Well running of the gauge coupling

Alternatives ?

4-F=Scalars, scalars, scalars…

4-F=Scalars, scalars, scalars…

- Use of a **scalar** to generate **4-F**

4-F=Scalars, scalars, scalars…

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking…

4-F=Scalars, scalars, scalars…

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking…

How to avoid the naturalness issue ?

Naturalness ?

TPS

Naturalness ?

- Push the **scalar mass** close to the **Planck scale**

Naturalness ?

- Push the **scalar mass** close to the **Planck scale**
- Make use of the **Large N**

Naturalness ?

TPS

- Push the **scalar mass** close to the **Planck scale**
- Make use of the **Large N**

$$\beta \;=\; \sum_k \lambda_k\, \alpha^k \;=\; \sum_k \frac{F^{(k)}(\alpha)}{N^k}$$

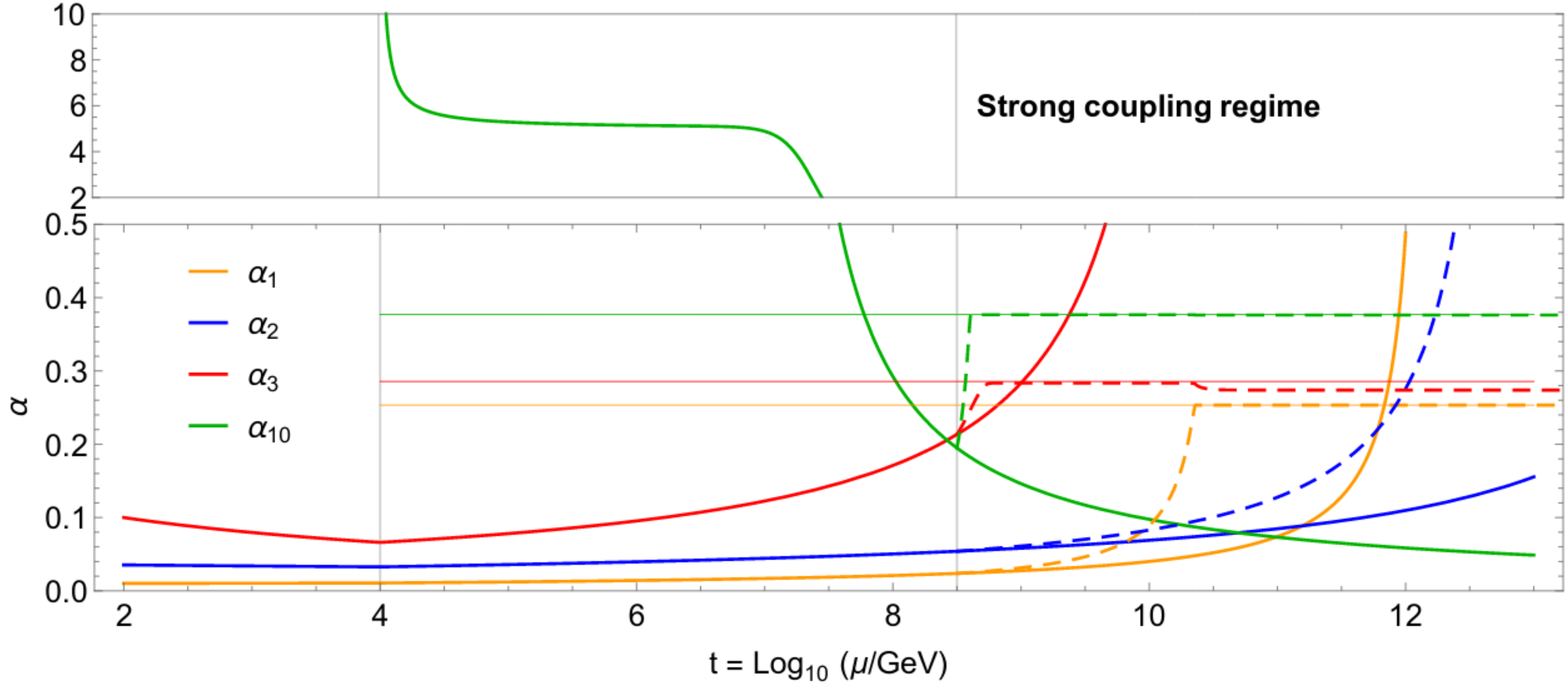
Naturalness ?

$$\beta \;\; \cong \;\; \alpha^2 \left[1 + \frac{F(\alpha)}{N}\right]$$

Naturalness ?

TPS

$$\beta \cong \alpha^2 \left[1 + \frac{F(\alpha)}{N}\right]$$



4-F=Scalars, scalars, scalars…

TPS

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking…

How to avoid the naturalness issue ?

4-F=Scalars, scalars, scalars...

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking...

How to avoid the naturalness issue ? ✓

4-F=Scalars, scalars, scalars...

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking...

Only possibility ??

4-F=Scalars, scalars, scalars...

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking...

Only possibility ??

- **Tumbling Theories :**

4-F=Scalars, scalars, scalars...

TPS

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking...

Only possibility ??

- **Tumbling Theories :** $G \to H \subset G, \quad \langle \Psi_{R_1} \Psi_{R_2} \rangle \neq 0$

4-F=Scalars, scalars, scalars...

TPS

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking...

↓

Only possibility ??

- **Tumbling Theories :**

$$G \to H \subset G, \quad \langle \Psi_{R_1} \Psi_{R_2} \rangle \neq 0$$
$$R_1 \otimes R_2 \ \text{ is only } H \text{ invariant}$$

4-F=Scalars, scalars, scalars...

- Use of a **scalar** to generate **4-F**
- Or **gauge mediation**, which requires **scalars** the breaking...

Only possibility ??

- **Tumbling Theories :**

$$G \to H \subset G, \quad \langle \Psi_{R_1} \Psi_{R_2} \rangle \neq 0$$
$$R_1 \otimes R_2 \ \text{ is only } H \text{ invariant}$$

- **Composite Mediator ?**

Thank you !

TPS

Set-Up

Low energy target M8 $\rightarrow$ Global Symmetry Pattern $SU(4)/Sp(4)$

Fundamental : 4 ψ

AntiSymmetric : 6 χ

$$H = \langle\ LU\ \rangle = \langle\ LD\ \rangle$$

ψ	$SU(2)_L$	$U(1)_Y$
L	2	0
U	1	1/2
D	1	$-1/2$

Strong Dynamics

TPS

ψ **Fundamental :** $U_d,\ D_u,\ U_u,\ D_d,\ L,\ \eta,\ \tilde{\eta},$

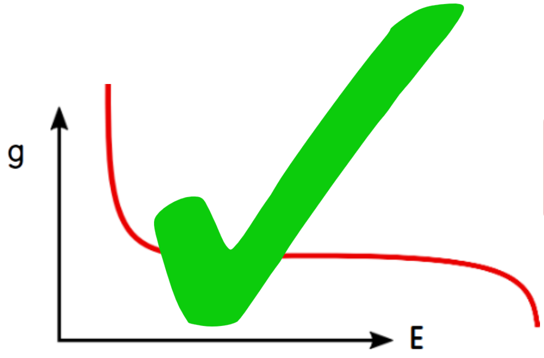
4 + 2 + 6 = 12 HyperFermions

$\rightarrow$ $G = SU(n),\ n \leq 12$

How many are light ($\leq \Lambda_{HC}$) ?
L + 2 neutral

χ **AntiSymmetric :** $\chi,\ \tilde{\chi}$ = 6 HyperFermions

Analytic tools : (PS & SD) $\rightarrow$



Need Lattice Input !!

4-F : Gauge Mediation

TPS

Step	Breaking Pattern
PS	$SU(8)_{PS} \times SU(2)_R \to SU(7)_{EHC} \times U(1)_E$
EHC	$SU(7)_{EHC} \to SU(4)_{CHC} \times SU(3)_c \times U(1)_X$
CHC	$SU(4)_{CHC} \times U(1)_X \times U(1)_E \to Sp(4)_{HC} \times U(1)_Y$

$$E_\mu \;:\; M_E^2 = \frac{g_{\rm PS}^2}{4}(v_{\rm EHC}^{\Psi})^2$$

$$C_\mu \;:\; M_C^2 = \frac{g_{\rm PS}^2}{4}(v_{\rm EHC}^{\Psi} + v_{\rm PS}^{\Phi})^2$$

$$\mathcal{L}_{\rm Kinetic} \supset -\frac{g_{\rm EHC}^2}{2M_E^2}\left(\bar{L}^3\bar{\sigma}^\mu q_L - \bar{t}_R^c\bar{\sigma}^\mu D_u^3 - \bar{b}_R^c\bar{\sigma}^\mu U_d^3\right)\left(\frac{1}{2}\bar{\chi}\bar{\sigma}_\mu U_t - \frac{1}{2}\bar{D}_b\bar{\sigma}_\mu\tilde{\chi} - \bar{\eta}\bar{\sigma}_\mu\chi + \bar{\tilde{\chi}}\bar{\sigma}_\mu\tilde{\eta}\right)$$

$$-\frac{g_{\rm PS}^2}{2M_C^2}\left(\bar{L}^3\bar{\sigma}^\mu l_L - \bar{\nu}_{\tau R}^c\bar{\sigma}^\mu D_u^3 - \bar{\tau}_R^c\bar{\sigma}^\mu U_d^3\right)\left(-\frac{1}{2}\bar{\chi}\bar{\sigma}_\mu\tilde{\eta} - \frac{1}{2}\bar{\eta}\bar{\sigma}_\mu\tilde{\chi}\right)$$

Quark-Lepton mass splitting !

HyperFermion Masses

TPS

$$M_{\chi\,\tilde{\chi}} = M_{\omega\,\tilde{\omega}} \leq \Lambda_{HC}$$

$$M_{U/D} \leq \Lambda_{HC}$$

$$M_L \leq \Lambda_{HC}$$

$$M_{\eta\,\tilde{\eta}} \leq \mathcal{O}(10)\Lambda_{HC}$$

This is possible !

$\downarrow$

(only λ_Δ can be large)