



Phenomenology of colour sextet baryons in composite Higgs models

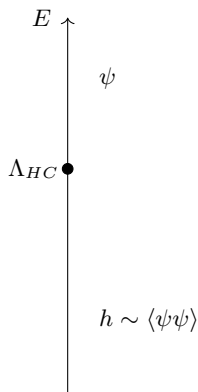
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IRN Terascale, IJCLab Orsay, April 20, 2026

Composite Higgs (HC) models with Partial Compositeness (PC)

There are concrete reasons to think SM is not fundamental:



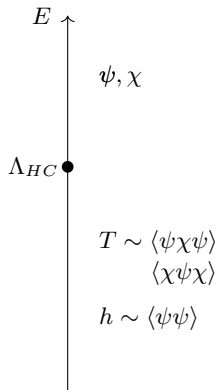
HC = HyperColor
HF = HyperFermions

- 1 **Naturalness problem** \implies CH
4D asymptotically free gauge theory with a new confinement interaction G_{HC} strongly coupled under Λ_{HC} .
No elementary scalars \implies Higgs generated dynamically as bound state of two ψ (composite)

$$\psi : G_F^\psi \rightarrow H_F^\psi \supset SU(2)_L \otimes SU(2)_R \quad (\text{EW sector})$$

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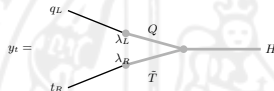
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- Naturalness problem \implies CH**
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- Origin of the heavy top quark mass \implies PC**
 Existence of bound states of 3 HF \rightarrow Top Partners T that mix with the SM top quarks.

$$\mathcal{L}_{PC} \sim -\lambda_L q_L Q - \lambda_R t_R^c T,$$



To match the top quantum numbers, we introduce another set of representations:

$$\chi : G_F^\chi \rightarrow H_F^\chi \supset SU(3)_c \quad (\text{color sector})$$

Minimal models

EW Sector breaking: ψ

The three minimal cosets preserving custodial symmetry $G \rightarrow H \supset G_{CS}$ and generating the Higgs bidoublet, are:

- $SU(5)/SO(5)$ real;
- $SU(4)/Sp(4)$ pseudo-real;
- $SU(4) \otimes SU(4)' / SU(4)_D$ complex.

Color Sector breaking: χ

The three minimal cosets, preserving the color group $G \rightarrow H \supset G_{QCD}$, are:

- $SU(6)/SO(6)$ real;
- $SU(6)/Sp(6)$ pseudo-real;
- $SU(3) \otimes SU(3)' / SU(3)_D$ complex.

\Rightarrow 12 Minimal models [Ferretti 2013]

New particles zoology

Spin 0 $\langle\psi\psi\rangle, \langle\chi\chi\rangle \sim h, \pi, S$

- new pNGBs with EW quantum numbers $S \sim \langle\psi\psi\rangle$ including the Higgs boson,
- new pNGBs with Color quantum numbers $\pi \sim \langle\chi\chi\rangle$.

Spin 1/2 $\langle\psi\chi\psi\rangle, \langle\chi\psi\chi\rangle \sim T, Q$

Depending on the representations, these baryons can be constructed as:

- $\psi\chi\psi$ yielding only color-triplet resonances,
- $\chi\psi\chi$ producing a richer spectrum: singlets, triplets, sextets or octets under $SU(3)_c$

$$Q_1, Q_3, Q_6, Q_8$$

Spin 1 $\langle\psi\sigma_\mu\psi\rangle, \langle\chi\sigma_\mu\chi\rangle \sim \mathcal{V}_\mu, \mathcal{A}_\mu$

new Spin-1 resonances that mix with the SM gauge bosons W, Z, g.

In the literature, the LHC phenomenology of most of these particles has already been explored.

Models and pNGB Spectrum

Setup: We focus on the phenomenology of $Q_6 \Rightarrow$ models with $\chi\psi\chi$.

| Class | Model | ψ repr. | χ repr. | $\psi\psi$ | $\chi\chi$ |
|-------|--------|--------------|--------------|--------------------|----------------|
| C1 | M1, M2 | real | real | S^{++}, S^+, S^0 | π_8, π_6 |
| C2 | M5 | real | pseudo-real | S^{++}, S^+, S^0 | π_8, π_3 |
| C3 | M6, M7 | real | complex | S^{++}, S^+, S^0 | π_8 |
| C4 | M12 | complex | complex | S^+, S^0 | π_8 |

- **C4** has a different ψ representation.
- We focus on **C1–C3**, which share the same EW pNGB sector:

$$\mathbf{14} \rightarrow (\mathbf{2}, \mathbf{2}) \oplus (\mathbf{3}, \mathbf{3}) \oplus (\mathbf{1}, \mathbf{1}) \quad \text{of } SO(5) \rightarrow SU(2)_L \otimes SU(2)_R$$

$$m_S \gtrsim 450 \text{ GeV} \quad m_\pi \gtrsim 1.4 \text{ TeV}$$

Hyperbaryon Spectrum: $\chi\psi\chi$

Color spectrum

| C1 | C2 | C3 |
|--|--|----------------------------|
| $\mathcal{B}_S \equiv (Q_8, Q_6)$ | $\mathcal{B}_S \equiv (Q_8, Q_6, Q_1)$ | $\mathcal{B}_6 \equiv Q_6$ |
| $\mathcal{B}_A \equiv (Q_8, Q_3, Q_1)$ | $\mathcal{B}_A \equiv (Q_8, Q_3)$ | $\mathcal{B}_3 \equiv Q_3$ |
| $\mathcal{B}_1 \equiv \hat{Q}_1$ | $\mathcal{B}_1 \equiv \hat{Q}_1$ | |

EW spectrum

Each state forms a quintuplet of $SU(5) \rightarrow SO(5) \rightarrow SU(2)_L \otimes SU(2)_R$

$$\mathbf{5} \rightarrow (\mathbf{2}, \mathbf{2}) \oplus (\mathbf{1}, \mathbf{1})$$

For **sextets**: $Q_6 = Q_6^{-5/3} \oplus (3 \times Q_6^{-2/3}) \oplus Q_6^{1/3}$ under $SU(3)_c \times U(1)_Q$

For **triplets**: $Q_3 = Q_3^{5/3} \oplus (3 \times Q_3^{2/3}) \oplus Q_3^{-1/3} = \left(\begin{pmatrix} X_{5/3} \\ X_{2/3} \end{pmatrix}, \begin{pmatrix} T_L \\ B_L \end{pmatrix}, iT_R \right) \dots$

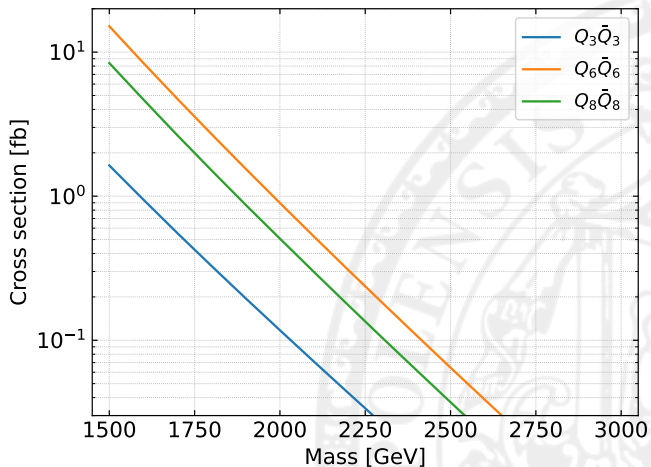
$$m_8 \gtrsim 2.5\text{--}2.7 \text{ TeV} \quad m_3 \gtrsim 1.5 \text{ TeV}$$

Pair production cross-section

Using MadGraph5_aMC@NLO:

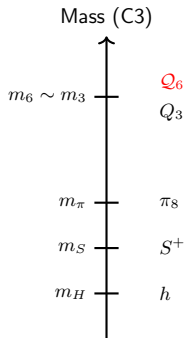
$$\sqrt{s} = 13 \text{ TeV}$$

$$\mu_R = \mu_F = m$$



Mass Hierarchies and Decay Channels: C3

$$\mathcal{L} \sim c_{ij} \bar{B}_i \bar{\sigma}^\mu \partial_\mu \Pi_\chi \mathcal{B}_j \Rightarrow \boxed{Q_6 \rightarrow \pi_8 Q_3^c}$$



$$Q_3 = \left(\begin{pmatrix} X_{5/3} \\ X_{2/3} \end{pmatrix}, \begin{pmatrix} T_L \\ B_L \end{pmatrix}, iT_R \right).$$

- $\pi_8 \rightarrow t\bar{t}$,
- $B_L \rightarrow b$ via PC;
- $X_{2/3}, T_L, T_R \rightarrow t$ via PC,
- for low m_6 , the dominant decay of $Q_6^{5/3} \rightarrow (\bar{X}_{5/3}\pi_8)^*$ is via:

$$X_{5/3} \rightarrow W^+ X_{2/3} \rightarrow W^+ t$$

from kinetic coupling $\bar{X}_{5/3} W^+ X_{2/3}$.

$$Q_6^{-5/3} \rightarrow (\bar{X}_{5/3}\pi_8)^*, \quad Q_6^{-2/3} \rightarrow \bar{t}\pi_8, \quad Q_6^{1/3} \rightarrow \bar{b}\pi_8$$

Signatures

Combining this with the decays of the pNGBs and baryons:

$$Q_6^{1/3} \rightarrow \bar{b} \bar{t} t$$

$$Q_6^{-2/3} \rightarrow \bar{t} \bar{t} t$$

$$Q_6^{-5/3} \rightarrow \bar{t} W^- \bar{t} t$$

We showed the result only for C3, but C1 and C2 also have the same signatures. C1 also has other decay options, but we expect **368** to be the most important.

So far, no searches at LHC for sextet fermions \implies recasts of existing searches.
We look at pair production \implies final states with 6 top quarks

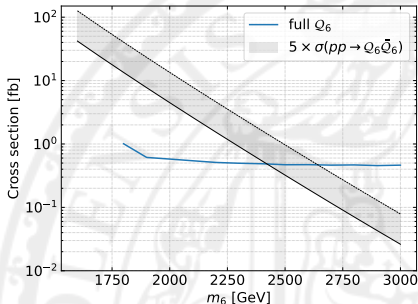
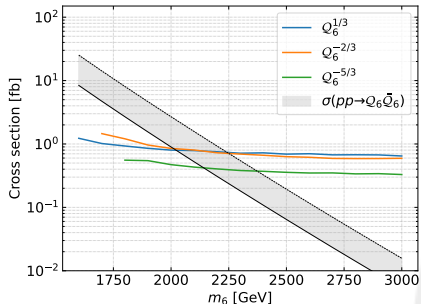
Bounds from $Q_6 \rightarrow Q_{\bar{3}}\pi_8$ with $m_{\pi_8} = 1.5 \text{ TeV}$

Problem: the current showering tools do not support the $3 \times 6 \times 8$ color flow.

Solution \rightarrow **Surrogate model:** Q_6 is replaced by a triplet, with rescaled cross section.

We use:

- Pythia8 for parton showering and hadronization,
- MadAnalysis5 for the recasting.



Dominant bounds come from ATLAS-SUSY-2018-31 and ATLAS-SUSY-2018-17.

The lower line of the shaded cross-section region: LO

The upper line: with $K = 3 \sim K$ -factor of the octets and gluinos.

Summary

- Composite models with partial compositeness offer a solution to the naturalness problem and the origin of the heavy top quark mass,
- They predict a huge spectrum of new particles and resonances. Among them are also exotic Baryons like sextets under $SU(3)_C$,
- The pair production of sextets leads to signatures with 6t final states. Unfortunately, there is no search available that looks directly at this signature.
- Recast gives us bounds for these particle masses of $m_6 \geq 2.6 \text{ TeV}$

Models and PNGBs spectrum

In this work we focus on the pheno of $Q_6 \implies$ subset of models with $\chi\psi\chi$

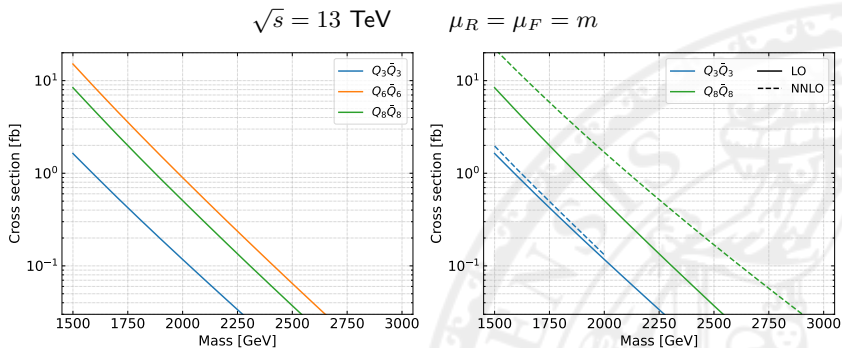
| Class | Model | G_{HC} | ψ repr. | χ repr. | $\psi\psi$ | $\chi\chi$ |
|-------|----------|---------------------|--|--|--------------------|----------------|
| C1 | M1, M2 | $SO(7), SO(9)$ | $5 \times \mathbf{F}$ (real) | $6 \times \mathbf{Spin}$ (real) | S^{++}, S^+, S^0 | π_8, π_6 |
| C2 | M5 | $Sp(4)$ | $5 \times \mathbf{A}_2$ (real) | $6 \times \mathbf{F}$ (pseudo-real) | S^{++}, S^+, S^0 | π_8, π_3 |
| C3 | M6 M7 | $SU(4)$ $SO(10)$ | $5 \times \mathbf{A}_2$ (real) $5 \times \mathbf{F}$ (real) | $3 \times (\mathbf{F}, \overline{\mathbf{F}})$ (complex) $3 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$ (complex) | S^{++}, S^+, S^0 | π_8 |
| C4 | M12 | $SU(5)$ | $4 \times (\mathbf{F}, \overline{\mathbf{F}})$ (complex) | $3 \times (\mathbf{A}_2, \overline{\mathbf{A}}_2)$ (complex) | S^+, S^0 | π_8 |

The representations are the fundamental \mathbf{F} , two-index antisymmetric \mathbf{A}_2 and spinor \mathbf{Spin} of G_{HC} .

C4 has a different ψ rep. For the phenomenology we focused just in the first three class, that have comon features.

Pair production cross-section

Using MadGraph5_aMC@NLO:



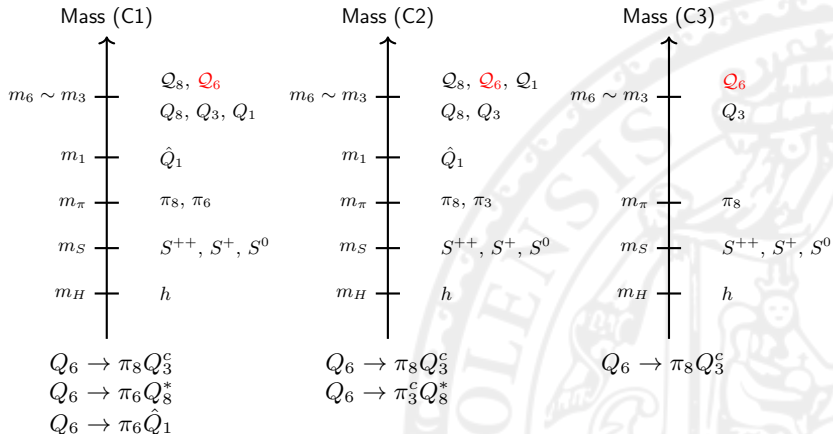
For NNLO we display the cross-section calculations for the gluino [Beenakker2016] and triplet top partner [ATLAS2022].

For Q_6 no higher-order calculations are available.

So far, no searches at LHC for sextet fermions \implies recasts of existing searches.

Mass Hierarchies and Interactions

$$\mathcal{L} \sim c_{ij} \bar{B}_i \bar{\sigma}^\mu \partial_\mu \Pi_\chi B_j \Rightarrow B_S \pi B_A$$



We also have, in addition, from PC:

$$\mathcal{L}_{PC} \supset \tilde{\lambda}_L q_L \pi_8 Q_6 + \tilde{\lambda}_R t_R^c \pi_8 Q_6^c + \text{H.c.}$$

Summary of the decay channels

Combining this with the decays of the pNGBs and other baryons representations:

| | All models | | C1 | |
|-------------------|---|-------------------|---|-------------|
| $Q_{6,B}^{1/3}$ | $\bar{b}\pi_8 \rightarrow \bar{b}t\bar{t}$ | dominant | $\hat{Q}_1^1\pi_6 \rightarrow bb + \text{MET}$ | competitive |
| $Q_{6,TL}^{-2/3}$ | $\bar{t}\pi_8 \rightarrow \bar{t}t\bar{t}$ | dominant | $\hat{Q}_1^0\pi_6 \rightarrow bb + \text{MET}$ | competitive |
| $Q_{6,TR}^{-2/3}$ | $\bar{t}\pi_8 \rightarrow \bar{t}t\bar{t}$ | dominant | $\hat{q}_1^0\pi_6 \rightarrow bb + \text{MET}$ | competitive |
| $Q_{6,X}^{-2/3}$ | $\bar{t}\pi_8 \rightarrow \bar{t}t\bar{t}$ | suppressed | $\hat{Q}_1^0\pi_6 \rightarrow bb + \text{MET}$ | dominant |
| $Q_{6,X}^{-5/3}$ | $\bar{t}S^-\pi_8 \rightarrow \bar{t}t\bar{b}\bar{t}$ | 3-body | $\hat{Q}_1^{-1}\pi_6 \rightarrow bb + \text{MET}$ | dominant |
| | $\bar{b}S^{--}\pi_8 \rightarrow \bar{b}t\bar{b}W^-t\bar{t}$ | 3-body | | |
| | $\bar{t}W^-\pi_8 \rightarrow \bar{t}W^-t\bar{t}$ | 3-body, heavy S | | |

$X_{5/3}$ decay

$$\mathcal{L}_{\text{PC}} \supset -\lambda_L q_L \mathcal{O}_L - \lambda_R t_R^c \mathcal{O}_R + \text{H.c.}, \quad (1)$$

- $X_{5/3} \rightarrow bS^{++}$
- $X_{5/3} \rightarrow tS^+$,
- $X_{5/3} \rightarrow W^+t$ via $X_{2/3} \rightarrow$ suppressed

$$S^+ \rightarrow t\bar{b}, \quad S^{++} \rightarrow W^+ S^{+(*)} \rightarrow W^+ t\bar{b}. \quad (2)$$

$$\pi_8 \rightarrow t\bar{t}, \quad \pi_6 \rightarrow b\bar{b}, \quad \pi_3 \rightarrow \bar{b}\bar{s}. \quad (3)$$

M12

The model M12, classified as C4 in , is notable for allowing hyperbaryon singlets of both types, $\psi\chi\psi$ and $\chi\psi\chi$. It is defined by $G_{\text{HC}} = \text{SU}(5)$ with $(\psi, \tilde{\psi}) \in (\mathbf{F}, \bar{\mathbf{F}})$ and $(\chi, \tilde{\chi}) \in (\mathbf{A}_2, \bar{\mathbf{A}}_2)$, hence the global symmetry is $G = \text{SU}(4)_\psi \times \text{SU}(4)_{\tilde{\psi}} \times \text{SU}(3)_\chi \times \text{SU}(3)_{\tilde{\chi}} \times \text{U}(1)^3$. Due to the properties of the $\text{SU}(5)$ representations, one can form the following singlets of G_{HC} :

$$\mathbf{5} \otimes \mathbf{10} \otimes \mathbf{10}, \quad \bar{\mathbf{10}} \otimes \mathbf{5} \otimes \mathbf{5}, \quad \text{and conjugate,} \quad (4)$$

which correspond to the following composite operators:

$$\chi\psi\chi, \quad \tilde{\chi}\tilde{\psi}\tilde{\chi}, \quad \psi\tilde{\chi}\psi, \quad \tilde{\psi}\chi\tilde{\psi}, \quad (5)$$

$$\bar{\chi}\psi\bar{\chi}, \quad \bar{\chi}\tilde{\psi}\bar{\chi}, \quad \tilde{\psi}\tilde{\chi}\tilde{\psi}, \quad \bar{\psi}\chi\bar{\psi}. \quad (6)$$

Of those, only the baryons of type $\psi\chi\psi$ may be used as top-partners and they only contain colour triplets (no exotic QCD charges here).