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# A Higgs mass shift to 125 GeV and a multi-jet supersymmetry signal: Miracle of the flippons at the $\sqrt{s} = 7$ TeV LHC

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ABSTRACT

We describe a model named No-Scale $\mathcal{F}$-$SU(5)$ which is simultaneously capable of explaining the dual signals emerging at the LHC of (i) a 124–126 GeV Higgs boson mass $m_h$, and (ii) tantalizing low-statistics excesses in the multi-jet data which may attributable to supersymmetry. These targets tend to be mutually exclusive in more conventional approaches. The unified mechanism responsible for both effects is the introduction of a rather unique set of vector-like multiplets at the TeV scale, dubbed *flippons*, which (i) can elevate $m_h$ by around 3–4 GeV via radiative loop corrections, and (ii) flatten the running of the strong coupling and color-charged gaugino, resulting in a prominent collider signal from production of light gluino pairs. This well-motivated theoretical framework maintains consistency with all key phenomenological constraints, and all residual parameterization freedom may in principle be fixed by a combination of the two experiments described. We project that the already collected luminosity of 5 fb$^{-1}$ may be sufficient to definitively establish the status of this model, given appropriate data selection cuts.


## 1. Introduction

### 1.1. The two-pronged LHC mission

The chiral electroweak (EW) $SU(2)_L \times U(1)_Y$ gauge symmetry of the Standard Model (SM) prohibits the expression of tree-level fermionic Dirac masses, while the massless chiral symmetry limit simultaneously softens the naïvely expected linear divergence of fermionic loops to be instead manifest in logarithms. Exact gauge symmetry protects the masses of non-Abelian force-carriers to all orders. Having nullified the zeroth order masses, Planck-small mass terms may be transferred out of symmetry-preserving interactions with a fundamental scalar "Higgs" field during a radiatively triggered spontaneous breakdown of the $SU(2)_L \times U(1)_Y$ vacuum. By coupling every SM field to a half-integrally spin-shifted partner, supersymmetry (SUSY) extends the favorable fermionic birth-right to fields of the bosonic sector, generating precise counter-terms to problematic loops via the circulation of partners bearing opposite spin-statistics, and taming the catastrophic quadratic divergence of the scalar Higgs field itself. A dual search for these ostensibly independent mechanisms constitutes the nominal *raison d'être* of the Large Hadron Collider (LHC).

### 1.2. The LHC Higgs search strategy

The LHC strategy for the hunt of the SM Higgs boson: (i) is based upon the gluon pair fusion to Higgs triangle diagram calculated in 1978 by Georgi et al. (GGMN) [1], which is the leading production mechanism by a merit factor of $\mathcal{O}(10)$, and (ii) prominently features the Higgs to two gamma triangle diagram calculated in 1976 by Ellis et al. (EGN) [2], which is the cleanest decay mode in the relevant mass range. In the Minimal Supersymmetric SM extension (MSSM), holomorphy of the superpotential and anomaly cancellation for the fermionic Higgsinos each imply that independent complex $SU(2)_L$ Higgs doublets must separately provide mass to the up-like and down-like fields. The resulting eight real degrees of freedom are reduced by three in the transfer of a longitudinal polarization to the massive $W^{\pm}$- and $Z^0$-bosons, leaving five massive physical Higgs fields after symmetry breaking. Moreover, non-SM fields will circulate around both the GGMN production triangle and the EGN decay triangle, in principle modifying both the Higgs production cross section and decay width and mode, and thus also impacting the observed detection limits. Fortunately, the extra contributions are generally negligible at

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the leading precision. It is generally expected that the lightest CP-even field $h$ would manifest itself similarly to the single physical Higgs of the SM, although there remain notable distinctions, including an explicit formula for the tree-level mass-splitting, which indicates that the light Higgs must have a mass $m_h$ below that of the $Z$-boson at around 91 GeV. Such a light field would have easily been detected at LEP, which has placed a lower bound on the MSSM Higgs of 114 GeV. However, a critical loophole allows SUSY, and even the minimal MSSM formulation, to escape the null result intact; radiative contributions to the squared Higgs mass $m_h^2$ from the extremely heavy (and thus strongly Higgs-coupled) top quark are sufficient to lift the SUSY construction out of danger.

### 1.3. The miracle of the flippons

In reality, specific model-based predictions for the Higgs and SUSY structure are intimately correlated, as we shall demonstrate within the context of a particular phenomenologically favorable construction named No-Scale $\mathcal{F}$-$SU(5)$ [3–15], which is defined by the convergence of the $\mathcal{F}$-lipped $SU(5)$ [16–18] grand unified theory (GUT), two pairs of hypothetical TeV-scale vector-like supersymmetric multiplets, dubbed *flippons*, with origins in $\mathcal{F}$-theory [19–23], and the dynamically established boundary conditions of No-Scale Supergravity [24–28]. Careful numerical analysis of the viable No-Scale $\mathcal{F}$-$SU(5)$ parameter space yields a prediction for $m_h$ in the range of 119.0 GeV to 123.5 GeV [29], consistent with limits from the CMS [30], ATLAS [31,32], CDF and D0 Collaborations [33]. However, in light of the most recent CMS and ATLAS reports [34,35] of a Higgs signal at 124–126 GeV with independent local significances greater than $3\sigma$ over background (or around $2\sigma$ each after global "look elsewhere" compensation), there is a critical modification that we now entertain. By coupling to the Higgs, the vector-like *flippon* multiplet will itself have an impact on the predicted value of $m_h$ [36,37]. Just as radiative top-quark loops once elevated $m_h$ to save supersymmetry (and were in fact taken as suggestive evidence for a heavy top quark prior to the observation by D0 and CDF), radiative loops in heavy vector-like multiplets may provide a second such boost, but this time to save No-Scale $\mathcal{F}$-$SU(5)$, and to provide suggestive evidence for the new *flippon* field.

We will demonstrate explicitly that No-Scale $\mathcal{F}$-$SU(5)$ may convincingly explain this exciting new signal, while simultaneously accounting for tantalizing excesses at lower statistical significance in the search for SUSY via multi-jet production at ATLAS [38] and CMS [39]. This is particularly noteworthy, because the two results will tend to be mutually exclusive for more conventional MSSM constructions. In particular, the mechanism for elevation of the Higgs mass will typically correspond to squark and gluino masses which are far too heavy to have yet peeked above the SM background for the initial $\sqrt{s} = 7$ TeV operating phase of the LHC. No-Scale $\mathcal{F}$-$SU(5)$ takes advantage of the same strongness of the Higgs-top quark coupling which provides the primary lifting of the SUSY Higgs mass to generate a hierarchically light partner stop in the SUSY mass-splitting. However, this rather generic mechanism is not in itself enough. The model further leverages the same vector-like multiplets which provide the secondary Higgs mass perturbation to flatten the renormalization group equation (RGE) running of universal color-charged gaugino mass, blocking the standard logarithmic enhancement of the gluino mass at low energies, and producing the distinctive mass ordering $M(\tilde{t}_1) < M(\tilde{g}) < M(\tilde{q})$ of a light stop and gluino, both substantially lighter than all other squarks. We will demonstrate that the consequence of this spectrum is a spectacular signal of SUSY events in the ultra-high jet multiplicity channels, which is not just in passive compliance with LHC production limits, but is moreover an active enhancement of the theoretical and experimental accord. We project that the already collected luminosity of 5 $\mathrm{fb}^{-1}$ may be sufficient to definitively establish the status of this SUSY signature, given appropriate data selection cuts. At this intersection of the two great LHC causes, we moreover find the parameterization freedom of the model to be exhausted in a manner that is profoundly consistent with all existing phenomenological constraints. This is the *Miracle of the Flippons*.

## 2. The No-Scale $\mathcal{F}$-$SU(5)$ model

The No-Scale $\mathcal{F}$-$SU(5)$ construction [3–15] derived from local F-Theory model building inherits all of the most beneficial phenomenology of flipped $SU(5)$ [16–18,40], including fundamental GUT scale Higgs representations (not adjoints), natural doublet–triplet splitting, suppression of dimension-five proton decay and a two-step see-saw mechanism for neutrino masses, as well as all of the most beneficial theoretical motivation of No-Scale Supergravity [24–28], including a deep connection to string theory in the infrared limit, the natural incorporation of general coordinate invariance (general relativity), a mechanism for SUSY breaking which preserves a vanishing cosmological constant at the tree level (facilitating the observed longevity and cosmological flatness of our Universe [24]), natural suppression of CP violation and flavor-changing neutral currents, dynamic stabilization of the compactified spacetime by minimization of the loop-corrected scalar potential and a dramatic reduction in parameterization freedom.

The dimension five proton decays mediated by colored Higgsinos are highly suppressed due to the missing partner mechanism and TeV-scale $\mu$ term. However, the dimension five proton decay non-renormalizable operators suppressed by the Planck scale generically give the very fast proton decays, which is a well-known problem in the supersymmetric GUTs. Interestingly, in the string model building, there exists at least one anomalous $U(1)_X$ gauge symmetry, which may be used to suppress those dimension five proton decay operators [41].

Written in full, the gauge group of Flipped $SU(5)$ is $SU(5) \times U(1)_X$, which can be embedded into $SO(10)$. The generator $U(1)_{Y'}$ is defined for fundamental five-plets as $-1/3$ for the triplet members, and $+1/2$ for the doublet. The hypercharge is given by $Q_Y = (Q_X - Q_{Y'})/5$. There are three families of Standard Model (SM) fermions, whose quantum numbers under the $SU(5) \times U(1)_X$ gauge group are

$$F_i = (\mathbf{10}, \mathbf{1}); \qquad \bar{f}_i = (\bar{\mathbf{5}}, -\mathbf{3}); \qquad \bar{l}_i = (\mathbf{1}, \mathbf{5}), \tag{1}$$

where $i = 1, 2, 3$. There is a pair of ten-plet Higgs for breaking the GUT symmetry, and a pair of five-plet Higgs for electroweak symmetry breaking (EWSB).

$$H = (\mathbf{10}, \mathbf{1}); \qquad \overline{H} = (\overline{\mathbf{10}}, -\mathbf{1}),$$
$$h = (\mathbf{5}, -\mathbf{2}); \qquad \bar{h} = (\bar{\mathbf{5}}, \mathbf{2}). \tag{2}$$

Since we do not observe mass degenerate superpartners for the known SM fields, SUSY must itself be broken around the TeV scale. In the minimal supergravities (mSUGRA), this occurs first in a hidden sector, and the secondary propagation by gravitational interactions into the observable sector is parameterized by universal SUSY-breaking "soft terms" which include the gaugino mass $M_{1/2}$, scalar mass $M_0$ and the trilinear coupling $A$. The ratio of the low energy Higgs vacuum expectation values (VEVs) $\tan\beta$, and the sign of the SUSY-preserving Higgs bilinear mass term $\mu$ are also undetermined, while the magnitude of the $\mu$ term and its bilinear soft term $B_\mu$ are determined by the $Z$-boson mass $M_Z$ and $\tan\beta$ after EWSB. In the simplest No-Scale scenario, $M_0 = A = B_\mu = 0$

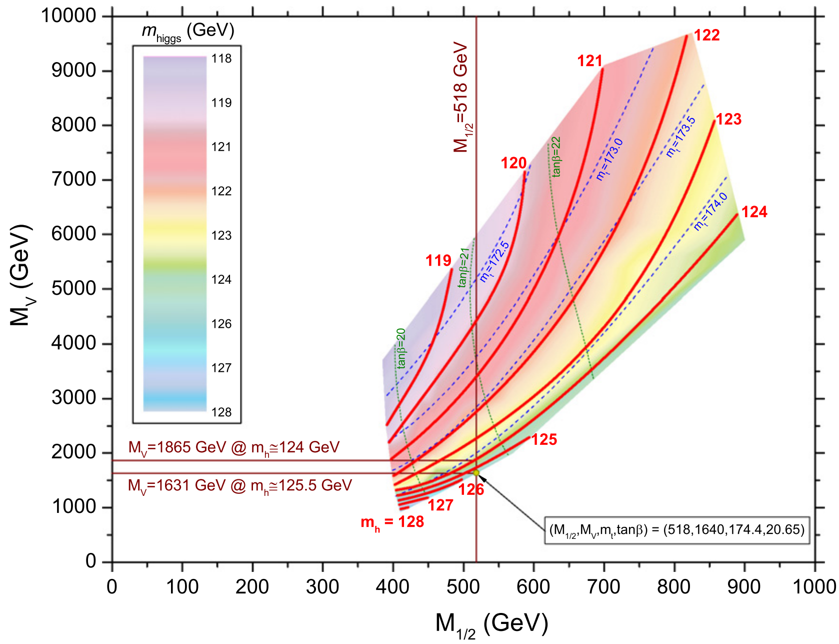


**Fig. 1.** The space of bare-minimal constraints [9] on the No-Scale $\mathcal{F}$-$SU(5)$ model is presented in the $(M_{1/2}, M_V)$ plane, with contour overlays designating the $\tan\beta$ and $m_t$ parameter ranges, in addition to the corrected Higgs mass $m_h$, inclusive of the shift from vector-like multiplet interactions.

at the unification boundary, while the complete collection of low energy SUSY-breaking soft terms evolve down with a single non-zero parameter $M_{1/2}$. Consequently, the particle spectrum will be proportional to $M_{1/2}$ at leading order, rendering the bulk "internal" physical properties invariant under an overall rescaling. The matching condition between the low-energy value of $B_\mu$ that is demanded by EWSB and the high-energy $B_\mu = 0$ boundary is notoriously difficult to reconcile under the RGE running. The present solution relies on modifications to the $\beta$-function coefficients that are generated by the *flippon* loops.

Naturalness in view of the gauge hierarchy and $\mu$ problems suggests that the *flippon* mass $M_V$ should be of the TeV order. A "$\mu$" term for the *flippon* masses can be forbidden by either a discrete or continuous symmetry. Also, we may only have trilinear Yukawa terms in the superpotential in the usual string model building. The *flippon* masses can be generated via invocation of (i) the Giudice–Masiero mechanism [42,43], where a suitable "$\mu$" term may be generated from high-dimensional operators, or (ii) additional F-theoretic Standard Model singlets, to which the *flippons* may couple and subsequently obtain a mass as those singlets acquire VEVs. The latter scenario is similar to the solution to the "$\mu$" problem in the Next-to-the-Minimal Supersymmetric Standard Model (NMSSM). Avoiding a Landau pole for the strong coupling constant restricts the set of vector-like multiplets which may be given a mass in this range to only two constructions with flipped charge assignments, which have been explicitly realized in the $F$-theory model building context [19–21]. We adopt the multiplets

$$XF = (\mathbf{10},\mathbf{1}) \equiv (XQ, XD^c, XN^c); \qquad \overline{XF} = (\overline{\mathbf{10}}, -\mathbf{1}),$$
$$Xl = (\mathbf{1}, -\mathbf{5}); \qquad \overline{Xl} = (\mathbf{1},\mathbf{5}) \equiv XE^c, \tag{3}$$

where $XQ$, $XD^c$, $XE^c$ and $XN^c$ carry the same quantum numbers as the quark doublet, right-handed down-type quark, charged lepton and neutrino, respectively. Alternatively, the pair of $SU(5)$ singlets may be discarded, but phenomenological consistency then requires the substantial application of unspecified GUT thresholds. In either case, the (formerly negative) one-loop $\beta$-function coefficient of the strong coupling $\alpha_3$ becomes precisely zero, flattening the RGE running, and generating a wide gap between the large $\alpha_{32} \simeq \alpha_3(M_Z) \simeq 0.11$ and the much smaller $\alpha_X$ at the scale $M_{32}$ of the intermediate flipped $SU(5)$ unification of the $SU(3)_C \times SU(2)_L$ subgroup. This facilitates a very significant secondary running phase up to the final $SU(5) \times U(1)_X$ unification scale [22], which may be elevated by 2–3 orders of magnitude into adjacency with the Planck mass, where the $B_\mu = 0$ boundary condition fits like hand to glove [3,44,45]. This natural resolution of the "little hierarchy" problem corresponds also to true string-scale gauge coupling unification in the free fermionic string models [19,46] or the decoupling scenario in F-theory models [20,21], and also helps to address the monopole problem via hybrid inflation.

A majority of the bare-minimally constrained [9] No-Scale $\mathcal{F}$-$SU(5)$ parameter space depicted in Fig. 1, which is defined by simultaneous consistency with (i) the dynamically established high-scale boundary conditions $M_0 = A = B_\mu = 0$ of No-Scale Supergravity, (ii) radiative electroweak symmetry breaking, (iii) precision LEP constraints on the lightest CP-even Higgs boson $m_h$ [47,48] and other light SUSY chargino and neutralino mass content, (iv) the world average top-quark mass 172.2 GeV $\leqslant m_t \leqslant$ 174.4 GeV, and (v) a single, neutral supersymmetric cold dark-matter (CDM) candidate providing a relic density within the 7-year WMAP limits $0.1088 \leqslant \Omega_{\mathrm{CDM}} \leqslant 0.1158$ [49], remains viable even after careful comparison against the first inverse femtobarn of LHC data [13,15]. Moreover, a highly favorable "golden" subspace [3,4,29] exists which may simultaneously account for the key rare process limits on the muon anomalous magnetic moment $(g-2)_\mu$ and the branching ratio of the flavor-changing neutral current decays $b \to s\gamma$ and $B_s^0 \to \mu^+\mu^-$. The intersection of these experimental bounds is highly non-trivial, as the tight theoretical constraints, most notably the vanishing of $B_\mu$ at the high-scale boundary, render the residual parameterization deeply insufficient for arbitrary tuning of even isolated predictions, let alone the union of all predictions.

In addition, a top-down consistency condition on the gaugino boundary mass $M_{1/2}$ is dynamically determined at a secondary local minimization of the minimum of the Higgs potential $V_{\min}$,

**Table 1**
Spectrum (in GeV) for $M_{1/2} = 518$ GeV, $M_V = 1640$ GeV, $m_t = 174.4$ GeV, $\tan\beta = 20.65$. Here, $\Omega_\chi = 0.1155$ and the lightest neutralino is greater than 99% Bino. For the rare process constraints, $\mathrm{Br}(b \to s\gamma) = 2.76 \times 10^{-4}$, $\Delta a_\mu = 12.5 \times 10^{-10}$, and $\mathrm{Br}(B_s^0 \to \mu^+\mu^-) = 3.8 \times 10^{-9}$. The partial lifetime for proton decay in the leading $(e|\mu)^+\pi^0$ channels falls around $4 \times 10^{34}$ Y [22,23].

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\tilde{\chi}_1^0$ | 99 | $\tilde{\chi}_1^\pm$ | 216 | $\tilde{e}_R$ | 196 | $\tilde{t}_1$ | 558 | $\tilde{u}_R$ | 1053 | $m_h$ | 125.4 |
| $\tilde{\chi}_2^0$ | 216 | $\tilde{\chi}_2^\pm$ | 900 | $\tilde{e}_L$ | 570 | $\tilde{t}_2$ | 982 | $\tilde{u}_L$ | 1144 | $m_{A,H}$ | 972 |
| $\tilde{\chi}_3^0$ | 896 | $\tilde{\nu}_{e/\mu}$ | 565 | $\tilde{\tau}_1$ | 108 | $\tilde{b}_1$ | 934 | $\tilde{d}_R$ | 1094 | $m_{H^\pm}$ | 976 |
| $\tilde{\chi}_4^0$ | 899 | $\tilde{\nu}_\tau$ | 551 | $\tilde{\tau}_2$ | 560 | $\tilde{b}_2$ | 1046 | $\tilde{d}_L$ | 1147 | $\tilde{g}$ | 704 |

which is demonstrably consistent with the bottom-up phenomenological approach [5,6,14]. This fixing of the supermultiplet $F$-terms for the compactification radii $R \sim 1/M_{\mathrm{String}} \propto 1/M_{1/2}$ in terms of the mass scale $M_{1/2}$ is analogous to the fixing of the Bohr atomic radius $a_0 = 1/(m_e\alpha)$ in terms of the physical electron mass and charge, by minimization of the electron energy [50]. In both cases, the spectrum scales according to variation in the selected constants, while leaving the relative internal structure of the model intact.

Naïve mathematical manipulations may treat the notion of the infinite cavalierly; Nature abhors it. As the infinities of the black-body radiator led Planck to quantization of the electromagnetic field, avoidance of Planck-scale divergences in the cosmological constant may today lead us to the No-Scale boundary conditions, dynamically established by a suitably chosen Kähler potential. The implementation of this boundary in a manner that is consistent with precision low energy phenomenology is facilitated by adoption of the flipped $SU(5)$ GUT structure, and the perturbing influence of extra vector-like fields. The feasible near-term detectability of these *flippon* multiplets, so named for their distinctive flipped charge assignments, presents a prime target for the ongoing LHC search.

## 3. The Higgs mass perturbation

In 1947, Lamb and Retherford observed the 1058 MHz splitting of the $2S_{1/2}$ Hydrogen level from the otherwise identical total angular momentum doublet $2P_{1/2}$ with unit orbital excitation. Coping with this small *finite* correction required the budding computational apparatus of renormalization, but the first real quantum electrodynamic calculations, attending in isolation to the photon vacuum polarization, predicted a shift of −27 MHz which is incorrect in both magnitude and sign. However, the calculation was not itself incorrect, but merely incomplete. With the realization that the electron propagator and vertex corrections similarly contribute at single loop order, the amended sum agreed emphatically with experiment, and the age of field theory was begun in earnest. In like manner, the mild disagreement between the baseline No-Scale $\mathcal{F}$-$SU(5)$ $m_h$ prediction [29] and the latest ATLAS and CMS measurements [34,35] does not indict the validity of the calculated model effects, so long as there remain viable cards to be played. In fact, recognizing the potential of the *flippons* to elevate the Higgs mass, but having yet no compelling experimental need to introduce the complication, we previously favored rather heavier benchmark values for the vector-like mass $M_V$ which would suppress their contribution [29]. With the experimental focus now becoming more clear, and our rather narrow range of bare $m_h$ predictions appearing in this context to be somewhat light, the time has come for careful reanalysis. The resulting 3-4 GeV upward shift in $m_h$, into the center of the experimental limelight, strikes us as the most serendipitous of all outcomes: small enough to justify the prior use of a first order calculation, but large enough to be an essential final ingredient. It provides the first concrete mechanism for fixing the elusive $M_V$ parameter, and directly ties the existence of the *flippon* field to an immediate phenomenological consequence. We expect this effect to decouple at leading order from the remainder of the described phenomenology, as is the standard result in perturbative expansions.

The mechanism for the desired shift is the following pair of Yukawa interaction terms between the MSSM Higgs and the vector-like *flippons* in the superpotential, *cf.* Eqs. (2) and (3).

$$W = \frac{1}{2} Y_{xd} XFXFh + \frac{1}{2} Y_{xu} \overline{XF}\,\overline{XF}\bar{h}. \tag{4}$$

Being vector-like rather than chiral, the *flippons* are also afforded a proper "diagonal" Dirac mass. After the $SU(5) \times U(1)_X$ gauge symmetry is broken down to the SM, the relevant Yukawa couplings are

$$W = Y_{xd} XQ\,XD^c H_d + Y_{xu} XQ^c XDH_u. \tag{5}$$

We employ the RGE improved one-loop effective Higgs potential approach to calculate the contributions to the lightest CP-even Higgs boson mass from the vector-like particles [37,51]. The relevant shift in the Higgs mass-square is approximated as [52]

$$\Delta m_h^2 = -\frac{N_c M_Z^2}{8\pi^2} \times \cos^2 2\beta \left(\hat{Y}_{xu}^2 + \hat{Y}_{xd}^2\right) t_V + \frac{N_c v^2}{4\pi^2} \times \hat{Y}_{xu}^4 \left(t_V + \frac{1}{2} X_{xu}\right), \tag{6}$$

with

$$\hat{Y}_{xu} = Y_{xu} \sin\beta; \qquad \hat{Y}_{xd} = Y_{xd} \cos\beta,$$
$$\tilde{A}_{xu} = A_{xu} - \mu \cot\beta; \qquad t_V = \ln \frac{M_S^2 + M_V^2}{M_V^2},$$
$$X_{xu} = \frac{-2M_S^2(5M_S^2 + 4M_V^2) + 4(3M_S^2 - 2M_V^2)\tilde{A}_{xu}^2 + \tilde{A}_{xu}^4}{6(M_V^2 + M_S^2)^2}, \tag{7}$$

where $N_c$ is the number of colors carried by the vector-like fields, $M_S$ is the soft SUSY-breaking mass evaluated at the Higgs scale, and $A_{xu}$ is the soft SUSY-breaking trilinear term for the Yukawa superpotential element $Y_{xu} XQ^c XDH_u$. For simplicity, we take $Y_{xd} = 0$. From the two-loop RGE analyses, we determined that the maximal Yukawa couplings $Y_{xu}$ are about 0.96, 1.03, and 1.0 for $\tan\beta = 2$, $\tan\beta \sim 23$, and $\tan\beta = 50$, respectively [52], and thus choose a working value of $Y_{xu} = 1.0$. The corrected Higgs boson mass will be

$$m_h = \sqrt{(\tilde{m}_h)^2 + \Delta m_h^2}, \tag{8}$$

where $\tilde{m}_h$ is the "bare" Higgs mass, neglecting the shift from the vector-like coupling. For specificity, we consider a benchmark point with inputs $M_{1/2} = 518$ GeV, $M_V = 1640$ GeV, $m_t = 174.4$ and $\tan\beta = 20.65$, which yields the bare Higgs mass prediction $\tilde{m}_h = 121.4$ GeV. The SUSY spectrum for this benchmark is presented in Table 1. Noting that the scalar masses will be similar to those of the top quarks, we approximate $M_S = 1$ TeV, and $A_{xu} = -1.3$ TeV. At the benchmark, we obtain $\Delta m_h^2 = 986.1\ \mathrm{GeV}^2$, corresponding to a corrected Higgs mass of $m_h = 125.4$ GeV.

The parameter values at the benchmark point are not chosen idly. In particular, the gaugino boundary mass $M_{1/2}$ is responsible for setting the overall scale of the SUSY spectrum, and we shall demonstrate in the next section that a value in the neighborhood of 518 GeV is optimal for matching the observed excesses in multi-jet production events at CMS [39] and ATLAS [38]. By contrast, the spectrum, and thus the rate of event production, is largely indifferent to the vector-like mass. Nevertheless, preservation of the fundamental $B_\mu = 0$ boundary at the high scale implies an exceedingly strong parameter interdependence such that fluctuations (for example) of the thresholds contributed by the top quark, SUSY partners, or *flippon* fields, might conspire against modifications (for instance) to the Yukawa coupling boundary or $\tan\beta$, to keep the condition intact. In Fig. 1, the contours of $\tan\beta$ are seen to run approximately along constant $M_{1/2}$, such that the jet count observations also tightly constrain this parameter, which spans already a rather narrow range across the full parameter space. By contrast, the top quark mass $m_t$ contours do vary strongly in the inverse with the vector-like mass. We additionally overlay onto Fig. 1 an extrapolation of the corrected Higgs mass. This is achieved by use of a simplified formula for $\Delta m_h^2$ [51] which implements the leading dependence of the *flippon* mass $M_V$, with larger shifts corresponding to lighter vector-like multiplets. We also account for a weaker dependence on the soft term mass by its proportionality to $M_{1/2}$, approximating $M_S = 2M_{1/2}$. The overall numerical scale of the shift is calibrated against a second detailed calculation at $(M_{1/2}, M_V) = (518, 1840)$ GeV which yields $\Delta m_h^2 = 811.5\ \text{GeV}^2$. The extrapolation is found to agree with the original calculation at $M_V = 1640$ GeV to about 3% in $\Delta m_h^2$.

$$m_h \simeq \sqrt{\tilde{m}_h^2 + (87.81\ \text{GeV})^2 \times \left(\ln x - \frac{5}{6} + \frac{1}{x} - \frac{1}{6x^2}\right)},$$
$$x \equiv 1 + \left(\frac{2M_{1/2}}{M_V}\right)^2. \tag{9}$$

The effect of the shift term on the Higgs contours is to make the curves run more horizontally at low $M_V$ values, in keeping with the strong gradient in that coordinate. This works in tandem with the top quark mass, whose elevation likewise lifts the bare Higgs mass prediction $\tilde{m}_h$. For both reasons, larger net values of the Higgs mass $m_h$ occur toward the lower boundary of the plot, just prior to the extremity of a single deviation from the top quark world average, at $m_t \simeq 174.4$ GeV. We find that the maximum Higgs mass for $M_{1/2} = 518$ GeV occurs around $M_V = 1631$ GeV at $m_h \simeq 125.5$ GeV, and that the Higgs mass of $m_h \simeq 124.0$ GeV occurs for about $M_V = 1865$ GeV, as shown in Fig. 1.

## 4. Next stop-gluino masses

Achieving a 125 GeV Higgs mass in basic MSSM constructions is actually not so difficult; it is simply a question of whether one is willing to swallow the consequences. The bitter pill for such a heavy value of $m_h$ will be extremely heavy squarks. To generate $m_h = 125$ GeV will typically require squark masses in excess of 5–6 TeV, with a gluino mass of similar scale. To achieve $m_h = 125$ GeV in this manner one may begin to contemplate soft SUSY-breaking scalar and gaugino masses so large as to imperil the very mechanism being advanced: supersymmetry as a remedy for the ailments of the gauge hierarchy. Of more immediately tangible concern, gluino and squark masses approaching 5 TeV will produce no discernible SUSY signature at the current operating energy of the LHC. Of course, Nature cares little for such provincial trifles; except that we believe the lightly distinctive fragrance [15] of an emerging SUSY signal perfuses already the early data. A SUSY spectrum elevated to 5 TeV is far beyond the reach of the $\sqrt{s} = 7$ TeV LHC for many years to come, and could not possibly explain low-statistics signal that may plausibly have already begun its inevitable effusion from the trillions of recorded collisions. If the emerging SUSY signal and the putative 124–126 GeV Higgs mass are indeed legitimate, then there is another way forward.

The modifications to the $\beta$-function coefficients from introduction of the *flippon* multiplets have a parallel effect on the RGEs of the gauginos. In particular, the color-charged gaugino mass $M_3$ likewise runs down flat from the high energy boundary, obeying the relation $M_3/M_{1/2} \simeq \alpha_3(M_Z)/\alpha_3(M_{32}) \simeq \mathcal{O}(1)$, which precipitates a conspicuously light gluino mass assignment. Likewise, the large mass splitting expected from the heaviness of the top quark via its strong coupling to the Higgs (which is also key to generating an appreciable radiative Higgs mass shift $\Delta m_h^2$) is responsible for a rather light stop squark $\tilde{t}_1$. The distinctively predictive $M(\tilde{t}_1) < M(\tilde{g}) < M(\tilde{q})$ mass hierarchy of a light stop and gluino, both much lighter than all other squarks, is stable across the full No-Scale $\mathcal{F}$-$SU(5)$ model space, but is not precisely replicated in any phenomenologically favored constrained MSSM (CMSSM) constructions of which we are aware. This spectrum generates a unique event topology starting from the pair production of heavy squarks $\tilde{q}\bar{\tilde{q}}$, except for the light stop, in the initial hard scattering process, with each squark likely to yield a quark-gluino pair $\tilde{q} \to q\tilde{g}$. Each gluino may be expected to produce events with a high multiplicity of virtual stops, via the (possibly off-shell) $\tilde{g} \to \tilde{t}$ transition, which in turn may terminate into hard scattering products such as $\to W^+W^-b\bar{b}\tilde{\chi}_1^0$ and $W^-b\bar{b}\tau^+\nu_\tau\tilde{\chi}_1^0$, where the $W$-bosons will produce mostly hadronic jets and some leptons. The model described may then consistently exhibit a net product of eight or more hard jets emergent from a single squark pair production event, passing through a single intermediate gluino pair, resulting after fragmentation in a spectacular signal of ultra-high multiplicity final state jet events. From our phenomenological analysis of the $\mathcal{F}$-$SU(5)$ bare-minimally constrained parameter space in Fig. 1, the gluino mass $m_{\tilde{g}}$ ranges from about $m_{\tilde{g}} \simeq 540$ GeV (corresponding to an $M_{1/2} \simeq 385$ GeV) to around $m_{\tilde{g}} \simeq 1.2$ TeV (corresponding to an $M_{1/2} \simeq 900$ GeV).

We have carefully studied the expected $\mathcal{F}$-$SU(5)$ production excesses in the high multiplicity jet channels [8,11–13,15], undertaking a detailed and comprehensive Monte Carlo simulation, employing industry standard tools [54–58]. We have painstakingly mimicked [8,15] the leading multi-jet selection strategies of the CMS [53] and ATLAS [38] Collaborations, using a post-processing script of our own design [59]. All 2-body SUSY processes have been included in our simulation. Our conclusion is that the best fit to the jet production excesses observed at both detectors occurs in the vicinity of the $M_{1/2} = 518$ GeV strip of Fig. 1 which was isolated for attention in the prior section. Lighter values of $M_{1/2}$ will allow for lighter *flippons* and a heavier top quark, and thus also a heavier Higgs. However, values much below about $M_{1/2} = 480$ GeV are considered to be excluded for over-production of SUSY events. Values much larger than the target range will have some difficulty achieving a sufficiently large Higgs mass. In Figs. 2 and 3, we overlay counts for the No-Scale $\mathcal{F}$-$SU(5)$ jet production (summed with the official SM backgrounds) onto histograms illustrating the current status of the LHC multi-jet SUSY search, representing just over 1.1 $\text{fb}^{-1}$ of luminosity integrated by the ATLAS [38] and CMS [53] experiments, respectively. The statistical significance of the ATLAS overproduction, as gauged by the indicator of signal (observations minus background) to background ratio $S/\sqrt{B+1}$, is quite low for $\geqslant 7$ jets in the search strategy of Fig. 2, somewhat greater than 1.0, although the CMS overproduction significance for $\geqslant 9$ jets in the search strategy of Fig. 3 is just above 2.0. We project

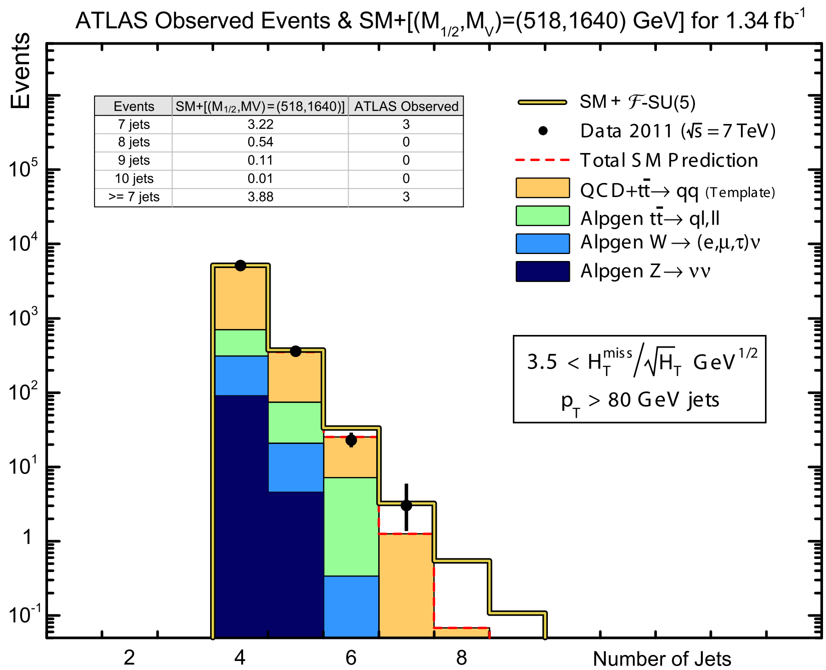


**Fig. 2.** An ATLAS Collaboration plot [38] (present in the arXiv source repository supplementing the cited document) representing 1.34 $fb^{-1}$ of integrated luminosity at $\sqrt{s} = 7$ TeV is reprinted with an overlay summing our Monte Carlo collider-detector simulation of the No-Scale $\mathcal{F}$-$SU(5)$ model benchmark ($M_{1/2} = 518$ GeV, $M_V = 1640$ GeV) with the ATLAS SM background.

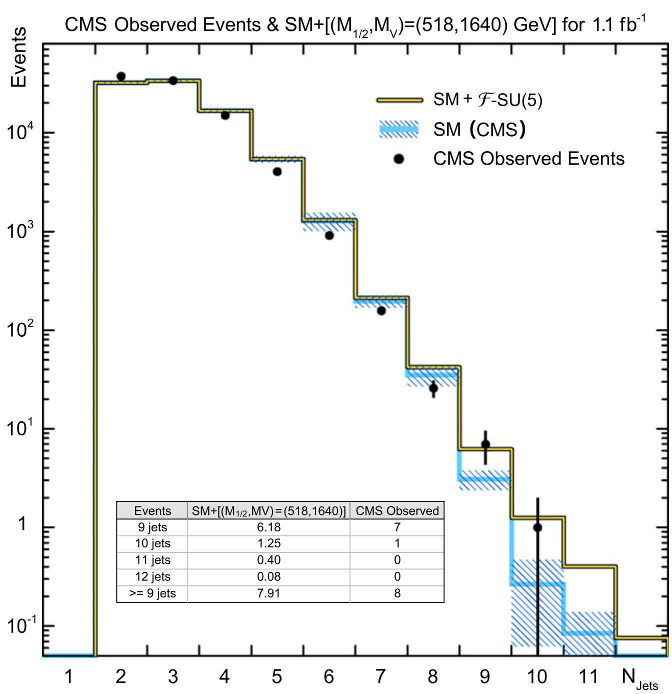


**Fig. 3.** A CMS Collaboration plot [53] representing 1.1 $fb^{-1}$ of integrated luminosity at $\sqrt{s} = 7$ TeV is reprinted with an overlay summing our Monte Carlo collider-detector simulation of the No-Scale $\mathcal{F}$-$SU(5)$ model benchmark ($M_{1/2} = 518$ GeV, $M_V = 1640$ GeV) with the CMS SM background.

in Table 2 that the already collected 5 $fb^{-1}$ data set may be sufficient to reach the gold standard signal significance of 5, at least for the CMS search strategy, although both approaches appear to scale well with higher intensities.

## 5. Conclusions

We have described a model named No-Scale $\mathcal{F}$-$SU(5)$ which is simultaneously capable of explaining the dual signals emerging at the LHC of (i) a 124–126 GeV Higgs boson mass $m_h$, and (ii) tantalizing low-statistics excesses in the multi-jet data which may attributable to supersymmetry. These targets tend to be mutually exclusive in more conventional approaches. The unified mechanism responsible for both effects is the introduction of a rather unique set of vector-like multiplets at the TeV scale, dubbed *flippons*, which (i) can elevate $m_h$ by around 3–4 GeV via radiative loop corrections, and (ii) flatten the running of the strong coupling and color-charged gaugino, resulting in a prominent collider signal

**Table 2**
Projections for the ATLAS and CMS signal significance at 5 $\text{fb}^{-1}$ of integrated luminosity, in the ultra-high jet multiplicity channels. Event counts for $\mathcal{F}$-$SU(5)$ are based on our own Monte Carlo of the $M_{1/2} = 518$ GeV, $M_V = 1640$ GeV benchmark. SM backgrounds are scaled up from official collaboration estimates [38,53].

| | CMS 5 $\text{fb}^{-1}$ | | | | | ATLAS 5 $\text{fb}^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 9j | 10j | 11j | 12j | $\geqslant 9$j | 7j | 8j | 9j | 10j | $\geqslant 7$j |
| $\mathcal{F}$-$SU(5)$ | 14.0 | 4.5 | 1.4 | 0.3 | 20.3 | 7.3 | 1.8 | 0.4 | 0.1 | 9.6 |
| SM | 14.0 | 1.2 | 0.4 | 0.0 | 15.6 | 4.7 | 0.3 | 0.0 | 0.0 | 4.9 |
| $S/\sqrt{B+1}$ | 3.6 | 3.0 | 1.2 | 0.3 | **5.0** | 3.1 | 1.6 | 0.4 | 0.1 | **3.9** |

from production of light gluino pairs. This well-motivated theoretical framework maintains consistency with all key phenomenological constraints, and all residual parameterization freedom may in principle be fixed by a combination of the two experiments described. We project that the already collected luminosity of 5 $\text{fb}^{-1}$ may be sufficient to definitively establish the status of this model, given appropriate data selection cuts.

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