# Effective operators coupling adjoint scalars to SM gauge bosons

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# Quick Motivation

Color adjoint scalars exist in many BSM scenarios, such as Minimal Flavor Violating Models or R-symmetric extensions of the MSSM. Proposed search channels for include searches such as $t\bar{t}$ pairs, dijets, and W/Z plus jets.

This talk explores scenarios in which color scalars decay through loops to SM gauge bosons and in particular on a decay to a photon and a gluon.

# Effective Lagrangian

For a scalar octet coupling to SM gauge bosons, where we have assumed that they can only decay through loops of heavy intermediate particles, we can write down an effective Lagrangian of the form:

$$\mathcal{L} = \frac{1}{2}(D^\mu S)^\dagger_a (D^\mu S)_a - \frac{m_s^2}{2} S^a S^a + g_1 S^a G^a_{\mu\nu} B^{\mu\nu} + g_2 d^{abc} S^a G^{b\mu\nu} G^c_{\mu\nu}$$

$D^\mu = \partial^\mu + i g_s T_a G^\mu_a$

The couplings have dimension of $[M]^{-1}$ corresponding to the scale of physics in loops.

# Term of Interest

$$g_1 S^a G^a_{\mu\nu} B^{\mu\nu}$$

This operator is of particular interest as it gives us a coupling between the scalar octet and photons and Z bosons.

If this can be constructed, it allows for us to look for scalar octets in pp collisions in a much cleaner channel than dijets.

These type of effective operators will work with scalar adjoints under any SM gauge group.

# Decays

With these effective operators, there are only two paths for these scalars to decay into.

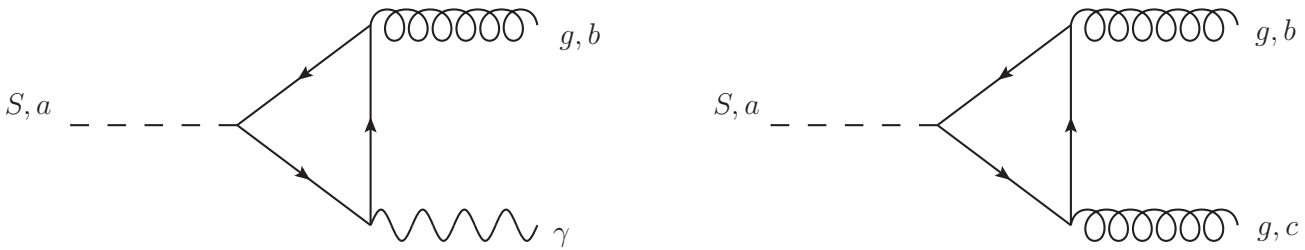
$$\Gamma(S \to g\gamma) = \frac{g_1^2 m_S^3}{8\pi} \qquad \Gamma(S \to gg) = \frac{5 g_2^2 m_S^3}{12\pi}$$

The two different branching ratios can be given in terms of the couplings.

$$BR_{g\gamma} = \frac{g_1^2}{g_1^2 + \frac{10}{3} g_2^2} \qquad BR_{gg} = \frac{g_2^2}{\frac{3}{10} g_1^2 + g_2^2}$$

# Branching Ratios

So is $BR_{g\gamma}$ non-negligible?




Decay through a heavy quark loops to final states.

$$M_{g\gamma} \propto Q\sqrt{\alpha\alpha_s}\delta^{ab} \qquad M_{gg} \propto \alpha_s \frac{1}{2} d^{abc}$$

$$\Gamma_{g\gamma} \propto 8Q^2\alpha\alpha_s \qquad \Gamma_{gg} \propto \frac{10}{3}\alpha_s^2$$

$$\frac{\Gamma_{g\gamma}}{\Gamma_{gg}} = \frac{12}{5} Q^2 \frac{\alpha}{\alpha_s}$$

Taking $Q \sim 1$, and the values of $\alpha$, $\alpha_s$ at the Z mass, $BR_{g\gamma} \sim .14$

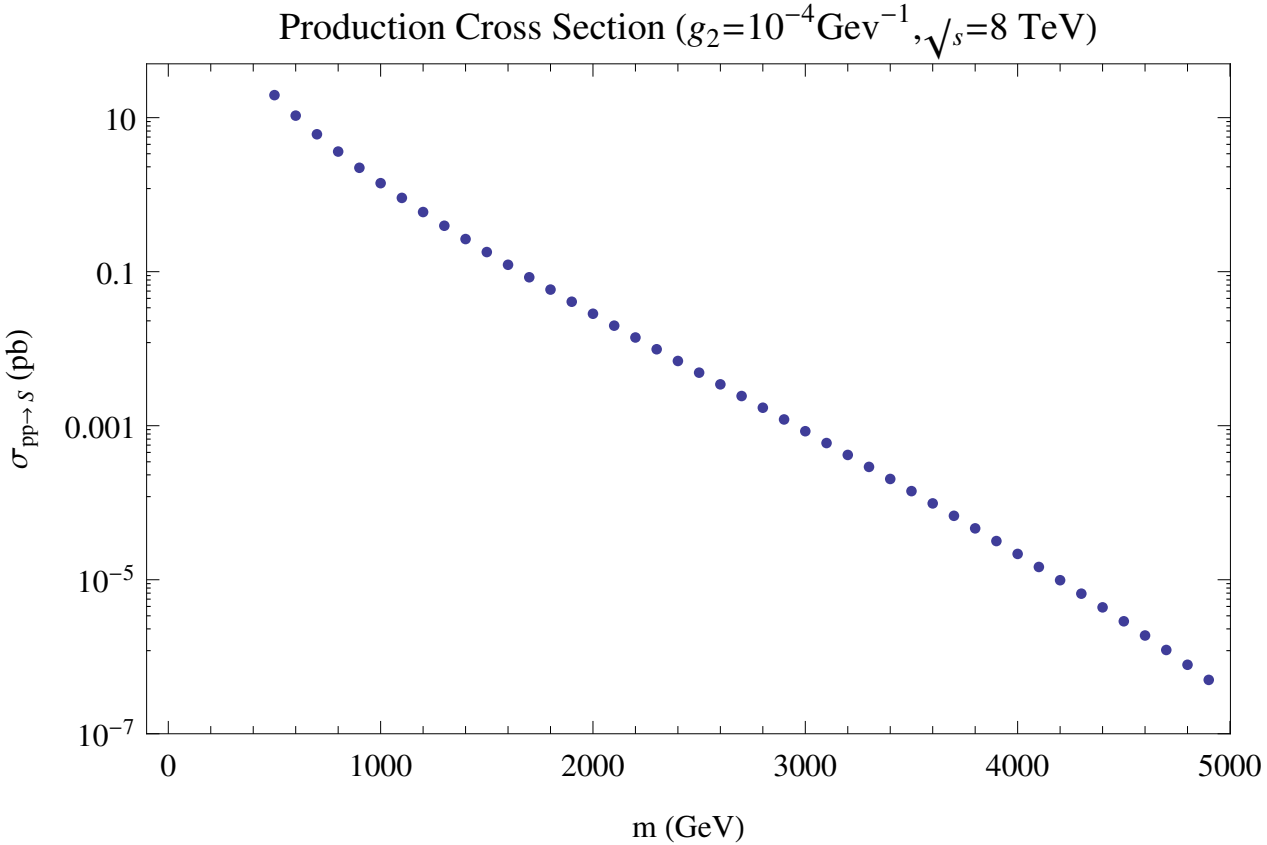
# Production Cross Section

Looking into producing these scalars on shell through the gluon fusion process,

$$\sigma(pp \to S) = \Gamma(S \to gg)\varepsilon \frac{16\pi^2}{s m_S} \int_{\frac{m^2}{s}}^{1} \frac{dx}{x} f_g(x) f_g(\frac{m_S^2}{sx})$$

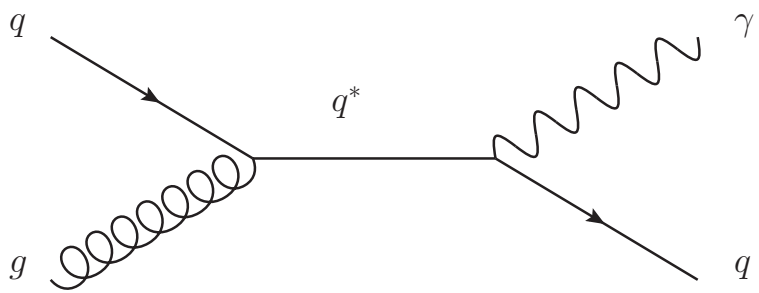
- $\varepsilon = \frac{1}{32}$ takes into account changing between summing over and averaging over spins
- $x$ is the momentum fraction carried by the gluons
- $f_g$ is the parton distribution function for the gluon

# Single Production




Production cross section of a single scalar octet in pp collisions at $\sqrt{s} = 8\ TeV$ with $g_2 = 10^{-4}\ GeV^{-1}$. These cross sections were generated in MADGRAPH.

# Current LHC searches




Excited quark compton scattering.

Current searches for a photon and jet resonance are mainly aimed at looking for excited quark states that decay to jet and a photon.

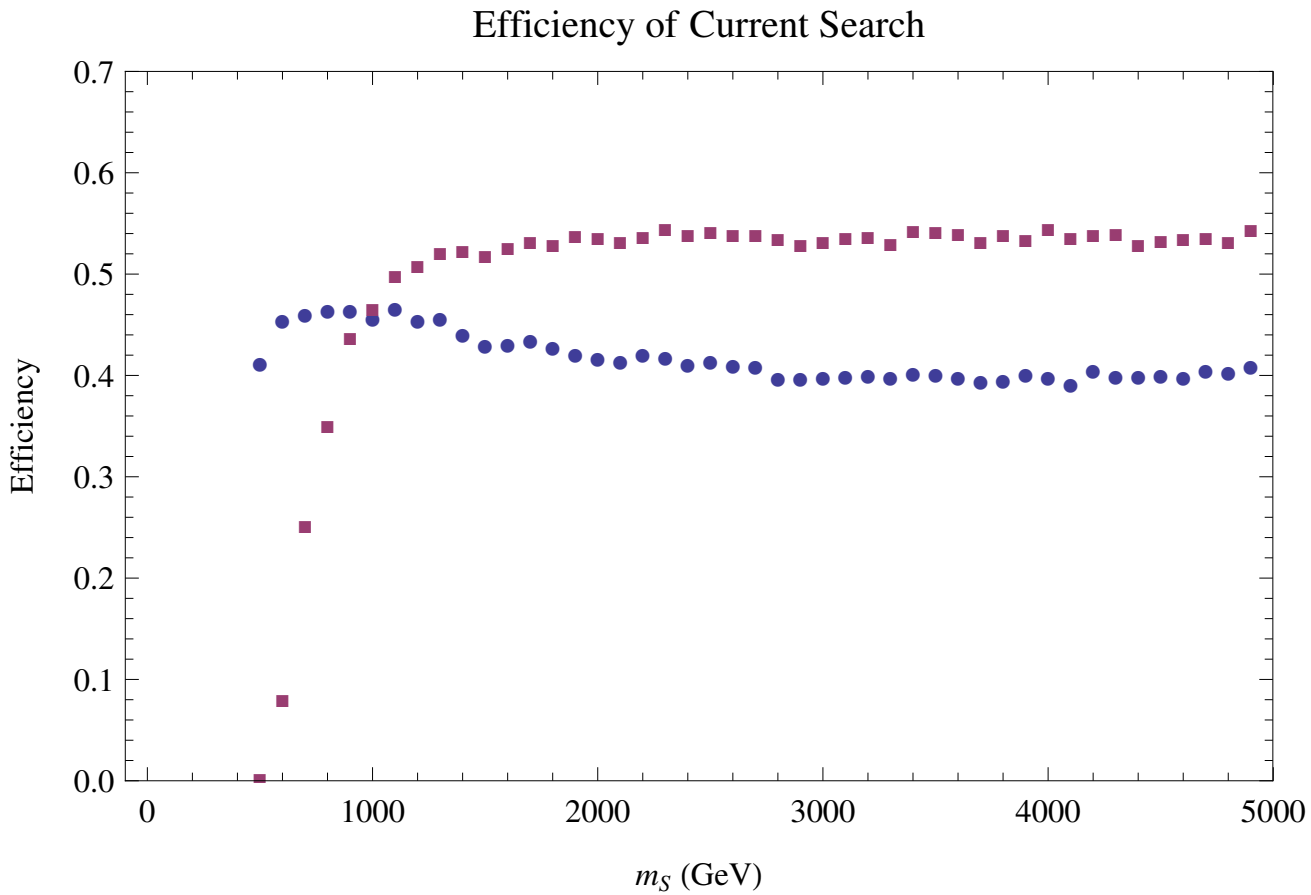
The only SM background to these sorts of decays come from QCD.

# Current search parameters

| CMS Selection<br>CMS PAS EXO-13-003 |
| --- |
| Photon ID |
| $p_T^{\gamma} > 170\ GeV$ |
| $\lvert\eta^{\gamma}\rvert < 1.4442$ |
| $p_T^{jet} > 170\ GeV$ |
| $\lvert\eta^{jet}\rvert < 3.0$ |
| $\Delta\phi(\gamma, jet) > 1.5$ |
| $\lvert\Delta\eta(\gamma, jet)\rvert < 2.0$ |
| $M_{\gamma,jet} > 560\ GeV$ |

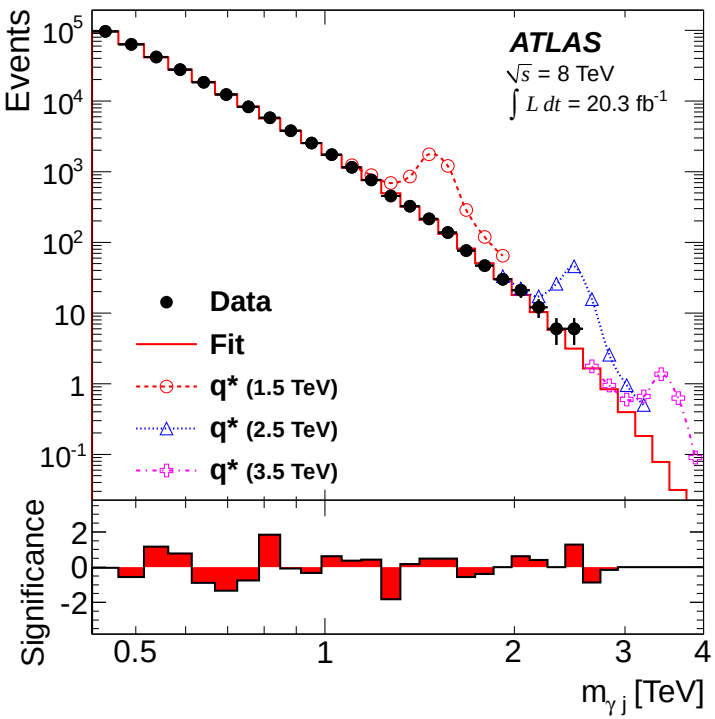
| ATLAS Selection<br>ATLAS-CONF-2013-059 |
| --- |
| Photon ID |
| $p_T^{\gamma} > 125\ GeV$ |
| $\lvert\eta^{\gamma}\rvert < 1.37$ |
| $p_T^{jet} > 125\ GeV$ |
| $\lvert\eta^{jet}\rvert < 3.0$ |
| $\Delta R(\gamma, jets) > 1.0$ |
| $\lvert\Delta\eta(\gamma, jet)\rvert < 1.6$ |

# Efficiency of current searches

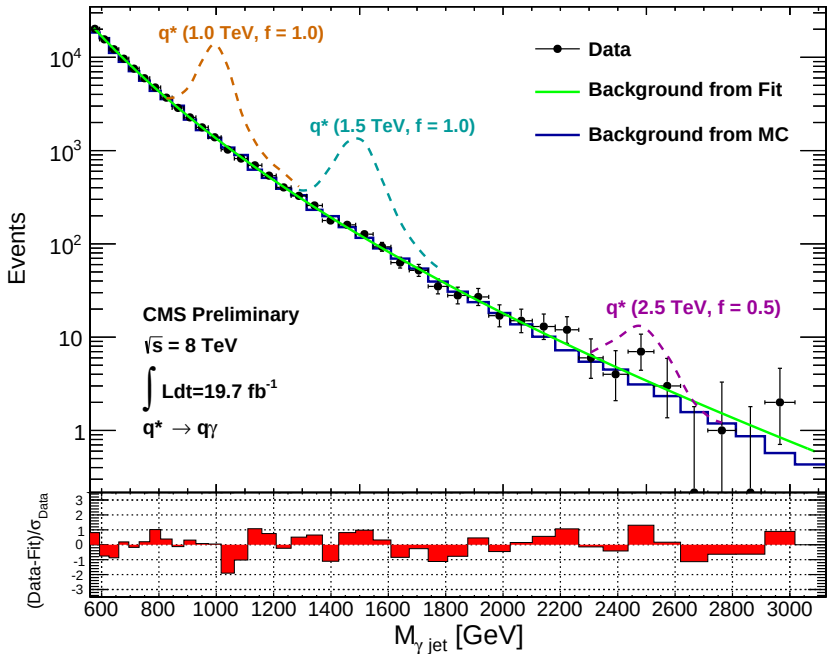



Efficiency of simulated events passing current search criteria.

# Current Search Results

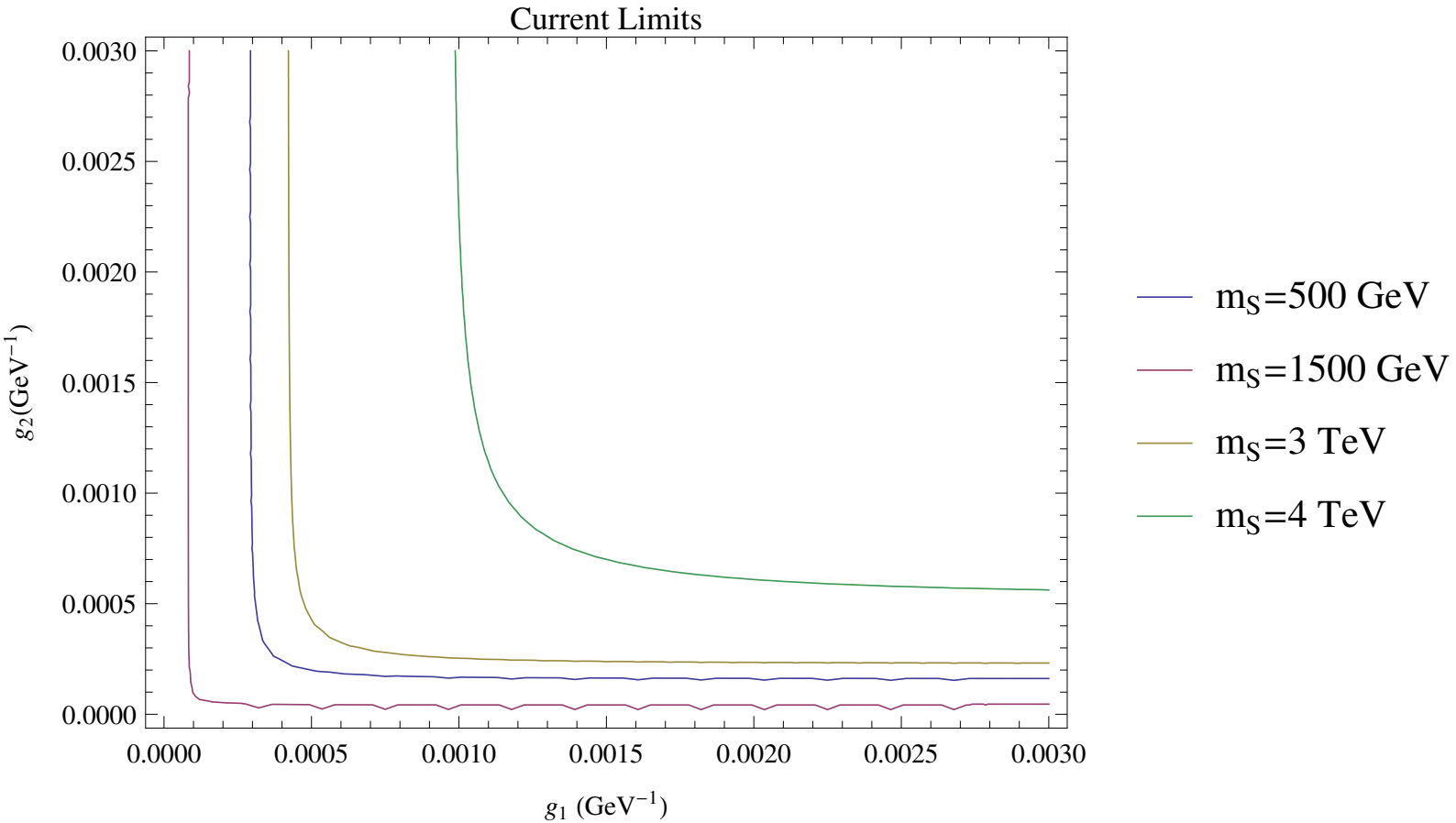



ATLAS-CONF-2013-059




CMS PAS EXO-13-003

# Limits




Parameter space above the curves are excluded at 95% confidence level.

# Summary

- We have recast current CMS and ATLAS searches and put limits on the simplest case
- To complete the current analysis, one needs to look at Z decay path
- Can also look into other operators of a similar form to couple adjoint scalars to SM gauge bosons, i.e. $S^i W^i_{\mu\nu} B^{\mu\nu}$ or $S^a_i W^i_{\mu\nu} G^{\mu\nu}_a$