Model Building for Back-To-The-Future Trigger

-We want event-N triggered + event N-1 in the previous bunch crossing (BC) (t=25 ns, ct=7.5 m) not.

-We'll see particle χ_1 in event N-1 and particles χ_0 + Y in event N, χ_1 -> χ_0 + Y.

-To avoid standard triggers on N-1 event, strong preference for χ_1 SM neutral (or millicharged).

-Since MET is involved in the N trigger, χ_0 should also be neutral.

-For χ_1 lifetime largish (to decay it in the next BC), we need small $\Delta=\chi_1 - \chi_0$ and/or χ_1-χ_0-Y coupling

-Hence the simplest choice, SUSY-reminiscent, is to take Y=γ (SM photon). Y=Z,h also possible.

-With only x_1-x_0-γ vertex very small cross-section ($\gamma\gamma$F @LHC with highly off-shell photon).
We add a new scalar s produced resonantly in gluon fusion, and decaying into $\chi_1\,\chi_1$. [2 couplinhgs]

The relevant Lagrangian reads $\mathscr{L} \supset \frac{C_{ggs}}{\Lambda} s\, G^{\mu\nu} G_{\mu\nu} + \frac{C_{\chi\chi\gamma}}{\Lambda} \bar{\chi}_1 \sigma_{\mu\nu} F^{\mu\nu} \chi_0 + \mathrm{h.c} + y_\chi^1 \bar{\chi}_1 s \chi_1 + \mathscr{L}_{mass}$

6 free parameters: $\frac{C_{ggs}}{\Lambda}, \frac{C_{\chi\chi\gamma}}{\Lambda}, y_\chi^1, m_{\chi_1}, m_{\chi_0}, m_s$ $\Longrightarrow$ Can we trade them for a more ``physical'' set? Constraints?

Parametrization and constraints (I)

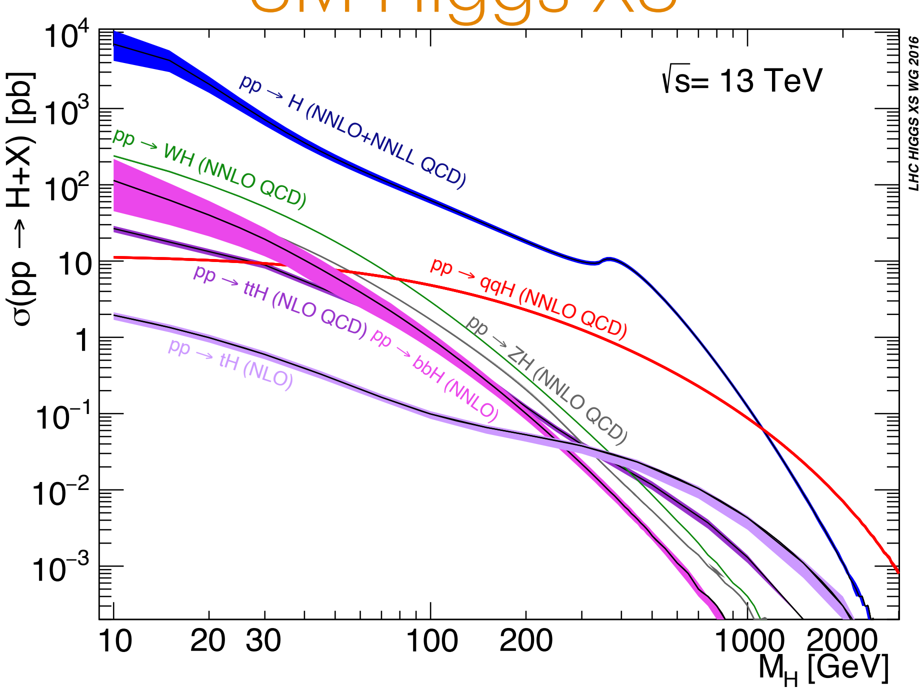
$$\mathscr{L} \supset \frac{C_{ggs}}{\Lambda} s\, G^{\mu\nu}G_{\mu\nu} + \frac{C_{\chi\chi\gamma}}{\Lambda} \bar{\chi}_1 \sigma_{\mu\nu} F^{\mu\nu} \chi_0 + \mathrm{h.c} + y_\chi^1 \bar{\chi}_1 s \chi_1 + \mathscr{L}_{mass}$$

Can be traded for $\sigma_s (m_S) = \sigma$ (gg -> s) which is only function of m_S. We can relate this σ_s to $\sigma_{s,SM}$ by considering either a a new heavy quark Q (or vector-like quark), or via a direct mixing with the SM Higgs (h). We will have

$$\sigma(pp \to s) = \left[\frac{C_{ggS}^{(Q)}}{\Lambda}\right]^2 f(m_S) = \left[\frac{C_{ggS}^{Q}}{C_{ggh}^{(t)}} \frac{C_{ggh}^{(t)}}{\Lambda}\right]^2 f(m_S) = \left(\frac{C_{ggS}^{(Q)}}{C_{ggh}^{(t)}}\right)^2 \times \sigma_{s,SM}(m_S)$$

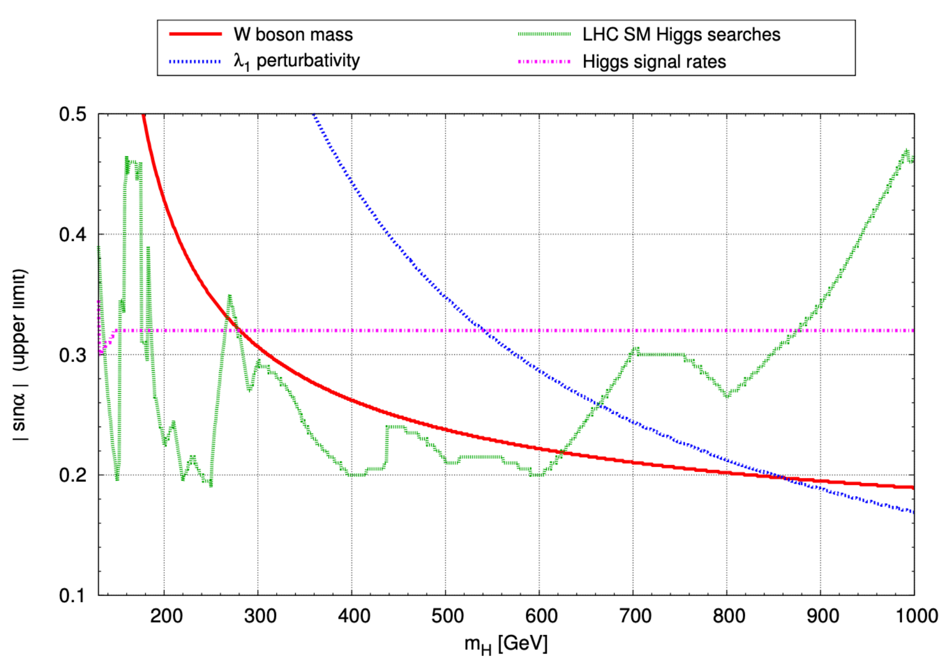
For a heavy quark Q, and the parenthesis would be traded by $\sin^2(\alpha)$ if we consider that s mixes with h.

SM Higgs XS



https://twiki.cern.ch/twiki/pub/LHCPhysics/HiggsXSBR/plotAll_13tev_BSM_sqrt.pdf

Bounds on mixing angle



Robens, 2205.06295

m_S =600 GeV
$\sigma_{s,SM}(600)$~3 pb, $\sin^2\alpha$~0.04,
σ_s <= 120 fb

m_S =1000 GeV
$\sigma_{s,SM}(1000)$~0.2 pb, $\sin^2\alpha$~0.02,
σ_s <= 5 fb

m_S =1500 GeV
$\sigma_{s,SM}(1000)$~0.02 pb, $\sin^2\alpha$~0.02,
σ_s <= 0.5 fb

Parametrization and constraints (II)

$$\mathscr{L} \supset \frac{C_{ggs}}{\Lambda} s\, G^{\mu\nu}G_{\mu\nu} + \frac{C_{\chi\chi\gamma}}{\Lambda}\bar{\chi}_1\sigma_{\mu\nu}F^{\mu\nu}\chi_0 + \mathrm{h.c} + y^1_\chi \bar{\chi}_1 s \chi_1 + \mathscr{L}_{mass}$$

Other searches that might apply: 1) di-jet Z′ searches 2) monojet

1) $\sigma_{jj}(m_s) = \sigma_s(m_s)BR(s \to gg)$, but the latter is given by $1/[1+(y_\chi \Lambda / C_{ggs})^2]$, small for large enough y_χ.

2) $\sigma(pp \to sj, s \to \chi_1\chi_1)$ constrained by monojet, if we assume χ_1 decays are undetected. This should be only a function of m_s, but a non-trivial one, since the shape of pT(j) would depend on m_s.

Exclusive Signal Region	EM2	EM4	EM6	EM8	EM9	EM11
Data events (139 fb^{-1})	313 912	102 888	10 203	1663	738	187
SM prediction	314 000 ± 3500	101 600 ± 1200	10 000 ± 180	1640 ± 40	754 ± 20	182 ± 6
$W \to e\nu$	16 000 ± 1000	3980 ± 250	280 ± 19	35.8 ± 2.6	13.4 ± 1.0	3.01 ± 0.24
$W \to \mu\nu$	23 600 ± 500	5940 ± 120	481 ± 12	66.8 ± 2.3	31.2 ± 1.2	7.8 ± 0.4
$W \to \tau\nu$	54 900 ± 800	15 430 ± 260	1243 ± 29	167 ± 6	77.4 ± 2.9	15.5 ± 0.8
VBF W + jets	2340 ± 300	1010 ± 150	140 ± 27	29 ± 7	16 ± 5	5.0 ± 1.9
$Z \to ee$	–	–	–	–	–	–
$Z \to \mu\mu$	597 ± 15	97.4 ± 2.7	4.51 ± 0.15	1.49 ± 0.05	0.60 ± 0.02	–
$Z \to \tau\tau$	530 ± 14	115.0 ± 3.3	8.31 ± 0.28	0.90 ± 0.04	0.40 ± 0.02	2.10 ± 0.08
$Z \to \nu\nu$	192 800 ± 2100	67 400 ± 1000	7000 ± 170	1180 ± 40	534 ± 20	126 ± 6
VBF Z + jets	3900 ± 500	2170 ± 310	370 ± 60	86 ± 17	45 ± 10	13.7 ± 3.3
single-t	2800 ± 700	550 ± 180	15 ± 8	–	–	–
$t\bar{t}$	8900 ± 700	2000 ± 150	100 ± 8	8.2 ± 1.0	2.4 ± 0.4	0.30 ± 0.05
Diboson	6200 ± 1000	2700 ± 500	350 ± 70	71 ± 15	33 ± 8	–
Multijet	1100 ± 1100	57 ± 57	0.6 ± 0.6	0.1 ± 0.1	–	–
Noncollision background	240 ± 240	46 ± 46	8 ± 8	6 ± 6	–	–
SUSY, $m(\tilde{t}, \tilde{\chi}^0) = (600, 580)$ GeV	562 ± 70	516 ± 60	159 ± 19	44 ± 6	28 ± 4	8.2 ± 1.1
DMA, $m(\chi, Z_A) = (1, 2000)$ GeV	770 ± 30	684 ± 27	212 ± 9	79 ± 4	47.9 ± 2.3	18.7 ± 1.1
Dark energy, $M_2 = 1486$ GeV	286 ± 7	320 ± 11	125 ± 7	52 ± 5	33.6 ± 3.2	14.6 ± 1.8

ATLAS, 2102.10874, 139 fb^{-1}

From the paper:
"Values of $\sigma \times A \times \epsilon$ above 736 fb (for IM0) and above 0.3 fb (for IM12) are excluded at 95% CL."

We'd need to compute A, ϵ for our model. But they should be $O(10^{-2,-3})$ and hence comparable with those from single s production from last slide.

Parametrization and constraints (III)

$$\mathscr{L} \supset \frac{C_{ggs}}{\Lambda} s\ G^{\mu\nu} G_{\mu\nu} + \frac{C_{\chi\chi\gamma}}{\Lambda} \bar{\chi}_1 \sigma_{\mu\nu} F^{\mu\nu} \chi_0 + \mathrm{h.c} + y^1_\chi \bar{\chi}_1 s \chi_1 + \mathscr{L}_{mass}$$

I can't fathom a relevant constraint here,
except the coupling not being too large (unitarity)

This coefficient enters only in the χ_1 decay, then $\tau(\chi_1) = \tau = f(C_{\chi\chi\gamma}/\Lambda, m_{\chi 1}, m_{\chi 0})$. So use τ instead of $\chi\chi\gamma$ coupling!

Note: in the current Pythia simulation we force the $\chi 1 \to \chi 0\, \gamma$ decay using oneChannel. This might not give the required tensor structure (need to read and think about it!).
-We can always make a MG5 model and then shower the parton level events with Pythia.
-I recall Gareth saying Pythia lifetime does not agree with the estimation of 2301.05252, this ought to be checked.

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! 5) Process selection
Higgs:useBSM = on
HiggsBSM:allH2 = on
35:m0 = 600.
1000023:m0 = 300.0
1000022:m0 = 247.5
1000023:tau0 = 7500
1000022:mayDecay = off  ! this line is probably not necessary. Better safe than sorry

! Force H0 > N2 N2, N2 > N1 gamma decays
35:oneChannel = 1 1.000 100 1000023 1000023
1000023:oneChannel 1 1.000 100 1000022 22
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Alternative model: Hadronic final states (instead of photons)

To our previous Lagrangian:

$$\mathscr{L} \supset \frac{C_{ggs}}{\Lambda} s\, G^{\mu\nu}G_{\mu\nu} + \frac{C_{\chi\chi\gamma}}{\Lambda}\bar{\chi}_1\sigma_{\mu\nu}F^{\mu\nu}\chi_0 + \mathrm{h.c} + y_\chi^1 \bar{\chi}_1 s \chi_1 + \mathscr{L}_{mass}$$

We can add terms for scalar-new fermions interactions (at d=4 for s, d=5 for H^+H)

$$\mathscr{L}_{\chi-\phi} \supset \sum_{i,j}\left(y_\chi^{i,j}\bar{\chi}_i s \chi_j + \mathrm{h.c.}\right) + \sum_{i,j}\left(\frac{C_{h\chi\chi}^{ij}}{\Lambda}\bar{\chi}_i H^\dagger H \chi_j + \mathrm{h.c.}\right)$$

Assuming s,H mix with angle $\alpha : s \to c_\alpha s + s_\alpha h, H \to -s_\alpha s + c_\alpha h$

Warnings:
-abuse of notation with s used for gauge and mass state.
-s and h get vevs
-missing sqrt[2] from H to h

Scalar couplings

$$g_{s\chi_i\chi_j} = y_\chi^{i,j} c_\alpha - \frac{C_{h\chi\chi}^{i,j}}{\Lambda} v s_\alpha \approx y_\chi^{i,j}$$

It is enough to keep y_{11} being > y_{00} and y_{01}]

Higgs mixing contribution doubly suppressed: by EFT and by mixing.

$$g_{h\chi_i\chi_j} = y_\chi^{i,j} s_\alpha + \frac{C_{h\chi\chi}^{i,j}}{\Lambda} v c_\alpha$$

-To have chi1 being long-lived, we need small h-x_1-x_0 coupling it should be enough to have y_{10} = 0 (get all lifetime from EFT).

-Note that the partial width is also going to be small due to a) 3-body decay and b) off-shellness of the Higgs

Seems that the following works:

y_{11}=1, y_{10}=0, y_{00}=0, C_{hxx} all equal and set by x_1 lifetime (or C_{hxx} only non-zero for Ch_{01})