Revealing BSM composite dynamics via topological interactions at future colliders

based on
E. Molinaro, F. Sannino, A.E. Thomsen, NV,
arXiv:1706.04037

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Outline

Compelling theories to explain the EWSB:

The Higgs is composite and pNGB

- Which composite dynamics generates the Higgs and other composite resonances?

Insights through **anomalous interactions** (analogy with $\pi \rightarrow \gamma\gamma$ in QCD)

- degrees of freedom of the strong gauge dynamics

  (~ number of colors)
- embedding of the EW sector in the coset

  (vacuum alignment angle)

SU(4)/Sp(4)

Minimal composite model with fermionic UV completion

4 Weyl fermions in $(1,2)_0 \oplus (1,1)_{-1/2} \oplus (1,1)_{+1/2}$ of $\mathrm{SU(3)_c \times SU(2)_L \times U(1)_Y}$

and in Pseudo-Real of **new strong gauge group** G_{TC} No gauge anomalies

$$\mathcal{L}_{\mathrm{TC}} = -\frac{1}{4}\mathcal{G}^{A}_{\mu\nu}\mathcal{G}^{A,\mu\nu} + i\overline{\psi}_a\overline{\sigma}^{\mu}D_{\mu}\psi^a - \tfrac{1}{2}\left(\psi^a m_{ab}\epsilon\,\psi^b + \mathrm{h.c.}\right)$$

$$\left\langle \psi^a \epsilon\, \psi^b \right\rangle = f^2 \Lambda\, \Sigma_0^{ab} \qquad \mathrm{SU(4)} \to \mathrm{Sp(4)} \qquad \text{5 NGB} \qquad W_L^{\pm}, Z_L + h + \eta$$

For $m_{ab} \to 0$ Extra (anomalous) global U(1) symmetry, with associated particle η' (QCD analogy)

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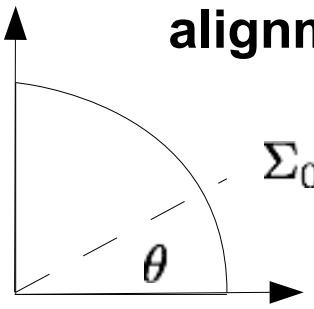
$\sin\theta = 1$
(TC limit)

Top contrib.

vacuum alignment



$\sin\theta = 0$ (No EWSB)

Gauge contribution

$$v = 2\sqrt{2} f \sin\theta$$

Fine-tuning ~ sinθ

In the CW potential, in order to have EWSB and a light Higgs

SU(4)/Sp(4)

Minimal composite model with fermionic UV completion

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vacuum alignment

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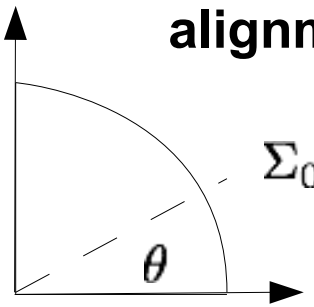
Top contrib.



$\sin\theta = 0$ (No EWSB)

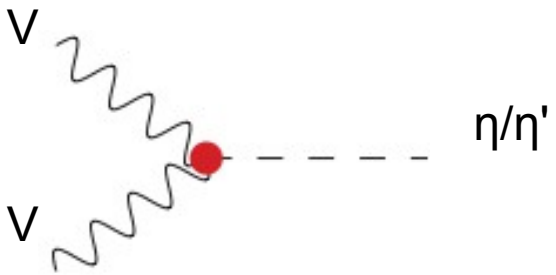
Gauge contribution

From LHC Higgs data:

$\sin\theta < 0.56\ (0.35)$

If modification to the top coupling is taken into account ($y_t = \cos\theta\, y_t^{SM}$)

WZW terms



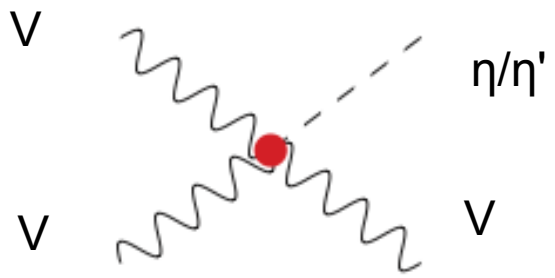
Couplings of the anomalous interactions are directly proportional to d(R), the dimension of the technifermion representation under G_{TC} (~ N)

large-N CHM especially interesting for studies of anomalous interactions at future colliders

$$-\frac{d(R)\alpha_{\rm EM}\cos\theta\sin\theta}{32\pi v}\eta\left[\frac{2}{c_w s_w}A_{\mu\nu}\tilde{Z}^{\mu\nu}+\frac{c_w^2-s_w^2}{c_w^2 s_w^2}Z_{\mu\nu}\tilde{Z}^{\mu\nu}+\frac{2}{s_w^2}W^+_{\mu\nu}\tilde{W}^{-\mu\nu}\right]$$

$$-\frac{d(R)\alpha_{\rm EM}\sin\theta}{48\pi v}\eta'\left[3A_{\mu\nu}\tilde{A}^{\mu\nu}+3\frac{c_w^2-s_w^2}{c_w s_w}A_{\mu\nu}\tilde{Z}^{\mu\nu}+\frac{3-6c_w^2s_w^2-\sin^2\theta}{2c_w^2s_w^2}Z_{\mu\nu}\tilde{Z}^{\mu\nu}+\frac{3-\sin^2\theta}{s_w^2}W^+_{\mu\nu}\tilde{W}^{-\mu\nu}\right]$$

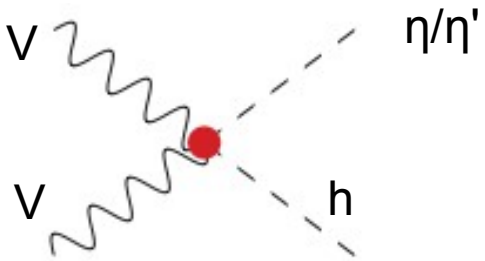
WZW terms



Gauged WZW action also generates η/η' interactions with 3 gauge bosons:

$$-i\frac{d(R)\alpha_{\rm EM}^{3/2}\cos\theta\sin\theta}{4\sqrt{\pi}v}\varepsilon^{\mu\nu\rho\sigma}\partial_\mu\eta\left[\frac{2}{s_w^2}A_\nu+\frac{2c_w^2-\sin^2\theta}{c_w s_w^3}Z_\nu\right]W_\rho^+W_\sigma^-$$

$$-i\frac{d(R)\alpha_{\rm EM}^{3/2}\sin\theta}{12\sqrt{\pi}v}\varepsilon^{\mu\nu\rho\sigma}\partial_\mu\eta'\left[\frac{6-2\sin^2\theta}{s_w^2}A_\nu+\frac{6c_w^2-(1+2c_w^2)\sin^2\theta}{c_w s_w^3}Z_\nu\right]W_\rho^+W_\sigma^-$$



... and with 2 gauge bosons and the Higgs

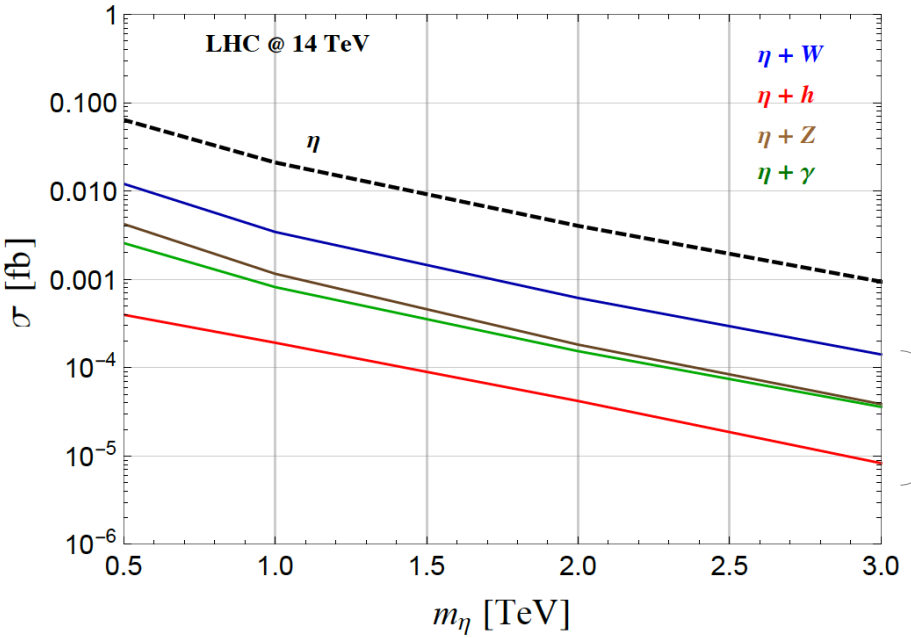
$$-\frac{d(R)\alpha_{\rm EM}\sin^3\theta}{16\pi v^2}\varepsilon^{\mu\nu\rho\sigma}\left[\frac{4}{c_w s_w}\partial_\mu h\partial_\nu\eta A_\rho Z_\sigma\right.$$

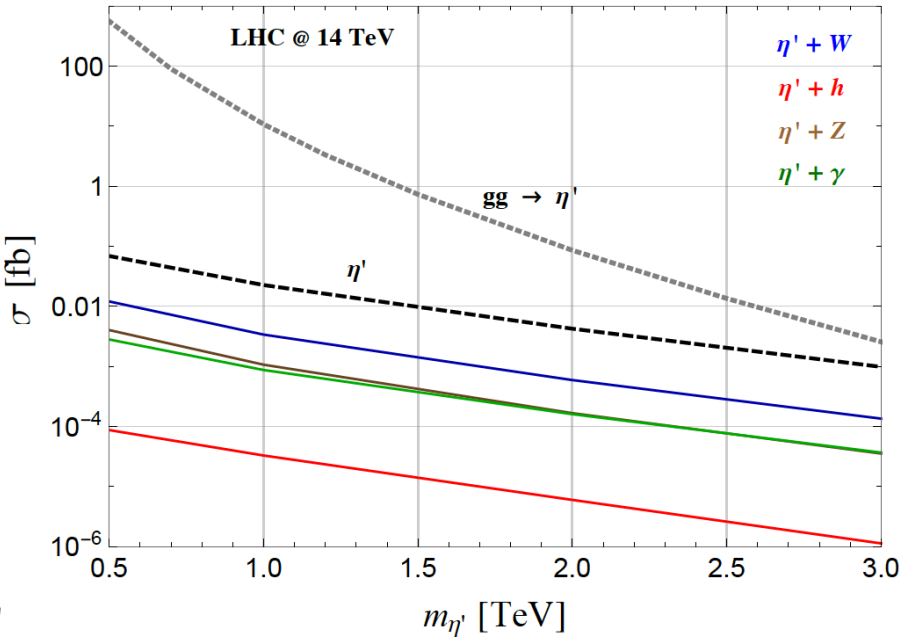
$$\left.+h\overleftrightarrow{\partial_\mu}\eta\left(\frac{c_w^2-s_w^2}{c_w^2 s_w^2}Z_{\nu\rho}Z_\sigma+\frac{1}{s_w^2}\left(W^+_{\nu\rho}W^-_\sigma+W^-_{\nu\rho}W^+_\sigma\right)+\frac{1}{c_w s_w}\left(A_{\nu\rho}Z_\sigma+Z_{\nu\rho}A_\sigma\right)\right)\right]$$

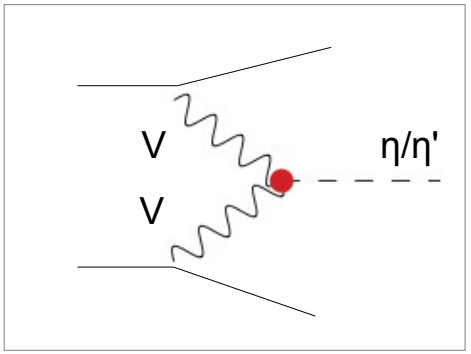
$$-\frac{d(R)\alpha_{\rm EM}\cos\theta\sin^3\theta}{24\pi v^2}\varepsilon^{\mu\nu\rho\sigma}h\partial_\mu\eta'\left[\frac{1}{c_w^2 s_w^2}Z_{\nu\rho}Z_\sigma+\frac{1}{s_w^2}\left(W^+_{\nu\rho}W^-_\sigma+W^-_{\nu\rho}W^+_\sigma\right)\right]$$

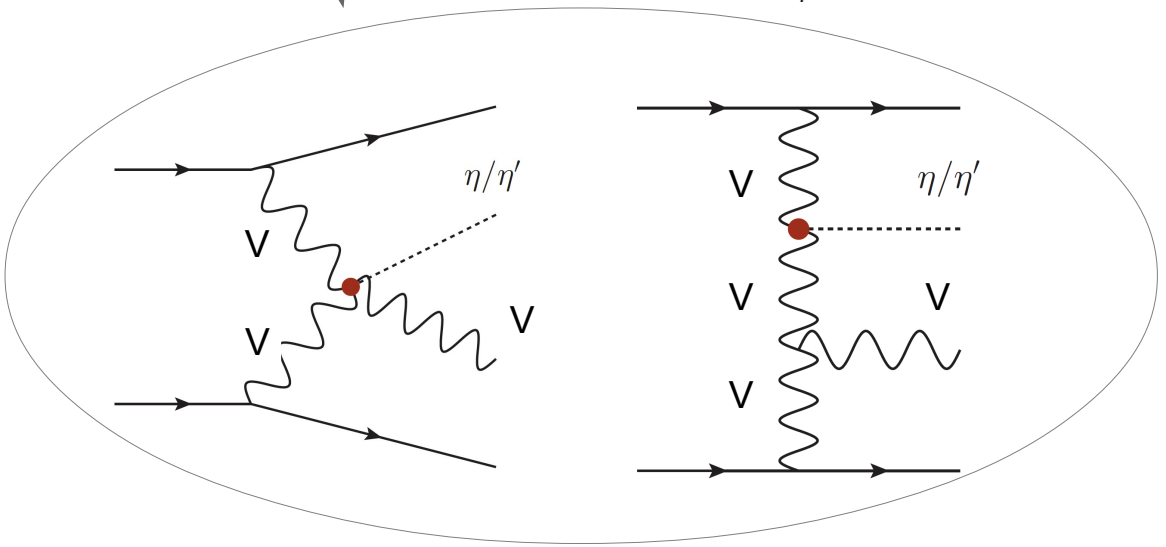
Note: no anomalous triple- quartic-gauge couplings are generated

LHC-14

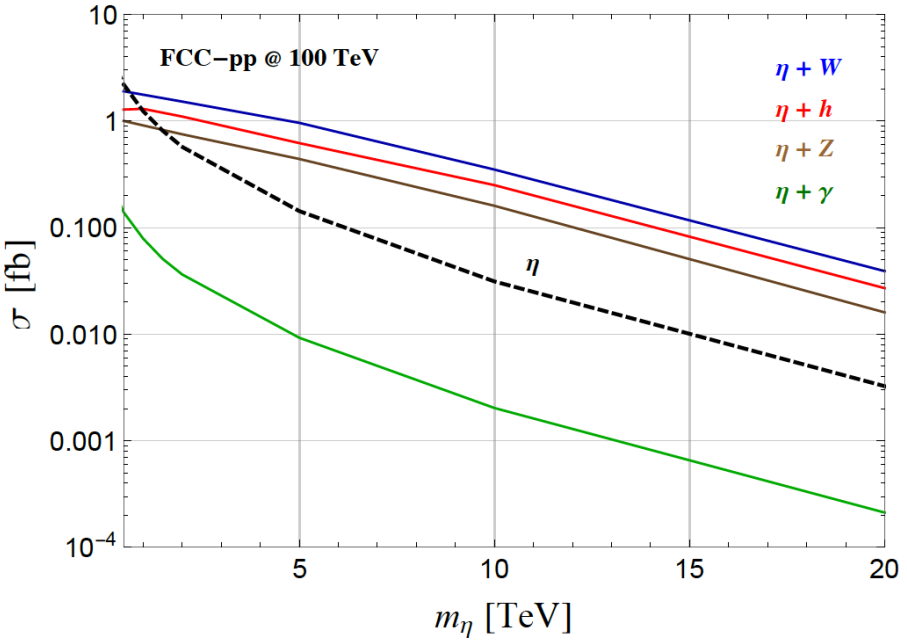

LHC @ 14 TeV
η + W
η + h
η + Z
η + γ
η
σ [fb]
m_η [TeV]

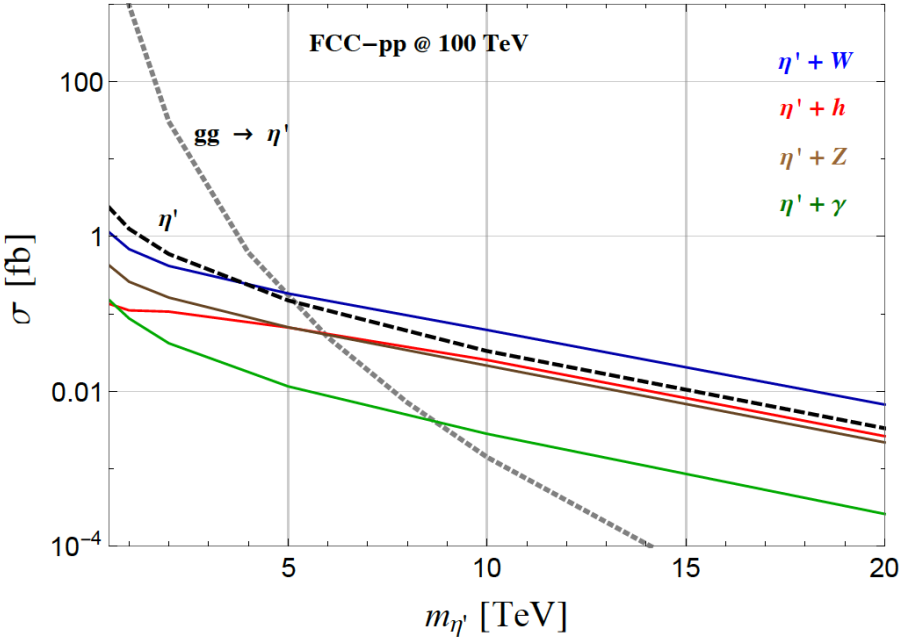

LHC @ 14 TeV
η' + W
η' + h
η' + Z
η' + γ
gg → η'
η'
σ [fb]
$m_{\eta'}$ [TeV]

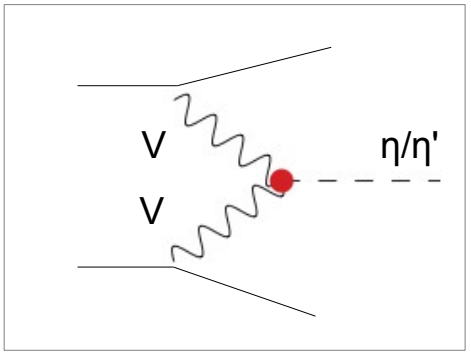

V
V
η/η'


η/η'
V
V
V
η/η'
V
V
V

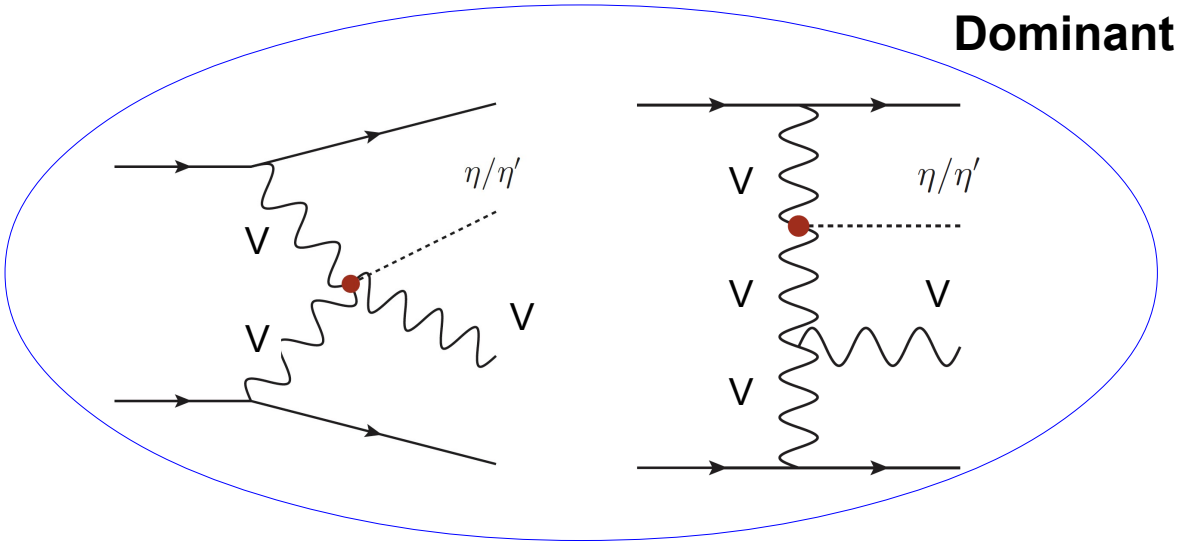
FCC-pp @ 100 TeV







Dominant

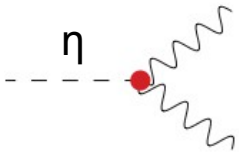


η/η' decays

Depend on the flavor structure of the model: pseudoscalar interactions with SM fermions

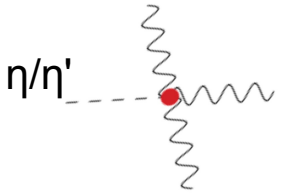
We consider the scenario where the top mass is generated from 4-F interactions:

$$y_t' f \overline{Q}_\alpha \,\mathrm{Tr}\left[P^\alpha \Sigma\right] t_\mathrm{R} \supset -\frac{m_{top}}{v}\,\bar{t}_\mathrm{L}\, t_\mathrm{R}\,(v + \cos\theta\, h - i \sin\theta\, \eta')$$



$\eta \to VV$ via topological interactions $\eta' \to t\bar{t}$

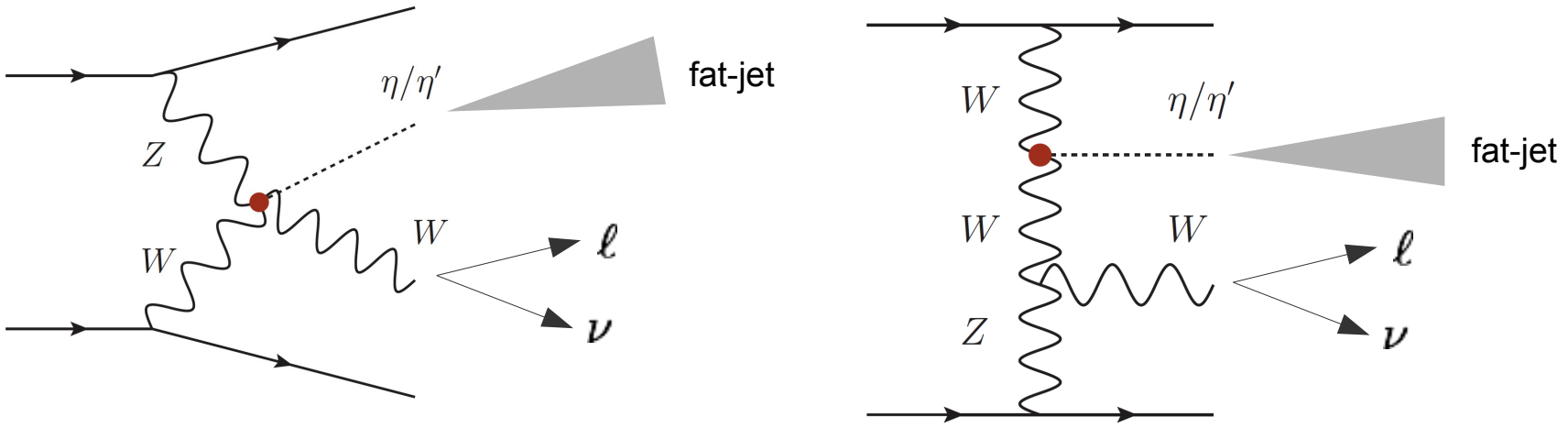
Note: For masses above ca. 5 TeV, the pseudoscalar decays into 3 bosons mediated by WZW interactions become dominant



The signal (η/η' + W)

Production via topological interactions (interference between diagrams with 4 and 3 bosons interactions)

$$\eta \to VV \to \text{jets} \qquad \eta' \to t\bar{t} \to \text{jets}$$

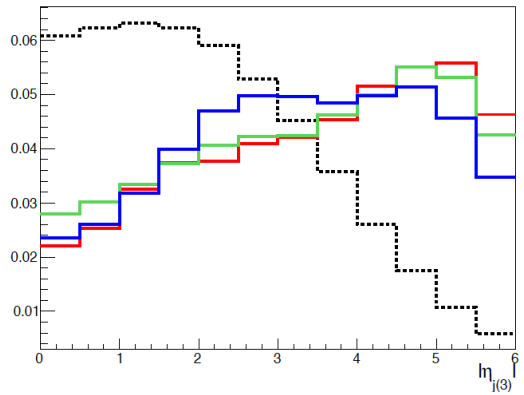


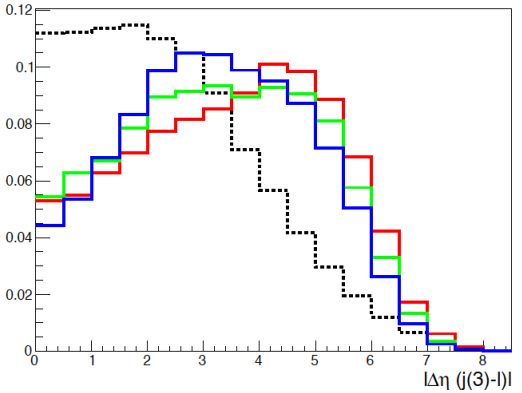
We reconstruct a single fat-jet from the hadronic decays of the η/η' (Jets clustered by FastJet with R=1.5)

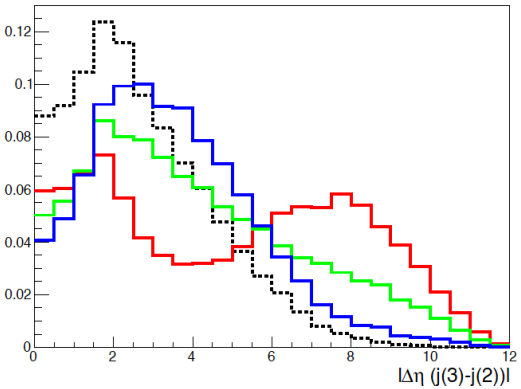
$$\ell + n\,\text{jets} + \not{E}_T\ , \qquad n \geq 3\,, \qquad \ell \equiv e, \mu$$

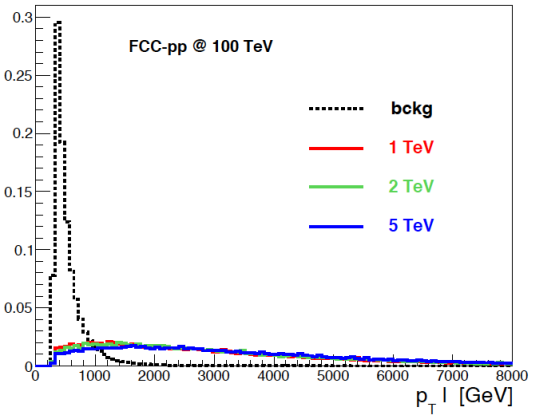
Dominant Background: W+jets

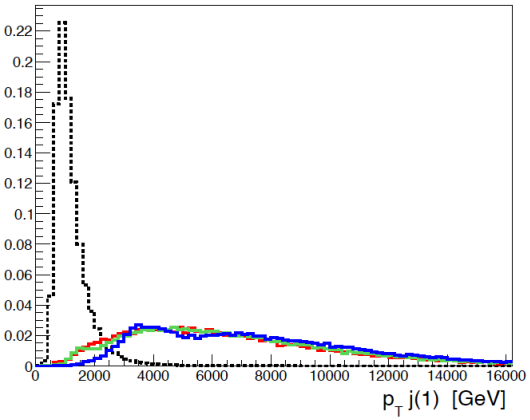
VBF kinematics + energetic final state

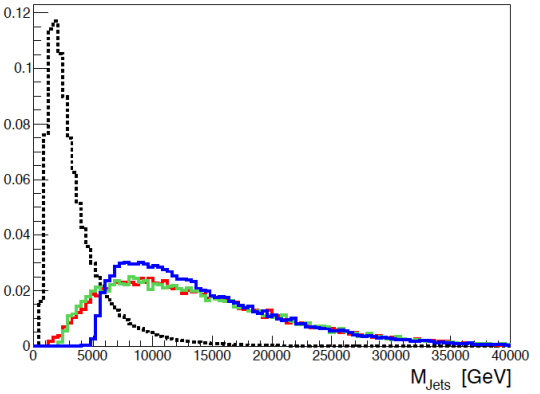






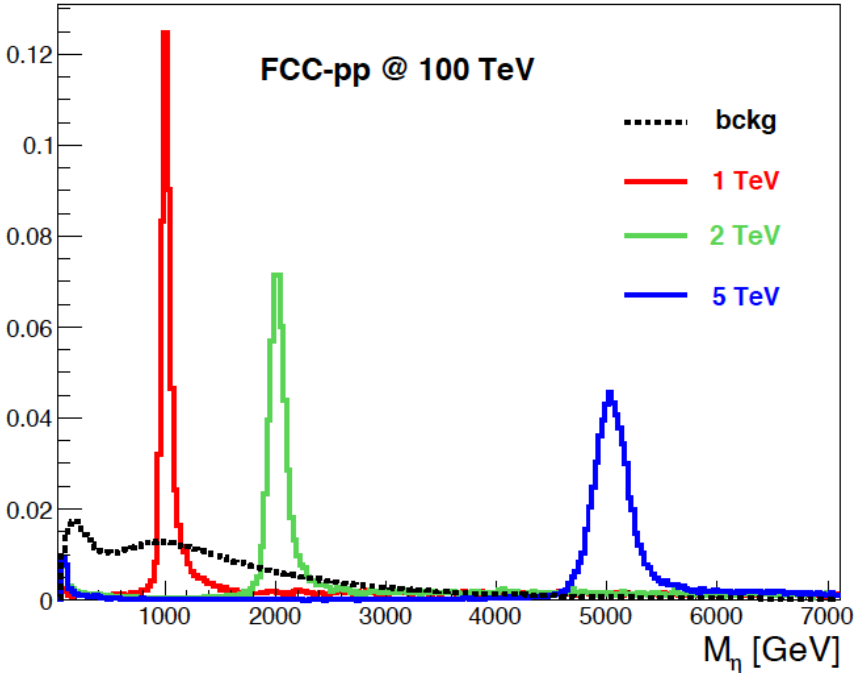






$m_{\eta/\eta'}$ [TeV]	$p_T\ \ell$ [TeV]	$\not{E}_T$ [TeV]	p_T j(1) [TeV]	M_{Jets} [TeV]	$\lvert\Delta\eta(j(3)-j(2))\rvert$
0.5	0.3	0.3	4	6	5
1	0.6	0.6	4	8	5
2	0.6	0.6	5	9	5
5	1.5	1.5	6	10	3

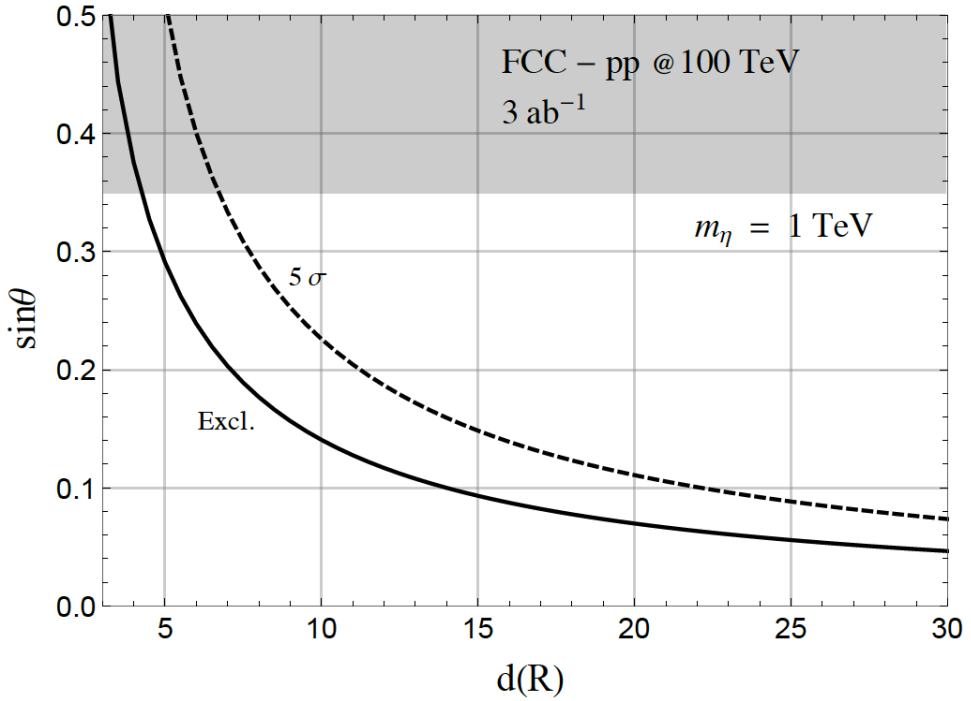
$$|\eta_{j(3)}| > 2, \quad |\Delta\eta\,(j(3)-\ell)| > 2, \quad |\Delta\eta\,(j(3)-j(1))| > 2$$

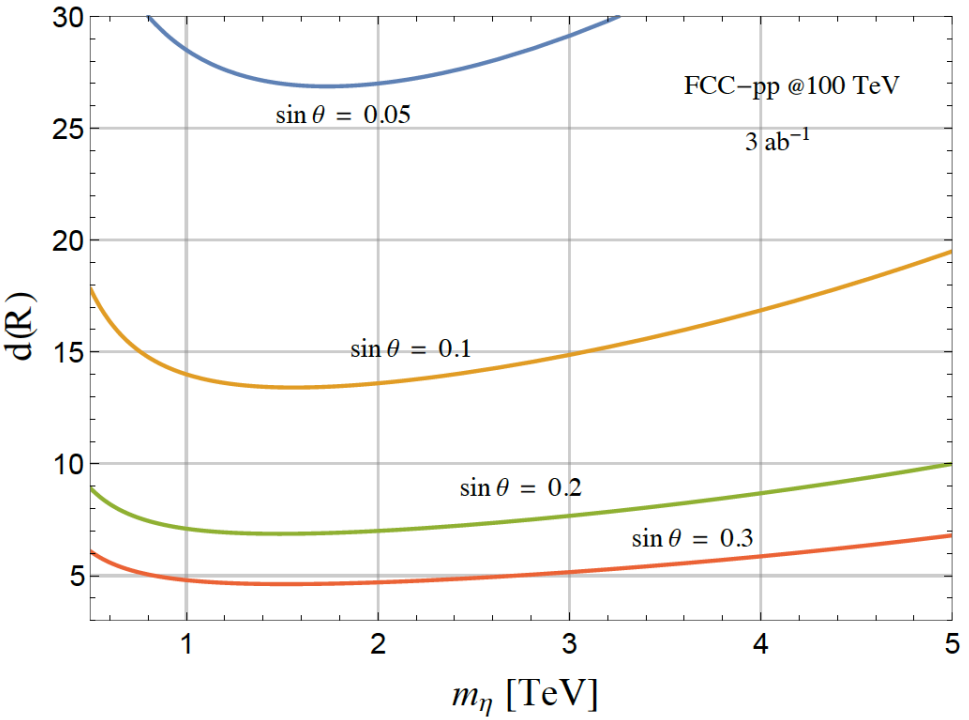


Easy reconstruction of the η/η' resonance:
It basically coincides with the leading fat-jet

$m_{\eta/\eta'}$ [TeV]	0.5	1	2	5
$M_{\eta/\eta'}$ [TeV]	[0.48, 0.54]	[0.93, 1.2]	[1.9, 2.2]	[4.6, 5.8]

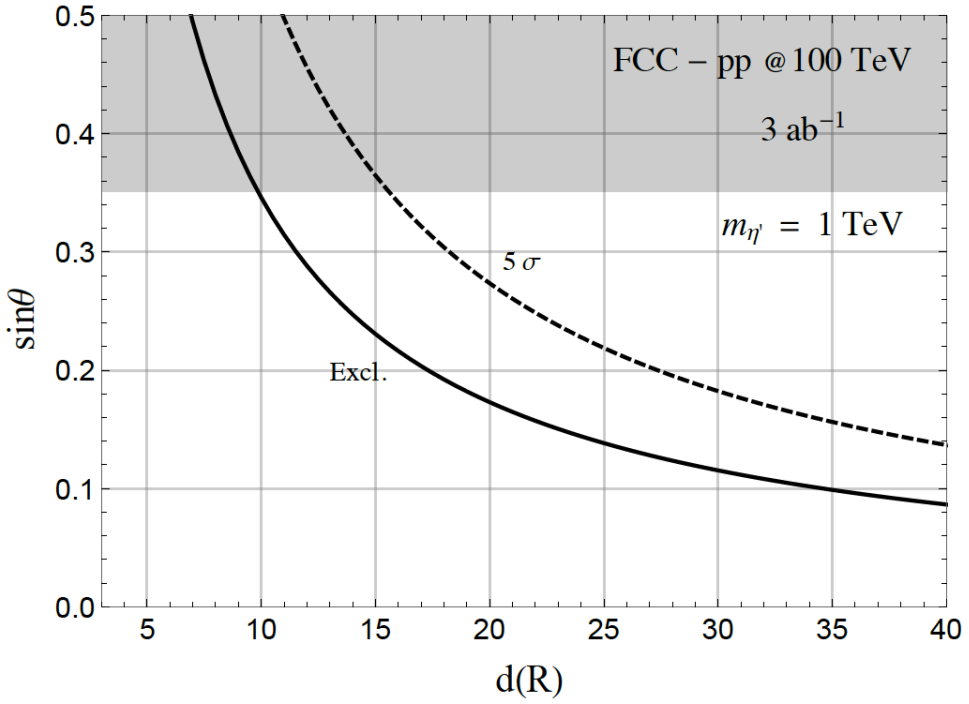
η signal

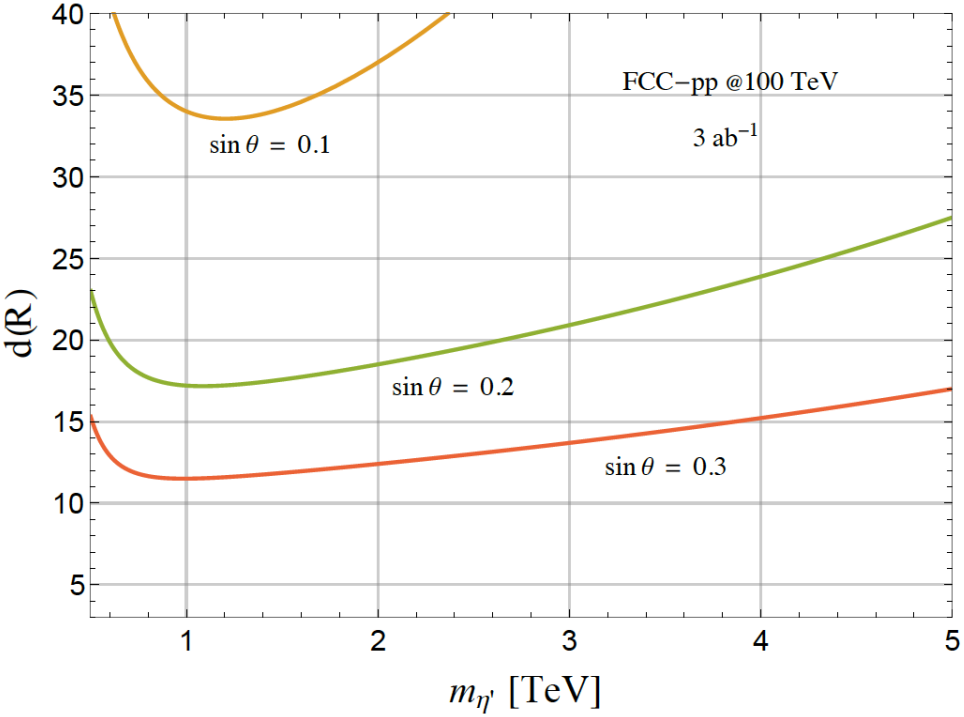




Wide FCC-pp reach on the fundamental parameters of the composite dynamics (d(R)) and the EWSB mechanism (sinθ)

η' signal


FCC – pp @100 TeV
3 ab^{-1}
$m_{\eta'}$ = 1 TeV
5 σ
Excl.
sinθ
d(R)
0.0
0.1
0.2
0.3
0.4
0.5
5
10
15
20
25
30
35
40


FCC–pp @100 TeV
3 ab^{-1}
sin θ = 0.1
sin θ = 0.2
sin θ = 0.3
d(R)
$m_{\eta'}$ [TeV]
5
10
15
20
25
30
35
40
1
2
3
4
5

Conclusions

- Enlightening phenomenology connected to the topological sector of Composite Higgs Models
- η/η' + W associated production via anomalous interactions is dominant at the FCC-pp (peculiar VBF kinematics)
- FCC-pp can directly probe the fundamental structure of the new strong dynamics related to the EWSB (N, sinθ)
- Study for minimal CHM SU(4)/Sp(4) can be generalized to scenarios with larger cosets and particle content

$$\Sigma = \exp\left[\frac{i}{f}\left(\frac{1}{2\sqrt{2}}\eta' + \pi_i Y^i + hY^4 + \eta Y^5\right)\right]\Sigma_0$$

$$\mathcal{A} = \mathcal{A}_\mu \,\mathrm{d}x^\mu, \quad \mathrm{d}\mathcal{A} = \partial_\mu \mathcal{A}_\nu \,\mathrm{d}x^\mu \mathrm{d}x^\nu$$
$$\mathrm{d}\Sigma = \partial_\mu \Sigma \,\mathrm{d}x^\mu, \quad \alpha = \mathrm{d}\Sigma\,\Sigma^\dagger.$$

$$\Gamma_{\rm WZW} = c\int_{M^5} \mathrm{Tr}\,\left[\alpha^5\right] + 10ic\int_{M^4} \mathrm{Tr}\,\left[\mathcal{A}\alpha^3\right]$$

η/η' VV
$$-10c\int_{M^4} \mathrm{Tr}\,\left[(\mathrm{d}\mathcal{A}\,\mathcal{A} + \mathcal{A}\mathrm{d}\mathcal{A})\alpha\right] - 5c\int_{M^4} \mathrm{Tr}\,\left[\mathrm{d}\mathcal{A}\mathrm{d}\Sigma\mathcal{A}^{\rm T}\Sigma^\dagger - \mathrm{d}\mathcal{A}^{\rm T}\mathrm{d}\Sigma^\dagger\mathcal{A}\Sigma\right]$$

η/η' VVh
$$-5c\int_{M^4} \mathrm{Tr}\,\left[\Sigma\mathcal{A}^{\rm T}\Sigma^\dagger(\mathcal{A}\alpha^2 + \alpha^2\mathcal{A})\right] + 5c\int_{M^4} \mathrm{Tr}\,\left[(\mathcal{A}\alpha)^2\right]$$

η/η' VVV
$$+10ic\int_{M^4} \mathrm{Tr}\,\left[\mathcal{A}^3\alpha\right] + 10ic\int_{M^4} \mathrm{Tr}\,\left[(\mathrm{d}\mathcal{A}\,\mathcal{A} + \mathcal{A}\,\mathrm{d}\mathcal{A})\Sigma\mathcal{A}^{\rm T}\Sigma^\dagger\right]$$
$$-10ic\int_{M^4} \mathrm{Tr}\,\left[\mathcal{A}\alpha\mathcal{A}\Sigma\mathcal{A}^{\rm T}\Sigma^\dagger\right]$$
$$+10c\int_{M^4} \mathrm{Tr}\,\left[\mathcal{A}^3\Sigma\mathcal{A}^{\rm T}\Sigma^\dagger\right] + \tfrac{5}{2}c\int_{M^4} \mathrm{Tr}\,\left[(\mathcal{A}\Sigma\mathcal{A}^{\rm T}\Sigma^\dagger)^2\right],$$

$$c = -id(R)/480\pi^2$$