Composite Higgses: smoking guns at the LHC

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project CompHS (FKPPL)

Joint FKPPL and TYL/FJPPL workshop
IPHC, Strasbourg

The teams

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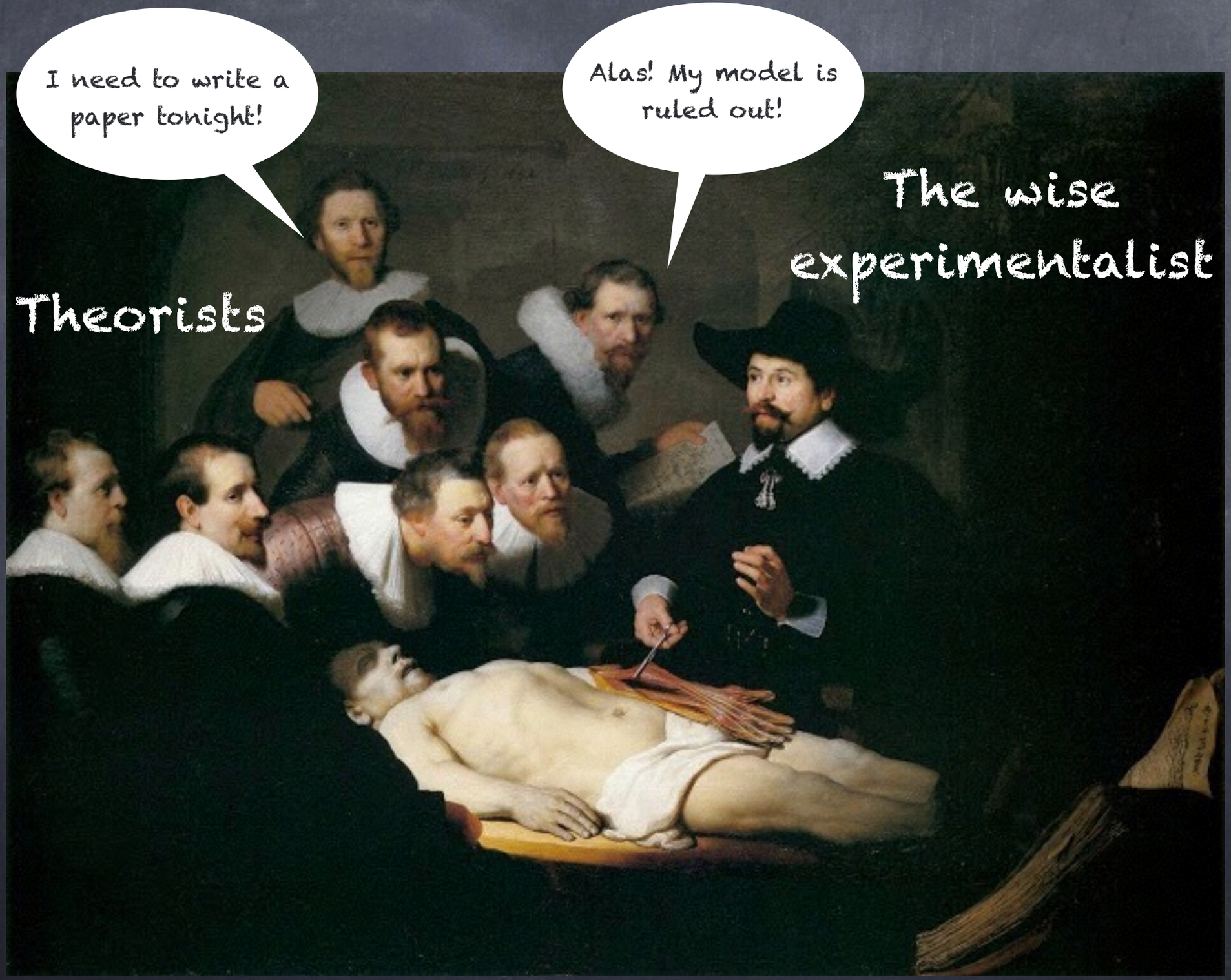
We obtained a PHC STAR grant
in 2015-16

Publications: 8 + 2 proc.

- G.Cacciapaglia, H.Cai, T.Flacke, S.J.Lee, A.Parolini, H.Serodio, "Anarchic Yukawas and top partial compositeness: the flavour of a successful marriage", JHEP 2015
- G.Cacciapaglia, H.Cai, A.Deandrea, T.Flacke, S.J.Lee, A.Parolini, "Composite scalars at the LHC: the Higgs, the Sextet and the Octet", JHEP 2015
- H.Cai, T.Flacke, M.Lespinasse, "A composite scalar hint from di-boson resonances?", 2015
- A.Belyaev, C.Cacciapaglia, H.Cai, T.Flacke, A.Parolini, H.Serodio, "Singlets in composite Higgs models in light of the 750 GeV diphoton excess", PRD 2016
- G.Cacciapaglia, A.Parolini, "Light 't Hooft top partners", PRD 2016
- A.Belyaev, C.Cacciapaglia, H.Cai, G.Ferretti, T.Flacke, A.Parolini, H.Serodio, "Di-boson signatures as standard candles for partial compositeness", JHEP 2017
- G.Cacciapaglia, H.Cai, A.Carvalho, A.Deandrea, T.Flacke, B.Fuks, D.Majumder, H.S.Shao, "Probing vector-like quark models with Higgs boson pair production" 2017
- N.Deutschmann, T.Flacke, J.S.Kim, "Current LHC limits on minimal Universal Extra dimensions", 2017

The ideal world:



The real world:

Struggling to put together a model in the midst of "buzzers"!

Flavour!

Higgs couplings!

No DM!

EWPTs!

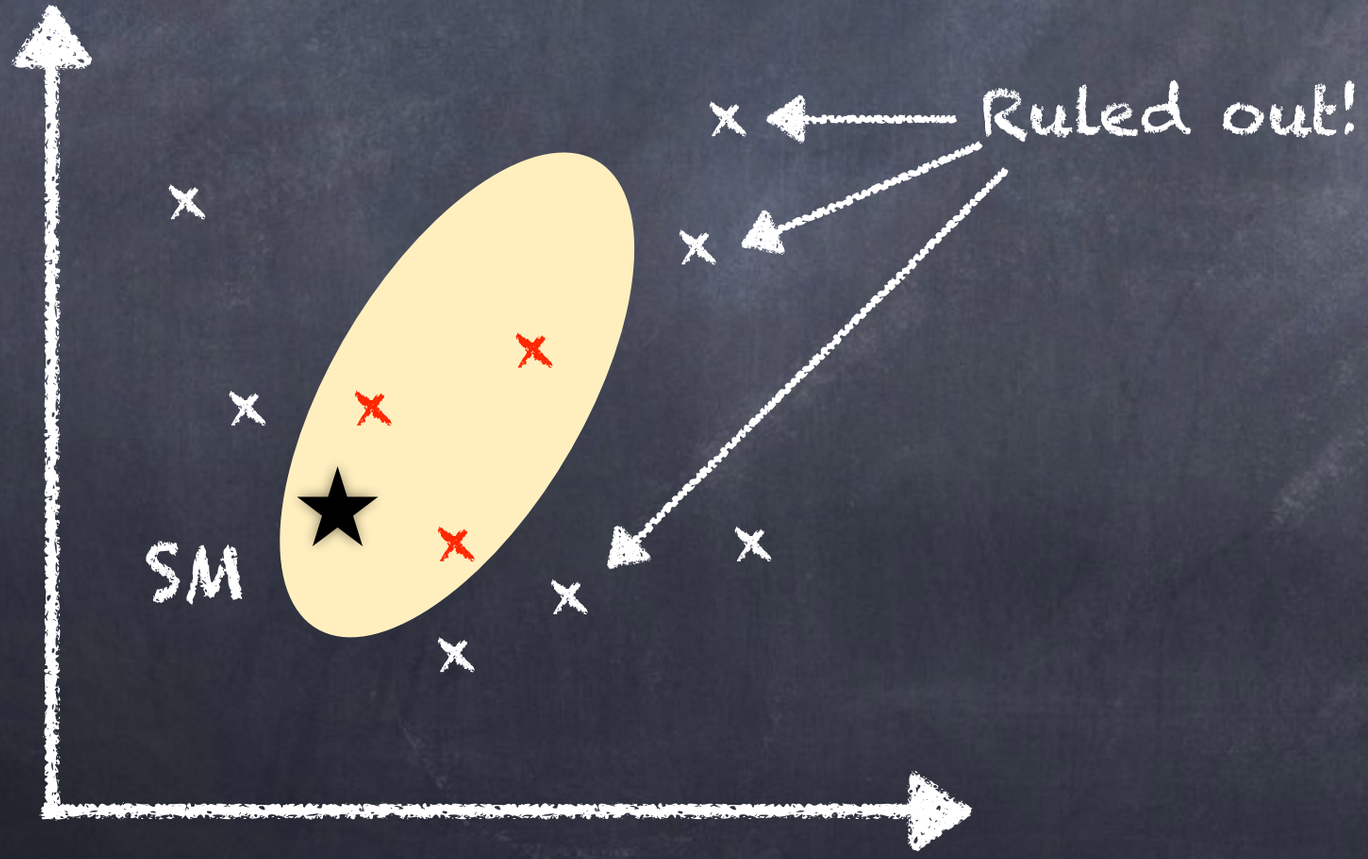
Top couplings!

No bumps!

Higgs mass!

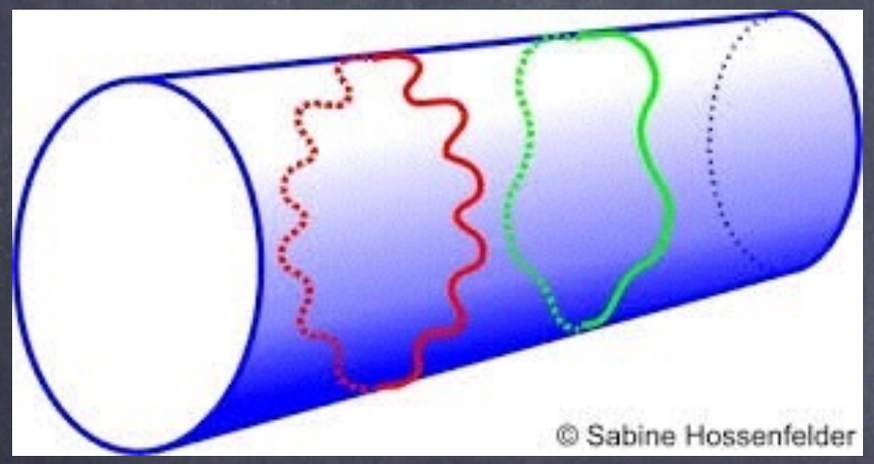
What is our job?

- Models can be ruled out, but cannot be proven right!



Models that can be excluded: UEDs

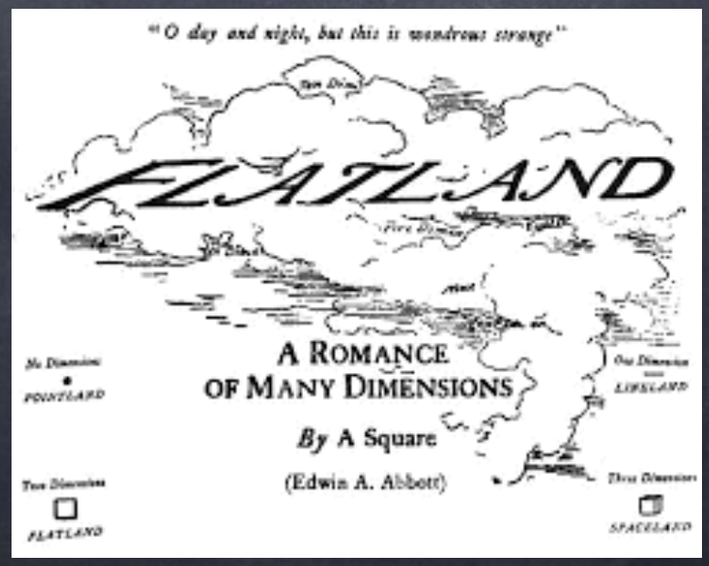
- Model of Dark Matter based on extra dimensions!



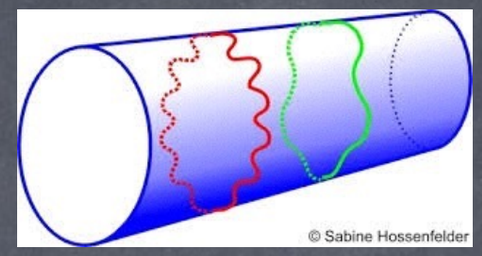
XD fields -> tower of KK states

frequencies -> KK masses

geometry -> KK parities



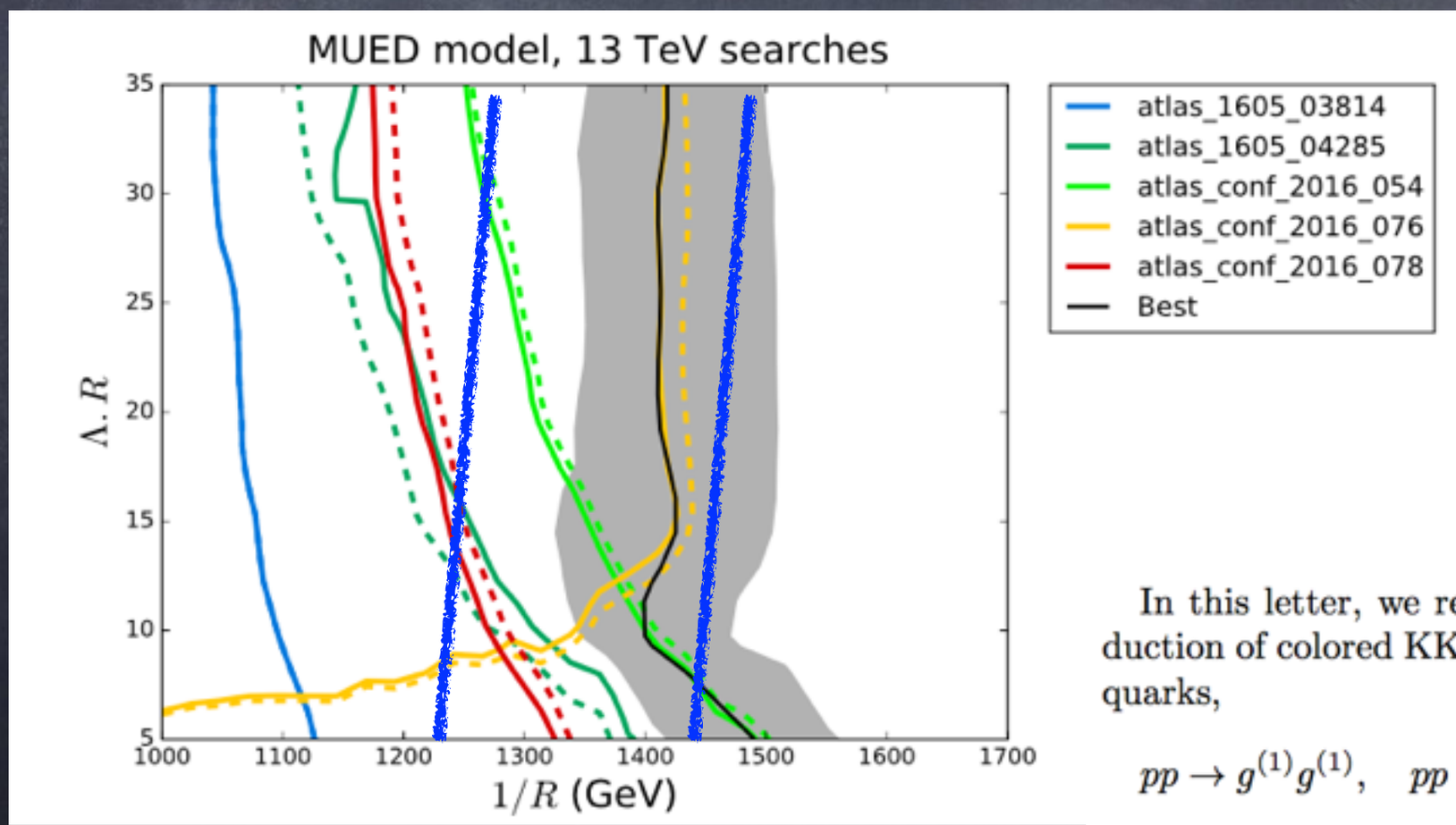
Models that can be excluded: UEDs



- Model of Dark Matter based on extra dimensions!

1702.00410

On the verge of exclusion!



In this letter, we restrict ourselves to the strong production of colored KK modes such as KK gluons and KK quarks,

$$pp \to g^{(1)} g^{(1)}, \quad pp \to Q_i^{(1)} Q_j^{(1)}, \quad pp \to g^{(1)} Q_j^{(1)}, \quad (1)$$

How can we rule out our favourite model(s)?

10000 GeV — Resonances: Z', ...

5000 GeV —

Top partners

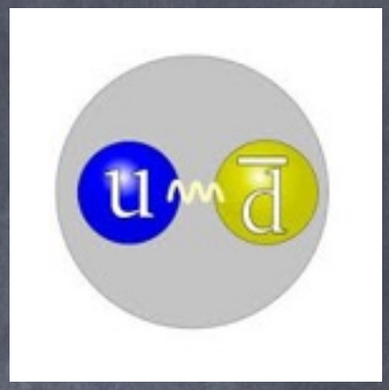
1000 GeV —

f - comp. scale

500 GeV — Extra scalars?

100 GeV — Higgs

Compositeness



- Higgs close to SM-like

$$\frac{g_{hVV}}{g_{hVV}^{SM}} \sim \cos\theta \sim 1 - \frac{1}{2}\sin^2\theta$$

$$\sin\theta \sim \frac{v}{f} < 0.2$$

(EW precision)

The hot potato: flavour!

1501.03818, ...

100,000 TeV — Λ_{flavour} — Light flavours

near-conformal dynamics

10 TeV — $\Lambda \sim 4\pi f$ — Vectors — + top mixing

1 TeV — f — Condensation scale (extra pions) — + top partners

100 GeV — $v_{\text{SM}} \sim f \sin\theta$ — EWSB

A fermionic theory of top partners

$\mathcal{G}_{\rm TC}$: rep R rep R′ 1312.5330, 1604.06467

Q χ $T' = QQ\chi$ or $Q\chi\chi$

SM : EW colour + hypercharge

global : $\langle QQ \rangle \neq 0$

↓

pNGB Higgs
DM?

a) $\langle \chi\chi \rangle \neq 0$

coloured pNGBs
di-boson

b) $\langle \chi\chi \rangle = 0$

light top partners
from 't Hooft anomaly
conditions?

Global symmetries

More precisely, the global symmetries are:

$$SU(N_Q) \times SU(N_\chi) \times U(1)_Q \times U(1)_\chi$$

WZW term:

$$\mathcal{L} \supset \frac{g_i^2}{32\pi^2}\frac{\kappa_i}{f_a}\, a\, \epsilon^{\mu\nu\alpha\beta} G^i_{\mu\nu} G^i_{\alpha\beta}\,,$$

Coefficients depend on the underlying dynamics!

G = A, W, Z, g !!!

1512.04508

Anomalous U(1) -> heavy η'

Orthogonal U(1) -> pNGB a

Decays and production only via WZW anomaly.

Model zoology

1604.06467

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Real	Real	SU(5)/SO(5) × SU(6)/SO(6)				
$SO(N_{\rm HC})$	$5\times\mathbf{S}_2$	$6\times\mathbf{F}$	$N_{\rm HC}\geq 55$	$\frac{5(N_{\rm HC}+2)}{6}$	1/3	/	
$SO(N_{\rm HC})$	$5\times\mathbf{Ad}$	$6\times\mathbf{F}$	$N_{\rm HC}\geq 15$	$\frac{5(N_{\rm HC}-2)}{6}$	1/3	/	
$SO(N_{\rm HC})$	$5\times\mathbf{F}$	$6\times\mathbf{Spin}$	$N_{\rm HC}=7,9$	$\frac{5}{6}$, $\frac{5}{12}$	1/3	$N_{\rm HC}=7,9$	M1, M2
$SO(N_{\rm HC})$	$5\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\rm HC}=7,9$	$\frac{5}{6}$, $\frac{5}{3}$	2/3	$N_{\rm HC}=7,9$	M3, M4
	Real	Pseudo-Real	SU(5)/SO(5) × SU(6)/Sp(6)				
$Sp(2N_{\rm HC})$	$5\times\mathbf{Ad}$	$6\times\mathbf{F}$	$2N_{\rm HC}\geq 12$	$\frac{5(N_{\rm HC}+1)}{3}$	1/3	/	
$Sp(2N_{\rm HC})$	$5\times\mathbf{A}_2$	$6\times\mathbf{F}$	$2N_{\rm HC}\geq 4$	$\frac{5(N_{\rm HC}-1)}{3}$	1/3	$2N_{\rm HC}=4$	M5
$SO(N_{\rm HC})$	$5\times\mathbf{F}$	$6\times\mathbf{Spin}$	$N_{\rm HC}=11,13$	$\frac{5}{24}$, $\frac{5}{48}$	1/3	/	
	Real	Complex	SU(5)/SO(5) × SU(3)²/SU(3)				
$SU(N_{\rm HC})$	$5\times\mathbf{A}_2$	$3\times(\mathbf{F},\overline{\mathbf{F}})$	$N_{\rm HC}=4$	$\frac{5}{3}$	1/3	$N_{\rm HC}=4$	M6
$SO(N_{\rm HC})$	$5\times\mathbf{F}$	$3\times(\mathbf{Spin},\overline{\mathbf{Spin}})$	$N_{\rm HC}=10,14$	$\frac{5}{12}$, $\frac{5}{48}$	1/3	$N_{\rm HC}=10$	M7
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4\times\mathbf{F}$	$6\times\mathbf{A}_2$	$2N_{\rm HC}\leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	2/3	$2N_{\rm HC}=4$	M8
$SO(N_{\rm HC})$	$4\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\rm HC}=11,13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\rm HC}=11$	M9
	Complex	Real	SU(4)²/SU(4) × SU(6)/SO(6)				
$SO(N_{\rm HC})$	$4\times(\mathbf{Spin},\overline{\mathbf{Spin}})$	$6\times\mathbf{F}$	$N_{\rm HC}=10$	$\frac{8}{3}$	2/3	$N_{\rm HC}=10$	M10
$SU(N_{\rm HC})$	$4\times(\mathbf{F},\overline{\mathbf{F}})$	$6\times\mathbf{A}_2$	$N_{\rm HC}=4$	$\frac{2}{3}$	2/3	$N_{\rm HC}=4$	M11
	Complex	Complex	SU(4)²/SU(4) × SU(3)²/SU(3)				
$SU(N_{\rm HC})$	$4\times(\mathbf{F},\overline{\mathbf{F}})$	$3\times(\mathbf{A}_2,\overline{\mathbf{A}}_2)$	$N_{\rm HC}\geq 5$	$\frac{4}{3(N_{\rm HC}-2)}$	2/3	$N_{\rm HC}=5$	M12
$SU(N_{\rm HC})$	$4\times(\mathbf{F},\overline{\mathbf{F}})$	$3\times(\mathbf{S}_2,\overline{\mathbf{S}}_2)$	$N_{\rm HC}\geq 5$	$\frac{4}{3(N_{\rm HC}+2)}$	2/3	/	
$SU(N_{\rm HC})$	$4\times(\mathbf{A}_2,\overline{\mathbf{A}}_2)$	$3\times(\mathbf{F},\overline{\mathbf{F}})$	$N_{\rm HC}=5$	4	2/3	/	

Model zoology

$G_{\rm HC}$	ψ	χ	Restrictions	$-q_\chi/q_\psi$	Y_χ	Non Conformal	Model Name
	Pseudo-Real	Real	SU(4)/Sp(4) × SU(6)/SO(6)				
$Sp(2N_{\rm HC})$	$4\times\mathbf{F}$	$6\times\mathbf{A}_2$	$2N_{\rm HC}\leq 36$	$\frac{1}{3(N_{\rm HC}-1)}$	2/3	$2N_{\rm HC}=4$	M8
$SO(N_{\rm HC})$	$4\times\mathbf{Spin}$	$6\times\mathbf{F}$	$N_{\rm HC}=11,13$	$\frac{8}{3}$, $\frac{16}{3}$	2/3	$N_{\rm HC}=11$	M9

Defines $\tan\zeta$

Theory confines!

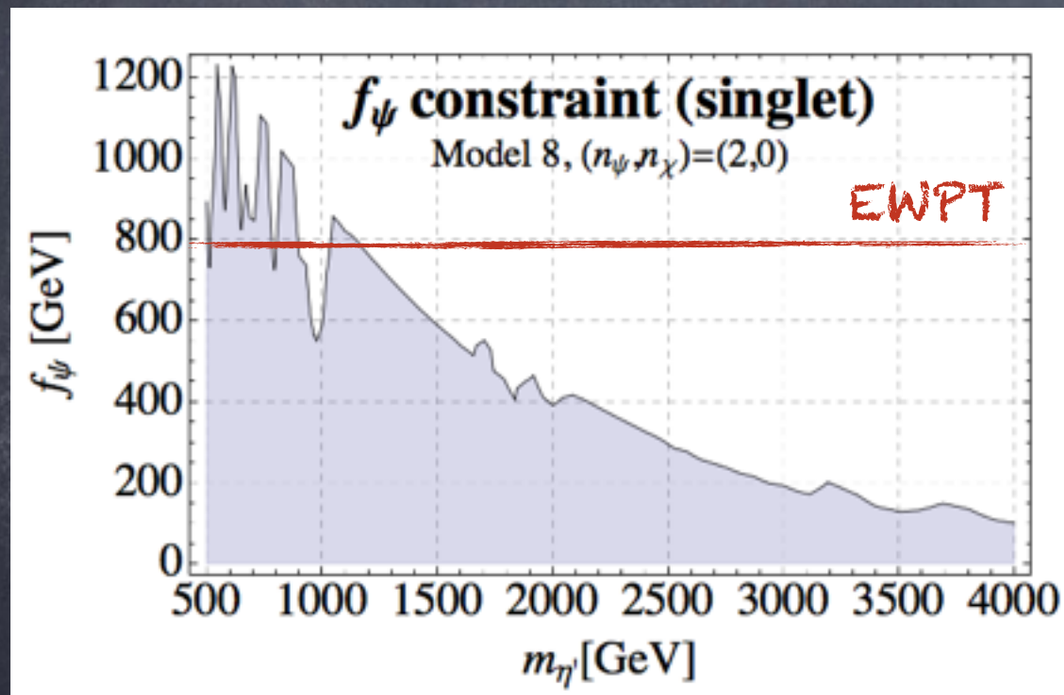
$$T'=\psi\psi\chi$$

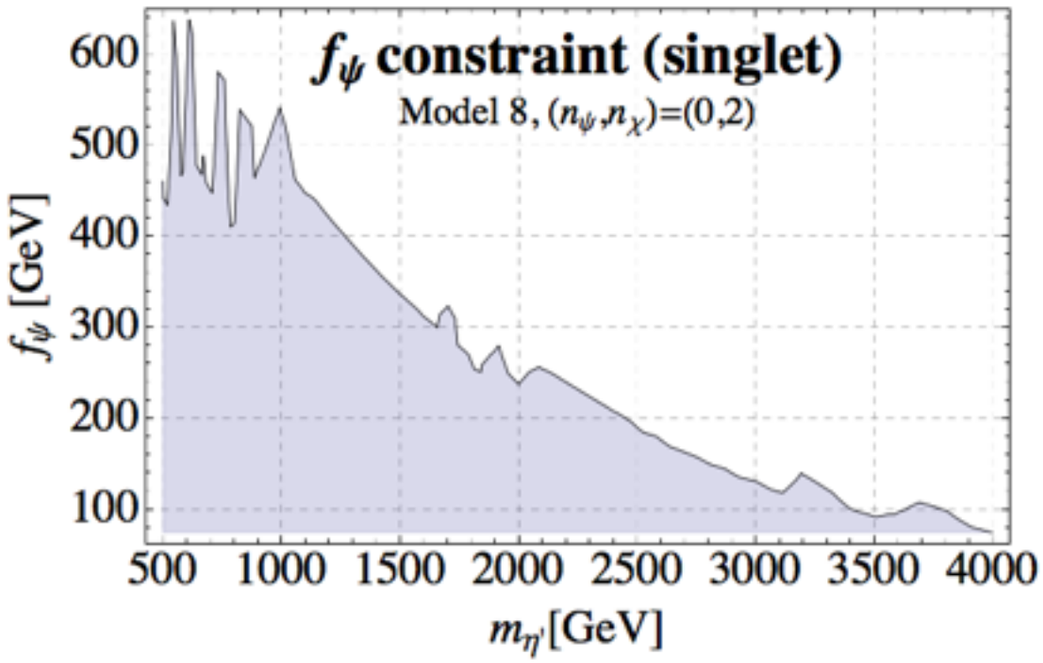
Note: there is enough baryons to give mass to the top (and bottom) only!

Model M8

1610.06591

"a" too light for the LHC! $\left.\frac{m_a}{m_{\eta'}}\right|_{\max} = 0.20$





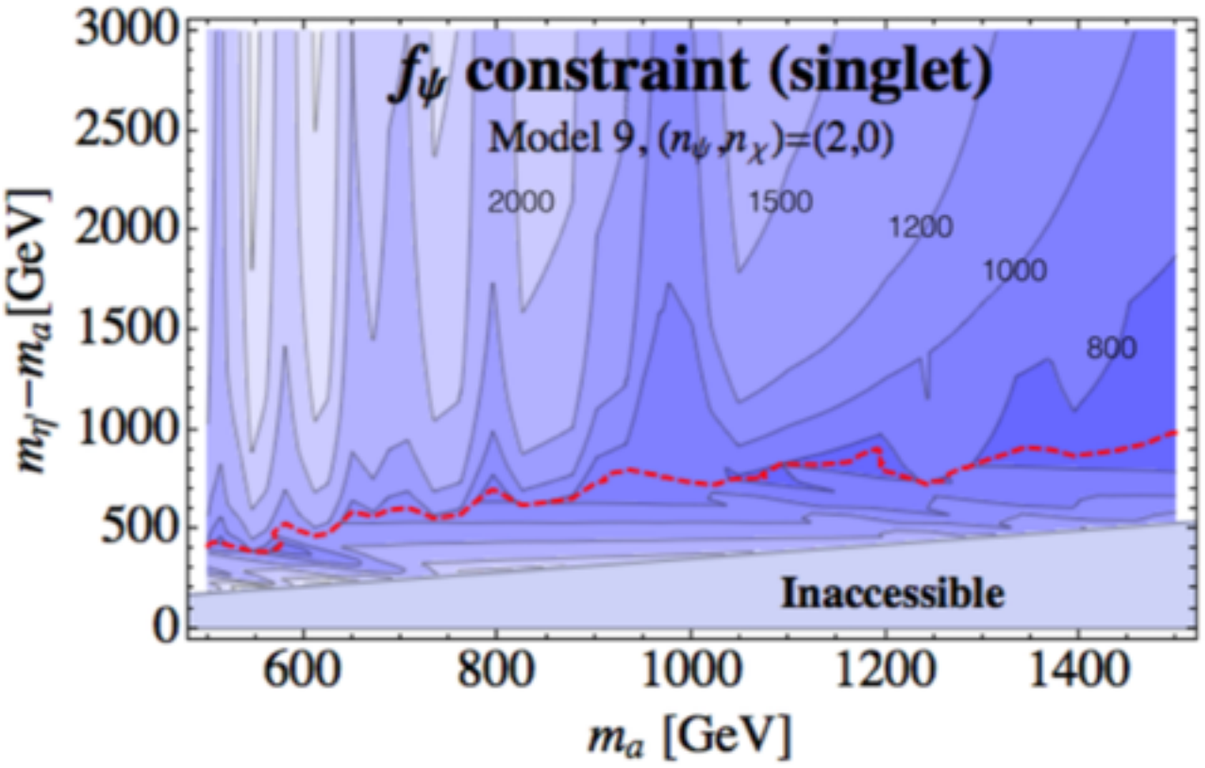
For light masses: bounds competitive with EW precision!

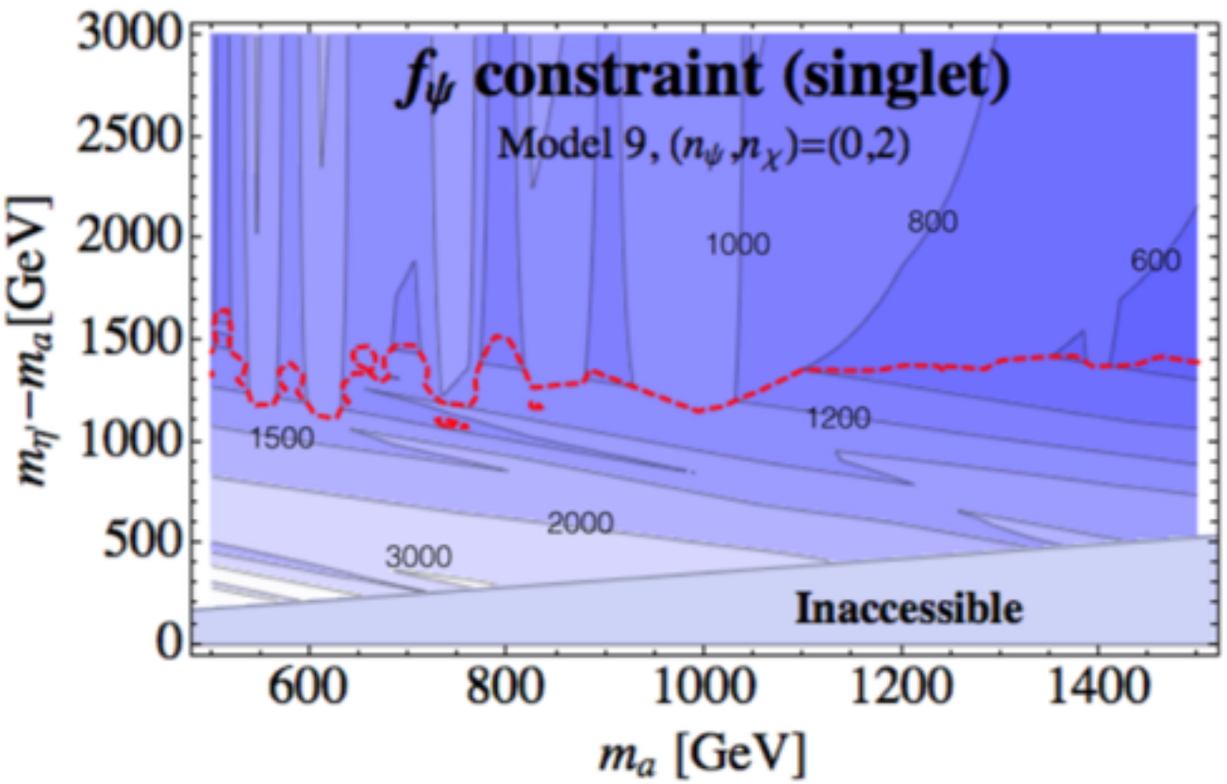
Larger top couplings: reduced diboson rates due to tt BR.

Model M9

$$\left.\frac{m_a}{m_{\eta'}}\right|_{\max} = 0.74$$

1610.06591





Above red line, bound driven by "a"!

Bounds stronger than EW precision
in most of the parameter space!

There is a lot of meat on the grill...

Models to exclude

Signals of compositeness

Understanding dynamics of composite models

Opportunities for ILC/FCC

Flavour anomalies?

Cosmological history?

... ?

There is a lot of meat on the grill... also for vegs!

Models to exclude

Signals of compositeness

Understanding dynamics of composite models

Opportunities for ILC/FCC

Flavour anomalies?

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... ?