Composite models and vector-like quarks at the LHC

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Based on collaboration with FJPPL team HEP03:
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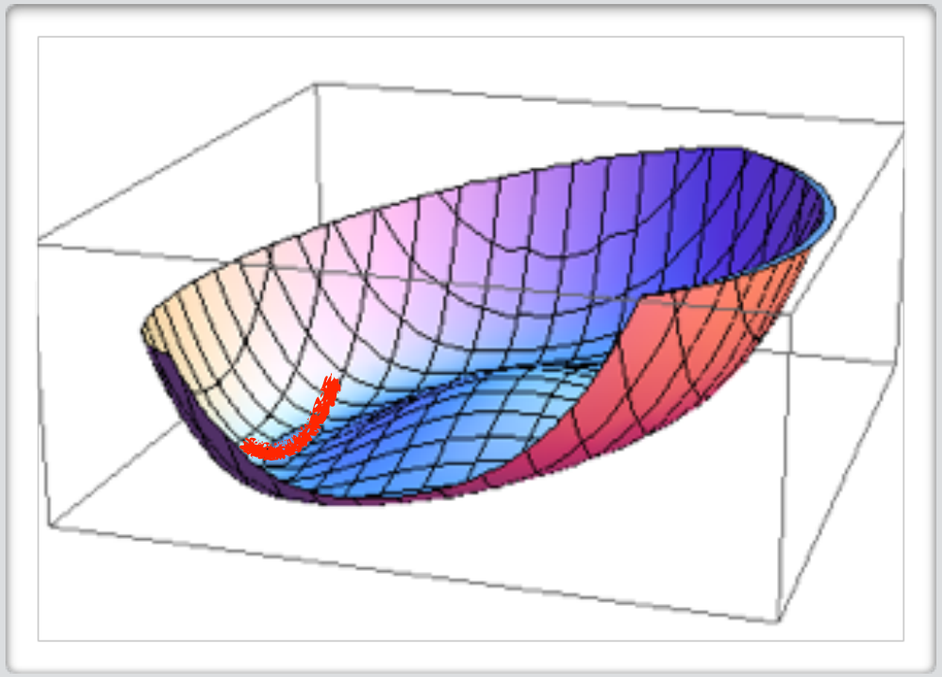
Strong dynamics in the EW sector

Global symmetry:

$$G \rightarrow H$$

$$SU(2)xU(1) \rightarrow U(1)_{em}$$



SM gauge symmetry

"pions" h, WL, ZL

Higgs boson light as pNGB of the broken symmetry of the strong sector, parameterisation with an effective chiral Lagrangian, detailed computations in terms of the fundamental fermionic states

Which models, which resonances?

- Strong dynamics for the EW sector:
  - spin 1 (popular guess but S parameter needs extra contribution (axial-vector, …), via Drell-Yan mainly, typically heavy
  - spin 0 (new composite scalars, PNGB)
  - spin 1/2 (new vector-like fermions)
- Extended SM scalar sector
- Extended gauge sector

Scalars in TeV strong dynamics

- Higgs: pNGB or mixture pNGB-Composite
- Composite scalars can be lighter than vectors (indications from lattice calculations with specific strong dynamics)
- A pseudo-scalar "η" with WZW anomaly couplings is present in the spectrum and can be in the TeV range.
  - Couplings are calculable in terms of the dynamics
  - Fermiophobic η is a realistic case in composite models

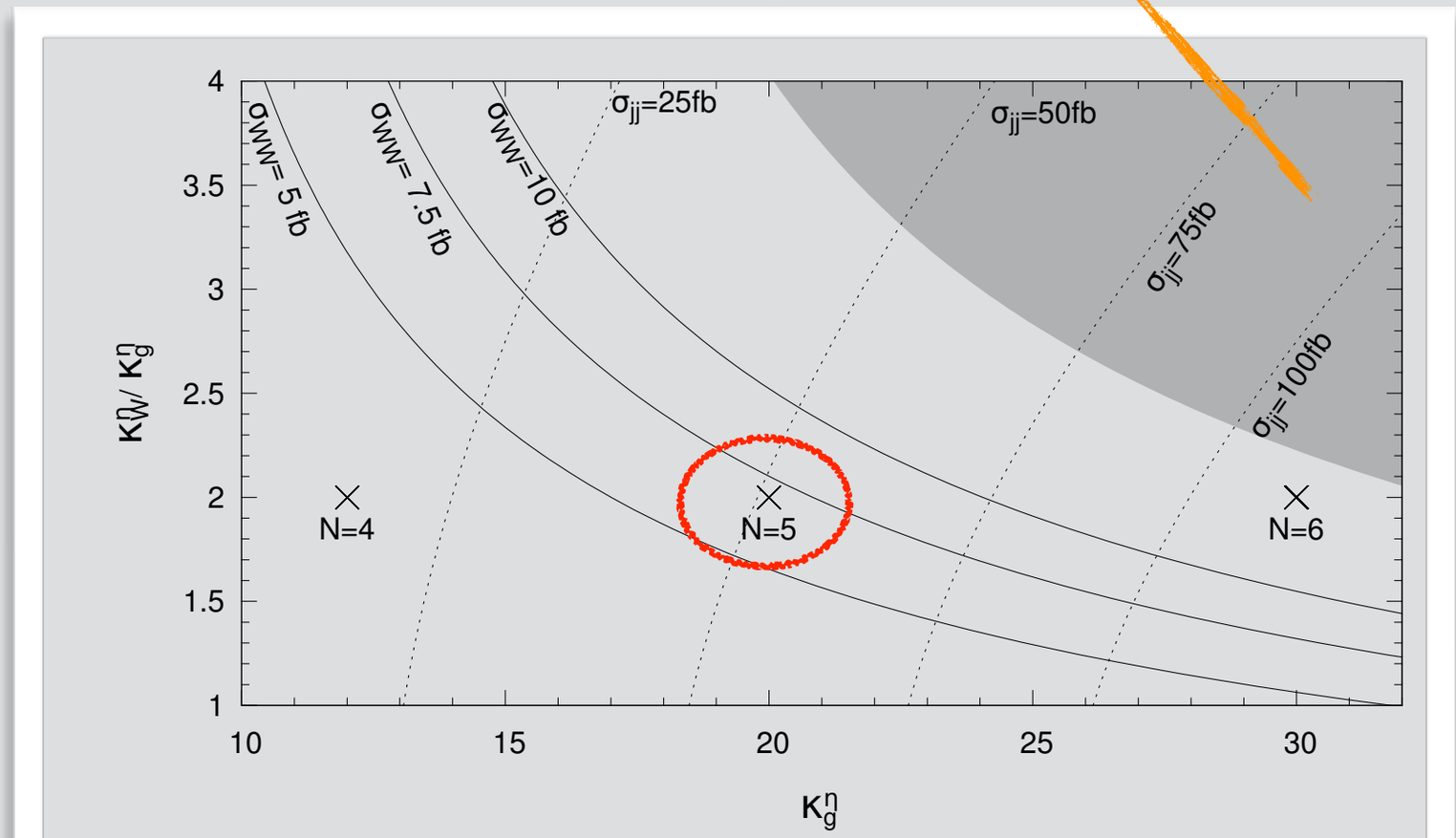
See hep-ph/1502.04718 for details of the scalar sector in minimal SU(4)/Sp(4) case and hep-ph/0809.0713 for the model.

Numerical results

decay mode	BR
gg	83%
WW	11.2%
ZZ	3.2%
$Z\gamma$	2%
$\gamma\gamma$	0.4%

BR for η of 2 TeV and $\kappa_W^\eta/\kappa_g^\eta = 2$.

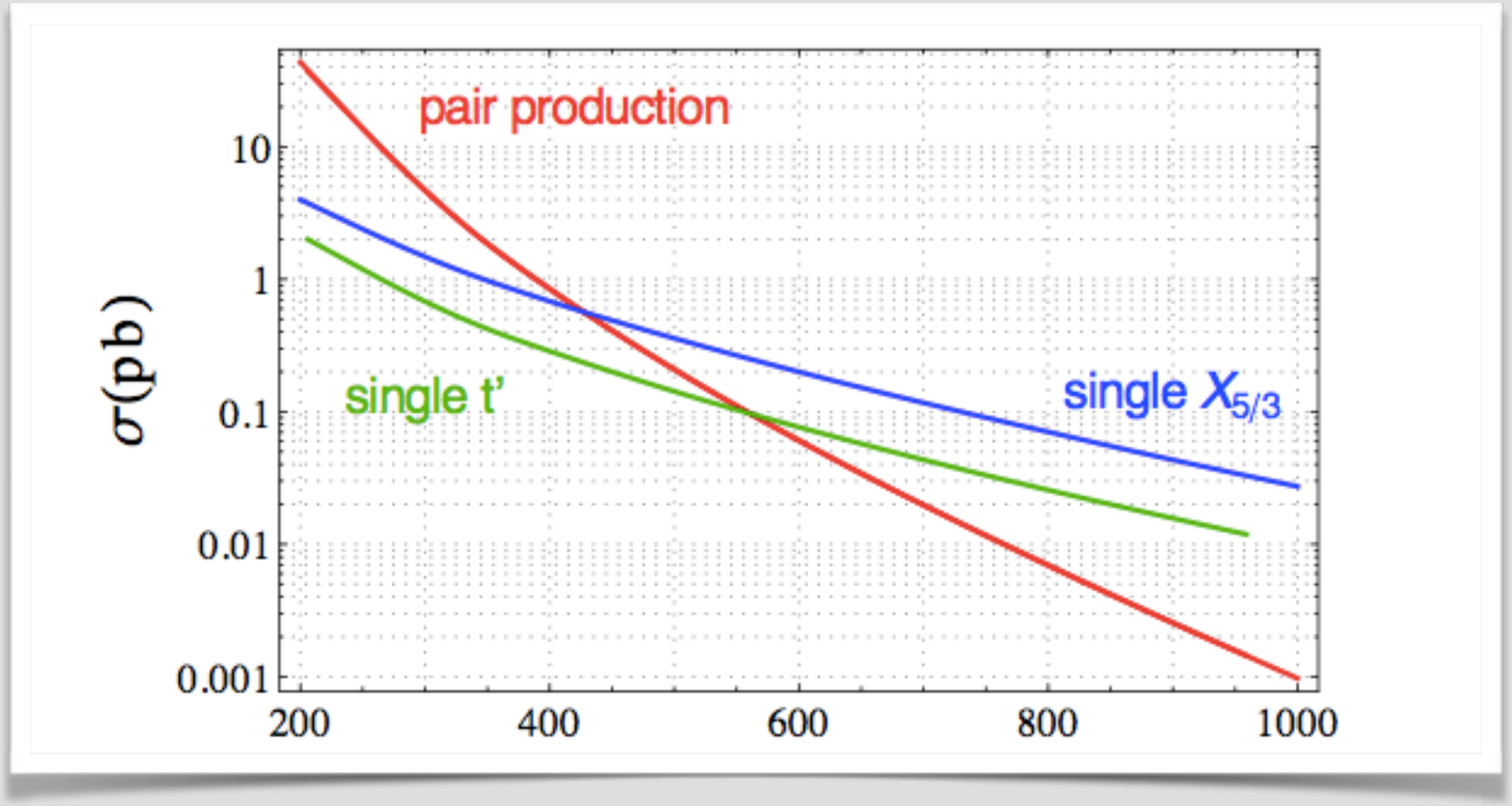
shaded area excluded by γγ > 0.5 fb



Mass value is not predicted but such resonances are expected in composite models (see our Phys. Rev. Lett. 115 (2015) no.17, 171802

Vector-like quarks

- Unique window to test models (Xdim, composite, Little Higgs, SUSY) and good theoretical motivation
- Reach at LHC substantial and only partially exploited
- Mixings with all the 3 SM generations important (production/decay)
- Single production dominant with present mass bound at LHC (~800 GeV)



Simplest multiplets (and SM quantum numbers)

	SM	Singlets	Doublets	Triplets
	$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$	(t') (b')	$\begin{pmatrix} X \\ t' \end{pmatrix} \begin{pmatrix} t' \\ b' \end{pmatrix} \begin{pmatrix} b' \\ Y \end{pmatrix}$	$\begin{pmatrix} X \\ t' \\ b' \end{pmatrix} \begin{pmatrix} t' \\ b' \\ Y \end{pmatrix}$
$SU(2)_L$	2	1	2	3
$U(1)_Y$	$q_L = 1/6$ $u_R = 2/3$ $d_R = -1/3$	2/3 -1/3	1/6 7/6 -5/6	2/3 -1/3
$\mathcal{L}_Y$	$-\frac{y_u^i v}{\sqrt{2}} \bar{u}_L^i u_R^i$ $-\frac{y_d^i v}{\sqrt{2}} \bar{d}_L^i V_{CKM}^{i,j} d_R^j$	$-\frac{\lambda_u^i v}{\sqrt{2}} \bar{u}_L^i U_R$ $-\frac{\lambda_d^i v}{\sqrt{2}} \bar{d}_L^i D_R$	$-\frac{\lambda_u^i v}{\sqrt{2}} U_L u_R^i$ $-\frac{\lambda_d^i v}{\sqrt{2}} D_L d_R^i$	$-\frac{\lambda_i v}{\sqrt{2}} \bar{u}_L^i U_R$ $-\lambda_i v \bar{d}_L^i D_R$
$\mathcal{L}_m$		$-M\bar{\psi}\psi$ (gauge invariant since vector-like)		
Free parameters		4 $M + 3 \times \lambda^i$	4 or 7 $M + 3\lambda_u^i + 3\lambda_d^i$	4 $M + 3 \times \lambda^i$

Mixing with more VL multiplets

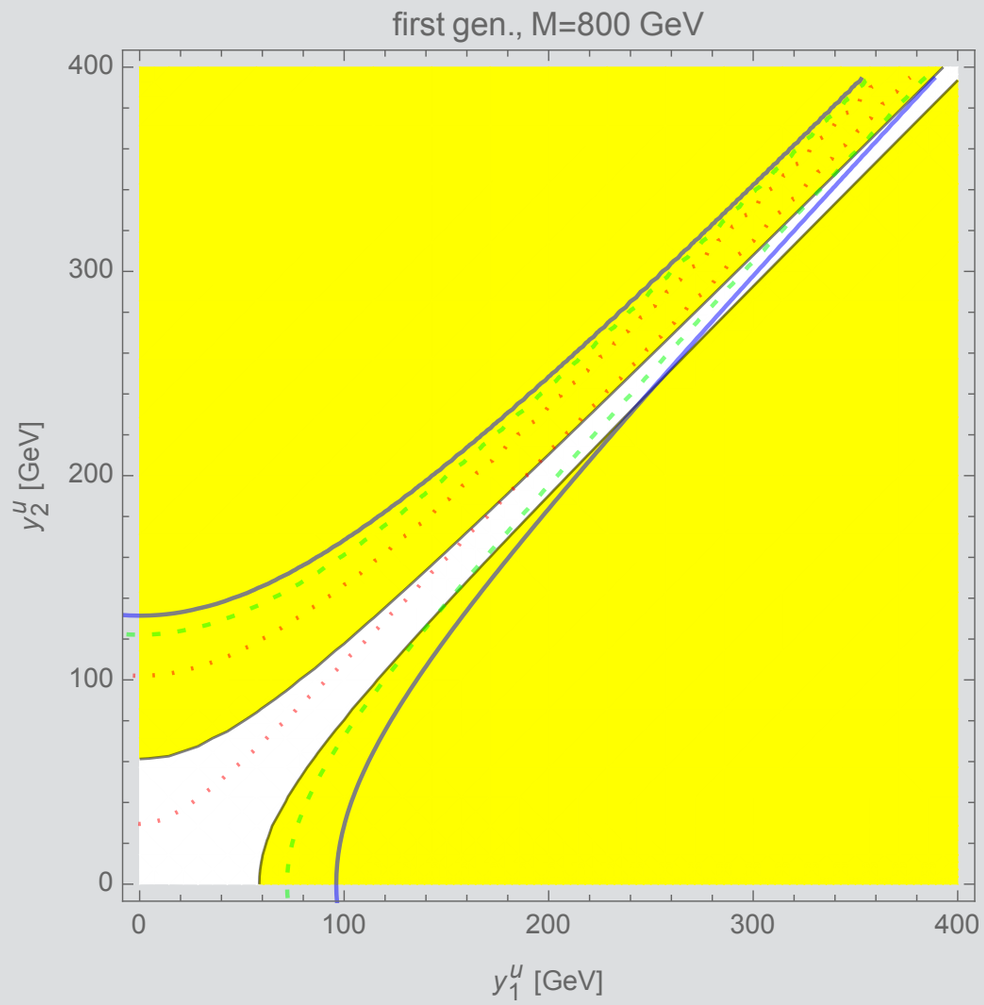
ArXiv:1305.4172 M.Buchkremer et al.

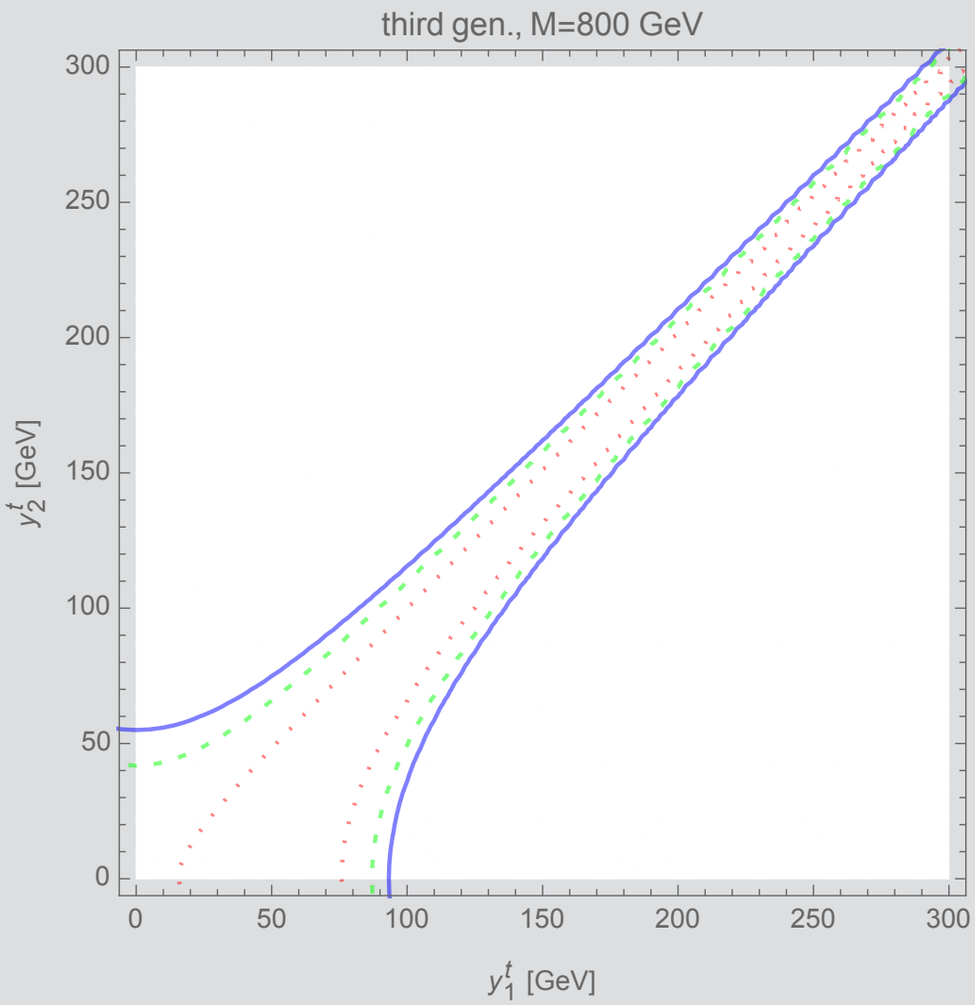
integer isospin multiplets

$$\mathcal{L}_{\text{mass}} = \bar{q}_L \cdot \left(\begin{array}{ccc|ccc|ccc} \mu_1 & 0 & 0 & 0 & \dots & 0 & x_{1,n_d+4} & \dots & x_{1,N} \\ 0 & \mu_2 & 0 & 0 & \dots & 0 & x_{2,n_d+4} & \dots & x_{2,N} \\ 0 & 0 & \mu_3 & 0 & \dots & 0 & x_{3,n_d+4} & \dots & x_{3,N} \\ \hline y_{4,1} & y_{4,2} & y_{4,3} & M_4 & 0 & 0 & & & \\ \vdots & \vdots & \vdots & 0 & \ddots & 0 & & \omega_{\alpha\beta} & \\ y_{n_d+3,1} & y_{n_d+3,2} & y_{n_d+3,3} & 0 & 0 & M_{n_d+3} & & & \\ \hline 0 & 0 & 0 & & & & M_{n_d+4} & 0 & 0 \\ \vdots & \vdots & \vdots & & \omega'_{\alpha\beta} & & 0 & \ddots & 0 \\ 0 & 0 & 0 & & & & 0 & 0 & M_N \end{array}\right) \cdot q_R + h.c.$$

semi-integer isospin multiplets

Interplay of VLQ multiplets





Doublet Y = 1/6 and Doublet Y = 7/6 (Section 3.4): EWP bounds at 1σ (red- dashed), 2σ (green-dashed) and 3 σ (blue) for VL quarks coupling with the first (left panel) and third (right panel) SM generations, compared with the region excluded at 3σ by tree-level bounds (yellow region in the left panel).
M = 800 GeV, ω = ω′ = 0. (from our JHEP 1509 (2015) 012)

Conclusions and perspectives

- Current limits with the 7 and 8 TeV LHC data span up to 700-800 GeV in mass for vector like quarks (actual limit depends on the choice of parameters).
- Run 2 data is is under present scrutiny and brings further important bounds.
- Our FJPPL team is investigating realistic set-ups in composite models with vector-like quarks (two or more multiplets, full mixing structure).