Resonances + Top partners + Dark Matter

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J. Yepes, arXiv:1811.06059

J. Yepes and A. Zerwekh, hep-ph:1806.06694

S. Norero, J. Yepes and A. Zerwekh, hep-ph:1807.02211

J. Yepes and A. Zerwekh, Int. J. Mod. Phys. A **33** (2018) no.11, hep-ph:1711.10523.

Top partner-resonances phenomenology

* Modelling top partners-vector/scalar resonances interplay.
* Vector/Scalar decay channels.
* Heavy spin-1/spin-0 production.
* Top partners production mechanisms.

Dark matter issues

* Eluding Xenon1T DD experiments in a vector dark matter scenario.
* Invoking New Physics from a Composite Higgs to evade DD bounds.

Composite Higgs

* Appealing alternative in healing the *hierarchy problem*.
* Minimal SSB $SO(5) \rightarrow SO(4)$ at scale f
* 4 massless PNGBs $\Rightarrow$ $SU(2)_L$ Higgs doublet
* PNGBs:

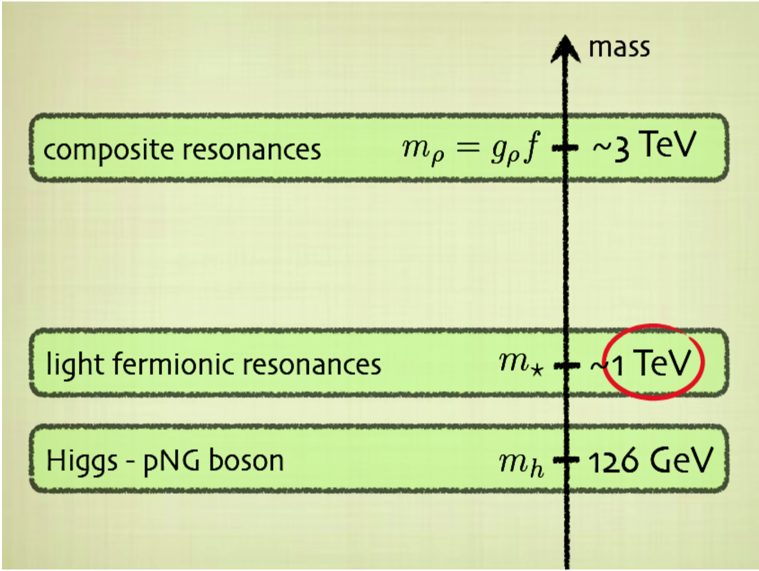
$$U = \exp\left[i \frac{\sqrt{2}}{f} \Pi^i \, T^i \right]$$

T^i: coset $SO(5)/SO(4)$-generators Π^i: PNGB fields.

* Explicit $\not{SO(5)}$ via couplings to: SM fermions + gauge bosons.
* Tunning level $\Rightarrow$ $\xi = \frac{v^2}{f^2}$: controls low energies SM departures

EPWTs $\rightarrow \xi = \{0.1, 0.2, 0.25\} \leftrightarrow f \approx \{800, 550, 490\}$GeV

Composite Higgs



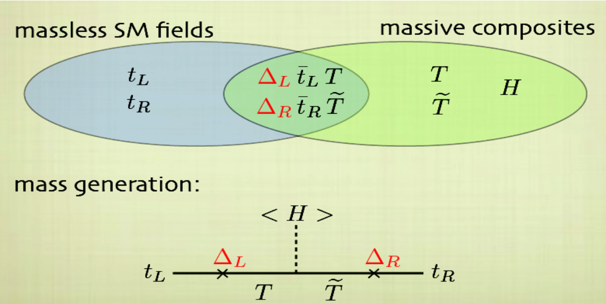
Matter sectors

* Massless elementary fields: SM field sector q & no Higgs

* Massive composite fields: Higgs + composite resonances

* Partial compositeness $\Rightarrow$ elementary-composite mixings

$$\mathcal{L}^{\rm UV}_{\rm mix} = \sum_q y\, \bar{q}\, \mathcal{O}_q \qquad \mathcal{O}_q \text{ shapes embeddings} \begin{cases} q_L^{\mathbf{5}}, & u_R^{\mathbf{5}} \\ q_L^{\mathbf{14}}, & u_R^{\mathbf{1}} \end{cases}$$



Top partners

$SO(4)$-Ψ_4

$SO(4)$-Ψ_1

$$\overbrace{\begin{pmatrix} \mathcal{T} \\ \mathcal{B} \end{pmatrix}_{\frac{1}{6}} \qquad \begin{pmatrix} X_{5/3} \\ X_{2/3} \end{pmatrix}_{\frac{7}{6}}}$$

$$\Downarrow$$

$$\widetilde{\mathcal{T}}$$

* $\mathbf{M}_{\mathbf{\Psi}+\mathbf{q}} = \{\mathbf{M}_{4+5}, \mathbf{M}_{4+14}, \mathbf{M}_{1+5}, \mathbf{M}_{1+14}\}$ $\quad$ q shaped by $\mathcal{O}_q$

* $M_{\mathbf{4(1)}} \simeq g_{\mathbf{4(1)}} f$ & $M_{\mathbf{4(1)}} \sim 0.5 - 1.5$ TeV & $1 \lesssim g_{\mathbf{4(1)}} \lesssim 3$

$SU(2)_L \times SU(2)_R$ - resonances

Spin-1

Spin-0

* $\rho_L^\mu = (\mathbf{3}, \mathbf{1}) + \rho_R^\mu = (\mathbf{1}, \mathbf{3})$

$\eta = (\mathbf{1}, \mathbf{1})$

* $m_\rho \simeq g_\rho f$ & $1 < g_\rho < 4\pi$

Matter interplay

Fermion currents – resonances couplings

Spin-1

$$\mathscr{L}_{\mathbf{M}+\rho_\chi} \sim \alpha_i^\chi \, \mathcal{J}^\mu_{i\chi} \, \rho_{\mu\chi} \; + \; \text{h.c.}$$

Spin-0

$$\mathscr{L}_{\mathbf{M}+\eta} \sim \frac{\alpha_i}{f} \, \mathcal{J}^\mu_i \partial_\mu \eta \; + \; \text{h.c.}\,,$$

Fermionic 2nd rank tensors – resonance strength

Spin-1

$$\mathscr{L}^{\text{mag}}_{\mathbf{M}+\rho_\chi} = \frac{1}{f} \, \beta_i^\chi \, \mathcal{J}^{\mu\nu}_{i\chi} \, \rho_{\mu\nu\chi} + \text{h.c.}$$

Spin-0

No couplings!

$i = \{q,\, \psi,\, q\psi,\, u\psi\}$ $\quad \alpha_i,\, \alpha_i^\chi,\, \beta_i^\chi$ weighting coeffs.

Vector–fermion interplay

$\mathbf{M}_{4+5}$	$\mathbf{M}_{4+14}$
$\mathcal{J}^{\mu}_{q} = \overline{q}^{\mathbf{5}}_{L}\,\gamma^{\mu}\,\overline{T}\,q^{\mathbf{5}}_{L}$ $\mathcal{J}^{\mu}_{\psi} = \overline{\Psi}_{\mathbf{4}}\,\gamma^{\mu}\,\tau\,\Psi_{\mathbf{4}}$ $\mathcal{J}^{\mu}_{u\psi} = \left(\overline{u}^{\mathbf{5}}_{R}\,\overline{T}\,U\right)_{j}\gamma^{\mu}\,(\Psi_{\mathbf{4}R})^{j}$ $\mathcal{J}^{\mu}_{q\psi} = \left(\overline{q}^{\mathbf{5}}_{L}\,\overline{T}\,U\right)_{j}\gamma^{\mu}\,(\Psi_{\mathbf{4}L})^{j}$	$\mathcal{J}^{\mu}_{q} = \left(U^{T}\,\overline{q}^{\mathbf{14}}_{L}\,U\,T\right)_{5\,j}\gamma^{\mu}\left(U^{T}\,q^{\mathbf{14}}_{L}\,U\right)_{j\,5}$ $\mathcal{J}^{\mu}_{\psi} = \overline{\Psi}_{\mathbf{4}}\,\gamma^{\mu}\,\tau\,\Psi_{\mathbf{4}}$ $\mathcal{J}^{\mu}_{q\psi} = \left(U^{T}\,\overline{q}^{\mathbf{14}}_{L}\,U\,T\right)_{5\,j}\gamma^{\mu}\,(\Psi_{\mathbf{4}L})^{j}$
$\mathcal{J}^{\mu\nu}_{\psi} = \overline{\Psi}_{\mathbf{4}L}\,\sigma^{\mu\nu}\,\tau\,\Psi_{\mathbf{4}R}$ $\mathcal{J}^{\mu\nu}_{q\psi} = \left(\overline{q}^{\mathbf{5}}_{L}\,\overline{T}\,U\right)_{j}\sigma^{\mu\nu}\,(\Psi_{\mathbf{4}R})^{j}$ $\mathcal{J}^{\mu\nu}_{u\psi} = \left(\overline{u}^{\mathbf{5}}_{R}\,\overline{T}\,U\right)_{j}\sigma^{\mu\nu}\,(\Psi_{\mathbf{4}L})^{j}$ $\mathcal{J}^{\mu\nu}_{qu} = \overline{q}^{\mathbf{5}}_{L}\,\sigma^{\mu\nu}\,\overline{T}\,u^{\mathbf{5}}_{R}$	$\mathcal{J}^{\mu\nu}_{\psi} = \overline{\Psi}_{\mathbf{4}L}\,\sigma^{\mu\nu}\,\tau\,\Psi_{\mathbf{4}R}$ $\mathcal{J}^{\mu\nu}_{q\psi} = \left(U^{T}\,\overline{q}^{\mathbf{14}}_{L}\,U\,T\right)_{5\,i}\sigma^{\mu\nu}\,(\Psi_{\mathbf{4}R})^{i}$
$\mathbf{M}_{1+5}$	$\mathbf{M}_{1+14}$
$\mathcal{J}^{\mu}_{q} = \overline{q}^{\mathbf{5}}_{L}\,\gamma^{\mu}\,\overline{T}\,q^{\mathbf{5}}_{L}$ $\mathcal{J}^{\mu}_{q\psi} = \left(\overline{q}^{\mathbf{5}}_{L}\,U\right)\gamma^{\mu}\,\Psi_{\mathbf{1}L}$	$\mathcal{J}^{\mu}_{q} = \left(U^{T}\,\overline{q}^{\mathbf{14}}_{L}\,U\,T\right)_{5\,j}\gamma^{\mu}\left(U^{T}\,q^{\mathbf{14}}_{L}\,U\right)_{j\,5}$
$\mathcal{J}^{\mu\nu}_{q\psi} = \left(\overline{q}^{\mathbf{5}}_{L}\,U\right)\sigma^{\mu\nu}\,\Psi_{\mathbf{1}R}$ $\mathcal{J}^{\mu\nu}_{qu} = \overline{q}^{\mathbf{5}}_{L}\,\sigma^{\mu\nu}\,\overline{T}\,u^{\mathbf{5}}_{R}$	–

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Scalar–fermion interplay

$\mathbf{M}_{4+5}$	$\mathbf{M}_{4+14}$
$\mathcal{J}^\mu_q = \overline{q}^{\mathbf{5}}_L\ \gamma^\mu\ q^{\mathbf{5}}_L$ $\mathcal{J}^\mu_u = \overline{u}^{\mathbf{5}}_R\ \gamma^\mu\ u^{\mathbf{5}}_R$ $\mathcal{J}^\mu_\psi = \overline{\Psi}_{\mathbf{4}}\,\gamma^\mu\ \Psi_{\mathbf{4}}$ $\mathcal{J}^\mu_{q\psi} = \left(\overline{q}^{\mathbf{5}}_L\ U\right)_j \gamma^\mu\ (\Psi_{\mathbf{4}L})^j$ $\mathcal{J}^\mu_{u\psi} = \left(\overline{u}^{\mathbf{5}}_R\ U\right)_j \gamma^\mu\ (\Psi_{\mathbf{4}R})^j$	$\mathcal{J}^\mu_q = \left(U^T\,\overline{q}^{\mathbf{14}}_L\ U\right)_{5\,j}\ \gamma^\mu\ \left(U^T\ q^{\mathbf{14}}_L\ U\right)_{j\,5}$ $\mathcal{J}^\mu_\psi = \overline{\Psi}_{\mathbf{4}}\,\gamma^\mu\ \Psi_{\mathbf{4}}$ $\mathcal{J}^\mu_{q\psi} = \left(U^T\,\overline{q}^{\mathbf{14}}_L\ U\right)_{5\,j}\ \gamma^\mu\ (\Psi_{\mathbf{4}L})^j$ $\mathcal{J}^\mu_u = \bar{u}_R\,\gamma^\mu\ u_R$
$\mathbf{M}_{1+5}$	$\mathbf{M}_{1+14}$
$\mathcal{J}^\mu_q = \overline{q}^{\mathbf{5}}_L\ \gamma^\mu\ q^{\mathbf{5}}_L$ $\mathcal{J}^\mu_u = \overline{u}^{\mathbf{5}}_R\ \gamma^\mu\ u^{\mathbf{5}}_R$ $\mathcal{J}^\mu_\psi = \overline{\Psi}_{\mathbf{1}}\ \gamma^\mu\ \Psi_{\mathbf{1}}$ $\mathcal{J}^\mu_{q\psi} = \left(\overline{q}^{\mathbf{5}}_L\ U\right)^5\ \gamma^\mu\ \Psi_{\mathbf{1}L}$ $\mathcal{J}^\mu_{u\psi} = \left(\overline{u}^{\mathbf{5}}_R\ U\right)^5\ \gamma^\mu\ \Psi_{\mathbf{1}L}$	$\mathcal{J}^\mu_q = \left(U^T\,\overline{q}^{\mathbf{14}}_L\ U\right)_{5\,j}\ \gamma^\mu\ \left(U^T\ q^{\mathbf{14}}_L\ U\right)_{j\,5}$ $\mathcal{J}^\mu_\psi = \overline{\Psi}_{\mathbf{1}}\ \gamma^\mu\ \Psi_{\mathbf{1}}$ $\mathcal{J}^\mu_{q\psi} = \left(U^T\,\overline{q}^{\mathbf{14}}_L\ U\right)_{5\,5}\ \gamma^\mu\ \Psi_{\mathbf{1}L}$ $\mathcal{J}^\mu_{u\psi} = \bar{u}_R\,\gamma^\mu\ \Psi_{\mathbf{1}R}$

S. Norero, J. Yepes and A. Zerwekh, hep-ph:1807.02211

Comments on ρ and Ψ-production

* Spin-0 & spin-1 resonances impact on PNGBs scattering: Contino 2011 *et al.*....
* Heavy triplet resonances impact@ LHC in:$\{l^+l^-, l\nu_l, \tau^+\tau^-, jj, t\bar{t}\}$ & $\{WZ, WW, WH, ZH\}$: Cárcamo 2017 *et al.*, Shu 2015-2016...
* Vector resonance mass $\sim 2.1 - 3$ TeV.
* Stringent experimental constraints on $\Psi_\mathbf{4}$ and $\Psi_\mathbf{1}$ from direct searches: S. Chatrchyan *et al.* 2014.
* Pair production mechanism driven mostly by QCD interactions $\rightarrow$ $m_{X_{5/3}} \sim 800$ GeV & $m_{X_{2/3}} \sim 700$ GeV.
* Experimental searches: for singly produced partners & searches for pair production $\Rightarrow$ Bounds on singly produced partners: De Simone *et al.*, Azatov 2013, Matsedonskyi 2015.... **9**-plet case analysed $m_9 \gtrsim 1$ TeV: Matsedonskyi 2014.

As example: Heavy spin-1 production

Charged

$$\mathscr{L}_{ud\rho_i^\pm} = -\frac{1}{\sqrt{2}}\, \bar{u}\, \not{\rho}_i^+ \left(g_{u_L d_L \rho_i^+}\, P_L + g_{u_R d_R \rho_i^+}\, P_R \right) d \;+\; \text{h.c.},$$

Neutral

$$\mathscr{L}_{ff\rho_i^0} = \sum_{f=u,d} \bar{f}\, \not{\rho}_i^0 \left(g_{f_L f_L \rho_i^0}\, P_L + g_{f_R f_R \rho_i^0}\, P_R \right) f\,.$$

Spin-1 decays

* Fermionic channels

$$\mathscr{L}_{Xf\rho^\pm} = -\frac{1}{\sqrt{2}} \left[\sum_{f=u,d} \bar{X} \not{\rho}^+ \left(g_{X_L f_L \rho^+}\, P_L + g_{X_R f_R \rho^+}\, P_R \right) f \;+\; \bar{X} \not{\rho}^+ \left(g_{X_L X'_L \rho^+}\, P_L + g_{X_R X'_R \rho^+}\, P_R \right) X' \right] + \text{h.c.},$$

$$\mathscr{L}_{Xf\rho^0} = \sum_{f=u,d} \bar{X}\, \not{\rho}^0 \left(g_{X_L f_L \rho^0}\, P_L + g_{X_R f_R \rho^0}\, P_R \right) f \;+\; \text{h.c.} \;+\; \bar{X}\, \not{\rho}^0 \left(g_{X_L X_L \rho^0}\, P_L + g_{X_R X_R \rho^0}\, P_R \right) X,$$

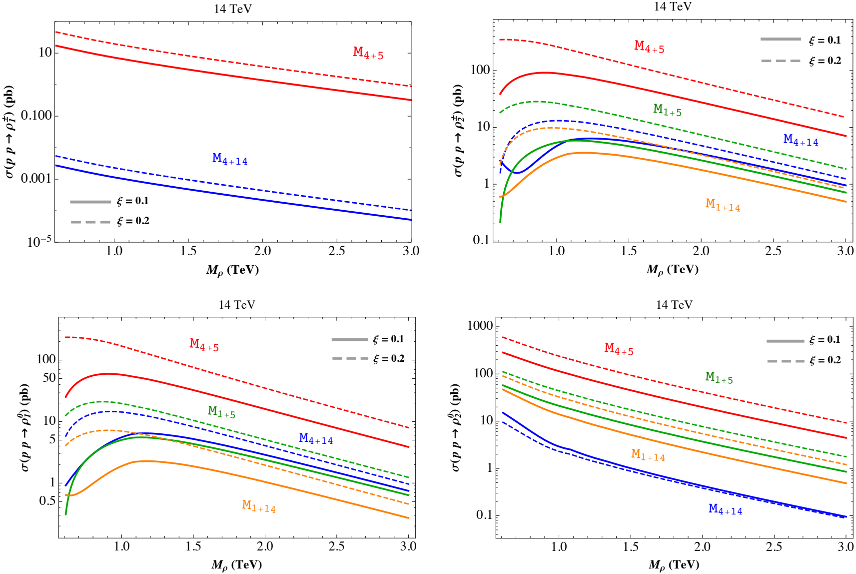
* Gauge & Gauge-Higgs modes

$$\mathscr{L}_{\rho^\pm WZ} = i \left(g^{(1)}_{\rho^+ WZ}\, \rho^+_{\mu\nu}\, W^{-\mu}\, Z^\nu \;-\; g^{(2)}_{\rho^+ WZ}\, W^-_{\mu\nu}\, \rho^{+\mu}\, Z^\nu \;+\; g^{(3)}_{\rho^+ WZ}\, Z^{\mu\nu}\, \rho^+_\mu\, W^-_\nu \;+\; \text{h.c.} \right),$$

$$\mathscr{L}_{\rho^0 WW} = i \left(g^{(1)}_{\rho^0 WW}\, W^+_{\mu\nu}\, W^{-\mu}\, \rho^{0\nu} \;+\; \text{h.c.} \right) \;+\; \frac{i}{2} g^{(2)}_{\rho^0 WW}\, \rho^0_{\mu\nu}\, W^{+\mu}\, W^{-\nu},$$

$$\mathscr{L}_{\rho Vh} = g_{\rho^+ Wh} \left(\rho^+_\mu\, W^{-\mu}\, h \;+\; \text{h.c.} \right) \;+\; g_{\rho^0 Zh}\, \rho^0_\mu\, Z^\mu\, h,$$

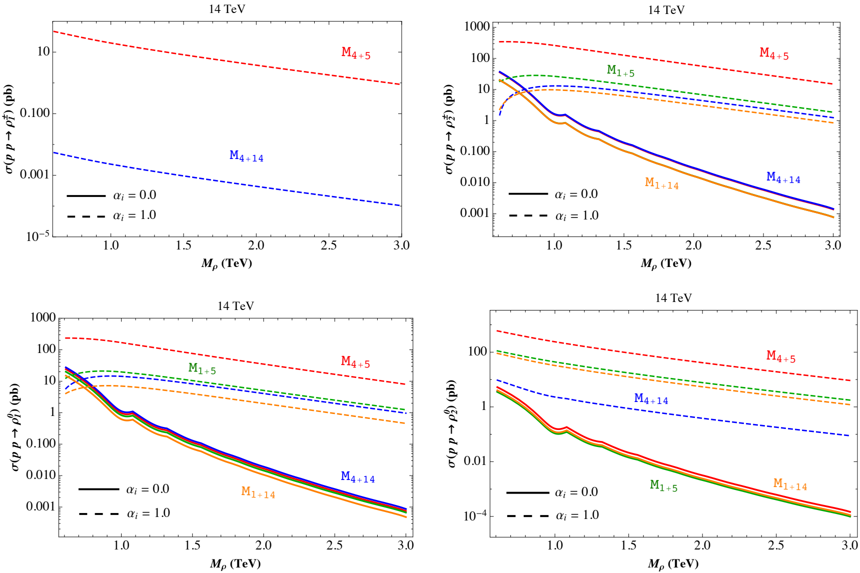
Heavy spin-1 production



Setting $\alpha = 1$ @ $\sqrt{s} = 14$ TeV.

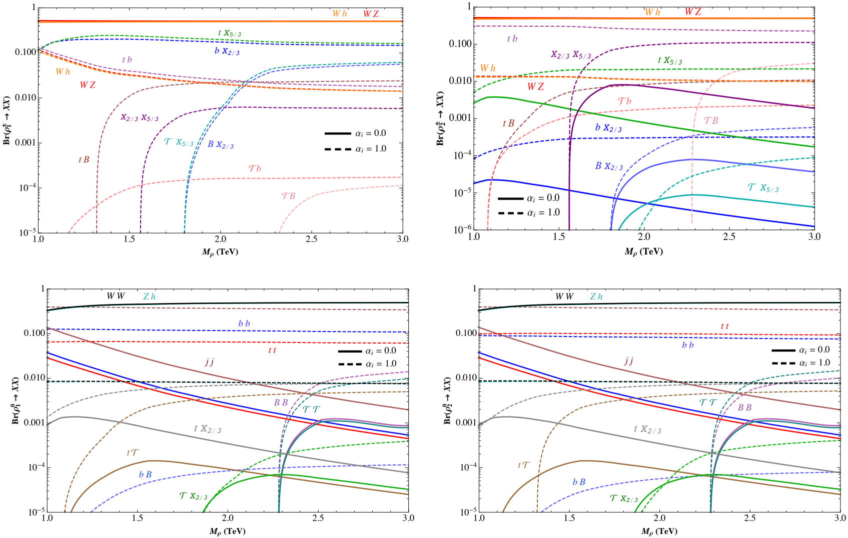
J. Yepes and A. Zerwekh, hep-ph:1806.06694

Impact of $\alpha \mathcal{J} \cdot \rho$



Comparing two different situations $\alpha = 0, 1$ for $\xi = 0.2$ @ $\sqrt{s} = 14$ TeV.

ρ-Branching ratios

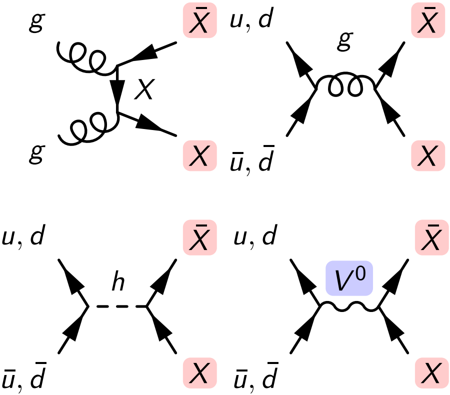


Comparing two different situations $\alpha = 0, 1$ for $\xi = 0.2$ @ $\mathbf{M}_{4+5}$

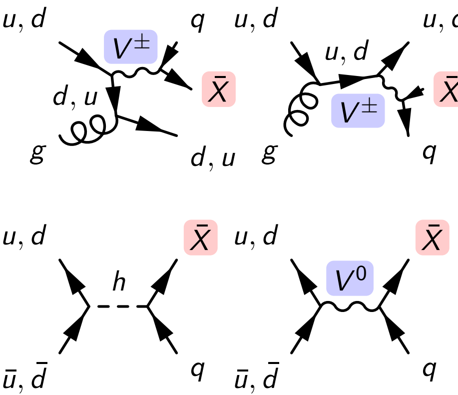
Yielding top partners

QCD-driven+SM gauge-Higgs mediated+intermediation of $\rho^{\pm}$ & ρ^0

Double production

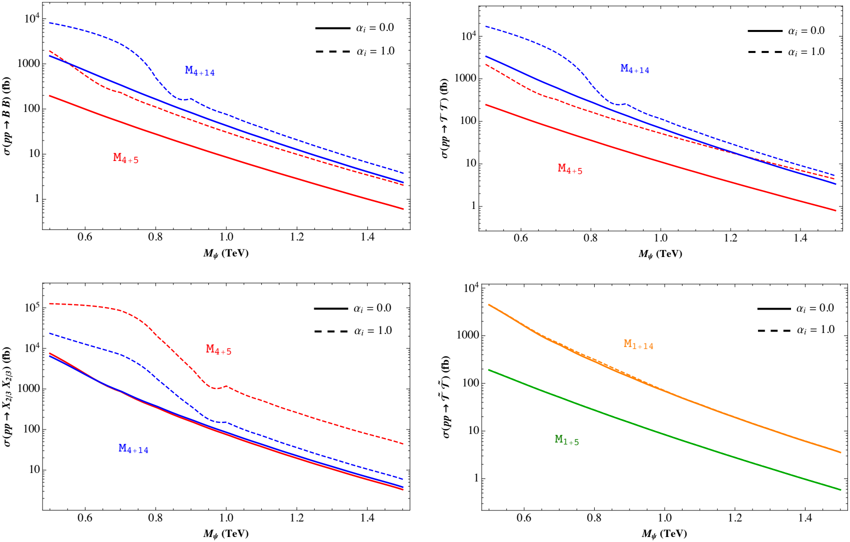


Single production



$V^{\pm} = W^{\pm}, \rho^{\pm}_{1,2}$ & $V^0 = Z, \gamma, \rho^0_{1,2}$ q any up/down-like quark couple to $X = \{T, B, X_{2/3}, X_{5/3}, \widetilde{T}\}$

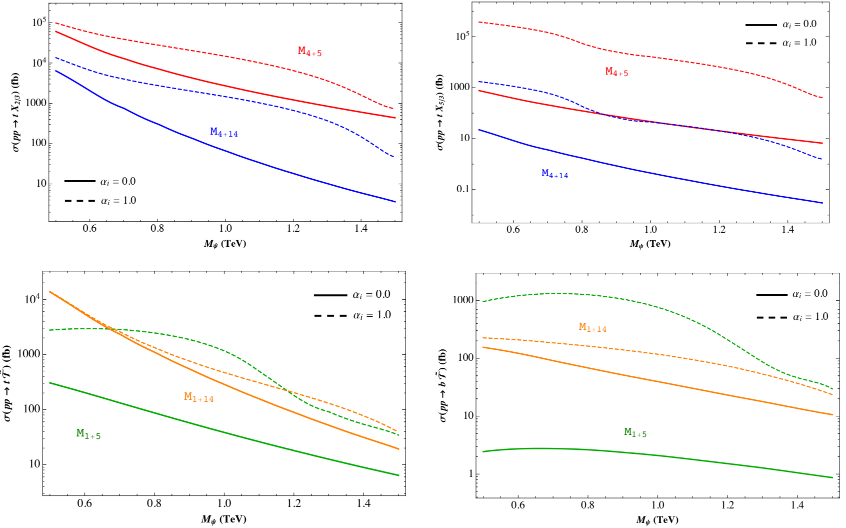
Top partner Double production



Comparing two different situations $\alpha = 0, 1$ for $\xi = 0.2$ @ $\sqrt{s} = 14$ TeV.

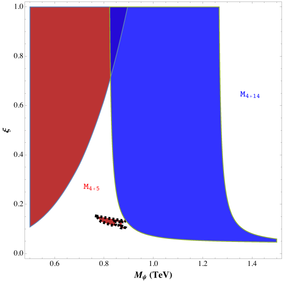
J. Yepes and A. Zerwekh, hep-ph:1806.06694

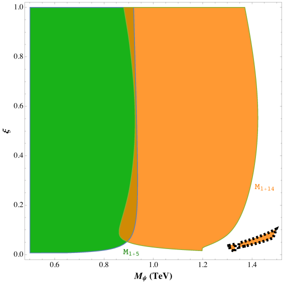
Top partner Single production



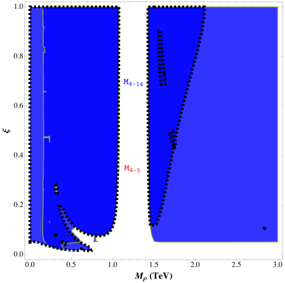
Comparing two different situations $\alpha = 0, 1$ for $\xi = 0.2$ @ $\sqrt{s} = 14$ TeV.

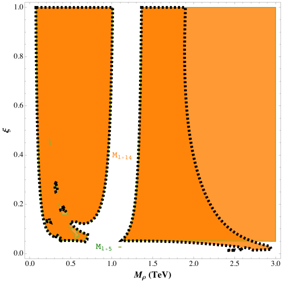
(M_Ψ, ξ), $M_\rho = 3$ TeV





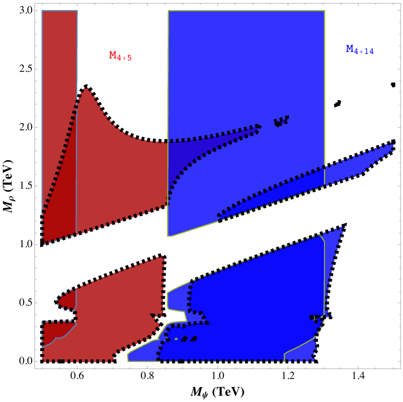
(M_ρ, ξ), $M_\Psi = 1.25$ TeV

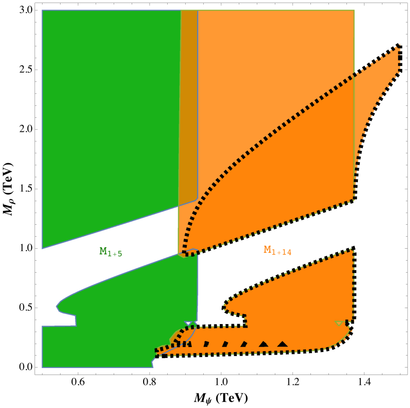




Top partner searches bounds (CMS-2018) via top-like decays into *Wb* for $\alpha = 0, 1$ (thick-dashed border).

$(M_\Psi,\ M_\rho),\ \xi = 0.2$





CMS bounds (A. M. Sirunyan *et al.*, 2018) on top partner searches through decays into *Wb* final states imposed

J. Yepes and A. Zerwekh, hep-ph:1806.06694

SUMMARY

* Interplay among three matter sectors: SM elementary fields + top partners Ψ_4-Ψ_1 permitted by $SO(4)$ + vector/scalar resonances ρ/η of $SU(2)_L \times SU(2)_R$ in a $SO(5)$ CHM.

* ρ coupled to: $SO(5)$ $\mathcal{J}^\mu + \mathcal{J}^{\mu\nu}$. η derivatively coupled to $\mathcal{J}^\mu$.

* Heavy spin-1/spin-0 production & decays thoroughly studied along M_ρ/M_η.

* $\rho^\pm$-ρ^0 dominantly yielded at $\mathbf{M}_{4+5}$. $\sigma_{\text{Prod}} \sim 400$ pb (20 pb) & ~ 600 pb (10 pb) at $M_\rho \sim 0.6$ TeV (3 TeV).

* η dominantly yielded at $\mathbf{M}_{4+5}$. $\sigma_{\text{Prod}} \sim 150$ pb (0.1 pb) at $M_\eta \sim 0.6$ TeV (3 TeV) for $\xi = 0.2$.

* ρ-production increased by $\alpha\,\mathcal{J} \cdot \rho$. Two situations tested $\alpha = 0, 1$.

* η-production slightly altered by $\alpha\,\mathcal{J} \cdot \partial\eta$ (GB f-suppression).

* Double-single partner final states computed. Impact of extra couplings analysed.

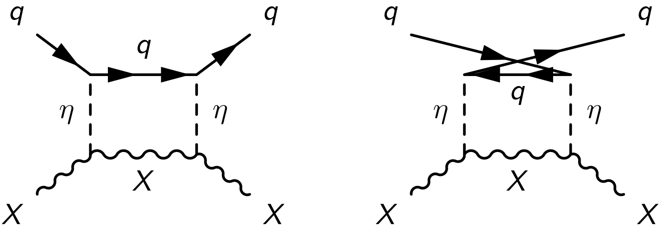
* Involved parameter spaces explored by imposing recent CMS bounds on top-like searches. Extra couplings restrict them further.

TACKLING DARK MATTER

* Vector dark matter (VDM) X + scalar mediator η.

$$\mathscr{L}_{\rm X} = -g_{X\eta} M_X \, X^\mu X^\dagger_\mu \, \eta - i\eta \sum_q g_{\eta q} \bar{q} \gamma_5 q.$$

* Loop-level scattering cross sections



* $\sum_q g^2_{X\eta} g^2_{\eta q} \mathcal{C}^q_{\rm loop} \; X^\dagger_\mu X^\mu \bar{q} q \;\Rightarrow\; \sigma^{\rm SI}_{{\rm DM}N} = \frac{\mu^2_{\rm DMN}}{\pi} |\mathcal{C}(M_X, M_\eta)|^2$

$$\mathcal{C}(M_X, M_\eta) \approx \sum_q g^2_{X\eta} \, g^2_{\eta q} \, m_N \, \frac{2}{27} \, f_{\rm TG} \, \mathcal{C}(M_X, M_\eta, m_q), \qquad f_{\rm TG} \sim 0.89 \;\&\; \mu_{\rm DMN} = \frac{M_X m_N}{M_X + m_N}$$

TACKLING DARK MATTER

Pseudo-bilinear couplings $g_{\eta q} \overset{\text{UV}}{\Longleftarrow} \cancel{SO(5)}$ via mass mixing terms:

TACKLING DARK MATTER

Pseudo-bilinear couplings $g_{\eta q} \overset{\text{UV}}{\Longleftarrow}$ ~~$SO(5)$~~ via mass mixing terms:

* $\mathscr{L}_{q\psi\eta} = \eta \left[y_{q\psi} \left(\overline{q}^{\mathbf{5}}_L U\right)_i (\Psi_{\mathbf{4}R})^i + y_{u\psi} \left(\overline{u}^{\mathbf{5}}_R U\right)_i (\Psi_{\mathbf{4}L})^i + \tilde{y}_{q\psi} \left(\overline{q}^{\mathbf{5}}_L U\right)_5 \Psi_{\mathbf{1}R} + \tilde{y}_{u\psi} \left(\overline{u}^{\mathbf{5}}_R U\right)_5 \Psi_{\mathbf{1}L} \right] + \text{h.c.}$

$$\mathbf{M}_{4+5}: \quad g_{\eta q} = \sqrt{\frac{\xi}{2}} \frac{\left(\eta_R\, \text{Im}(y_{q\psi}) - \eta_L \left(\eta_L^2 + 1\right) \text{Im}(y_{u\psi})\right)}{\left(\eta_L^2 + 1\right)^{3/2}}$$

$$\mathbf{M}_{1+5}: \quad g_{\eta q} = \sqrt{\frac{\xi}{2}} \frac{\left(\tilde{\eta}_L\, \text{Im}(\tilde{y}_{u\psi}) - \tilde{\eta}_R \left(\tilde{\eta}_R^2 + 1\right) \text{Im}(\tilde{y}_{q\psi})\right)}{\left(\tilde{\eta}_R^2 + 1\right)^{3/2}}$$

* $\mathscr{L}'_{q\psi\eta} = \eta \left[y_{q\psi} \left(U^t \overline{q}^{\mathbf{14}}_L U\right)_{i\,5} (\Psi_{\mathbf{4}R})^i + y_{qu} \left(U^t \overline{q}^{\mathbf{14}}_L U\right)_{5\,5} u^{\mathbf{1}}_R + \tilde{y}_{q\psi} \left(U^t \overline{q}^{\mathbf{14}}_L U\right)_{5\,5} \Psi_{\mathbf{1}R} \right] + \text{h.c.}$

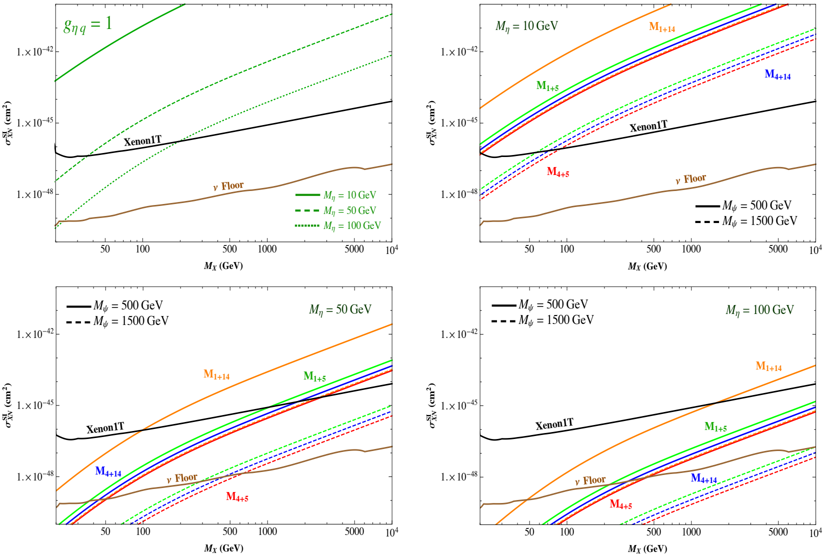
$$\mathbf{M}_{4+14}: \quad g_{\eta q} = \sqrt{2\,\xi} \frac{\left(i\, \eta_L \eta_R\, \text{Re}(y_{q\psi}) - \left(\eta_L^2 + 1\right) \text{Im}(y_{qu})\right)}{\left(\eta_L^2 + 1\right)^{3/2}},$$

$$\mathbf{M}_{1+14}: \quad g_{\eta q} = -\sqrt{2\,\xi} \sqrt{\tilde{\eta}_R^2 + 1}\, \text{Im}(y_{qu})$$

* $\eta_{L(R)} \equiv \frac{y_{L(R)} f}{M_{\mathbf{4}}}$ & $\tilde{\eta}_{L(R)} \equiv \frac{\tilde{y}_{L(R)} f}{M_{\mathbf{1}}} \Rightarrow$ with $y, \tilde{y}$ from Yukawa int. alike $\mathscr{L}_{q\psi\eta}, \mathscr{L}'_{q\psi\eta}$.

J. Yepes, arXiv:1811.06059.

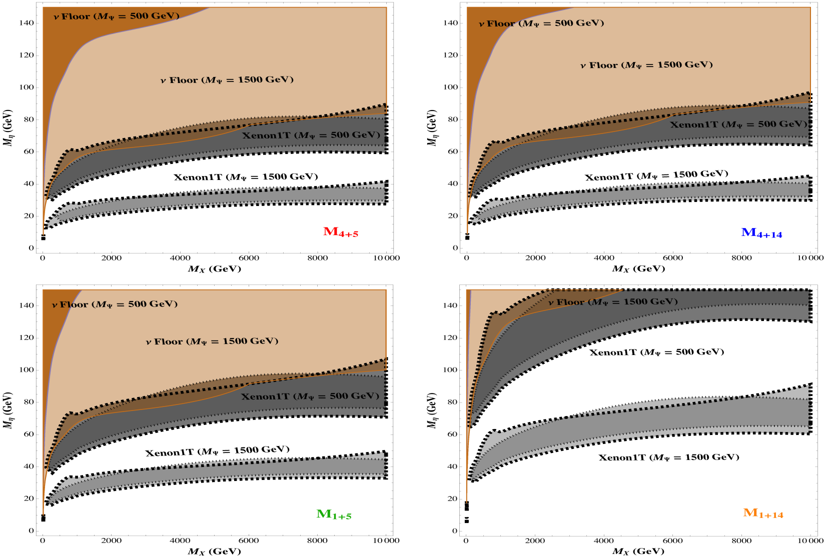
SI DM-nucleon scattering cross section



Im(y) = Re(y) = Im($\tilde{y}$) = 1/2 & $y_R = \tilde{y}_R = 1$ & y_L-$\tilde{y}_L$ properly fixed to conserve m_t (fermion rotation)

J. Yepes, arXiv:1811.06059.

Parameter spaces (M_Ψ, M_η)



Dashed-dotted bordered areas stand for the 1σ-2σ Xenon1T values.

J. Yepes, arXiv:1811.06059.

Remarks

* $\mathbf{M}_{4+5}$, $\mathbf{M}_{4+14}$ $\mathbf{M}_{1+5}$ suppress $\sigma^{\rm SI}_{{\rm DM}N}$ more effectively.

* For a large M_Ψ, $g_{\eta q}$ in $\mathbf{M}_{1+14}$ involves a suppression only from the ξ-dependence, unlike to the others whose suppression is directly enhanced by the contribution of the η and $\tilde{\eta}$-parameters.

* $\mathbf{M}_{1+14}$ is disfavoured in eluding the latest DD Xenon1T bounds.

* Future observations will help us in discriminating the best framework among $\mathbf{M}_{4+5}$, $\mathbf{M}_{4+14}$ and $\mathbf{M}_{1+5}$ for the explanation of the DD experiments.

SUMMARY

* Loop-level $\sigma^{\rm SI}_{{\rm DM}N}$ in a simple VDM model.

* Scalar mediator coupled to vector dark field and to the SM quarks via pseudo-bilinear interactions.

* Dark matter-mediator masses bounded by the latest DD experiments.

* Effective mediator-quark couplings suppressing $\sigma^{\rm SI}_{{\rm DM}N} \to$ DD Xenon1T limits eluded.

* NP from CHM responsible for such suppression. Top partners mass scale suppressing the effective pseudo-bilinear couplings.

Thanks

Backup ;)

Matter sectors

- Massless elementary fields: SM field sector q & no Higgs
- Massive composite fields: Higgs + composite resonances
- Partial compositeness $\Rightarrow$ elementary-composite mixings

$$\mathcal{L}_{\text{mix}}^{\text{UV}} = \sum_q y\, \bar{q}\, \mathcal{O}_q \qquad \mathcal{O}_q \text{ shapes elementary embeddings}$$

$\Downarrow$

5-plet | **14**-plet

$$q_L^{\mathbf{5}} = \frac{1}{\sqrt{2}} \begin{pmatrix} i d_L \\ d_L \\ i u_L \\ -u_L \\ 0 \end{pmatrix} \quad u_R^{\mathbf{5}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ u_R \end{pmatrix}$$

$$q_L^{\mathbf{14}} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 0 & 0 & i d_L \\ 0 & 0 & 0 & 0 & d_L \\ 0 & 0 & 0 & 0 & i u_L \\ 0 & 0 & 0 & 0 & -u_L \\ i d_L & d_L & i u_L & -u_L & 0 \end{pmatrix}$$

Top partners

* 4-plet $\Psi_\mathbf{4}$ + singlet $\Psi_\mathbf{1}$ of $SO(4)$

$$\Psi_\mathbf{4} = \frac{1}{\sqrt{2}} \begin{pmatrix} i\mathcal{B} - iX_{5/3} \\ \mathcal{B} + X_{5/3} \\ i\mathcal{T} + iX_{2/3} \\ -\mathcal{T} + X_{2/3} \end{pmatrix}, \qquad \Psi_\mathbf{1} = \widetilde{\mathcal{T}}$$

* $\mathbf{M_{\Psi+q}} = \{\mathbf{M}_{4+5}, \mathbf{M}_{4+14}, \mathbf{M}_{1+5}, \mathbf{M}_{1+14}\}$ $\quad$ q shaped by $\mathcal{O}_q$

Vector resonances

* Spin-1 $\rho_L^\mu = (\mathbf{3}, \mathbf{1})$ + $\rho_R^\mu = (\mathbf{1}, \mathbf{3})$ of $SU(2)_L \times SU(2)_R$

* Parametrized by a mass $m_\rho \simeq g_\rho f$ & $1 < g_\rho < 4\pi$

Fermion–vector interplay

* Fermion currents coupled to spin-1 resonances

$$\mathscr{L}_{\mathbf{M}+\rho_\chi} \sim \frac{1}{\sqrt{2}}\,\alpha_i^\chi\,\mathcal{J}^\mu_{i\chi}\,(\rho_{\mu\chi} - e_{\mu\chi}) \; + \; \text{h.c.}$$

* Fermionic 2nd rank tensors coupled to resonance strength field

$$\mathscr{L}^{\text{mag}}_{\mathbf{M}+\rho_\chi} = \frac{1}{f}\,\beta_i^\chi\,\mathcal{J}^{\mu\nu}_{i\chi}\,\rho_{\mu\nu\chi} \; + \; \text{h.c.}\,,$$

$i = \{q,\, \psi,\, q\psi,\, u\psi\}$ $\quad$ α_i^χ and β_i^χ weighting coefficients.

$\mathbf{M}_{4+5}$ and $\mathbf{M}_{1+5}$ coupled to ρ

$$\mathscr{L}_{\text{elem}} = i\,\overline{q}_L \not{D}\, q_L \;+\; i\,\overline{u}_R \not{D}\, u_R\,,$$

$$\mathscr{L}_{\text{comp}} = i\,\overline{\Psi}_{\mathbf{4}} \not{\nabla} \Psi_{\mathbf{4}} - M_{\mathbf{4}}\,\overline{\Psi}_{\mathbf{4}}\Psi_{\mathbf{4}} \;+\; (\Psi_{\mathbf{4}} \leftrightarrow \Psi_{\mathbf{1}}) \;+\; \frac{f^2}{4} d^2 \;+\; \left(i\,c_{41}\,(\overline{\Psi}_{\mathbf{4}})^i \gamma^\mu d^i_\mu \Psi_{\mathbf{1}} + \mathrm{h.c.}\right)$$

with ∇ standing for $\nabla = \not{D} + i\not{e}$. The mass terms mixing the elementary and top partners are described via

$$\mathscr{L}_{\text{mix}} = y_L f \left(\overline{q}^{\mathbf{5}}_L\, U\right)_i (\Psi_{\mathbf{4}R})^i \;+\; y_R f \left(\overline{u}^{\mathbf{5}}_R\, U\right)_i (\Psi_{\mathbf{4}L})^i \;+\; \text{h.c.} \;+\; ,\tilde{y}_L f \left(\overline{q}^{\mathbf{5}}_L\, U\right)_5 \Psi_{\mathbf{1}R} \;+\; \tilde{y}_R f \left(\overline{u}^{\mathbf{5}}_R\, U\right)_5 \Psi_{\mathbf{1}L} \;+\; \text{h.c.}$$

$\mathbf{M}_{4+14}$ and $\mathbf{M}_{1+14}$ coupled to ρ

$$\mathscr{L}_{\text{elem}} = i\,\overline{q}_L \not{D}\, q_L\;,$$

whereas the composite counterpart is reshuffled as

$$\mathscr{L}_{\text{comp}} \quad\to\quad \mathscr{L}_{\text{comp}} + i\,\overline{u}_R \not{D}\, u_R \;+\; \left(i\,c_{41}\,(\overline{\Psi}_{\mathbf{4}})^i \gamma^\mu d^i_\mu \Psi_{\mathbf{1}} \;+\; i\,c_{4u}\,(\overline{\Psi}_{\mathbf{4}})^i \gamma^\mu d^i_\mu u_R + \text{h.c.}\right),$$

The elementary and top partners sector are mixed via

$$\mathscr{L}_{\text{mix}} = y_L\, f \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{i\,5} (\Psi_{\mathbf{4}R})^i \;+\; \tilde{y}_L\, f \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{5\,5} \Psi_{\mathbf{1}R} \;+\; y_R\, f \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{5\,5} u^{\mathbf{1}}_R \;+\; \text{h.c.}$$

$\mathbf{M}_{4+5}$ and $\mathbf{M}_{1+5}$ coupled to η

$$\mathscr{L}_{\text{elem}} = i\,\overline{q}_L \not{D}\, q_L \;+\; i\,\overline{u}_R \not{D}\, u_R ,$$

$$\mathscr{L}_{\text{comp}} = i\,\overline{\Psi}_{\mathbf{4}} \not{\nabla} \Psi_{\mathbf{4}} - M_{\mathbf{4}}\,\overline{\Psi}_{\mathbf{4}}\Psi_{\mathbf{4}} \;+\; (\Psi_{\mathbf{4}} \leftrightarrow \Psi_{\mathbf{1}}) \;+\; \frac{f^2}{4} d^2 \;+\; \Big(i\, c_{41}\, (\overline{\Psi}_{\mathbf{4}})^i \gamma^\mu d^i_\mu \Psi_{\mathbf{1}} + \text{h.c.} \Big)$$

Elementary-top partners mixing & trilinear couplings fermion-fermion-scalar

$$\mathscr{L}_{\text{mix}} = y_L f \left(\overline{q}^{\mathbf{5}}_L\, U\right)_i (\Psi_{\mathbf{4}R})^i \;+\; y_R f \left(\overline{u}^{\mathbf{5}}_R\, U\right)_i (\Psi_{\mathbf{4}L})^i \;+\; \text{h.c.} \;+\; , \tilde{y}_L f \left(\overline{q}^{\mathbf{5}}_L\, U\right)_5 \Psi_{\mathbf{1}R} \;+\; \tilde{y}_R f \left(\overline{u}^{\mathbf{5}}_R\, U\right)_5 \Psi_{\mathbf{1}L} \;+\; \text{h.c.}$$

$$\mathscr{L}_{\text{mix}-\eta} = \Big[y_{q\psi} \left(\overline{q}^{\mathbf{5}}_L\, U\right)_i (\Psi_{\mathbf{4}R})^i \;+\; y_{u\psi} \left(\overline{u}^{\mathbf{5}}_R\, U\right)_i (\Psi_{\mathbf{4}L})^i \;+\; \text{h.c.} \;+\; tildey_{q\psi} \left(\overline{q}^{\mathbf{5}}_L\, U\right)_5 \Psi_{\mathbf{1}R} \;+\; \tilde{y}_{u\psi} \left(\overline{u}^{\mathbf{5}}_R\, U\right)_5 \Psi_{\mathbf{1}L} \;+\; \text{h.c.}$$

$\mathbf{M}_{4+14}$ and $\mathbf{M}_{1+14}$ coupled to η

$$\mathscr{L}_{\text{elem}} = i\,\overline{q}_L \not{D}\, q_L \,,$$

$$\mathscr{L}_{\text{comp}} \quad \to \quad \mathscr{L}_{\text{comp}} + i\,\overline{u}_R \not{D}\, u_R \;+\; \Big(i\, c_{41}\, (\overline{\Psi}_{\mathbf{4}})^i \gamma^\mu d^i_\mu \Psi_{\mathbf{1}} \;+\; i\, c_{4u}\, (\overline{\Psi}_{\mathbf{4}})^i \gamma^\mu d^i_\mu u_R + \text{h.c.} \Big) ,$$

Elementary-top partners mixing & trilinear couplings fermion-fermion-scalar

$$\mathscr{L}_{\text{mix}} = y_L\, f \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{i\,5} (\Psi_{\mathbf{4}R})^i \;+\; \tilde{y}_L\, f \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{5\,5} \Psi_{\mathbf{1}R} \;+\; y_R\, f \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{5\,5} u^{\mathbf{1}}_R \;+\; \text{h.c.}$$

$$\mathscr{L}_{\text{mix}} = \Big[y_{q\psi} \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{i\,5} (\Psi_{\mathbf{4}R})^i \;+\; \tilde{y}_{q\psi} \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{5\,5} \Psi_{\mathbf{1}R} \;+\; y_{qu} \left(U^t\, \overline{q}^{\mathbf{14}}_L\, U\right)_{5\,5} u^{\mathbf{1}}_R \;+\; \text{h.c.} \Big] \eta$$

Dim-6 operators

$\mathbf{M}_{4+5}$		$\mathbf{M}_{4+14}$
$\mathcal{O}_{qq} = \frac{1}{2}\, \mathcal{J}_q\, \mathcal{J}_q$	$\mathcal{O}^{(3)}_{q\psi} = \mathcal{J}_q\, \mathcal{J}_{q\psi}$	$\mathcal{O}_{qq} = \frac{1}{2}\, \mathcal{J}_q\, \mathcal{J}_q$ $\mathcal{O}^{(2)}_{q\psi} = \mathcal{J}_q\, \mathcal{J}_\psi$ $\mathcal{O}_{\psi\psi} = \frac{1}{2}\, \mathcal{J}_\psi\, \mathcal{J}_\psi$ $\mathcal{O}^{(3)}_{q\psi} = \mathcal{J}_q\, \mathcal{J}_{q\psi}$ $\mathcal{O}^{(1)}_{q\psi} = \frac{1}{2}\, \mathcal{J}_{q\psi}\, \mathcal{J}_{q\psi}$ $\mathcal{O}^{(4)}_{q\psi} = \mathcal{J}_\psi\, \mathcal{J}_{q\psi}$
$\mathcal{O}_{\psi\psi} = \frac{1}{2}\, \mathcal{J}_\psi\, \mathcal{J}_\psi$	$\mathcal{O}^{(4)}_{q\psi} = \mathcal{J}_\psi\, \mathcal{J}_{q\psi}$	
$\mathcal{O}^{(1)}_{q\psi} = \frac{1}{2}\, \mathcal{J}_{q\psi}\, \mathcal{J}_{q\psi}$	$\mathcal{O}^{(2)}_{u\psi} = \mathcal{J}_\psi\, \mathcal{J}_{u\psi}$	
$\mathcal{O}^{(1)}_{u\psi} = \frac{1}{2}\, \mathcal{J}_{u\psi}\, \mathcal{J}_{u\psi}$	$\mathcal{O}^{(1)}_{qu\psi} = \mathcal{J}_q\, \mathcal{J}_{u\psi}$	
$\mathcal{O}^{(2)}_{q\psi} = \mathcal{J}_q\, \mathcal{J}_\psi$	$\mathcal{O}^{(2)}_{qu\psi} = \mathcal{J}_{q\psi}\, \mathcal{J}_{u\psi}$	

$\mathbf{M}_{1+5}$	$\mathbf{M}_{1+14}$
$\mathcal{O}_{qq} = \frac{1}{2}\, \mathcal{J}_q\, \mathcal{J}_q$ $\mathcal{O}^{(1)}_{q\psi} = \frac{1}{2}\, \mathcal{J}_{q\psi}\, \mathcal{J}_{q\psi}$ $\mathcal{O}^{(2)}_{q\psi} = \mathcal{J}_q\, \mathcal{J}_{q\psi}$	$\mathcal{O}_{qq} = \frac{1}{2}\, \mathcal{J}_q\, \mathcal{J}_q$

Wilson coefficients

$\mathbf{M}_{4+5}$	$\mathbf{M}_{1+5}$
$c_{u_L u_L} = \frac{1}{8}(\xi - 1)\left[4\eta_L \alpha_q^L \alpha_{q\psi}^L + \left(\alpha_q^L\right)^2 + \alpha_q^R\left(4\eta_L \alpha_{q\psi}^R + \alpha_q^R\right)\right]$	$c_{u_L u_L} = \frac{1}{8}(\xi - 1)\left[\left(\alpha_q^L\right)^2 + \left(\alpha_q^R\right)^2\right]$
$c_{d_L d_L} = \frac{1}{8}\left[-4\eta_L \alpha_q^L \alpha_{q\psi}^L - \left(\alpha_q^L\right)^2 - \alpha_q^R\left(4\eta_L \alpha_{q\psi}^R + \alpha_q^R\right)\right]$	$c_{d_L d_L} = -\frac{1}{8}\left[\left(\alpha_q^L\right)^2 + \left(\alpha_q^R\right)^2\right]$
$c_{u_L d_L} = -\frac{1}{8}(\xi - 2)\left[12\eta_L \alpha_q^L \alpha_{q\psi}^L + 3\left(\alpha_q^L\right)^2 - \alpha_q^R\left(4\eta_L \alpha_{q\psi}^R + \alpha_q^R\right)\right]$	$c_{u_L d_L} = -\frac{1}{8}(\xi - 2)\left[3\left(\alpha_q^L\right)^2 - \left(\alpha_q^R\right)^2\right]$
$\mathbf{M}_{4+14}$	$\mathbf{M}_{1+14}$
$c_{u_L u_L} = \frac{1}{8}(5\xi - 1)\left[4\eta_L \alpha_q^L \alpha_{q\psi}^L + \left(\alpha_q^L\right)^2 + \alpha_q^R\left(4\eta_L \alpha_{q\psi}^R + \alpha_q^R\right)\right]$	$c_{u_L u_L} = \frac{1}{8}(5\xi - 1)\left[\left(\alpha_q^L\right)^2 + \left(\alpha_q^R\right)^2\right]$
$c_{d_L d_L} = \frac{1}{8}(2\xi - 1)\left[4\eta_L \alpha_q^L \alpha_{q\psi}^L + \left(\alpha_q^L\right)^2 + \alpha_q^R\left(4\eta_L \alpha_{q\psi}^R + \alpha_q^R\right)\right]$	$c_{d_L d_L} = \frac{1}{8}(2\xi - 1)\left[\left(\alpha_q^L\right)^2 + \left(\alpha_q^R\right)^2\right]$
$c_{u_L d_L} = -\frac{1}{8}(7\xi - 2)\left[12\eta_L \alpha_q^L \alpha_{q\psi}^L + 3\left(\alpha_q^L\right)^2 - \alpha_q^R\left(4\eta_L \alpha_{q\psi}^R + \alpha_q^R\right)\right]$	$c_{u_L d_L} = -\frac{1}{8}(7\xi - 2)\left[3\left(\alpha_q^L\right)^2 - \left(\alpha_q^R\right)^2\right]$

Before fermion mass diagonalization & up to $\mathcal{O}(\eta)$ and $\mathcal{O}(\xi)$

Top partners EOM: $\mathbf{M}_{4+5} + \mathbf{M}_{1+5}$

LH components

$$\mathcal{T}_L \to -\frac{\xi}{4}\,\frac{\eta_L}{\eta_L^2+1}\,t_L\,, \qquad X_{5/3,L} \to 0 \qquad \tilde{\mathcal{T}}_L \to \sqrt{\frac{\xi}{2}}\,\frac{\tilde{\eta}_L}{\left(\tilde{\eta}_R^2+1\right)\sqrt{\eta_L^2+1}}\,t_L$$

$$\mathcal{B}_L \to 0 \qquad X_{2/3,L} \to \frac{\xi}{4}\,\frac{\eta_L}{\sqrt{\eta_L^2+1}}\,t_L$$

RH components

$$\mathcal{T}_R \to \sqrt{\frac{\xi}{2}}\,\frac{\eta_R}{\left(\eta_L^2+1\right)\sqrt{\tilde{\eta}_R^2+1}}\,t_R\,, \qquad X_{5/3,R} \to 0\,, \qquad \tilde{\mathcal{T}}_R \to -\frac{\xi}{2}\,\frac{\tilde{\eta}_R}{\tilde{\eta}_R^2+1}\,t_R\,,$$

$$\mathcal{B}_R \to -\tilde{\eta}_R\,b_R\,, \qquad X_{2/3,R} \to -\sqrt{\frac{\xi}{2}}\,\frac{\eta_R}{\sqrt{\tilde{\eta}_R^2+1}}\,t_R\,.$$

with

$$\eta_{L(R)} \to \frac{y_{L(R)}f}{M_4} \equiv \frac{y_{L(R)}}{g_4}\,, \qquad \tilde{\eta}_{L(R)} \to \frac{\tilde{y}_{L(R)}f}{M_1} \equiv \frac{\tilde{y}_{L(R)}}{g_1}$$

Top partners EOM: $\mathbf{M}_{4+14} + \mathbf{M}_{1+14}$

LH components

$$\mathcal{T}_L \to -\frac{5\,\xi}{4}\,\frac{\eta_L}{\eta_L^2+1}\,t_L\,,\quad X_{5/3,L} \to 0\quad \tilde{\mathcal{T}}_L \to -\frac{\sqrt{2}\,\xi}{\sqrt{\eta_L^2+1}}\left(\tilde{\eta}_L - \tilde{\eta}_R^2 - \frac{M_4}{M_1}\eta_R\tilde{\eta}_R\right)\,t_L\,,$$

$$\mathcal{B}_L \to -\frac{\xi}{2}\,\frac{\eta_L}{\eta_L^2+1}\,b_L\quad X_{2/3,L} \to \frac{3\,\xi}{4}\,\frac{\eta_L}{\sqrt{\eta_L^2+1}}\,t_L$$

RH components

$$\mathcal{T}_R \to -\sqrt{2}\,\xi\,\frac{\sqrt{\tilde{\eta}_R^2+1}}{\eta_L^2+1}\,\eta_L\left(\frac{M_1}{M_4}\tilde{\eta}_R + \eta_R\right)\,t_R\,,\qquad X_{5/3,L} \to 0\,,\qquad \tilde{\mathcal{T}}_R \to -\tilde{\eta}_R\,t_R\,,$$

$$\mathcal{B}_R \to -\tilde{\eta}_R\,b_R \qquad\qquad X_{2/3,R} \to 0$$

with

$$\eta_{L(R)} \to \frac{y_{L(R)}f}{M_4} \equiv \frac{y_{L(R)}}{g_4}\,,\qquad \tilde{\eta}_{L(R)} \to \frac{\tilde{y}_{L(R)}f}{M_1} \equiv \frac{\tilde{y}_{L(R)}}{g_1}$$

Physical fermion masses: **5**-plets embeddings

Mass matrices for the top-like and bottom-like sectors

$$\begin{pmatrix} 0 & \frac{1}{2} f\,\xi\,y_L & f(1-\frac{\xi}{2})y_L & -\frac{f\sqrt{\xi}\,\tilde{y}_L}{\sqrt{2}} \\ -\frac{f\sqrt{\xi}\,y_R}{\sqrt{2}} & -M_4 & 0 & 0 \\ \frac{f\sqrt{\xi}\,y_R}{\sqrt{2}} & 0 & -M_4 & 0 \\ f\sqrt{1-\xi}\,\tilde{y}_R & 0 & 0 & -M_1 \end{pmatrix}, \qquad \begin{pmatrix} 0 & f y_L \\ 0 & -M_4 \end{pmatrix}$$

being defined in the fermion field basis $\left(t,\ X_{2/3}\ \mathcal{T},\ \widetilde{\mathcal{T}}\right)^T$ and $(b,\ \mathcal{B})^T$ respectively. After diagonalization the physical masses are

$$m_t = \sqrt{\frac{\xi\,(\tilde{\eta}_L\,\tilde{\eta}_R M_1 - \eta_L \eta_R M_4)^2}{2\left(\eta_L^2+1\right)\left(\tilde{\eta}_R^2+1\right)}}\,, \qquad m_{\widetilde{\mathcal{T}}} = M_1\sqrt{\tilde{\eta}_R^2+1}\,, \qquad m_{\mathcal{B}} = M_4\sqrt{\frac{\eta_L^2+1}{\tilde{\eta}_R^2+1}}\,,$$

$$m_{\mathcal{T}} = M_4\sqrt{\eta_L^2+1}\,, \qquad m_{X_{2/3}} = m_{X_{5/3}} = M_4\,,$$

where the parameters $\eta_{L(R)}$ are defined through

$$\eta_{L(R)} \equiv \frac{y_{L(R)} f}{M_4}\,, \qquad \tilde{\eta}_{L(R)} \equiv \frac{\tilde{y}_{L(R)} f}{M_1}\,.$$

Physical fermion masses: **14**-plets embeddings

Mass matrices for the top-like and bottom-like sectors

$$\begin{pmatrix} -f\sqrt{2(1-\xi)\xi}\,y_R & \frac{1}{2}f\left(2\xi+\sqrt{1-\xi}-1\right)y_L & \frac{1}{2}f\left(-2\xi+\sqrt{1-\xi}+1\right)y_L & -f\sqrt{2(1-\xi)\xi}\,\tilde{y}_L \\ 0 & -M_{\mathbf{4}} & 0 & 0 \\ 0 & 0 & -M_{\mathbf{4}} & 0 \\ 0 & 0 & 0 & -M_{\mathbf{1}} \end{pmatrix}$$

while the one for the bottom-like sector becomes

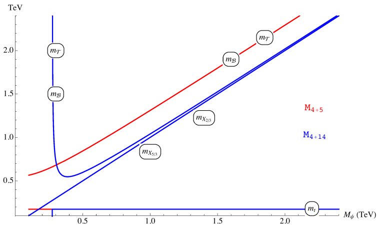
$$\begin{pmatrix} 0 & f\sqrt{1-\xi}\,y_L \\ 0 & -M_{\mathbf{4}} \end{pmatrix}$$

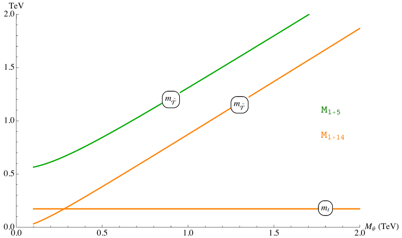
The corresponding physical masses are

$$m_t = \sqrt{2}\sqrt{\frac{\xi\left(M_{\mathbf{1}}\tilde{\eta}_L\tilde{\eta}_R + M_{\mathbf{4}}\eta_R\right)^2}{\left(\eta_L^2+1\right)\left(\tilde{\eta}_R^2+1\right)}}\,, \qquad m_{\widetilde{\mathcal{T}}} = \frac{M_{\mathbf{1}}}{\sqrt{\tilde{\eta}_R^2+1}}\,, \qquad m_{\mathcal{B}} = M_{\mathbf{4}}\sqrt{\frac{\eta_L^2+1}{\tilde{\eta}_R^2+1}}\,,$$

$$m_{\mathcal{T}} = M_{\mathbf{4}}\sqrt{\eta_L^2+1}\,, \qquad m_{X_{2/3}} = m_{X_{5/3}} = M_{\mathbf{4}}\,,$$

Physical fermion masses





Spectrum of masses and their dependence on the NP scale $M_{\mathbf{4}} = M_{\mathbf{1}} = M_\Psi$ for the fourplet (left) and singlet cases (right), for $\xi = 0.2$ and setting $\eta_L = \eta_R$, $\tilde{\eta}_L = \tilde{\eta}_R$.

Some effective couplings

Concerning the set $g_{ff\eta}$ and $g_{XX\eta}$ we have

$$g_{tt\eta} = 0\,, \qquad g_{bb\eta} = \frac{\tilde{\eta}_R y_{q\psi}}{\sqrt{\left(\eta_L^2+1\right)\left(\tilde{\eta}_R^2+1\right)}}\,, \qquad g_{\mathcal{T}\mathcal{T}\eta} = -\frac{\eta_L y_{q\psi}}{\sqrt{\eta_L^2+1}}\,,$$

$$g_{\mathcal{B}\mathcal{B}\eta} = -\frac{\eta_L y_{q\psi}}{\sqrt{\left(\eta_L^2+1\right)\left(\tilde{\eta}_R^2+1\right)}}\,, \qquad g_{X_{2/3}X_{2/3}\eta} = g_{X_{5/3}X_{5/3}\eta} = 0.$$

For the set $g_{f_L f_L \eta}$ and $g_{X_L X_L \eta}$ one has

$$g_{t_L t_L \eta} = g_{b_L b_L \eta} = \frac{\eta_L\left(\alpha_\psi \eta_L + 2\alpha_{q\psi}\right) + \alpha_q}{\sqrt{2}f\left(\eta_L^2+1\right)}\,, \qquad g_{\mathcal{T}_L \mathcal{T}_L \eta} = g_{\mathcal{B}_L \mathcal{B}_L \eta} = \frac{\alpha_\psi + \eta_L\left(\eta_L \alpha_q - 2\alpha_{q\psi}\right)}{\sqrt{2}f\left(\eta_L^2+1\right)}\,,$$

$$g_{X_{2/3_L} X_{2/3_L}\eta} = g_{X_{5/3_L} X_{5/3_L}\eta} = \frac{\alpha_\psi}{\sqrt{2}f}.$$

The degeneracy among some couplings are spoiled once higher ξ-order terms are considered. For $g_{f_R f_R \eta}$ and $g_{X_R X_R \eta}$ we have

$$g_{t_R t_R \eta} = \frac{\alpha_u}{\sqrt{2}f\left(\tilde{\eta}_R^2+1\right)}\,, \qquad g_{b_R b_R \eta} = \frac{\alpha_\psi \tilde{\eta}_R^2}{\sqrt{2}f\left(\tilde{\eta}_R^2+1\right)}\,, \qquad g_{\mathcal{T}_R \mathcal{T}_R \eta} = \frac{\alpha_\psi}{\sqrt{2}f}\,,$$

ρ-low energy effects

* $E \ll m_{\rho_L} \ll \Lambda \Rightarrow$ integ. out $\rho \xrightarrow{\text{EOM}}$ $\rho^\mu_\chi \sim \sum_i \frac{\alpha^\chi_i}{\sqrt{2}} \frac{g^2_{\rho_\chi}}{m^2_{\rho_\chi}} \mathcal{J}^\mu_{i\chi}$

$$\mathscr{L}_{\mathbf{M}+\rho_\chi} \xrightarrow{\rho-\text{EOM}} -\sum_{i,j} \alpha^\chi_i \, \alpha^\chi_j \, \frac{g^2_{\rho_\chi}}{m^2_{\rho_\chi}} \mathcal{O}^\chi_{ij}, \qquad \mathcal{O}^\chi_{ij} = \mathcal{J}^\chi_i \, \mathcal{J}^\chi_j$$

* $M_{\mathbf{4(1)}} < m_\rho \Rightarrow$ integrating out $\Psi \xrightarrow{\text{EOM}}$ $\Psi \sim$ elementary fields

$$\mathscr{L}_{\mathbf{M}+\rho_\chi} + \mathscr{L}^{\text{mag}}_{\mathbf{M}+\rho_\chi} \xrightarrow[\Psi-\text{EOM}]{\rho-\text{EOM}} -\frac{1}{f^2}\sum_i c_i \, \mathcal{O}_i - \frac{1}{f}\sum_V c^{mag}_V \, \mathcal{O}^{mag}_V$$

*

$$\mathcal{O}_{u_L u_L} = (\bar{u}_L \gamma_\mu u_L)^2 \quad \mathcal{O}_{u_L d_L} = (\bar{u}_L \gamma_\mu u_L)(\bar{d}_L \gamma_\mu d_L) \quad \mathcal{O}_{d_L d_L} = (\bar{d}_L \gamma_\mu d_L)^2$$

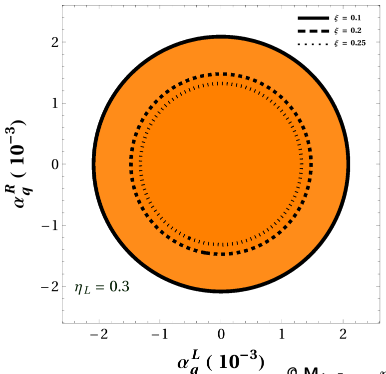
$$\mathcal{O}^{mag}_\gamma = \bar{u}\,\sigma^{\mu\nu}\,u\,A_{\mu\nu}$$

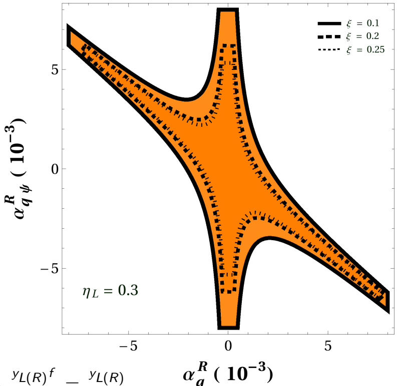
Flavour & $\Delta F = 2$ operators

FCNC processes mostly constrained by the down quark sector

$$\frac{1}{f^2}\, c_{d_L\,d_L}\, \mathcal{O}_{d_L\,d_L} \quad\rightarrow\quad \frac{1}{f^2}\, (V^{\dagger}_{\mathrm{CKM}i3} V_{\mathrm{CKM}3j})^2\, \kappa^2_{ij}\, c_{d_L\,d_L}\, [\bar{d}_i \gamma_\mu d_j][\bar{d}_i \gamma^\mu d_j] \qquad \begin{cases} U(3)^2_{\mathrm{LC}}\,, & \kappa_{ij} = 0 \\ U(3)^2_{\mathrm{RC}}\ \&\ U(2)^2_{\mathrm{RC}}\,, & \kappa_{ij} = 1 \end{cases}$$

$$U(3)^2_{RC}\,:\, |c_{d_L d_L}| \lesssim 5.4 \times 10^{-7}_{(1,2)} \qquad U(2)^2_{RC}\,:\, |c_{d_L d_L}| \lesssim 2.4 \times 10^{-6}_{(1,3)}$$





© $\mathbf{M}_{4+5}$ $\qquad \eta_{L(R)} \rightarrow \dfrac{y_{L(R)}\, f}{M_4} \equiv \dfrac{y_{L(R)}}{g_4}$

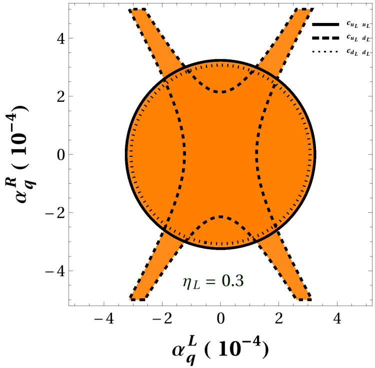
Compositeness constraints

Light quark compositeness related to the one of the top quark

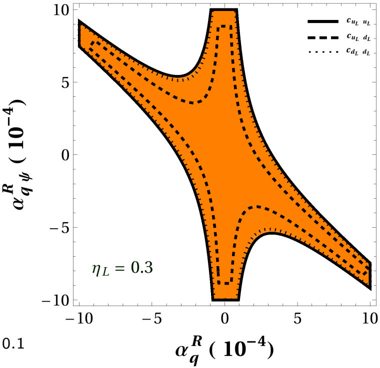
$$\mathcal{O}_{qq}^{(1)} = (\bar{q}_L \gamma^{\mu} q_L)(\bar{q}_L \gamma_{\mu} q_L) \sim \{\mathcal{O}_{u_L\, u_L},\, \mathcal{O}_{u_L\, d_L},\, \mathcal{O}_{d_L\, d_L}\} \quad \Rightarrow \quad c_{u_L\, u_L} = 2\, c_{u_L\, d_L} = c_{d_L\, d_L} = c_{qq}^{(1)}$$

$$\mathcal{O}_{qq}^{(1)} \quad \Rightarrow \text{jet's angular distributions departures}$$

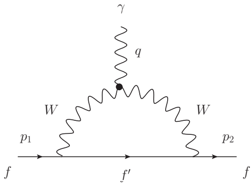
Wilson coefficient bounded as $(5.0\,\text{TeV})^{-2}$ $\Rightarrow$ $c_{qq}^{(1)}$ $\Longrightarrow$
$$\begin{cases} c_{u_L\, u_L} \;\&\; c_{d_L\, d_L} \lesssim \{1.2,\, 0.6,\, 0.5\} \times 10^{-8} \\ c_{u_L\, d_L} \lesssim \{0.6,\, 0.3,\, 0.25\} \times 10^{-8} \end{cases}$$



$\xi = 0.1$



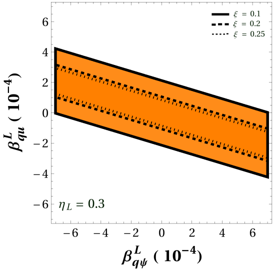
Fermionic EDMs

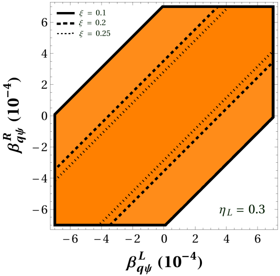


$$+\frac{i}{2}\epsilon_{\mu\nu\rho\sigma} W^{+}_{\mu} W^{-}_{\nu} A^{\rho\sigma} \quad \Rightarrow \quad \mathcal{A}_f \equiv -i\, d_f\, \overline{u}\,(p_2)\; \sigma_{\mu\nu} q^{\nu} \gamma^{5}\, u\,(p_1)$$

$$d_f = \frac{c_\gamma^{mag}}{f} \begin{cases} \mathbf{M}_{4+5}: & \left|\frac{d_f}{e}\right| = \left|\frac{\sqrt{\xi}}{4\sqrt{2}f}\left[\eta_R\left(\beta^L_{q\psi} - \beta^R_{q\psi}\right) + \beta^L_{qu} + \eta_L\left(\beta^L_{u\psi} - \beta^R_{u\psi}\right) - \beta^R_{qu}\right]\right| \\ \mathbf{M}_{4+14}: & \left|\frac{d_f}{e}\right| = \left|\frac{1}{4f}\sqrt{\frac{\xi}{2}}\,\eta_R\left(\beta^L_{q\psi} - \beta^R_{q\psi}\right)\right| \\ \mathbf{M}_{1+5}: & \left|\frac{d_f}{e}\right| = \left|\frac{\sqrt{\xi}}{4\sqrt{2}f}\left(\beta^L_{qu} - \beta^R_{qu}\right) + i\,\frac{(\xi-2)}{4\sqrt{2}f}\,\tilde{\eta}_R\left(\beta^L_{q\psi} + \beta^R_{q\psi}\right)\right| \end{cases}$$

Neutron EDM bound $\left|\frac{d_n}{e}\right| < 2.9 \times 10^{-26}$ cm , at 90% CL





Heavy spin-0 production

$$\mathscr{L}_{ff\eta} = \sum_{f=u,d} \left[g_{ff\eta}\, \bar{f}\, f\, \eta \;+\; \bar{f}\, \partial\!\!\!/ \eta \left(g_{f_L f_L \eta}\, P_L + g_{f_R f_R \eta}\, P_R \right) f \right]$$

Spin-0 decays

* Fermionic channels: single partner

$$\mathscr{L}_{Xf\eta} = \sum_{f=u,d} \left[g_{Xf\eta}\, \bar{X}\, f\, \eta \;+\; \bar{X}\, \partial\!\!\!/ \eta \left(g_{X_L f_L \eta}\, P_L + g_{X_R f_R \eta}\, P_R \right) f \right] \;+\; \text{h.c.}$$

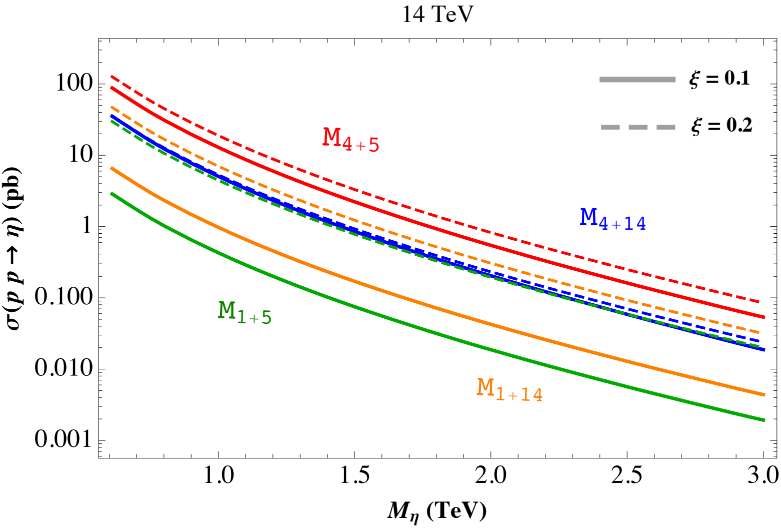
* Fermionic channels: double partner

$$\mathscr{L}_{XX\eta} = g_{XX\eta}\, \bar{X}\, X\, \eta \;+\; \bar{X}\, \partial\!\!\!/ \eta \left(g_{X_L X_L \eta}\, P_L + g_{X_R X_R \eta}\, P_R \right) X$$

* Gauge & Gauge-Higgs modes

$$\mathcal{L}_\eta \supset \frac{f^2}{4} \left(2 a_\eta \frac{\eta}{f} + b_\eta \frac{\eta^2}{f^2} \right) \mathrm{Tr}\left[d_\mu d^\mu \right]$$

Heavy spin-0 production



Setting $\alpha = 1$ @ $\sqrt{s} = 14$ TeV.

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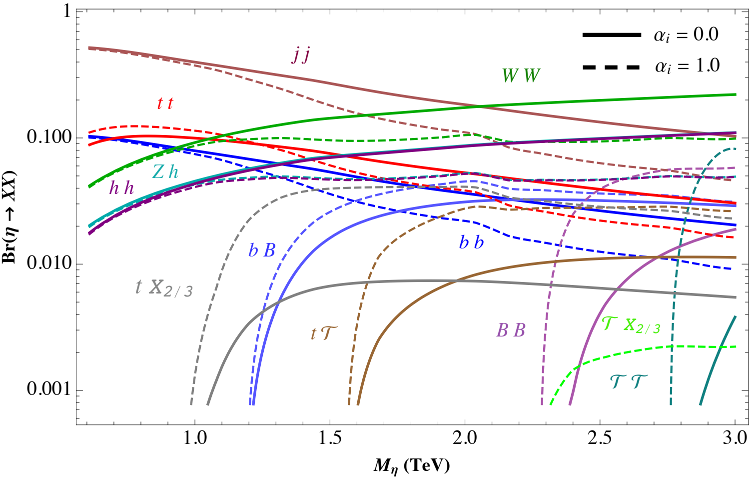
η-Branching ratios

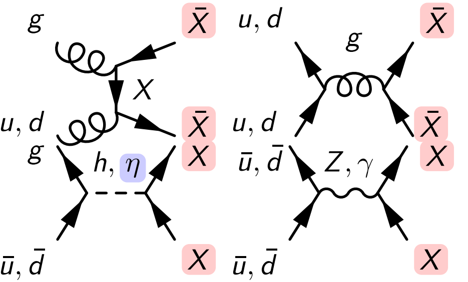


Comparing two different situations $\alpha = 0, 1$ for $a_\eta = 1/2$ & $\xi = 0.2$ @ $\mathbf{M}_{4+5}$

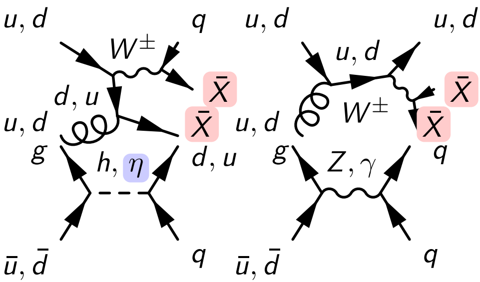
Yielding top partners

QCD-driven+SM gauge-Higgs mediation+intermediation of η

Double production

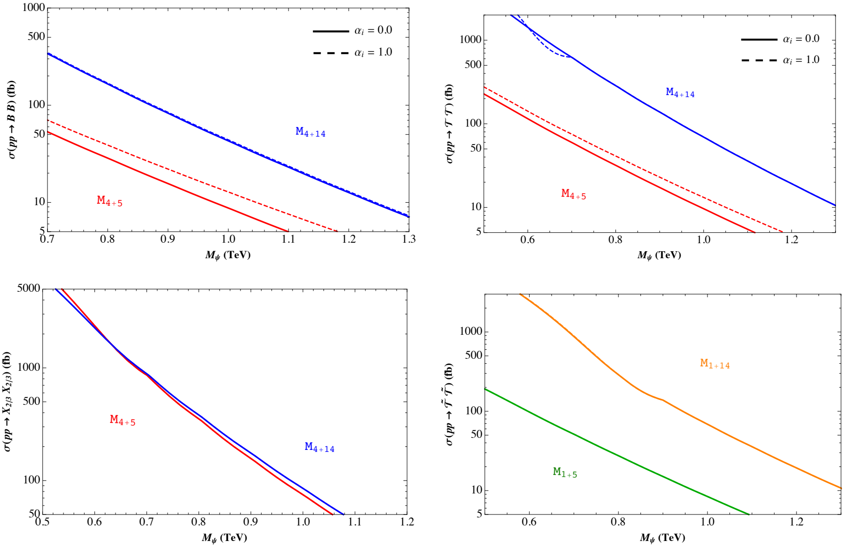


Single production



q any up/down-like quark couple to $X = \{T, B, X_{2/3}, X_{5/3}, \widetilde{T}\}$

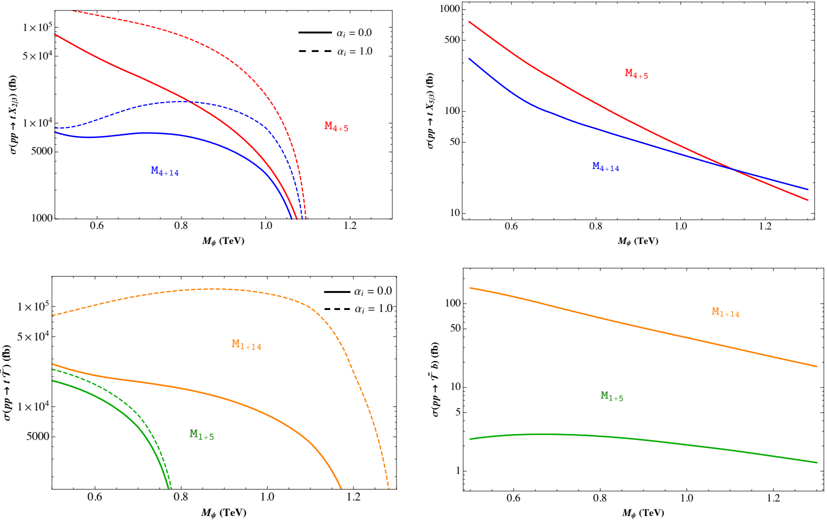
Top partner Double production



Comparing two different situations $\alpha = 0, 1$ for $\xi = 0.2$ @ $\sqrt{s} = 14$ TeV.

S. Norero, J. Yepes and A. Zerwekh, hep-ph:1807.02211

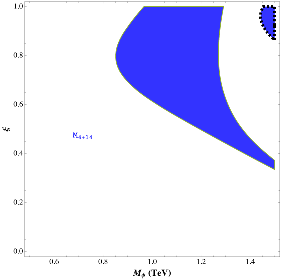
Top partner Single production

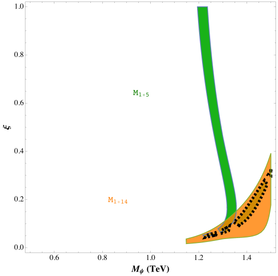


Comparing two different situations $\alpha = 0, 1$ for $\xi = 0.2$ @ $\sqrt{s} = 14$ TeV.

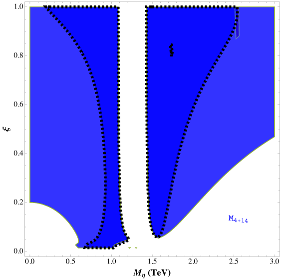
Parameter spaces

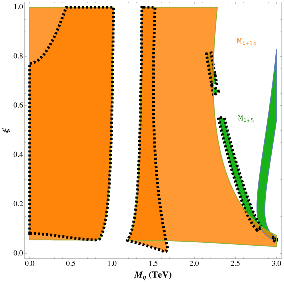
(M_Ψ, ξ), $M_\eta = 3$ TeV



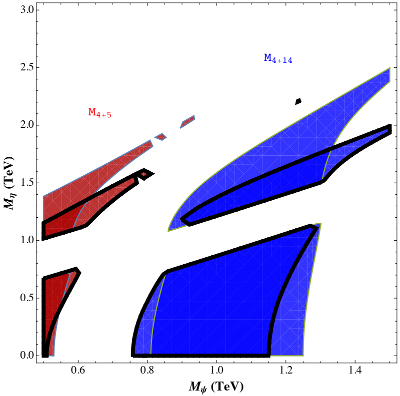


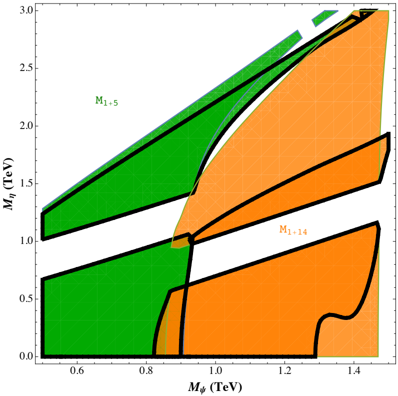
(M_η, ξ), $M_\Psi = 1.25$ TeV





$(M_\Psi,\ M_\eta)$, $\xi = 0.2$





CMS bounds (A. M. Sirunyan *et al.*, 2018) on top partner searches through decays into *Wb* final states imposed

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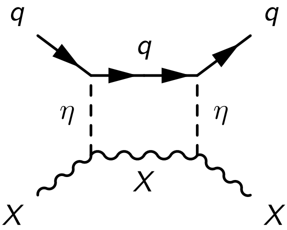
* Loop-level scattering cross sections



* $\sum_q g_{X\eta}^2 g_{\eta q}^2 \mathcal{C}_{\text{loop}}^q \; X_\mu^\dagger X^\mu \bar{q} q \;\Rightarrow\; \sigma_{\text{DM}N}^{\text{SI}} = \frac{\mu_{\text{DMN}}^2}{\pi} |\mathcal{C}(M_X, M_\eta)|^2$

$$\mathcal{C}(M_X, M_\eta) \approx \sum_q g_{X\eta}^2\, g_{\eta q}^2\, m_N\, \frac{2}{27}\, f_{\text{TG}}\, \mathcal{C}(M_X, M_\eta, m_q), \qquad f_{\text{TG}} \sim 0.89 \;\&\; \mu_{\text{DMN}} = \frac{M_X m_N}{M_X + m_N}$$

$$\mathcal{C}(M_X, M_\eta, m_q) = \frac{m_q M_X^2}{16\pi^2} \left[D_0\left(m_q^2, M_X^2, M_X^2, m_q^2; s, t; m_q^2, M_\eta^2, M_X^2, M_\eta^2\right) + D_0\left(m_q^2, M_X^2, M_X^2, m_q^2; t, u; m_q^2, M_\eta^2, M_X^2, M_\eta^2\right)\right]$$