Bilepton production at the LHC

Gennaro Corcella

INFN - Laboratori Nazionali di Frascati

1. **Introduction**
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G.C., C. Corianò, A. Costantini and P.H. Frampton, PLB773 (2017) 544; 1806.04536 (PLB)

The SM is a complete and succesful theory, but presents some open issues

It does not include gravity, nor explains quark/lepton families and heaviness of 3rd family

Neutrino masses and oscillations, along with Dark Matter and baryon asymmetry

Strong CP problem in QCD: smallness of θ in $\mathcal{L}_\theta \sim \theta F_{\mu\nu}\tilde{F}^{\mu\nu}$

Theoretical arguments (hierarchy problem) call for extensions of the SM

Supersymmetry (e.g. MSSM) and large extra dimensions: pretty appealing, but heavily constrained by LHC data

This talk: phenomenology of a scenario not fully investigated

331 (bilepton) model can be already discovered or ruled out at TeV scale

Main signatures: doubly-charged scalars and vectors with $L = \pm 2$

Current experimental analyses focused on doubly-charged (scalar) Higgs bosons in several models (e.g. LRSM), with $\mathrm{BR}(H^{\pm\pm} \to \ell^+\ell^+) = 1$

ATLAS: $\sqrt{s} = 13$ TeV, $\mathcal{L} = 36\ \mathrm{fb}^{-1}$, $m(H^{\pm\pm}) > 660 - 870$ GeV

CMS: $\sqrt{s} = 13$ TeV, $\mathcal{L} = 12.9\ \mathrm{fb}^{-1}$, $m(H^{\pm\pm}) > 800 - 820$ GeV

331 Model (a.k.a. bilepton model): (Frampton'92, Pisano-Pleitez'92)

$$SU(3)_C \times SU(3)_L \times U(1)_X \to SU(3)_C \times SU(2)_L \times U(1)_Y \to SU(3)_C \times U(1)_{\rm em}$$

(Hyper)charges in $SU(3)_L \times U(1)_X$: $Y_{\mathbf{3}(\bar{\mathbf{3}})} = \pm\beta T_8 + X\mathbf{1}$ $\quad Q_{em,\mathbf{3}(\bar{\mathbf{3}})} = Y_{\mathbf{3}} \pm T_3$

$U(1)_X$ charges consistent with SM $q_{X,\mathbf{3}(\bar{\mathbf{3}})} = 1/6 \pm \beta/(2\sqrt{3})$; Minimal 331: $\beta = \sqrt{3}$

Quarks: asymmetric treatment of the third family with respect to first and second

Exotic quarks – D, S: charge -4/3; T: charge +5/3

$$Q_1 = \begin{pmatrix} u_L \\ d_L \\ D_L \end{pmatrix}, \; Q_2 = \begin{pmatrix} c_L \\ s_L \\ S_L \end{pmatrix}, \; Q_{1,2} \in (3, 3, -1/3)$$

$$Q_3 = \begin{pmatrix} t_L \\ b_L \\ T_L \end{pmatrix}, \quad Q_3 \in (3, \bar{3}, 2/3)$$

$(d,s,b)_R \in (\bar{3}, 1, 1/3)$, $(u,c,t)_R \in (\bar{3}, 1, \text{-}2/3)$, $(D,S)_R \in (\bar{3}, 1, 4/3)$, $T_R \in (\bar{3}, 1, \text{-}5/3)$

Lepton sector is 'democratic':

$$\ell = \begin{pmatrix} \ell_L \\ \nu_\ell \\ \bar{\ell}_R \end{pmatrix}, \quad \ell \in (1, \bar{3}, 0), \quad \ell = e, \mu, \tau$$

Anomaly cancellation between families for $N_C = N_{\rm families}$ and not for each generation

Electroweak symmetry breaking: three scalar triplets of $SU(3)_L$

$$\rho = \begin{pmatrix} \rho^{++} \\ \rho^{+} \\ \rho^{0} \end{pmatrix} \in (1,3,1),\ \eta = \begin{pmatrix} \eta^{+} \\ \eta^{0} \\ \eta^{-} \end{pmatrix} \in (1,3,0),\ \chi = \begin{pmatrix} \chi^{0} \\ \chi^{-} \\ \chi^{--} \end{pmatrix} \in (1,3,-1)$$

Breaking $SU(3)_L \times U(1)_X \to SU(2)_L \times U(1)_Y$ through $\langle\rho\rangle$

New vectors Z', $Y^{\pm\pm}$, $Y^{\pm}$ and exotic D, S and T get mass $L(D,S) = +2$; $L(T) = -2$

(Y^{++}, Y^{+}) (Y^{--}, Y^{-}): bileptons with $L(Y)$=±2; $\mathrm{BR}(Y^{++} \to \ell^+\ell^+ = 1)$, $\ell = e, \mu, \tau$

Usual breaking $SU(2)_L \times U(1)_Y \to U(1)_{em}$ through $\langle\eta\rangle$ and $\langle\chi\rangle$

Scalar sextet necessary for lepton masses

$$\sigma = \begin{pmatrix} \sigma_1^{++} & \sigma_1^{+}/\sqrt{2} & \sigma^0/\sqrt{2} \\ \sigma_1^{+}/\sqrt{2} & \sigma_1^{0} & \sigma_2^{-}/\sqrt{2} \\ \sigma^0/\sqrt{2} & \sigma_2^{-}/\sqrt{2} & \sigma_2^{--} \end{pmatrix} \in (1,6,0)$$

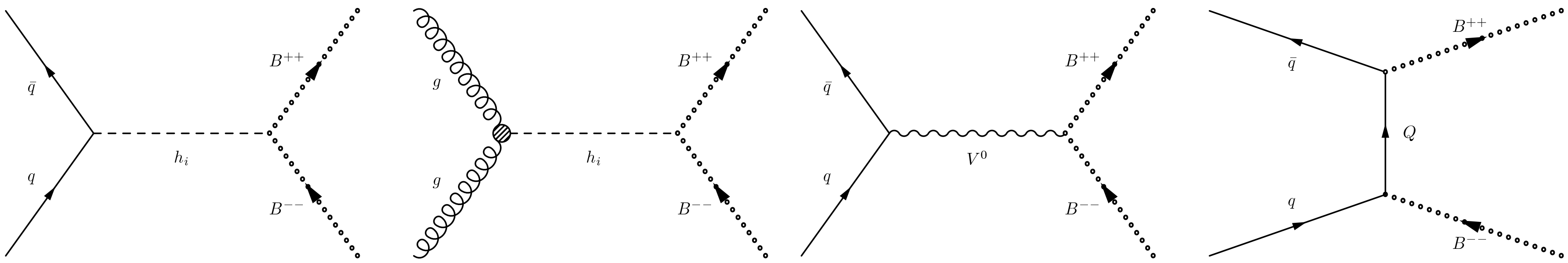
Yukawa Lagrangian: $\mathcal{L}^Y = \mathcal{L}^{\eta}_{tripl.} + \mathcal{L}^{\sigma}_{sext.}$

Neutral Higgses: h_1, h_2, h_3, h_4, h_5 (scalar); a_1, a_2, a_3 (pseudoscalar);

Charged Higgses: $h_1^{\pm}$, $h_2^{\pm}$, $h_3^{\pm}$ (singly charged) and $h_1^{\pm\pm}$, $h_2^{\pm\pm}$, $h_3^{\pm\pm}$ (doubly charged)

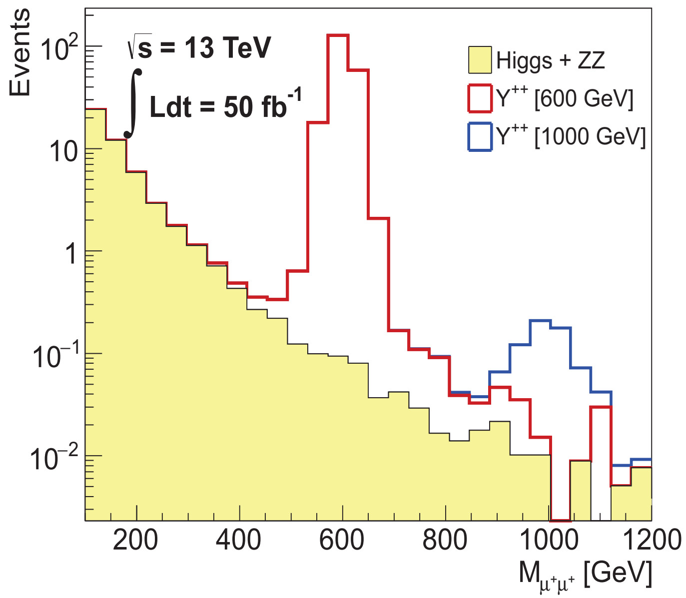
$\mathrm{BR}(h_1^{\pm\pm} h_1^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) \simeq 1/3,\ \ell = e, \mu, \tau$ (sextet signature – BRs specific to our model)

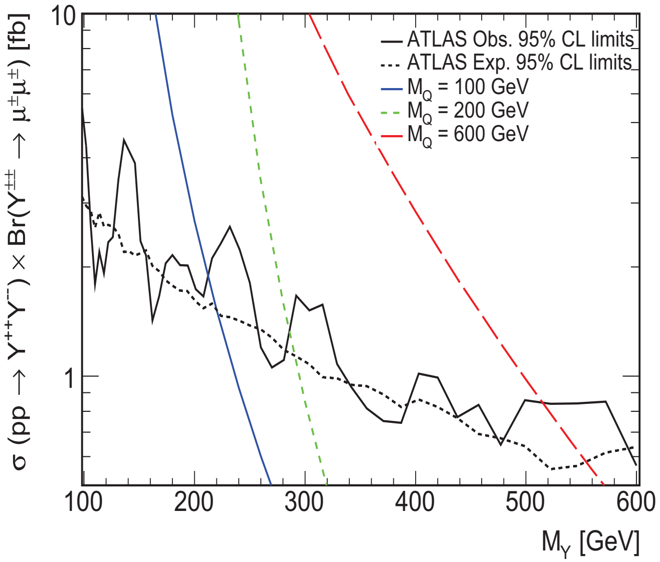
Final states with 2 SS lepton pairs ($B = h_1, Y$): $pp \to B^{++}B^{--} \to (\ell^+\ell^+)(\ell^-\ell^-)$



(a) (b) (c) (d)

Dilepton invariant mass and comparison with ATLAS results (A.Nepomuceno et al,'16)





Exclusion limits: $m_{Y^{++}} >$250-500 GeV (7 TeV, 5 fb^{-1}); 850 GeV (13 TeV, 50 fb^{-1})

Warning: comparison is done with searches for scalar $H^{\pm\pm}$, while $Y^{\pm\pm}$ is a vector

Exploring scalar and vector bileptons at LHC $(H^{\pm\pm} = h_1^{\pm\pm})$

Doubly-charged observables in simplified EFT exhibits large spin effects (A.Alloul et al,'13)

Investigation of scalar and vector bileptons at LO in a companion 331 scenario at 7 TeV: higher cross section for YY than HH because of helicity arguments (E.R.Barreto et al,'11)

Our work: full MC implementation, accounting for latest LHC BSM exclusion limits

Benchmark Point (SARAH)		
$m_{h_1} = 126.3$ GeV	$m_{h_2} = 1804.4$ GeV	$m_{h_3} = 2474.0$ GeV
$m_{h_4} = 6499.8$ GeV	$m_{h_5} = 6528.1$ GeV	
$m_{a_1} = 1804.5$ GeV	$m_{a_2} = 6496.0$ GeV	$m_{a_3} = 6528.1$ GeV
$m_{h_1^\pm} = 1804.5$ GeV	$m_{h_2^\pm} = 1873.4$ GeV	$m_{h_3^\pm} = 6498.1$ GeV
$m_{h_1^{\pm\pm}} = 878.3$ GeV	$m_{h_2^{\pm\pm}} = 6464.3$ GeV	$m_{h_3^{\pm\pm}} = 6527.7$ GeV
$m_{Y^{\pm\pm}} = 878.3$ GeV	$m_{Y^\pm} = 881.8$ GeV	$m_{Z'} = 3247.6$ GeV
$m_D = 1650.0$ GeV	$m_S = 1660.0$ GeV	$m_T = 1700.0$ GeV

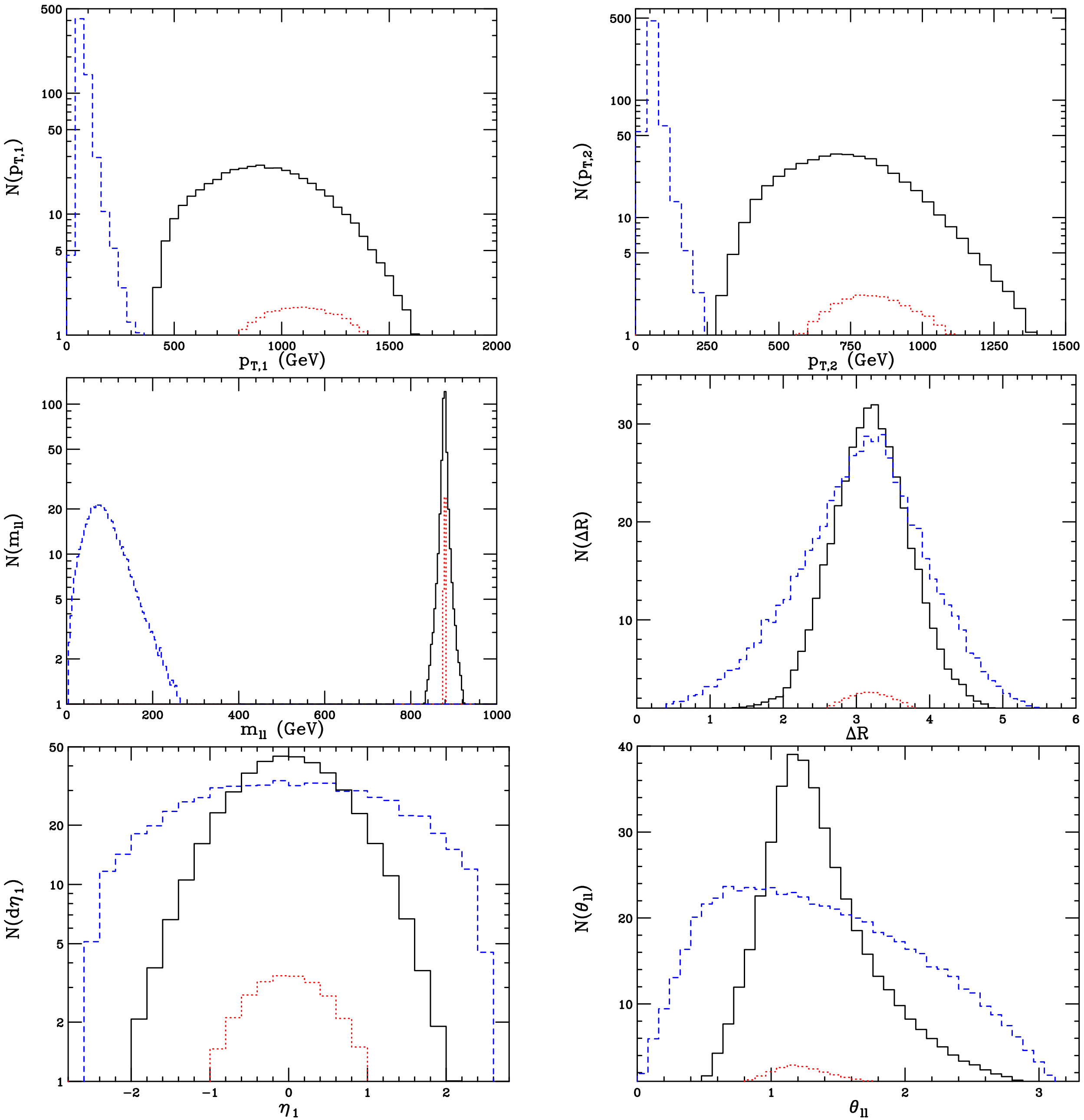
$pp \to Y^{++}Y^{--}(H^{++}H^{--}) \to (\ell^+\ell^+)(\ell^-\ell^-)$; $p_{T,\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, $\Delta R_{\ell\ell} > 0.1$

$$\text{Significance}: \quad s = \frac{S}{\sqrt{B+\sigma_B^2}} \quad ; \quad \sigma_B = 0.1 \times B$$

13 TeV, 300 fb^{-1}: $\sigma_{YY} \simeq 4.3$ fb; $\sigma_{HH} \simeq 0.3$ fb; $\sigma_{ZZ} \simeq 6.1$ fb; $s_{YY} \simeq 6.9$; $s_{HH} \simeq 0.6$

14 TeV, 3000 fb^{-1}: $\sigma_{YY} \simeq 6.0$ fb; $\sigma_{HH} \simeq 0.4$ fb; $\sigma_{ZZ} \simeq 6.6$ fb; $s_{YY} \simeq 9.0$; $s_{HH} \simeq 0.7$

Simulation with MadGraph+HERWIG, $\sqrt{s} = 13$ TeV, $\mathcal{L} = 300$ fb^{-1}



Solid: vector bileptons; Dots: scalar bileptons; Dashes: ZZ background

Conclusions and outlook

Present absence of new physics at LHC calls for exploring unconventional scenarios

331 model predicts asymmetric third quark family and anomaly cancellation

Main signature: vector or scalar bileptons

Full implementation of 331 model in Monte Carlo simulation

Vector bileptons can be detected at 6-9 σ (Run II and HL-LHC); scalars are suppressed

In progress:

Discussion with ATLAS/CMS exotics WGs towards joint analyses

Reconsidering exclusion limits in terms of vector bileptons

Exploring other reference points

Phenomenology of exotic quarks and other scalars in the 331 model