Grand Unification in the light of preliminary LHC hints of W_R

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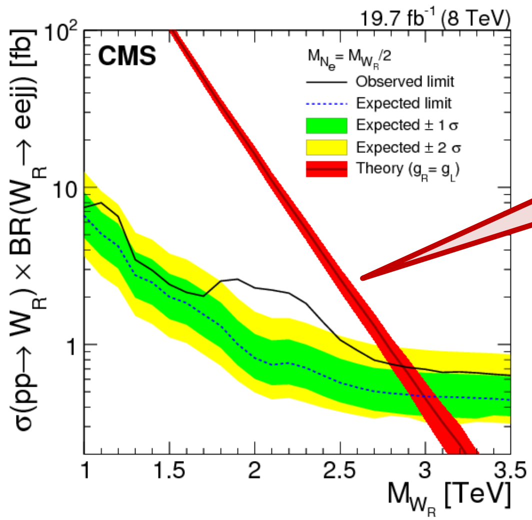
T. Bandyopadhyay, B. Brahmachari and AR, JHEP **023**, 02 (2016)

Plan

- Data
- Left-right symmetry (LRS)
- Interpretation
- $g_L \neq g_R$, Kinematic suppression, …
- Grand unification
- SO(10) $\Rightarrow$ LRS
- Symmetry-breaking route consistent with $M_R \sim$ TeV?
- Only one route of descent can accommodate
- Conclusions

ee *jj* excess in CMS LHC Run-1 data

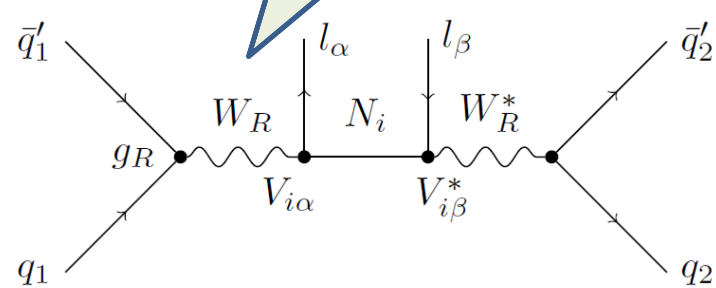
$\sqrt{s}$ = 8 TeV, $\int \mathscr{L}\, dt$ = 19.7 fb^{-1}



LRS Model with $g_L = g_R$
And $m_N/m_W = 0.5$

$$p\bar{p} \to W_R \to ll' + 2jets$$

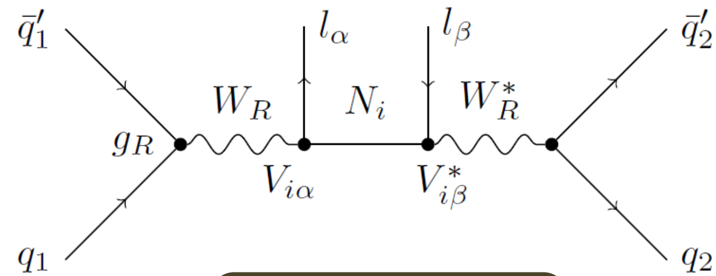
The signal channel



- No excess in μμ *jj* mode
- Same sign leptons: only 1 out of 14 events

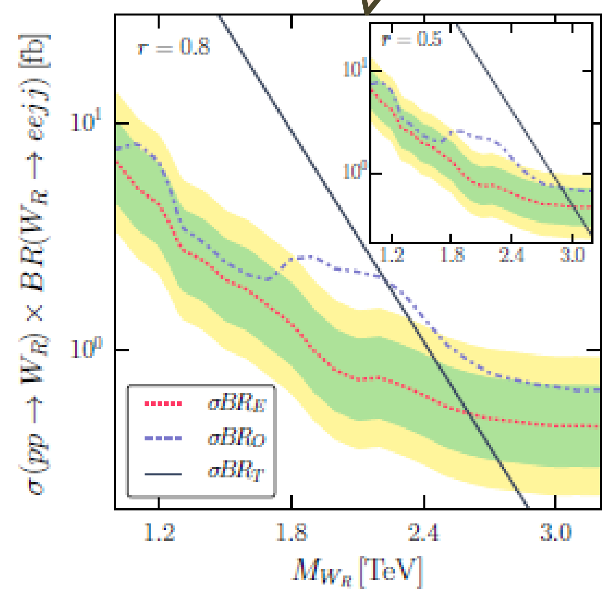
Kinematic suppression?

Two step process: $W_R \rightarrow N_i\ l_\alpha$
$N_i \rightarrow l_\beta\, j\, j$



η = 1, |Vne| =1

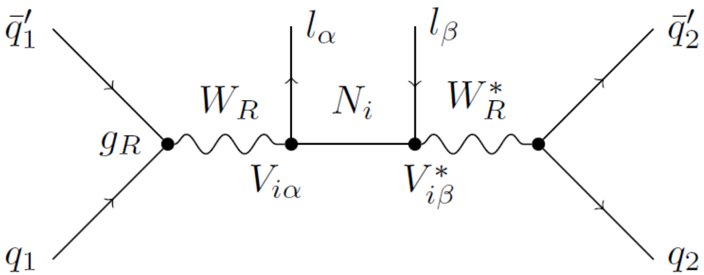
$$\sigma BR_T \equiv \sigma(pp \rightarrow W_R)\cdot BR(W_R \rightarrow eejj)$$
$$\propto \eta^2 |V_{N_l l'}|^4 (1-r^2)^2 (2+r^2)$$



- $\eta = g_R / g_L$
- $r = m_N / m_{WR}$

LRS with $g_L \neq g_R$? Lepton mixing?

Two step process: $W_R \to N_i\ l_\alpha$
$N_i \to l_\beta\, j\, j$



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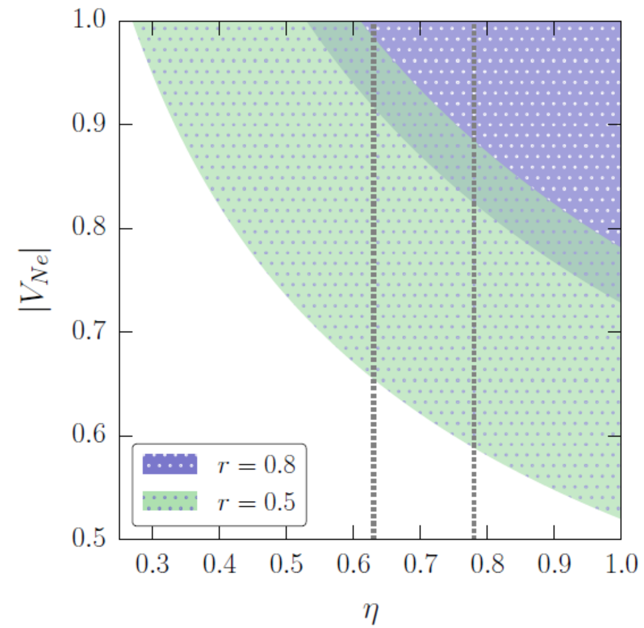
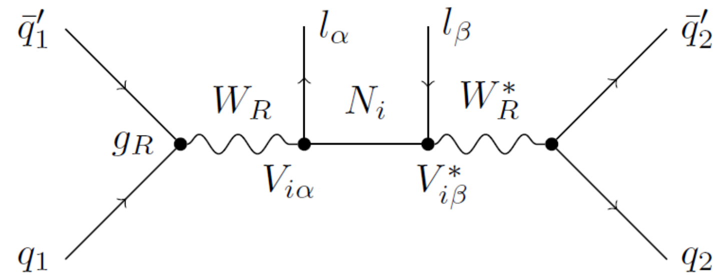
- $\eta = g_L / g_R$
- $r = m_N / m_{WR}$



$g_L \neq g_R$? Lepton mixing? Kinematic suppression?

Two step process: $W_R \to N_i\ l_\alpha$
$N_i \to l_\beta\, j\, j$



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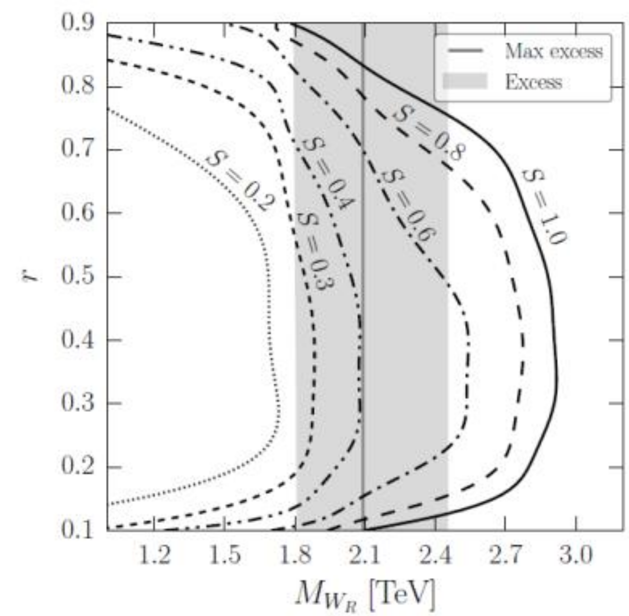


- $\eta = g_R / g_L$
- $r = m_N / m_{WR}$
- $S = \eta\ |V_{N\ e}|^2$

Some virtues of SO(10), Symmetry breaking

- Includes left-right symmetry, right-handed neutrino, neutrino mass
- L $\Leftrightarrow$ R discrete symmetry and $SU(2)_R$ breaking can be decoupled.

- Pati-Salam $SU(4)_C \times SU(2)_L \times SU(2)_R$ – quark lepton unification – is also a subgroup.

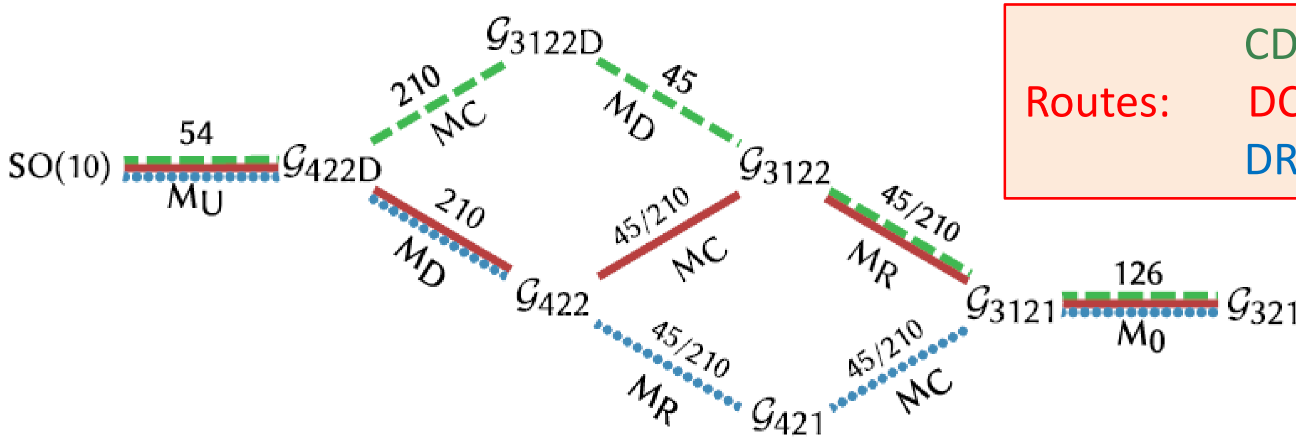
Lepton No. as fourth colour $\begin{pmatrix} u_1, u_2, u_3, \nu_e \\ d_1, d_2, d_3, e \end{pmatrix}$

- M_C scale of $SU(4)_C \rightarrow SU(3)_C \times U(1)_{B-L}$ breaking
- M_R scale of $SU(2)_R$ breaking $\sim$ TeV
- M_D scale of left-right discrete symmetry breaking ($g_L \neq g_R$ below this scale)

Which ordering of symmetry breaking scales are consistent with M_R ~ 1 TeV?

What is $\eta = g_R / g_L$ from GUT?

Breaking routes of SO(10)



- M_C scale of $SU(4)_C$ breaking
- M_R scale of $SU(2)_R$ breaking
- M_D scale of left-right discrete symmetry breaking ($g_L \neq g_R$ below this scale)

Which routes are consistent with M_R ~ 1 TeV?

DRC route, other routes of SO(10) breaking

- For the DRC route $M_C < M_R \sim 1$ TeV
- Such a low M_C -- $SU(4)_C$ breaking scale -- conflicts with bounds on leptoquark bosons from processes such as $K_L \rightarrow \mu\, e$ etc. ($> 10^6$ GeV)
- So, DRC not consistent with $M_R \sim 1$ TeV

DRC route does not allow $M_R \sim$TeV!

Examine CDR and DCR routes: gauge coupling unification?

$$\frac{1}{\alpha^g(\mu_i)} = \frac{1}{\alpha^g(\mu_j)} + b^g_{ji} \ln\left(\frac{\mu_j}{\mu_i}\right)$$

1 loop RG eqn

In compact notation: $w_i^g = w_j^g + b_{ji}^g \Delta_{ji}$

Beta-function coefficients

$$w_i^g = w_j^g + b_{ji}^g \Delta_{ji}$$

b_{ji}^g gets contributions from the gauge fields, fermion fields, and scalar fields

$$b_{ji}^g = -\frac{11}{3} C_2(G) + \frac{2}{3} T_2(F) + \frac{1}{6} T_2(S)$$

Gauge fields

Chiral Fermions

Real scalars

- ❖The gauge contribution is fixed at every stage by the unbroken symmetry
- ❖No extra fermions are introduced $\Rightarrow$ fixes fermion contribution
- ❖Many scalars are required for SSB. Their contributions are significant

Minimal fine tuning/Extended Survival Hypothesis: As few scalars light as possible

Minimal fine tuning, coupling matching

At any scale all scalar submultiplets are heavy except those necessary for symmetry breaking at lower energy

$$w_i^g = w_j^g + b_{ji}^g \Delta_{ji}$$

- At symmetry breaking, gauge coupling continuity is maintained

  e.g., at M_C $SU(4)_C \rightarrow SU(3)_C \times U(1)_{B-L}$ $\Rightarrow g_4(M_C) = g_3(M_C) = g_{B-L}(M_C)$
- When two U(1) factors merge at symmetry breaking the couplings are related.

  e.g. when $U(1)_{B-L} \times U(1)_R \rightarrow U(1)_Y \Rightarrow w_Y = (3/5)\, w_R + (2/5)\, w_{B-L}$

The CDR Route

$$SO(10) \rightarrow G_{422D} \rightarrow G_{3122D} \rightarrow G_{3122} \rightarrow G_{3121} \rightarrow G_{321}$$

$[15,1,1]_+ \subset 210$

$[1,0,1,1]_- \subset 210$

$[1.0.1.3] \subset 210$

$b^3_{CD} = -7$, $b^{B-L}_{CD} = 7$, $b^{2L}_{CD} = -2$, $b^{2R}_{CD} = -2$

$b^3_{DR} = -7$, $b^{B-L}_{DR} = 11/2$, $b^{2L}_{DR} = -3$, $b^{2R}_{DR} = -2$

Large scalar contributions

$\Rightarrow w^{2L}_R - w^{2R}_R = (1/2\pi)\,(b^{2L}_{DR} - b^{2R}_{DR})\Delta_{DR} = -(1/2\pi)\,\Delta_{DR}$

and $w^3_R - w^{B-L}_R = (1/2\pi)\,\{(-25/2)\Delta_{DR} - 14\,\Delta_{CD}\}$

The CDR Route

$$SO(10) \rightarrow G_{422D} \rightarrow G_{3122D} \rightarrow G_{3122} \rightarrow G_{3121} \rightarrow G_{321}$$

$w^{2L}{}_R - w^{2R}{}_R = (1/2\pi)\,(b^{2L}{}_{DR} - b^{2R}{}_{DR})\Delta_{DR} = -(1/2\pi)\,\Delta_{DR}$

and $w^{3}{}_R - w^{B-L}{}_R = (1/2\pi)\,\{(-25/2)\Delta_{DR} - 14\,\Delta_{CD}\}$

Ignoring the running over the small range M_R to M_Z and using

$3\,w^{2R}{}_R + 2w^{B-L}{}_R = 5w^{Y}{}_R$ one gets

$\Rightarrow$ $3\,w^{2L}{}_Z + 2w^{3}{}_Z - 5w^{Y}{}_Z = (1/2\pi)\,(28)\Delta_{CR}$

Left-side from low-energy data $\Rightarrow$ $M_C = 10^{18}\,M_R \sim 10^{21}$ GeV

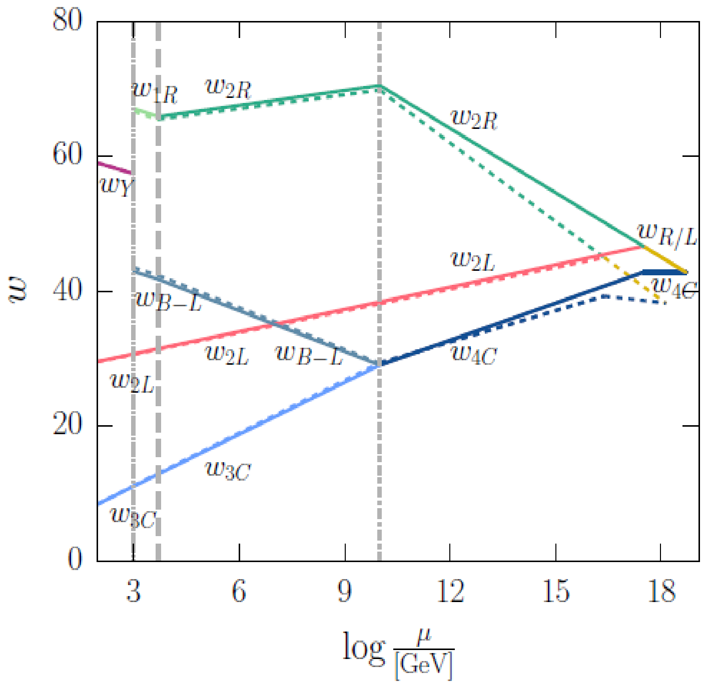
$M_C > M_{Pl}$ CDR Route also inadmissible!

The DCR Route

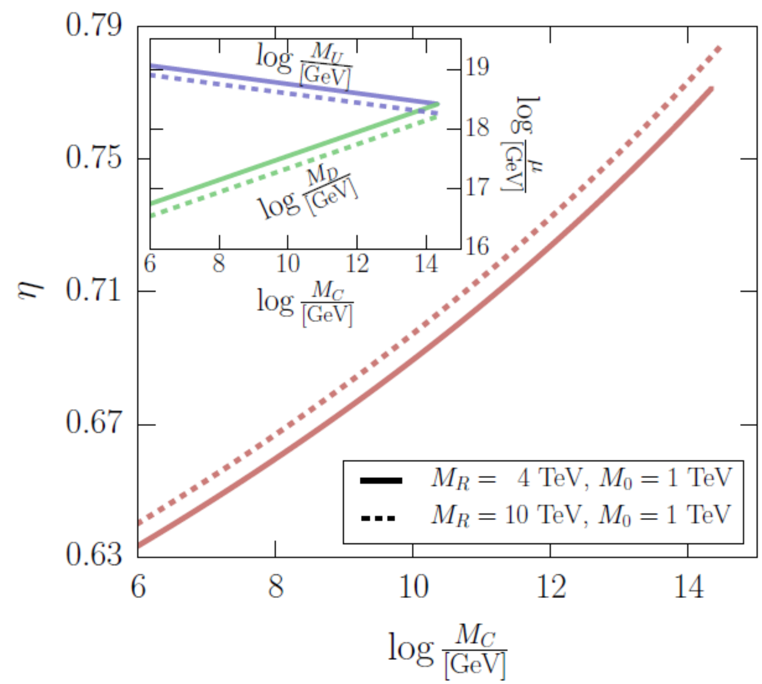
$$SO(10) \rightarrow G_{422D} \rightarrow G_{422} \rightarrow G_{3122} \rightarrow G_{3121} \rightarrow G_{321}$$

The only remaining route!

This one is viable.



Gauge coupling evolution with $M_C = 10^{10}$ GeV



$0.78 \geq g_R/g_L \geq 0.64$

Unification and intermediate scales

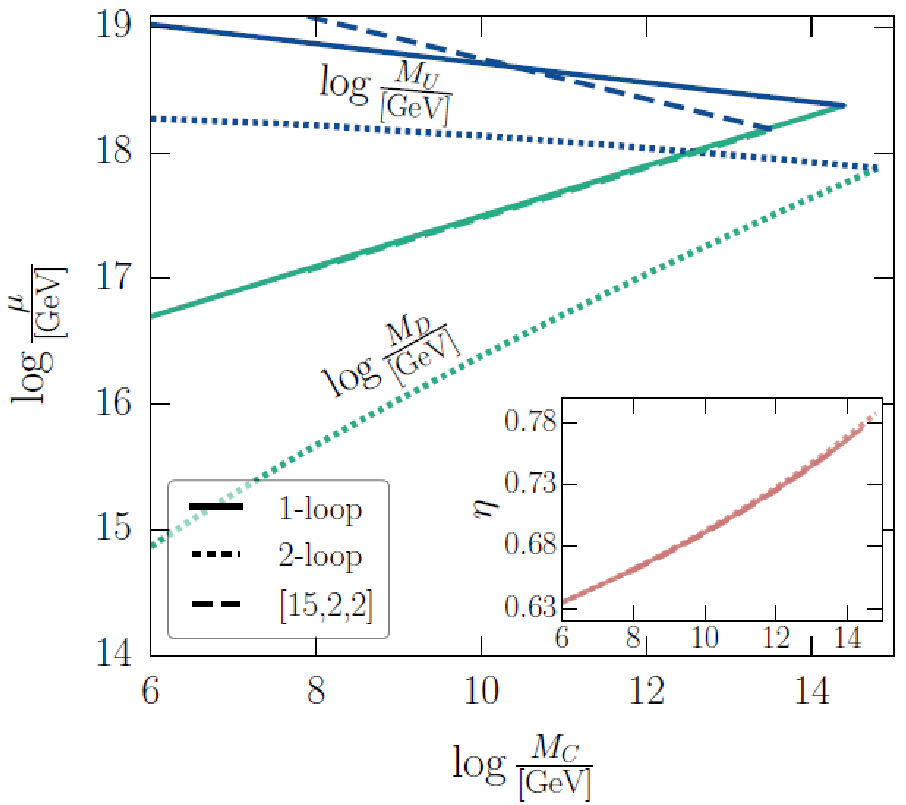
!

The DCR Route

$$SO(10) \rightarrow G_{422D} \rightarrow G_{422} \rightarrow G_{3122} \rightarrow G_{3121} \rightarrow G_{321}$$

Two loop calculation

Note $M_U \geq 10^{18}$ GeV
p-lifetime very large



!

Conclusions

- Excess seen by CMS in ee *jj* channel can be interpreted in terms of W_R-boson production
- With $g_L = g_R$, $r = m_N/m_W = 0.5$, and $V_{Ne} = 1$ does not agree.
- One or more of $g_L \neq g_R$, $r \neq 0.5$, $V_{Ne} \neq 1$ changes this.

- SO(10) GUT includes LRS.
- It gives $g_L \neq g_R$ if D-parity is broken at a high scale
- Most symmetry breaking routes cannot satisfy $M_R \sim$ TeV
- Allowed only if symmetry breaks in the order is $M_D > M_C > M_R$
- Unification scale is around 10^{18} GeV. p-decay suppressed!

Thank You!