The darkness within: Unification & revival of the right

by

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tifr

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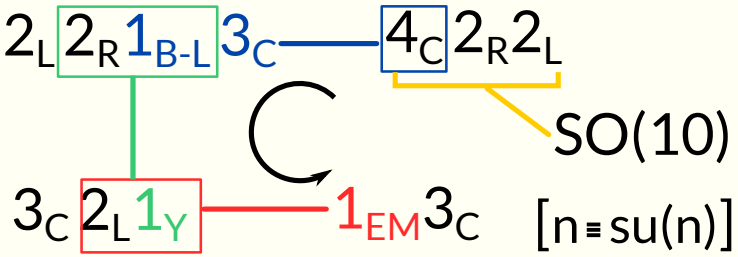
Unified Left-Right Formalism



SM

Quarks: $\begin{bmatrix} u_L \\ d_L \end{bmatrix} + u_R + d_R$ Leptons: $\begin{bmatrix} \nu_L \\ e_L \end{bmatrix} + e_R$

↓

LRS

Quarks: $\begin{bmatrix} u_L \\ d_L \end{bmatrix} \begin{bmatrix} u_R \\ d_R \end{bmatrix}$ Leptons: $\begin{bmatrix} \nu_L \\ e_L \end{bmatrix} \begin{bmatrix} N_R \\ e_R \end{bmatrix}$

↓

Pati Salam

$$\underbrace{\begin{bmatrix} u^r & u^g & u^b & \nu_e^l \\ d^r & d^g & d^b & e^l \end{bmatrix}}_{SU(4)_C}$$

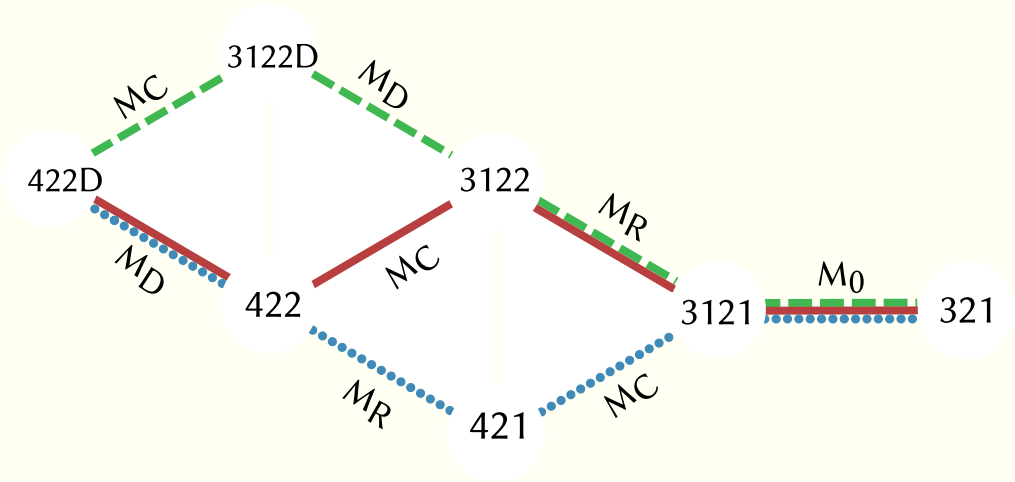
- $L \leftrightarrow R$: $\mathcal{L} \to \mathcal{L}' = \mathcal{L}$
- η gets *vev*: $g_L \neq g_R$

SO(10)

- All the fermions (15+1) of a generation reside in the same representation of $SO(10) \rightarrow$ 16 dim.
  - Left-right symmetric
  - Leptons, quarks have the same footing
- Contains an element which acts as the discrete $L \leftrightarrow R$ operator
  - Adjoint (45 dim.) and other representations have scalars odd under this operator

  $\Longrightarrow$ Satisfactory explanation of spontaneous parity breaking possible
- No redundant fermions needed
- Only one rank above SM, i.e., 5 diagonal generators in place of the SM 4.

Symmetry Breaking



$M_C > M_D > M_R$

$M_D > M_C > M_R$

$M_D > M_R > M_C$

constraints

1. $M_{\text{Pl}} > M_U \gtrsim 10^{15.5}$ GeV $\longrightarrow$ Proton Decay
2. $M_U > M_P \gtrsim 10^{12}$ GeV $\longrightarrow$ Domain Walls
3. $M_U > M_C \gtrsim 10^{06}$ GeV $\longrightarrow$ Strange Decays ($K_L/B_{d,s} \xrightarrow{\text{lptqrk}} \mu e$)
4. $M_U > M_R > M_0 \gtrsim 1$ TeV $\longrightarrow$ Kept at $\mathcal{O}$(TeV)

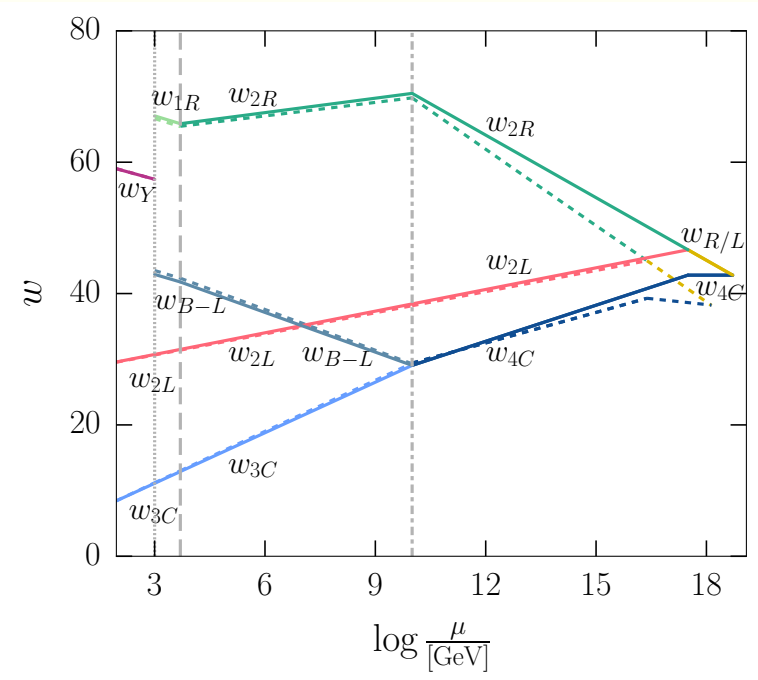
$$B_{DC} > 2/3b + B_{CR}$$

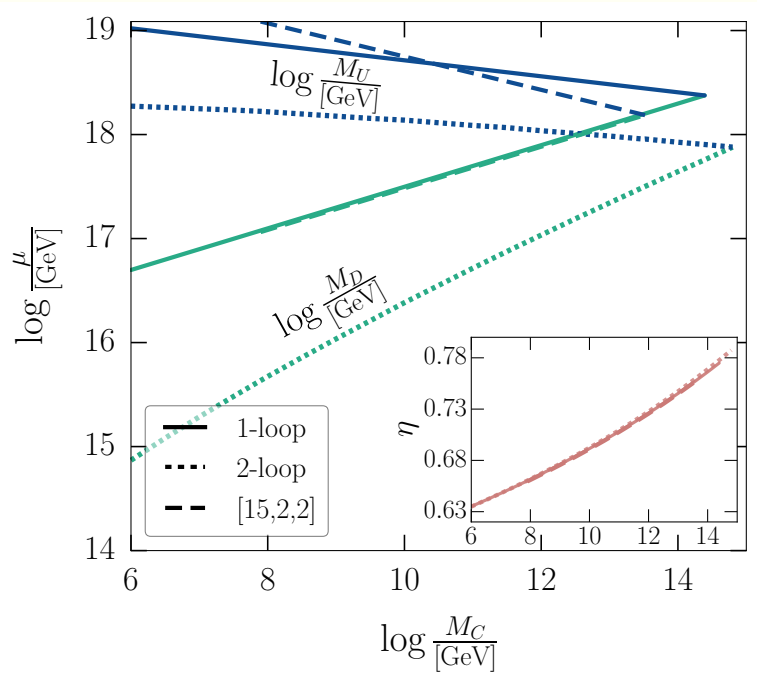
Minimal SO(10) without dark matter

Scalar minimalism:

At any stage of intermediate symmetry only those sub-multiplets survive which are *required* to break a symmetry at that stage or a subsequent stage. (The extended survival hypothesis (ESH))

$$422D \xrightarrow[(1,1,1)]{M_D} 422 \xrightarrow[(15,1,1)]{M_C} 3122 \xrightarrow[(15,3,1)]{M_R} 3121 \xrightarrow[(10,2,2)]{M_0} G_{SM}$$





The natural Z2

- **U(1)** broken by scalar of charge **'n'** $\longrightarrow$ remnant $\mathbf{Z_n}$
- $U(1)_{B-L}$ of LRS broken by the B-L=2 Δ_R, $\longrightarrow$ remnant Z_2
  - $P \equiv (-1)^{3(B-L)}$, "matter parity" if you will!
- Z_2 inherent in gauge structure

- SM Fermions:
  - Leptons: $3(B-L) = -3$, i.e. 'odd'
  - Quarks: $3(B-L) = -1$, i.e. 'odd'
- Scalars: $3(B-L) = 0$, i.e. 'Even'

- Fermions with $B - L =$ even, belong in the dark sector
- The other way round for scalars

Model Mechanics

'Real' (Self-conjugate) $SU(2)$ multiplets

$X_L \oplus X_R \equiv (1_C, (2m+1)_L, 1_R, 0) \oplus (1_C, 1_L, (2m+1)_R, 0)$

$m \in \mathbb{N}$

- For each multiplet:
  - 1 Majorana fermion
  - m pairs of Dirac fermions
  - electric charges 1 to m

Mass

$$\mathcal{L}_{X_M} = \frac{\mathcal{M}_i}{2}\left(\overline{X_L^{i\,c}} X_L^i + R \leftrightarrow L\right) + \frac{h_i}{2}(v_\eta + \eta)\left(\overline{X_L^{i\,c}} X_L^i - R \leftrightarrow L\right) + h.c.$$

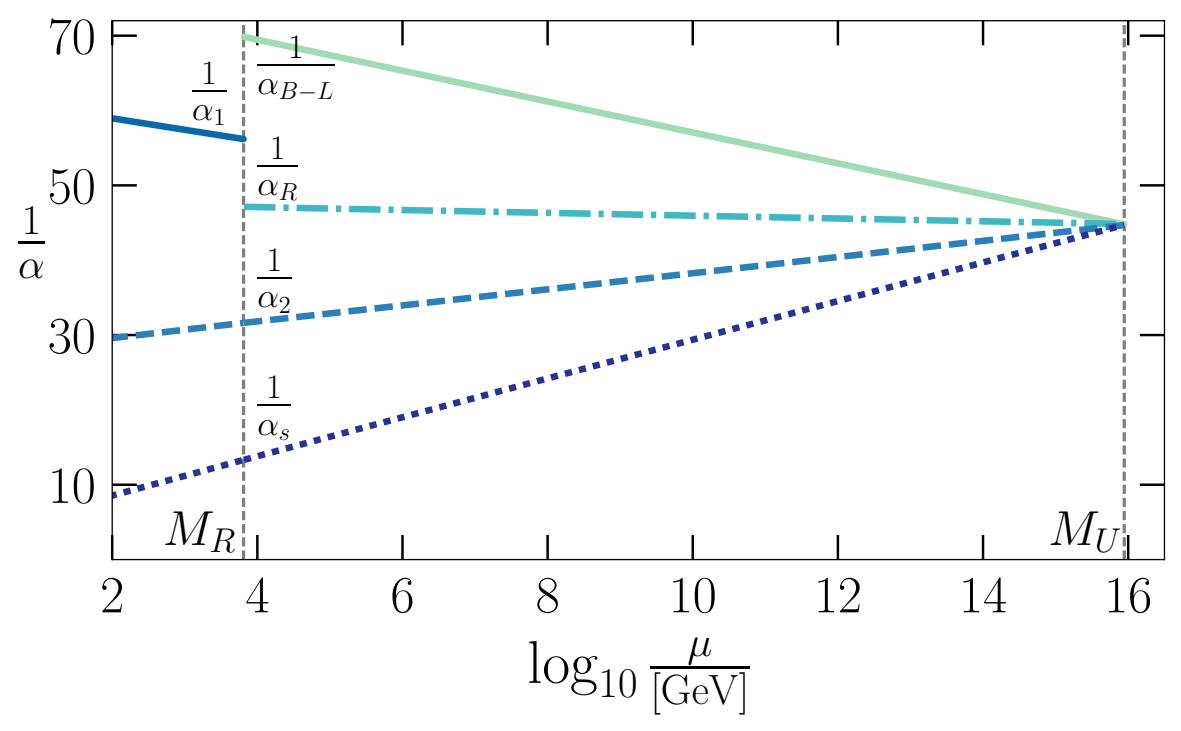
After $L \leftrightarrow R$ breaks

$$M_i^L = \mathcal{M}_i + h_i v_\eta;\ M_i^R = \mathcal{M}_i - h_i v_\eta$$

$M_L \longrightarrow$ High scale

$M_R \longrightarrow$ Low scale

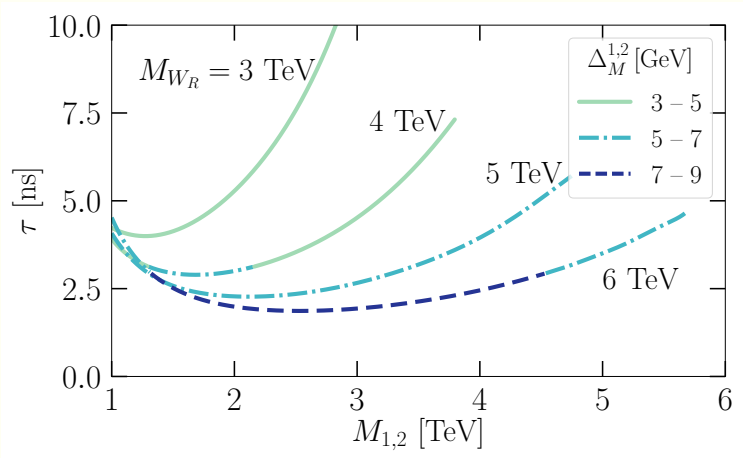
Gauge Coupling Unification



$g_R = 0.52$
$g_U = 0.53$
$4 < M_R < 9$ TeV
$M_U \sim 10^{16}$ GeV

Triplets (m=1)

- 1 gen $\rightarrow M_R \sim \mathcal{O}(\mathrm{PeV})$
- 2 gen $\rightarrow M_R \sim \mathcal{O}(\mathrm{TeV})$



SO(10)

Embedding

$$45 \supset (1,3,1) + (1,1,3) \quad + \quad (15,1,1) + (6,2,2)$$

$$\mathcal{L}_{\text{Mass}} = -\frac{\mathcal{M}_{1,2}}{2}\overline{45_F^{1,2^C}}45_F^{1,2} + h.c. \ ,$$

For triplets

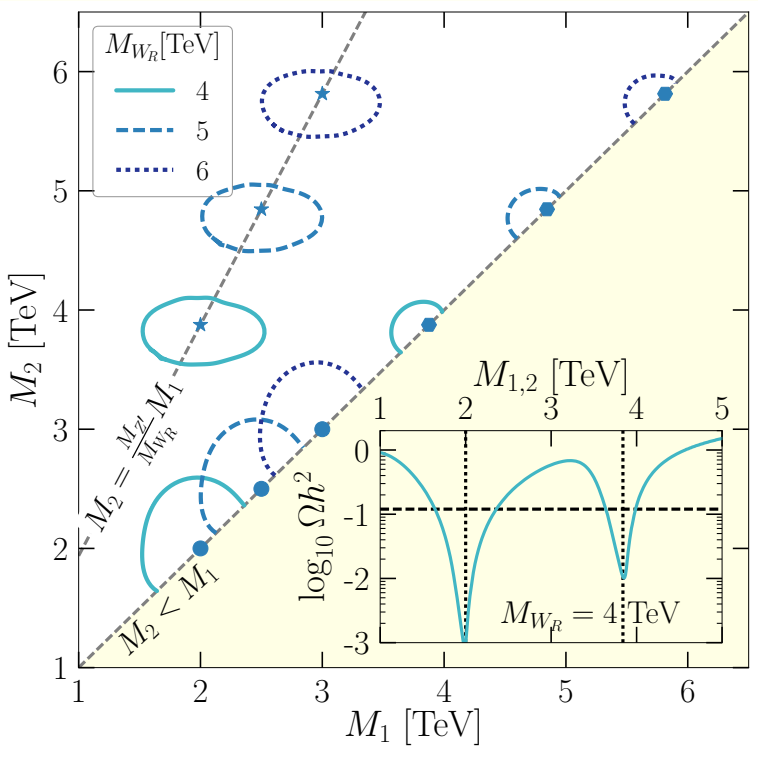
$$M_i^L = \mathcal{M}_i + h_i v_\eta; \ M_i^R = \mathcal{M}_i - h_i v_\eta$$

(15,1,1),(6,2,2)

Do not couple to $\eta \longrightarrow$ No splitting

Only consistent way of keeping the mass of a submultiplet low

Relic Density



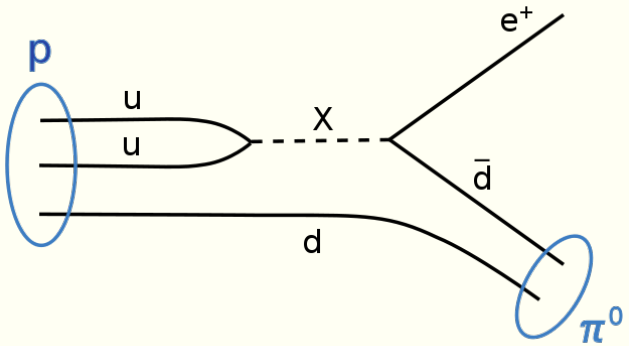
- Resonance mediated
- Around:
  - $(W_R, W_R), (Z', Z'), (W_R, Z')$
- $\chi^{\pm}\chi^0 \to SM\ SM$
- $\chi^{+}\chi^{-} \to SM\ SM$
- $\chi^0\chi^0 \to W_R W_R$

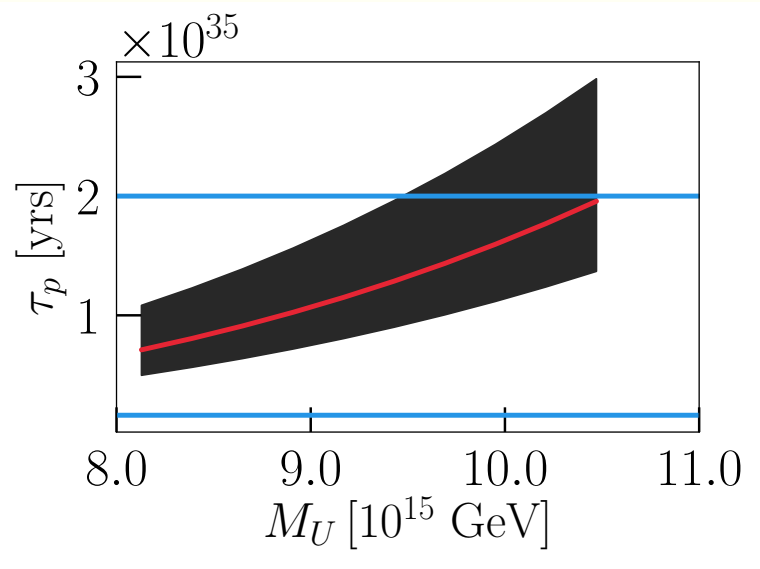
- g_R, M_R, M_χ determined $\Longrightarrow$ Highly predictive
- Very small leeway for parameters to vary
- Falsifiable $\longrightarrow$ How???

Proton Decay

Protons decay in unified theories

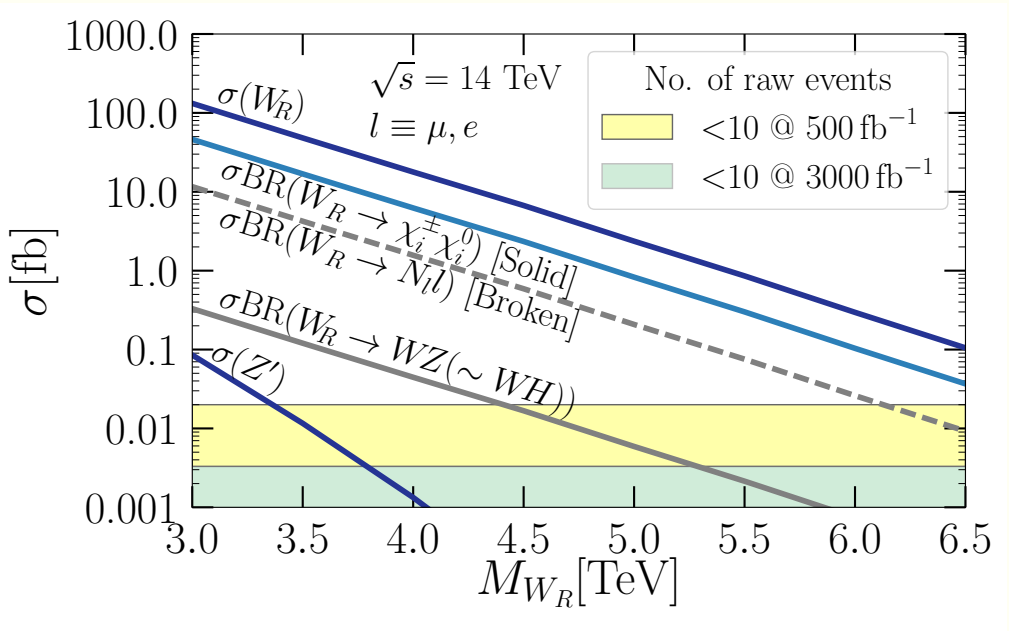
- Leptoquark gauge bosons
- Dominant Channels
  - $p \to \pi^0 e^+ / K^+ \overline{\nu}$





- Super-K exclusion
  - $\tau_p > 1.6 \times 10^{34}$ yrs.
- Hyper-K projected [2045]
  - $\tau_p \gtrsim 2 \times 10^{35}$ yrs.

Collider Searches (W_R)

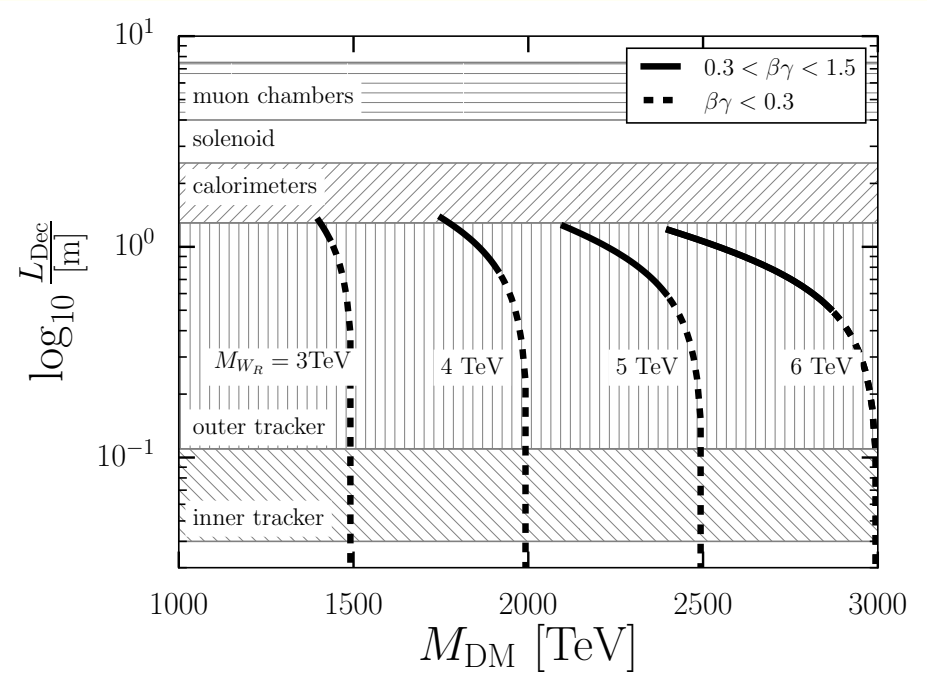


- $M_{Z'} \sim 1.9 \times M_{W_R}$
- $M_{\chi 1} = M_{\chi 2} = M_N$

- χ lighter than W_R
- Wildly different branching fractions
- Slim parameter space
- Easy to distinguish from standard LRS

Collider Searches (χ)

$$pp \to W_R^+ \to \chi^0 \chi^+ \to \chi^0 \chi^0 jj$$



- $\tau \sim$ ns
- $L = \beta c \gamma \tau$
- $L \to 0.1 - 1$m

- $\beta\gamma \longrightarrow$ Bethe Bloch

$\longrightarrow$ Highly ionizing

- Easy to distinguish from SM
- CMS, ATLAS, MoEDAL $\longrightarrow$ Longlived heavy charged particle searches

Conclusions

- Unified models $\rightarrow$ answers to questions raised by SM
- Notoriously difficult to have 'clean' unification with $\mathcal{O}(\text{TeV})$ Physics
- We propose a left-right symmetric SO(10) 'formalism':
  - Mechanism to keep parts of larger fermionic multiplets light
  - Suitable dark matter candidates
  - Highly restricted parameter space
  - Falsifiability at all thresholds

Acknowledgements

Work presented here appears in:

- "Left-right model with TeV fermionic dark matter and unification," trip and A.Raychaudhuri
  Phys. Lett. B **771** (2017) 206
- "Implications of the CMS search for W_R on grand unification," trip, B. Brahmachari and A. Raychaudhuri
  JHEP **1602** (2016) 023

Thank You

Questions/Input/Critique?