Dark matter in left-right symmetric standard model

triplet scalar dark matter portal

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1803

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`http://gfif.udea.edu.co`

Focus on

arXiv:1703.08148 (PRD)

In collaboration with

C. Arbeláez (UFSM)& M. Hirsch (IFIC)

Table of Contents

Review of SM

Lorentz transformation

Boost in x

$$\{x^\mu\} = \begin{pmatrix} t \\ x \\ y \\ z \end{pmatrix} \to \begin{pmatrix} t' \\ x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \frac{t+vx}{\sqrt{1-v^2}} \\ \frac{x+vt}{\sqrt{1-v^2}} \\ y \\ z \end{pmatrix} = \begin{pmatrix} \cosh\xi & \sinh\xi & 0 & 0 \\ \sinh\xi & \cosh\xi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} t \\ x \\ y \\ z \end{pmatrix}$$

$$x'^\mu \to x^\mu = {\Lambda_x}^\mu{}_\nu x^\nu\,,$$

where ($c = 1$)

$$\cosh\xi = \gamma \qquad \sinh\xi = v\gamma, \qquad \text{and} \qquad \gamma = \frac{1}{\sqrt{1-v^2}}.$$

In general

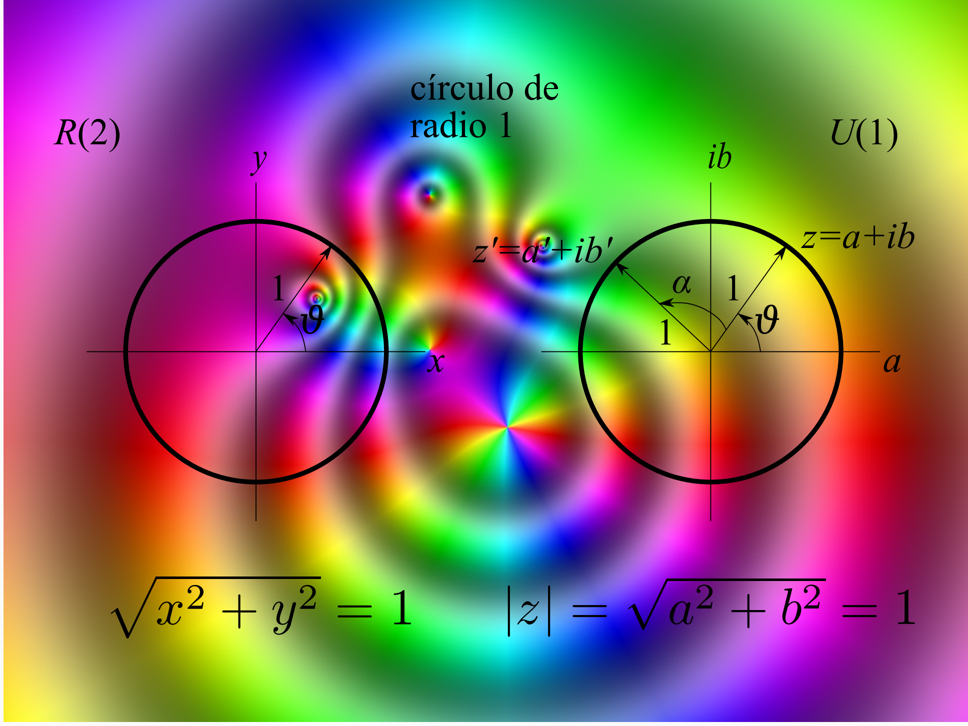
$$\Lambda^\mu{}_\nu = [\exp(\boldsymbol{\xi}\cdot\mathsf{K} + i\boldsymbol{\theta}\cdot\mathsf{L})]^\mu{}_\nu$$

$$x'\cdot y' = x'_\mu y'^\mu = x_\mu y^\mu\,, \qquad \text{if:} \qquad g_{\alpha\beta} = \Lambda^\mu{}_\alpha g_{\mu\nu}\Lambda^\nu{}_\beta\,.$$

Theorem of Noether

For each continuous simetry there is at least one conserved charge.

Emmy Noether (1882-1935)



círculo de
radio 1
R(2)
U(1)
y
x
1
ϑ
ib
a
z=a+ib
z′=a′+ib′
α
1
1
ϑ
√(x² + y²) = 1
|z| = √(a² + b²) = 1

Only fields

Lorentz :

$$\mathcal{L} = -\tfrac{1}{4}\left(\partial^\mu A^\nu - \partial^\nu A^\mu\right)\left(\partial_\mu A_\nu - \partial_\nu A_\mu\right) . \tag{1}$$

$$\begin{aligned}
A^\mu(x) \to A'^\mu(x) =& \Lambda^\mu{}_\nu A^\nu(\Lambda^{-1}x) && \text{Vector field}\\
\phi(x) \to \phi'(x) =& \phi(\Lambda^{-1}x) && \text{Scalar field}\\
\psi_\alpha(x) \to \psi'_\alpha(x) =& [S(\Lambda)]_\alpha{}^\beta \psi_\beta(\Lambda^{-1}x)\,, && \text{Left Weyl spinor}\\
(\psi_\alpha(x))^\dagger = \psi^\dagger_{\dot\alpha}(x) \to \psi'^\dagger_{\dot\alpha}(x) =& [S^*(\Lambda)]_{\dot\alpha}{}^{\dot\beta} \psi^\dagger_{\dot\beta}(\Lambda^{-1}x)\,, && \text{Right anti-Weyl spir}
\end{aligned}$$

With

$$S(\Lambda) = \exp\left(\boldsymbol{\xi}\cdot\frac{\boldsymbol{\sigma}}{2} + i\boldsymbol{\theta}\cdot\frac{\boldsymbol{\sigma}}{2}\right) ,$$

where $\boldsymbol{\sigma} = (\sigma_1, \sigma_2, \sigma_3)$ are the Pauli matrices. $\overline{\boldsymbol{\sigma}} \equiv -\boldsymbol{\sigma}$.

Only fields

Lorentz+$U(1)$:

$$\mathcal{L} = \partial_\mu \phi^* \partial^\mu \phi - m^2 \phi^* \phi - \lambda \left(\phi^* \phi\right)^2 \ . \tag{1}$$

$$\begin{aligned}
A^\mu(x) \to A'^\mu(x) =& \Lambda^\mu{}_\nu A^\nu(\Lambda^{-1}x) && \text{Vector field}\\
\phi(x) \to \phi'(x) =& \phi(\Lambda^{-1}x) && \text{Scalar field}\\
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With

$$S(\Lambda) = \exp\left(\boldsymbol{\xi} \cdot \frac{\boldsymbol{\sigma}}{2} + i\boldsymbol{\theta} \cdot \frac{\boldsymbol{\sigma}}{2}\right) \ ,$$

where $\boldsymbol{\sigma} = (\sigma_1, \sigma_2, \sigma_3)$ are the Pauli matrices. $\overline{\boldsymbol{\sigma}} \equiv -\boldsymbol{\sigma}$.

Weyl spinor

$$\begin{aligned}\mathcal{L} =& i\psi^\dagger_{\dot\alpha}\overline{\sigma}^{\mu\dot\alpha\alpha}\partial_\mu\psi_\alpha - m\left(\psi^\alpha\psi_\alpha + \psi^\dagger_{\dot\alpha}\psi^{\dagger\dot\alpha}\right)\\ =& i\psi^\dagger\overline{\sigma}^\mu\partial_\mu\psi - m\left(\psi\psi + \psi^\dagger\psi^\dagger\right)\,. \end{aligned} \tag{2}$$

Only if

$$S^\dagger a^\nu S =(\Lambda)^\nu{}_\rho a^\rho\,,$$

Electron field: *one in four*: Dreiner,... arXiv:0812.1594 (PR)

Scalar product: $\;{}^{\alpha}{}_{\alpha}\;$ and $\;{}_{\dot\alpha}{}^{\dot\alpha}\,.$

Name	Symbol Name	Lorentz Na
e_L: left electron	ξ_α	$[S]_\alpha{}^\beta$
$(e_L)^\dagger = e_R^\dagger$: right positron	$(\xi_\alpha)^\dagger = \xi^\dagger_{\dot\alpha}$	$[S^*]_{\dot\alpha}{}^{\dot\beta}$
e_R: right electron	$(\eta^\alpha)^\dagger = \eta^{\dagger\,\dot\alpha}$	$\left[(S^{-1})^\dagger\right]^{\dot\alpha}$
$(e_R)^\dagger = e_L^\dagger$: left positron	η^α	$\left[(S^{-1})^T\right]^{\alpha}$

$$\begin{aligned}\mathcal{L} =& i\xi^\dagger_{\dot\alpha}\overline{\sigma}^{\mu\,\dot\alpha\alpha}\partial_\mu\xi_\alpha + i\eta^\alpha\sigma^\mu_{\alpha\dot\alpha}\partial_\mu\eta^{\dagger\,\dot\alpha} - m\left(\eta^\alpha\xi_\alpha + \xi^\dagger_{\dot\alpha}\eta^{\dagger\,\dot\alpha}\right)\\ =& i\xi^\dagger\overline{\sigma}^\mu\partial_\mu\xi + i\eta\sigma^\mu\partial_\mu\eta^\dagger - m\left(\eta\xi + \xi^\dagger\eta^\dagger\right) + \;.\end{aligned}$$

Electron field: *one in four*: Dreiner,... arXiv:0812.1594 (PR)

Scalar product: $\quad {}^{\alpha}{}_{\alpha} \quad$ and $\quad {}_{\dot\alpha}{}^{\dot\alpha}$.

Name	Symbol Name	Lorentz Na
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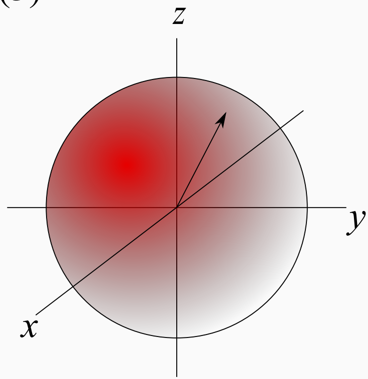
e_R: right electron	$(\eta^\alpha)^\dagger = \eta^{\dagger\,\dot\alpha}$	$\left[(S^{-1})^\dagger\right]^{\dot\alpha}$
$(e_R)^\dagger = e_L^\dagger$: left positron	η^α	$\left[(S^{-1})^T\right]^{\alpha}$

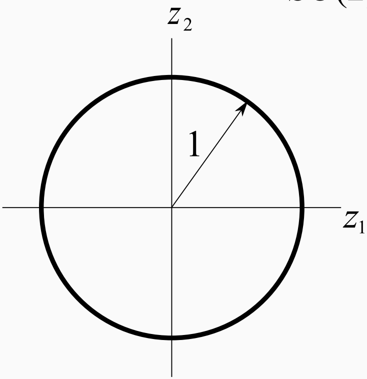
$$\mathcal{L} = i \begin{pmatrix} \xi^\dagger_{\dot\alpha} & \eta^\alpha \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} 0 & \sigma^\mu_{\alpha\dot\alpha} \\ \overline{\sigma}^{\mu\,\dot\alpha\alpha} & 0 \end{pmatrix} \begin{pmatrix} \partial_\mu \xi_\alpha \\ \partial_\mu \eta^{\dagger\,\dot\alpha} \end{pmatrix} - m \begin{pmatrix} \xi^\dagger_{\dot\alpha} & \eta^\alpha \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

3 generadores

$R(3)$

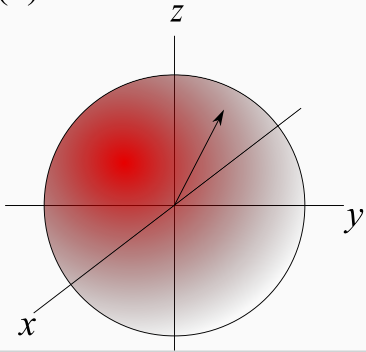


$SU(2)$

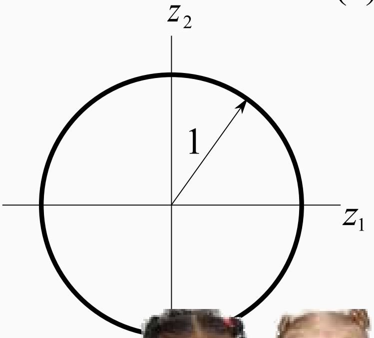


3 generadores

$R(3)$



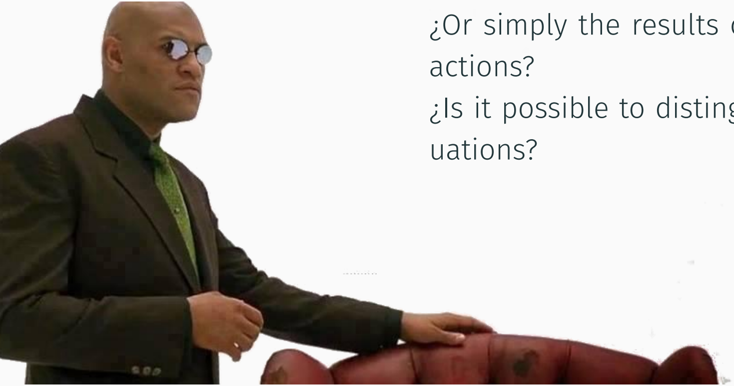
$SU(2)$



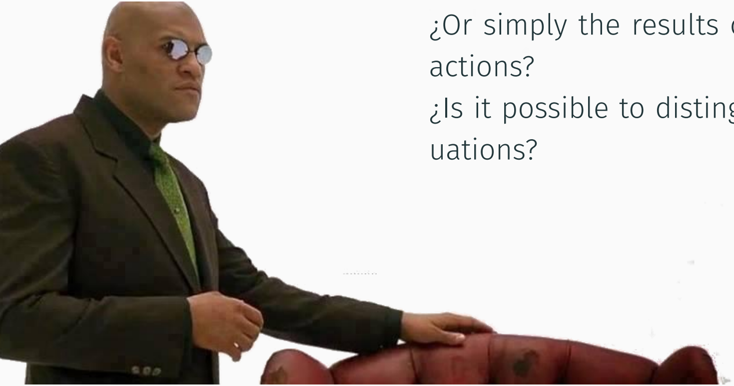
$SU(2)_L$ in an ideal Universe

$$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \qquad Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$$

Massless states with same (hyper)charge!



¿Is the mass something real?
¿Or simply the results of some interactions?
¿Is it possible to distinguish both situations?



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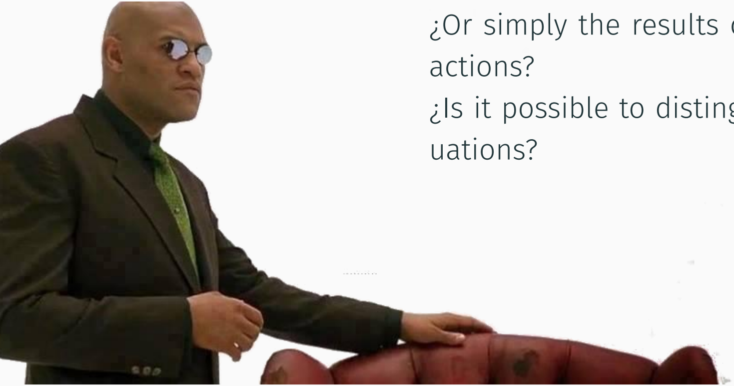
Answer

- Prediction of charm quark (Bjorken-Glashow 1964)
- W and Z mass and SM Higgs boson



¿Is the mass something real?
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¿Is it possible to distinguish both situations?

Answer

- Prediction of charm quark (Bjorken-Glashow 1964)
- W and Z mass and SM Higgs boson
- $m_{\text{proton}} \gg 2m_u + m_d$

Consider the left-quark up: u

$$\Psi_L^u = \begin{pmatrix} u_L \\ u_L \\ u_L \end{pmatrix}$$

From global to local

Let $U(x) \in SU(N)$ and Ψ a multiplet of left spinors under $SU(N)$. We replace ∂_μ by the covariant derivative $\mathcal{D}_\mu$:

$$\Psi \to \Psi' = U\Psi\,, \qquad \Psi^\dagger \to \Psi'^\dagger = \Psi^\dagger U^\dagger\,,$$

$$\mathcal{D}_\mu\Psi \to (\mathcal{D}_\mu\Psi)' = U\left(\mathcal{D}_\mu\Psi\right)\,, \quad (\mathcal{D}_\mu\Psi)^\dagger \to (\mathcal{D}_\mu\Psi)'^\dagger = (\mathcal{D}_\mu\Psi)^\dagger\, U^\dagger\,,$$

since the mass term is forbidden

$$\mathcal{L}_{SU(N)} = i\Psi\,\overline{\sigma}^\mu\mathcal{D}_\mu\Psi - \frac{1}{2}\operatorname{Tr}\left(G_{\mu\nu}G^{\mu\nu}\right)$$

with the following $N \times N$ matrix equations ($\alpha_N \equiv g^2/4\pi$ is the $SU(N)$ coupling)

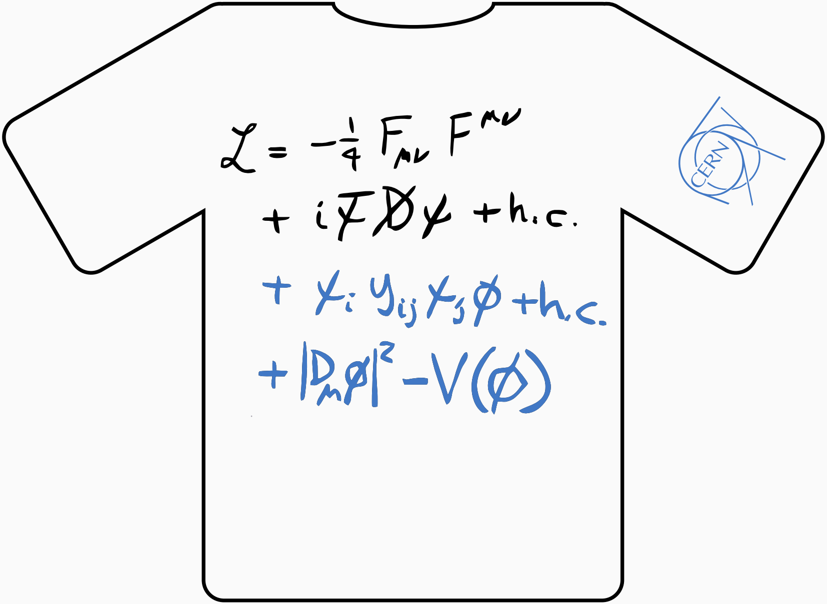
$$\mathcal{D}_\mu = \mathbf{1}\partial_\mu - igG_\mu\,, \qquad \widehat{G}_{\mu\nu} = \frac{i}{g}\left[\mathcal{D}_\mu, \mathcal{D}_\nu\right]$$

Details: `http://fisica.udea.edu.co`$\to$`cursos`$\to$ `Física Subatómica`

Standard Model Lagrangian (simplified version)

$$
\begin{aligned}
\mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
& + i \bar{\psi} \not{D} \psi + h.c. \\
& + \psi_i y_{ij} \psi_j \phi + h.c. \\
& + |D_\mu \phi|^2 - V(\phi)
\end{aligned}
$$

Standard Model Lagrangian (simplified version)

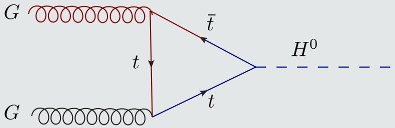


$$
\begin{aligned}
\mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
& + i \bar{\psi} \not{D} \psi + h.c. \\
& + \psi_i y_{ij} \psi_j \phi + h.c. \\
& + |D_\mu \phi|^2 - V(\phi)
\end{aligned}
$$

Higgs production and decay

Gluon fusion

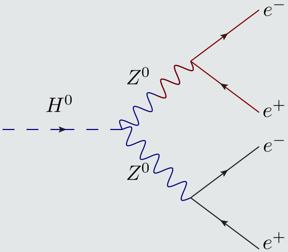
$i\bar{\psi}\not{D}\psi$



$\chi_i y_{ij} \chi_j \phi$

Golden channel

$|D_\mu \phi|^2$



$i\bar{\psi}\not{D}\psi$

Standard Model: particles

$SU(3)_c$

$d_L^1 \quad d_L^2 \quad d_L^3$

$d_R^1 \quad d_R^2 \quad d_R^3$

Standard Model: particles

$SU(3)_c$

$$\begin{array}{ccc} d_L^1 & d_L^2 & d_L^3 \\ u_L^1 & u_L^2 & u_L^3 \\ d_R^1 & d_R^2 & d_R^3 \\ u_R^1 & u_R^2 & u_R^3 \end{array}$$

Standard Model: particles

$SU(3)_c$

$$\begin{array}{ccccccccc}
d_L^1 & d_L^2 & d_L^3 & s_L^1 & s_L^2 & s_L^3 & b_L^1 & b_L^2 & b_L^3 \\
u_L^1 & u_L^2 & u_L^3 & c_L^1 & c_L^2 & c_L^3 & t_L^1 & t_L^2 & t_L^3 \\
d_R^1 & d_R^2 & d_R^3 & s_R^1 & s_R^2 & s_R^3 & b_R^1 & b_R^2 & b_R^3 \\
u_R^1 & u_R^2 & u_R^3 & c_R^1 & c_R^2 & c_R^3 & t_R^1 & t_R^2 & t_R^3
\end{array}$$

Standard Model: particles

$SU(3)_c$

$$
\begin{array}{c}
G_1 \\ G_2 \\ \vdots \\ G_8
\end{array}
\left\{
\begin{array}{ccccccccccccc}
d_L^1 & d_L^2 & d_L^3 & s_L^1 & s_L^2 & s_L^3 & b_L^1 & b_L^2 & b_L^3 & \rightarrow & d_L^\alpha & s_L^\alpha & b_L^\alpha \\
u_L^1 & u_L^2 & u_L^3 & c_L^1 & c_L^2 & c_L^3 & t_L^1 & t_L^2 & t_L^3 & & u_L^\alpha & c_L^\alpha & t_L^\alpha \\
d_R^1 & d_R^2 & d_R^3 & s_R^1 & s_R^2 & s_R^3 & b_R^1 & b_R^2 & b_R^3 & \rightarrow & d_R^\alpha & s_R^\alpha & b_R^\alpha \\
u_R^1 & u_R^2 & u_R^3 & c_R^1 & c_R^2 & c_R^3 & t_R^1 & t_R^2 & t_R^3 & \rightarrow & u_R^\alpha & c_R^\alpha & t_R^\alpha
\end{array}
\right.
$$

Standard Model: particles

$$SU(3)_c$$

$$
\begin{array}{ll|ccccccccc|c|ccc}
 & & & & & & & & & & & & e_R & \mu_R & \tau_R \\
 & & & & & & & & & & & & e_L & \mu_L & \tau_L \\
 & & & & & & & & & & & & \nu_L^e & \nu_L^\mu & \nu_L^\tau \\
G_1 & \multirow{4}{*}{$\left\{\begin{array}{c} \\ \\ \\ \\ \end{array}\right.$} & d_L^1 & d_L^2 & d_L^3 & s_L^1 & s_L^2 & s_L^3 & b_L^1 & b_L^2 & b_L^3 & \multirow{2}{*}{$\rightarrow$} & d_L^\alpha & s_L^\alpha & b_L^\alpha \\
G_2 & & u_L^1 & u_L^2 & u_L^3 & c_L^1 & c_L^2 & c_L^3 & t_L^1 & t_L^2 & t_L^3 & & u_L^\alpha & c_L^\alpha & t_L^\alpha \\
\vdots & & d_R^1 & d_R^2 & d_R^3 & s_R^1 & s_R^2 & s_R^3 & b_R^1 & b_R^2 & b_R^3 & \rightarrow & d_R^\alpha & s_R^\alpha & b_R^\alpha \\
G_8 & & u_R^1 & u_R^2 & u_R^3 & c_R^1 & c_R^2 & c_R^3 & t_R^1 & t_R^2 & t_R^3 & \rightarrow & u_R^\alpha & c_R^\alpha & t_R^\alpha
\end{array}
$$

$$SU(3)_c \times SU(2)_L$$

$$\begin{array}{rl} & \begin{array}{ccc} e_R & \mu_R & \tau_R \end{array} \\ W^\pm \left\{ \begin{array}{c} \\ \\ \end{array} \right. & \left. \begin{array}{ccc} e_L & \mu_L & \tau_L \\ \nu_L^e & \nu_L^\mu & \nu_L^\tau \end{array} \right\} \quad L_1 \quad L_2 \quad L_3 \end{array}$$

$$\begin{array}{c} G_1 \\ G_2 \\ \vdots \\ G_8 \end{array} \left\{ \begin{array}{l} W^\pm \left\{ \begin{array}{ccccccccc} d_L^1 & d_L^2 & d_L^3 & s_L^1 & s_L^2 & s_L^3 & b_L^1 & b_L^2 & b_L^3 \\ u_L^1 & u_L^2 & u_L^3 & c_L^1 & c_L^2 & c_L^3 & t_L^1 & t_L^2 & t_L^3 \end{array} \right. \to \left. \begin{array}{ccc} d_L^\alpha & s_L^\alpha & b_L^\alpha \\ u_L^\alpha & c_L^\alpha & t_L^\alpha \end{array} \right\} \quad Q_1^\alpha \quad Q_2^\alpha \quad Q_3^\alpha \\ \qquad\quad \begin{array}{ccccccccc} d_R^1 & d_R^2 & d_R^3 & s_R^1 & s_R^2 & s_R^3 & b_R^1 & b_R^2 & b_R^3 \\ u_R^1 & u_R^2 & u_R^3 & c_R^1 & c_R^2 & c_R^3 & t_R^1 & t_R^2 & t_R^3 \end{array} \begin{array}{c} \to \\ \to \end{array} \begin{array}{ccc} d_R^\alpha & s_R^\alpha & b_R^\alpha \\ u_R^\alpha & c_R^\alpha & t_R^\alpha \end{array} \end{array} \right.$$

$$m_i = 0$$

Standard Model: particles

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

$$
\begin{array}{c} Z^0 \\ \gamma \end{array}
\left\{
\begin{array}{l}
\begin{array}{ll} & W^{\pm} \left\{ \begin{array}{c} \\ \\ \end{array} \right. \end{array}
\begin{array}{ccc} e_R & \mu_R & \tau_R \\ e_L & \mu_L & \tau_L \\ \nu_L^e & \nu_L^\mu & \nu_L^\tau \end{array}
\begin{array}{c} \\ \left. \begin{array}{c} \\ \\ \end{array} \right\} \end{array}
\quad L_1 \quad L_2 \quad L_3 \\
\begin{array}{c} G_1 \\ G_2 \\ \vdots \\ G_8 \end{array}
\left\{
\begin{array}{l}
W^{\pm} \left\{ \begin{array}{ccccccccccccc}
d_L^1 & d_L^2 & d_L^3 & s_L^1 & s_L^2 & s_L^3 & b_L^1 & b_L^2 & b_L^3 & \to & d_L^\alpha & s_L^\alpha & b_L^\alpha \\
u_L^1 & u_L^2 & u_L^3 & c_L^1 & c_L^2 & c_L^3 & t_L^1 & t_L^2 & t_L^3 & \to & u_L^\alpha & c_L^\alpha & t_L^\alpha
\end{array} \right\} \quad Q_1^\alpha \quad Q_2^\alpha \quad Q_3^\alpha \\
\phantom{W^{\pm} \{} \begin{array}{ccccccccccccc}
d_R^1 & d_R^2 & d_R^3 & s_R^1 & s_R^2 & s_R^3 & b_R^1 & b_R^2 & b_R^3 & \to & d_R^\alpha & s_R^\alpha & b_R^\alpha \\
u_R^1 & u_R^2 & u_R^3 & c_R^1 & c_R^2 & c_R^3 & t_R^1 & t_R^2 & t_R^3 & \to & u_R^\alpha & c_R^\alpha & t_R^\alpha
\end{array}
\end{array}
\right.
\end{array}
\right.
$$

$$m_i = 0 \qquad\qquad Y_{u_L} = Y_{d_L}$$

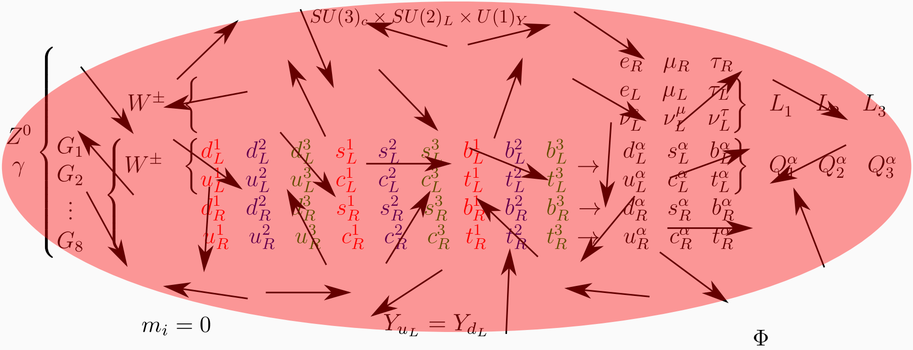
Standard Model: particles

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

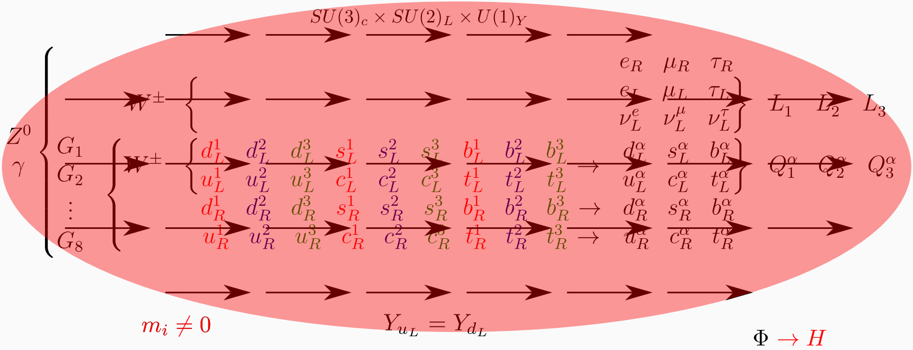
$$
\begin{array}{ccccccccccccccccccccc}
 & & & & & & & & & & & & e_R & \mu_R & \tau_R & & & & 3 \\
 & & W^\pm & & & & & & & & & & e_L & \mu_L & \tau_L & L_1 & L_2 & L_3 & 3 \\
 & & & & & & & & & & & & \nu_L^e & \nu_L^\mu & \nu_L^\tau & & & & \\
Z^0 & G_1 & W^\pm & d_L^1 & d_L^2 & d_L^3 & s_L^1 & s_L^2 & s_L^3 & b_L^1 & b_L^2 & b_L^3 & \to & d_L^\alpha & s_L^\alpha & b_L^\alpha & Q_1^\alpha & Q_2^\alpha & Q_3^\alpha & 3 \\
\gamma & G_2 & & u_L^1 & u_L^2 & u_L^3 & c_L^1 & c_L^2 & c_L^3 & t_L^1 & t_L^2 & t_L^3 & & u_L^\alpha & c_L^\alpha & t_L^\alpha & & & & \\
 & \vdots & & d_R^1 & d_R^2 & d_R^3 & s_R^1 & s_R^2 & s_R^3 & b_R^1 & b_R^2 & b_R^3 & \to & d_R^\alpha & s_R^\alpha & b_R^\alpha & & & & 3 \\
 & G_8 & & u_R^1 & u_R^2 & u_R^3 & c_R^1 & c_R^2 & c_R^3 & t_R^1 & t_R^2 & t_R^3 & \to & u_R^\alpha & c_R^\alpha & t_R^\alpha & & & & 3 \\
\hline
2 & 8 & 2=12 & & & & & & & & & & & & & & & & & 15
\end{array}
$$

$$m_i = 0 \qquad\qquad Y_{u_L} = Y_{d_L}$$

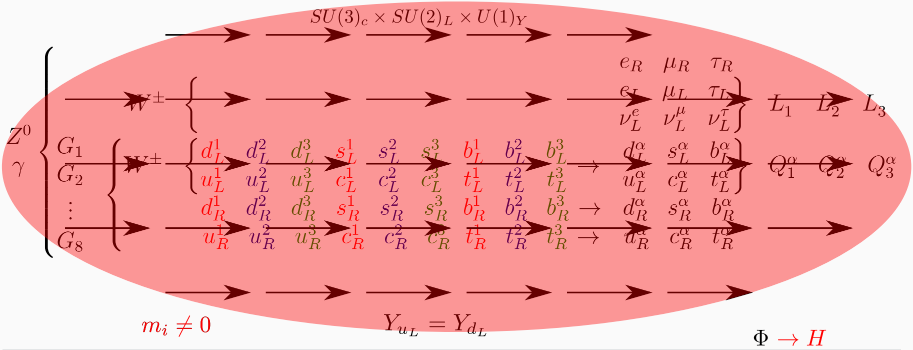
Standard Model: particles



Standard Model: particles



Standard Model: particles



SM fields + Gauge + Lorentz Invariance→*Lagrangian*

Electroweak superconductor (*Higgs condensate*) with emergent masses which allows

- confined baryons (nuclear physics)
- atoms (chemistry)

Links

`http:fisica.udea.edu.co` $\rightarrow$ cursos

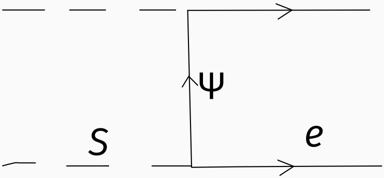
- CNF-665: Física subatómica:
- CNF-666: Teoría Cuántica de Campos

Dark matter and unification

Dark matter

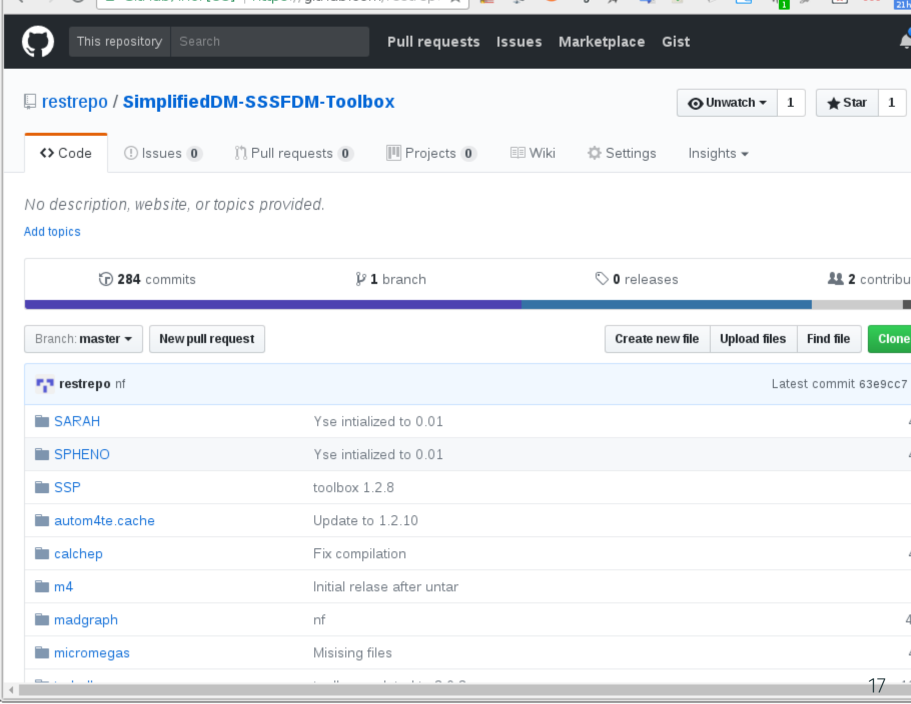
Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$\begin{pmatrix}\nu_L & e_L\end{pmatrix}^T$	$\begin{pmatrix}\xi_{1\alpha} & \xi_{2\alpha}\end{pmatrix}^T$	1	2	$-1/2$	$+1$
$(e_R)^\dagger$	η_1^α	1	1	$+1$	$+1$
$(\psi_R)^\dagger$	η_2^α	1	1	$+1$	-1
ψ_L	$\xi_{3\alpha}$	1	1	-1	-1
S		1	1	0	-1

$$\mathcal{L} = M_\psi \left[(\psi_R)^\dagger \psi_L \,(\psi_L)^\dagger \psi_R\right] + h_S \left[S\,(e_R)^\dagger \psi_L + S\,(\psi_L)^\dagger e_R\right] \qquad (3)$$



SARAH

Ve


This repository
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restrepo / SimplifiedDM-SSSFDM-Toolbox
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Add topics
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1 branch
0 releases
2 contribu
Branch: master
New pull request
Create new file
Upload files
Find file
Clone
restrepo nf
Latest commit 63e9cc7
SARAH
Yse intialized to 0.01
SPHENO
Yse intialized to 0.01
SSP
toolbox 1.2.8
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Update to 1.2.10
calchep
Fix compilation
m4
Initial relase after untar
madgraph
nf
micromegas
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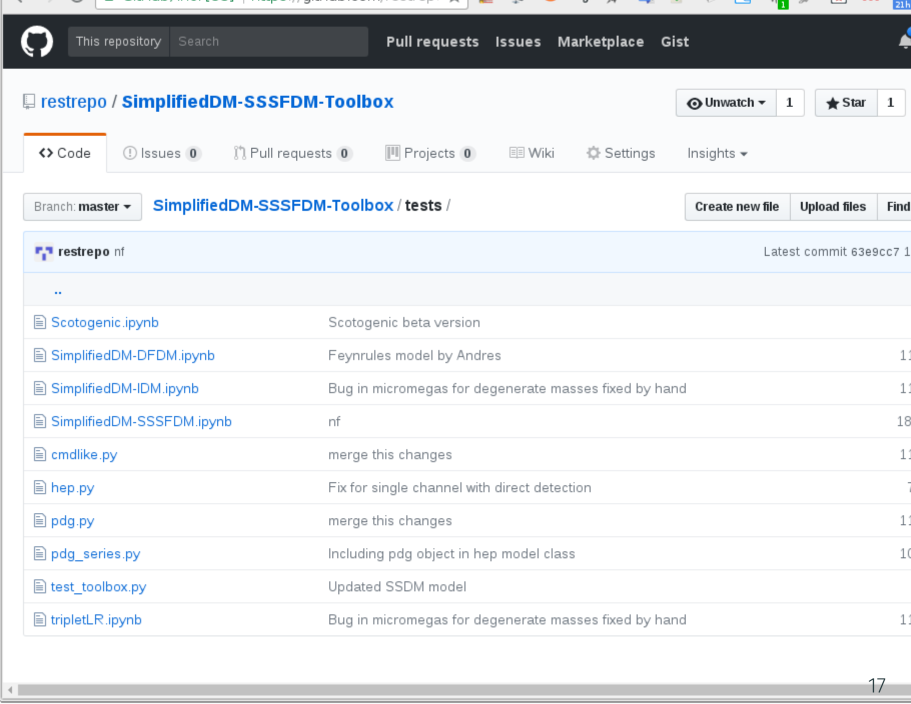
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Insights
Branch: master
SimplifiedDM-SSSFDM-Toolbox / tests /
Create new file
Upload files
Find
restepo nf
Latest commit 63e9cc7
..
Scotogenic.ipynb
Scotogenic beta version
SimplifiedDM-DFDM.ipynb
Feynrules model by Andres
SimplifiedDM-IDM.ipynb
Bug in micromegas for degenerate masses fixed by hand
SimplifiedDM-SSSFDM.ipynb
nf
cmdlike.py
merge this changes
hep.py
Fix for single channel with direct detection
pdg.py
merge this changes
pdg_series.py
Including pdg object in hep model class
test_toolbox.py
Updated SSDM model
tripletLR.ipynb
Bug in micromegas for degenerate masses fixed by hand

Reproducibility

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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Singlet Scalar Singlet (charged) Fermion dark matter model

SSSFDM

- arXiv:1307.6181
- arXiv:1307.6480

Particle content

In [61]:

```
%%latex
\begin{array}{llllll}
\text{Name} & \text{Symbol} & \text{SU}(3)_c & \text{SU}(2)_L & \text{U}(1)_
 \begin{pmatrix}\nu_L & e_L\end{pmatrix}^{\operatorname{T}}&
\begin{pmatrix}\xi_{1\alpha} & \xi_{2\alpha} \end{pmatrix}^{\operatorname{T}
(e_R)^{\dagger} & \eta^{\alpha}_1 & \mathbf{1} & \mathbf{1} & +1 & +1 \\
(\psi_R)^{\dagger} & \eta^{\alpha}_2 & \mathbf{1} & \mathbf{1} & +1 & -1 \\
\psi_L & \xi_{3\alpha} & \mathbf{1} & \mathbf{1} & -1 & -1 \\
\end{array}
```

Name	Symbol	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	Z_2
$\begin{pmatrix}\nu_L & e_L\end{pmatrix}^{\mathrm{T}}$	$\begin{pmatrix}\xi_{1\alpha} & \xi_{2\alpha}\end{pmatrix}^{\mathrm{T}}$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$+1$
$(e_R)^{\dagger}$	η^{α}_1	$\mathbf{1}$	$\mathbf{1}$	$+1$	$+1$
$(\psi_R)^{\dagger}$	η^{α}_2	$\mathbf{1}$	$\mathbf{1}$	$+1$	-1
ψ_L	$\xi_{3\alpha}$	$\mathbf{1}$	$\mathbf{1}$	-1	-1

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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After the spontaneous symmetry breaking, the relevant Yukawa terms are

$$
\begin{aligned}
\mathcal{L} =& \frac{h_e v}{\sqrt{2}}\left(\eta_1^{\alpha}\xi_{2\alpha} + \xi^{\dagger}_{2\dot\alpha}\eta_1^{\dagger\dot\alpha}\right) + M_\psi\,\left(\eta_2^{\alpha}\xi_{3\alpha} + \xi^{\dagger}_{3\dot\alpha}\eta_2^{\dagger\dot\alpha}\right) + h_S\left(S\eta_1^{\alpha}\xi_{3\alpha} + S\xi^{\dagger}_{3\dot\alpha}\eta_1^{\dagger\dot\alpha}\right)\\
=& \frac{h_e v}{\sqrt{2}}\begin{pmatrix}\eta_1^{\alpha} & \xi^{\dagger}_{2\dot\alpha}\end{pmatrix}\begin{pmatrix}\xi_{2\alpha}\\ \eta_1^{\dagger\dot\alpha}\end{pmatrix} + M_\psi\,\begin{pmatrix}\eta_2^{\alpha} & \xi^{\dagger}_{3\dot\alpha}\end{pmatrix}\begin{pmatrix}\xi_{3\alpha}\\ \eta_2^{\dagger\dot\alpha}\end{pmatrix}\\
&+\left[h_S S\begin{pmatrix}\eta_1^{\alpha} & \xi^{\dagger}_{2\dot\alpha}\end{pmatrix}\begin{pmatrix}1 & 0\\ 0 & 0\end{pmatrix}\begin{pmatrix}\xi_{3\alpha}\\ \eta_2^{\dagger\dot\alpha}\end{pmatrix} + \text{h.c}\right]\\
=& \frac{h_e v}{\sqrt{2}}\begin{pmatrix}\xi^{\dagger}_{2\dot\alpha} & \eta_1^{\alpha}\end{pmatrix}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\begin{pmatrix}\xi_{2\alpha}\\ \eta_1^{\dagger\dot\alpha}\end{pmatrix} + M_\psi\,\begin{pmatrix}\xi^{\dagger}_{3\dot\alpha} & \eta_2^{\alpha}\end{pmatrix}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\begin{pmatrix}\xi_{3\alpha}\\ \eta_2^{\dagger\dot\alpha}\end{pmatrix}\\
&+\left[h_S S\begin{pmatrix}\xi^{\dagger}_{2\dot\alpha} & \eta_1^{\alpha}\end{pmatrix}\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\begin{pmatrix}1 & 0\\ 0 & 0\end{pmatrix}\begin{pmatrix}\xi_{3\alpha}\\ \eta_2^{\dagger\dot\alpha}\end{pmatrix} + \text{h.c}\right]
\end{aligned}
$$

Defining

$$
e = \begin{pmatrix}\xi_{2\alpha}\\ \eta_1^{\dagger\dot\alpha}\end{pmatrix} = \begin{pmatrix}e_L\\ e_R\end{pmatrix} \qquad \Psi = \begin{pmatrix}\xi_{3\alpha}\\ \eta_2^{\dagger\dot\alpha}\end{pmatrix} = \begin{pmatrix}\psi_L\\ \psi_R\end{pmatrix}
$$

the relevant Yukawa Lagrangian in terms of Dirac fermions is

$$
\begin{aligned}
\mathcal{L} =& \frac{h_e v}{\sqrt{2}} e^{\dagger}\gamma^0 e + M_\psi\,\Psi^{\dagger}\gamma^0\Psi + \left(h_S S e^{\dagger}\gamma^0 P_L\Psi + \text{h.c}\right)\\
=& \frac{h_e v}{\sqrt{2}}\bar{e}e + M_\psi\,\overline{\Psi}\Psi + h_S\left(S\,\bar{e}\Psi_L + \text{h.c}\right)\,,
\end{aligned}
$$

where

$$
\Psi_L = P_L\Psi = \begin{pmatrix}\psi_L\\ 0\end{pmatrix}\,.
$$

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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In [1]:
```
%pylab inline
```

```
Populating the interactive namespace from numpy and matplotlib
```

In [2]:
```
import pandas as pd
import numpy as np
from matplotlib.colors import LogNorm
import os, sys, inspect
import commands
from hep import *
```

Check one point

In [3]:
```
a=hep(MODEL='SimplifiedDMSSSFDM')
```

`a-object` is an object with many attributes and methods. Use the tab to explore them. Some of them are

- a.Series: pandas Series object with the "relevant" variables
- a.LHA: Input LesHouces file as pyslha object
- a.runSPheno() -> a.LHA_out: return LHA output files as pyslha object
- a.runmicromegas() -> a.runSPheno() -> Updated the `a-object` with micrOMEGAS "relevant" output

In [4]:
```
pd.Series(a.LHA.blocks['MINPAR'].entries)
```

Out[4]:
```
1    2.5500000E-01  # Lambda1IN
2      0.0000000E+00  # LamSHIN
3       0.0000000E+00  # LamSIN
4     2.0000000E+02  # MS2Input
5        2.0000000E+02  # MSFIN
```

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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```
dtype: object
```

In [5]:

```
v=a.vev
lambda_1=0.26
lambda_SH=0.
MS=150**2
MF=200
Yse=1.9
Ymu=0
Ytau=0
devnull=commands.getoutput('rm -f SPheno.spc.%s' %a.MODEL)
a.LHA.blocks['SPHENOINPUT'].entries[55]='0              # Calculate one lo
a.LHA.blocks['SPHENOINPUT'].entries[520]='0.            # Write effective H
a.LHA.blocks['MINPAR'][1]='%0.8E       # lambda1'  %lambda_1
a.LHA.blocks['MINPAR'][2]='%0.8E       # lambdaSH'  %lambda_SH
a.LHA.blocks['MINPAR'][4]='%0.8E       # MS'  %MS
a.LHA.blocks['MINPAR'][5]='%0.8E       # MF' %MF
a.LHA.blocks['YSIN'][1]='%0.8E       # Ys(1)' %Yse
a.LHA.blocks['YSIN'][2]='%0.8E       # Ys(1)' %Ymu
a.LHA.blocks['YSIN'][3]='%0.8E       # Ys(3)' %Ytau
moc=a.runmicromegas(Direct_Detection=True)
print 'Omega h^2, SI proton, neutron =',a.Series.Omega_h2,a.Series.proton_SI
```

```
Omega h^2, SI proton, neutron = 0.111 0.0 0.0
```

Scan the parameter space

In [ ]:

```
import time
st=time.time()
a=hep(MODEL='SimplifiedDMSSSFDM')
v=a.vev
Omega_h2_delta=0.0022
```

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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Scan the parameter space

In [ ]:

```
import time
st=time.time()
a=hep(MODEL='SimplifiedDMSSSFDM')
v=a.vev
Omega_h2_delta=0.0022
CL=3
Omega_h2=0.1197
Omega_h2_exp=[Omega_h2-CL*Omega_h2_delta,Omega_h2,Omega_h2+CL*Omega_h2_delta
lambda_1=0.26
lambda_SH=0
a.LHA.blocks['SPHENOINPUT'].entries[55]='0              # Calculate one loo
a.LHA.blocks['SPHENOINPUT'].entries[520]='0.            # Write effective H

df=pd.DataFrame()
a.LHA.blocks['SPHENOINPUT'].entries[55]='0              # Calculate one loo
dfmin=100 #40
dfmax=600 #1E4
npoints=1000
df_masses=np.logspace(np.log10(dfmin),np.log10(dfmax),npoints) #np.array([20
DEBUG=False
for i in range(1):
    for MF in df_masses:
        rm1=10**np.random.uniform(np.log10(1E-2),np.log10(3))
        r=rm1+1.
        M_S=MF/r
        MS2=M_S**2-a.vev**2*lambda_SH
        Yse_range=np.logspace(np.log10(np.pi),np.log10(1E-3),200)
        Omega_h2_old=1E32
        for Yse in Yse_range:
            devnull=commands.getoutput('rm -f SPheno.spc.%s' %a.MODEL)
            Ymu=0. #10**np.random.uniform(-log10(1E-3),np.log10(np.pi),)
```

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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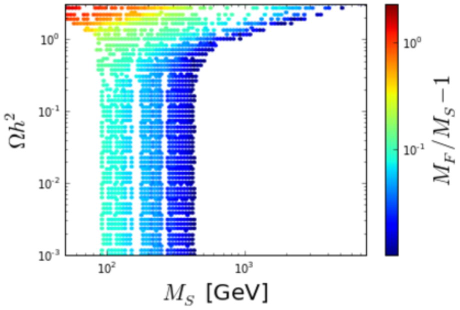
In [34]:
```
df=df[df.MF>=100]
plt.hexbin(df.ss,df.Ys1,df.MF/df.ss-1,xscale='log',yscale='log',norm=LogNorr
cl=plt.colorbar()
cl.set_label(r'$M_F/M_S-1$',size=20)
plt.xlim(50,df.MF.max())
plt.xlabel(r'$M_S$ [GeV]',size=20)
plt.ylabel(r'$\Omega h^2$',size=20)
```

Out[34]: <matplotlib.text.Text at 0x7fc18defe5d0>



In [20]:
```
MF_max=600
plt.hexbin(df[df.MF<MF_max].MF,df[df.MF<MF_max].ss,df[df.MF<MF_max].Ys1,norr
cb=plt.colorbar()
x=np.linspace(100,1000,10)
plt.plot(x,x,'k--')
```

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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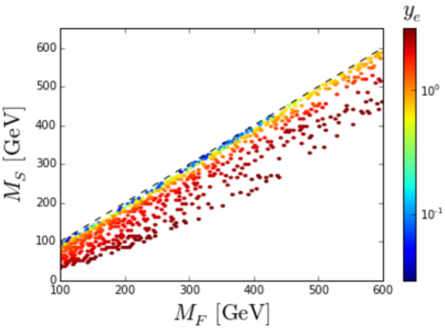
In [20]:

```
MF_max=600
plt.hexbin(df[df.MF<MF_max].MF,df[df.MF<MF_max].ss,df[df.MF<MF_max].Ys1,norr
cb=plt.colorbar()
x=np.linspace(100,1000,10)
plt.plot(x,x,'k--')

plt.xlabel(r'$M_F\ {\rm [GeV]}$',size=20)
plt.ylabel(r'$M_S\ {\rm [GeV]}$',size=20)
plt.text(630,680,r'$y_e$',size=20)
plt.xlim(100,600)
plt.ylim(0,650)

plt.tight_layout()
#plt.savefig('singlet_exc.pdf')
```



localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSFD

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```
In [7]: from madgraph import *

In [10]: generate_cross_section(a.MODEL,processes=['generate p p > fre frebar'],sqrts

In [11]: launch_cross_section(a.MODEL)

Out[11]: (0.02713, 5e-05)

In [12]: from madgraph import *
a=hep(MODEL='SimplifiedDMSSSFDM')

generate_cross_section(a.MODEL,processes=['generate p p > fre frebar'],sqrts
v=a.vev
lambda_1=0.26
lambda_SH=0
a.LHA.blocks['SPHENOINPUT'].entries[55]='0              # Calculate one loo
a.LHA.blocks['SPHENOINPUT'].entries[520]='0.            # Write effective H
df=pd.DataFrame()
dfmin=100 #40
dfmax=600 #1E4
npoints=11
df_masses=np.linspace(dfmin,dfmax,npoints) #np.array([200]) 1E-4
for MF in df_masses:
        M_S=20
        MS2=M_S**2-a.vev**2*lambda_SH
        Yse=1.
        devnull=commands.getoutput('rm -f SPheno.spc.%s' %a.MODEL)
        Ymu=0. #10**np.random.uniform( log10(1E-3),np.log10(np.pi) )
        Ytau=0. #10
        a.LHA.blocks['MINPAR'][1]='%0.8E       # lambda1'  %lambda_1
        a.LHA.blocks['MINPAR'][2]='%0.8E       # lambdaSH'  %lambda_SH
        a.LHA.blocks['MINPAR'][4]='%0.8E       # MS2'  %MS2
        a.LHA.blocks['MINPAR'][5]='%0.8E       # MF' %MF
```

localhost:8888/notebooks/prog/toolbox/mybinders/SimplifiedDM/SSSFDM/tests/SimplifiedDM-SSSF

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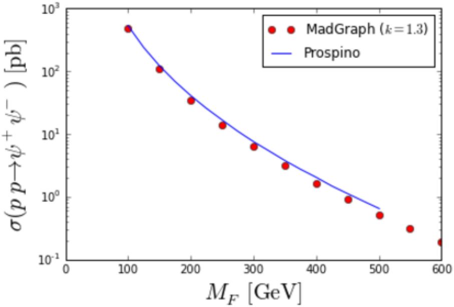
In [19]:
```
plt.semilogy(df.MF,df.cs*1000*1.3,'ro',label='MadGraph ($k=1.3$)')
plt.semilogy(pr.mc1,pr.cs,label='Prospino')
plt.xlabel(r'$M_F\ \rm{[GeV]}$',size=20)
plt.ylabel(r'$\sigma(p\ p\to \psi^+\psi^-)\ \rm{[pb]}$',size=20)
plt.legend(loc='best')
```

Out[19]: <matplotlib.legend.Legend at 0x7f4243c7b290>



Results in Poster Session:

Marta Liliana Sánchez Pélaez

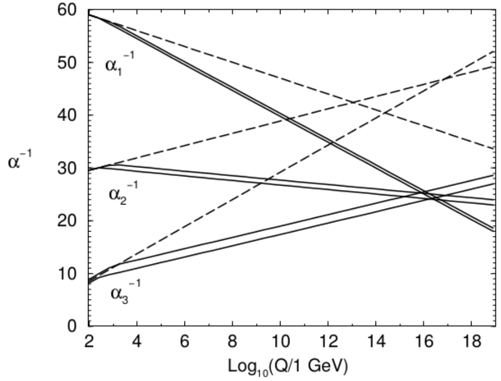
Unification: $SO(10)$

$$\mathbf{16}_{F_i} = \begin{pmatrix} {u_R}^\dagger \\ {u_R}^\dagger \\ {u_R}^\dagger \\ u_L \\ u_L \\ u_L \\ d_L \\ d_L \\ d_L \\ {d_R}^\dagger \\ {d_R}^\dagger \\ {d_R}^\dagger \\ \nu_L \\ e_L \\ {e_R}^\dagger \\ N \end{pmatrix}_i \qquad \Rightarrow \mathcal{L}_{SM} \supset h\, \mathbf{16}_F \times \mathbf{16}_F \times \mathbf{10}_S + \text{h.c}$$

Not-susy SO(10) $\to SU(5) \to$ SU(3)$_C \times SU(2)_L \times$ U(1)$_Y \times Z_2$

Standard Model: Z_2-even	New Z_2-odd particles
Fermions: $\mathbf{16}_F$	$\mathbf{10}_F, \mathbf{45}_F, \cdots$
Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$	$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate, and can improve gauge coupling unification



Not-susy SO(10) $\to SU(5) \to \mathrm{SU}(3)_C \times SU(2)_L \times \mathrm{U}(1)_Y \times Z_2$

Standard Model: Z_2-even	New Z_2-odd particles
Fermions: $\mathbf{16}_F$	$\mathbf{10}_F, \mathbf{45}_F, \cdots$
Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$	$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate. and can improve gauge coupling unification

	fermions	scalars
$SU(2)_L \times U(1)_Y$ representation	even $SO(10)$ representations	odd $SO(10)$ representations
$\boxed{3_0}$	$\boxed{45}$, 54, 210	144
1_0	45, 54, 126, 210	16, 144
$2_{\pm 1/2}$	10, 120, 126, 210, 210′	16, 144

$SU(3)_C$: **3** (T), **6**, $\boxed{\mathbf{8}\ (\Lambda)}$

$$m_{3_0} = 2.7 \text{ TeV}, \qquad m_\Lambda \sim 10^{10} \text{ TeV}, \qquad m_{\text{GUT}} \sim 10^{16} \text{ GeV}\,.$$

arXiv:0912.1545 (Frigerio-Hambye)

Not-susy SO(10) $\to SU(5) \to$ SU(3)$_C \times SU(2)_L \times$ U(1)$_Y \times Z_2$

Standard Model: Z_2-even	New Z_2-odd particles
Fermions: $\mathbf{16}_F$	$\mathbf{10}_F, \mathbf{45}_F, \cdots$
Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$	$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate. and can improve gauge coupling unification

	fermions	scalars
$SU(2)_L \times U(1)_Y$ representation	even $SO(10)$ representations	odd $SO(10)$ representations
$\boxed{1_0}$	$\boxed{45}$, 54, 126, 210	16, 144
$\boxed{2_{\pm 1/2}}$	$\boxed{10}$, 120, 126, 210, 210′	16, 144
$\boxed{3_0}$	$\boxed{45}$, 54, 210	144

$SU(3)_C$: $\mathbf{3}$ (T), $\mathbf{6}$, $\boxed{\mathbf{8}\ (\Lambda)}$

Split-SUSY like

arXiv:1509.06313 (C. Arbelaez, R. Longas, D.R, O. Zapata)

Not-susy SO(10) $\to SU(5) \to$ SU(3)$_C \times SU(2)_L \times$ U(1)$_Y \times Z_2$

Standard Model: Z_2-even	New Z_2-odd particles
Fermions: $\mathbf{16}_F$	$\mathbf{10}_F, \mathbf{45}_F, \cdots$
Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$	$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate, and can improve gauge coupling unification

	fermions	scalars
$SU(2)_L \times U(1)_Y$ representation	even $SO(10)$ representations	odd $SO(10)$ representations
1_0	45, 54, 126, 210	16, 144
$2_{\pm 1/2}$, $2^S_{1/2}$	10, 120, 126, 210, 210$'$	16, 144
3_0	45, 54, 210	144

$SU(3)_C$: **3** (T), **6**, **8** (Λ)

Radiative hybrid seesaw (Parida 1106.4137) or 1509.06313

Partial Split-SUSY-like spectrum: bino-higgsino-wino

+ $\downarrow$

$\mathbf{10}'_H$ with fermion DM or, $\mathbf{16}_H, \cdots$ with scalar DM

Not-susy SO(10) $\to SU(5) \to \mathrm{SU}(3)_C \times SU(2)_L \times \mathrm{U}(1)_Y \times Z_2$

Standard Model: Z_2-even	New Z_2-odd particles
Fermions: $\mathbf{16}_F$	$\mathbf{10}_F, \mathbf{45}_F, \cdots$
Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$	$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate, and can improve gauge coupling unification

	fermions	scalars
$SU(2)_L \times U(1)_Y$ representation	even $SO(10)$ representations	odd $SO(10)$ representations
1_0	45, 54, 126, 210	16, 144
$2_{\pm 1/2}$ $2^S_{1/2}$	10, 120, 126, 210, 210′	16, 144
3_0	45, 54, 210	144

$SU(3)_C$: 3 (T), 6, 8 (Λ)

1509.06313

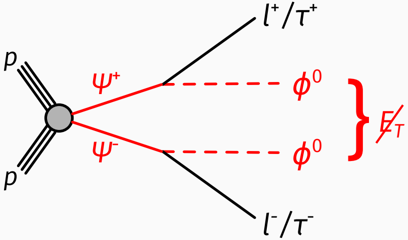
SUSY-like spectrum: bino-higgsino-wino

+

↓

$\mathbf{10}'_H$ with fermion DM or, $\mathbf{16}_H, \cdots$ with scalar DM

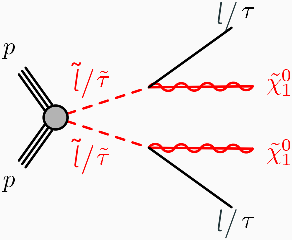
Dilepton plus transverse missing energy signal

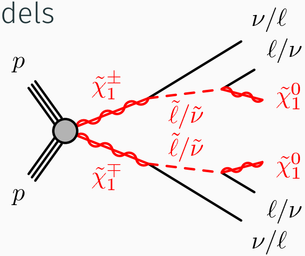


SU$(2)_L$ assignments:

$\Psi = 1, 2(\Psi), 3(\Sigma)\,, \qquad \Phi = 1, 2\,,$ with $m_{\rm DM} \sim m_h/2\,.$

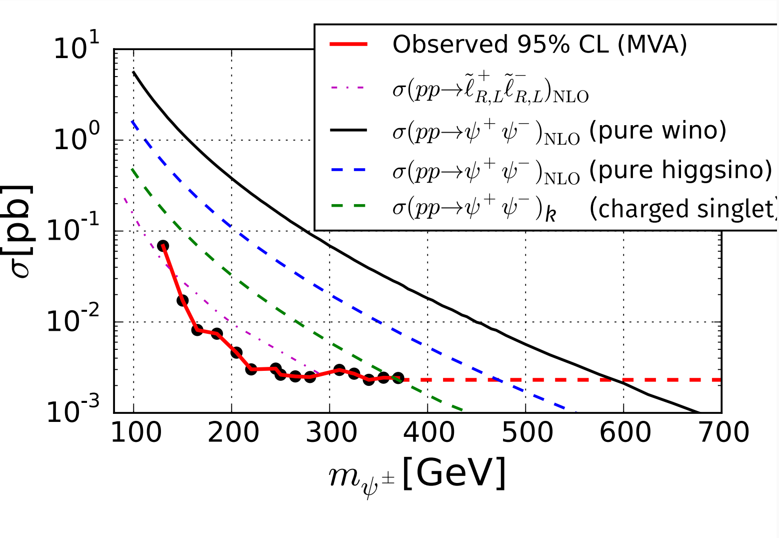
Simplified SUSY models





Smaller cross sections. Intermediate states and smaller lepton $\not{p}_T$

$m_{\phi^0} = 60$ GeV



Full analysis on flavor space: F. von der Pahlen, G. Palacio, DR, O. Zapata arXiv:1605.01129 [PRD]

Singlet-Doublet-Triplet fermion dark-matter

The most general SO(10) invariant Lagrangian contains the following Yukawa terms

$$-\mathcal{L} \supset Y \mathbf{10}_F \mathbf{45}_F \mathbf{10}_H + M_{\mathbf{45}_F} \mathbf{45}_F \mathbf{45}_F + M_{\mathbf{10}_F} \mathbf{10}_F \mathbf{10}_F$$

Basis

$$\boldsymbol{\psi}^0 = \left(N, \Sigma^0, \psi_L^0, (\psi_R^0)^\dagger\right)^T$$

$$\mathcal{M}_{\boldsymbol{\psi}^0} = \begin{pmatrix} M_N & 0 & -y\, c_\beta v/\sqrt{2} & y\, s_\beta v/\sqrt{2} \\ 0 & M_\Sigma & f\, c_{\beta'} v/\sqrt{2} & -f\, s_{\beta'} v/\sqrt{2} \\ -y\, c_\beta v/\sqrt{2} & f\, c_{\beta'} v/\sqrt{2} & 0 & -M_D \\ y\, s_\beta v/\sqrt{2} & -f\, s_{\beta'} v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$

$\mathbf{10}_F \to \psi_L, (\psi_R)^\dagger$

$\mathbf{45}_F \to \Sigma, \Lambda$

$\mathbf{45}'_F \to N$

arXiv:1511.06495: signals at 100 TeV collider

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$$-\mathcal{L} \supset Y 10_F 45_F 10_H + M_{45_F} 45_F 45_F + M_{10_F} 10_F 10_F$$

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$$\mathcal{M}_{\psi^0} =$$

$$\begin{pmatrix} M_N & 0 & -y\, c_\beta v/\sqrt{2} & y\, s_\beta v/\sqrt{2} \\ 0 & M_\Sigma & f\, c_{\beta'} v/\sqrt{2} & -f\, s_{\beta'} v/\sqrt{2} \\ -y\, c_\beta v/\sqrt{2} & f\, c_{\beta'} v/\sqrt{2} & 0 & -M_D \\ y\, s_\beta v/\sqrt{2} & -f\, s_{\beta'} v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$

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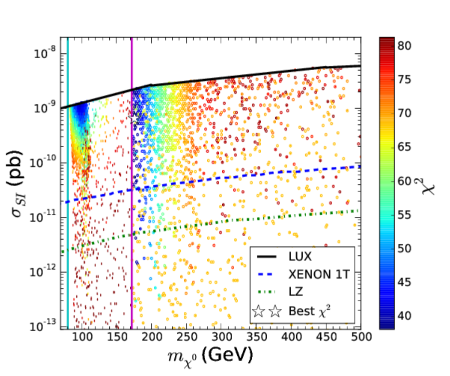

S. Horiuchi, O. Macias, DR, A. Rivera, O. Zapata, 1602.04788 (JCAP)

Singlet-Doublet-Triplet fermion dark-matter

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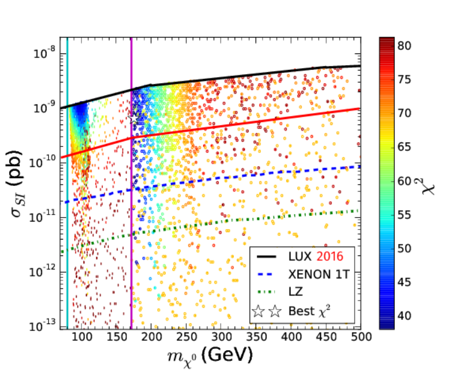

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Singlet-Doublet-Triplet fermion dark-matter

The most general SO(10) invariant Lagrangian contains the following Yukawa terms

$$-\mathcal{L} \supset Y 10_F 45_F 10_H + M_{45_F} 45_F 45_F + M_{10_F} 10_F 10_F + \mathcal{L}(10_\Phi \qquad).$$

Basis

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$$\mathcal{M}_{\psi^0} = \begin{pmatrix} M_N & 0 & -y\, c_\beta v/\sqrt{2} & y\, s_\beta v/\sqrt{2} \\ 0 & M_\Sigma & f\, c_{\beta'} v/\sqrt{2} & -f\, s_{\beta'} v/\sqrt{2} \\ -y\, c_\beta v/\sqrt{2} & f\, c_{\beta'} v/\sqrt{2} & 0 & -M_D \\ y\, s_\beta v/\sqrt{2} & -f\, s_{\beta'} v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$

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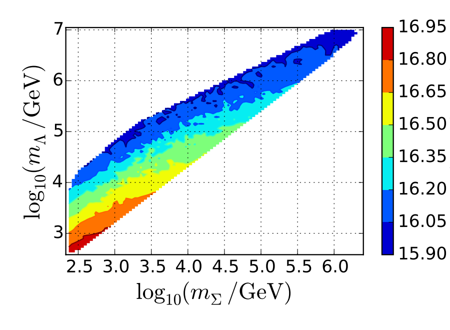
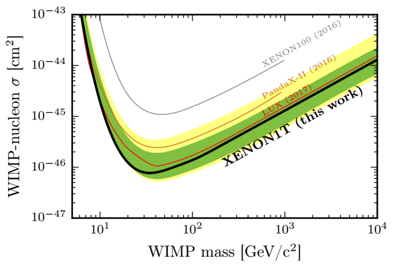


Split-SUSY: like $M_\Phi = 2$ TeV

Is the glass half empty or half full?

Tree-level SM-portal could be fully excluded in the near future

- Singlet scalar dark matter
- Inert doublet model
- Tree-level SM-portal dark matter $\cdots$



In this talk we explore

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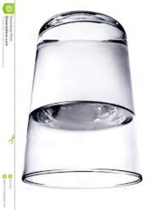

In this talk we explore

- Recover SM-portals in LR models

Is the glass half empty or half full?

Tree-level SM-portal could be fully excluded in the near future

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- Inert doublet model
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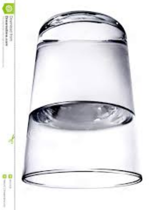


In this talk we explore

- Recover SM-portals in LR models
- New portals in LR models

Left-Right symmetric realization

Singlet-doublet fermion dark matter

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Φ	1	$(1, 2, 2, 0)$	0	10
χ, χ^c	1	$(1, 2, 2, 0)$	$1/2$	10
N	1	$(1, 1, 1, 0)$	$1/2$	45

Table 1: The relevant part of the field content. Note that, the two fermion doublets χ and χ^c come from an only fermionic LR bidoublet. In the third column the relevant fields are characterized by their $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ quantum numbers while their SO(10) origin is specified in the fourth column.

Unification

m_{LR} (GeV)	$3_c 2_L 2_R 1_{B-L}$	m_G (GeV)
2×10^3	$\Phi_{1,2,2,0} + 2\Phi_{1,1,3,-2} + \Psi_{1,1,3,0} + \Phi_{1,1,3,0} + \Phi_{8,1,1,0}$	1.65×10^{16}
$\vdots$	$\vdots$	$\vdots$

Table 2: $\Delta_{L,R} = 2\Phi_{1,1,3,-2}$. m_{LR} and m_G are given in GeV.

Triplets

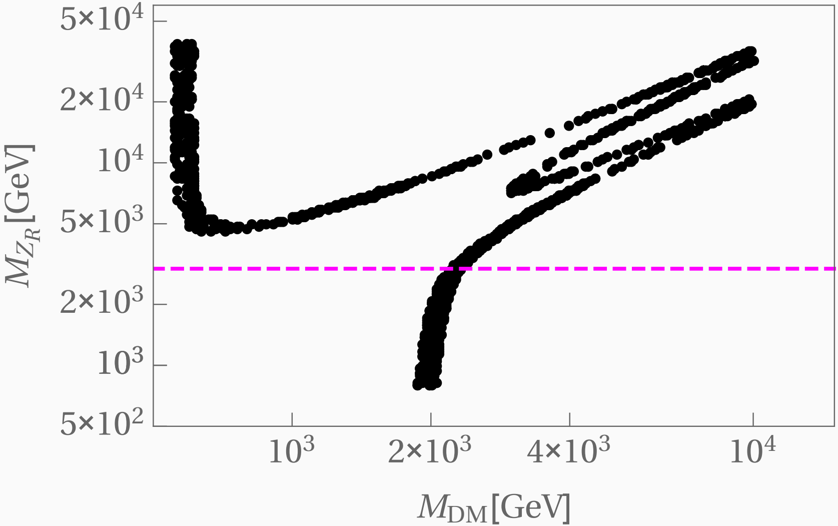
Minimal Left-Right Symmetric Standard Model

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
Q^c	3	$(\bar{3}, 1, 2, -\frac{1}{3})$	1/2	16
L	3	$(1, 2, 1, -1)$	1/2	16
L^c	3	$(1, 1, 2, +1)$	1/2	16
Φ	1	$(1, 2, 2, 0)$	0	10
Δ_R	1	$(1, 1, 3, -2)$	0	126

Left-singlet right-triplet DM

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
Q^c	3	$(\bar{3}, 1, 2, -\frac{1}{3})$	1/2	16
L	3	$(1, 2, 1, -1)$	1/2	16
L^c	3	$(1, 1, 2, +1)$	1/2	16
Φ	1	$(1, 2, 2, 0)$	0	10
Δ_R	1	$(1, 1, 3, -2)$	0	126
Ψ_{1130}	1	$(1, 1, 3, 0)$	1/2	45

$\Omega h^2 = 0.1199 \pm 0.0027$ at 3σ



Mixed Left-singlet right-triplet DM

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
Q^c	3	$(\bar{3}, 1, 2, -\frac{1}{3})$	1/2	16
L	3	$(1, 2, 1, -1)$	1/2	16
L^c	3	$(1, 1, 2, +1)$	1/2	16
Φ	1	$(1, 2, 2, 0)$	0	10
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Δ_R	1	$(1, 1, 3, -2)$	0	126
Ψ_{1130}	1	$(1, 1, 3, 0)$	1/2	45
Ψ_{1132}	1	$(1, 1, 3, 2)$	1/2	126
Ψ_{113-2}	1	$(1, 1, 3, -2)$	1/2	$\overline{126}$

Setup

$$\Psi_{1132} = \begin{pmatrix} \Psi^{+}/\sqrt{2} & \Psi^{++} \\ \Psi^{0} & -\Psi^{+}/\sqrt{2} \end{pmatrix}, \qquad \bar{\Psi}_{113-2} = \begin{pmatrix} \Psi^{-}/\sqrt{2} & \overline{\Psi}^{0} \\ \Psi^{--} & -\Psi^{-}/\sqrt{2} \end{pmatrix}. \tag{4}$$

$$\begin{aligned} L \supset & M_{11} \operatorname{Tr}(\Psi_{1130}\Psi_{1130}) + M_{23} \operatorname{Tr}(\Psi_{1132}\bar{\Psi}_{113-2}) \\ & + \lambda_{13} \operatorname{Tr}(\Delta_R \bar{\Psi}_{113-2}\Psi_{1130}) + \lambda_{12} \operatorname{Tr}(\Delta_R^{\dagger}\Psi_{1132}\Psi_{1130}), \end{aligned} \tag{5}$$

$$\tan\gamma = \frac{\lambda_{13}}{\lambda_{12}}, \qquad \lambda = \sqrt{\lambda_{12}^2 + \lambda_{13}^2}. \tag{6}$$

Blind spot at

$$M_{23}\sin 2\gamma - M_{\mathrm{DM}} = 0 \tag{7}$$

Proper relic density scan

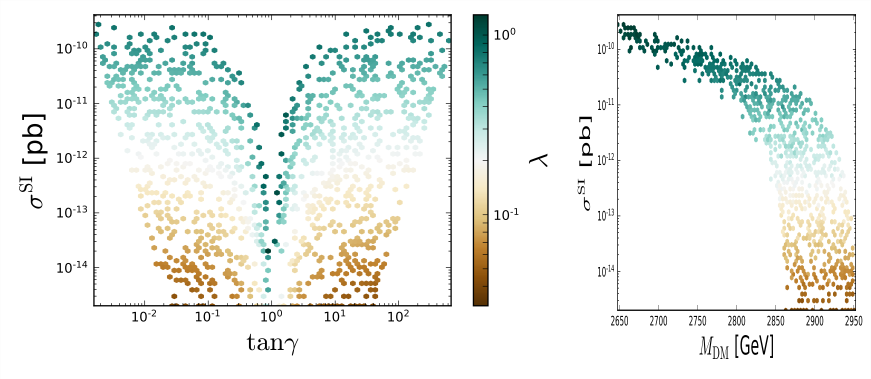

Figure 2: $M_{11} = 50$ TeV $2.7 < M_{23}/\text{TeV} < 3.1$ (Right: $\tan\gamma > 5$)

$\Omega h^2 = 0.1199 \pm 0.0027$ at 3σ

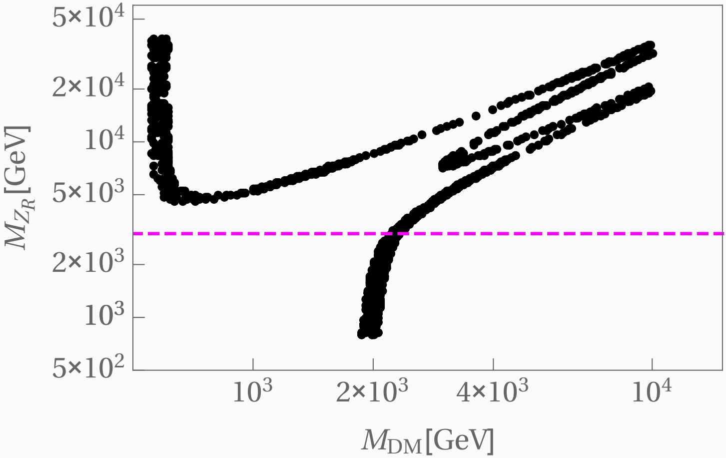

Figure 3:

$\Omega h^2 = 0.1199 \pm 0.0027$ at 3σ

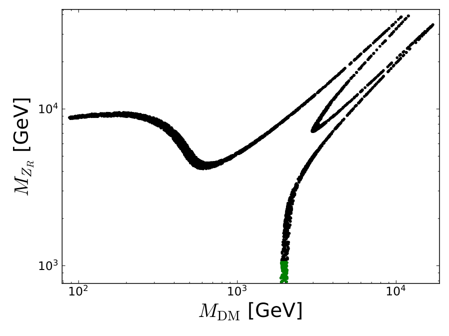

Figure 3: Proper relic density scan: v_R : $[2, 50]$ TeV, M_{23} : $[0.2, 50]$ TeV, M_{11} : 50 TeV, $\tan\gamma = -1$ and $\lambda = 0.14$.

Direct detection cross section

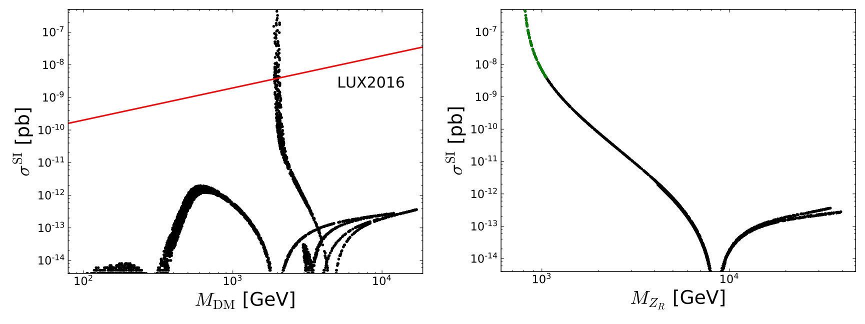

Figure 4: v_R : $[2, 50]$ TeV, M_{23} : $[0.2, 50]$ TeV, M_{11} : 50 TeV, $\tan\gamma = -1$ and $\lambda = 0.14$.

Unification

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
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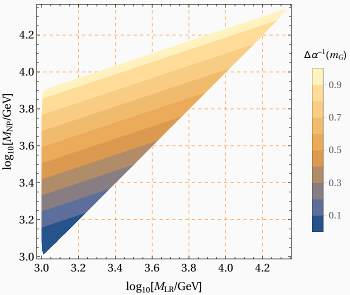
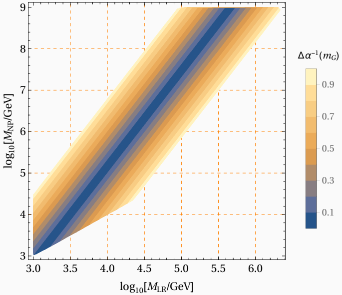
Ψ_{1130}	1	$(1, 1, 3, 0)$	1/2	45
Ψ_{1132}	1	$(1, 1, 3, 2)$	1/2	126
Ψ_{113-2}	1	$(1, 1, 3, -2)$	1/2	$\overline{126}$
Ψ_{1310}	1	$(1, 3, 1, 0)$	1/2	45
Ψ_{8110}	1	$(1, 1, 8, 0)$	1/2	45
$\Psi_{321\frac{1}{3}}$	1	$(3, 2, 1, 1/3)$	1/2	16
$\Psi_{321-\frac{1}{3}}$	1	$(1, 2, 3, -1/3)$	1/2	$\overline{16}$

Unification quality





Conclusions

In addition to accommodate usual simplified dark matter models, Left-right symmetric standard models have additional DM portals:

New Δ_R portal for direct detection of left-singlet right-triplet mixed dark matter, in companion with left-singlets charged and doubly charged fermions.

Next: Search for them in compressed spectra scenarios at the LHC

Thanks!