Composite Higgs and Dark Matter

Research Project
TPPC

Advisors

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Research Project: Dark Matter in Composite Higgs

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- **Motivation**:

  - Why Composite Higgs?

- Naturalness of the Higgs mass:
  - New physics related to the Higgs boson (1-10)TeV scale.

- Composite Higgs:
  - New massless degrees of freedom: **techniquarks**
  - New gauge group, **technicolor**
  - Strong coupling scale $\Lambda = (1 - 10) TeV$

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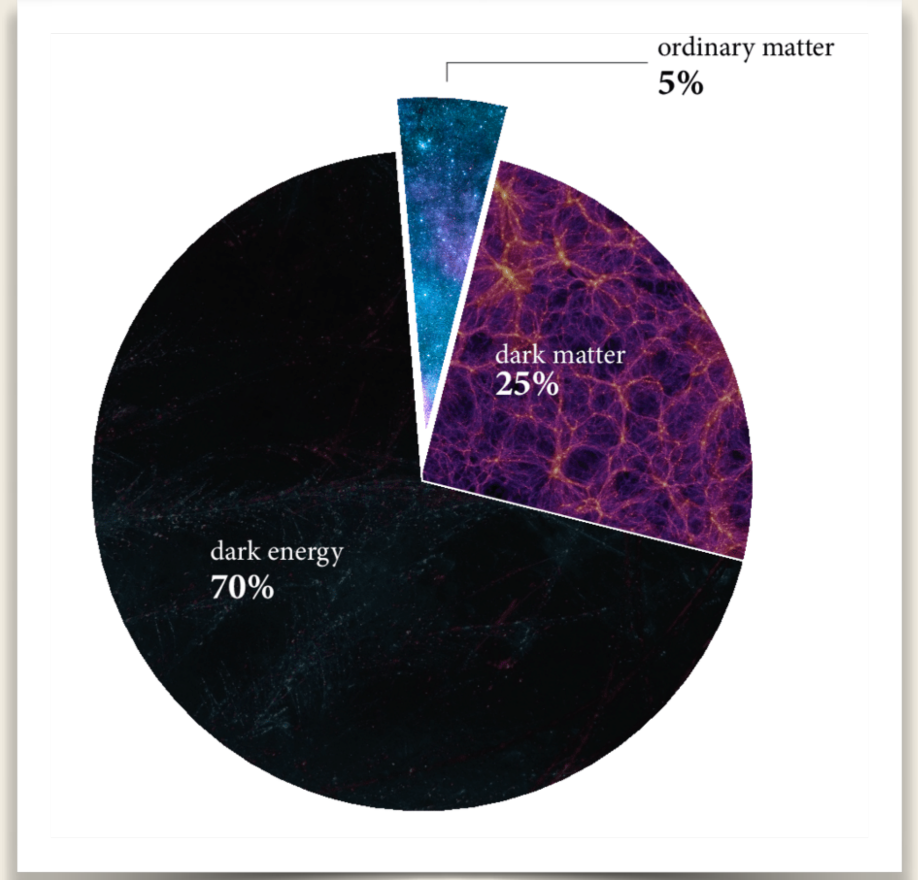
- **Motivation:**

  - Why Dark Matter?

- Observational Evidence
  - Curve velocities of stars around a galaxy
  - Virial Theorem
  - Gravitational Lensing
  - Bullet Cluster

- Theoretical Evidence
  - Hot Big Bang Puzzle for structure formation

- What do they tell us?
  - DM does not interact with light
  - It is very unlikely to carry colour charge
  - Stable on Cosmological timescales



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- **Motivation**:

Field	SU(3)	SU(2)	U(1)_Y	Q=Y+T3L
DM	1	n	Y	0

- Stability implies symmetry
  - It is usually imposed a $\mathbb{Z}_2$ symmetry under which:

$$P \cdot \chi = -\chi \qquad\qquad P \cdot SM = SM$$

so that all the operators with an odd number of DM are forbidden.

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- **Motivation**:
  - Why Dark Matter in Composite Higgs?
    - Thermal Masses for a Weakly Interacting Massive Particle (WIMP) are of the order of the scale Λ.
    - Techniquarks are supposed to form many bound states charged under Weak Group.

- **Question:**

  - Could the new physics related to Higgs boson also be connected to the Dark Matter?
  - Could the $\mathbb{Z}_2$ symmetry that ensures the DM stability be explained by the Composite Higgs symmetry?
  - What kind of particle should it be?

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- **Preliminary results**:
  - Are the $\mathbb{Z}_2$ properties of transformation needed in order to have a stable Dark Matter?
  - Can we combine the Lorentz symmetries and a $\mathbb{Z}_2$ to forbid operators with an odd number of DM?

Scalar case	DM	SM fermions
$\mathbb{Z}_2$	1	1
	1	-1
	-1	1
	-1	-1

Fermionic case	DM	SM fermions
$\mathbb{Z}_2$	1	1
	1	-1
	-1	1
	-1	-1

  - What about $\mathbb{Z}_2$ for scalars?
- **Scalar must be even**

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- **Preliminary results**:
  - Where does this $\mathbb{Z}_2$ symmetry come from?
  - What is the quality of this symmetry?
  - Can it be embedded in a symmetry belonging to the Composite Higgs itself?

- **Composite Higgs symmetries**:

QCD

$$SU(2)_L \times SU(2)_R \times U(1)_L \times U(1)_R \to SU(2)_V \times U(1)_V$$

Technicolor

$$\mathscr{G} \times U(1)_X \to \mathscr{H} \times U(1)_X \supset SU(2)_L \times SU(2)_R \times U(1)_X$$

$$Y = T_R^3 + X$$

- Goldstone Bosons $\in \mathscr{G}/H$

π^a $\qquad$ H

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- **Preliminary results**:
  - Could $U(1)_X$ work as a $\mathbb{Z}_2$?

$$U(\alpha)_X \cdot \varphi_X = e^{i\alpha X}\varphi_X \quad \Rightarrow \quad U(\pi)_X \cdot \varphi_X = e^{i\pi X}\varphi_X$$

  - If we suppose X to be integer then, depending on wether X is even or odd:

$$U(\pi)_X \cdot \varphi_X = \pm\, \varphi_X$$

  - When the charges are not integers, they can be rescaled to ensure they all become integer values!
- $U(1)_X$ **conservation implies a** $\mathbb{Z}_2$ **symmetry**
  - Is it exactly conserved?
  - If it is an accidental global symmetry of the strong sector it is broken by the SM;
  - If it is gauged there would introduce an other gauge boson
  - the only possibility is that it is spontaneously broken, by a scalar field with an even X charge.

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- **Preliminary results**:

◦ Can we apply this mechanism to $U(1)_Y$ in the SM+DM framework?

Field	$U(1)_Y$
L	$-1/2$
e_R	-1
q_l	$1/6$
u_R	$2/3$
d_R	$-1/3$
H	$1/2$
χ	$1/n$

SM+DM, Y charges

$$n = 4, Y \to 12Y$$

Field	$U(1)_Y$	$\mathbb{Z}_2 \subset U(1)_Y$
L	-6	$+$
e_R	-12	$+$
q_l	2	$+$
u_R	8	$+$
d_R	-4	$+$
H	6	$+$
χ	1	-

SM+DM, Y charges, for n=4

◦ But

$$Q = T_L^3 + Y,\ Q(DM) = 0 \quad \rightarrow \quad n_{max} = 2$$

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- **Preliminary results**:

  - We can focus on $SU(2)_L \times SU(2)_R \times U(1)_X$:

Tabella 5: Doublet: elementary fields charged under $SU(2)_R$.

Field	$SU(2)_L \times SU(2)_R$	T_R	$U(1)_X$	$\mathbb{Z}_2'$	$\mathcal{L}_{mix}$	$\mathcal{L}_{mass}$
l_L	$(2,1)$	0	$-1/2$	-1		
L	$(2,1)$	0	$-1/2$		$\bar{l}_L L$	
l_R	$(1,2)$	$\pm 1/2$	$-1/2$	-1		
E_R	$(1,2)$	$\pm 1/2$	$-1/2$		$\bar{l}_R E_R = \bar{\nu}_R E_R^u + \bar{e}_R E_R^d$	$E_R \bar{L} H$
q_L	$(2,1)$	0	$1/6$	-1		
Q_L	$(2,1)$	0	$1/6$		$\bar{q}_L Q_L$	
q_R	$(1,2)$	$\pm 1/2$	$1/6$	-1		
Q_R	$(1,2)$	$\pm 1/2$	$1/6$		$\bar{q}_R Q_R = \bar{u}_R Q_R^u + \bar{d}_R Q_R^d$	$U_R H \bar{Q}_L$
H	$(2,2)$	$1/2$	0	$+1$		
H_1	$(1,3)$	0	0	$+1$		
H_2	$(1,3)$	1	-1	$+1$		
χ_f	$(3,1)$	0	0	$+1$		
χ_s	$(3,2)$	$-1/2$	$1/2$	-1		
$\mathbb{X}_f$	$(3,1)$	0	0	$+1$		
$\mathbb{X}_s$	$(3,2)$	$-1/2$	$1/2$	-1		

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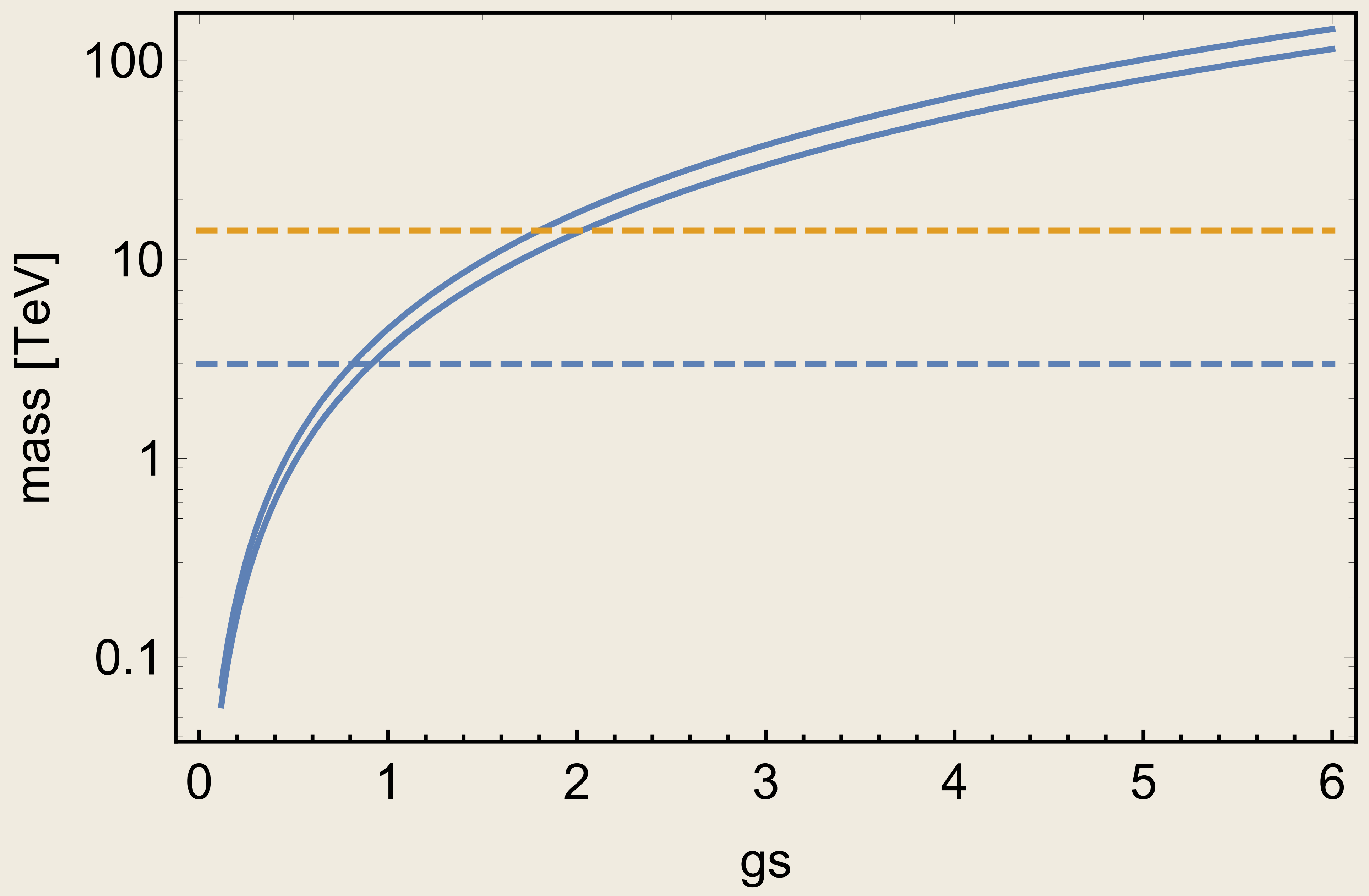
- **Future direction**:

- Phenomenological Consequences:

  - Thermal mass computation ✔
  - Collider signatures ⊕
  - BBN phenomenology ⊕

Thank you
for your attention

DM mass: (3,1) vs (5,1)



DM mass: (3,2) vs (5,2)