



A Simplified Model of Dark Matter Interacting Primarily with Gluon

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Dark Matter: Probes

- Relic density of Dark Matter (DM) is measured from CMBR (cosmic microwave), weak lensing, BAO (acoustic oscillations)...
- Direct detection via interactions with heavy nuclei
- Indirect detection via annihilations of DM pairs.
- DM is usually probed at hadron colliders in the missing transverse energy (MET) channels.

Simplest DM Model

- SM singlet scalar dark matter (χ)
- May couple with Z, W, h, t, b.. Typically, not with g
- Odd under a Z_2 symmetry group for stability
- Our Model:
 - ' ϕ ' scalar charged under SU(3)_C.
 - ' χ ' SM singlet scalar
 - Marginal operator allows, the unusual, DM-Gluon coupling.

$$\mathcal{L} \supset \lambda_d \ \phi^{\dagger} \phi \ \chi^{\star} \chi$$

Gluphillic DM Model

- A colored scalar which does not decay will have a primordial density and form heavy bound states.
- Experiments on water sampled from deep sea strongly constrain such particle¹
- Decay width of a colored scalar decaying to light quarks is proportional to the square of the coupling and the mass of the scalar.

$$\Gamma \sim y^2 m_{\phi}$$
 where, $y \gtrsim 10^{-20}$

1. Yamagata et.al. Phys.Rev. D47 (1993) 1231–1234

Gluphillic Scalar DM (GSDM)



 $\mathcal{L} \supset \left(\mathcal{D}_{\mu}\phi\right)^{2} + \left(\partial_{\mu}\chi\right)^{2} + \frac{1}{2}m_{\phi}^{2}\phi^{\dagger}\phi + \frac{1}{2}m_{\chi}^{2}\chi^{\star}\chi$

 $+\lambda_d \phi^{\dagger} \phi \chi^* \chi$

 $+\eta\epsilon^{\alpha\beta\gamma}\epsilon_{ijk}u^{i}_{R\alpha}u^{j}_{R\beta}\phi^{k}_{\gamma}+h.c.$

Gluphillic Scalar DM (GSDM)

- In general ϕ may belong to any representation of $SU(3)_c$.
- We explore the case of color triplet scalar below.
- Flavor constraints on such a particle are strong.
- We assume an interaction within MFV framework
 - The colored-scalar interact only with right chiral up-sector quarks.($SU(3)_{u_R}$ flavor symmetry)

$$\mathcal{L} \supset \eta \epsilon^{\alpha \beta \gamma} \epsilon_{ijk} u^{i}{}_{R\alpha} u^{j}{}_{R\beta} \phi^{k}{}_{\gamma} + h.c.$$

Relic Density



Constraints on masses of the DM ' χ ' and colored scalar ' ϕ '. The color contour represent product of coupling and color factor for a representation **r** and number of flavors N_f .

Relic Density



Constraints on masses of the DM ' χ ' and colored scalar ' ϕ '.

Dark Matter: Direct Detection



Xenon: 105 kg Liq Xe (Italy)

Direct Detection Bounds



GSDM: Colored Scalar at LHC

• Representative Feynman diagrams.



loop.

(c) Mediator + top quark production followed by decay of the mediator into top and an unflavored jet.



(d) Pair productoin of mediators followed by decay into two fermions.

 $\mathcal{L} \supset \left(\mathcal{D}_{\mu}\phi\right)^{2} + \left(\partial_{\mu}\chi\right)^{2} + \frac{1}{2}m_{\phi}^{2}\phi^{\dagger}\phi + \frac{1}{2}m_{\chi}^{2}\chi^{\star}\chi + \lambda_{d}\phi^{\dagger}\phi\chi^{\star}\chi + \eta\epsilon^{\alpha\beta\gamma}\epsilon_{ijk}u^{i}_{R\alpha}u^{j}_{R\beta}\phi^{k}_{\gamma} + h.c.$

Collider Constraints on Colored Scalar



 The constraints are extended by the tt + 1j search[1209.6593,ATLAS]. The purple region is ruled out. Updated bound: 510 GeV (13 TeV).

DM Signature at Colliders: Monojet

- There are No Tree Level couplings of the DM with gluons.
- The monojet process arises at 1-loop.
- To start, we find the Effective Field Theory (EFT) operator in the limit of large mediator mass.

$$\frac{\alpha_s}{M^2} G^{\mu\nu}{}_a G_{\mu\nu}{}^a \chi^\dagger \chi$$

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• Weak constraints from EFT.

$$\frac{\lambda_d T_r}{48\pi M^2} \le \frac{1}{(207 GeV)^2}$$

Monojet: 1-Loop

- EFT is not applicable when mediator masses are small and or MET cuts are large.
- Complete loop calculation is necessary to probe this model at LHC.







Monojet: Loop Calculation

- Monojet amplitude at 1-loop is calculated with 3 methods:
- By hand > Integrated using OneLoop library
- FeynRules > FeynArts > FormCalc > LoopTools
- FeynRules (NLOCT) > Madgraph (NLOCT)



Monojet: Cross section

• Constraints from CMS [Eur. Phys.J. C75 no. 5, (2015) 235] monojet search.



Monojet: Projections

• Reach of LHC-13 in high luminosity limit to constraint GDSM.



Monojet: Projections

• Reach of Future Circular (hadron) Collider to constraint GDSM.



Summary: Gluphillic DM

- We propose a model where a scalar DM preferentially couples with gluons.
- We find that tree-level annihilation gives the correct relic density of DM.
- We calculate the loop-induced monojet process and find that effective field theory underestimates the cross section by a factor of 2 when mediator mass is comparable to the cuts.

Summary: Gluphillic DM

- Colored scalars which can decay give a rich signature at LHC and can be discovered in multi-jet final state searches.
- With the assumption of a light dark matter (1GeV) color triplet scalar can be constrained up to 50 GeV with high luminosity at LHC.
- With 3 ab⁻¹, LHC can discover a color octet mediator with mass ~200 GeV and dim 15 mediator of mass 500 GeV.
- FCC can probe much larger masses up to TeV scale within a low 300 fb^{-1} luminosity.

Backup

Madgraph(NLOCT) vs Fortran Code

