Big Bang Theory



Effective WIMPs

Spencer Chang (University of Oregon) w/R. Edezhath, J. Hutchinson, M. Luty arXiv:1307:8120 Also see talks by Zhang et.al. 1308.0592 Bai et.al. 1308.0612 Tait et.al. 1308.2679

How are dark matter signals correlated?

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Direct Detection

Indirect Detection

Collider

Effective DM see e.g. Beltran e.t.al., Goodman et.al., Bai et.al.

Consider only dark matter state w/ one effective operators to SM at a time

$$\frac{\mathcal{O}_{DM}\mathcal{O}_{SM}}{\frac{1}{M_*^2}} \left(\bar{\chi}\gamma_\mu\chi\right)\left(\bar{q}\gamma^\mu q\right)$$

Pros: Simple 2-d parameter space, allows comparison between monojets and direct detection

Cons: WIMP miracle put in by hand, potentially new signals in UV completion, multiple operators may be important

A Complete Model: PMSSM Study Cahill-Rowley et.al. 1305.6921



Pros: Theoretically Motivated, All Effects (e.g. NLO, coannihilation)

Cons: Multi-dimensional parameter space, signal correlations harder to see, sensitive to theory priors

Approaches

A complete WIMP theory, e.g. Supersymmetric Dark Matter

We are proposing a useful compromise: "Effective WIMPs"

Effective WIMP

For a UV complete model, typically have to add new particles (however see Minimal DM, Higgs Portal) $\mathcal{L}_{int} = \lambda \chi(SM)(\widetilde{SM})^*$

If we assume DM is gauge singlet, have to introduce partners to SM particles

3 parameters: masses of DM, partner and interaction strength. However, can fix one by relic abundance

Natural Z₂ symmetry for DM stability

Discrete Choices

We considered DM of spin 0, 1/2, 1 with renormalizable couplings to left-handed quarks

From flavor assume quark partners are degenerate and DM couples to all, first two or just third generation

DM can be "real or complex"

Effective Interaction

Relic Abundance, Indirect



Caveat: QCD

production of Q



Collider

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Direct Detection

Impose relic abundance to get rates

Direct Detection vs Relic Abundance

For complex dark matter (e.g. Dirac or complex scalar) no symmetry to forbid vector-vector coupling to quarks

Due to large matrix element of quark vector operator in nucleons, one finds



XENON100 limit requires multi-TeV DM which is uninteresting for colliders

Real Dark Matter Models

Due to suppressed matrix elements, not ruled out by direct detection unless $m_{DM} \approx m_Q$ due to s-channel resonance





For real DM, t-channel process allows to produce same sign quark partners, using valence quark pdfs

Its xsec goes as λ^4 , which for relic abundance grows as m_Q^4 , thus compensating for pdf drop



New t-channel Process

For real DM, t-channel process allows to produce same sign quark partners, using valence quark pdfs

Its xsec goes as λ^4 , which for relic abundance grows as m_Q^4 , thus compensating for pdf drop

Monojet



Monojet



Monojet













Primer to 4 papers



Conclusions

- * Effective WIMPs are useful complete DM theories w/ simple 2d parameter space after imposing Ω_{DM}
- Direct detection and colliders are complementary in the parameter space
- Real DM models least constrained, new collider process of same sign quark partner production through t-channel DM
- Good starting point to analyze limits or any excesses

Extra Slides

Majorana 3rd Gen Only



Much weaker constraints from colliders and direct detection due to small b-quark content of proton

Vector DM All Quarks

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Major boost to dijet search due to fermion Q xsec

Smaller direct detection limits due to smaller interaction strength

Vector DM 3rd Generation Quarks



Real Scalar DM



All quarks 3rd gen quarks

Light gen quark model is completely ruled out by XENON100 and colliders

Monojet features

 $\sum_{x \in g_s^2} \frac{m_{Q_s}^2}{p_{Q_s}^2} \xrightarrow{Q_s} q_{q_s}^2 \xrightarrow{Q_s} q_{q_s}^2$

Near degeneracy, jets from ISR crucial for jets+MET searches

Typically dominated by gluon fusion but t-channel process has different ISR

Not precisely modeled by simplified models

Effective WIMP Recap

Improved reach for collider searches through new process of t-channel DM exchange constraining ~ TeV quark partners

Monojet has a MET "bump" due to Qχ production

An et.al. arXiv: 1308.0592 Comparison of effective operator vs full mediator

Majorana Analysis by Bai, Berger 1308.0612

Coupled to up quarks

Coupled to down quarks

Real Scalar DM coupled to light quarks

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Nonperturbative Coupling

Perturbative Region ruled out by monojet and XENON100