Probing Baryogenesis with Displaced Vertices at the LHC

Aniket Joglekar
University of California Riverside
with Yanou Cui, Brian Shuve and Yushin Tsai
to appear

Pheno 2018

Outline

- Displaced Vertex (DV) searches
- WIMP Baryogenesis Motivation
- WIMP Baryogenesis and lifetime of the WIMP
- LHC Phenomenology

DV Searches

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- Low backgrounds
- Immense potential for exotic searches:

  Hidden sectors, RPV, TeV scale seesaw mechanism, Baryogenesis

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- Observed baryon density >>> antibaryon density

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- Another outstanding puzzle : dark matter
- DM and Baryon density are of same order of magnitude
- Coincidence ? What if the two are linked?

WIMP Baryogenesis

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- If decays with B, C and CP violation, then all Sakharov conditions are satisfied
- Baryogenesis

WIMP Baryogenesis

- χ must decay after the freeze-out : $T_f > T_D$
- χ must decay before BBN : $T_D > T_{BBN}$
- If the scales are well separated such then Boltzmann equations give

$$Y_B(0) = \epsilon_{\rm CP} \int_0^{T_{\rm D}} \frac{dY_{\chi B}}{dT} \exp\left(- \int_0^T \frac{\Gamma_{\rm W}(T')}{H(T')} \frac{dT'}{T'} \right) dT$$

$$+ Y_B^{\rm ini} \exp\left(- \int_0^{T_{\rm ini}} \frac{\Gamma_{\rm W}(T)}{H(T)} \frac{dT}{T} \right)$$

In weak wash-out limit $\Gamma_{\rm W} < H$,

$$Y_B(0) \simeq \epsilon_{\rm CP} Y_{\chi B}(T_{\rm f}), \quad \Omega_B(0) = \epsilon_{\rm CP} \frac{m_p}{m_{\chi B}} \Omega_{\chi B}^{\tau \to \infty}$$

Y. Cui, R. Sundrum arXiv:1212.2973

WIMP Baryogenesis

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- $\Omega_{\chi_B}^{\tau\to\infty}$: Relic density if the WIMP were stable
- Two species of χ can have observed density ratio of

$$\frac{\Omega_B}{\Omega_{\rm DM}} \approx \frac{1}{5}$$

due to difference in masses and couplings of two species

Simplified Model

$$\Delta\mathcal{L} = \lambda_{ij}\phi d_i d_j + \varepsilon_i \chi \bar{u}_i \phi + M_\chi^2 \chi^2 + y_i \psi \bar{u}_i \phi + M_\psi^2 \psi^2$$
$$+ \alpha \chi^2 S + \beta |H|^2 S + M_S^2 S^2 + \text{h.c.}$$

- Has necessary ingredients :

  B violating decay : $\chi \to \phi^* u$, $\phi \to dd$

  CP violation via ψ mediated interference

- Final piece : Thermal non-equilibrium needs $T_D < T_f$

  Lifetime needs to be long enough to last till $T < T_f$

Simplified Model

- Freeze-out is near weak scale ~ 10^{-12} s

- Lifetime > 10^{-11} or 10^{-10} s

  Length > 1 mm or 1 cm

- BBN is MeV scale so upper bound is large enough to not take into account as far as DV motivation is concerned

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- Above can be promoted to SUSY
- Diquarks to squarks, ψ to gauginos
- S can be decoupled leading to χ production only via portal coupling

$$\mathcal{L} \supset \frac{\lambda_{S\chi\chi}}{2} \sin\alpha \; h\chi\chi$$

LHC Phenomenology

- Higgs production via gluon fusion is proportional to
- Portal coupling is proportional to $\cos\alpha$
- Production cross-section is low for production via offshell Higgs

$$\lambda_{S\chi\chi}\sin 2\alpha$$

- Existing DV searches even at 8 TeV can probe colored states 1 TeV (esp. CMS dijet search arXiv:1411.6530)
- Singlet portal suffers from lower production cross-section

LHC Phenomenology

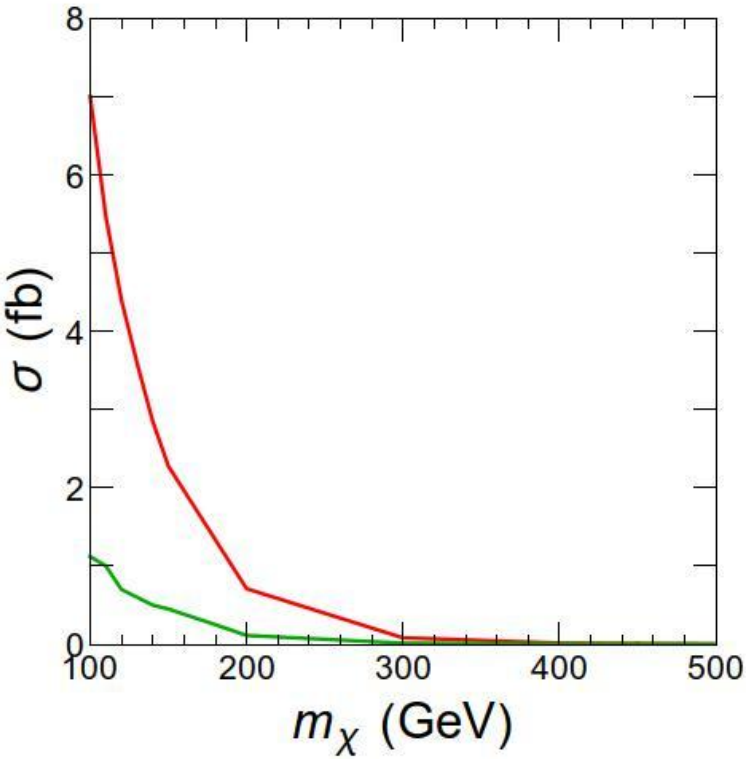
- In principle, independent parameters

$$m_\chi,\ c\tau_\chi \quad \text{and} \quad \lambda_{S\chi\chi} \sin 2\alpha$$

- From WIMP Baryogenesis perspective interesting parameter space is singlet masses of less than TeV scale
- Lifetime has lower bound from non-equilibrium condition
- Mixing angle is bound by Higgs coupling measurement

LHC Phenomenology

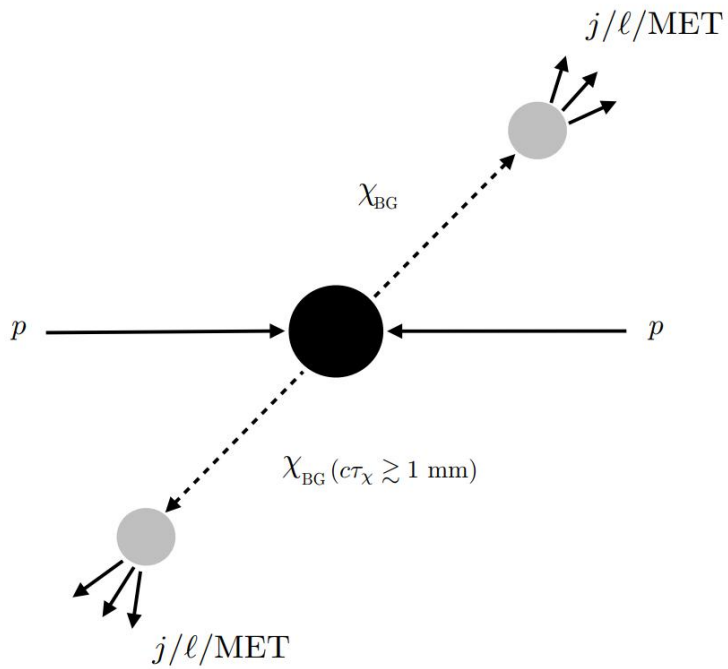
- Singlet production cross section

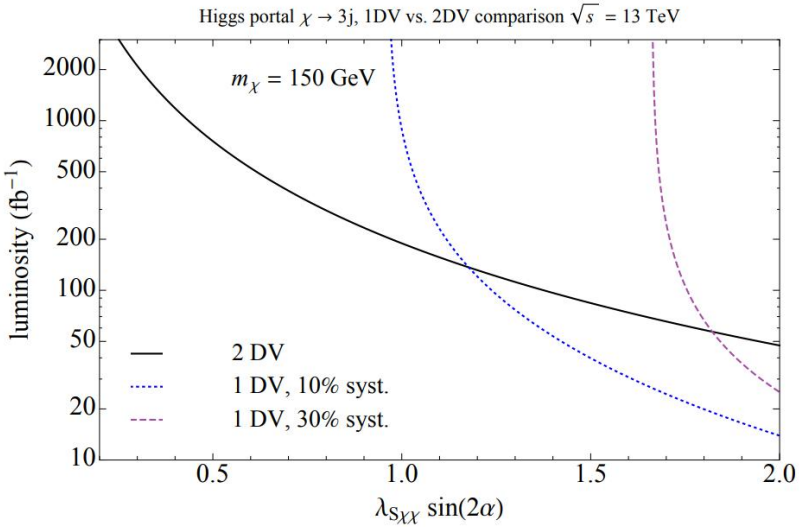


- Probing $m_x > 300$ GeV is production constrained
- What about $m_X < 200$ GeV?

LHC Phenomenology

- H_T trigger > 500 GeV reduces signal efficiency for low mass particles
- Tag 2 DV in which reduces background to almost zero
- Can allow lowering of H_T threshold





(a) $\langle L_{xy} \rangle = 3$ cm

Y. Cui, B. Shuve arXv:1409.6729

LHC Phenomenology

- 2DV tagging will reduce signal efficiency greatly for medium to large lifetimes
- For very large lifetimes there is MET+j
- For in-between range how to lower H_T threshold?
- MET trigger is more forgiving, so 1DV+MET

Summary

- Displaced Vertex (DV) searches are theoretically well motivated
- WIMP baryogenesis can address both puzzles and can provide explanation for coincidence in densities
- Probe at LHC for masses at electroweak scale will need some modification of kinematic thresholds