Phenomenology of Fermionic Asymmetric Dark Matter

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Why is a fermionic ADM attractive?

Evidences of BSM

- Structure formation (Inflation)
- Existence of Dark Energy
- Neutrino masses and mixings → Heavy right-handed neutrinos
- Baryon asymmetry of Universe → Heavy right-handed neutrinos
- Existence of Dark Matter ← Residual discrete symmetry

Heavy right-handed neutrinos
↓
$U(1)_{B-L}$ gauge symmetry
↓
Residual discrete symmetry

Why $U(1)_{B-L}$ works?

- $U(1)_{B-L}$ can be spontaneously broken by VEV having a B-L charge 2.
- The SM involves only B-L odd fermions and B-L even (zero) bosons,

A New fermion(boson) with a even(odd) B-L charge becomes stable!
Particle (either fermion or boson) with a fractional B-L charge is OK.

⇩

Possible DM candidates

1. A fermion which is singlet under $U(1)_{B-L}$ → e.g. Neutralino in MSSM.
2. A boson charged under $U(1)_{B-L}$ → Severe limit from neutron stars.
3. A fermion which is charged under $U(1)_{B-L}$ ← Today's topic.

Properties of a fermionic ADM

① From detailed balance among chemical potentials of SM particles and ADM,

$$\frac{(\mathrm{B}-\mathrm{L})_{\mathrm{SM}}}{(\mathrm{B}-\mathrm{L})_{\mathrm{DM}}} = \frac{79}{22\,Q_{\mathrm{DM}}^2} \longrightarrow m_{\mathrm{DM}} = \frac{30}{97}\frac{79}{22}\frac{\Omega_{\mathrm{DM}}}{\Omega_b}\frac{m_N}{Q_{\mathrm{DM}}} \simeq \frac{5.7\,\mathrm{GeV}}{Q_{\mathrm{DM}}}$$

without depending on details of ADM interactions! [Ibe, S.M., Yanagida, 2012]

② When $Q_{DM} = O(1)$, $m_{DM} \ll m_Z$, ADM must be singlet under SM gauge groups.

③ Singlet fermion ADM does not have any renormalizable interactions, so that additional light particles (mediator) must be introduced to have a large annihilation X-section between dark and anti-dark matter particles.

Minimal setup — Singlet scalar mediator!

$$\mathcal{L} = i\overline{\chi}\,(\partial\!\!\!/ - m_\chi)\,\chi + \frac{1}{2}\left[(\partial\phi')^2 - m_{\phi'}^2\phi'^2\right] - \kappa\,\overline{\chi}\chi\phi' - V(H', \phi')$$

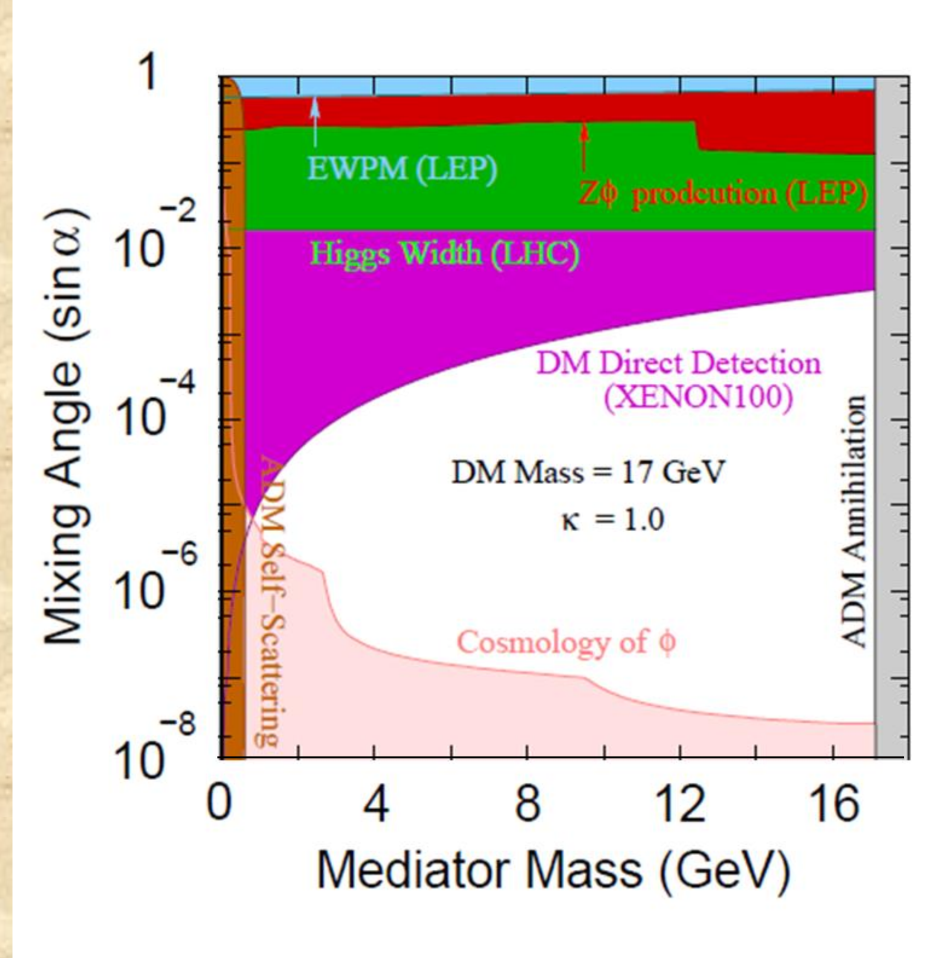
$$h = (\cos\alpha)\,h' - (\sin\alpha)\,\phi' \quad \& \quad \phi = (\sin\alpha)\,h' + (\cos\alpha)\,\phi'$$

① m_χ = 17 GeV (Q_{DM} = 1/3) & κ = 1 as a sample point.

② Focusing on the region $m_\phi < m_\chi$ (Annihilation process $\chi\chi \to \phi\phi$)

③ $\sin\alpha$: = free parameter (It has typically a value of $10^{-2} - 10^{-4}$)

Summary (constraints & prospects)



1. DM & Anti-DM annihilation.
2. Direct detection of DM.
3. DM self-scatterings.
4. Cosmology of the mediator ϕ.
5. Z ϕ production @ LEP
6. Electroweak precision @ LEP.
7. Higgs measurement @ LHC.
8. Direct ϕ production @ LHC.
9. ϕ production from H @ LHC.
10. Upsilon decay to ϕ & γ.
11. Beam dumping experiments.
12. Supernova cooling, etc.

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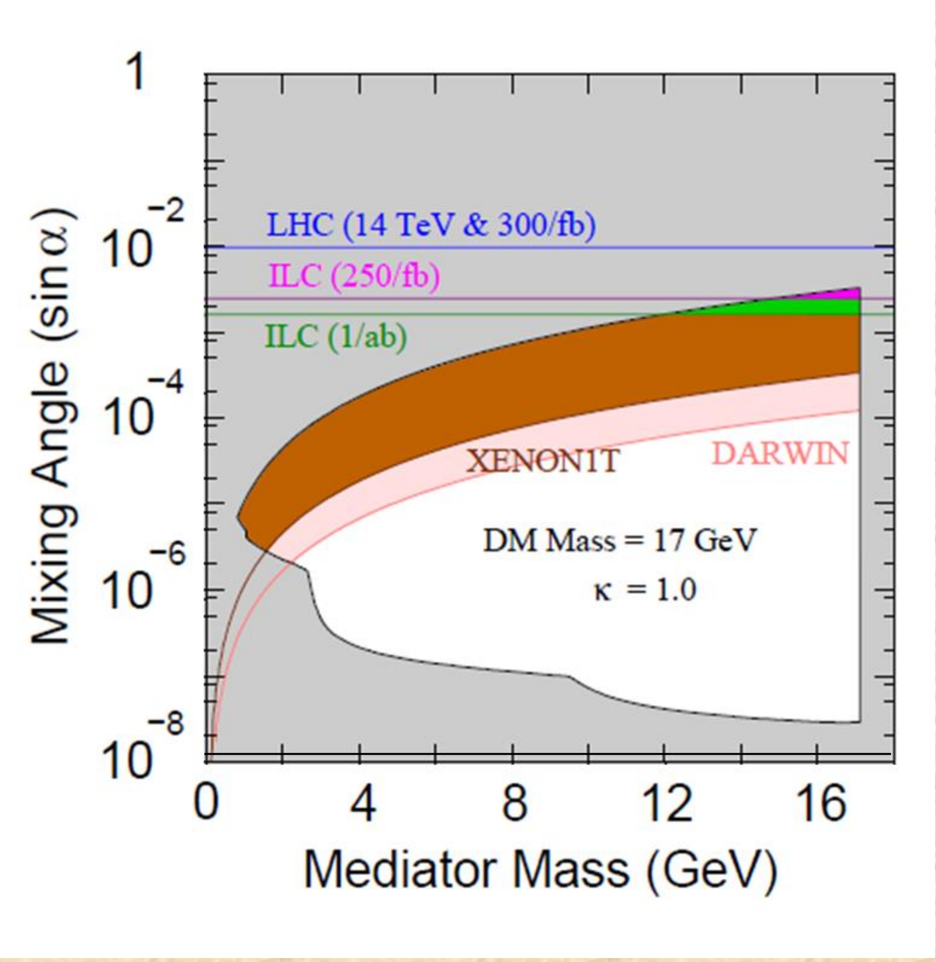

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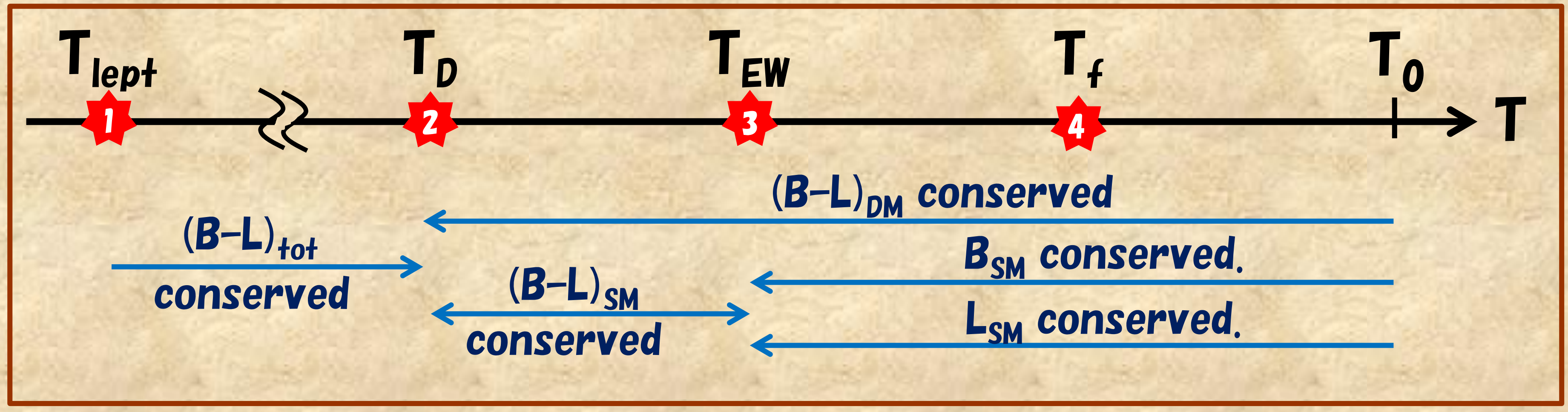
- Fermionic ADM is interesting from the viewpoint of gauged $U(1)_{B-L}$.
- Fermionic ADM requires an additional light mediator (a real scalar in the minimal case), which makes low energy phenomenology being rich.
- Among experiments, DM direct detections will be the most important.

Backup (Thermal history of the ADM)



1. **B-L asymmetry** is produced. ADM (DM and Anti-DM) is expected to be chemical & thermal equilibrium. After that, $(B-L)_{tot}$ is preserved.
2. **Interactions maintaining equilibrium between ADM & SM** sectors are decoupled. After that, $(B-L)_{DM}$ & $(B-L)_{SM}$ are individually preserved.
3. **Sphaleron process** is decoupled. After that, all of B_{SM} , L_{SM} and $(B-L)_{DM}$ are individually preserved. B_{SM} gives BAU observed today.
4. **Annihilation between DM & Anti-DM** occurs. Symmetric component is eliminated and either DM or Anti-DM survived, which gives the DM density observed today. Annihilation must be efficient enough.