THE 4TH KIAS WORKSHOP ON PARTICLE PHYSICS AND COSMOLOGY

ACCIDENTAL DARK MATTER: A CASE IN SCALE INVARIANT B-L MODEL

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BASED ON AN UNBORN PAPER, WITH P. KO, Y. ORIKAS AND XX YY

Outline

Matter Stability in the SM

Implanted to dark matter

- Without new gauge symmetry
- With gauged B-L

Matter stability in SM

- Proton is accidentally stable due to

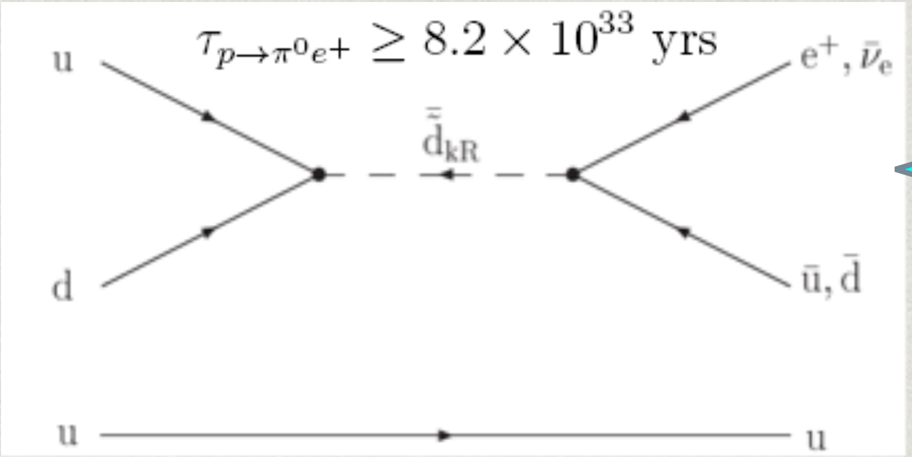
  Gauge and spacetime symmetries: $SU(3)_C * SU(2)_L * U(1)_Y$*Poincare

  Matter content: well arranged fermions and a Higgs doublet

  Renormalizable: dimension-5 operators violating *B* & *L* are absent

- SUSY: An example violating the SM structure

  Adding new particles may be dangerous, e.g., squarks in SUSY



New symmetries are then required in the low energy effective model to forbid renormalizable operators violating B&L. For example, in MSSM R-parity should be imposed. However, **global symmetries may be not reliable**!

Implanted to dark matter (DM)

- Scale invariance (SI) and singlet scalar

Updating the SM spacetime symmetries by SI may justify the technique face of hierarchy problem W. A. Bardeen, FERMILAB-CONF-95-391-T.

Accidental WIMP DM in the SI-SM: the nontrivial face of trivial real singlet DM via Higgs portal arXiv:1401.5609, Jun Guo and Z. Kang

$$-\mathcal{L} = \frac{\lambda}{2}(\Phi^\dagger\Phi)^2 + \frac{\lambda_{ij}}{2}\Phi^\dagger\Phi S_i S_j + \frac{\lambda_{ijkl}}{4!} S_i S_j S_k S_l,$$

SI kills cubic term $S_iS_jS_k$, thus giving rise to an accidental Z_2. **Scalar singlet is the unique candidate** given EW-VEV is the dominant source for the particle mass origin.

- What if right-handed neutrinos are incorporated?

We need RHNs N to generate nonzero neutrino masses, but then we encounter Z_2 breaking term SN^2

Implanted to dark matter (DM)

- Beautiful rescue by $U(1)_{B\text{-}L}$

  Accidental DM needs it to forbid SN^2

  RHNs need it to gain legitimacy (by virtue of anomaly cancelation)

  Scale invariance needs it to break SI (by Coleman-Weinberg approach)

- The minimal scale invariant *B-L* model (SIBL)

S. Iso, N. Okada and Y. Orikasa, Phys. Lett. B 676, 81 (2009)

$$\mathcal{L} = V(H,\Phi) + \left(\frac{1}{2}\lambda_{N,i}\Phi\bar{N}_i^c N_i + Y_{N,ij}\bar{\ell}H^\dagger N + h.c.\right) + \mathcal{L}_{\rm SM}$$

$$V(H,\Phi) = \frac{\lambda_h}{2}|H|^4 - \lambda_{h\phi}|H|^2|\Phi|^2 + \frac{\lambda}{2}|\Phi|^4$$

Induce EWSB

Make <Φ>~10 TeV via CW mechanism

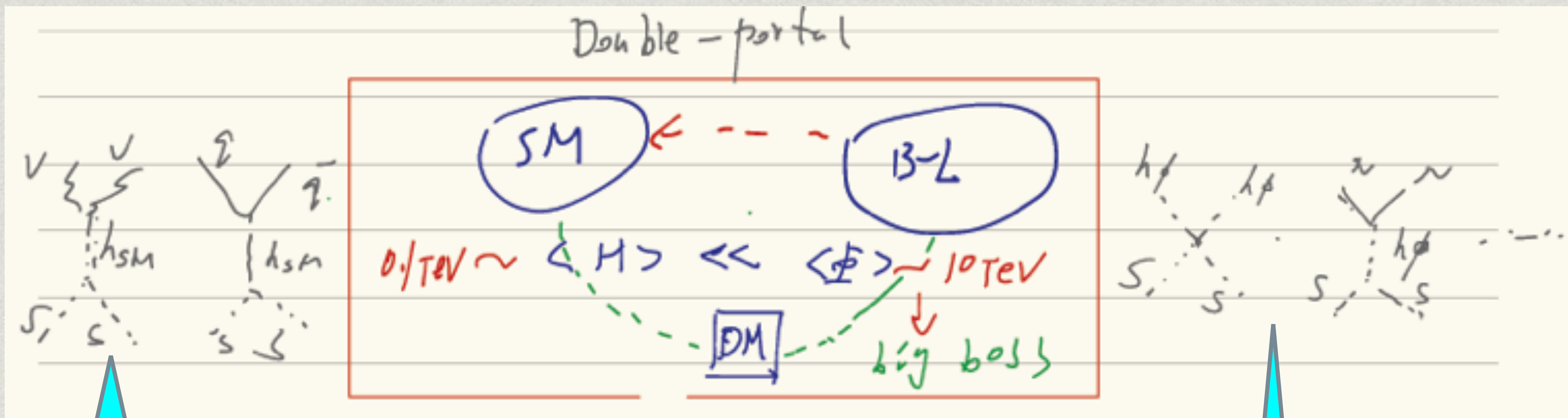
- Accidental Z_2 real singlet DM revives

$$\mathcal{L}_{DM} = \frac{1}{2}\lambda_{sh}S^2(H^\dagger H) + \frac{1}{2}\lambda_{s\phi}S^2(\Phi^\dagger\Phi) + \frac{\lambda_s}{4}S^4.$$

Implanted to dark matter (DM)

- Clear ways to dark matter relic density

Old story: Higgs-portal & New scenario: Φ-portal



1. DM mainly gets mass from weakly coupling to Φ
2. DM mainly annihilates via the Higgs-portal
3. DM mainly is constrained by direct detections

$$\langle \sigma v \rangle \simeq \frac{1}{8\pi}\frac{1}{4m_S^2}\frac{\sqrt{m_S^2 - m_\phi^2}}{m_S}|\mathcal{M}_{SS\to\phi\phi}|^2 \simeq \frac{1}{16\pi}\frac{\lambda_{s\phi}}{v_\phi^2}$$

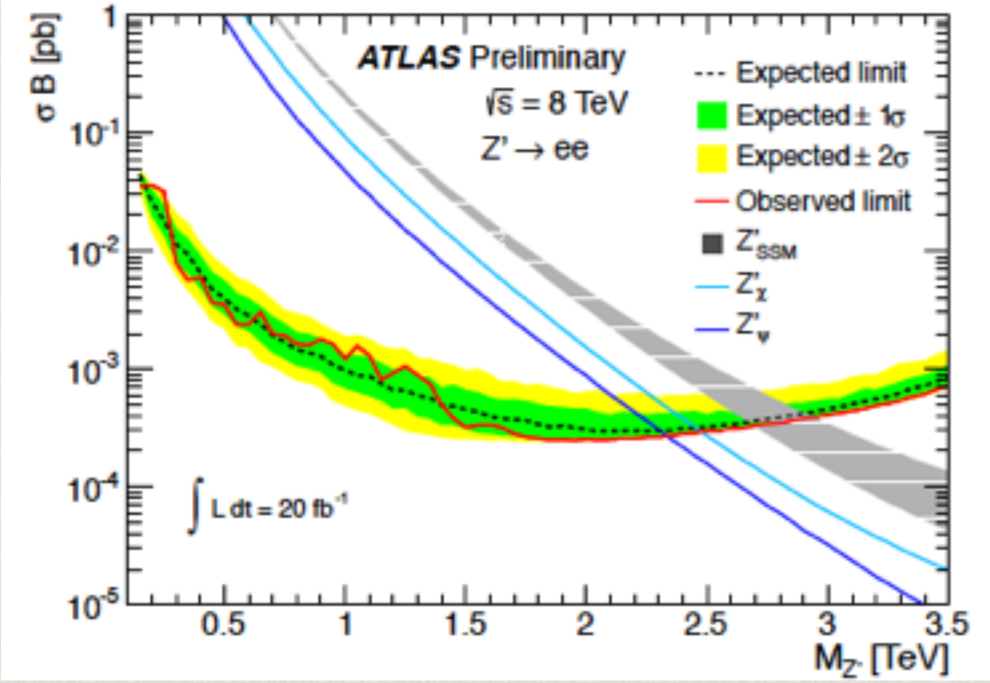
1. Turn off the Higgs-portal, then **DM becomes invisible at LUX/XENON**
2. Mass origin and interaction of DM are “unified” in this portal
3. PGSB can be naturally lighter than DM, so DM annihilate into them
4. Two parameters model. A large coupling & smaller VEV are needed…next page：

Implanted to dark matter (DM)

- More about Φ-portal

A large VEV <Φ> above 5 TeV from the LHC bound on di-lepton resonance, produced by

$$q\bar{q} \rightarrow Z' \rightarrow e^+ e^-$$



DM triggers SI spontaneously breaking?!!

A large $\lambda_{s\phi}^2 S^2 |\Phi|^2$ means DM may dominate over Z' in the contributions to the CW effective potential

$$V(\phi_{\rm cl}) = A\phi_{\rm cl}^4 + B\phi_{\rm cl}^4 \log\frac{\phi_{\rm cl}^2}{Q^2}$$

$$B = \frac{1}{64\pi^2}\left(3 \times Q_\Phi^4 g_{B-L}^4 - 2\sum_i (\lambda_{N,i}/\sqrt{2})^4\right) < \Delta B = +\frac{1}{64\pi^2}\frac{\lambda_{s\phi}^2}{2}$$

Implanted to dark matter (DM)

- *B-L* charged case: Accidental Z3

Scalar S_X with peculiar charge like $X = 1.11$ will not be considered

The only nontrivial case is $X = \pm 2/3$

P. Ko and Y. Tang, JCAP 1405, 047 (2014).

$$\mathcal{L}_{Z_3} = \lambda_1 |S_X|^2 |\Phi|^2 + \left(\frac{\lambda_3}{3} \Phi S_X^3 + c.c. \right) + \lambda_2 |S_X|^2 |H|^2 + V(H, \Phi).$$

- Importance of $S_X^3 \Phi$ dynamics

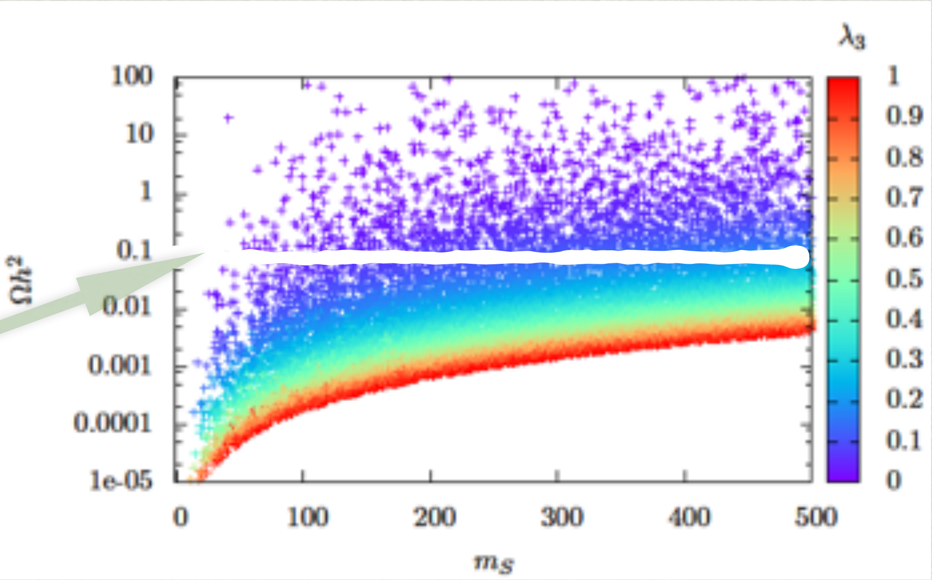
Separating DM mass generation from annihilation

1. Z′ is almost irrelevant in DM annihilating, because of the LHC constraint on Z′

$$\left\langle \sigma_{SS^* \to Z' \to f\bar{f}} v \right\rangle \sim \frac{v^2}{64\pi} \frac{g_{B-L}^4}{m_{Z'}^4} m_{\rm DM}^2 < 10^{-3} \left(\frac{m_{\rm DM}}{1 \rm TeV} \right)^2 \rm pb$$

2. By contrast, the semi-annihilation is **not suppressed by large VEV <Φ>**

$$\left\langle \sigma_{SS \to S^* + \rm PGSB} v \right\rangle \sim \frac{1}{64\pi} \frac{\lambda_3^2}{m_S^2}$$



Conclusions

- Why is dark matter stabile is a basic question. Our answer, motivated by proton stability in SM, is that it is accidentally stable due to the fundamental symmetries and field content of the model.

- We implement this idea in the scale invariant gauged B-L models, getting an accidental Z_2 (Z_3) symmetry for a real singlet scalar (B-L charged scalar). They can have good dark matter phenomenologies.

Thanks!