# Photon Lines From Decaying Goldstini Dark Matter

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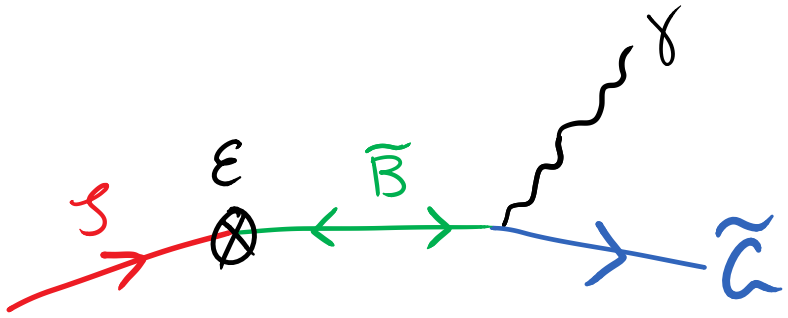
M. McCullough, J. Thaler, ZT, and Mobolaji Williams, forthcoming.

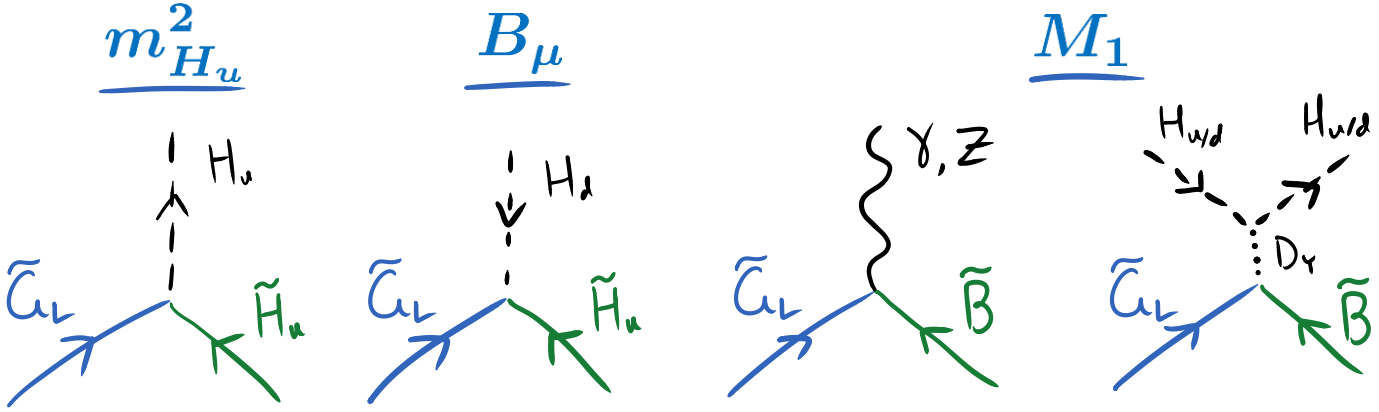
# Outline

- Goldstini Overview
- Bino-Goldstini Kinetic Mixing
- Goldstini Decay
- Indirect Detection



# The Goldstino

- Spontaneous ~~SUSY~~ → massless Goldstone *fermion*
  - Goldstino $\tilde{G}_L$
- Couplings ~ soft ~~SUSY~~ effects



# The Goldstino

- Spontaneous ~~SUSY~~ → massless Goldstone *fermion*
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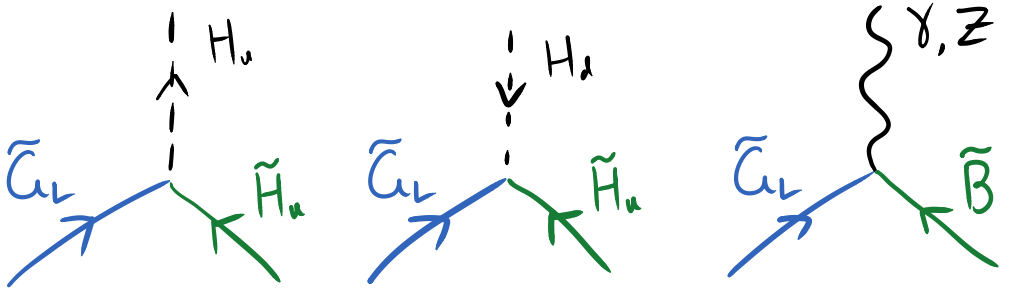
- Couplings ~ soft ~~SUSY~~ effects

(eaten by gravitino $\tilde{G}$ in SUGRA)

$m^2_{H_u}$ $B_\mu$

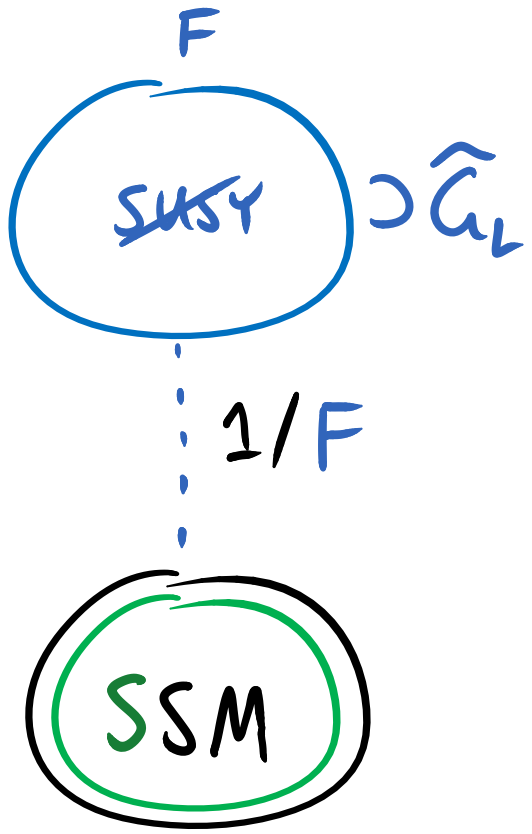



OR: derivative coupling to supercurrent

$$\frac{1}{F}\partial_\mu \tilde{G}_L j^\mu$$

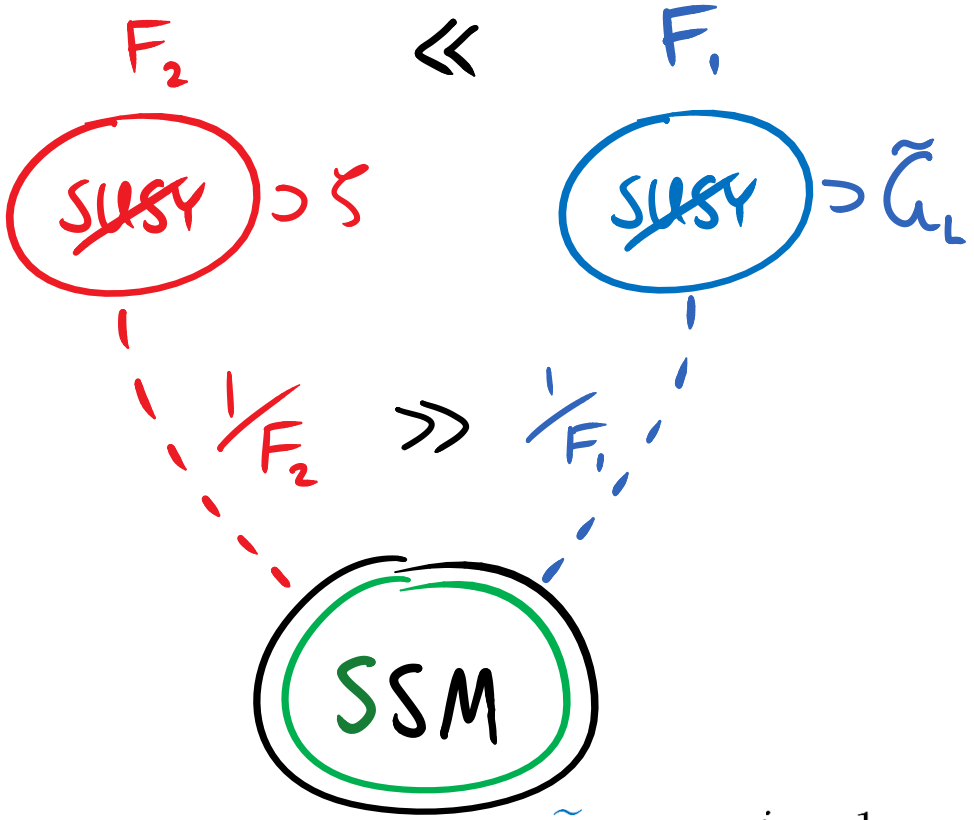
# Hidden Sector(s)

- ~~SUSY~~ in a Hidden Sector with strength $F$
- Couplings to visible sector suppressed by $1/F$
- Only light $\widetilde{G}_L$ relevant



# Goldstini

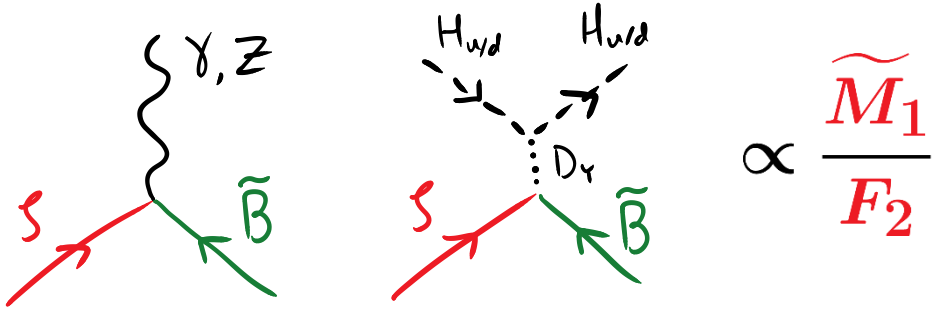
- ~~SUSY~~ in multiple hidden sectors
- New Goldstini $\zeta$
- Different Couplings
- Novel Phenomenology




$$\tilde{G}_L \propto F_i \chi^i + \frac{1}{\sqrt{2}} D_a \lambda^a$$

# Goldstini Couplings

- $\zeta$ couplings to SSM:
  - $\propto$ Sector 2-derived ~~SUSY~~ effects
  - (Only) suppressed by $F_2 \ll F_1$




$$\propto \frac{\widetilde{M}_1}{F_2}$$

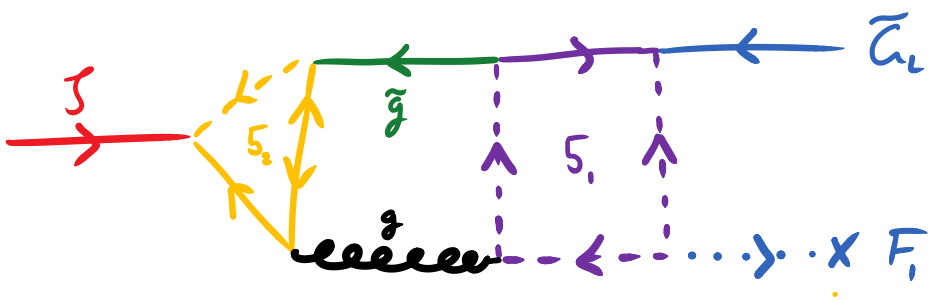
No derivatively-coupled basis!

# Goldstini Mass

- Tree: $m_\zeta = 2m_{3/2}$
- Loop: SSM couplings induce

$$\frac{1}{(16\pi^2)^n}\int d^4\theta\, \frac{1}{\Lambda} X_1^\dagger X_1 X_2 \qquad m_\zeta = \frac{1}{(16\pi^2)^n}\frac{F_1}{\Lambda}\frac{F_1}{F_2}$$

  - Argurio et al. 1102.2386 (gauge mediation)




keV - TeV range

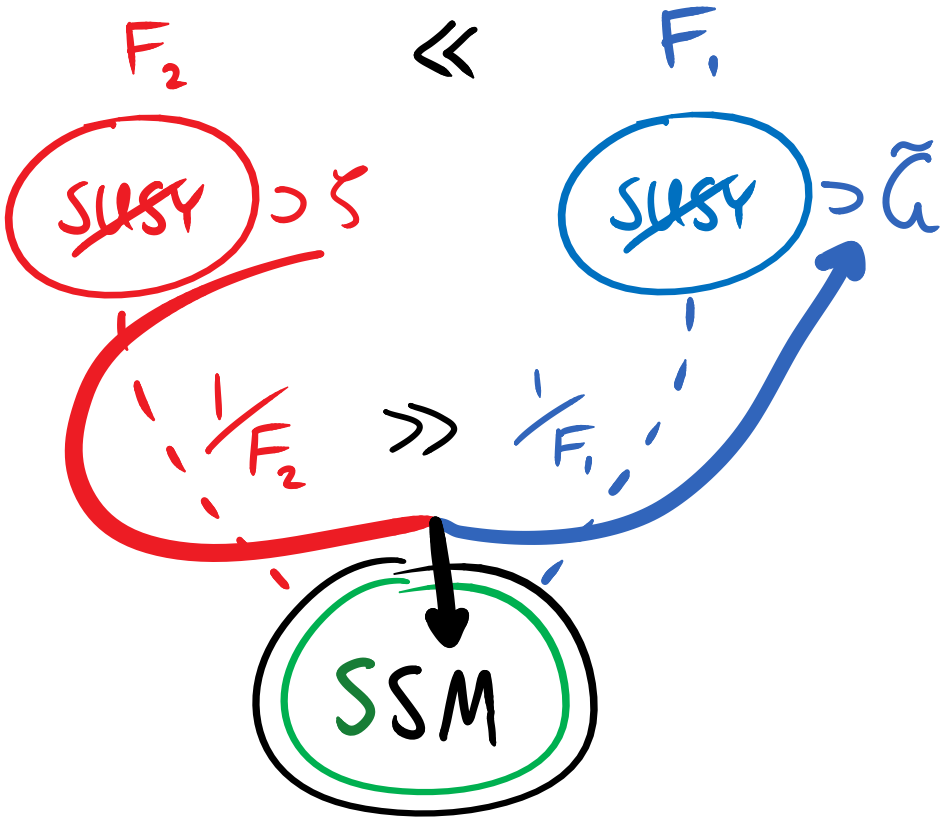
# Goldstini Dark Matter

- $\zeta$ can be dark matter!
  - $\Omega_\zeta \gg \Omega_{3/2}$
- Can decay!

$$\zeta \to \mathrm{SM} + \tilde{G}$$

$$\tau \sim 10^{22} - 10^{42}\ \mathrm{s}$$

- Cosmological time scales



# SUSY-Breaking Fayet-Iliopoulos Terms

$$\int d^4\theta \, \frac{\xi_2}{2F_2^2} |X_2|^2 \mathcal{D}^\alpha W_\alpha \quad \supset \quad g' \xi_2 D_Y$$

- Generically Present
  - 1-loop in Gauge mediation!


$$\xi_2 \approx \frac{1}{16\pi^2} \frac{F_2^2}{M_2^2}$$

# SUSY-Breaking Fayet-Iliopoulos Terms

$$\int d^4\theta \, \frac{\xi_2}{2F_2^2} |X_2|^2 \mathcal{D}^\alpha W_\alpha \supset g' \xi_2 D_Y$$

- Generically Present
  - 1-loop in Gauge mediation!
- Dangerous for single ~~SUSY~~
  - Need e.g. Messenger Parity
- Fine for multiple ~~SUSY~~ !


$$\xi_2 \approx \frac{1}{16\pi^2} \frac{F_2^2}{M_2^2}$$

$$\Delta m_i^2 = g'^2 Y_i \xi_2$$

# Bino-Goldstino Kinetic Mixing

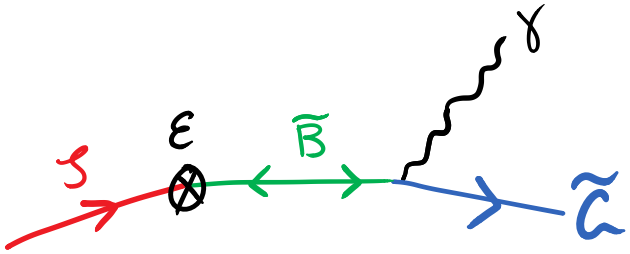
$$\int d^4\theta \, \frac{\xi_2}{2F_2^2} |X_2|^2 \mathcal{D}^\alpha W_\alpha = \int d^2\theta \, \frac{\epsilon}{2} W_2^\alpha W_\alpha^Y$$

- Accompanies FI Term $\quad \supset -i\epsilon \, \zeta^\dagger \bar{\sigma}^\mu \partial_\mu \widetilde{B}$

- Allows $\zeta \to \gamma + \widetilde{G}$

$$\epsilon \approx \frac{g' \xi_2}{\sqrt{2} F_2}$$

$$\Gamma_\zeta = \frac{\epsilon^2 m_\zeta^5 \cos^2 \theta_W}{16\pi^2 F^2}$$



# Parameter Estimates

- Wide range allowed: $10^{-3} \lesssim \epsilon \lesssim 10^{-16}$
  - Gauge Mediation
  - D-term ~~SUSY~~
- keV-TeV Goldstini allowed

$$\epsilon \approx \frac{g'}{16\pi^2}\frac{F_2}{M_2^2}$$

$$\Gamma = \frac{m_\zeta^5\,\epsilon^2\cos^2\theta_W}{16\pi F^2} \approx (10^{28}\ \mathrm{s})\left(\frac{\sqrt{F}}{40\ \mathrm{TeV}}\right)^4\left(\frac{7.1\ \mathrm{keV}}{m_\zeta}\right)^5\left(\frac{10^{-3}}{\epsilon}\right)^2$$

$$\Gamma_\zeta \approx (10^{30}\ \mathrm{s})\left(\frac{M_2}{10^{14}\ \mathrm{GeV}}\right)^4\left(\frac{250\ \mathrm{GeV}}{m_\zeta}\right)^5\left(\frac{10^{-2}}{F_2/F_1}\right)^2$$

# Sanity Check

- For $\widetilde{G}_L = F_i \chi^i + D_a \lambda^a / \sqrt{2}$
  - $\langle D_{\rm EM} \rangle = 0$
  - No $\widetilde{G}_L$-$\widetilde{\gamma}$ mixing!

$$\int d^4\theta \, \frac{\xi_1}{2F_1^2} |X_1|^2 \mathcal{D}^\alpha W_\alpha$$

$$V_Y \to V_Y - \epsilon \frac{g'}{\sqrt{2}} \frac{|X_1|^2}{F_1}$$

$$\int d^2\theta \, \epsilon \frac{M_1}{F_1} X_1 W_1^\alpha W_\alpha^Y = 0!$$

(NL rep)

# Sanity Check

- For $\widetilde{G}_L = F_i \chi^i + D_a \lambda^a / \sqrt{2}$
  - $\langle D_{\rm EM} \rangle = 0$
  - No $\widetilde{G}_L$-$\widetilde{\gamma}$ mixing!
- Not true for $\zeta$!
  - Need ~~multiple SUSY~~
  - $\zeta$ not derivatively coupled

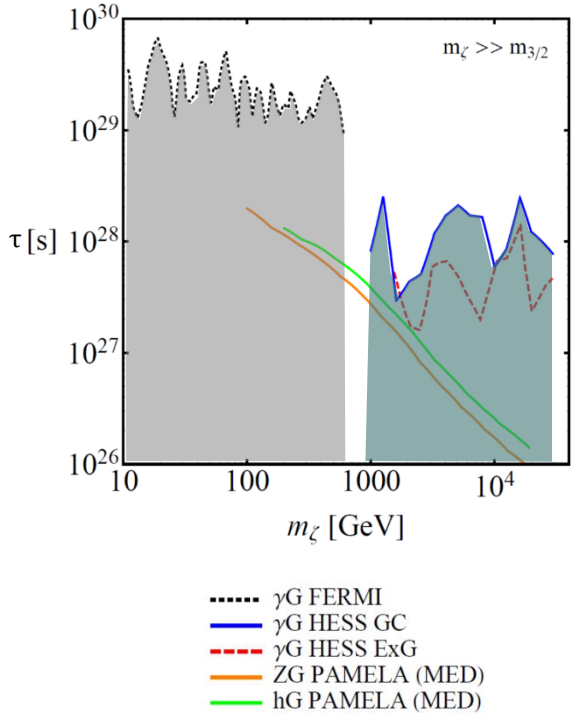
$$\int d^4\theta \, \frac{\xi_2}{2F_2^2} |X_2|^2 \mathcal{D}^\alpha W_\alpha$$

$$V_Y \to V_Y - \epsilon \frac{g'}{\sqrt{2}} \frac{|X_2|^2}{F_2}$$

$$\int d^2\theta \, \epsilon \frac{M_1}{F_1} X_1 W_2^\alpha W_\alpha^Y \neq 0 !$$

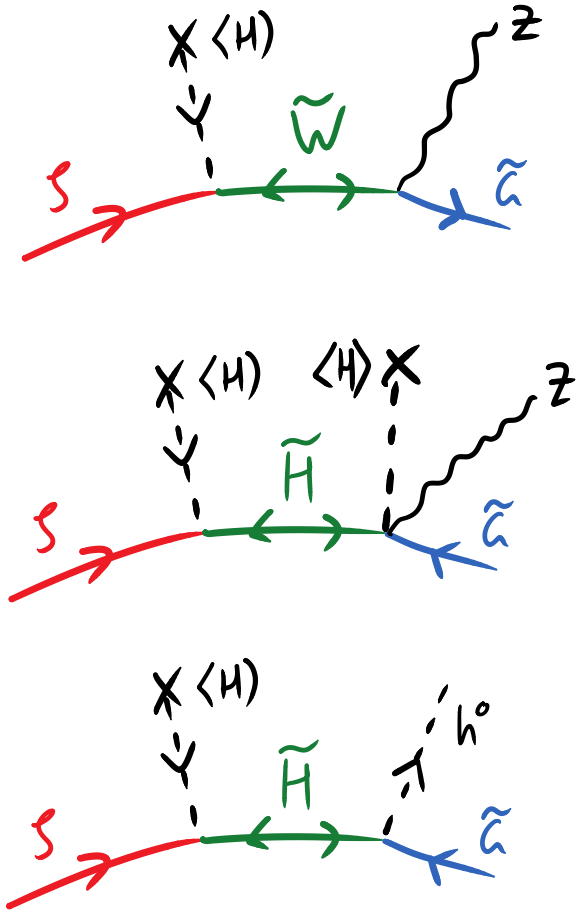
# Indirect Detection

- $\zeta \to \gamma + \tilde{G}$
- Monochromatic Photon line!
- Can isolate from astrophysical backgrounds
- $\gamma$-, X-ray telescopes:
  - FERMI, HESS
  - XMM-Newton (3.5 keV?)



# Other Decay Modes

- $Z,\ h,\ f\overline{f}$
- Suppressed by
  - Phase Space
  - $(M_Z/M_{\mathrm{SUSY}})^2$
  - Loop Factors (GGM)
- Caveat: RG Effects

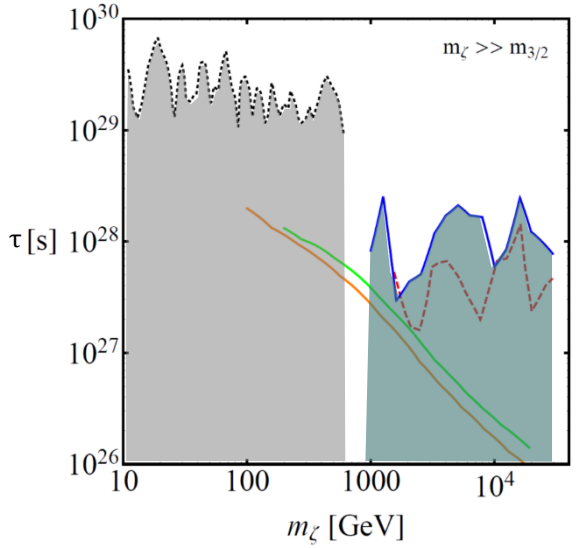


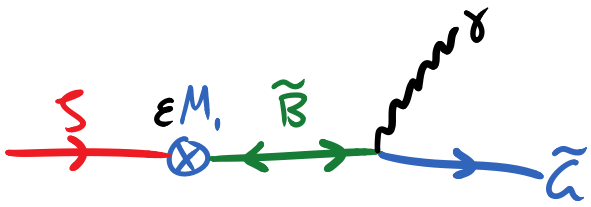
# Conclusions

- Goldstino $\zeta$: DM candidate!
- Photon line from decay to gravitino

$$\zeta \to \gamma + \widetilde{G},$$

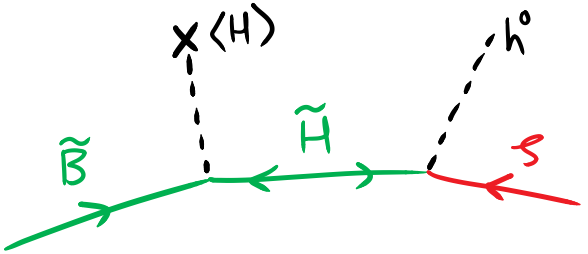
- Kinetic Mixing
- Weak scale down to X-rays



# Backup: Collider Phenomenology

- For decaying $m_\zeta \gtrsim 100\ \mathrm{GeV}$
  - LOSP always collider-stable.
- Lighter?
  - LOSP → $\zeta$ decays interesting!
  - Lifetime (if displaced)
  - Odd decays: Bino → h + $\zeta$
    - ZT & J. Thaler, 1103.1631

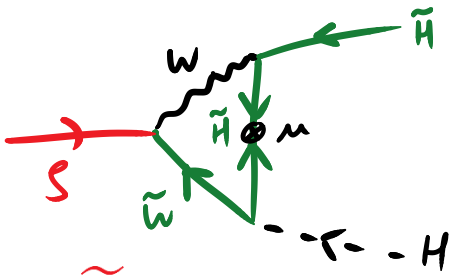


# Backup: Goldstino Problem?

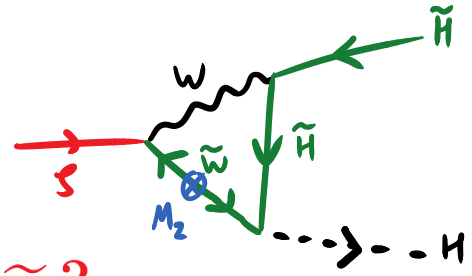
- Overproduction in Early Universe?
  - Still have gravitino problem
  - Goldstino Problem may be worse (not always!)
  - Low reheating temperature needed
- Loophole: Ultralight gravitino (<10 eV)
  - But Goldstino decays quickly (~1/F^2)
  - Goldstino DM < 1 GeV

# Backup: Goldstino Coupling RG Effects

- $\widetilde{m}^2_{H_{u/d}}$, $\widetilde{B}_\mu$ could be small at messenger scale!
  - Mass-*squared*
  - Gauge mediation?
- RG flows can greatly enhance
- FI terms / Kinetic mixing not enhanced




$$\frac{d\widetilde{B}_\mu}{dt} \propto \mu \widetilde{M}_2$$




$$\frac{d\widetilde{m}^2_{H_{u/d}}}{dt} \propto M_2 \widetilde{M}_2$$