Light WIMP with Scalar Mediator Implications from Higgs Precision

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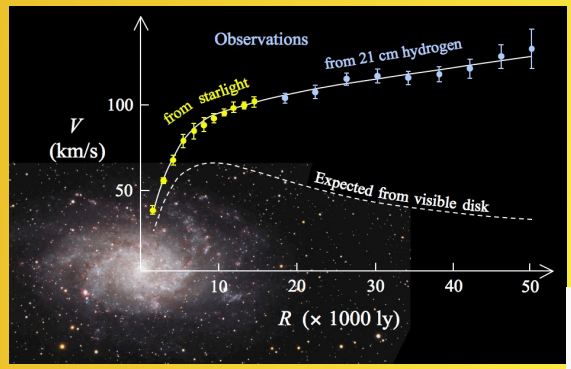
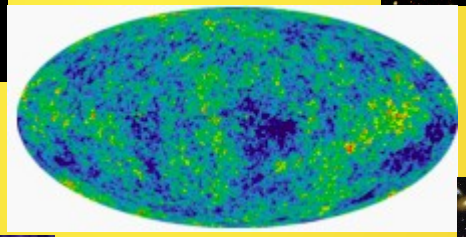
Introduction

- Dark matter



wikipedia.org Extended rotation curve of M33

NASA

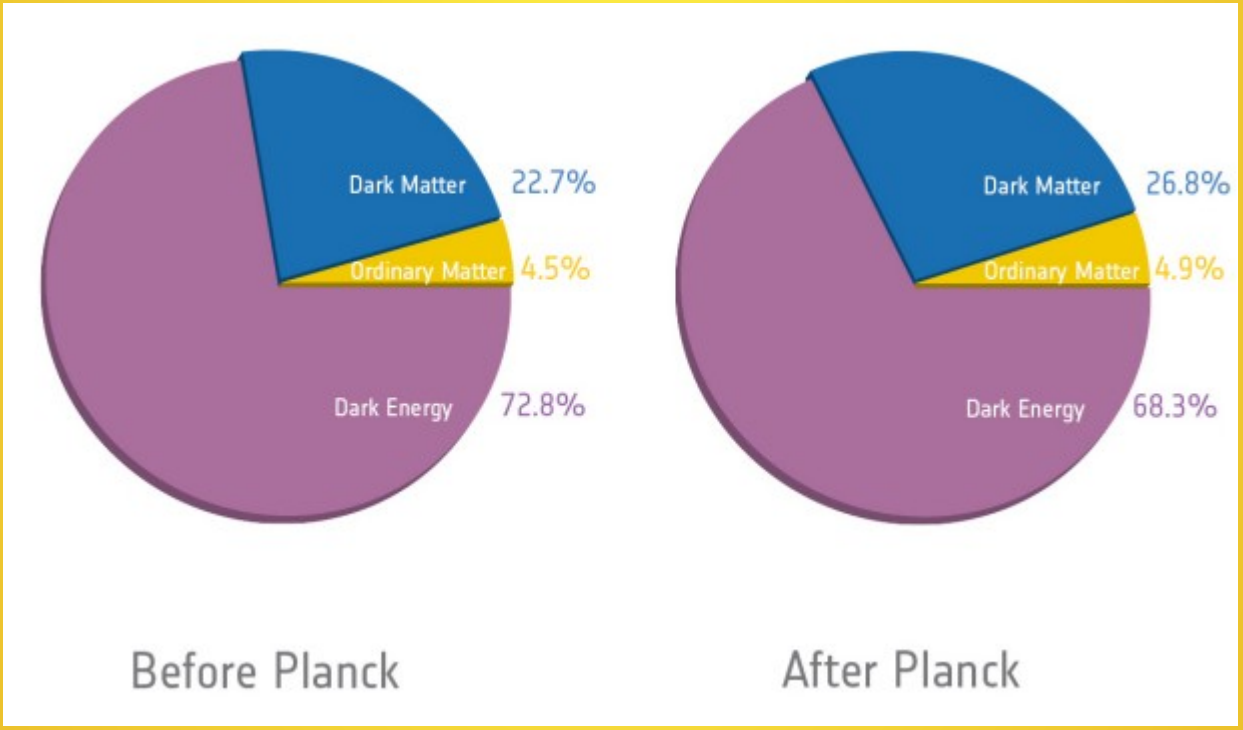


Hubble Space Telescope

astro-ph/0504097

Introduction

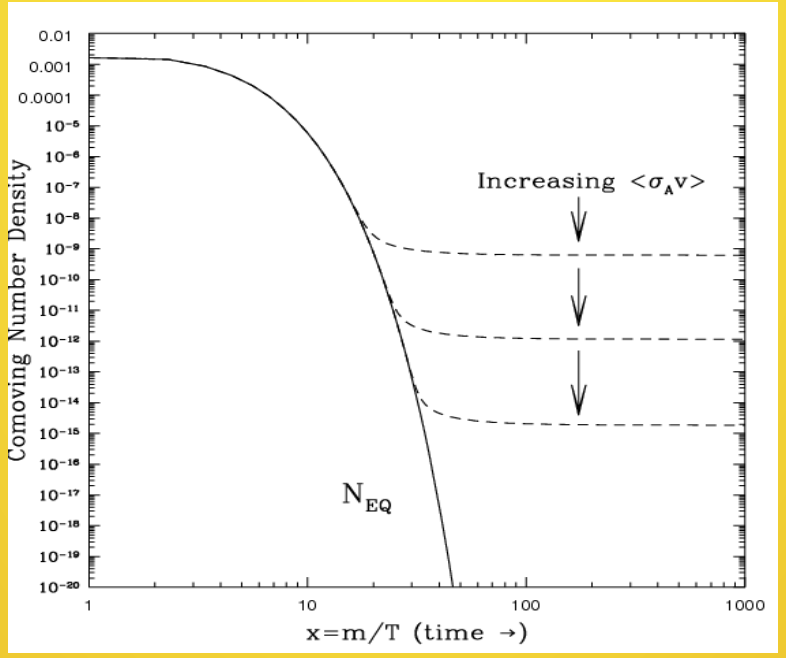
- Dark matter relic abundance is about 25% of our Universe.



Planck Collaboration

Introduction

- Thermally produced DM: Freeze-out mechanism.
- Weakly interacting DM(WIMP), gives the correct DM relic abundance.



Dan Hooper: 0901.4090

Introduction

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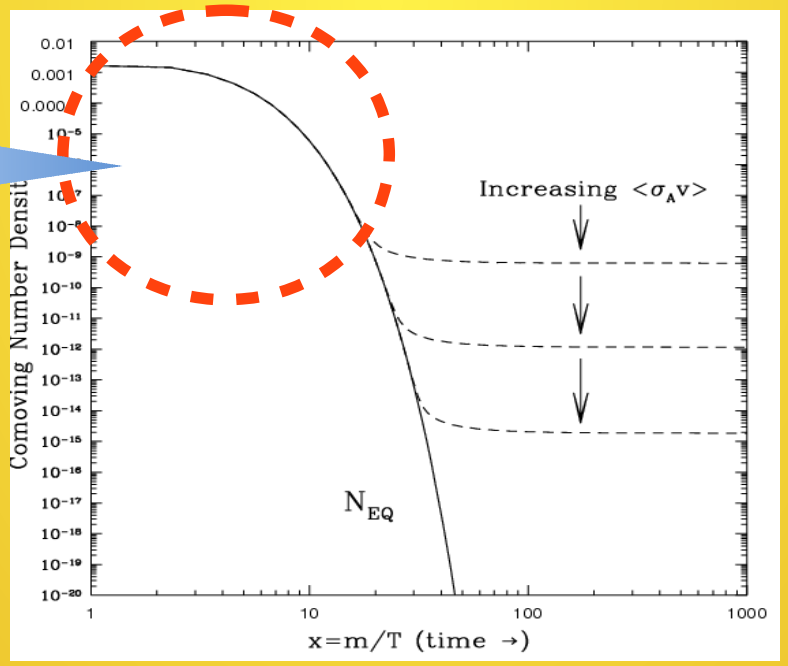
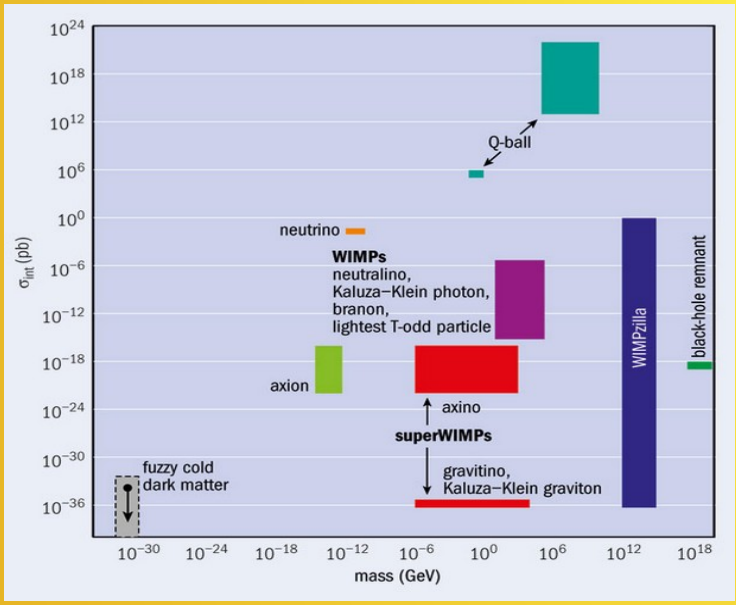
thermal equilibrium



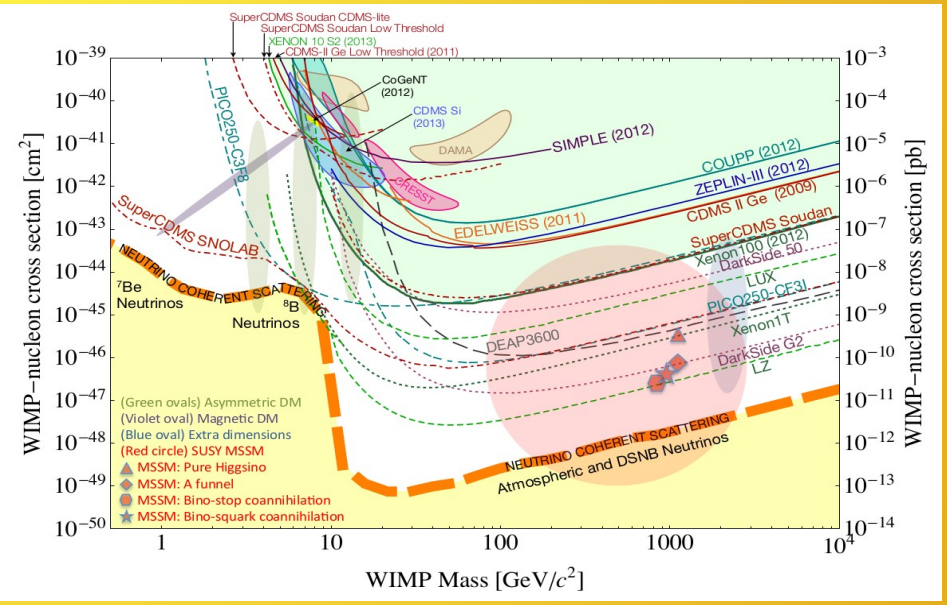
Dan Hooper: 0901.4090

Introduction

- The mass of WIMP from GeV to O(100) TeV.
- O(100) GeV WIMP suffer strong constraint from direct detection searches.



Towards Dark Matter Discovery 2018

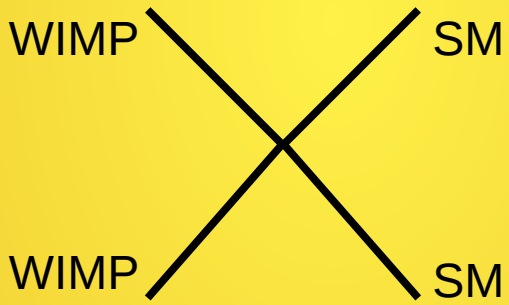


P. Cushman et. al.:1310.8327v2

Introduction

- Sub-GeV thermal produced WIMP.
- Lee-Weinberg limit. Require thermal DM mass larger than GeV.

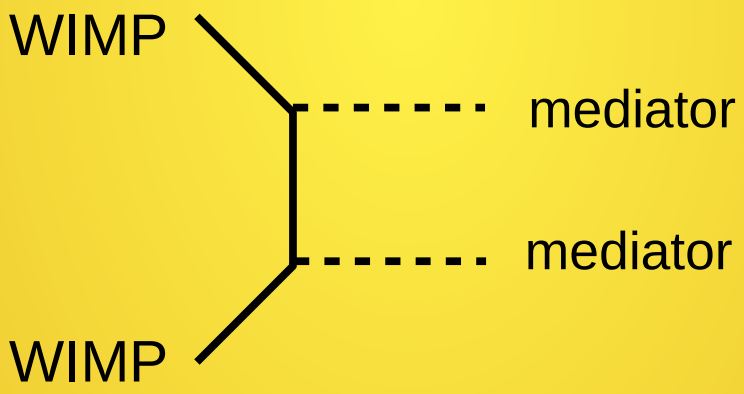
B. W. Lee, S. Weinberg: PRL. 39(1977), 165.



- Separate thermal and DM annihilation processes.

Introduction

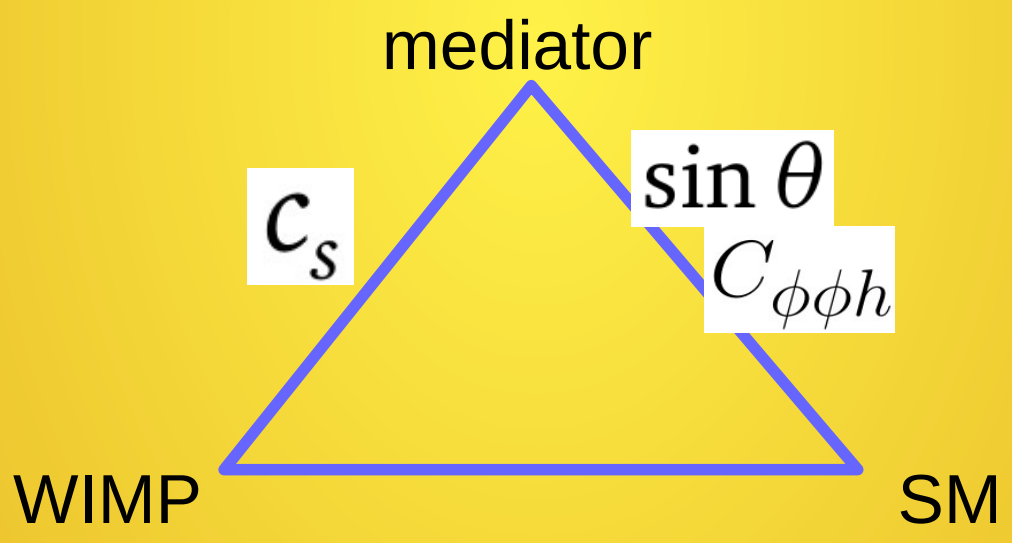
- Relic abundance and DM annihilation.
- DM+DM → mediator+mediator:



- The mass of mediator is also Sub-GeV.

Introduction

- Thermal equilibrium.
- WIMP ↔ mediator ↔ SM.



S.Matsumoto, Y.L Sming Tsai, P.Y. Tseng

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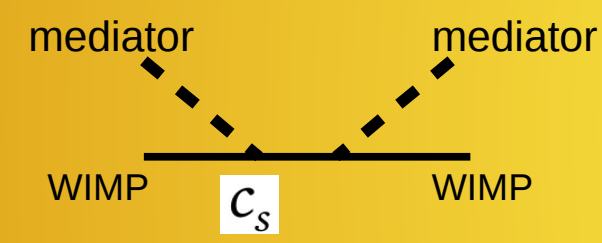

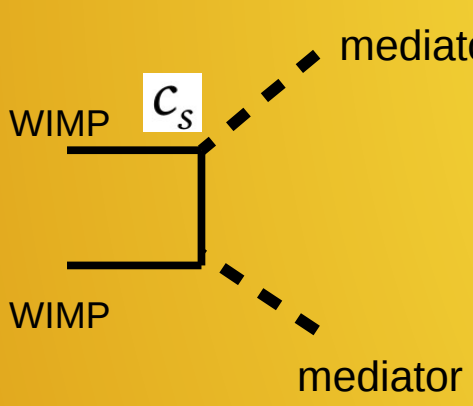

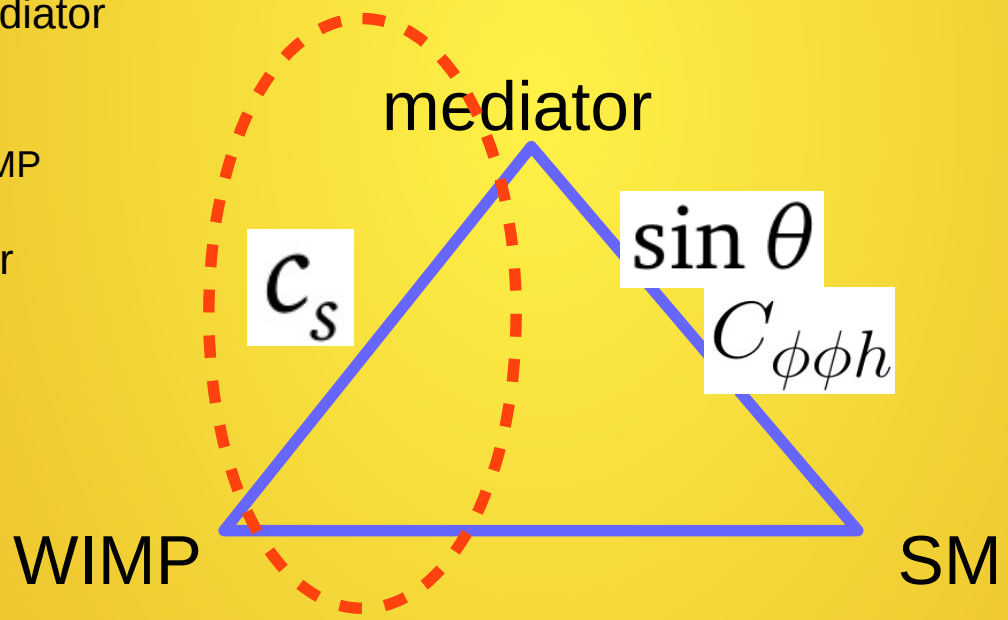

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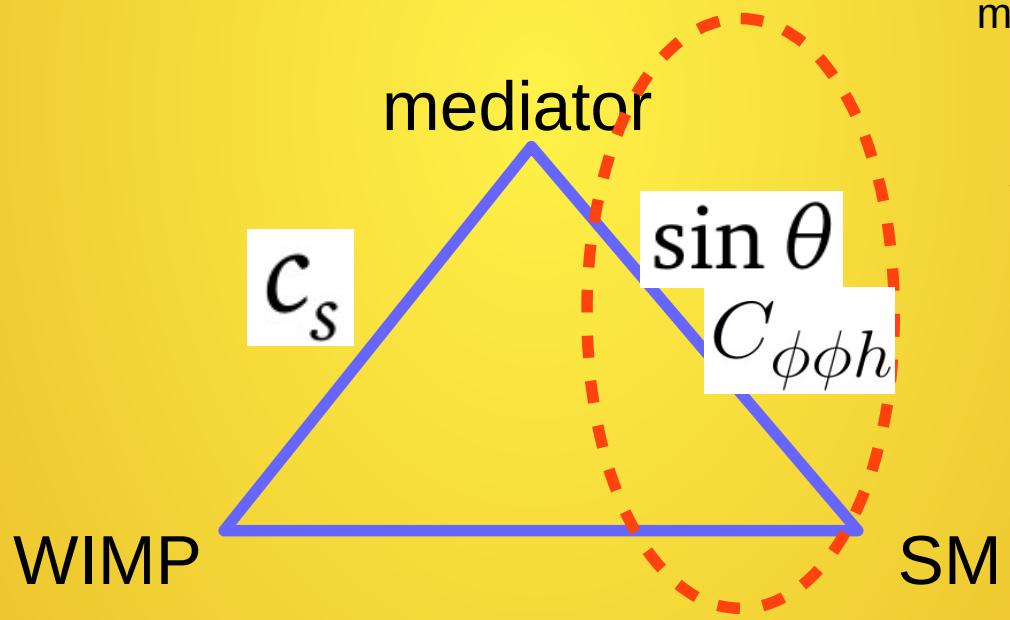

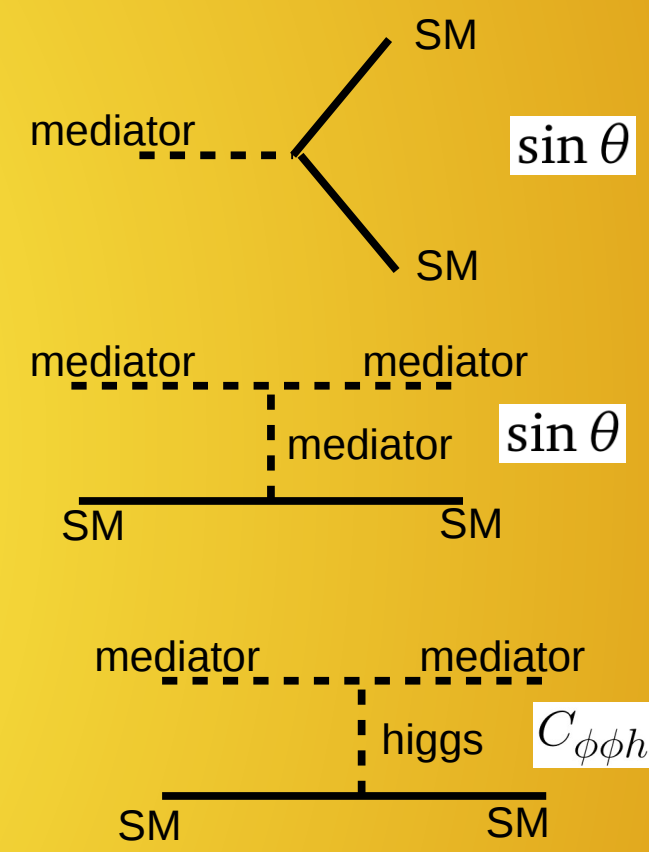

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Light WIMP with scalar mediator

- Minimal Model. Gauge invariant and renormalizability.
- Majorana DM and a scalar mediator:

$$\mathscr{L} = \mathscr{L}_{\rm SM} + \frac{1}{2}\bar{\chi}(i\partial\!\!\!/ - m_\chi)\chi + \frac{1}{2}(\partial\Phi)^2 - \frac{c_s}{2}\Phi\bar{\chi}\chi - \frac{c_p}{2}\Phi\bar{\chi}i\gamma_5\chi - V(\Phi, H),$$

$$\begin{aligned} V_H(H) &= \mu_H^2 H^\dagger H + \frac{\lambda_H}{2}(H^\dagger H)^2, \\ V_\Phi(\Phi) &= \mu_1^3\Phi + \frac{\mu_\Phi^2}{2}\Phi^2 + \frac{\mu_3}{3!}\Phi^3 + \frac{\lambda_\Phi}{4!}\Phi^4, \\ V_{\Phi H}(\Phi, H) &= A_{\Phi H}\Phi H^\dagger H + \frac{\lambda_{\Phi H}}{2}\Phi^2 H^\dagger H. \end{aligned}$$

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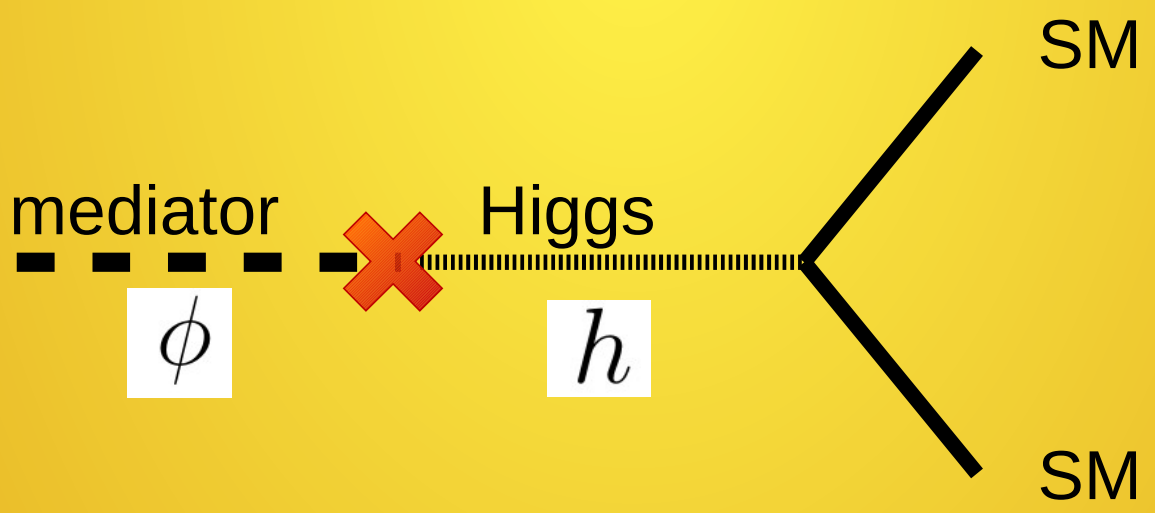
Light WIMP with scalar mediator

- The $A_{\Phi H}\Phi H^{\dagger}H$ allowed the mixing between Higgs doublet and scalar singlet

$$\begin{pmatrix} h \\ \phi \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} h' \\ \phi' \end{pmatrix}$$



Light WIMP with scalar mediator

- Higgs precision measurement at LHC:

$$\Delta \mathrm{BR}(h_{125} \to ZZ) \lesssim 10\% \Rightarrow |\sin\theta| \lesssim 0.32$$

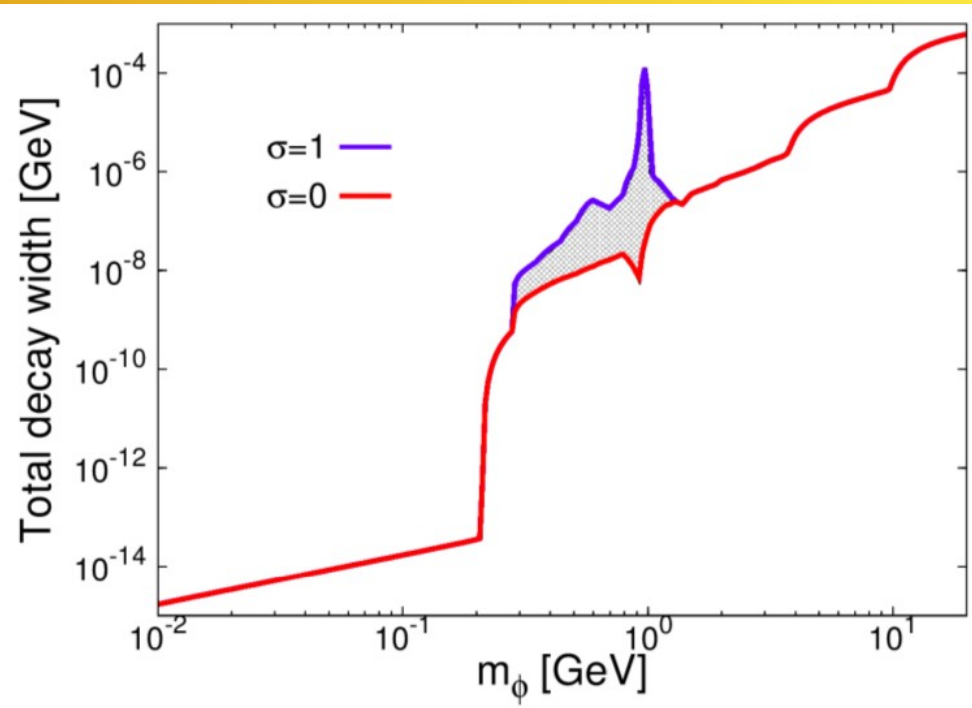
- At ILC (250GeV), improve the Higgs precision measurement:

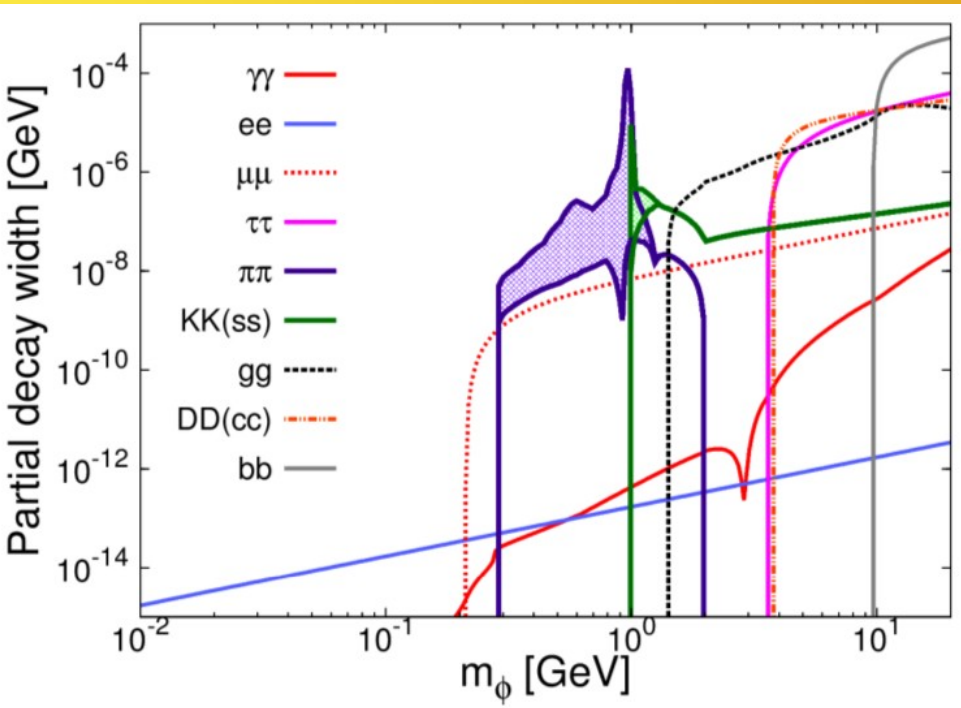
$$\Delta \mathrm{BR}(h_{125} \to ZZ) \lesssim 0.5\% \Rightarrow |\sin\theta| \lesssim 0.07$$

H. Baer et. al., ILC: 1306.6352

Light WIMP with scalar mediator

- Mediator width and branching ratio:





$$\sin\theta = 1, \ \Gamma_\phi \propto \sin^2\theta$$

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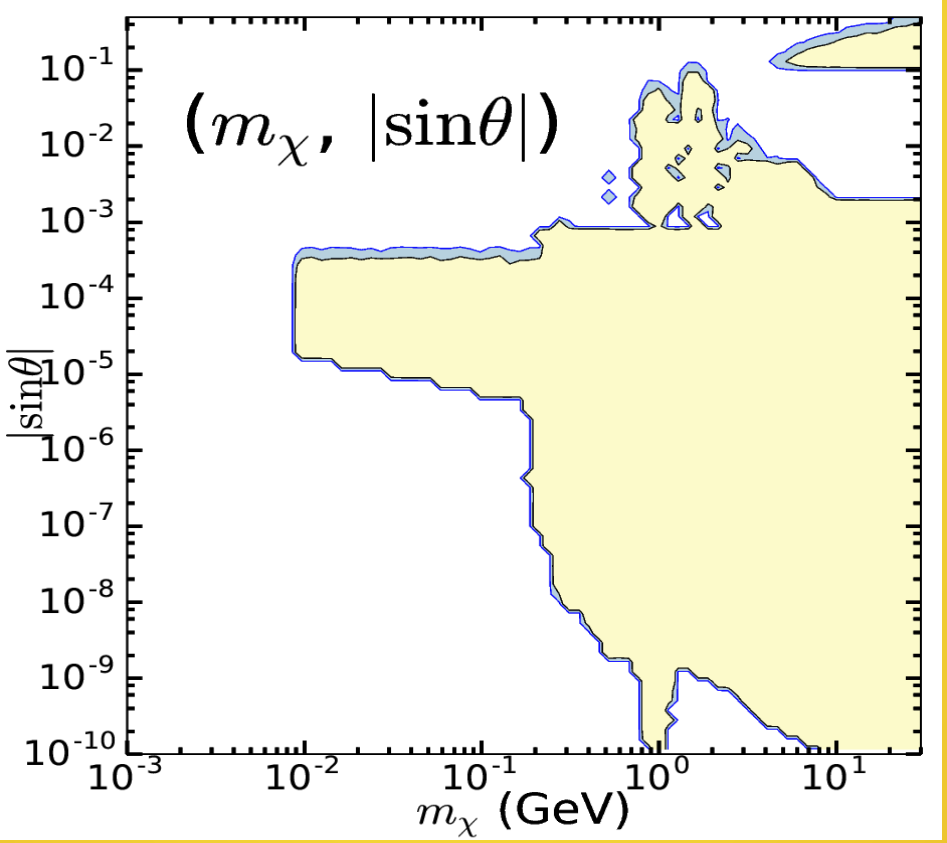
Constraints

- Current experimental constraints for light WIMP. Lower mass limit for WIMP **9MeV**.



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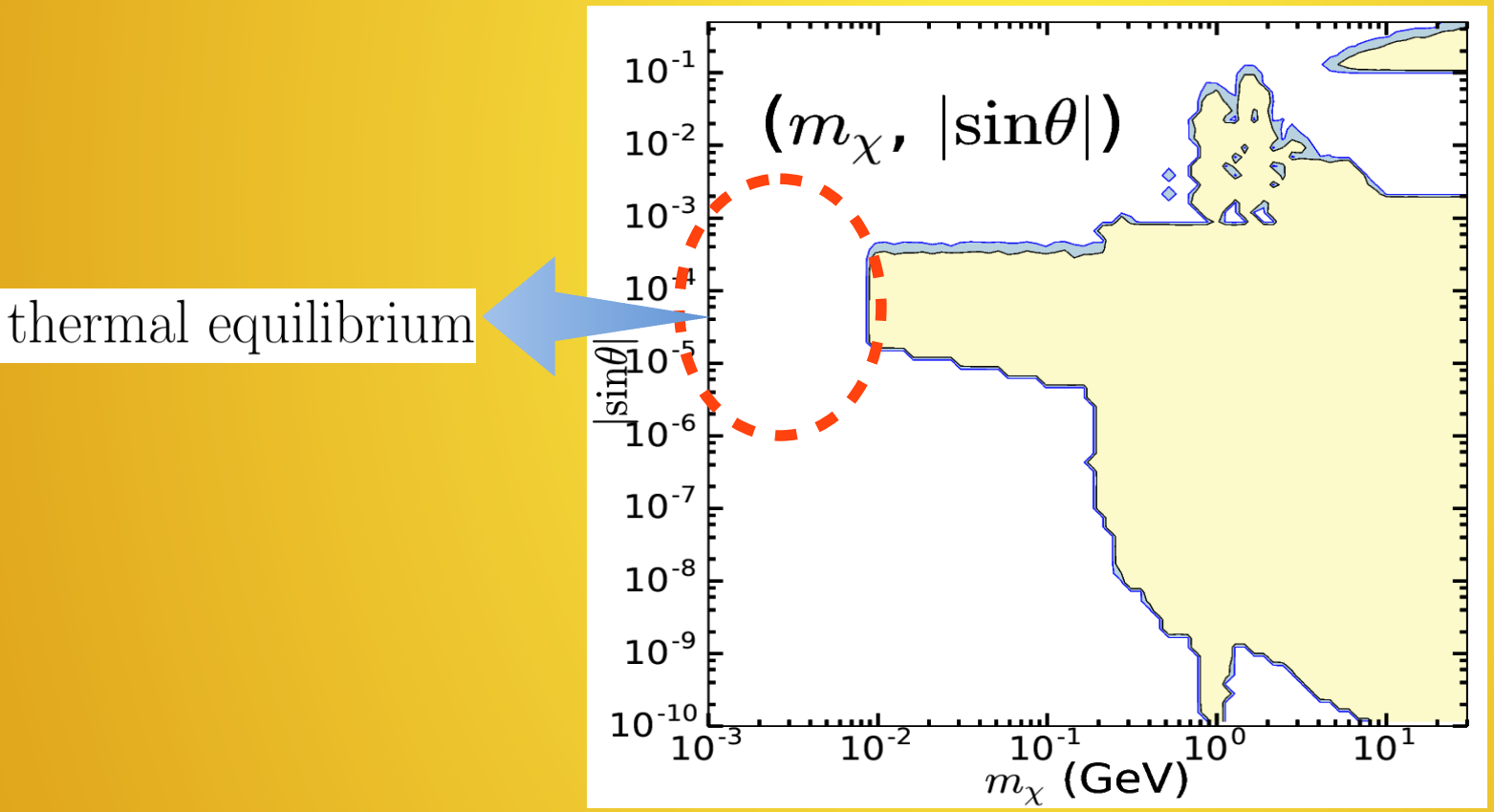

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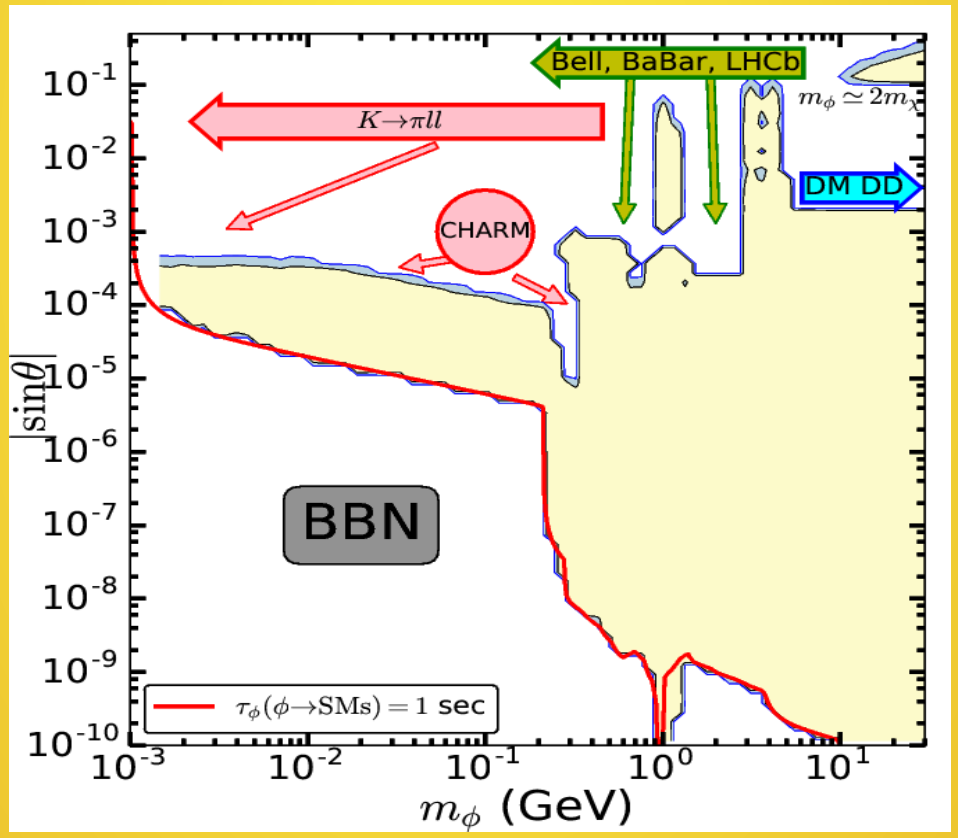
Constraints

- Current experimental constraints for light mediator. Lower limit for mediator mass **1 MeV**.



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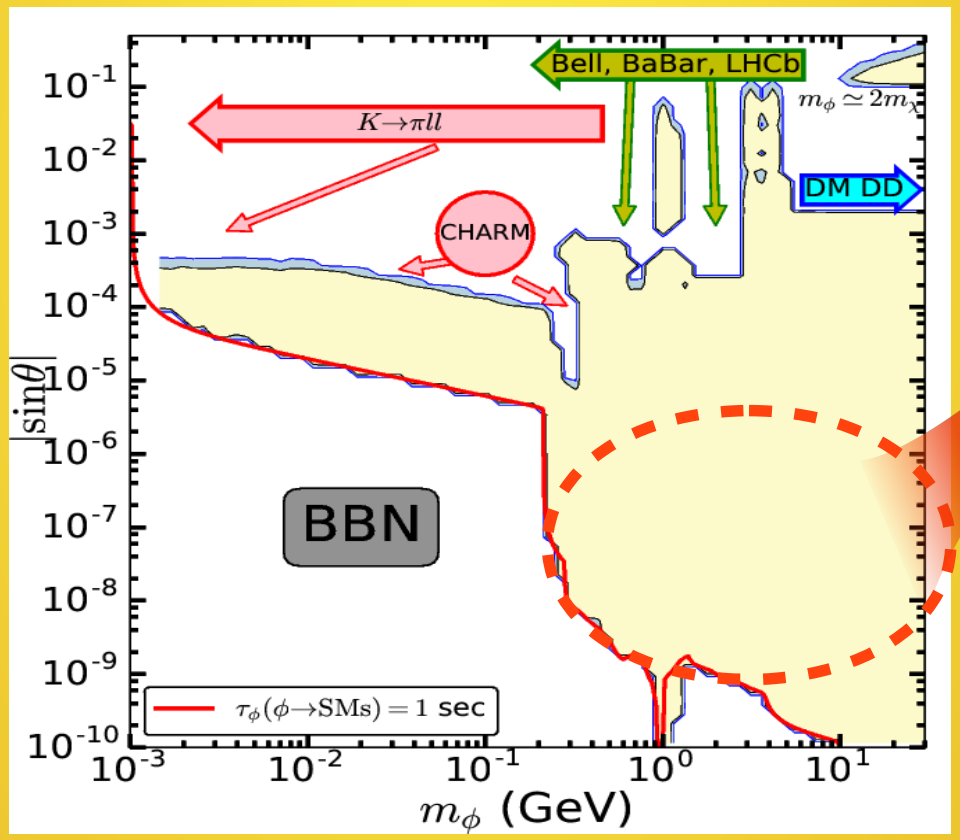

The $\sin\theta$ too small,

but $C_{h\phi\phi}$ need to be large

to maintain thermal equilibrium.

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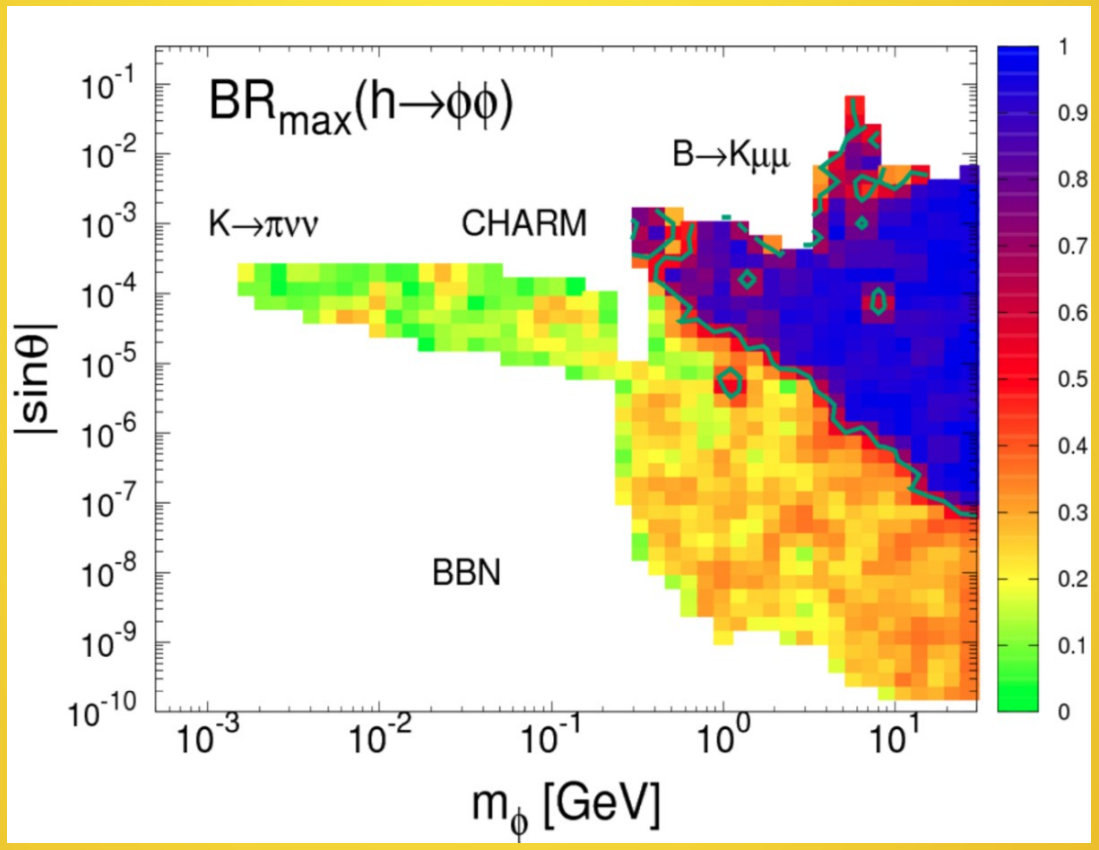
Constraints

- Current experimental constraints for light mediator



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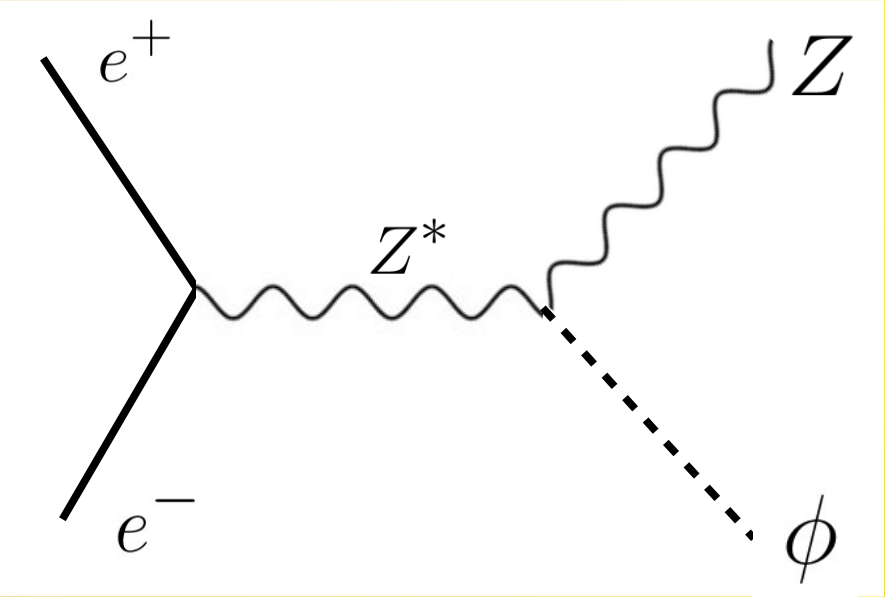
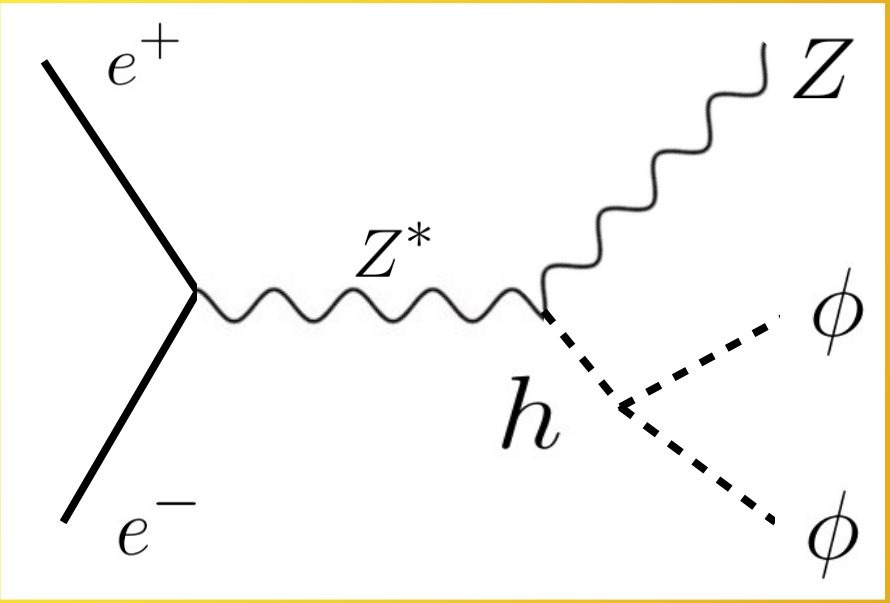
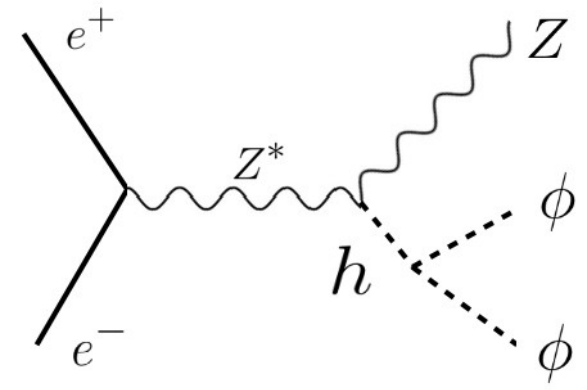
Constraints

- Mediator produced at ILC





Constraints

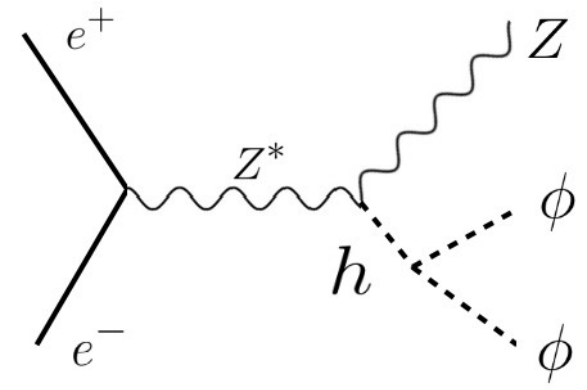


- From the Higgs-mediator-mediator coupling

$$C_{\phi\phi h} \simeq \frac{2(m_\phi^2 - \mu_\Phi^2)}{v_H}$$

$$\Gamma(h \to \phi\phi) \simeq \frac{C_{\phi\phi h}^2}{32\pi m_h}$$

Constraints



- If the mixing angle with Higgs is very small, mediator becomes long-live particle.

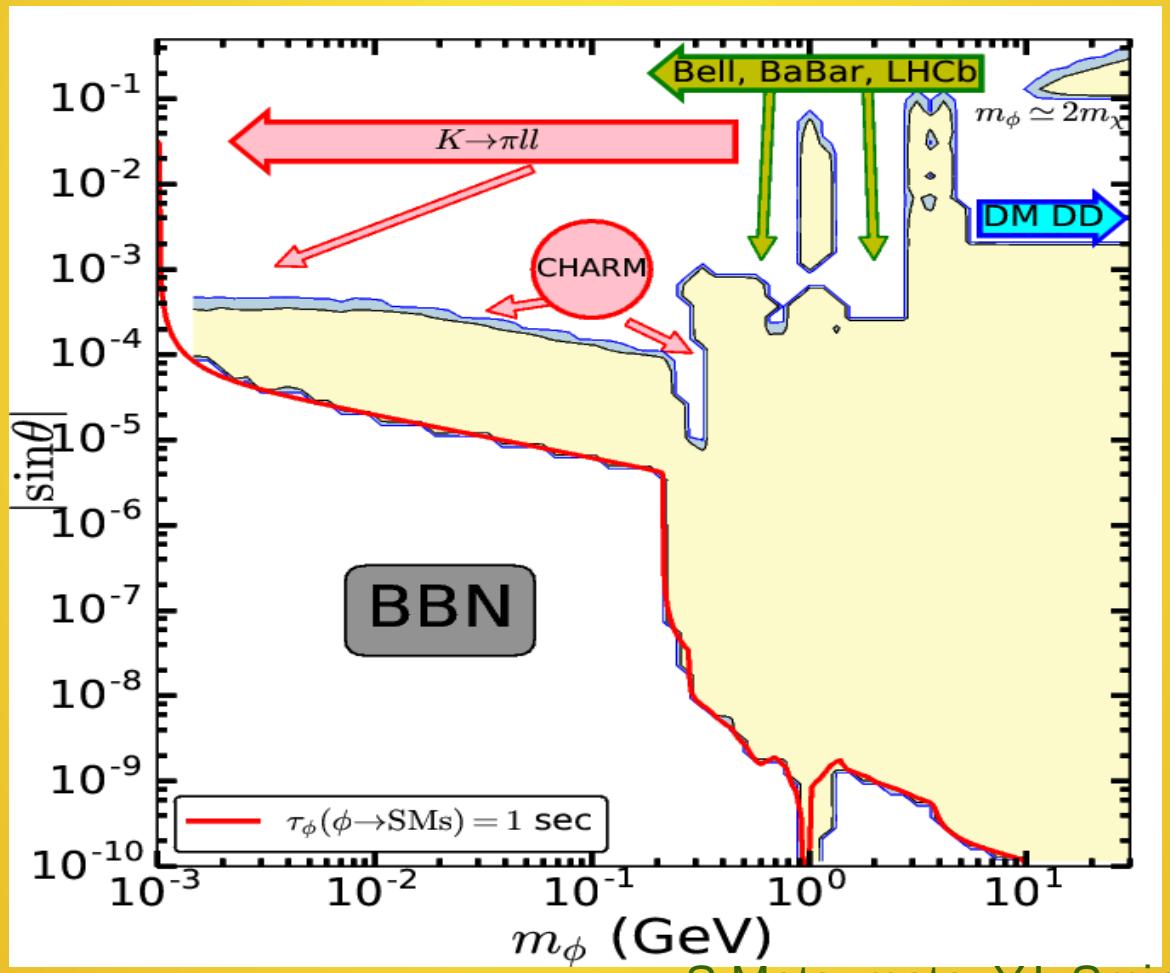
- Invisible Higgs decay at ILC (250GeV):

$$\Delta \mathrm{BR}(h_{125} \to \mathrm{invisible}) \lesssim 0.44\%$$

H. Baer et. al., ILC: 1306.6352

Constraints

Invisible Higgs decay at ILC (250GeV):



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Constraints

- Current experimental constraints for light mediator

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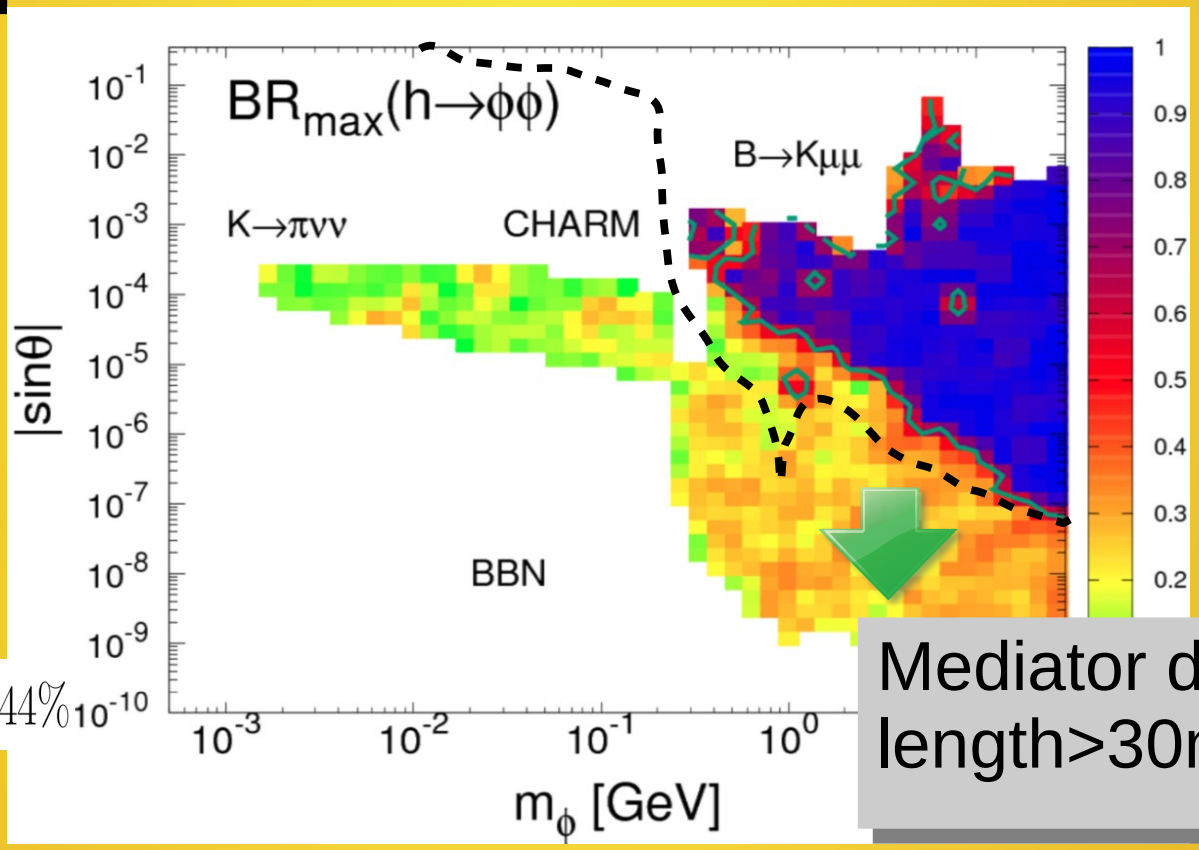

Mediator decay length>30m

H. Baer et. al., ILC: 1306.6352

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Summary

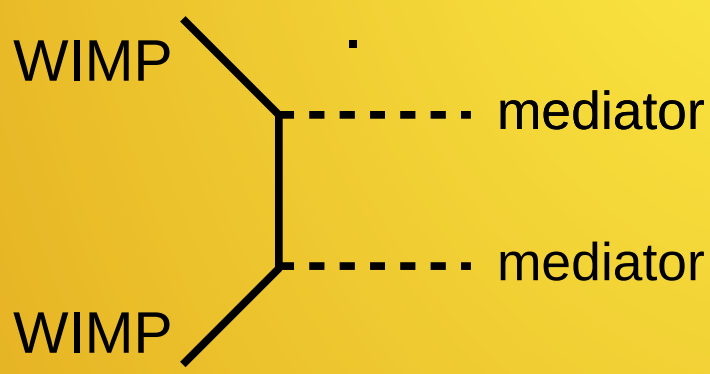
- We demonstrated the WIMP DM can be **Sub-GeV** with the help of mediator to maintain **thermal equilibrium** and give correct **relic density**.
- We wrote down a Higgs portal model, which is gauge invariant and renormalizable.
- The 125 GeV Higgs decays into pair of long-live mediators as invisible decay. Can be searched at ILC.

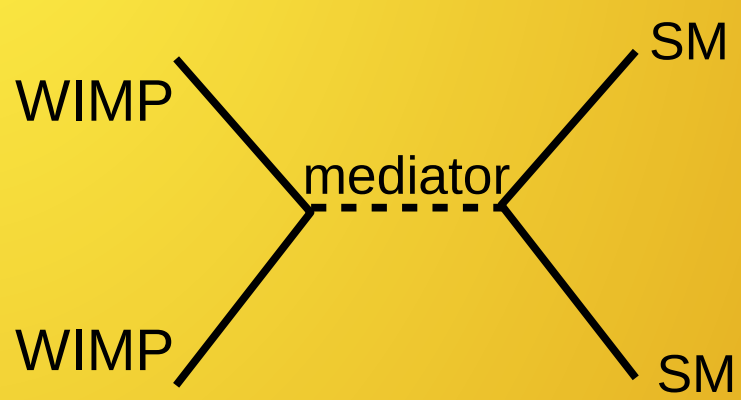
Thank You !

Back Up

Constraints

- Relic abundance and thermal equilibrium.
- When $m_\chi \geq m_\phi$, t-channel WIMP annihilate into a pair of mediators.
- When $m_\chi \leq m_\phi$, s-channel WIMP annihilate into $m_\chi \sim m_\phi/2$. The resonance enhancement





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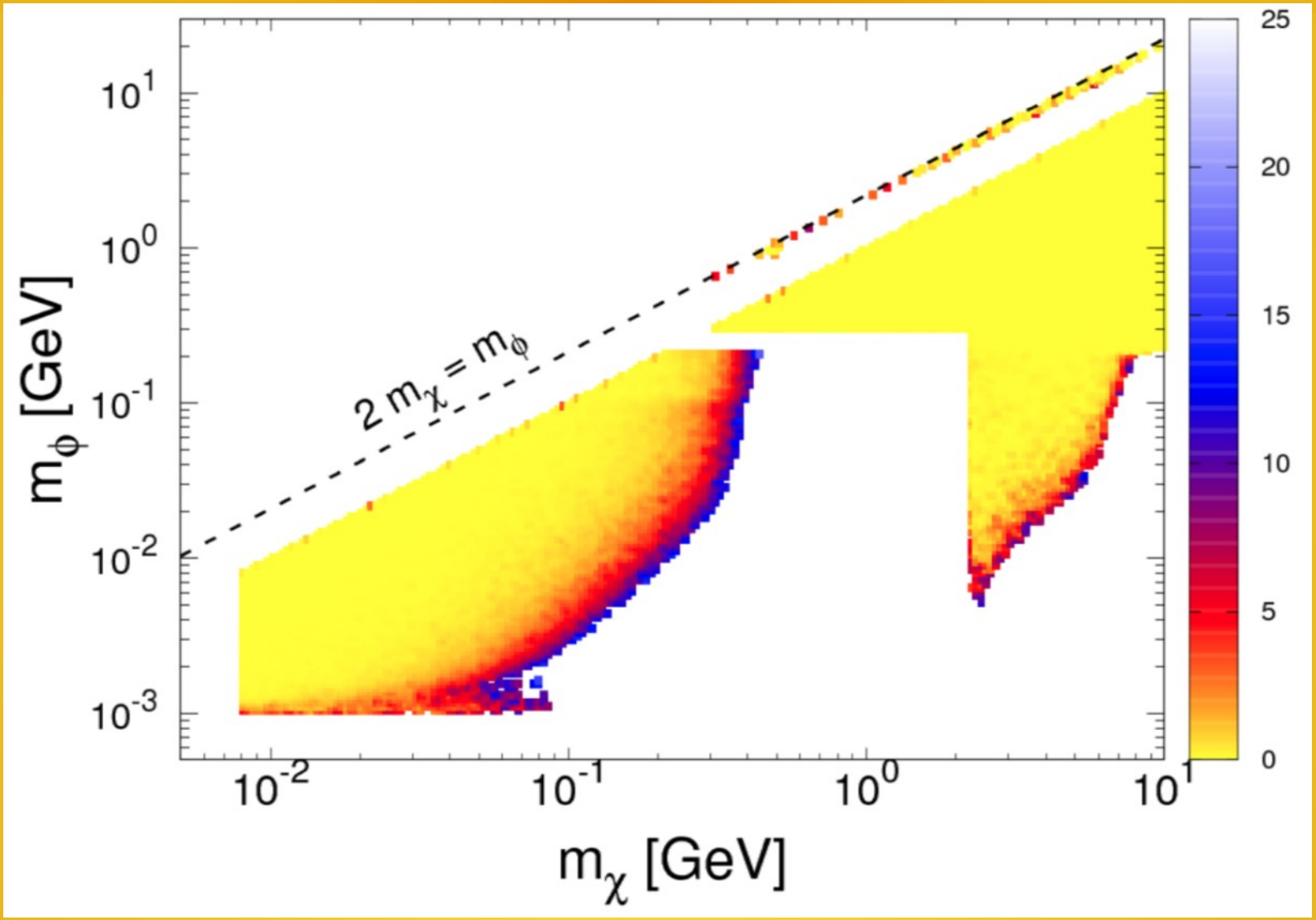
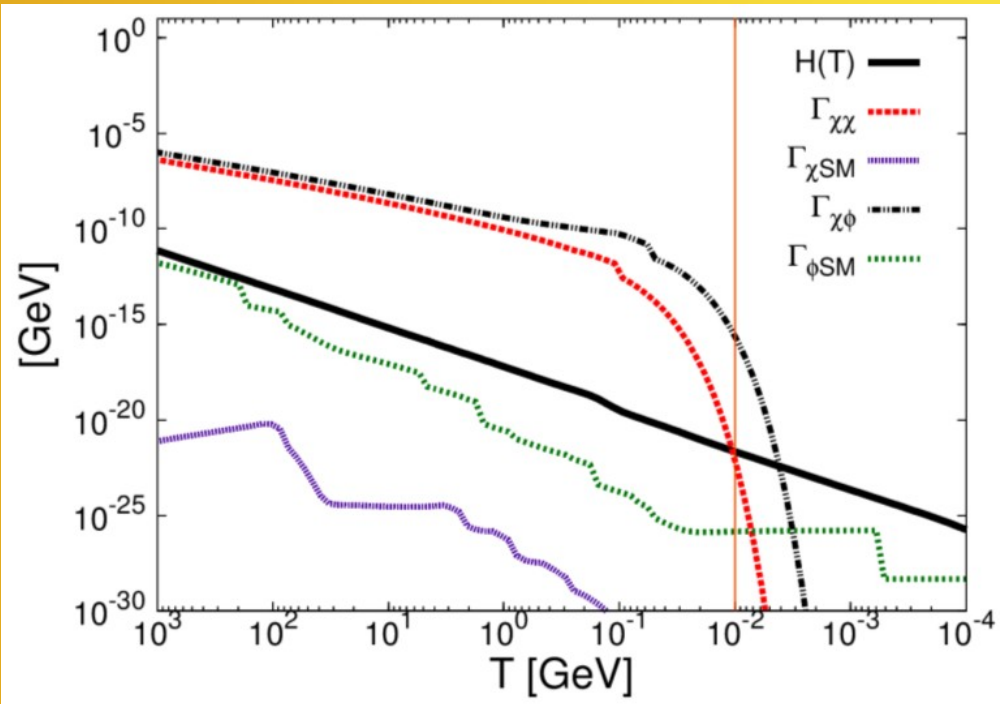
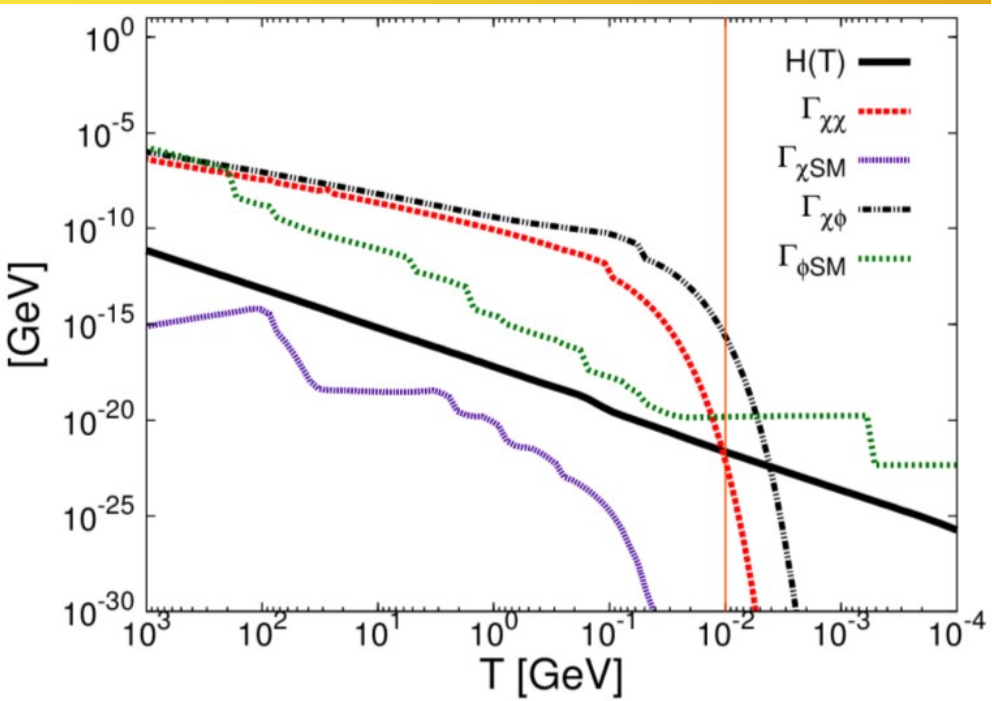


Constraints

WIMP ↔ mediator ↔ SM.





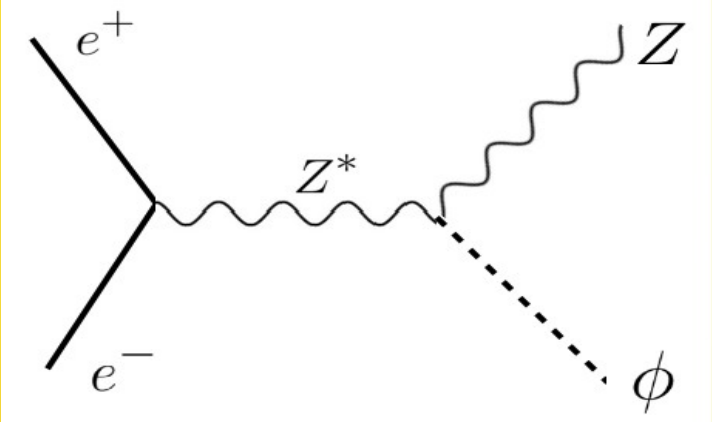
$$(m_\chi, c_s, m_\phi, \sin\theta, \mu_3) = (200\text{MeV}, 0.022, 100\text{MeV}, 10^{-6}, 10\text{MeV})$$

$$(200\text{MeV}, 0.1, 50\text{MeV}, 10^{-3}, 10\text{MeV})$$

Constraints

- When the mediator is lighter than 10 GeV. The LEP constraint is stronger than that from ILC, because of lower center mass energy.

Y. Wang,J. List,M. Berggren: 1801.08164



ILC

- From the Higgs-mediator-mediator coupling, in small mixing angle limit, s.t. decay length is longer than ~30m. For example, $m_\phi = 20\ \mathrm{GeV}, \sin\theta < 10^{-7}$

$$C_{\phi\phi h} \simeq \frac{2(m_\phi^2 - \mu_\Phi^2)}{v_H}$$

$$\Gamma(h \to \phi\phi) \simeq \frac{C_{\phi\phi h}^2}{32\pi m_h}$$

$$\Delta\mathrm{BR}(h_{125} \to \mathrm{invisible}) \lesssim 0.44\%$$

$$\Rightarrow C_{\phi\phi h} < 0.7\ \mathrm{GeV}, \mathrm{or}\ |m_\phi^2 - \mu_\Phi^2| < 90\ \mathrm{GeV}^2$$