Dark matter explained through two distinct ideas related to Higgs

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In collaboration with
S. Chakdar, K. Ghosh and S. Nandi, arXiv:1410.7331 [hep-ph] (Submitted to PRD)
K.S. Babu, S. Chakdar and R.N Mohapatra, Phys. Rev. D 91, 075020, arXiv:1412.7745

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Outline of Talk

- Dark matter through multiple higgs signals at the ILC
  - Motivation
  - Model and formalism
  - Phenomenology
  - Results
- Warm dark matter in two higgs doublet models
  - Model and formalism
  - Cosmological details
  - Allowed parameter space and results
  - X-ray anamoly explanation
- Conclusions

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- Also assume post-inflationary reheating in two univereses different and parallel universe colder than our universe.This makes possible to maintain the successful prediction of BBN

Running of the strong coupling constant

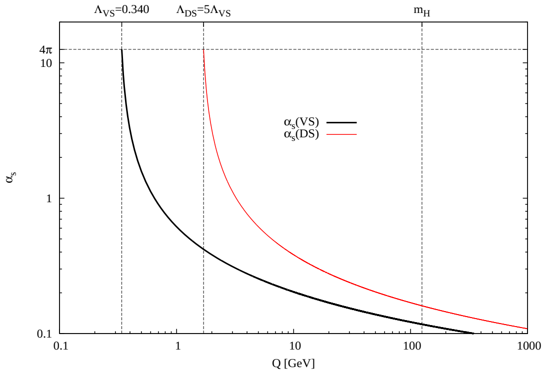

Figure : The running of the strong coupling constant in the visible sector and dark sector shows $\alpha_S^{DS}(Q = m_H = 125\ \mathrm{GeV}) = 1.4\ \alpha_S^{VS}(Q = m_H = 125\ \mathrm{GeV})$.

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- The recoil mass to the Z-boson is the invariant mass of the decay products against which the Z-boson recoils:

$$M^2_{recoil} = (\sqrt{s} - E_Z)^2 - |\vec{p}_Z|^2 = s + M_Z^2 - 2E_Z\sqrt{s}$$

where M_Z=Z-boson mass as reconstructed from the decay products, E_Z is the corresponding energy and $\sqrt{s} = 250$ GeV

Results in direct Higgs decays and Recoil to the Z-boson in ILC

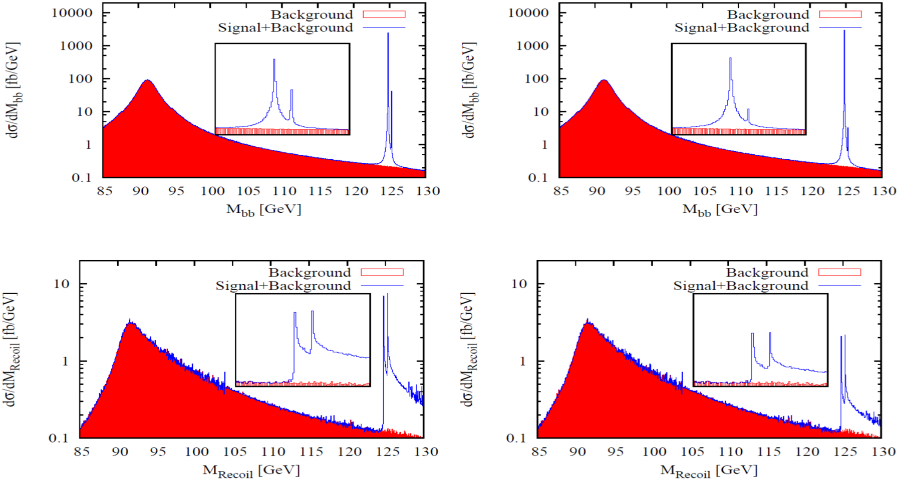

Figure : Invariant mass distributions of $b\bar{b}$ pairs(top panel) and recoil mass distribution for invisible Higgs decays(bottom panel) where $m_{h_{SM}} = 124.75$ GeV and $m_{h_{DH}} = 125.25$ GeV. $123\ \mathrm{GeV} < m_{bb} < 127\ \mathrm{GeV}$ regions magnified in insets.

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- Consider proposed ILC as it has advatages of clean environment, precise measurements and large number of Higgs boson production. In ILC Higgs masses with δm ~ 100 MeV will be possible
- Find that for $\sqrt{s} = 250$ GeV ILC with 500 MeV mass splitting we can see two clear mass peaks when the Higges decay to $b\bar{b}$ or invisibly.

Warm Dark Matter in Two Higgs Doublet Models

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- In this work we focus on alt possibility with 2HDMs consisting of warm dark matter candidate in the form of neutral scalar boson having mass $\sim$ keV
- This scenario is completely consistent with known observations and would have distinct signatures at colliders as well as in cosmology and astrophysics

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- With tiny breaking of Z_2, $\sigma \to \gamma\gamma$ can occur with lifetime longer than age of the universe which can explain reported anomaly in the X-ray spectrum for $m_\sigma = 7.1$ keV

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- $m_A^2 = m_\sigma^2 - 2\lambda_5 v^2$ and $m_{H^\pm}^2 = m_\sigma^2 - (\lambda_4+\lambda_5)v^2$, ($m_\sigma \sim$ keV, m_A and $m_{H^\pm}$ can be $\sim$ few hundred GeV)

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- At very high temperature N was in thermal equilibrium. 2 and 3 body decays of N will come into equilibrium at T_d at which N would begin to decay. If T_d in range 150 - 1 MeV, decay products as do the photons gain entropy
- Since σ froze out at $T \approx 150$ MeV, N decay causes temp of photons to increase relative to that of σ. Thus a dilution in abundance of σ is realized.
- $T_d >$1 MeV, so BBN is not affected. The desired range for the lifetime of N is thus $\tau_N = (10^{-4} - 1)$ sec

Allowed parameter space in $M_N - Y_N$ plane

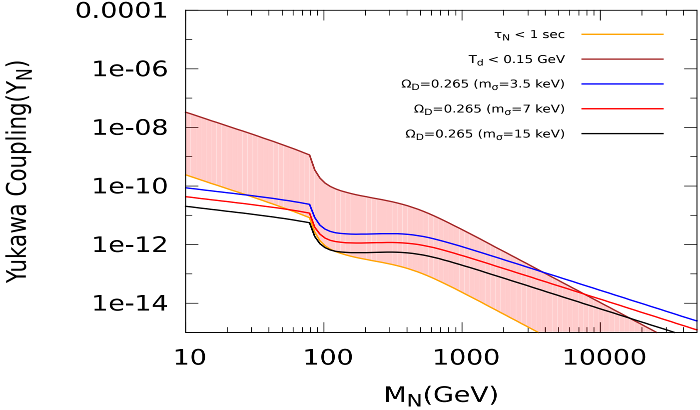

Figure : Allowed parameter space in $M_N - Y_N$ plane in shown. The shaded region corresponds to decay temperature T_d of N in the range 150 MeV-1 MeV. The three solid curves generate the correct dark matter density Ω_D for three values of the WDM mass : $m_\sigma = \{3.5, 7, 15\}$ keV

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- Once σ develops a vev u, it also mixes with SM Higgs field h, but this effect is subleading for the decay $\sigma \to \gamma\gamma$

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- The model can also explain the anomalous X-ray signal reported by different groups in the extra-galactic spectrum.
- The charged scalar and the pseudoscalar in the model cannot be much heavier than a few hundred GeV so could be detectable at the colliders

Thank you!

Backup Slide: Symmetry breaking of Parallel universe model

- Our gauge symmetry is $SU(4)_C \times SU(2)_L \times SU(2)_R$
- $SU(4)$ color symmetry is spontaneously broken to $SU(3)_C \times U(1)_{B-L}$ in the usual Pati-Salam way using the Higgs fields $(15, 1, 1)$ at a scale V_c,where $V_c > 2300\,TeV$(Valencia, Willenbrock, 1994)
- $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ can be broken to the SM using the Higgs representations $(1, 3, 1) + (1, 1, 3)$ at a scale V_{LR}, where $V_{LR} > 2.5\,TeV$
- Finally the remaining symmetry is broken to the $U(1)_{EM}$ using the Higgs bi-doublet $(1, 2, 2)$ and $(15, 2, 2)$. Similar Higgs representations are used to break the symmetry in the parallel universe to $U'(1)$
- $SU(4)_C \otimes SU(2)_L \otimes SU(2)_R \rightarrow SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \rightarrow SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \rightarrow U(1)_{EM}$

Backup Slide: Details of higgs sector of Parallel universe model

- A study of the Higgs potential shows a parameter space where only one neutral Higgs in the bi-doublet remains light and becomes very similar to the SM Higgs in our universe. Similar is true in the parallel universe
- The quartic Higgs interactions $\lambda(H_{VS}^\dagger H_{VS})(H_{DS}^\dagger H_{DS})$ leads to mixing between the two light SM like Higgs fields:

$$\mathcal{L}_{Scalar} \supset m_{VS}^2 h_1^2 + m_{DS}^2 h_2^2 + 2\lambda v_{VS} v_{DS} h_1 h_2$$

from which two mass eigenstates and mixing can be calculated

- The two physical light Higgs states are defined as,

$$\begin{aligned} h_1^{(p)} &= \cos\theta\ h_1 + \sin\theta\ h_2 \\ h_2^{(p)} &= -\sin\theta\ h_1 + \cos\theta\ h_2 \end{aligned}$$

- The masses and the mixing angle of these physical states are given by,

$$\begin{aligned} m^2_{h_1^{(p)},h_2^{(p)}} &= \frac{1}{2}[(m_{VS}^2 + m_{DS}^2) \mp \sqrt{(m_{VS}^2 - m_{DS}^2)^2 + 4\lambda^2 v_{VS}^2 v_{DS}^2}] \\ \tan 2\theta &= \frac{2\lambda\ v_{VS}\ v_{DS}}{m_{DS}^2 - m_{VS}^2}. \end{aligned}$$

where $v_{VS} \simeq v_{DS} \simeq 250 GeV$