# Leptonic Higgs

## - A Portal of Dark Matter

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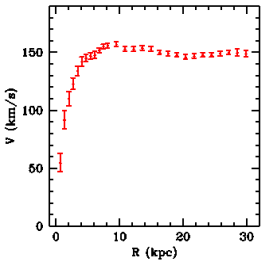
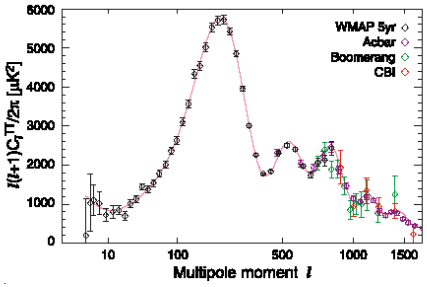
UC Berkeley

Muon Collider Physics Workshop at Fermilab Nov 12,2009

With

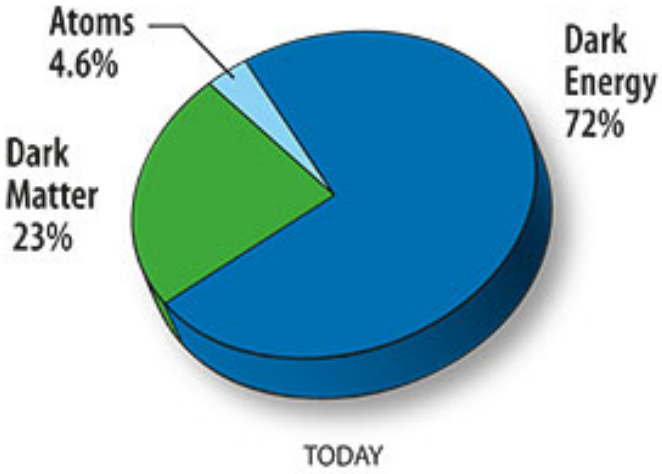
L. Hall and P. Kumar **arXiv:0902.0814**



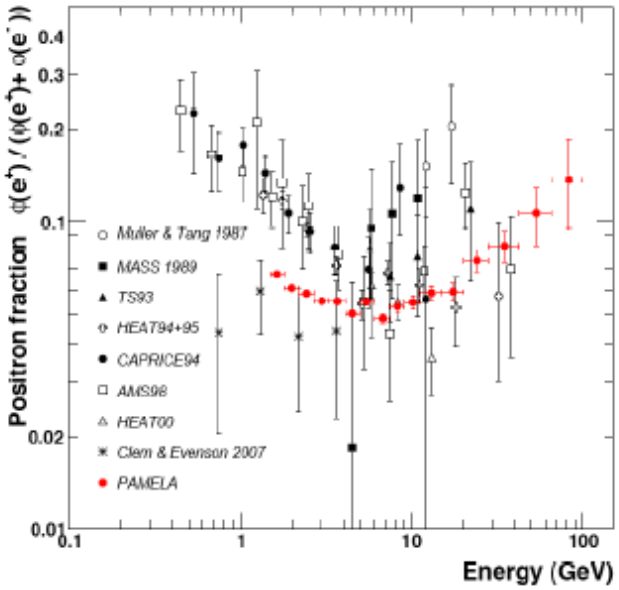

# Dark matter exist !

( Modified Gravity is always a possibility although it has become harder )

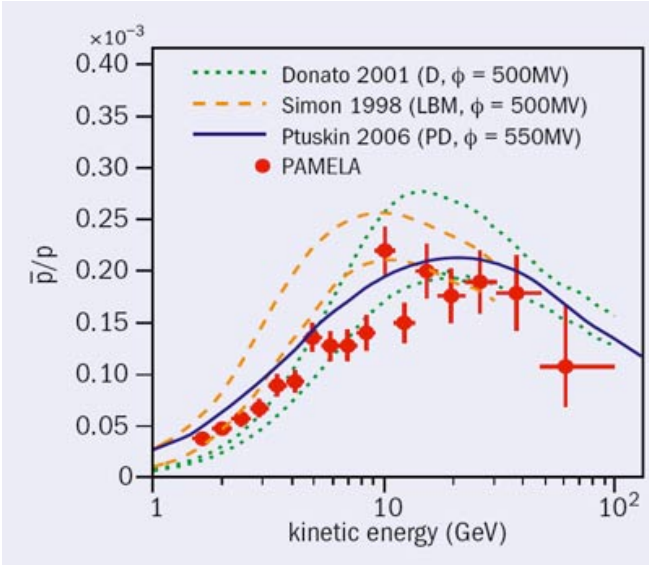



The question is :

What are they ??




PAMELA
Adriani et al., 2008




**Note :**

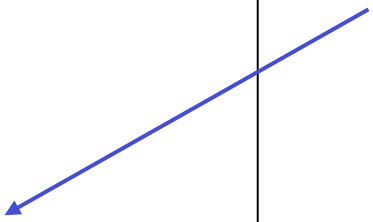
**Excess of e+**

**But not p-**

If it is from dark matter

It tells us a great deal of information about the nature of DM

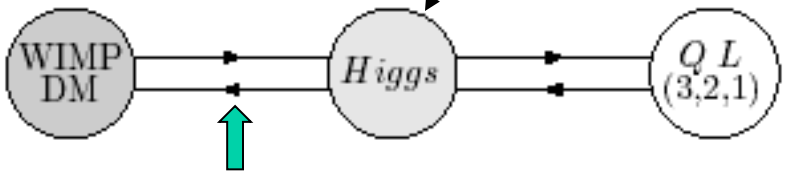
- Large production rate
  - Sommerfeld enhancement
  - Non-thermal production
  - Asymmetric dark matter
  - Decay
- Like lepton better than quark
  - Hadron heavier than lepton --- kinematic
  - "Leptonic" dark sector --- symmetry



# Dark Matter and Higgs

Weak scale mass

Weak scale physics




General picture if DM is SM singlet

- Silveira & Zee

Higgs portal

- March-Russell etc.

Sounds like a good match, could even be strongly related (strong coupling ??)

Then, this is the result


PAMELA data suggest leptonic symmetry

# Leptonic Higgs : Type IV 2HDM

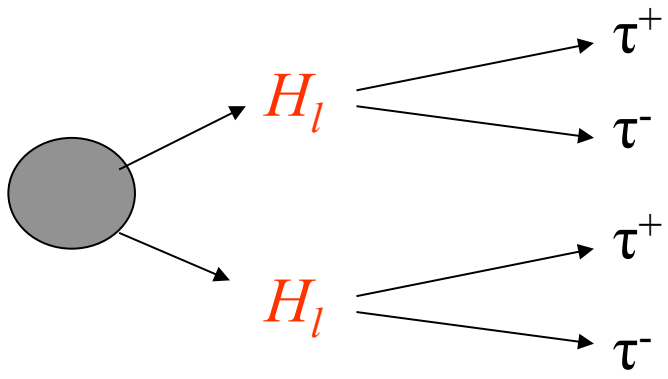
$$Q_i H_q u_j + Q_i H_q d_j + L_i H_l e_j + H_l O_{dark}$$

Has a Chiral Leptonic symmetry (parity) where

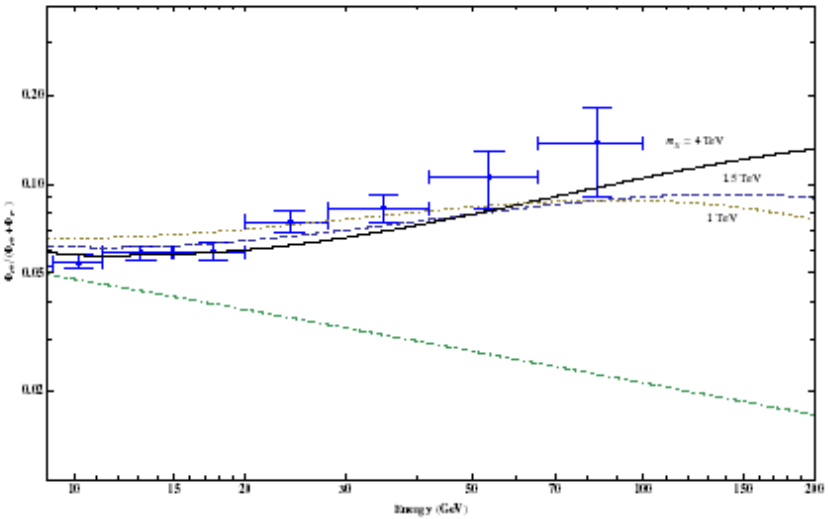
$$L = (-,+) \qquad e = (+,-) \qquad H_l = (-,-)$$

Basic picture :

Annihilation or decay

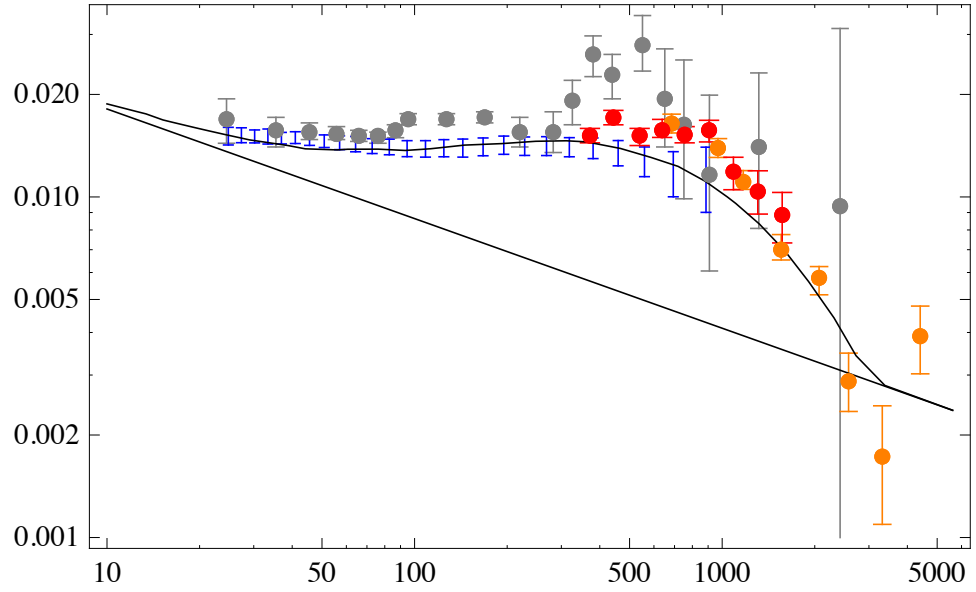



Or other topology and different leptonic final state depending on dark matter model




$$\chi \to H + A \to 4\tau$$

FERMI/GLAST



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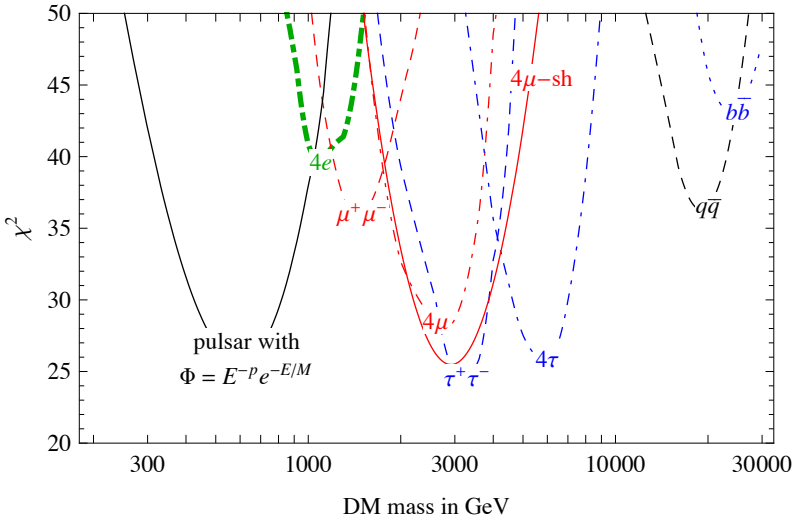
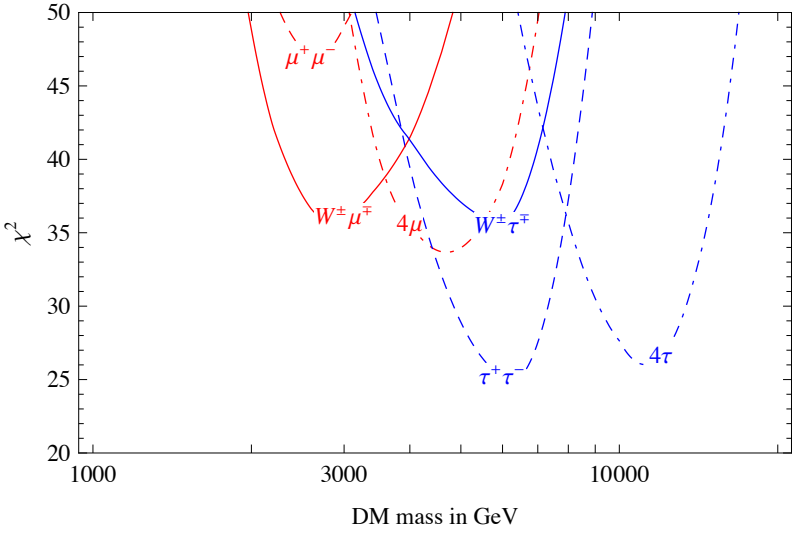
arXiv:0905.0480

DM annihilation




DM decay



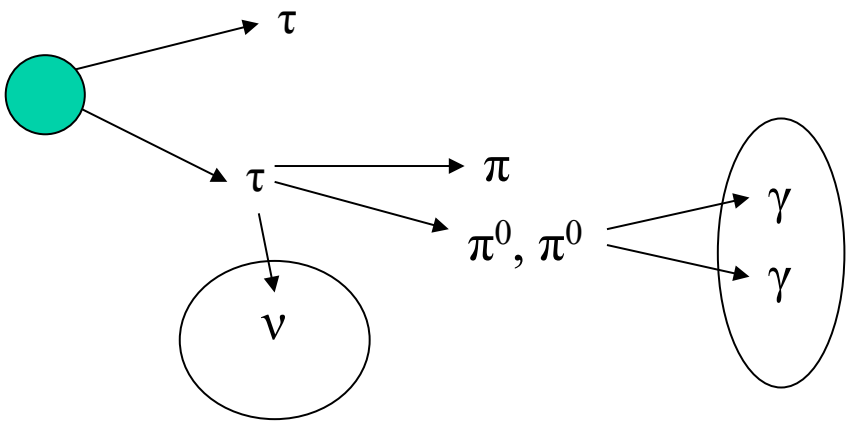
# Constraint from Photon and neutrino

No strong and positive result pose only constraint on dark matter model.

Decaying dark matter is safe from these constraints

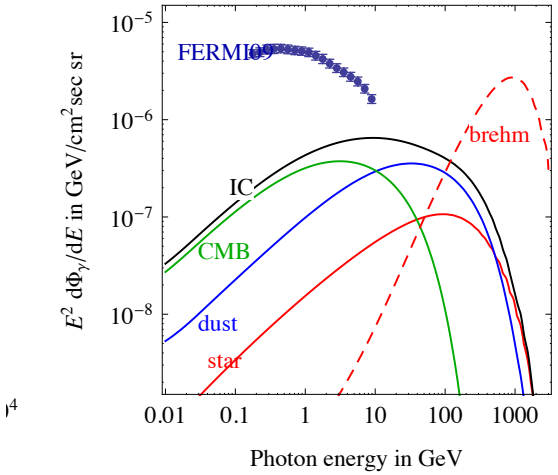
(quite strong from neutrino but still safe)

DM with $M = 3.\,\mathrm{TeV}$ that annihilates into $\tau^+\tau^-$ with $\sigma v = 2.0 \times 10^{-22}\ \mathrm{cm}^3/\mathrm{s}$




Lot of neutrino

Predict Hard photon

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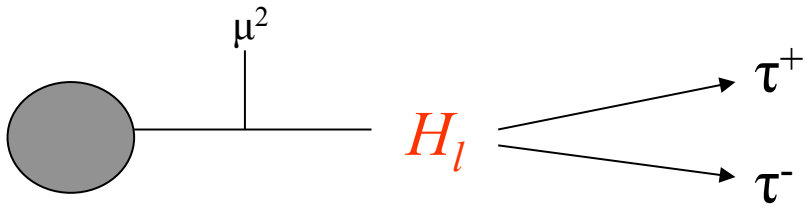
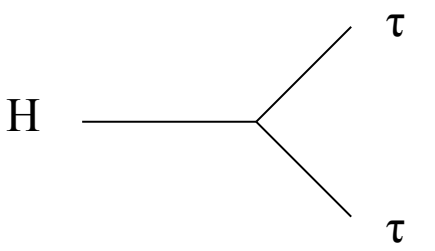
Annihilation is disfavored. Consider decaying dark matter.



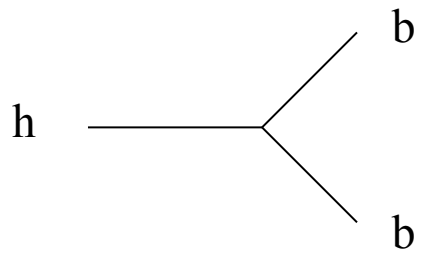

(Best fit decay channel)

$$\mu^2 H_D^\dagger H_l$$

## Phenomenology of leptonic Higgs :




$y_\tau$ is enhanced by $1/\tan\beta$




$y_b$ is not enhanced

} Unlike SUSY

$H_q$ and $H_l$ unavoidable mix.

$$H_q^0 = v_q + h_q + ia_q \qquad H_l^0 = v_l + h_l + ia_l$$

$$A = a_l \cos\beta - a_q \sin\beta \qquad Z_{||} = a_l \sin\beta + a_q \cos\beta$$

$$H = h_l \cos\alpha - h_q \sin\alpha \qquad \mathrm{h} = h_l \sin\alpha + h_q \cos\alpha$$

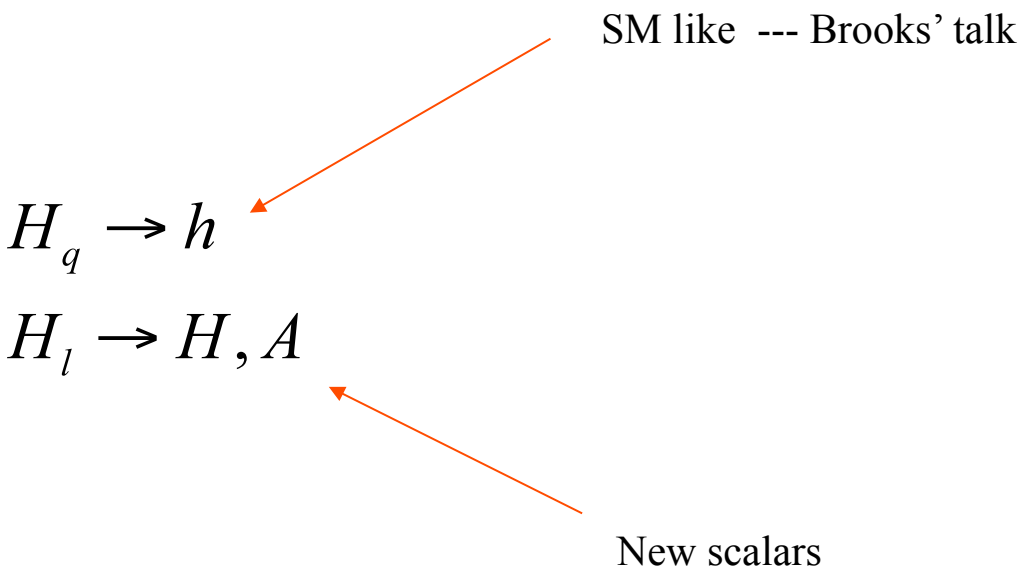
$$\boxed{\tan\beta = \frac{v_l}{v_q} \neq 0}$$

Leptonic Higgs $\equiv$ $tan\,\beta$ $<<$ 1

$$\Rightarrow \quad \tan\alpha \propto v_l \ll 1$$

(leptonic parity)

At leading approximation :



# Constraint on the parameters

$m_H + m_A > 185$ GeV ← From LEP

$|m_H - m_A| < m_Z$ ← Prevent H from decaying to Z

$m_H < 2m_W$ ← Prevent H from decaying to W

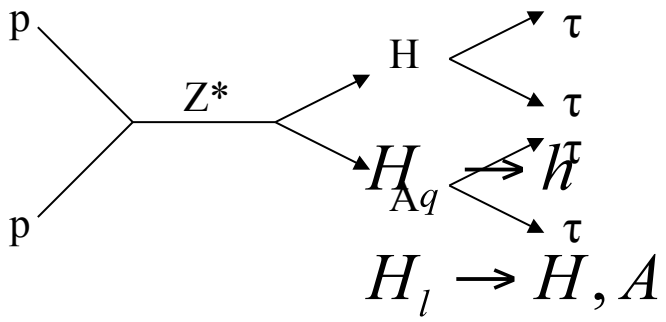
$m_H < 2m_A$ ← Prevent H from decaying to AA (spectrum is too soft)

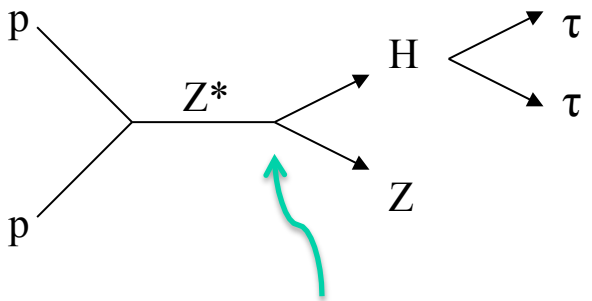
$$60 \sim \frac{2m_Z}{3} < m_A < 2m_W + m_Z \sim 250$$

$$45 \sim \frac{m_Z}{2} < m_H < 2m_W \sim 160$$

Imply non-decoupling at LHC

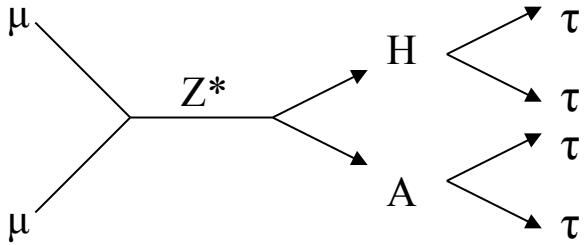
# LHC searches

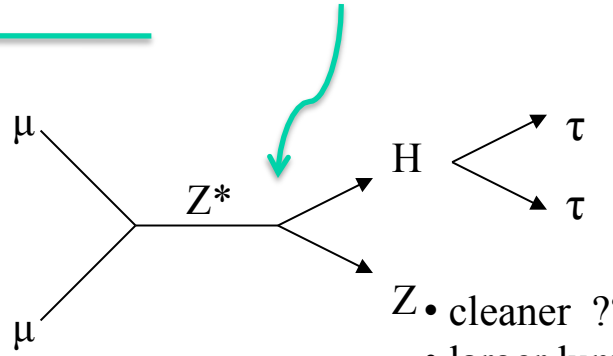



$v_l$ / $v_q$ suppressed compared SM h
Provide non-suppressed μμ from Z

# μC searches

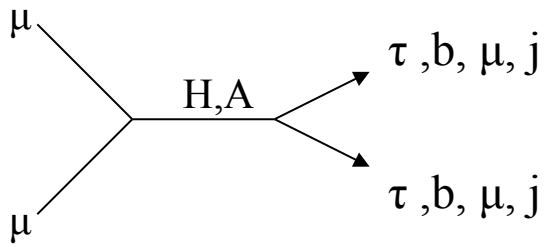



- cleaner ??
- larger luminosity
- Don't need high energy

Q : τ tagging remain important. Can we tag τ better at μC ?

# Single Higgs production at μC




$\sigma=\sigma_{SM}/\tan^2\beta$

Enhanced by larger muon Yukawa coupling . Could be one discovery channel.

Found new scalar resonance, measuring branching ratio $\Gamma_{\tau\tau} : \Gamma_{bb} : \Gamma_{\mu\mu} : \Gamma_{jj}$
Can tell us WHICH 2HDM it is

## Flavor blind 2HDM

Barger, Hewett, Phillips **Phys.Rev.D41:3421,1990**.

Inert Higgs SUSY ??? Leptonic Higgs

| Models | I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|---|
| | VEV | $A_f$ | VEV | $A_f$ | VEV | $A_f$ | VEV | $A_f$ |
| $\begin{pmatrix} u \\ d \end{pmatrix}$ | 2 | $\cot\beta$ | 2 | $\cot\beta$ | 2 | $\cot\beta$ | 2 | $\cot\beta$ |
| | 2 | $-\cot\beta$ | 1 | $\tan\beta$ | 1 | $\tan\beta$ | 2 | $-\cot\beta$ |
| $\begin{pmatrix} \nu \\ l \end{pmatrix}$ | 2 | $-\cot\beta$ | 1 | $\tan\beta$ | 2 | $-\cot\beta$ | 1 | $\tan\beta$ |

Other possibility : low energy left-right model. Bidoublet → two doblets

| **SUSY** | $\mathbf{m_\tau^2}$ | $\mathbf{m_b^2}$ | $\mathbf{m_\mu^2}$ | $\mathbf{m_s^2 + m_c^2\,(t_\alpha/t_\beta)^2}$ |
|---|---|---|---|---|
| Leptonic Higgs | $m_\tau^2$ | $m_b^2(t_\alpha/t_\beta)^2$ | $m_\mu^2$ | $(m_s^2 + m_c^2)\,(t_\alpha/t_\beta)^2$ |
| Blind Type III | $m_\tau^2$ | $m_b^2(t_\alpha/t_\beta)^2$ | $m_\mu^2$ | $m_s^2\,(t_\alpha/t_\beta)^2 + m_c^2$ |
| Spectator Higgs | Not directly related to mass | | | (Bogdan) - flavor |

- total cross section provide over all scale and fixed the factor $(t_\alpha/t_\beta)$
- total width can provided invisible decay width.

## Conclusion

• Leptonic Higgs can serve as a messenger of DM to explain the observed PAMELA and FERMI/GLAST data.

•Predict extra scalars with mass ~ 100 – 200 GeV that gives interesting Higgs physics at the LHC and muon collider

• μC in particular, has the unique potential to identify the type of general 2HDM

• We need good particle identification at μC

## Outlook

2HDM is well motivated (appear in many models like Z'), We should call it H'

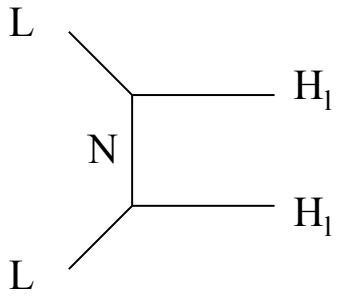
It will be interesting to see to what extend can μC distinguish different 2HDM in model independent way

# Models of dark matter

## LLN model

$$L_{dark} = \lambda L H_l N + m_L L L^c + m_N N N$$

annihilation




Need $\lambda \sim 3\text{-}4$

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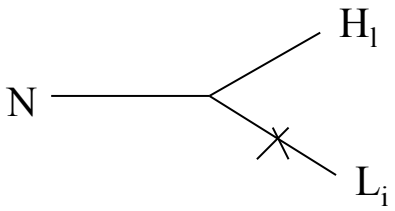
$$\delta L_{dark} = \delta m^i L_i L^c + .....$$

decay




$$\chi \rightarrow (A, H) + \nu_l \rightarrow \tau^+ \tau^- \nu_l$$

$$or$$

$$\chi \rightarrow H^\pm + l^\mp \rightarrow \tau^\pm l^\mp \nu_\tau$$

Innert doublet model

$$L_{dark} = \lambda (H_l)^2 (H_D)^2 + ....$$

Singlet scalar model

$$L_{dark} = \lambda (H_l)^2 (\Phi)^2 + ....$$