### Higgs and Dark Matter hints of an Oasis in the Desert

Michele Papucci LBNL

w/ C.Cheung & K.Zurek, 1203.5106

Planck 2012, May 30th 2012



The 125GeV hint may be the Higgs

- Is weak scale natural? (Experimental question)
- If nothing else is found, till which energies the "Standard Model" can be valid?



The 125GeV hint may be the Higgs

- Is weak scale natural? (Experimental question)
- If nothing else is found, till which energies the "Standard Model" can be valid?

### Stability of the Electroweak Vacuum



 Question has been addressed long time ago in the Standard Model

### Stability of the EW vacuum

- Higgs quartic coupling (a.k.a. m<sub>H</sub>) runs at loop level
- Can run non-perturbative or <u>negative</u>
- In the Standard Model depending on the values of the Higgs and top masses there might be another minimum at large field values
- Our vacuum could be absolutely stable, unstable or metastable (but sufficiently long lived)
- For a given Higgs mass, stability constraint up to which scale the SM is a valid theory

$$(4\pi)^2 \frac{d\lambda}{d\log Q} = 12\lambda_H^2 - 12y_t^4 + 12\lambda y_t^2 + \dots$$





- We know there is physics beyond the standard model that requires new dynamics
  - neutrino masses
  - dark matter
  - baryonic asymmetry
- Some of the models presented to address these questions require new interactions with the Higgs
- minimally including these new ingredients may change the Higgs stability picture → different cutoff

## **SM+WIMP DM**

- WIMP Dark matter is "unique":
  - weak scale mass → many decades in energy to affect Higgs
  - couplings can be sizable •
  - indipendent constraints → correlations with Direct
    Detection measurements

Explore Higgs stability of SM+WIMP DM in the rest

 $\sim <\sigma v > \sim 1 \text{ pb}$ 

## **SM+WIMP DM**

 Explore lower SU(2)xU(1) representations w/ spin 0 and 1/2 DM

Figure 5: Same as Fig. (3) but for SM + doublet scalar and varying  $\kappa_D$  with  $\lambda_D = \lambda'_D =$ theories and the MSSM is  $\tilde{g}_d^\prime/\sqrt{2}$ theories and the MSSM is B $\leftrightarrow$  $y_S$  $M_1$  $m_S \leftrightarrow$ • Explore clow ef effective for the second secondusing the notation of [10].  $\epsilon \tilde{H}_{u}$  thermore, in the limit of  $\theta_{x}^{c}$  act sup  $\tilde{\theta}_{x}$  symmetry,  $\tilde{g}_{u}^{(\prime)} = g$ and  $\tilde{g}_{dt}^{(\prime)} = g^{(\prime)} \cos \beta$ . using the notation of [10]., Furthermore, in the limit of exact supersymmetry,  $\tilde{g}_{u}^{(\prime)} = g^{(\prime)}$ and For the case of new s calar we consider the following the  $\kappa_S^2 H^2$  $\overline{\lambda}_{S_{-2}} = \overline{\kappa}_{S_{-2}}$ singlet scalar: singlet scalar:  $-\Delta \mathcal{L} = \frac{2}{1} \frac{m_S S + 2}{m_S S^2 + \frac{2}{\lambda_S}} \frac{S + 2}{2} \frac{S + 1}{|I|}^{S}$ singlet scalar:  $-\Delta \mathcal{L} = \frac{1}{2} \frac{m_S S^2 + \frac{\lambda_S}{\lambda_S}}{m_T T^2 + \frac{\lambda_T}{2}} \frac{S^4 + \frac{\kappa_S}{\kappa_S}}{T^4 + \frac{\kappa_T}{2}} \frac{S^2 |I|^2}{T^2 |I|^2}$ triplet scalar:  $-\Delta \mathcal{L} = \frac{1}{2} \frac{m_T T^2 + \frac{\lambda_T}{\lambda_D}}{T^4 + \frac{\kappa_T}{2}} \frac{T^2 |I|^2}{T^2 |I|^2}$ loublet scalar:  $-\Delta \mathcal{L} = \frac{1}{m_D} |D|^2 + \frac{\lambda_D}{2} |D|^4 + \frac{2\kappa_D}{2} |D|^2 |I|^2 + \frac{\kappa_D'}{2} |DH^\dagger|^2.$  $m_{SD}$ doublet scalar: doublet scalar:  $-\Delta \mathcal{L} = m_D |D|^2 + \frac{\lambda_D}{2} |D|^4 + \frac{\kappa_D}{2} |D|^2 |H|^2 + \frac{\kappa'_D}{2} |DH^{\dagger}|^2.$ Here S and T are real scalars while D is a complex scalar. Contrary to the fermionic can waster doublet scalar case can have direct couplings to the Higgs and therefore can be con

 $t_{\text{preview}} = \frac{1}{2} + \frac{1}{2}$ theories and the MSS  $m_T$ theories and the ASSAN using th and  $\tilde{a}$ in the limit of  $y_{\text{track}}$  act super the following theories: Symmetry,  $\tilde{g}_{u}^{(\prime)}$ Turthermore, we consider US . Furthermore, in the limit of exact supersymmetry,  $\tilde{g}\tilde{g}$ and CENSE CENSE singlet scalar:  $\kappa_{2} \pi^{2} \pi^{2} \pi^{2}$ triplet scalar:  $2 m_S S^2$  $-\underline{}^{\underline{\nu}}m_TT^2 +$ ScalatripTdpscalar:  $\frac{1}{D} \sum_{j=1}^{2} \frac{\lambda_{D}}{\lambda_{m}} |D|^{4} \frac{2\kappa_{D}}{\kappa_{m}} |D|^{2} |H|^{2} + \frac{\kappa_{D}}{2} |DH^{\dagger}|^{2}.$ doublet scalar: tripfetscalar:  $|D|^2 |H|^2 + \frac{\kappa_D}{2} |DH^{\dagger}|^2.$ doublet scalar: Here Sangh Tease real scalars while Dris appropriate Co pure doublet scalar case can have direct couplings to the Higgs and therefore 2 and be constructed. Here S and T are real scalars while D is a complex scalar. Contrary to the fermionic case 3 and 3 are real scalars while D is a complex scalar. ware doublet scalar case can have direct couplings to the Higgs and therefore can be con

 $t_{\text{preview}} = \frac{1}{2} + \frac{1}{2}$ theories and the MSS  $m_T$ theories and the ASSAN using th and  $\tilde{a}'$ the following theories: urthermore, we consider Symmetry,  $\tilde{g}_{u}^{\prime\prime}$ US . Furthermore, in the limit of exact suppress motory,  $\tilde{g}_{u}^{\ell}$ and Reception  $Z_2$  sym<sup>2</sup> singlet scalar:  $\kappa_2 \pi_2 \pi_1 \pi_1^2$ triplet scalar:  $2 \overline{m}_S S^2$  $-\frac{\mathbf{z}}{-}m_TT^2 +$ ScalatripTdpscalar:  $\frac{\lambda_D}{\lambda_m} |D|^4 \frac{2\kappa_D}{|\kappa_m} |D|^2 |H|^2 + \frac{\kappa_D}{2} |DH^{\dagger}|^2.$  $D|_{2}^{2}\perp$ doublet scalar: tripetscalar:  $|D|^2 |H|^2 + \frac{\kappa_D}{2} |DH^{\dagger}|^2.$ doublet scalar: Here Sand Trase real scalar while Dris appropriate Co pure doublet scalar case can have direct couplings to the Higgs and therefore 2 and be constructed. Here S and T are real scalars while D is a complex scalar. Contrary to the fermionic case 3 and 3 are real scalars while D is a complex scalar. ware doublet scalar case can have direct couplings to the Higgs and therefore can be con

heories and the MSSM is  $\mathbf{P}_{\mathbf{P}} = \mathbf{P}_{\mathbf{P}} =$ theories and the MSSM is theories and the MSSM is theories and the ASS ising the notation of the contact hermore in the Hipit of et using the notation of KU. Enthermore in the  $exact < supersymptotic try, <math>q_u$  $g_{u}$  and  $g_{u}$  and  $g_{u}$  and  $g_{u}$  and  $g_{u}$  in the following stress process in the  $\tilde{g}_{u}^{(\prime)}$ and  $\mathcal{G}_{d}$  = inglessialar:  $-\Delta \mathcal{L}$  =  $+ \frac{\kappa_S}{\kappa_s} S^2 [H]^2$  $\overline{A}m_SS^2$ + Horr the case of new scalars we consider the  $Z_2$  sym'  $m_S S$ singlet scalar: triblet scalar: triplet scalar:  $= 2 \tilde{m}_S S^2 + 2 S^4 + 2 S^2 |H|^2$  $-\Delta \mathcal{L}$ tsingettseatar:  $-\Delta \mathcal{L} = \frac{2}{2}m_T T^2 + \frac{\lambda_T}{2}T^4 + \frac{\kappa_T}{2}T^2 |H|^2$ Scalafriplet scalar:  $-\Delta \mathcal{L} = \frac{-m_T T^2}{2} + \frac{-m_T T^2}$ doublet scalar: doublet scalari D14 doublet scalar: Kraban Dorbretts alars while Dis appropriate patar. Bondary to the forming the cas oure doubled scalars and scalars while ches a singles the Higgs and therefore can be constant of the second of the purdereusland calarecesal can have direct couplings to the Higgs and therefore can be correst oure deresteresealare dass alare while the property sealing sandranger the termber of termbe ware doublet scalar case can have direct couplings to the Higgs and therefore can be con

heories and the MSSM is  $\mathbf{P}_{\mathbf{P}} = \mathbf{P}_{\mathbf{P}} =$ theories and the MSSM is theories and the MSSM is theories and the ASS using the notation of the set of thermore an the Hipit of . Harthermore in the the notation of KIN  $q_{act} < supe g_{synynetry}, q_{u}$  $\tilde{\mathbf{D}}$  [ $\mathbf{M}$ ]. Eurthermomon in the limit of exact supersymmetry,  $\tilde{g}_{u}^{(\prime)}$ we consider the following theories:  $g_{u}$  the most spectrum of [10] a month consider, it the following the states upper symmetry,  $\tilde{g}_{u}^{(\prime)}$ and  $\mathcal{G}_{d_1}$  = single scalar:  $+\frac{\hbar S}{\hbar S} S^2 [H]^2$  $-\Delta \mathcal{L} =$  $\overline{A}m_SS^2$ + Horr the case of mewscalars we consider the  $Z_2$  sym' singlet scalar: msS tripletsgalar: triplet scalar:  $2 m_S S^2 + 2 S^4 + 2 S^2 |H|^2$  $-\Delta \mathcal{L}$ =tsingettsealar:  $-\Delta \mathcal{L} = \frac{2}{2}m_T^2 T^2 + \frac{\lambda_T}{\lambda_2}T^4 + \frac{\kappa_T}{2}T^2|H|^2 \mathbf{1}$ ScalafripleDealar:  $\Delta \mathcal{C} = \frac{2}{m} \sum_{D} |D|^2 \pm \frac{2}{m} |D|^4 \pm \frac{2\kappa_D}{\kappa_D} |D|^2 |D|^2 + \frac{2}{4}$ doublet scalar: doublet scalati doublet scalar: Here ban Darpreets alars while Dis a promplex spatar. But ary to the forming the cas oure doubled school are calar while they in the fings of the fliggs and therefore can be can purdereusland calarecesal can have direct couplings to the Higgs and therefore can be correst oure deresteresealare dass alare while the progener was a progener and the terminations ware doublet scalar case can have direct couplings to the Higgs and therefore can be con

## SM+WIMP DM

• Fermionic Dark matter can couple to the Higgs only if it comes in two representations (otherwise Minimal Dark Matter with <u>fixed</u> mass)



he cape of new ferminative consider the following theorem:  $10^{10} = 10^{2}H^{c} \pm 10^{14}H^{*}$  (GeV) A (GeV)

 $\begin{aligned} & (H^c \equiv \epsilon H^*) \\ & (H^c \equiv E^*) \\ & (H^c \equiv H^*) \\ & (H^c \equiv H^*$ 



# Methodology

 $M_{1} \bullet \operatorname{Run}_{2} \overset{g'}{\to} \operatorname{loop}_{2} \overset{g'}{\to} \overset{g'}{$ 

• Compute refit abundance and  $\sigma_{SI}$ 

the limit of exact supersymmetry,  $\tilde{g}_{u}^{(\prime)} = g^{(\prime)} \sin \beta$ • Check for (meta)-stability and perturbativity

e following theories:

#### For Scalars:

 ${}^{2} + \frac{\lambda_{S}}{2} \underbrace{\text{Stabfligg phong all}}_{\text{the field directions:}} \text{Perturbativity in all the couplings} (:= scale at which RGEs blow up)}_{\text{(:= scale at which RGEs blow up)}}$   ${}^{2} + \frac{\lambda_{T}}{2} \begin{bmatrix} \Gamma_{\lambda H}^{4} \neq \frac{\kappa_{T}}{2} 0 T^{2} |H|^{2} \\ \lambda_{S} \geq 0 \\ D \neq \frac{\kappa_{S}}{2} \geq 0 \end{bmatrix} + \frac{\kappa'_{D}}{2} |D|^{4} \neq \frac{\kappa_{D}}{2} \sqrt{D} \neq H | + \frac{\kappa'_{D}}{2} |D| + \frac{\kappa'_{D}}{2} |D| = \frac{\kappa_{S}^{2} < 16\pi^{2}/4, \qquad \lambda_{S}^{2} < 16\pi^{2}/44}{\kappa_{D}^{2}, \kappa_{D}^{2} < 16\pi^{2}/2, \qquad \lambda_{D}^{2} < 16\pi^{2}/12.}$ 

## Results

#### Fermionic DM tend to lower the cutoff scale (acts like the top)



#### Theoretical uncert' reduced for low cutoffs

#### Scalar DM tend to stabilize the Higgs potential

SM + Triplet Scalar



### Full picture:



## Full picture:





## Full picture:



## Full picture:



## Full picture:



## Full picture:



### Fermionic DM Changing the mass



Abundance fixes the couplings → cutoff gets lower for heavier masses

### Fermionic DM Changing the DM composition



### Direct detection & the desert

• Dark Matter detection provides an indication of how low additional new physics can be



#### • Constraints more complicated:

SM + Triplet Scalar



#### $\Lambda$ determined by

#### • Constraints more complicated:

SM + Triplet Scalar



#### • Constraints more complicated:

SM + Triplet Scalar



#### • Constraints more complicated:

SM + Triplet Scalar



## Summary

- If a Standard Model-like Higgs and no other sign of new physics is found, the interesting question is how heavy new physics can be
- WIMP DM is a well motivated and appealing extension of the SM
- The presence of WIMP DM coupling to the Higgs modifies the wellknown SM answer and in many cases tend to lower the SM cutoff
- Cutoff can be as low as 10-100 TeV
- Low cutoffs easier to be probed
- If SM-like Higgs and WIMP DM only things found, we will have indications of how light other NP must be → presence of "oases" in the energy desert