

# Large loop-coupling enhancement of a 750 GeV pseudoscalar from a light

Stefano Di Chiara



Keemilise ja  
Bioloogilise Füüsika Instituut  
National Institute of Chemical Physics and Biophysics

SD, A. Hektor, K. Kannike, L. Marzola, M. Raidal; arXiv:1603.07263

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# Motivations

Latest LHC data at 13 TeV ( $3.3 \text{ fb}^{-1}$ ) show diphoton events excess at 750 GeV with local significance of  $3.4\sigma$  at CMS and  $3.9\sigma$  at ATLAS

Simplest interpretation: SM particle content extended by EW singlet spin-zero field  $S$ , with  $m_S = 750 \text{ GeV}$ , coupled only to a vector quark  $Q_v$ , with  $m_{Q_v} \sim 700 \text{ GeV}$ , but...

$$\sigma(pp \rightarrow S \rightarrow \gamma\gamma) \sim 10 \text{ fb} \Rightarrow y_{Q_v}^S \sim 10, \Lambda_{UV} = O(\text{TeV})$$

This is unsatisfactory and increasing multiplicity  $N_f \times d_f$  of  $Q_v$  helps only up to a point: such large couplings might be a consequence of strong dynamics or...

# Decay width to diphoton

Decay widths of scalar  $H$  and pseudoscalar  $A$  to  $\gamma\gamma$  mediated by fermions  $f$ :

$$\Gamma_{\gamma\gamma} = \frac{\alpha_e^2 m_S^3}{256\pi^3 v_w^2} \left| \sum_f a_f N_f e_f^2 F_f^S \right|^2, \quad a_f = \frac{y_f v_w}{\sqrt{2} m_f}, \quad S \in \{A, H\}$$

with

$$F_f^H = -2\tau_f [1 + (1 - \tau_f) f(\tau_f)], \quad F_f^A = -2\tau_f f(\tau_f), \quad \tau_f = \frac{4m_f^2}{m_S^2}$$

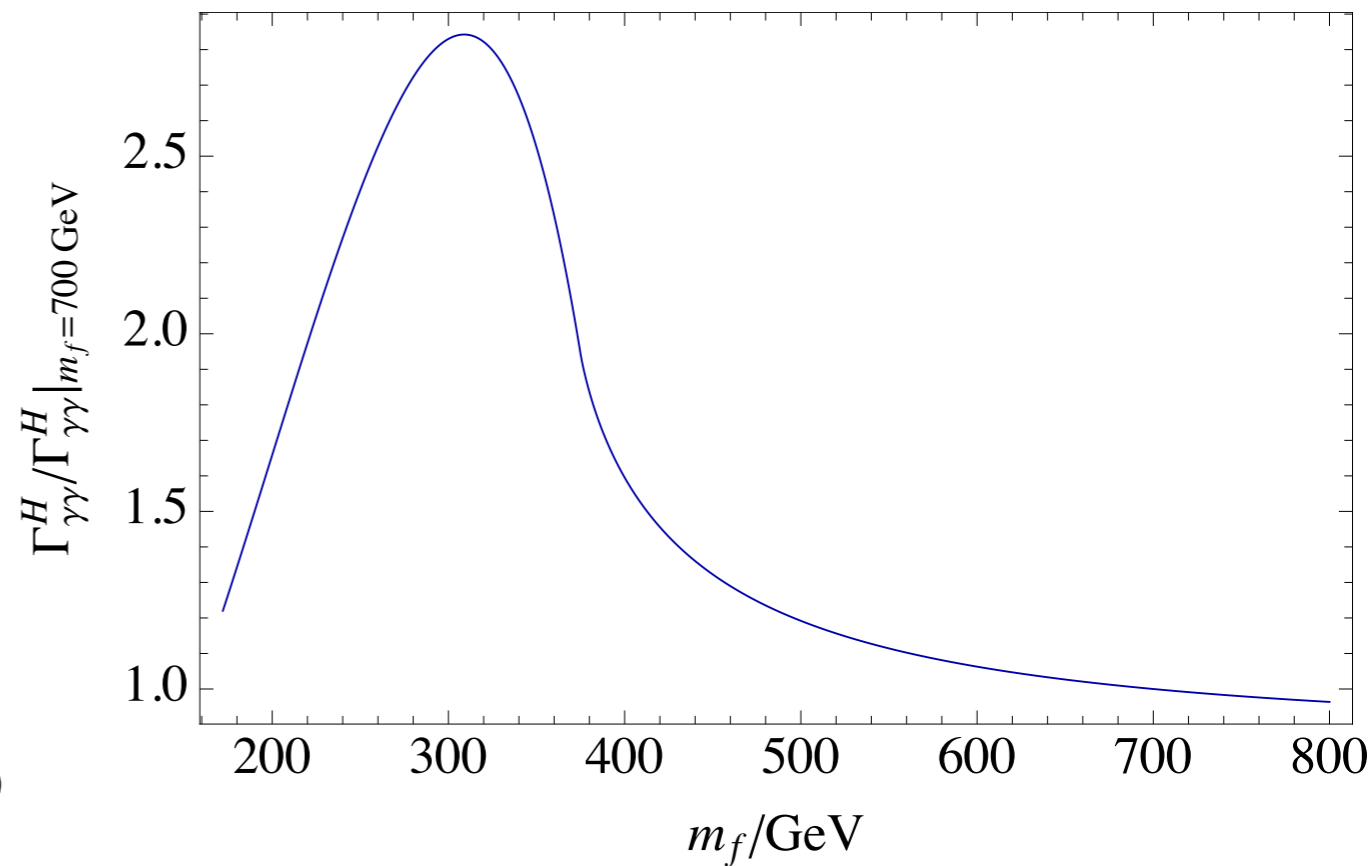
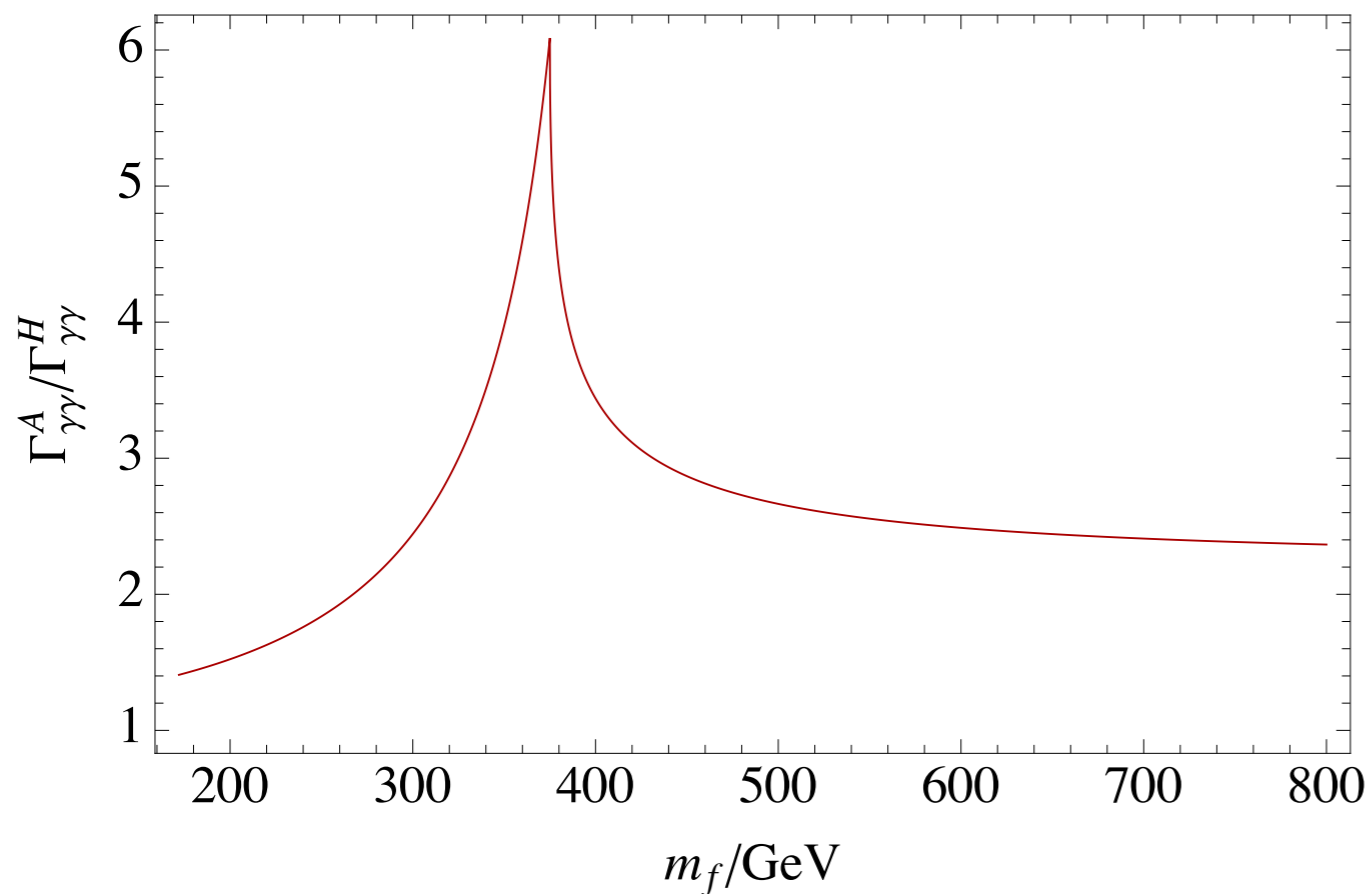
Pseudoscalar partial amplitude is affected by a discontinuity

$$\lim_{m_f \rightarrow (m_A/2)^\pm} F_f^A = \frac{\pi^2}{2}, \quad F_f^A|_{m_f=m_A/2} = \pi^2,$$

Ellis et al.'76

# Decay width to diphoton

Left panel : Ratio of decay rate to  $\gamma\gamma$  of  $A$  to that of  $H$  mediated by fermion of mass  $m_f$ . Right panel:  $H$  decay rate to  $\gamma\gamma$  normalized to  $m_f = 700$  GeV case



Near the threshold:  $y_f^A / y_f^H \simeq 1/3.5 \Rightarrow \Gamma_{\gamma\gamma}^A = \Gamma_{\gamma\gamma}^H$

SD et al.'16

# Experimental limits

Diphoton cross section at LHC in the narrow width approximation:

$$\sigma(pp \rightarrow A \rightarrow \gamma\gamma) = C_{gg} \frac{\Gamma_{gg} \Gamma_{\gamma\gamma}}{s m_A \Gamma_{\text{tot}}}, \quad \Gamma_{gg} = \frac{\alpha_s^2 m_A^3}{128 \pi^3 v_w^2} \left| \sum_f a_f F_f^A \right|^2,$$

with

$$C_{gg} = 2137, \quad m_A = 750 \text{ GeV}, \quad \sqrt{s} = 13 \text{ TeV}$$

Gluon-fusion process mediated by top quark not viable because of  $t\bar{t}$  channel 8 TeV LHC constraint & large contribution to  $\Gamma_{\text{tot}}$ .

Experimental limits on vector quark masses range from 705 to 846 GeV, but relaxed to 690 GeV for decays to light quarks only. Vector charged leptons must be heavier than 400 GeV, but limit relaxed to 104 GeV for decays to nearly degenerate SU(2) neutral component.

Martin et al.'09, CMS-12-013, CMS-14-001, ATLAS PRD92(2015), Abbiendi et al. EPJC29(2003)

# Model

Scalar and vector fermion content:  $\mathbb{Z}_2$  symmetry to avoid lepton-number violating couplings, with all the SM fermions but the 1st and 2nd quark generation even under  $\mathbb{Z}_2$ . Bonus:  $N$  dark matter (DM) candidate.

Field	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$\mathbb{Z}_2$
$H$	1	$\begin{pmatrix} \phi^+ \\ (v_w + h + i\phi^0) / \sqrt{2} \end{pmatrix}$	1/2	+
$A$	1	$A$	0	+
$L$	1	$\begin{pmatrix} N \\ E \end{pmatrix}$	-1/2	-
$E'$	1	$E'$	-1	-
$Q$	3	$\begin{pmatrix} U \\ D \end{pmatrix}$	1/6	-
$U'$	3	$U'$	2/3	-

SD et al.'16

# Lagrangian

- Vector fermions: gauge invariant mass terms, no anomalies
- Yukawa couplings to  $H$  generate SU(2) doublet mass splitting
- Yukawa couplings to  $A$  give (only) diboson widths
- CP symmetry: no terms odd in  $A$  (no  $A \rightarrow hh$  decays),  $\lambda_{AH} > 0$
- $\lambda_A$  and  $\lambda_{AH}$  to stabilize SM vacuum

$$\begin{aligned} \mathcal{L} \supset & \left[ y_L^L \bar{L}_L H E'_R + y_L^R \bar{L}_R H E'_L + y_Q^L \bar{Q}_L \tilde{H} U'_R + y_Q^R \bar{Q}_R \tilde{H} U'_L + \text{H.c.} \right] \\ & - iy_L A \bar{L} \gamma^5 L - iy_E A \bar{E}' \gamma^5 E' - iy_Q A \bar{Q} \gamma^5 Q - iy_U A \bar{U}' \gamma^5 U' \\ & + m_L \bar{L} L + m_{E'} \bar{E}' E' + m_Q \bar{Q} Q + m_{U'} \bar{U}' U' \\ & - m_A^2 A^2 - \lambda_A A^4 - \lambda_{AH} A^2 |H|^2 . \end{aligned}$$

# LHC diphoton signal

Choice of initial conditions:

$$\sigma (pp \rightarrow A \rightarrow \gamma\gamma) = 6 \text{ fb} ,$$

$$y_E = y_U = -y_L = -y_Q \equiv y_\nu ,$$

$$m_D = m_T = 700 \text{ GeV} , m_{T'} = 705 \text{ GeV} ,$$

Two DM scenarios:

Scenario	$m_N$ (GeV)	$m_{\chi_1^\pm}$ (GeV)	$m_{\chi_2^\pm}$ (GeV)	$y_\nu$
I	375	380	390	0.41
II	1200	1205	1210	1.09

Small EW doublet mass splitting imposed by  $T$  parameter constraint



# LHC @ 8 TeV bounds

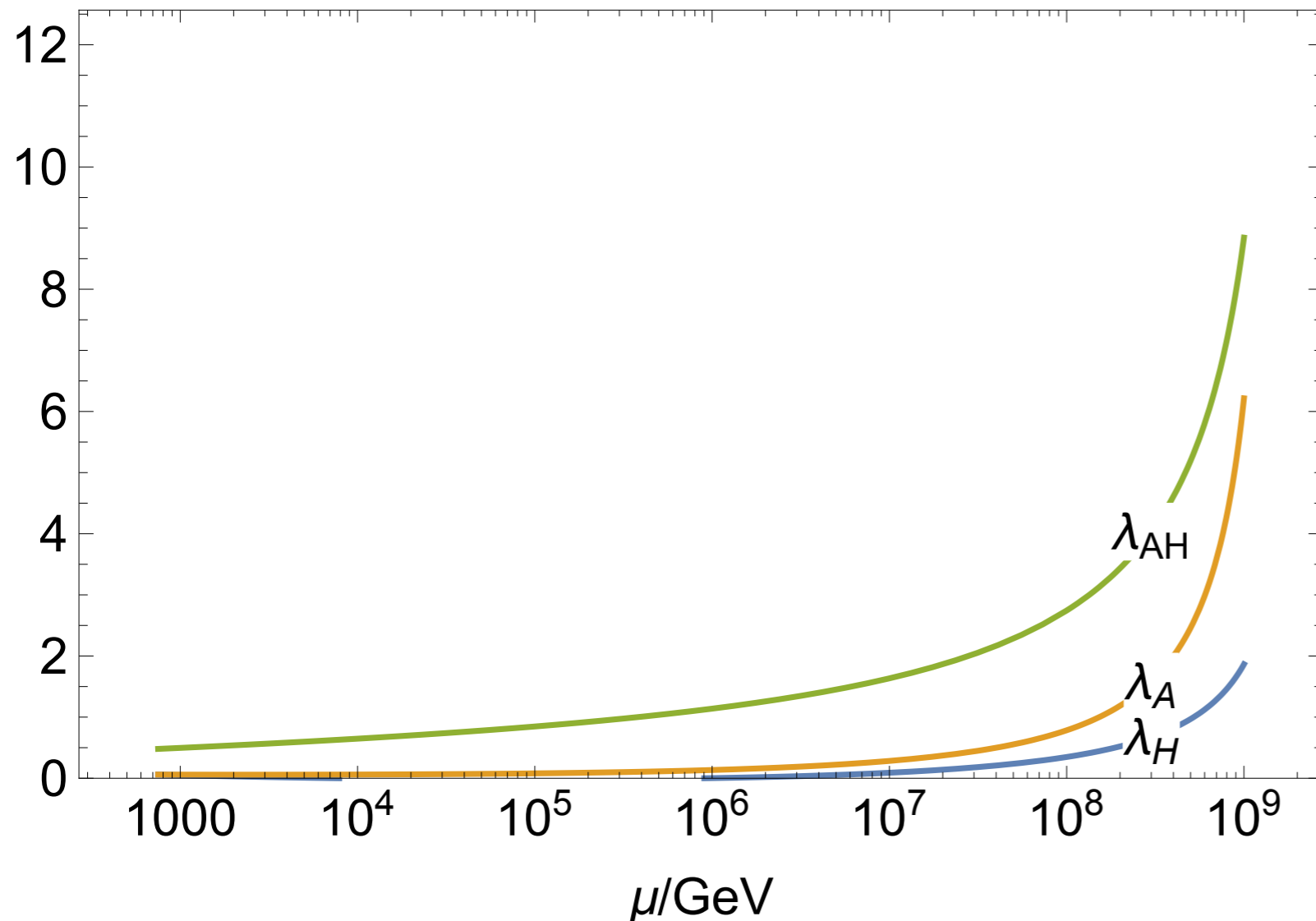
Complementary channels at 8 TeV LHC: prediction at 1 loop for the two scenarios satisfies experimental upper bound for each channel

	$\sigma_I^{\text{th}}(\text{fb})$	$\sigma_{II}^{\text{th}}(\text{fb})$	$\sigma_{\text{max}}^{\text{exp}}(\text{fb})$
$jj$	38	199	$2.5 \times 10^3$
$WW$	1.63	2.54	40
$ZZ$	0.08	0.08	12
$Z\gamma$	0.04	0.14	11

SD et al.'16, Franceschini et al.'15

# UV cutoff scale

Run SM couplings from  $m_t$  to 750 GeV within SM, use as initial conditions, fix  $\lambda_A$  and  $\lambda_{AH}$  to maximize  $\Lambda_{UV}$ , defined as  $\lambda_{AH}(\Lambda_{UV}) = 4\pi$ , and avoid  $\lambda_H(\mu) < 0$ :

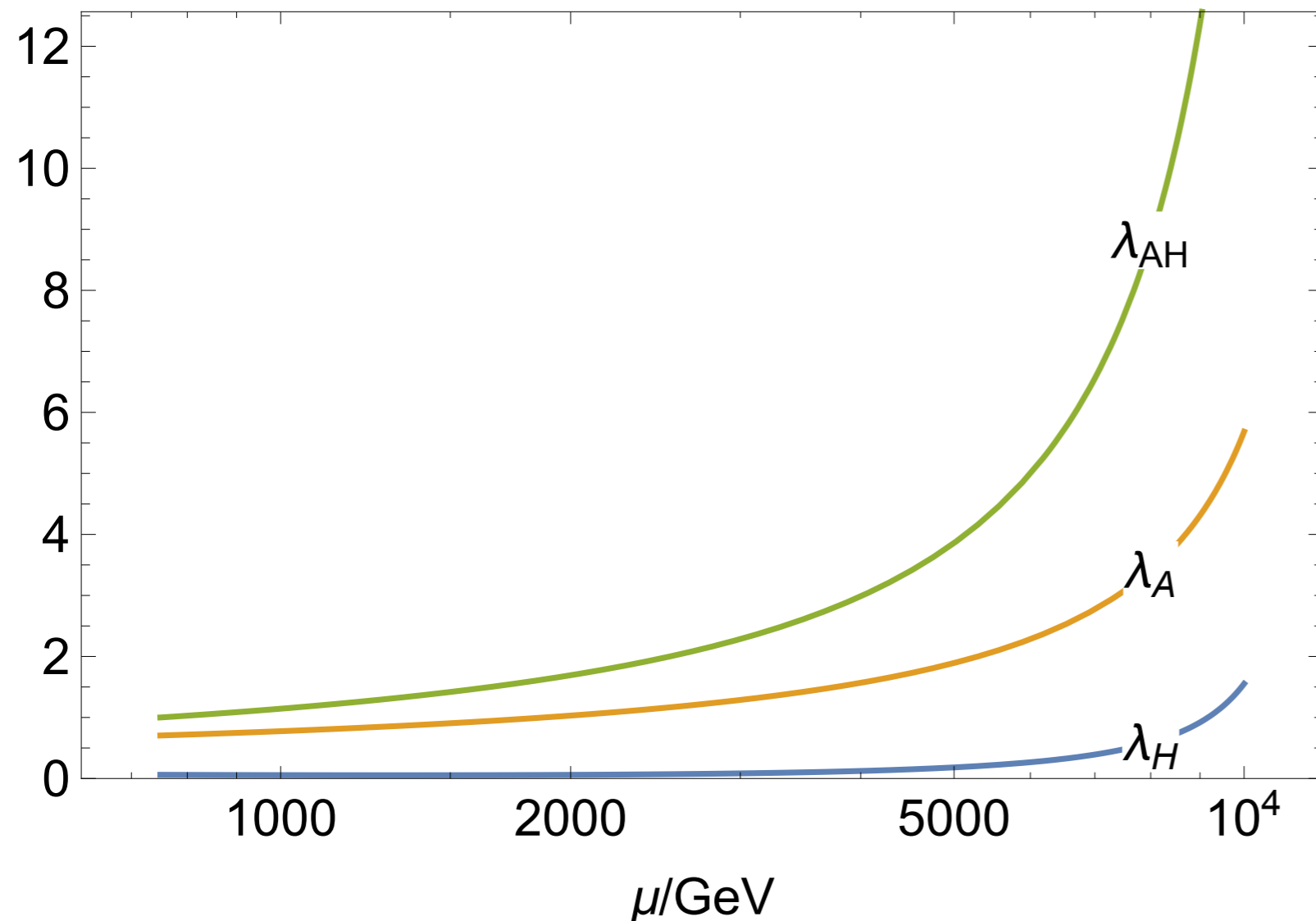


- scenario 1:  $\Lambda_{UV} = 10^9$  GeV
- scenario 2:  $\Lambda_{UV} = 10^4$  GeV
- Stable potential for both scenarios

SD et al.'16

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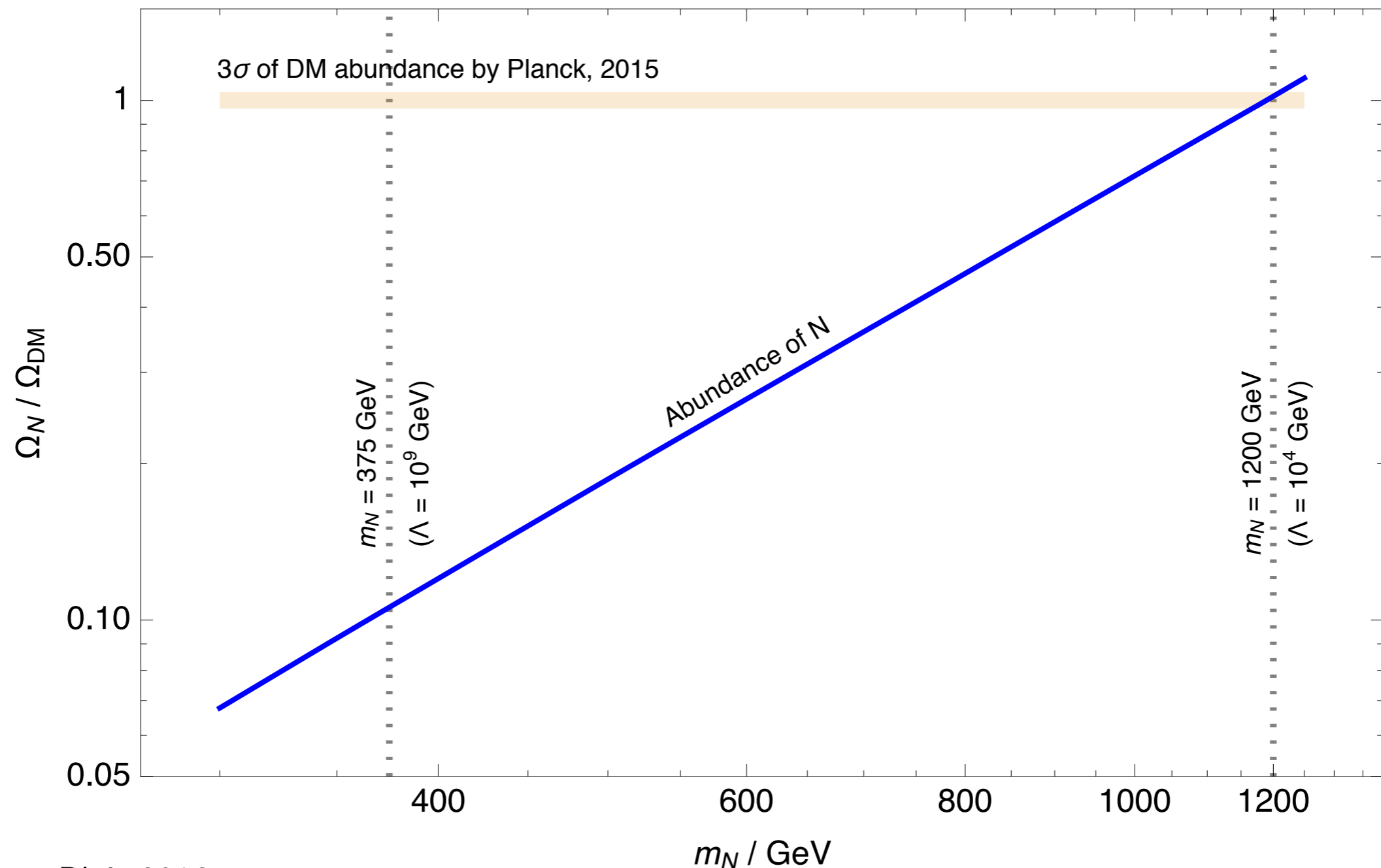
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# DM Abundance

Vector neutrino  $N$  has only weak interaction = authentic WIMP: annihilations to SM particles mediated by  $Z$ . Fraction of DM relic abundance that  $N$  can account for, as a function of  $m_N$ :



# Conclusions

- Large diphoton excess can be produced via threshold effects rather than large tree level couplings
- Cutoff scale (without tuning) equal to  $10^9$  GeV
- Byproduct: viable DM candidate
- SM vacuum stabilization

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Thank you!

# Backup Slides

# Decay width to diphoton

$$\Gamma_{H \rightarrow \gamma\gamma} = \frac{\alpha_e^2 m_H^3}{256\pi^3 v_w^2} \left| \sum_i N_i e_i^2 F_i \right|^2,$$

where  $N_i$  is the number of colors,  $e_i$  the electric charge, and

$$F_V = [2 + 3\tau_V + 3\tau_V (2 - \tau_V) f(\tau_V)] a_V,$$

$$F_f = -2\tau_f [1 + (1 - \tau_f) f(\tau_f)] a_f,$$

$$F_S = \tau_S [1 - \tau_S f(\tau_S)] a_S, \quad \tau_i = \frac{4m_i^2}{m_H^2},$$

with

$$f(\tau_i) = \begin{cases} \arcsin^2 \sqrt{1/\tau_i} & \tau_i \geq 1 \\ -\frac{1}{4} \left[ \log \frac{1 + \sqrt{1 - \tau_i}}{1 - \sqrt{1 - \tau_i}} - i\pi \right]^2 & \tau_i < 1 \end{cases}.$$

In the limit of heavy particles:  $F_V = 7$ ,  $F_f = -\frac{4}{3}$ ,  $F_S = -\frac{1}{3}$ .