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

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

PASCOS, Vietnam - 2016

Motivations

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

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

$$\sigma\left(pp \to S \to \gamma\gamma\right) \sim 10 \text{ fb} \ \Rightarrow \ y^S_{Q_v} \sim 10\,, \ \Lambda_{\text{UV}} = O(\text{TeV})$$

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

ATLAS-2015-081, CMS-15-004, Franceschini et al.'15

Decay width to diphoton

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

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

with

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

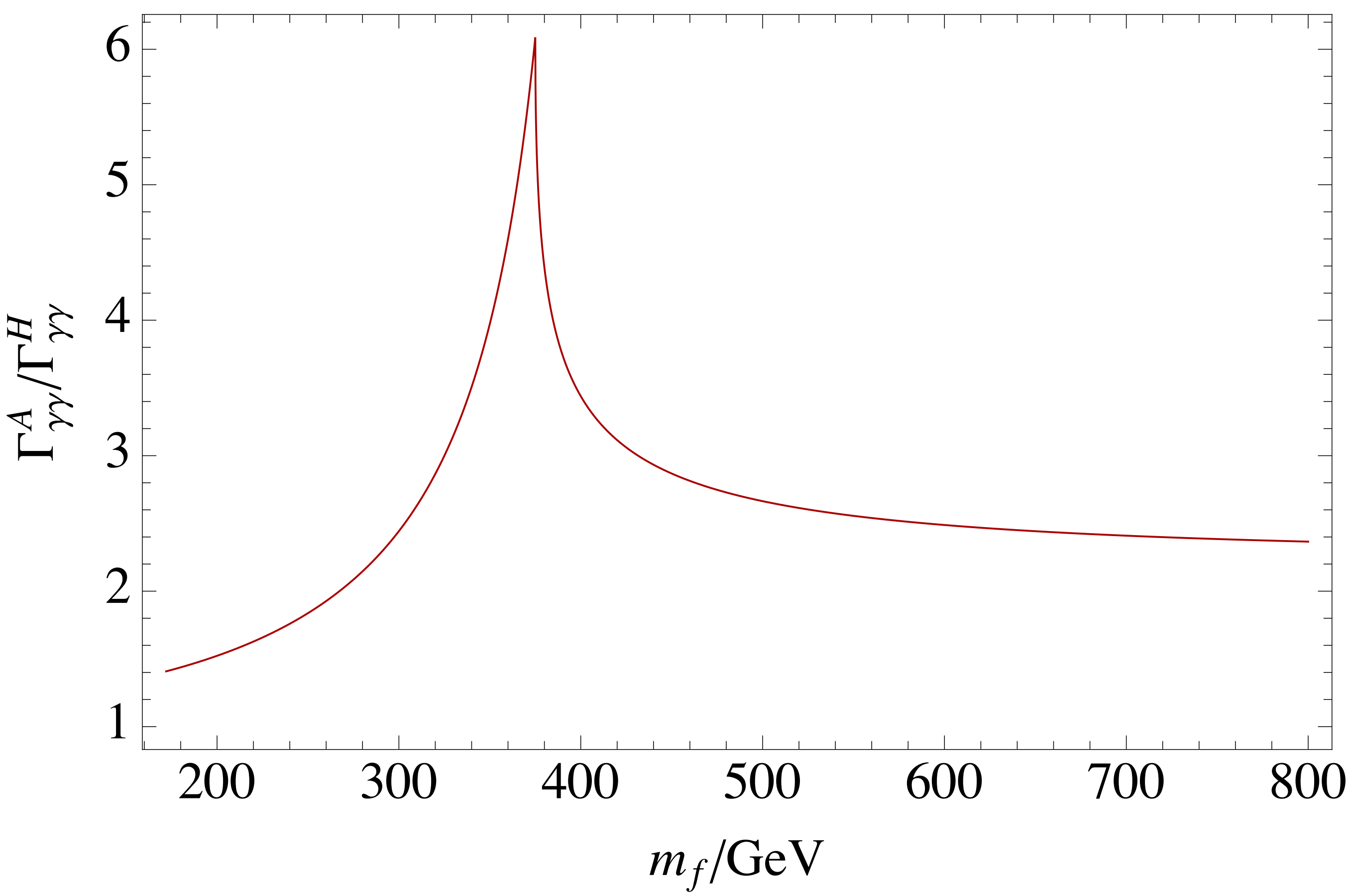
Pseudoscalar partial amplitude is affected by a discontinuity

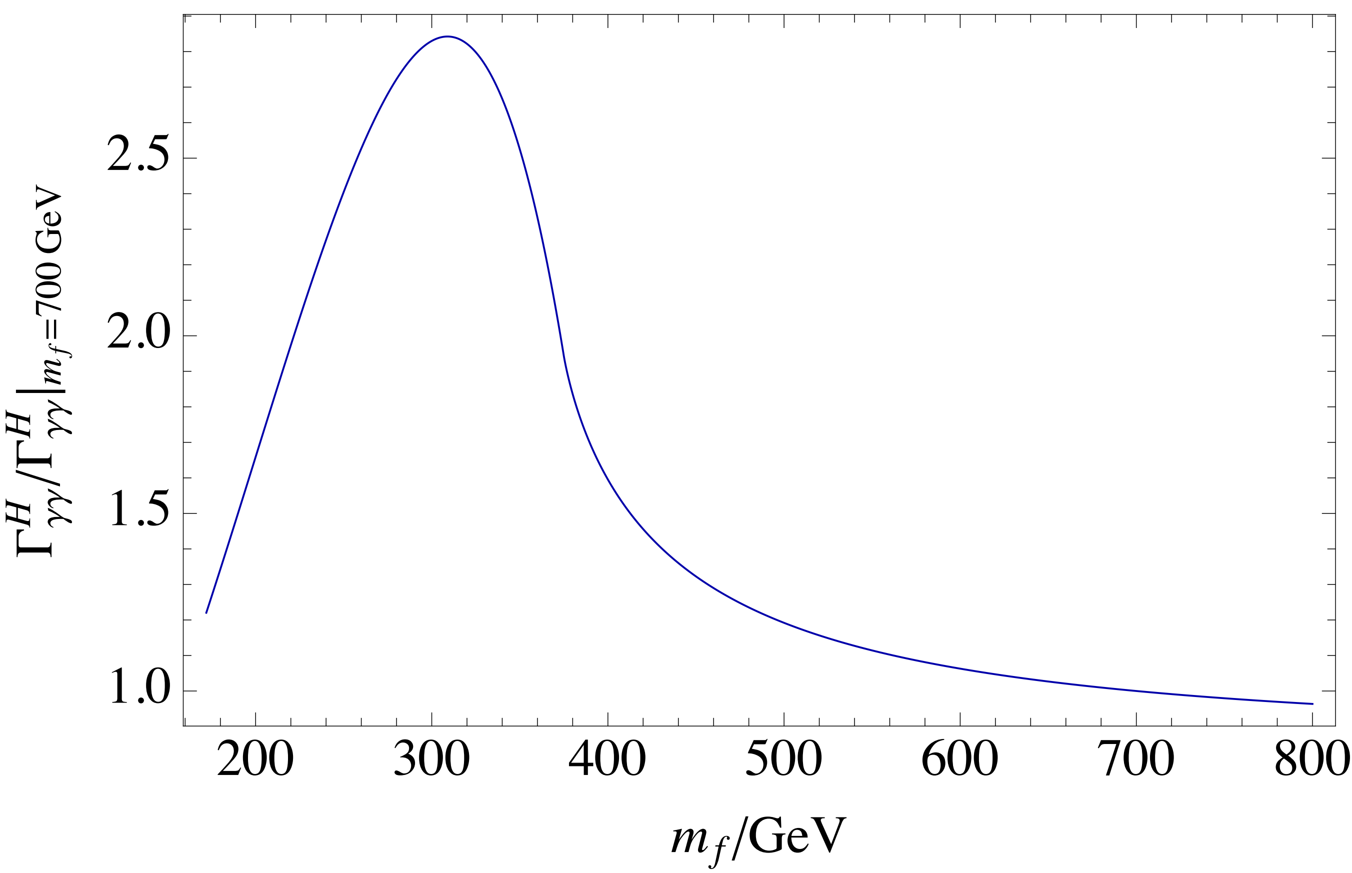
$$\lim_{m_f \to (m_A/2)^\pm} F_f^A = \frac{\pi^2}{2} , \; F_f^A|_{m_f = m_A/2} = \pi^2 ,$$

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: $y_f^A/y_f^H \simeq 1/3.5 \;\Rightarrow \Gamma^A_{\gamma\gamma} = \Gamma^H_{\gamma\gamma}$

SD et al.'16

Experimental limits

Diphoton cross section at LHC in the narrow width approximation:

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

with

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

Gluon-fusion process mediated by top quark not viable because of $t\bar{t}$ channel 8 TeV LHC constraint & large contribution to Γ_{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	$\begin{pmatrix} \phi^+ \\ \left(v_w + h + i\phi^0\right)/\sqrt{2} \end{pmatrix}$	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 $A \to hh$ decays), $\lambda_{AH} > 0$
- λ_A and λ_{AH} to stabilize SM vacuum

$$
\begin{aligned}
\mathcal{L} \supset & \left[y_L^L \bar{L}_L H E_R' + y_L^R \bar{L}_R H E_L' + y_Q^L \bar{Q}_L \tilde{H} U_R' + y_Q^R \bar{Q}_R \tilde{H} U_L' + \text{H.c.} \right] \\
& - i y_L A \bar{L} \gamma^5 L - i y_E A \bar{E}' \gamma^5 E' - i y_Q A \bar{Q} \gamma^5 Q - i y_U A \bar{U}' \gamma^5 U' \\
& + m_L \bar{L} L + m_{E'} \bar{E}' E' + m_Q \bar{Q} Q + m_{U'} \bar{U}' U' \\
& - m_A^2 A^2 - \lambda_A A^4 - \lambda_{AH} A^2 |H|^2 \,.
\end{aligned}
$$

LHC diphoton signal

Choice of initial conditions:

$$\sigma\left(pp \to A \to \gamma\gamma\right) = 6 \text{ fb}\,,$$
$$y_E = y_U = -y_L = -y_Q \equiv y_v\,,$$
$$m_D = m_T = 700 \text{ GeV}\,,\ m_{T'} = 705 \text{ GeV}\,,$$

Two DM scenarios:

Scenario	m_N (GeV)	$m_{\chi_1^\pm}$ (GeV)	$m_{\chi_2^\pm}$ (GeV)	y_v
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

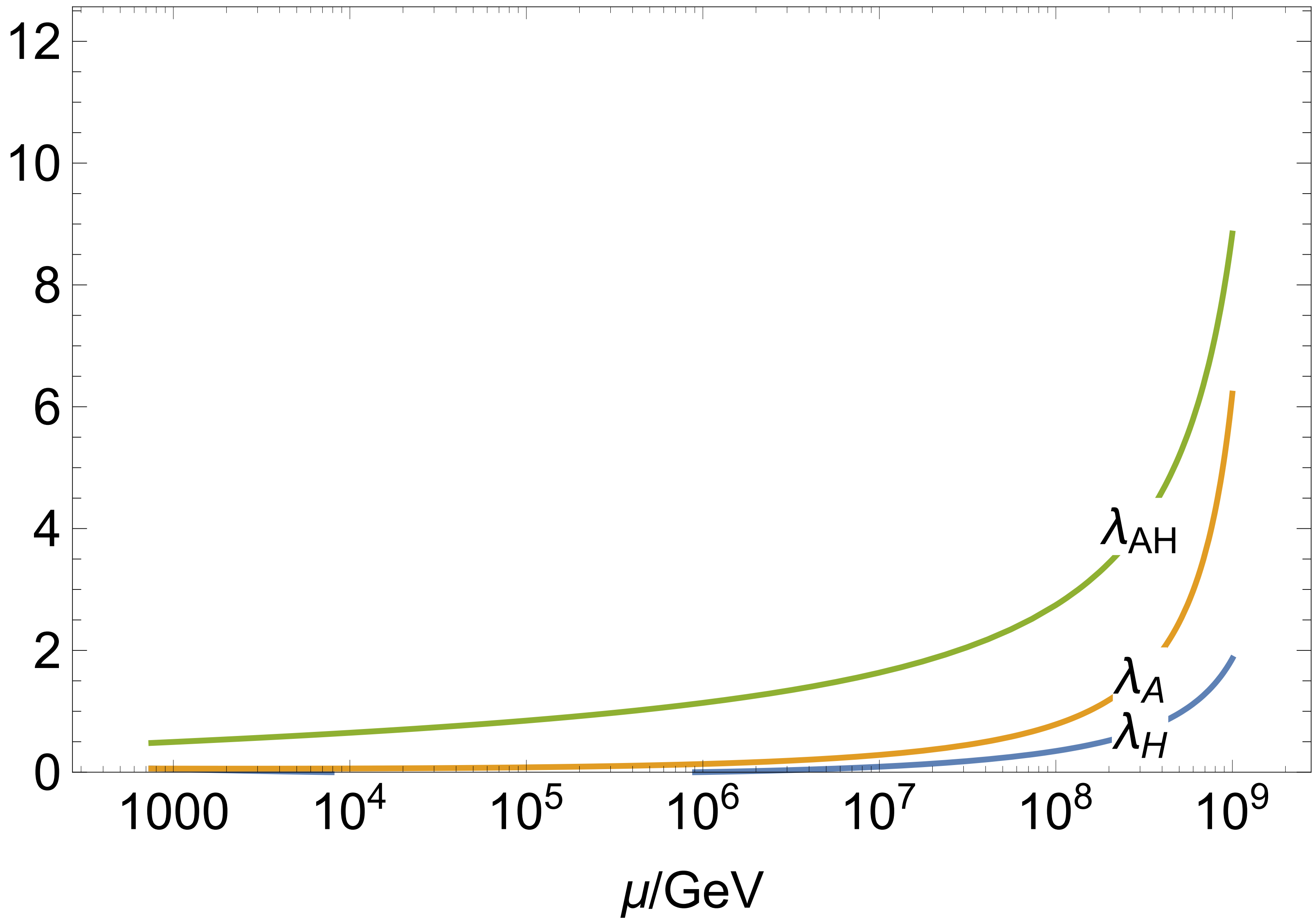
Complementary channels at 8 TeV LHC: prediction at 1 loop for the two scenarios satisfies experimental upper bound for each channel

	$\sigma_{\rm I}^{\rm th}({\rm fb})$	$\sigma_{\rm II}^{\rm th}({\rm fb})$	$\sigma_{\rm max}^{\rm exp}({\rm fb})$
jj	38	199	2.5×10^3
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 λ_A and λ_{AH} to maximize Λ_{UV}, defined as $\lambda_{AH}(\Lambda_{\text{UV}}) = 4\pi$, and avoid $\lambda_H(\mu) < 0$:

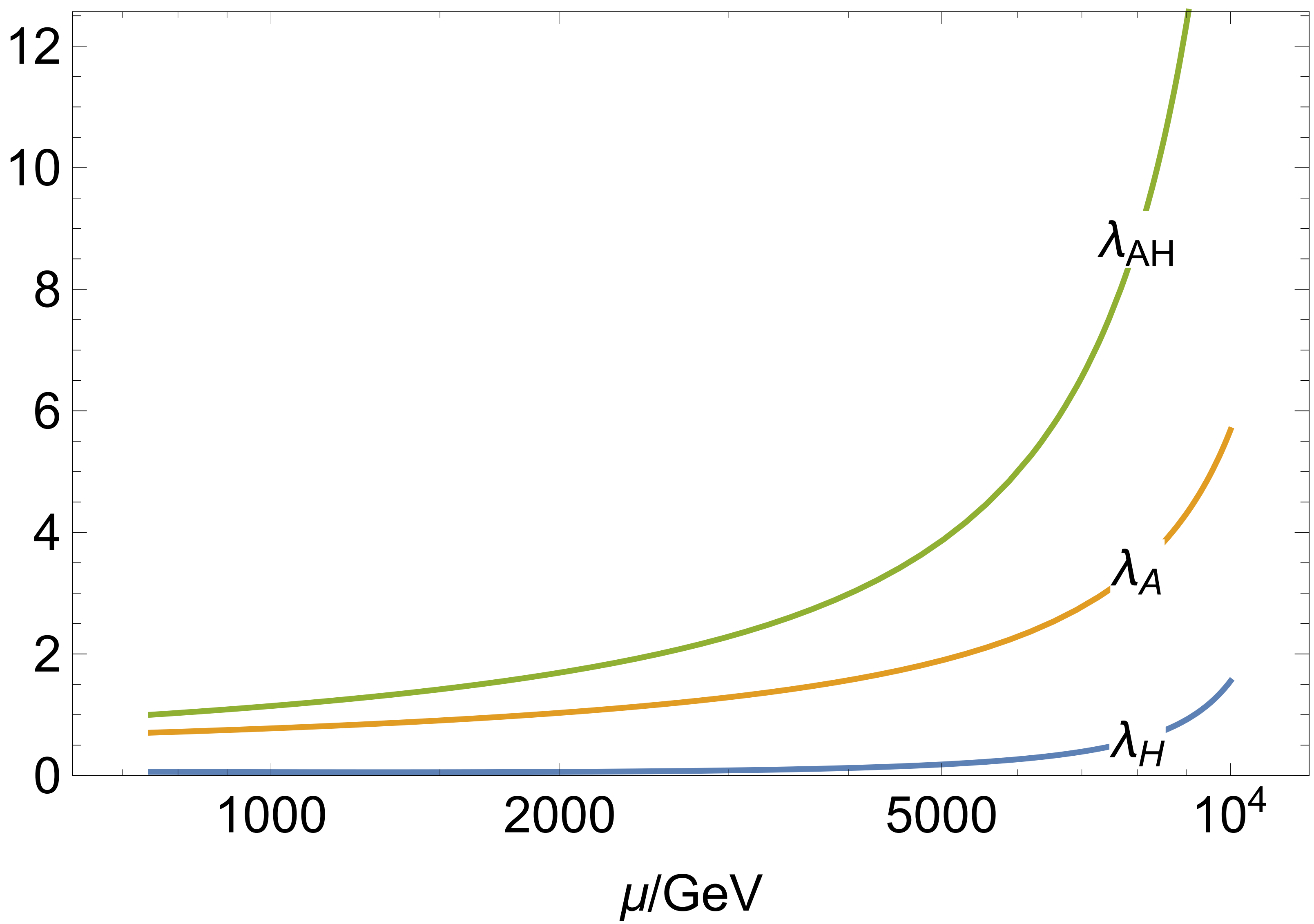


SD et al.'16

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

UV cutoff scale

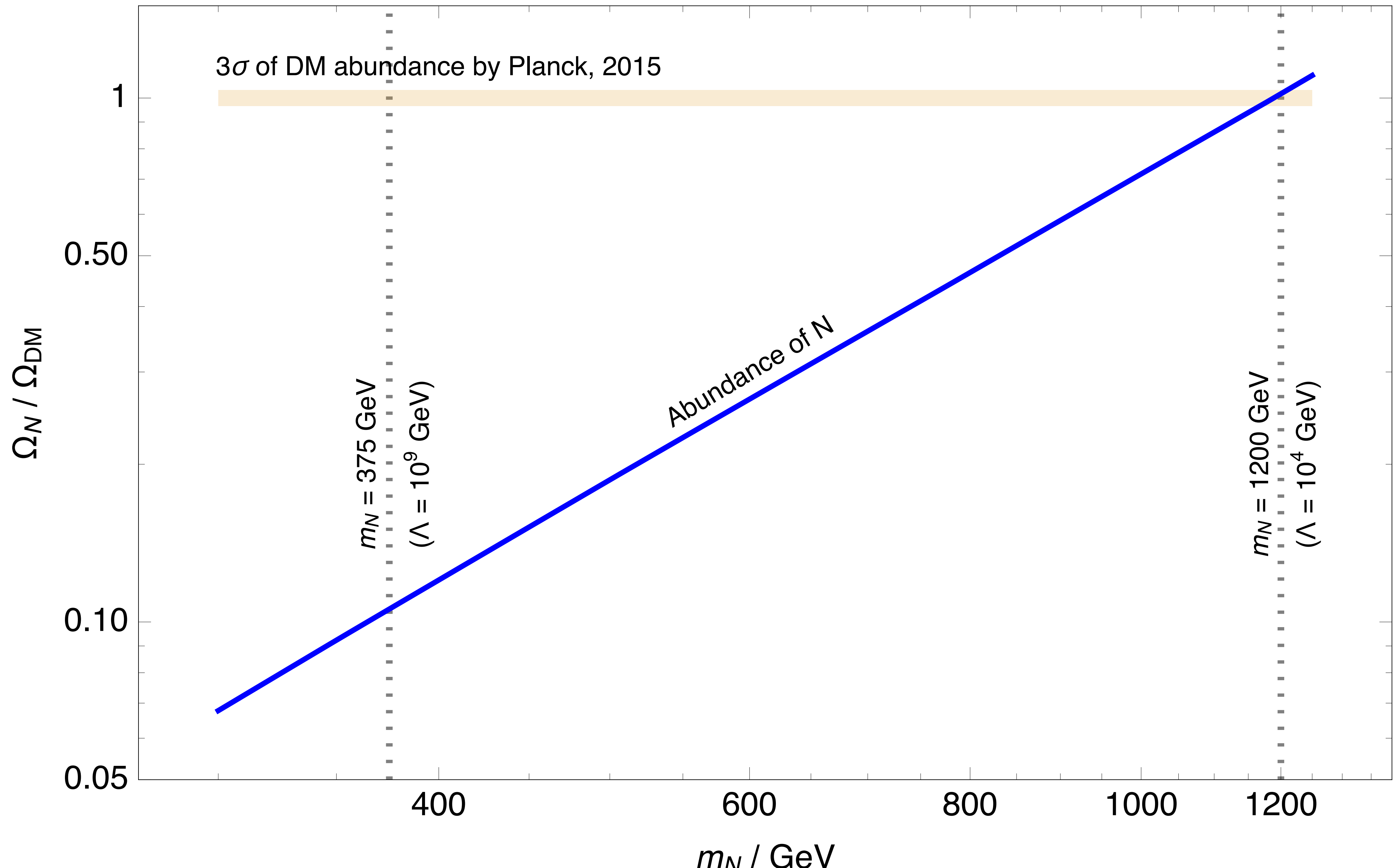
Run SM couplings from m_t to 750 GeV within SM, use as initial conditions, fix λ_A and λ_{AH} to maximize $\Lambda_{\rm UV}$, defined as $\lambda_{AH}\left(\Lambda_{\rm UV}\right) = 4\pi$, and avoid $\lambda_H(\mu) < 0$:



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

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:

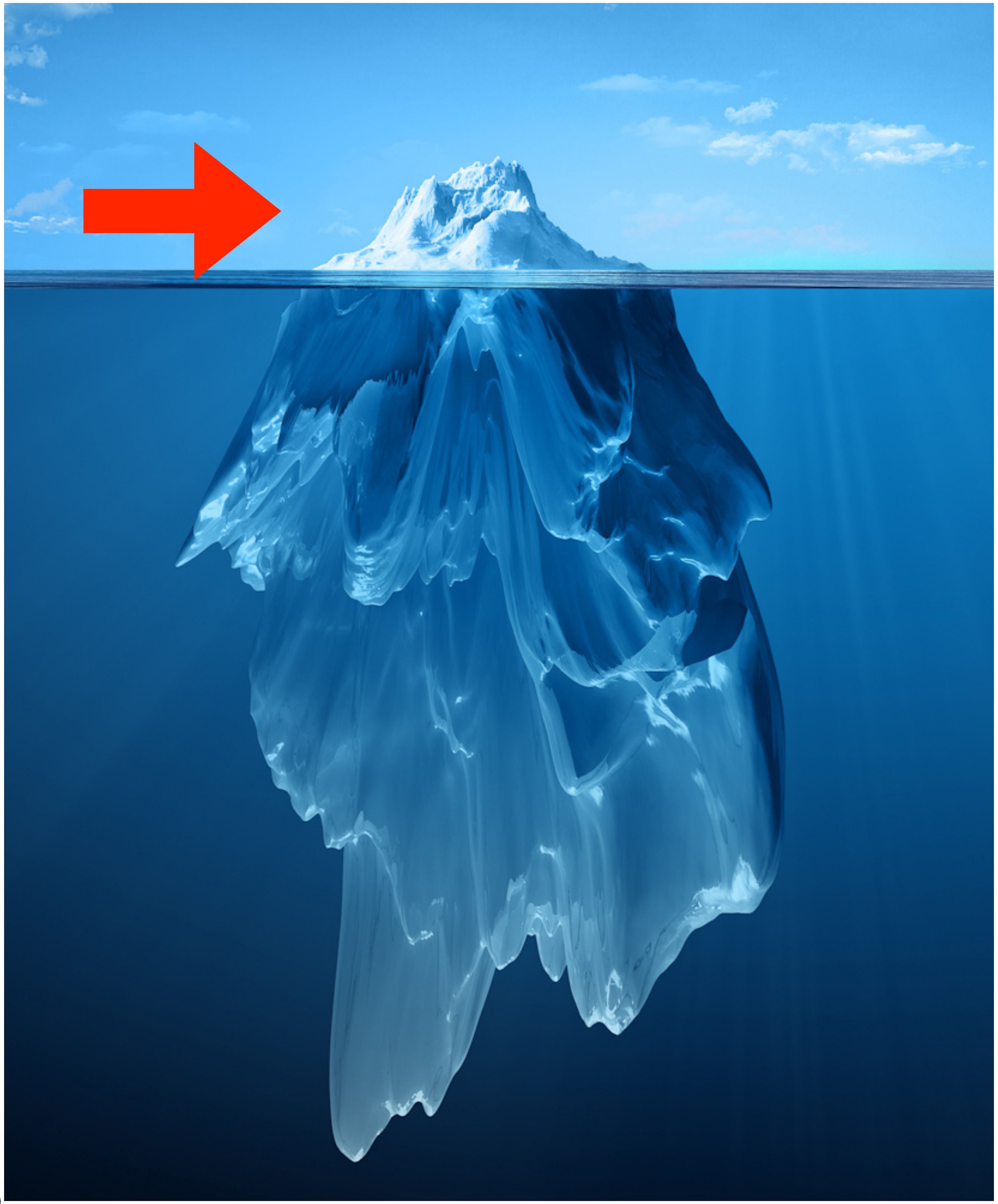


Conclusions

- 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

750 GeV Summary

750 GeV Summary

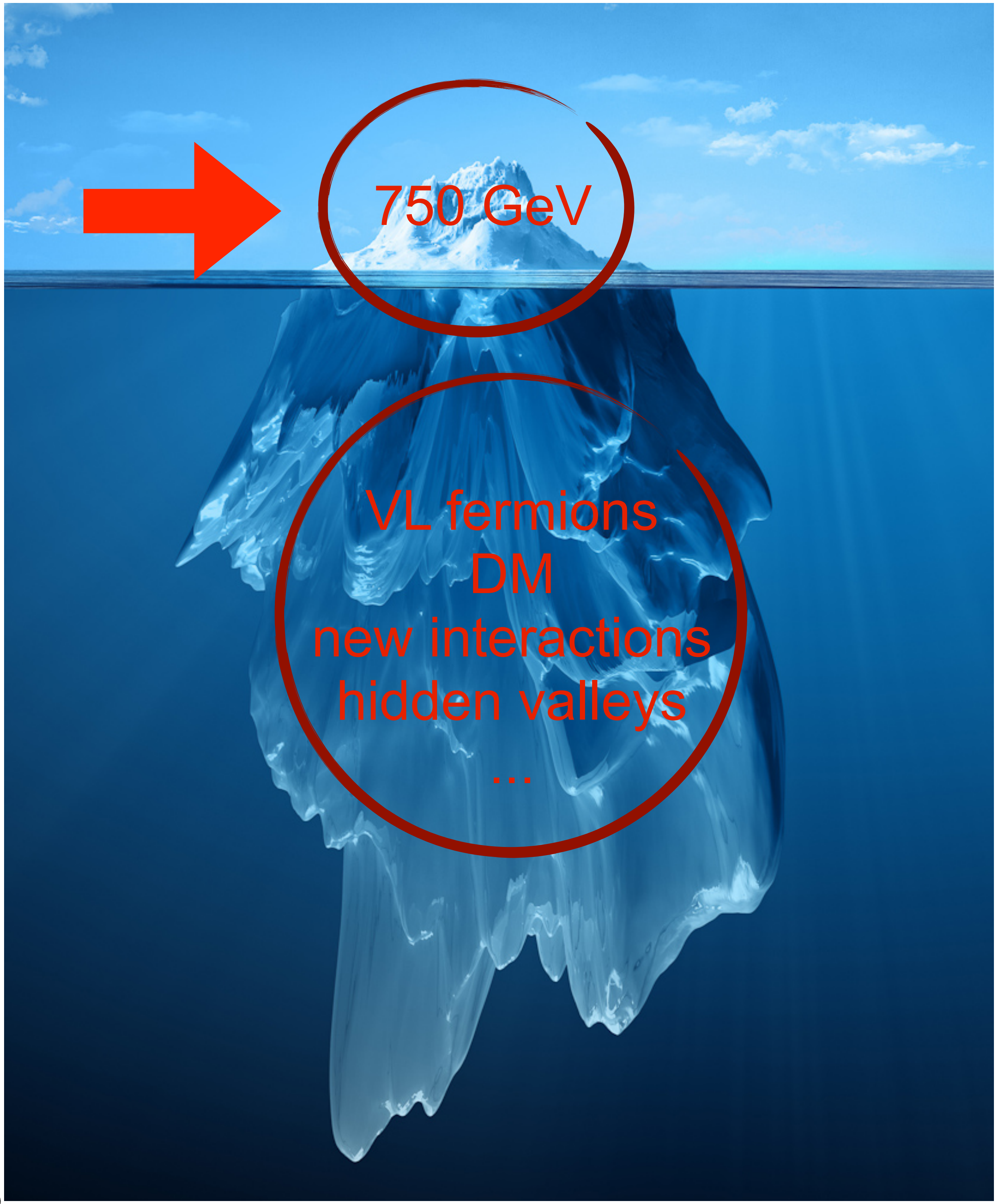


750 GeV Summary

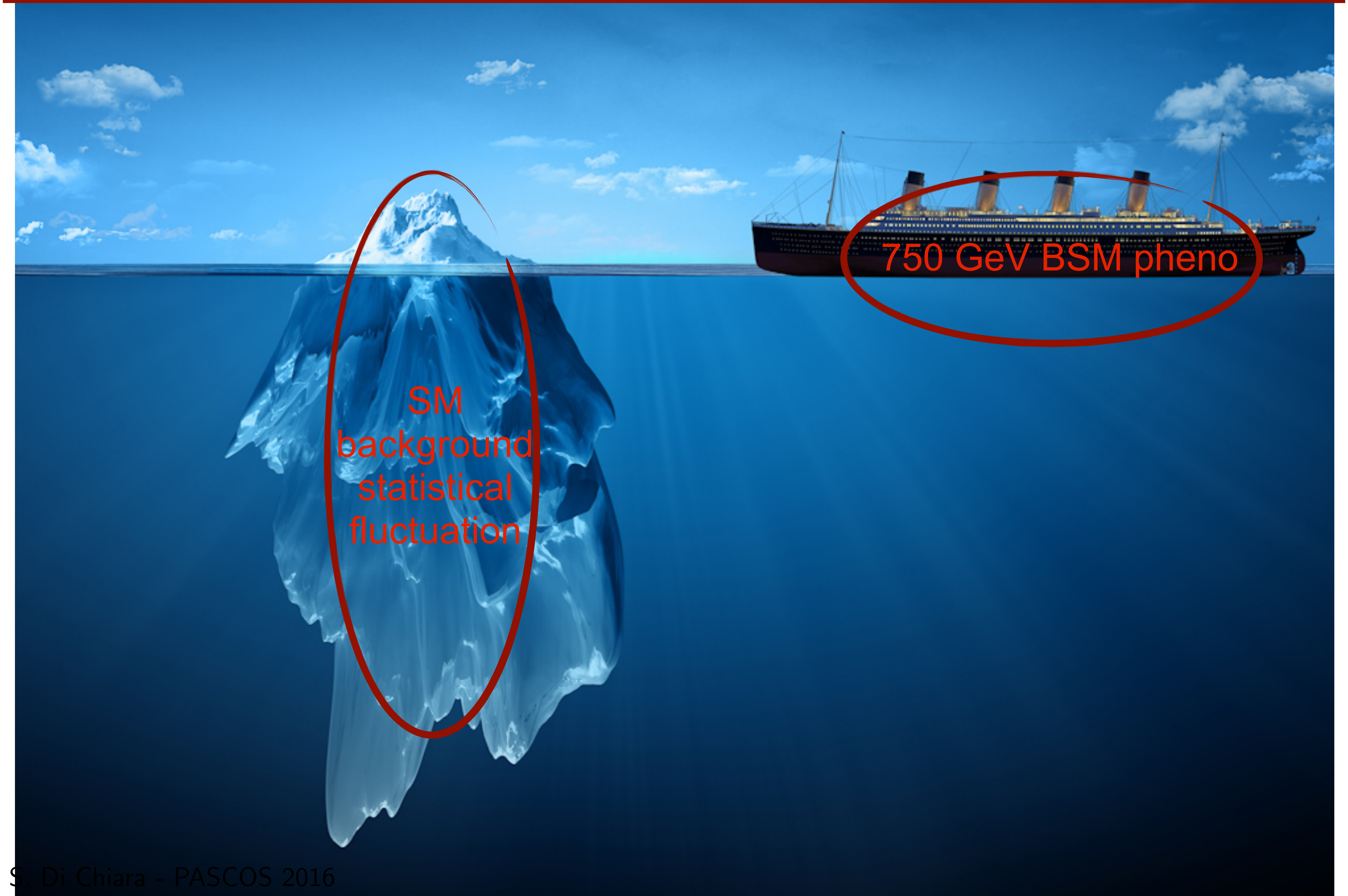
750 GeV Summary

750 GeV Summary

750 GeV Summary



750 GeV Summary

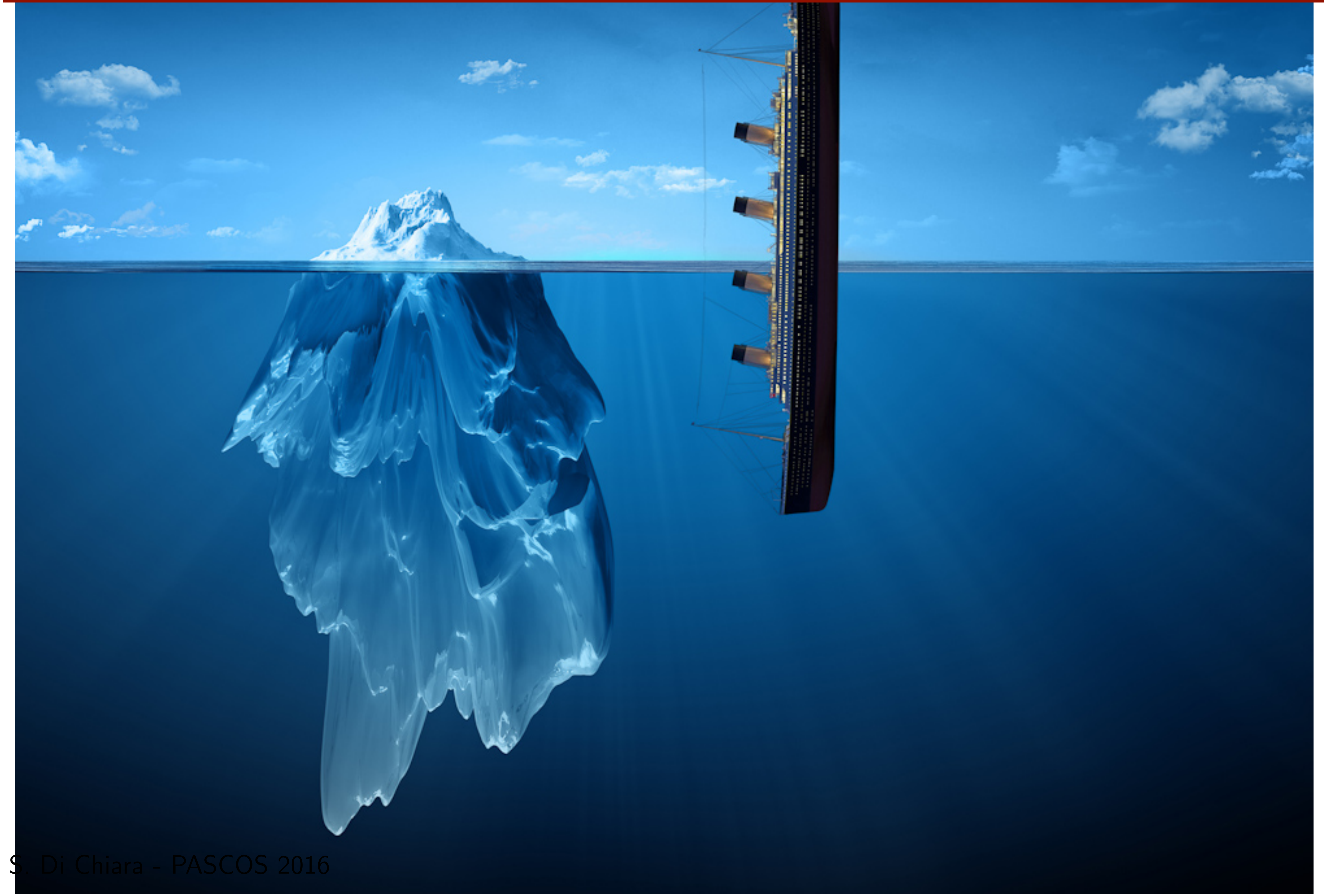


750 GeV Summary

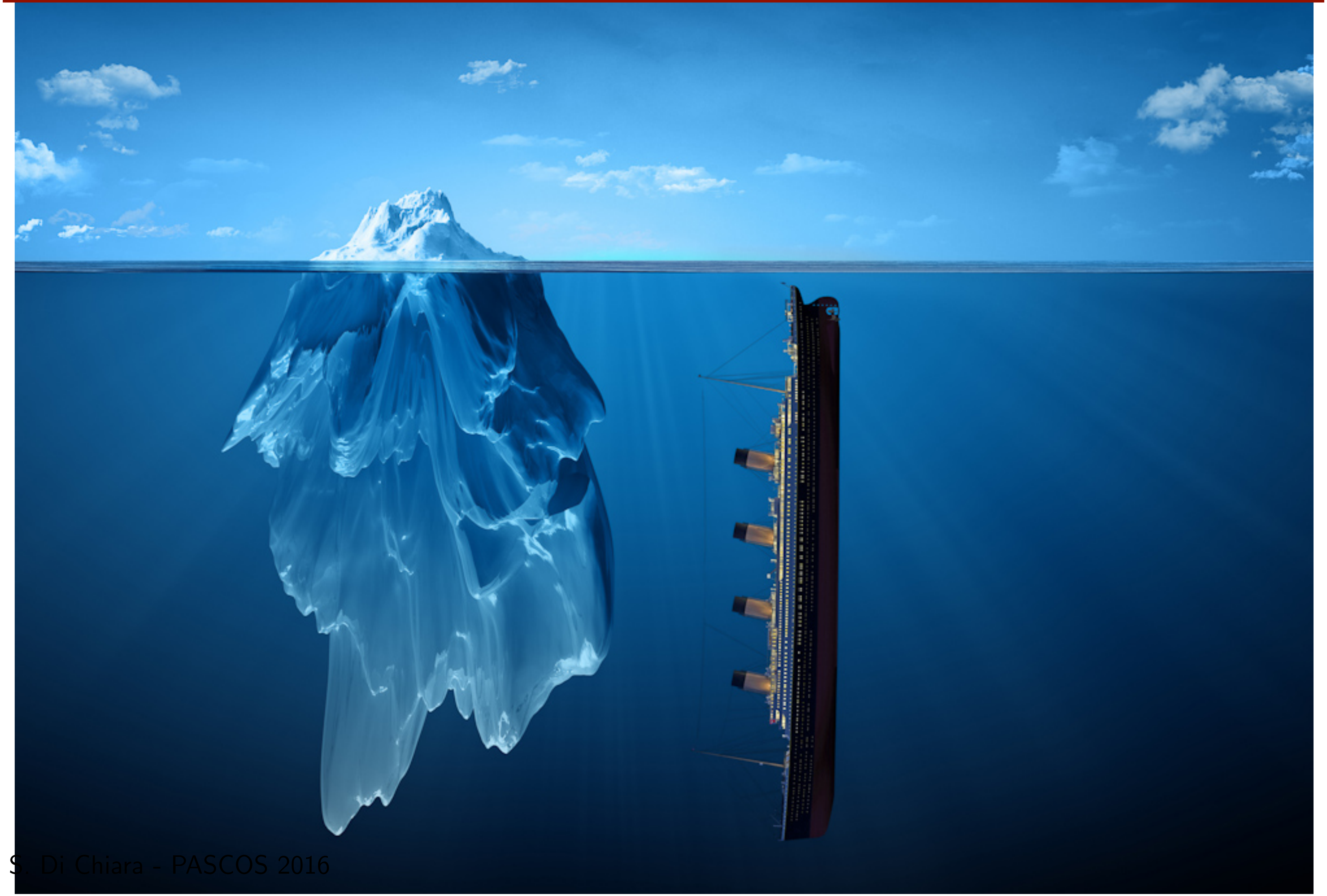
750 GeV Summary

750 GeV Summary

750 GeV Summary



750 GeV Summary

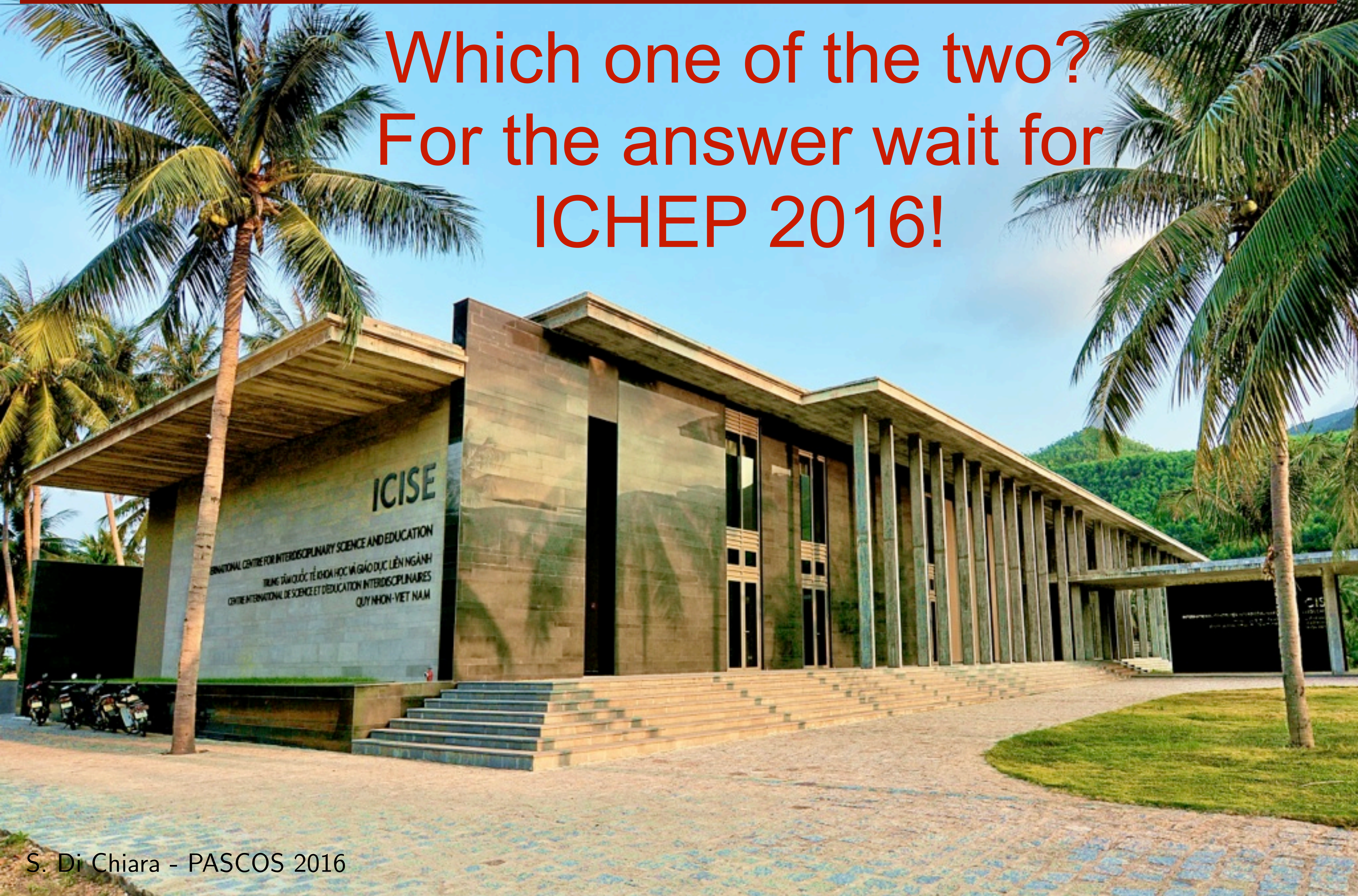


750 GeV Summary

750 GeV Summary

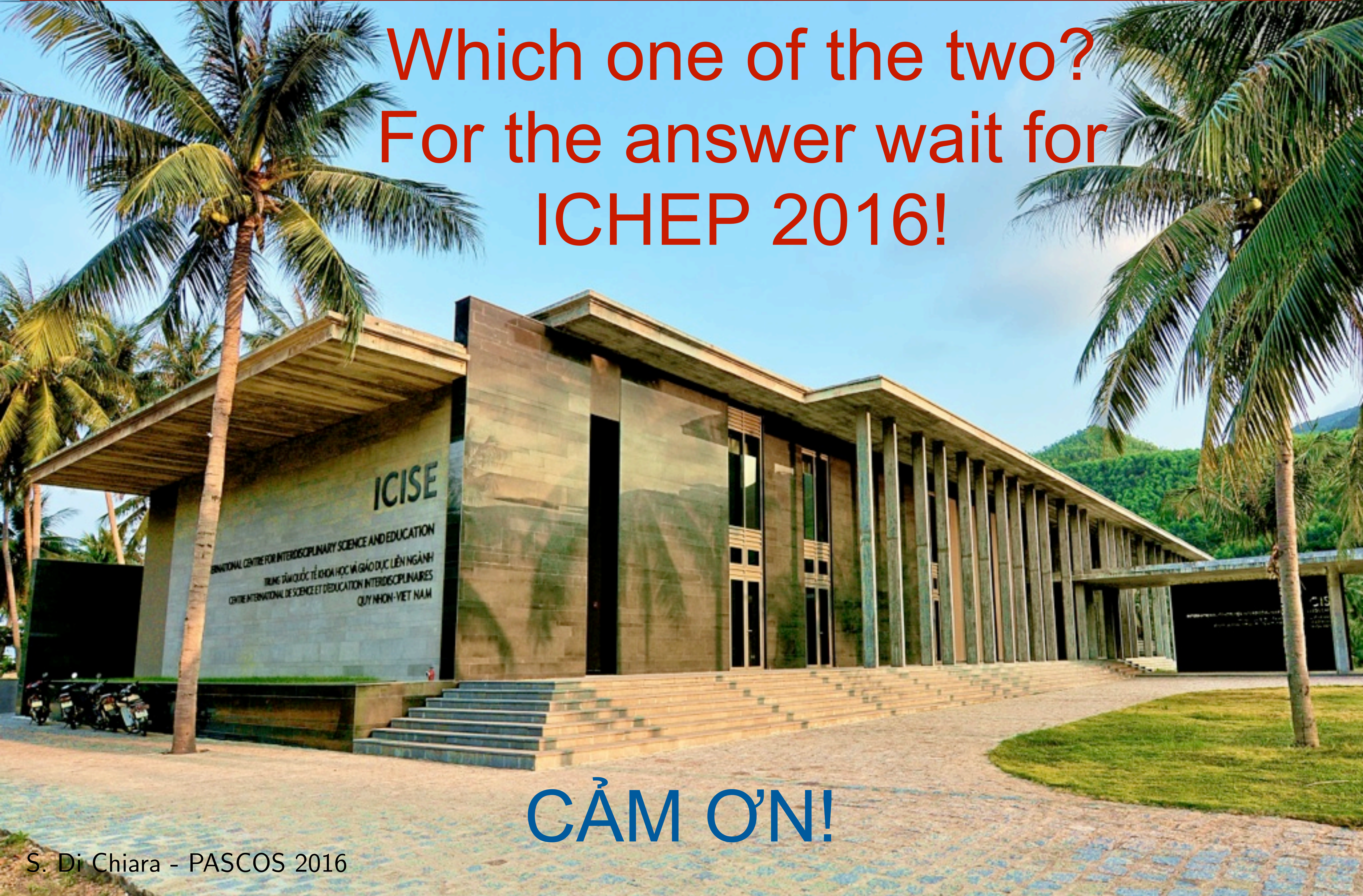
750 GeV Summary

Which one of the two?
For the answer wait for
ICHEP 2016!



750 GeV Summary

Which one of the two?
For the answer wait for
ICHEP 2016!



CẢM ƠN!

Backup Slides

Decay width to diphoton

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

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

$$\begin{aligned} F_V &= \left[2 + 3\tau_V + 3\tau_V \left(2 - \tau_V\right) f(\tau_V)\right] a_V \, , \\ F_f &= -2\tau_f \left[1 + \left(1 - \tau_f\right) f(\tau_f)\right] a_f \, , \\ F_S &= \tau_S \left[1 - \tau_S f(\tau_S)\right] a_S , \quad \tau_i = \frac{4m_i^2}{m_H^2} \, , \end{aligned}$$

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: $F_V = 7$, $F_f = -\frac{4}{3}$, $F_S = -\frac{1}{3}$.