Electroweak Symmetry Breaking, Dark Matter and the Inert Doublet Model

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Based on work done in collaboration with Thomas Hambye
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arXiv:0707.0633

Evidences for Dark Matter

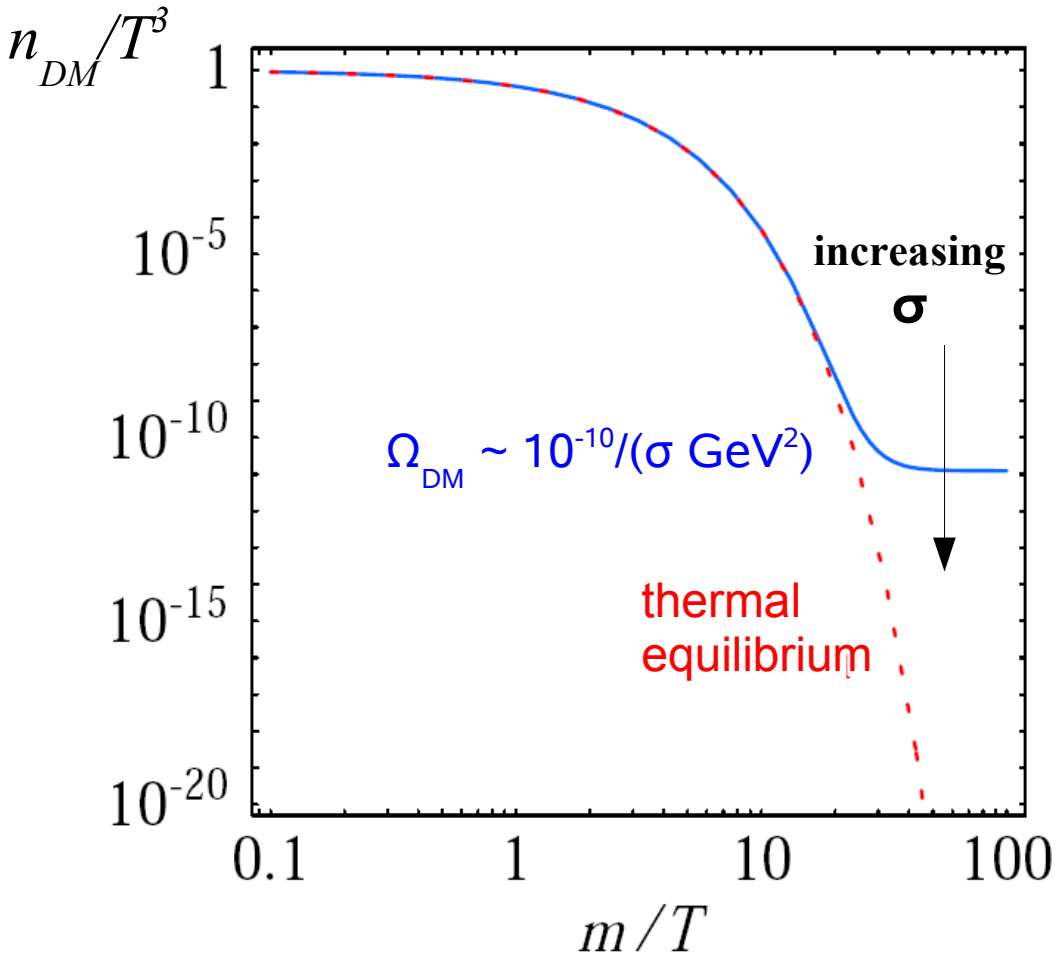
- Large scale structures formation ★★★
- Clusters of galaxies ★★
- Rotation curve of spiral galaxies ★

Observations concur to indicate that $\Omega_{DM} \sim 0.25$

(i.e. about 5 times the contribution of baryons)

The Weakly Interacting Massive Particle paradigm (WIMP)

Dark Matter stable but $\sigma(\text{DM DM} \rightarrow \text{SM particles}) \neq 0$



$\Omega_{DM} \sim 0.25$

→ $\sigma \sim$ pb

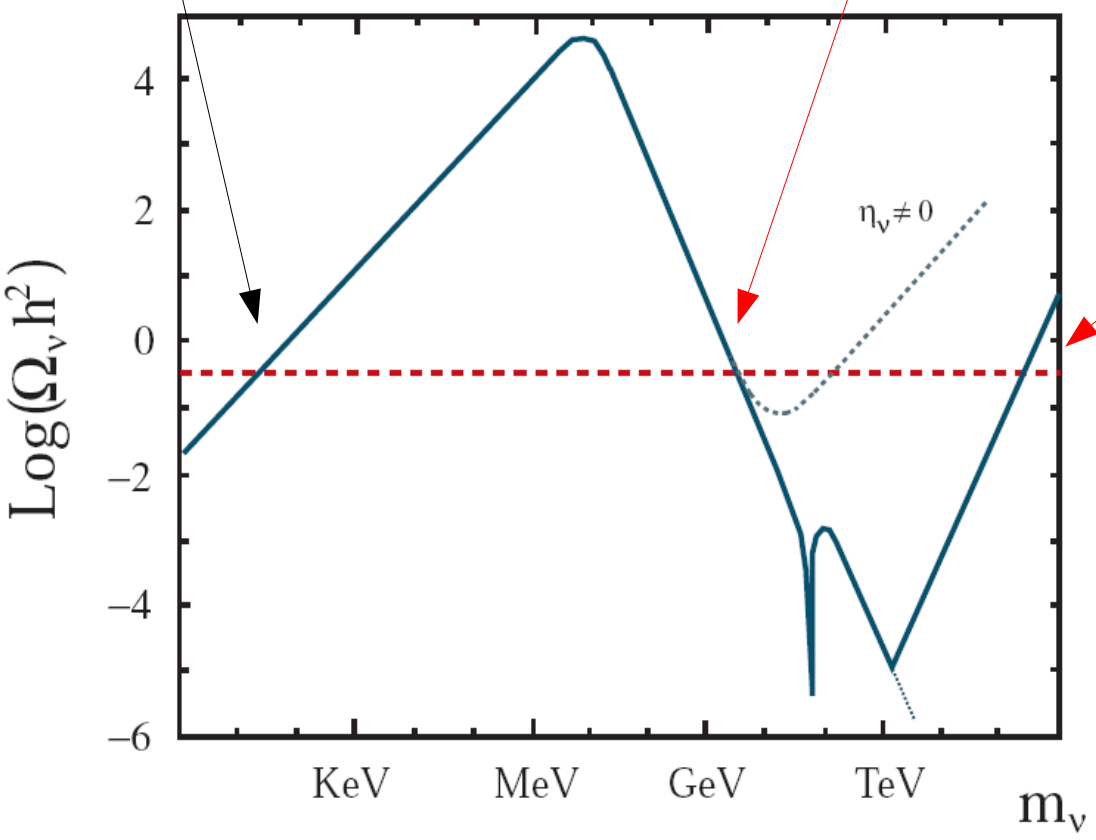
Typical of weak interactions

A weak cross section but a variety of mass scales...

$M_{DM} \sim 28$ eV Cowsik-McClelland bound

$M_{DM} \sim 1$ GeV Lee-Weinberg bound

$M_{DM} \sim 100$ TeV
Griest-Kamionkosvki
unitarity bound



From K. Olive (TASI lectures on DM)

Can we relate further dark matter to the electroweak scale ?

The MSSM and the Neutralino Spin 1/2

M_{SUSY} and μ ⟷ $\langle v \rangle$ and M_{LSP}

UED and KK dark matter Spin 1

M_{SM} and $1/R$

The Inert Doublet Model

• Standard Model with 2 Brout-Englert-Higgs doublets and Z_2 symmetry

$$H_1 \to H_1 \qquad H_2 \to -H_2$$

→ All SM fields are even (*e.g.* no FCNC)

• Vacuum

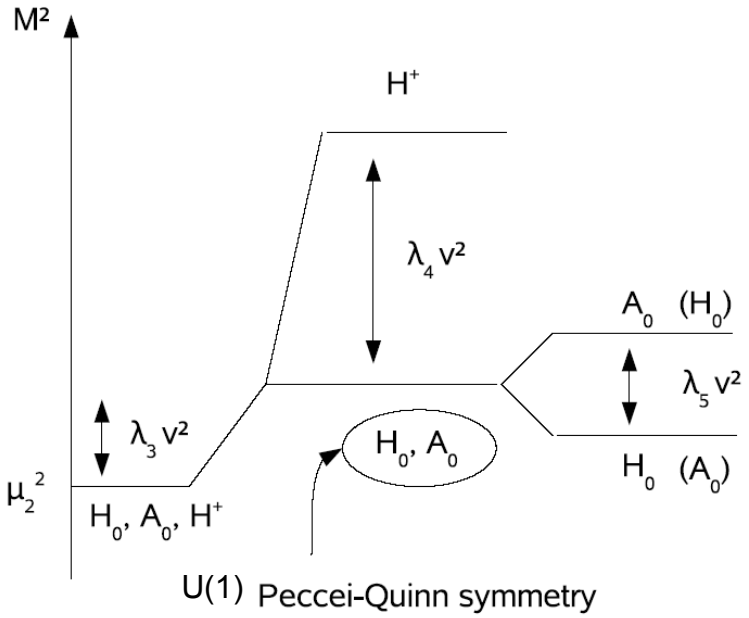
$$\langle H_1 \rangle = \frac{v}{\sqrt{2}} \qquad \langle H_2 \rangle = 0 \quad \to \quad H_0 \; A_0 \; \& \; H^+$$

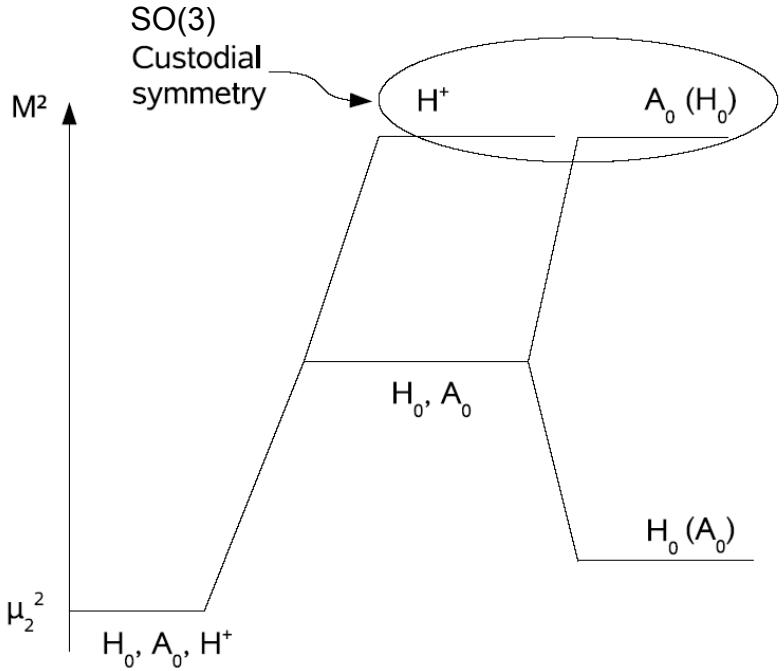
→ H_0 stable neutral scalar = Spin 0 dark matter

Deshpande & Ma (1978); Ma (2006); Barbieri, Hall & Rychkov (2006)

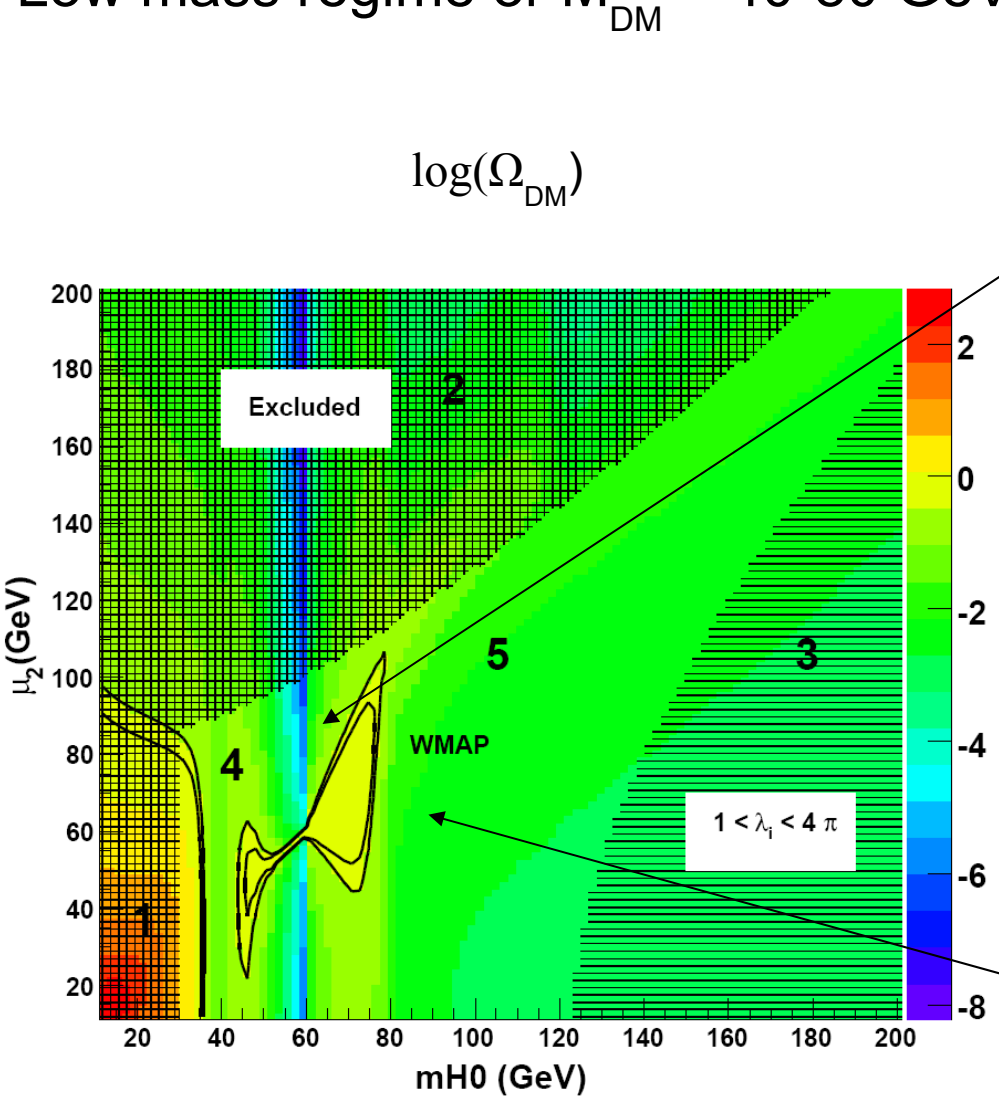
$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4$$

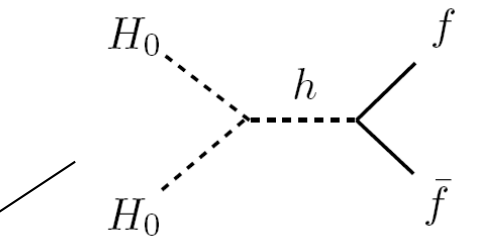
$$+ \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + h.c.\right]$$

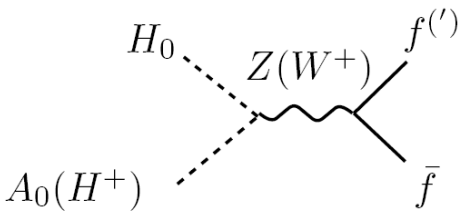




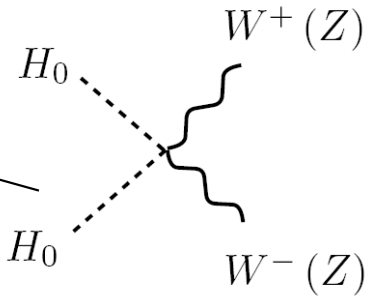
Low mass regime or M_{DM} ~ 40-80 GeV





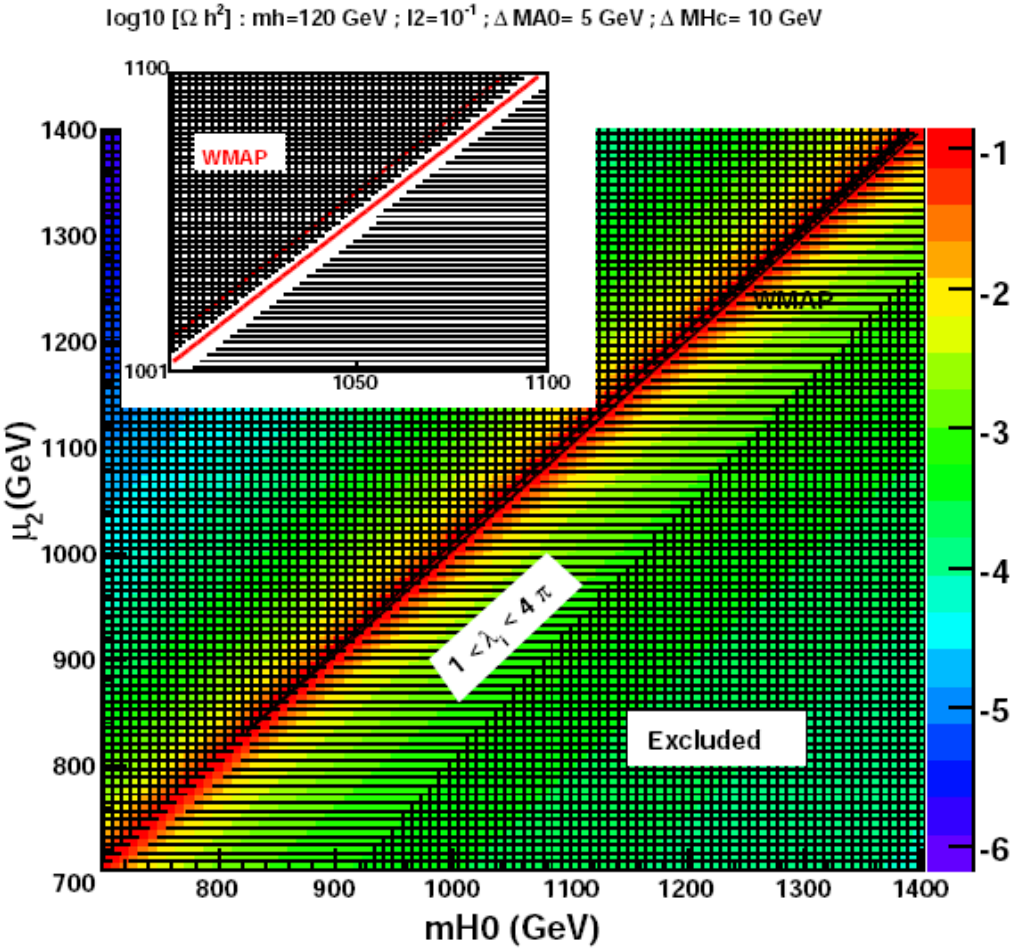


Coannihilation effects

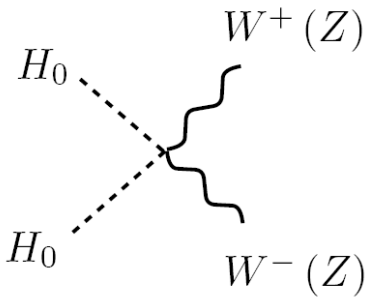


Barbieri, Hall & Rychkov (2006); Lopez Honorez, Oliver, Nezri &Tygtat (2006)

High mass regime or M_{DM} ~ 800 GeV up to a few TeV



Essentially



(+ related diagrams)

Cirelli, Fornengo & Strumia (2006); Lopez Honorez, Oliver, Nezri &Tygtat (2006)

Can we relate further M_{H0} to the electroweak scale ?

If $\mu_2^2 << \upsilon^2 = -\mu_1^2/\lambda$ then $M_{DM}^2 \sim \lambda' \upsilon^2$

→ only low mass solutions i.e. M_{DM} ~ 40-80 GeV

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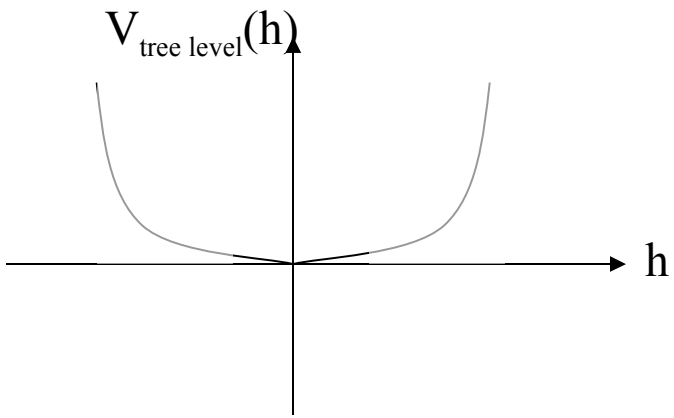
Can we go further ?

What if both $|\mu_1^2|$ and $|\mu_2^2| << \upsilon^2$?

Radiative Electroweak Symmetry Breaking



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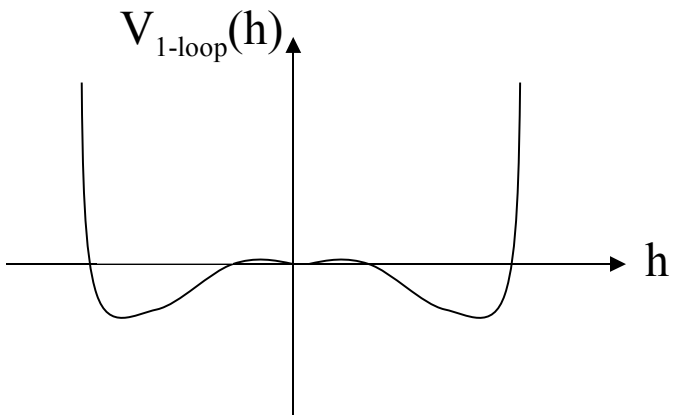

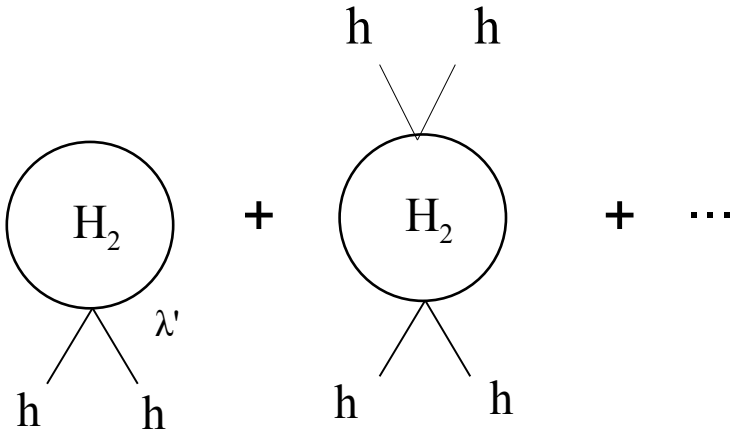

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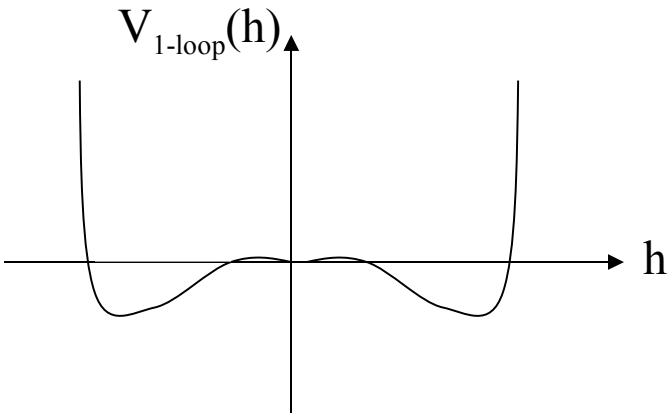
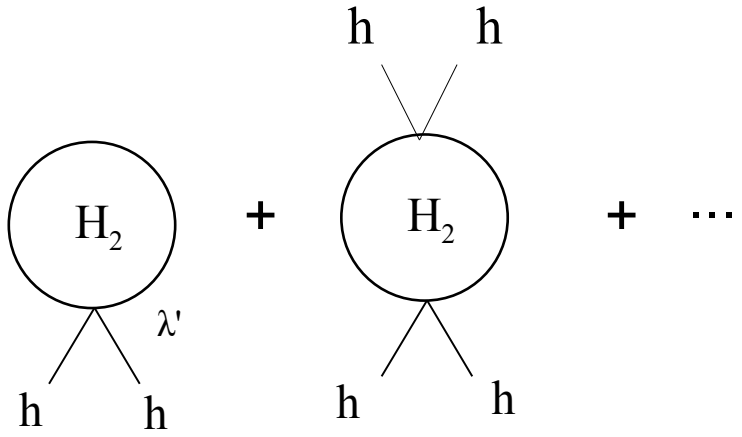
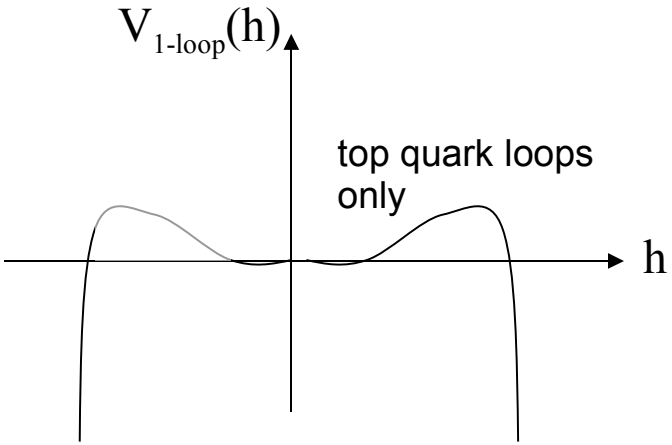




Standard Model radiative corrections dominated by top quark loops



- Dark matter loops have the right sign to break the EW symmetry
- Need relatively large quartics

$\lambda' \sim 6\, g_t^2$ but still perturbative

Phenomenology of EW symmetry breaking in the IDM

- Radiative EWSB requires large quartic couplings

→ A_0 and/or H^+ heavy, above ~ 350 GeV

- DM requires a light H_0 ~ 60-70 GeV

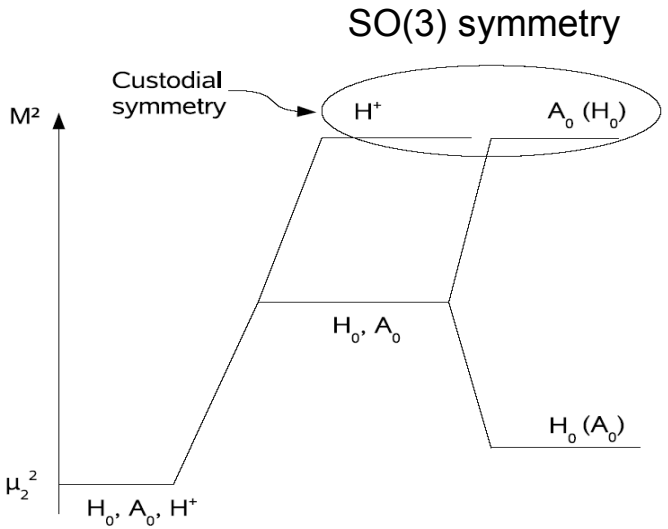
→ Large mass splittings within the Inert Doublet

LEP constraints on ρ (or ΔT) parameter !

$$\alpha T = \Pi_{WW}/M_W^2 - \Pi_{ZZ}/M_Z^2$$

Sensitive to mass splittings
but $\alpha T = 0$ if $M_{A_0} = M_{H^+}$ or $M_{H_0} = M_{H^+}$

→ Natural in IDM



Extreme instances with $\mu_1 = \mu_2 = 0$ (Coleman-Weinberg solutions)

Large couplings

Custodial symmetry

	λ_1	λ_2	λ_3	λ_4	λ_5	M_h	M_{H_0}	M_{A_0}	$M_{H^\pm}$	h_{BR}	W_{BR}
I	-0.11	0	5.4	-2.8	-2.8	120	12	405	405	100%	0%
I	-0.11	-2	5.4	-2.7	-2.7	120	43	395	395	100%	0%
I	-0.11	-3	5.4	-2.6	-2.6	120	72	390	390	94%	6 %
I	-0.30	0	7.6	-4.1	-4.1	180	12	495	495	100%	0 %
I	-0.30	-2.5	7.6	-3.8	-3.8	180	64	470	470	100%	0 %
II	-0.18	-3	-0.003	4.6	-4.7	120	39	500	55	100%	0 %
II	-0.29	-5	-0.07	5.5	-5.53	150	54	535	63	0%	100 %

TABLE I: Instances of parameters with WMAP DM abundance. Also given are the relative contribution of Higgs mediated annihilation (h_{BR}) and gauge processes (W_{BR}).

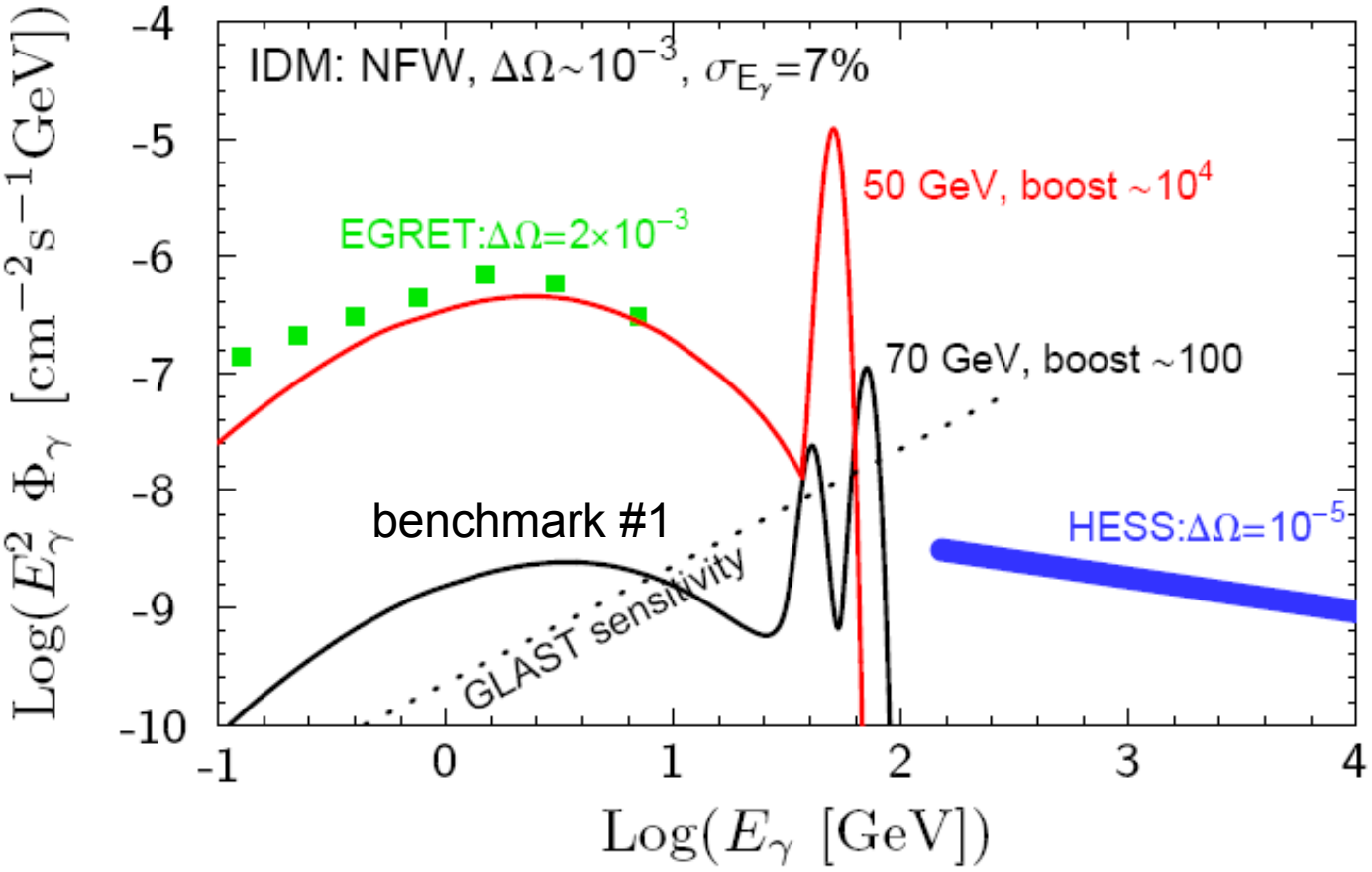
Thomas Hambye & M.T.

Astroparticle prospects

DM candidate	I. Ωh^2	II. Cold	III. Neutral	IV. BBN	V. Stars	VI. Self	VII. Direct	VIII. γ-rays	IX. Astro	X. Probed	Result
SM Neutrinos	×	×	✓	✓	✓	✓	✓	–	–	✓	×
Sterile Neutrinos	∼	∼	✓	✓	✓	✓	✓	✓	✓!	✓	∼
Neutralino	✓	✓	✓	✓	✓	✓	✓!	✓!	✓!	✓	✓
Gravitino	✓	✓	✓	∼	✓	✓	✓	✓	✓	✓	∼
Gravitino (broken R-parity)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sneutrino $\tilde{\nu}_L$	∼	✓	✓	✓	✓	✓	×	✓!	✓!	✓	×
Sneutrino $\tilde{\nu}_R$	✓	✓	✓	✓	✓	✓	✓!	✓!	✓!	✓	✓
Axino	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SUSY Q-balls	✓	✓	✓	✓	∼	–	✓!	✓	✓	✓	∼
B^1 UED	✓	✓	✓	✓	✓	✓	✓!	✓!	✓!	✓	✓
First level graviton UED	✓	✓	✓	✓	✓	✓	✓	×	×	✓	×[a]
Axion	✓	✓	✓	✓	✓	✓	✓!	✓	✓	✓	✓
Heavy photon (Little Higgs)	✓	✓	✓	✓	✓	✓	✓	✓!	✓!	✓	✓
Inert Higgs model	✓	✓	✓	✓	✓	✓	✓	✓!	–	✓	✓
Champs	✓	✓	×	✓	×	–	–	–	–	✓	×
Wimpzillas	✓	✓	✓	✓	✓	✓	✓	✓	✓	∼	∼

Table from « Dark Matter : a ten-point test » by Bertone, Masiero & Taoso, arXiv:0711.4996

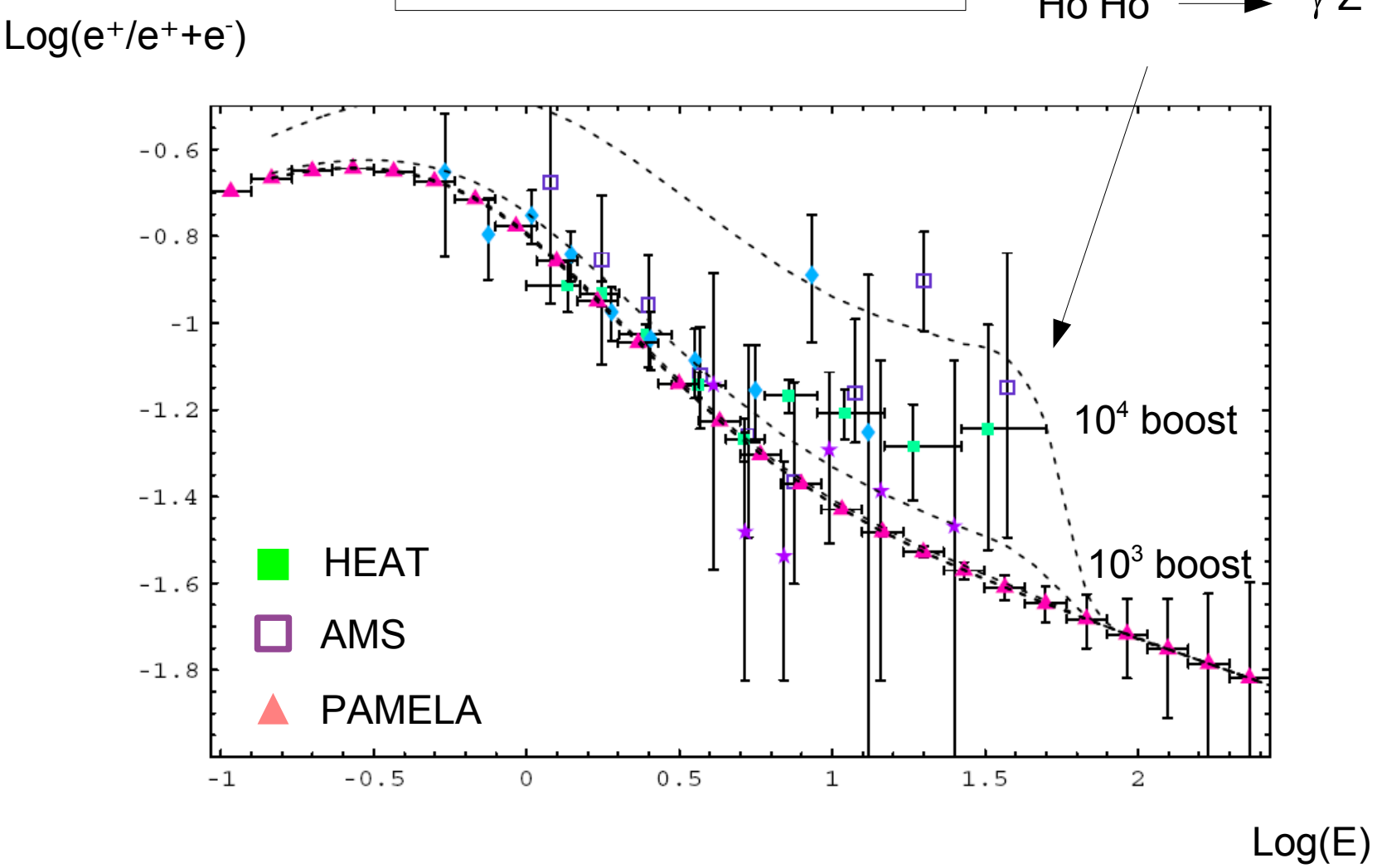
Other large one-loop effects: annihilation in γγ and γ Z



Gustafson, Lundrstrom, Bergstrom and Edsjo

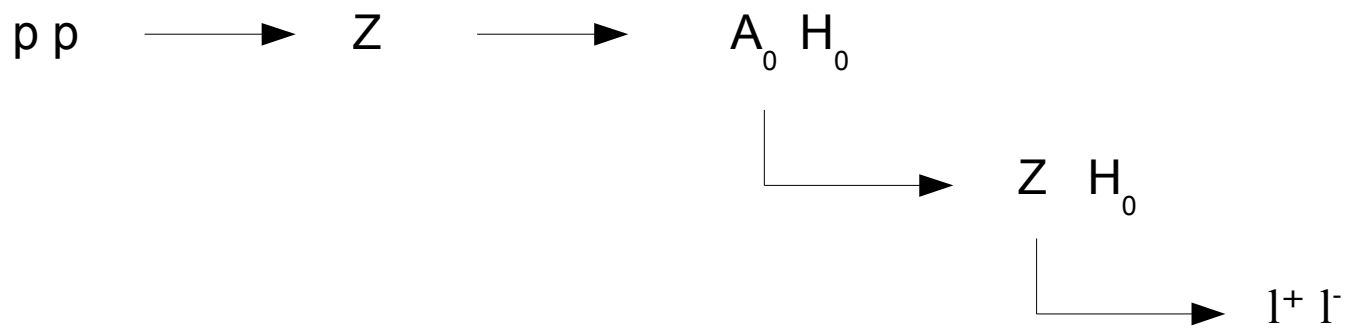
Positron flux for benchmark #1

Ho Ho → γ Z



Nezri, Vertongen & T.: work in progress

LHC prospects ?



SM background for pp $\longrightarrow$ $l^+ l^- + \not{E}_T$?

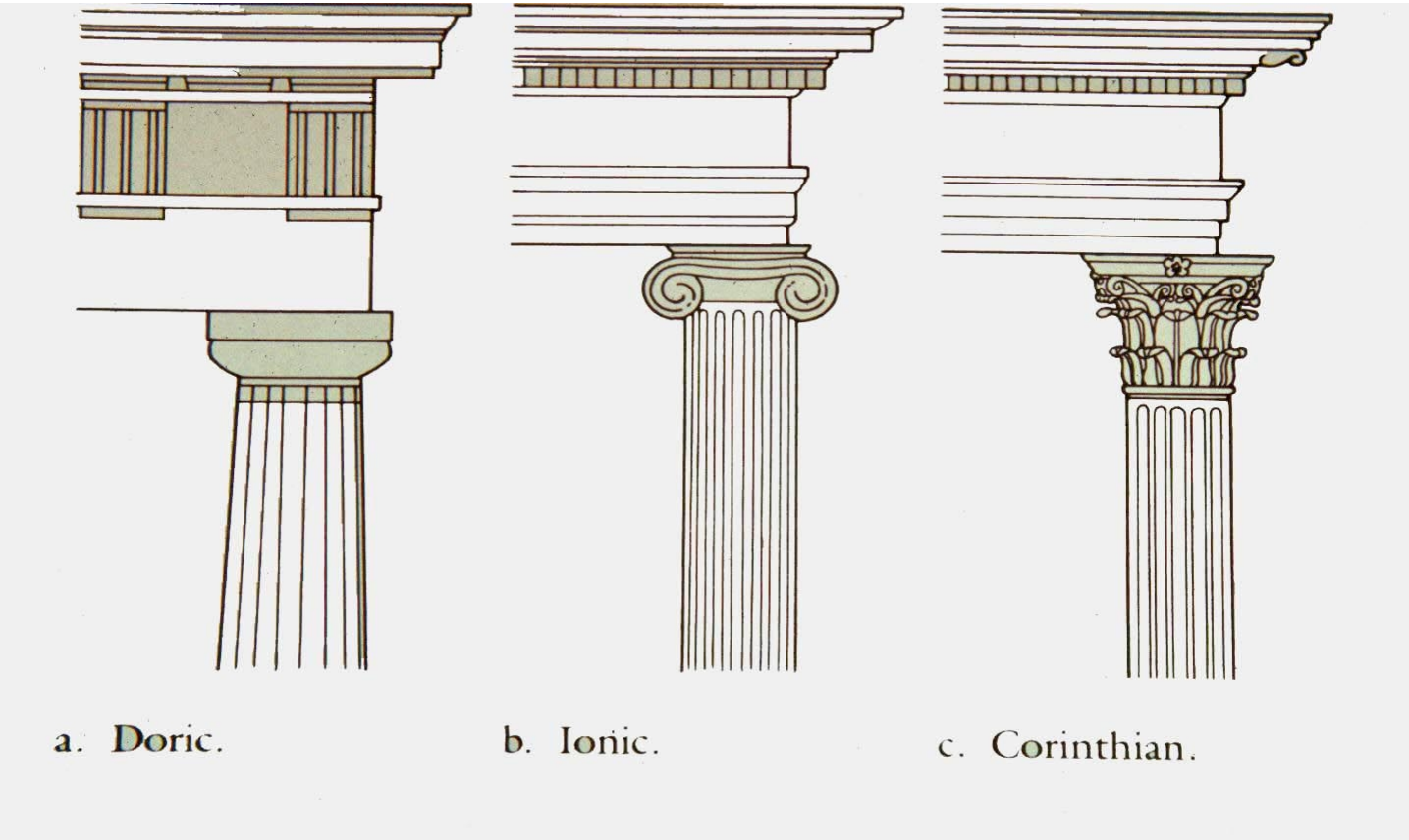
p p $\longrightarrow$ ZZ/γ with Z into neutrinos and Z/γ $\longrightarrow$ $l^+ l^-$

$\longrightarrow$ $W^+ W^-$ with W $\longrightarrow$ $l\,\nu$

Observation at 5 σ claimed to be possible with 300 fb^{-1}

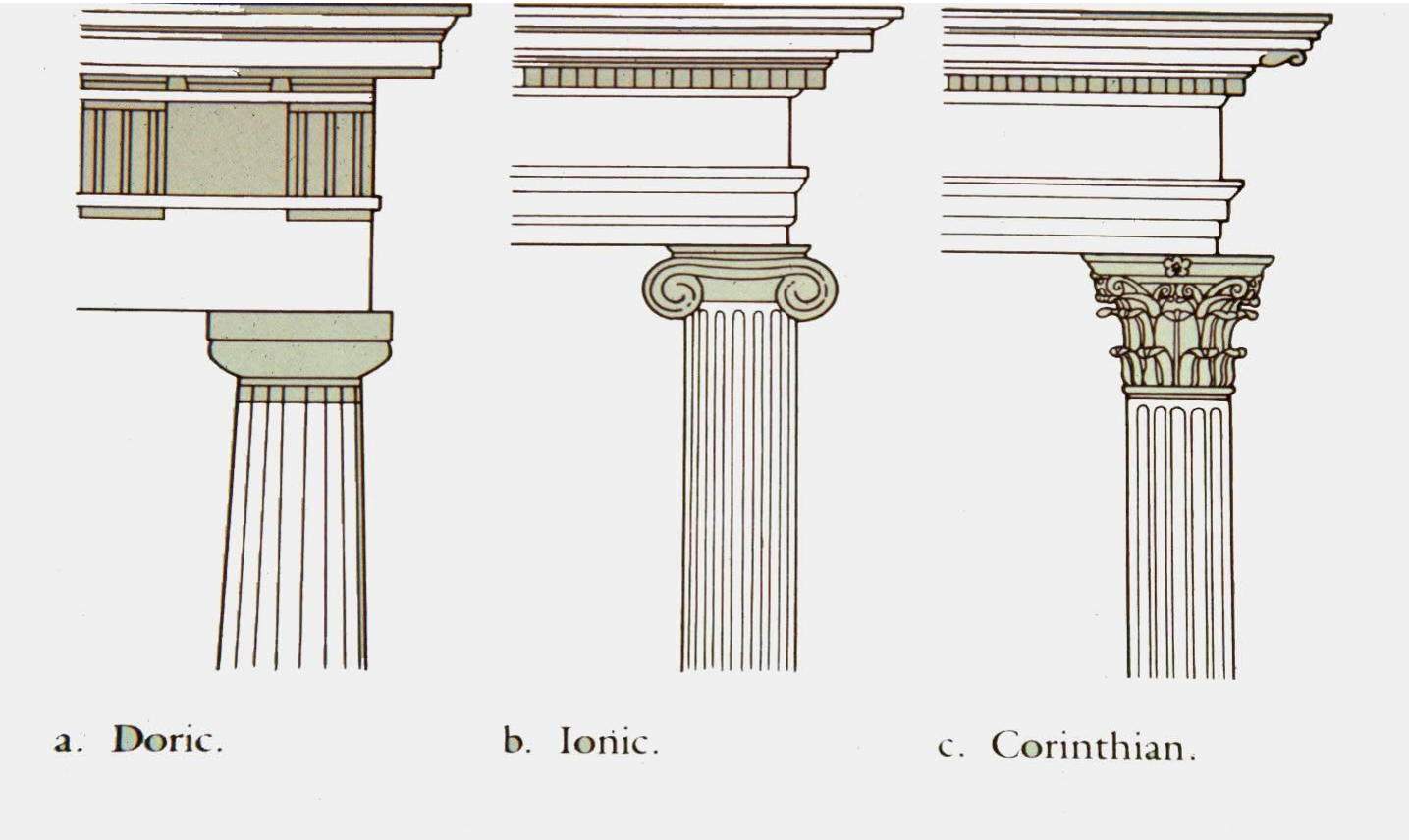
Cao, Ma & Rajasekaran (2007)

A new archetype?



a. Doric. b. Ionic. c. Corinthian.

A new archetype?



Spin 0	Spin ½	Spin 1
Inert Doublet	Neutralino	Heavy photon