Introdução à Física de Partículas

Introduction to particle Physics

(4/4)

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Escola de Professores no CERN em Língua Portuguesa 2019

CERN Portuguese Language Teachers Programme 2019

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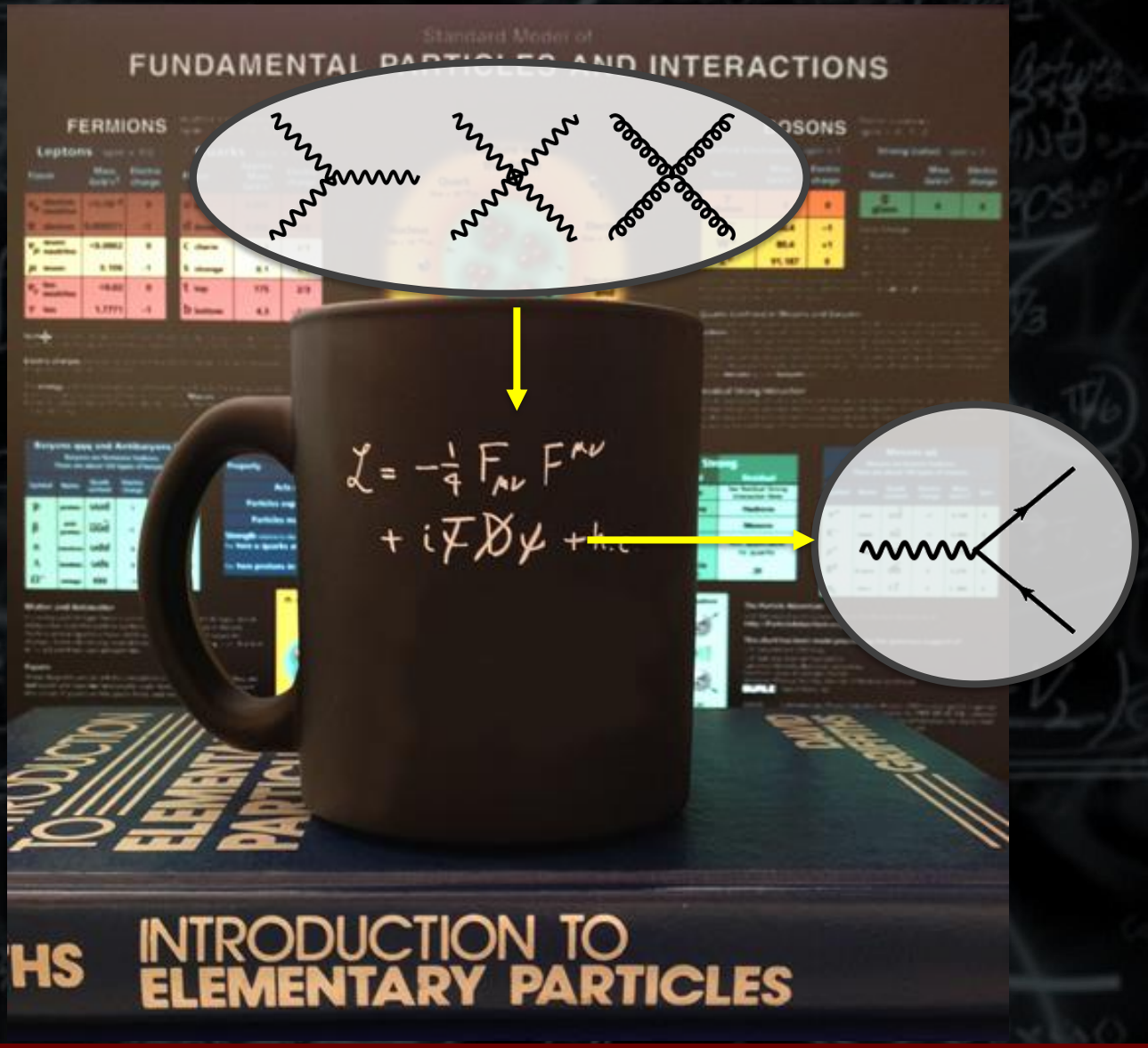
Até agora a chávena do CERN é assim:



1964

O mecanismo ABEGHHK'tH

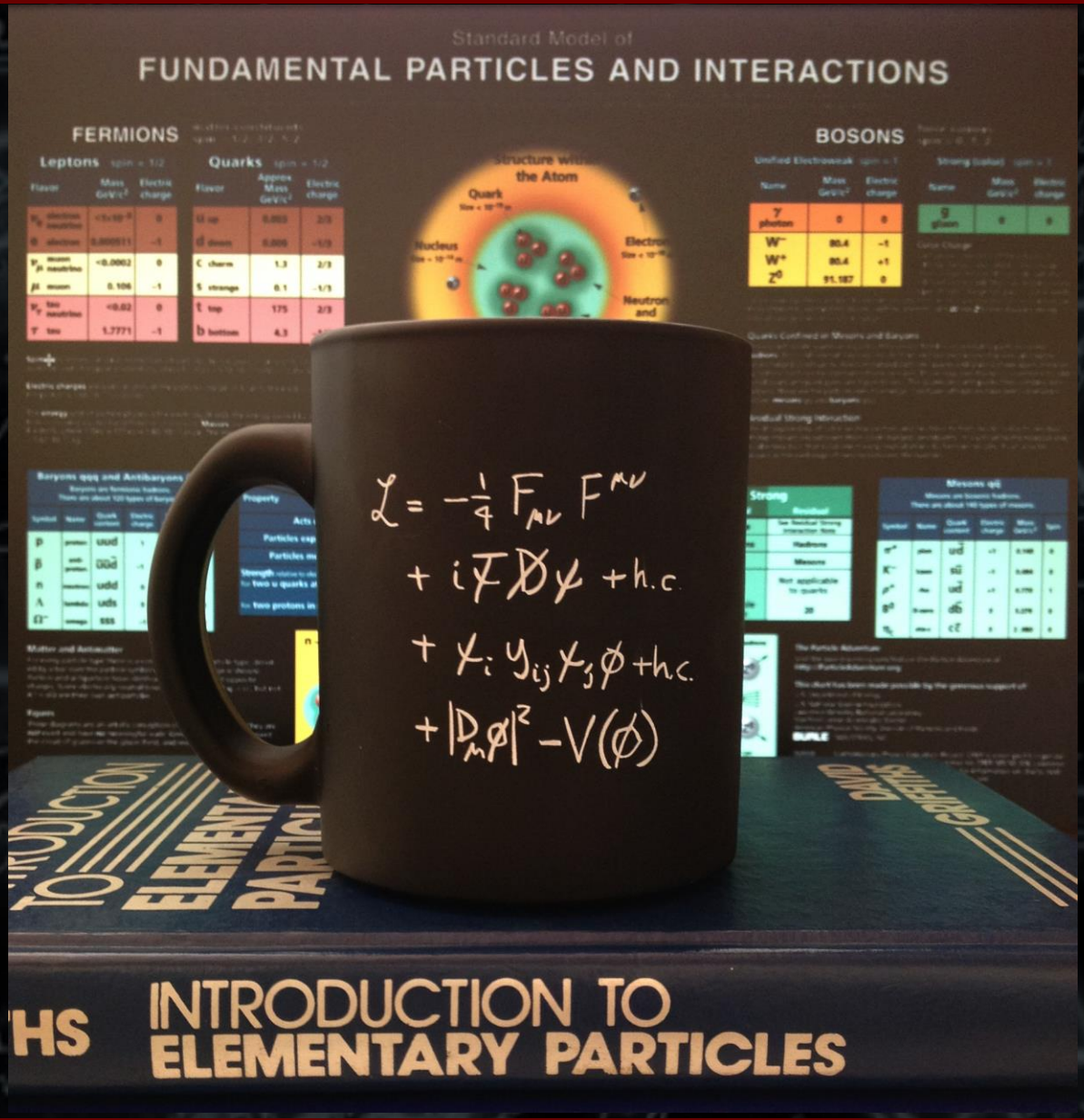
Anderson, Brout, Englert, Guralnik, Hagen, Higgs, Kibble and 't Hooft

Φ

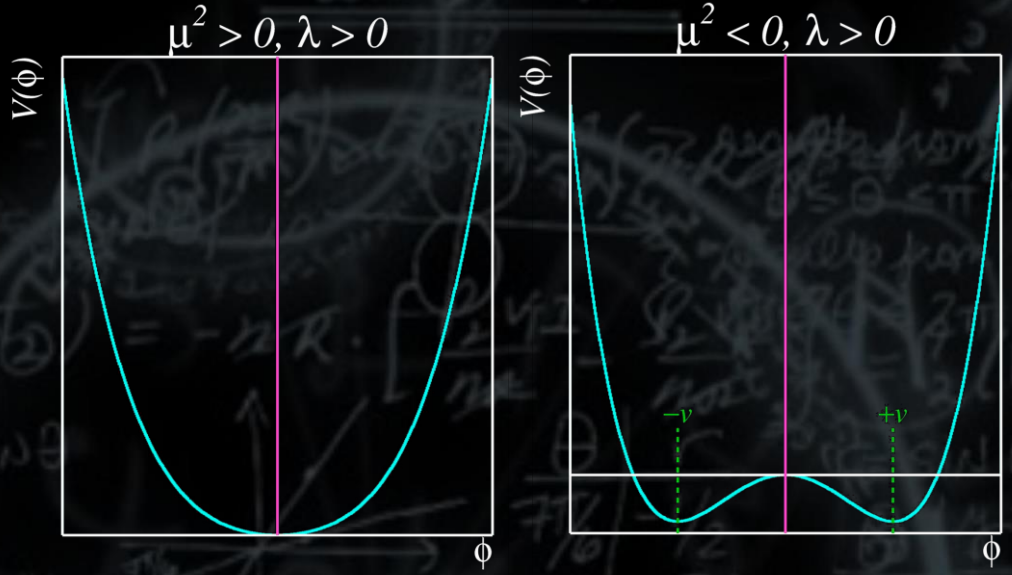
Como funciona então o mecanismo ABEGHHK'tH?

O CAMPO DE HIGGS...

A chávena CERN depois de introduzir o Φ



O MECANISMO DE HIGGS



$$V(\phi) = \mu^2 |\phi|^2 + \lambda |\phi|^4$$

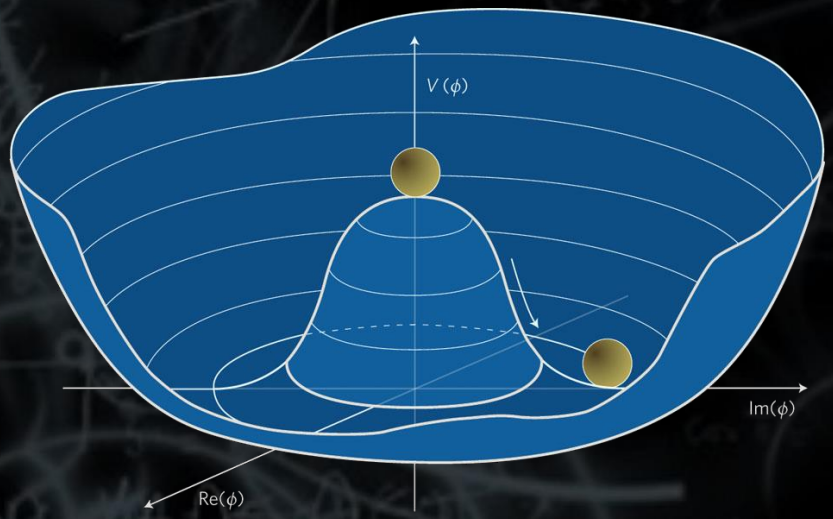
"NO VÁCUO": $v = \sqrt{-\frac{\mu^2}{2\lambda}}$

Essencial para o mecanismo de Higgs funcionar.

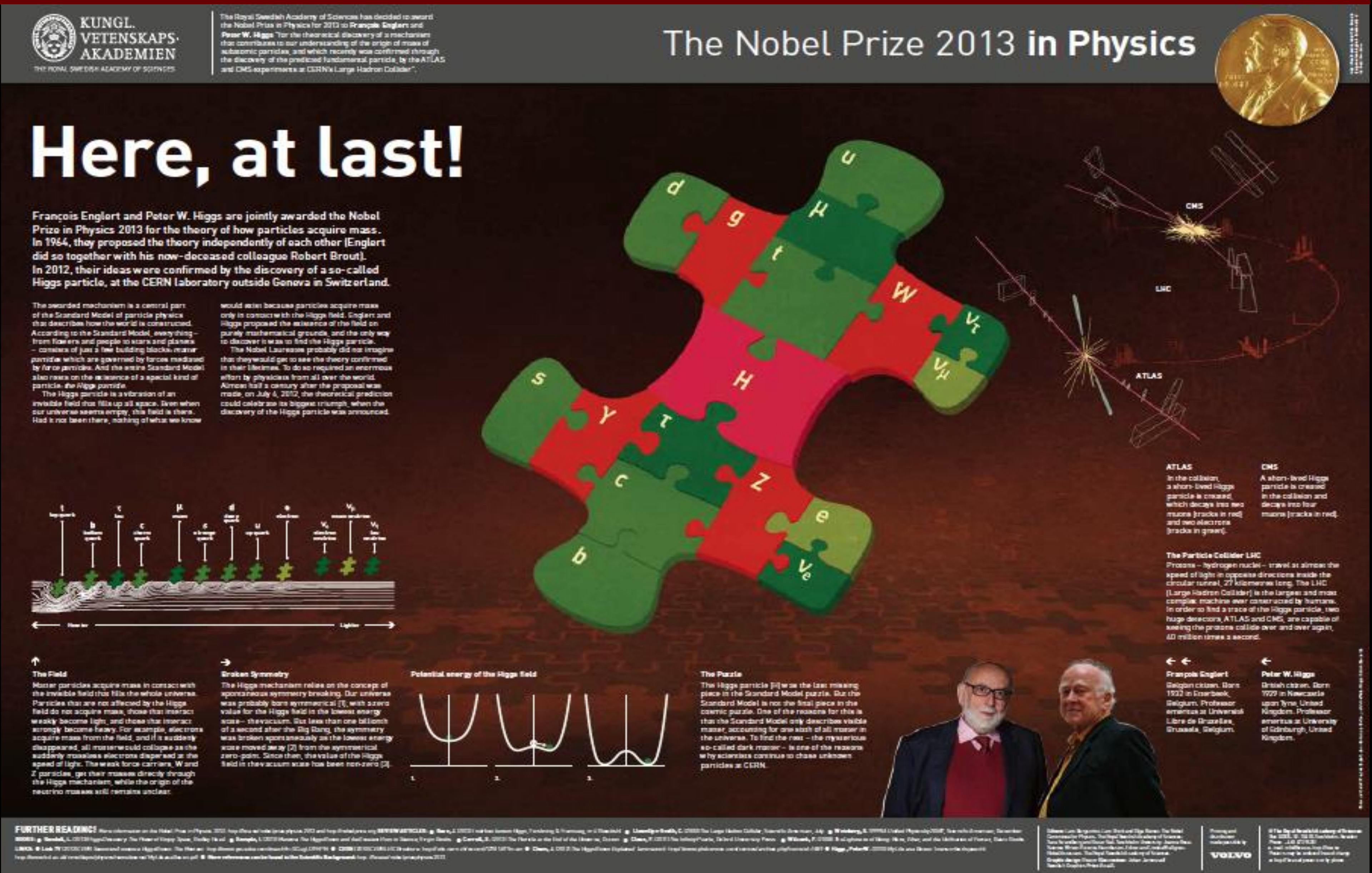
A simetria é quebrada espontâneamente!!

Os bosões de gauge (W e Z) e os fermiões adquirem massa!

E... O FOTÃO PERMANECE SEM MASSA!!!



PRÉMIO NOBEL DA FÍSICA 2013



O MECANISMO DE HIGGS

Algumas previsões da teoria:

$$M_Z \cos\theta_W = M_W \;,\; \sin^2\theta_W = 1 - M_W^2/M_Z^2$$

$$M_W^2 \sin^2\theta_W = \frac{e^2}{4\pi\sqrt{2}\,G_F}$$

Os bosões W e Z foram descobertos no CERN em 1983.

$M_W = 80.385 \pm 0.015$ GeV

$M_Z = 91.1876 \pm 0.086$ GeV

O detector gargamelle

O prémio Nobel da Física foi atríbuido a Rubbia e Van De Meer em 1984;

"for their decisive contributions to the large project, which led to the discovery of the field particles W and Z, communicators of weak interaction"

O NOBEL PARA O MODELO PADRÃO



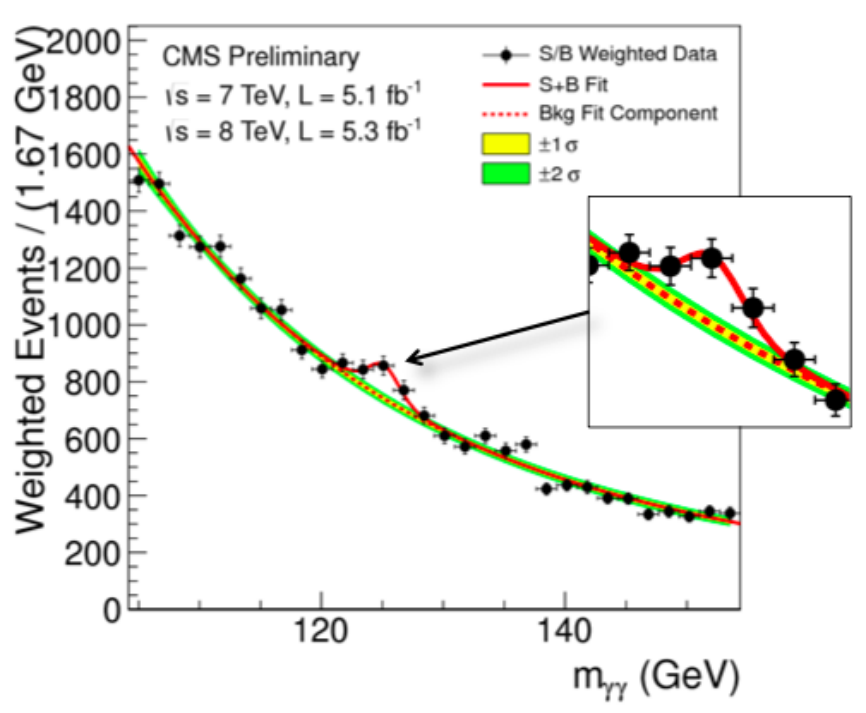
O prémio Nobel da Física foi atríbuido a Glashow, Weinberg e Salam em 1979;

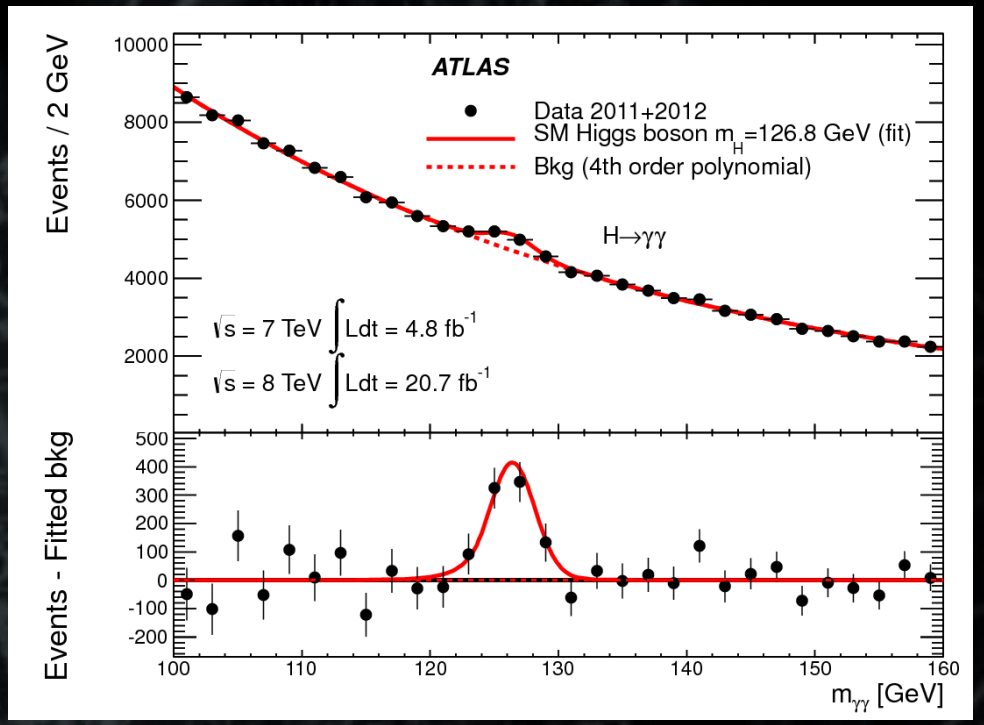
"for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, the prediction of the weak neutral current".

Até ao dia 4 de Julho de 2012 não se sabia nada sobre o que estava por detrás da quebra de simetria electrofraca.

Até que...

BORN ON THE 4TH OF JULY





"The discovery of a particle consistent with the Higgs boson opens the way to more detailed studies, … , and is likely to shed light on other mysteries of our Universe."

Rolf Heuer, CERN D.G., Press Release July 4, 2012

"We are reaching into the fabric of the Universe at the level never done before… We are in the edge of a new exploration."

Joe Incandela, CMS spokesperson, Press Conference, July 4, 2012

O ACONTECIMENTO CIENTÍFICO MAIS MEDIÁTICO

"ENTÃO A MASSA VEM TODA DO HIGGS?"

Protão p = uud: $2 m_u + m_d = 11$ MeV

Só 1% da massa do protão é devida à massa em repouso dos quarks, ou seja…

Apenas uma infima parte da massa é devida ao mecanismo de Higgs…

E AGORA?

"Nineteenth-Century Clouds over the Dynamical Theory of Heat and Light"

Lord Kelvin, 27 de Abril 1900

As núvens negras de Kelvin

Incapacidade de detectar o Éter e a "Catástrofe ultra-violeta"

A Física estaria limitada à medição de quantidades conhecidas com grande precisão...

Kelvin não podia estar mais enganado...

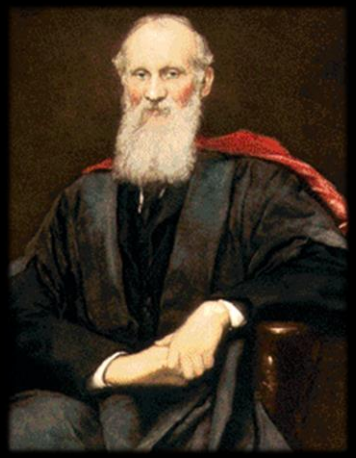
Stephen Hawking (1998)

"Com a descoberta iminente do bosão de Higgs não há nada fundamentalmente novo a ser descoberto. Tudo o que há a fazer é medir com mais precisão."

REPETIÇÃO DA HISTÓRIA?

O QUE DIRIA KELVIN AGORA?

"Twentieth first-Century Clouds over the electroweak theory"



"A beleza e a clareza da teoria electrofraca está obscurecida por algumas núvens"

As núvens do Pedro:

- Matéria escura e energia escura

- Porque existe mais matéria que anti-matéria no Universo?
- Porquê 3 famílias?;
- Problema da Hierarquia;
- Porque é que as massas das partículas elementares são o que são;
- Porque é que os neutrinos são muito mais leves do que os leptões carregados e os quarks;
- Será que as 3 (ou 4) forças se unificam a alguma escala?;
- Será que as partículas elementares são mesmo elementares?;

PORQUE FÍSICA PARA ALÉM DO MP?

EVIDÊNCIAS EXPERIMENTAIS PARA A EXISTÊNCIA DE NOVA FÍSICA

Assimetria matéria-antimatéria

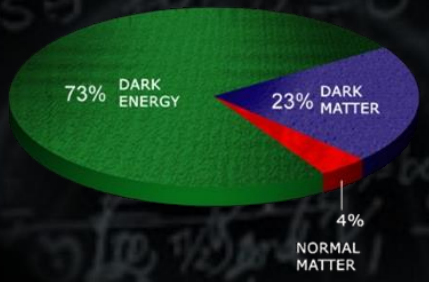
O MP falha em explicar porque razão existe um excesso de matéria no Universo ou “porque estamos de facto aqui!”

FERMIÕES

Leptões spin =1/2			Quarks spin =1/2		
Sabor	Massa GeV/c^2	Carga Eléctrica	Sabor	Massa Aprox. GeV/c^2	Carga Eléctrica
ν_L neutrino* mais leve	$(0-2)\times10^{-9}$	0	**u** up	0.002	2/3
e electrão	0.000511	−1	**d** down	0.005	−1/3
ν_M neutrino* intermédio	$(0.009-2)\times10^{-9}$	0	**c** charm	1.3	2/3
μ muão	0.106	−1	**s** strange	0.1	−1/3
ν_H neutrino* pesado	$(0.05-2)\times10^{-9}$	0	**t** top	173	2/3
τ tau	1.777	−1	**b** bottom	4.2	−1/3

Massas de neutrinos

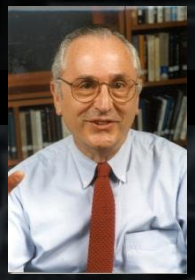
No MP os neutrinos não têm massa, mas de facto hoje sabemos que estas partículas são massivas (com uma massa muito menor que os restantes fermiões).



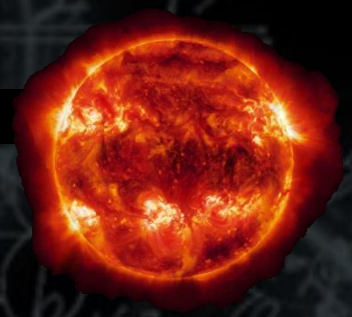
Problema da matéria escura

23% do budget de energia do Universo surge sob a forma de matéria escura. O MP não tem um candidato para a matéria escura.

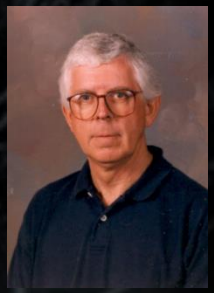
1964: MISTÉRIO DOS NEUTRINOS DESAPARECIDOS



Bachall



N_{ν_e} N'_{ν_e}



Davis

$$\frac{N'_{\nu_e}}{N_{\nu_e}} = \frac{1}{3}$$

- O número de neutrinos que saem do Sol está mal calculado, OU
- A experiência está errada.

OSCILAÇÕES DE NEUTRINOS

$\nu_e \rightarrow \nu_\mu$

$$P = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2}{4E}L\right)$$

$$\Delta m^2 = m_2^2 - m_1^2$$

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2015 to **Takaaki Kajita** and **Arthur B. McDonald** "for the discovery of neutrino oscillations, which shows that neutrinos have mass".

The Nobel Prize 2015 **in Physics**

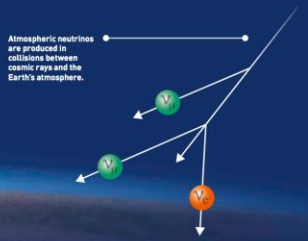
Chameleons of space

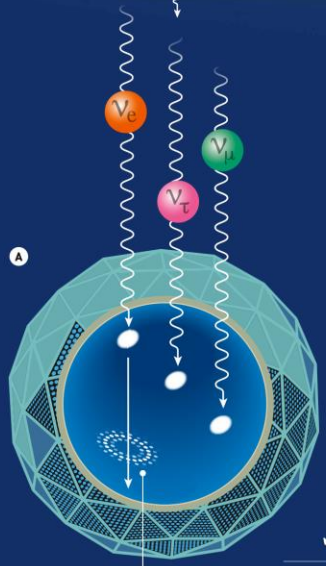
Takaaki Kajita in Japan and Arthur B. McDonald in Canada were key scientists in two large research groups that discovered that neutrinos change identities, which requires that neutrinos have mass. The discovery has changed our understanding of the innermost workings of matter and may prove crucial to our view of the universe.

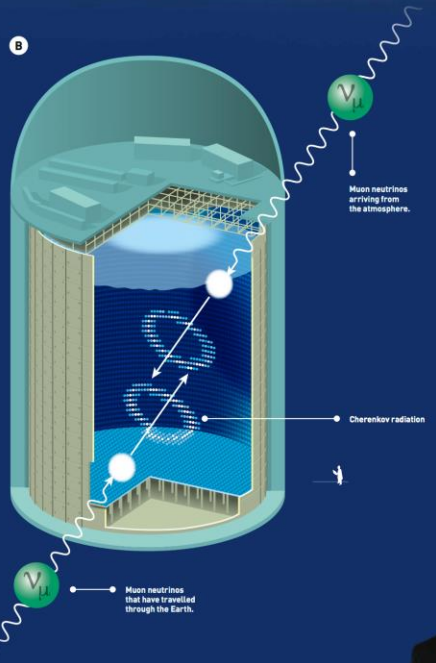
The discovery of neutrino identity changes has resolved a neutrino puzzle that physicists had wrestled with for decades. Compared to theoretical calculations of the number of neutrinos, up to two-thirds of them were missing in measurements performed on Earth. The two research groups discovered that the neutrinos had changed identities, which led to the conclusion that neutrinos must have some mass, however small. This discovery was historic for particle physics, as its Standard Model requires neutrinos to be massless. Thus new physics is now needed.

The Earth is constantly bombarded by neutrinos. Many are created in reactions between cosmic radiation and the Earth's atmosphere. Others are produced in nuclear reactions inside the Sun. Thousands of billions of neutrinos stream through our bodies every second. The combined weight of neutrinos is estimated to be roughly equal to that of all visible stars in the universe.

Hardly anything can stop the neutrinos; they are amongst nature's most elusive elementary particles. Experiments are continuing to uncover the all but hidden world of neutrinos. New discoveries about their deepest secrets are expected to change our current understanding of the history, structure and future of the universe.

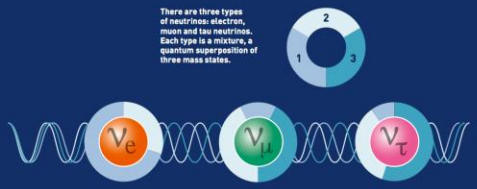






A Sudbury Neutrino Observatory
The detector measured neutrinos from the Sun. Its tank, filled with heavy water, was placed two kilometres under the surface of the Earth. Signals from all three types of neutrinos were registered in the tank. The sum of the neutrinos corresponded to what was expected, but there were not enough electron neutrinos – they must have changed identity.

B Super-Kamiokande
The detector measured atmospheric neutrinos. Its tank, filled with water, was placed one kilometre under the surface of the Earth. The muon neutrinos that arrived straight at Super-Kamiokande from the atmosphere were more numerous than those that arrived at the detector after passing through the Earth. The muon neutrinos that travelled further thus had time to change identity and become another type of neutrino.



Neutrino oscillations
Neutrinos change identities as they travel through space. Quantum physics is required to explain this magic, where the neutrinos are represented by superposed waves that correspond to neutrino states with different masses. When the neutrinos travel, these waves go out of phase and are superposed in different ways. The superposition in any given location yields the probability of which type of neutrino is most likely to be found there. These probabilities vary from one location to another – oscillate – and the neutrinos appear in their various identities. This is only possible if neutrinos have mass.

Arthur B. McDonald
Canadian citizen. Born 1943 in Sydney, Canada. Professor Emeritus at Queen's University, Kingston, Canada.

Takaaki Kajita
Japanese citizen. Born 1959 in Higashimatsuyama, Japan. Director of Institute for Cosmic Ray Research and Professor at University of Tokyo, Kashiwa, Japan.

FURTHER READING More information on the Nobel Prize in Physics 2015: *http://kva.se/nobelphysics2015* and *http://nobelprize.org* **BOOKS:** ● **Jayawardhana, R.** (2013) *Neutrino Hunters: The Thrilling Chase for a Ghostly Particle to Unlock the Secrets of the Universe*, Scientific American/Farrar, Straus and Giroux ● **Close, F.** (2010) *Neutrino*, Oxford University Press **POPULAR SCIENCE ARTICLES:** ● **Huth, P. O.** (2005) High Energy Neutrinos from the Cosmos, *http://nobelprize.org* ● **Bahcall, J. N.** (2004) Solving the Mystery of the Missing Neutrinos, *http://nobelprize.org* ● **McDonald, A. B., Klein, J. R.** and **Wark, D. L.** (2003) Solving the Solar Neutrino Problem, *Scientific American*, Vol. 288, no. 4, April ● **Kearns, E., Kajita, T.** and **Totsuka, Y.** (1999) Detecting Massive Neutrinos, *Scientific American*, Vol. 281, no. 2, August
LINKS: ● **Super-Kamiokande Homepage:** *www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html* ● **Sudbury Neutrino Observatory Homepage:** *www.sno.phy.queensu.ca* ● **More references can be found in the Scientific Background:** *http://kva.se/nobelphysics2015*

Editors: Lars Bergström, Olga Botner, Gunnar Ingelman and Anne L'Huillier, The Nobel Committee for Physics, The Royal Swedish Academy of Sciences; Joanna Rose, Science Writer; Sara Gustavsson, Editor, and Laura Alexis, Nobel Assistant, The Royal Swedish Academy of Sciences. **Graphic design:** Ritator **Illustrations:** Johan Jarnestad/Infographics.se **Print:** Åtta45

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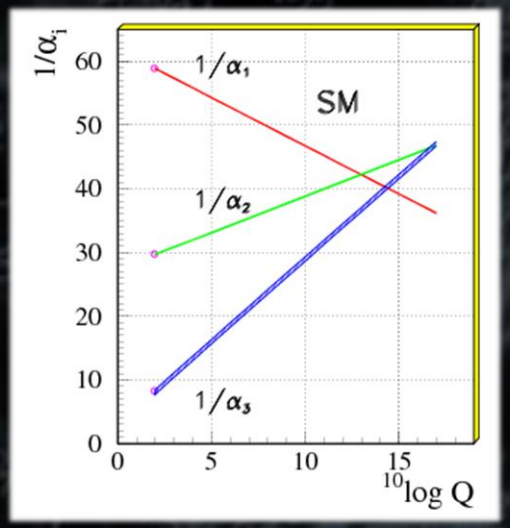
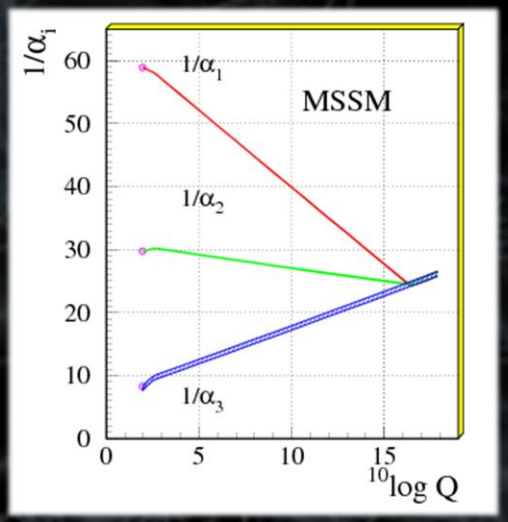
UNIFICAÇÃO DAS INTERAÇÕES FUNDAMENTAIS

Propriedade	Interacção Gravítica	Interacção Fraca (Electrofraca)	Interacção Electromagnética (Electrofraca)	Interacção Forte
Actua em:	Massa – Energia	Sabor	Carga Eléctrica	Carga de cor
Partículas afectadas:	Todas	Quarks, Leptões	Electricamente carregadas	Quarks, Gluões
Partículas mediadoras:	Gravitão (ainda por observar)	W^+ W^- Z^0	γ	Gluões
Intensidade a 10^{-18} m	10^{-41}	0.8	1	25
Intensidade a 3×10^{-17} m	10^{-41}	10^{-4}	1	60

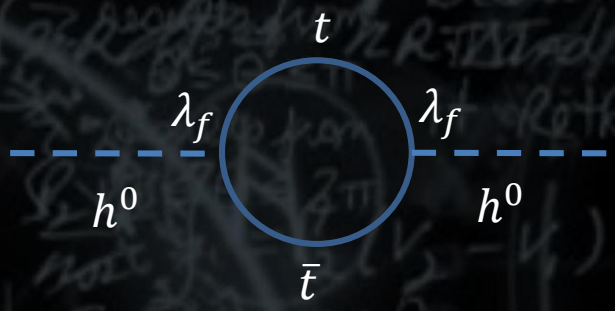
SE O MP FOR VÁLIDO ATÉ À ESCALA DE PLANCK AS 3 (4) FORÇAS FUNDAMENTAIS UNIFICAM-SE OU NÃO?





PROBLEMA DA HIERARQUIA DE ESCALAS

$$V(\phi) = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda'\phi^4 \longrightarrow m^2 = -2\mu^2$$



Vamos supor o SM válido até a uma escala Λ

$$m_{h^0}^2 \simeq m^2 - \frac{\lambda_f^2 \Lambda_{\text{Planck}}^2}{16\pi^2} \simeq (125\ \text{GeV})^2 \qquad \Lambda_{\text{Planck}} = 1.2 \times 10^{19}\text{GeV}$$

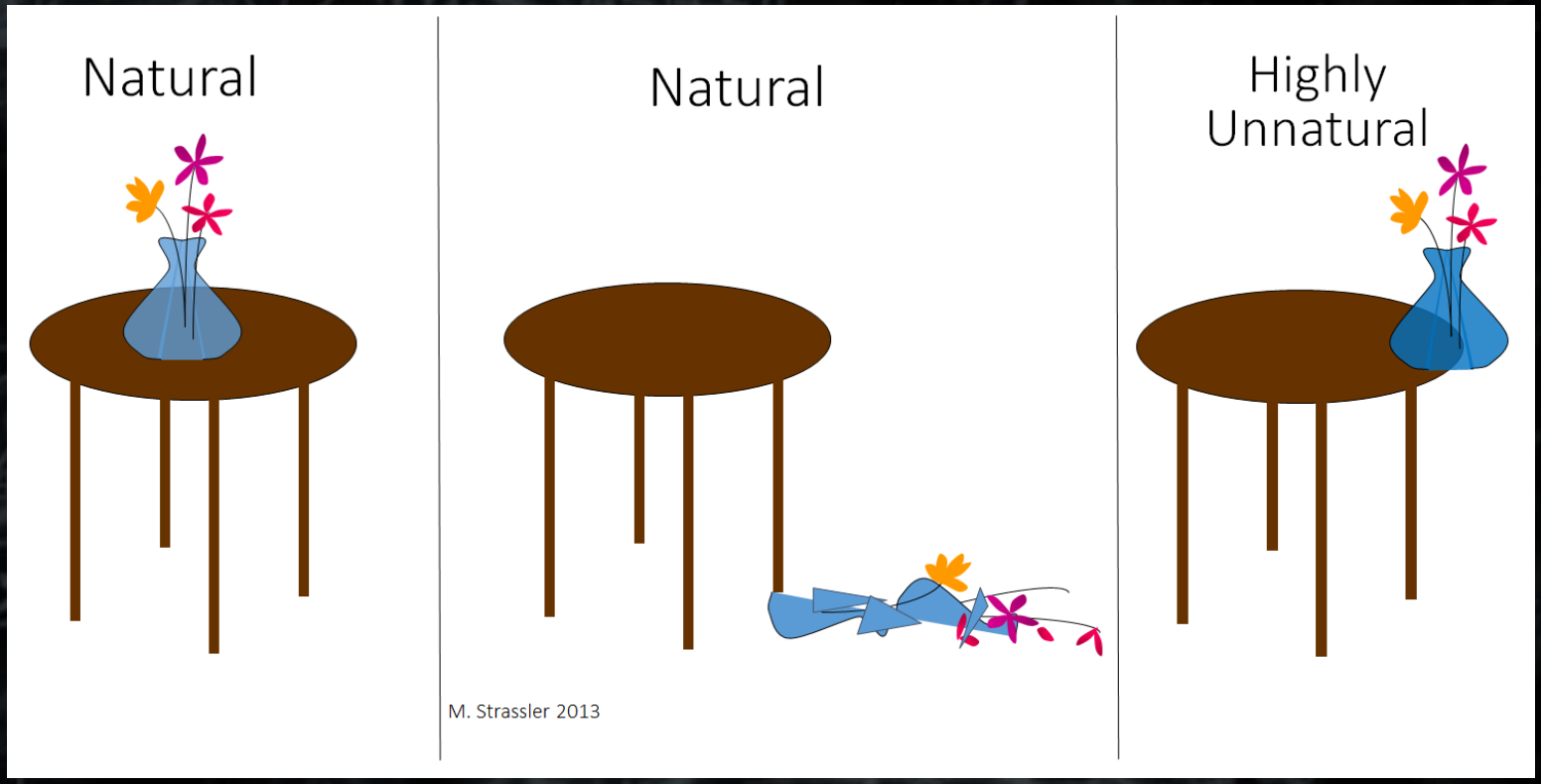
$$m^2 \simeq 91000000000000000000000000015625\ \text{GeV}^2$$

$$\frac{\Lambda_{\text{Planck}}^2}{16\pi^2} \simeq 91000000000000000000000000000000\ \text{GeV}^2$$

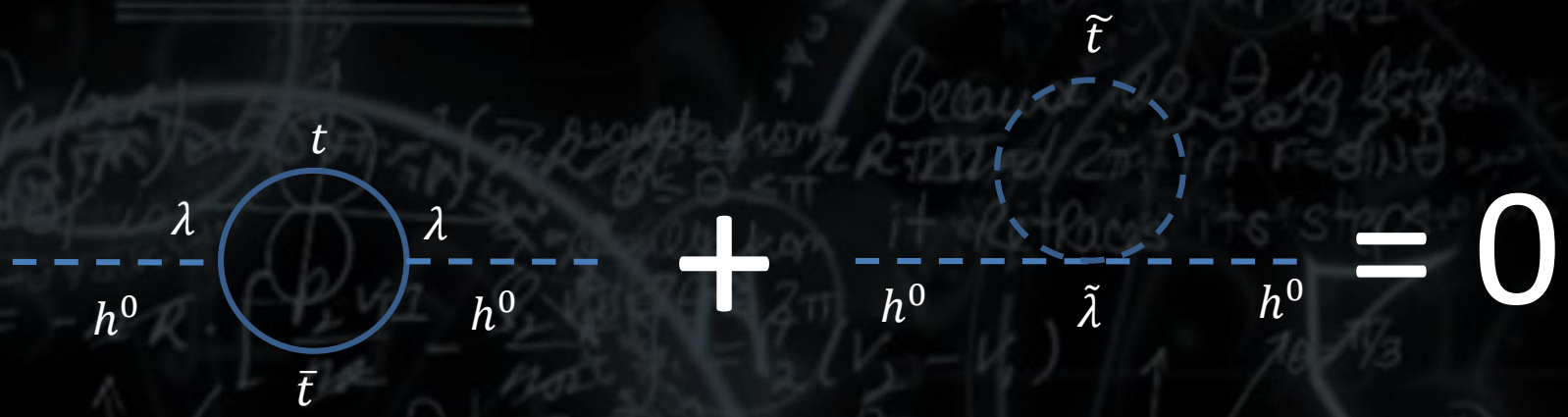
O PROBLEMA DA HIERARQUIA DE ESCALAS

FINE-TUNNING!!!

PROBLEMA DA HIERARQUIA DE ESCALAS



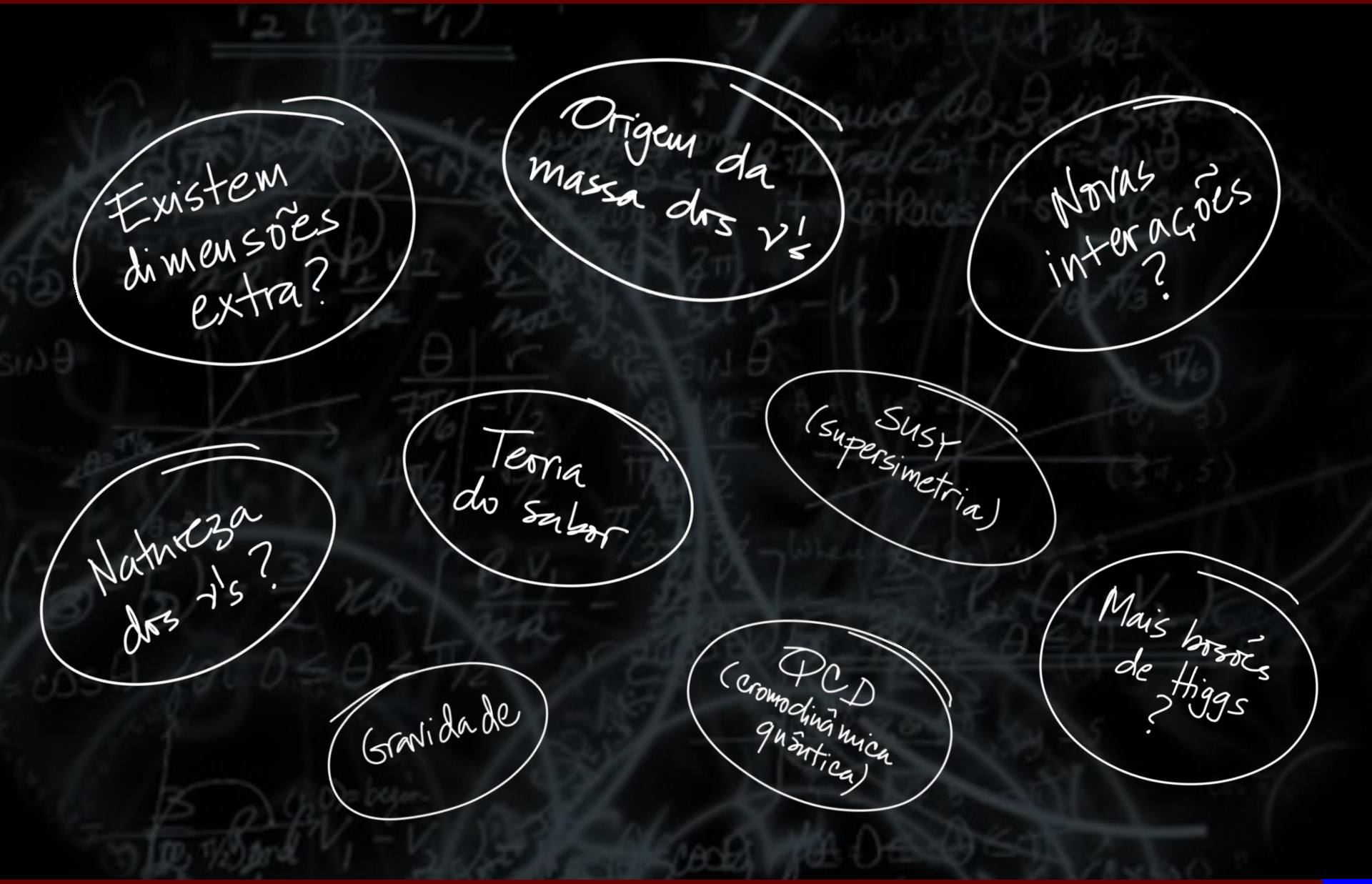
SOLUÇÃO PARA O PROBLEMA DA HIERARQUIA



$$\text{Se } \tilde{\lambda} = -\lambda^2$$

SUSY

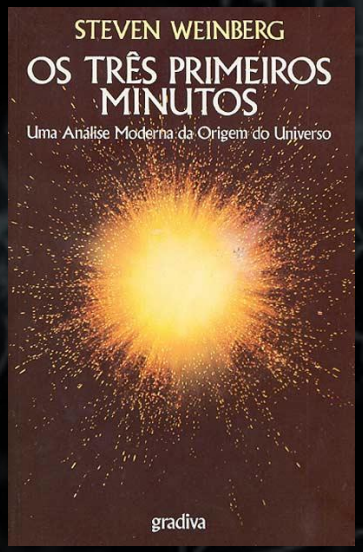
PORQUE FÍSICA PARA ALÉM DO MP?

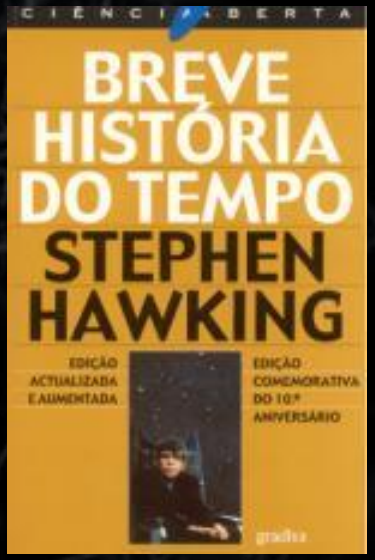


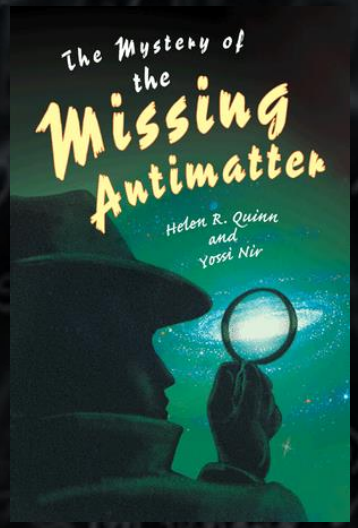
"We are reaching into the fabric of the Universe at the level never done before… We are in the edge of a new exploration."

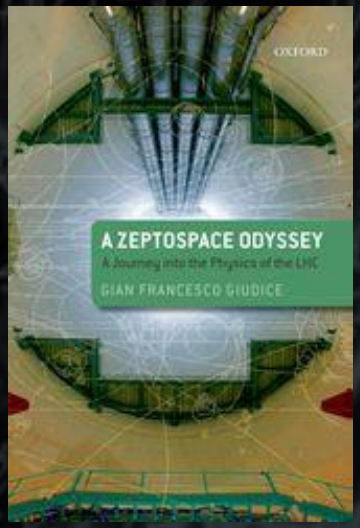
Joe Incandela, CMS spokesperson, Press Conference, July 4, 2012

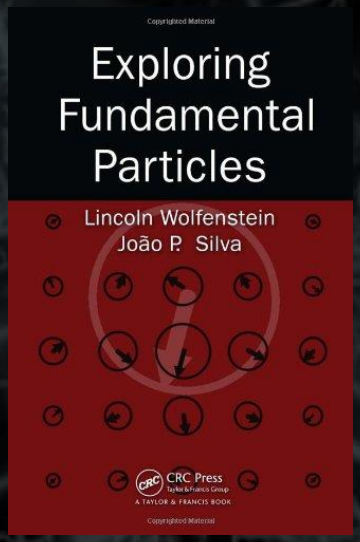
ALGUNS LIVROS (Os mais actuais em inglês)

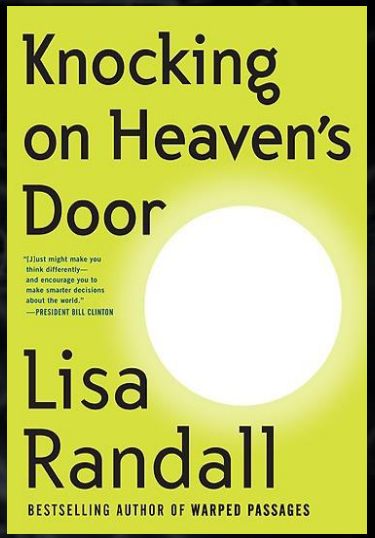












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