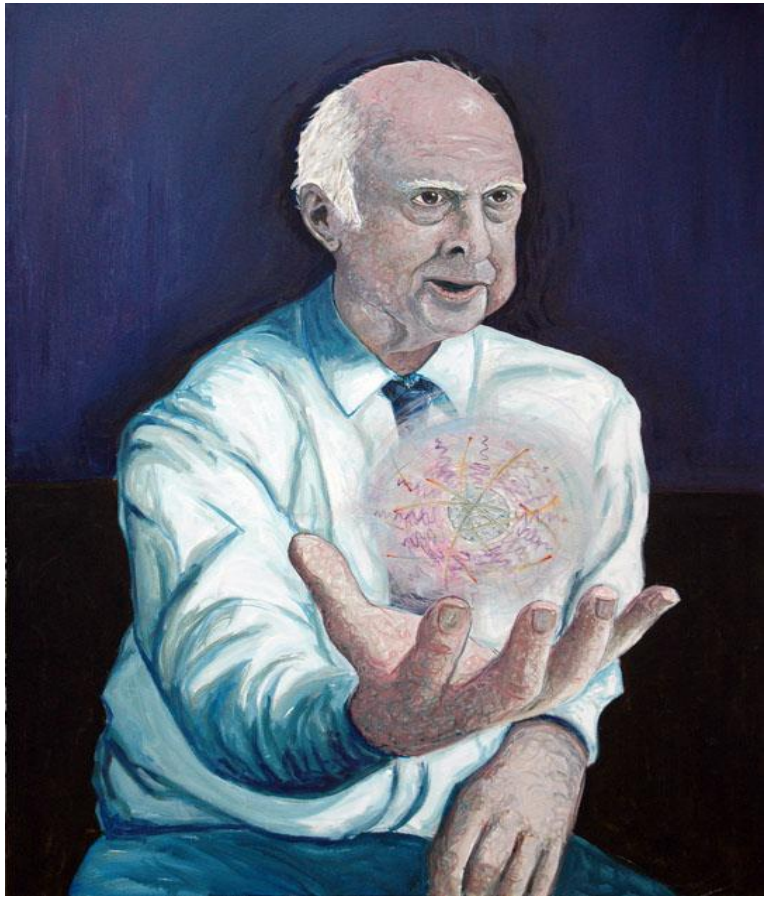
Da necessidade à descoberta: o Bóson de Higgs



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por vários slides: https://dl.dropbox.com/u/3565227/Talks/ENFPC2012_SFNovaes_final.pdf

A necessidade do Bóson de Higgs

Tudo começa no monumental trabalho de Maxwell:

As equações de Maxwell podem ser reescritas na sua forma tensorial:

$$\partial_\mu F^{\mu\nu} = \frac{4\pi}{c} J^\mu$$

Onde:

$$[F^{\mu\nu}] = \begin{pmatrix} 0 & -E_x & -E_y & -E_z \\ E_x & 0 & -B_z & B_y \\ E_y & B_z & 0 & -B_x \\ E_z & -B_y & B_x & 0 \end{pmatrix}$$

e J^μ **é a quadricorrente**

$$F^{\mu\nu} = (\partial^\mu A^\nu - \partial^\nu A^\mu)$$

Ou:

A_μ **é o quadripotencial**

Nota Bene:

$$F^{\mu\nu} = (\partial^\mu A^\nu - \partial^\nu A^\mu)$$

é invariante sob Transformações de GAUGE:

$$A_\mu \to A_\mu + \partial_\mu \lambda$$

Que não alteram, portanto, os campos elétricos e magnéticos!!

O Eletromagnetismo de Maxwell sugere SIMETRIA de GAUGE

Lagrangiana de Maxwell

- Incluindo cargas e correntes:

$$L = \frac{-1}{16\pi} F^{\mu\nu} F_{\mu\nu} - \frac{1}{c} J^{\mu} A_{\mu}$$

- A equação de Euler-Lagrange leva às equações de Maxwell com correntes:

$$\partial_{\mu} F^{\mu\nu} = \frac{4\pi}{c} J^{\mu}$$

$J^\mu = 0$ **leva à lagrangiana de um campo vetorial sem massa propagando-se livremente no espaço-tempo:**

$$L = \frac{-1}{16\pi} F^{\mu\nu} F_{\mu\nu}$$

Esta lagrangiana é invariante de GAUGE e é parte integrante da Eletrodinâmica Quântica, a QED: a mais precisa teoria científica já formulada!

Na QED, o campo vetorial A_μ **é interpretado como sendo o FÓTON, o intermediador das interações eletromagnéticas!**

MAS: a lagrangiana de um campo vetorial massivo inclui o termo de massa.

$$L = \frac{-1}{16\pi} F^{\mu\nu} F_{\mu\nu} + \frac{1}{8\pi} \left(\frac{mc}{\hbar}\right)^2 A^\nu A_\nu$$

(a Lagrangiana de Proca)

PROBLEMA: o termo de massa NÃO é invariante sob transformações de gauge:

$$A_\mu \to A_\mu + \partial_\mu \lambda$$

E os campos vetoriais responsáveis pelas interações fracas são massivos:

M_W ~ 81 GeV e M_Z ~ 91 GeV

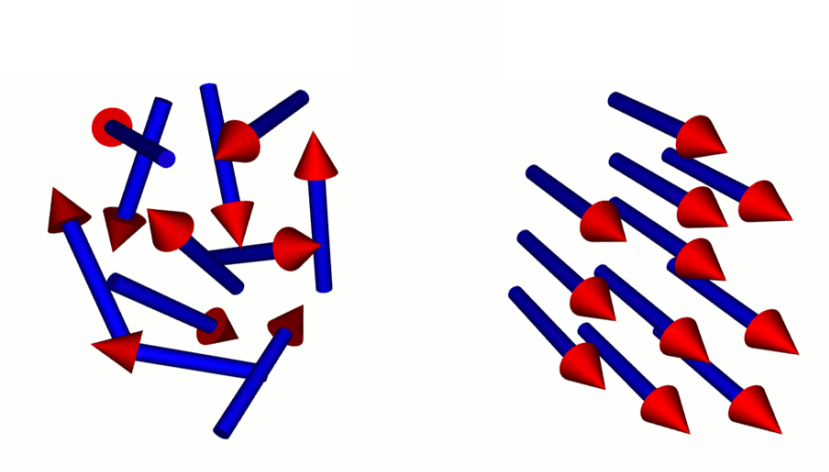
“Se quisermos reproduzir o sucesso da QED para as interações fracas, precisamos de um mecanismo que opere o “milagre” de introduzir campos vetoriais massivos que não violem a Simetria de Gauge”.

Esta é a essência do

M E C A N I S M O
D E
H I G G S

O Mecanismo de Higgs quebra espontaneamente a Simetria de Gauge:

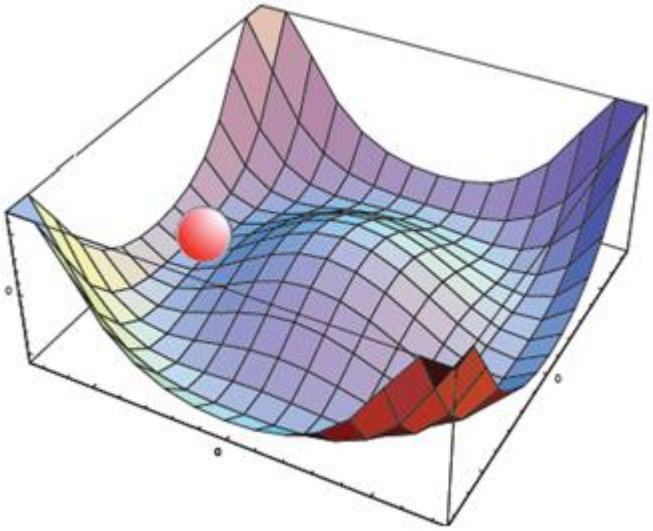
Exemplos de Quebra Espontânea de Simetria:



MECANISMO DE HIGGS

Introduz-se um campo que apresente um valor esperado no vácuo (VEV) diferente de zero:

$$L = \frac{1}{2}(\partial_\mu \phi_1)(\partial^\mu \phi_1) + \frac{1}{2}(\partial_\mu \phi_2)(\partial^\mu \phi_2) + \frac{1}{2}\mu^2(\phi_1^2 + \phi_2^2) - \frac{1}{4}\lambda^2(\phi_1^4 + \phi_2^4)$$



Mínimos do potencial ocorrem para:

$$\phi_1^2 + \phi_2^2 = \mu^2/\lambda^2$$

Vamos observar o que acontece com o termo cinético da lagrangiana de Higgs:

$$L = \frac{1}{2}(\partial_\mu \phi)^*(\partial^\mu \phi)$$

onde:

$$\phi = \phi_1 + i\phi_2$$

"Truque": este termo torna-se invariante de gauge substituindo a derivada pela derivada covariante:

$$D_\mu = \partial_\mu + i\frac{q}{\hbar c}A_\mu$$

Aparecerá um termo proporcional a:

$$(\phi^*\phi)\ A^\nu A_\nu$$

Quando o campo de Higgs adquire valor esperado no vácuo:

$$\langle \phi \rangle = \text{VEV} = \mu/\lambda$$

$$(\phi^* \phi)\, A^\nu A_\nu \quad \longrightarrow \quad \langle \phi \rangle^2 A^\nu A_\nu = \left(\mu/\lambda\right)^2 A^\nu A_\nu$$

Pode ser comparado com o termo de massa da Lagrangiana de Proca:

$$\frac{1}{8\pi}\left(\frac{mc}{\hbar}\right)^2 A^\nu A_\nu$$

Que equivale a massa para os campos vetoriais:

$$m = 2\sqrt{\pi}\, q \;\; \mu/\lambda$$

O Mecanismo de Higgs torna possível a extensão do Princípio de Gauge para as interações fracas.
Trabalho de Glashow, Weinberg e Salan
(Prêmio Nobel)

Standard Model

$$\mathcal{L}_{SM} = \sum_{\Psi} \bar{\Psi}\, i \not{D}(A, W, Z)\, \Psi$$

$$-\frac{1}{4} \sum_{V} F^{a}_{\mu\nu}(V) F^{a\mu\nu}(V)$$

- Gauge Sector

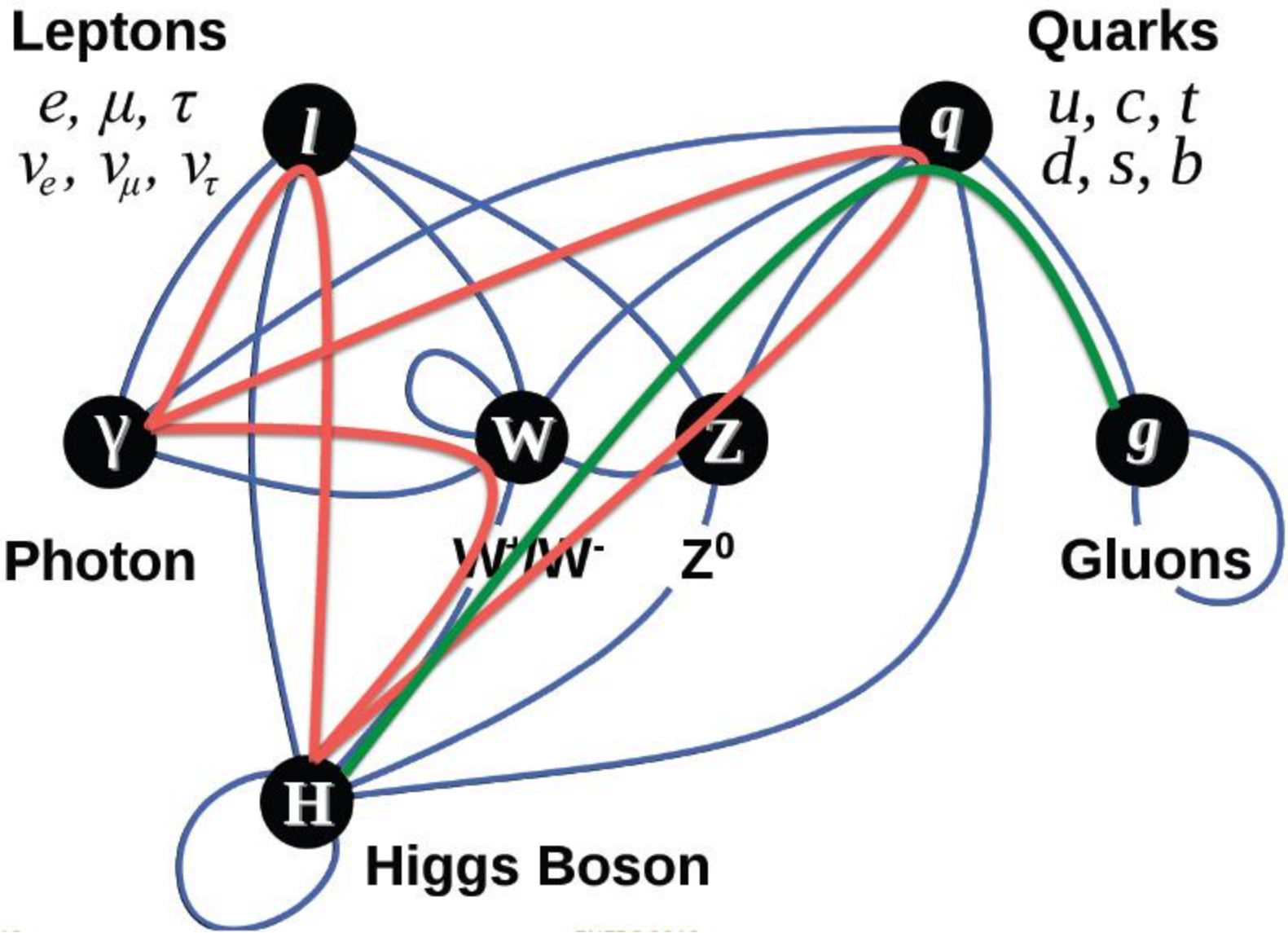
$$+ |\mathcal{D}_{\mu}\phi|^2 - V(\phi^{\dagger}\phi)$$

- EWSB Sector

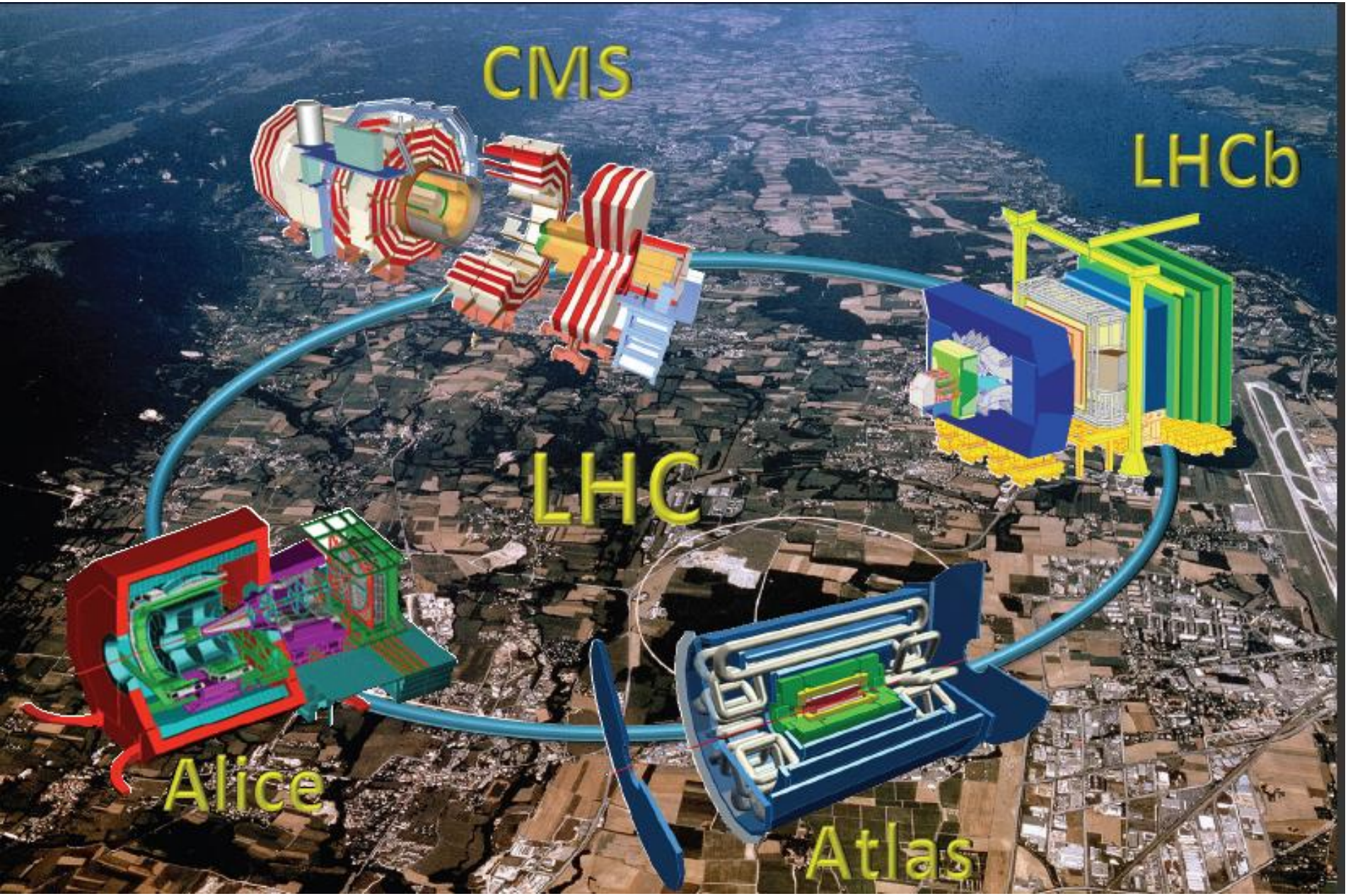
$$+ \bar{\Psi}_i \lambda_{ij} \Psi_j \phi + h.c.$$

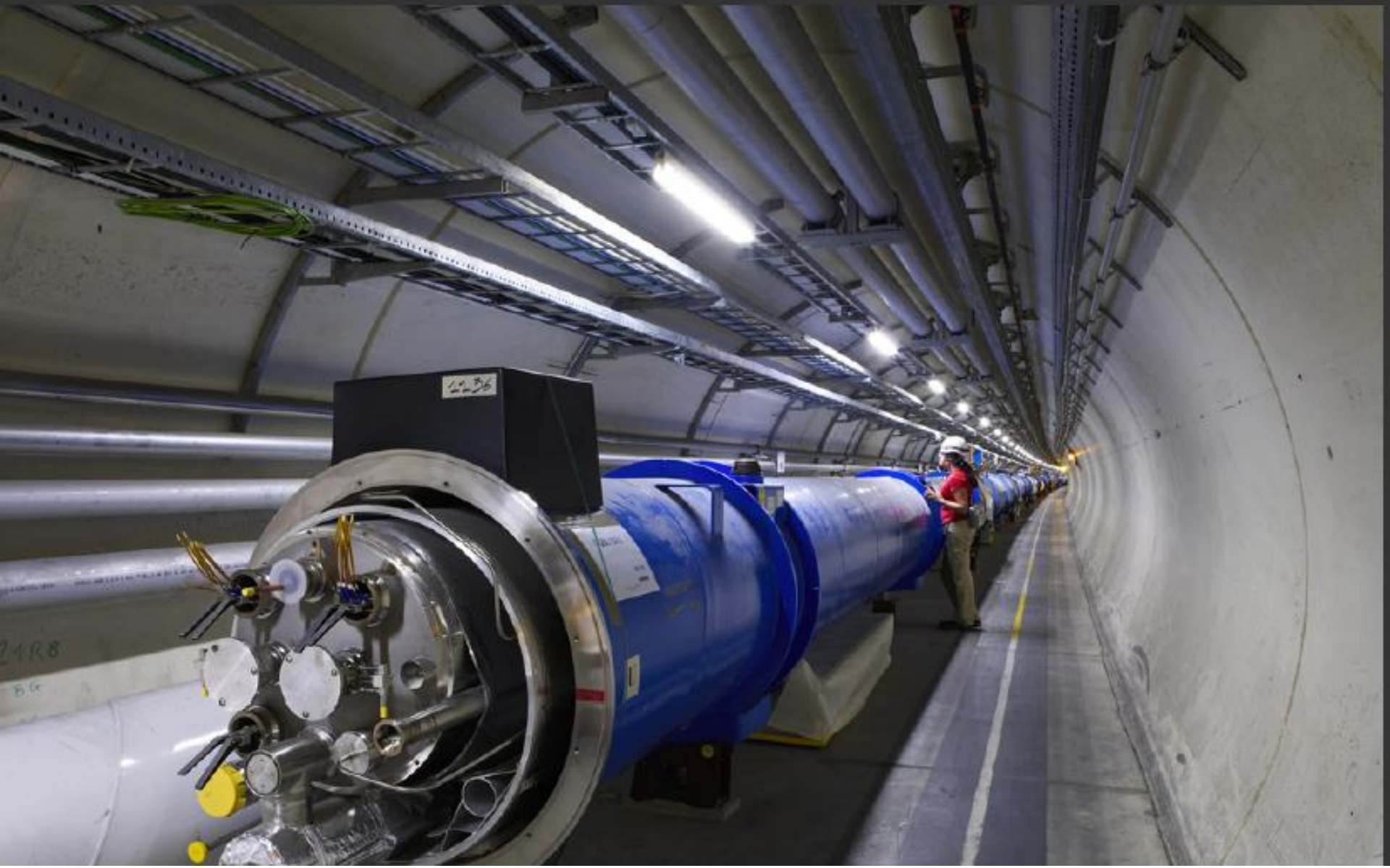
- Flavor Sector

Standard Model

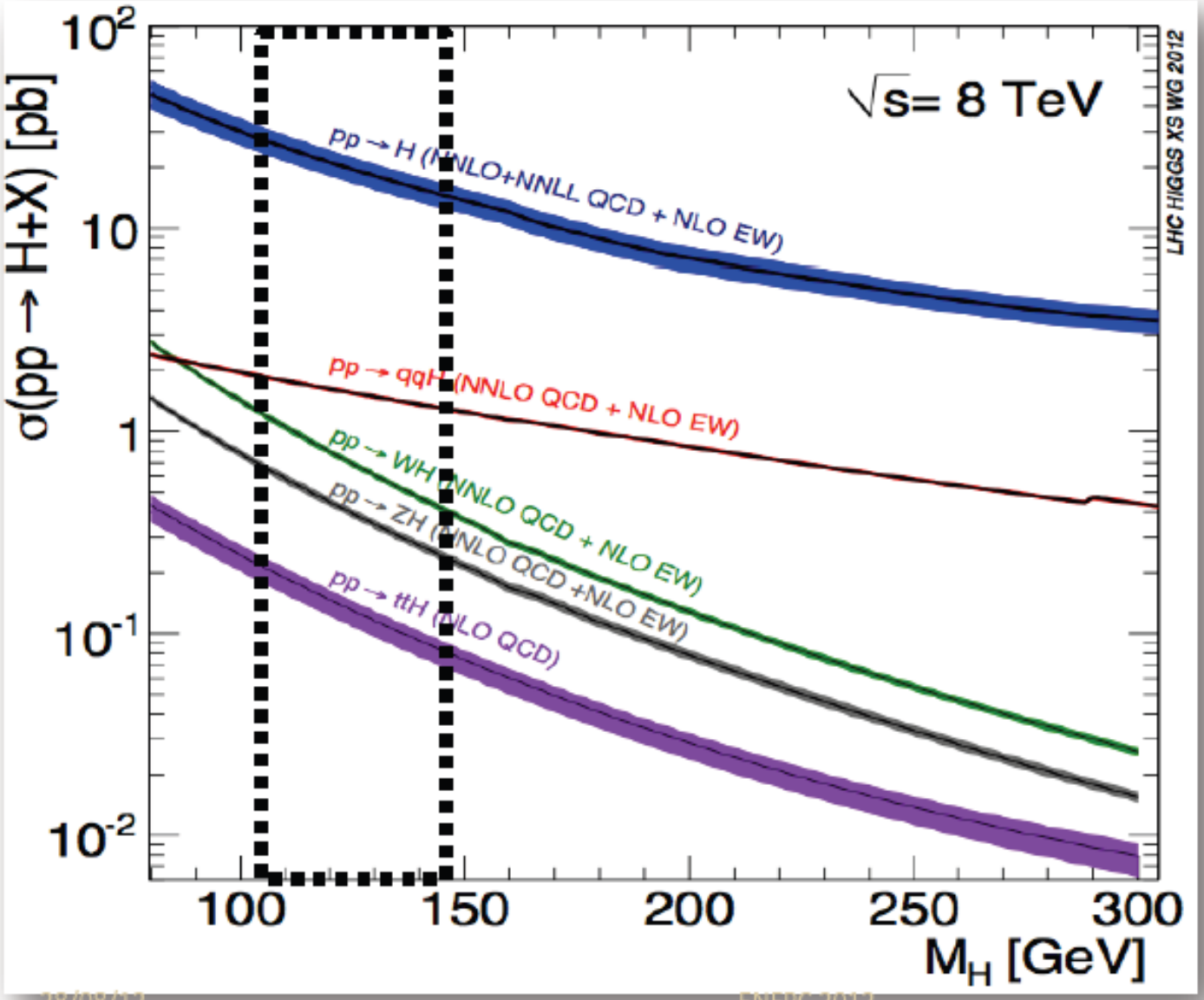


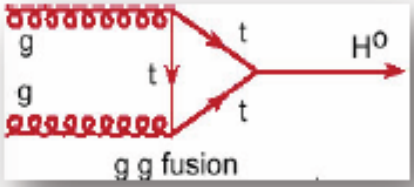
A Procura pelo Bóson de Higgs

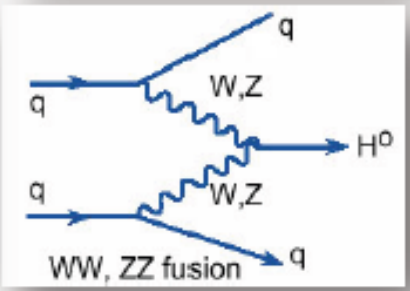

CMS
LHCb
LHC
Alice
Atlas

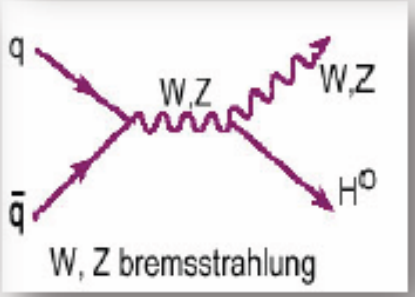


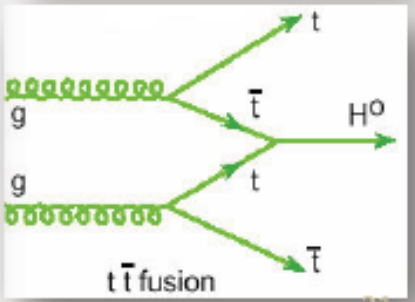
Higgs boson production





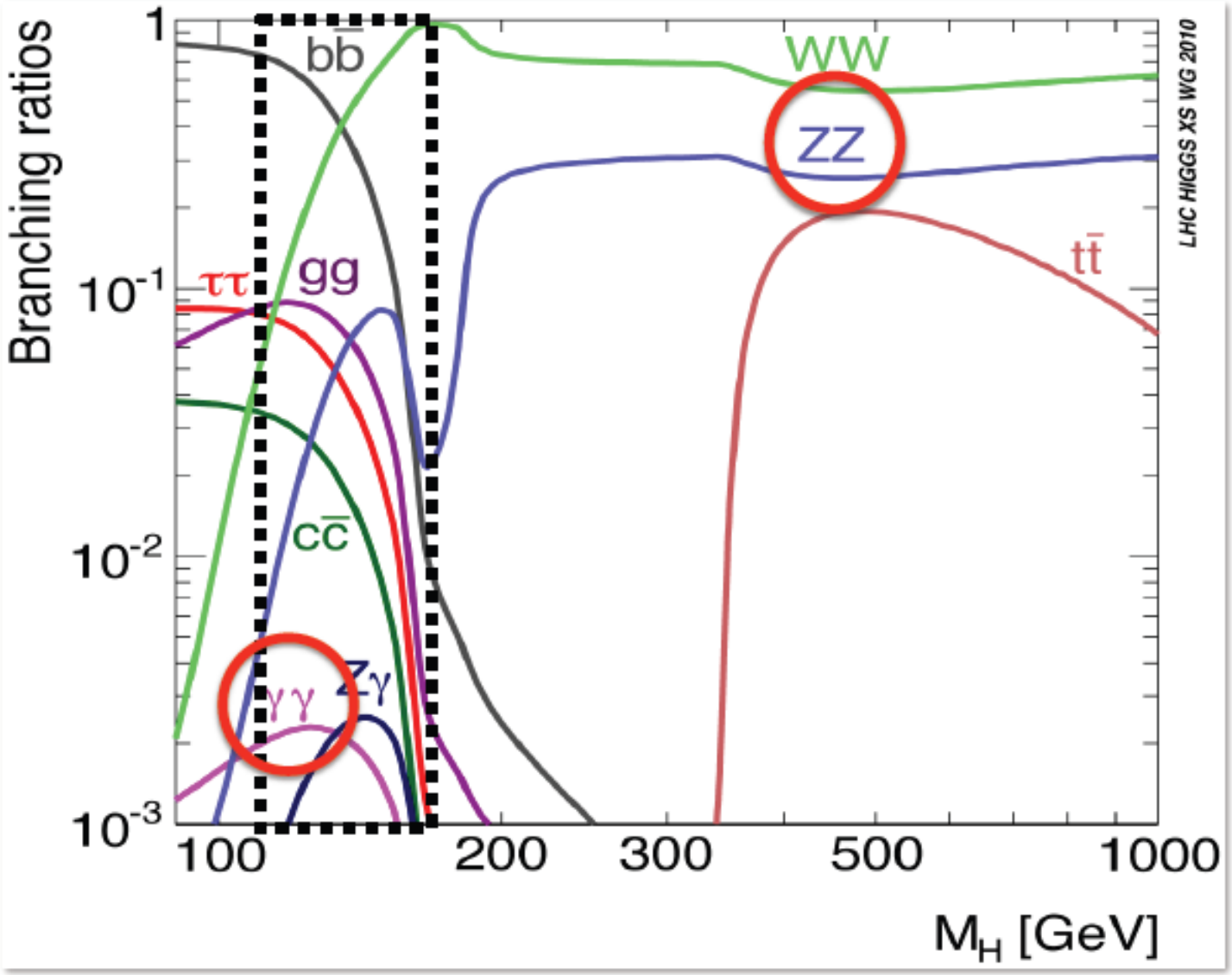




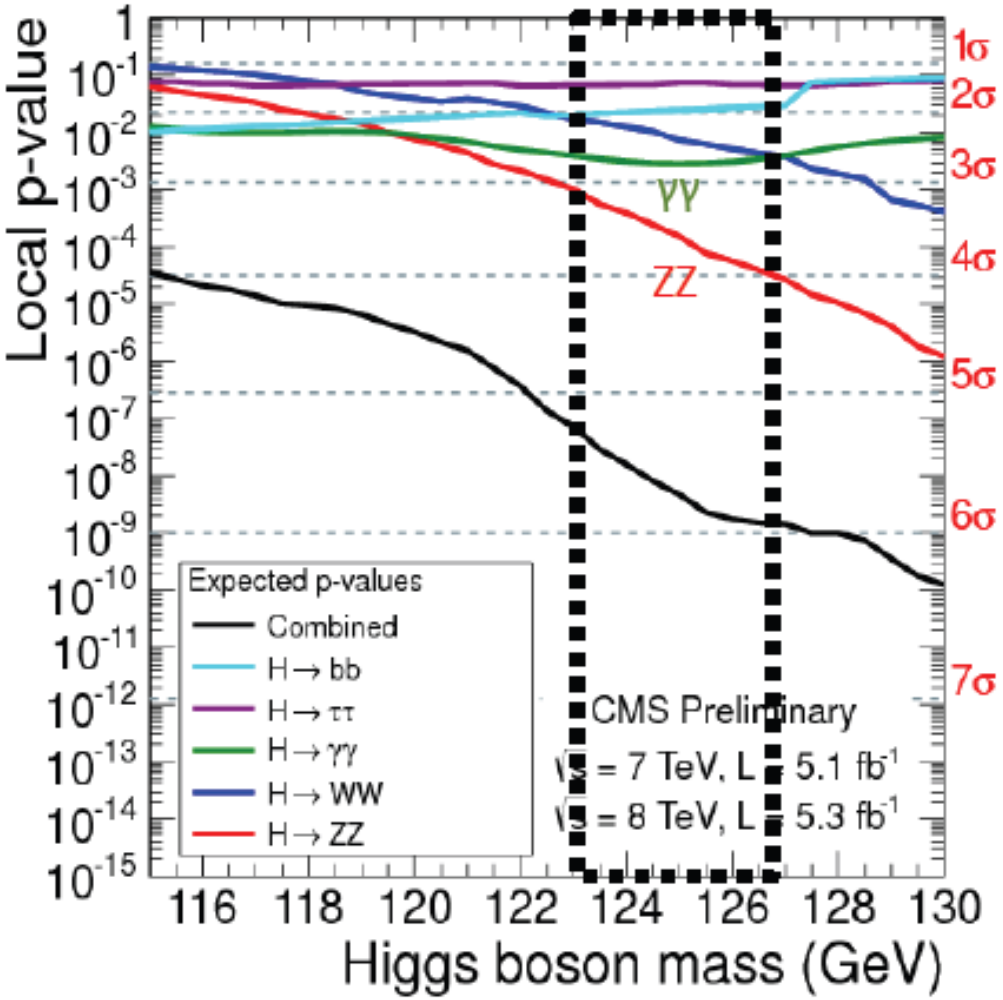


Higgs boson decays

- 5 Channels
  - WW
  - ZZ
  - bb
  - ττ
  - γγ
- Best mass resolution
  - ZZ → 4l
  - γγ

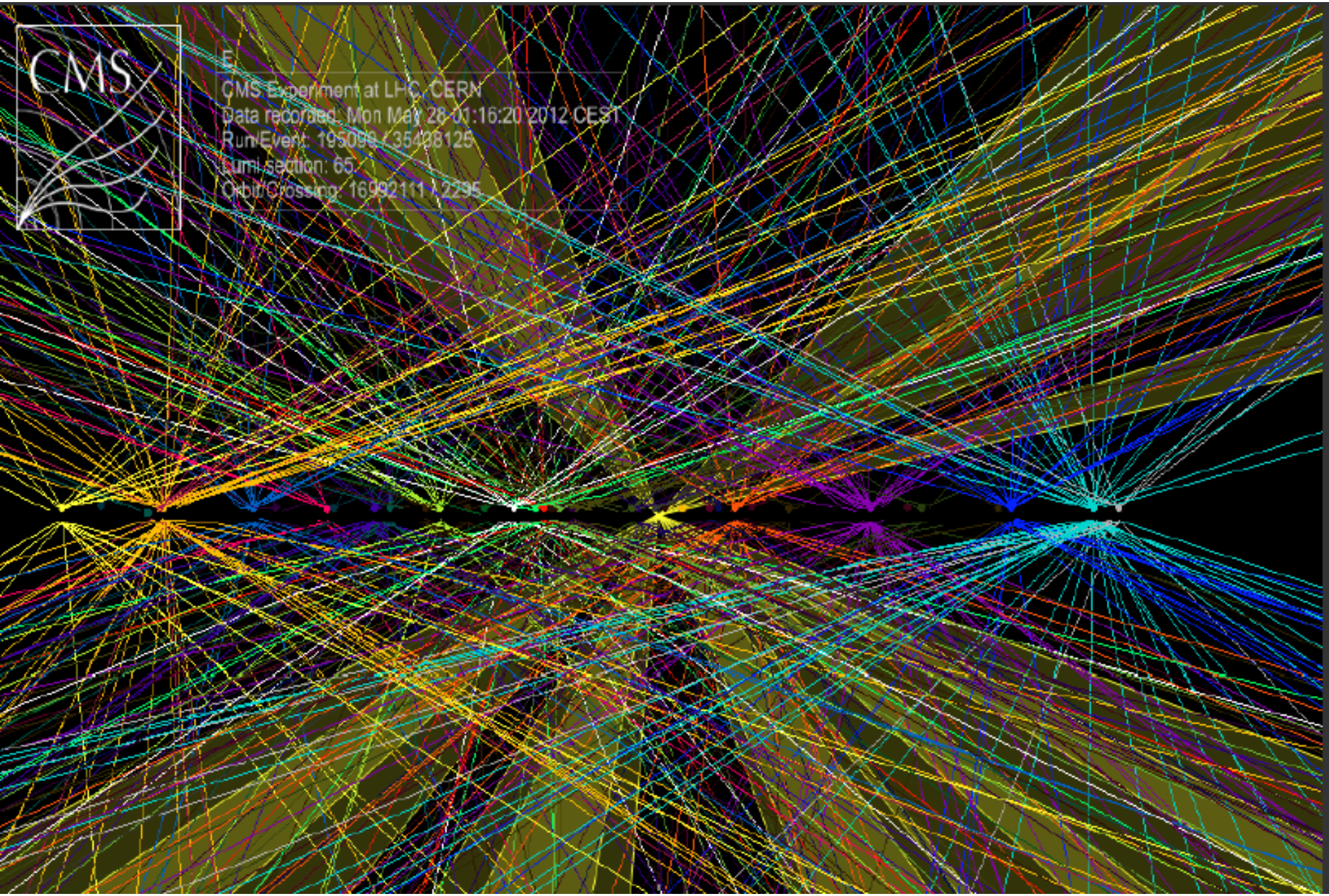


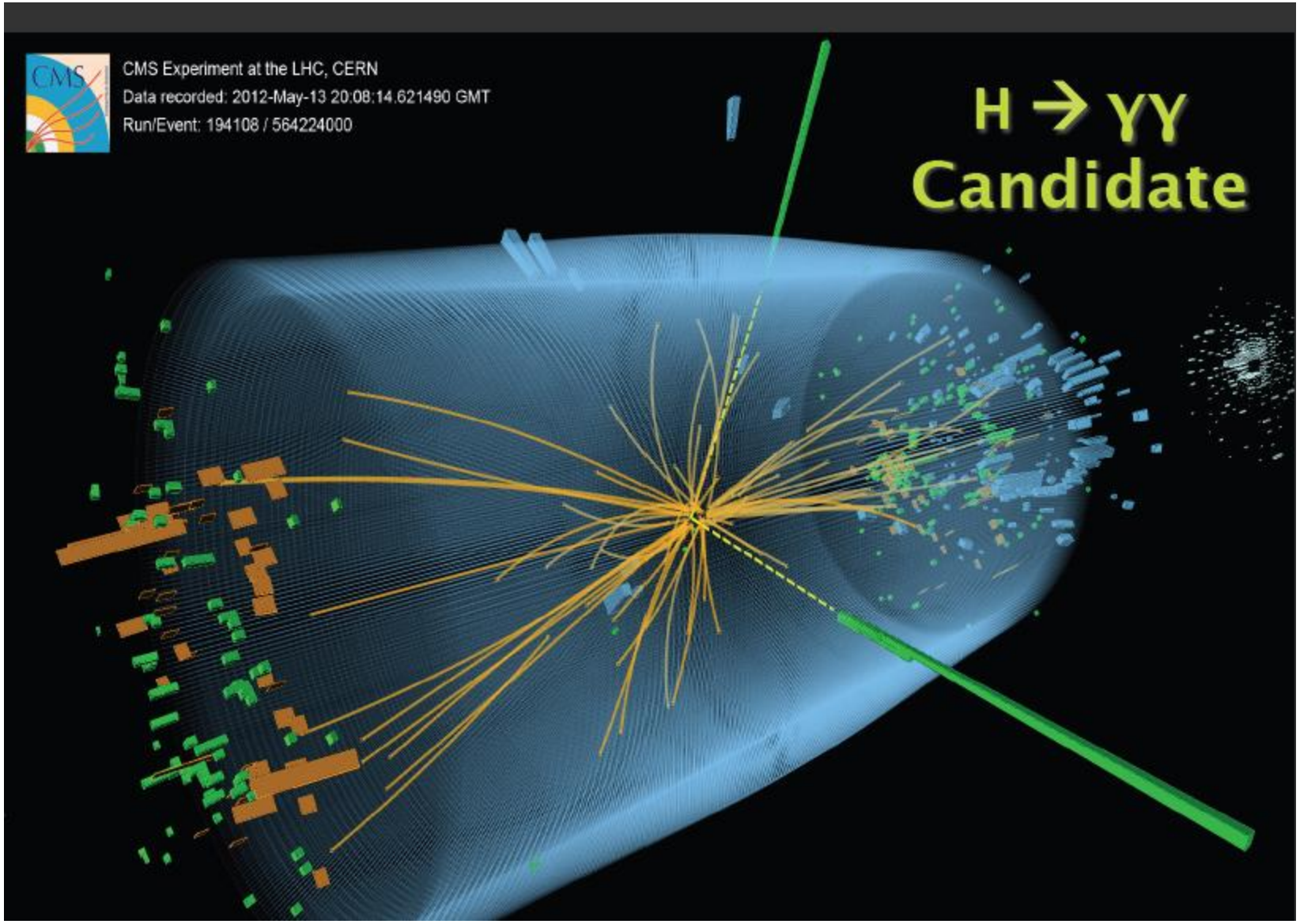
CMS Discovery Potential



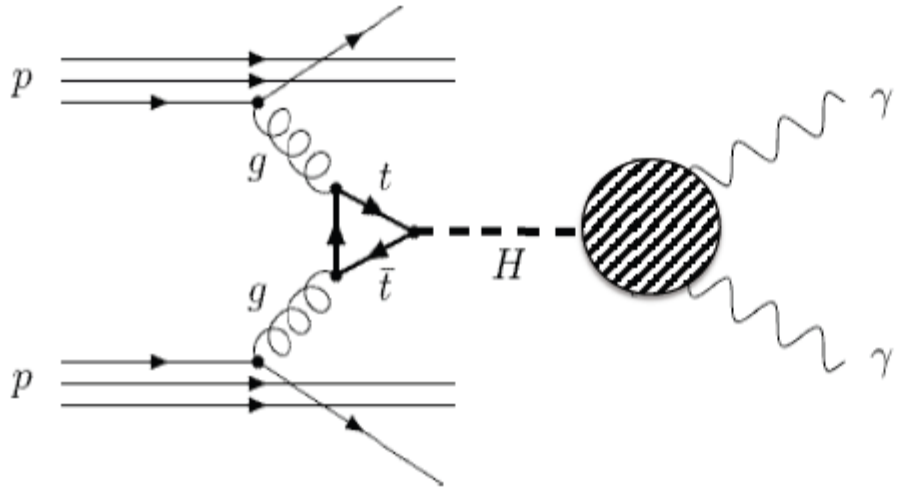
p-values

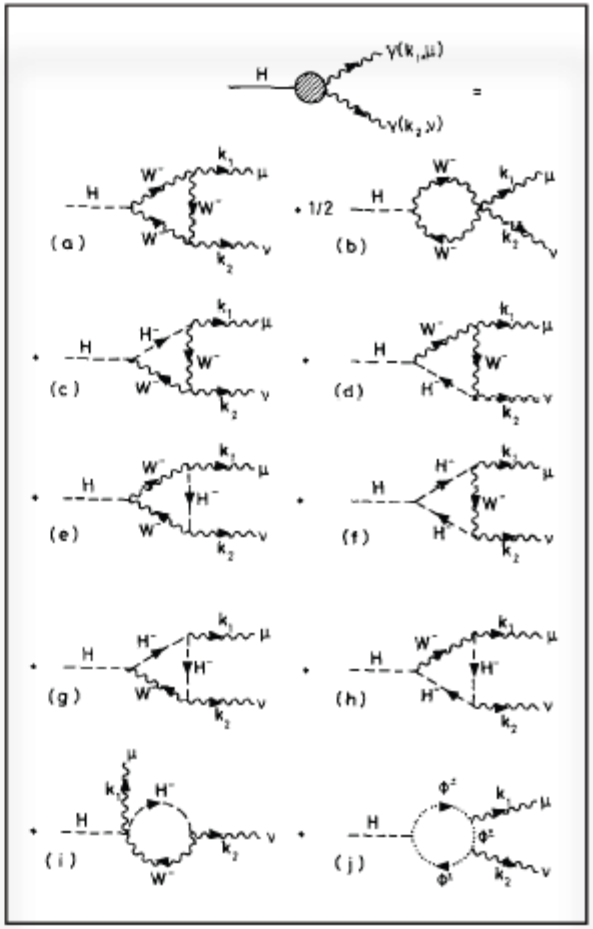
- Probability that the background fluctuates to an excess as large as the (average) signal expected for a SM Higgs.


CMS
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35408125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H → γγ
Candidate

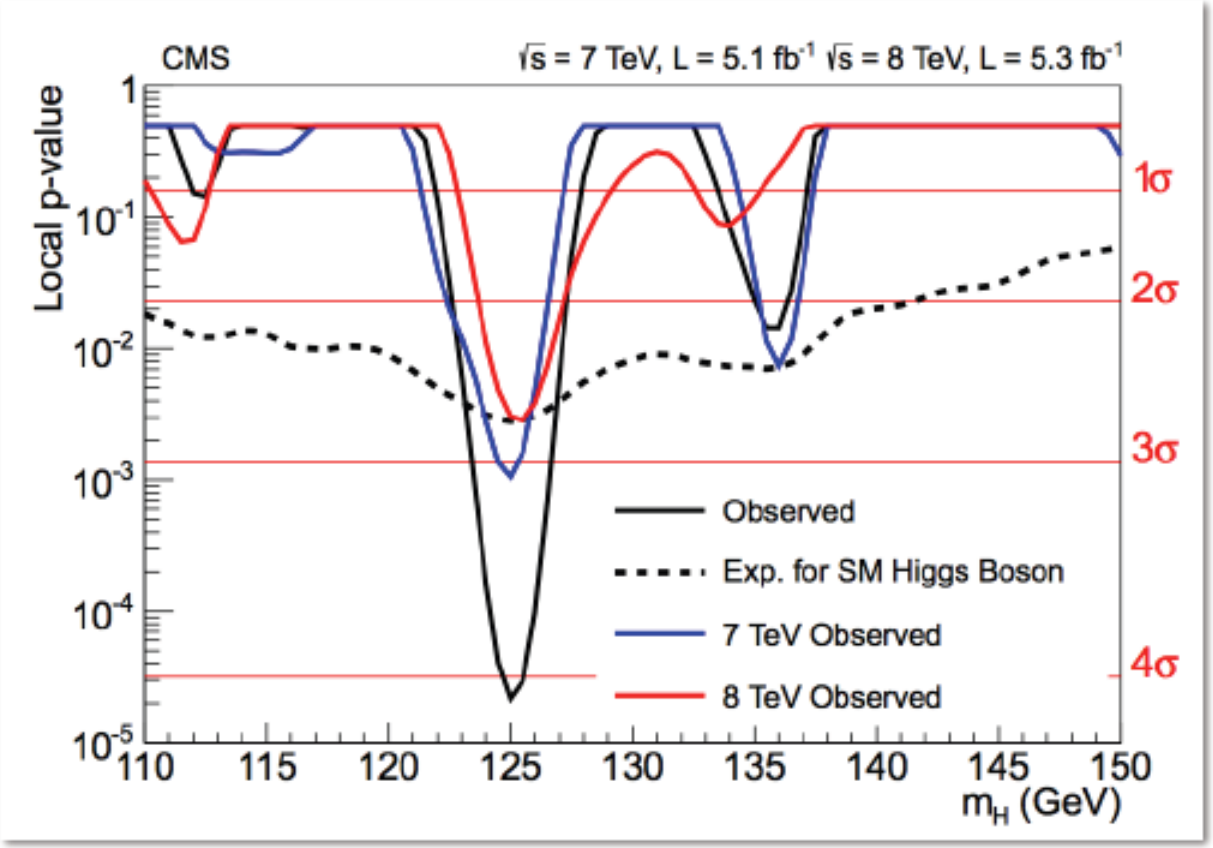
$pp \to gg \to H \to \gamma\gamma$





Ellis, Gaillard, Nanopoulos (1976)

p-Values for the γγ Channel



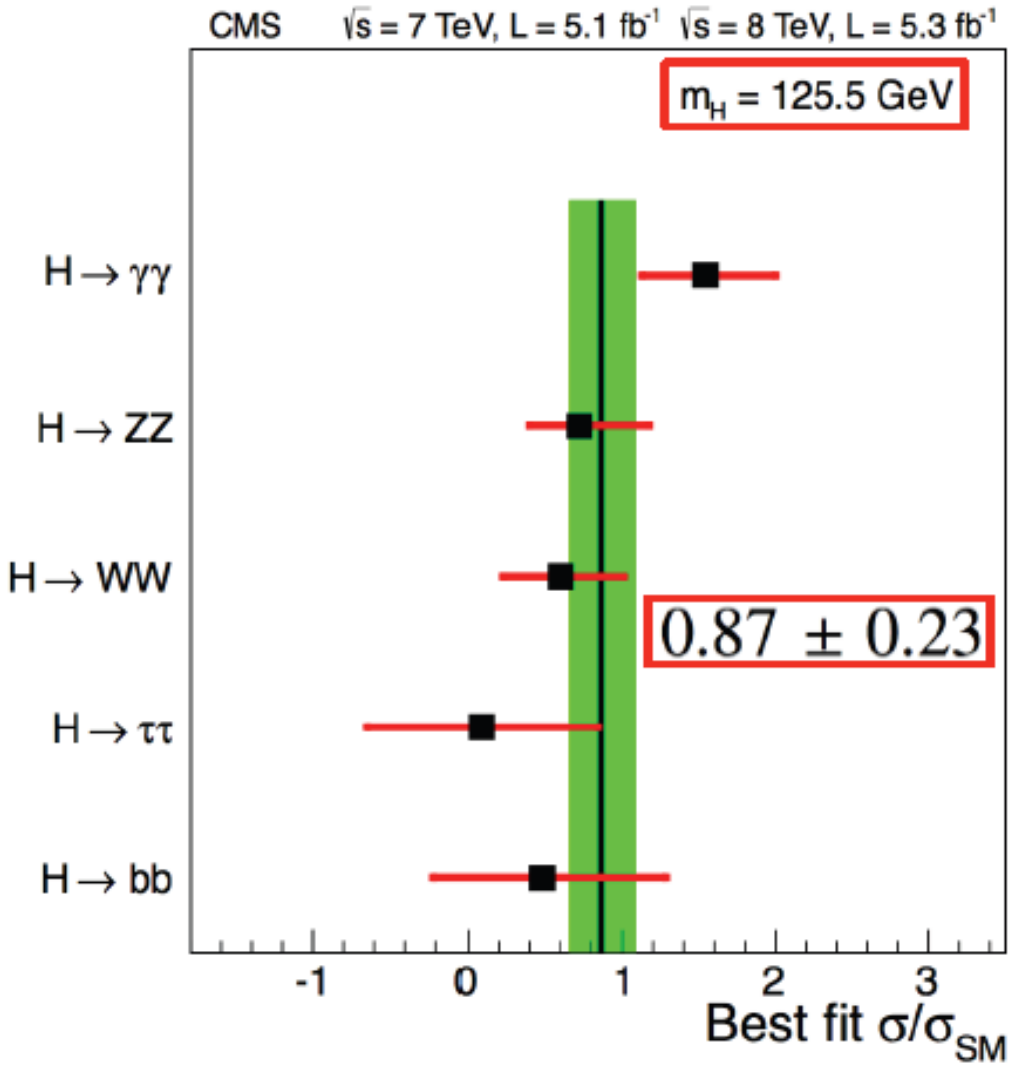
Minimum local p-value at 125 GeV with a local significance of 4.1 σ

Similar excess in 2011 and 2012

Independent cross check analyses give similar results

Global significance in the full search range (110-150 GeV): 3.2 σ

Compatibility with the SM Higgs Boson



CMS Conclusion

A new boson was observed

with a mass of

$125.3 \pm 0.4\ (\text{stat}) \pm 0.5\ (\text{syst})$

at significance level of

$5\ \sigma$

ATLAS Conclusion

Clear evidence for the production of a neutral boson with mass of

126.0 ± 0.4 (stat) ± 0.4 (sys) GeV

and significance of

5.9 σ

corresponding to a background fluctuation probability of

1.7×10^{-9}

I think we have it. Do you agree?

Rolf-Dieter Heuer
Director General of CERN
4 July 2012

Obrigado pela atenção!