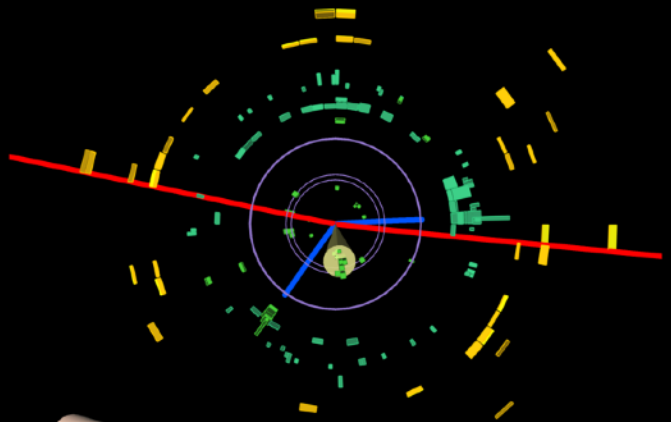
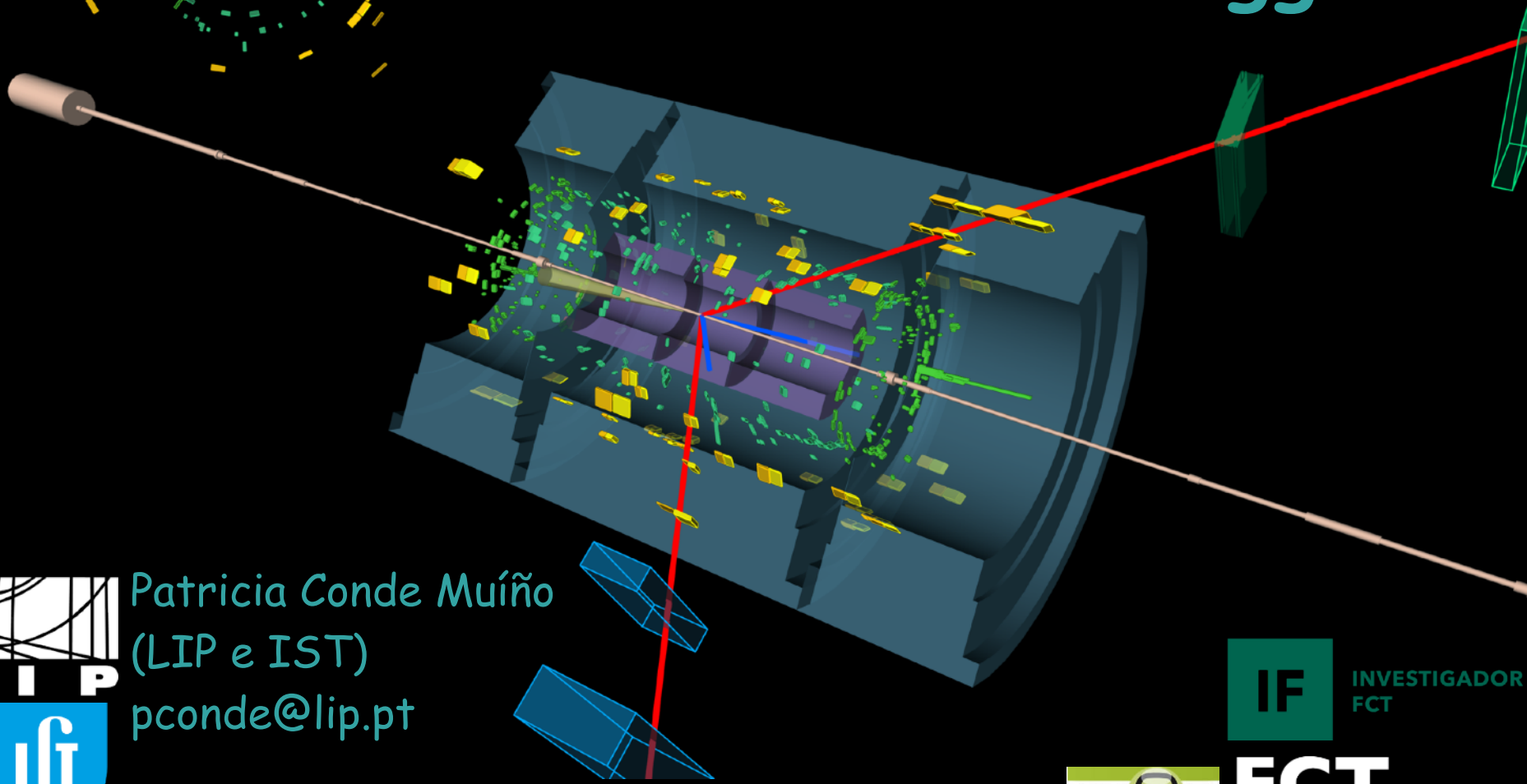


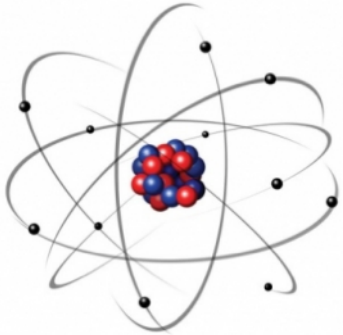
O bosão de Higgs

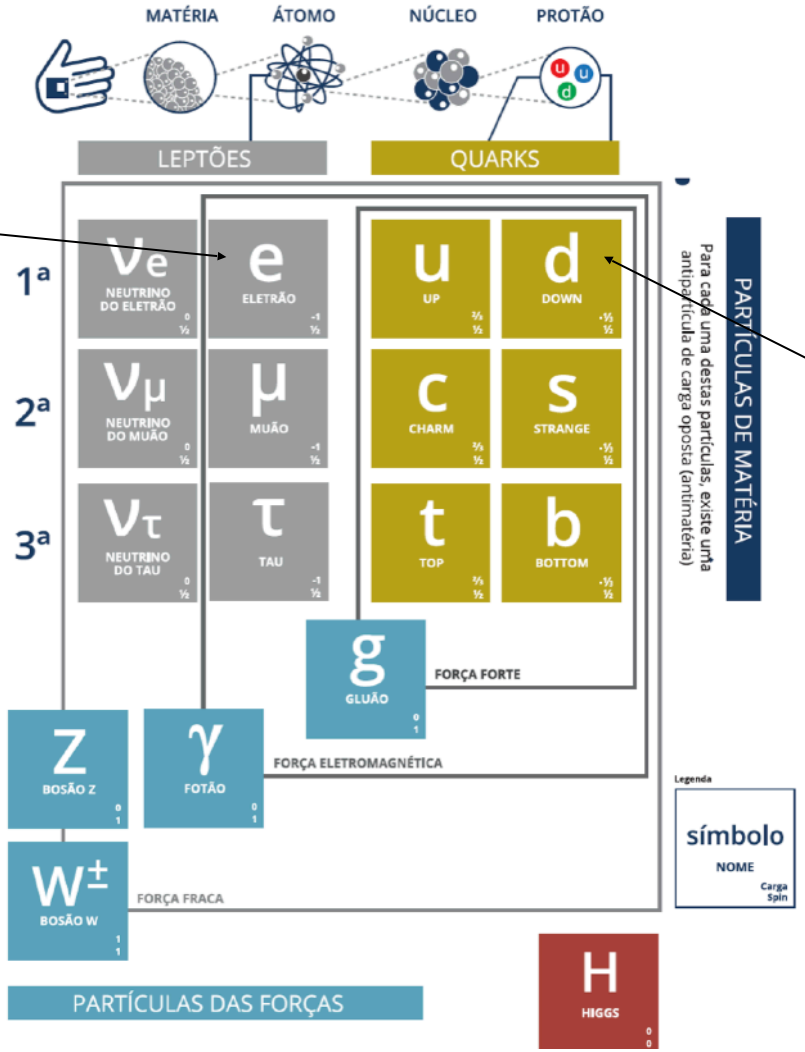


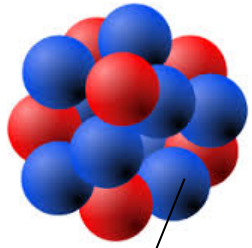
Patricia Conde Muíño
(LIP e IST)
pconde@lip.pt

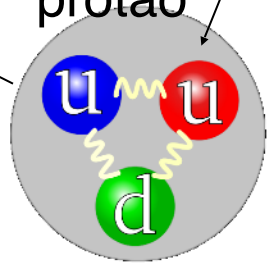
IF INVESTIGADOR FCT
POPH PROGRAMA OPERACIONAL POTENCIAL HUMANO
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

O Modelo Padrão da Física de Partículas



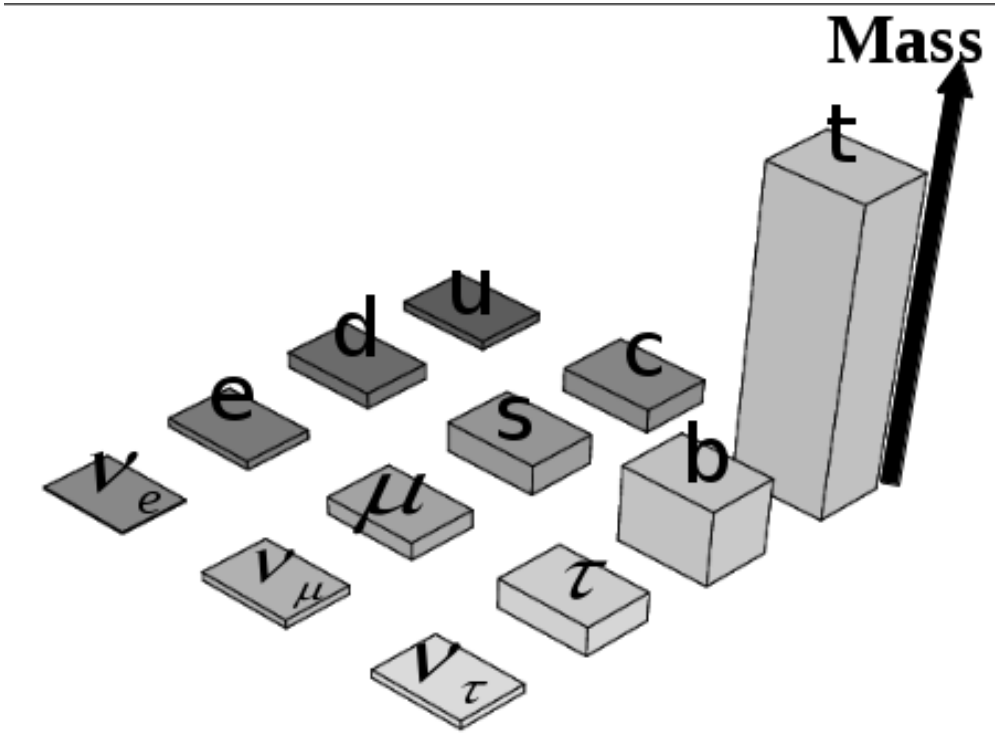






O problema da massa no Modelo Padrão

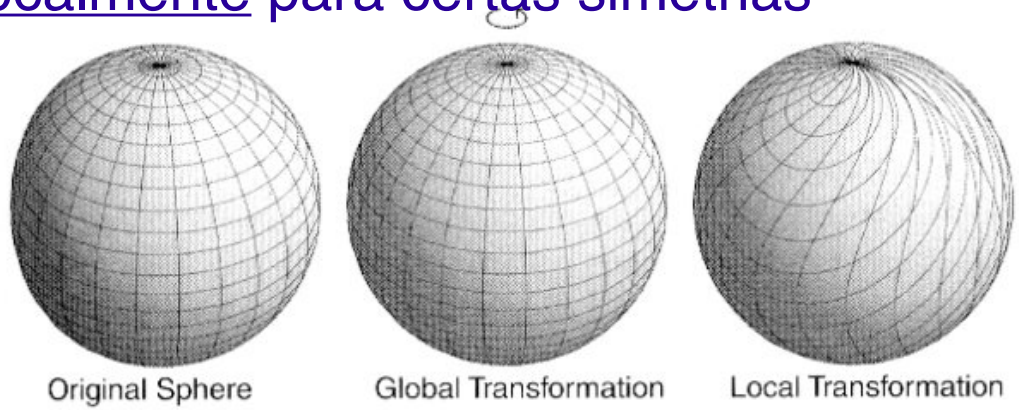
- Porque uma diferença tão grande nas massas d fundamentais?



Simetrias na Teoria de Campo

- Simetrias → Interações!

  equações invariantes localmente para certas simetrias



Grupo de simetrias do Modelo Padrão

mudança de fase	rotações em 3D	generalização do SU(2)

$$U(1) \times SU(2) \times SU(3)$$

Fotão Electromagnetismo	Interacções fracas Bosões W^+, W^-, Z	Interação forte Gluões

Interacções electrofracas

- Introduzidas no MP através de uma teoria gauge baseada na simetria $SU(2)_L \times U(1)_Y$

Lagrangiano das partículas libres

$$\mathcal{L} = -\frac{1}{2} \boldsymbol{W}_{\mu\nu} \cdot \boldsymbol{W}^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

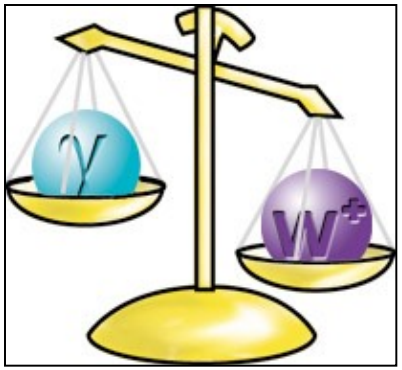
Termos cinéticos e de interacção dos campos W e B

$$+ \overline{\psi}_L \gamma^\mu \left(i\partial_\mu - g' \frac{Y}{2} B_\mu - g \frac{1}{2} \boldsymbol{\tau} \cdot \boldsymbol{W}_\mu \right) \psi_L$$

$$+ \overline{\psi}_R \gamma^\mu \left(i\partial_\mu - g' \frac{Y}{2} B_\mu \right) \psi_R$$

Interacções fermiónicas

- Os termos de massa violam a simetria!
- Como se resolve isto?



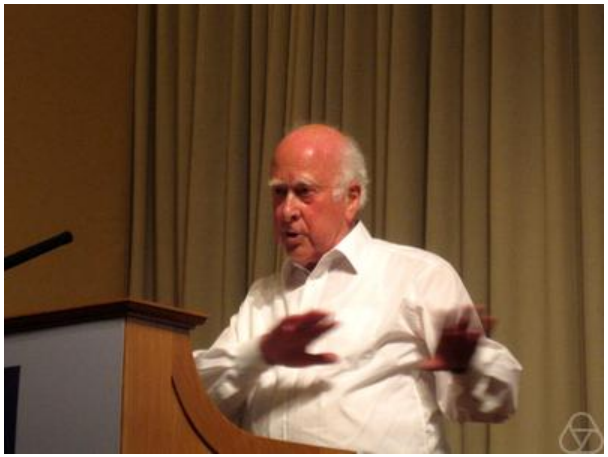
Solução

★Mecanismo de Higgs

★(ou Mecanismo de Higgs-Brout-Englert

★ou Mecanismo de Higgs-Brout-Englert-Guralnik-Hagen-Kibble)

★Proposto em 1964 por 3 grupos distintos

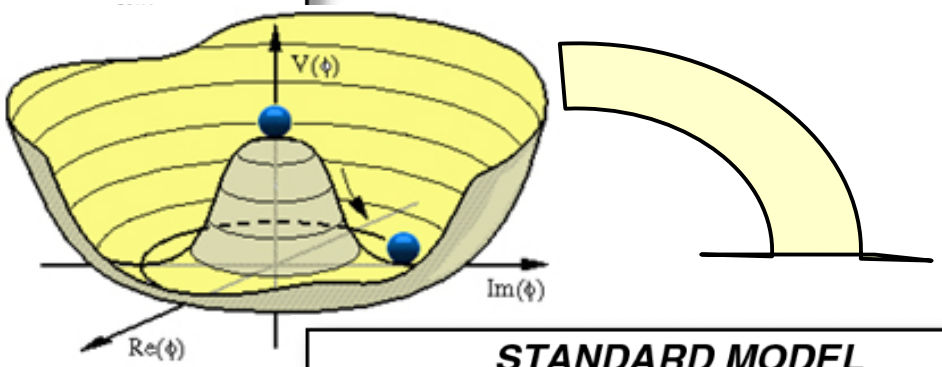


O mecanismo de Higgs

HIGGS FIELD

Complex weak isospin scalar doublet Φ with scalar potential $V[\Phi]$

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad V[\Phi] = \mu^2 \Phi^\dagger \Phi + \lambda\,(\Phi^\dagger \Phi)^2 \quad (\lambda > 0,\ \mu^2 < 0)$$



STANDARD MODEL

Yang-Mills $SU(2)_L \times U(1)_Y$

massless gauge bosons W_μ and B_μ

and *massless* fermions ψ

$$\mathcal{L} = -\frac{1}{2} W_{\mu\nu} \cdot W^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$
$$+ \left| \left(i\partial_\mu - g' \frac{Y}{2} B_\mu - g \frac{1}{2} \boldsymbol{\tau} \cdot W_\mu \right) \Phi \right|^2 - V(\Phi)$$
$$+ \bar{\psi}_L \gamma^\mu \left(i\partial_\mu - g' \frac{Y}{2} B_\mu - g \frac{1}{2} \boldsymbol{\tau} \cdot W_\mu \right) \psi_L$$
$$+ \bar{\psi}_R \gamma^\mu \left(i\partial_\mu - g' \frac{Y}{2} B_\mu \right) \psi_R$$

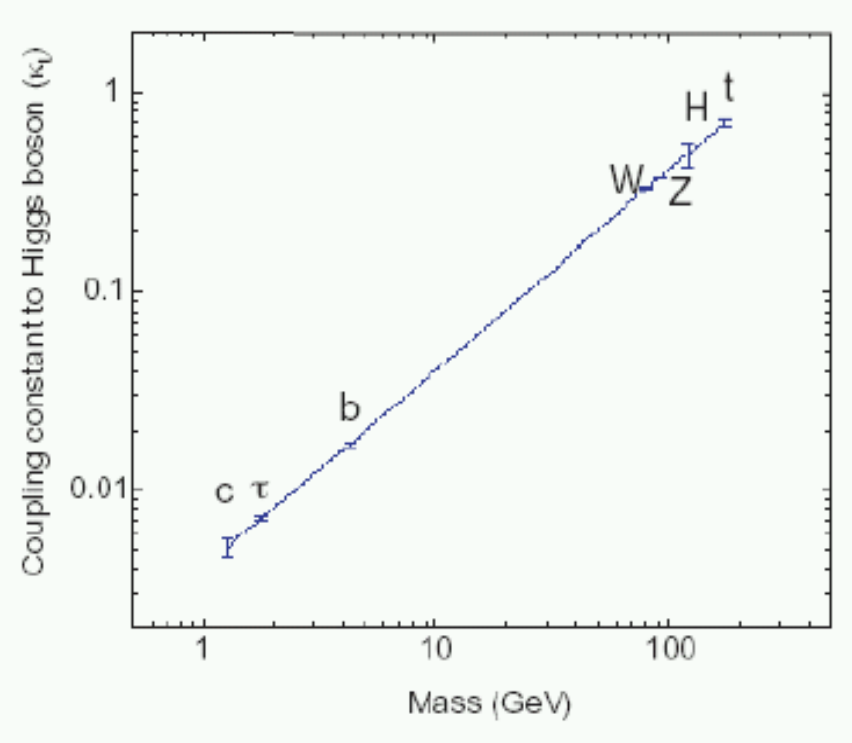
SPONTANEOUS SYMMETRY BREAKING

One component acquires non-zero vacuum expectation value

$$\langle 0|\Phi|0\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \longrightarrow \Phi(x) = \frac{1}{\sqrt{2}} \exp\left(i \frac{\xi \cdot \tau}{2v} \right) \begin{pmatrix} 0 \\ v + H(x) \end{pmatrix}$$

Prevê uma nova partícula: o Bosão de Higgs!

As massas



- As massas das partículas são proporcionais ao seu acoplamento ao bosão de Higgs
- Declive predito pela teoria:
  $v = 2M_W/g = 246$ GeV
- Acoplamentos aos fermiões determinados experimentalmente a través das medidas das massas

MASSIVE GAUGE BOSONS

$$W_\mu^\pm = \frac{1}{2}(W_\mu^1 \mp iW_\mu^2) \qquad M_W = \frac{gv}{2}$$

$$Z_\mu = -B_\mu \sin\theta_W + W_\mu^3 \cos\theta_W \qquad M_Z = \frac{M_W}{\cos\theta_W}$$

$$A_\mu = B_\mu \sin\theta_W + W_\mu^3 \cos\theta_W \qquad M_\gamma = 0$$

MASSIVE FERMIONS

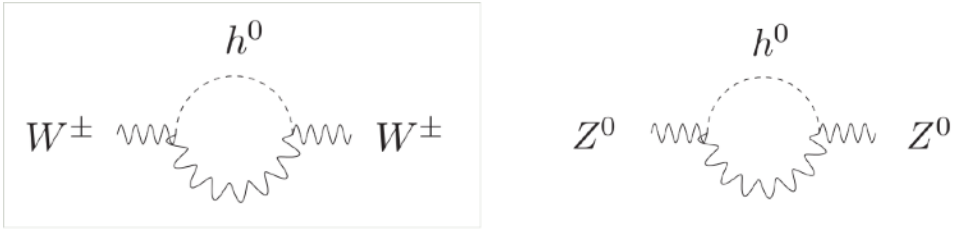
Yukawa couplings of Higgs to fermions

$$g_f\left[\bar{\psi}_L \Phi \psi_R + \bar{\psi}_R \Phi^\dagger \psi_L\right]$$

$$e.g.,\ m_e = \frac{g_e v}{\sqrt{2}}$$

Corrections to EW observables

★Electroweak observables are sensitive to masses of top quark and Higgs through radiative corrections



$$M_W^2 = \rho\, M_Z^2 \cos^2\theta_W$$

$$(\rho-1) \sim M_{top}^2$$

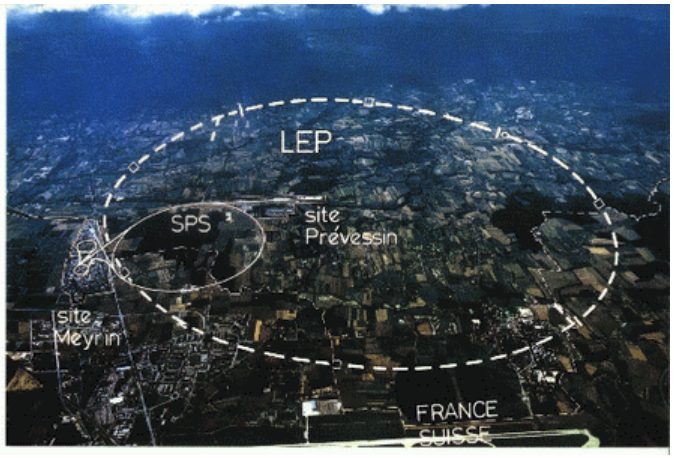
$$(\rho-1) \sim \ln M_H$$

★Precise measurements of electroweak observables can be used to constraint the Higgs boson mass

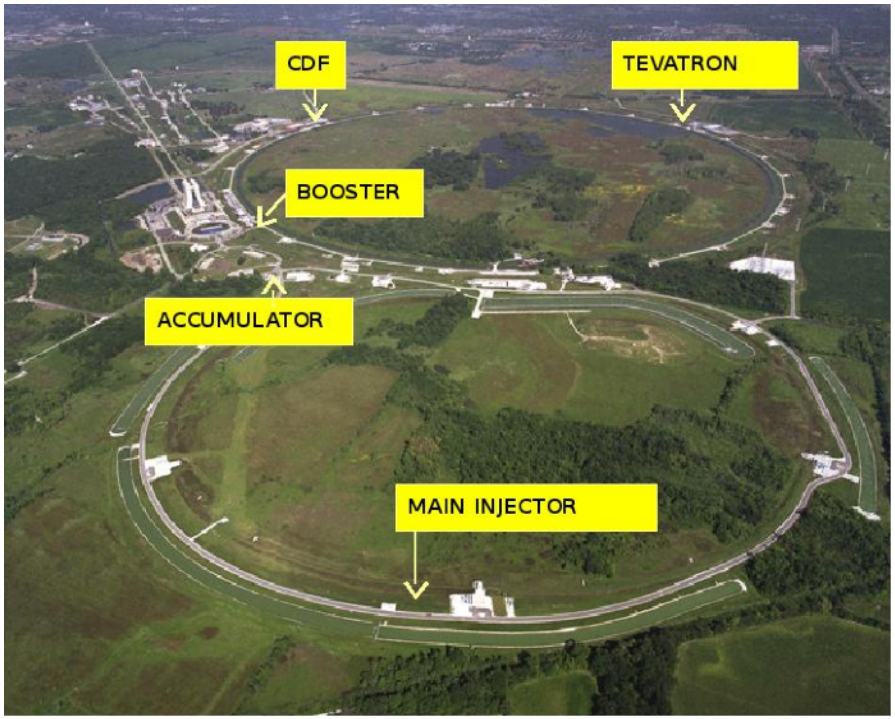
Sensitivity to Higgs mass is only logarithmic:
Need ultra-precise measurements!

20 anos de procuras do Higgs antes do LHC

- LEP: e^--e^+ (CERN)

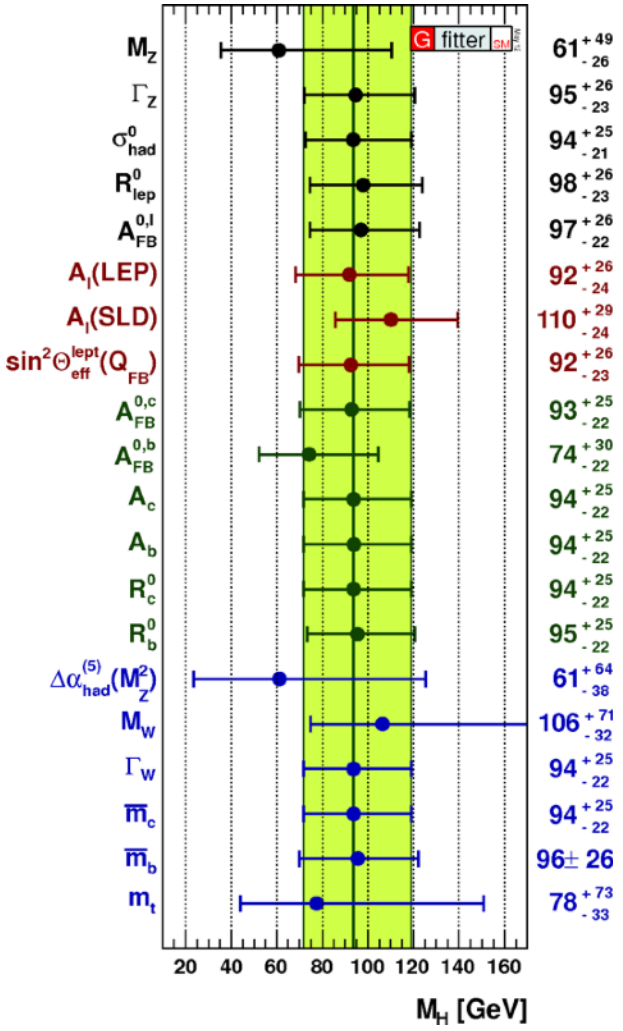


Tevatron p-pbar (Fermilab)



Experimental constraints before the LHC

Large list of observables used in global fits to the electroweak precision data



Experimental constraints before the LHC

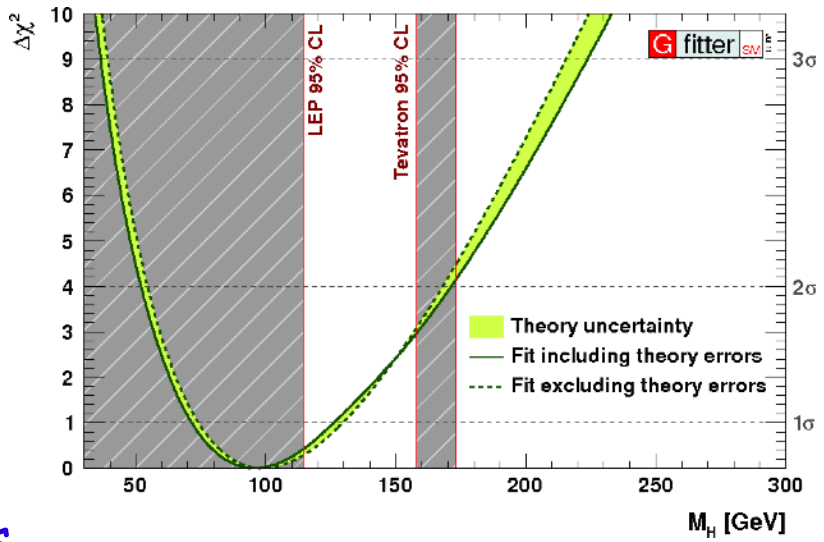
★Fits to the EW observables predict:

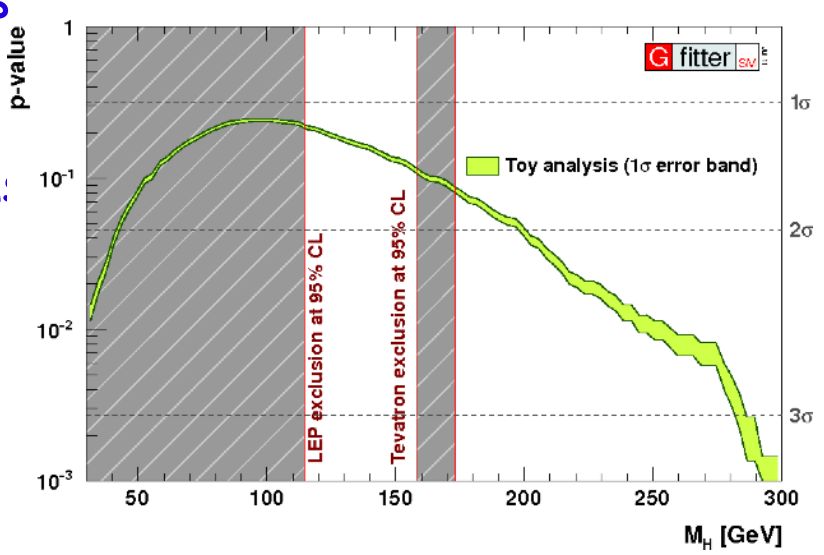
- Best Fit mass: $m_H = 94^{+25}_{-22}$ GeV
- Upper limit at 95% CL from fits:
  - $m_H < 169$ GeV

★But the fit is not too bad for masses up to 200 GeV or so

★Direct searches excluded the region at 95% CL:

- LEP: $m_H < 114.5$ GeV
- Tevatron: $147 < m_H < 180$ GeV

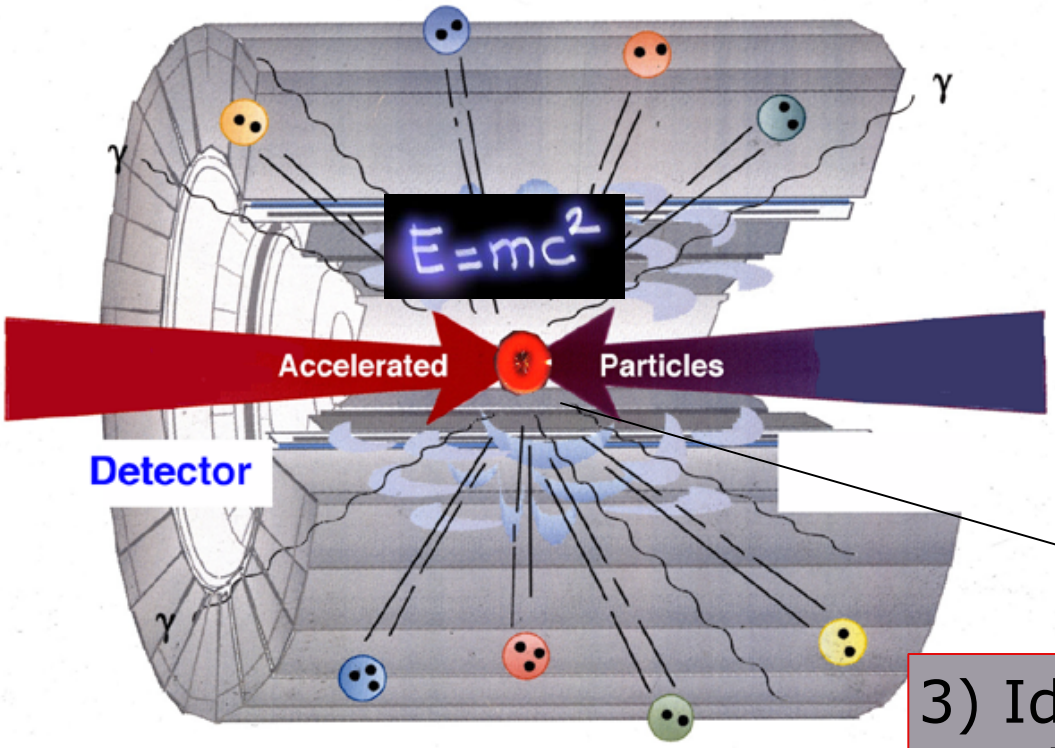




A procura do Higgs no LHC

Desvendando o mistério da massa...

Métodos experimentais

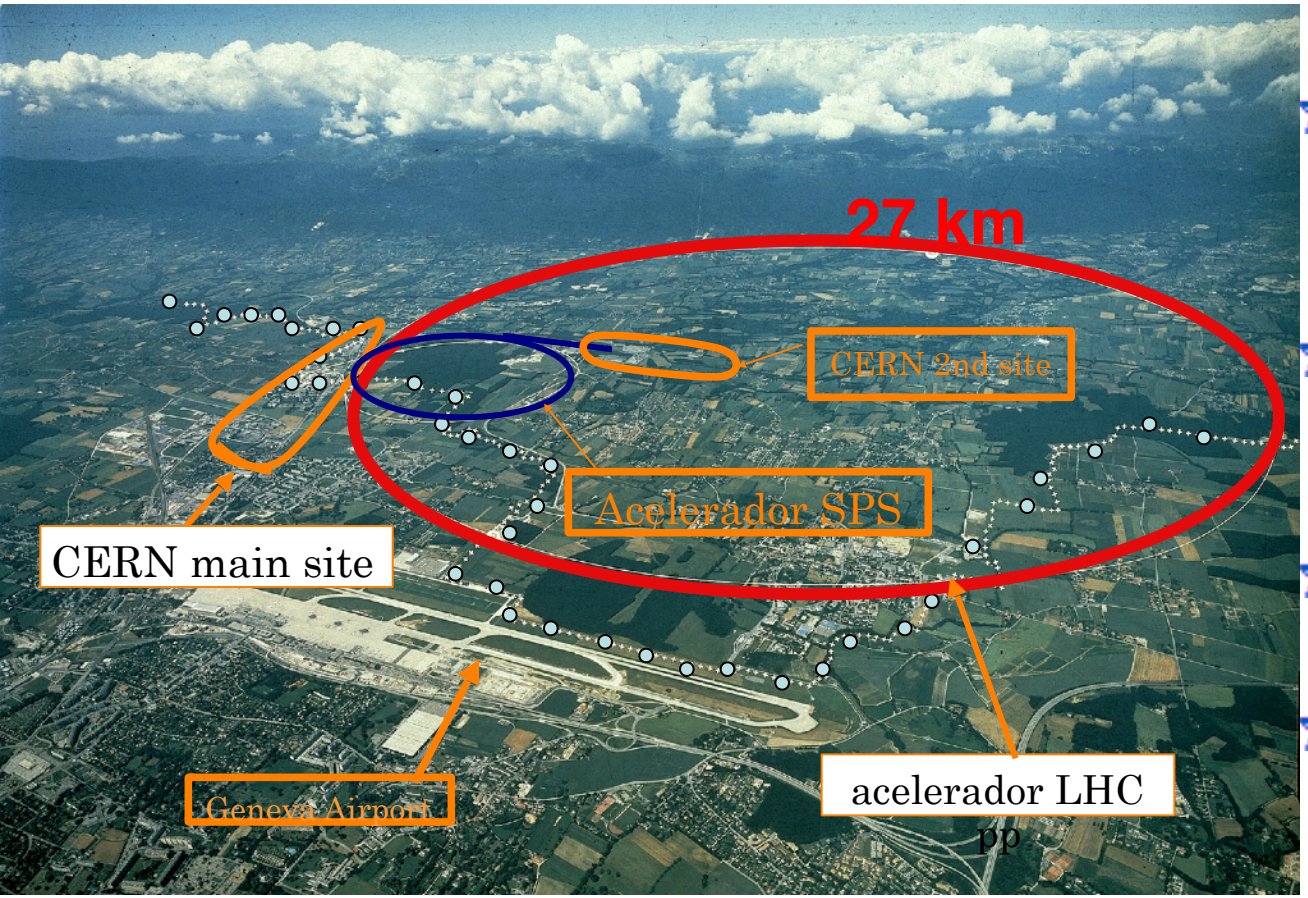


1) Concentrar a energia nas partículas (**acelerador**)

2) **Colidir** partículas

3) Identificar as partículas criadas com o **detector** (investigar novas propriedades)

O Large Hadron Collider (LHC)

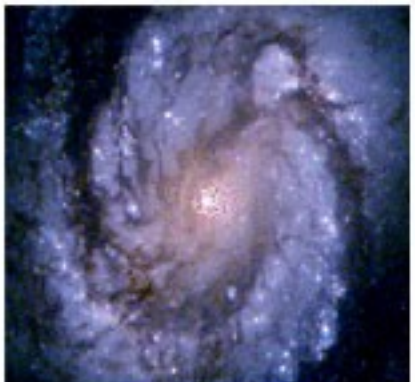


- Colisões pp
  - 7 TeV em 2010/11
  - 8 TeV em 2012
- 40 milhões de cruzamentos dos feixes por segundo!
- Até 40 interações pp num cruzamento!
- 4 experiências
  - ATLAS, CMS, ALICE, LHCb

Energia do LHC

TeV: 10^{12} eV

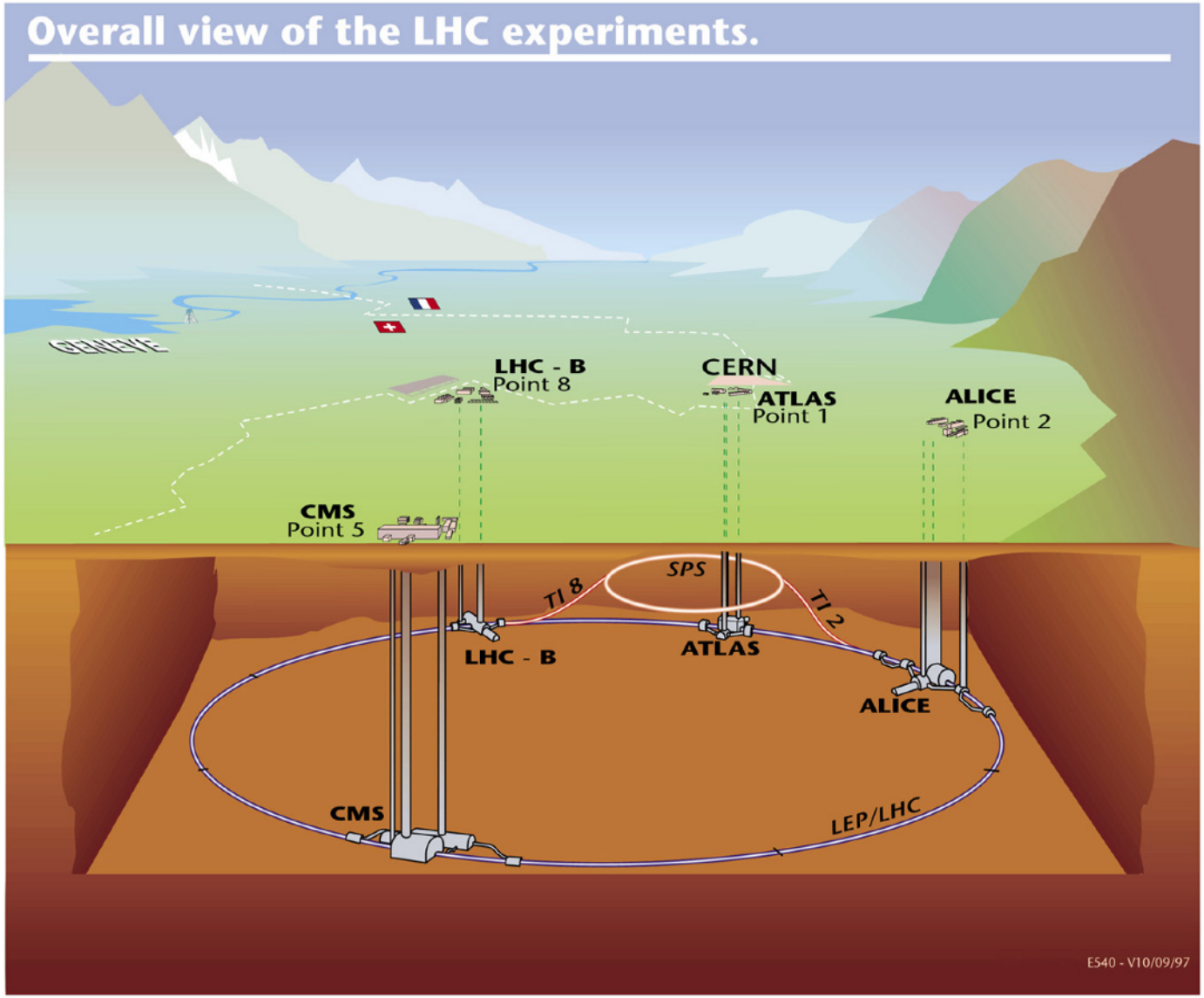
x



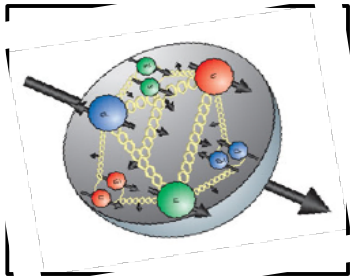
= 1 TeV

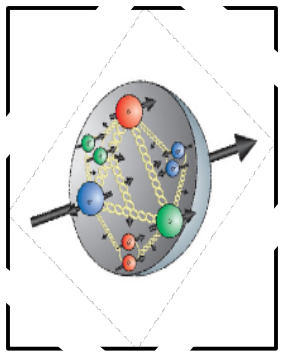
1 TeV é equivalente a 1 bateria por cada estrela da nossa galáxia

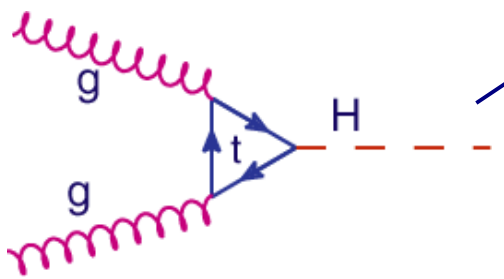
4 experiências no LHC

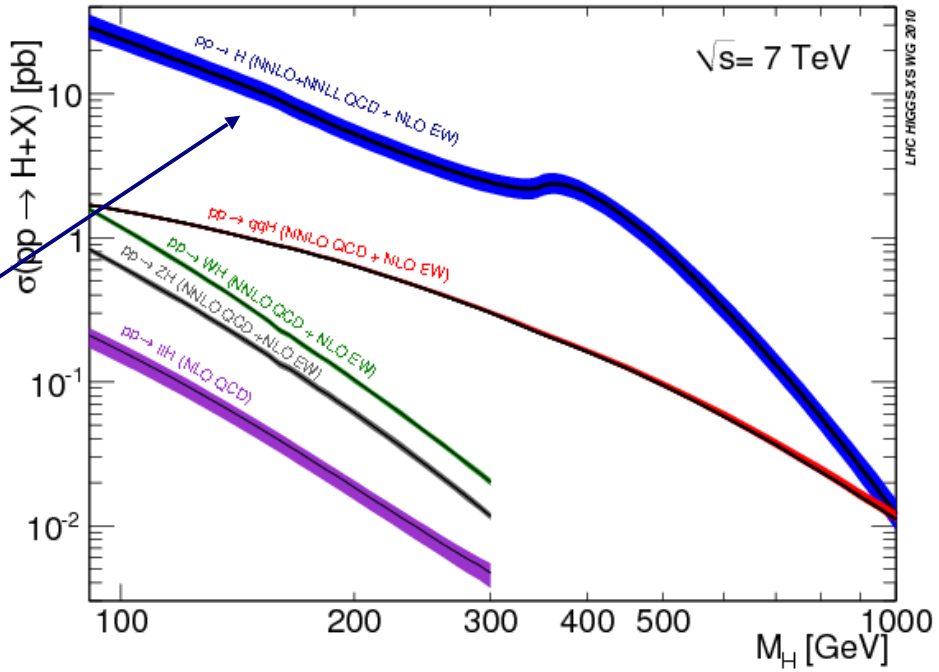


A produção do bosão de Higgs

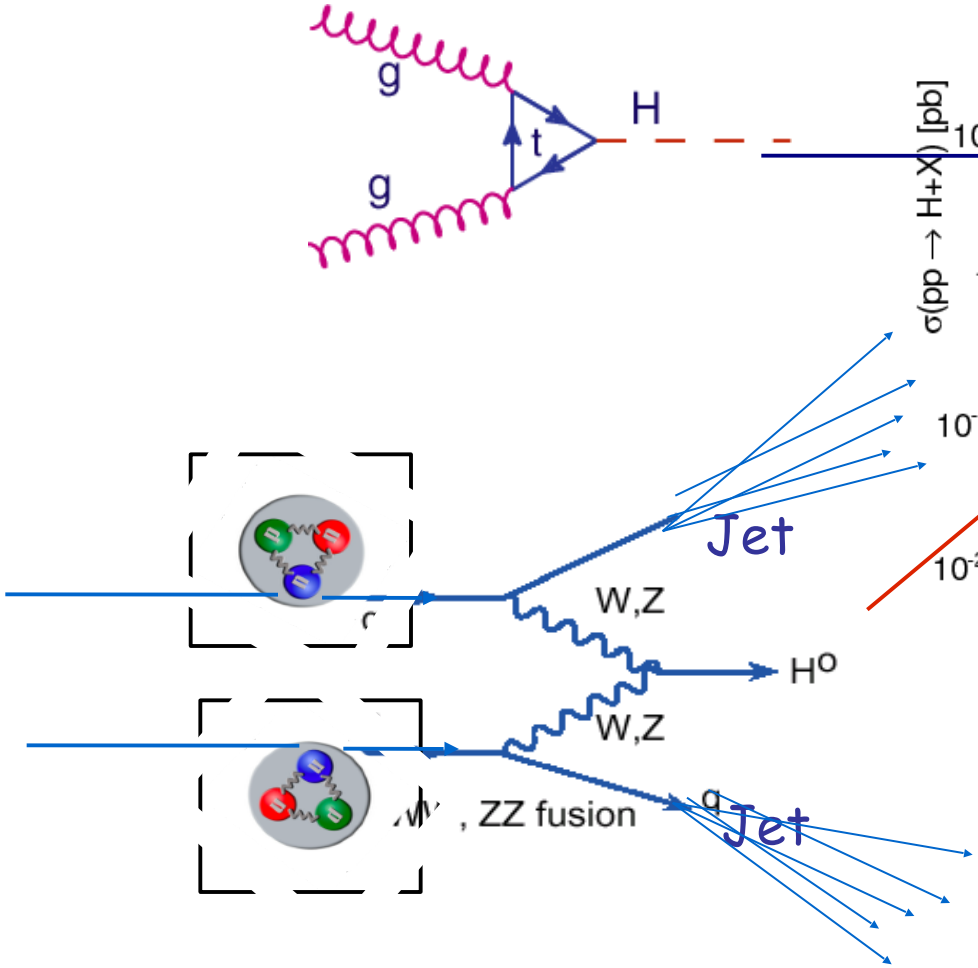


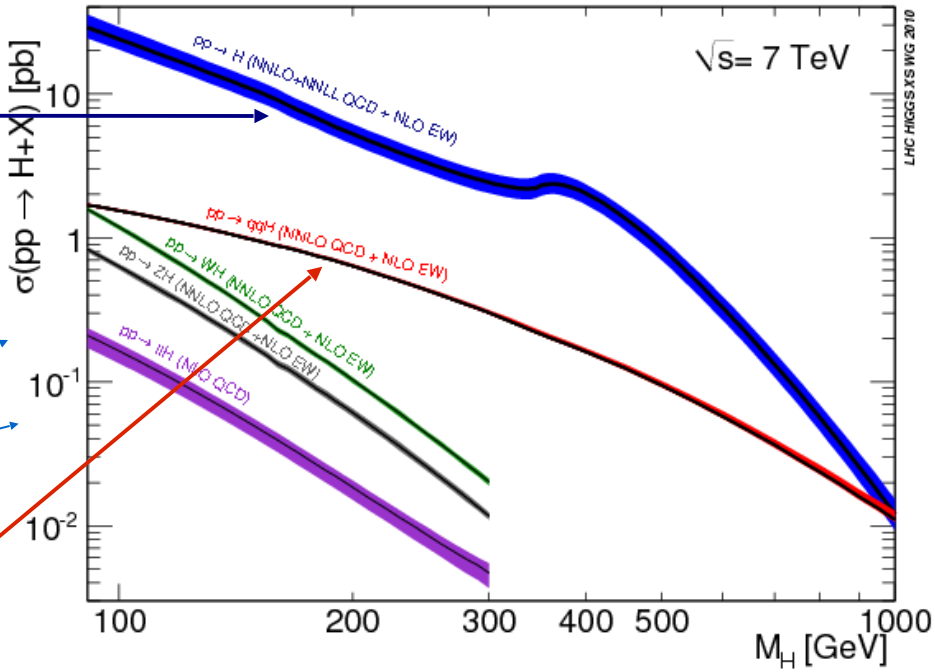




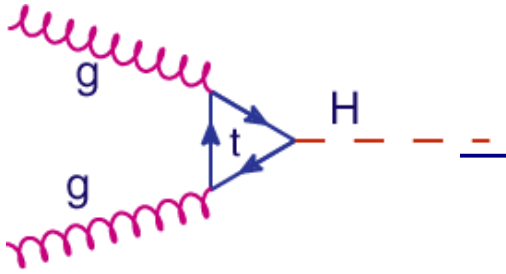


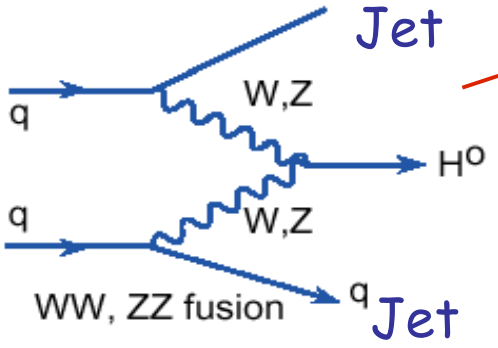
A produção do bosão de Higgs

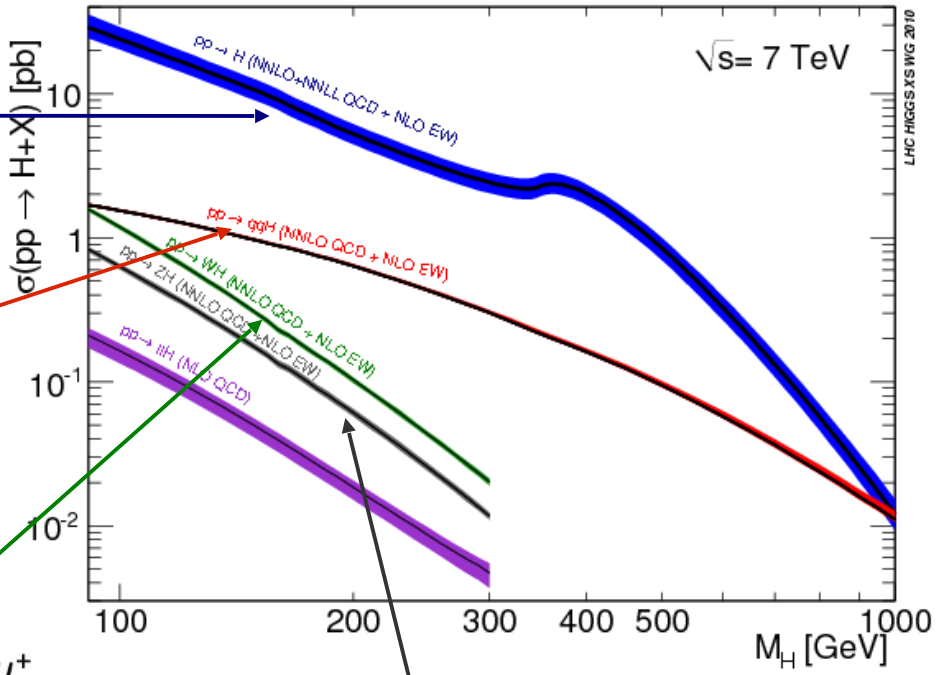


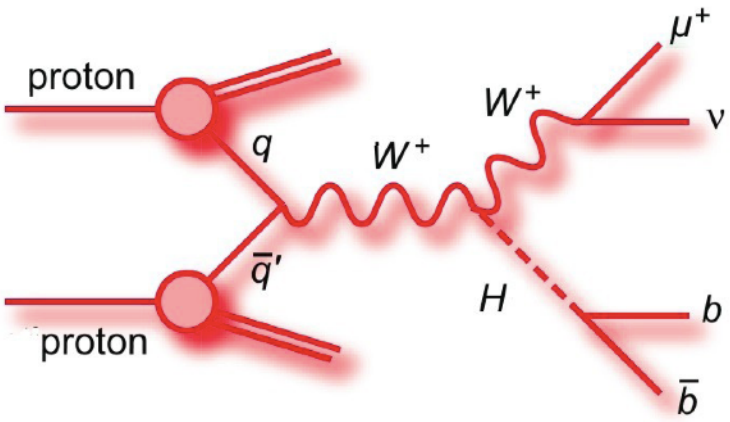


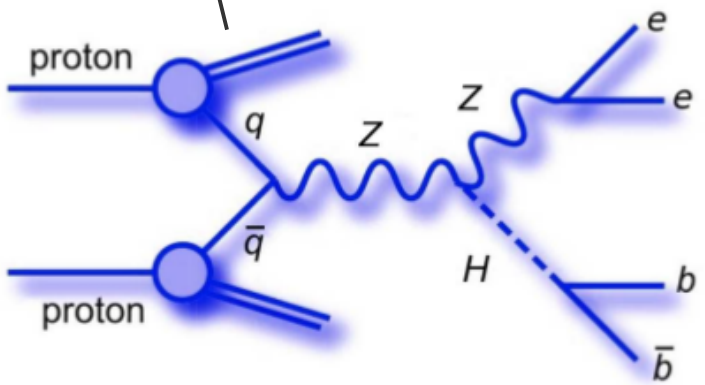
A produção do bosão de Higgs





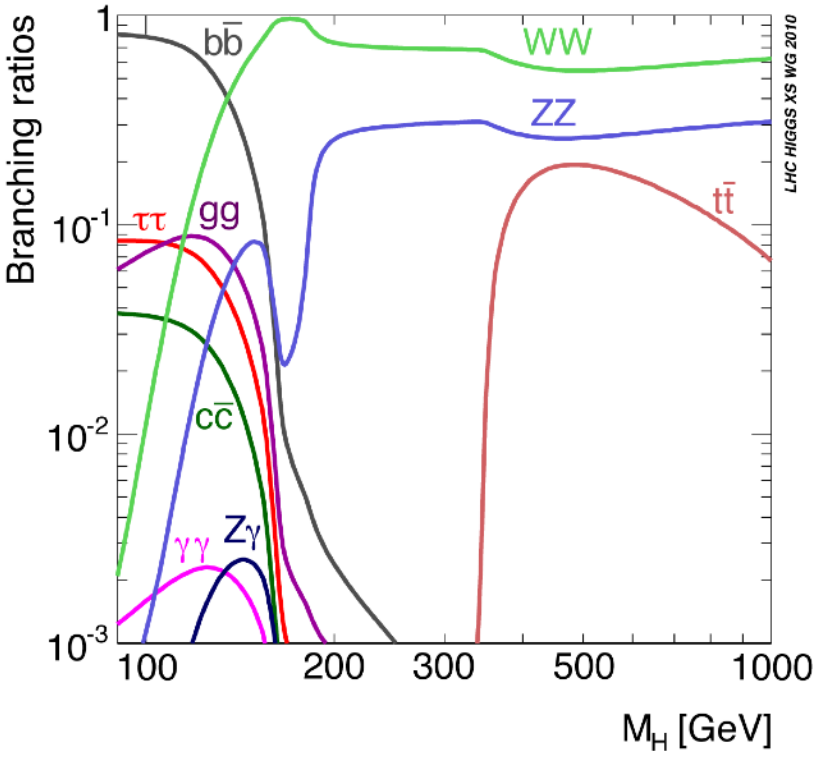






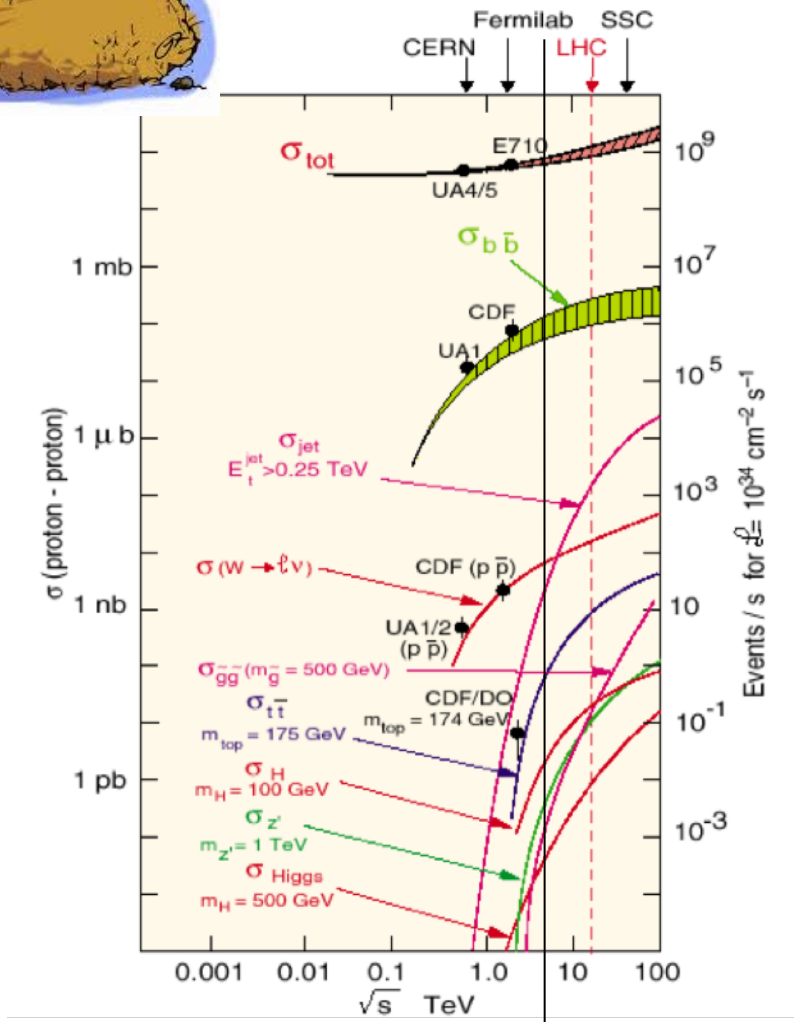
Modos de decaimento do Higgs no MP

- ★O bosão de Higgs decai imediatamer
  - ★ Só podemos observar as partículas desintegração
  - ★ As probabilidades de decaimento de



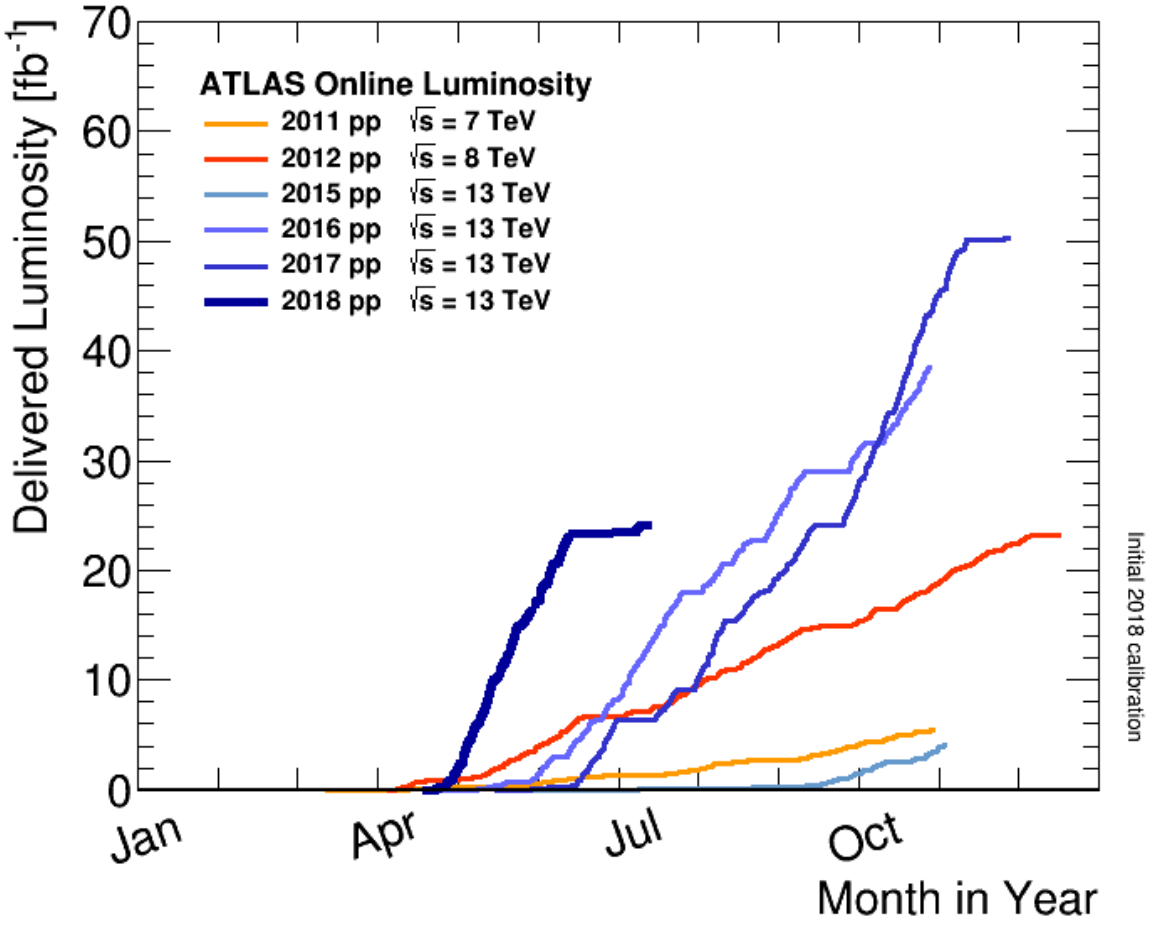
Canal de procura: modo de produção + modo de decaimento

Por que é tão difícil?

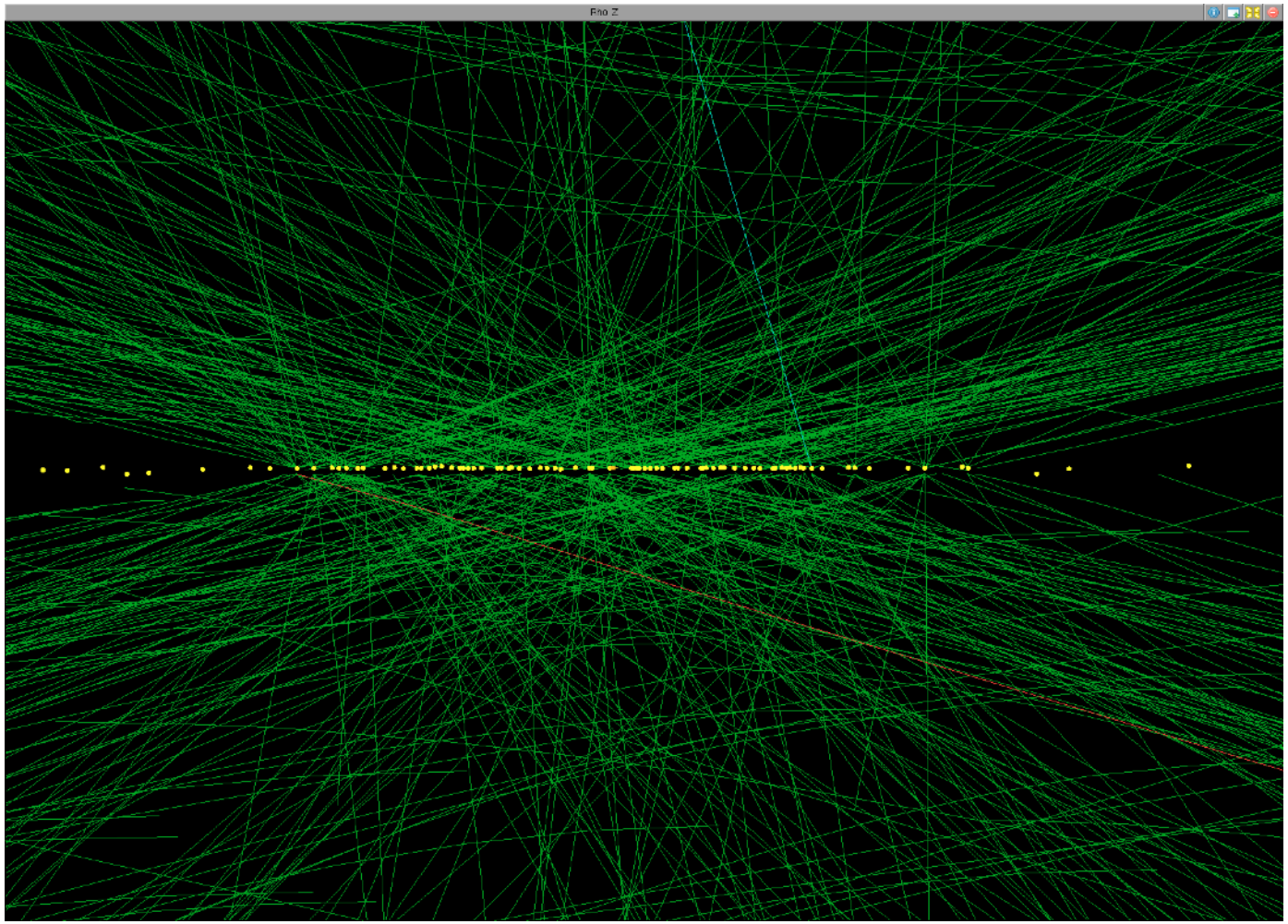


- Secção eficaz de produção de:
  - jatos ~ 100.000.000 vezes maior que a do Higgs
  - Jatos b ~10.000.000 vezes maior que a do Higgs
  - Bosões W: perto de 10000 vezes maior que a do Higgs
- Precisamos de modos de desintegração difíceis de confundir
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow ZZ \rightarrow ll\, l'l'$
  - $H \rightarrow WW \rightarrow l\nu l\nu$

LHC integrated luminosity

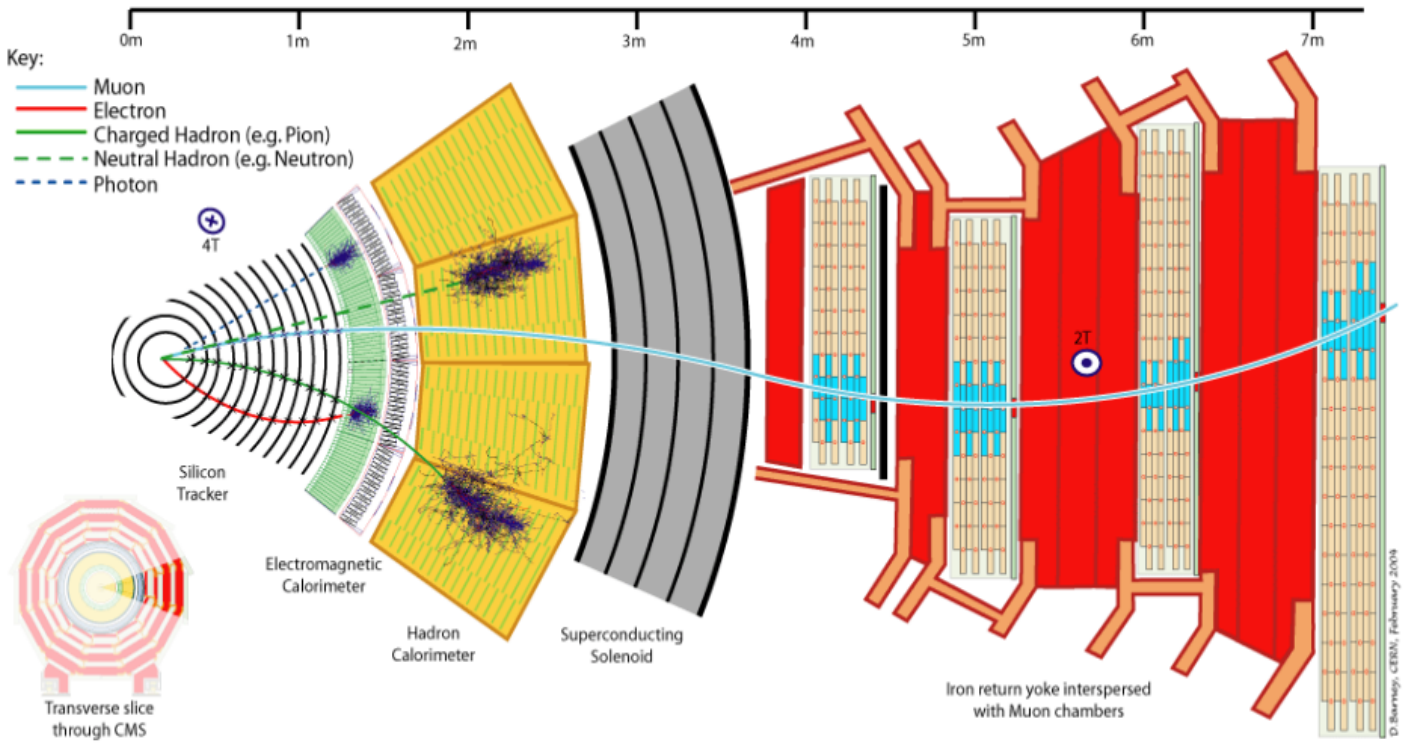


Pile-up



- CMS event
- 78 reconstructed vertices
- Extreme case up to now

Identificação das partículas no CMS



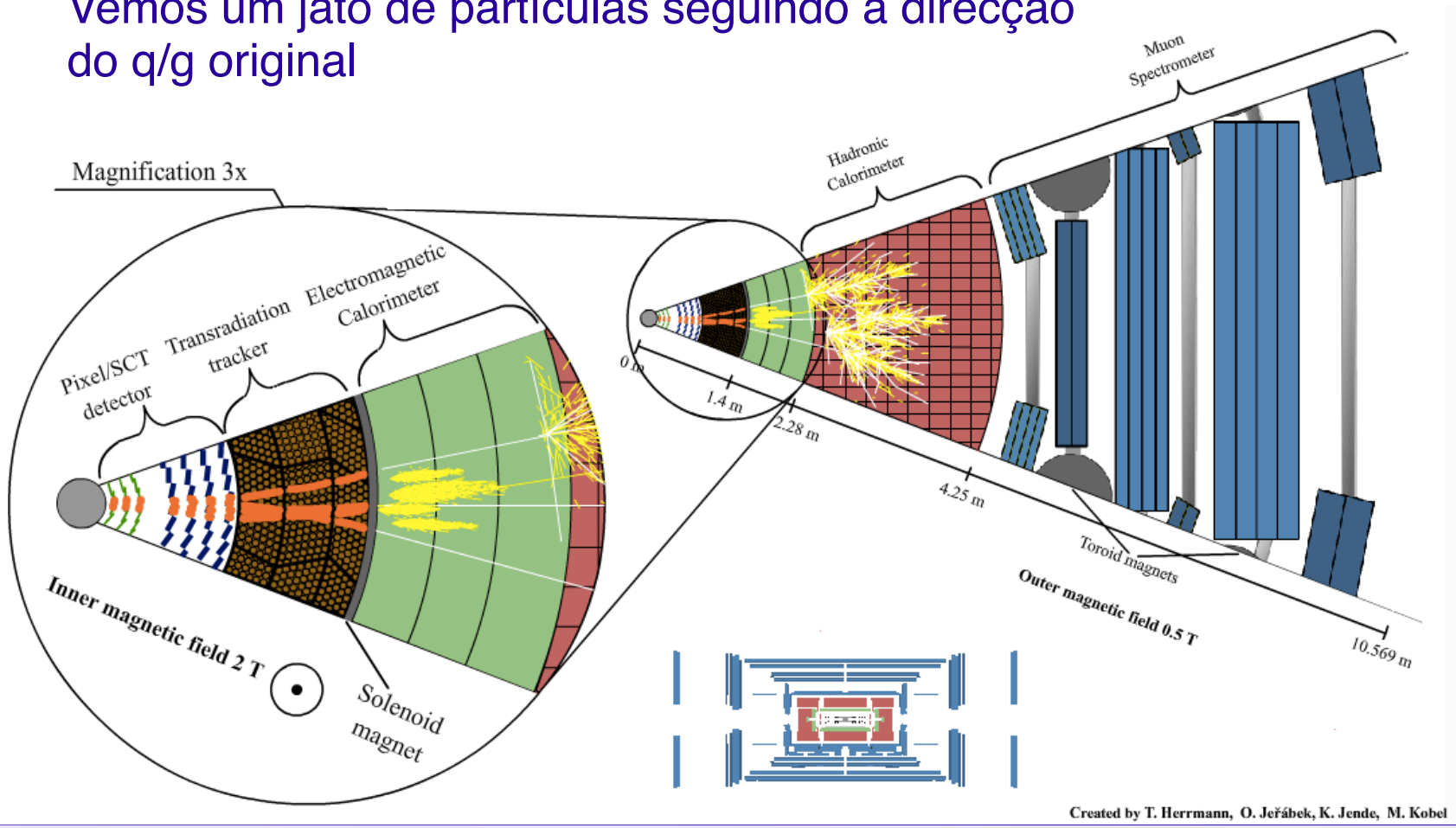
★Princípios básicos do detector CMS: os mesmos que em ATLAS

★Tecnologia, detalhes diferentes

Jatos

- Os quarks e gluões não existem em liberdade: hadronizam

  Vemos um jato de partículas seguindo a direcção do q/g original

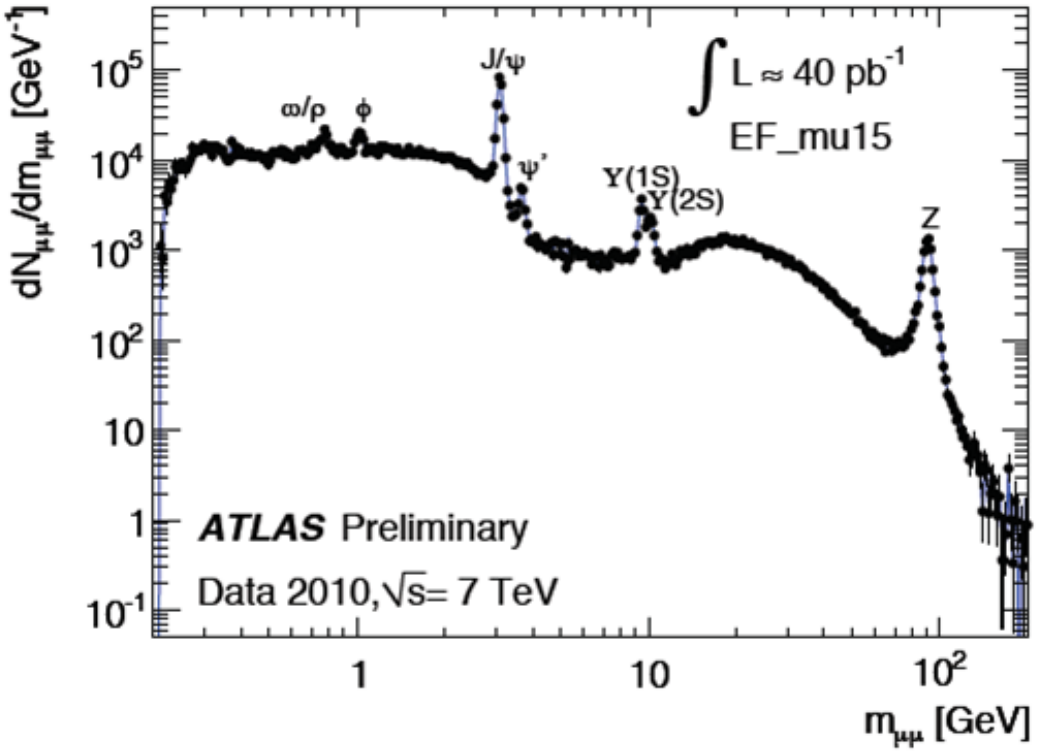


Reconstrução das partículas

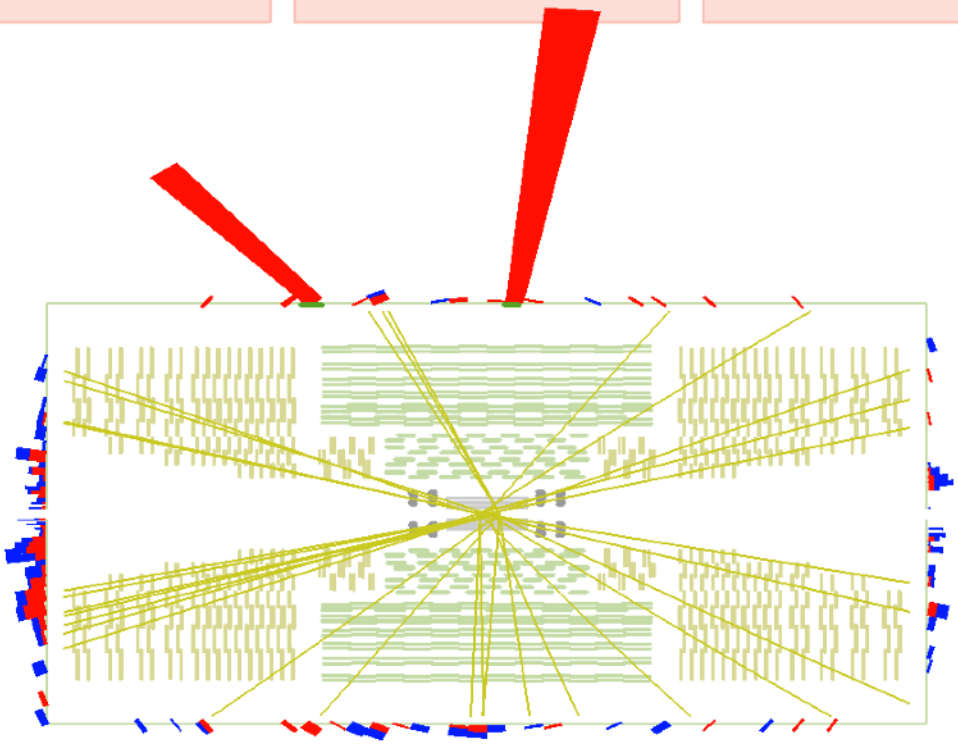
- A traves das propriedades das partículas produzidas na desintegração podemos inferir as propriedades do Higgs:

$$E^2 = (mc^2)^2 + (pc)^2$$

- 20 anos de física das partículas num só histograma

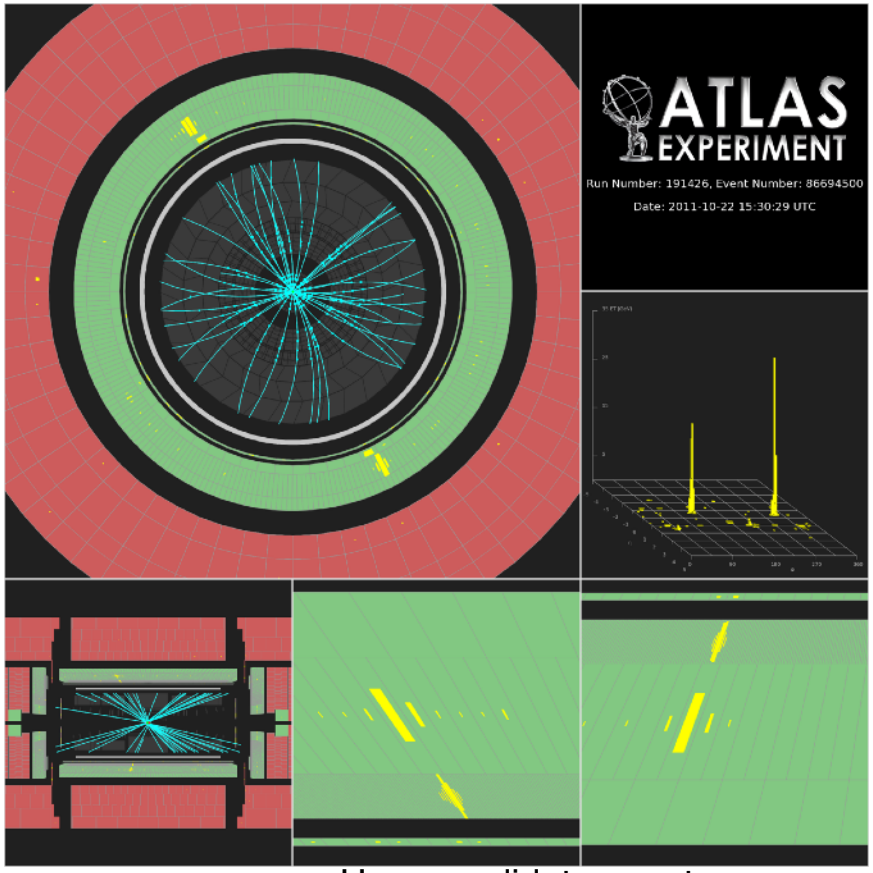


$H \rightarrow \gamma\gamma$



CMS Experiment at LHC, CERN
Data recorded: Sun May 13 22:08:14 2012 CEST
Run/Event: 194108 / 564224000
Lumi section: 575

H→γγ analysis



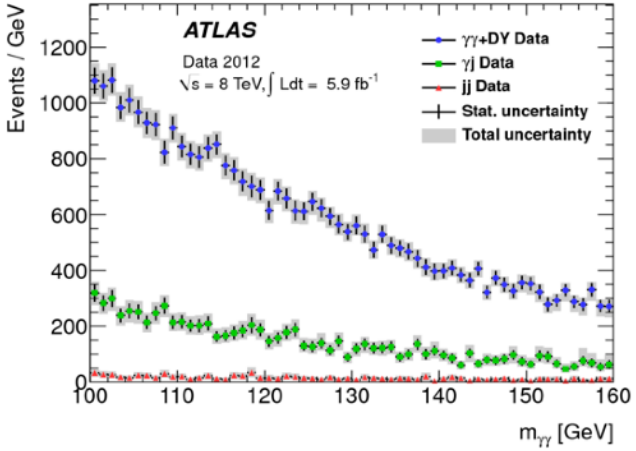
H→γγcandidate event

arXiv: 1207.7214

- Two isolated photons
- Search for a narrow peak on a large continuum

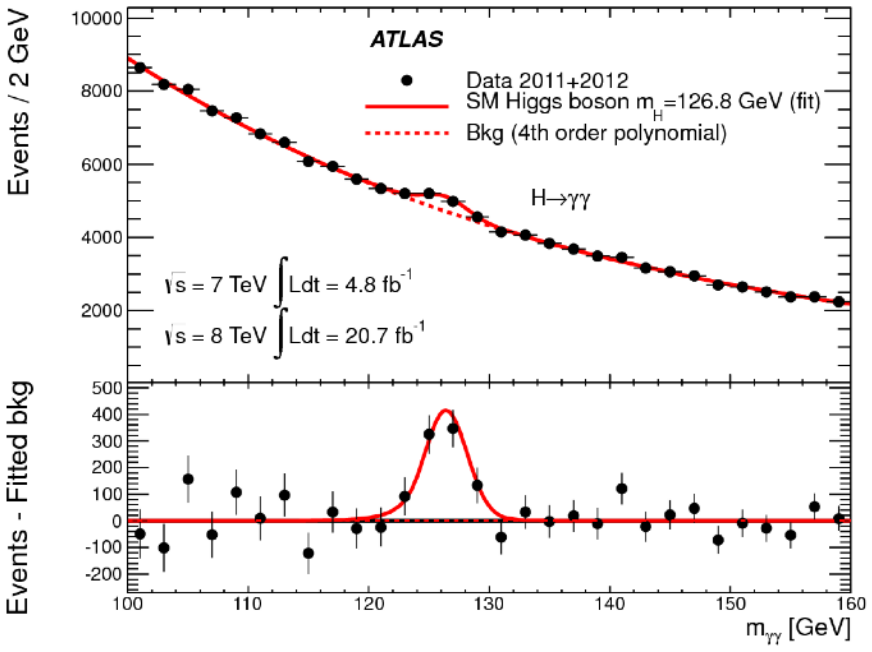
★Main background:

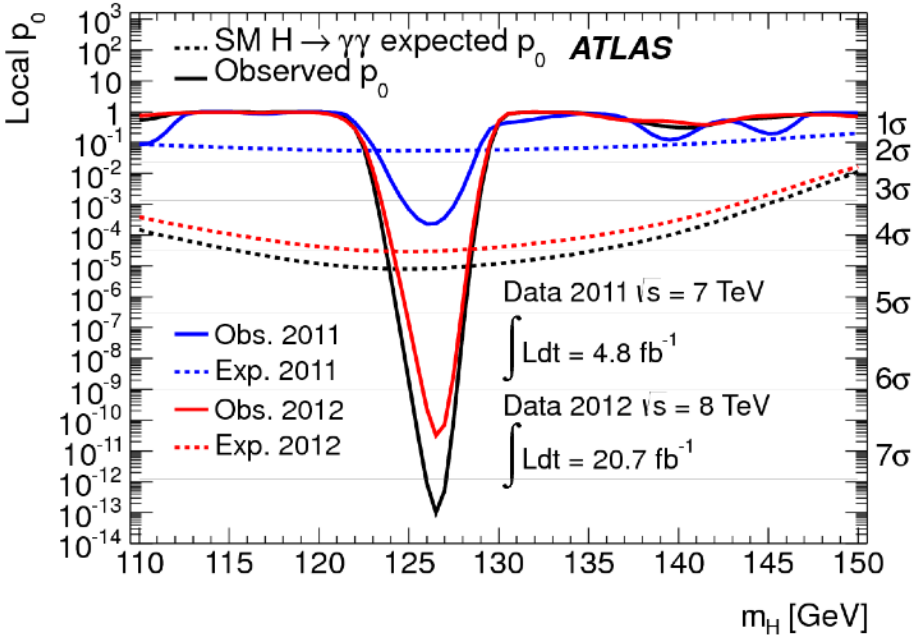
- Continuum gg production
- γ+jet, jet+jet



H→γγ results

Run 1 results

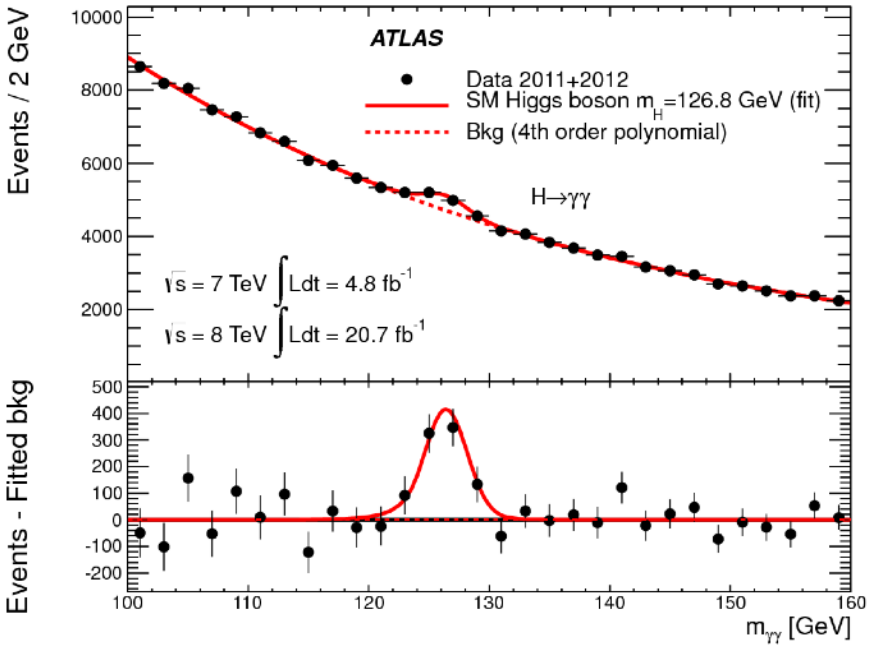


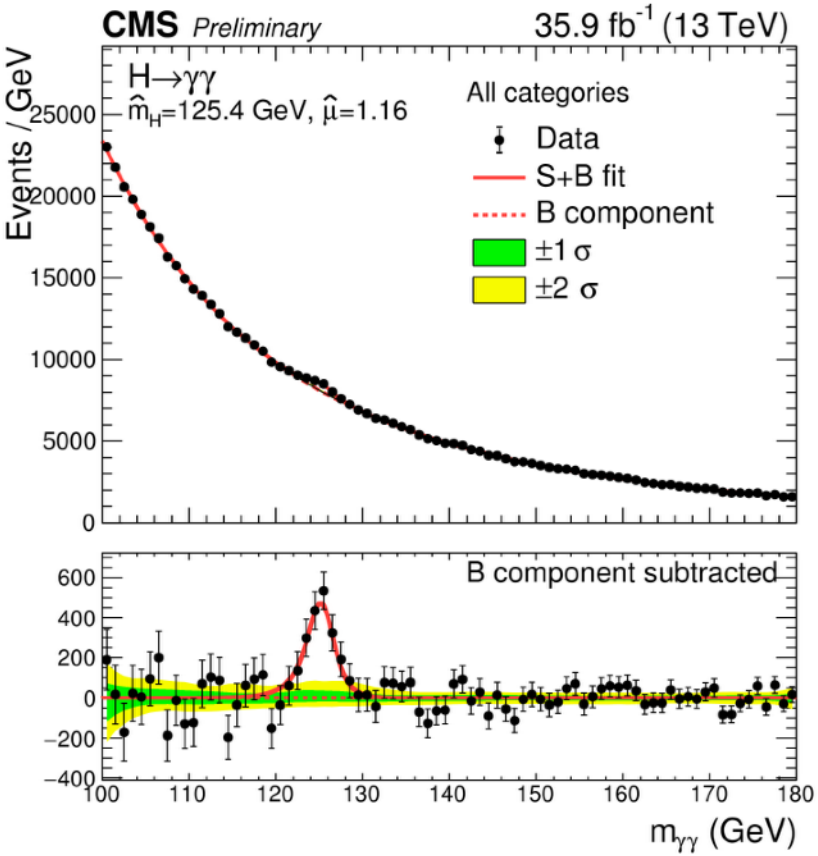


$$\mu_H = (\sigma_{obs} \times BR_{obs})/(\sigma_{SM} \times BR_{SM}) = 1.55^{+0.33}_{-0.28}$$

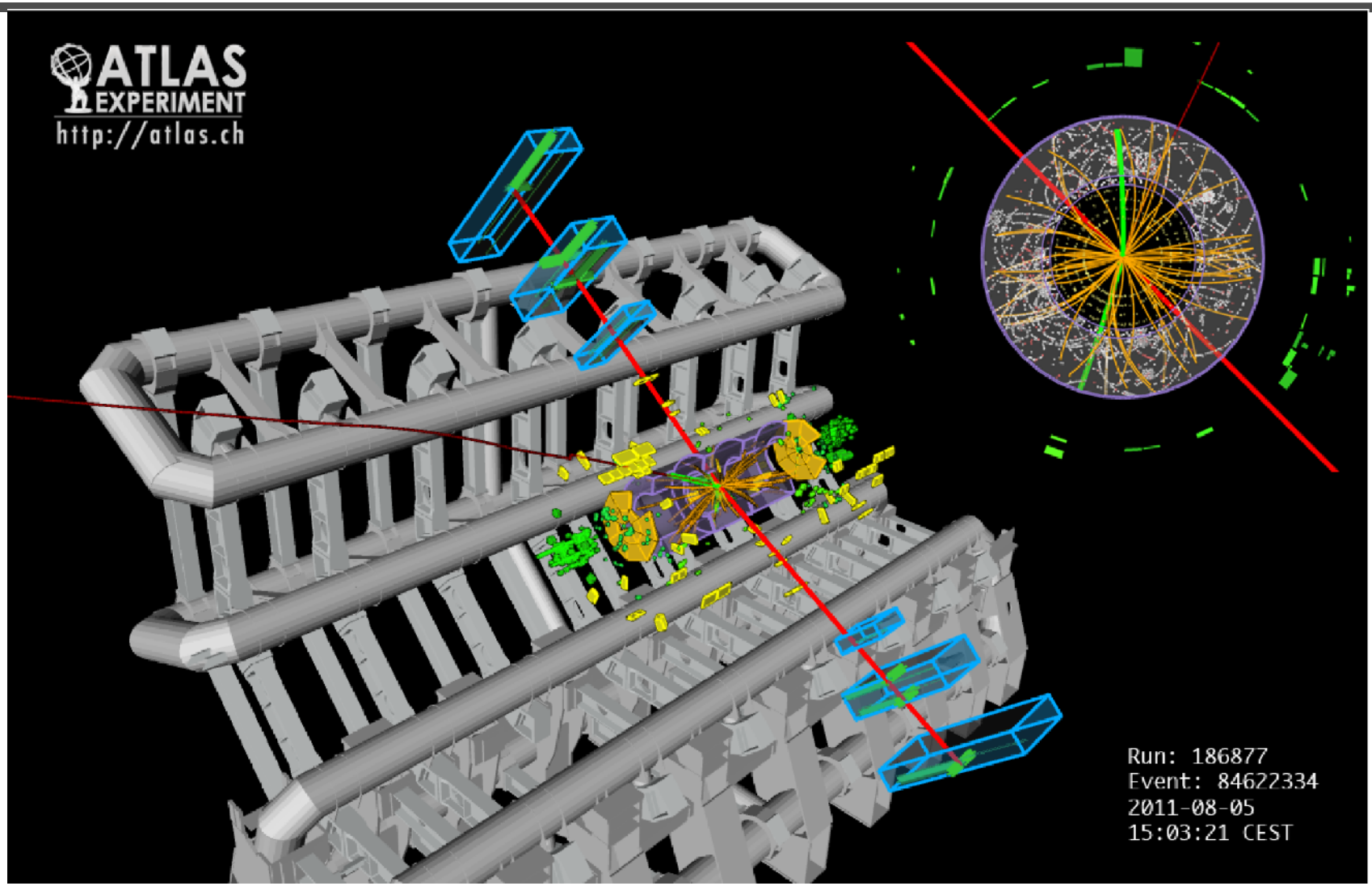
H→γγ results

Run 1 results

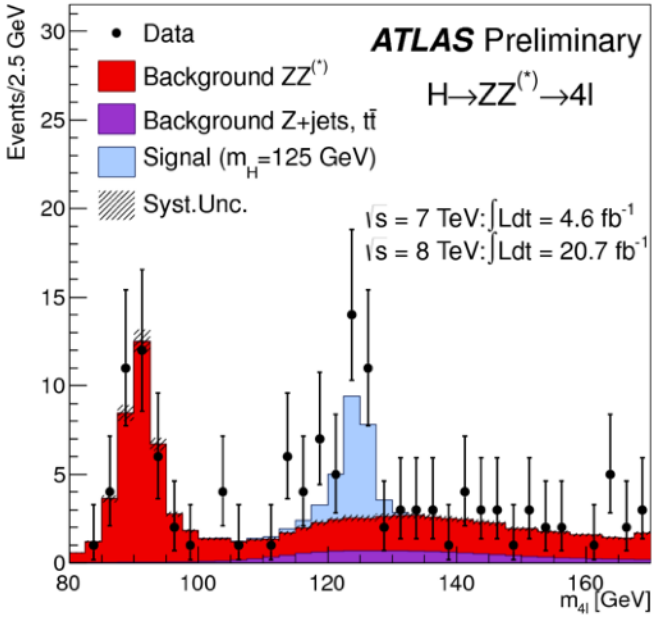




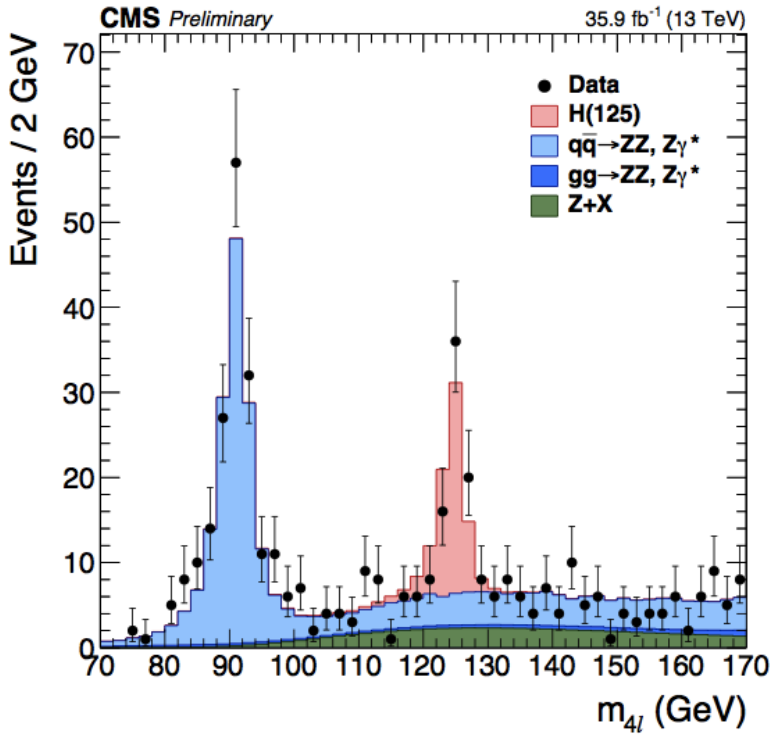
H→ZZ→4leptons



H→ZZ→4leptons results



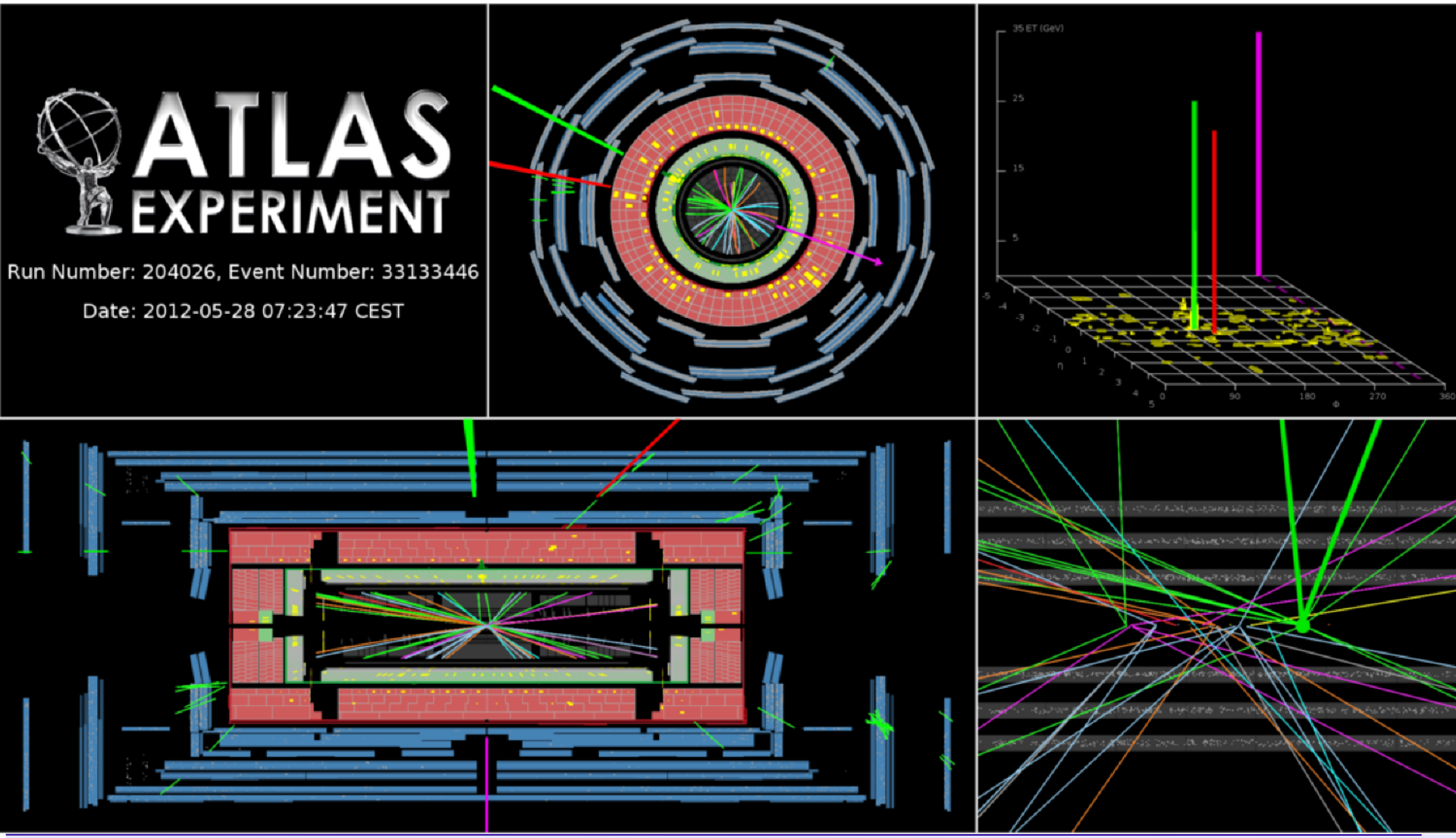
- Latest Run 2 results



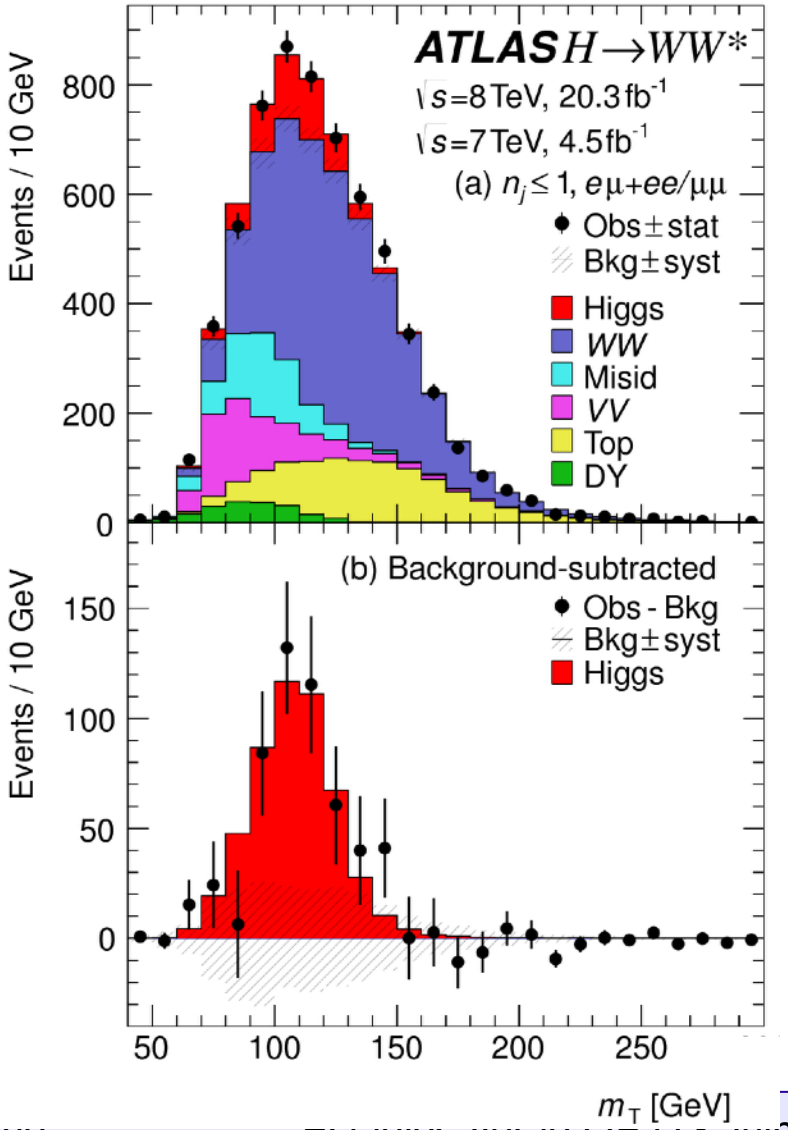
- ATLAS peak at 124.3 GeV

  Probabilidade de flutuação do fundo ~ 0.000000000001

H→WW→eν μν

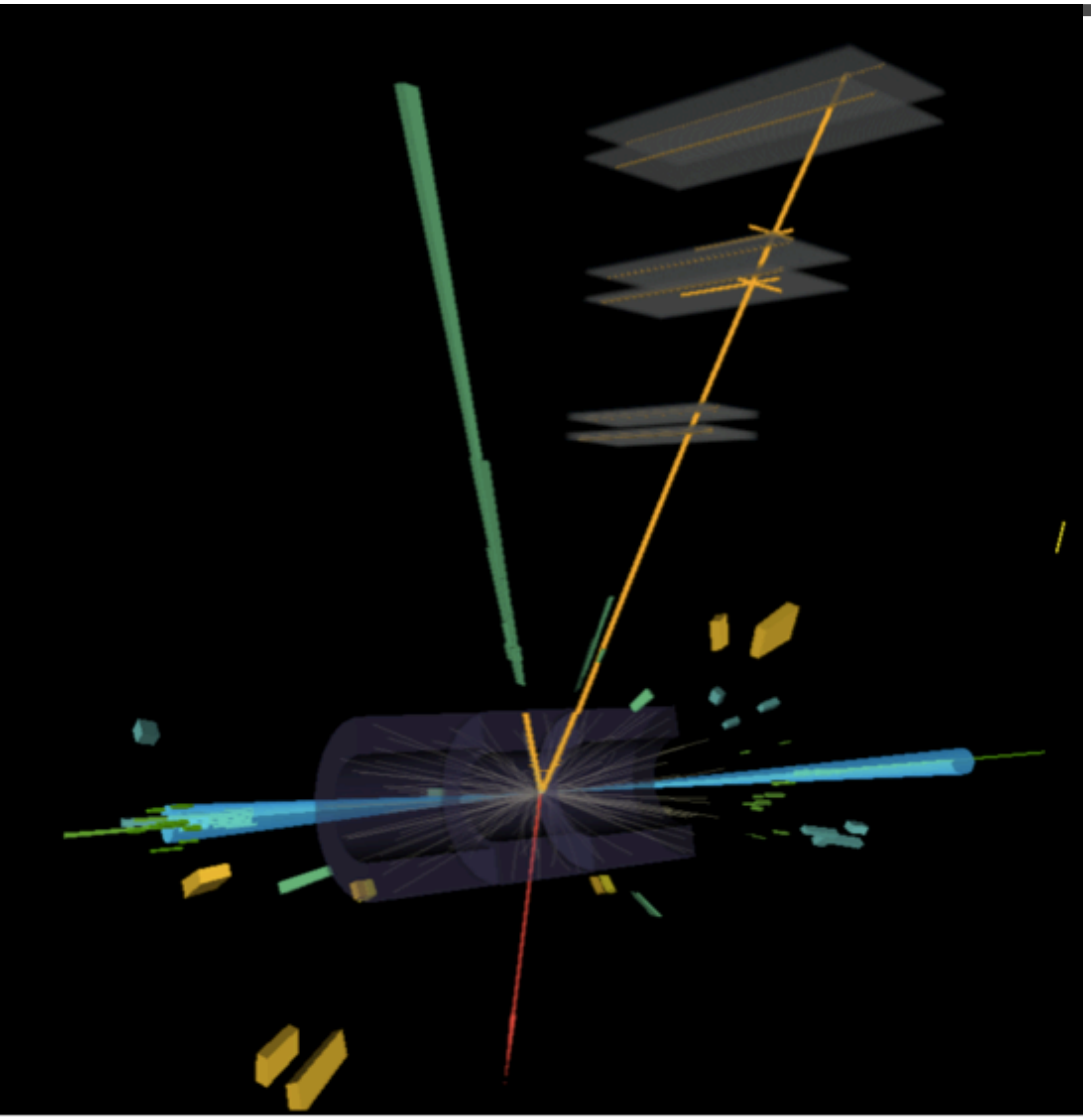

ATLAS
EXPERIMENT
Run Number: 204026, Event Number: 33133446
Date: 2012-05-28 07:23:47 CEST
35 ET (GeV)
25
15
5
90
180
270
360

H→WW→lν lν

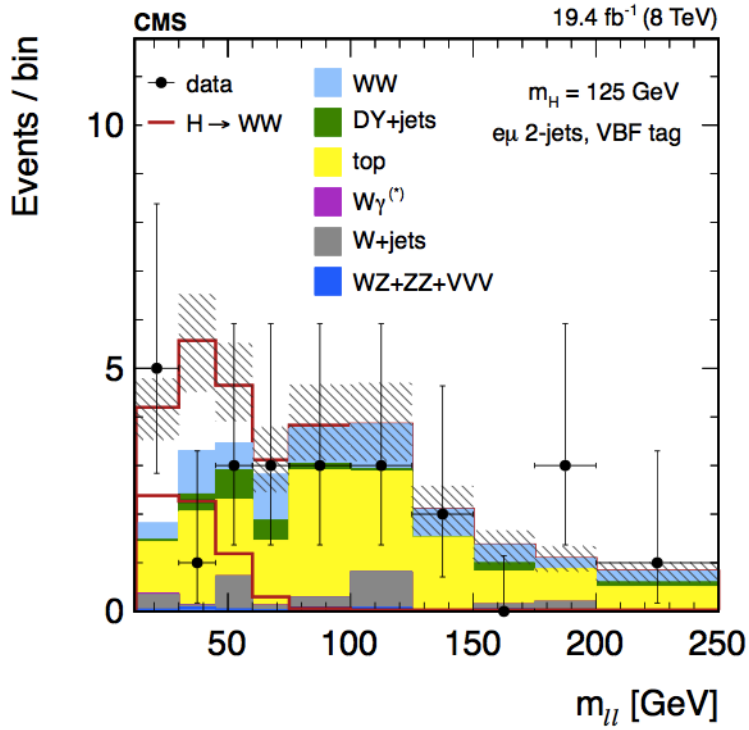


https://twiki.cern.ch/twiki/pub/AtlasPublic/HiggsPublicResults//WW-FixedScale.gif

Vector boson fusion H®WW production



- Dominated by VBF
- Large rapidity gap between jets



Encontramos uma partícula nova!
Mas... será o bosão de Higgs??

Descoberta: inicio de uma nova fase...

- Temos de medir as suas propriedades
  - Se produz com a probabilidade que esperamos?
  - Decai como é suposto?
  - Tem as propriedades que esperamos?

- O que já sabemos:
  - É um bosão, pela forma em como decai
  - Tem carga zero
  - Massa por volta de 125-126 GeV

E agora que?

- Ter um bosão de Higgs é a opção mais simples no Modelo Padrão
- Podería haver 5 Higgses!

  A partícula descoberta

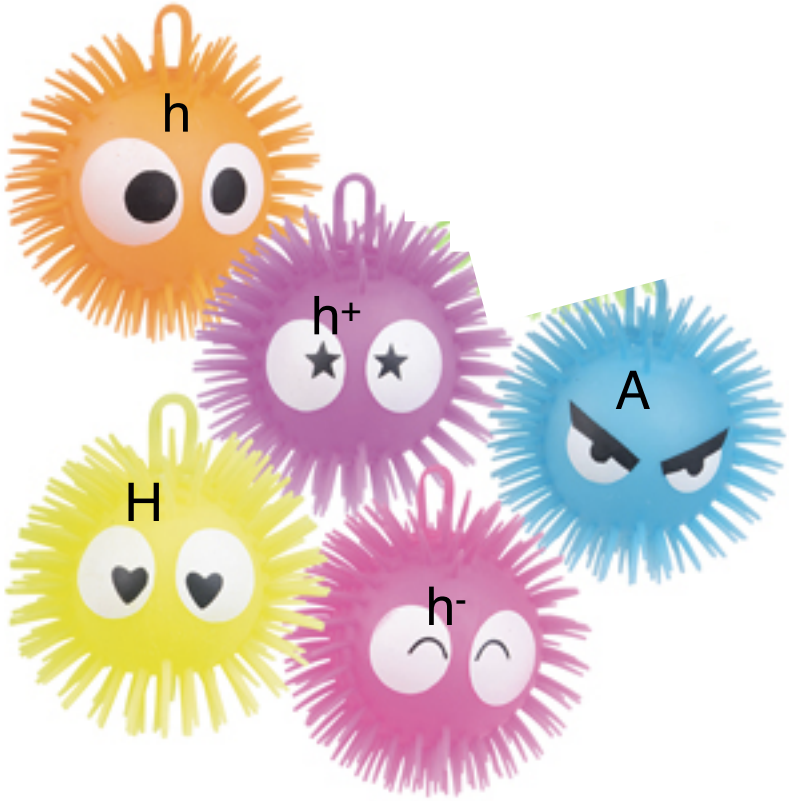
  agora podería ser o Higgs

  mais ligeiro
- Super-Symmetry (SUSY)

  Também há 5 bosões de Higgs
- Tecnicolor

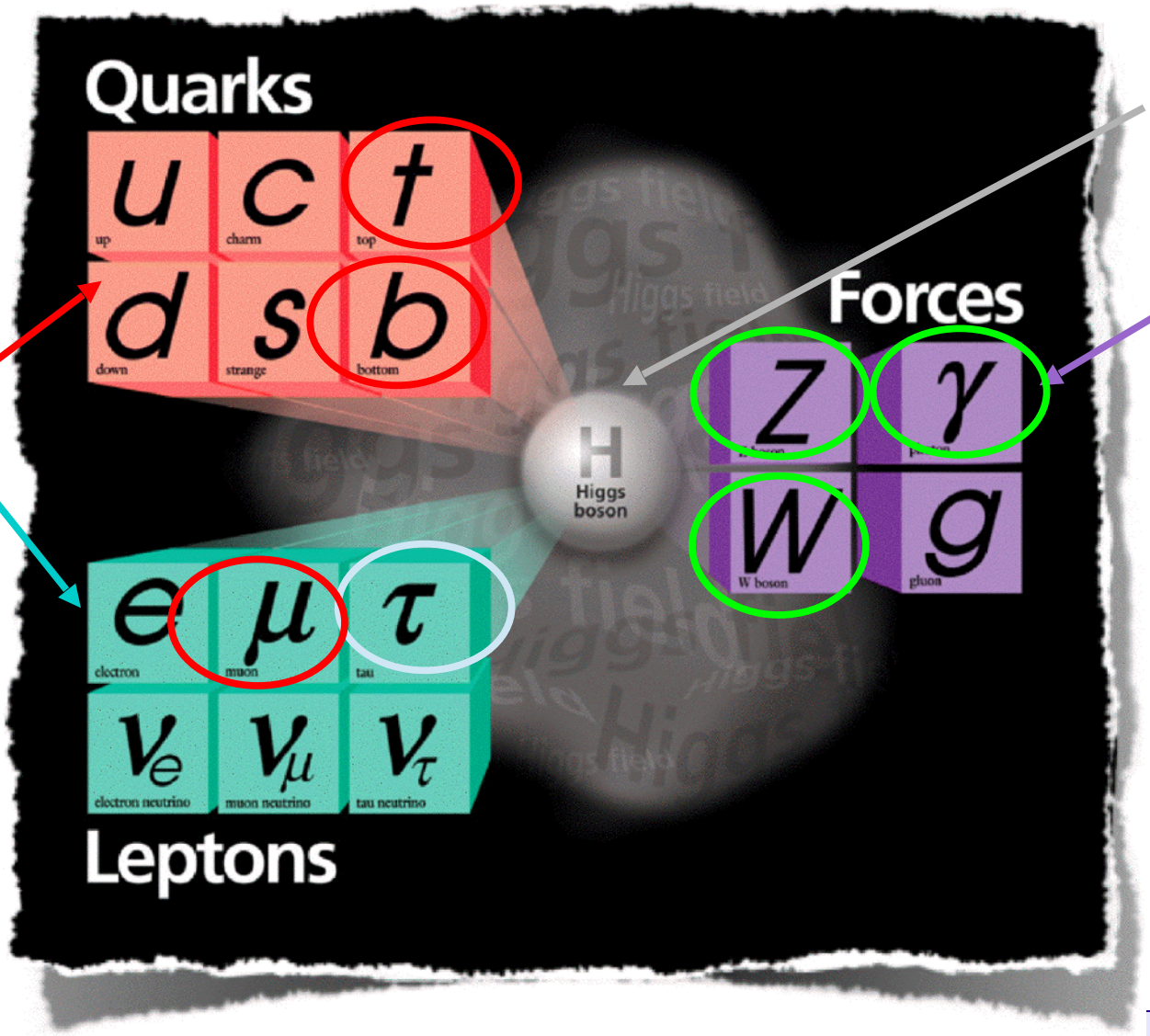
  O bosão de Higgs seria um

  estado ligado de tecniquarks
- ...



Previsões menos precisas que no caso do Higgs do MP

O Modelo Padrão da Física das Partículas



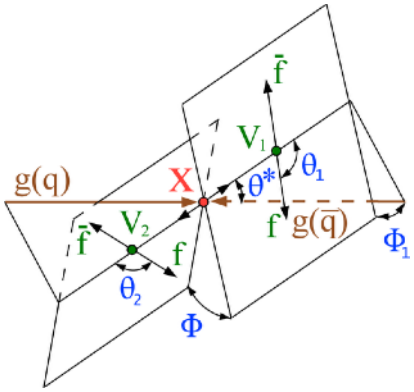
Spin 0

Spin 1

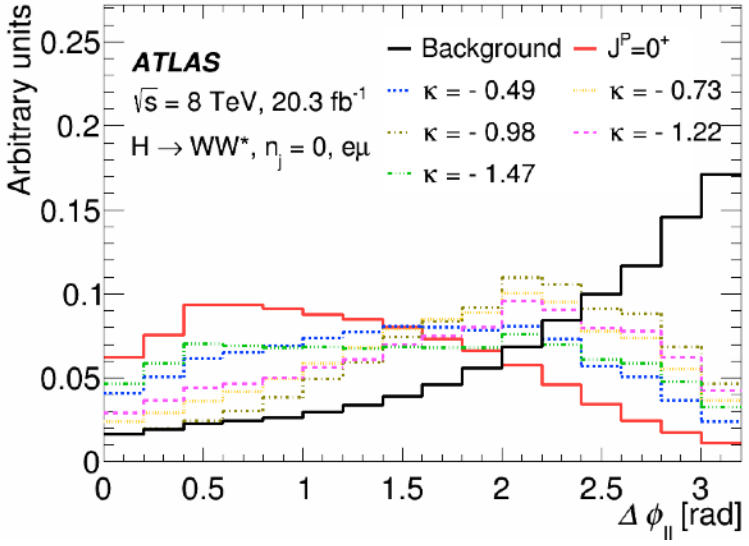
Spin 1/2

Spin e paridade

- Can be determined looking at angular distributions of the decay products



Example from H → WW analysis

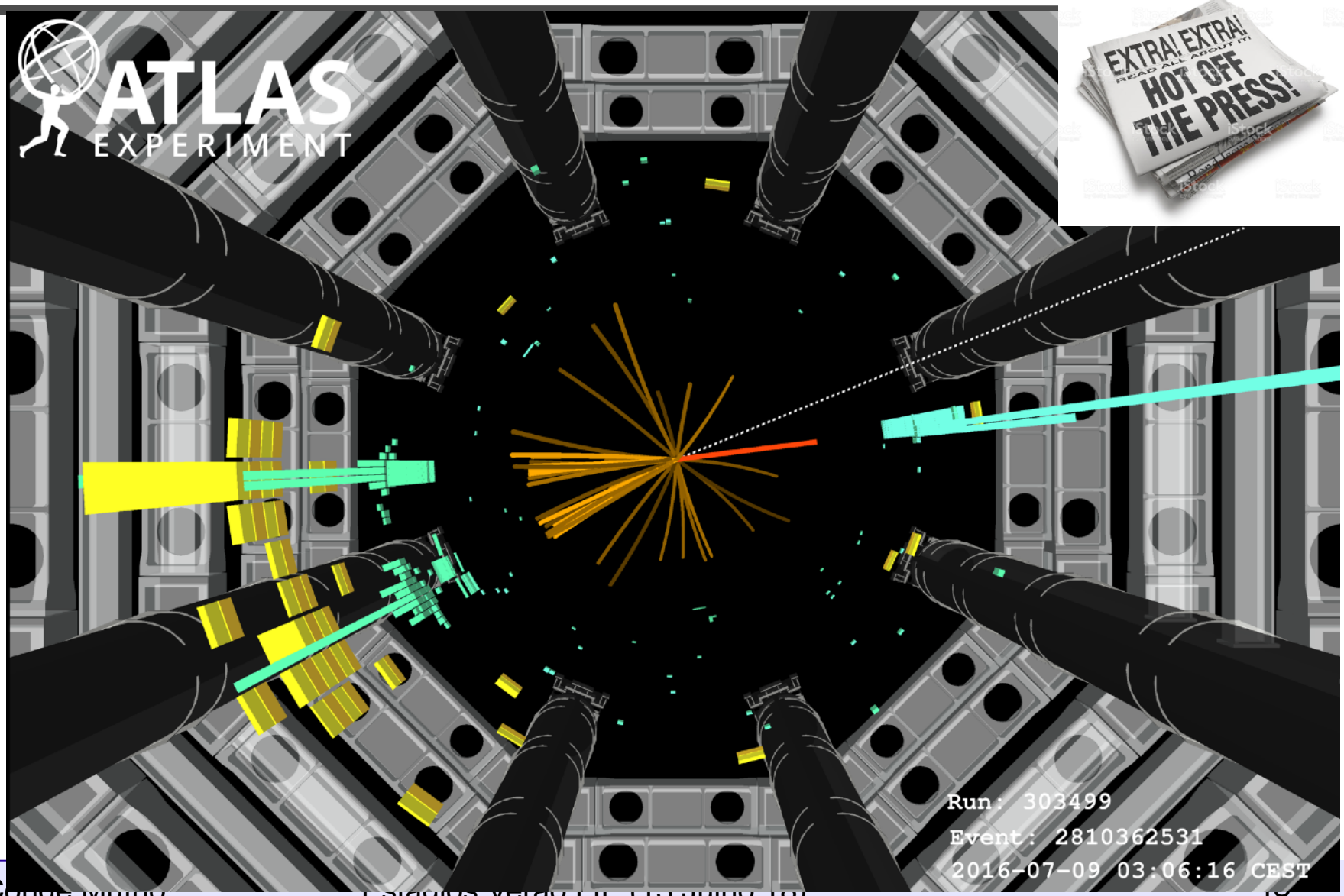


Both ATLAS and CMS excluded alternative Spin and parity hypothesis at > 95% CL

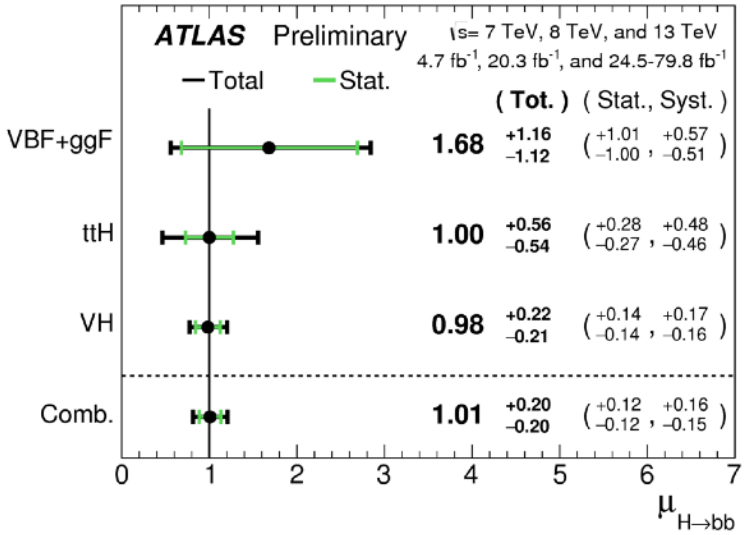
Combination of the three main bosonic channels

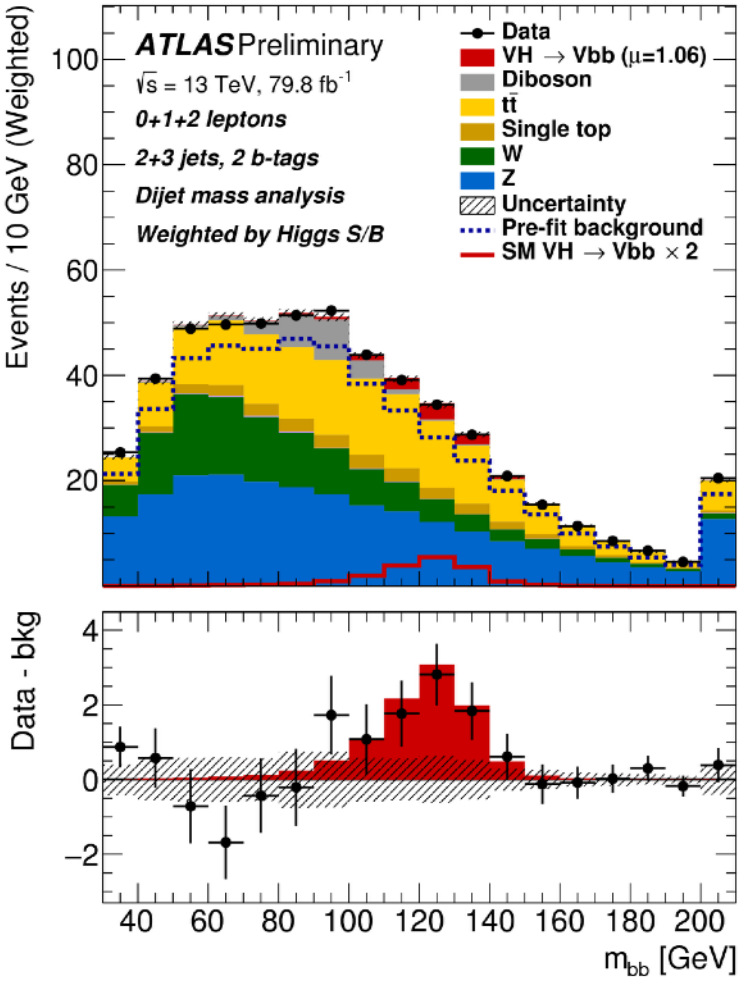
Prémio Príncipe de Asturias:

Evidence of Higgs decaying to b-quarks



Observation of Higgs decaying to b-quarks





Acknowledgement

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Backup