

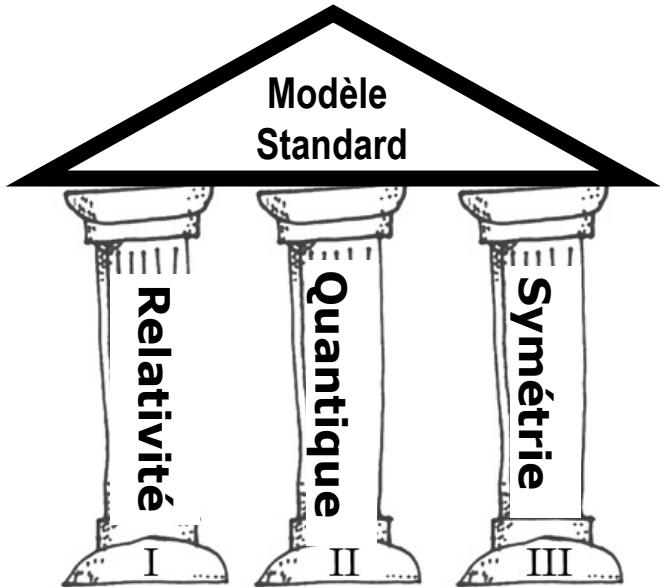
$$\begin{aligned}
& -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \frac{1}{2}ig_s^2 (\bar{q}_i^a \gamma^\mu q_j^a) g_\mu^a + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \\
& \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2}m_h^2 H^2 - \\
& \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0 \phi^0 - \theta_h [\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-)] + \\
& \frac{2M^2}{g^2} \alpha_h - ig c_w [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - Z_\mu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - \\
& W_\nu^- \partial_\nu W_\mu^+)] - igs_w [\partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - A_\nu (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + A_\mu (W_\nu^+ \partial_\nu W_\mu^- - \\
& W_\nu^- \partial_\nu W_\mu^+)] - \frac{1}{2}g^2 W_\mu^+ W_\mu^- W_\nu^+ W_\nu^- + \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\mu^+ W_\nu^- + g^2 c_w^2 (Z_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\mu^0 W_\nu^+ W_\nu^-) + \\
& g^2 s_w^2 (A_\mu W_\mu^+ A_\nu W_\nu^- - A_\mu A_\nu W_\nu^+ W_\mu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - \\
& g\alpha [H^3 + H\phi^0 \phi^0 + 2H\phi^+ \phi^-] - \frac{1}{8}g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + \\
& 2(\phi^0)^2 H^2] - gM W_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^0 Z_\mu^0 H - \frac{1}{2}ig [W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W_\mu^- (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \\
& \frac{1}{2}g [W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W_\mu^- (H \partial_\mu \phi^+ - \phi^+ \partial_\mu H)] + \frac{1}{2}g \frac{1}{c_w} (Z_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig \frac{s_w^2}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - \\
& W_\mu^- \phi^+) + igs_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + igs_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \\
& \frac{1}{4}g^2 W_\mu^+ W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \frac{1}{4}g^2 \frac{1}{c_w^2} Z_\mu^0 Z_\mu^0 [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
& W_\mu^- \phi^+) - \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z_\mu^0 A_\mu \phi^+ \phi^- - g^2 \frac{s_w^2}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - g^2 \frac{s_w^2}{c_w} A_\mu A_\nu \phi^+ \phi^- - \bar{e}^\lambda (\gamma \partial + m_d^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \\
& \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + igs_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{1}{3}(u_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(d_j^\lambda \gamma^\mu d_j^\lambda)] + 4s_w^2 Z_\mu^0 [(\nu^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - \\
& 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + \\
& (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{ig}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger \gamma^\mu (1 + \gamma^5) u_j^\kappa)] + \frac{ig}{2\sqrt{2}} \frac{m_u^\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \frac{g}{2} \frac{m_u^\lambda}{M} [H(\bar{e}^\lambda e^\lambda) + i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}_i^\lambda C_{\lambda\kappa} (1 - \gamma^5) d_i^\kappa) + \\
& m_u^\lambda (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \gamma^5) d_j^\kappa)] + \frac{ig}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\kappa) - m_u^\kappa (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 - \gamma^5) u_j^\kappa)] - \frac{g}{2} \frac{m_u^\lambda}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \\
& \frac{g}{2} \frac{m_d^\lambda}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_d^\lambda}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_d^\lambda}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - \\
& \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + igs_w W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + igs_w W_\mu^+ (\partial_\mu \bar{Y} X^- - \partial_\mu \bar{X}^+ Y) + \\
& \partial_\mu \bar{X}^0 X^+ + igs_w W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + ig c_w Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + i \\
& \partial_\mu \bar{X}^- X^-) - \frac{1}{2}gM [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{2} \bar{X}^0 X^0 H] + \frac{1}{2c_w^2} igM [X^0 X^+ \phi^+ - X^0 X^- \phi^-] + igM [X^+ X^+ \phi^0 - X^- X^- \phi^0]
\end{aligned}$$

Modèle Standard: Introduction à la Session

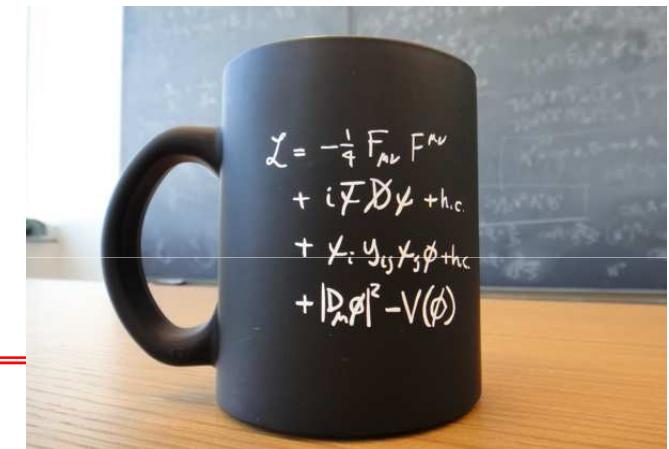
... ou la petite histoire de deux mastodontes.



Modèle Standard



- Décrit dans un même cadre les particules élémentaires ("briques" de matière) et leurs interactions ("ciment").



Basé sur:

- **Relativité Restreinte**
 - Abolition du temps universel, Espace-Temps, Notion de Masse-Energie,...
- **Mécanique Quantique**
 - Description du monde microscopique
- **Symétries**
 - liées aux lois de conservation

Standard Model (SM) = Quantum Field Theory, based on the local gauge invariance under $SU(3)_C \times SU(2)_L \times U(1)_Y$

Particle Physics: State of the art in ~1960

~1960, known particles are:

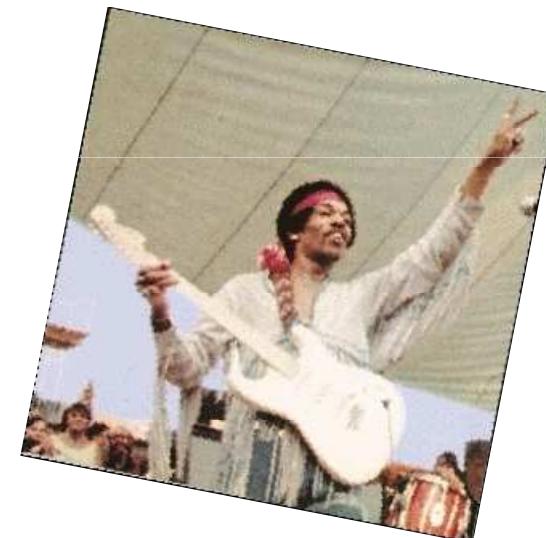
- electron, muon, neutrinos(ν_e), (+ anti-particles)
- photon,
 - + many others: pions ($\pi^{+/-}$, π^0), kaons ($K^{+/-}$, K^0), hyperons (Λ^0), ...

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In the next 20 years, world will dramatically change...



1961: electroweak unification $SU(2) \times U(1)$
(Glashow)

1962: Neutrino μ
(Lederman, Schwartz, Steinberger)

1964: Quark Model (u, d, s)
(Gell-Mann, Zweig)

1964: BEH mechanism

1967: « A model of leptons »
(Weinberg, Salam)

1970: GIM mechanism
(need a fourth quark!)

1972: 3 generations of quarks !
(Kobayashi, Maskawa)

1973: Asymptotic Freedom
(Politzer, Gross, Wilczek)

1974: Charm Quark
(J/ ψ : Richter, Ting)

1973: Discovery of Neutral Current (Gargamelle, CERN)

1975: Tau Lepton
(Perl)

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1975: The Standard Model, a quantum field theory based on the local gauge invariance $SU(3)_C \times SU(2)_L \times U(1)_Y$ was in place

A few remaining things at that time:

- Observed the vector bosons
- Reveal the third family
- + origin of family, grand unification, etc...

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**1973: Discovery of Neutral Current
(Gargamelle, CERN)**

1975: Tau Lepton
(Perl)

1977: Quark Bottom
(Υ)

**1983 Découverte des
Bosons Z & W – UA1 UA2 CERN
SppS ($pp\bar{p}$, $\sqrt{s}=540$ GeV)**

Tunnel du SSC
en chantier: 1987-1993
(87 km, 40 TeV)

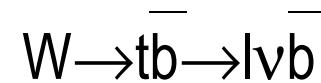
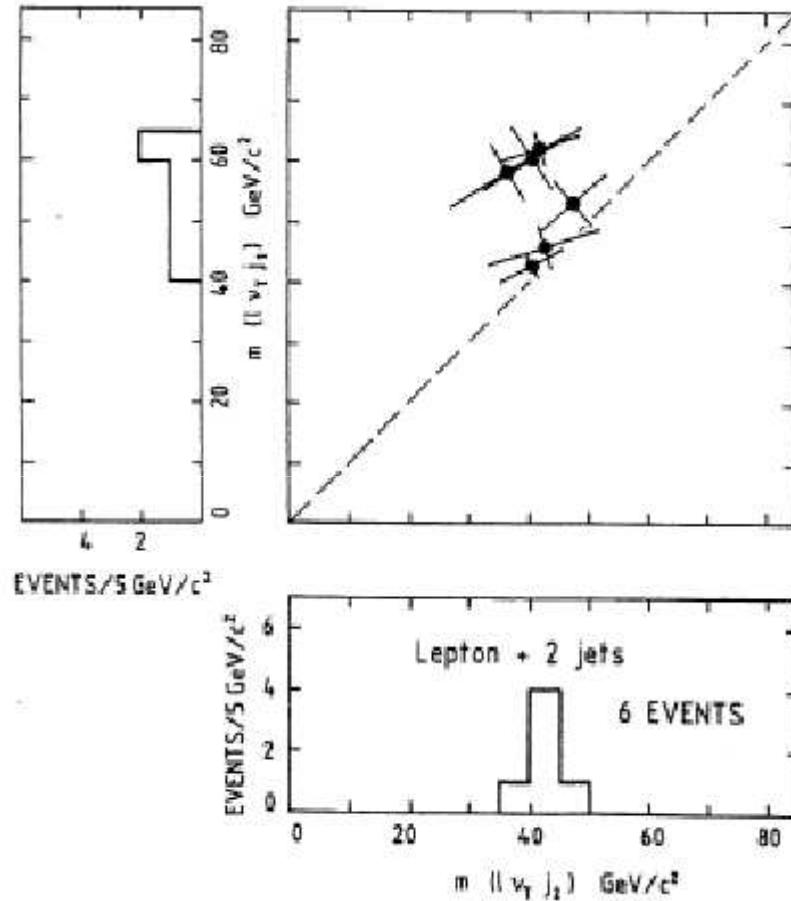
ECFA meeting in Lausanne – 1984:
Fondations pour le Large Hadron Collider

LHC Workshop in Aachen – 1989:
Fondations pour les expériences LHC

... LEP, SLC, Tevatron, HERA, b-factory

TeVatron or the second discovery of Top Quark

1983-1984



- Electron plus missing energy plus jet events interpreted as top quark.

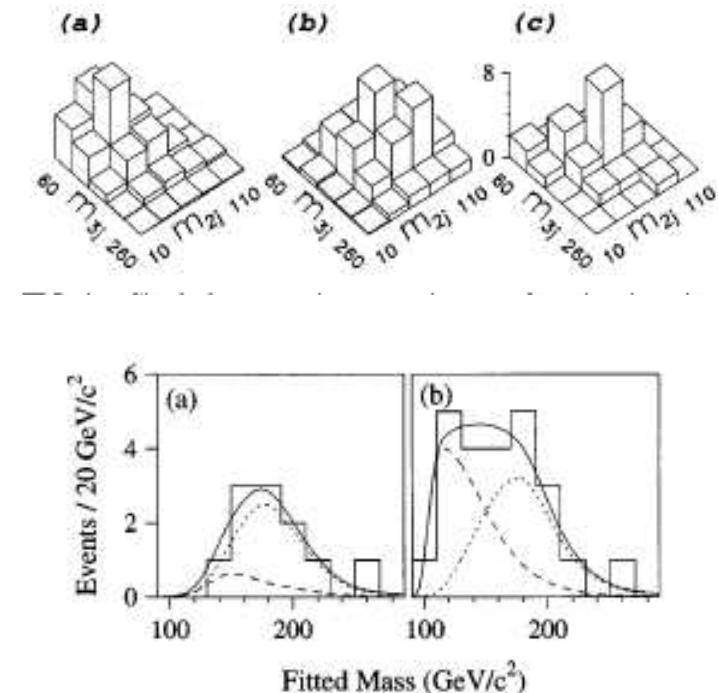
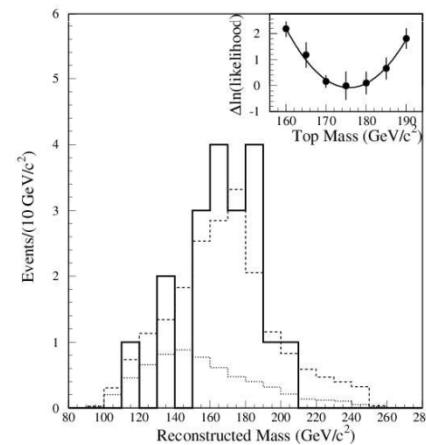
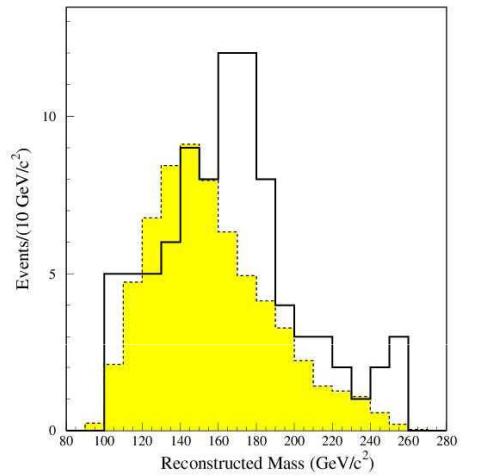
*"The $M_T(\text{ev})$ distribution of electron events with jets recently observed in the UA1 experiment at CERN may be interpreted as being due to a **t-quark with mass 25 to 40 GeV**"*

Barger, Martin and Phillips, PLB 125B, 342 (1983)

- UA(2) did not confirm... and later on set best limits on top quark: $m_t > 69 \text{ GeV}$ (1990)
- UA(1) disappeared with more data...

TeVatron or the second discovery of Top Quark

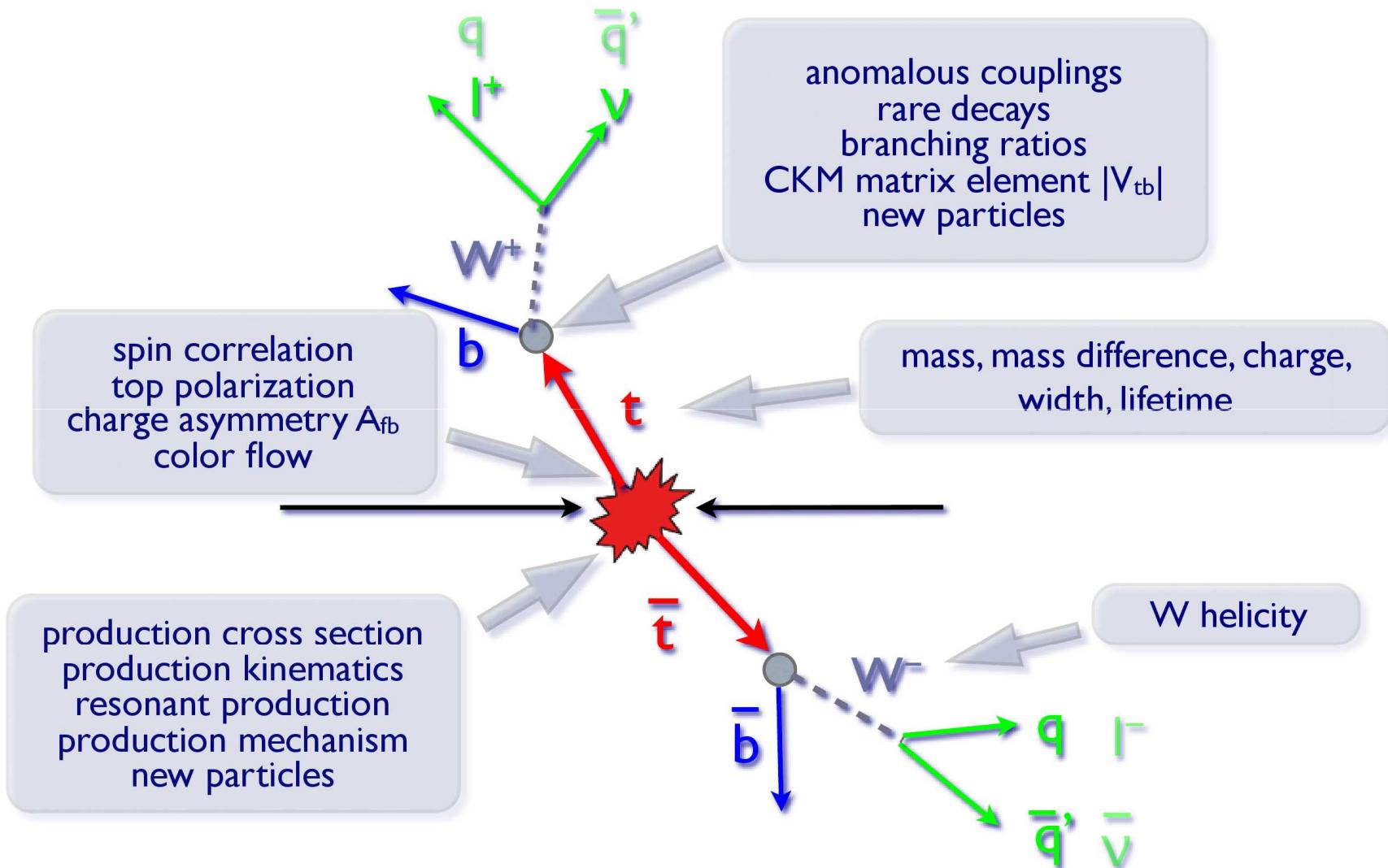
March 1995



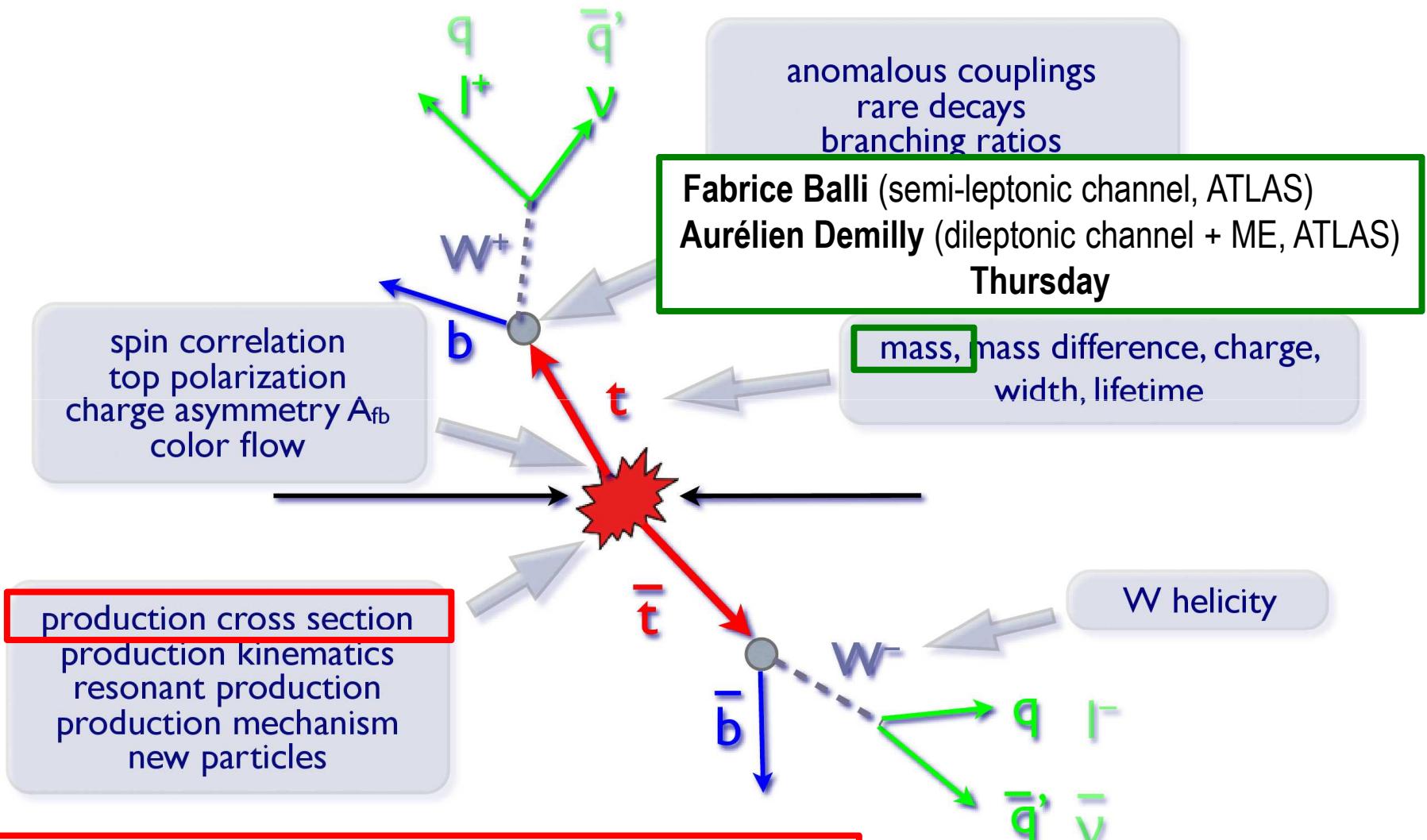
Significance: 4.8 σ
 $m_t = 176 +/- 13 \text{ GeV}$

Significance: 4.6 σ
 $m_t = 200 +/- 25 \text{ GeV}$

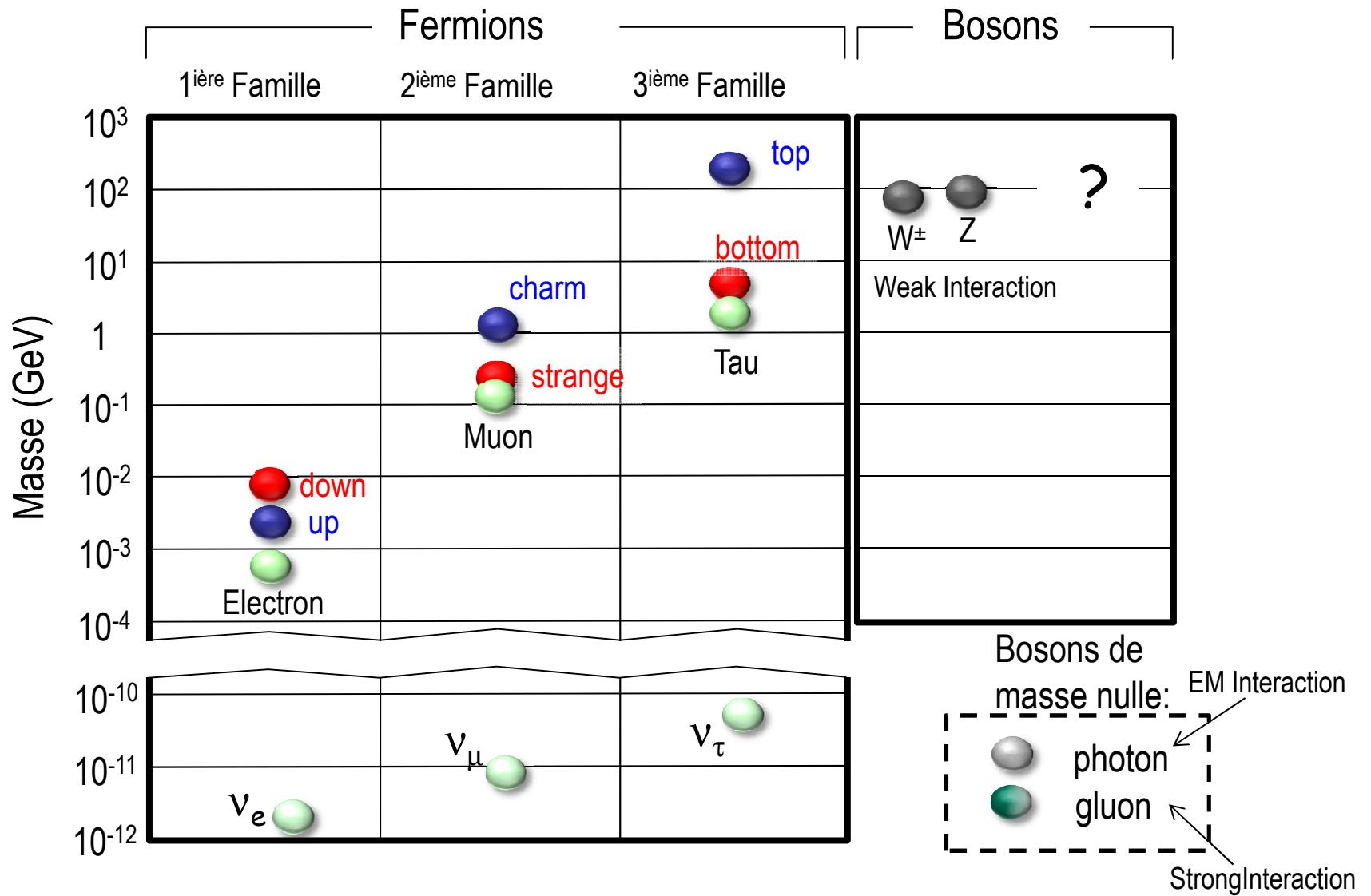
Top Quark Physics



Top Quark Physics



Standard Model: “The Big Picture”

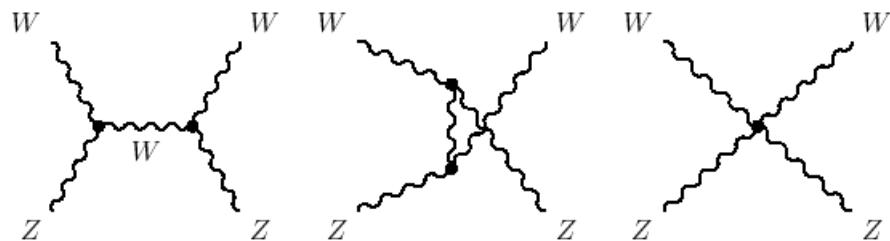


Standard Model (SM): don't say anything on the origin (or hierarchy) of masses...

Unitarité et nécessité d'une nouvelle “structure”

... pas qu'une question d'origine de la masse.

En l'absence de “régulation” appropriée,
la théorie donne des **résultats absurdes à l'échelle du TeV !**



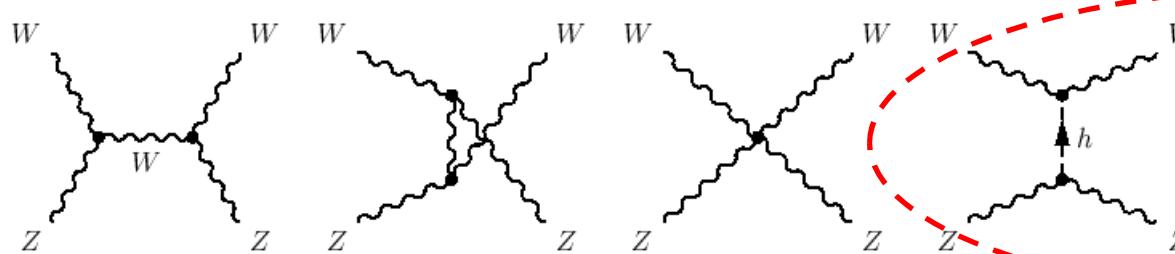
A haute E,
probabilité de diffusion > 1 !!!

Il faut “quelque chose” (“techni-couleur”, bosons vecteurs lourds ? etc...)
pour préserver l'unitarité

Unitarité et nécessité d'une nouvelle “structure”

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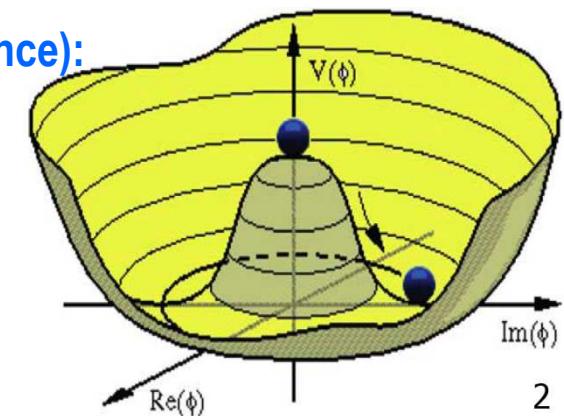
Unitarité parfaite
si $m_H < 600-800 \text{ GeV}$

Brout, Englert, Higgs (1964)
(+ Guralnik, Kibble, Hagen)

Glashow, Salam, Weinberg (1967)

Solution la plus économique (pas la plus “triviale”, si sans conséquence):

- Champ scalaire existant dans tout l'Univers
 - Valeur moyenne non-nulle dans le vide
- Responsable de la “brisure de symétrie électro-faible”
 - W , Z + fermions élémentaires acquièrent une masse.
- Un degré de liberté supplémentaire : **un nouveau boson scalaire (de masse inconnue)**



The Brout-Englert-Higgs Mechanism...

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout

Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium

(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS

Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964

VOLUME 13, NUMBER 16

PHYSICAL REVIEW LETTERS

19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs

Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland

(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,[†] C. R. Hagen,[‡] and T. W. B. Kibble

Department of Physics, Imperial College, London, England

(Received 12 October 1964)

From John Ellis

- Higgs pointed out a massive scalar boson

$$\{\partial^2 - 4\varphi_0^2 V'''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \quad (2b)$$

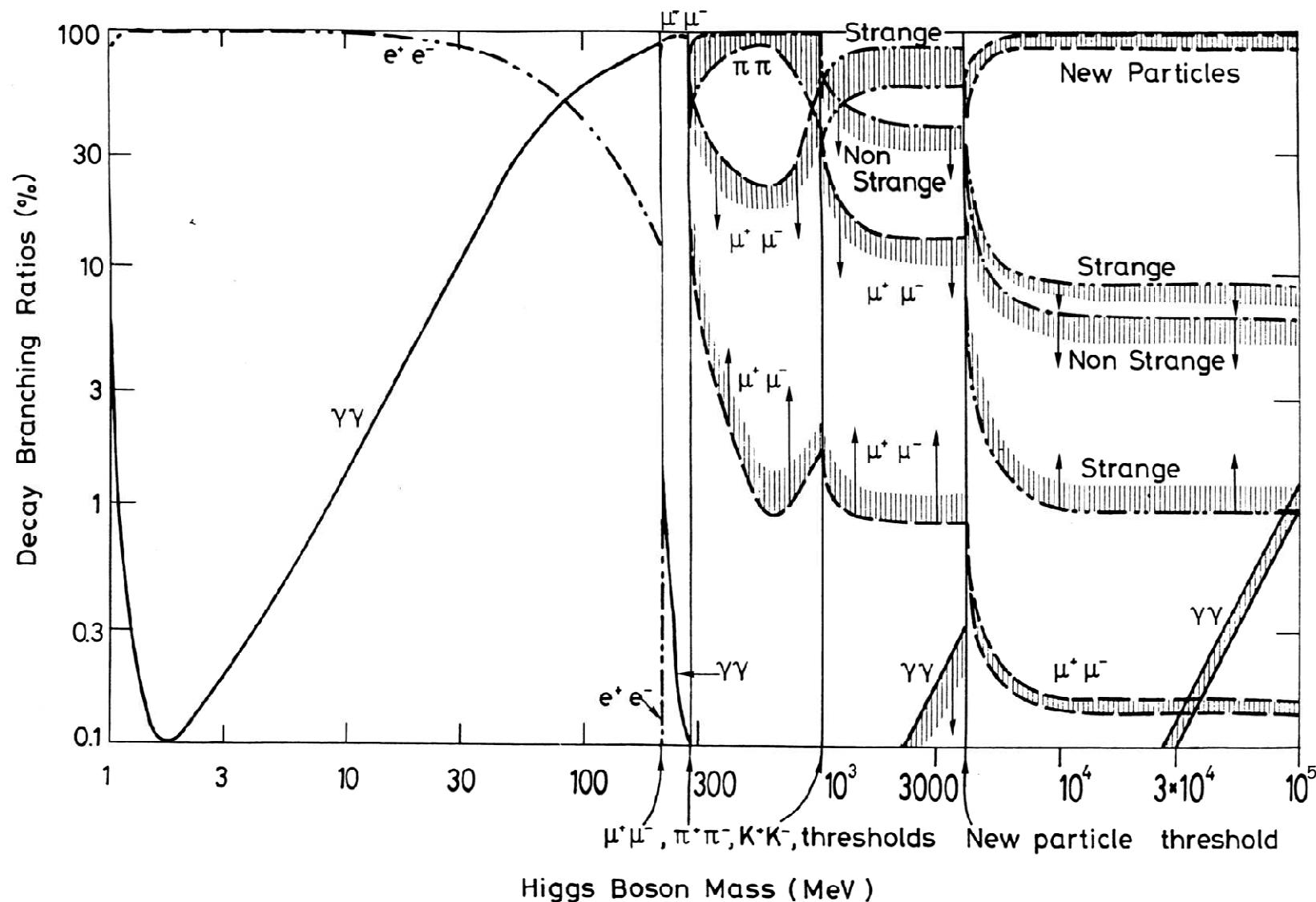
Equation (2b) describes waves whose quanta have

(bare) mass $2\varphi_0\{V'''(\varphi_0^2)\}^{1/2}$.

- “... an essential feature of [this] type of theory ... is the prediction of incomplete multiplets of vector and scalar bosons”
- Englert, Brout, Guralnik, Hagen & Kibble did not comment on its existence

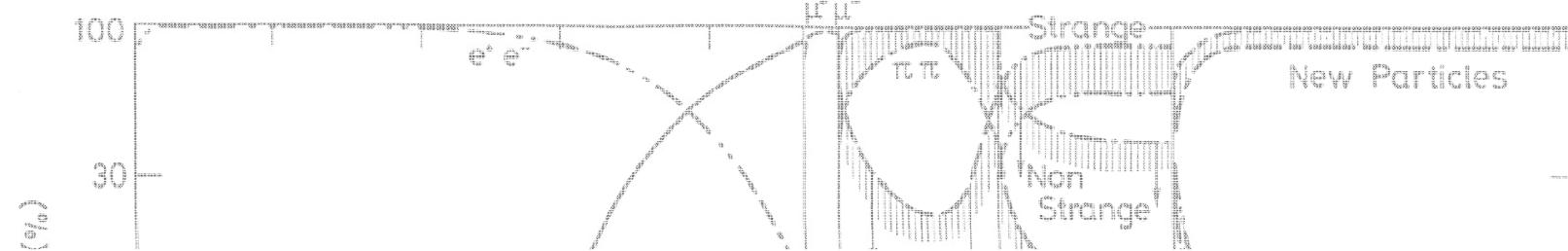
Higgs Boson: State of the art (1975)

J. Ellis, M.K. Gaillard, D.V. Nanopoulos, NPB106 (1976) 292

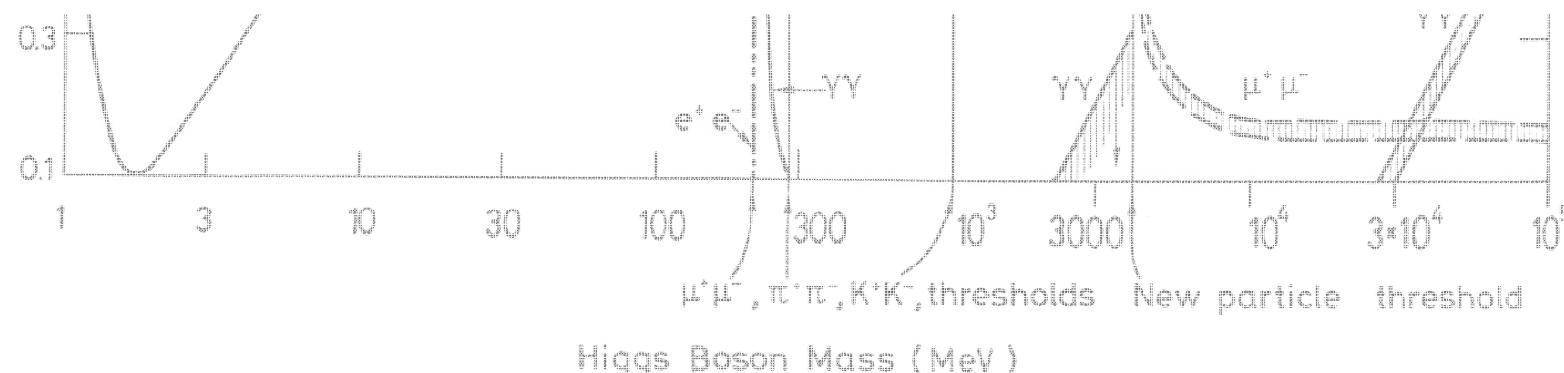


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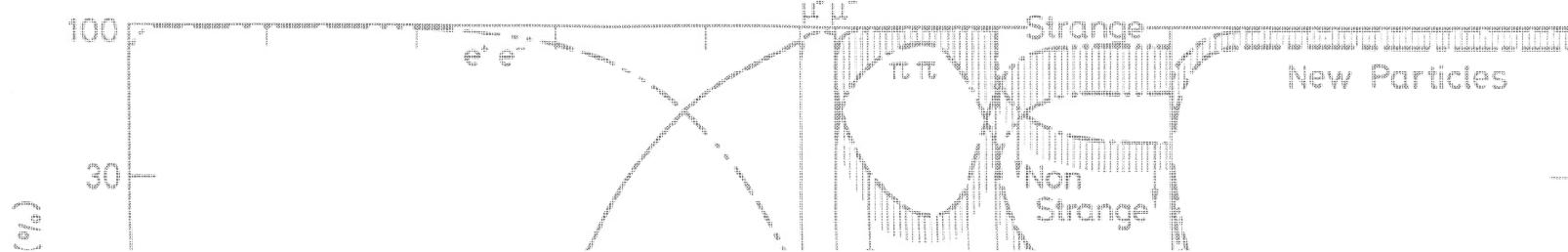


We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm ^{3),4)} and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

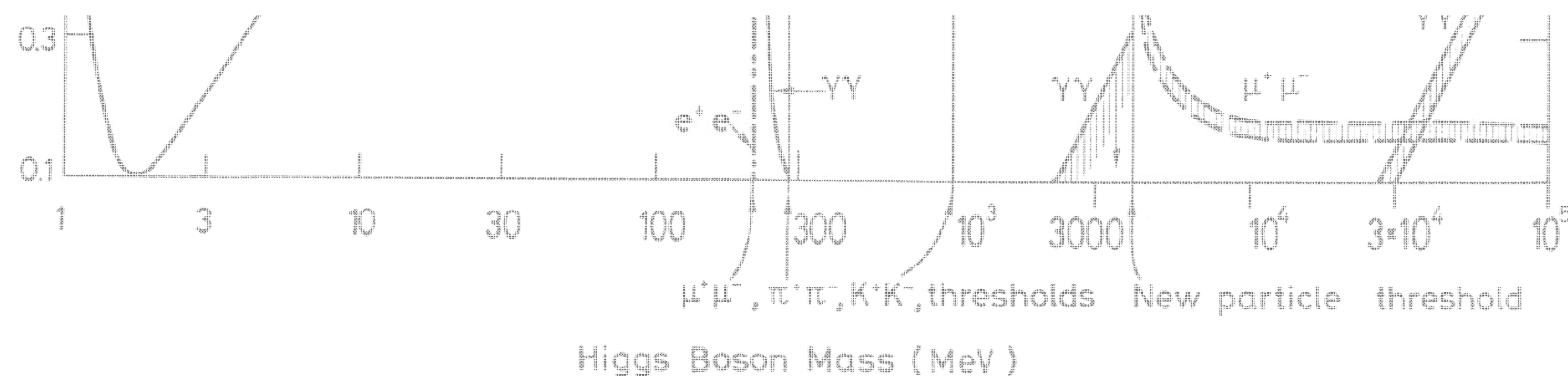


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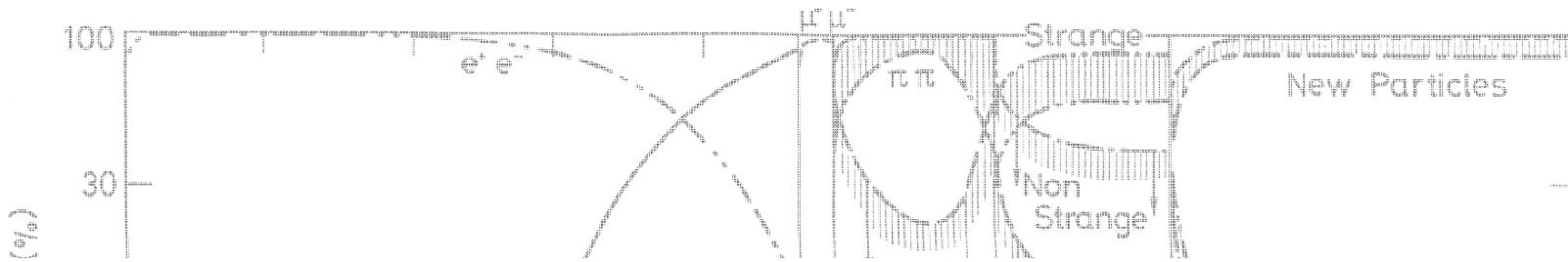
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Higgs Boson: State of the art (1975)



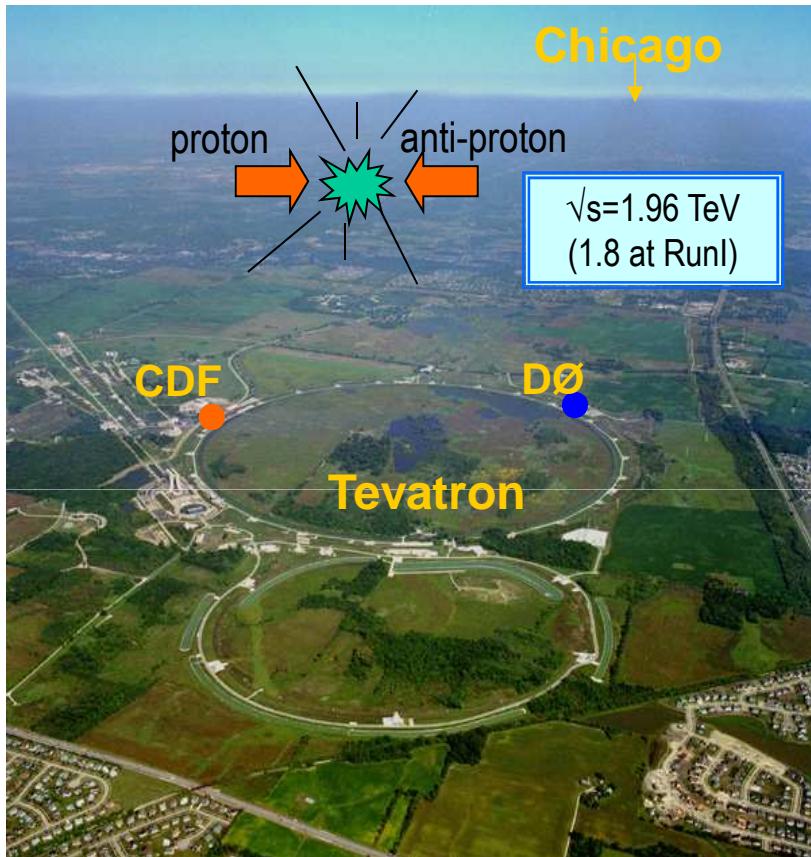
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Hadron Colliders of this session

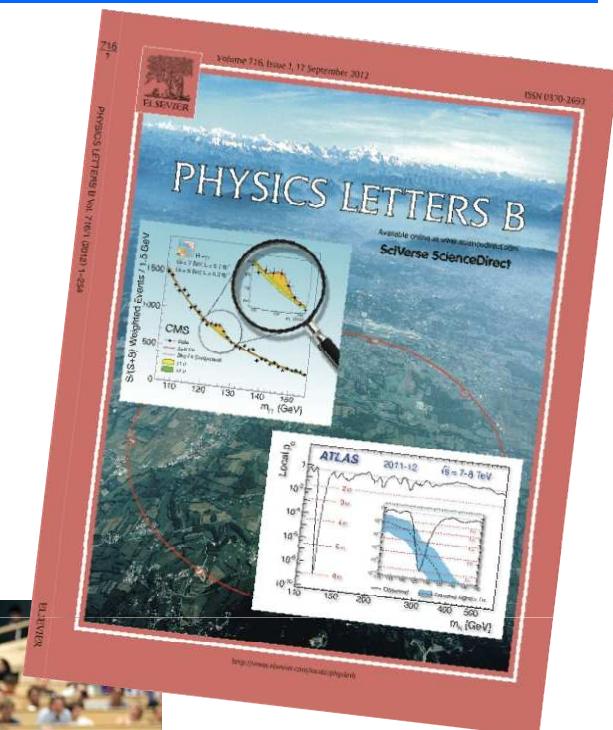
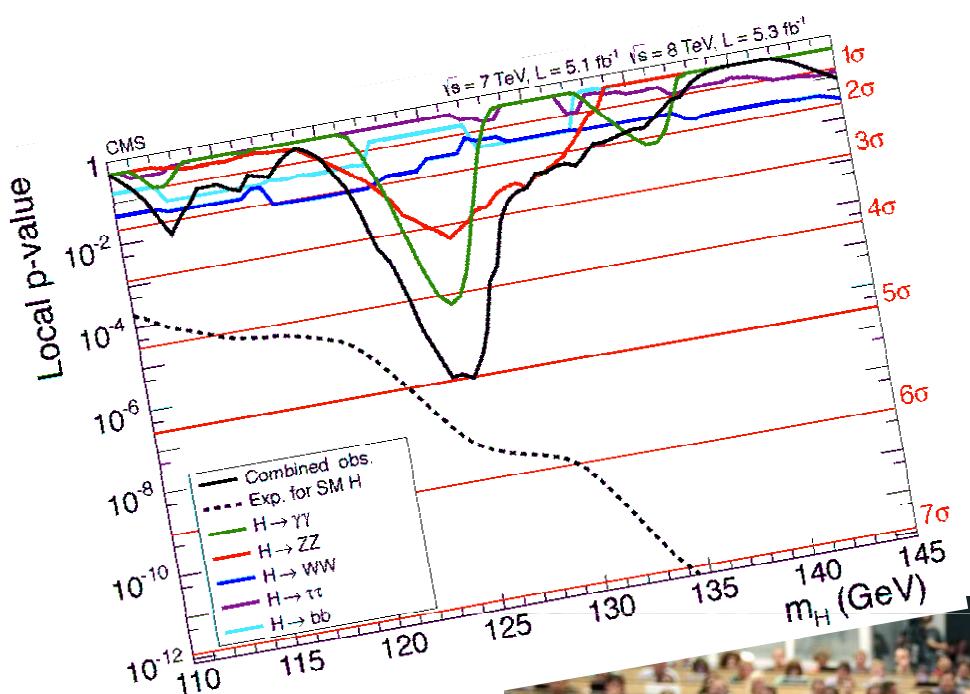
TeVatron (1992-2011)



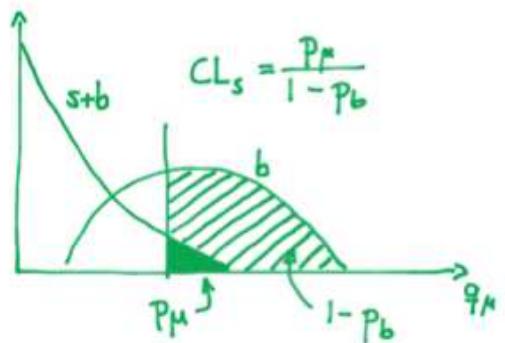
LHC (2009-?): pp, heavy ions & p-N collider
2009: $\sqrt{s}=900 \text{ GeV}$
2010-2011: $\sqrt{s}=2.76 \text{ TeV}$, then 7 TeV (march 2010),
2012: $\sqrt{s}=8 \text{ TeV}$.
2015: $\sqrt{s}=13 \text{ TeV} ?$



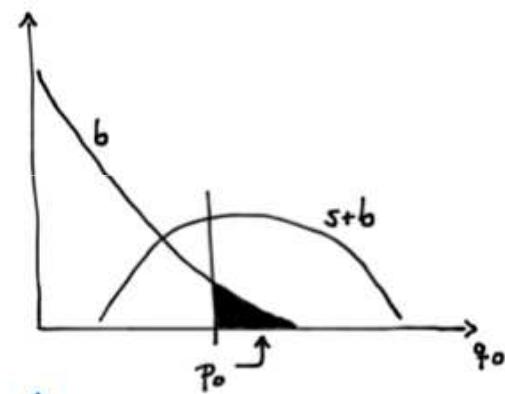
July 4th Discovery...



Interlude : Quelques définitions utiles...

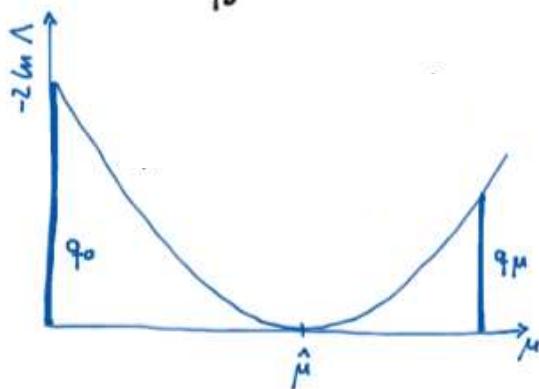


Test de compatibilité
avec l'hypothèse
signal+bruit de fond

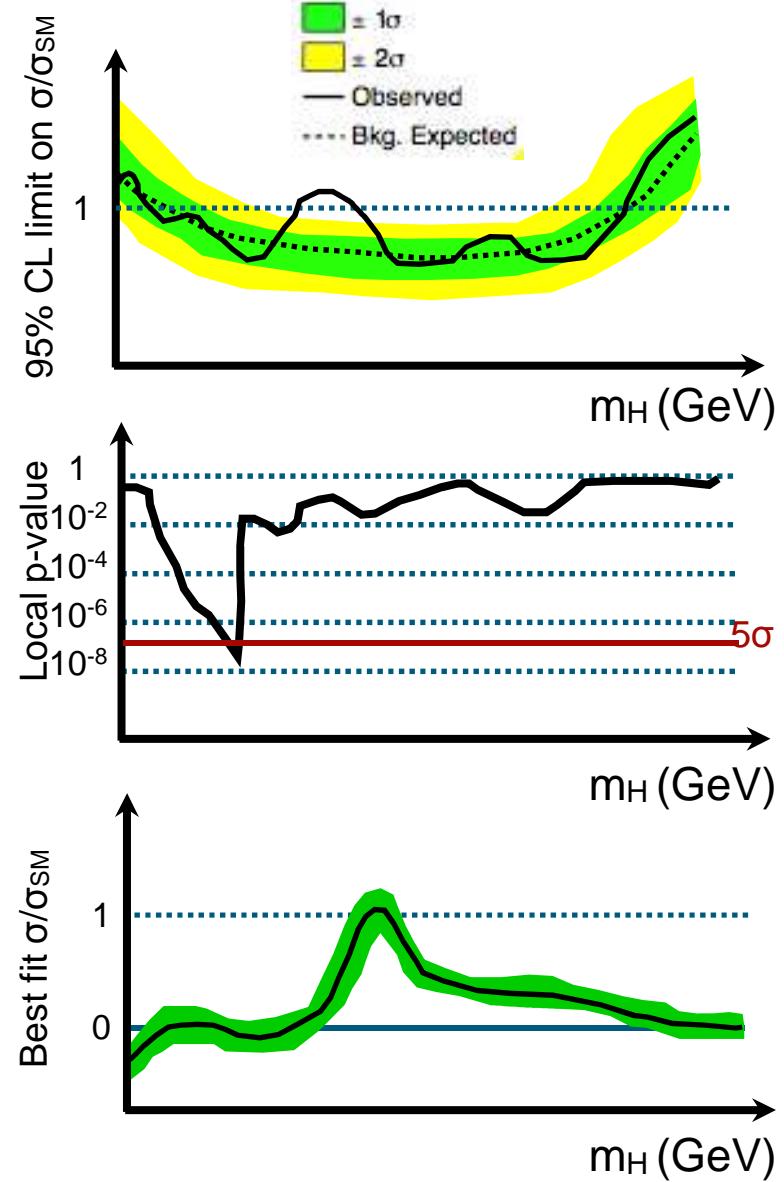


Quantifie la probabilité
d'un excès par rapport
au bruit de fond seul

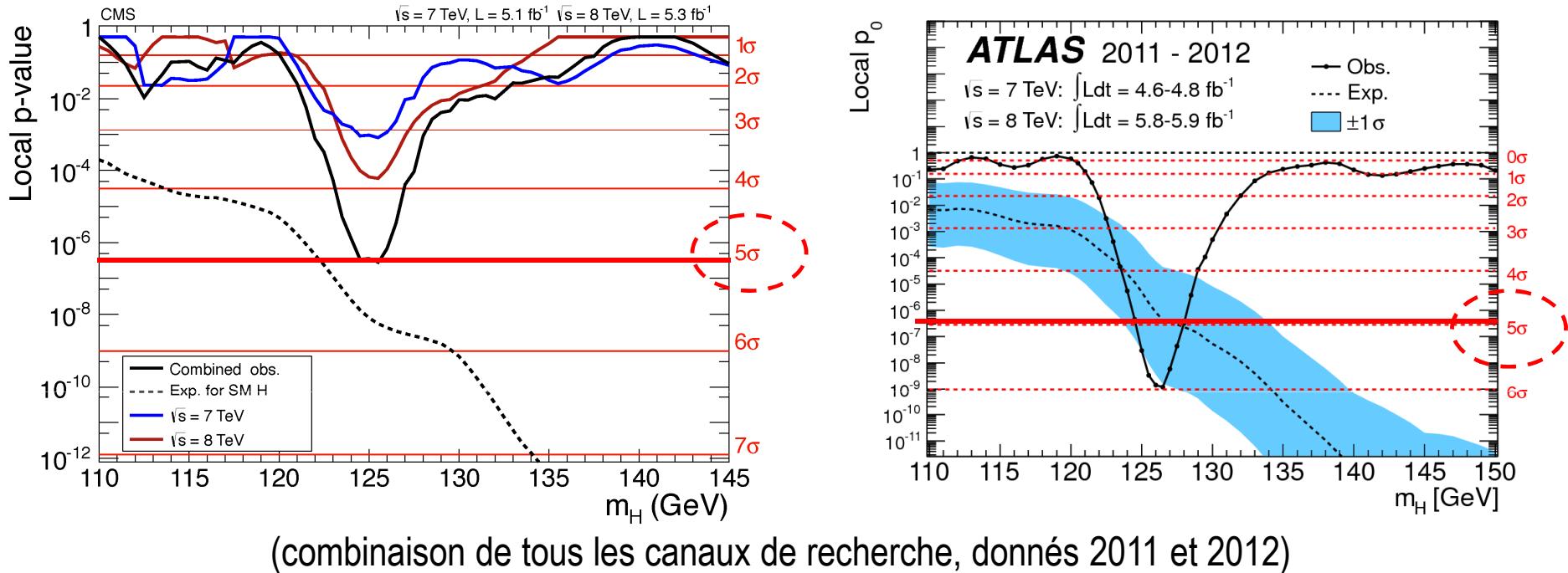
$5\sigma \sim 1/3$ millions
 $3\sigma \sim 1/700$



Evalue l'intensité
du signal

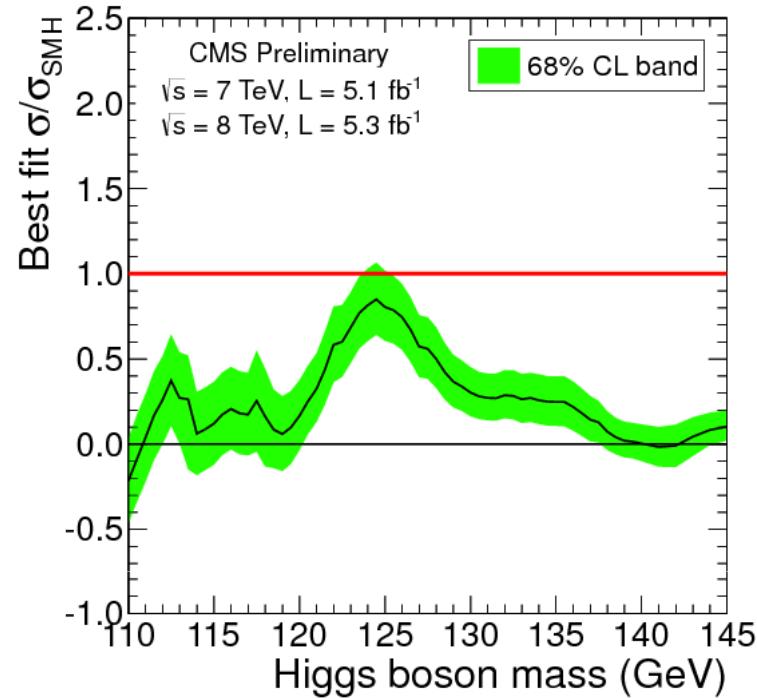


Qu'a-t-on découvert au juste ?

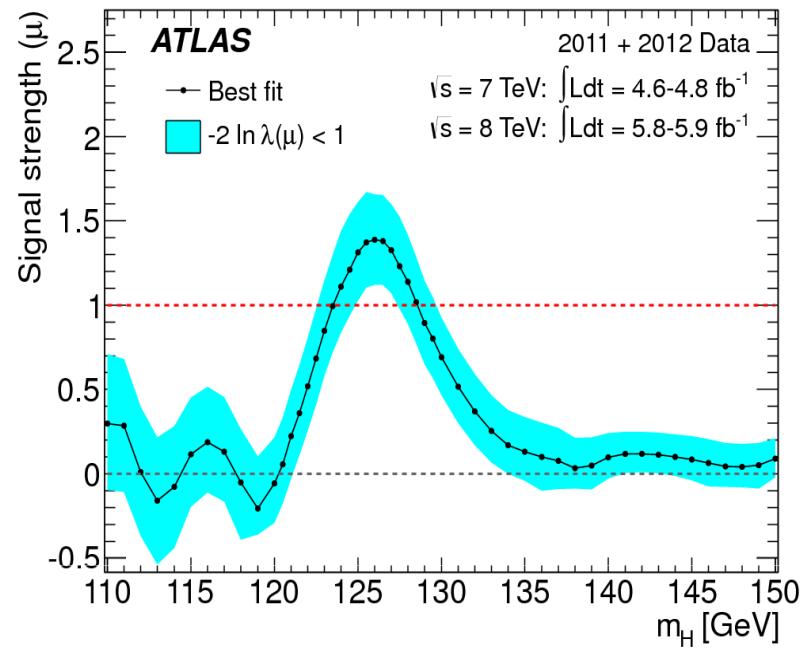


Un excès d'évènements non-compatible avec une fluctuation du bruit de fond (**> 5 déviations standards**),

Qu'a-t-on découvert au juste ?



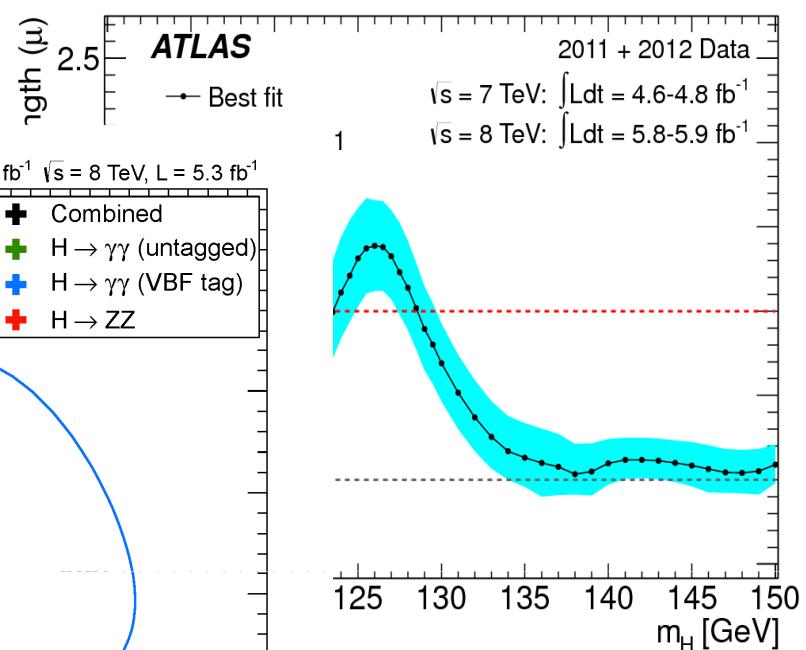
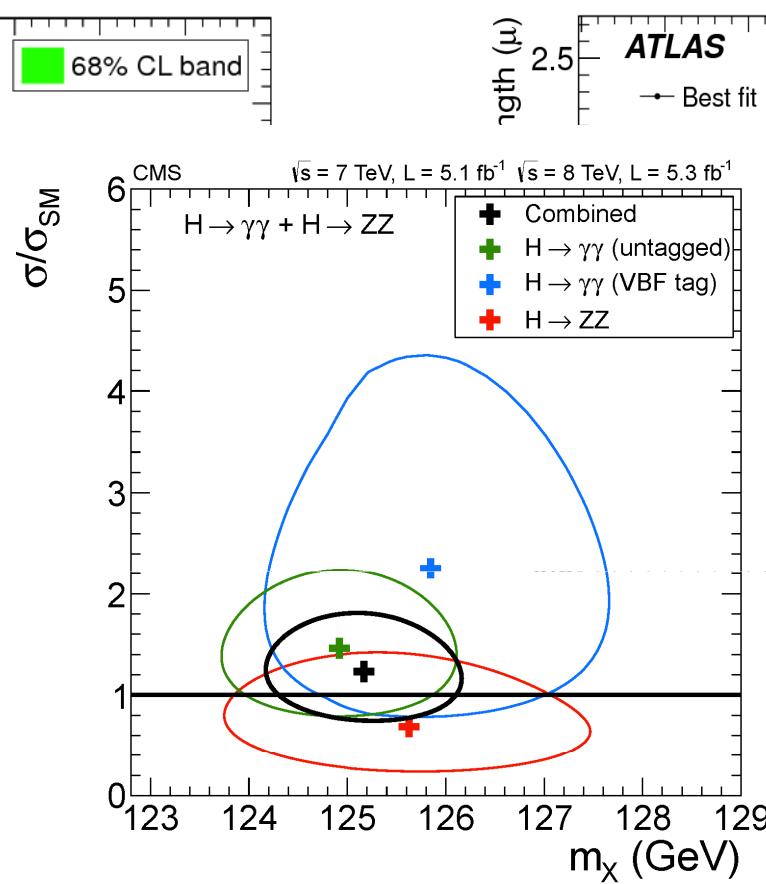
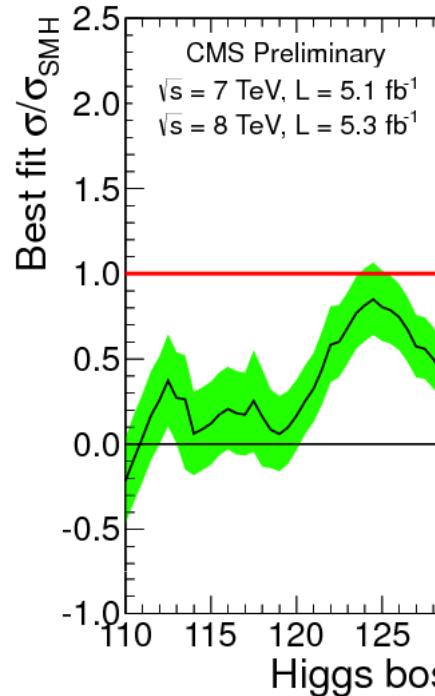
Meilleur ajustement : 0.87 ± 0.23 (@~125 GeV)



Meilleur ajustement : 1.4 ± 0.3 (@~126 GeV)

Un excès d'évènements non-compatible avec une fluctuation du bruit de fond (**> 5 déviations standards**), correspondant à la production d'un **boson**, **compatible avec le boson de Higgs MS**,

Qu'a-t-on découvert au juste ?



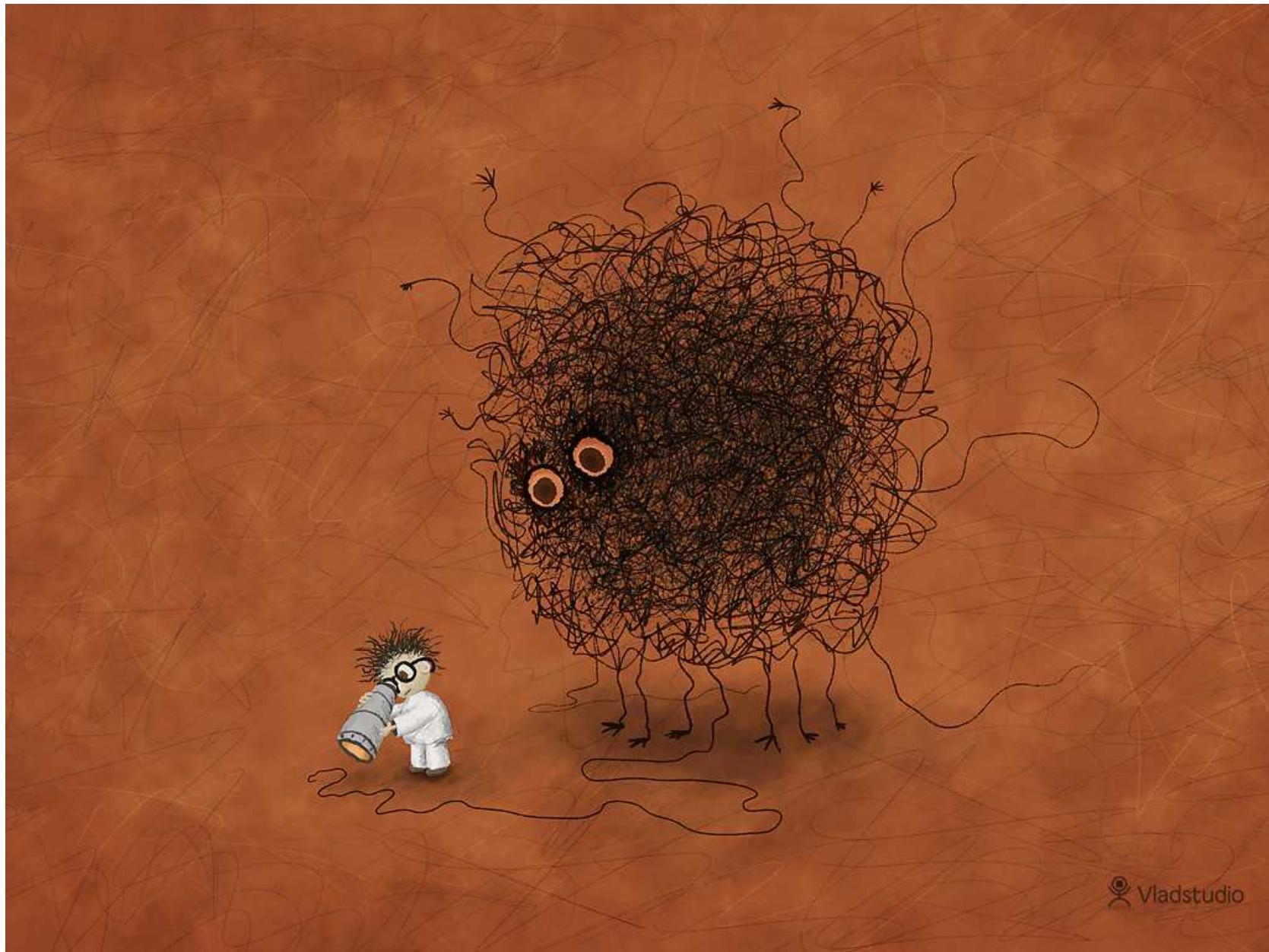
nent : 1.4 ± 0.3 (@~126 GeV)

Un excès d'évènements non-compatible avec une fluctuation du bruit de fond (> 5 déviations standards), correspondant à la production d'un **boson**, compatible avec le **boson de Higgs MS**, avec **une masse autour de 125 GeV**.

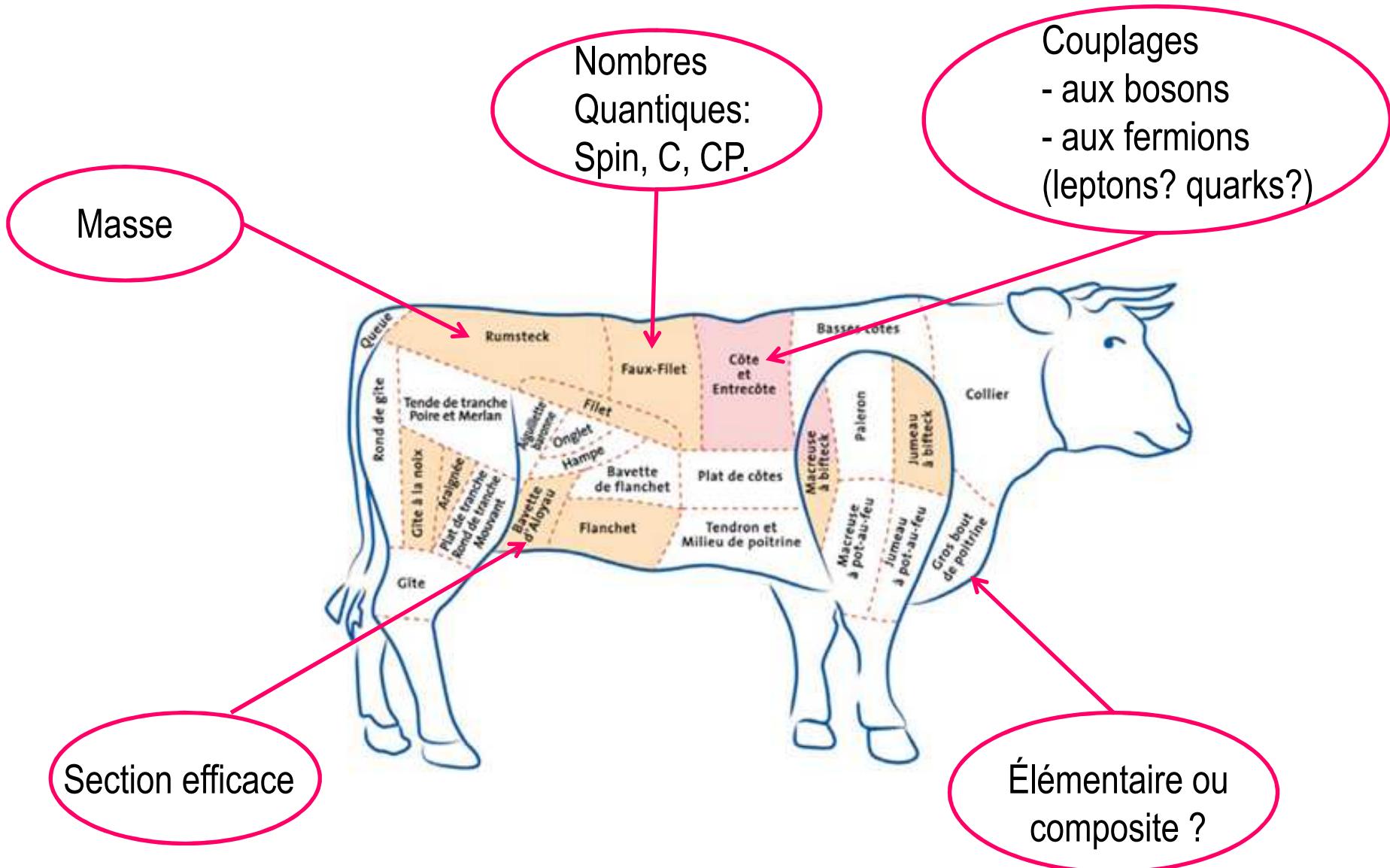
La découverte de ce boson est très récente...



... on peut s'attendre à quelques surprises !



Anatomie de la bête



Anatomie de la bête

Guillaume Lefebvre (ATLAS, this session)

Mykhailo Dalchenko, (CMS, this afternoon)

Narei Lorenzo Martinez (ATLAS, this afternoon)

es:
Spin, C, CP.

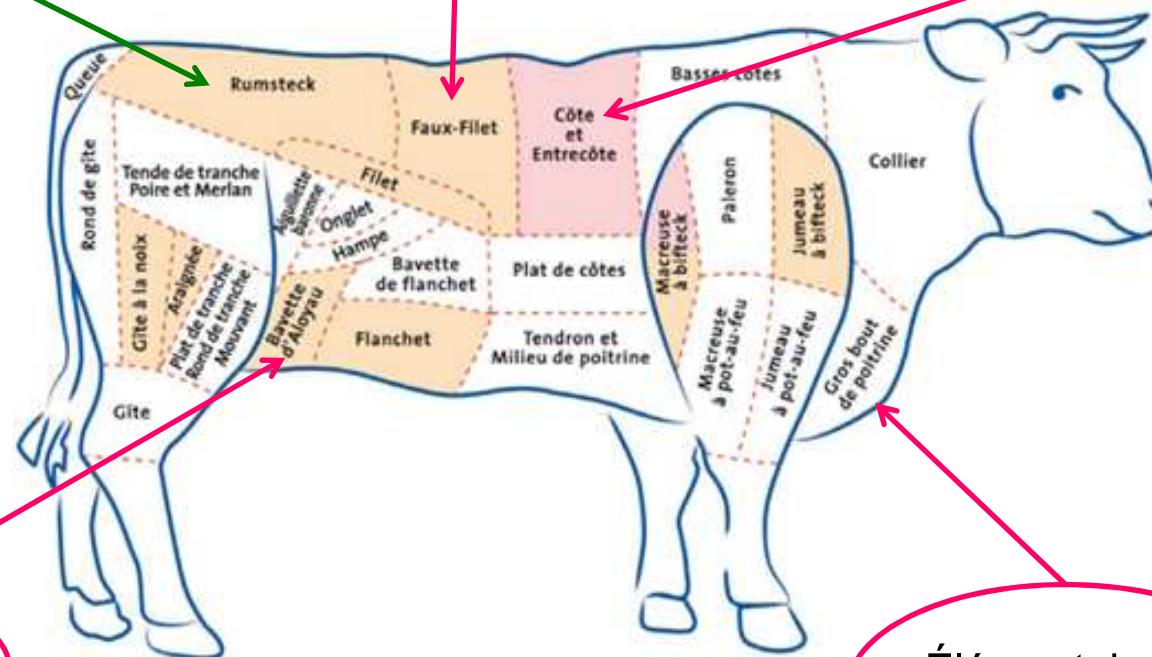
Couplages

- aux bosons

- aux fermions

(leptons? quarks?)

Masse



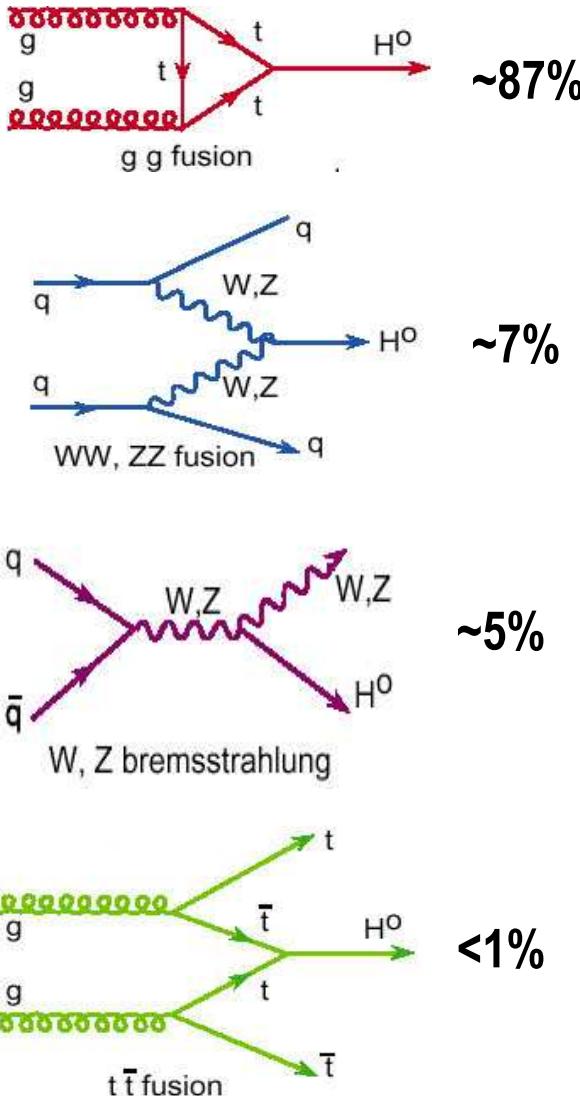
Section efficace

Élémentaire ou
composite ?

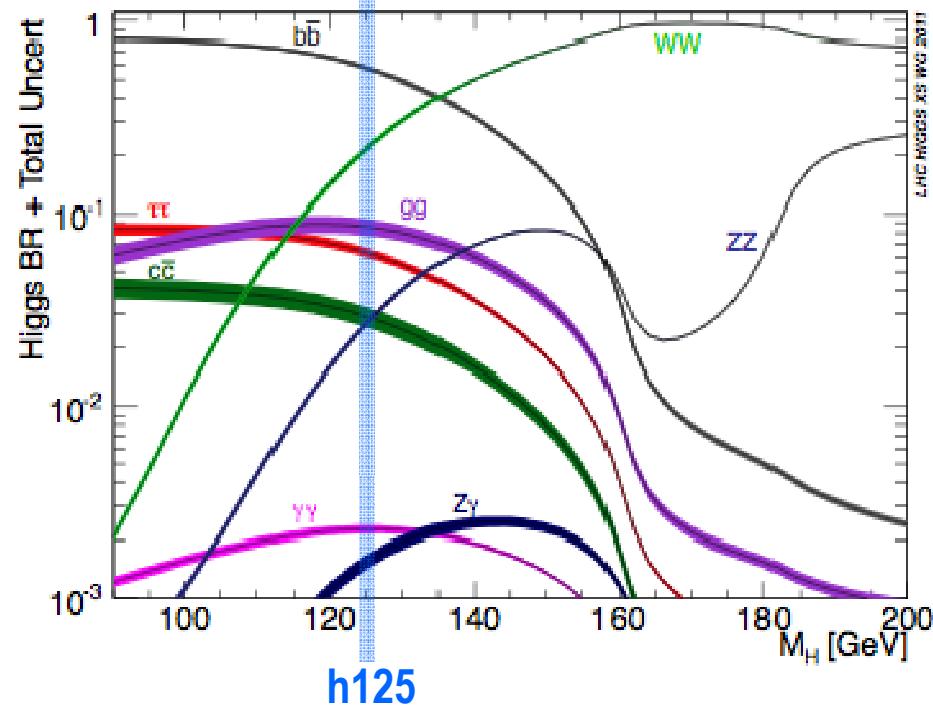
Un peu de Higgsologie...

Production...

@125 GeV



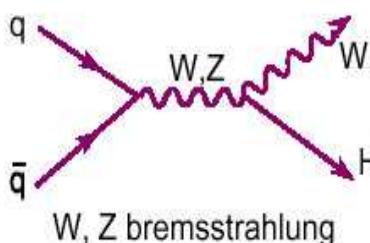
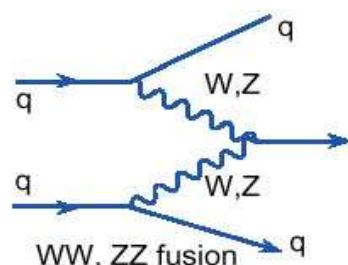
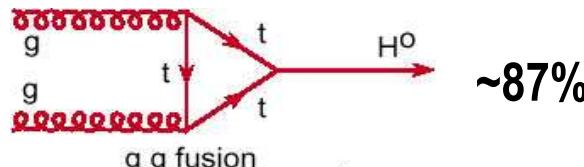
... et désintégration.



- De nombreux modes de désintégrations accessibles @ 125 GeV !
- Une chance pour les mesures de couplage !

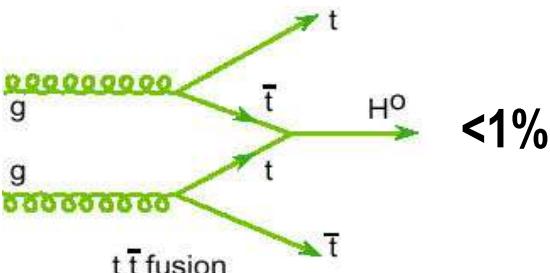
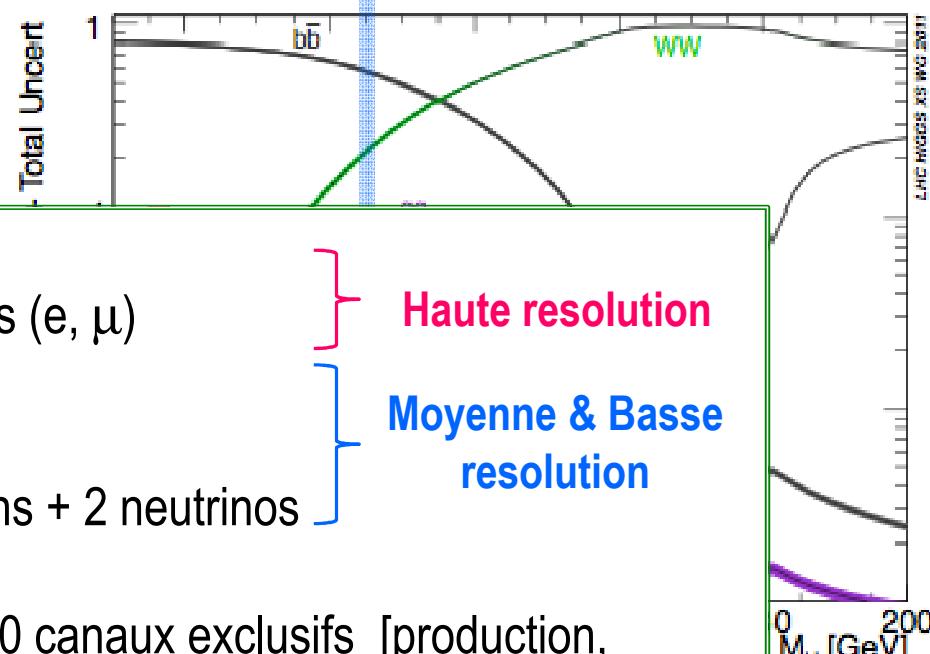
Un peu de Higgsologie...

Production...



- $H \rightarrow \gamma\gamma$
- $H \rightarrow ZZ \rightarrow 4 \text{ leptons } (e, \mu)$
- $H \rightarrow \tau\tau$
- $H \rightarrow b\bar{b}$
- $H \rightarrow WW \rightarrow 2 \text{ leptons} + 2 \text{ neutrinos}$

... et désintégration.



- De nombreux modes de désintégrations accessibles @ 125 GeV !
- Une chance pour les mesures de couplage !

Un peu de Higgsologie...

Camelia Rangel (ATLAS, this afternoon)

Elodie Tiouchichine (ATLAS, this afternoon)

Ivo Naranjo (CMS, Wednesday)

$H \rightarrow \gamma\gamma$

$H \rightarrow ZZ \rightarrow 4 \text{ leptons } (e, \mu)$

$H \rightarrow \tau\tau$

$H \rightarrow bb$

$H \rightarrow WW \rightarrow 2 \text{ leptons} + 2 \text{ neutrinos}$

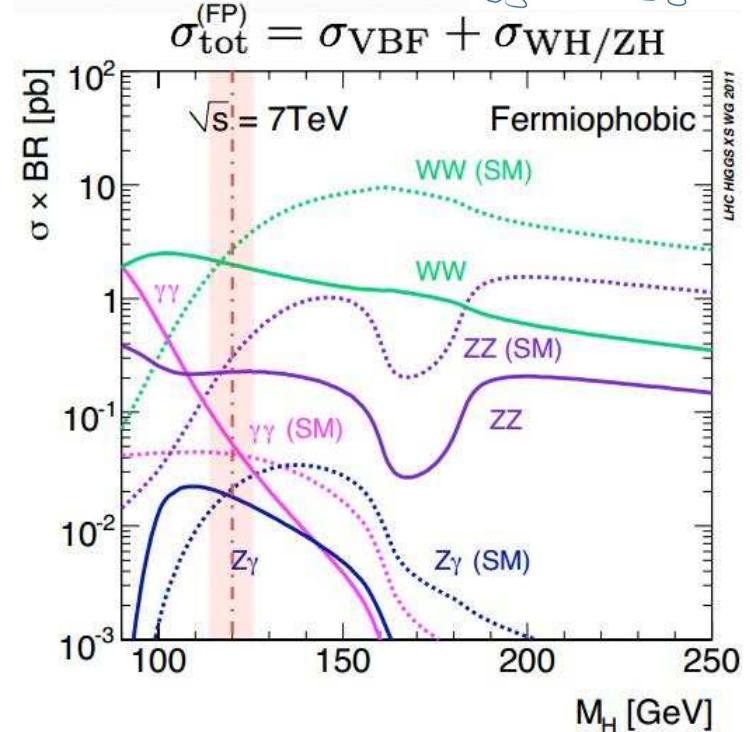
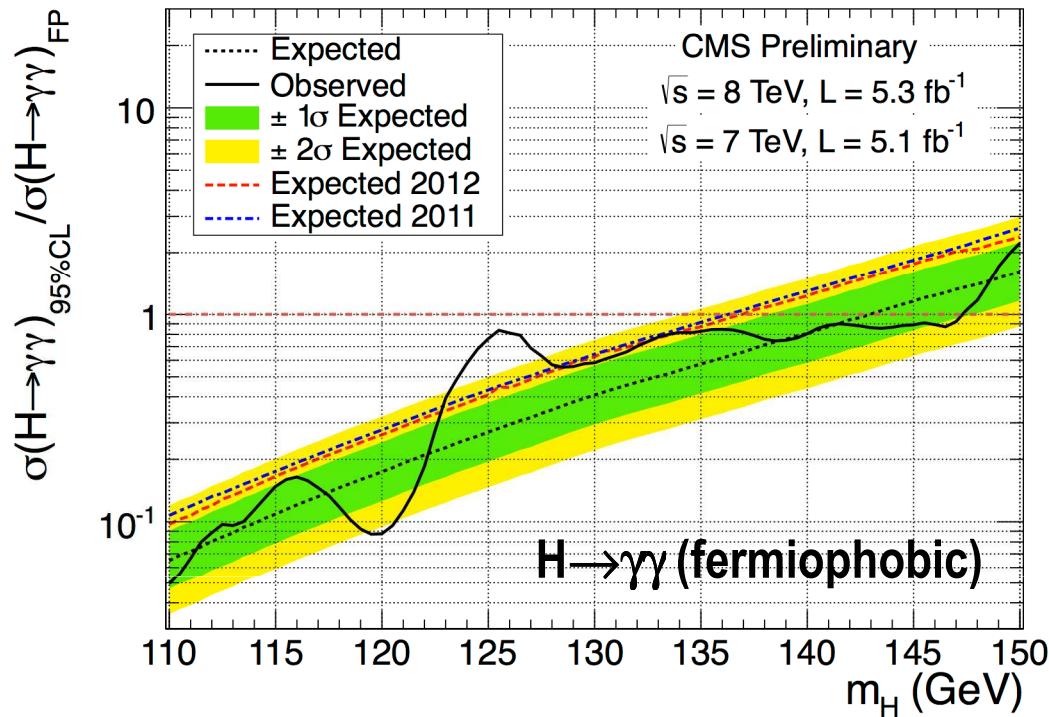
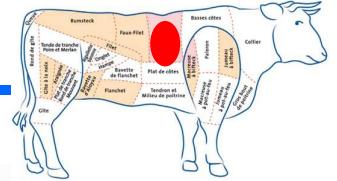
(près de 100 canaux exclusifs [production, désintégration, classes] combinés dans ATLAS & CMS)

Lion Alio (ATLAS, ZH, Wednesday)

Dikai Li (DØ, WH, Wednesday)

Emilien Chapon (DØ, Wednesday)

[Couplages] aux fermions ?

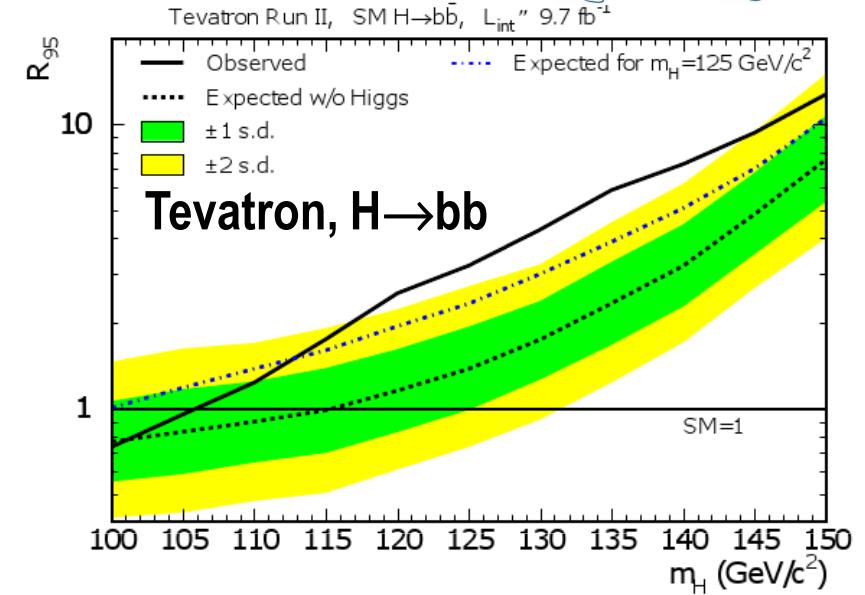
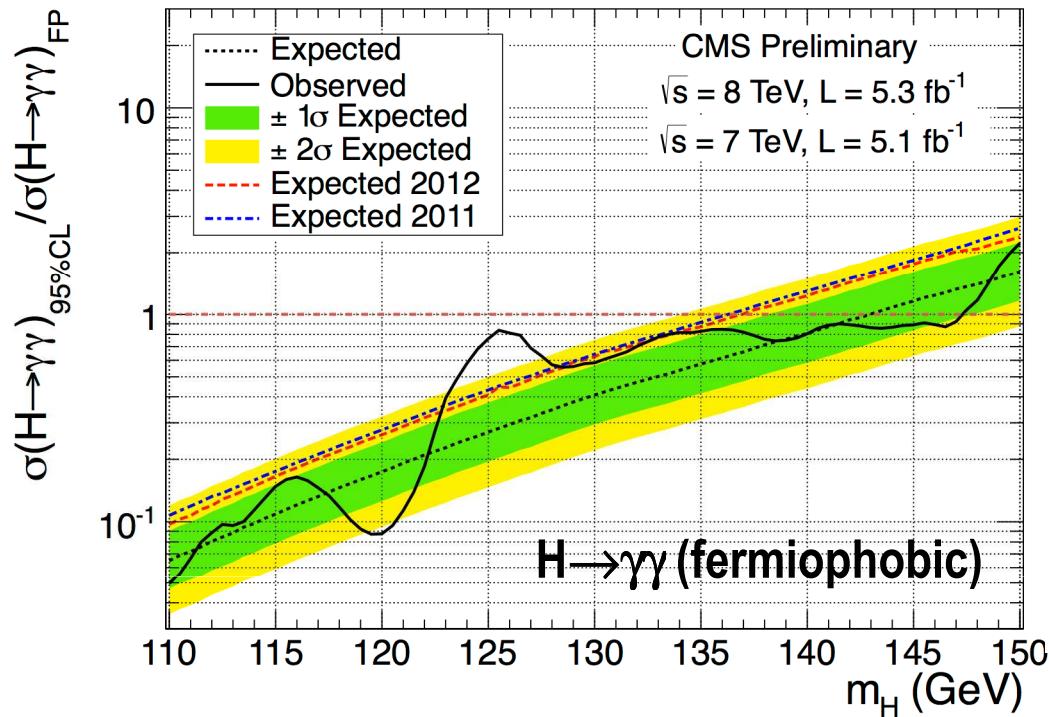
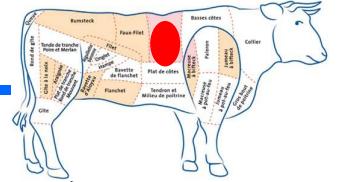


- Test de modèle purement “fermio-phobique”
- Production par fusion de gluons ou ttH interdits

Exclu à 99% CL dans le domaine de masse 110 – 134 GeV.

CMS HIG-12-022 (July 2012)

[Couplages] aux fermions ?

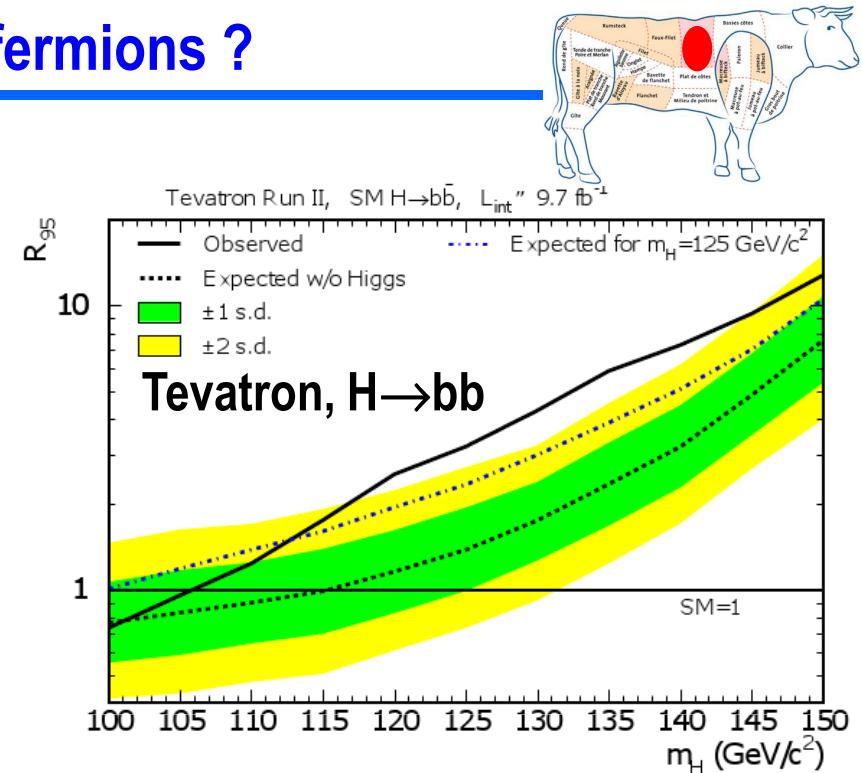
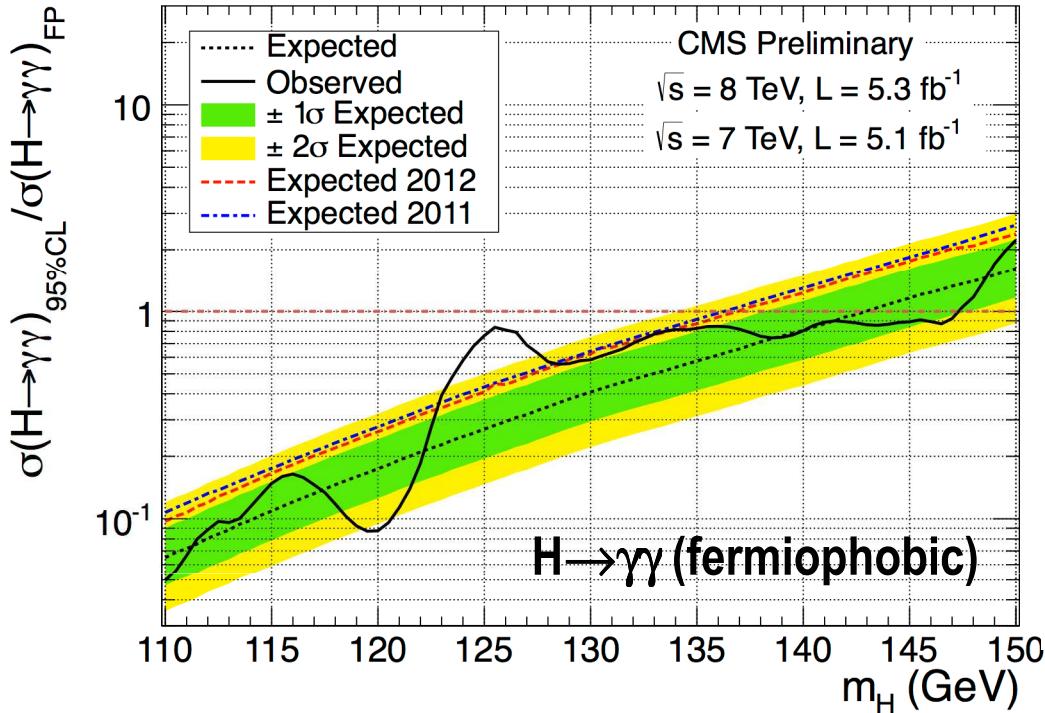


- Recherche du H en 2 quarks b au TeVatron
- Excès à ~ 3 sigmas...

Le nouveau boson se couple (au moins) aux quarks ?

Phys. Rev. Lett. 109, 071804 (2012)

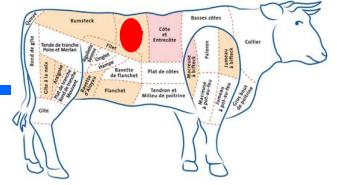
[Couplages] aux fermions ?



- Recherche du H en 2 quarks b au TeVatron
- Excès à ~ 3 sigmas...

**Couplages directs aux quarks... et aux leptons:
réponse définitive > 2015**

[Nombre Quantique] Spin : une approche naïve...



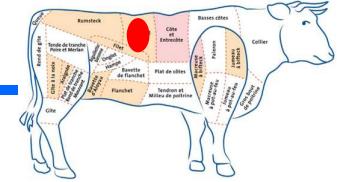
Nouveau boson : se désintègre en di-photons et ZZ.

Spin of particle	$\gamma\gamma$	ZZ^*	$\tau\tau$	bb
Spin 0	😊	😊	😊	😊
Spin 1	😢	😊	😊	😊
Spin 2	😊	😊	😢	😊
Seen?	Yes	Yes	Not yet	Not yet

Interdit par le théorème
de Landau-Yang.

Il peut être de spin 0 ou 2

[Nombre Quantique] Spin : 0 vs 2

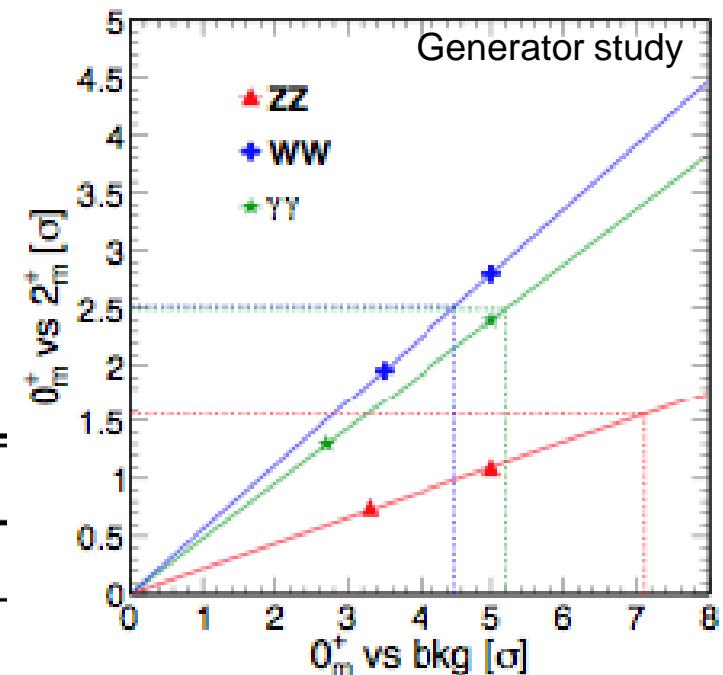


➤ Spin 0 vs. Spin 2: $gg \rightarrow H \rightarrow VV$

- Hypothèse: résonnance se souplant de la même façon que des gravitons KK
- Utilise essentiellement $H \rightarrow \gamma\gamma$, $H \rightarrow WW$ (mais petite contribution de ZZ aussi)
- distribution angulaire ($\cos\theta^*$), $\Delta\phi(l,l)$, $m(l,l)$

➤ Projections à 8 TeV avec 35 /fb :

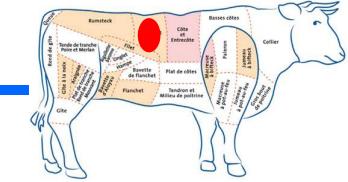
scenario	$X \rightarrow WW$	$X \rightarrow \gamma\gamma$
$0_m^+ \text{ vs background}$	4.5	5.2
$0_m^+ \text{ vs } 0_m^-$	1.1	0.0
$0_m^+ \text{ vs } 2_m^+$	2.5	2.5



arXiv:1202.6660
arXiv:1208.4018
arXiv:1209.1037
arXiv:1209.5268

En combinant ATLAS et CMS à Moriond,
possibilité de séparer les hypothèses spin 0 et 2.

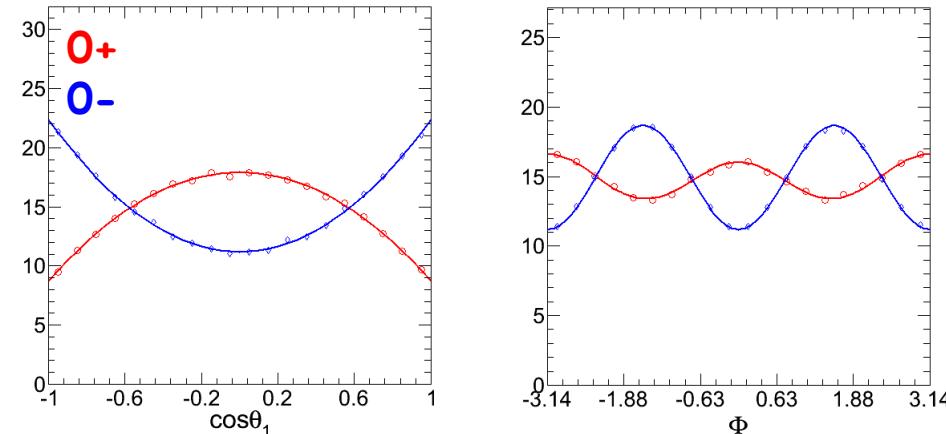
[Nombre Quantique] Parité



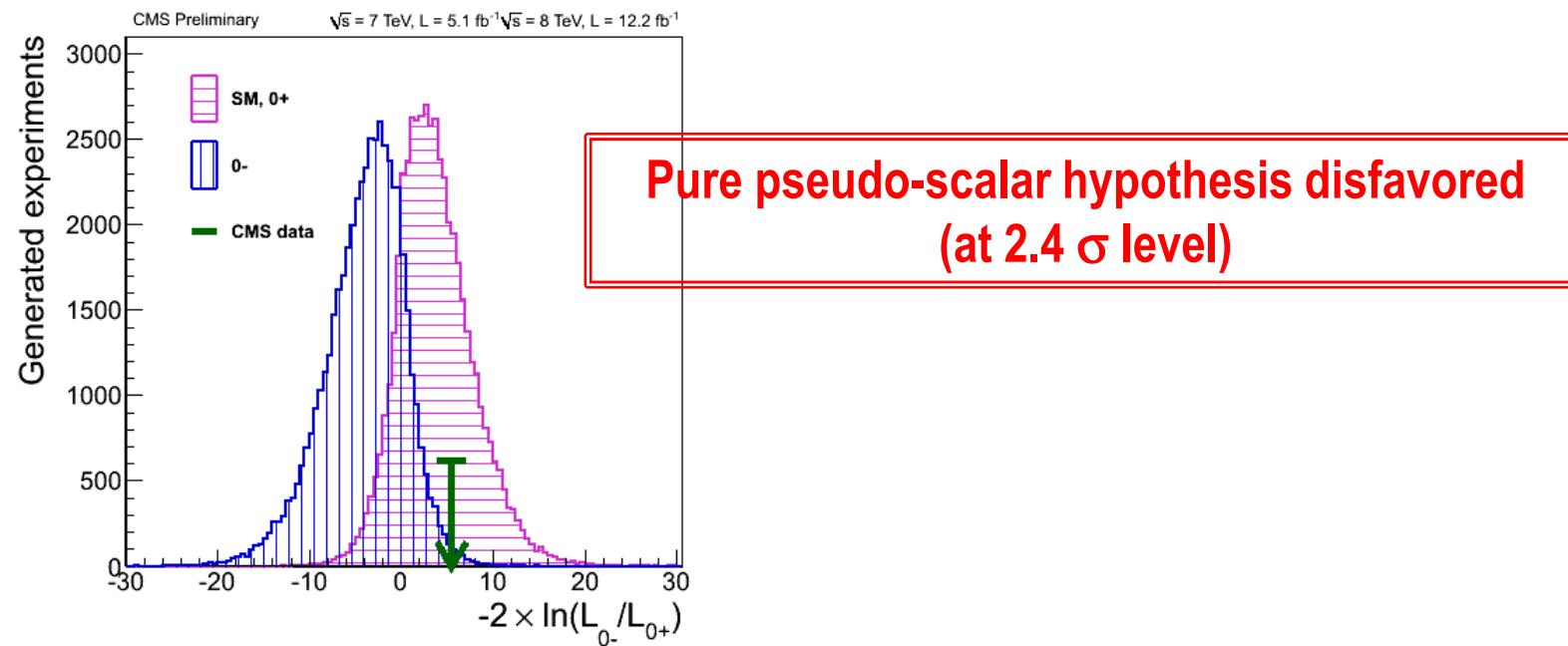
➤ $H \rightarrow ZZ \rightarrow 4 \text{ leptons}$:

- Distributions angulaires:

On peut différencier les hypothèses scalaire (0^+ , SM) and pseudo-scalaires (0^-)



HCP Conference, Kyoto, Novembre 2012



Sessions

Today

09:25 Etude des corrections électrofaibles dans les processus QCD, de la théorie à l'expérience

Presenter(s): MERIC, Nicolas (*LPNHE*)

Location: Maison du Kleebach

09:50 Etude sur la b-Jet Energy Scale avec des événements top-antitop

Presenter(s): LEFEBVRE, Guillaume (*LPNHE*)

Location: Maison du Kleebach

14:30 Electron momentum, scale and resolution in the CMS experiment at LHC

Presenter(s): DALCHENKO, Mykhailo (*LLR*)

Location: Maison du Kleebach

14:55 Electron reconstruction in ATLAS/ Background-like lepton study in MC and Data

Presenter(s): TIOUCHICHINE, Elodie (*CPPM*)

Location: Maison du Kleebach

15:20 Calibration of the ATLAS EM calorimeter and Higgs mass measurement.

Presenter(s): LORENZO MARTINEZ, Narei (*LAL*)

Location: Maison du Kleebach

15:45 Z radiative decays studies and Higgs searches in the gamma gamma and Z gamma channel

Presenter(s): RANGEL, Camila (*LPNHE*)

Location: Maison du Kleebach

09:00 Timing alignment of the LAr calorimeter of the ATLAS experiment and studies of the Z boson transverse momentum

Presenter(s): KEOSHKERIAN, Houry (*LAPP*)

Location: Maison du Kleebach

09:25 Research the decay channel of Higgs ZH->wbb with the aid of ghost-association for b-tagging

Presenter(s): ALIO, Lion (*CPPM*)

Location: Maison du Kleebach

09:50 Recherche du Boson de Higgs se désintégrant en paire de leptons Taus.

Presenter(s): NARANJO FONG, Ivo Nicolas (*LLR Ecole Polytechnique*)

Location: Maison du Kleebach

10:45 Search for the SM Higgs boson decaying to WW with the D0 detector at the Tevatron

Presenter(s): CHAPON, Émilien (*SPP/Irfu/CEA Saclay*)

Location: Maison du Kleebach

11:10 Search for the Higgs boson in a final state with lepton, MET and jet

Presenter(s): LI, Dikai (*LPNHE*)

Location: Maison du Kleebach

11:35 Testing the Standard Model at low-energy with aSPECT

Presenter(s): MAISONOBE, Romain (*Institut Laue-Langevin*)

Location: Maison du Kleebach

09:00 Measurement of the top-antitop production cross section in the all-hadronic channel in 4.7 fb⁻¹ of pp collisions at 7 TeV with the ATLAS detector

Presenter(s): BERTELLA, Claudia Bertella (*CPPM*)

Location: Maison du Kleebach

09:25 Mesure de la masse du quark top à l'aide du détecteur ATLAS dans le canal semi-leptonique

Presenter(s): BALLI, Fabrice (*CEA Saclay*)

Location: Maison du Kleebach

Thursday

09:50 Mesure de la masse du quark top dans le canal dileptonique ee avec la méthode des éléments de matrice avec ATLAS au LHC

Presenter(s): DEMILLY, Aurélien (*LPNHE Paris*)

Location: Maison du Kleebach

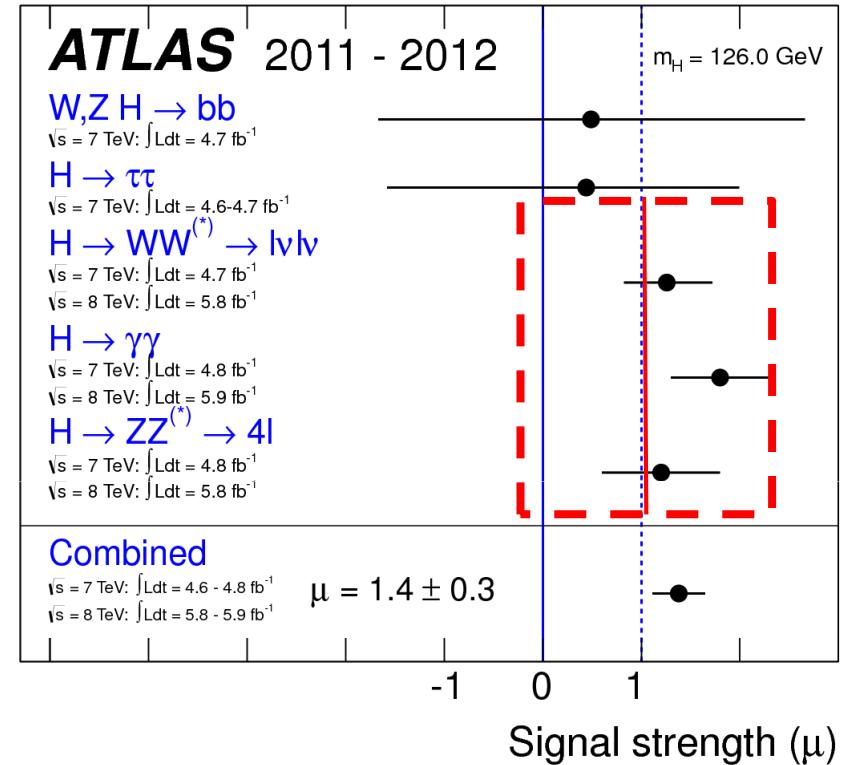
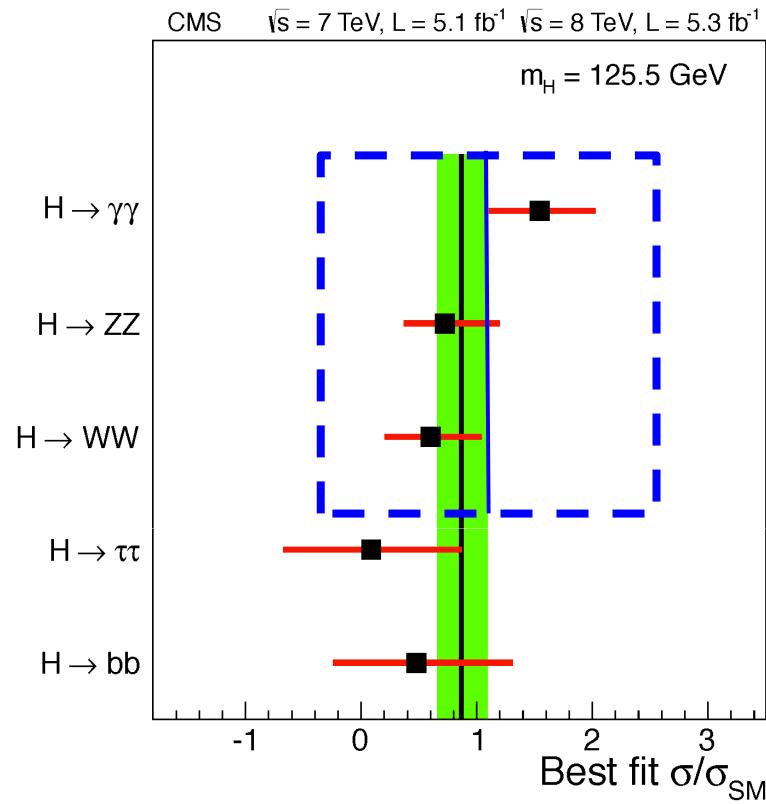
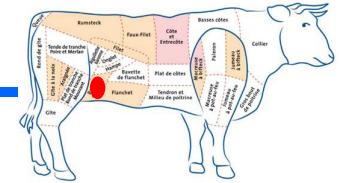
BACK UP SLIDES

Conclusion

- Nous avons **découvert un nouveau boson** (vraisemblablement un boson de scalaire “à la Higgs”).
 - **Le LLR est aux premières loges !**
- Les couplages et l'intensité du signal sont pour l'instant (au vue des grandes erreurs...) **compatibles avec un boson de Higgs “standard”**. Mais:
 - Observé grâce à $\rightarrow ZZ$, $\gamma\gamma$. Taux de $\gamma\gamma$ un peu élevé... A voir avec plus de données.
 - Recherche en paire de fermions ($\rightarrow \tau\tau$, $\rightarrow bb$) ne permettent pas encore de distinguer entre prédition MS et absence de signal (=au-delà du MS !) (**tension dans VBF $H \rightarrow \tau\tau$...**)
 - $\sim 3\sigma$ prévus en $H \rightarrow \tau\tau$ pour 2012 / expérience. **Réponse définitive après 2014 ??**
- **Informations précieuses seront déjà disponibles avec l'ensemble des données 2011+2012** (Moriond 2013 ? + combination ATLAS/CMS ?)
 - Mesure de la masse (mieux qu'un 1%)
 - Couplages aux bosons et fermions
 - Nombres quantiques (spin/parité)
- Seulement 1% des données du programme total (1000 fb-1 en 2025) utilisé jusqu'ici !
 - Doublement de l'énergie dans le centre de masse (7 TeV \rightarrow 13, 14 TeV en 2014).

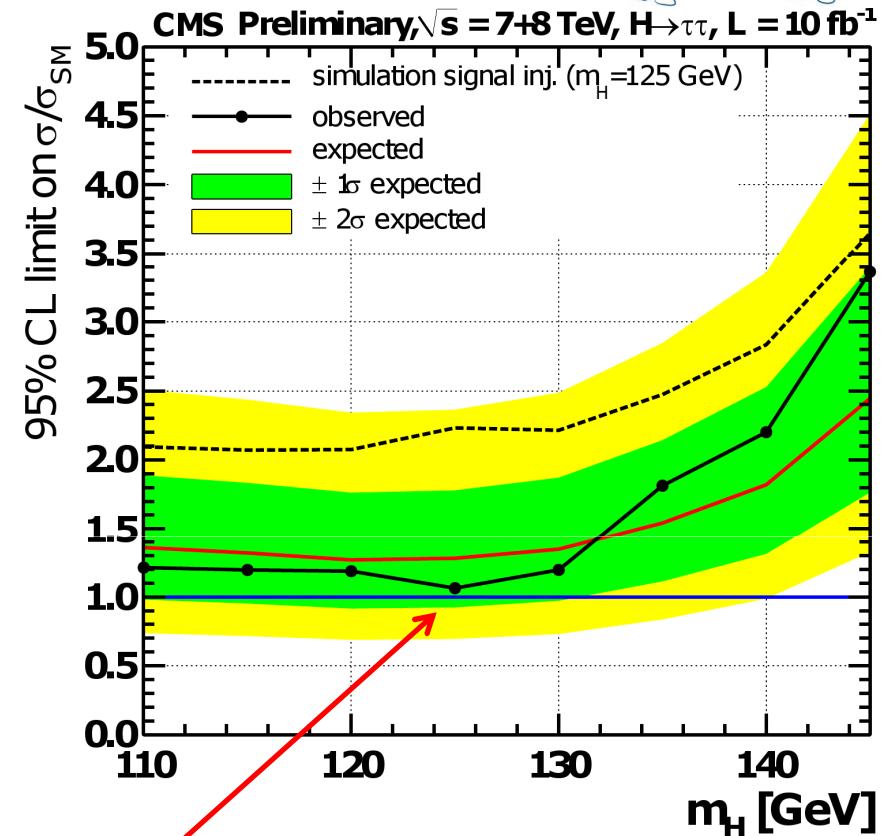
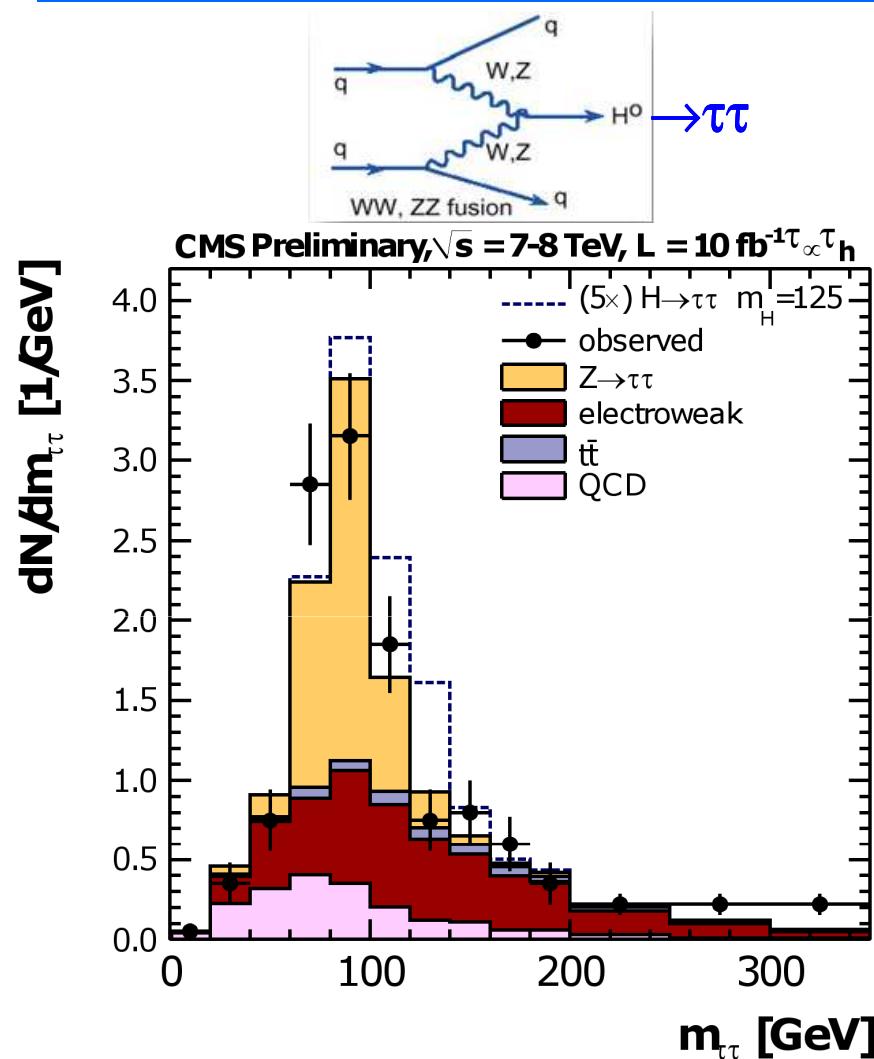
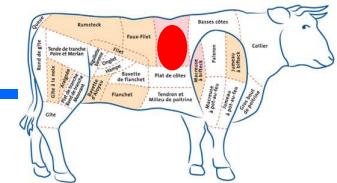
Le programme de mesures et découvertes au LHC s'annonce riche et extrêmement passionnant !

[Compatibilité avec le Modèle Standard]



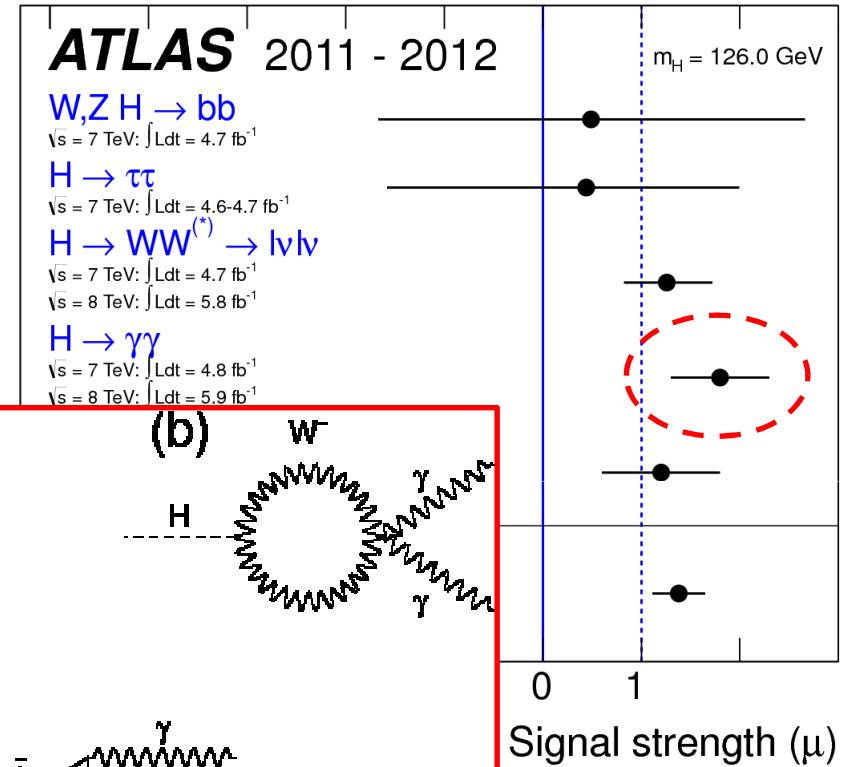
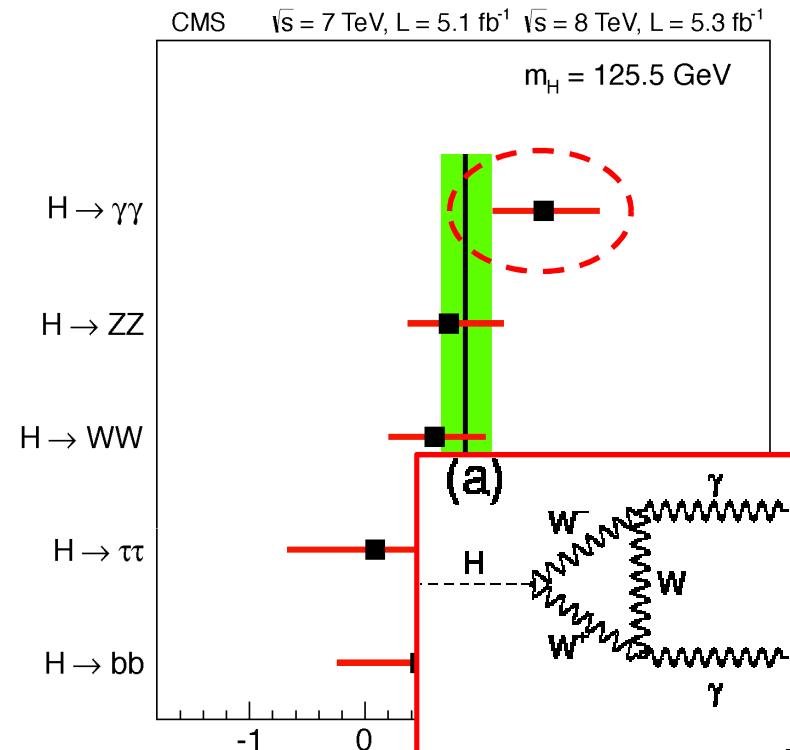
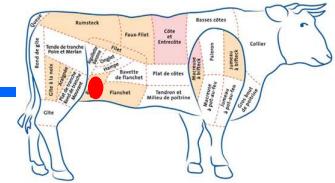
- Résultats similaires pour CMS et ATLAS;
- Résultats compatibles avec le MS compte tenu des incertitudes
- Tension (?) entre canaux gg, ZZ, WW et $\tau\tau$, bb

[Couplages] aux leptons ?



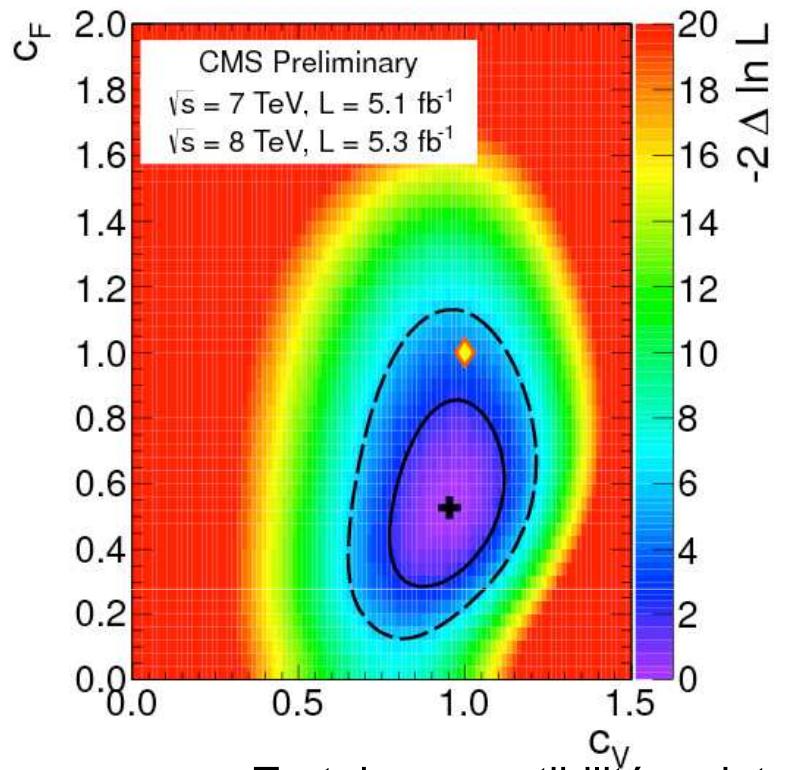
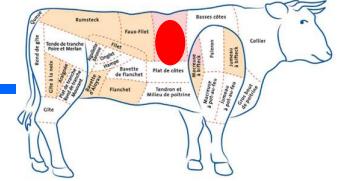
- Exclusion @ 93% CL (effet à ~2 sigmas...)
- Mise à jour à HCP (cf Ivo)

[Compatibilité avec le Modèle Standard]



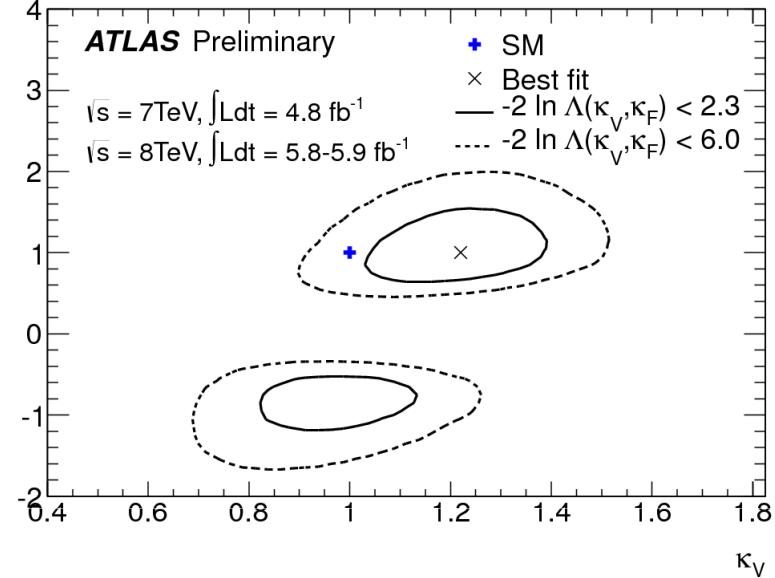
- Pas de couplage direct du photon au Higgs
- Un taux plus élevé que prévu... Indications de nouvelles particules lourdes (chargées) ???

[Couplages] Résumé

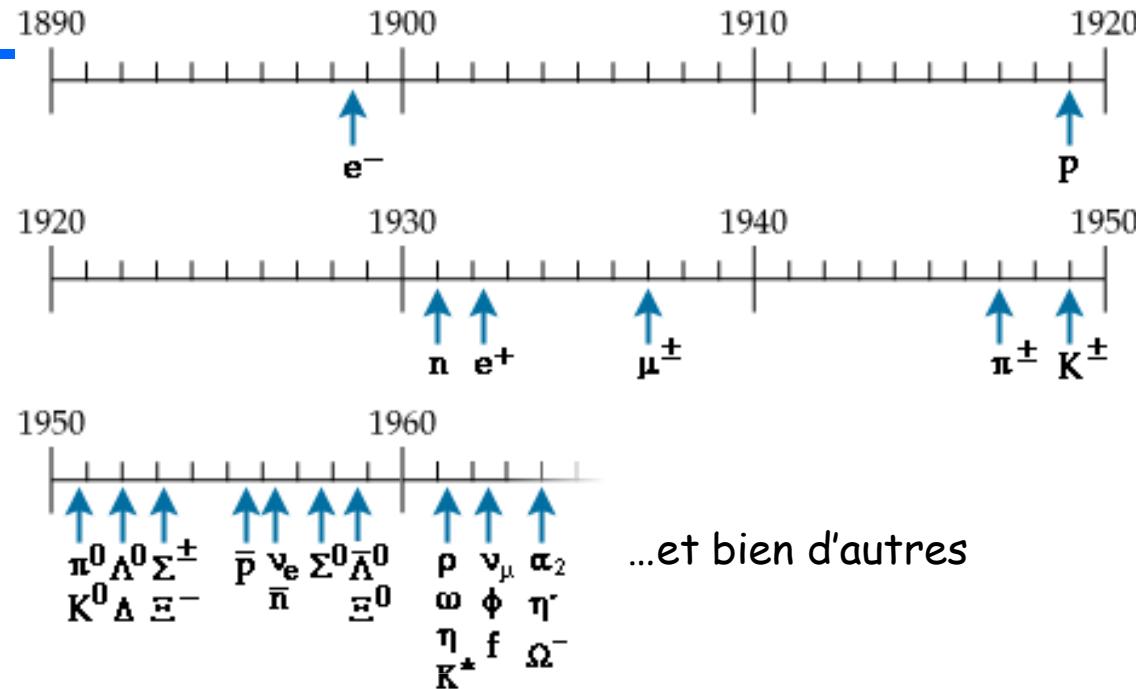


Test de compatibilité en introduisant 2 paramètres: CV, CF)
 c_V and $c_F = c_b = c_t = c_T$

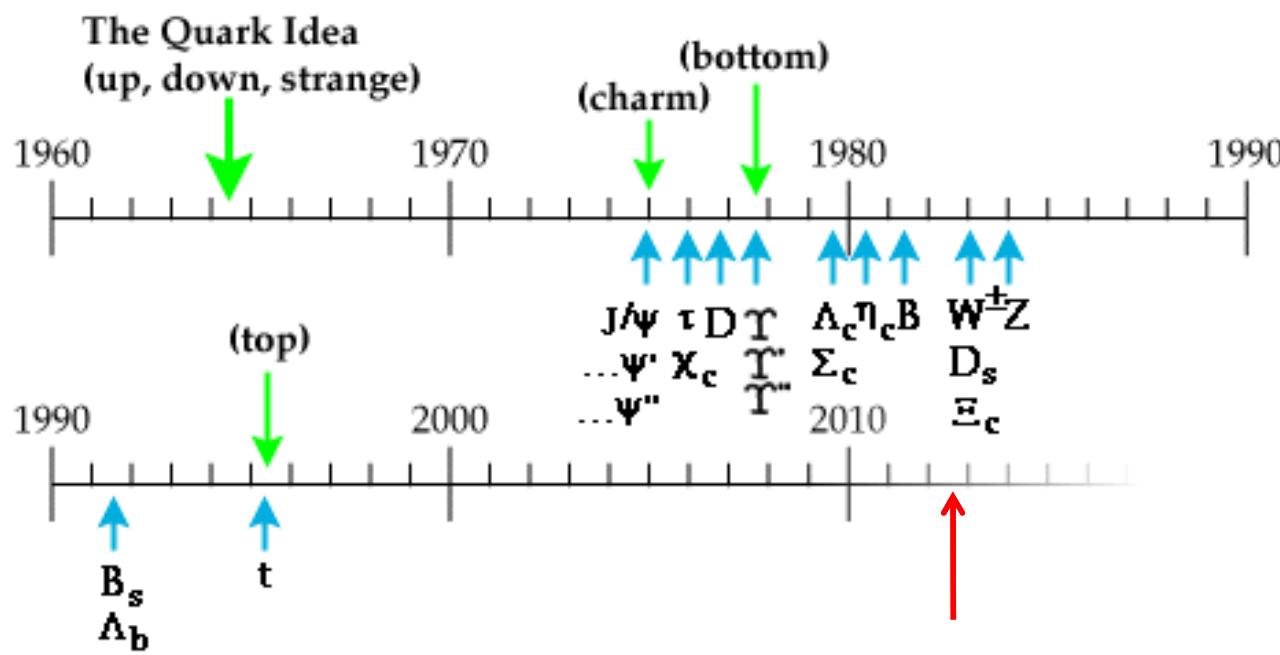
CMS: “Meilleur ajustement” de CF poussé vers le bas par l’excès en VBF $\gamma\gamma$ et le déficit en $\tau\tau$.



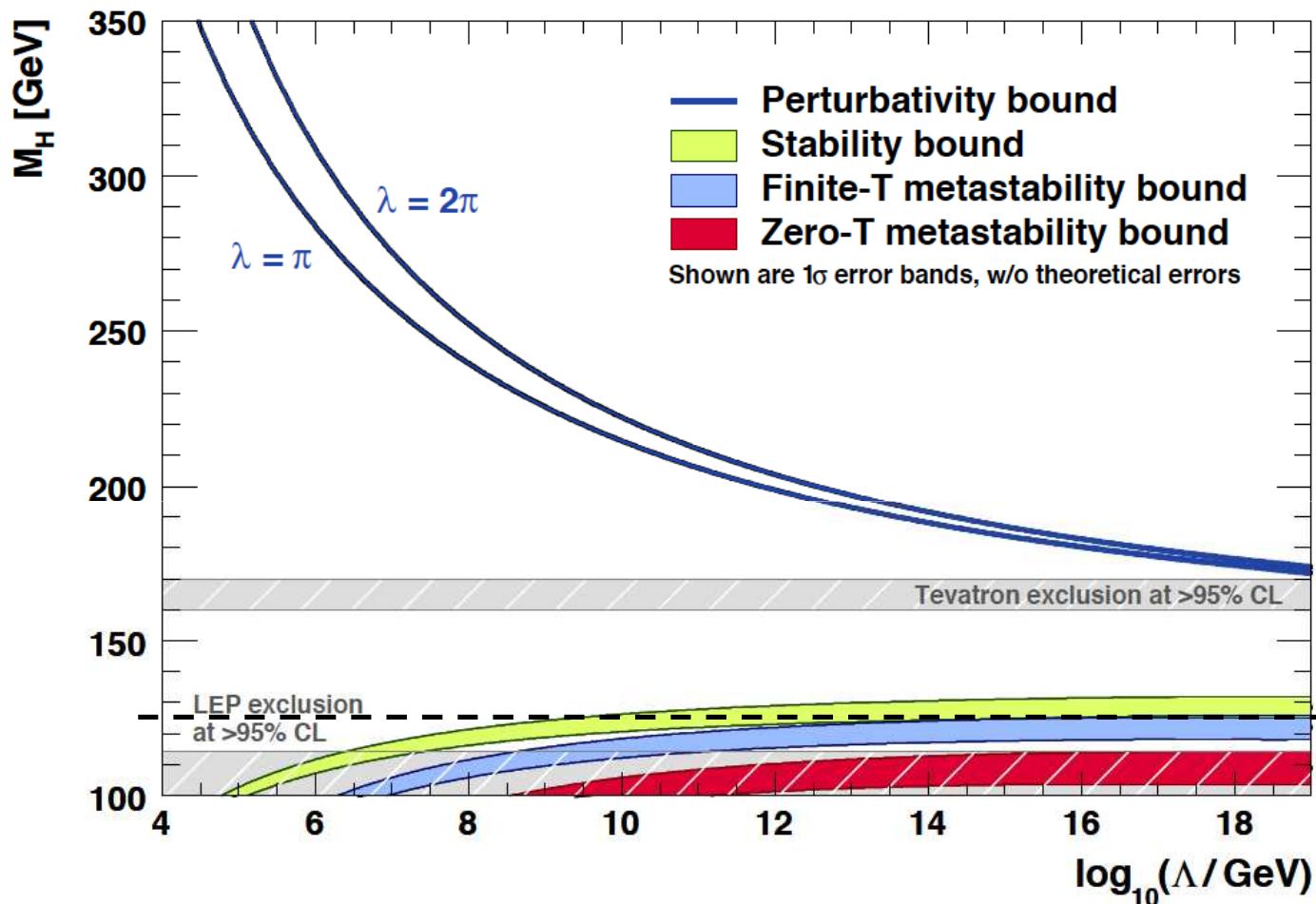
- Compatible (pour le moment...) avec le MS à 95% CL
- Plus de données sont nécessaires pour tirer des conclusions définitives...



Une maturation
d'un siècle...

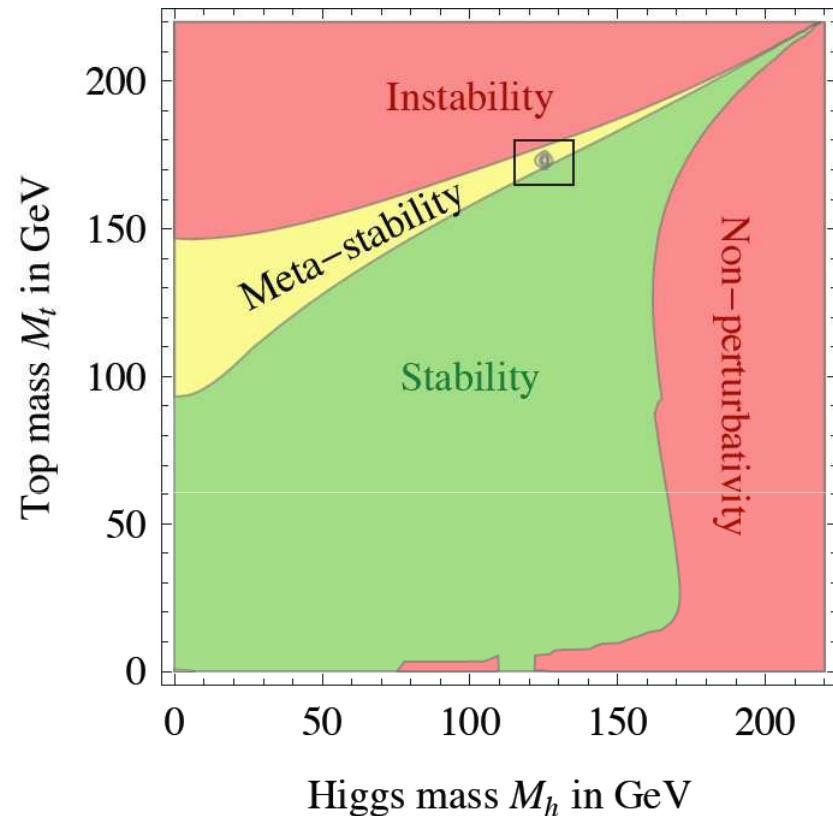


Spéculations à l'échelle de Planck : Stabilité du vide



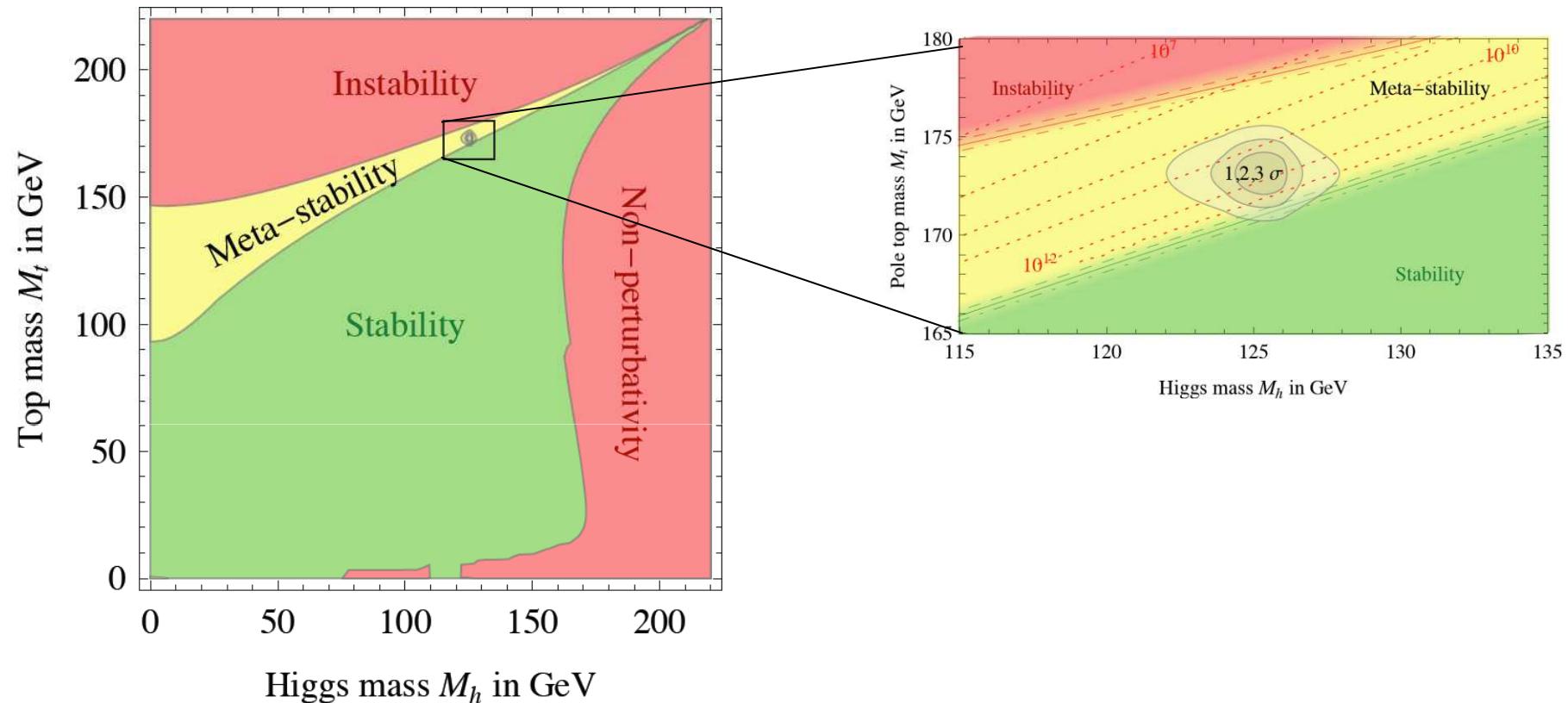
Pour $m_H \sim 125$ GeV, nous sommes probablement dans une région où le potentiel de Higgs n'est pas stable...

Spéculations à l'échelle de Planck : une région particulière...



G. Degrassi et al., JHEP 1208 (2012) 098

Spéculations à l'échelle de Planck : une région particulière...



- Nous vivons dans une région très particulière de l'espace des paramètres...
- Mesurer m_{top} & m_H avec grande précision est nécessaire !

-
- 1961: Glashow: electroweak unification $SU(2) \times U(1)$
 - 1962: Neutrino mu:
 - 1964: Gell-Mann/Zweig: quark model
 - 1964: Brout-Englert-Higgs + (GKH)
 - 1967: "A model of leptons" (Weinberg, Salam)
 - 1970: Mécanisme GIM
 - 1972: Kobayashi, Maskawa => 3 generations of quarks
 - 1973: Asymptotic Freedom (Politzer, Gross, Wilczek)
 - 1973: Courants neutres
 - 1975: lepton taus
 - 1976: quark charm (ψ),
 - 1977: quark bottom (χ),
 - 1983: bosons W & Z
 - 1995: quark top
 - 2000: neutrino tau

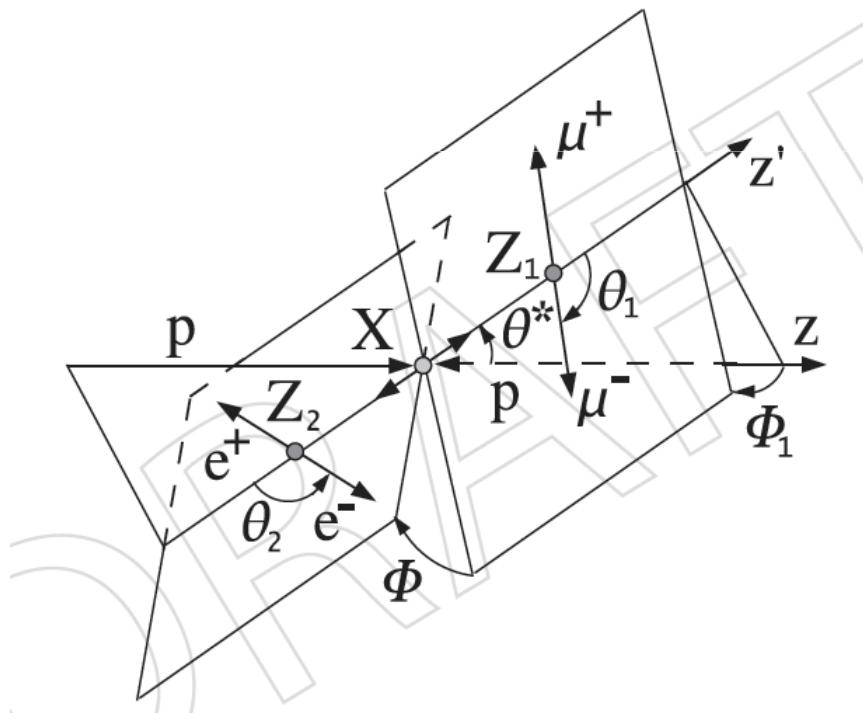
Angles

θ^* : angle between the parton collision axis z and $X \rightarrow ZZ$ decay axis z' (in X rest frame)

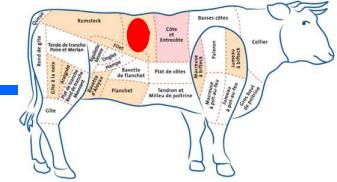
Φ_1 : angle between zz' plane and plane of $Z_1 \rightarrow ff$ (in X rest frame)

θ_i : angle between direction of fermions f_i from $Z_i \rightarrow f_i f_i$ and direction opposite the X in the Z_i rest frame ($i=1,2$ for the first and second Z)

Φ : angle between the decay planes of the two Z systems (in X rest frame)



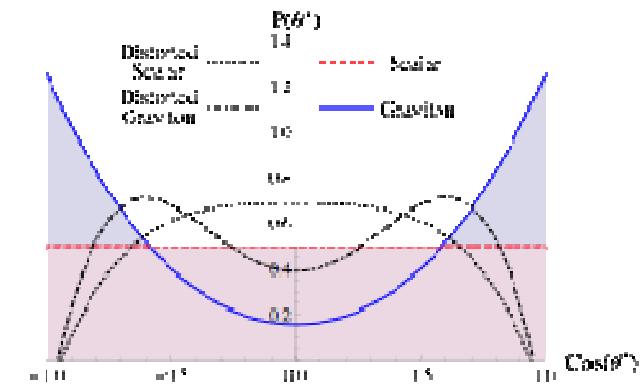
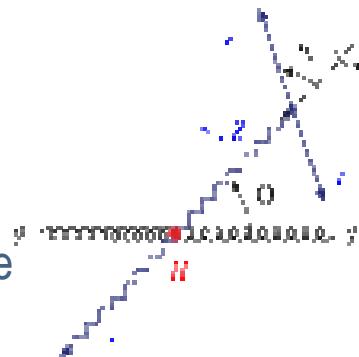
[Nombre Quantique] Spin : 0 vs 2



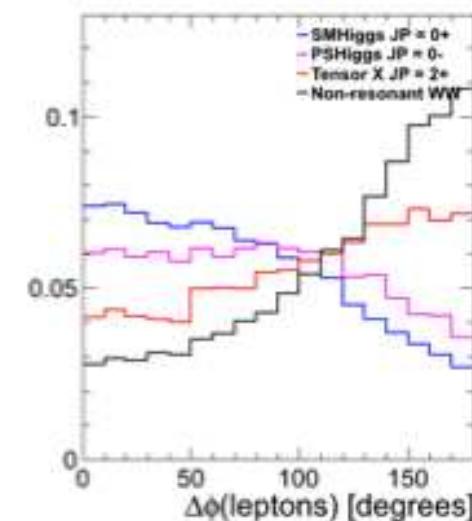
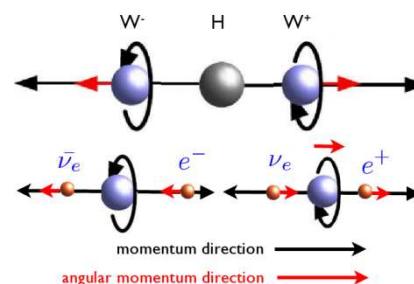
➤ Spin 0 vs. Spin 2: $gg \rightarrow H \rightarrow VV$

Hyothèse: résonnance se souplant de la même façon que des gravitons KK

- $gg \rightarrow H \rightarrow \gamma\gamma$ and $gg \rightarrow H \rightarrow Z\gamma$
- Spin 0: plat en $\cos\theta^*$
- Spin 2: polynome de 2e degrés en $\cos^2\theta^*$
- θ^* : angle de production dans le centre de masse du système di-photon au LHC.

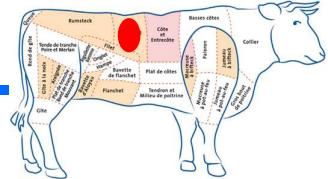


- $gg \rightarrow H \rightarrow WW$
- Spin 0: petit $\Delta\phi(l,l)$, et petit m_{ll} (spin correlation, $H \rightarrow VV$, V-A structure)
- Spin 2: grand $\Delta\phi(l,l)$



arXiv:1202.6660
arXiv:1208.4018
arXiv:1209.1037
arXiv:1209.5268

[Nombre Quantique] Spin : 0 vs 2

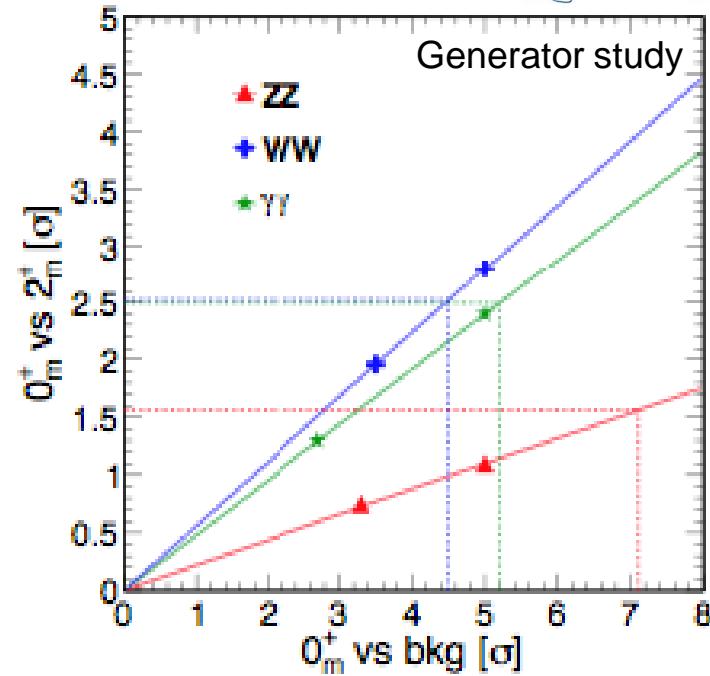


- Projections à 8 TeV avec 35 /fb.
(pour $gg \rightarrow H \rightarrow VV$)

Significance attendue (séparation d'hypothèses) vs
Significance d'observation du signal pour des
hypothèses de Spin 0 et 2.

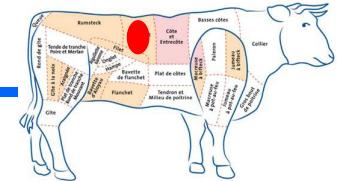
- Projections à 8 TeV avec 35 /fb :

scenario	$X \rightarrow WW$	$X \rightarrow \gamma\gamma$
$0_m^+ \text{ vs background}$	4.5	5.2
$0_m^+ \text{ vs } 2_m^+$	2.5	2.5



**En combinant ATLAS et CMS à Moriond,
possibilité de séparer les hypothèses spin 0 et 2.**

[Nombre Quantique] Parité



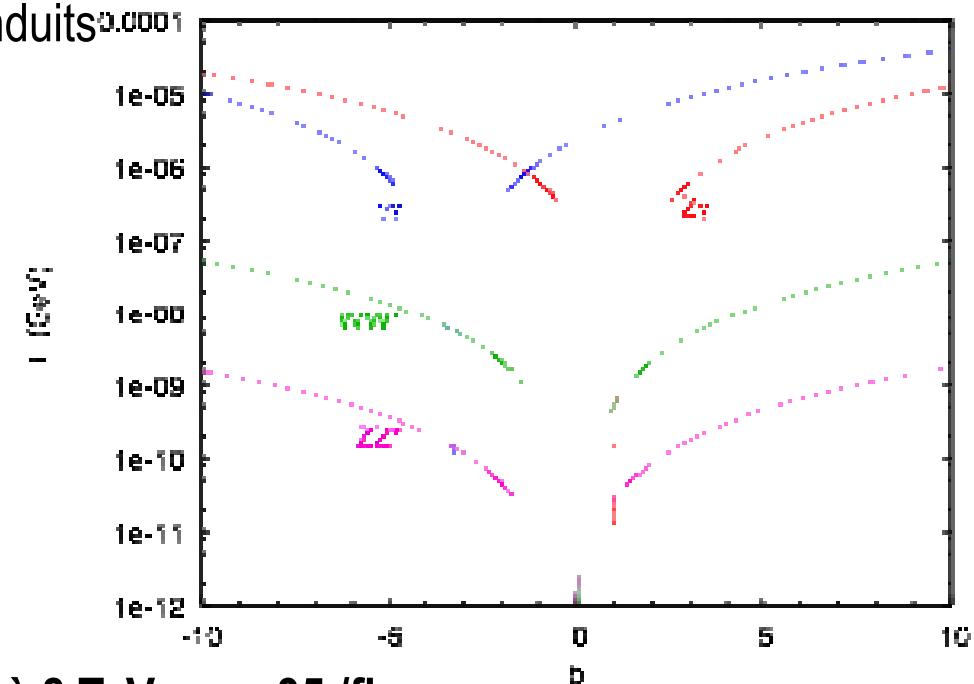
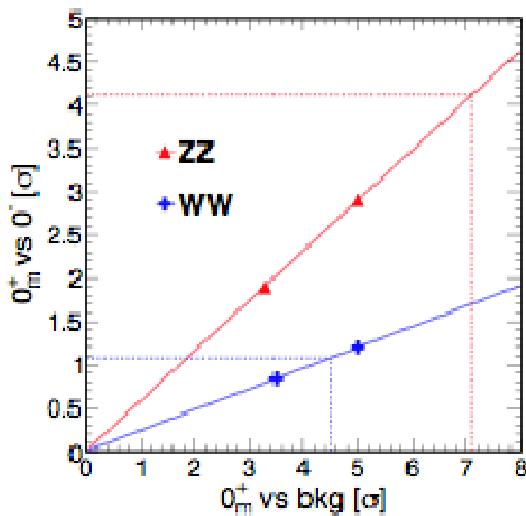
Tentant : hypothèse pseudo-scalaire (0-) est exclue...

Corrélations entre les BR's pseudo-scalaires induits par des boucles: $\gamma\gamma$, $Z\gamma$, ZZ et WW

En utilisant les taux de $\gamma\gamma$ et ZZ observés, on peut prédire ceux de WW et $Z\gamma$:

$$\text{Taux}_{(0^-) \rightarrow WW} = (\text{Taux}_H \rightarrow WW) / 440$$

$$\text{Taux}_{(0^-) \rightarrow Z\gamma} = (\text{Taux}_H \rightarrow Z\gamma) \times 170$$



➤ Projections à 8 TeV avec 35 /fb:

scenario	$X \rightarrow ZZ$	$X \rightarrow WW$
$0_m^+ \text{ vs background}$	7.1	4.5
$0_m^+ \text{ vs } 0^-$	4.1	1.1

arXiv:1208.2692
arXiv:1208.4018

A considérer aussi: $0+/0-$ mixing...

Scalar vs PseudoScalar

$$\frac{h}{v} m_Z^2 Z_\mu Z^\mu \quad \text{vs.} \quad \frac{h}{v} \epsilon^{\mu\nu\rho\sigma} Z_{\mu\nu} Z_{\rho\sigma}$$

The first operator occurs in the standard model at tree level, and leads to a preference for decays into longitudinally polarized Z bosons.

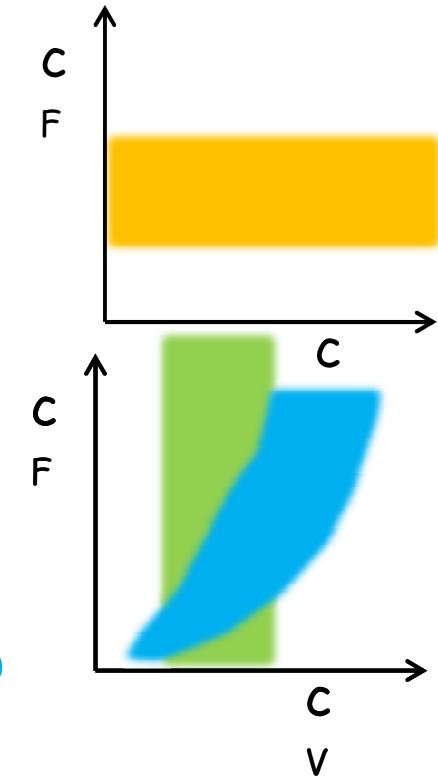
The other is the lowest order coupling possible for a pseudoscalar, and leads to decays into transversely polarized Z bosons only.

By looking at the angular distributions of the leptons from Z decays (a transverse Z prefers to emit leptons along the direction of motion, while a longitudinal Z - perpendicularly to the direction of motion) one can determine the relative amount of transverse and longitudinal Z bosons in the Higgs sample, and thus discriminate between the two operators

Test des Couplages Fermioniques et Bosoniques

Test compatibility w.r.t SM predictions by introducing two parameters (c_V , c_F) modifying the expected signal yields in each mode through simple LO expressions

Production	Decay	LO SM
VH	$H \rightarrow bb$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$
ttH	$H \rightarrow bb$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$
VBF	$H \rightarrow \tau\tau$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$
ggH	$H \rightarrow \tau\tau$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$
ggH	$H \rightarrow ZZ$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$
ggH	$H \rightarrow WW$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$
VBF	$H \rightarrow WW$	$\sim \frac{C_V^2 \times C_V^2}{C_F^2}$
ggH	$H \rightarrow \gamma\gamma$	$\sim \frac{C_F^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$
VBF	$H \rightarrow \gamma\gamma$	$\sim \frac{C_V^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$





Difficult to separate a pure CP state from an admixture of CP-even and CP-odd components

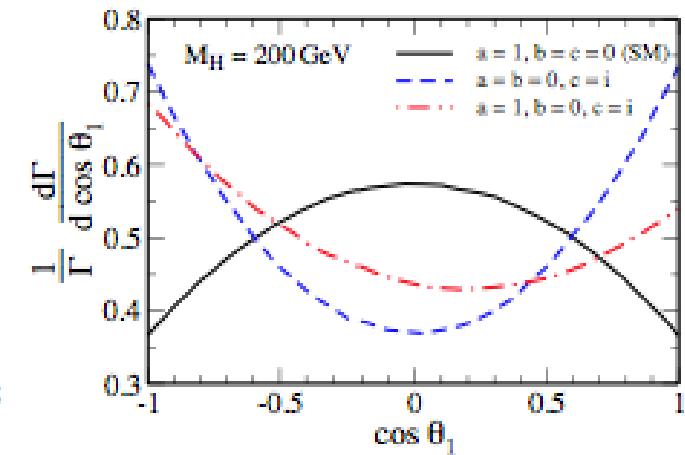
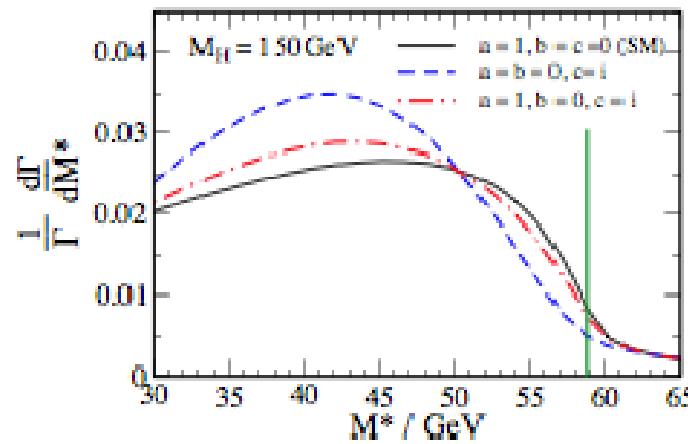
Profiting of the fully reconstructed kinematics of the $H \rightarrow ZZ$ decay modes

$$V_{HZZ} = \frac{ig \cos \theta_W}{\cos \theta_W} \left[a g_{\mu\nu} + b \frac{p_\mu p_\nu}{m_Z^2} - c t_{\mu\nu\alpha\beta} \frac{p^\alpha k^\beta}{m_Z^2} \right]$$

SM coupling (CP even) CP even CP odd

The SM is given by $a=1$, $b=c=0$
 a can always be chosen to be real,
 b and c can be complex

- m_{Z^*} hard to distinguish a CP mixed state
- Asymmetry for the CP mixed state in angular distributions



Couplings



Accurate prediction of the couplings
in SM and in any renormalized theory

$$\mathcal{L}_{\leq m_h}^{\text{eff}} \approx c_V \left(\frac{2m_W^2}{v} W_\mu^+ W_\mu^- + \frac{m_Z^2}{v} Z_\mu^2 \right) h + c_b \frac{m_b}{v} \bar{b} b h + c_b \frac{m_\tau}{v} \bar{\tau} \tau h + c^\gamma \frac{2\alpha}{9\pi v} F_{\mu\nu}^2 h + c^g \frac{\alpha_S}{12\pi v} G_{\mu\nu}^2 h + \mathcal{L}(h \rightarrow \text{inv})$$

in the SM:

$$c_V = c_b = c_\tau = c^\gamma = c^g = 1$$

$$\mathcal{L}(h \rightarrow \text{inv}) \approx 0$$

Assumptions

- The signals observed in the different channels originate from a single narrow resonance
- Zero-width approximation for the state
- CP-even state

$$(\sigma \times \text{BR})(ii \rightarrow H \rightarrow ff) = \sigma_{SM}(ii \rightarrow H) \times \text{BR}_{SM}(H \rightarrow ff) \times \frac{c_i^2 c_f^2}{c_H^2}$$

Couplings

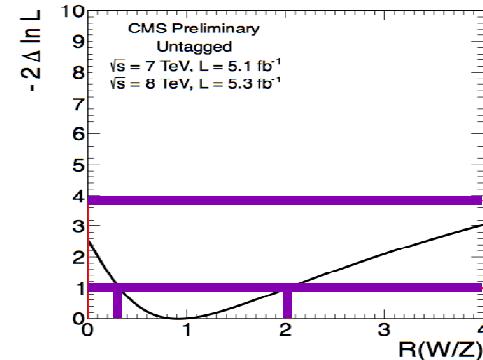


Probing the custodial symmetry

Check that $c_V = c_W = c_Z$ using the WW and ZZ observed signal strength

Result compatible with SM
within the large uncertainties

$$R_{W/Z} = 0.9^{+1.1}_{-0.6}$$



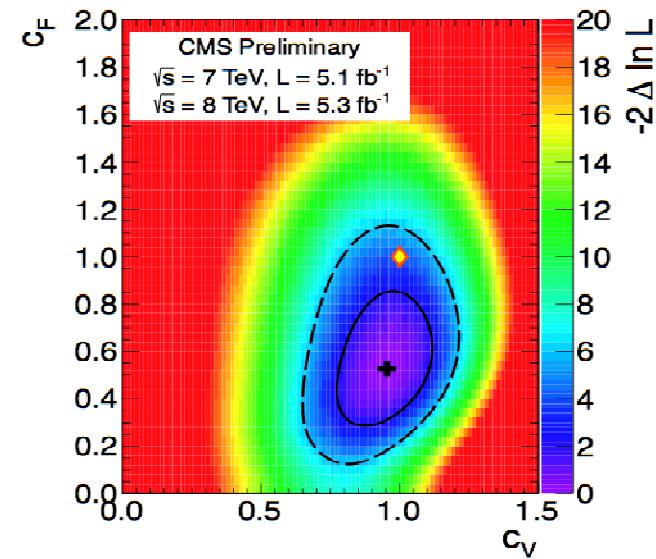
Scaling of fermions and bosons couplings

Introduced only two parameters

c_V and $c_F = c_b = c_t = c_T$

Best fit c_F driven to low values by
VBF $\gamma\gamma$ excess and $\tau\tau$ deficit

Data compatible with
SM prediction at 95% C.L.



Couplings

arXiv:1209.0040



Going from 2 to 5

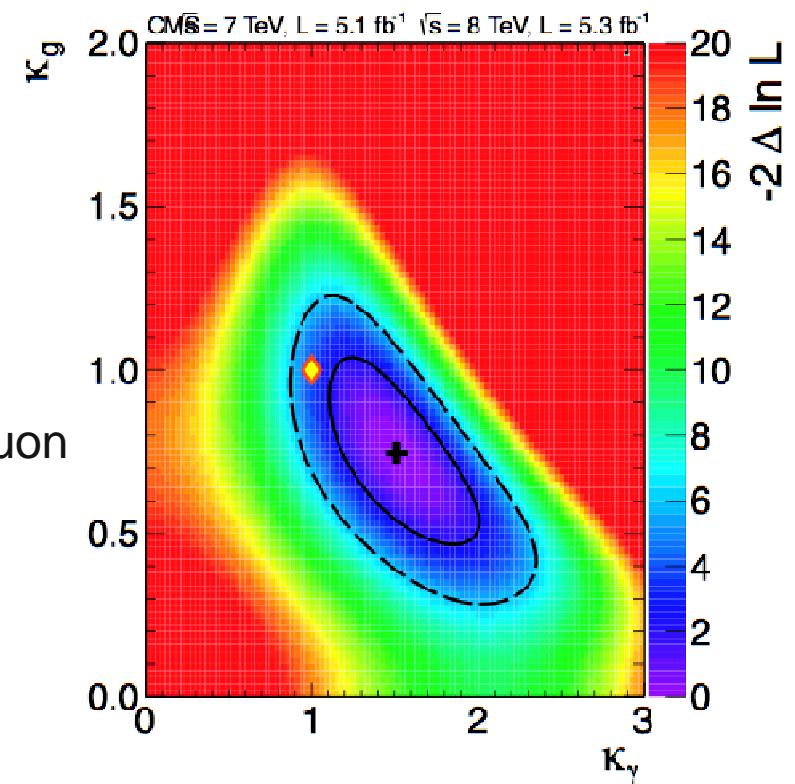
Probing the fermion sector

In extension of the SM the Higgs bosons couple differently to different types of fermions

- up-type fermions vs down-type fermions
- quarks vs leptons

Probing the loop structure and invisible or undetectable decays

Allow new physics in loop-induced couplings to gluon and photons and assume no BSM decay modes



Parametrization without assumptions on new physics contributions

Spin

arXiv:0905.4314
arXiv:1208.6002



Spin 0 vs. Spin 2: VBF signature

VBF is expected to be the 7% of the SM production rate, jet tagging ID will reduce the experimentally observed rate even further

$q\bar{q} \rightarrow H \rightarrow VV$

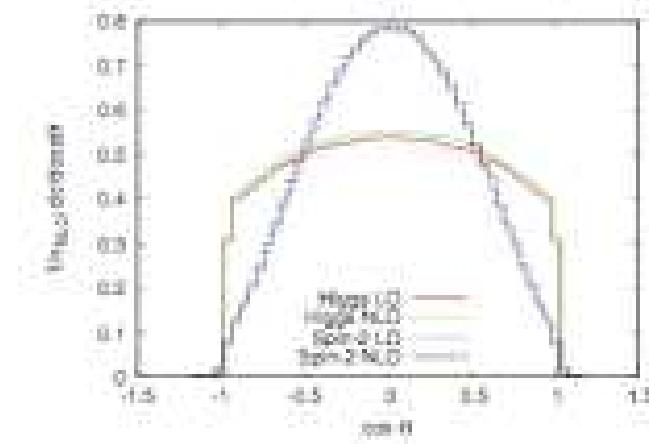
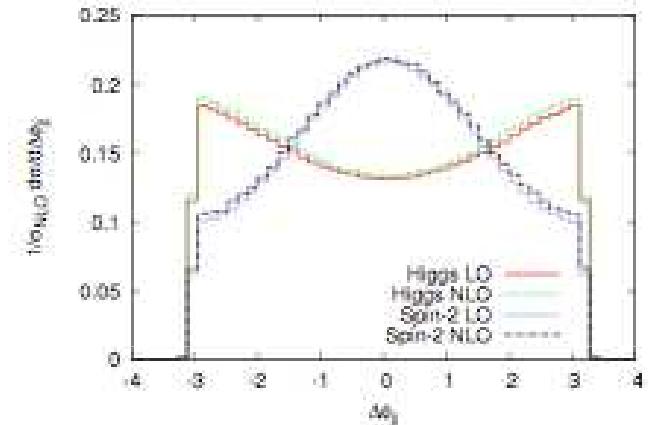
Azimuthal angle difference of the two tagging jets

Independent of NLO corrections and Spin-2 couplings

$q\bar{q} \rightarrow H \rightarrow \gamma\gamma$

Angle between the momentum of an initial-state electroweak boson and an outgoing photon in the rest frame of the resonance

Analogous distribution: cosine of the angle between a final-state photon and the first or second tagging jet in the rest frame of the resonance



Spin 0 vs. Spin 2: VH signature

'Higgs' + gauge boson invariant-mass distribution

BR

Production cross section at 8 TeV

>20K Higgs/fb

Decay branching ratio

Process	Branching ratio
$H \rightarrow bb$	5.77×10^{-1}
$H \rightarrow cc$	2.91×10^{-2}
$H \rightarrow \tau\tau$	6.32×10^{-2}
$H \rightarrow \mu\mu$	2.20×10^{-4}
$H \rightarrow gg$	8.57×10^{-2}
$H \rightarrow \gamma\gamma$	2.28×10^{-3}
$H \rightarrow Z\gamma$	1.54×10^{-3}
$H \rightarrow WW$	2.15×10^{-1}
$H \rightarrow ZZ$	2.64×10^{-2}
$\Gamma_H [\text{GeV}]$	4.07×10^{-3}

fermions

gauge bosons

Process	Cross Section (pb)
gg	$19.5 (\pm 14\%)$
VBF	$1.6 (\pm 3\%)$
VH	$0.70 (\pm 4\%)$
ZH	$0.39 (\pm 5\%)$
ttH	$0.13 (\pm 17\%)$

More states? Composite?



No evidence for any excess above backgrounds
Strong constraints imposed



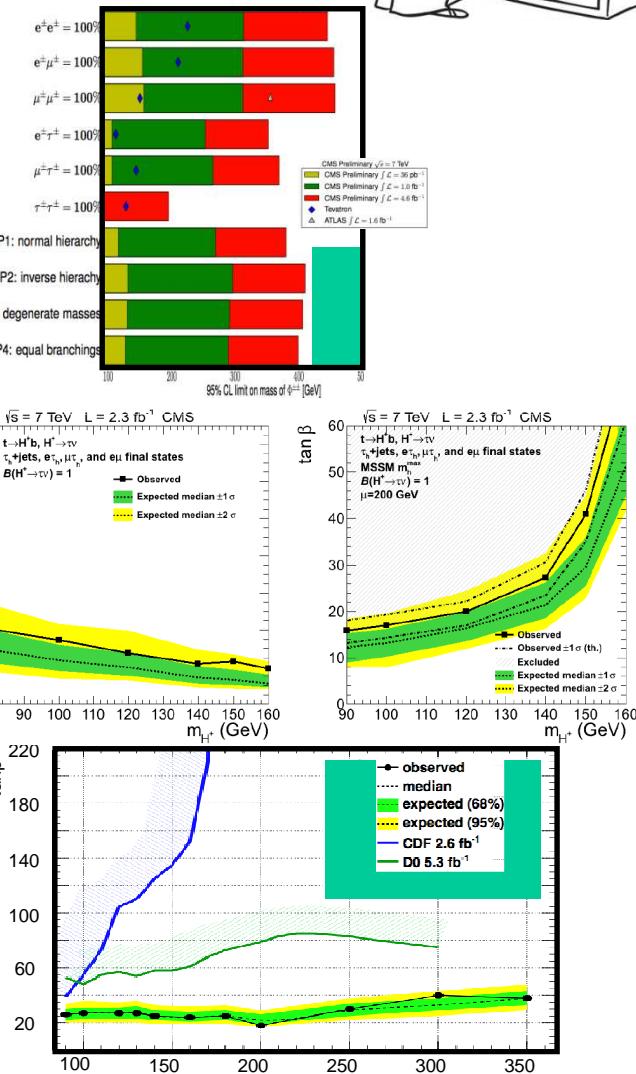
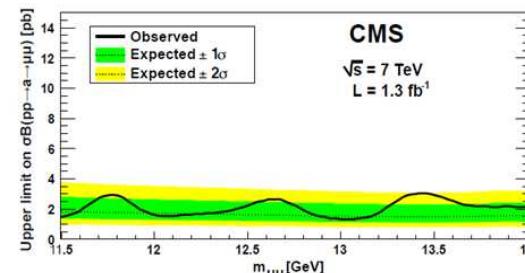
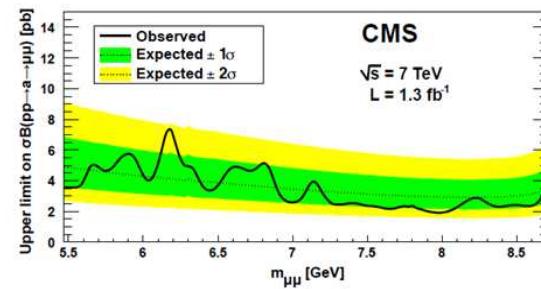
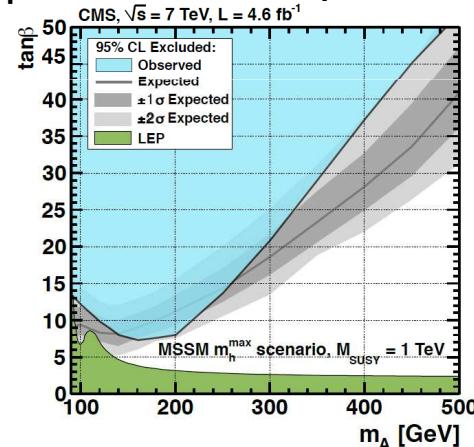
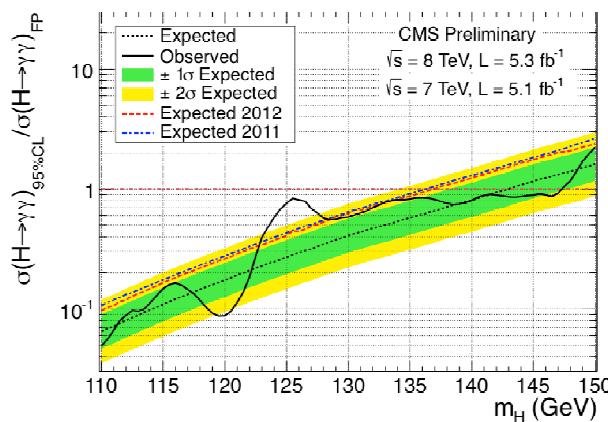
Fermiophobic / SM4 / Technicolor

MSSM charged Higgs

MSSM neutral Higgs

Higgs doubly charged

Higgs decaying to light pseudo-scalar particles



More states? Composite?

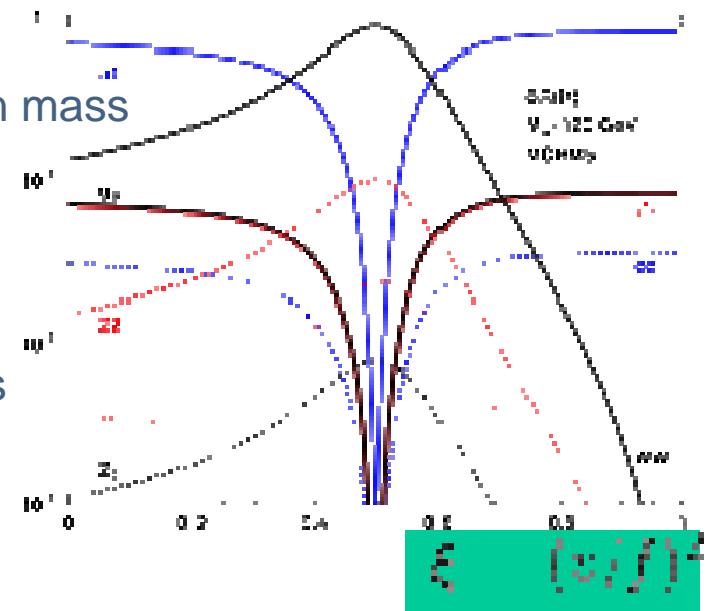
arXiv:1209.0040
arXiv:1003.3251



Decoupling limit

Many models have an extended Higgs sector allowing one Higgs boson SM like. The large uncertainties in the properties measurements leave room for these models

- The Two Higgs Doublet Models
different loop-induced couplings (top), enhanced $\gamma\gamma$ rate
- The Minimal Supersymmetric Standard Model
enhanced $\gamma\gamma$ rate and/or suppression of bb (and also $\tau\tau$)
- The Next to Minimal Supersymmetric Standard Model
3 CP-even Higgses ($h_{1,2,3}$) and two of them can be close in mass (almost degenerated) and one below the LEP limit
- A strongly interacting light Higgs
light and narrow Higgs-like scalar but it is a bound state from some strong dynamics, deviations from the SM Higgs couplings controlled by the parameter ξ



Self-interaction

arXiv:0310056
arXiv:0211224
arXiv:0204087
arXiv:1206.5001

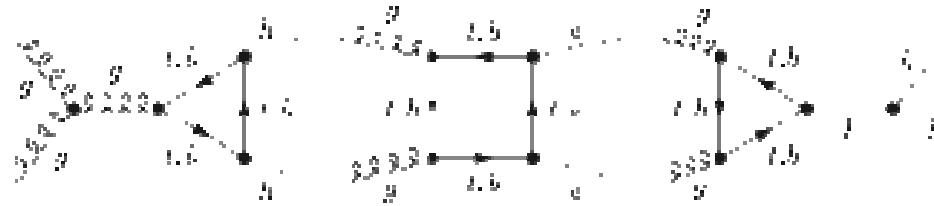


The measurement of the Higgs potential

Essential to fully reveal the nature of the mechanism responsible for EWSB

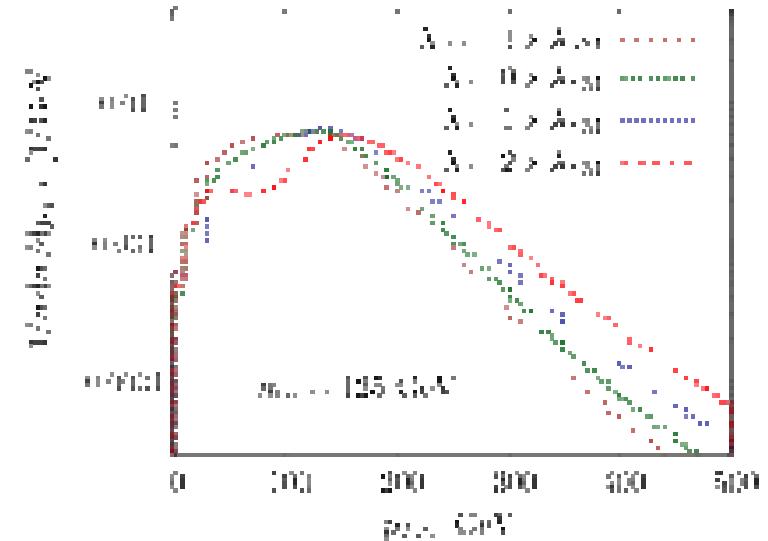
Two main components: the trilinear coupling ($\lambda_{H\bar{H}H}$) and the quartic coupling (λ_{HHHH})

$\lambda_{H\bar{H}H}$ can be measured at LHC



@ 14 TeV $\sigma(pp \rightarrow HH) = 34 \text{ fb}$

The $HH \rightarrow b\bar{b}\gamma\gamma$ channel has a BR of 0.27%
Predicted yield of ~ 10 events/ 100 fb^{-1} @ 14 TeV pp
After analysis cuts: S/B ratio ~ 0.7 (B is mainly ttH)



Using shape analysis to discriminate scenarii

Masse

$M_X = 125.3 \pm 0.4 \text{ (stat.)}$
 $\pm 0.5 \text{ (syst.)}$
 $= 125.3 \pm 0.6 \text{ GeV}$

126:0 0:4 (stat) 0:4 (sys) GeV