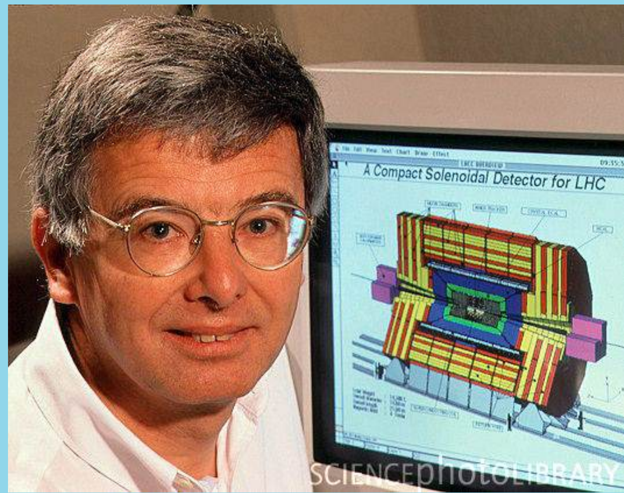
Michel Della Negra

PRIX ANDRÉ LAGARRIGUE

André Lagarrigue

2014

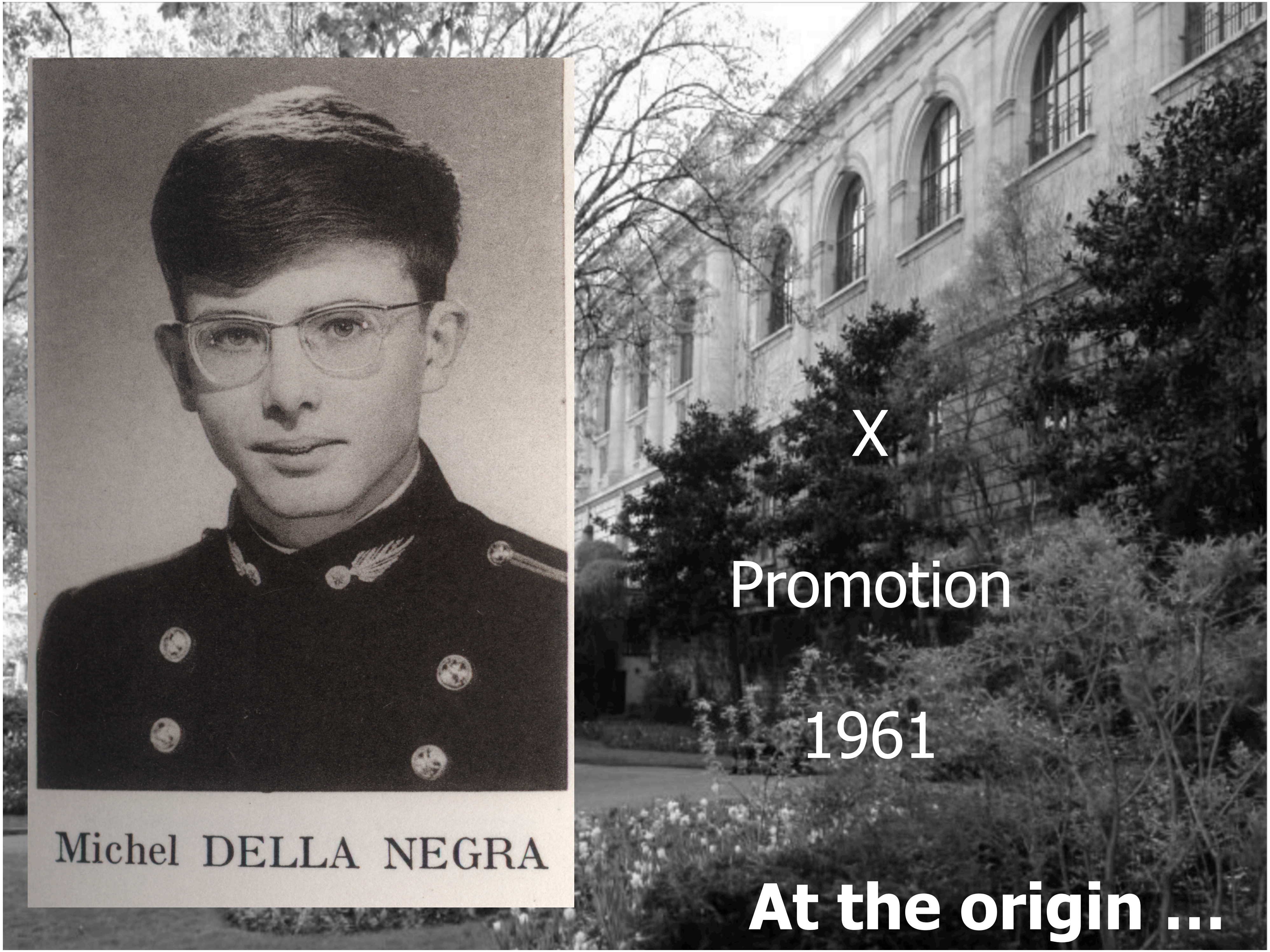


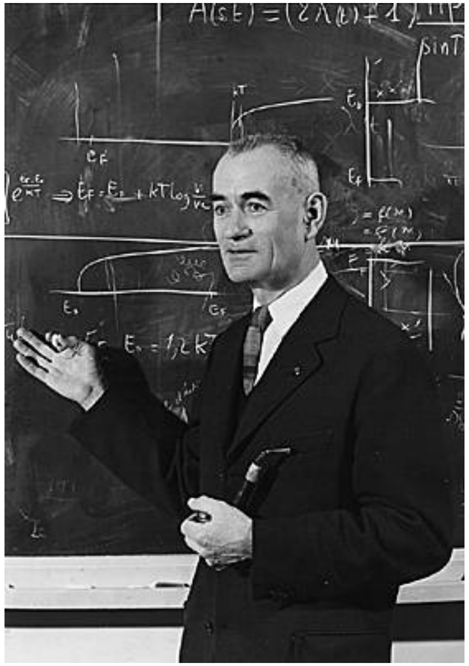
From the First Data to the Higgs Boson Discovery

… and beyond

Yves Sirois, Laboratoire Leprince-Ringuet, Ecole Polytechnique

14 décembre 2015


Michel DELLA NEGRA
X
Promotion
1961
At the origin …

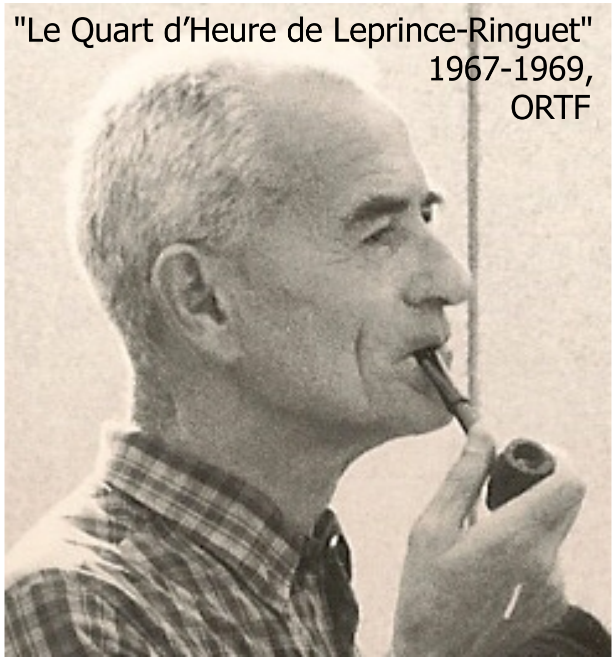


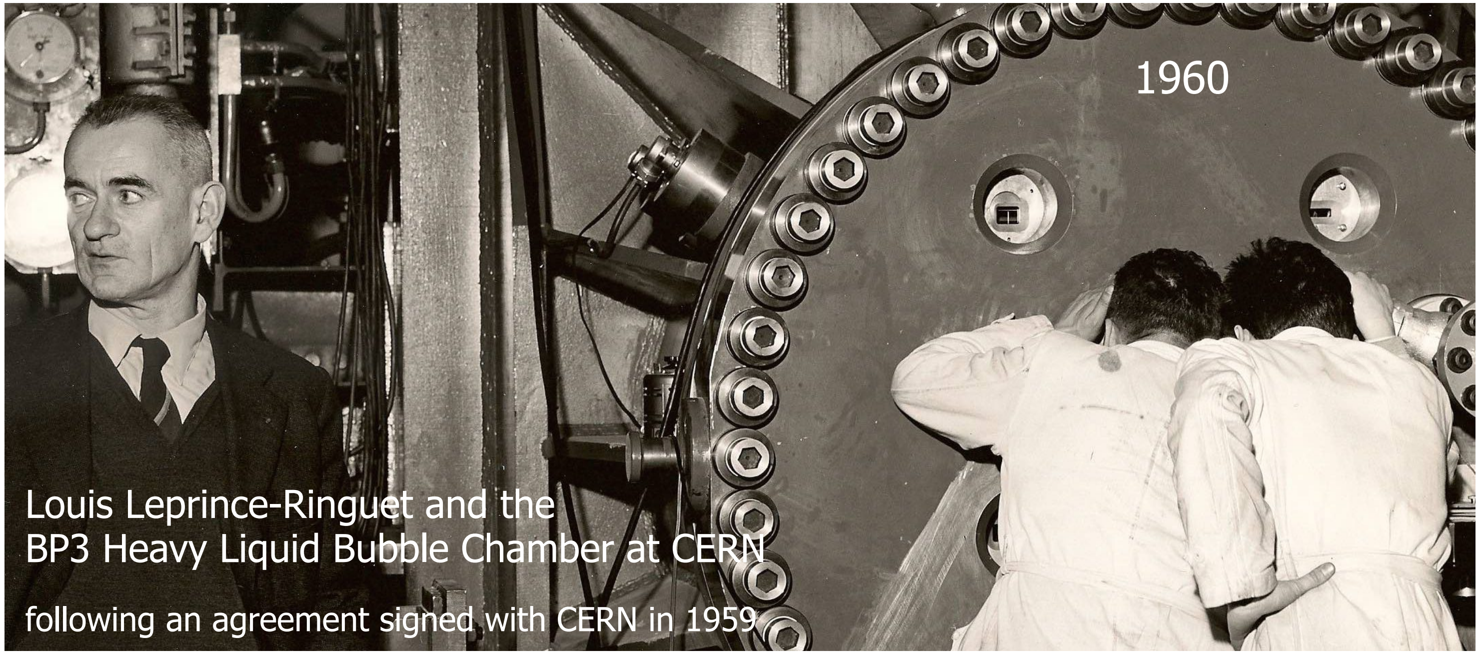
L.L.-R. 1960

… course at the École Polytechnique

L.L.-R. 1967

… a famous physics outreach TV show





…

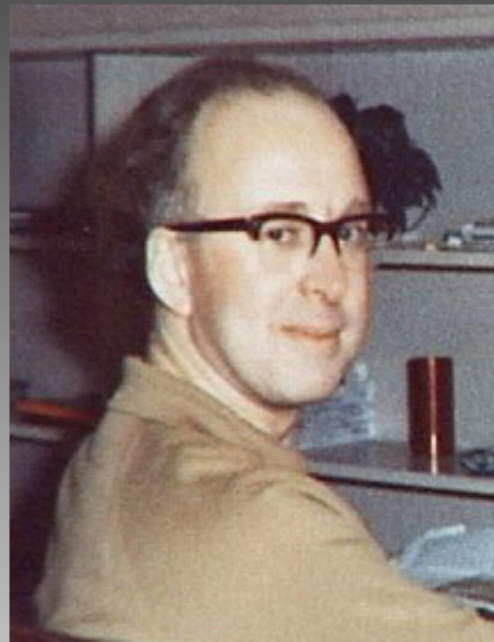
1973
André
Laguarrigue
LAL

Spontaneous symmetry breaking ("BEH") mechanism - 1964

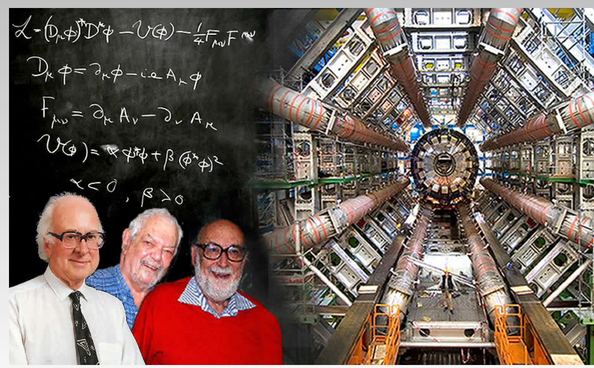
Robert Brout

François Englert

Peter Higgs



… the origin of one of the greatest scientific adventure of modern times



The Road to the Higgs Boson

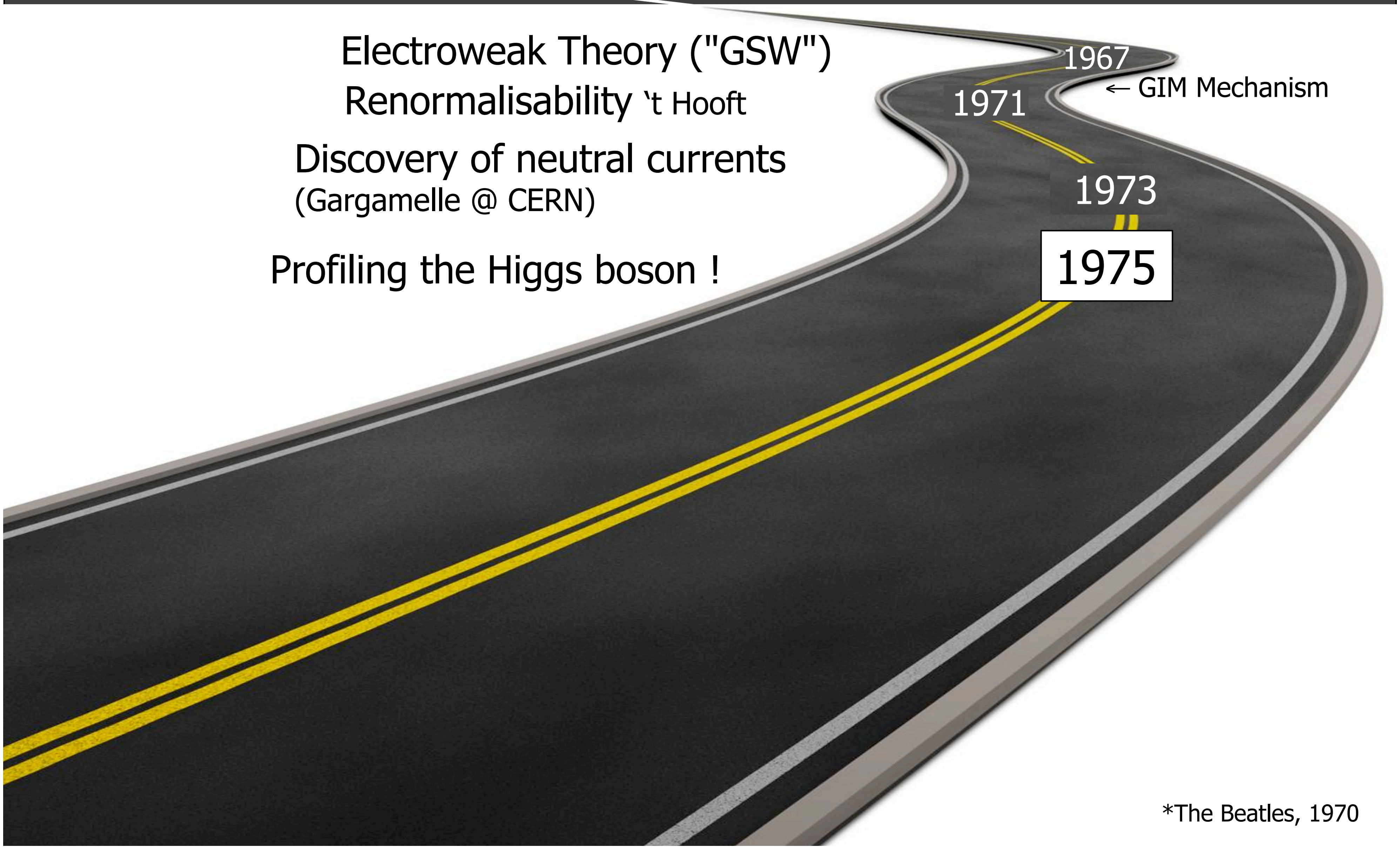
Spontaneous symmetry breaking ("BEH") mechanism - 1964

Electroweak Theory ("GSW")

Renormalisability ‛t Hooft

Discovery of neutral currents
(Gargamelle @ CERN)

Profiling the Higgs boson !



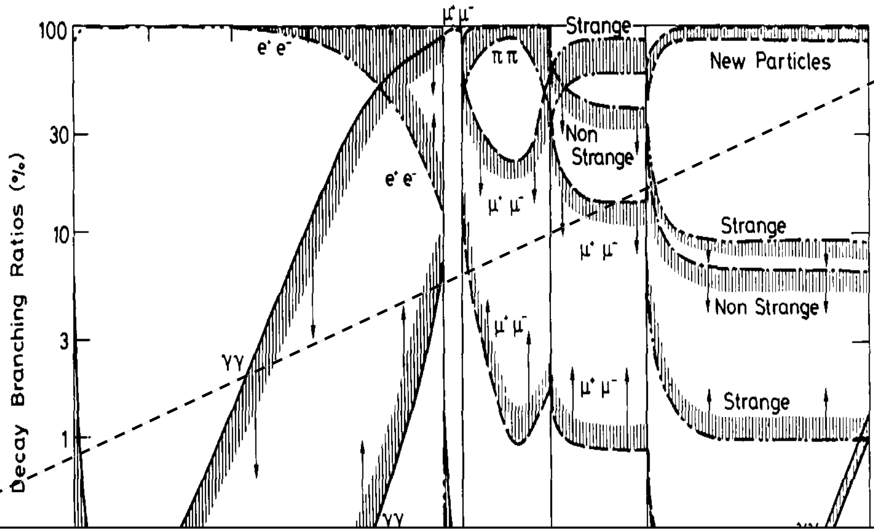
*The Beatles, 1970

Nuclear Physics B106 (1976) 292–340

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Received 7 November 1975



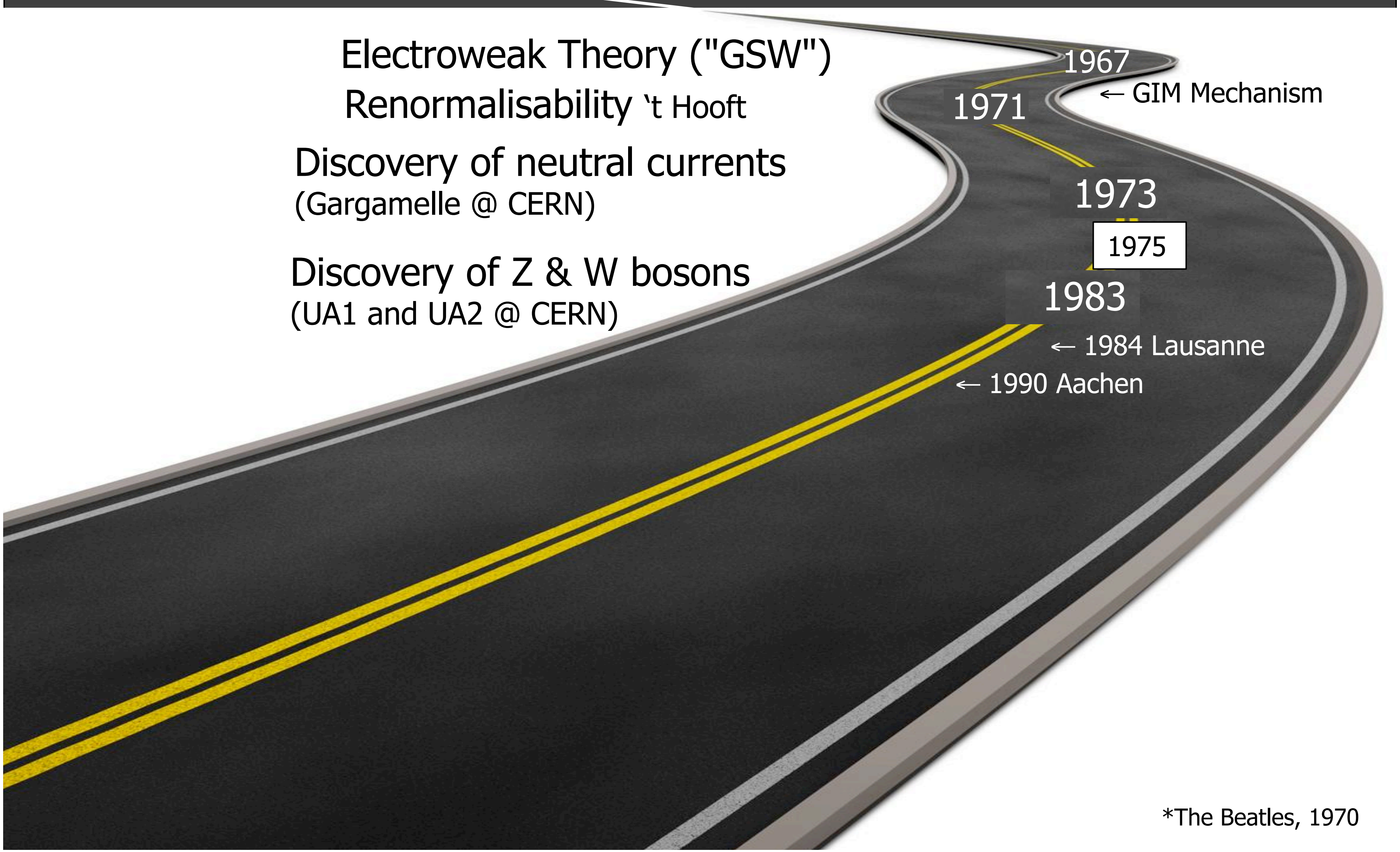
We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons 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.

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, ...

... 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,

The Long and Winding Road*

Spontaneous symmetry breaking ("BEH") mechanism - 1964



*The Beatles, 1970

EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

Large Hadron Collider Workshop

CERN 90–10
ECFA 90–133

Michel and the Higgs boson physics

SEARCH FOR H → Z*Z* → 4 LEPTONS AT LHC

Higgs Study Group

M. Della Negra, D. Froidevaux, K. Jakobs, R. Kinnunen,
R. Kleiss, A. Nisati and T. Sjöstrand

1. Introduction and Motivation

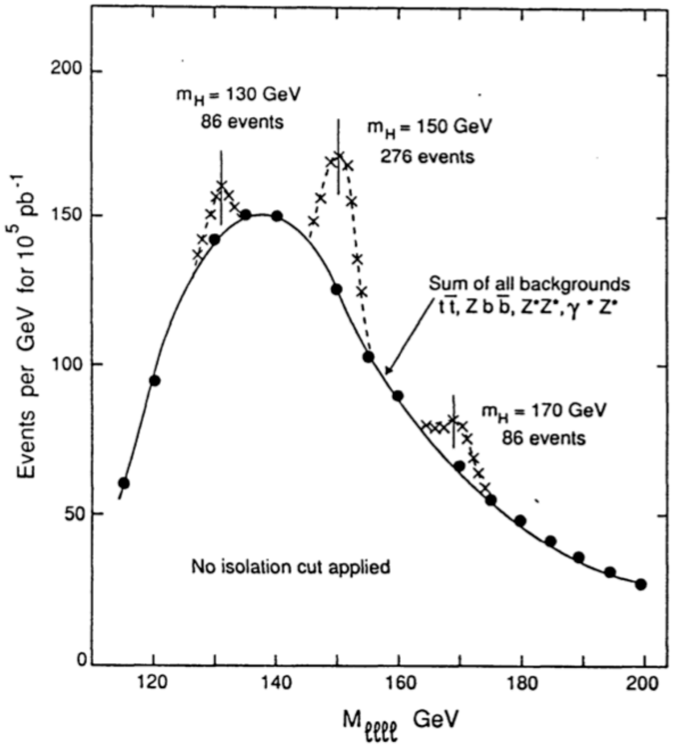
The work reported here was prompted by the need to understand how the gold–plated $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$ (ℓ = e or μ) channel could be extended to Higgs masses below 2 m_Z, and by previous studies which reported possible large backgrounds to this process [1]. Since the observation of the so–called intermediate mass Higgs, $m_Z \leq m_H \leq 2m_Z$, is well–known by now to be one of the most difficult experimental challenges for future hadron colliders such as LHC or SSC, we felt that there was really a need for a thorough study of the most promising channel in this Higgs mass range. We have therefore performed a calculation as complete as possible of potential backgrounds to 4–lepton final states in this mass range, and we have studied the effectiveness of good momentum resolution (obviously a problem mainly addressed to muon detection) and lepton isolation (a problem for calorimetry only at luminosities of 10^{34} cm^{-2} s^{-1}) at rejecting these backgrounds, which arise mainly from non–resonant and non–isolated multi–lepton final states.

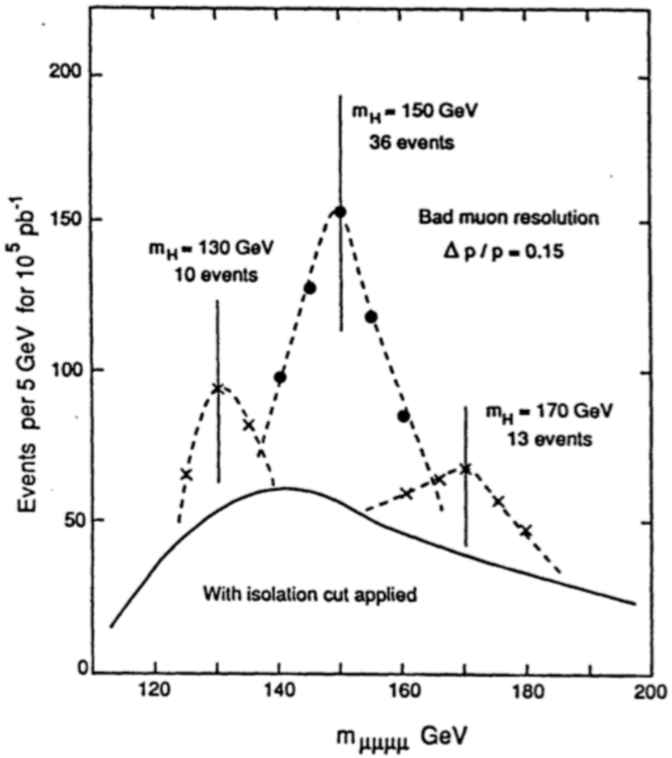
Many other « things » discussed at the Workshop such as Supersymmetry, Z'/W', Excited Fermions and Compositeness, Leptoquarks, … have not been found

SEARCH FOR H → Z*Z* → 4 LEPTONS AT LHC

Higgs Study Group

M. Della Negra, D. Froidevaux, K. Jakobs, R. Kinnunen,
R. Kleiss, A. Nisati and T. Sjöstrand

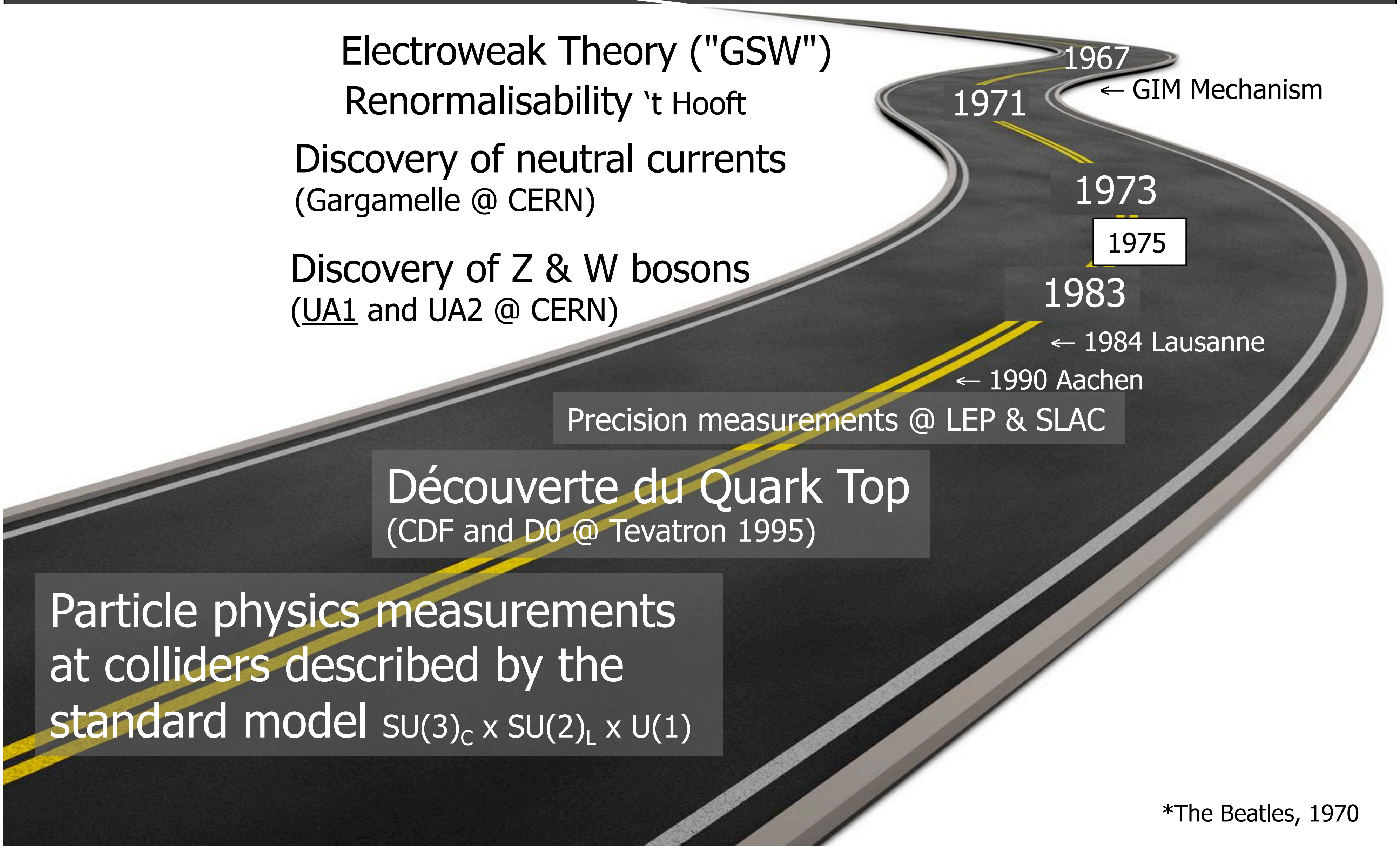




The low rates expected, even with good lepton acceptance, $p_T^{\ell} > 10$ GeV and $|\eta_{\ell}| < 3$, lead to the conclusion, that a clear observation of a possible Higgs signal in this channel requires identification of both electrons and muons. Lepton isolation cuts have also been carefully studied and proven to yield sufficient rejection against non–isolated leptons from b–quark decay, to reduce the $t\bar{t}$ and $Zb\bar{b}$ backgrounds to the level of the irreducible Z^*Z^*, γ^*Z^* background. The Higgs signal would then clearly appear above background, for a total integrated luminosity of 10^5 pb^{-1} and for $130 \leq m_H \leq 2m_Z$.

The Long and Winding Road*

Spontaneous symmetry breaking ("BEH") mechanism - 1964

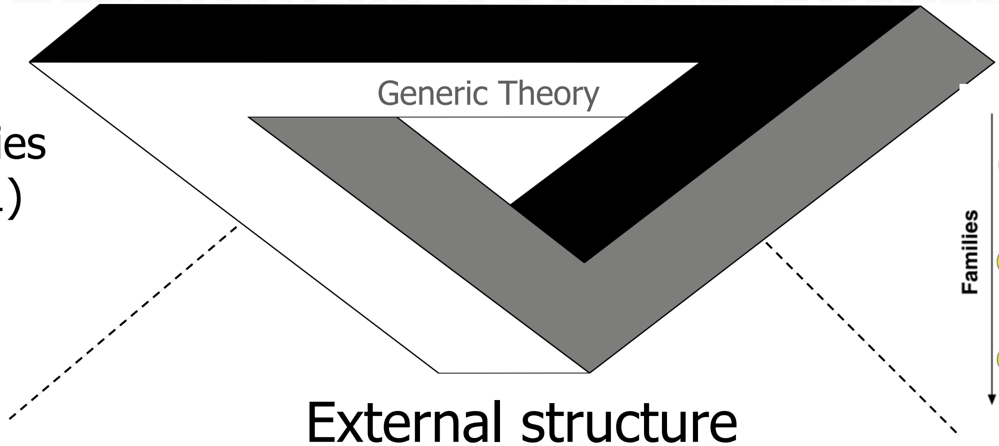


*The Beatles, 1970

Chronicle of a Death Foretold

Gauge Bosons

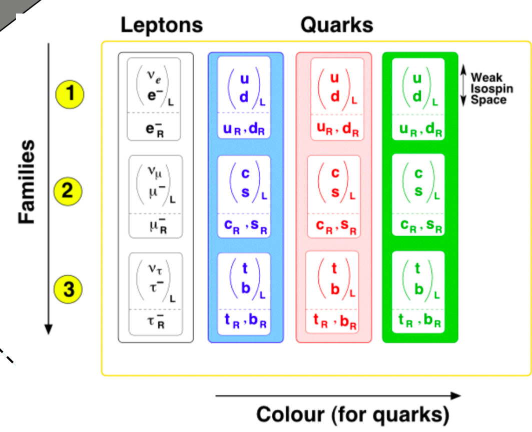
Gauge Symmetries
SU(3)xSU(2)xU(1)



External structure

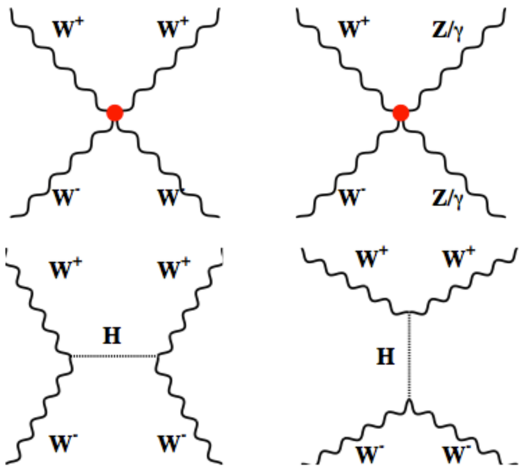
BEH Mechanism, Higgs boson

Fermions



- There must exist additional structure to explain the origin of mass,
  i.e. to preserve gauge symmetries at the fundamental level
- Additional structure is needed to preserve unitarity

One cannot save the theory by injecting measured observables i.e to allow for renormalization as for electrodynamics



$$A\left(W_L^+W_L^- \rightarrow Z_L Z_L\right) = \frac{G_F E^2}{8\sqrt{2}\pi}\left(1 - \frac{E^2}{E^2 - m_H^2}\right)$$

SM limited to E < ~ 1 TeV in absence of regularisation

e.g. the H boson allows for exact unitarization

H boson or equivalent or new physics at the TeV scale ?

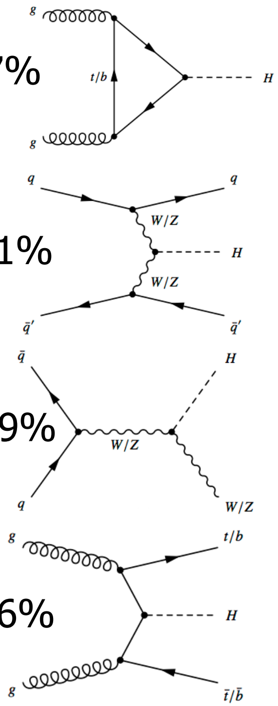
Production and Decay of the H Boson

87%

7.1%

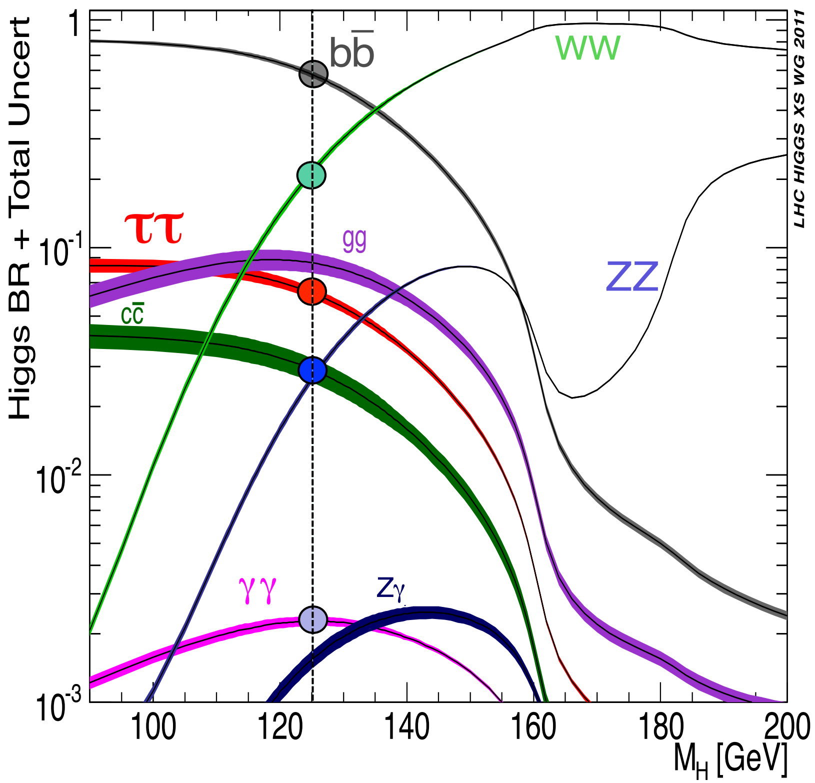
4.9%

0.6%



⇕

σ/σ_{tot} (M_H = 125 GeV)



ΔM/M ~ 1-2% High resolution

H → γγ Rare, S/B < 1

H → ZZ* → 4ℓ Very rare, S/B >> 1

ΔM/M ~ 10-20% Medium resolution

H → bb Abundant, S/B << 1

H → ττ Abundant, S/B < 1

ΔM/M > 30% Low resolution

H → WW*→ 2ℓ2ν Very abundant, S/B < 1

4 production modes × 5 decay modes (γγ, ZZ, WW, ττ, bb)

~ 100 exclusive final states (production, decay, event categories) are contributing for M_H ~ 125 GeV !

Exploring New Avenues

picture not blurred only available live

- The work on e/g and Pflow started in started already for the CMS Detector (Vol. I) and Physics (Vol. II) Technical Design Reports LHCC 2006-021
- This was made possible thanks to the precious support of the CMS top Management [Michel / Jim]

In an experiment undergoing a phase transition from a Federation of Projects (for the construction) to a single experiment (for the physics), the support of the CMS top management [Michel / Jim] was essential shake the structure and create new bridges

Previously: e/γ were under the « umbrella » of the ECAL project …
Jets were under the « umbrella » of the HCAL project …
Tracks were under the « umbrella » of the Tracker project …
etc.

<u>Some dogmas that would needed to be shaken:</u>

« You'll never manage to do better than Kalman-Filter (short) tracks for electrons »
« Iterative tracking is hopeless in such an environment »

Tracking experts

« Combined track-clusters are too complicated … calorimeters are simple … »

ECAL experts

« Particle-flow will never work at a hadronic collider »

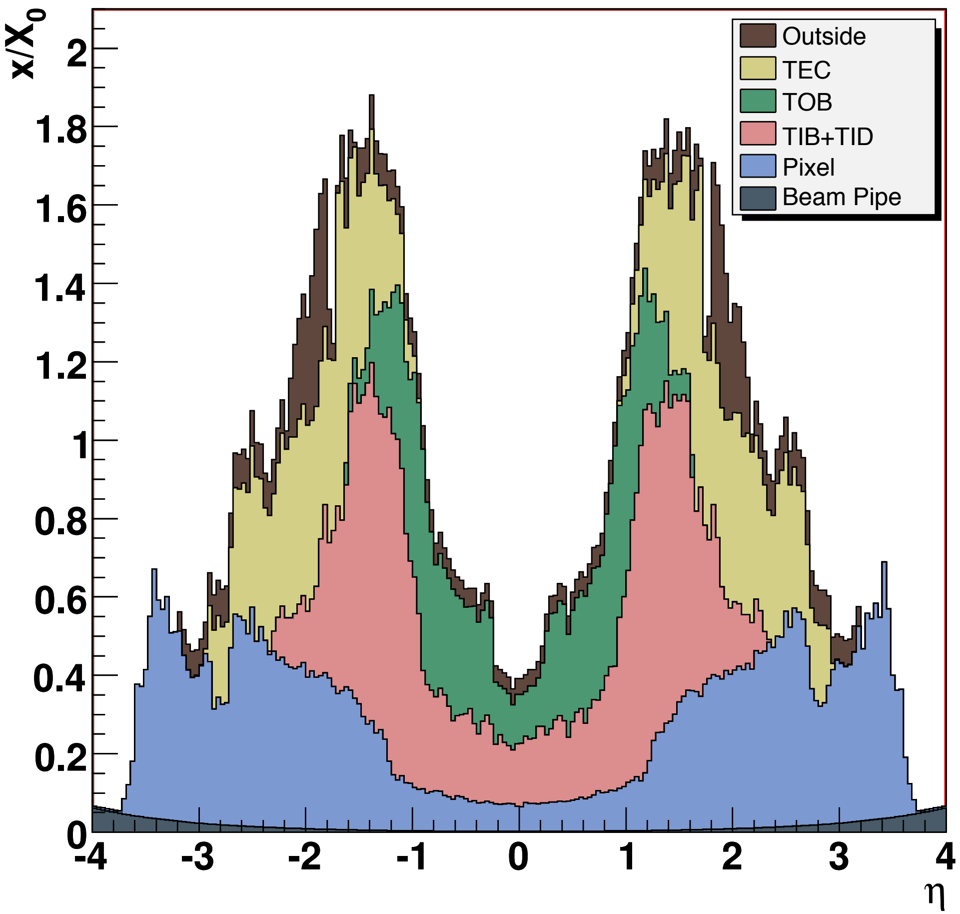
HCAL experts

Everything was in place for the discovery in 2011-2012

Higgs boson physics at LHC is largely about measurement, identification, and isolation of photons (γ) or leptons e, μ, τ_h

e (γ)

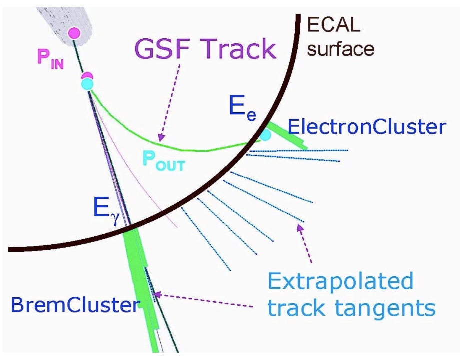
- Severely hampered at low P_T: tracker material and 3.8 Tesla field !
- Reconstruction and Identification required to climb mountains



30-40 % of primary γ's convert before reaching the ECAL

Electrons radiate (Bremss.) when traversing the tracker Si layers

e.g. CMS

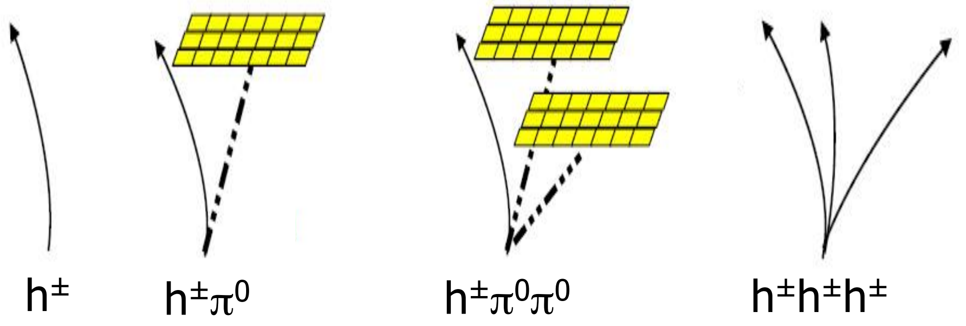


Need to combine tracker and ECAL information to best estimate energy-momentum and get a handle on the amount of Bremms. and energy lost !

Higgs boson physics at LHC is largely about measurement, identification, and isolation of photons (γ) or leptons e, μ, τ_h

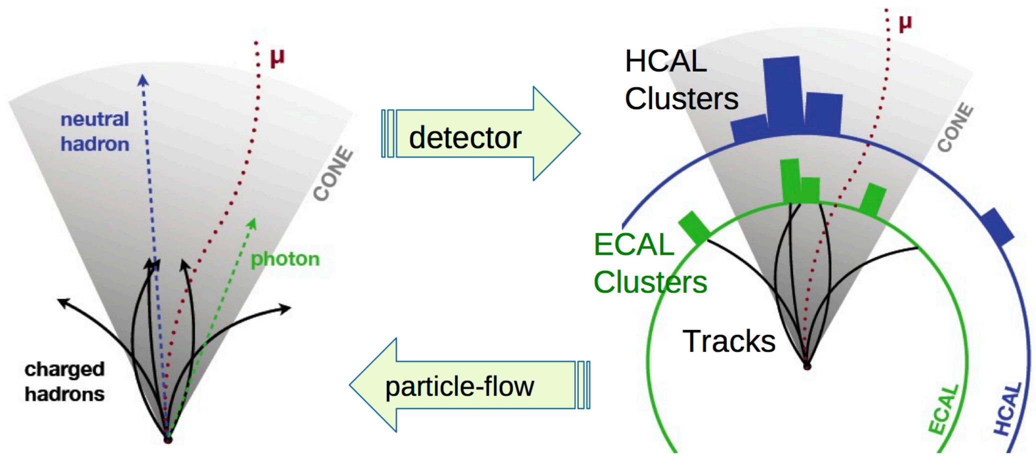
τ_h

- Need to distinguish decays modes (different E scales, fake rates, …)



1) Decay mode finding
   Require a valid π, ρ, α
2) Isolation with $\Delta\beta$ vertex
   $\Sigma P_T < 2$ GeV ; cone of $\Delta R = 0.5$
3) Electron rejection
   Pflow e; Brem detection
4) Muon rejection
   Compatibility with leading track

- Best achieved with **Particle Flow*** Techniques where the signals from the detectors is completely deconvoluted back to “particles”



List of individual particles used to build jets, measure missing E_T, reconstruct and identify taus leptons and tag b-jets etc.

From CMS Top Management

picture not blurred only available live

Back to Ground Work

APOLLO 11

The PFlow Received Prestigious Support

- After having led the CMS Collaboration, one of the two largest experiment in HEP history, for some 16 Years, Michel Della Negra came "down" and joined the efforts of the PFlow/τ group in 2007
- This was a truly great and humble move driven by pure intellectual curiosity which had a BIG impact in CMS (especially for young people !) Suddenly people understood that PFflow would converge*** and become a standard approach for CMS

*** Somehow, Michel has always radiated this confidence; contaminating other people with the idea that « it will work » irrespective of the difficulties !

The first of a series of famous « I found a bug » postings by Michel !

==================

Forum: Particle Flow
Date: 10 Aug, 2007
From: Michel Della Negra <*Michel Della Negra*>
Subject: Bug in PFTrackTransformer

Dear PF experts and users,

In debugging PF taus in the endcaps, I found a bug, which affects the matching TK/ECAL clusters in barrel as well. The track extrapolation to shower max in PFTrackTransformer has a bug:

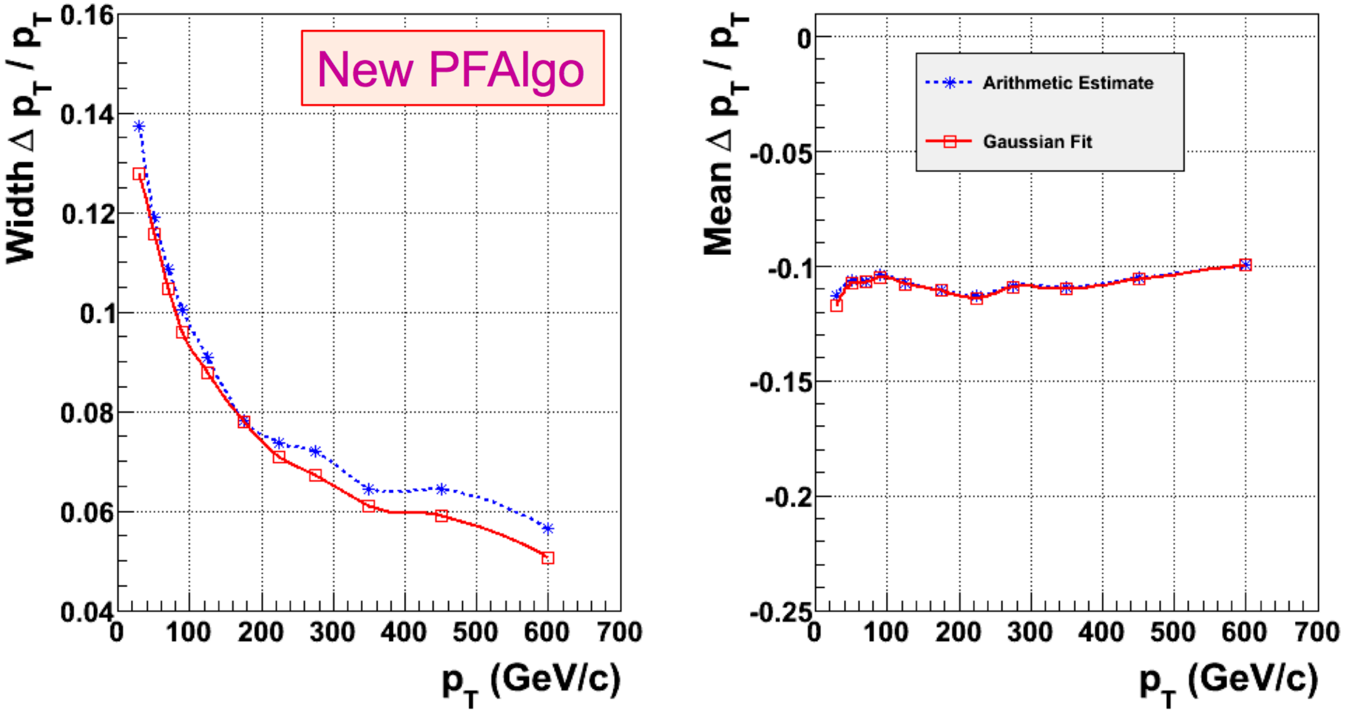
Particle Flow and Tau Id meeting

chaired by Patrick Janot (CERN), Rick Cavanaugh (Inst. for High Energy Physics & Astrophysics, University of Florida)

Monday, 15 December 2008 from **16:30** to **18:30** (Europe/Zurich)

CERN (40-S2-A01)

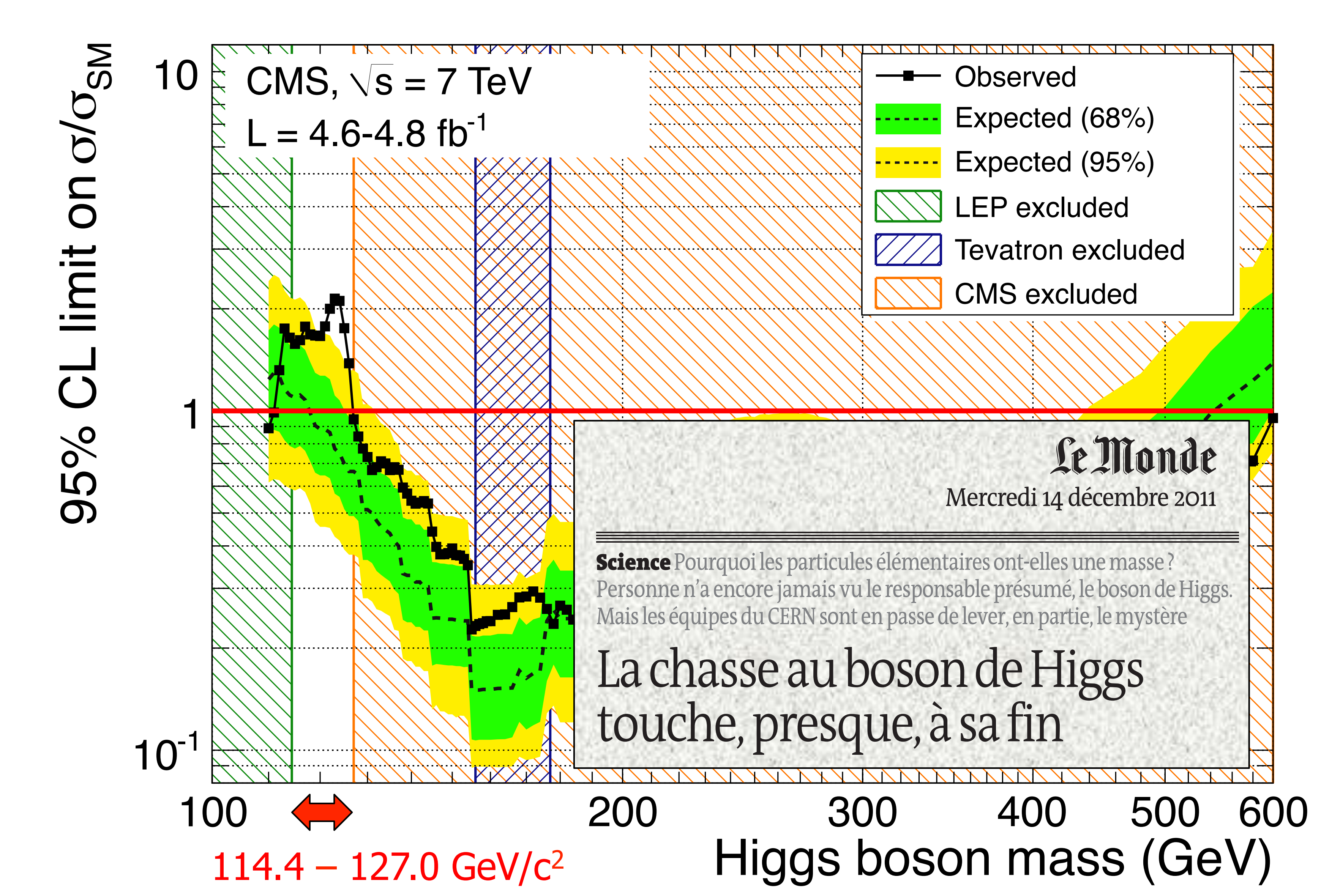
17:30 - 17:50	Low pT Jet Studies *20'* Speaker: Michel Della Negra (CERN)
17:50 - 18:00	Application of Michel's changes to QCD Dijets *10'* Speaker: Patrick Janot (CERN)



Making History ... and Drinking Champagne

picture not blurred only available live

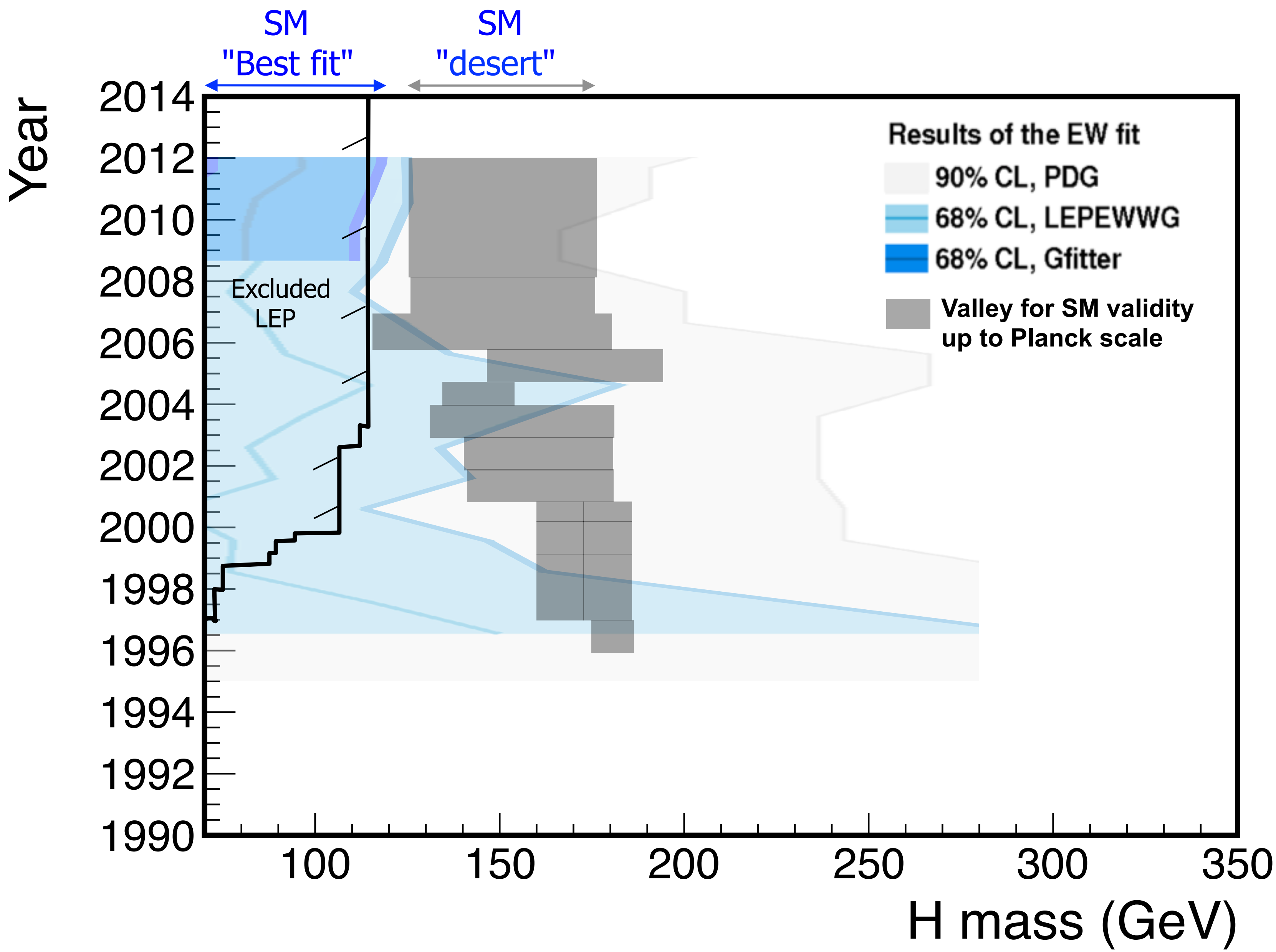
Décember 2011



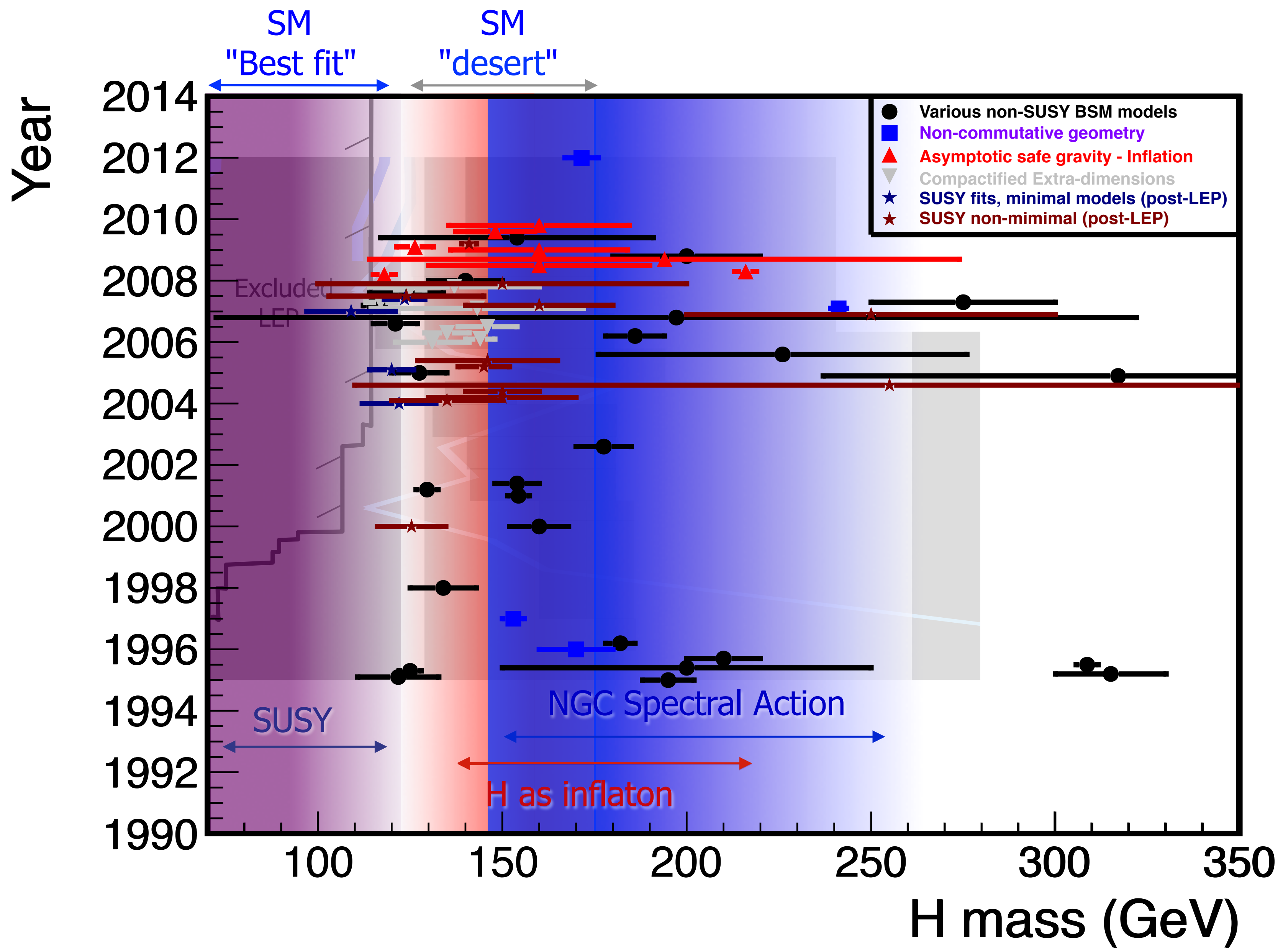
Moriond 2012

Similar results from ATLAS

The H boson mass : Theory vs Experiment

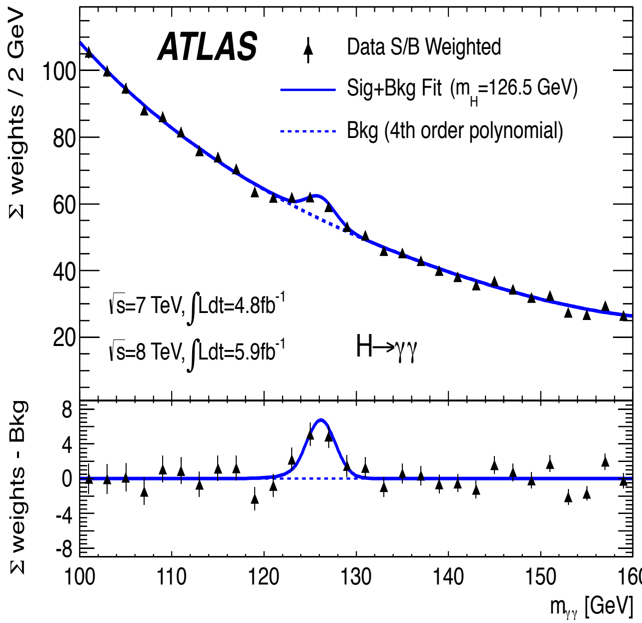


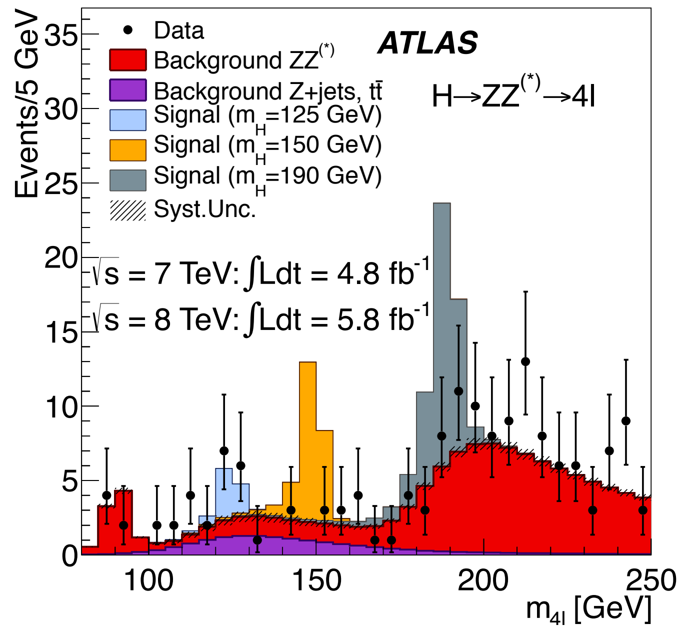
The H boson mass : Theory vs Experiment



ATLAS

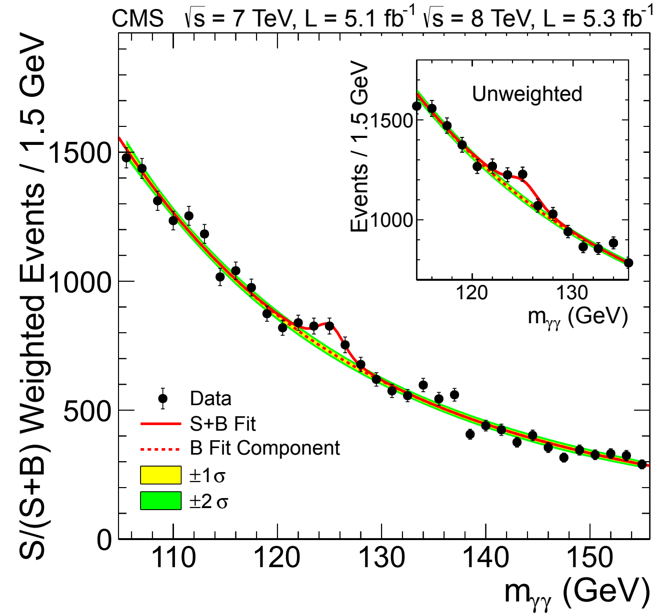
Phys.Lett. B716 (2012) 1-29

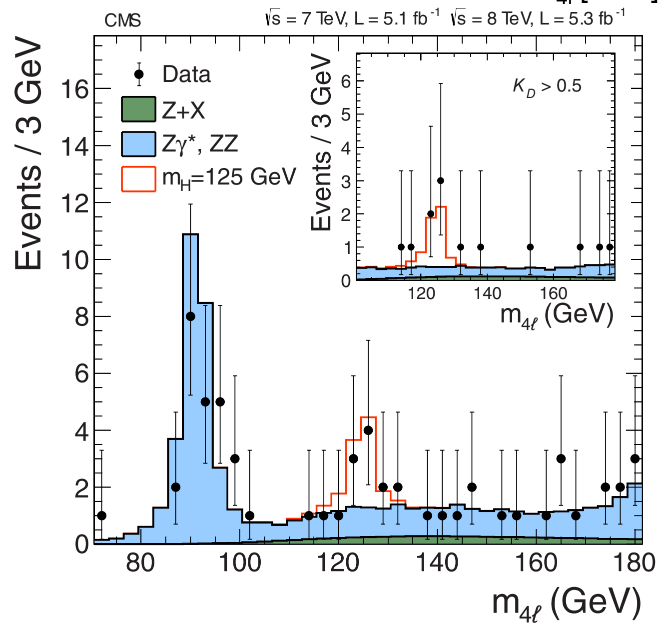




CMS

Phys.Lett. B716 (2012) 30-61

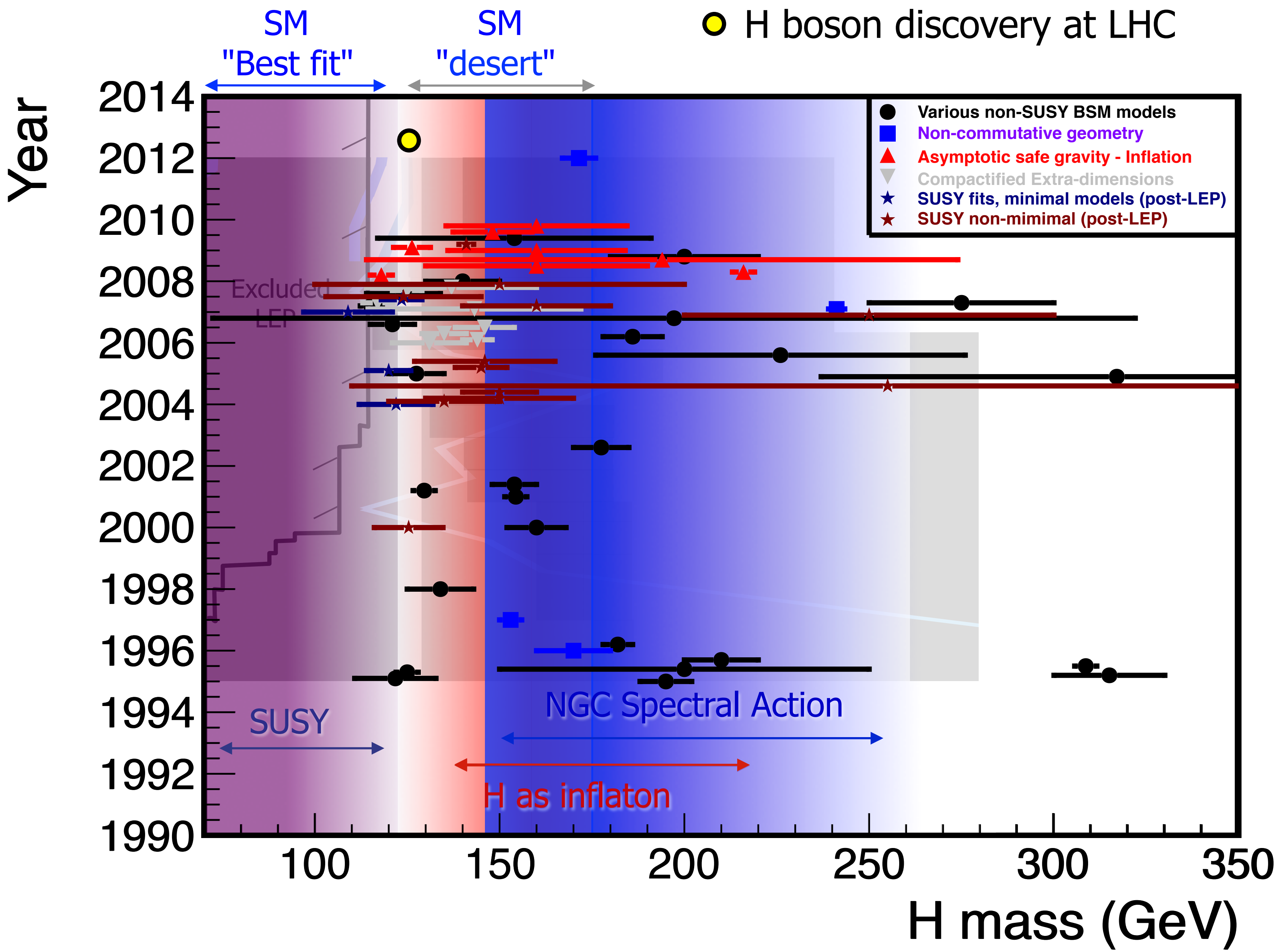




J U L Y 2 0 1 2

Discovery at $M_X \sim 125$ GeV, in both ATLAS and the CMS experiments combining $X \rightarrow \gamma\gamma$ and ZZ* channels (additional evidence from $X \rightarrow WW^*$)

The H boson mass : Theory vs Experiment



European Physical Society

PRIZE

The 2013 High Energy and Particle Physics Prize

for an outstanding contribution to High Energy Physics

is awarded to the

ATLAS and CMS collaborations

"for the discovery of a Higgs boson, as predicted by the Brout-Englert-Higgs mechanism"

and to

Michel Della Negra, Peter Jenni, and Tejinder Virdee

"for their pioneering and outstanding leadership rôles in the making of the ATLAS and CMS experiments"

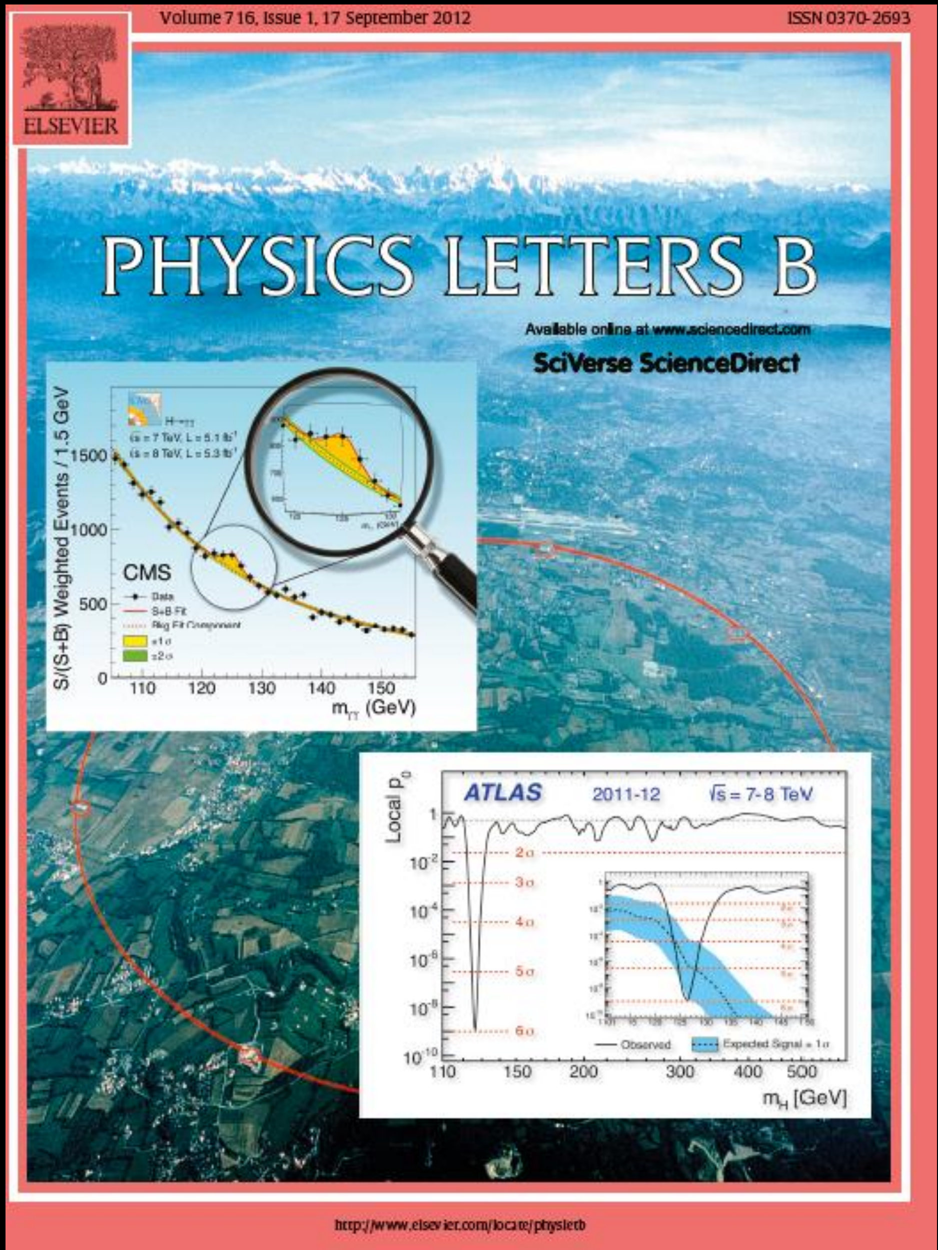
John Dudley
President
European Physical Society

Paris Sphicas
Chairman
High Energy and Particle Physics Division

Stockholm, Sweden, July 2013

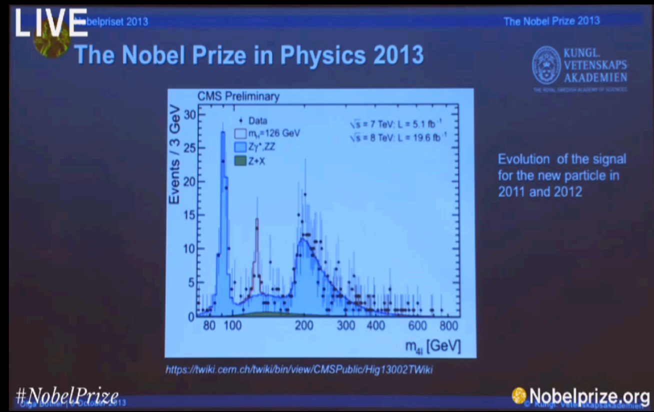
From the Discovery to the Nobel Prize

July 2012



≥ 5160 citations / experiment so far

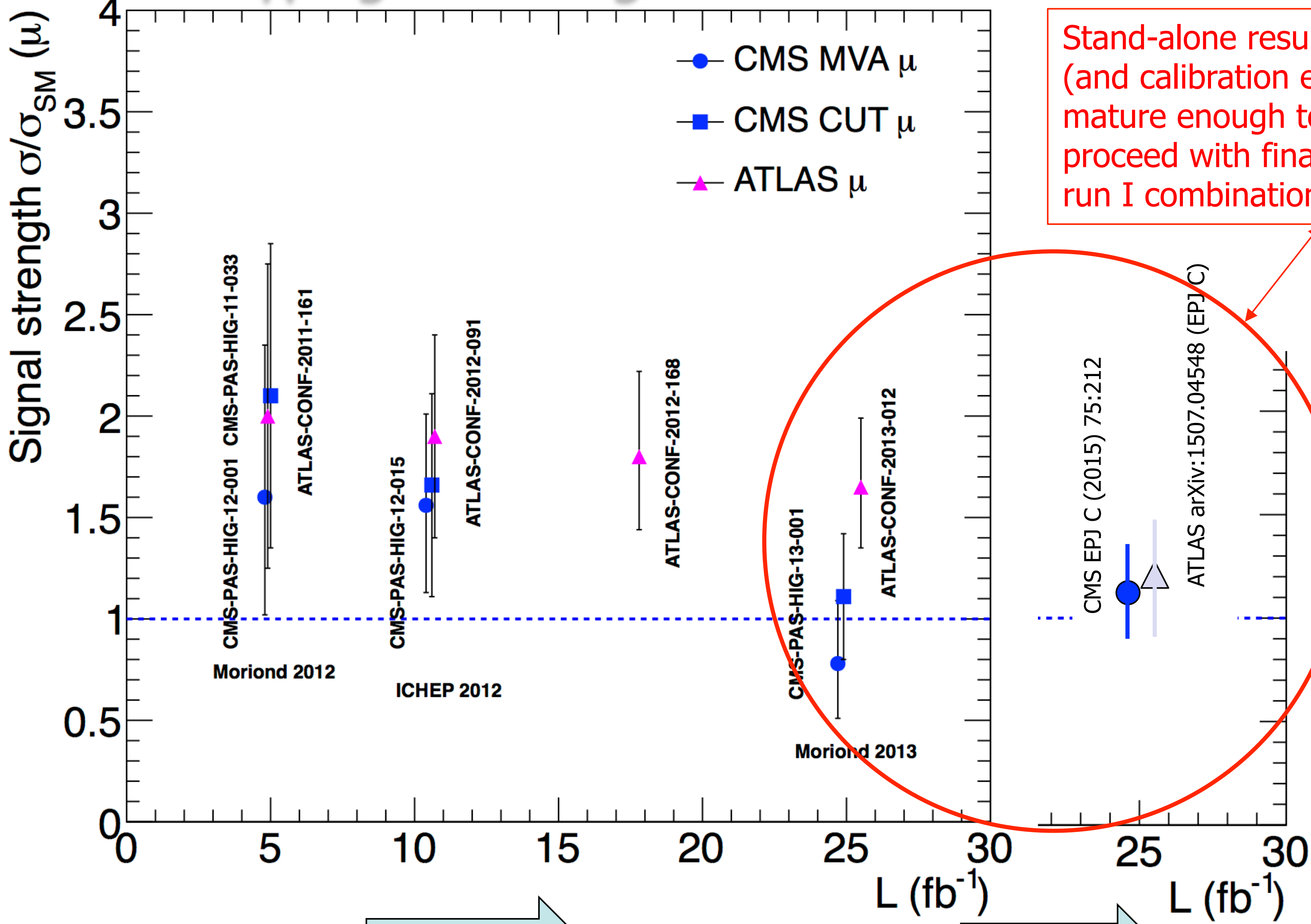
October 2013



"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

Reminder from yesterday

$H \rightarrow \gamma\gamma$ signal strength – vs $\mathcal{L}$ and Time



Stand-alone results (and calibration etc.) mature enough to proceed with final run I combination

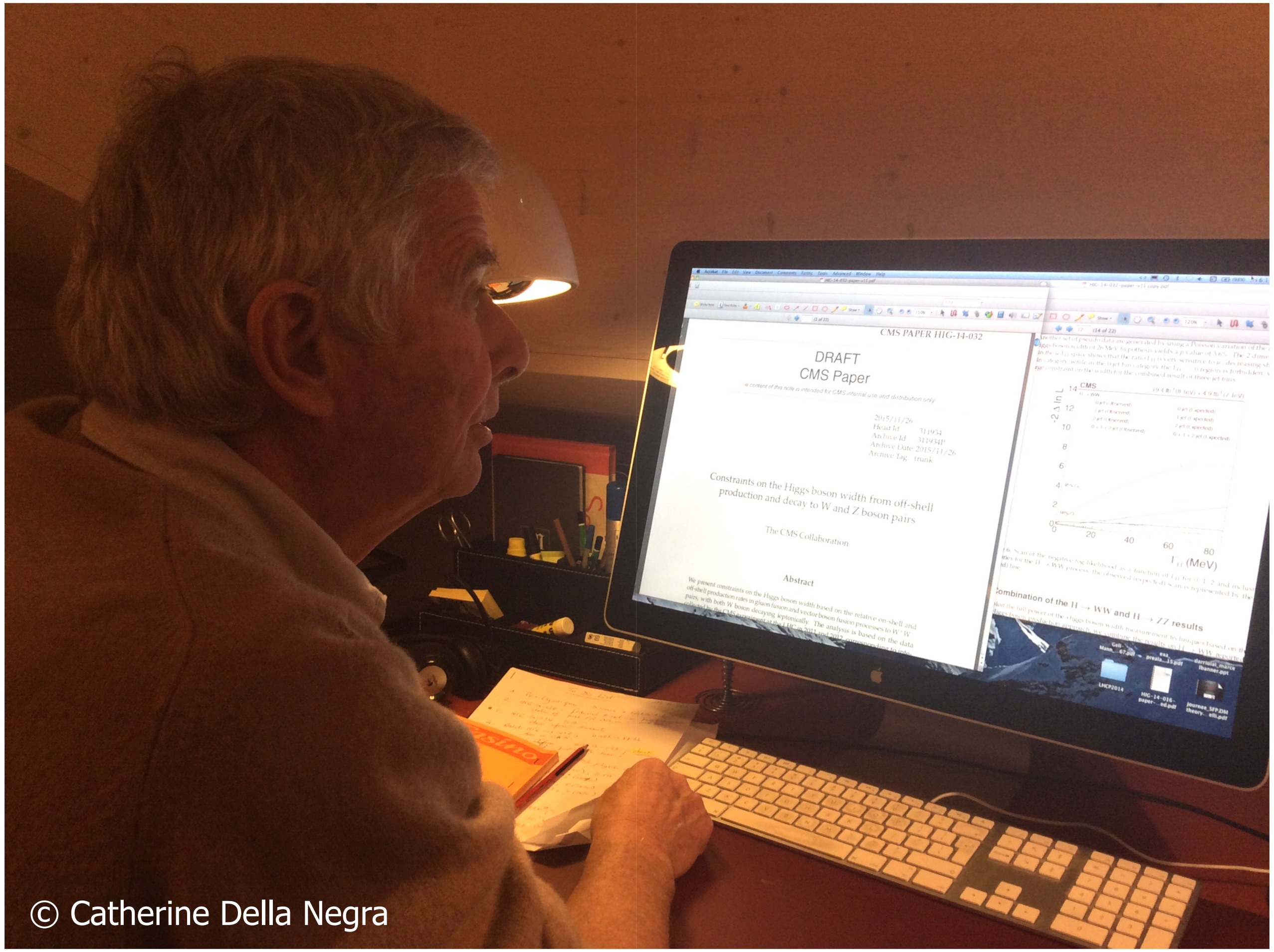
Luminosity

Time

Adapted from P. Meridiani, May 2013

Higgs Publication Committee

- Michel bas been on the CMS Higgs publication committee since the origin and currently acts as the Chair
- No-one else in CMS has reviewed, read, commented, and influence has many CMS Higgs boson publications (63 published so far !)



Christmas 2012 and the First H Spin-Parity Paper

29 December 18h27

De: "yves.sirois@cern.ch" <yves.sirois@cern.ch>
Objet: Rép : CMS-HIG-12-041-003: Paper submitted to arXiv.org and the journal
Date: 29 décembre 2012 18:27:19 UTC+1
À: <Paraskevas.Sphicas@cern.ch>
Cc: Michel Della Negra <Michel.Della.Negra@cern.ch>, Egidio Longo <egidio.longo@roma1.infn.it>, George Alverson <George.Alverson@cern.ch>, "John Conway" <John.Conway@cern.ch>

Thanks very much Paris,
Thanks for the great care and help from the PubCom.
And congratulations !

Cheers
Yves

Le 29 déc. 2012 à 18:17, <Paraskevas.Sphicas@cern.ch> a écrit :

Dear CMS collaborators,
The draft document may be found at this URL: http://cds.cern.ch/record/1502670
It is version no. 3 entitled:

`On the mass and spin-parity of the Higgs boson candidate via its decays to Z boson pairs`
http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=HIG-12-041
This is the final version, submitted to the arXiv and the journal (PRL).

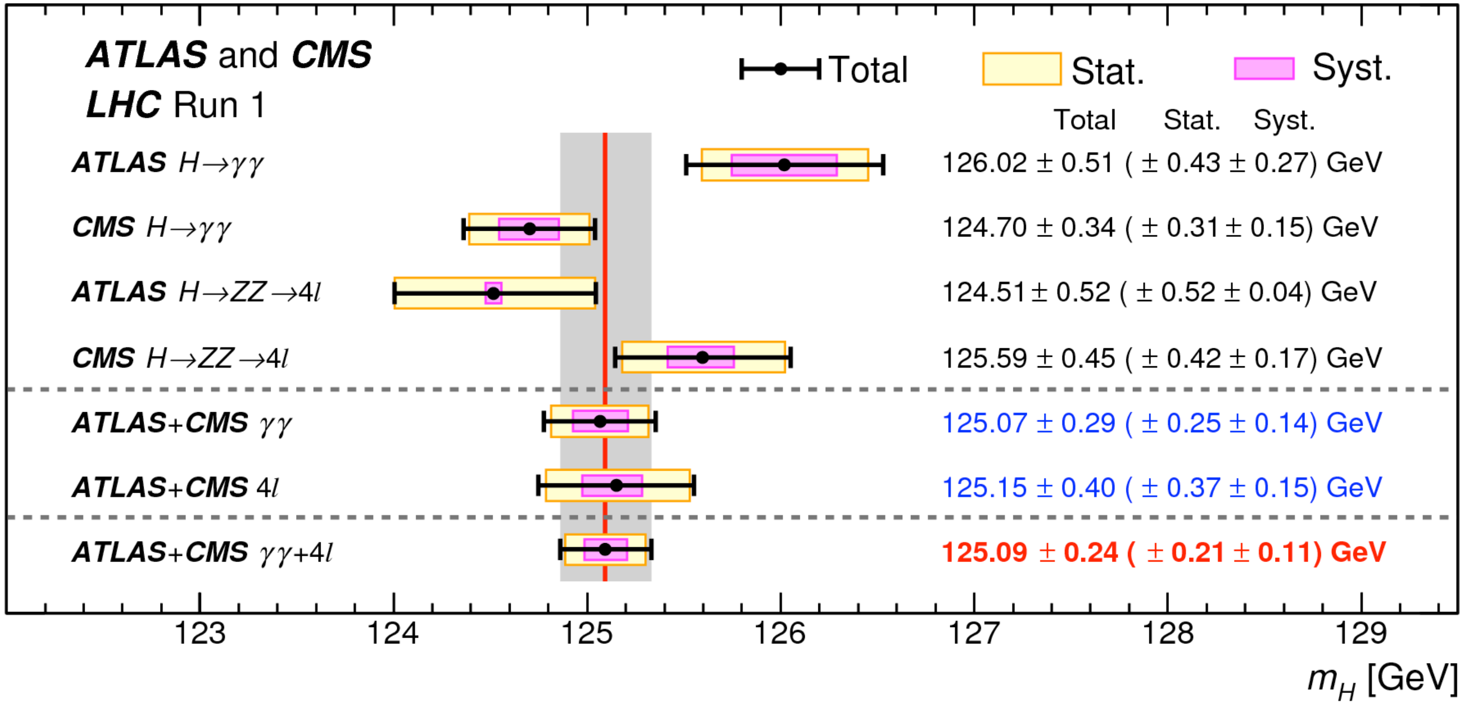
Kind regards,
Michel Jean Della Negra,Egidio Longo
PubComm-HIG chairs
Paris Sphicas
PubComm Cha

Paper sent to PRL !!!

Maybe a X-mass vacation next year ?

H boson Mass – LHC Combination

- Mass measured with high precision in $\gamma\gamma$ and ZZ $\rightarrow$ 4ℓ channels



- Some tension but opposite for $\gamma\gamma$ and 4ℓ between ATLAS and CMS; (p-value ~10%) for the four measurements
- Very good agreement in the central values

$$m_H^{\gamma\gamma} = 125.07 \pm 0.29 \text{ GeV} = 125.07 \pm 0.25\,(\text{stat.}) \pm 0.14\,(\text{syst.}) \text{ GeV}$$

$$m_H^{4\ell} = 125.15 \pm 0.40 \text{ GeV} = 125.15 \pm 0.37\,(\text{stat.}) \pm 0.15\,(\text{syst.}) \text{ GeV}$$

M_H = 125.09, narrow width, pure CP even state (0^+)

Signal Strengths / Stand-Alone

- Consistently obtained here for the LHC mass M_H = 125.09 GeV
- Some values differ slightly from those of earlier publications

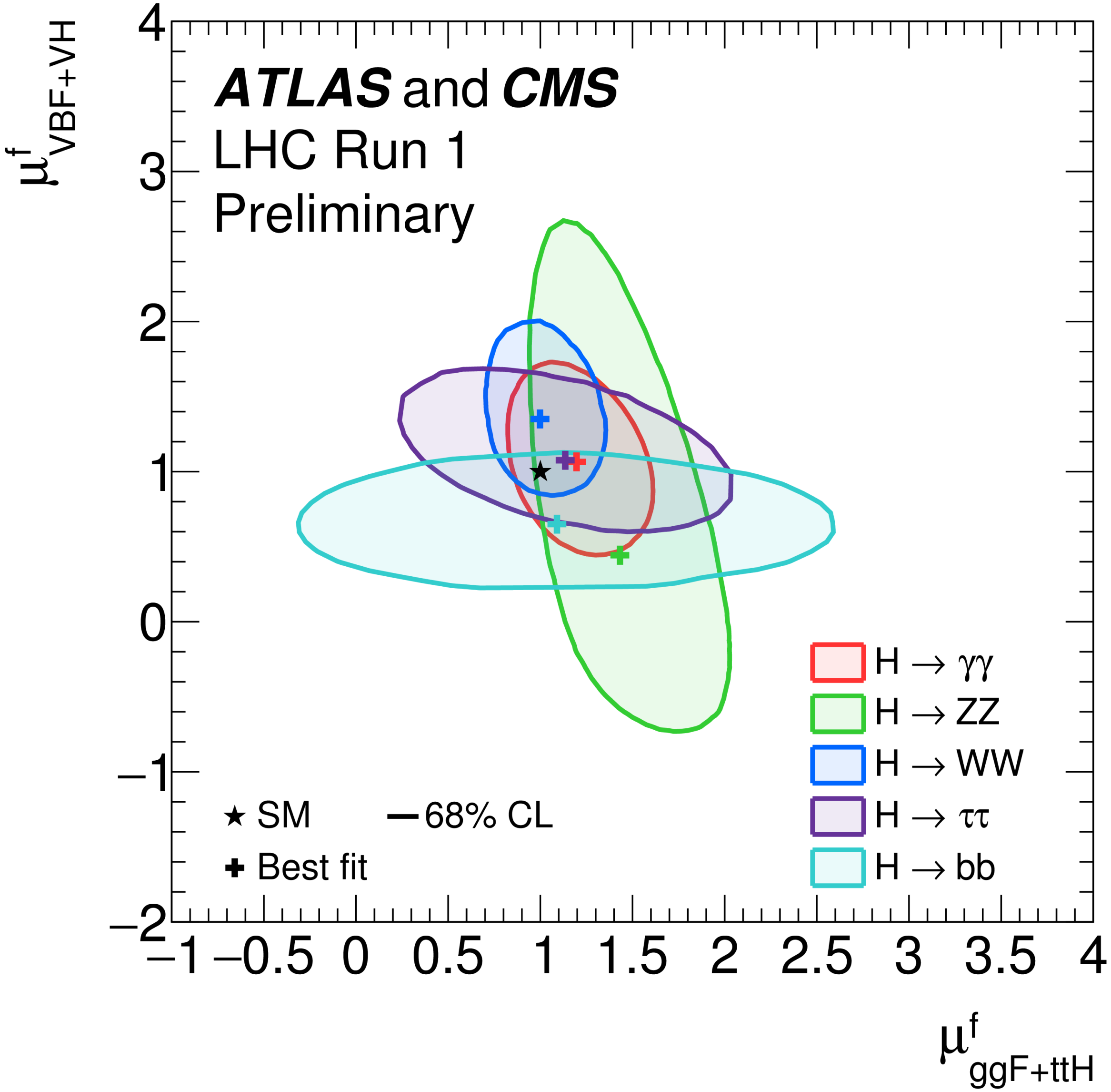
Channel	References for individual publications		Signal strength [μ] from results in this paper (Section 5.2)		Signal significance [σ] from results in this paper (Section 5.2)	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$H \to \gamma\gamma$	[27]	[50]	$1.15^{+0.27}_{-0.25}$	$1.12^{+0.25}_{-0.23}$	5.0	5.6
			$\left(^{+0.26}_{-0.24}\right)$	$\left(^{+0.24}_{-0.22}\right)$	(4.6)	(5.1)
$H \to ZZ \to 4\ell$	[51]	[52]	$1.51^{+0.39}_{-0.34}$	$1.05^{+0.32}_{-0.27}$	6.6	7.0
			$\left(^{+0.33}_{-0.27}\right)$	$\left(^{+0.31}_{-0.26}\right)$	(5.5)	(6.8)
$H \to WW$	[53, 54]	[55]	$1.23^{+0.23}_{-0.21}$	$0.91^{+0.24}_{-0.21}$	6.8	4.8
			$\left(^{+0.21}_{-0.20}\right)$	$\left(^{+0.23}_{-0.20}\right)$	(5.8)	(5.6)
$H \to \tau\tau$	[56]	[57]	$1.41^{+0.40}_{-0.35}$	$0.89^{+0.31}_{-0.28}$	4.4	3.4
			$\left(^{+0.37}_{-0.33}\right)$	$\left(^{+0.31}_{-0.29}\right)$	(3.3)	(3.7)
$H \to bb$	[37]	[38]	$0.62^{+0.37}_{-0.36}$	$0.81^{+0.45}_{-0.42}$	1.7	2.0
			$\left(^{+0.39}_{-0.37}\right)$	$\left(^{+0.45}_{-0.43}\right)$	(2.7)	(2.5)
$H \to \mu\mu$	[58]	[59]	-0.7 ± 3.6	0.8 ± 3.5		
			(± 3.6)	(± 3.5)		
ttH production	[60–62]	[64]	$1.9^{+0.8}_{-0.7}$	$2.9^{+1.0}_{-0.9}$	2.7	3.6
			$\left(^{+0.72}_{-0.66}\right)$	$\left(^{+0.88}_{-0.80}\right)$	(1.6)	(1.3)

Measured

(expected)

Slight ttH prod. excess … and slight H → bb decay deficit

Signal Strength μ: Production and Decay (2)



- Assume that μ_F^f and m_V^f are the same for $\sqrt{s}$ = 7 and 8 TeV
- 10-parameter fit of μ_F^f and m_V^f for each of the 5 decay channels

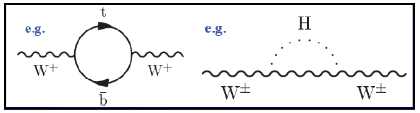
p-value of 88% for the compatibility with SM expectation !!

Reminder from yesterday

State of the Art

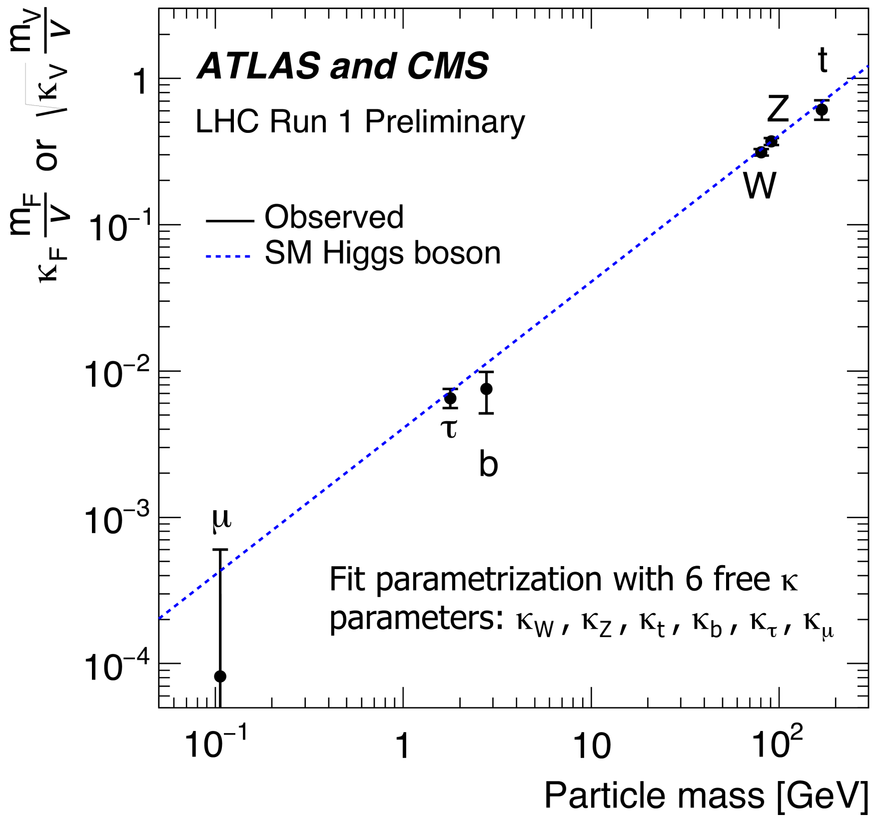
Couplings to fermions and to weak bosons
(verified to ~15-30% precision)

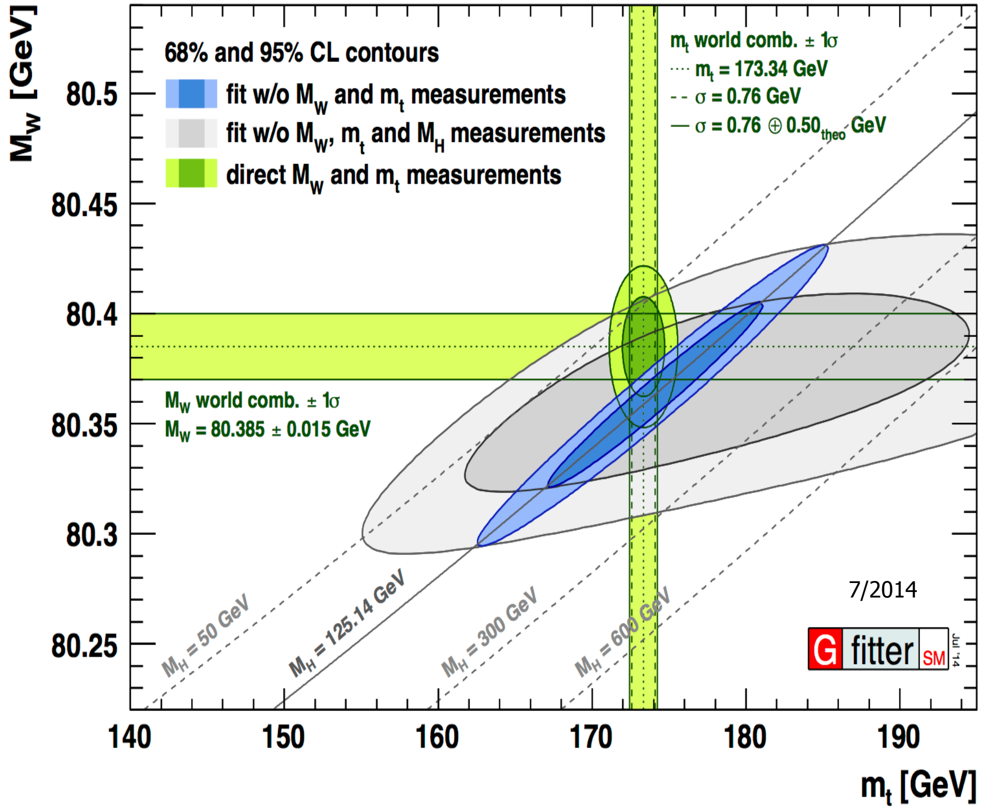
Rad. corrections:



W, Z meas. sensitive to M_{top} M_H

Run I Legacy $M_H = 125.09 \pm 0.24$ GeV



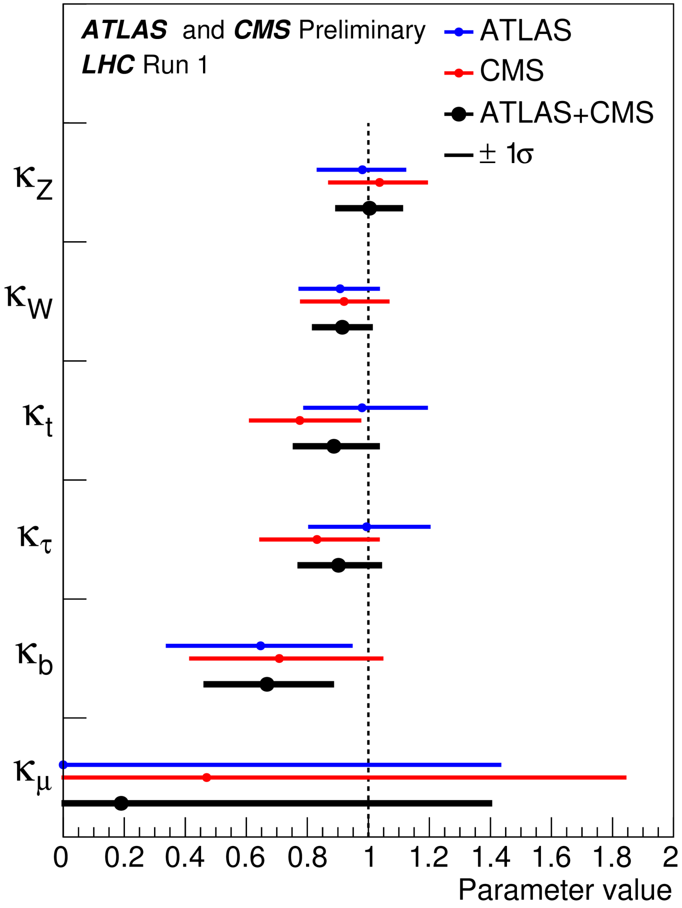


- SM-like Higgs at ~125 GeV is compatible with global EWK data at 1.3σ (p = 0.18)
- Indirect constraints now superior to some precise direct W, Z measurements

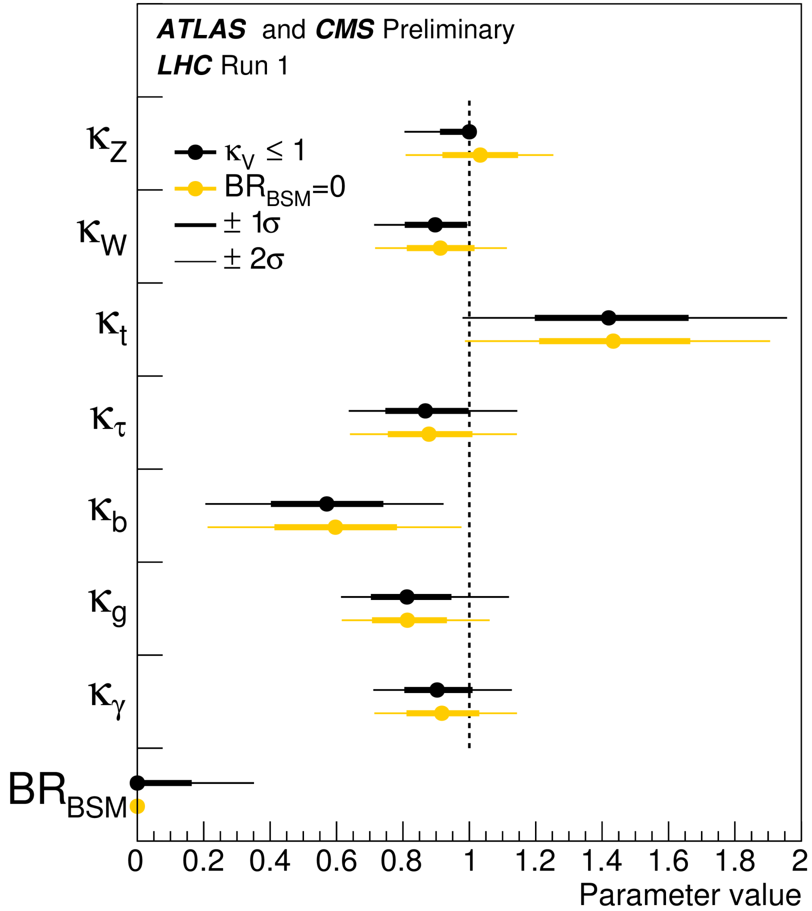
Indirect (EWK fit): $M_W = 80.359 \pm 0.011$
Direct (World average): $M_W = 80.385 \pm 0.015$

Test SM Couplings to Fermions and Bosons

Assuming no BSM in the loops:
i.e. assume SM for κ_γ and κ_g



Allowing for BSM in the loops:
i.e. allow effective couplings for κ_γ and κ_g



- Signal strengths in different channels are consistent with 1 (SM)
- Tension: Excess at 2.3 σ level for ttH Deficit of 2.4σ in BR^{bb}/BR^{ZZ}

The H Boson discovery is now firmly established

A truly astonishing achievement !

- Our understanding has evolved from the question of the *structure of matter* to that of the *very origin of interactions (local gauge symmetries) and matter (interactions with Higgs field)*
- We understand the quantum origin of mass for particles (scalar field, BEH mechanism) and for hadrons (dynamics in the strong sector)
- Ignoring gravitation, we have for the first time in the history of science a theory which is at least in principle complete, consistent, and coherent at all scales … (up to the Planck scale ?)
- The History of the early universe (and the nature of vacuum) is changed

But …

- The H boson is not a gauge boson
  (its mass is not protected by symmetries of the theory)
- The H boson mass (and the H self-coupling) is arbitrary

The H Boson discovery is now firmly established

It is not over !

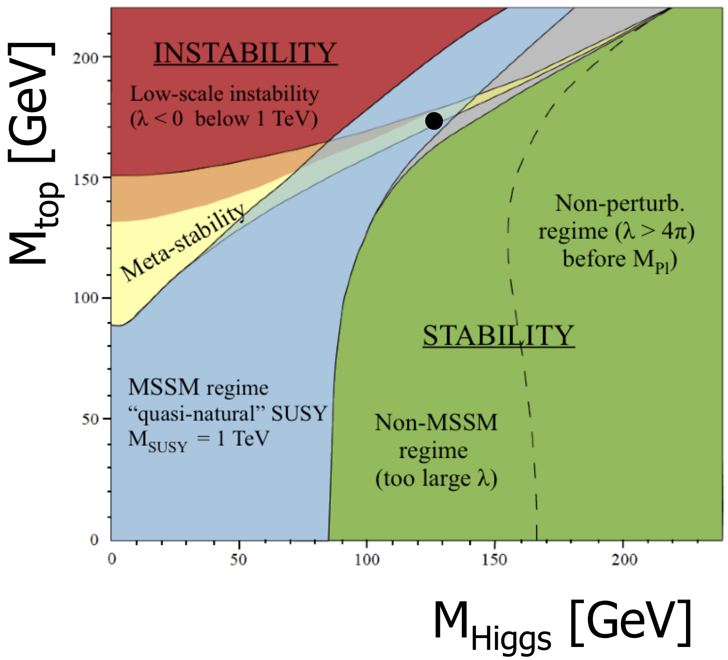
- The complexity of the Standard Model is encoded a scalar sector

$$\mathscr{L}_{\mathrm{SM}} = \mathscr{L}_{\mathrm{gauge}}(A_a, \psi_i) + \mathscr{L}_{\mathrm{Higgs\ (Symm.\ Break.)}}(\phi, A_a, \psi_i)$$

Natural
verified with high precision; stable and highly symmetric
(gauge and flavour symmetries)

Ad hoc
Necessary (other mass terms forbidden by EWK gauge symmetries); QM unstable; at the origin of flavour structure and all other problems of the SM

G. Isodori et al.

- 

Can we avoid the arbitrariness of the Higgs sector ? (get self-coupling via gauge sector ?)

Does nature requires an extended scalar sector ?

Can we avoid a Hierarchy problem relative to Planck scale ?

We have found particles of spin 0, ½, and 1; where are the spin 2 particles connected to gravitation ? (extra-dimension ?)

ATLAS and CMS physics results from Run 2

Tuesday, 15 December 2015 from **15:00 to 17:00** (Europe/Zurich)

CERN (500-1-001 - Main Auditorium)