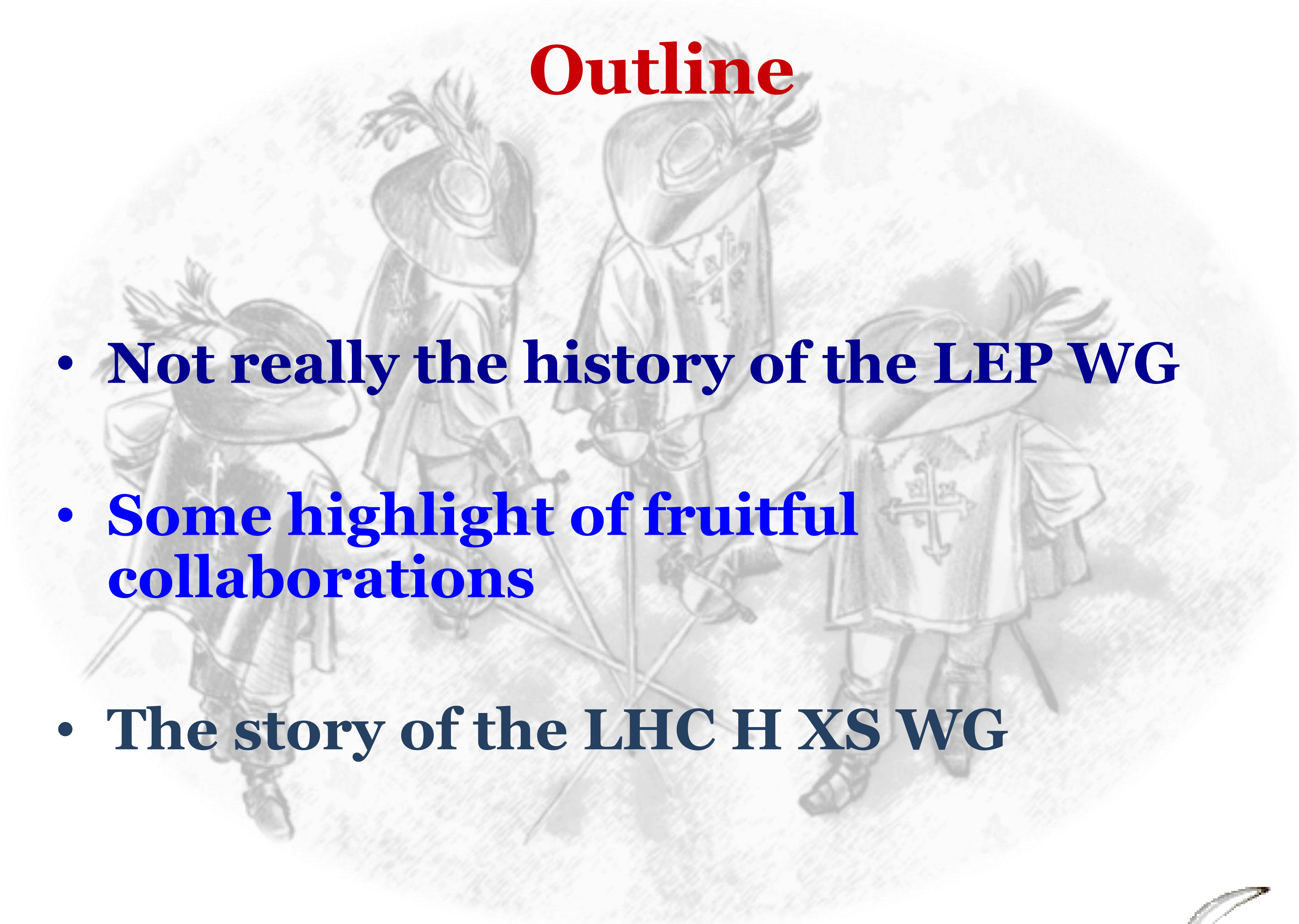
Bringing theorists and experimentalists together: the LEP and LHC working groups

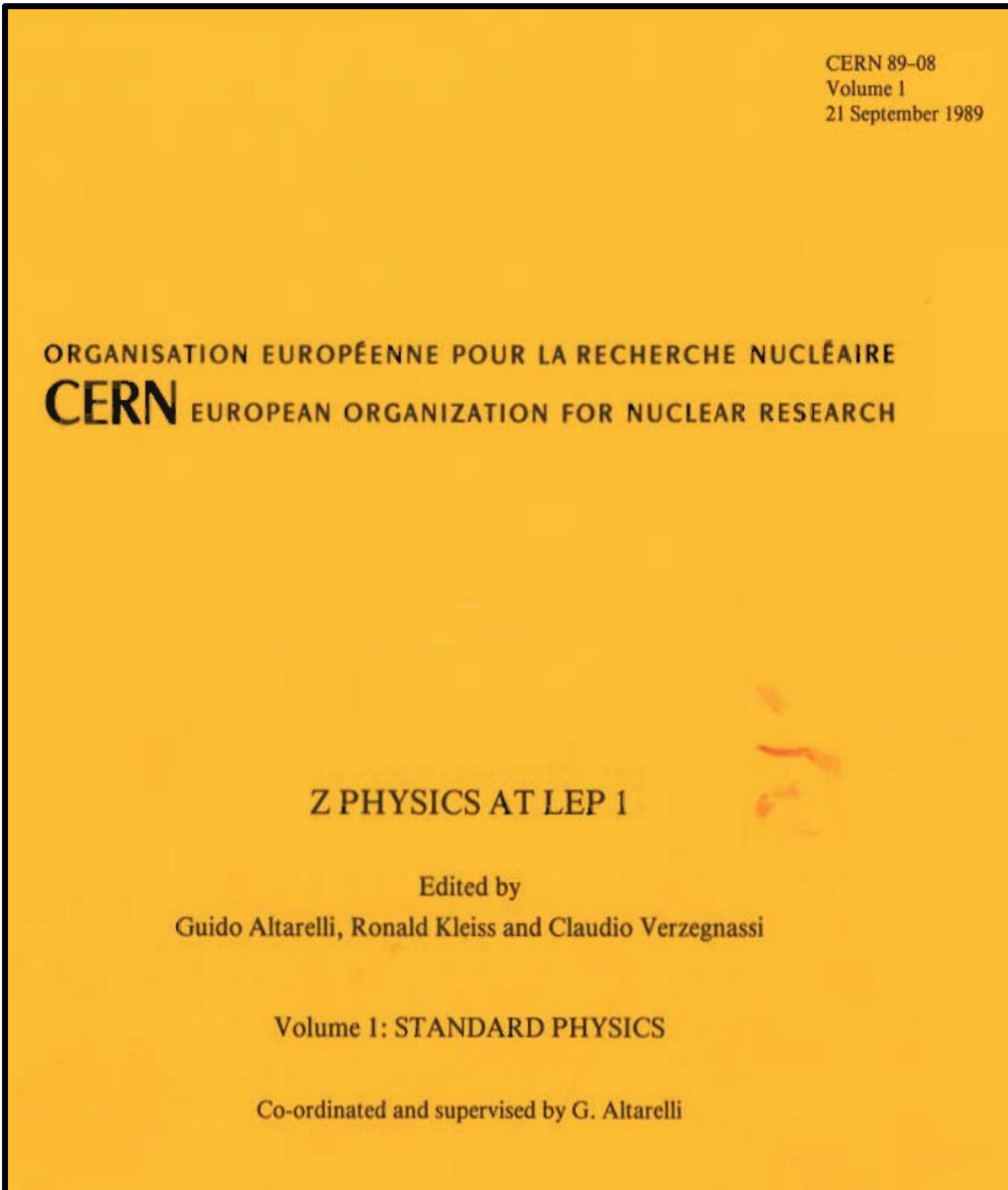
all for one and one for all

Outline



- **Not really the history of the LEP WG**
- **Some highlight of fruitful collaborations**
- **The story of the LHC H XS WG**

Preparing LEP


CERN 89-08
Volume 1
21 September 1989

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Z PHYSICS AT LEP 1

Edited by
Guido Altarelli, Ronald Kleiss and Claudio Verzegnassi

Volume 1: STANDARD PHYSICS

Co-ordinated and supervised by G. Altarelli

A textbook for all the students and non, starting at LEP

Lots of work:
- SM,
- Higgs
- new physics
- predictions, analyses,
- event generators,
- software…

Both experiments and theory did much better than expected !

For example:
MZ, Gamma_Z ~ 10 MeV
→ we got 2 MeV

The birth of the LEP EW WG

Gigi Rolandi:

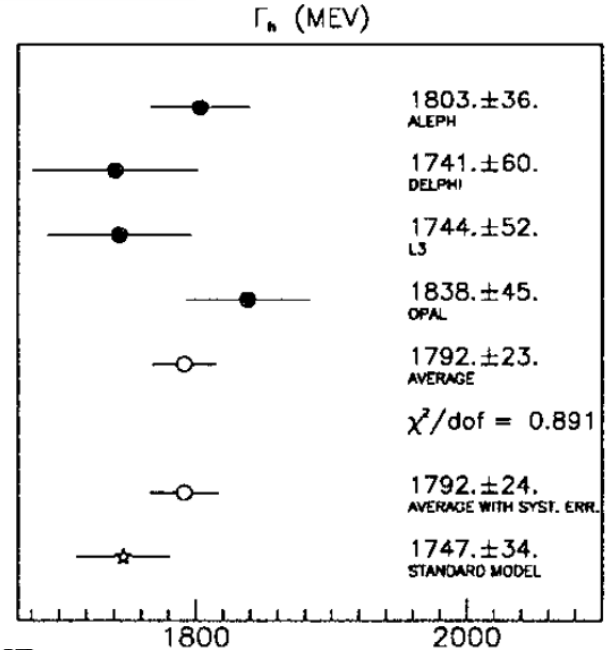
I remember to have gone to Moriond in 1990 and Jean Francois Grivaz asked me to give a talk comparing the results of the 4 LEP experiments. In that occasion I did the first plots with the 4 results and with the combination – with error bars.

They liked the talk and thus I gained an additional week -Moriond QCD- with the promise to re-give the talk !

Compilation of results on electroweak parameters from SLC and LEP

Luigi Rolandi
Dipartimento di Fisica e Sezione INFN Trieste
and
CERN PPE

May 14, 1990



Abstract

The measurements of the Z mass and widths done by the LEP and SLC experiments are compared and averaged taking into account the common systematic errors. From the overall sample of about 80,000 hadronic decays and 7,000 leptonic decays one obtains:

$$M_Z = 91.171 \pm 0.032\ GeV$$

$$\Gamma_Z = 2538 \pm 28\ MeV$$

$$\Gamma_{ll} = 83.6 \pm 1.0\ MeV$$

$$\Gamma_{had} = 1792 \pm 24\ MeV$$

$$\Gamma_{inv} = 500 \pm 21\ MeV$$

From these measurements and assuming the Standard Model value for Γ_{ll}/Γ_{ν}, the number of light neutrino is found to be :

$$N_{\nu} = 3.04 \pm 0.12$$

PROCEEDINGS of Moriond 1990

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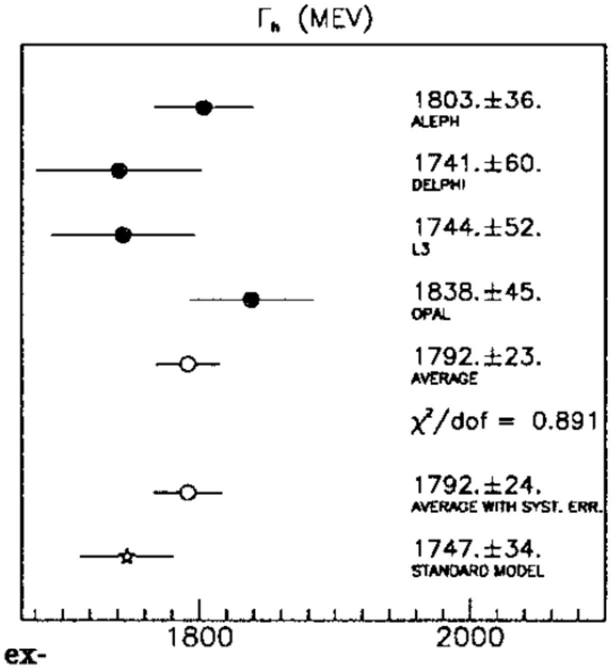

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PROCEEDINGS of Moriond 1990

After 2 weeks of data taking,
we knew there were 3 neutrinos!

Conclusion of the talk

The measurements of the Z parameters from the average of the four LEP experiments are in agreement with the prediction of the Standard Model. In 1990, LEP may produce a factor of 10 more data. In order to improve the interpretation of the experimental data and to reduce the systematic errors to the size of future statistical errors we will need:

- LEP energy calibration with polarization to reduce the systematic error on M_Z
- A better computation , possibly a more precise Monte Carlo, of the small-angle bhabha cross section in order to improve the measurement of the luminosity
- A better understanding of the QED radiative correction that will be the systematic limit for the measurement of the total width
- A better computation, possibly an order α^2 Monte Carlo, of the large angle bhabha cross section to improve the systematic error on the "t-channel subtraction".

Experiment and theory have "run" together towards high precision for luminosity: from 3.2 % to 0.054% (TH) - 0.034% (EXP) (limiting precision on the N_neutrinos)

Conclusion of the talk

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A very special collaboration

- The LEP Energy Working Group was established at the beginning of the LEP program with the task of determining the collision energies.
- The group consisted of physicists from the experiments, and machine physicists and engineers from the accelerator.
- The primary purposes of the work was to provide input to the Z mass and width measurements, and the W mass determination.

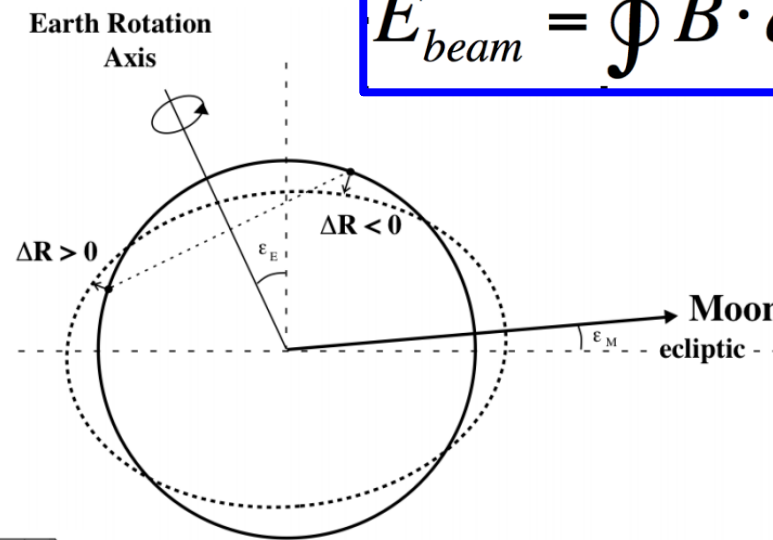
The LEP Energy Working Group

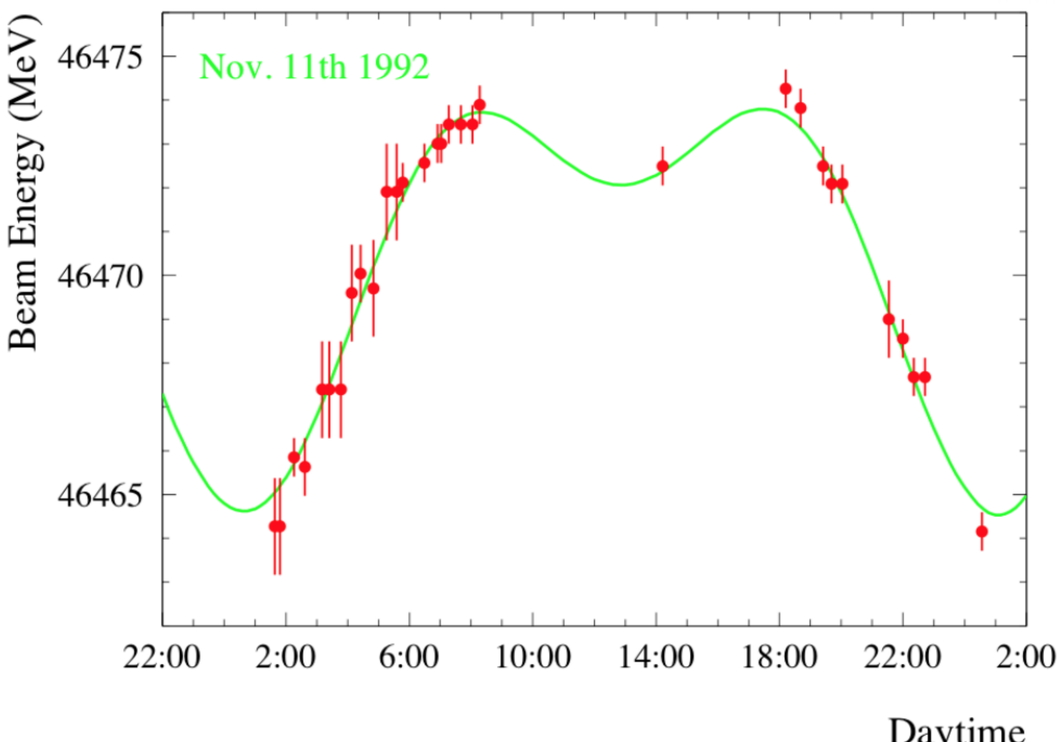
R. Assmann[1)], M. Böge[1,a)], R. Billen[1)], A. Blondel[2)], E. Bravin[1)], P. Bright-Thomas[1,b)], T. Camporesi[1)], B. Dehning[1)], A. Drees[3)], G. Duckeck[4)], J. Gascon[5)], M. Geitz[1,c)], B. Goddard[1)], C.M. Hawkes[6)], K. Henrichsen[1)], M.D. Hildreth[1)], A. Hofmann[1)], R. Jacobsen[1,d)], M. Koratzinos[1)], M. Lamont[1)], E. Lancon[7)], A. Lucotte[8)], J. Mnich[1)], G. Mugnai[1)], E. Peschardt[1)], M. Placidi[1)], P. Puzo[1,e)], G. Quast[9)], P. Renton[10)], L. Rolandi[1)], H. Wachsmuth[1)], P.S. Wells[1)], J. Wenninger[1)], G. Wilkinson[1,10)], T. Wyatt[11)], J. Yamartino[12,f)], K. Yip[10,g)]

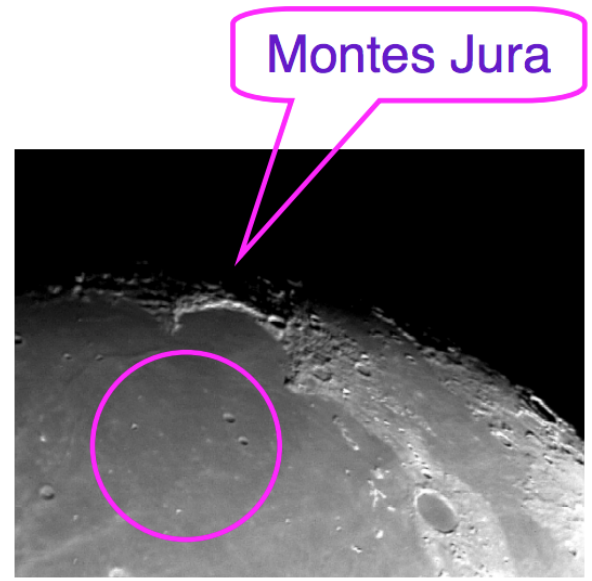
We found the moon

$$E_{beam} = \oint B \cdot dl$$

- Length of beam orbit fixed by RF freq
- Earth tides change length of tunnel (1mm in 27km). Magnets move w.r.t. beam
- Extra contribution from quadrupole fields off central orbit changes E_{beam}
- Amplitude ~10MeV



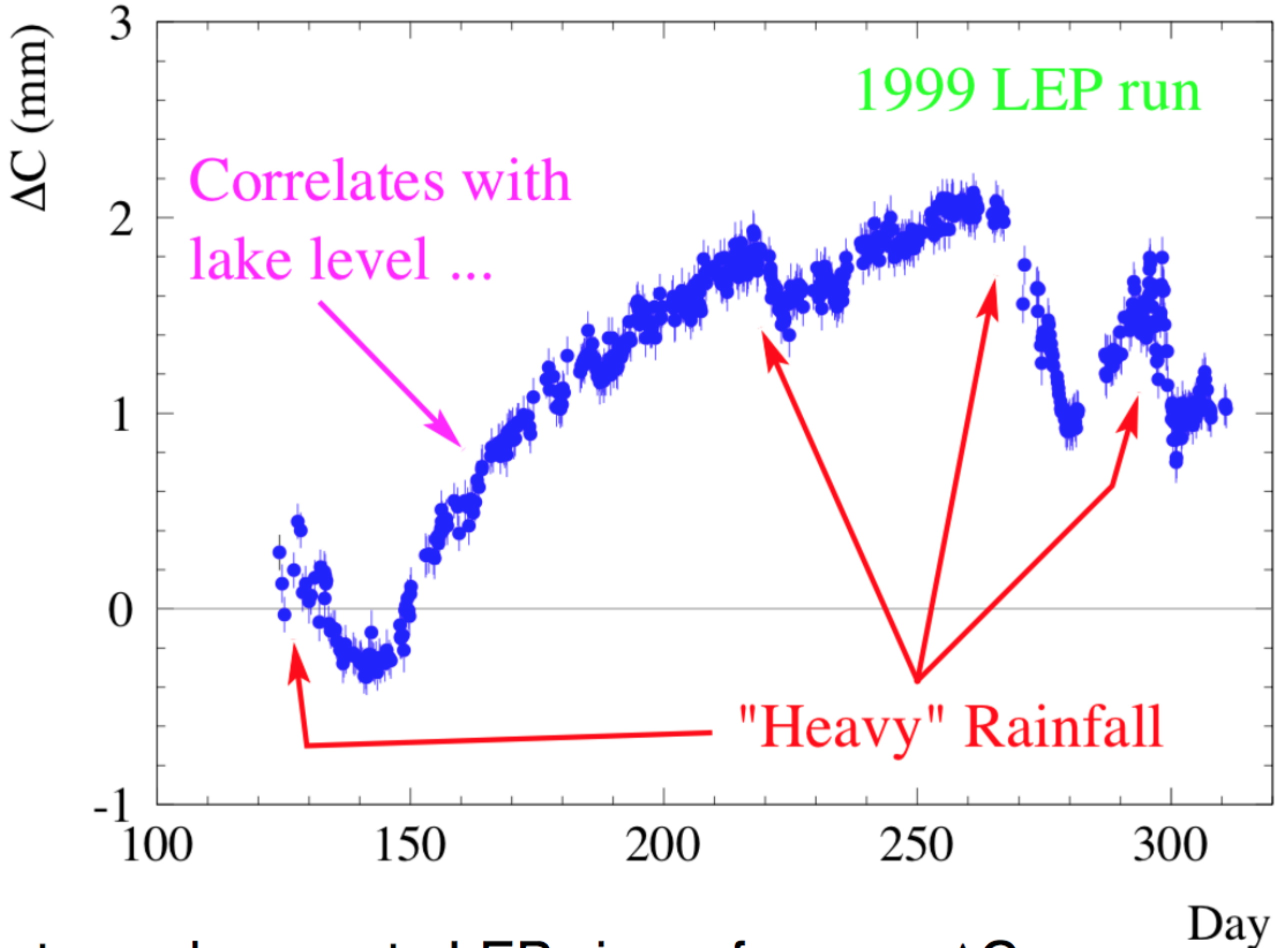




Lunar Hadron Collider?

We found water

$$E_{beam} = \oint B \cdot dl$$

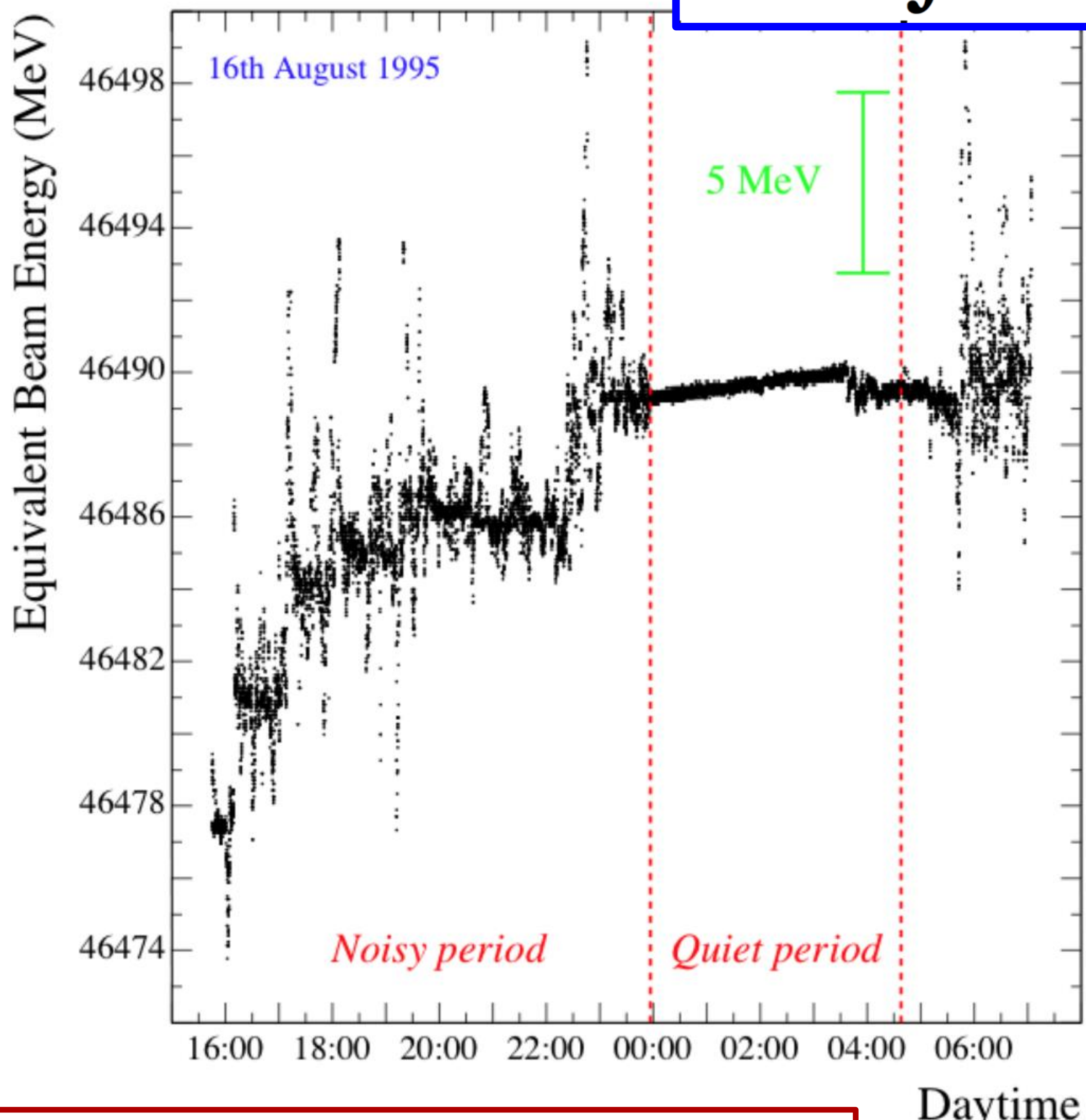


- Long term changes to LEP circumference, ΔC
- But some discrepancies remained until 1995, especially for measurements during long fills

NMR probes

$$E_{beam} = \oint B \cdot dl$$

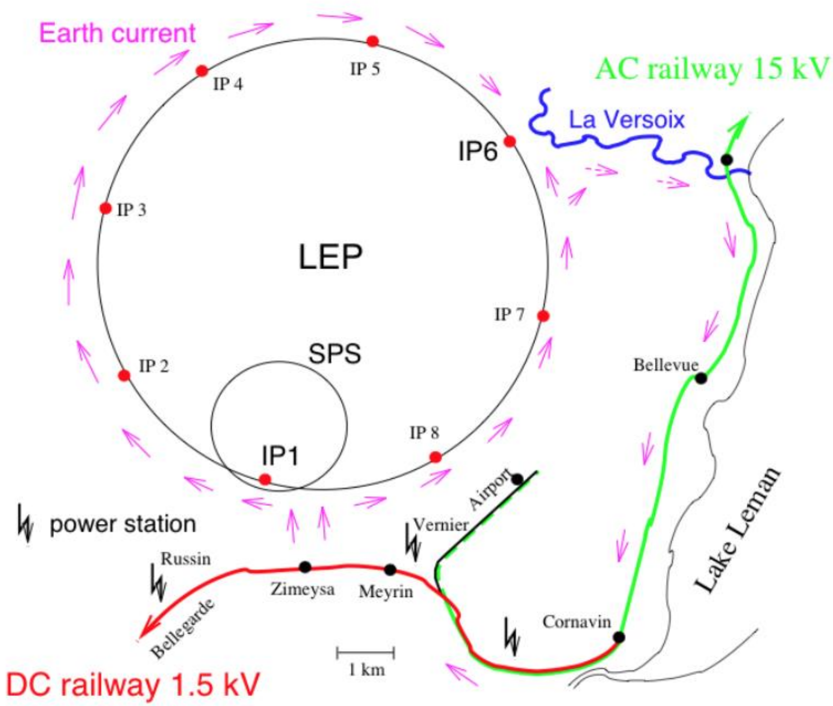
- 1995 - installed two NMR probes in LEP dipoles on opposite sides of the ring
- Noise related to human activity in daytime; quiet over night
- General trend - energy increases during fill
- Measuring E_{beam} at the end of fill gives a ~5 MeV bias on average

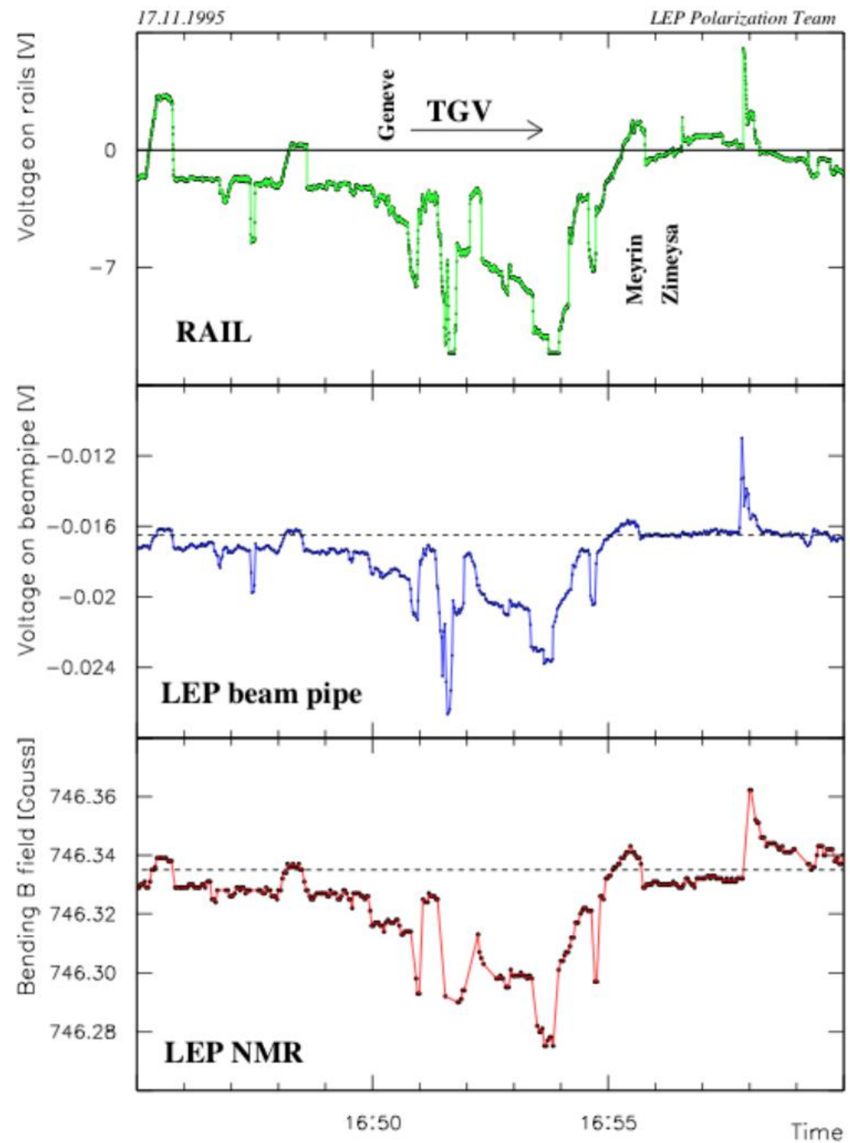


IF YOU FIND THE EQUIPMENT WICH IS OFF DURING THE NIGHT, YOU WILL GET A CASE OF CHAMPAGNE

We found the trains

- Vagabond currents from French DC electric trains
- Measured current on beam pipe and NMR field change





The first published evidence of vagabond currents which we have been able to find is in Nature, Vol.58, NO. 1509, 29 September, 1898, p. 533. The few paragraphs included in a report of 'Physics at the British Association' describe well the source of the phenomena which have affected LEP.

Corrections for pre-1995 data

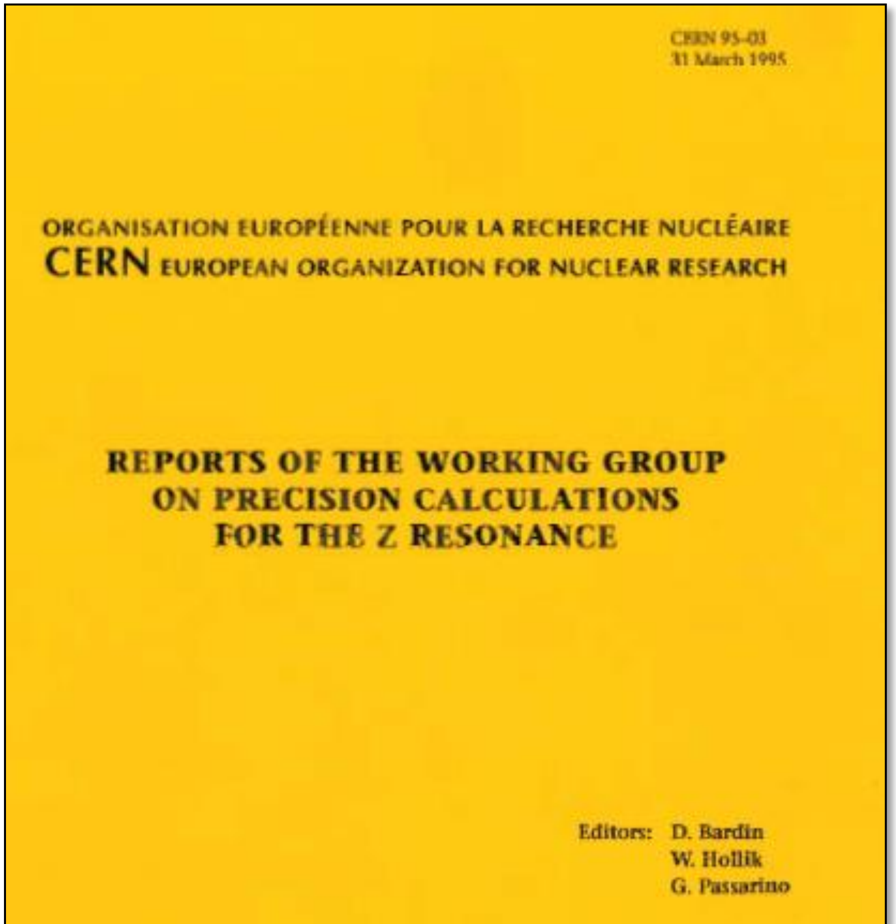
- Model to correct for magnetic behaviour, extrapolating back from end-of-fill resonant depolarisation measurements
  - Time of day
  - Time from start of fill
  - Magnet temperatures
  - (RF configuration, and other IP effects)
- Confirmed with more NMR probes in the tunnel during LEP2 times

Final E_{CM} uncertainty on Z mass : 1.7 MeV

$M_Z = 91.1875 \pm 0.0021$ GeV

2×10^{-5}

Wrapping up


CERN 95-03
31 March 1995

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

REPORTS OF THE WORKING GROUP
ON PRECISION CALCULATIONS
FOR THE Z RESONANCE

Editors: D. Bardin
W. Hollik
G. Passarino

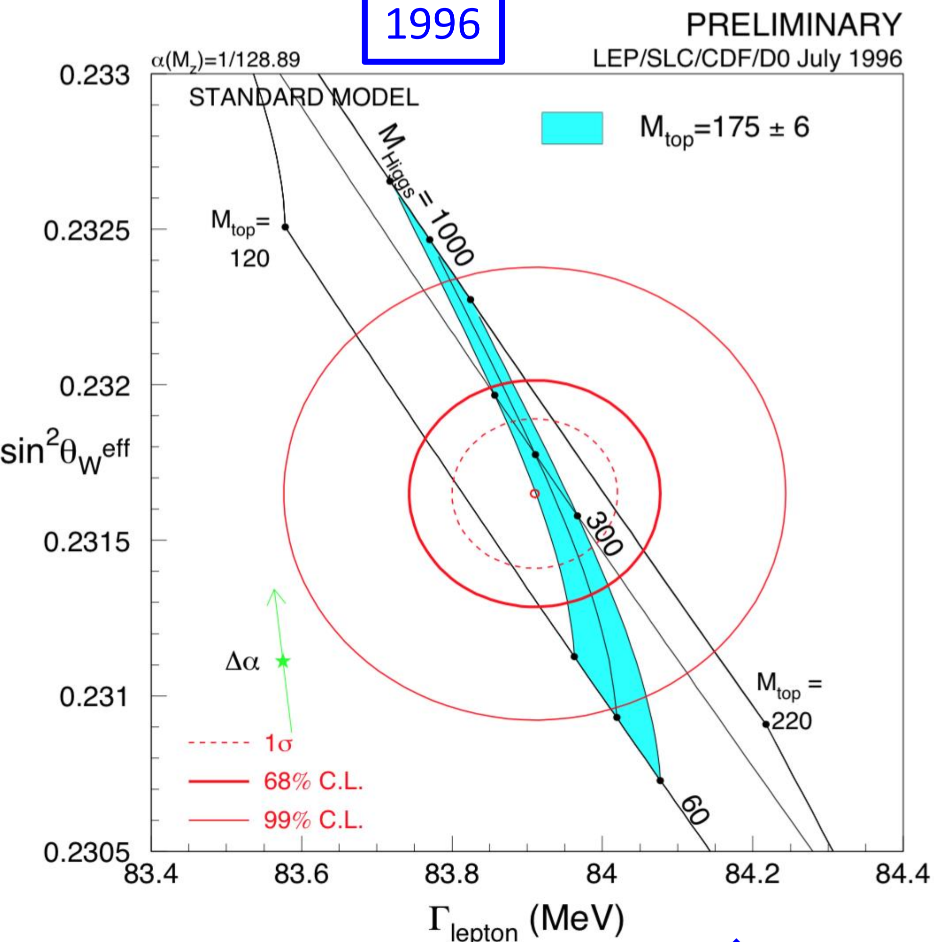
Glasgow 1994

"Precision Calculations for the Z "

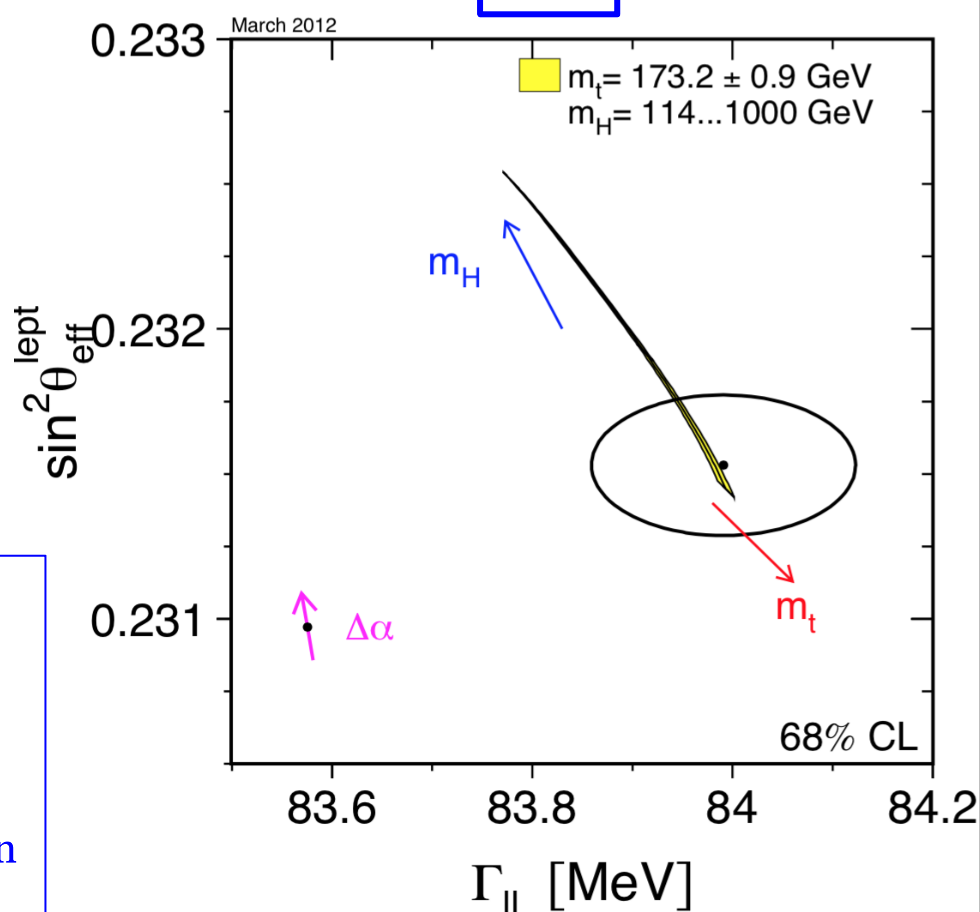
G. Passarino

The discovery of the EW radiative corrections

1996



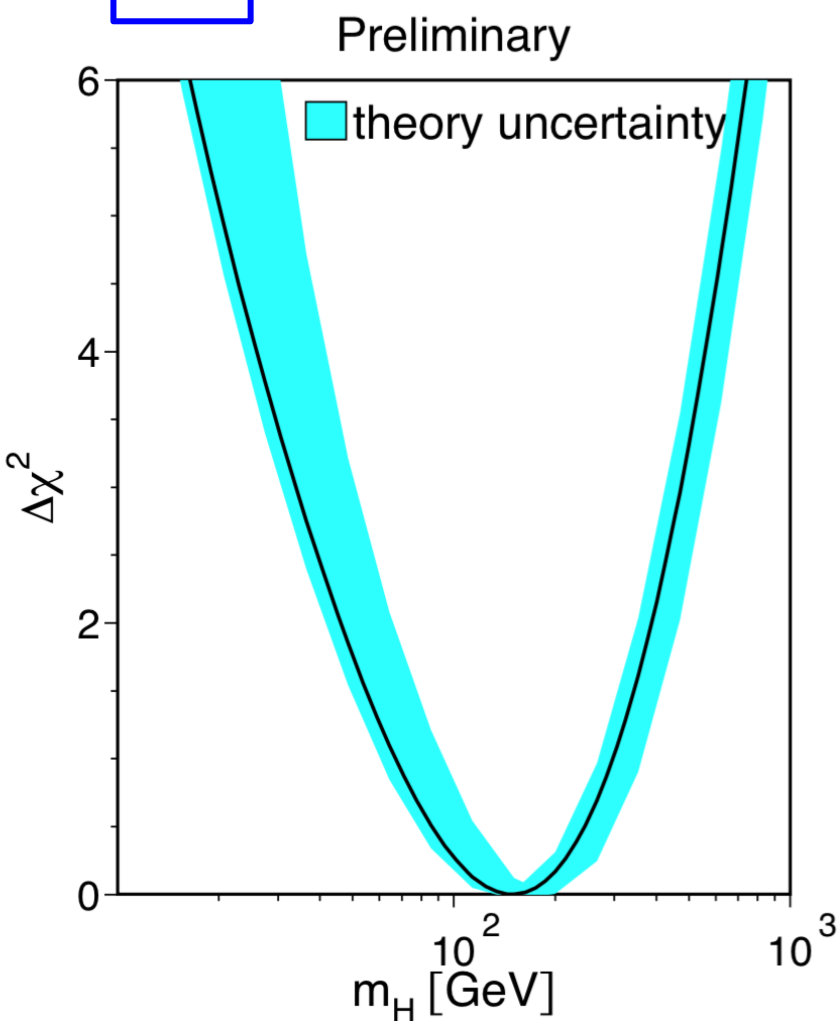
2012



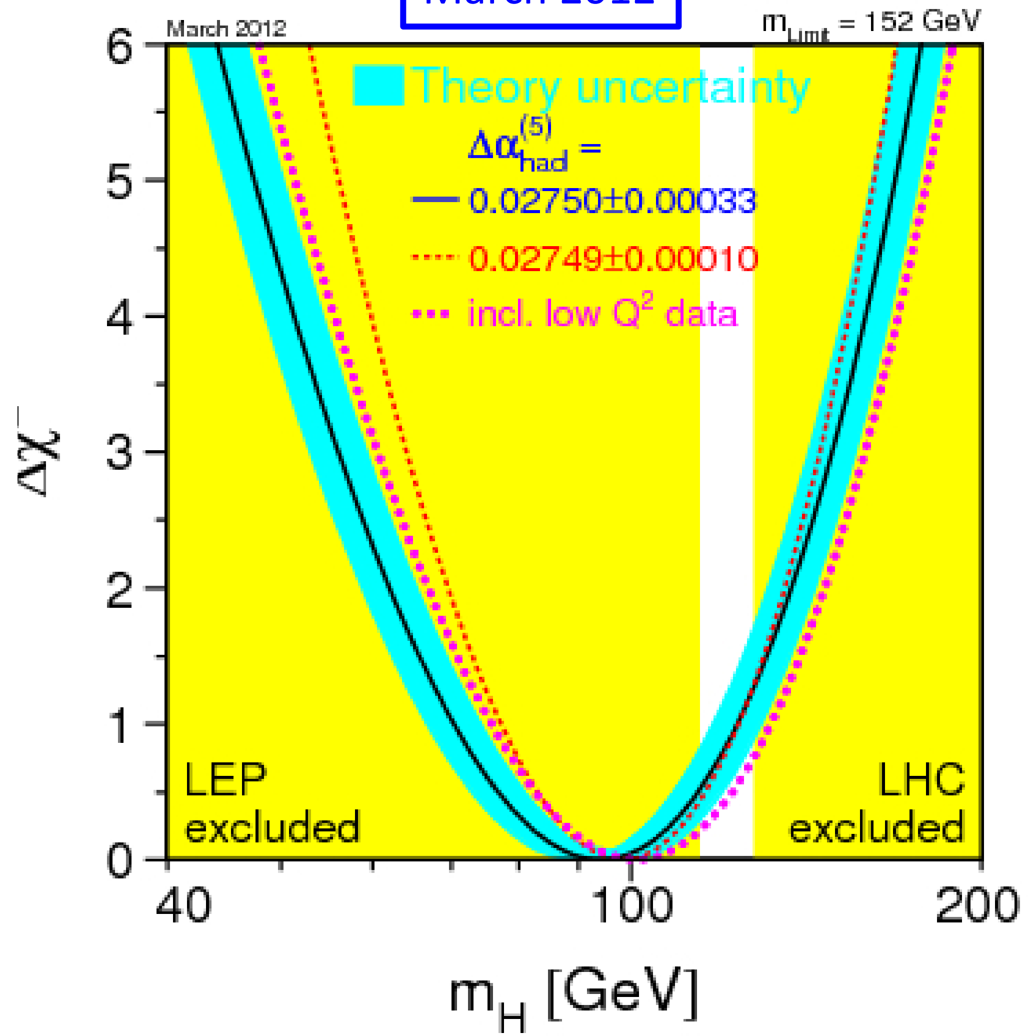
EPS 1993, Marseille
Bolek Pietrzyk remembers that
L.B. Okun in his summary talk said that
the EW genuinely radiative corrections are not
observed at LEP (in fact the data at that time
were in agreement with the Born approximation
within one sigma).

THE BIRTH OF THE "BLUE BAND"

1996



March 2012



Chiara Mariotti

Date: Tue, 29 Mar 94 11:04:38 SET
From: BARDINDY@cernvm.cern.ch
Subject: Agenda
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vysotsky@vscrna.cern.ch

Dear Colleagues,
please find enclosed our agenda (nearly final, I hope).
Following your suggestions to start the afternoon session as early as possible, I changed the reservation for the afternoon session from the TH Conference Hall to the Build. 5 room, where our first meeting took place. The afternoon session will be probably needed, since we would like to have a lot of time for discussions after each talk.
See you soon at the meeting,
Dima Bardin.

31 March 1994

==

Agenda of the Second Meeting of the LEP-I Precision Calculations Working Group

Thursday, March 31st

Morning session: 9.30 - 13.00, TH Conference Hall

Afternoon session: 14.00 - 17.00, Room 5.3-004

1.
Dima Bardin
"Where we are with the code updates and comparisons?" - 15 minutes
==
2.
Wolfgang Hollik
"Remarks on electroweak uncertainties" - 10 minutes
==
3.
Giampiero Passarino
"Different codes and different options a road to understand theoretical uncertainties". - 10 minutes
==
4.

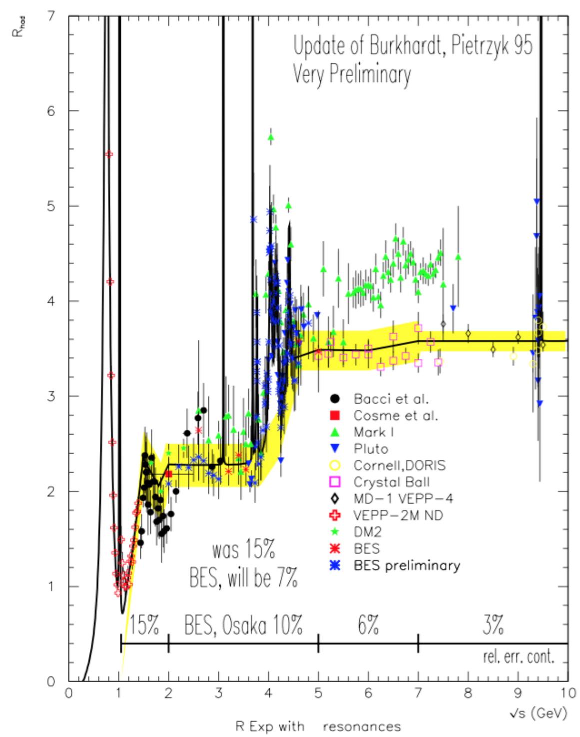
Widening the collaboration: $\Delta\alpha^{5}_{had}$

Bolek Pietrzyk→ In Warsaw ICHEP 1996, Bolek went around asking experiments to measure Rhad, only BES agreed

→ in ICHEP Osaka 2000 Bolek showed the effect of BES on Rhad, and thus on MH

"without this result, we could have excluded the SM Higgs"

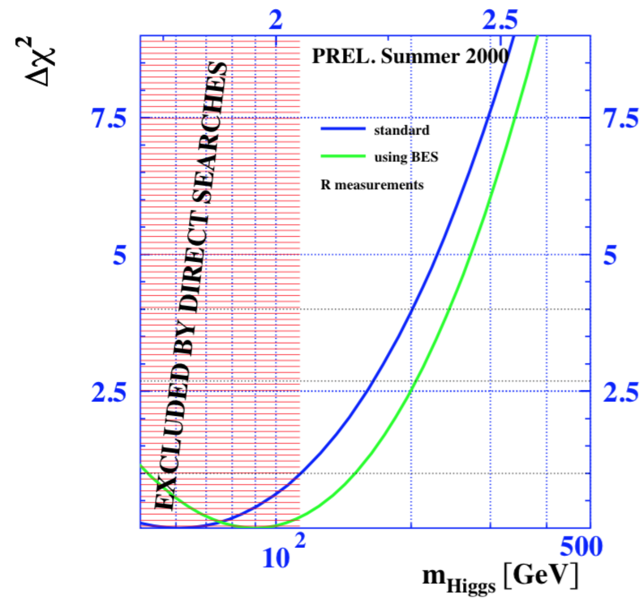
α_{QED} with new BES measurements



$\Delta\alpha^{(5)}_{had}(s) = 0.02755 \pm 0.00046 \leftarrow$ very preliminary

was 0.0280 ± 0.0007, central value changed by 0.7σ

$\rightarrow \alpha^{-1} = 128.945 \pm 0.060$

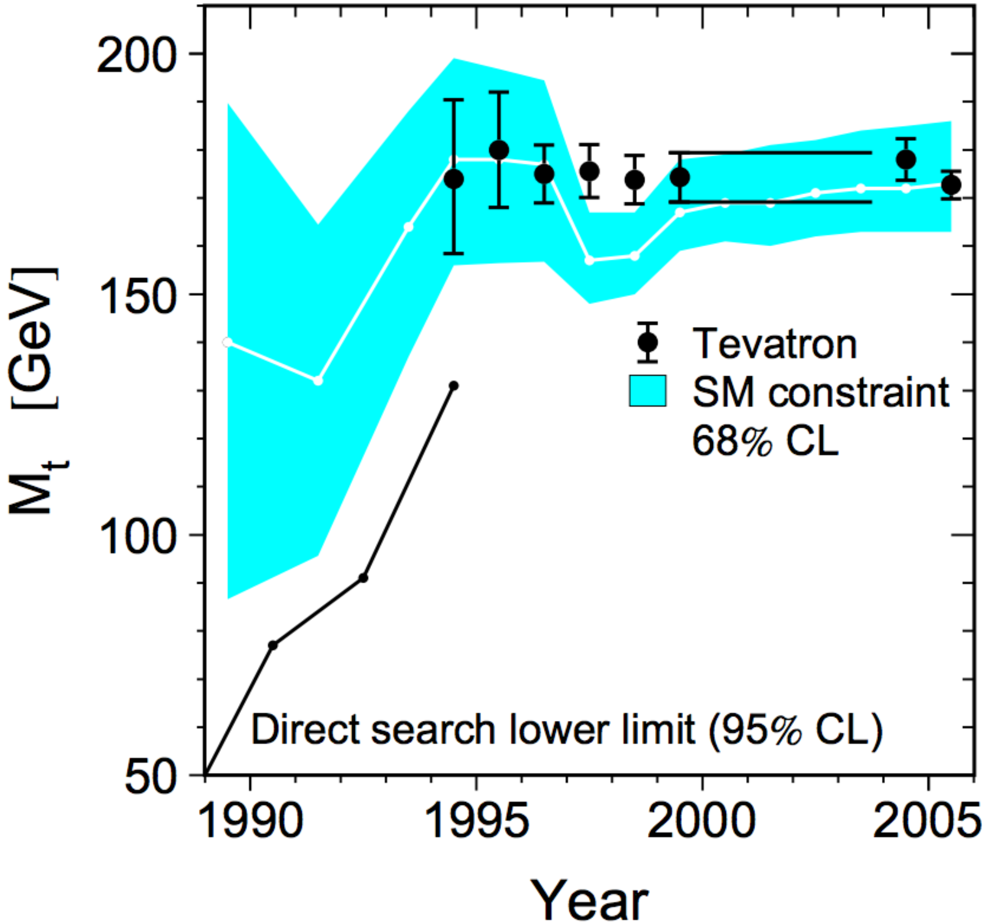


minimum moves to 90 GeV, upper limit moves to 210 GeV

BEFORE BES $m_H = 62^{+53}_{-30}$ GeV

H. Burkhardt and B. Pietrzyk, Phys. Lett. 513B(2001)46

Top mass



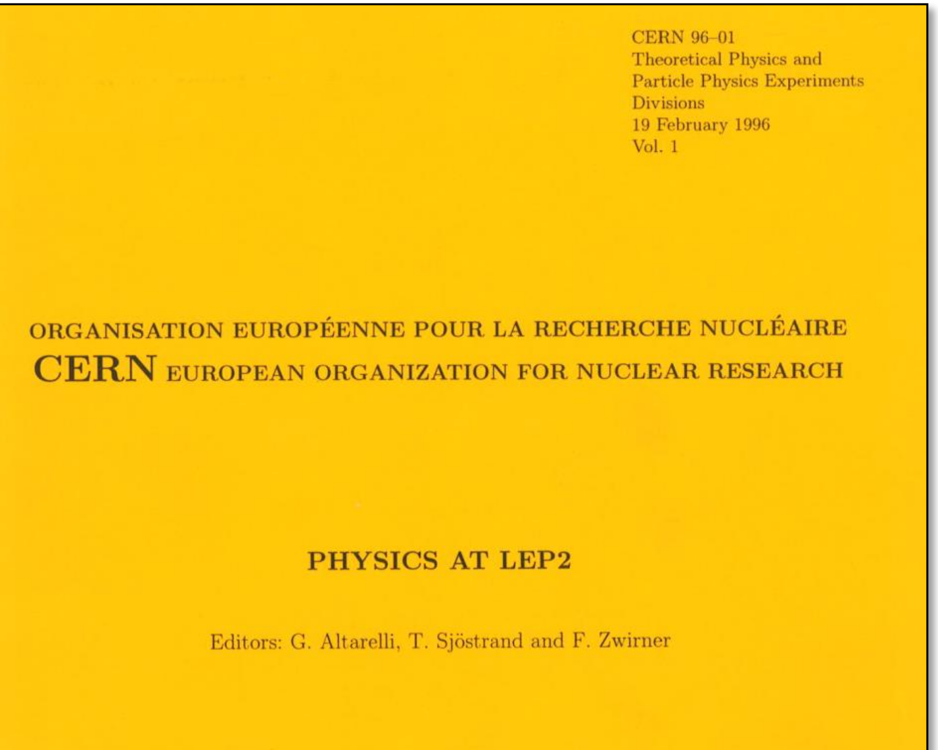
This plot shows, vs years:

- Improvement in TH calc.
- The effect in 1994 of the beam energy measurement with the resonant depolarization that allowed to measure with high precision the Z width and thus -> precise TOP mass

- 1994 CDF evidence, 1995 CDF+D0 discovered the Top exactly where LEP+TH fitted/predicted
  → relative precise predictions of MH

→ **change the way of plotting: before "vs Mtop", then "vs MH"**

Towards LEP2


CERN 96-01
Theoretical Physics and
Particle Physics Experiments
Divisions
19 February 1996
Vol. 1

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PHYSICS AT LEP2

Editors: G. Altarelli, T. Sjöstrand and F. Zwirner

- Higgs Physics
- (- b-tagging
  - dimension of the beam !)
- SM physics
  - WW physics

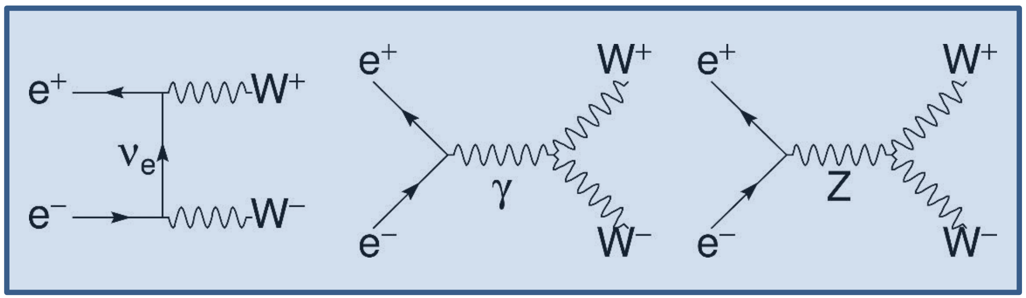
A very special example of th-exp interaction : the WW cross section

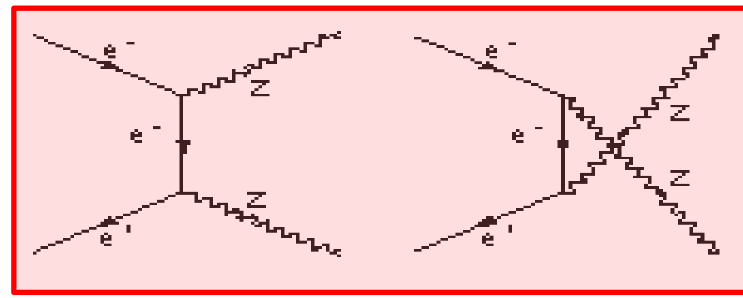
- The definition of the signal
- The first measurements
- The final result

thanks to R.Chierici, F.Cossutti, R.Tenchini

Four-fermions: refreshing quantum mechanics

- A process is only well defined on the basis of its final state. It is in principle incorrect, and meaningless, to discuss about WW/ZZ/single boson and so on
  - In practice, it is a useful approximation to define processes as a set of Feynman diagrams
    - The procedure is known not to be gauge invariant
    - One should show that interference effects are under control (small w.r.t. signal)
    - They must be accounted for ! Either as part of the signal or of the background !
  - Examples are given by the "WW" (CC03) and "ZZ" (NC02) production

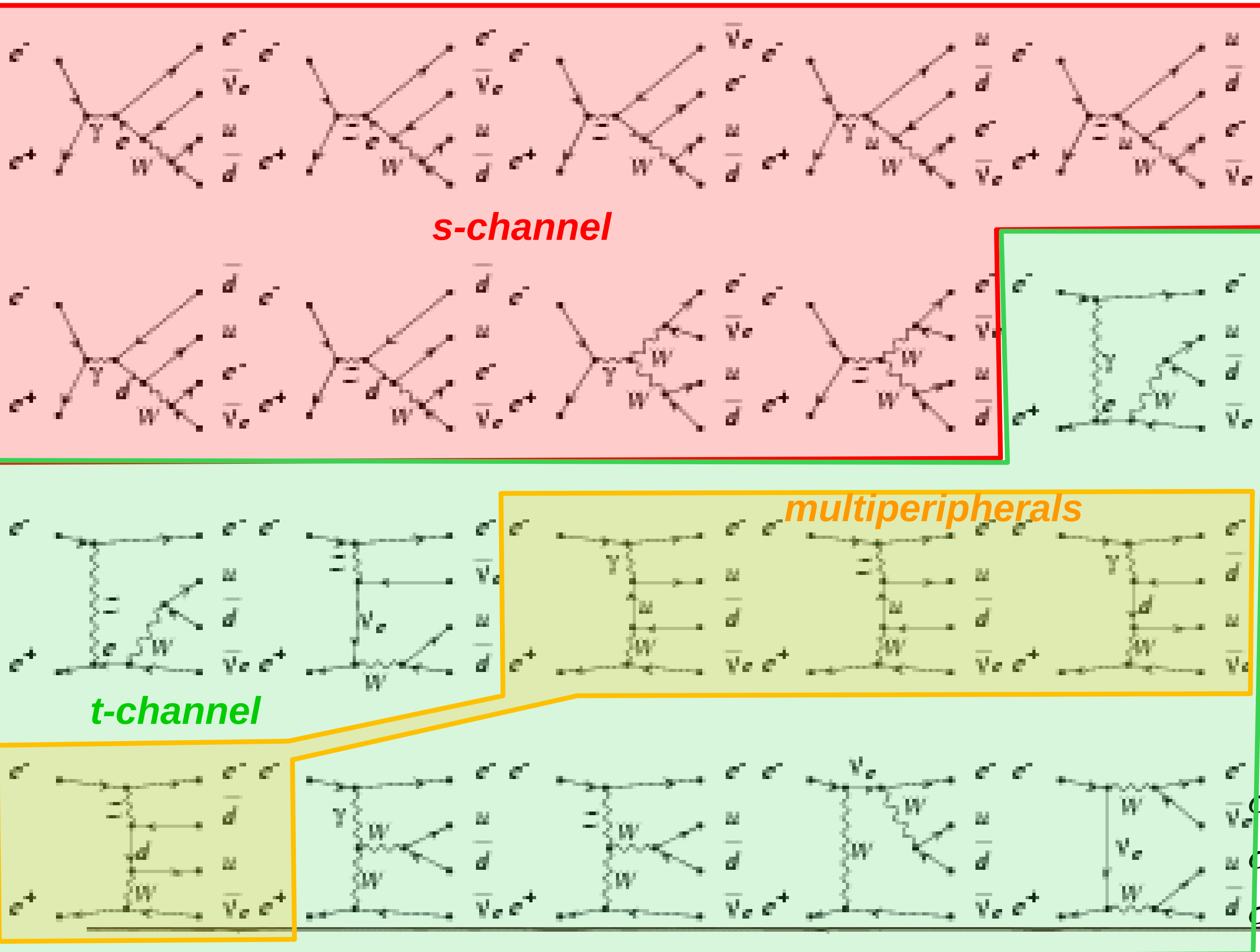




  - To be noticed that the above contributions do interfere already (e.g. $\ell\nu\ell\nu$ final states)
  - Often also called "doubly resonant contributions", to be distinguished from "singly resonant contributions" (single W, single Z), and "non resonant contributions" (t-channel di-boson scattering)

Signal definitions must be agreed upon !

- In general this is not possible: the signal is defined on the basis of the final state and properly chosen phase space cuts (example: single W in eνud)



Only the t-channel graphs (gauge invariant def.n) with cuts per channel to reduce multiperipherals

$e^- \nu_e\ qq'$ (CC20)	$m(qq') > 45$ GeV
$e^- \nu_e\ l^+ \nu_l$ (CC18)	$E\ l^+ > 20$ GeV
$e^- \nu_e\ e^+ \nu_e$ (Mix56)	$E\ e^+ > 20$ GeV $\lvert\cos\theta e^+\rvert < 0.95$ $\lvert\cos\theta e^-\rvert > 0.95$

$\sigma_{SM} = 450\div600$ fb $(e\,\nu_e\, qq')$

$\sigma_{SM} = 60\div90$ fb $(e\,\nu_e\, l\,\nu_l)$

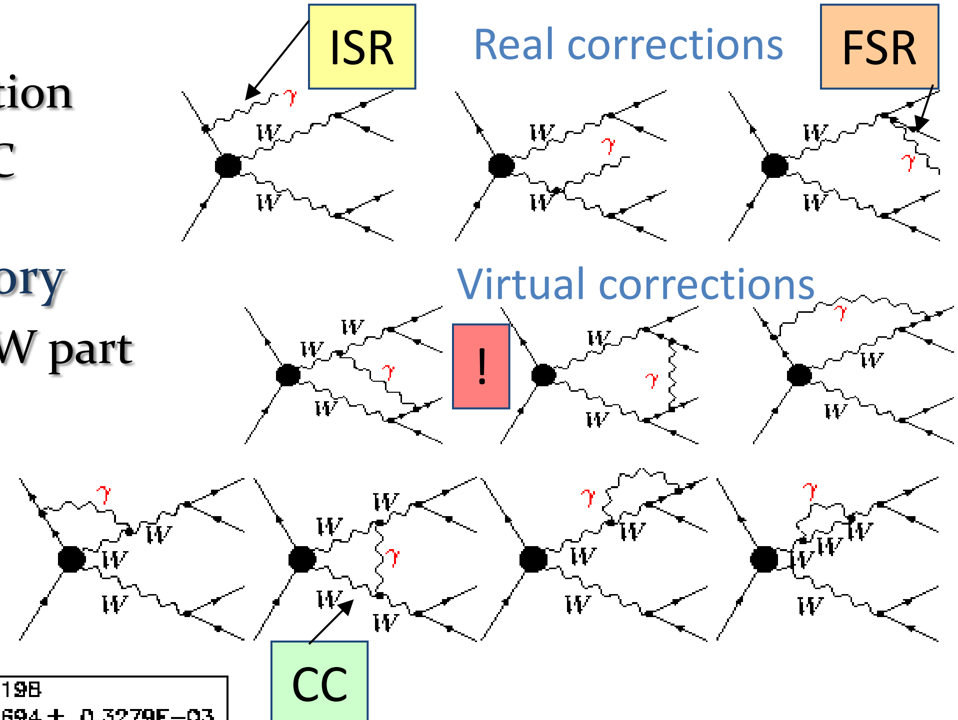
$\sigma_{SM} = 30\div50$ fb $(e\,\nu_e\, e\,\nu_e)$

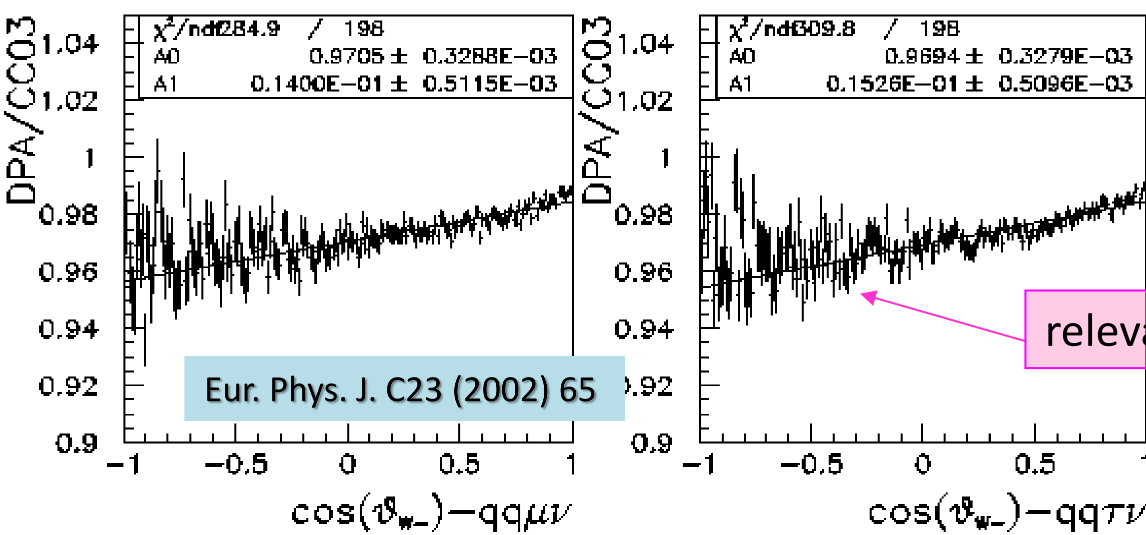
R.CHIERICI

An important digression

- Still in year 2000 all LEP experiments in agreement, but 2% discrepancy with respect to the theory predictions
  - ➢ Intense period of TH-EXP collaboration
  - ➢ MCs only accounted for ISR+FSR+CC
- Full O(α) beyond possibility for theory
  - ➢ Calculation was provided for the WW part only in the so-called Double Pole Approximation (DPA)

    (RacoonWW, YFSWW)





Eur. Phys. J. C23 (2002) 65

⇒ Ws do talk to each other !

➢ change in total cross-section and in differential cross-sections

relevant effect (~2%) on σ_{WW}, $d\sigma/d\theta_W$

Data and theory in excellent agreement afterwards…

A very special example of th-exp interaction : the WW cross section

R. CHIERICI:

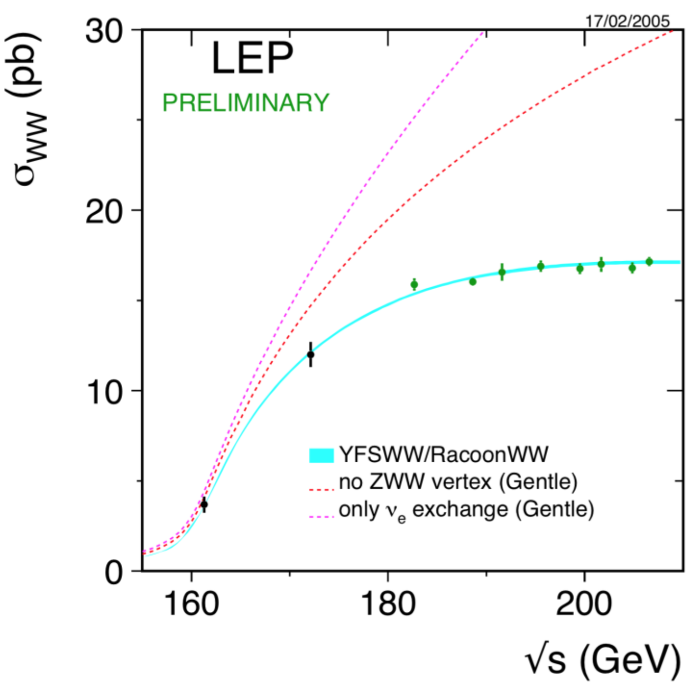
- 2% significant discrepancy in sigmaWW

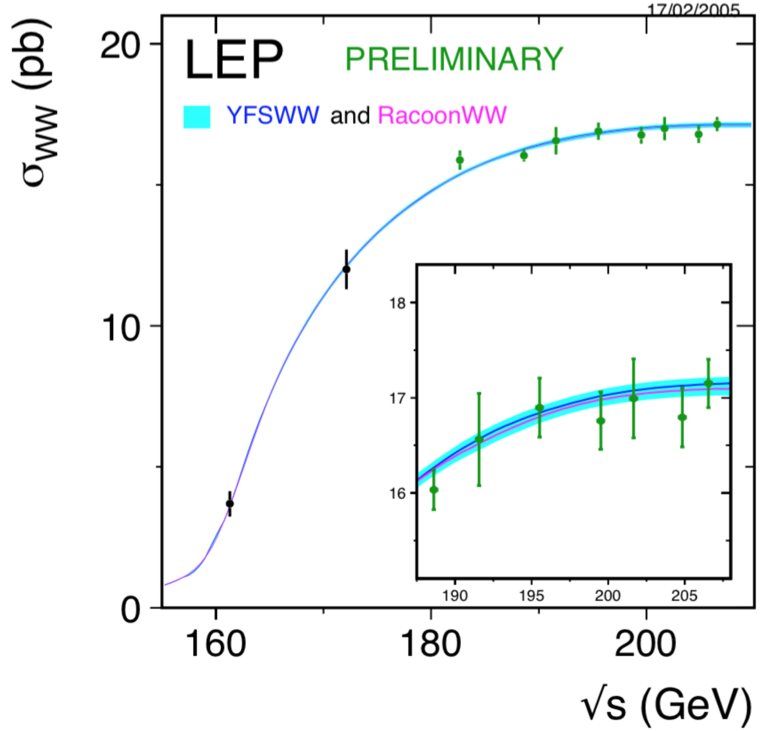
- Adding the NLO EW correction in DPA (double pole appr.n) TH cross sections agreed with data

- But these corrections were distorting the differential distributions in an important way.
- TGC measurements stopped to get these corrections implemented in the MC

- “not only at LEP1 we can test the SM at loop level, but also at LEP2.” “Moreover, the data at 3 sigma could discriminate the best implementation at NLO with DPA (Racoon) w.r.t approximations (Koralw)

A very special example of th-exp interaction : the WW cross section





G.P. convener of the SM parallel session Tampere 1999 asked the speaker that ended his talk saying that there was good agreement between the data and the SM: "What do you mean by 'Standard Model' ? "

LEP Working Groups

LEP Energy WG

LEP QCD WG

LEP 4-Jets WG

Electroweak WG

LEP Heavy Flavour Steering group

b-hadron lifetimes WG

B-oscillations WG

LEP Vcb WG

LEP Vub WG

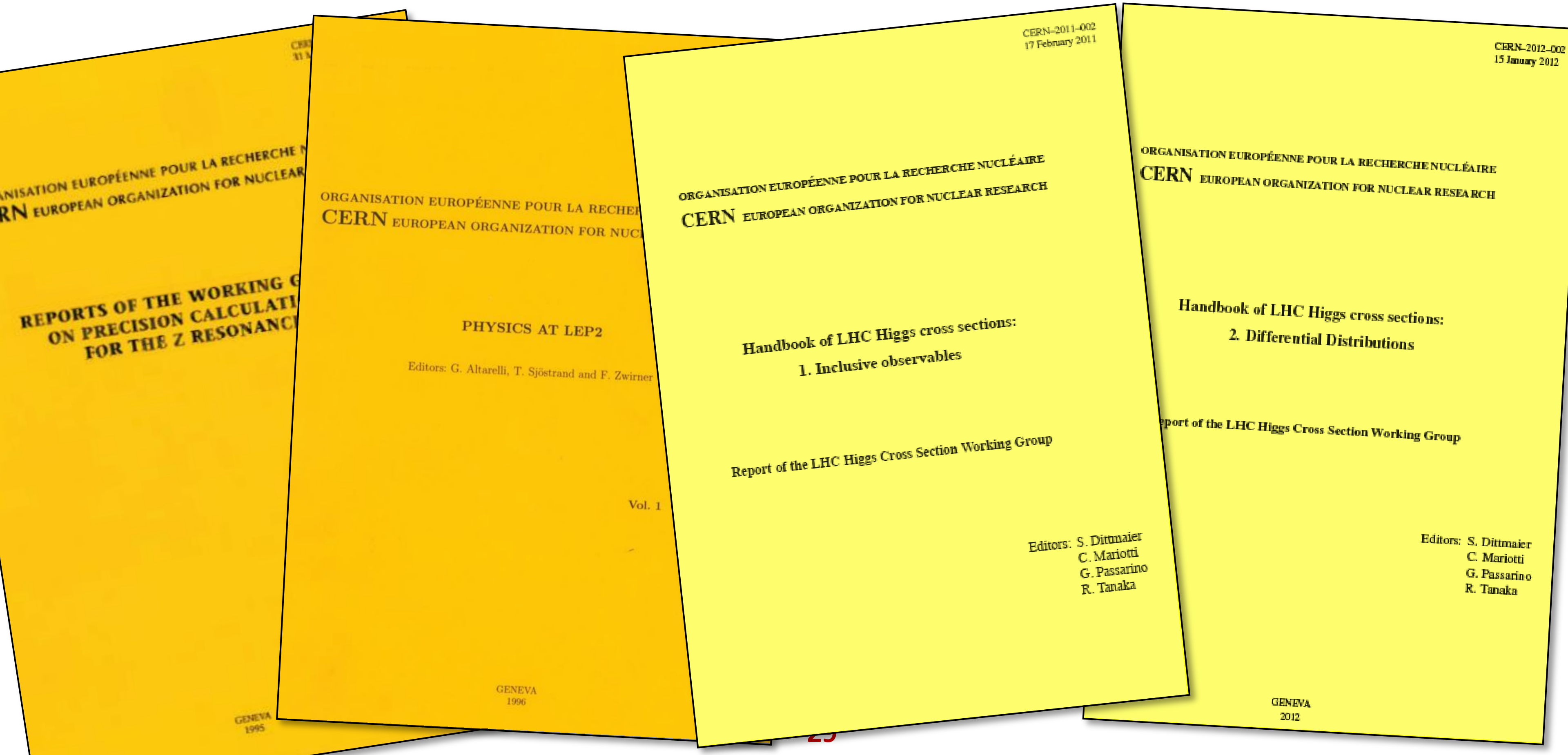
LEP Higgs WG

LEP Exotica WG

LEP SUSY WG

Da LEP a LHC:
Paving the Road to Discovery

- LEP1: Z line shape, electroweak precision measurements - 1990 -1995
- LEP2: Single Boson and WW production; Higgs Physics - 1995 - 2000
- LHC: Higgs Cross Section Working Group - 2009 →



Not only physics….

At the beginning of LEP there were no cell-phone, no laptops, email (?) (cernvm or bitnet)
But the collaboration TH/EXP was incredible intense and going down to small details

For example:

PS:
For using your code with other programs, it would be nice if you could start each subroutine/function name with the same (two) lettes, eg. TO, so that there is no possibility for name clashes.
Same holds for common blocks.

or

Within our fitting program, we call the theoretical analytical programs for one energy, and one final-state at a time. TOPAZ0 on the other hand calculates for a given energy the quantities for all final states. How could one change that not to spend CPU time on unwanted final-states? Added to this one could separate the common ew calculations from the cross/section asym calculations.
Furthermore, could you add the calculation of A_c in analogy to A_b?

Thanks for your help and best regards.

From Giampiero email archive

THE LHC Higgs Cross Section Working Group

2008

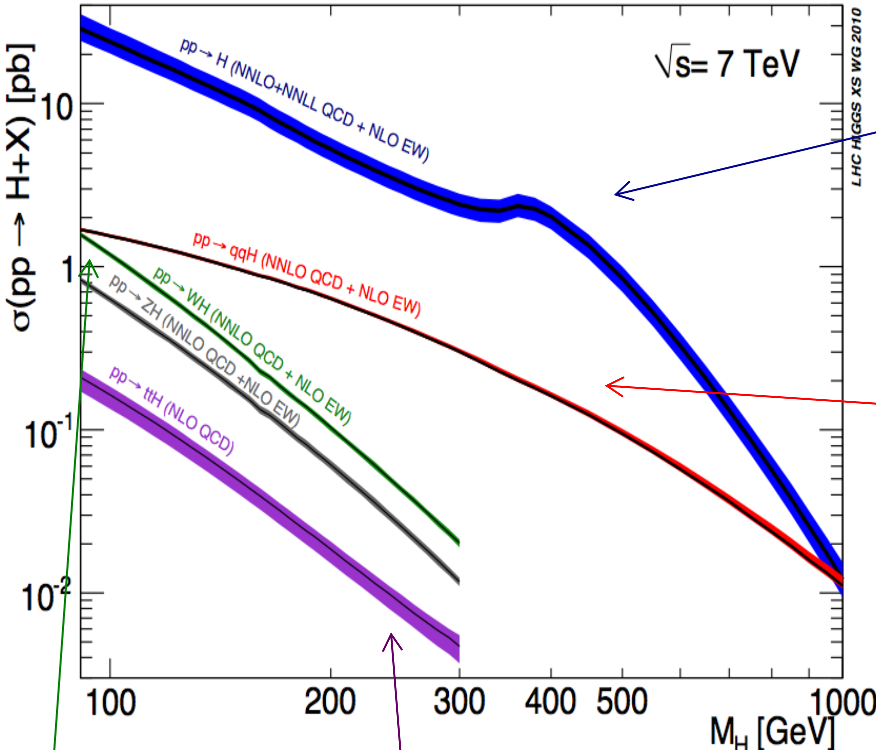
4 July 2012

LAL Nov 2011 https://indico.cern.ch/event/158675/session/8/contribution/13/material/slides/0.pdf

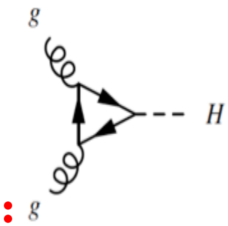
A bit of history

- In 2008 **Giampiero Passarino** had the idea of the group for the first time, underlying the urgency, since a discovery could come sooner than expected!
- In August 2009 we met at the cafeteria of B40 (Passarino, Mariotti, Murray, Nisati, Qian and Stoeckli)
- In Torino, in November 2009 (the exact day LHC delivered the very first pp interaction !) the group was formed and the program was discussed.
- Jan 2010 the experiments formally recognize it.

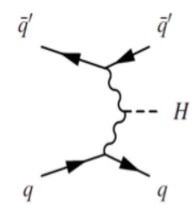
Higgs production at LHC (2012)



ggF: NNLO+NNLL QCD + NLO EW



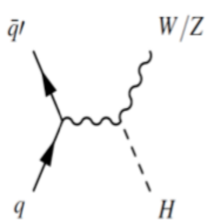
qqH: D + NLO EW

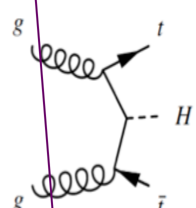


the LHC H XS WG

WH: NNLO QCD + NLO EW

ZH: NNLO QCD + NLO EW



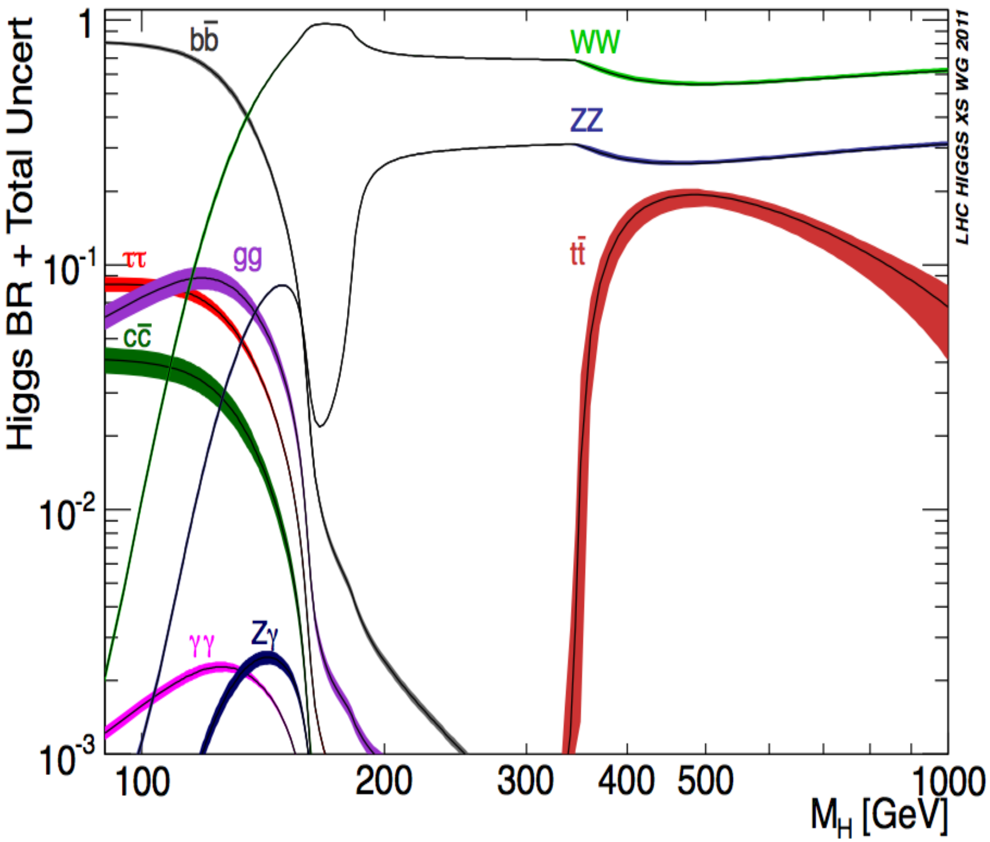


ttH: NLO QCD

	$K_{NNLO/NLO}$ ($K_{NLO/LO}$)	Scale	PDF+a_S	Total error
ggF	+25% (+100%)	+12% -7%	±8%	+20 - 15%
VBF	<1% (+5-10%)	±1%	±4%	±5%
WH/Z H	+2-6% (+30%)	±1%	±4%	±5%
ttH	- (+5-20%)	+4% -10%	±8%	+12 - 18%

Branching Ratios (2012)

$$\Gamma_H = \Gamma^{HD} - \Gamma^{HD}_{ZZ} - \Gamma^{HD}_{WW} + \Gamma^{Proph.}_{4f} + \Gamma^{HD}_{\gamma\gamma}\delta^{QED}_{\gamma ff}$$

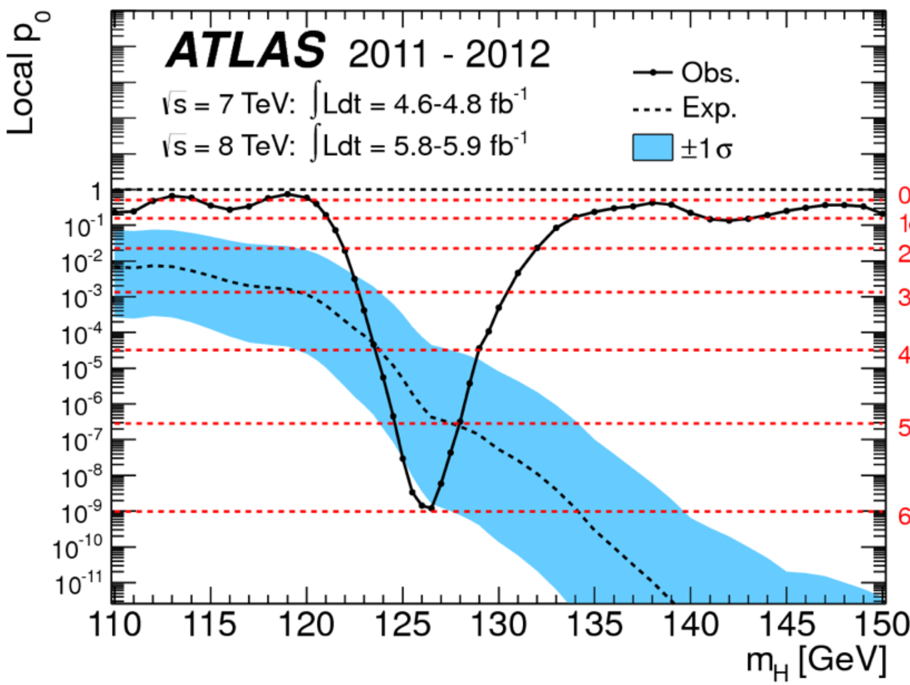


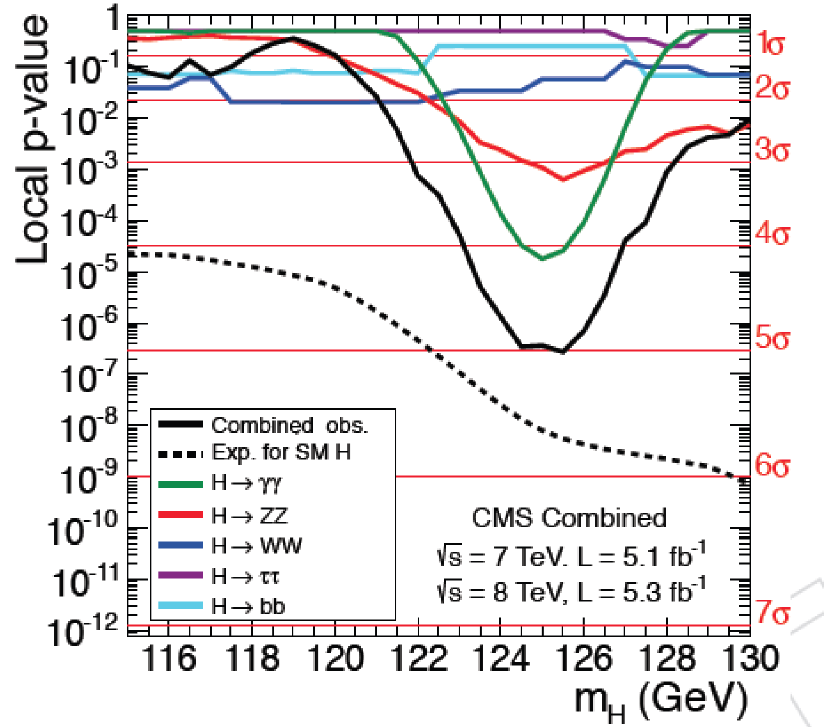
MH	Decay	THU	PU	Total
120 GeV	H→γγ	±2.9%	±2.5%	±5.4%
	H→bb	±1.3%	±1.5%	±2.8%
	H→ττ	±3.6%	±2.5%	±6.1%
150 GeV	H→WW	±0.3%	±0.6%	±0.9%
	H→ZZ	±0.3%	±0.6%	±0.9%

HD=HDecay NLO QCD +NLO EW

Proph = Prophecy4f NLO QCD+NLO EW

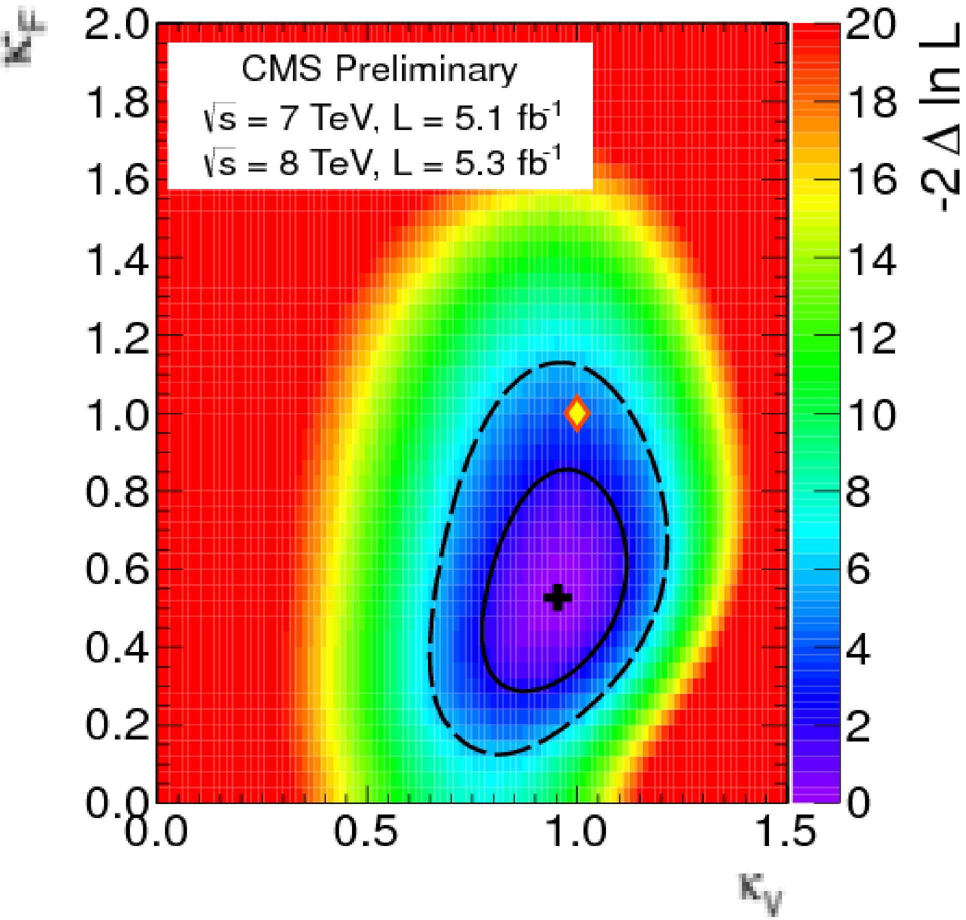
4 July 2012: the Higgs discovery

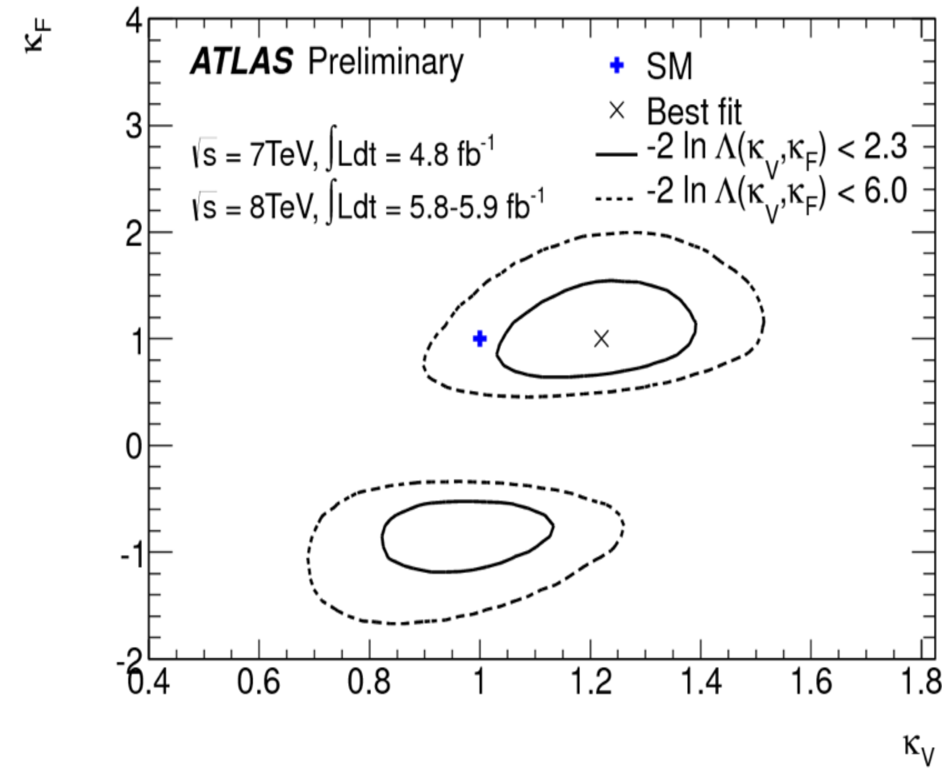




Is it a SM Higgs boson?

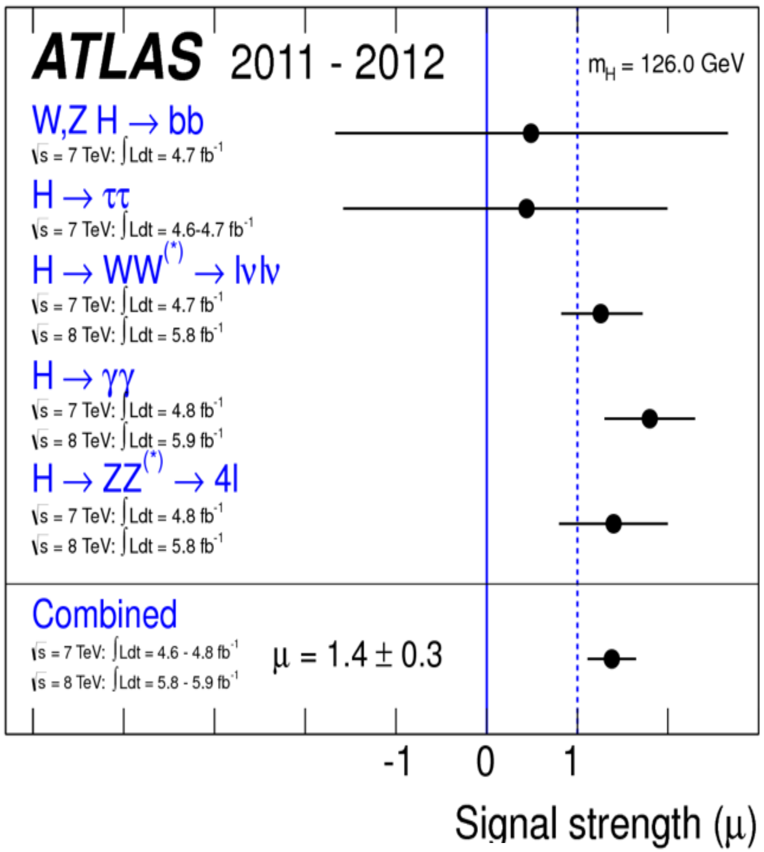
4 July 2012

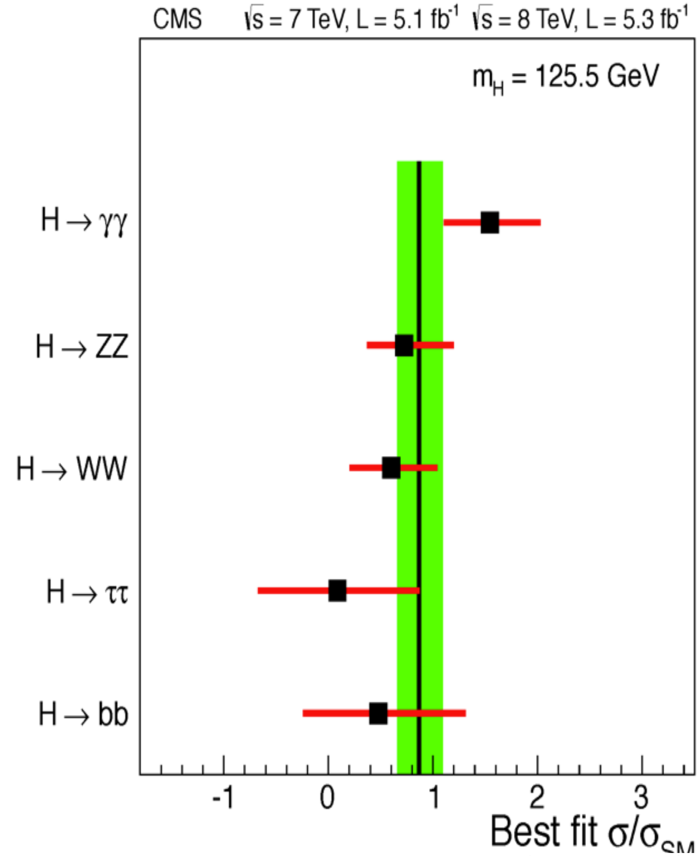


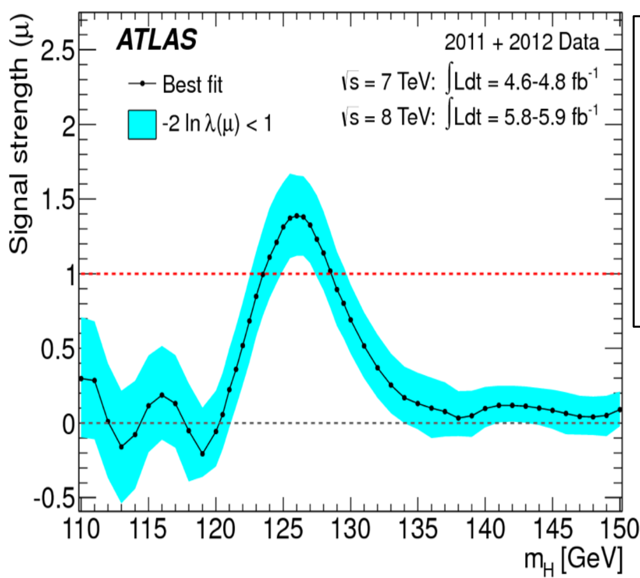


- **data compatible with SM prediction at 95% C.L.**
- Best fit κ_F driven to low values by VBF γγ excess and ττ deficit.
- **More data needed to draw any definite conclusion.**

Best fit

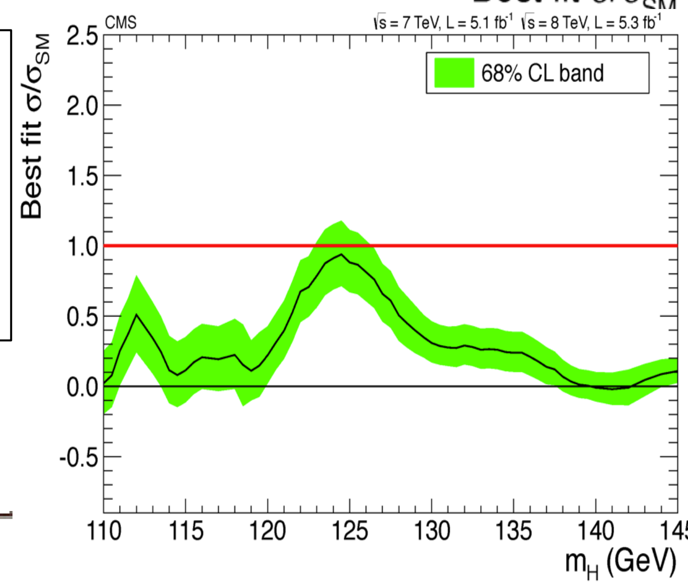






Atlas:
1.4 ±0.3 @126 GeV

CMS:
0.87 ± 0.23 @ 125.5 GeV



The results

- The Yellow Report 1 (CERN-2011-002) 17-Feb-2011:
  Handbook of LHC Higgs cross sections:
  1. Inclusive variables

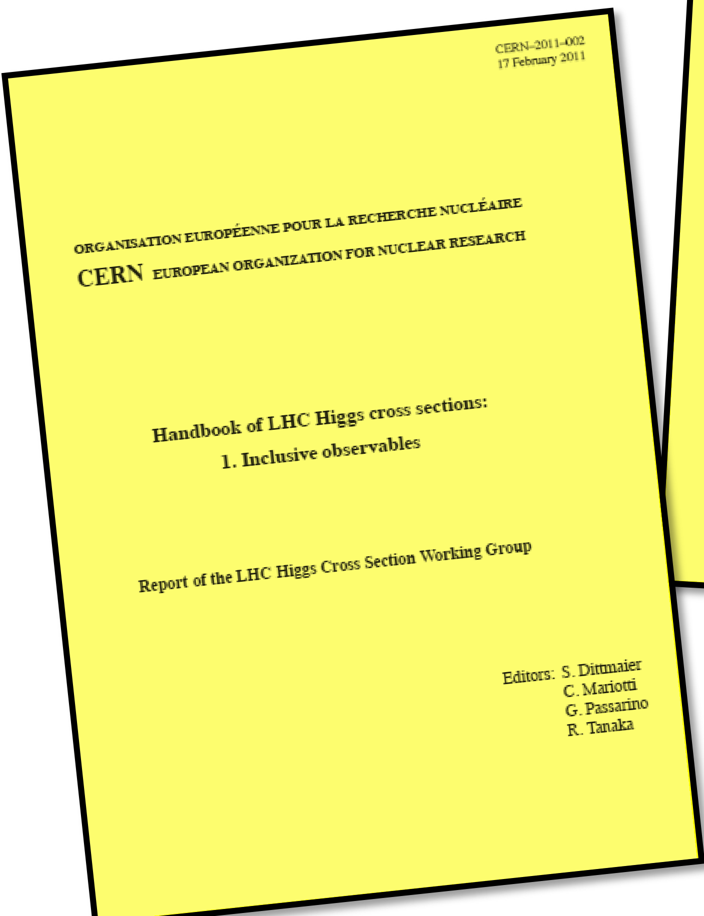
  891 citation, 64 authors

- The Yellow Report 2 (CERN-2012-002) 12-Jan-2012
  Handbook of LHC Higgs cross sections:
  2. Differential distributions

  460 citation, 141 authors

- The Yellow Report 3 (CERN-2013-004) 29 July 2013
  Handbook of LHC Higgs cross sections:
  3. Higgs Properties

  365 citations, 157 authors

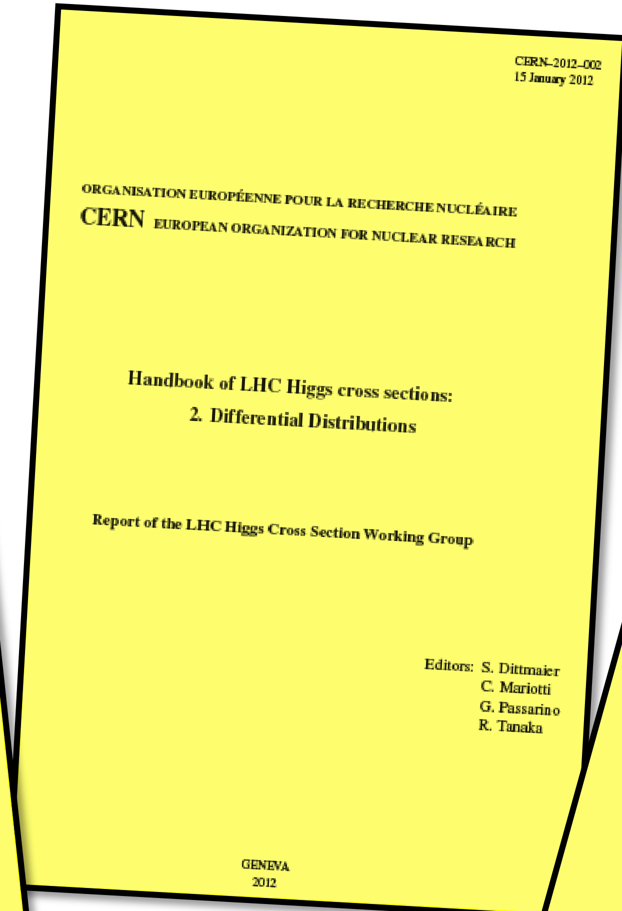

CERN–2011–002
17 February 2011

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
1. Inclusive observables

Report of the LHC Higgs Cross Section Working Group

Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka


CERN–2012–002
15 January 2012

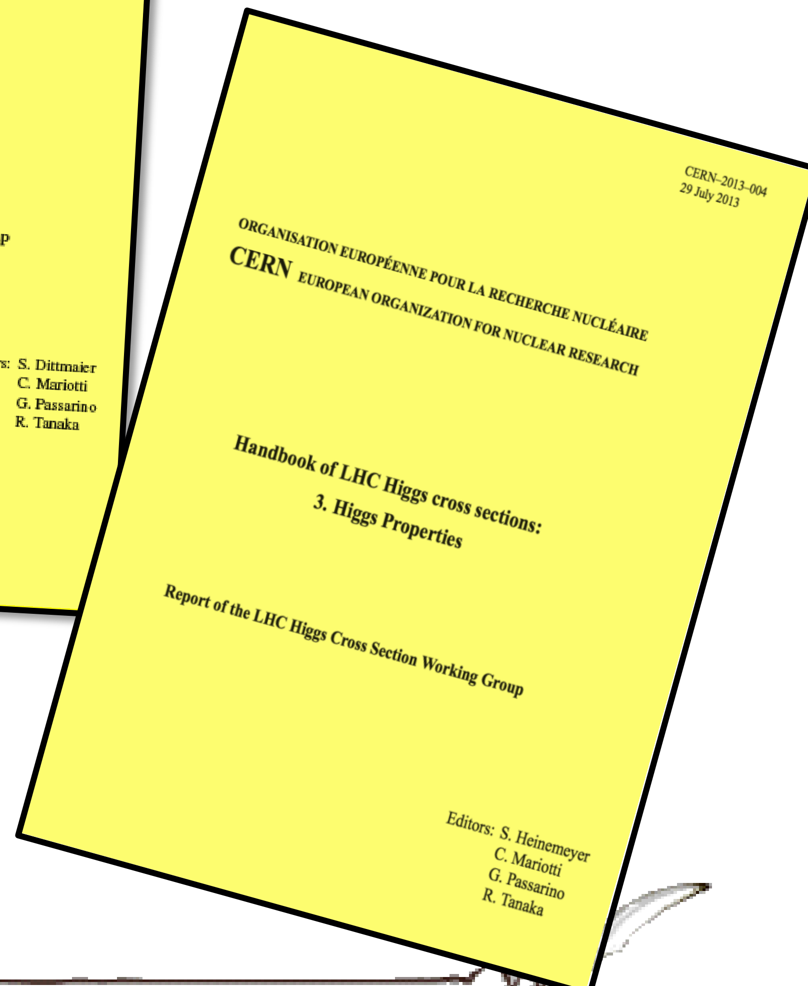
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
2. Differential Distributions

Report of the LHC Higgs Cross Section Working Group

Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

GENEVA
2012


CERN–2013–004
29 July 2013

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

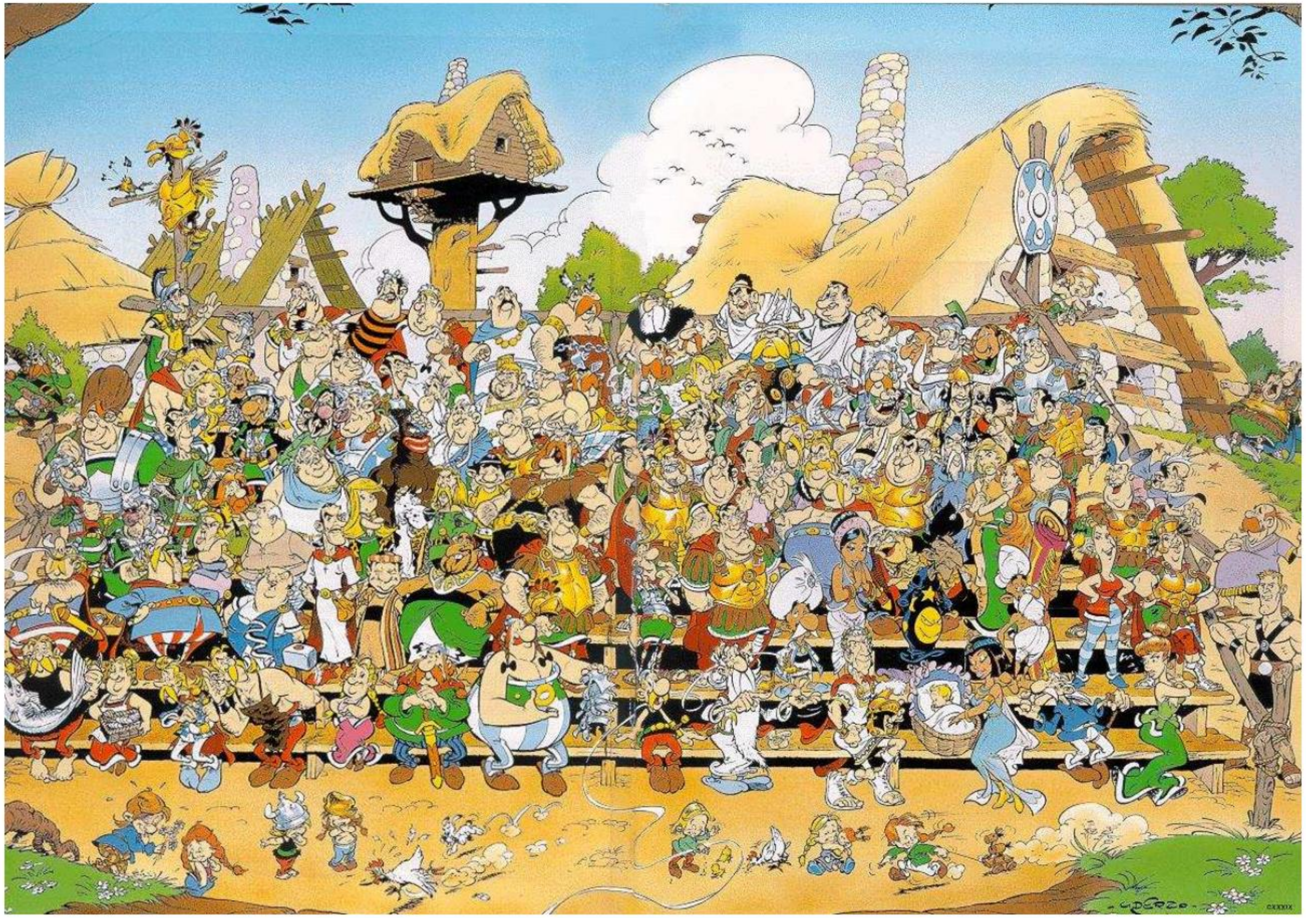
Handbook of LHC Higgs cross sections:
3. Higgs Properties

Report of the LHC Higgs Cross Section Working Group

Editors: S. Heinemeyer
C. Mariotti
G. Passarino
R. Tanaka

On the road…

It’s a lot of work ...



S. Dittmaier

... but acting as a team we can make it !

.... and we did it !

So let’s continue.