LEP ∞

surely a personal picture, with all the biases that implies

Giampiero Passarino

Dipartimento di Fisica Teorica, Università di Torino, Italy
INFN, Sezione di Torino, Italy

Abstract

Why we are not anymore what we have been

Prelude: **Experimental** Progress

- The Exp. progress made in the **1990's** is remarkable in many ways. With the **right experiments** we can reveal the fine details of high energy phenomena.
- Around **LEP** Shutdown we known that physics at the **microscopic scale** has a basis as **rationale** as chemistry.
- Everything moves, **not by magic**, but because there is a **mechanism at work**, the **Standard Model**.
- Everything is encouraging for the major **unsolved** aspects of the breaking of electroweak gauge symmetry.

Rating ......

▷ to be compared with **our knowledge** at, say, 1989 Lepton-Photon Conference.

⋆⋆⋆⋆ – $\rho = 1$, **SM** uniqueness of **group & representations**, **renormalizable gauge theory**

– $N_\nu = 3$.

– Any deviation from **MSM** is **soft**

– Z, W bosons are **not composite**, therefore **TeV** scale severely constrained

– *stringent limits* on **new** physics

⋆⋆⋆ – one-side 95% **CL Higgs** upper limit 210 GeV,

– nitid evidence for **radiative corrections** beyond running of $\alpha_{\rm QED}$, therefore **SM** correct at *loop level*

– absence of evidence for **anomalous couplings**

– Lepton universality and SM couplings to quarks and leptons

– M_Z is a **fundamental** constant of nature

– **Gauge-symmetry** is **not** a low energy approximation, therefore **SM** correct and unique

Summarizing: **SM** is real before our eyes and not a
Se non è vero è ben trovato
construct

The means by which we have achieved **our understanding** is that of using **accelerators** that go to the **basic scale**.

In a category of its own

XXX LEPEWWG activities **&** theoretical input

– **precise RC**

– **Packages**: *ALIBABA, BHLUMI, KKKMC, TOPAZ0, MIZA & ZFITTER*

– **Packages**: *Gentle, (Next)calibur, Koralw, YFSWW, Grace, RacoonWW, Wphact & WTO*

Sociology around LEP:

It is interesting to examine the **environment** in which the LEP **technology** has been developed. One way is through the **Kühn tower**.

the Pushers: higly-specialized experts, QED, QCD etc

△ △ △

the Smugglers: those who assemble a code mooncursing it

△ △ △

the Users: the experimental community at large

∇ Some sort of **universal language** has been created to allow a **meaningful** communication

A new language:

The Pseudo-Observables

- The **PO** are related to measured **cross-sections** and **asymmetries** by some deconvolution or **unfolding** procedure.

- The concept itself of **pseudo-observability** is rather difficult to define.

- One way to introduce it is to say that the experiments **measure** some **primordial** (basically **cross-sections** and thereby **asymmetries** also) quantities which are then

- **reduced** to secondary quantities under some set of **specific assumptions**.

- Within these assumptions the secondary quantities, the **PO**, also deserve the label of **observability**.

What did we really learn?

- Faced with this situation, the **anti-realist** may conclude *so much for metaphysics* and insist that

all that theories can tell us is

how the world could be (van Fraassen 1991).

- A possible alternative would be for **realism** to retreat from a **metaphysics** of objects entirely
- and develop an **ontology** of structure compatible with the *physics* (Ladyman 1998) of Lep.

- An early (**before Lep**) attempt to do this in the **quantum context** can be seen in the work of Cassirer

- However, the **neo-Kantian** elements in Cassirer's **structuralist approach** may lead one to wonder whether this suggestion actually takes us too far from **realism**.

Such an approach can also be articulated within the *Lep picture*.

- ☐ Returning to the more developed views of both **Weyl** and **Wigner**, particles can be understood as **ontologically constituted**, in Lep theoretical terms, as **sets of invariants**,

  - ▷ such as *rest mass, charge or spin*,

- ☐ or in terms of **pseudo-observables**

  - ▷ such as *widths, peak cross sections, effective asymmetries and sinuses*

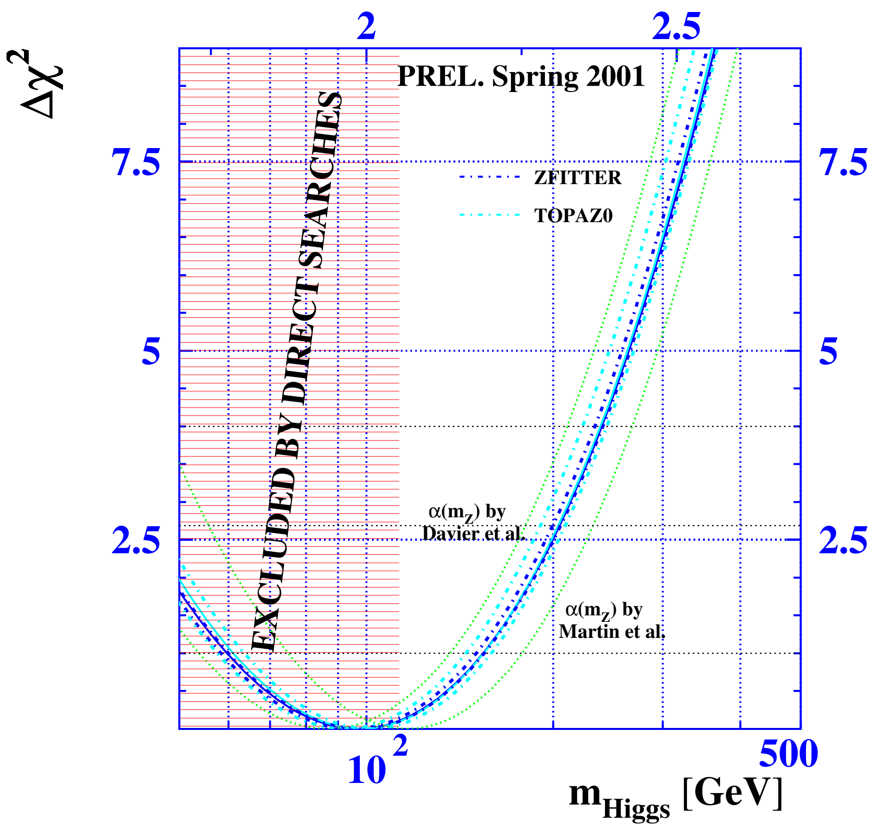
- ☐ The suggestion that particles might be seen as aspects of **pseudo-observability** again fits nicely with **structural realism**.

- ☐ However, in the absence of further **metaphysical explication** of the notion of theory itself (**Higgs is missing**), it is not yet clear whether or not such an approach **collapses**.

(again) Rating . . . . . .

⋆⋆⋆⋆⋆ – PO **fitters**

Ratio Nature/SM is **ontologically constituted** as the result of the existence of PO-fitters. Out of many two survived . . .



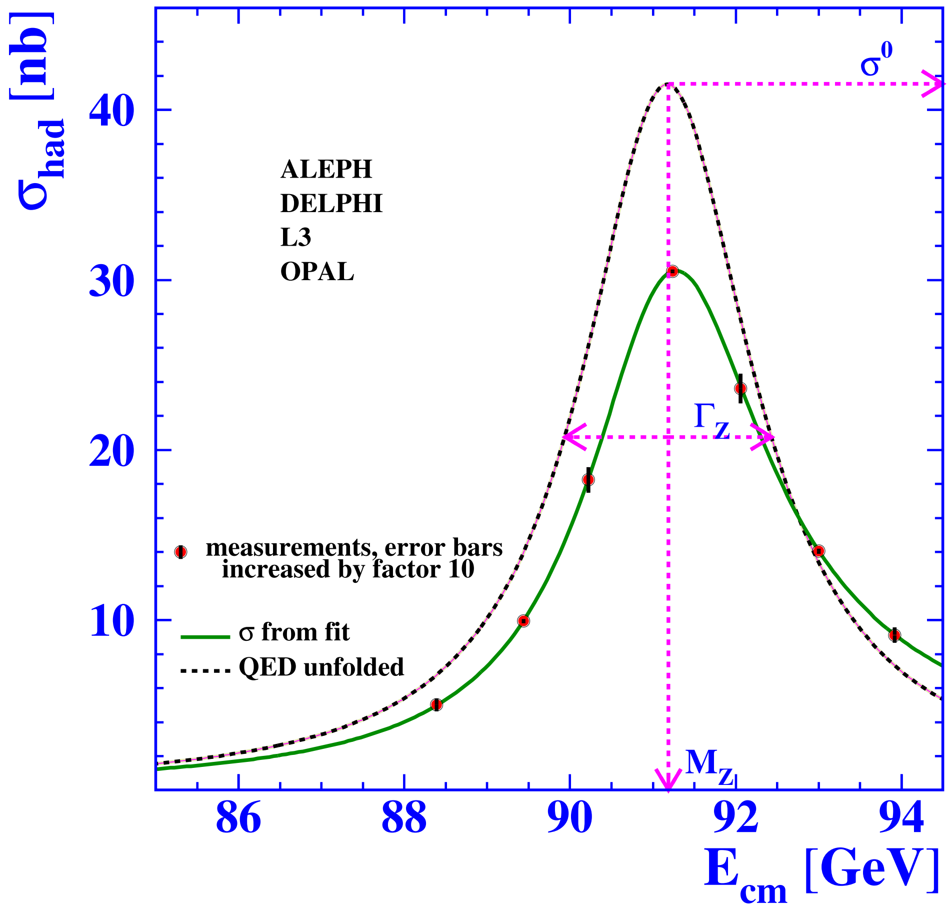
⋆⋆⋆⋆ – $e^+e^- \to \overline{f} f$ **semianalytical**

Things may change, or be changing, but **SA**-codes ≡ heritage of theoretical ideas and the only vehicle to reduce **data** to **PO** through fitting.

– G_F **new determination**, with error with *negligible* effect in the fits.

– **QED** ⊕ **QCD** **external blocks**

QED is uninteresting but **huge** & **essential**, **QCD** is **interesting** & **essential**, they *MUST* be under control.

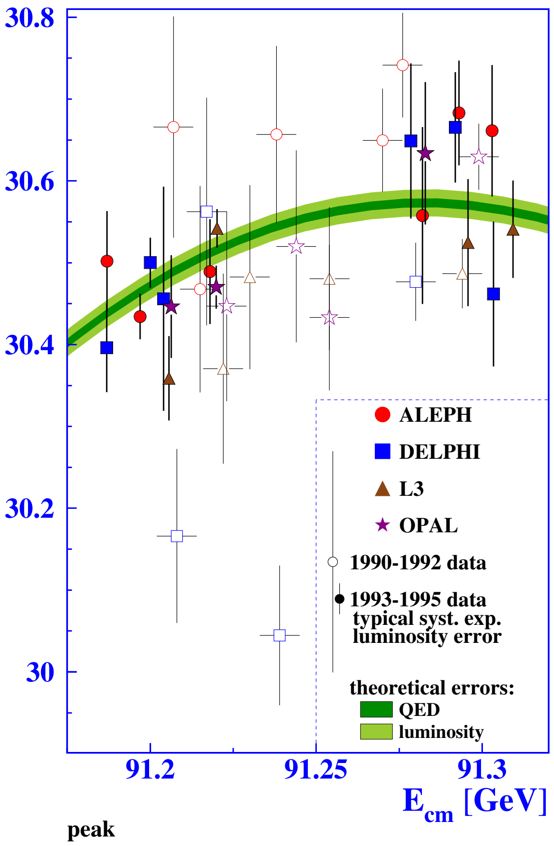


QED contd

s-channel $\mathcal{O}\left(\alpha^2 L^n\right)$, $n = 0, 1, 2$ (Calculations), $\mathcal{O}\left(\alpha^3 L^3\right)$ important for Z **lineshape**

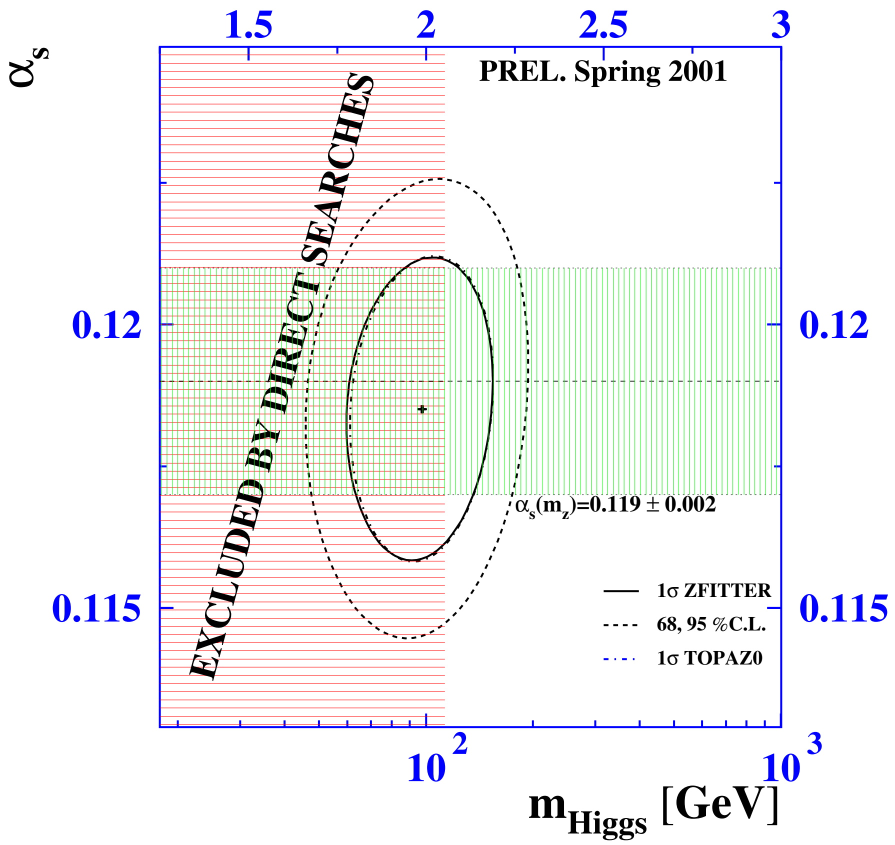
Differences and uncertainties amount to at most ± 0.1 MeV on M_Z and Γ_Z and $\pm 0.01\%$ on $\sigma_{\rm h}^0$ (**MIZA, TOPAZ0** and **ZFITTER**) LEP EWWG/LS 2000-01

non-annihilation (Bhabha) both **SF** and **PS** have been analyzed, uncertainty estimated to be **0.061%** (**BHLUMI**)



QCD contd

- □ The **running** of α_S & assessment of **TU**, power corrections, **NNLO** for σ_{had}, Γ_{had} and R_{had}, **NLO** for 4-jets and massive quarks.



$\star\star\star$ – $e^+e^- \to \overline{f}f$ **model independent**

Realistic O directly in terms of **PO**

– $e^+e^- \to \overline{f}f$ **true MC**

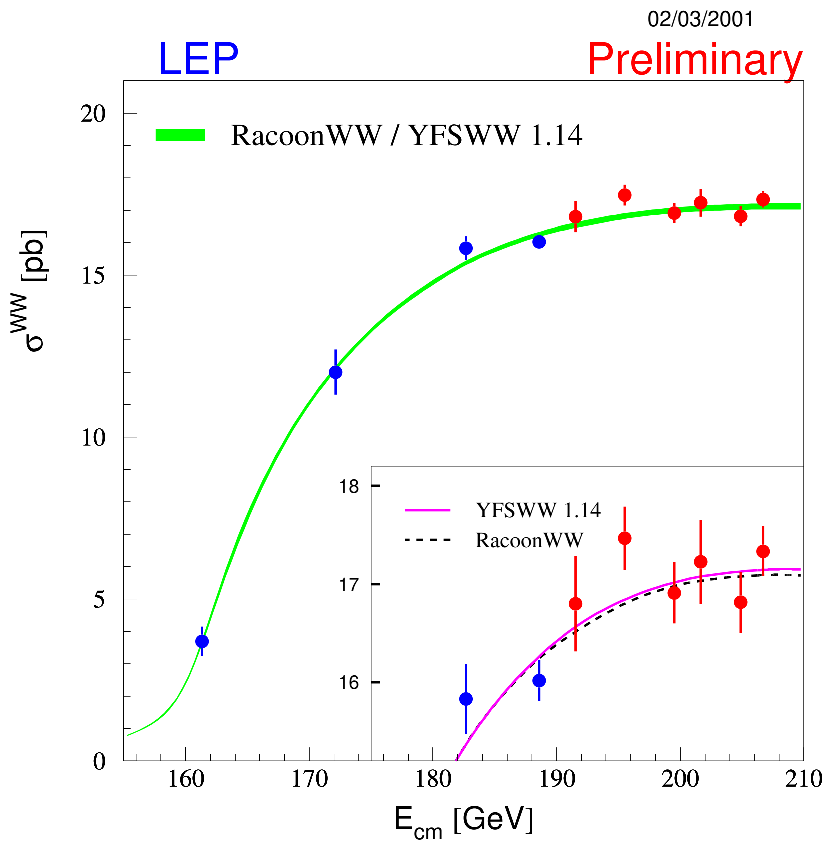
This could be the **future**

– $e^+e^- \to WW \to 4\,\mathrm{f}$ **DPA**

The best ever done for $e^+e^- \to n, \quad n > 2$, *essential* for M_W.

– **next-to-leading two-loop EW**

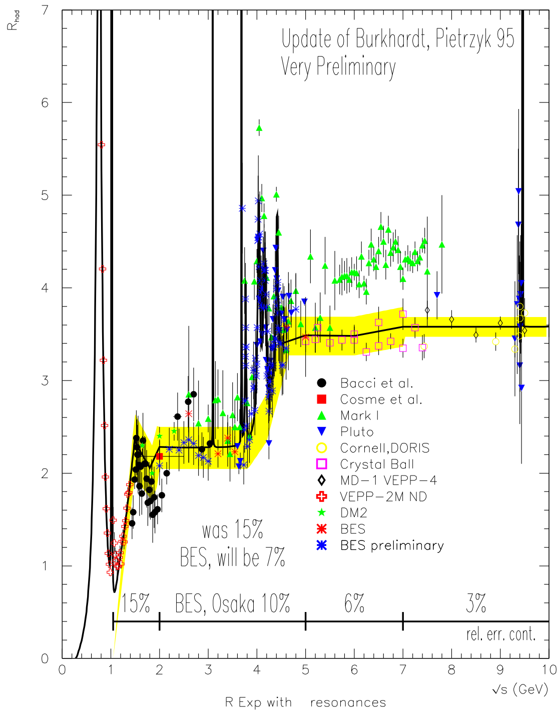
A **milestone** in high precision physics, a **great** step forward in reducing **TU**.



⋆⋆⋆ – QCD & $\alpha_{\rm QED}$

Nobody was dreaming that:
the values of $R_{\rm had}$ measured by **BES** are generally lower than earlier data and now closer to the perturbative **QCD** predictions

α_{QED} with new BES measurements



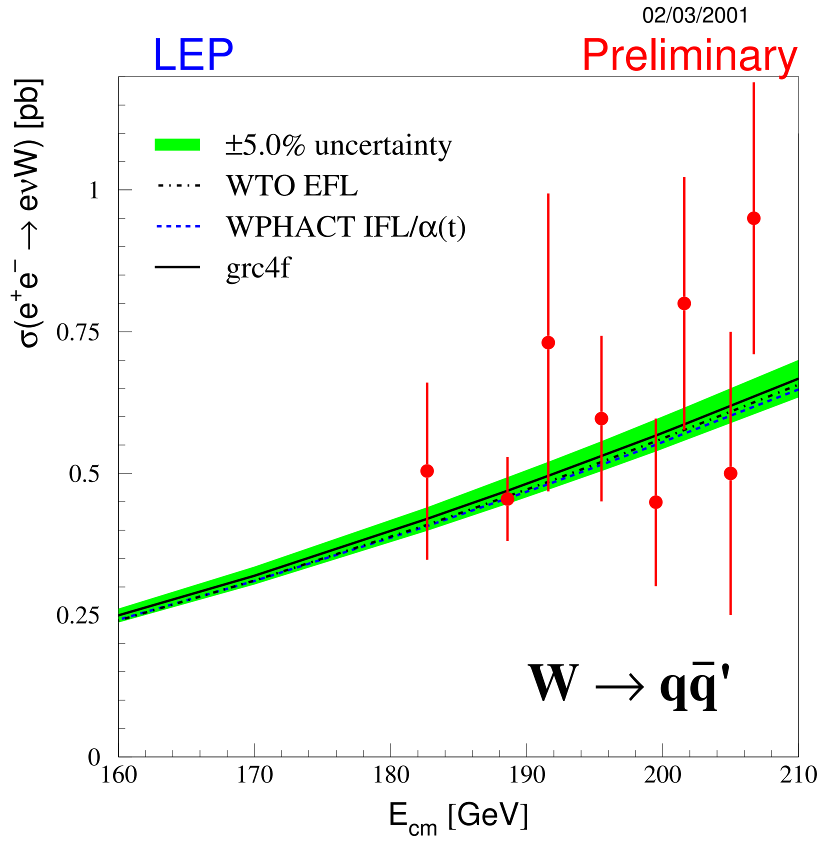
$\Delta\alpha^{(5)}_{had}(s)$ = 0.02755 ± 0.00046 ← very preliminary

was 0.0280 ± 0.0007, central value changed by 0.7σ
→ α^{-1} = 128.945 ± 0.060

July 28, 2000 The global fit to EW data Bolek Pietrzyk

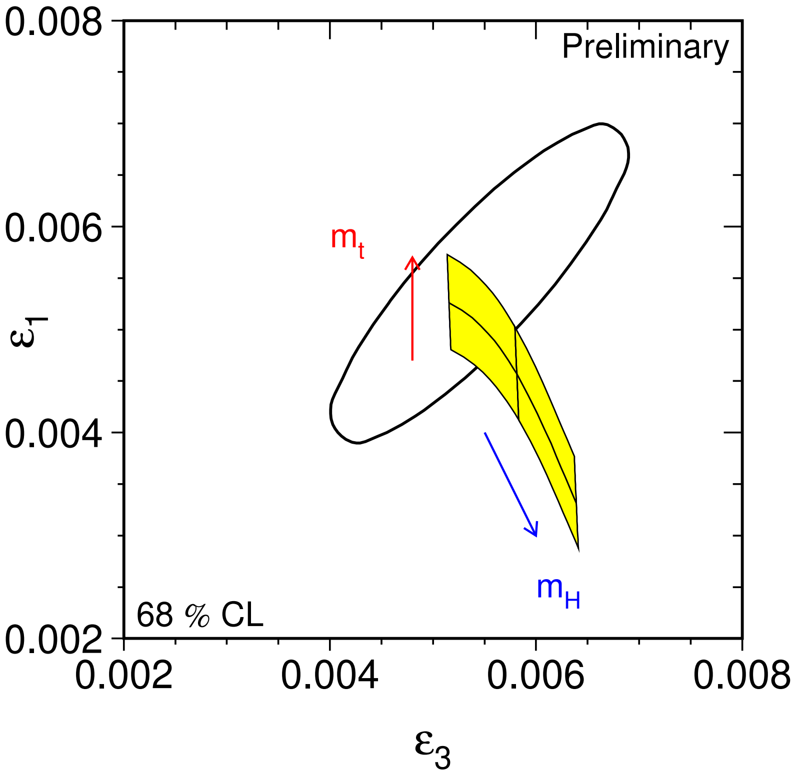
⋆⋆⋆ – **Fermion-Loop**

The best ever done for **non-annihilation** four-fermion production.



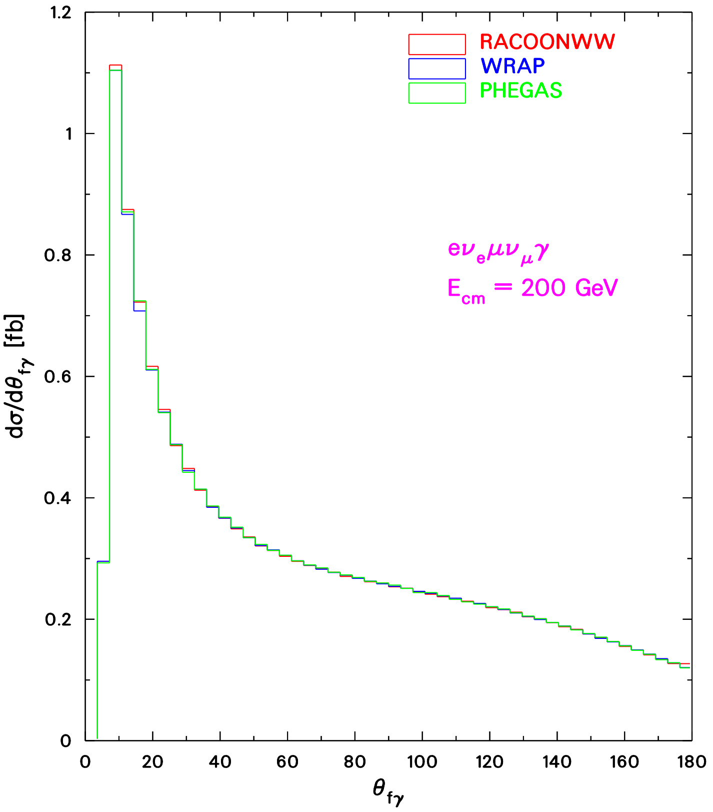
⋆⋆⋆ – **Model-independent fits**

The **dike** between **SM** and **cunterfait**



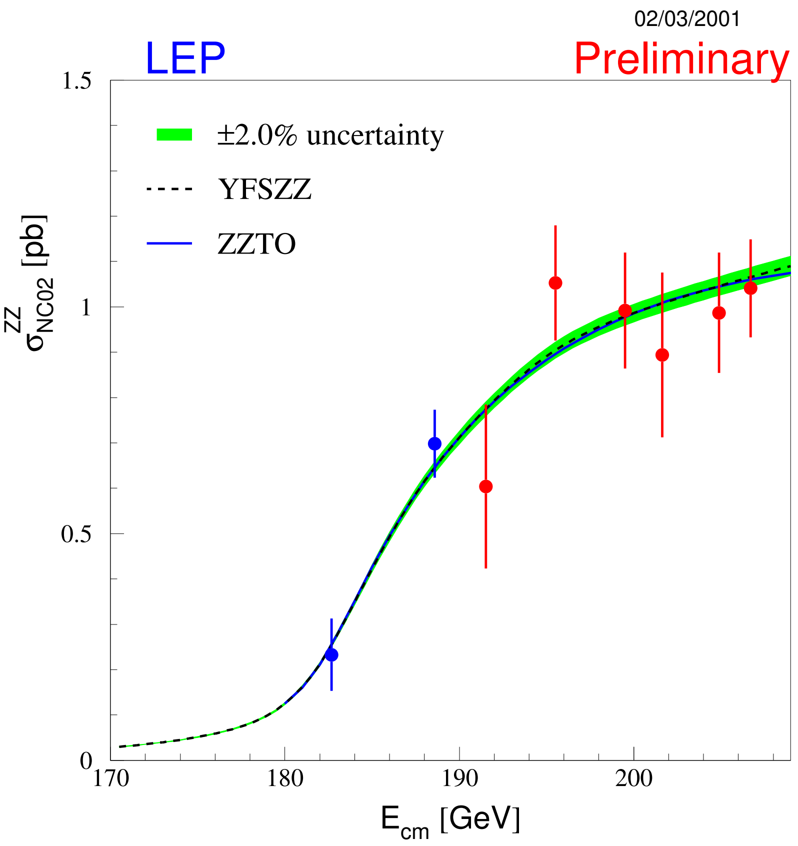
⋆⋆ – $e^+e^- \to \overline{f}_1 f_2 \overline{f}_3 f_4$ **Born**

– **Single-W** with **Fermion-Loop**



⋆ – **Single-W** without **Fermion-Loop**

– ZZ without **DPA**



– ⋆ – **All** *ad hoc*, **effective** solutions that mimic **our ignorance**.

Our experience in the 1990's

- $\triangleright$ we can view *EW physics* directly and not by **indirectly** matching low energy experimental results to **obscure** theoretical predictions (see what happened before),
- $\triangleright$ the **SM** provides a *rationale description* of **particles** and their **interactions** in terms of **18** parameters,
- $\triangleright$ (*experiments have examined the particles and exhibited their properties*)
- $\triangleright$ of the 2 parameters associated with the **Higgs sector** only one is *truly unknown*
- $\triangleright$ Despite *math. consistency* the **SM** cannot provide a description of *EWSB*
- $\triangleright$ Yet **precision data** severely constrain M_H
- $\triangleright$ **SM** is believed to be an *effective theory* valid $< (\ll ?)\, \Lambda$, **precision data** point towards a smooth behavior (**no weird ideas will work**)

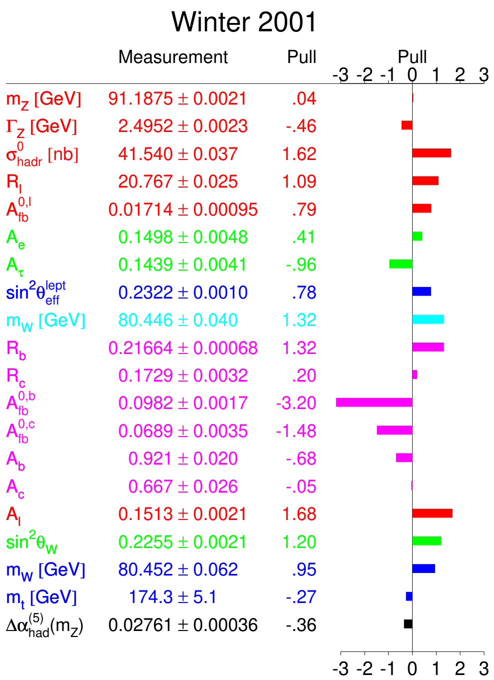
Dejavu...

A_{FB}^{b} is $3.2\,\sigma$ away from **SM**

alternatives are as usual ...

		statistical fluctuation	$\Rightarrow$	usually **unlikely**
$3.2\,\sigma$	$\in$	new physics	$\Rightarrow$	usually **weird**
		systematic error	$\Rightarrow$	usually **subtle**

Rings a bell?



Frequently forgotten aspects

- ▷ The single *most celebrated* figure of the LEP era required **theorists** (**experimenters**) to bridge in a meaningful way the gap towards the **experimental** (**theoretical**) side of particle physics.
- ▷ At this scale it was an **unprecedented phenomenon** which changed forever our way of working.
- ▷ At this level of **precision**, *discovery theoretical physics* must be sustained by *background theoretical physics*.
- ▷ The level of accuracy and architectural complexity of *theoretical* MC has no comparison with the previous era.
- ▷ To a large extent **phenomenology** is a void science in absence of data taking (*the sleep of experimenters generates monsters*).

Nevertheless the **next cycle** should be marked by a return to *pure* theoretical speculations (**extra-dimensions?**)

but we will never be the same again

if we do not forget how to match our new ideas,

immediately,

with the reality of the experimental side

. . . . . .

and now we have much better tools.

Why are we so **different**?

From **LEP Summer Study**, **Les Houches**, **September 1978**

- ▷ **p. 615**, *If its(Z) properties resemble at all the predictions of the simpler gauge models . . .*
- ▷ **p. 637**, *Most theorists now believe that weak, electromagnetic and strong interactions are described by gauge theories . . .*
- ▷ **p. 662**, *You sometimes get the impression these days that there is only one theory of strong interactions . . . but conclusive evidence is not yet available . . .*

Hard to split the merit between theory and experiments if now . . .

CERN-press

At the end of eleven years of running

(more than a soap opera!)

LEP will be remembered as the machine

that put the **Standard Model** on solid ground from **docg** to **doc**

- ▷ **Supersymmetry**: $\ominus$ soft **SUSY**-breaking $\Rightarrow$ many possibilities; $\oplus$ **ADLO** mass limits.

- ▷ $\oplus$ large extra-dimensions, **Unification** at **TeV**, $\ominus$ limits from indirect dearches.

by *popular* vote it is a *supersymmetric desert* !!!

$\boxed{\textbf{Theory}\text{: the remaining of the day}}$

we have been moving from a **mediaeval architecture** of radiative corrections

to the **renaissance** of **LEP period** and now one should not indulge in deciphering the intimate meaning of the **last digit** in the **last fit** of the **LEPEWWG**.

A new **frontier** is at the horizon: most likely it is goodbye to the one man show. Running a new **RC** project will be a little like running an experiment.