Status of the Standard Model and the possible improvements from LHC

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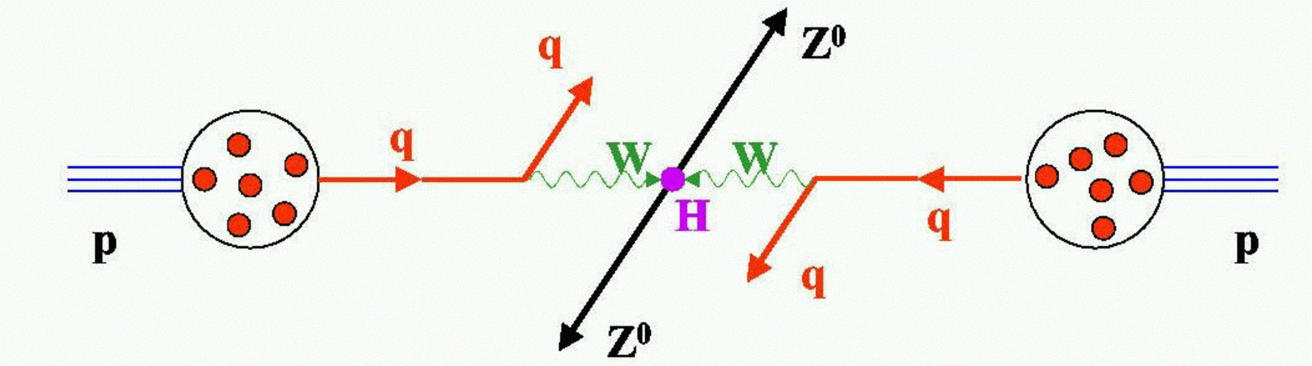
From the success of LEP and SLC

through the Tevatron

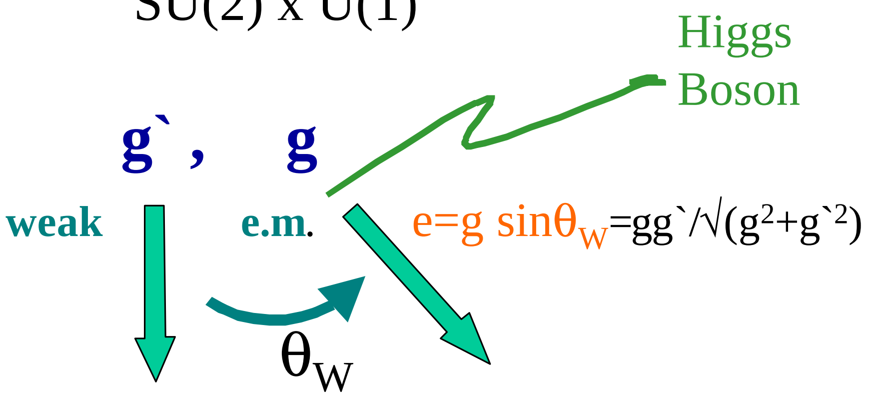
to LHC



The Standard Model

Quarks and leptons interacts exchanging Gauge bosons

Interaction	STRONG	ELECTROWEAK	
Local simmetry	SU(3)	SU(2) x U(1)	
Coupling constant	a_s	$g^`$, g	
Field	quarks	quarks leptons	charged particles
Gauge bosons	gluons	Z, W^+,W^-	γ



Higgs Boson

weak

e.m.

$e=g\sin\theta_W=gg^`/\sqrt{(g^2+g^{`2})}$

θ_W

The Standard Model

The fermions are not degenerate in mass: the symmetry is broken in the masses.

The symmetry is spontaneously broken via the Higgs mechanism

It is the Higgs that gives mass to fermions and bosons

SM does not predict the mass of the particles, but having them measured, predicts physics quantities at per mill level.

4 fundamental parameters: alpha_em, G_F, M_Z, $\sin\theta_W$

The first goal of LEP/SLD : measure the $\mathbf{M_Z}$ at the 10^{-4} !

γ Z W^+ W^- H

$$\begin{array}{ccc} \begin{pmatrix}\nu_e\\ e\end{pmatrix}_L & \begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}_L & \begin{pmatrix}\nu_\tau\\ \tau\end{pmatrix}_L \\ \nu_{eR} & \nu_{\mu R} & \nu_{\tau R} \\ e_R & \mu_R & \tau_R \end{array}$$

$$\begin{array}{ccc} \begin{pmatrix}u\\ d\end{pmatrix}_L & \begin{pmatrix}c\\ s\end{pmatrix}_L & \begin{pmatrix}t\\ b\end{pmatrix}_L \\ u_R & c_R & t_R \\ d_R & s_R & b_R \end{array}$$

BEFORE LEP

no top

no $\nu\tau$

no Higgs

DURING LEP

top (CDF/DO +”lep/sld”)

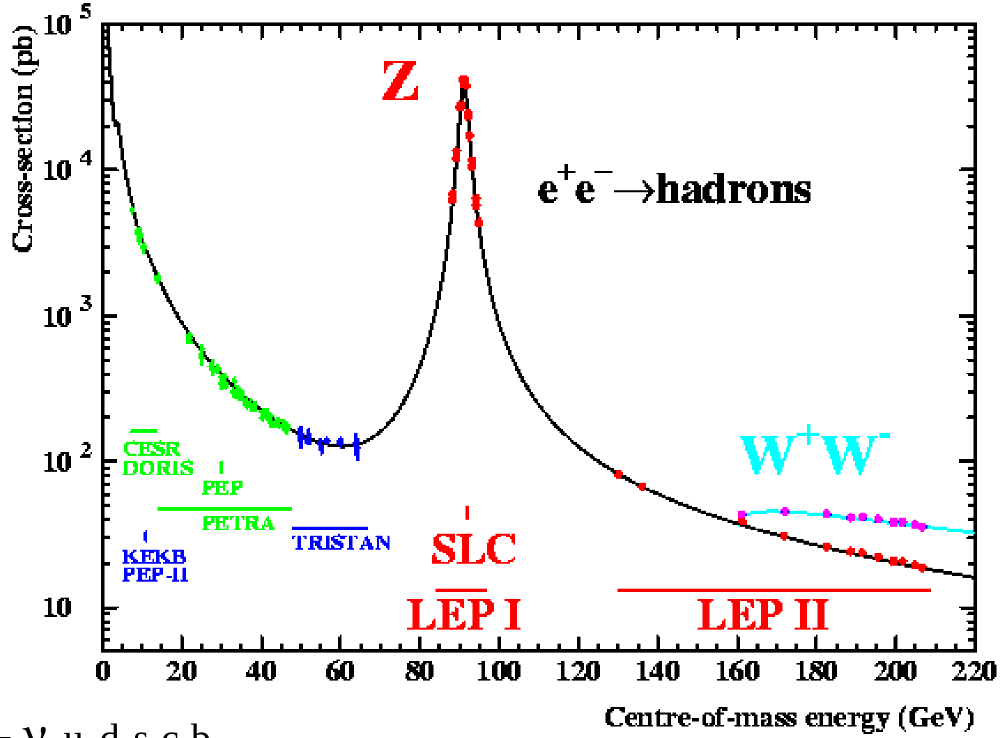
$\nu\tau$ (DONUT)

END of LEP: no Higgs!

But : “our way of thinking has been changed for ever” (R.Barbieri)

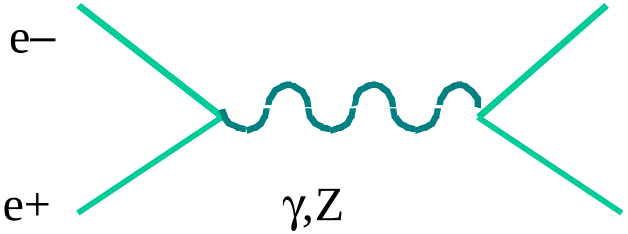
LEP/SLD: a precision test of the Standard Model

- By 1983 the SM was well established with the observation of neutral current in neutrino-electron scattering and the discovery of the W and Z at the SPS collider.
- LEP and SLD were proposed to measure with high precision the mass and width of the Z and of the W and the coupling of the Z with the fermions.



Why e+e- ?

Because the simplicity of the initial state is transmitted to the final state:



e-,μ-,τ–,ν,u,d,s,c,b

e+,μ+,τ+,ν,u,d,s,c,b

The precision observables

Are the ones that at tree level depend only on
α_{em}, G_F, M_Z, and $\sin\theta_W$

At tree level:

$G_F = \pi\alpha / \sqrt{2}\, m_W^2 \sin^2\theta_W$ relation between EM and Weak constants

$\rho \equiv m_W^2 / m_Z^2 \cos^2\theta_W = 1$ relation between neutral and charged weak coupling

ρ is determined by the Higgs structure of the theory

The interaction of the Z boson with fermions is given by the left- and right-handed couplings g_L and g_R:

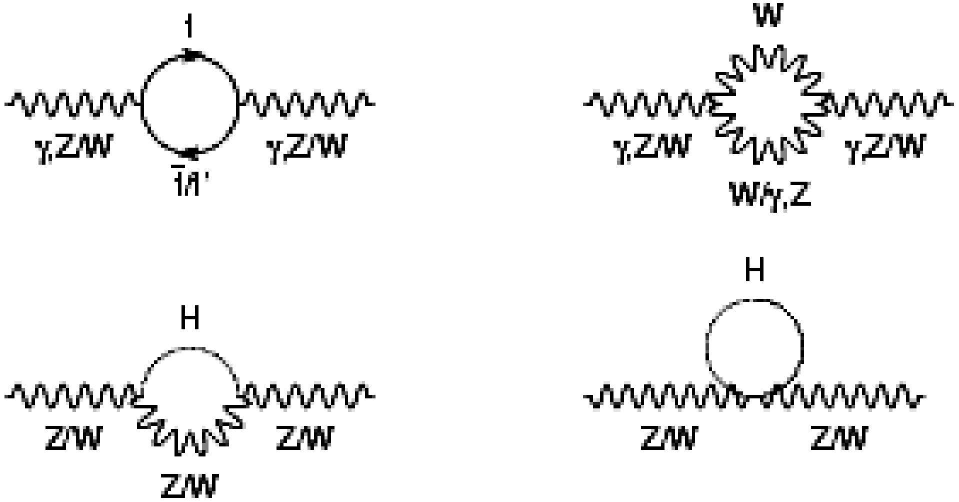
$g_L = \sqrt{\rho}\,(I_3 - Q \sin^2\theta_W)$ left fermions couple with Z and γ

$g_R = \sqrt{\rho}\,(Q \sin^2\theta_W)$ right fermions couples with γ

or alternatively Vector and Axial couplings:

$g_V = g_L - g_R$, $g_A = g_L + g_R$

Radiative corrections



modifies these tree level quantities:

$\bar{\rho} = 1 + \Delta\rho$ ($\rho = 1$ if Higgs doublet)

$\sin^2\theta_{eff} = (1 + \cos^2\theta_W / \sin^2\theta_W \, \Delta\rho + \ldots) \sin^2\theta_W$

$G_F = \pi\alpha / \sqrt{2} \, m_W^2 \sin^2\theta_W \cdot 1/(1-\Delta r)$

And $\Delta r = \Delta\alpha + \Delta r(top) + \Delta r(H)$

running of α_{em} coupling

m^2(top) dependence

log m(H) dependence

The LEP “DISCOVERY” !

The reached high precision allows to demonstrate the existence
of higher order ElectroWeak radiative correction
with many sigmas significance.

Via these correction LEP/SLD can also infers properties of of particles not produced at LEP/SLD: the top quark and the Higgs boson.

- In 94: the SM fit to the LEP+SLC data gave:

  m(top)=178 ± 11 ± 18 GeV/c^2

  CDF+D0 observed: m(top)=174 ± 10 ± 20 GeV/c^2
- Today:

  Using the measured m(top)

  $\Delta r = -0.032 \pm 0.002 + \ldots$

  and comparing with

  $\Delta r(\mathrm{exp}) = -0.0296 \pm 0.0022$ (9 sigma to QED!)

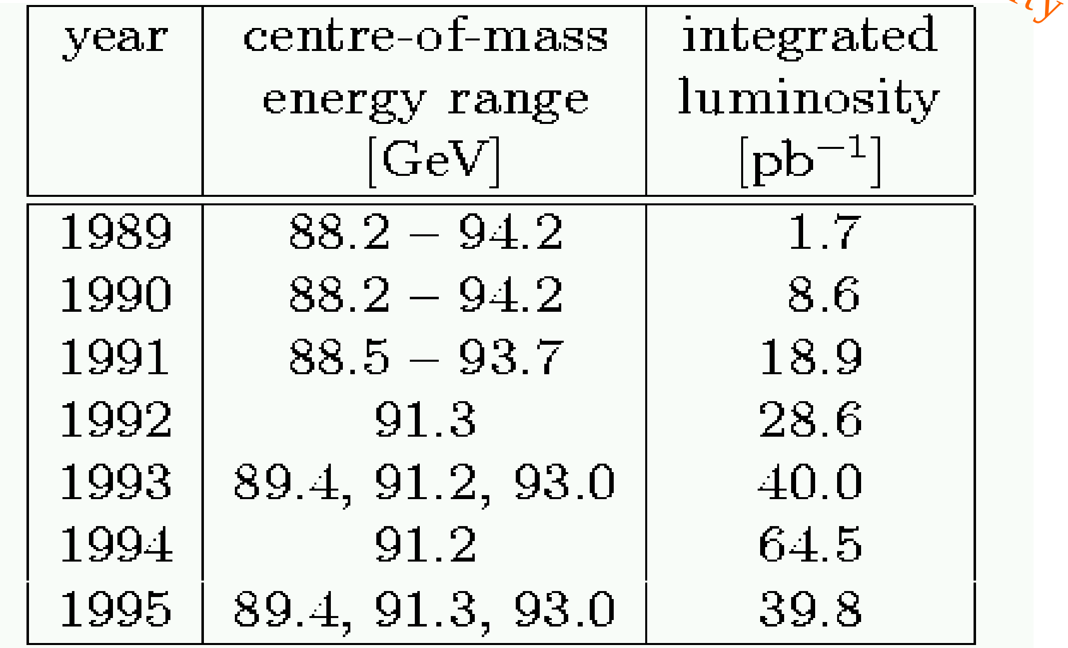
  Þ m(Higgs) is not large !

The LEP and SLD run

luminosity

polarization

LEP-1



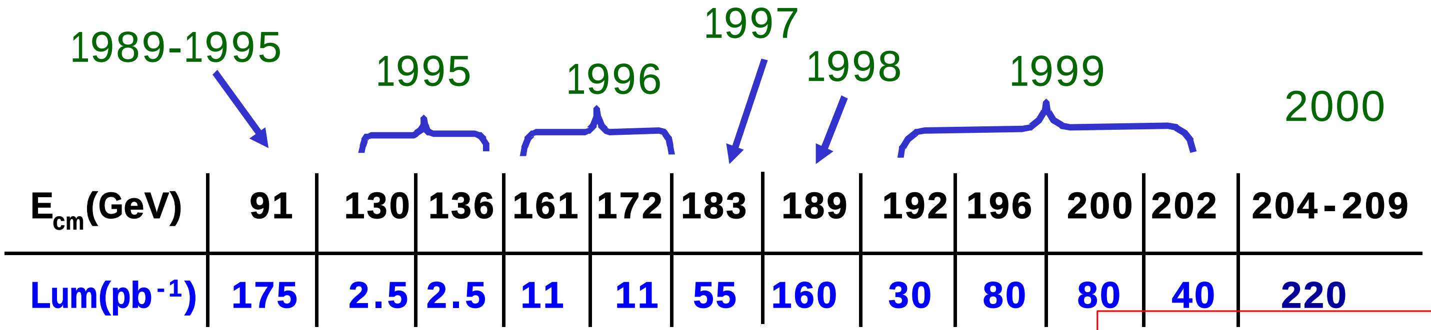
year	centre-of-mass energy range [GeV]	integrated luminosity [pb^{-1}]
1989	88.2 – 94.2	1.7
1990	88.2 – 94.2	8.6
1991	88.5 – 93.7	18.9
1992	91.3	28.6
1993	89.4, 91.2, 93.0	40.0
1994	91.2	64.5
1995	89.4, 91.3, 93.0	39.8

17 million events!

SLD

Year	$<P_e>$	Int Lum
1992	0.244	0.2
1993	0.630	1.2
1994/5	0.7723	2.2
1996	0.7616	1.3
1997/8	0.7292	8.0

540 k events



LEP1
+
LEP2

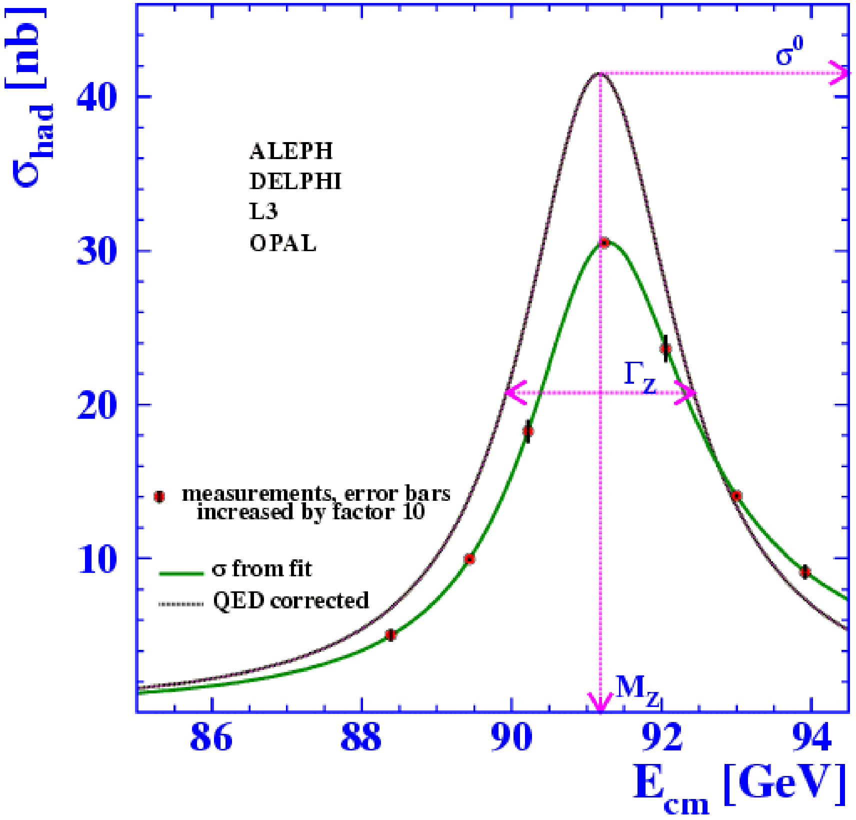
E_{cm}(GeV)	91	130	136	161	172	183	189	192	196	200	202	204-209
Lum(pb^{-1}) per exp.	**175**	**2.5**	**2.5**	**11**	**11**	**55**	**160**	**30**	**80**	**80**	**40**	**220**

Lum(LEP2) > 2 fb^{-1}

What we measure

Cross sections, widths and asymmetries

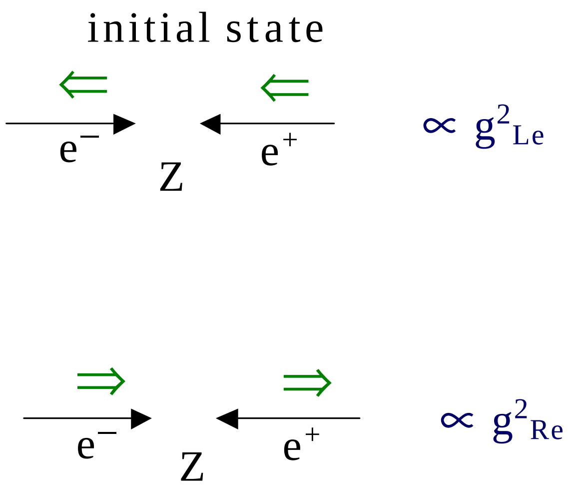
from an energy scan around the Z resonance



The Z mass	M_Z
Total Z width	Γ_Z
Z peak cross section	σ^0_{had}
Ratios	$R^0_l = \Gamma_{had}/\Gamma_{ll}$ $R^0_b\ R^0_c\ R^0_s = \Gamma_{qq}/\Gamma_{had}$
Asymmetries:	A_{FB} , A_{LR} for leptons and quarks
Polarizations	P_l

To reach the ‰ precision : initial state e+e− (energy and luminosity)
and final state f+f- should be so precisely now

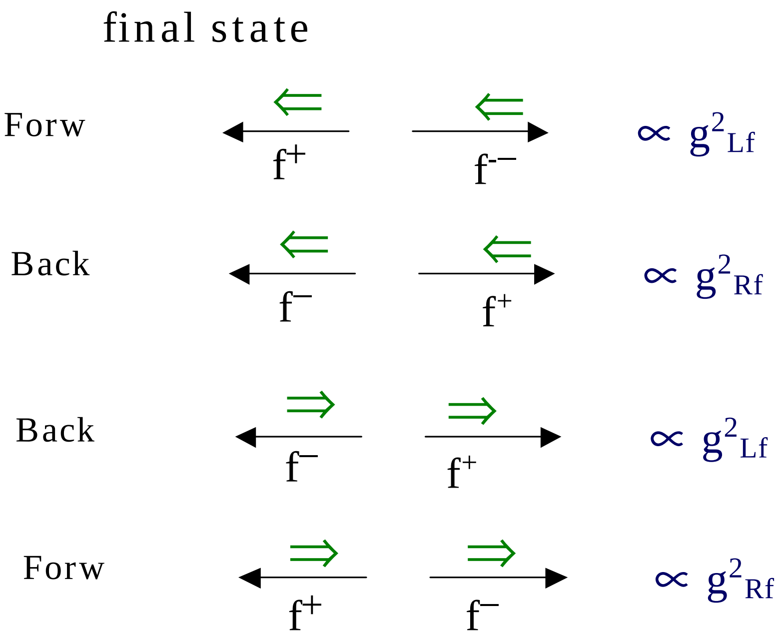
Measuring asymmetries



initial state

e^- Z e^+ $\propto g^2_{Le}$

e^- Z e^+ $\propto g^2_{Re}$



final state

Forw f^+ f^- $\propto g^2_{Lf}$

Back f^- f^+ $\propto g^2_{Rf}$

Back f^- f^+ $\propto g^2_{Lf}$

Forw f^+ f^- $\propto g^2_{Rf}$

$g_V = g_L - g_R$
$g_A = g_L + g_R$

σ_{LR} difference between σ for Left and Right handed incoming fermions

σ_{pol} difference between σ for Left and Right handed outgoing fermions

σ_{FB} difference between σ for outgoing fermions going Forward or Backward

$$A_{LR} = \sigma_{LR} / \sigma_{TOT} = Ae = 2\, g_{Ae}\, g_{Ve} / (g^2_{Ae} + g^2_{Ve})$$

$$A_{FB} = \tfrac{3}{4}\, \sigma_{FB} / \sigma_{TOT} = \tfrac{3}{4}\, Ae\, Af$$

$$A_{pol} = \sigma_{pol} / \sigma_{TOT} = Af = 2\, g_{Af}\, g_{Vf} / (g^2_{Af} + g^2_{Vf})$$

Measuring asymmetries (2)

$$\begin{cases} g_L = \sqrt{\rho}\,(I_3 - Q \sin^2\theta_W) \\ g_R = \sqrt{\rho}\,(Q \sin^2\theta_W) \end{cases} \qquad \begin{cases} g_V = g_L - g_R \\ g_A = g_L + g_R \end{cases} \qquad \begin{cases} g_v = \sqrt{\rho}\,(I_3 - 2\,Q \sin^2\theta_W) \\ g_A = \sqrt{\rho}\, I_3 \end{cases}$$

From asymmetry measurements $\Rightarrow \sin^2\theta_W$ and ρ

At SLC : the electrons are polarized (up to 72%)
then SLD can measure all the cross sections (LR, FB, pol...)
and determine Ae and Af for any identified fermion

At LEP: only measure FB cross sections and τ polarization
so Ae·Af for any identified fermion
and Aτ (and Ae from A^{τ}_{FB} and Pτ)

The Luminosity

$$\boxed{\sigma_{tot} = (N-N_{bkg})/ Lum}$$

via the Bhabha scattering: $e^+ e^- \rightarrow e^+ e^-$

The 4 LEP experiments devoted a huge effort in the measurement of the luminosity, installing new detectors and reaching a precision on the Luminosity of less than 0.1%

In parallel the theoreticians refined and improved the computation of the Bhabha scattering reaching the precision of 0.5%

This is at the moment the dominant error on the number of neutrinos

The energy calibration

Precise knowledge of the center-of-mass energy is essential for the determination of the mass and width of the Z (and of the W at LEP2).

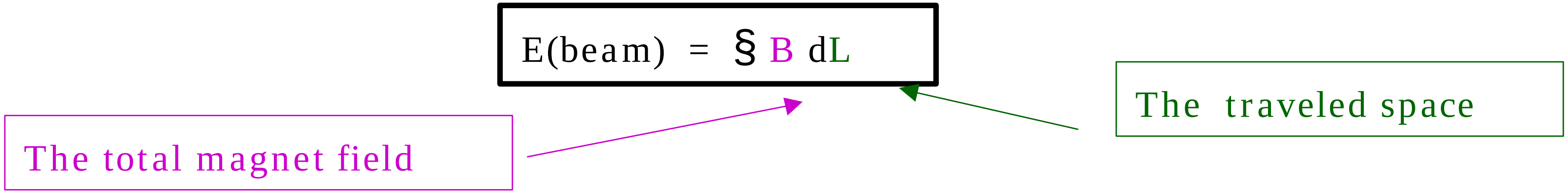
The uncertainty on the absolute energy scale affects the mass

The error in the difference in energy between energy points influences the width

The precision on the center of mass energy is the dominant error on the measurement of the mass and width of the Z (and the W) even though INCREDIBLE precision has been reached:

1.7 MeV at 45 GeV

and 15 MeV at 200 GeV



E(beam) = § B dL

The total magnet field

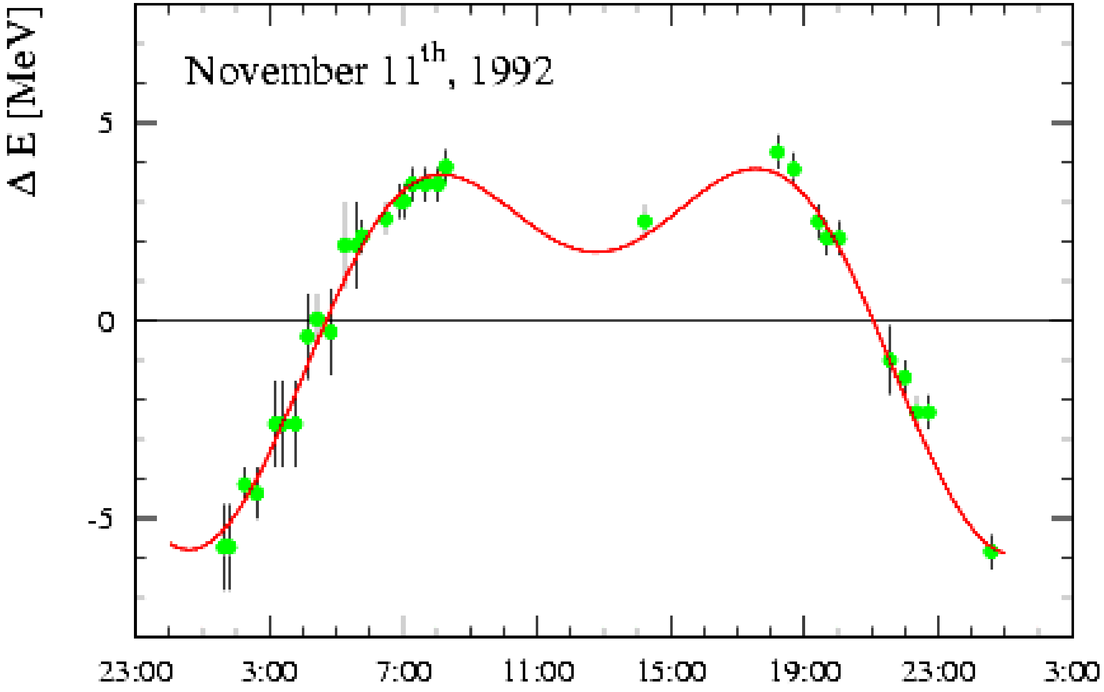
The traveled space

The LEP energy: the effect of the moon

The moon tides move the earth surface up-down 25 cm in Geneva (i.e. a local change of earth radius of 4 10^{-8}).

⇒ the total LEP orbit is changed by less than a millimeter.

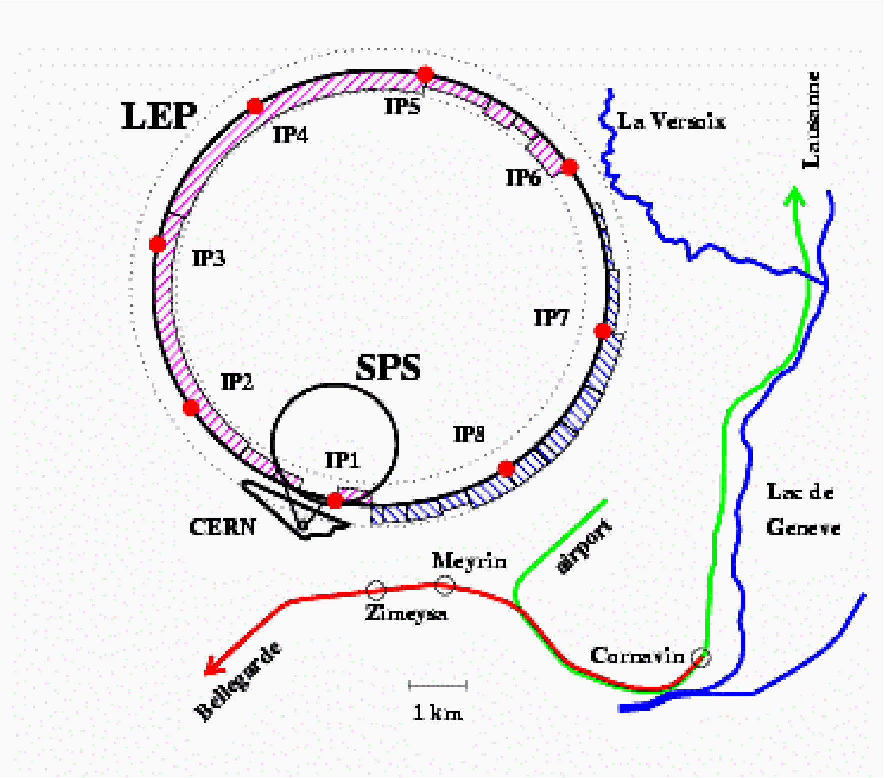
But LEP feels it !!!!! Up to 10 MeV variation, but well understood!

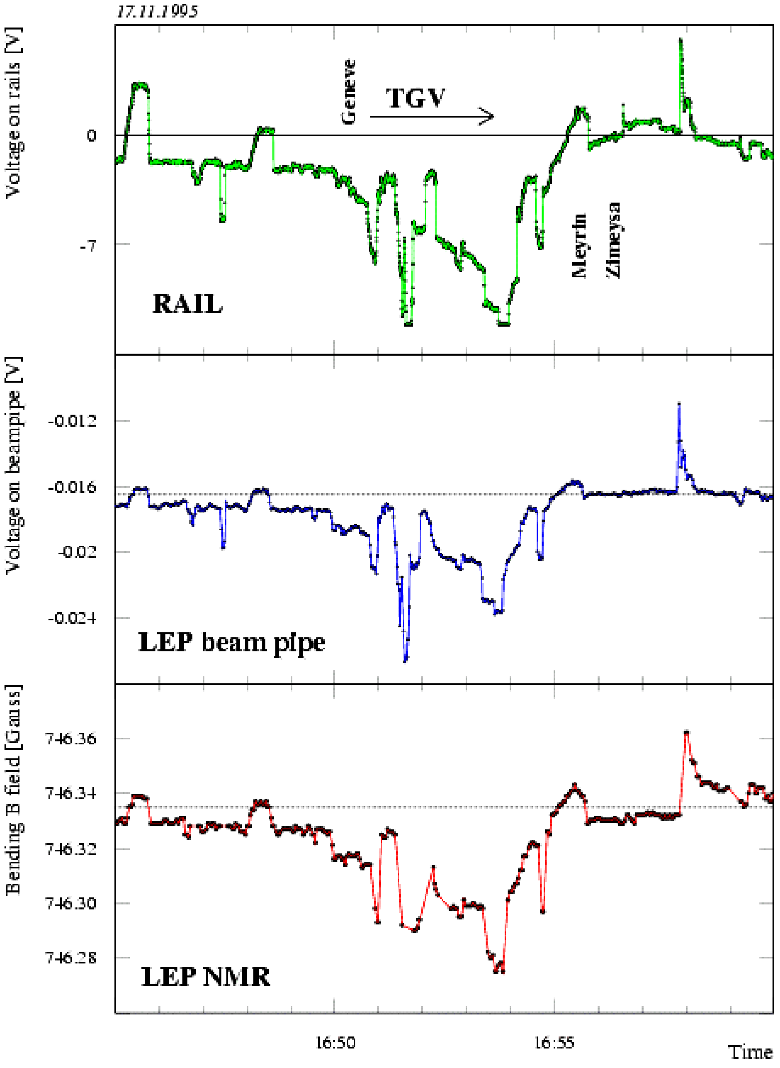


Similar effects come also from the water level of the Geneva Lake

The LEP energy: the effect of the TGV

Vagabonds currents cause drift in dipole field during a fill up to 10 MeV equivalent.





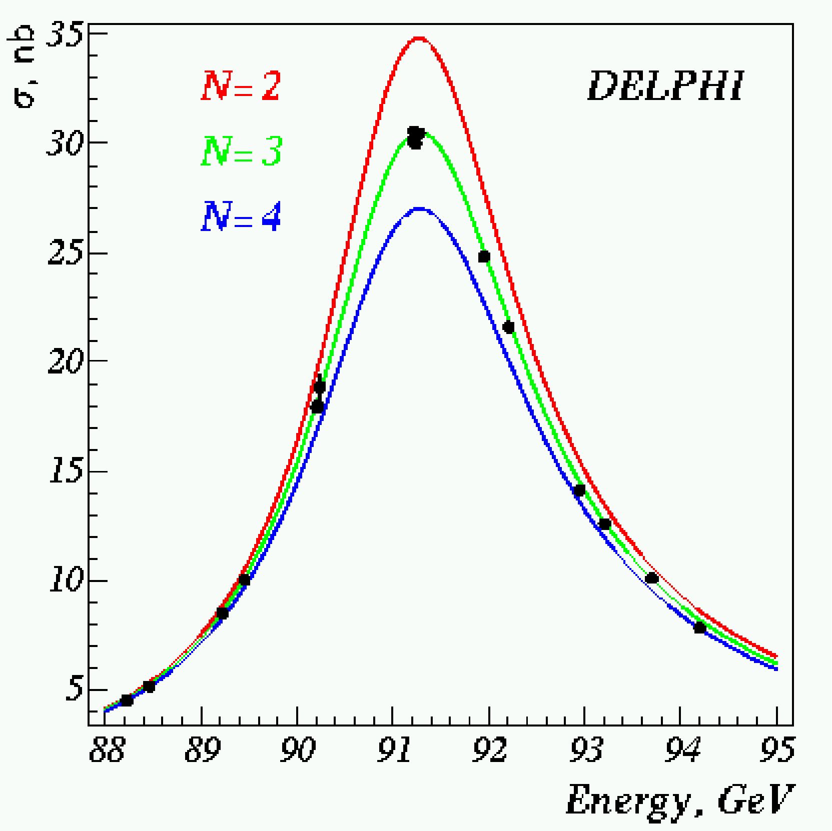
The Z line shape

$2 \cdot 10^{-5}$ accuracy for one of the most fundamental constants !

$\mathbf{m_Z} = 91.1874 \pm \mathbf{0.0021}$ **GeV**

1989: $m_Z = 91.12 \pm 0.16$ GeV

The total Z width: $\Gamma_Z = 2.4952 \pm 0.0023$ GeV



From the measured Γ_{inv}/Γ_{ll}

divinding by $\Gamma_{\nu\nu}/\Gamma_{ll}$ from SM

where $\Gamma_{inv} = \Gamma_Z - \Gamma_{had} - \Gamma_{ll}$

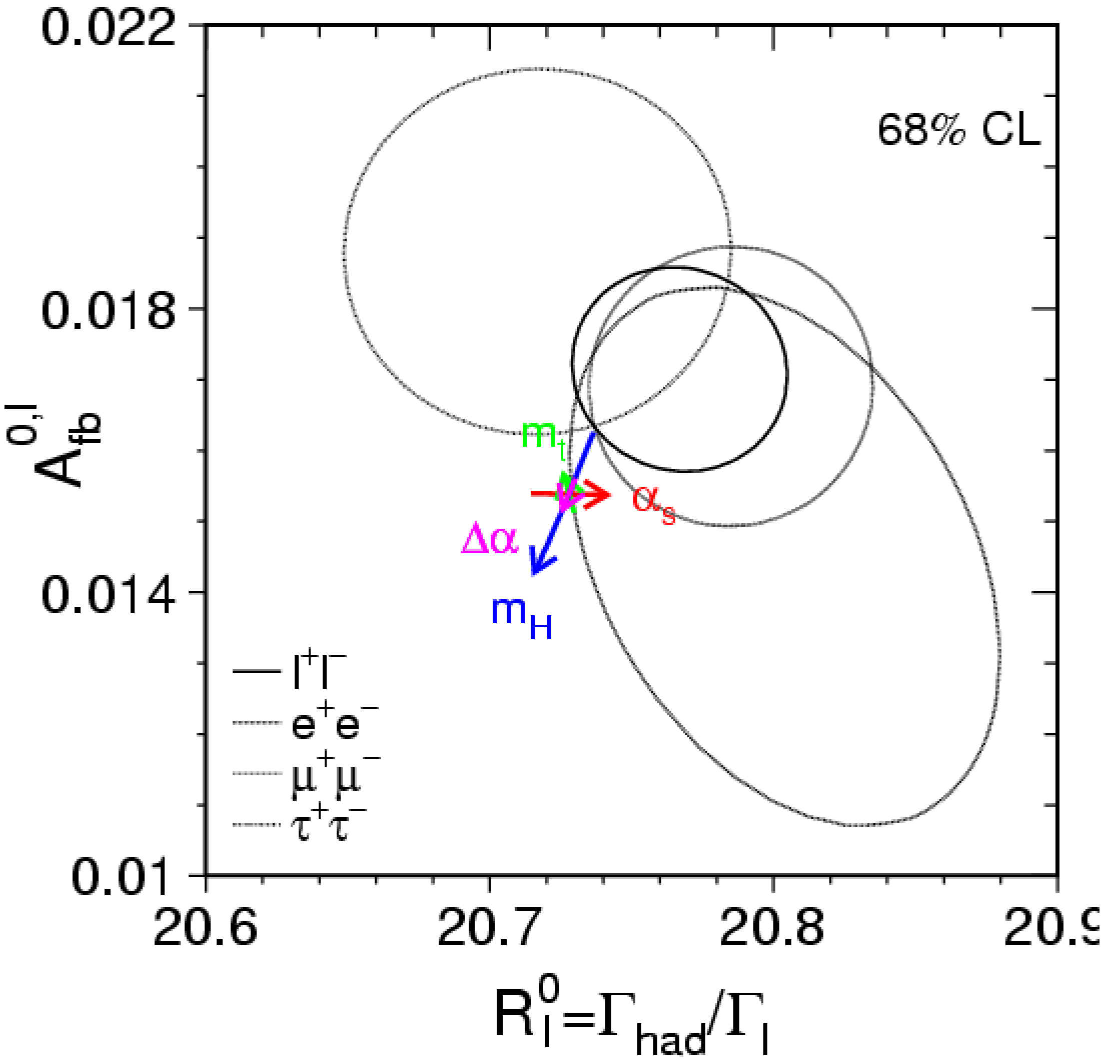
$N(\nu) = 2.9841 \pm 0.0083$

2σ below 3

1989: $N(\nu) = 3.0 \pm 0.9$

The lepton universality

The measurement of the widths and asymmetries for the 3 lepton flavours and assuming the lepton universality



The SM is for

m(top)=174.3 ± 5.1 GeV

m(H)= 300 $^{+700}_{-200}$ GeV

$\alpha_s(m_Z)$= 0.119 ± 0.002

The Z coupling to leptons

From LEP:

$A_{FB} = 3/4\, A_e A_f$

Leptonic widths ∝ $g^2_{Vf}+g^2_{Af}$

τ polarization

From SLD:

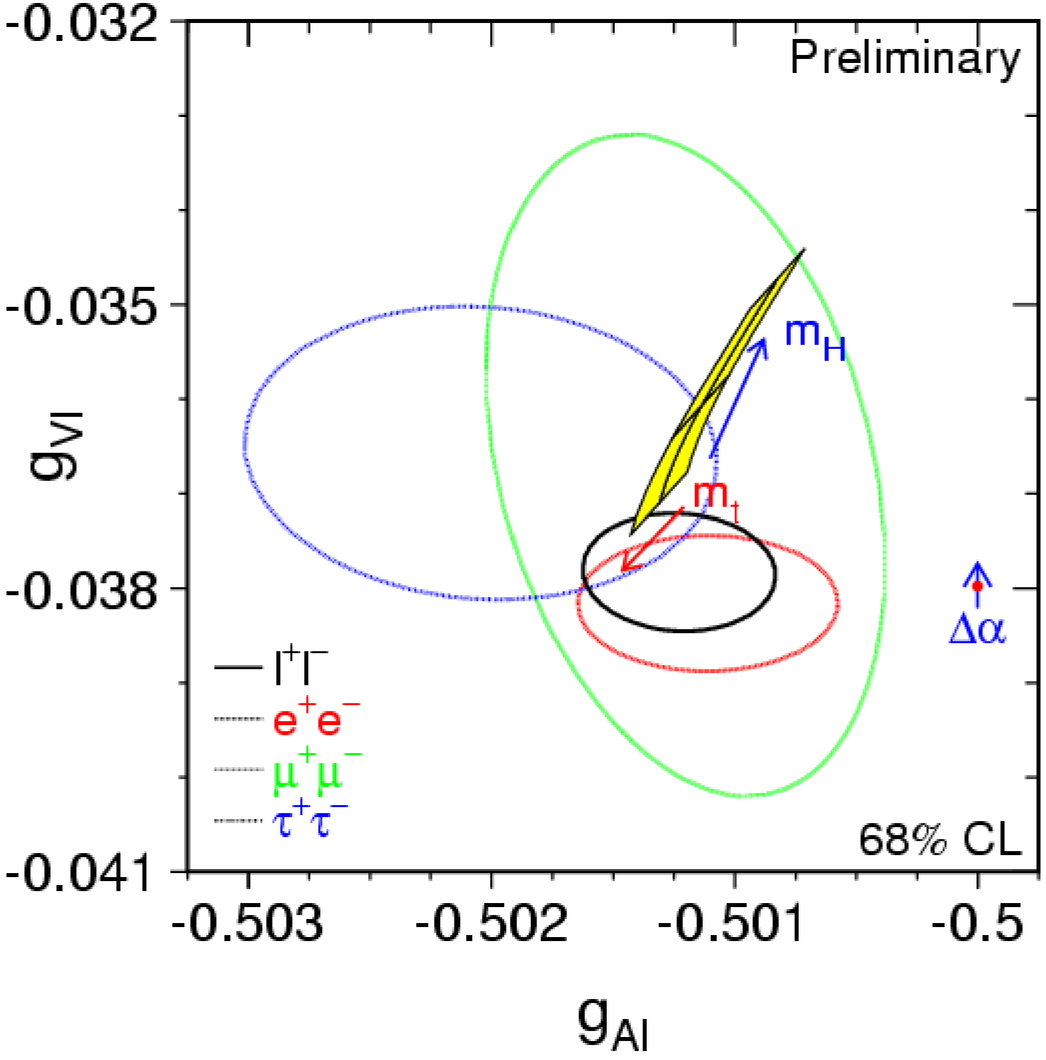
A_{LR}

And Ae, Aμ, Aτ

$A_f \propto g_{Vf}/g_{Af}$

$g_v = \sqrt{\rho}\,(I_3 - 2\,Q\,\sin^2\theta_W)$

$g_A = \sqrt{\rho}\,I_3$



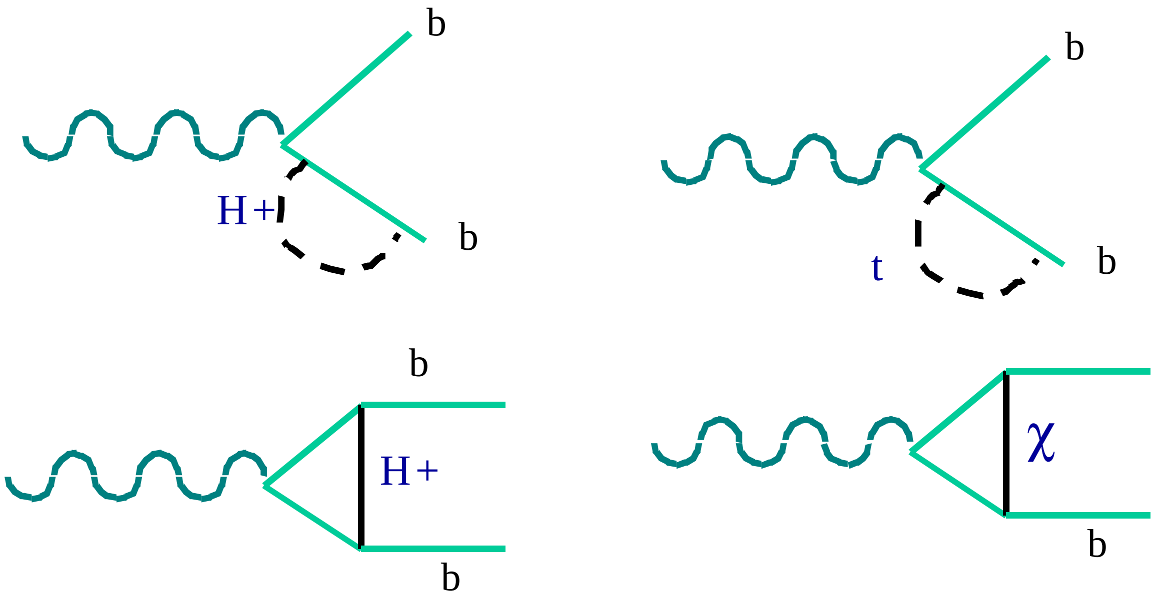
Þ $\bar{\rho}^{lept} = 1.0050 \pm 0.0010$

5σ above the tree-level value of 1, proving that we indeed see EW radiative correction, in agreement with SM

The heavy quarks

Only towards 1995 the experiments could do precise measurements with heavy quarks, thanks to the microvertex detectors and to sophisticated analysis techniques.

The b quark is particular interesting because is in the same weak doublet with the top and because of the vertex correction diagrams:



LEP measure : $\Gamma_b, \Gamma_c \propto g^2_{vq}+g^2_{Aq}$ and $A_{FB}(b,c)=3/4\ A_eA_f$, $A_f \propto g^2_{vq}/g^2_{Aq}$

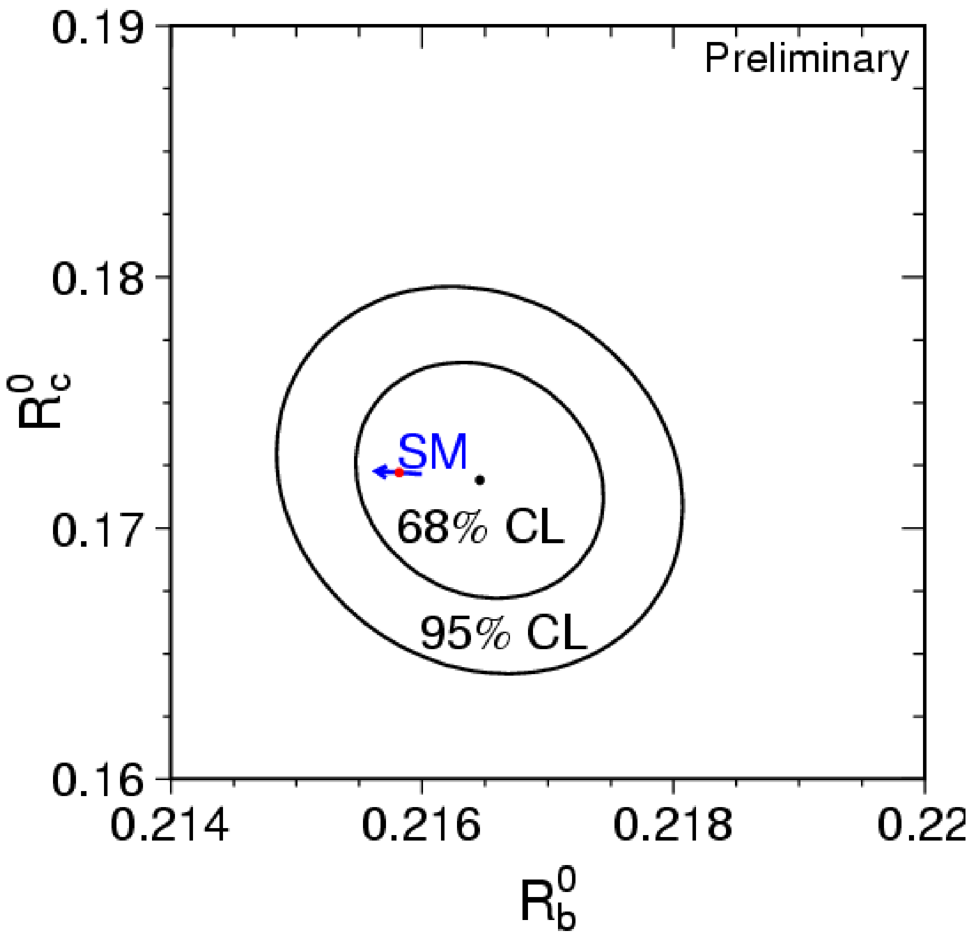
SLD measure: Γ_b, Γ_c and A_b and A_c

Rb and Rc as a test of the SM

$R_q = \Gamma_{qq}/\Gamma_{had}$

Rb measured with **3‰** precision !!!

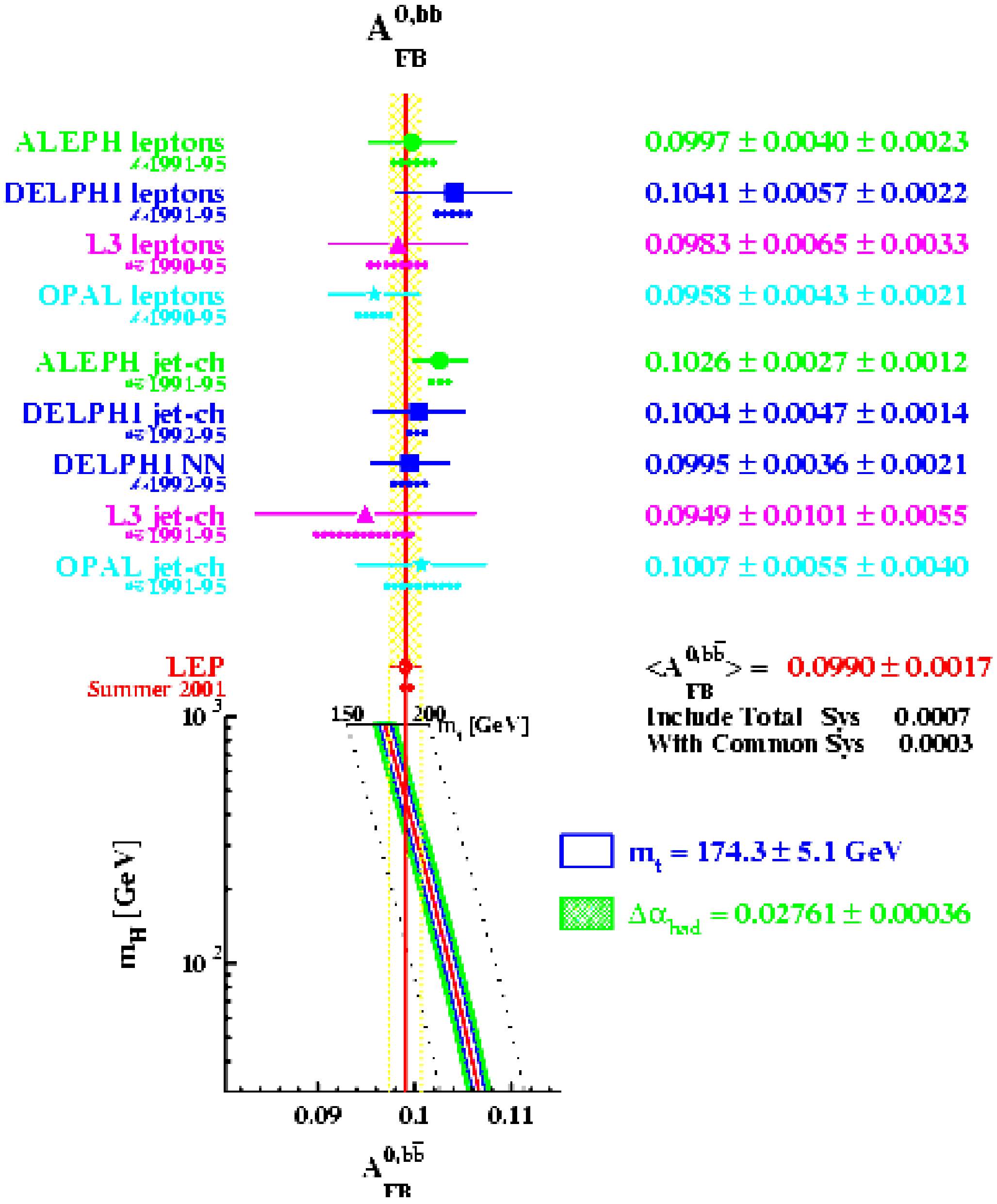
Rc measured with 1.8% precision



In 1995 there was a 3.5 sigma discrepancy between experimental results and SM prediction.

A better understanding of the detector, of the b-tagging procedure and of the method of the Rq extraction, resolved the discrepancy.

The b and c asymmetries



2.8 σ discrepancy with SM

$A^{b}_{FB}=3/4\ A_e\ A_b$

A_e dominated by SLD

But good agreem. LEP-SLD

A_b (LEP only)=0.891±0.022

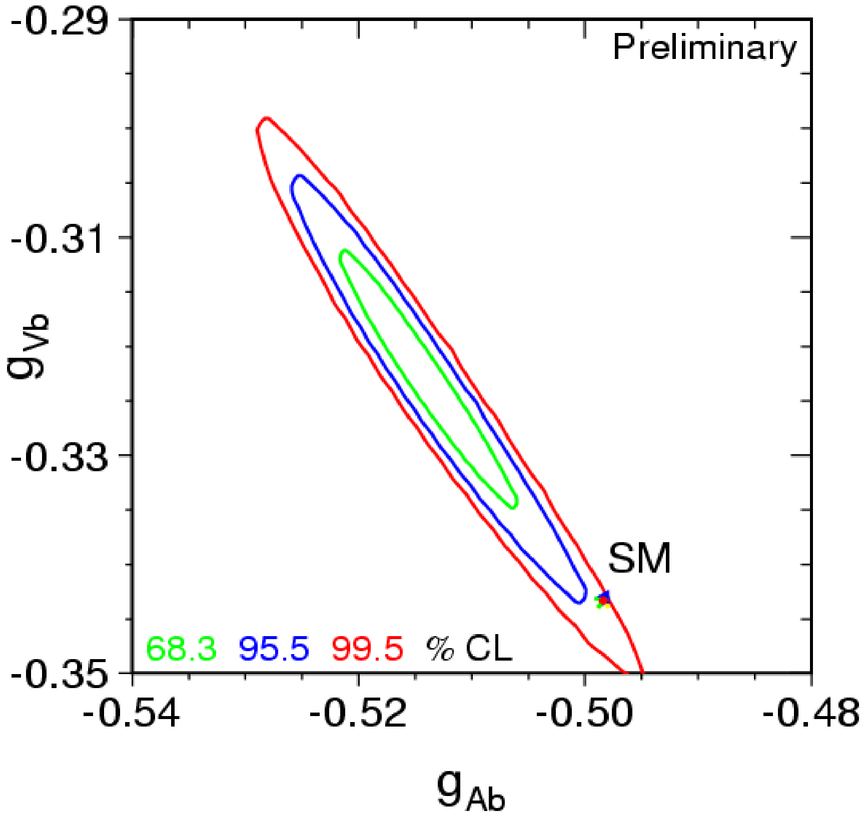
A_b (SLD only)=0.921 ± 0.020

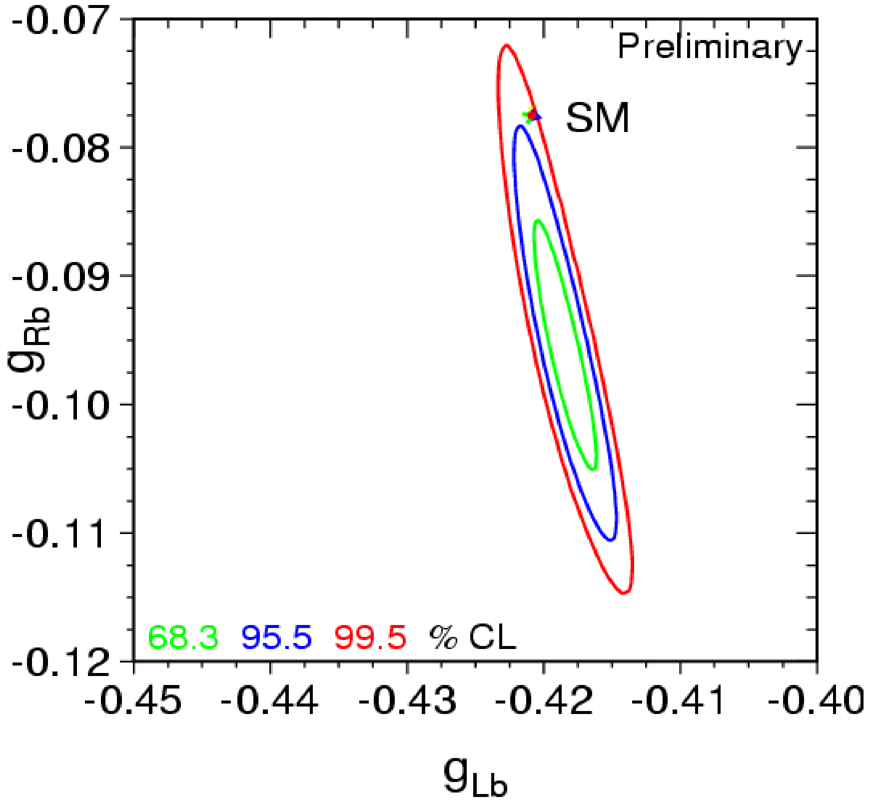
Agree within 1 sigma!

A_b(LEP+SLD) = 0.899 ± 0.013

0.935 SM

The right and left components





Strong correlation of g_{Ab} g_{Vb} due to constraint on sum of squares

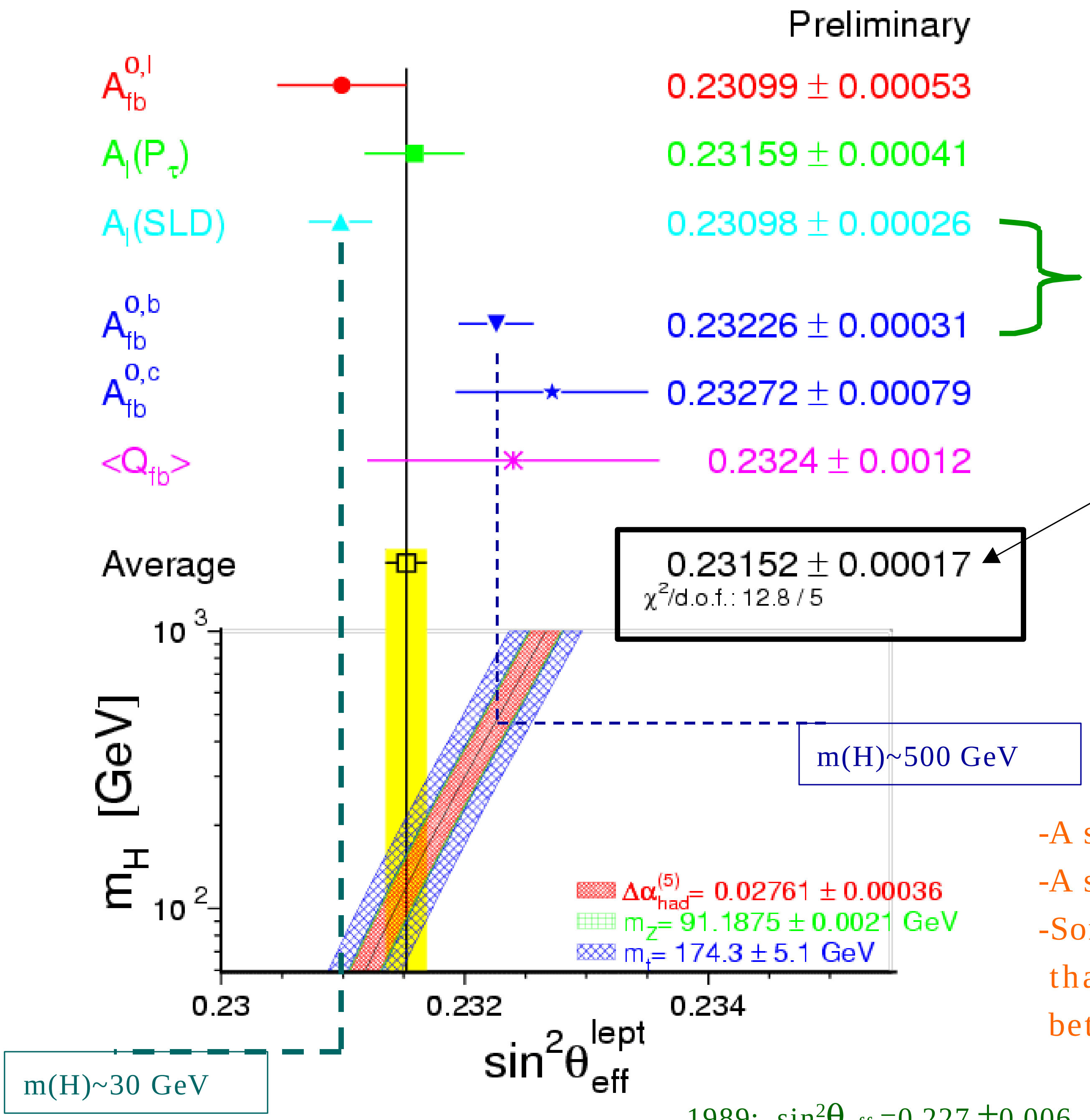
From precise R_b. Deviation from SM mainly from g_{Rb}

⇒ $\bar{\rho}^b = 1.064 \pm 0.021$

3 sigma away from SM, but

20 time less precise than ρ^{lept}

$\sin^2\theta_{eff}$



m(H)~30 GeV

m(H)~500 GeV

3.3σ discrepancy

dominated by uncertainty on α_{em}

Prob = 2.5%

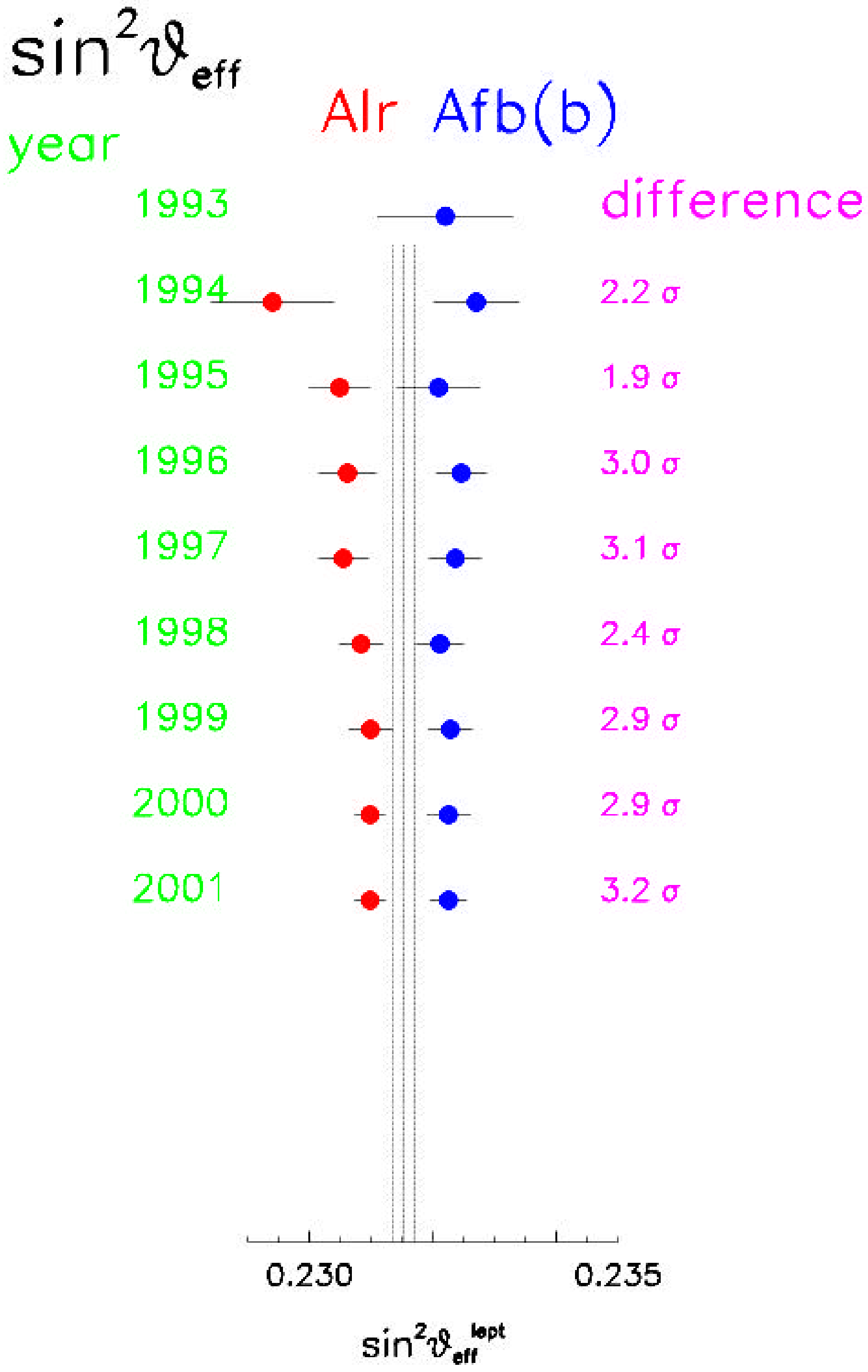
Only average $\sin^2\theta_{eff}$ is consistent with m(H)~100 GeV

-A statistical fluctuation?

-A systematic problem?

-Something "new" that shows up in a difference between lepton and quark?

1989: $\sin^2\theta_{eff} = 0.227 \pm 0.006$

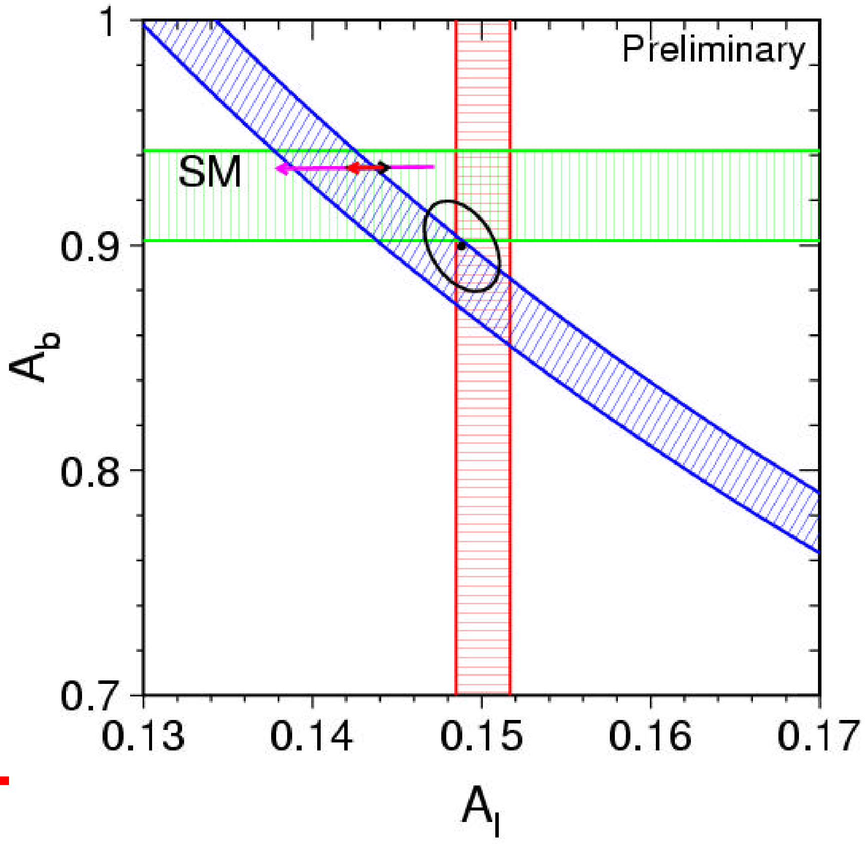


This difference is small but it is there since the "beginning".

First was thought as a LEP-SLD difference, now as lepton vs quark difference

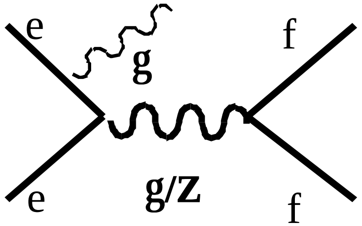
Since Ae (SLD) = Ae(LEP)

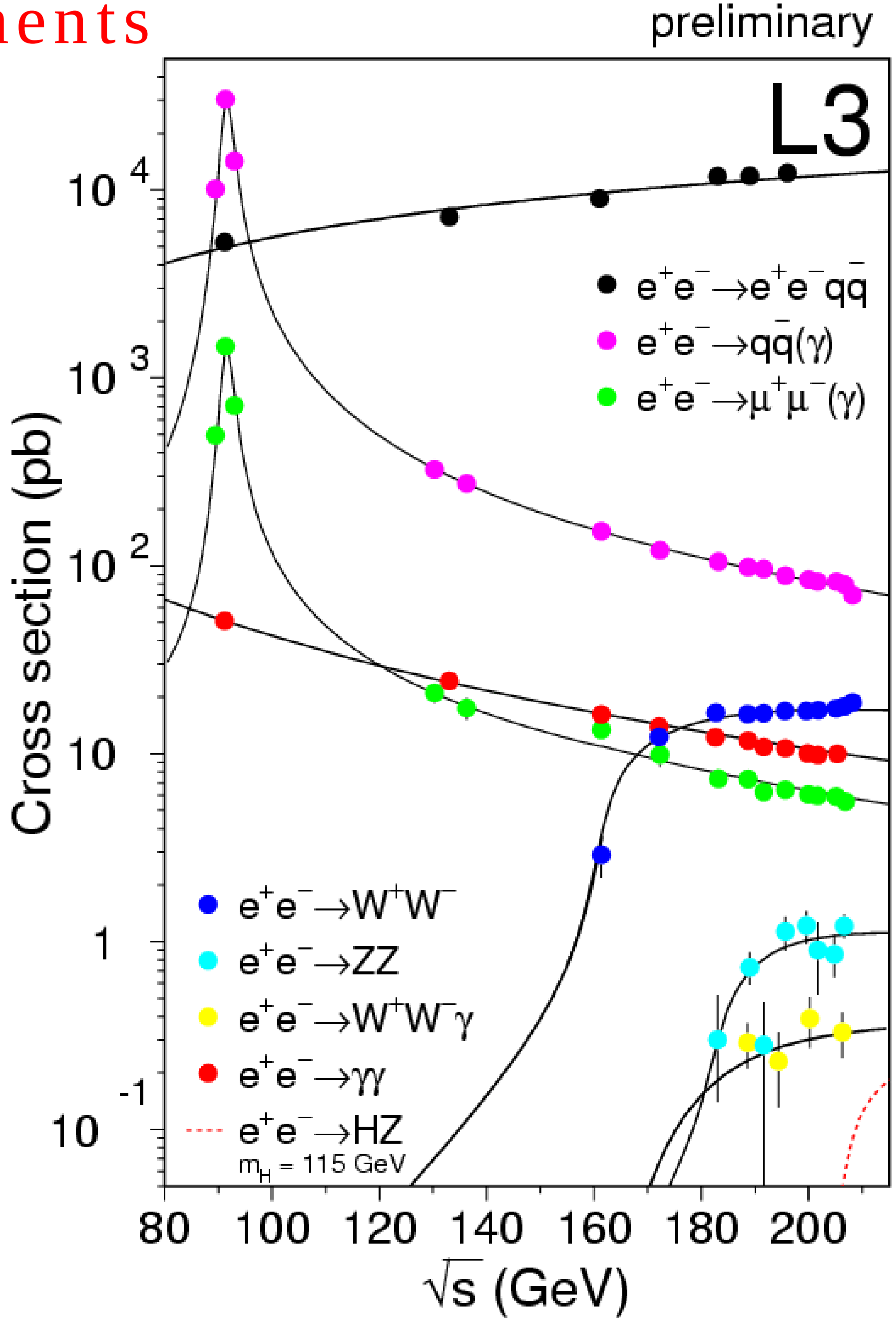
Ab (SLD) = Ab(LEP)



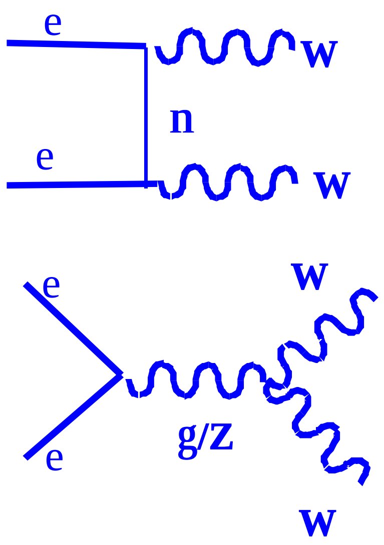
The measurements at LEP2

2-fermions

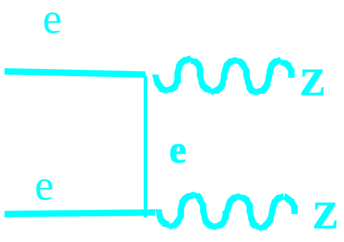




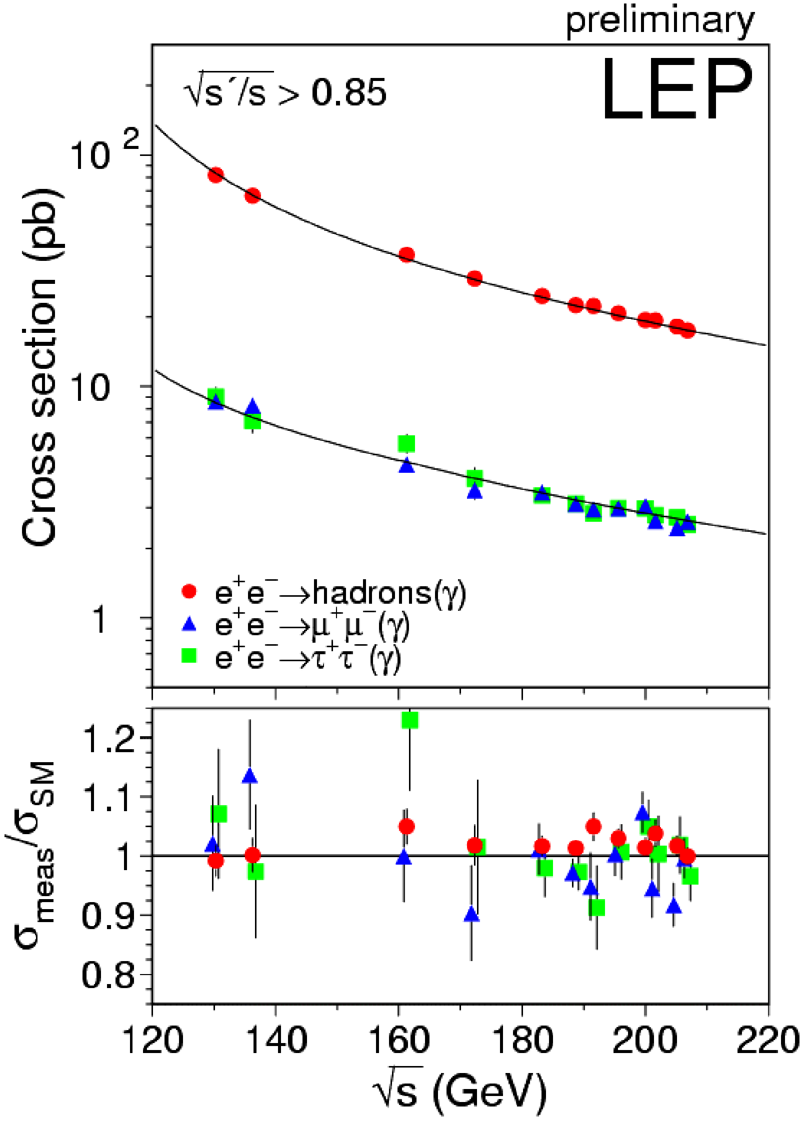
WW



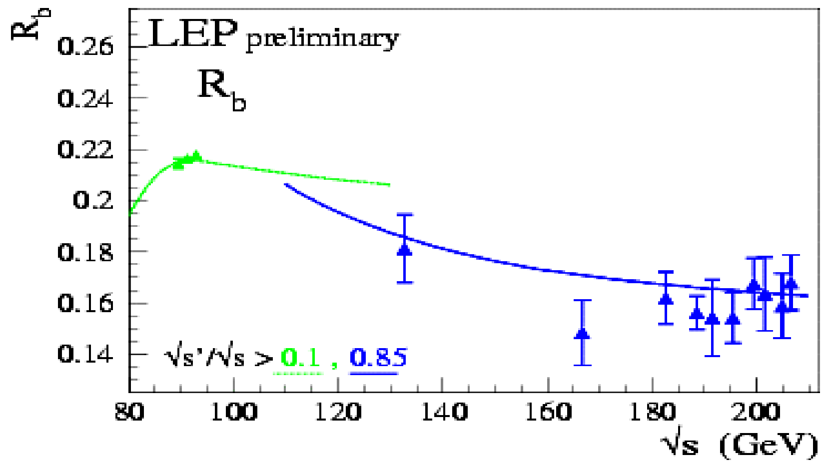
ZZ

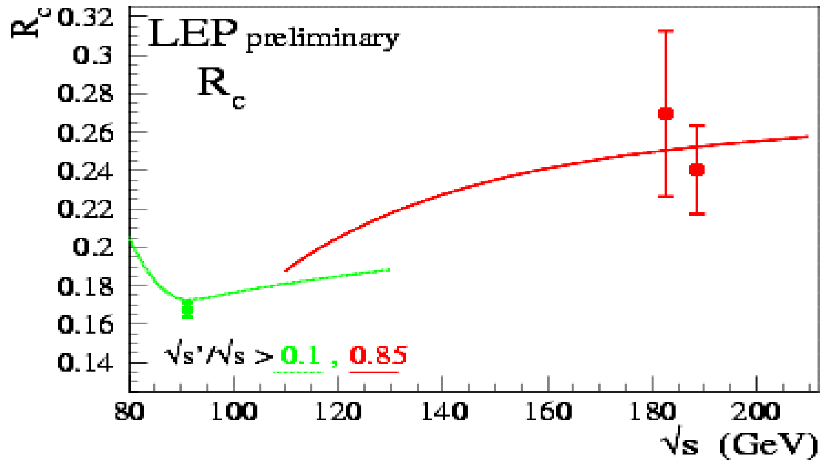


2 fermions cross sections and asymmetries



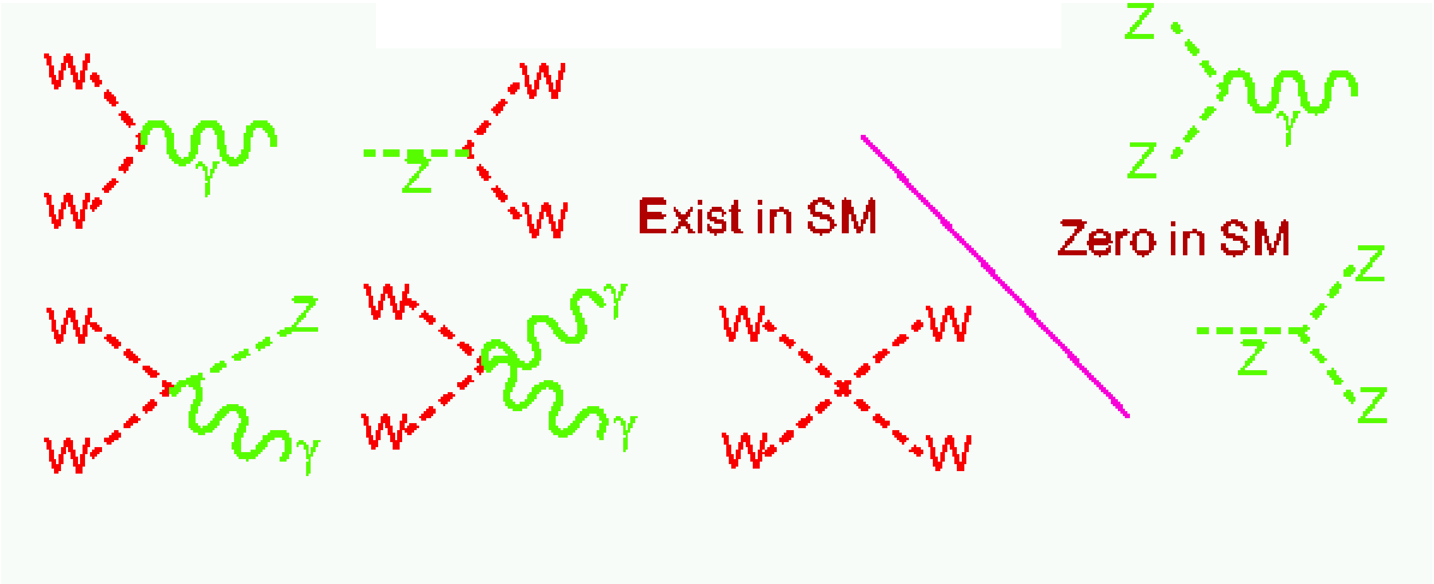
Important to extract limits on new physics:
Contact Interactions, new heavy bosons,
Extra-dimensions, LeptoQuark, excited f....





good agreement with SM

Triple and Quartic Gauge Coupling

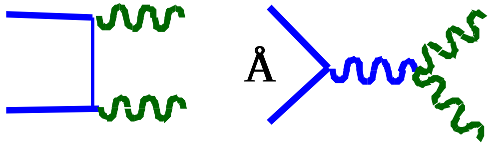


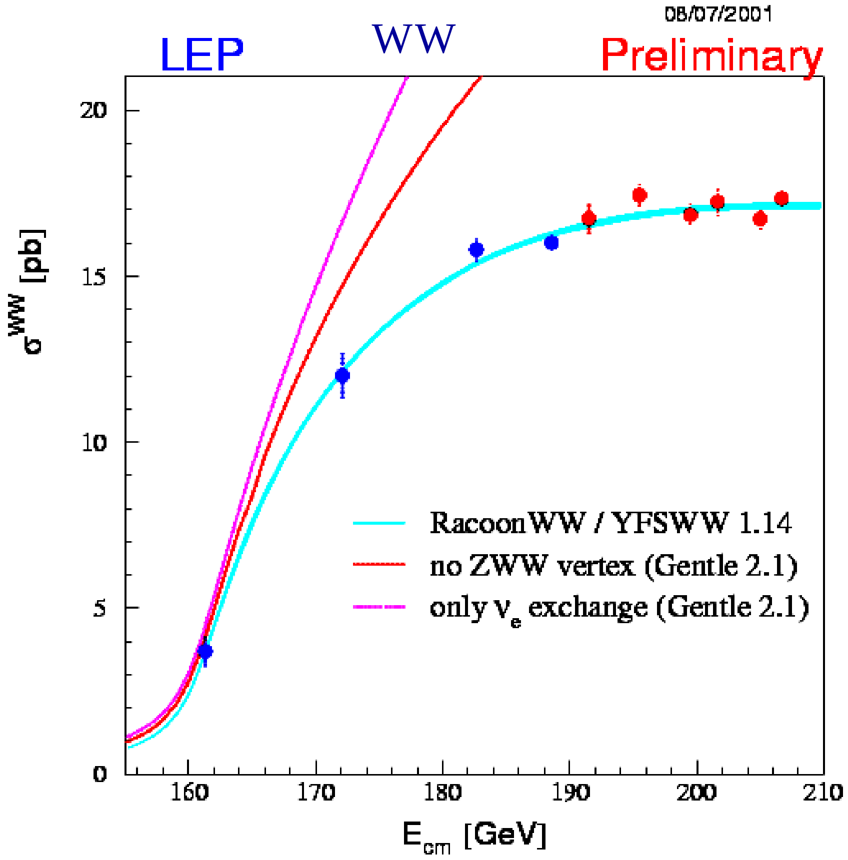
TGC AND QGC are determined by the gauge structure of the theory:
SU(2) is a NON abelian theory: the gauge bosons interact between them
U(1) is abelian: photons do not have TGC.

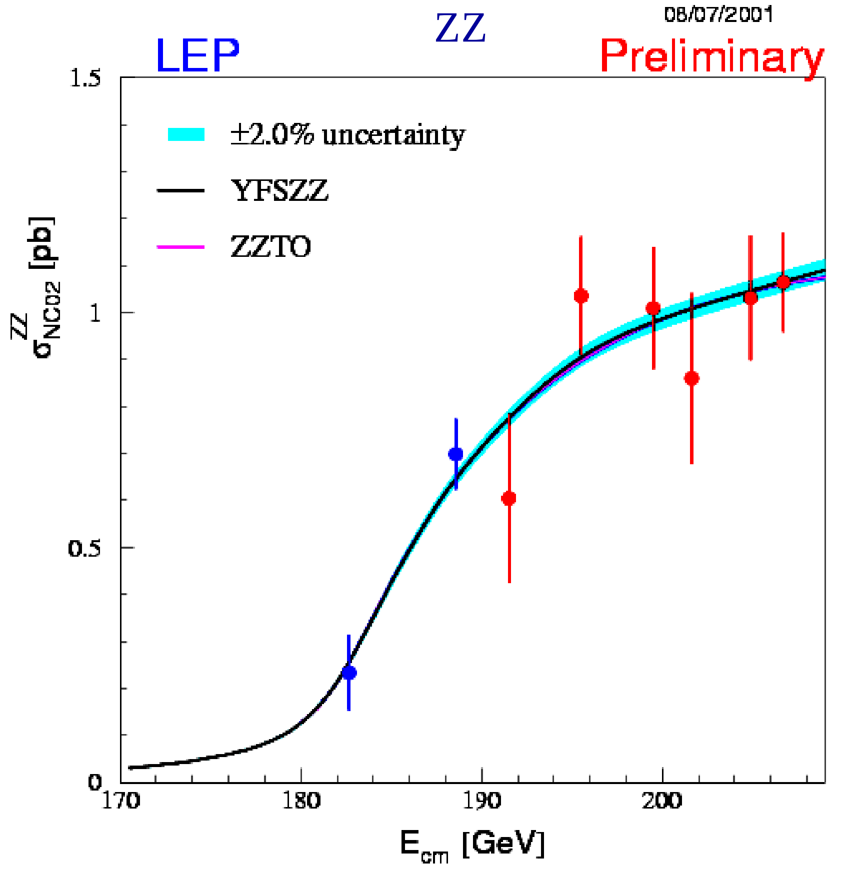
VERY important result that confirm the theory is to see the effect of this !

Much more fun if we would see a deviation w.r.t. the SM !!!

4 fermions cross sections







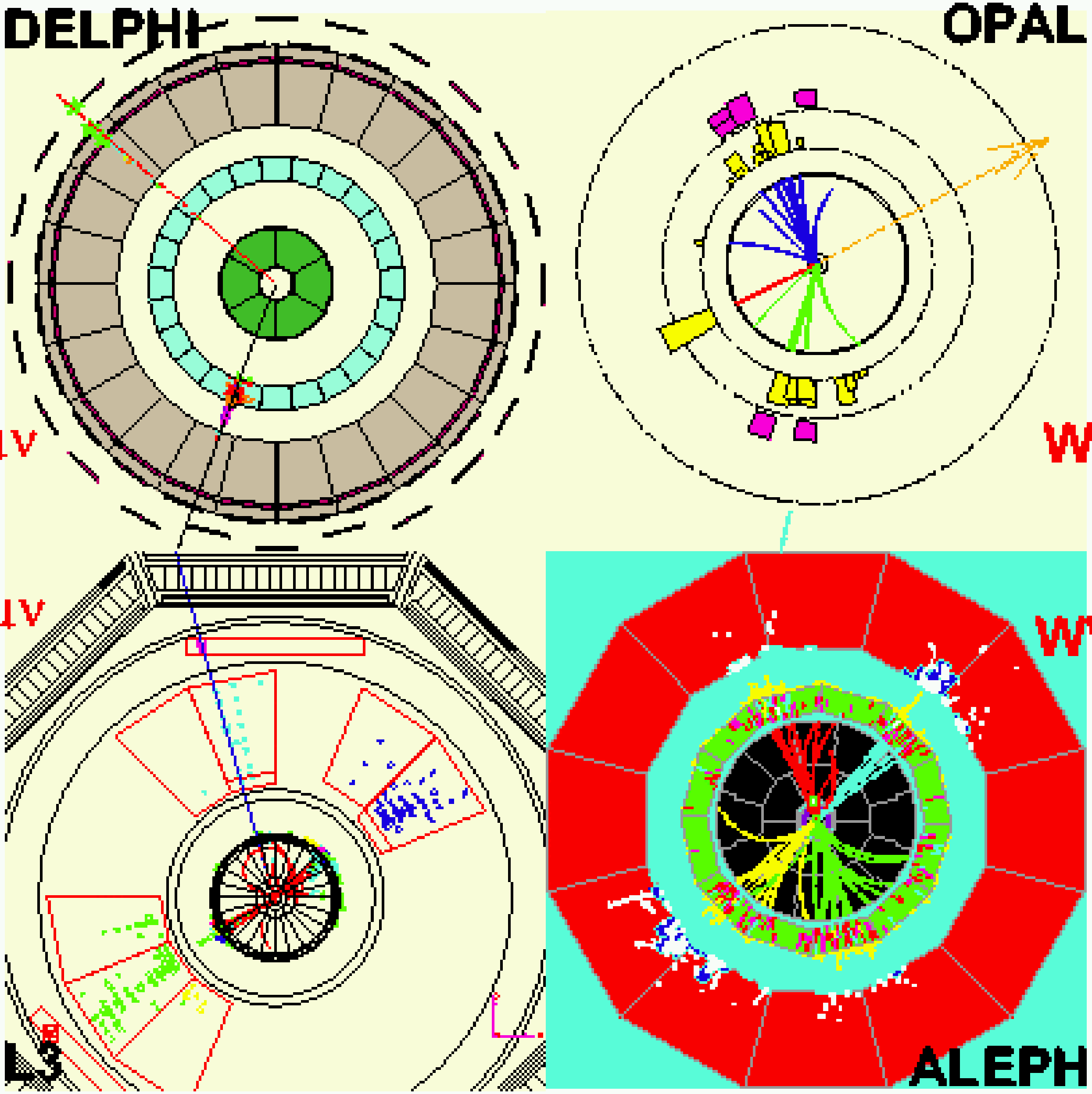
~40000 WW events at LEP

Recent theoretical progress on $O(\alpha)$.
Rad.Corr. modify the kinem. distributions
(mass,boost…) and give a
global -1.5% shift in $\sigma(WW)$

All 5 final states are measured:
qqqq,qqll,qqnn,llvv,llll

DELPHI measures also
$Z\gamma^*$ cross section.

WW events



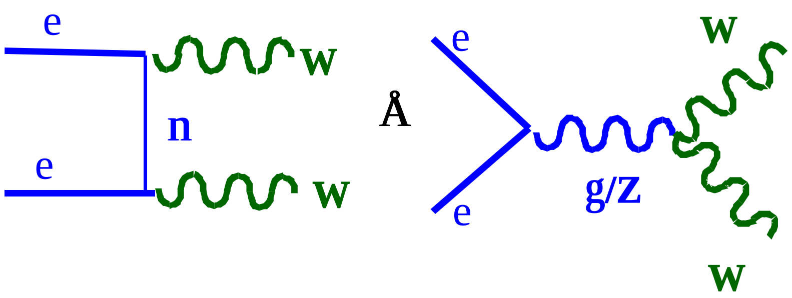
$WW \to e\nu\mu\nu$

$WW \to q\bar{q}\mu\nu$

$WW \to q\bar{q}e\nu$

$WW \to q\bar{q}q\bar{q}$

The measurement of the W mass



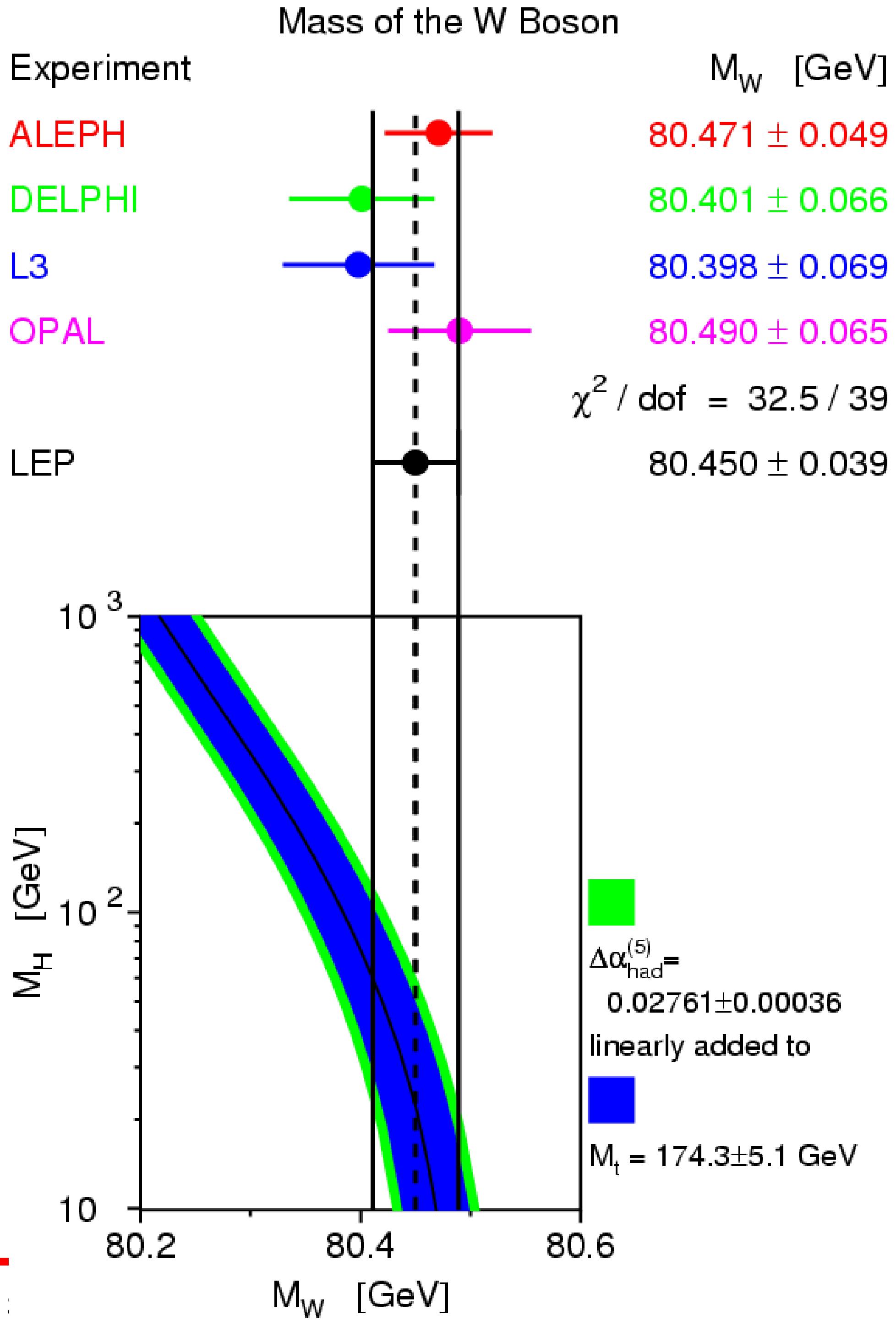
At LEP ~40000 W+W- events:

45.6% WW–> hadrons

★ 43.8% WW–> leptons+hadrons

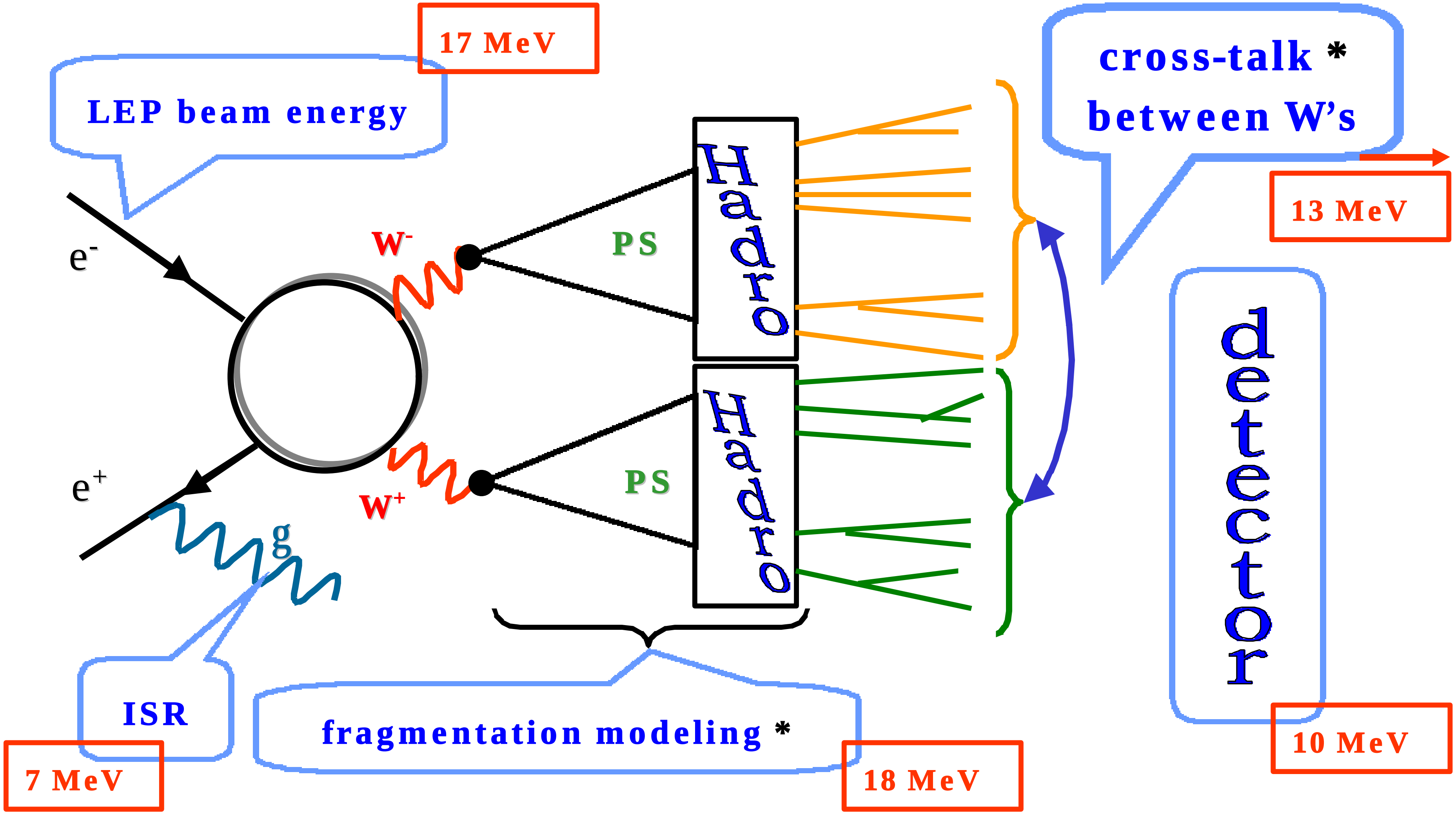
10.6% WW–> leptons

A lot of work still going on on systematic hoping to reach an error of ~35 MeV



1989: M_W=80.0 ± 0.36 GeV

Systematic errors on M_W



LEP beam energy **17 MeV**

ISR **7 MeV**

fragmentation modeling * **18 MeV**

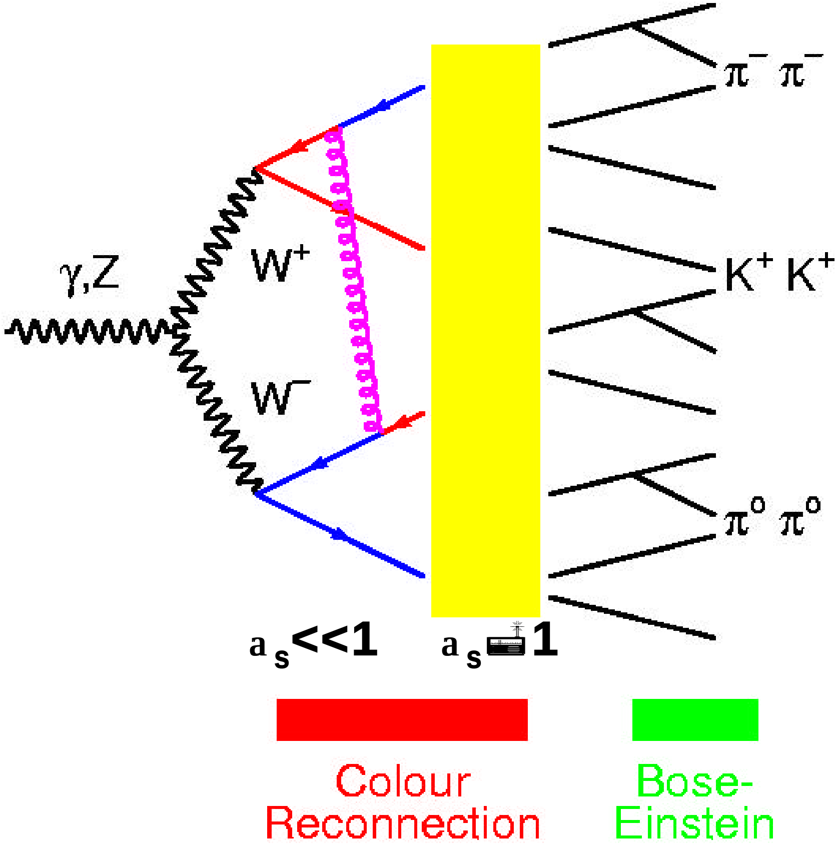
cross-talk * between W's **13 MeV**

detector **10 MeV**

* processes not known from first principles

Cross talk between W

The most difficult measurements, affetc only the final state **qqqq**



Bose Einstein Correlation

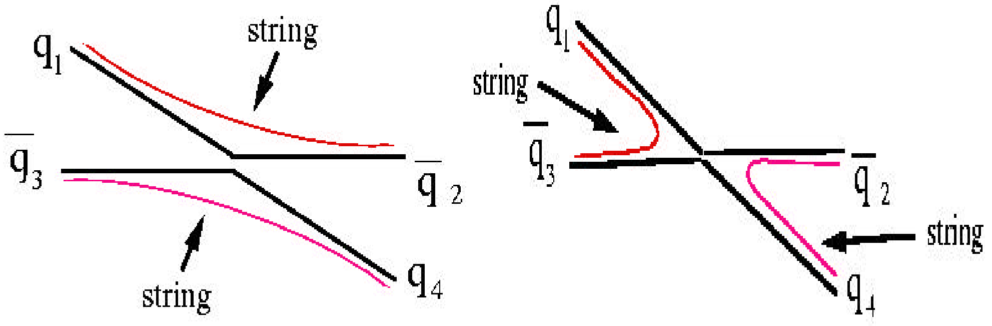
between hadrons in the final state after fragmentation.
Pions of same charge coming from the same boson interact between them.
If they interact as well with the pions from the other boson, the W mass distribution could be distorted.

25 MeV

Color Reconnection

between “coloured” objects in the region of non-perturbative QCD

40 MeV

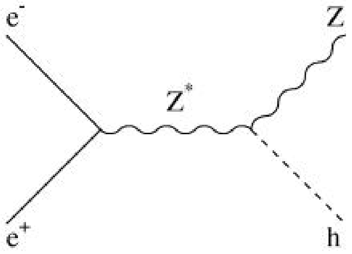


Both these phenomena are not implemented in the MC used by the collaborations

Total (qqqq + 0 from qqln) = 13 MeV

The direct Higgs search

Higgsstrahlung

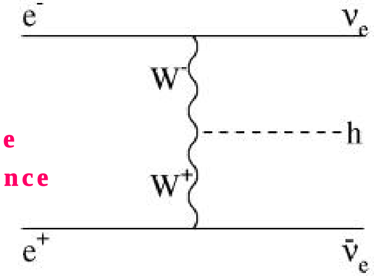


Dominant mode

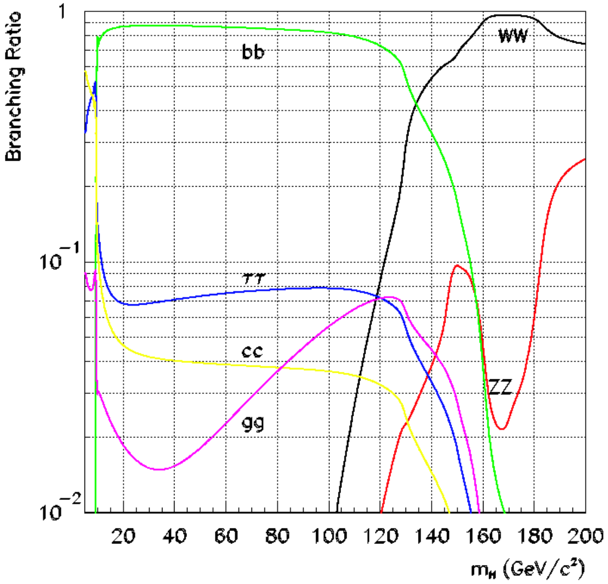
$m(H) \leq \sqrt{s}-m(Z)$

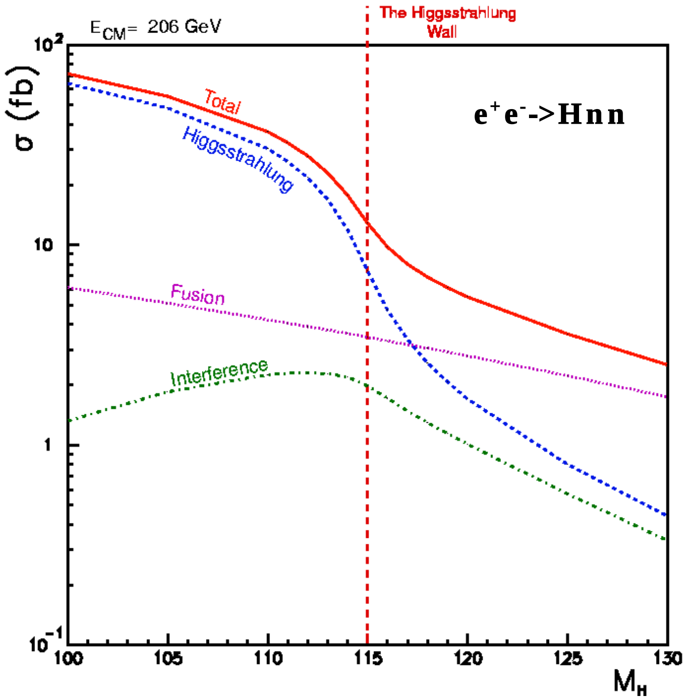
+ positive interference

WW fusion



possibility to go beyond !

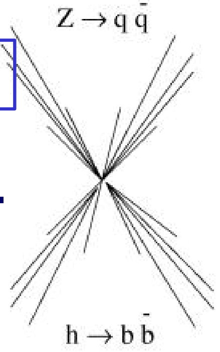


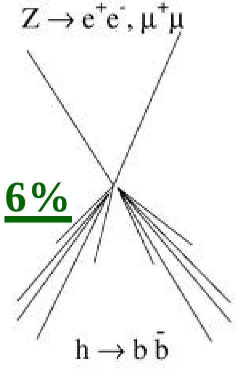


$\sigma \sim 40$ fb

4 jets

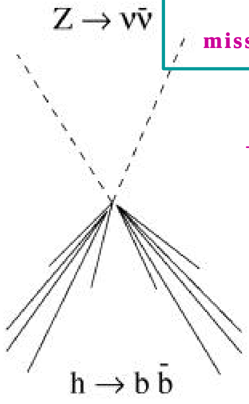
60%





6%

2 jet & 2 lepton

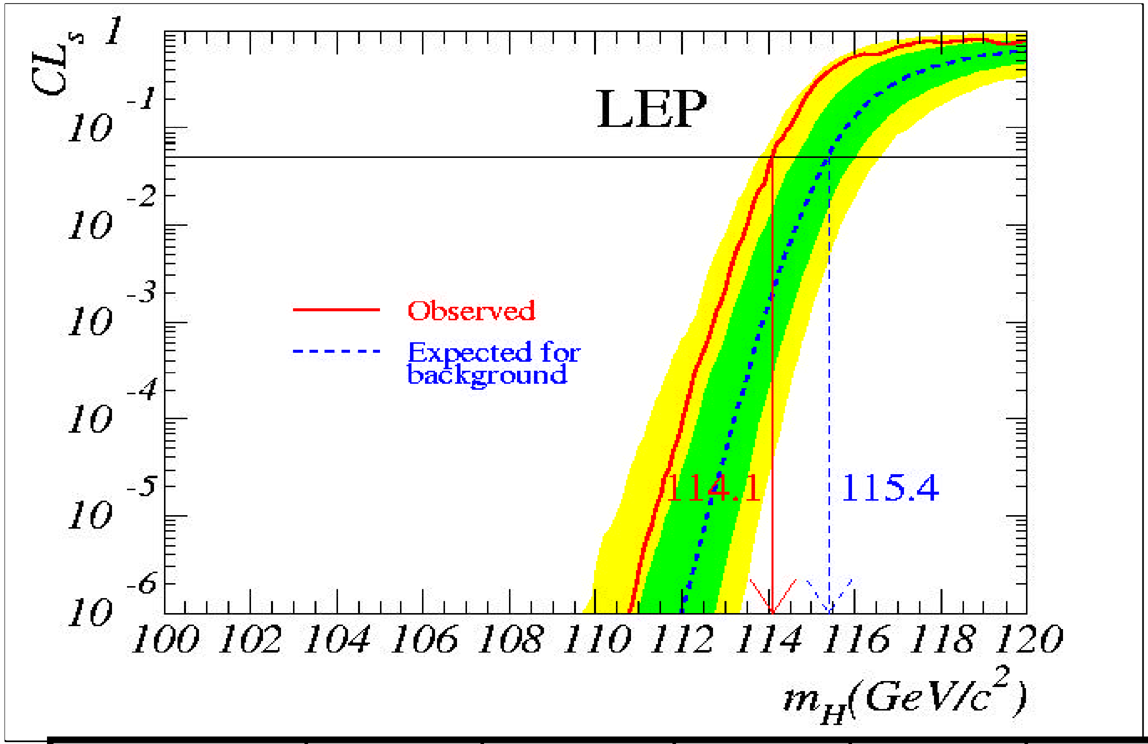


2 jets & missing energy

19%

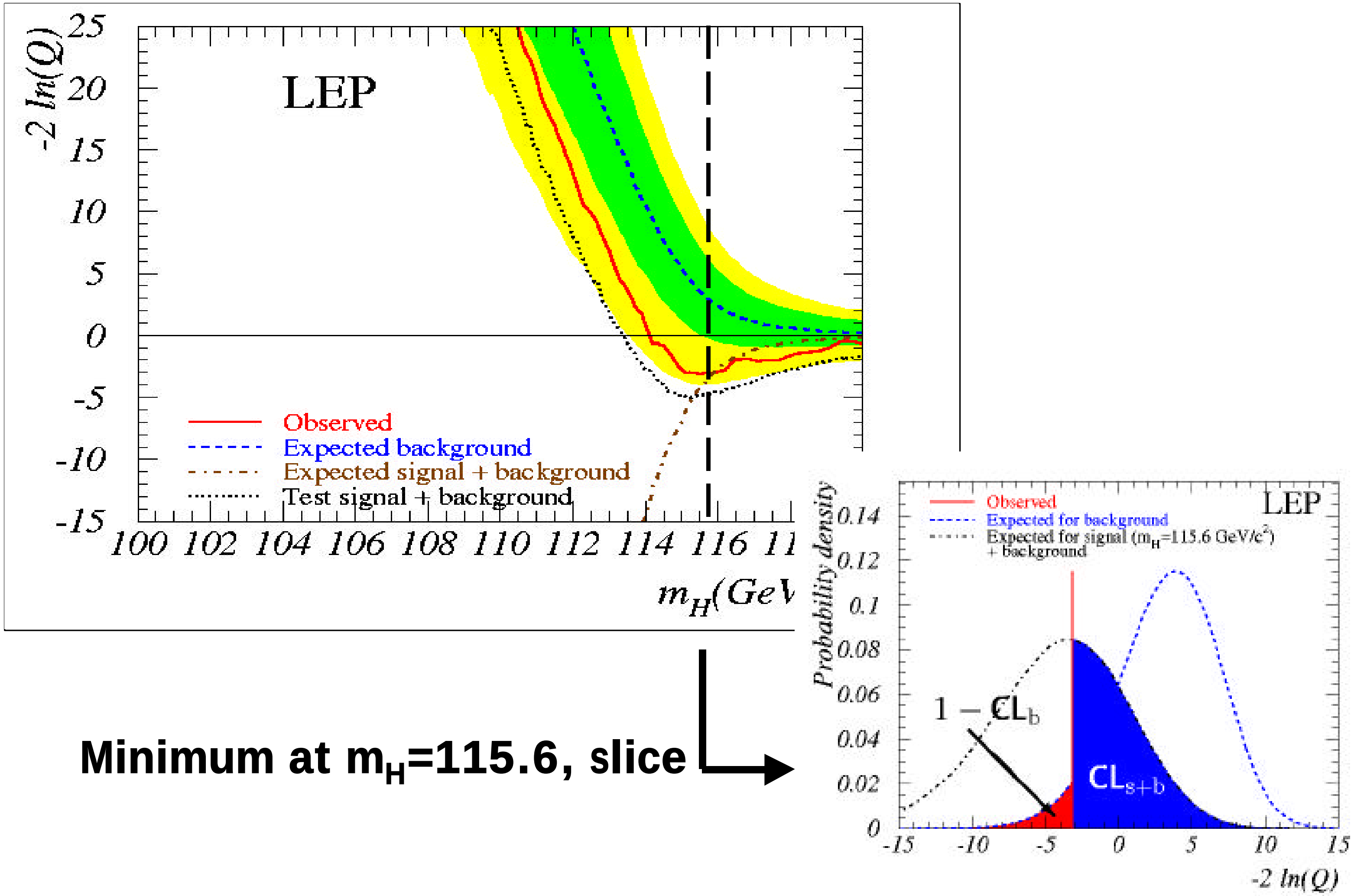
Or a t instead of the b

The preliminary result of the direct Higgs search



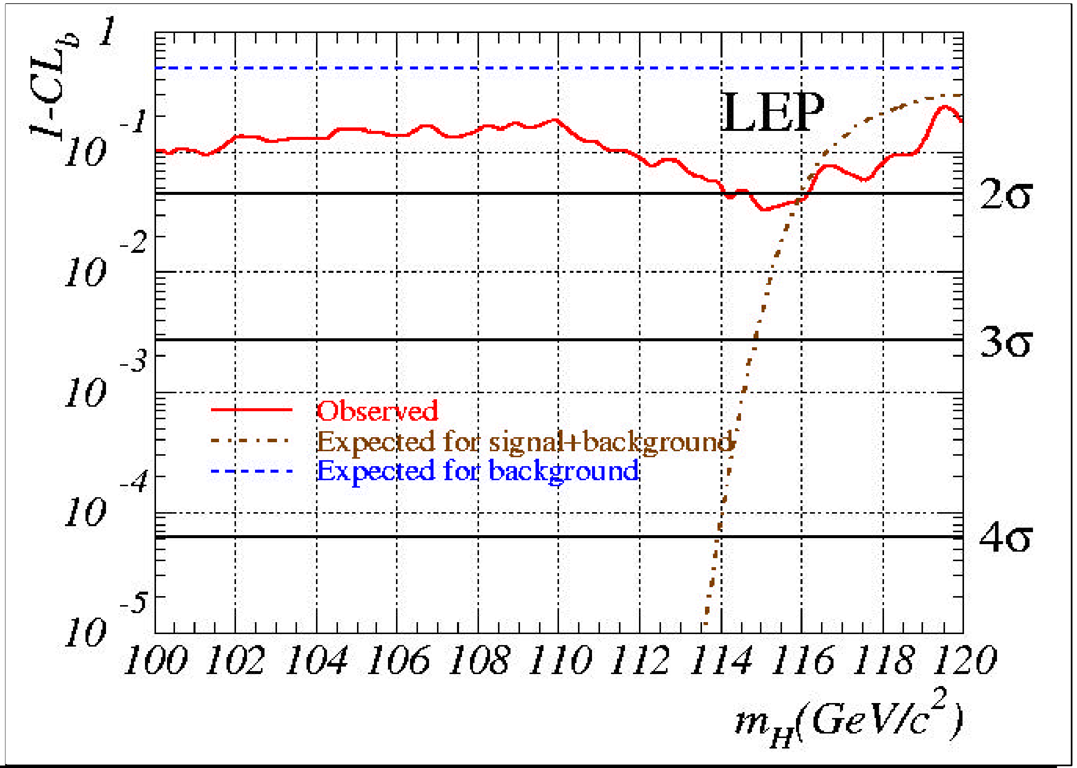
Limit on m_H	ALEPH	DELPHI	L3	OPAL	LEP
Expected	**113.8**	**113.5**	**112.7**	**112.6**	115.4
Observed	111.5	114.3	112.2	109.4	114.1

Is there an excess at high mass?



Minimum at m_H=115.6, slice

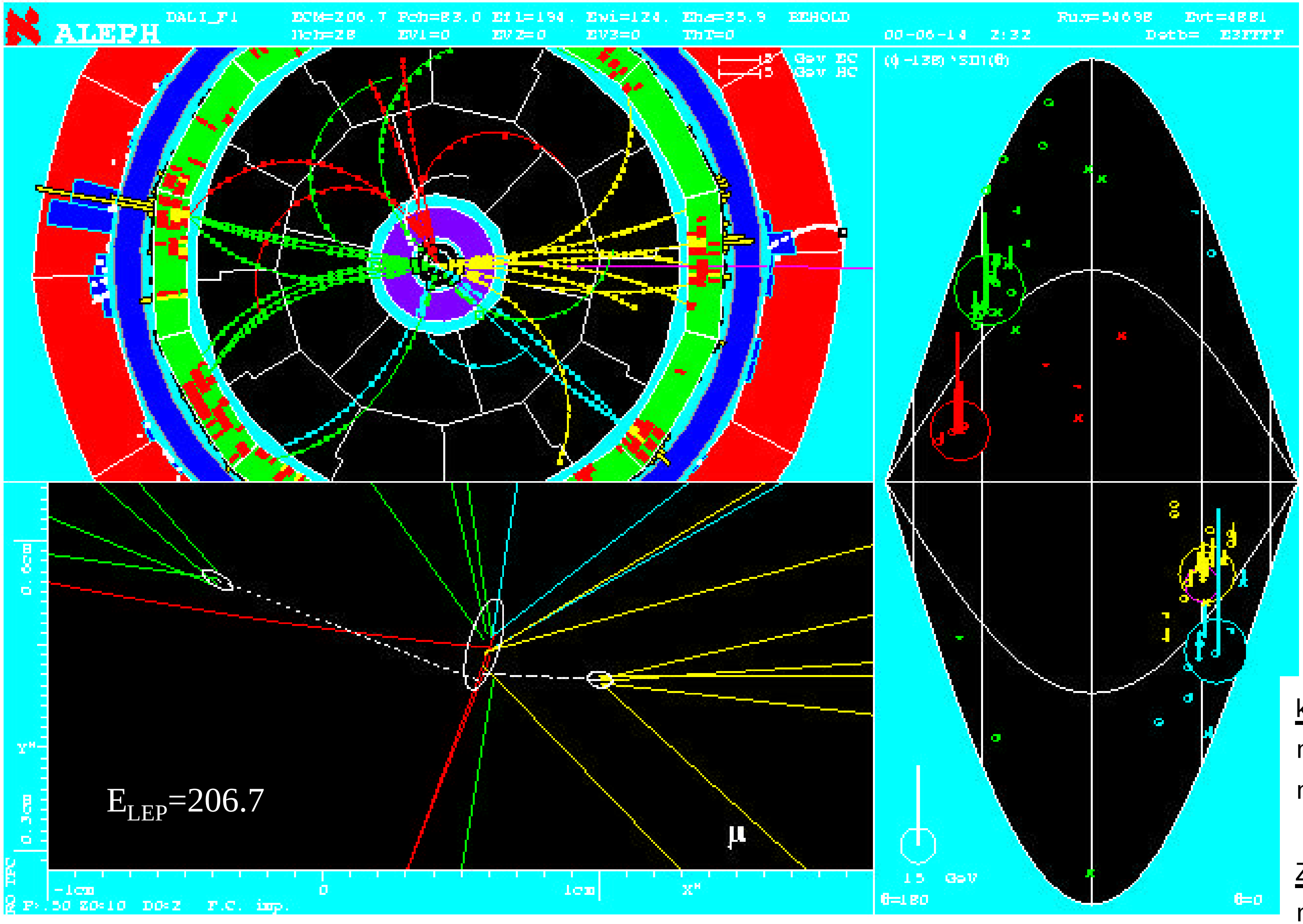
Probability of a local fluctuation



$(m_H=115.6)$	ALEPH	DELPHI	L3	OPAL	LEP
1-CL$_b$	0.0023	0.88	0.25	0.22	0.035

DLO
0.48

Aleph candidate #1



2 b cand.

HZ hyp.

m_H=114 GeV ±3 GeV

NN = 0.996

jet	**b-tag:**
Z	
1	**0.14**
2	**0.01**
H	
3	**0.99**
4	**0.99**

kin. mass fit

m_H=112.4GeV

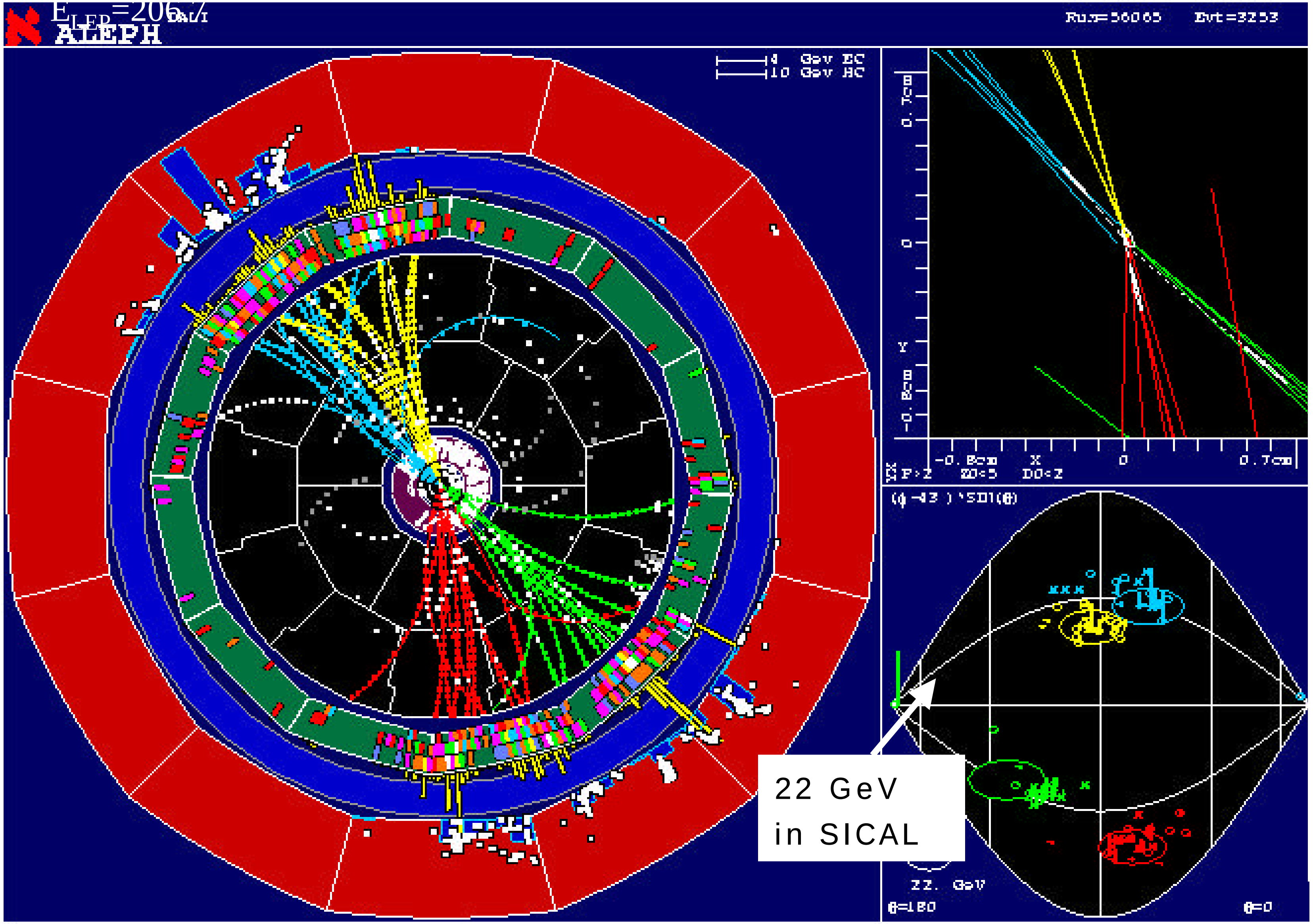
m_Z=93.3GeV

ZZ hyp.

m_Z=102 GeV

m_Z=91.7GeV

Aleph candidate #2



22 GeV
in SICAL

4 b cand.

HZ hyp.

m_H=
112.8 GeV

NN = 0.997

jet	**b-tag:**
Z	
1	**0.994**
2	**0.78**
H	
3	**0.993**
4	**0.999**

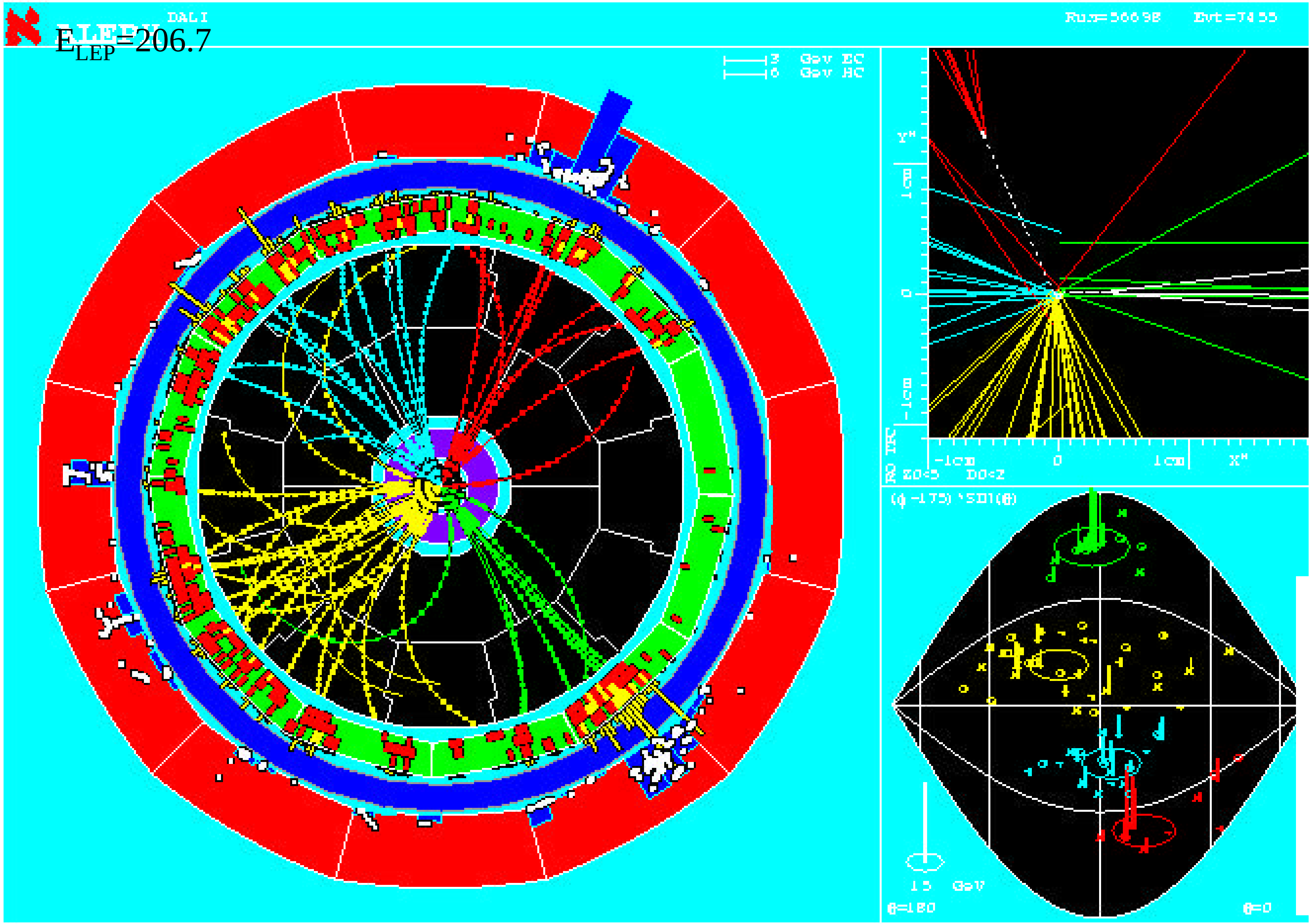
Evis=
252 GeV

very bad
kin. fit!

⇒

assumption: 22 GeV in SICAL is beam related

Aleph candidate #3


E_{LEP}=206.7

4 b cand.

m_H=110 GeV

±3 GeV

NN = 0.999

jet b-tag:

Z

1 0.99

2 0.84

H

kin. mass fit

m_H=109.1GeV

m_Z=92.3GeV

ZZ hyp.

m_Z=100 GeV

m_Z= 99 GeV

The NuTev new result

NuTev study weak interactions via νN scattering

left-handed leptons -> weak charged current
right-handed leptons -> weak neutral + charged current

$$R \equiv \frac{\sigma(\nu\ N \rightarrow \nu\ X) - \sigma(\bar{\nu}\ N \rightarrow \bar{\nu}\ X)}{\sigma(\nu\ N \rightarrow \mu^{-} X) - \sigma(\bar{\nu}\ N \rightarrow \mu^{+} X)} = g^2_L - g^2_R$$

$$\Rightarrow \sin\theta_W = 0.2277 \pm 0.0013(\text{stat}) \pm 0.009(\text{syst})$$
$$- 0.00022 \times (M^2_{top} - 175^2)/\ 50^2$$
$$+ 0.00032 \times \ln(\ M(H)/150)$$

Global SM fit
0.2227 ± 0.00037

World direct
84.45 ± 0.04 GeV

$$\sin^2\theta_W \equiv 1 - m^2_W/m^2_Z \Rightarrow m^2_W = 80.14 \pm 0.08 \text{ GeV}$$

THIS MEASUREMENT IS NOT INCLUDED IN THE RESULTS YET

The global ElectroWeak fit

Use precise LEP/SLD and Tevatron EW data to probe SM

PLUS: $\sin^2\theta_W$ from νN scattering, atomic parity violation of Cs

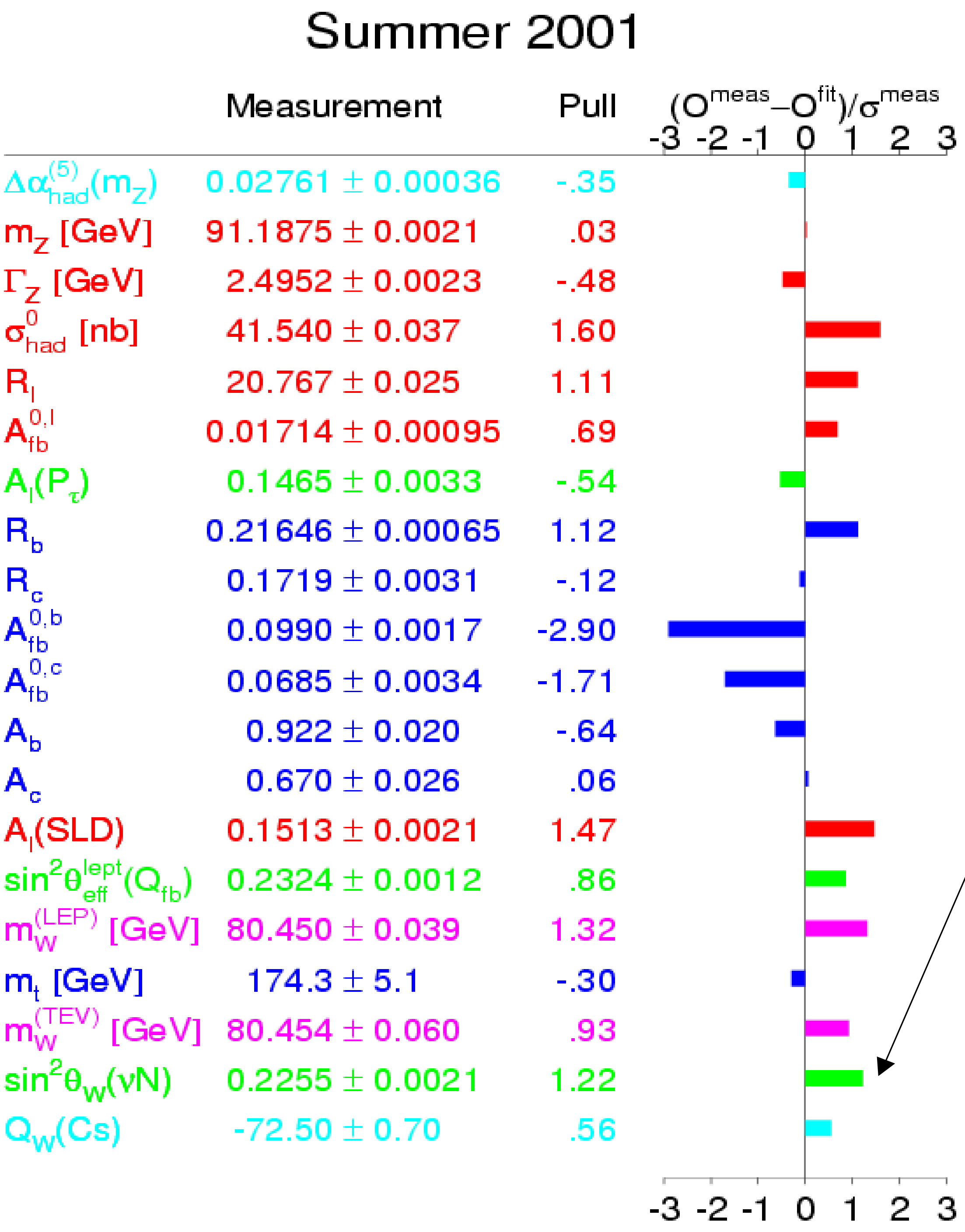
SM predictions from ZITTER and TOPAZ0 programs

Parameters:

m_Z	measured precisely by LEP-1 data	$2 \cdot 10^{-5}$
$\alpha_s(m_Z)$	measured precisely by LEP-1 data	$1.6 \cdot 10^{-2}$
$\alpha_{em}(m_Z)$	requires use of R(low E) for hadronic corrections	
m_W, m_{top}	measured at Tevatron and LEP-2, but also extracted indirectly from other EW measurements	
m(H)	can then be predicted !	

The global EW fit

Summer 2001



	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.35
m_Z [GeV]	91.1875 ± 0.0021	.03
Γ_Z [GeV]	2.4952 ± 0.0023	-.48
σ^0_{had} [nb]	41.540 ± 0.037	1.60
R_l	20.767 ± 0.025	1.11
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.69
$A_l(P_\tau)$	0.1465 ± 0.0033	-.54
R_b	0.21646 ± 0.00065	1.12
R_c	0.1719 ± 0.0031	-.12
$A^{0,b}_{fb}$	0.0990 ± 0.0017	-2.90
$A^{0,c}_{fb}$	0.0685 ± 0.0034	-1.71
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.47
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
$m_W^{(LEP)}$ [GeV]	80.450 ± 0.039	1.32
m_t [GeV]	174.3 ± 5.1	-.30
$m_W^{(TEV)}$ [GeV]	80.454 ± 0.060	.93
$\sin^2\theta_W(\nu N)$	0.2255 ± 0.0021	1.22
$Q_W(Cs)$	-72.50 ± 0.70	.56

Overall consistency:
8.6% probability
22.9/15 χ^2/d.o.f.

The quark asymmetries give the sizeable contribution to the χ^2

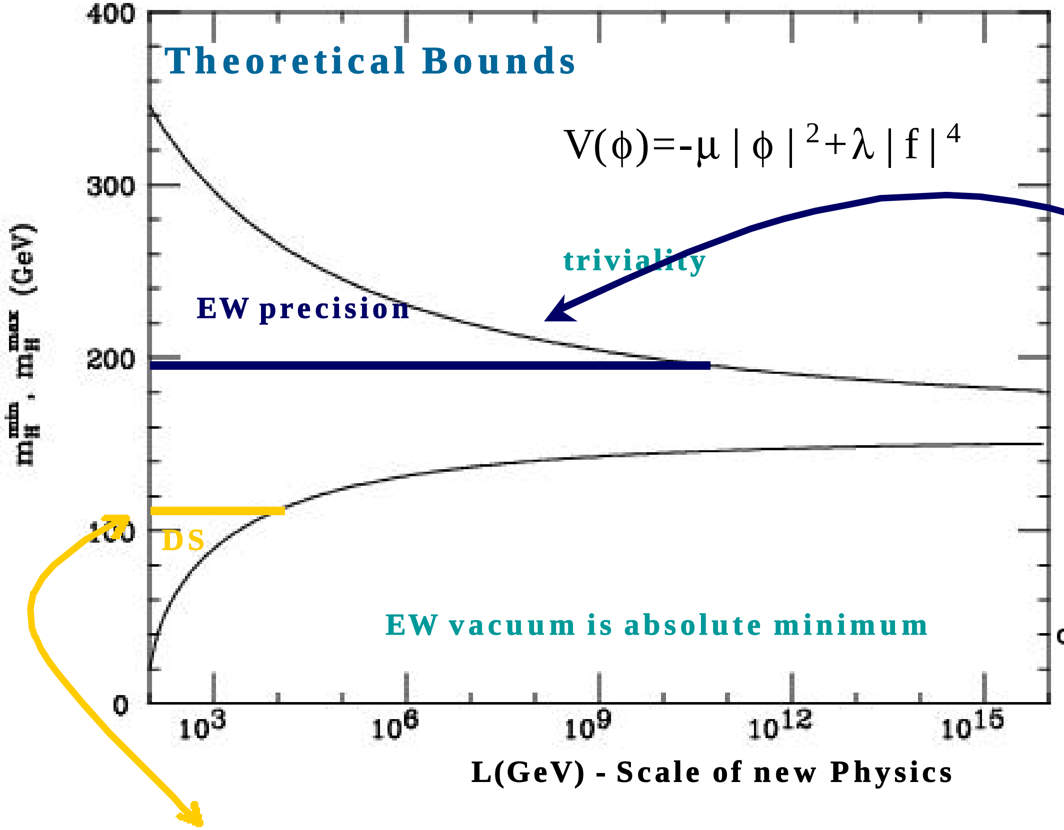
BUT not yet included:
New measurement of $\sin\theta_W$ by NuTeV 3σ higher than SM
–> ~ 1 % probability
higher χ^2/d.o.f. !!!

$N(\nu) = 2.9841 \pm 0.0083$

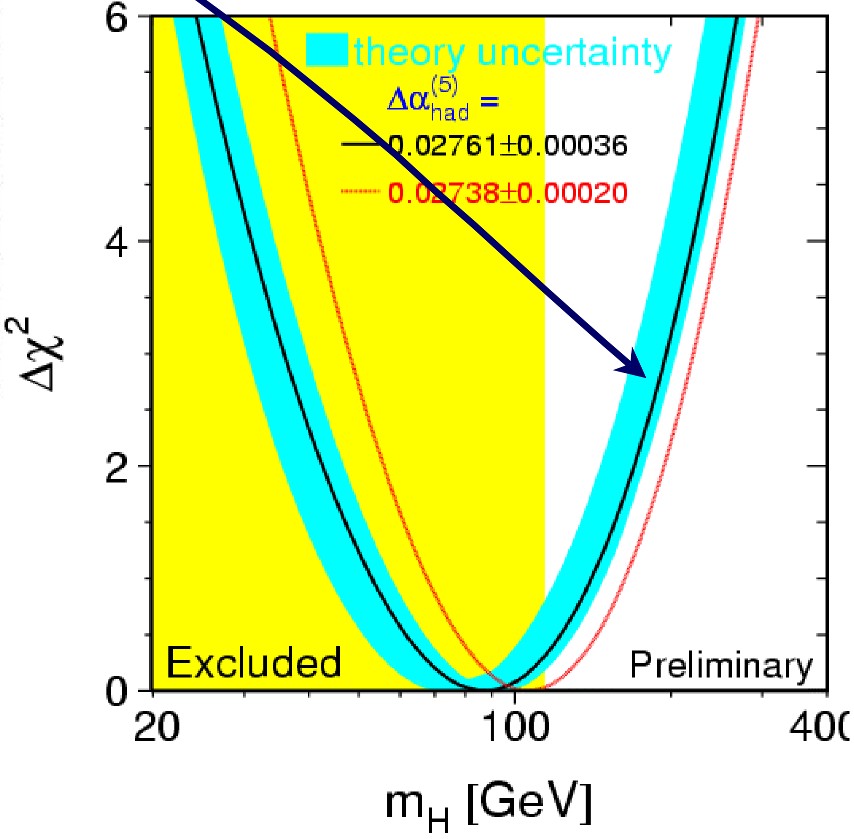
Direct measurement from single γ
$N(\nu) = 2.80 \pm 0.09$

SM Higgs

NEW
a_{em} BES →
A_{FB}(b,c) →
M(W) ←



m(H)£ 196 GeV/c^2
at 95% CL



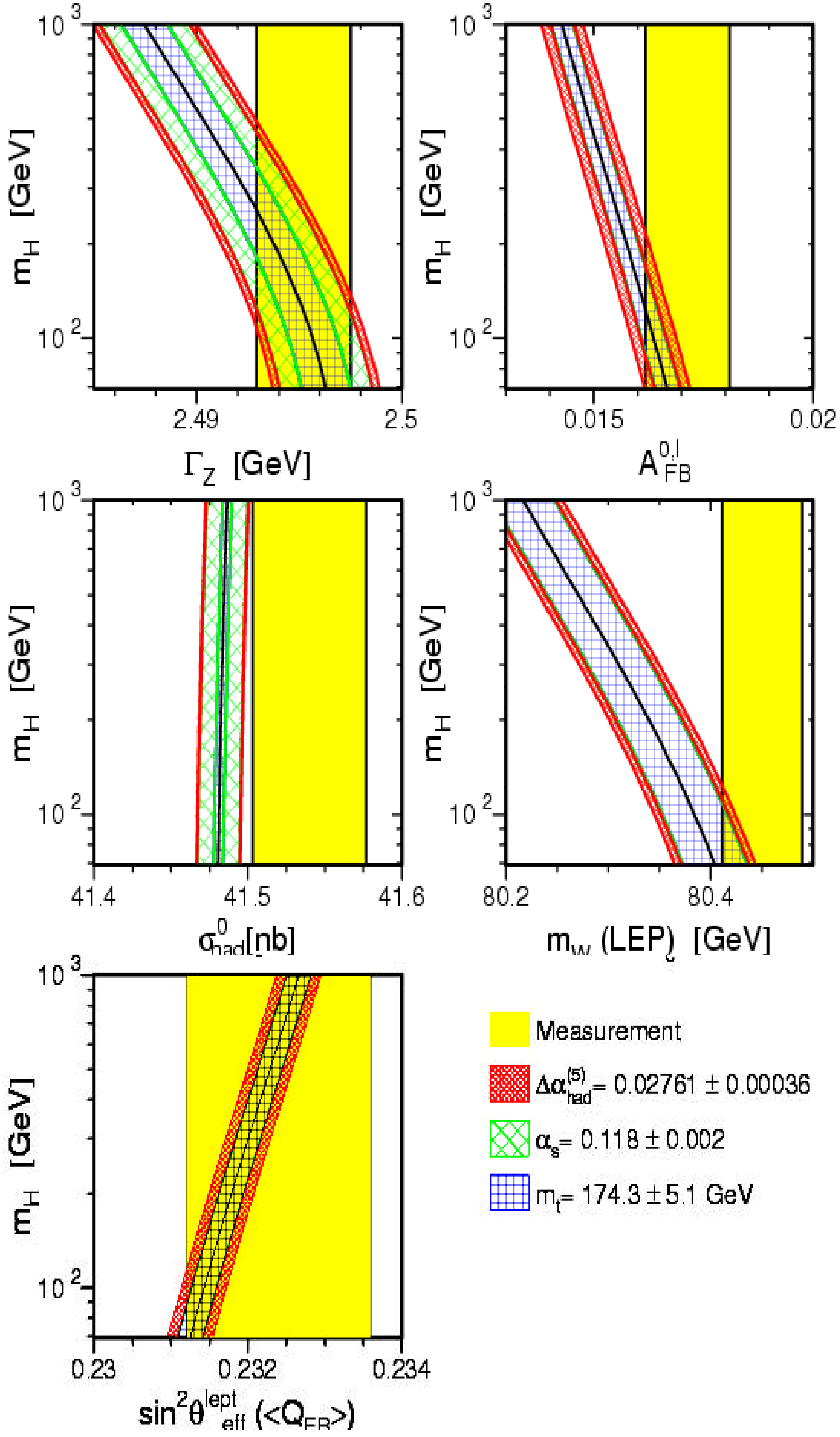
Direct Search

m(H) ≥ 114.1 GeV/c^2

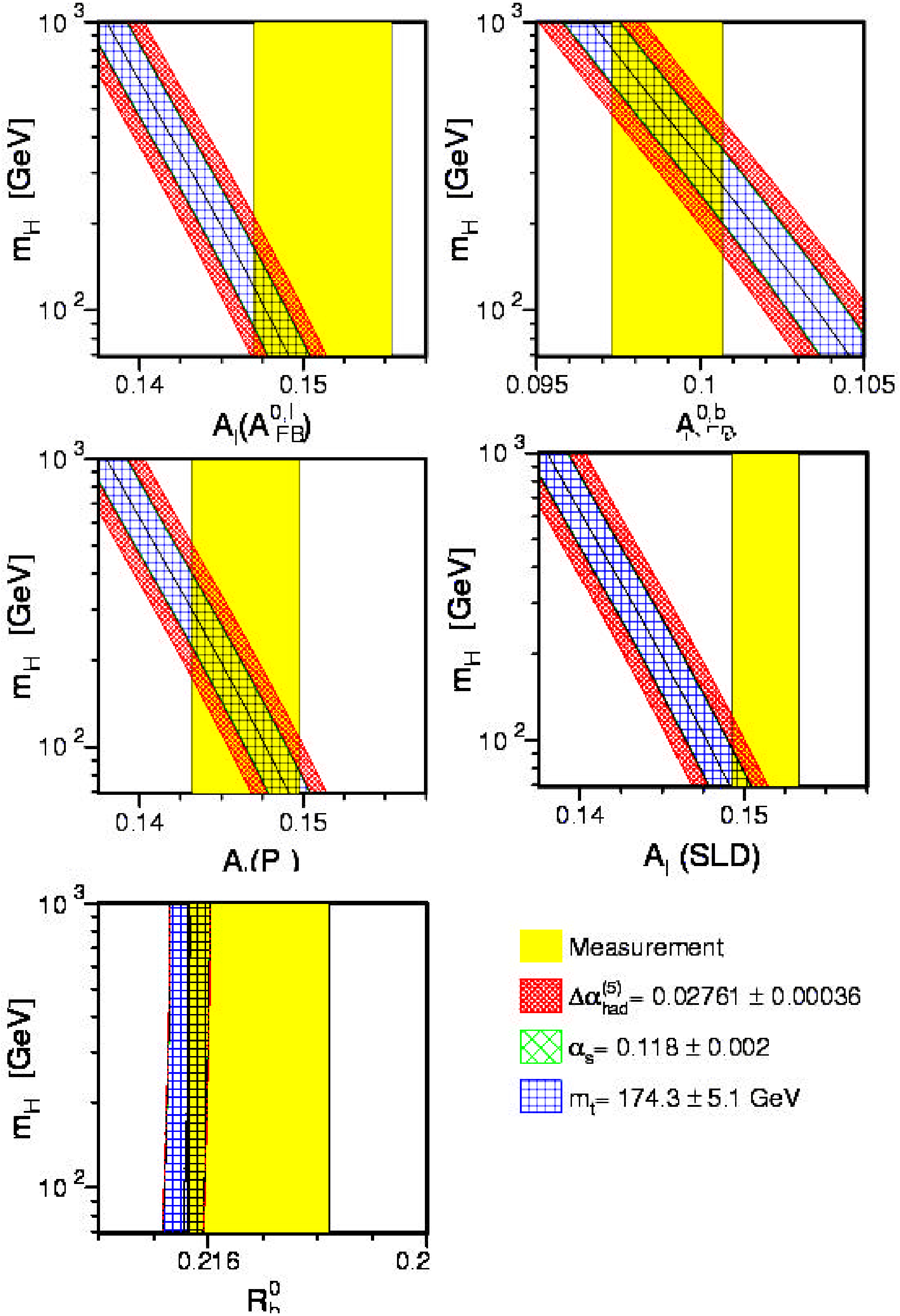
at 95% CL

EW precision measurements

$m(H)=88^{+53}_{-35}$ GeV/c^2

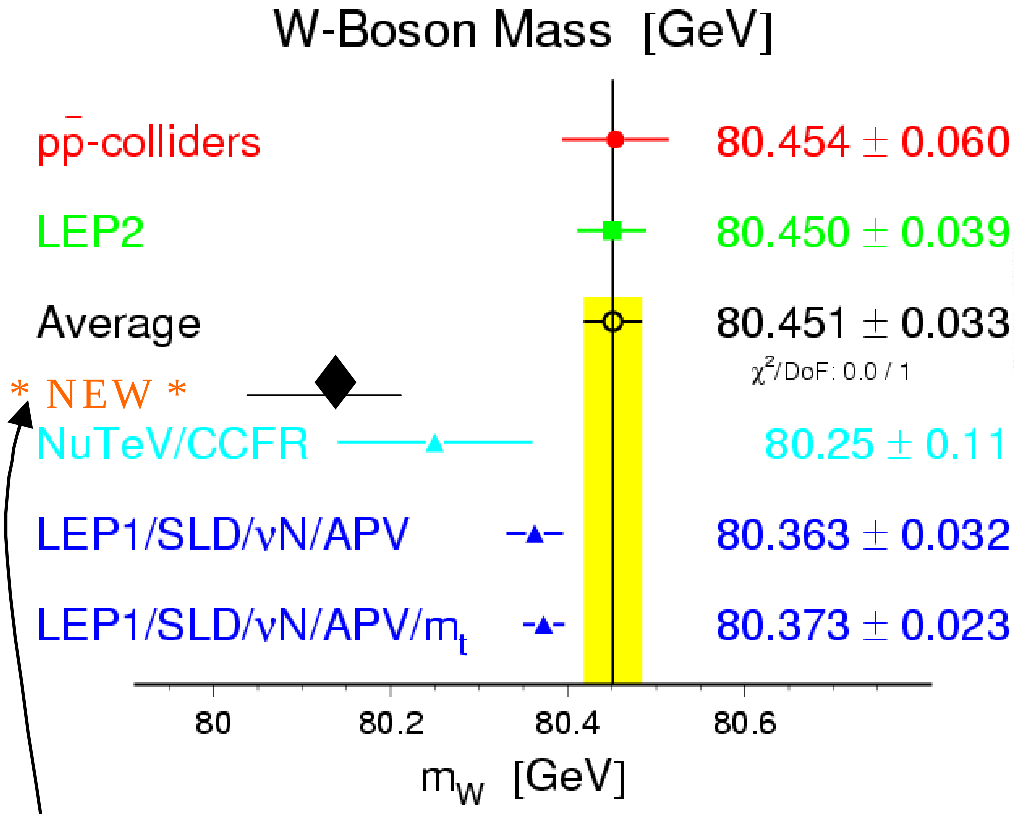


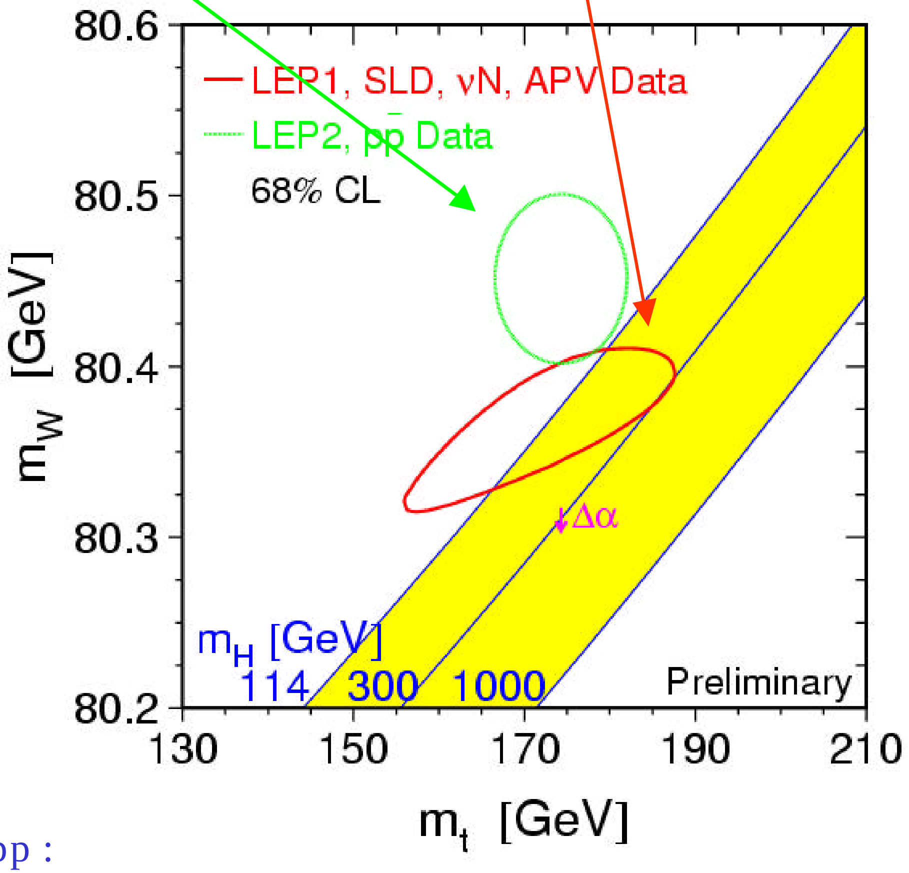
m_H [GeV]
10^3
10^2
2.49
2.5
Γ_Z [GeV]
0.015
0.02
A_FB^0,l
41.4
41.5
41.6
σ_had^0 [nb]
80.2
80.4
m_W (LEP) [GeV]
0.23
0.232
0.234
sin²θ_eff^lept (<Q_FB>)
Measurement
Δα_had^(5) = 0.02761 ± 0.00036
α_s = 0.118 ± 0.002
m_t = 174.3 ± 5.1 GeV



m_H [GeV]
10^3
10^2
0.14
0.15
A_l(A_FB^0,l)
0.095
0.1
0.105
A_FB^0,b
A_l(P_τ)
A_l (SLD)
0.216
0.2
R_b^0
Measurement
Δα_had^(5) = 0.02761 ± 0.00036
α_s = 0.118 ± 0.002
m_t = 174.3 ± 5.1 GeV

Mass of the W: direct and indirect





m_W from ee and pp :
very different systematic

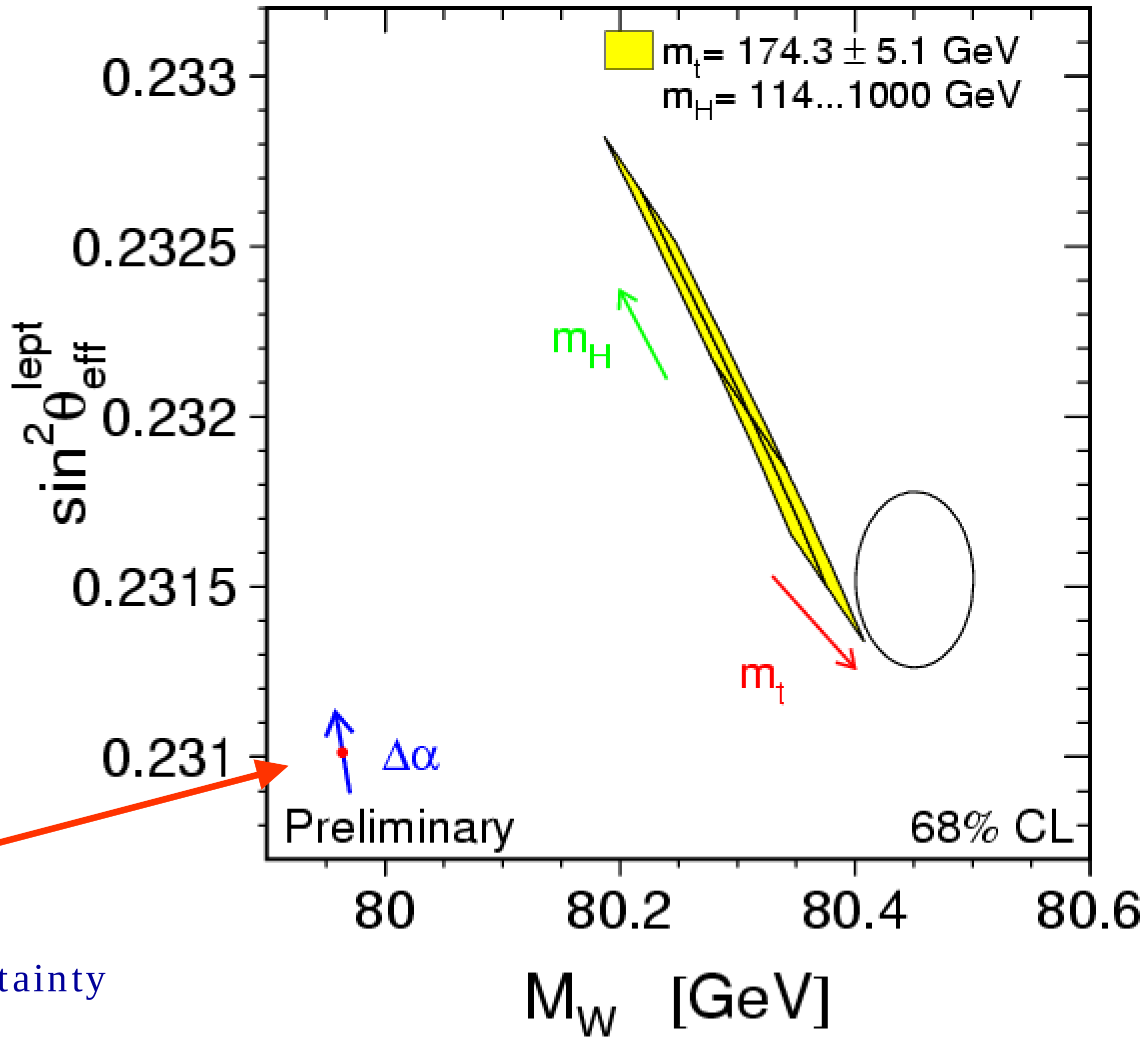
1.9 σ agreement

NEW value from NuTev (Dic-2001)
80.14±0.08 : 4σ away to direct m_W

Direct m_W –> very low Higgs mass

Consistency

The data seems to prefer
a very light Higgs
and a higher top mass!!



The “Born” prediction:
shown only α running and its uncertainty

The presence of weak radiative correction !!!

Alpha QED at M(Z)

*Dominating the uncertainty on $\sin^2\theta_W$

*A big uncertainty on the indirect determination of the Higgs mass comes from the value used for α_{em}

$\alpha\,(0) = 1.137.03599976(50)$ 3.7 ppb

At the Z we need $\alpha(M^2_Z)$. The running is written as:

$$\alpha(M^2_Z) = \frac{\alpha\,(0)}{1 - \Delta\alpha_{e\mu\tau}(s) - \Delta\alpha^{(5)}_{had}(s) - \Delta\alpha_{top}(s)}$$

Very well known

Computed from R at low energies

$$\Delta\alpha^{(5)}_{had}(M^2_Z) = \alpha\ M^2_Z / 3\pi\ \mathrm{Re} \int ds\ R(s) /(s(s - M^2_Z - i\varepsilon)$$

depending on the way the group treat the data and integrate the results can differ :

used now: Burkhardt and Pietrzyk 2001: $\Delta\alpha^{(5)}_{had}(M^2_Z) = 0.02761 \pm 0.00036$

using the old used value of Jegerlener of 0.02804 ± 0.00065

the central value of the Higgs mass is lowered by ~40 GeV

The factor of 2 improvement of B+P comes from the new BES-II result

Alpha QED

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu\mu)}$$

$$\sigma(e^+e^- \to \mu\mu) = 4\pi\alpha^2(0)/3s$$

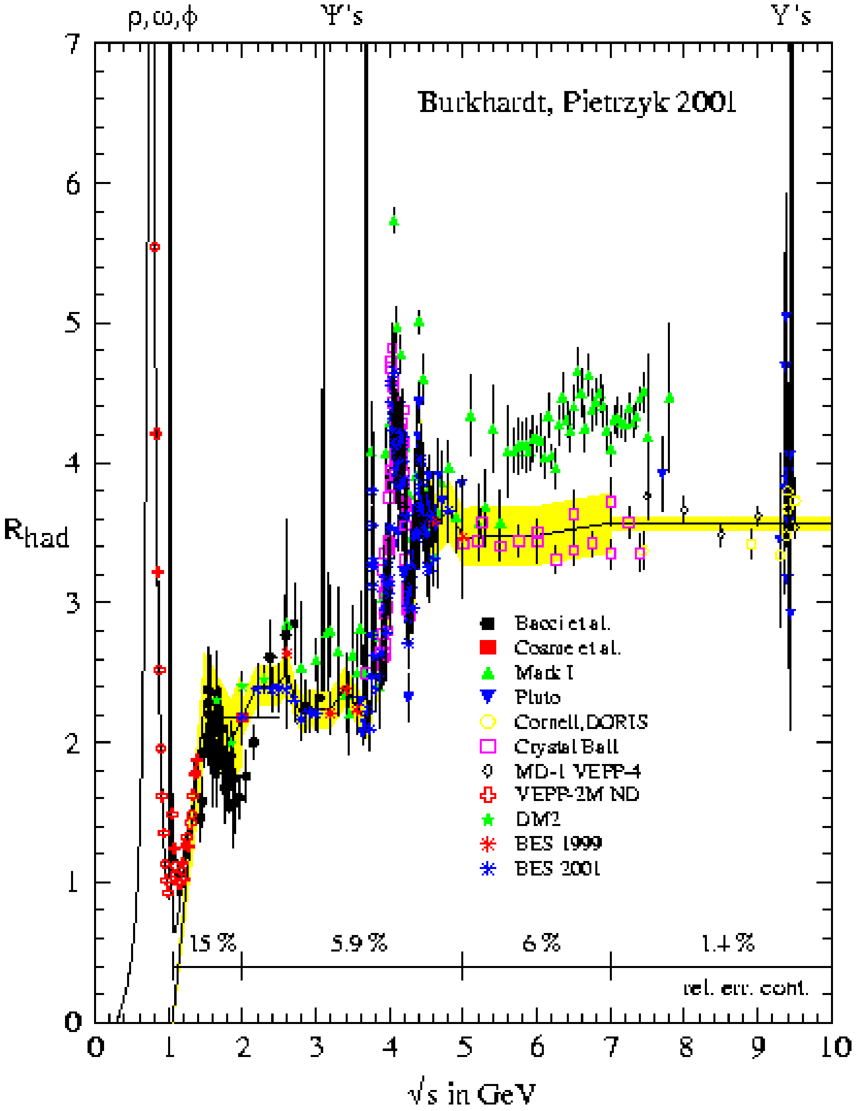
BES-II new measurement of R

From 85 √s value from 2-4.8 GeV

Factor 2-3 improvement on R !

NEW measurements will come

from KLOE and Babar +…



AS OF TODAY:

Foundation of the standard Model

α_{em}	is the less well kown:	**3.1×10^{-4}**	**700ppm**
M(Z)		**2×10^{-5}**	**23ppm**
G_F		**8.6×10^{-6}**	**9 ppm**

ALL OK …but if we really want to find some problems….:

$\sin^2\theta_W$ from leptons and quarks disagree $\sim 3\sigma$

(m(H)_LEP ~ 30 GeV /m(H)_b,c ~ 500 GeV)

m(W) direct and indirect

m(W) direct ~ 80.451 ± 0.033 $\sim 2\sigma$

m(W) indirect ~ 80.373 ± 0.023

$A_{FB}(b)$ deviates from SM prediction $\sim 3\sigma$

N(n) direct (fit EW) and indirect (single γ) $\sim 2\sigma$

AND

$\sin^2\theta_W$ /Mw from NuTev make the SM fit probability much worst

AND the 2σ effect on the direct Higgs search !

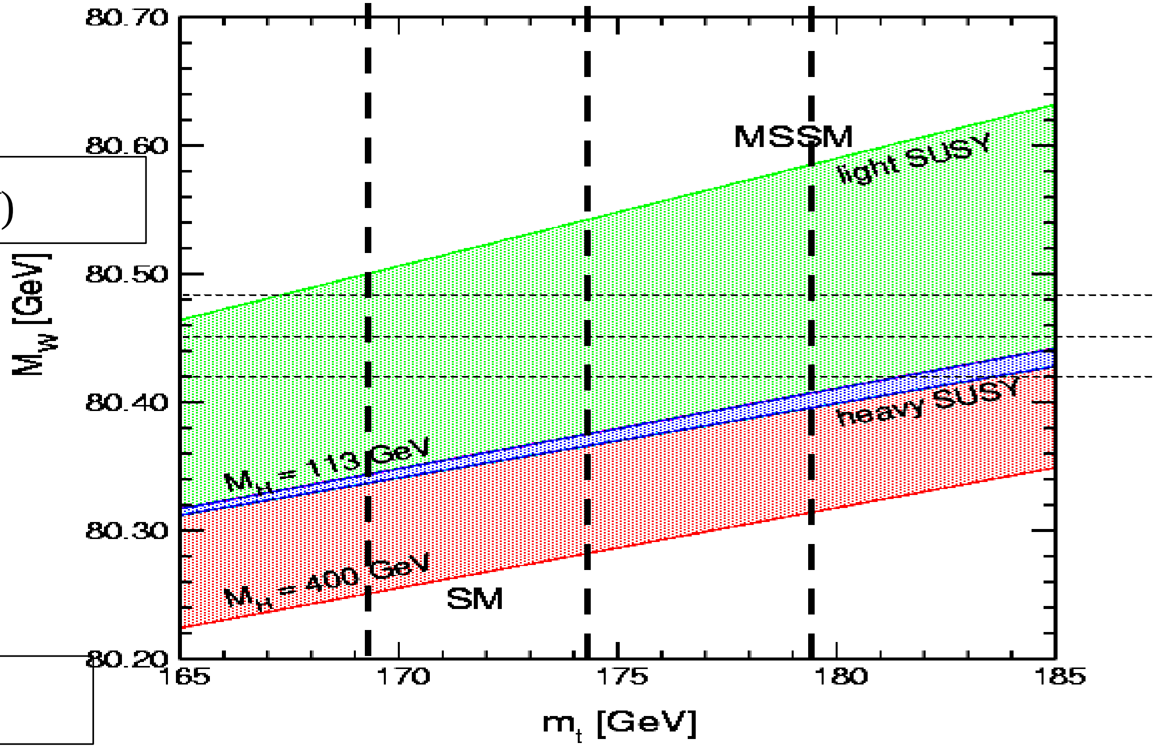
The top and W at future colliders

Electroweak precision observables provide the basis for consistency test of the SM or its extensions (ex MSSM) (we can think of the top mass effect on the MSSM !).

Direct and indirect measurements should match for a stringent test.

If the Higgs is found or not, it is mandatory to precisely know the EW observables to understand which is the mechanism that breaks the symmetry.

m(W)= 80.451 ±0.033 GeV)



m(top)= 174.3 ±5.1 GeV)

The top and W at future colliders

✱From the previous results and from the expression of the weak radiative correction we need to improve the top mass uncertainty!

$$\Delta\rho = 3G_\mu m^2_{top}/(8\pi^2\sqrt{2})$$

* And even more the W mass:

$$m_W = \left(\frac{\pi\alpha_{em}}{\sqrt{2}G_F}\right)^{1/2} \frac{1}{\sin\theta_W\sqrt{1-\Delta r}} \longrightarrow f(m^2_{top}, \log(m_H))$$

$$\boxed{D\,m_W = 0.7 ´ 10^{-2}\,D\,m_{top}}$$

to get similar error

THE GOAL : $D m(top) < 2\ \mathrm{GeV}$,

$D m_W < 15\ \mathrm{MeV}$

–> constraint the Higgs Mass to 25%.

–> if Higgs found, consistency check of theory

What is new at the TEVATRON

E(p) = 980 GeV

RUN IIa (2001-4): 2fb^{-1} / RUN IIb (2005-7): 15 fb^{-1}

CDF and D0 have been rebuilt significantly

New ideas and experience from RUN I

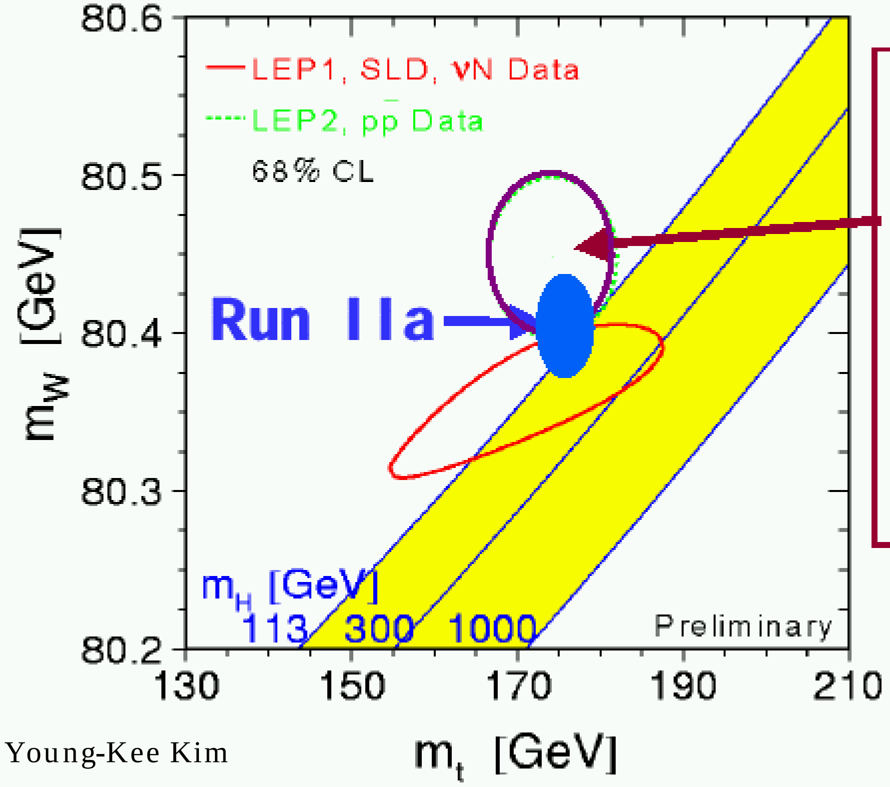
Physics Potential increased by 400 –900 times w.r.t. RUN I

- 15k (IIa) – 100k (IIb) B–> J/ψ K –>μμ K
- 10^7 (IIa) – 10^8 (IIb) W events
- 5 k – 40 k top –top events
- Higgs and SUSY possible

GOAL: understanding electroweak symmetric breaking

Þ Mw, Mtop, Higgs boson search

ElectroWeak Precision Measurements



Young-Kee Kim

Tevatron Run I :

M_{top} = 174.3 $\pm$ 5.1 GeV

M_W = 80.452 $\pm$ 0.062 GeV

LEP II :

M_W = 80.450 $\pm$ 0.039 GeV

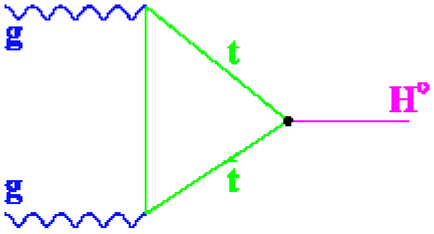
End of RUN IIa

DMw = ±30 MeV /exp

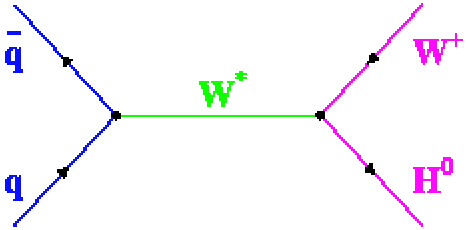
Dmtop = ± 3 GeV /exp

The Higgs at Tevatron

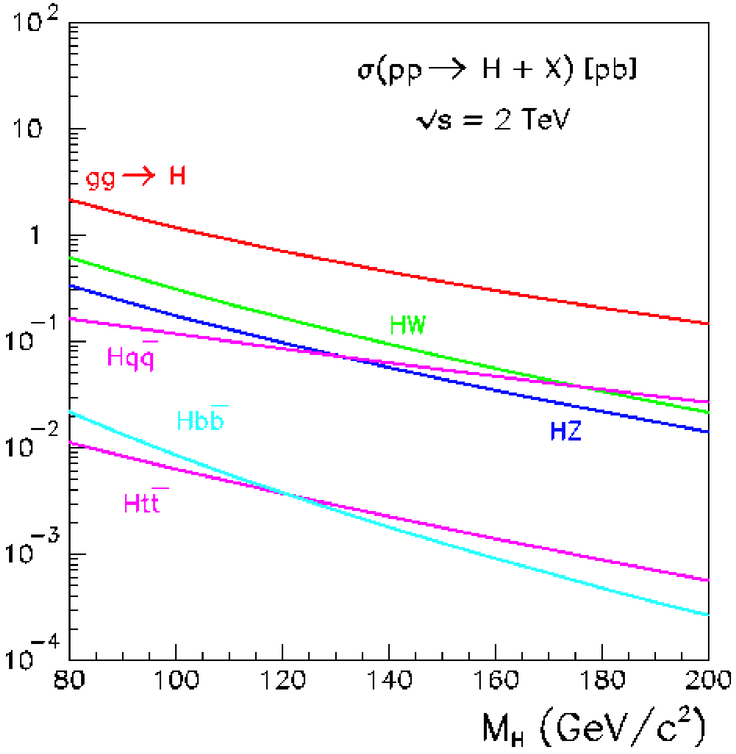
Gluon fusion



σ ~ 1pb

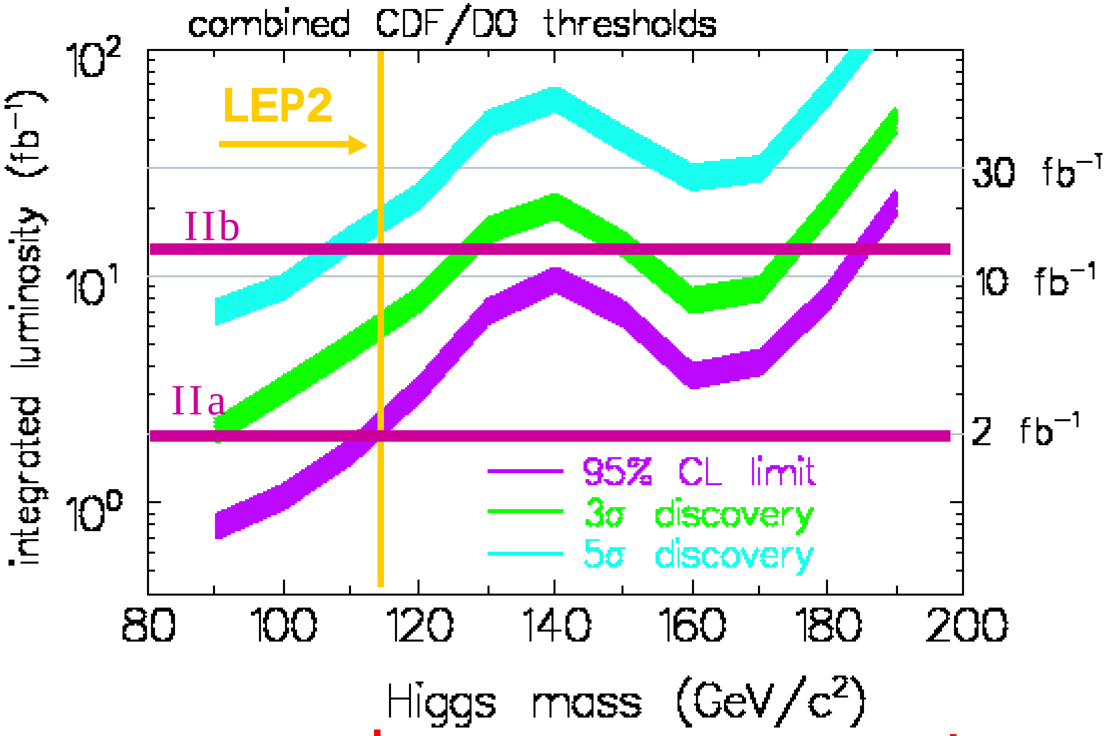


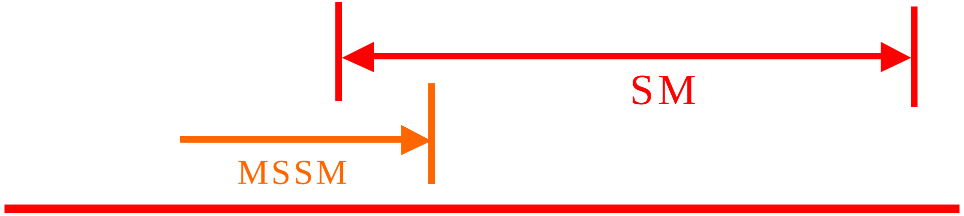
Associated production



Combining all the channels

assuming 10% resolution on M(bb),
30% improvement in S/B





The LHC physics goals

Ecm = 14 TeV

2006 - 2008 : L= 10 fb^{-1} per year

2008 - ? : L= 100 fb^{-1} per year

- Understand origin of particle masses and EW symmetry breaking mechanism:

→ look for a Standard Model Higgs boson from LEP2-Tevatron limit of 114-180 (?) GeV up to 1 TeV

→ final word about SM Higgs mechanism

- Perform precision measurements beyond sensitivity of previous exp.:

-- W, TGC, top

-- QCD

-- B-physics and CP violation

-- etc.

- Look for physics beyond the Standard Model

new physics at ~ TeV scale is expected

-- SUSY : explore up to masses of ~ 3 TeV

→ final word about low-E SUSY

-- other scenarios: leptoquarks, technicolour/new strong int., additional ℓ/q/W/Z, etc. up to m~ 5 TeV

-- **who knows ?**

LHC as t/b/W/Z/H/susy…-particle factory

Process	Events/s	Events/year	Other machines (total statistics)
$W \rightarrow e\nu$	15	10^{8}	10^{4} LEP / 10^{7} Tev.
$Z \rightarrow ee$	1.5	10^{7}	10^{7} LEP
$t\bar{t}$	0.8	10^{7}	10^{5} Tevatron
$b\bar{b}$	10^{5}	10^{12}	10^{8} Belle/BaBar
$\tilde{g}\tilde{g}$ (m=1 TeV)	0.001	10^{4}	—
H (m=0.8 TeV)	0.001	10^{4}	—
QCD jets $p_T > 200$ GeV	10^{2}	10^{9}	10^{7}

Rates are at production
and per experiment
at 10^{33} cm^{-2} s^{-1}

→ Mass reach: up to ≈ 5 TeV
→ Precision measurements dominated by systematic (mainly performed at low L)

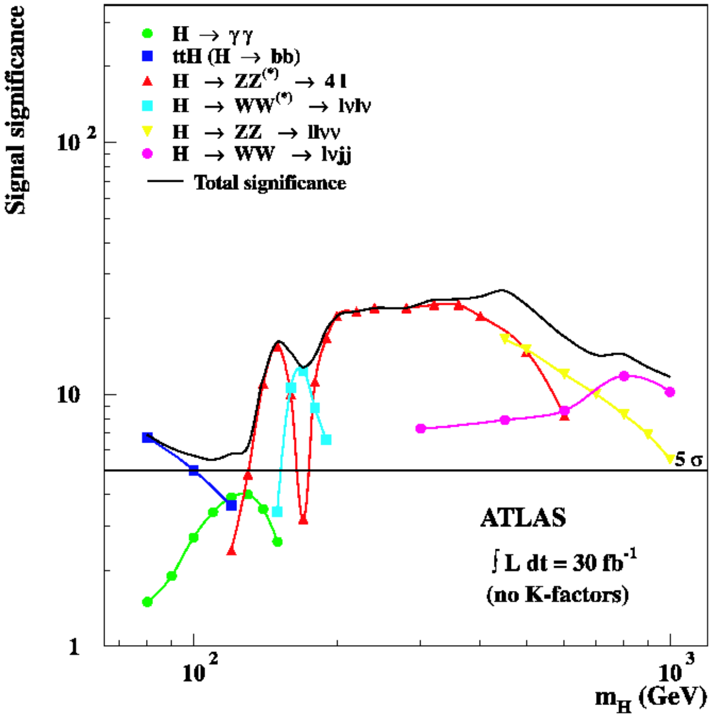
Higgs at LHC

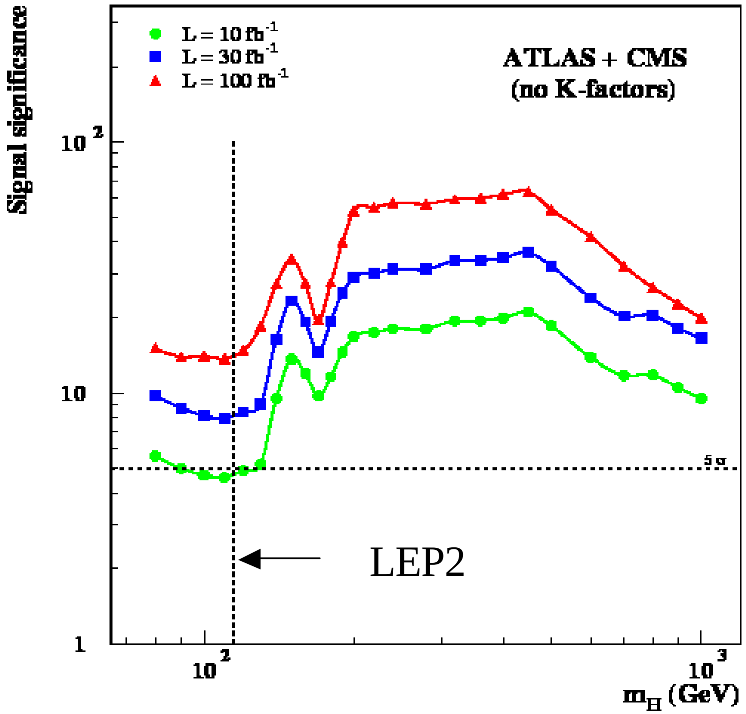
Summing all the channels for 30fb^{-1}:

m_H<130 GeV/c^2 : H–>γγ, bb

m_H<180 GeV/c^2 : H–>WW

m_H>180 GeV/c^2 : H–> ZZ





Higgs properties: ~ 0.1% -1% accuracy on Mass

~ 20% precision on couplings and BR

SM vs MSSM nature

Future prospects

Tevatron Run 2 has began:

projection (Run-2a) $\Delta M_W = \pm 30$ MeV /exp

$\Delta m_{top} = \pm 3$ GeV

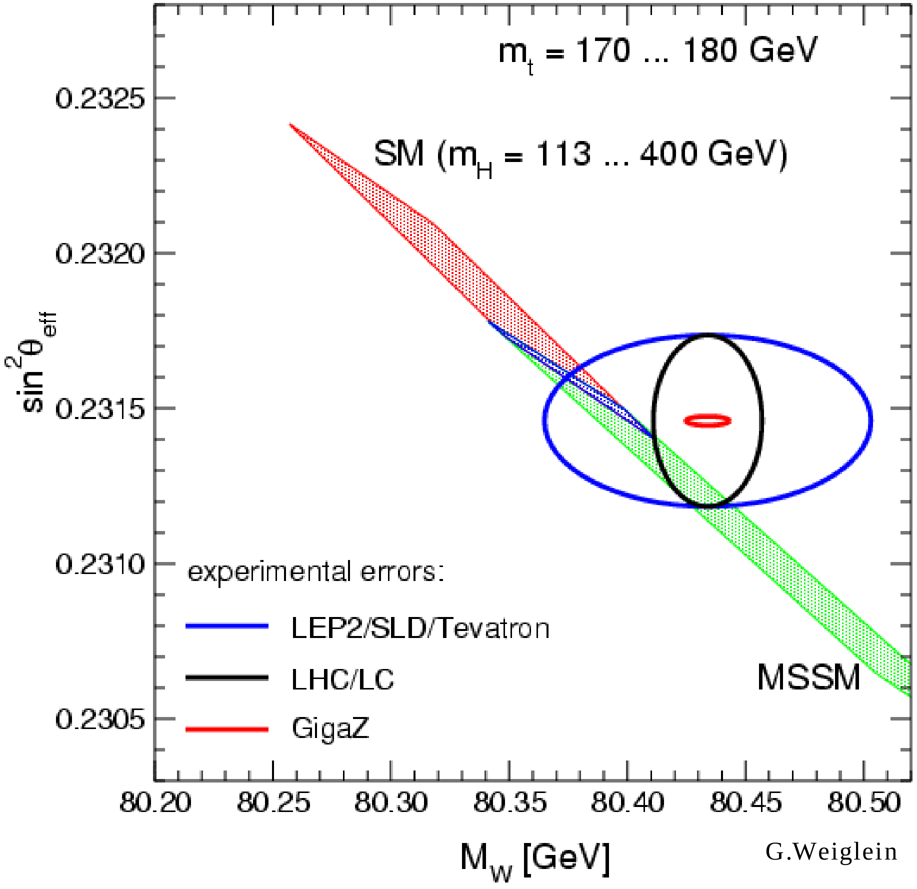
LHC (2006?): $\Delta M_W = \pm 15$ MeV

$\Delta m_{top} = \pm 1.5$ GeV

LC (?) : $\Delta M_W = \pm 6$ MeV

$\Delta m_{top} = \pm 0.2$ GeV

Old values….! Only for illustrations…



G.Weiglein

Summary

LEP+SLD+Tevatron+….. had test the SM with very high precision:

We now know that radiative corrections exist

That the theory is a Gauge Non Abelian Theory

That 3 families exist (top and ν_τ)

That the coupling constants run

We know better the CKM matrix

And also we learned a lot from what we did not see !

Theory and experiments collaborated fruitfully and still should/will to explore the high energy domain

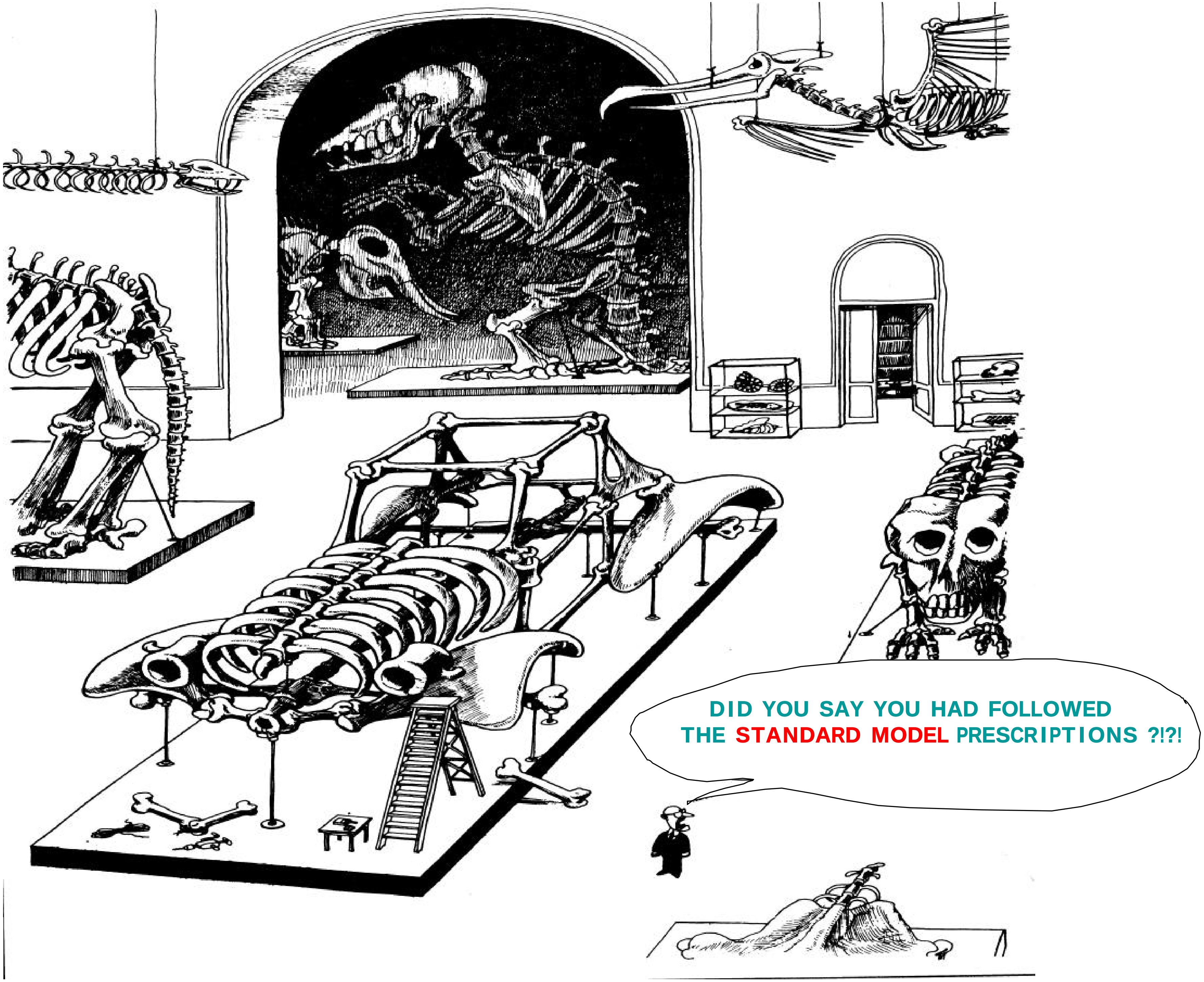
Maybe the Tevatron and then LHC and LC finally will discover the mechanism that break the symmetry and gives us mass

Few intriguing 2-3 σ effects…not larger !!! (and NuTeV?)

–>fortunately the SM seems in very good shape

–>unfortunately since New Physics seems still far away…

OR !?


DID YOU SAY YOU HAD FOLLOWED THE STANDARD MODEL PRESCRIPTIONS ?!?!