LEP Precision Results

Tatsuo Kawamoto

University of Tokyo

(tatsuo.kawamoto@cern.ch)

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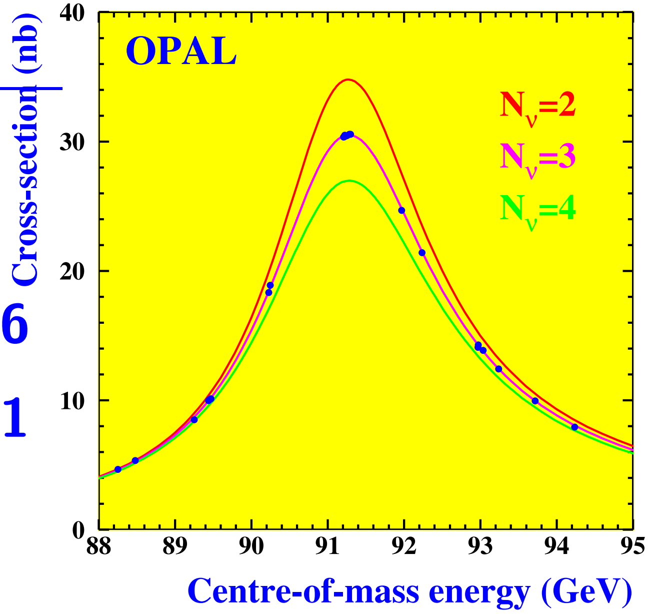
ICEPP LEP sympsium

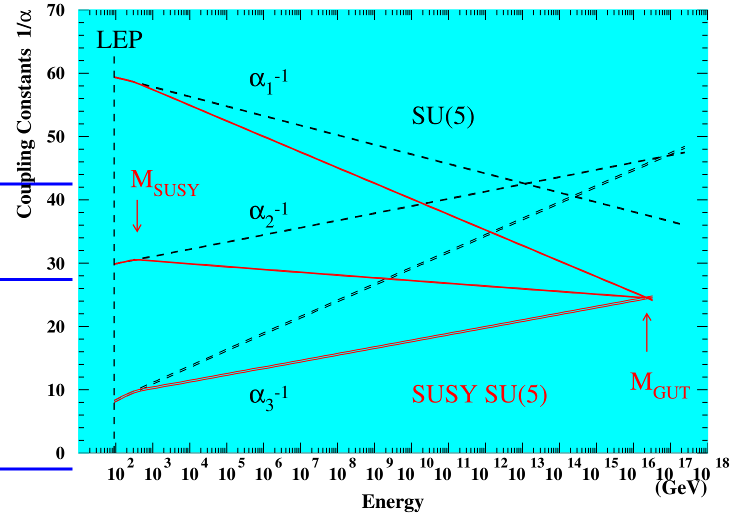
12 years of LEP running

1 $\mathbf{fb^{-1}} \times 4$, 20,000,000 Z, 40,000 WW, some Higgs ??

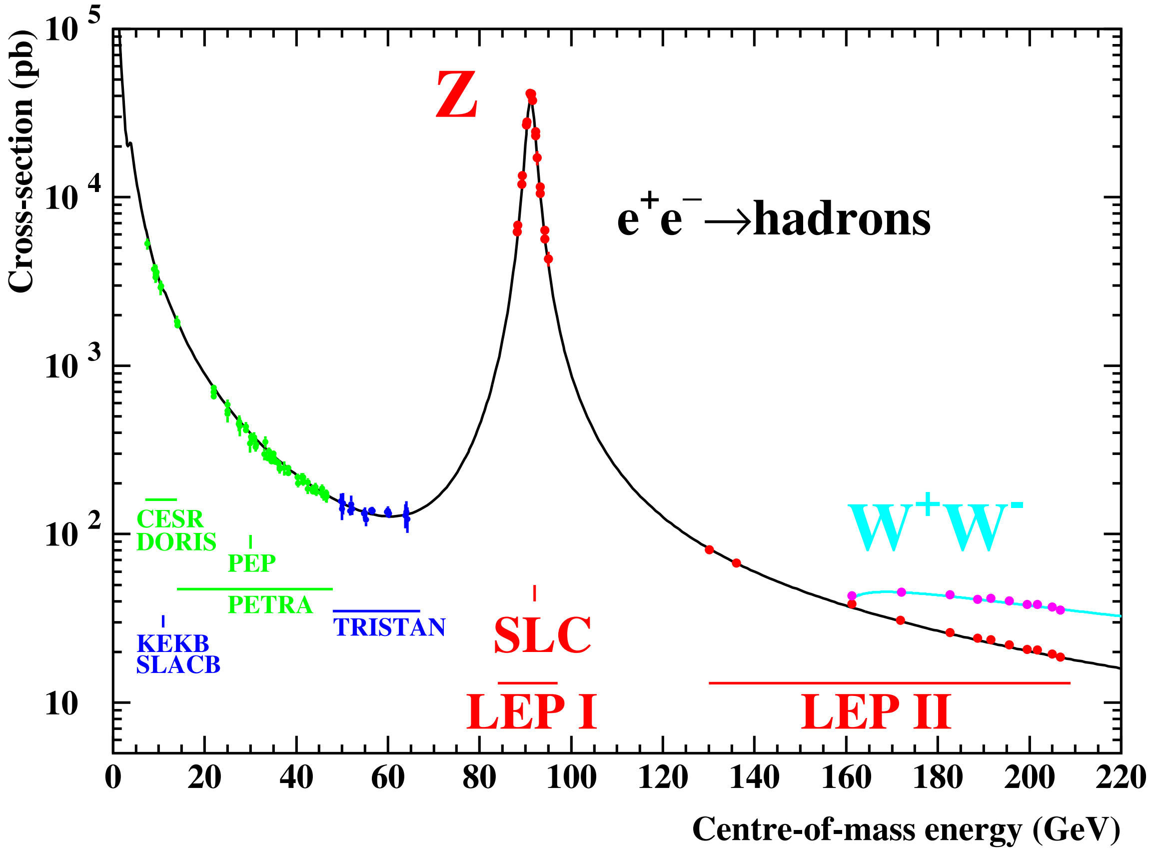
Progress over 12 years

	1988 PDG	2001
m_Z	$\pm$1.8 GeV	$\pm$ 2.1 MeV
Γ_Z	$<$5.6 GeV	$\pm$ 2.3 MeV
$g_{A\ell}$	-0.498$\pm$0.027	-0.50123$\pm$0.00026
$g_{V\ell}$	-0.044$\pm$0.036	-0.03783$\pm$0.00041
$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$	$\pm$0.0064	$\pm$0.00017
N_ν	$<$5.9	2.9841$\pm$0.0083
m_W	$\pm$1.3 GeV	$\pm$ 33 MeV
Γ_W	$<$5.6 GeV	$\pm$90 MeV
m_H	$>$3.9 GeV	$>$114 GeV
α_s	$\pm$0.02	$\pm$0.002
$1/\alpha(m_Z)$	$\pm$0.12	$\pm$0.05





e^+e^- Collider LEP

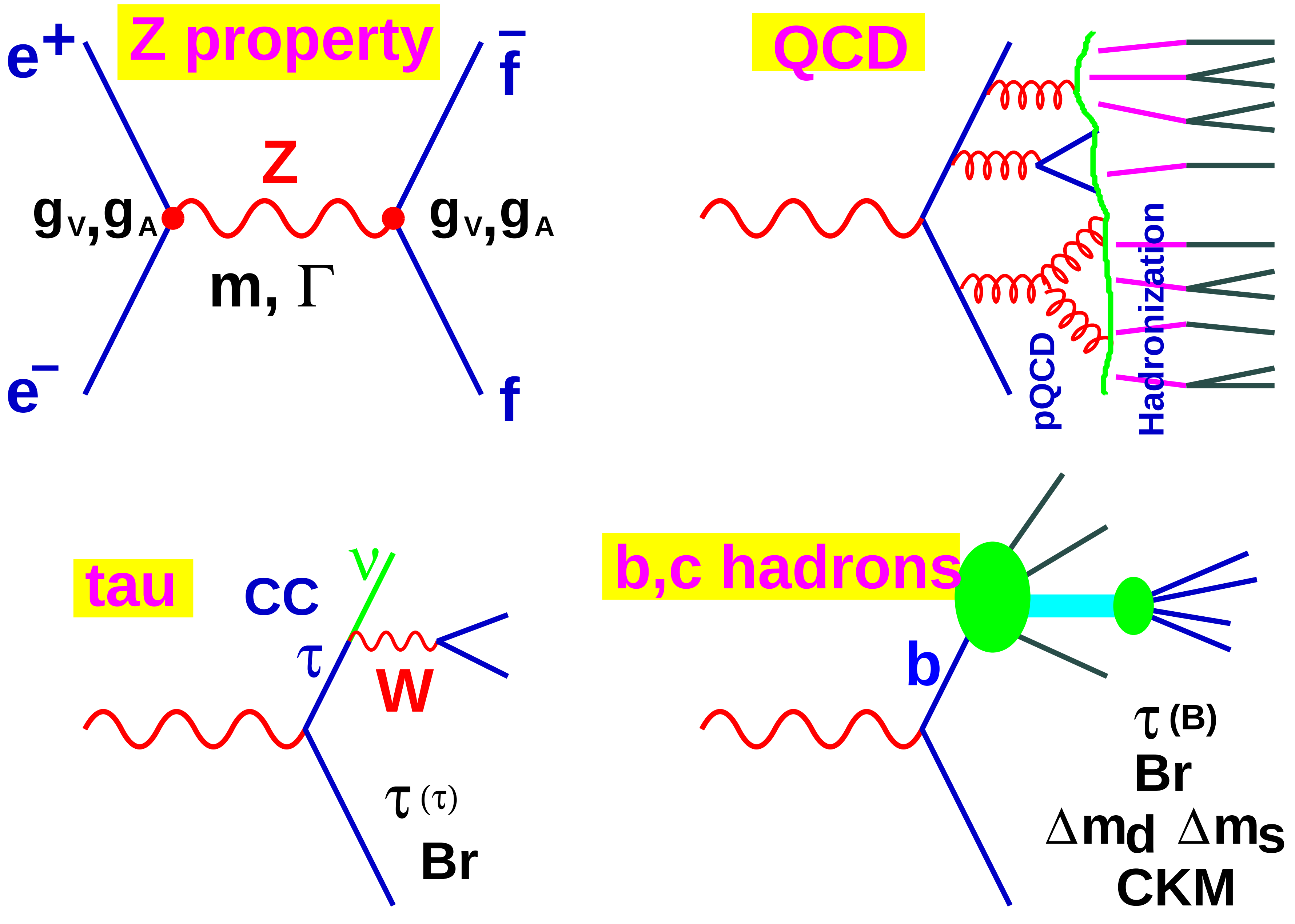


- All known Gauge bosons
  - γ
  - Z
  - $W^{\pm}$
  - g

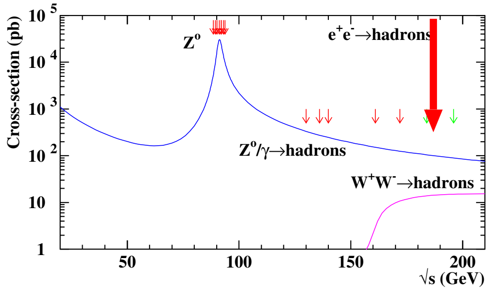
  $SU(2)_L \times U(1)_Y$, $SU(3)_c$
- All known ℓ and q

  (except t)
- Energy fronteer
  - Searches
  - Higgs
  - whatever beyond the SM

at the Z


Z property
e+
e−
f̄
f
Z
gV,gA
gV,gA
m, Γ
QCD
pQCD
Hadronization
tau
CC
ν
τ
W
τ (τ)
Br
b,c hadrons
b
τ (B)
Br
Δmd Δms
CKM

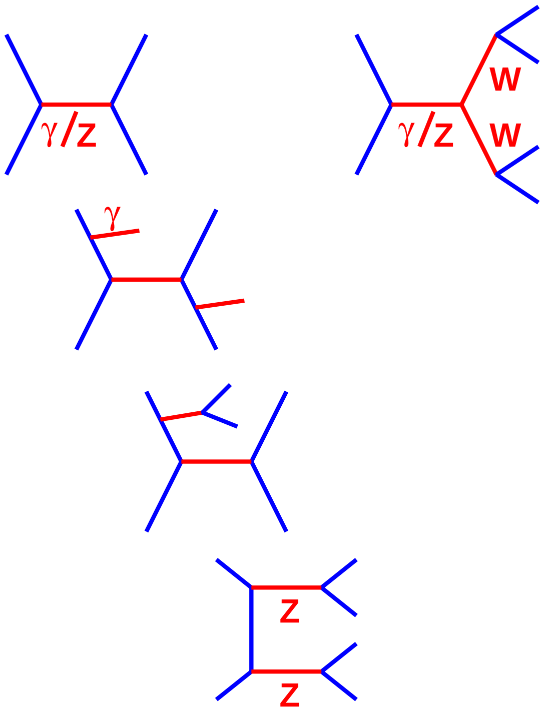
at Higher energies



- W
  - A fundamental parameter

$$\rho = \frac{m_W^2}{m_Z^2 \sin^2\theta_W}, \; G_F = \frac{\pi\alpha}{\sqrt{2} m_W^2 \sin^2\theta_W}, \; \ldots$$

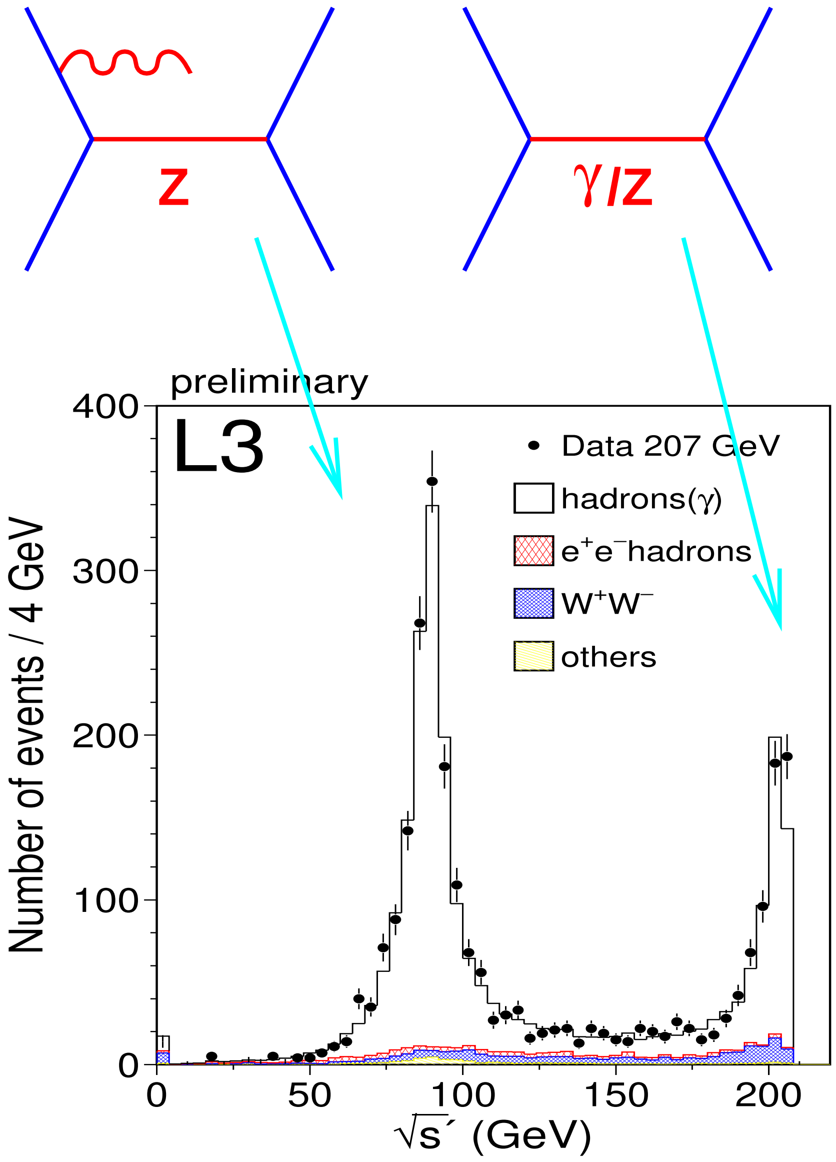
- 2f via $\gamma + Z$



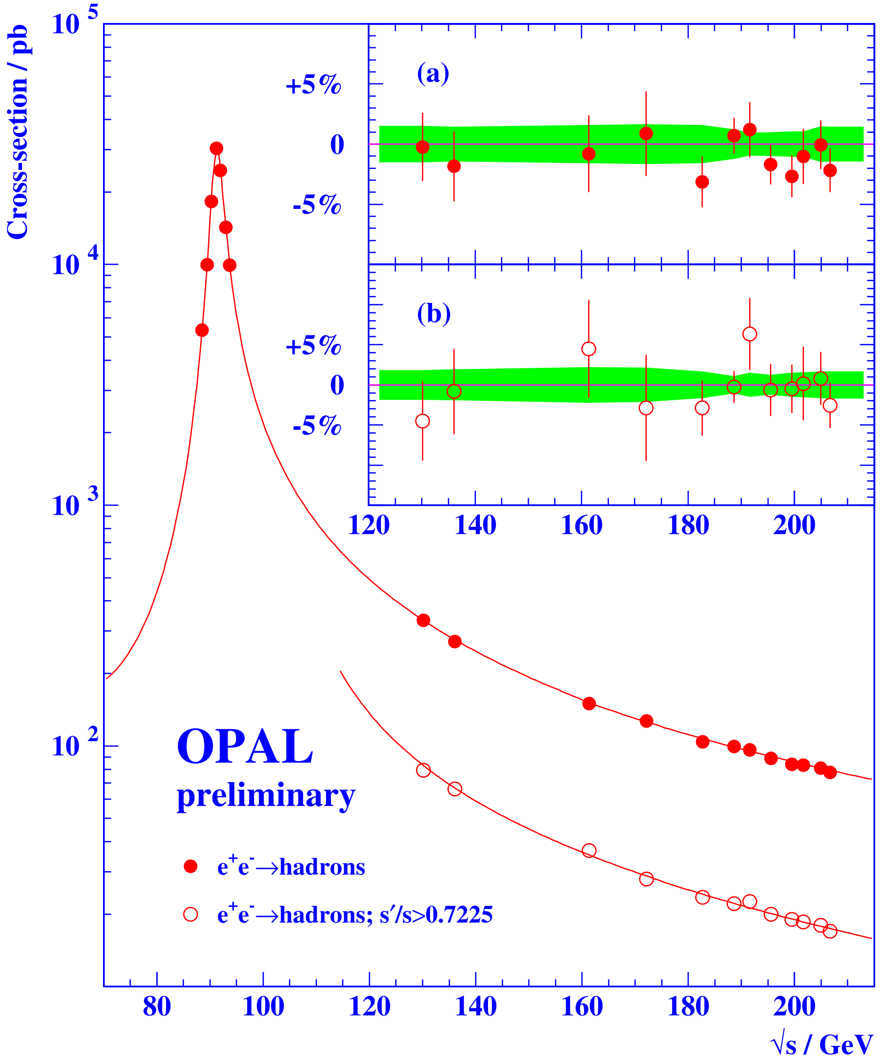
- 4f become important :
  - New calculations
  - Experimental tests
  - Background for searches

- Any deviations from the SM?

2f at LEP2

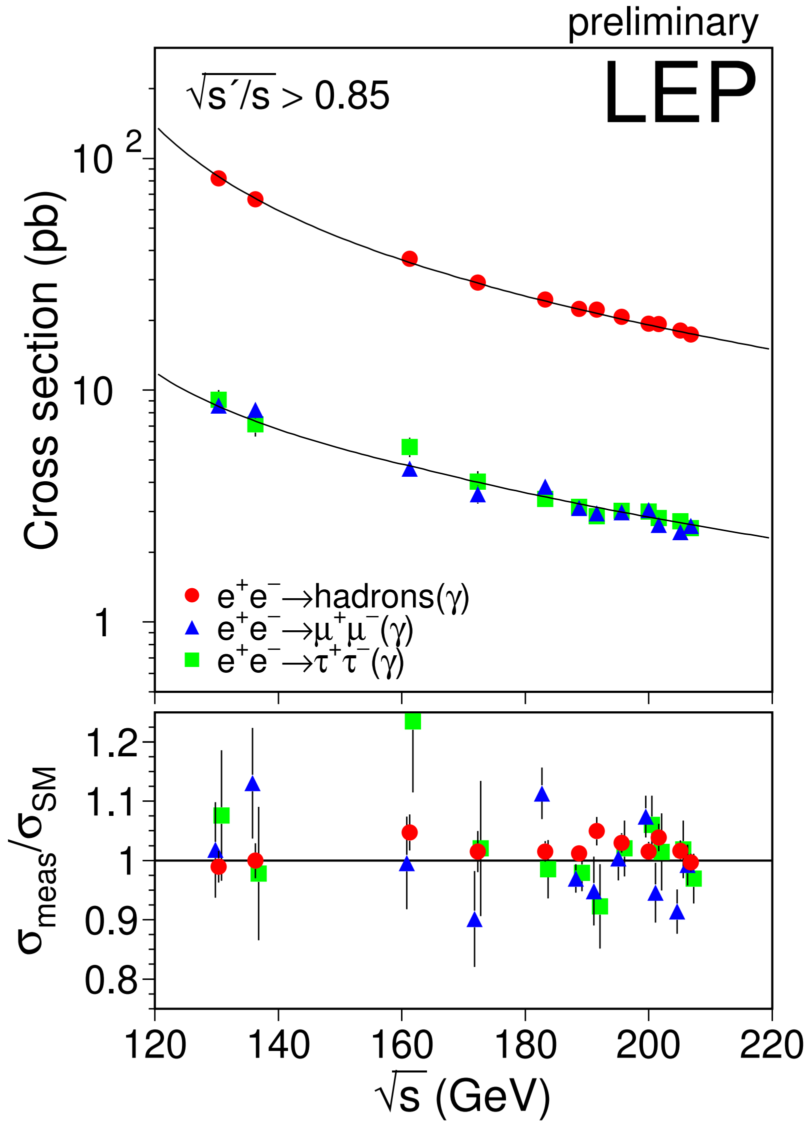


Hadronic cross−section

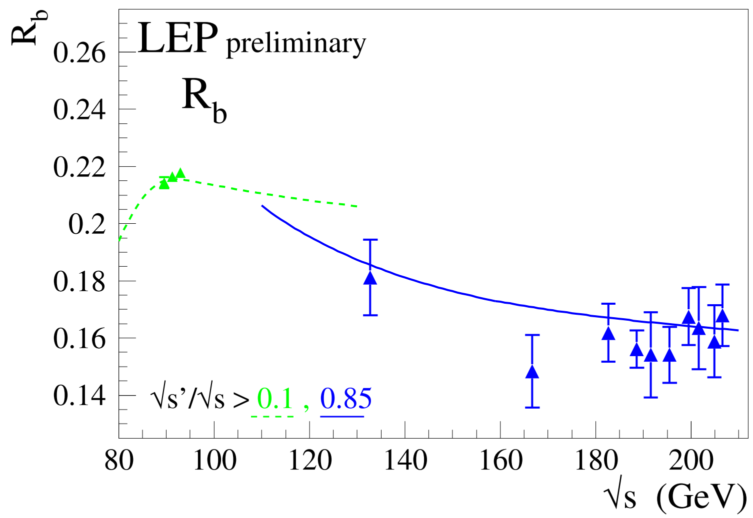


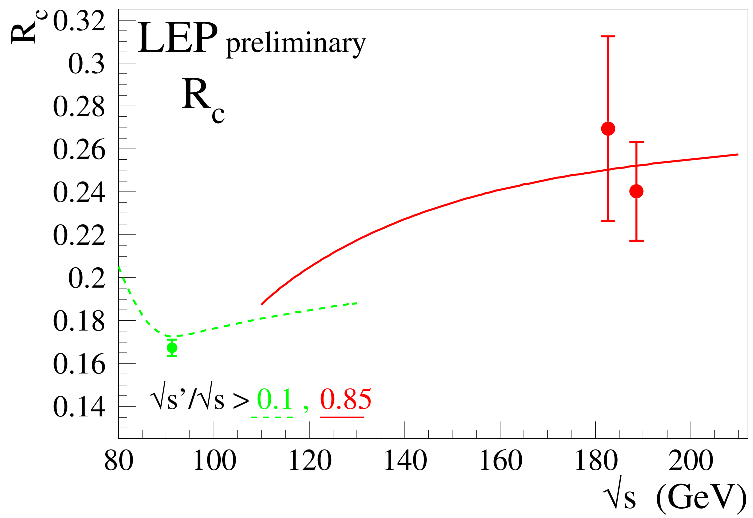
2f at LEP2

- $q\bar{q}$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, $b\bar{b}$, $c\bar{c}$



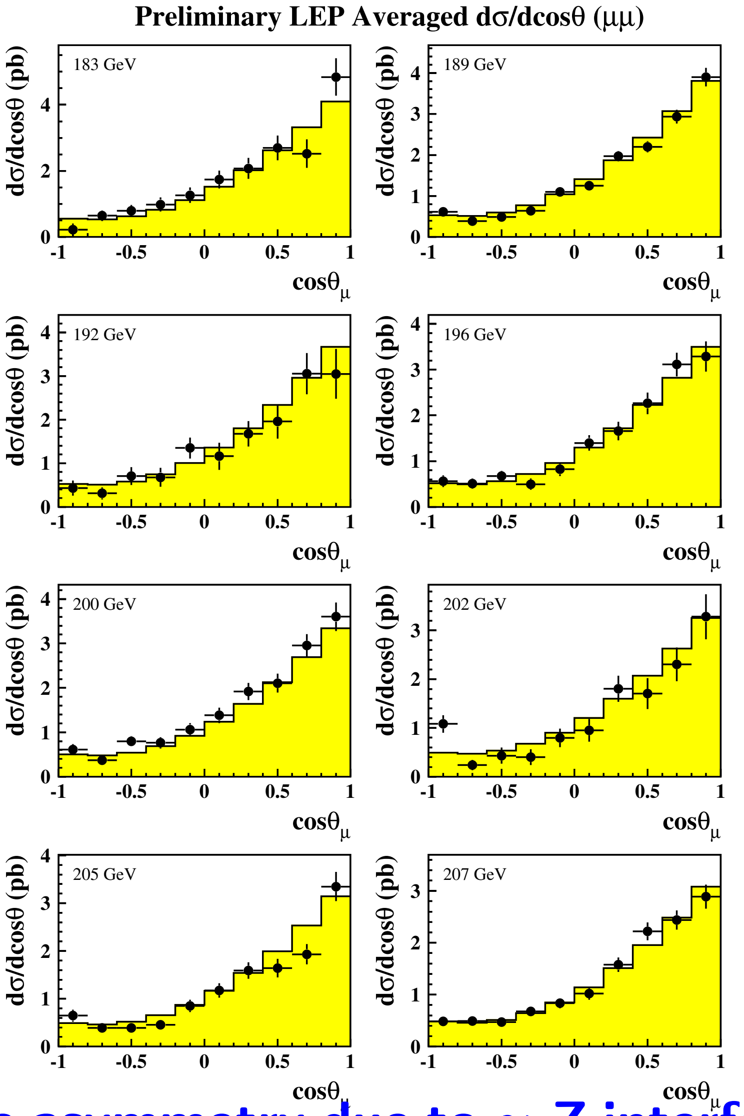
- Compare with S.M calculations Zfitter



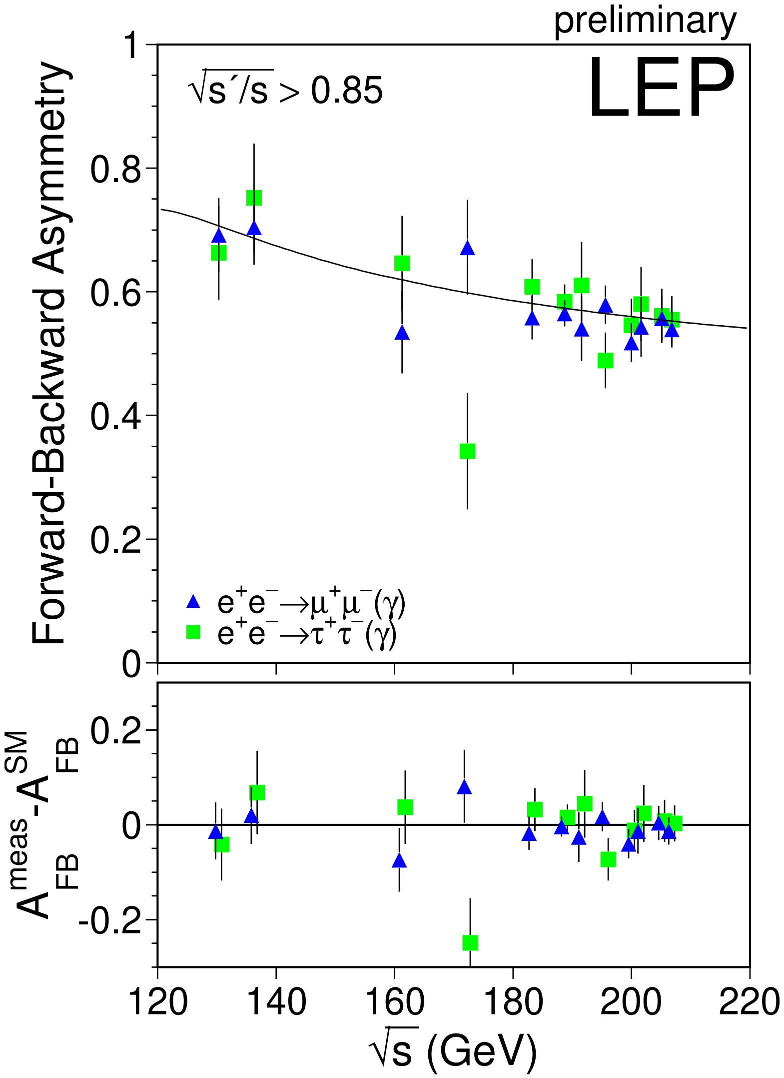


2f at LEP2

- Differential cross-section $\frac{d\sigma_\mu}{d\cos\theta}$

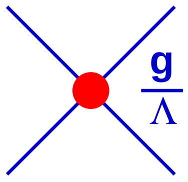


- $A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$



Large asymmetry due to γ-Z interference

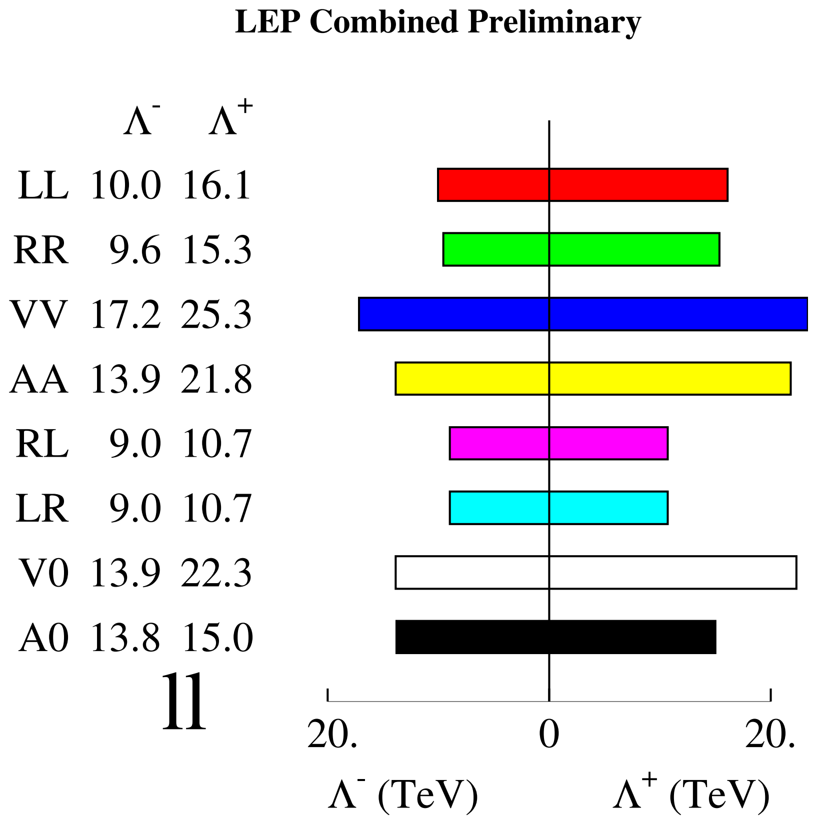
2f at LEP2 : interpretations



- **Z′**

- **Contact interactions**

$$\frac{g^2}{\Lambda^2}\sum_{L,R}\eta_{i,j}[\bar{e}_i\gamma^\mu e_i][\bar{f}_j\gamma_\mu f_j]$$



- LEP2 data constrain the mass
- LEP1 data constrain mixing angle

Model	Mass limit (GeV)
χ	630
ψ	510
η	400
$L-R$	950

LEP preliminary

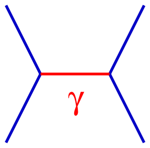
From $e^+e^- \rightarrow \ell^+\ell^-$

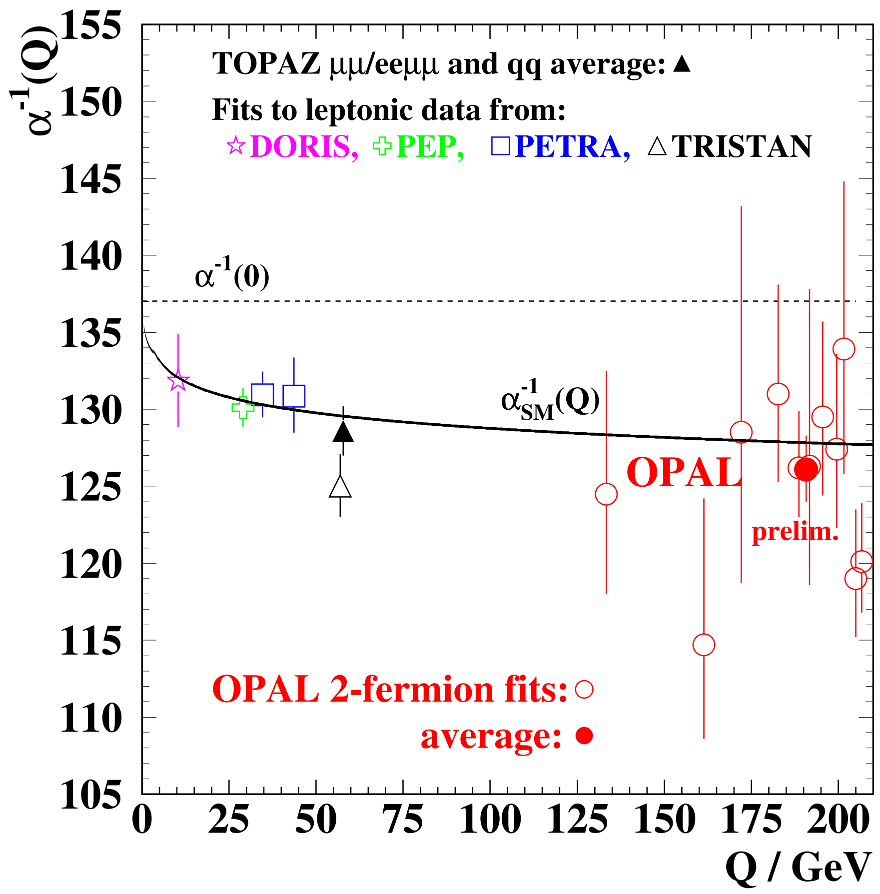
Limits on $\Lambda \sim$ 10 TeV $(g^2/4\pi = 1)$

2f at LEP2 : interpretations

- **Running of $\alpha(s)$**

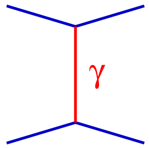
From $\sigma(f\bar{f})$, $A_{FB}(f\bar{f})$:

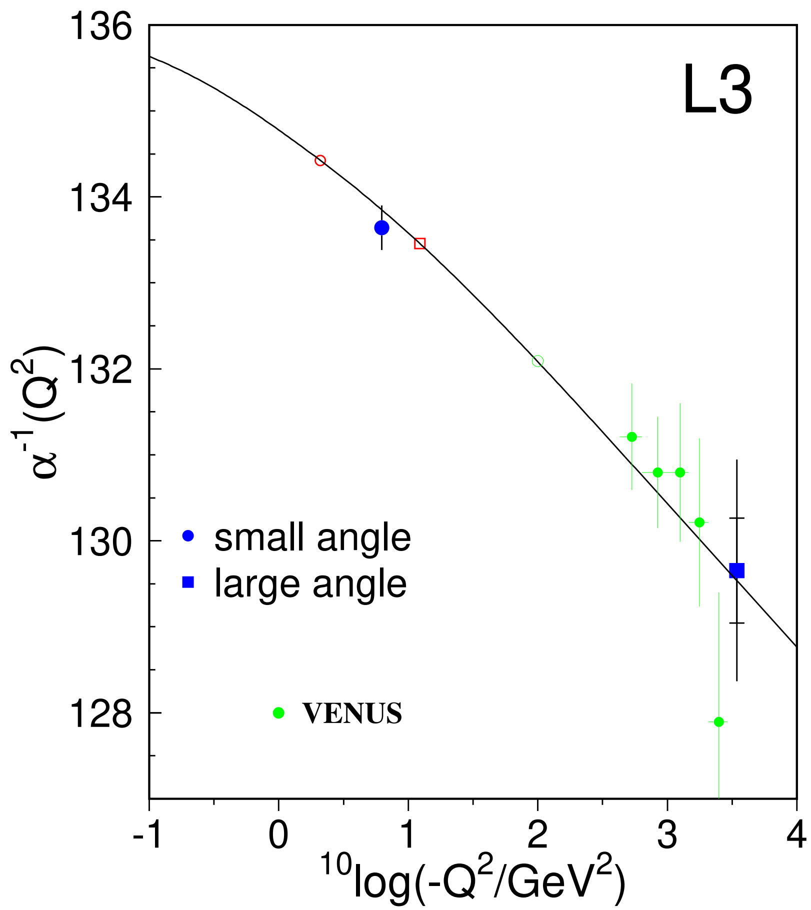




- **Running of $\alpha(t)$**

From $e^+e^- \to e^+e^-$:





2f at LEP2 : interpretations

- Low scale gravity in extra dimension

- Indirect : $\sigma(\mathrm{f\bar{f}}, \gamma\gamma, \mathrm{W^+W^-}, \mathrm{ZZ}, ..)$

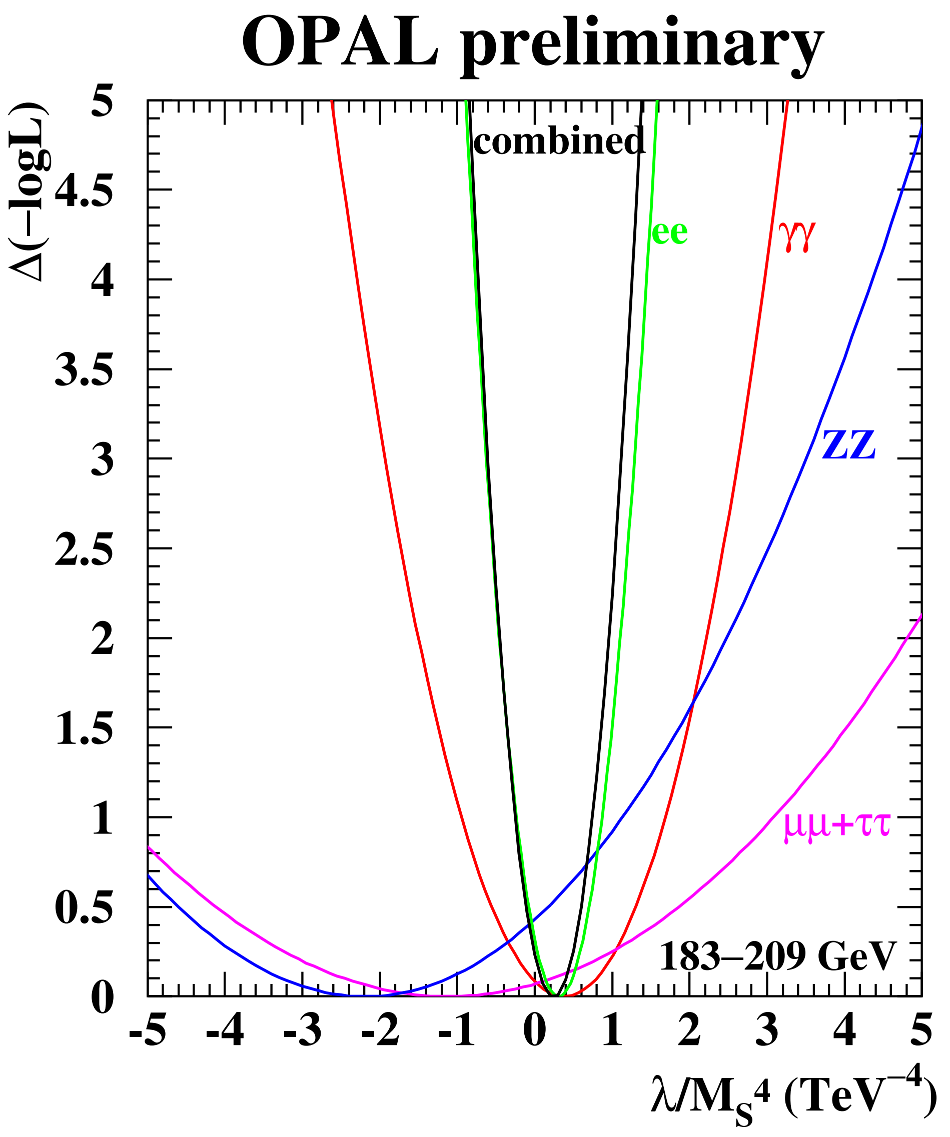
$$\sigma = \sigma_{\mathrm{SM}} + B_{\mathrm{int}} \frac{\lambda}{M_s^4} + C(\frac{\lambda}{M_s^4})^2$$

Indirect limit on M_s

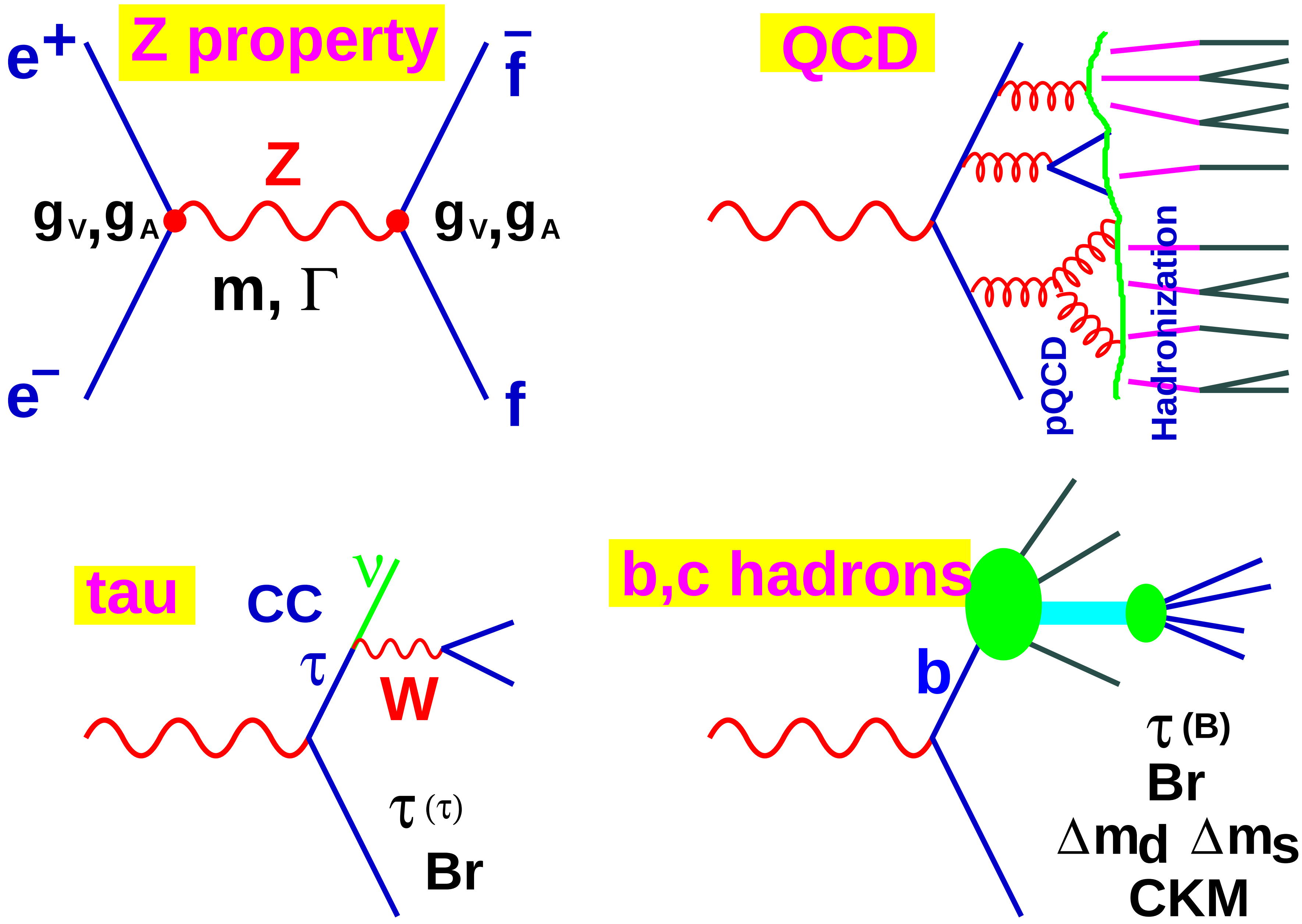
λ	$+1$	-1
M_s (TeV) 95% CL	1.03	1.17

Prelim.

- Direct : $\mathrm{e^+e^-} \to \gamma G$



at the Z



Z property
e^+
$\bar{f}$
Z
g_V, g_A
g_V, g_A
m, Γ
e^-
f
QCD
pQCD
Hadronization
tau
CC
ν
τ
W
$\tau^{(\tau)}$
Br
b,c hadrons
b
$\tau^{(B)}$
Br
Δm_d Δm_s
CKM

QCD

- $e^+e^- \longrightarrow q\bar{q}$
  - Purely leptonic initial state : long distance effects modest.

At Z
  - High statistics : 4M $Z \rightarrow q\bar{q}$
  - High purity $q\bar{q}$ sample : $p > 99\%$
  - Unbiased $q\bar{q}$ sample : $\varepsilon > 99\%$

At LEP2
  - Allow wide energy range for QCD tests

- $\gamma^*\gamma^* \longrightarrow q\bar{q}$, $\gamma^*\gamma \longrightarrow q\bar{q}$, $\gamma\gamma \longrightarrow q\bar{q}$
  - Complementary QCD studies

- Long hisotry: PETRA, PEP, TRISTAN,$\longrightarrow$ LEP
- Shower development, Hadronization, decays..
- New 'tools': jet finder, event shape variables, MCs ..
- Theory developments: NLO, NNLO,

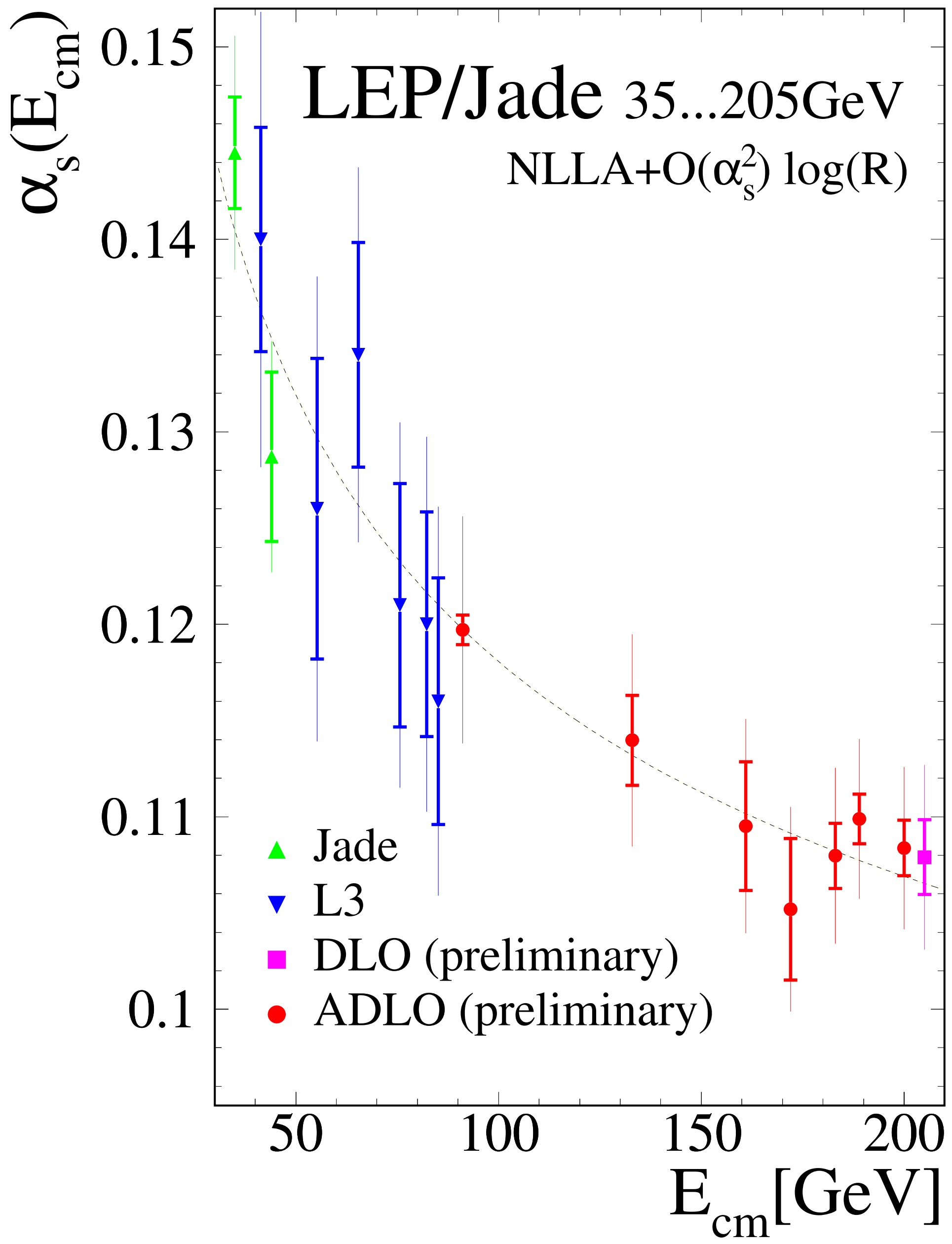
- > 200 hadron phys. papers, > 30 2γ papers

QCD

- $\alpha_s(m_Z) = 0.121 \pm 0.005$: NLO jets, event shape
- $\alpha_s(m_Z) = 0.120 \pm 0.003$: NNLO R_ℓ, R_τ
- Running of α_s, asymptotic freedom
- Non Abelian structure : gluon self coupling
- Quark - Gluon difference
- Gluon coherence
- Deeper understanding of hadronization
- Running b quark mass
- Gluon splitting to b, c
- Flavour independence of α_s
- 2γ : F_γ^2, scaling violation, ...
- ....

QCD

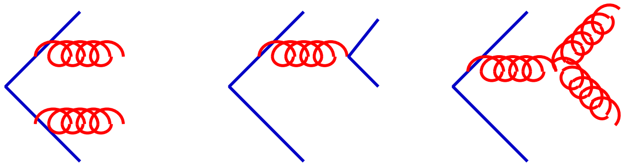
- α_s **from event shape : NLLA calculation.**



QCD

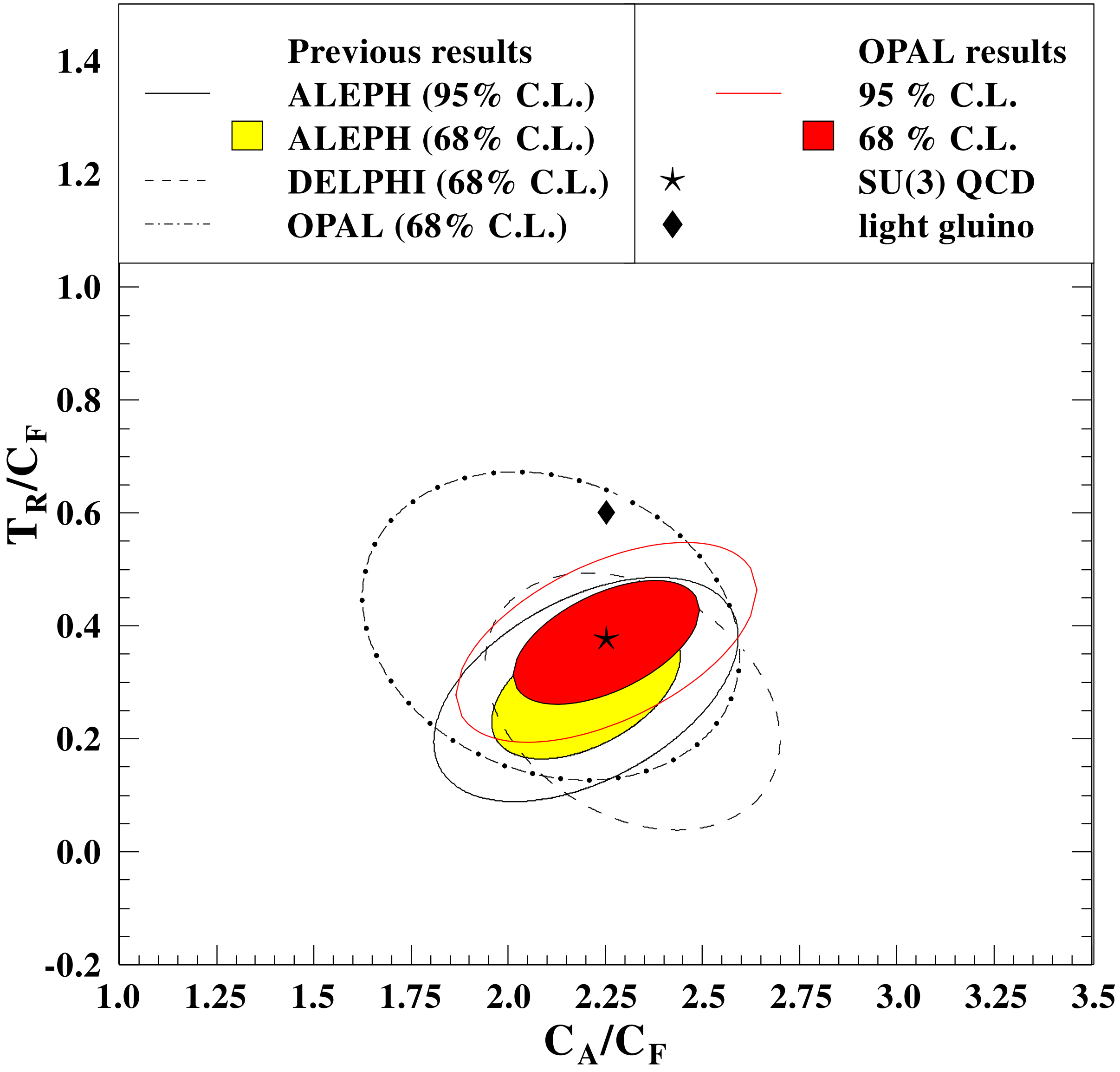
- QCD color factors
- Structure of underlying Gauge group

4 jet events :

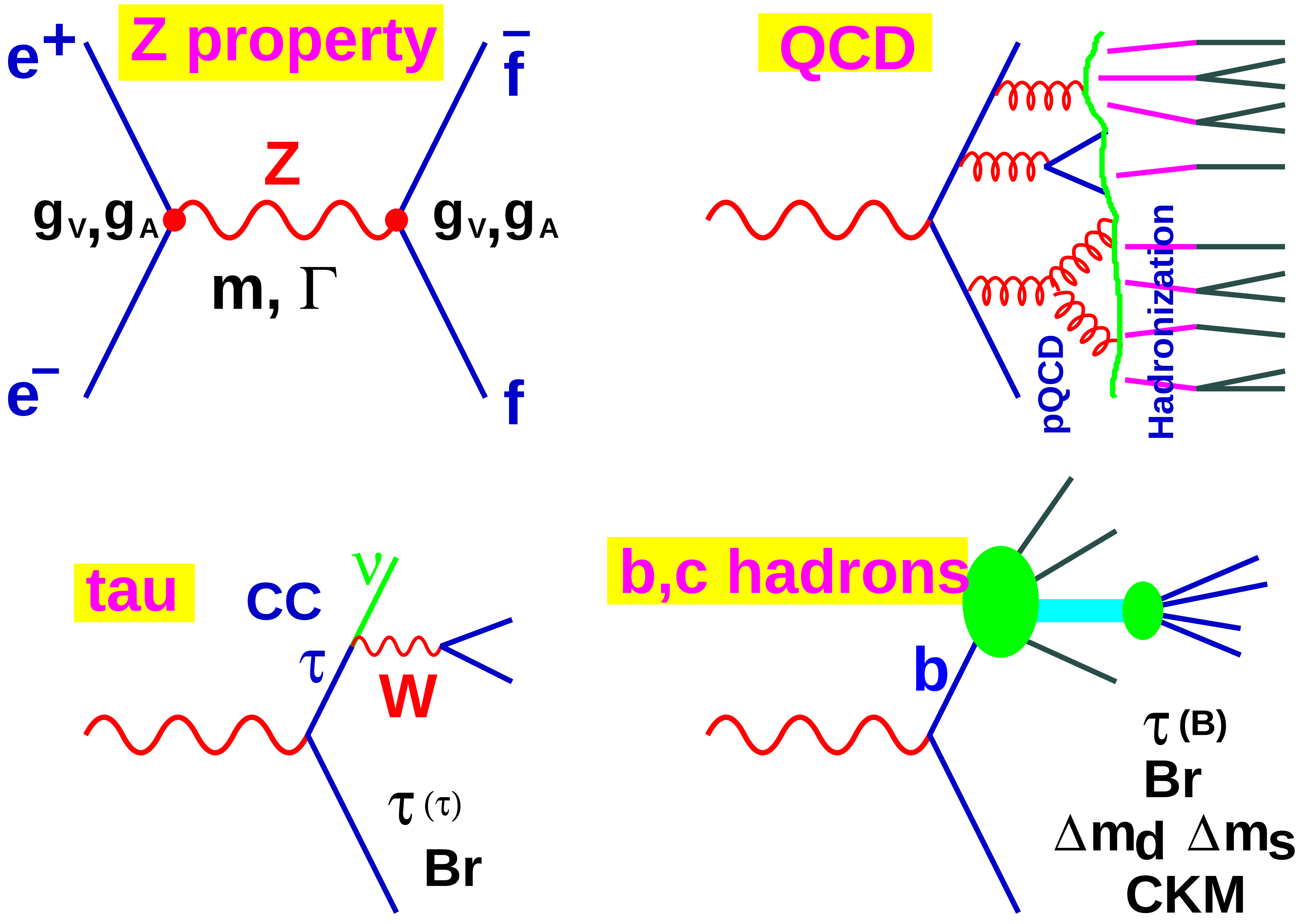


angular correlation, event shape

- New NLO analysis



at the Z


Z property
e^+
e^-
Z
g_V, g_A
g_V, g_A
m, Γ
$\bar{f}$
f
QCD
pQCD
Hadronization
tau
CC
ν
τ
W
$\tau^{(\tau)}$
Br
b,c hadrons
b
$\tau^{(B)}$
Br
Δm_d Δm_s
CKM

Zedometry

Electroweak interaction

fermion(L) weak-isospin doublet, fermion(R) singlets

$$\begin{pmatrix} \nu_\ell \\ \ell \end{pmatrix}_L , \begin{pmatrix} \mathrm{u} \\ \mathrm{d} \end{pmatrix}_L , \ell_R, \mathrm{u}_R, \mathrm{d}_R$$

SU$(2)_L \times$ U$(1)_Y$ local gauge symmetry: $Q = T^3 + Y/2$

$$g, g' \qquad\qquad W_\mu^1, W_\mu^2, W_\mu^3, B_\mu$$

Symmetry breaking by the Higgs mechanism

$$W_\mu^1, W_\mu^2 \rightarrow \mathrm{W}^\pm \qquad : \text{massive}$$

Zedometry

Mixing of two neutral fields

$$\begin{aligned} A_\mu &= \cos\theta_W B_\mu + \sin\theta_W W^3_\mu && : \text{massless} \\ Z_\mu &= -\sin\theta_W B_\mu + \cos\theta_W W^3_\mu && : \text{massive} \end{aligned}$$

$$\tan\theta_W = g'/g$$

$$\frac{m_W}{m_Z} = \cos\theta_W \quad : \quad \rho = \frac{m_W^2}{m_Z^2\cos^2\theta_W} = 1$$

$Z - f\bar{f}$ couplings

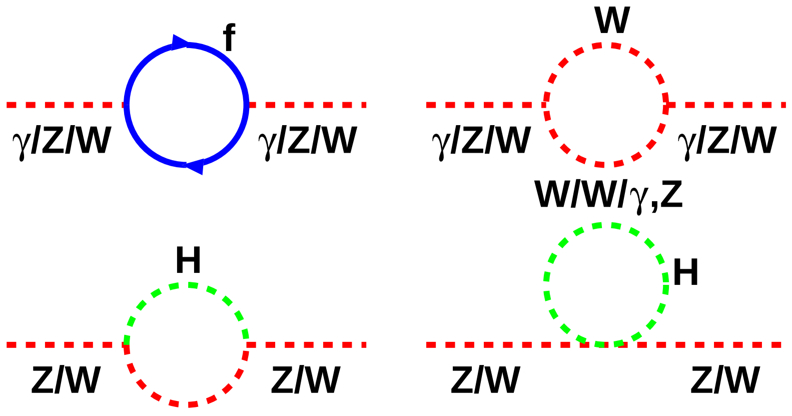
$$\begin{aligned} g_L &= T^3 - Q\sin^2\theta_W \\ g_R &= Q\sin^2\theta_W \end{aligned}$$

alternatively:

$$\begin{aligned} g_V \equiv g_L + g_R &= T^3 - 2Q\sin^2\theta_W \\ g_A \equiv g_L - g_R &= T^2 \end{aligned}$$

Zedometry

EW higer order effects



$$
\begin{aligned}
\rho &= 1+\Delta\rho \\
g_A &= \sqrt{\rho}T^3 \\
g_V &= \sqrt{\rho}(T^3 - 2Q\sin^2\theta_{\rm eff}) \\
\sin^2\theta_{\rm eff} &= \left(1+\frac{\cos^2\theta_{\rm W}}{\sin^2\theta_{\rm W}}\Delta\rho + \ldots\right)\sin^2\theta_{\rm W}
\end{aligned}
$$

$$
G_F = \frac{\pi\alpha}{\sqrt{2}m_{\rm W}^2\sin^2\theta_{\rm W}}\frac{1}{1-\Delta r}
$$

function of $m_{\rm Z}$, $m_{\rm t}$, $m_{\rm H}$, ...

Zedometry

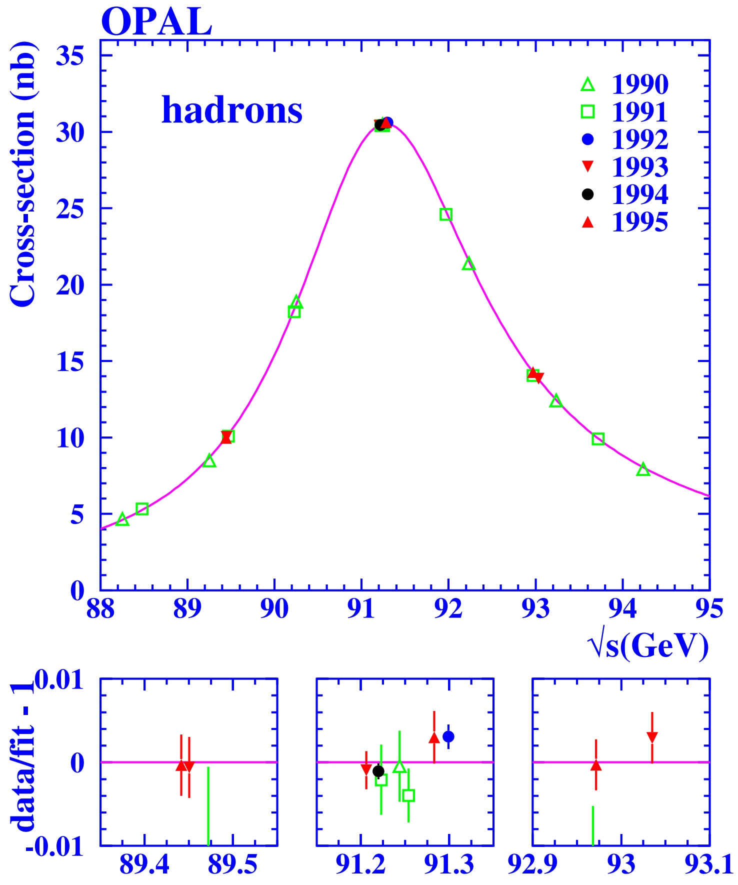
Model independently : $e^+e^- \to Z \to f\bar{f}$

Z : spin 1 resonance :

$$\sigma(s) = \sigma_f^0 \frac{s}{(s - m_Z{}^2)^2 + s/m_Z^2 \Gamma_Z{}^2}$$

$$\sigma_f^0 = \frac{12\pi}{m_Z^2} \frac{\Gamma_e \Gamma_f}{\Gamma_Z^2} = \frac{12\pi}{m_Z^2} B(Z \to e^+e^-) B(Z \to f\bar{f})$$

σ_f^0, m_Z, Γ_Z are determined from the 'lineshape'.

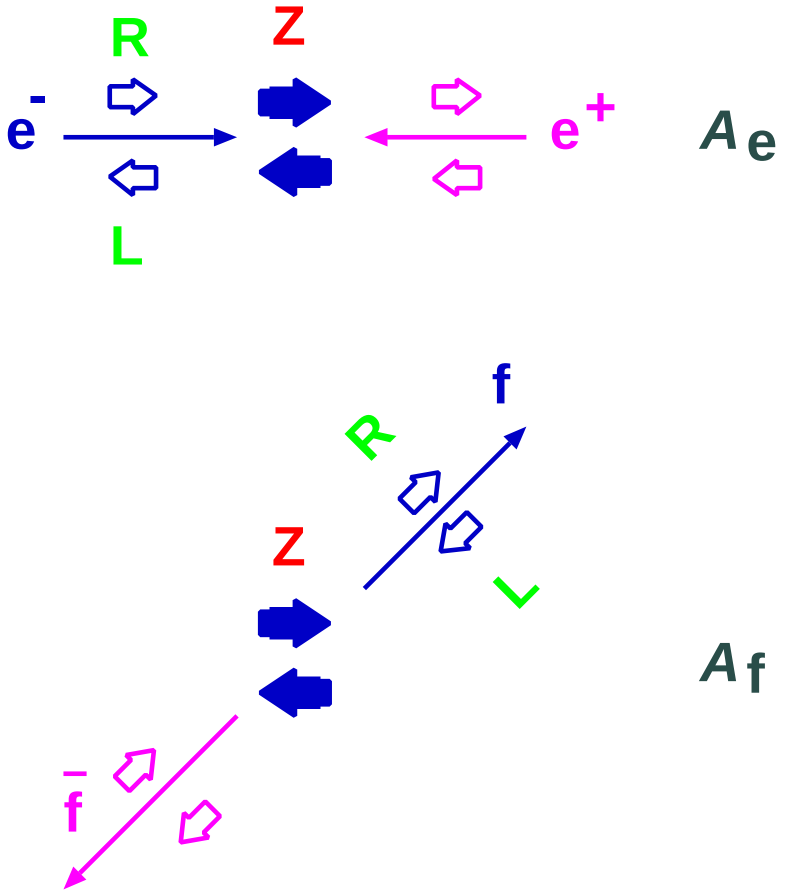


Zedometry

Model independently : $e^+e^- \longrightarrow Z \longrightarrow f\bar{f}$

Z : spin 1 resonance :

$$
\begin{aligned}
\sigma_{LL}(\cos\theta) &\propto g^2_{Le} g^2_{Lf}(1+\cos\theta)^2 \\
\sigma_{LR}(\cos\theta) &\propto g^2_{Le} g^2_{Rf}(1-\cos\theta)^2 \\
\sigma_{RL}(\cos\theta) &\propto g^2_{Re} g^2_{Lf}(1-\cos\theta)^2 \\
\sigma_{RR}(\cos\theta) &\propto g^2_{Re} g^2_{Rf}(1+\cos\theta)^2
\end{aligned}
$$



Unpolarised beam

$$
\begin{aligned}
\sigma(\cos\theta) &= \frac{1}{2}(\sigma_{LL}+\sigma_{LR}+\sigma_{RL}+\sigma_{RR}) \\
&\propto (g^2_{Ve}+g^2_{Ae})(g^2_{Vf}+g^2_{Af}) \times \\
&\quad (1+\cos^2\theta + 2\mathcal{A}_e\mathcal{A}_f\cos\theta)
\end{aligned}
$$

$$
\mathcal{A}_e = \frac{2 g_{Ve} g_{Ae}}{g^2_{Ve}+g^2_{Ae}} \quad , \quad \mathcal{A}_f = \frac{2 g_{Vf} g_{Af}}{g^2_{Vf}+g^2_{Af}}
$$

Zedometry

Model independently : $\mathrm{e^+e^- \to Z \to f\bar{f}}$

Asymmetries

Forward-backward asymmetry

$$A_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}} = \frac{3}{4}\mathcal{A}_{\mathrm{e}}\mathcal{A}_{\mathrm{f}}$$

τ polarisation : asymmetry of final-state helicity

$$P(\cos\theta) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{\mathcal{A}_\tau(1+\cos^2\theta) + 2\mathcal{A}_{\mathrm{e}}\cos\theta}{(1+\cos^2\theta) + 2\mathcal{A}_{\mathrm{e}}\mathcal{A}_\tau\cos\theta}$$

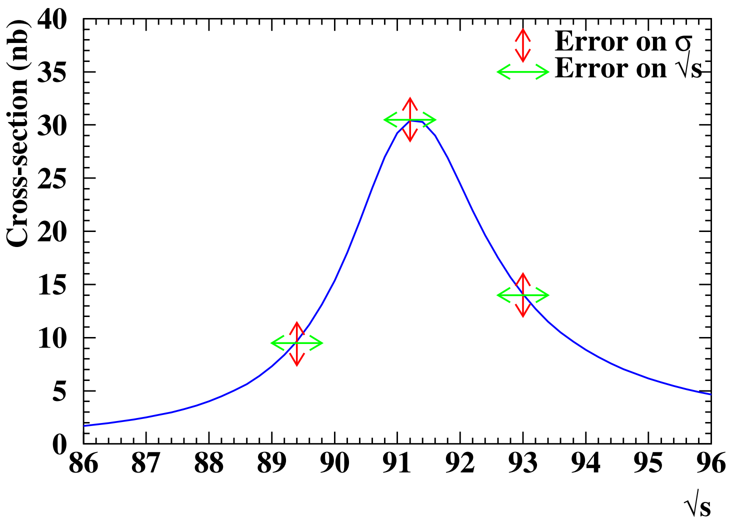
With polarised e^- : Not at LEP, but at SLC

$$A_{LR} = \frac{\sigma_{LL} + \sigma_{LR} - \sigma_{RL} - \sigma_{RR}}{\sigma_{tot}} = \mathcal{A}_{\mathrm{e}}$$

$$A_{FBLR} = A_{LR}(F) - A_{LR}(B) = \frac{3}{4}\mathcal{A}_{\mathrm{f}}$$

Zedometry

Lineshape



$$\sigma(s) = \sigma_f^0 \frac{s}{(s - m_Z{}^2)^2 + s/m_Z^2 \Gamma_Z{}^2} + (\gamma) + (\gamma - Z)$$

Systematics key issues:

- Control of ε, bkg
- Precision luminosity
- Precision LEP energy
- Precision Radiative corrections

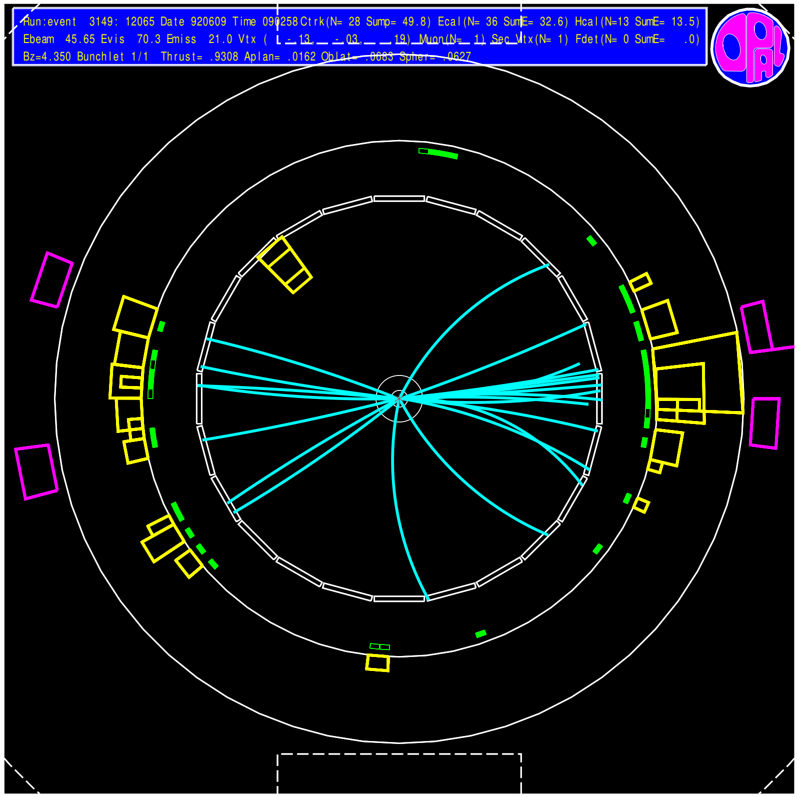
- **4.5 M $Z \to q\bar{q}$: stat-error 0.05%**

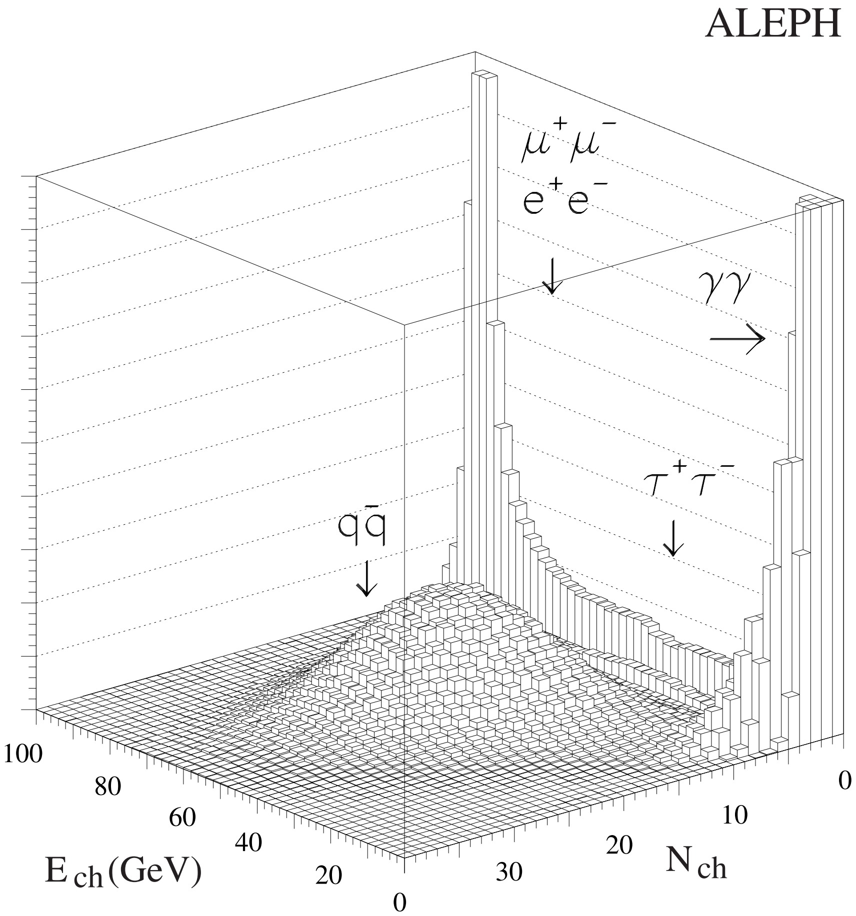
And, a careful combination of resutls from 4 experiments

All done at $< 0.1\%$ level.

Zedometry

Z decay event selection



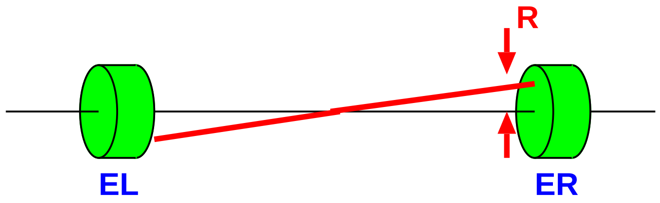


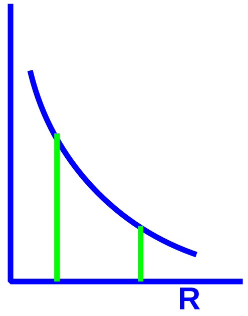
Good separation among $q\bar{q}$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ and bgd

Zedometry

Luminosity determination from the $e^+e^- \to e^+e^-$ process

- **Precision detector**

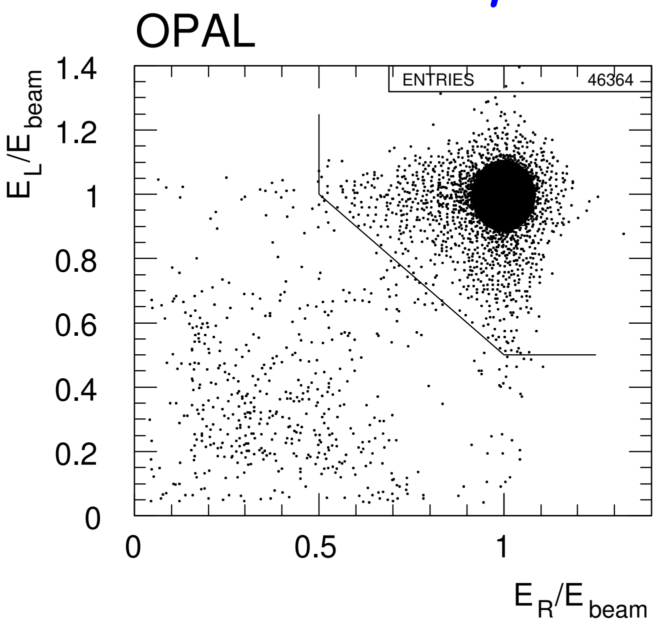




- **Precision calculation**
  - Higer order QED
  - Quality MC generator

Theory error = 0.061% (0.054%)

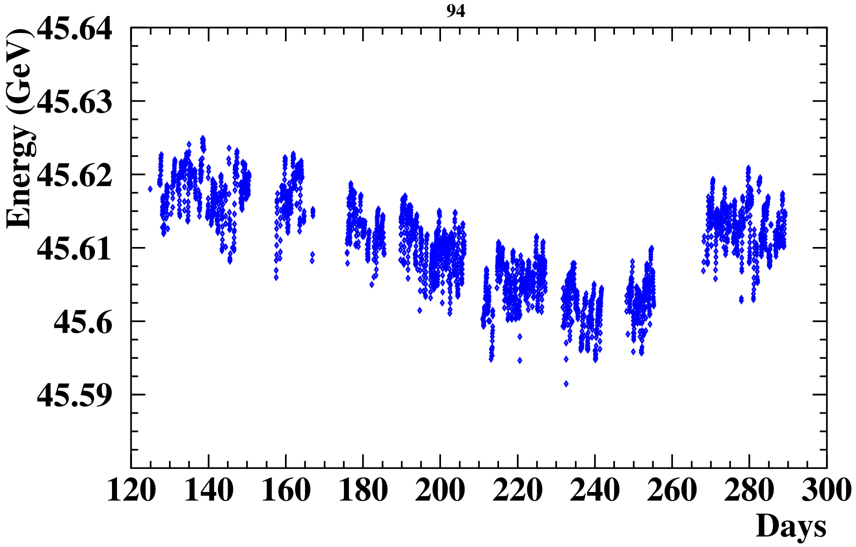
R controlled to 10 μm level

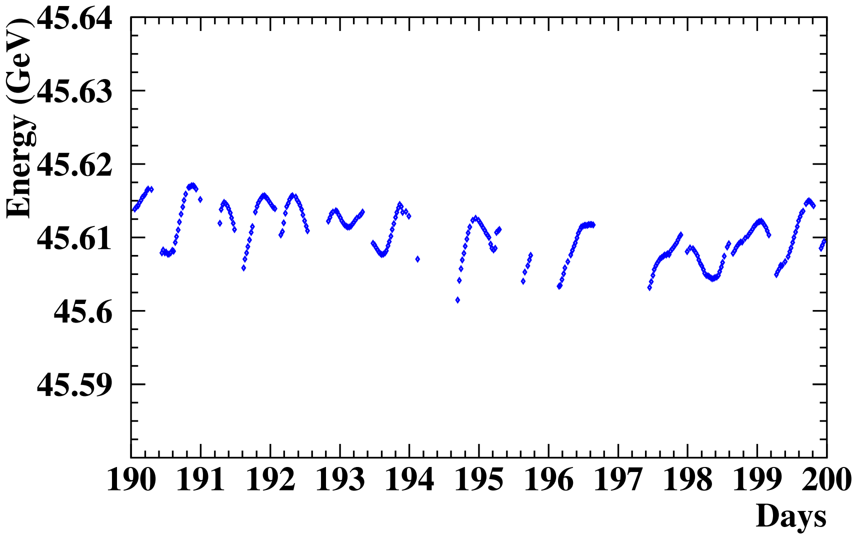


Experimental error : 0.03%

Zedometry

Precision LEP energy





- **Resonant Spin Depolarisation**
- **Accurate monitoring**

$\longrightarrow$

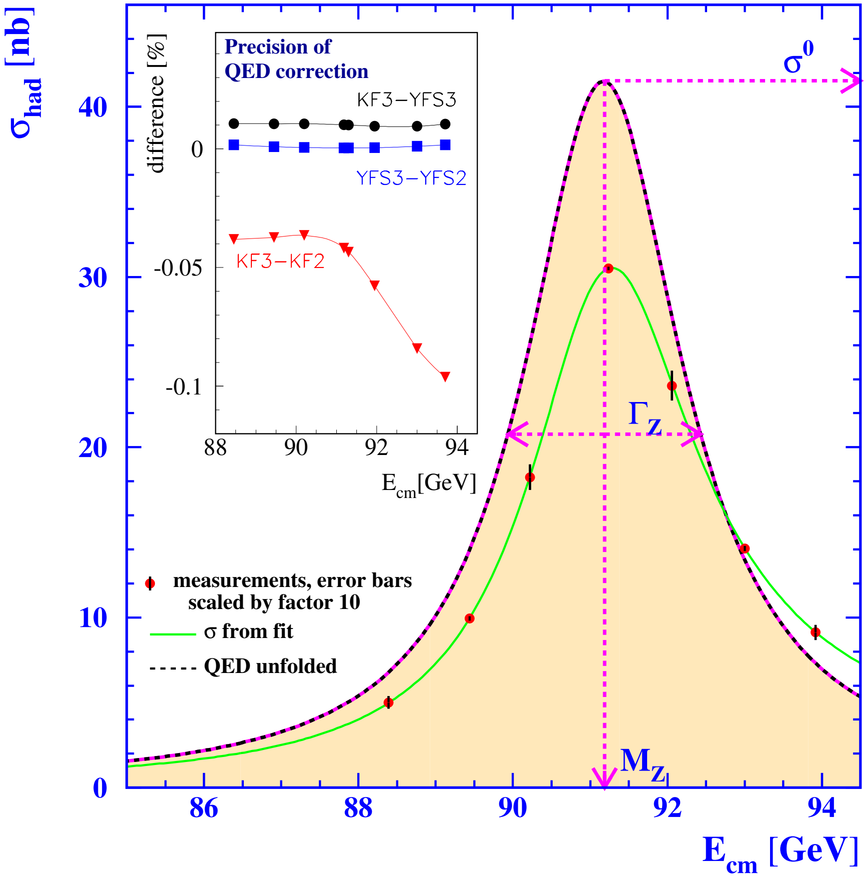
$$\Delta m_Z = \pm 1.7 \text{ MeV}$$

$$\Delta \Gamma_Z = \pm 1.2 \text{ MeV}$$

Zedometry

Precision Radiative Correction, EW calculations

- QED correction



- **M.I. parameters :**

  $m_Z,\ \Gamma_Z,\ \Gamma_\ell,\ g_{V\mathrm{f}},\ g_{A\mathrm{f}},\ \ldots$

$\longleftrightarrow$

- **Cross-sections, asymmetries**

  $\sigma(s;\mathrm{cuts\ on\ s'},\cos\theta,..),\ \ldots$

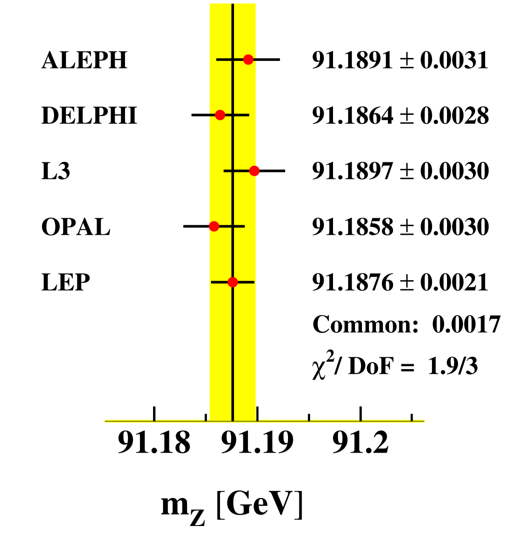
$\longleftrightarrow$

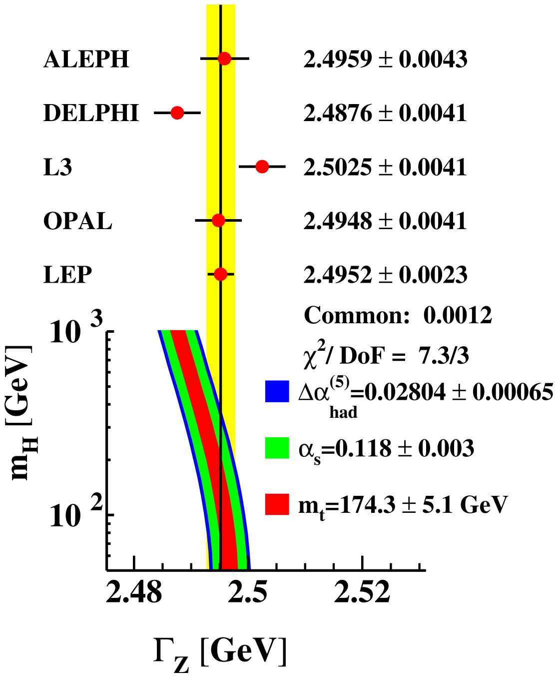
- **SM parameters**

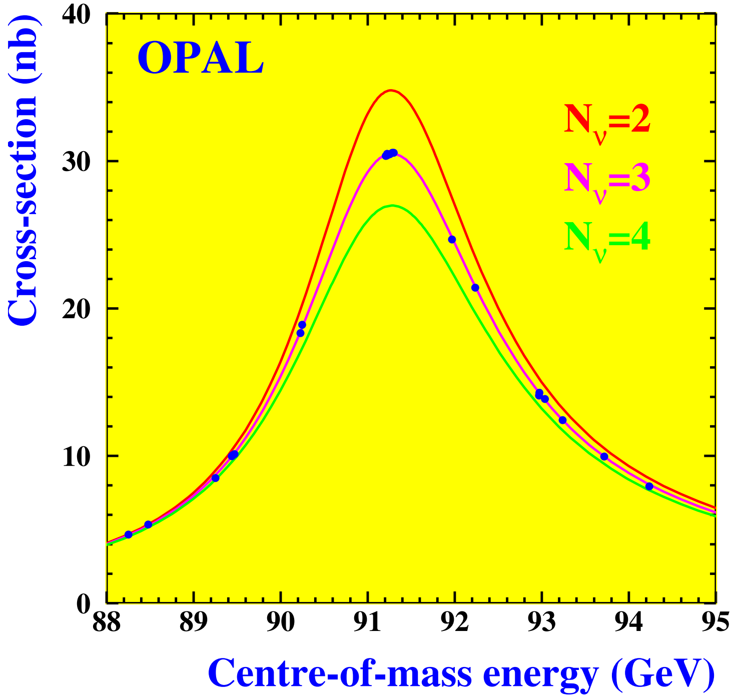
  $m_Z,\ \alpha,\ G_F,\ \alpha_S,\ m_t,\ m_H$

Controlled typically to 10^{-4} level.

Zedometry







$$\Gamma_{\rm inv} = \Gamma_Z - \Gamma_{\rm had} - \Gamma_e - \Gamma_\mu - \Gamma_\tau$$

$$(\Gamma_{\rm inv}/\Gamma_\ell)/(\Gamma_\nu/\Gamma_\ell)_{\rm SM} = 2.9841 \pm 0.0083$$

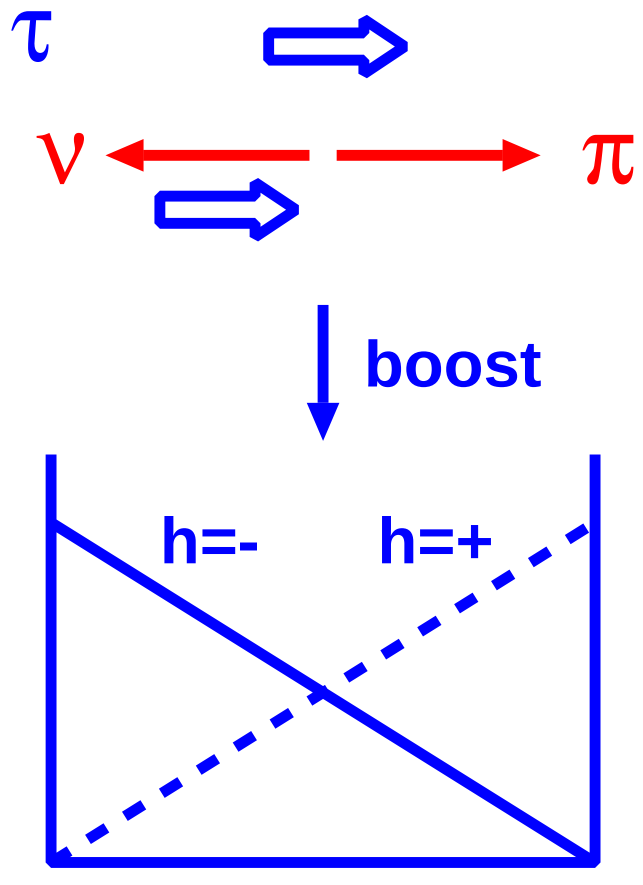
$$\Delta\Gamma_{\rm inv} = -2.7 \pm 1.6 \ \ \text{MeV}$$

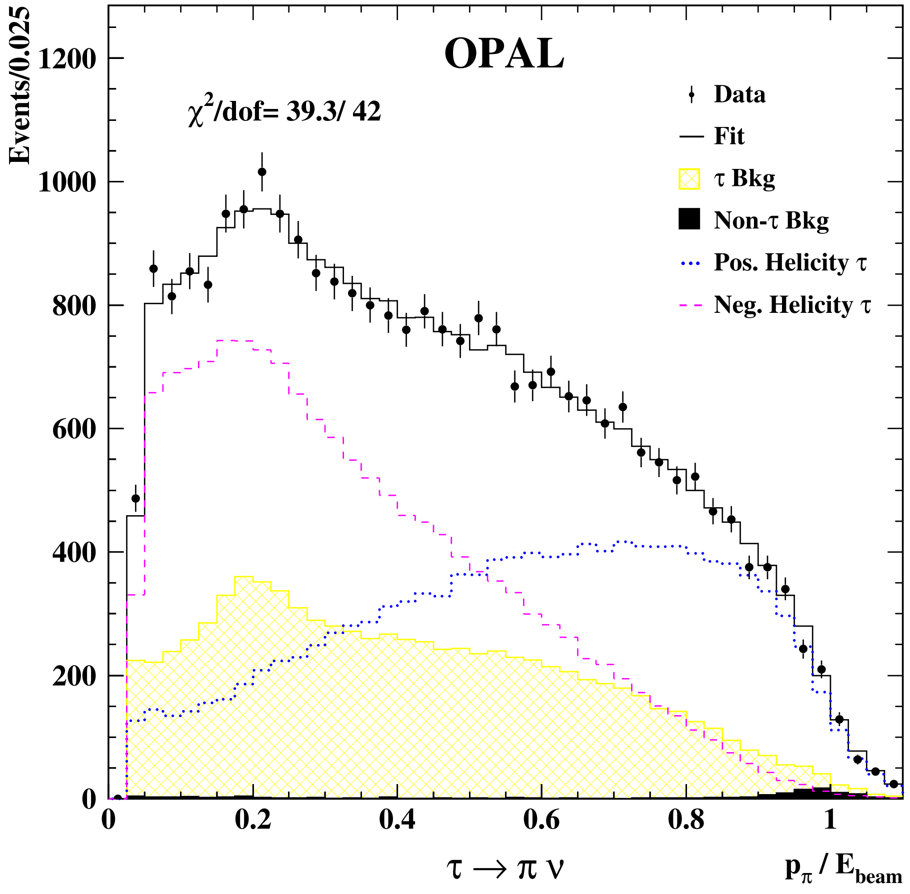
$$\Delta\Gamma_{\rm inv} < 2.0 \ \ \text{MeV} \ \ \text{at } 95\% \ \ \text{C.L}$$

Zedometry

τ polarisation : analysing τ helicity

ex. $\tau \to \pi\nu$

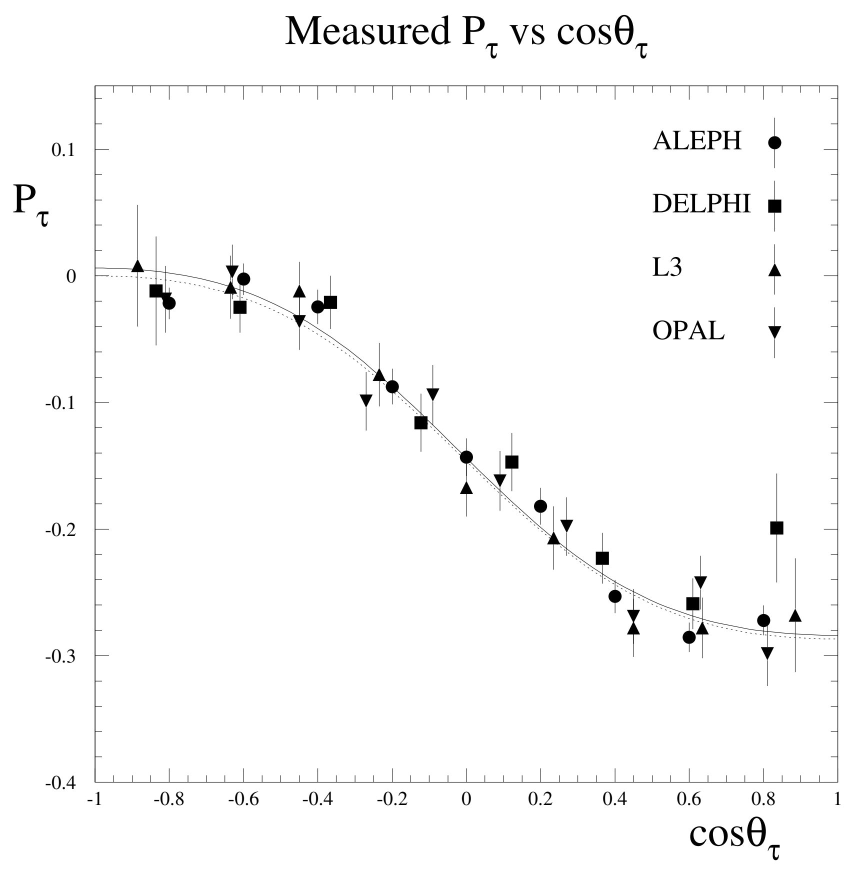


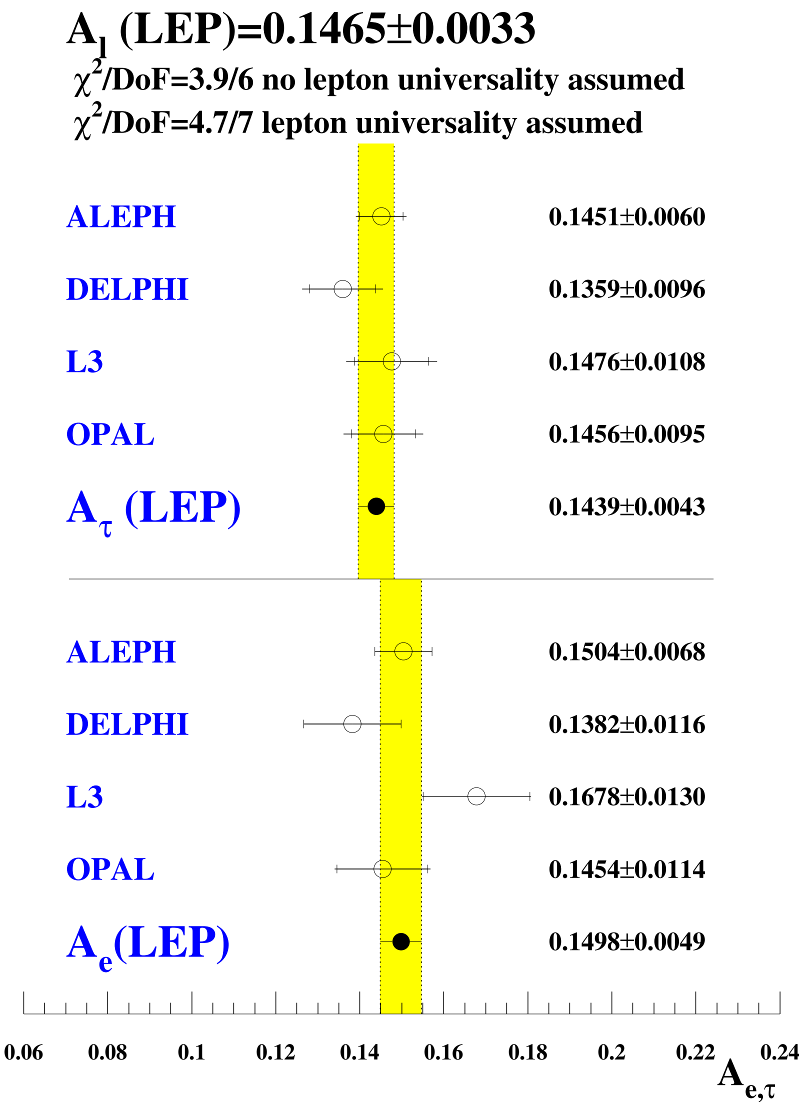


decay modes $\tau \longrightarrow \pi\nu, \rho\nu, \ell\nu\nu$, $a_1\nu$ are analysed.

Zedometry

τ polarisation : analysing τ helicity

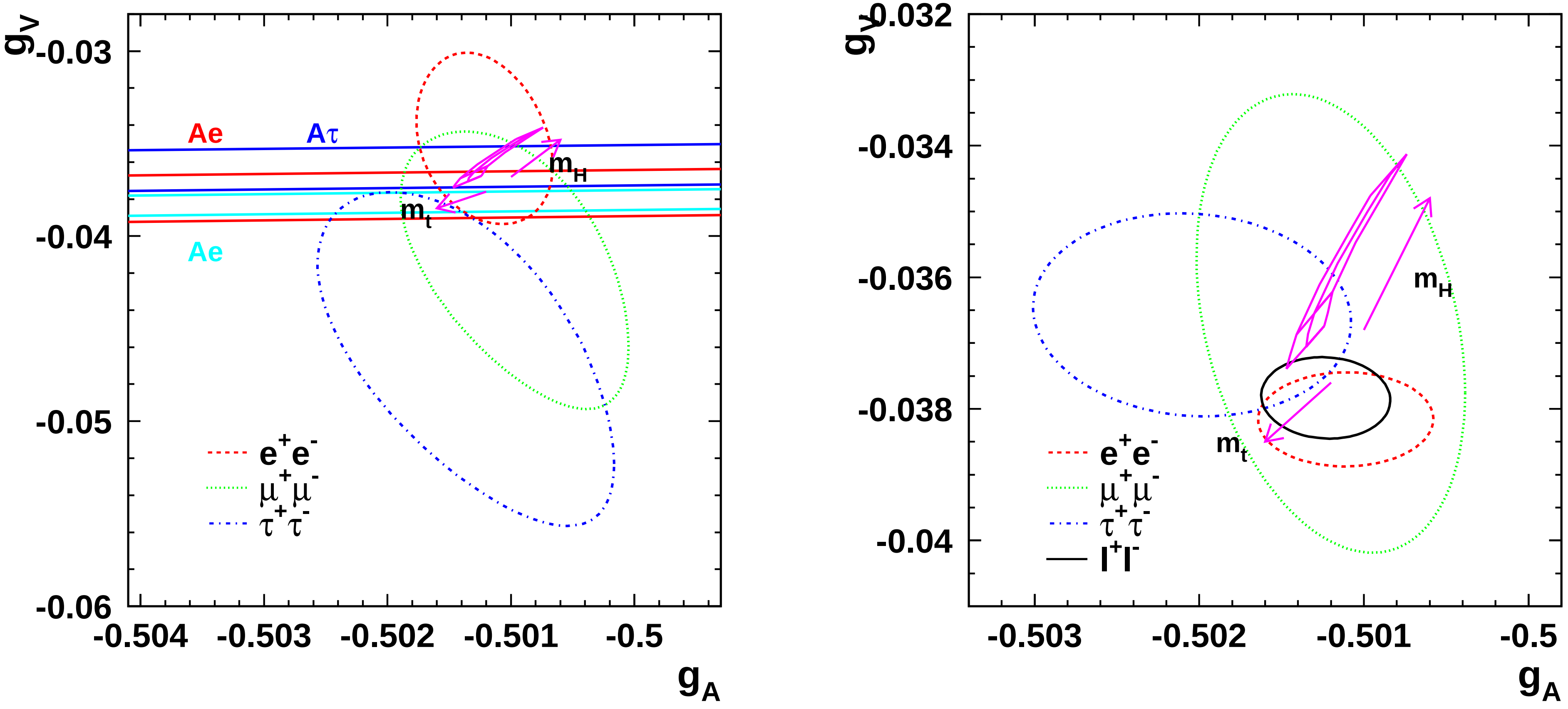




$$P(\cos\theta) = \frac{\mathcal{A}_\tau(1+\cos^2\theta) + 2\mathcal{A}_e\cos\theta}{(1+\cos^2\theta) + 2\mathcal{A}_e\mathcal{A}_\tau\cos\theta}$$

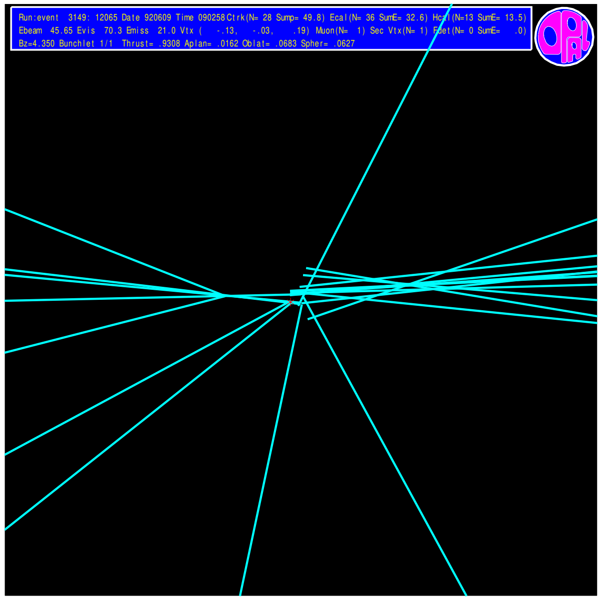
Zedometry

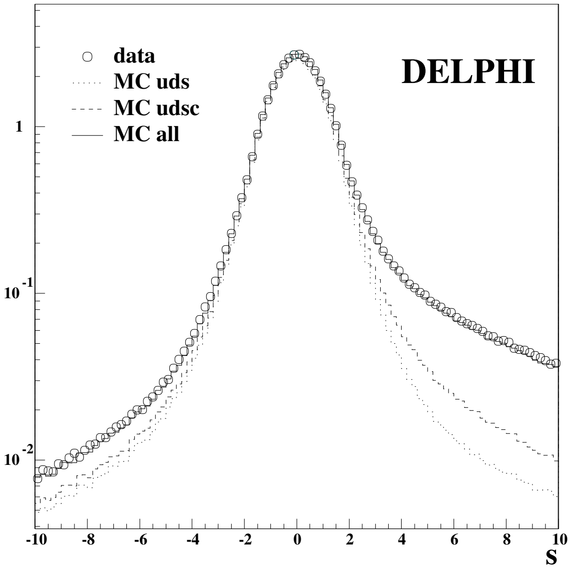
Lepton couplings and Lepton universality



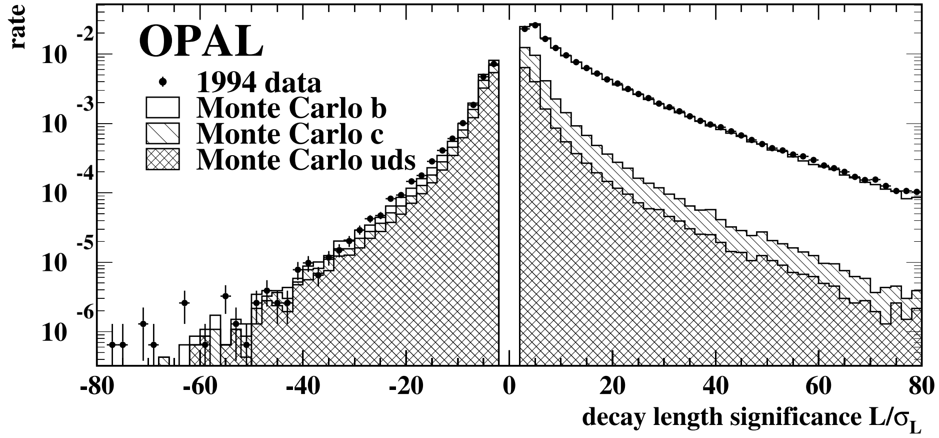
$$\Gamma_\ell \propto g_{V\ell}^2 + g_{A\ell}^2 \quad , \quad \mathcal{A}_\ell = 2(g_{V\ell}/g_{A\ell})/(1+(g_{V\ell}/g_{A\ell})^2)$$

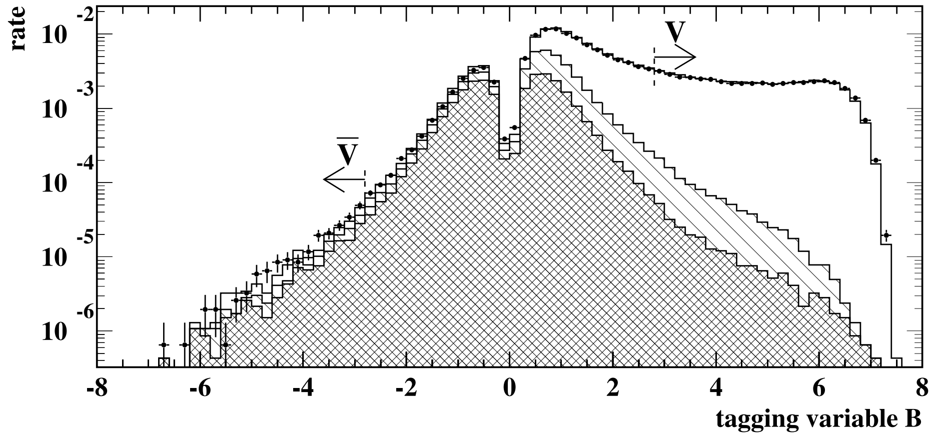
Zedometry





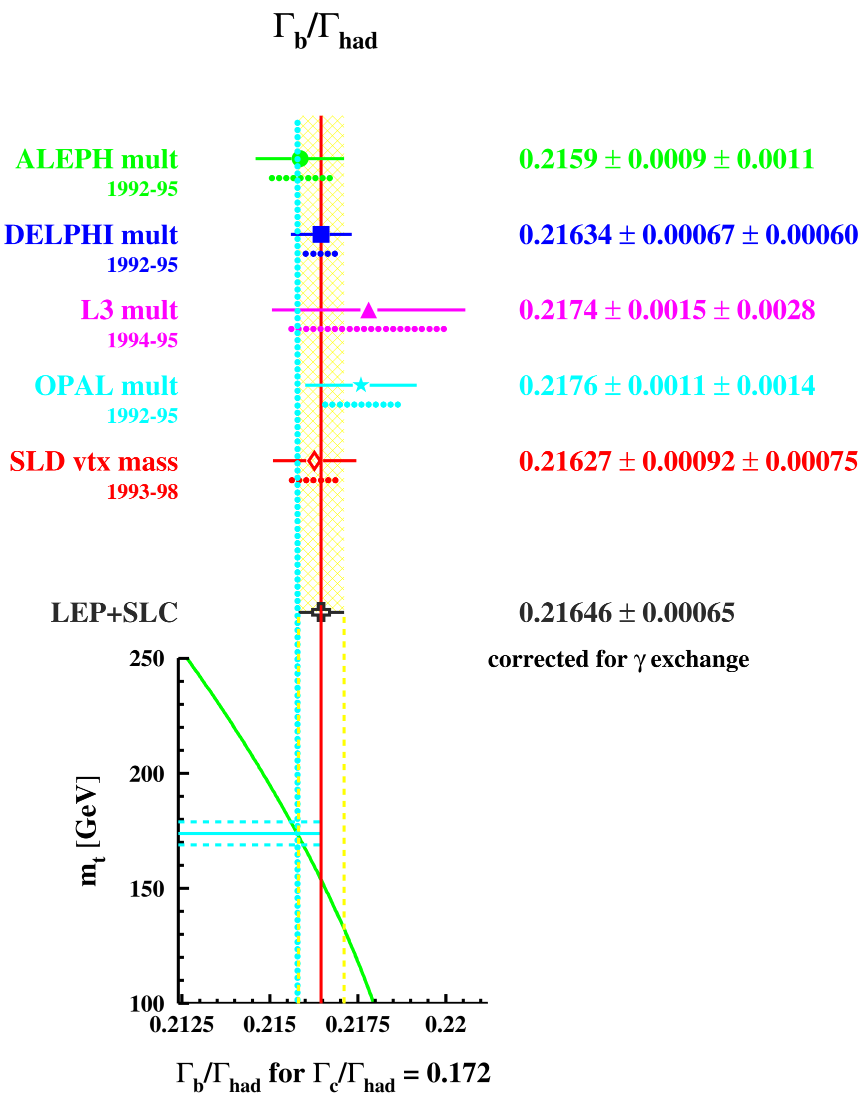
Heavy flavours : b and c



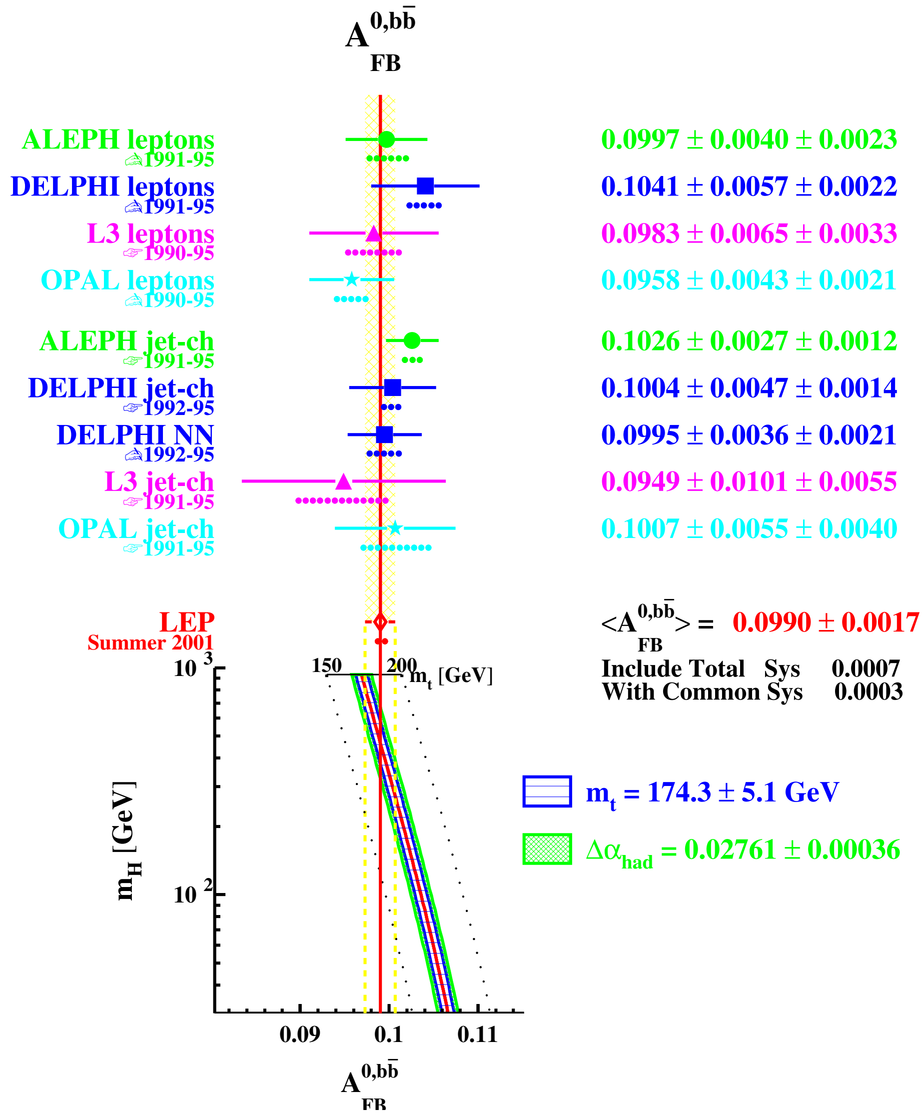


long B lifetime, high p, p_T leptons, ...

Zedometry



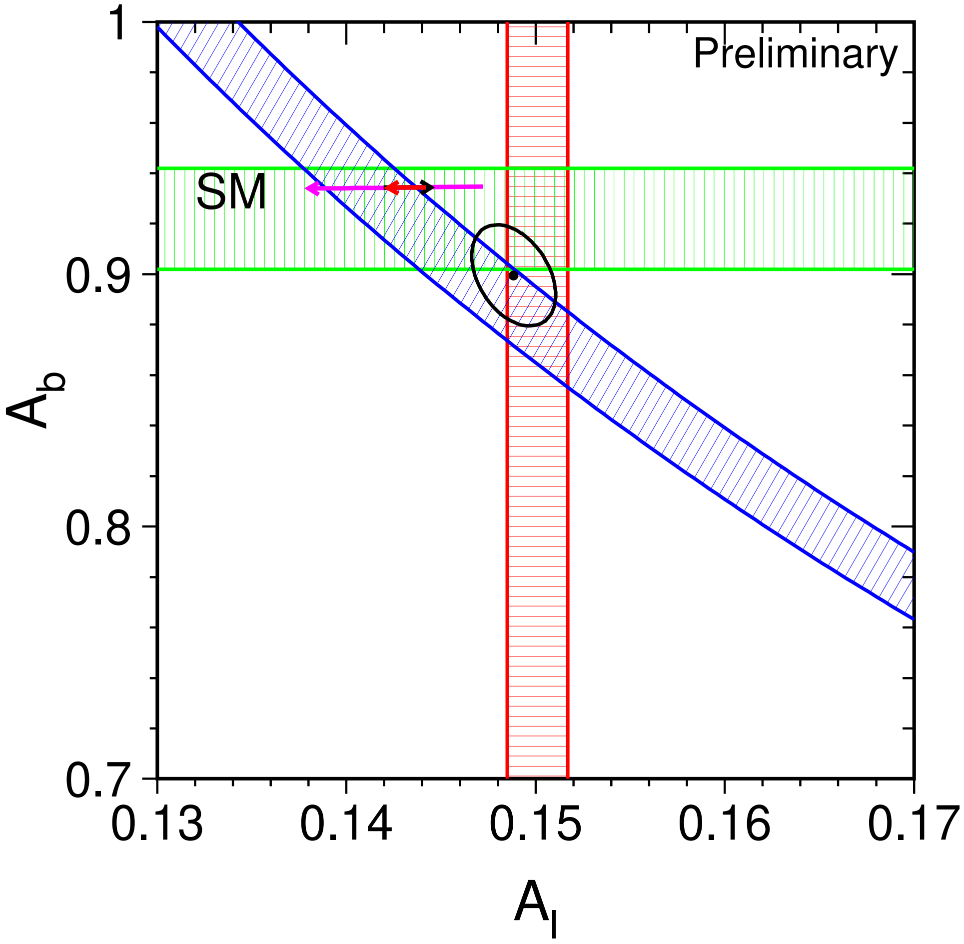
from the b rate

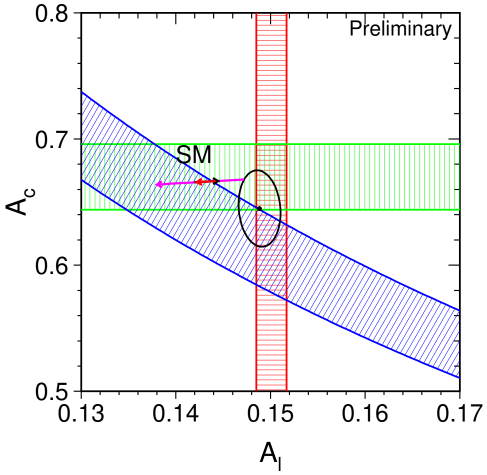


from b F-B asymmetry

Zedometry

The asymmetry parameter $\mathcal{A}_f$ from lepton, b and c asymmetries





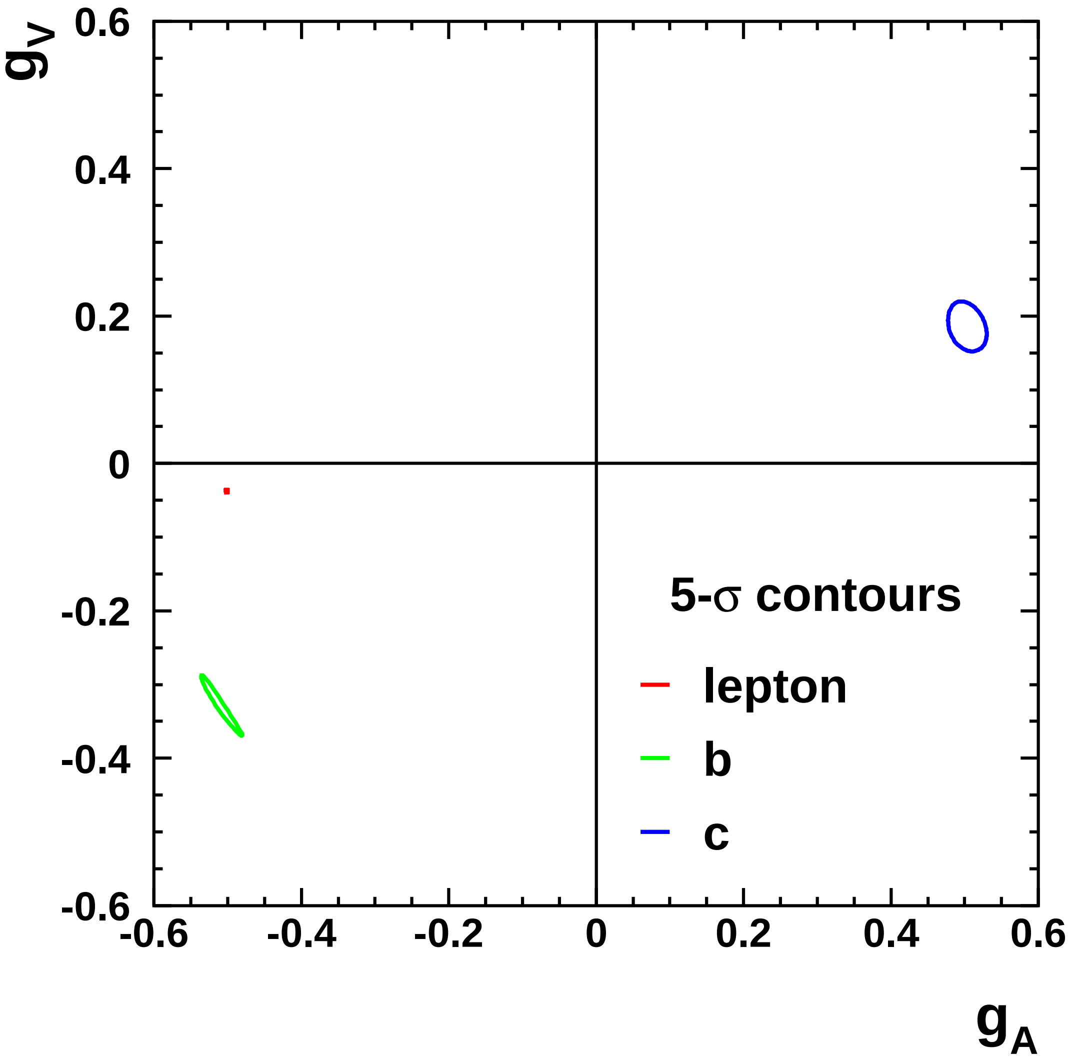
- $\mathcal{A}_\ell$ from lepton asymmetries
- $A_{FB}^{0,b} = \frac{3}{4}\mathcal{A}_\ell\mathcal{A}_b$ from b asymmetry
- $\mathcal{A}_b$ from SLC/SLD A_{FBLR}

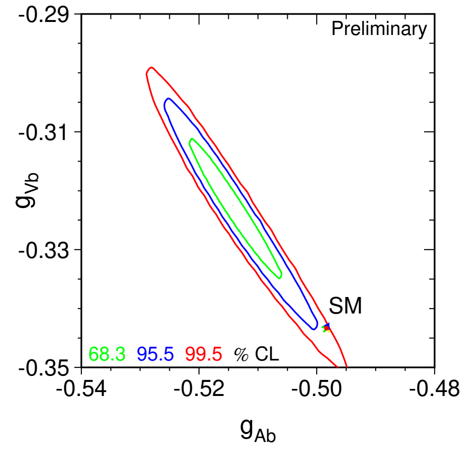
are consistent each other.

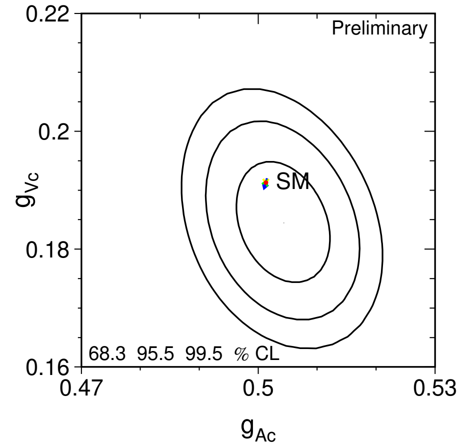
But, combined $\mathcal{A}_b = 0.899 \pm 0.013$ is lower than the SM value (0.935) by 2.8 σ.

Zedometry

Fermion couplings from Γ_f and $\mathcal{A}_f$







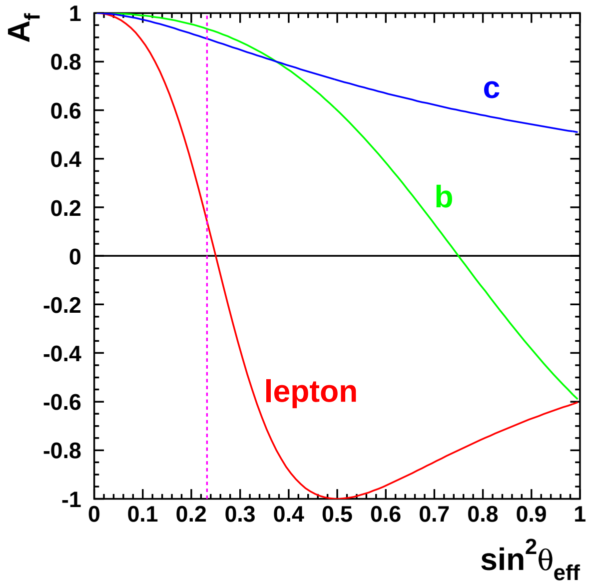
Zedometry

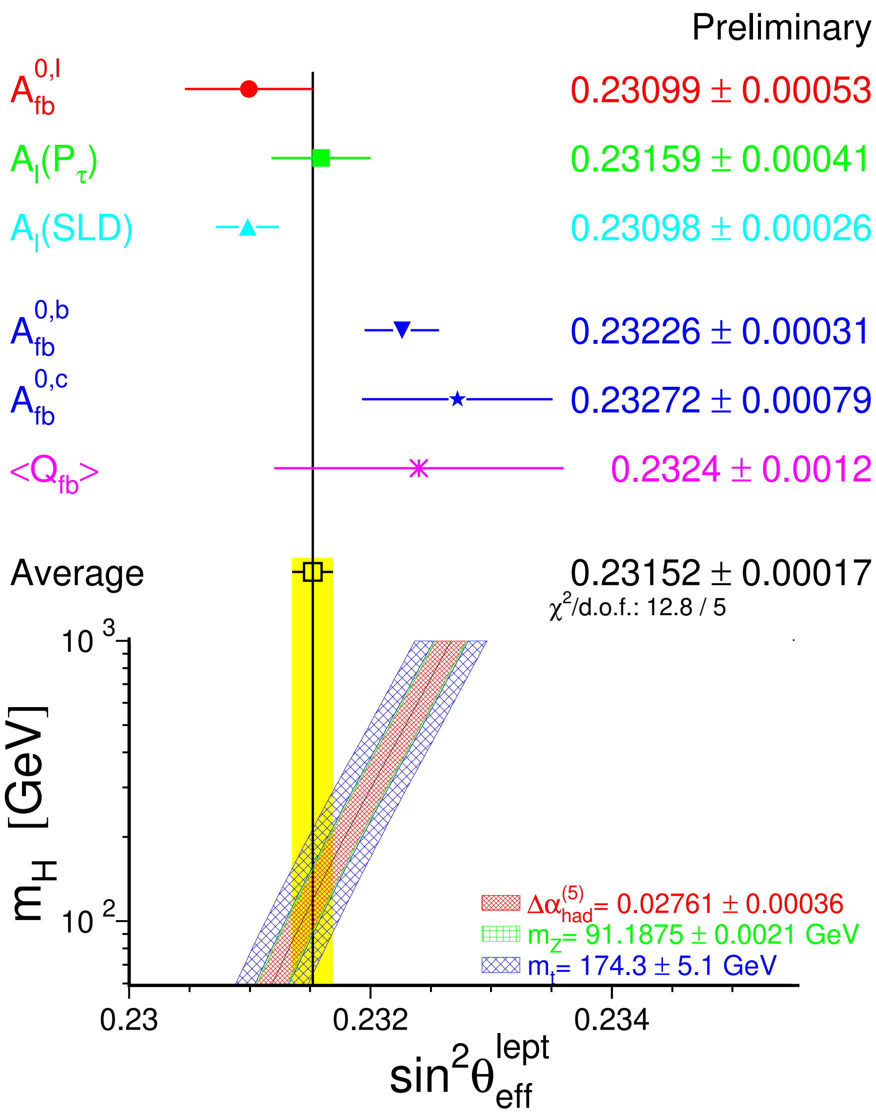
EW mixing angle $\sin^2\theta_{\rm eff}^{\rm lept}$

$$\sin^2\theta_{\rm eff}^{\rm lept} = \frac{1}{4}\left(1 - \frac{g_{V\ell}}{g_{A\ell}}\right)$$

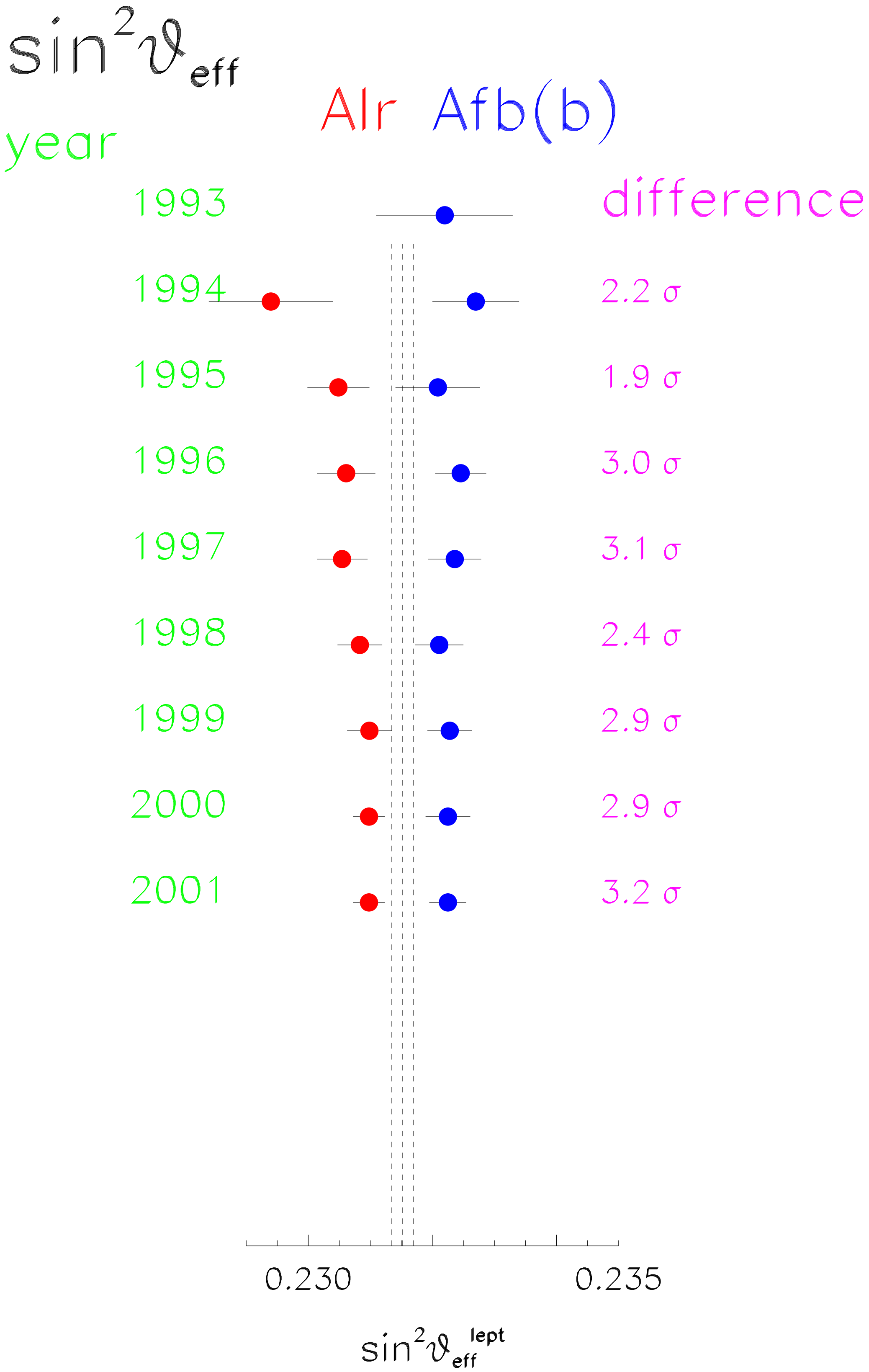
- $g_{V\ell}$, $g_{A\ell}$ from lepton asymmetry
- $\mathcal{A}_\ell$ from $A_{\rm FB}^{0,b}/\mathcal{A}_{\rm b}$, $A_{\rm FB}^{0,c}/\mathcal{A}_{\rm b}$

  In SM, $\mathcal{A}_{\rm b}, \mathcal{A}_{\rm c}$ are very constant





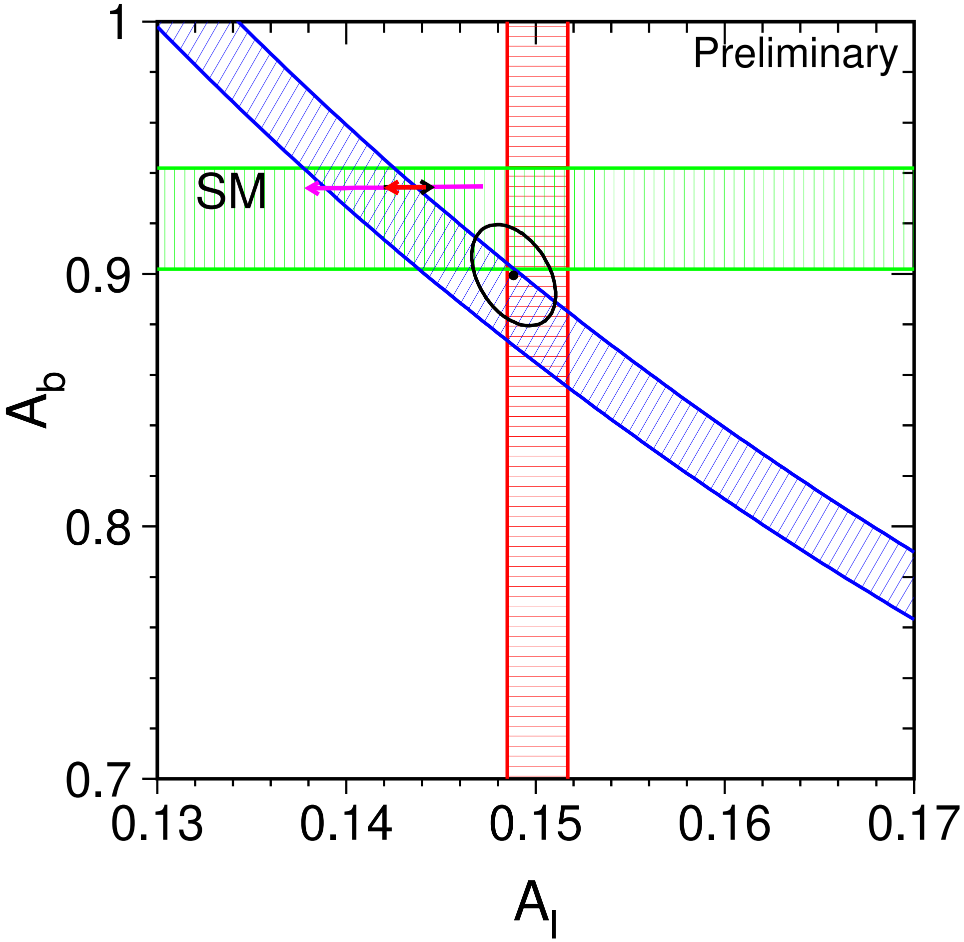
Zedometry



$\sin^2\vartheta_{eff}$
year
Alr Afb(b)
difference
1993
1994 2.2 σ
1995 1.9 σ
1996 3.0 σ
1997 3.1 σ
1998 2.4 σ
1999 2.9 σ
2000 2.9 σ
2001 3.2 σ
0.230
0.235
$\sin^2\vartheta_{eff}^{lept}$

Zedometry

lepton and b asymmetries



- $\mathcal{A}_{\rm b}$ (SLC/SLD) does not tell much.
- Fluctuation of lepton or b data ?
- Some bias on lepton or b data ?
- Something wrong with the SM ?

  New Physics?

- Some $A_{\rm FB}^{0,\rm b}$ yet to be finalised
- In future at Linear colliders ?
- In future at LHC !

  Potentially as good as LEP/SLD

  Parton distribution is a challenge

SM vs precision data

$$\mathcal{O} = \mathcal{O}(m_Z, m_t, m_H, \alpha(m_Z), \alpha_s(m_Z); G_F)$$

LEP

- **Lineshape** $m_Z, \Gamma_Z, \sigma^0_{\rm had}, R_\ell, A_{\rm FB}^{0,\ell}$
- $P(\tau)$ $\mathcal{A}_e,\ \mathcal{A}_\tau$
- **b, c** $R_b, R_c, A_{\rm FB}^{0,b}, A_{\rm FB}^{0,c}$
- $Q_{\rm FB}$ $\sin^2\theta_{\rm eff}^{\rm lept}$

SLD

- **b, c** R_b, R_c
- **L-R asym** $\mathcal{A}_\ell, \mathcal{A}_b, \mathcal{A}_c$

$p\bar{p}$, LEP2

- m_t, m_W

νN

- $\sin^2\theta_W$

$$R_\ell = \Gamma_{\rm had}/\Gamma_\ell$$

$$A_{\rm FB}^{0,f} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

$$\mathcal{A}_f = \frac{2 g_{Vf} g_{Af}}{g_{Vf}^2 + g_{Af}^2}$$

$$g_{V\ell}/g_{A\ell} = 1 - 4\sin^2\theta_{\rm eff}^{\rm lept}$$

$$\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$$

Parameters : $\alpha(m_Z)$

- Running of E.M. coupling
  vacuum polarization

$$\alpha(s) = \frac{\alpha(0)}{1 - \Delta\alpha_\ell(s) - \Delta\alpha^{(5)}_{h(s)} - \Delta\alpha_t(s)}$$

- $\Delta\alpha_\ell(s)$ leptonic : can be calculated.
- $\Delta\alpha_t(s)$ top : small, m_t dependence.
- $\Delta\alpha^{(5)}_h(s)$ light quarks : Involves QCD

Evaluation using dispersion integral:

$$\Delta\alpha^{(5)}_h(s) = -\frac{\alpha s}{3\pi} P \int_{4m_\pi^2}^{\infty} \frac{R(s')}{s'(s'-s)} ds'$$

Need hadronic cross-section $R(s)$ data at all energy.

- Main source of uncertainty:
  $\sqrt{s} = 2 - 5$GeV : old data

eg. Eidelmann, Jegerlehner (1995)
$\Delta\alpha^{(5)}_h(s) = 0.02804 \pm 0.0065$

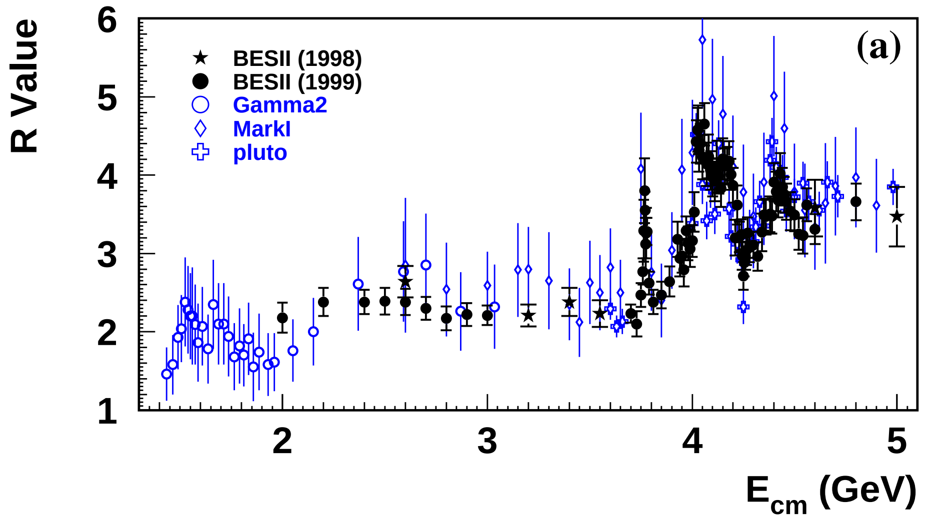
- Attempts using pQCD

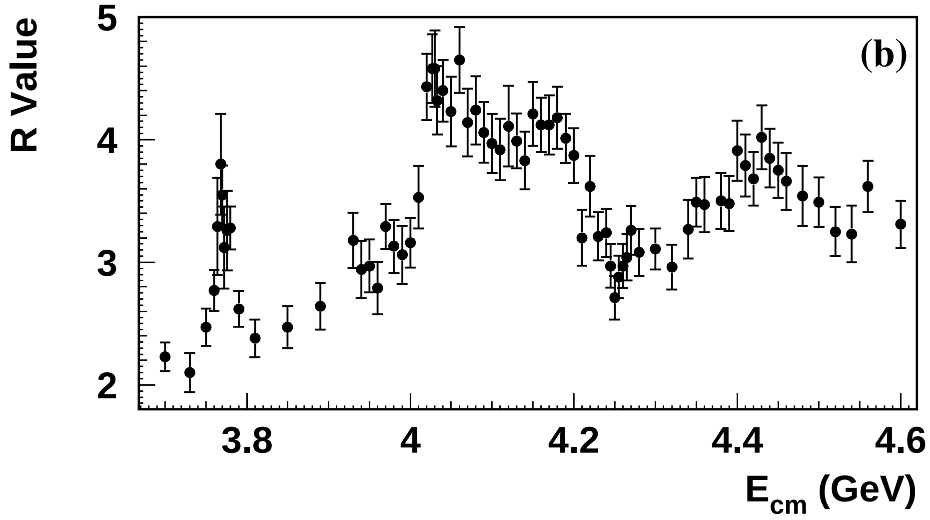
eg. Davier, Höcker (1998)
$\Delta\alpha^{(5)}_h(s) = 0.02784 \pm 0.0026$

- Good data are needed.

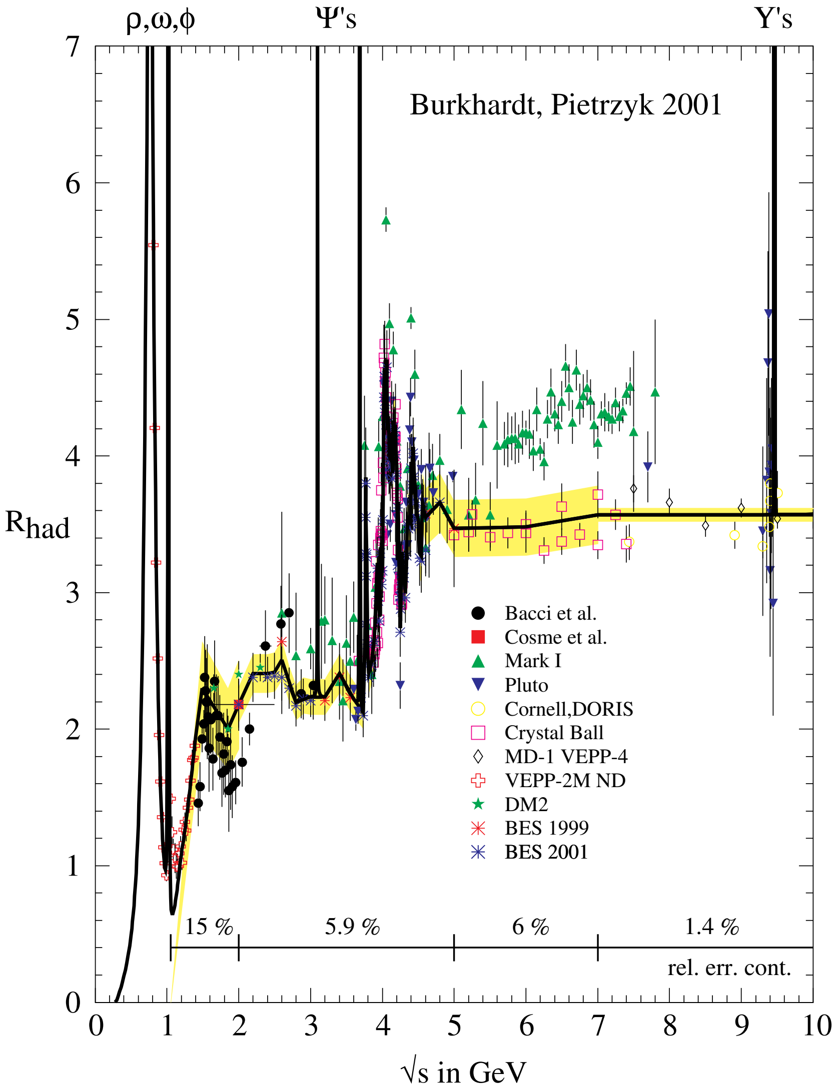
Parameters : $\alpha(m_Z)$

- **BES collaboration has measured R (hep-ex/0102003)**

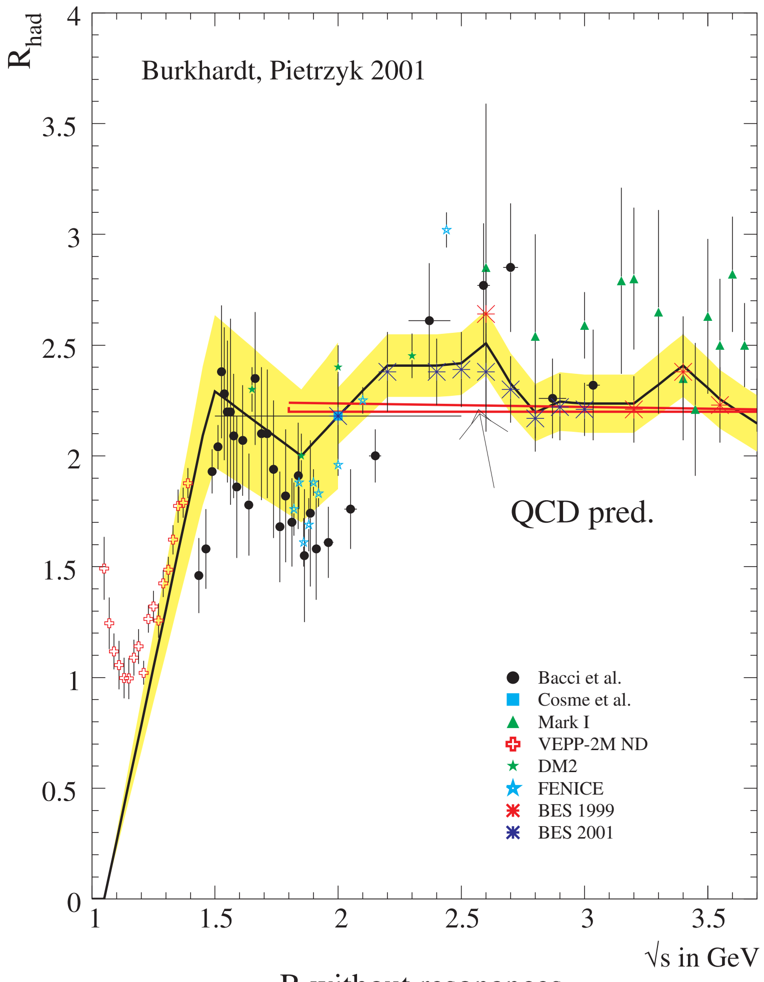




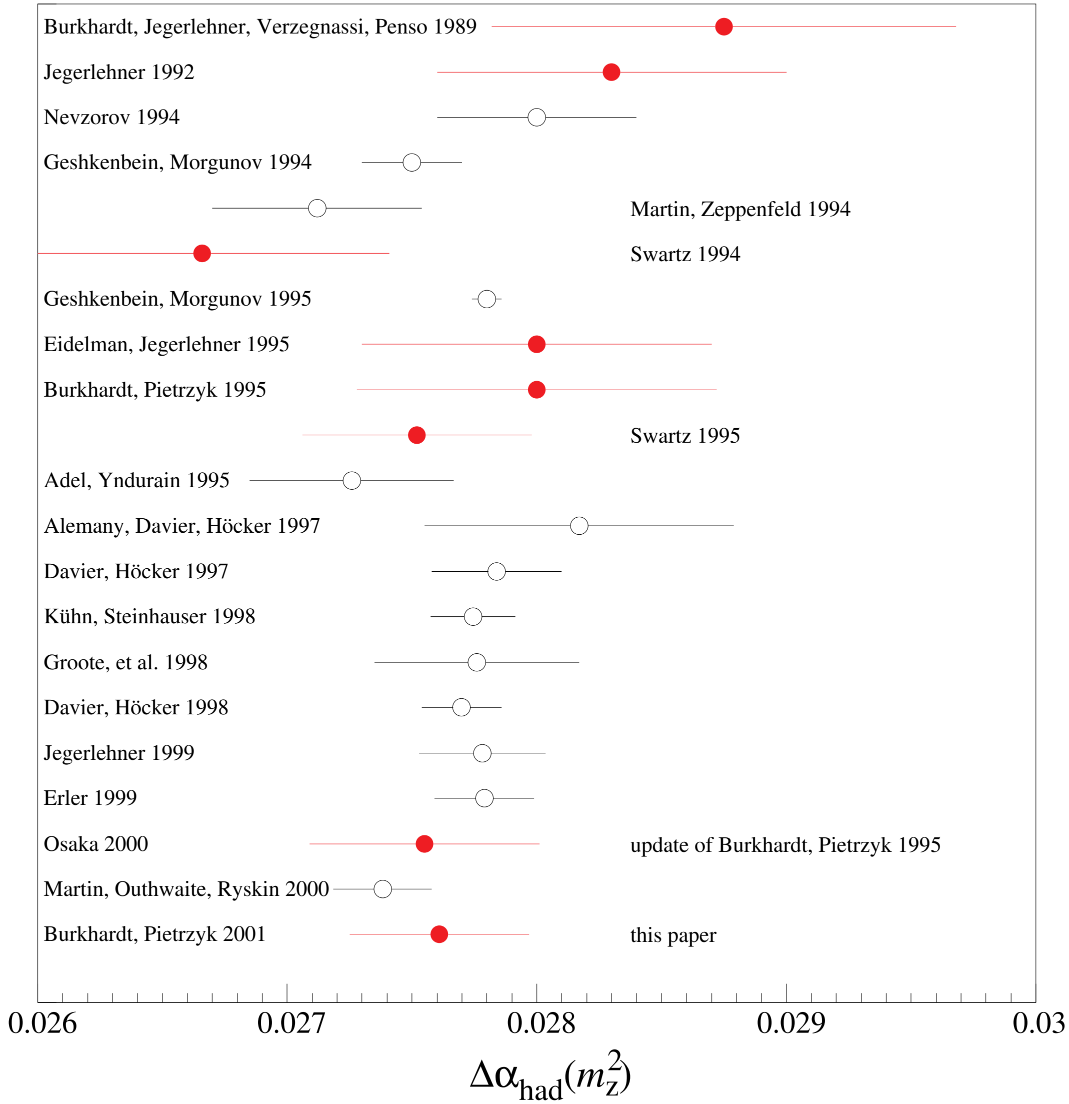
- **New evaluation using new data**



Parameters : $\alpha(m_Z)$



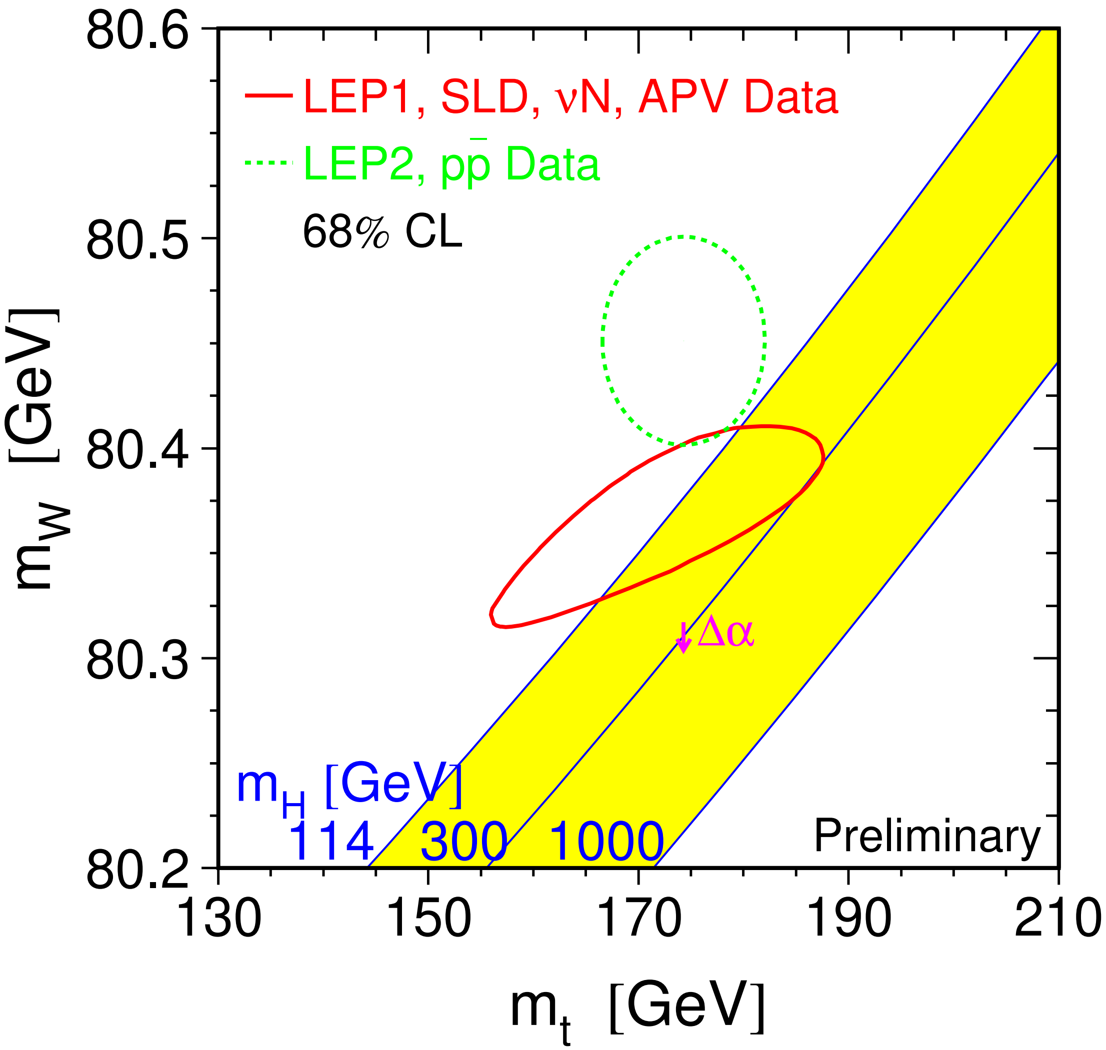
R without resonances



$$\Delta\alpha_{\mathrm{h}}^{(5)}(m_Z) = 0.02761 \pm 0.00036$$

lapp-exp 2001-03, accepted by PLB

SM fits



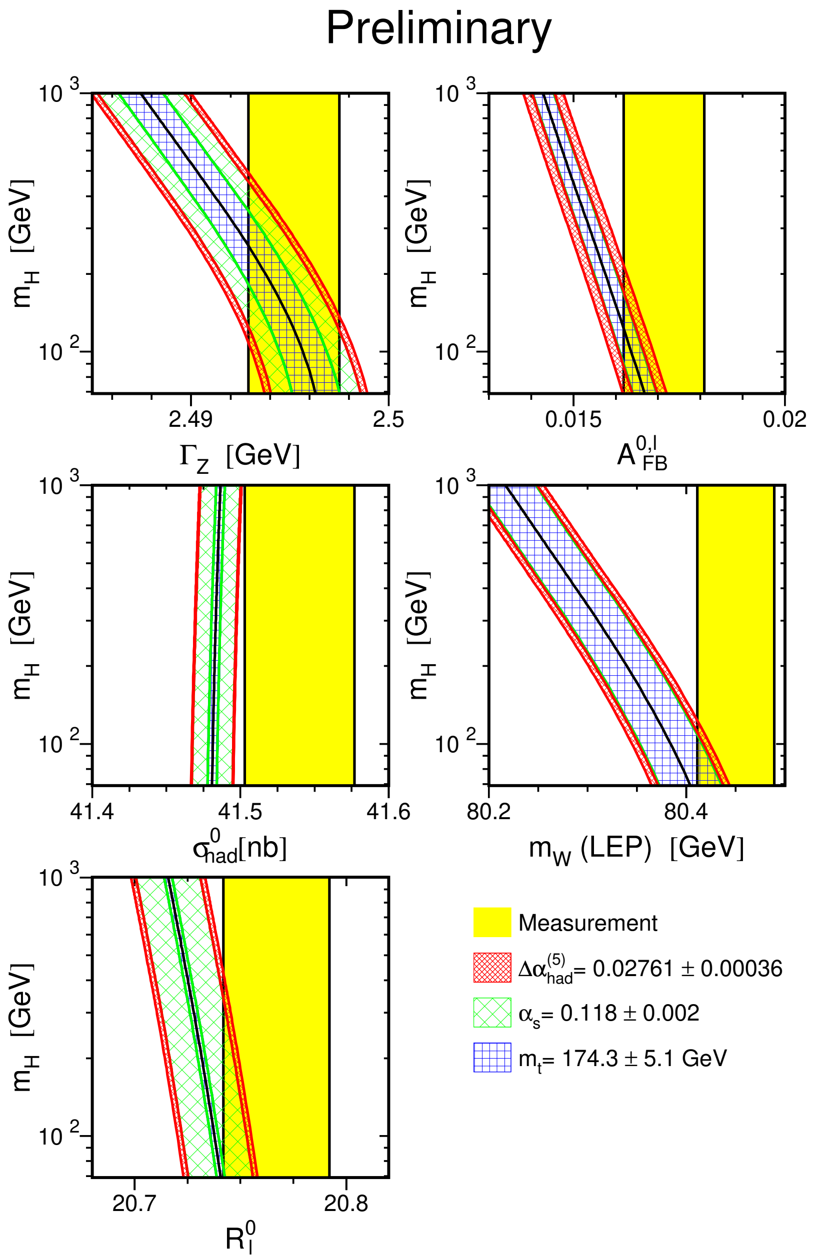
Summer 2001 preliminary

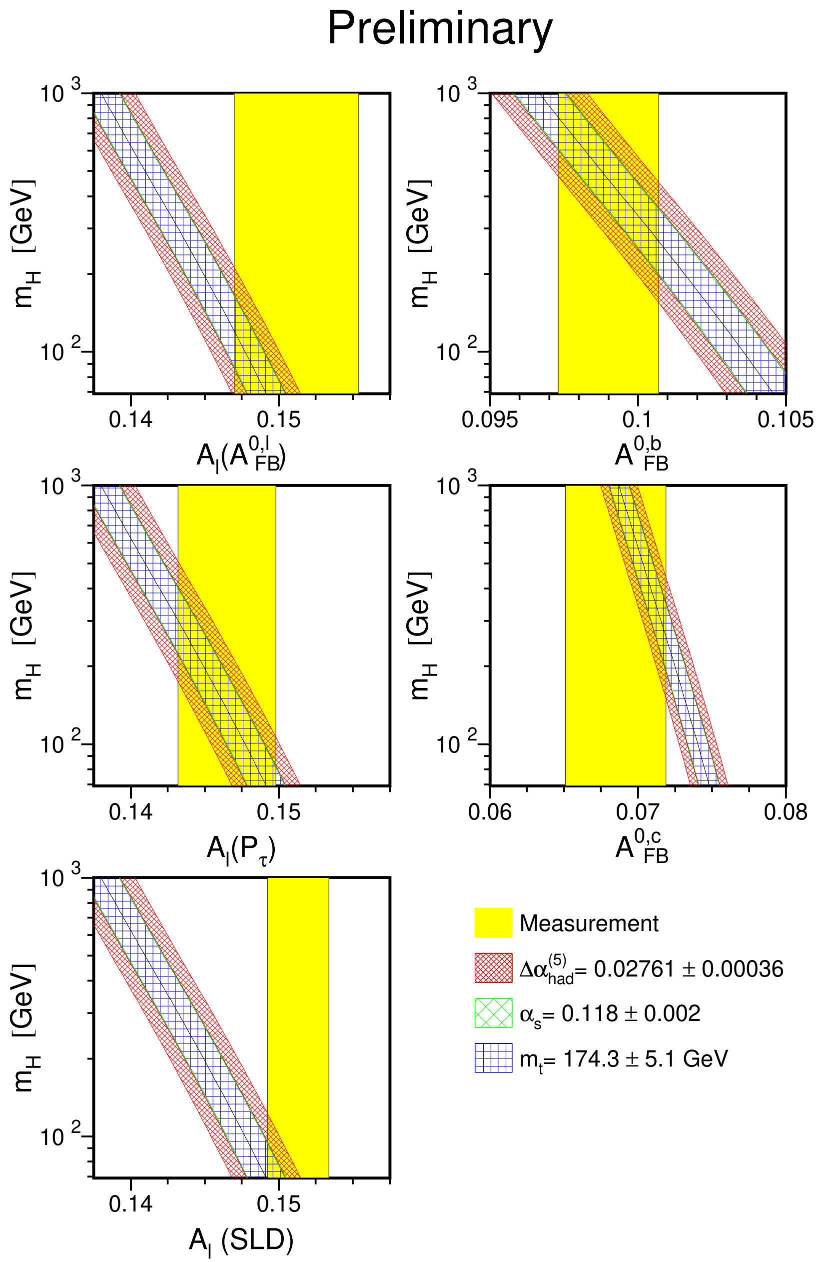
- **Indirect determination**
  SM fit to data – $(m_{\mathrm{W}}, m_{\mathrm{t}})$

- $m_{\mathrm{W}}, m_{\mathrm{t}}$ **direct meas.**

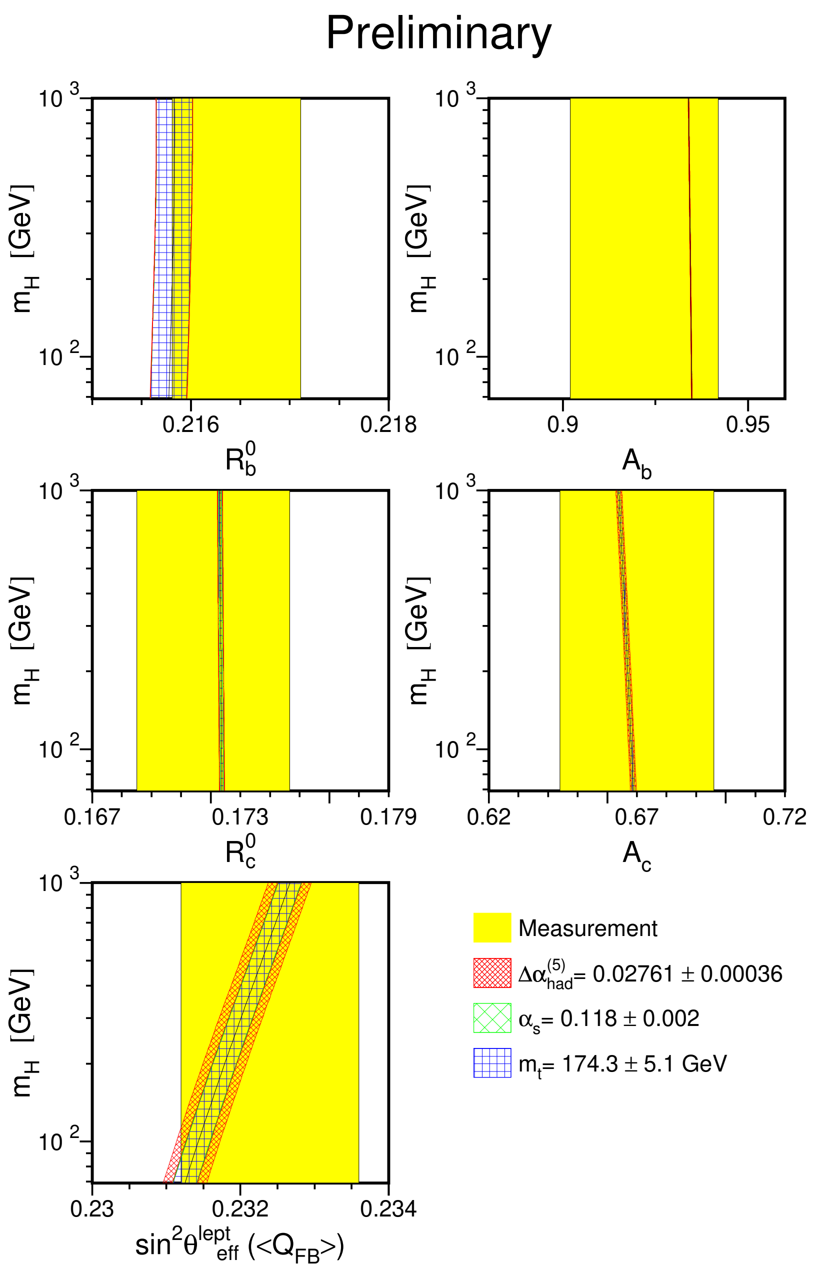
Direct and Indirect m_{W} are $\approx$ consistent.

Dependence on m_{H}





Dependence on m_{H}



SM fit results

	all data w/o m_W, m_t	all data w/o m_W	all data w/o m_t	all data
m_t GeV	169^{+12}_{-9}	173^{+5}_{-5}	181^{+11}_{-9}	176^{+4}_{-4}
m_H GeV	81^{+109}_{-40}	108^{+70}_{-44}	126^{+182}_{-69}	88^{+53}_{-35}
$\alpha_s(m_Z)$	0.1187 ± 0.0027	0.1189 ± 0.0027	0.1186 ± 0.0028	0.1183 ± 0.0027
χ^2/d.o.f	19/12	19/13	22.6/14	22.9/15
$\sin^2\theta^{\rm lept}_{\rm eff}$	0.23150 ± 0.00016	0.23151 ± 0.00016	0.23139 ± 0.00015	0.23136 ± 0.00014
$1 - \frac{m_W^2}{m_Z^2}$	0.22333 ± 0.00063	0.22313 ± 0.00045	0.22248 ± 0.00045	0.22263 ± 0.00036
m_W GeV	80.363 ± 0.032	80.373 ± 0.023	80.406 ± 0.023	80.398 ± 0.019

Higgs mass from the Standard Model fit

- **Summer 2001 result**

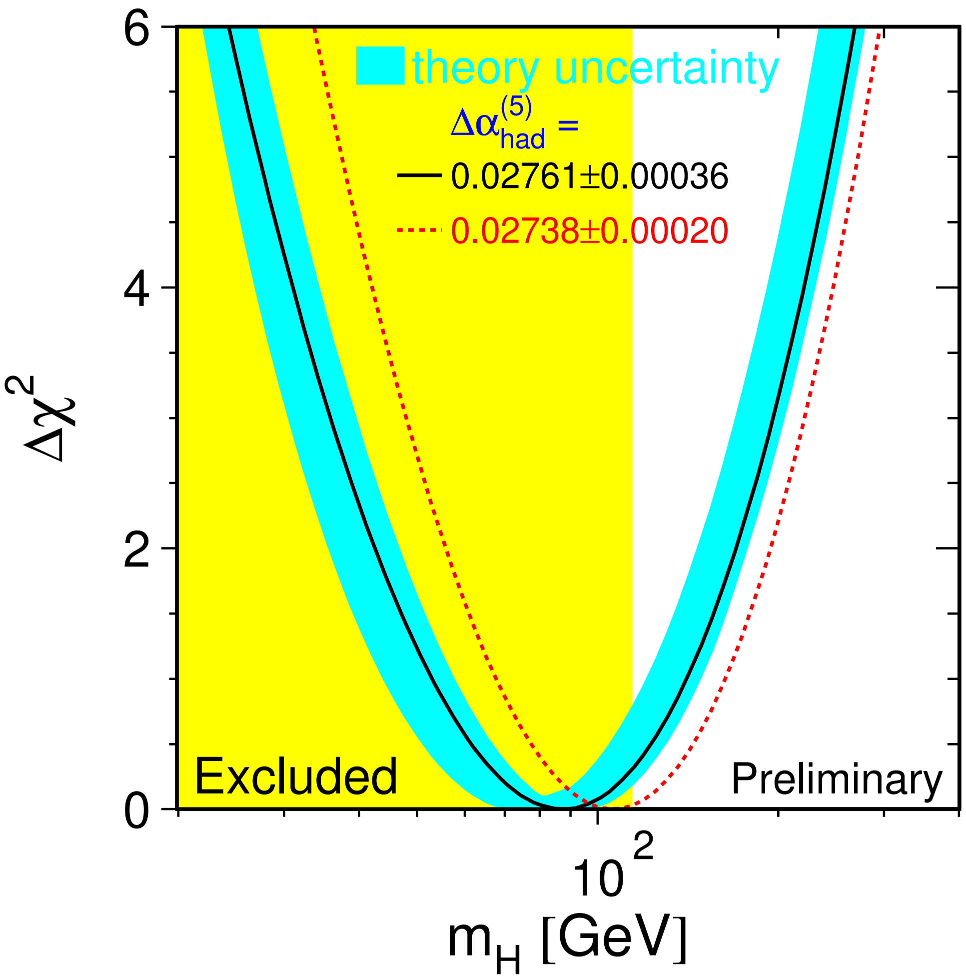
$\chi^2_{min} = 22.9/15$ **d.o.f**

- $m_{\rm H} = 88^{+53}_{-35}$ **GeV**
- $m_{\rm H} < 196$ **GeV (95 % CL)**

- **Direct search :**

- $m_{\rm H} > 114$ **GeV (95 % CL)**

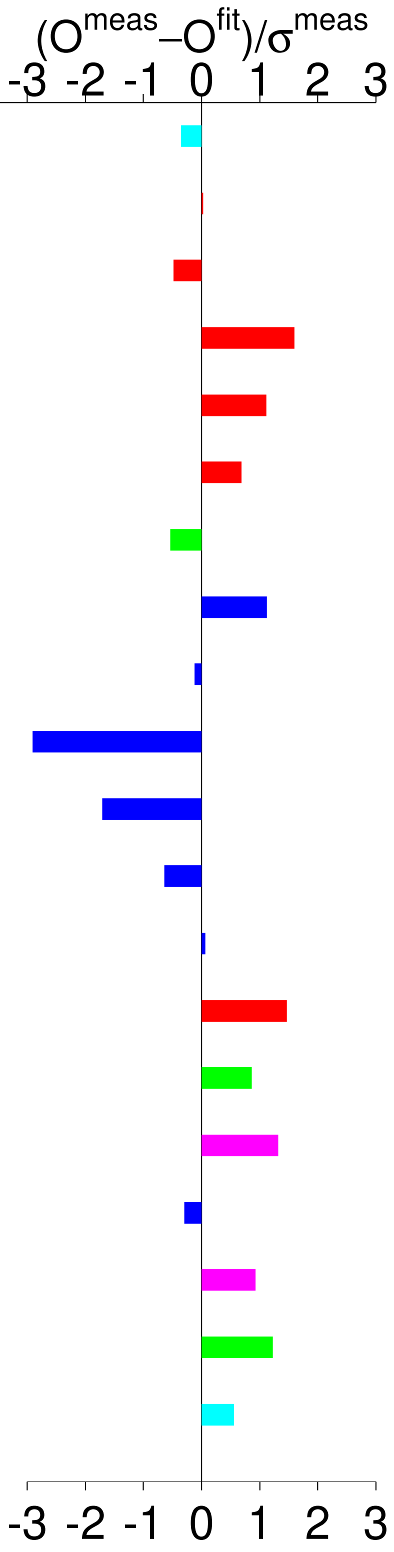
- **Fits using ZFITTER, TOPAZ0**



Global fit goodness

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



S.M. fits

New result from NuTeV (νN scattering) on $\sin\theta_{\mathrm{W}} = 1 - m_{\mathrm{W}}^2/m_{\mathrm{Z}}^2$ (Oct 2001)

$$\sin\theta_{\mathrm{W}} = 0.2277 \pm 0.0016 - 0.00022(m_{\mathrm{t}}^2 - 175^2)/50^2 + 0.00033\log(m_{\mathrm{H}}/150)$$

$\longrightarrow$

$m_{\mathrm{W}} = 80.14 \pm 0.08$ GeV

$\leftrightarrow$ 3.6 σ

$m_{\mathrm{W}} = 80.451 \pm 0.033$ GeV (Direct measurement)

Impact on the SM fit

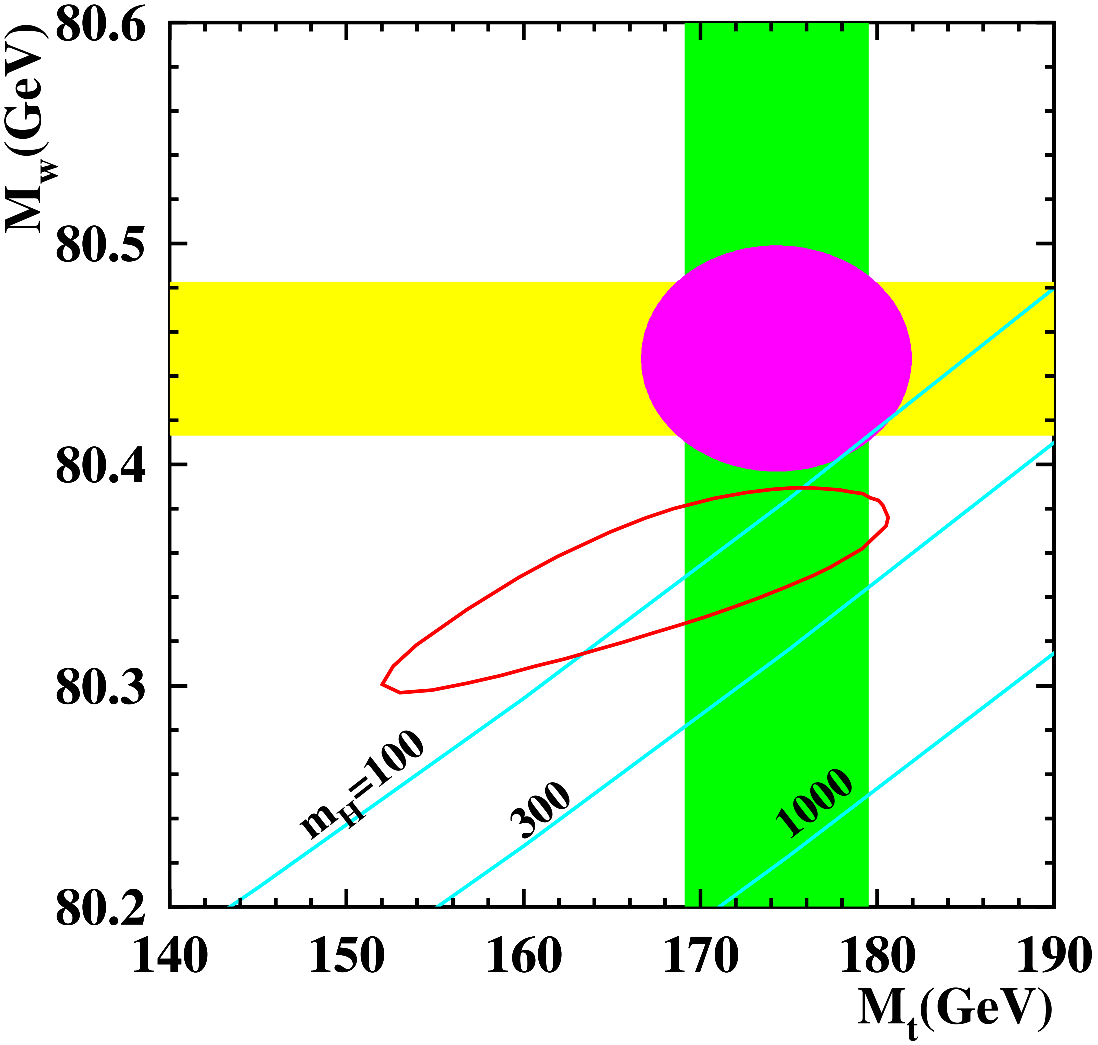
$m_{\mathrm{H}} = 90 \leftarrow 88$ GeV

$\chi^2/\mathrm{d.o.f} = 30.6/15\ (P = 0.99\%) \leftarrow 22.9/15$

Pull of the NuTeV $\sin\theta_{\mathrm{W}}$ from the SM fit = 3.0 $\leftarrow$ 1.2

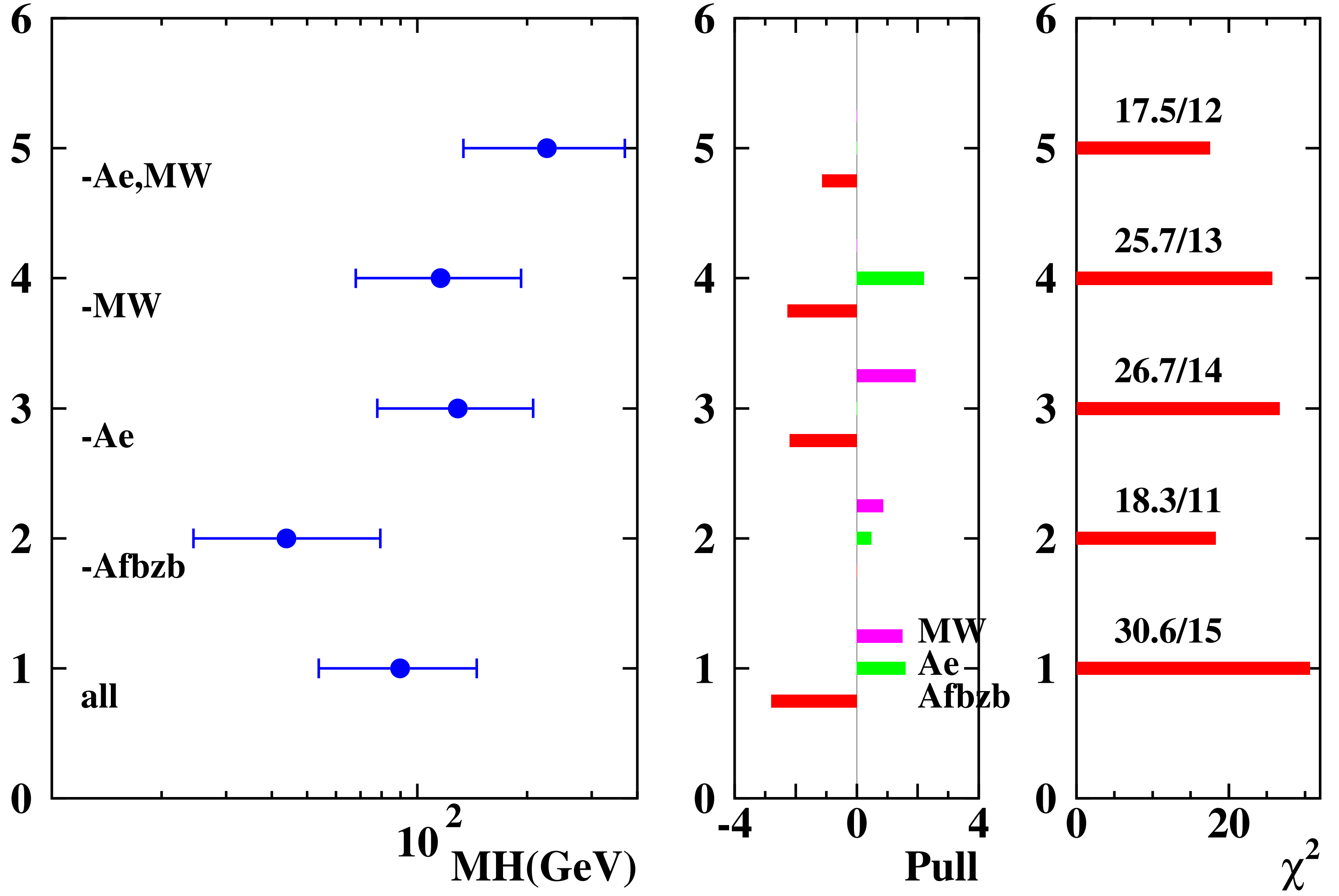
S.M. fits

m_{W} vs m_{t} with the new NuTeV result



S.M. fits

Dependence of $m_{\rm H}$ on dataset



Summary

- The SM works fine.
- A few 2-3 σ deviations
- EW data favour low mass higgs.

  $m_{\mathrm{H}} = 88^{+53}_{-35}$ GeV

  $m_{\mathrm{H}} < 196$ GeV (95 % CL)
- b, c, m_{W} are to be finalized
- Improved m_{W}, m_{t} to come from Tevatron (and LHC) in future

Big question

- Where is the Higgs?