τ Universality and Precision Measurements

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τ Universality and Precision Measurements

① 'Data'

i) "CC": τ_τ, Michel parameters, $W \to \tau\nu$, ..

important interplay... $\longrightarrow$ x^{e}_{eff} 'LEP vs SLD'

ii) "NC": $e^+e^- \to \gamma, Z \to \tau^+\tau^-$ vs $e^+e^-/\mu^+\mu^-$

② 'Some Models' of Universality Violation

i) mix τ with <u>exotics</u>

ii) Z-Z' mixing w/ Z' having <u>gen. dep.</u> <u>couplings</u>

iii) give τ a <u>new</u> <u>intrinsic</u> property : $x^{\tau}_{Z,\gamma}$

How are they doing ? Sensitivity ?

③ Conclusions

τCF'94

TGR:ZZC

τ_τ is THE <u>Classic</u> test of τ Universality ...

→ input : m_τ , $B_{e,\mu}$ ⊕ SM RC ⊕ τ_μ

→ output : τ_τ <u>or</u> G_τ/G_μ ∴ <u>looks</u> <u>excellent</u> !

remember ...

$$\frac{G_\tau}{G_\mu} = \frac{\text{"}1-\Delta r\text{"}}{1-\Delta r_\tau} \xrightarrow[\text{SM}]{} 1 + O\left(\frac{\alpha}{\pi}\frac{m_\tau^2}{M_W^2}\right) = 1 + O(10^{-6}) \;!$$

- But .... BSM large non-universal's may exist which may be significant

e.g., $\longrightarrow 1 + O\left(\frac{\alpha}{\pi}\frac{m_\tau^2}{M_W^2}\tan^2\beta\right) = 1 + \underline{O(10^{-3})}$!!

↳ probed at <u>TCF</u> !

<u>Michel Parameters : is $\tau\nu_\tau W$ V-A ?</u>

	"LE" †	LEP * (Swain)	"WA"
ρ	0.730 ± 0.026	0.748 ± 0.041 (A)	0.749 ± 0.022
δ	—	0.83 ± 0.17 (A, LB)	0.83 ± 0.17
ξ	0.90 ± 0.18	1.07 ± 0.17 (A, LB)	1.02 ± 0.13 *
η	0.03 ± 0.18 ± 0.12	—	0.03 ± 0.18 ± 0.12
h	1.25 ± 0.26	0.951 ± 0.058 (A)	0.965 ± 0.057 *

impressive, very nice, but so what ?

⟹ implications for precision EW measurements

!!

† All data 7/94 + before

* DPF '94 (conflict with Glasgow) ? (Patterson)

$$\tau_\ell^{-1} \equiv B_{\ell\ell'}^{-1} \cdot \left[\frac{G_\ell^2 m_\ell^5}{192\pi^3}\right] \cdot f(x_{\ell,\ell'}) \cdot \left\{1 + \frac{3}{5}\left(\frac{m_\ell^2}{M_W^2}\right) + O\left(\frac{m_\ell^4}{M_W^4}\right)\right\} \cdot \left[1 + \frac{\alpha(m_\ell)}{2\pi}\left(\frac{25}{4} - \pi^2\right) + (3.3 \pm 1.8)\left(\frac{\alpha(m_\ell)}{\pi}\right)^2 + O\left(\frac{\alpha}{\pi} x_{\ell,\ell'}\right)\right]$$

Data for Comparison

$B(\ell^- \to \ell' \nu_\ell \bar{\nu}_{\ell'})$

data!

data!

Phase Space Correction

$(x \equiv m_{\ell'}^2/m_\ell^2)$

finite M_W correction

very well known QED correction

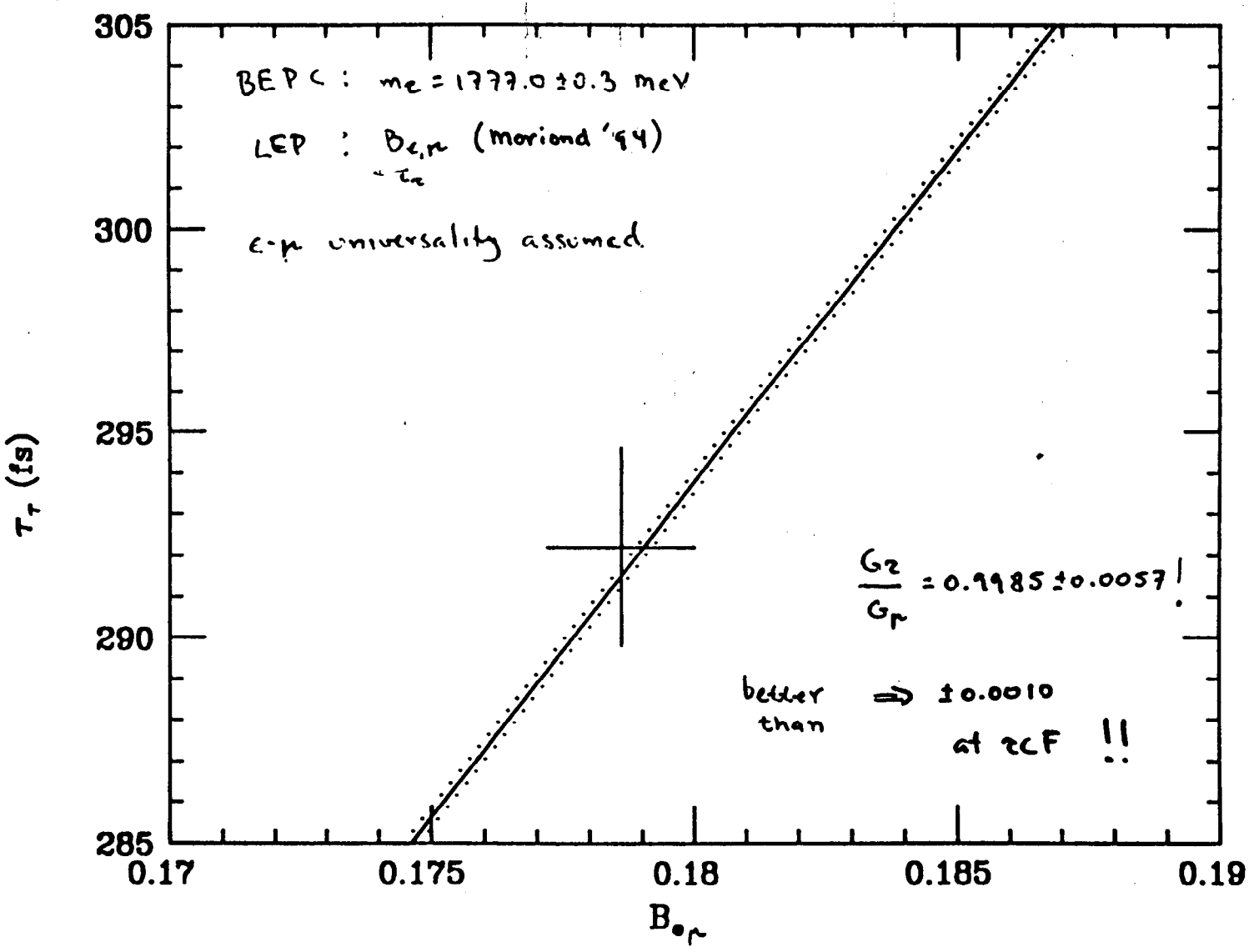
estimate

known

$O(10^{-5})$

This is the <u>definition</u> of $\underline{\underline{G_\ell}}$!!!

BEBC : DPF'94 $1776.96^{+0.18+0.20}_{-0.19-0.16}$!



* Patterson & Glasgow
$m_\tau = 1777.00 \pm 0.26$
$\tau_\nu = 290.8 \pm 1.5$
$B_e = 17.66 \pm 0.11$
$B_\mu = 17.18 \pm 0.12$
→ 0.9956 ± 0.0035 ~1σ low

Patterson & Glasgow

ν_τ HELICITY

- CONSIDER $\tau \to \pi\nu$

$\tau^- \rightrightarrows$ $\nu_\tau \leftarrow\!\bullet\!\rightarrow \pi^-$ LEFT-HANDED ν_τ FAST π

$\tau^- \rightrightarrows$ $\pi^- \leftarrow\!\bullet\!\rightarrow \nu_\tau$ RIGHT-HANDED ν_τ SLOW π

- TAU HELICITY CORRELATION

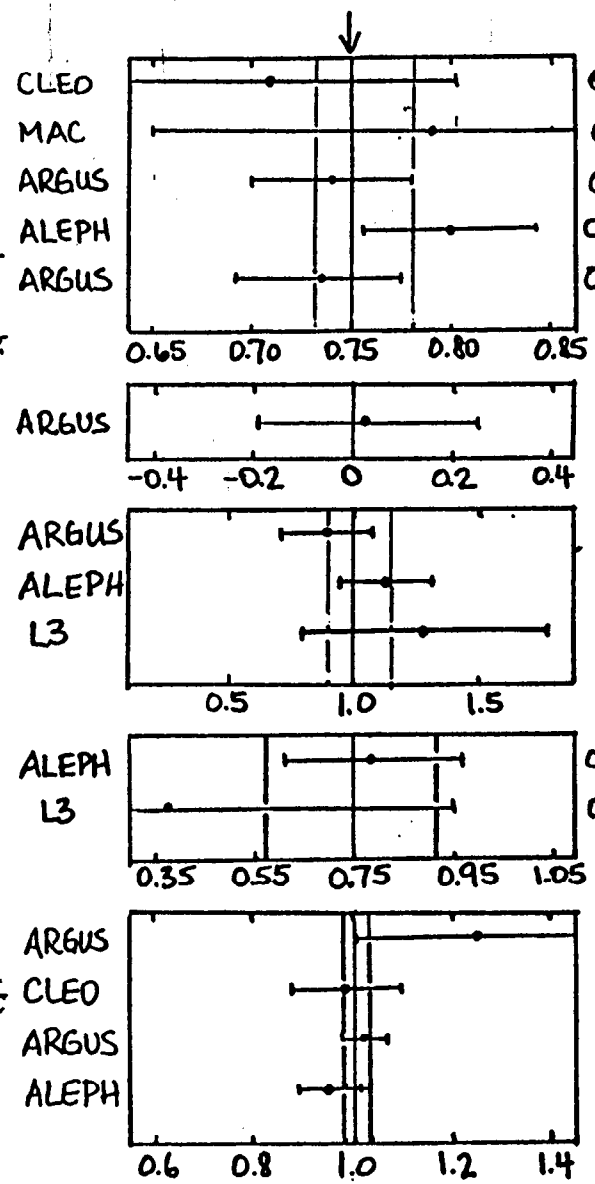
$\tau \leftarrow\!\bullet\!\rightarrow \tau$ FROM SPIN 1 γ^*, Z

MOMENTUM CORRELATIONS IN $\pi\pi$ EVENTS CAN YIELD ν_τ HELICITY

ALEPH
- ISOLATE $\tau\tau$ SAMPLE: e vs μ, e vs π...
- SIMULTANEOUS FIT FOR $\rho, \eta, \xi, \delta, h_{\nu_\tau}, p_\tau$

ARGUS
- USE $\tau \to \rho\nu$ vs. $\tau \to \rho\nu$ ENERGY AND ANGULAR CORRELATIONS TO EXTRACT $h_{\nu\tau}$

CLEO
- USE $\tau \to \pi\nu$ vs $\tau \to \pi\nu$ TO EXTRACT h_{ν_τ} 12



AND ν_τ HELICIT

CLEO	$0.71 \pm 0.09 \pm 0.03$	ρ
MAC	$0.79 \pm 0.10 \pm 0.10$	
ARGUS	$0.742 \pm 0.035 \pm 0.020$	
ALEPH	$0.798 \pm 0.032 \pm 0.026$ ●	
ARGUS	$0.735 \pm 0.036 \pm 0.020$ ●	
	0.757 ± 0.024	
ARGUS	$0.03 \pm 0.18 \pm 0.12$ ●	η
ARGUS	$0.90 \pm 0.15 \pm 0.10$	ξ
ALEPH	$1.13 \pm 0.17 \pm 0.07$ ●	
L3	1.29 ± 0.49 ●	
	1.03 ± 0.12	
ALEPH	$0.79 \pm 0.17 \pm 0.06$ ●	δ
L3	0.38 ± 0.57 ●	
	0.75 ± 0.17	
ARGUS	$1.25 \pm 0.23^{+0.15}_{-0.08}$	h_ν
CLEO	$0.99 \pm 0.06 \pm 0.09$ ●	
ARGUS	$1.022 \pm 0.028 \pm 0.030$ ●	
ALEPH	$0.951 \pm 0.051 \pm 0.028$ ●	
	1.002 ± 0.032	

● = NEW

LEP P_τ data is a major source of the conflict with SLD over $\sin^2\theta_{eff}$:

P_τ^{LEP} (Glasgow) $\rightarrow$ $x_{eff} = 0.2325 \pm 0.0009$

A_{LR} (SLD) $\rightarrow$ " $= 0.2294 \pm 0.0010$

However: LEP actually measures $\begin{cases} \xi \cdot P_\tau & \text{for } \tau \to \ell \\ h \cdot P_\tau & \text{for } \tau \to \pi, \rho, a, \end{cases}$

+ Assumes V-A for $\tau \nu_\tau W$; ie, $\xi = h = 1$

{ ... which has prompted them to measure $\xi, h, \delta, \xi, \ldots$!! (double correlations) }

- If f is the 'weight' of the $\tau \to \ell$ data, then

$$\text{"}P_\tau\text{"} = \frac{2(1-4x_0)}{1+(1-4x_0)^2} = k \cdot P_\tau^{true} = k \cdot \frac{2(1-4x)}{1+(1-4x)^2}$$

'apparent' averaged result

V-A Hypothesis $x_{eff}^0 = 0.2325 \pm 0.0009$

actual x_{eff}

where: $k \equiv f\xi + (1-f)h$, $f_{\text{Moriond '94}} = 0.2868$ (no new result but probably ~0.25 now)

$\therefore$ $k < 1 \rightarrow x_{eff} < x_0$

- 'model-independent' approach $\rightarrow$ take ξ, h from data + allow 1σ variation.

$\rightarrow x_{eff} = 0.2311 \pm 0.0009$ [$A_{FB}^\ell \rightarrow 0.23107 \pm 0.00090$]

- 'Toy model': i) e-μ universality + purely LH cc's
  ii) τ may have a RH piece
  iii) eμτ univ. in Z couplings...

$$\mathcal{L} = \frac{4G}{\sqrt{2}} J_\ell^+(L) \left[g_{LL} J_\tau(L) + g_{LR} J_\tau(R) \right] + h.c.$$

$$\rightarrow \quad r \equiv g_{LR}^2 / g_{LL}^2 \quad \underline{\text{small}}$$

			WA	
Michel's change ...	$\rho = \frac{3}{4}(1+r)^{-1}$	$< 3/4$	✓	
	$\delta = \frac{3}{4}(1+3r)^{-1}$	$< 3/4$	✗	(ok, with $\Delta\delta$)
	$\xi = (1+3r)/(1+r)$	> 1	✓	←
	$h = (1-r)/(1+r)$	< 1	✓	←
	$\eta = 0$	0	✓	

- Use 'r' to parameterize $h, \xi \neq 1$ (Plot)
- RHC can lower x_{eff} extracted from P_τ !!!

  perhaps to $\underline{0.2311 \pm 0.0009}$

- LEP will try to get better h, ξ (η, δ, ρ) info

  BUT: **TCF** will remove this problem **completely**

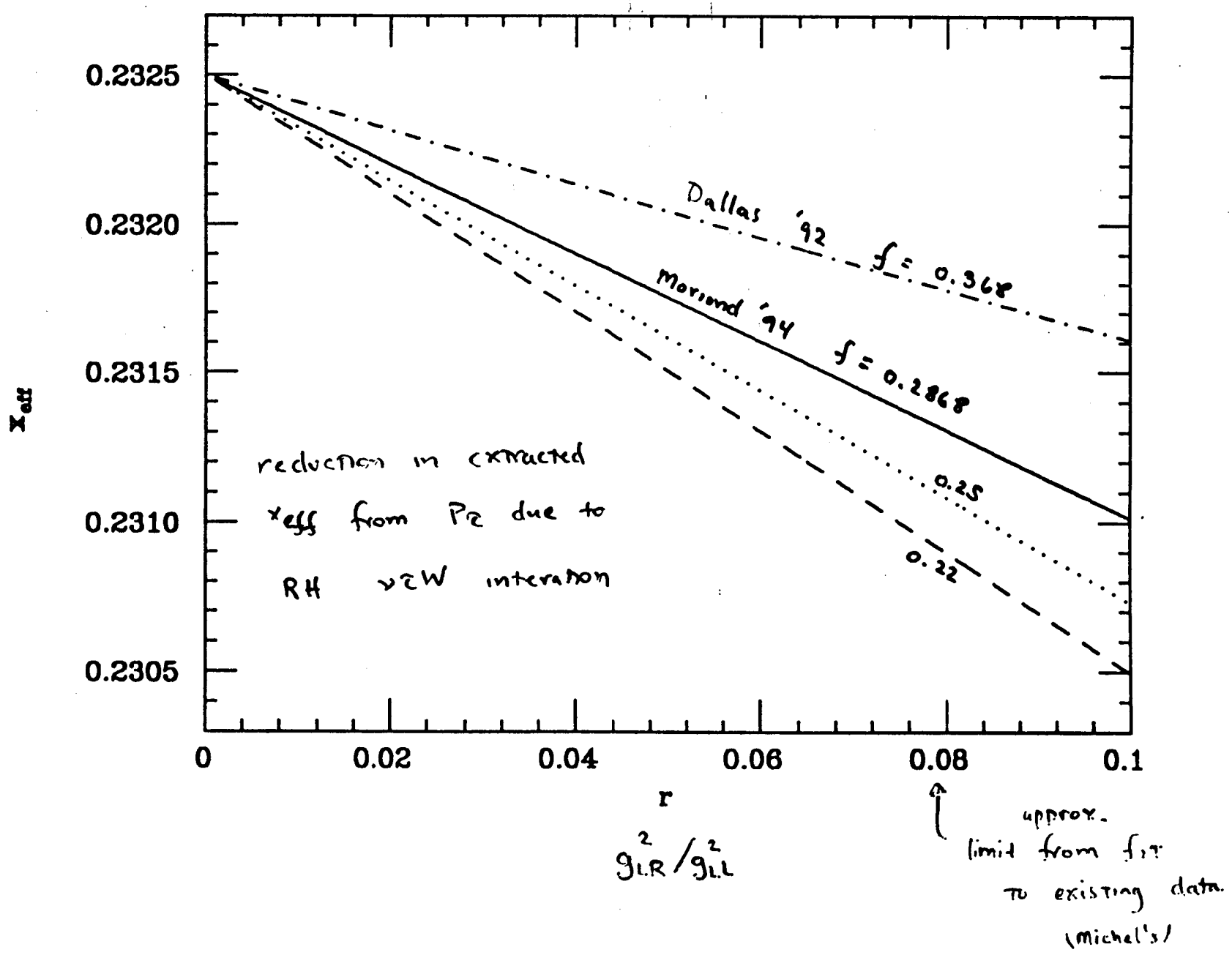
  $\Longrightarrow \Delta\xi \rightarrow \pm 0.025 \qquad \Delta h \rightarrow \pm 0.004$!

- Great in itself, but will clarify precision EW measurement

  + help with LEP/SLD data comparisons...

  may be even more important as precision improves

  to $\Delta \sin^2\theta_W = \pm 0.0003$ level


0.2325
0.2320
0.2315
0.2310
0.2305
x_{eff}
0
0.02
0.04
0.06
0.08
0.1
r
g_{LR}^2/g_{LL}^2
Dallas '92 f = 0.368
Morioond '94 f = 0.2868
0.25
0.22
reduction in extracted
x_{eff} from P_τ due to
RH $\nu_\tau W$ interaction
approx.
limit from fit
to existing data
(Michel's)

$\left\{\begin{matrix}\text{SLD}\\ \text{LEP}\end{matrix}\right\}$ data ⊕ e-μ universality imply

$$\Rightarrow \begin{cases} \dfrac{\Gamma_\tau}{\Gamma_{\mu\mu}} = 1.0045 \pm 0.0045 \quad (!) \\[2ex] \dfrac{P_\tau}{P_\tau^{un}} = 0.9591 \pm 0.0744 \end{cases}$$

(not neces. = A_τ !)

$$\frac{A_{FB}^{\tau}}{A_{FB}^{un}} = \frac{A^{\tau}}{A^{e\mu}} = 1.367 \pm 0.169$$

$$\uparrow \qquad [1.0255 \pm 0.0681]$$

$$A_{FB}^{\ell} = \frac{3}{4} A_e A_\ell \quad \underline{\text{assumed}}$$

- For discussion I will assume $\nu_\tau \tau W$ is LH.
- LEP collaborations <u>also</u> assume $Z\bar{\tau}\tau$ is V,A .... (plot)

$\Rightarrow$ Γ_τ vs $\Gamma_{e,\mu}$ generally provides the best constraints on τ Univerality violating models

Some Possibilities ....

i) τ <u>mixes</u> with some other, '<u>exotic</u>' $Q=-1$ fermion (E) thru angle ϕ $\{\phi_{L,R} \leftrightarrow s_{L,R}, c_{L,R}\}$ - 'old standby'

Some Typical Cases

T_{3L}	T_{3R}	
0	0	vector-like singlet
0	$-1/2$	mirror fermion
$-1/2$	$-1/2$	vector-like doublet
-1	0	isotriplet

- $s_L \neq 0$ REDUCES G_τ/G_μ $\Rightarrow$ $s_L \lesssim 0.10$ @ 95% CL

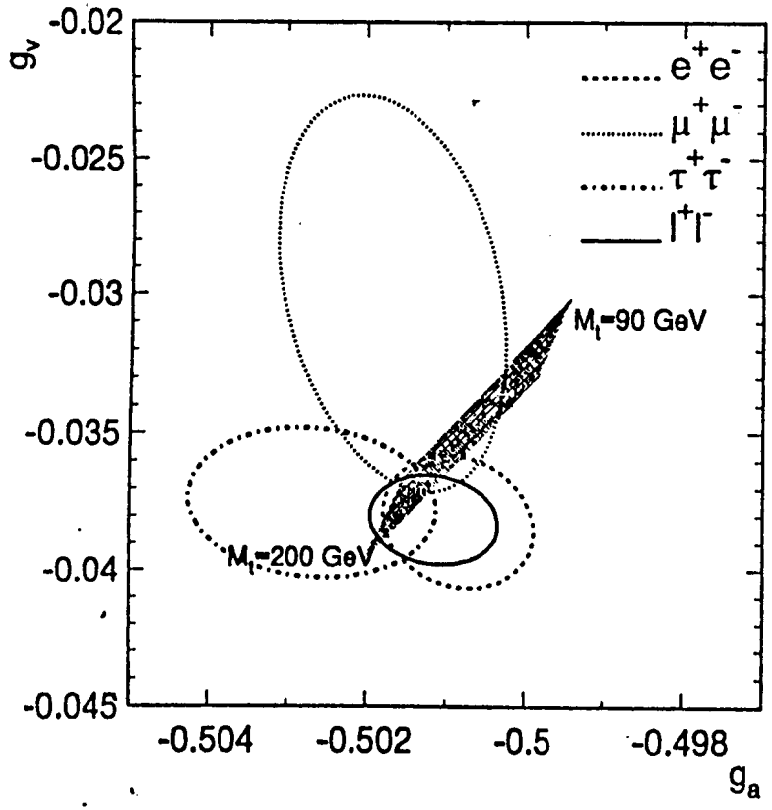
s_R has no direct CC effect .. assume $s_L = s_R \equiv s$ ...

Schaile & Glasgow '94

Combined fits

LEP + SLC

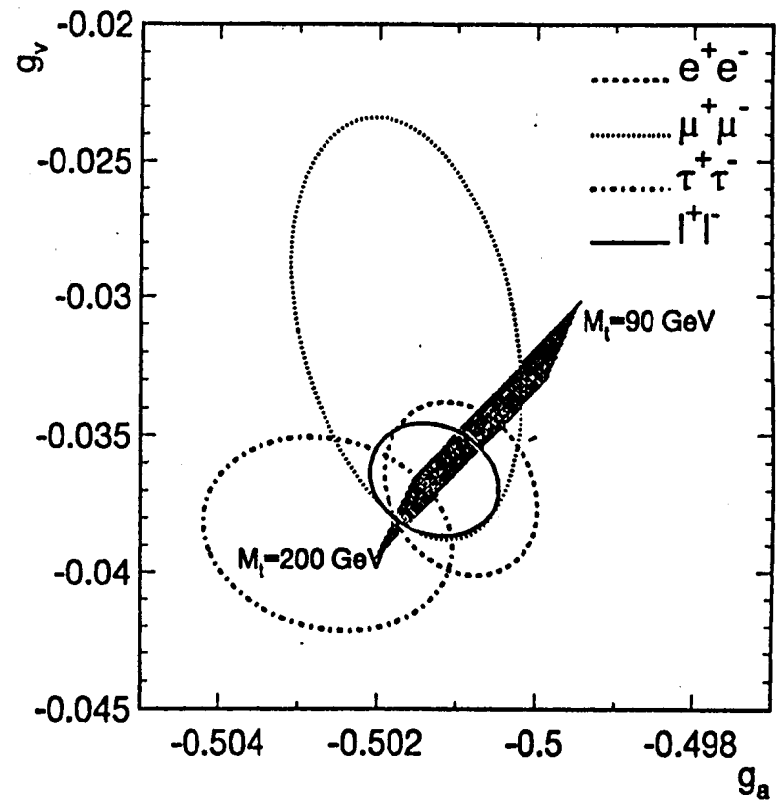
68% C.L.



Γ_ℓ, A_{FB}^ℓ, P_τ, A_{LR}

LEP only

68% C.L.



Assumes V-A $\tau\nu W$ coupl.

and $Z\ell^+\ell^-$ is v, a only

(factorization)

$$v_\tau = \left[-\tfrac{1}{2} + 2x\right]_{SM} + s_L^2\,(T_{3L} + \tfrac{1}{2}) + s_R^2\, T_{3R}$$

$$a_\tau = \left[-\tfrac{1}{2}\right]_{SM} + s_L^2\,(T_{3L} + \tfrac{1}{2}) - s_R^2\, T_{3R}$$

} mixing-modified $Z\tau\tau$ couplings (Figs)

$\rightarrow$ { T: $\lesssim 0.08$; m: $\lesssim 0.03$; VS: $\lesssim 0.05$; VD: $\lesssim 0.05$ } better than CC...

ii) τ has an 'anomalous-magnetic moment'-type coupling to Z $\left(\sim \frac{g}{2c_W} \frac{\kappa_\tau^Z}{2m_\tau} \bar{\tau}\sigma_{\mu\nu} q^\nu \tau Z^\mu \right)$

- old idea for $Z \to \gamma$ ..... { $Z \to \tau\tau\gamma$: $|\kappa_\tau^\gamma| < 0.11$ (Grifols + Mendez); TRISTAN better! (TGL) }
- 'positive' indication for $Z \to b\bar{b}$ (another talk) (no 'CC' influence')
- fit to Γ, P_τ + A_{FB}^τ w/ e-μ universality

$$\rightarrow \quad \kappa_\tau^Z = \left(-1.3^{+4.1}_{-1.5}\right) \cdot 10^{-3} \quad @\ 95\%\ CL$$

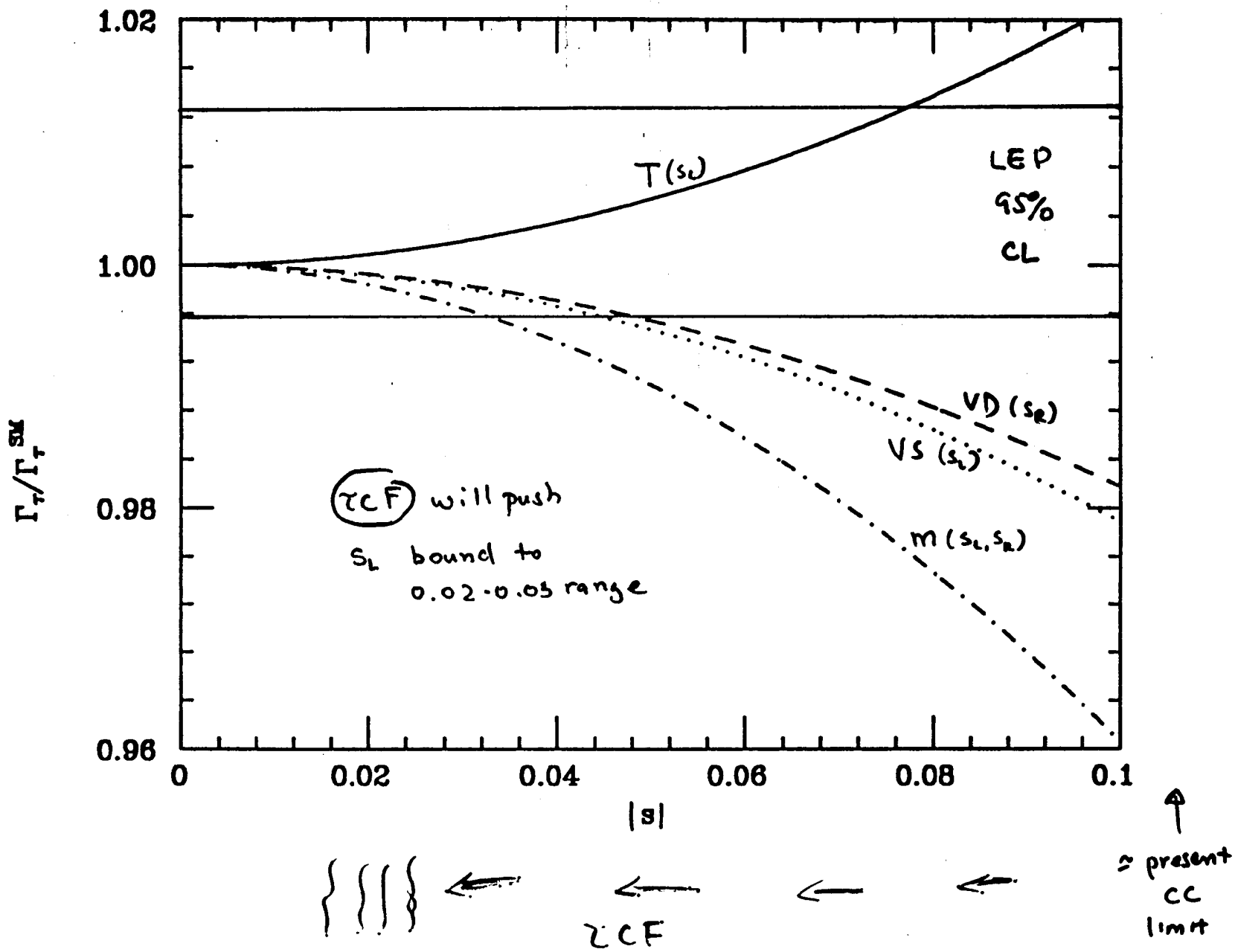
$$[\,O(\alpha/2\pi)\,]$$

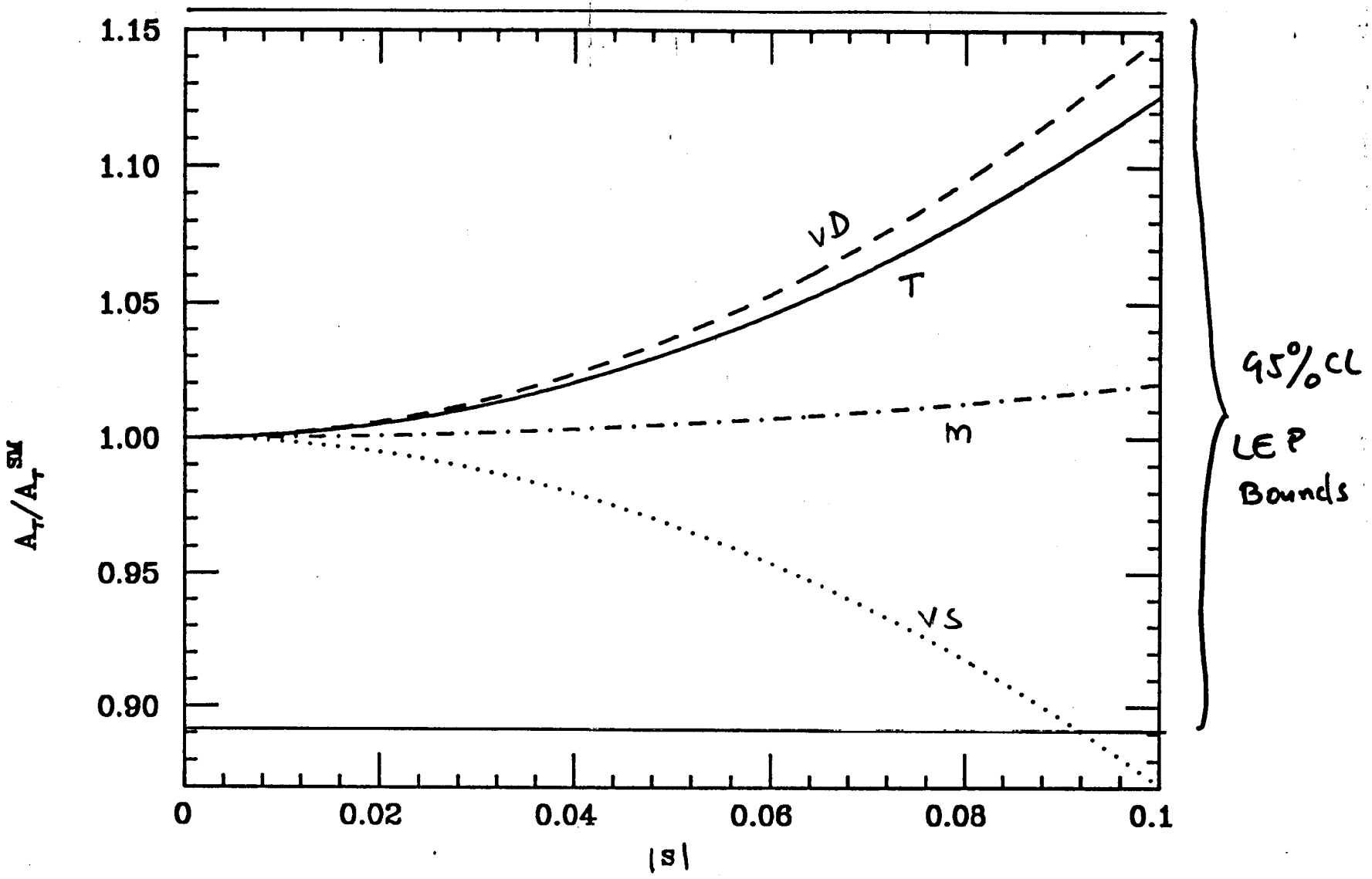
- As before ... limit mostly <u>dominated</u> by $\Gamma_{\tau,e,\mu}$ data

  ~ one order of magnitude BETTER than <u>NEW</u> κ_τ^γ bound from TRISTAN data.. (hi-precision τCF may surpass TRISTAN)

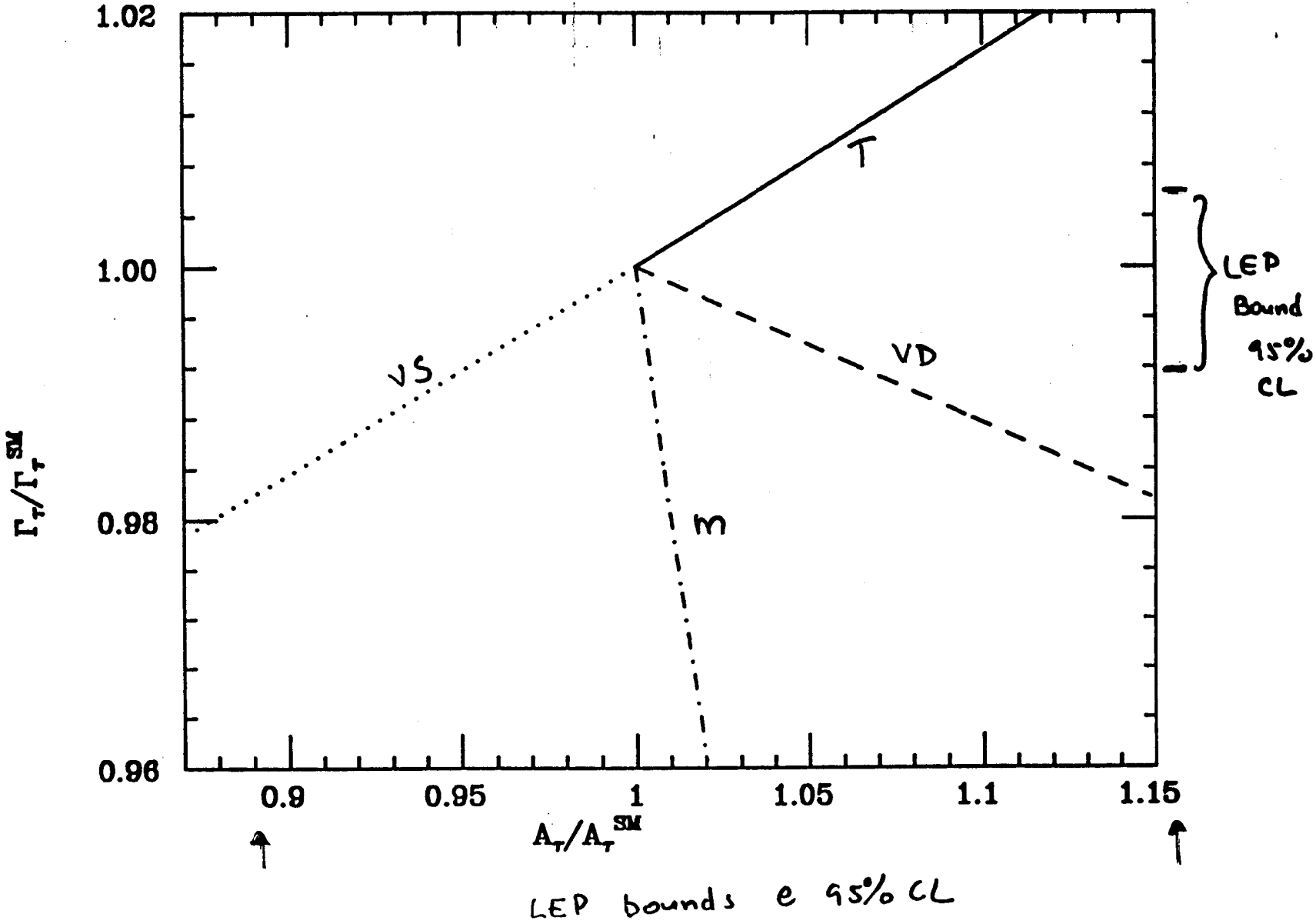
<u>Note</u>: leptonic asymmetries for both scenarios still not quite competative with Γ's {⊕ $\underline{P_\tau}$ for κ_τ^Z}

more important for κ_τ^Z


1.02
1.00
0.98
0.96
0
0.02
0.04
0.06
0.08
0.1
|s|
$\Gamma_\tau/\Gamma_\tau^{SM}$
T(s)
LEP
95%
CL
VD (s_R)
VS (s_L)
m (s_L, s_R)
τCF will push
s_L bound to
0.02-0.05 range
τCF
≈ present
CC
limit



no bounds yet....


1.02
1.00
0.98
0.96
0.9
0.95
1
1.05
1.1
1.15
$\Gamma_\tau/\Gamma_\tau^{SM}$
A_τ/A_τ^{SM}
T
VS
VD
m
LEP Bound 95% CL
LEP bounds @ 95% CL

Nardi, Roulet + Tommasini
DPF study '94

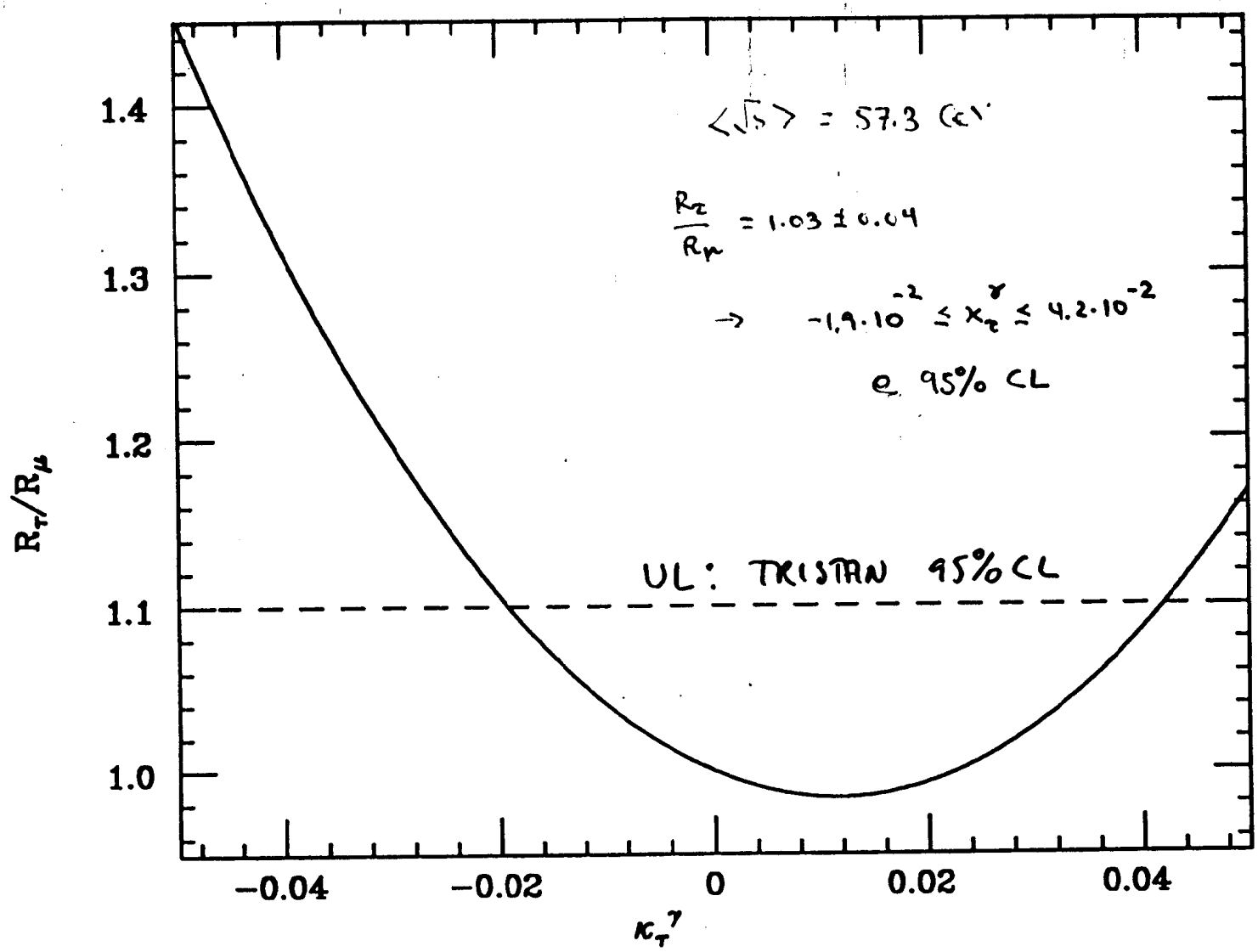
Note that in the quark sector the limits on the mixings of the b are surprisingly stringent. This is because both $s_L^b 2$ and $s_R^b 2$ tend to *decrease* the theoretical value of the partial decay width $Z \to b\bar{b}$ ($\Gamma_b \simeq [\Gamma_b]_{SM}(1 - 2.3 s_L^b 2 - 0.4 s_R^b 2)$) thus worsening the already existing $\sim 3\sigma$ discrepancy between the SM expectation and the experimental value.

Table 3: 90% C.L. upper limits on the ordinary-exotic flavor diagonal mixing angles for individual fits (one angle at a time is allowed to vary) and joint fits (all angles allowed to vary simultaneously). Only the results for $\Lambda = 2$, corresponding to neutrinos mixed with heavy singlets are shown. Some of the results are preliminary. A complete list of final results will be given in Ref. [9]. In most cases the observables more effective in setting the constraints are the LEP measurements of partial widths and asymmetries[20]. The limits have been derived assuming the values $m_t = 170\,\mathrm{GeV}$ and $M_H = 200\,\mathrm{GeV}$ for the top and the Higgs mass in the theoretical expressions.

	Individual	Joint		Individual	Joint
$(s_L^e)^2$	0.0016	0.0054	$(s_L^u)^2$	0.0022	0.012
$(s_R^e)^2$	0.0020	0.0018	$(s_R^u)^2$	0.010	0.023
$(s_L^\mu)^2$	0.0013	0.0049	$(s_L^d)^2$	0.0026	0.016
$(s_R^\mu)^2$	0.0019	0.0040	$(s_R^d)^2$	0.0066	0.019
$(s_L^\tau)^2$	0.0011	0.0037	$(s_L^s)^2$	0.0036	0.019
$(s_R^\tau)^2$	0.0018	0.0034	$(s_R^s)^2$	0.021	0.59 ?
			$(s_L^c)^2$	0.0044	0.024
$(s_L^{\nu_e})^2$	0.0053	0.0053	$(s_R^c)^2$	0.0097	0.043
$(s_L^{\nu_\mu})^2$	0.0020	0.0052	$(s_L^b)^2$	0.0017	0.0031
$(s_L^{\nu_\tau})^2$	0.0055	0.017	$(s_R^b)^2$	0.0091	0.015

3.3. Limits on a Z_1 from E_6 from ordinary-ordinary fermion mixing

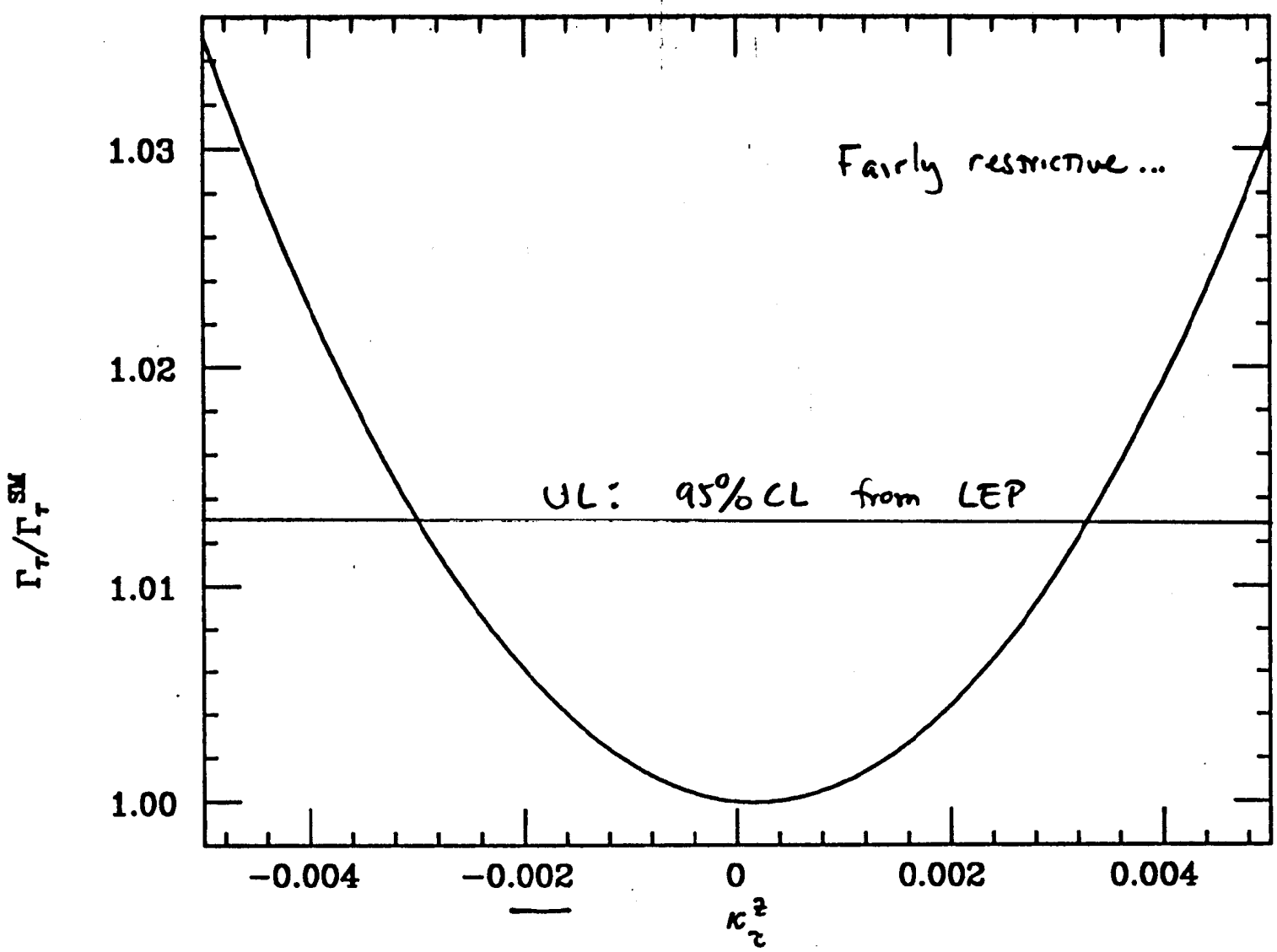
E_6 GUTs are well known examples of theories where additional fermions and new neutral gauge bosons are simultaneously present. For a general breaking of E_6 (rank 6) to the SM (rank 4) it is possible to define a whole class of Z_1 bosons corresponding to a linear combination of the two additional Cartan generators. We parametrize this combination in terms of an angle β. Fermions are assigned to the fundamental $\underline{27}$ representation of the group which contains 12 additional states for each generation, among which we have a vector doublet of new leptons $(N\ E^-)_L^T$, $(E^+\ N^c)_L^T$. Non-diagonal mass terms with the standard $(\nu\ e^-)_L^T$ and e_L^c leptons will give rise respectively to ordinary-ordinary and ordinary-exotic mixings, and in particular will induce LFV L and R chiral couplings between the first and second generation, allowing for LFV processes as $\mu \to eee$[12] and μ-e conversion in nuclei[13]. Very stringent experimental limits exist for both these processes[18,24]. Due to the expected suppression of the ordinary-exotic mixings, the LFV couplings in the R sector can be neglected. We stress that the assumption that the only source



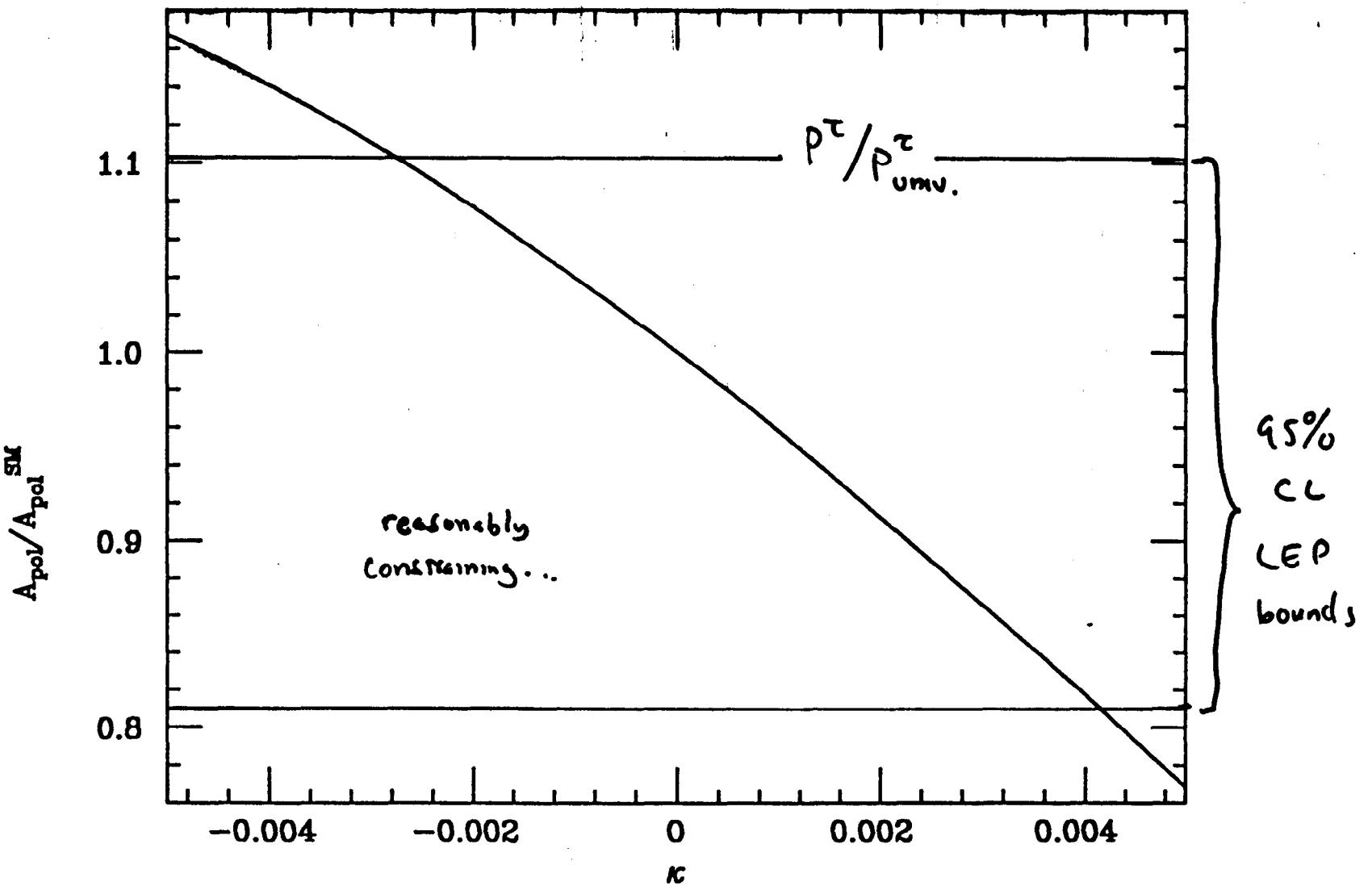
hi-stat τcF may be competative

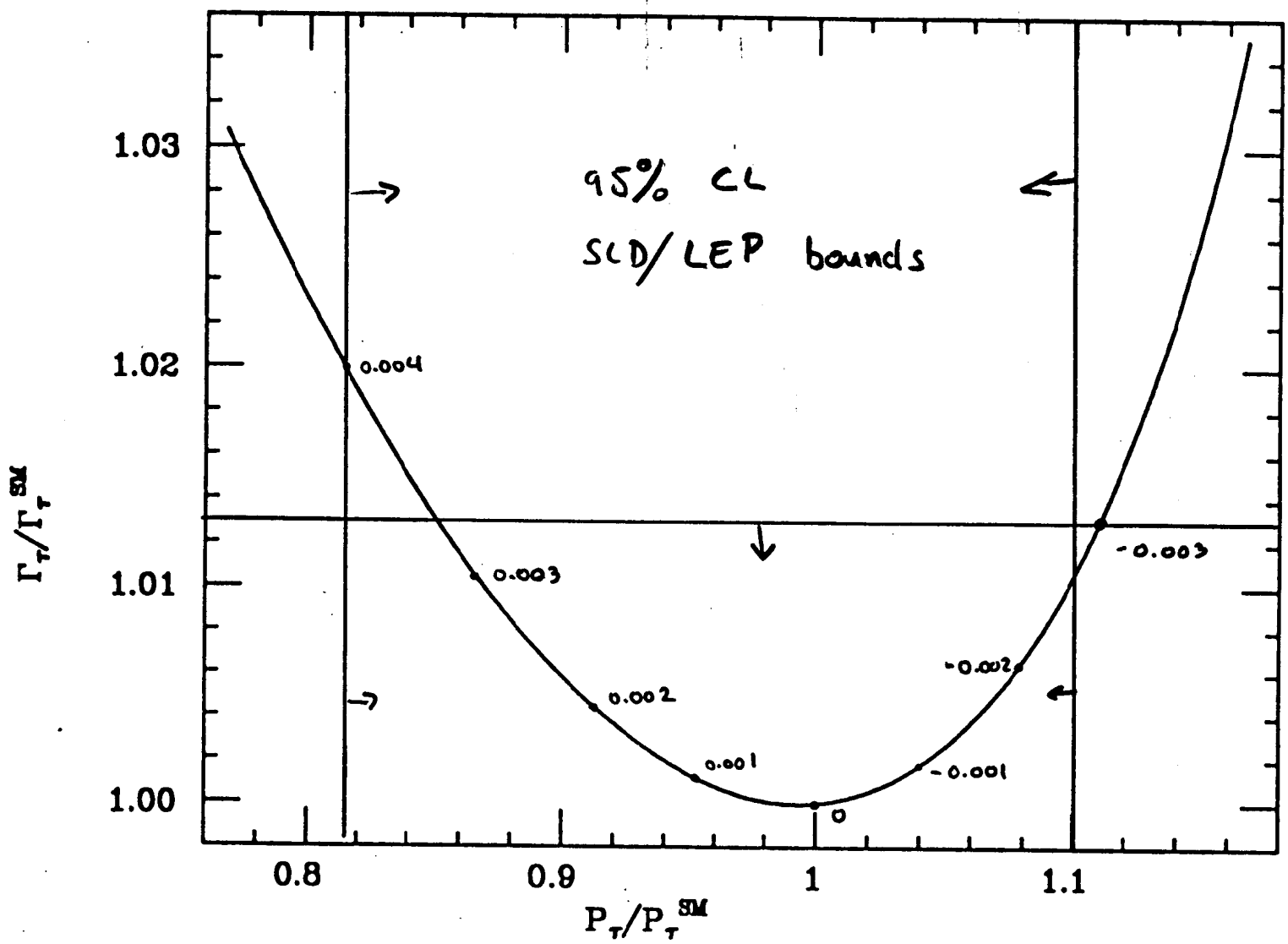
$Z \to \tau\tau\gamma$

$|\kappa_\tau^\gamma| < 0.11$ @ 95% CL



$\frac{1}{2\pi}\alpha \simeq 1\cdot 10^{-3}$!


$P^\tau/P^\tau_{\text{unv.}}$
1.1
1.0
0.9
0.8
A_{pol}/A_{pol}^{SM}
reasonably
constraining...
95%
CL
LEP
bounds
−0.004
−0.002
0
0.002
0.004
κ


95% CL
SLD/LEP bounds
1.03
1.02
1.01
1.00
0.8
0.9
1
1.1
$\Gamma_\tau/\Gamma_\tau^{SM}$
P_τ/P_τ^{SM}
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003

(iii) Z-Z' mixing w/ Z' having generation dependent couplings

- τ <u>and</u> b couplings changed relative to first two generations $\{Li + Ma\}$

$$\Gamma_i \sim N_i^2 \left\{ 1 + \left(1 - 4x_i(/3)\right)^2 \right\} \quad \text{with} \quad \begin{cases} x_{12} = \dfrac{x}{N_{12}} \\ x_3 = \dfrac{x}{N_3} \end{cases}$$

- $N_{12}^2 \sim 1 + 0.0077 \cdot \left(\frac{\epsilon}{0.008}\right)(1-p)\cdot p \geq 1$
- $N_3^2 \sim 1 - 0.0077 \cdot \left(\frac{\epsilon}{0.008}\right)(1-p)^2 \leq 1$

$\Rightarrow \frac{G_\tau}{G_\mu} \equiv 1 + \underline{\underline{\epsilon}}$

$\therefore \; x_3 \geq x \geq x_{1,2} \;+\; \Gamma_3 \leq \Gamma \leq \Gamma_{1,2} \;\therefore$ $\Gamma_b/\Gamma_b^{SM} < 1$ ✓

$\Gamma_\tau/\Gamma_\tau^{univ} < 1$ hmm

$x_\tau > x_{e,\mu}$ ✓? $\{0 \leq p \leq 1\}$

Not likely

$\longrightarrow$ Pushes Γ_b (Γ_τ) 'right' (wrong) way .... $\therefore$

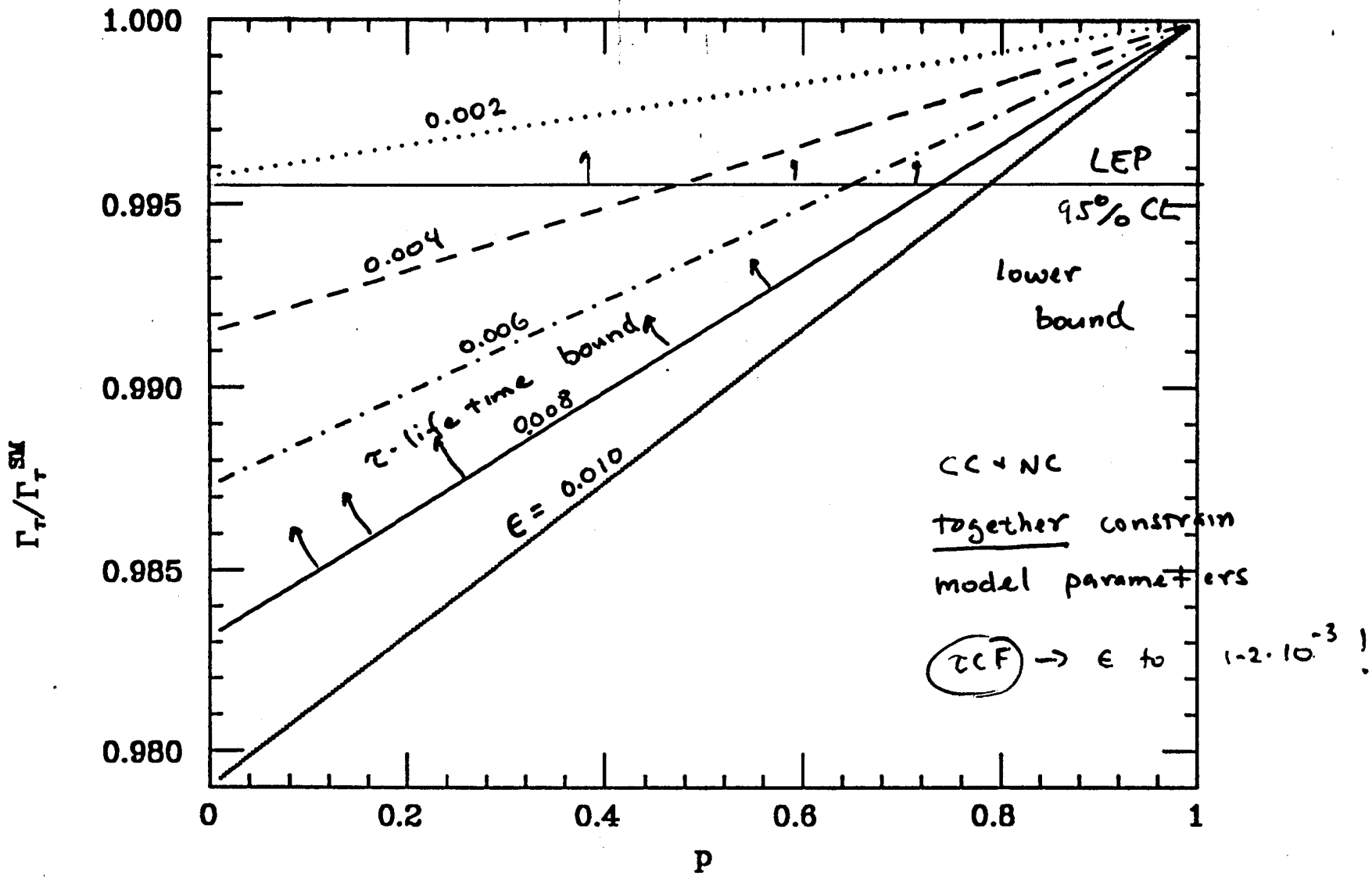
Γ_τ highly restrictive ; not asymmetries

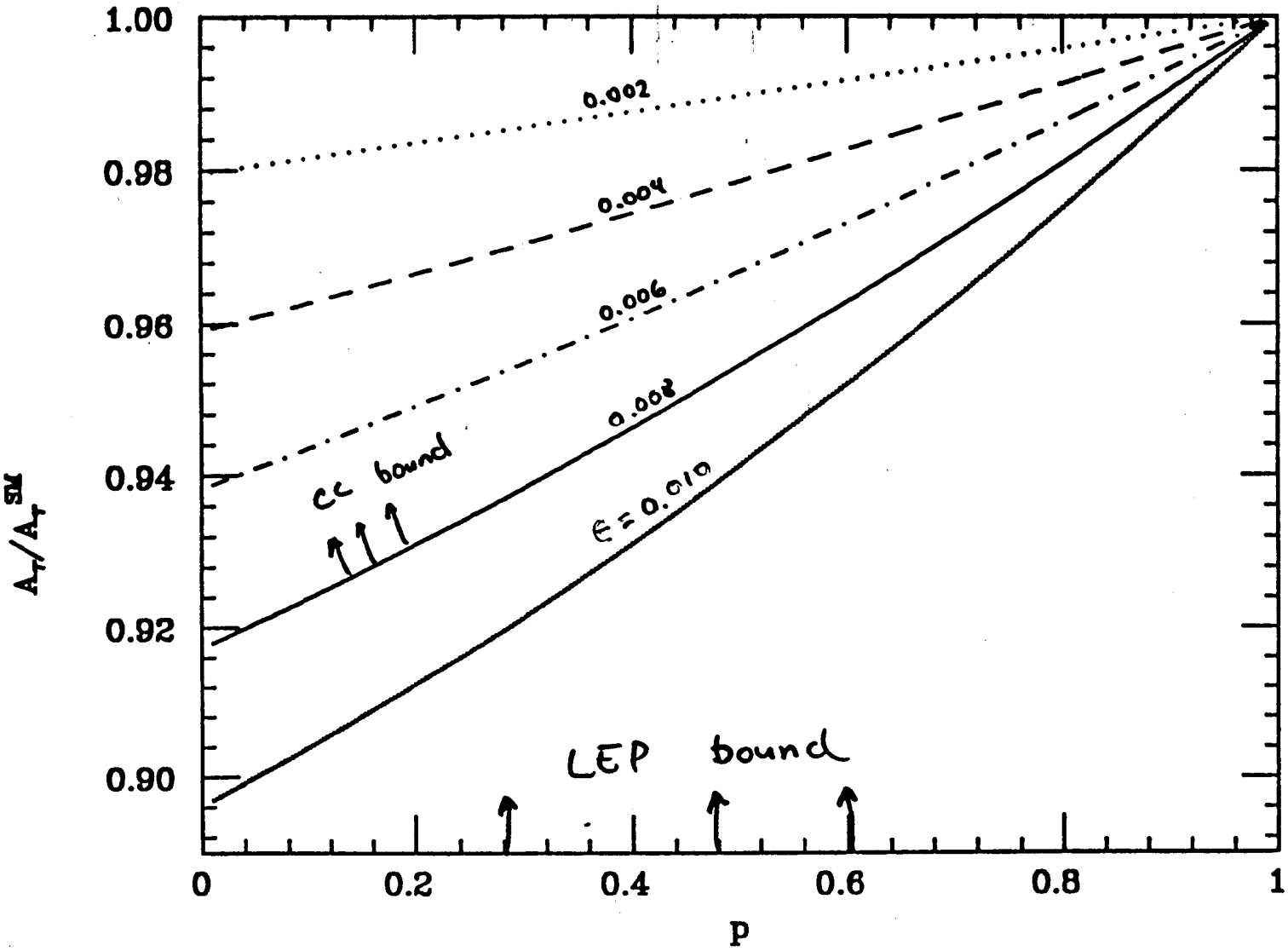
- Strong interplay between precision <u>CC</u> + NC constraints

$\hookrightarrow$ τCF will force ϵ to $\sim(1\text{-}2)\cdot 10^{-3}$ level...

- <u>Remember too</u> (but beyond scope of THIS talk...)

Many non-universality models <u>also</u> predict FC τ decays, e.g, $\tau \to \mu e^+ e^-$, $\mu \nu \bar{\nu}$, $3e$, 3μ, etc, at <u>some</u> level !


1.000
0.995
0.990
0.985
0.980
0
0.2
0.4
0.6
0.8
1
p
$\Gamma_\tau/\Gamma_\tau^{SM}$
0.002
0.004
0.006
0.008
ε = 0.010
τ-lifetime bound
LEP
95% CL
lower
bound
CC + NC
together constrain
model parameters
τCF → ε to 1-2·10^-3 !


1.00
0.98
0.96
0.94
0.92
0.90
0
0.2
0.4
0.6
0.8
1
p
A_T/A_T^{SM}
0.002
0.004
0.006
0.008
$\epsilon = 0.010$
cc bound
LEP bound

Conclusions

i) Both L.E.E. + LEP/SLD are closing-in on the possibility of τ non-universality by probing the $\tau\nu_\tau W$ + $Z\tau\bar{\tau}$ couplings - complementary! • CC vs NC •

ii) <u>However</u> some models 'predict' such small effects that <u>only</u> τcF can see them ... <u>still</u> lots of room

iii) τ-universality + assumptions about τ's have influence elsewhere - test of EW RC in SM $\leftrightarrow$ 'SLD vs LEP' perhaps only resolvable with τcF ...

iv) non-universality + FC τ decays are linked in many models $\therefore$ hi-lumi required beyond LEP to be visible

v) only τcF can probe BSM loop effects ... necessary to <u>truely</u> establish universality