Test of lepton universality in Upsilon Decays:

Searching for a light Higgs boson

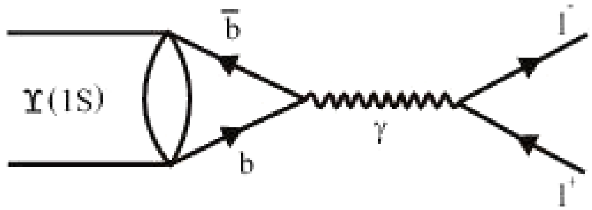
Miguel A. Sanchis-Lozano*

Department of Theoretical Physics & IFIC
University of Valencia – CSIC
Spain

*email: mas@ific.uv.es

Testing Lepton Universality

BF(ϒ→ e+ e-) =BF(ϒ→ μ+ μ-) = BF(ϒ→ τ + τ -)



Channel: *	BF[e^+e^-]	BF[$\mu^+ \mu^-$]	BF[$\tau^+\tau^-$]	$R_{\tau/l}$(nS)
ϒ(1S)	2.38 ± 0.11 %		2.66 ± 0.11 %	0.12 ± 0.06
ϒ(1S)		2.48 ± 0.06 %	2.66 ± 0.11 %	0.07 ± 0.05
ϒ(2S)	1.92 ± 0.17 %		2.03 ± 0.28 %	0.06 ± 0.10
ϒ(2S)		1.93 ± 0.17 %	2.03 ± 0.28 %	0.05 ± 0.10
ϒ(3S)	1.92 ± 0.24 %		2.51 ± 0.26 %	0.31 ± 0.17
ϒ(3S)		2.18 ± 0.21 %	2.51 ± 0.26 %	0.15 ± 0.15

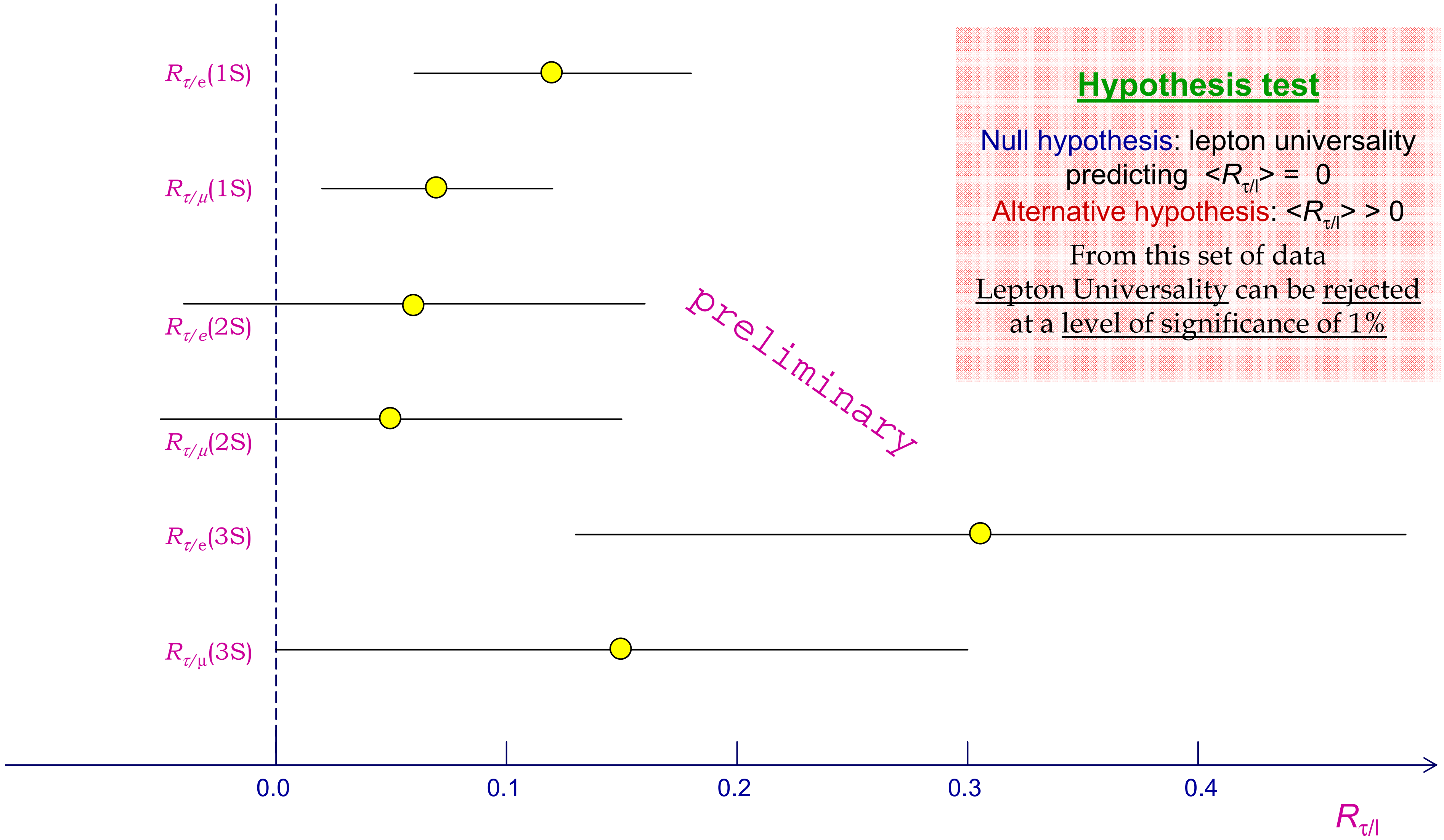
*Obtained from recent CLEO data and already existing PDG values
Statistical and systematic (conservative) errors are summed in quadrature
Error bars should decrease according to CLEO on-going analysis
New results from CLEO expected very soon

↑ preliminary

Lepton Universality
in Upsilon decays implies
<$R_{\tau/l}$> =0

$$R_{\tau/\ell}(\mathrm{nS}) = \frac{\Gamma_{\Upsilon(nS)\to\gamma_s\tau\tau}}{\Gamma_{\ell\ell}^{(em)}} = \frac{B_{\tau\tau}-B_{\ell\ell}}{B_{\ell\ell}} = \frac{B_{\tau\tau}}{B_{\ell\ell}} - 1$$

Lepton Universality Breaking?



Hypothesis test

Null hypothesis: lepton universality predicting $\langle R_{\tau/l} \rangle = 0$

Alternative hypothesis: $\langle R_{\tau/l} \rangle > 0$

From this set of data Lepton Universality can be rejected at a level of significance of 1%

(Hidden) systematic errors?

There could be hidden systematic errors in the extraction of the muonic and tauonic branching fractions from experimental data, e.g. use is made of lepton universality as an intermediate step

$B_{ee} = B_{\mu\mu} = B_{\tau\tau}$

Defining: $\widehat{B}_{\mu\mu} = \Gamma_{\mu\mu} / \Gamma_{\text{had}}$

hep-ex/9409004
hep-ex/0409027

$$B_{\mu\mu} = \Gamma_{\mu\mu} / \Gamma_{\Upsilon} = \frac{\widetilde{B}_{\mu\mu}}{1+3\widetilde{B}_{\mu\mu}} \Rightarrow B_{\mu\mu} = \frac{\widetilde{B}_{\mu\mu}}{1+B_{ee}+B_{\mu\mu}+B_{\tau\tau}}$$

☆ The muonic branching fraction would be **overestimated** if $\widetilde{B}_{\mu\mu} \leq \widetilde{B}_{\tau\tau}$

$B_{ee} = B_{\mu\mu} = B_{\tau\tau}$

Defining: $\widehat{B}_{\tau\tau} = \Gamma_{\tau\tau} / \Gamma_{\text{had}}$

$$B_{\tau\tau} = \Gamma_{\tau\tau} / \Gamma_{\Upsilon} = \frac{\widetilde{B}_{\tau\tau}}{1+3\widetilde{B}_{\tau\tau}} \Rightarrow B_{\tau\tau} = \frac{\widetilde{B}_{\tau\tau}}{1+B_{ee}+B_{\mu\mu}+B_{\tau\tau}}$$

☆ The tauonic branching fraction would be **underestimated** if $\widetilde{B}_{\mu\mu} \leq \widetilde{B}_{\tau\tau}$

☆ Besides phase space disfavors the tauonic decay mode by ~ 1% (Van-Royen Weisskopf formula)

Searching for a light non-standard Higgs

Our conjecture to interpret a possible Lepton Universality breakdown

photon unseen! *

$\Upsilon(nS) \to \gamma_s \; A^0(\to \ell^+\ell^-)$

$\Upsilon(nS) \to \gamma_s \; \eta_b^{(*)}(\to A^{0*} \to \ell^+\ell^-)$

Van Royen-Weisskopf formula

$$\Gamma_{\ell\ell}^{(em)} = 4\alpha^2 Q_b^2 \frac{|R_n(0)|^2}{M_\Upsilon^2} \times \underbrace{(1+2x_\ell)(1-4x_\ell)^{1/2}}_{\text{(smoothly) decreasing function of } x_\ell}$$

with $x_\ell = m_\ell^2 / M_\Upsilon^2$

n=1,2,3 and A^0 stands for a light (possibly CP-odd) Higgs particle

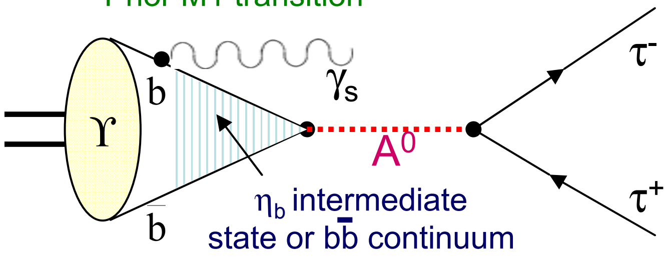
Tree-level NP process theoretically very simple!

Key ideas:

- Such NP contribution would be unwittingly ascribed to the leptonic branching fraction (photon undetected!*) actually only for the tauonic decay mode

- A leptonic mass dependence of the decay width would break lepton universality. Contribution from the SM should be negligible

Prior M1 transition



*Missing energy technique employed
But photons can be searched for in data recorded on tape
However, they likely **would not be monochromatic!**

Prejudice against a light Higgs?

Notice that a light non-standard Higgs boson has **not** been excluded by LEP direct searches for a broad range of model parameters in different scenarios

Two-Higgs Doublet Model (II)*

Higgs sector

$$\hat{H}_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad \hat{H}_d = \begin{pmatrix} H_d^+ \\ H_d^0 \end{pmatrix}$$

Coupling of fermions and the CP-odd Higgs A^0

In a 2HDM of type II

$$L_{int}^{f\bar{f}} = -\tan\beta \frac{A^0}{v} m_f \bar{d}\,(i\gamma_5)\,d \;,\; d = d, s, b, e, \mu, \tau$$

$$L_{int}^{f\bar{f}} = -\cot\beta \frac{A^0}{v} m_f \bar{u}\,(i\gamma_5)\,u \;,\; u = u, c, t, \nu_e, \nu_\mu, \nu_\tau$$

*The MSSM is a particular 2HDM(II) realization

CPC: 1 CP-odd Higgs (A^0)

2 CP-even Higgses

$h^0 = -\eta_1 \sin\alpha + \eta_2 \cos\alpha$

$H^0 = \eta_1 \sin\alpha - \eta_2 \cos\alpha$

2 charged $H^\pm$

At tree level: $M_{H^\pm}^2 = M_{A^0}^2 + M_{W^\pm}^2$

In a general 2HDM: $M_{H^\pm}^2 = M_{A^0}^2 + \frac{1}{2}(\lambda_5 - \lambda_4)v^2$

tanβ stands for the 2 Higgs VEVs ratio $\langle H_u \rangle / \langle H_d \rangle$ and v=246 GeV

A large value of tanβ would imply a large A^0 coupling to the bottom quark but a small coupling (i.e. small cot β) to the charm quark. Therefore, in the quest for NP effects we will focus on bottomonium decays and spectroscopy but not on charmonium as this is the case (see PDG)

CPV MSSM

At one-loop level, MSSM with complex parameters is not CP conserving

The three Higgs neutral bosons mix together and the resulting three physical mass eigenstates H_1, H_2 and H_3 ($M_{H1} < M_{H2} < M_{H3}$) have mixed parities

Higgs couplings to the Z boson would vary: the H_1ZZ coupling can be significantly suppressed raising the possibility of a relatively light H_1 boson having evaded detection at LEP [hep-ph/0211467]

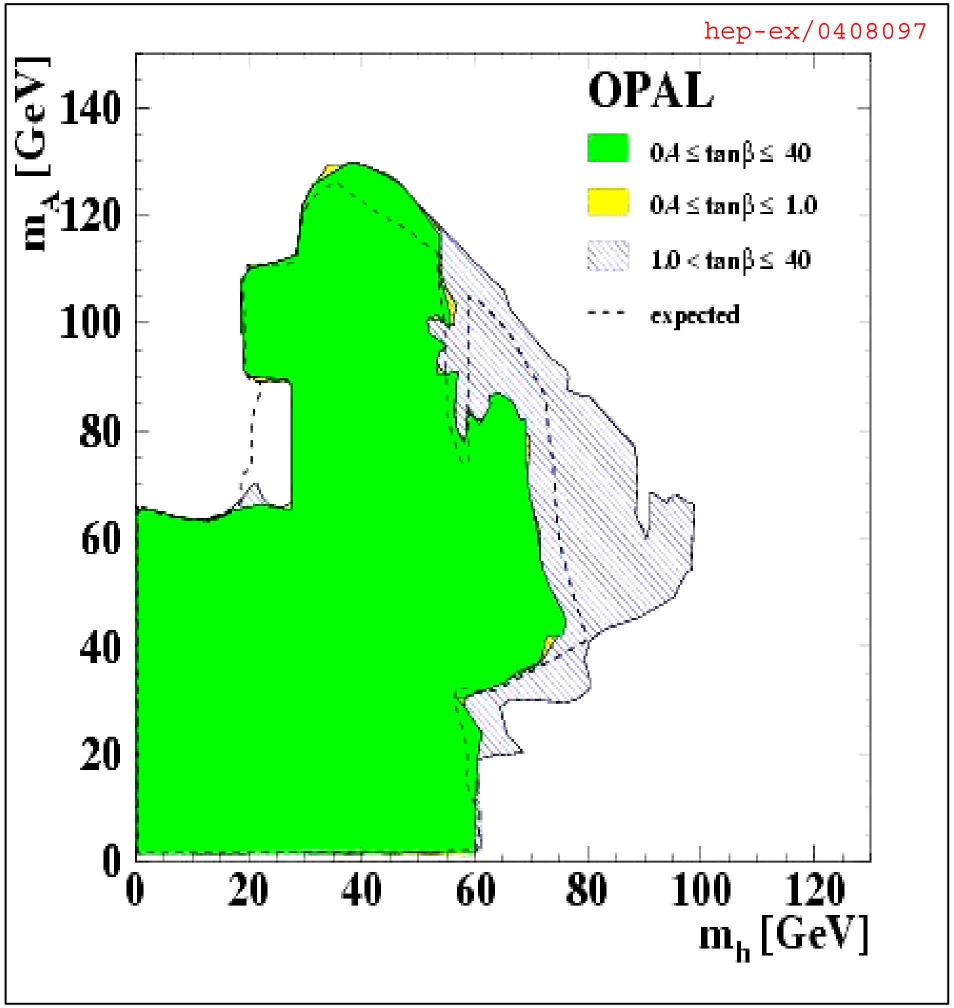
Other scenarios

composite Higgs [hep-ph/0008192]

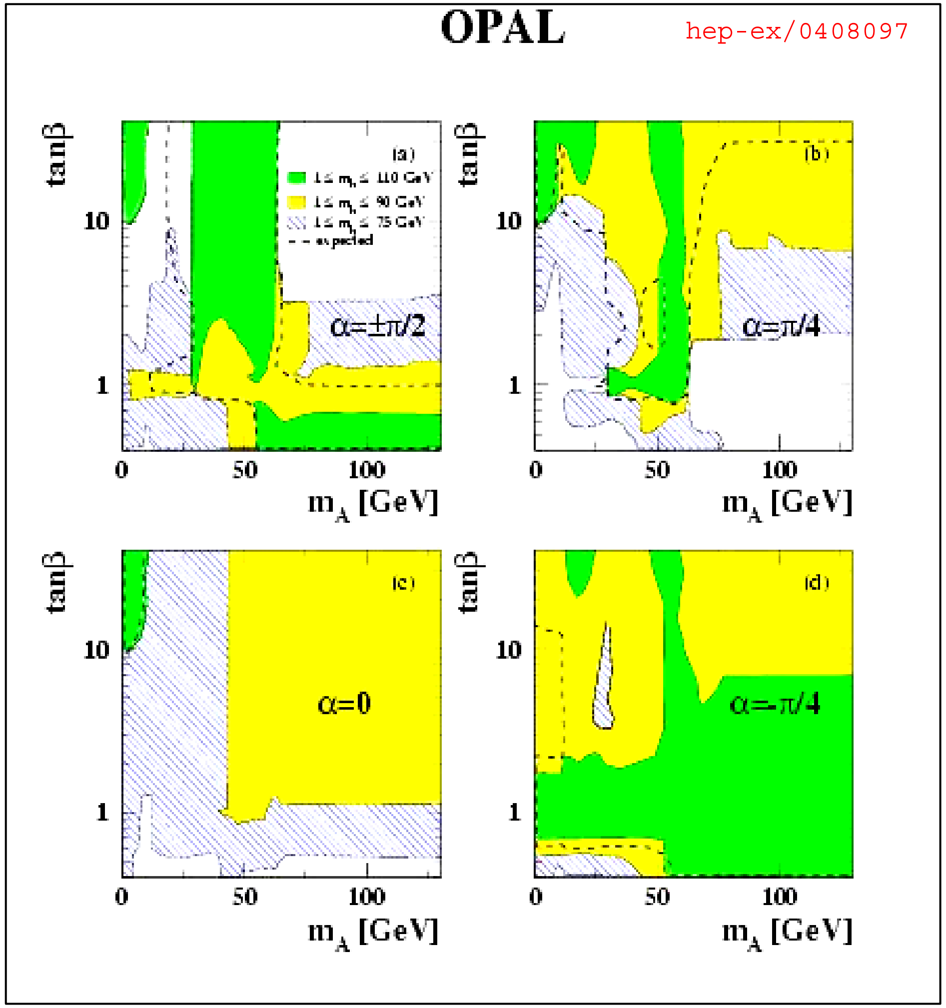
extra dimensions: e.g. graviscalars, radions [hep-ph/9811350],

little Higgs models

Light Higgs windows at LEP (2HDM(II))

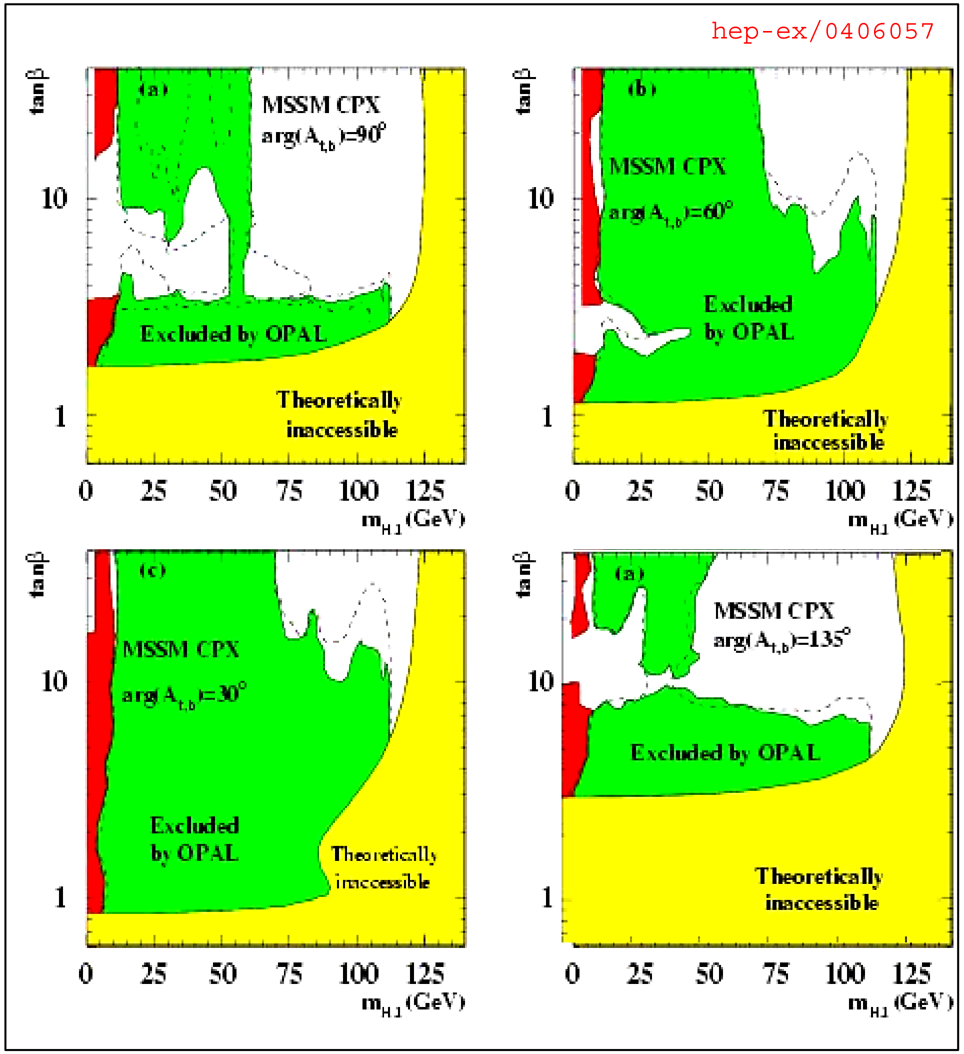


Excluded (m_A,m_h) region independent of the CP even Higgs mixing angle α, from flavor-independent and b-tagging searches at LEP interpreted according to a 2HDM(II)



Excluded regions in the (m_A,tanβ) plane for different choices of α. In the MSSM $-\pi/2 \leq \alpha \leq 0$; in a general 2HDM(II) $-\pi/2 \leq \alpha \leq \pi/2$

Light Higgs windows at LEP (MSSM CPV)



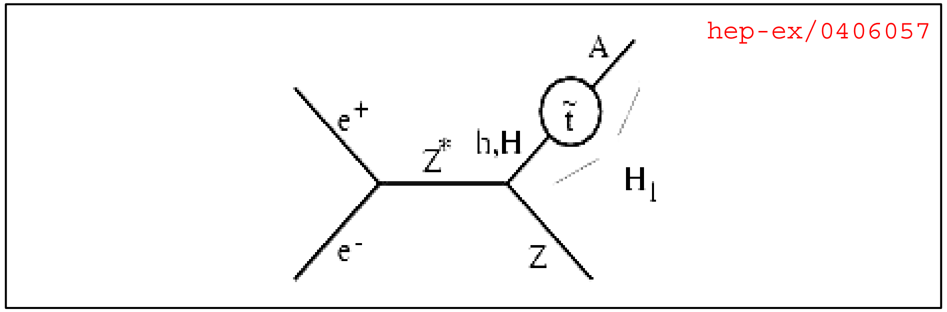
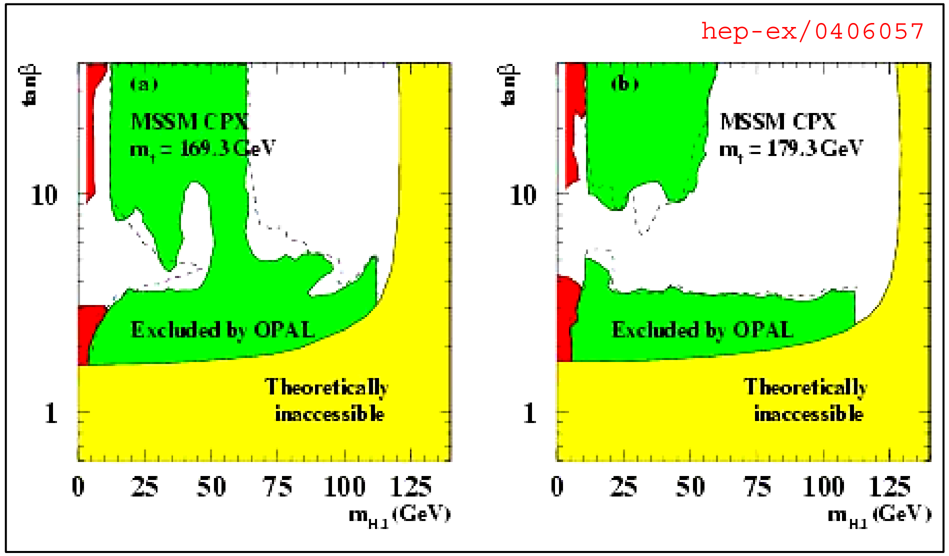


Diagram illustrating the effective coupling of a Higgs mass eigenstate H1 to the Z. Only the CP-even admixture h and H couple to Z while the CP-odd A does not: hence the coupling of the H_1 is reduced wrt a CPC scenario.



CPX MSSM 95% exclusion areas using scans with different values of arg ($A_{t,b}$). The region excluded by Yukawa searches, Z-width constraints or decay independent searches is shown in red

CPX MSSM 95% exclusion areas using scans with different values of the top mass

Next-to-Minimal Supersymmetric Standard Model (NMSSM)

A new singlet superfield is added to the Higgs sector: $\hat{H}_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad \hat{H}_d = \begin{pmatrix} H_d^+ \\ H_d^0 \end{pmatrix}, \quad \hat{S}$

The μ-problem of the MSSM would be solved by introducing in the superpotential the term

$$W_{Higgs} = \lambda \hat{S} (\hat{H}_u \hat{H}_d) + \frac{\kappa}{3} \hat{S}^3 \quad \Rightarrow \quad V_{soft} = \lambda A_\lambda S (H_u \circ H_d) + \frac{\kappa}{3} A_\kappa S^3 + h.c.$$

Spontaneous breaking of the PQ symmetry

Breaks explicitly the PQ symmetry

where $\mu = \lambda x, \quad x = <S> = \mu / \lambda$

leading to a light CP-odd scalar for small κ, i.e. slight U(1) Peccei-Quinn symmetry breaking

Spontaneous breaking → NGB (massless), an "axion" (+QCD anomaly) ruled out experimentally

If the PQ symmetry is not exact but explicitly broken → provides a mass to the (pseudo) NGB

Higgs sector in the NMSSM: (seven)

- 2 neutral CP-odd Higgs bosons ($A_{1,2}$)
- 3 neutral CP-even Higgs bosons ($H_{1,2,3}$)
- 2 charged Higgs bosons ($H^\pm$)

For small κ the A_1 would be the lightest Higgs:

$$M_{A_1}^2 \cong -3 \left(\frac{\kappa}{\lambda} \right) A_\kappa \mu$$

Favored decay mode: $H_{1,2} \to A_1 A_1$
hard to detect at the LHC [hep-ph/0406215]

$$A_1 = \cos\theta_A \, A_{MSMS} + \sin\theta_A \, A_s$$

Coupling of A_1 to down type fermions: [hep-ph/0404220]

$$\propto \frac{m_f^2 v}{x} \delta, \quad \Rightarrow \cos\theta_A \tan\beta$$

$$\cos^2\theta_A \cong \frac{v^2}{x^2 \tan^2\beta} \delta^2, \quad \delta = \frac{A_\lambda - 2\kappa x}{A_\lambda + \kappa x}$$

Numerical estimates

Contribution from the "continuum"

Let us perform a perturbative calculation of the contribution from the "continuum", i.e. without formation of intermediate $b\bar{b}$ bound states assuming the **Higgs boson off-shell**

$$\Gamma(\Upsilon \to \gamma l^+ l^-) = \frac{1}{32 M_\Upsilon^2} \frac{1}{(2\pi)^3} \int |A(\Upsilon \to \gamma l^+ l^-)|^2 \, dm_{\ell\ell}^2 \, dm_{\ell\gamma}^2 \qquad M_\Upsilon \le M_{A^0}$$

where the square amplitude is $$|A(\Upsilon \to \gamma \ell^+ \ell^-)|^2 = \frac{64\,\alpha\, m_{\ell\ell}^2\, m_\ell^2\, m_b^2\, |R_n(0)|^2 \tan^4\beta}{9 M_\Upsilon^2 [m_{\ell\ell}^2 - M_A^2]^2 v^4}$$

and the decay width (leading term):

$$\Gamma[\Upsilon(nS) \to \gamma \ell^+ \ell^-] \approx \frac{\alpha |R_n(0)|^2 \tan^4\beta}{144\pi^3 v^4} \left[\log\left(\frac{M_{A^0}^2}{M_{A^0}^2 - M_\Upsilon^2}\right) - 1\right] \times m_\tau^2, \quad M_{A^0} > M_\Upsilon$$

$$R_\tau = \frac{M_\Upsilon^2 \tan^4\beta}{64\,\alpha\,\pi^3 v^4} \left[\log\left(\frac{M_{A^0}^2}{M_{A^0}^2 - M_\Upsilon^2}\right) - 1\right] \times m_\tau^2$$

→ Rather large values of tanβ (≥ 50) are needed to obtain $R_\tau \sim 10\%$

One should also consider: $$\Gamma[A^0 \to \tau^+\tau^-] \approx \frac{m_\tau^2 \tan^2\beta}{8\pi v^2} M_{A^0} (1 - 4x_\tau)^{1/2} \quad \to \quad B(A^0 \to \tau^+\tau^-) \approx 1$$

even for moderate tanβ

$\Upsilon(nS) \to \gamma A^0 (\to \tau^+ \tau^-)$

Higgs boson on-shell $M_{A^0} \le M_\Upsilon$

$$R_\tau = \frac{M_\Upsilon^2 \tan^2\beta}{8\pi\alpha v^2}\left(1 - \frac{M_{A^0}^2}{M_\Upsilon^2}\right)$$

Wilczek formula

$M_\Upsilon - M_{A^0} = 0.25$ GeV → $R_\tau = 0.1$, tanβ ~ 15

Somewhat higher values of tanβ in a relativistic treatment

Experimentally excluded region $\Upsilon \to \gamma$ +"nothing":
BF < 1.3 x10^{-5} for M_{A0} < 5 GeV
[CLEO, PRD 51, 2053 (1995)]

Numerical estimates

Intermediate bound states

We consider that a prior magnetic dipole transition of the Upsilon yields an intermediate bound state, subsequently annihilating into a lepton pair via A^0 (or H_1)-exchange

$$\Upsilon(nS) \rightarrow \gamma_s\, \eta_b\, (\rightarrow A^{0*}\, (H_1^*) \rightarrow l^+ l^-)$$

Intermediate real 0^{-+} state

In a 2HDM(II)

$$\Gamma(\eta_b \rightarrow \ell^+\ell^-) = \frac{3 m_b^4 m_\ell^2 (1-4x_\ell)^{1/2} |R_n(0)|^2 \tan^4\beta}{2\pi^2 (M_{\eta_b}^2 - M_{A^0}^2)^2 v^4}$$

The NP contribution would almost saturate the η_b decay rate even for moderate tanβ if ΔM is not too large !

Mass difference between the Higgs boson and the η_b

$$\Delta M = |M_{A^0} - M_{\eta_b}|$$

$$R_\tau \approx \frac{m_b^2 \tan^4\beta\, k^3}{8\pi^2\alpha(1+2x_\tau)\Gamma_{\eta_b} v^4} \times \frac{m_\tau^2}{\Delta M^2}$$

A cascade decay formula applies:

$$B(\Upsilon \rightarrow \gamma_s \ell^+\ell^-) \cong B(\Upsilon \rightarrow \gamma_s \eta_b) \times B(\eta_b \rightarrow \ell^+\ell^-)$$

$$B(\Upsilon \rightarrow \gamma_s \eta_b) = \frac{\Gamma^{M1}_{\Upsilon\rightarrow\gamma\eta_b}}{\Gamma_\Upsilon} = \frac{1}{\Gamma_\Upsilon} \times \frac{4\alpha I Q_b^2 k^3}{3 m_b^2}$$

M1 transition probability

$$P^\Upsilon(\eta_b^* \gamma_s) \approx 10^{-3} - 10^{-4}$$

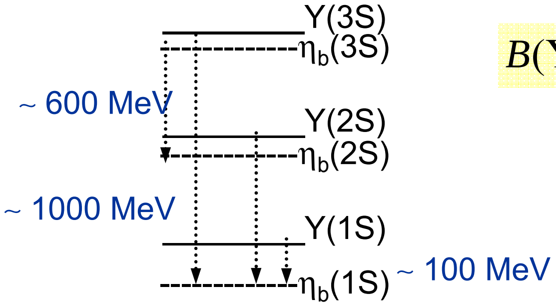
For tanβ ≥ 30

and ΔM=0.25 GeV

$$B(\Upsilon(nS) \rightarrow \gamma\, \tau^+\tau^-) \cong B(\Upsilon(nS) \rightarrow \gamma\, \eta_b(n'S))$$

$$R_\tau \approx \frac{B(\Upsilon \rightarrow \gamma_s \tau\tau)}{B_{ee}} \approx 1-10\%$$

Allowed and hindered M1 Transitions between $\Upsilon(3S)$, $\Upsilon(2S)$ and $\Upsilon(1S)$ States



ΔM (GeV)

Numerical estimates

CP-even Higgs boson

A light CP-even Higgs boson is not excluded by LEP searches for parameter ranges of a 2HDM

A CP-even Higgs boson can couple to an intermediate χ_{b0} resonance after a E1 transition of the Υ

Intermediate real 0^{++} state

$$\Upsilon(nS) \to \gamma\ \chi_{b0}\ (\to h^0 \to \tau^+\tau^-)$$
$$(\to H_1 \to \tau^+\tau^-)$$

n=2,3

Decay channel open only for Υ(2S) and Υ(3S) resonances

Cascade decay via χ_{b0} resonances

$$\text{h - b}\bar{\text{b}}/\ell^+\ell^- \text{ coupling}: -\frac{\sin\alpha}{\cos\beta} = \sin(\alpha-\beta) - \tan\beta\cos(\beta-\alpha)$$

h^0-mediated decay width under the assumption that $\sin(\alpha-\beta) \approx 0$

i.e. non-decoupling limit: h^0 couplings deviate maximally from SM whereas the H^0 becomes a SM-like Higgs:

$$\Gamma(\chi_{b0} \to \ell^+\ell^-) = \frac{27 m_b^2 m_\ell^2 (1-4x_\ell)^{3/2} |R_n'(0)|^2 \tan^4\beta}{8\pi^2 (M_{\chi_{b0}}^2 - M_{A^0}^2)^2 v^4}$$

Again only for the tauonic mode would the NP contribution be significant leading to lepton universality breaking!

Normalizing the above partial width to

$$\Gamma_{\chi_{b0}} \approx \Gamma[\chi_{b0} \to gg] = \frac{96\alpha_s^2 |R_n'(0)|^2}{M_{\chi_{b0}}^4}$$

setting $\alpha_s(M_\Upsilon) = 0.15$ and $|R'_n(0)|^2 = 1.5$ GeV^5 $\to$ $\Gamma_{\chi_{b0}} \approx 320\ \text{keV}$

Using ΔM=0.25 GeV, $\tan\beta \approx 15 \to B(\chi_{b0}\to\tau^+\tau^-) \approx 6\%$ and $B(\Upsilon \to \gamma\, \chi_{b0}) \approx$ 3-6% (PDG) as reference values, we get:

$$B(\Upsilon \to \gamma_s \tau^+\tau^-) \approx B(\Upsilon \to \gamma_s \chi_{b0}) \times B(\chi_{b0} \to \tau^+\tau^-) \cong 0.002 - 0.003$$

$\to$ $R_\tau \approx 0.1$, $\tan\beta \sim 15$

Miguel A. Sanchis-Lozano
IFIC-Valencia

Possible spectroscopic consequences in bottomonium

"Is there any point to which you would wish to draw my attention?"
"To the curious incident of the dog in the night-time"
"The dog did nothing in the night-time"
"That was the curious incident", remarked Sherlock Holmes
from "Silver Blaze" by A.C.D.

Searches for η_b states at CLEO: **No signal found!**

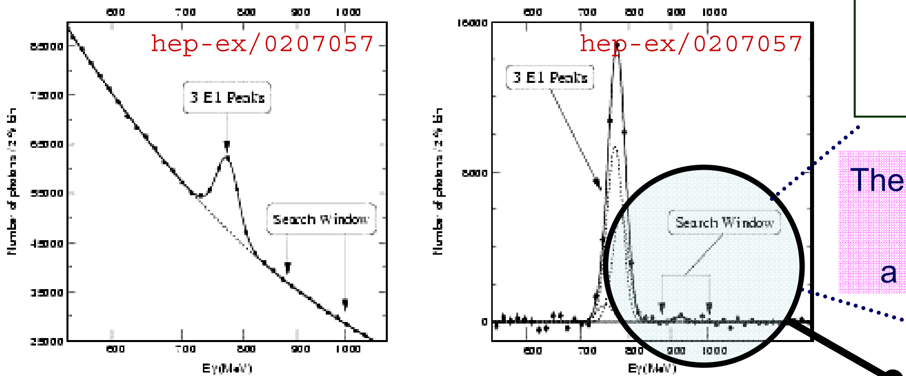
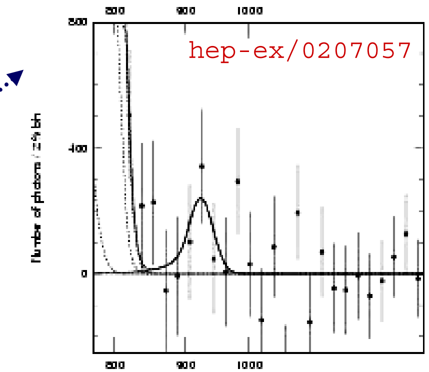
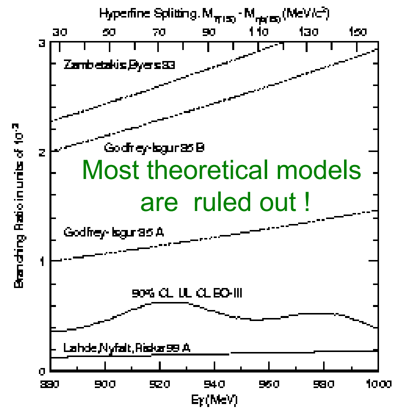


FIG. 2. The inclusive photon spectrum in the E1 peak ($\chi_b(2P_J) \to \gamma\Upsilon(1S)$) and the η_b search region (left) and the background-subtracted spectrum (right).

If η_b decay happens to be saturated by the A^0-mediated channel $\eta_b \to A^{0*} \to \tau^+\tau^-$

The search for η_b states would be a way of hunting a light non-standard Higgs!

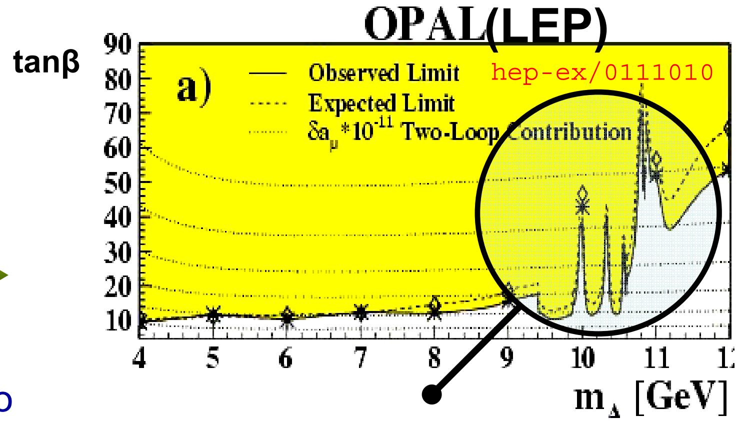




- Broad η_b states? Widths of order 50 MeV could be expected even for moderate values of tanβ (~ 30)

- A^0-η_b mixing? Mass shift yielding larger hyperfine splitting than expected in the SM (i.e. more than ~100 MeV).
  Drees and Hikasa, PRD 41, 1547 (1990)

  Higgs Yukawa couplings to fermions can be affected too, allowing quite large tanβ for special Higgs mass values



Based on:

hep-ph/0510374
hep-ph/0503266
hep-ph/0407320
hep-ph/0307313
hep-ph/0210364
hep-ph/0206156

- **If lepton universality is found to be (slightly) broken in Upsilon decays,** the simplest explanation would require a light non-standard mediated Higgs contribution (subsequent to a M1 transition of the Υ resonance) unwittingly ascribed to the tauonic decay mode
  - Reasonable values of tanβ in a 2HDM(II) are needed to yield $R_{\tau/l}$ of order 10%
  - Different scenarios beyond the SM could explain such a LU breaking
  - Further exp tests suggested:
    - **search for soft (non-monochromatic) photons in the $\tau^+\tau^-$ sample of Upsilon decays**
    - **seek after the η_b resonance**
    - **polarization studies of the tau…**

- **If not,** those light Higgs mass windows could be closed!

> Relevance of a Super B Factory running on the Υ region !!!
> Complementary to other searches at the LHC

- Keep also an eye on the related issues:
  - g-2 muon anomaly (which might require a CP-odd light Higgs contribution in a two-loop calculation)
  - Searches for dark matter in the universe

Light Neutralino Dark Matter

- Neutralino dark matter is generally assumed to be relatively heavy, with a mass near the electroweak scale

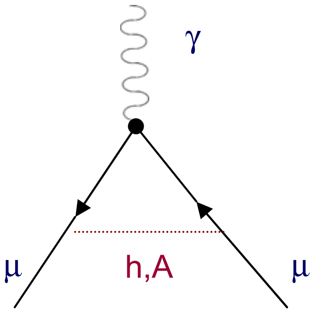
- It has been shown, however, that the claims of dark matter detection made by DAMA can be reconciled with null results of CDMS II if one considers a WIMP lighter than approximately 10 GeV [hep-ph/0504010]

- A very light CP-odd Higgs can make possible a very light neutralino to annihilate via such a light Higgs boson exchange [hep-ph/0509024]

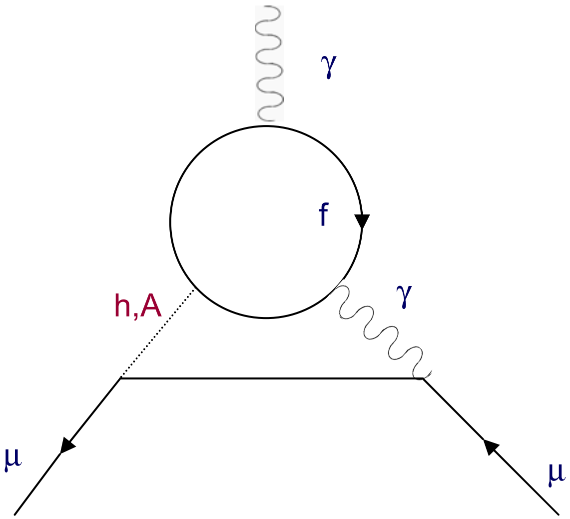
$$\tilde{\chi}^0\,\tilde{\chi}^0 \rightarrow A^0 \rightarrow \text{pions} \rightarrow \text{muons} \rightarrow \text{positrons}$$

leading to low-enery positrons which would generate the 511 keV gamma-ray emission observed from the galactic bulge by INTEGRAL/SPI experiment

g-2 muon anomaly in a 2HDM(II)

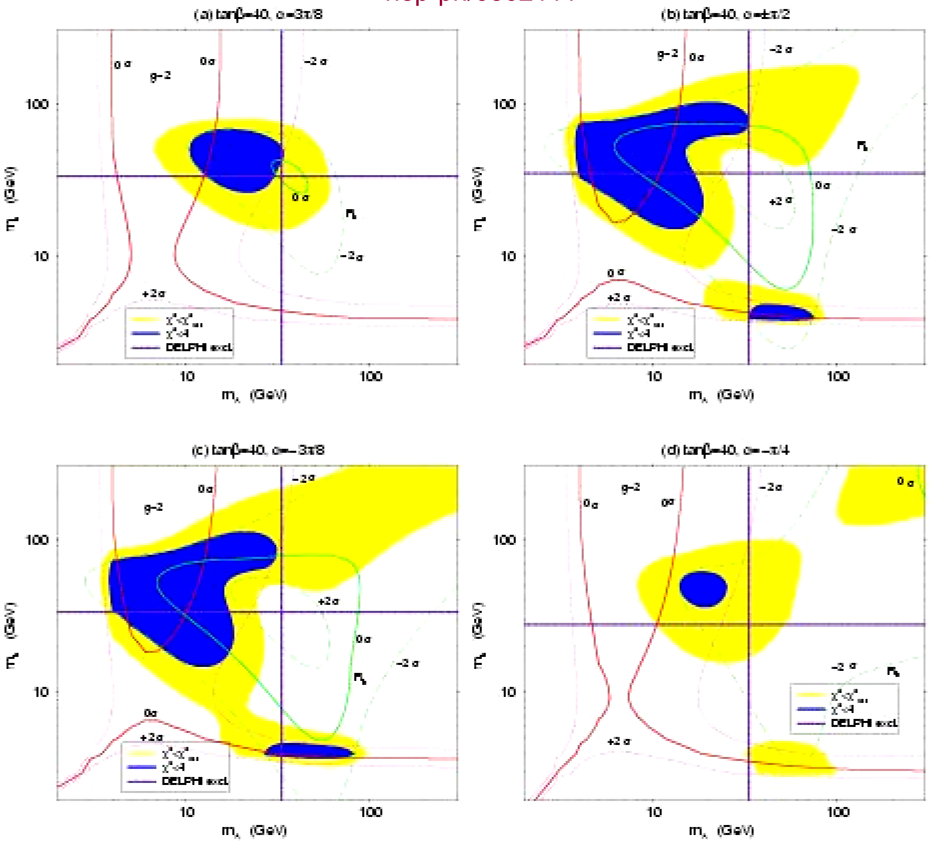


One.loop vertex correction



Two-loop vertex correction

hep-ph/0302111



The 2σ allowed regions in the (m_A, m_h) plane due to the constraints of a_μ and R_b for tanβ=40. The blue region is where the total χ^2 is less than 4 while the yellow region is where the total χ^2 is less than the χ^2 (SM)

MSSM (CPV)

- The Higgs potential is explicitly CP-conserving if all Higgs potential parameters are real. Otherwise, CP is explicitly violated
- CP-violation is generated by loop effects involving top and bottom squarks
- CP-violation can modify drastically the tree-level couplings of the Higgs particles to fermions and gauge bosons
- The CP parities of the neutral Higgs bosons may be mixed by radiative effects involving the third generation of squarks
- Under CP violation, the mass of the CP-odd Higgs scalar is no longer an eigenvalue but rather an entry in a general 3 x 3 neutral Higgs mass matrix

$$M_{SP}^2 \sim m_t^4 \, \mathrm{Im}(\mu A_t) / v^2 M_{SUSY}^2$$

where

μ is the mixing parameter of the two Higgs superfields

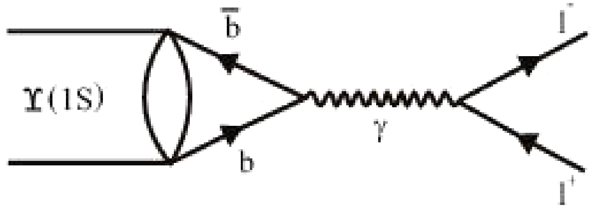
A_t denotes the soft SUSY-breaking trilinear coupling of the Higgs bosons to top squarks

v=246 GeV VEV of the Higgs

M_{SUSY} stands for the common SUSY-breaking scale

Testing Lepton Universality

BF($\Upsilon\to$ e+ e-) =BF($\Upsilon\to\mu$+ μ-) = BF($\Upsilon\to\tau$ + τ -)



Channel: *	BF[e^+e^-]	BF[$\mu^+\mu^-$]	BF[$\tau^+\tau^-$]	$R_{\tau/l}$(nS)
Υ(1S)	2.38 ± 0.11 %		2.60 ± 0.13 %	0.09 ± 0.07
Υ(1S)		2.48 ± 0.06 %	2.60 ± 0.13 %	0.05 ± 0.05
Υ(2S)	1.92 ± 0.17 %		2.11 ± 0.15 %	0.10 ± 0.12
Υ(2S)		1.93 ± 0.17 %	2.11 ± 0.15 %	0.09 ± 0.12
Υ(3S)	1.92 ± 0.24 %		2.55 ± 0.24 %	0.33 ± 0.18
Υ(3S)		2.18 ± 0.21 %	2.55 ± 0.24 %	0.17 ± 0.15

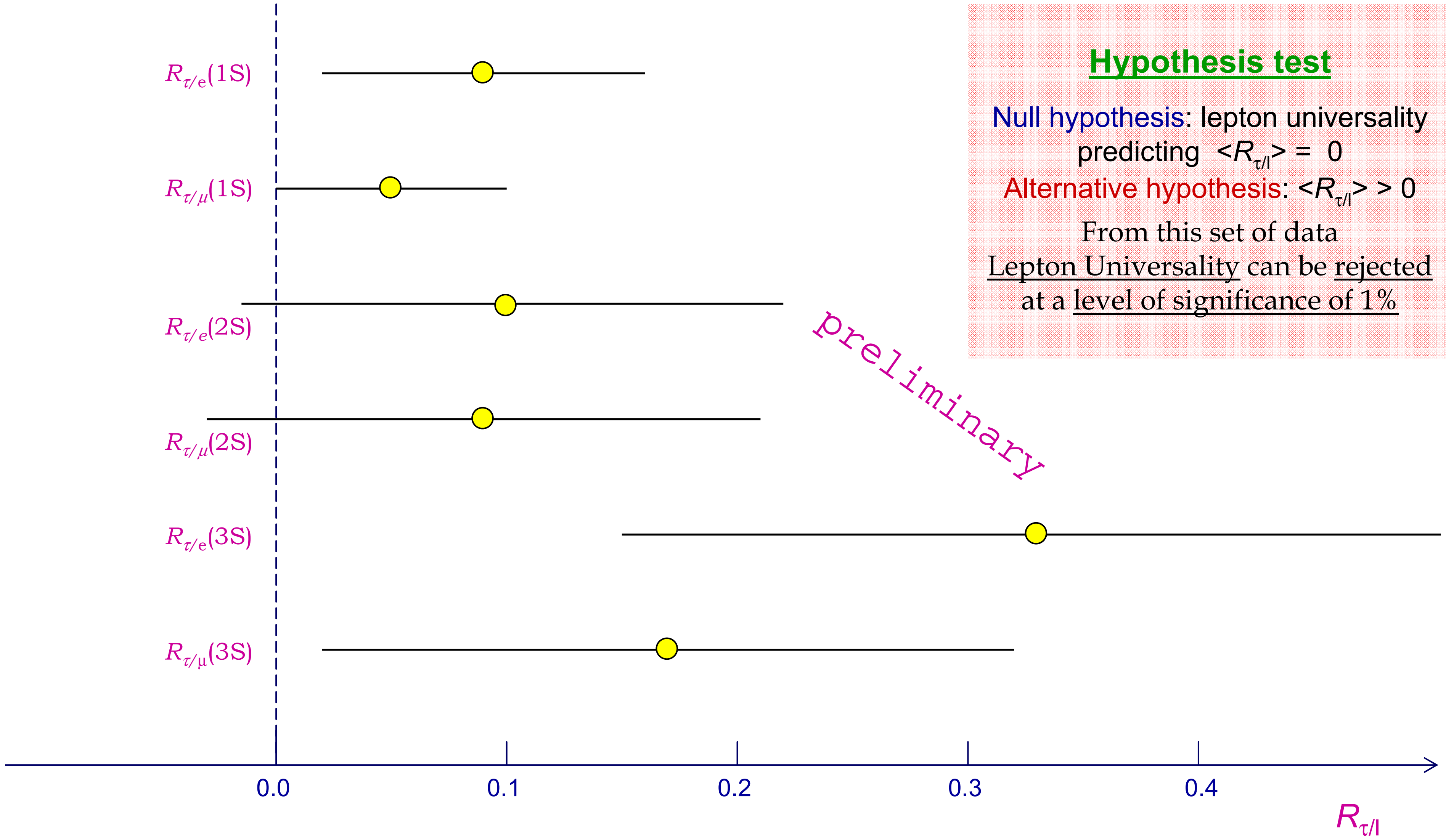
*Obtained from recent CLEO data and already existing PDG values
Statistical and systematic (conservative) errors are summed in quadrature
Error bars should decrease according to CLEO on-going analysis

PRELIMINARY

Lepton Universality
in Upsilon decays implies
<$R_{\tau/l}$> =0

$$R_{\tau/\ell}(\mathrm{nS}) = \frac{\Gamma_{\Upsilon(nS)\to\gamma_s\tau\tau}}{\Gamma_{\ell\ell}^{(em)}} = \frac{B_{\tau\tau}-B_{\ell\ell}}{B_{\ell\ell}} = \frac{B_{\tau\tau}}{B_{\ell\ell}} - 1$$

Lepton Universality Breaking?



Hypothesis test

Null hypothesis: lepton universality predicting $\langle R_{\tau/l}\rangle = 0$

Alternative hypothesis: $\langle R_{\tau/l}\rangle > 0$

From this set of data Lepton Universality can be rejected at a level of significance of 1%