New physics searches in quarkonium decays
- theory -

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Next-to-Minimal-Supersymmetric Standard Model (NMSSM)

Higgs sector

Things should be as simple as possible, but not simpler

A. Einstein

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

New gauge−singlet superfield

$$W = \lambda S H_u H_d + \frac{1}{3}\kappa S^3 + \cdots$$

$$V_{soft} = \lambda A_\lambda S H_u H_d + \frac{1}{3}\kappa A_\kappa S^3 + h.c. + \cdots$$

Six "free" parameters vs three in the MSSM :

$\kappa \quad \lambda \quad A_\kappa \quad A_\lambda \quad \mu \quad \tan\beta$

$$B_{eff} = A_\lambda + \kappa s$$

Physical Higgs bosons: (seven)

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

PQ symmetry or $U(1)_R$ slightly broken

↓

light pseudoscalar Higgs

Non-singlet component

Singlet component

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

$$\tan\beta = v_u / v_d$$

A_1 coupling to down type fermions $\propto X_d = \cos\theta_A \tan\beta$

Might be not too small for high tanβ

A_λ = -200 GeV
A_κ = -15 GeV
μ = 150 GeV
tan β= 40

A_λ ~ - K μ / λ

K - *(4/3)* λ =0

0.1 ≤| cos θ_A |≤ 0.5

X_d = cosθ_A tanβ

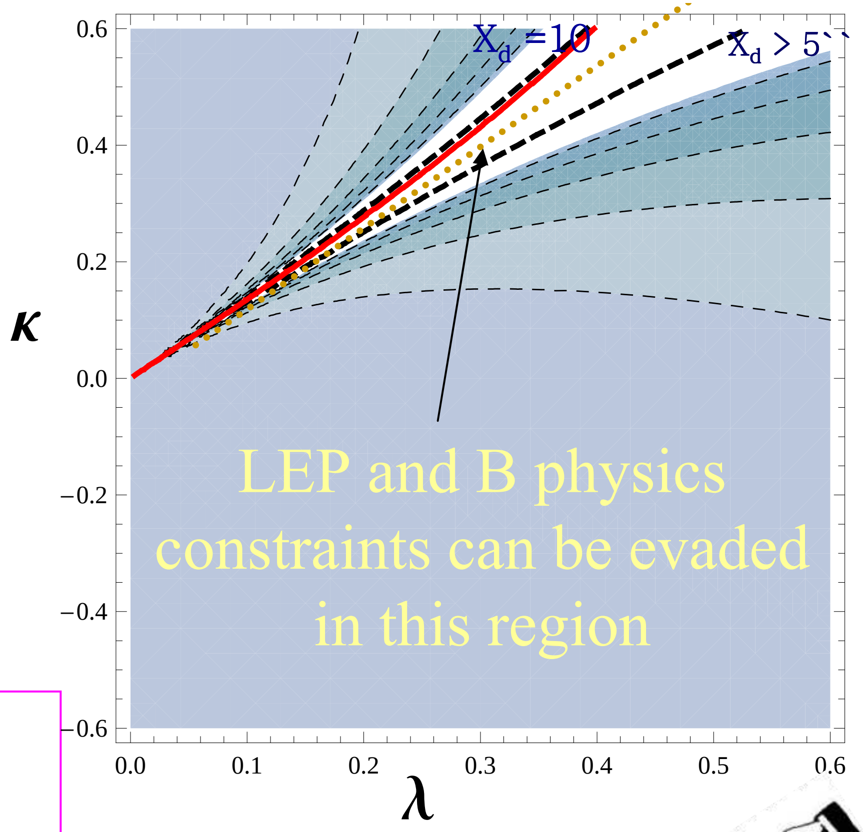
At large tanβ: $\sin 2\beta \approx \dfrac{2}{\tan\beta}$

$$\cos\theta_A \cong -\frac{\lambda v\,(A_\lambda - 2\kappa s)\sin 2\beta}{2\lambda s\underbrace{(A_\lambda + \kappa s)}_{B_{eff}} + 3\kappa A_\kappa s\sin 2\beta}$$

$$B_{eff},\ (\lambda A_\lambda + \kappa\mu) \to 0$$

$$m_{A_1}{}^2 \cong 3s\left(\frac{3\lambda A_\lambda \cos^2\theta_A}{3\sin 2\beta} - 2\kappa A_\kappa \sin^2\theta_A\right)$$

tanβ ~ 1/ [A_λ+ K μ / λ]
Ananthanarayan & Pandita, hep-ph/9601372



LEP and B physics constraints can be evaded in this region

The same region of the parameter space of the NMSSM yields simultaneously:

A_1 mass near 10 GeV

Large X_d (at high tan β)

$$M_A^2 = \frac{2\mu\, B_{eff}}{\sin 2\beta} = \frac{A_\lambda + \kappa s}{\sin 2\beta} \Rightarrow \text{Moderate!}$$

The (somewhat old) Proposal

Since 2002

1) Test of Lepton Universality* in Υ(1S,2S,3S) decays to taus at (below) the few percent level @ a (Super) B factory

Mod. Phys. Lett. A17 (2002) 2265
Int. J. Mod. Phys. A19 (2004) 2183

More recently

2) Possible Distorsion of Bottomonium Spectroscopy due to mixing of η_b states and a light CP-odd Higgs

Phys. Rev. Lett. 103 (2009) 111802

It is hard to find a black cat in a dark room, especially if there is no cat

Confucius

* Lepton universality: Gauge bosons couple to all lepton species with equal strength in the SM

Present status of Lepton Universality (PDG)

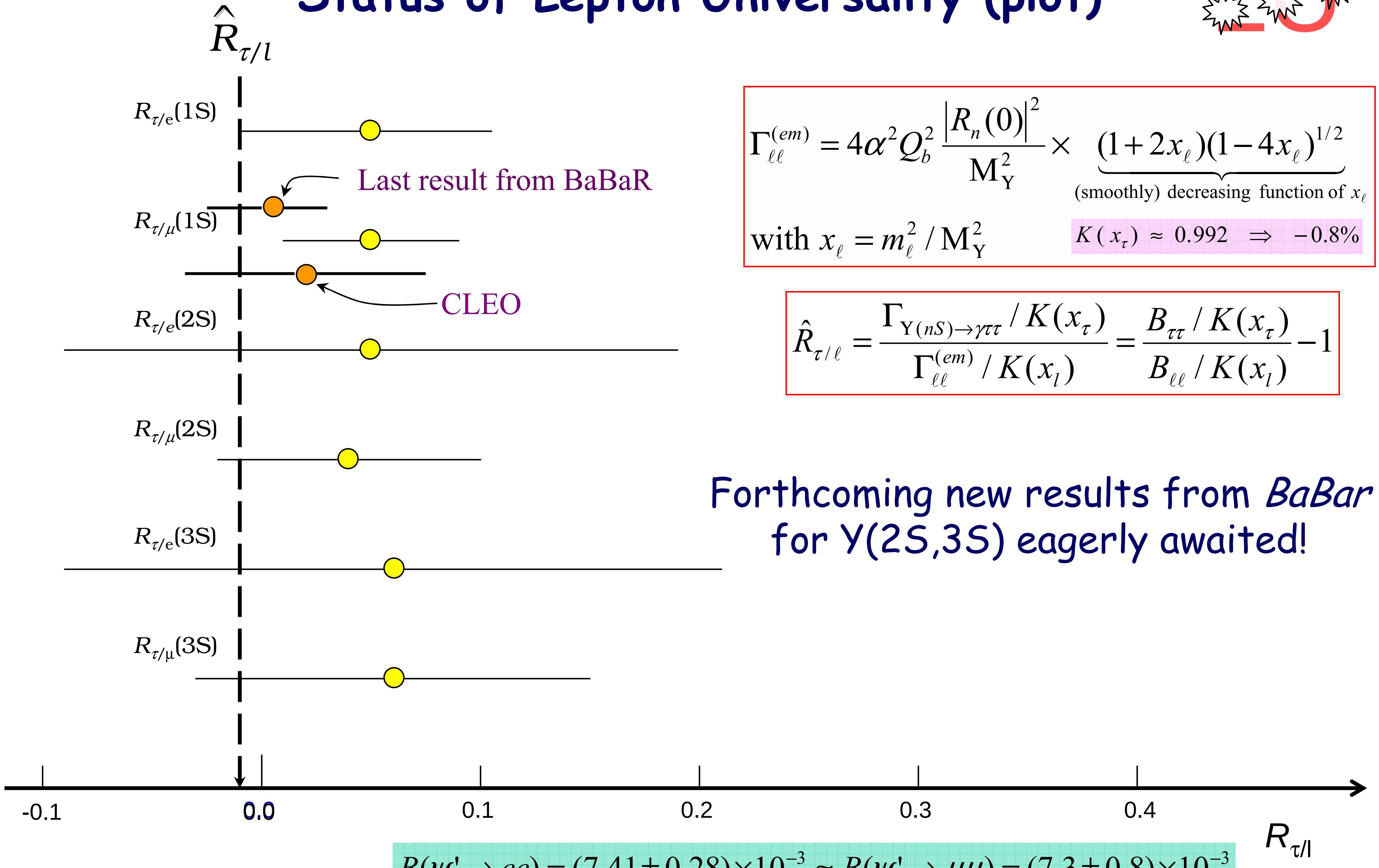
$$\mathrm{BF}\ [\Upsilon \to e^+e^-] = \mathrm{BF}\ [\Upsilon \to \mu^+\mu^-] = \mathrm{BF}\ [\Upsilon \to \tau^+\tau^-]$$

Channel	*BF* [e^+e^-]	*BF* [$\mu^+ \mu^-$]	*BF* [$\tau^+\tau^-$]	$R_{\tau/e}$	$R_{\tau/\mu}$
$\Upsilon(1S)$	2.48 ± 0.11 %	2.48 ± 0.05 %	2.62 ± 0.10 %	0.05 ± 0.06	0.05 ± 0.04
$\Upsilon(2S)$	1.91 ± 0.16 %	1.93 ± 0.17 %	2.01 ± 0.21 %	0.05 ± 0.14	0.04 ± 0.06
$\Upsilon(3S)$	2.18 ± 0.21 %	2.18 ± 0.21 %	2.30 ± 0.30 %	0.06 ± 0.16	0.06 ± 0.09

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

Lepton Universality in Upsilon decays implies $< R_{\tau/l} > = 0$ (actually -0.08)

Status of Lepton Universality (plot)



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

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

$K(x_\tau) \approx 0.992 \Rightarrow -0.8\%$

$$\hat{R}_{\tau/\ell} = \frac{\Gamma_{\Upsilon(nS)\to\gamma\tau\tau}/K(x_\tau)}{\Gamma_{\ell\ell}^{(em)}/K(x_l)} = \frac{B_{\tau\tau}/K(x_\tau)}{B_{\ell\ell}/K(x_l)} - 1$$

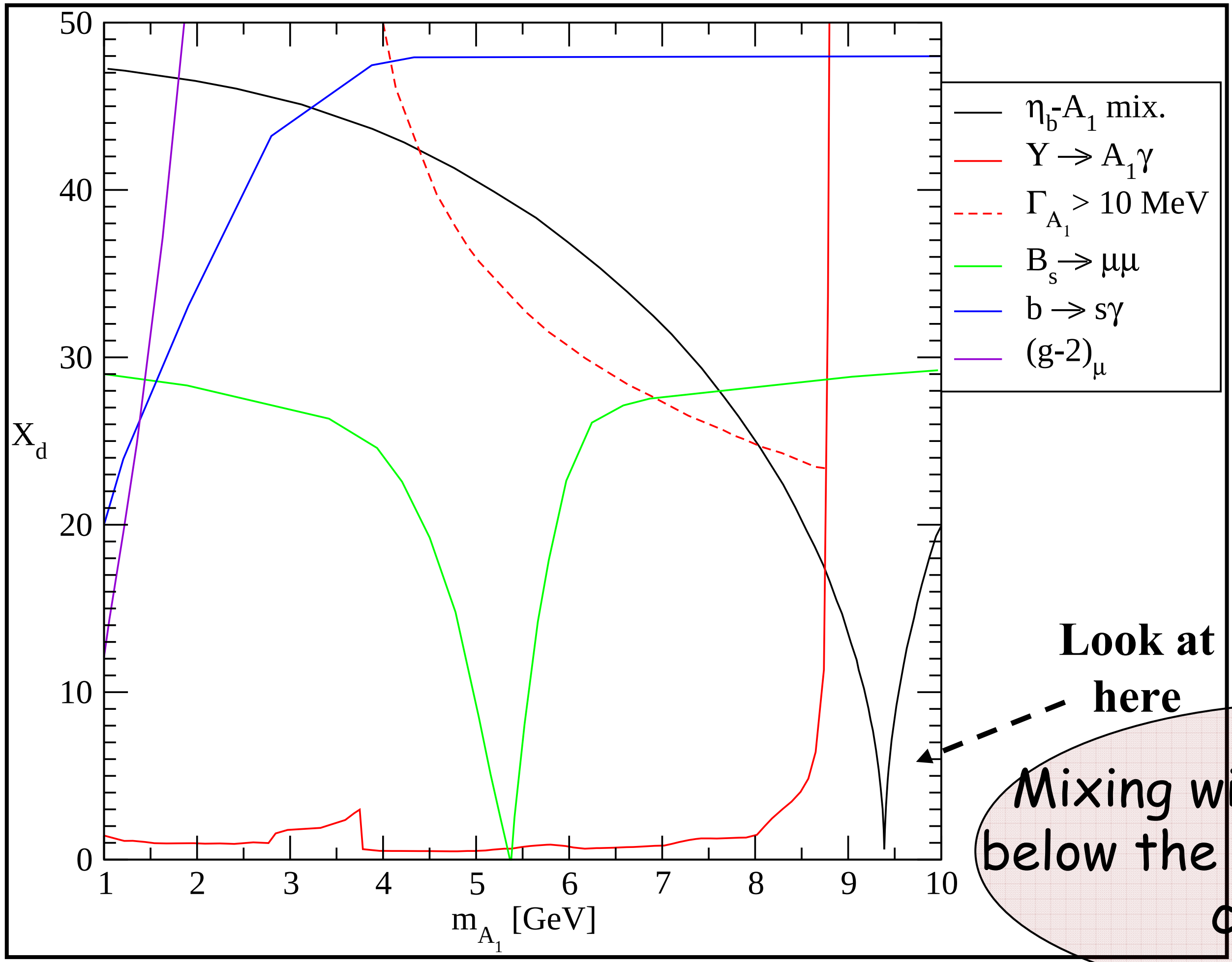
Forthcoming new results from *BaBar* for Υ(2S,3S) eagerly awaited!

For charmonium

$$B(\psi' \to ee) = (7.41 \pm 0.28)\times 10^{-3} \approx B(\psi' \to \mu\mu) = (7.3 \pm 0.8)\times 10^{-3}$$
$$> B(\psi' \to \tau\tau) = (2.8 \pm 0.7)\times 10^{-3}$$

Upper bounds for all parameters scanned in the NMSSM

F.Domingo, U. Ellwanger, E. Fullana, C. Hugonie and M.A.S.L., arXiv: 0810.4736



Look at here

$B_s \to \mu\mu$ puts limits about the B_s mass

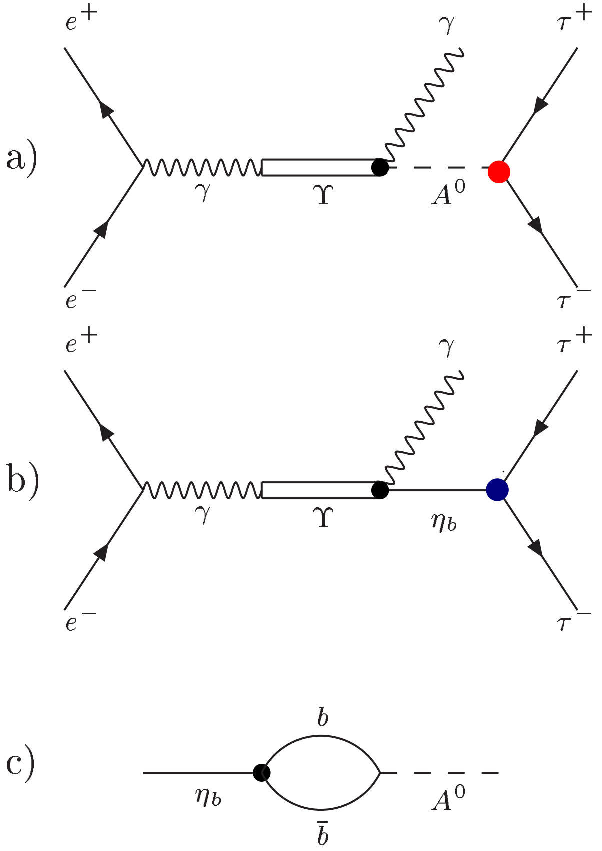
CLEO, BaBaR searches for $\Upsilon \to \gamma\, A_1$ puts stringent limits for $m_{A1} < 9$ GeV

BaBar discovery of $\eta_b(1S)$ puts limits about 9.4 GeV

Mixing with η_b resonances below the b-bbar threshold can occur

Mixing of a pseudoscalar Higgs A_1 and a η_b resonance

$e^+ e^- \to \Upsilon \to \gamma\, \tau^+ \tau^-$



Drees & Hikasa
PRD 41 (1990) 1547

hep-ph/0702190

$$\mathbf{M}^2 = \begin{pmatrix} m_{A_{10}}^2 - i m_{A_{10}} \Gamma_{A_{10}} & \delta m^2 \\ \delta m^2 & m_{\eta_{b0}}^2 - i m_{\eta_{b0}} \Gamma_{\eta_{b0}} \end{pmatrix}$$

A_{10} , η_{b0}
unmixed states

A_1 , η_b
mixed (physical)
states

$$A_1 = \cos\alpha\ A_{10} + \sin\alpha\ \eta_{bo}$$

$$\eta_b = \cos\alpha\ \eta_{b0} - \sin\alpha\ A_{10}$$

$$g_{A^0\tau\tau} = \cos\alpha\ g_{A_0^0\tau\tau} + \sin\alpha\ \overset{\mathbf{0}\nearrow}{g_{\eta_{bo}\tau\tau}}$$

$$g_{\eta_b\tau\tau} = \cos\alpha\ \overset{\mathbf{0}\nearrow}{g_{\eta_{b0}\tau\tau}} - \sin\alpha\ g_{A_0^0\tau\tau}$$

The η_b decays to leptons because of its mixing with the CP-odd Higgs

$$\delta m^2 \approx \left(\frac{3m_{\eta_b}^3}{4\pi v^2}\right)^{1/2} |R_{\eta_b}(0)| \times X_d \qquad \sin 2\alpha \approx \delta m^2$$

$$\Gamma_{A^0} = |\cos\alpha|^2\ \Gamma_{A_0^0} + |\sin\alpha|^2\ \Gamma_{\eta_{bo}}$$

$$\Gamma_{\eta_b} = |\cos\alpha|^2\ \Gamma_{\eta_{b0}} + |\sin\alpha|^2\ \Gamma_{A_0^0}$$

Resonant and non-resonant decays with $\eta_b(nS)$ –A_1 mixing

The "Higgs" is to be produced through the A_1- components of the mixed states no matter which production mechanism is considered.
In turn, the decay of physical pseudoscalar states into taus should also take place via their A_1- components.

$$\boxed{R_{\tau/\ell} = R^{A_1}_{\tau/\ell} + R^{\eta_b}_{\tau/\ell}}$$

$$\boxed{R_{\tau/\ell} = \overbrace{\frac{B[\Upsilon(nS)\to\gamma A_1]}{B[\Upsilon(nS)\to\ell^+\ell^-]}\times B[A_1\to\tau^+\tau^-]}^{\textit{Non-resonant}} + \underbrace{\frac{B[\Upsilon(nS)\to\gamma\eta_b(kS)]}{B[\Upsilon(nS)\to\ell^+\ell^-]}\times B[\eta_b(kS)\to\tau^+\tau^-]}_{\textit{Resonant}}}$$

$$B[A_1\to\tau\tau] = B[A_{10}\to\tau\tau]\times\frac{\cos^2\alpha\Gamma_{A_{10}}}{\cos^2\alpha\Gamma_{A_{10}}+\sin^2\alpha\Gamma_{\eta_{bo}}}$$

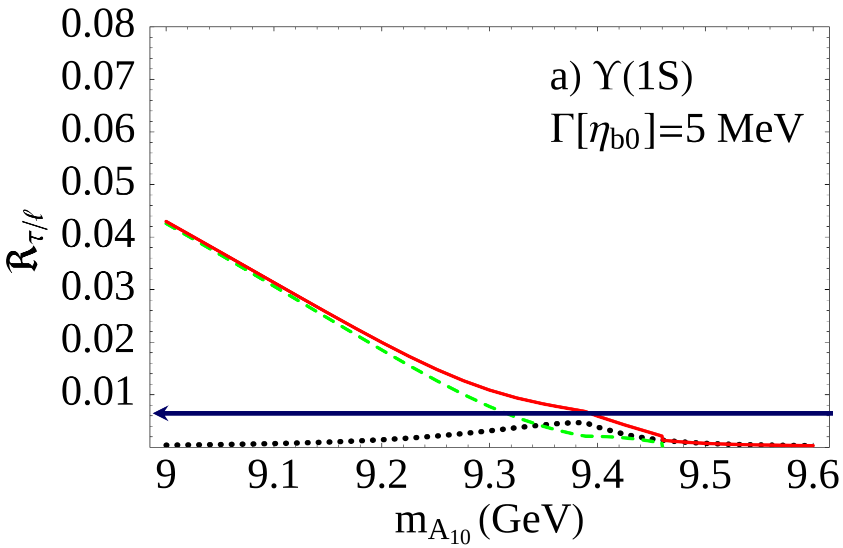
$$B[\eta_b(nS)\to\tau\tau] = B[A_{10}\to\tau\tau]\times\frac{\sin^2\alpha\Gamma_{A_{10}}}{\cos^2\alpha\Gamma_{A_{10}}+\sin^2\alpha\Gamma_{\eta_{bo}}}$$

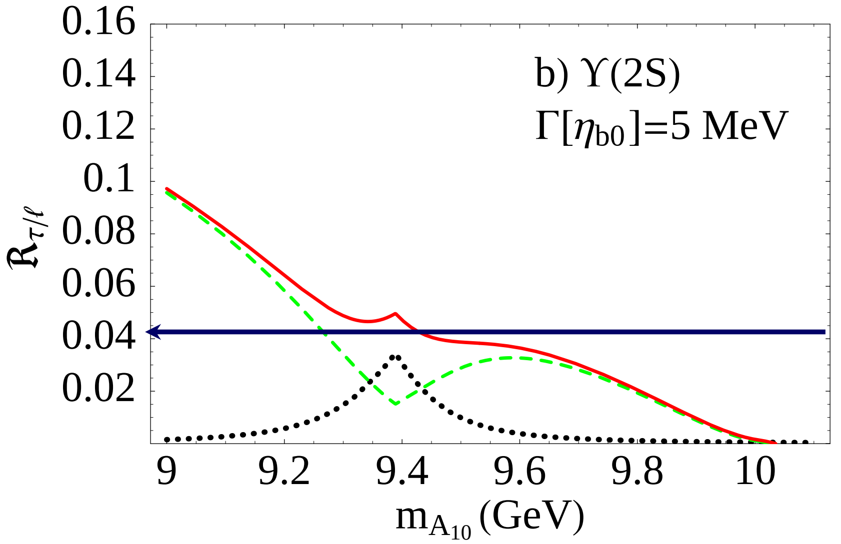
Mixing effect in the decay

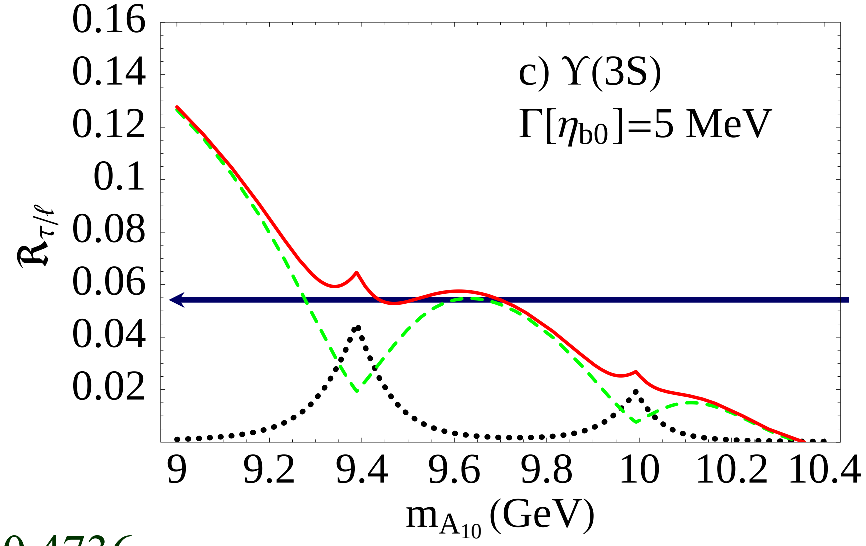
hep-ph/0702190 arXiv: 0810.4736

Expected LU breaking

$$R^{non-res}_{\tau/\ell} + R^{res}_{\tau/\ell} = R_{\tau/\ell}$$







X_d=12, $\Gamma_{\eta_{b0}}$ = 5 MeV

Green line: non-resonant decay
Black line: resonant decay
Red line: sum

arXiv: 0810.4736

Spectroscopic consequences for the bottomonium family

General mixing matrix

(in collaboration with F. Domingo & U. Ellwanger)

$$\mathcal{M}^2 = \begin{pmatrix} m^2_{\eta_b^0(1S)} & 0 & 0 & \delta m_1^2 \\ 0 & m^2_{\eta_b^0(2S)} & 0 & \delta m_2^2 \\ 0 & 0 & m^2_{\eta_b^0(3S)} & \delta m_3^2 \\ \delta m_1^2 & \delta m_2^2 & \delta m_3^2 & m_A^2 \end{pmatrix} .$$

$$\begin{aligned} \delta m_1^2 &\simeq (0.14 \pm 10\%)\ \mathrm{GeV}^2 \times X_d \ , \\ \delta m_2^2 &\simeq (0.11 \pm 10\%)\ \mathrm{GeV}^2 \times X_d \ , \\ \delta m_3^2 &\simeq (0.10 \pm 10\%)\ \mathrm{GeV}^2 \times X_d \ . \end{aligned}$$

Non-relativistic
calculation

Physical states = (mass) eigenstates of the above matrix

$$\eta_i = P_{i,1}\ \eta_b^0(1S) + P_{i,2}\ \eta_b^0(2S) + P_{i,3}\ \eta_b^0(3S) + P_{i,4}\ A\ .$$

i=1,2,3,4

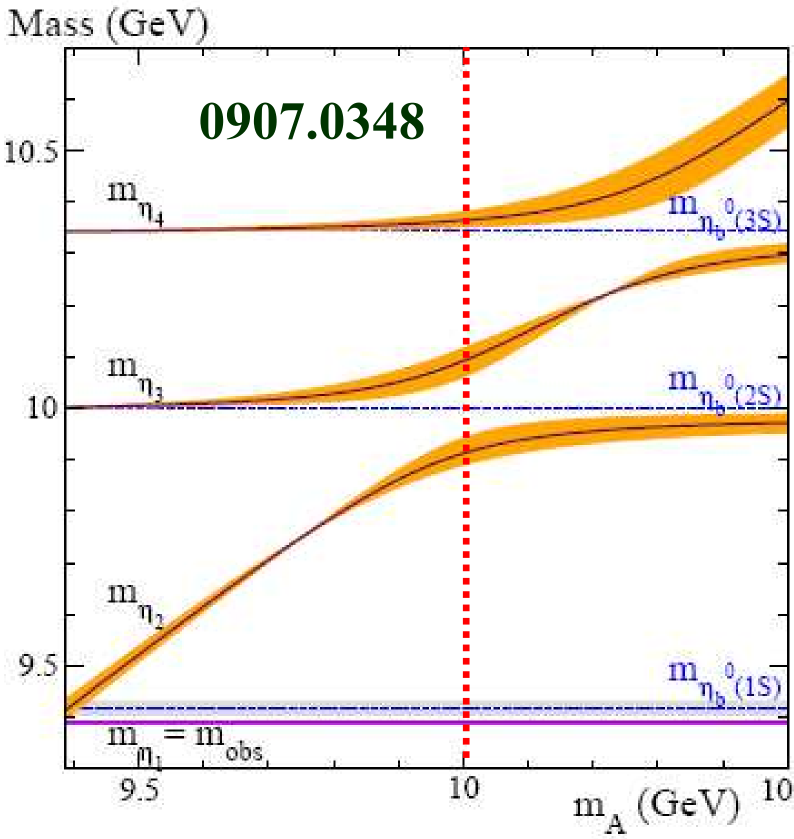
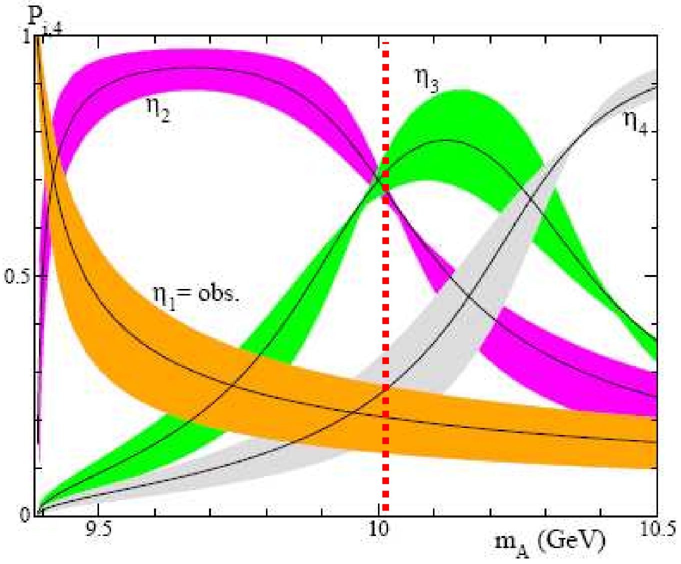
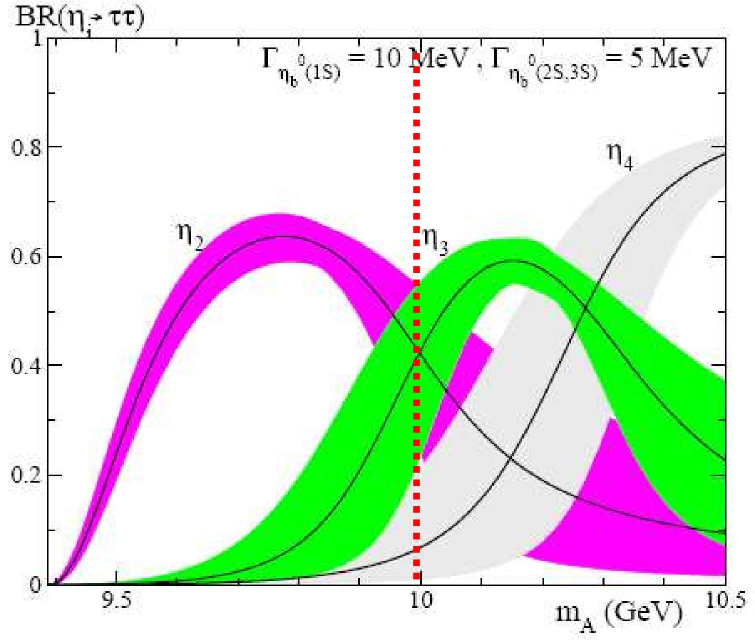


FIG. 2: The masses of all eigenstates as function of m_A.

Possible scenarios:
deeply entangled with search strategies



G. 3: The A-components $|P_{i,4}|$ for all 4 eigenstates as func ns of m_A.



'IG. 4: The branching ratios into $\tau^+\tau^-$ for the eigenstates $_2$, η_3 and η_4 as functions of m_A.

(Light) Dark Matter @ the NMSSM

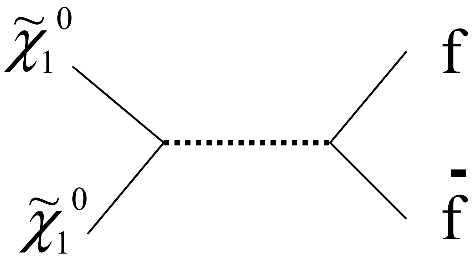
with a singlet component

WIMP candidate = lightest neutralino $\tilde{\chi}_1^0$

J.F. Gunion, D, Hooper, B. McElrath: hep-ph/0509024

For a recent analysis see Das and Ellwanger, **arXiv:1007.1151** [hep-ph]

- Efficient annihilation could happen through **a light CP-odd Higgs A_1** yielding the observed relic abundance



However it may eventually lead to an exceedingly efficient annihilation if $m_{A_1} \approx 2\ m_\chi$

- Scattering off nuclei

  - Spin-independent: through CP-even Higgs exchange
  - Spin-dependent: through Z^0 vector meson exchange

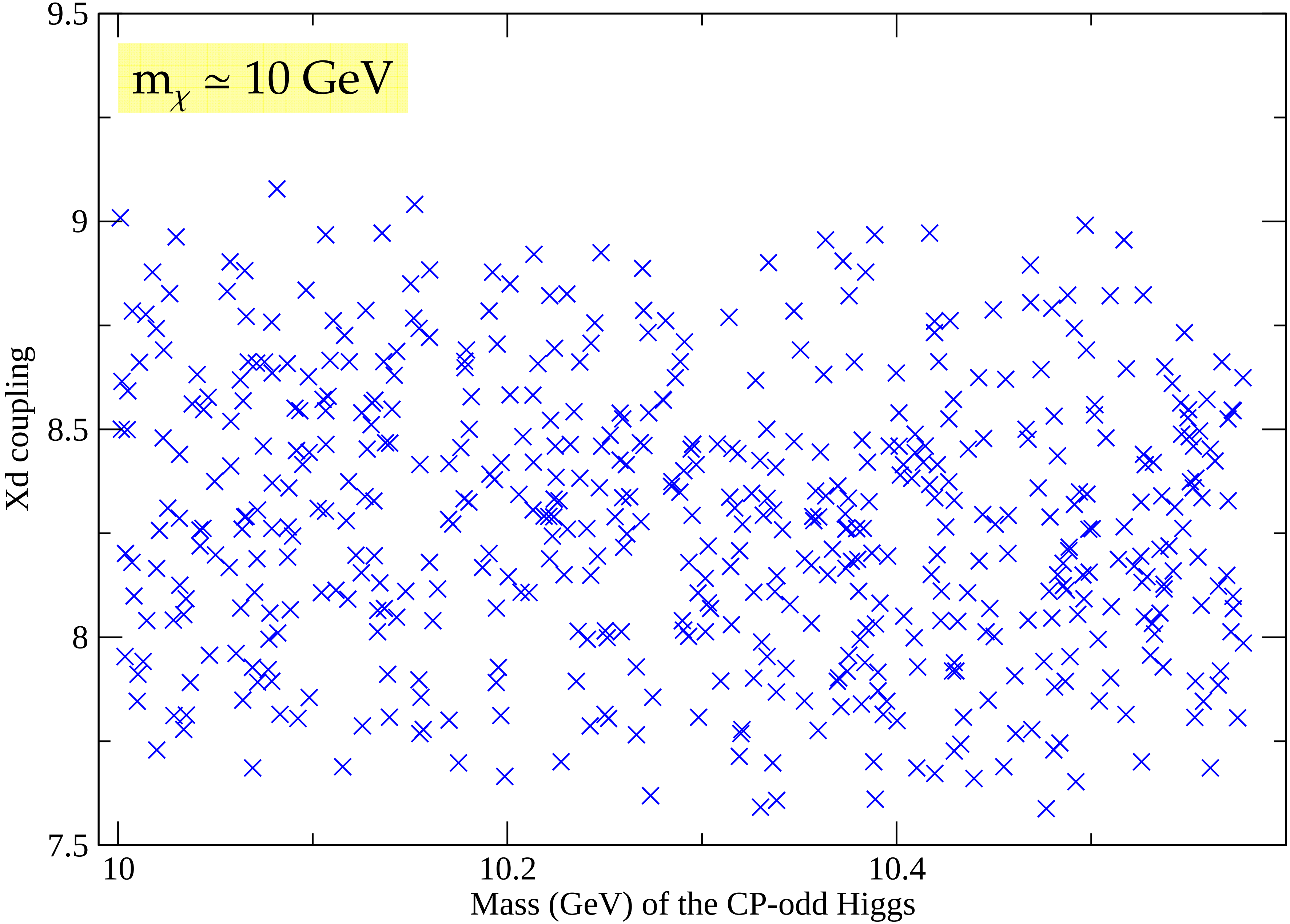
Scan of the NMSSM parameter space

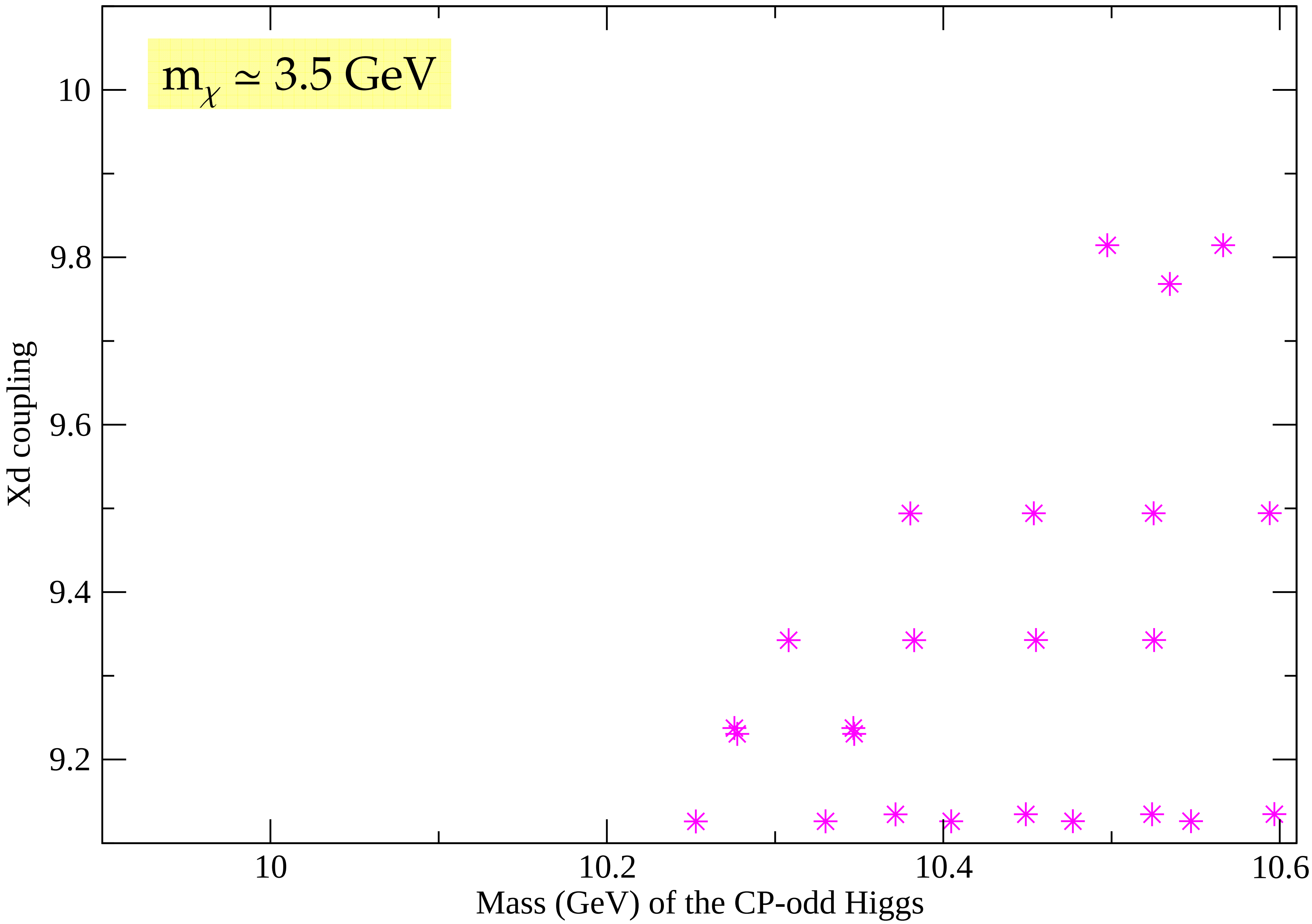
Using **NMSSMTools_2.3.6** (with WMAP bounds on)
(by Ellwanger, Gunion and Hugonie)

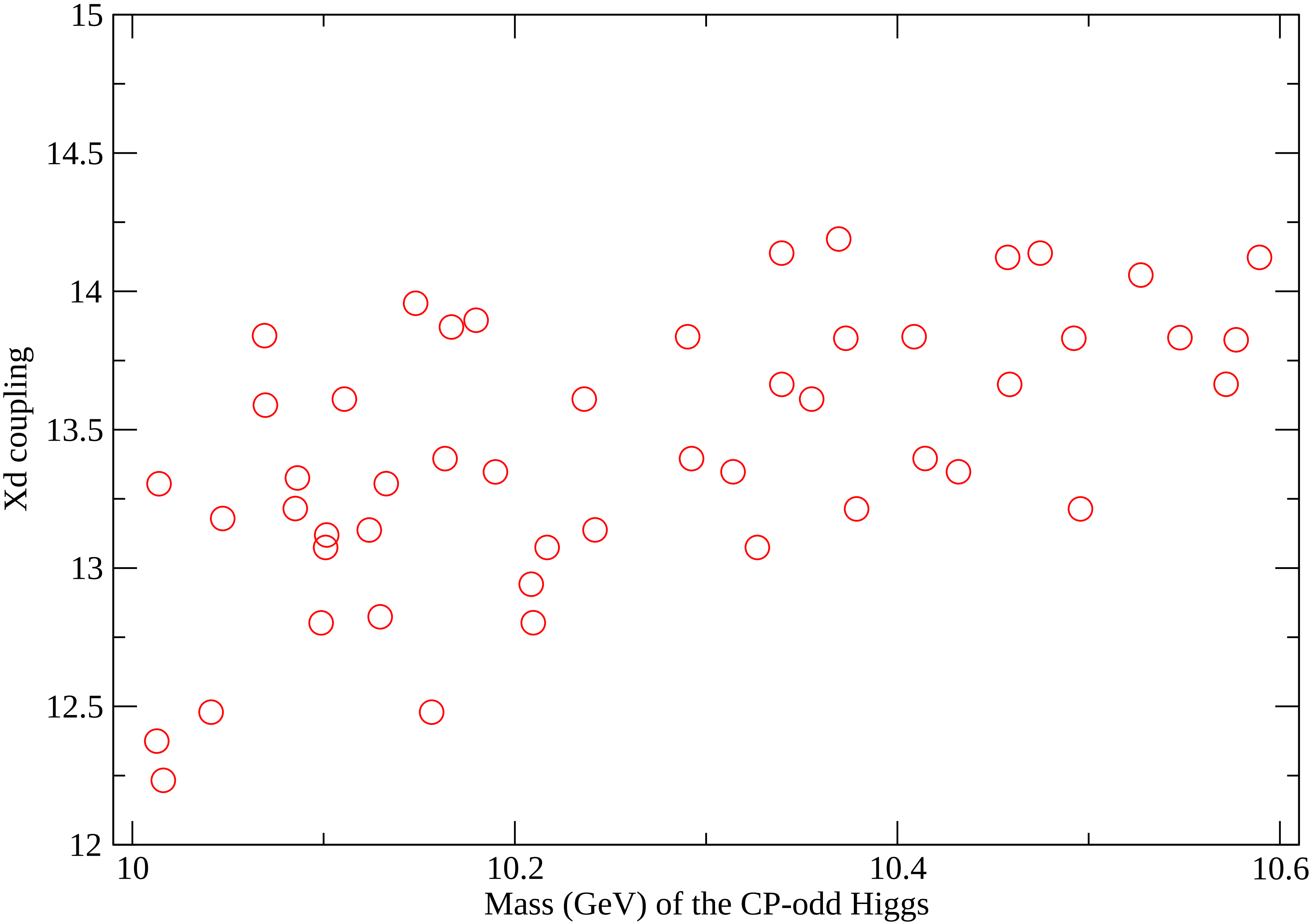
There are regions of the parameter space of the NMSSM where the following conditions can be satisfied simultaneously:

- All LEP and B physics bounds
- DM relic abundance (WMAP bounds) for a neutralino mass $\lesssim$ 10 GeV
- Mass of the lightest pseudoscalar Higgs A_1 of order of 10 GeV
- coupling of the CP-odd Higgs A_1 to down-type fermions of order 10 implying a sizable lepton universality breaking in Upsilon decays
- The mixing of the A_1 with η_b resonances might change dramatically the analysis of the scattering of neutralinos by nuclei, especially the spin-dependent cross section due a pseudoscalar mediator

(commonly neglected)

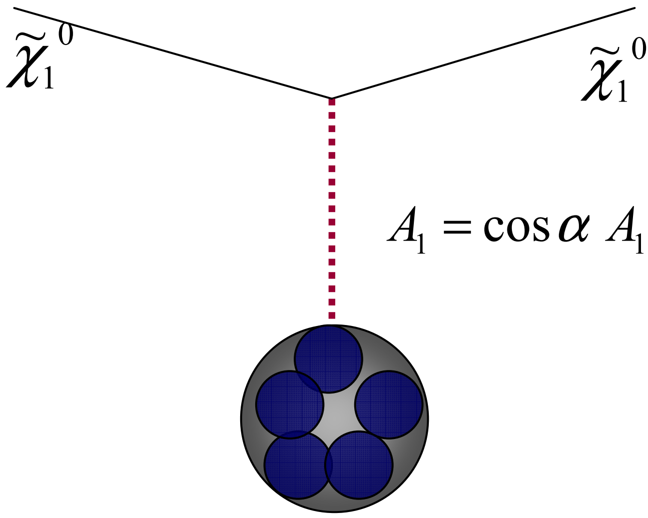

$m_\chi \simeq 10$ GeV
9.5
9
8.5
8
7.5
Xd coupling
10
10.2
10.4
Mass (GeV) of the CP-odd Higgs


$m_\chi \simeq 3.5$ GeV
Xd coupling
9.2
9.4
9.6
9.8
10
10
10.2
10.4
10.6
Mass (GeV) of the CP-odd Higgs


15
14.5
14
13.5
13
12.5
12
10
10.2
10.4
10.6
Xd coupling
Mass (GeV) of the CP-odd Higgs

Direct observation of dark matter

WIMP scattering off a nucleus



$$A_1 = \cos\alpha\ A_{10} + \sin\alpha\ \boxed{\eta_{bo}} \longrightarrow$$

Possible enhancement

$$\mathrm{BF}[\eta_c \to p\,\bar{p}] \approx 10^{-3}$$ PDG

Perhaps
substantial coupling
of η_b to nucleons too

EMC nuclear effect

Vector Meson Dominance for the photon:
the physical photon as a superposition of
a bare photon and ρ, ω, ϕ,..

Pseudoscalar meson dominance
The mediator is a mixing of A_1 and η_b

Spin-dependent interaction
Velocity suppression factor
$(v/c)^2 \sim 10^{-6}$; v neutralino velocity

$\longleftrightarrow$

$(m_b/m_s)^2 \sim 10^2$
$(m_Z/m_A)^2 \sim 10^2$
$g_{\eta_b pp}$ *not small?*

Still negligible contribution (?)

Conclusions

The search for the η_b **(2S)** state(s) by BaBar is ***crucial***
to rule out/discover a light CP-odd Higgs
in the range $2m_\tau < m_{A_1} < 2m_B$ (open window: 9.6-10.5 GeV)

The η_b(2S)-like state mass measurement might
yield a hyperfine splitting $m_{Y(2S)} - m_{\eta_b(2S)}$
in disagreement with SM expectations

Test of lepton universality in Y(2S, 3S) decays
should be another hint of NP
LU breaking expectedly larger than for the Y(1S)

A light neutralino with mass (GeV) $3 \lesssim m_\chi \lesssim 10$ and coupling $X_d \simeq 8\text{-}14$
is viable in a special region of the parameter space of the NMSSM

Physical (mixed) states η_i (i=1,2,3,4) might modify
the coupling of neutralinos to ordinary matter
(affecting annihilation and scattering cross sections)

Back-up

Next-to-Minimal Supersymmetric Standard Model (NMSSM)

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

In general more extra SM singlets can be added: hep-ph/0405244

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 $\mu = \lambda x, \quad x = <S> = \mu / \lambda$ If κ =0 → U(1) Peccei-Quinn symmetry

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 leading to a light CP-odd scalar for small κ

If λ and κ zero → U(1)$_R$ symmetry; if U(1)$_R$ slightly broken → a light pseudoscalar Higgs boson too

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 ($H^\pm$)

The A_1 would be the lightest Higgs:

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

Favored decay mode: $H_{1,2} \rightarrow A_1 A_1$

hard to detect at the LHC [hep-ph/0406215]

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

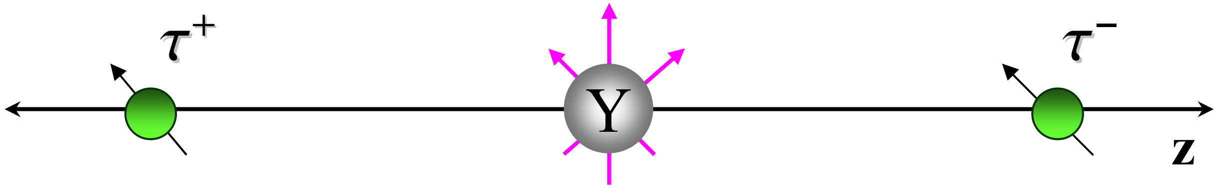
Coupling of A_1 to down type fermions:

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

[hep-ph/0404220]

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

Leptonic decay mode: $\Upsilon(nS) \to \tau^+\tau^-$ vs $\Upsilon(nS) \to \mu^+\mu^-$



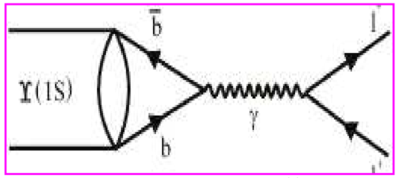
- For transverse polarization of Υ(nS), the helicity of leptons gives no difference
- For longitudinal polarization of Υ(nS), **lepton helicity** favours the tauonic mode

  (as e.g. in $\pi \to \mu\,\nu_\mu$ versus $\pi \to e\,\nu_e$)
- **Phase space** favours the muonic decay mode

$$\boxed{\begin{array}{ll} \Gamma_{\ell\ell}^{(em)} = 4\alpha^2 Q_b^2 \dfrac{|R_n(0)|^2}{\mathrm{M}_\Upsilon^2} \times \underbrace{(1+2x_\ell)(1-4x_\ell)^{1/2}}_{\text{(smoothly) decreasing function of } x_\ell} & \\ \text{with } x_\ell = m_\ell^2 / \mathrm{M}_\Upsilon^2 & K(x_\ell) \approx (1-6x_\ell) \end{array}}$$

For Υ(1S): $K(x_\tau) \approx 0.992 \Rightarrow -0.8\%$

Leptonic width of ϒ resonances



Lowest Feynman diagram

- Γ_{ll} (as presented in the PDG tables) is an ***inclusive*** **quantity:**

$\Upsilon \to l^+ l^-$ is accompanied by an infinite number of soft photons

The test of lepton universality can be seen as complementary to searches for a (monochromatic) photon in the $\Upsilon \to \gamma\, \tau\tau$ channel

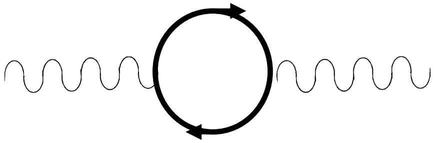
- To order α^3: $\Gamma_{ll} = \Gamma_{ll}^{0} [\, 1+\delta_{vac} + \delta_{vertex}\,] \sim \Gamma_{ll}^{0} [\, 1+\delta_{vac}\,]$

Warning!

$3\alpha / 4\pi \sim 0.17\%$

7.6%

$\delta_{vac} = \delta_{ee} + \delta_{\mu\mu} + \delta_{\tau\tau} + \delta_{quarks}$



Contribution potentially dangerous for testing lepton universality **if final-state radiation is not properly taken into account in the MC to obtain the detection efficiency** in the analysis of experimental data

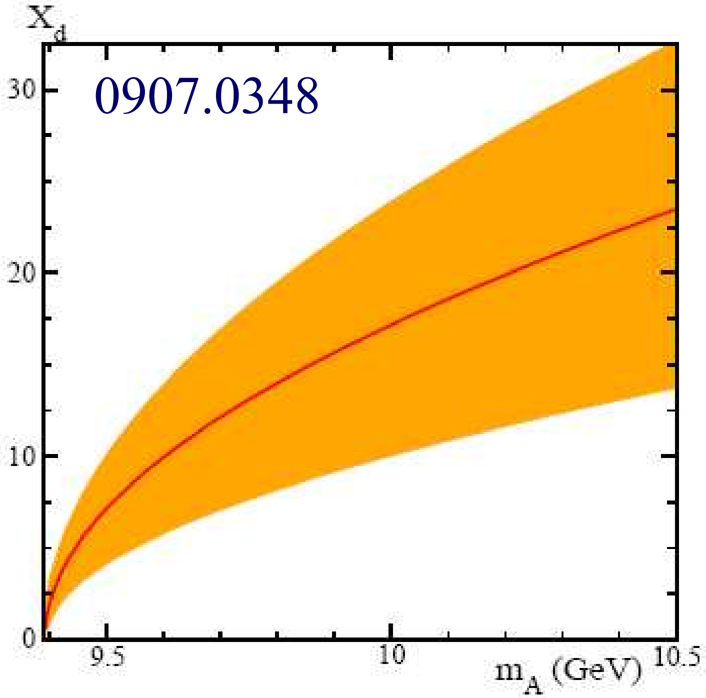
Albert et al. Nucl. Phys. B 166 (1980) 460

- Divergencies/singularities free at any order: Bloch and Nordsieck theorem & Kinoshita-Sirlin-Lee-Nauenberg theorem

“Requirement” on X_d from the $\eta_b(1S)$ mass measurement

Hyperfine splitting $M_{Y(1S)}$-$M_{\eta_b(1S)}$ = 69.9 ± 3.1 MeV (BABAR)

Hyperfine splitting $M_{Y(1S)}$-$M_{\eta_b(1S)}$ = 42 ± 13 MeV (pQCD)



0907.0348

FIG. 1: X_d as a function of m_A (in GeV) such that one eigenvalue of $\mathcal{M}^2$ coincides with the BABAR result (1).

Resonant and non-resonant decays without mixing

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

QCD+binding energy effects
small for a pseudoscalar A^0
Polchinski, Sharpe and Barnes
Pantaleone, Peskin and Tye
Nason

Leading-order Wilczek formula
with binding-state, QCD + relativistic corrections: *F = ½*

quite uncertain
especially ~ 9 GeV

- *Non-resonant decay*

$$R_{\tau/\ell}^{non-res} = \frac{G_F m_b^2 X_d^2}{\sqrt{2}\,\pi\,\alpha}\left(1-\frac{m_{A^0}^2}{m_\Upsilon^2}\right)\cdot F$$

- *Resonant decay*

$$R_{\tau/\ell}^{res} = \frac{B[\Upsilon\to\gamma\eta_b]}{B[\Upsilon\to l^+l^-]}$$

Wavefunction
overlap

M1 transition probability

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

Naïve view!

Why should LU be useful to search for a light CP-odd Higgs?

- **Direct observation of monochromatic photons from radiative decays** of Upsilon resonances may not be that easy especially for

$$m_{A_1} \in [\, 9.4,\, 10.5 \,]\ \text{GeV}$$

As suggested by ***J. Gunion***
hep-ph/0502105
also historically employed in
the search for a light Higgs

- The peak in the photon energy spectrum could be **broader than expected**

because **two (or more)** peaks resulting from both A_1 and η_b channels **might not be easily disentangled**

Naive approach

$$\Upsilon(nS) \to \gamma\ A_1 (\to \tau^+ \ \tau^-)$$

n, n' = 1,2,3

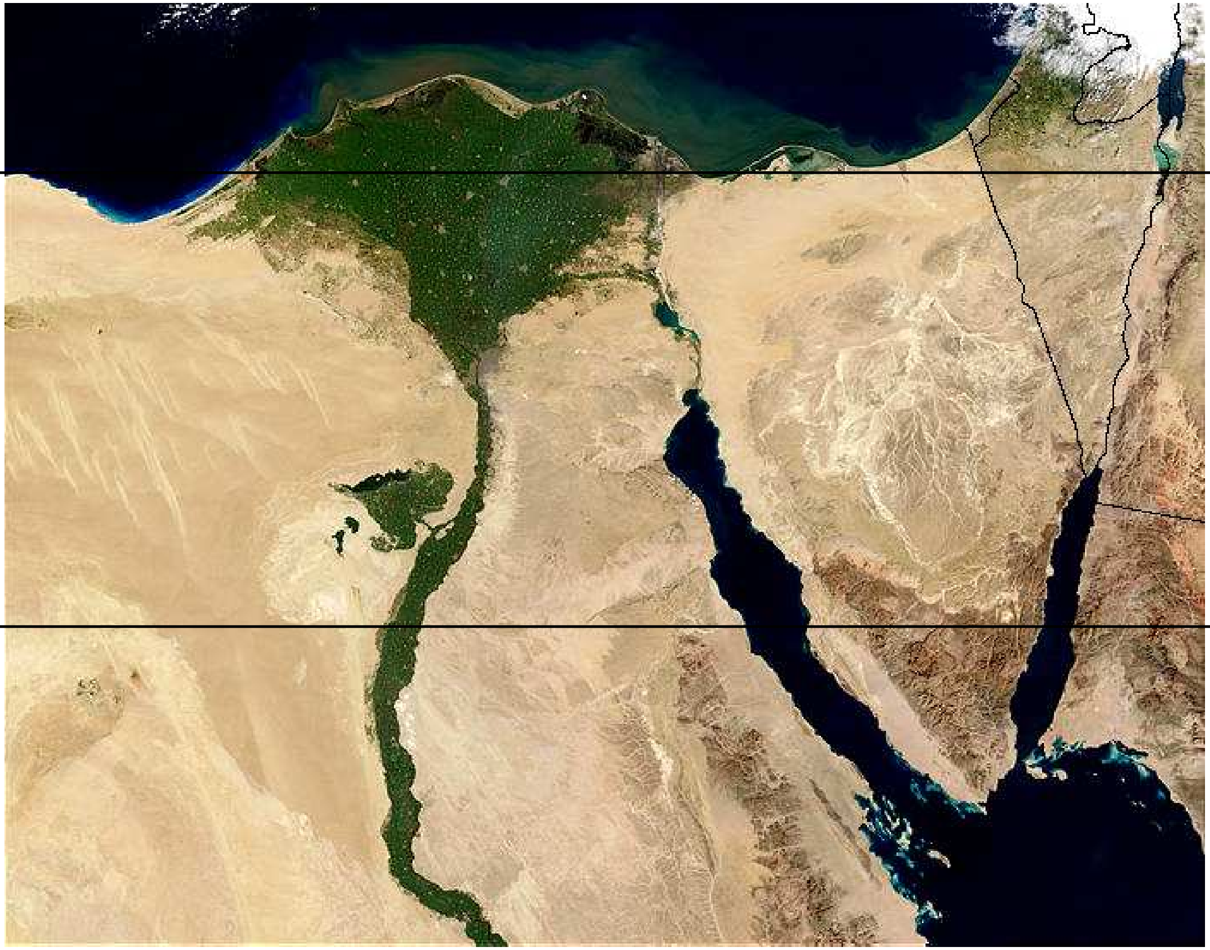
$$\Upsilon(nS) \to \gamma\, \eta_b\, (n'S)\ [\to A_1^* \to \tau^+ \tau^-\,]$$

Cerro dos picos - Argentina

A_1-η_b mixing yields additional difficulties for exp detection as we shall see!

An analogy: the Nile delta

“Scanning”



Actually seen!

Many channels spreading over a broad region

Expected Signal:

Narrow river with plenty of water

A “naïve” explorer moving across the delta:

The Nile river does not exist!

Dark matter: bounds from B factories

BaBar

$$BF[Y(1S) \to invisible] < 3\times10^{-4}$$

arXiv:0908.2840 [hep-ex]

scalar mediator

$$BF[Y(3S) \to \gamma + invisible] < (0.7-31)\times10^{-6} \quad , \; m_A < 7.8\,\mathrm{GeV}$$

(pseudo) scalar mediator

arXiv:0808.0017 [hep-ex]

Effort should be put on the search for
light dark matter (e.g. neutralinos)
such that

$$\boxed{2\mathrm{m}_\chi \sim \mathrm{m}_{\mathrm{A}_1} \sim 10\ \mathrm{GeV}}$$

$$Y(3S) \to \gamma A_1(\to \tilde{\chi}_1^0\, \tilde{\chi}_1^0)$$

NOT YET EXCLUDED
by B factories searches

Small photon energy
Detection not that easy!