Searches for New Physics at BaBar

Concetta Cartaro
SLAC
For the BaBar Collaboration

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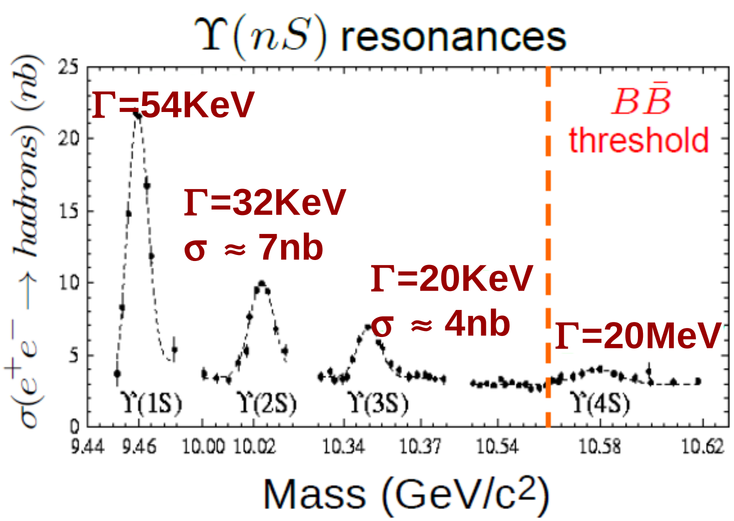
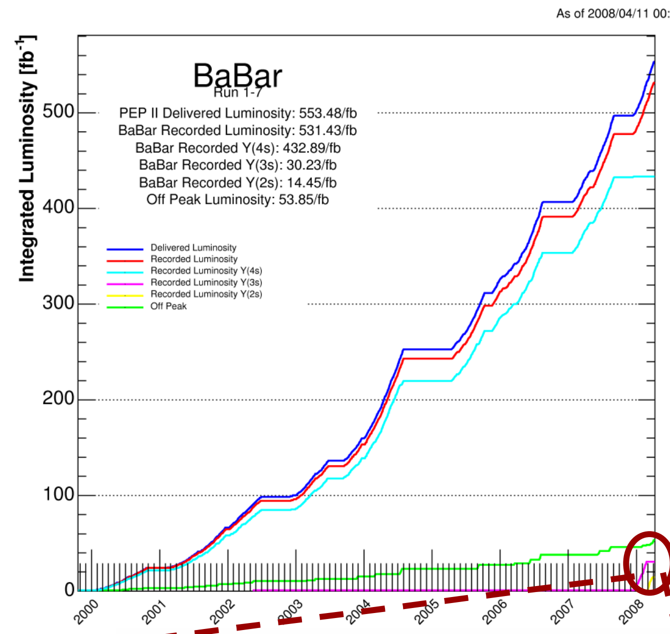
Outline

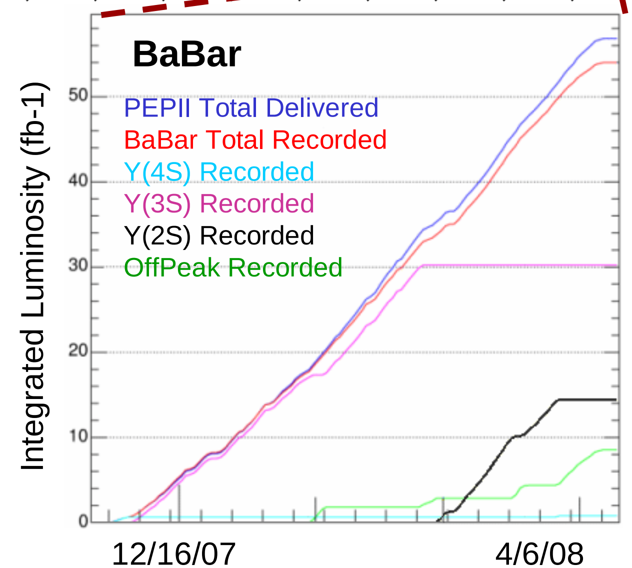
- Searches for Charged Lepton Flavor Violation
  - $\Upsilon(2S,3S) \rightarrow l\tau$ ($l=e,\mu$)
  - $\tau \rightarrow l\gamma$
  - $\tau \rightarrow 3l$ ($l=e,\mu$)
- Test of Lepton Universality
  - $\Upsilon(1S) \rightarrow \gamma A^0$, $A^0 \rightarrow l^+ l^-$
  - $\Upsilon(1S) \rightarrow \gamma \eta_b(1S)$, $\eta_b \rightarrow \gamma A^0 \rightarrow l^+ l^-$
- And just for the sake of completeness
  - Searches for Higgs and Dark Matter
    - $\Upsilon(2S,3S) \rightarrow \gamma A^0$, $A^0 \rightarrow \mu^+ \mu^-$
    - $\Upsilon(3S) \rightarrow \gamma A^0$, $A^0 \rightarrow \tau^+ \tau^-$
    - $\Upsilon(3S) \rightarrow \gamma A^0$, $A^0 \rightarrow$ invisible
    - $\Upsilon(3S) \rightarrow \pi^+ \pi^- \Upsilon(1S)$, $\Upsilon(1S) \rightarrow$ invisible

BaBar Data

- BaBar datasets:
  - Υ(4S): 470 x 10^6 decays (430 fb^{-1})
    - Offpeak sample of 44.8fb^{-1} collected ~40MeV below the Υ(4S)
  - Υ(3S): 122 x 10^6 decays (28.5 fb^{-1})
  - Υ(2S): 99 x 10^6 decays (14.4 fb^{-1})
    - offpeak samples of 1.4fb^{-1} and 2.4fb^{-1} collected ~30 MeV below the Υ(2S) and Υ(3S)
  - Rare BFs at $\Upsilon(nS)_{n=1,2,3}$ enhanced by $\Gamma(\Upsilon(4S))/\Gamma(\Upsilon(nS)) = O(10^3)$
- A B-Factory is also a Flavor Factory
  - σ_{BB} ~ 1.05nb
  - σ_{cc} ~ 1.30nb
  - $\sigma_{\tau\tau}$ ~ 0.92nb
  - σ_{uds} ~ 2.09nb

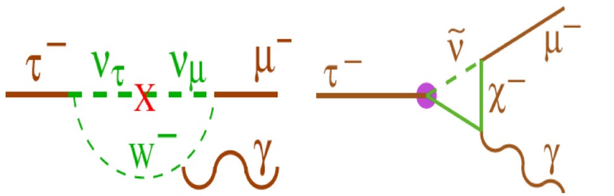


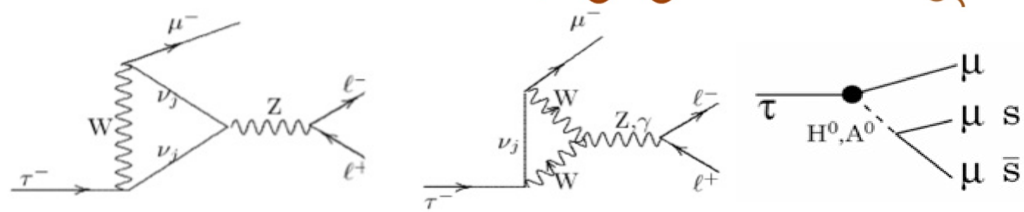


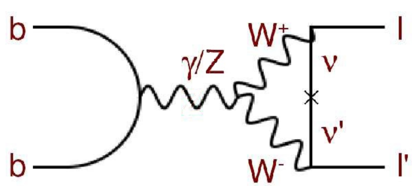


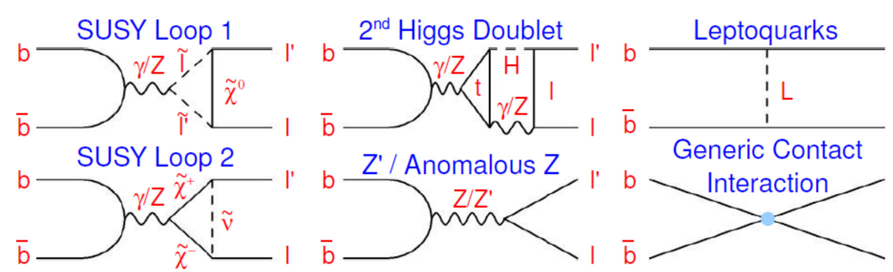
Lepton Flavor Violation

- Standard Model
  - $m_\nu \neq 0 \rightarrow$ Neutral LFV is allowed
  - Charged LFV is suppressed at tree level by a factor $((\Delta m_\nu^2)/M_W^2)^2 \sim O(10^{-48})$
    - Experimentally unobservable
- Many mechanisms beyond the SM
  - CLFV enhanced up to experimental sensitivity
    - Its observation would be an unambiguous sign of New Physics
- Large Υ(2S), Υ(3S) datasets offer significant improvement w.r.t. previous ULs: $BF(\Upsilon(2S/3S) \rightarrow \mu\tau) = O(10^{-5})$
  - CLEO PRL 101, 201601 2008
- LFV searched in
  - $\Upsilon(nS) \rightarrow l\tau$
  - $\tau \rightarrow (e/\mu)\gamma$
  - $\tau \rightarrow 3l$





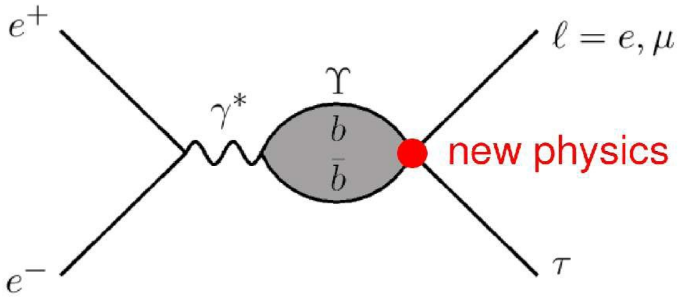




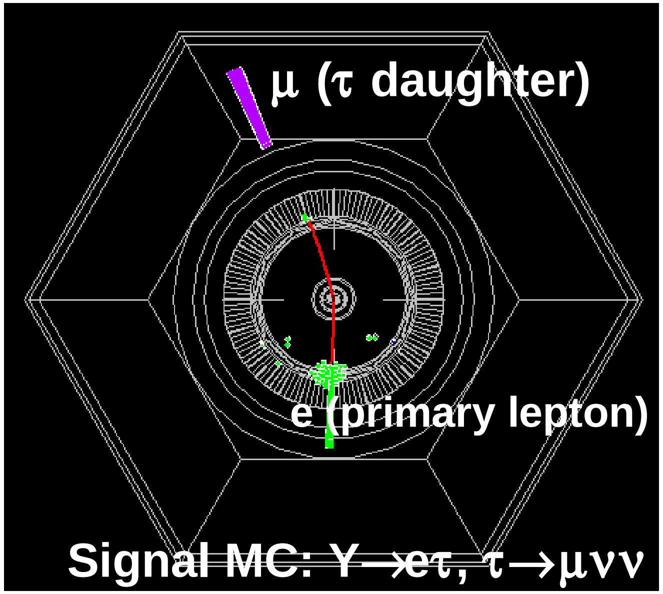
Υ(2S,3S)→lτ (l=e,μ)

PRL 104, 151802 2010

- Search for e+e– →Υ(2S,3S)→μτ/eτ
- Select τ decays to one charged track and additional π^0's (ρ,a_1)
- Lepton (e/μ) has nearly the full beam energy and the τ decays with missing energy in the other hemisphere
- Lepton identification:
  - misid: 10^{-1}(l→π) to 10^{-6} (μ→e)

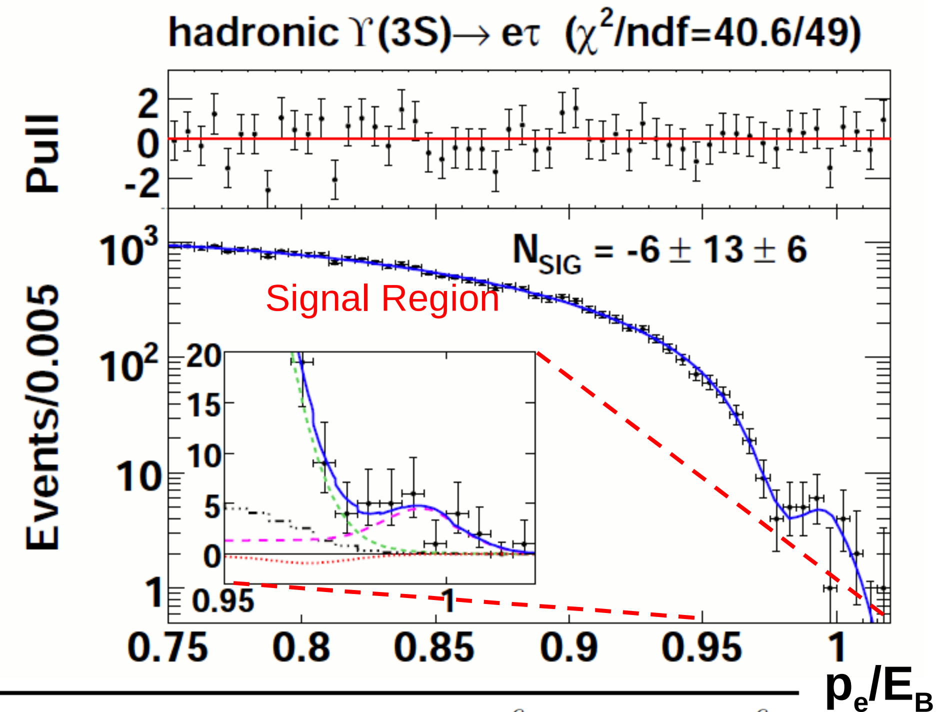


Process	τ Decay	Channel
Υ(3S)→eτ	τ→μνν	leptonic eτ
Υ(3S)→eτ	$\tau\to\pi^{\pm}\pi^0\nu/\pi^{\pm}\pi^0\pi^0\nu$	hadronic eτ
Υ(3S)→μτ	τ→eνν	leptonic μτ
Υ(3S)→μτ	$\tau\to\pi^{\pm}\pi^0\nu/\pi^{\pm}\pi^0\pi^0\nu$	hadronic μτ



$\Upsilon(2S,3S)\to l\tau$ ($l=e,\mu$)

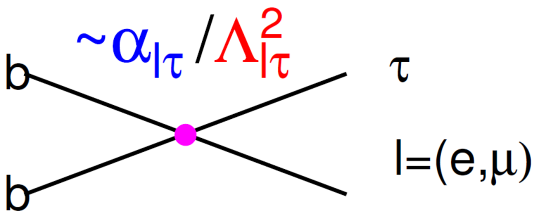
- Extract signal by fitting discriminating variable:
  - CM lepton momentum / beam energy
- Global PDF
  - **Signal**: Gaussian core + non Gaussian tails
  - **τpair bkg**: poly $\otimes$ Gaussian detector resolution function
  - **Bhabha/μ pair bkg**: Gaussian + threshold function (ARGUS)
  - **πhadron bkg**
- Perform Bayesian likelihood technique to extract 90% CL upper limits $O(10^{-6})$ on CLFV Y decay BFs
- Signal yields consistent with zero within 1.8σ



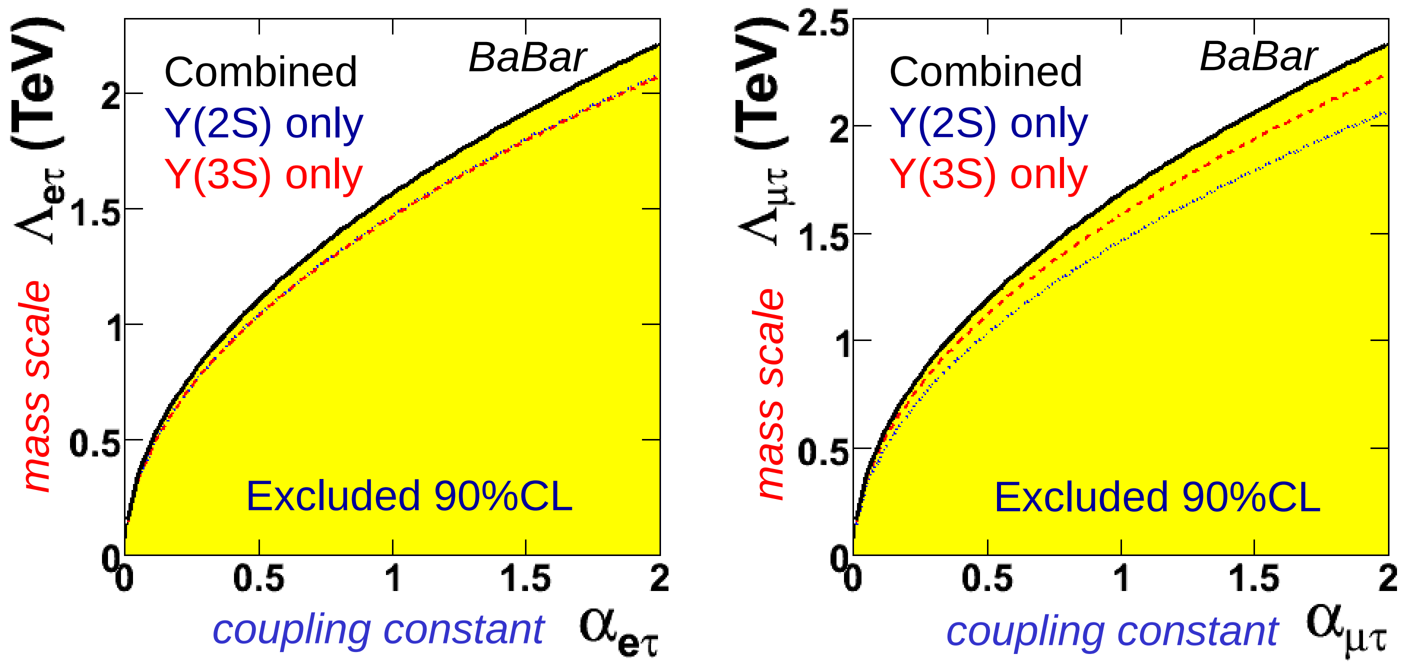
	$\mathcal{B}$ (10^{-6})	UL (10^{-6})	Improvement factor
$\mathcal{B}(\Upsilon(2S)\to e^\pm\tau^\mp)$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	<3.2	First!
$\mathcal{B}(\Upsilon(2S)\to \mu^\pm\tau^\mp)$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	<3.3	x3.7
$\mathcal{B}(\Upsilon(3S)\to e^\pm\tau^\mp)$	$1.8^{+1.7+0.8}_{-1.4-0.7}$	<4.2	First!
$\mathcal{B}(\Upsilon(3S)\to \mu^\pm\tau^\mp)$	$-0.8^{+1.5+1.4}_{-1.5-1.3}$	<3.1	x5.5

Y(2S,3S)→lτ(l=e,μ)

- CLFV Y decays: contact interaction with NP *coupling constant* and *mass scale*



$$\frac{\alpha^2_{l\tau}}{\Lambda^4_{l\tau}} = \frac{BF(\Upsilon(3S)\to l\tau)}{BF(\Upsilon(3S)\to ll)} \frac{2q_b\alpha^2}{(M_{\Upsilon(nS)})^4} \qquad l = (e,\mu)$$

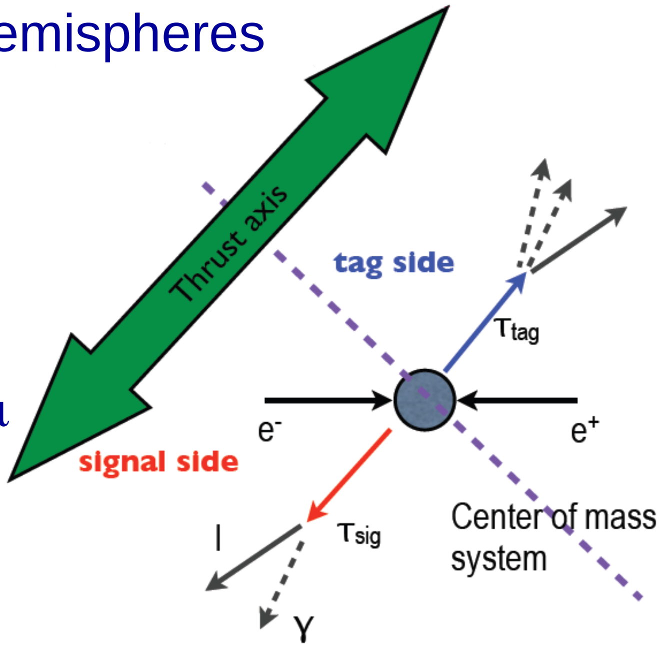


Silagadze Phys. Scripta 64.128 & Black et al. PRD 66.053002

$\tau \to (e/\mu)\gamma$

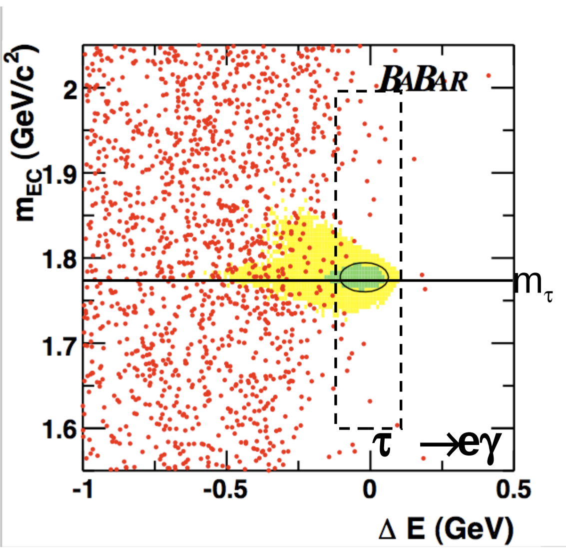
PRL104, 021802 (2010)

- Reconstructed $ee \to \tau\tau$ events divided in two hemispheres
- Signal side
  - $M(l^{\pm}\gamma) \sim M\tau$
  - $E(l^{\pm}\gamma)_{CM} \sim \sqrt{s}/2$
  - One γ with $E(\gamma)_{CM} > 1GeV$
  - One track with $p_{CM} < 0.77\sqrt{s}/2$ identified as e or μ
  - γ and l back-to-back in τ-rest frame

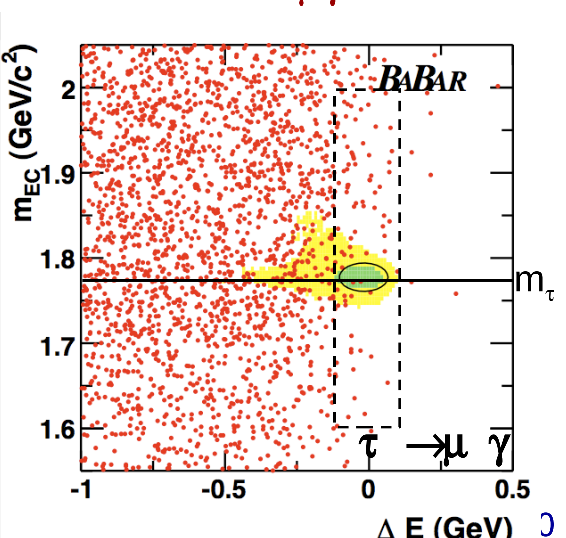


- Tag side
  - Standard 1-prong or 3-prong decay
  - 4 tags, different selections for each tag
  - Optimized for best UL
- Backgrounds
  - τ-pairs (irreducible), $e^+e^-\gamma/\mu^+\mu^-\gamma$ hadronic τ decays with π mis-id

$\tau \to (e/\mu)\gamma$



Signal efficiency: 4% for $\tau \to e\gamma$ and 6% for $\tau \to \mu\gamma$



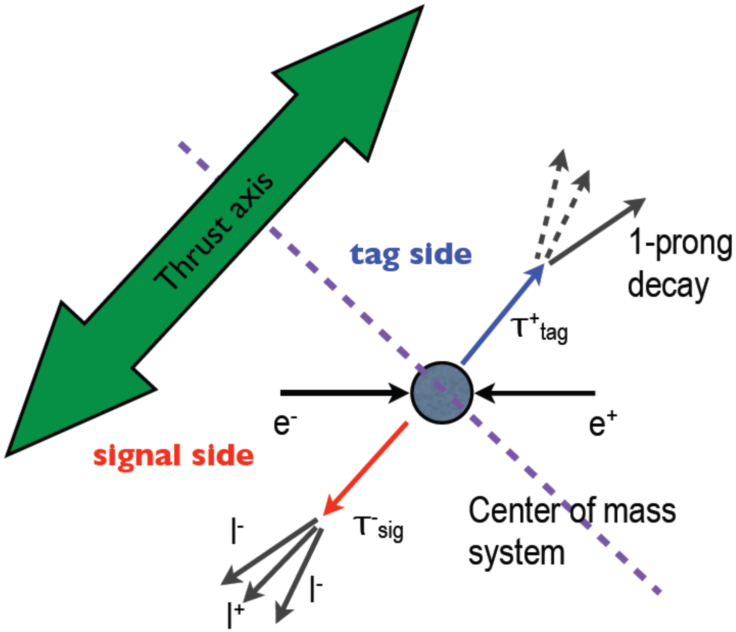
- Signal extraction
  - $\Delta E = E(l\gamma)_{CM} - \sqrt{s}/2$
  - m_{EC} beam energy constrained τ mass
- Expected background extracted from fits to the fit box
- Number of events in the 2sigma region compatible with background expectations
- Upper limits @90% CL
  - $BR(\tau \to e\gamma) < 3.3 \times 10^{-8}$
  - $BR(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$

Previous:
1.1×10^{-7} (BABAR, PRL96, 041801 (2006))
4.5×10^{-8} (Belle, PL B666, 16 (2008))

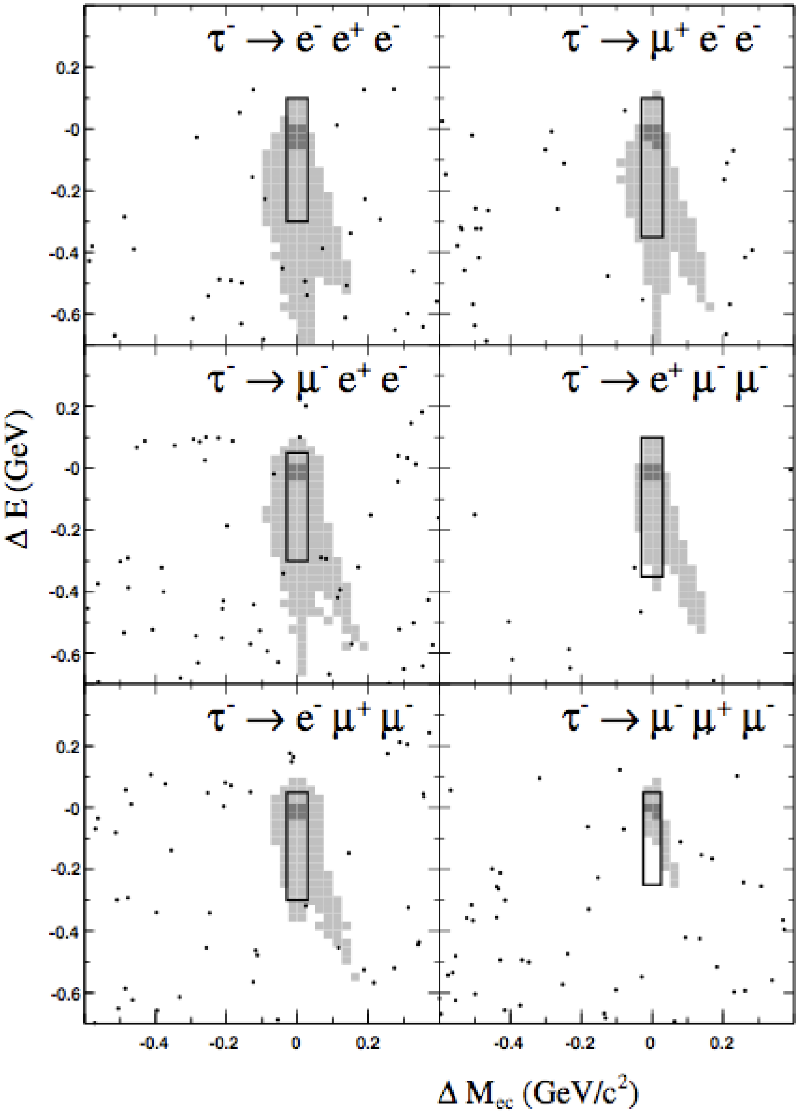
$\tau \rightarrow$ 3leptons

arXiv:1002.4550 (sub. PRD-RC)

- Search for six signal channels
  - $\tau^- \to e^- e^+ e^-$
  - $\tau^- \to \mu^- \mu^+ e^-$
  - $\tau^- \to \mu^- e^+ e^-$
  - $\tau^- \to \mu^- e^+ \mu^-$
  - $\tau^- \to e^- \mu^+ e^-$
  - $\tau^- \to \mu^- \mu^+ \mu^-$
- Require 4 charged tracks in the event
- Signal side
  - 3 charged particles identified
    e or μ with $M(3l) \sim M_\tau$ and $E(3l) \sim \sqrt{s}/2$
- Tag side
  - Look for 1-prong τ decays
- Use PID to reject
  - qqbar events
  - Bhabha and $\mu\mu$ pairs
  - Standard $\tau\tau$ decays
- Other selection criteria are channel dependent



$\tau \to 3$leptons



- Signal extraction
  - $\Delta E = E(3l)_{CM} - \sqrt{s}/2$
  - $\Delta M_{EC} = m_{EC} - m_\tau$
- Improved since last result
  - PRL95, 251803 (2007)
- Not too bad wrt Belle analysis using factor 1.7 more statistics
  - Phys.Lett.B687:139-143,2010

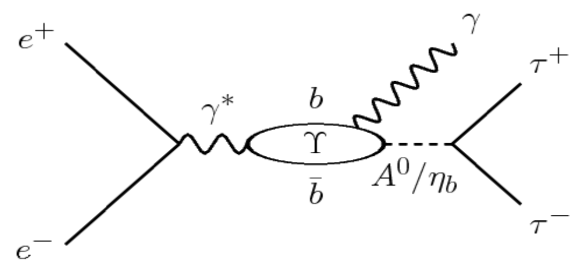
Channel	UL@90%CL (10^{-8})	
	BaBar	BELLE
e-e+e-	2,9	2,7
μ-e+e-	2,2	1,8
e-μ+e-	1,8	1,5
μ-μ+e-	3,2	2,7
μ-e+μ-	2,6	1,7
μ-μ+μ-	3,3	2,1
e-e+e-	2,9	2,7
μ-e+e-	2,2	1,8

Signal efficiency between 6-13% varying with the channel

Test of Lepton Universality

- In the SM couplings between gauge bosons and leptons are independent of lepton flavor
- SM expectation for $R_{ll'} = BR(\Upsilon(1S) \rightarrow l^+l^-)/BR(\Upsilon(1S) \rightarrow l'^+l'^-)$ is ~1
  - except for small lepton-mass effects, $R_{\tau\mu}$~0.992
- NMSSM: deviations of $R_{ll'}$ from SM expectation are possible in the hypothesis of existence of a light pseudo-scalar Higgs boson A^0
  - $\Upsilon(1S) \rightarrow \gamma A^0$, $A^0 \rightarrow l^+l^-$
  - $\Upsilon(1S) \rightarrow \eta_b(1S)\gamma$, $\eta_b \rightarrow \gamma A_0 \rightarrow l^+l^-$
- If the photon is undetected the leptons would be associated to the Y(1S)
  - Apparent LU violation, effect greater in τ channel (4%)
- If the photon is detected, then search for a peak in the E_γ distribution
- Previous result: $R_{\tau\mu}(\Upsilon(1S)) = 1.02 \pm 0.02(stat) \pm 0.05(syst)$
  - CLEO PRL 98,052002 2007

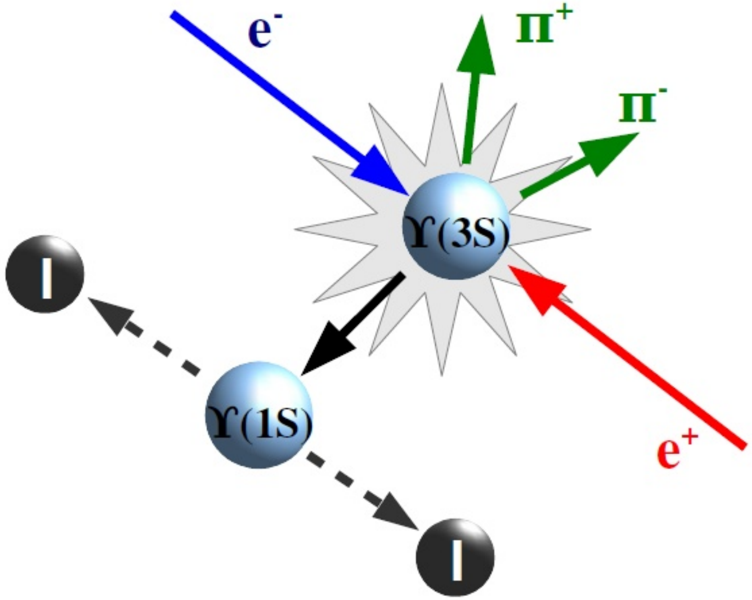
Int.J.Mod.Phys. A19, 2183 (2004);
PL B653, 67 (2007);
JHEP 0901, 061 (2009)



Υ(1S)→ll

Phys.Rev.Lett.104:191801,2010

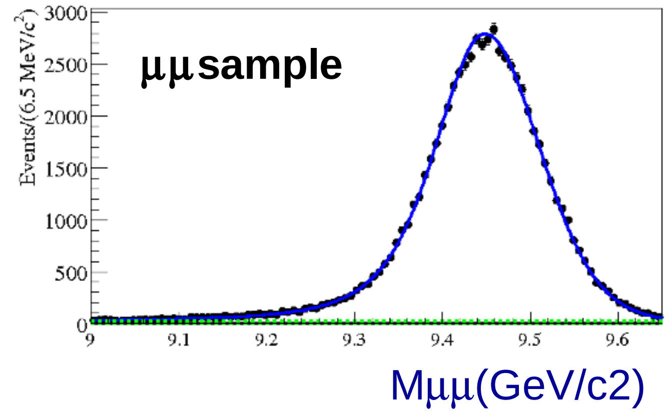
- Υ(1S) from the Υ(3S)→$\pi^+\pi^-$Υ(1S) transition
  - BF(Υ(3S)→Υ(1S)$\pi^+\pi^-$) ~ 5%
- Search for Υ(1S)→μμ and Υ(1S)→ττ
  - select 1-prong tau decays
  - 4-charged tracks + photons in final state
  - Separate selections for μμ and ττ
- Backgrounds: qqbar, QED, Υ(1S) generic decays

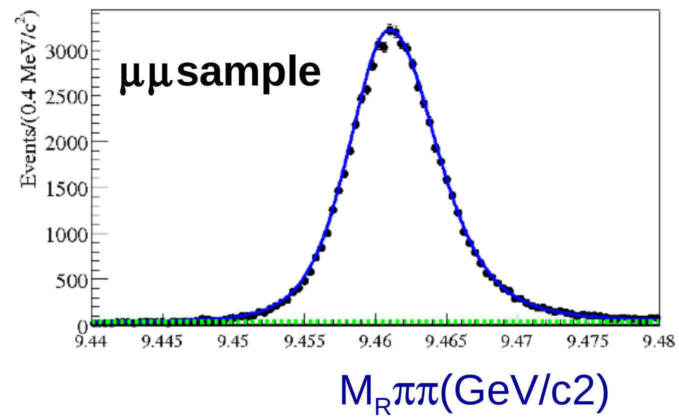


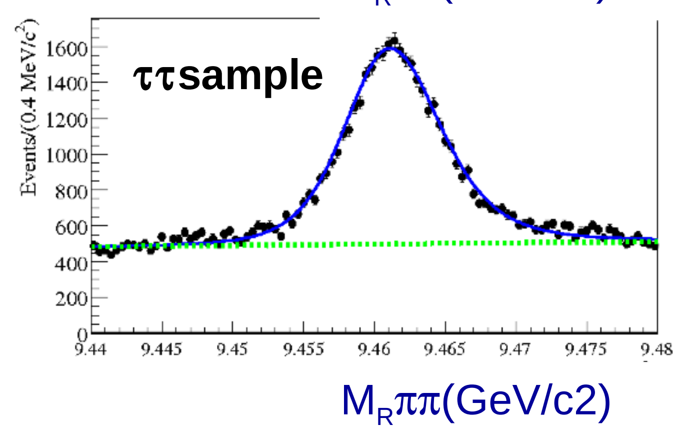
Signal efficiency: $e_{\mu\mu}$=45%, $e_{\tau\tau}$=17% (from MC)

Υ(1S)→ll

- Unbinned extended ML fit
  - $M(\mu\mu)$ = dimuon invariant mass
  - $M_R(\pi\pi)$ = mass recoiling against dipion system = $\sqrt{s + M^2_{\pi^+\pi^-} - 2\cdot\sqrt{s}\cdot\sqrt{M^2_{\pi^+\pi^-} + p^{*2}_{\pi^+\pi^-}}}$
- μμ channel
  - 2D likelihood fit to $M(\mu\mu)$ and $M_R(\pi\pi)$
- ττ channel
  - 1D likelihood fit to $M_R(\pi\pi)$
- Perform simultaneous fit to 2 samples to extract $R_{\tau\mu}$
  - PDFs chosen from a data sub-sample (~1/10 of the total), then discarded







$R_{\tau\mu}(\Upsilon(1S)) = 1.005 \pm 0.013(stat) \pm 0.022(syst)$

$\Upsilon(1S) \to ll$

- No deviation from SM ($R_{\tau\mu}$=0.992) observed

$R_{\tau\mu}(\Upsilon(1S)) = 1.005 \pm 0.013(stat) \pm 0.022(syst)$

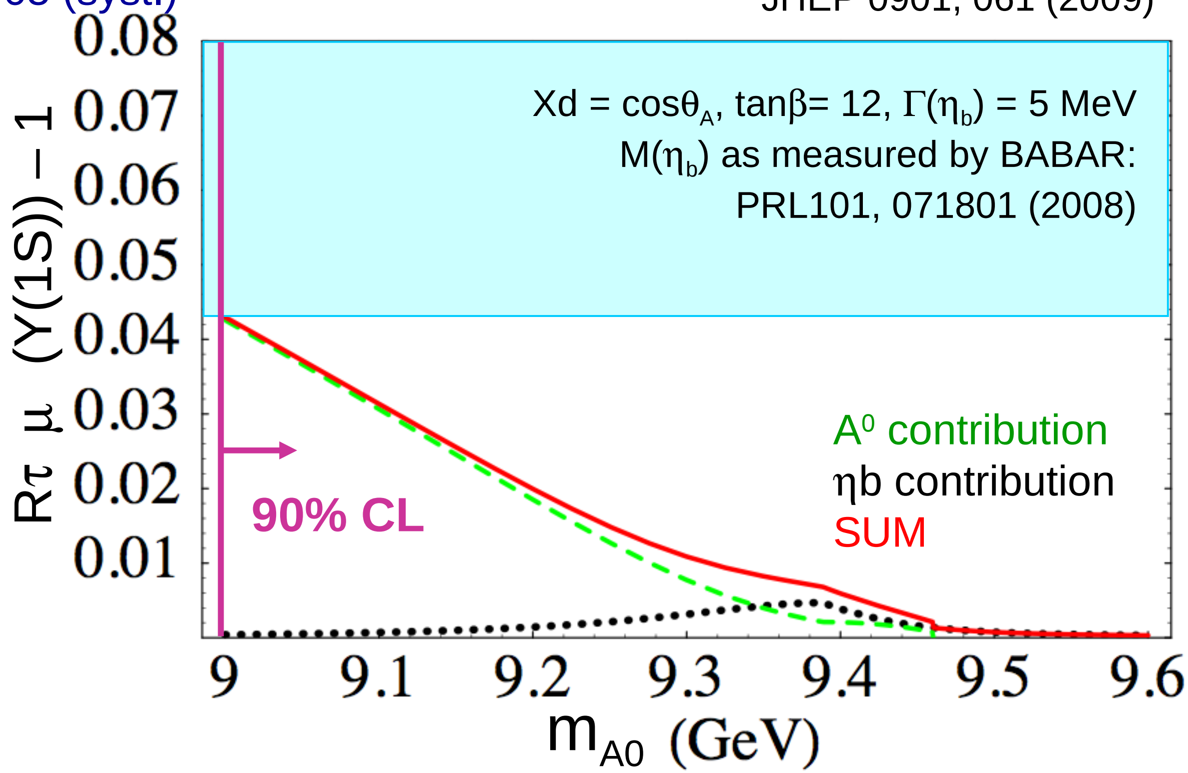
Previous best result by CLEO:

$R_{\tau\mu}(\Upsilon(1S))$: 1.02 ± 0.02 (stat.) ± 0.05 (syst.)

PRL98, 052002 (2007)

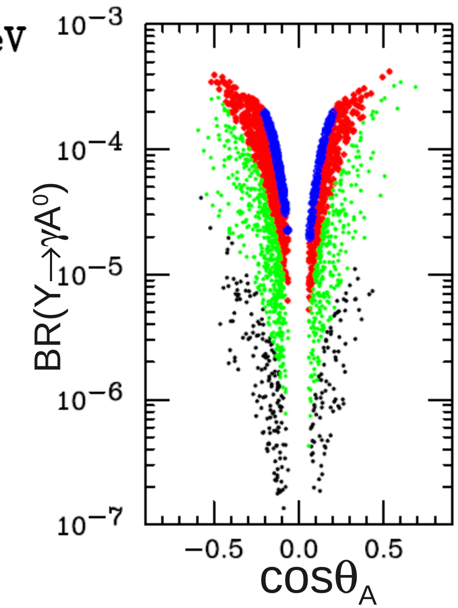
- Excluded $m(A^0)<9$ GeV/c^2 @90%C.L.

JHEP 0901, 061 (2009)



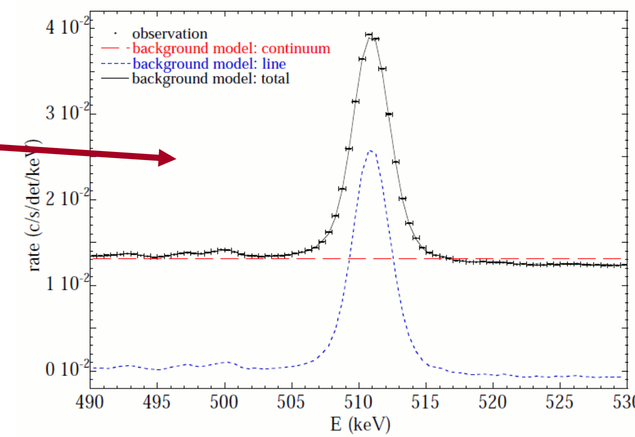
Light Higgs and Dark Matter

- Light CP-odd Higgs bosons arise in many beyond SM scenarios
- NMSSM solution
  - Next-to MSSM adds a Higgs singlet field to the MSSM Higgs doublet and from the mixing arises a CP-odd Higgs field
    - $A^0 = \cos\theta_A \, A_{MSSM} + \sin\theta_A \, A_{Singlet}$
  - For $m_{A0} < 2m_B$ the lightest CP-even Higgs (h_0) can evade LEP bounds by $h^0 \rightarrow A^0A^0$



PRL 95:041801 (2005)
PRD 76:051105 (2007)

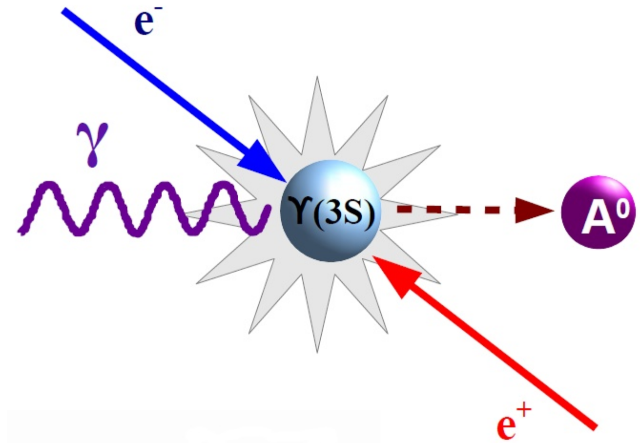
- Dark Matter may consist of several components
  - Low mass component not ruled out
  - Existing direct detection experiments insensitive
- INTEGRAL anomaly: observe excess of 511 keV photons from galactic center positrons annihilating at rest
  - Positrons may be produced by low mass DM annihilation (PRL 92, 101301 2004)
- May be observed in Υ decays with BF(Υ(1S)→χχ) up to (4-18)x10[-6] (arXiv:0712.0016v2 [hep-ph])



INTEGRAL: Nature 458 (2009) 607
FERMI: PRL 102 (2009) 181101

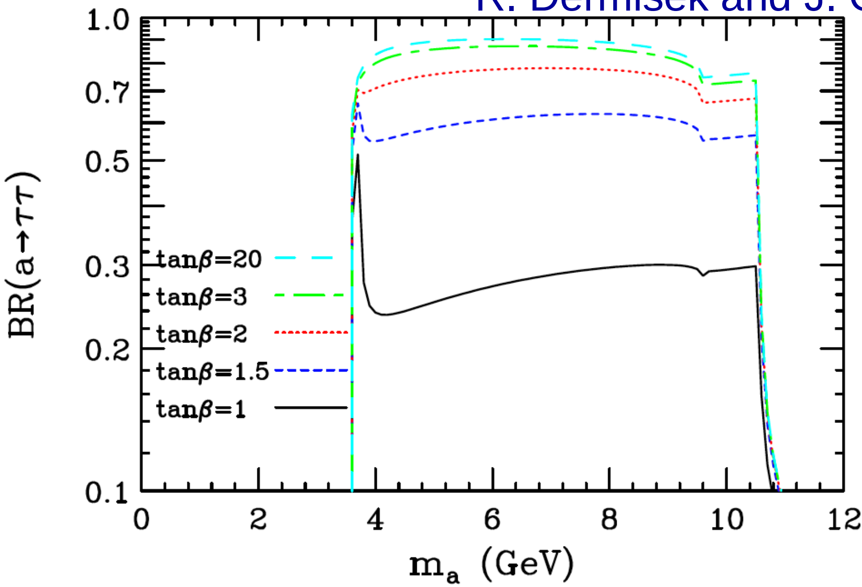
A^0 Production

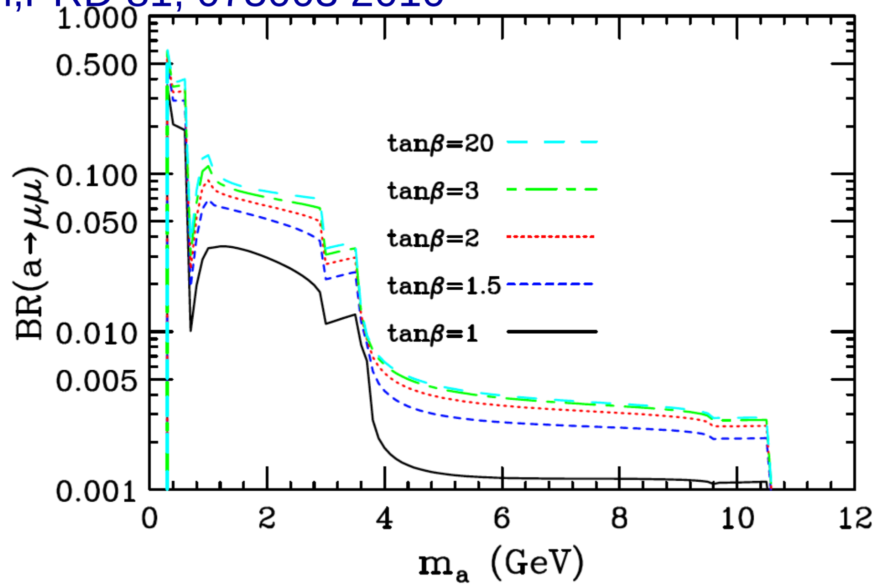
- A^0 can be produced in 2-body radiative decays of narrow Y states
  - $\Upsilon(2S,3S) \to \gamma A^0$
    - $A^0 \to \tau^+\tau^-$ dominant in $m_{A0} > 2m_\tau$
    - $A^0 \to \mu^+\mu^-$ dominant in $m_{A0} < 2m_\tau$
    - $A^0 \to$ invisible ($\to \chi\chi$ pairs)



$$E^*_\gamma = \frac{m^2_\Upsilon - m^2_{A^0}}{2m_\Upsilon}$$

R. Dermisek and J. Gunion, PRD 81, 075003 2010

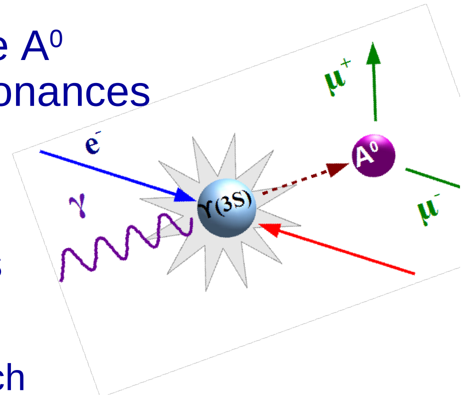


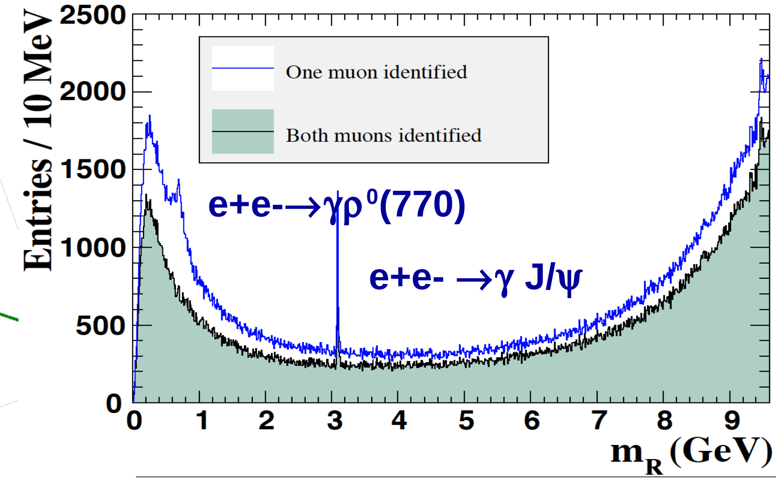


Υ(2S,3S)→γA⁰, A⁰→μ⁺μ⁻

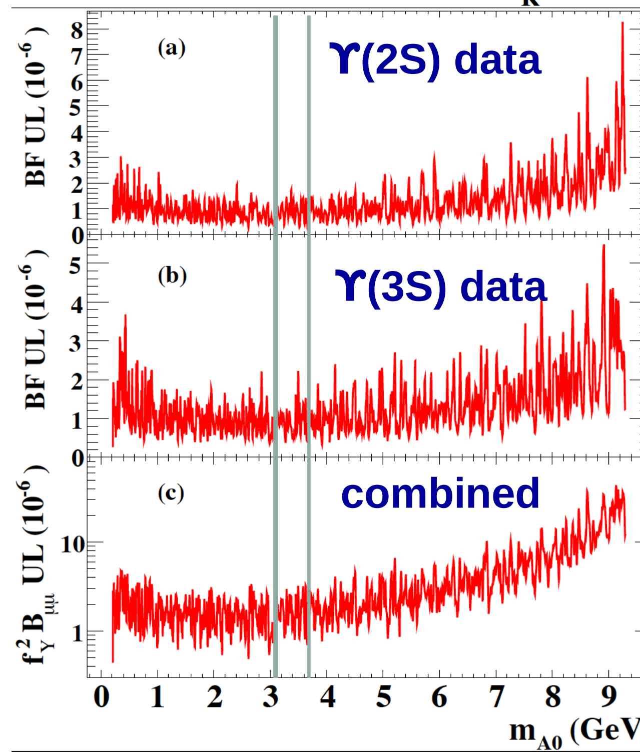
PRL 103, 081803 (2009)

- Fully reconstruct final state with two back-to-back charged tracks (identified as muon) and one photon in the CM frame
- Scan $\mu^+\mu^-$ invariant mass for the A^0 peak accounting for known resonances
  - ρ, ω, J/ψ, ψ(2S), Υ(1S)
- Extended unbinned ML fit in 1951 intervals of reduced mass $m_R=\sqrt{(m_{A0}^2+4m_\mu^2)}$
  - J/ψ and ψ(2S)excluded from search





- Upper limits @ 90% CL
  - $BF(\Upsilon(2S)\to\gamma A^0) \times BF(A^0\to\mu^+\mu^-) < (0.26 – 8.3) \times 10^{-6}$
  - $BF(\Upsilon(3S)\to\gamma A^0) \times BF(A^0\to\mu^+\mu^-) < (0.27 – 5.5) \times 10^{-6}$
  - $BF(\eta_b\to\mu^+\mu^-) < 0.9\%$
- No signal observed at m_{A0} ~ 214 MeV (HyperCP)
  - HyperCP, PRL94,021801(2005)



$$\frac{\mathcal{B}(\Upsilon(nS)\to\gamma A^0)}{\mathcal{B}(\Upsilon(nS)\to l^+l^-)} = \frac{f_\Upsilon^2}{2\pi\alpha}\left(1-\frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)$$

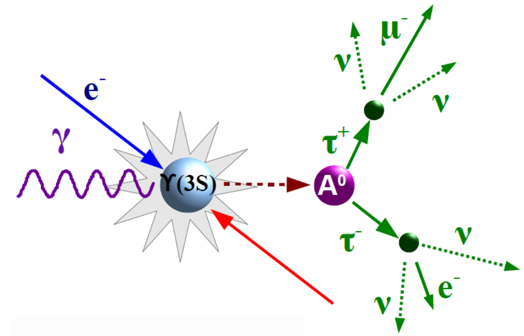
Effective Yukawa coupling of A0 to boundstate b quark

$\Upsilon(3S)\to\gamma A^0$, $A^0\to\tau^+\tau^-$

PRL 103, 181801 (2009)

- Look for both $\tau\to\mu\nu\nu$ and $\tau\to e\nu\nu$
  - Final states: $\gamma\mu\mu$, $\gamma e\mu$, γee
  - A^0 mass obtained from $E\gamma$ and known CM energy
  - Background from τ-pair and 2 photons processes plus peaking background $\Upsilon(1S)$ from $\Upsilon(2,3S)$ decays: $\Upsilon(3S)\to\gamma\chi_{bJ}(2P)$, $\chi_{bJ}(2P)\to\gamma\Upsilon(nS)$ (n=1,2; J=0,1,2)

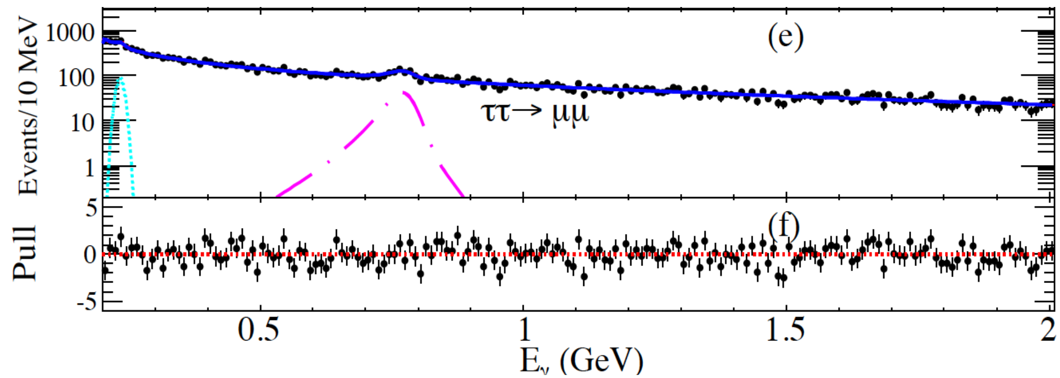
$$E^*_\gamma = \frac{m^2_\Upsilon - m^2_{A^0}}{2m_\Upsilon}$$



Signal efficiency: ~ 10-14% (ee), 22-26% (eμ), 12-20% (μμ) (as function of Eγ)

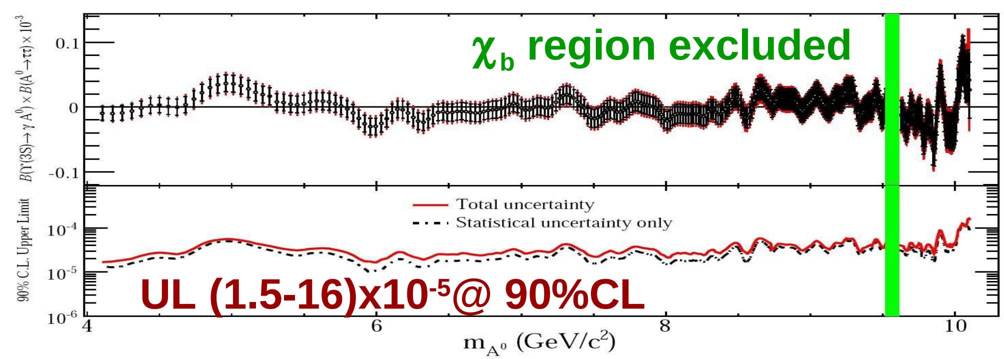
Scans for peaks in Eγ spectrum in the range 4.03GeV < m_{A0} < 10.10 GeV (307 points)

- signal is a peaking contribution of known width varying with Eγ
- simultaneous binned ML fit to eeγ, μμγ, and eμγ final states



Upper Limit

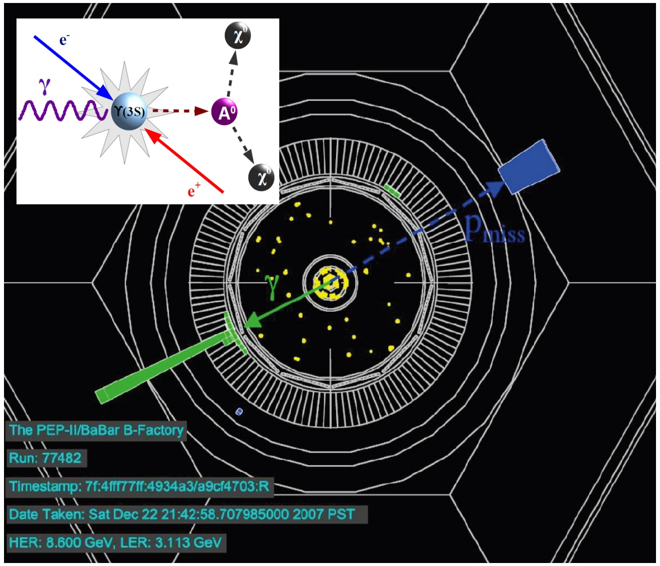
- $B(\Upsilon(3S)\to\gamma A^0)\times B(A^0\to\tau^+\tau^-)$ < (1.5 – 16) x 10^{-5} at 90% C.L.
- $BF(\eta_b\to\tau^+\tau^-)$ < 8%



$\Upsilon(3S)\to\gamma A^0$, $A^0\to$invisible

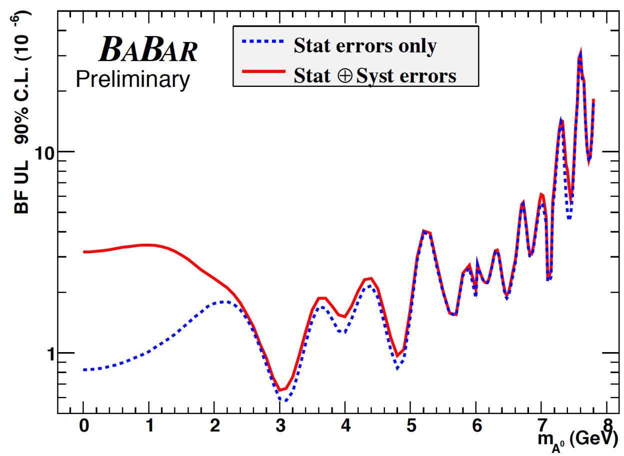
arXiv:0808.0017

- $A^0 \to\chi^0\chi^0$ can be dominant in some NMSSM scenarios with light neutralino LSP
- Single photon with E_γ>2.2GeV, no charged tracks
- Optimization in 2 regions
  - Low E^*_γ : $2.2 < E^*_\gamma < 3.7$ GeV
  - High E^*_γ : $3.2 < E^*_\gamma < 5.5$ GeV
  - Different QED backgrounds in the two regions: $e^+e^- \to\gamma\gamma$ and $e^+e^- \to(e^+e^-)\gamma\gamma$

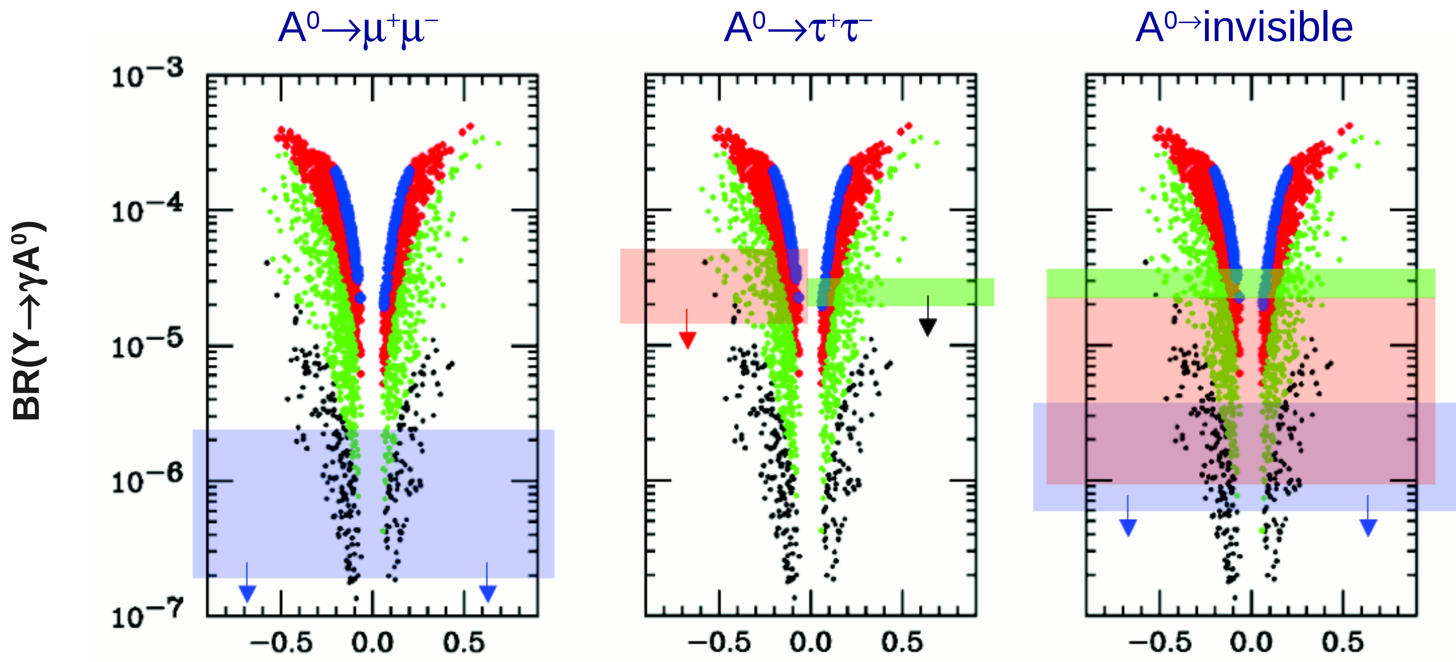


Signal efficiency: ~10% (E*γ> 3 GeV), ~20% (E*γ< 3 GeV)

- Unbinned ML fits to m_X^2 distribution in steps of 0.1GeV where $m_X2 \equiv m_{\Upsilon(3S)}^2 - 2E^*\gamma\, m_{\Upsilon(3S)}$
  - Low E*γ: $0<m_{A0}<6$GeV
  - High E*γ: $6<m_{A0}<7.8$ GeV
- Upper limit
  - $B(\Upsilon(3S)\to\gamma A^0)\times B(A^0\to$ invisible) < $(0.7\text{-}31)\times 10^{-6}$ at 90% C.L. for $m_{A0}\leq 7.8$ GeV



NMSSM and BaBar Limits



$m_{A0} < 2m\tau$

$2m\tau < m_{A0} < 7.5$ GeV

$7.5 < m_{A0} < 8.8$ GeV

$2m\tau < m_{A0} < 7.5$ GeV

$7.5 < m_{A0} < 8.8$ GeV

$m_{A0} < 2m\tau$

$\tan\beta=10$, $\mu=150$ GeV,
$M_{1,2,3}=100,200,300$GeV

$m_{A0} < 2m\tau$

$2m\tau < m_{A0} < 7.5$ GeV

7.5 GeV $< m_{A0} < 8.8$ GeV

8.8 GeV $< m_{A0} < 9.2$ GeV

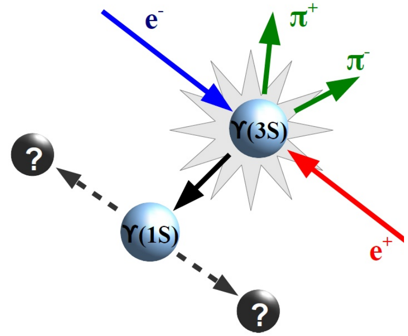
A^0 non-singlet fraction($\cos\theta_A$)

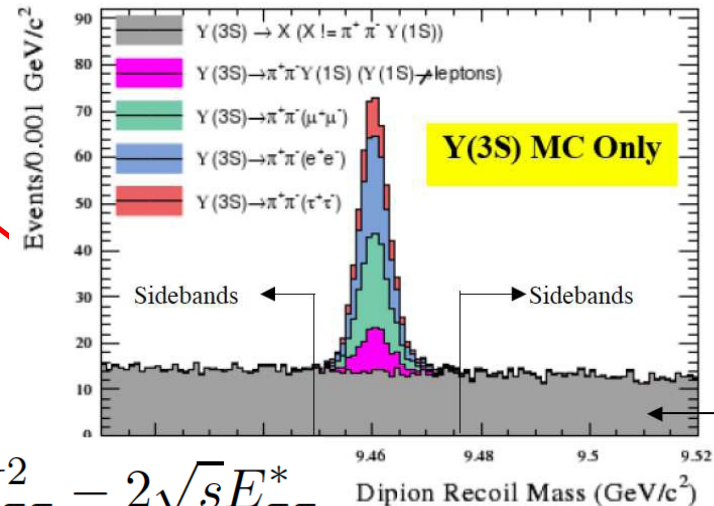
$A^0 = \cos\theta_A\, A_{MSSM} + \sin\theta_A\, A_{Singlet}$

Υ(1S)→invisible

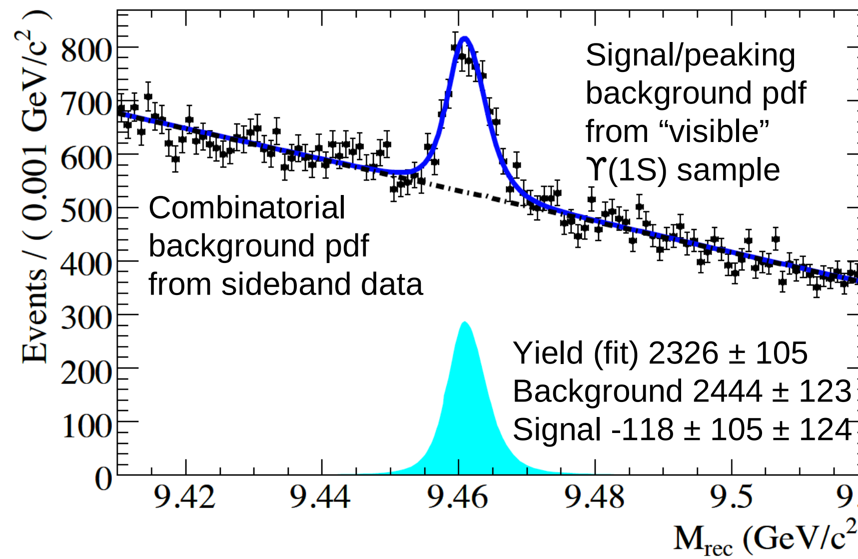
PRL 103, 251801 (2009)

- B(Υ(1S)→νν)~1 x 10^{-5} in SM
  - can be enhanced to ~10^{-4}–10^{-3} by decays into pairs of low mass weakly interacting Dark Matter candidates
- Υ(1S) from the Υ(3S)→$\pi^+\pi^-$ Υ(1S) transition
- Dipion recoil mass M_{rec} peaking at Υ(1S) mass
- No other significant additional activity in detector
- Unbinned ML fit to M_{rec}
- Observed yield consistent with expected peaking background





$$M^2_{rec} = s + M^2_{\pi\pi} - 2\sqrt{s}E^*_{\pi\pi}$$



Previous measurements BF(Υ(1S) → invisible)

CLEO: BF < 3.9 x 10^{-3} @ 90% CL PRD 75 (2007) 031104

Belle: BF < 2.5 x 10^{-3} @ 90% CL PRL 98 (2007) 132001

B(Υ(1S)→ invisible) = (-1.6 ± 1.4(stat) ± 1.6(syst)) x 10^{-4} < 3.0 x 10^{-4} at 90% C.L.

Conclusions

- Υ(2S) and Υ(3S) can provide direct constraint on NP
- Constraints on LFV can probe NP at TeV scale
  - BR UL $O(10^{-6})$
  - improved plus new limits
- Test of LU
  - >2x improvement provides stringent test of SM and helps to constraint A^0 mass
- Light Higgs
  - Probe of NMSSM
- Light Dark Matter
  - 10x improvement on $A^0 \rightarrow$ invisible
- More to come...

References

Searches for Charged Lepton Flavor Violation

- $\Upsilon(2S,3S)\to l\tau$ ($l=e,\mu$) (2010) **Phys.Rev.Lett. 104, 151802 2010**
- $\tau\to l\gamma$ (2010) **Phys.Rev.Lett. 104,021802(2010)**
- $\tau\to 3l$ ($l=e,\mu$) (2010) **arXiv: 1002.4550, Sub: PRD**

Searches for Lepton Universality Test

- $\Upsilon(1S)\to\gamma A^0$, $A^0\to l^+l^-$ (2010)
- $\Upsilon(1S)\to\eta_b(1S)\gamma$, $\eta_b\to\gamma A^0\to l^+l^-$ (2010)

Phys.Rev.Lett.104:191801,2010

Searches for Higgs and Dark Matter

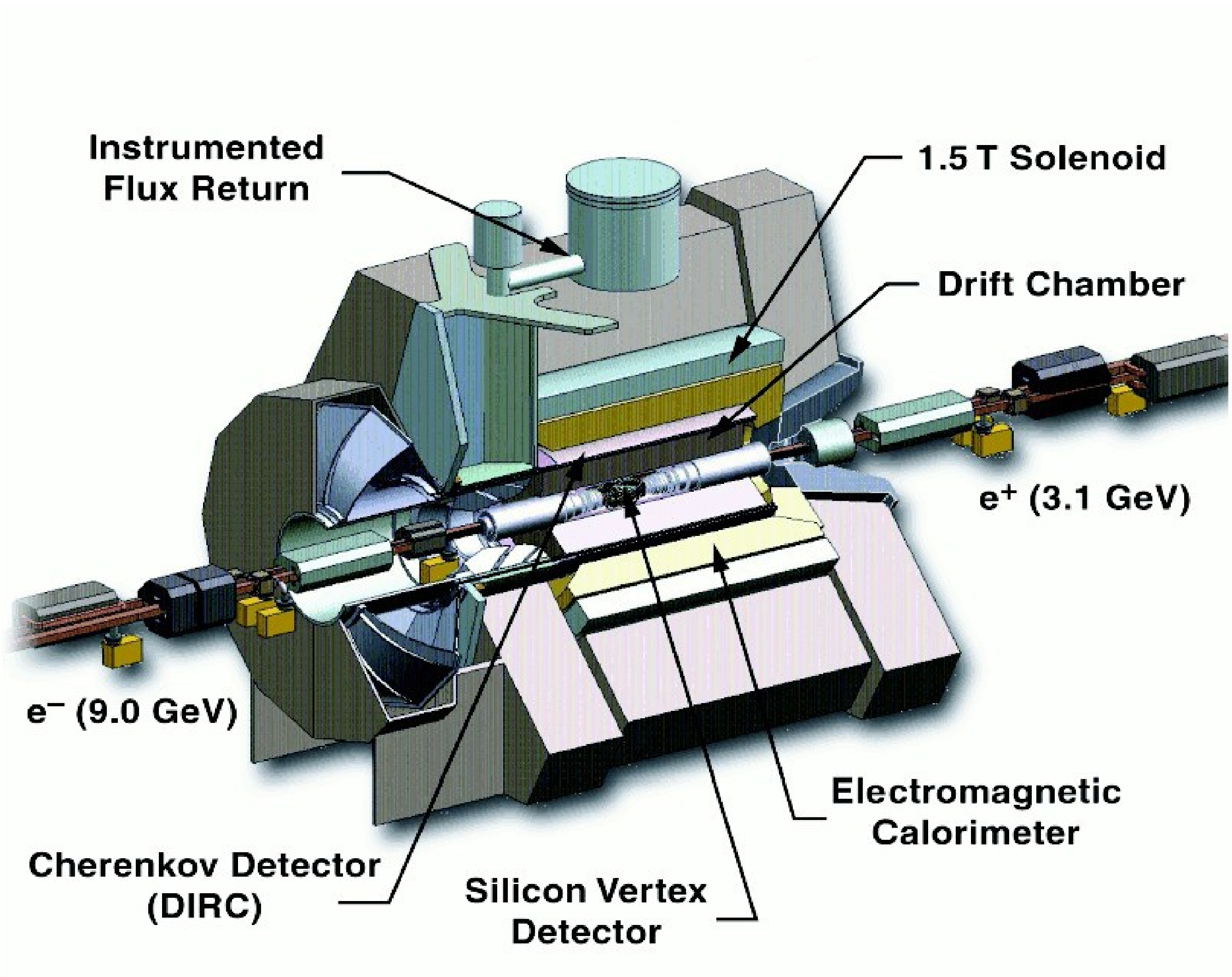
- $\Upsilon(2S,3S)\to\gamma A^0$, $A^0\to\mu^+\mu^-$ (2009) **Phys.Rev.Lett. 103, 081803 (2009)**
- $\Upsilon(3S)\to\gamma A^0$, $A^0\to\tau^+\tau^-$ (2009) **Phys.Rev.Lett. 103, 181801 (2009)**
- $\Upsilon(3S)\to\gamma A^0$, $A^0\to$invisible (2008) **arXiv:0808.0017**
- $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S)\to$invisible (2009) **Phys.Rev.Lett. 103, 251801 (2009)**

Other searches for New Physics

- $B\to K^*\nu\nu$ (2008) **Phys.Rev.D78, 072007,2008**
- $B\to K^*ll$ (2009) **Phys.Rev.Lett.102:091803,2009** **Phys.Rev.D79:031102,2009**
- $B\to\tau\nu$ (soon)

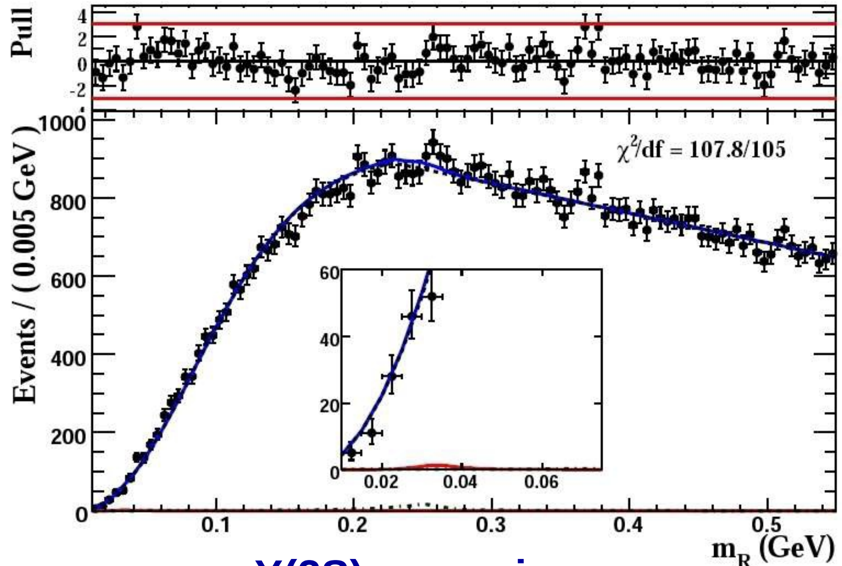
Backup

BaBar Detector

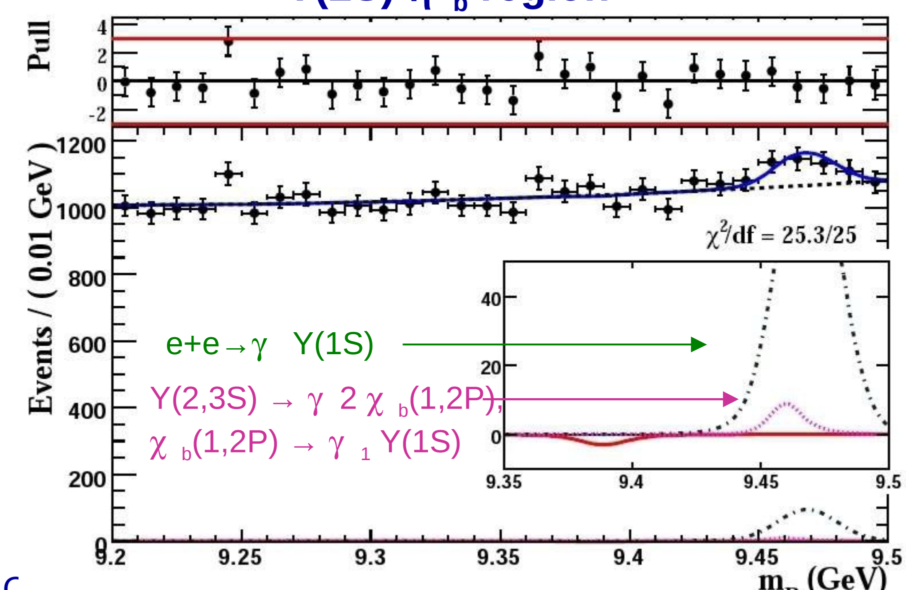


$\Upsilon(2S,3S)\to\gamma\ A^0,\ A^0\to\mu^+\mu^-$

Υ(3S) HyperCP region

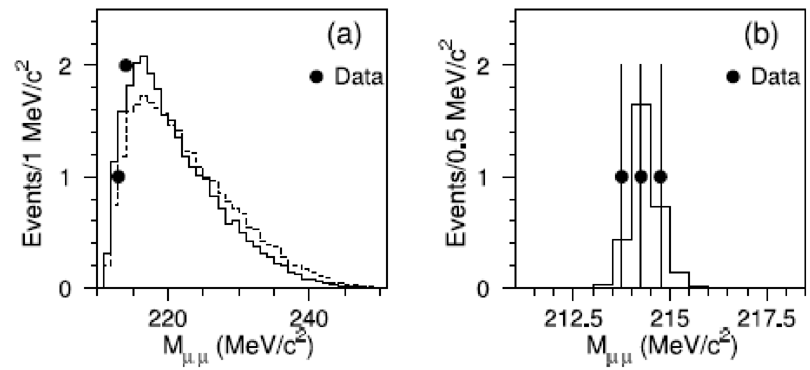


Υ(2S) η_b region



Form factor decay (solid)
Uniform phase space decay (dashed)

Resonant decay



HyperCP PRL 94, 021801 2005

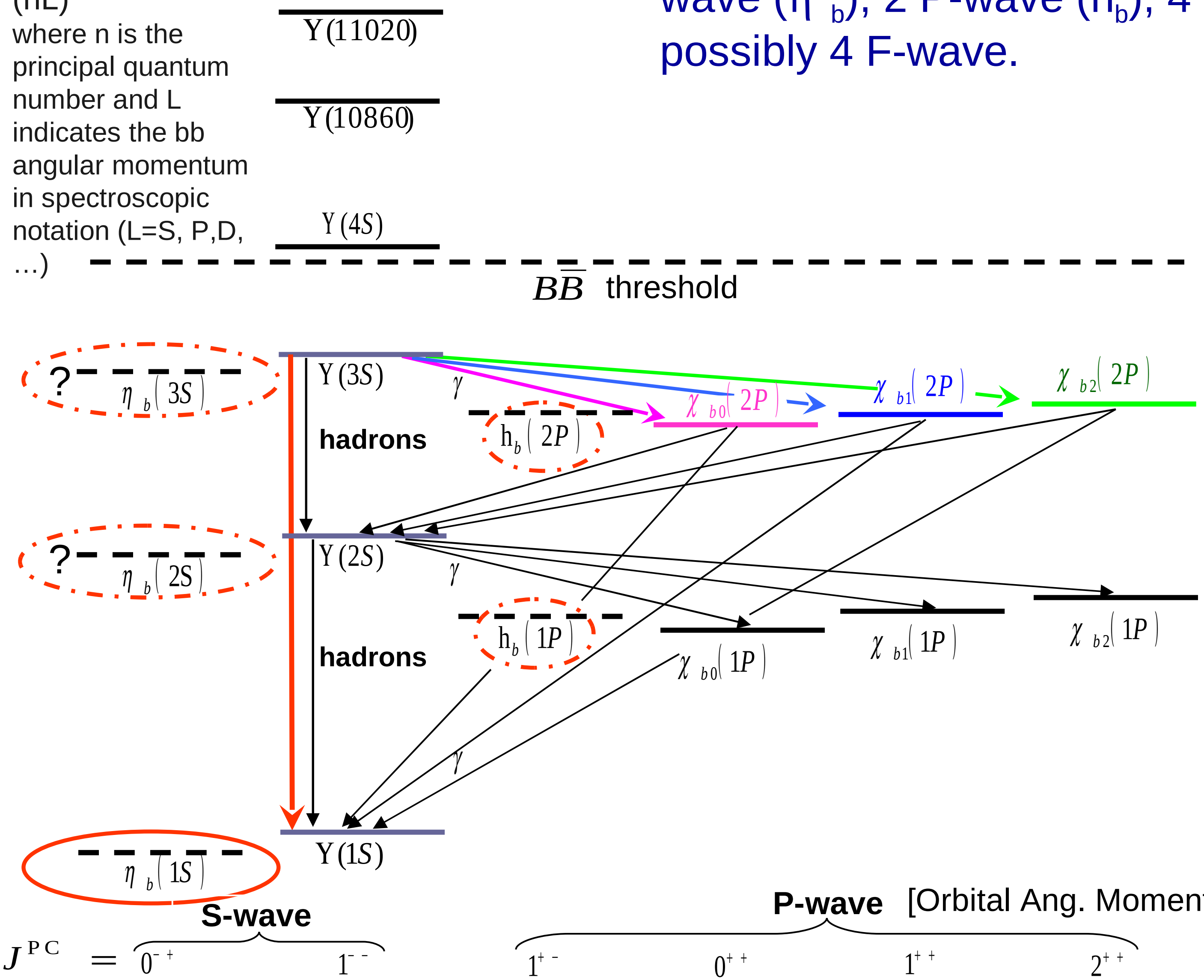
HyperCP experiment observed a resonance structure in $\Sigma\to p\mu\mu$ scattering. Light scalar decay to $\mu\mu$?

η_b recently discovered by BaBar (PRL 101, 071801 2008): check at $M\eta_b$=9.38GeV but $\eta_b\to\mu\mu$ not sizable

Bottomonium Spectrum

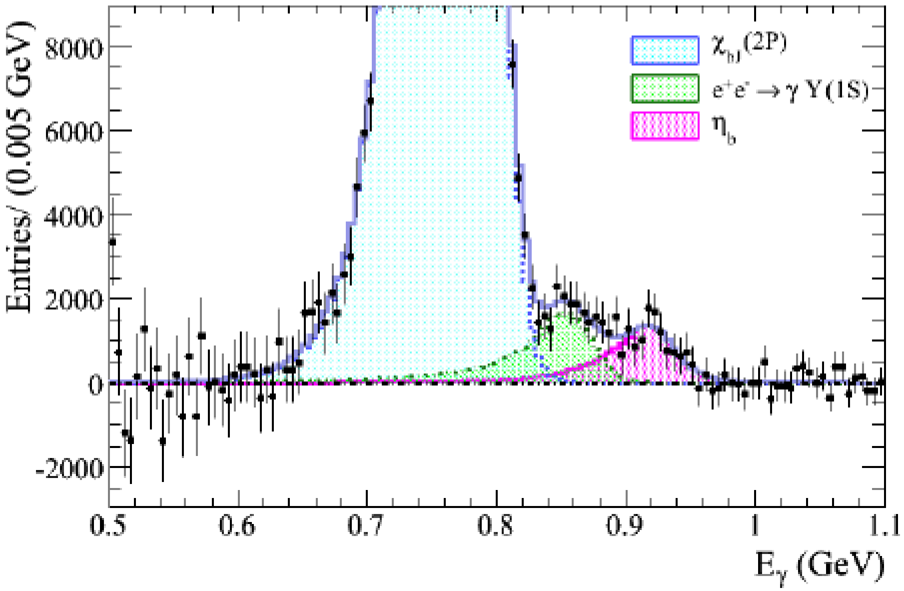
- bb states below Υ(3S) not yet discovered: 3 S-wave (η_b), 2 P-wave (h_b), 4 D-wave and possibly 4 F-wave.

(nL)
where n is the principal quantum number and L indicates the bb angular momentum in spectroscopic notation (L=S, P,D, ...)



η_b Observation

BaBar, PRL 101, 071801 (2008)



Fitted signal yield:

19200 ± 2000 (stat.) ± 2100 (syst.)

Branching Fraction:

$(4.8 \pm 0.5 \pm 1.2) \times 10^{-4}$

Fitted Mean: $E_\gamma = 921.2^{+2.1}_{-2.8} \pm 2.4\,\text{MeV}$

Mass: $9388.9^{+3.1}_{-2.3} \pm 2.7\,\text{MeV}/c^2$

Hyperfine Splitting: $71.4^{+2.3}_{-3.1} \pm 2.7\,\text{MeV}/c^2$