Searches for Lepton-Flavor Violating, and for Invisible, Upsilon Decays at BaBar

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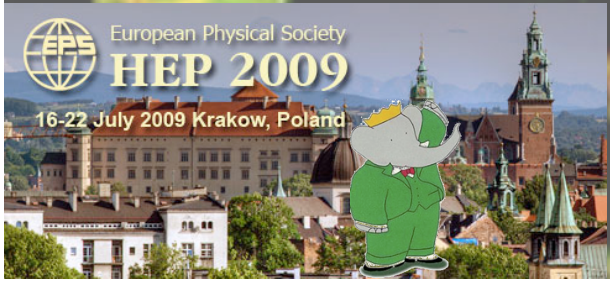
Representing the BaBar Collaboration

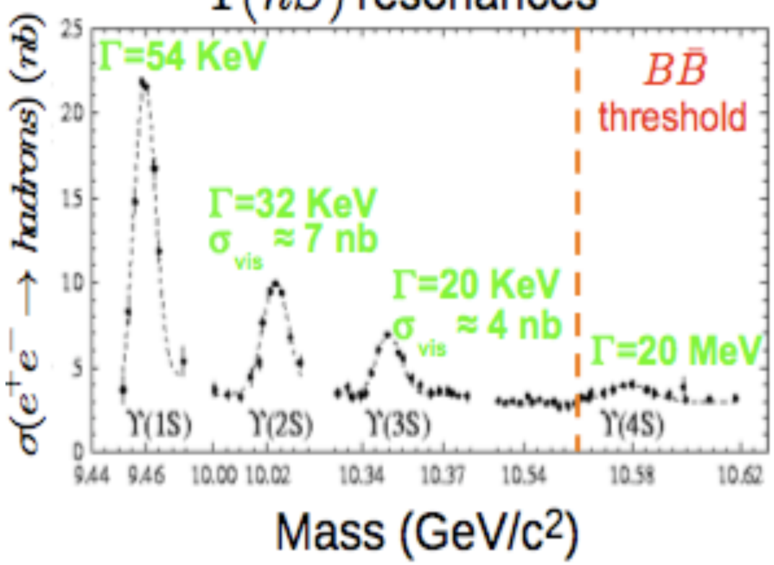
July 18, 2009



The BABAR Run 7 Dataset

PEP II - asymmetric energy $e^+ e^-$ collider operating at the Υ resonances

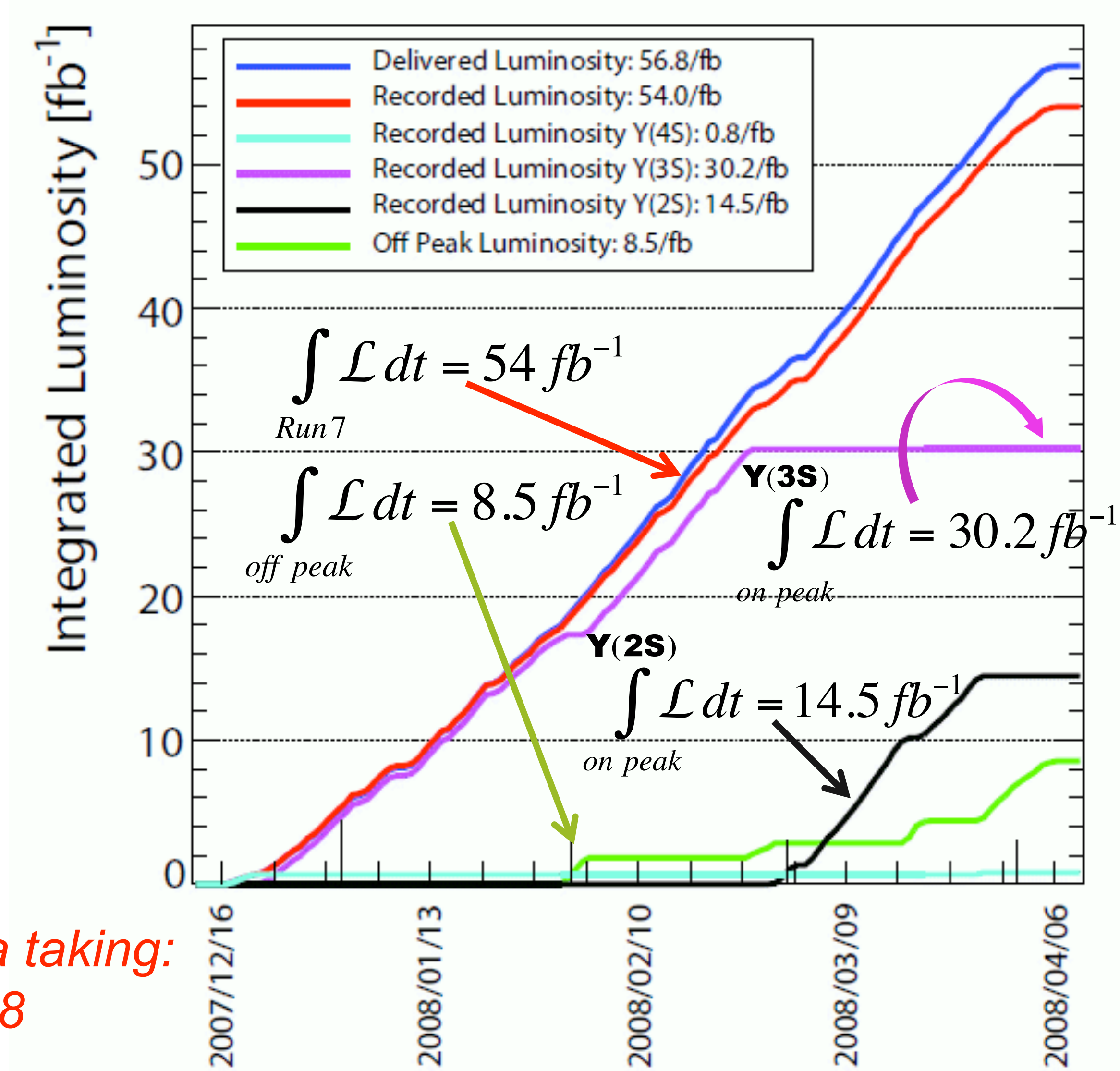
$\Upsilon(nS)$ resonances



➤ Bottomonium datasets

Υ	$1S$	$2S$	$3S$
BABAR		100 M	120 M
CLEO	20 M	9 M	6 M
BELLE	100 M	50 M	11 M

➤ BABAR recorded Luminosity in Run 7

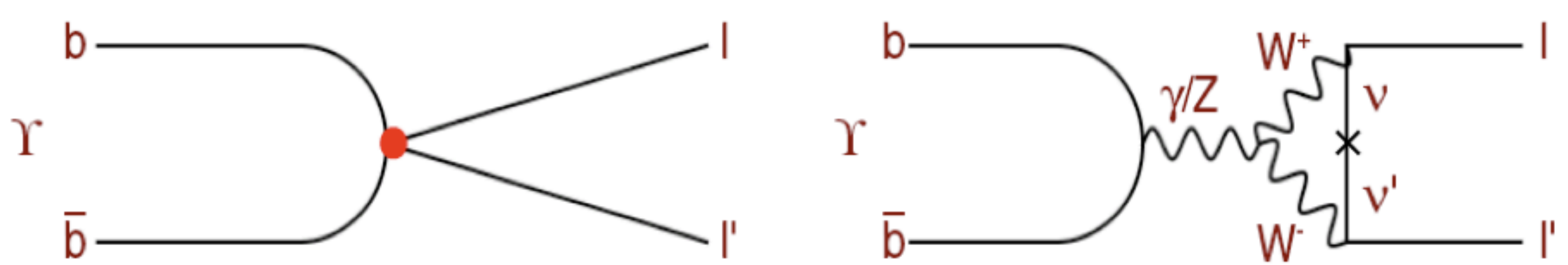


End of data taking: Apr. 7, 2008

Lepton Flavor Violation

- Lepton flavor violation (LFV)
  - not forbidden by SM gauge symmetry
  - most new models naturally include LFV vertex
- In SM, LF is conserved for zero degenerate ν masses
- Now we have clear indication that ν's have finite mass
  $\Rightarrow$ Lepton Flavor is violated in Nature: but by how much?
- SM extended to include finite ν mass and mixing predicts CLFV

Minimal Standard Model ($m_\nu = 0$) — Standard Model ($m_\nu \neq 0$)

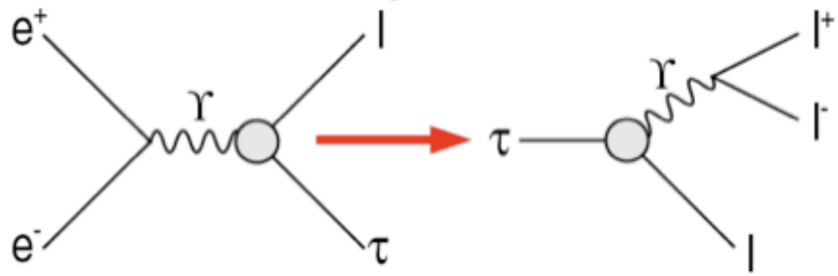


forbidden — $BF \sim ((\Delta m_\nu^2)/M_W^2)^2 < 10^{-48} \rightarrow$ unobservable

What rates might we observe?

- $\Upsilon \to l\tau$ related to $\tau \to lll$ via re-ordering of input/output lines

S.Nussinov, R.D.Pecci, X.M.Zhang
PRD 63, 016003 (2001)



$$BR(\Upsilon \to l\tau) \leq BR(\tau \to lll) \frac{\Gamma(W \to l\nu)^2}{\Gamma(\Upsilon)\Gamma(\Upsilon \to l^+ l^-)} (M_\Upsilon / M_W)^6$$

- $BR(\tau \to lll) < 2\text{-}4 \times 10^{-8}$ → **$BF(\Upsilon(3S) \to l\tau) < 3\text{-}6 \times 10^{-3}$**

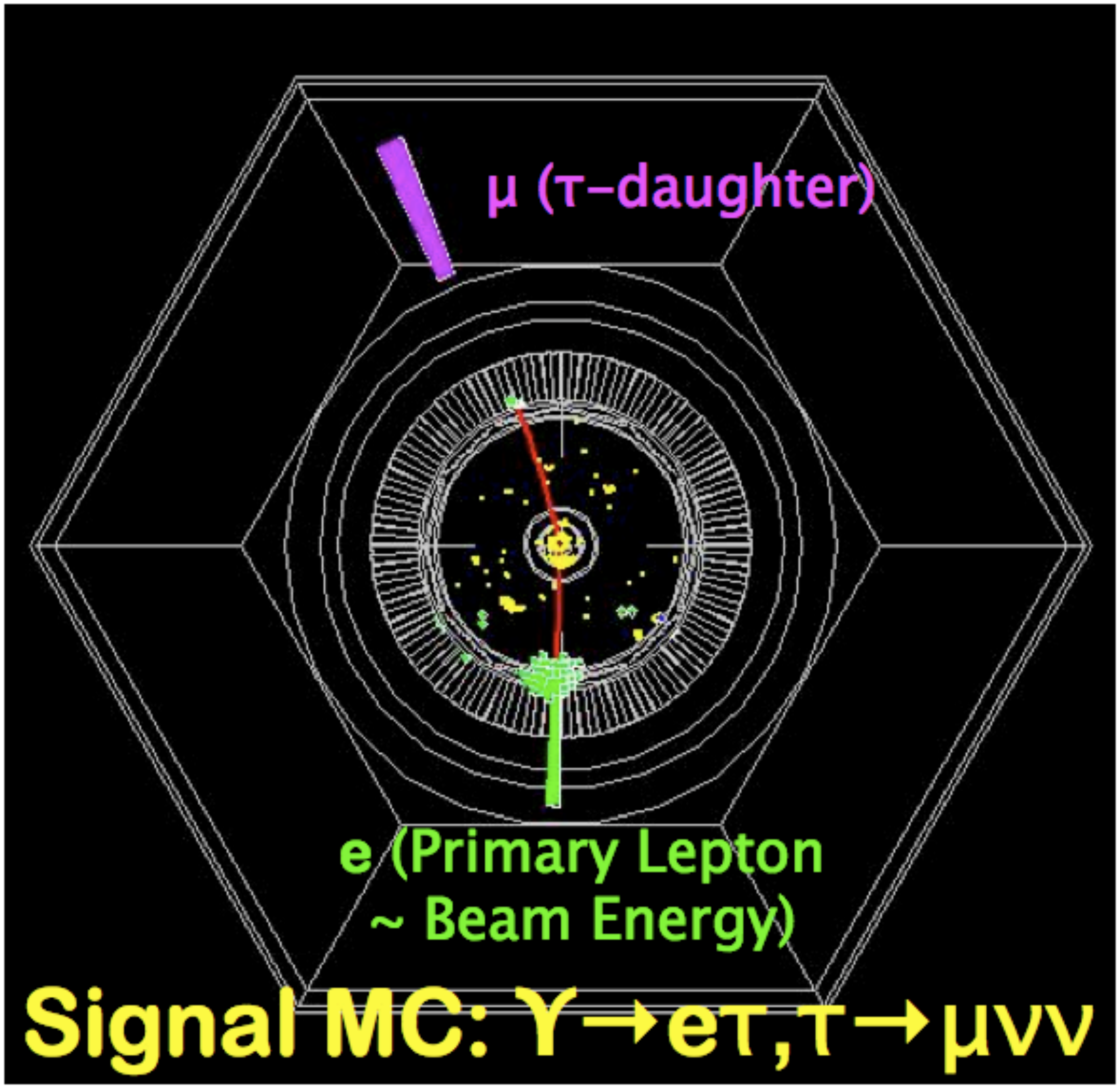
BaBar Collab., PRL 99, 251803 (2007)

Belle Collab., PLB 660, 154 (2008)

CLEO limit: **$BF(\Upsilon(3S) \to \mu\tau) < 20.3 \times 10^{-6}$**

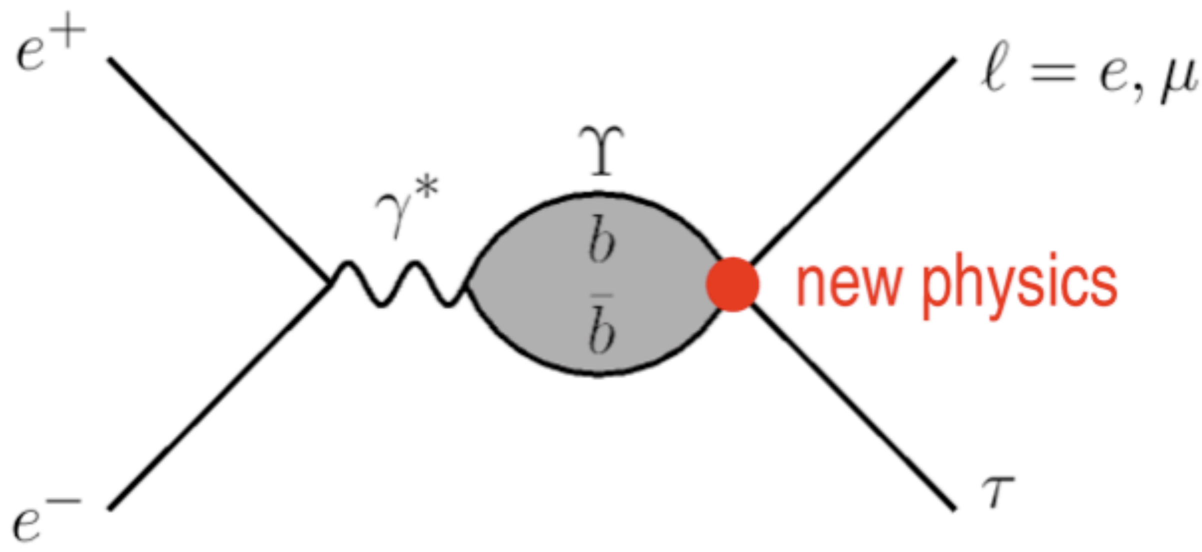
CLEO Collab., PRL 101, 201601 (2008)

What we're looking for…



...unambiguous signature of new physics!

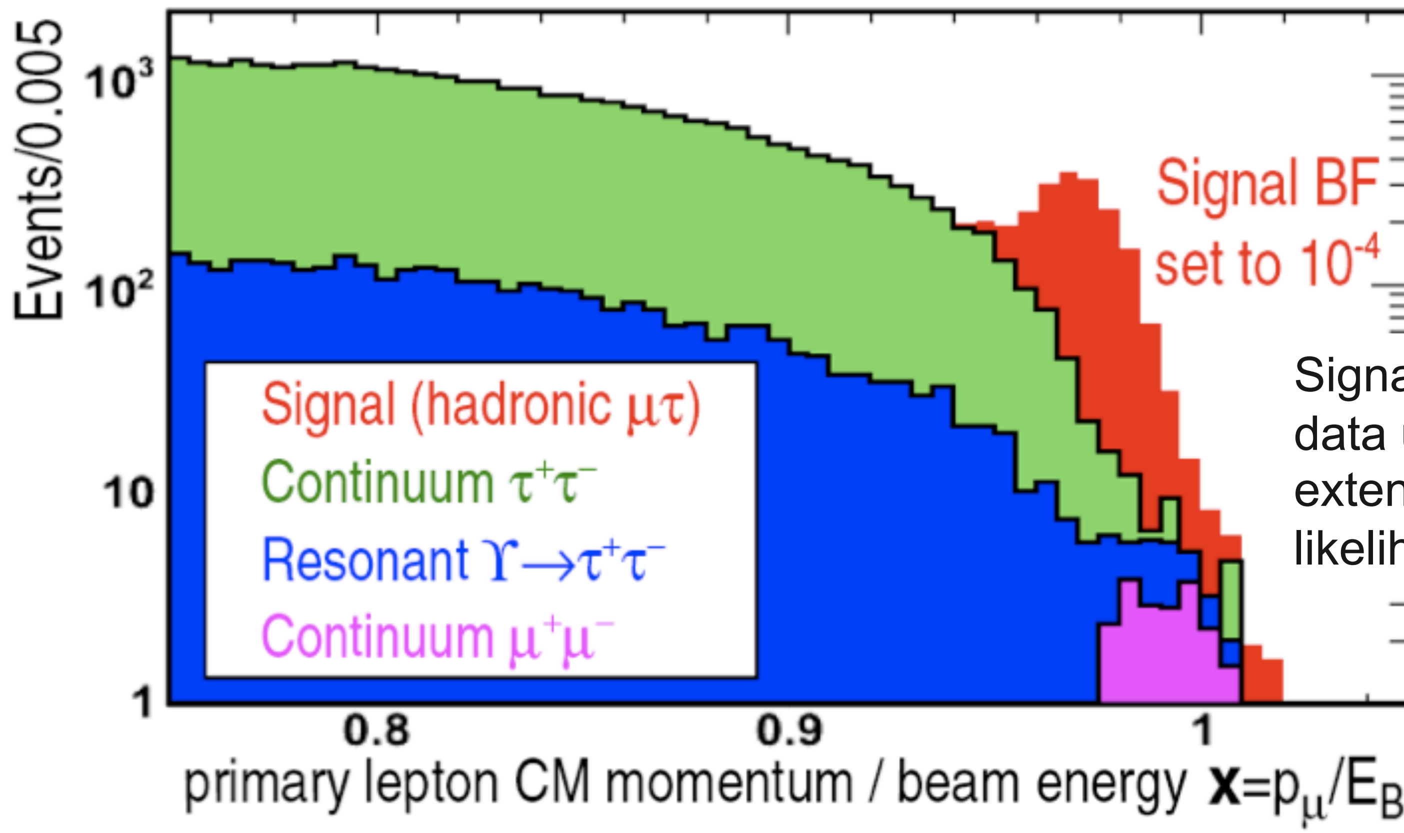
Event Selection



Process	τ Decay	Channel
$\Upsilon(3S) \to e\tau$	$\tau \to \mu\nu_\tau\bar{\nu}_\mu$	leptonic $e\tau$
$\Upsilon(3S) \to e\tau$	$\tau \to \pi^+\pi^0\nu_\tau / \pi^+\pi^0\pi^0\nu_\tau$	hadronic $e\tau$
$\Upsilon(3S) \to \mu\tau$	$\tau \to e\nu_\tau\bar{\nu}_e$	leptonic $\mu\tau$
$\Upsilon(3S) \to \mu\tau$	$\tau \to \pi^+\pi^0\nu_\tau / \pi^+\pi^0\pi^0\nu_\tau$	hadronic $\mu\tau$

- Reconstruct final state from
  - two oppositely charged tracks
  - one or two additional neutral pions
- Primary lepton (e/μ) near beam energy
- τ decay with missing energy in other hemisphere decaying into a lepton with opposite flavor or ρ/a_1
- τ decay with same flavor lepton or a single π vetoed to reduce QED bkgd.

The Discriminating Variable

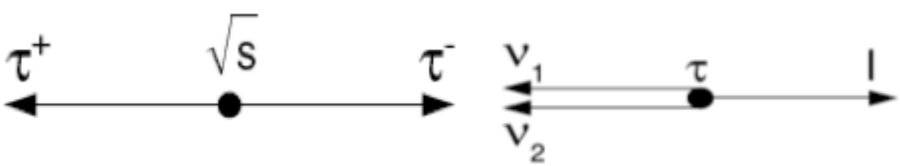


Signal extracted in data using unbinned extended maximum likelihood fit.

$E_l = (m_\Upsilon^2 - m_\tau^2 + m_l^2)/(2\,m_\Upsilon)$ $\quad p_l/E_B = \sqrt{4\,(E_l^2 - m_l^2)/m_\Upsilon^2}$

Signal: peak ~ 0.97

Bhabha/Mu-pair Background: peak ~ 1.0



Tau-pair Background: Kinematic cut-off ~ 0.97

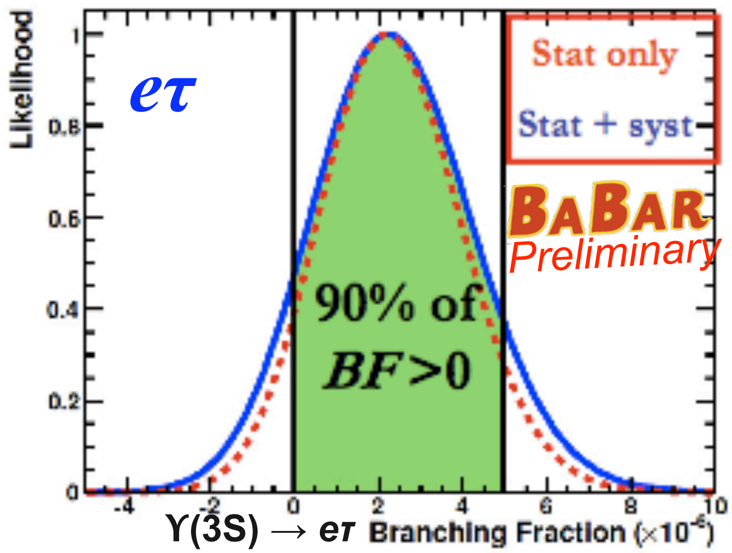
LFV Results

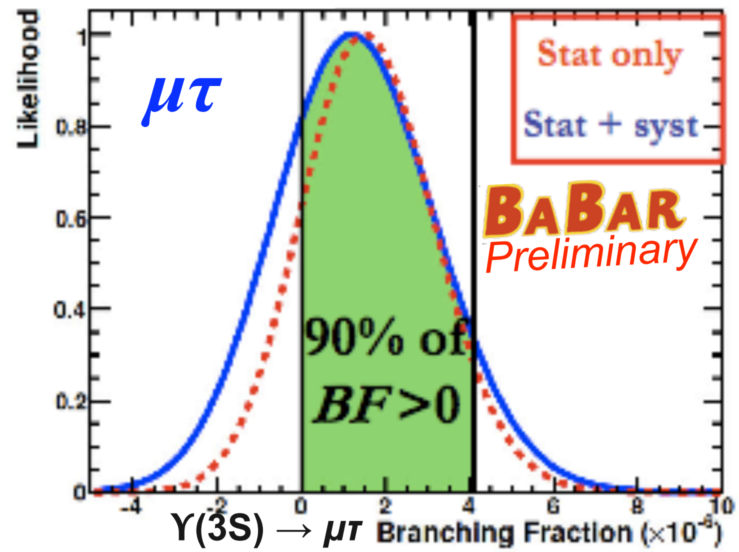
BABAR arXiv:0812.1021

$\Upsilon(3S)$ sample of $(116.7\pm1.2) \times 10^6$ or $27.5\ fb^{-1}$

	UL	MPV
$BF(\Upsilon(3S) \to e^+\tau^\mp)\ (\times10^{-6})$	< 5.0	$2.2^{+1.9}_{-1.8}$
$BF(\Upsilon(3S) \to \mu^+\tau^+)\ (\times10^{-6})$	< 4.1	$1.2^{+1.9}_{-1.9}$

Significant signal ***not observed*** ⇒ set limit.





90% C.L. upper limits

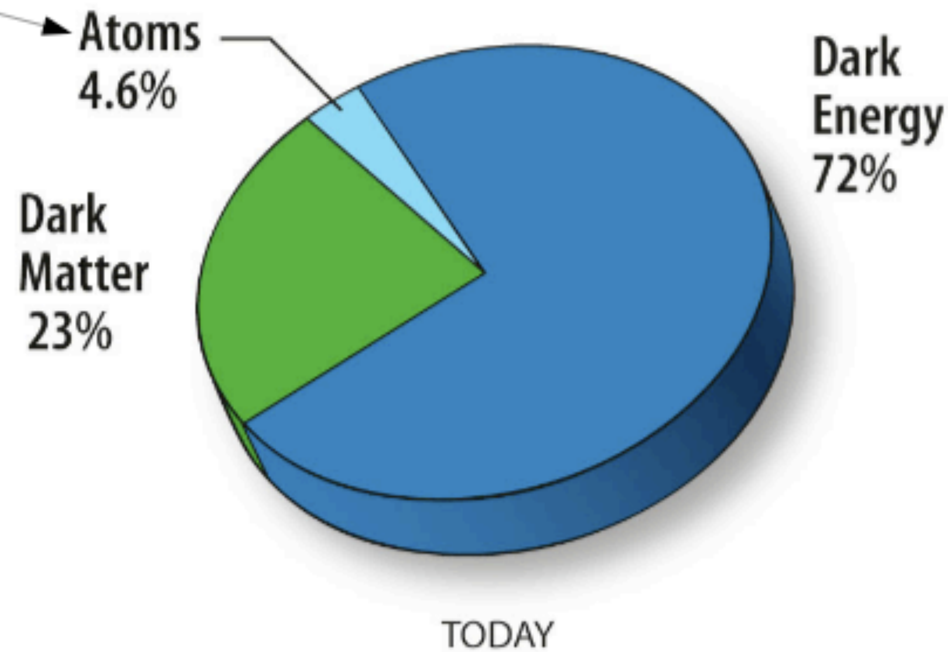
$BF(\Upsilon(3S) \to e\tau) < 5.0 \times 10^{-6}$ — First upper limit

$BF(\Upsilon(3S) \to \mu\tau) < 4.1 \times 10^{-6}$ — Factor > 4 improvement to CLEO

$\Upsilon \to$ invisible: Motivation

This is not simple

Why should this be any simpler? Perhaps there are light and heavy components



Standard Model Prediction: $BR(\Upsilon \to \nu\bar{\nu}) \approx 1 \times 10^{-5}$

Below current experimental sensitivity...

Light Dark Matter:

(McElrath, arXiv:0712.0016 and Phys.Rev. D72 (2005) 103508)

p-wave annihilation in early universe:

$$BR(\Upsilon \to \text{invisible}) < 2 \times 10^{-3}$$

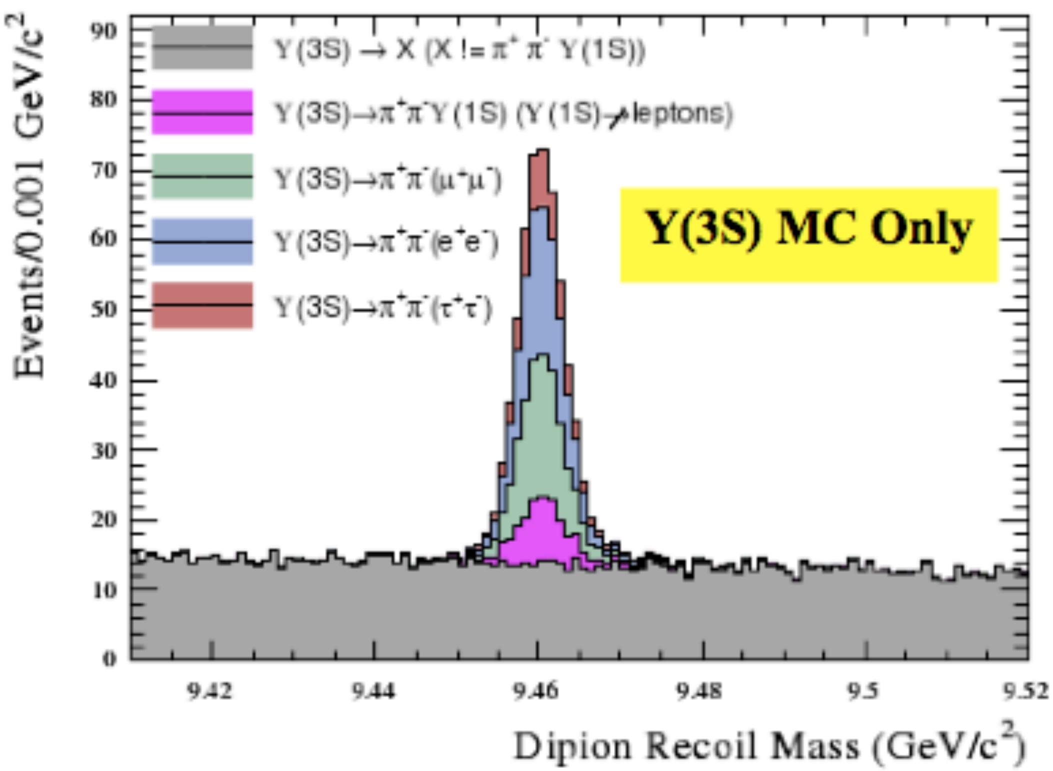
s-wave annihilation in early universe:

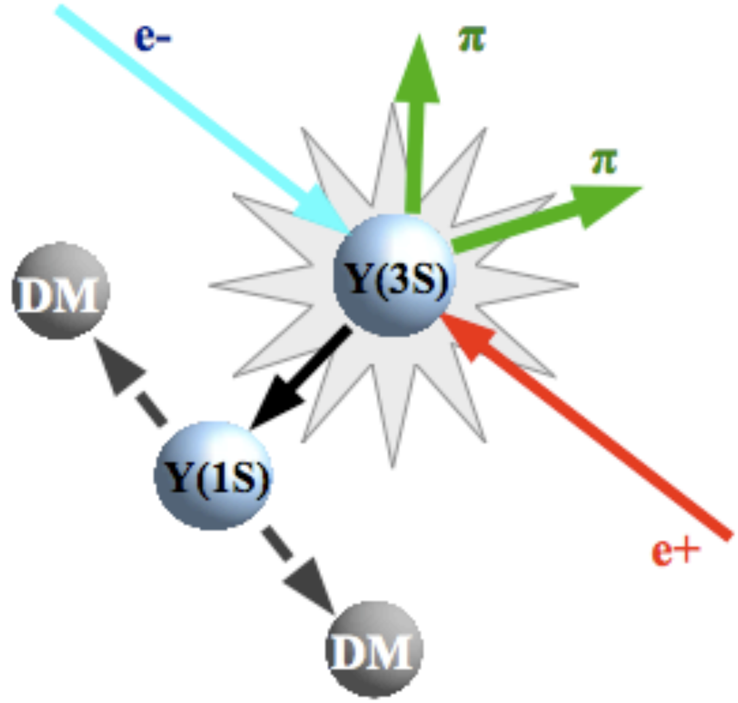
$$BR(\Upsilon \to \text{invisible}) < 5 \times 10^{-4}$$

Best Experimental Constraint (Belle): $BR(\Upsilon \to \text{invisible}) < 2.5 \times 10^{-3}$

ϒ(1S) → invisible: Strategy

Leverage the charged dipion transition to the ϒ(1S) (4.48%) to suppress background



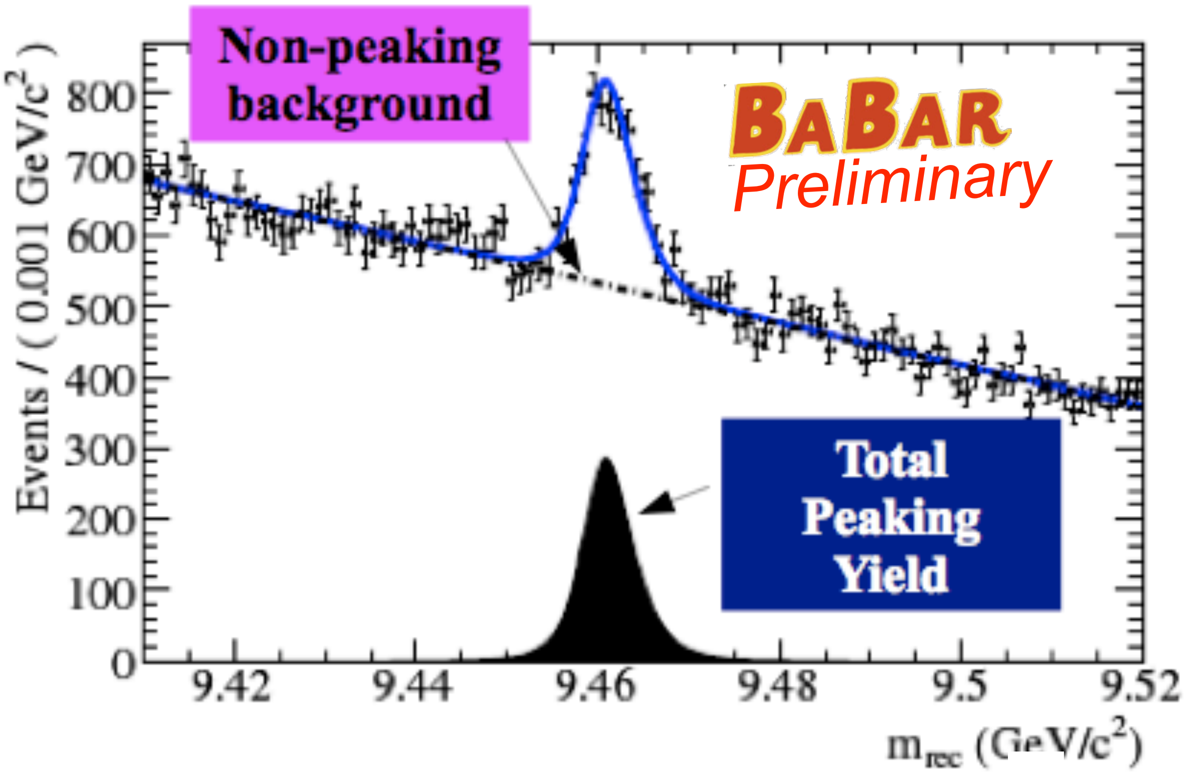


$$m^2_{recoil} = s + m^2_{\pi\pi} - 2E_{\pi\pi}\sqrt{s}$$

Υ(1S) → invisible: Results (I)

FIT INGREDIENTS:
- **Peaking Model: fix all parameters, float yield**
- **Non-Peaking Model: float all parameters and yield**

BF INGREDIENTS:
- **Υ(3S) Count: 91.4M**
- **Peaking Background: fixed at 2444 ± 123 events**
- **Corrected Signal Efficiency: 17.8%**
- **Dipion transition rate: 4.48%**



$$N_{signal} = -118 \pm 105 \pm 124$$

$$BR(\Upsilon(1S) \to \text{invisible}) = (-1.6 \pm 1.4 \pm 1.7) \times 10^{-4}$$

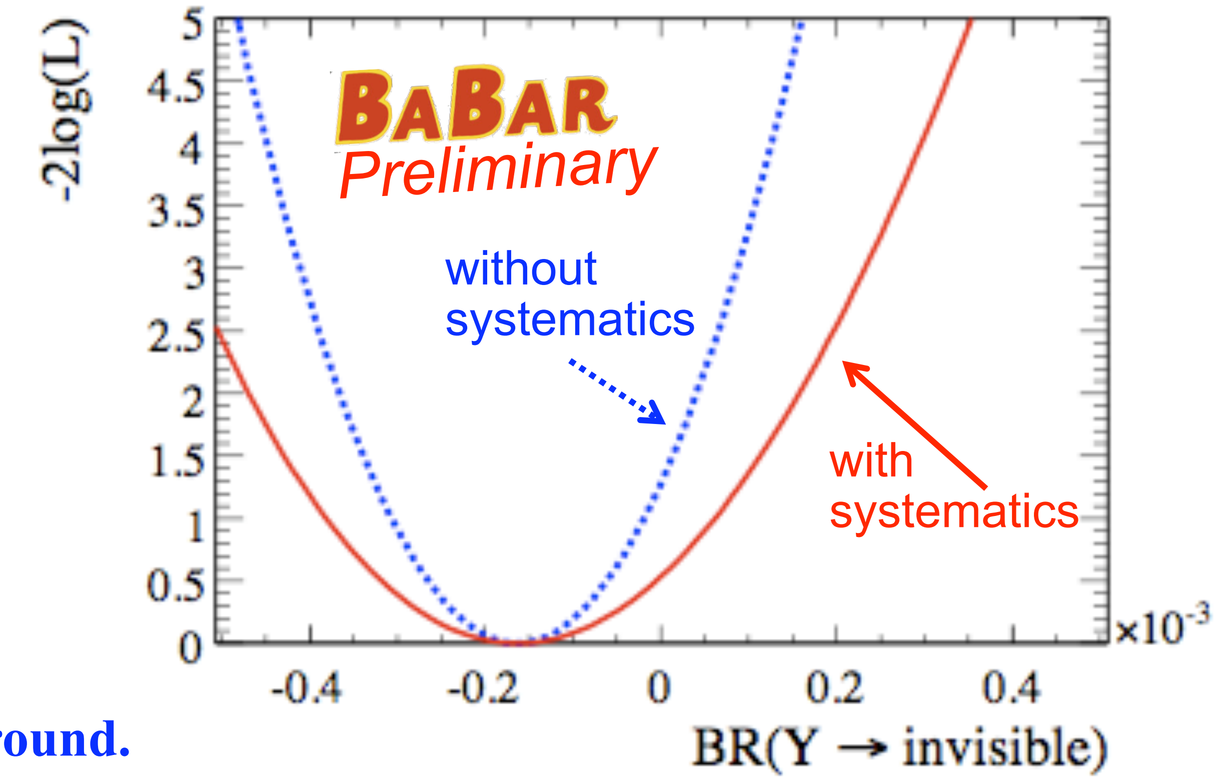
Υ(1S) → invisible: Results (II)

- We use a Bayesian technique to set the upper limit

Incorporate systematic uncertainty (as a Gaussian) into the likelihood function.

Integrate above BF=0 until we find the point where 90% of the area lies in the integral

Results in slightly conservative limit, due to negative fluctuation of background.



$$BR(\Upsilon(1S) \rightarrow \text{invisible}) < 3.0 \times 10^{-4} \text{ at } 90\% \text{ C.L.}$$

NEW RESULT!

Conclusions

BABAR Preliminary Results

arXiv:0812.1021

90% C.L. upper limits

$BF(\Upsilon(3S) \rightarrow e\tau) < 5.0 \times 10^{-6}$ — First upper limit

$BF(\Upsilon(3S) \rightarrow \mu\tau) < 4.1 \times 10^{-6}$ — Factor > 4 improvement to CLEO

BRAND NEW RESULT!:
To be uploaded & submitted this week!

$$BR(\Upsilon(1S) \rightarrow \text{invisible}) < 3.0 \times 10^{-4} \text{ at } 90\% \text{ C.L.}$$

Factor > 8 improvement to Belle!