THE SEARCH FOR NEW PHYSICS IN RARE DECAYS AT BABAR

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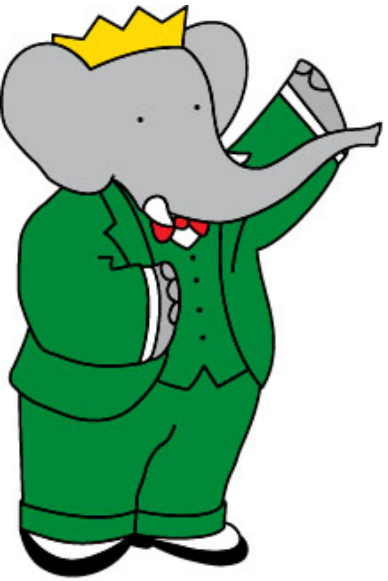
on behalf of the BaBar Collaboration
Presented at the Brookhaven Forum 2010



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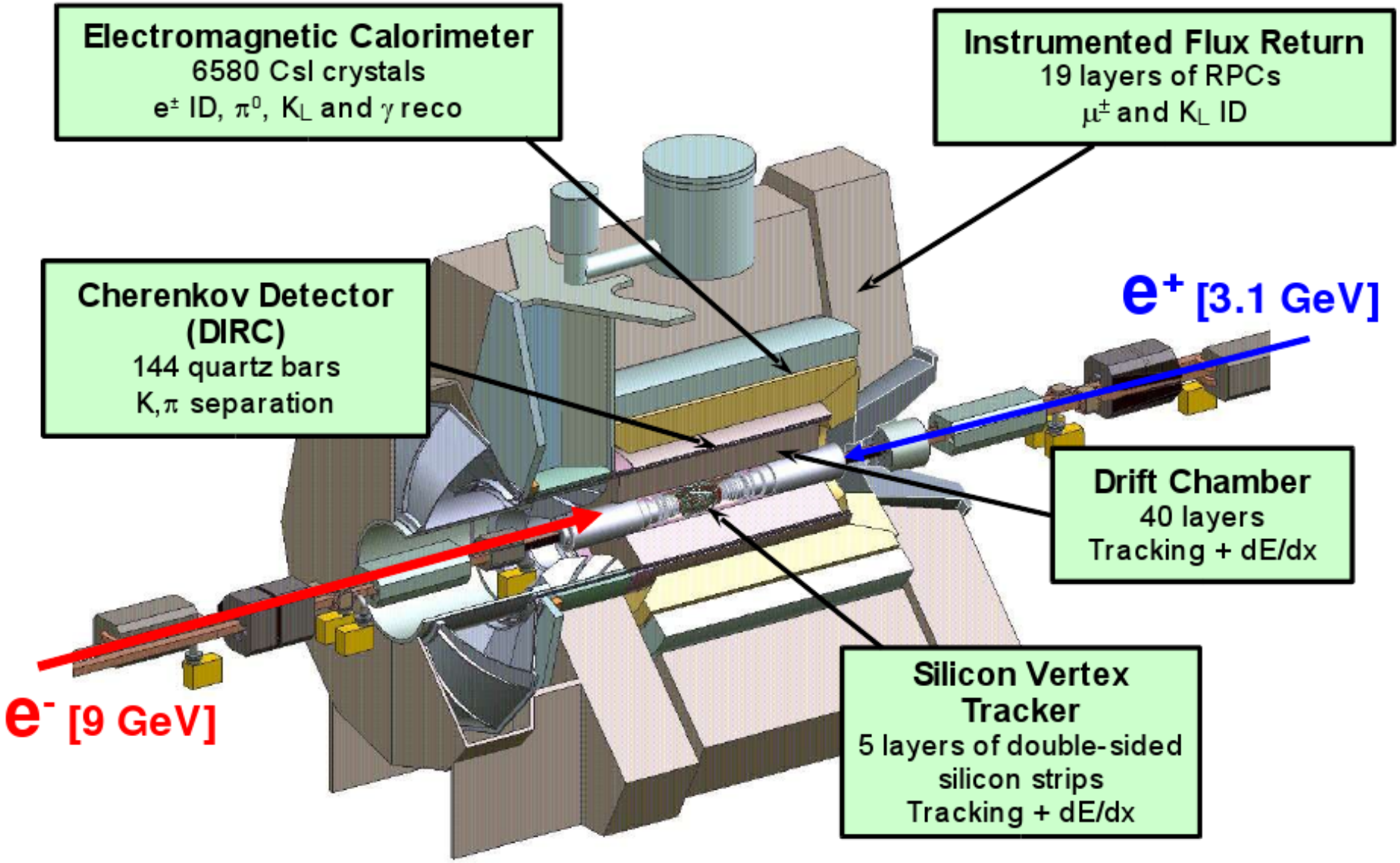
OVERVIEW

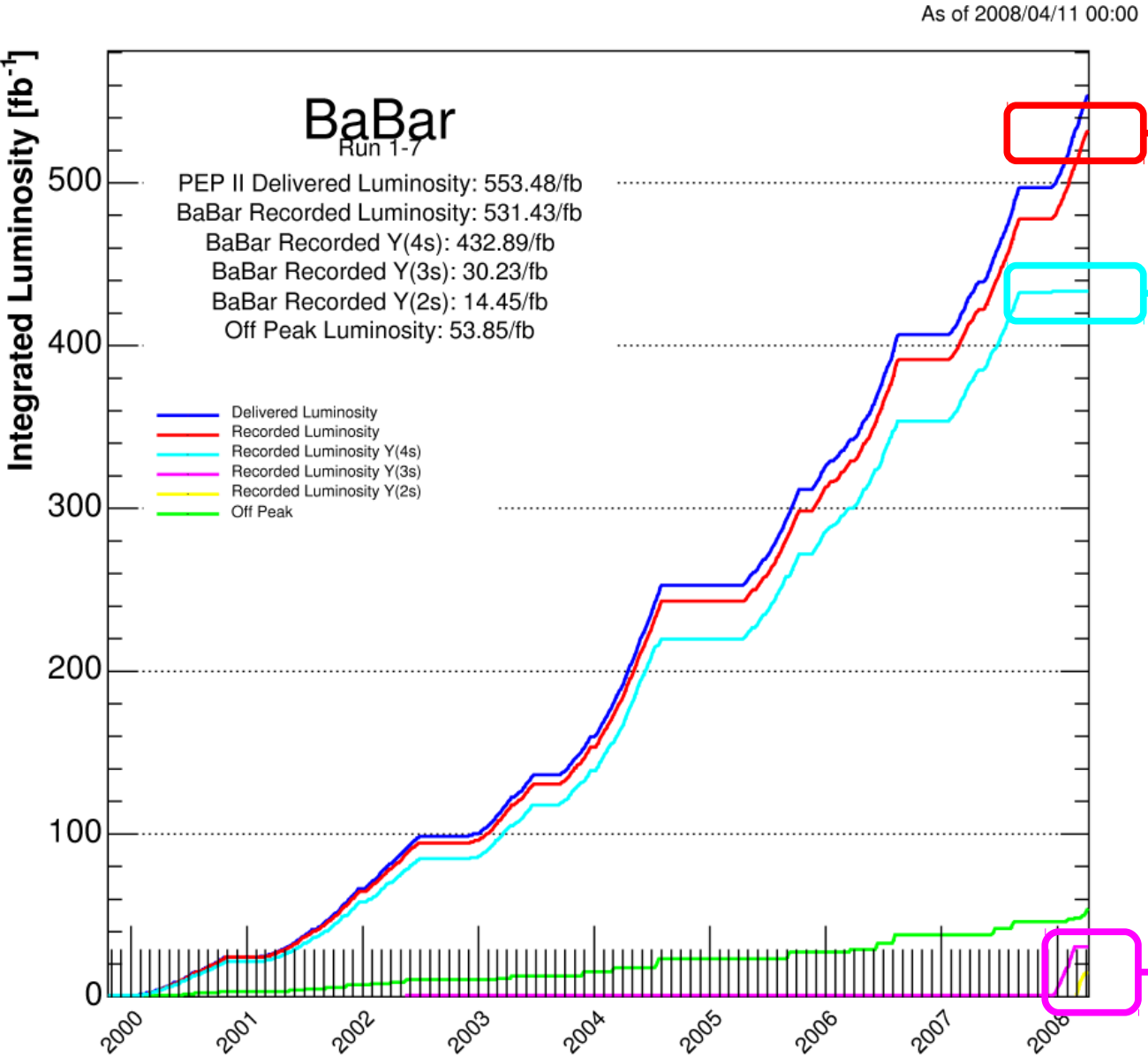
- The BaBar Experiment
- Rare B Decays
  - $B \to$ leptons
- Rare Bottomonium Decays
  - $\Upsilon \to$ invisible
  - $\Upsilon \to$ leptons (+ γ)
- Rare Tau Decays
  - $\tau \to \gamma \ell$

The BaBar Experiment

BaBar is a large acceptance experiment with excellent particle reconstruction and identification capability



DATASET



963 million τ leptons (2000-2008)

~470 million BB pairs (2000-2007)

120 million Υ(3S) and 99 million Υ(2S) mesons (2007-2008)

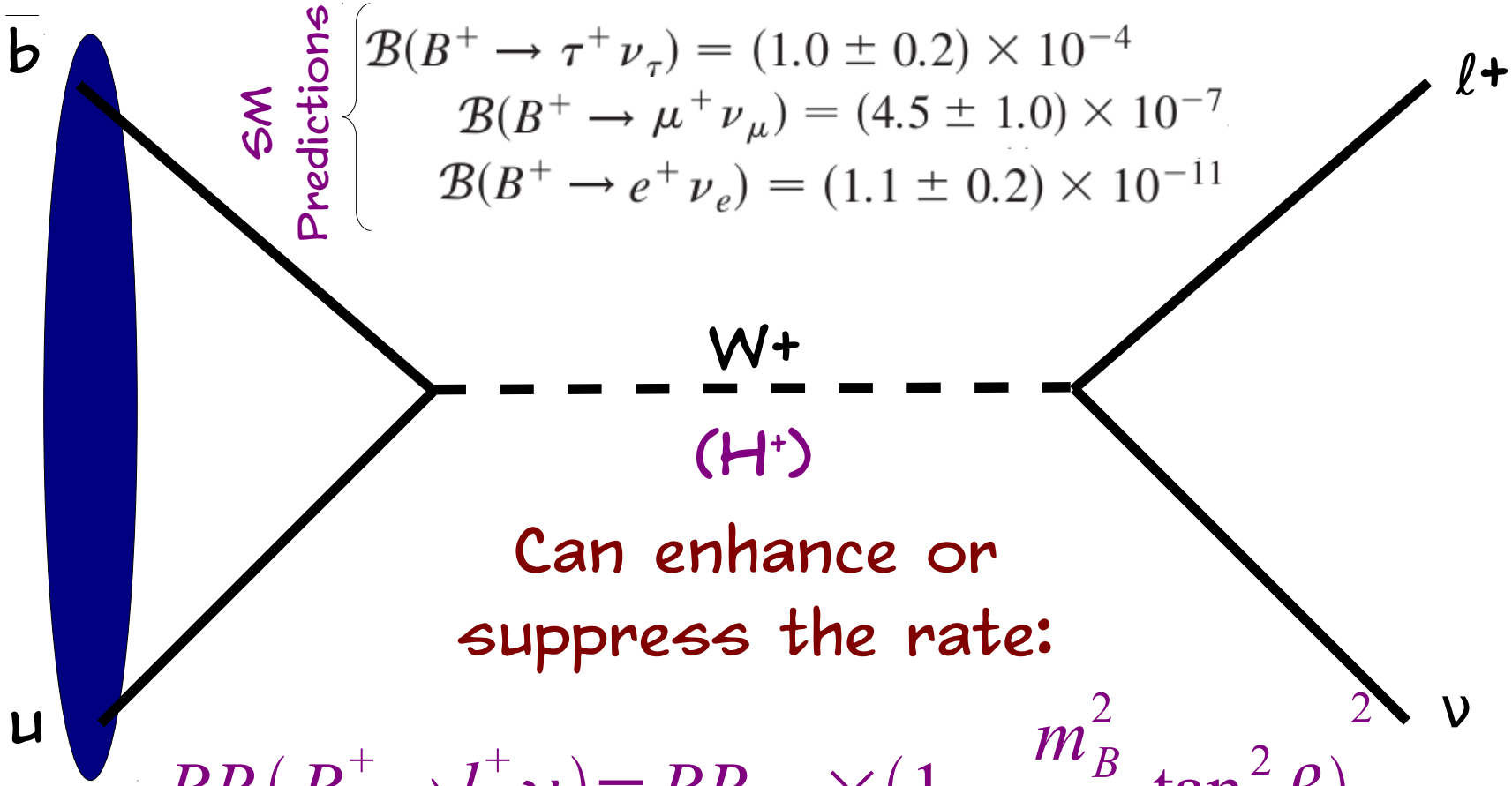
Rare B Decays

THEORETICAL MOTIVATION

$$BR(B^+ \to l^+ \nu)_{SM} \propto m_{l^+}^2 |V_{ub}|^2 \tau_B f_B^2$$

SM Predictions

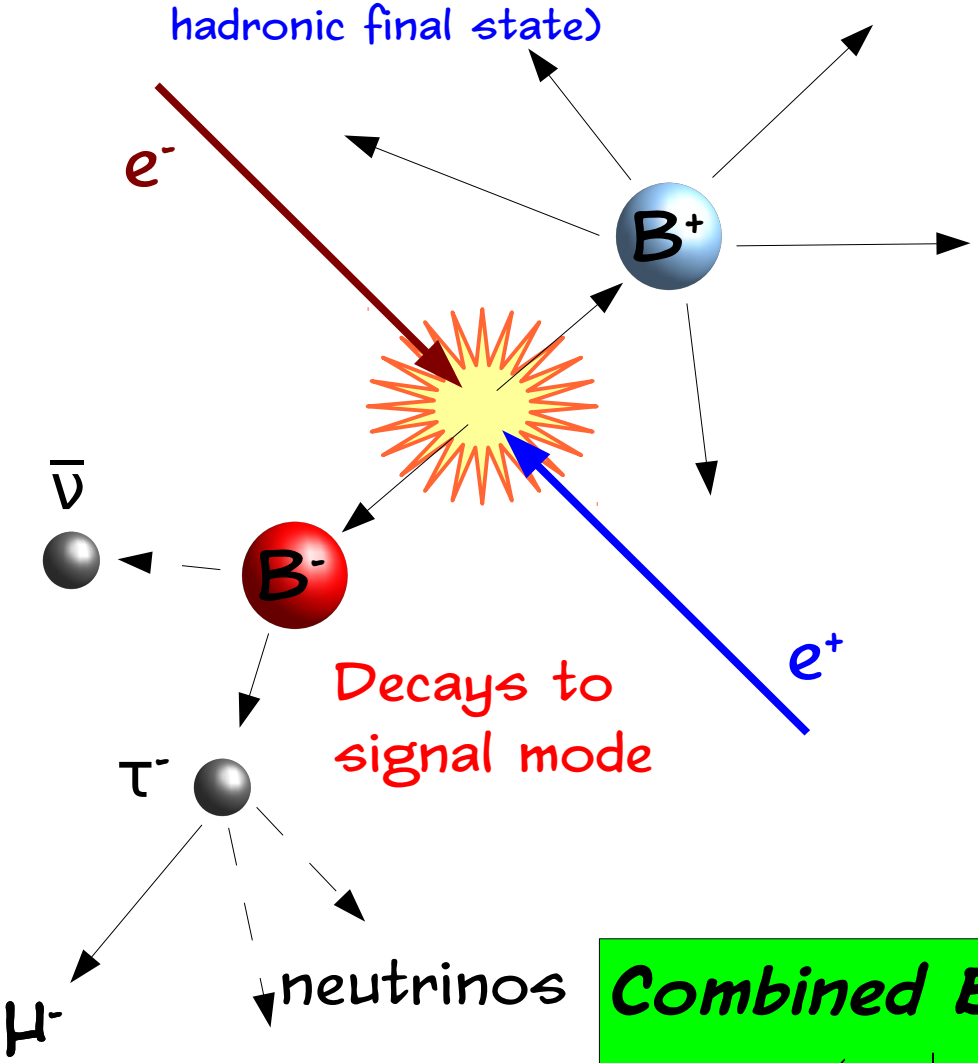
$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = (1.0 \pm 0.2) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \mu^+ \nu_\mu) = (4.5 \pm 1.0) \times 10^{-7}$$
$$\mathcal{B}(B^+ \to e^+ \nu_e) = (1.1 \pm 0.2) \times 10^{-11}$$

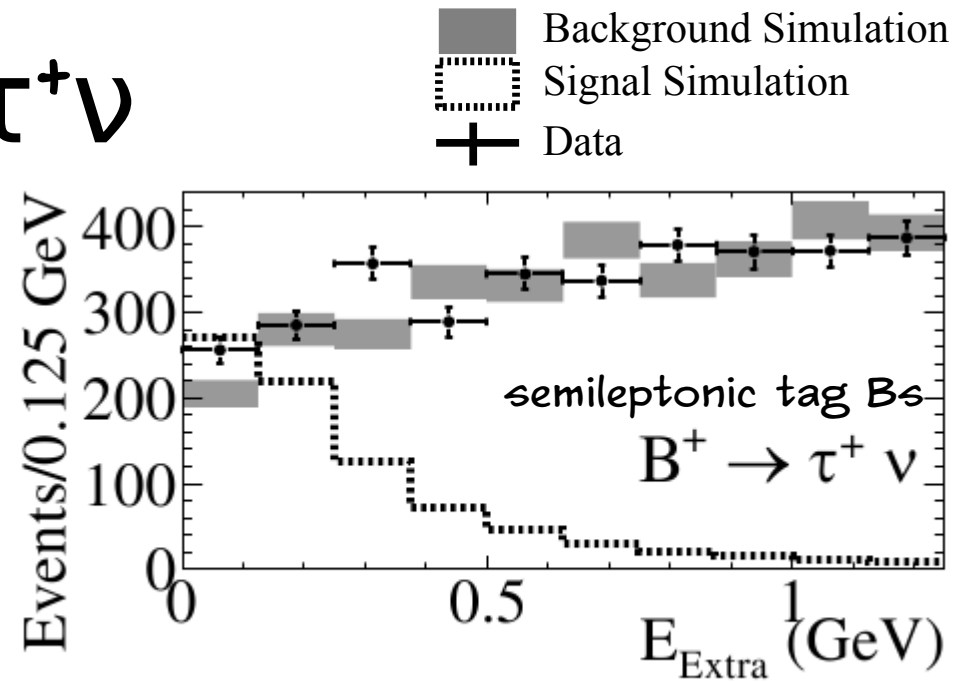


Can enhance or suppress the rate:

$$BR(B^+ \to l^+ \nu) = BR_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2} \tan^2 \beta\right)$$

$B^+ \to \tau^+ \nu$





Mode	$\mathcal{N}_{bg}^{data}$	$N_{\rm obs}$	Branching fraction ($\times 10^{-4}$)
$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau$	81 ± 12	121	(3.6 ± 1.4)
$\tau^+ \to \mu^+ \nu_\mu \overline{\nu}_\tau$	135 ± 13	148	$(1.3^{+1.8}_{-1.6})$
$\tau^+ \to \rho^+ \overline{\nu}_\tau$	59 ± 9	71	$(2.1^{+2.0}_{-1.8})$
$\tau^+ \to \pi^+ \overline{\nu}_\tau$	234 ± 19	243	$(0.6^{+1.4}_{-1.2})$
$B^+ \to \tau^+ \nu_\tau$	509 ± 30	583	$(1.7 \pm 0.8 \pm 0.2)$

Combined BaBar Results:

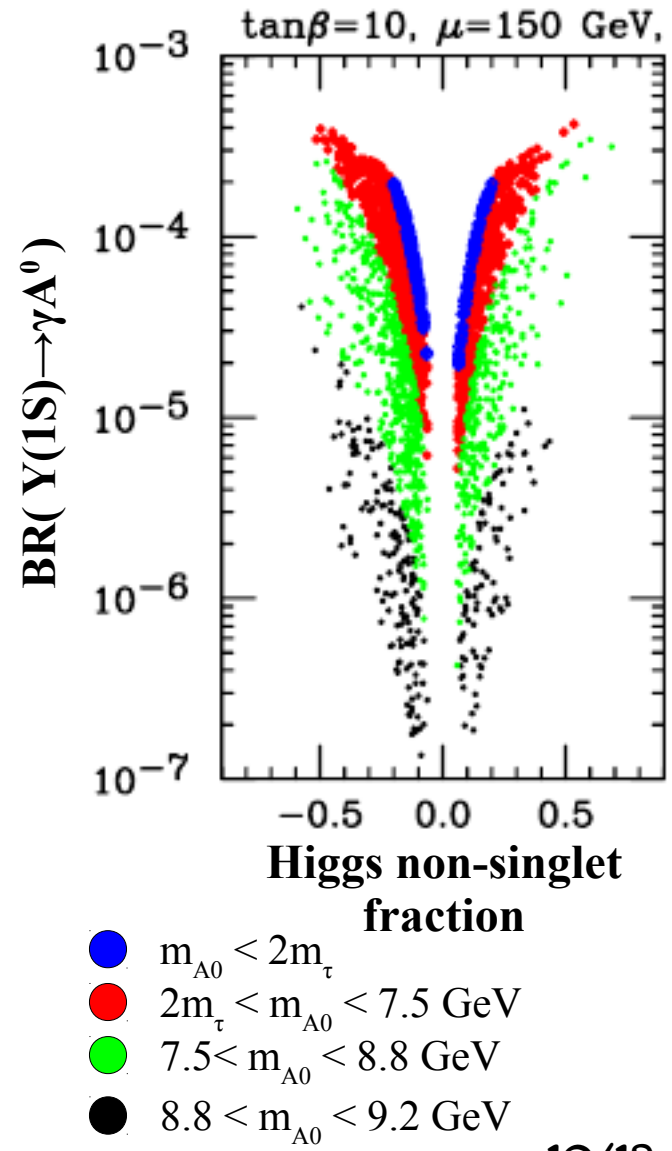
$$BR(B^+ \to \tau^+ \nu) = (1.7 \pm 0.6) \times 10^{-4}$$

Rare Bottomonium Decays

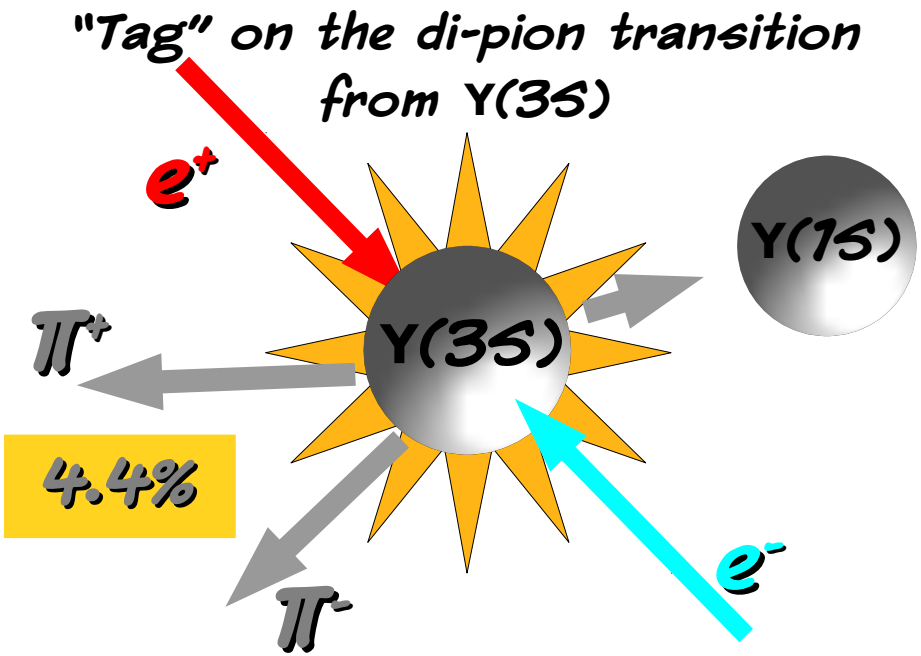
MOTIVATION

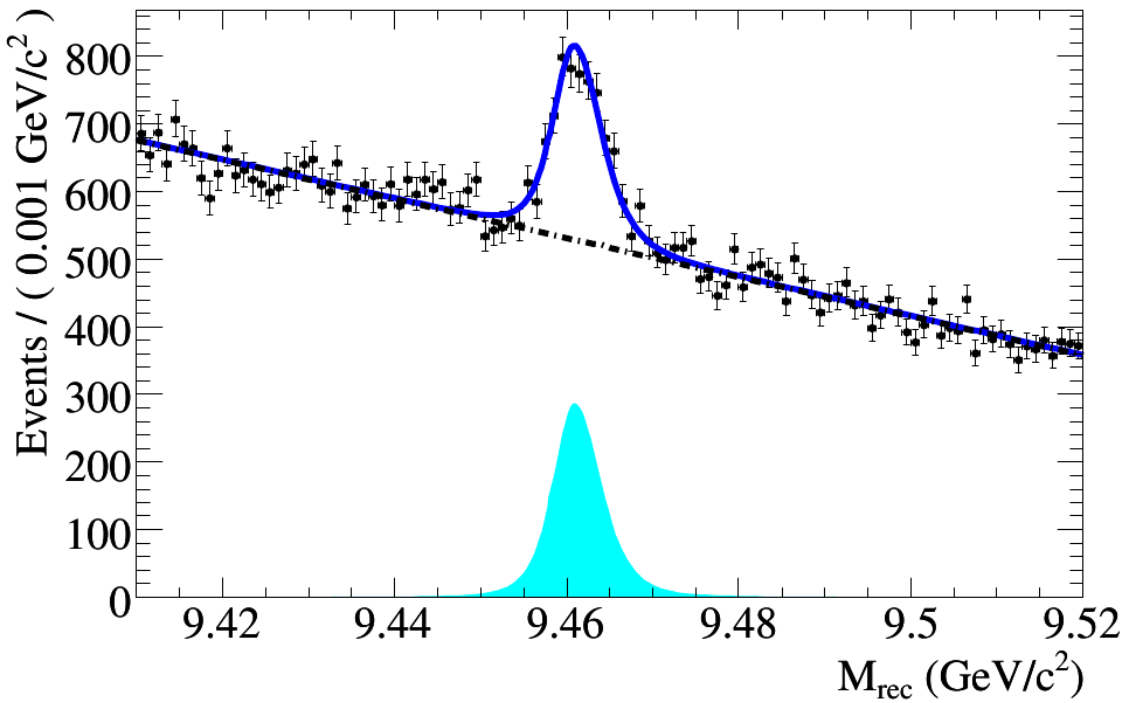
- Low-mass dark matter
  - what if dark matter is not just one particle, but a whole spectrum?
- Low-mass Higgs (A^0)
  - Possible in NMSSM without contradicting previous measurement
- Lepton flavor violation
  - Allowed in SUSY

Phys.Rev.D76:051105,2007



Υ(1S) → INVISIBLE





Leading limitations on sensitivity:

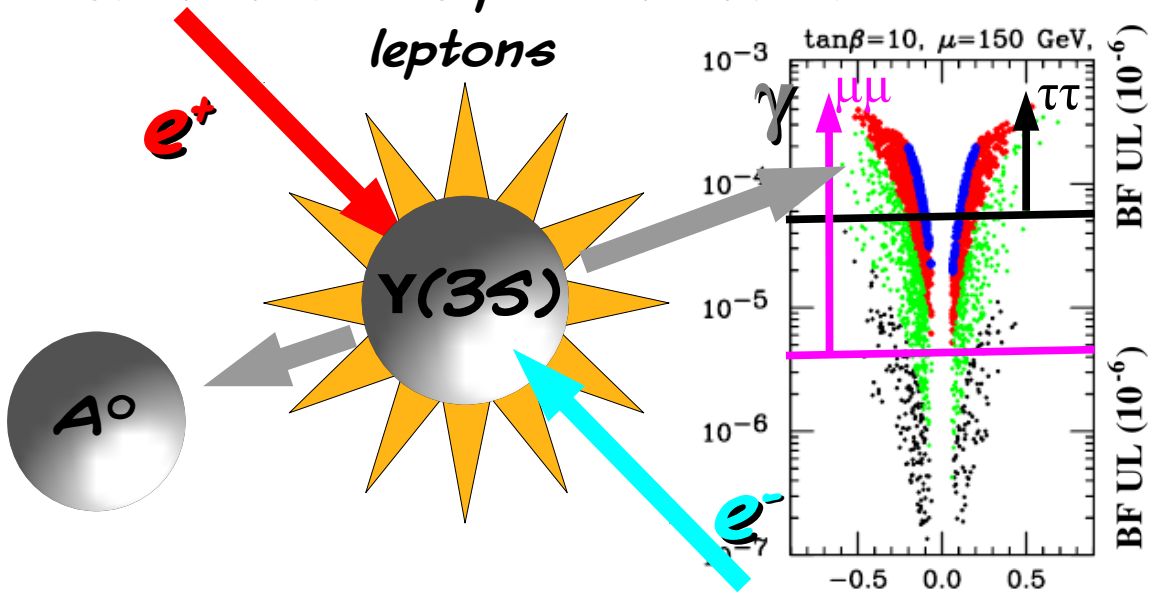
- significant non-peaking background (reject using data-based multi-variate approach)
- peaking background from unreconstructed $\Upsilon \to \ell^+\ell^-$ decays

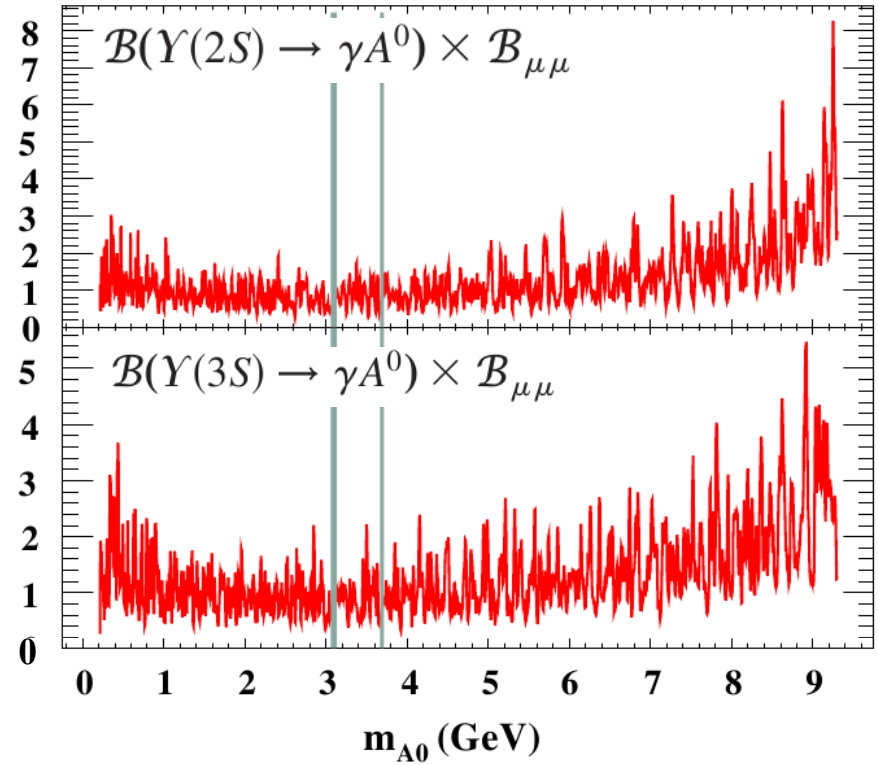
Results:

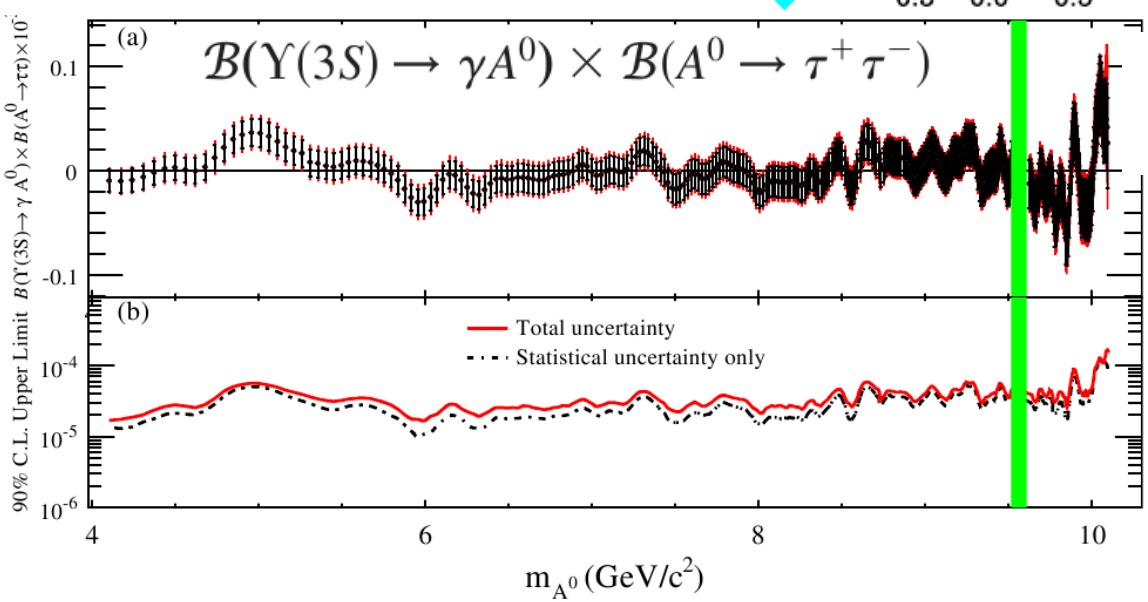
$$BR(\Upsilon(1S) \to \text{invisible}) = (-1.6 \pm 1.4_{\text{stat}} \pm 1.6_{\text{syst}}) \times 10^{-4}$$

Υ(nS) → γ + HIGGS

Reconstruct the photon and two leptons



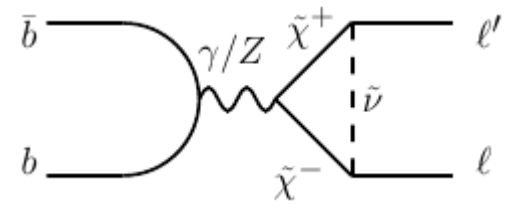




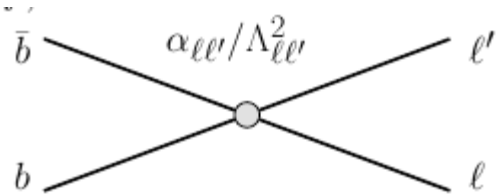
Results:

No discoveries; limits set in the range of 10^{-4} - 10^{-6} on product of branching ratios.

LEPTON FLAVOR VIOLATION

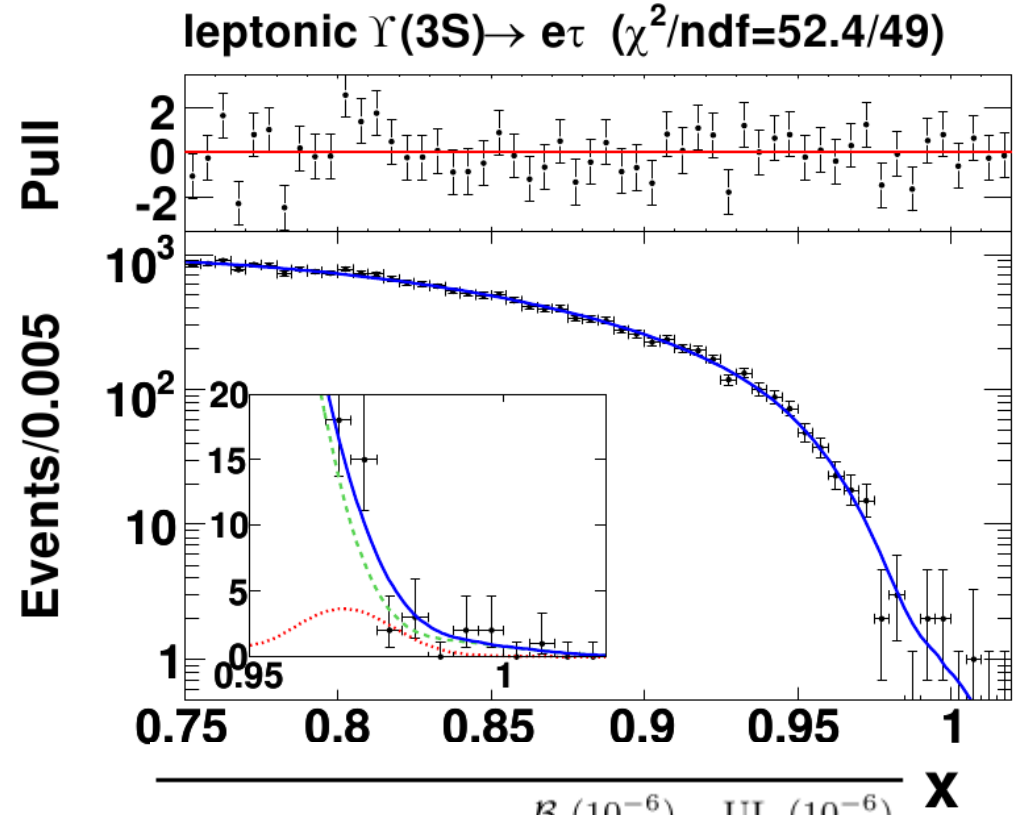


(SUSY)



(Generic)

$$\frac{\alpha^2_{\ell\tau}}{\Lambda^4_{\ell\tau}} = \frac{\mathcal{B}(\Upsilon(nS) \to \ell^\pm\tau^\mp)}{\mathcal{B}(\Upsilon(nS) \to \ell^+\ell^-)} \frac{2q_b^2\alpha^2}{(M_{\Upsilon(nS)})^4}$$



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

Look for $\Upsilon(3S)\to\ell\tau$

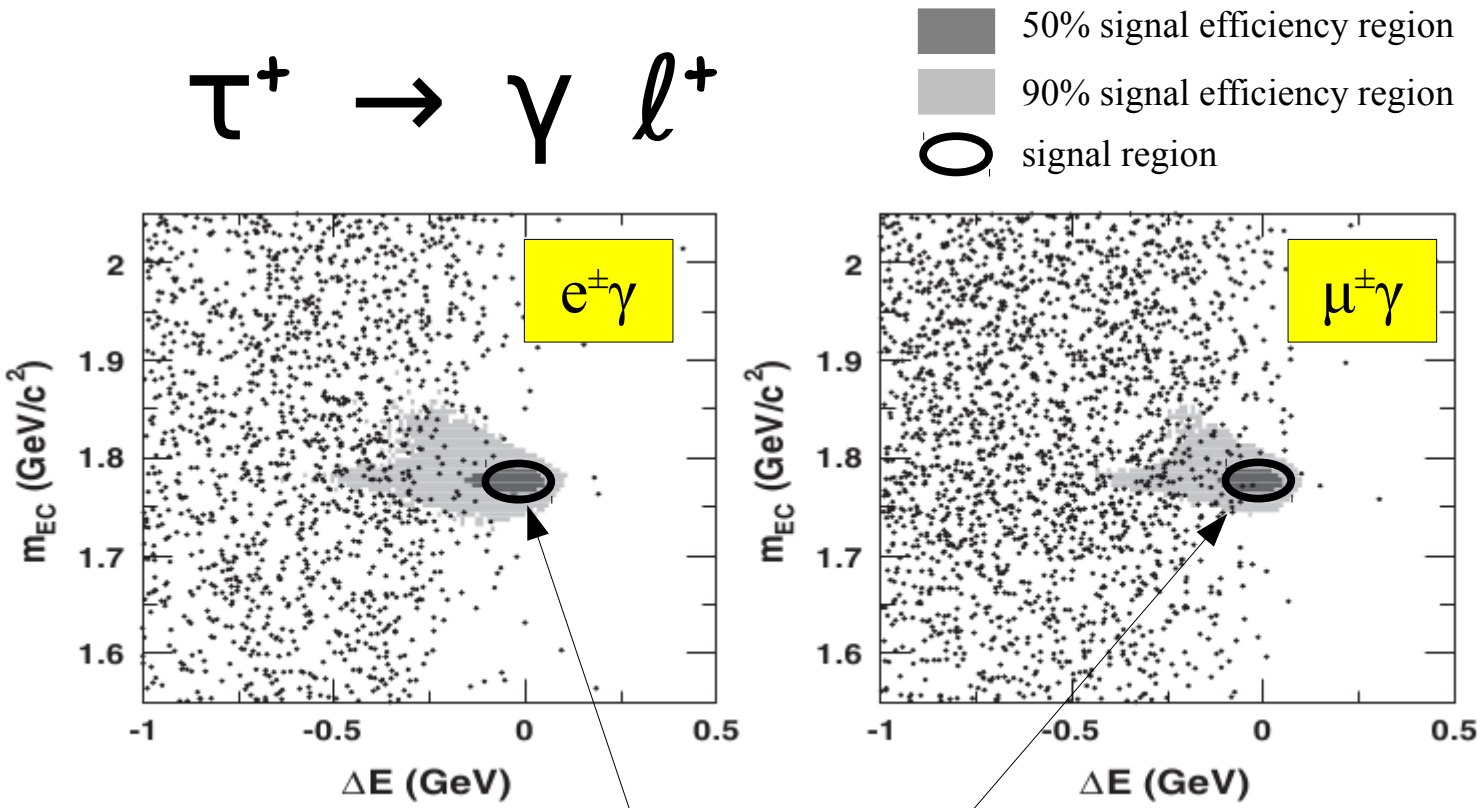
- the primary (non-tau) lepton should satisfy $x=p_l/E_{beam}\approx 0.97$
- use $\mu^\pm$, $\pi^\pm$ final states of $\tau^\pm$
- use kinematic and event shape variable to suppress $e^+e^-\to\ell^+\ell^-$ backgrounds

Rare Tau Decays

$\tau^+ \rightarrow \gamma\ \ell^+$

Even with neutrino mixing, rate is unmeasurable in SM

- unambiguous sign of new physics



0 events observed

2 events observed (consistent with background)

Fully reconstructable tau final state allows for use of strong collider kinematic constraints

- tag the other tau decay using 1-prong and 3-prong topologies

m_{EC}: tau mass, using reco. momentum and collider energy

ΔE: difference between reco. energy (assuming tau mass) and collider energy

Decay modes	UL ($\times 10^{-8}$) obs	exp
$\tau^{\pm} \rightarrow e^{\pm}\gamma$	3.3	9.8
$\tau^{\pm} \rightarrow \mu^{\pm}\gamma$	4.4	8.2

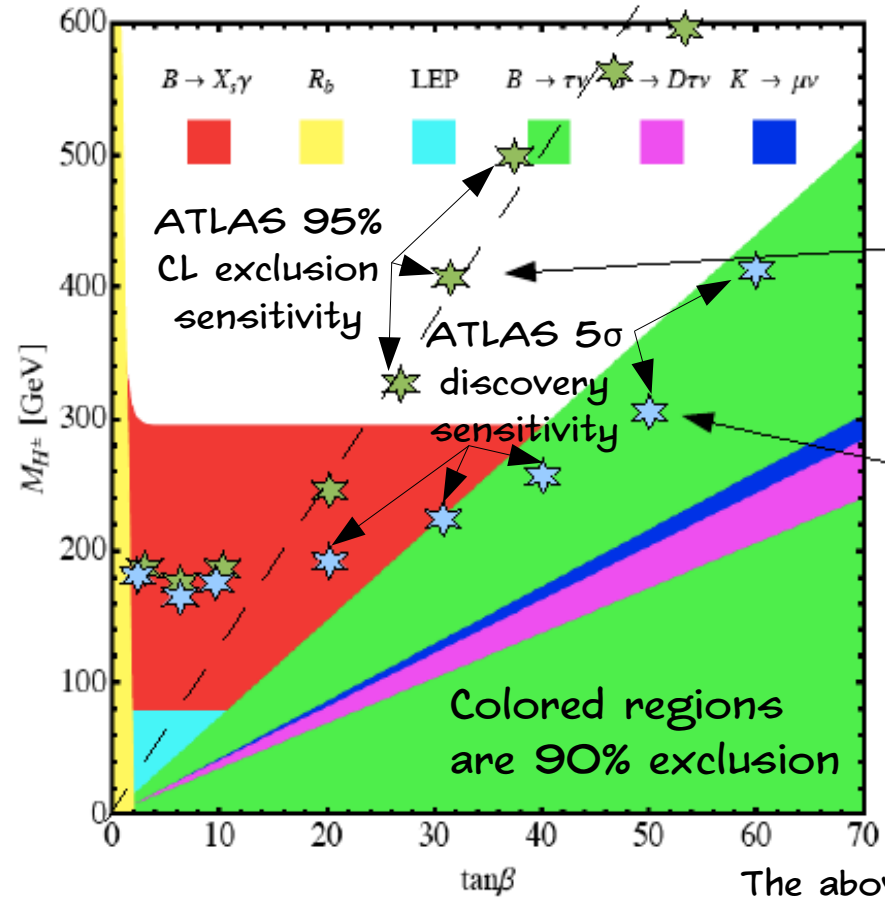
Conclusions

Rare B Decays

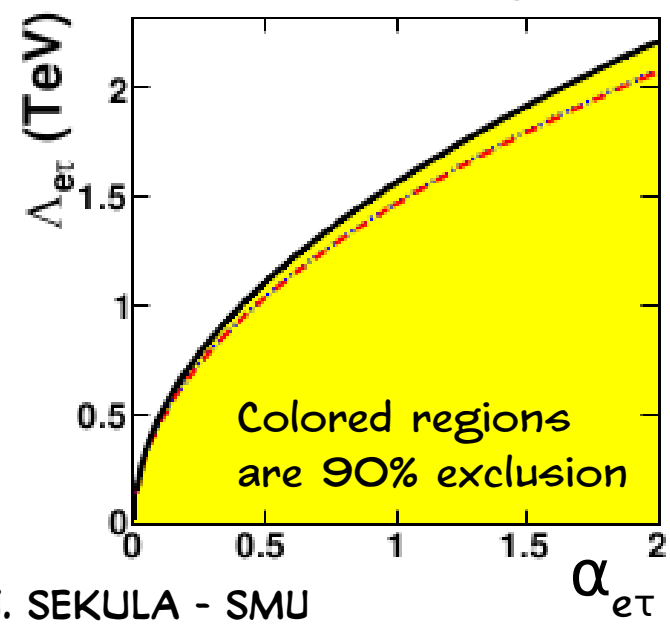
- no evidence for deviations from the SM (~few sigma)

Rare bottomonium/tau Decays

- no evidence for new physics
- tests range over a variety of models



ATLAS sensitivity in MSSM mh-max scenario (30/fb)



The above plot is from U. Haisch (arXiv:0805.2141) with ATLAS points added by S. Robertson

OUTLOOK

- LHC Era
  - indirect constraints from flavor factories point to the need for direct searches at the highest energies that can be probed at hadron colliders
- Super flavor factories
  - needed to make definitive measurements (leptonic B decays)
  - needed to cut into/through model prediction spaces for new physics

BACKUP SLIDES

REFERENCES

The BABAR Collaboration and B. Aubert, "A Search for B+ -> tau+ nu Recoiling Against B- -> D0 l- nu X," Phys. Rev. D (81) 051101. 0912.2453 (December 12, 2009), http://arxiv.org/abs/0912.2453.

The BABAR Collaboration: B Aubert, "A Search for Invisible Decays of the Upsilon(1S)," Phys.Rev.Lett.103:251801,2009. 0908.2840 (August 19, 2009), http://arxiv.org/abs/0908.2840.

The BABAR Collaboration and B. Aubert, "Searches for Lepton Flavor Violation in the Decays tau -> e gamma and tau -> mu gamma," Phys.Rev.Lett.104:021802,2010. 0908.2381 (August 17, 2009), http://arxiv.org/abs/0908.2381.

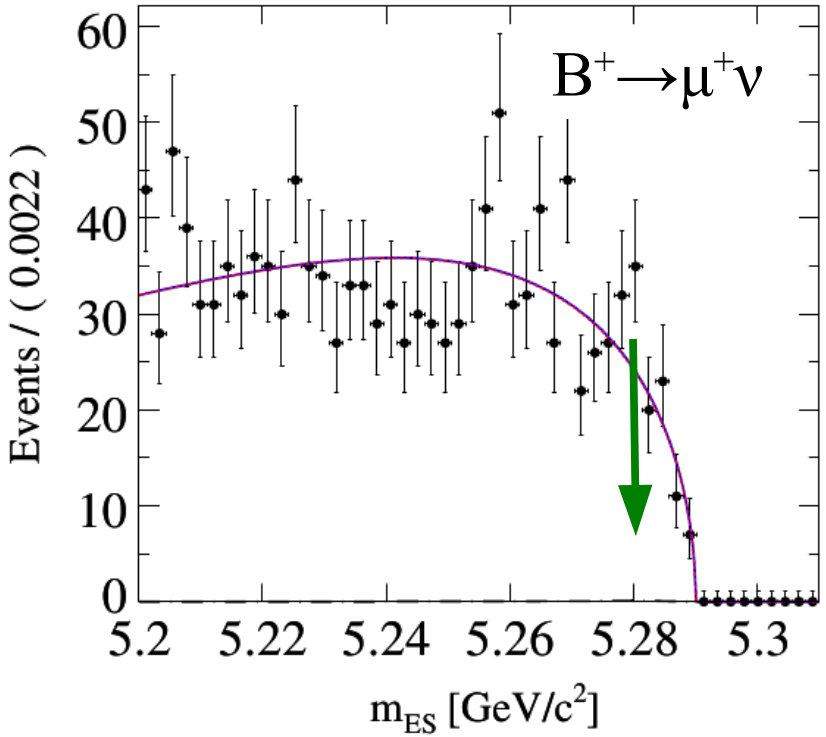
The BABAR Collaboration and B. Aubert, "Search for a low-mass Higgs boson in Y(3S)-->gamma A^0, A^0-->tau^+tau^- at BABAR," Phys.Rev.Lett.103:181801,2009. 0906.2219 (June 11, 2009), http://arxiv.org/abs/0906.2219.

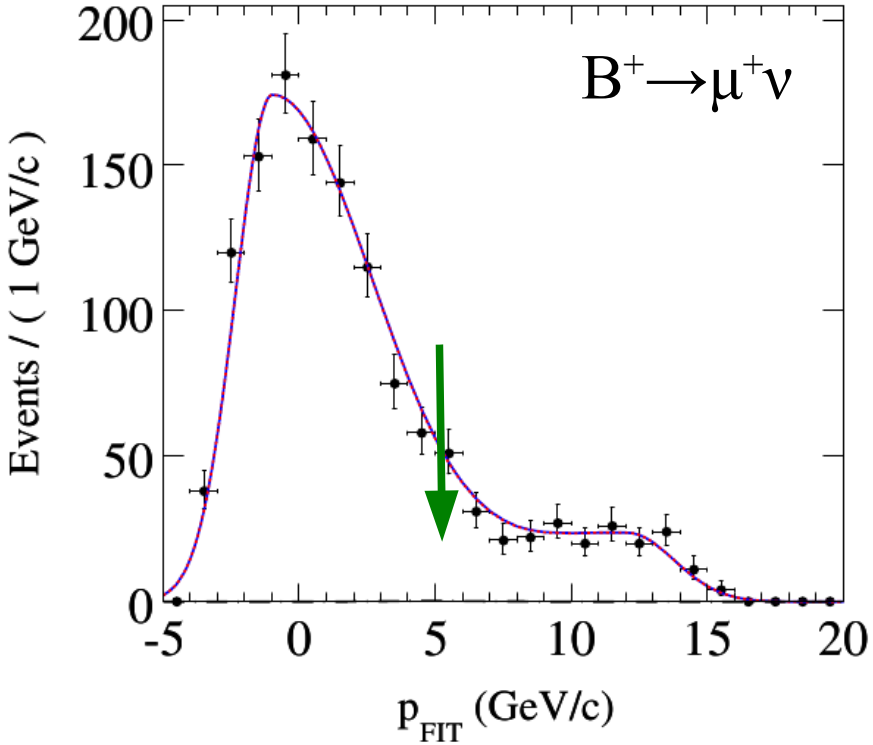
The BABAR Collaboration and B. Aubert, "Search for Charged Lepton Flavor Violation in Narrow Upsilon Decays," Phys.Rev.Lett.104:151802,2010. 1001.1883 (January 12, 2010), http://arxiv.org/abs/1001.1883.

The BABAR Collaboration and B. Aubert, "Search for Dimuon Decays of a Light Scalar Boson in Radiative Transitions Upsilon -> gamma A0," Phys.Rev.Lett.103:081803,2009. 0905.4539 (May 27, 2009), http://arxiv.org/abs/0905.4539.

The BABAR Collaboration and B. Aubert, "Search for the Rare Leptonic Decays \boldmath$\to\Blnu\ell$ ($\ell=e,\mu$)," Phys.Rev.D79:091101,2009. 0903.1220 (March 6, 2009), http://arxiv.org/abs/0903.1220.

$B^+ \to \ell^+ \nu$





Search inclusively for a high-momentum lepton.

Reject background using:

- "event shape" techniques
- inclusive reconstruction of second B in the event
- lepton momentum

Results: limits at 90% C.L.

$$BR(B^+ \to \mu^+ \nu) < 1.0 \times 10^{-6}$$

$$BR(B^+ \to e^+ \nu) < 1.9 \times 10^{-6}$$