Searches for New Physics at BaBar

Milind V. Purohit

Univ. of South Carolina

for the BaBar collaboration

- Rare Upsilon Decays
- Rare Tau Decays
- Leptonic decays of the D_s meson and f_{D_s}

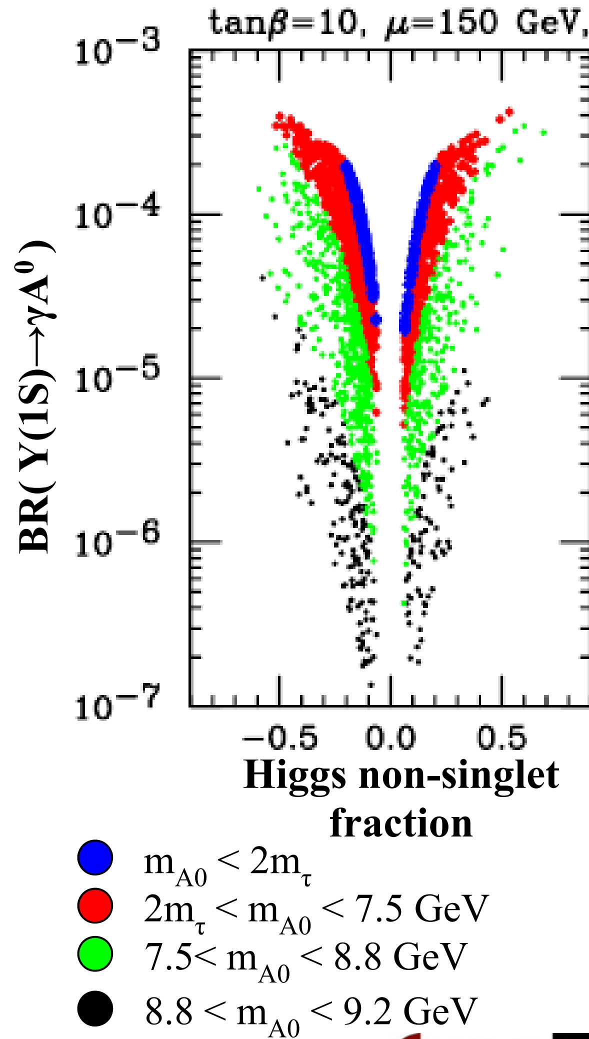
Rare Upsilon Decays: Motivation

- 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

•Standard Model predicts ~ 1 x 10^{-5} for $b\bar{b} \rightarrow \nu\bar{\nu}$

•Possible decays to low mass pairs: 10^{-4} to 10^{-3}
[See e.g., McElrath, Phys. Rev. D72, 103508 (2005).]

Phys.Rev.D76:051105,2007



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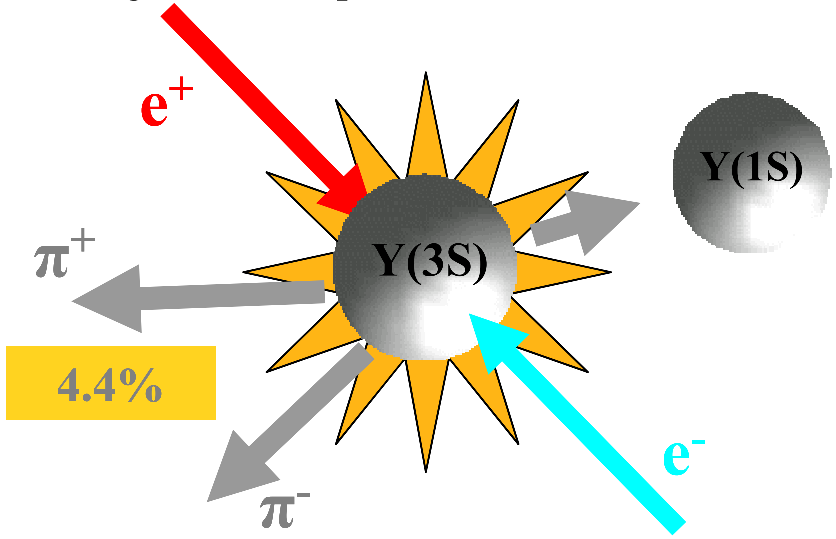
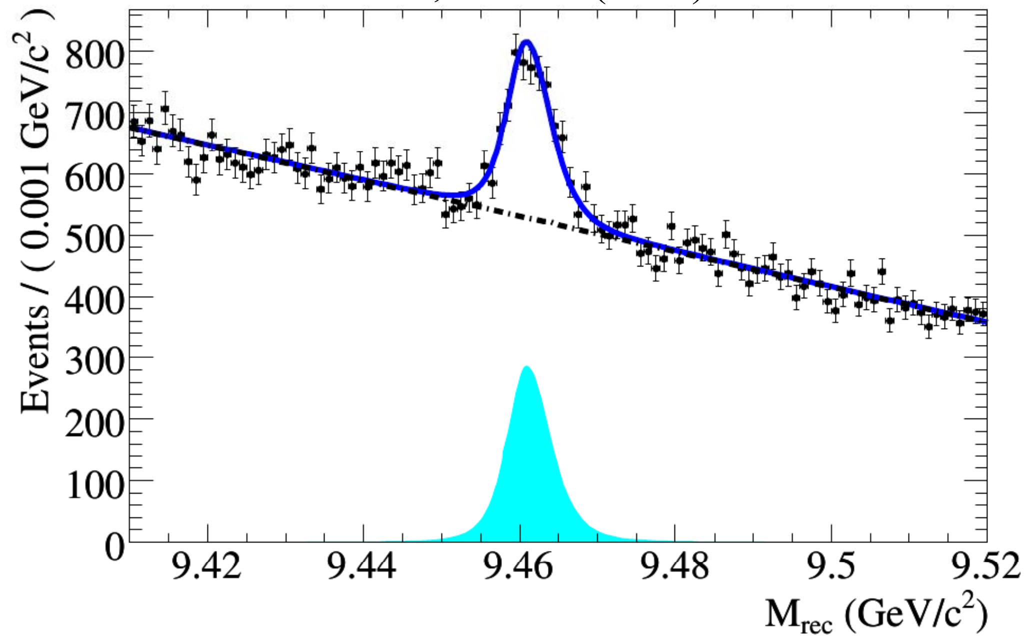
Υ(1S) → invisible

"Tag" on the di-pion transition from Υ(3S)



PRL 103, 251801 (2009)



Leading limitations on sensitivity:

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

Signal: 2326 ± 105 events
Expected Background: 2451 ± 38 events
(mainly from ee, μμ and a little ττ)

- Results: BF [Υ(1S) → invisible] = (-1.6 ±1.4 ± 1.6) x 10^{-4}

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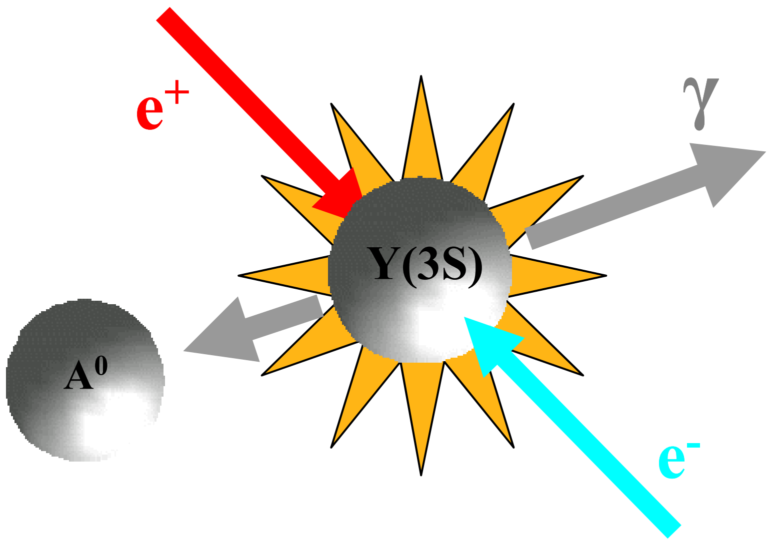
$\Upsilon(nS) \rightarrow \gamma A^0$

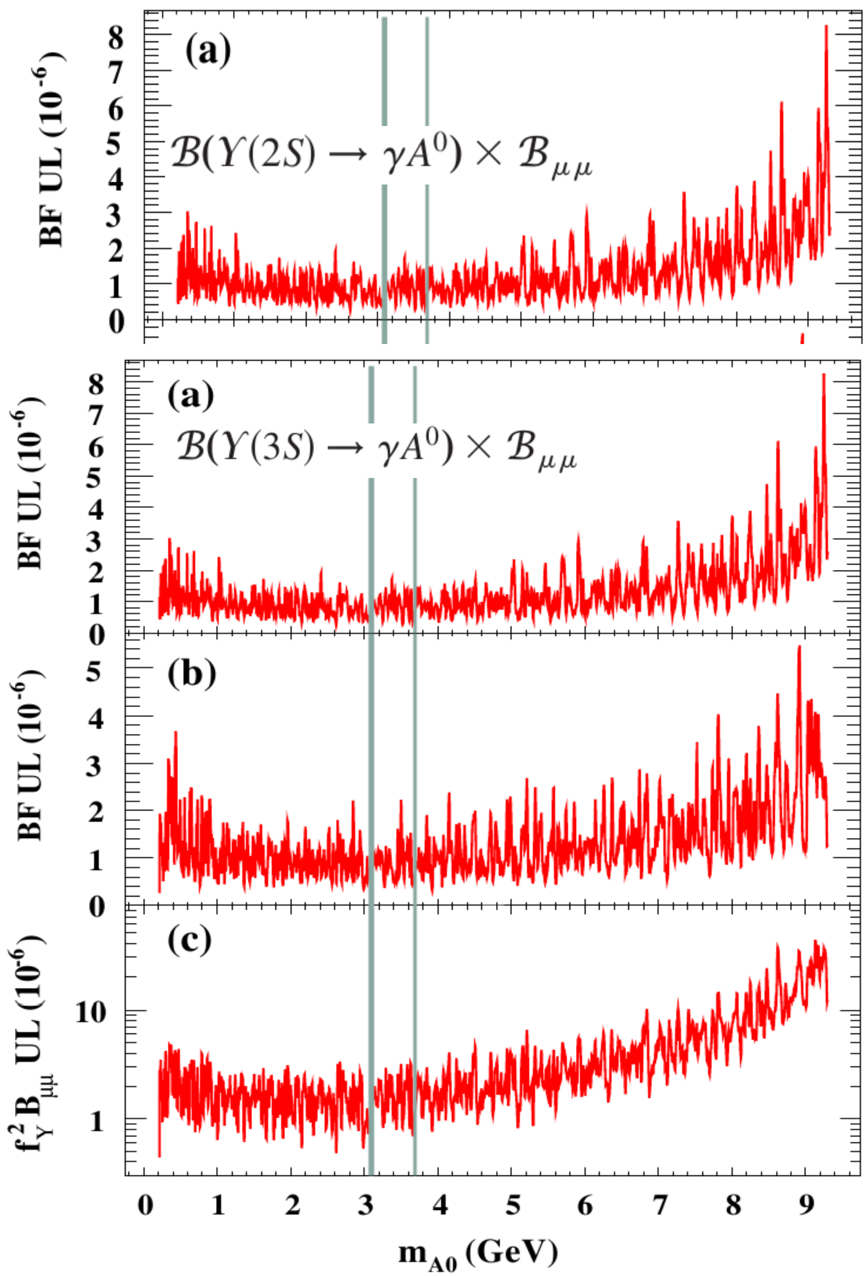
http://arxiv.org/abs/0905.4539

•Search for low mass A^0, where $A^0 \rightarrow \mu\mu$, $\tau\tau$, or invisible final states

•Reconstruct the photon and two leptons

Note: Bars indicate regions around J/ψ and ψ(2S), which are excluded from the search





Results:

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

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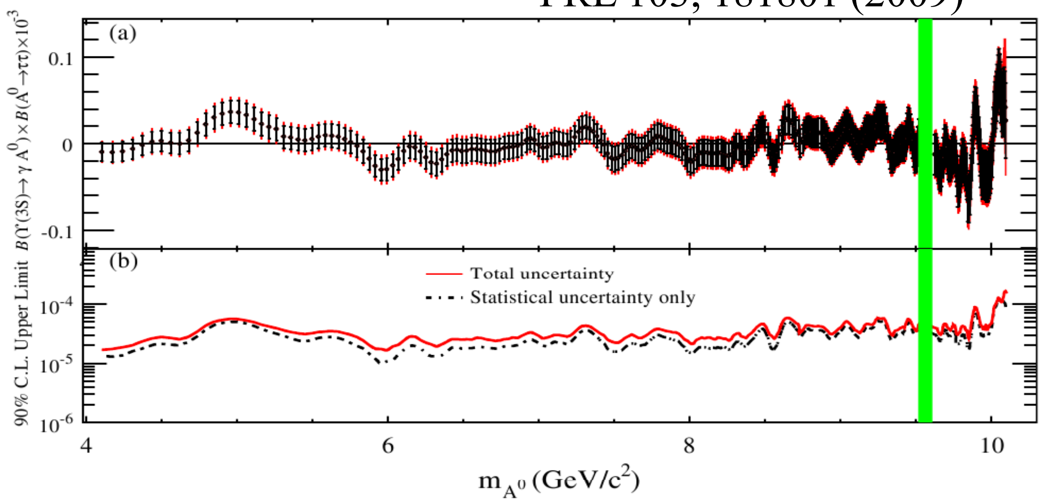
Results for $\Upsilon(3S) \rightarrow \gamma A^0$

$$\mathcal{B}(\Upsilon(3S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \tau^+\tau^-)$$

PRL 103, 181801 (2009)



- Used 122 M $\Upsilon(3S)$ events.
- We fix E_γ in steps of $\sigma/2$ as we scan the mass.
- Excluded region due to $\chi_{bJ}(2P) \rightarrow \gamma\Upsilon(1S)$ shown as a green band.
- 90% CL Upper Limits on BF product range: (1.5 - 16) x 10^{-5}.

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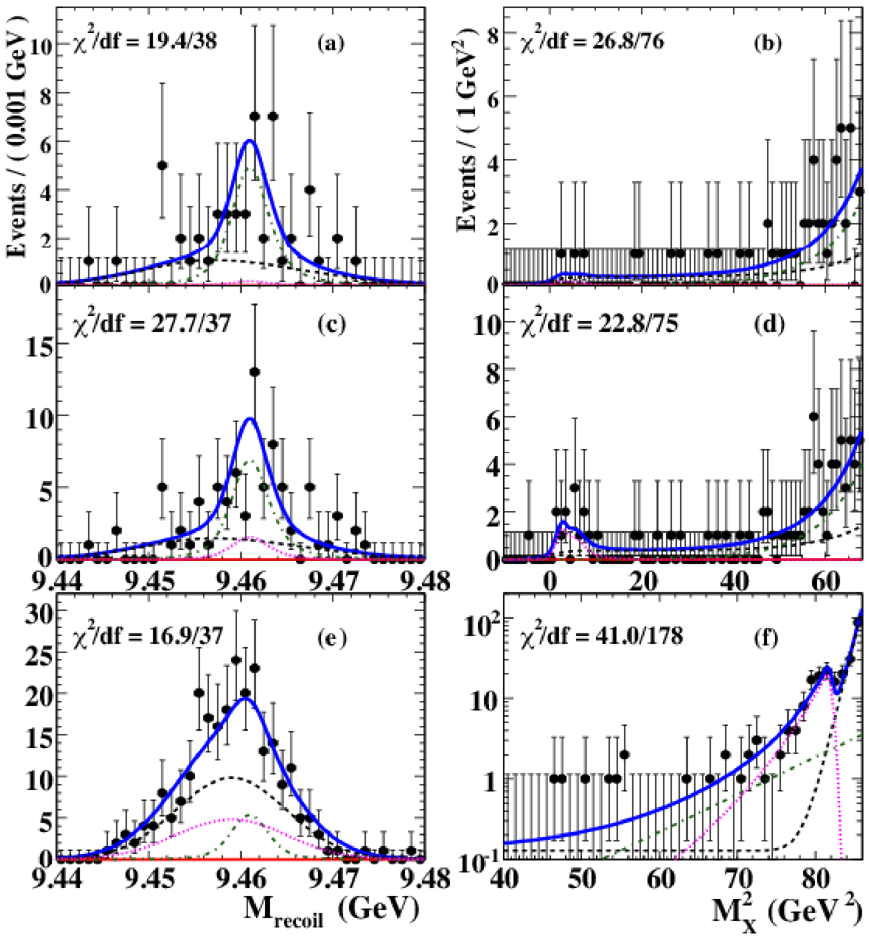
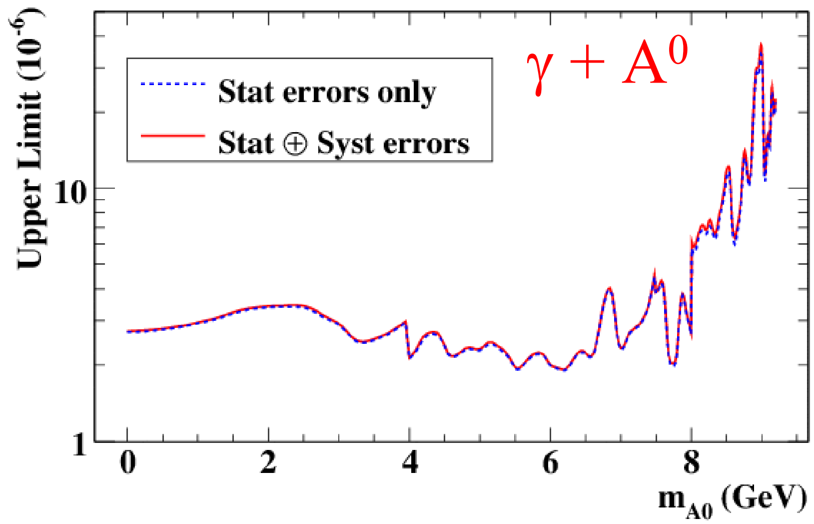
Υ(1S) → γ + invisible

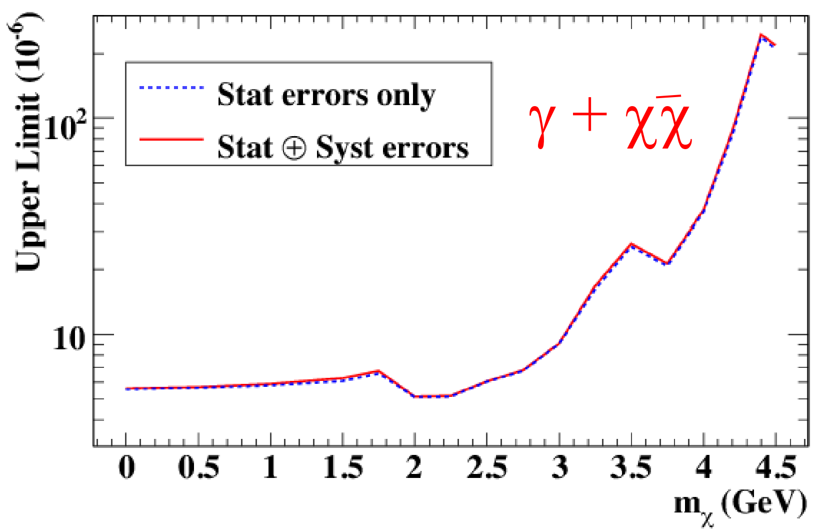
- 98 M events
- No evidence found
- 90% CL Upper Limits set

arXiv:1007.4646



- Low mass, no IFR
- Low mass, IFR
- High mass





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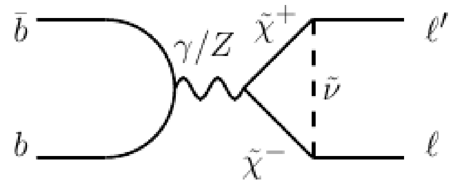
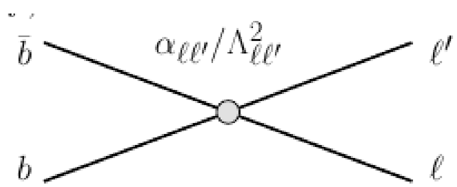
Charged Lepton Flavor Violation in Narrow Upsilon Decays

Look for Y(nS)→ℓτ

PRL 104, 151802 (2010)



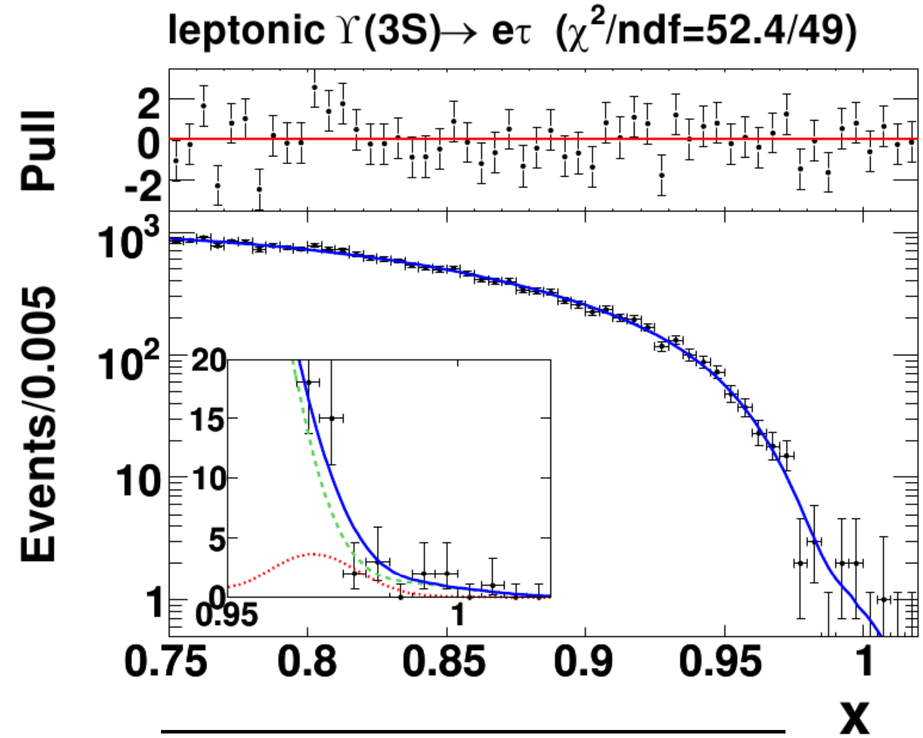
(SUSY)



(Generic)

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

- Absence of hadronic BB states enhances BF for narrow Upsilon resonances
- The primary (non-tau) lepton should satisfy $x=p_1/E_{beam}\approx 0.97$
- use $\mu^\pm$, $\pi^\pm$ final states of $\tau^\pm$
- use kinematic and event shape variable to suppress e+e-→ℓ+ℓ- backgrounds



	$\mathcal{B}$ (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

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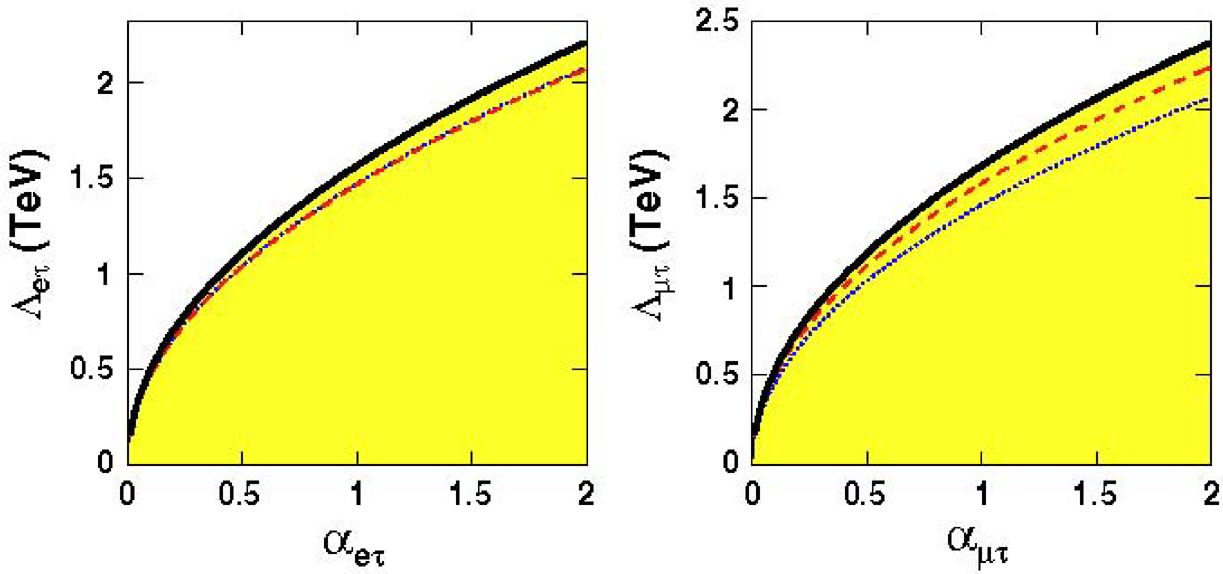
Rare Upsilon Decays
Conclusions



PRL 104, 151802 (2010)

Charged LFV
in Narrow Upsilon Decays

FIG. 2 (color online). Excluded regions of effective field theory parameter spaces of mass scale $\Lambda_{\ell\tau}$ versus coupling constant $\alpha_{\ell\tau}$. The dotted blue line is derived from $\Upsilon(2S)$ results only, the dashed red line is derived from $\Upsilon(3S)$ results only, and the solid black line indicates the combined results. The yellow shaded regions are excluded at 90% C.L.

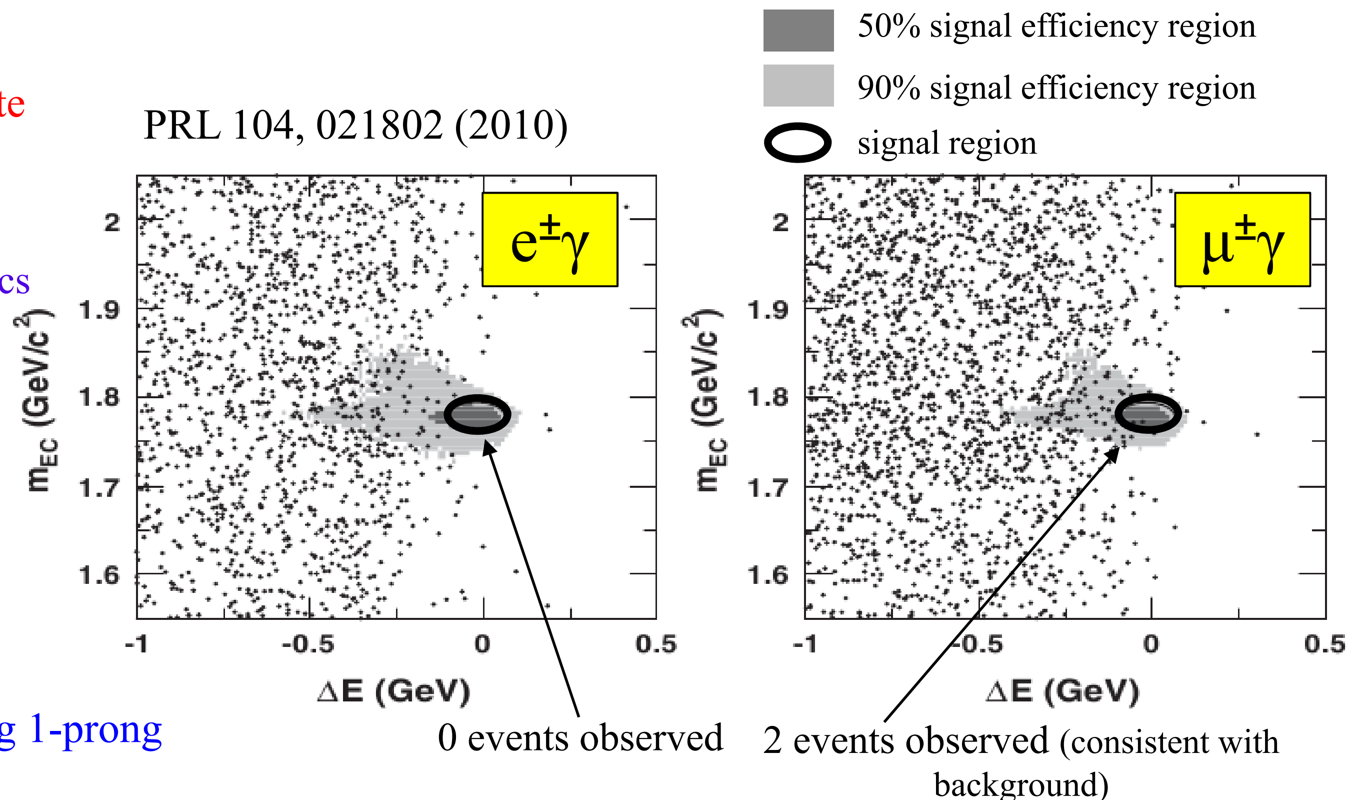
No evidence for new physics; tests range over a variety of models.

Rare Tau Decays: $\tau^+ \rightarrow \ell^+ \gamma$

•Even with neutrino mixing, rate is unmeasurably small in SM

•Unambiguous sign of new physics

PRL 104, 021802 (2010)



•Tag the other tau decay using 1-prong and 3-prong topologies.

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

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

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

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

TABLE I. Means and resolutions of m_{EC} and ΔE distributions for the signal MC events, the numbers of observed (obs) and expected (exp) events inside the 2σ signal ellipse, the signal efficiencies (ε), and the 90% C.L. upper limits (UL).

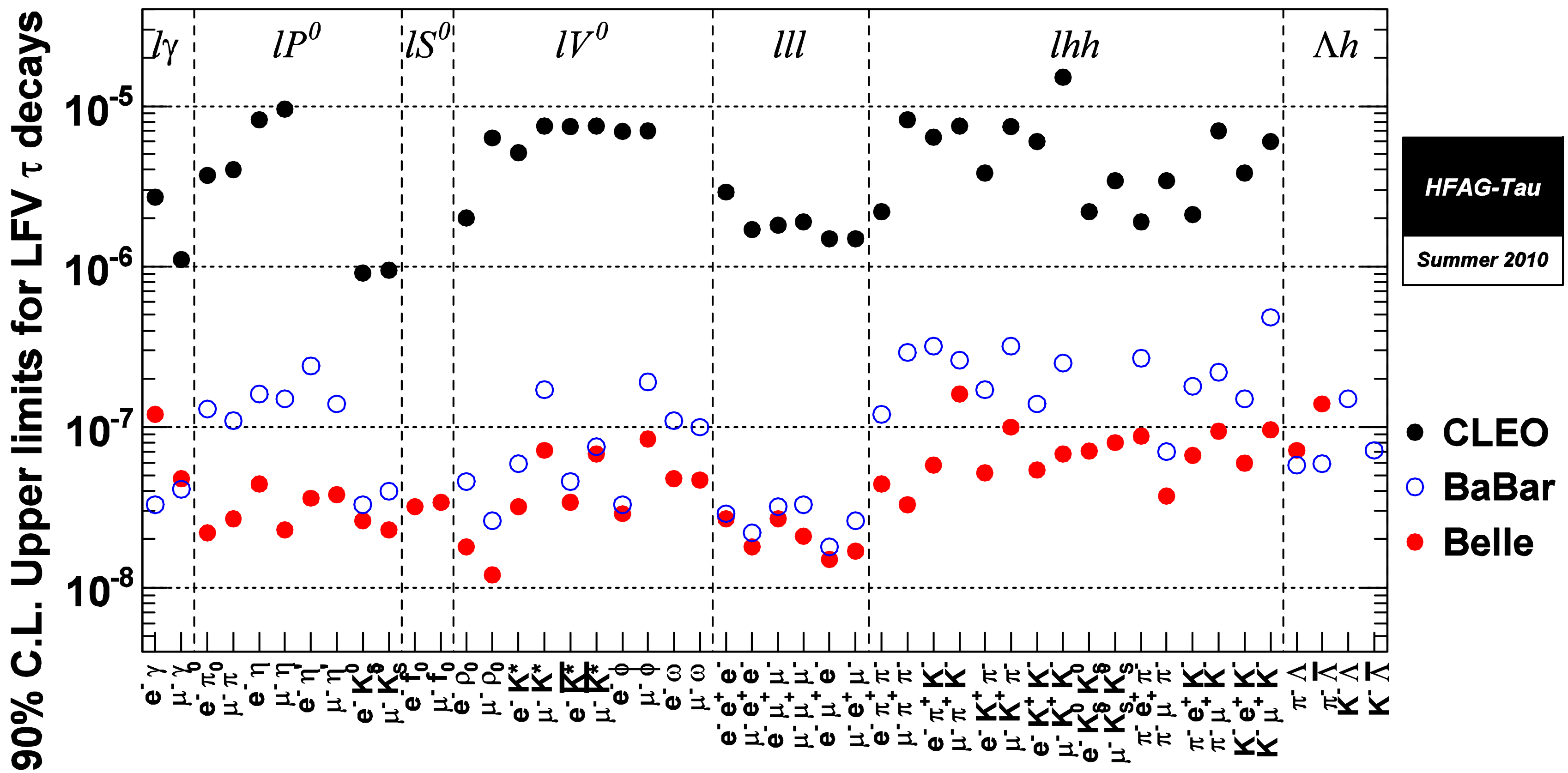
Decay modes	$\langle m_{EC} \rangle$ (MeV/c^2)	$\sigma(m_{EC})$ (MeV/c^2)	$\langle \Delta E \rangle$ (MeV)	$\sigma(\Delta E)$ (MeV)	2σ signal ellipse obs	2σ signal ellipse exp	ε (%)	UL ($\times 10^{\ 8}$) obs	UL ($\times 10^{\ 8}$) exp
$\tau^+ \rightarrow e^+ \gamma$	1777.3	8.6	−21.4	42.1	0	1.6 ± 0.4	3.9 ± 0.3	3.3	9.8
$\tau^+ \rightarrow \mu^+ \gamma$	1777.4	8.3	−18.3	42.2	2	3.6 ± 0.7	6.1 ± 0.5	4.4	8.2

- Systematics included: 7.7% and 7.4% in $e^+ \gamma$ and $\mu^+ \gamma$ modes, respectively.

- SM prediction: BF ~ 10^{-54}

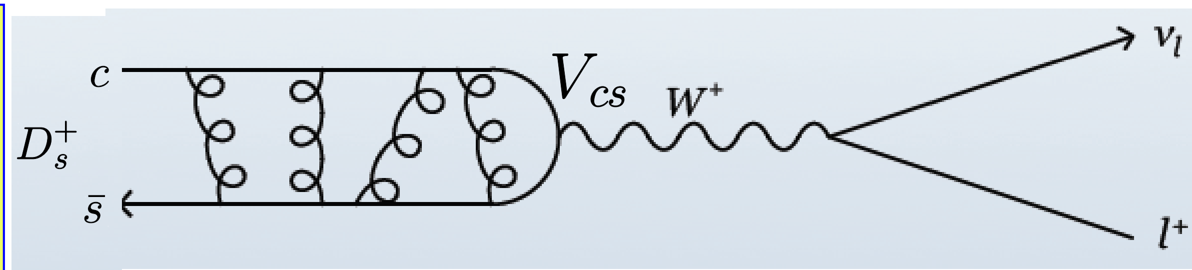
- We see no indication of new physics: our limits are
- BF ($\tau^+ \rightarrow e^+ \gamma$) < 3.3×10^{-8}
- BF ($\tau^+ \rightarrow \mu^+ \gamma$) < 4.4×10^{-8}

Upper limits for Tau LFV Decays



$D_s^+ \to \ell\nu$ Decays: Motivation

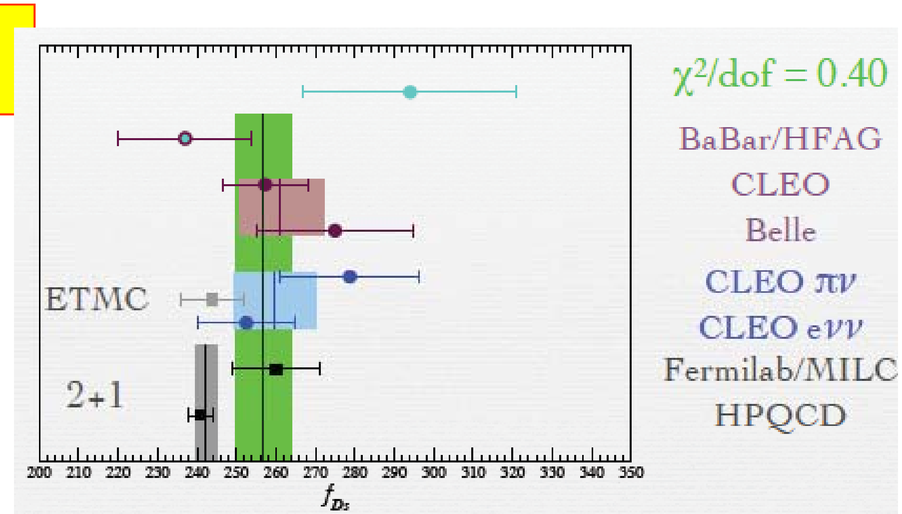
The measurement of the leptonic decay relative branching fraction can be used to measure the decay constant f_{Ds}



$$\Gamma = \frac{G_F^2 M_{D_s^+}^3}{8\pi}\left(\frac{m_\ell}{M_{D_s^+}}\right)^2\left(1-\frac{m_\ell^2}{M_{D_s^+}^2}\right)^2 |V_{cs}|^2 f_{D_s}^2$$

The global average(HFAG) and the recent unquenched lattice QCD expectations show some disagreement

- New physics could include:
  - Charged Higgs boson propagator.
  - Leptoquarks.
  - SUSY...



New preliminary results presented at FPCP2010
- **Fermilab/MILC(2010): fDs = 261.4 ± 9.2**
- **HPQCD(2010): fDs = 247 ± 2**

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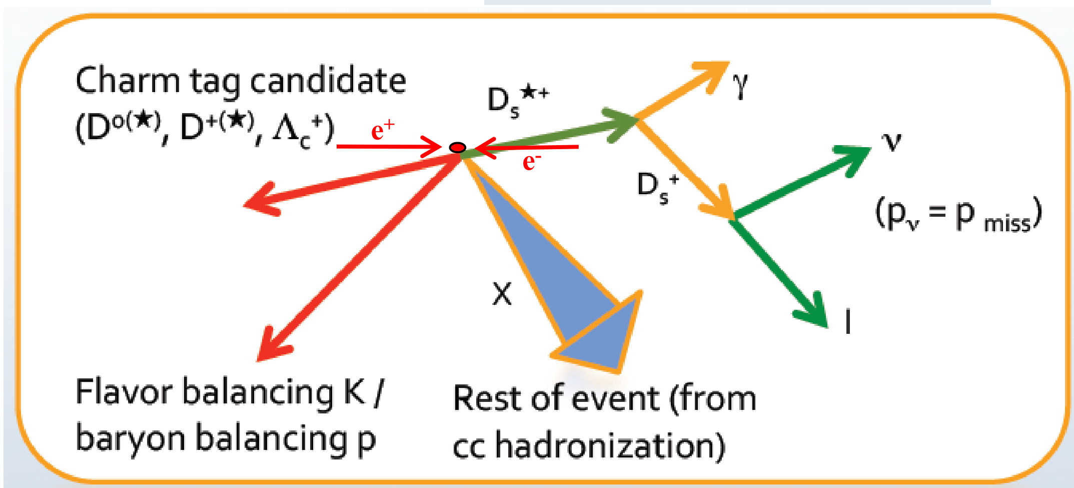
Analysis strategy

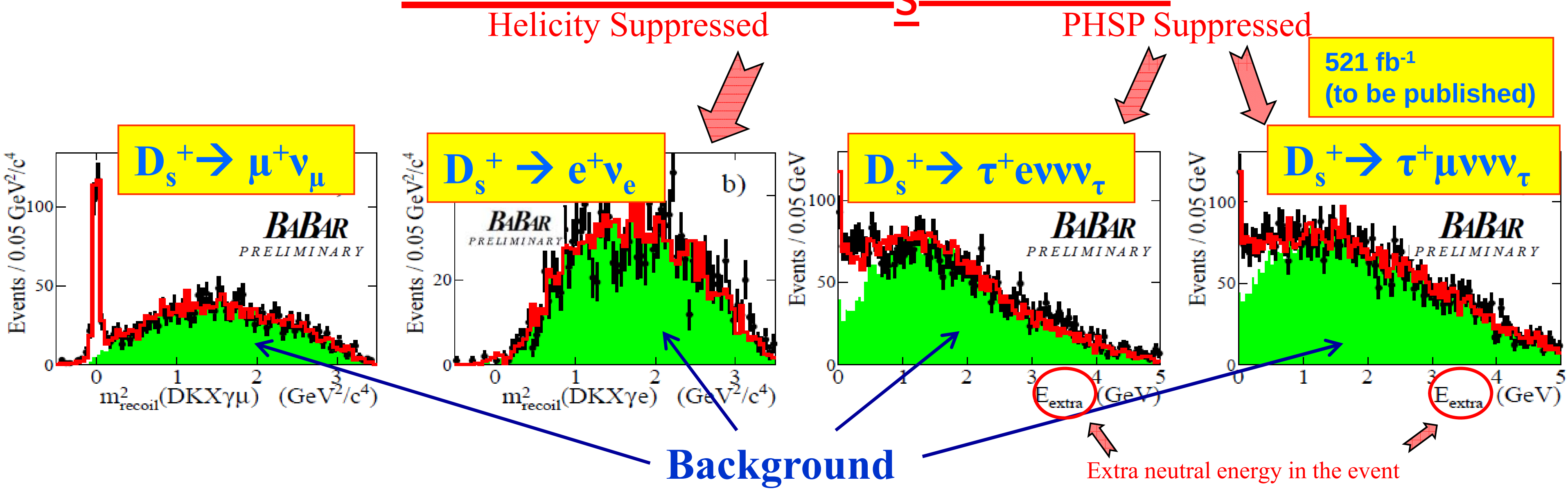
- **Inclusive D_s candidates**
  - **The signal consists of D_s* candidates decaying to Ds γ**
  - **The D_s candidate is reconstructed from the four-momentum recoiling against the DKXγ ($D = D^{0(*)}$, $D^{+(*)}$, Λc^+; K = Ks, K^+,(p); X = π^+, π^0)**
- **Within this sample, the $D_s^+ \rightarrow \ell^+ \nu \ell$ (ℓ = e, μ, τ) events are selected**
  - **One more track, identified as e/μ, is required**

Yields corrected by efficiency to obtain the branching fractions:

$$B(D_s^+ \to l\nu) = \frac{N(D_s^+ \to l\nu)}{N(D_s^+)\varepsilon_{l\nu}}$$



Results for $D_s^+ \rightarrow \ell\nu$



Decay	Signal Yield	$\mathcal{B}(D_s^+ \to \ell^+ \nu_\ell)$	f_{D_s} (MeV)
$D_s^+ \to e^+ \nu_e$	$6.1 \pm 2.2 \pm 5.2$	$< 2.3 \times 10^{-4}$ at 90% C.L.	
$D_s^+ \to \mu^+ \nu_\mu$	275 ± 17	$(6.02 \pm 0.38 \pm 0.34) \times 10^{-3}$	$265.7 \pm 8.4 \pm 7.7$
$D_s^+ \to \tau^+_{e\nu\nu} \nu_\tau$	408 ± 42	$(5.07 \pm 0.52 \pm 0.68) \times 10^{-2}$	$247 \pm 13 \pm 17$
$D_s^+ \to \tau^+_{\mu\nu\nu} \nu_\tau$	340 ± 32	$(4.91 \pm 0.47 \pm 0.54) \times 10^{-2}$	$243 \pm 12 \pm 14$

Normalization mode of many Ds decays!

The hadronic $Ds^+ \rightarrow K^+K^-\pi^+$ used to cross-check the method

$$\mathcal{B}(D_s^+ \to K^+K^-\pi^+) = (5.78 \pm 0.20(\text{stat}) \pm 0.30(\text{syst}))\%$$

$$f_{D_S} = (258.6 \pm 6.4(\text{stat}) \pm 7.5(\text{syst}))\ \text{MeV}$$

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f_{D_s} Conclusion

- We have used a novel event reconstruction at BaBar to obtain very competitive measurements:
  - $B(D_s \rightarrow \mu\nu) = (6.02 \pm 0.38 \pm 0.34) \times 10^{-3}$
  - $B(D_s \rightarrow e\nu) < 2.3 \times 10^{-4}$ CLEO: $< 1.3 \times 10^{-4}$
  - $B(D_s \rightarrow \tau\nu) = (5.00 \pm 0.35 \pm 0.49) \times 10^{-2}$
  - $B(D_s \rightarrow K^+K^-\pi^+) = (5.78 \pm 0.20 \pm 0.30) \times 10^{-2}$ CLEO: $(5.5 \pm 0.23 \pm 0.16) \times 10^{-2}$
  - $f_{Ds} = (258.6 \pm 6.4 \pm 7.5)$ MeV, consistent with LQCD prediction on previous slide

- Demonstrated powerful reconstruction method:
  - Used full dataset (~750M $c\bar{c}$ pairs)
  - Obtained absolute D_s branching fraction
  - Modeled hadronization effectively.

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 search for new physics
  - needed to make definitive measurements (leptonic B decays)

Extra Slides

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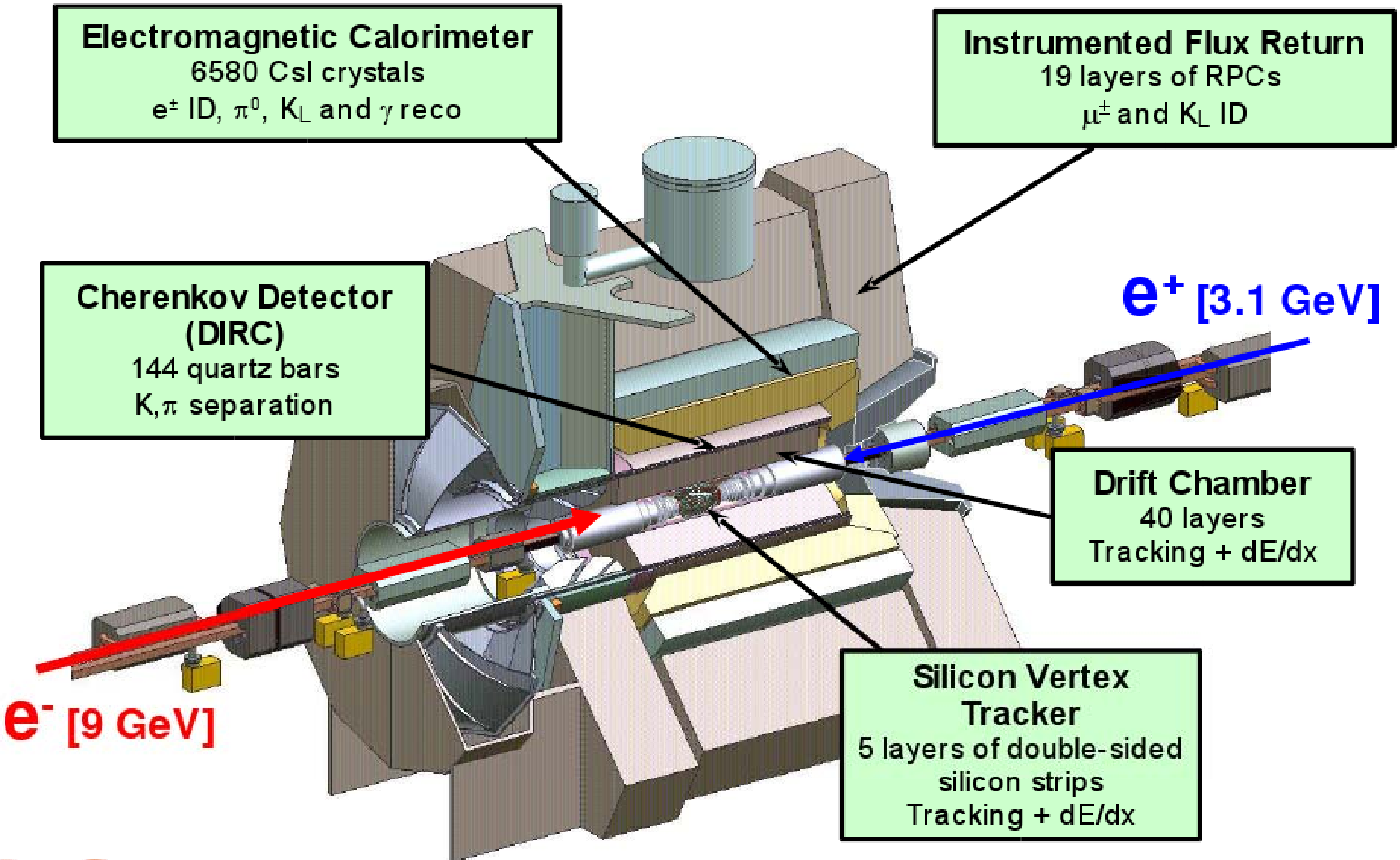
The BaBar Detector

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



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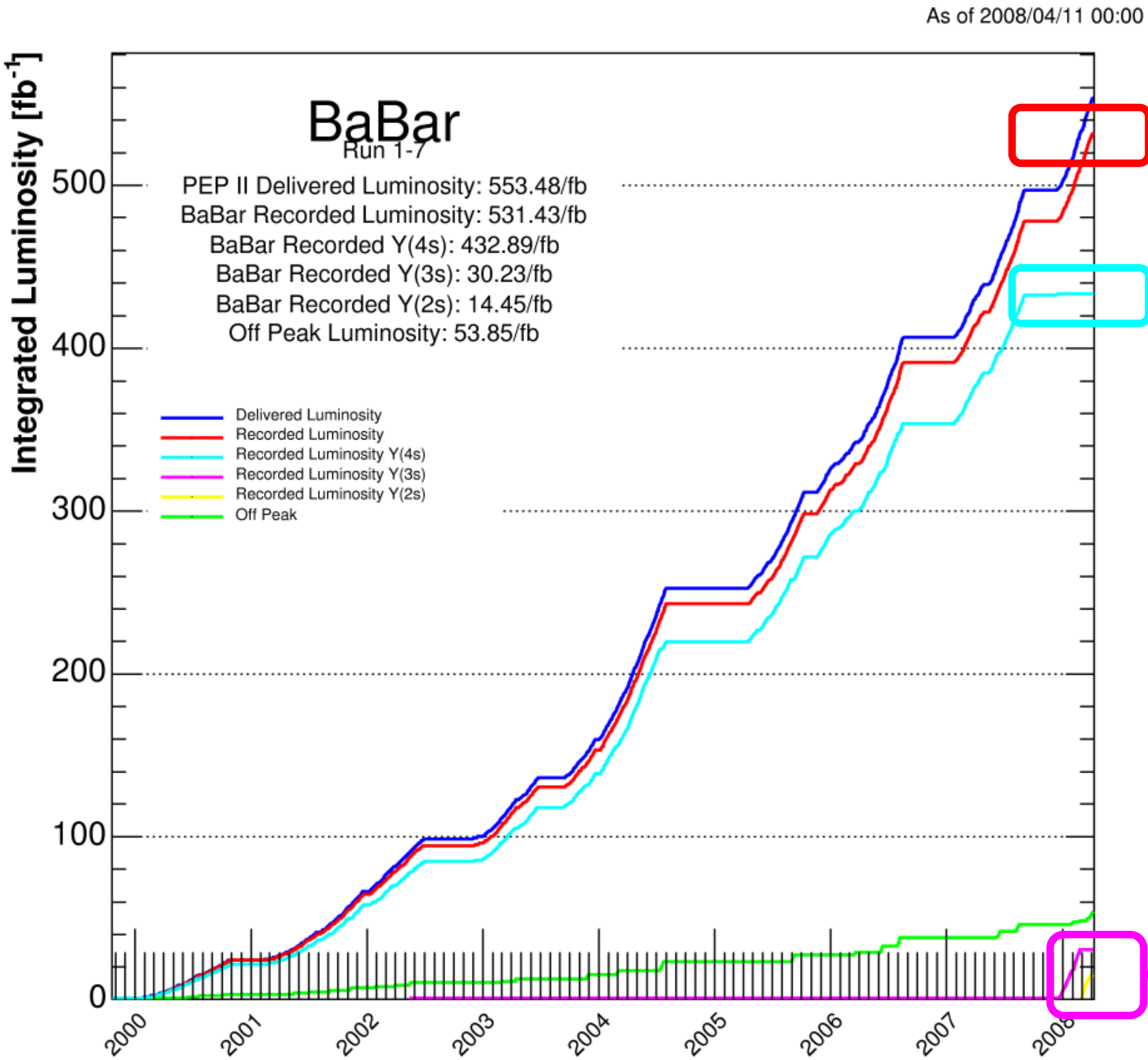
BaBar Dataset



963 million τ leptons (2000-2008)

~470 million BB pairs (2000-2007)

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

Fully Inclusive D_s Sample

521 fb^{-1}

Most Relevant Selection criteria:

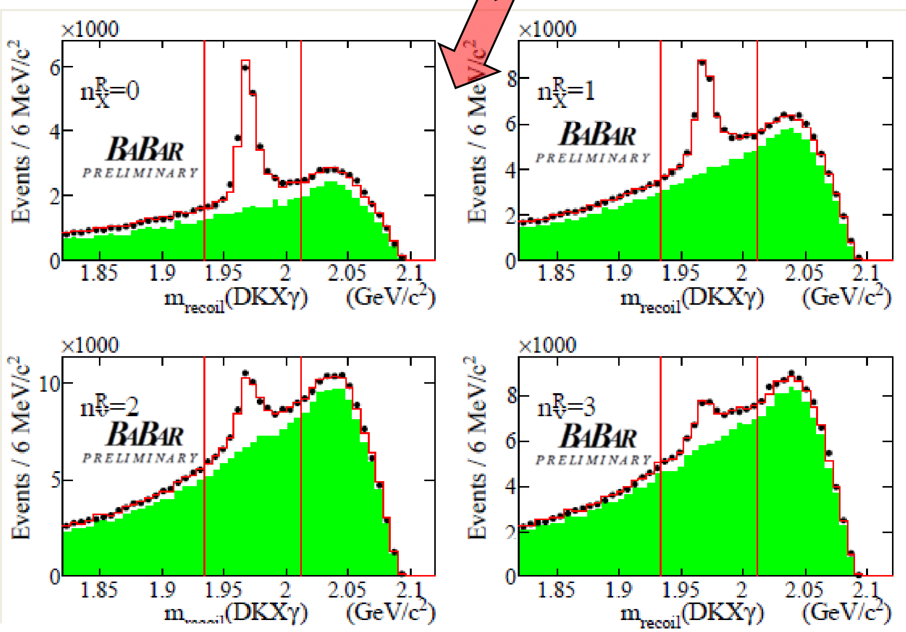
- $p^*(Ds) > 3.0$ GeV/c
- mrecoil(DKX) within ~2.5σ of the Ds* PDG mass value
- $E\gamma > 120$ MeV + π^0 and η vetoes

N.B.

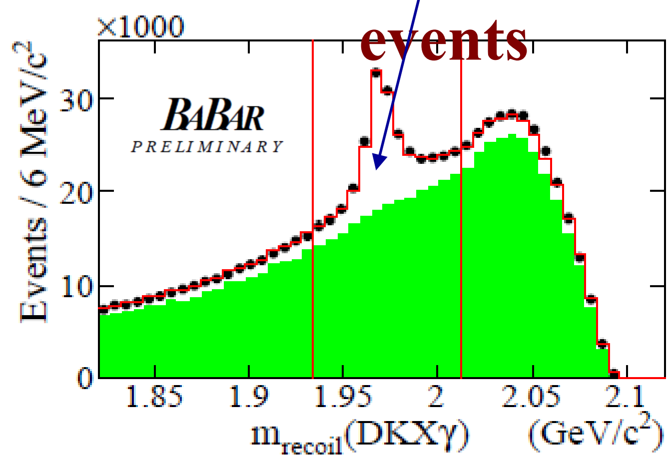
mrecoil(DKX) ≡ m(Ds*)

mrecoil(DKX γ) ≡ m(Ds)

Result of 2D fit $m_{recoil}(DKX\gamma)$ vs. $n^R x$ ($n^R x$ = Number of reconstructed pions in X system)



Total



$(67.2\pm1.5)\times10^3$ events

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Comparison to Belle, CLEO-c

- The comparison of this result and other measurements is shown below

Mode	Experiment	f_{D_s}(MeV)
$D_s \rightarrow l\nu$	This measurement	258.6 ± 6.4 ± 7.5
$D_s \rightarrow \mu\nu$	Belle	275 ± 16 ± 12
$D_s \rightarrow \mu\nu$	CLEO-c	264 ± 15 ± 7
$D_s \rightarrow \tau\nu; \tau \rightarrow e\nu\nu$	CLEO-c	273 ± 16 ± 8
$D_s \rightarrow \tau\nu; \tau \rightarrow \pi\nu$	CLEO-c	310 ± 25 ± 8
	Belle-CLEO-c combined	277 ± 9
$D_s \rightarrow \mu\nu / D_s \rightarrow \phi\pi$	BaBar	283 ± 17 ± 7 ± 14